Recent results of the high-energy polarized p-p program at RHIC at BNL

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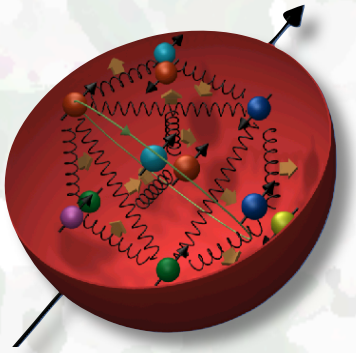

Outline

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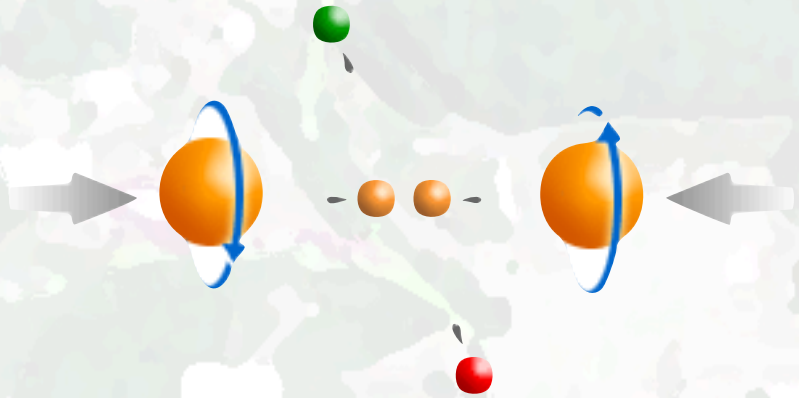

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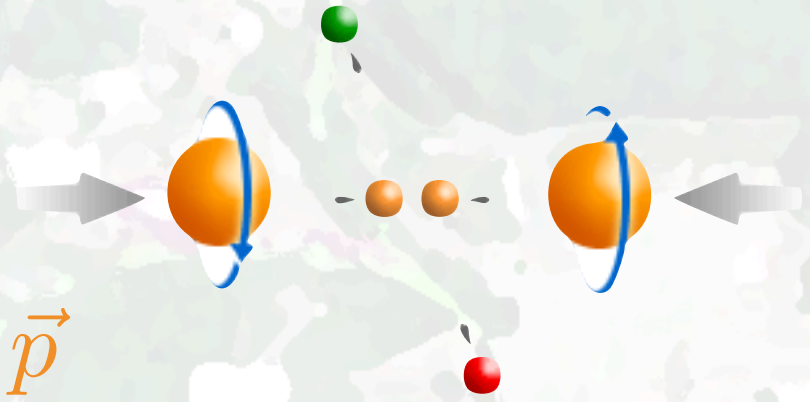

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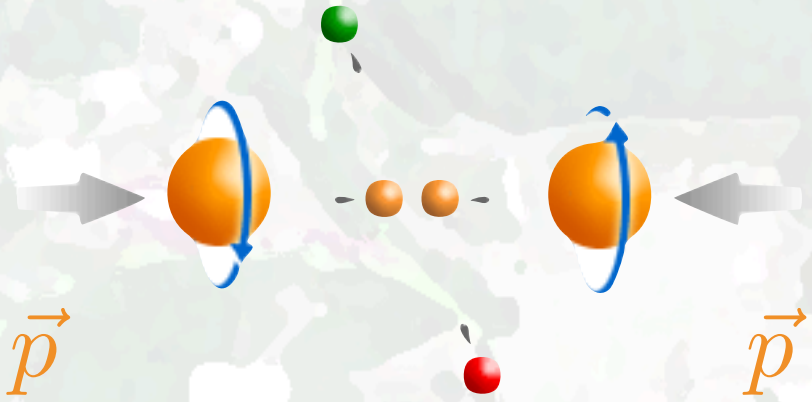

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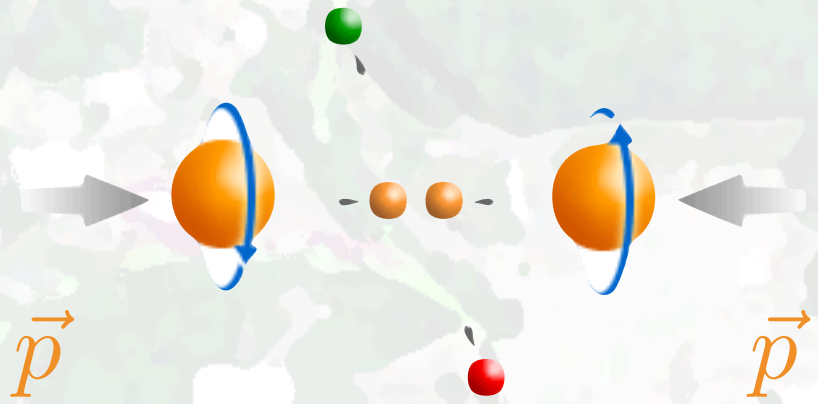

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- Experimental aspects: RHIC / STAR
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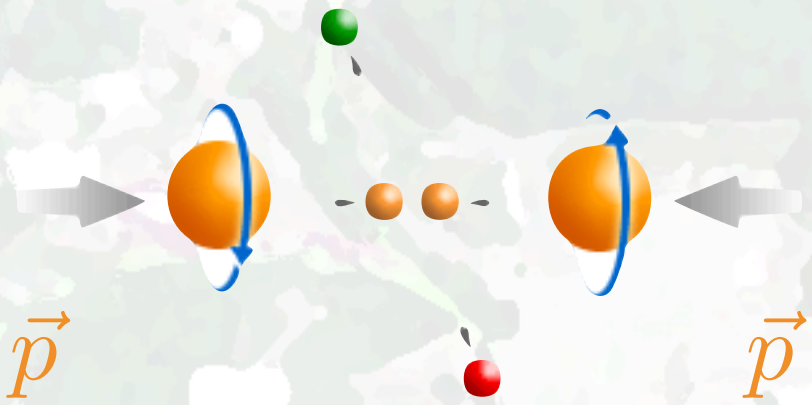

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- ΔG - Recent Results

  Inclusive Jet and
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- Experimental aspects:
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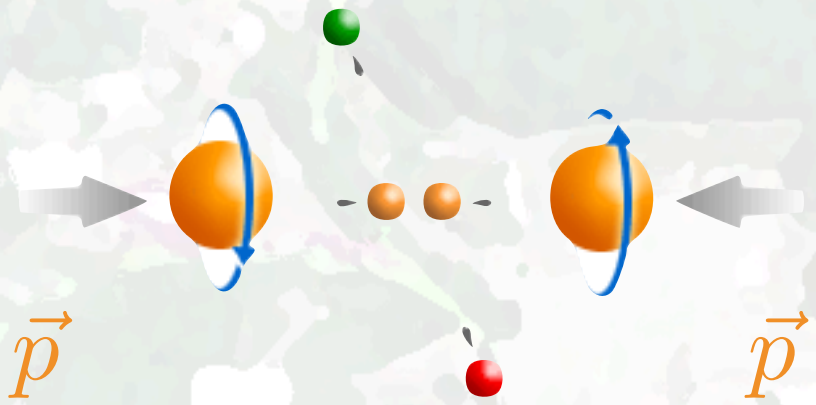

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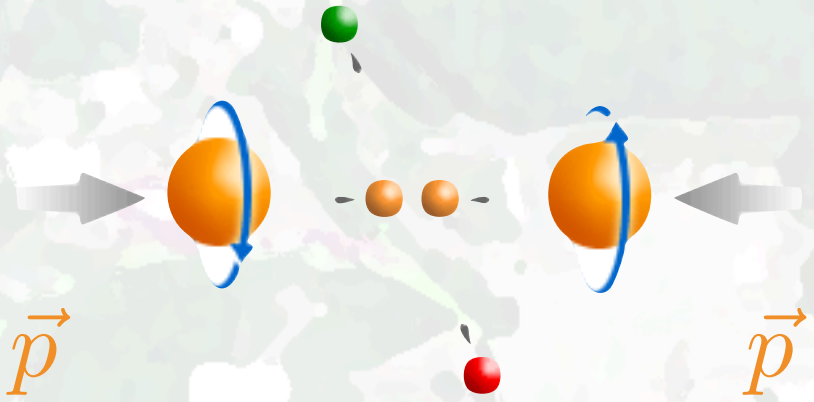

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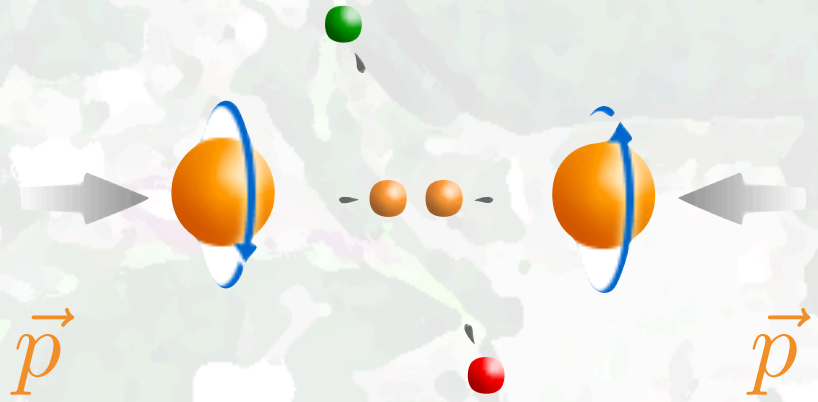

- Summary and Outlook

Introduction

- Exploring the proton spin structure and dynamics

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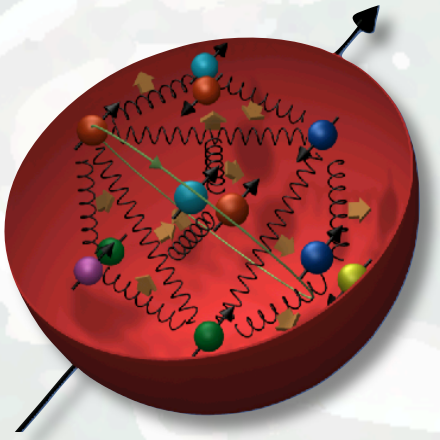

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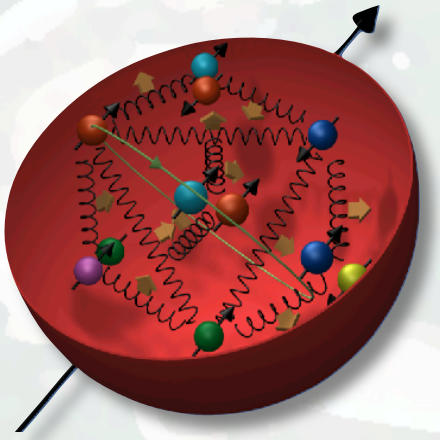

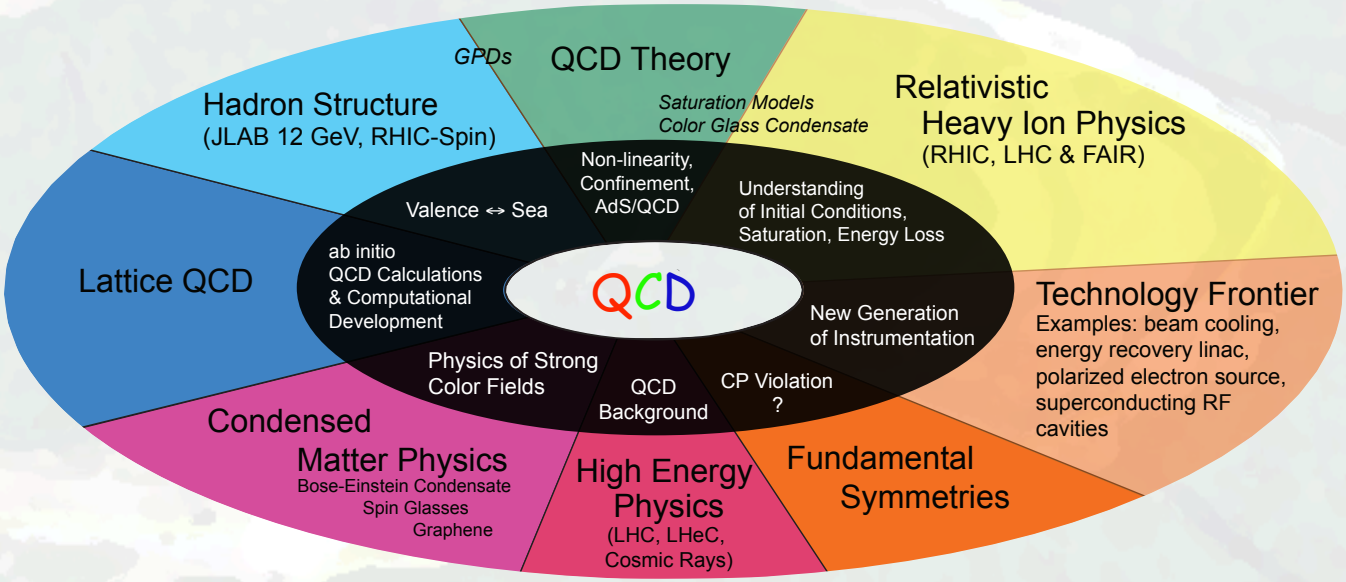

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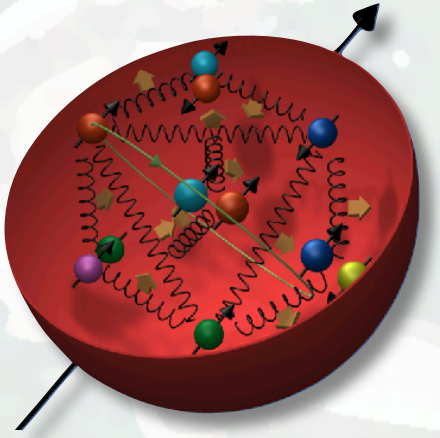

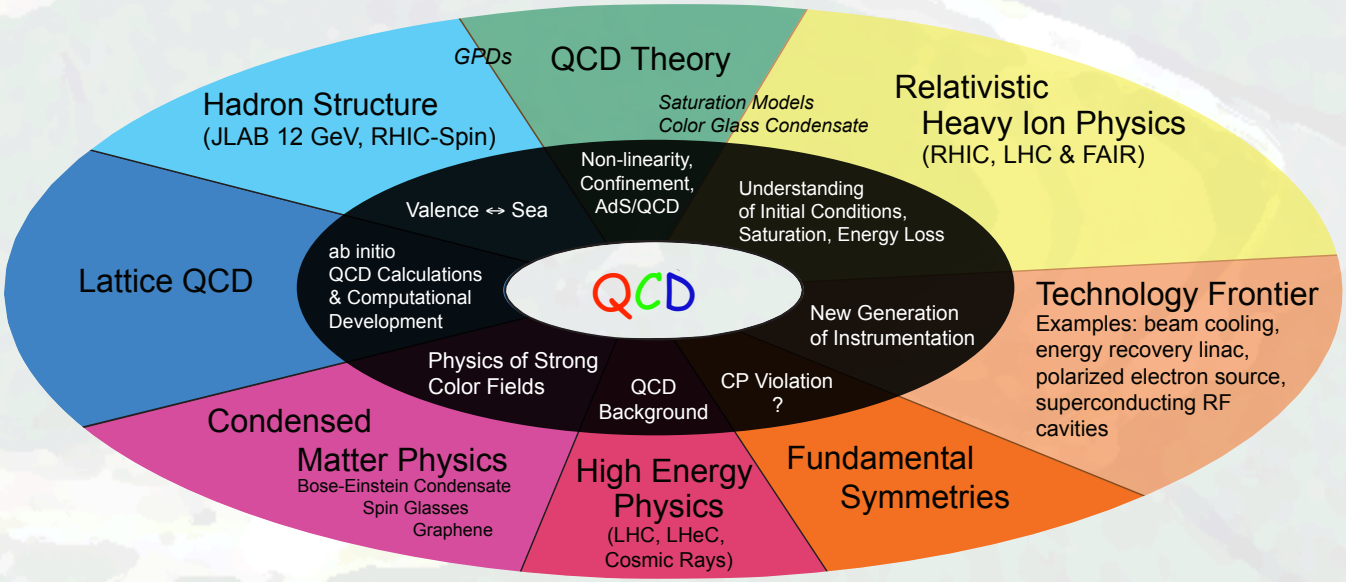

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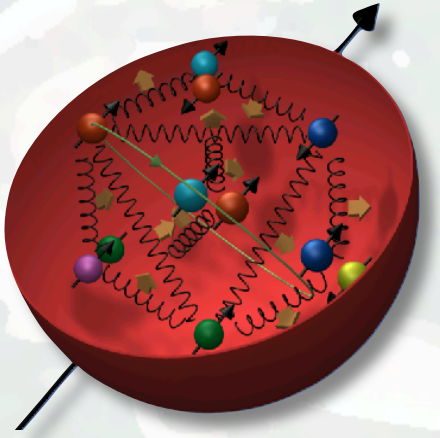

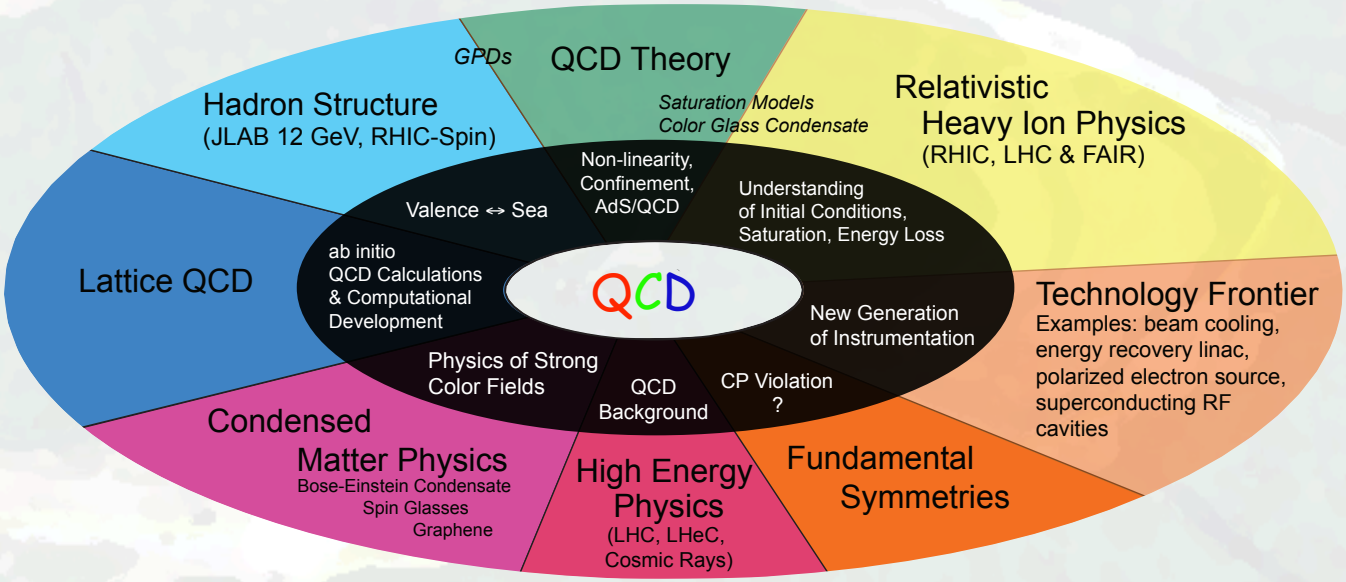

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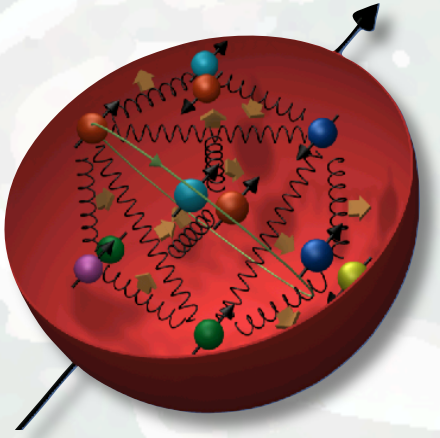

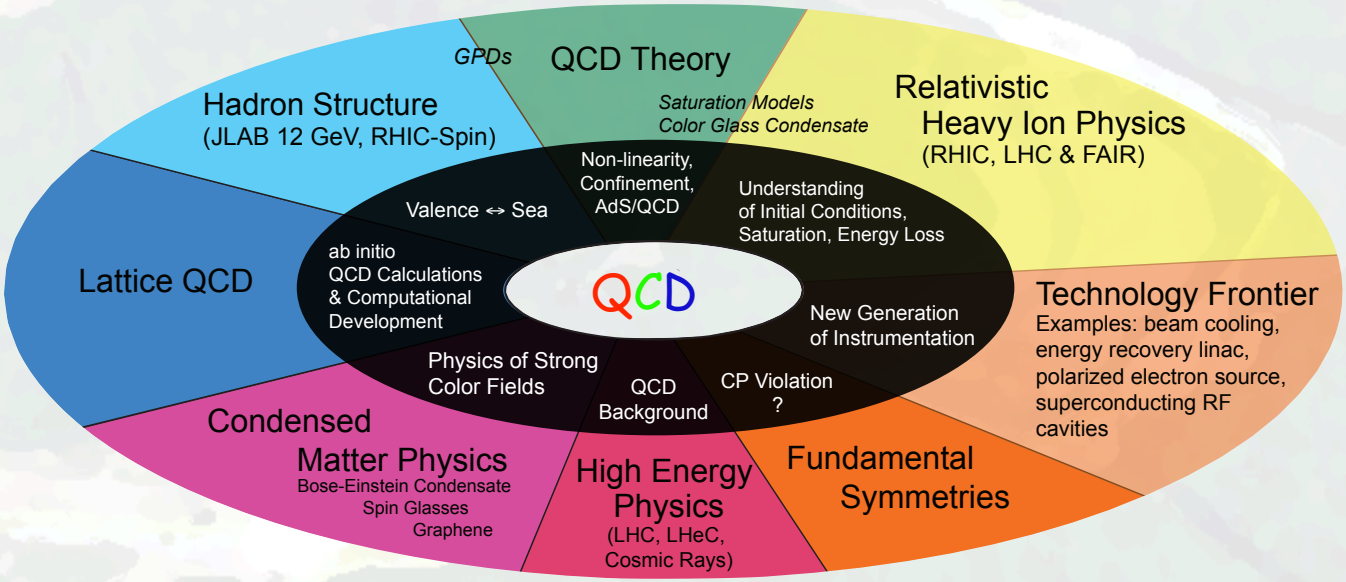

Structure and dynamics of proton (**mass**) (→ visible universe) originates from QCD-interactions!

What about **spin** as another fundamental quantum number?

Synergy of experimental progress and theory (Lattice QCD / Phenomenology incl. phenomenological fits / Modeling) critical!

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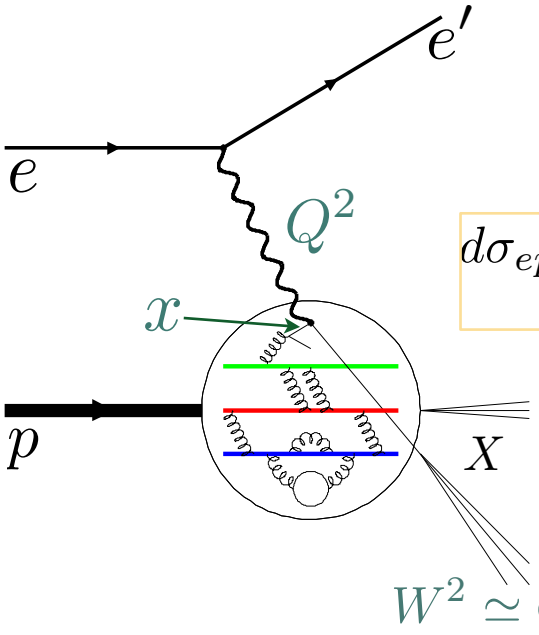

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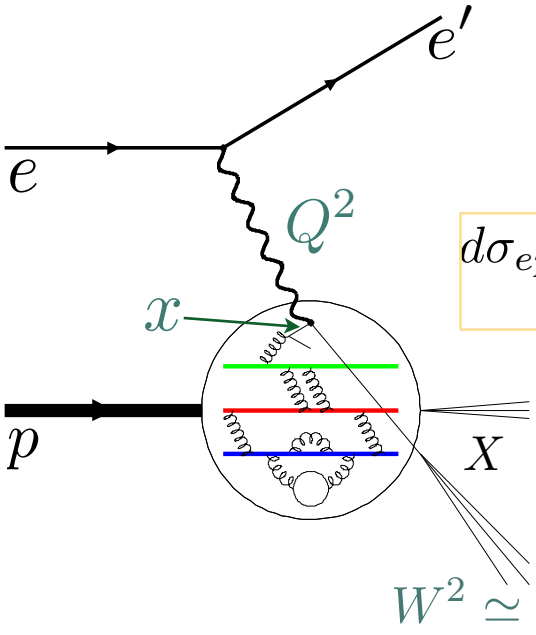

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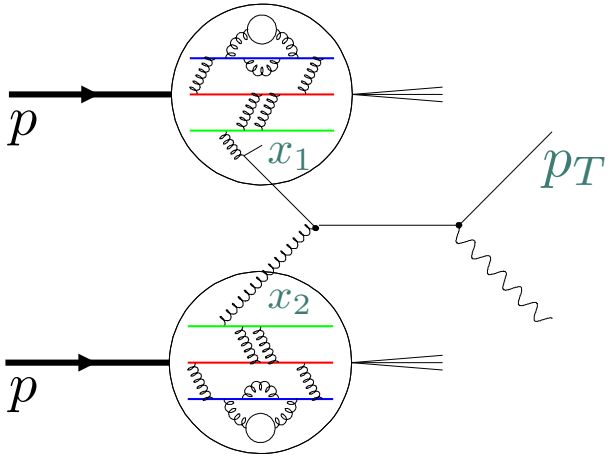

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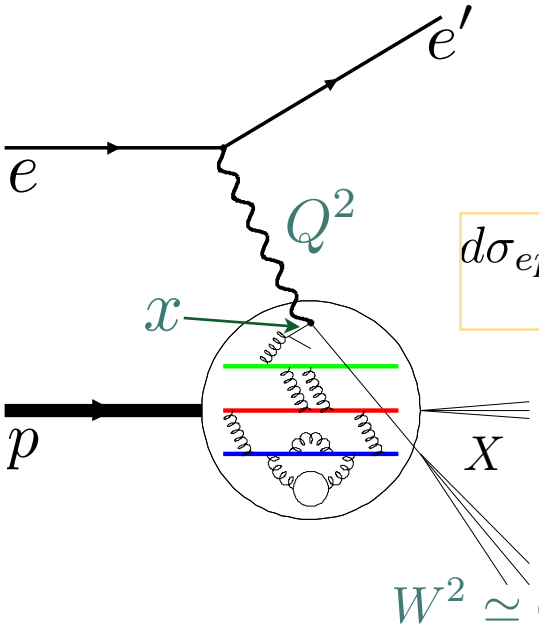

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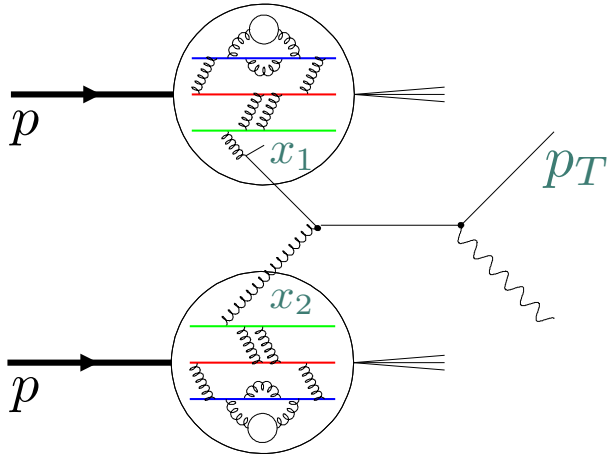

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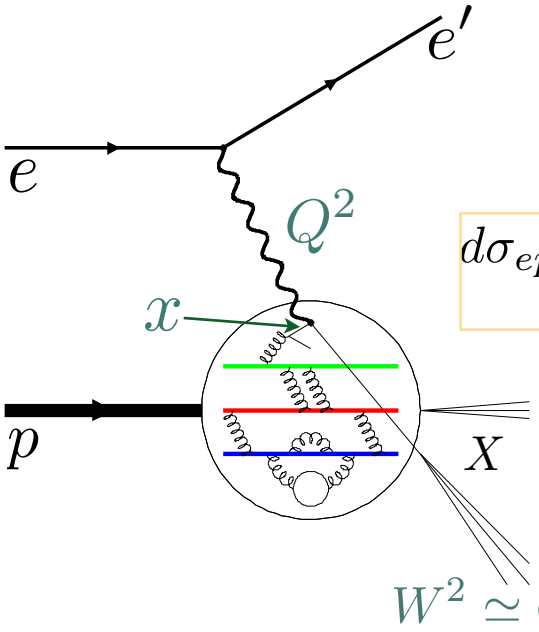

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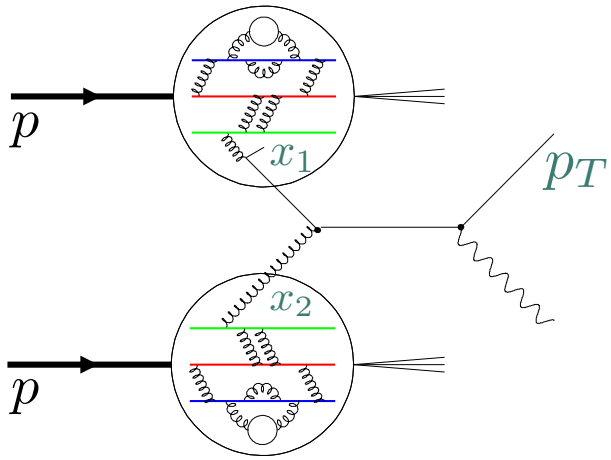

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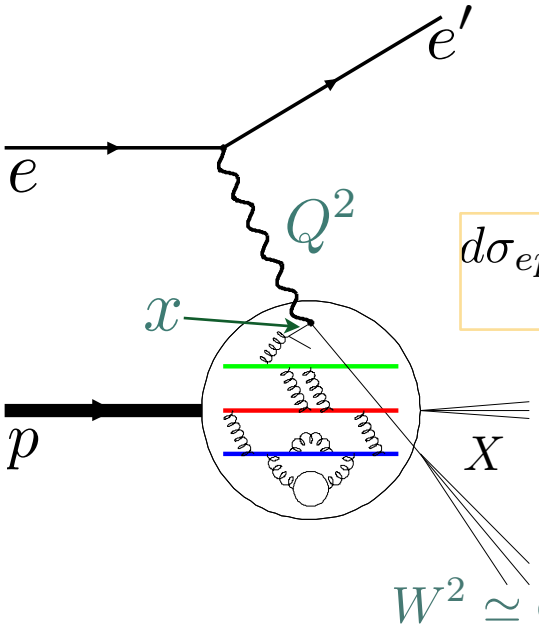

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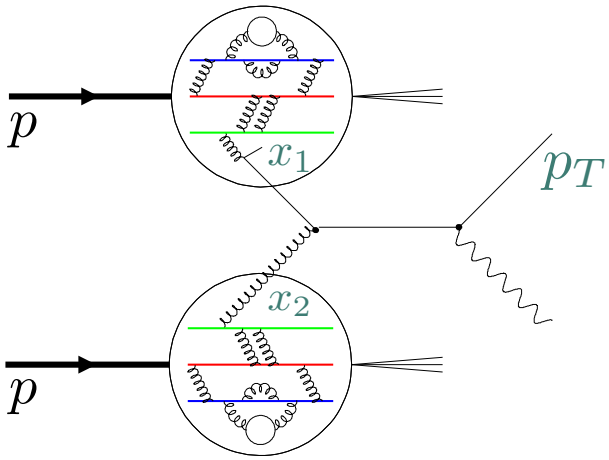

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Momentum contribution

$$f(x) =$$

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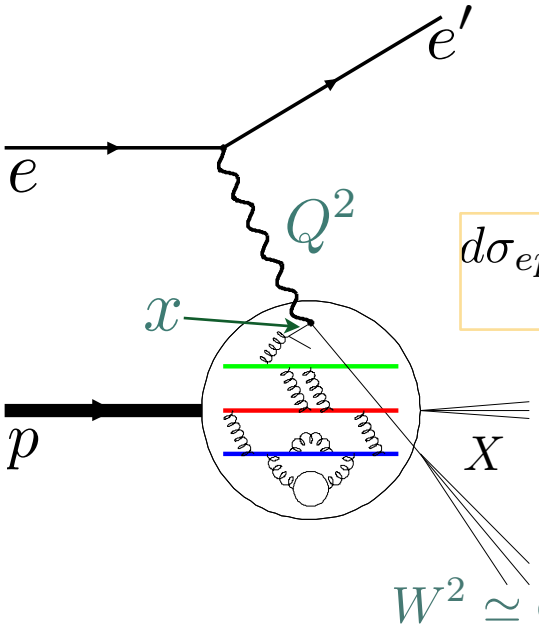

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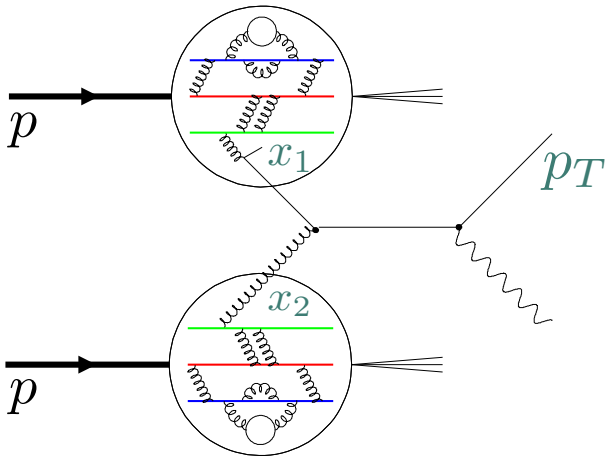

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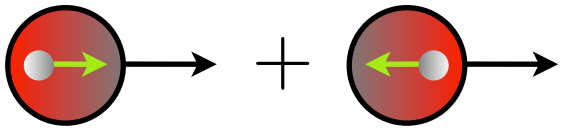
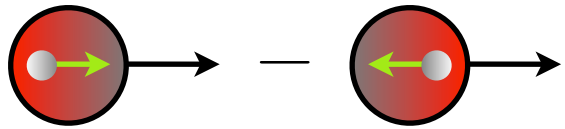


$$f^+(x) + f^-(x)$$

$$\Delta f(x) =$$



$$f^+(x) - f^-(x)$$

Spin contribution

Theoretical foundation

- What do we know about the polarized quark and gluon distributions?
  - Spin carried by quarks is very small ($\Delta\Sigma \sim 0.3$)!

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$$\frac{1}{2} = \langle S_q \rangle + \underbrace{\langle S_g \rangle + \langle L_q \rangle + \langle L_g \rangle}_{\Delta G}$$

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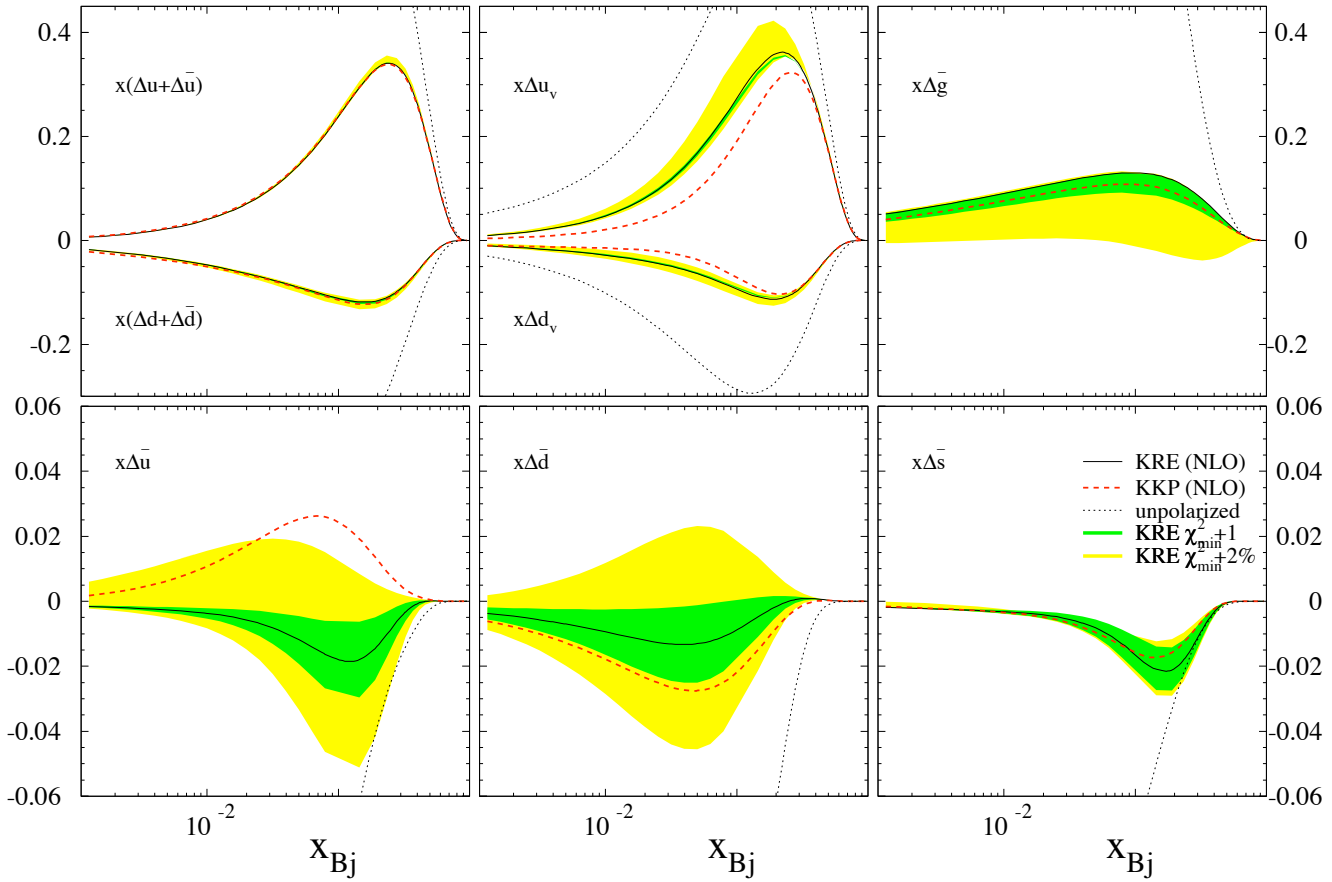

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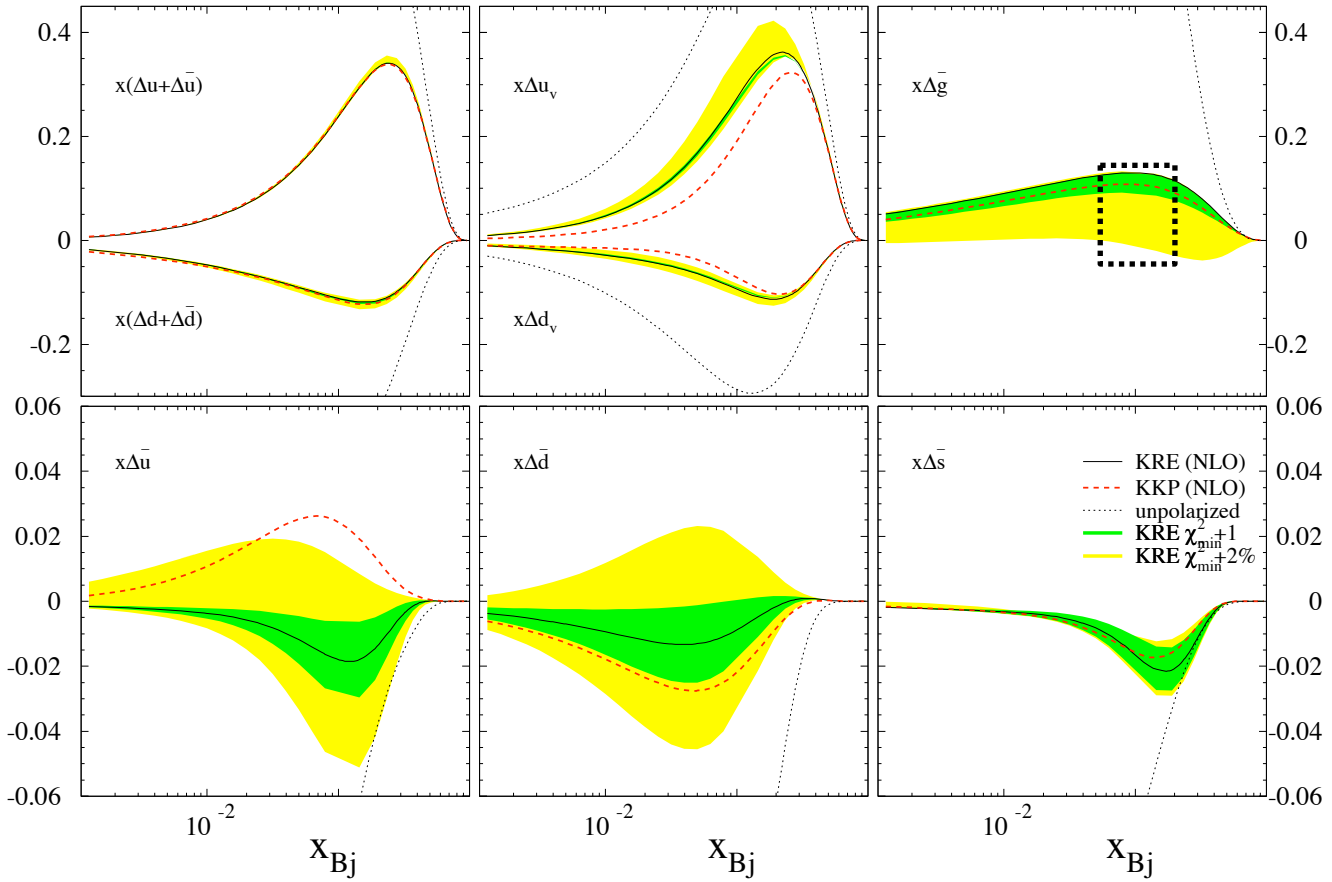

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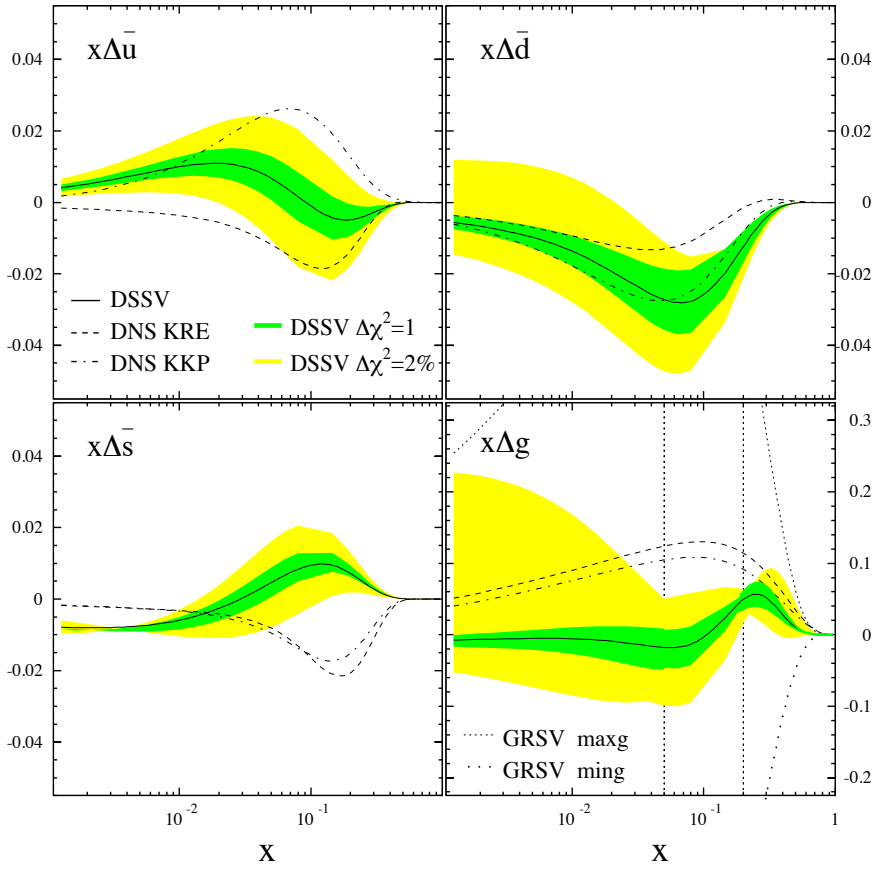

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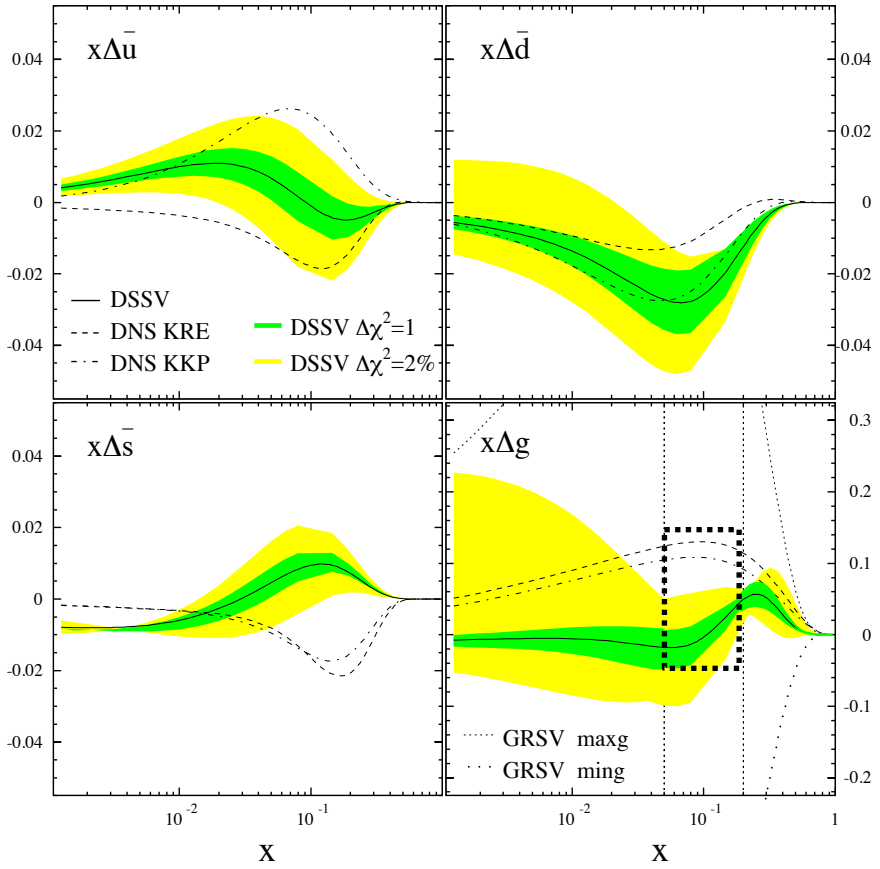

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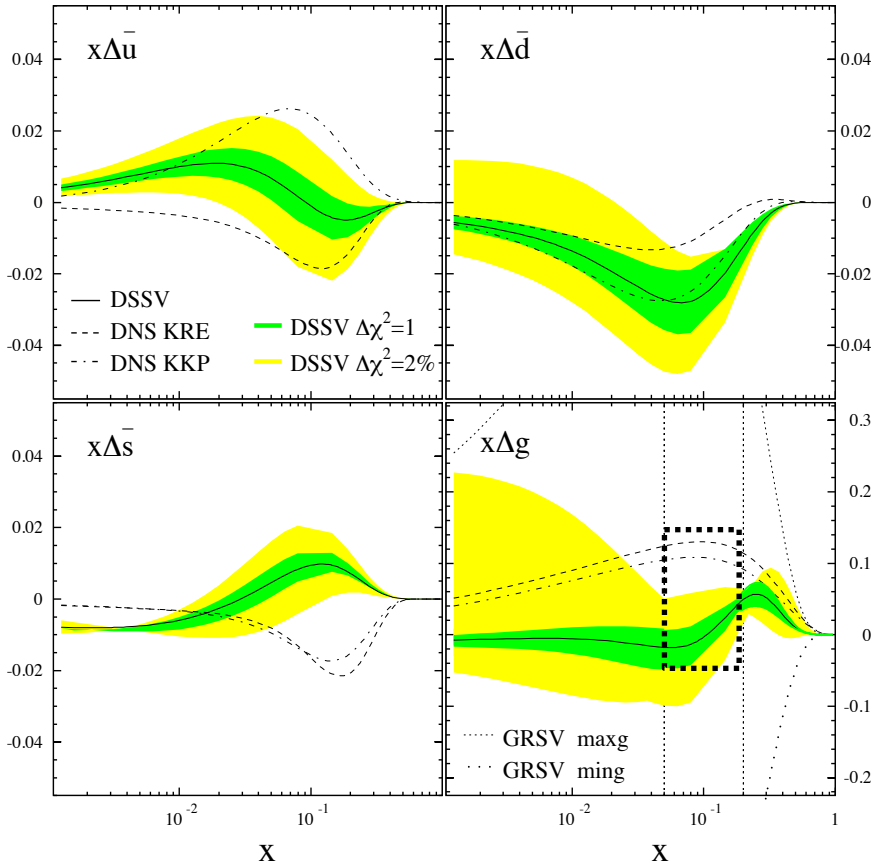

Substantial improvement for 0.05<x<0.2

Large uncertainties at low x

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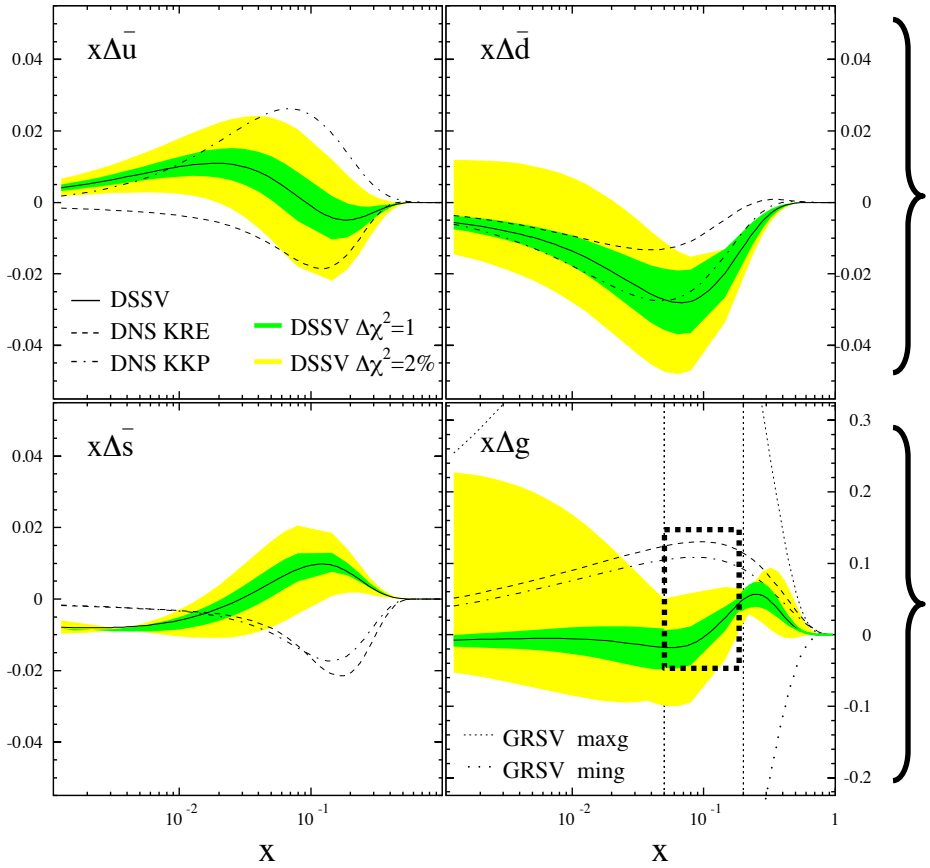

u/d sea-quarks large uncertainties!

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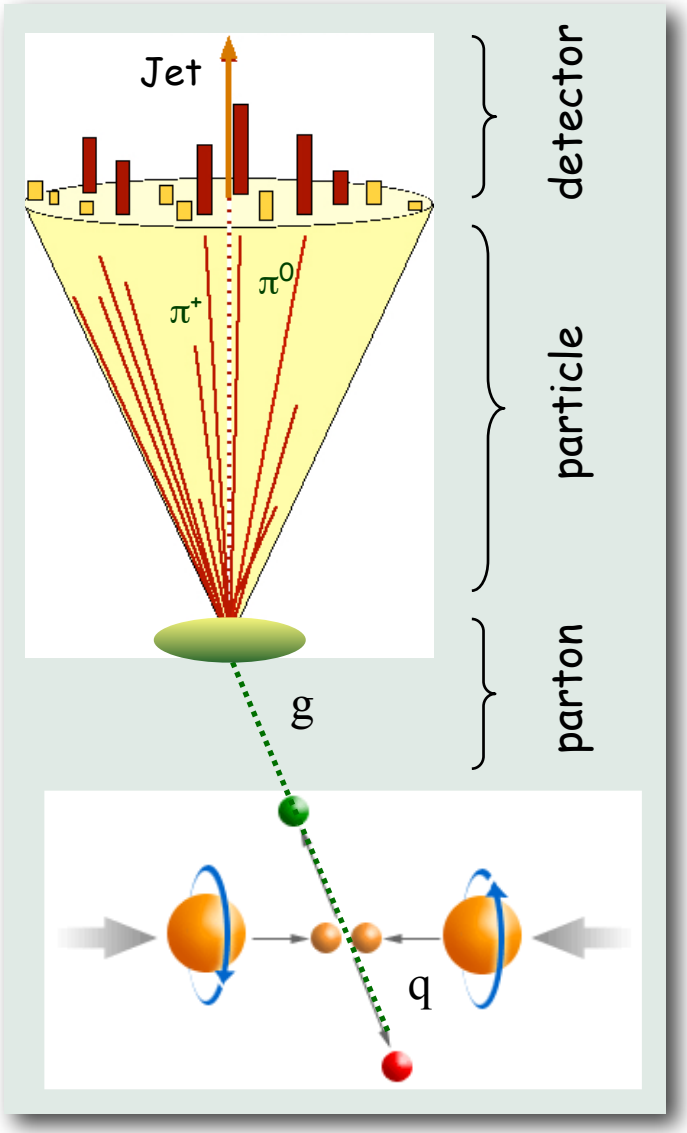

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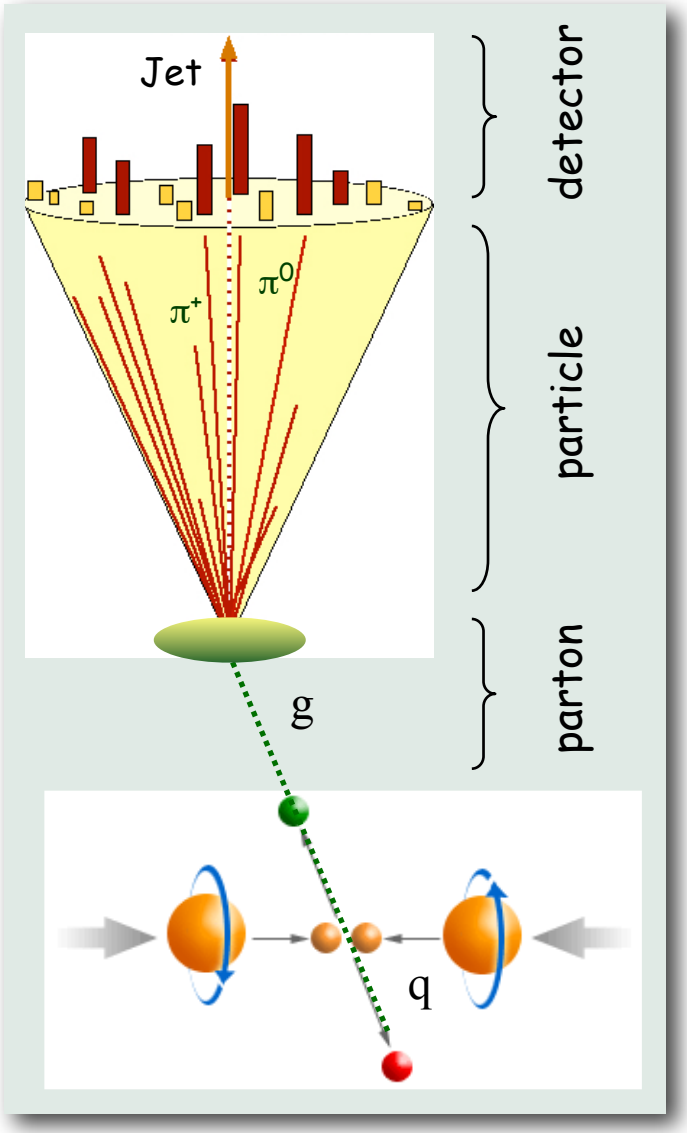

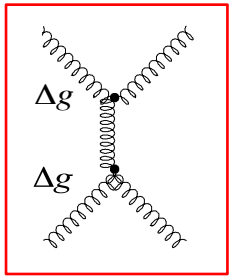

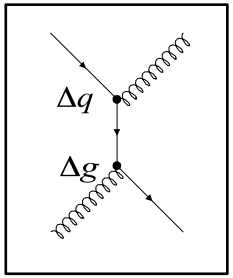

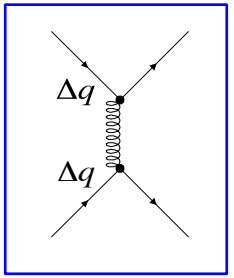

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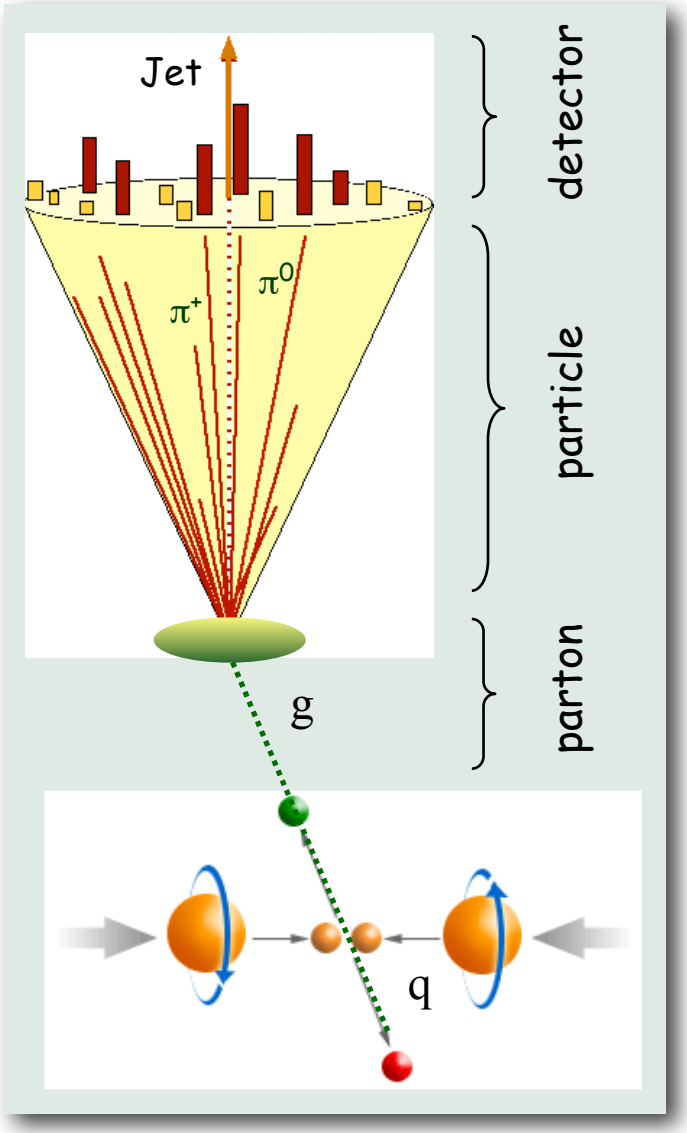
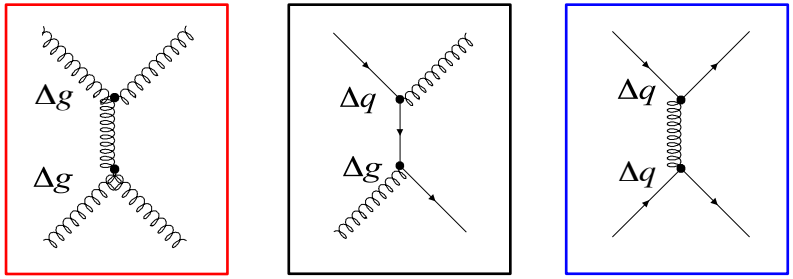
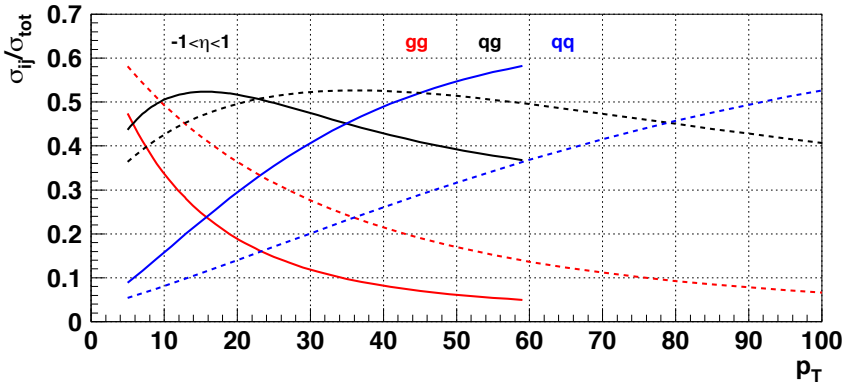
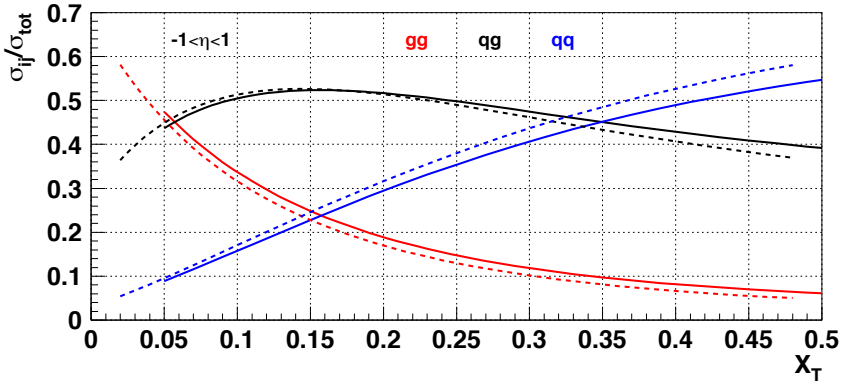




Inclusive Jet production (200GeV: Solid line / 500GeV: Dashed line)





$$x_T = 2p_T/\sqrt{s}$$

Theoretical foundation

Theoretical foundation

- Gluon polarization - Correlation Measurements

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  - Correlation measurements provide access to partonic kinematics through Di-Jet/Hadron production and Photon-Jet production

$$x_{1\,(2)} = \frac{1}{\sqrt{s}}\left(p_{T_3} e^{\eta_3(-\eta_3)} + p_{T_4} e^{\eta_4(-\eta_4)}\right)$$

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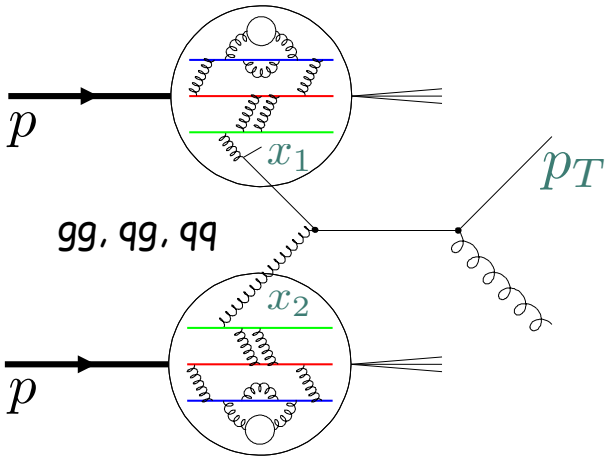

Di-Jet production

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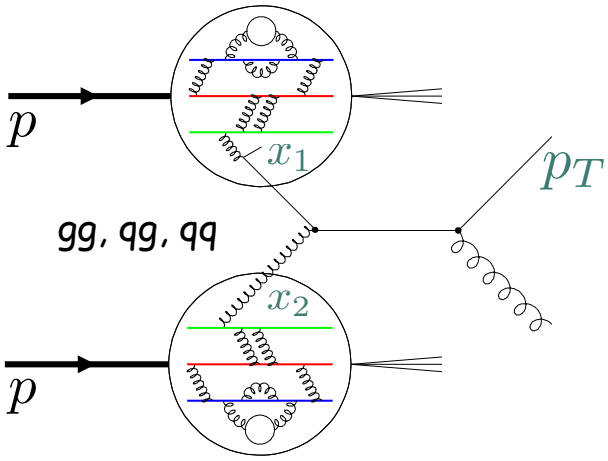
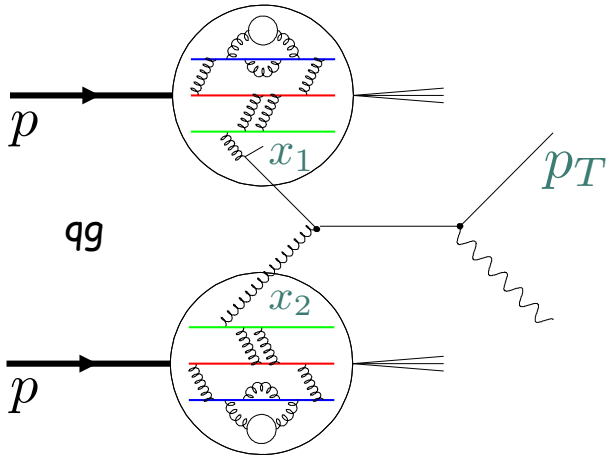


Di-Jet production



Photon-Jet production

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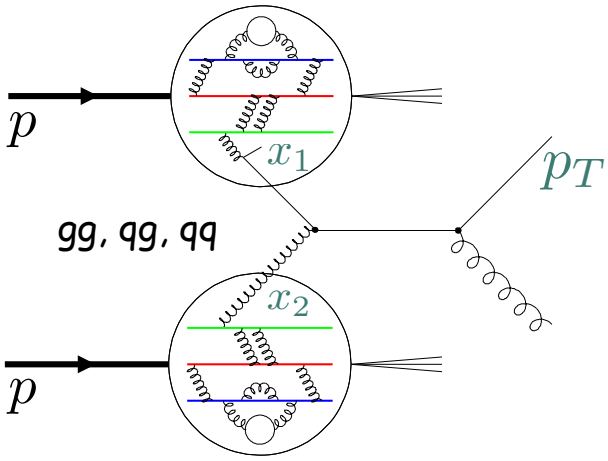

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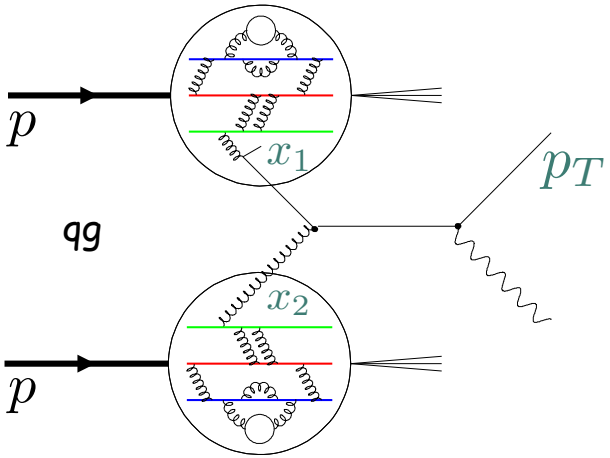

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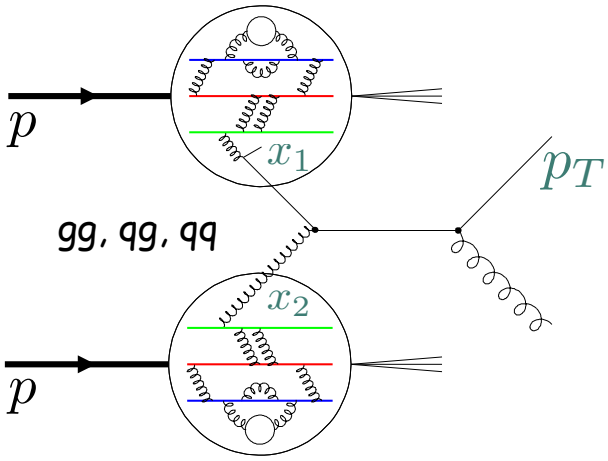
    - Di-Jets: All three (LO) QCD-type processes contribute: gg, qg and qq with relative contribution dependent on topological coverage



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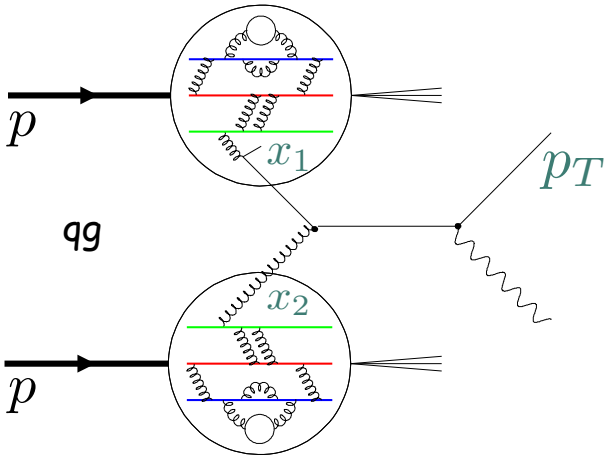

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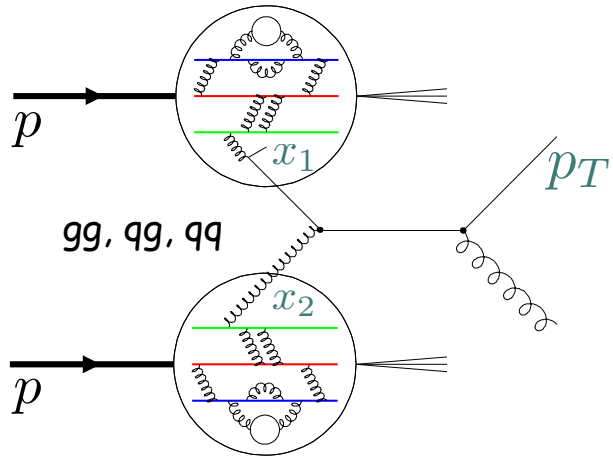

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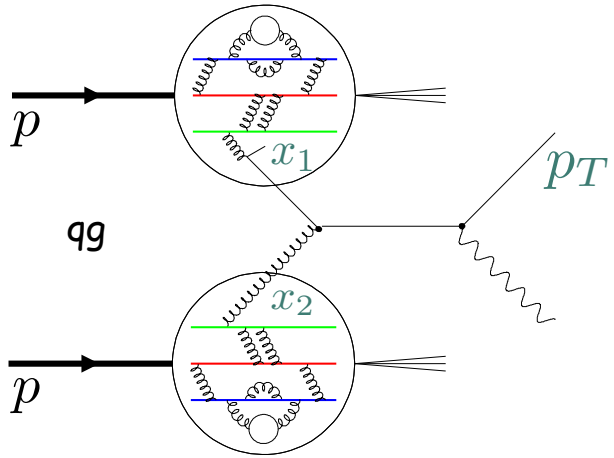

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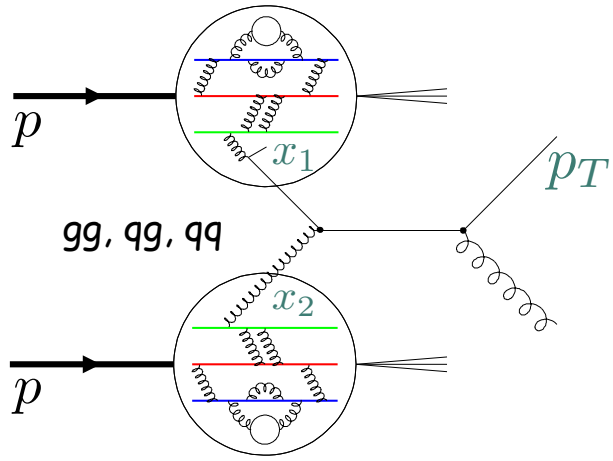

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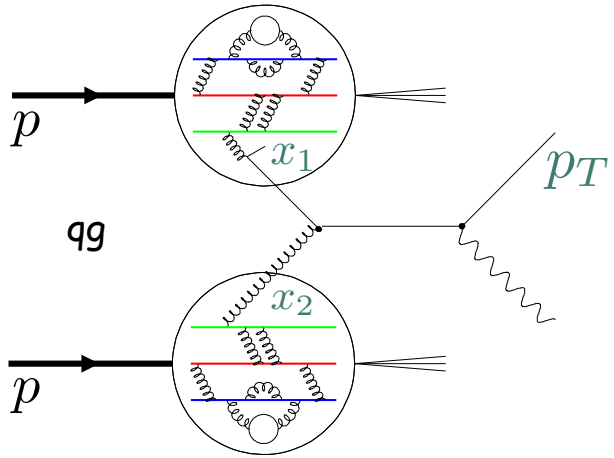

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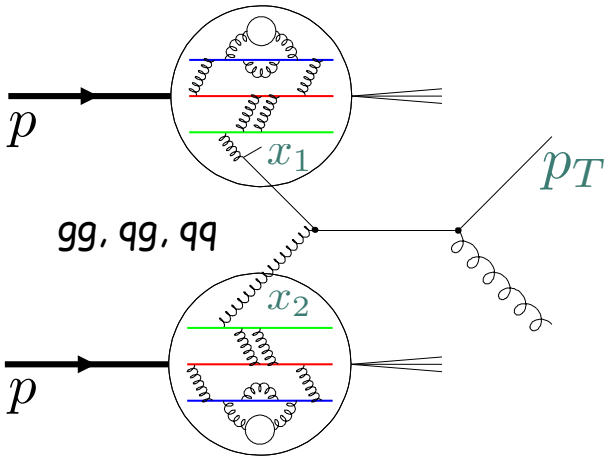

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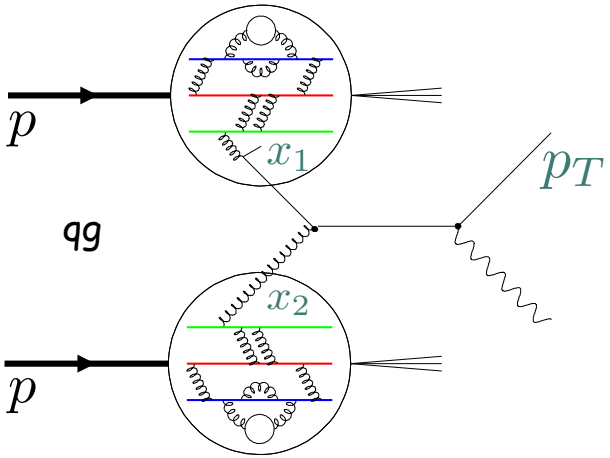

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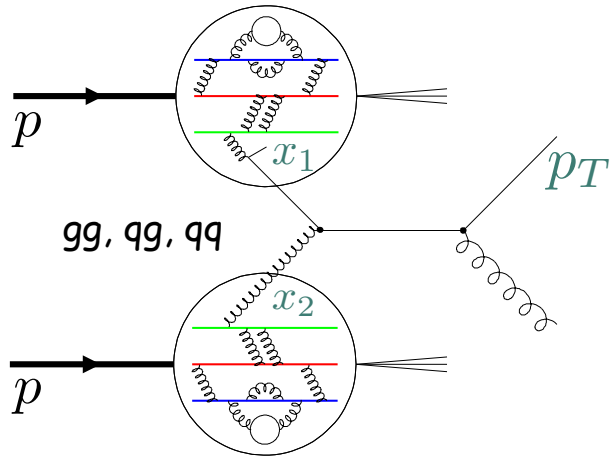
    - Photon reconstruction more challenging than jet reconstruction
    - Full NLO framework exists ⇒ Input to Global analysis



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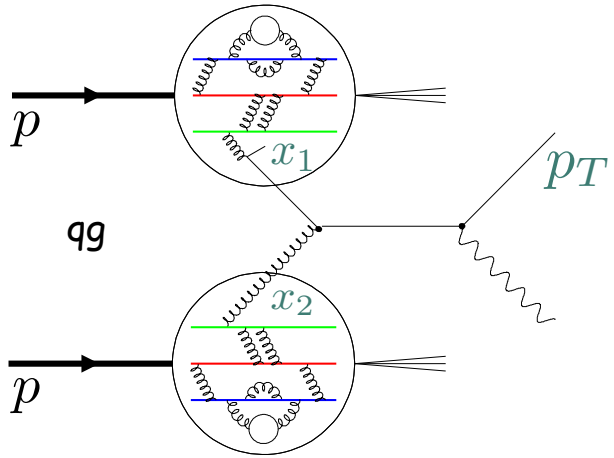

Photon-Jet production

Theoretical foundation

Theoretical foundation

- Gluon polarization - Extraction

Theoretical foundation

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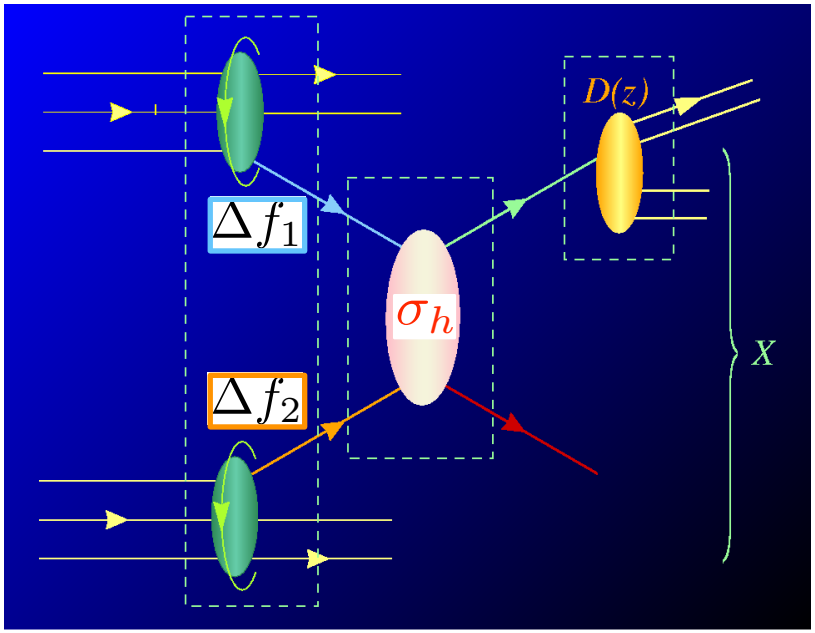

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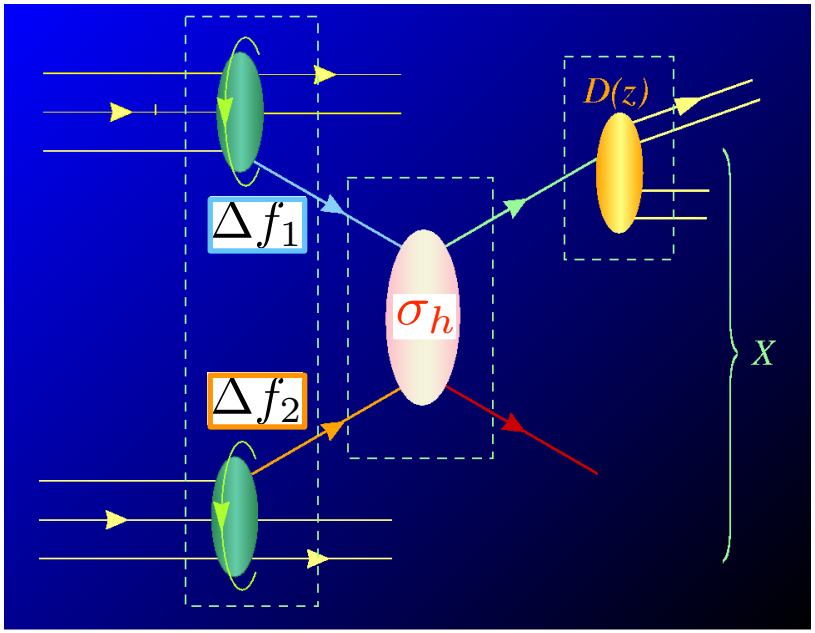
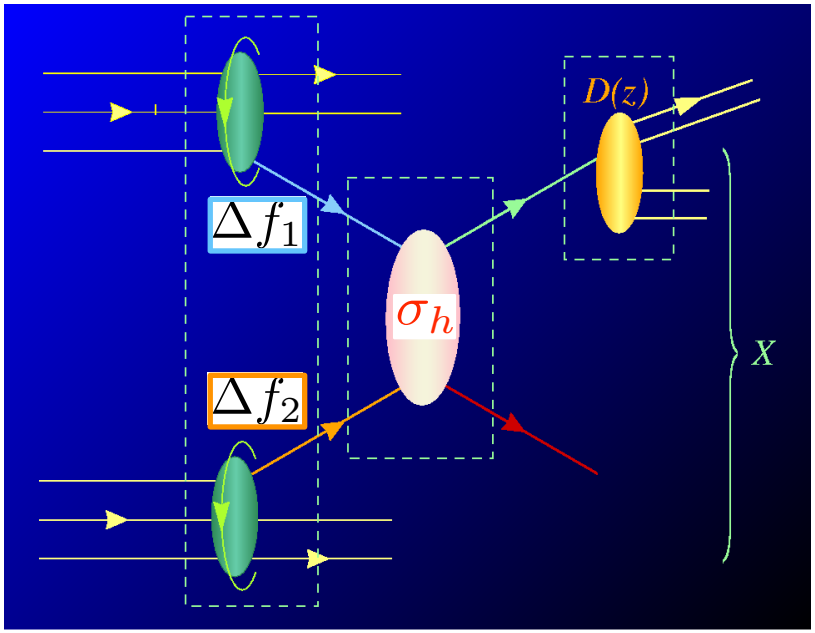


$$A_{LL} = \frac{d\Delta\sigma}{d\sigma}$$

Theoretical foundation

- Gluon polarization - Extraction

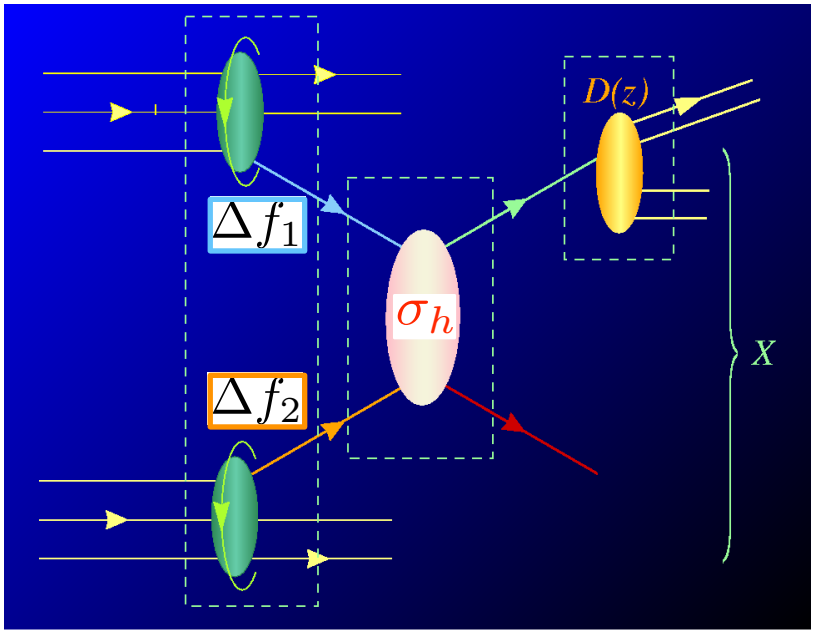


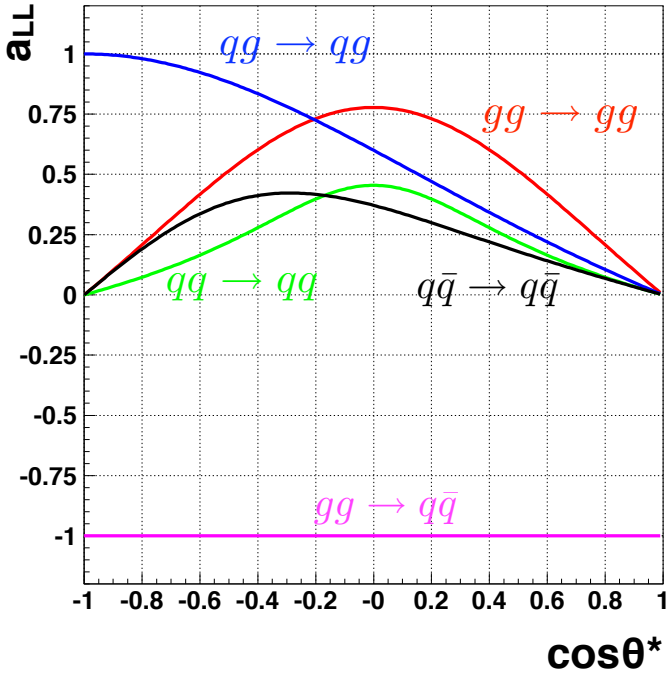
$$A_{LL} = \frac{d\Delta\sigma}{d\sigma}$$

$$\propto \frac{\Delta f_1 \otimes \Delta f_2 \otimes \sigma_h \cdot a_{LL} \otimes D_f^h}{f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h}$$

Theoretical foundation

- Gluon polarization - Extraction





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Theoretical foundation

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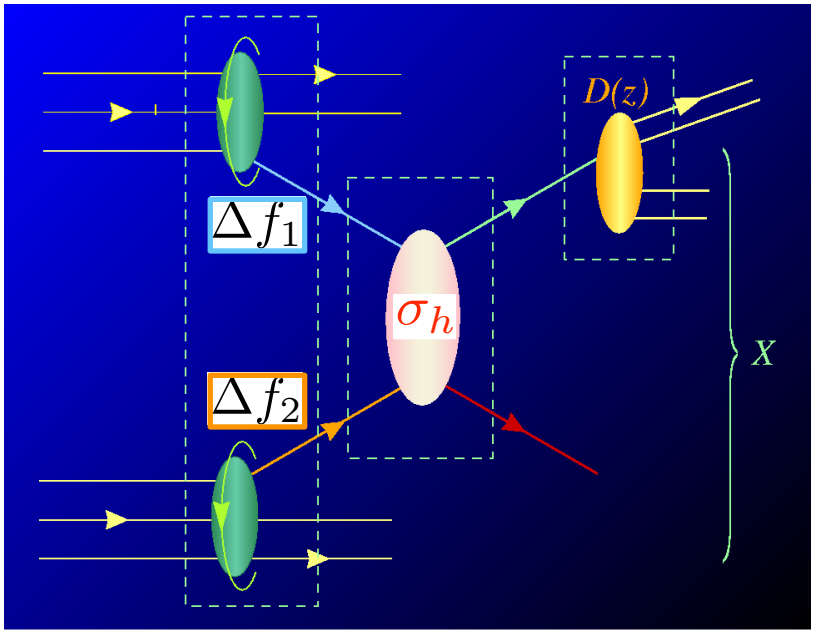

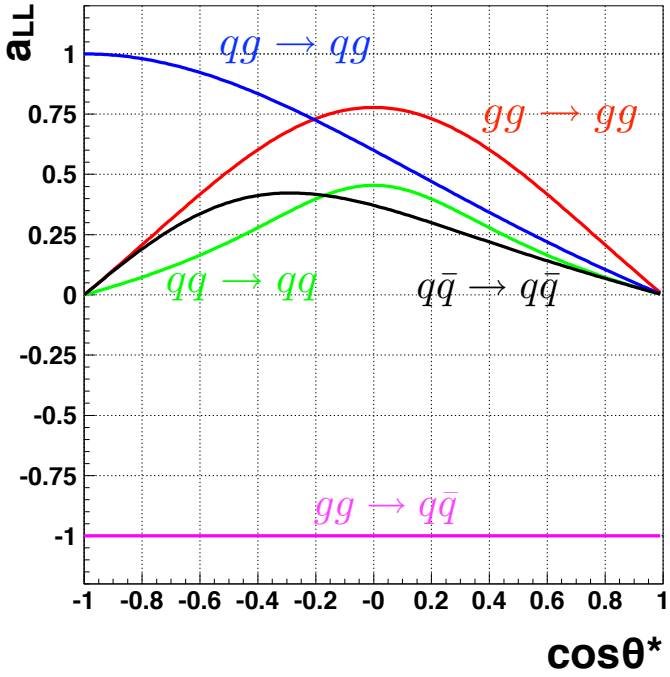

long-range | short-range | long-range

$$A_{LL} = \frac{d\Delta\sigma}{d\sigma}$$

$$a_{LL} = \frac{\Delta\sigma_h}{\sigma_h}$$

Input

$$\propto \frac{\Delta f_1 \otimes \Delta f_2 \otimes \sigma_h \cdot a_{LL} \otimes D_f^h}{f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h}$$

Theoretical foundation

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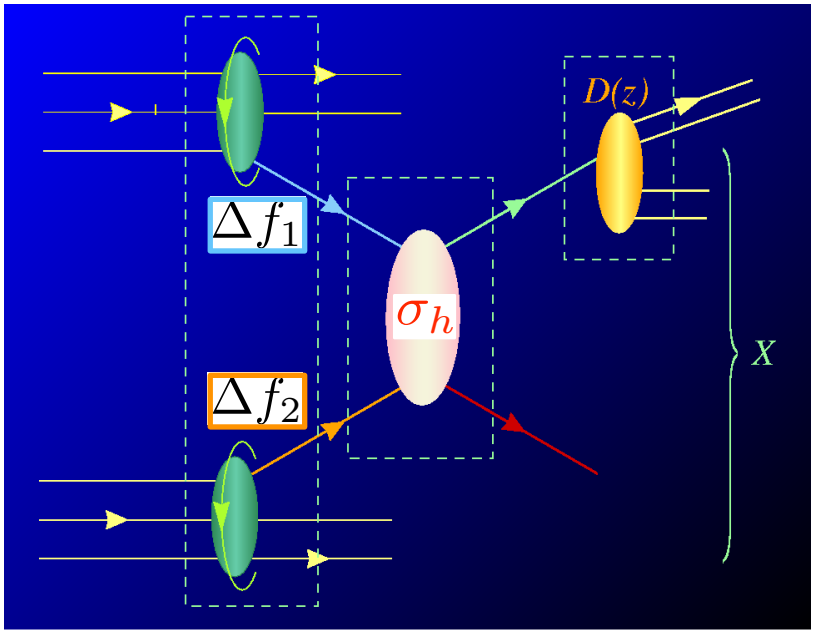

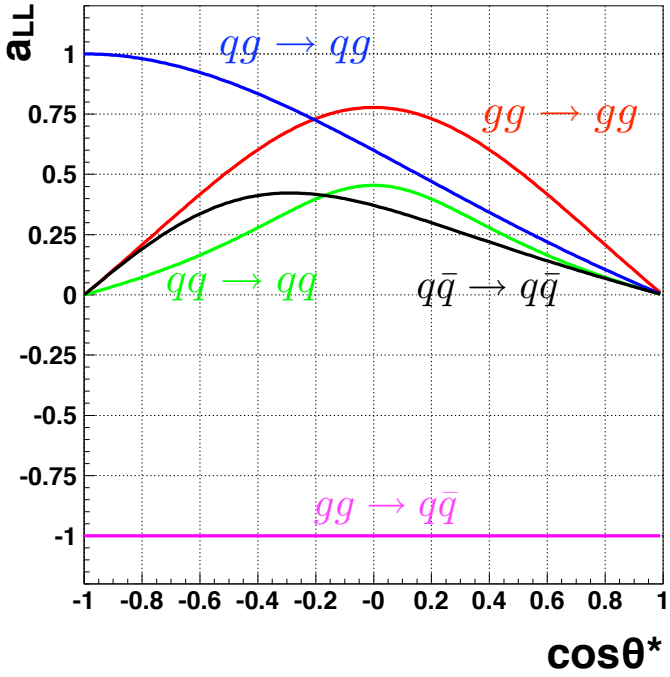

long-range short-range long-range

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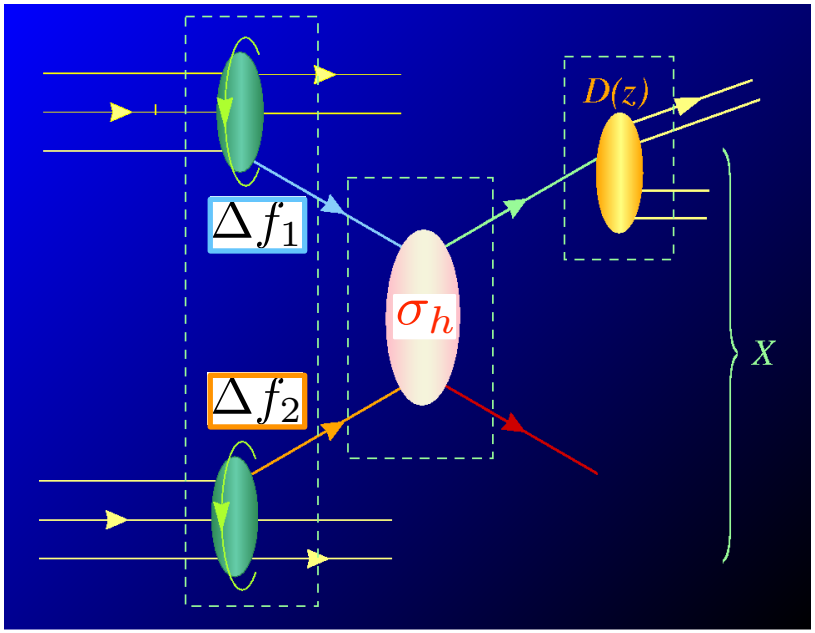
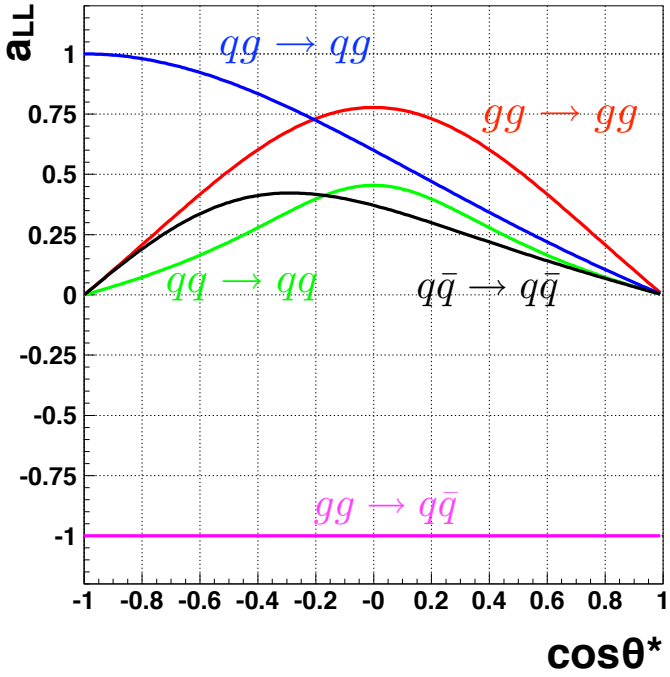
Δf_1 Δf_2 $a_{LL} = \frac{\Delta\sigma_h}{\sigma_h}$ } Input

Theoretical foundation

- Gluon polarization - Extraction

Extract $\Delta g(x,Q^2)$ through Global Fit (Higher Order QCD analysis)!





long-range | short-range | long-range

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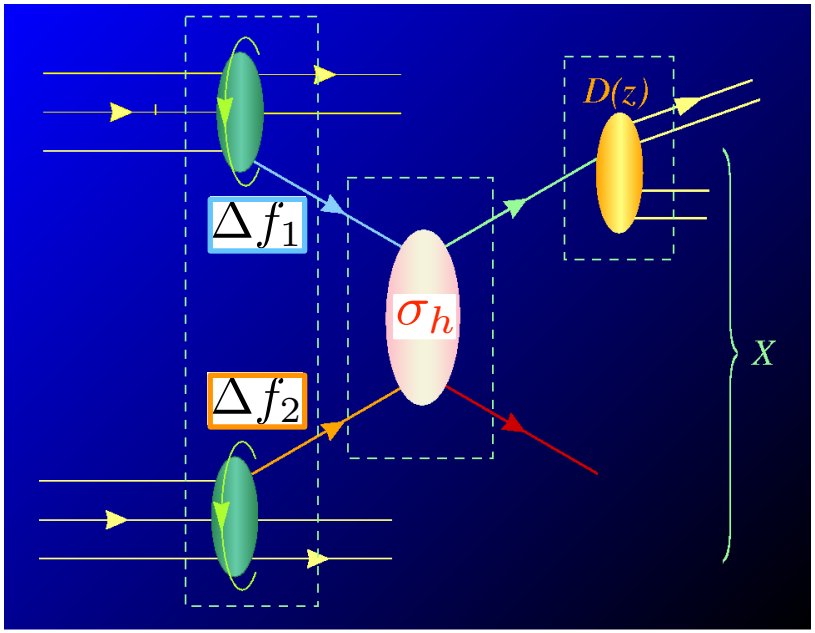

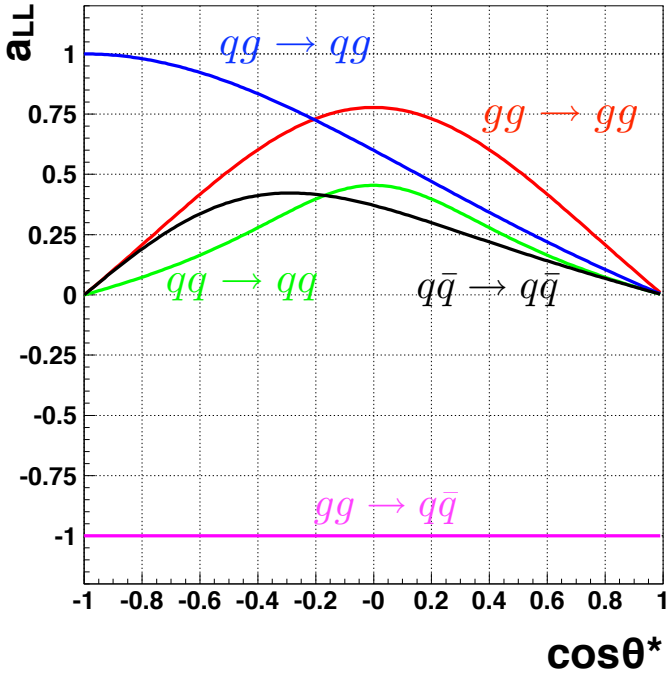

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long-range | short-range | long-range

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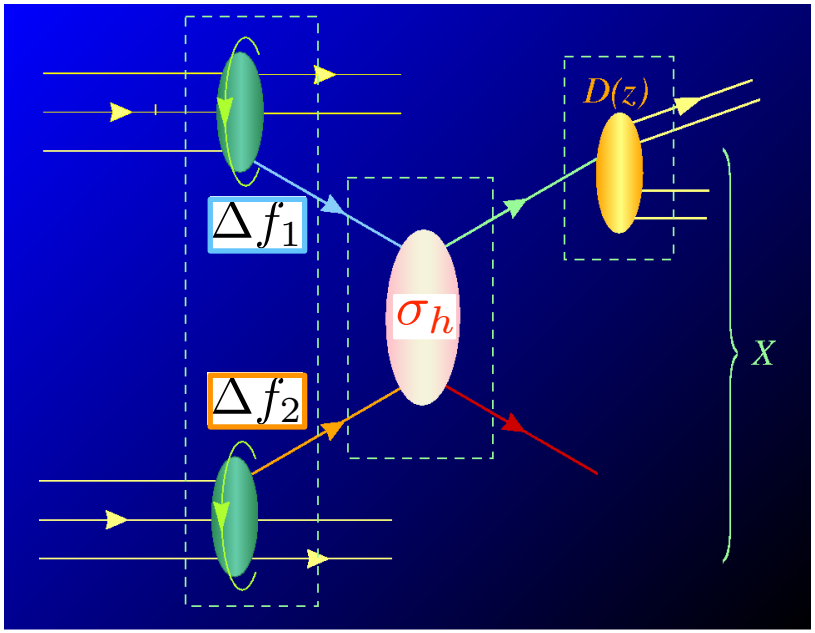

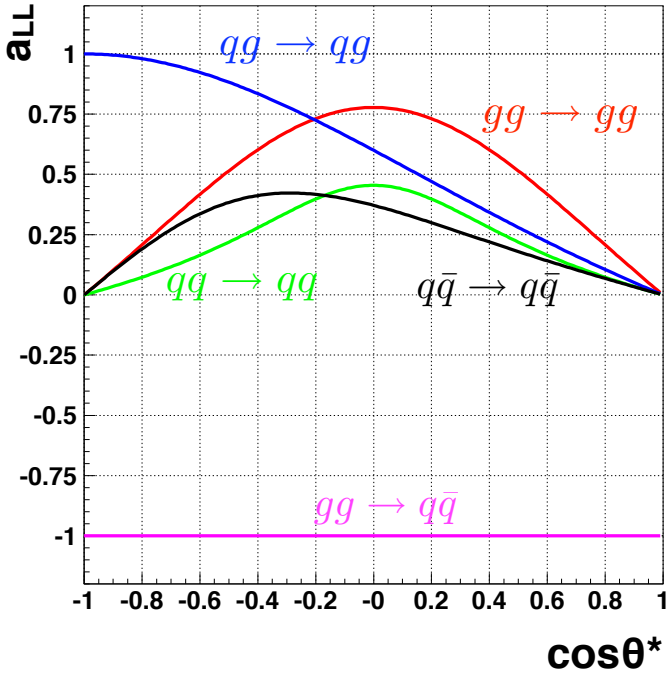

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Input

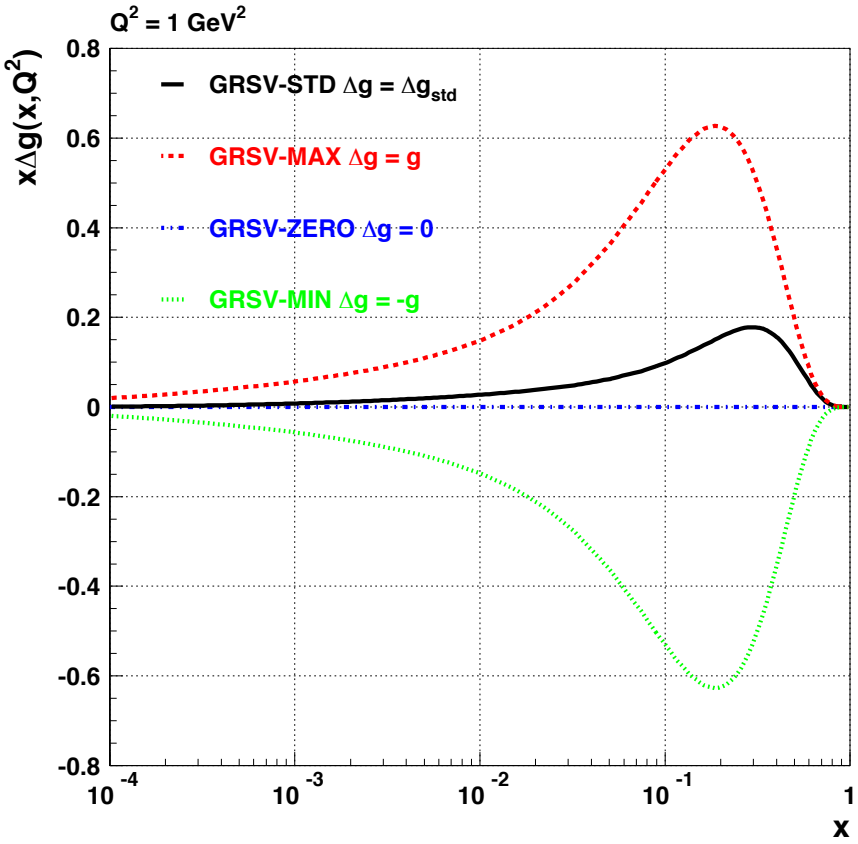
Theoretical foundation

Theoretical foundation

- Gluon polarization - Sensitivity

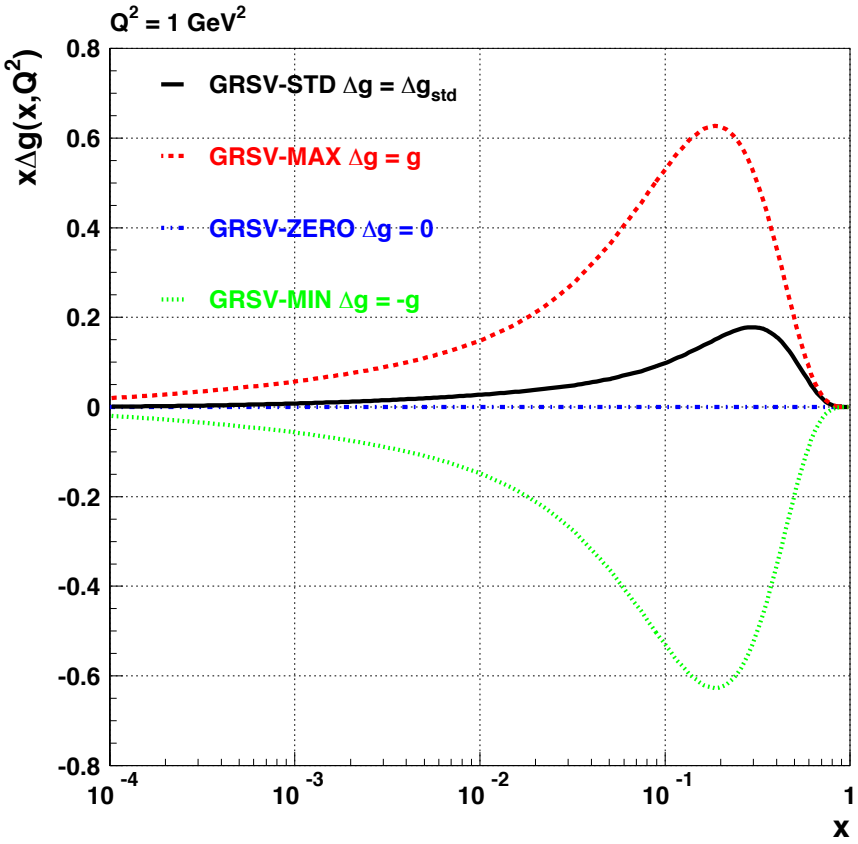
Theoretical foundation

Gluon polarization - Sensitivity



Theoretical foundation

Gluon polarization - Sensitivity



- Examine wide range in Δg: $-g < \Delta g < +g$
- GRSV-STD: Higher order QCD analysis of polarized DIS experiments!

$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$

Theoretical foundation

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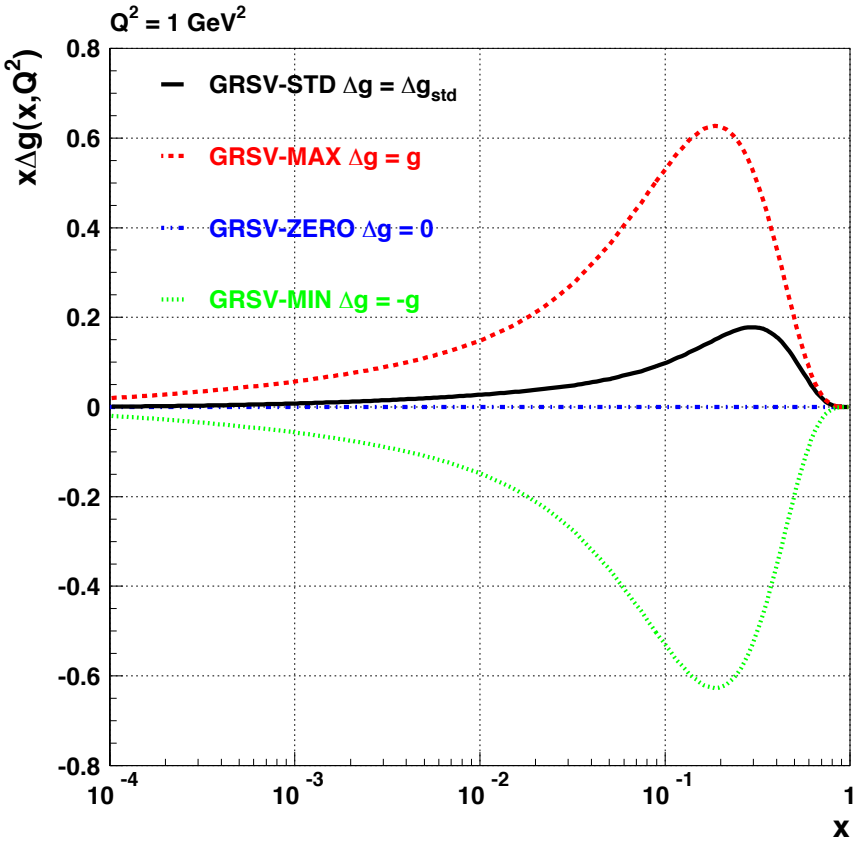

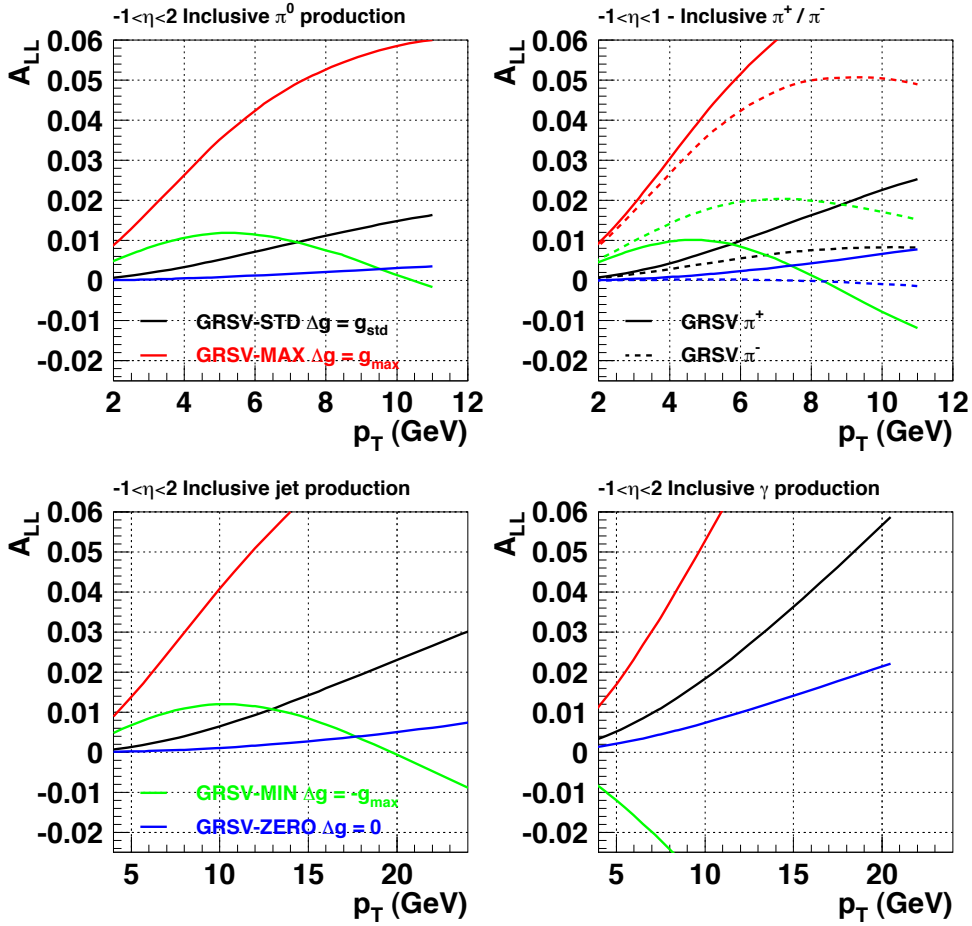

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(central rapidity)

Theoretical foundation

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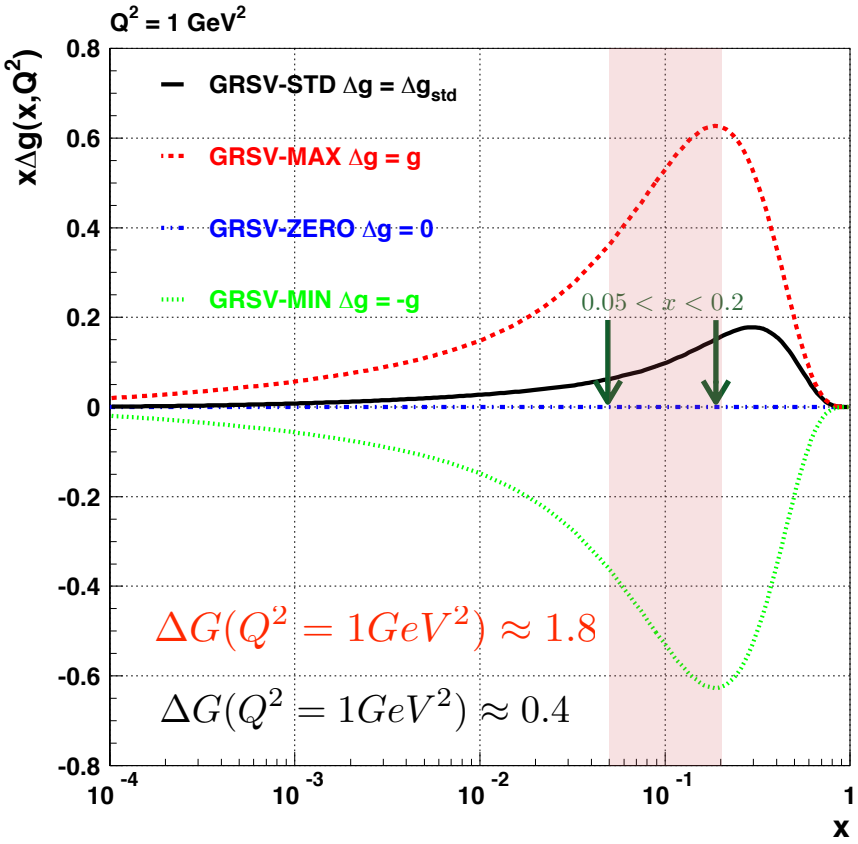

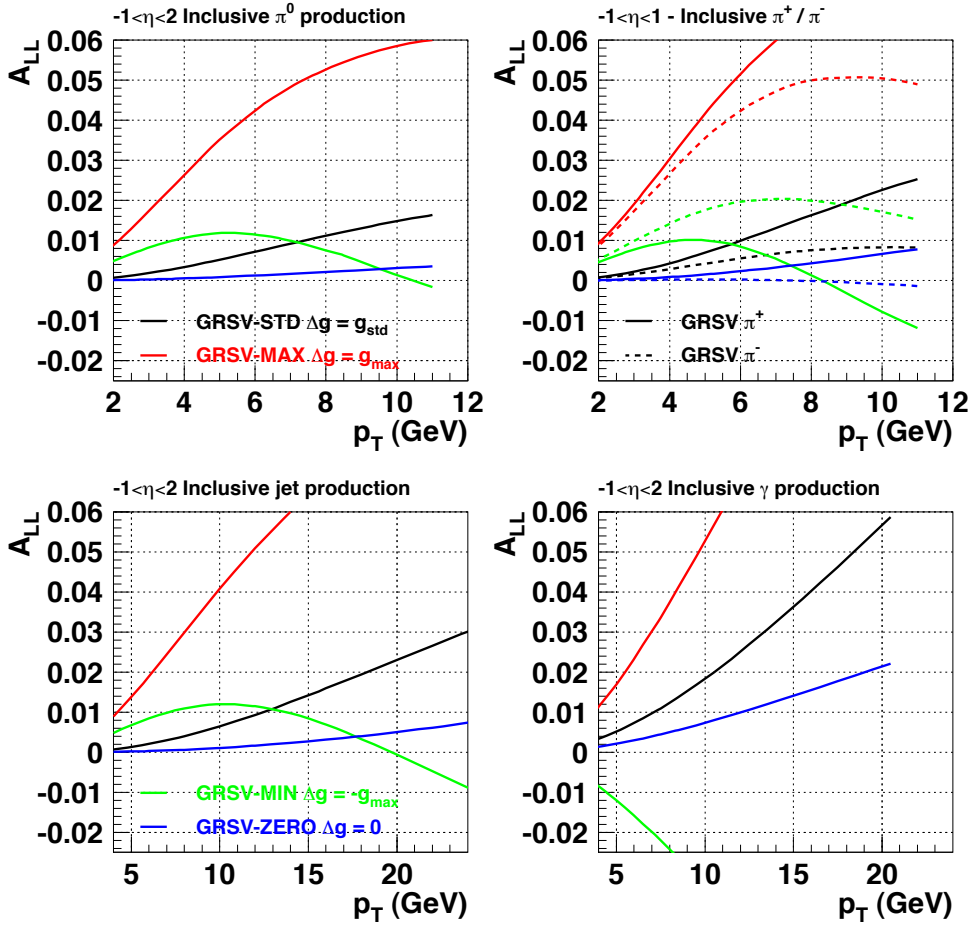

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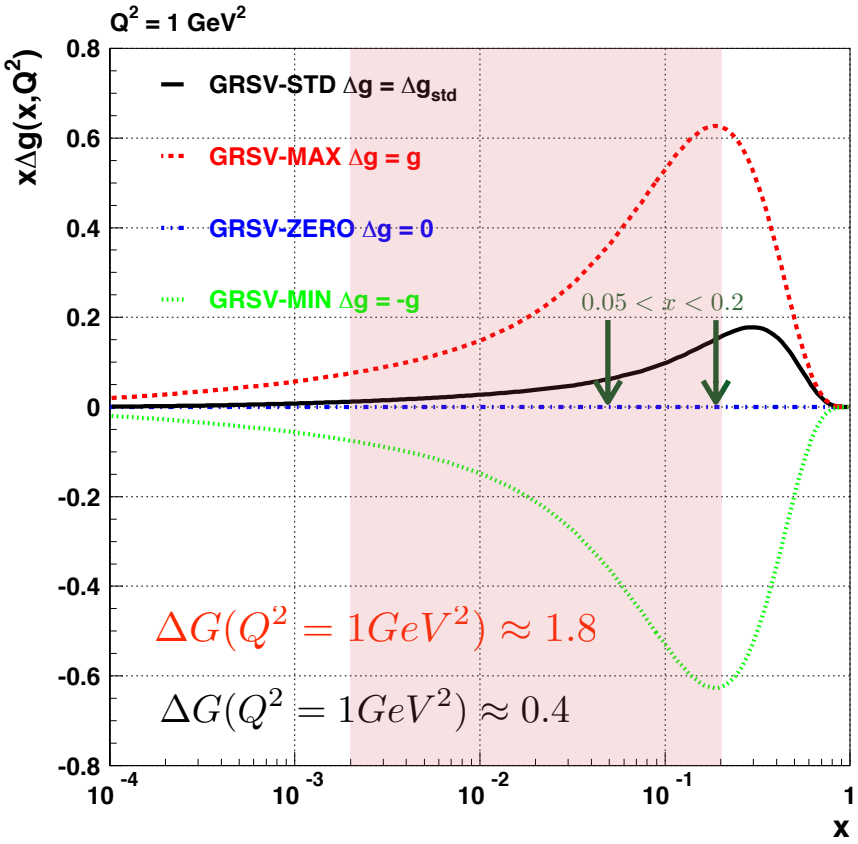
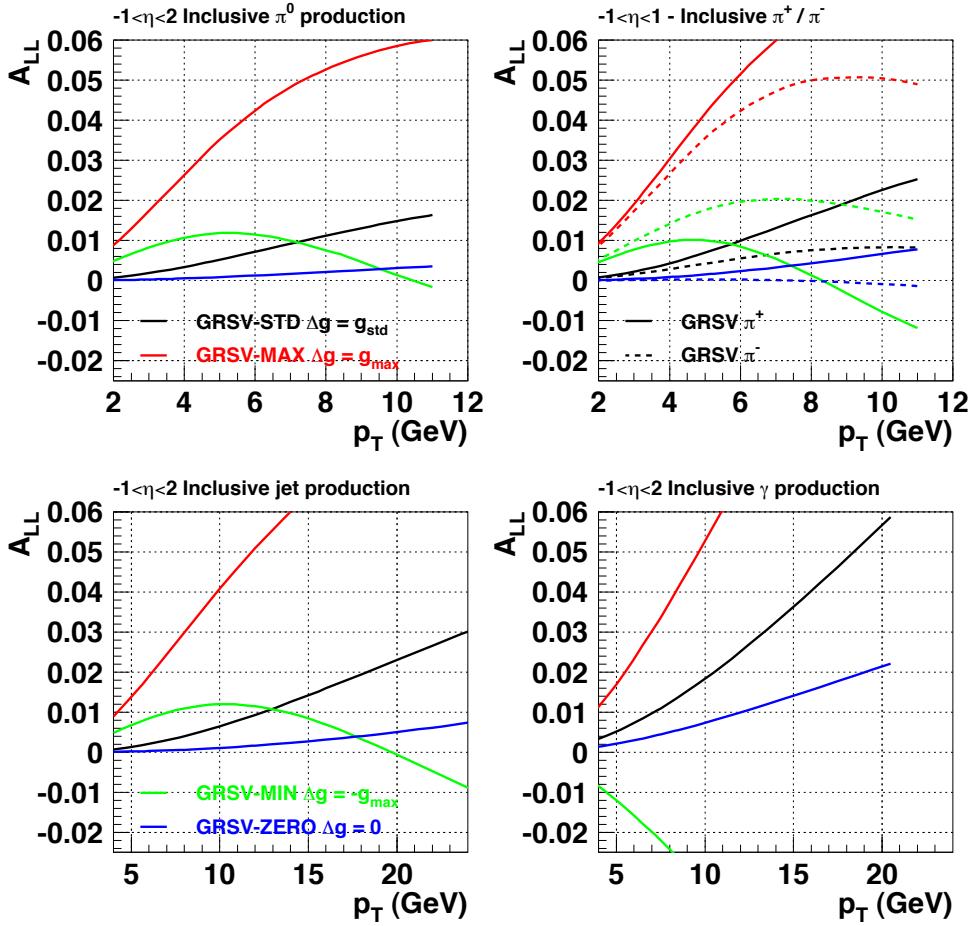
Gluon polarization - Sensitivity





- Examine wide range in Δg: $-g < \Delta g < +g$
- GRSV-STD: Higher order QCD analysis of polarized DIS experiments!

$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$

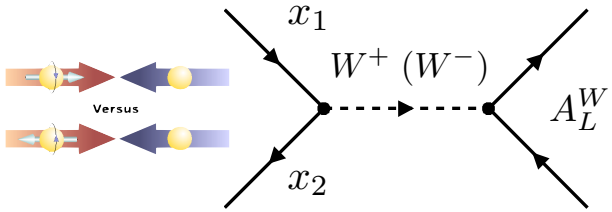
$$x_{\text{parton}} \simeq 2p_T/\sqrt{s}$$

(central rapidity)

Theoretical foundation

- STAR W program in e-decay mode at mid-rapidity and forward/backward rapidity

$u\,/\Delta u\;(d\,/\Delta d)$



$\Delta\bar{d}\,/\bar{d}\;(\Delta\bar{u}\,/\bar{u})$

$\nu_e\;(\bar{\nu}_e)$

$e^+\;(e^-)$

$$A_L^W = \frac{1}{P}\frac{N^+(W) - N^-(W)}{N^+(W) + N^-(W)}$$

$$y_l = y_W + \underbrace{\frac{1}{2}\ln\frac{1+\cos\theta^*}{1-\cos\theta^*}}_{y_l^*}$$

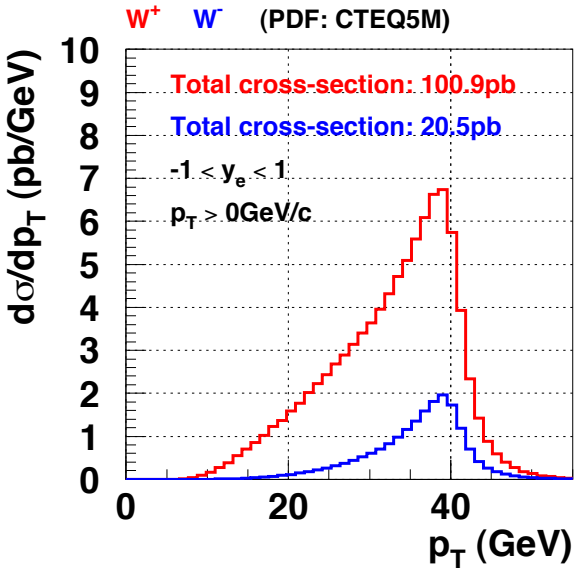
$$p_T = p_T^* = \frac{M_W}{2}\sin\theta^*$$

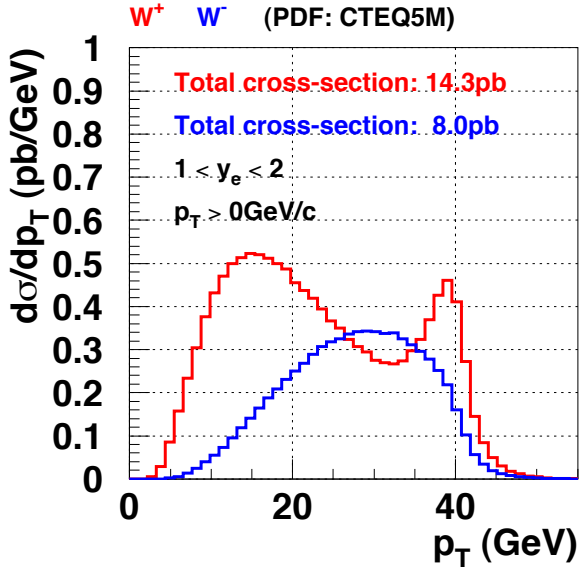
$$x_1 = \frac{M_W}{\sqrt{s}}e^{y_W}$$

$$x_2 = \frac{M_W}{\sqrt{s}}e^{-y_W}$$

$$\frac{M_W}{\sqrt{s}} = 0.16$$

- Key signature: High p_T lepton (e^-/e^+)(Max. $M_W/2$) - Selection of W^+/W^- : Charge sign discrimination of high p_T lepton
- Required: Lepton/Hadron discrimination



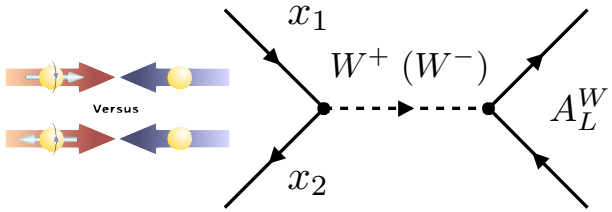


Total (√s=500GeV) σ(W⁺)=135pb and σ(W⁻)=42pb

Theoretical foundation

- STAR W program in e-decay mode at mid-rapidity and forward/backward rapidity

$u/\Delta u\ (d/\Delta d)$



$\Delta\bar{d}/\bar{d}\ (\Delta\bar{u}/\bar{u})$

$\nu_e\ (\bar{\nu}_e)$

$e^+\ (e^-)$

$$A_L^W = \frac{1}{P}\frac{N^+(W) - N^-(W)}{N^+(W) + N^-(W)}$$

$$y_l = y_W + \underbrace{\frac{1}{2}\ln\frac{1+\cos\theta^*}{1-\cos\theta^*}}_{y_l^*}$$

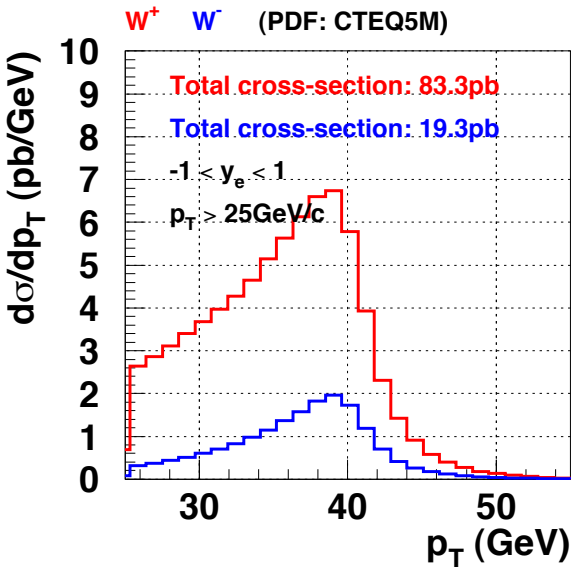
$$p_T = p_T^* = \frac{M_W}{2}\sin\theta^*$$

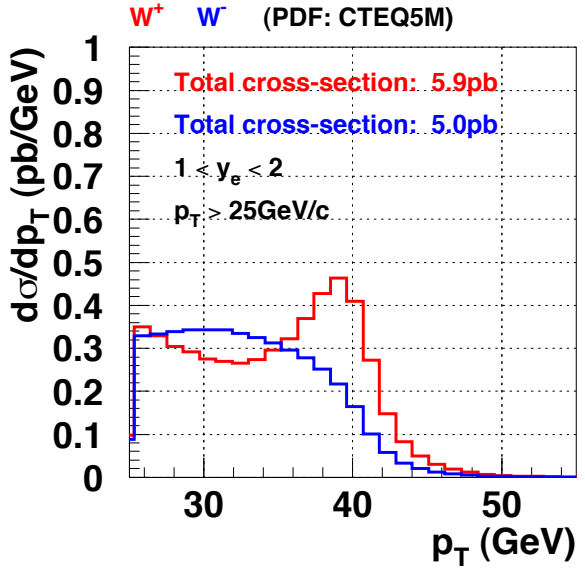
$$x_1 = \frac{M_W}{\sqrt{s}}e^{y_W}$$

$$x_2 = \frac{M_W}{\sqrt{s}}e^{-y_W}$$

$$\frac{M_W}{\sqrt{s}} = 0.16$$

- Key signature: High p_T lepton (e^-/e^+)(Max. $M_W/2$) - Selection of W^+/W^- : Charge sign discrimination of high p_T lepton
- Required: Lepton/Hadron discrimination





Total (√s=500GeV) σ(W⁺)=135pb and σ(W⁻)=42pb

Theoretical foundation

- W boson kinematics relevant for STAR rapidity acceptance

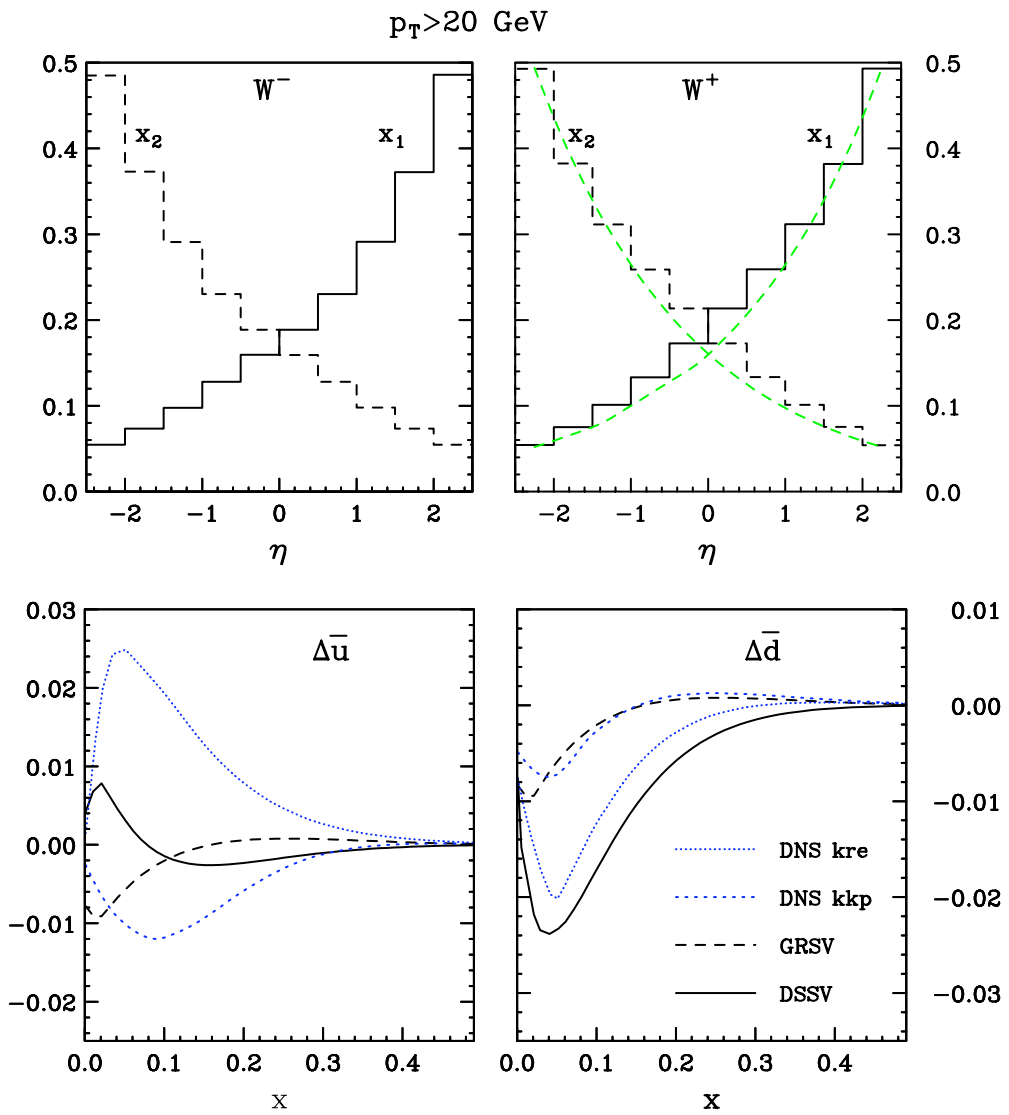
  - Leptonic rapidity inherits relation to mean x

  - Forward rapidity:
    - $\eta > 0$
    - $\langle x_1 \rangle$ larger than $\langle x_2 \rangle$

  - Backward rapidity:
    - $\eta < 0$
    - $\langle x_1 \rangle$ less than $\langle x_2 \rangle$

  - Mid-rapidity:
    - $\eta \sim 0$
    - $\langle x_1 \rangle$ similar to $\langle x_2 \rangle$

$< X >$



$$< X_{1,2} > \simeq \frac{M_W}{\sqrt{S}} e^{[\pm\eta/2]}$$

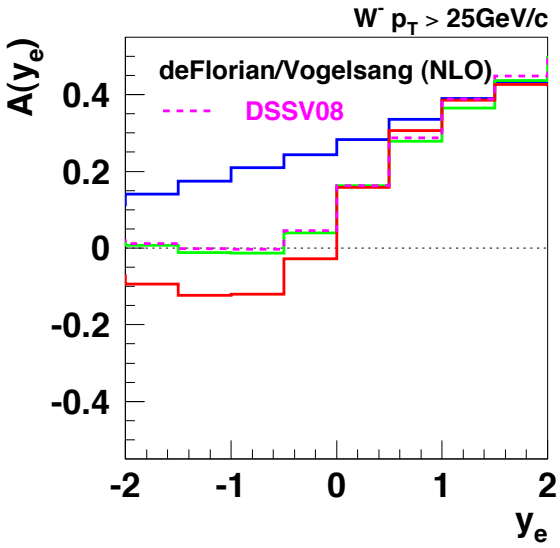
D. deFlorian and W. Vogelsang, hep-ph/1003.4533

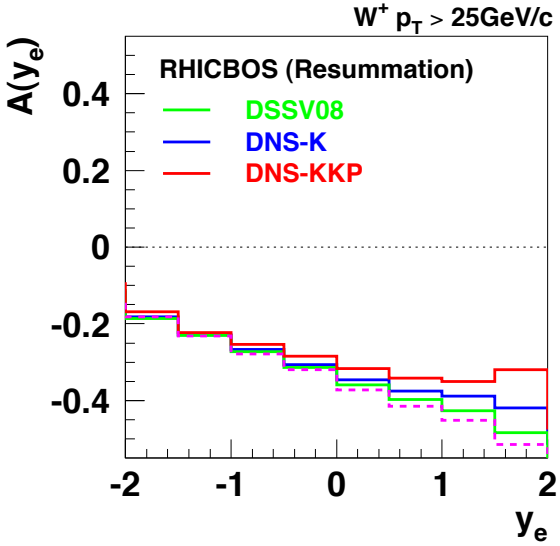
Theoretical foundation

- A_L behavior for STAR mid-rapidity and forward/backward rapidity region

Theoretical foundation

- A_L behavior for STAR mid-rapidity and forward/backward rapidity region





Calculations:

1) RHICBOS: P.M. Nadolsky and C.-P. Yuan, Nucl. Phys. B666 (2003) 31.

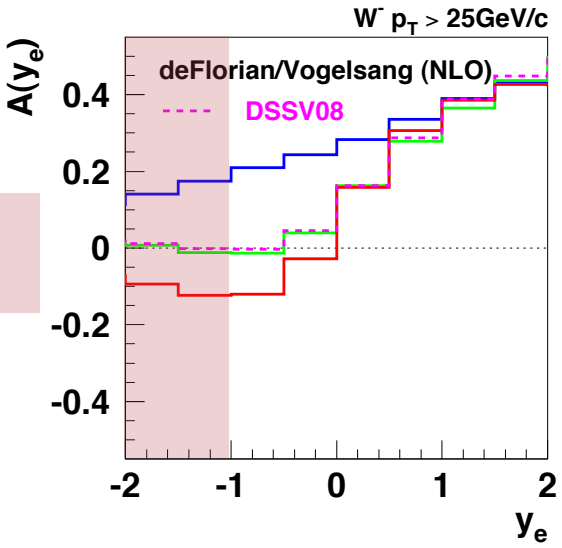
2) deFlorian / Vogelsang: D. deFlorian, private communications.

Theoretical foundation

- A_L behavior for STAR mid-rapidity and forward/backward rapidity region

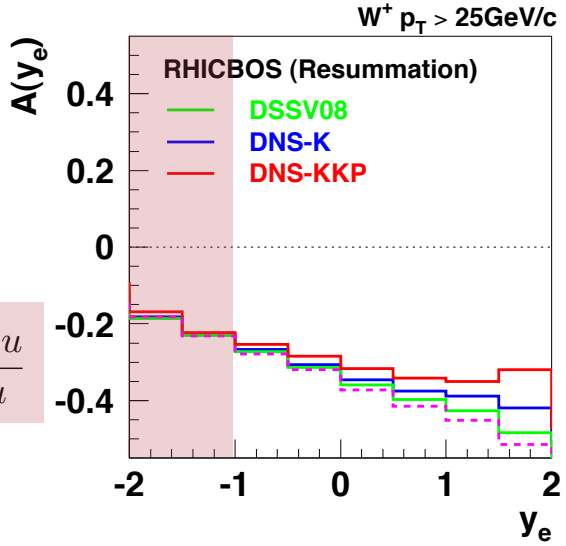
$$A_L^{W^-} = \frac{\Delta\bar{u}}{\bar{u}}$$

$$x_1 \ll x_2$$



$$A_L^{W^+} = -\frac{\Delta u}{u}$$

$$x_1 \ll x_2$$



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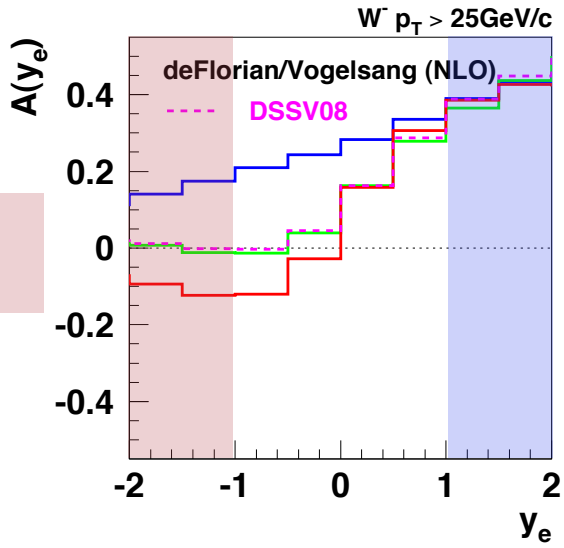
Theoretical foundation

- A_L behavior for STAR mid-rapidity and forward/backward rapidity region

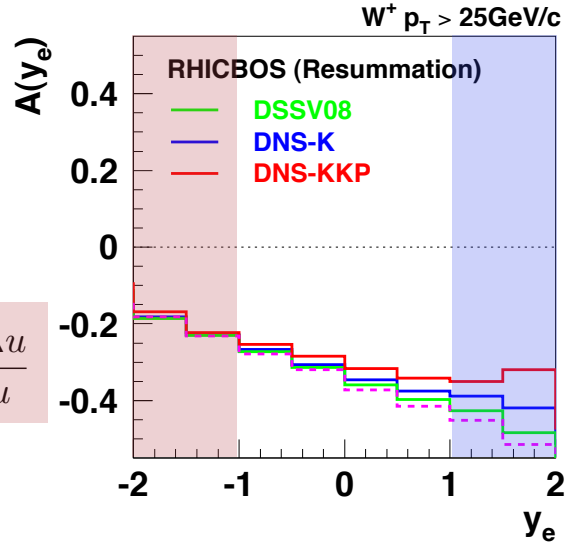


$$A_L^{W^-} = \frac{\Delta \bar{u}}{\bar{u}}$$

$x_1 \ll x_2$

$$A_L^{W^-} = -\frac{\Delta d}{d}$$

$x_1 \gg x_2$



$$A_L^{W^+} = -\frac{\Delta u}{u}$$

$x_1 \ll x_2$

$$A_L^{W^+} = \frac{\Delta \bar{d}}{\bar{d}}$$

$x_1 \gg x_2$

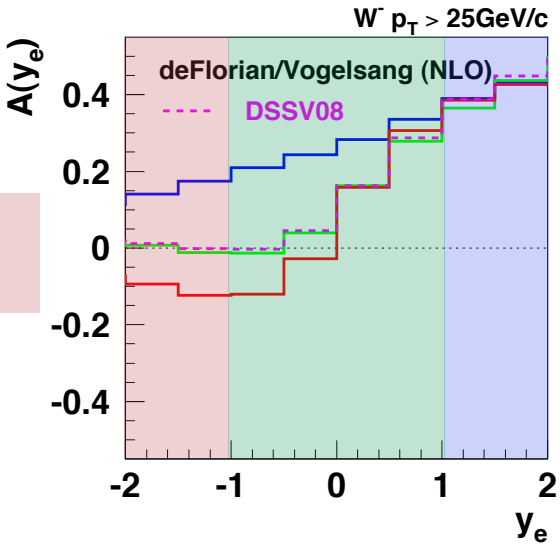
Calculations:

1) RHICBOS: P.M. Nadolsky and C.-P. Yuan, Nucl. Phys. B666 (2003) 31.

2) deFlorian / Vogelsang: D. deFlorian, private communications.

Theoretical foundation

- A_L behavior for STAR mid-rapidity and forward/backward rapidity region



$$A_L^{W^-} = \frac{\Delta\bar{u}}{\bar{u}}$$

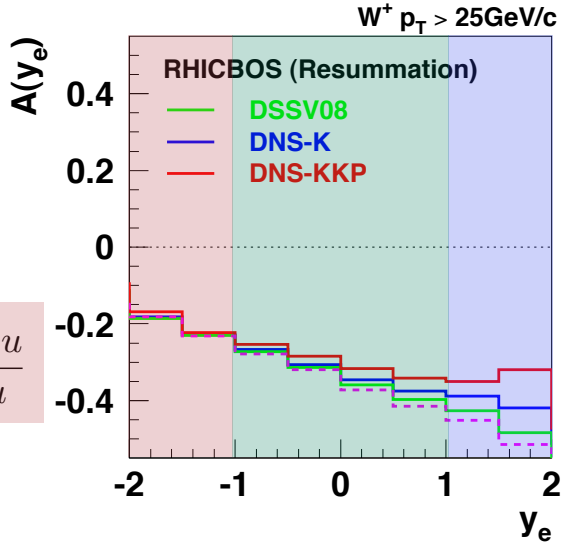
$x_1 \ll x_2$

$$A_L^{W^-} = -\frac{\Delta d}{d}$$

$x_1 \gg x_2$

$$A_L^{W^-} = \frac{1}{2}\left(\frac{\Delta\bar{u}}{\bar{u}} - \frac{\Delta d}{d}\right)$$

$x_1 = x_2$



$$A_L^{W^+} = \frac{\Delta\bar{d}}{\bar{d}}$$

$x_1 \gg x_2$

$$A_L^{W^+} = -\frac{\Delta u}{u}$$

$x_1 \ll x_2$

$$A_L^{W^+} = \frac{1}{2}\left(\frac{\Delta\bar{d}}{\bar{d}} - \frac{\Delta u}{u}\right)$$

Calculations:

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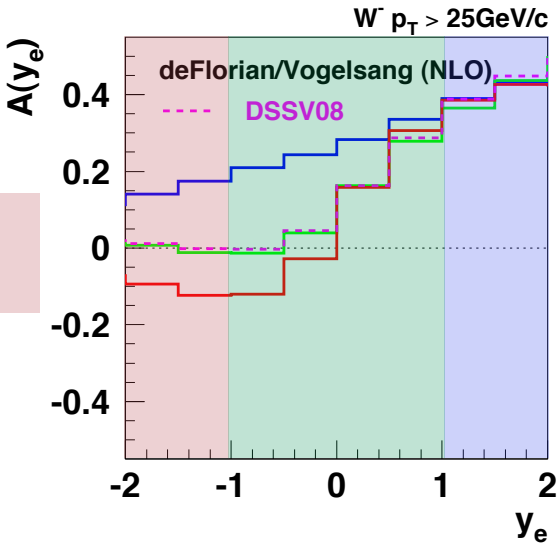
Theoretical foundation

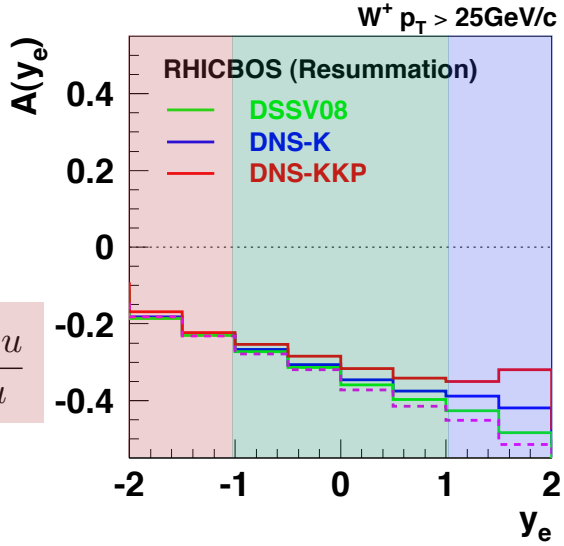
- A_L behavior for STAR mid-rapidity and forward/backward rapidity region



$$A_L^{W^-} = \frac{\Delta\bar{u}}{\bar{u}} \qquad x_1 \ll x_2$$

$$A_L^{W^-} = -\frac{\Delta d}{d} \qquad x_1 \gg x_2$$

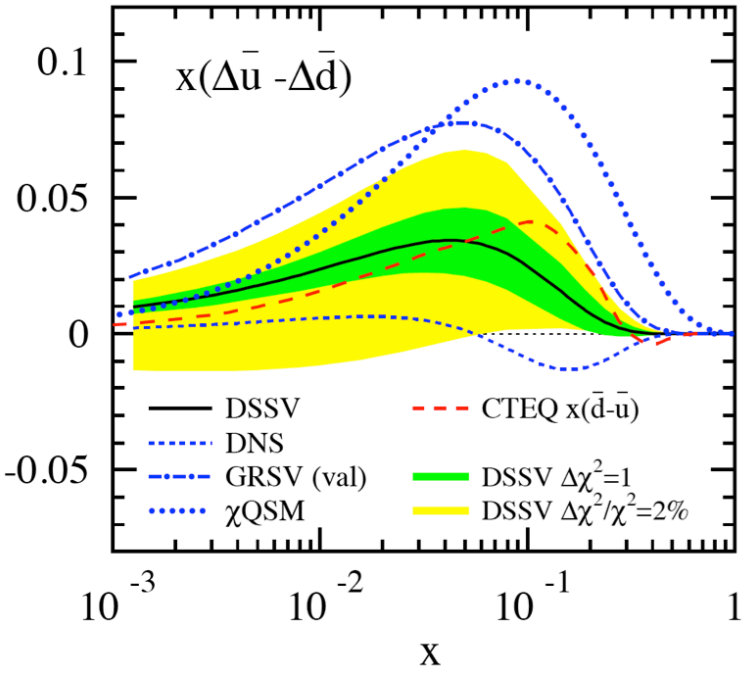
$$A_L^{W^-} = \frac{1}{2}\left(\frac{\Delta\bar{u}}{\bar{u}} - \frac{\Delta d}{d}\right) \qquad x_1 = x_2$$



$$A_L^{W^+} = \frac{\Delta\bar{d}}{\bar{d}} - \frac{\Delta u}{u}$$

$$A_L^{W^+} = -\frac{\Delta u}{u} \qquad x_1 \ll x_2$$

$$A_L^{W^+} = \frac{\Delta\bar{d}}{\bar{d}} \qquad x_1 \gg x_2$$



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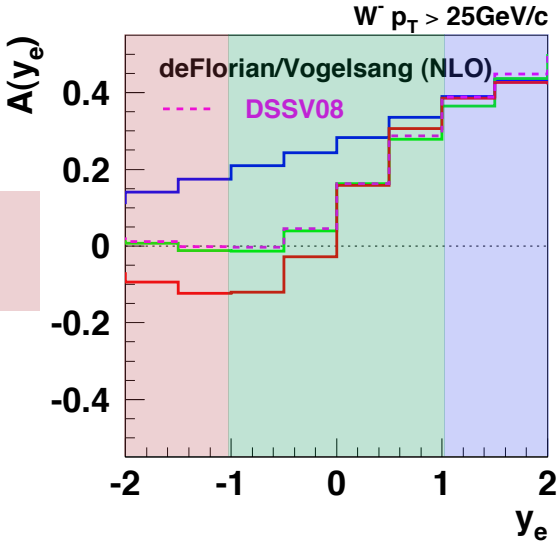
Theoretical foundation

- A_L behavior for STAR mid-rapidity and forward/backward rapidity region

$$A_L^{W^-} = \frac{\Delta\bar{u}}{\bar{u}} \qquad x_1 \ll x_2$$



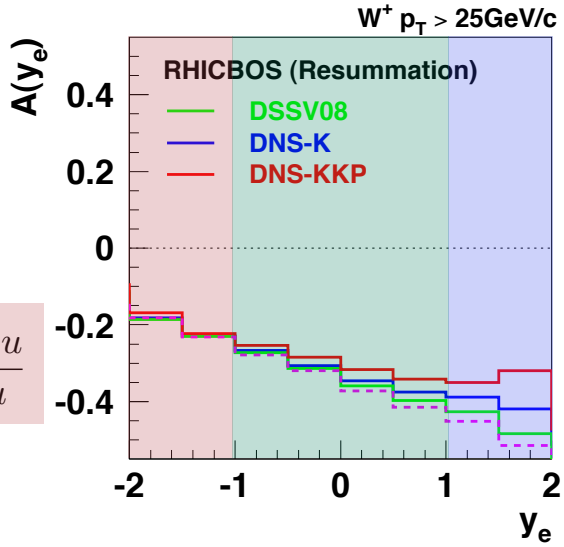
$$A_L^{W^-} = -\frac{\Delta d}{d} \qquad x_1 \gg x_2$$

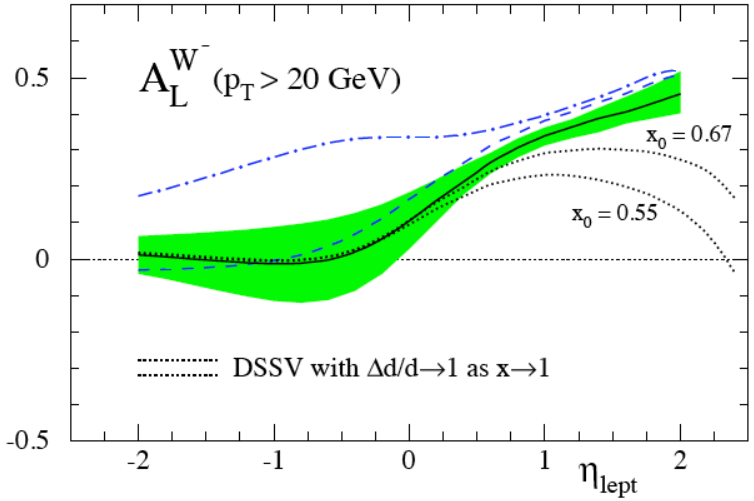
$$A_L^{W^-} = \frac{1}{2}\left(\frac{\Delta\bar{u}}{\bar{u}} - \frac{\Delta d}{d}\right) \qquad x_1 = x_2$$

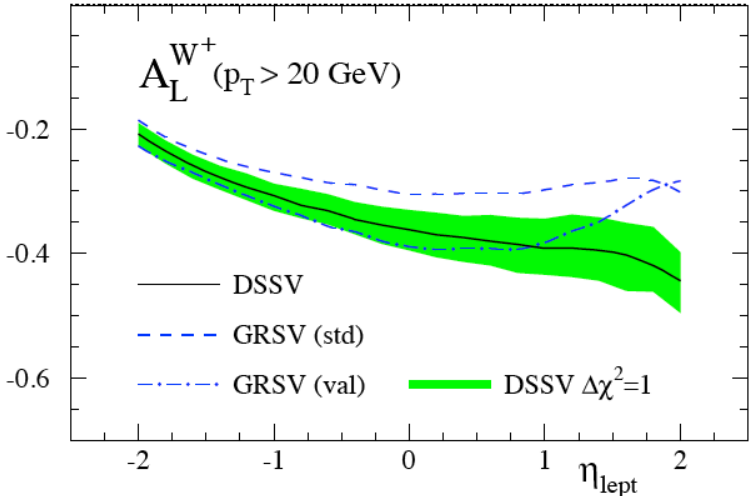
$$A_L^{W^+} = \frac{1}{2}\left(\frac{\Delta\bar{d}}{\bar{d}} - \frac{\Delta u}{u}\right)$$

$$A_L^{W^+} = \frac{\Delta\bar{d}}{\bar{d}} \qquad x_1 \gg x_2$$

$$A_L^{W^+} = -\frac{\Delta u}{u} \qquad x_1 \ll x_2$$







Calculations:

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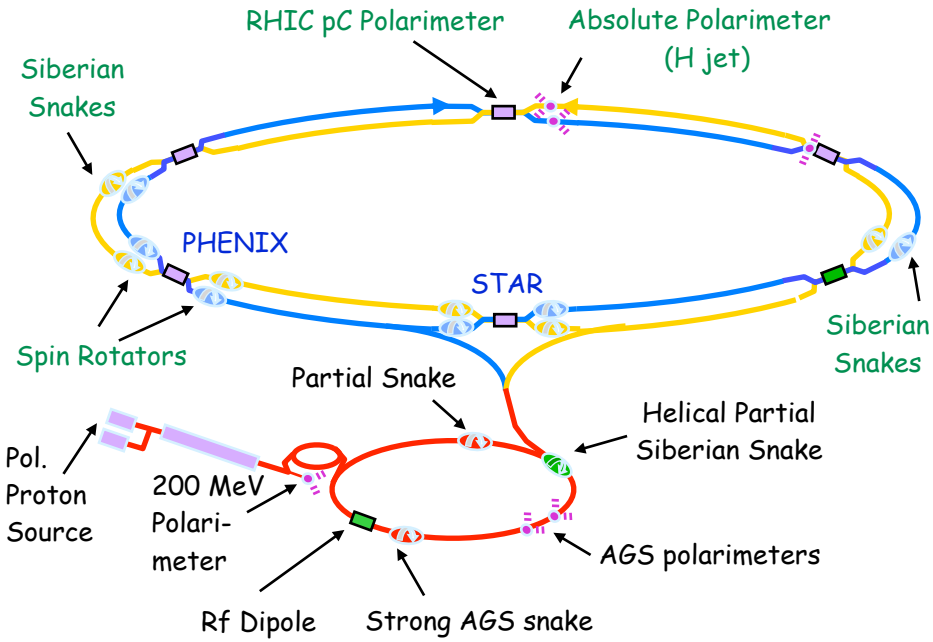
Collider: The First polarized p+p collider at BNL

Performance



RHIC RUN	s [GeV]	$L_{recorded}$ [pb^{-1}] (trans.)	$L_{recorded}$ [pb^{-1}] (long.)	Polarization [%]
RUN 2	200	0.15	0.3	15
RUN 3	200	0.25	0.3	30
RUN 4	200	0	0.4	40-45
RUN 5	200	0.4	3.1	45-50
RUN 6	200	3.4/6.8	8.5	60
RUN 8	200	7.8	-	45
RUN 9	200 / 500	-	25 / 10	55 / 40

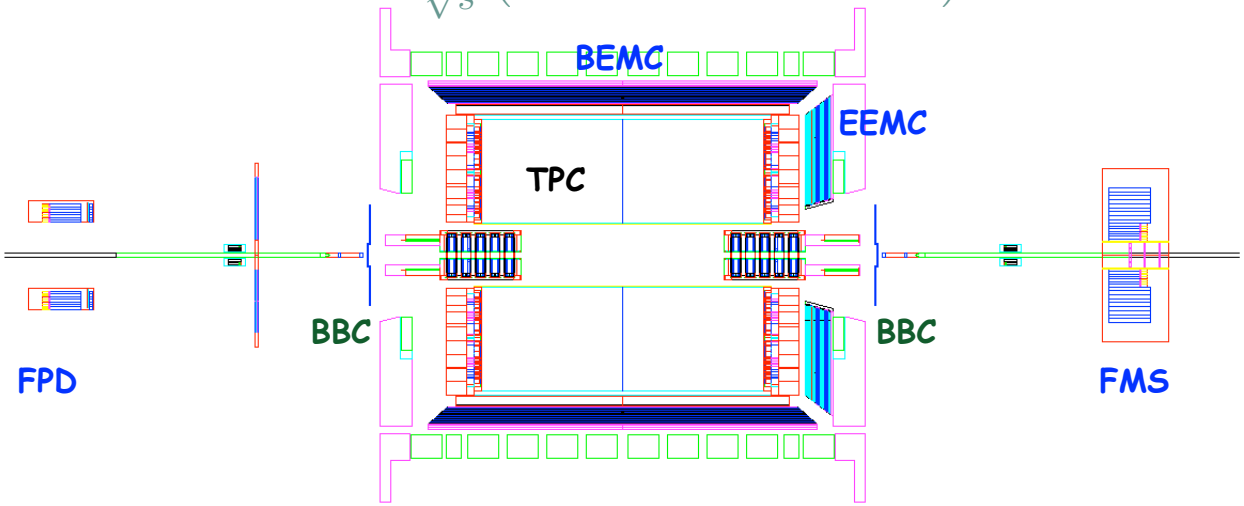
- Long 200GeV production runs at $\sqrt{s}$=200GeV (long. polarization): Run 6 / Run 9
- First collisions of polarized proton beams at $\sqrt{s}$=500GeV (long. polarization): Run 9

The STAR Experiment

Overview

- Wide rapidity coverage of **STAR calorimetry (Jets /Neutral Pions / Photons) system:**
  - FPD: -4.1 < η < 3.3
  - BEMC: -1.0 < η < 1.0
  - EEMC: 1.09 < η < 2.0
  - FMS: 2.5 < η < 4.0

$$x_{1\,(2)} = \frac{1}{\sqrt{s}}\left(p_{T_3}e^{\eta_3(-\eta_3)} + p_{T_4}e^{\eta_4(-\eta_4)}\right)$$

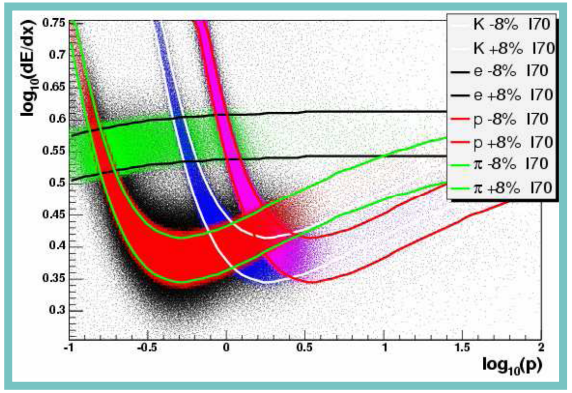


- **BBC/ZBC:** Relative luminosity and local polarimetry
- **BBC:** Minimum bias trigger

Key elements for STAR Δg(x) program:

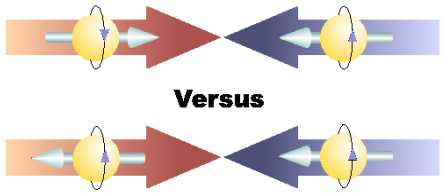
- Higher precision on Δg(x) : Luminosity / DAQ upgrade (DAQ 1000)
- Sensitivity to shape of Δg(x): Correlation measurements
- Low-x region of Δg(x): 500GeV program / Asymmetric collisions (Forward calorimetry)

- **TPC:** Tracking and PID using dE/dx for |η| < 1.3 and p_T < 15 GeV/c

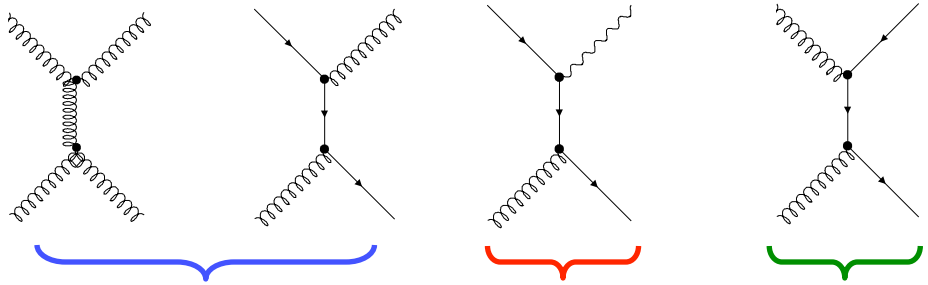


ΔG - Recent results

- What is required experimentally to measure the gluon spin contribution?
  - Double longitudinal-spin asymmetry: A_{LL}



$$\vec{p} + \vec{p} \rightarrow$$



$\boxed{\text{jets} + X}$ $\boxed{\gamma + X}$ $\boxed{c\bar{c}\,(b\bar{b}) + X}$

    - Study helicity dependent structure functions (Gluon polarization)!

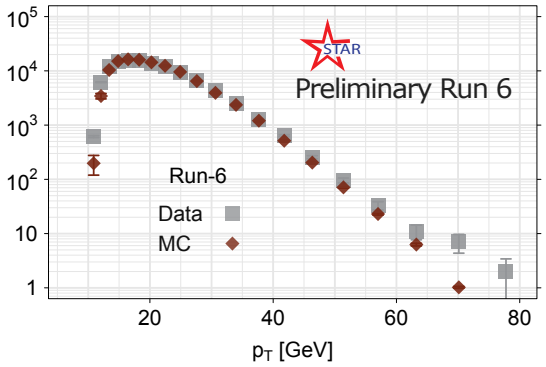
$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_1 P_2} \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}}$$

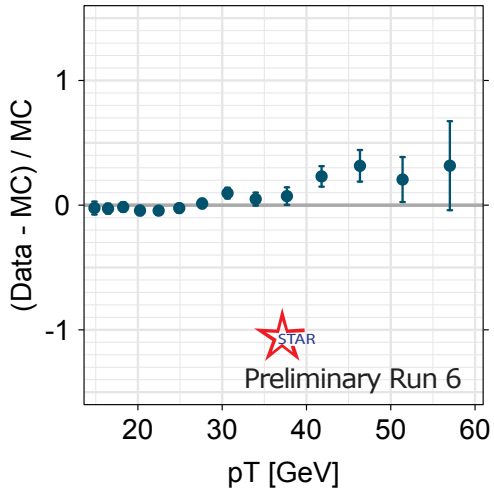
  - Require concurrent measurements:
    - Magnitude of beam polarization, $P_{1(2)}$ RHIC polarimeters } RHIC polarimeters
    - Direction of polarization vector
    - Relative luminosity of bunch crossings with different spin directions
    - Spin dependent yields of process of interest N_{ij}

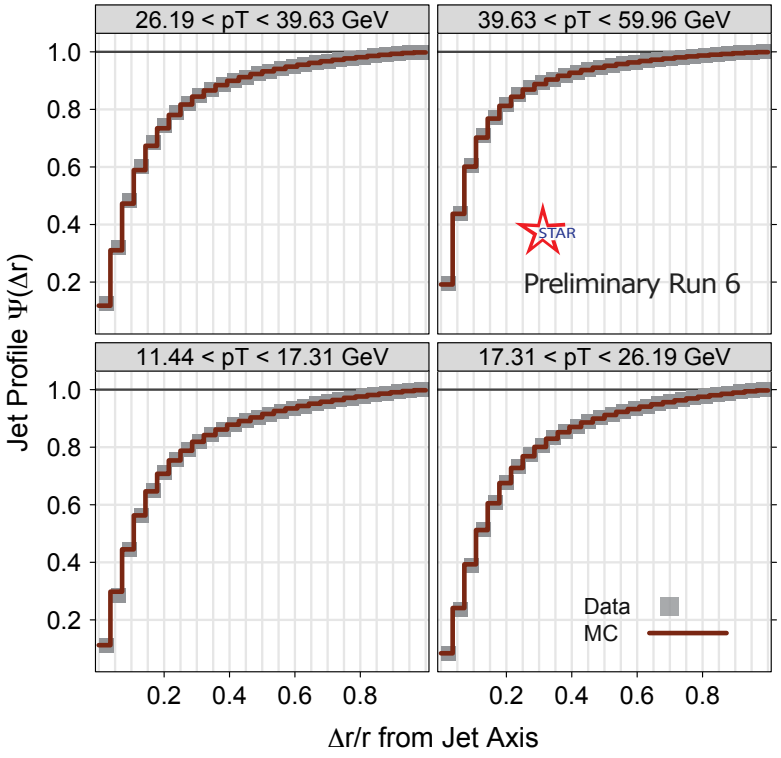
} STAR experiment

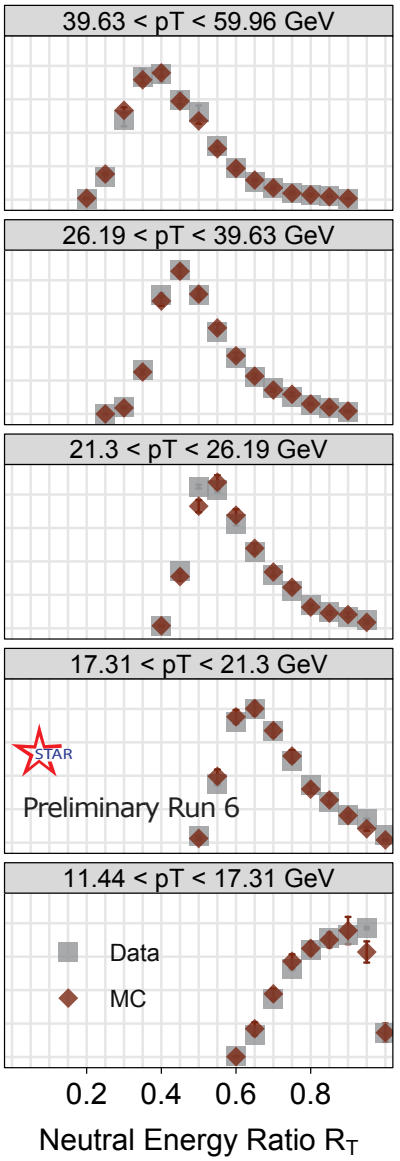
ΔG - Recent results: Jet production

Inclusive Jet production - Data Understanding - Run 6









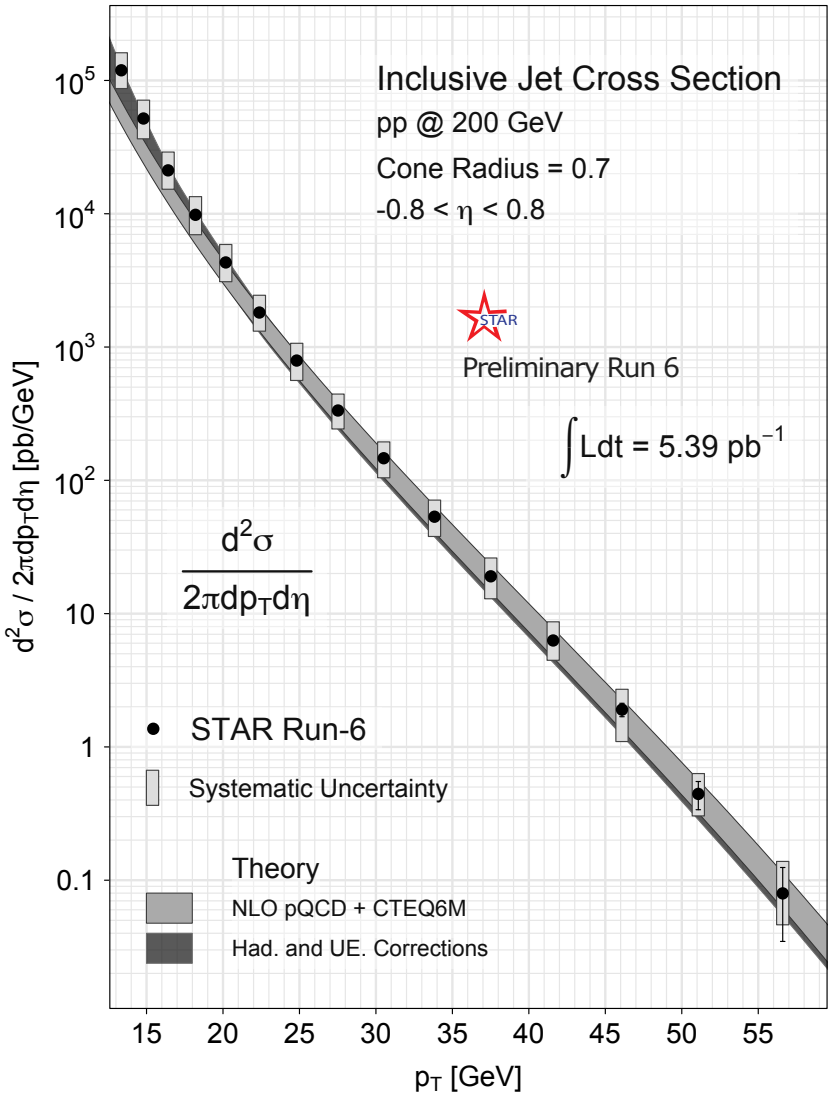
- Data correction based on PYTHIA MC samples
- Good Data/MC agreement

MC: Pythia 6.4 + Geant 3

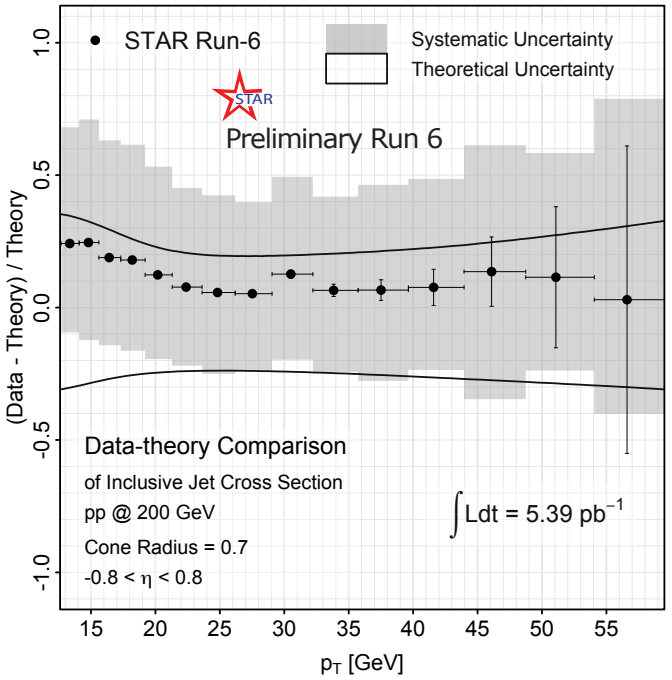
$$-0.8 < \eta < 0.8$$

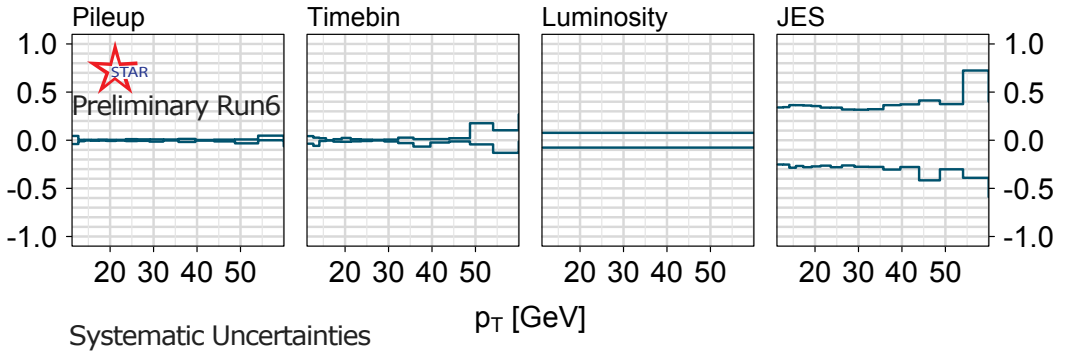
ΔG - Recent results: Jet production

STAR Run 6 Cross-section result: Mid-rapidity Inclusive Jet production



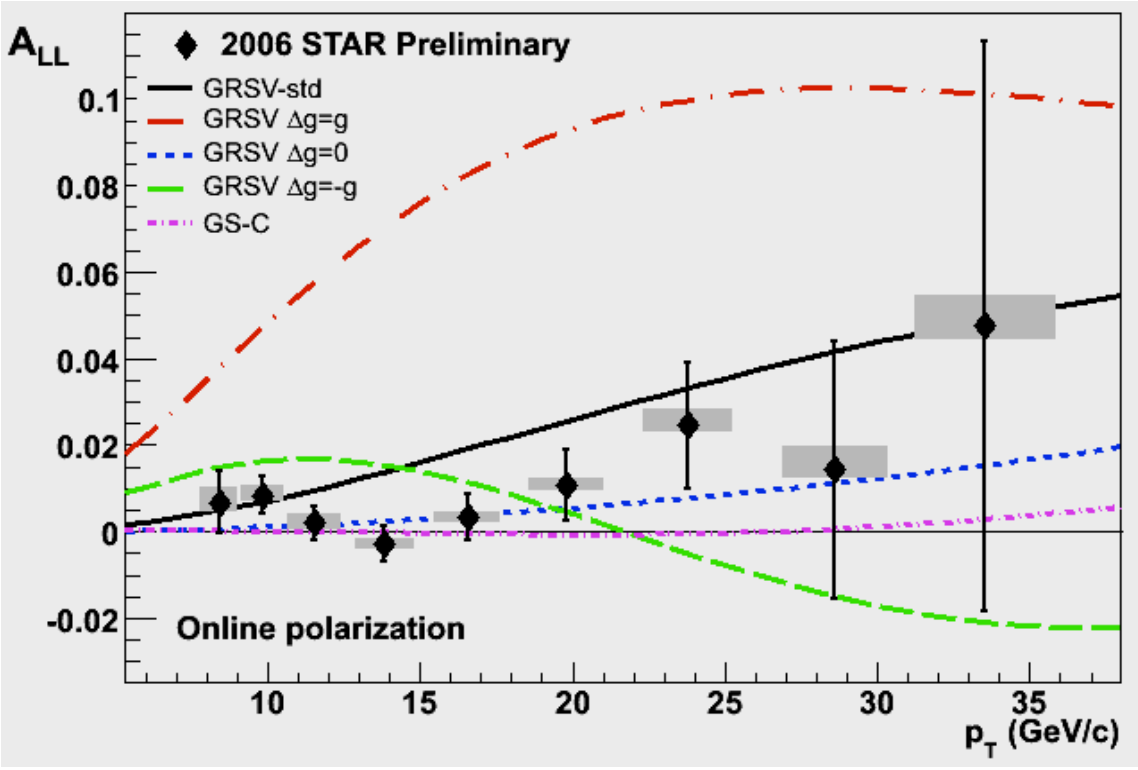
- Data are well described by NLO pQCD plus hadronization and underlying event corrections





ΔG - Recent results: Jet production

- STAR Run 5 / 6 A_{LL} result: Mid-rapidity inclusive jet production



A_{LL} systematics	(x 10^{-3})
Reconstruction + Trigger Bias	[-1,+3] (p_T dep)
Non-longitudinal Polarization	~ 0.03 (p_T dep)
Relative Luminosity	0.94
Backgrounds	1^{st} bin ~ 0.5 else ~ 0.1

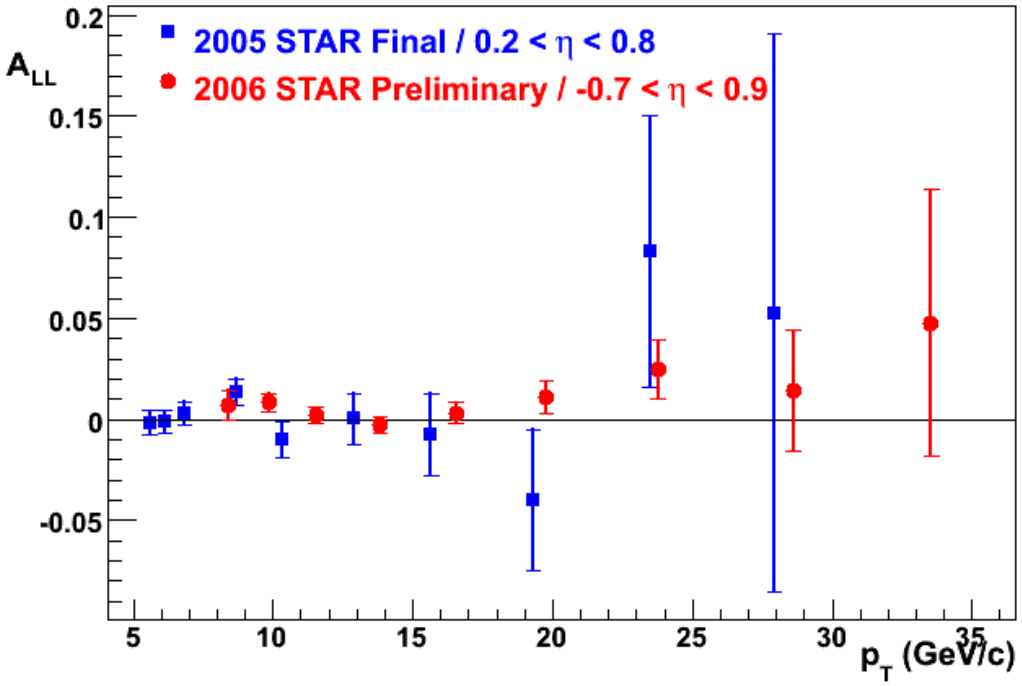
p_T systematic	± 6.7%

STAR Collaboration, PRL 100 (2008) 232003.

- RUN 6 results: GRSV-MAX / GRSV-MIN ruled out - A_{LL} result favor a gluon polarization in the measured x-region which falls in-between GRSV-STD and GRSV-ZERO
- Consistent with RUN 5 result (Factor 3-4 improved statistical precision for p_T>13GeV/c)

ΔG - Recent results: Jet production

- STAR Run 5 / 6 A_{LL} result: Mid-rapidity inclusive jet production



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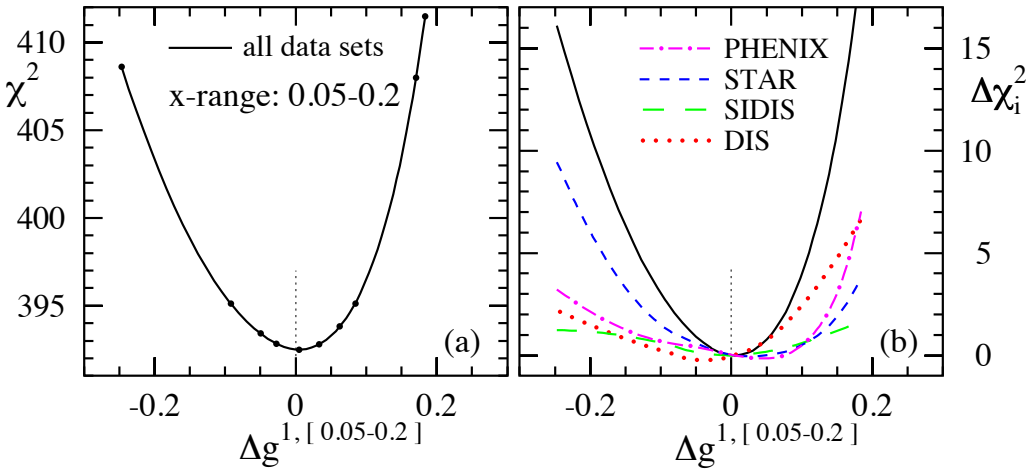
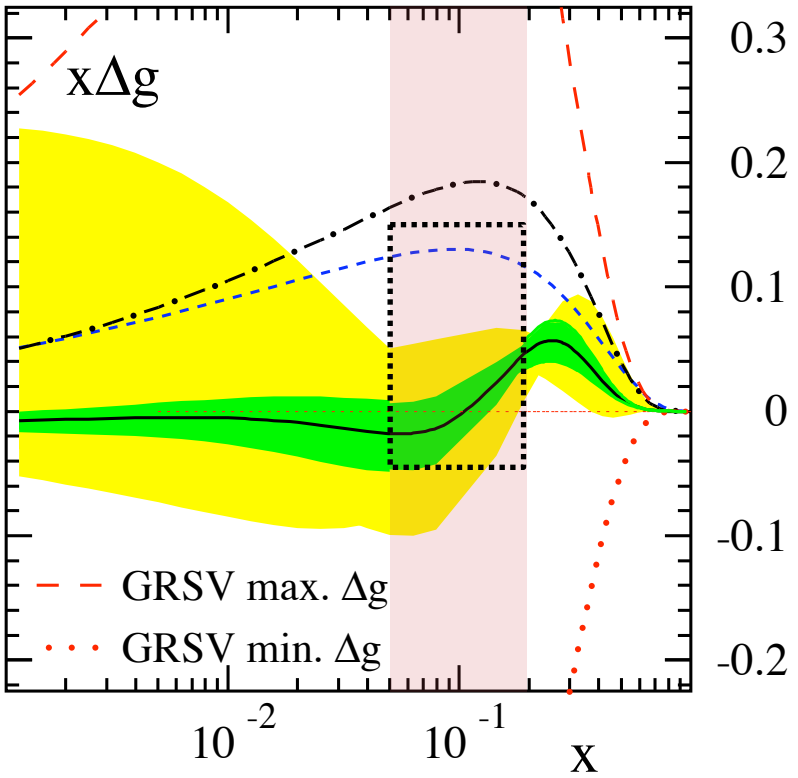
ΔG - Recent results: Global analysis

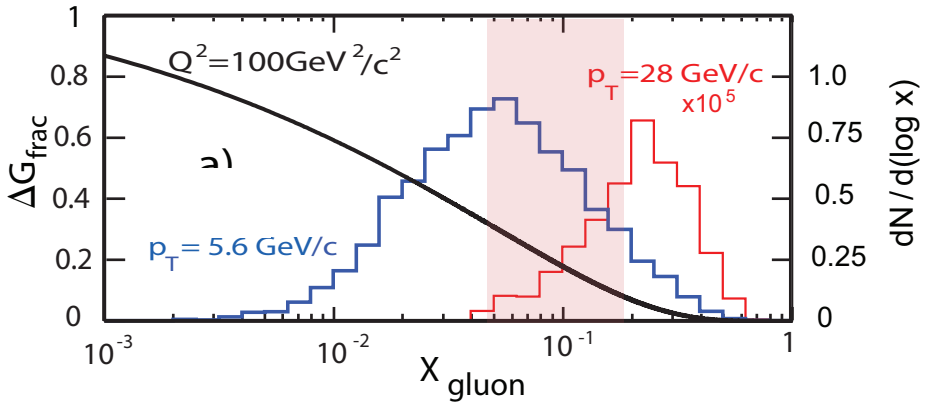
- Global analysis incl. RHIC pp data



- Strong constraint on the size of Δg from RHIC data for 0.05<x<0.2
- Evidence for a small gluon polarization over a limited region of momentum fraction
- Important: Mapping of x-dependence and extension of x-coverage needed!

D. de Florian et al. PRL 101 (2008) 072001.



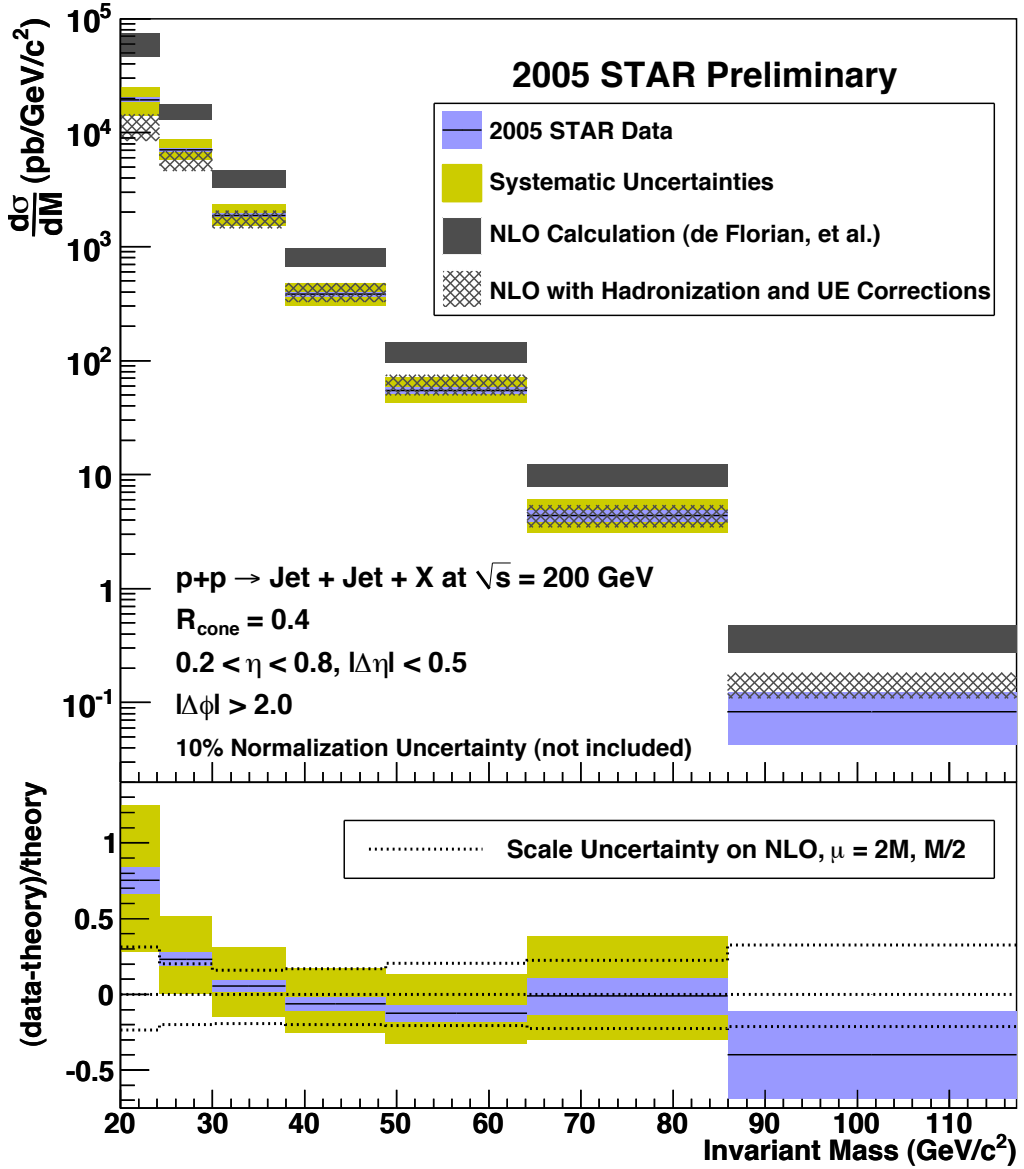


STAR Collaboration, PRL 100 (2008) 232003.

ΔG - Results: Di-Jet measurements

- STAR Run 5 Cross section result: First di-jet cross-section

  - Unpolarized differential cross-section vs. invariant mass M above 20GeV/c2
  - NLO theory predictions by D. deFlorian et al. using MRST2004 pdf-set with (▨) and without (■) Hadronization / UE Corrections over data inv. mass bins
  - Statistical uncertainties are shown in blue (▬)
  - Energy scale uncertainty is shown in yellow (▬)
  - Comparison to theory together with theory scale uncertainties



ΔG - Future prospects: Di-Jet measurements

- Run 9 STAR Beam-Use Request (BUR): Di-Jet projections

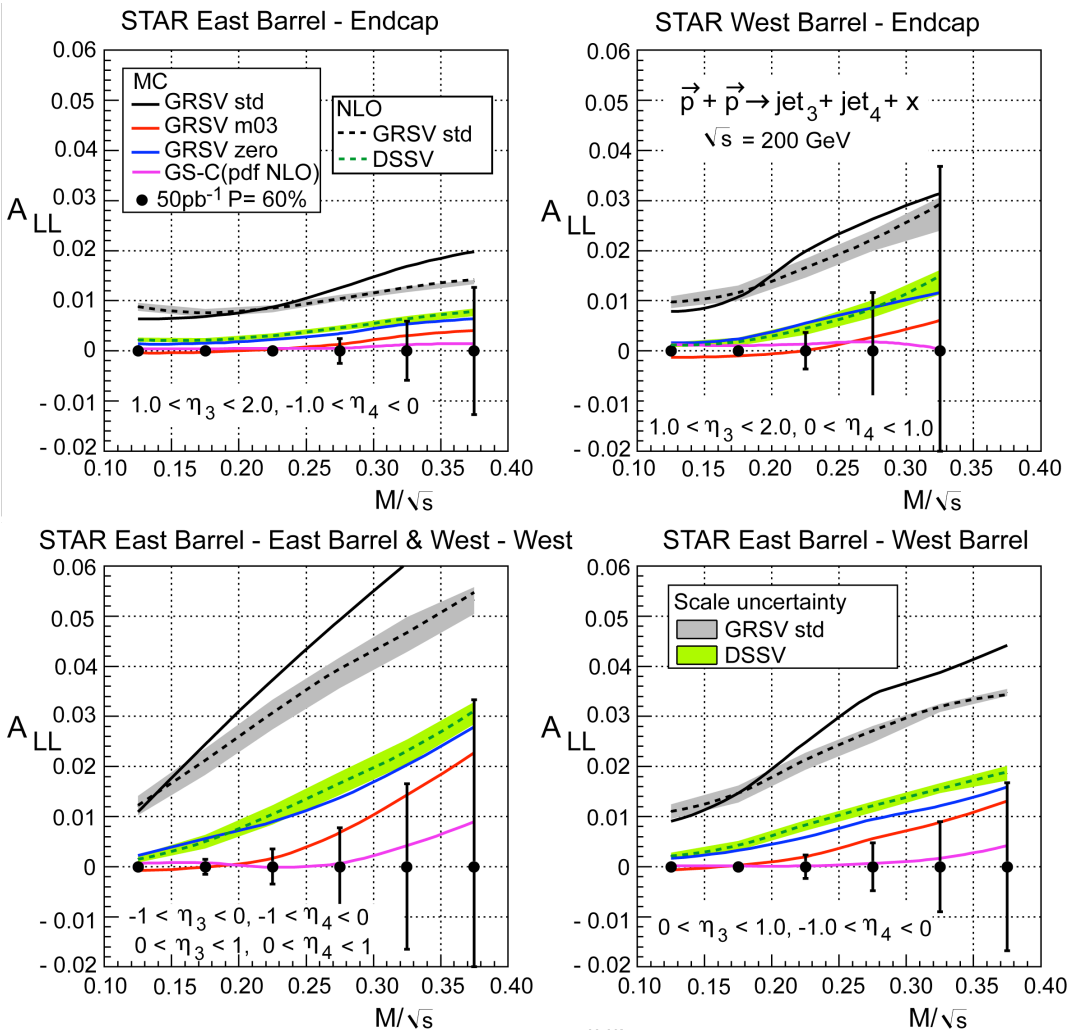
  - Substantial improvement in Run 9 from Di-Jet production: 200GeV

    Run just started: April 21, 2009 - June 28, 2009 (Recorded: 1/3 of Run 9 FOM = $P^4L \sim 6.5 pb^{-1}$)

  - Good agreement between LO MC evaluation and full NLO calculations

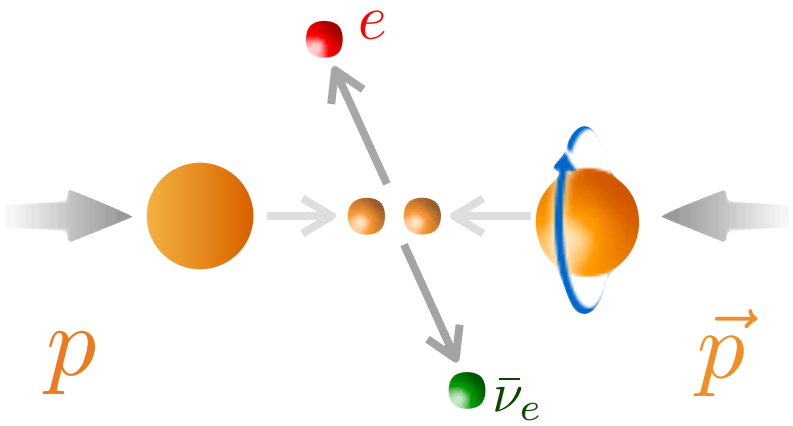
$$M = \sqrt{x_1 x_2 s} \qquad \eta_3 + \eta_4 = \ln \frac{x_1}{x_2}$$

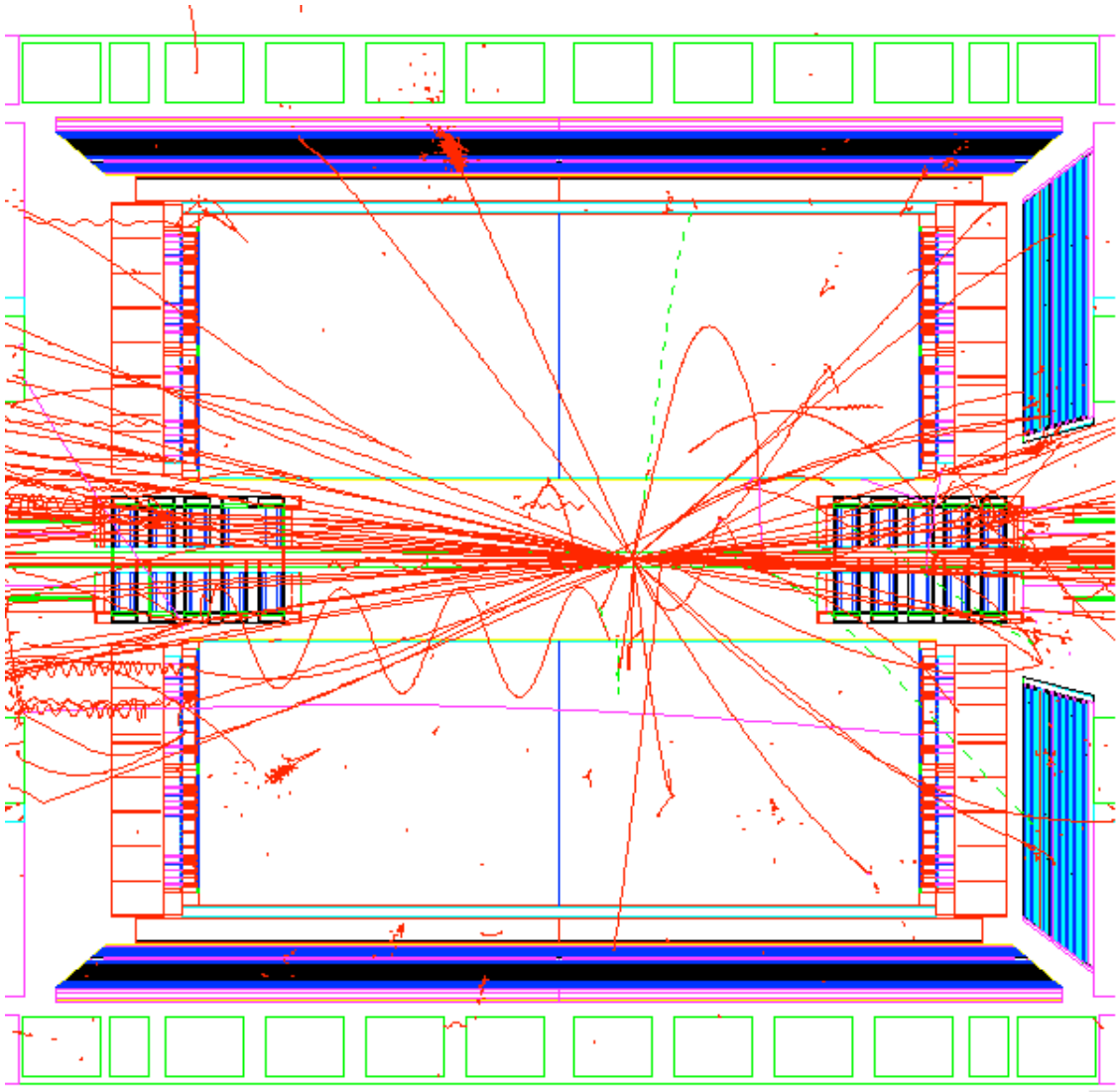
$$x_{1\,(2)} = \frac{1}{\sqrt{s}} \left(p_{T_3} e^{\eta_3 (-\eta_3)} + p_{T_4} e^{\eta_4 (-\eta_4)} \right)$$



W production results: Algorithm

- W reconstruction - Algorithm : Idea





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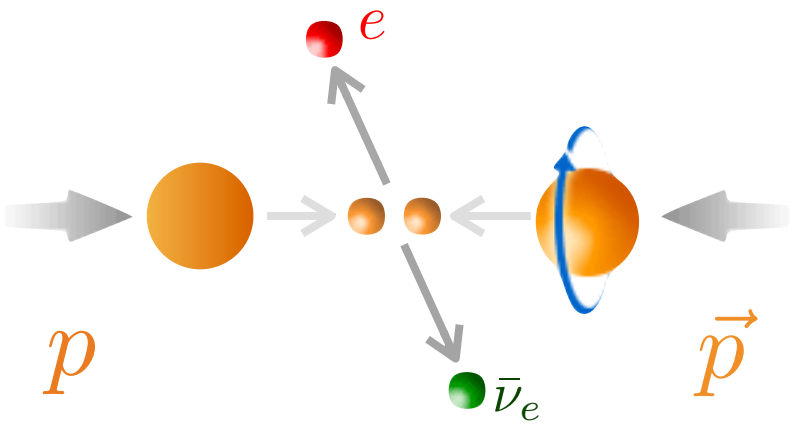

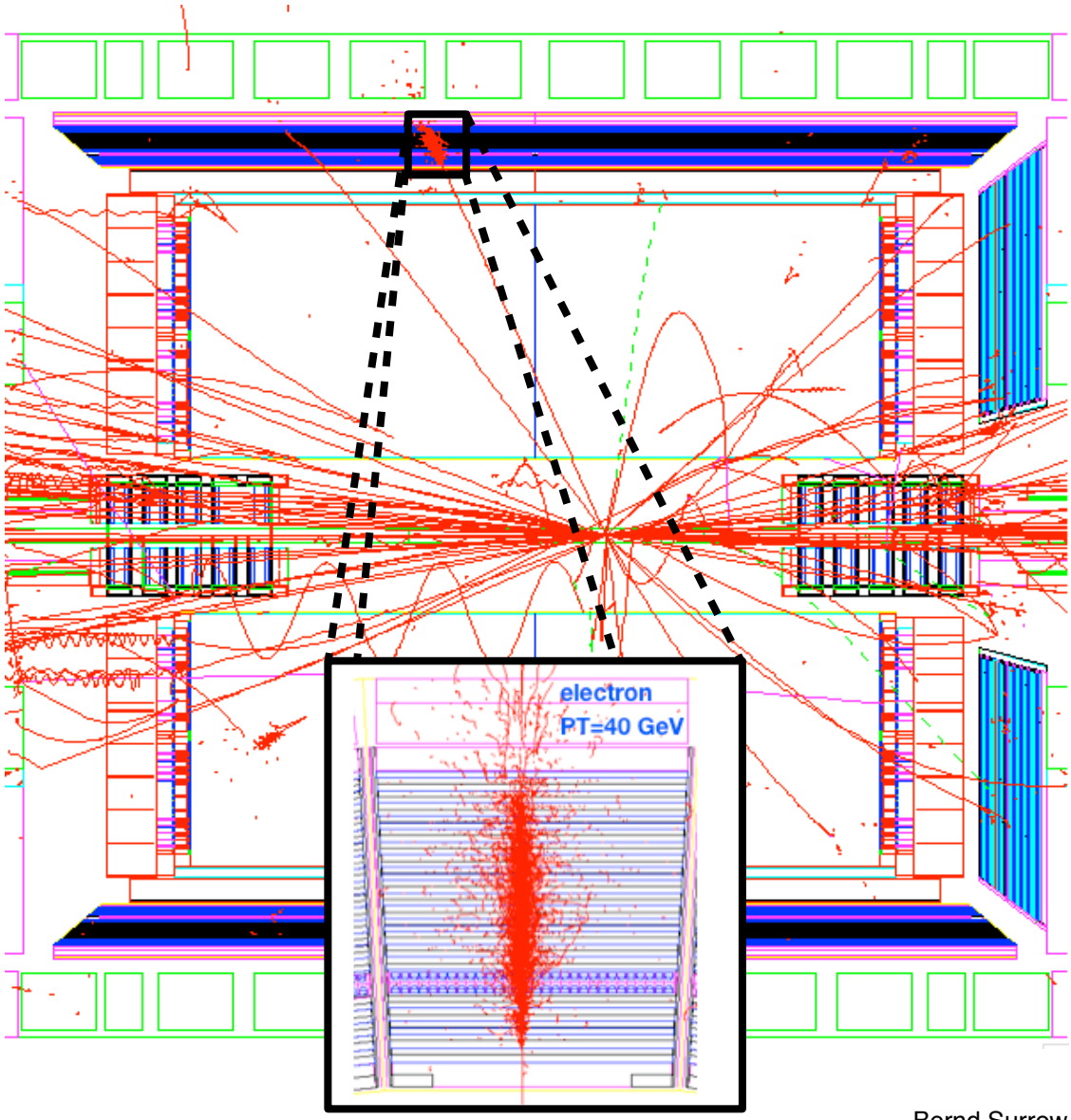

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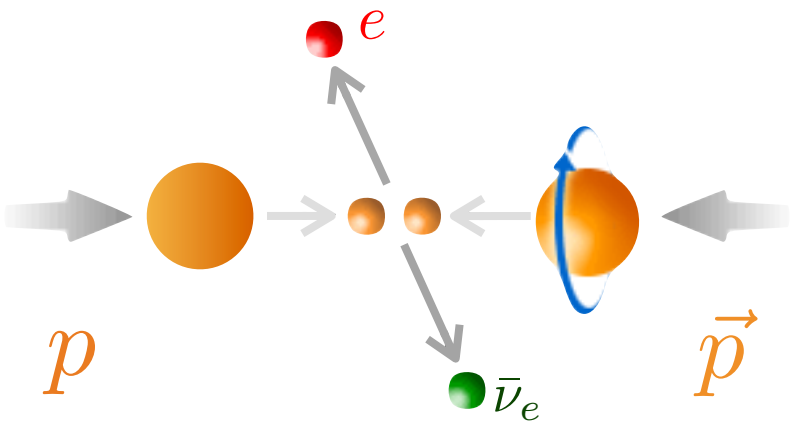
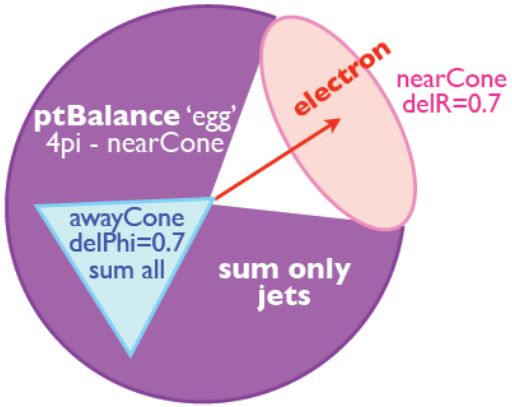
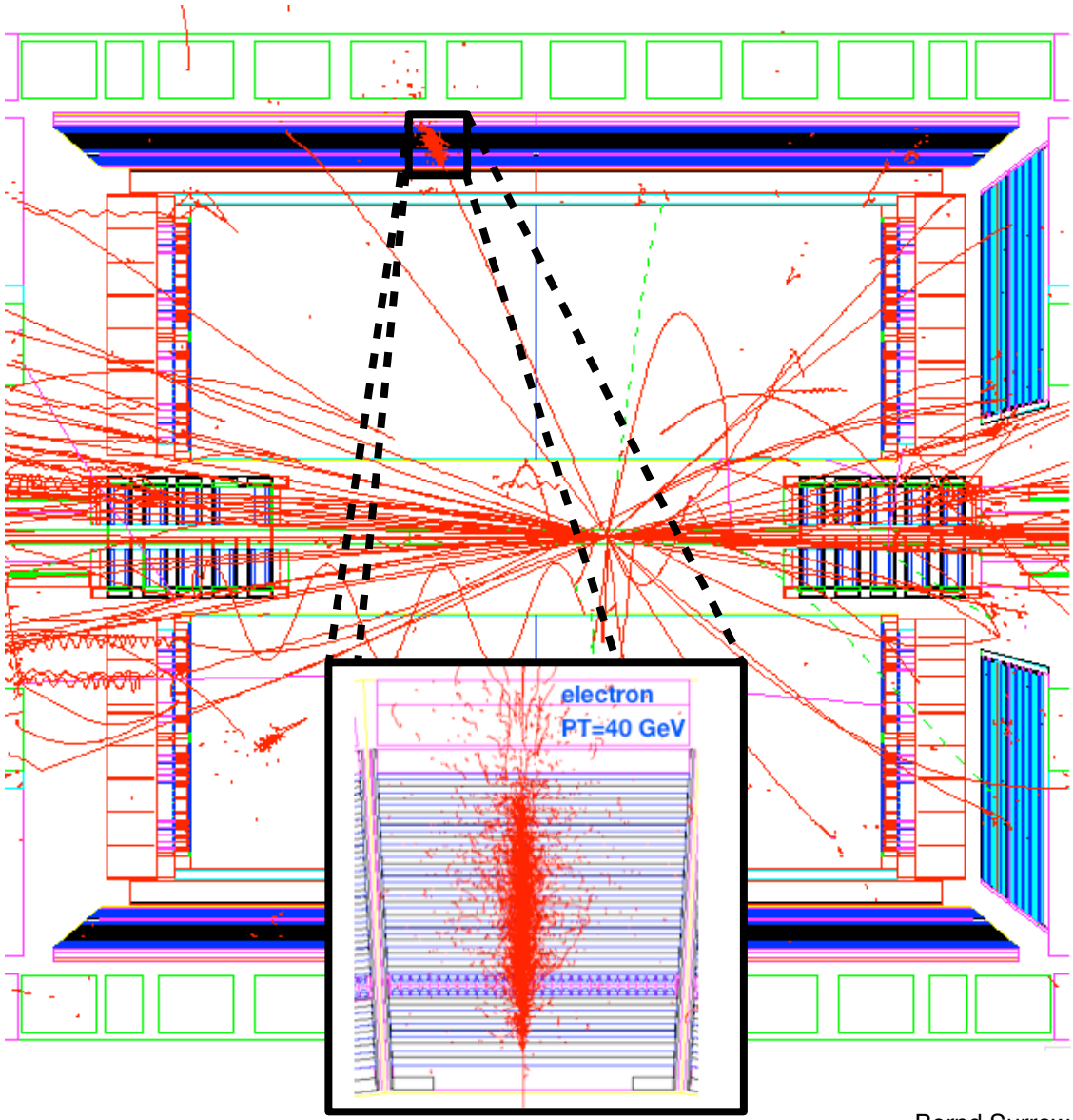


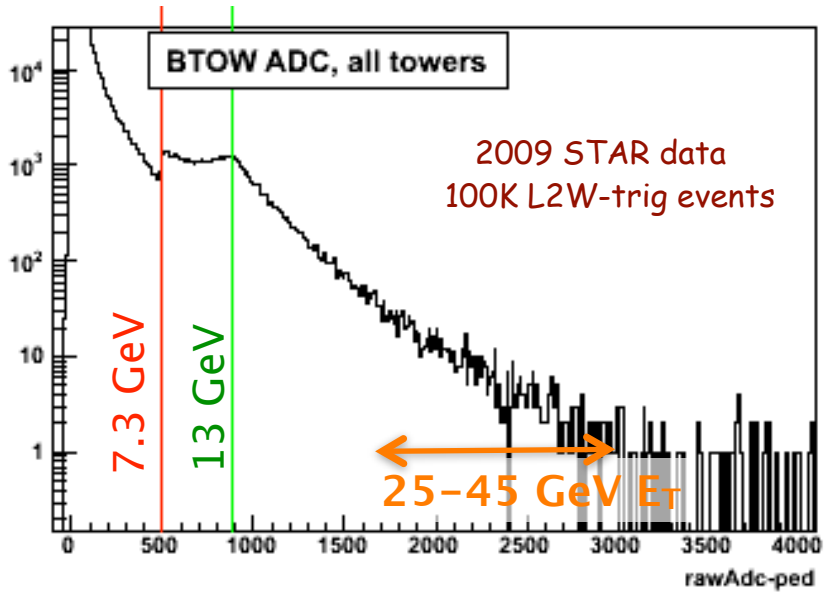
Transverse plane view





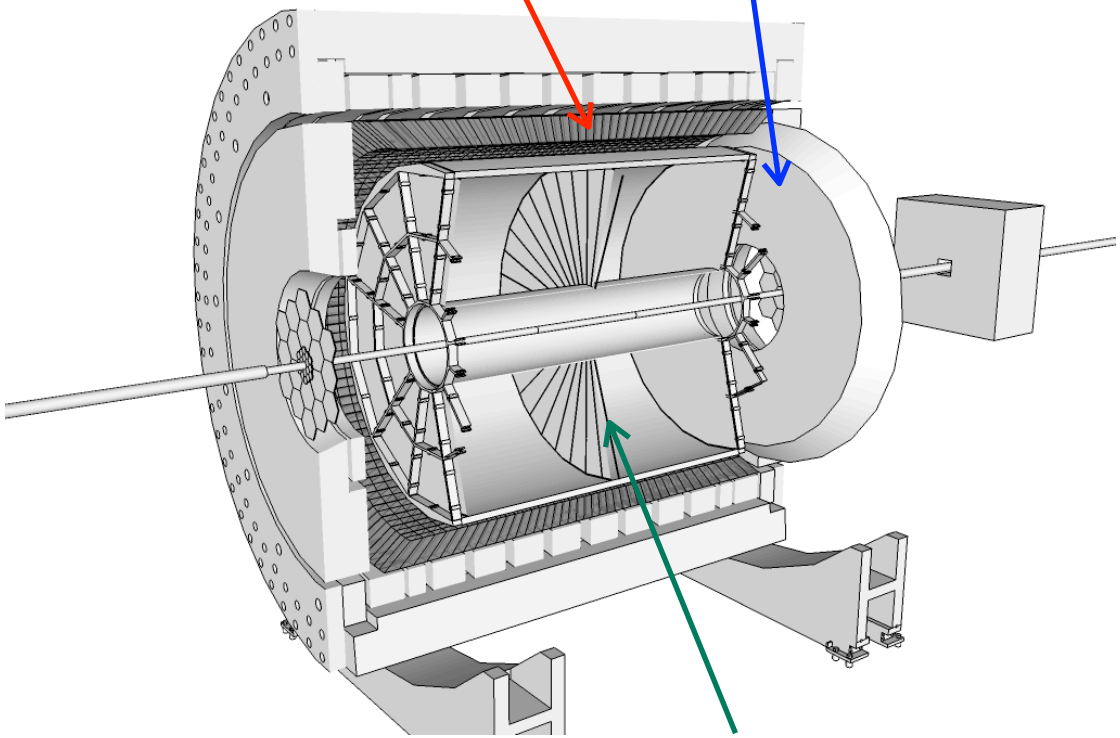
W production results:Trigger / Data taking

- STAR Data sample Run 9 / 500GeV and W Trigger



First STAR W analysis based on:

BTOW and ETOW (Veto cut only)



W-trigger:

L0: HT E_T > 7.3 GeV

L2: 2x2 cluster E_T > 13 GeV

Rate: Few Hz

Acquired during longitudinal pol. @ STAR:

- ~103 DAQ hours
- ~1.6M W-triggers

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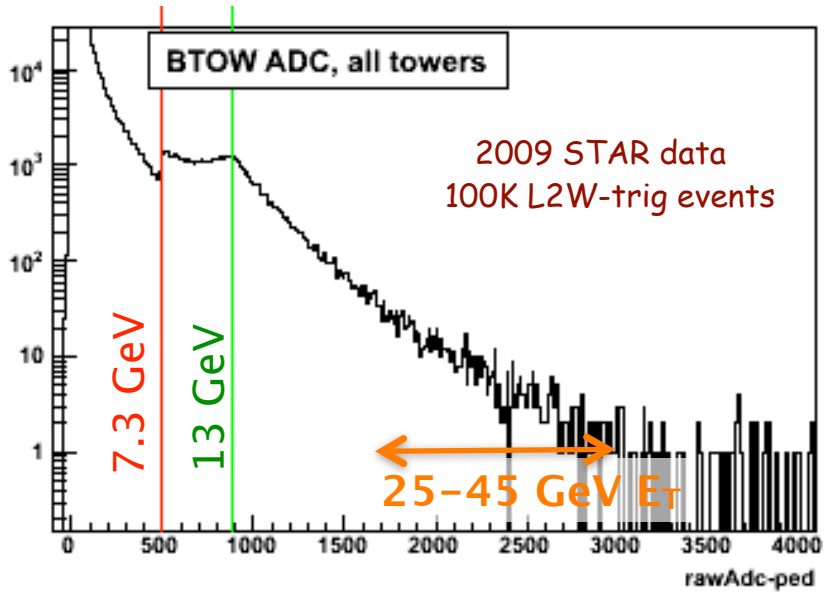

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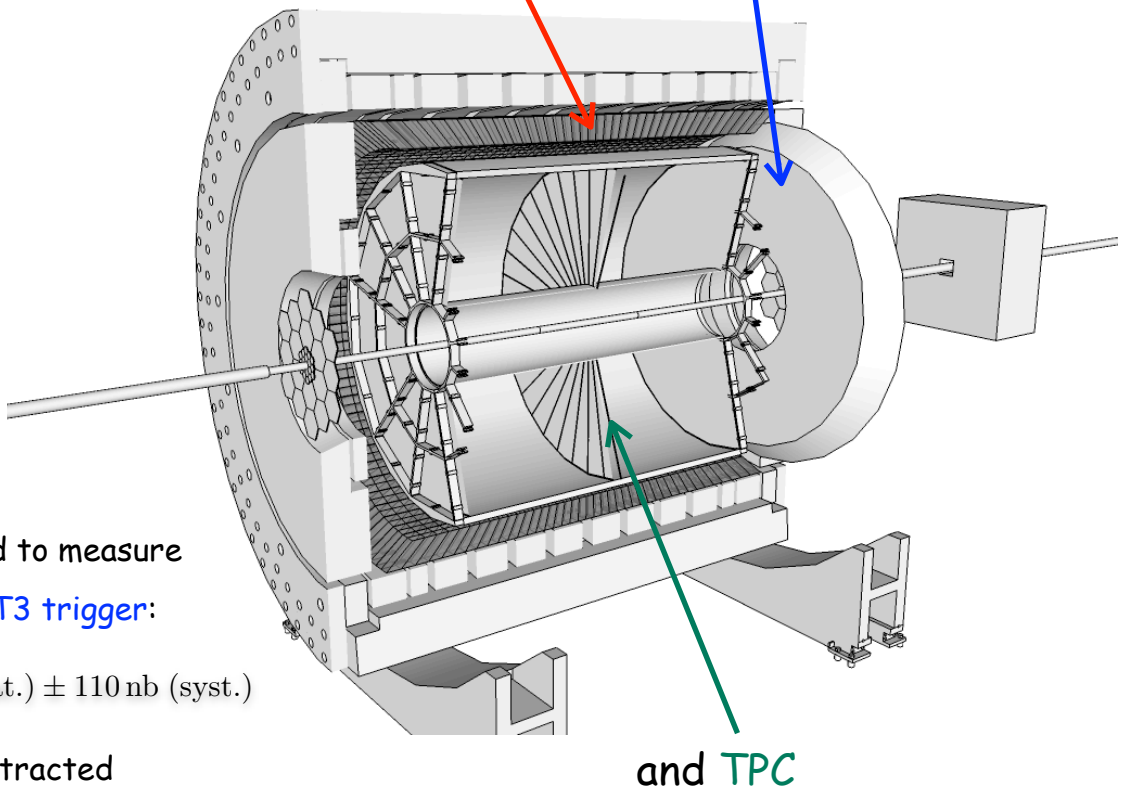

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Vernier scan method used to measure the cross section for BHT3 trigger:

$$\sigma_{\mathrm{BHT3}} = 481\,\mathrm{nb} \pm 10\,\mathrm{nb}\ (\mathrm{stat.}) \pm 110\,\mathrm{nb}\ (\mathrm{syst.})$$

From the background subtracted triggers and the cross section, get:

Integrated luminosity = 13.7 pb^{-1}!

W production results: W event

- Event display (W event candidate) and detector signature

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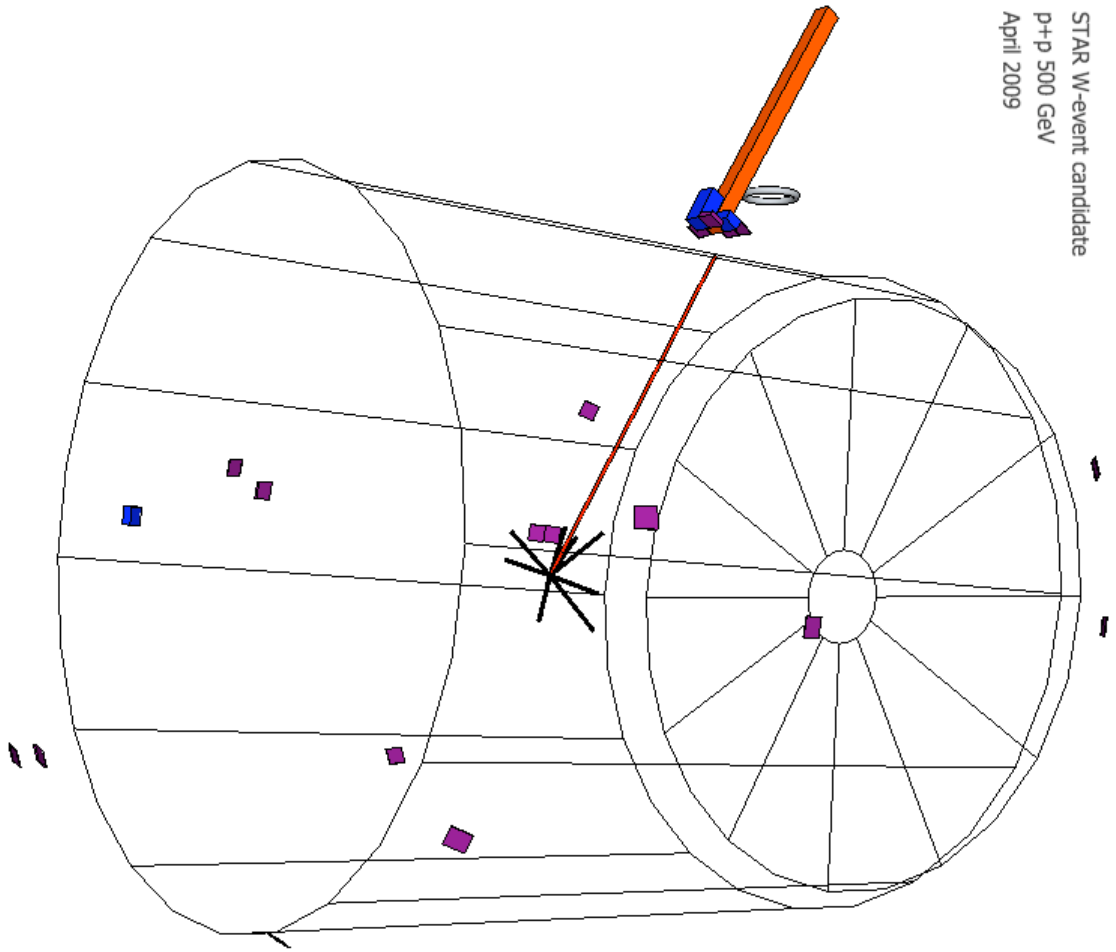
- Event display (W event candidate) and detector signature



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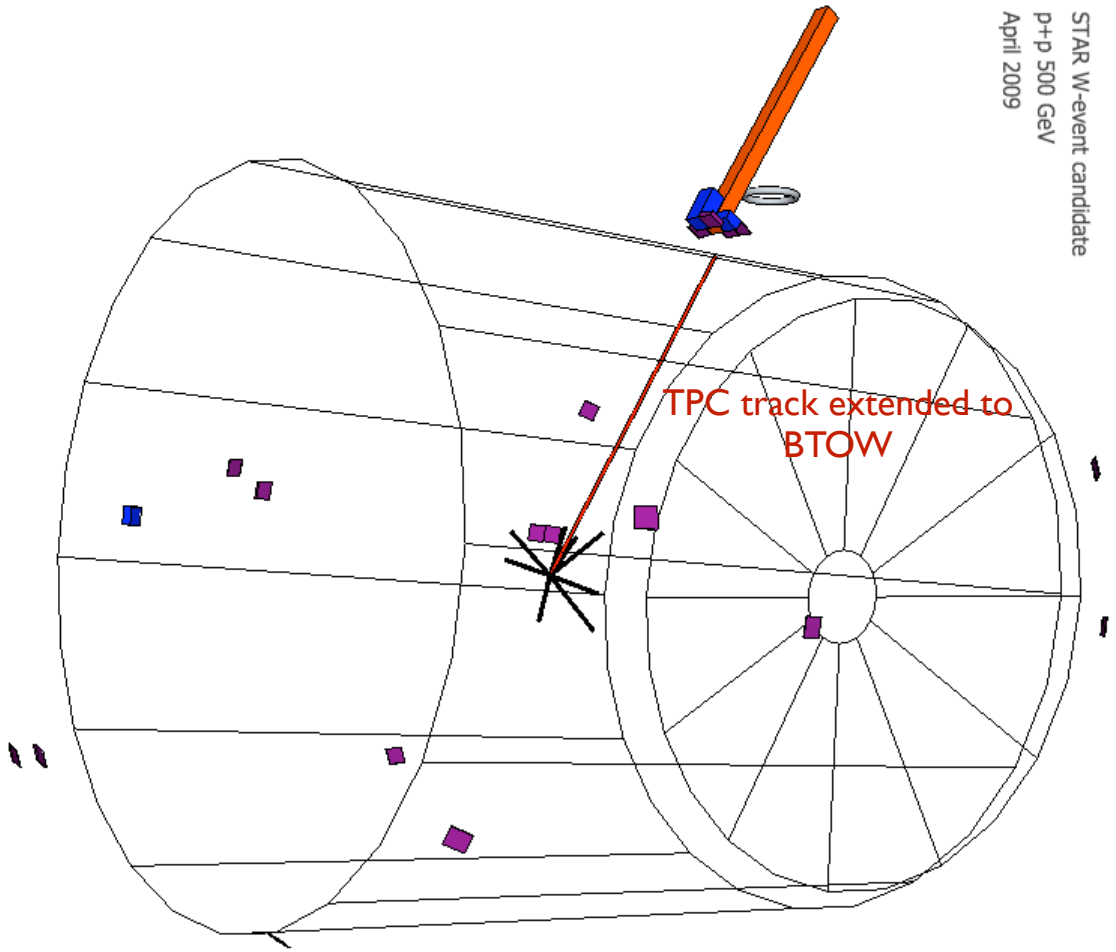

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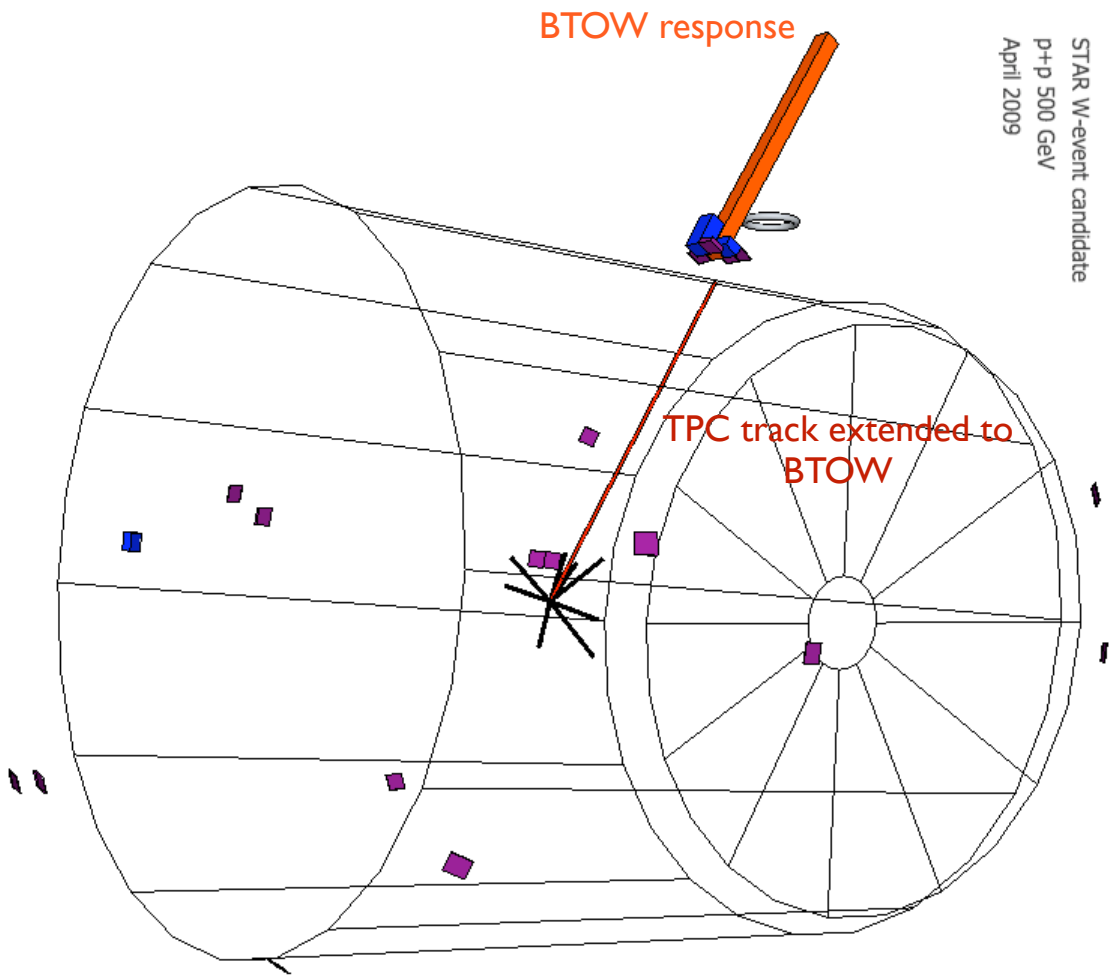
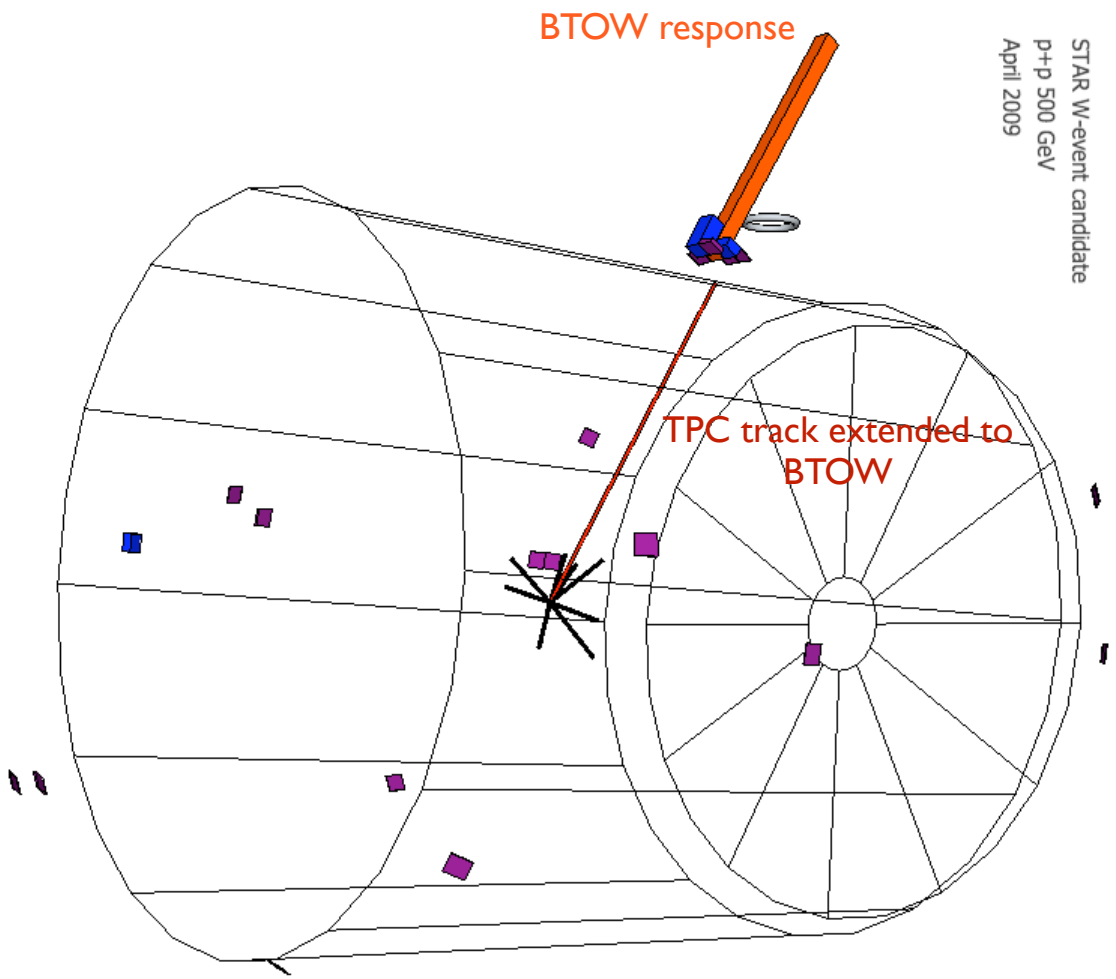


W production results: W event

- Event display (W event candidate) and detector signature

We found ~600 of those kinds of events!



W production results: QCD Background event

- Event display (Di-Jet event candidate) and detector signature

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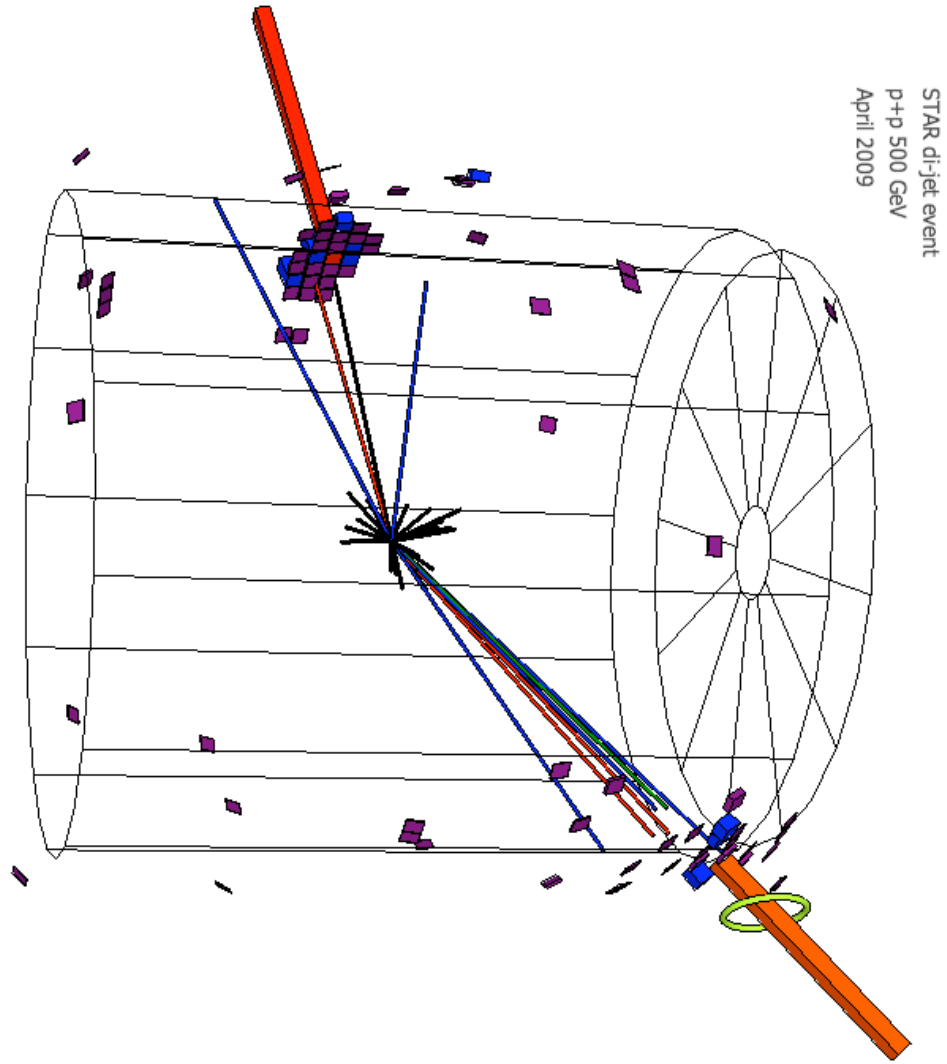
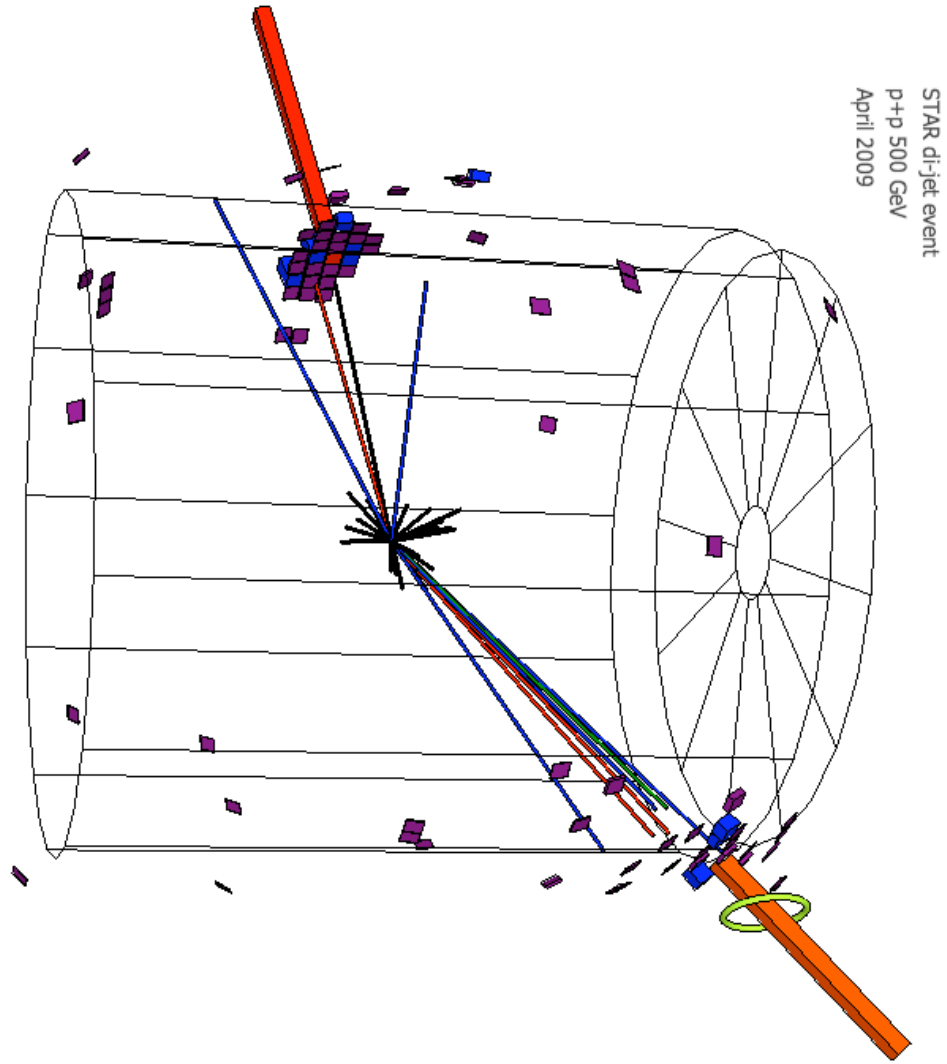


W production results: QCD Background event

- Event display (Di-Jet event candidate) and detector signature

We recorded and rejected ~1.5M of those kinds of events!



W production results: Z^0 event

- Event display (Z event candidate) and detector signature

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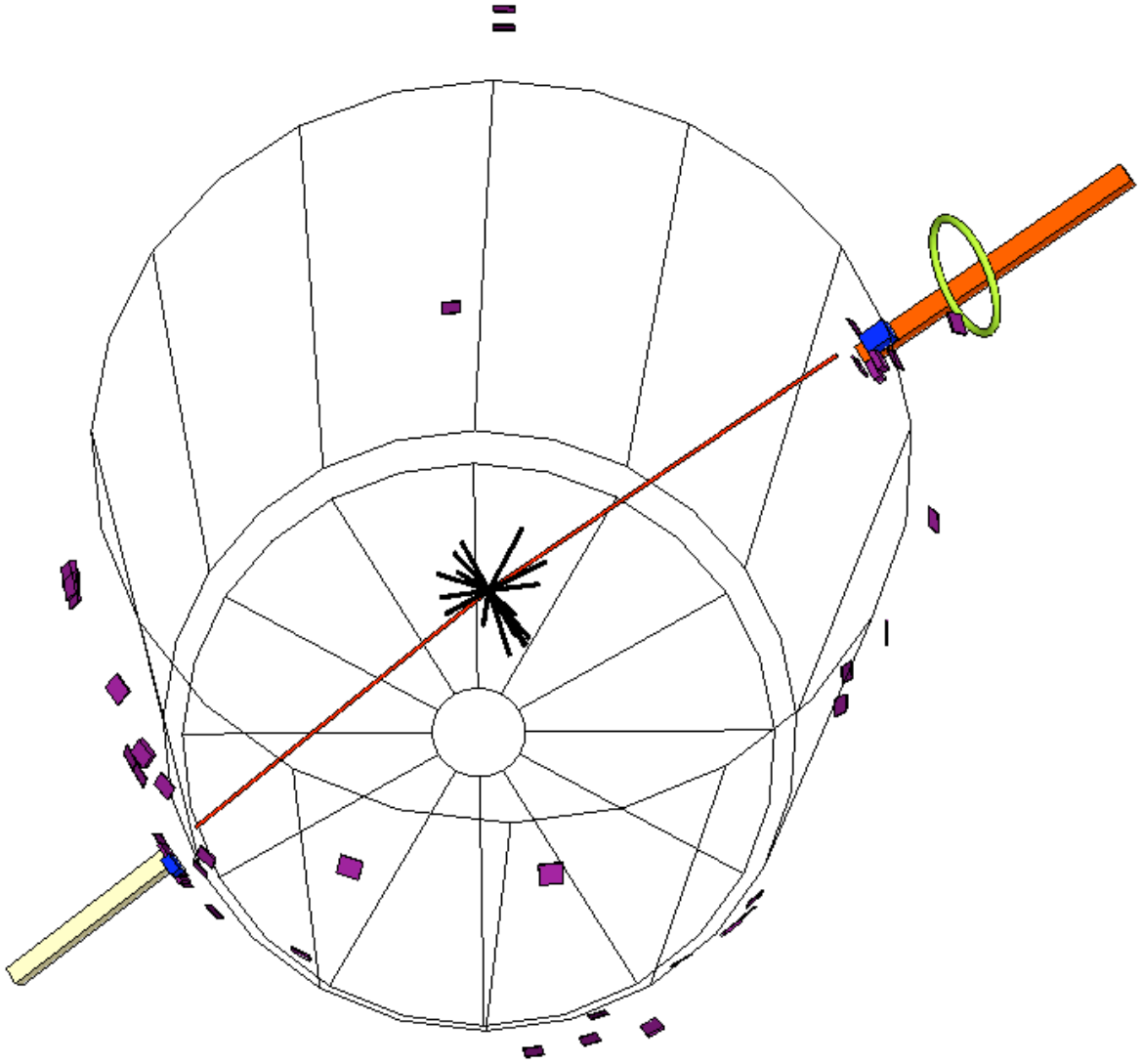
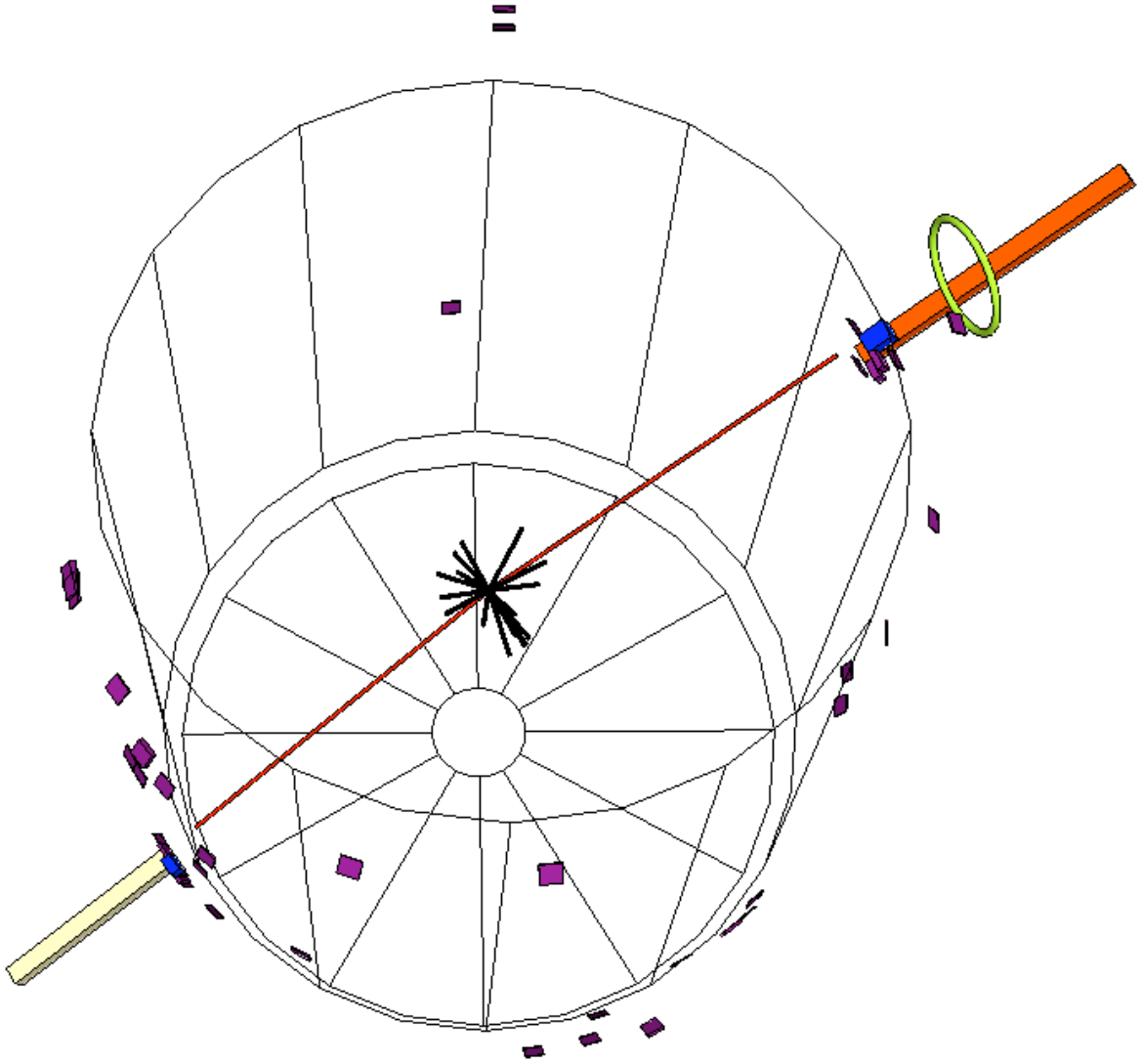


W production results: Z^0 event

- Event display (Z event candidate) and detector signature

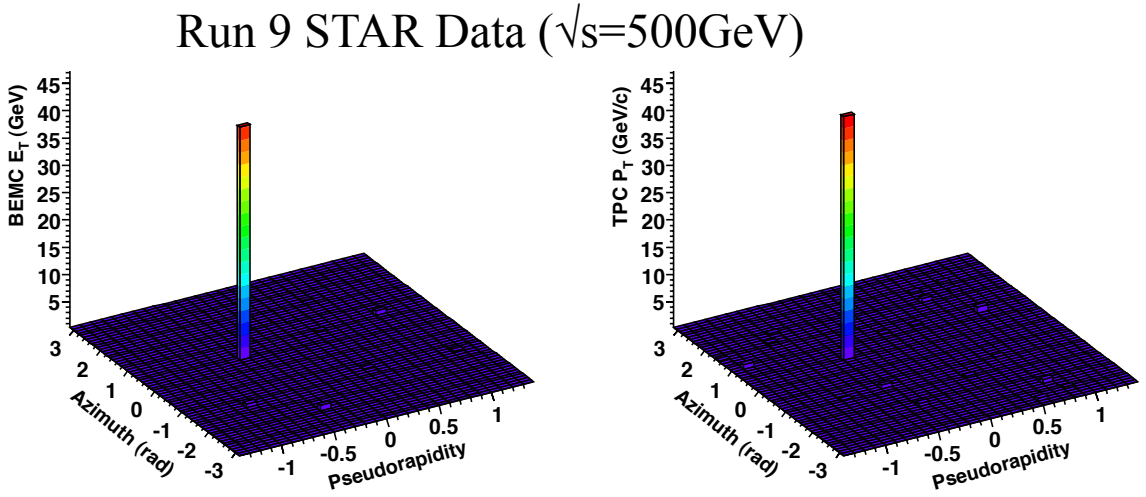
We found a handful of those kinds of events!



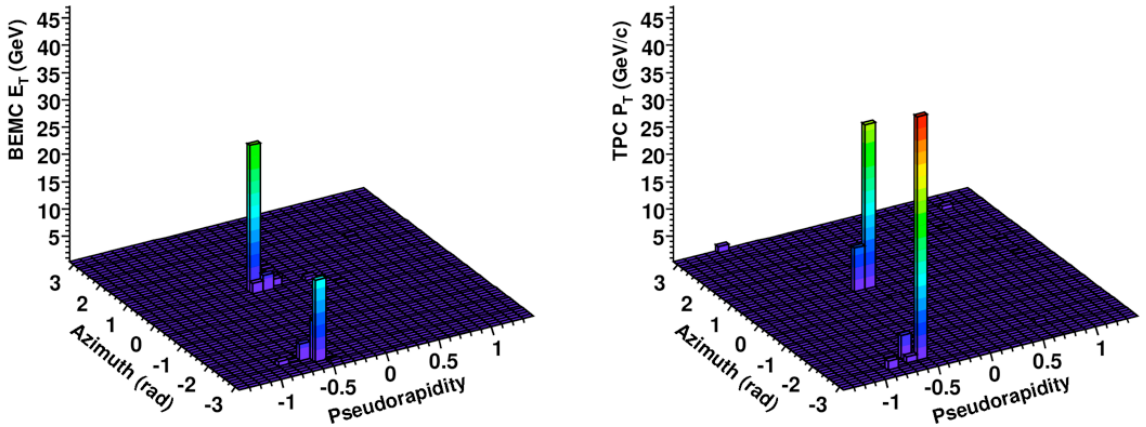
W production results: Lego plots

- Lego plots - STAR BEMC/TPC

W event



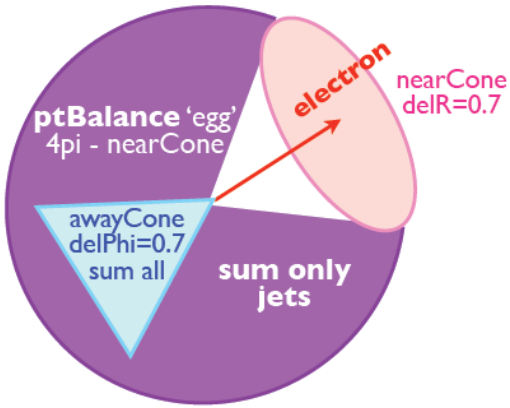
Di-Jet event

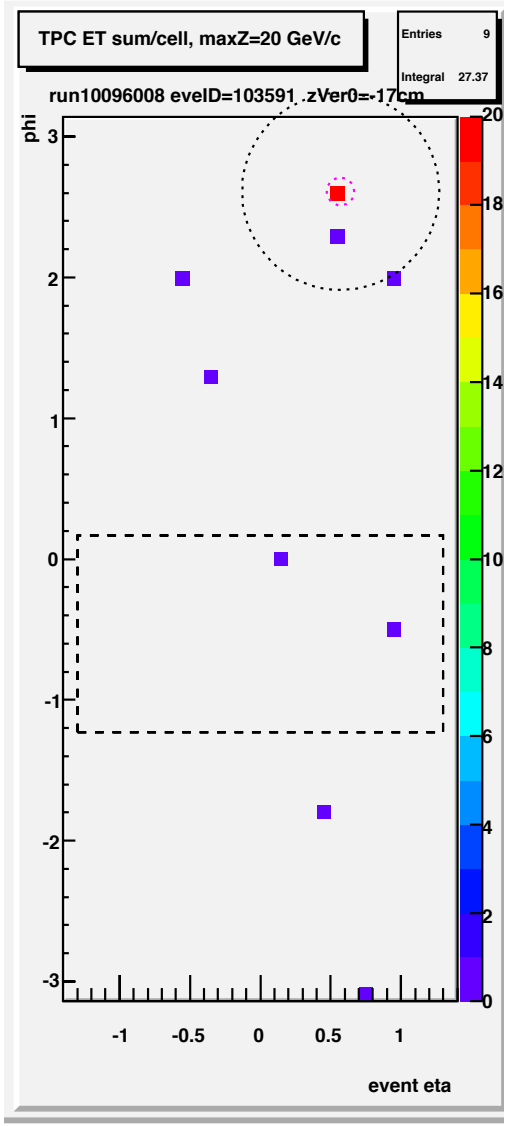


W production results: Algorithm Details

- W reconstruction - Algorithm : Details (1)

Transverse plane view





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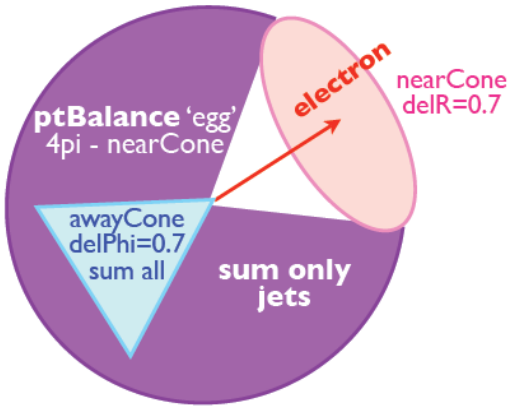

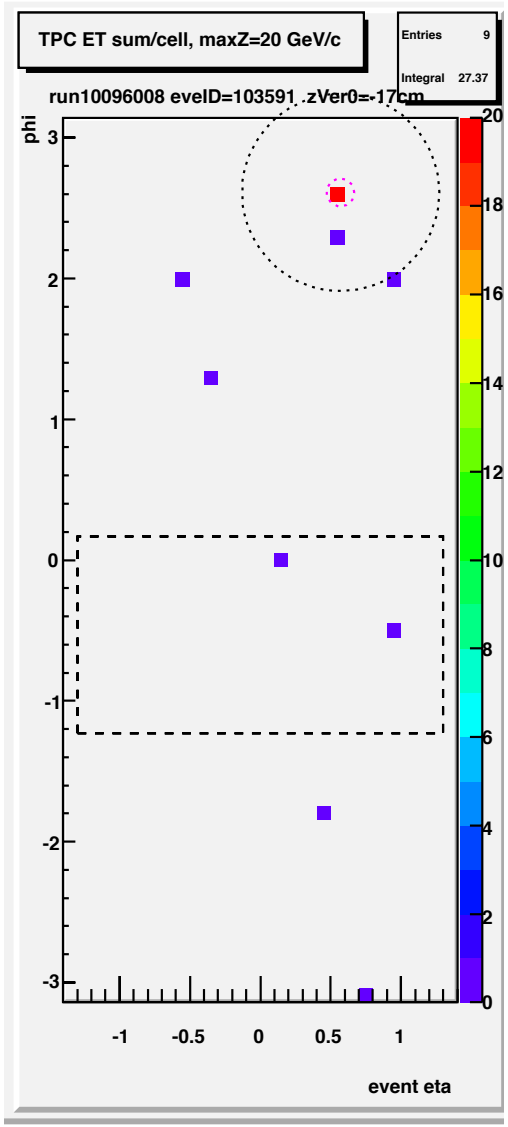

General:

- Select L2W-E_T triggered events
- Select vertices with |Z|<100 cm

W production results: Algorithm Details

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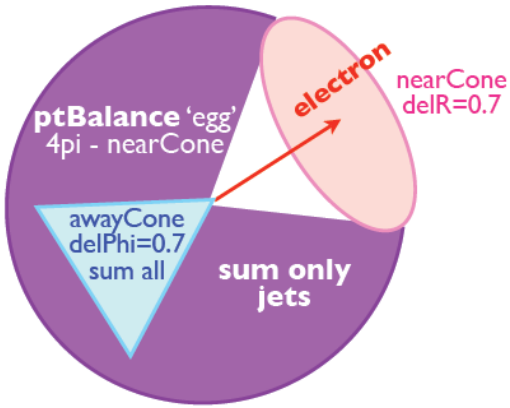

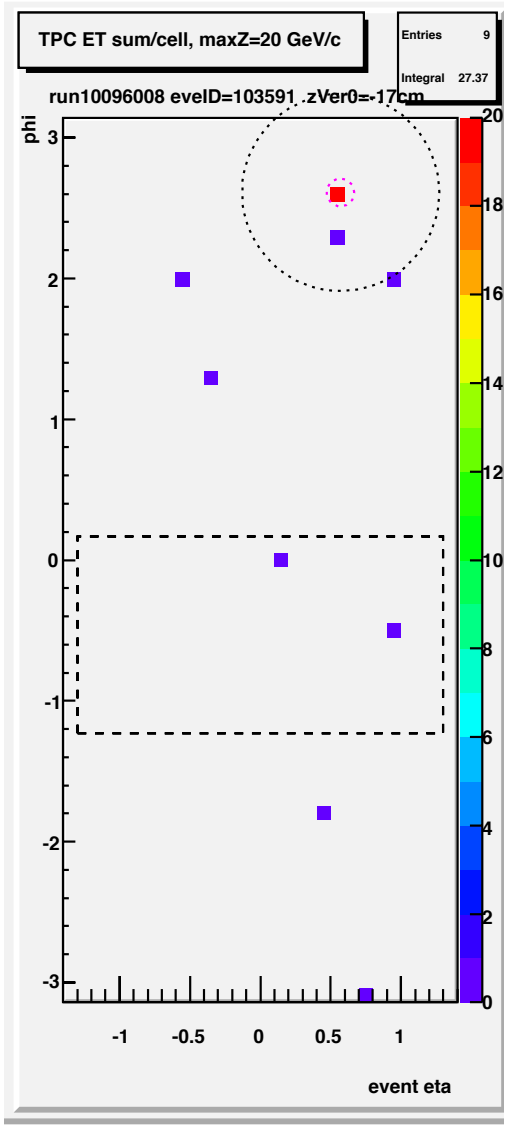

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Electron isolation cuts:

- Electron candidate is any primary TPC track with global P_T >10 GeV/c
- Extrapolate TPC track to BTOW tower
- Compute 2x2 tower cluster E_T, require E_T sum > 15 GeV
- Require the excess E_T in 4x4 tower patch over 2x2 patch to be below 5%
- Require distance of 2x2 cluster vs. TPC track below 7 cm

W production results: Algorithm Details

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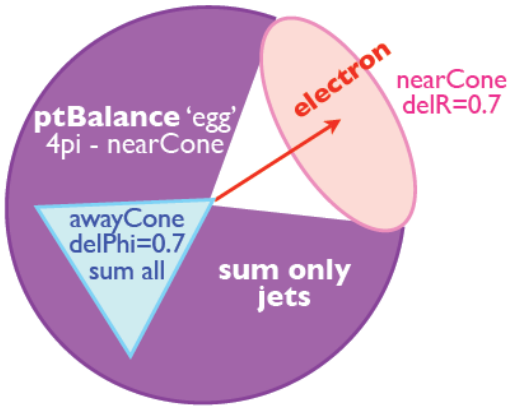
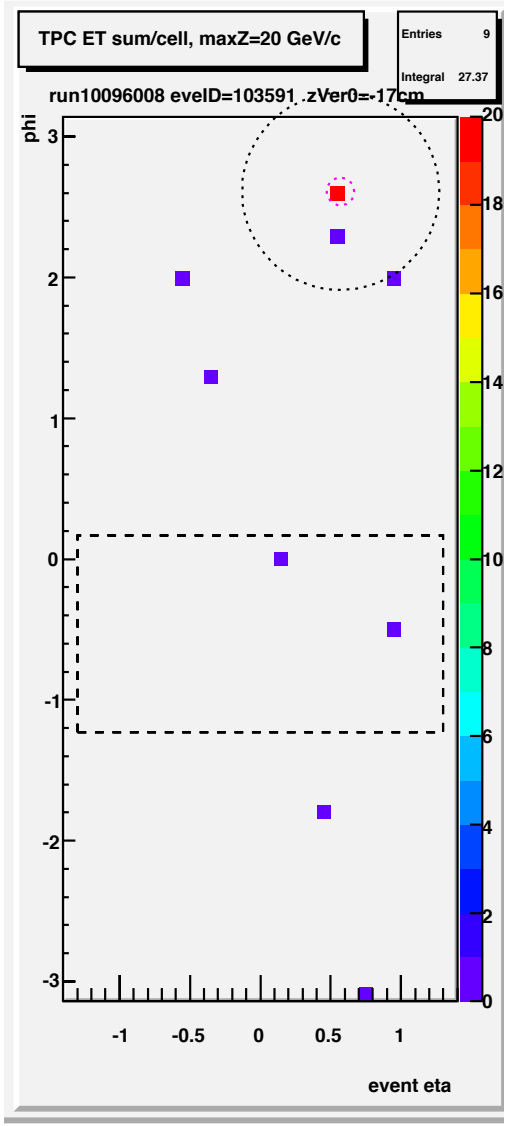
Transverse plane view





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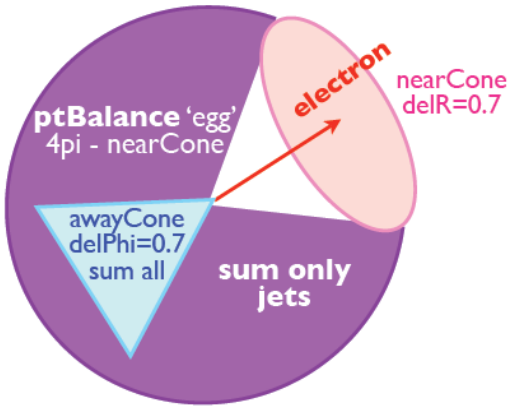
Near-cone veto:

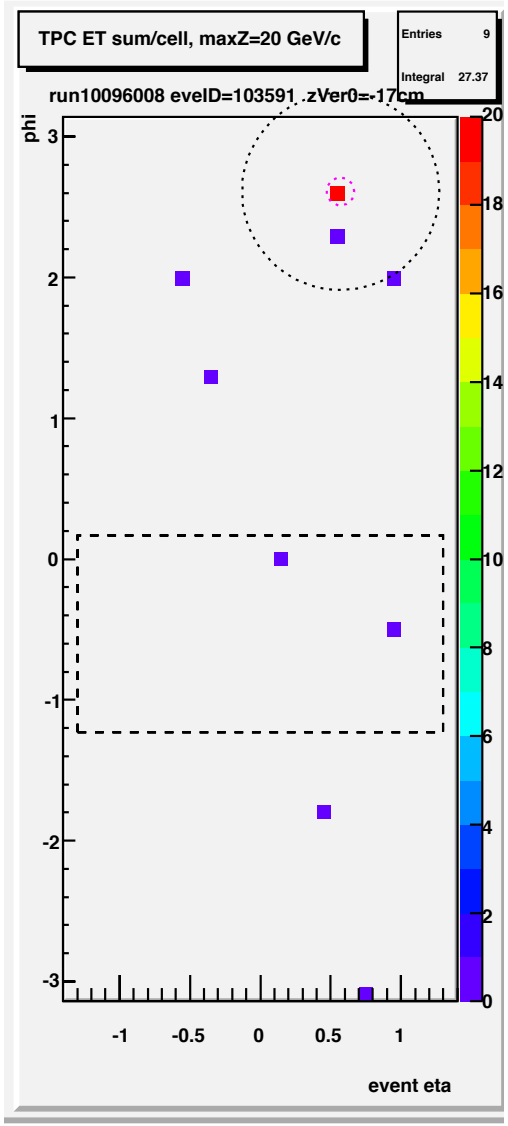
- Compute near-cone E_T sum of BEMC+TPC over $\Delta R=0.7$ in eta-phi space
- Require near-cone excess E_T below 12%

W production results: Algorithm Details

W reconstruction - Algorithm : Details (1)

Transverse plane view





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Away-'cone' cuts: p_T balance requirement

- Vector sum > 15GeV/c of: 2X2 tower cluster p_T and p_T of any number of jets outside near-cone
- E_T of jet > 3.5GeV

W production results: Algorithm Details

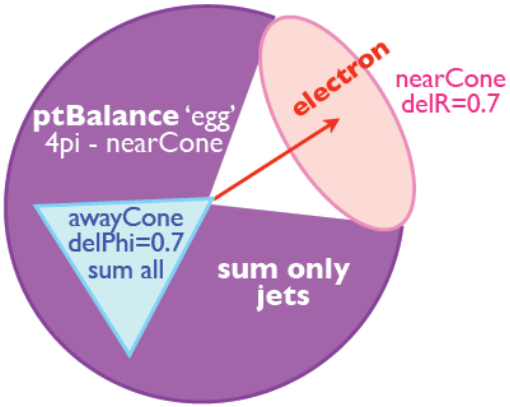
- W reconstruction - Algorithm : Details (2)

W production results: Algorithm Details

W reconstruction - Algorithm : Details (2)

- Lepton meas. in TPC (direction) and in BEMC (energy)
  - TPC & BEMC matching
- Suppress QCD background
  - BEMC cluster isolation
  - Near-side veto
  - Away-side veto

Transverse plane view



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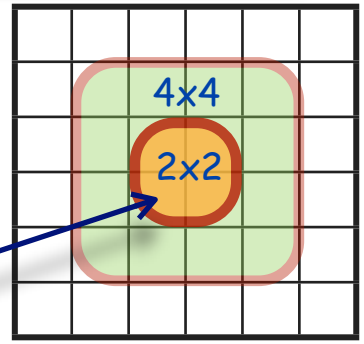
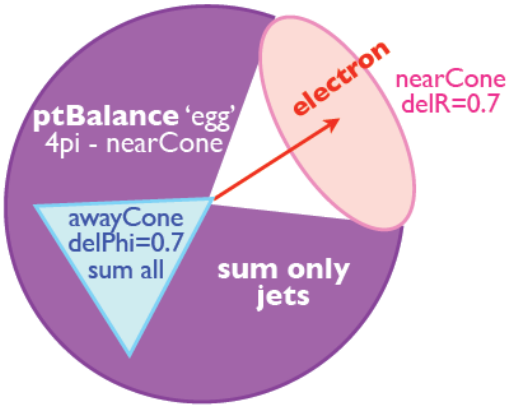
Select 2x2 cluster with highest E_T sum, must contain tower pointed by the track



TPC track extrapolated to BTOW tower grid

Transverse plane view



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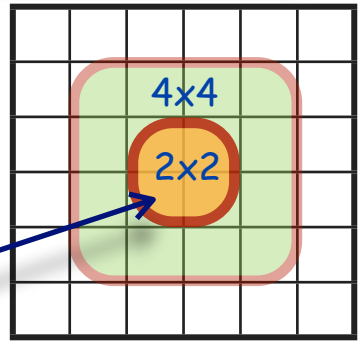
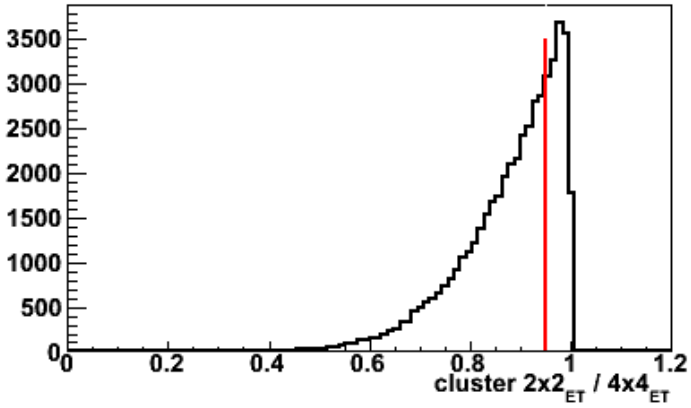
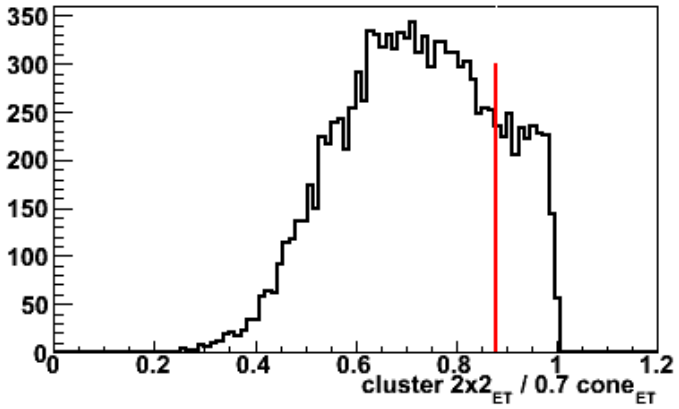
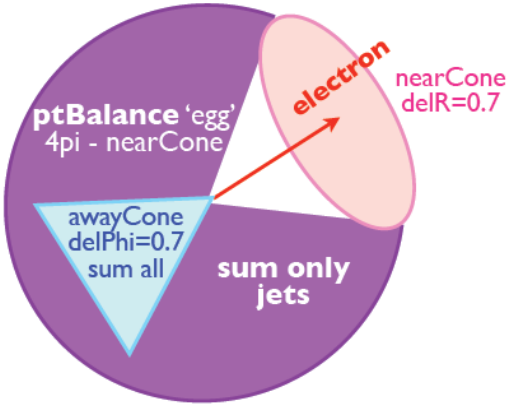






Transverse plane view

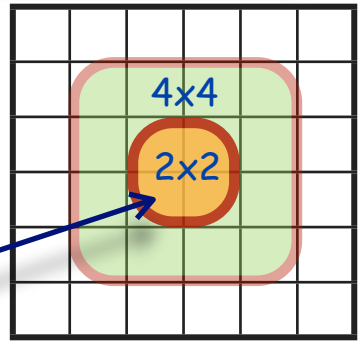


W production results: Algorithm Details

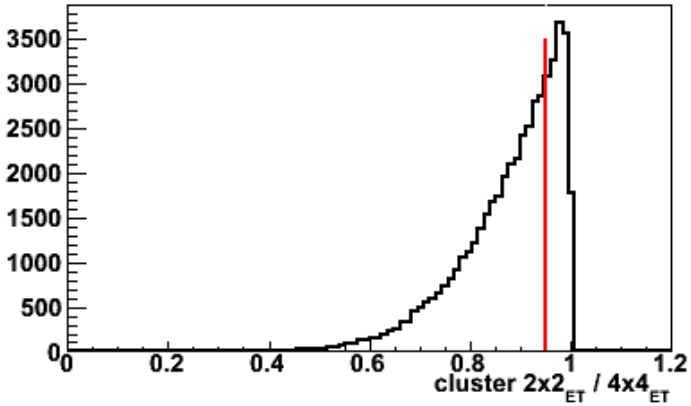
W reconstruction - Algorithm : Details (2)

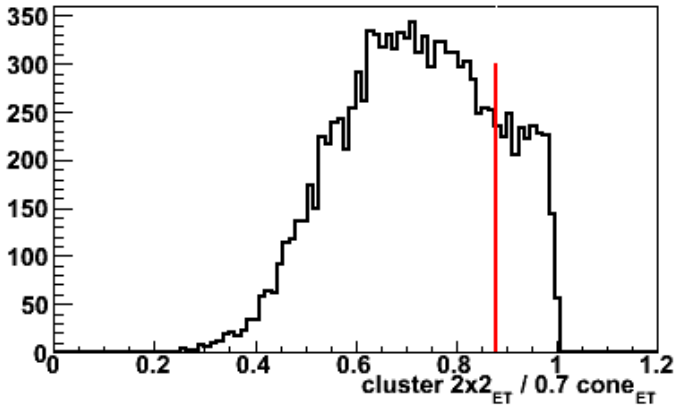
- Lepton meas. in TPC (direction) and in BEMC (energy)
  - TPC & BEMC matching
- Suppress QCD background
  - BEMC cluster isolation
  - Near-side veto
  - Away-side veto

Select 2x2 cluster with highest E_T sum, must contain tower pointed by the track

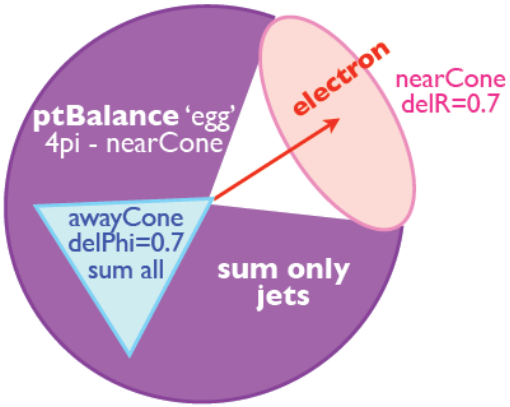


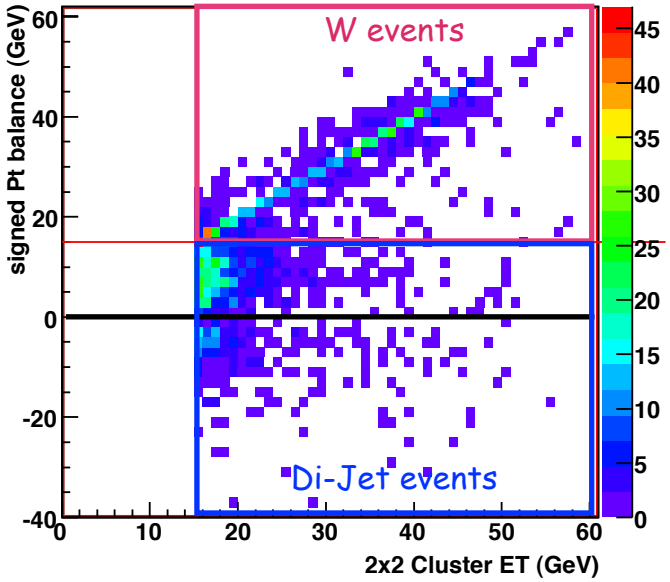
TPC track extrapolated to BTOW tower grid





Transverse plane view



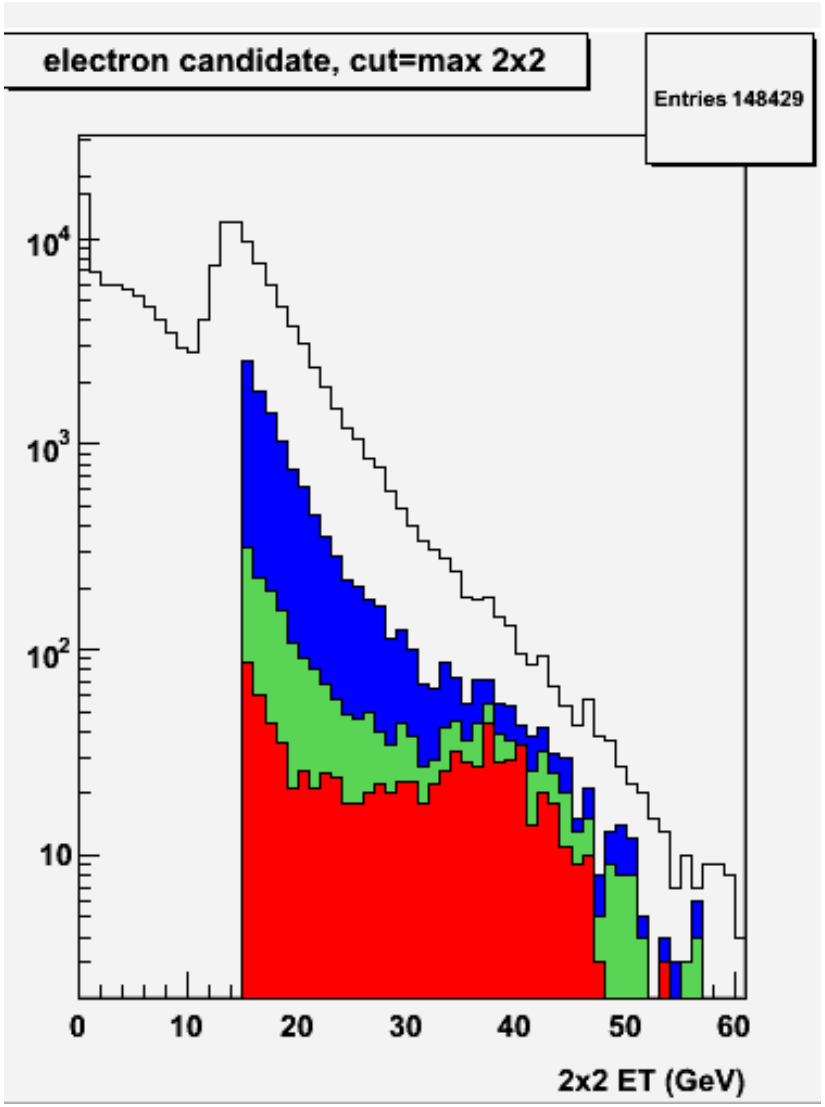


W production results: Algorithm Details

- Evolution of E_T distribution vs. cut ID

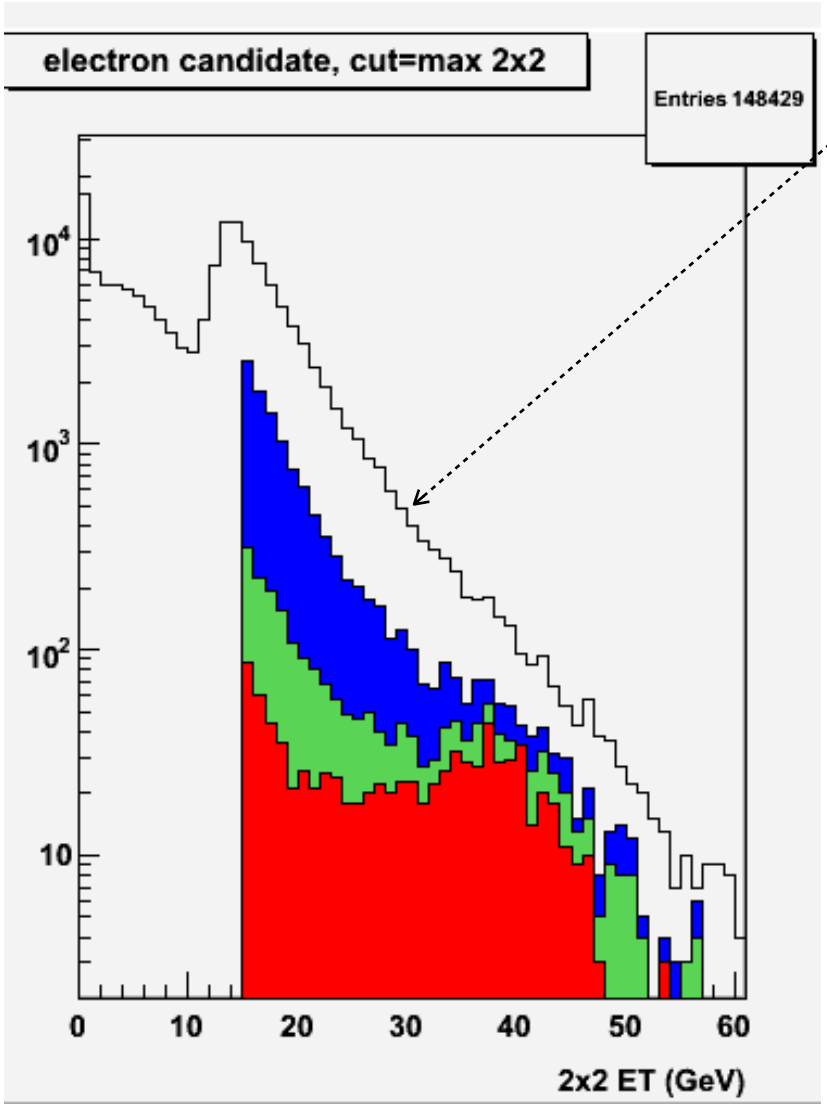
W production results: Algorithm Details

- Evolution of E_T distribution vs. cut ID



W production results: Algorithm Details

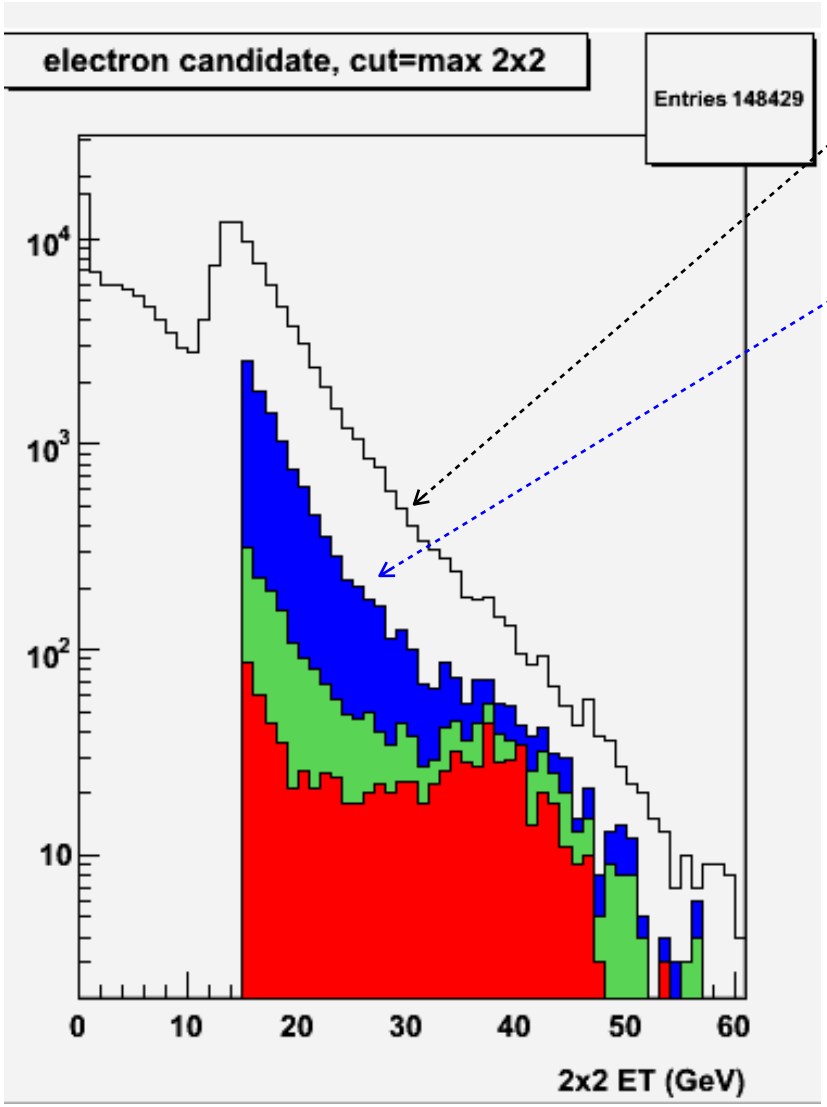
- Evolution of E_T distribution vs. cut ID



Starting raw distribution

W production results: Algorithm Details

- Evolution of E_T distribution vs. cut ID

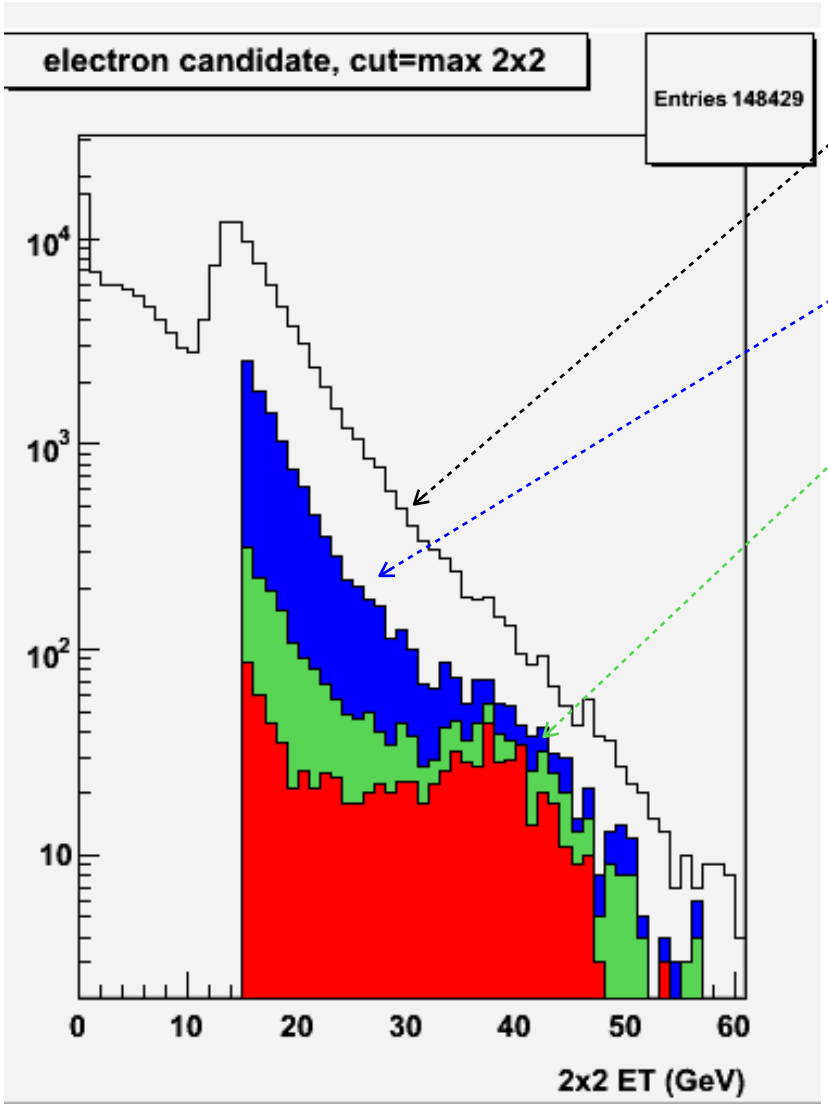


Starting raw distribution

Track-cluster match

W production results: Algorithm Details

- Evolution of E_T distribution vs. cut ID



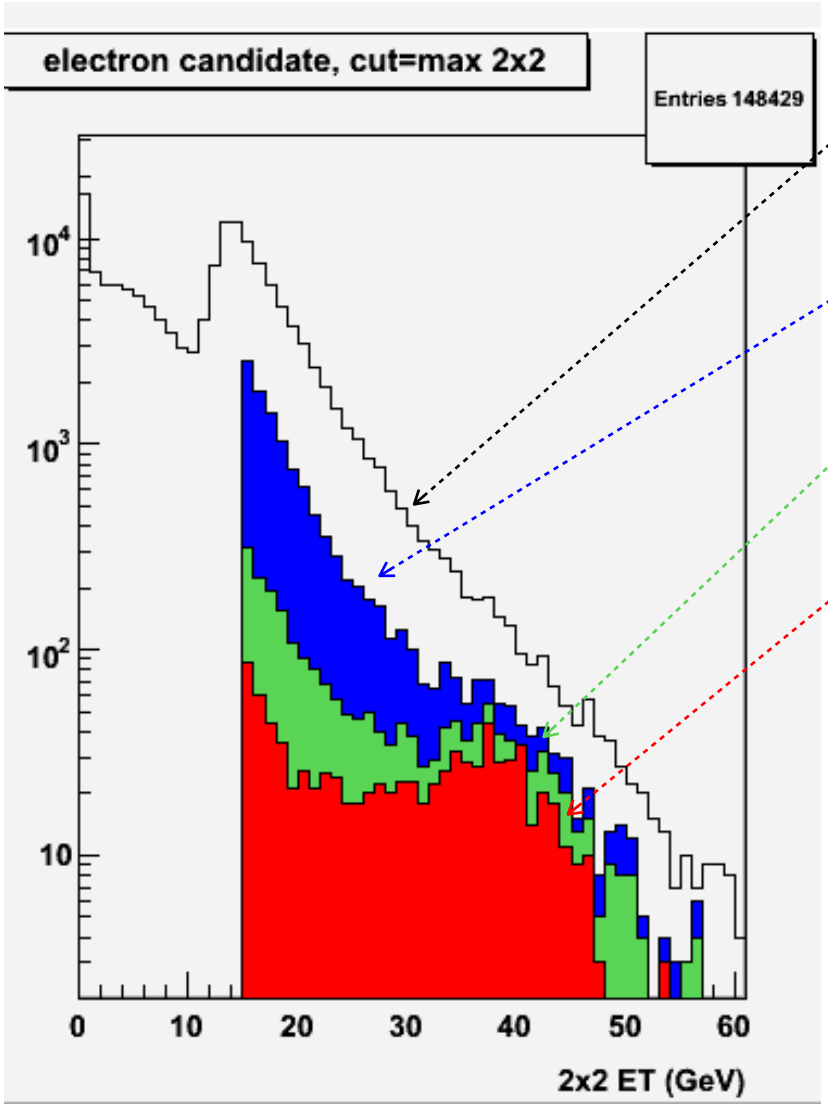
Starting raw distribution

Track-cluster match

No near cone E_T

W production results: Algorithm Details

- Evolution of E_T distribution vs. cut ID



Starting raw distribution

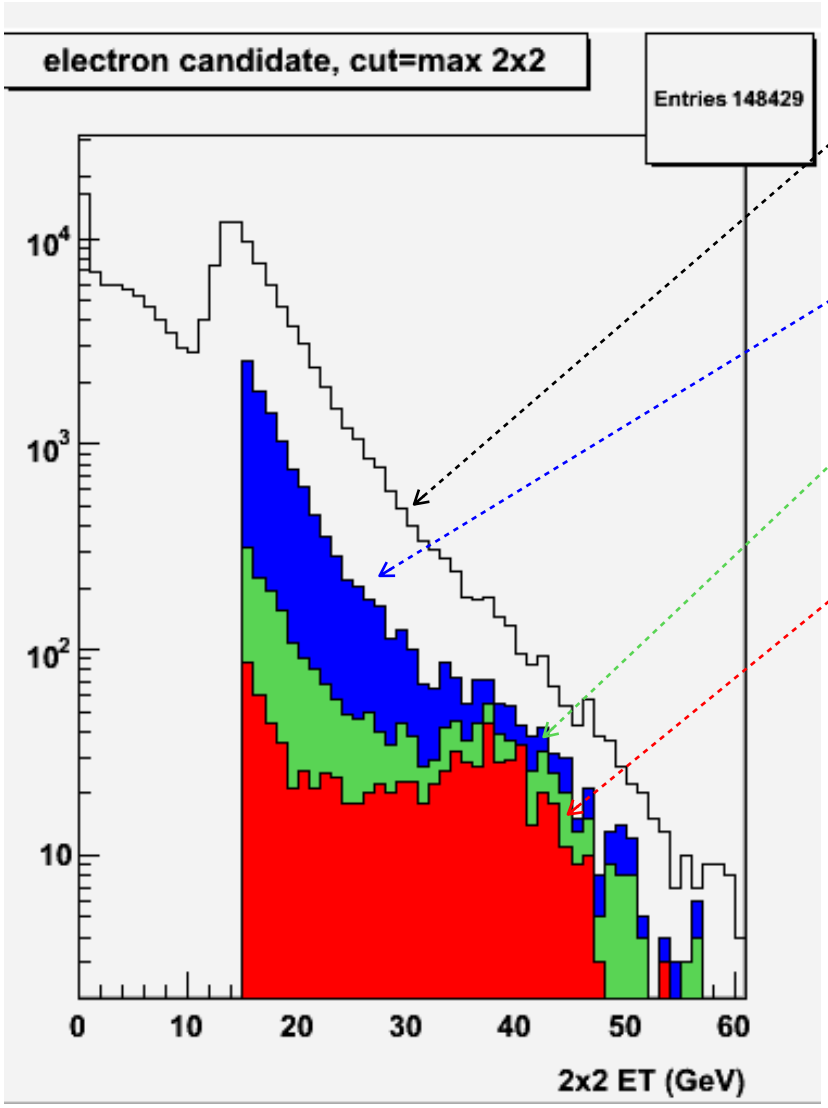
Track-cluster match

No near cone E_T

No away cone E_T

W production results: Algorithm Details

- Evolution of E_T distribution vs. cut ID



Starting raw distribution

Track-cluster match

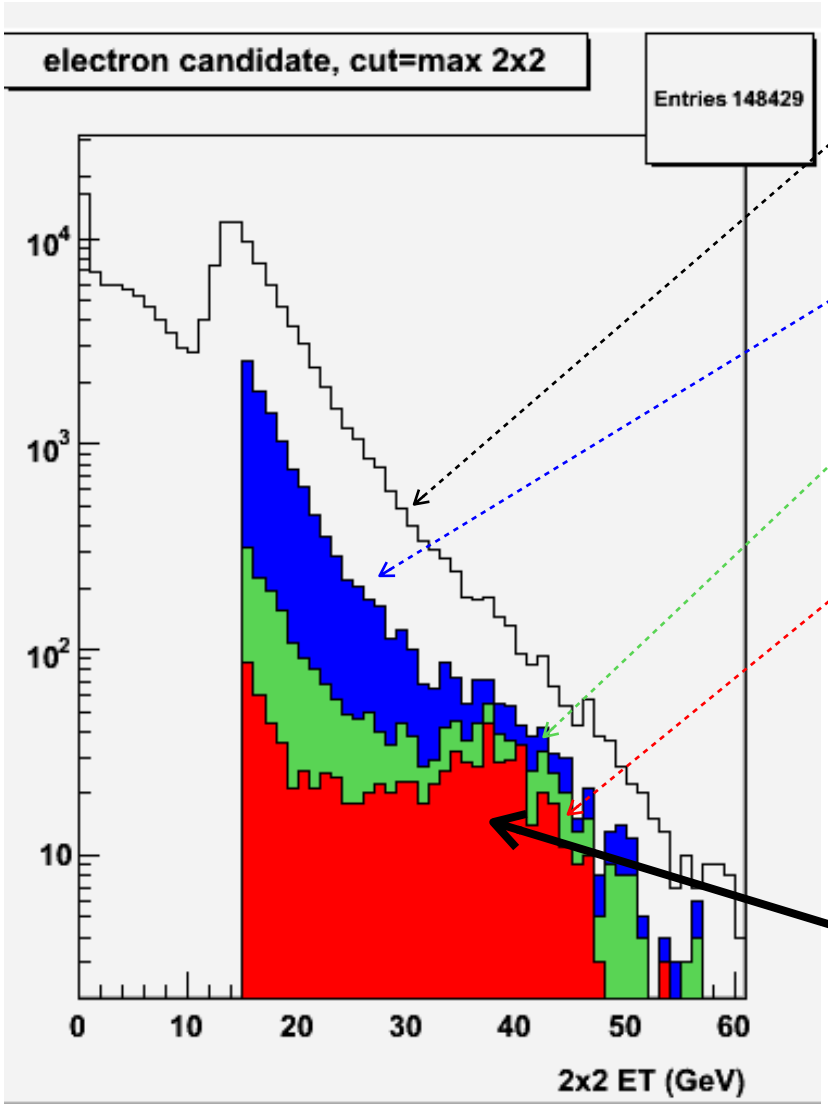
No near cone E_T

No away cone E_T

Using the algorithm a clear Jacobian peak can be seen characteristic for W production in contrast to QCD background!

W production results: Algorithm Details

- Evolution of E_T distribution vs. cut ID



Starting raw distribution

Track-cluster match

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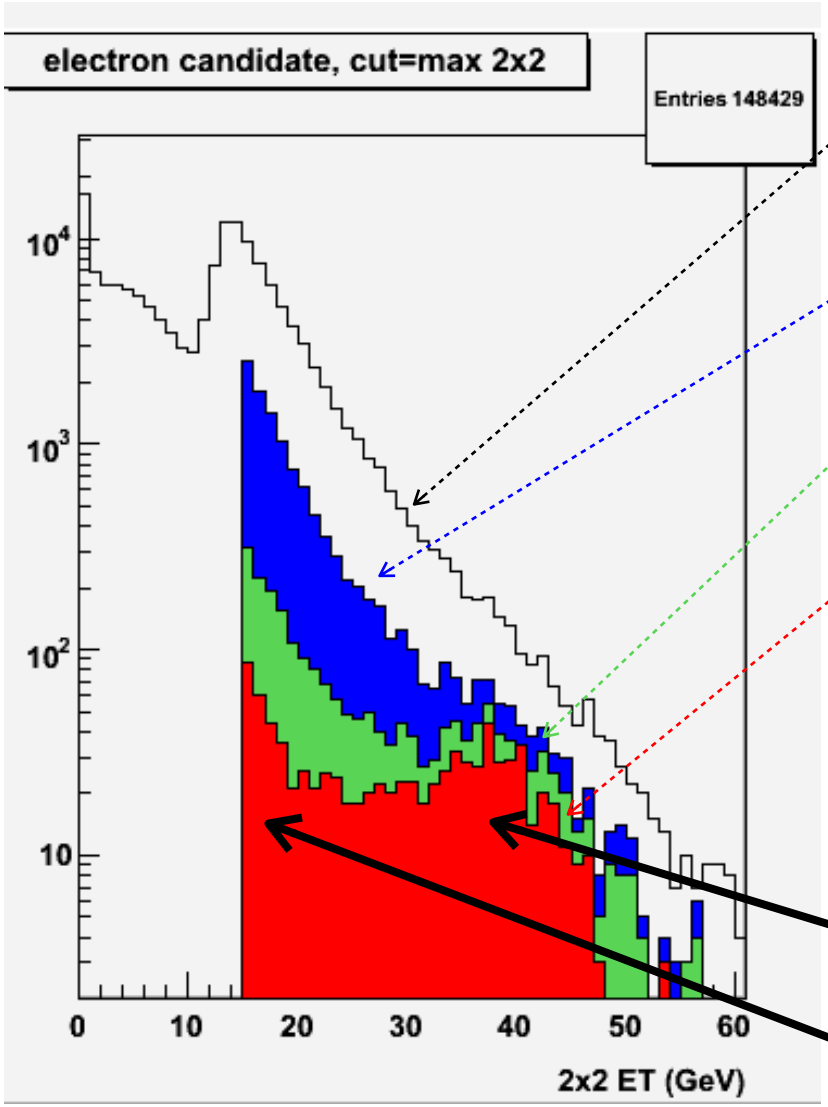
Using the algorithm a clear Jacobian peak can be seen characteristic for W production in contrast to QCD background!

W production results: Algorithm Details

- Evolution of E_T distribution vs. cut ID



Starting raw distribution

Track-cluster match

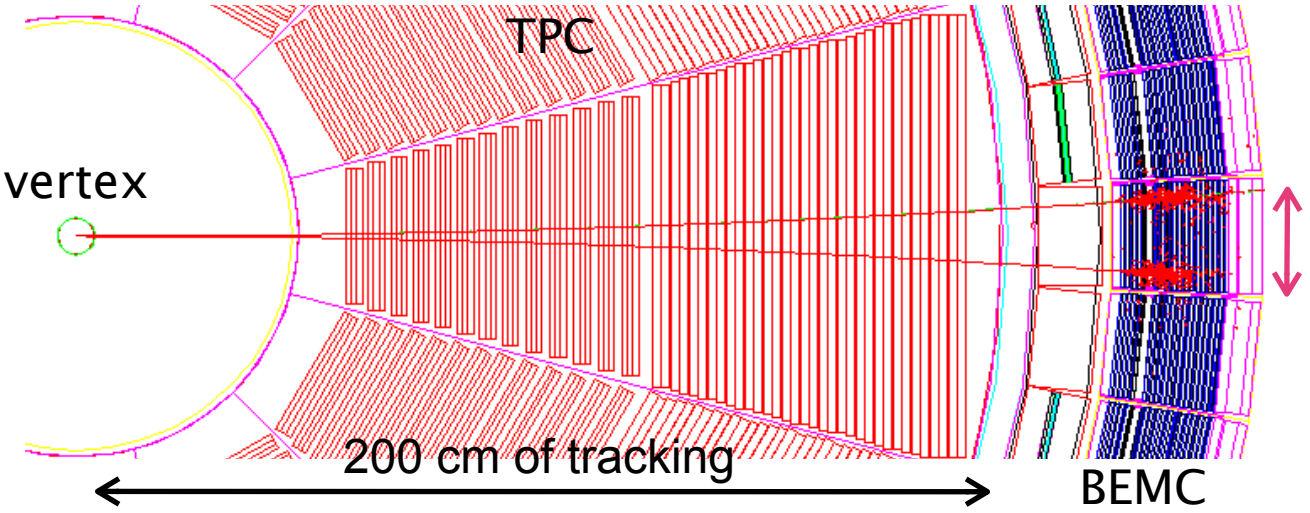
No near cone E_T

No away cone E_T

Using the algorithm a clear Jacobian peak can be seen characteristic for W production in contrast to QCD background!

W production results: Charge separation

- Mid-rapidity high p_T $e^{\pm}$ charge separation



positron p_T = 5 GeV

electron p_T = 5 GeV

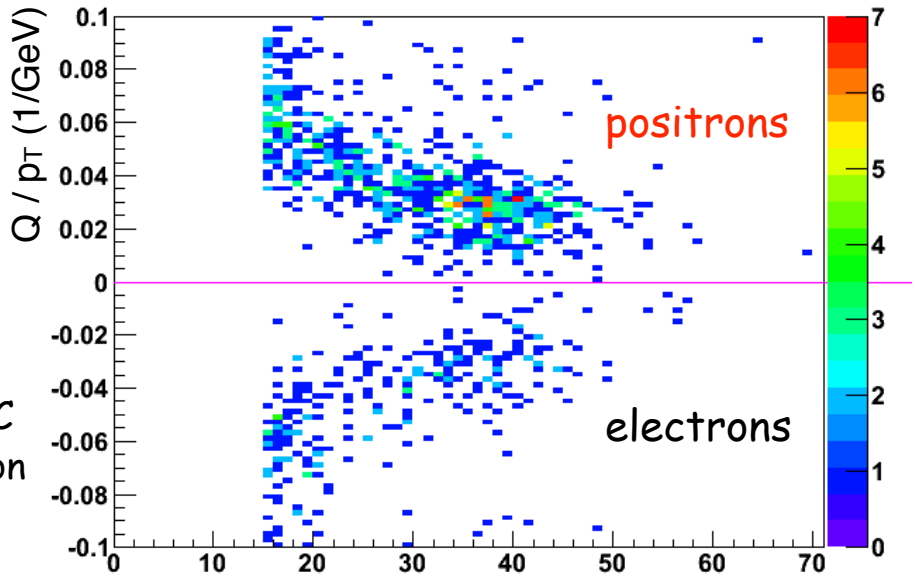
+/- distance D: ~1/P_T

p_T = 5 GeV : D ~15 cm

p_T = 40 GeV : D ~2 cm

Successful separation of different charge states!

Q: Charge-sign of reconstructed track



Final TPC calibration

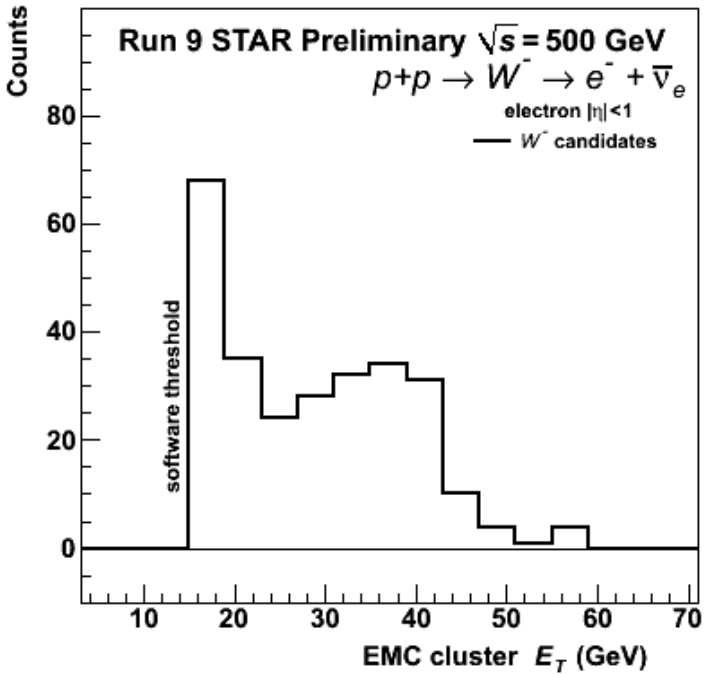
Assign:

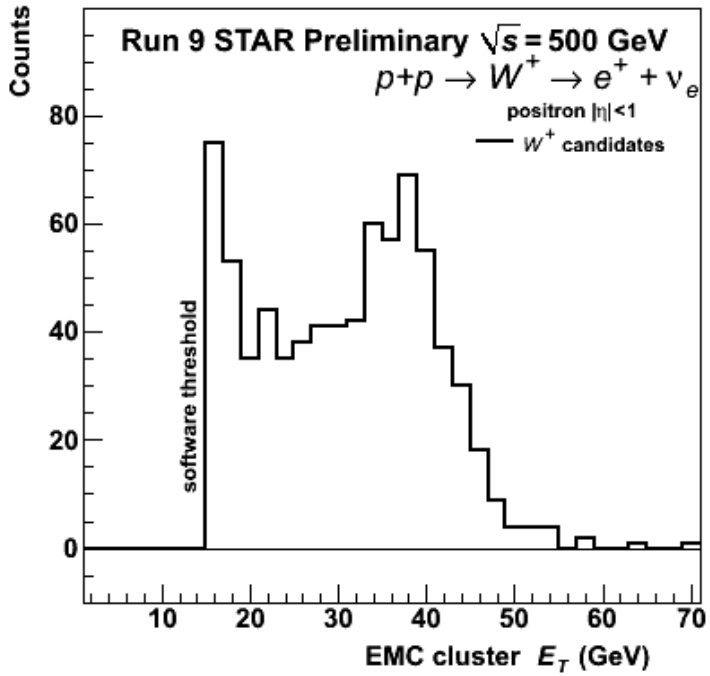
Q/p_T > 0 positrons

Q/p_T < 0 to be electrons

W production results: Charged-separated Yields

- Charge separated raw Signal / Jacobian Peak Distributions





- Charged separated W^+/W^- candidate distributions of the BEMC cluster transverse energy E_T (GeV)
- Cuts: All previously discussed cuts!

W production results: Background

- Background treatment

W production results: Background

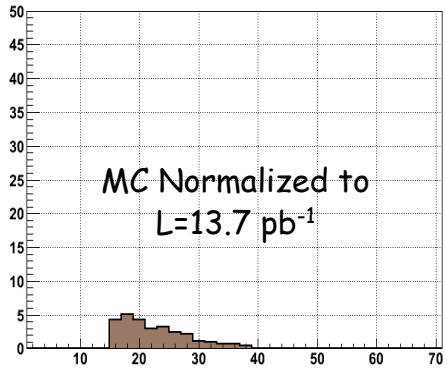
- Background treatment

PYTHIA+GEANT MC ⟶

$W \rightarrow \tau + \nu_\tau$

$\tau \rightarrow e + \nu_e + \nu_\tau$

W^+ distributions



W production results: Background

- Background treatment

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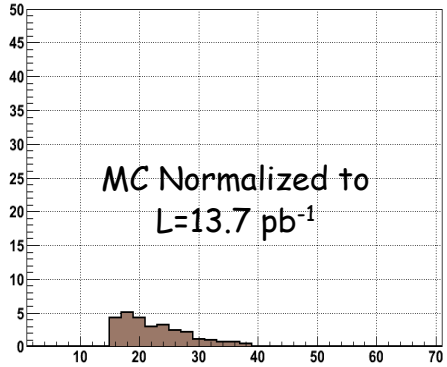
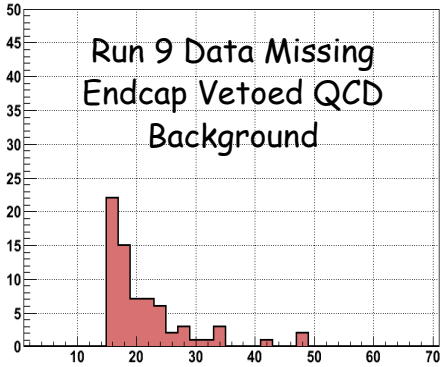
W^+ distributions



1. Run analysis with EEMC in veto cuts
2. Run analysis without EEMC in veto cuts
3. Subtract two raw signals



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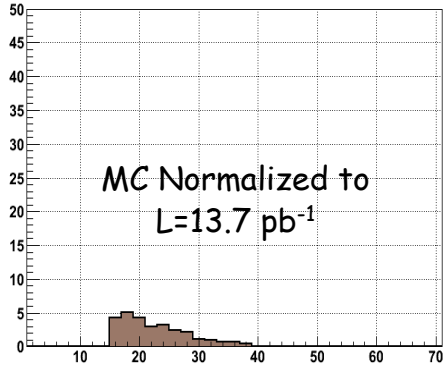

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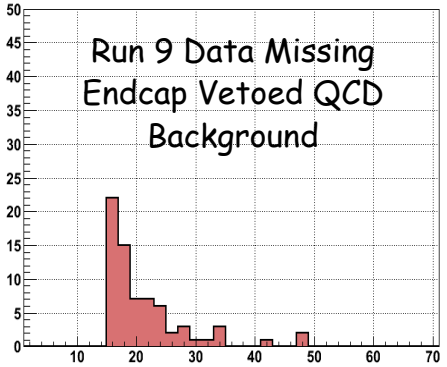
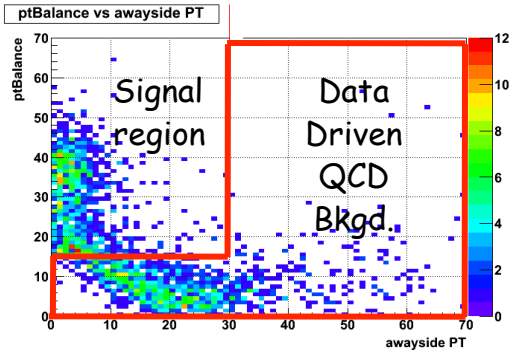
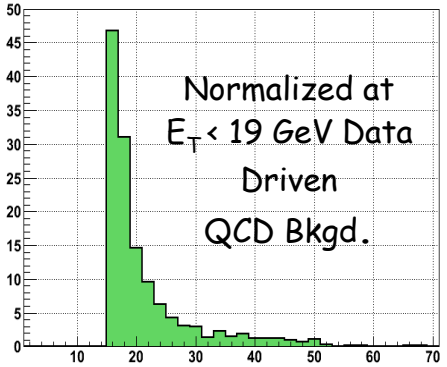




⟶



W production results: Background

- Background treatment

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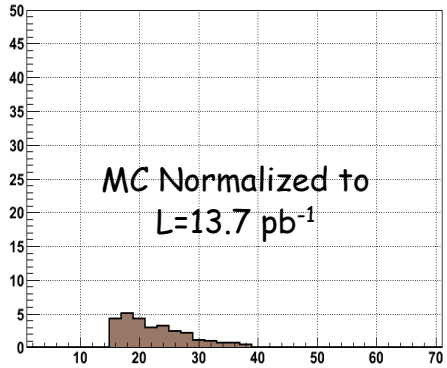
W^+ distributions



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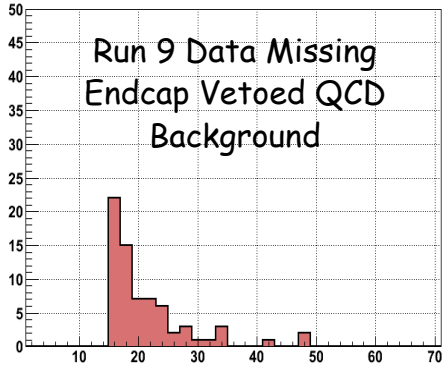
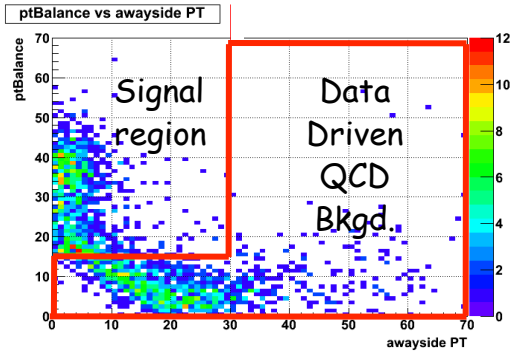
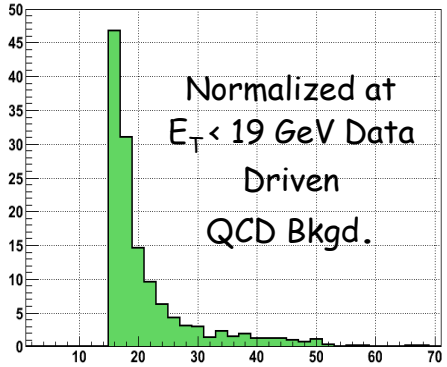




→



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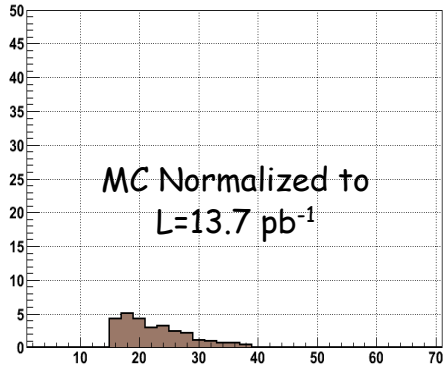
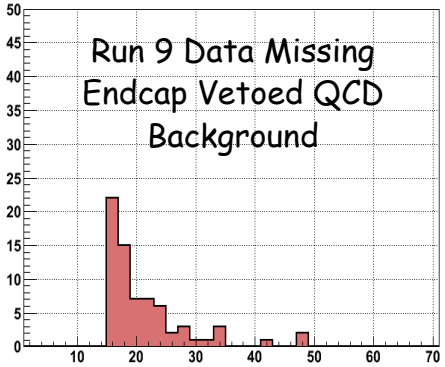
W^+ distributions





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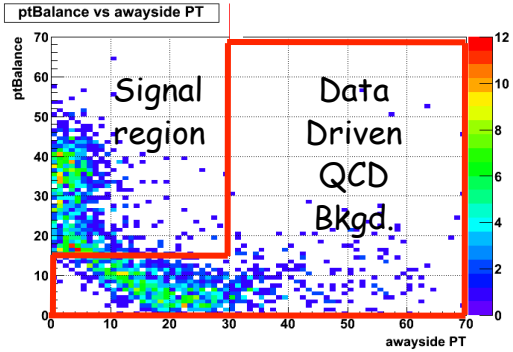

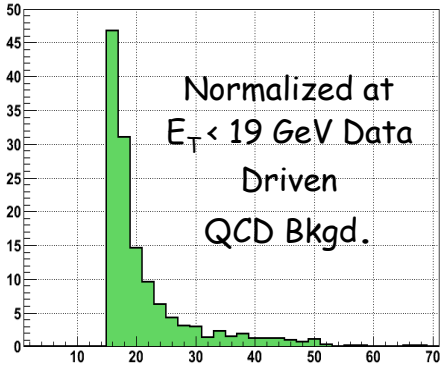

W production results: Background

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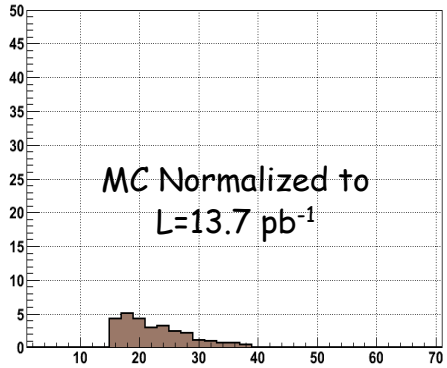
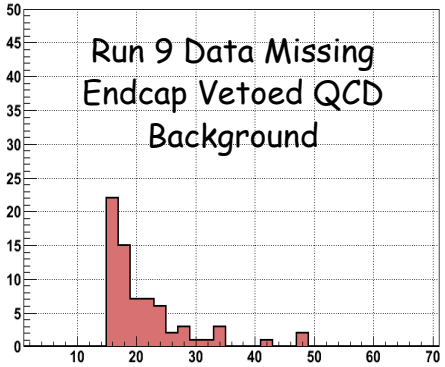
W^+ distributions





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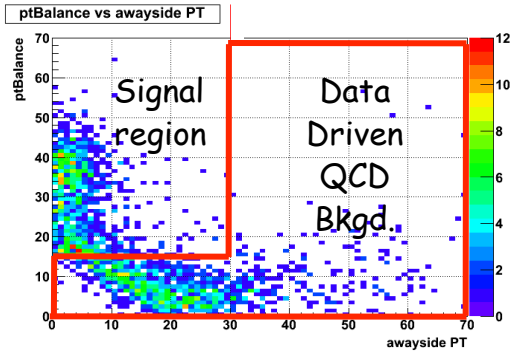

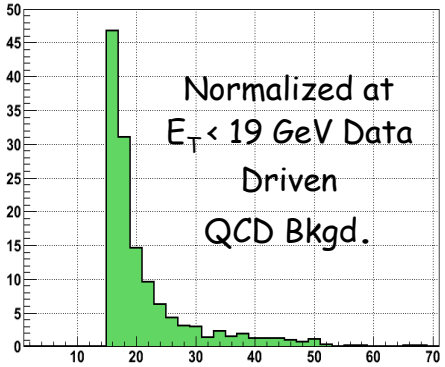

W production results: Background

- Background treatment

PYTHIA+GEANT MC →

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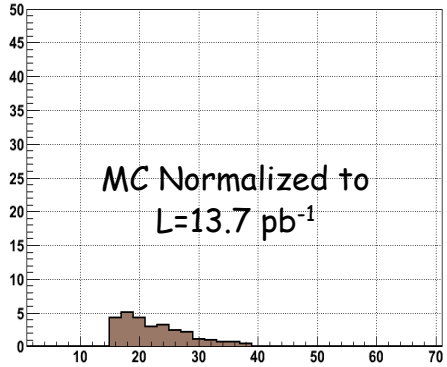
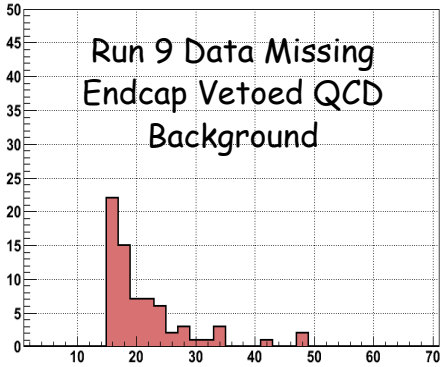
W⁺ distributions





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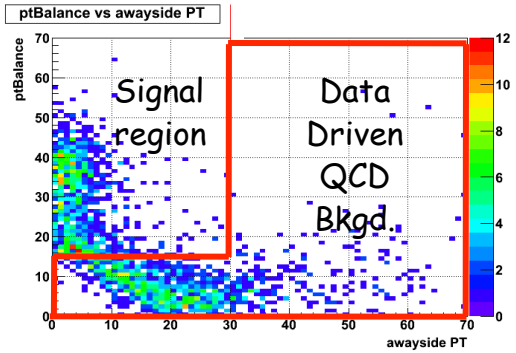
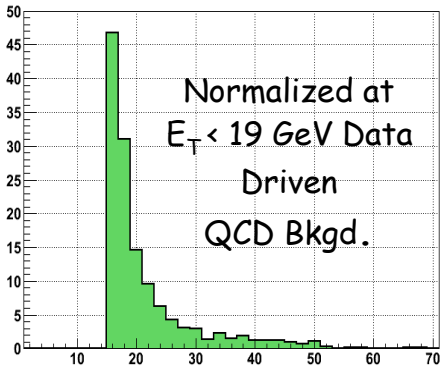
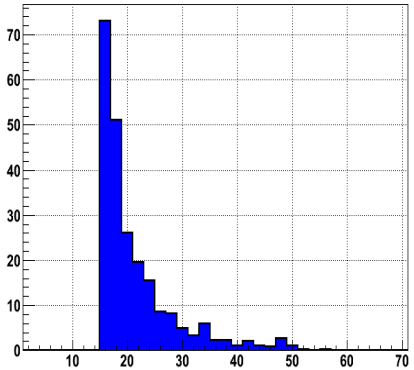




Total Background



EMC Cluster E_T (GeV)

W production results: Background

Background treatment

PYTHIA+GEANT MC →

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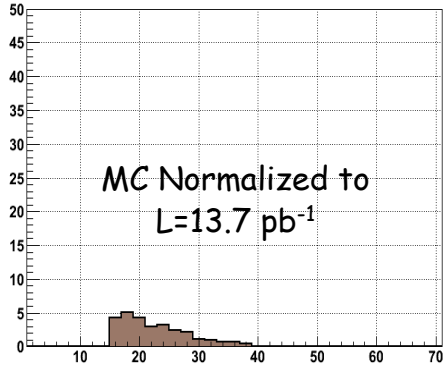
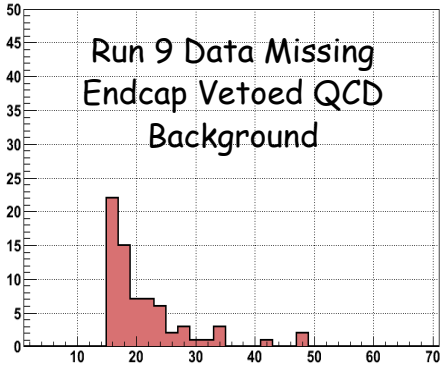
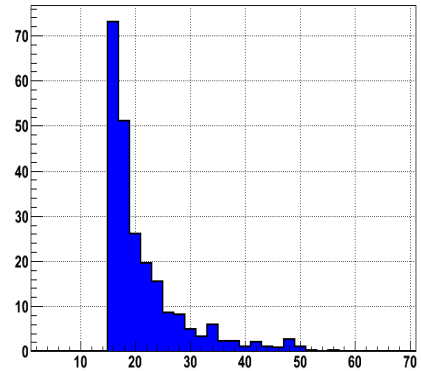
$\tau \rightarrow e + \nu_e + \nu_\tau$

W^+ distributions





Total Background



EMC Cluster E_T (GeV)

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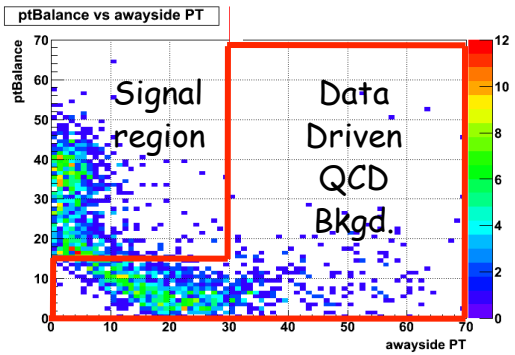
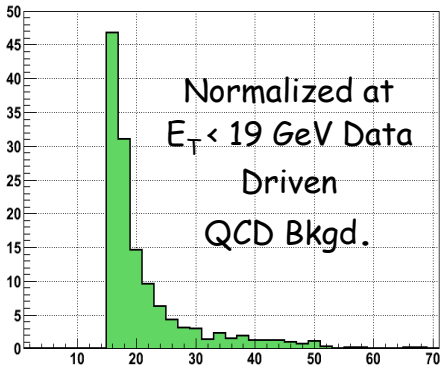
3. Subtract two raw signals



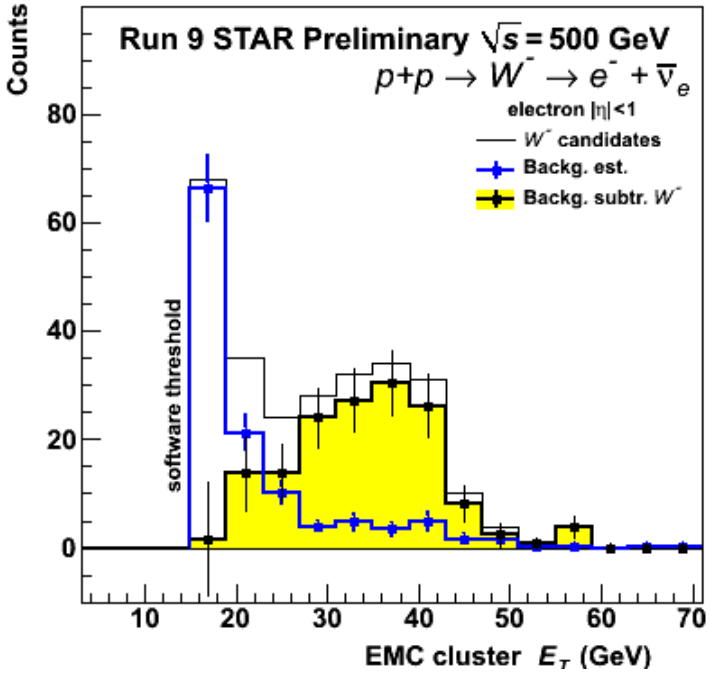


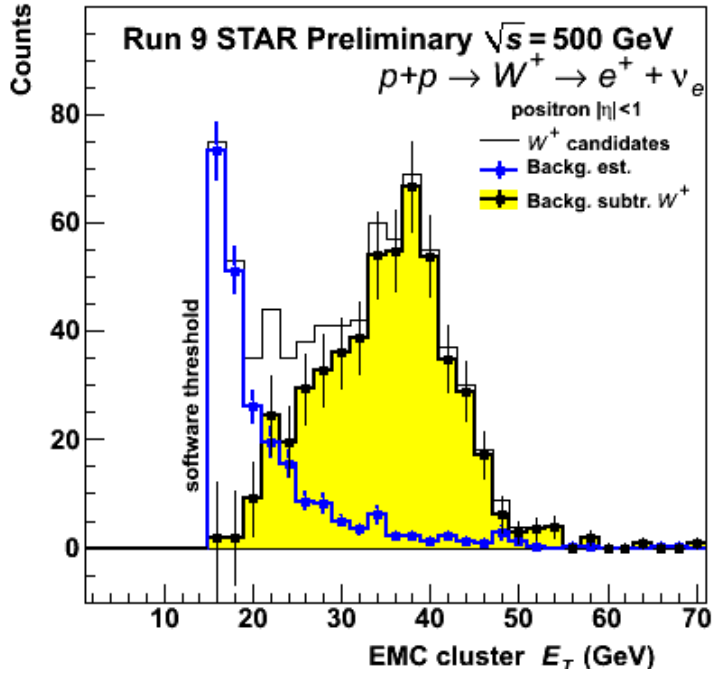
Background systematics:

- Calculate different data driven QCD background shapes by varying p_T balance and away-side p_T cuts
- Vary normalization region (E_T < 17 - 21 GeV)
- The largest deviation in each bin used for sys. error estimate

W production results: Background

- Background subtraction

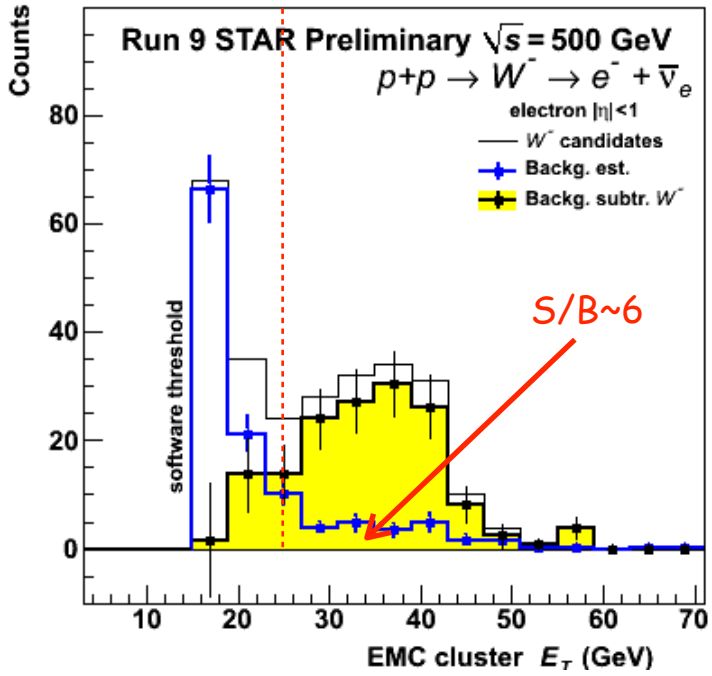


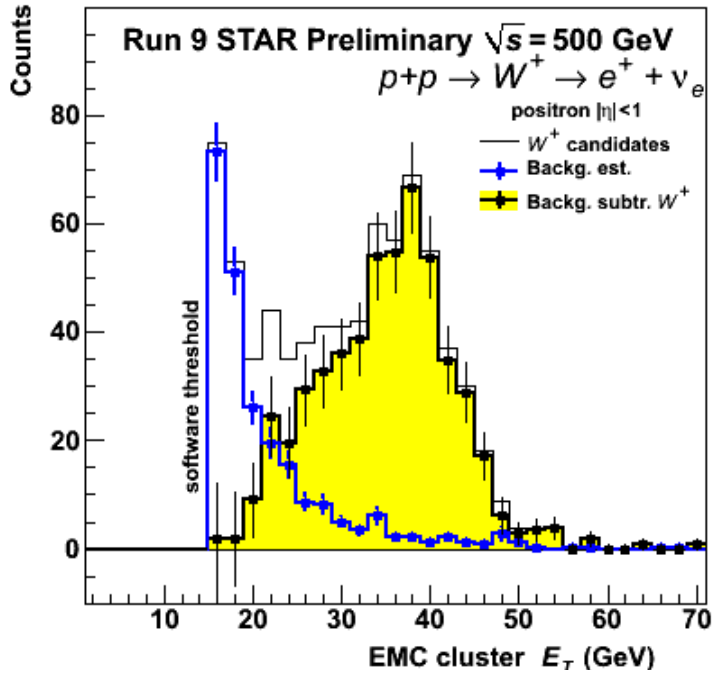


- Background distribution and background-subtracted signal distribution
- B/(S+B) (E_T > 25GeV) W^-: 16%
- B/(S+B) (E_T > 25GeV) W^+: 8%

W production results: Background

- Background subtraction





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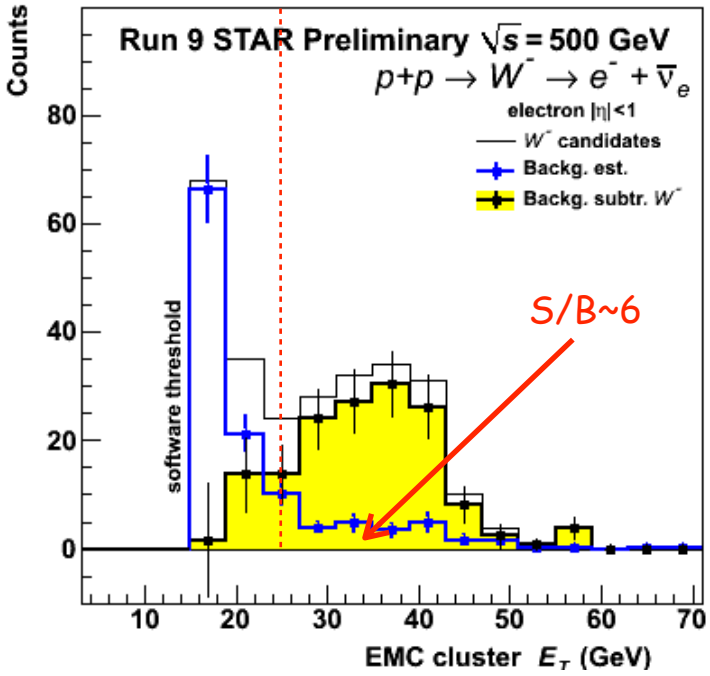

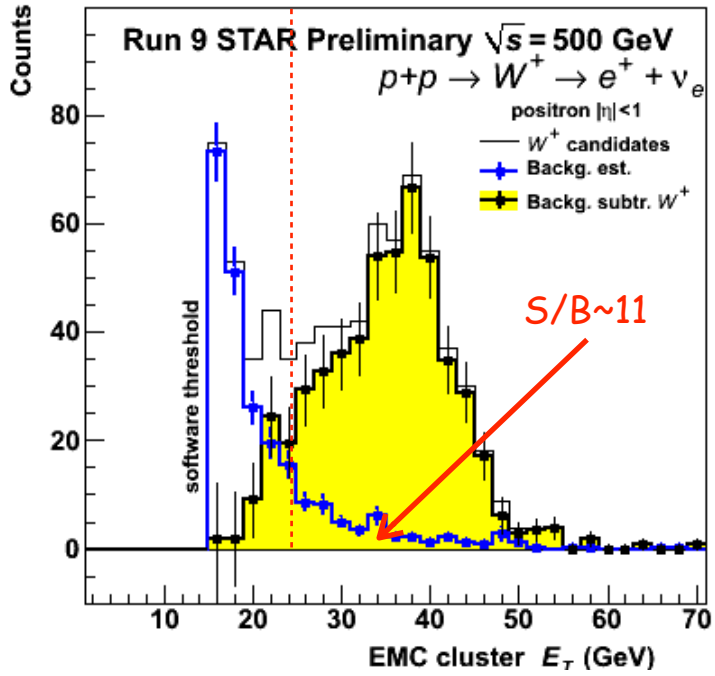

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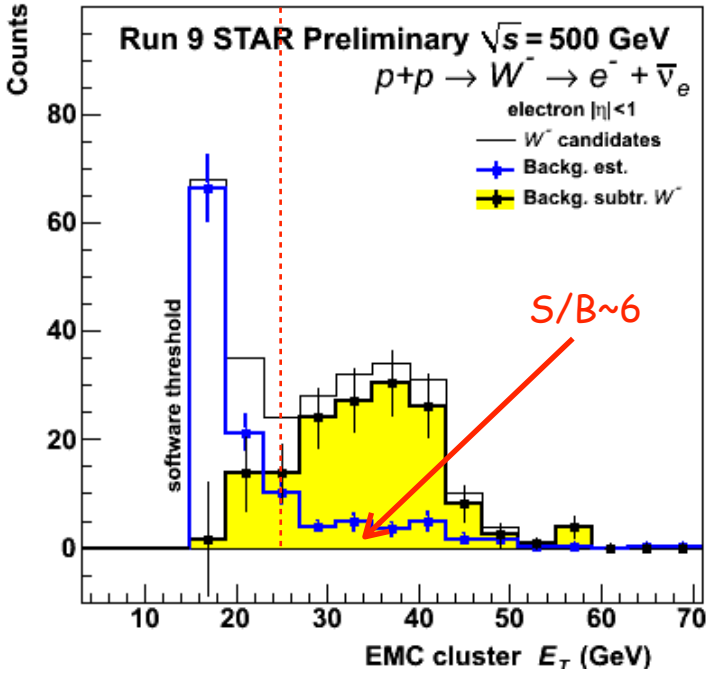

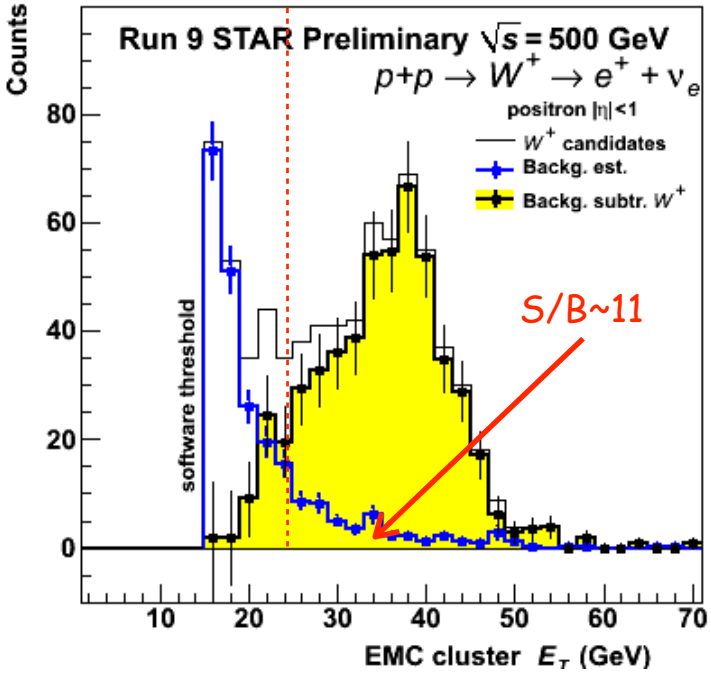

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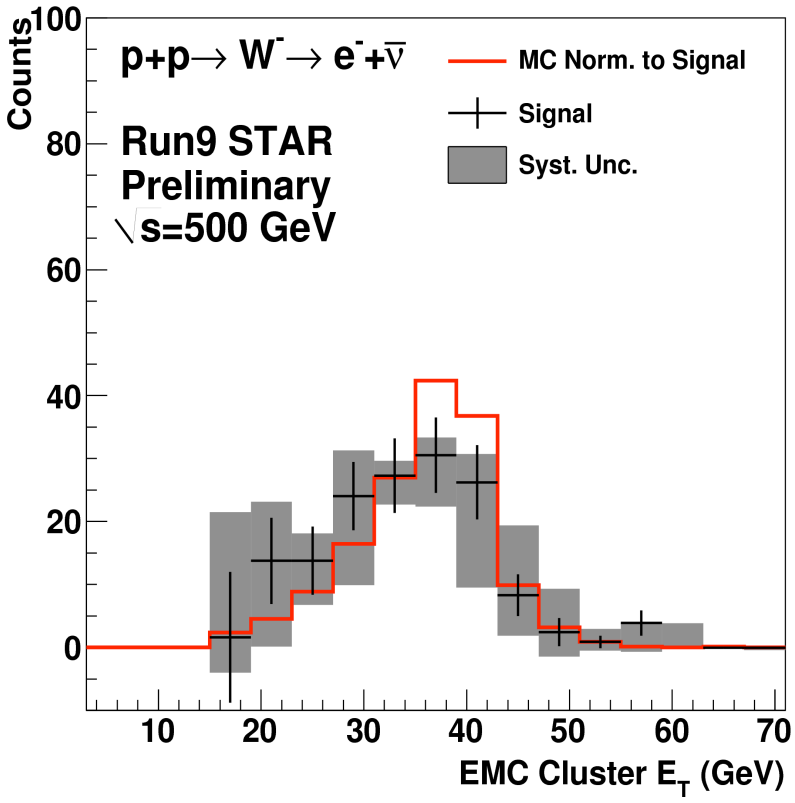
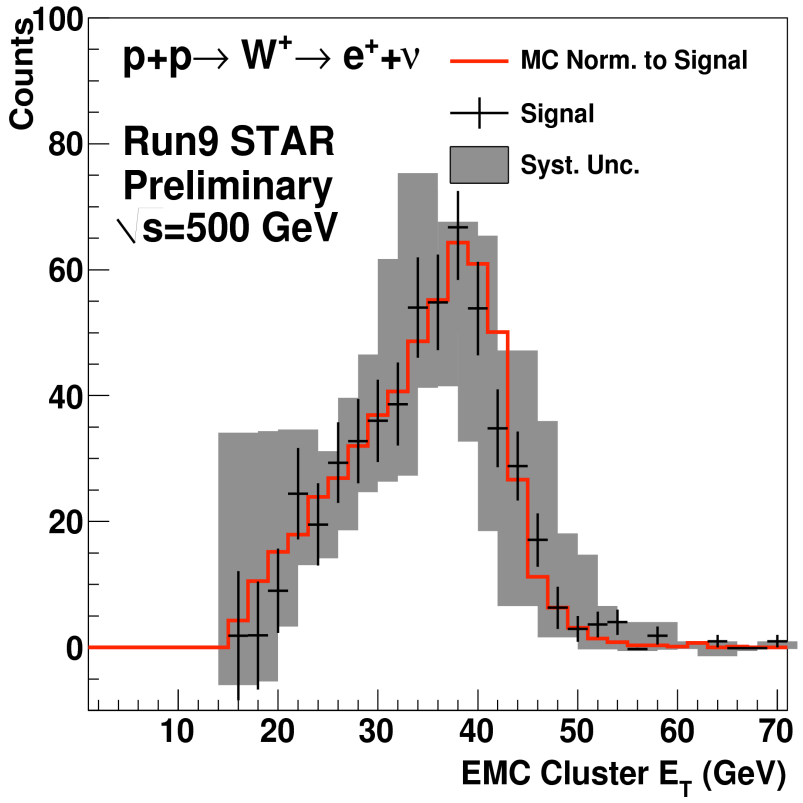
Background Events ($E_T > 25$ GeV)	$W^- \rightarrow e^- + \bar{\nu}_e$	$W^+ \rightarrow e^+ + \nu_e$
$W \rightarrow \tau + \nu_\tau$	2.7 ± 0.7	8.4 ± 2.2
Missing Endcap	14 ± 4	13 ± 4
Normalized QCD	$8.0\ ^{+20}_{-4}$	$25\ ^{+36}_{-9}$
Total	$25\ ^{+21}_{-7}$	$46\ ^{+36}_{-11}$

W production results: Data/MC comparison

- Data/MC Comparison of charge-separated Jacobian peak distributions

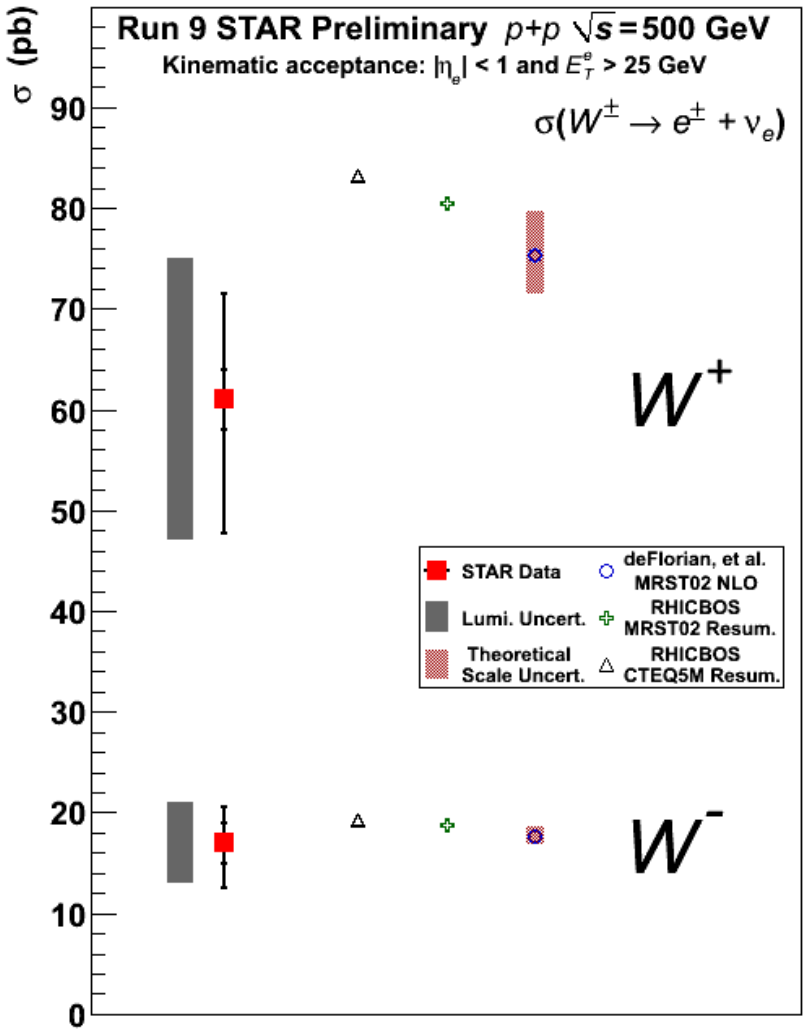




- Comparison of data and PYTHIA+GEANT simulations for W signal events at $\sqrt{s}$=500GeV
- Systematic uncertainties were estimated by varying cuts and normalization regions for QCD background and by varying BEMC energy scale uncertainty (±7.5%)

W production results: Cross-Section

- Total W^+/W^- Cross-section results



STAR Preliminary Run 9 (p+p $\sqrt{s}$=500 GeV)

$$\sigma_{W^+ \to e^+ + \nu} = 61 \pm 3\ (\text{stat.})\ ^{+10}_{-13}\ (\text{syst.}) \pm 14\ (\text{lumi.})\ \text{pb}$$

$$\sigma_{W^- \to e^- + \bar{\nu}} = 17 \pm 2\ (\text{stat.})\ ^{+3}_{-4}\ (\text{syst.}) \pm 4\ (\text{lumi.})\ \text{pb}$$

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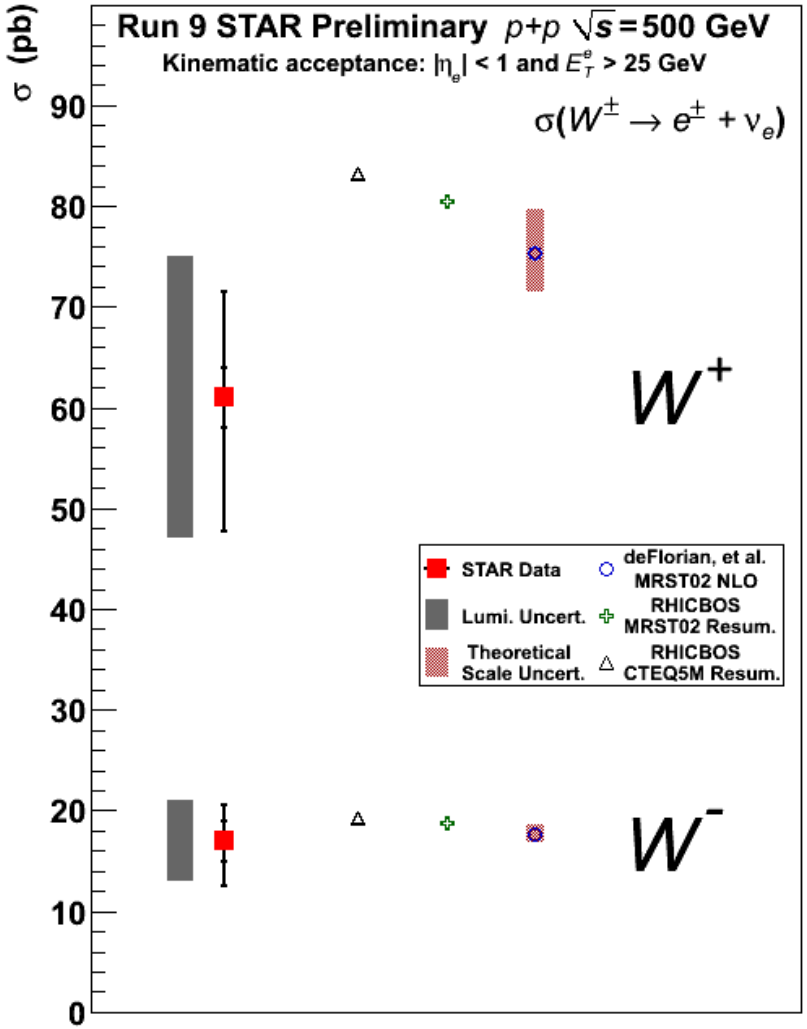

	$W^- \to e^- + \bar{\nu}_e$	$W^+ \to e^+ + \nu_e$
N_W^{obs}	156	513
N_{back}	$25\ ^{+21}_{-7}$	$46\ ^{+36}_{-11}$
ϵ_{total}	$0.56\ ^{+0.11}_{-0.09}$	$0.56\ ^{+0.12}_{-0.09}$
$\int Ldt\ (\mathrm{pb}^{-1})$	13.7 ± 3.2	13.7 ± 3.2

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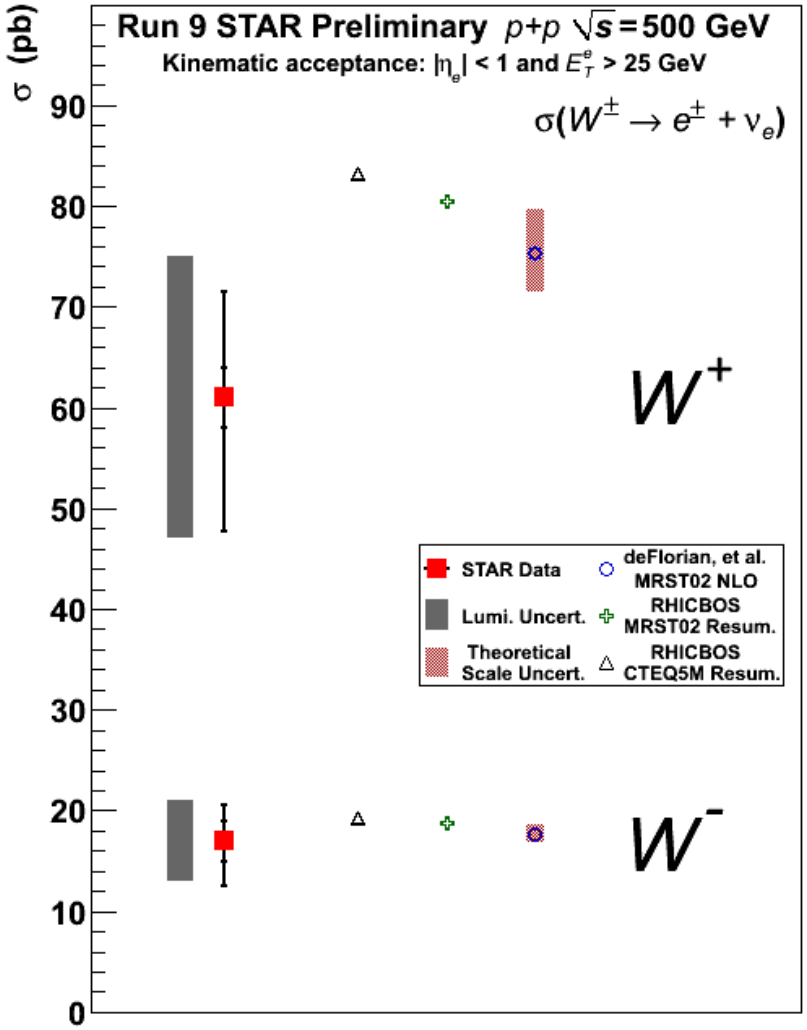

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- Reasonable agreement between measured and theory evaluated cross-sections within uncertainties!

W production results: Asymmetry

- Parity-violating single-spin asymmetry W^+/W^- A_L results

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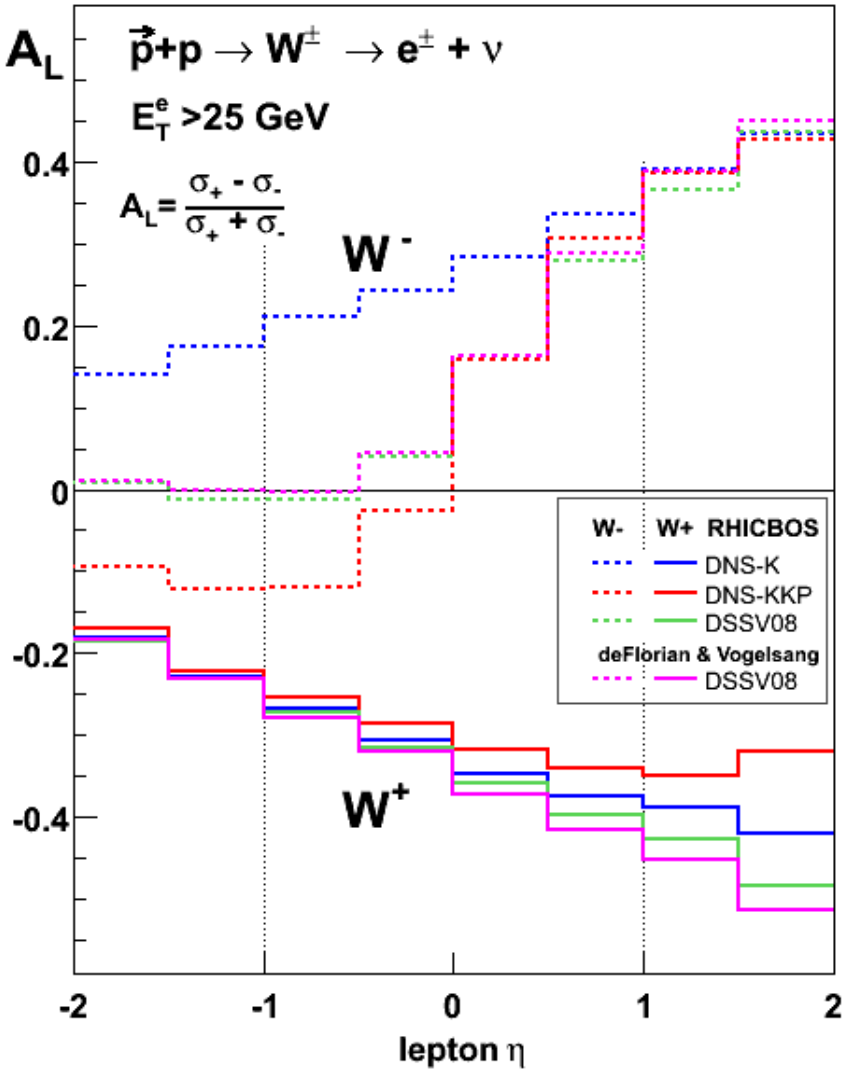

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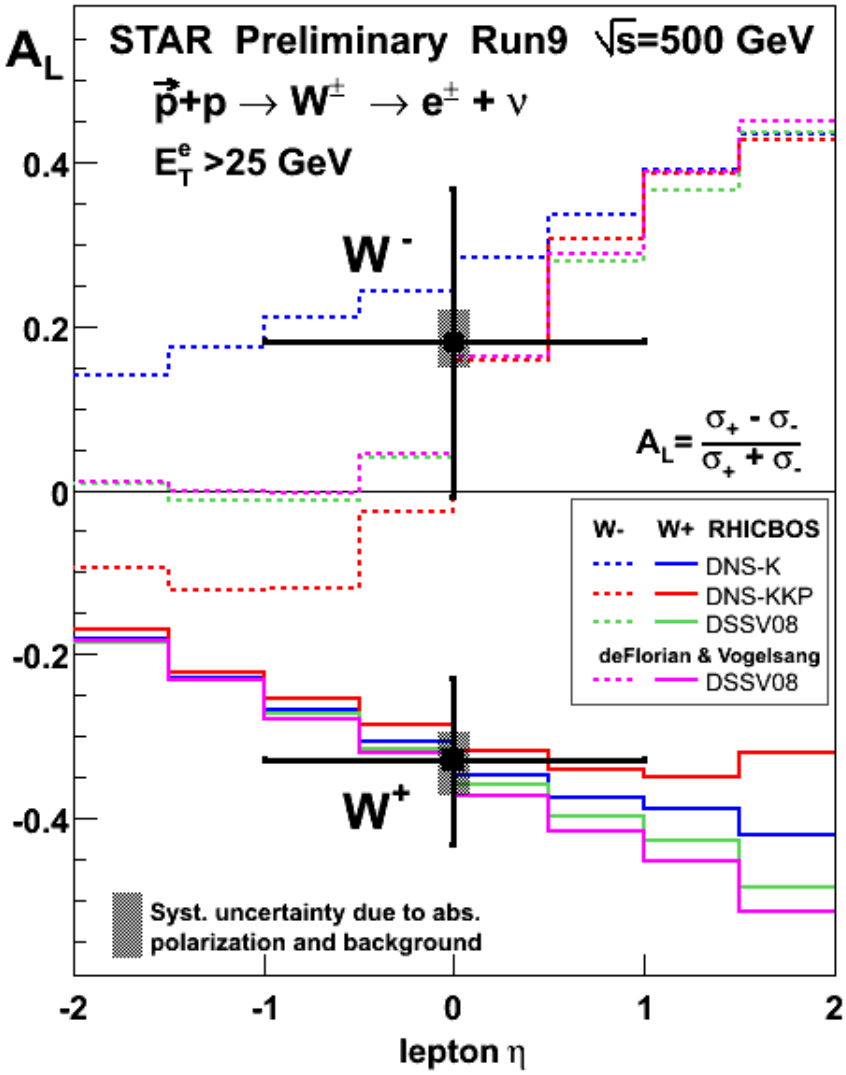

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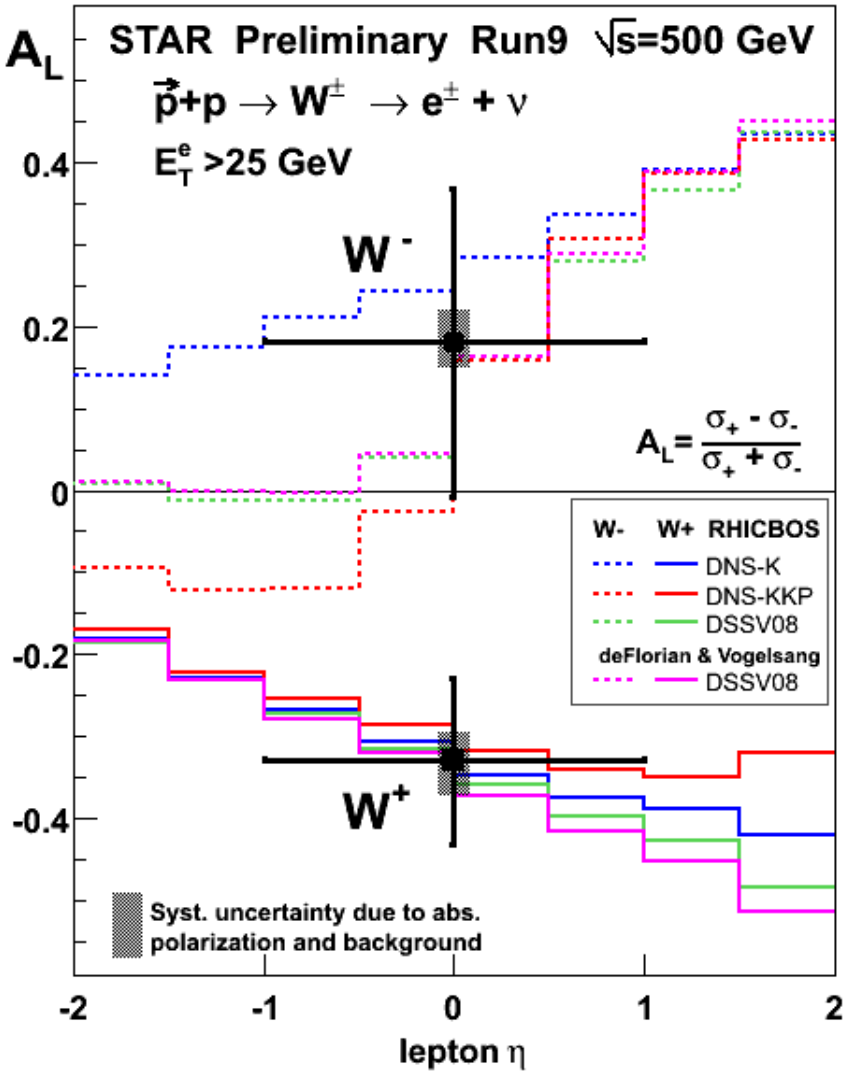

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$$A_L(W^+) = -0.33 \pm 0.10(\text{stat.}) \pm 0.04(\text{syst.})$$

$$A_L(W^-) = 0.18 \pm 0.19(\text{stat.}) \; ^{+0.04}_{-0.03}(\text{syst.})$$

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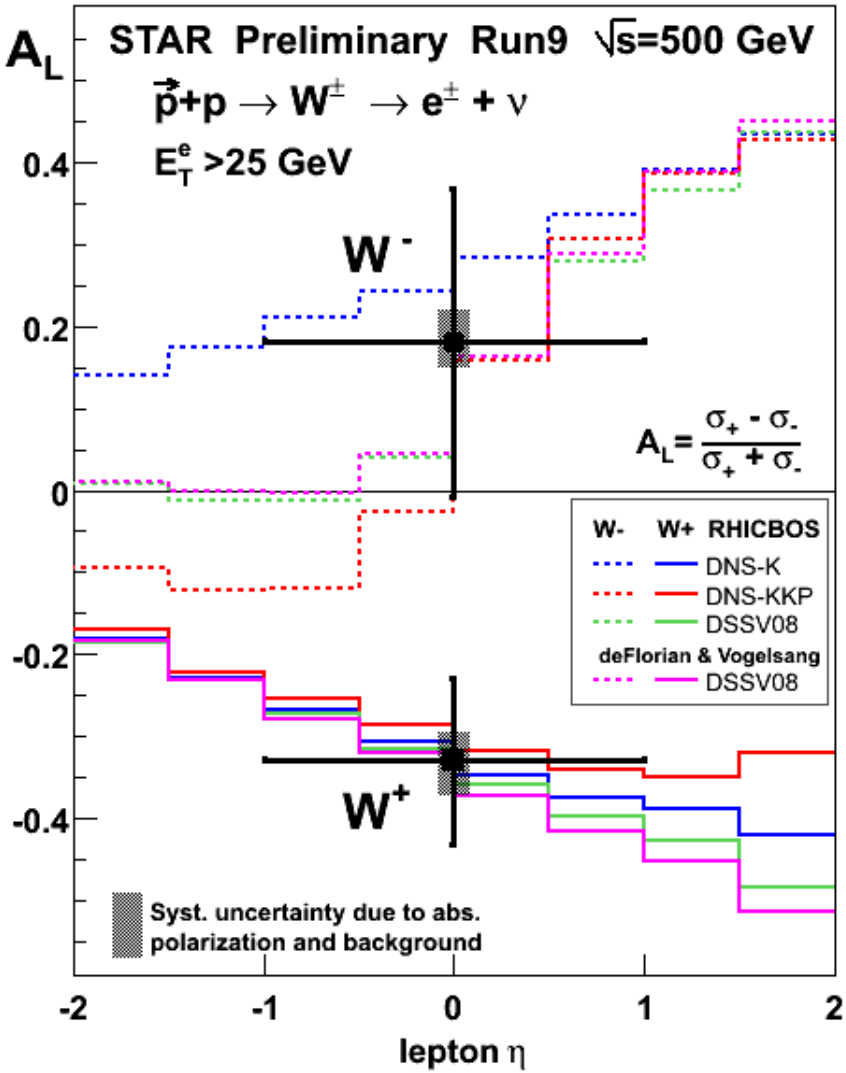

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- $A_L(W^+)$ negative with a significance of 3.3σ
- $A_L(W^-)$ central value positive
- Systematic errors of A_L under control
- TPC charge separation works up to $p_T \sim 50$GeV
- Measured asymmetries are in agreement with theory evaluations using polarized pdf's (DSSV) constrained by polarized DIS data (⇒ Universality of helicity distribution functions!)

Future W program: Overview

- STAR W program - Relevant detector systems

  - Calorimetry system with 2π coverage: BEMC (-1<η<1) and EEMC (1<η<2)
  - TPC: Tracking and particle ID
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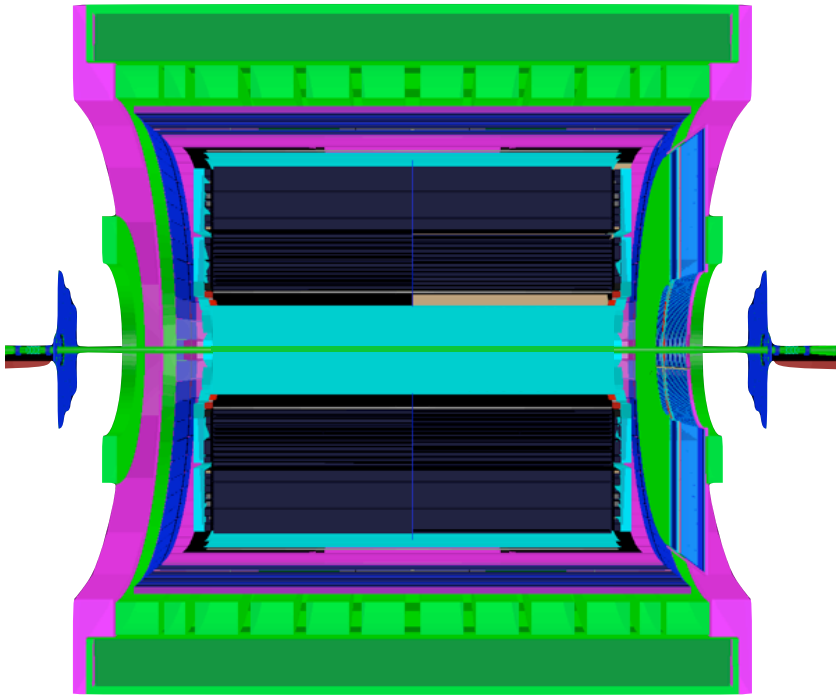

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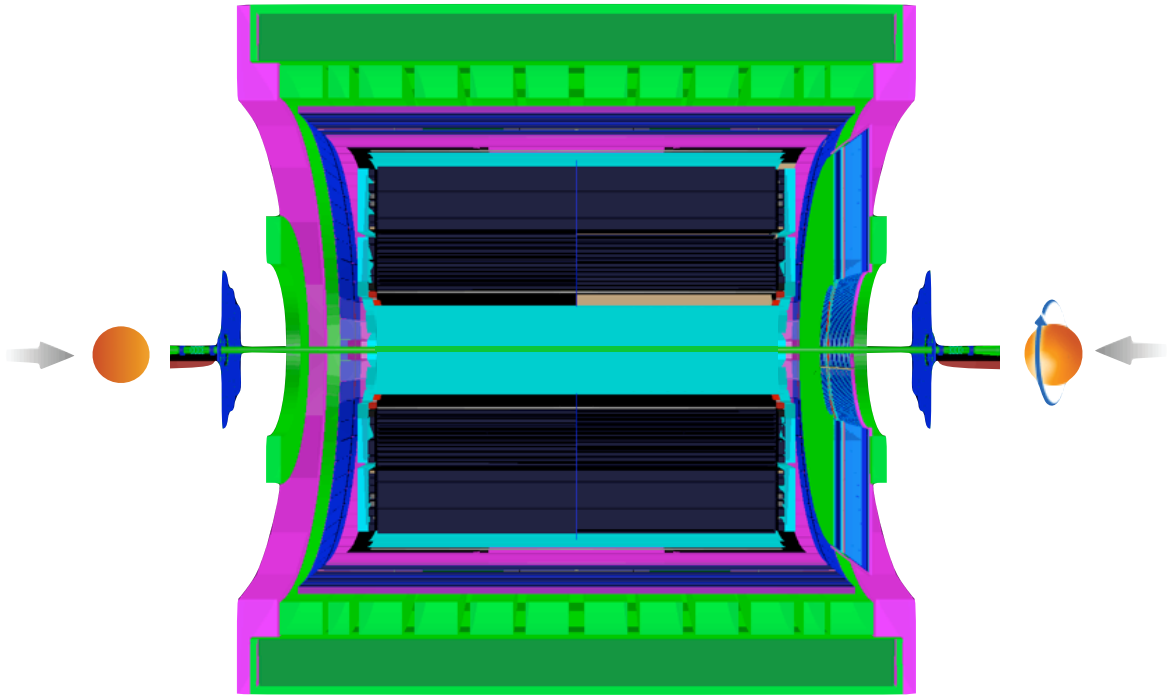

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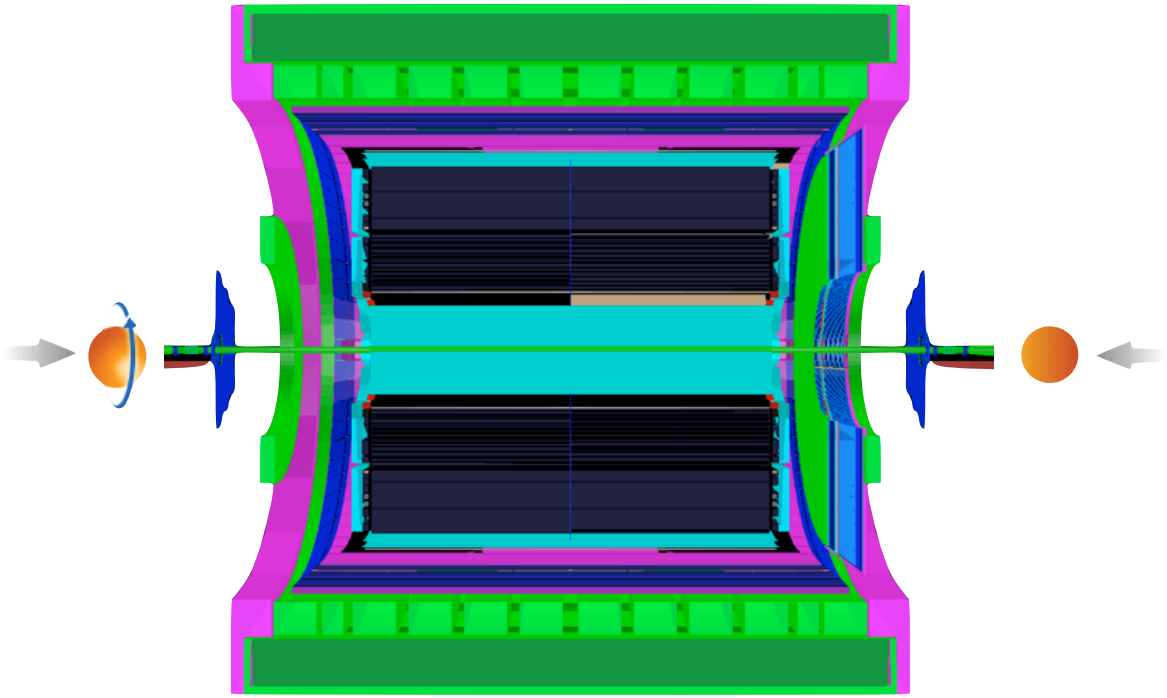

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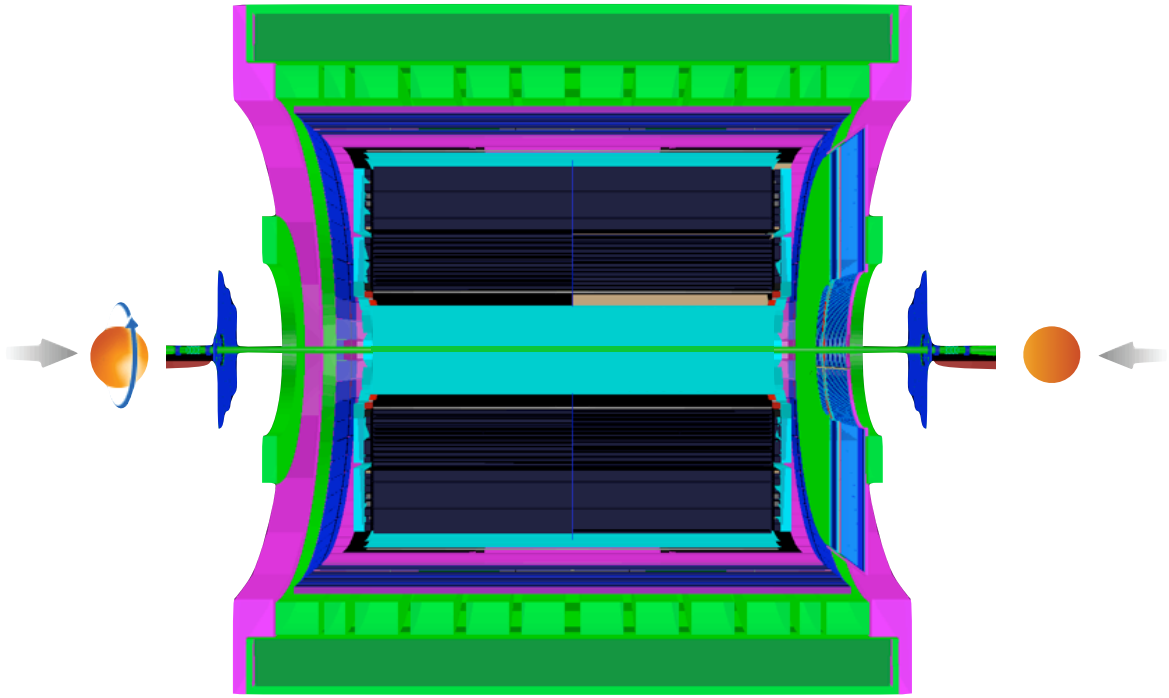

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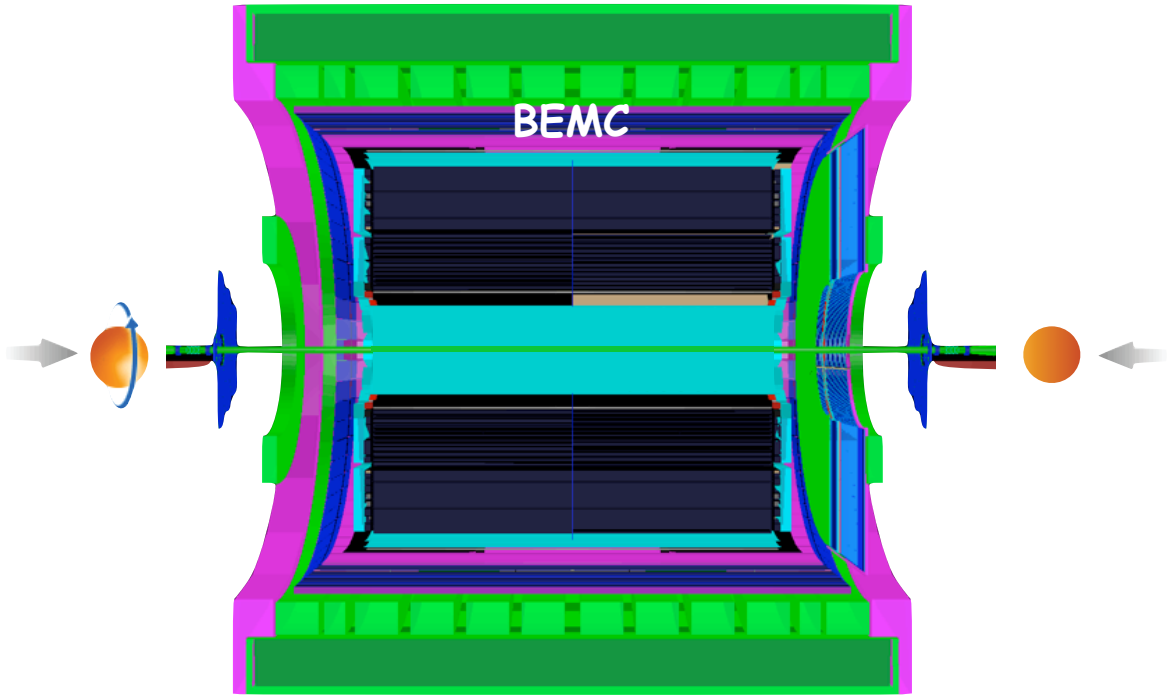

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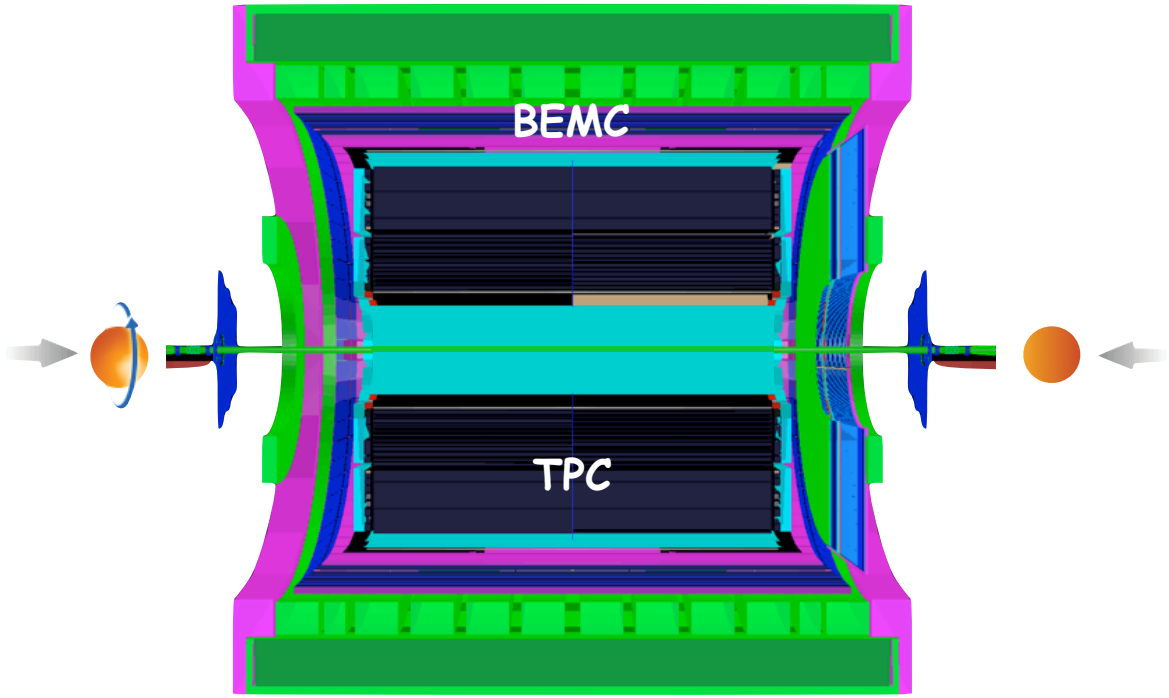

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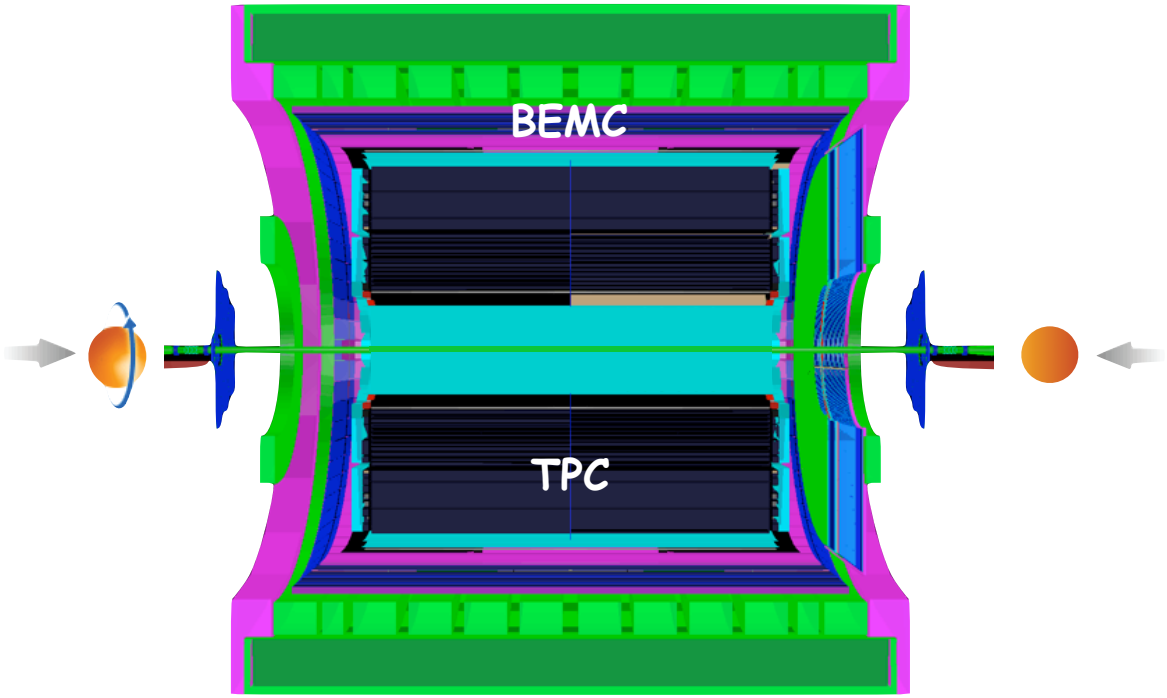

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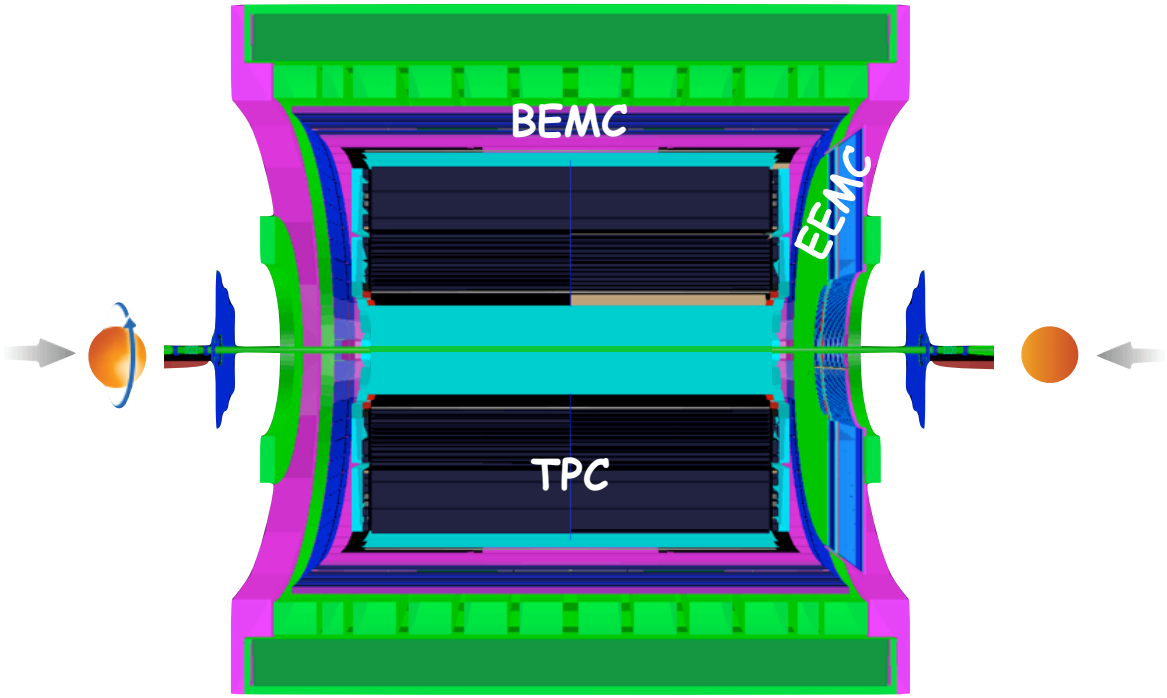

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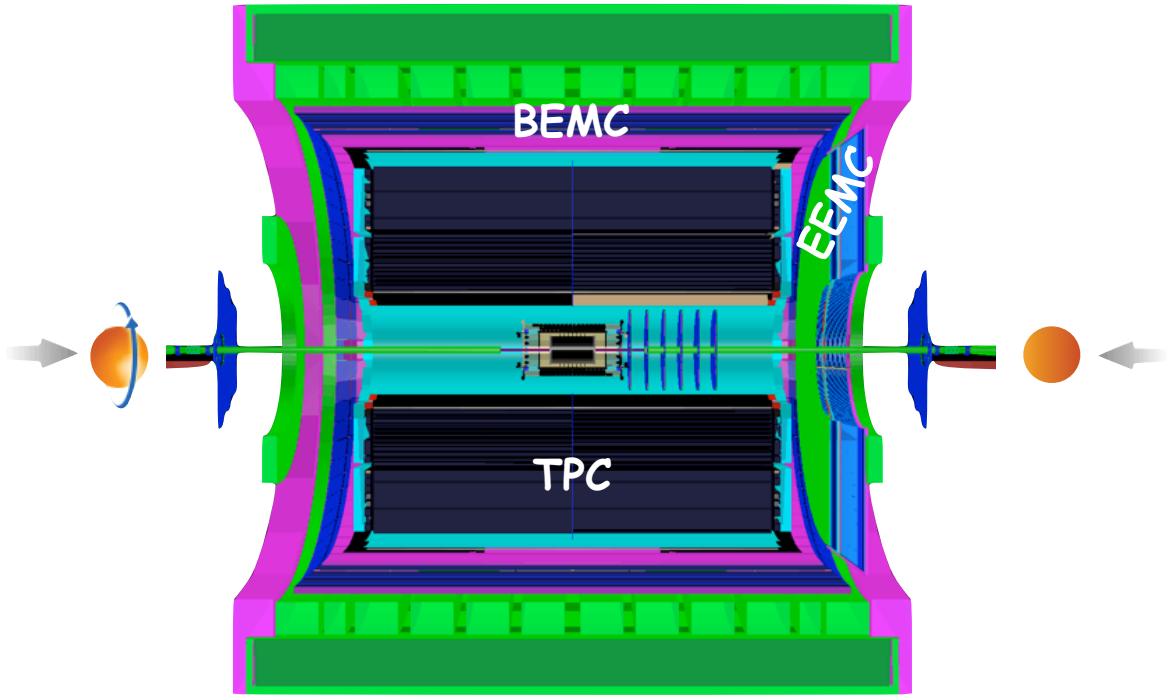

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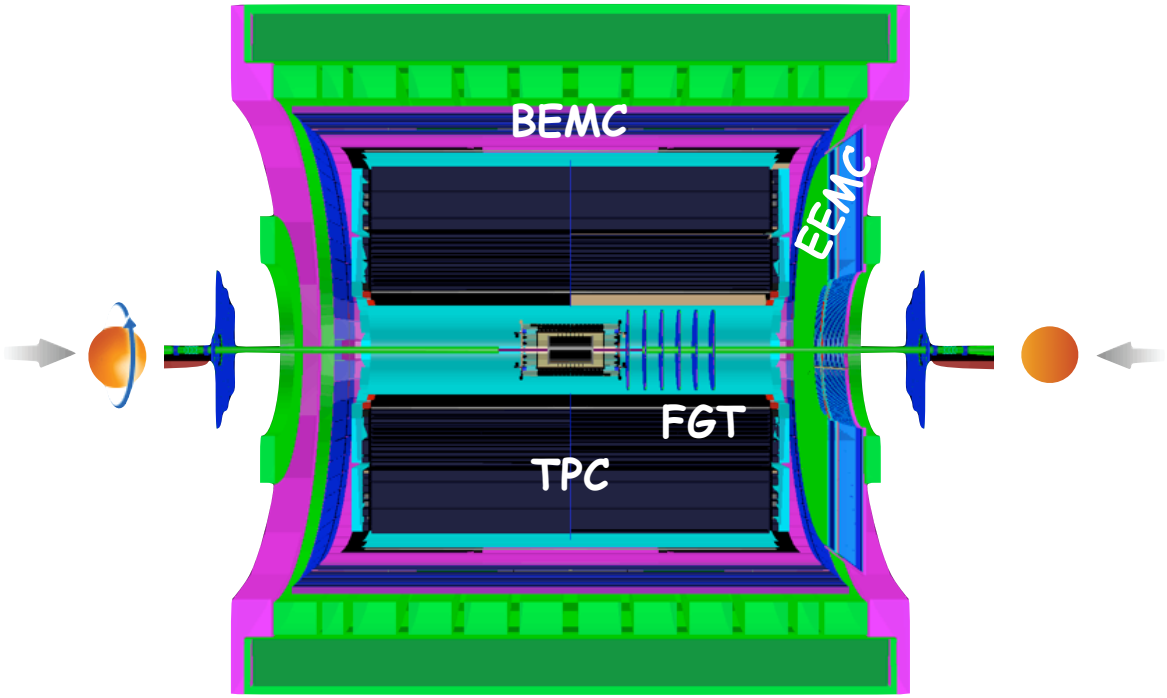

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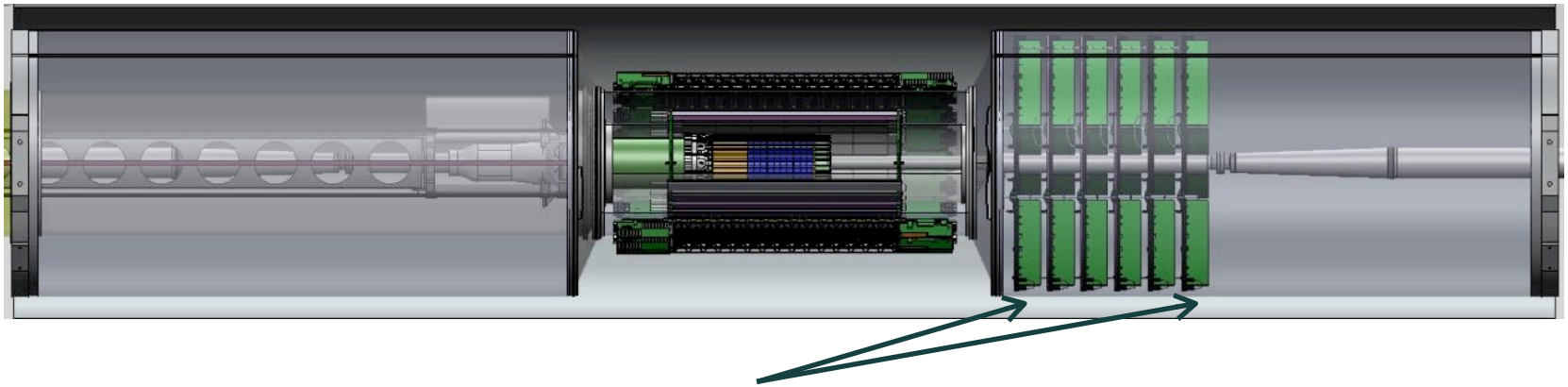
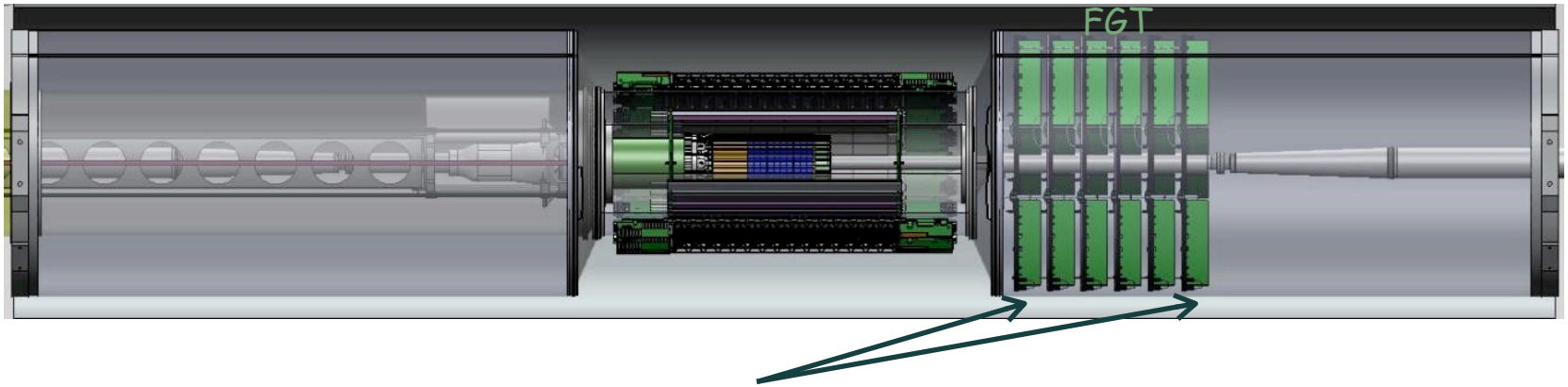
- FGT layout



- FGT: 6 light-weight triple-GEM disks using industrially produced GEM foils (Tech-Etch Inc.)
- New mechanical support structure
- Expected installation: Summer 2011

Future W program: FGT

- FGT layout



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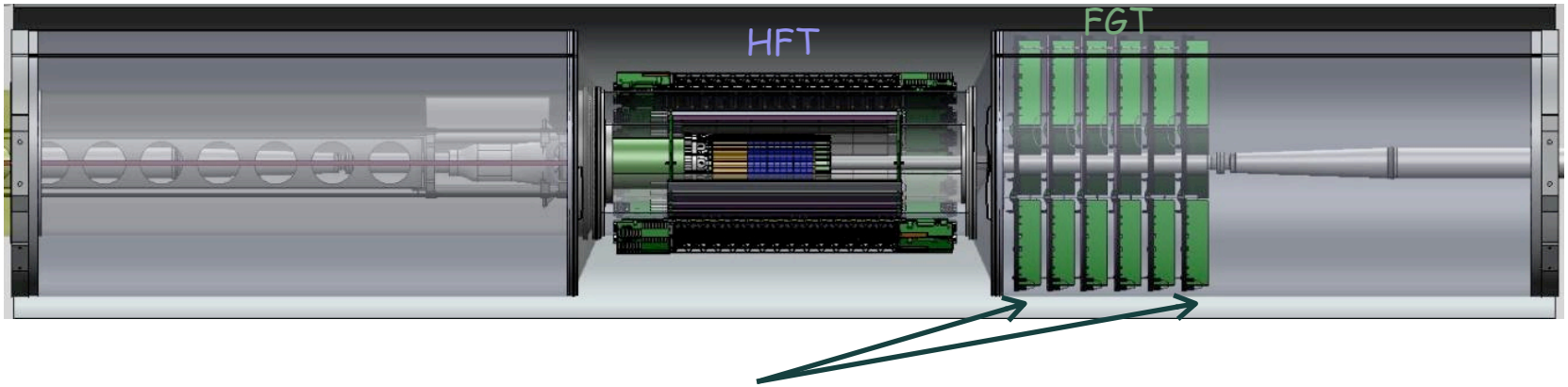

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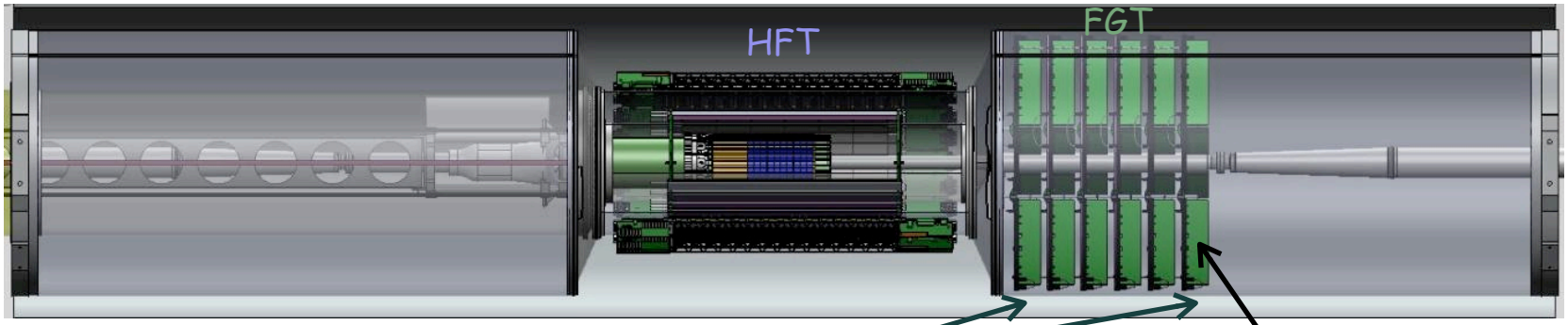

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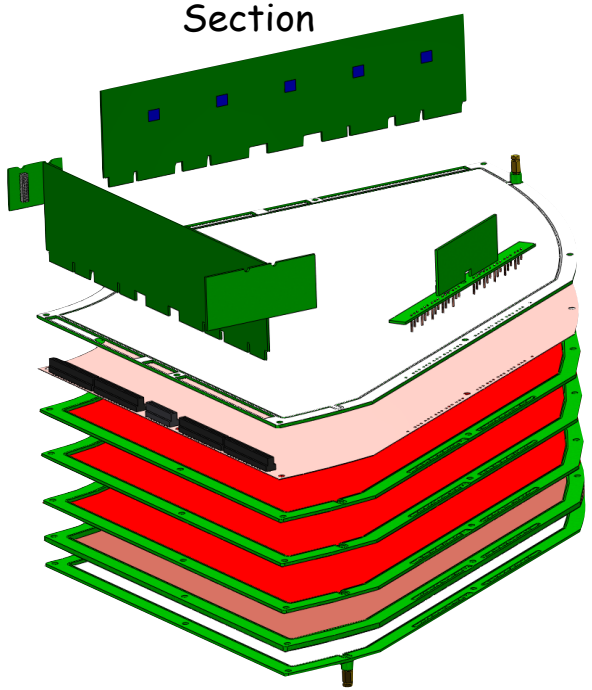
FGT Quarter Section



Future W program: FGT

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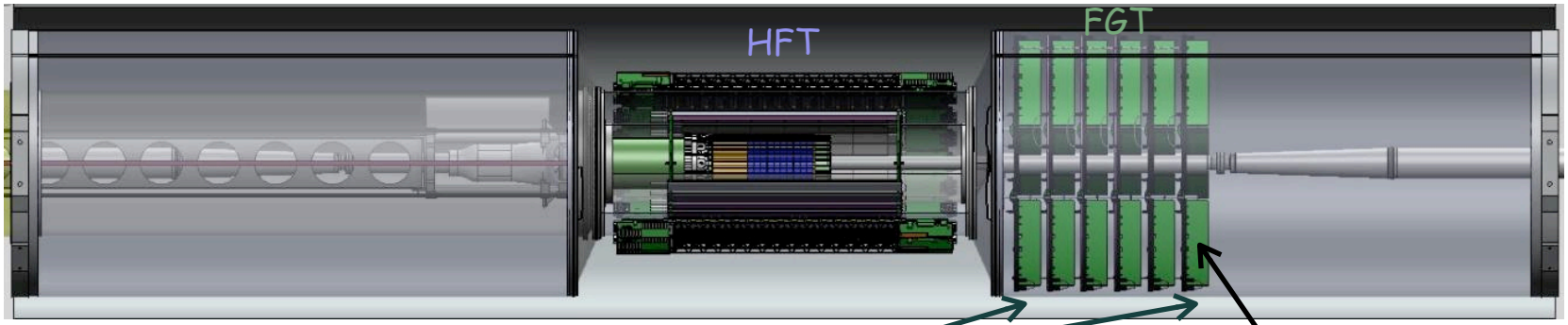

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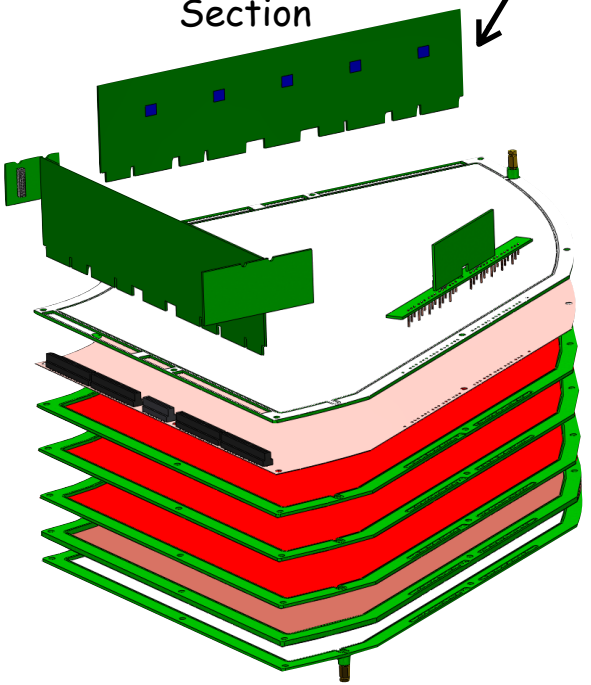
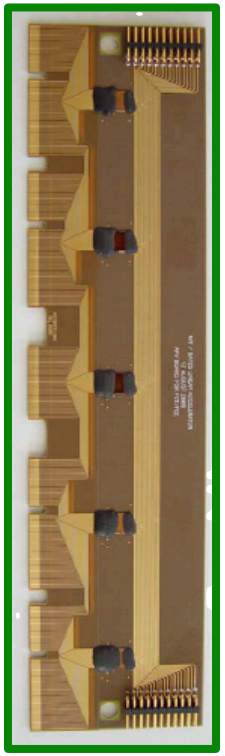
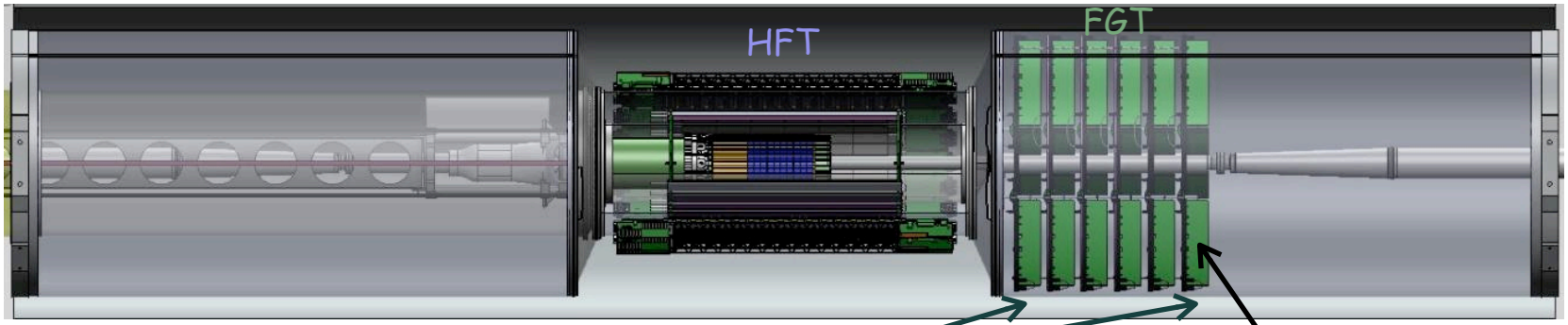


APV module



Future W program: FGT

- FGT layout



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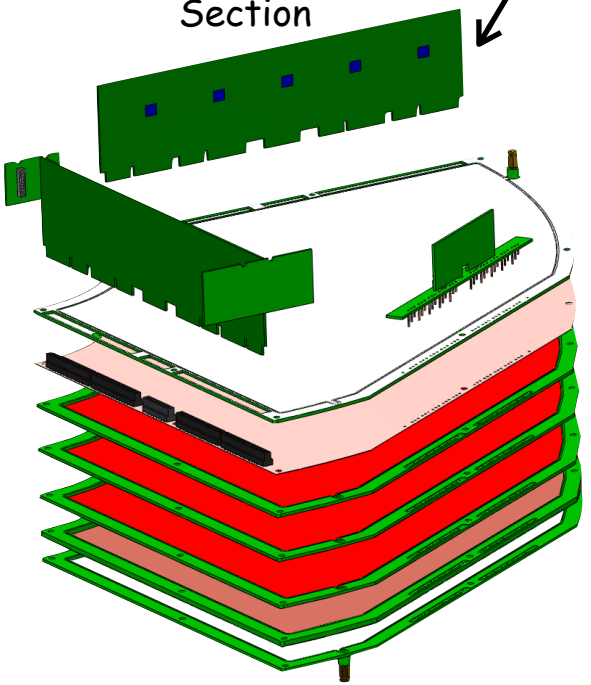
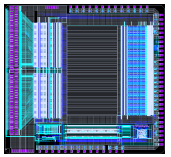


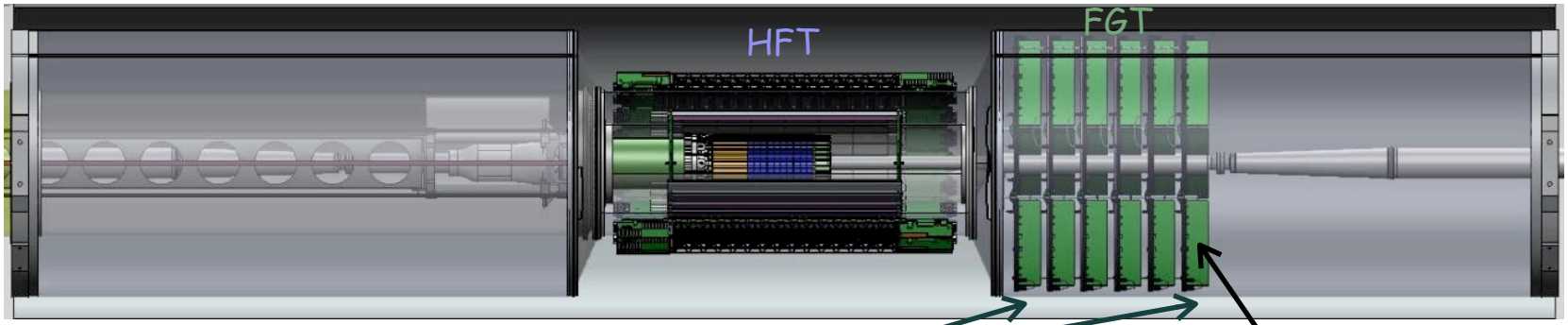
APV module



APV chip

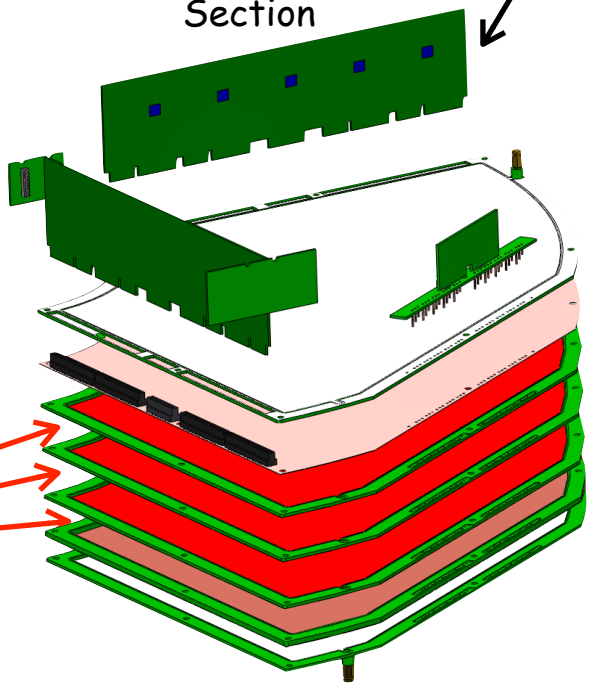
Future W program: FGT

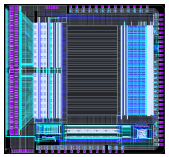
- FGT layout



FGT Quarter Section

APV module

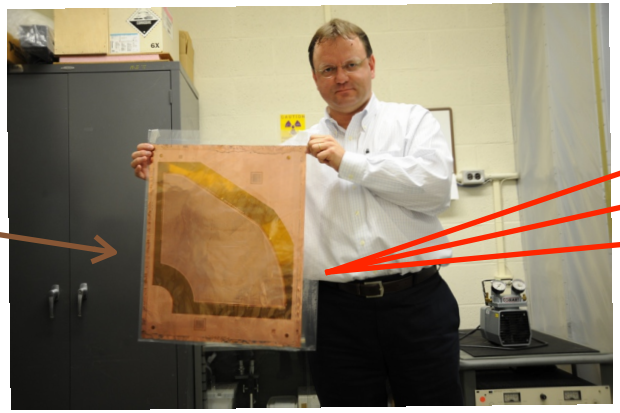




APV chip

- FGT: 6 light-weight triple-GEM disks using industrially produced GEM foils (Tech-Etch Inc.)
- New mechanical support structure
- Expected installation: Summer 2011

FGT GEM foil



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- A_L projections

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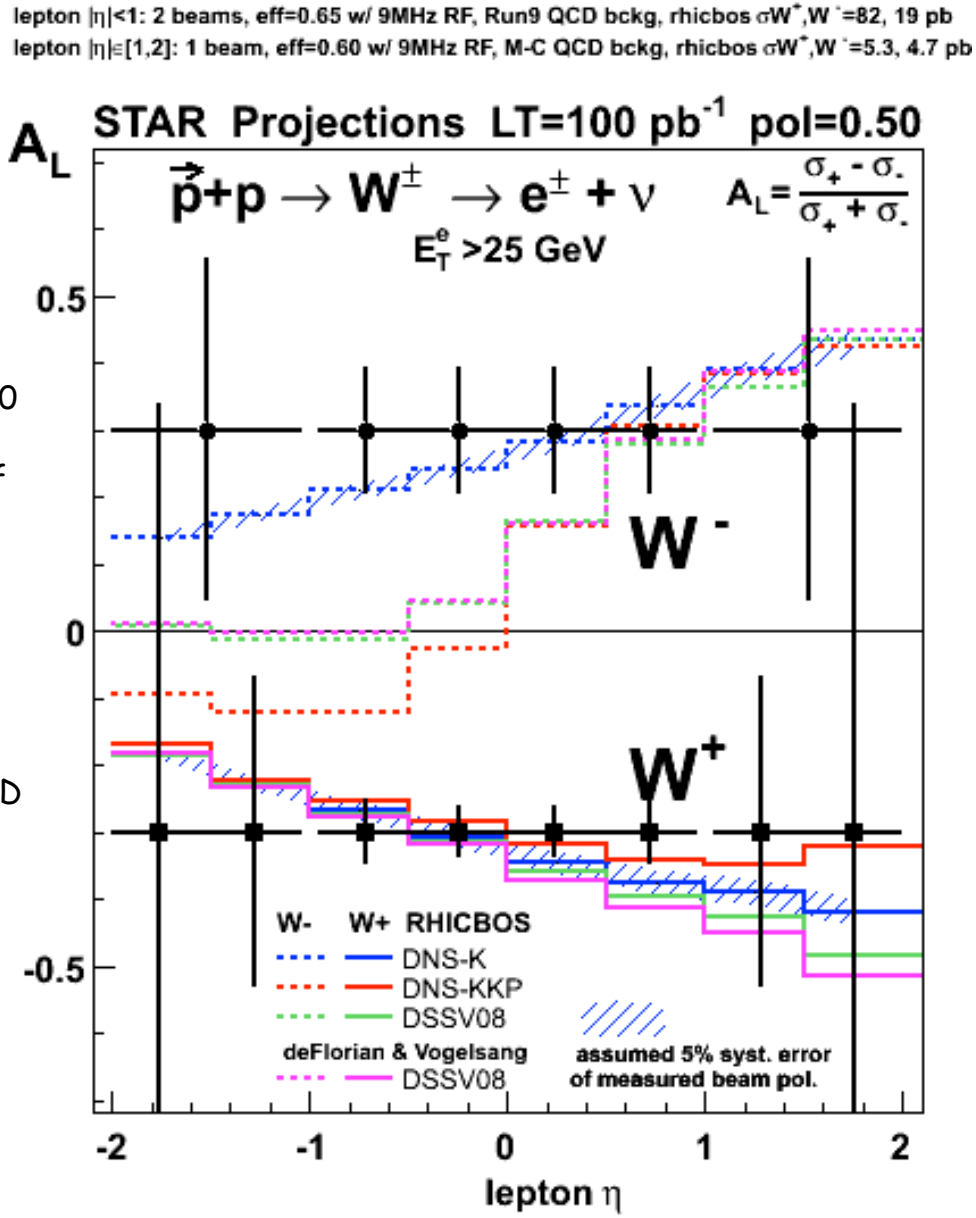

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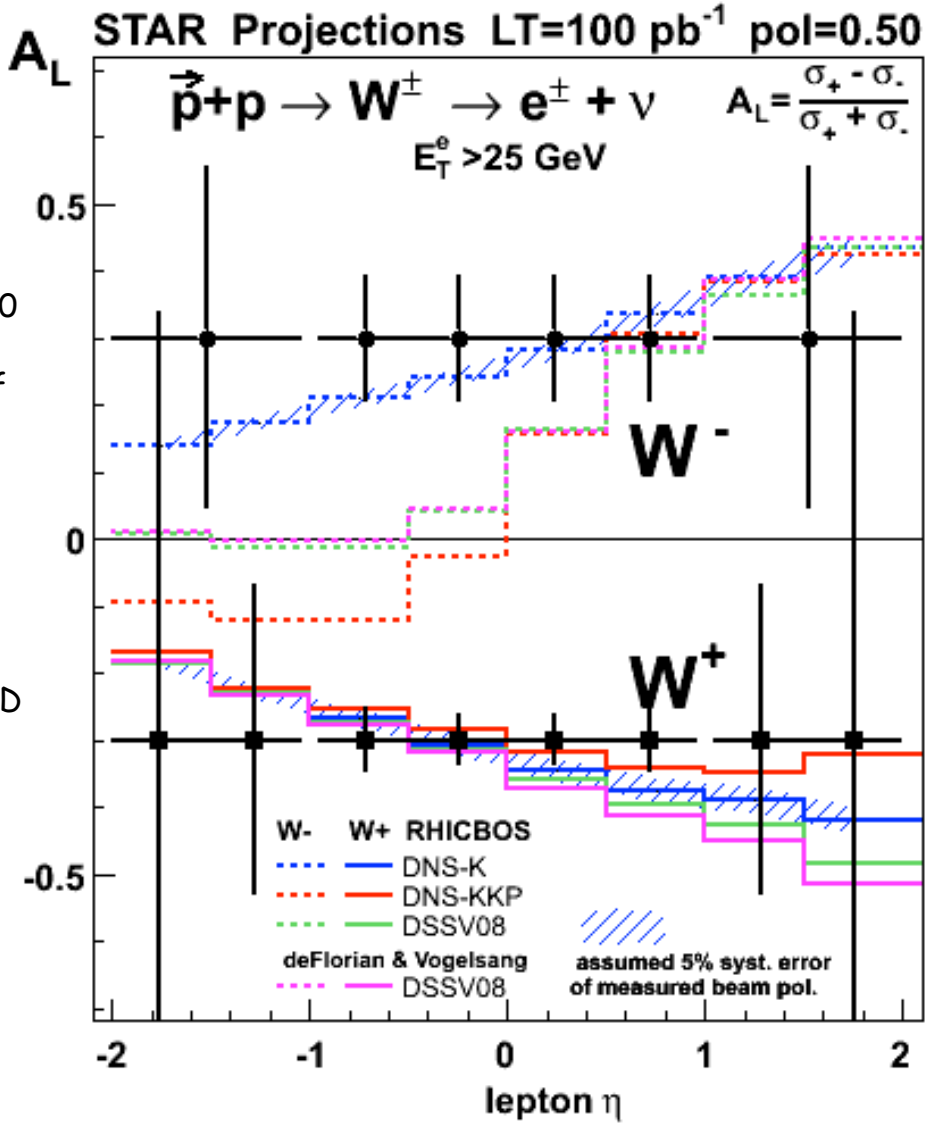

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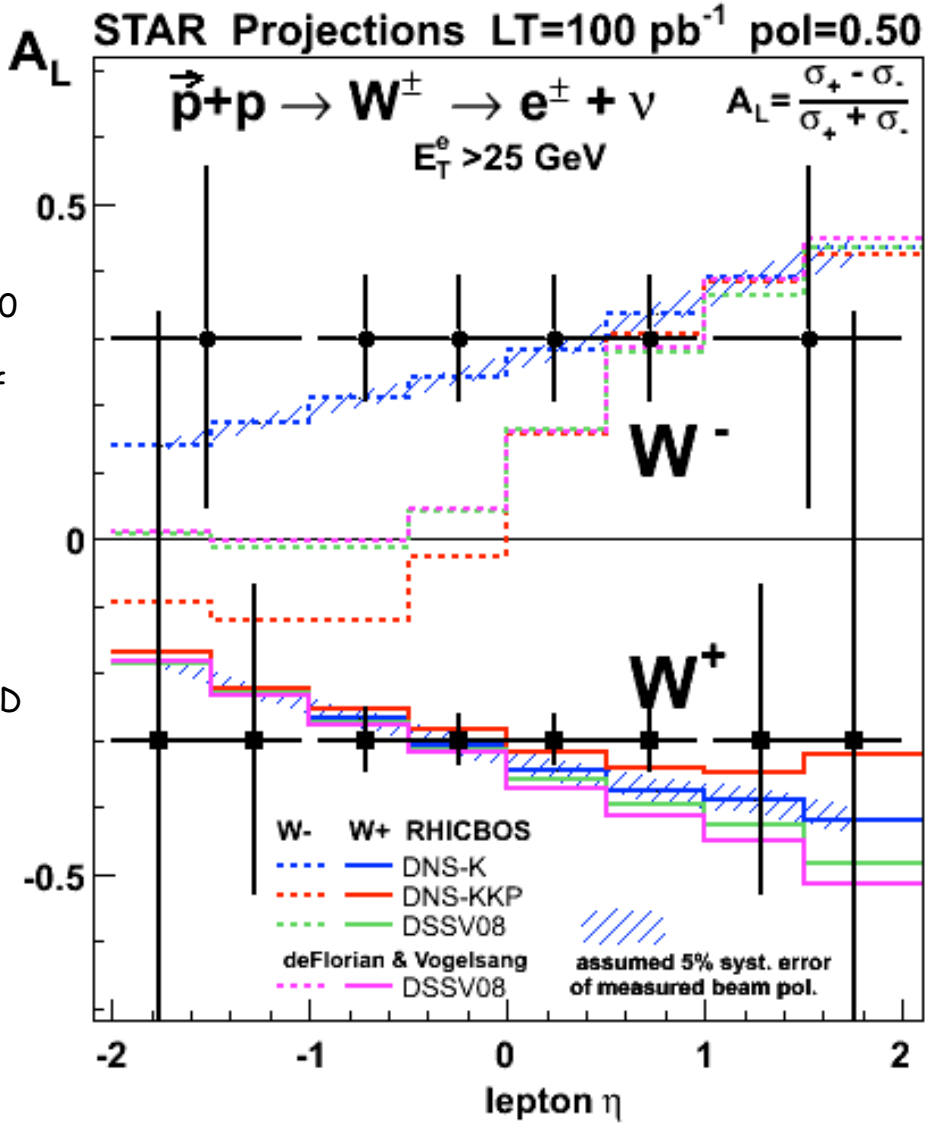

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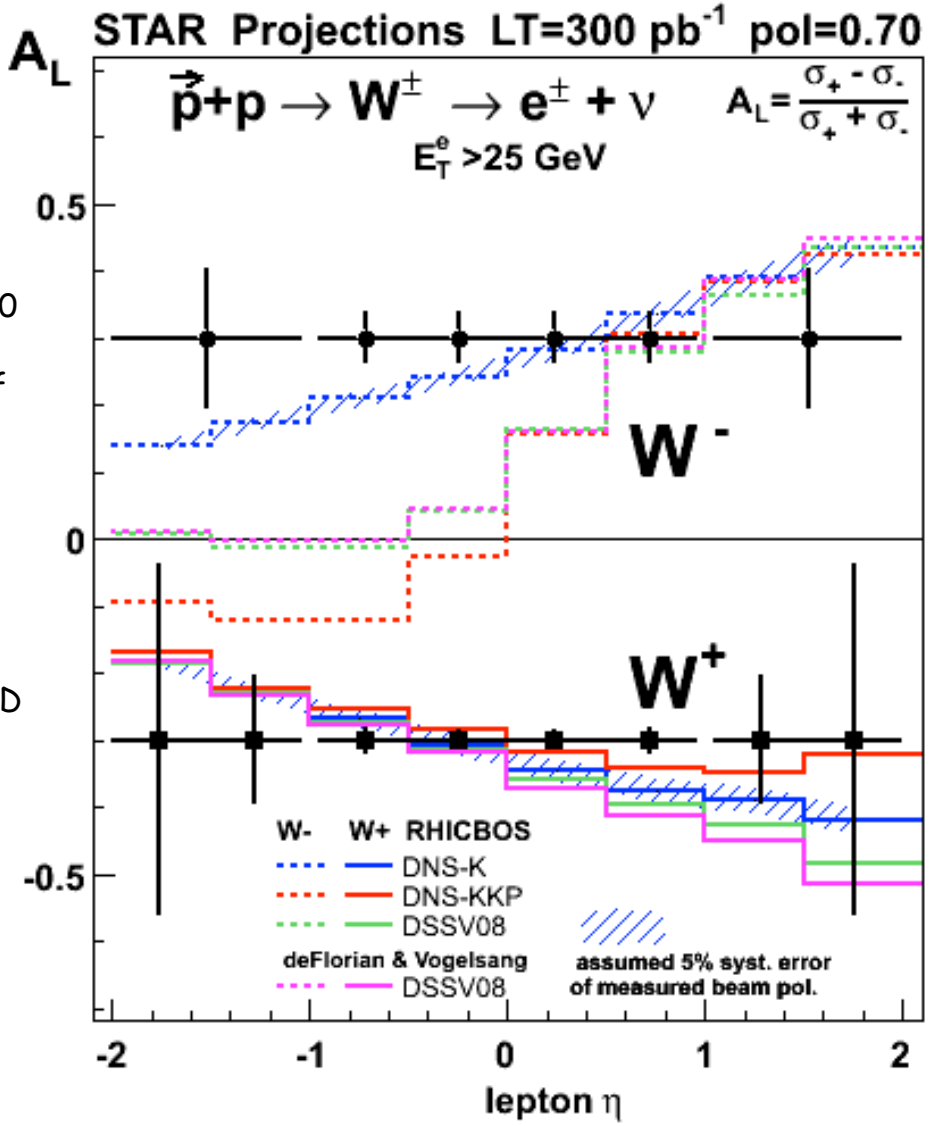

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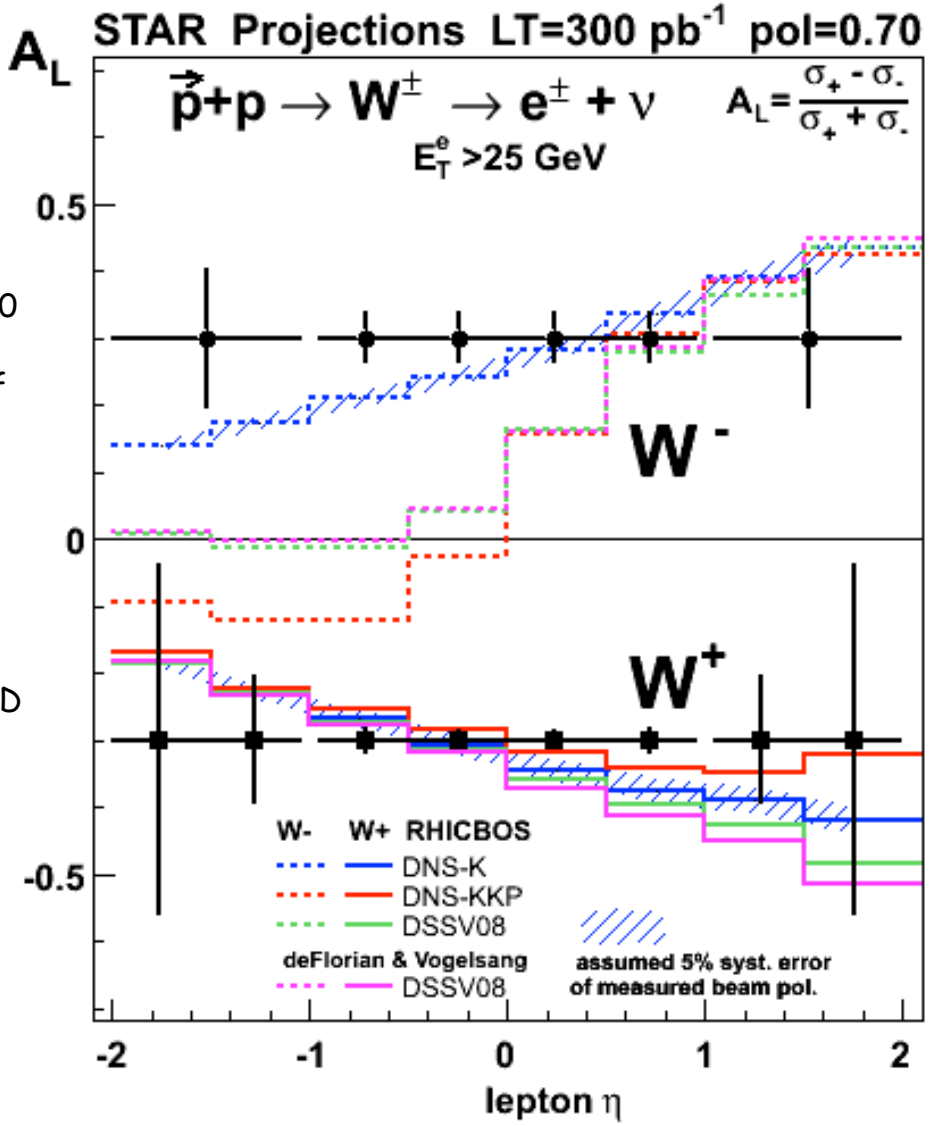

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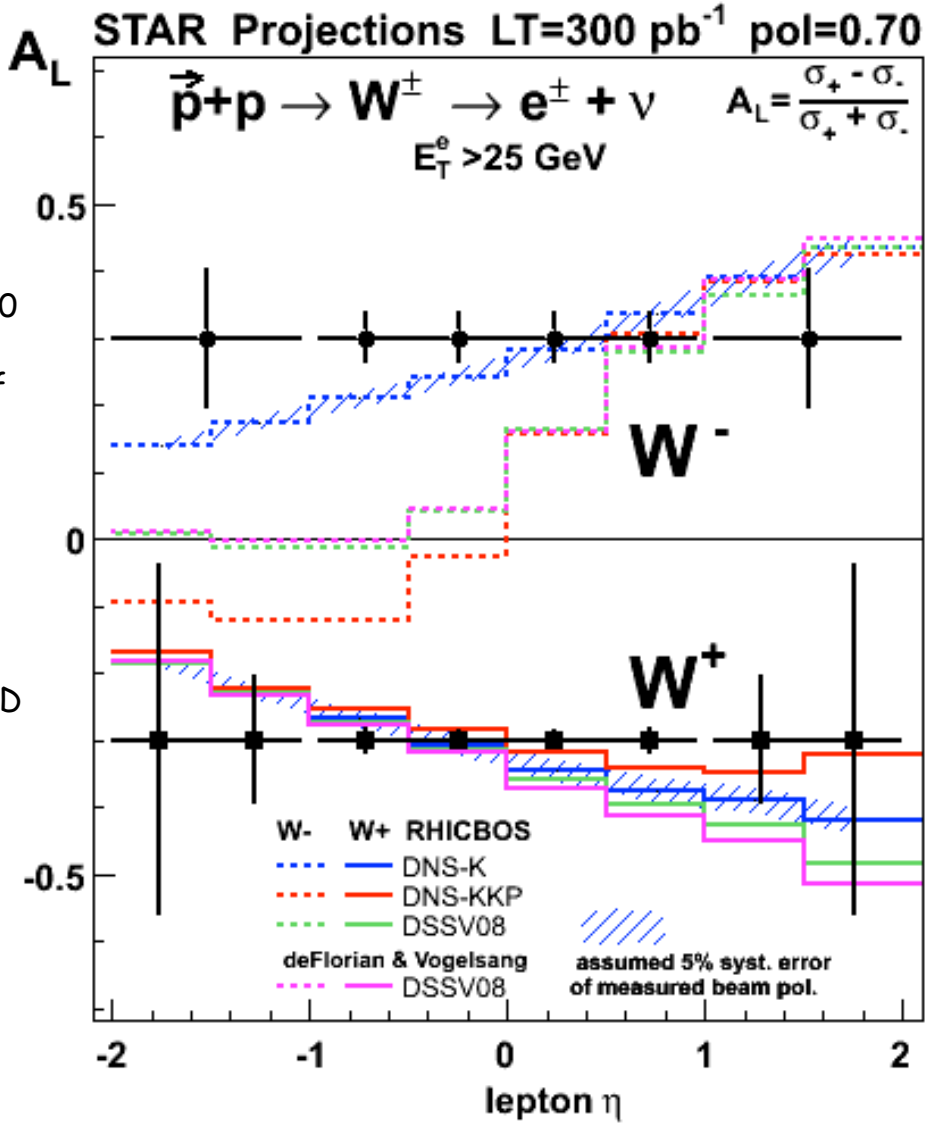

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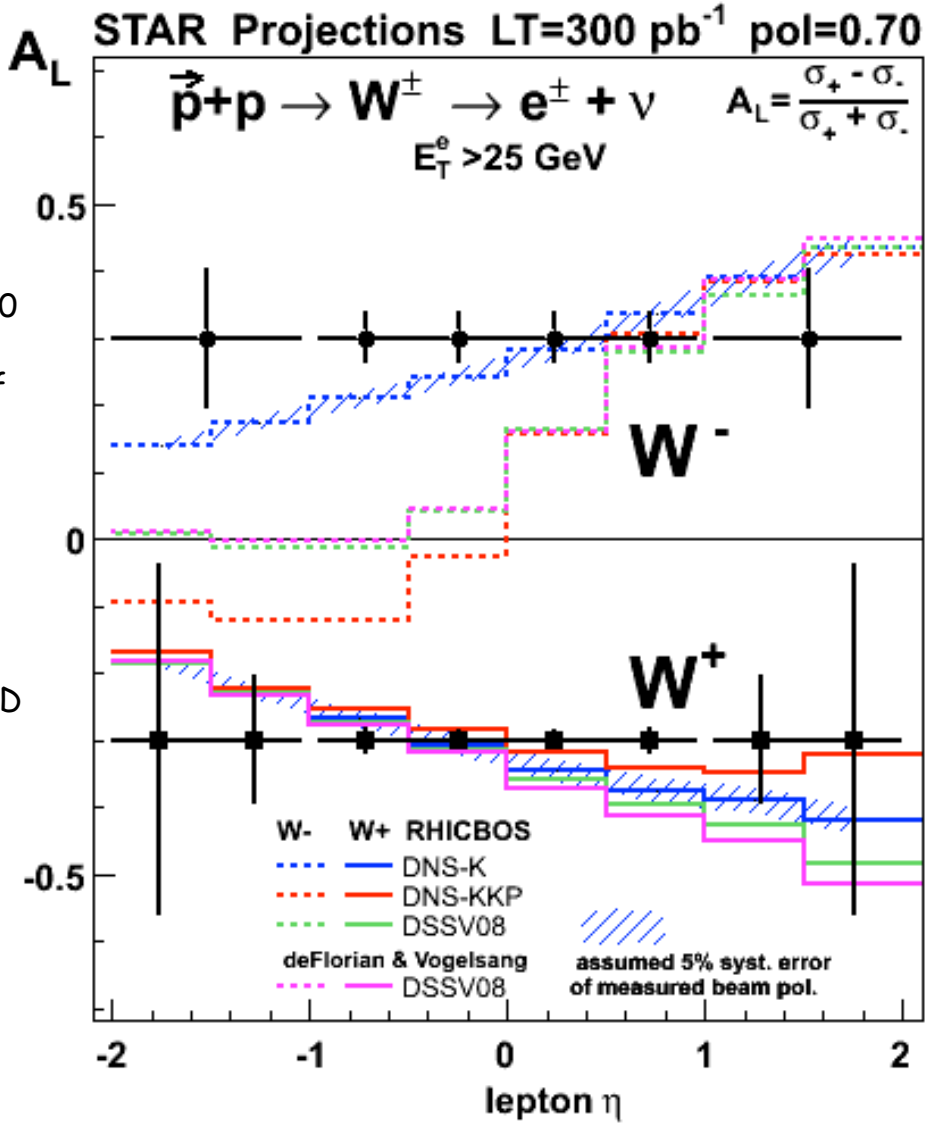

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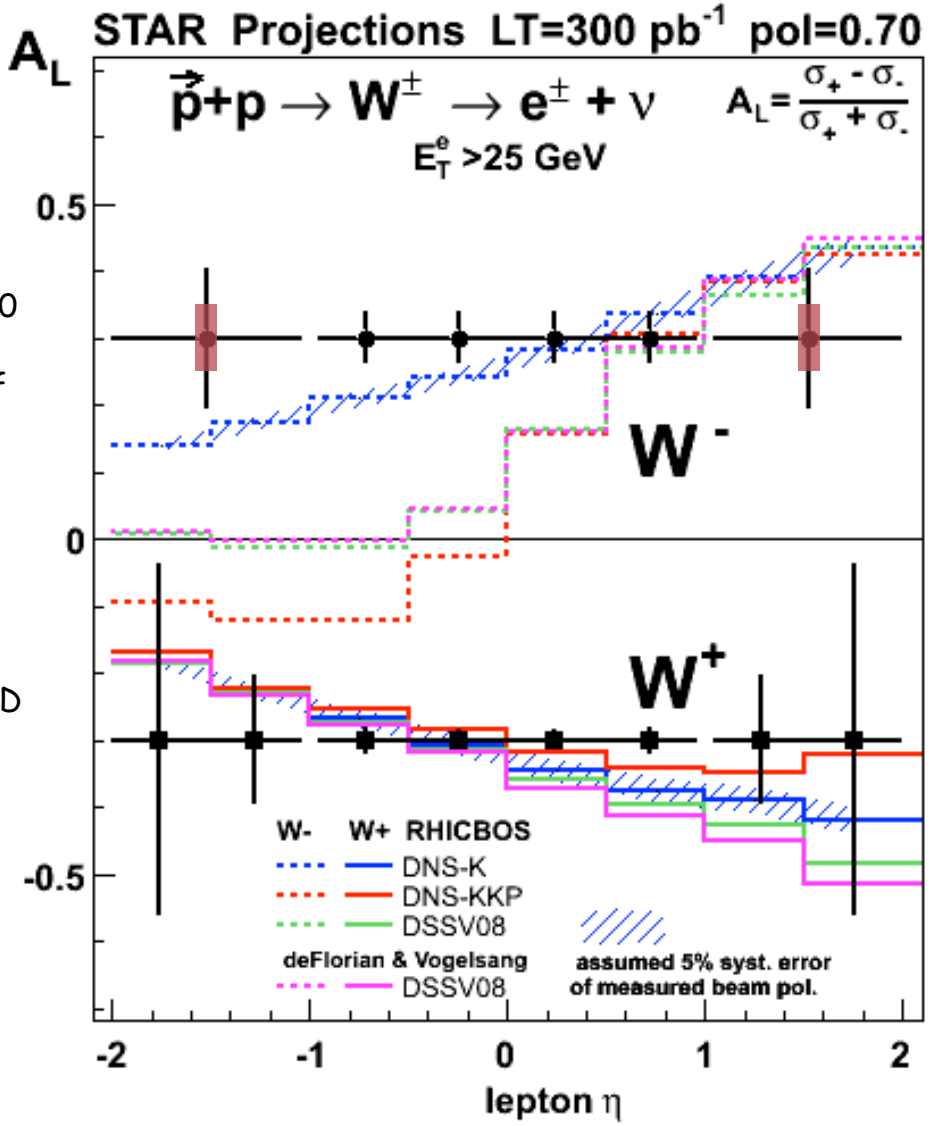

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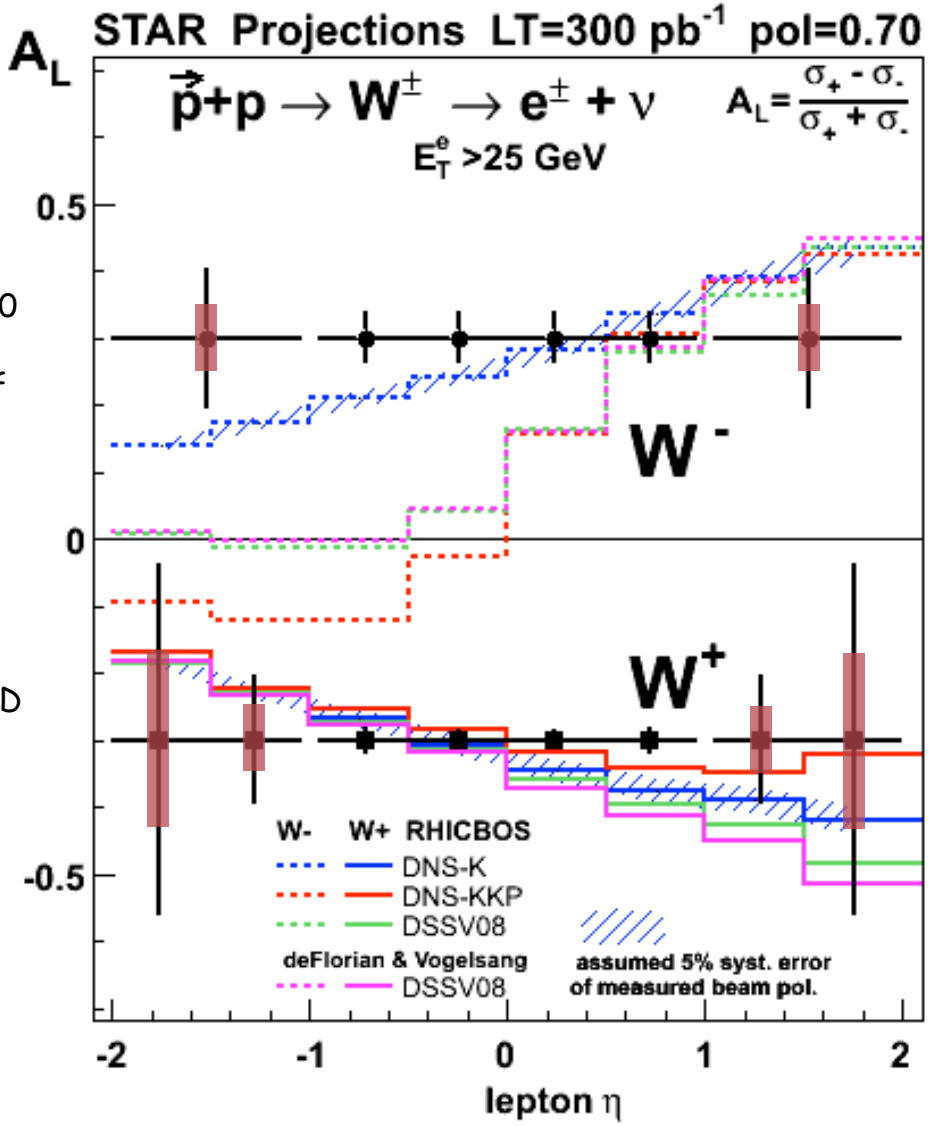

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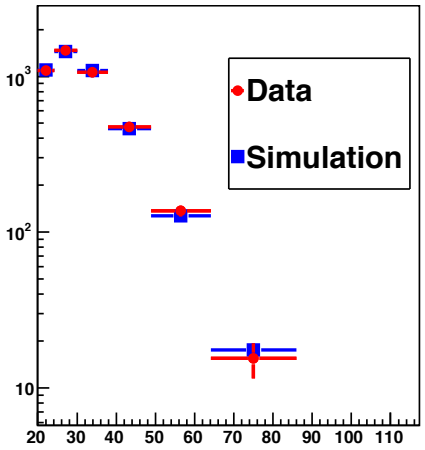
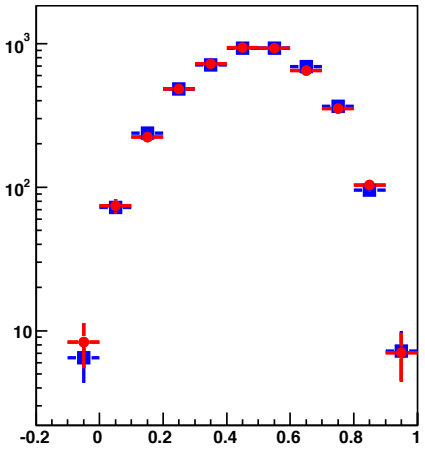
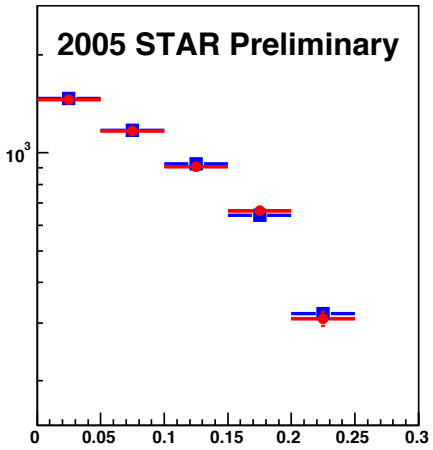
  - Future measurements of A_L at STAR at mid-rapidity and forward rapidity (Wide rapidity coverage!) are expected to play an important role in our understanding of the polarized QCD sea!

Backup

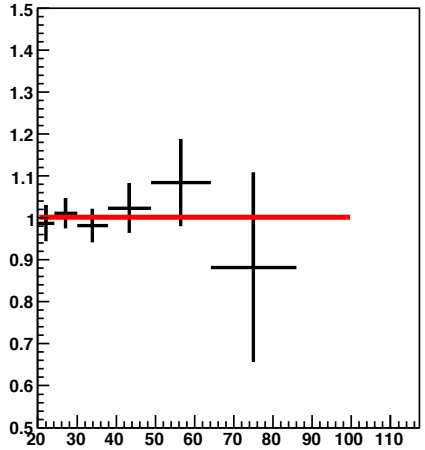
Correlation measurements: Di-Jet production - Data Understanding - Run 5

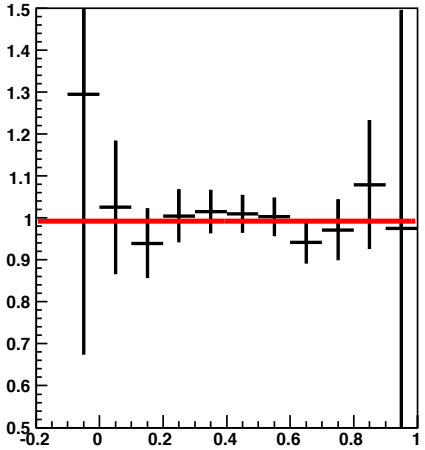


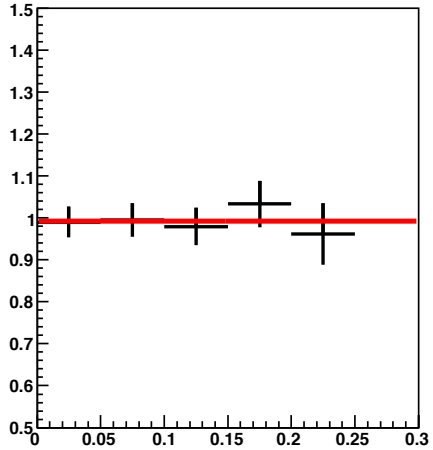




$\sqrt{s} = 200$ GeV $\quad \min(p_T) \geq 7.0$ GeV/c, $\max(p_T) \geq 10.0$ GeV/c $\quad -0.05 \leq \eta \leq 0.95 \quad |\Delta\eta| < 0.5 \quad |\Delta\varphi| > 2$







$$M = \sqrt{x_1 x_2 s} \qquad \eta_3 + \eta_4 = \ln \frac{x_1}{x_2} \qquad \cos\theta^* = \tanh\left(\frac{\eta_3 - \eta_4}{2}\right)$$

- Di-Jet distributions with asymmetric p_T cuts more appropriate for NLO comparison
- Very good agreement between data and PYTHIA MC simulations incl. detector effects

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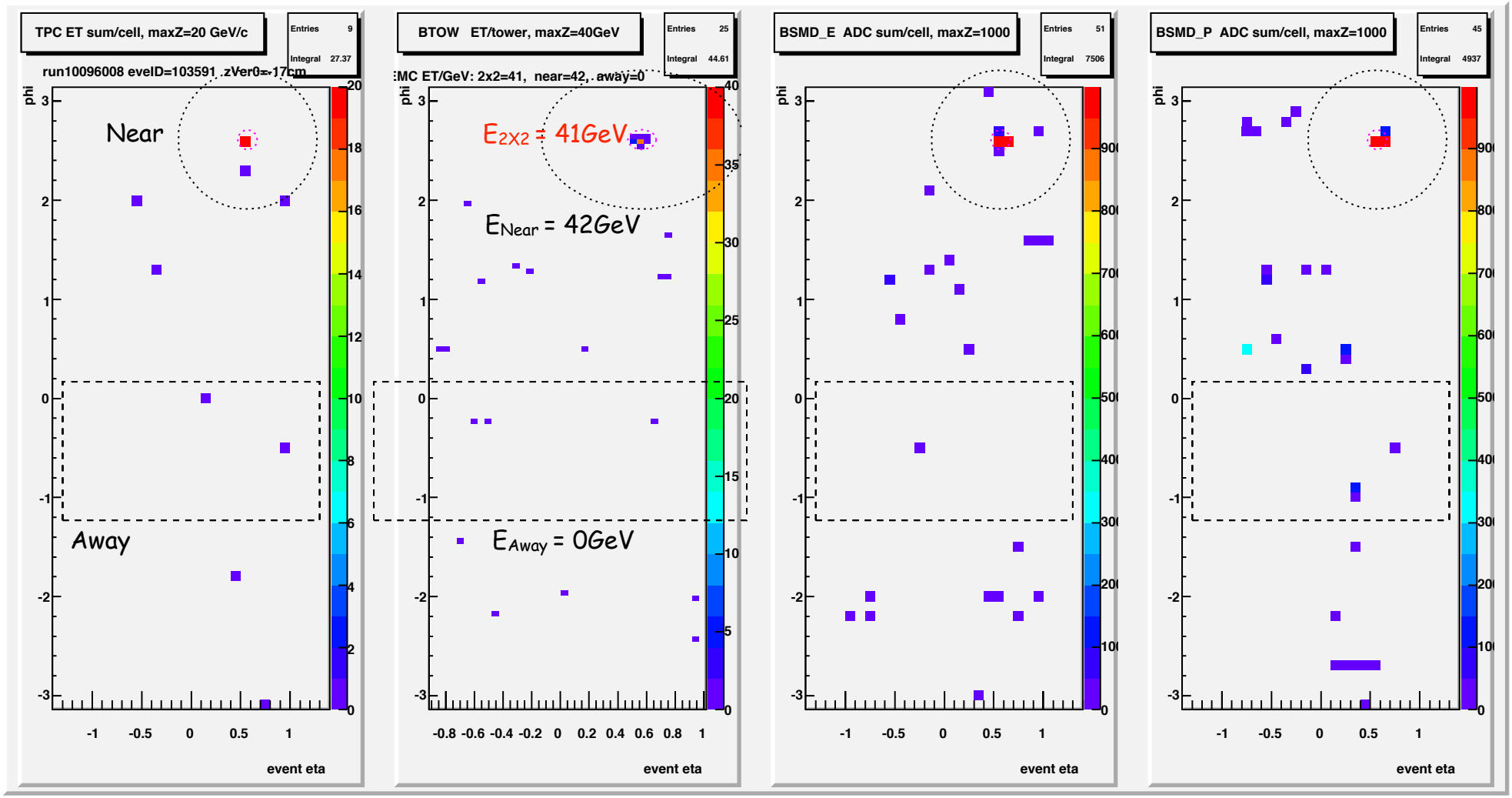
- Event display (W event candidate) and detector signature



TPC BTOW BSMD_E BSMD_P

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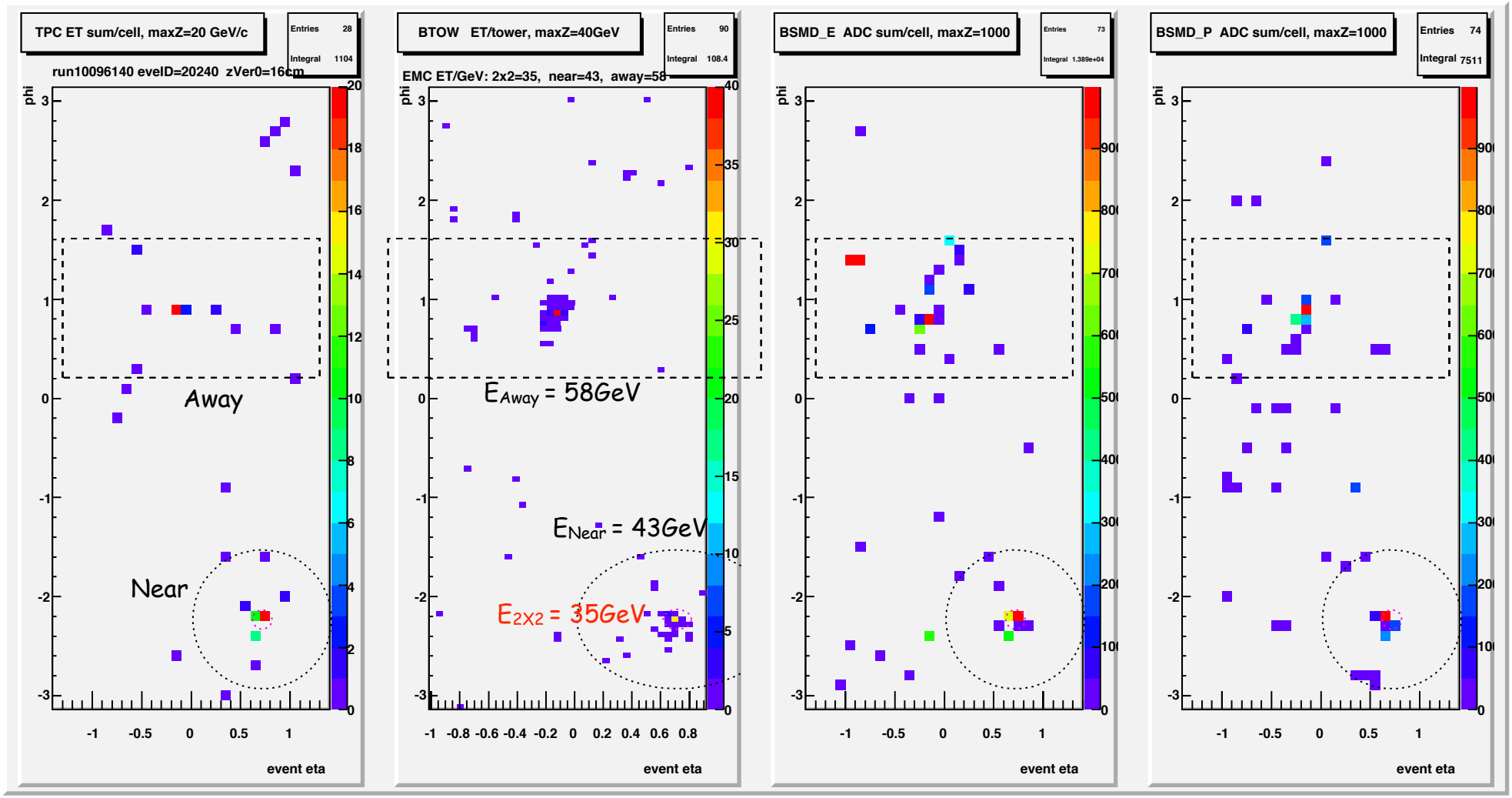

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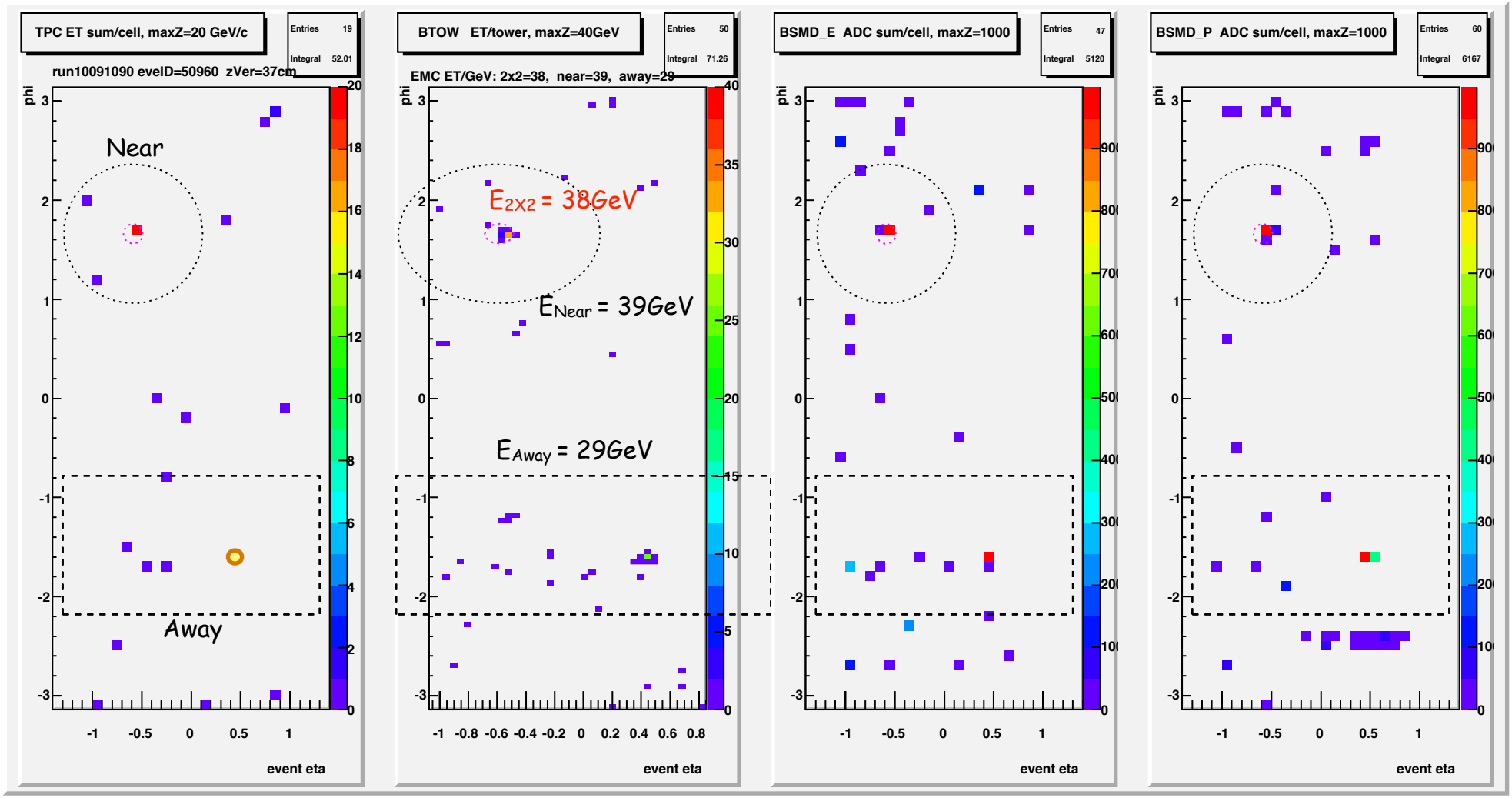

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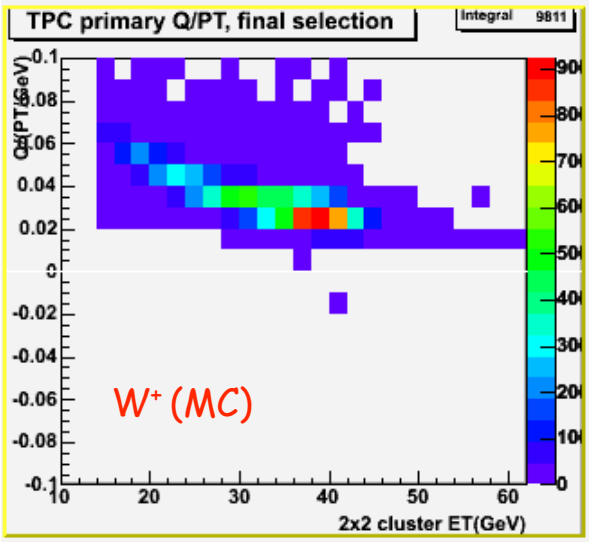

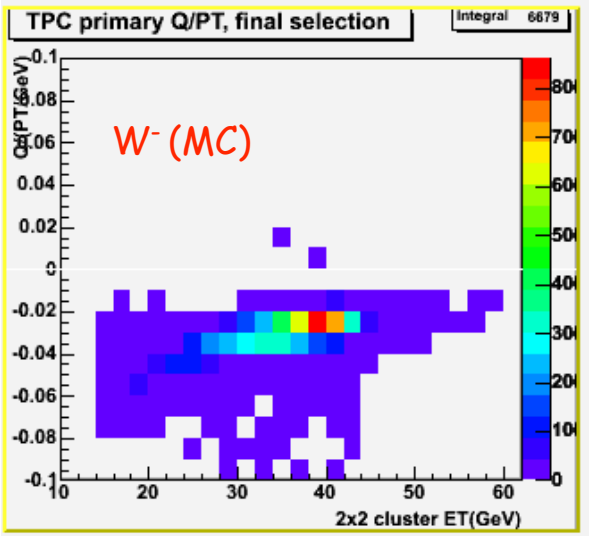

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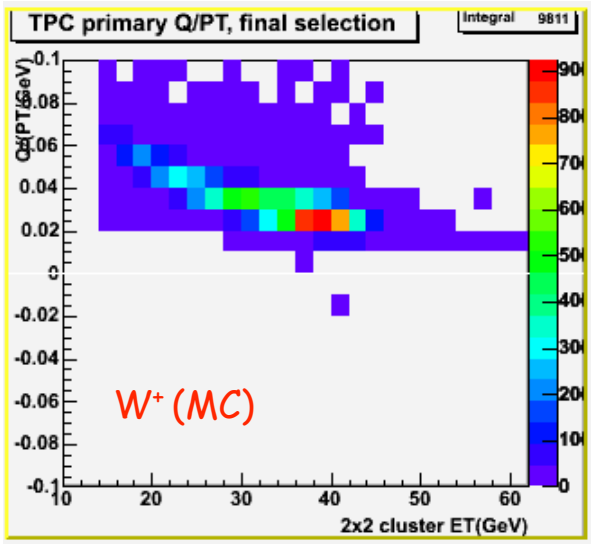

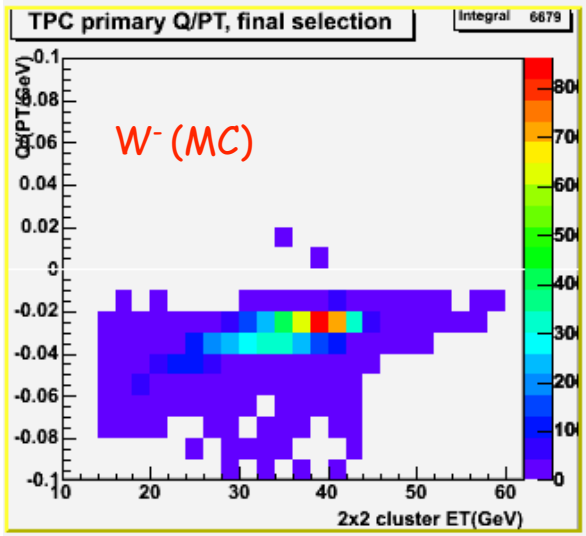

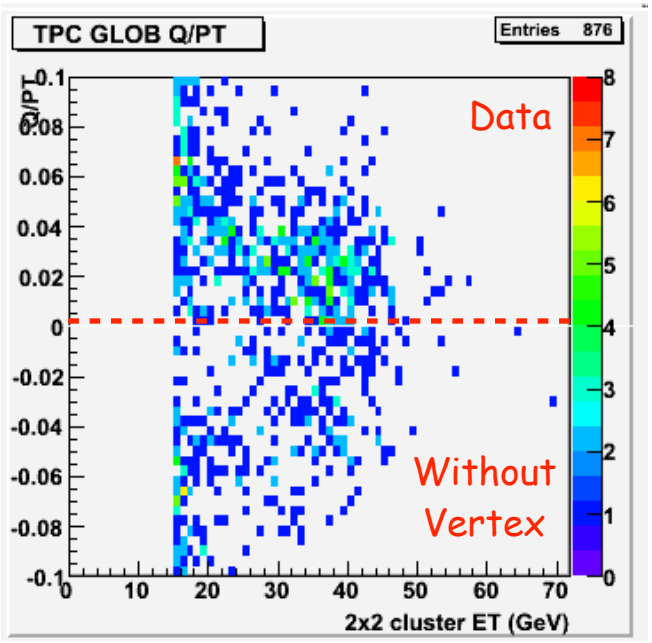

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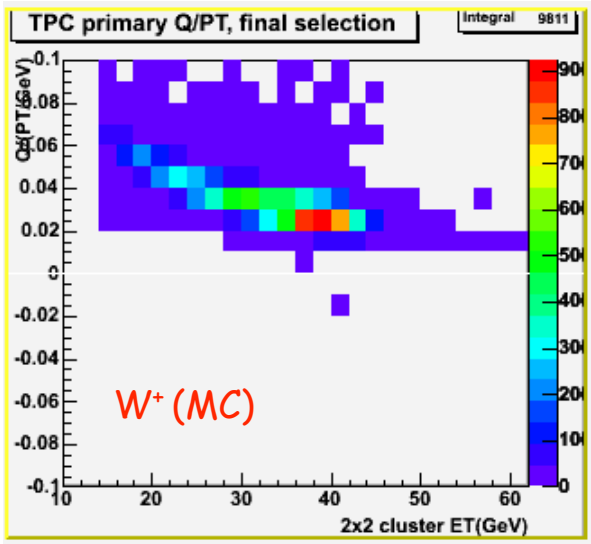
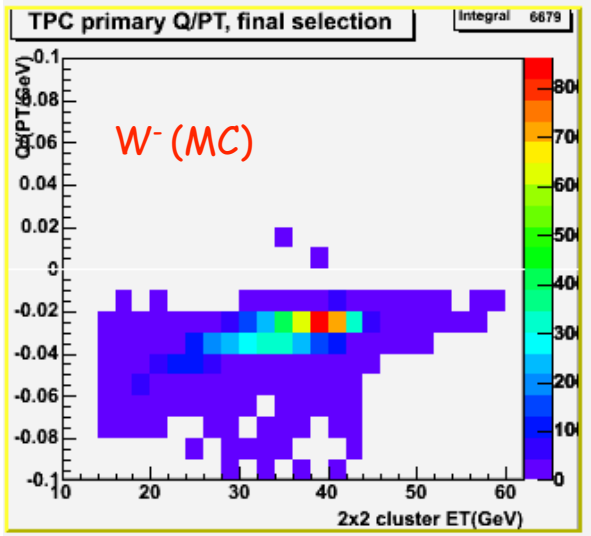
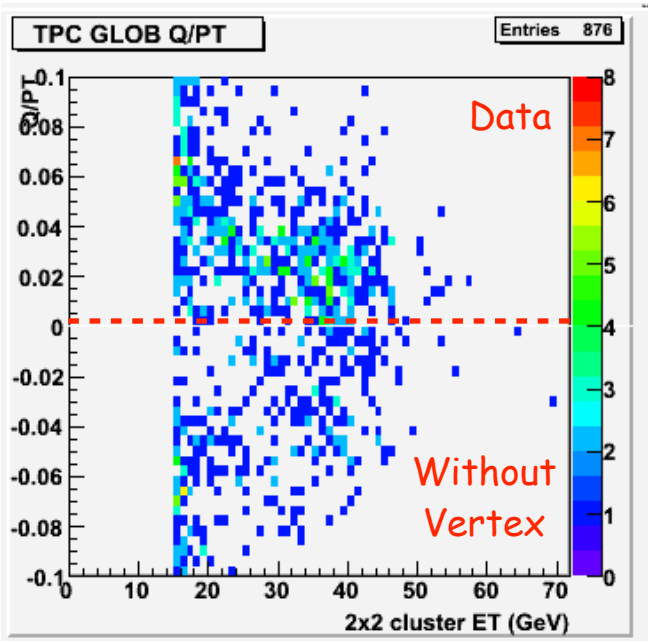
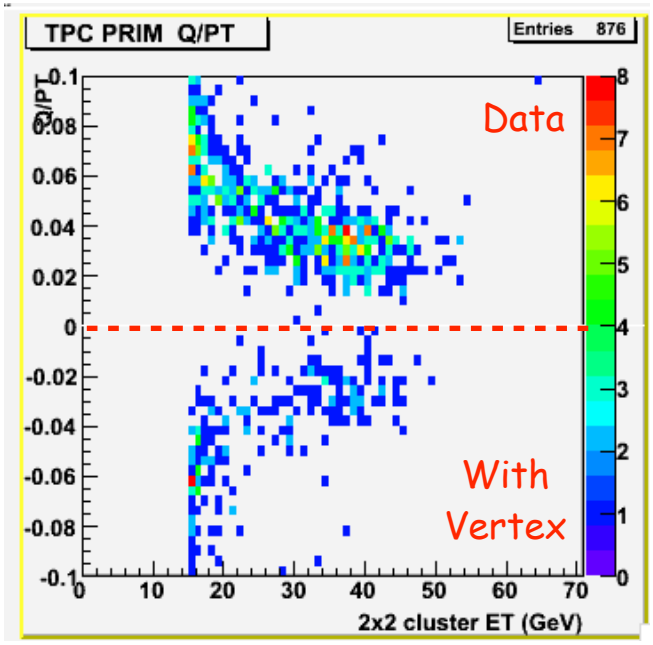


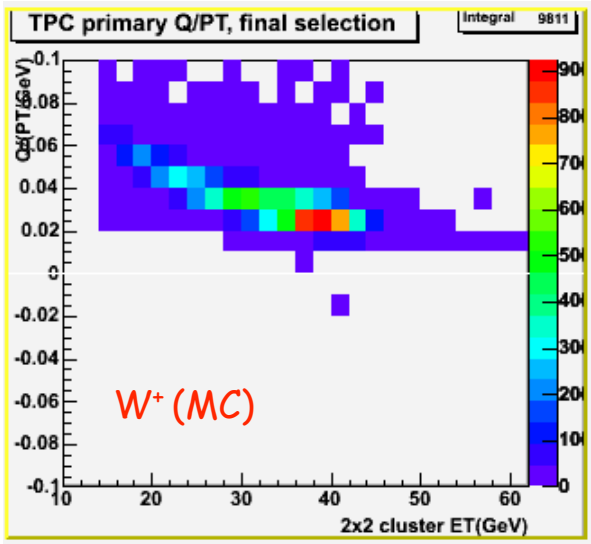


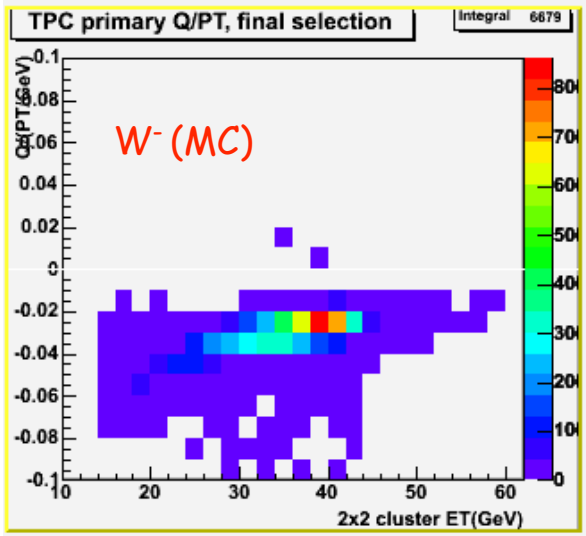


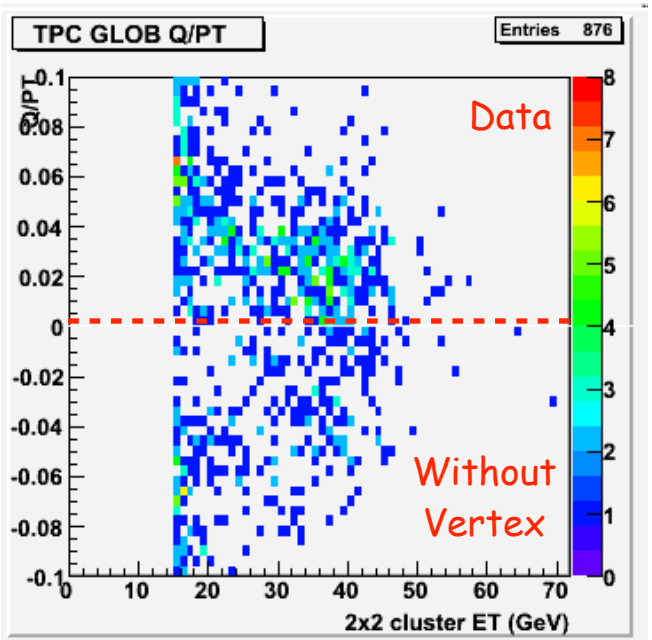


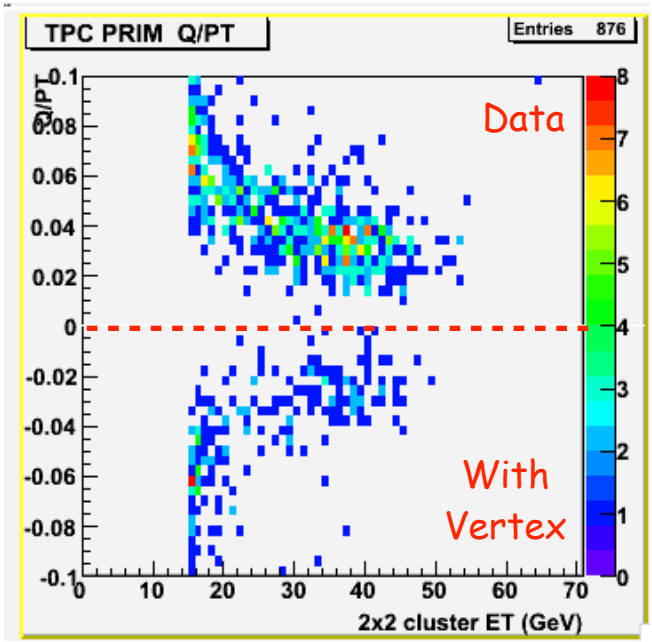
Backup

- Charge-sign discrimination : Data/MC comparison





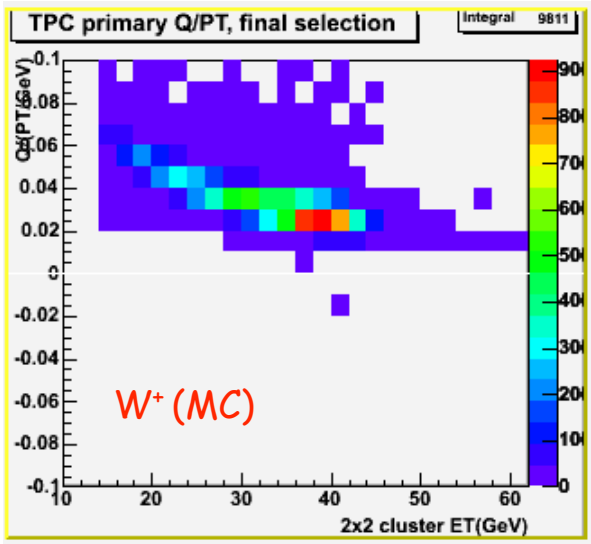


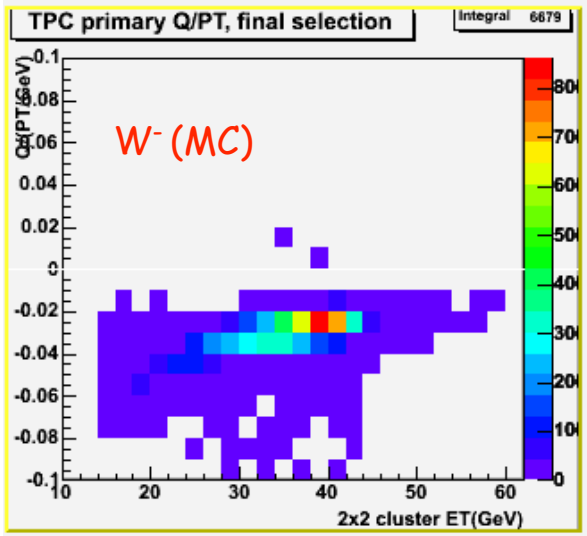


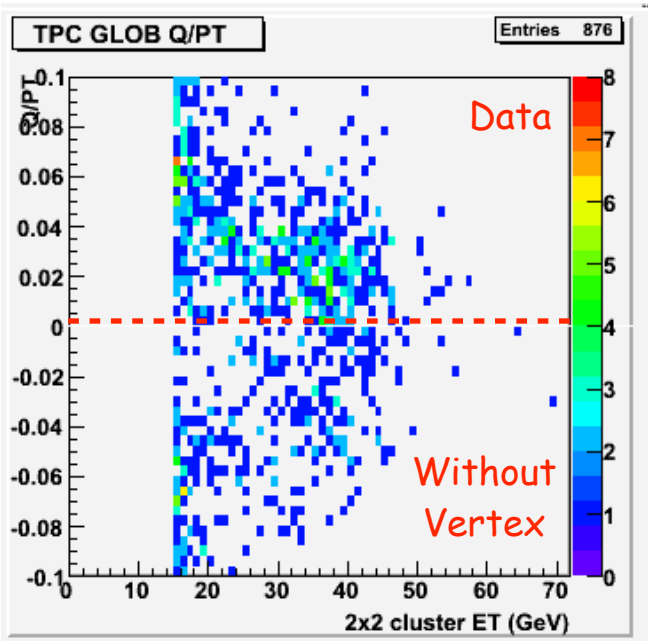
- Features as seen in MC for W^+/ W^- in sign/p_T vs. E_{2X2} also seen in data
- Critical: Vertex constraint

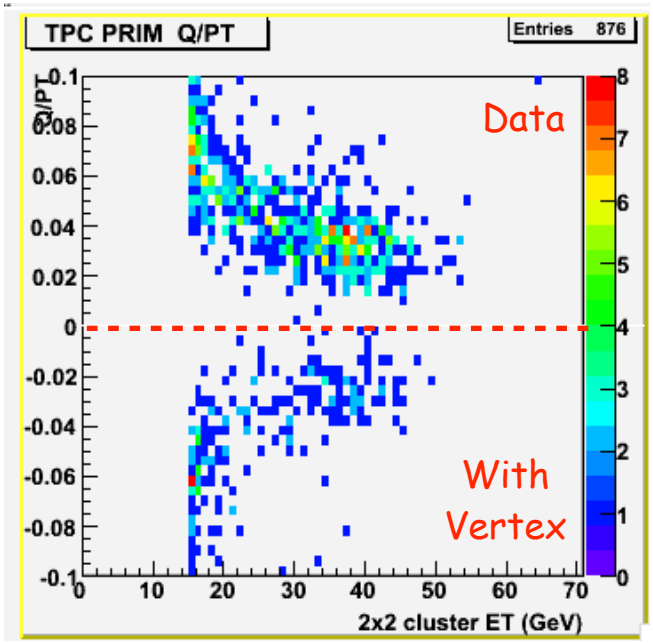
Backup

- Charge-sign discrimination : Data/MC comparison









- Features as seen in MC for W^+/ W^- in sign/p_T vs. E_{2X2} also seen in data
- Critical: Vertex constraint

With prelim. TPC calibration

Backup

- Total W^+/W^- Cross-section uncertainties
  - W reconstruction systematic uncertainties
    - Track reconstruction: 15 – 20%
    - Vertex reconstruction: 3%
    - BEMC Energy scale: < 1%
  - Normalization / Luminosity systematic uncertainty
    - Vernier scan absolute cross section: 23%
  - Background systematic uncertainty
    - Vary data driven QCD background shape and normalization region (E_T < 17 – 21 GeV)

Backup

- Parity-violating single-spin asymmetry W^+/W^- A_L uncertainties
  - Complete list of systematic uncertainties

W^+		W^-		
high	low	high	low	
0.09	**0.09**	0.09	0.09	Absolute polarization magnitude of both beams (P1+P2) (9.2%)
0.07	0.02	0.13	0.03	QCD unpolarized background
0.07	0.07	**0.14**	**0.14**	QCD pol. bckg. ~0: use 1/2 stat error of this test
0.01	0.00	0.01	0.00	Decay of pol. within fill
0.13	**0.11**	**0.21**	**0.17**	Total syst. in fraction of measured A_L

  - The following effects were found to be negligible:
    - Dilution of A_L due to swap of W^+/W^- charges : Tracks with false curvature were removed
    - A_{LL} P_1P_2 term cancels out
    - Transverse spin term negligible