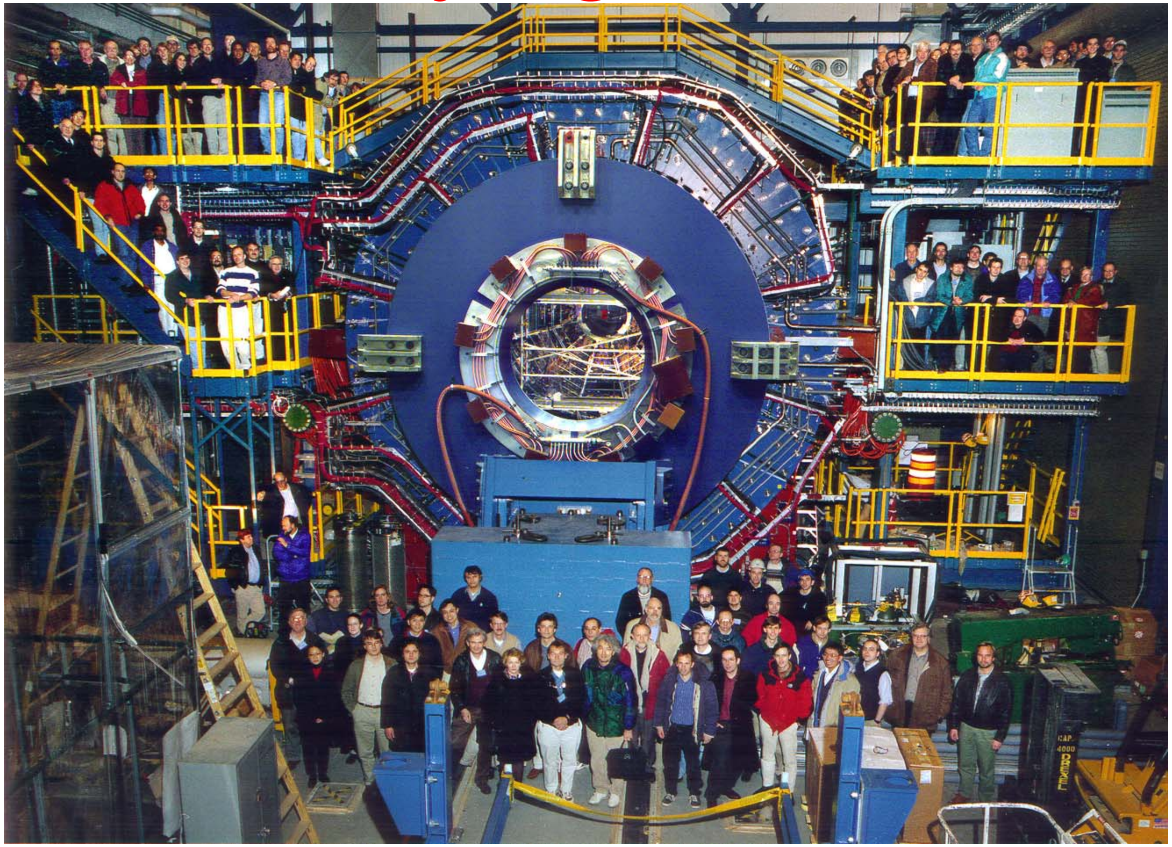
RHIC and STAR: New Tools for Studying the Proton's Spin



J. Sowinski

Indiana University

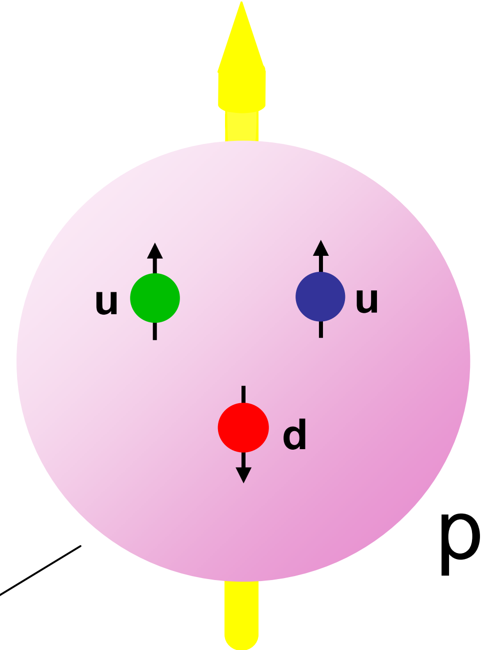
STAR Collaboration

- Current knowledge of the proton's spin
- RHIC and STAR
- Constraints on ΔG – γ-jet, di-jets and π^0s
- Transversity – Collins and Sivers functions
- Spin dependent flavor asymmetry of the sea quarks

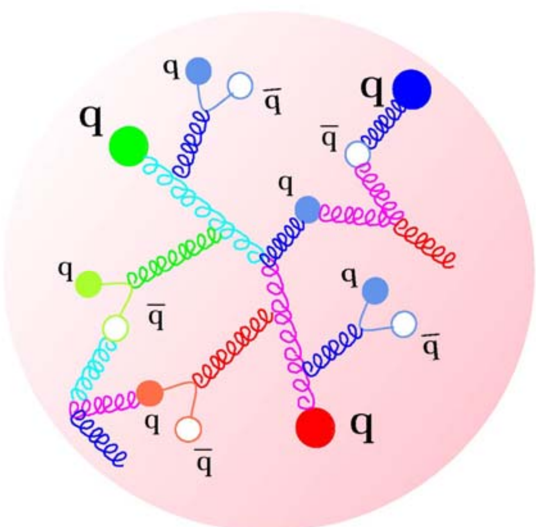
Where does the proton's spin come from?

p is made of 2 u and 1d quark

$$S = \frac{1}{2} = \sum S_q$$



Explains magnetic moment of baryon octet

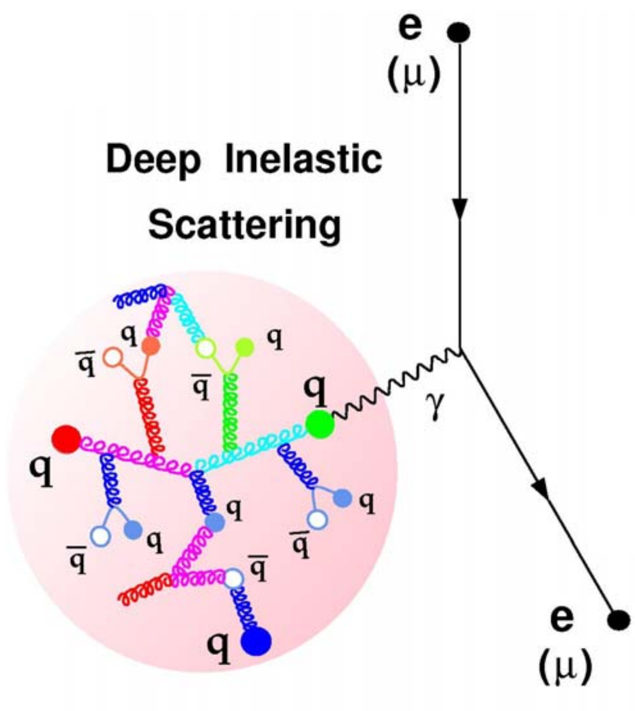


BUT partons have an x distribution and there are sea quarks and gluons

Check via electron scattering and find quarks carry only ~1/3 of the proton's spin!

$$S_z = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z^q + L_z^g$$

DIS used to investigate proton structure



Virtual γ → momentum transfer Q,
energy loss ν

Measure "structure functions" vs.
$x_{Bjorken} = Q^2/2M_N\nu$ and Q^2

Weak dependence

p_{parton}/p_{proton} in the
∞ momentum frame

Gluons are neutral and hence relatively insensitive to DIS

Spin structure functions

- Polarized beam and target
- Polarization along/opposite beam direction
- Measure difference between parallel and anti-parallel spin combinations
- Quark can only absorb photon of opposite helicity → Good spin analyzer

Unpolarized and Polarized Structure Functions

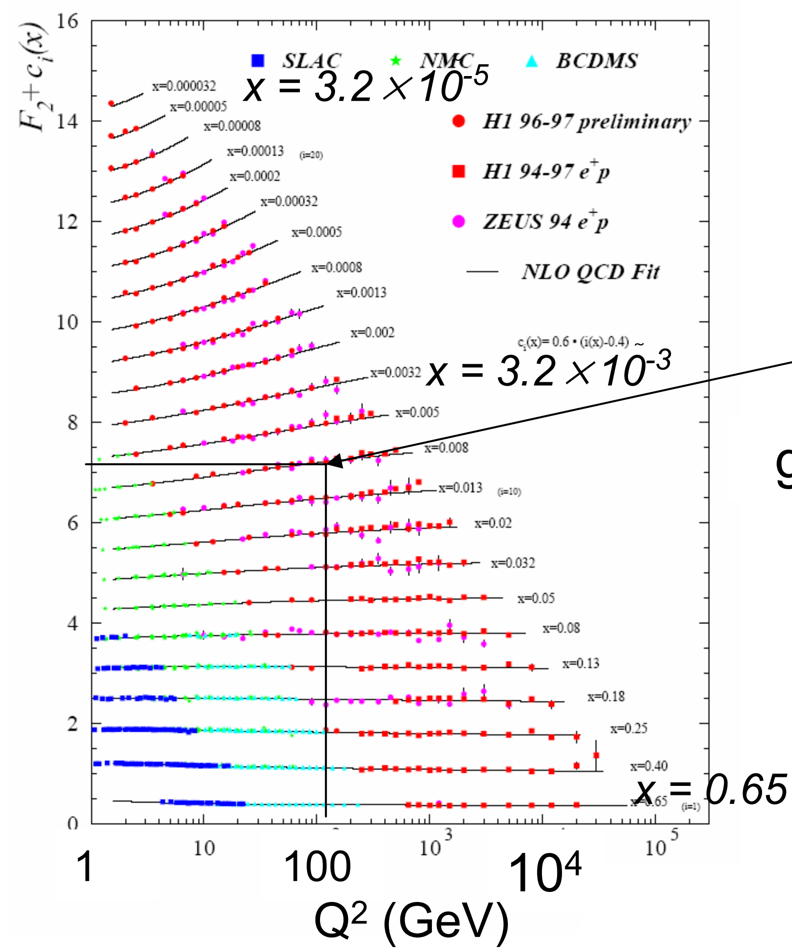
Parton Model → $F_2^p(x,Q^2) = \frac{1}{2}\,\Sigma e_i^2[q_i(x,Q^2) + \bar{q}_i(x,Q^2)]$ $\quad g_1^p = \frac{1}{2}\,\Sigma e_i^2[\Delta q_i(x,Q^2) + \Delta\bar{q}_i(x,Q^2)]$

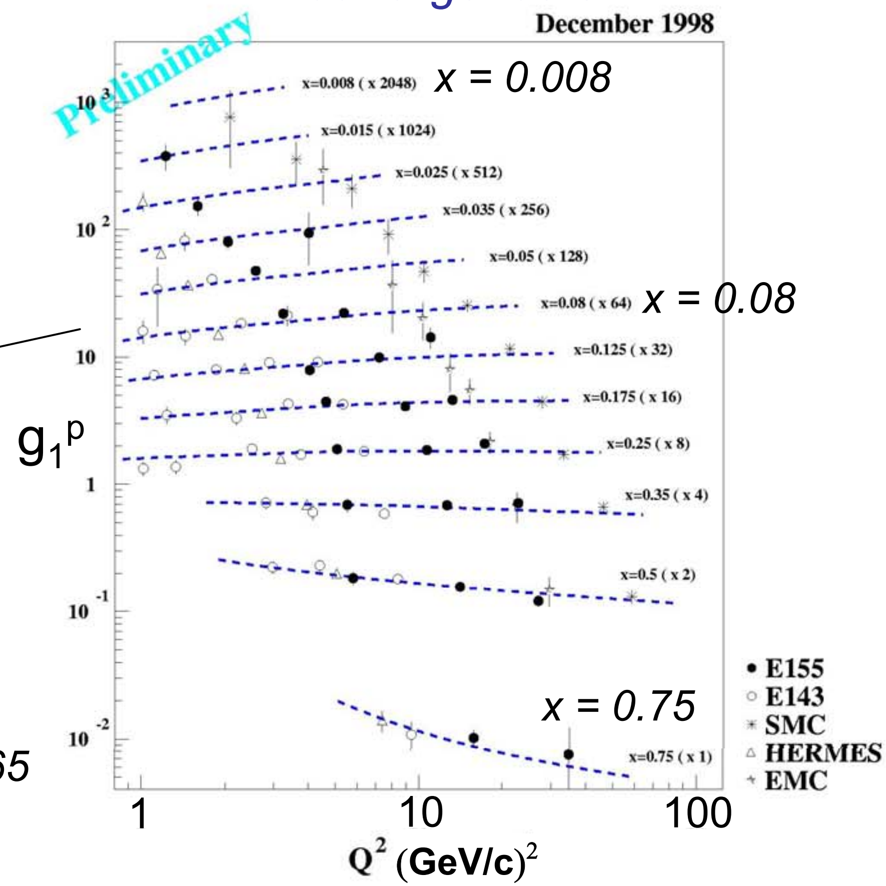
World data on F_2^p

World data on g_1^p

All fixed-target data

Unpolarized DIS Structure Function(x,Q²)





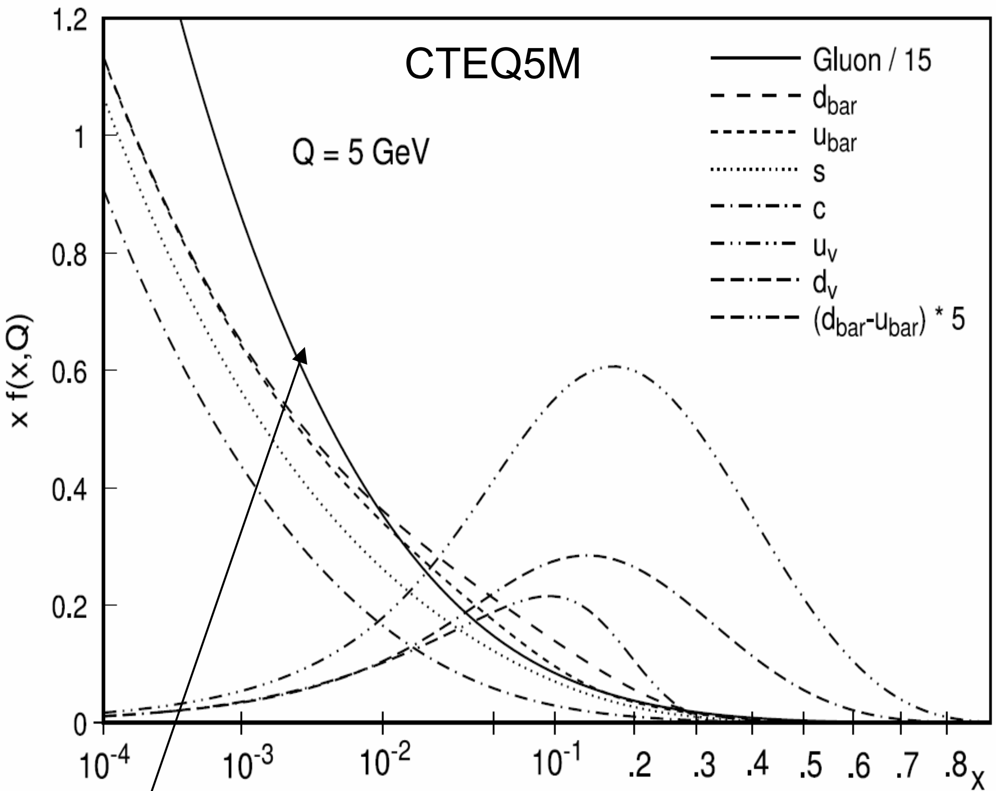
Polarized DIS Structure Function(x,Q²)

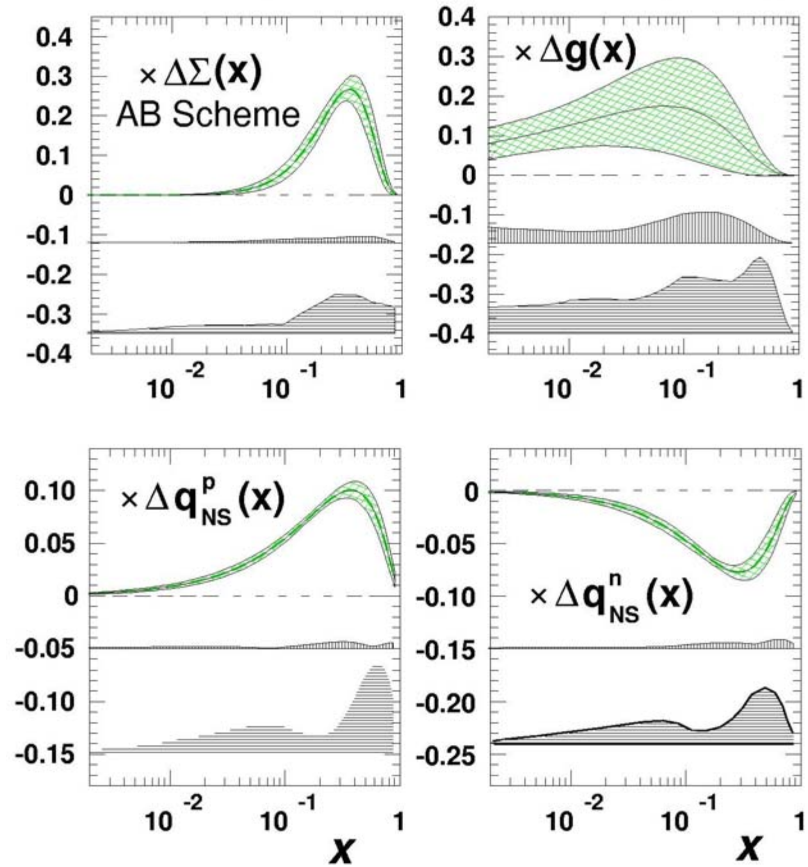
Small scaling violations with Q² give sensitivity to gluon distributions

Without e-p collider data, reduced range of x and Q² leaves gluon spin poorly determined

Parton Distribution Functions

SMC Analysis, PRD **58**, 112002 (1998)





Gluons carry ~1/2 the momentum (mass)!

Maybe we shouldn't be surprised that quarks carry only ~1/3 of proton's spin

ΔG is poorly constrained, even solutions with zero crossing allowed

First Moments at Q_0^2=1 GeV^2:

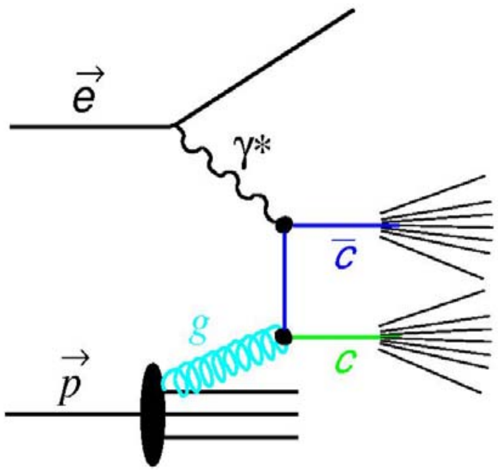
$\Delta\Sigma_{(\overline{MS})} = 0.19 \pm 0.05 \pm 0.04$

$\Delta\Sigma_{(AB)} = 0.38 \,^{+0.03}_{-0.03} \,^{+0.03}_{-0.02} \,^{+0.03}_{-0.05}$

$\Delta G_{(AB)} = 0.99 \,^{+1.17}_{-0.31} \,^{+0.42}_{-0.22} \,^{+1.43}_{-0.45}$

(just one example of many)

Semi-Inclusive Deep Inelastic Scattering

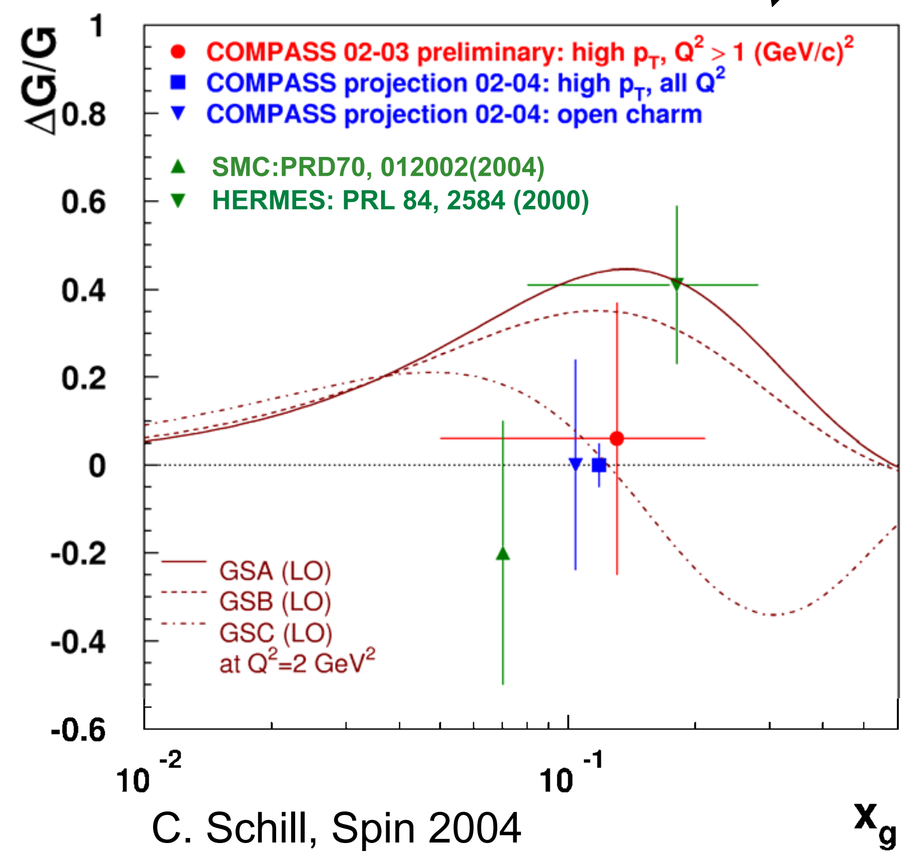


Photon - Gluon Fusion

- Open charm clean
- Leading hadrons have backgrounds from QCD-Compton and vector meson dominance

Hermes and COMPASS

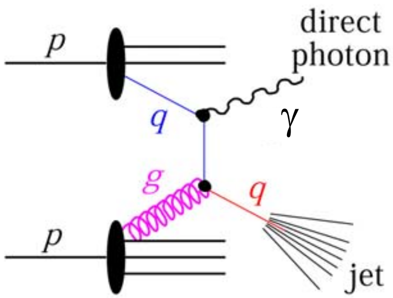
- Detect leading hadrons from jets
- Compass open charm
- Have announced results
- Kinematically difficult to cover broad x range w/o e-p collider



C. Schill, Spin 2004

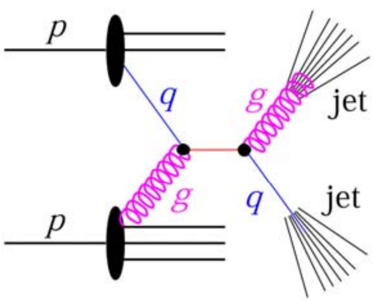
ΔG via partonic scattering from a gluon

Hard scattering ⟶ pQCD, factorization



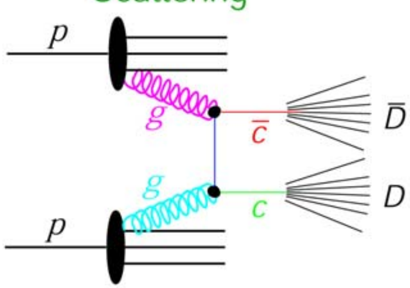
Quark - Gluon Compton Scattering

γ-jet coinc. rare



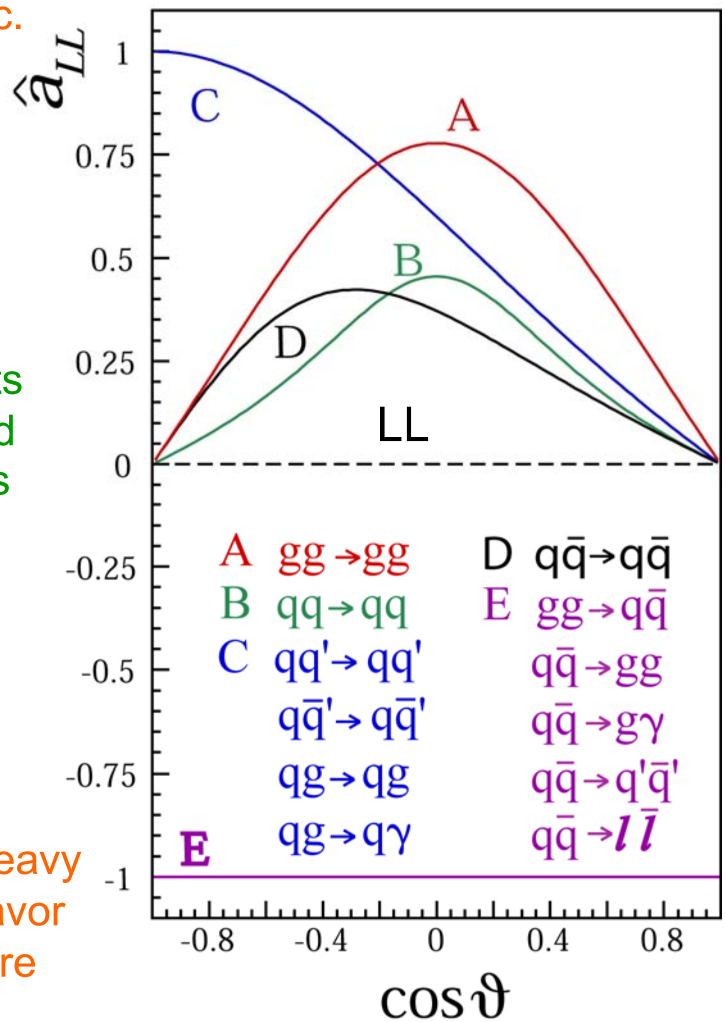
Quark - Gluon (also Gluon - Gluon) Elastic Scattering

Jets and π^0s



Gluon - Gluon Fusion

Heavy flavor rare



Measure → A_{LL}

Know from DIS → P_{part}

$$A_{LL} \sim P_g \times P_{part} \times \hat{a}_{LL}$$

"ΔG" → P_g

pQCD → $\hat{a}_{LL}$

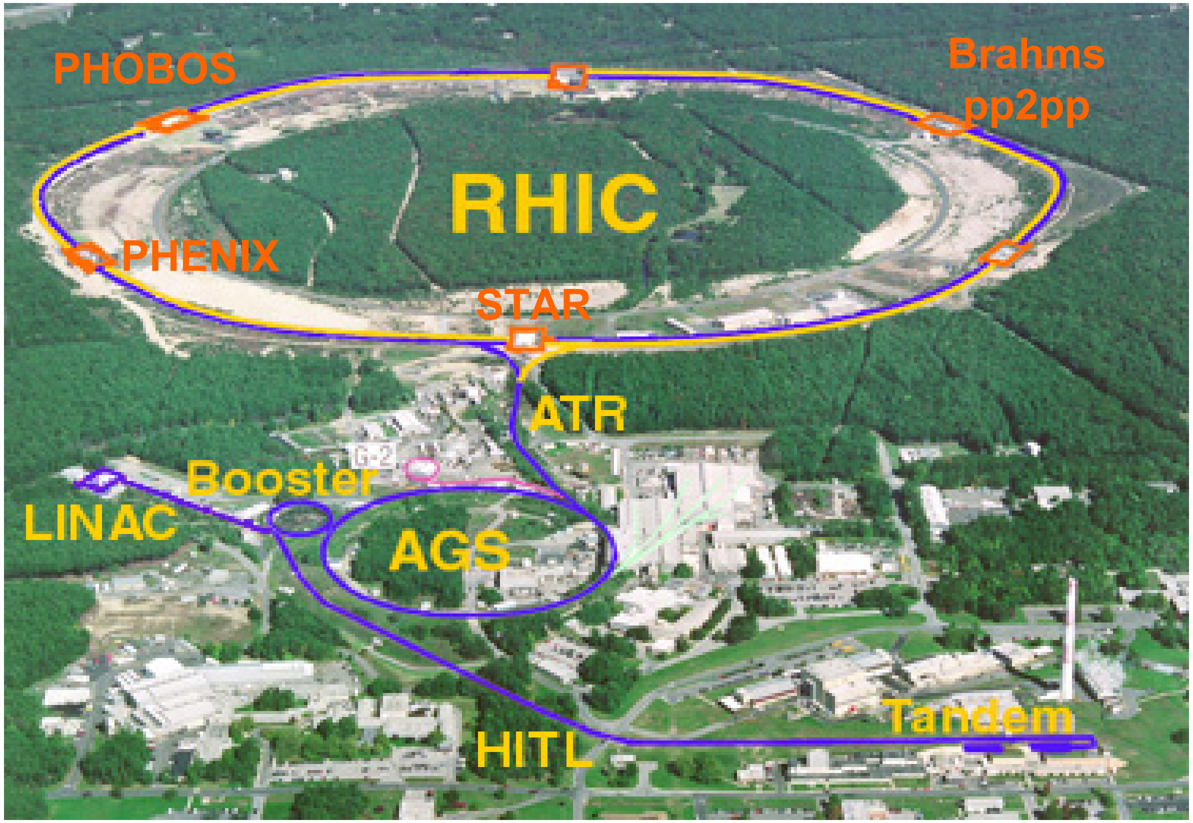
Prefer

- Dominant reaction mechanism
- Experimentally clean reaction mechanism
- Large $\hat{a}_{LL}$

STAR

BROOKHAVEN NATIONAL LABORATORY

The Relativistic Heavy Ion Collider



2.4 mile circ. Collider

$\sqrt{s} \leq 200 \text{ GeV/N}$

Heavy ions
- Au-Au
- Lighter ions
- Asymmetric d-Au

4+ detectors
- STAR
- PHENIX
- PHOBOS
- Brahms
- pp2pp (p-p only)

The first polarized p-p collider!

$$24\text{GeV} \leq \sqrt{s} \leq 500\text{GeV}$$

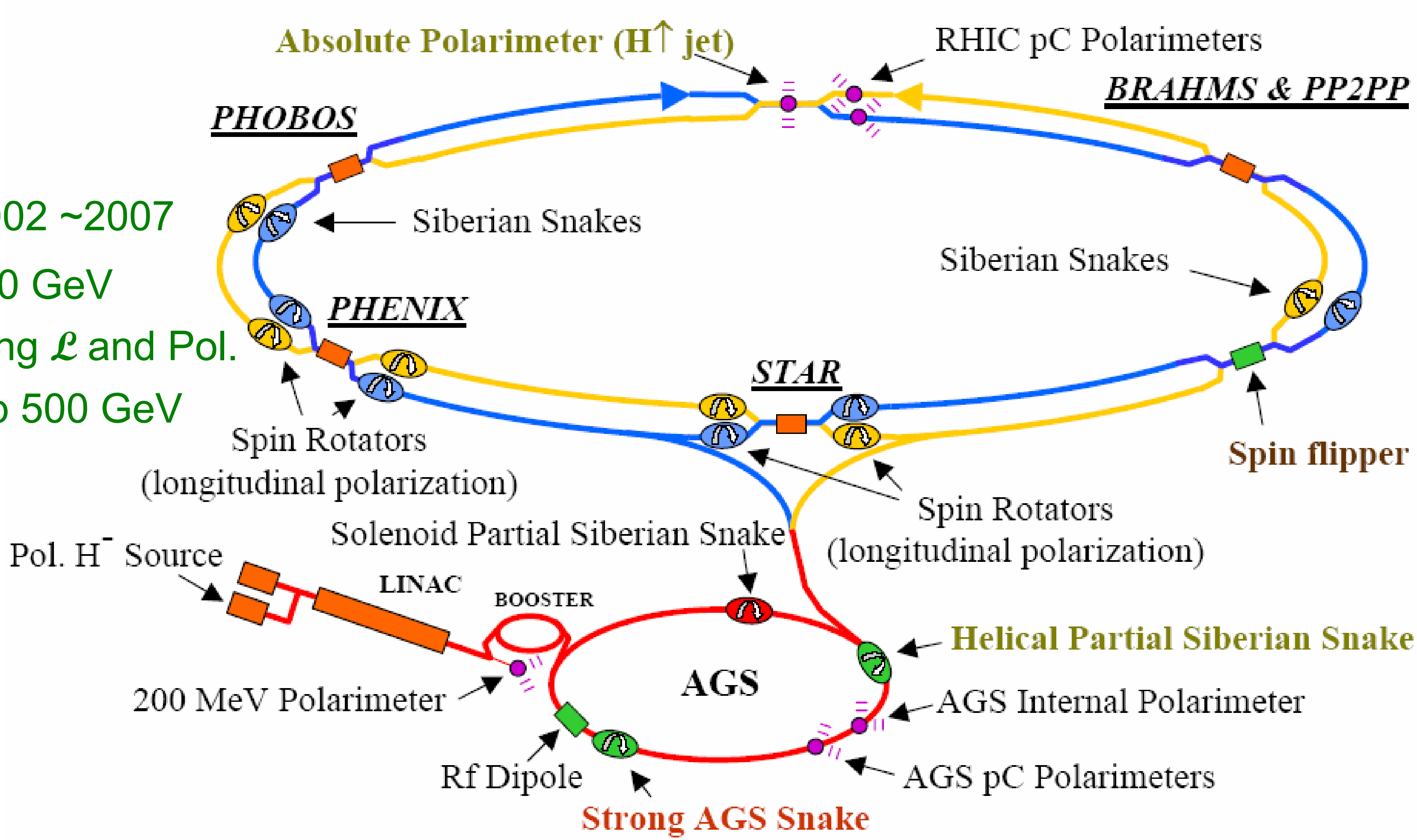
Polarized Proton Operation at RHIC

Year 2002 ~2007

$\sqrt{s}$ = 200 GeV

Improving $\mathcal{L}$ and Pol.

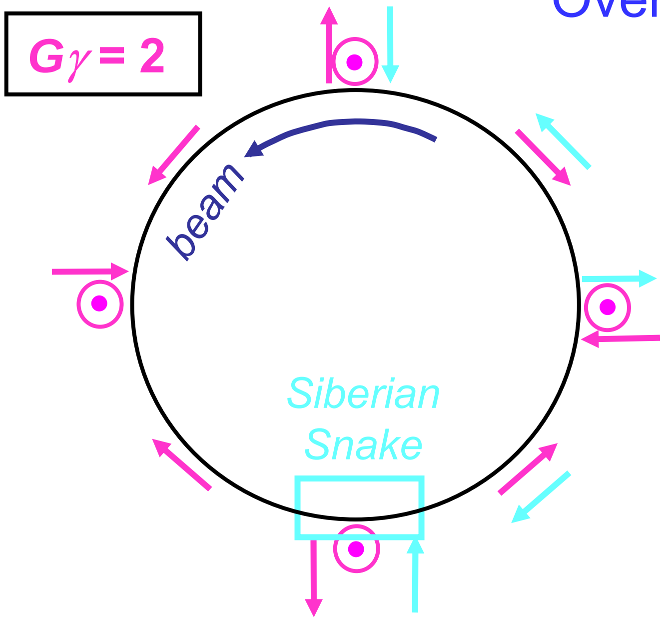
Develop 500 GeV



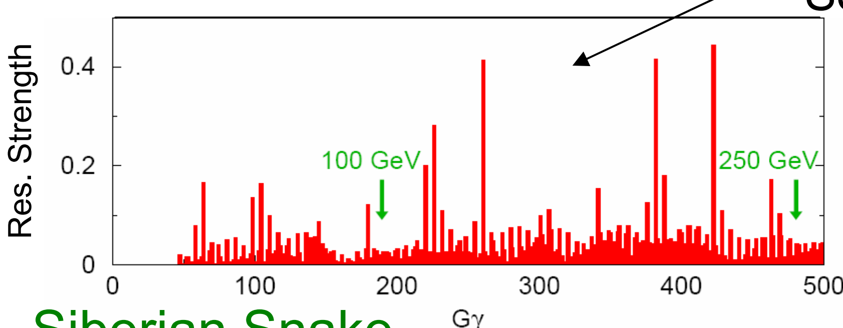
	2002	2003	2004	2005	2006	2007
• $\mathcal{L}$ ($s^{-1}cm^{-2}$)	0.5×10^{30}	2×10^{30}	3×10^{30}	8×10^{30}	17×10^{30}	48×10^{30}
• Int. $\mathcal{L}$ (pb^{-1} T/L)	0.3 pb^{-1}	0.5/0.4	0.5/0.4	4/7	28	86
• Pol.	0.2	0.3	0.40	0.45	0.65	0.70

Why is RHIC the 1st Polarized Collider?

Overcoming Depolarizing Resonances

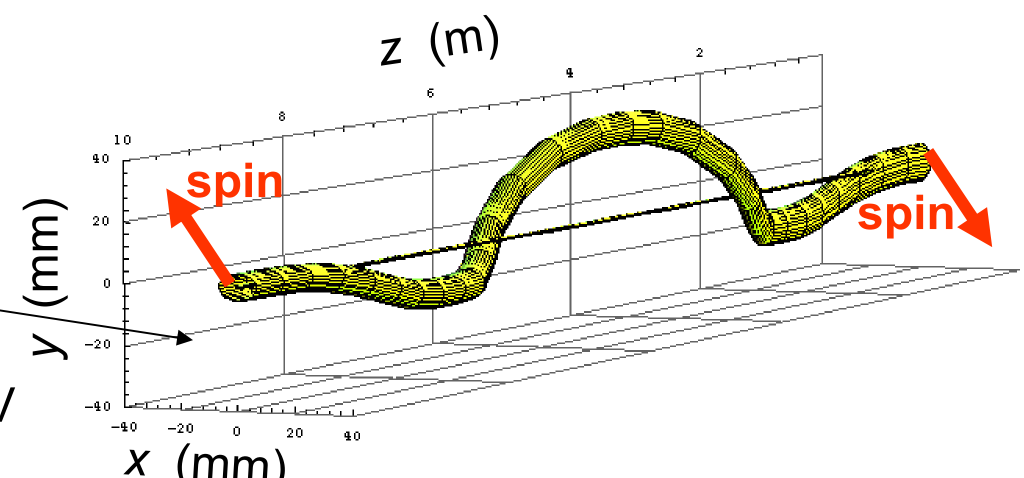


- Spin is vertical in RHIC
- In-plane components precess rapidly at spin tune (turns/orbit) = Gγ (~180 at 100GeV)
- Resonances from repetitive perturbations
  - Stray in-plane fields can rotate spin into plane, resonance when Gγ=integer
  - Focusing fields can also do this, resonance when Gγ=integer + betatron tune
  - Huge number of these in RHIC
- Solution Siberian Snakes
  - Idea from Novosibirsk
  - First proof in tests at IUCF Cooler ring



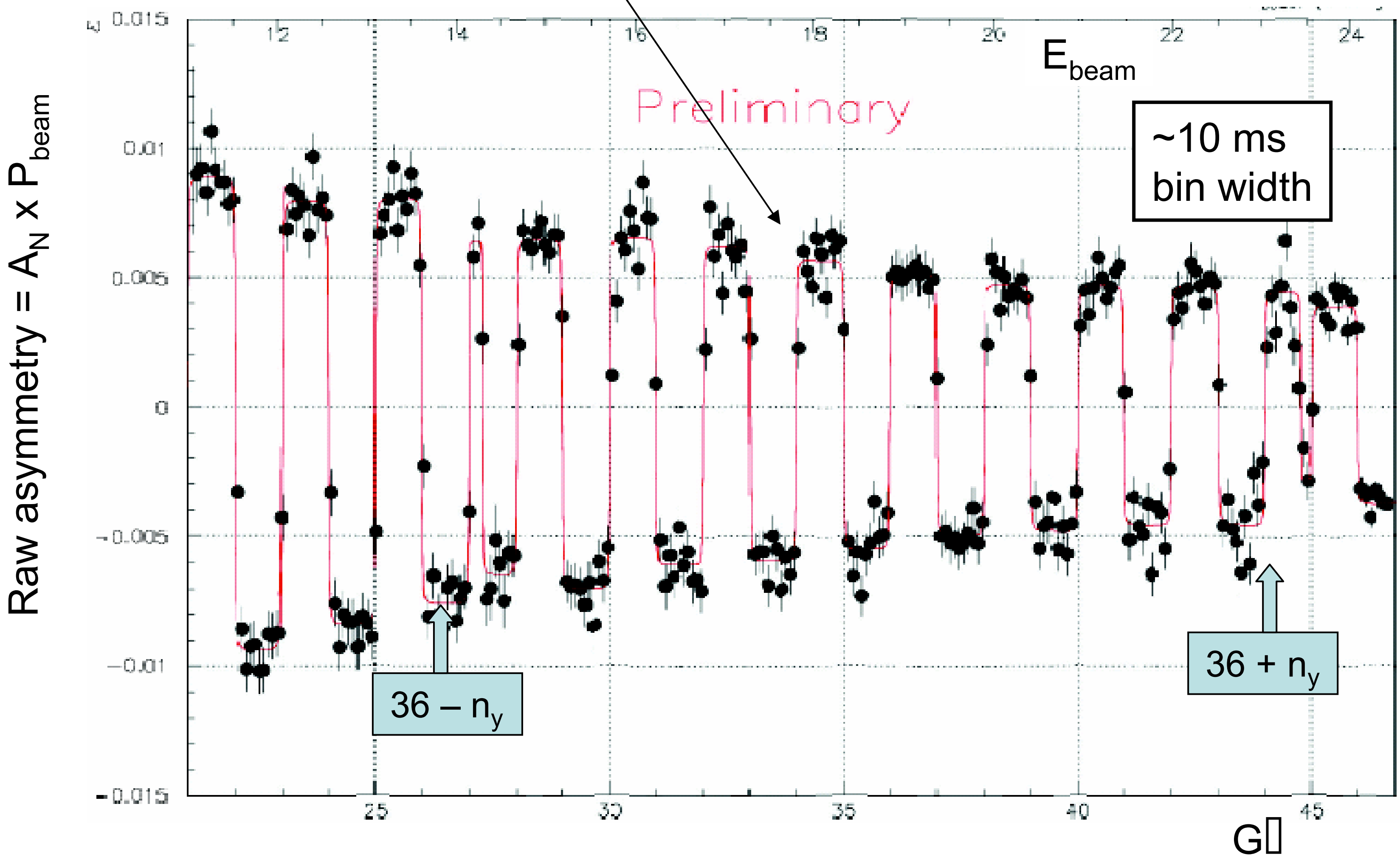
Siberian Snake

- Helical dipole magnet
- Rotates spin 180° no net beam defl.
- 2 in RHIC
- ~100% spin transmission to 100 GeV
- Same technology for spin rotators



AGS never designed for spin (space)
Resonances handled individually
For strongest ones spin flips!

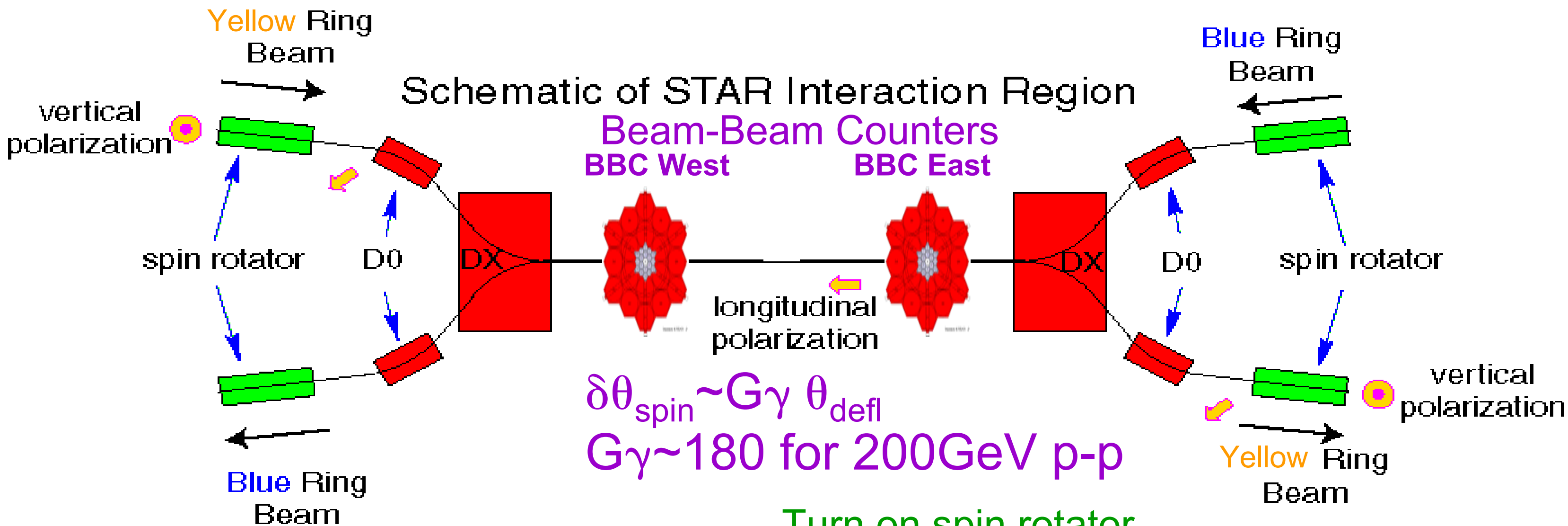
Solution is stronger partial snake ready for testing in coming run expect 70% pol. from AGS

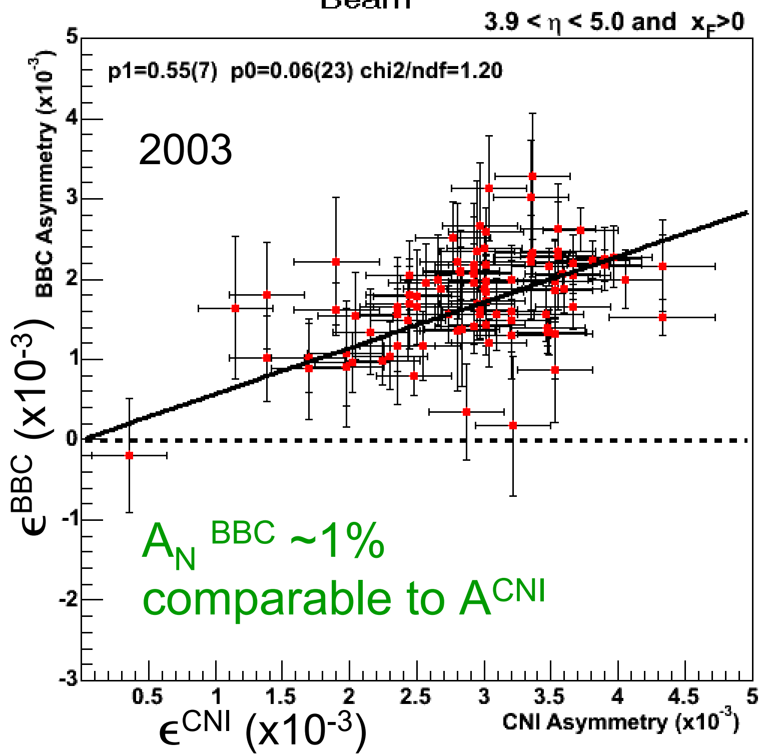


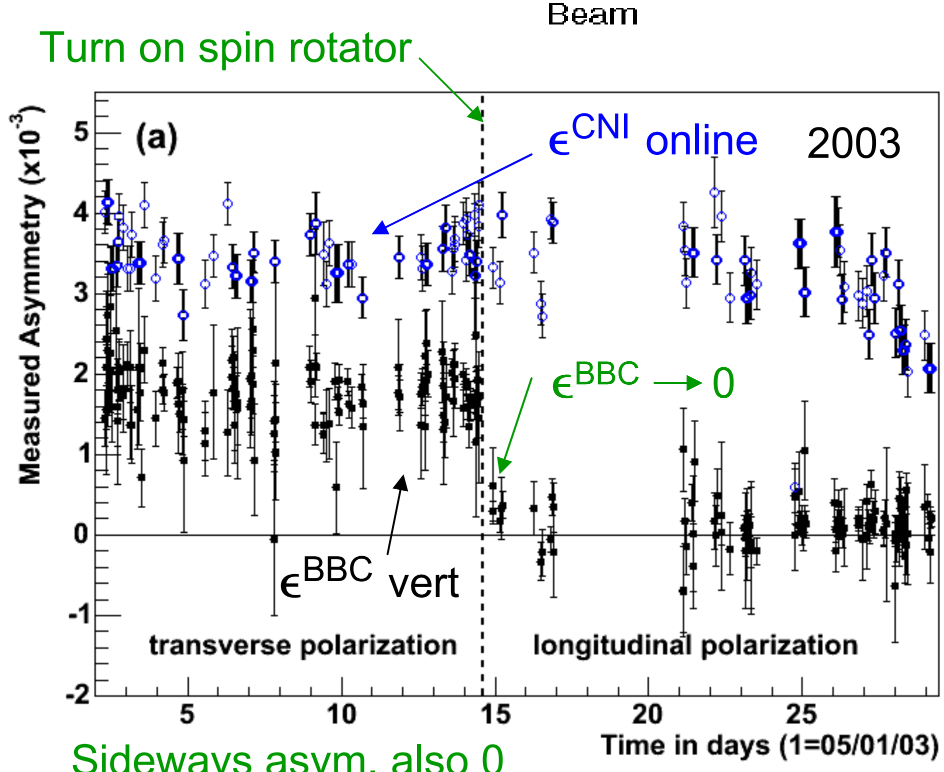
Imperfection resonances: spin flip at every $G\gamma = n$
Intrinsic resonances: spin flip at $G\gamma = 36 - n_y$ and $36 + n_y$

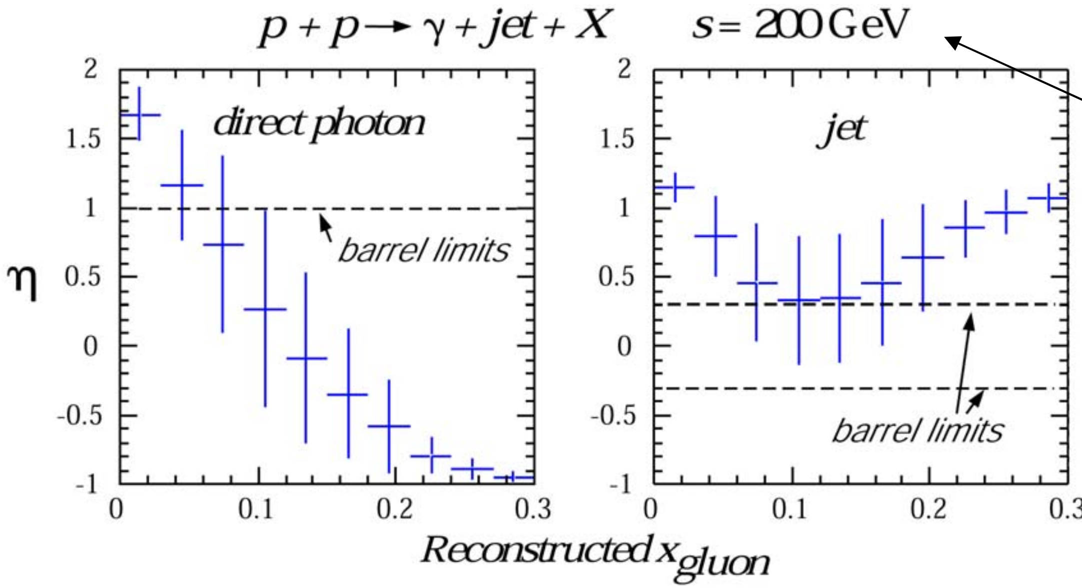
f.o.m.~$P^4 \mathcal{L}$!

How do we (know we) get longitudinal polarization?



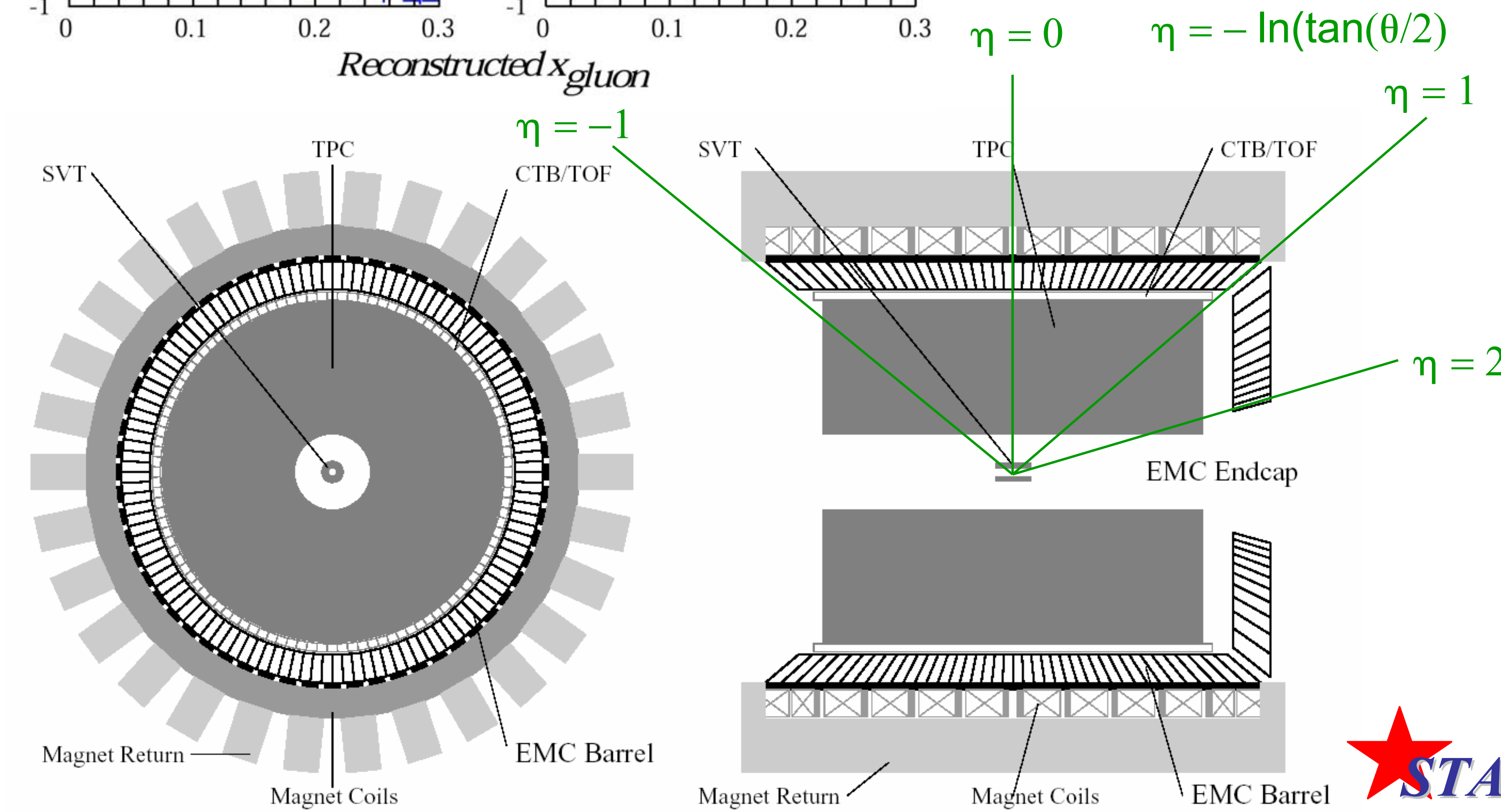


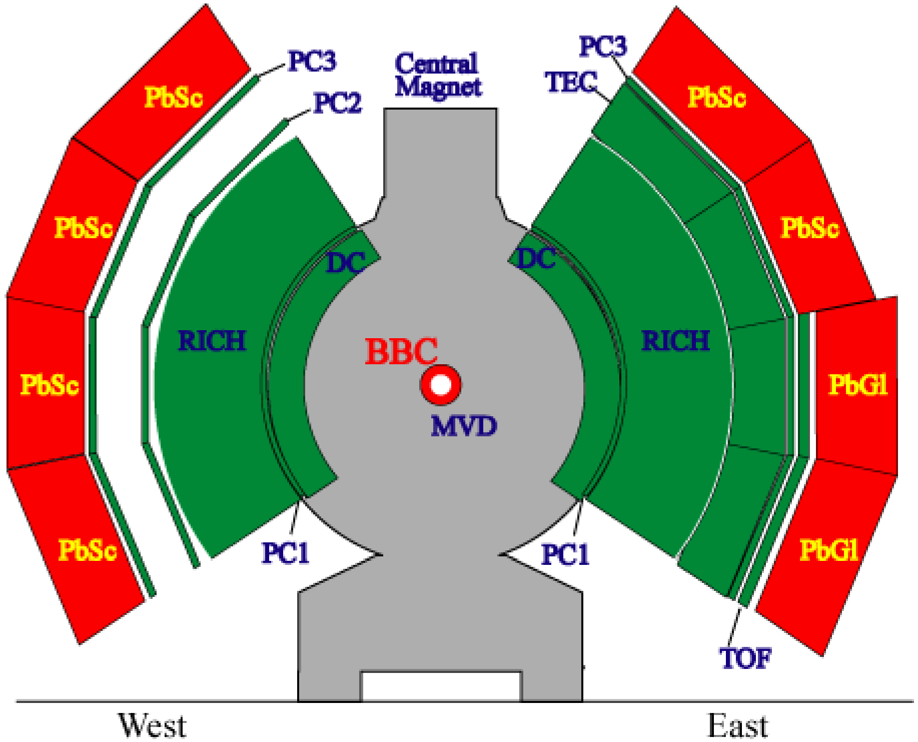




Physics puts premium on a large solid angle detector

- Kinematic coverage
- Coincident solid angle
- Jets are big r~0.7



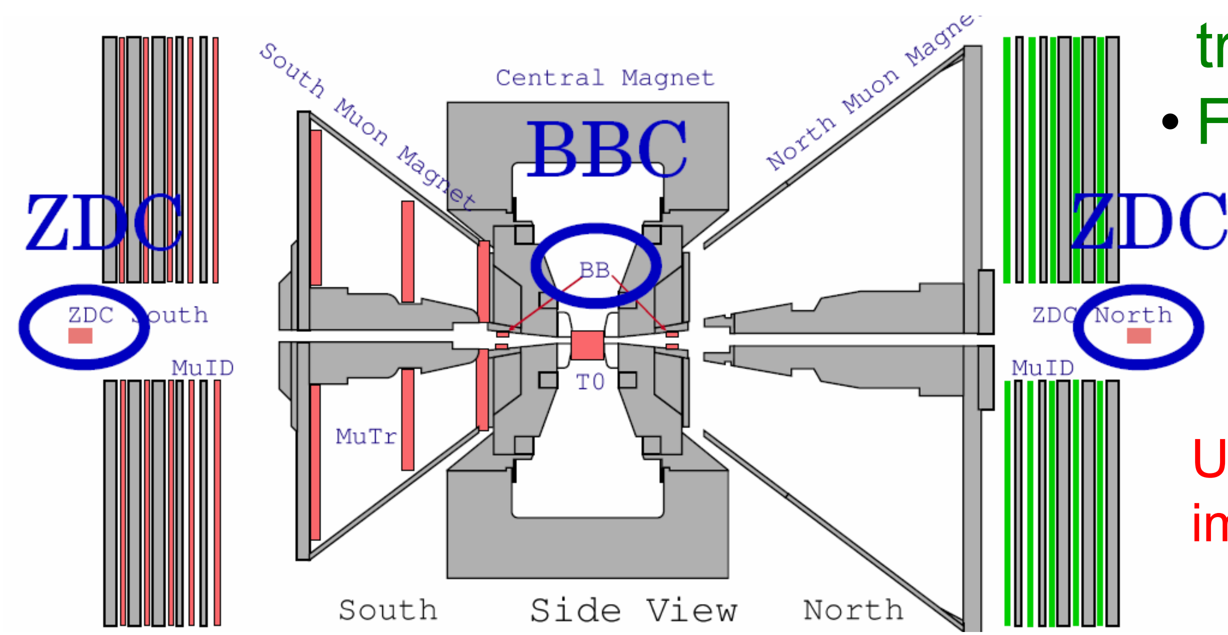


PHENIX

Sacrifice full coverege for good particle ID

μ detection forward

- RICH detectors central
- Some Pb glass
- Solenoidal B field and tracking
- Fast DAQ

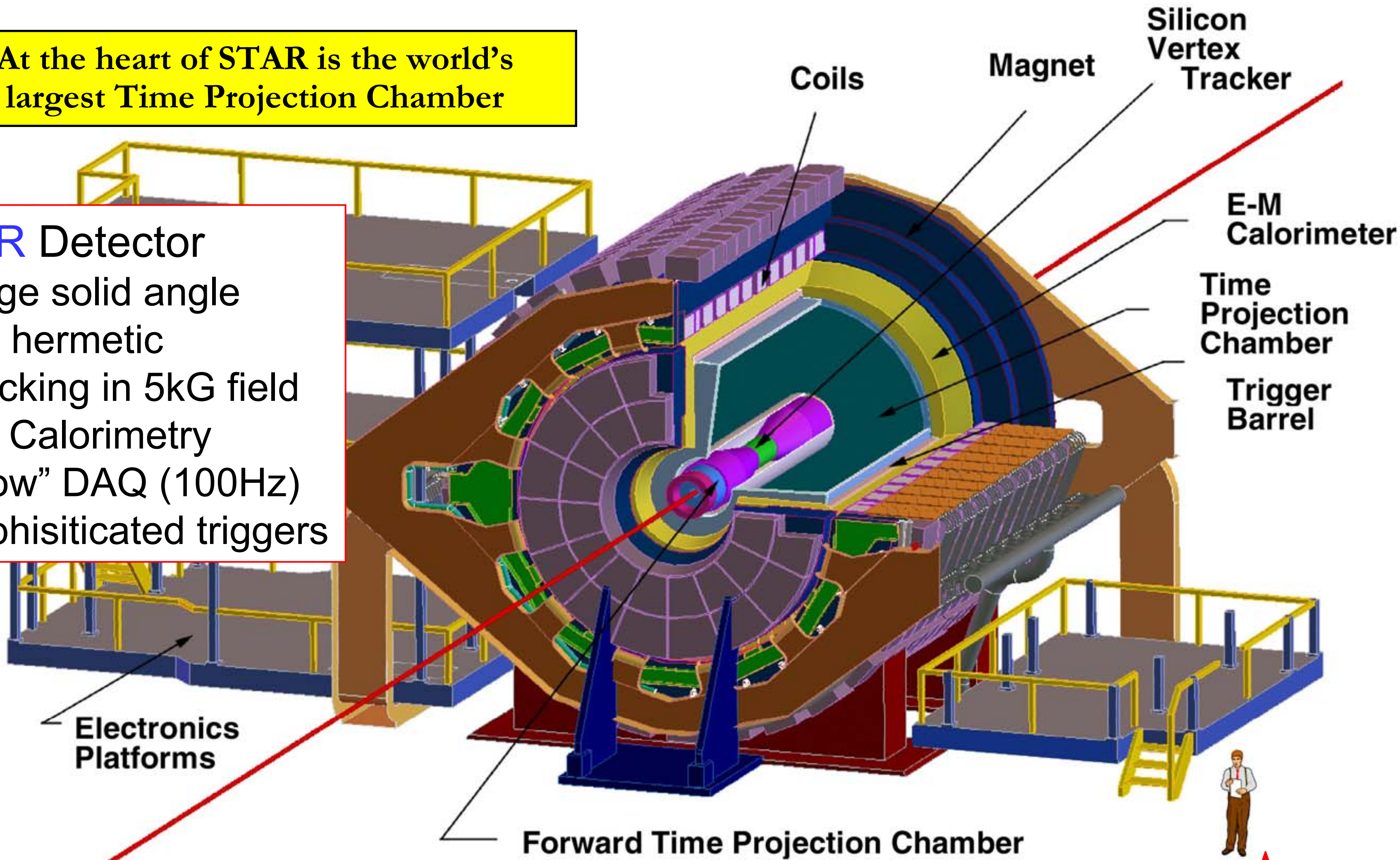


Upgrades planned to improve coverage for spin

Tools: The STAR Detector at RHIC

At the heart of STAR is the world's largest Time Projection Chamber

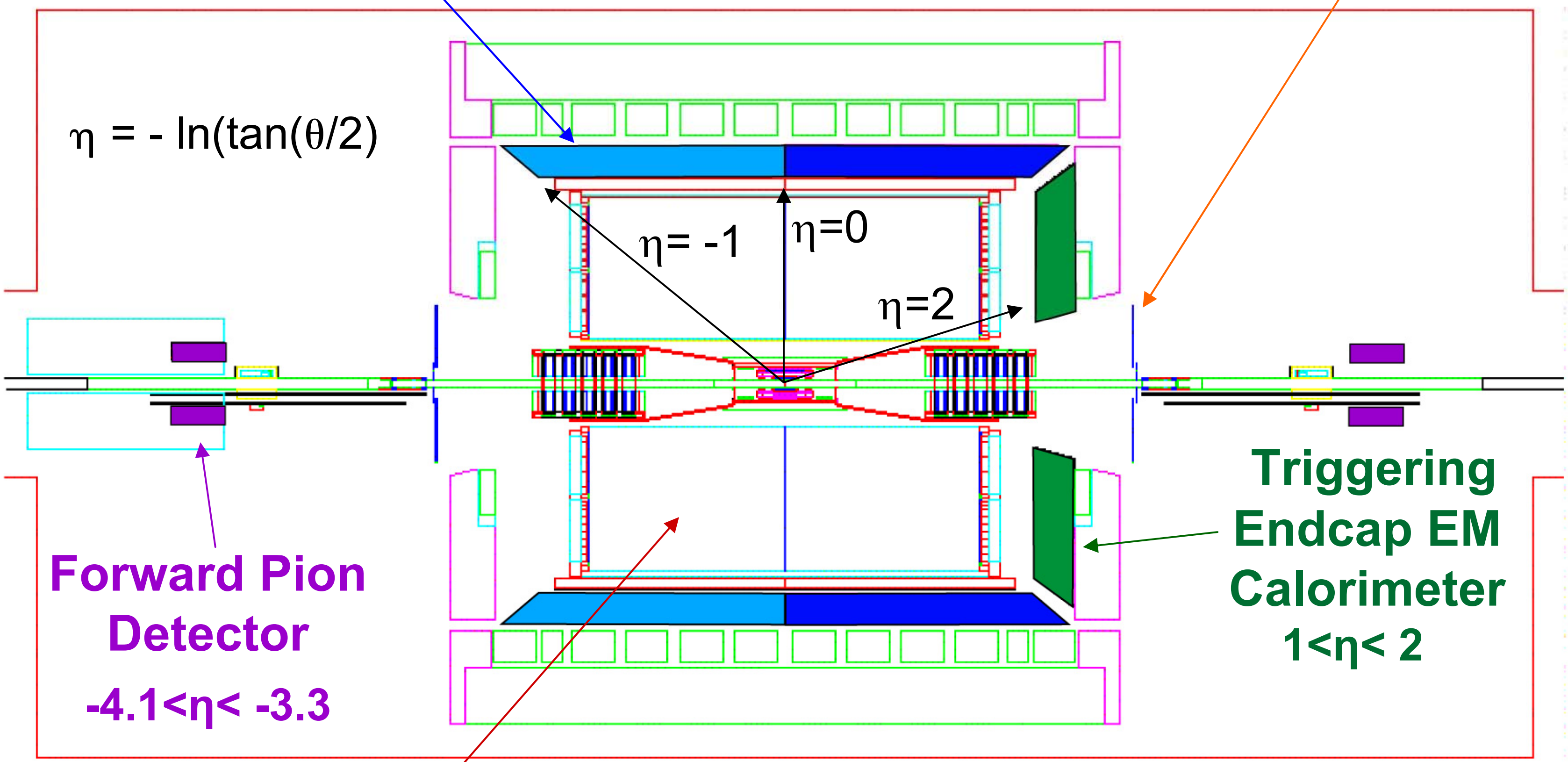
STAR Detector
- Large solid angle
- Not hermetic
- Tracking in 5kG field
- EM Calorimetry
- "Slow" DAQ (100Hz)
- Sophisiticated triggers



STAR

STAR Detector

Special interest for spin

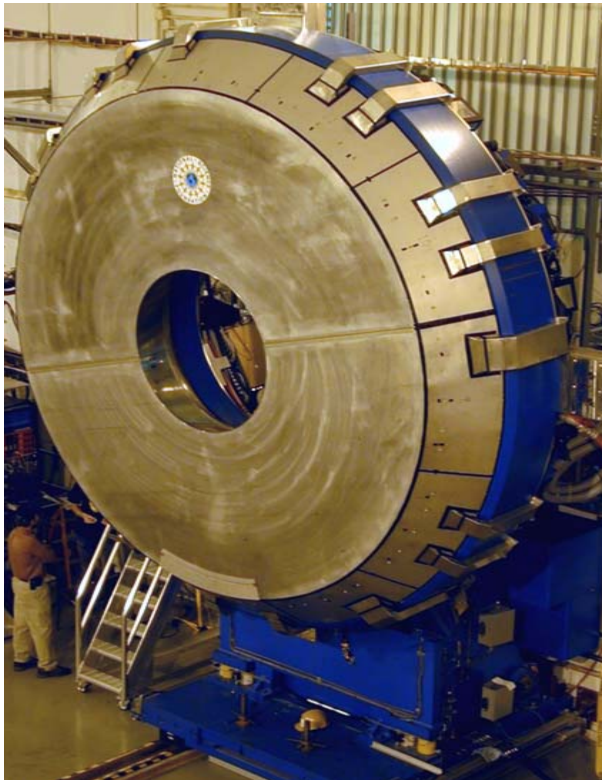


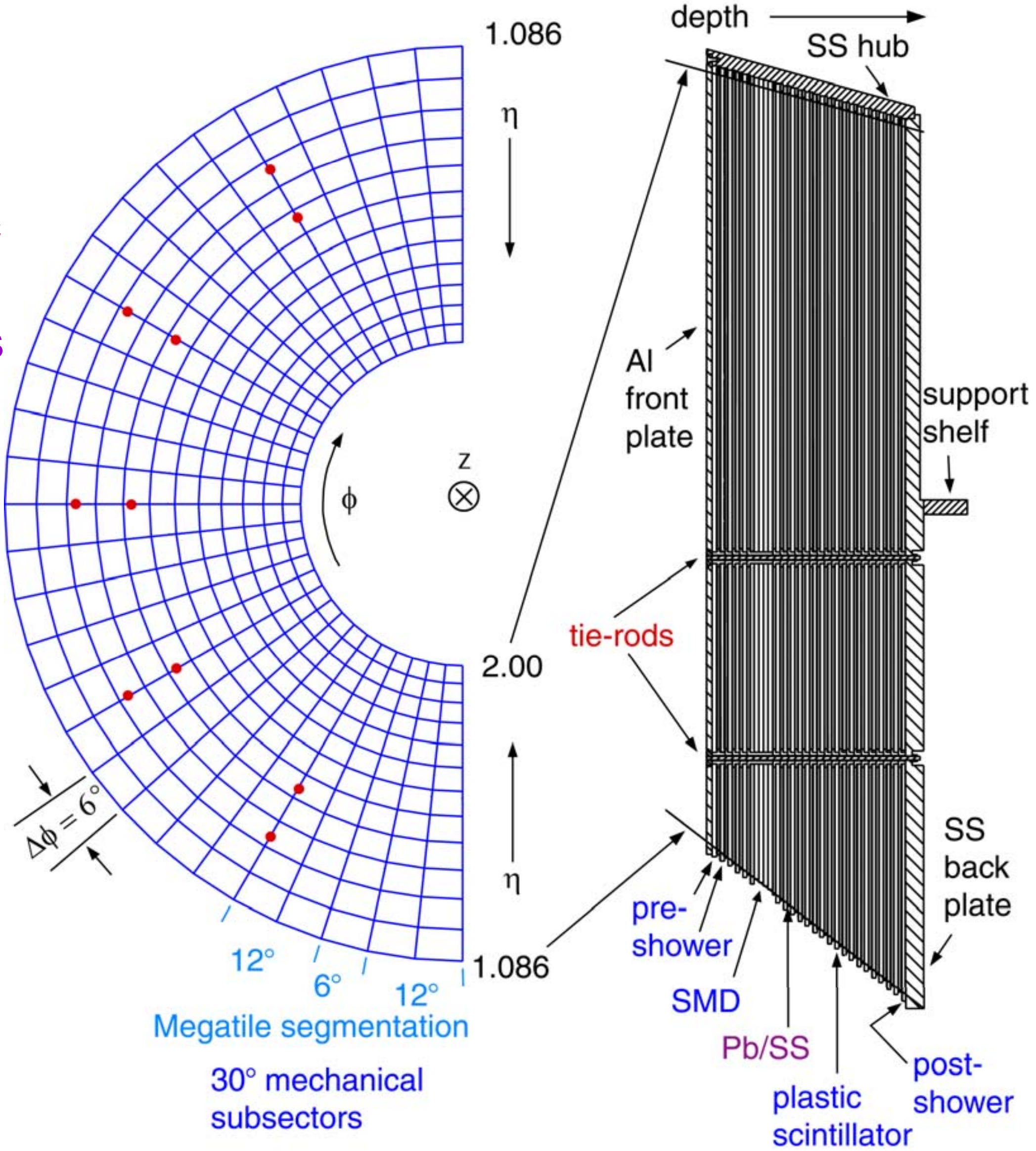
Solenoidal Magnetic
Field 5kG

2005

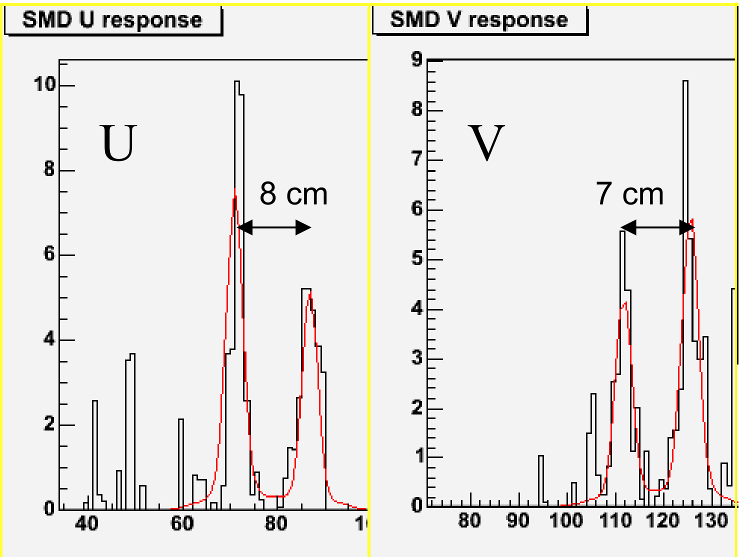
Endcap ElectroMagnetic Calorimeter

- Pb Scint sampling calorimeter
- 21 radiation lengths
- 720 projective towers
- Depth Segmentation
  - 2 preshower layers, e/h π^0/γ disc.
  - High position resol. SMD π^0/γ disc
  - Postshower layer e/h discc.
- L0 trigger- high tower, jet patches



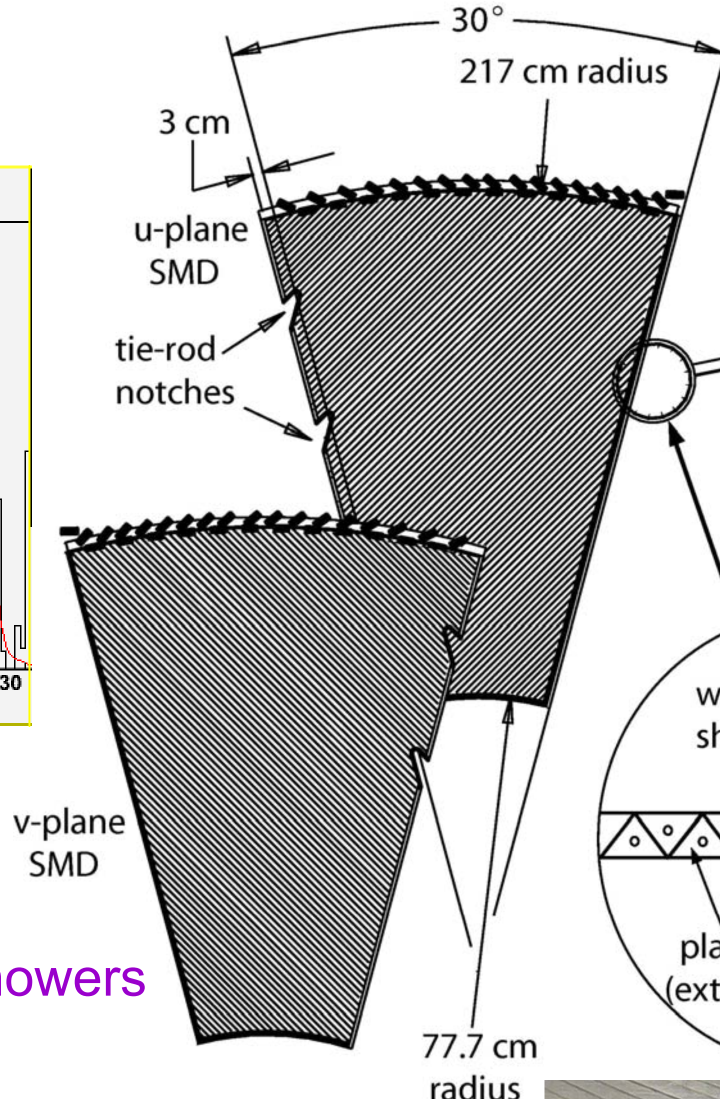


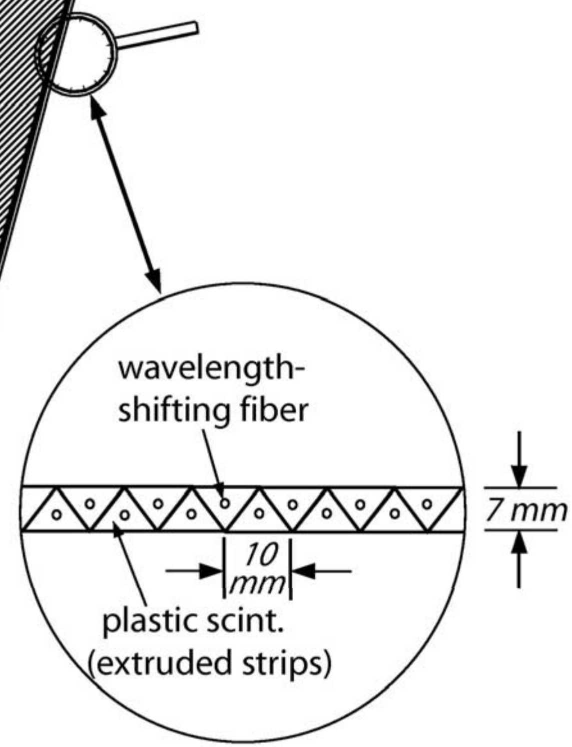
Shower Maximum Detector EEMC

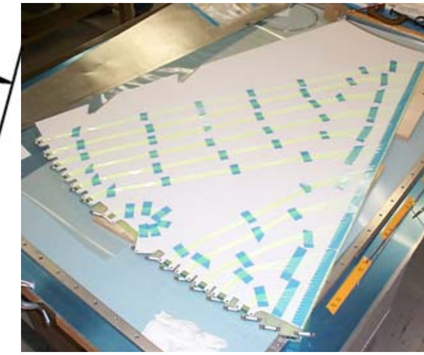


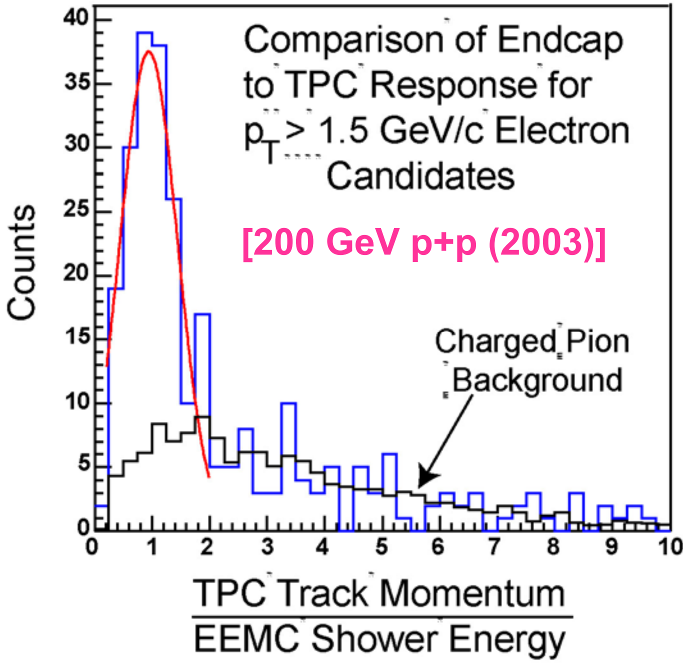
SMD profiles for a 9 GeV π^0 candidate

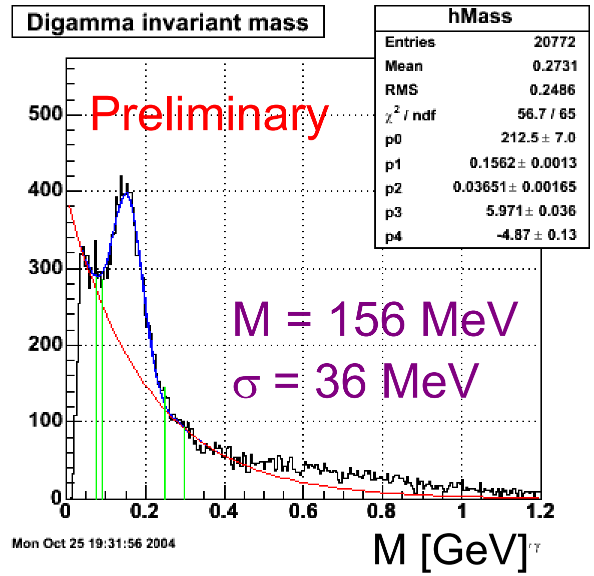
- Resolves closely spaced showers for $\pi - \gamma$ ID
- ~7000 individually read out scintillating strips
- U and V plane in each 30° sector
- Essentially no coverage gaps









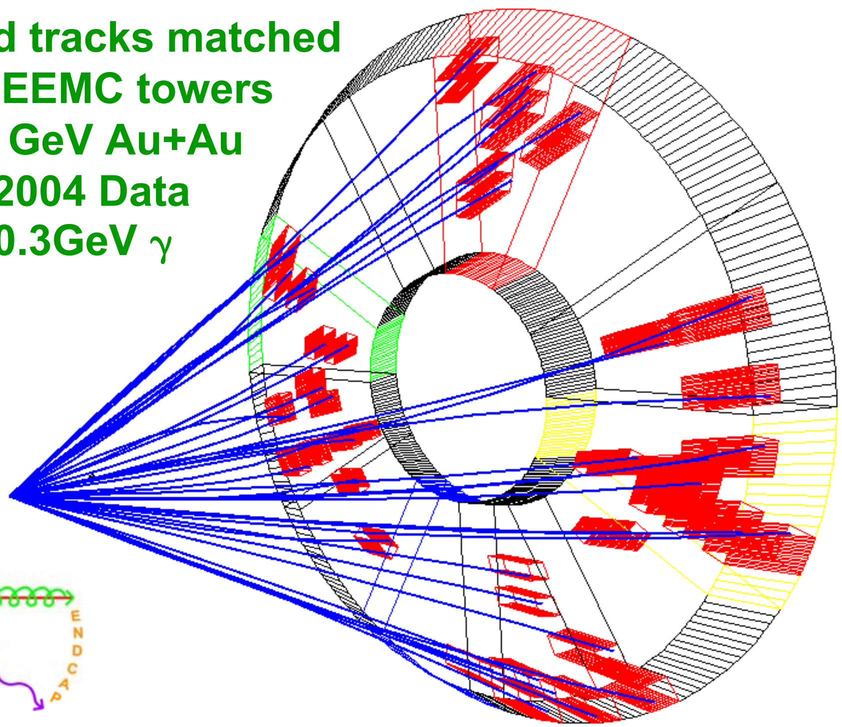


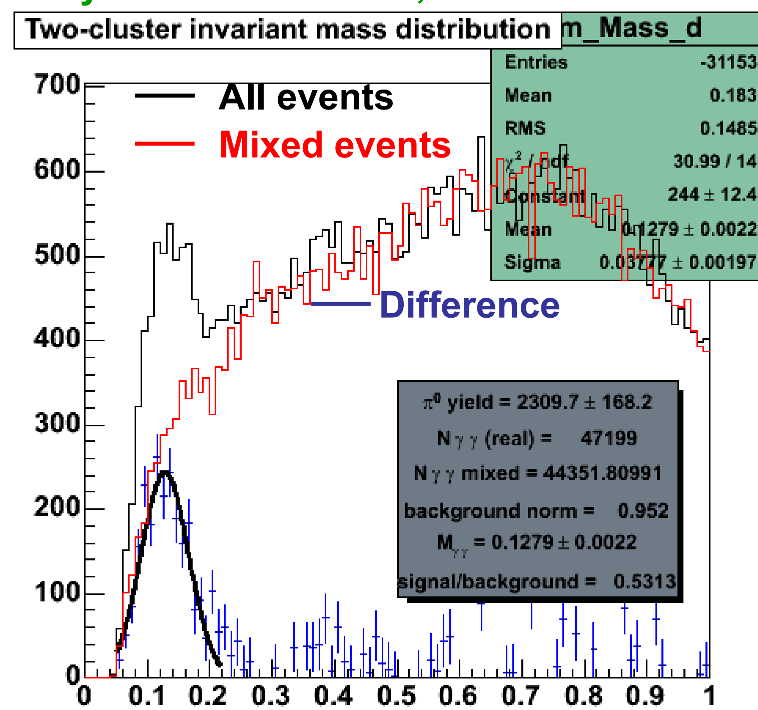
1st π^0 finder for pp 2004 production data

HT-low trigger
E_T > 1.92 GeV

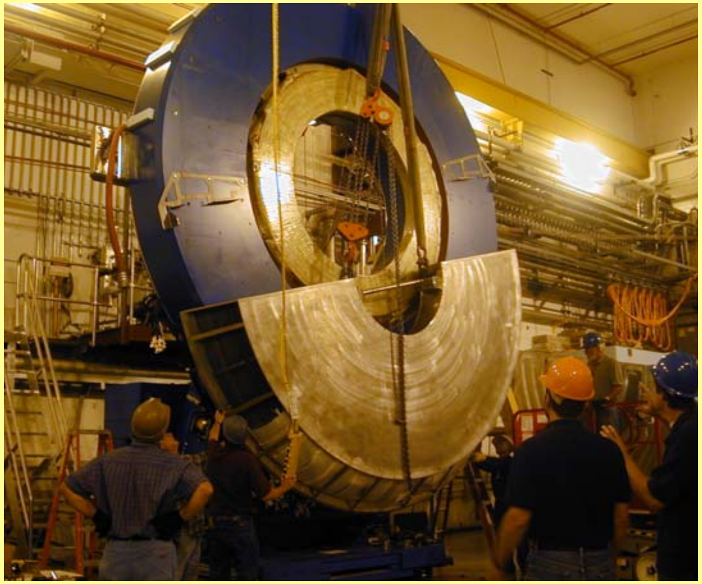
Online tower-only π^0 reconstruction, 200 GeV Au+Au

Charged tracks matched to fired EEMC towers for a 62 GeV Au+Au event. 2004 Data MIPs ~ 0.3GeV γ



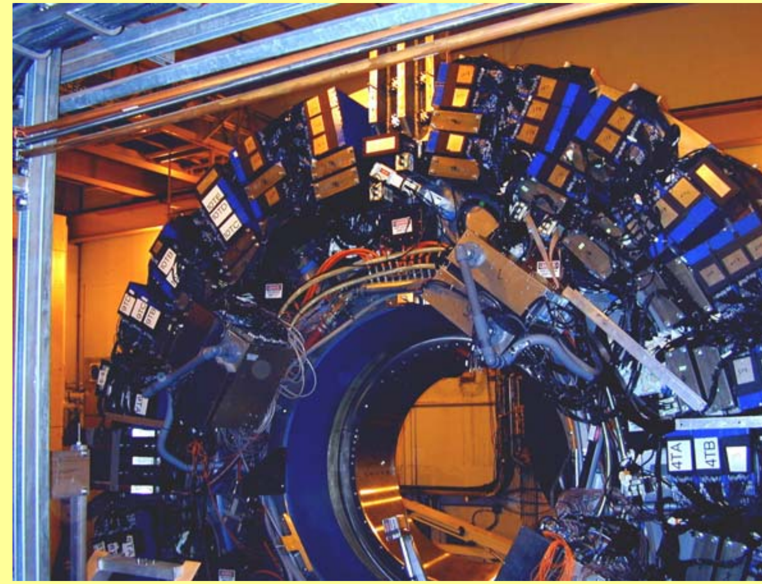


STAR ENDCAP



Lifting lower ½ into place

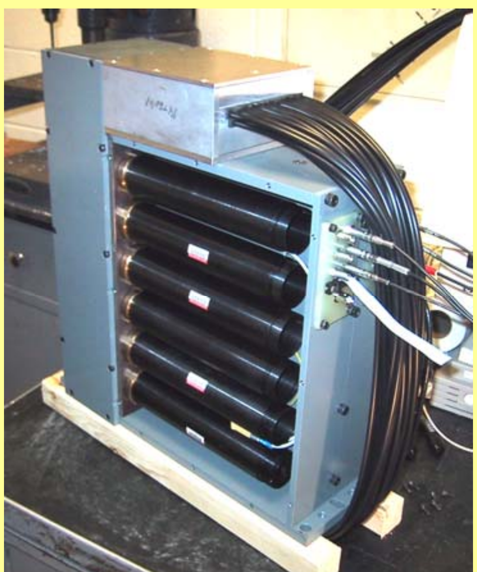
PMTs on back of poletip



Scintillator megatile

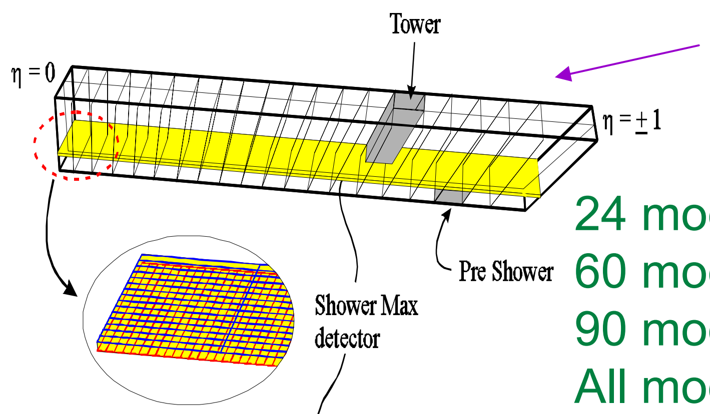
16 ch MAPMT and miniturized electronics

Internal Fiber Harness



PMT Box

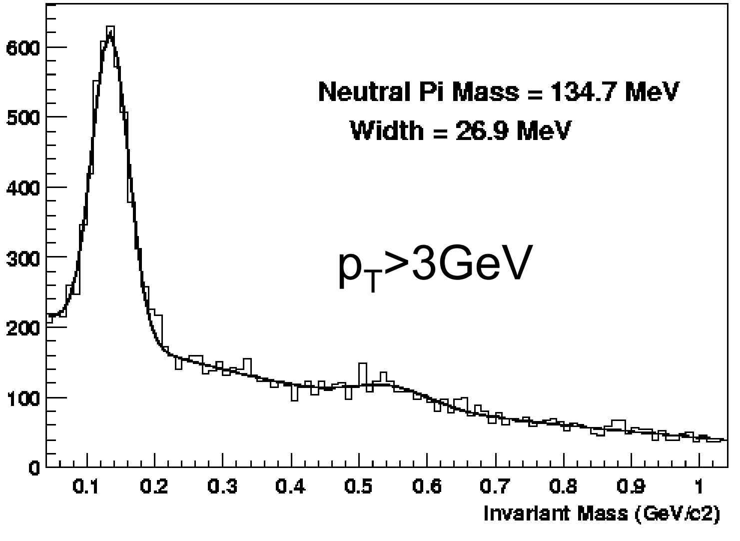
Barrel ElectroMagnetic Calorimeter

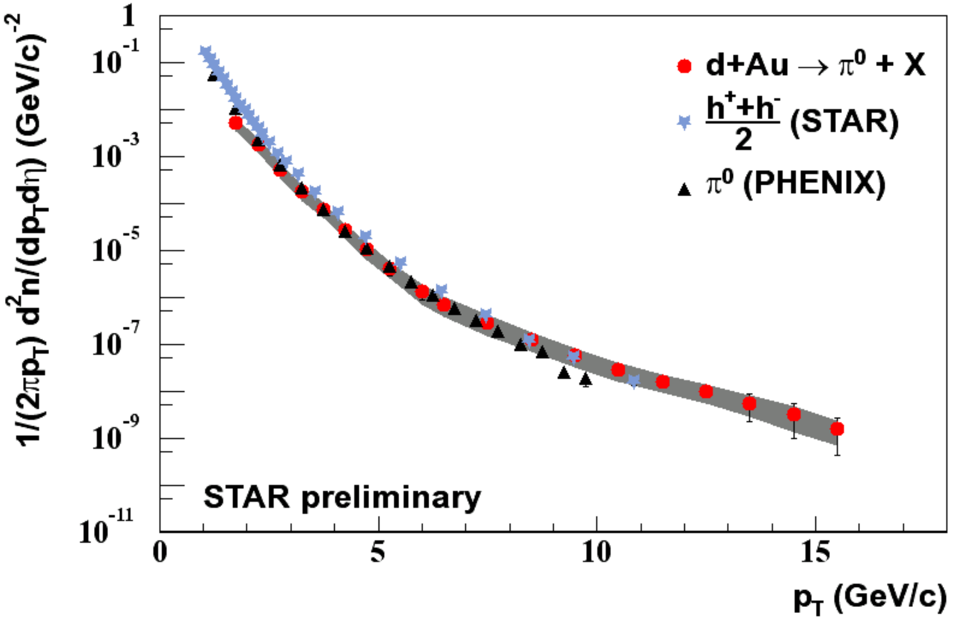


24 modules FY02
60 modules FY03
90 modules FY04
All modules (plan all elect.)FY05

Scinti. + Pb sandwich sampling EMC

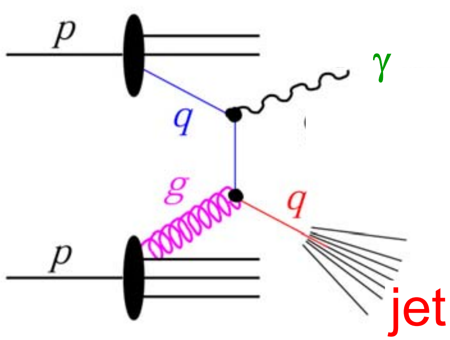
- 4800 projective towers (2π, -1<η <1)
- Shower Max Detector-gas detector-18K strips
- Pre Shower Detector (first 2 layers)
- High tower trigger & 1x1 (η, φ) jet trigger





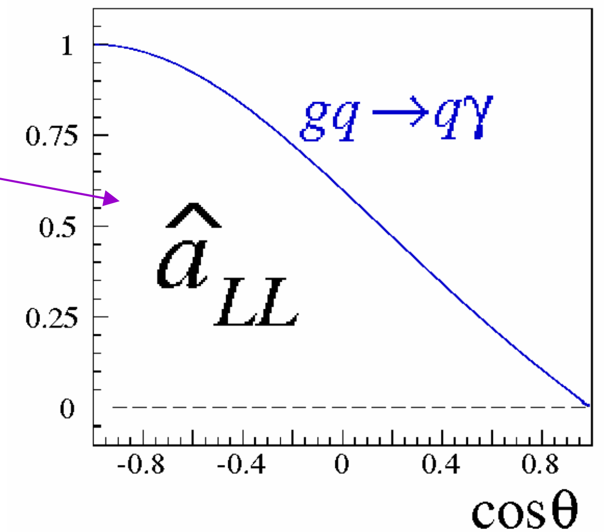
Quark – Gluon Compton Scattering

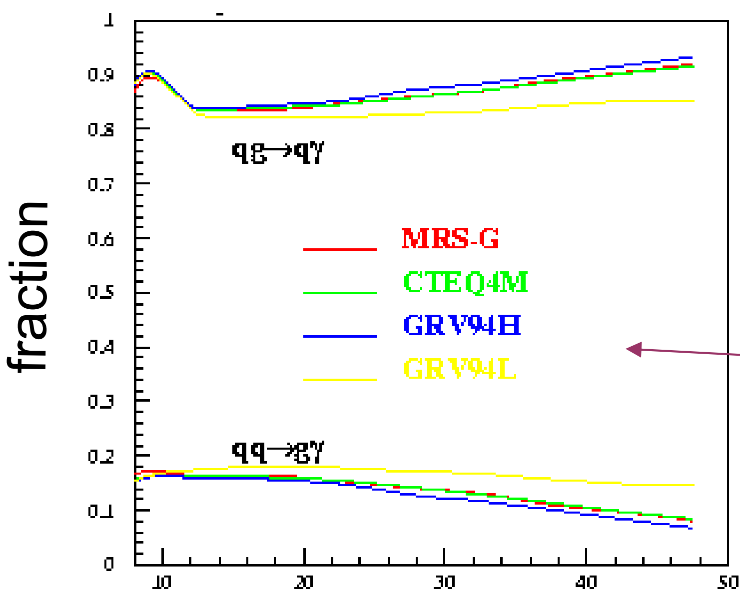
$\vec{p} + \vec{p} \longrightarrow$ Direct γ + Jet



Quark - Gluon Compton Scattering

Partonic $\hat{a}_{LL}$ is large for backscattering





Compton scattering dominates competing $q\bar{q} \rightarrow gg$ mechanism

Extracting ΔG from γ +Jet

Measure

$$A_{LL} = \frac{1}{P_{b1}} \frac{1}{P_{b2}} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}$$

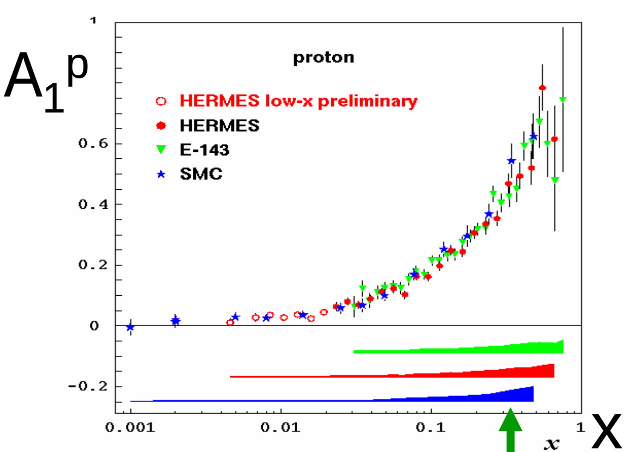
P_{b1}, P_{b2} Beam polarization 0.3-0.4 (0.7 in plan)

$N_{++\,(+-)}$ Yields for same vs. opposing beam helicity

R Ratio of luminosity for different beam helicities

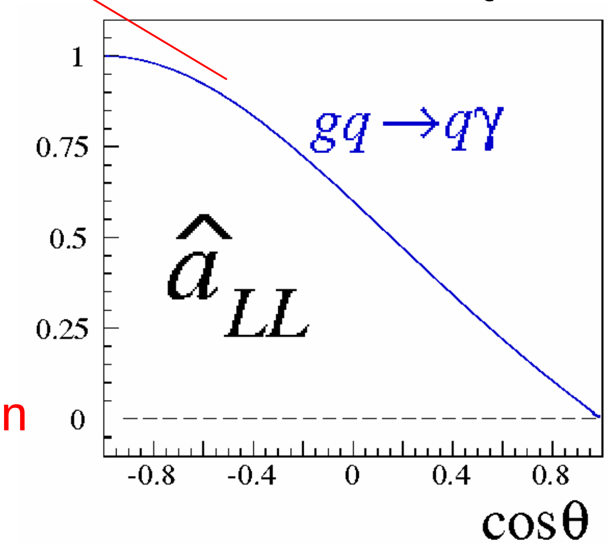
$$A_{LL} \approx \frac{\Delta g(x_1)}{g(x_1)} \otimes \frac{\sum_i e_i^2 \Delta q_i(x_2)}{\sum_i e_i^2 q_i(x_2)} \otimes \hat{a}_{LL}(gq \to q\gamma)$$

From QCD



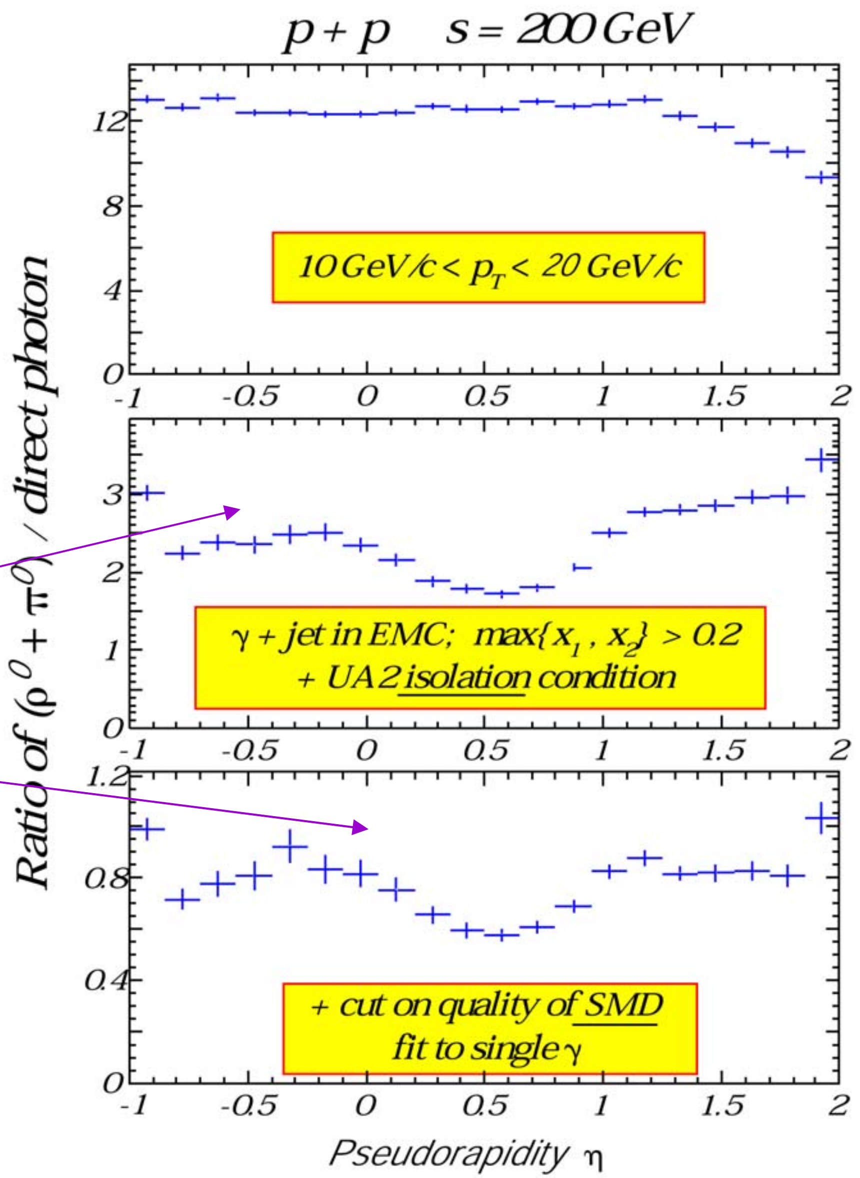
High x quark with high polarization

Exactly equal to A_1^p
as measured at pol. DIS
No Fragmentation function



STAR

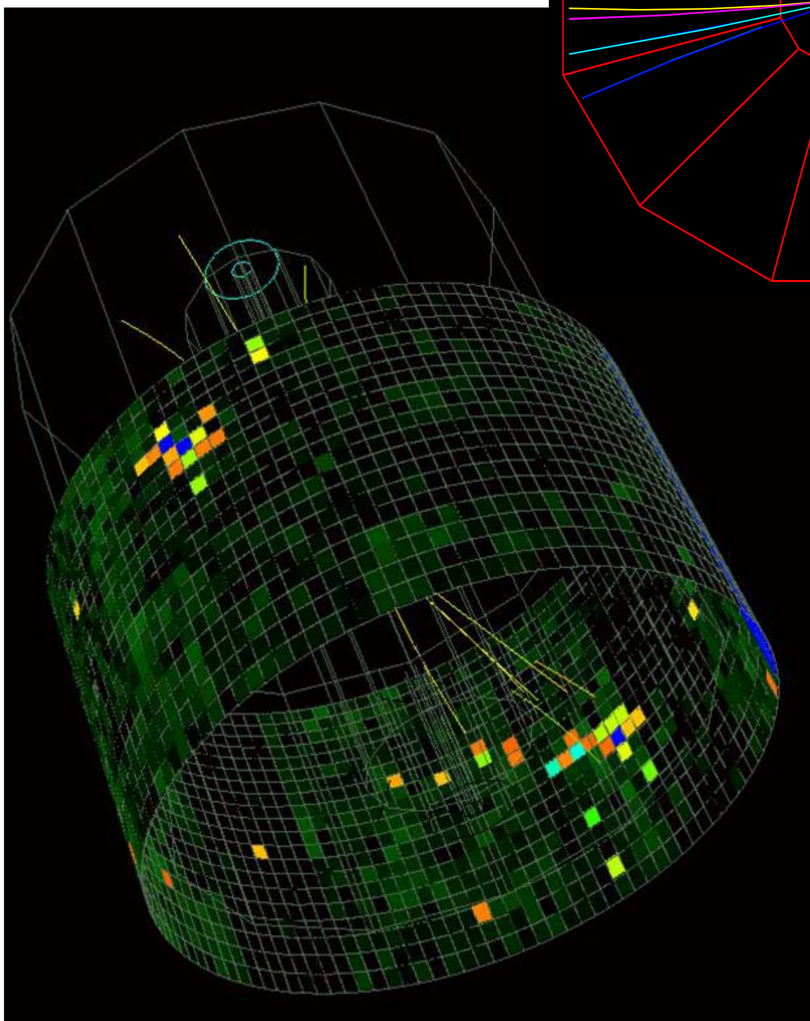
Separation of direct γs from π^0s

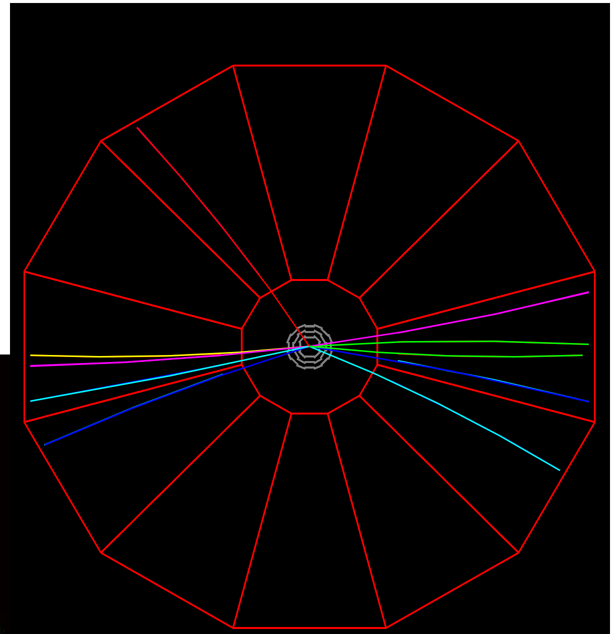


- Significant π^0 background
- Reduced to better than 1:1
  - Isolation cut
  - SMD particle ID
  - Preshower at higher energies
- Background subtraction of "π^0" sample from "γ" sample
- Increases errors on ΔG(x) by factor of 1.5-2.0

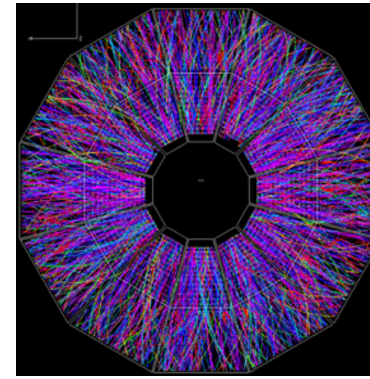
STAR

STAR sees p+p → dijets, real events



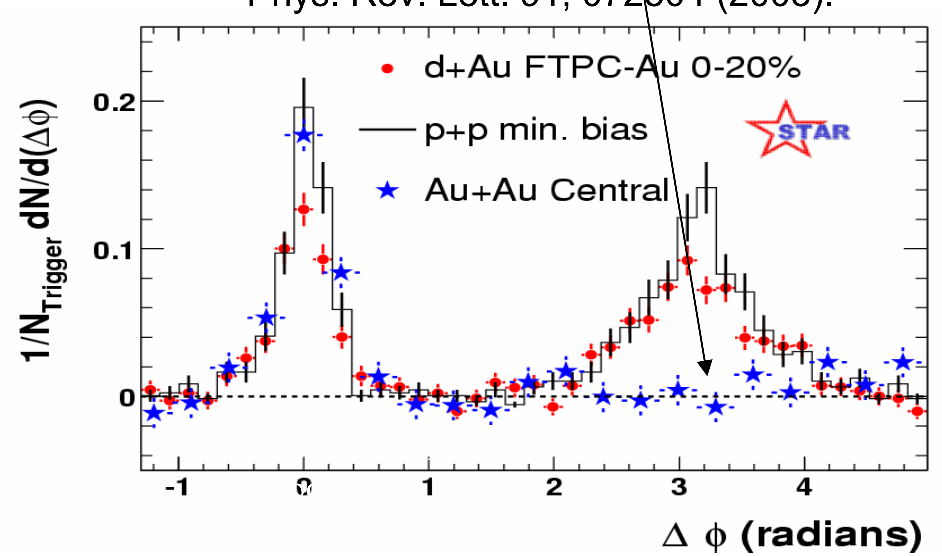


Jet finders are currently being tested on 2004 data



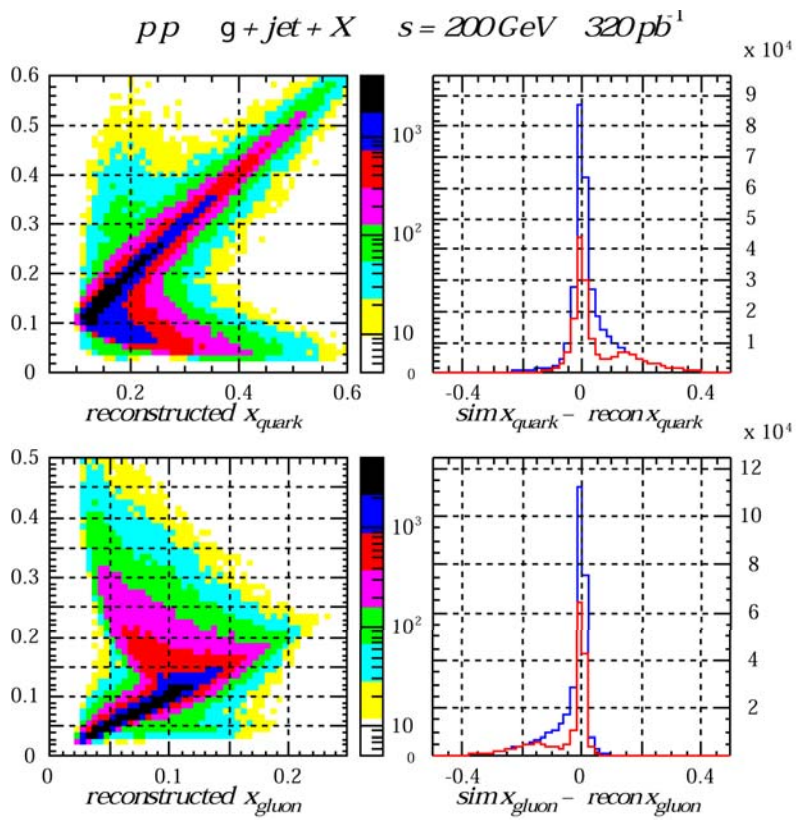
And the away-side jet in central Au-Au collisions disappears!

Phys. Rev. Lett. 91, 072304 (2003).



Kinematic Reconstruction

event by event

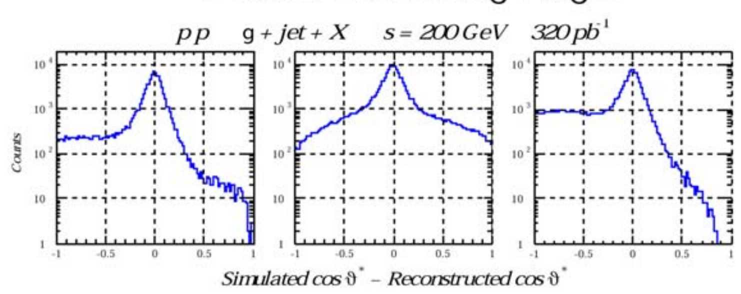


x quark

x gluon

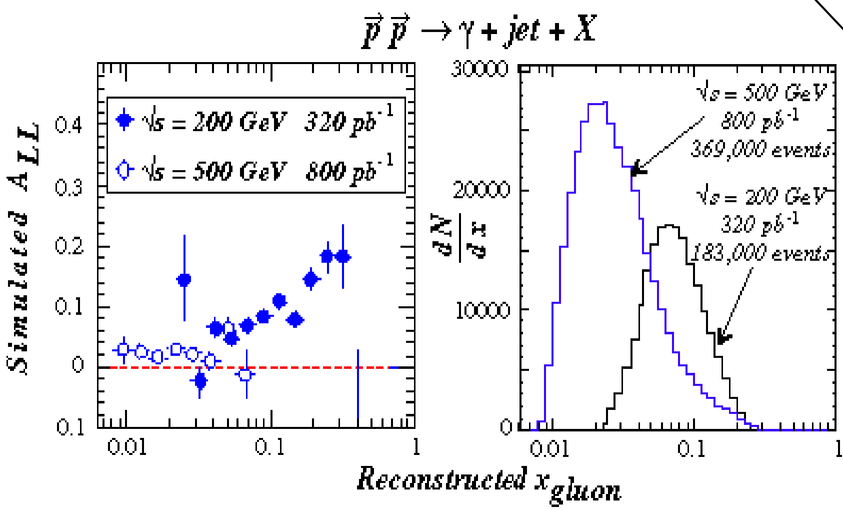
- Assume 2 body kinematics
- Neglect k_T
- Measure θ_{jet}, E_γ and θ_γ
- Extract x_1, x_2 and θ^*
- Assume larger of x_1 and x_2 = x_{quark}
- Assume lesser = x_{gluon}
- Make cut that one x > 0.2

Parton Scattering Angle

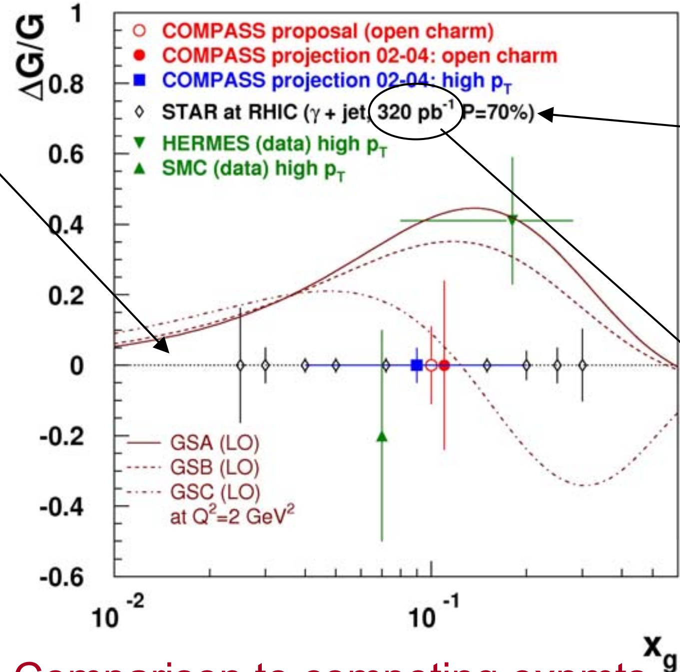


Expected ΔG Results –based on simulations

500 GeV data not in plot



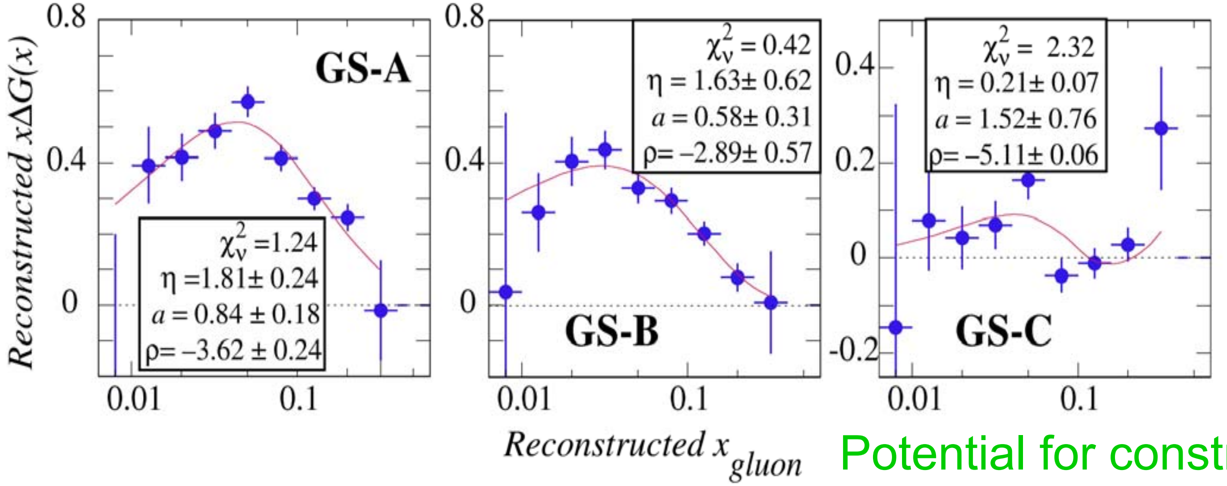
500 GeV important for low x



Comparison to competing expmts.

Eventually gives best determ. of Δg(x) for existing experiments.

But ℒ low in coming years



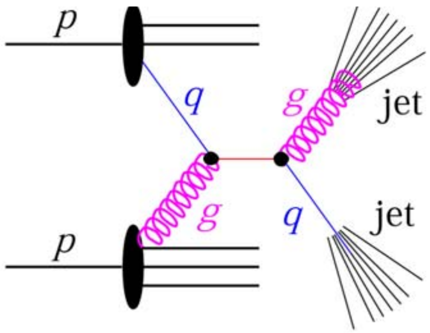
Fit integral of ΔG(x) determined to ±0.5

Potential for constraints on ΔG(x)

GS-A,B,C models of $x\Delta G(x)$ from Gehrmann and Stirling, PR **D53**, 6100 (1996).

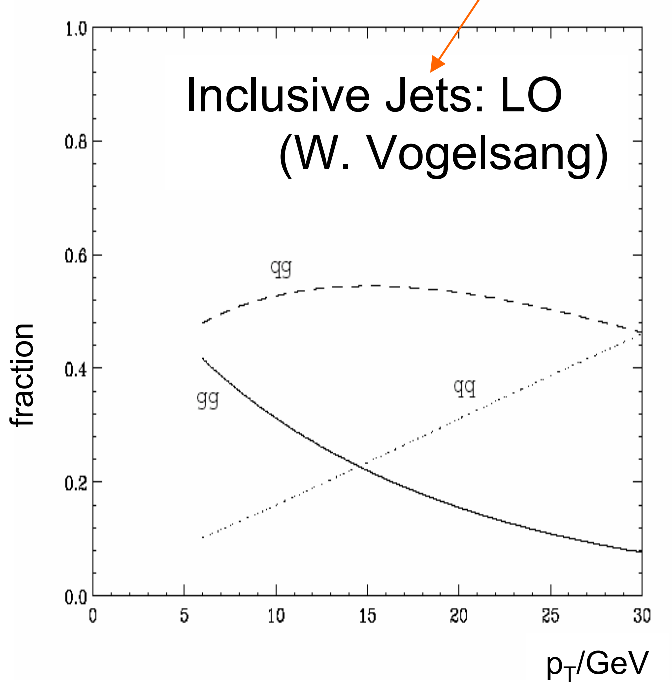
STAR

Inclusive jets are sensitive to ΔG



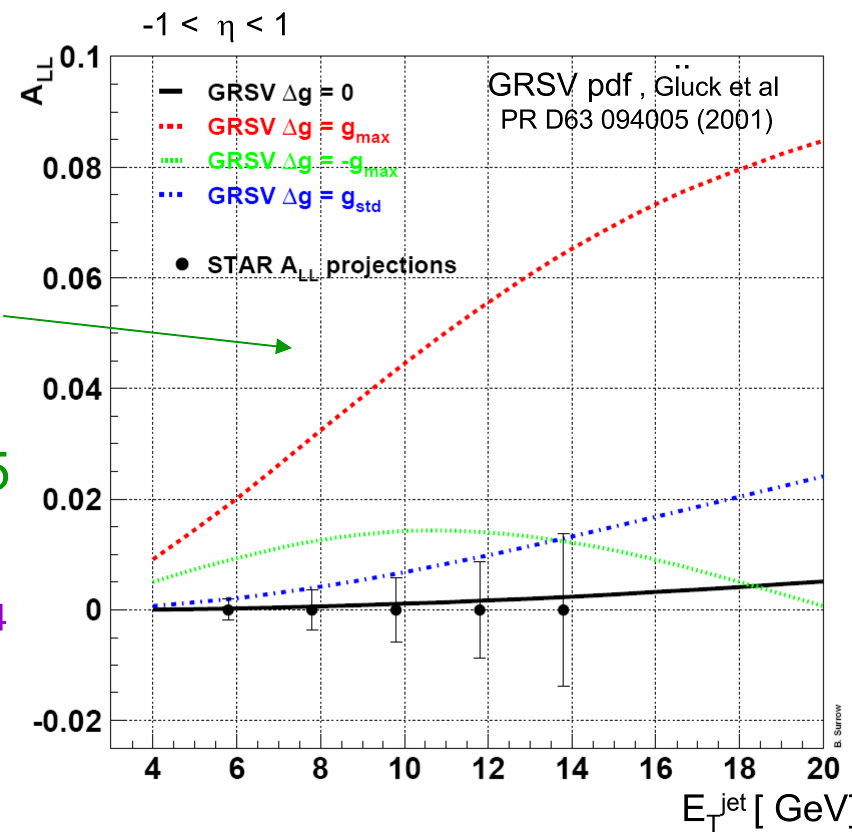
Quark - Gluon (also Gluon - Gluon) Elastic Scattering

But signal is mixture of multiple partonic subprocesses



Leads to small but significant A_{LL} in 2005

(~1/10 of these stats from 2004 currently being processed)

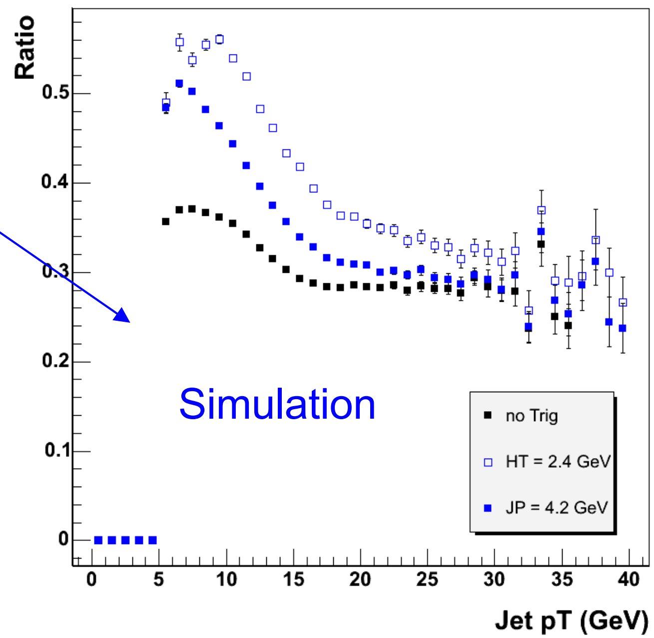


~1/3 of the jet energy is EM

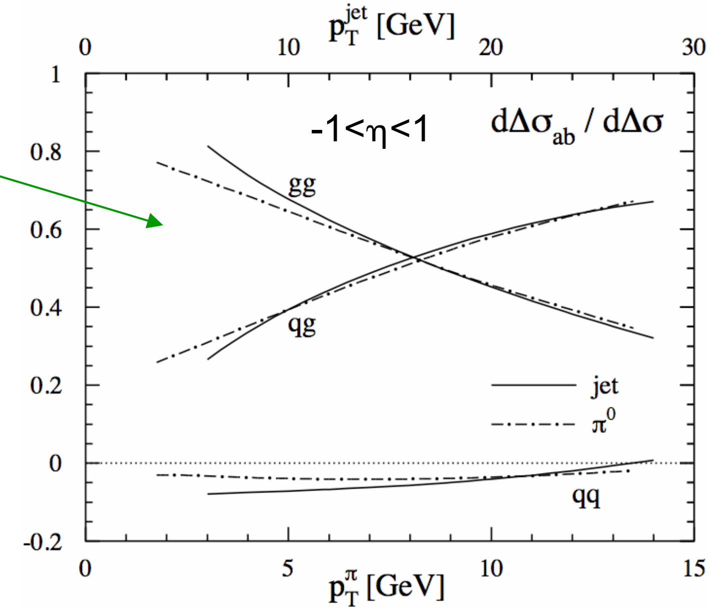
Use EM cals for triggering jets

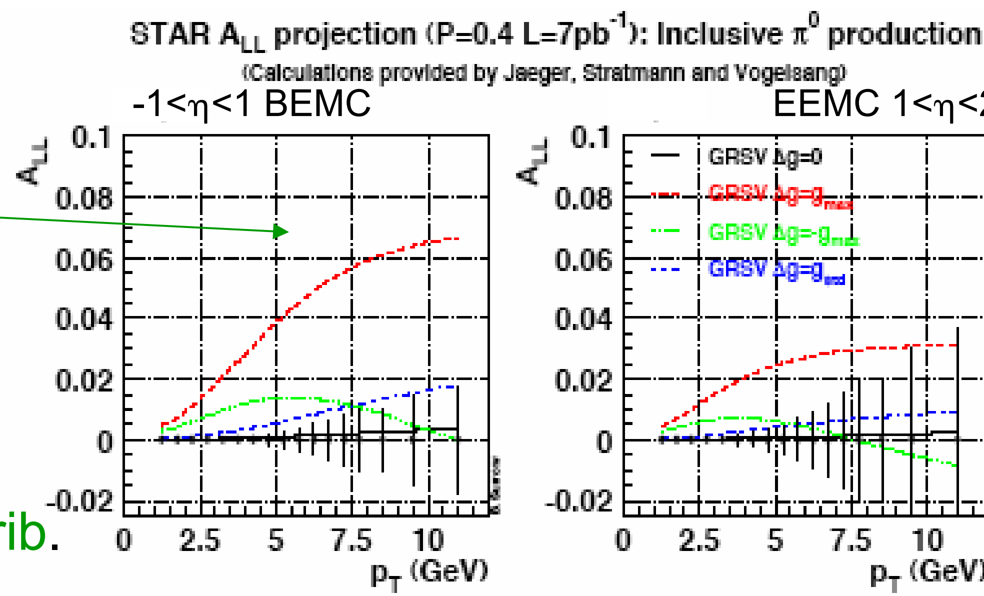
π^0s carry ~same physics

EmcE/JetE vs Jet pT (pT15)



Jager, Stratmann, Vogelsang NLO pQCD calculations
hep-ph/0404057



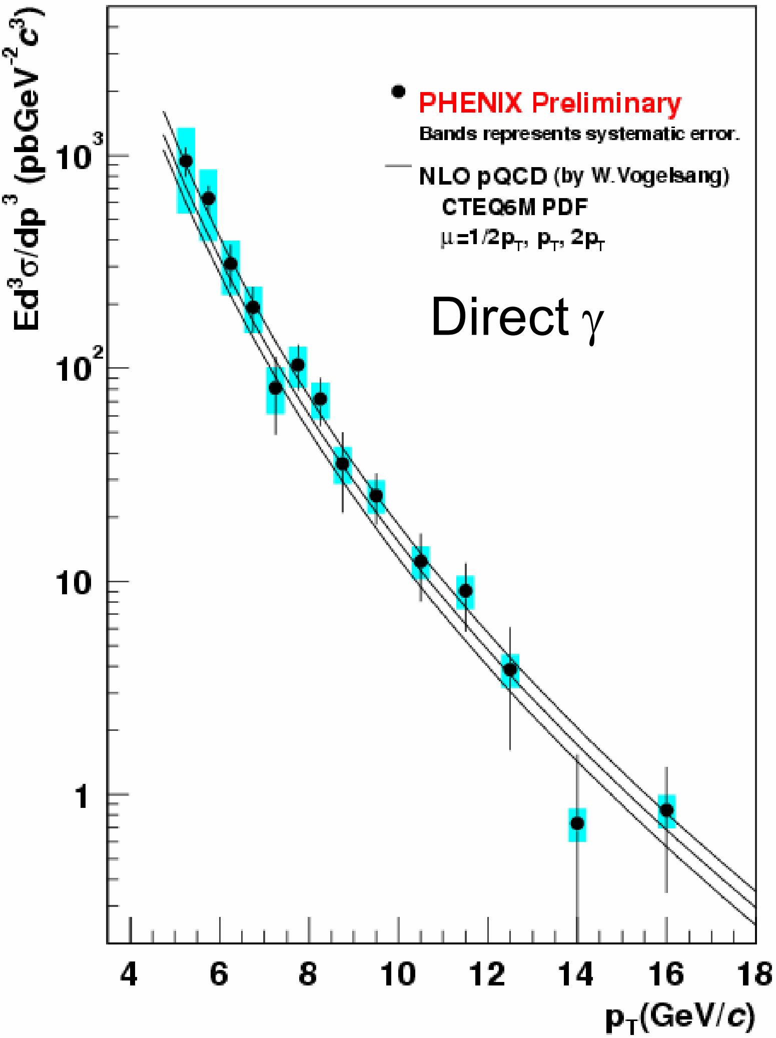


Significant const. on ΔG expected in 2005 data (~1/10 stats. from '04 being analyzed)

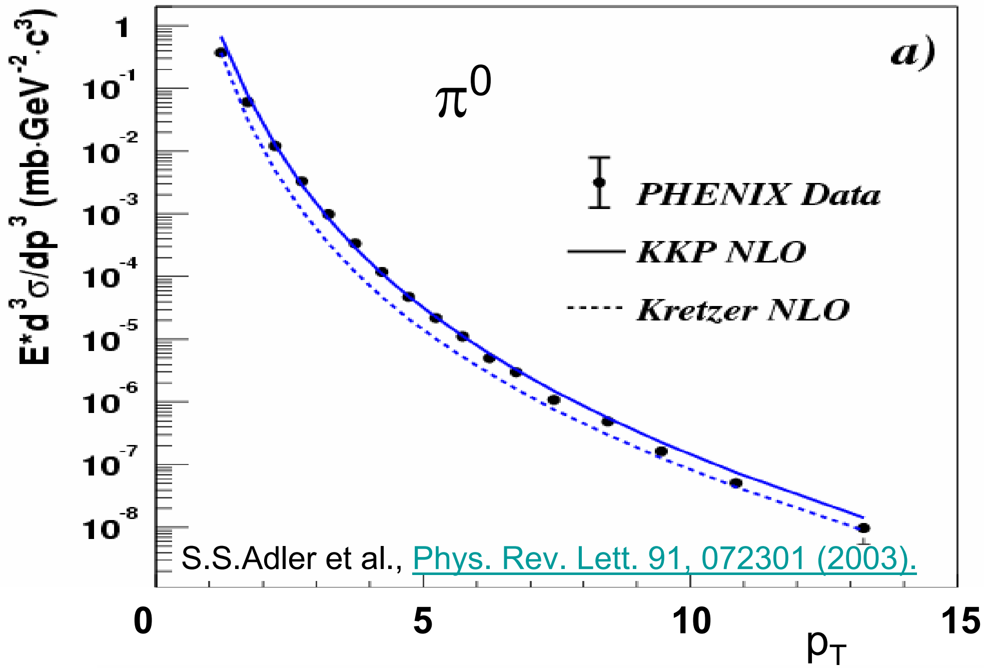
(error bar estimates too small p_T<6 GeV)

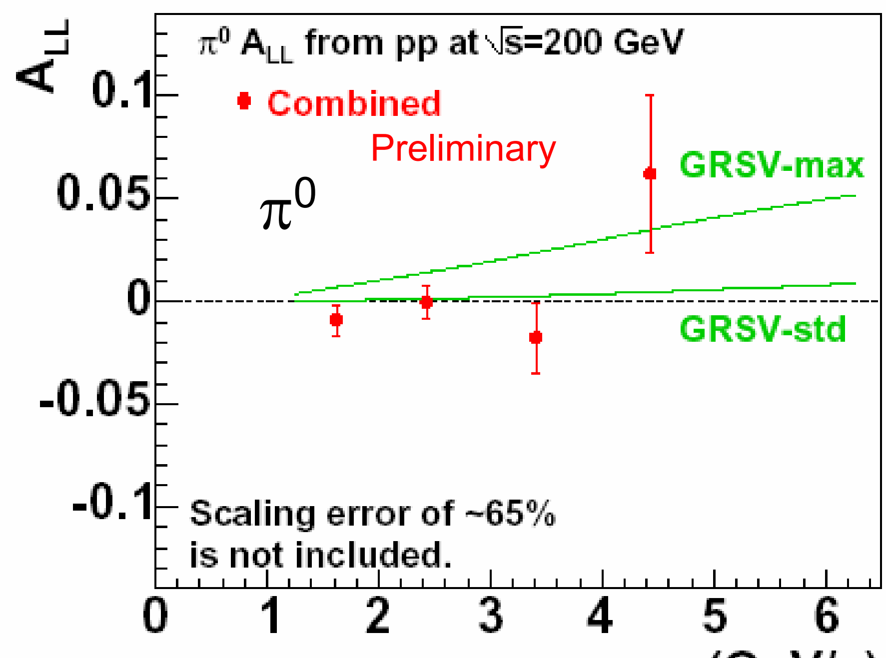
Signal changes in EEMC due to different partonic subprocess contrib.

PHENIX First Results



K. Okada Spin 2004



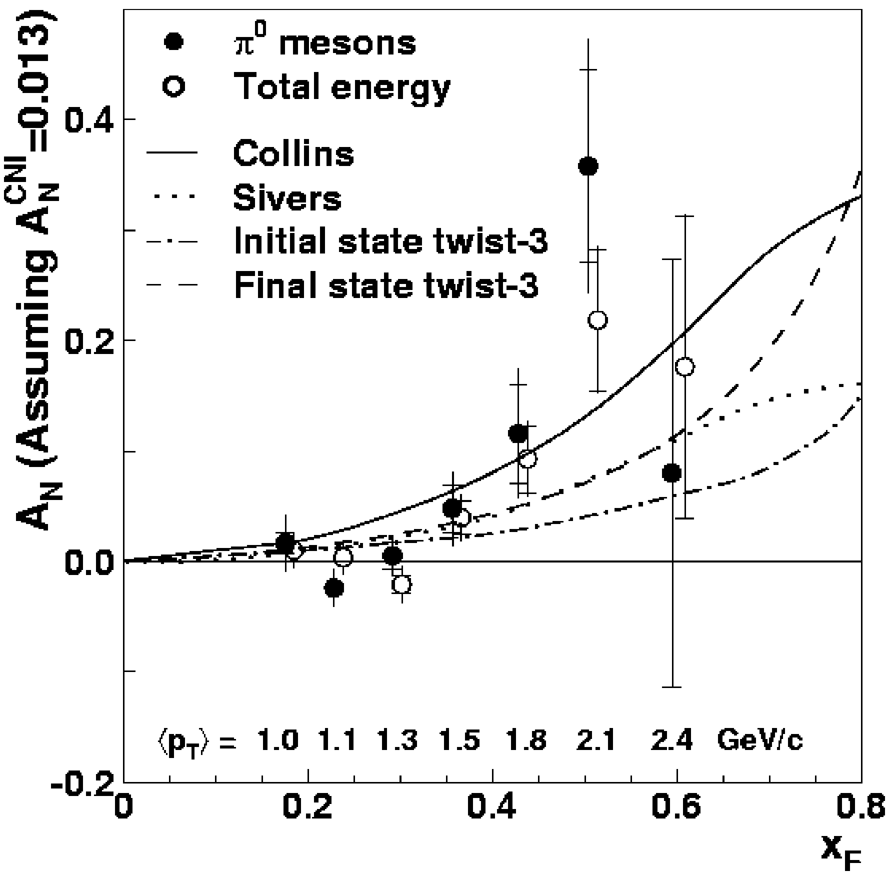


Y. Fukao Spin 2004

Large Analyzing Powers at RHIC

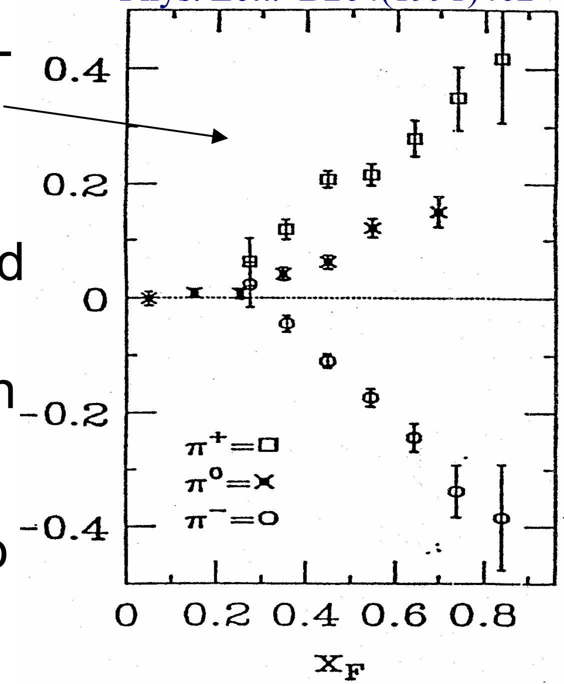
First measurement of A_N for forward π^0 production at $\sqrt{s}$=200GeV

STAR collab., PRL **92**, 171801 (2004); hep-ex/0310058.



Phys. Lett. B261(1991)201
Phys. Lett. B264(1991)462

Similar to FNAL E704 result at $\sqrt{s}$ = 20 GeV



E704 motivated studies of transverse spin effects

Now applied to STAR results

- Sivers: spin and k_T correlation in initial state (related to orbital angular momentum?)
- Collins: Transversity distribution function & spin-dependent fragmentation function
- Qiu and Sterman (initial-state) / Koike (final-state) twist-3 pQCD calculations

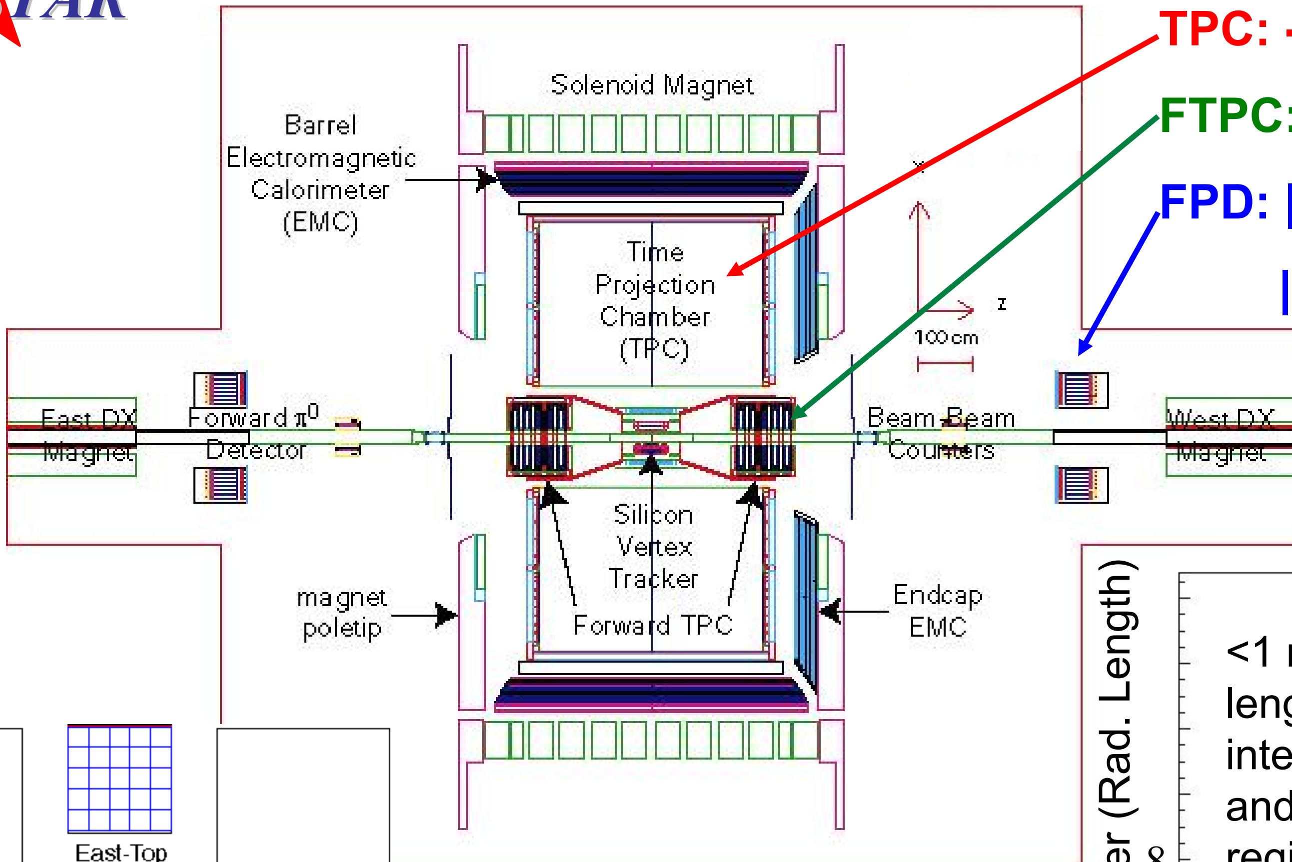
STAR Detector

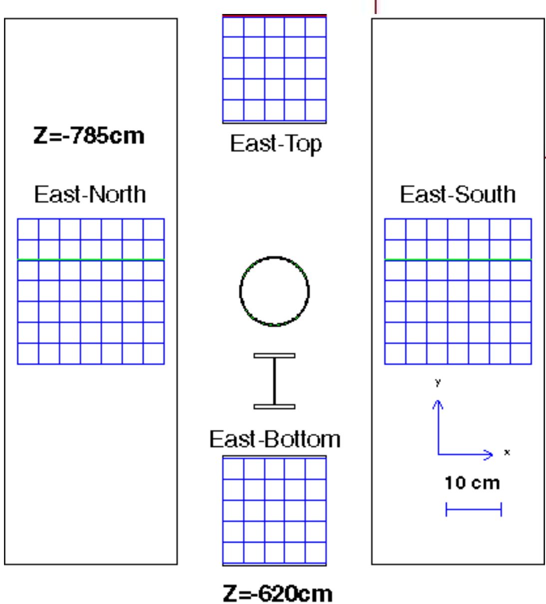
TPC: $-1.0 < \eta < 1.0$

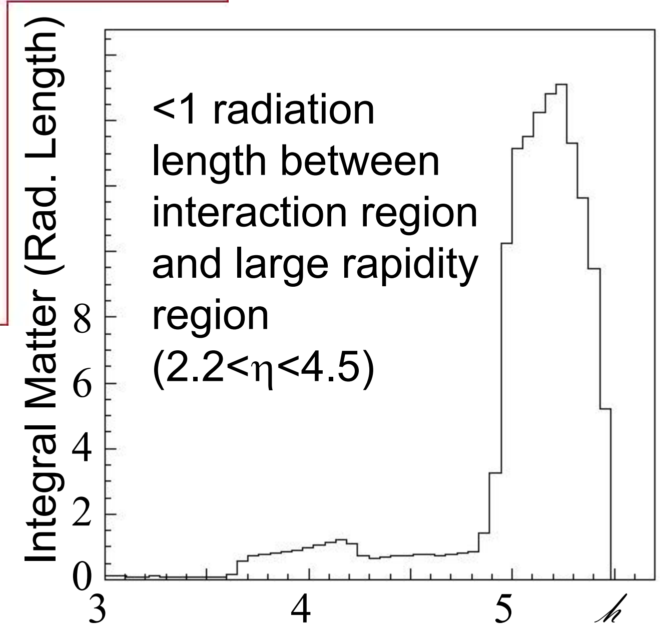
FTPC: $2.8 < |\eta| < 3.8$

FPD: $|\eta| \sim 3.8$ (p+p)

$|\eta| \sim 4.0$ (p+p, d+Au)



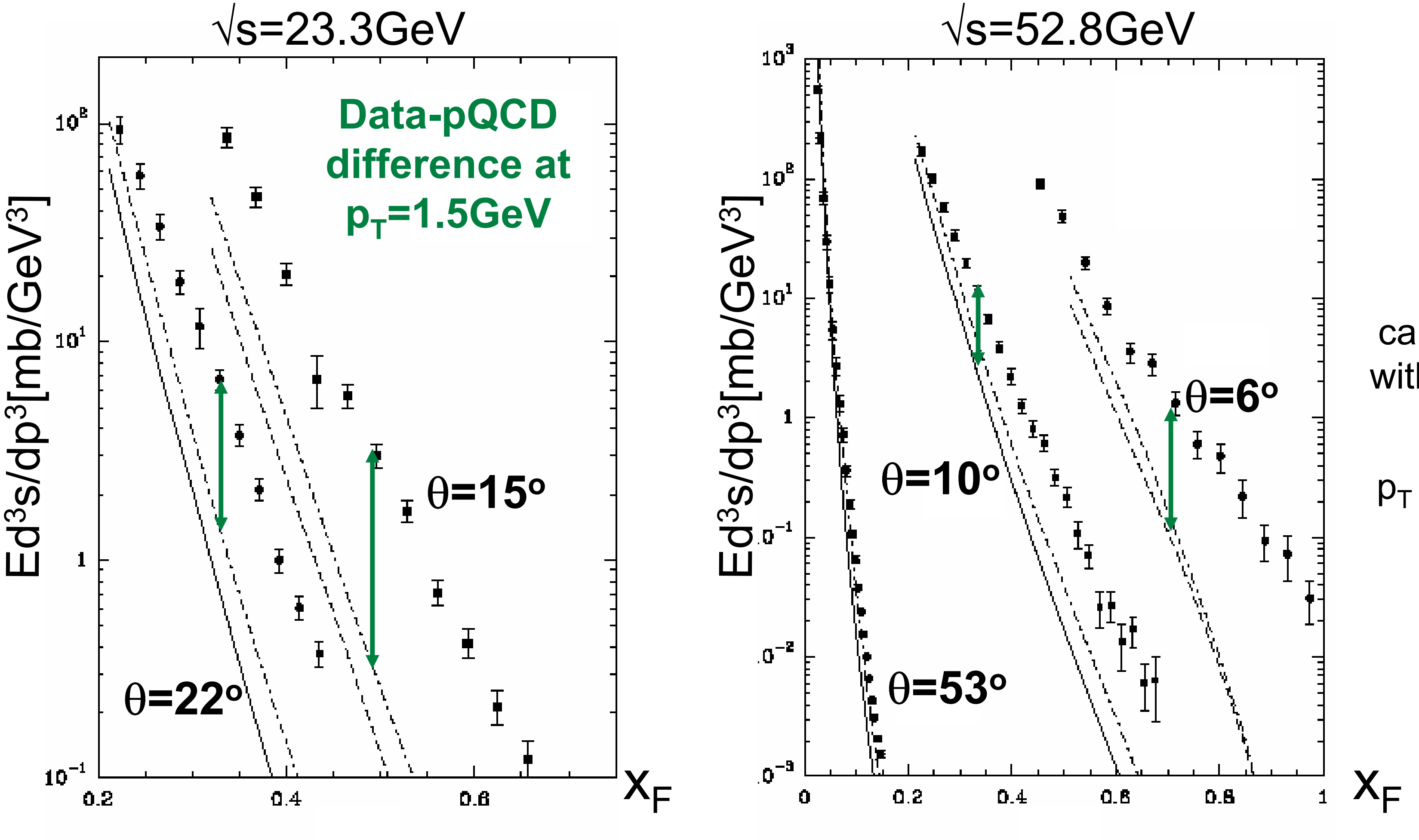




Forward π^0 Detector (FPD)

- **Pb-glass EM calorimeter**
- **Shower-Maximum Detector (SMD)**
- **Preshower**

Do we understand forward π^0 production in p + p?



2 NLO calculations with different scale:

p_T and $p_T/2$

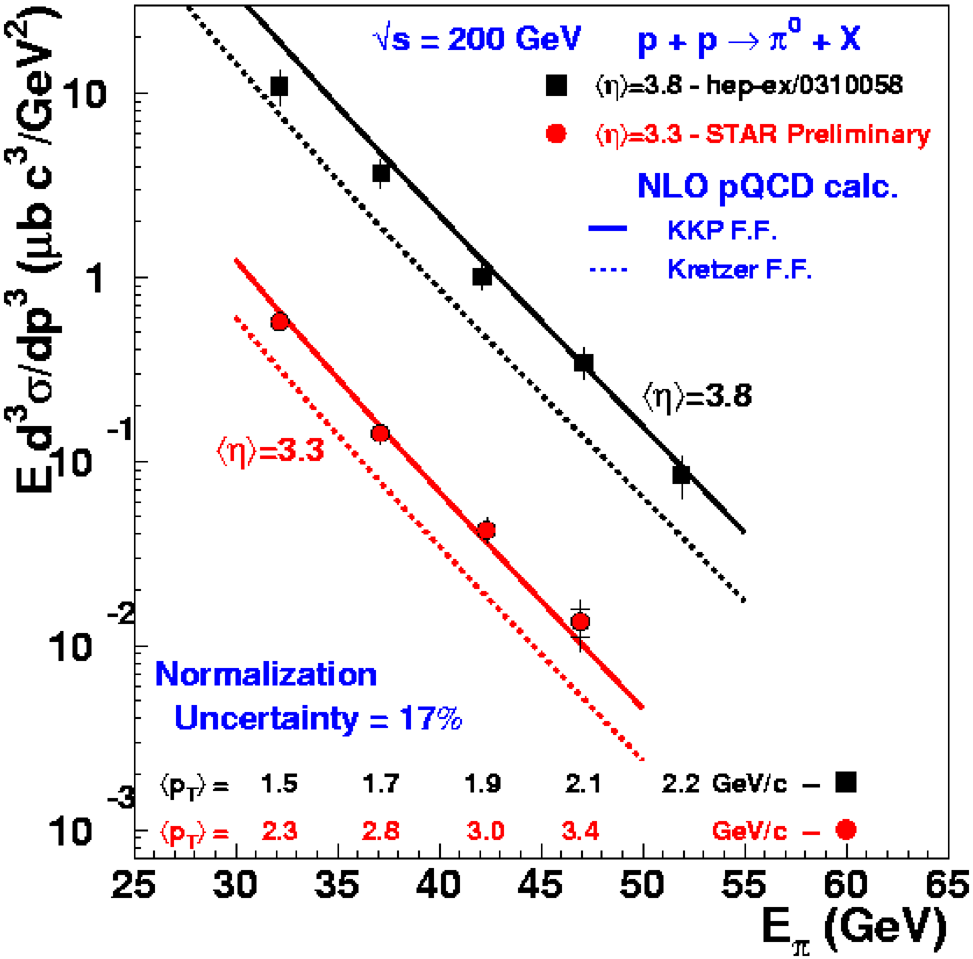
Bourelly and Soffer (hep-ph/0311110):

NLO pQCD calculations underpredict the data at low √s from ISR

s_{data}/s_{pQCD} appears to be function of θ, √s in addition to p_T

Do these pQCD processes apply to forward scattering at √s=200GeV ?

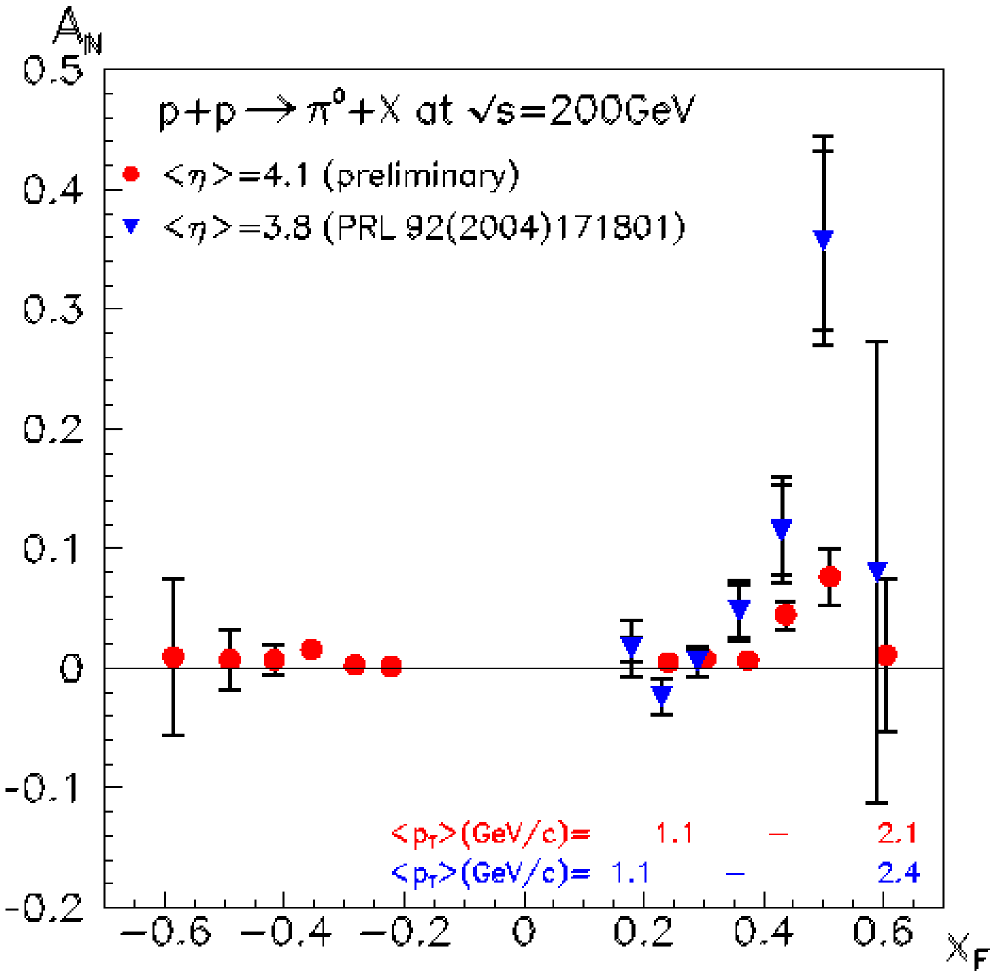
Forward production at √s << 200 GeV not well described by fixed-order pQCD calculations (Bourelly and Soffer, hep-ph/0311110)



- Run-2 STAR data at
  - <η>= 3.8 (PRL **92**, 171801 (2004); hep-ex/0310058)
  - <η>= 3.3 (hep-ex/0403012, Preliminary)
- NLO pQCD calculations (Vogelsang) at fixed □ with equal factorization and renormalization scales = p_T

→ **STAR data consistent with Next-to-Leading Order pQCD calculations, unlike at smaller √s**

New STAR Data



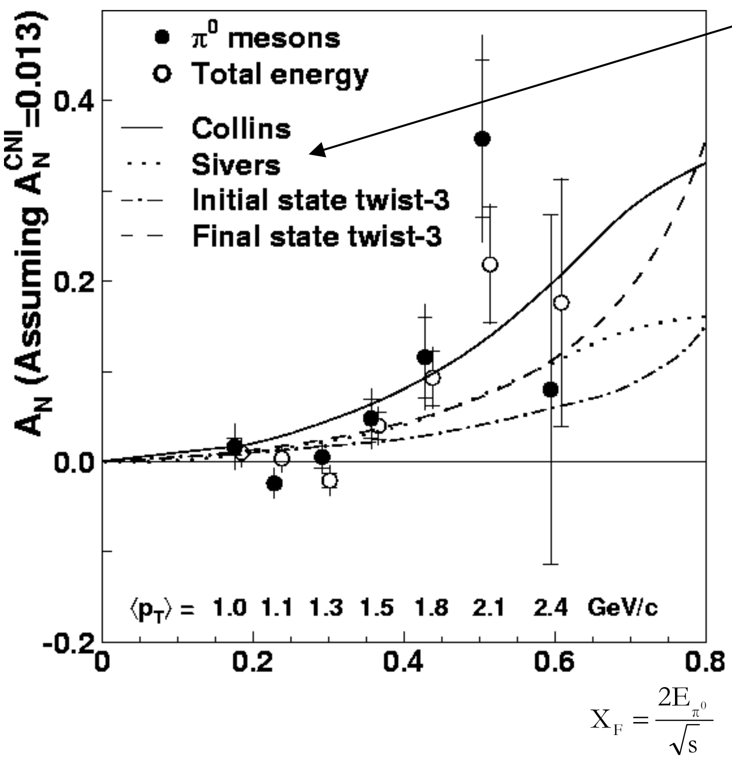
- Confirms previous results
- Rapid η dependence
- Small A_N at negative x_F

Released at Spin 2004
A. Ogawa

Analyzing Powers at Mid-Rapidity

Do processes invoked in forward scattering show up at large angles?

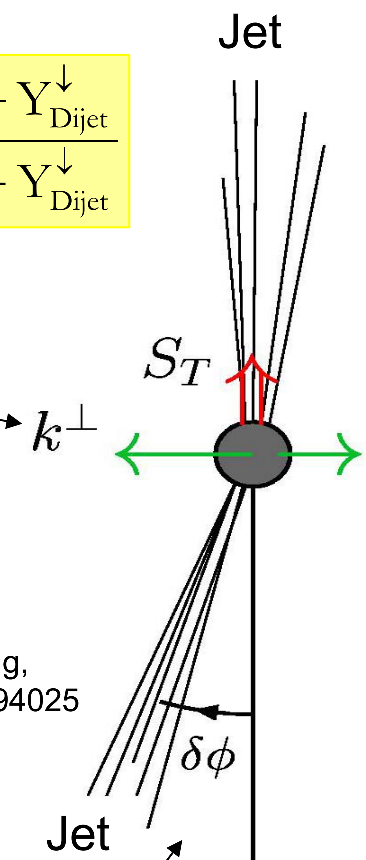
STAR Collab. Phys. Rev. Lett. **92** (2004) 171801



Measure

$$A_N = \frac{1}{Pol}\,\frac{Y^{\uparrow}_{Dijet} - Y^{\downarrow}_{Dijet}}{Y^{\uparrow}_{Dijet} + Y^{\downarrow}_{Dijet}}$$

For given parton at some x $k_T^L \neq k_T^R$

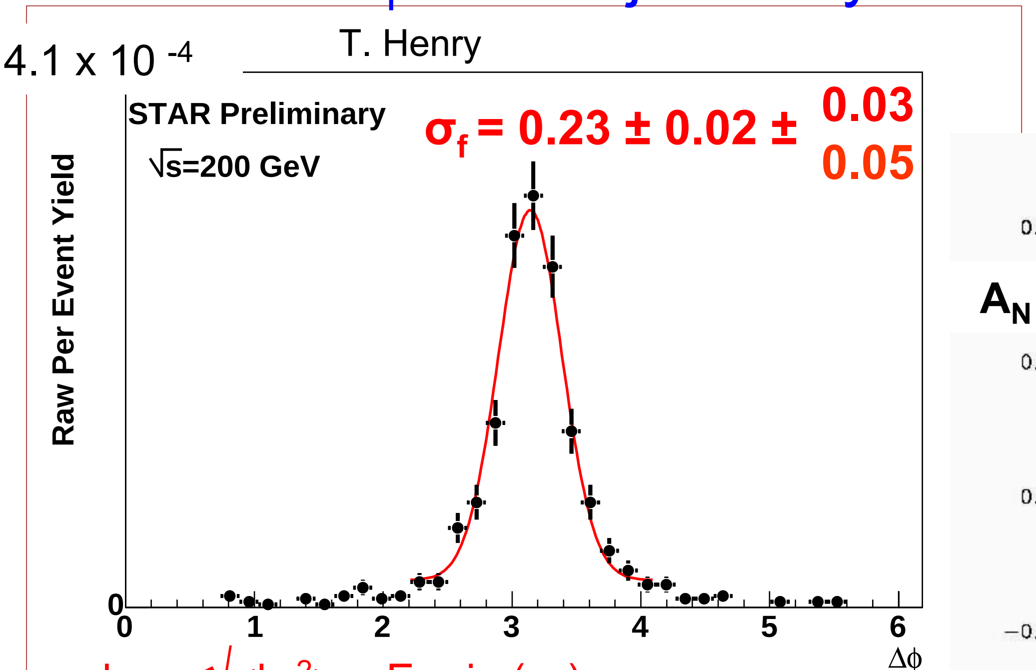


D. Boer and W. Vogelsang, Phys.Rev. D **69** (2004) 094025

Sivers Function – correlation between k_T and spin

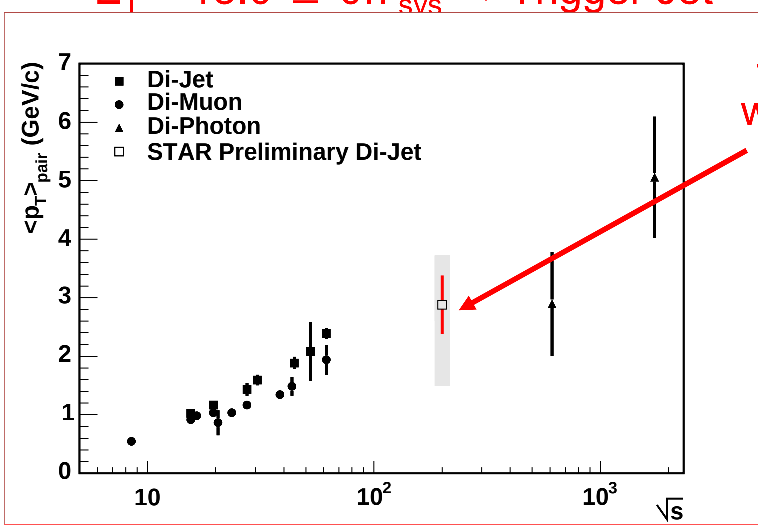
$$f_q(x,k^{\perp},s_P) = f_q(x,k^{\perp}) + \frac{1}{2}\Delta_q^N f_q(x,k^{\perp})\frac{S_P\cdot(P_p\times k^{\perp})}{|S_P||P_P||k^{\perp}|}$$

Partonic k_T from Dijet Analysis



$k_T = \sqrt{\langle k_T^2 \rangle} = E_T \sin(\sigma_\phi)$

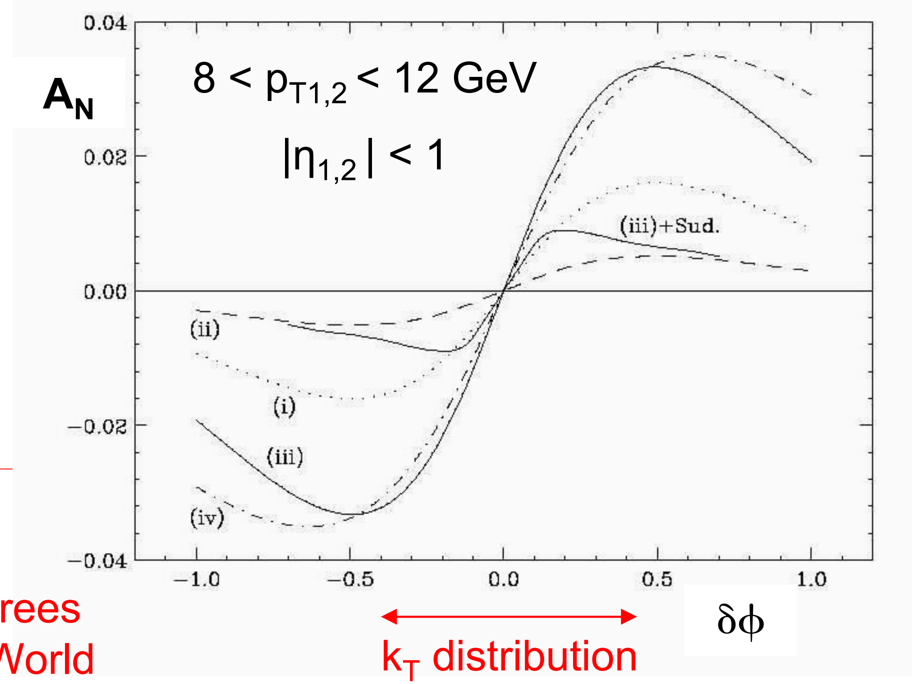
$E_T = 13.0 \pm 0.7_{sys} \rightarrow$ Trigger Jet



STAR agrees well with World Data on Partonic k_T

Sivers Effect Prediction

D. Boer and W. Vogelsang, Phys.Rev. D **69** (2004) 094025



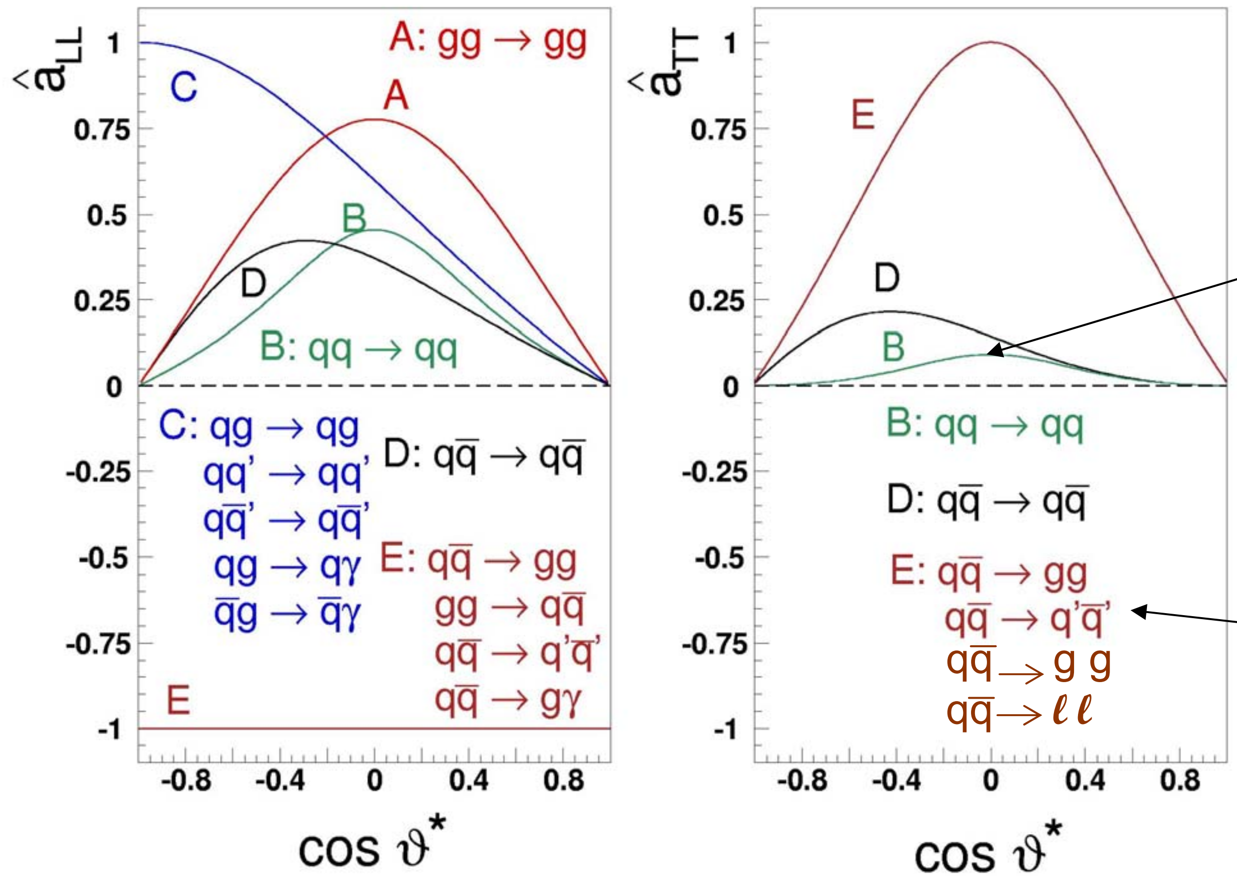
- Curves are for various gluonic Sivers functions
- Connection to partonic orbital angular momentum
- Suppressed by Sudakov effect

Transversity

$g_1^p = \frac{1}{2} \Sigma e_i^2 [\Delta q_i(x,Q^2) + \Delta \bar{q}_i(x,Q^2)]$ **Helicity or A_{LL}**

$h_1^p = \frac{1}{2} \Sigma e_i^2 [\delta q_i(x,Q^2) + \delta \bar{q}_i(x,Q^2)]$ **Transversity or A_{TT}**

- No relativistic effects → $\Delta q(x)=\delta q(x)$
- No gluon transversity → h_1 has different Q^2 evolution
- 1^{st} moment of h_1 = tensor charge → compare to lattice QCD



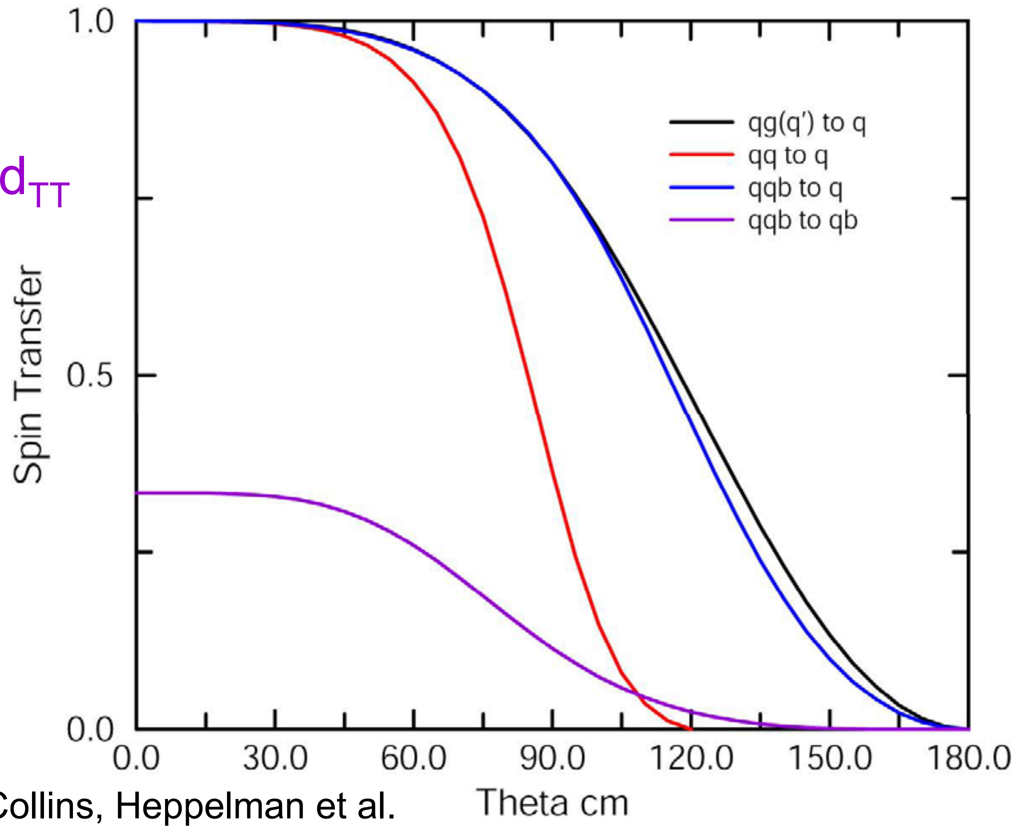
a_{TT} marginal ~90^0
Reasonable size A_{TT} for valence q but large p_T → high $\mathcal{L}$

Expect $\delta\bar{q}$ to be small
Determine in these channels if know δq
Dell-Yan in polarized $p\bar{p}$ collider.

Spin Transfer to Determine Transversity δq

The transverse polarization of quarks is preserved in scattering

d_{TT}



Collins, Heppelman et al.

Can we measure the polarization of scattered q?

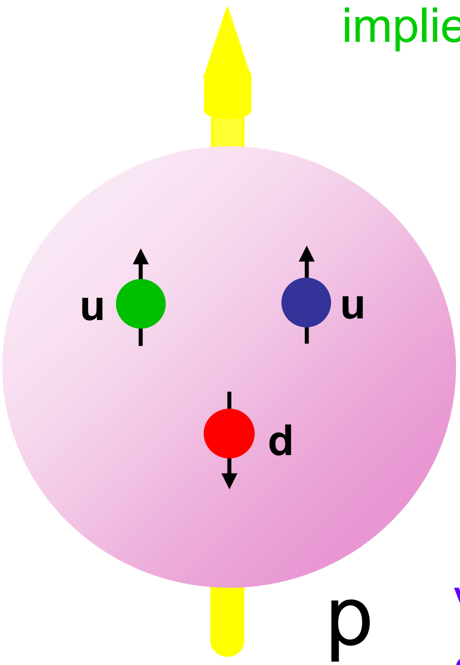
Fragmentation can be spin dependent!

- Collins functions
- Interference functions
- Leading hadron preference to one side of jet wrt $\vec{s} \times \vec{p}_{jet}$
- Preference for orientation of two leading hadrons wrt $\vec{s} \times \vec{p}_{jet}$

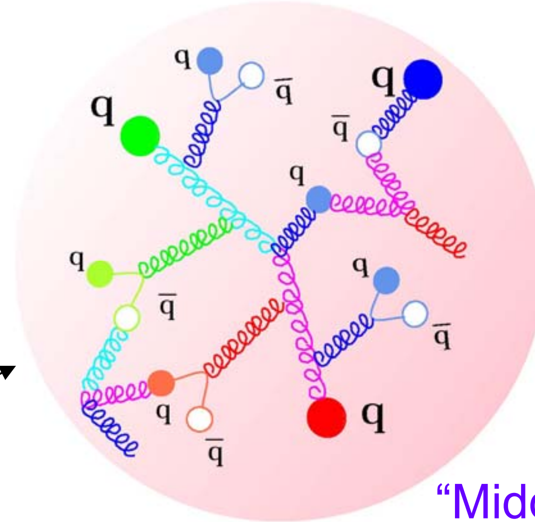
Measured jet asymmetry = $\delta q \times d_{TT} \times \varepsilon(z)$

Can be determined in e^+/e^-. Experiment from Belle being analyzed

How is the Sea Generated?

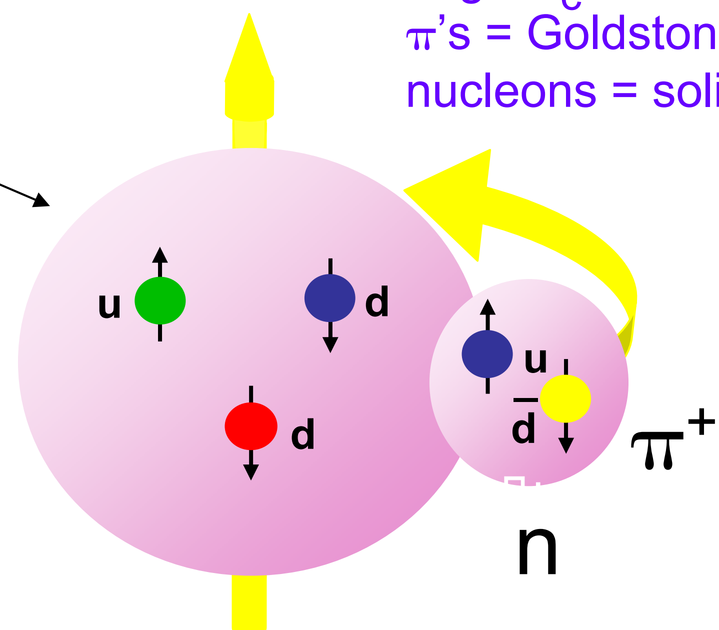


Perturbative picture implies that $\bar{u}(x) \sim \bar{d}(x)$



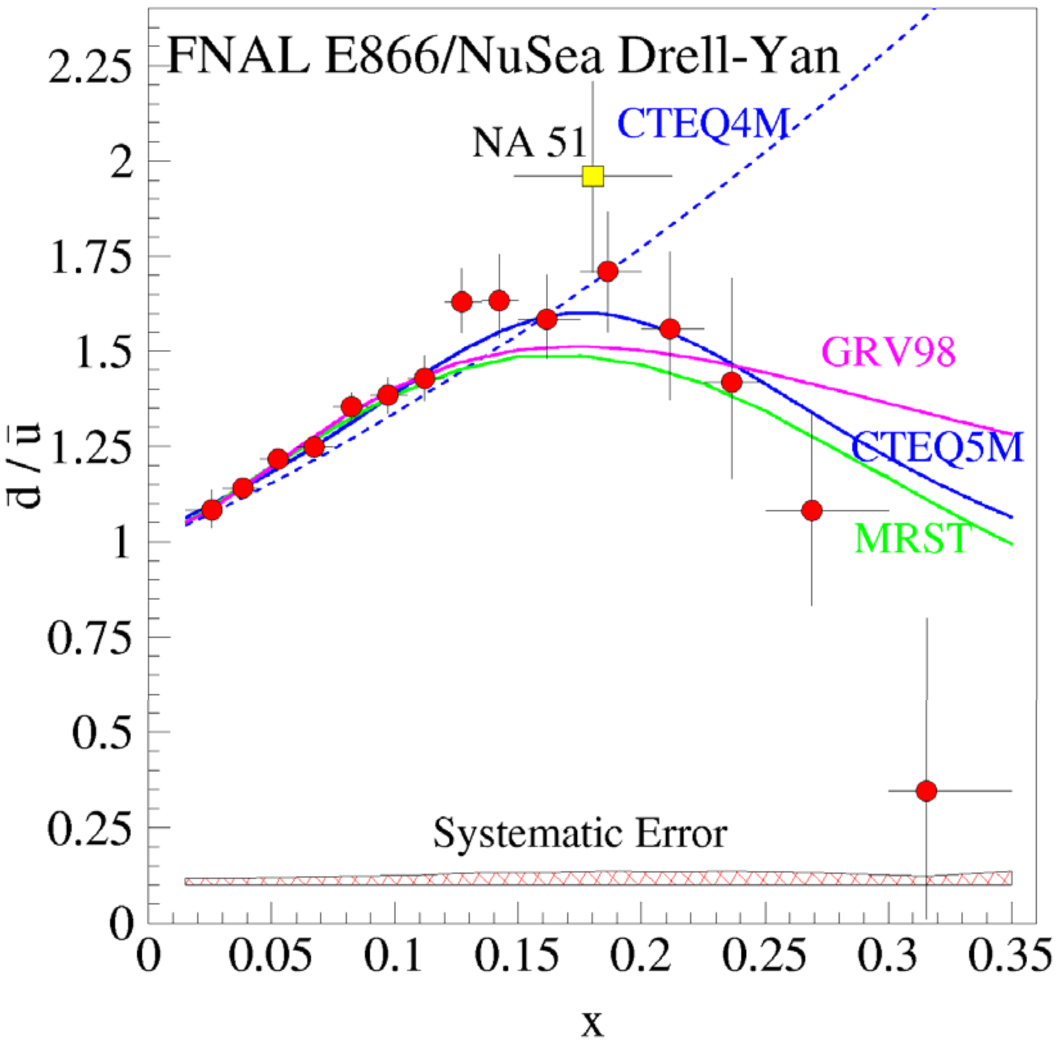
"Middle Ground"
chiral symmetry +
large N_c models
π's = Goldstone bosons
nucleons = solitons

Virtual π's imply an excess of $\bar{d}$ over $\bar{u}$



Until the 1st Measurements

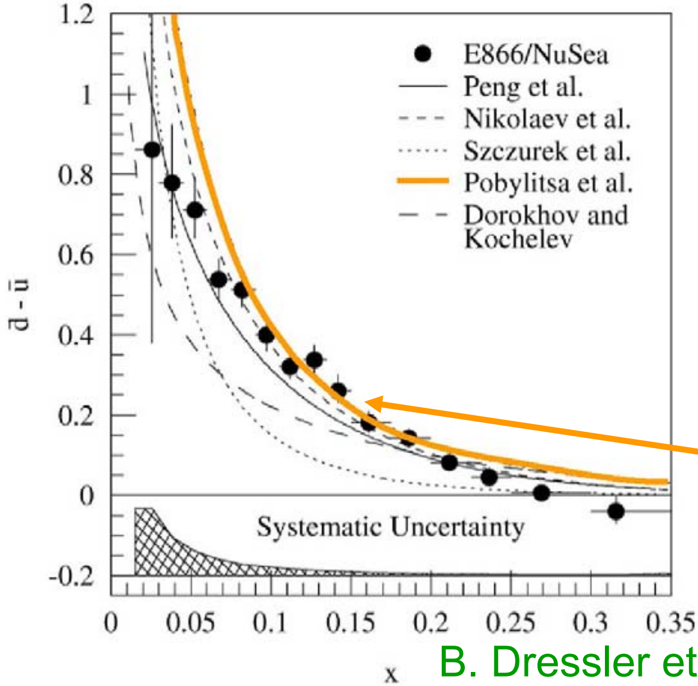
NMC and



- Non-perturbative processes seem to be needed in generating the sea
- What about flavor asymmetry in the spin of $\bar{u}$ and $\bar{d}$ for different models?

Polarized $\bar{q}$ Flavor Asymmetry

E866 Results

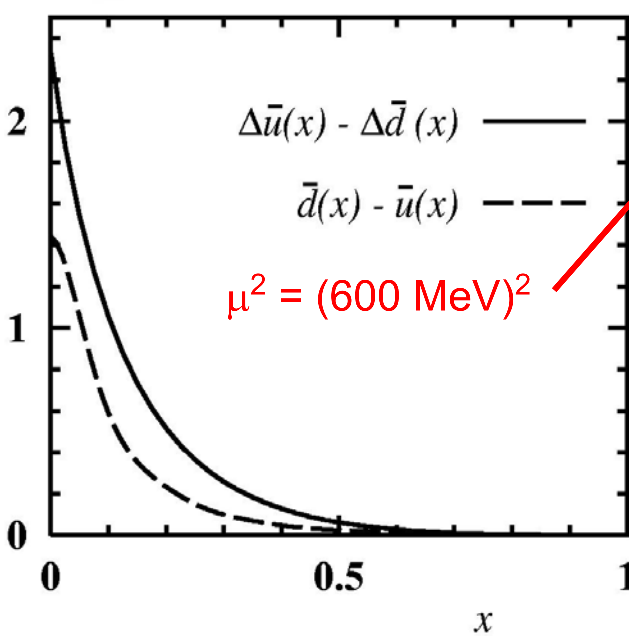


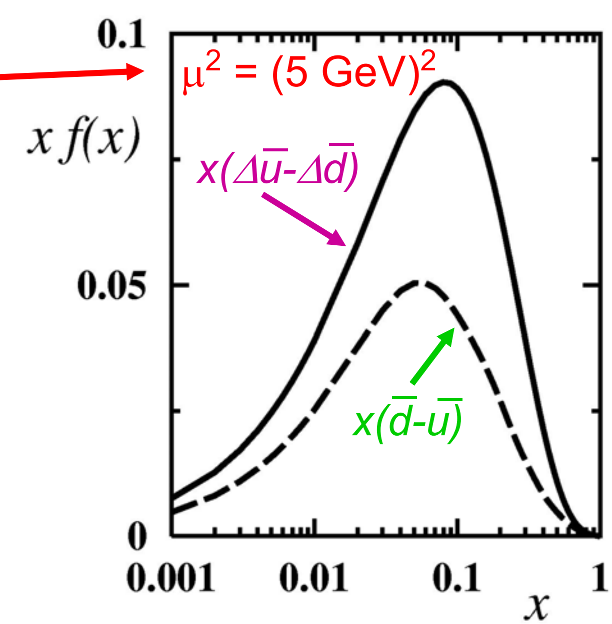
- $\bar{d}(x)$-$\bar{u}(x)$ and $\Delta\bar{u}(x)$-$\Delta\bar{d}(x)$ better for Q^2 evolution
- E866 Results are qualitatively consistent with pion cloud models, instanton models, chiral quark soliton models, etc.
  - Most quark-based models predict

$$\int_0^1 [\Delta\bar{u}(x)-\Delta\bar{d}(x)]dx \leq \int_0^1 [\bar{d}(x)-\bar{u}(x)]dx$$

  - Most meson-based models disagree

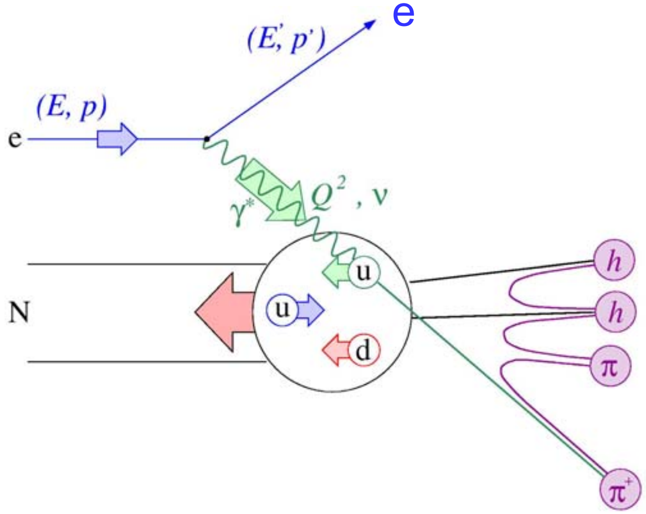
B. Dressler et al., Chiral Quark Soliton Model Predictions





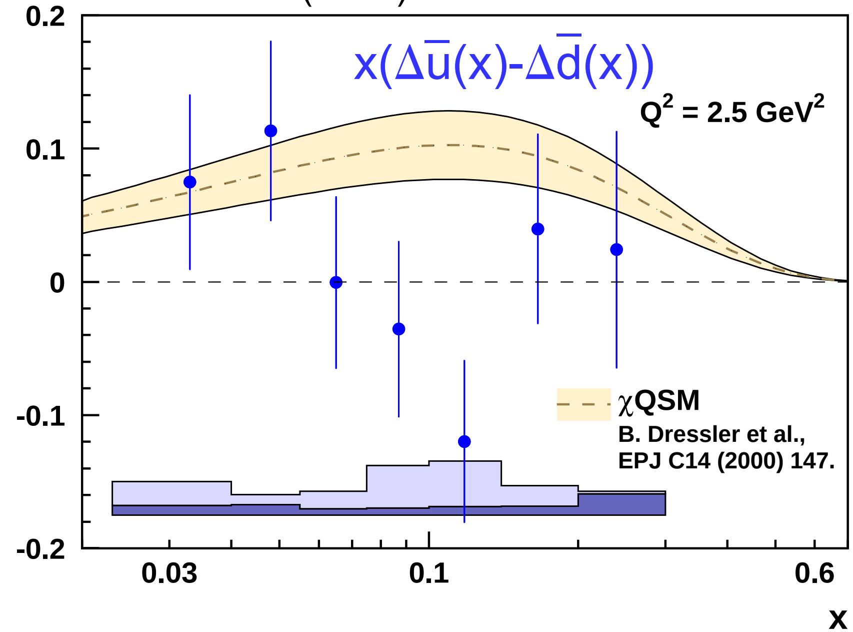
Measurements by Hermes have been used to extract $\Delta\bar{u}(x) - \Delta\bar{d}(x)$

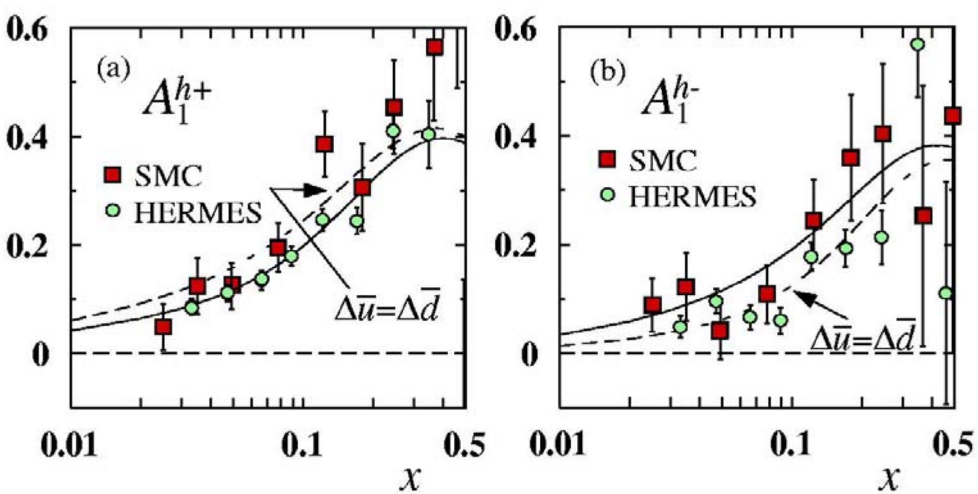
Semi-Inclusive DIS: $\vec{e} + \vec{N} \rightarrow e' + h + X$



h = π^+, π^-, k^+, k^-

PRL 92 (2004) 012005





Dressler et al., Eur. Ph. J. C14 (2000) 147

- Combined p and d data fit for all identified hadron A_1's
  - Input unpolarized q(x) pdf's
  - JETSET fragmentation fctns.
  - Simplifying assumptions on symmetries in sea quark dist.
- Results Controversial

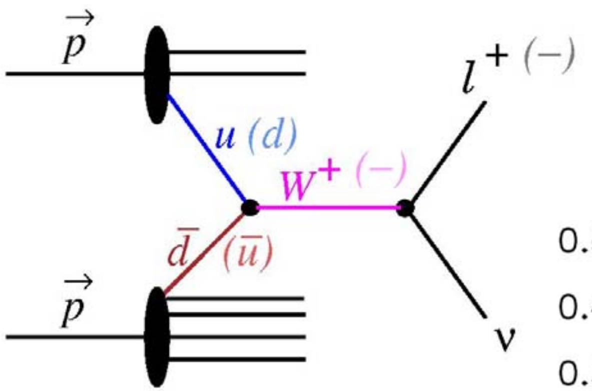
Future Upgrades – Inner and Forward Tracking

Polarized $\bar{q}$ Flavor Asymmetry $\Delta\bar{u}(x)$-$\Delta\bar{d}(x)$ related to the nature of the sea

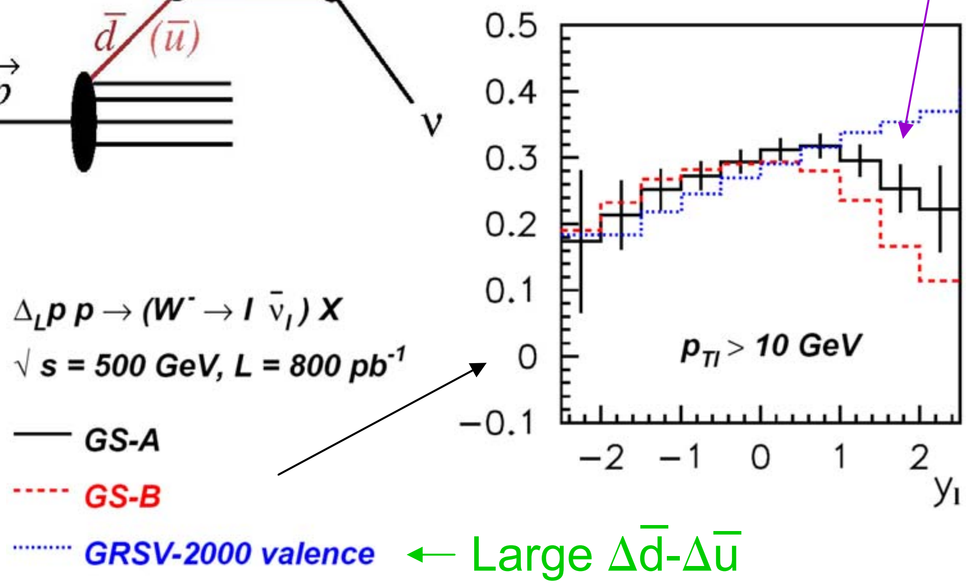
Parity violating long. asymmetry in W production allows extraction of

$$A_L^{W^-} \sim \bar{u}(x_1)\Delta d(x_2) + d(x_1)\Delta\bar{u}(x_2)$$

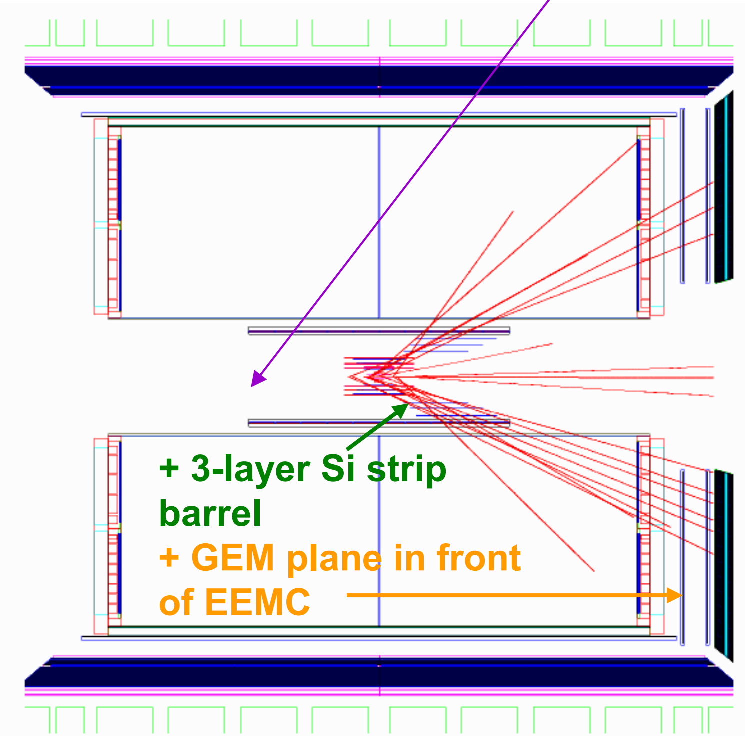
- Sensitivity in forward region
- Requires tracking for up to p_T~40 GeV e^+/e^- sign determination
- Tracking upgrade



Nadolsky and Yuan, Nucl. Phys. B666 (2003) 31.



← Large $\Delta\bar{d}$-$\Delta\bar{u}$



- Timescale and Physics
  - 2005 and 2006 - ~10 pb^{-1}
    - ΔG from π^0s and jets
    - Sivers and forward physics
  - 2007 – 100 pb^{-1} and P~70%
    - $\Delta G(x)$ from direct photon – jet
    - Transversity
  - 2008 – 100's pb^{-1}
    - First extensive 500 GeV Running
    - $\Delta G(x)$ from direct photon – jet … lower x
    - W's and Δu-Δd

From 20-Year Planning Study for RHIC 12/31/03

Comparison of Three Proposed STAR 5-Year Run Plans

Fiscal Year	27 weeks/year BUP (submitted 8/03)		"Optimized Constant Effort" Scenario		32 weeks each year run scenario	
2004	5+14 Au+Au 200	5+0 pp 200	5+14 Au+Au 200	5+0 pp 200	5+14 Au+Au 200	5+0 pp 200
2005	5+9 Au+Au Escan	5+5 pp 200	6+11 Au+Au Escan	5+12 pp 200	6+8 Au+Au Escan	5+10 pp 200
2006	5+9 d+Au 200	5+5 pp 200	5+9 d+Au 200	5+13 pp 200	5+8 d+Au 200	5+11 pp 200
2007	5+5 Au+Au 200	5+9 pp 200	5+15 Au+Au 200	5+8 Cu+Cu 200	5+10 Au+Au 200	5+9 Cu+Cu 200
2008	5+10 Au+Au 200	5+5 pp 500			5+10 Au+Au 200	5+9 pp 200
$\int L_{max}\,dt$ pp 200	76 pb^{-1}		88 pb^{-1}		156 pb^{-1}	
$\int L_{max}\,dt$ post-TOF Au+Au	1.4 nb^{-1}		1.6 nb^{-1}		2.1 nb^{-1}	
What's missing?	Any Cu+Cu 200; 2nd+3rd long pp		3rd long pp; 2 pp devel. chances		1 pp devel. chance	

Background slides follow

Symbol

abcdefghijklmnopqrstuvwxyz

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Univ math1

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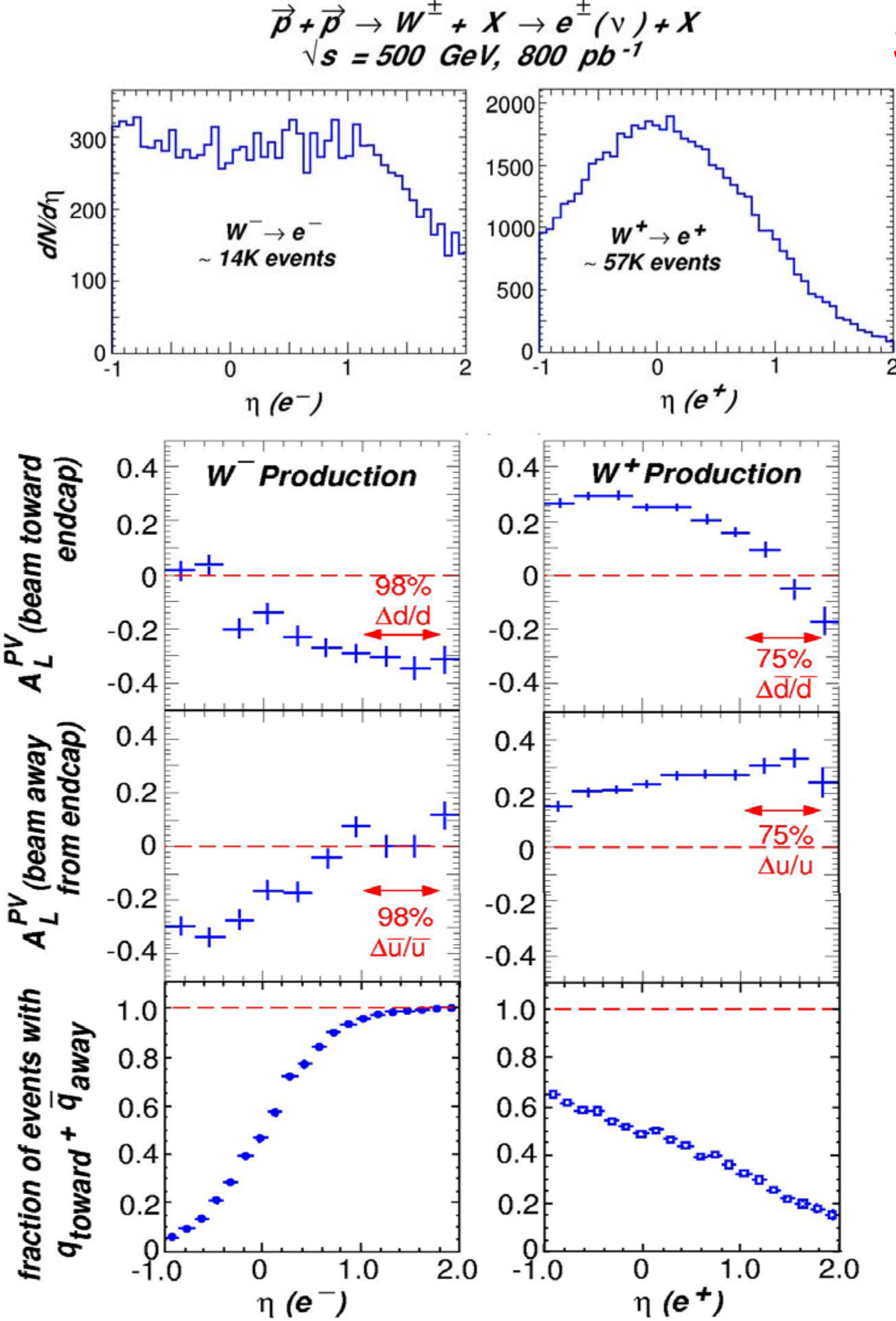
STAR Spin Physics Program – Near and Long Term

- Proton Spin Structure
  - **Gluon contributions to the proton's spin**
    - **$\langle \Delta G \rangle$ jets and π^0s**
    - **$q + g \rightarrow \gamma$ + jet, $\Delta G(x)$**
    - **Heavy flavors**
  - **Spin/momentum correlations**
    - **Sivers Functions – dijets**
    - **Collins Functions – Leading particle correl. in jets**
  - **Transversity**
  - **Flavor separated q, $\bar{q}$ – Origin of the sea**
- Standard Model tests
  - **Parity violation in jet production**

STAR

STAR Simulations of W Prod'n

By L.C. Bland

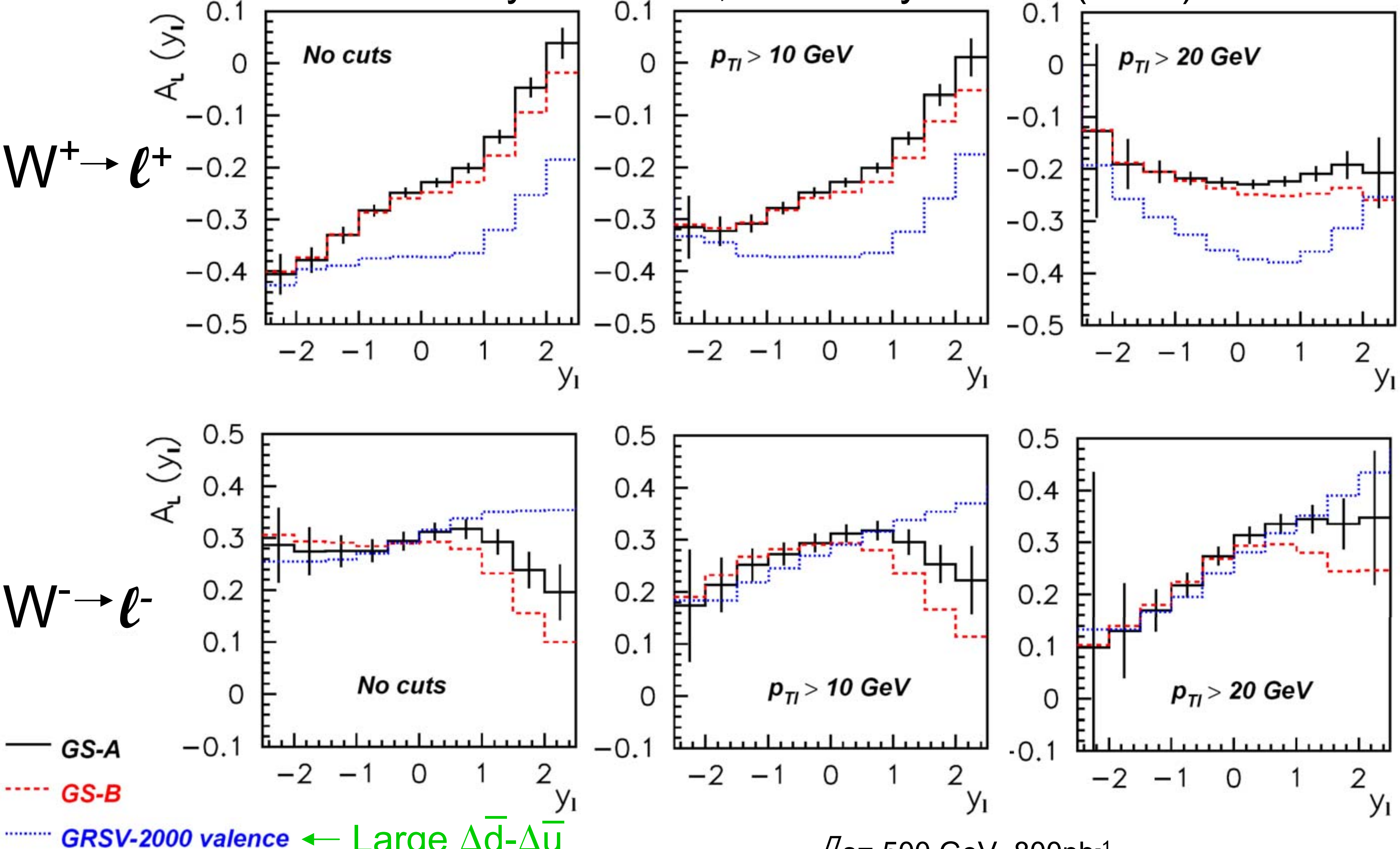


- Separate $u\bar{d}$ from $d\bar{u}$ by detecting the e^+ and $\tilde{e}$ from $u\bar{d}$ □ W^+□ e^+; du □$\tilde{W}$□ e^-
- Sensitivity to u vs. d comes from which beam spin is flipped and η distributions
- W momentum in direction of higher-x parton (usually q as opposed to $\bar{q}$)
- PV decay of L-handed $W^{\pm}$ □ CP □ in W rest frame: e^+ ($\tilde{e}$) emitted pref'ly along (opposite) W^+ ($\tilde{W}$) spin
- □ $\tilde{e}$ focused in q direction while e^+ is more spread out
- $\tilde{W}$ prod., $\tilde{e}$ in endcap strongly emphasizes d_{toward} $\bar{u}_{away}$ collisions
- Less clean separation for W^+ □ e^+
- Separation of antiquark and quark polarizations is kinematically cleanest in endcap region

A_L for leptons from W production

Leptonic kinematics, no detector simulation other than acceptance

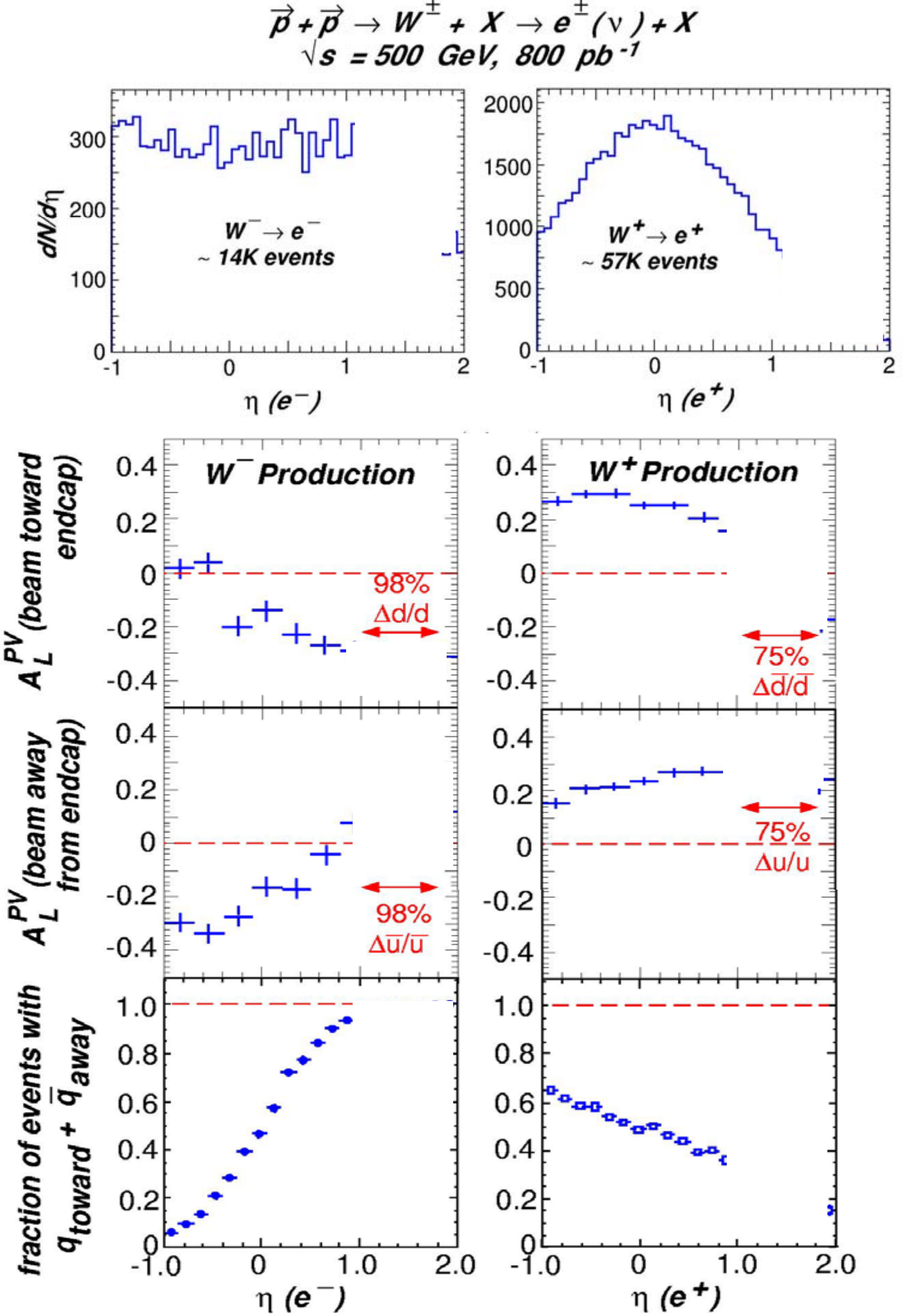
Nadolsky and Yuan, Nucl. Phys. B666 (2003) 31.



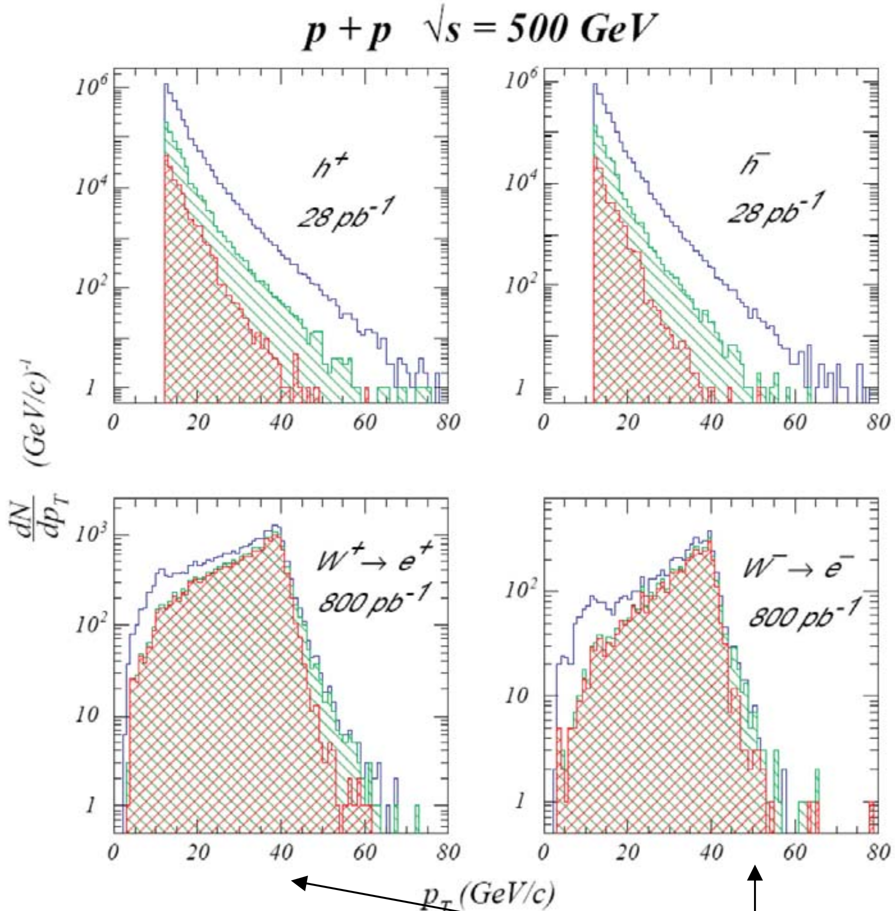
$\sqrt{s}$= 500 GeV 800pb^{-1}

What can be done before tracking upgrade?

- Restrict to $-1 < \eta < 1$
  - Not so many counts lost
  - But lose the range with best separation between flavors
  - Δd and $\Delta\bar{u}$ reasonable
  - Δu and $\Delta\bar{d}$ look hard to separate
  - First run likely to have low luminosity
- Extending range to 1.? needs detailed simulation – expect 1.5
  - Add EEMC SMD point
  - Add vertex from other tracks
  - Displace vertex away from EEMC?
- First 500 GeV run w/o full tracking upgrade would still be a good start



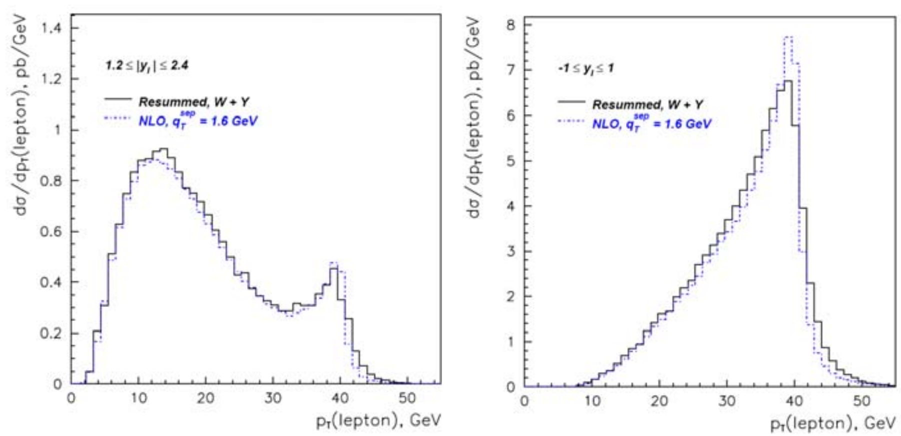
Good Tracking is Essential



Existing tracking degrades with η for η>1

- Fewer pad rows hit as η increases
- Pad row density decreases for η>1.5
- Miss SVT

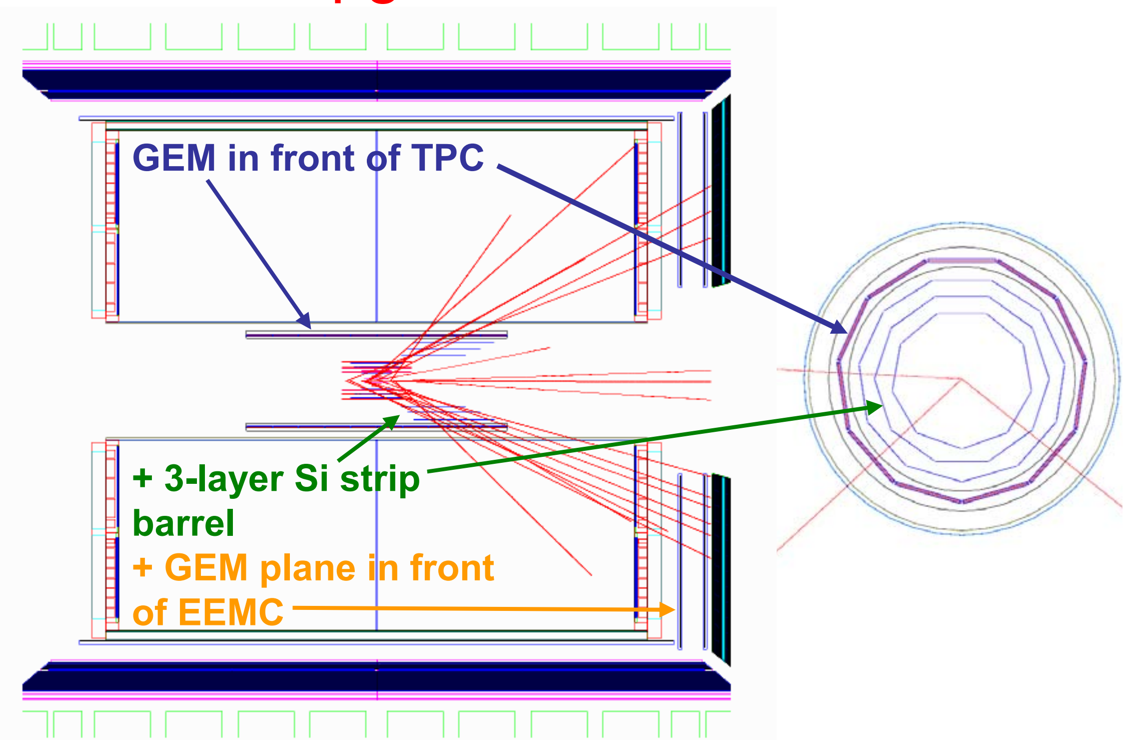
Nadolsky and Yuan

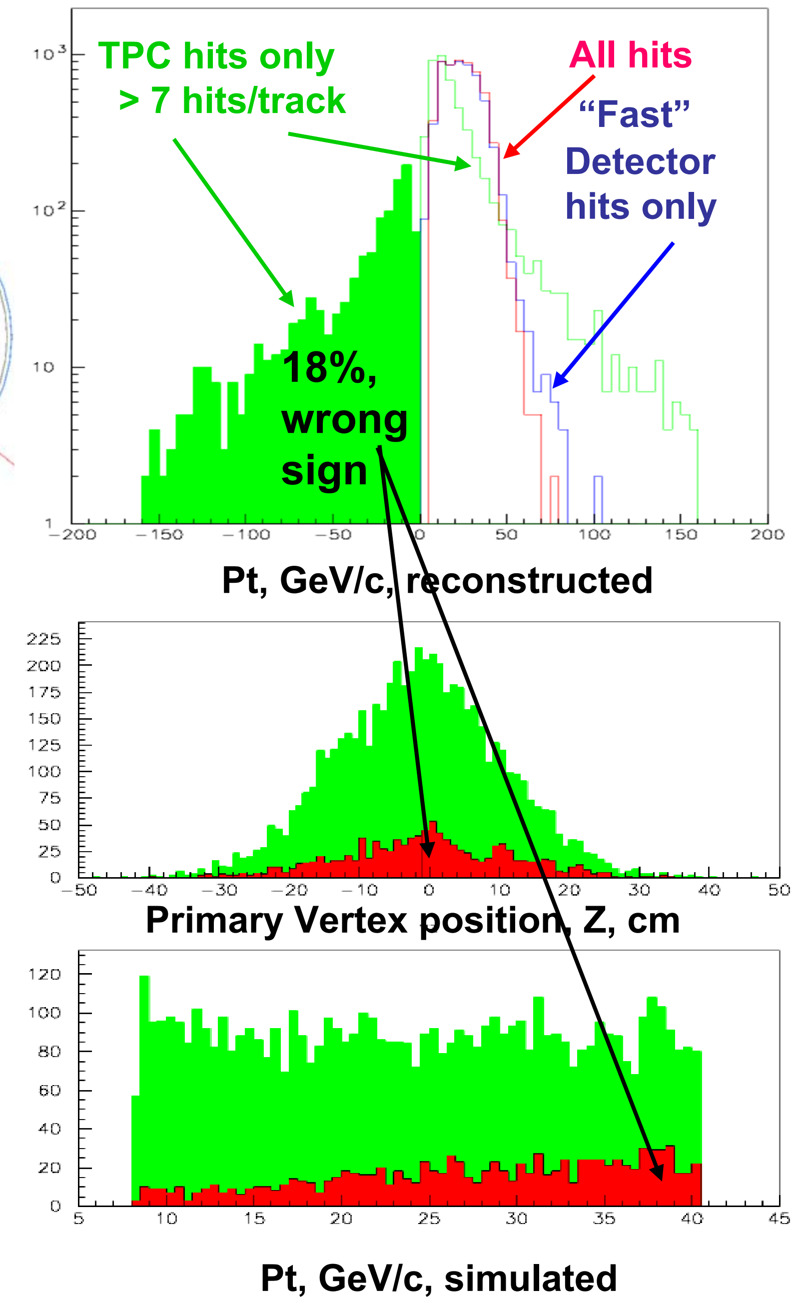


- Need to determine sign of p_T = 20-40 GeV/c electrons (minimum requirement)
- p_T/E_T^{cal} would help e/h discrimination
- Has to be done in high density of tracks
- Need TPC design resolution

These are all crucial for tracking in the region -1 < η < 1 as well, where tracking upgr. also of use

Upgrade: STAR Forward Tracking for W· vs. W˜



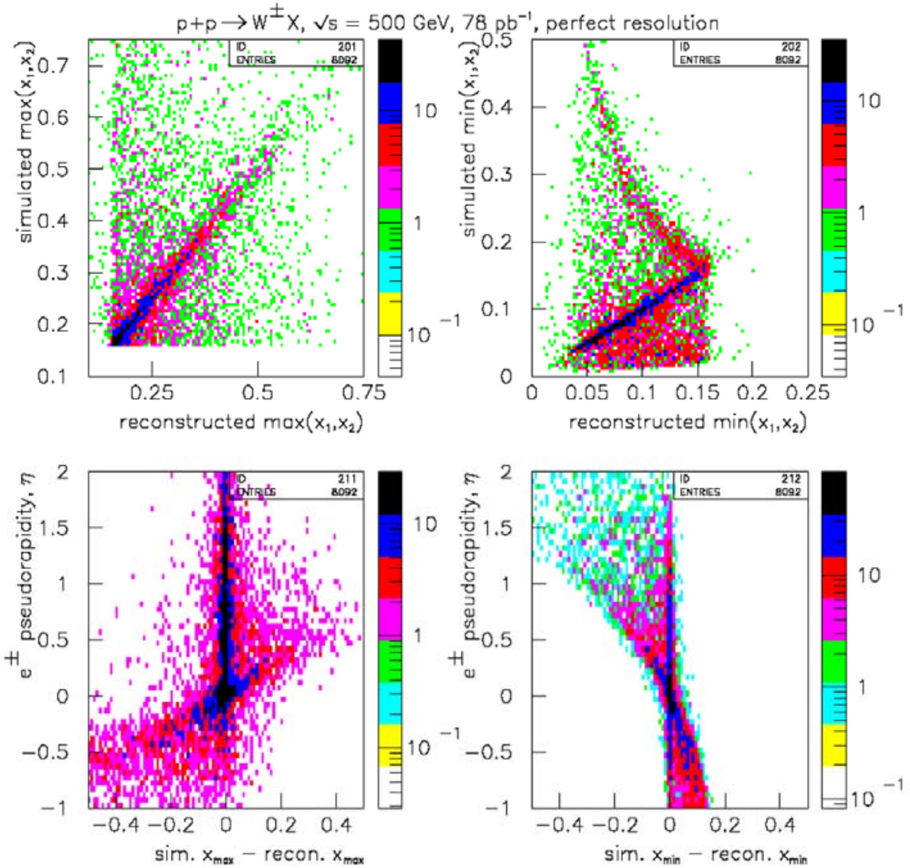


- Add inner tracking for forward region – Si with 50 μm resolution
- Add tracking in front of endcap – GEM with 100 μm resolution
- Simulations by N. Smirnoff for uniform 30 GeV π^- illumination of endcap region show added detectors can eliminate sign misidentification (sagitta =2.5mm)
- GEMS as fast detectors can help with pile up

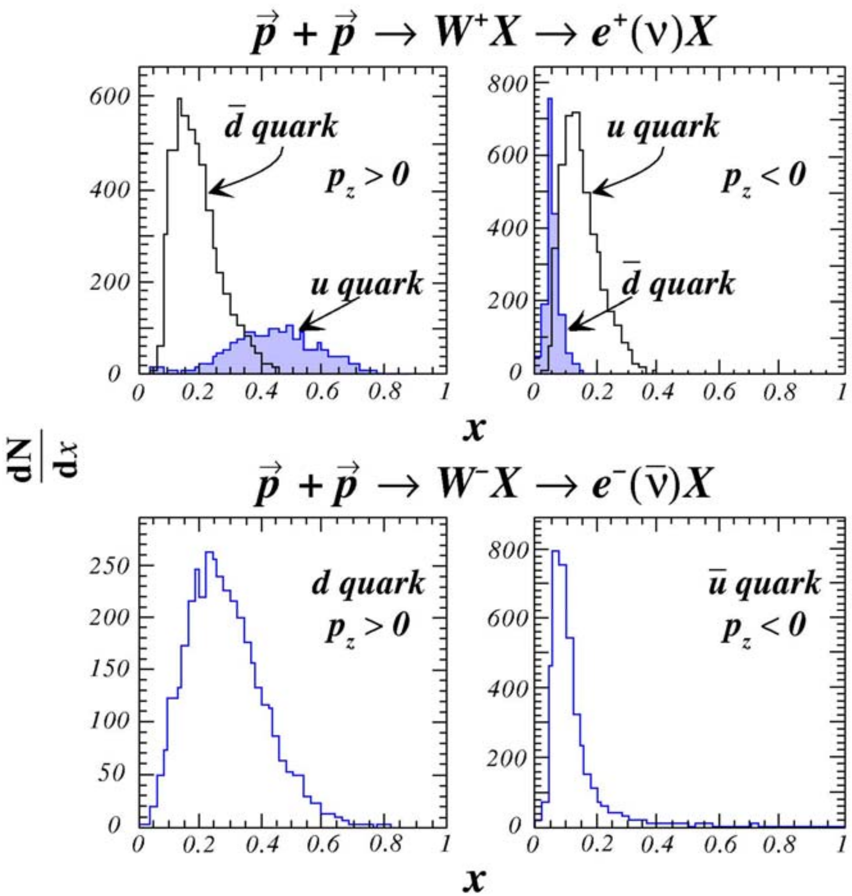
x Sensitivity and Possible x Dependence Extraction

One may approximately reconstruct $x_{1,2}$ from (e), p_T(e) event-by-event from 2-body fusion + 2-body decay, i.e., neglecting W width + transverse mom.

Works best in Endcap and for W^-

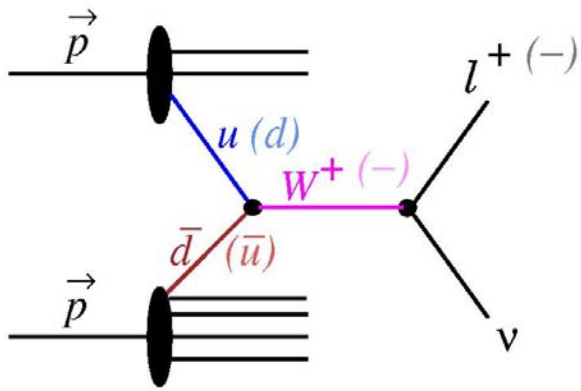


W's in Barrel + Endcap

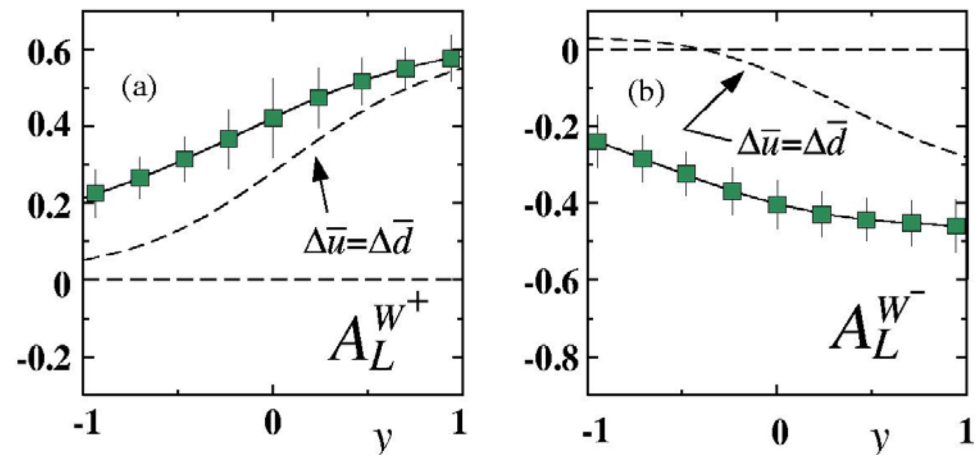


W's in Endcap

$W^{+(-)}$ Production in p-p at √s = 500 GeV/c^2



Dressler et al. predict large sensitivity

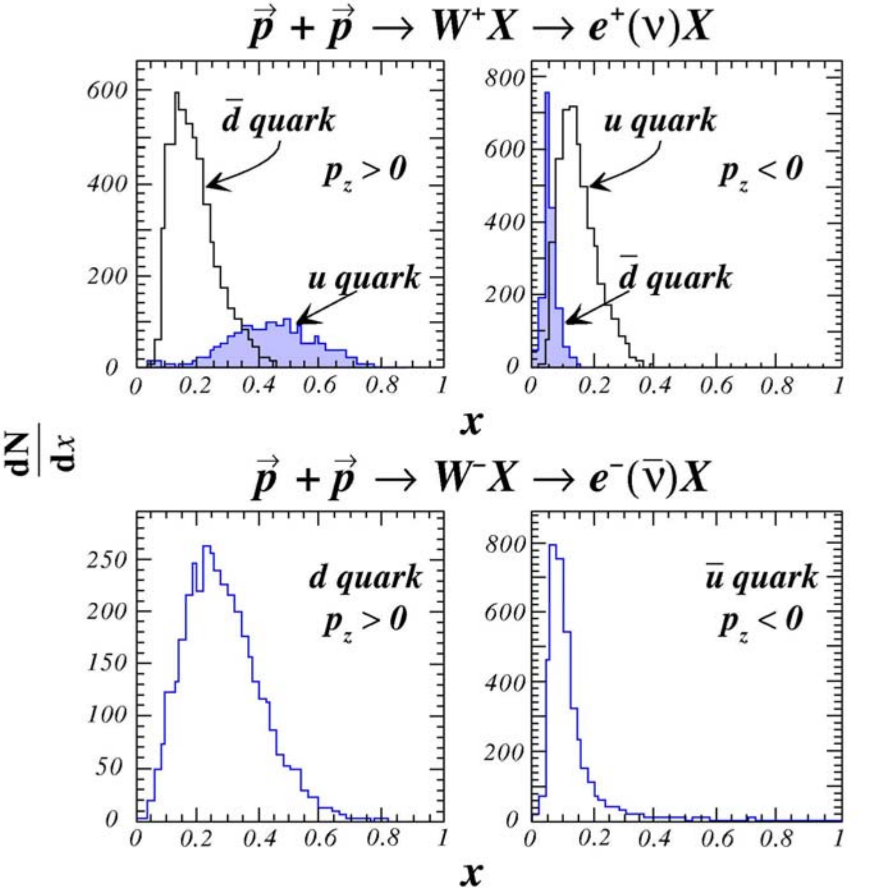


- V-A coupling
  - only LH u and RH $\bar{d}$ couple to W^+
  - Likewise LH d and RH $\bar{u}$ to W^-
  - Only LH W's produced
- Neutrino decay gives preferential directionality in decay

Parity violating single spin asymmetry A_L
(Helicity flip in one beam while averaging over other)

$A_L^{W^-} \sim$ $-d(x_1)\Delta\bar{u}(x_2)$

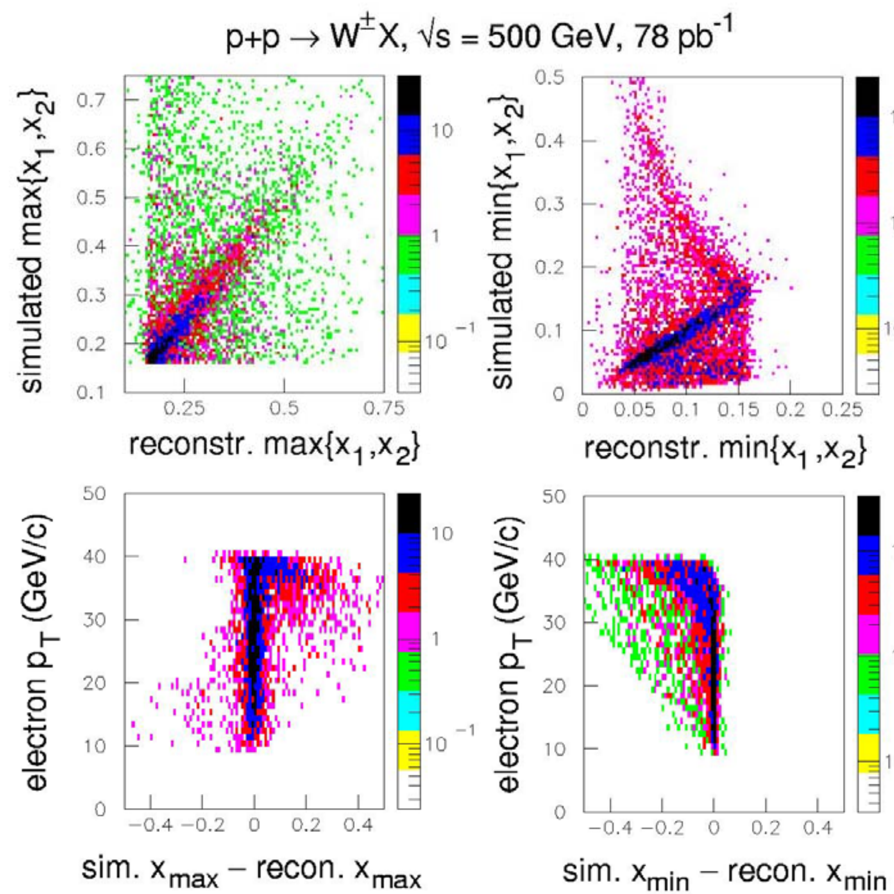
Allows kinematic separation especially for W^- in EEMC



Bjorken x Sensitivity of STAR W Prod'n

- **Ø 1 $\leq$ η_e $\leq$ 2 probes either asymmetric q_{toward} $\bar{q}_{away}$ or symmetric $\bar{d}_{toward}$ u_{away} collisions.**

- ***Sensitivity generally good for $x_{\bar{q}}$ $\geq$ 0.1, where chiral soliton model predicts largest flavor dep. of $\Delta\bar{q}/\bar{q}$***

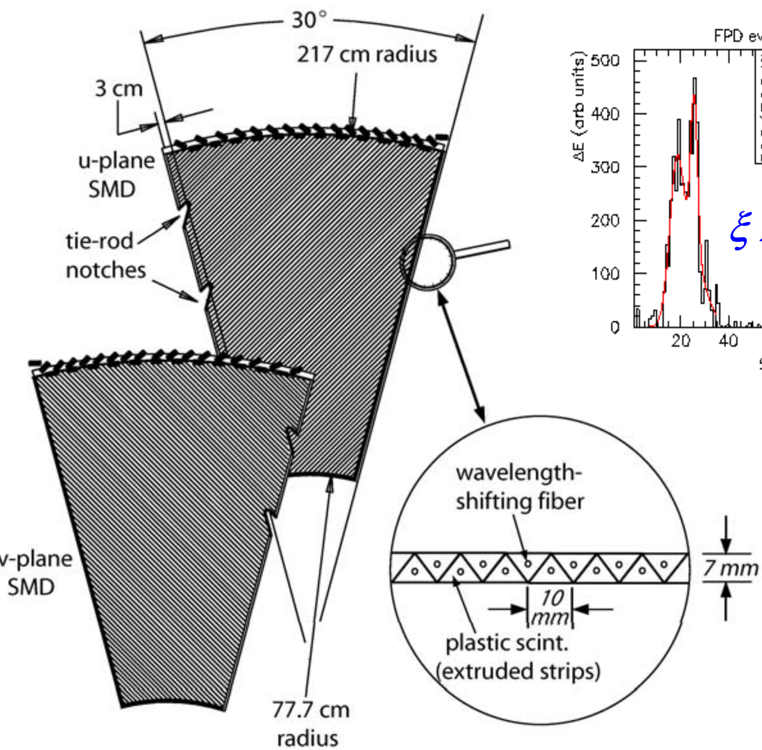


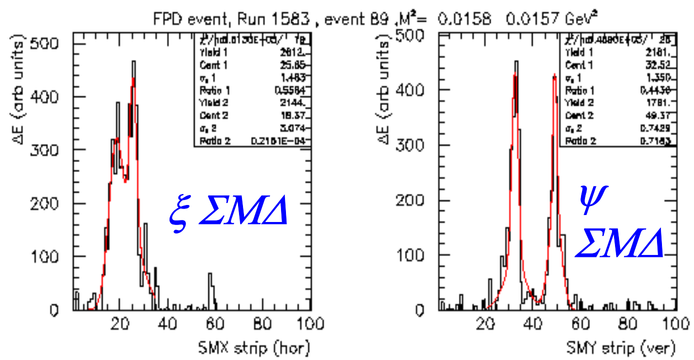
- ***One may approximately reconstruct $x_{1,2}$ from η(e), p_T(e) event-by-event from 2-body fusion + 2-body decay, i.e., neglecting W width + transverse mom.***

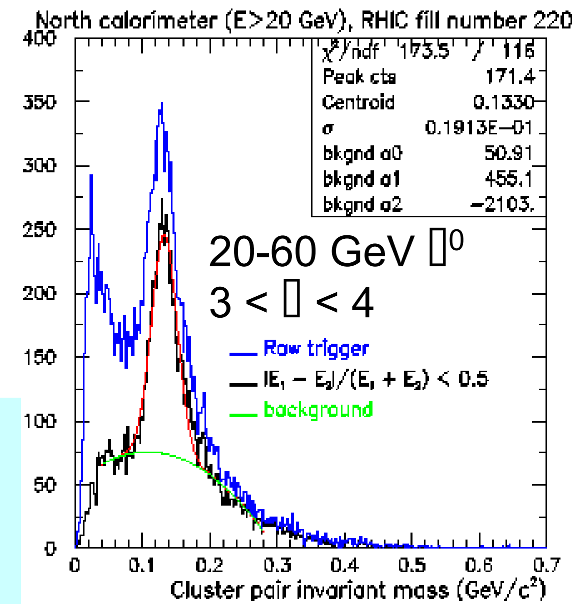
$\sqrt{x_1x_2} = M_W / \sqrt{s} = 0.16$ @ $\sqrt{s}$ = 500 GeV;

$(x_1 - x_2)/(x_1+x_2) = \tanh[\eta_e^{meas} - \eta_e^{rest}] = \tanh[\eta_e^{meas} - \cosh^{-1}(M_W / 2p_T^{meas})]$

EMC Shower-Maximum Detectors □ □/□ Discrimination

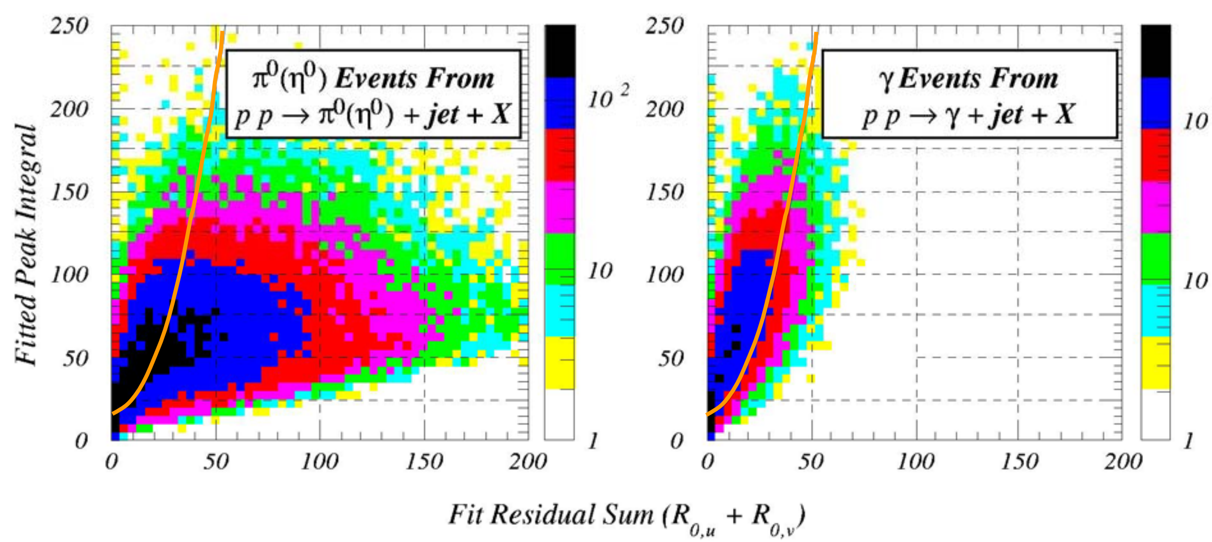






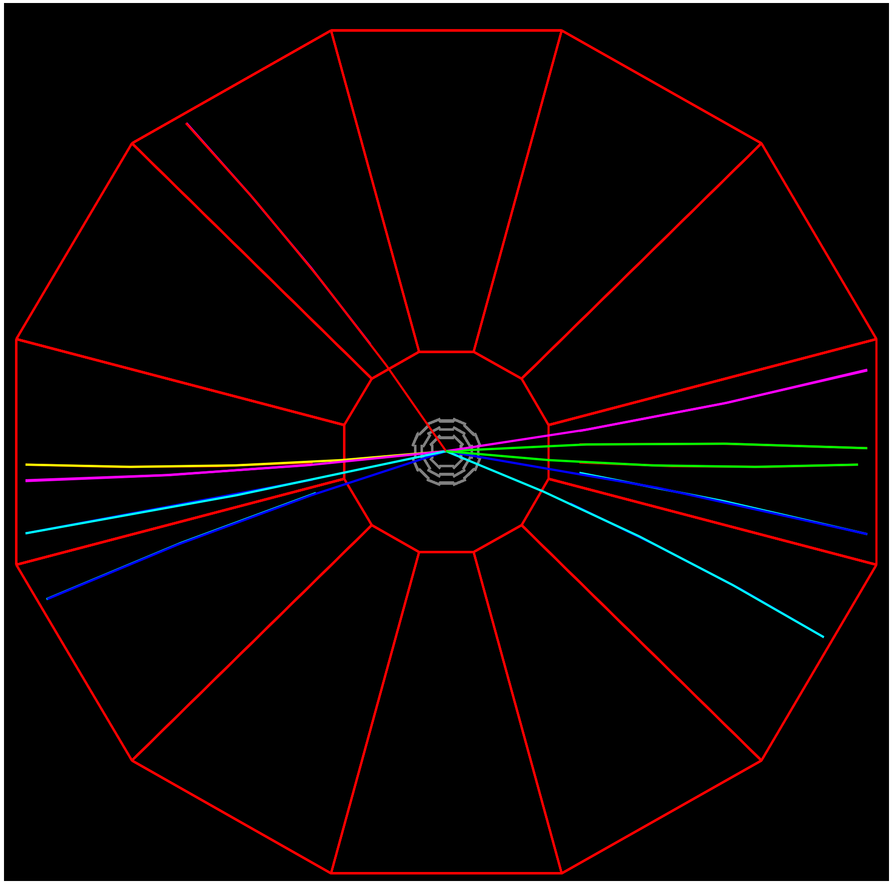
Fine-grained scint. strips (endcap, FPD) ~ 5 R.L. deep □ trans-verse shower profile, different for □ vs. □.

Simulation at right □ 80% □ retention + 80% □ rejection over p_T = 10-20 GeV/c range in endcap, using residuals to profile fit with single-photon peak shape.

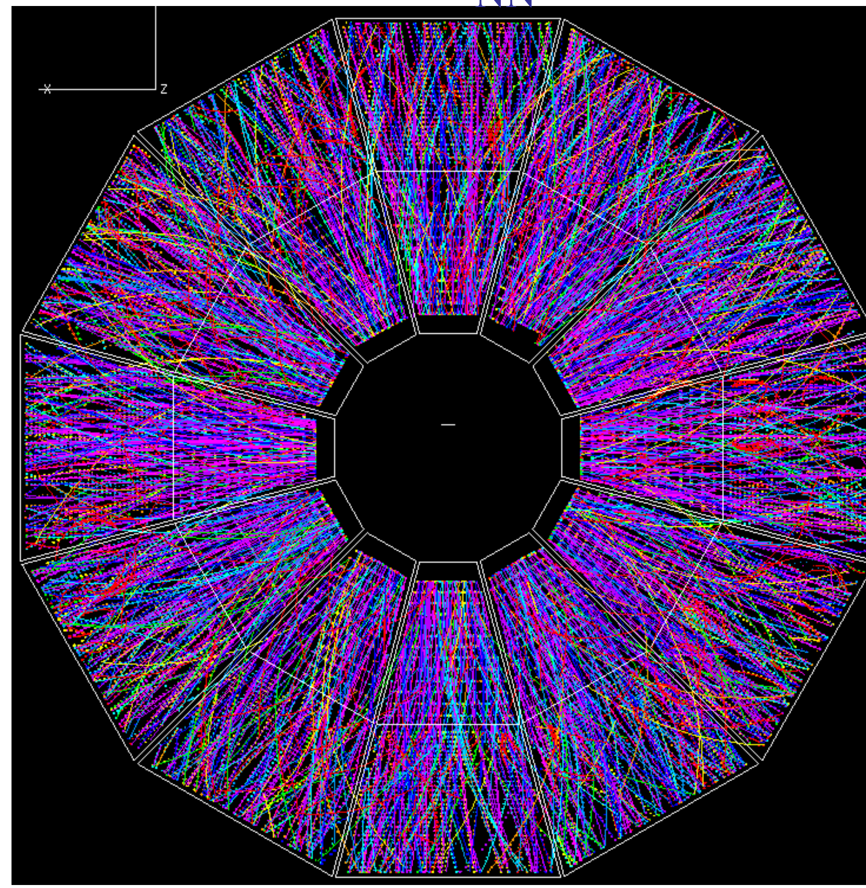


EMC's Facilitate Triggering on Jet Events

STAR p+p, $\sqrt{s}$ = 200 GeV



STAR Au+Au, $\sqrt{s}_{NN}$ = 200 GeV



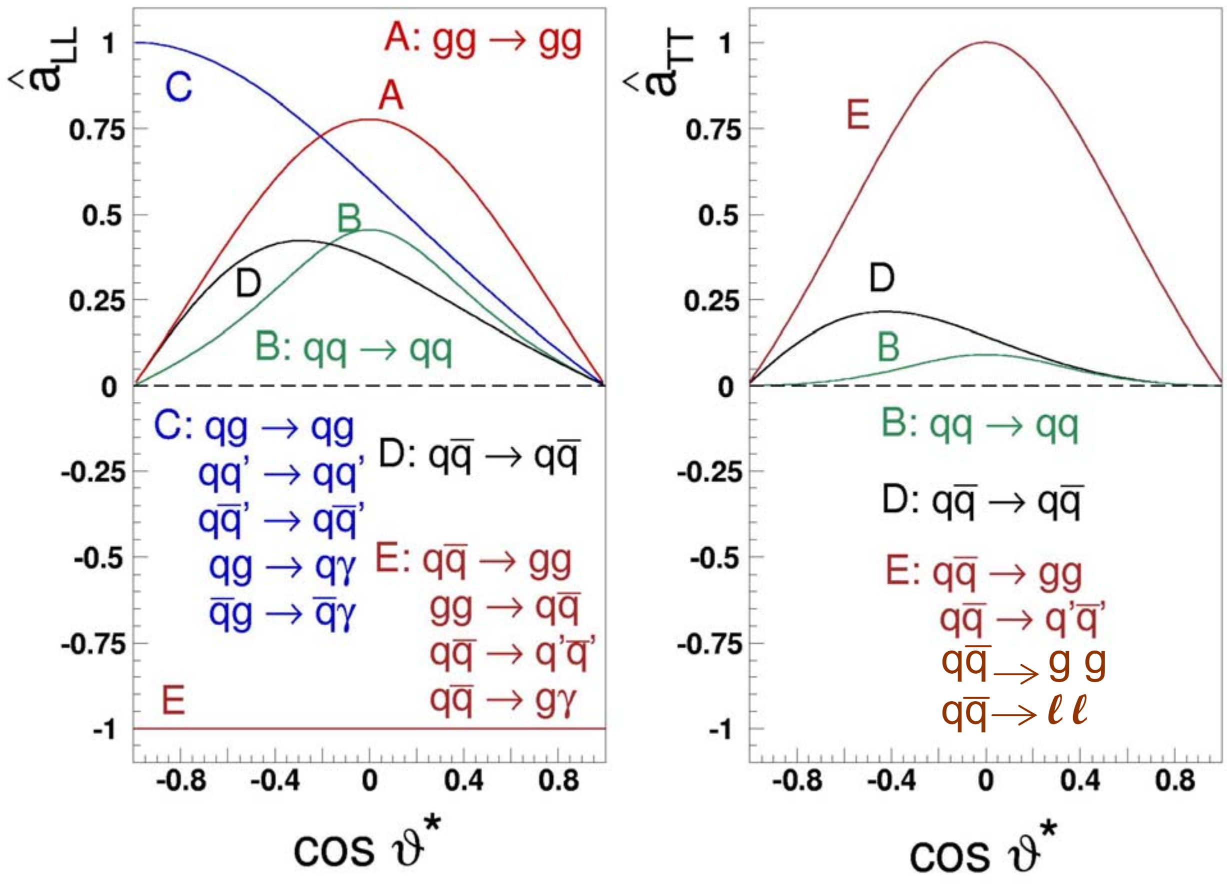
Or p+p at full luminosity with TPC pileup?

Algorithms developed to filter out pileup tracks -- by demanding consistency with vertex from tracks leading to prompt EMC hits, and/or with EMC hits themselves – work well in simulations. Unfortunately, pp luminosities obtained to date not high enough to test in real data!

What pp Spin Observables Does QCD Allow?

- L- and R-handed q sectors are separate (chiral symm.) but equal (parity).
- Parity ⇒ $a_L \equiv (\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-) = 0$
- α_s ⇒ no q helicity flip upon g emission/absorption (e.g., $q_L \to g + q_L$; $q_L + q_R \to g$) ⇒ $a_T \equiv (\sigma_\uparrow - \sigma_\downarrow)/(\sigma_\uparrow + \sigma_\downarrow) = 0$ at leading twist
- ⇒ need 2-spin observables: **probe g pol'n with highly polarized quarks!**

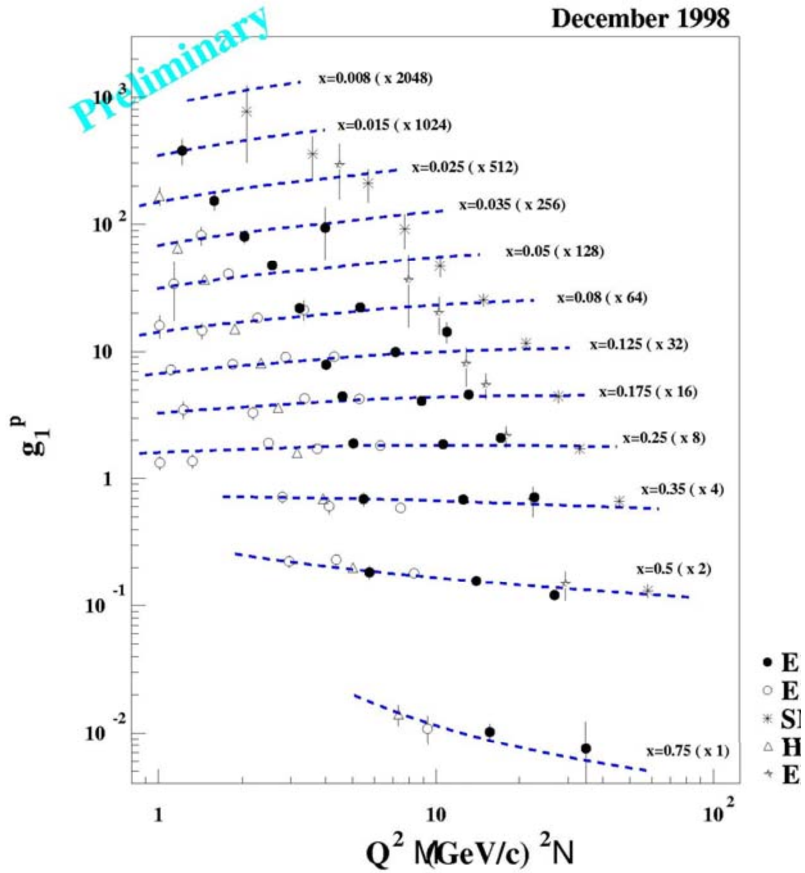
LO QCD spin observables

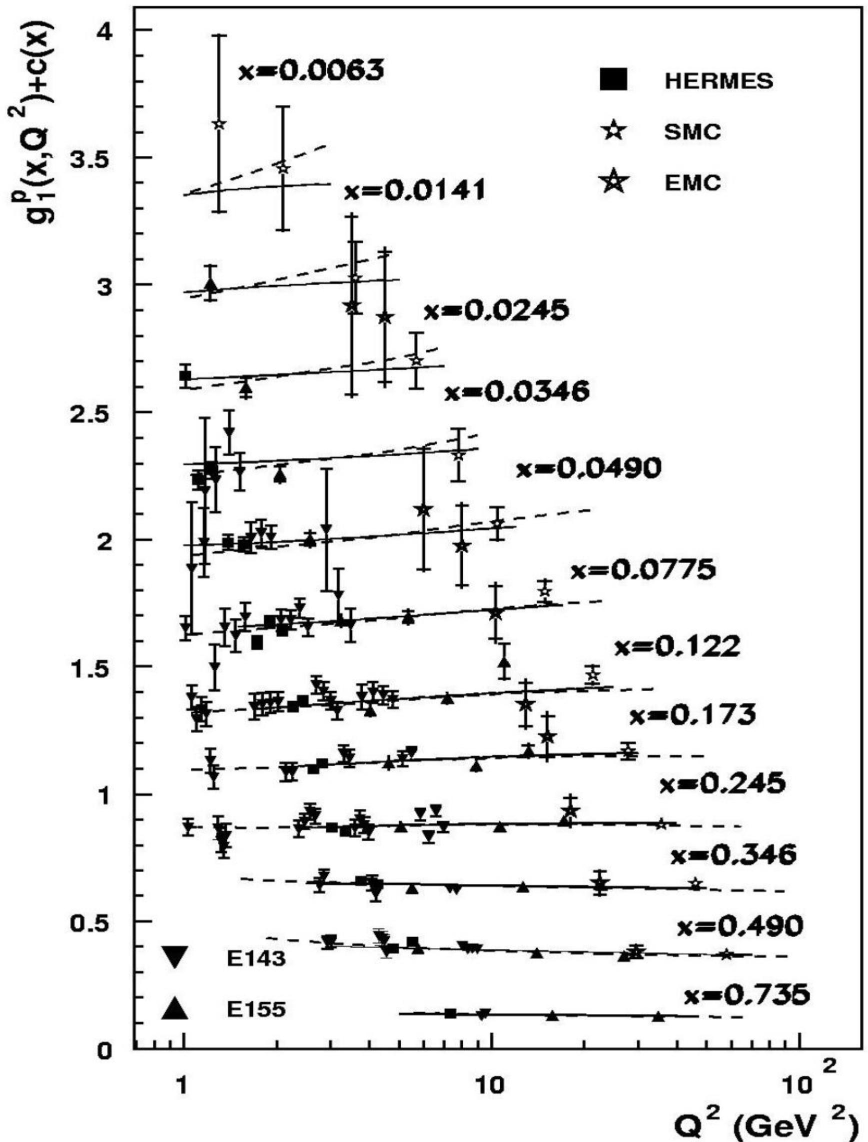


$$\hat{a}_{LL} \equiv \frac{(\sigma_{++} - \sigma_{+-})}{(\sigma_{++} + \sigma_{+-})},$$

where subscripts indicate parton helicity states

World data on g_1^p





Blümlein & Böttcher: fit to polarised data of

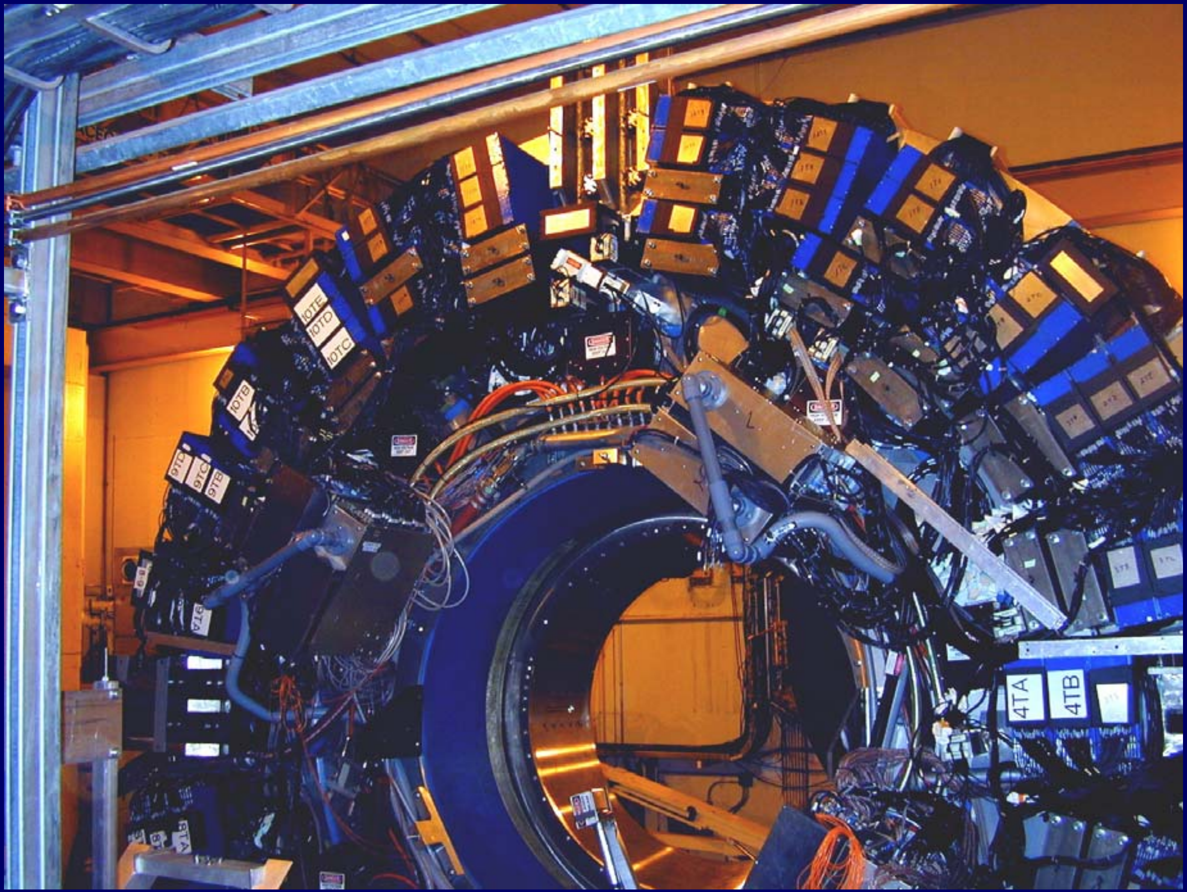
EMC, E142, E143, E155, SMC, Hermes

What I am not going to tell you

each is a seminar in itself

- More accelerator physics – Classical mechanics
- Polarized ion sources – Atomic physics
- Polarimetry – diffractive processes
- Polarization calibration – polarized targets and atomic physics
- Heavy ion program
- Phobos, Brahms, pp2pp, much about Phenix

Installed During 2003 Shutdown:

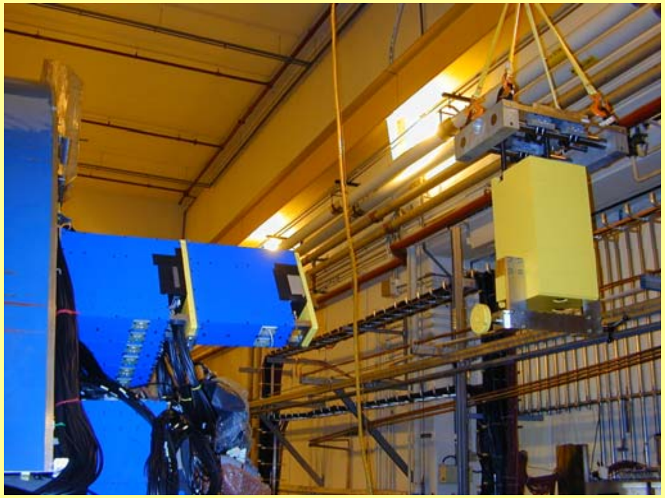


- Upper half mechanical structure
- All remaining active elements –2/3rds
- All clear fiber bundles from detectors to rear of poletip
- All remaining PMT boxes and electronics – Full tower coverage
- 1/3rd of MAPMT boxes (16) and associated electronics – SMD and pre/post-shower
- Diagnostics – LED and laser for all installed detectors
- HV system for full detector

(MA)PMT boxes and electronics on back of poletip

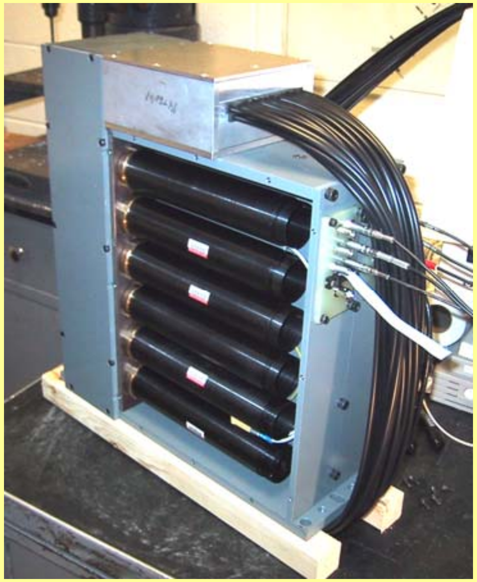
- 12 PMTs per box, one 6° sector of towers
- PMT housings built in Dubna
- CW bases from Dubna
- Box structure Texas A&M
- MAPMT testing and LEDs at KSU
- Assembly of PMT boxes to Valpo. U.
- All 720 channels installed
- ~97% fully functional

PMT Boxes

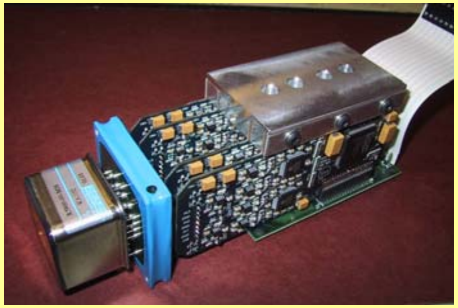


Box lifter for installation and repair

Internal Fiber Harness



PMT Box



MAPMT, CW base and 16 ch. FEE

MAPMT Boxes

□ SMD and pre/post-shower

- 12 MAPMTs (16 ch) per box
- 192 ch. FEE internal to box
- 4 Sectors - ~3000 ch. inst.
- 99.5% working

Megatile Production Line

- There are 120 different versions of megatiles
- 1/3rd of megatiles installed. Another 1/3rd complete.
- Also machine SMD modules and parts of mechanical structure
- Will run through next summer to complete all megatiles at present rate. Machining two shifts.

Στρυχτυρε Ινσταλλατιον

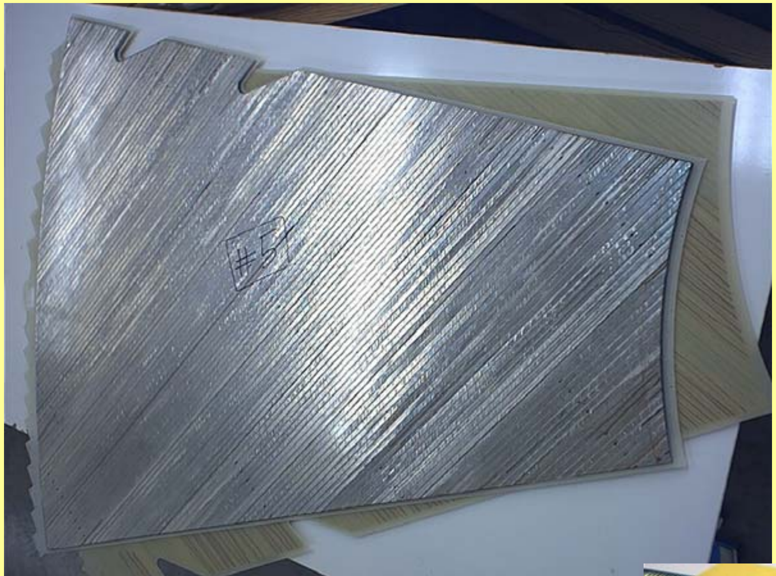
9/21/03 Εϖεν τορναδοσ χαν□τ στοπ υσ!

Ι νεϖερ τηουγητ ανψτηινγ ωουλδ μακε τηε ΕΕΜΧ λοοκ σμαλλ. Βυτ□

Ροτατε το ϖερτιχαλ ον στρονγβαχκ

0.2 δεγ φρομ ϖερτιχαλ. □ϑοην χουλδν□τ ψου δο βεττερ?□

Αλμοστ τηερε. 10/1/02



Φιβερ ρουτερ λαψερ ατταχη
ανδ φιβερσ ινσταλλεδ

Στριπσ ωραππεδ ιν αλυμινιζεδ μψλαρ ανδ γλυεδ ον ΦΡ4 συβστρατε

Φιβερσ τερμινατε ιν χοννεχτο

SMD Construction

Στριπσ ηαωε ηολε δοων μιδδλε φορ ωλσ φιβερ

2 ΣΜΔ λαψερσ ιν 3 πλανεσ = νο γαπ

PMT Boxes

- 12 PMTs per box, one 6° sector of towers
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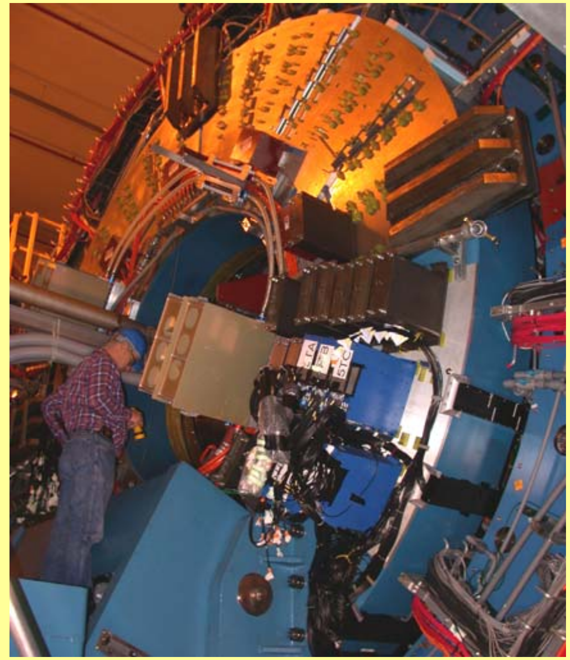
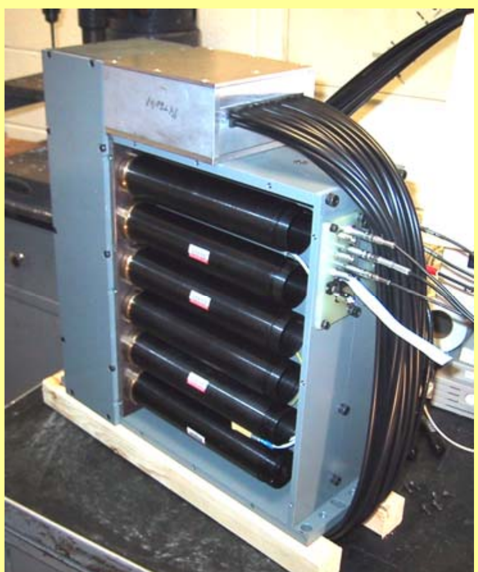
- CW bases from Dubna
- Box structure Texas A&M
- MAPMT testing and LEDs at KSU
- Assembly of PMT boxes to Valpo. U.
- 4 sectors installed

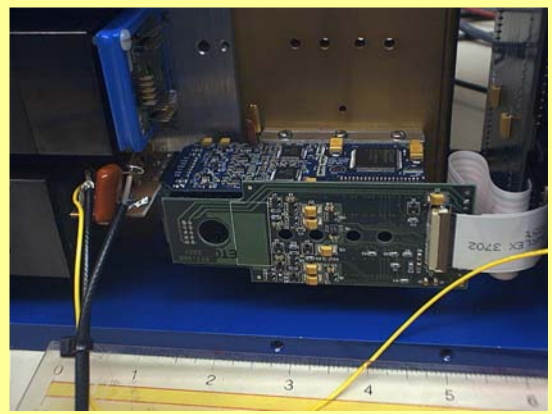


(ΜΑ)ΠΜΤ βοξεσ
ανδ ελεχτρονιχσ
ον βαχκ οφ πολετι

Ιντερναλ Φιβερ Ηαρνεσσ



ΠΜΤ Βοξ



ΜΑΠΜΤ, ΧΩ
βασε
ανδ 16 χη. ΦΕΕ

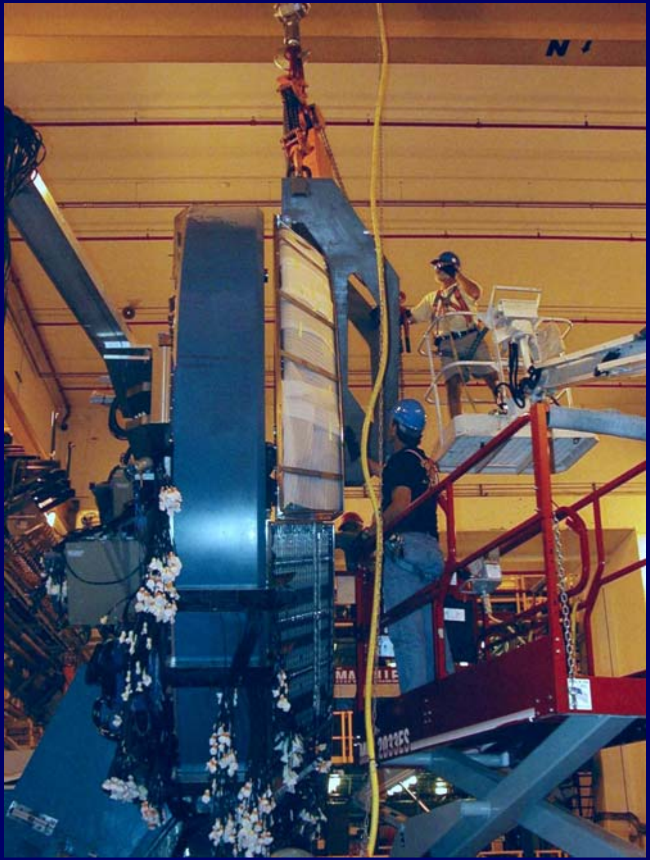
ΜΑΠΜΤ Βοξεσ

□ ΣΜΔ ανδ πρε/ποστ−σηοω

□12 ΜΑΠΜΤσ (16 χη) περ β

□ 192 χη. ΦΕΕ ιντερναλ το β

□ Φιναλ τεστινγ βεφορε προ



Upper half mounted 8/1/03

Some Assembly Required!