Vector Bosons at Hadron Colliders

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INTRODUCTION

Vector Bosons in the SM, Weak Currents, TGCs

DRELL-YAN PROCESSES

Clean Signals at HC's, Factorization, Precision Observables

PAIR PRODUCTION

V+gamma, Radiation Zero, Quantum Corrections, Tools

ASSOCIATE PRODUCTION WITH JETS

Jets, V+Jets at Tevatron & LHC, Polarization

The SM Lagrangian

$$\mathcal{L}_{SM} = \mathcal{L}_{YM} + \mathcal{L}_f + \mathcal{L}_H + \mathcal{L}_{\text{Yuk}}$$

Yang-Mills Piece

$$\begin{aligned}\mathcal{L}_{YM} &= \mathcal{L}_{QCD} + \mathcal{L}_{I_w} + \mathcal{L}_Y \\ &= -\frac{1}{4}\sum_{a=1}^{8} G^a_{\mu\nu} G^{a\mu\nu} - \frac{1}{4}\sum_{i=1}^{3} F^i_{\mu\nu} F^{i\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu}\end{aligned}$$

Color	Weak Isospin	Hypercharge
SU(3)	SU(2)	U(1)

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Where the Field Stregth Tensors are:

$$G^a_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu + g_1 f^{abc} A^b_\mu A^c_\nu$$

$$F^i_{\mu\nu} = \partial_\mu W^i_\nu - \partial_\nu W^i_\mu + g_2 \epsilon^{ijk} W^j_\mu W^k_\nu$$

$$B_{\mu\nu} = \partial_\mu B_\nu - \partial_\nu B_\mu$$

Combinations of the *W*'s and *B* gauge fields give rise to the physical Weak Vector Bosons and the photon

The SM Lagrangian

$$\mathcal{L}_{SM} = \mathcal{L}_{YM} + \mathcal{L}_f + \mathcal{L}_H + \mathcal{L}_{\text{Yuk}}$$

Dirac Piece

$$\mathcal{L}_f = \overline{\mathbf{Q}}_L \sigma^\mu \mathcal{D}_\mu \mathbf{Q}_L + \overline{\mathbf{u}}_R \sigma^\mu \mathcal{D}_\mu \mathbf{u}_R + \overline{\mathbf{d}}_R \sigma^\mu \mathcal{D}_\mu \mathbf{d}_R + \overline{L}_L \sigma^\mu \mathcal{D}_\mu L_L + \overline{e}_R \sigma^\mu \mathcal{D}_\mu e_R + \cdots$$

Quark Fields

Lepton Fields

And copies for the 3 families!

The SM Lagrangian

$$\mathcal{L}_{SM} = \mathcal{L}_{YM} + \mathcal{L}_f + \mathcal{L}_H + \mathcal{L}_{\text{Yuk}}$$

Dirac Piece

$$\mathcal{L}_f = \overline{\mathbf{Q}}_L \sigma^\mu \mathcal{D}_\mu \mathbf{Q}_L + \overline{\mathbf{u}}_R \sigma^\mu \mathcal{D}_\mu \mathbf{u}_R + \overline{\mathbf{d}}_R \sigma^\mu \mathcal{D}_\mu \mathbf{d}_R + \overline{L}_L \sigma^\mu \mathcal{D}_\mu L_L + \overline{e}_R \sigma^\mu \mathcal{D}_\mu e_R + \cdots$$

Each fermion field have a corresponding covariant derivative:

$$\mathcal{D}_\mu \mathbf{Q}_L = (\partial_\mu + g_1 \frac{i}{2} A_\mu^a \lambda^a + g_2 \frac{i}{2} W_\mu^i \tau^i + g_3 \frac{i}{2} y_1 B_\mu) \mathbf{Q}_L \ ,$$

$$\mathcal{D}_\mu \mathbf{u}_R = (\partial_\mu + g_1 \frac{i}{2} A_\mu^a \lambda^a + g_3 \frac{i}{2} y_2 B_\mu) \mathbf{u}_R \ ,$$

$$\mathcal{D}_\mu \mathbf{d}_R = (\partial_\mu + g_1 \frac{i}{2} A_\mu^a \lambda^a + g_3 \frac{i}{2} y_3 B_\mu) \mathbf{d}_R \ ,$$

$$\mathcal{D}_\mu L_L = (\partial_\mu + g_2 \frac{i}{2} W_\mu^i \tau^i + g_3 \frac{i}{2} y_4 B_\mu) L_L \ ,$$

$$\mathcal{D}_\mu e_R = (\partial_\mu + g_3 \frac{i}{2} y_5 B_\mu) e_R$$

Coupling constants

The SM Lagrangian

$$\mathcal{L}_{SM} = \mathcal{L}_{YM} + \mathcal{L}_f + \mathcal{L}_H + \mathcal{L}_{\text{Yuk}}$$

Higgs Lagrangian

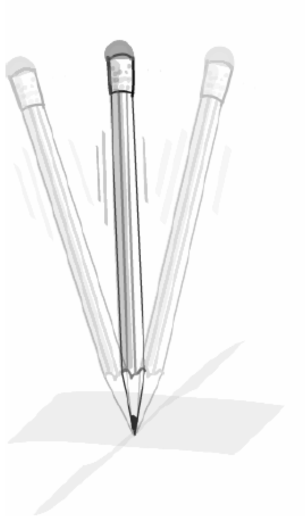
$$\mathcal{L}_H = (\mathcal{D}_\mu H)^\dagger (\mathcal{D}^\mu H) - V(H)$$

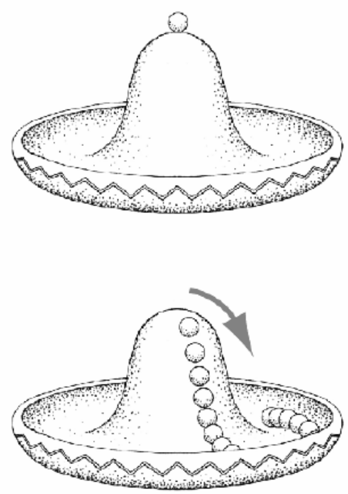
With *H* a complex scalar weak isospin doublet:

$$H = \begin{pmatrix} H_1 \\ H_2 \end{pmatrix}$$

And the Higgs potential given by:

$$V(H) = \mu^2 H^\dagger H + \lambda (H^\dagger H)^2$$





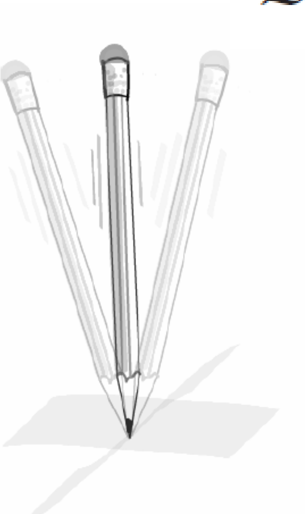
Source of the Spontaneous Symmetry Breaking (SU(2)XU(1) → U(1)) in the SM

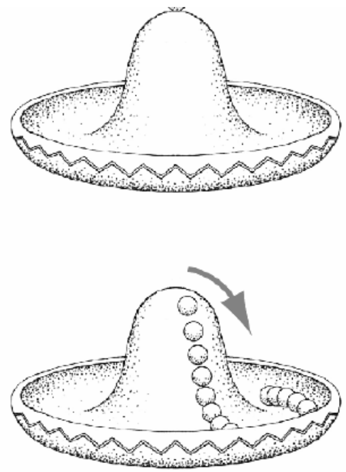
The SM Lagrangian

$$\mathcal{L}_{SM} = \mathcal{L}_{YM} + \mathcal{L}_f + \mathcal{L}_H + \mathcal{L}_{\rm Yuk}$$

Higgs Lagrangian

$$\mathcal{L}_H = (\mathcal{D}_\mu H)^\dagger (\mathcal{D}^\mu H) - V(H)$$





Pick a minimum and expand around it:

$$H = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + h \end{pmatrix}$$

And you end up with effective mass terms the (weak) gauge fields:

$$\frac{1}{2}(0, v) \left| \frac{1}{2} g_2 W_\mu^i \tau^i + \frac{1}{2} g_3 B_\mu \right|^2 \begin{pmatrix} 0 \\ v \end{pmatrix}$$

The SM Lagrangian

$$\mathcal{L}_{SM} = \mathcal{L}_{YM} + \mathcal{L}_f + \mathcal{L}_H + \mathcal{L}_{\text{Yuk}}$$

Higgs Lagrangian

$$\mathcal{L}_H = (\mathcal{D}_\mu H)^\dagger (\mathcal{D}^\mu H) - V(H)$$

With the physical Weak gauge bosons and the photon given by:

¡¡¡!!!

$$\begin{aligned} W_\mu^\pm &= \frac{1}{\sqrt{2}}(W_\mu^1 \mp i W_\mu^2) , \\ Z_\mu &= \frac{-g_3 B_\mu + g_2 W_\mu^3}{\sqrt{g_2^2 + g_3^2}} , \\ A_\mu &= \frac{g_2 B_\mu + g_3 W_\mu^3}{\sqrt{g_2^2 + g_3^2}} \end{aligned}$$

With Masses:

$$\begin{aligned} M_W^2 &= \frac{1}{4} g_2^2 v^2 , \\ M_Z^2 &= \frac{1}{4}(g_2^2 + g_3^2) v^2 , \\ M_A^2 &= 0 \end{aligned}$$

This simple (tree level) expressions agree well with experiment:

$$\begin{aligned} M_W &= 80.4 \ \text{GeV} \\ M_Z &= 91.2 \ \text{GeV} \end{aligned}$$

with $v \approx 174\sqrt{2}$ GeV

The SM Lagrangian

$$\mathcal{L}_{SM} = \mathcal{L}_{YM} + \mathcal{L}_f + \mathcal{L}_H + \mathcal{L}_{\text{Yuk}}$$

Yukawa Interactions

$$-\lambda_d \overline{\mathbf{Q}}_L H \mathbf{d}_R + h.c.$$

Yukawa coupling

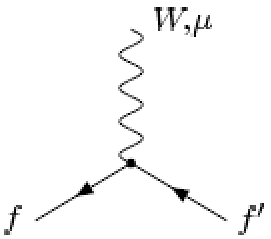
Which in an economical way end up producing, through the Spontaneous Symmetry breaking, effective masses for the fermion fields!

Mass:

$$m_d = \frac{\lambda_d v}{\sqrt{2}}$$

Electro Weak Gauge Bosons Interactions

W coupling to fermions

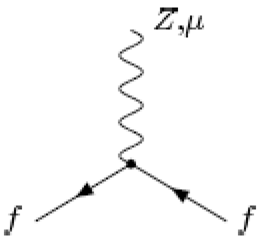


$$= \frac{-ig_2}{2\sqrt{2}}\gamma^\mu(1-\gamma_5)V_{ff'}$$

→ Where $V_{ff'}$ *corresponds to the CKM matrix for the quarks and is the identity for the Leptons*

→ The *W* couples only to left handed fermions

Z coupling to fermions



$$= \frac{-ig_2}{\cos\theta_W}\gamma^\mu(g_V^f + g_A^f\gamma_5)$$

→ Where θ_W is the Weak angle, and g_V and g_A are the vector an axial couplings:

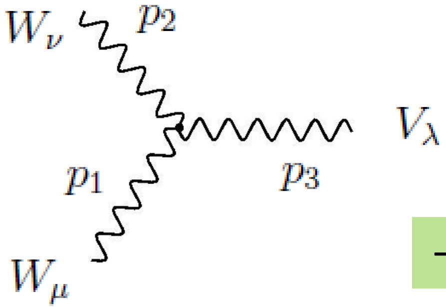
$$\sin\theta_W = g_3/\sqrt{g_2^2+g_3^2}$$

$$g_A^f = -\frac{1}{2}T_3^f$$

$$g_V^f = \frac{1}{2}T_3^f - \sin\theta_W{}^2 Q_f$$

More Interactions…

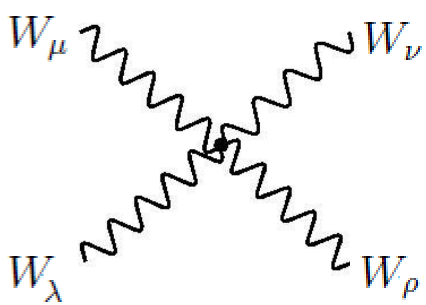
Triple gauge boson interactions



$$= -ig_V\left[(p_1 - p_2)_\lambda g_{\mu\nu} + (p_2 - p_3)_\mu g_{\nu\lambda} + (p_3 - p_1)_\nu g_{\lambda\mu}\right]$$

→ g_V is $g_2 \sin(\theta_W)$ for the photon and $g_2 \cos(\theta_W)$ for the *Z*

Four point interactions



$$= ig_2^2(2g_{\mu\nu}g_{\lambda\rho} - g_{\mu\lambda}g_{\nu\rho} - g_{\mu\rho}g_{\lambda\nu})$$

→ There are more four point interactions of the *WWVV* type
→ The photon couples to fermions as in QED (that is with strength proportional to the fermion charge)
→ Although the gluon is of course also a Vector Boson, its phenomenology is set apart due to QCD confinement

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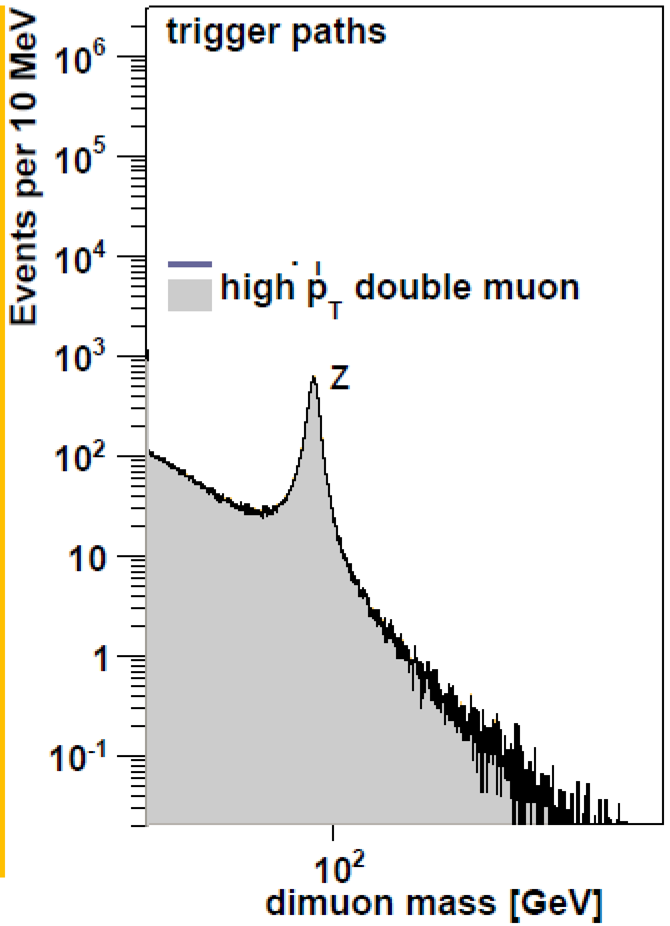
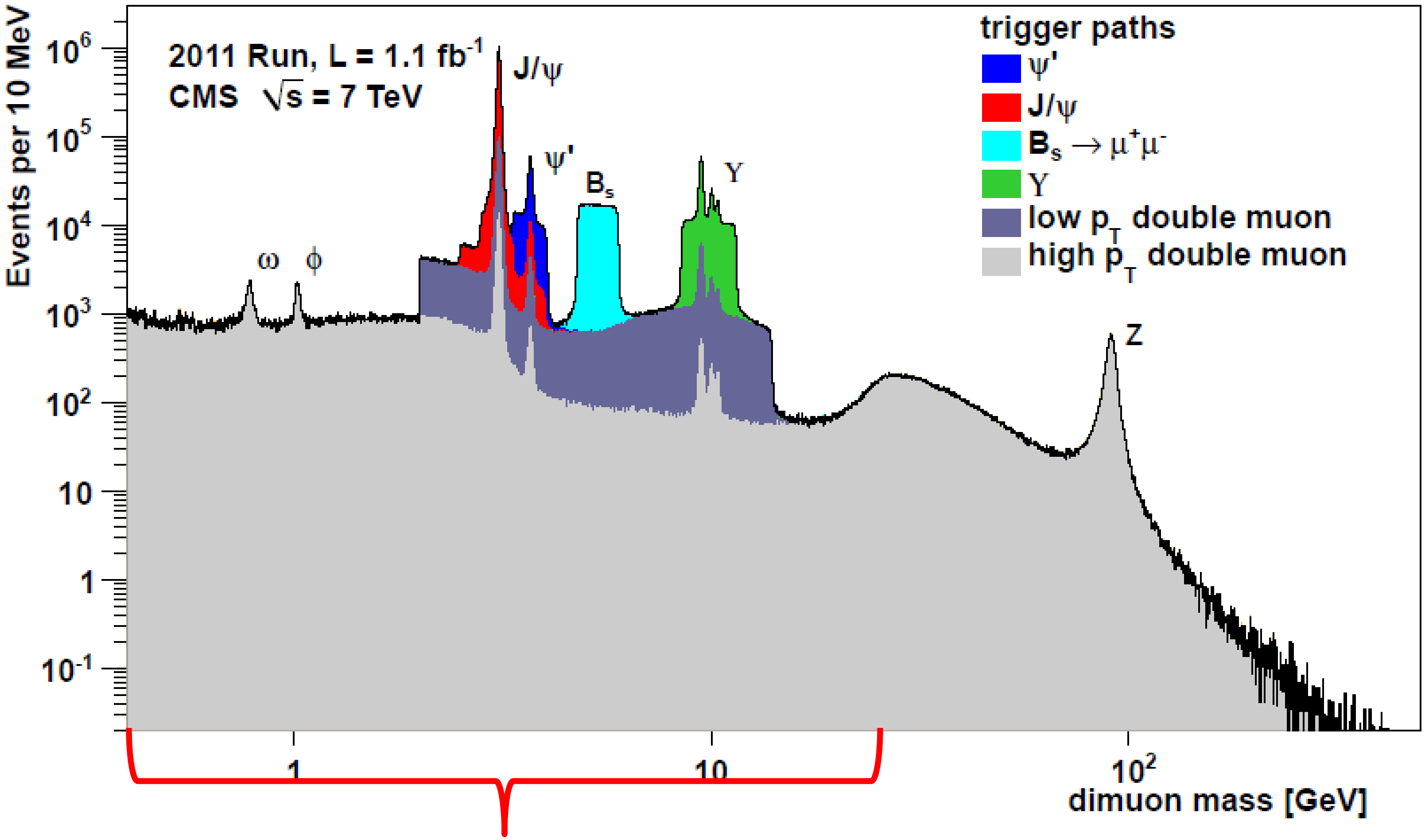
Drell-Yan Process: Z/W Production

→ Clean Signal at Hadron Colliders: lepton pair does not interact strongly
→ Proof of factorization at all orders
→ Then an input for PDF extraction
→ One of the best theoretically studied processes at Hadron Colliders with uncertainties down to few percent level
→ Standard Candle for detector calibration
→ Used for Luminosity measurements



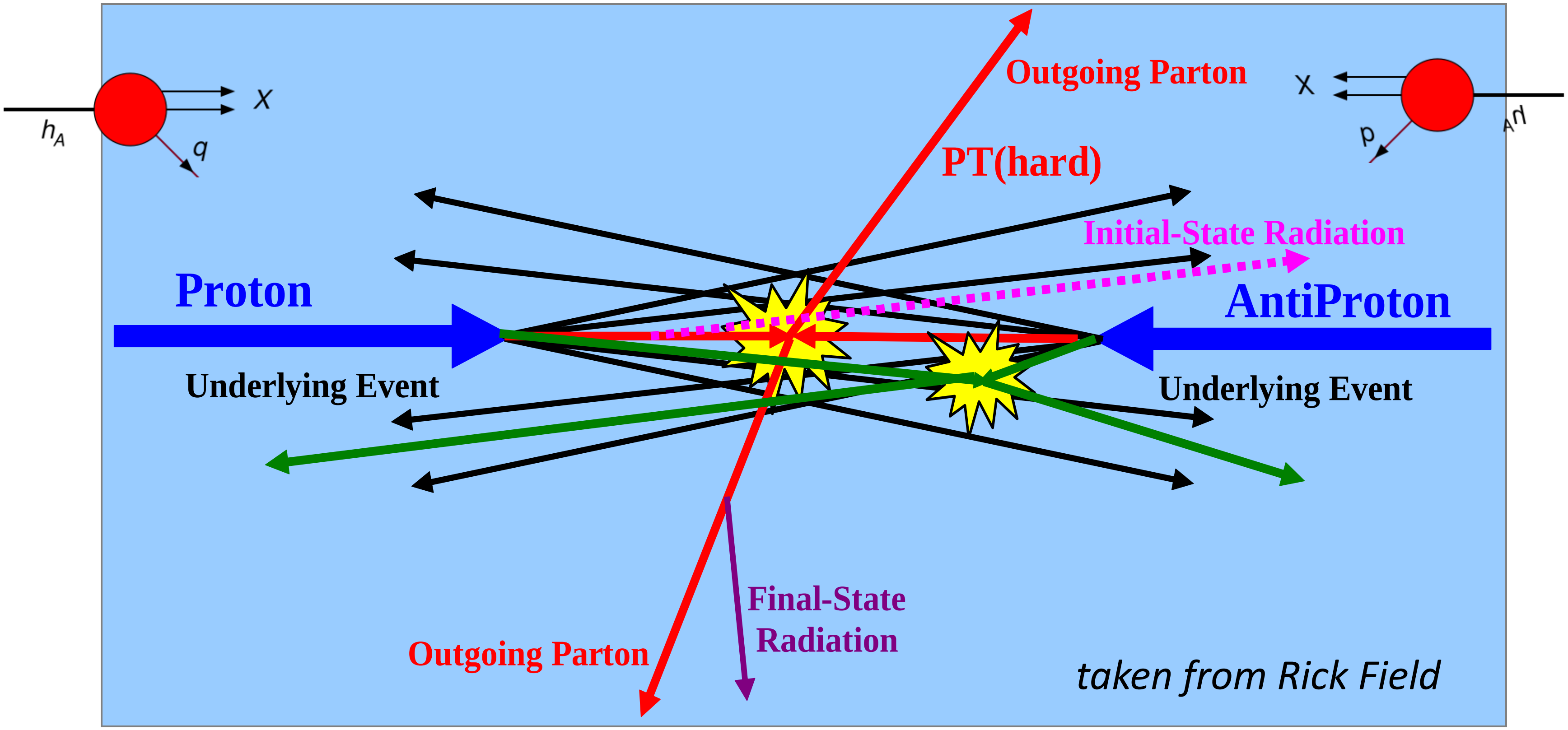
Drell-Yan Process: Z/W Production



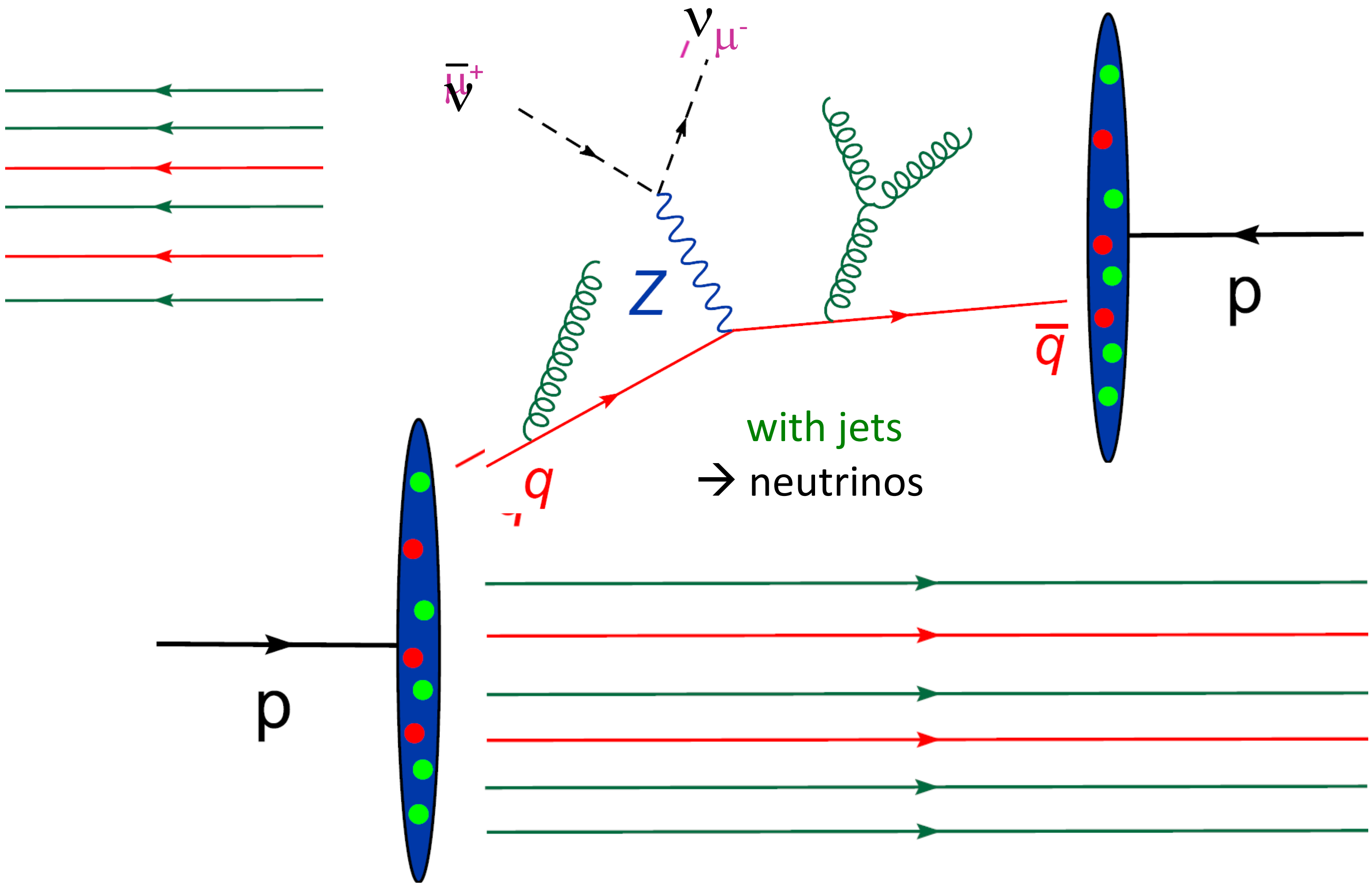
Non perturbative effects in the spectrum…

Scattering processes at hadron colliders:

A multi-layered problem

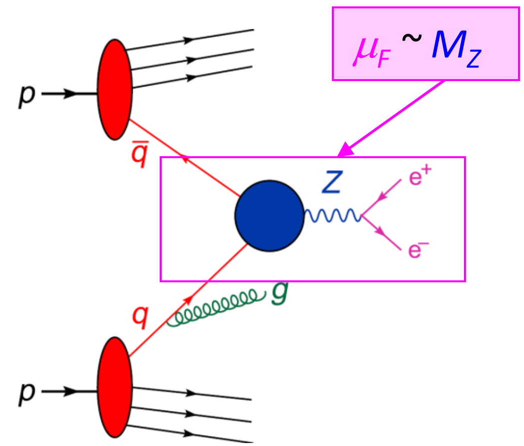


A Closer Look to the Hard Scattering



QCD Factorization & Parton Model

- Asymptotic freedom guarantees that at short distances (large transverse momenta), partons in the proton are almost free.
- Sampled "one at a time" in hard collisions.
  → QCD-improved parton model
  → Proven to all orders for Drell-Yan Processes (Collins, Soper, Sterman)



infrared safe final state

Parton distribution functions – known to ~ 4% for x ~ 0.01-0.1

factorization scale

$$\sigma^{pp\to X}(s;\alpha_s,\mu_R,\mu_F) = \sum_{a,b}\int_0^1 dx_1 \int_0^1 dx_2\, f_a(x_1,\alpha_s,\mu_F)\, f_b(x_2,\alpha_s,\mu_F) \times \hat{\sigma}^{ab\to X}(sx_1x_2;\alpha_s,\mu_R,\mu_F)$$

Partonic cross section, computable in perturbative QCD

partonic CM energy^2

renormalization scale

Partonic Cross Section in Perturbation Theory

$$\hat{\sigma}(\alpha_s, \mu_F, \mu_R) = [\alpha_s(\mu_R)]^{n_\alpha} \left[\hat{\sigma}^{(0)} + \frac{\alpha_s}{2\pi} \hat{\sigma}^{(1)}(\mu_F, \mu_R) + \left(\frac{\alpha_s}{2\pi}\right)^2 \hat{\sigma}^{(2)}(\mu_F, \mu_R) + \cdots \right]$$

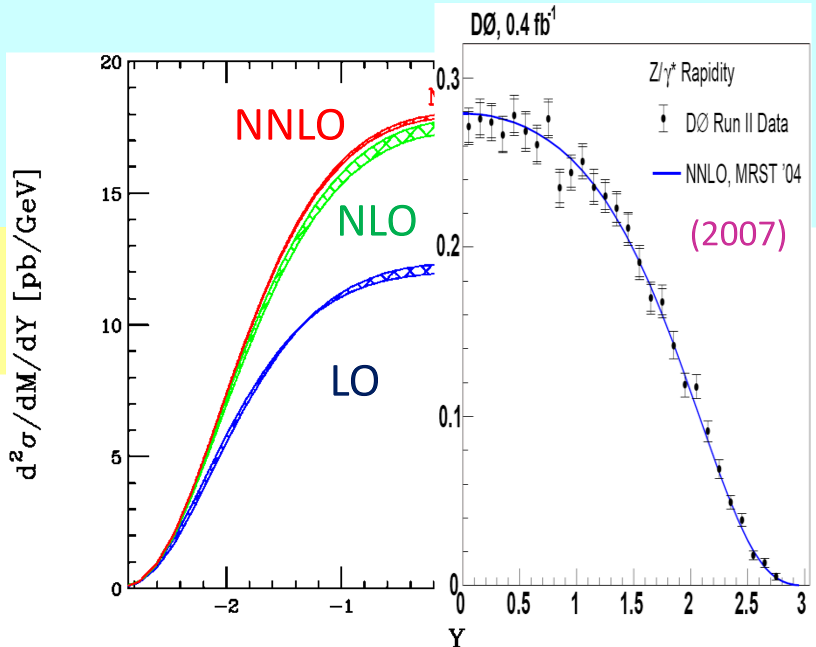
LO NLO NNLO

Problem: Leading-order, tree-level predictions only qualitative due to **poor convergence** of expansion in $\alpha_s(\mu)$ (setting $\mu_R = \mu_F = \mu$)

Example: *Z* production at Tevatron
Distribution in rapidity *Y*

$$Y = \frac{1}{2} \ln \left(\frac{E + p_z}{E - p_z} \right)$$

$$\frac{d\sigma}{dY} \quad \text{has} \quad n_\alpha = 0$$



still ~50% corrections, LO → NLO

[Anastasiou, Dixon, Melnikov, Petriello hep-ph/0312266]

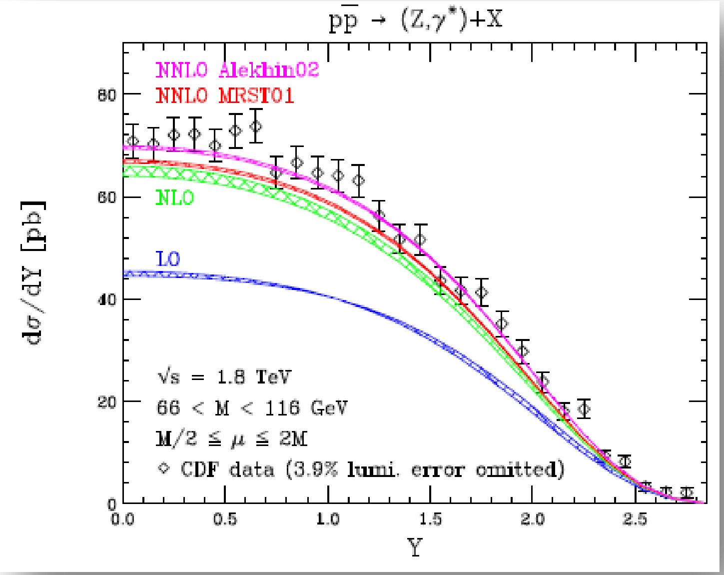
Drell-Yan Precision

→ Inclusive NNLO QCD corrections know for some time
→ Fully exclusive NNLO QCD results available
→ NLO Electroweak and QED corrections
→ Many efforts toward exact mixed EW-QCD and QED-QCD corrections…

Hamberg, van Neerven, Matsuura (1991)

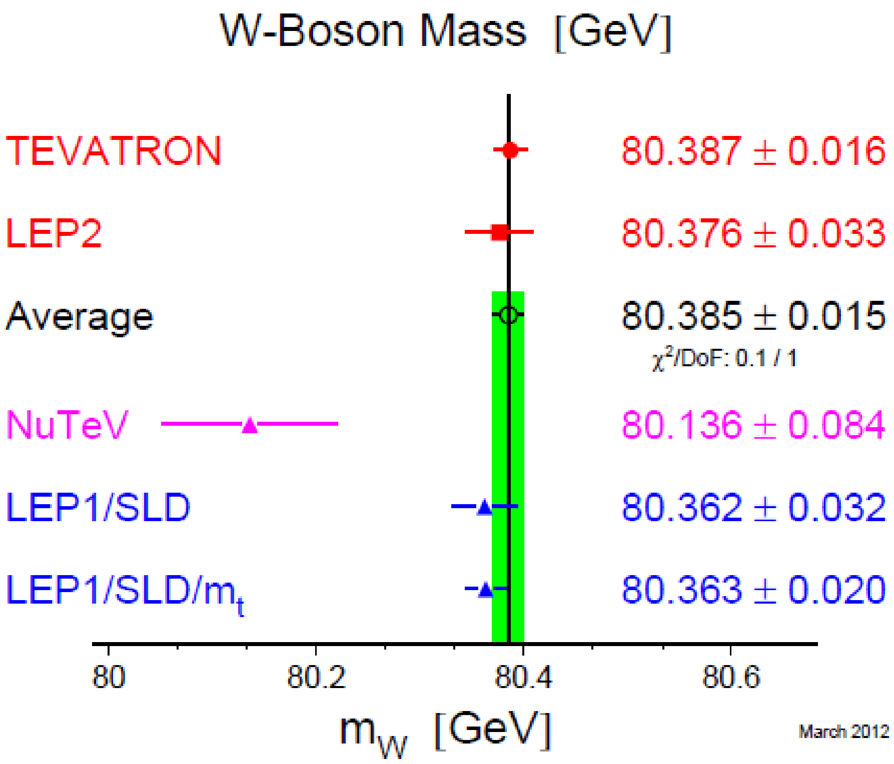
See for example: Gavin, Li, Petriello, Quackenbush (2012) ; Catani, Cieri, Ferrera, de Florian, Grazzini (2009)

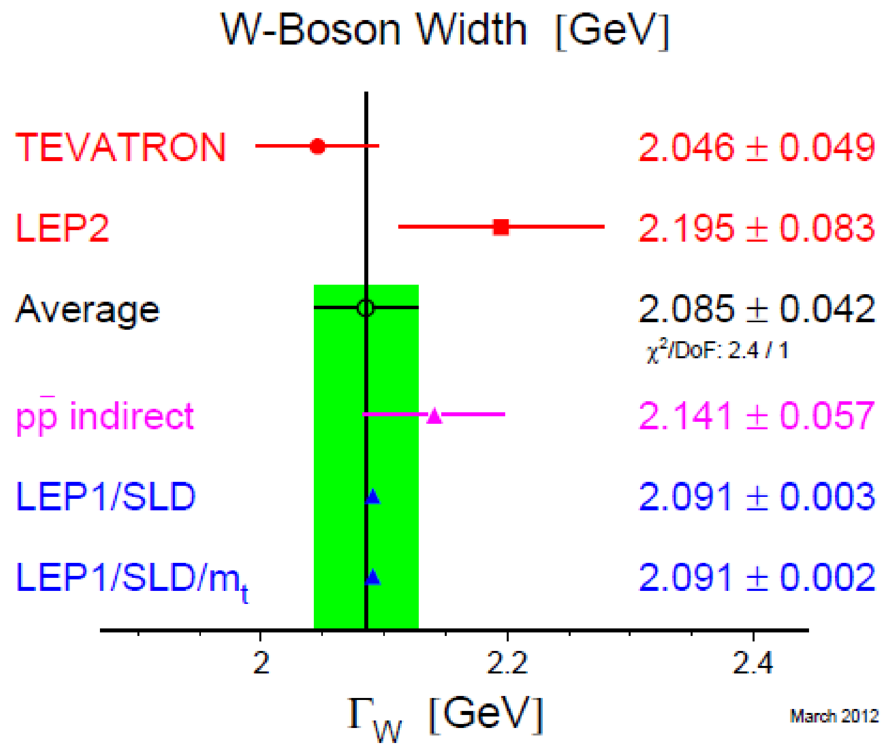
See for example: Baur, Keller, Wackeroth (1999) ; Dittmaier, Kramer (2002) ; Calame, Montagna, Nicrosini (2006)



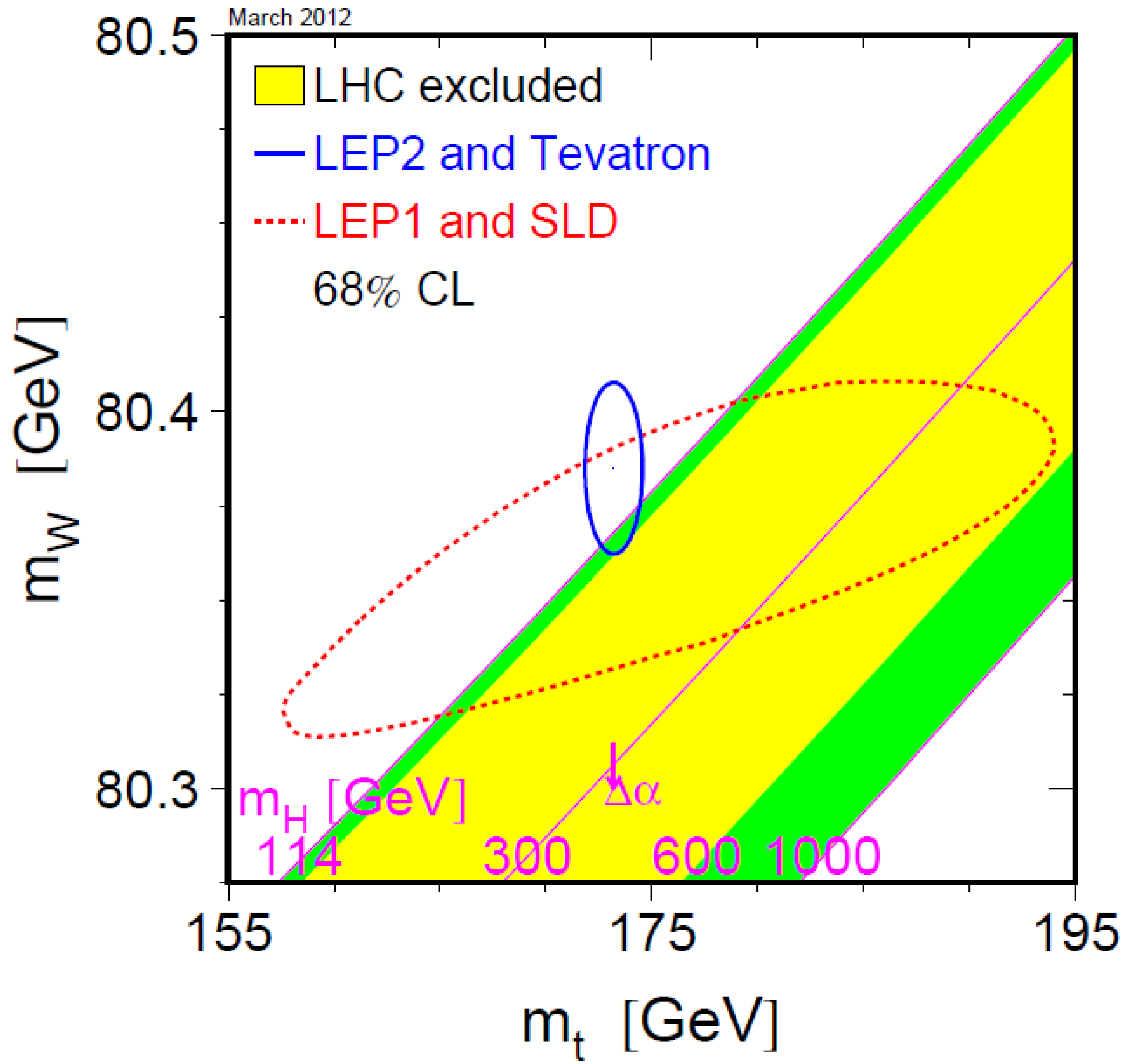
All this leaves the theory uncertainty for Drell-Yan observables at the few percent level!

Some Observables





mW vs mt



March 2012
80.5
80.4
80.3
LHC excluded
LEP2 and Tevatron
LEP1 and SLD
68% CL
m_W [GeV]
$\Delta\alpha$
m_H [GeV]
114
300
600
1000
155
175
195
m_t [GeV]

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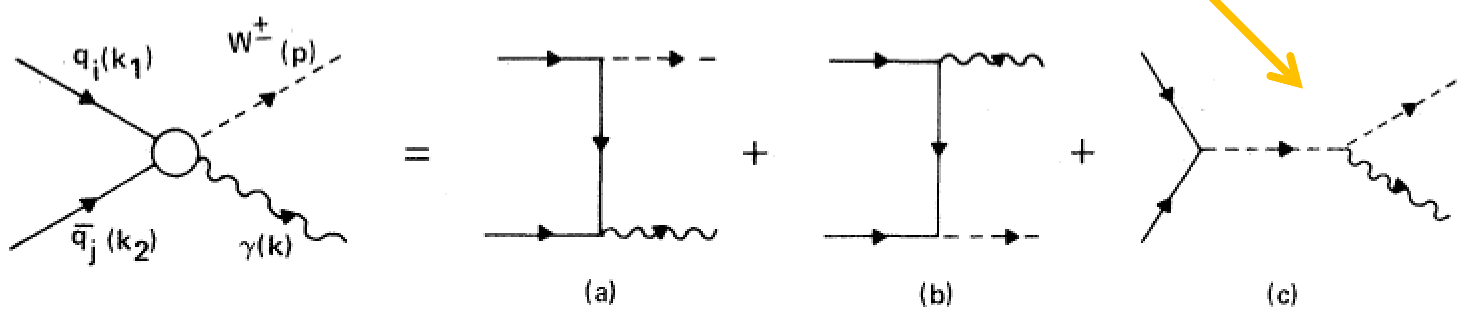
TESTING GAUGE STRUCTURE IN THE SM

$$q_i(k_1)\bar{q}_j(k_2) \to W^{\pm}(p)\gamma(k)$$

This process allows to measure the trilinear WWγ coupling

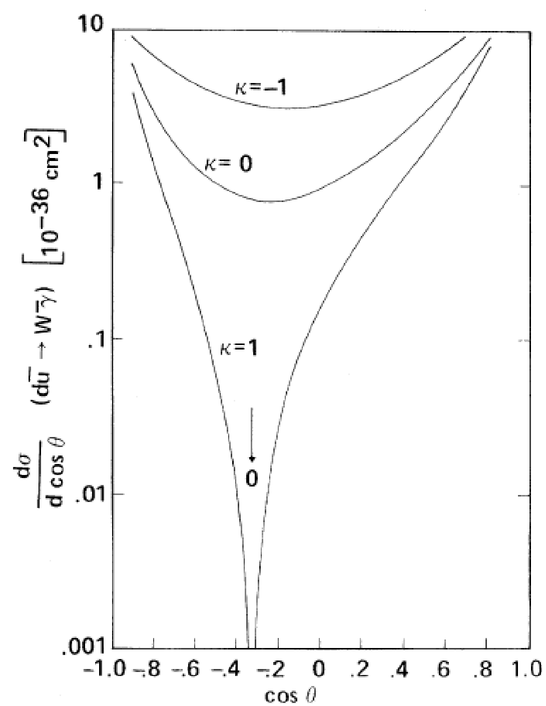


Mikaelian, Samuel, Sahdev; PRL 1979

First Born Level studies for measuring the *W* magnetic moment at hadron machine

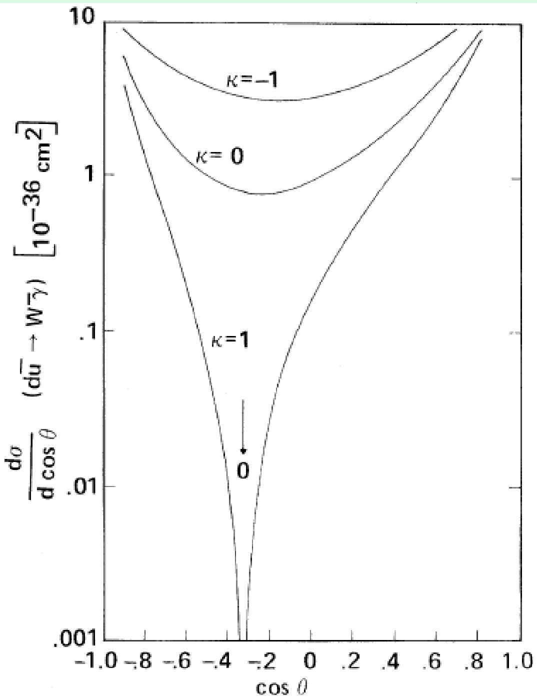
$$\mu_W = (e/2M_W)(1+\kappa)$$

In the SM κ = 1; κ ≠ 1 would be an aTGC



A CURIOUS RADIATION ZERO

Mikaelian, Samuel, Sahdev; PRL 1979



Θ is the angle between W^- and *d*

For *cos* θ = - 1/3 ; the diff cross section vanishes!

Goebel, Halzen, Levielle; PRD 1981

Actually the amplitude vanishes, due to factorization properties!

Indeed they prove that by general properties (mom conservation, on-shellness, charge conservation) 4-point gauge amplitudes can be arranged in forms like:

$$A = (Q_1 u - Q_2 t)\left[\frac{(p_2 \cdot \epsilon)t - (p_1 \cdot \epsilon)u}{stu}\right]$$

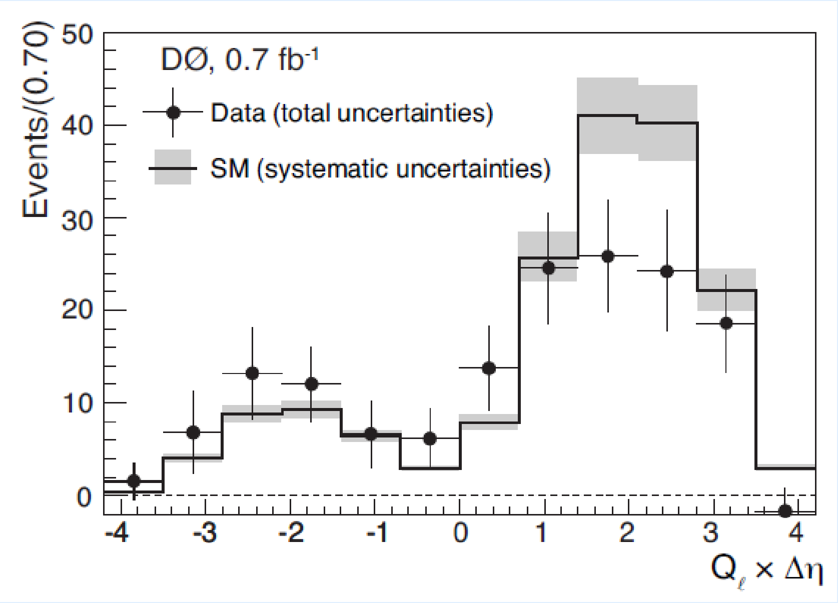
!!!

Bern, Carrasco, Johansson ; arXiv:0805.3993

Almost 3 decades later, the "spatial generalized Jacobi identity" used by GHL in their study, would be generalized to higher point amplitudes within the so called BCJ identities: Useful tool for gauge and gravity amplitudes!

RADIATION AMPLITUDE ZERO MEASURED!

At the hadron level the RAZ shows as a dip in the (η_e-η_γ) distribution. QCD corrections reduce slightly its size. Possible aTGCs basically wash it out.



D0 (**arXiv:0803.0030**) has made a dedicated RAZ study with a 0.7 fb^{-1} data set

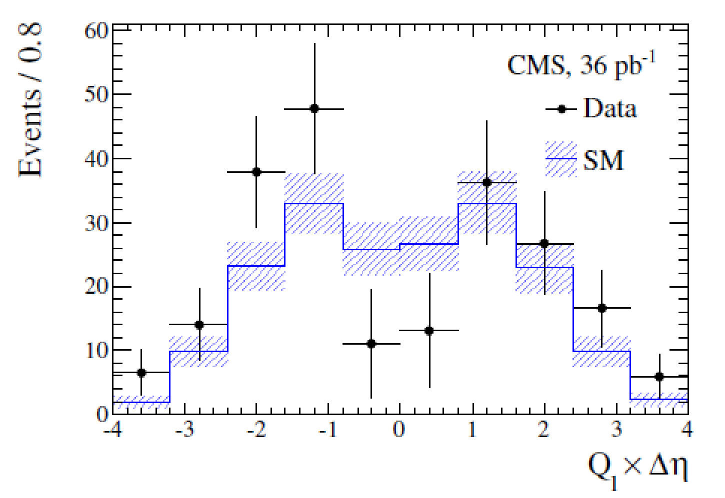
They get a 2.6σ significance for its measurement

Also constrained (CP-conserving) aTGCs to be in the ranges (consistent with the SM):

$$0.49 < \kappa_\gamma < 1.51$$

$$-0.12 < \lambda_\gamma < 0.13$$

OTHER RECENT Wγ AND Zγ MEASUREMENTS



CMS (**arXiv:1105.2758**) has made Wγ and Zγ measurement with a 36 pb^{-1} data set

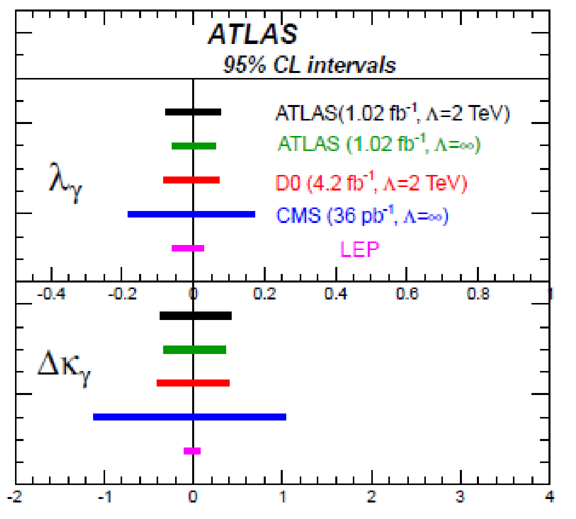
They see agreement with the SM prediction of a RAZ

Constrained (CP-conserving) aTGCs (WWγ, ZZγ and Zγγ)

ATLAS (**arXiv:1106.1592, arXiv:1205.2531**) has made Wγ and Zγ measurement with a 1.02 fb^{-1} data set

Made a dedicated study of total and diff cross sections

Discusses Wγ / Zγ ratios. Don't show RAZ study.



QUANTUM CORRECTIONS TO Wγ and Zγ PRODUCTION

Original work on the impact of QCD corrections in Wγ production was performed by Smith, Thomas and van Neerven in the late 80's

Smith, Thomas, van Neerven; Z.phys.C 1989

Ohnemus also studied Wγ and added QCD corrections to Zγ production

Ohnemus; PRD 1991

Studies of QCD corrections for general TGCs

Baur, Han, Ohnemus; PRD 1993

Fully differential studies at NLO

de Florian, Signer ; hep-ph/0002138

Fully differential (partial) Electroweak corrections

Hollik, Meier ; hep-ph/0402281
Accomando, Denner, Meier ; hep-ph/0509234

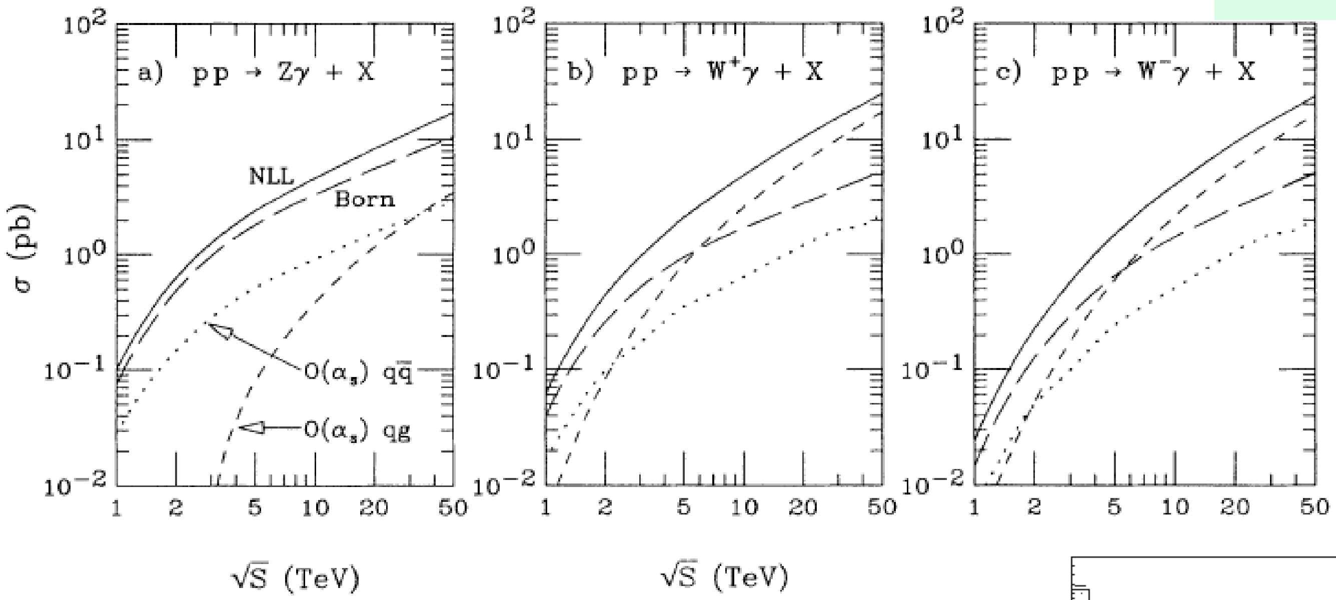
Recent update on general Vector Boson Pair production (including γ radiation from leptons)

Campbell, Ellis, Williams; arXiv:1105.0020

INCLUDED INTO MCFM (v6.0): A PARTON LEVEL NLO MONTECARLO PROGRAM

QCD CORRECTIONS: BRIEF RECOUNT

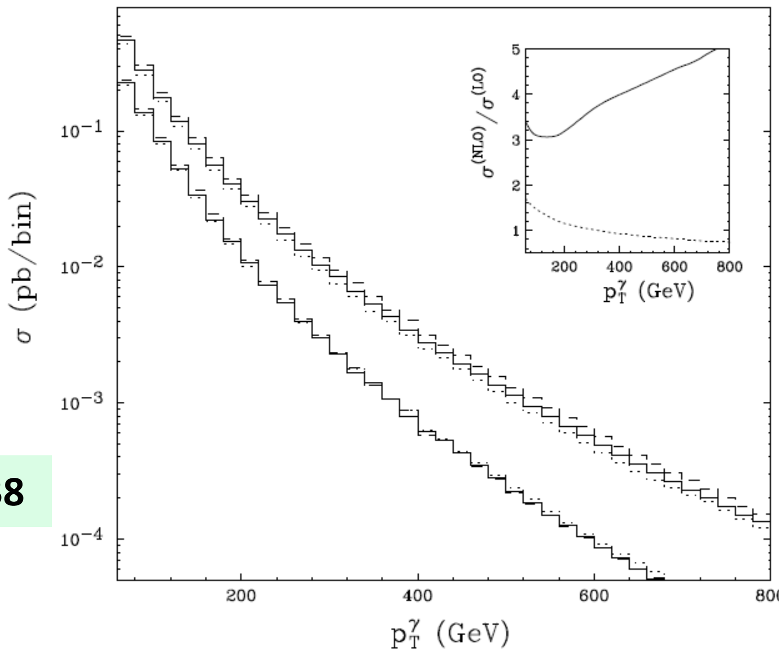
Ohnemus; PRD 1991



Corrections large, specially in Wγ with increased energy. Similar to Drell Yang effects

Considerable dependence of the corrections over PS (particularly over γ pT)

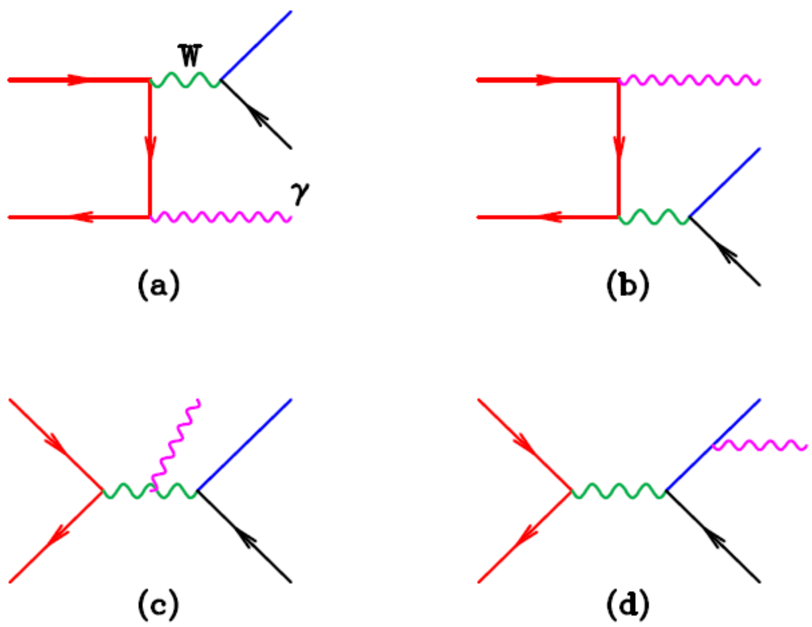
de Florian, Signer ; hep-ph/0002138



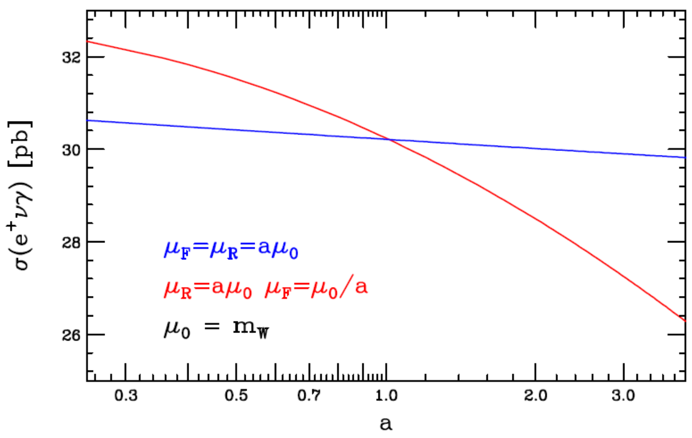
TOOLS: Wγ Production At The LHC

Campbell, Ellis, Williams; arXiv:1105.0020

Full set of tree level diagrams for $W(\to \ell\nu)\gamma$ production



And we get the typical theory plot:

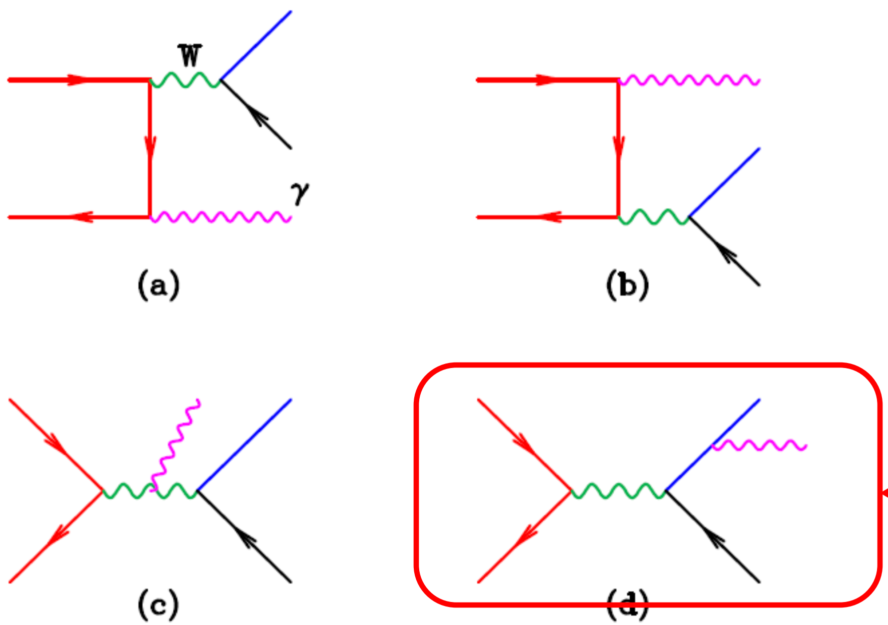


But we might be interested into learn much more than just scale dependence!!!

TOOLS: *Wγ Production At The LHC*

Campbell, Ellis, Williams; arXiv:1105.0020

Full set of tree level diagrams for $W(\to \ell\nu)\gamma$ production



For example: which sort of impact has in the quantum corrections the inclusion of (photon) “FSR” associated with this tree level diagram ???

CEW show a study like this and obtain the following:

TOOLS: Wγ Production At The LHC

Campbell, Ellis, Williams; arXiv:1105.0020

APPLY THESE DIFFERENT SET OF CUTS

$$\text{Basic Photon}: p_T^\gamma > 10 \text{ GeV}, \ |\eta_\gamma| < 5, \ R_{\ell\gamma} > 0.7, \ R_0 = 0.4, \ E_T^{max} = 3 \text{ GeV}.$$

$$M_T \text{ cut}: \text{Basic Photon} + M_T > 90 \text{ GeV}.$$

$$\text{Lepton cuts}: M_T \text{ cut} + E_T^{\text{miss}} > 25 \text{ GeV}, \ p_T^\ell > 20 \text{ GeV}, \ |\eta_\ell| < 2.5.$$

AND LOOK AT THE TOTAL RATES:

Decay	Cuts	$\sigma^{LO}(e^+\nu\gamma)$	$\sigma^{NLO}(e^+\nu\gamma)$
No FSR	Basic γ	4.88	8.74
	M_T cut	1.99	3.78
	Lepton cuts	1.49	2.73
Full	Basic γ	23.0	30.1
	M_T cut	2.12	3.94
	Lepton cuts	1.58	2.85

INTRODUCTION

Vector Bosons in the SM, Weak Currents, TGCs

DRELL-YAN PROCESSES

Clean Signals at HC's, Factorization, Precision Observables

PAIR PRODUCTION

V+gamma, Radiation Zero, Quantum Corrections, Tools

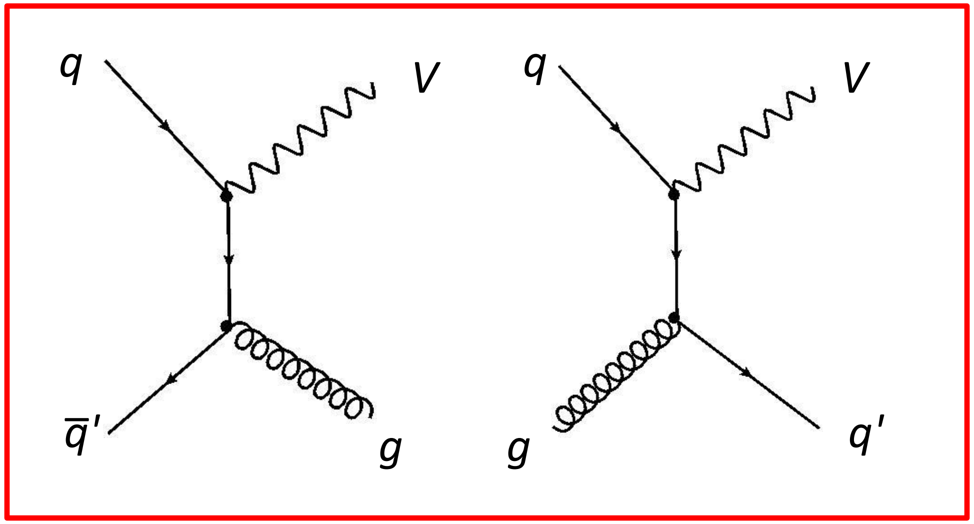
ASSOCIATE PRODUCTION WITH JETS

Jets, V+Jets at Tevatron & LHC, Polarization

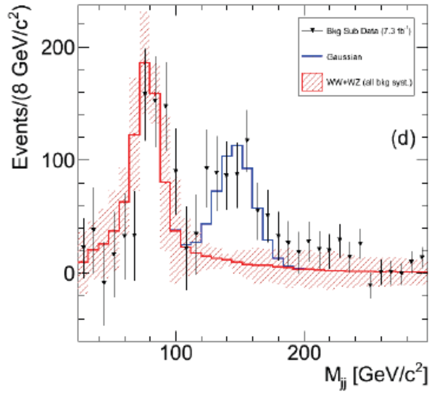
V Production in Association with Jets

→ More exclusive processes involving Weak Vector Bosons
→ Of key importance for testing both the SM and collider detectors
→ Associated to many signals of BSM
→ Important progress in tools for precise studies in W+1 jet at NNLO QCD and for NLO QCD correction with large jet multiplicity

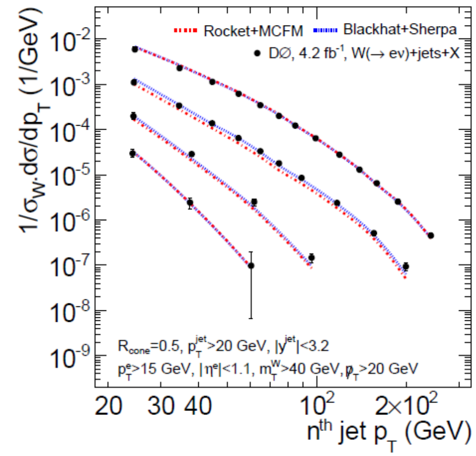
Leading diagrams:



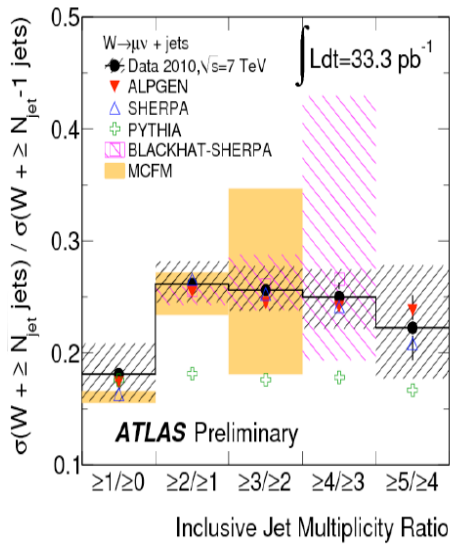
V+JETS: A IMPORTANT SIGNAL



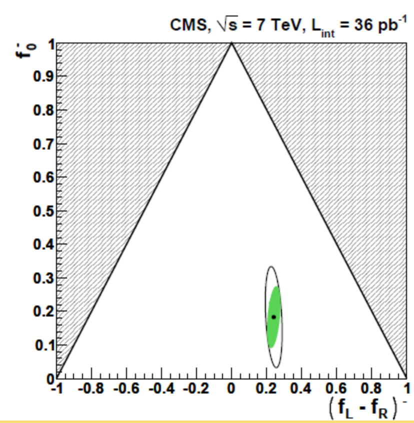
CDF Bump



D0 W+Jets Measurement
arXiv:1106.1457



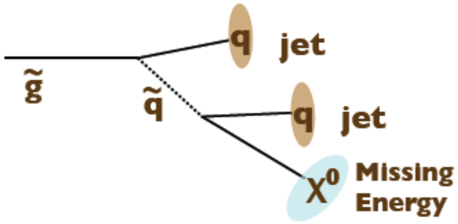
Atlas Jet Ratios



CMS Pol Measurement
arXiv:1104.3829

V + Jets at NLO for SUSY Searches

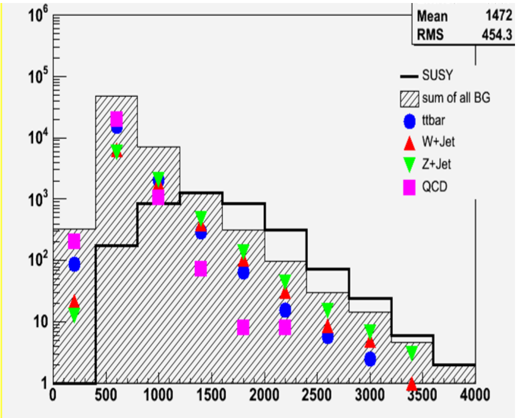
Gluino pair production with:



Mangano [arXiv:0809.1567]

$W^+ + 3\ \text{jet}$ followed by: $W^+ \rightarrow \bar{\tau}\nu_\tau \rightarrow \bar{\nu}_\tau\nu_\tau + \text{hadrons}$

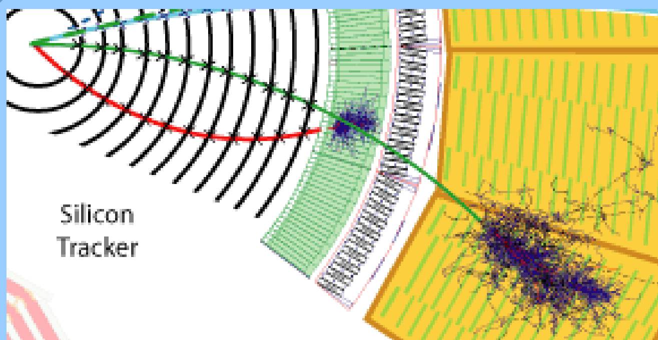
$Z\ +\ 4\ \text{jet}$ followed by: $Z \rightarrow \nu\bar{\nu}$



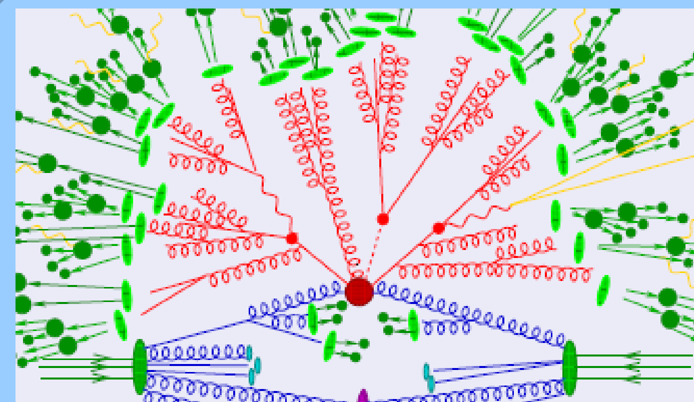
ATLAS simulation for missing ET + Jets signal

Jets

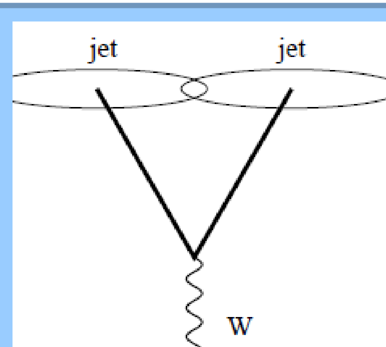
- Definition of complex objects



Detector towers



Shower simulations



Parton level calculations

Jets: Cones vs. Recombination

- ✓ Cone algorithms
  - ✓ Intutitive, clear jet structure
  - ✗ Complicated; problems with IR safety
  - ✓ Solved by SiSCone

Salam, Soyez [arXiv:0704.0292]

- ✓ Recombination algorithms (k_T etc)
  - ✓ Simple, IR safe
  - ✗ Messy jet structure
  - ✓ Solved by anti-k_T

Cacciari, Salam, Soyez [arXiv:0802.1189]

IR Safe Jet Algorithms

In the past, performance of implementations of IR safe jet algorithms, kept them away from practical use at hadron colliders: for example with the "standard" N^3 scaling of the kt algorithm, or the naive 2^N of seedless cone algorithms

Great progress in recent years:

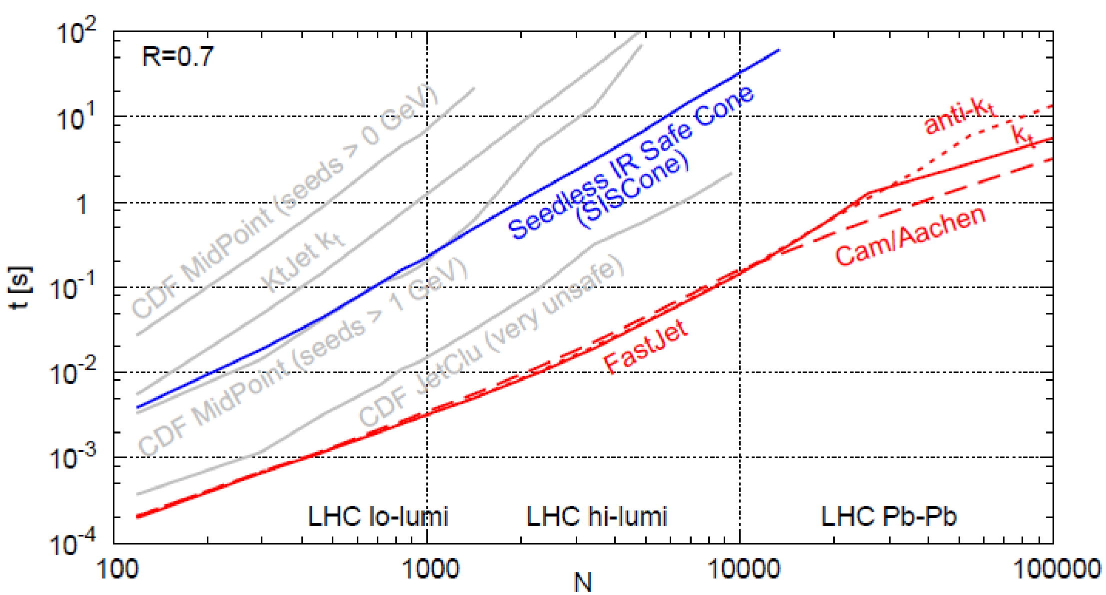
- Sequential recombination algorithms as kt / Cambrige-Aachen / anti-kt have been implemented with *N ln (N)* scaling [Cacciari, Salam hep-ph/0512210]
- A seedless infrared safe cone algorithm, SISCone, has appeared with *N^2 ln (N)* scaling [Salam, Soyez arXiv:0704.0292]

Available within FatJet http://fastjet.fr

Some typical event multiplicities at colliders:

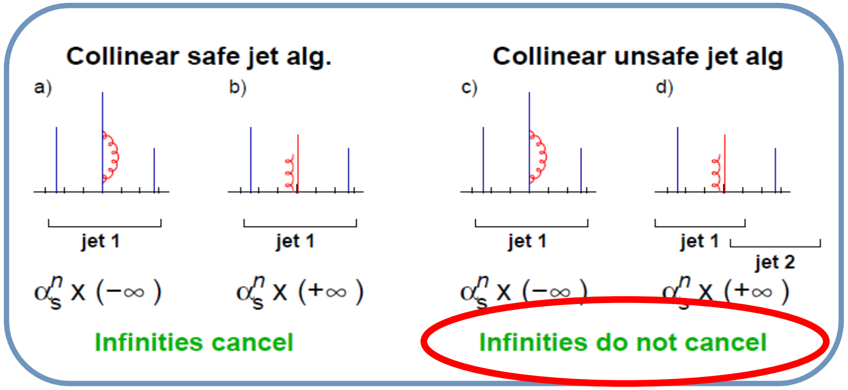
Type of event	N
e^+e^- event on the Z peak	50
Tevatron ($\sqrt{s} = 1.96$ TeV) dijet event	200
LHC ($\sqrt{s} = 14$ TeV) dijet event	500
LHC low-luminosity event (5 pileup collisions)	1000
LHC high-luminosity event (20 pileup collisions)	4000
RHIC Au Au event ($\sqrt{s} = 200$ GeV/nucleon)	3000
LHC Pb Pb event ($\sqrt{s} = 5.5$ TeV/nucleon)	30000

[Salam arXiv:0906.1833]

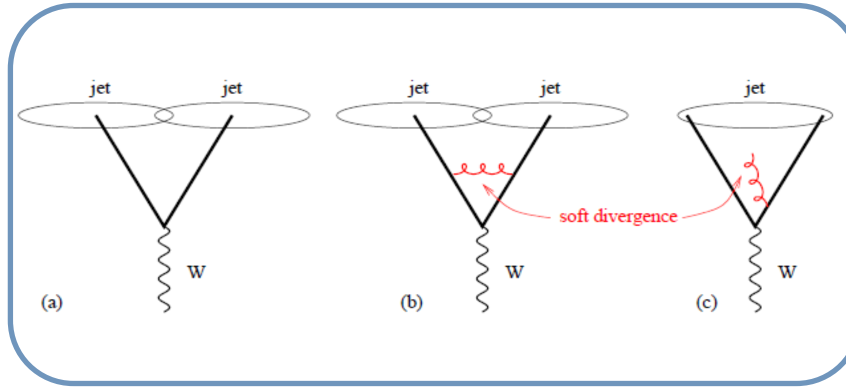


The need of IR safety

Collinear Configuration



Soft Configuration



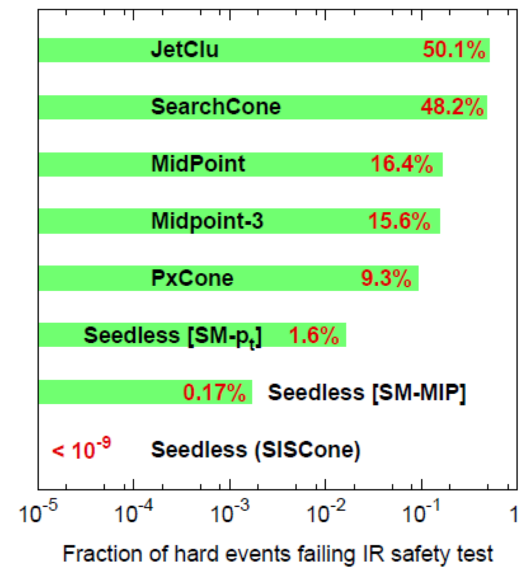
→ IRC unsafety makes data / pertubative calculation comparison hard (if at all meaningful)

→ Indeed, quantum corrections become useless for large enough multiplicity!

[Salam, Soyez arXiv:0704.0292]

Observable	1st miss cones at	Last meaningful order
Inclusive jet cross section	NNLO	NLO
$W/Z/H + 1$ jet cross section	NNLO	NLO
3 jet cross section	NLO	LO
$W/Z/H + 2$ jet cross section	NLO	LO
jet masses in 3 jets, $W/Z/H + 2$ jets	LO	none

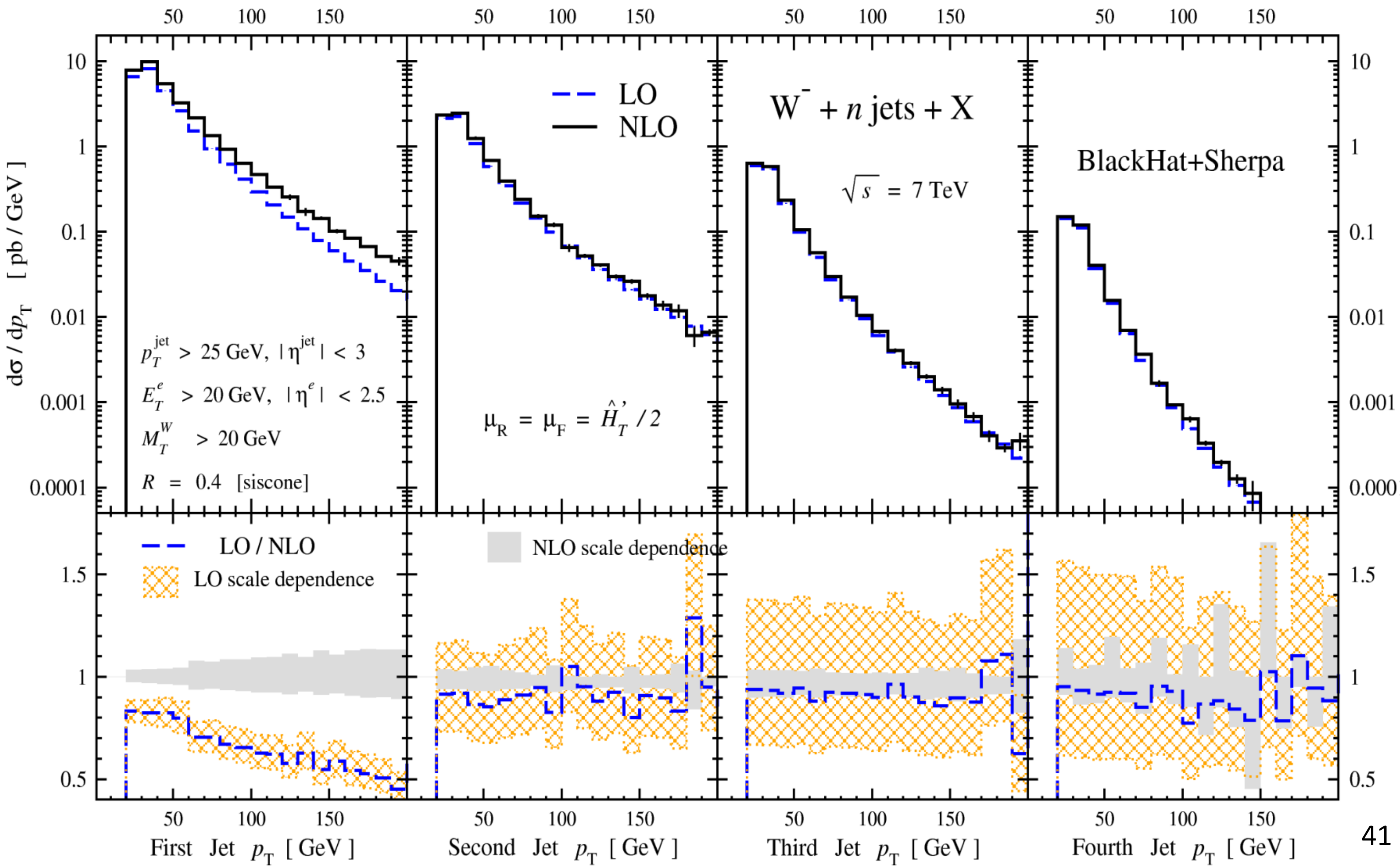
Testing IR safety of some commonly used cone algorithms



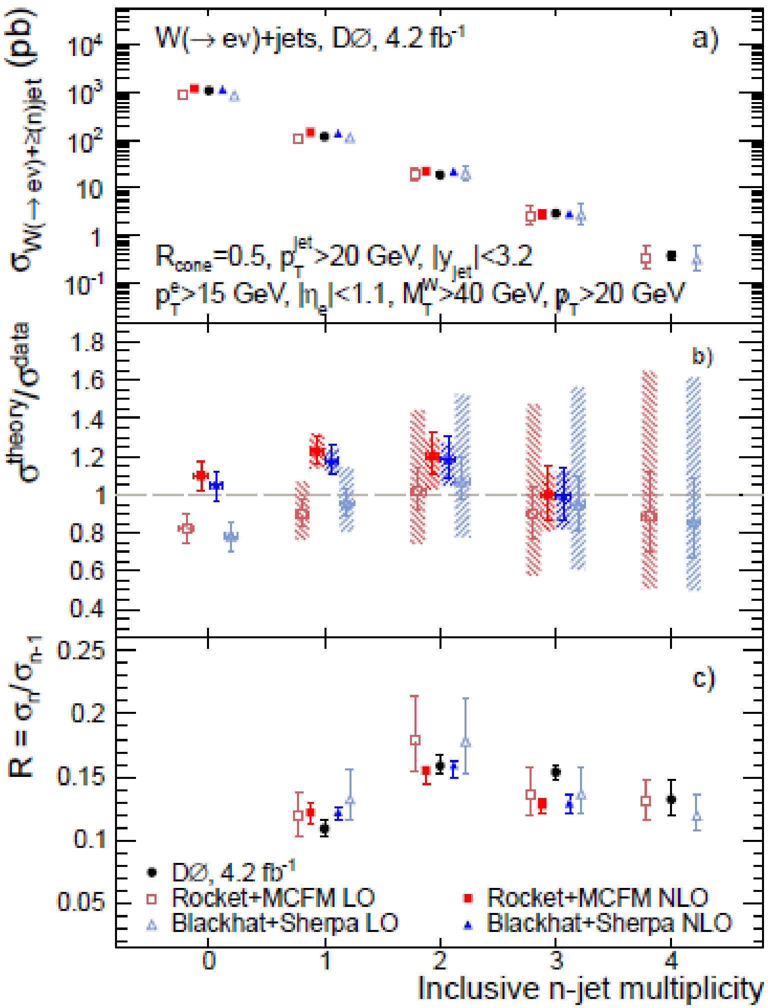
Both ATLAS and CMS use IR safe algorithms in their analyses!

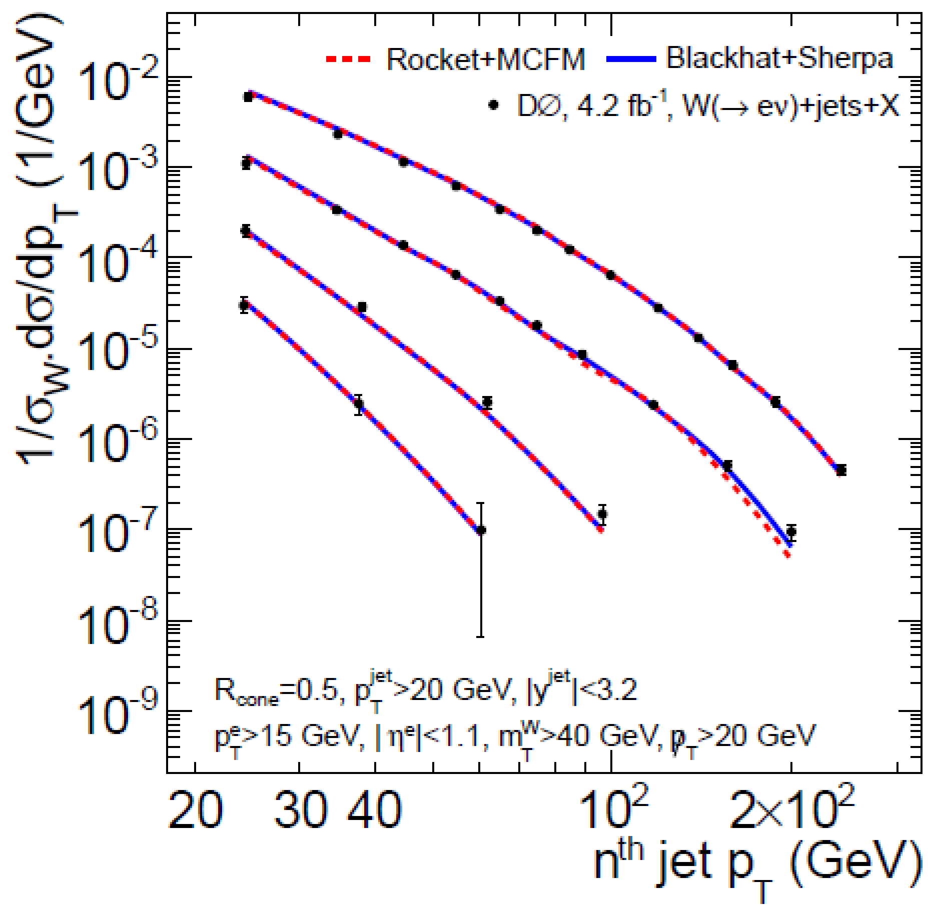
pp → W + 1,2,3,4-jets

W^- + n-jet + X softest jet p_T



W+Jets at the Tevatron



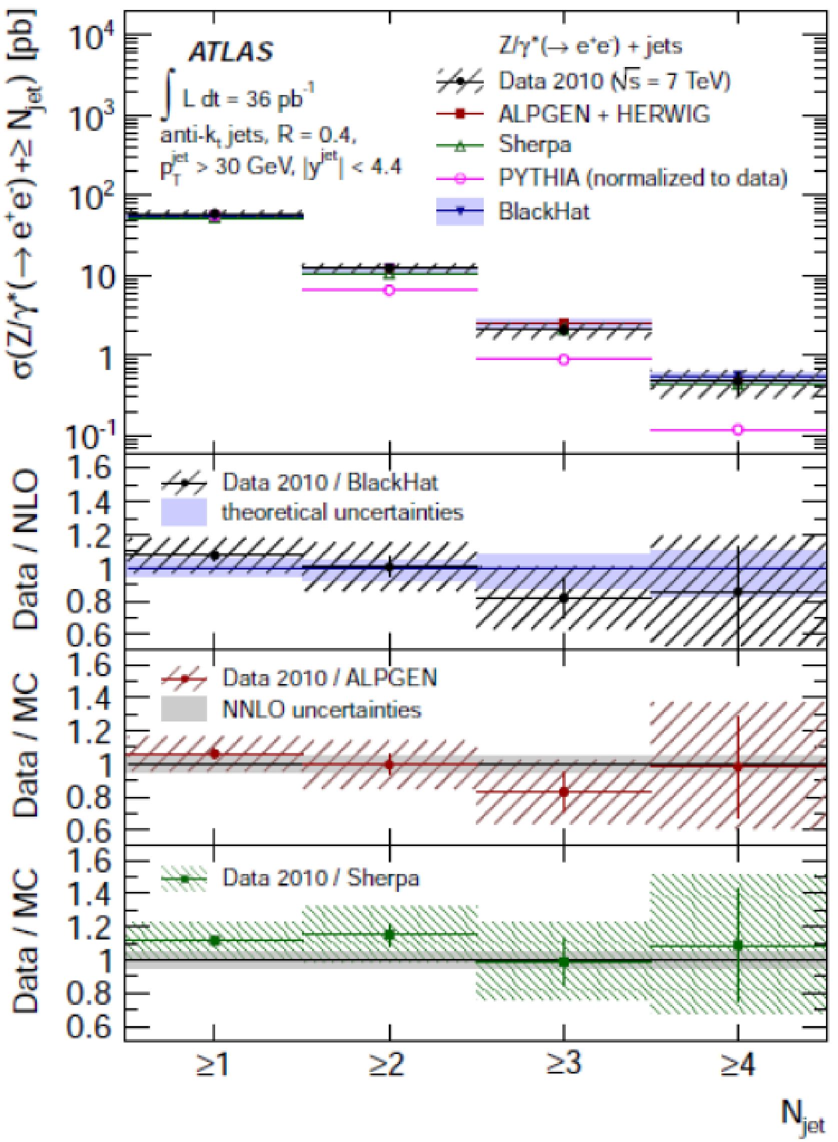


arXiv:1106.1457 [hep-ex]

Z+Jets at the LHC

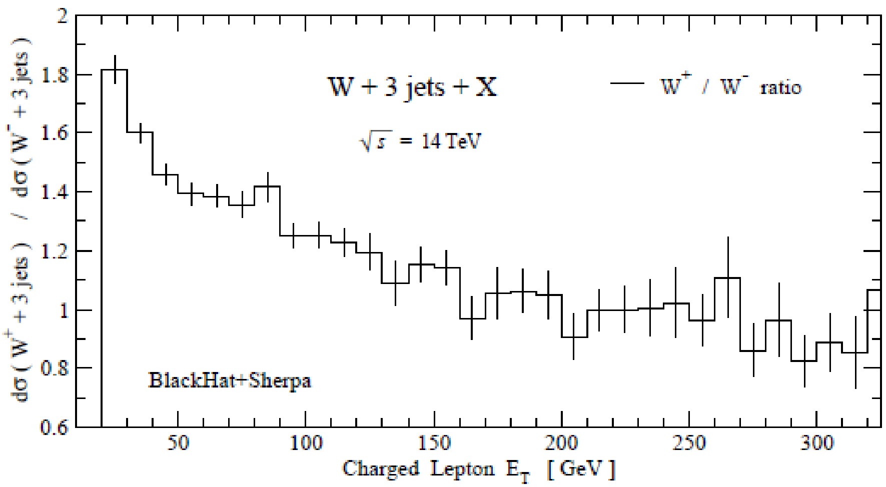
- 36 pb-1
- Inclusive cross section for each Multiplicity
- Good agreement of NLO with the data all the way to four jets

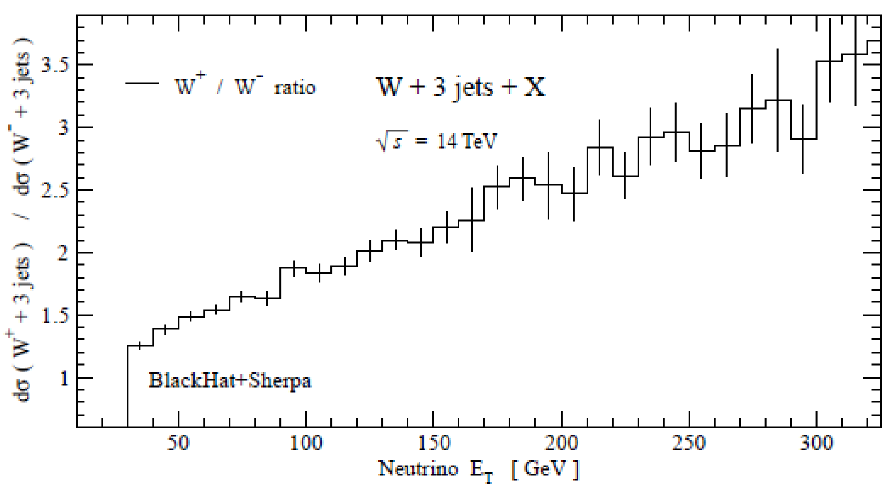
ArXiv:1111.2690



Leptonic E_T in W + 3 jets at LHC

[Berger, et al arXiv:0907.1984]





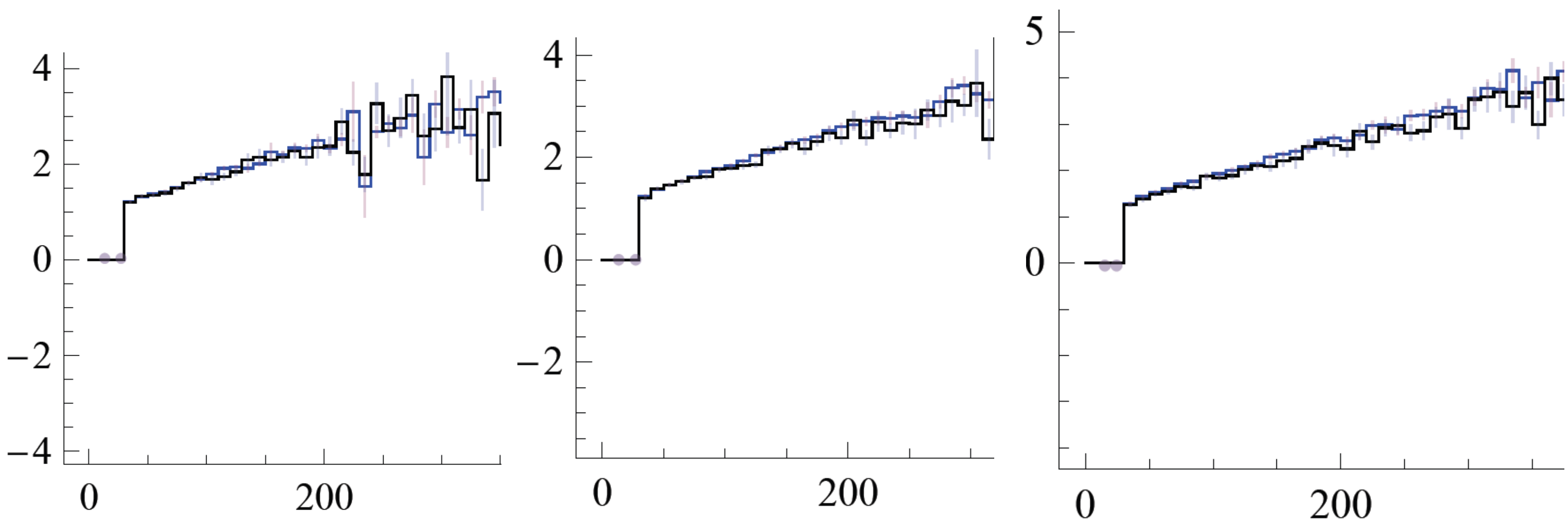
W^+/W^- transverse lepton ratios trace a remarkably large and stable left-handed W polarization at large $p_T(W)$

– independent of number of jets

– useful to separate W + n jets from top, maybe also from new physics

$W^{+/-}$ + n jets: Neutrino E_T

NLO LO



1 jet 2 jets 3 jets

Effect independent of multiplicity! Almost no difference from NLO and LO!

Similarly for charged lepton E_T

Top quark pairs very different

Main production channels are CP invariant:

$$gg \to t\bar{t} \qquad q\bar{q} \to t\bar{t}$$

Semi-leptonic decay involves (partially) left-handed W^+

$$t\bar{t} \to bW^+\bar{b}W^- \to b\,e^+\nu\,\bar{b}jj$$

But conjugate decay involves (same degree) right-handed W^-

$$t\bar{t} \to bW^+\bar{b}W^- \to bjj\,\bar{b}\,e^-\bar{\nu}$$

→ electron and positron have almost identical p_T distributions

→ A nice handle on separating *W*+jets from top

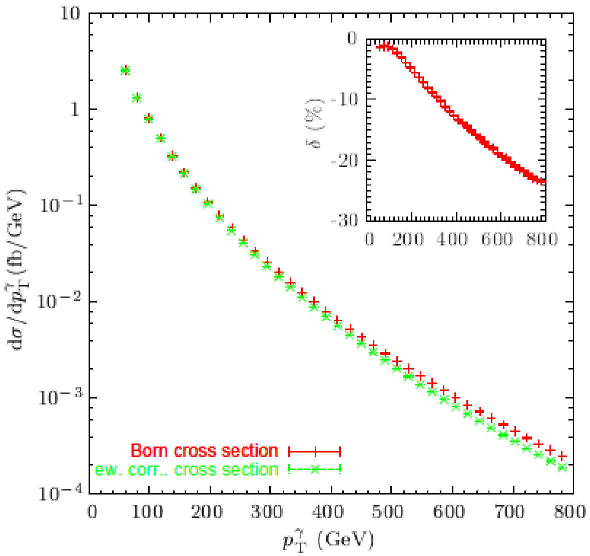
To be continued…

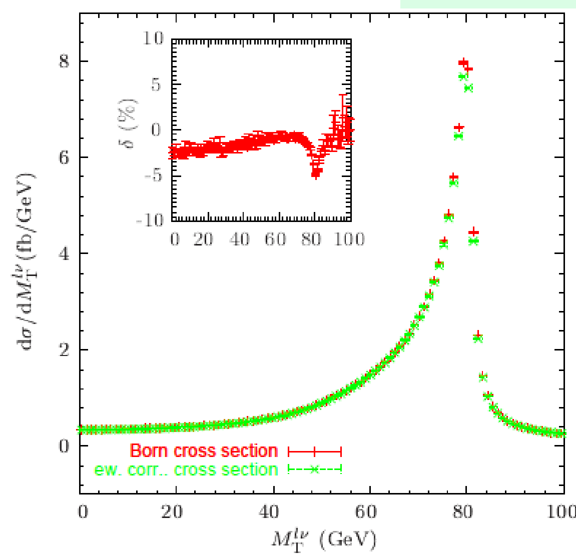
Few More Topics on Weak Vector boson production will also appear when we review tomorrow recent advancement on Higher Order Tools and Techniques…

Backup Slides…

ELECTROWEAK CORRECTIONS: BRIEF RECOUNT

Accomando, Denner, Meier ; hep-ph/0509234





Corrections moderate in Wγ ; in the order of -5% ; tend to increase when testing larger partonic CM energies

Similar observations for Zγ production.

Hollik, Meier ; hep-ph/0402281