CDF RESULTS on JETS and DIFFRACTION

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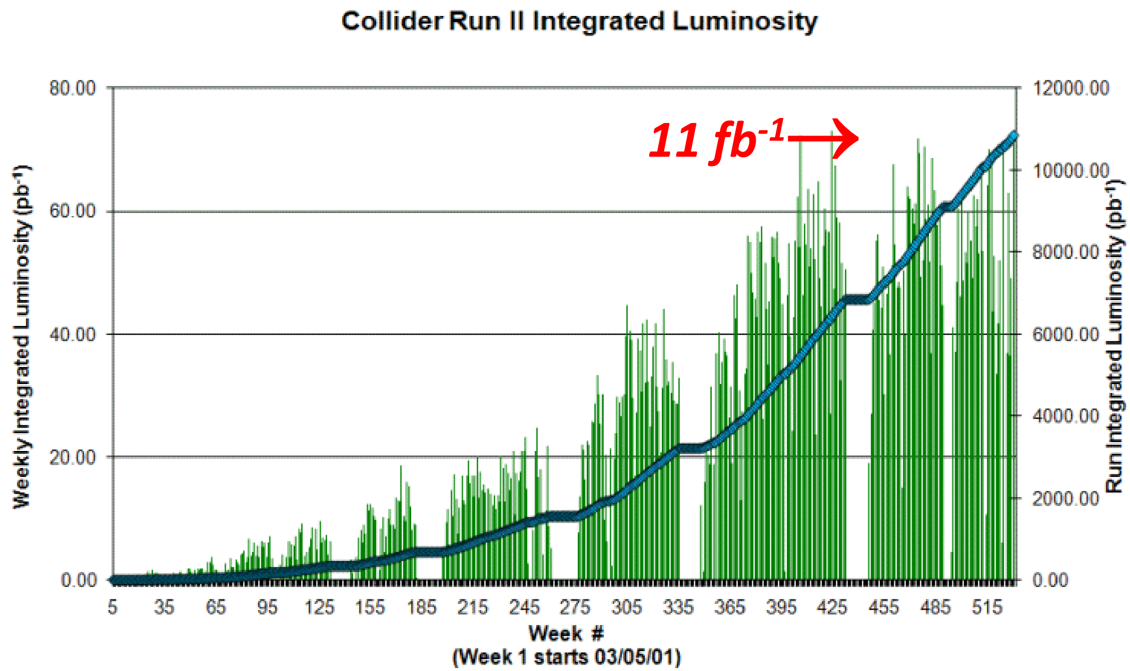
The Rockefeller University

Tevatron

Tevatron



Tevatron performing very well:

$50\ pb^{-1}$ per week

experiment efficiency ~90%

peak: $3.5 \times 10^{32}\ cm^{-2}s^{-1}$

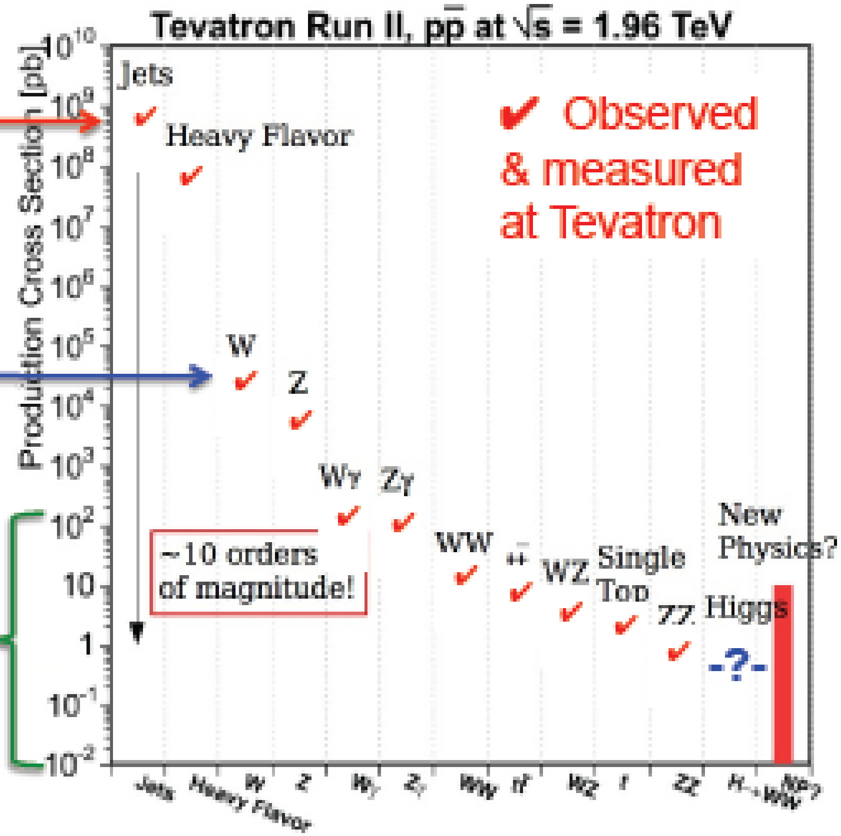
expecting $12\ fb^{-1}$ by end of FY11

SM Processes at the Tevatron

QCD jets

Inclusive
W production:
10-15% is W+jets

Dibosons,
t-quark, Higgs,
New Physics?



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   - Jet substructure studies
2. **VB+jets**
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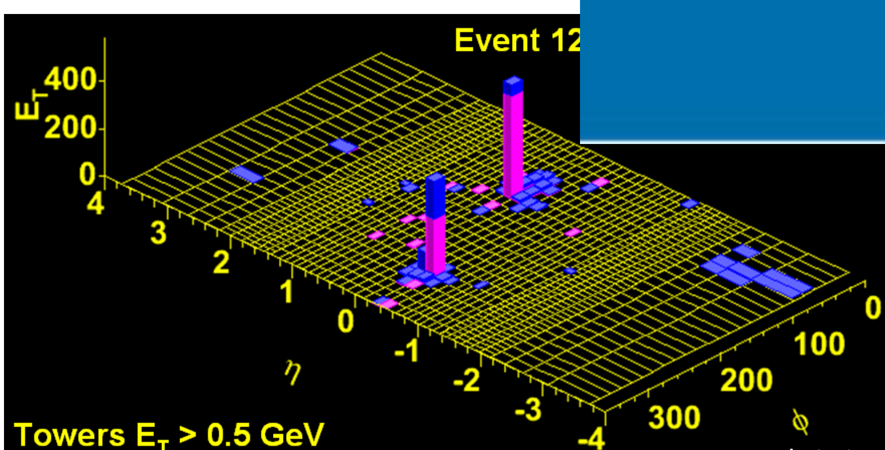
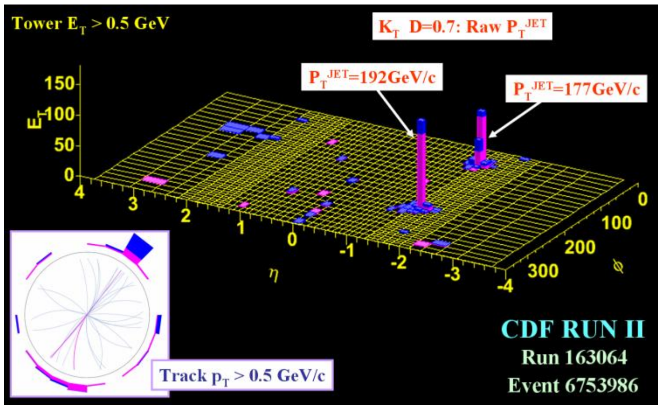
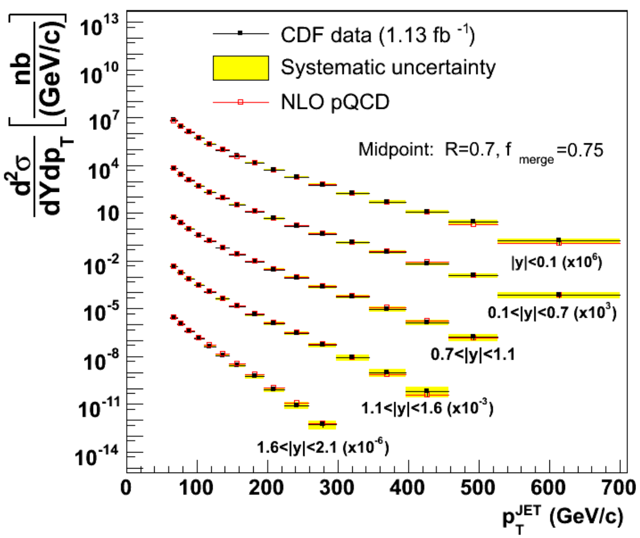
   - Z+jets
3. **VB+HF**
   - W+b
   - W+c
   - Z+b
4. **Diffraction**
   - W and Z
   - Exclusive Production – talk by Erik Brucken

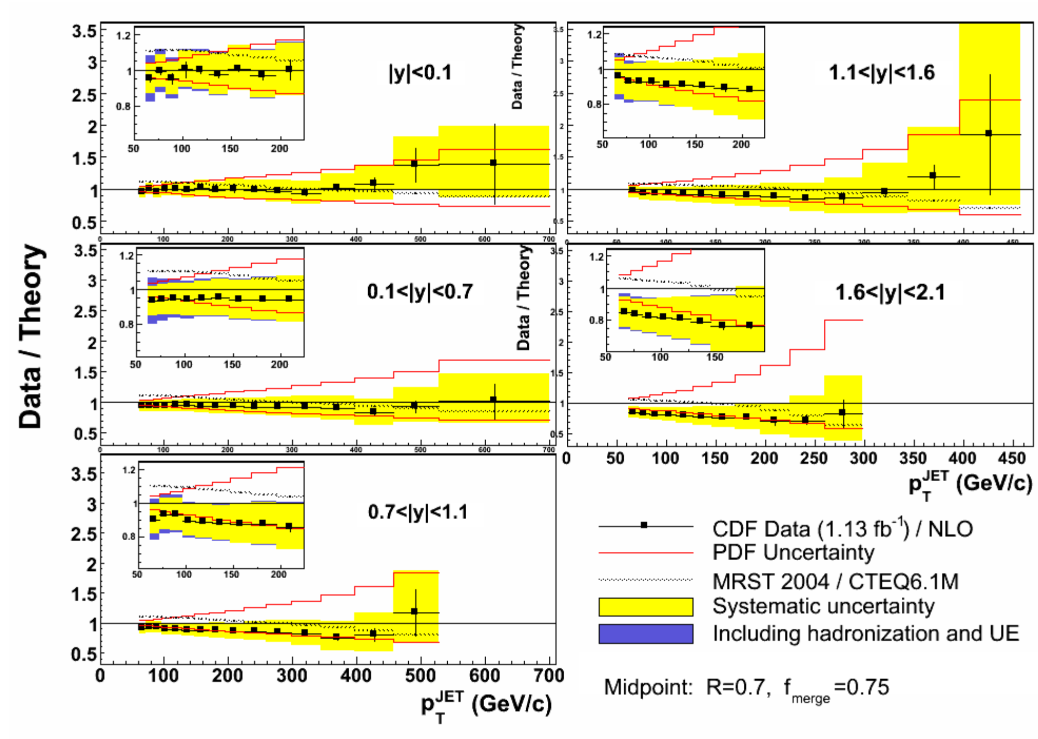

Which one is a jet
at the Tevatron?


Event 12
E_T
400
200
0
4
3
2
1
0
-1
-2
-3
-4
η
0
100
200
300
φ
Towers E_T > 0.5 GeV

Inclusive Jet Cross Section



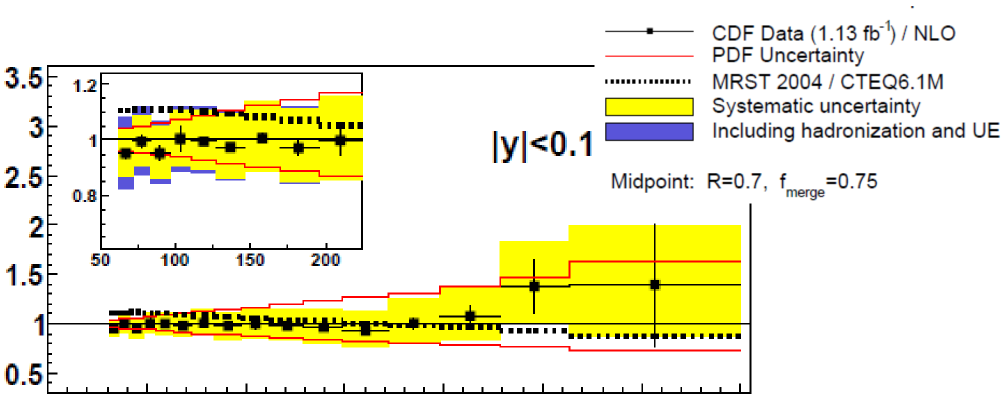


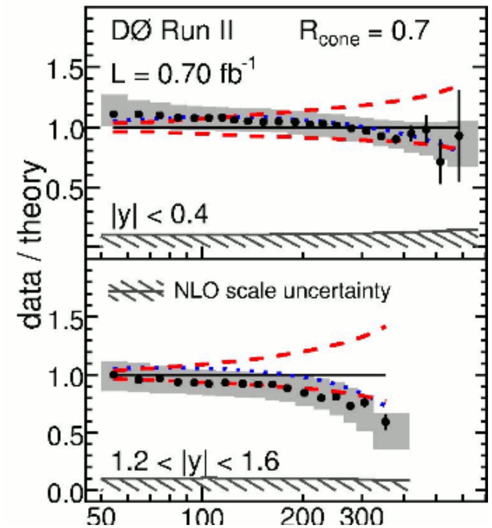


- Tests pQCD over 8 orders of magnitude
- highest p_T >600 GeV/c
- Measurement were done with 2 different clustering algorithms: Midpoint cone and k_T

Jet production –Precision regime

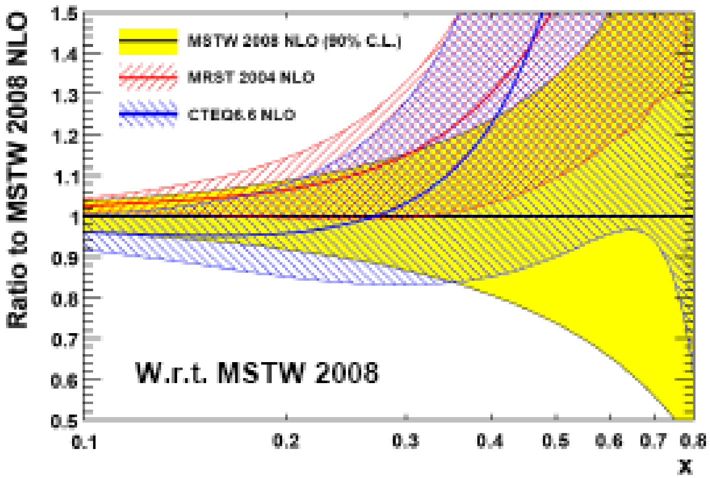
PDF input





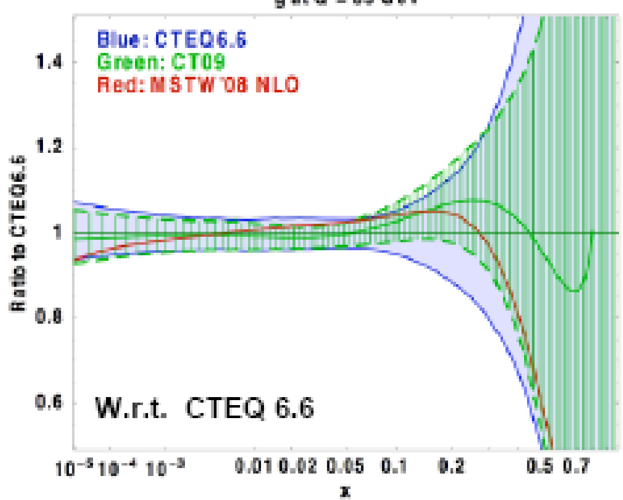
MSTW08: arXiv:0901.0002, Euro. Phys. J. C

Gluon distribution at $Q^2 = 10^4$ GeV^2



CT09: Phys.Rev.D80:014019,2009.

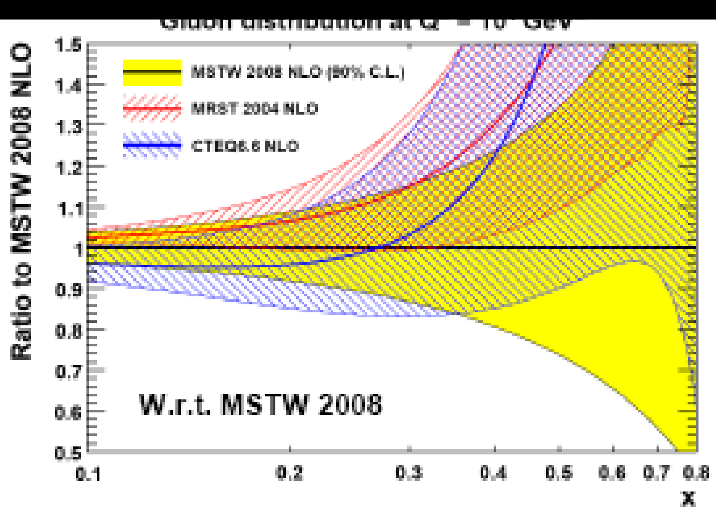
g at Q = 85 GeV

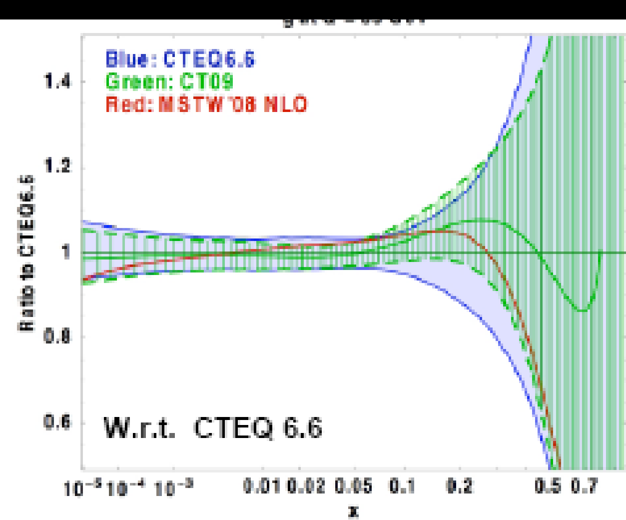


Jet production –Precision regime

PDF input

Conclusions from Les Houches QCD 2011:
“Tevatron jet data vital to pin down high-x gluon, giving smaller low-x gluon and therefore larger α_S in the global fit compared to a DIS-only fit.”





Jet production –Precision regime

PDF input

PDF sensitivity:

→ compare jet cross section at fixed

$x_T = 2\ p_T\ /\ sqrt(s)$

Tevatron (ppbar)

>100x higher cross section @ all x_T

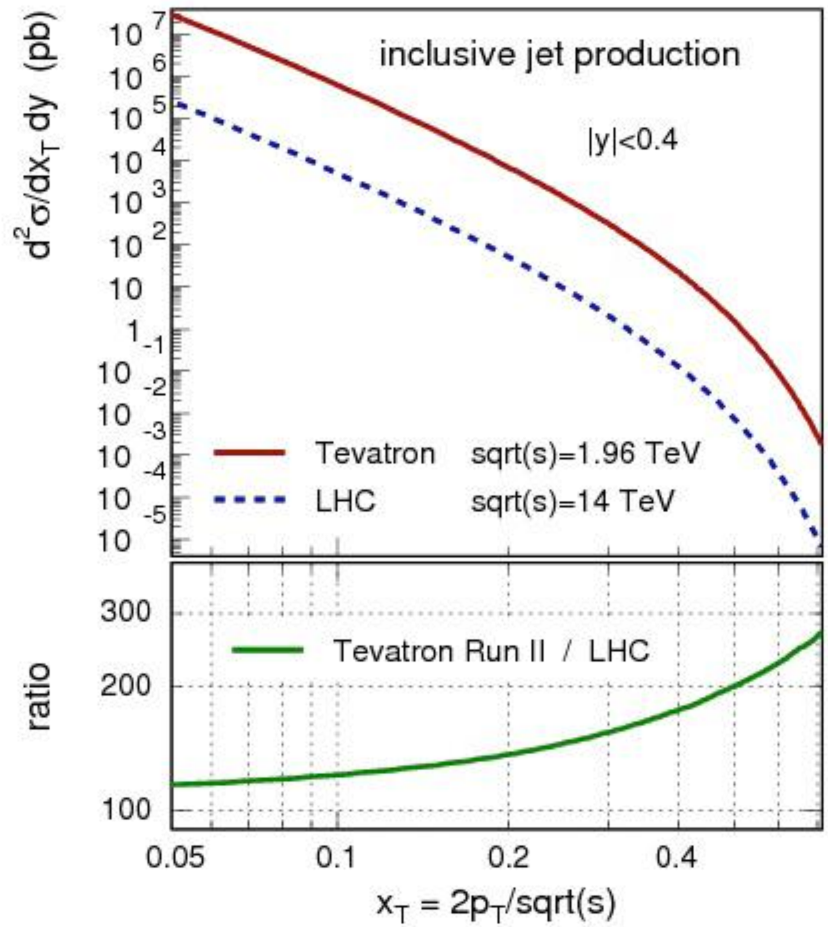
>200x higher cross section @ x_T >0.5

LHC (pp)

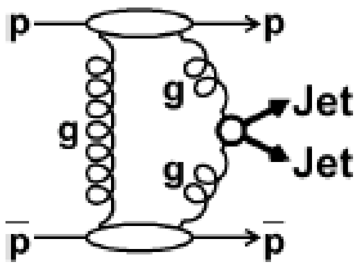
- need more than 2400 fb-1 luminosity to improve Tevatron@12 fb-1
- more high-x gluon contributions
- but more steeply falling cross sect.

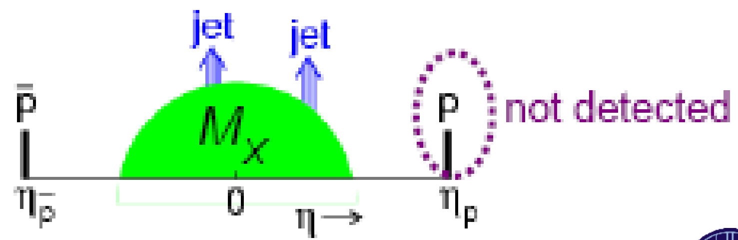
at highest p_T (=larger uncertainties)

Tevatron Results will dominate high-x gluon for several years



Exclusive Dijet Production

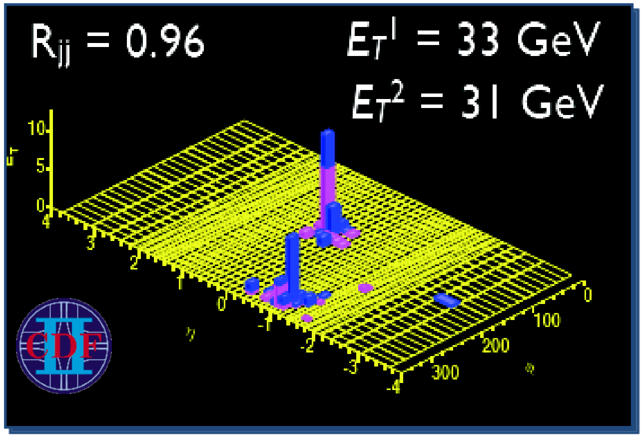


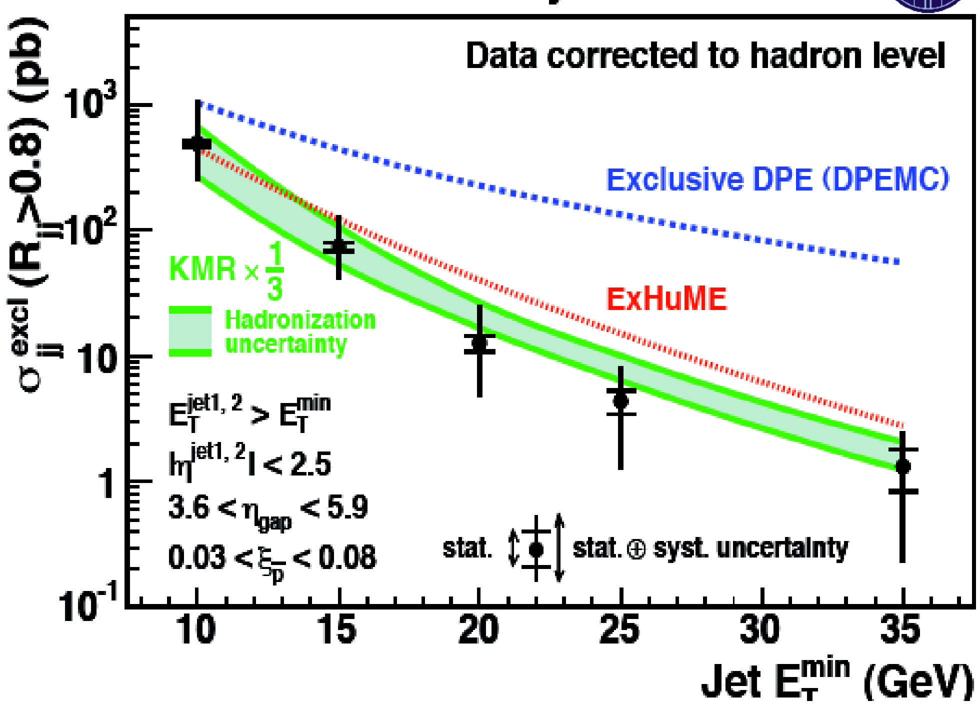


suppression at LO of the background sub-processes(J_z=0 selection rule)

“exclusive channel” →clean signal (no underlying event)

PRD 77, 052004 (2008)





Jet Substructure
Jet Mass

MOTIVATION : Mass of high-pT jets - important property, but only theor. studies:

o High mass:

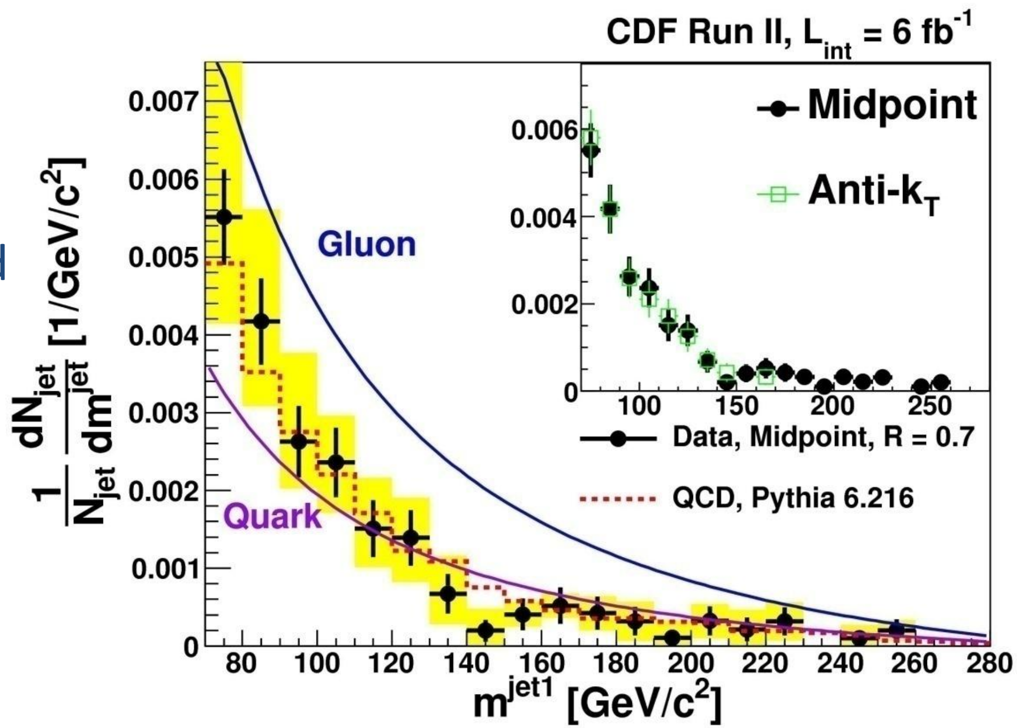
QCD NLO predictions for jet mass

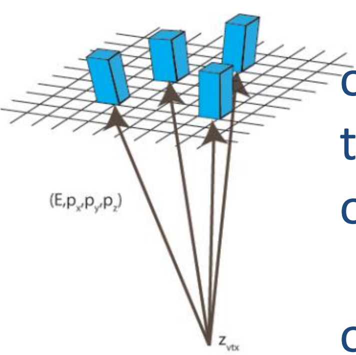
Ellis et al, 0712.2447

Alemeida, et al. 0810.0934

Such jets form significant background to new physics signals

Examples: high p_T tops, Higgs, neutralino …





o 4-vector sum over towers in jet

o Each tower is a particle with m = 0

o Four vector sum gives (E,p_x,p_y,p_z)

Selection: > 1 jet
p_T>400 GeV/c
0.1<|η|<0.7

Jet Substructure
Angularity and Planar Flow

Jet substructure variables that are insensitive to soft radiation at high jet mass:

Angularity :

$$\tau_a(R, p_T) = \frac{1}{m_J} \sum_{i \in jet} \omega_i \sin^a \vartheta_i [1 - \cos\vartheta_i]^{1-a}$$

- **Emphasizes cone-edge radiation**
- **For large m^{jet}, has analytic approximation**

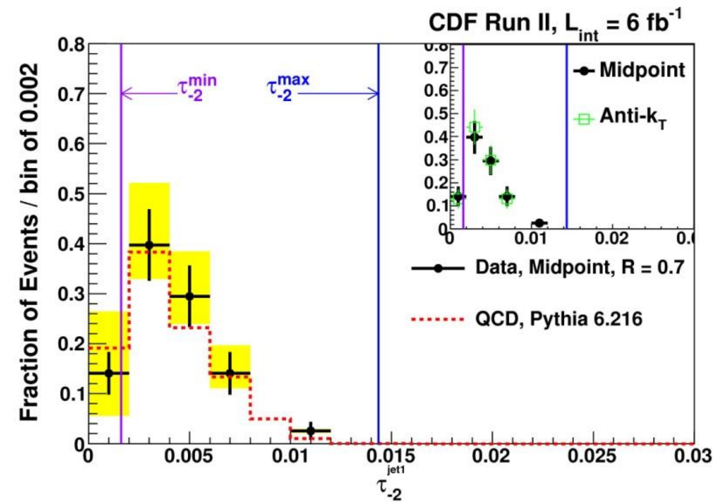
Planar flow:

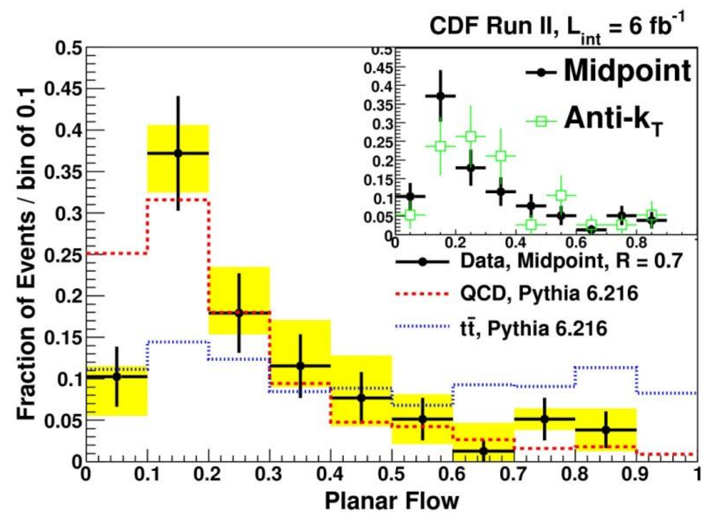
- ***w_i - energy of particle I***
- **λ_1, λ_2 are eigenvalues**

$$I_w^{kl} = \frac{1}{m_{jet}} \sum_i \frac{p_{i,k}}{w_i} \frac{p_{i,l}}{w_i};$$

$$Pf \equiv \frac{4\lambda_1\lambda_2}{(\lambda_1 + \lambda_2)^2}$$

Selection: > 1 jet
p_T>400 GeV/c 0.1<|η|<0.7
anti-top requirements





V + Jets Studies

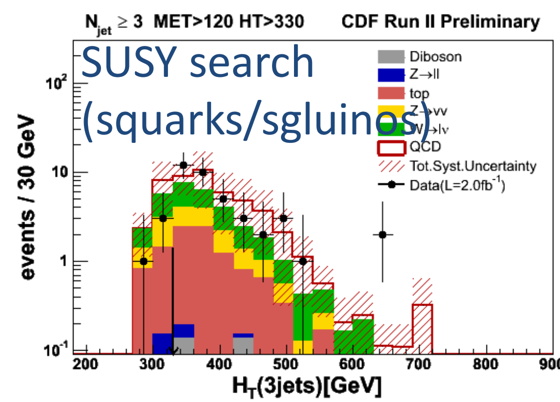
MOTIVATION:

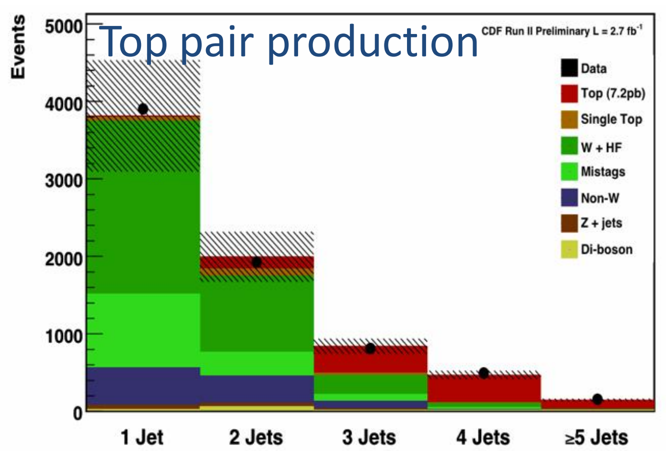
V + Jets Processes in many cases irreducible backgrounds

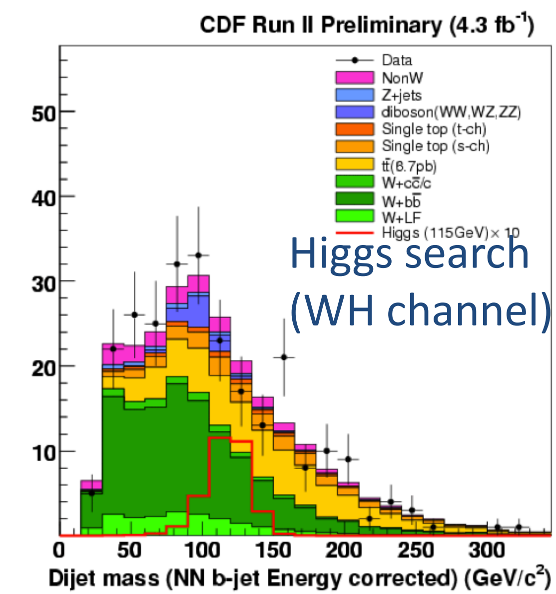
in searches for new physics

- 30% - 40% uncertainty in some of the processes (boson + HF)

- Need dedicate measurements on boson+jets

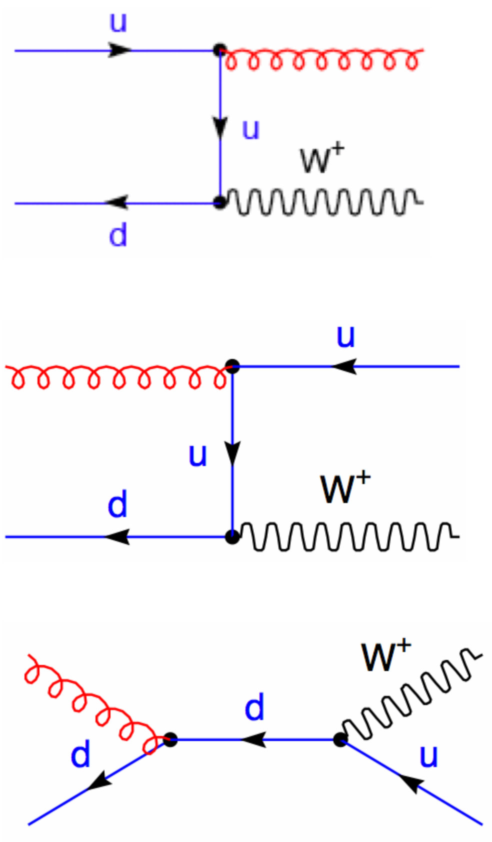






W+jets Production

LO diagrams for W+jet production



W Kinematic region

$M_T^W > 30 / 40\ GeV/c^2$ (μ/e)

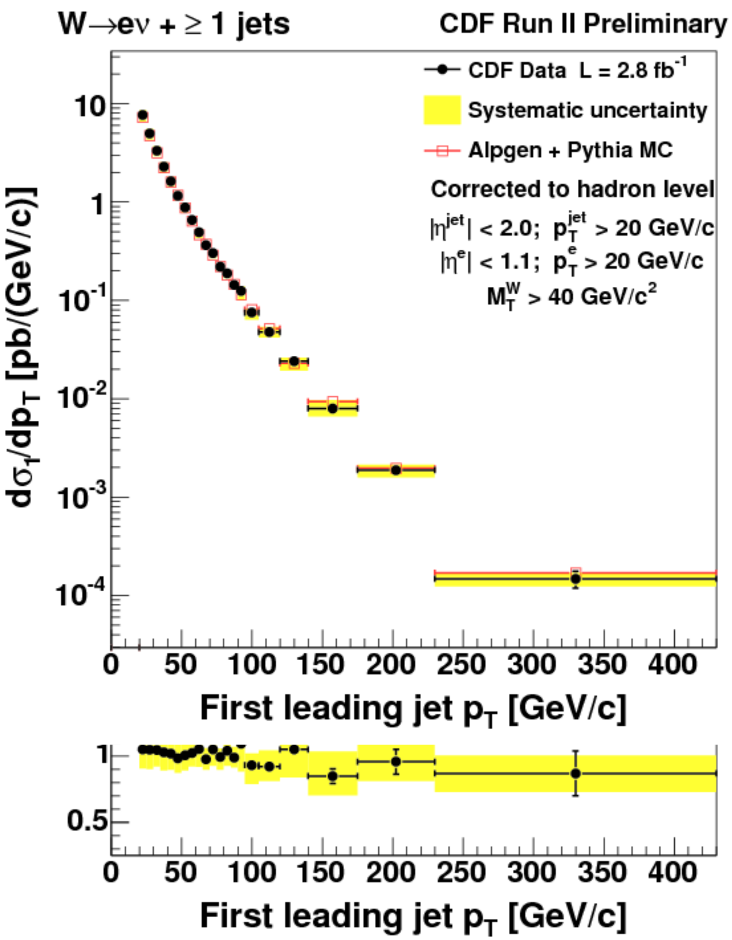
$P_T^l > 20$ GeV, $|\eta^1| < 1.1$

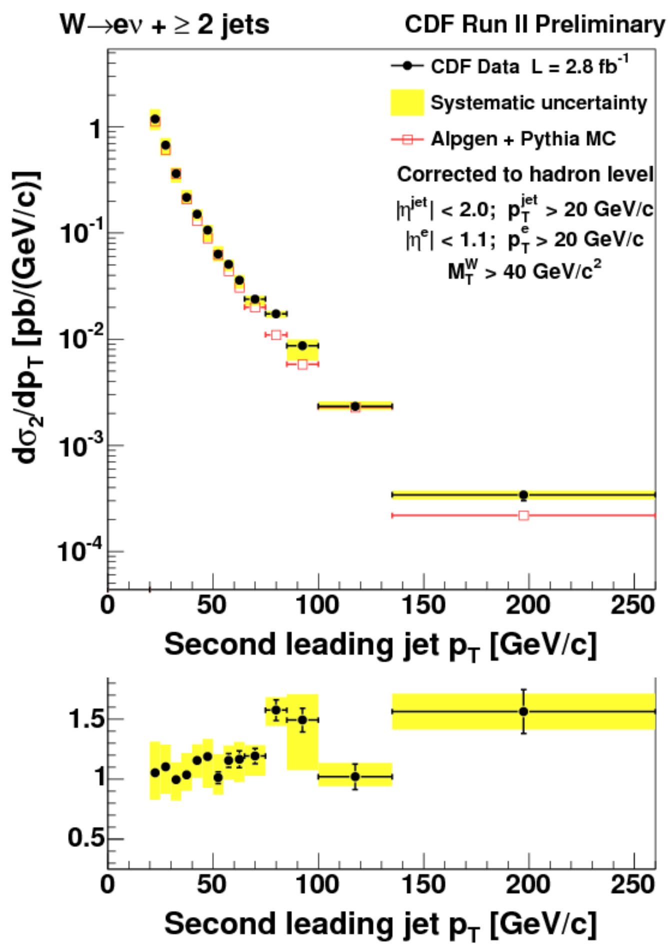
MIDPOINT jet R=0.4

Separate measurements in

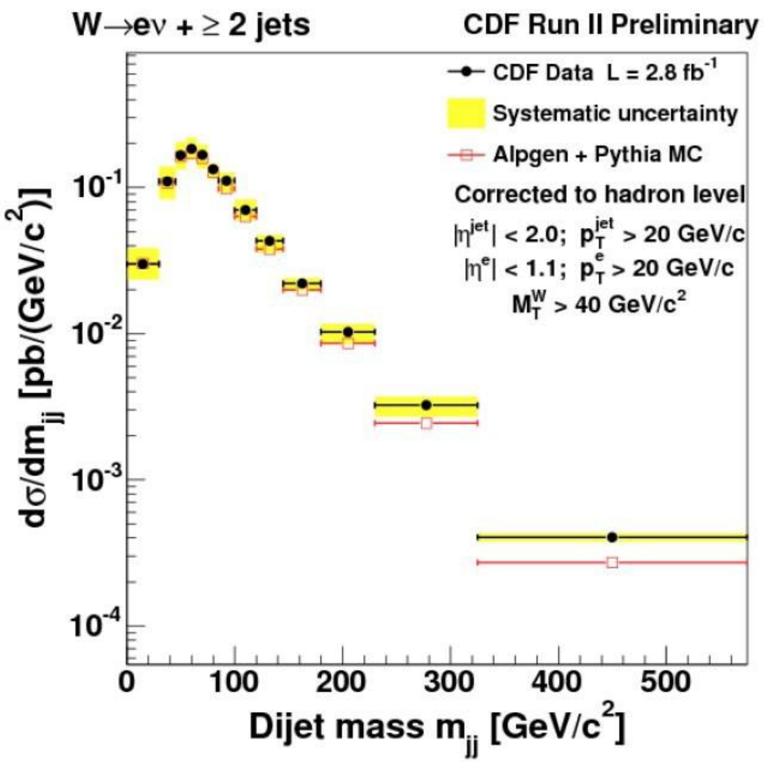
$W \rightarrow \mu\nu$ and $W \rightarrow e\nu$ channels

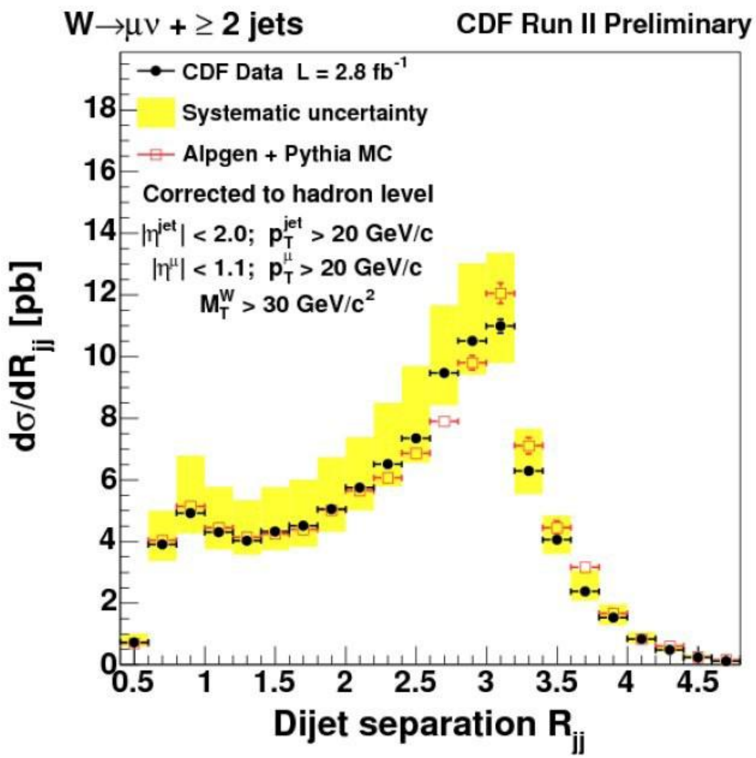
W+jets Production





W+jets





Alpgen+Pythia MC normalized to data for each Njet bin in control region M_T>20 GeV

Z/γ* (→ee)+Jets Production

CDF standard electron ID

– at least one cent. electron E^e_T>25 GeV

– $|\eta^{e1}|<1$, $|\eta^{e2}|$ <1 or 1.2 < $|\eta^{e2}|$<2.8

– 66 < M_{ee}<116 GeV/c^2

– No isolation requirements

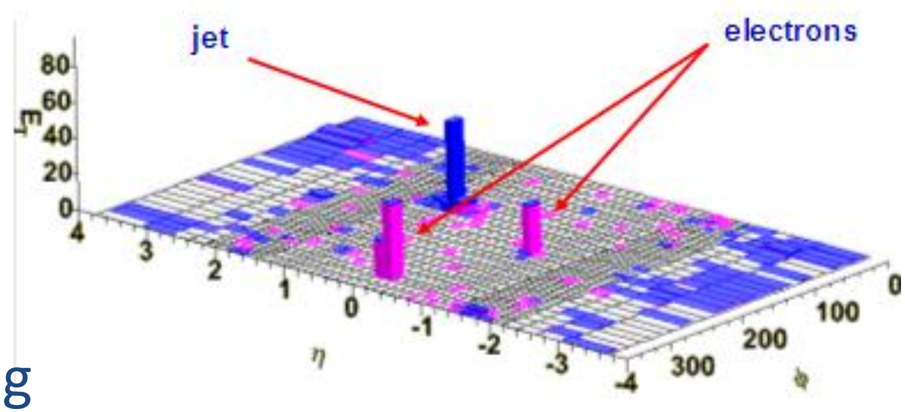
(to avoid bias at very high P_T jet)

- **At least one jet MidPoint (R=0.7)**

– Electrons removed before clustering

– P_T^{jet} >30 GeV/c; $|y^{jet}|$ < 2.1;

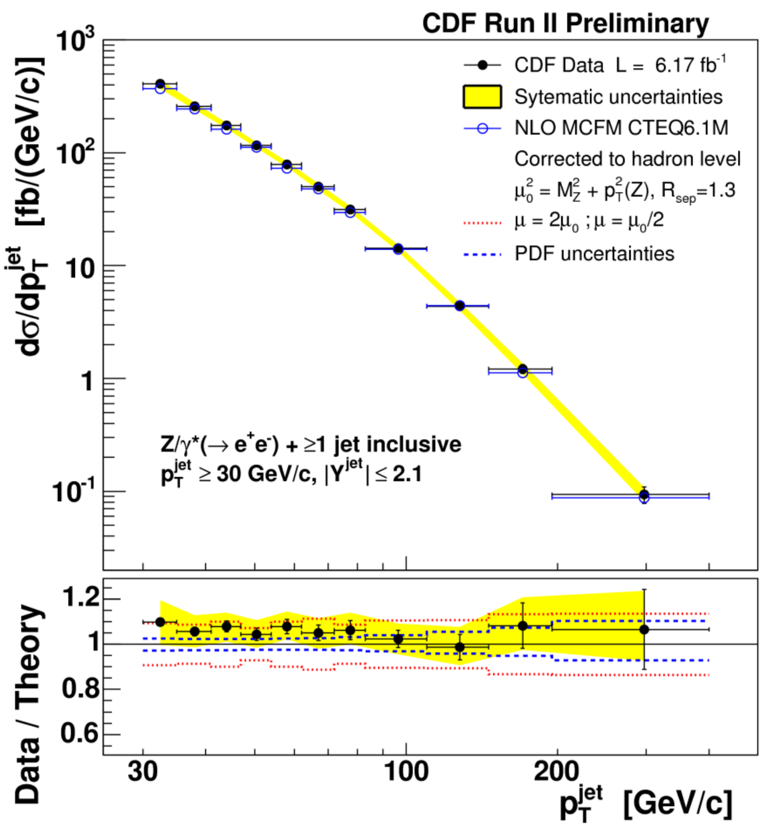
ΔR(e-jet) > 0.7

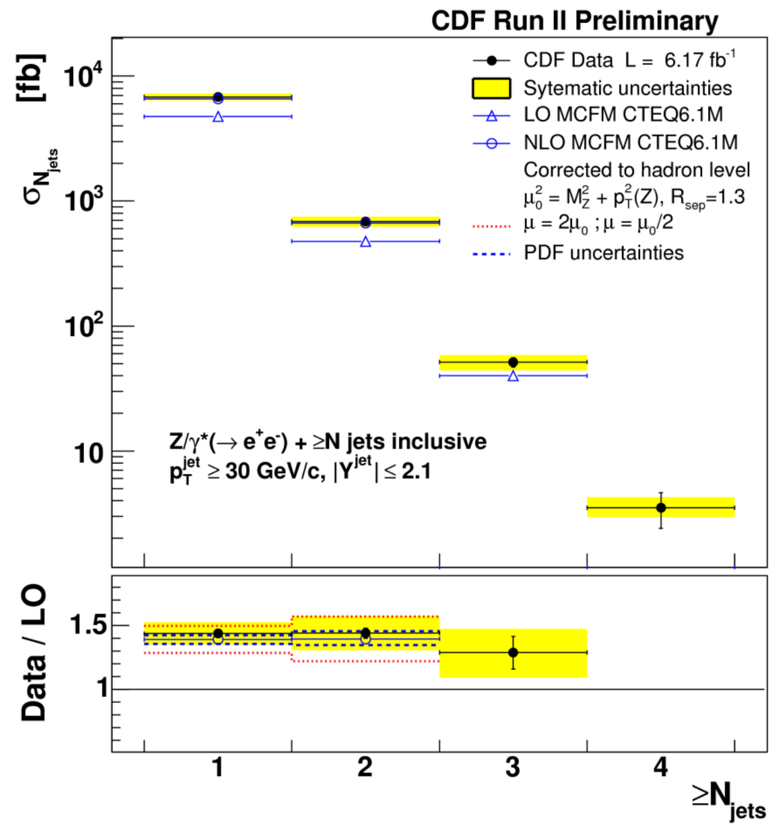


- **Measurement corrected for detector effects back to the hadron level and defined in the given limited kinematic region (no extrapolation made)**

$Z/\gamma^*(\rightarrow e^+e^-)$+Jets Production

Result with 1.7/fb in Phys.Rev. Lett. 100, 102001



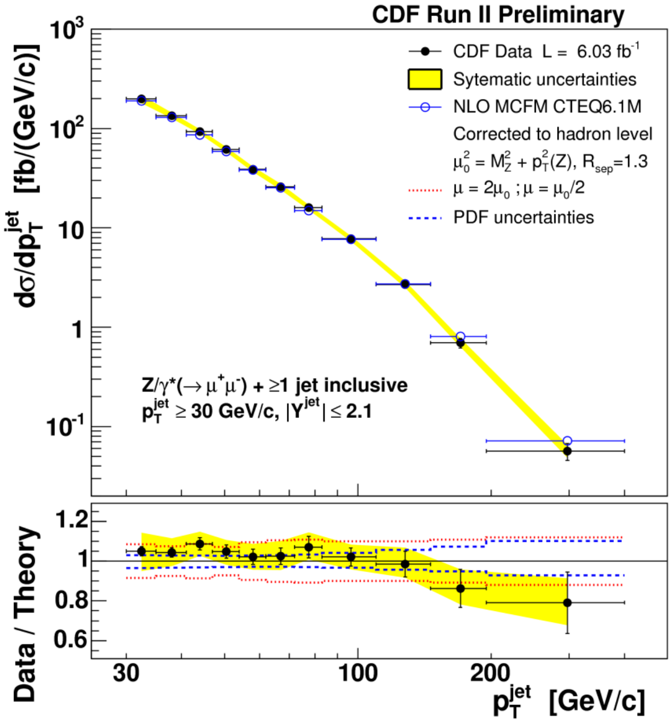


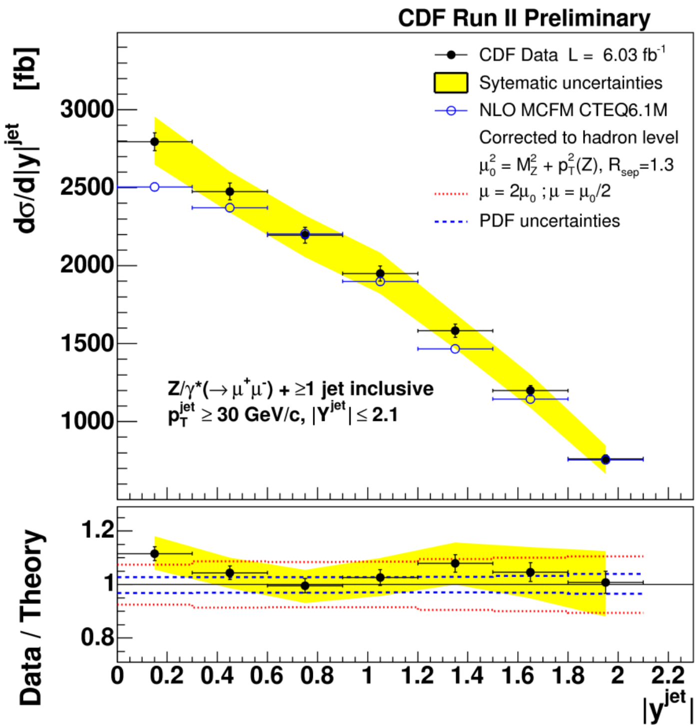
First Measurement of Z + ≥4 Jets

$Z/\gamma^*(\rightarrow\mu^+\mu^-)$+Jets Production

Same kinematic region of Z→ee+ jets to allow combination

p_T>25 GeV
$|\eta^1|<1$, $|\eta^2| <1$
$66 < M_{\mu\mu}<116$ GeV/c2





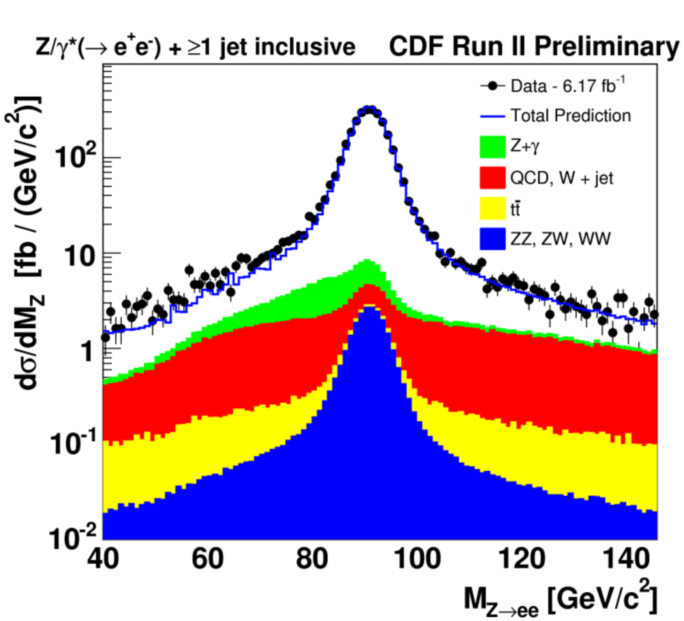
Good agreement with NLO pQCD (MCFM) predictions including non-pQCD corrections

Z/γ*+Jets Production

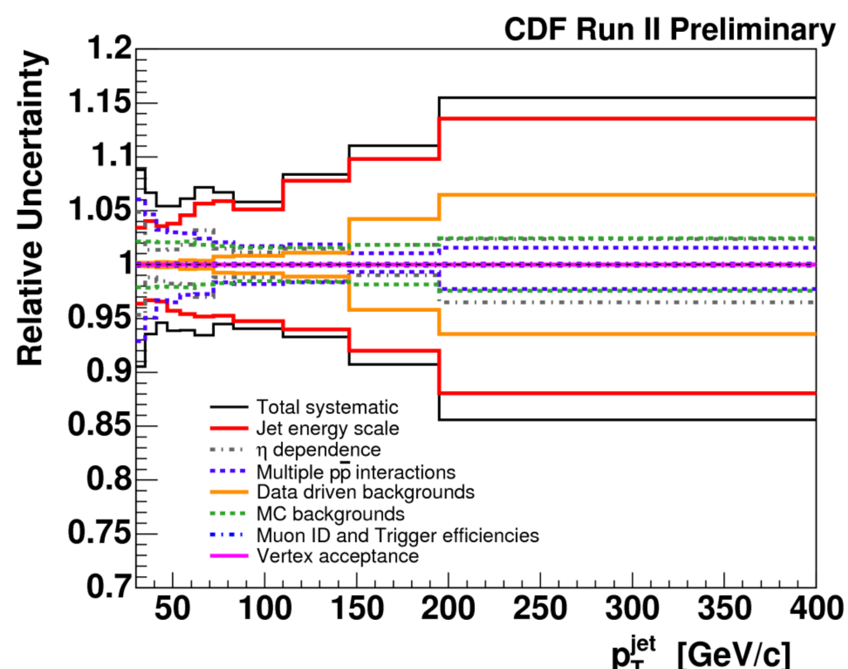
Data driven bckg
- QCD multi-jet
- W + jet
- μ and e fakes

MC bckg.
- Z + γ
- Top
- Diboson
- Z → ττ

- ~30 x 10^3 Z + ≥1 jet data events in 6 fb-1
- Total backgrounds between 5%-10%
- Main background is Z+γ



5% to 15% systematic uncertainties
Jet Energy Scale is the dominant



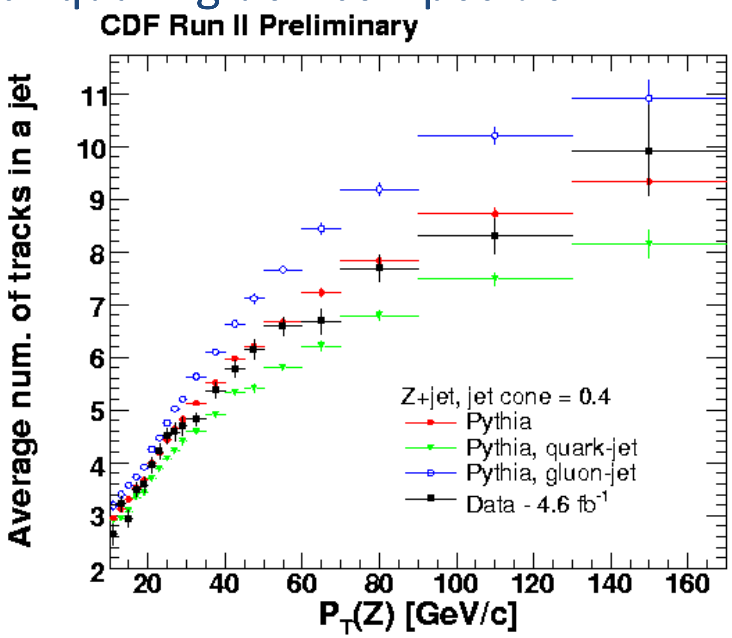
Z+jet – p_T balancing

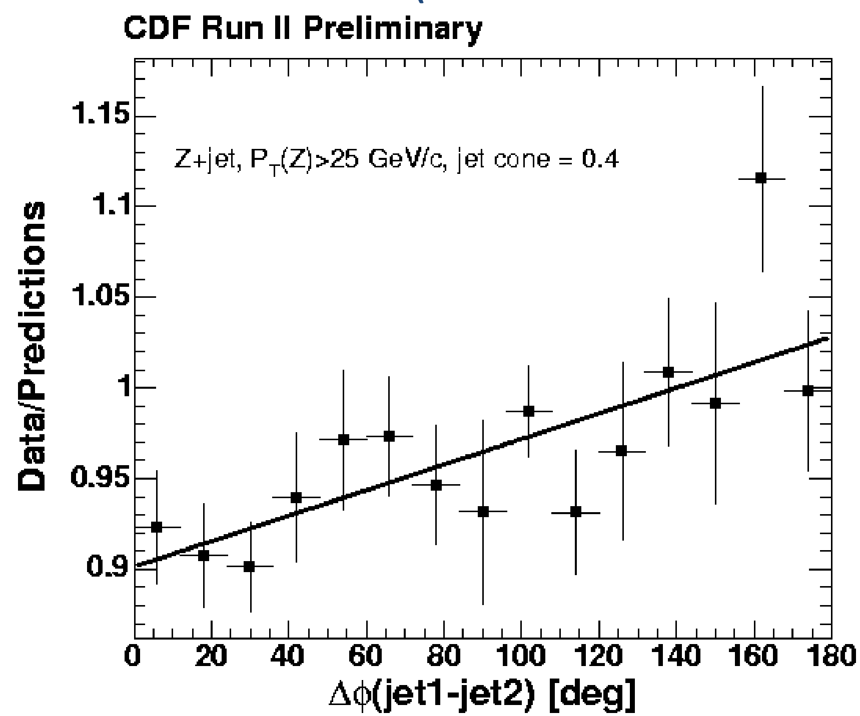
Nucl. Instrum. Methods Phys. A 622, 698

- Reduce uncertainties on meas. energy of had.jets
- Test QCD jet modeling
- Check quark-gluon composition

P_T-balance definition

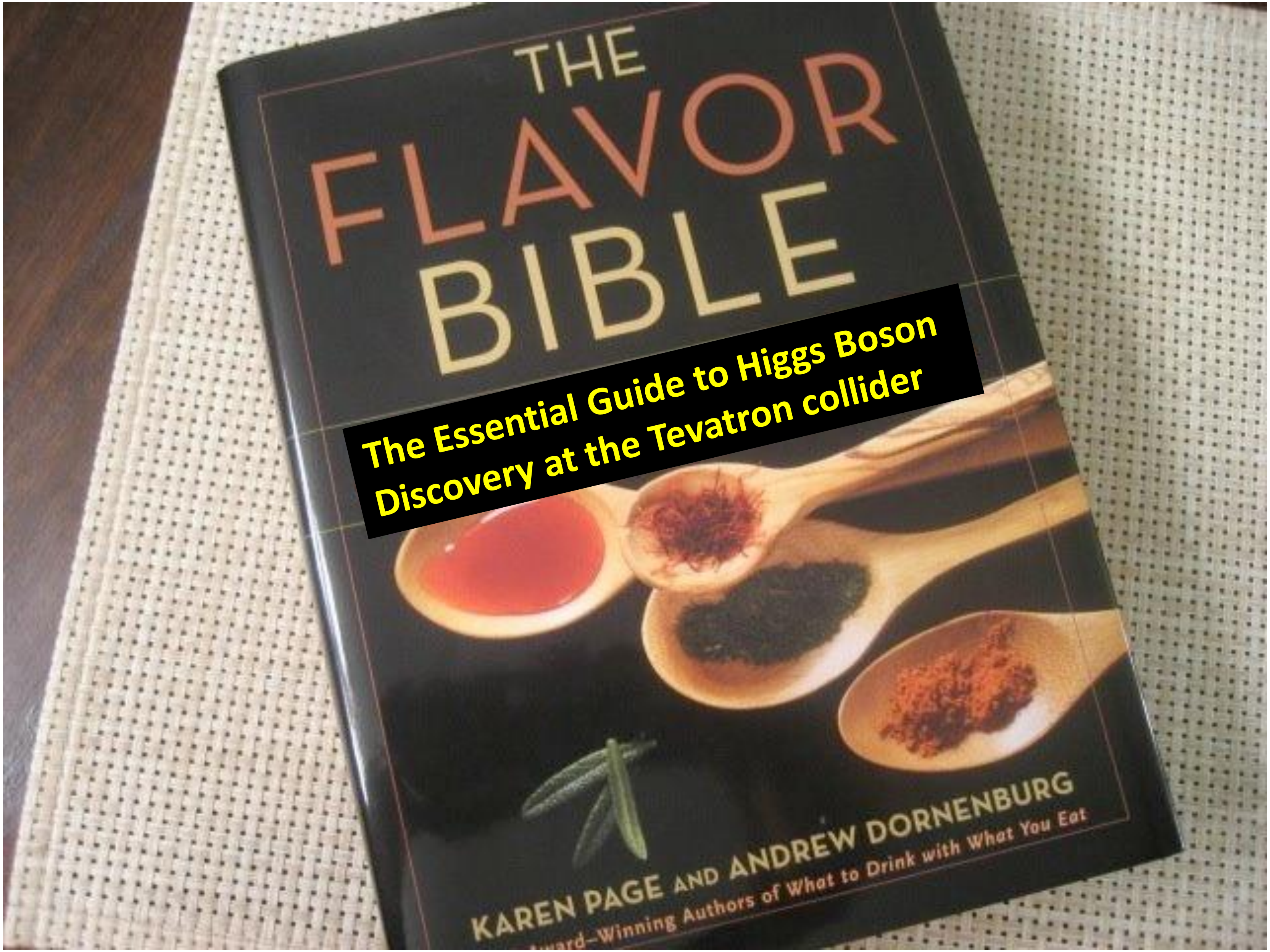
$\langle P_T(\text{jet1})/P_{T(}Z)\rangle$





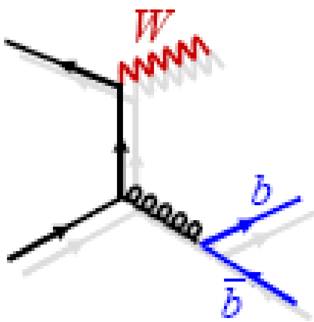
Out-of-cone radiation

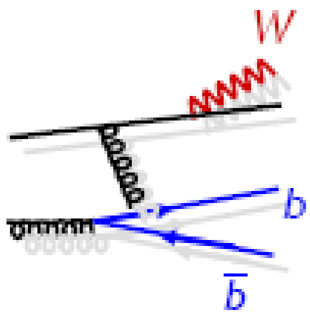
Mismodeling of large angle FSR in the MC is limiting the uncert. in hadron. jets energy

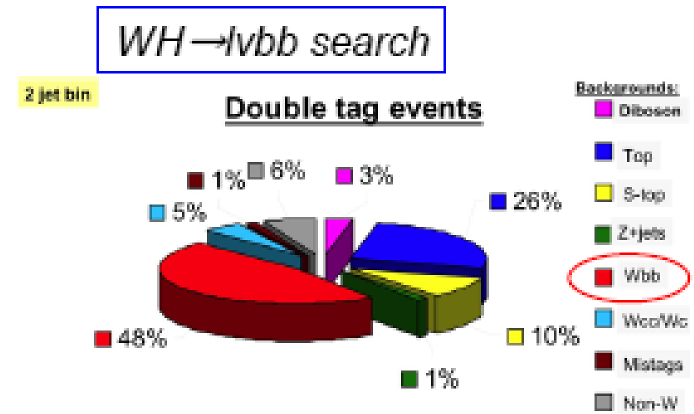

THE
FLAVOR
BIBLE
The Essential Guide to Higgs Boson
Discovery at the Tevatron collider
KAREN PAGE AND ANDREW DORNENBURG
Authors of What to Drink with What You Eat

W+b-Jet Production

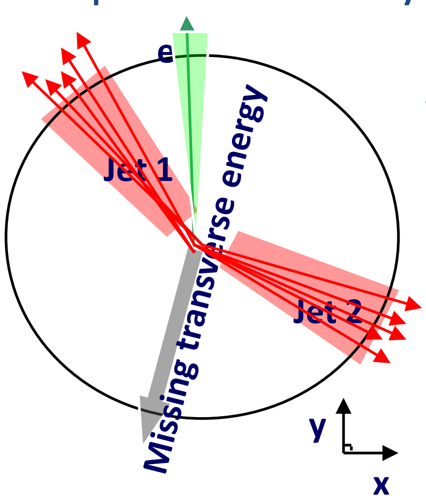
Large background for many rare analysis







Event Selection:
Leptonic W decays



$W \to l\nu$,
where l=e or μ
Jet E_T>20 GeV
$|\eta|<1.5$

CDF end view
Transverse plane

18% uncertainty on the measurement:
vertex modeling (8%);
b-tag effi. (6%), lumi. (6%)

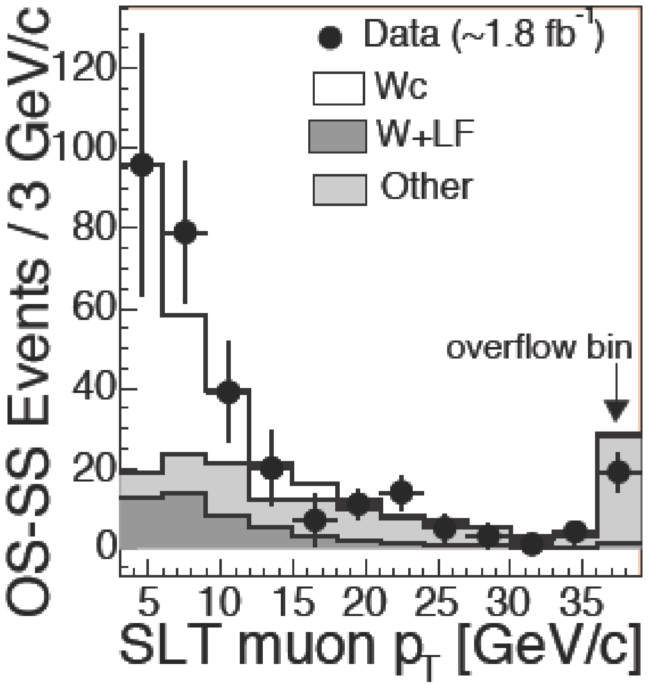
σ b-jets (W+b-jets) · BR(W → lν) =
2.74 ± 0.27 (stat) ± 0.42(syst) pb

NLO : 1.22±0.14 pb
Alpgen: 0.78pb

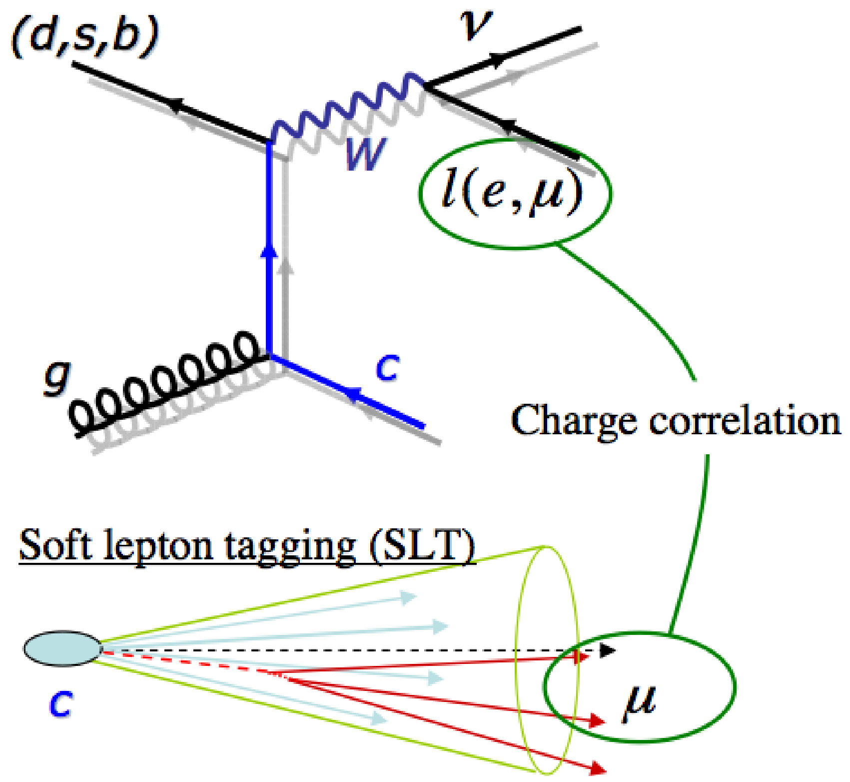
W+c Production

$\sigma_{Wc} x Br(W \to l\nu) = 9.8 \pm 3.2 pb$
NLO: 11.0±1.4(3.0) pb
when $p_T^c > 20$ GeV/c, $|\eta^c| < 1.5$

PRL 100, 091803 (2008)



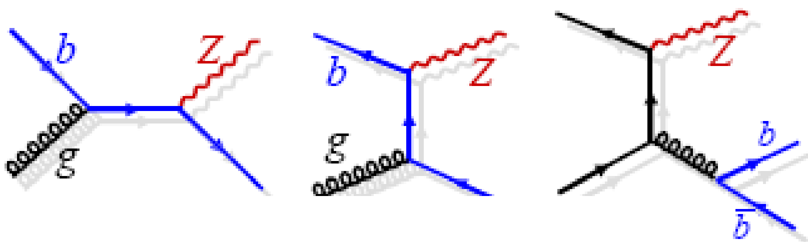
$$\sigma_{W+c} \times Br(W \to l\nu) = \frac{N_{measured}^{OS-SS} - N_{bkg}^{OS-SS}}{L \times A \times \varepsilon}$$



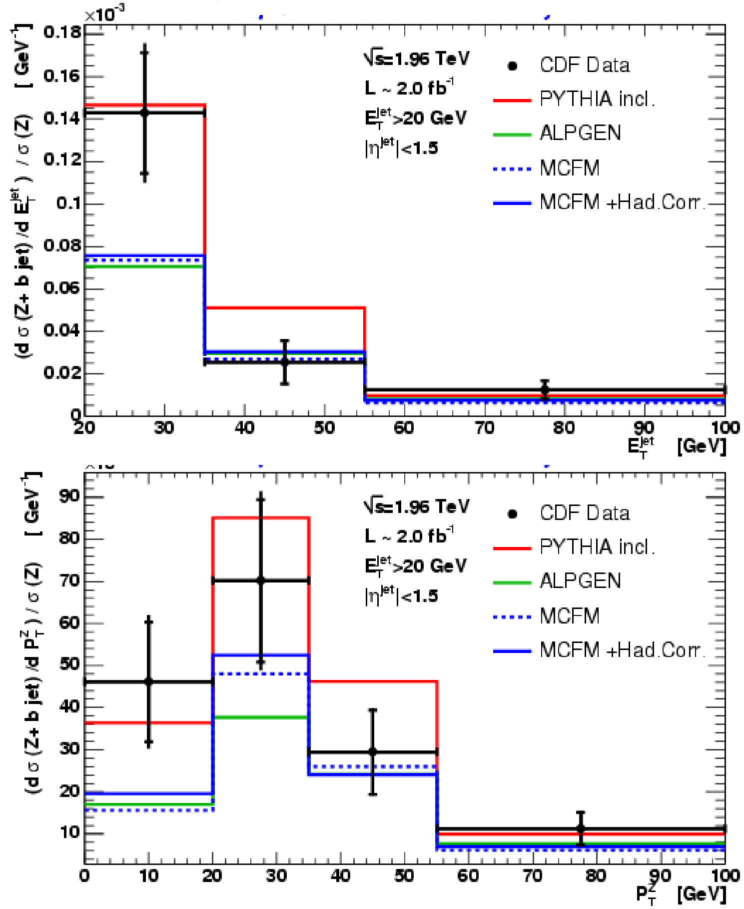
Z+b-Jet Production

Probe the less-known *b*-content of the proton

Backgrounds for SM Higgs search and SUSY



Phys. Rev. D79, 052008 (2009)



Event Selection:

both electron and muon channels

Jet E_T>20 GeV and |η|<1.5

σ(Z+b)/ σ(Z+jets)=2.08±0.33 ±0.34(%)

pQCD(MCFM) 1.8(%) for $Q^2=M_Z^2+P_{T,Z}^2$

2.2(%) for $Q^2=\langle P_{T,jet}^2\rangle$

Data and theory are in agreement but both have sizable uncertainties

Diffractive W/Z Production

Diffractive W/Z production probes the quark content of the Pomeron

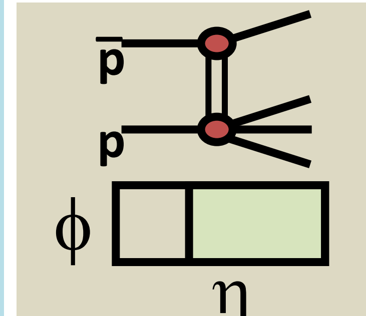
- production by gluons is
  suppressed by a factor of α_s and can be distinguished by an associated jet

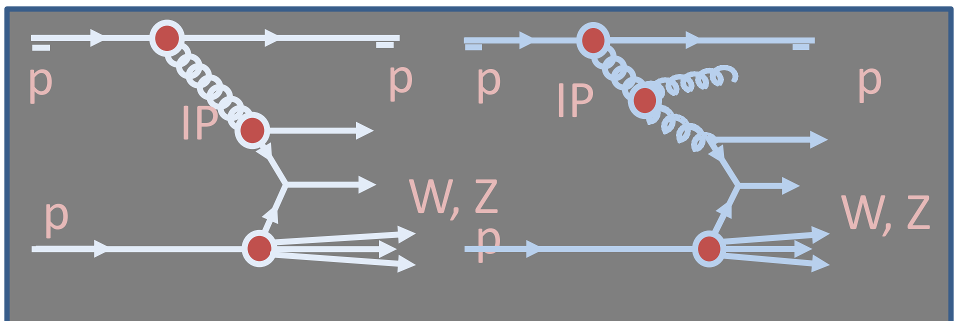
t - four-momentum transfer squared

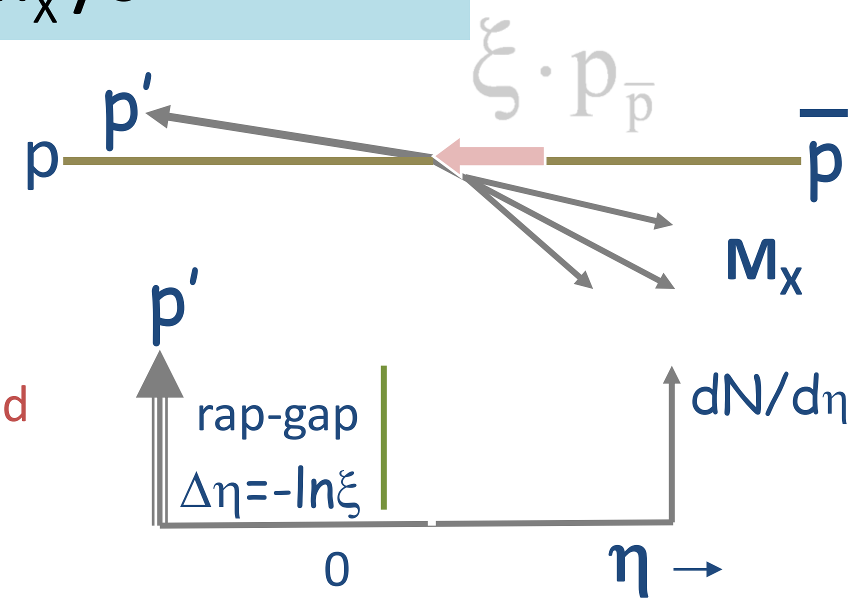
ξ- fractional momentum loss of pbar

M_X - mass of system X

$\xi = M_X^2/s$







- CDF Run I studies used rapidity gaps method PRL **78**, 2698 (1997)
  – Fraction of W events due to SD
  – **[1.15 0.51(stat) 0.20(syst)]%**

Diffractive W Production

Identify diffractive events using Roman Pots:

- accurate event-by-event ξ measurement
- no gap acceptance correction needed
- can still calculate ξ^{cal}

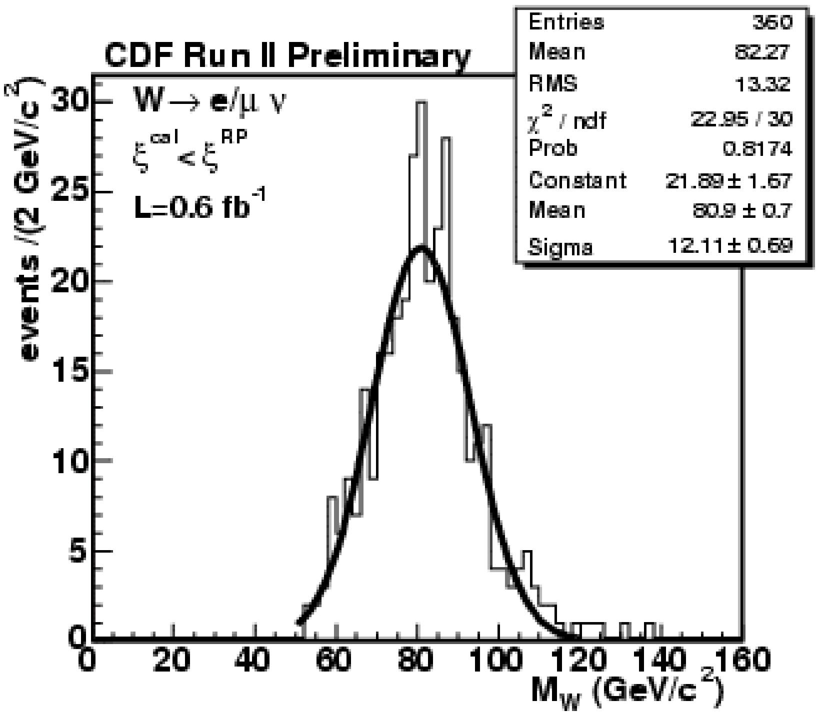
$$\xi^{cal} = \sum_{towers} \frac{E_T}{\sqrt{s}} e^{-\eta}$$

In W production, the difference between ξ^{cal} and ξ^{RP} is related to missing E_T and η_ν

$$\xi^{RP} - \xi^{cal} = \frac{E_T}{\sqrt{s}} e^{-\eta_\nu}$$

allows to determine:

neutrino and W kinematics

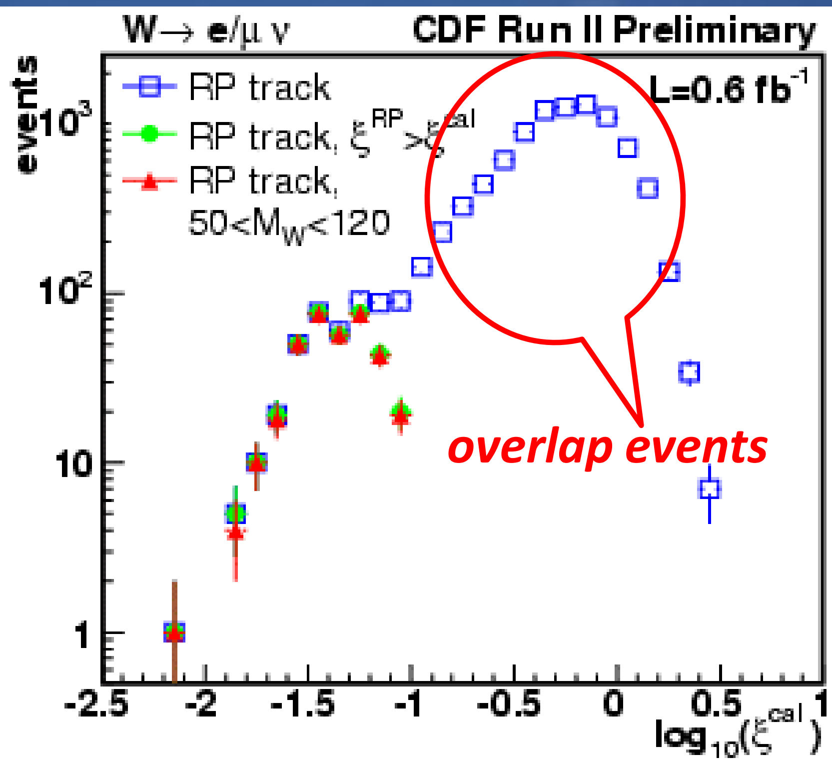


reconstructed diffractive W mass

Diffractive W Production

- $\xi^{cal} < \xi^{RP}$ requirement removes most events with multiple pbar-p interactions

- $50 < M_W < 120$ GeV/c^2 requirement on the reconstructed W mass cleans up possible mis-reconstructed events

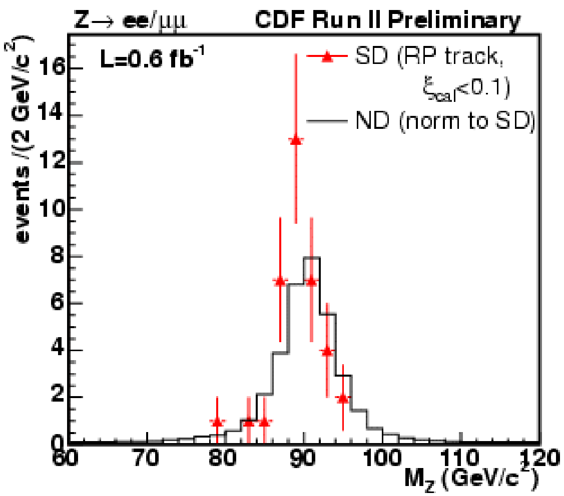


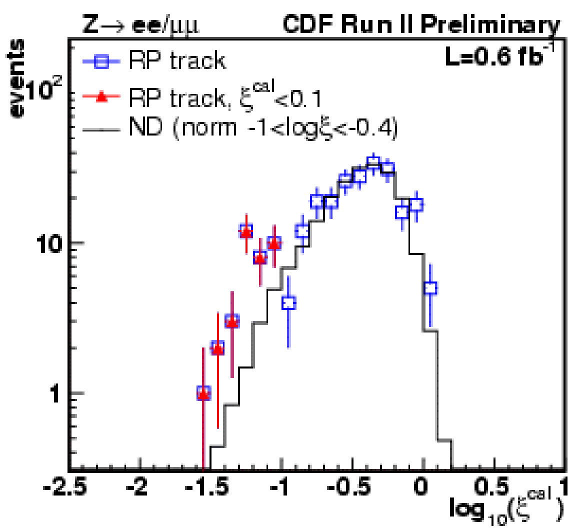
Fraction of diffractive W

R_W (0.03<ξ<0.10, |t|<1)= [0.97 ±0.05(stat) ±0.10(syst)]%

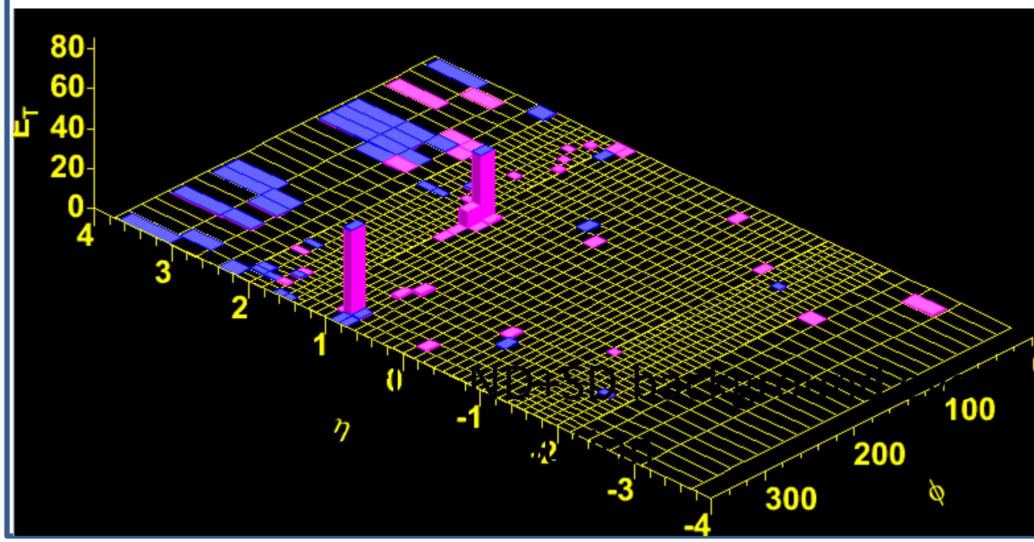
consistent with Run I result, extrapolated to all ξ

Diffractive Z





37 diffractive Z→ ee/μμ candidates
(RP track, ξ^{cal}<0.1)



Fraction of diffractive Z

R_Z (0.03< ξ <0.10, |t|<1)=
[0.85±0.20(stat) ±0.08(syst)]%

Conclusions

- Understanding of jet identification, JES, and systematics leads (in many cases) to experimental systematic uncertainties smaller than theoretical uncertainties

- Next level of measurements
  - measurements of jet substructure variables
  - validating phenomenological models for diffraction

- Comprehensive Tevatron V+jets/HF results provide detailed information for testing latest pQCD calculations and tuning event generators

More to come from the QCD program at the Tevatron

http://www-cdf.fnal.gov/internal/physics/qcd/qcd.html

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