Recent Experimental QCD Results

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DPF 2009
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26-31 JULY 2009
Wayne State University, Detroit, MI

Outline

- **Apologies**
- Introduction
- HERA
  - Only Structure Functions
- Tevatron
  - Inclusive Jet Production X-section
  - Dijet X-section
  - Dijet Angular Distribution
  - W + Jet Production
  - Z + Jet Production

In backup slides

- LHC
  - Underlying Event
  - Dijet Angular Decorrelation
  - Inclusive Jet Cross Section
  - Dijet Mass and Ratio
- Summary
- Acknowledgments

- Not Shown
  - ✓ HERA α_s
  - ✓ Most low p_T analyses
  - ✗ Tevatron W/Z + HF
  - ✗ Tevatron γ + jet
  - ✗ LHC Jet Shapes

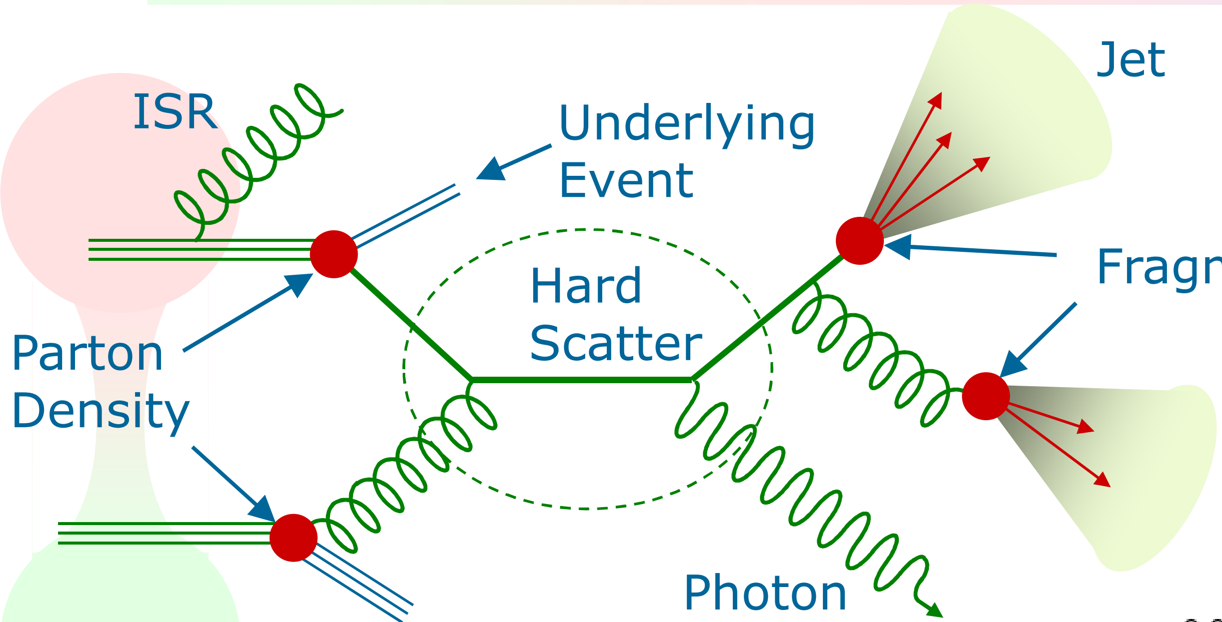
Advertisement

- QCD Sessions [Thursday & Friday parallel]
- Experimental Results

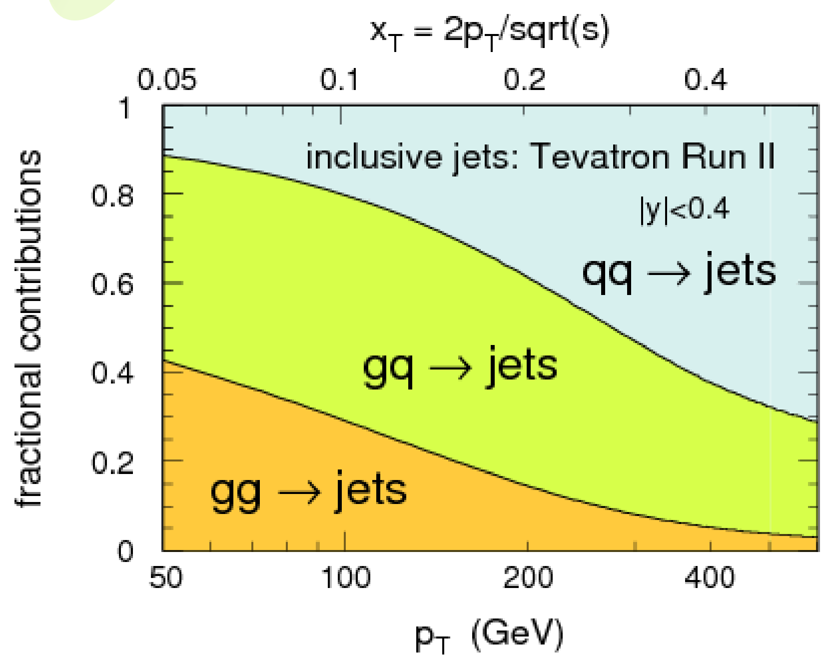
- Thursday
  - Culbertson [27] *Inclusive photon cross section at CDF*
  - Bandurin [189] *Double parton interactions with γ + 3 jet in DØ*
  - **Lincoln [184] *Dijet distributions in DØ***
  - **Lammers [187] *Differential Z/γ cross sections in DØ***

- Friday
  - Li [10] *Pion form factor at large Q^2*
  - Sokoloff [93] *Recent results on two photon physics at BaBar*

QCD Scattering Processes



- Jets of particles originate from hard collisions between quarks and gluons
- Quark and gluon density described by Parton Distribution Functions (PDFs)
- Proton remnants form underlying event

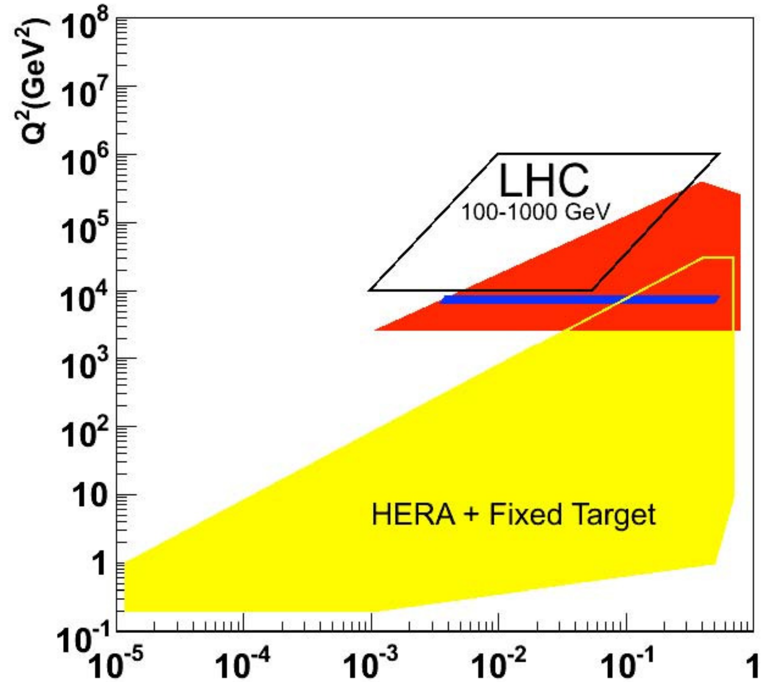


Motivation

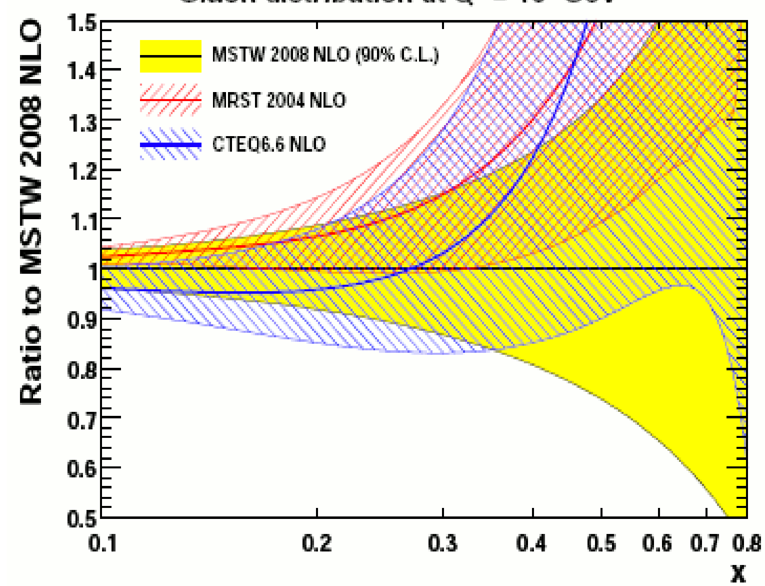
- Test perturbative QCD (pQCD) calculation
  - ➢ Jet production has the highest reach of energy and rapidity
- Constrain PDF at large Q^2 and medium-to-large x
  - ➢ Tevatron similar to LHC Q^2
  - ➢ PDFs of gluon, b, and s quarks
- Backgrounds to new physics
  - ➢ Wbb: low-mass SM Higgs
  - ➢ W/Z+jets: SUSY, 4th generation
- Search for new physics

Tevatron Inclusive jet x-section

Tevatron W/Z rapidity shape



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



H1-ZEUS combined HERA I cross sections

New combination based on the full HERA-I incl. data L=240pb^{-1}

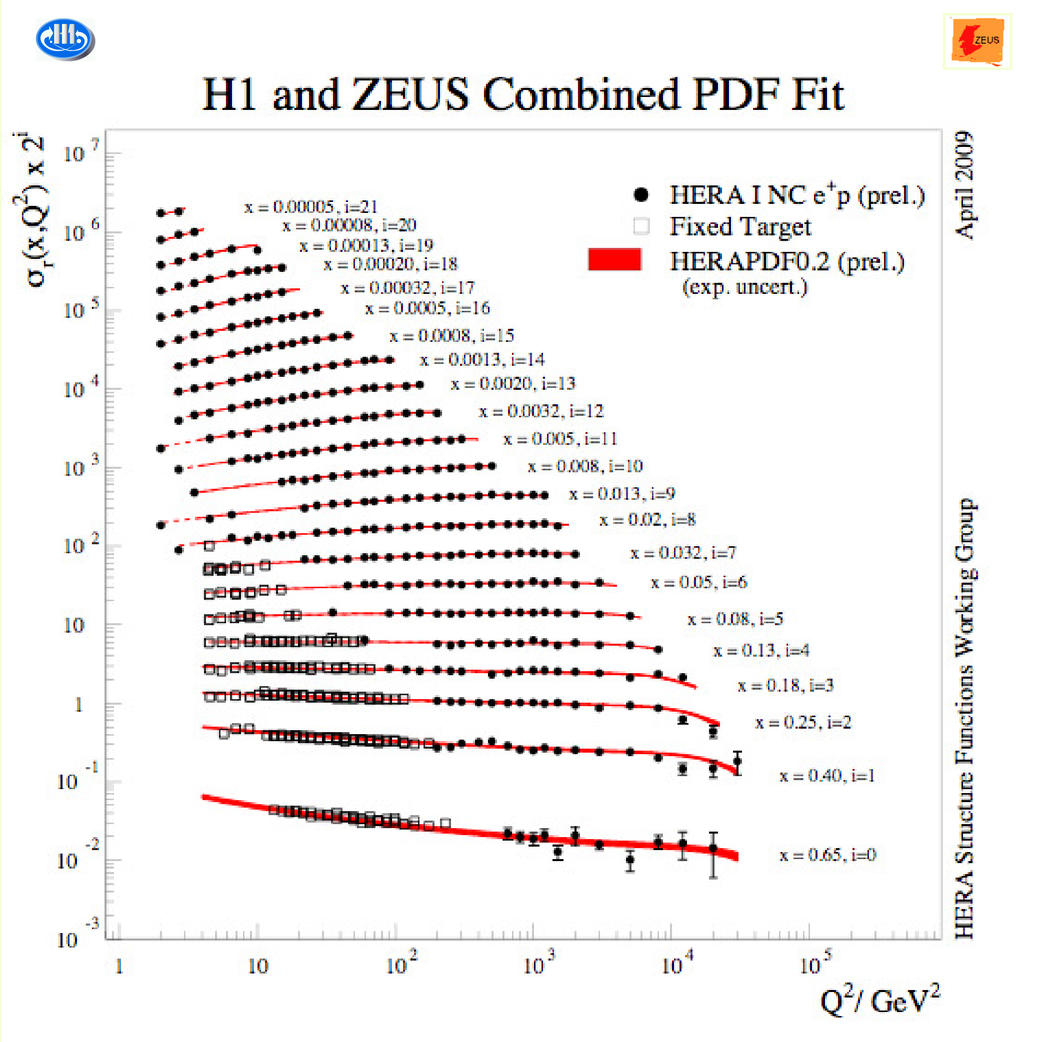
Added since 2008:
- Zeus 95-97 "low Q^2"
- H1 95-00 "low Q^2"
- H1 96-00 "Bulk"

Reduced systematic uncert. and O(1%) precision for:

$10 < Q^2 < 100$ GeV^2

Used as single input to a new QCD analysis:

$\Rightarrow$ HERAPDF0.2

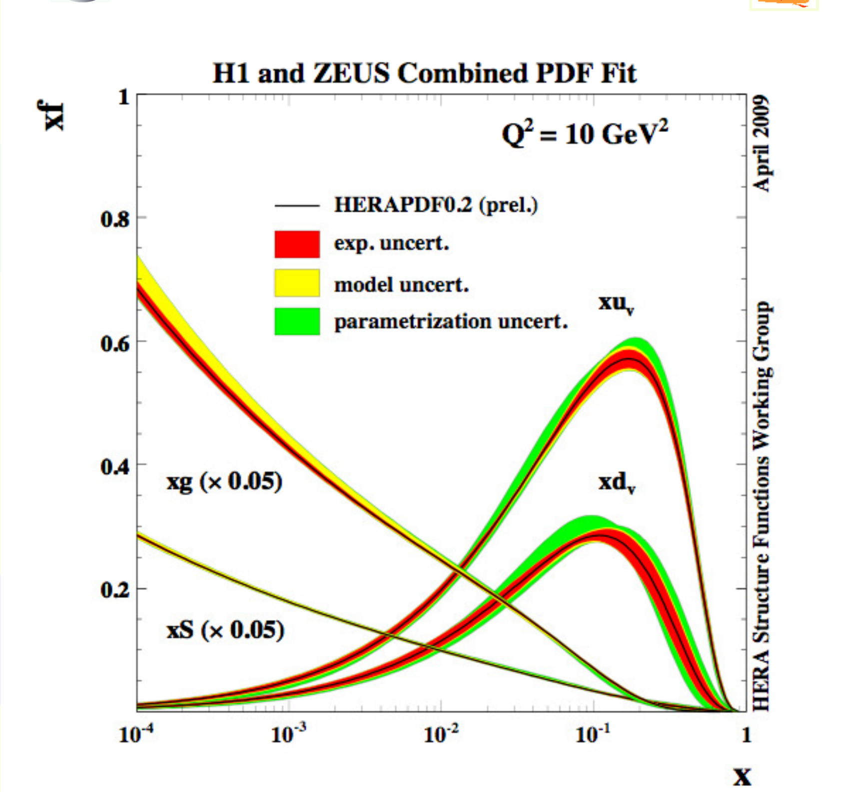


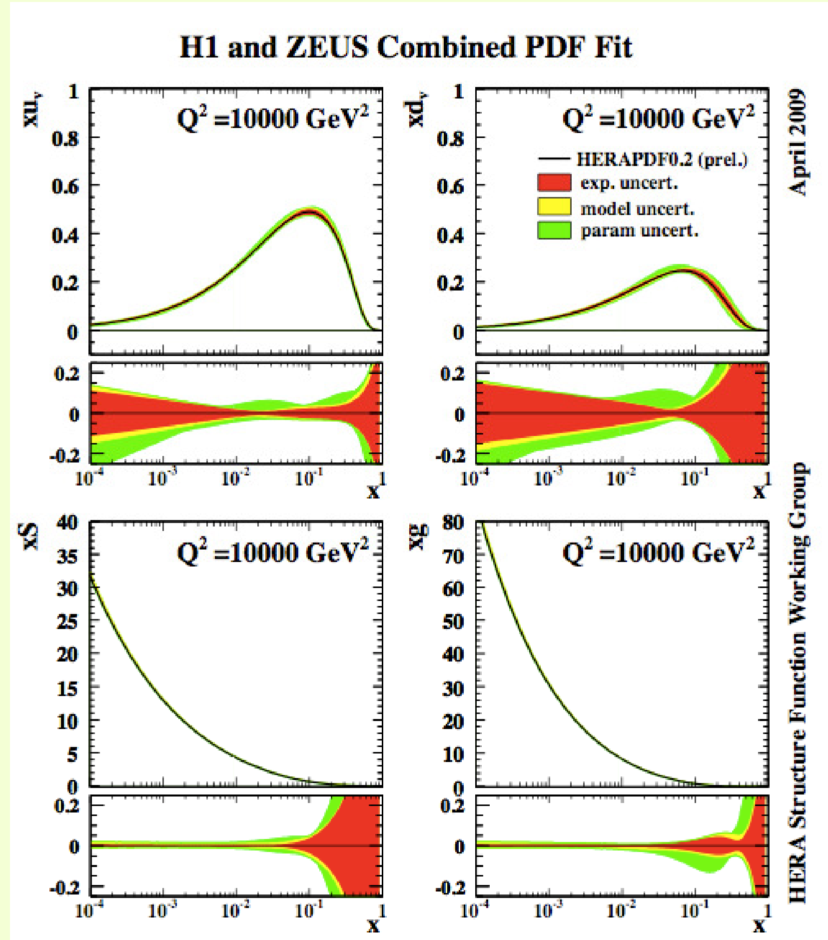
[Thur. QCD, GLAZOV, 420]

New PDF Fit to the combined HERA-I data

HERAPDF0.2:

- Very detailed study of PDFs uncert.
- Heavy Flavors

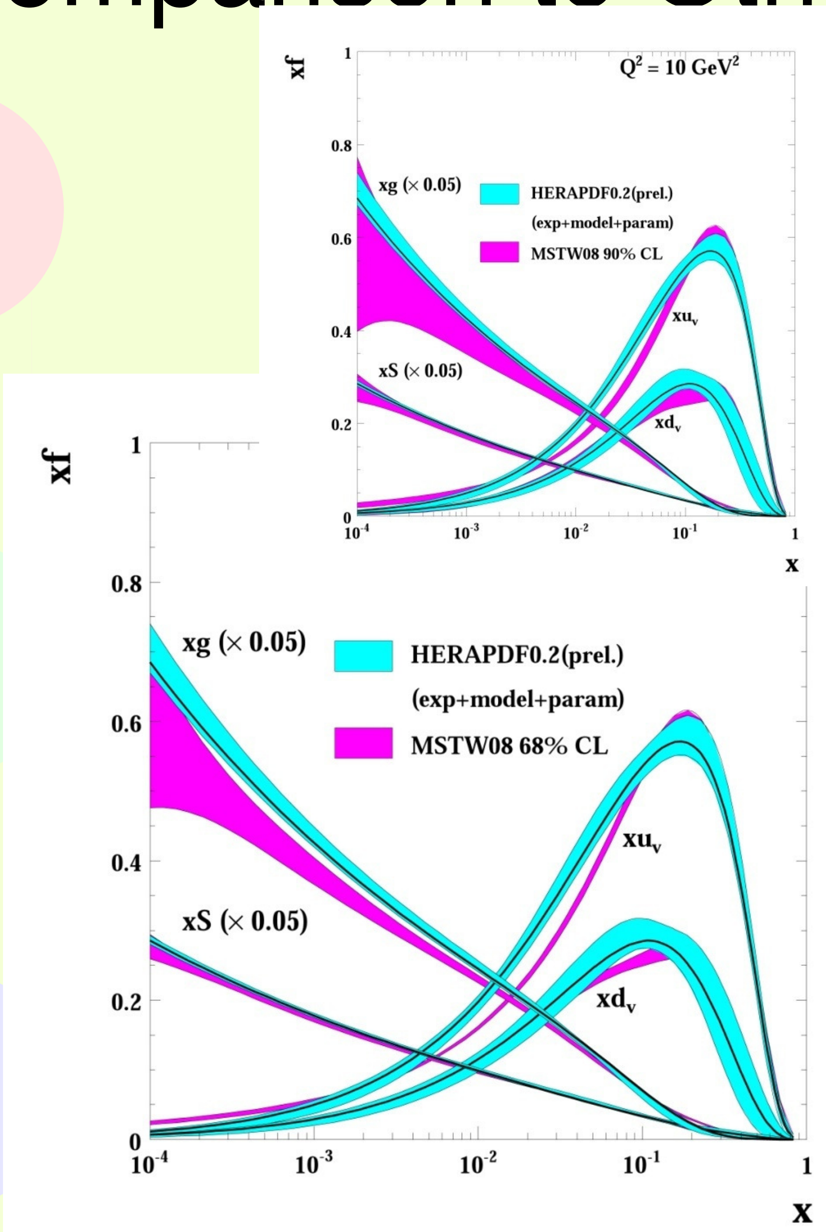


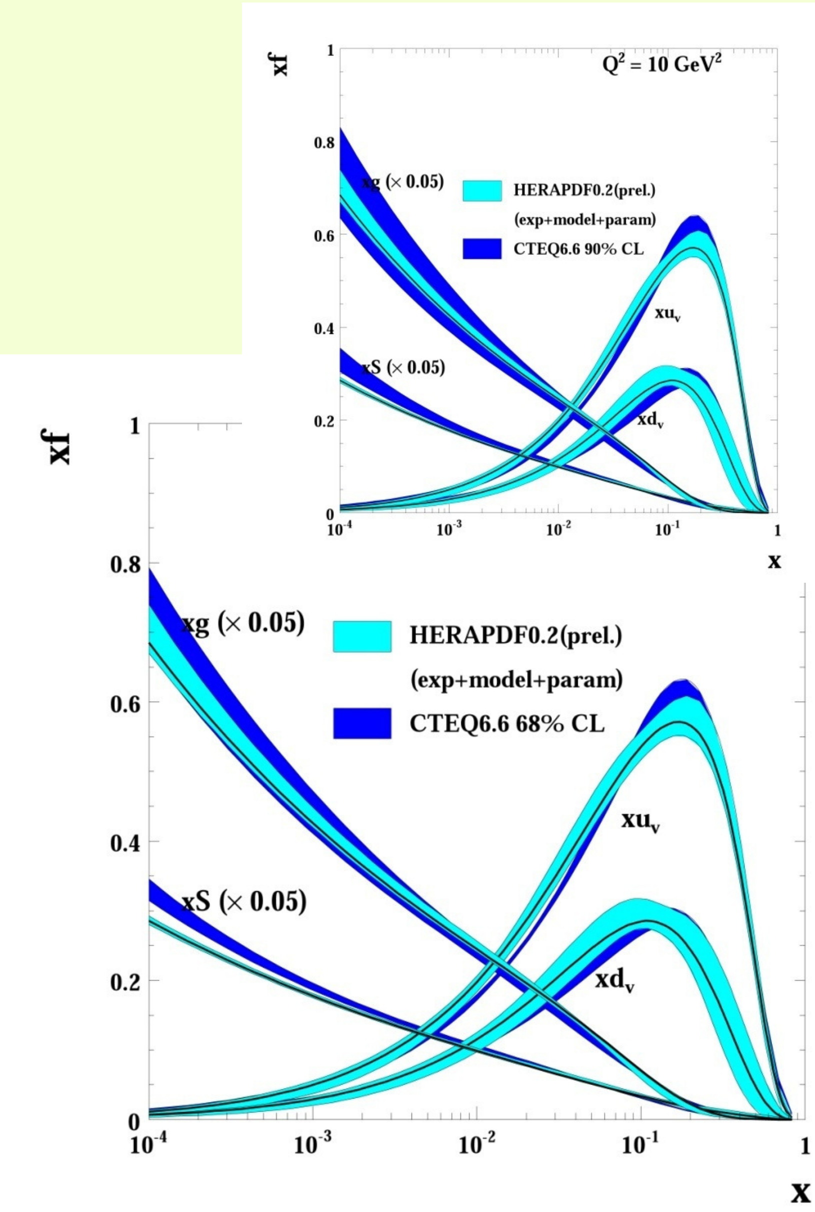


xS,xg high precision at low-x

Nuclear Physics B (Proc. Suppl.) 191 (2009) 5–15
H1prelim-09-045
ZEUS-prelim-09-011

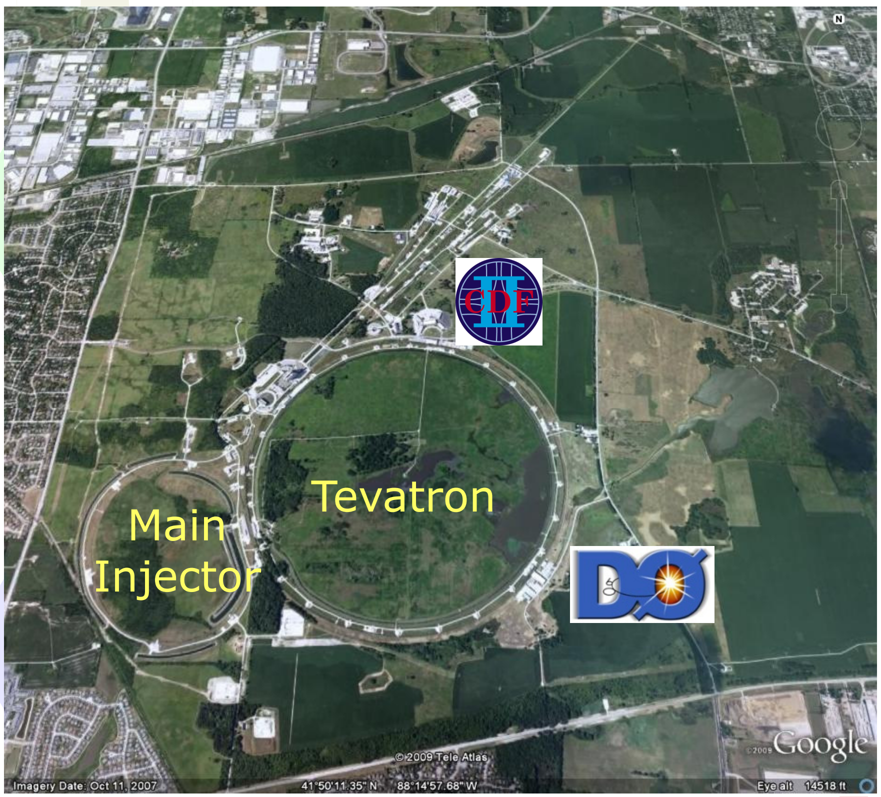
Comparison to Other Modern PDFs

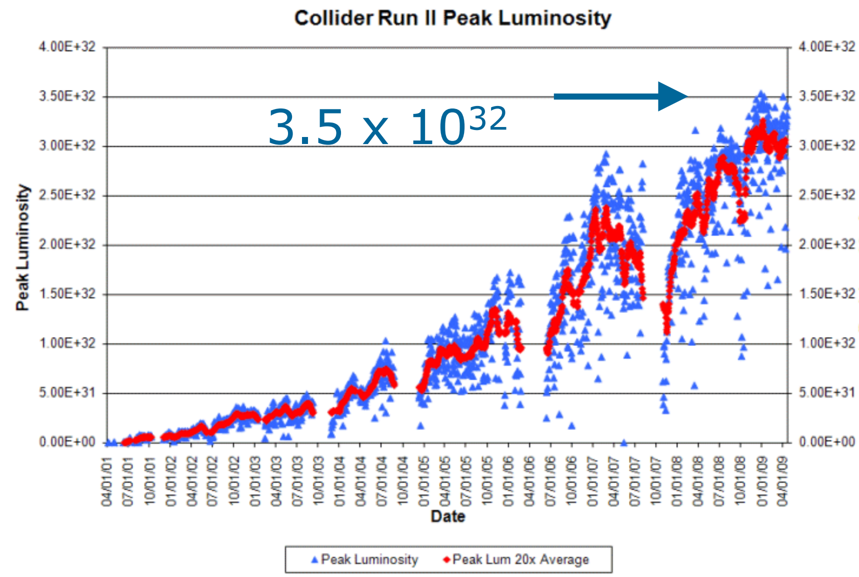


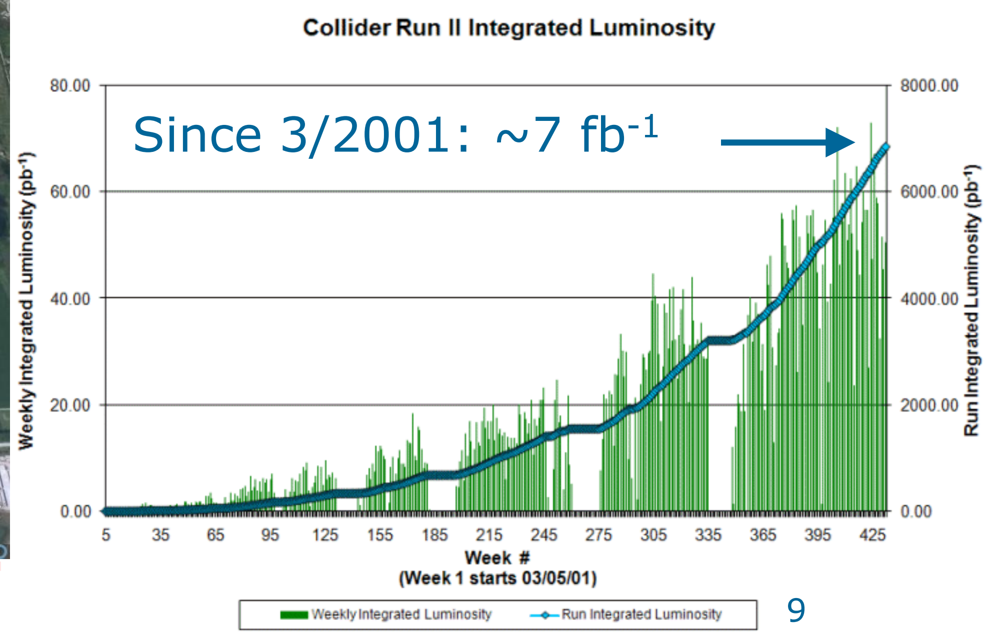


The Tevatron

- $\sqrt{s}$ = 1.96 TeV
- Peak Luminosity: 3.5×10^{32} $cm^{-2}s^{-1}$
- About 7 fb^{-1} delivered
- Experiments typically collect data with 80-90% efficiency



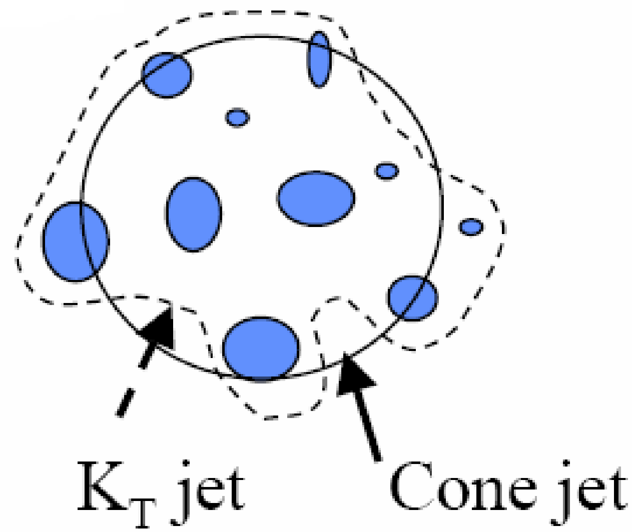




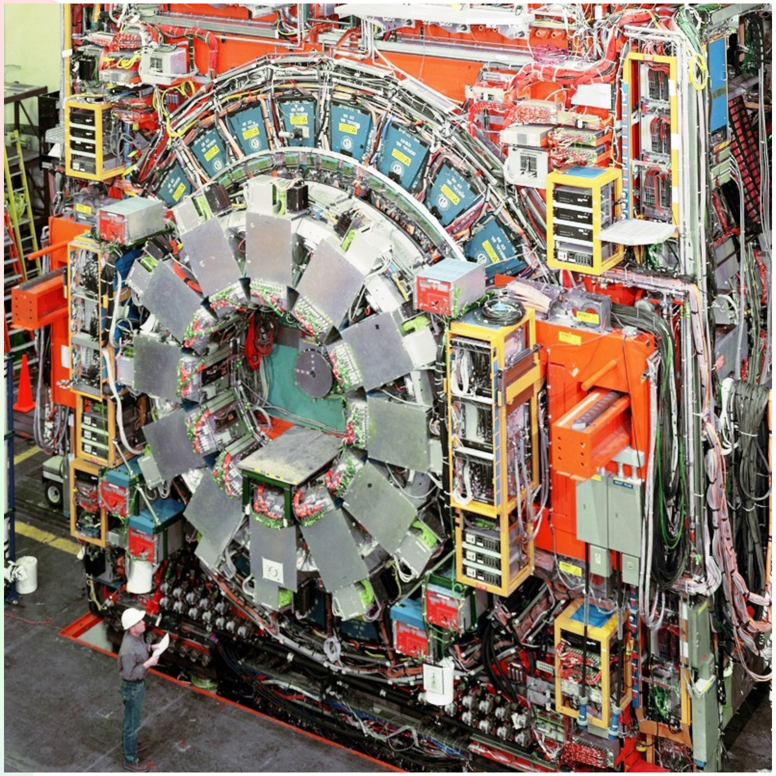
Jet Algorithms

Prog. Part. Nucl. Phys., 60, 484 (2008)

- Cone algorithm (most analyses)
  - Cluster objects based on their proximity in y-ϕ (η-ϕ) space
  - Starting from seeds, iteratively cluster particles in cones of radius R_{CONE} and look for stable cones (geometrical center = p_T-weighted centroid)
  - Uses midpoints between pairs of stable cones as additional seeds
  - → Infrared safe to NNLO
- Inclusive kT algorithm
  - Cluster objects based on their relative pT
  - D parameter controls merging termination and characterizes size of resulting jets
  - → Infrared safe to all orders, more difficult to model UE or MI



Detectors

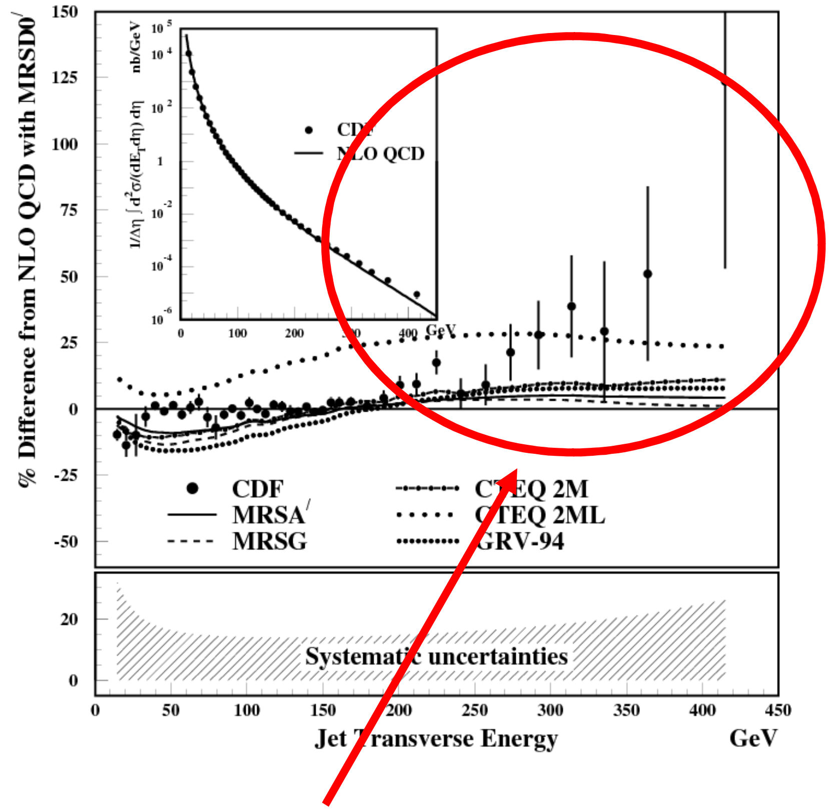


Each experiment has collected > 6/fb on tape

0.3 - 2.5/fb results in this talk

Inclusive Jet X-section

- Test pQCD calculation
- Constrain high-x gluon PDF
- Improvements compared to Run I
  - Increase energy by 150 GeV
  - Extend to wider rapidity region
  - Use cone (R=0.7) and kT (D=0.7) algorithms

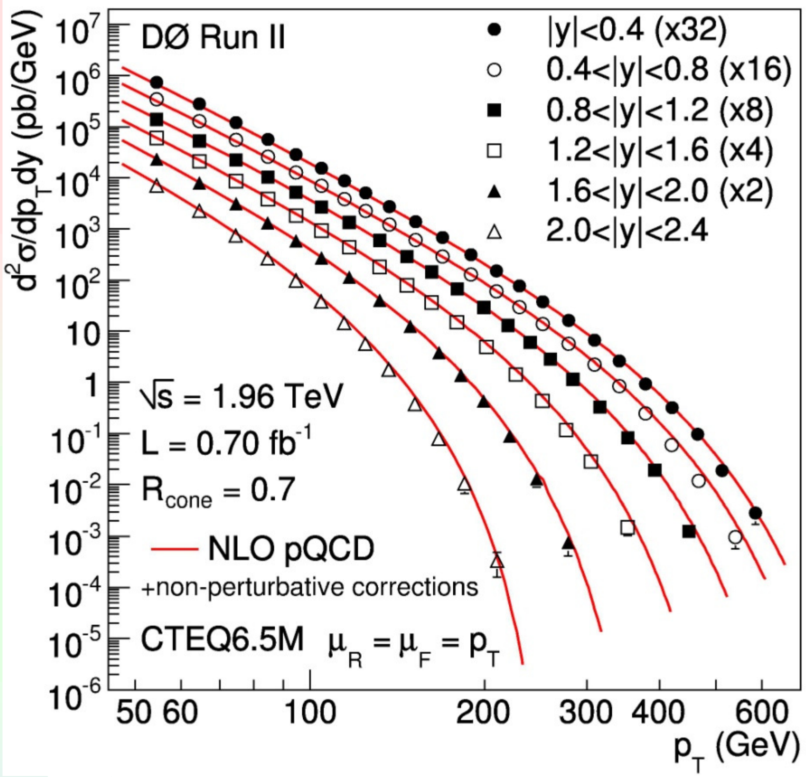


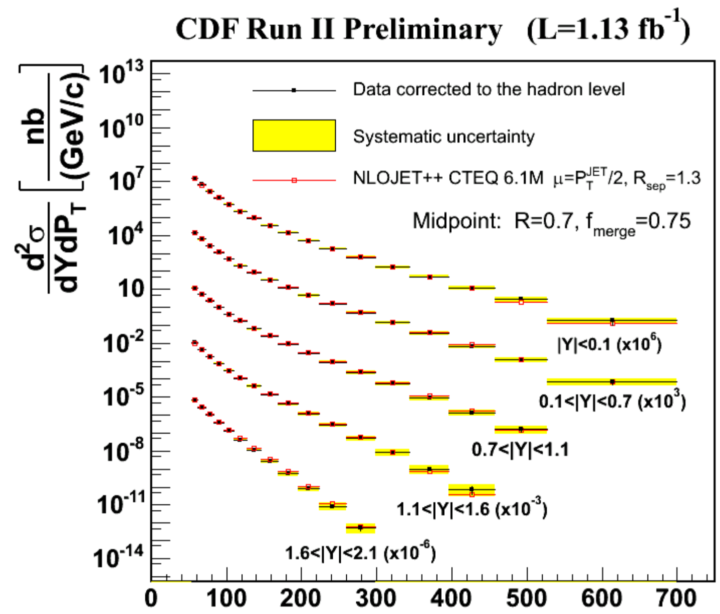
Excess > 160 GeV in CDF Run 1 data (1%)

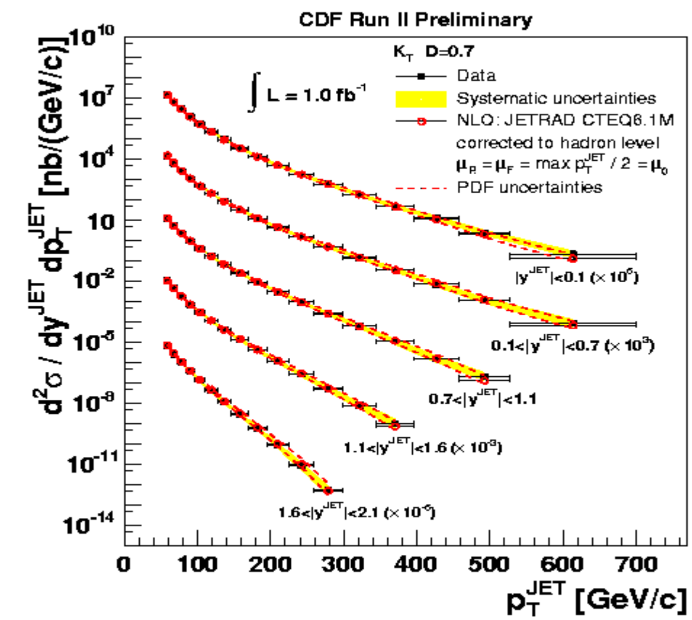
Phys. Rev. Lett. 77, 438 (1996)

Results included in CTEQ6, MRST2001

Run 2 Results







CDF Cone: Phys. Rev. D 74, 071103(R) (2006)

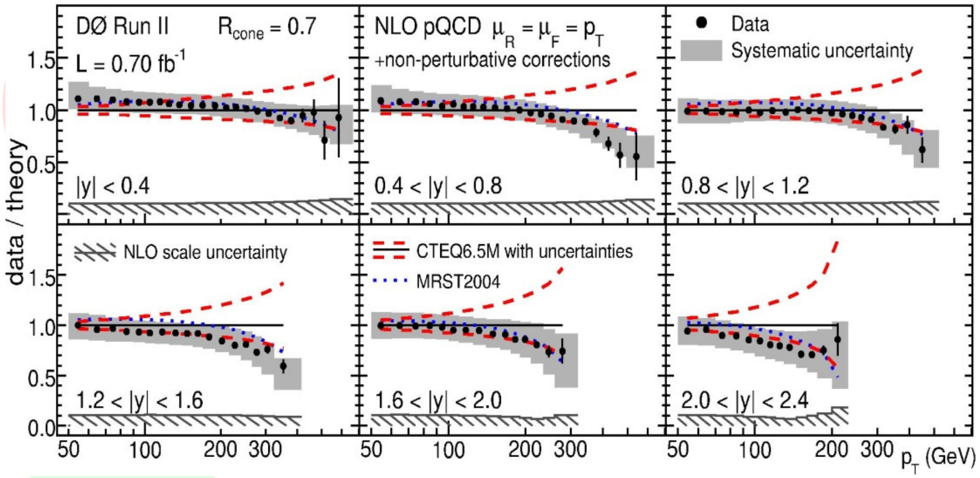
Phys. Rev. D 78, 052006 (2008)

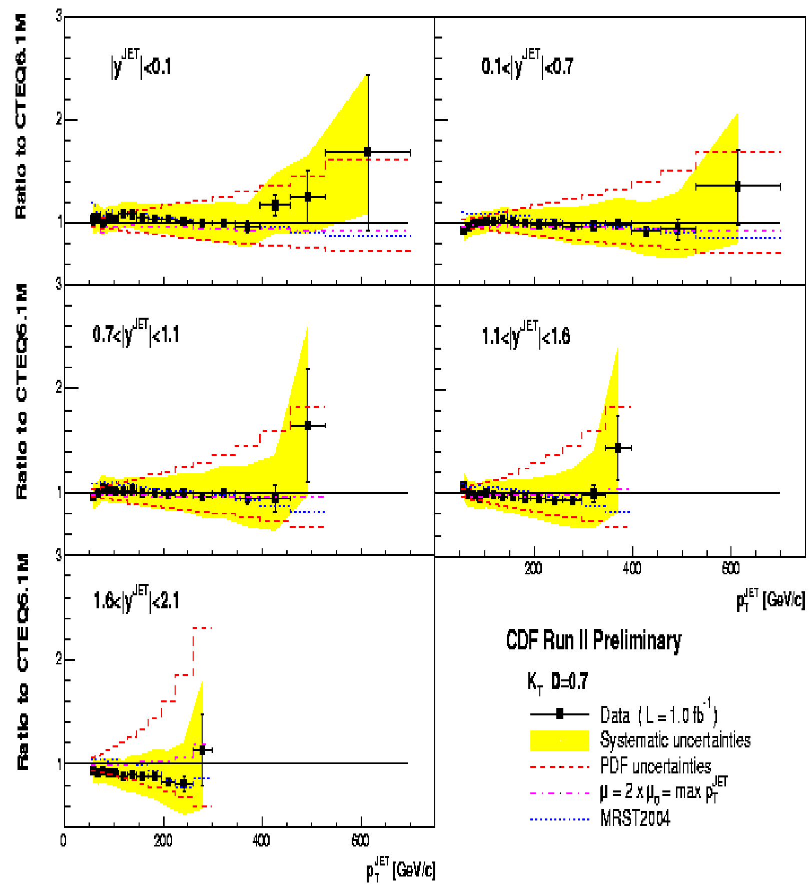
CDF kT: Phys. Rev. Lett. 96, 122001 (2006)

Phys. Rev. D 75, 092006 (2007)

D0 Cone: Phys. Rev. Lett. 101, 062001 (2008)

Run 2 Jet X-section Data/Theory

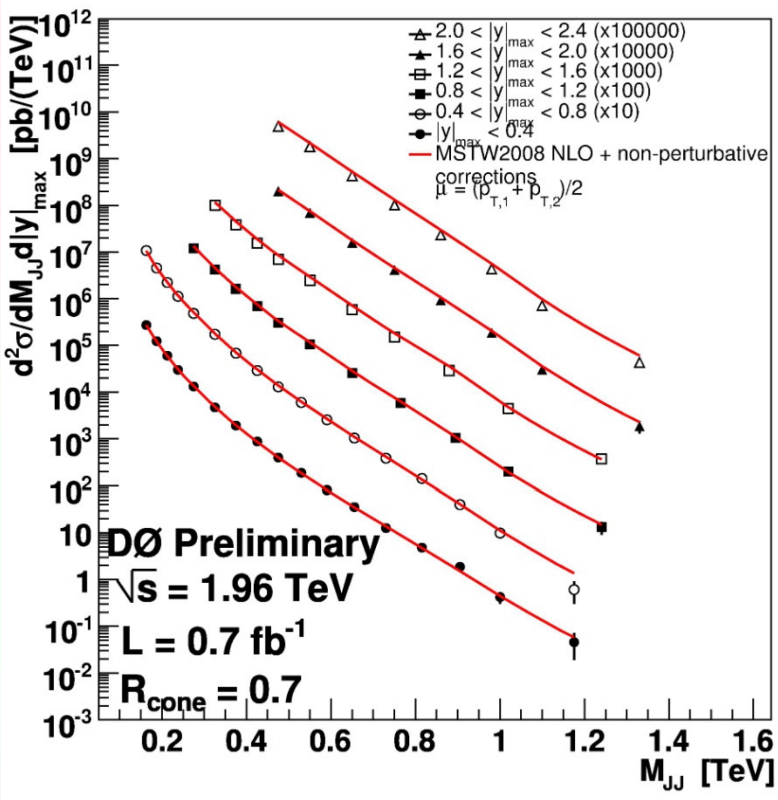


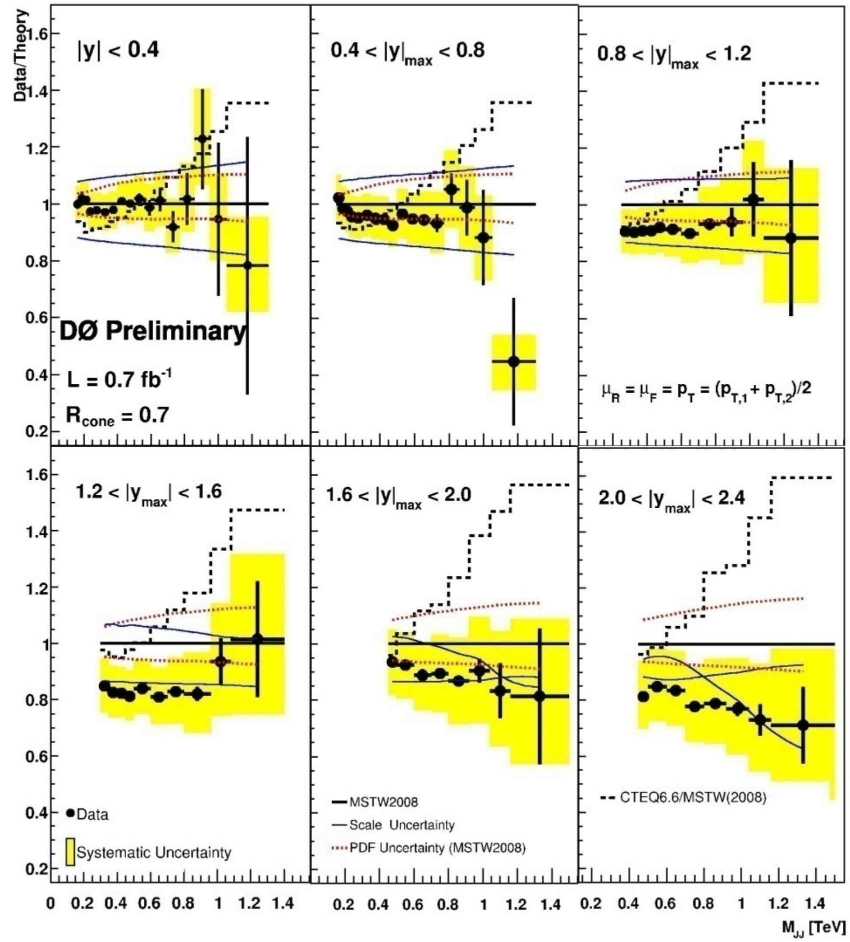


- Dominant sources of uncertainties
  - Data: jet energy scale (2-3% for CDF, 1.2-2% for D0)
  - Total uncertainties on σ: CDF (15-50%) and D0 (15-30%)
- Provide input to PDF
  - MSTW2008 uses CDF kT and D0 cone results
  - Reduced gluon PDF uncertainties
  - Data prefer lower gluon PDF at high-x

Dijet Mass X-Section

NEW!!

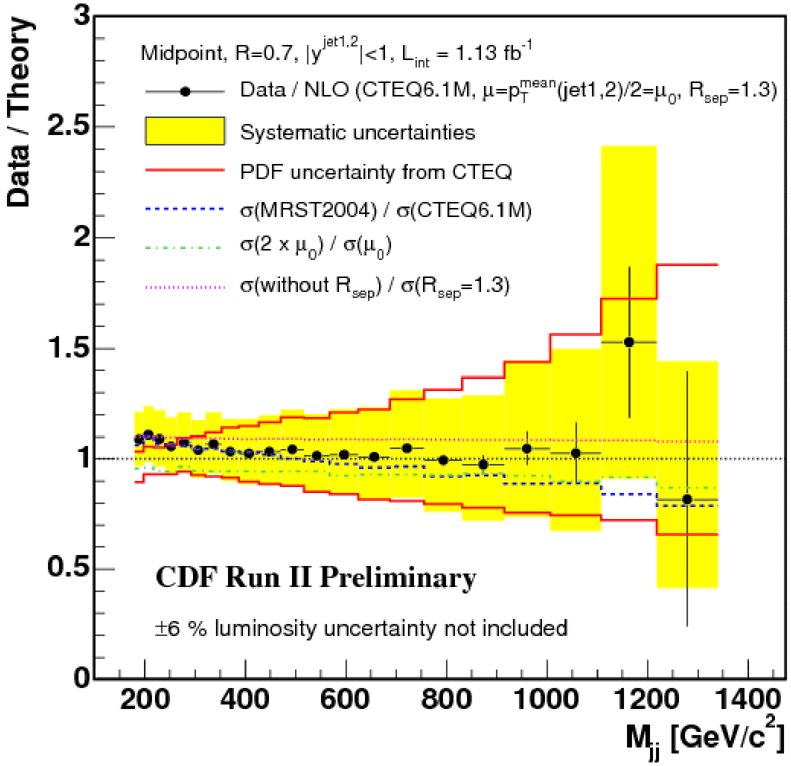


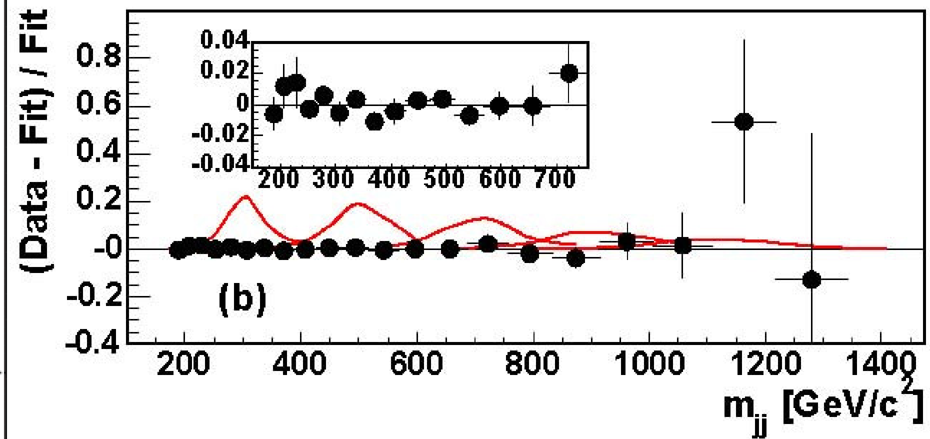


- Use MSTW 2008 NLO PDF!
- Limits on new physics work in progress
- Very large rapidity range

[Thu QCD, LINCOLN, 184]

Dijet Mass X-Section



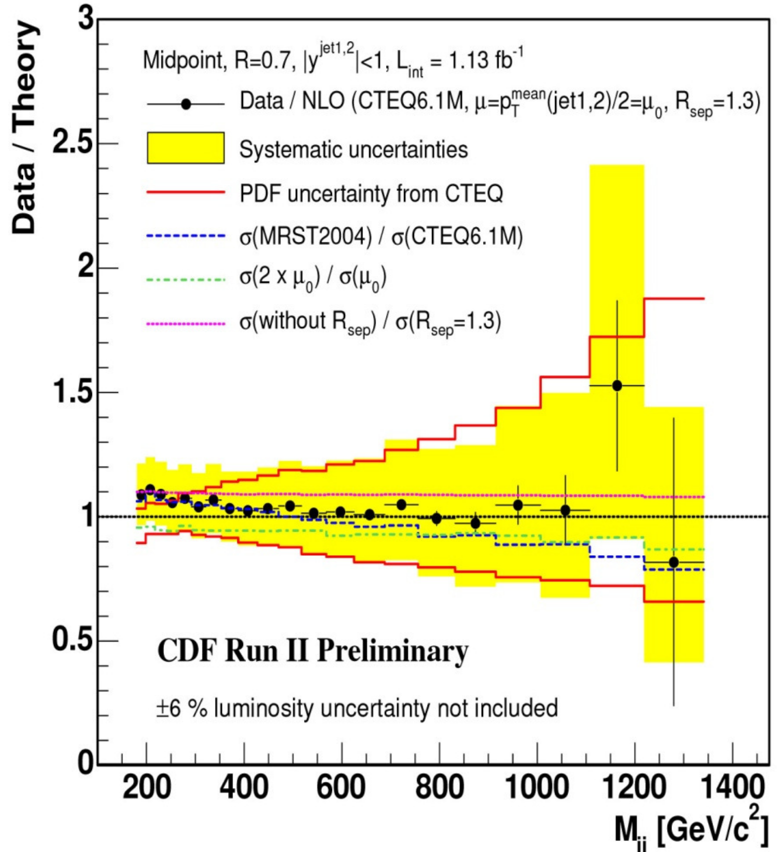


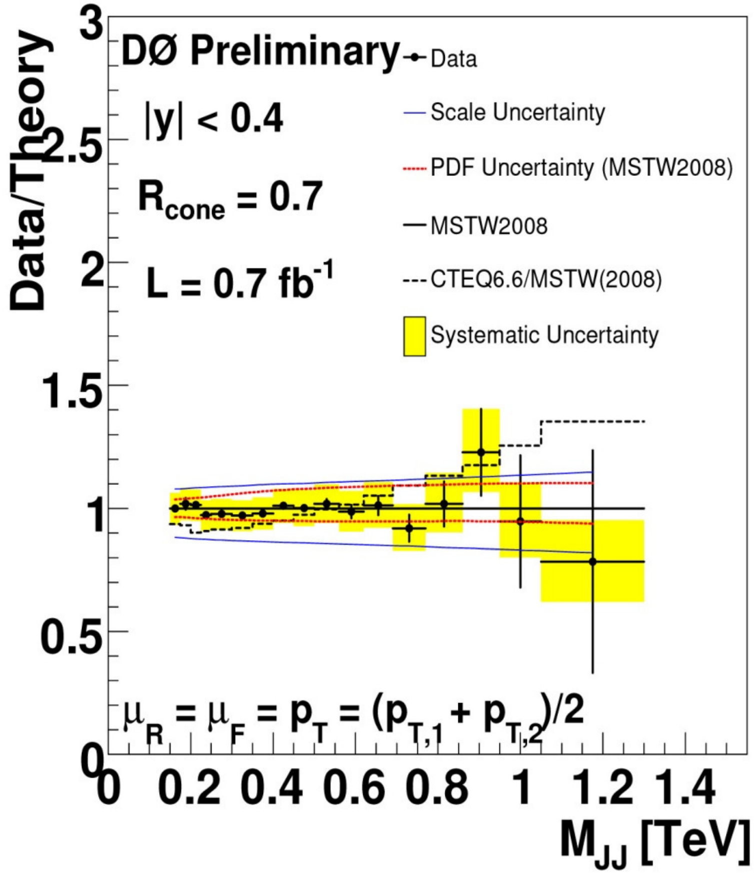
Model	Excluded mass GeV
axigluon, coloron	260-1250
E6 diquark	260-630
Color octet Techni- ρ	260-1100
Excited q	260-870

- Concentrate on central jets
- Good agreement between data and NLO prediction
- Best limits on resonance X→dijets

PRD 79 112002 (2009)

DZero/CDF Comparison





Unfair comparison

CDF 1.13 fb-1, |y| < 1

Dzero, 0.7 fb-1, |y| < 0.4

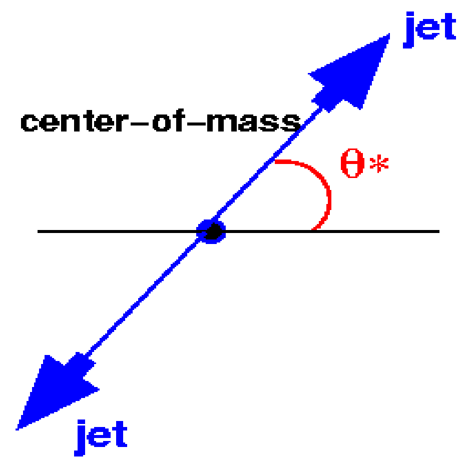
Just for systematics comparison. Dzero will have a hard time improving on this.

Dijet Angular Distribution

- Run 1 jet x-section best fit of compositeness scale Λ at 1.6 TeV (PDF or new physics?)

$$\sigma_{ij\to k} = \int dx_1 \int dx_2 f_i\,(x_1) f_j\,(x_2)\hat{\sigma}_{ij\to k}$$

- Shape of the dijet angular distributions as a function of dijet mass
  - Previous best Λ limits 2.7 TeV(2.4 TeV) for λ=+1(-1)

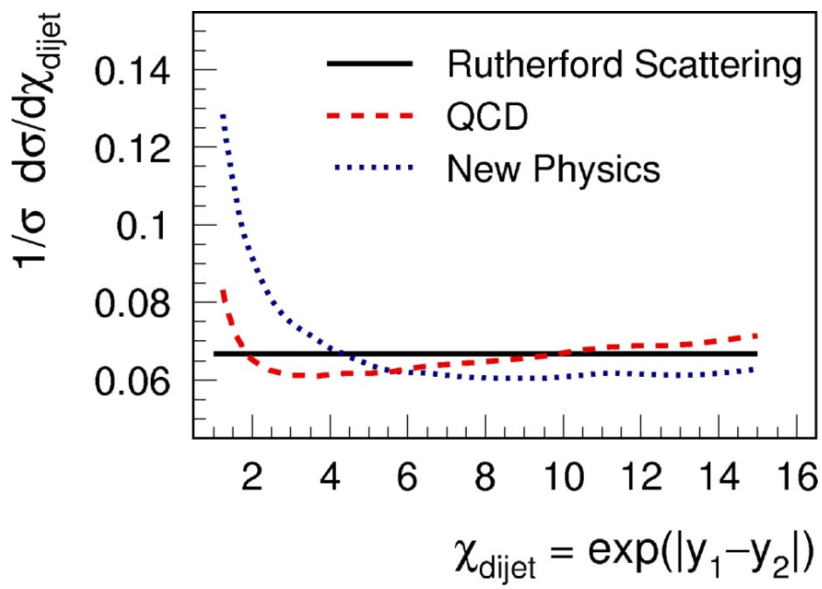


$$\cos\theta^* = \tanh(y^*),$$

$$y^* \equiv \frac{1}{2}(y_1 - y_2)$$

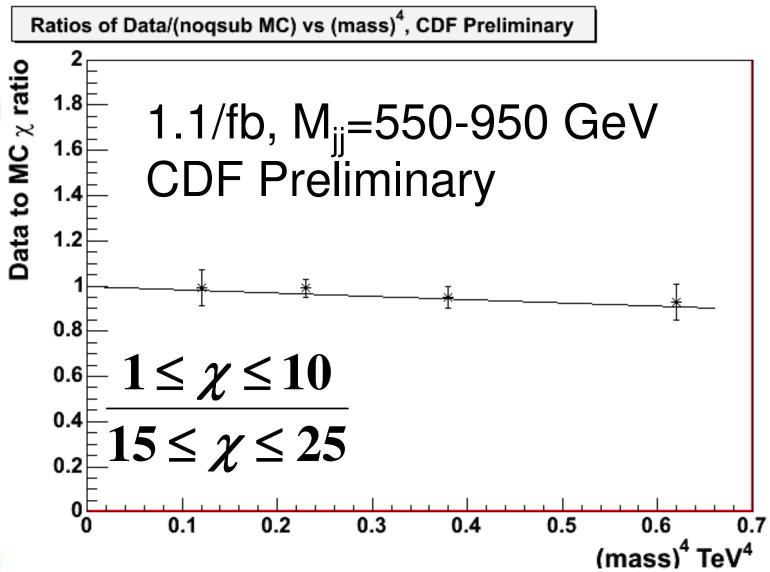
$$\chi_{dijet} = \exp(|y_1 - y_2|)$$

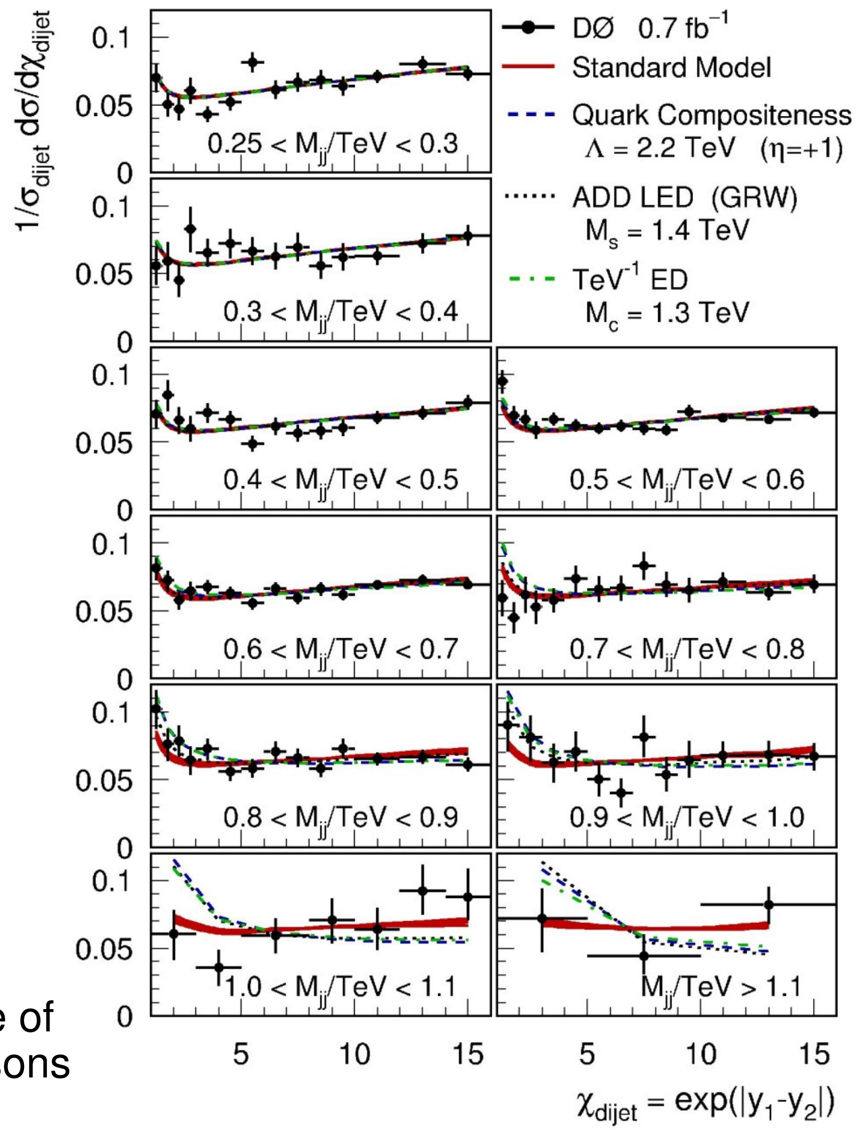
$$= \frac{1+\cos\theta^*}{1-\cos\theta^*}$$



[Thu QCD, LINCOLN, 184]

Run II Results



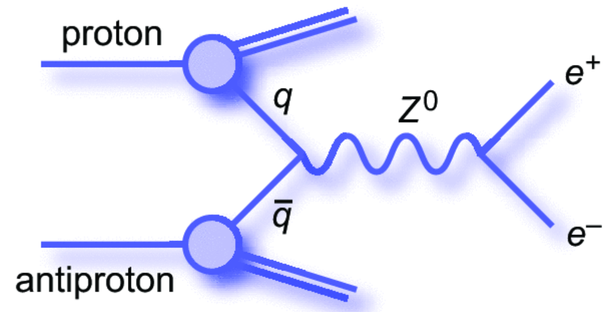


- Quark Compositeness ($q^* \rightarrow qg$)
  - CDF: $\Lambda > 2.4$ TeV for $\lambda = -1$
  - D0: $\Lambda > 2.91$ (2.97) TeV for $\lambda = +1$ (-1)
- ADD Large Extra Dimension (D0 only)
  - GRW: $M_s > 1.53$ TeV
- TeV^{-1} Extra Dimension (D0 only)
  - X-section modified due to the exchange of virtual KK excitations of SM Gauge Bosons
  - Compactification scale $M_c > 1.73$ TeV

arXiv.org:0906.4819

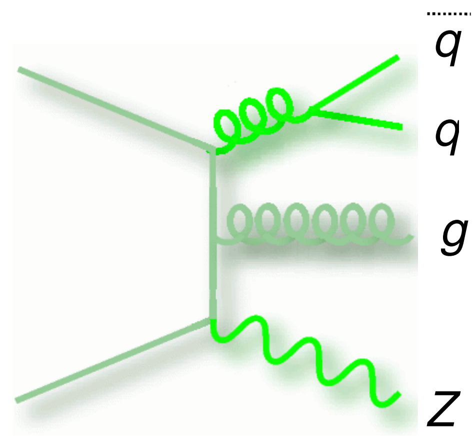
W/Z Production

Use leptonic W/Z decays as probe of QCD
- high Q^2 (~M_Z or M_W)
- very small backgrounds, right down to p_T ~ 0!

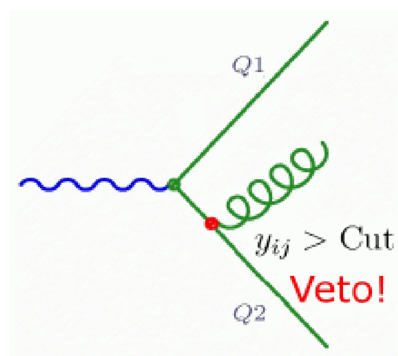


Concentrate on high pT final states: W/Z + jets
- regime of perturbative QCD

pQCD:
- LO W/Z + 1 - 6 partons
- NLO W/Z + 1, 2 (MCFM)
- new NLO W+3 (Rocket, Blackhat+SHERPA)



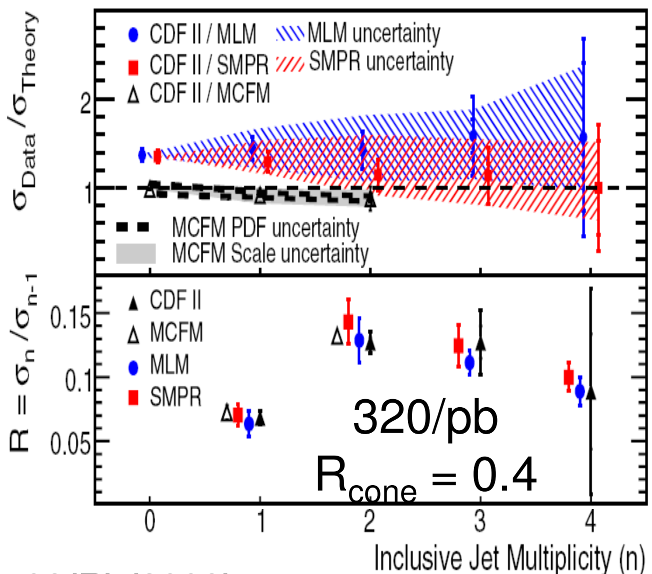
Event generators:
- LO 2 ->1, 2 + parton shower
  - PYTHIA, HERWIG
- LO 2 -> 1-6 + (vetoed) parton shower
  - ALPGEN, SHERPA



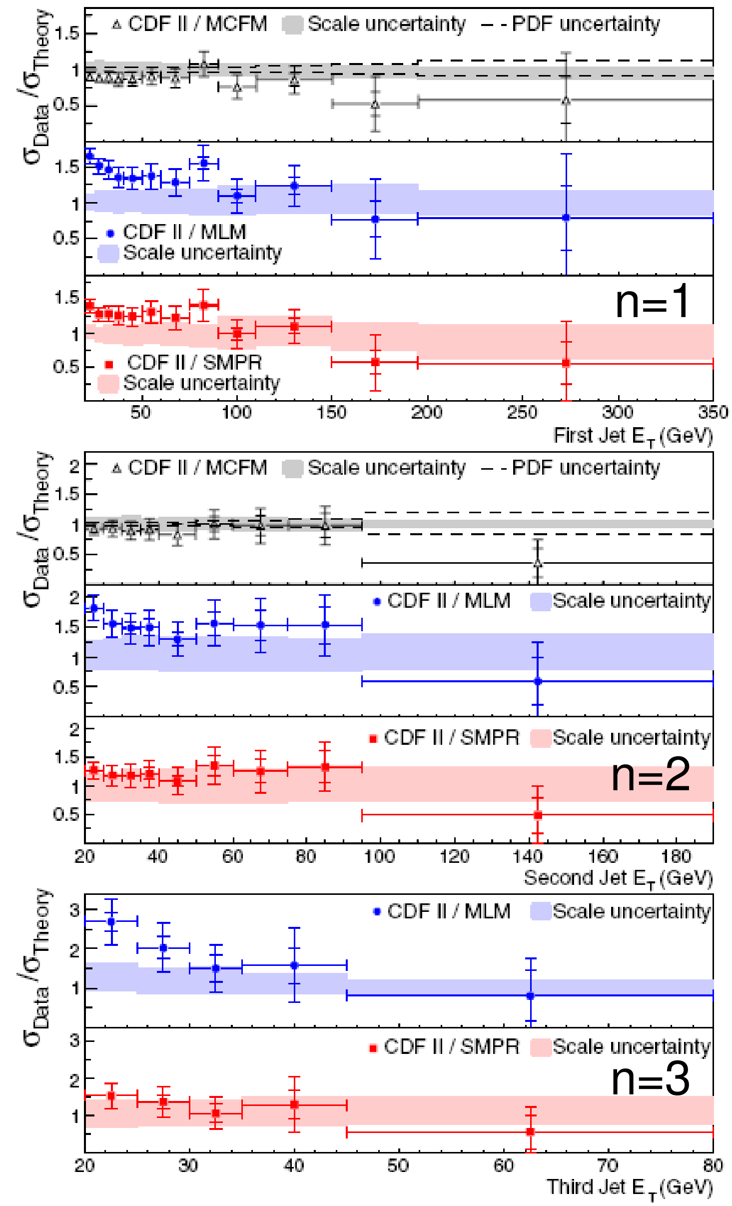
These generators are the main Tevatron and LHC tools,
- but, leading order → large uncertainties
- must to be tuned to data!

W(→eν)+ ≥ n Jet Production

Restricted
W phase space
$E_T(e) > 20$ GeV
$|\eta(e)| < 1.1$,
$E_T(\nu) > 30$ GeV
$m_T(W) > 20$ GeV

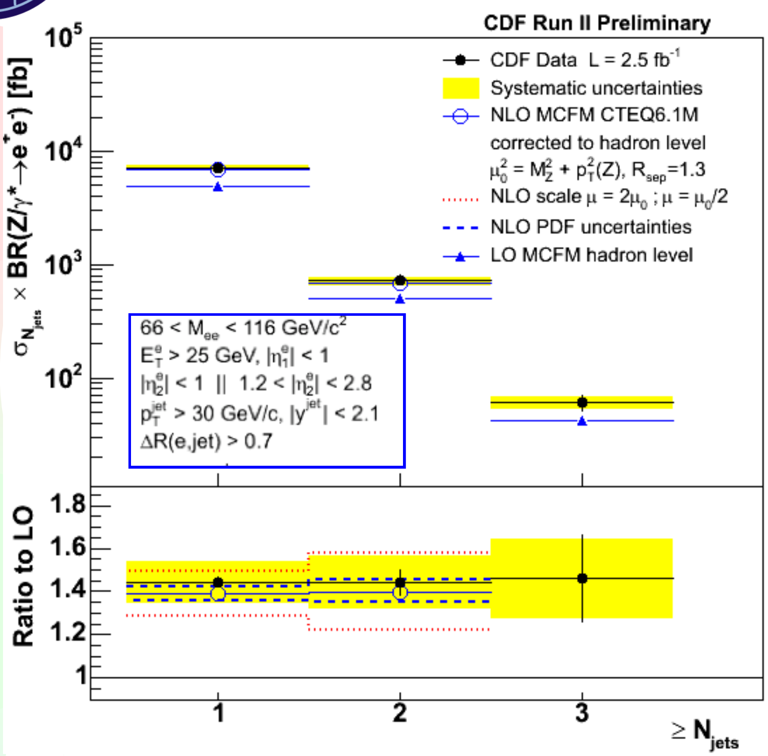


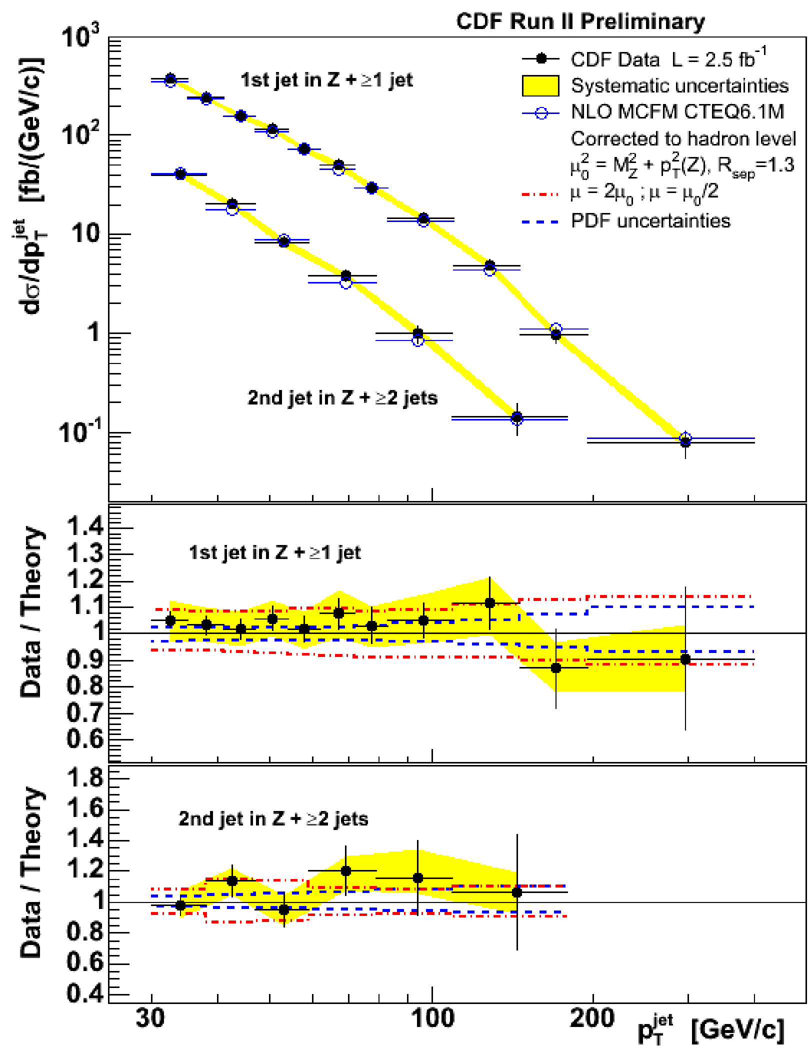
Phys. Rev. D 77, 011108(R) (2008)



- Background 10% (40%) to 90% for n=1(4)
  - Systematic uncertainties 15% to 50%(20%)
- Jet energy scale (low pt) and background (high pt) are dominant uncertainties
- Comparison
  - NLO: MCFM
  - MLM (LO): ALPGEN+ HERWIG+ MLM
  - SMPR (LO): MADGRAPH + PYTHIA+ CKKW

Z(→ee)+ ≥ n Jet Production

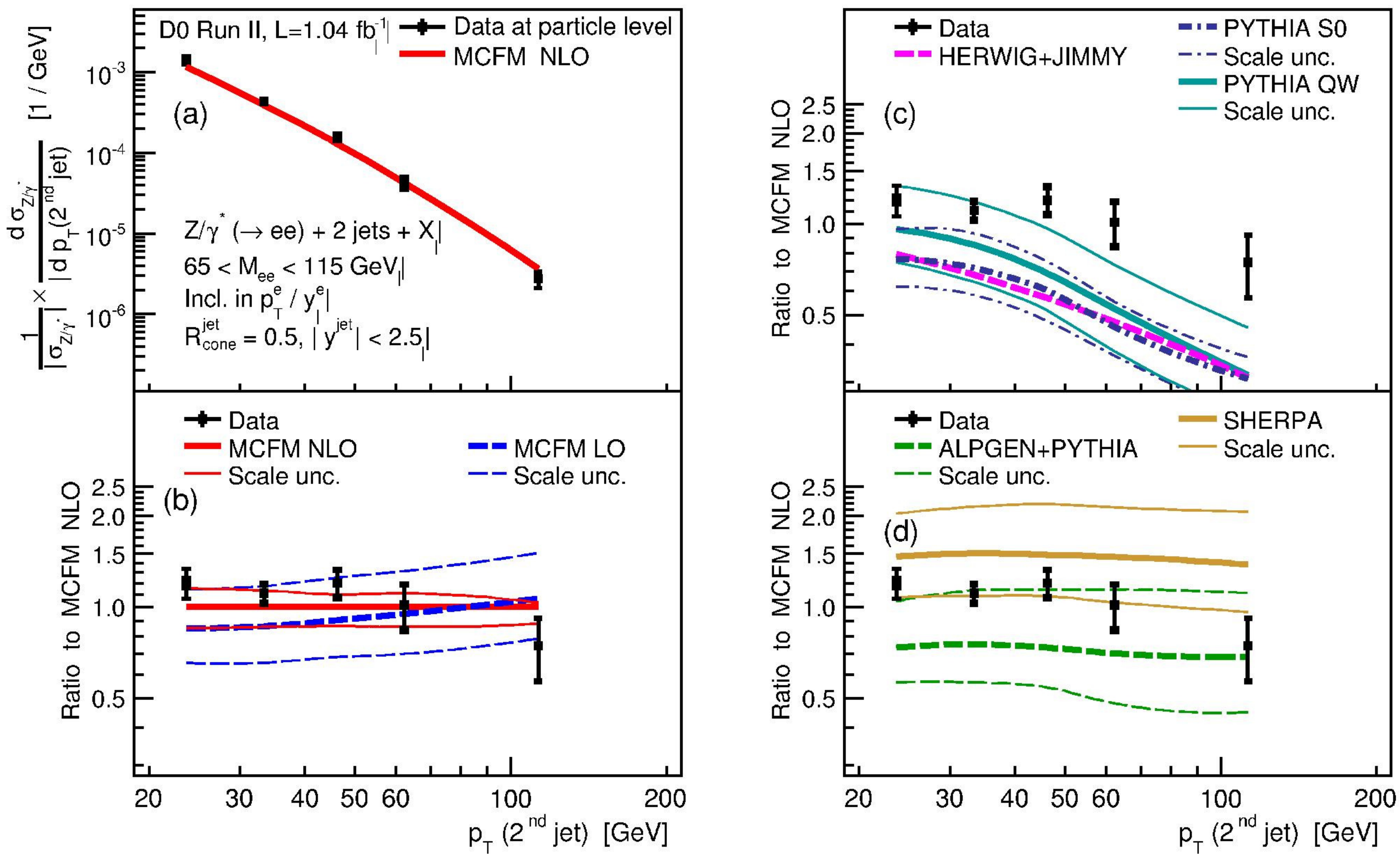




- Much cleaner compared to W+jets
  - ➢ 12(17)% background for n>=1(3)
- Good agreement with NLO MCFM
  - ➢ Systematic uncertainties 8 to 13%

Phys. Rev. Lett. 100, 102001 (2008)

Z(→ee)+ ≥ n Jet Production



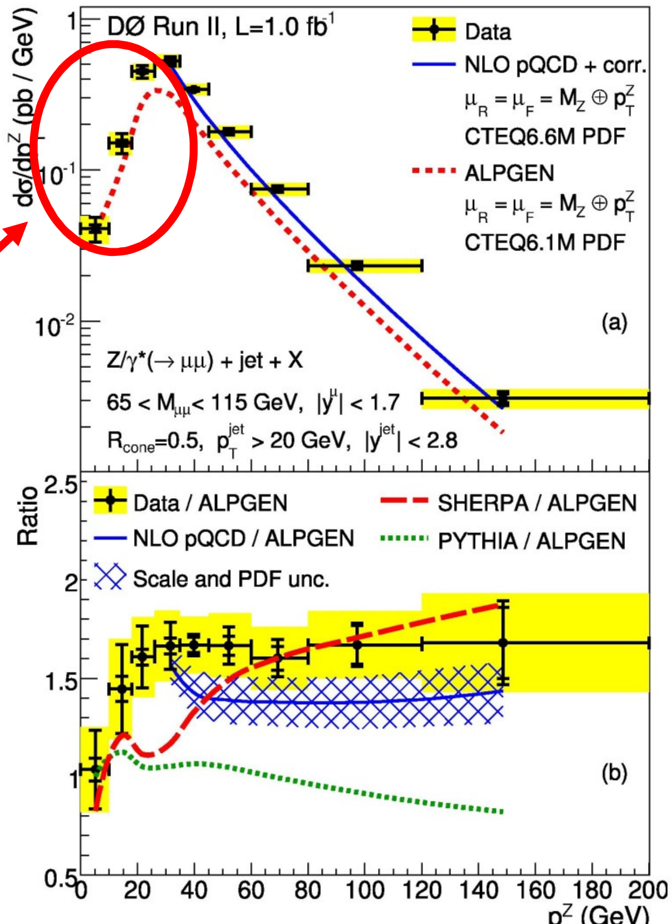
PLB **678**, 45 (2009)

- Also check several LO predictions
  - ➢ Parton-shower based generator disagree in shapes and normalization
  - ➢ Matrix element + Parton-shower generators describe shape better

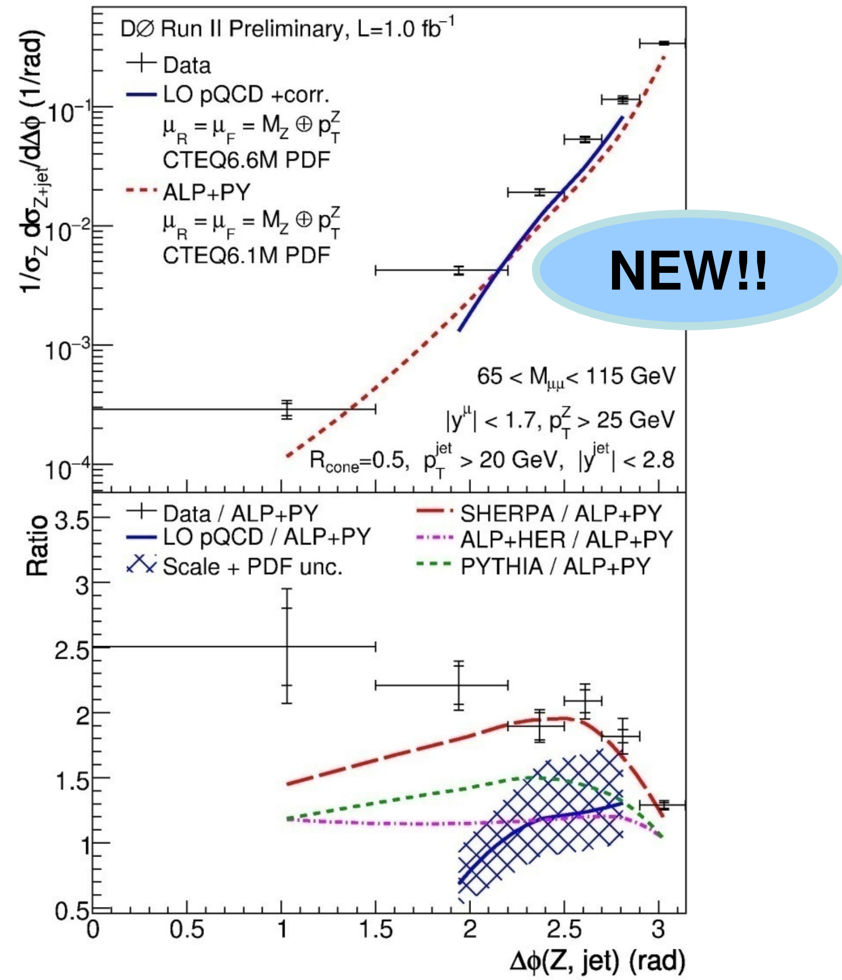
[Thur. QCD, LAMMERS, 187]

Z(→μμ)+ ≥ n Jet Production

Dominated by non-pQCD



PLB 669, 278 (2008)



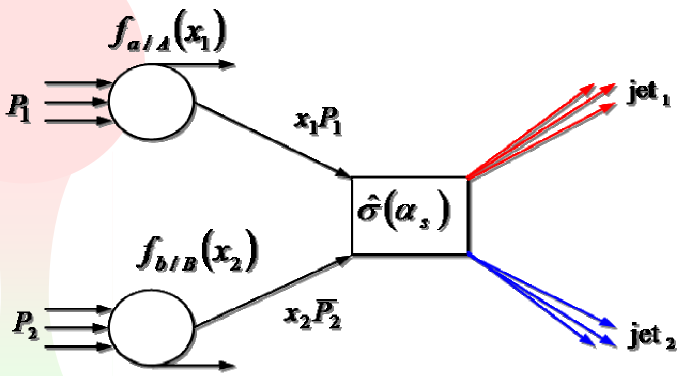
- Good agreement with NLO in p_T(jet), y(jet), p_T(Z), y(Z)

$\Delta\phi$: Only LO, not good agreement in shapes and normalization

[Thur. QCD, LAMMERS, 187]

Submitted to PLB Friday! arXiv:0907.4286

High p_T Jets at the LHC



$$\frac{d\sigma}{dP_T} \approx \sum_{a,b} \int dx_a f_{a/A}(x_a,\mu) \int dx_b f_{b/B}(x_b,\mu) \frac{d\hat{\sigma}}{dP_T}$$

N_{jets} / pb^{-1} $|y|<1.3$

Sqrt(s)	pT>0.5 TeV	pT>1 TeV
10	320 / pb^{-1}	5 / pb^{-1}
14	860 / pb^{-1}	20 / pb^{-1}

N_{dijets} / pb^{-1} $|\eta_1|, |\eta_2|<1.3$

Sqrt(s)	M_{jj}>1.4 TeV	M_{jj}>2TeV
10	50 / pb^{-1}	7.4 / pb^{-1}
14	140 / pb^{-1}	20 / pb^{-1}

For comparison, corresponding numbers from the Tevatron:

N_{jets} / pb^{-1} $|y|<0.8$

Sqrt(s)	pT>0.5 TeV	pT>1 TeV
2	0.05 / pb^{-1}	—

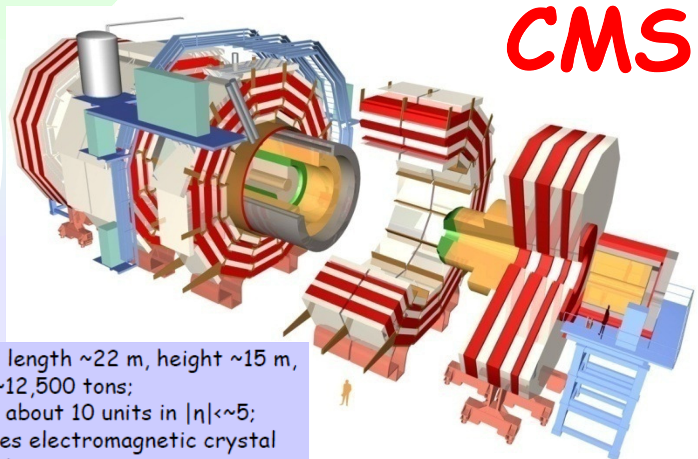
N_{dijets} / pb^{-1} $|\eta_1|, |\eta_2|<2.4$

Sqrt(s)	M_{jj}>1 TeV	M_{jj}>2TeV
2	0.03 / pb^{-1}	—

Jet Reconstruction at CMS and ATLAS

CMS

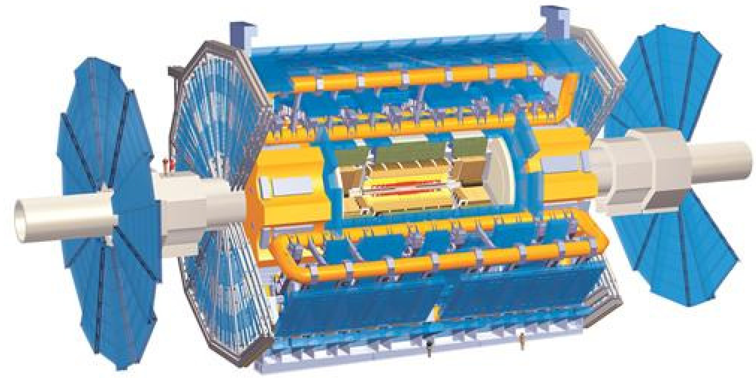
- Jet algorithms considered:
  - Seedless Cone, R=0.5, 0.7
  - KT, D=0.4, 0.6
  - Iterative Cone, R=0.5 (used in the trigger)
- Jet types:
  - Calorimeter jets (towers input).
  - JetPlusTrack (combined calorimeter and tracker information).
  - Particle Flow jets (particles input).
  - Track jets (track input).



• overall length ~22 m, height ~15 m, weight ~12,500 tons;
• covers about 10 units in |η|<~5;
• features electromagnetic crystal calorimetry;
• features hadronic scintillator calorimetry (typical e/h ≈1.3-1.5)

ATLAS

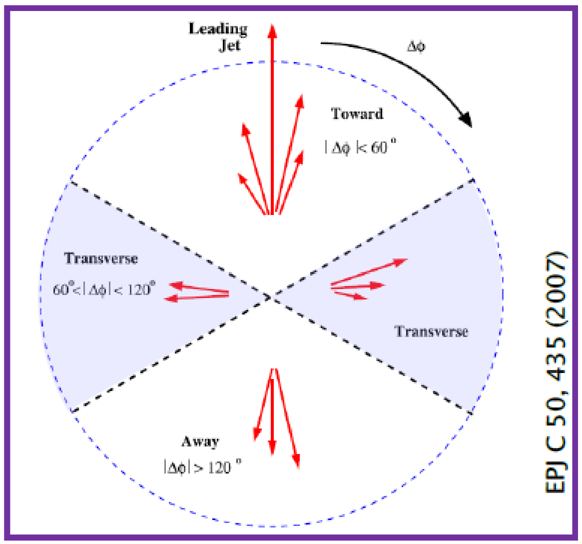
- Jet algorithms considered:
  - Anti KT, D=0.4, 0.6
  - Seeded Cone, R=0.4, 0.7
  - Seedless Cone, R=0.4, 0.7
  - KT, D=0.4, 0.6
- Jet types:
  - Calorimeter jets (towers or topological cell clusters input).
  - Energy Flow jets (combined calorimeter and tracker information).
  - Track jets (track input).

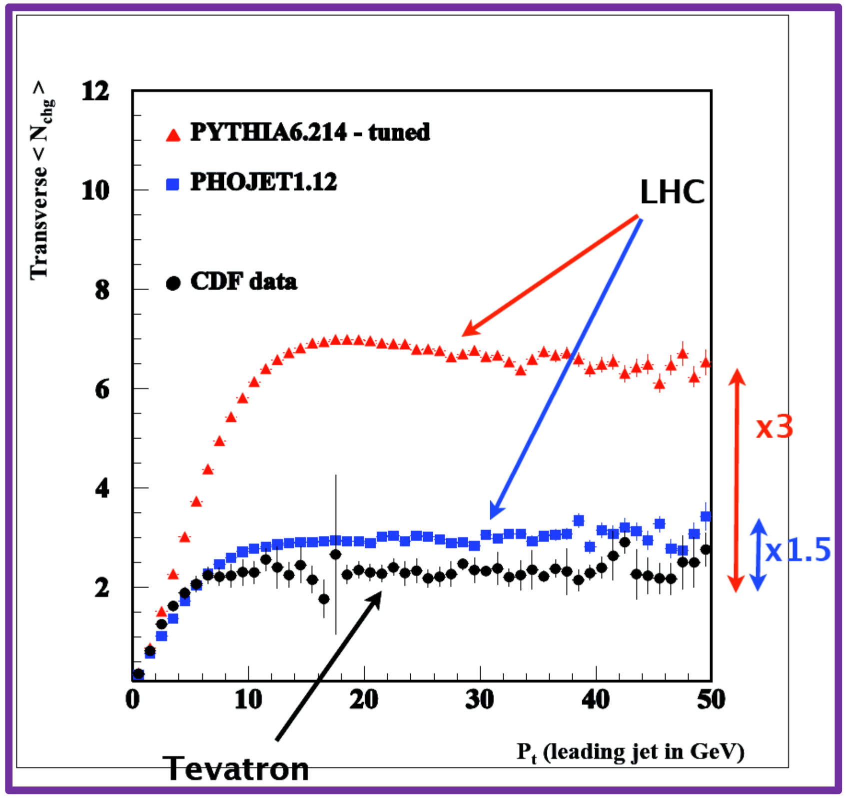


• overall length ~45 m, height ~22 m, weight ~7,000 tons;
• covers about 10 units in |η|<~5;
• features electromagnetic and hadronic liquid argon calorimetry (e/h≈1.4);
• features hadronic scintillator calorimetry (e/h≈1.4);

Underlying Event

- Study of the track multiplicity and p_T density in "transverse" jet region
  - CDF approach
  - Measurement used to tune MC event generators at the Tevatron
  - Naïve re-scaling of Tevatron will not work





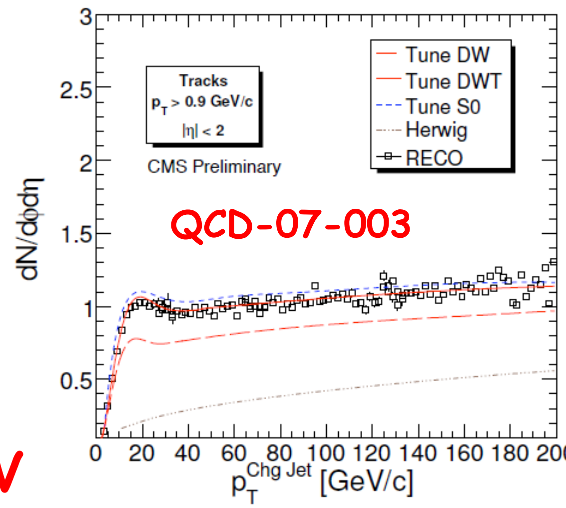
Large model dependence on LHC predictions from Tevatron data

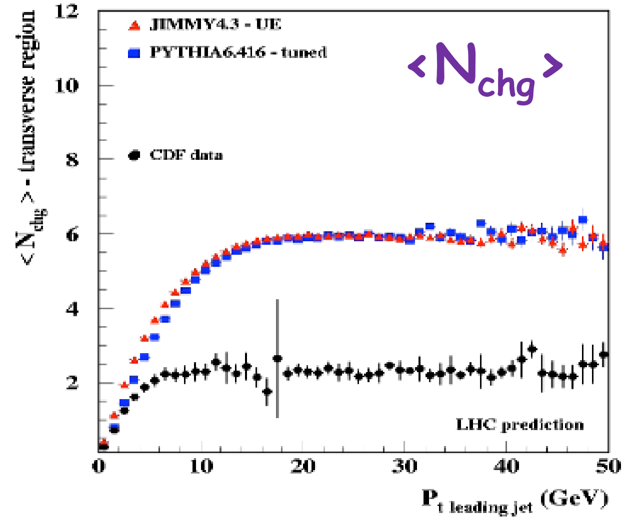
Underlying Event

CMS

ATLAS

Sensitivity to different MC tunes

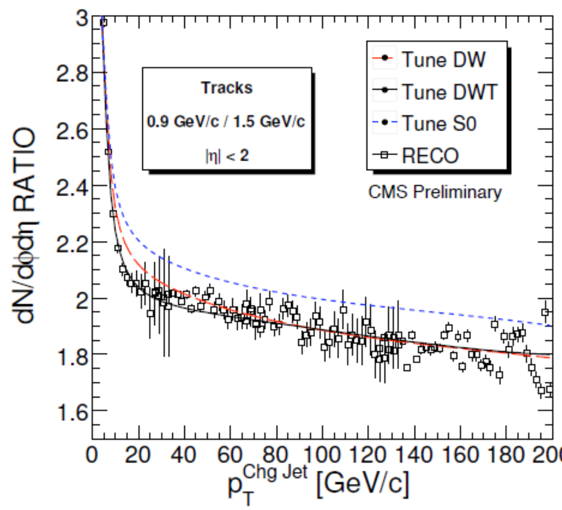


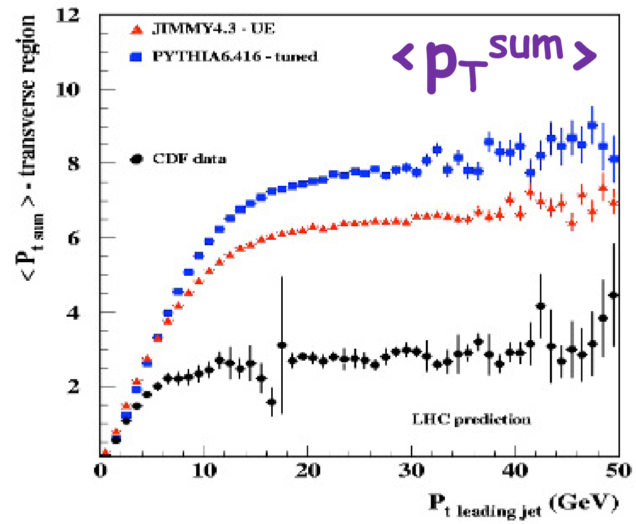


Tuned-Pythia and Jimmy predict same particle density

$\sqrt{s}$ = 14 TeV

Reduced systematic effects with ratio: 0.9/1.5





Tuned-Pythia predicts harder particles than Jimmy

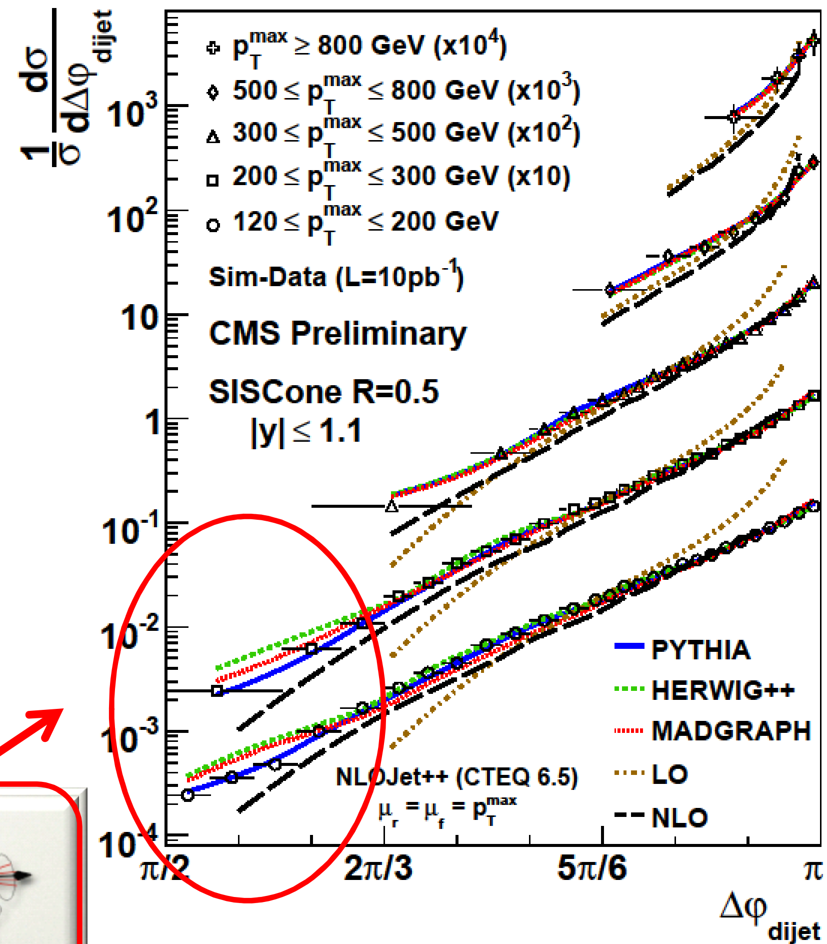
Dijet Angular Decorrelation

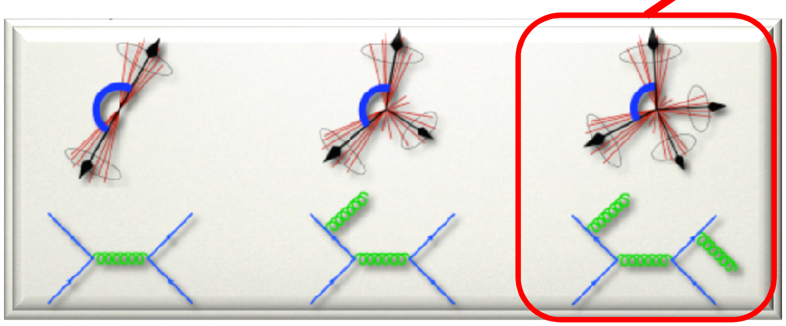
- Measurement of the azimuthal angle between the two leading jets.
- $\Delta\varphi$ distribution of leading jets is sensitive to higher order radiation w/o explicitly measuring the radiated jets
- Shape Analysis:

$$f\left(\Delta\varphi_{\text{dijet}}\right) = \frac{1}{\sigma_{\text{dijet}}}\left|\frac{d\sigma_{\text{dijet}}}{d\Delta\varphi_{\text{dijet}}}\right|$$

  - Reduced sensitivity to theoretical (hadronization, underlying event) and experimental (JEC, luminosity) uncertainties

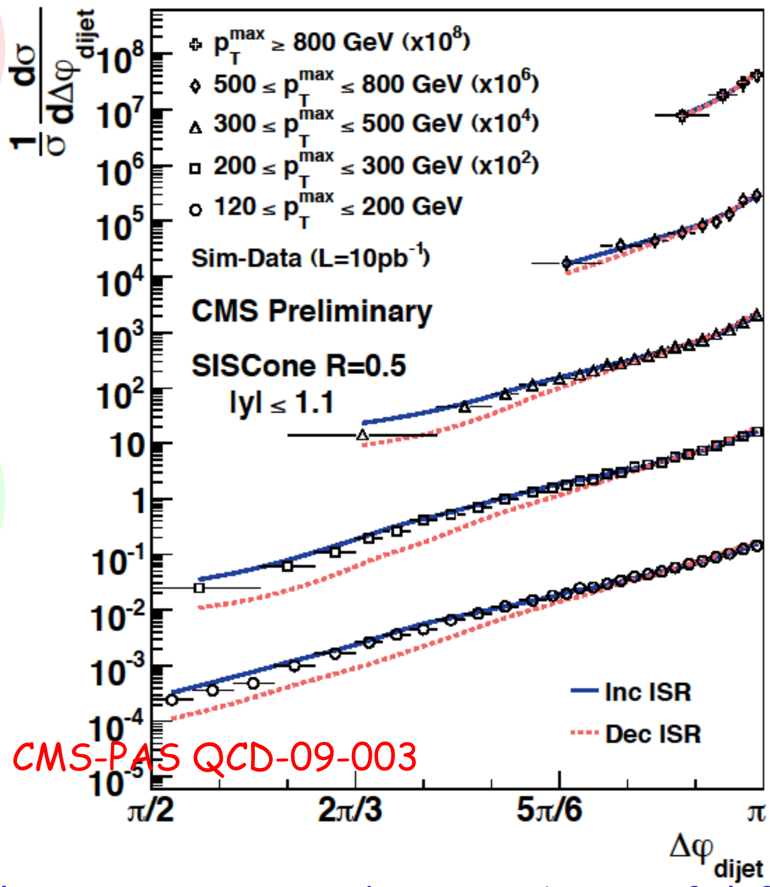
CMS PAS QCD-09-003



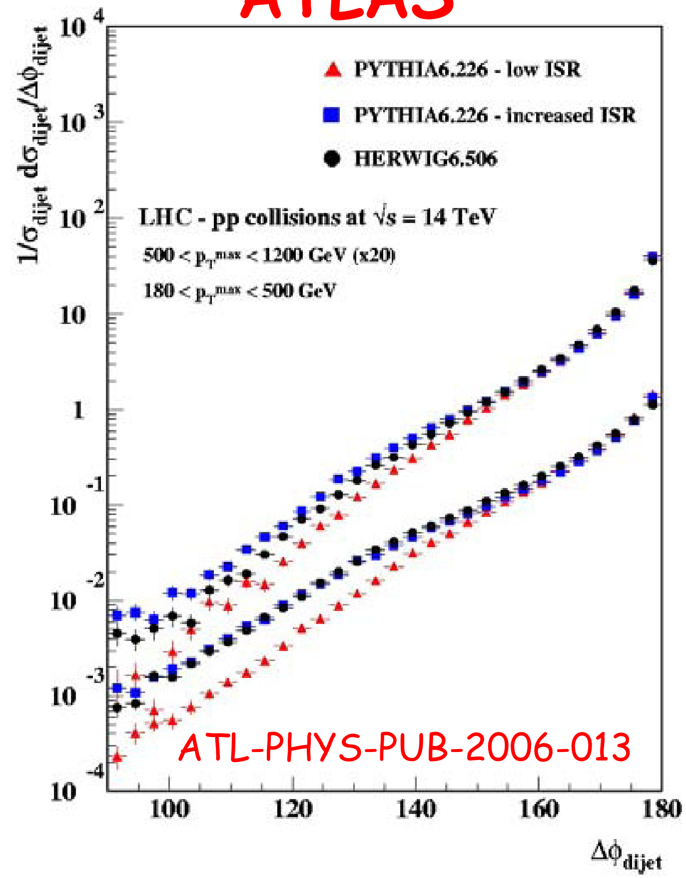


Dijet Angular Decorrelation (ii)

CMS



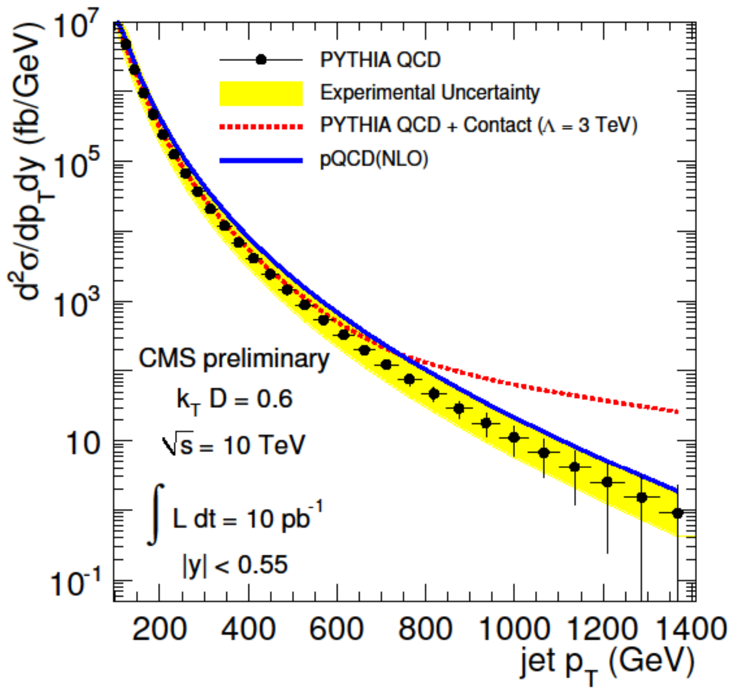
ATLAS

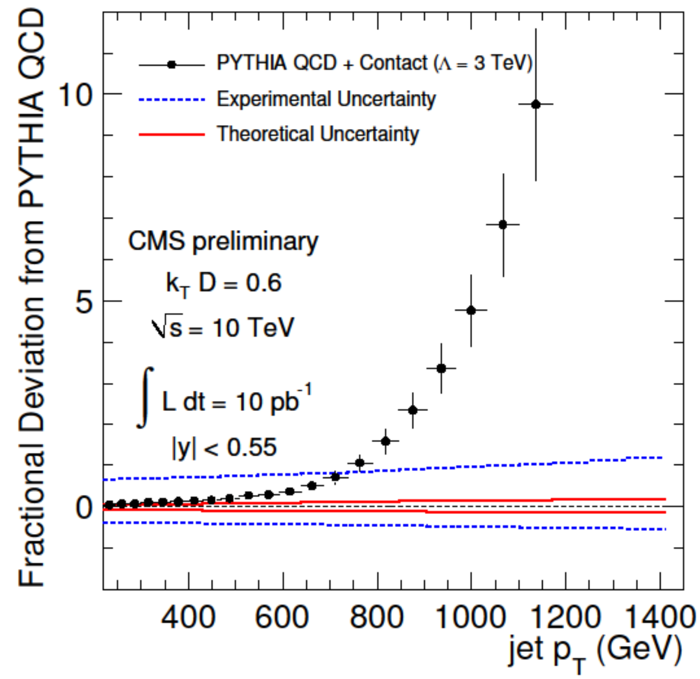


- Early measurement shown to be useful for tuning phenomenological parameters (ISR) in MC event generators
- Systematic uncertainties dominated by jet energy scale and jet energy resolution effects

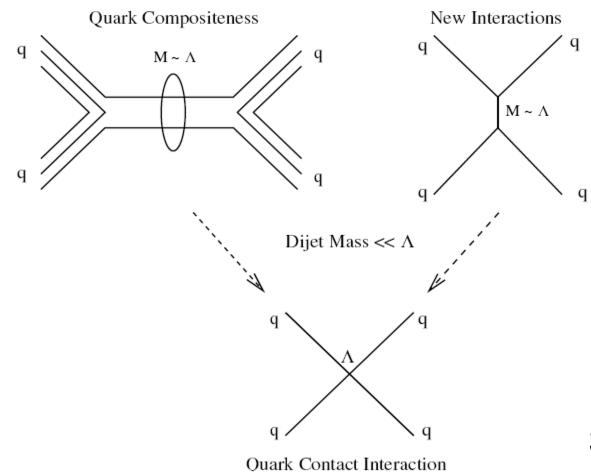
Inclusive Jet Cross Section

CMS PAS QCD-08-001





- Important jet commissioning measurement
- Can probe contact interactions beyond the Tevatron reach (2.7 TeV) with 10 pb^{-1} at 10 TeV
- Main uncertainty: Jet energy scale
  - assume 10% on day 1
- Can be used to constrain PDF's



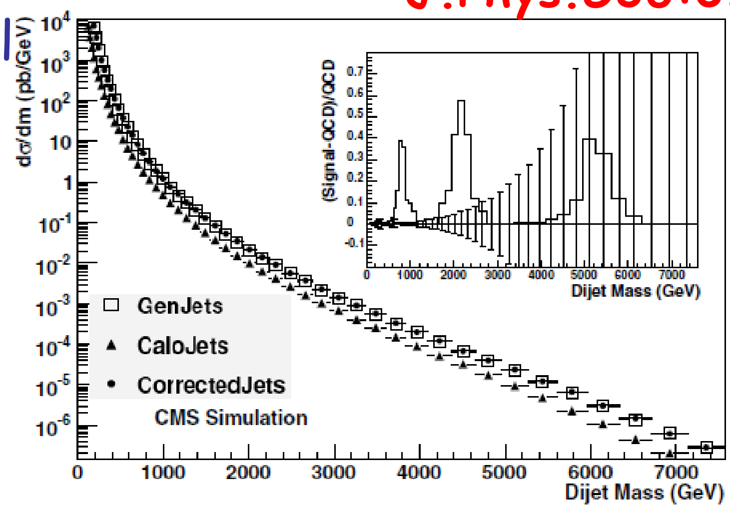
Dijet Mass and Ratio

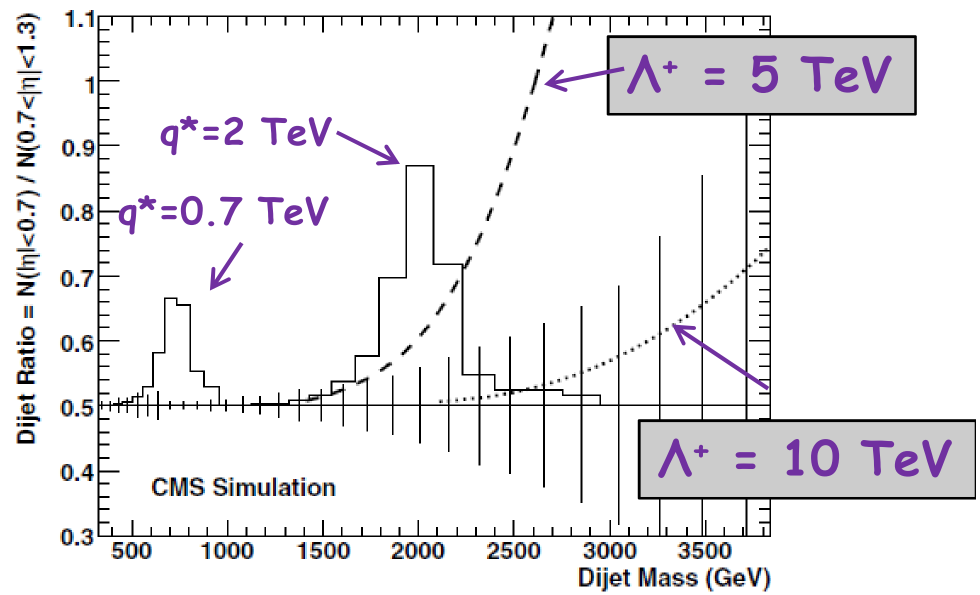
- The dijet mass distribution will be used to search for dijet resonances
- The dijet ratio is a simple measure of dijet angular distributions
  - N(|η|<0.7)/N(0.7<|η|<1.3)
  - Sensitive to contact interactions and dijet resonances
    - With ~100 pb-1 @ 14 TeV; discovery potential up to Λ = 7 TeV
- Dijet ratio has low systematic uncertainties and is a precision test of QCD at startup

J.Phys.G36:015004,2009

$\sqrt{s}$ = 14 TeV

L= 100 pb^{-1}





Summary

- HERA experiments continue to produce very precise results.
- The Tevatron is now producing QCD results of unprecedented precision for a hadron collider.
- LHC will start producing collisions "soon."
- After 20 years of R&D, construction, and installation the ATLAS and CMS detectors are ready for data

- QCD will continue to be a crucial field of study
  - In its own right
  - As a way to look for new physics
  - As a background for new physics

Acknowledgments

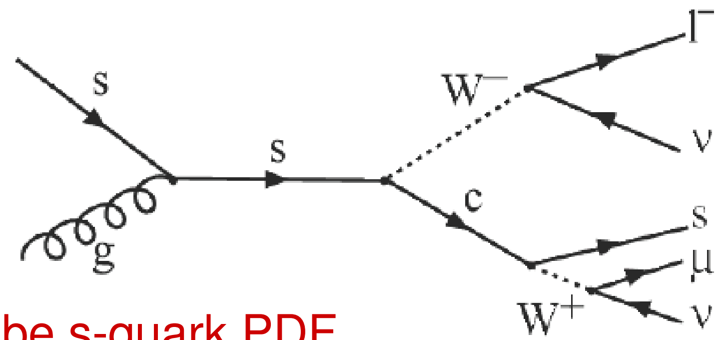
- Enrico Tassi, DIS 2009
- Stefan Schmitt, DIS 2009
- Voica Radescu, DIS 2009
- Mike Strauss, APS 2009
- Shin Shan Yu, Photon 2009
- Leonard Apanasevich, EPS 2009
- Gavin Hesketh, Fermilab W&C Seminar 2009

- These presentations were extensively mined for material for this talk.

Backup Slides

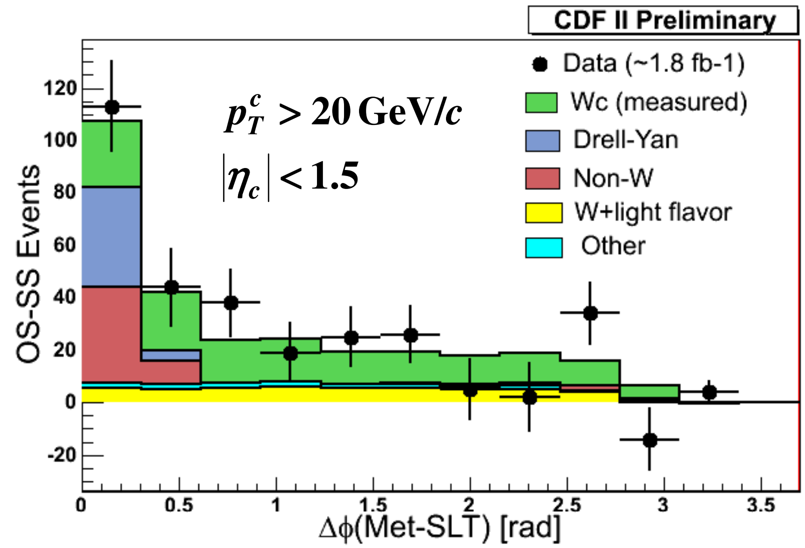
Heavy Flavor

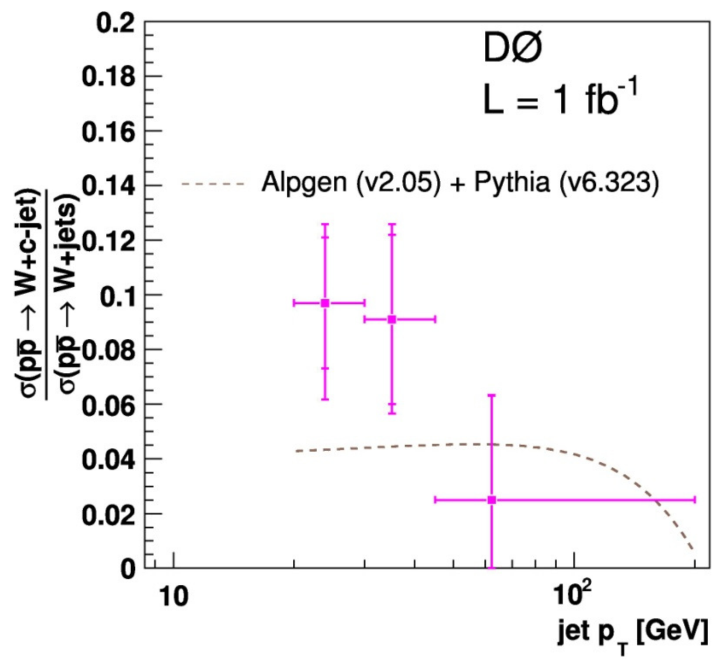
W + c Production



- Probe s-quark PDF
- Use soft-muon-tag to tag c
  - 90-60% (55%) efficiency for CDF (D0)
- Wc production have more OS than SS events
- Results
  - CDF: σ = **9.8 ± 2.8 (stat) + 1.4-1.6 (sys) ± 0.6 (lum) pb**, agree with NLO 11.0+1.4-3.0 pb
  - D0 σ ratio: **0.074 ± 0.019 (stat) + 0.012-0.014 (sys)**, agree with LO 0.044 ± 0.003

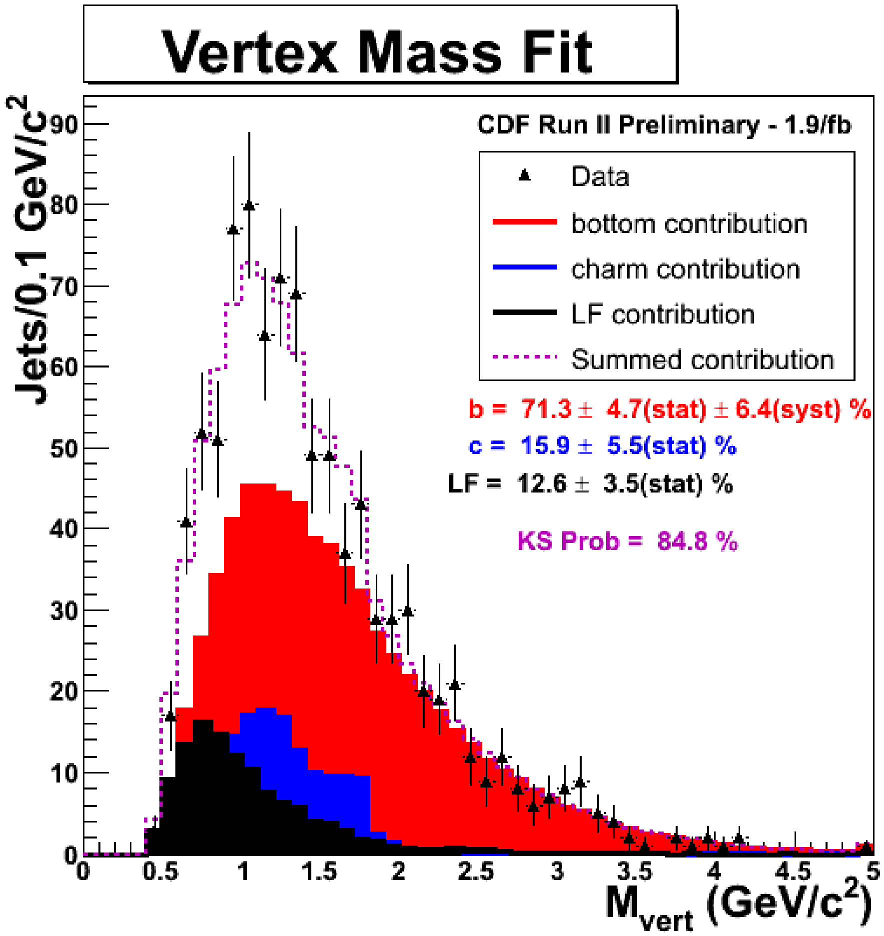
CDF: Phys. Rev. Lett. 100, 091803 (2008)
D0: Phys. Lett. B 666, 23 (2008)



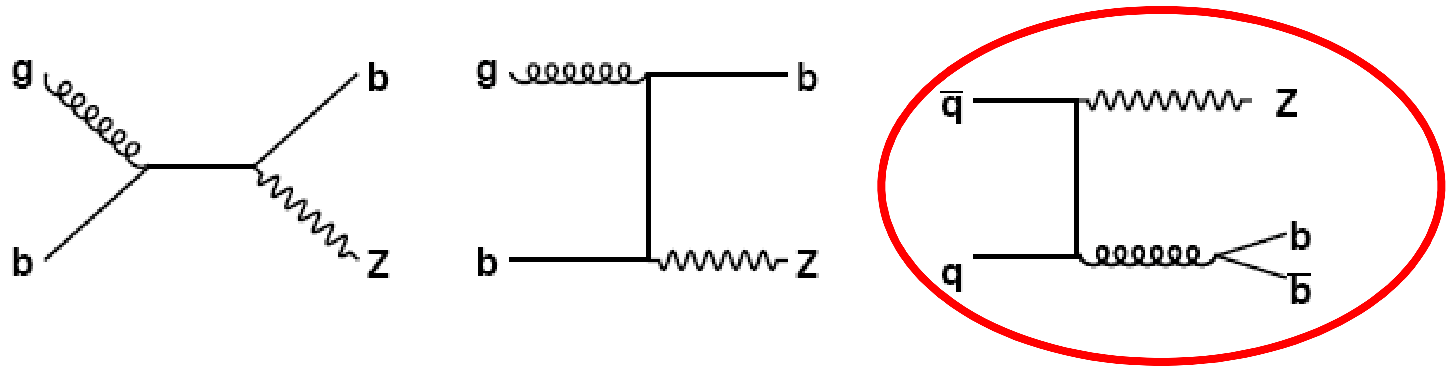


W + b Production (Per Jet)

- Tag b-jets by looking for secondary vertex contained in jets
- Fit the secondary vertex mass to obtain b purity
  - ➢ Largest uncertainty in modeling of b mass shape
- Results: σ = 2.74 ± 0.27 (stat) ± 0.42 (sys) pb, 3.5 times larger than ALPGEN prediction (0.78 pb)
  - ➢ NLO predictions will help



Z + Inclusive b Production

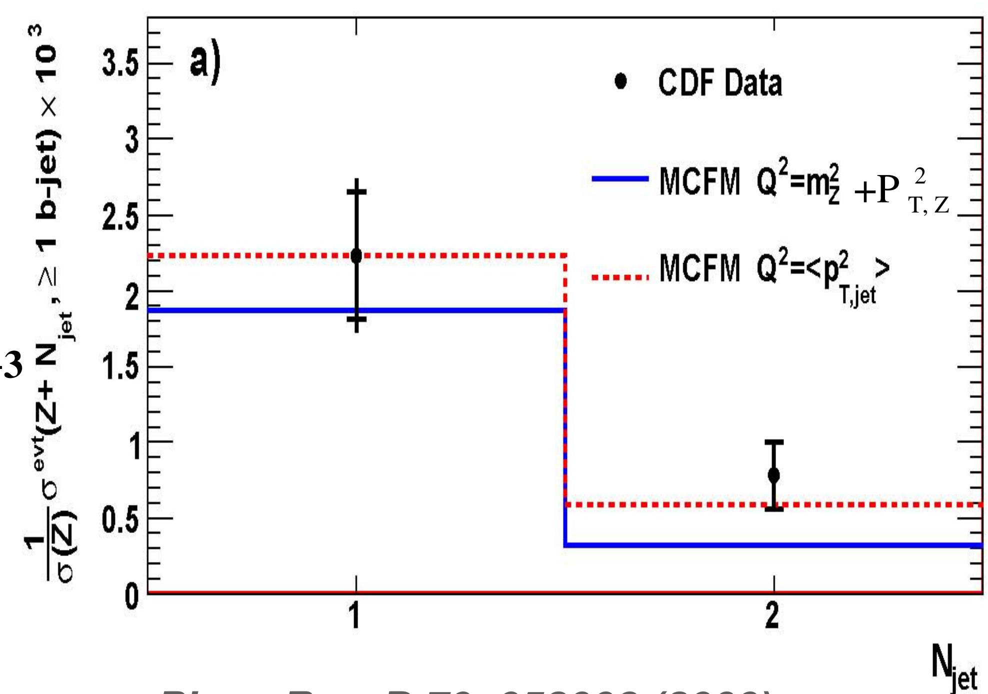


- Large dependence on scales
  - Lower scale preferred
- MCFM Zbb diagram not available for NLO

$$\frac{\sigma^{jet}(Z+b)}{\sigma(Z)} = (3.32 \pm 0.53 \pm 0.42) \times 10^{-3}$$

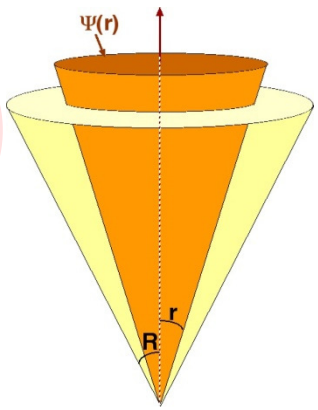
$$MCFM: 2.3\times 10^{-3} \ \ (Q^2 = M_Z^2 + P_{T,Z}^2)$$

$$: 2.8\times 10^{-3} \ (Q^2 = < P_{T,Jet}^2 >)$$

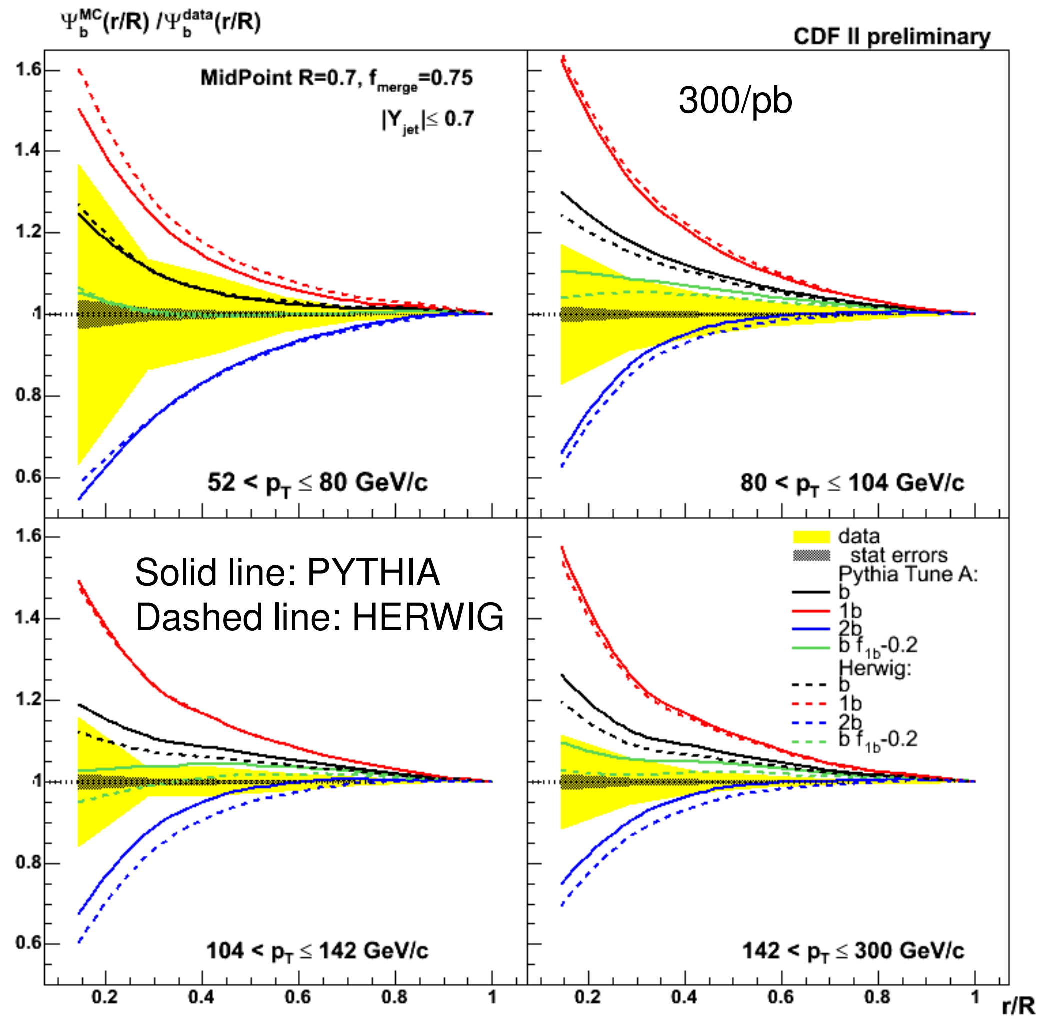


Phys. Rev. D 79, 052008 (2009)

b-jet Shape



- Fraction of momentum carried by particles within cone of r
- Indirectly probe the contribution of gluon-splitting
  - ➢ More 2-b quarks in a jet
  - ➢ 2-b jet broader than 1-b jet
  - ➢ Complimentary to Δϕ method
- Prefer 0.2 less than the default value of 1-b fraction in LO generator

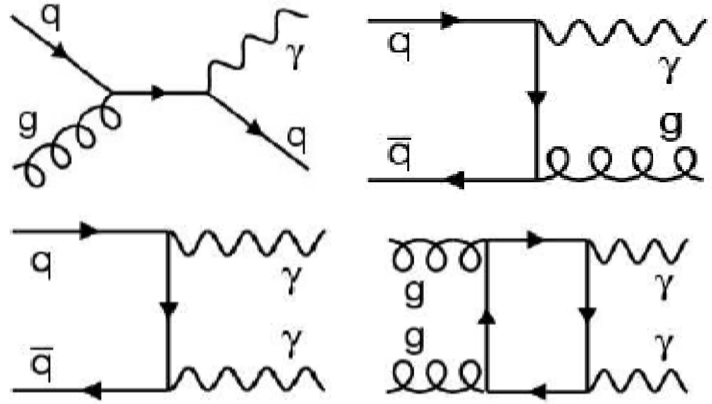


Phys. Rev. D 78, 072005 (2008)

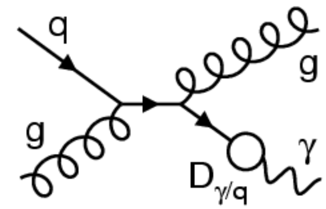
Photon + jets

Photon Production & Detection

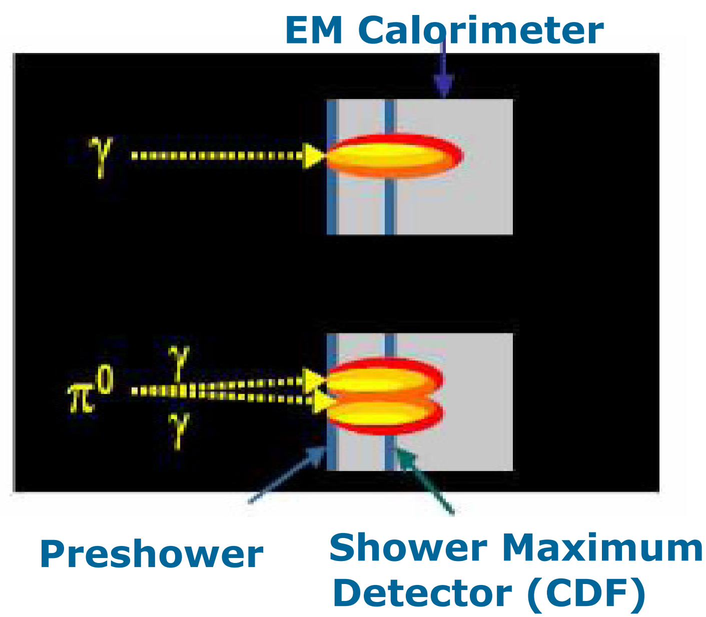
- Direct photons come unaltered from the hard scattering
  - Allows probe of hard scattering dynamics with fewer soft QCD effects
  - Probes gluon PDFs
- Background from neutral mesons and EM object in jets.
  - Use isolated photons
  - Purity of sample must be determined



plus some fragmentation effects

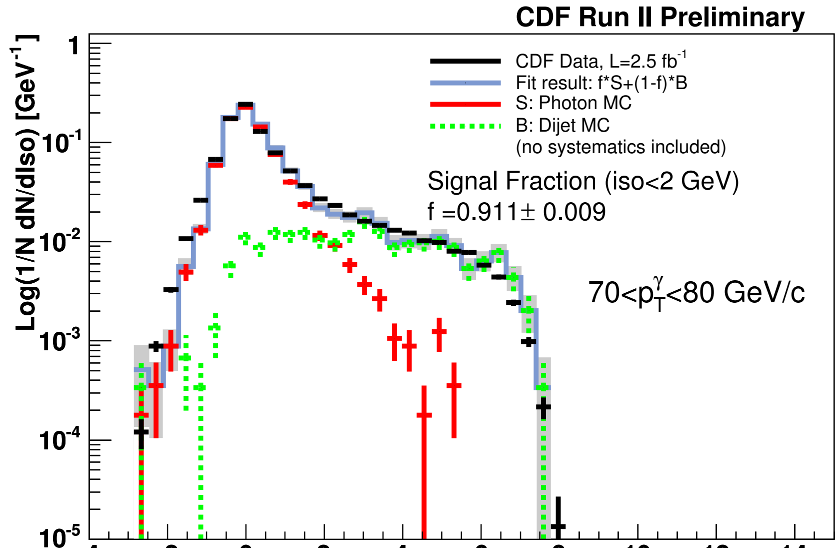


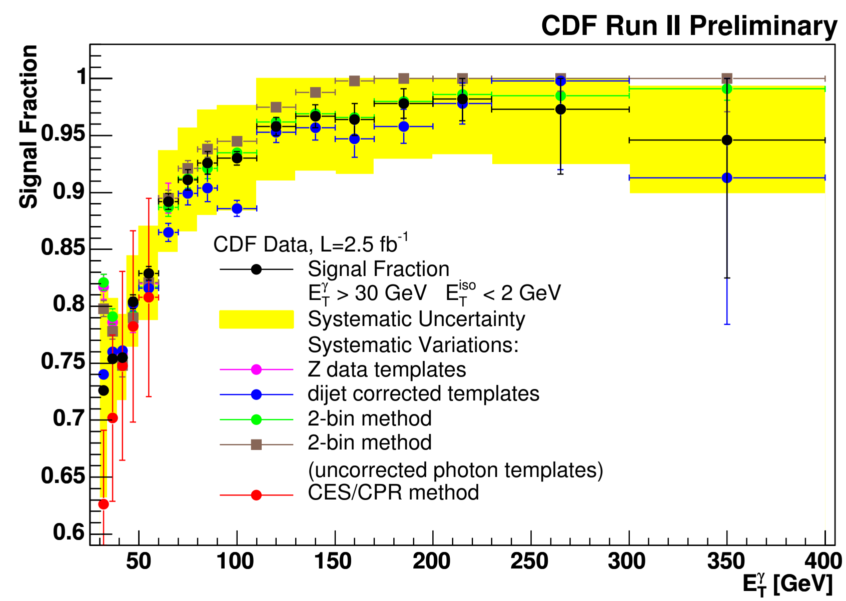
ElectroMagnetic Shower Detection



CDF Photon Purity

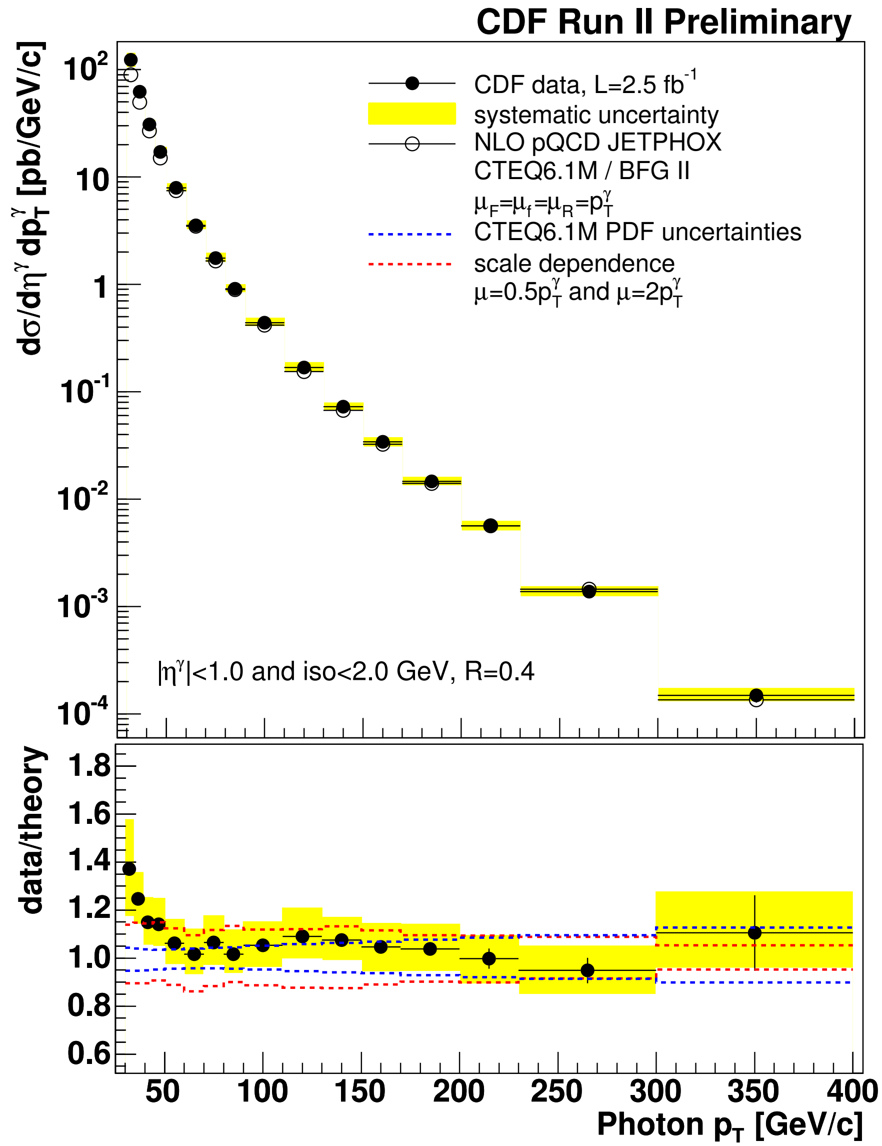
- CDF has new measurement of the inclusive isolated photon production cross section using 2.5 fb^{-1}!
- Use MC to create templates for photon and background isolation.
  - Done in bins of p_T
- Fit data to combination to determine photon signal fraction
  - Use other methods to determine systematic uncertainty





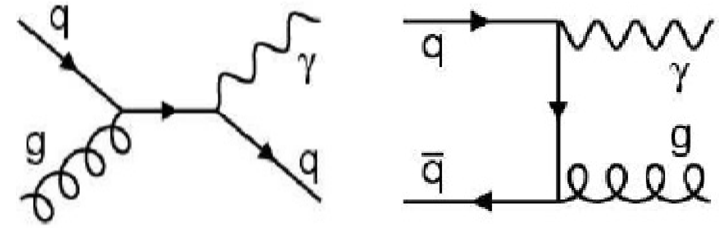
CDF Direct Photon Results

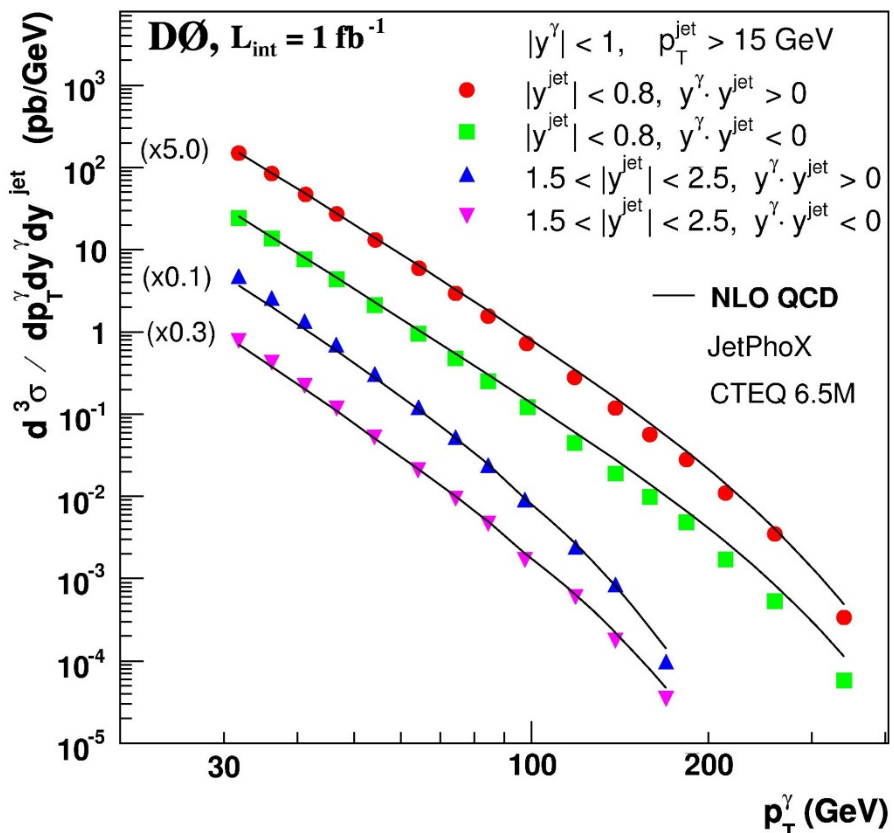
- Data/theory agree except at low p_T
  - Low p_T has historically been an area of disagreement.
  - Measurement to p_T = 400 GeV



Photon plus Jet Production

- Investigate source(s) for data/theory disagreement
  - measure differential distributions
  - tag photon and jet
  - reconstruct full event kinematics
- measure in 4 regions of y_γ, y_{jet}
  - photon: central ($|\eta|<1$)
  - jet: central / forward
  - same side / opposite side
- Dominant production at low p_T^γ (< 120 GeV) is through Compton scattering: $qg \rightarrow q+\gamma$
  - Probe PDF's in the range $0.007<x<0.8$ and $p_T^{\gamma} = 900<Q^2<1.6\times10^5$ GeV^2

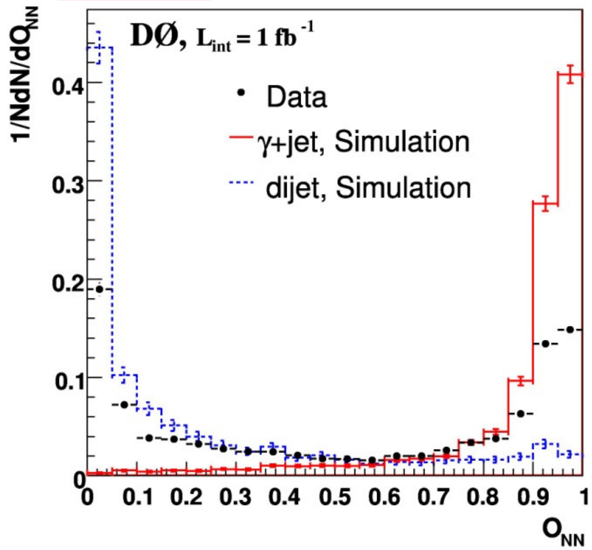


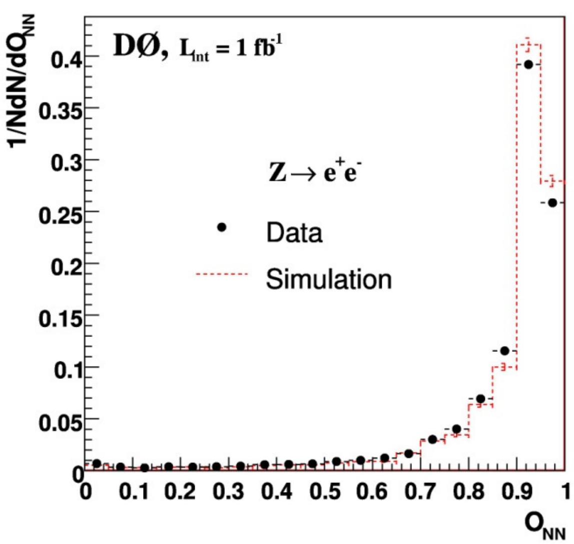


Phys.Lett.B666, 2008

DØ Photon Purity

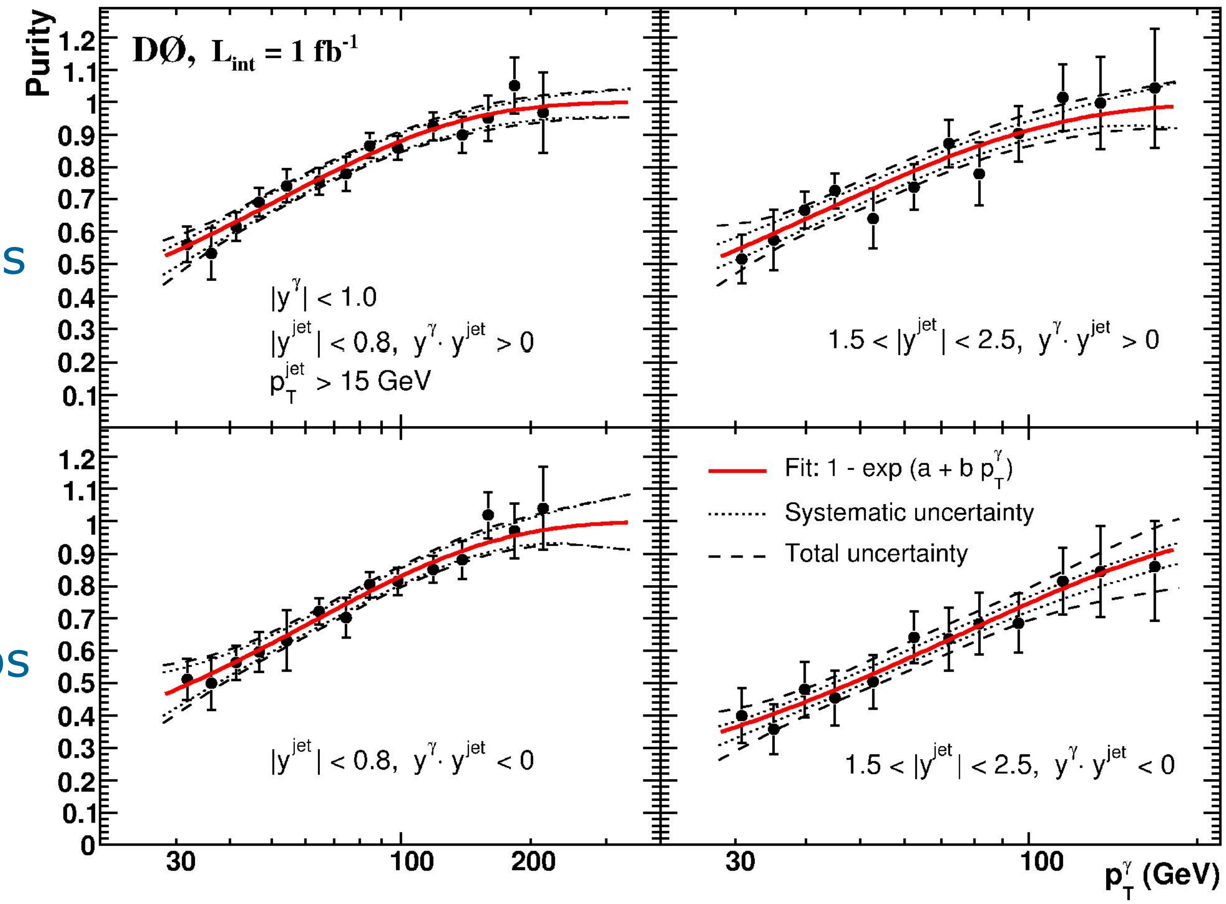
Neural net is used to determine photon purity





ss

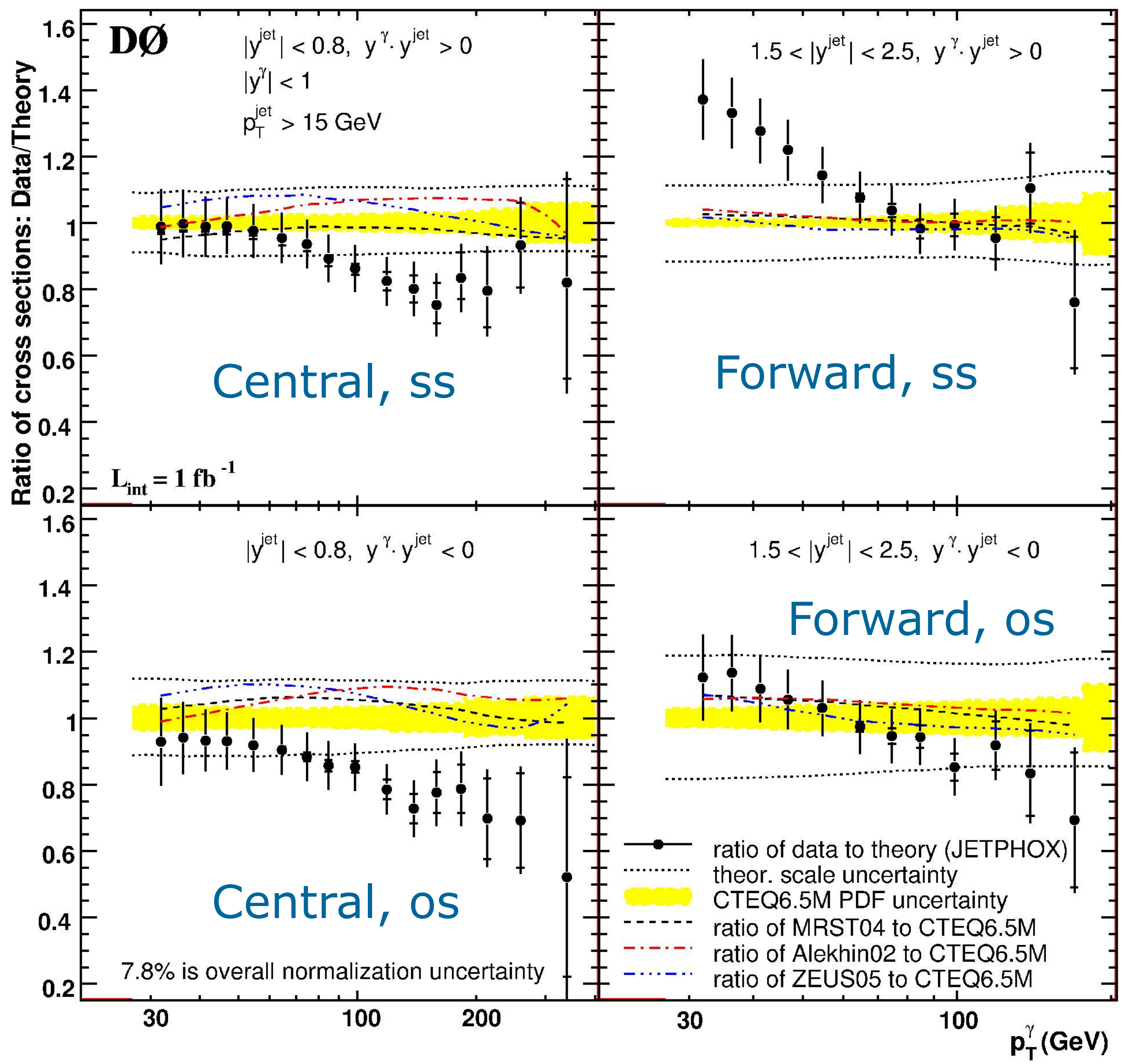
os



central forward

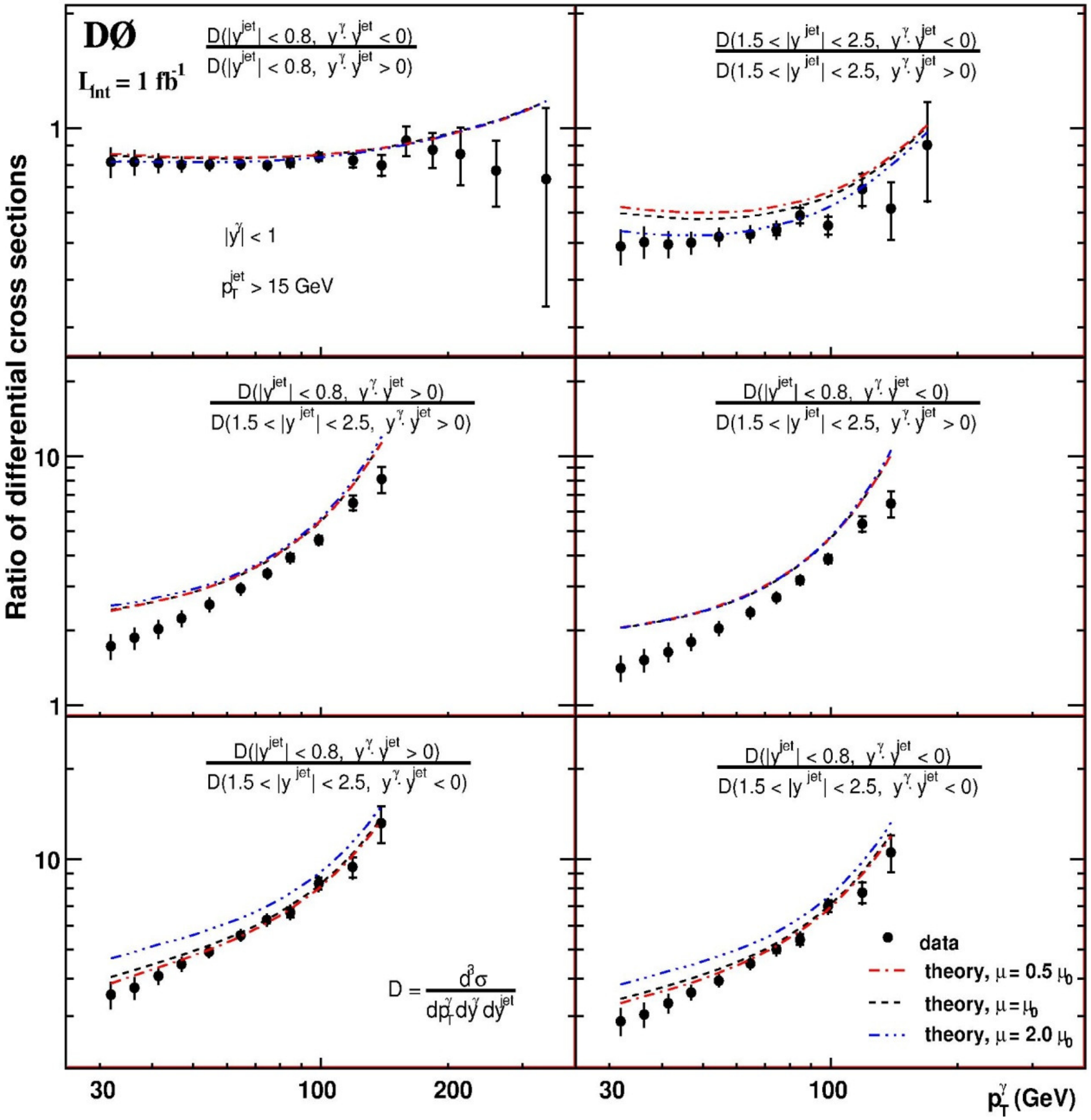
DØ Photon plus Jets Results

All shapes cannot be easily accommodated by any single theory



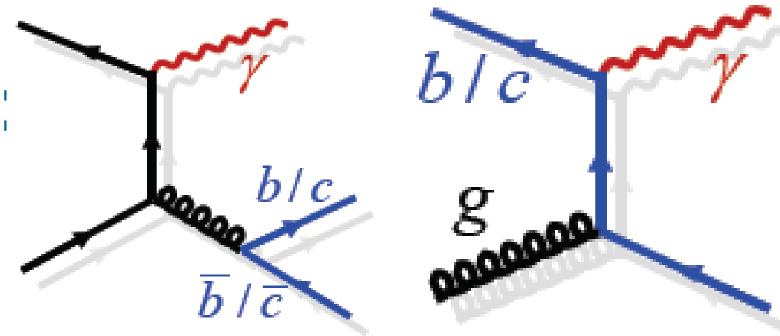
DØ Ratio of Regions

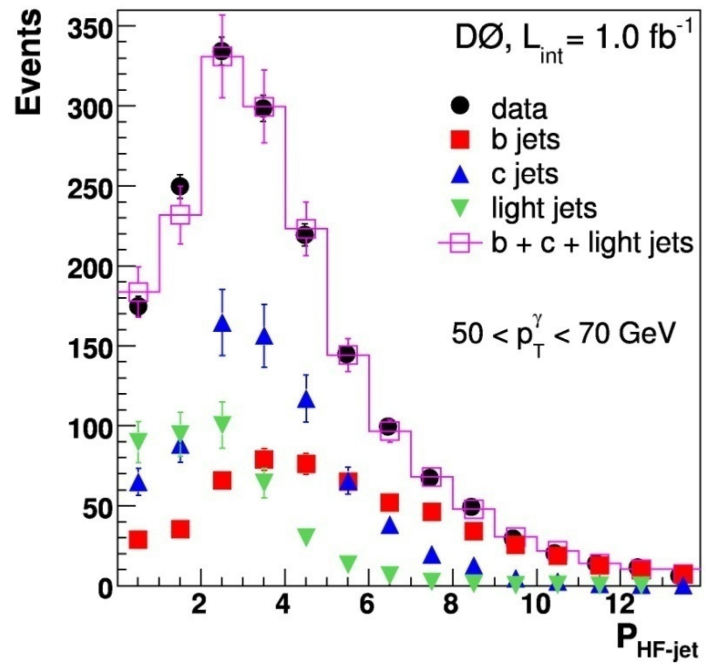
- Most errors cancel in ratios between regions (3-9% across most p_T^γ range)
- Data & Theory agree qualitatively
- A quantitative difference is observed in the central/forward ratios
- Need improved and consistent theoretical description for γ+ jet



DØ Photon plus HF (b/c) Jets

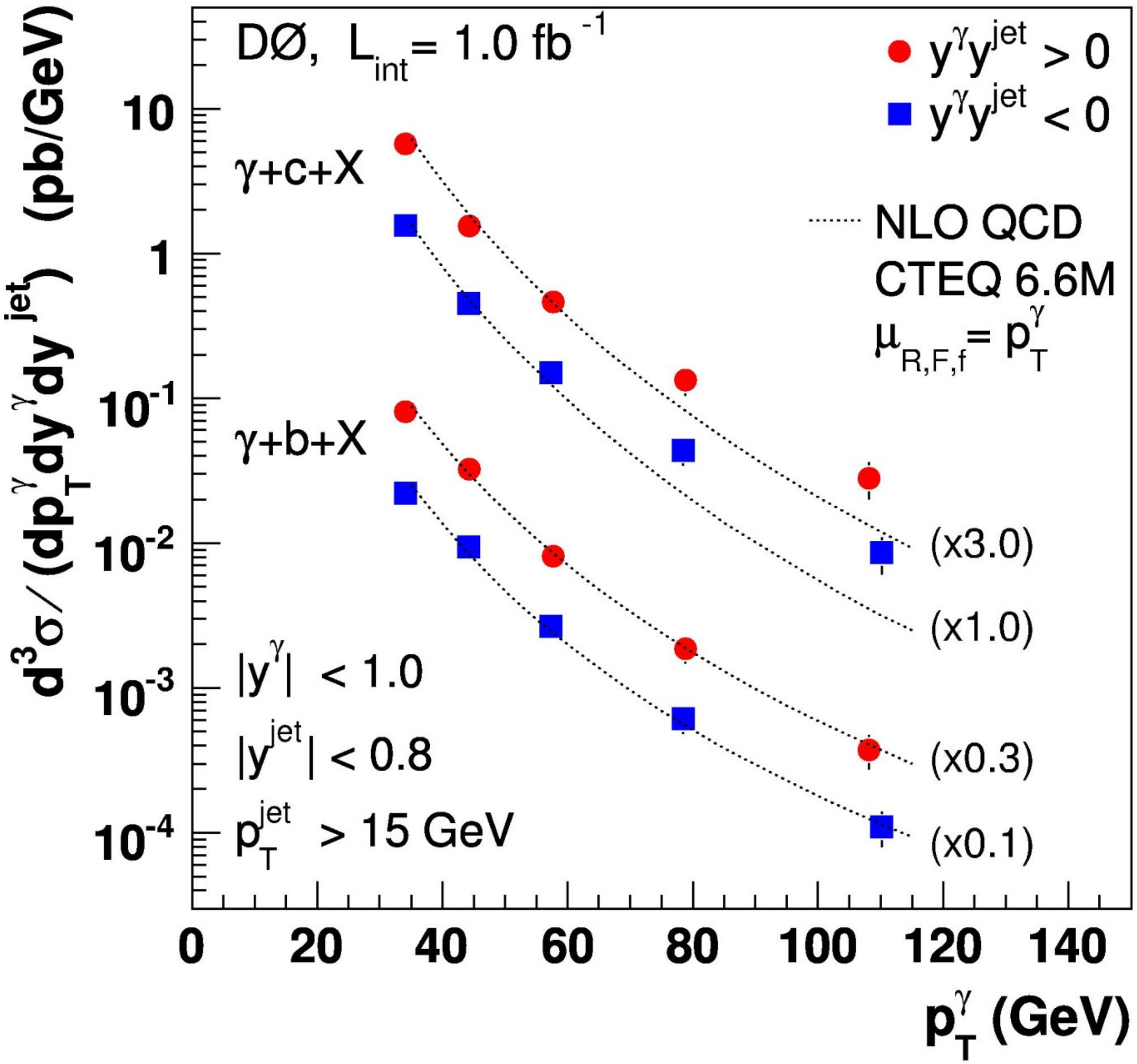
- Measure triple differential cross section: $d^3\sigma/(dp_T\, dy_\gamma\, dy_{jet})$
  - Jet and γ in central region
  - $y_\gamma y_{jet} > 0$
  - $y_\gamma y_{jet} < 0$
- Use MC template to determine particle fractions





PRL **102**, 192002 (2009)

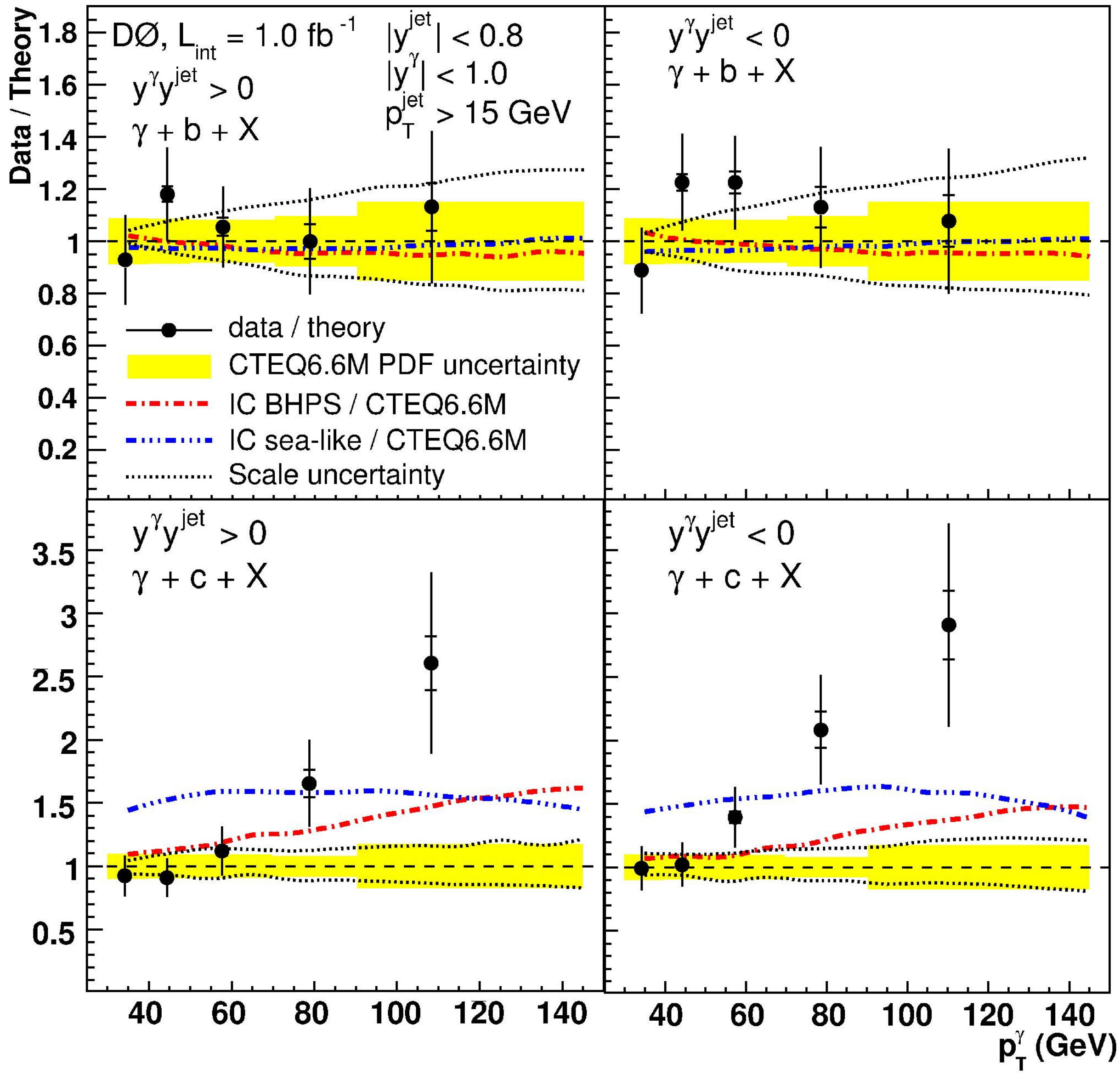
DØ Photon plus HF Results



Photon plus HF Data/Theory

Theory describes data for b jets but not for c jets.

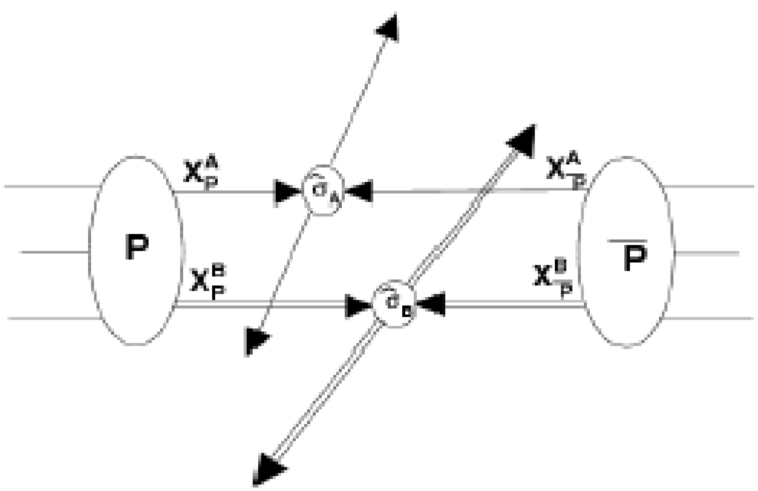
- Disagreement increases with higher p_T^γ
- Maybe too little intrinsic charm in proton, or not enough charm in gluon splitting from annihilation process.



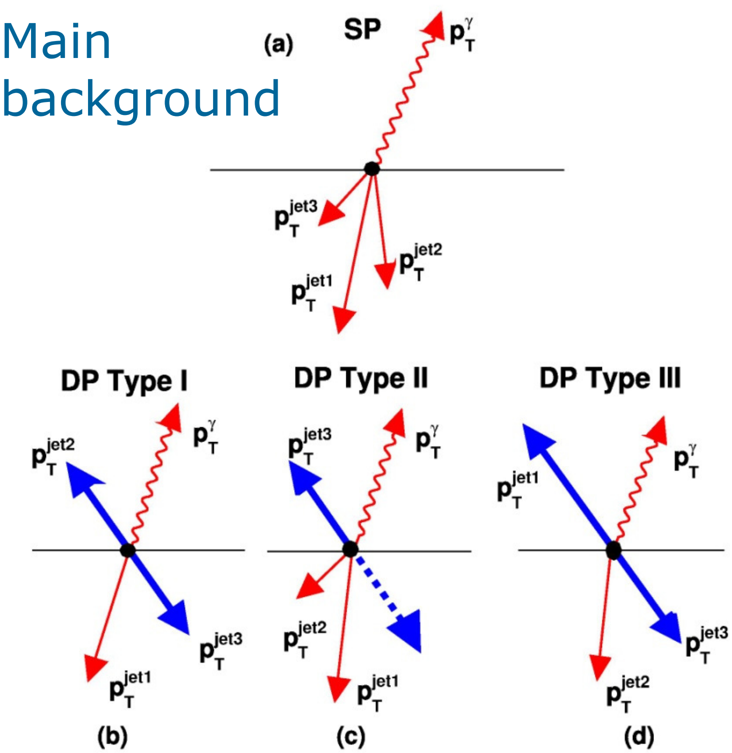
DØ Double Parton using 3 Jet+γ

- Study reactions in which two partons in a single proton interact
  - May impact PDFs
  - Help understand multiple interactions and high luminosity

$$\sigma_{DP} = \sigma_{\gamma j}\, \sigma_{jj}/\sigma_{eff}$$



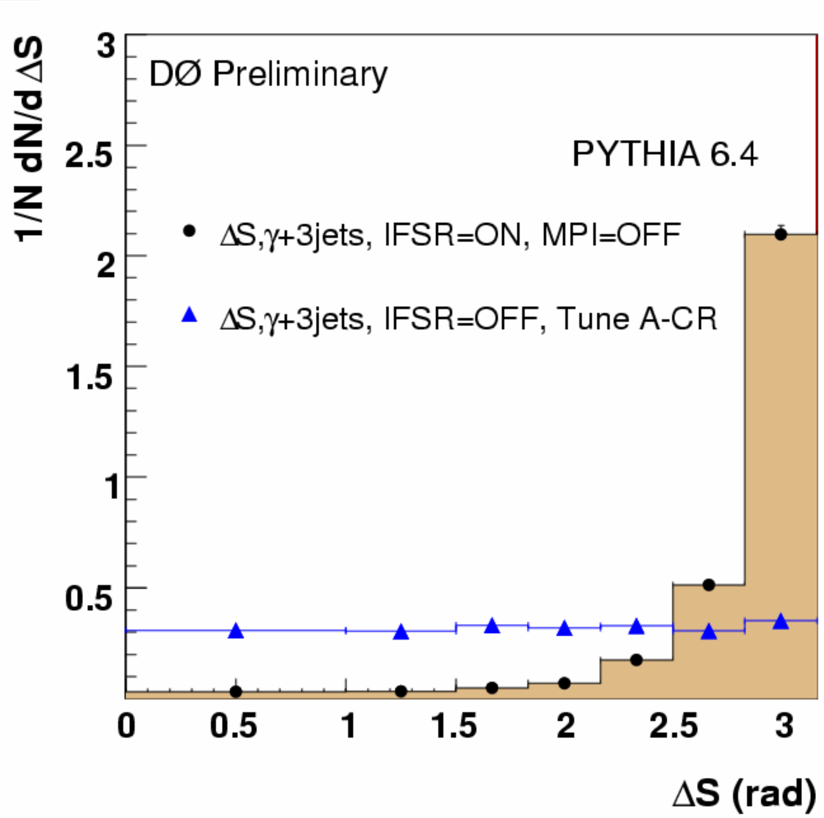
Main background

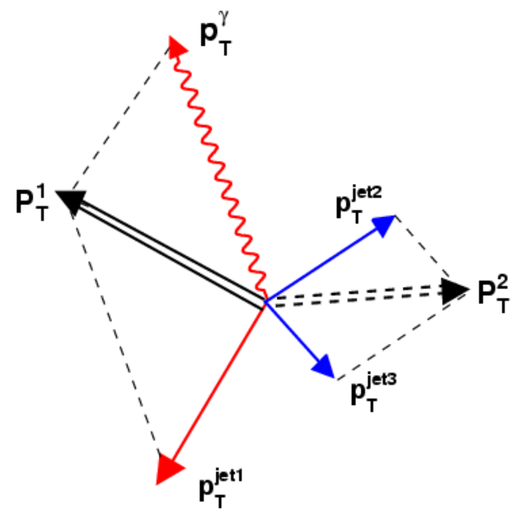


signal

Double Parton Signal Variables

Calculated for the pair that gives the minimum value of *S*.





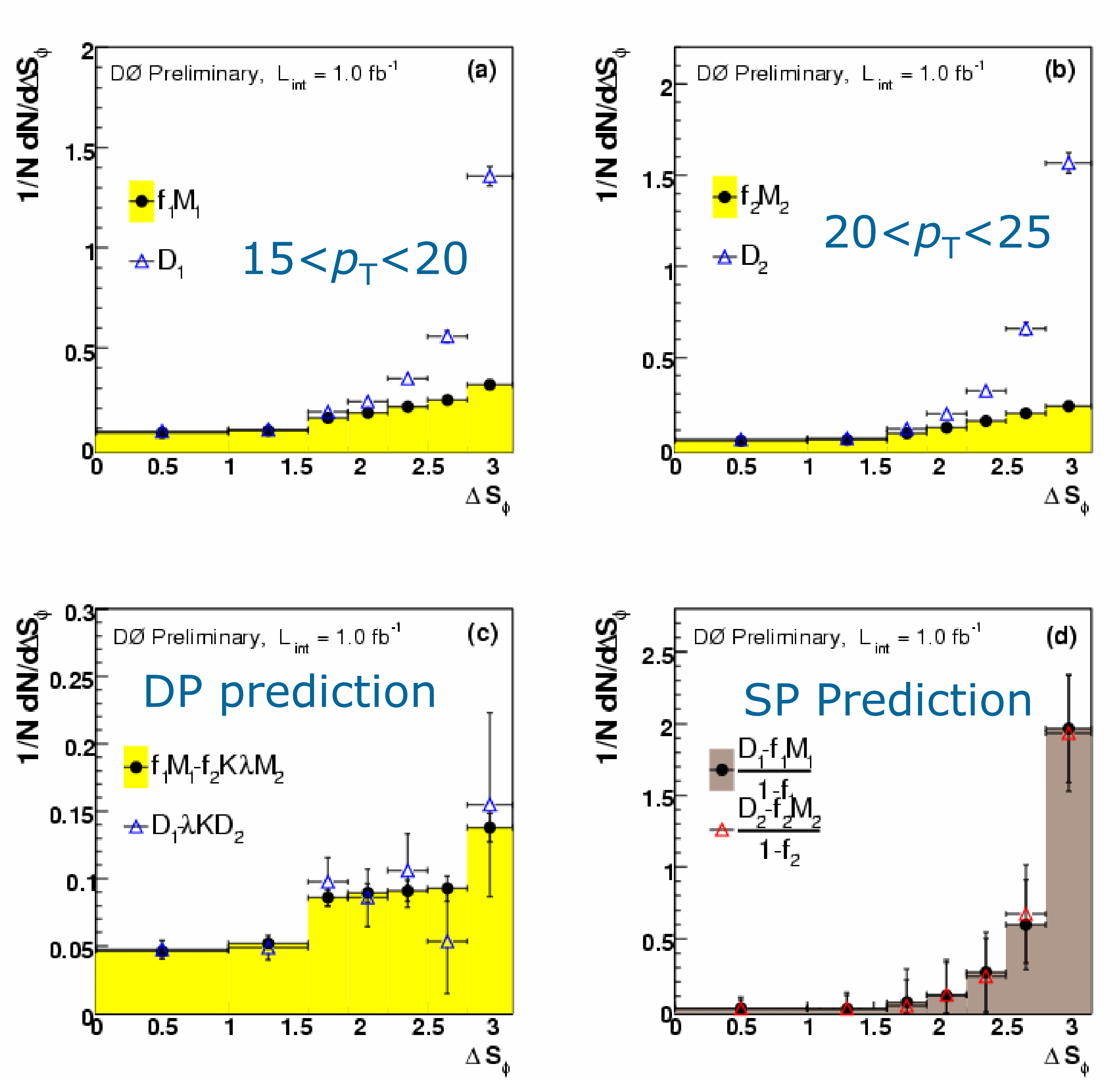
$$S_{\phi} = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{\Delta\phi(\gamma,i)}{\delta\phi(\gamma,i)}\right)^2 + \left(\frac{\Delta\phi(j,k)}{\delta\phi(j,k)}\right)^2}$$

$$S_{pT} = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{|\vec{P}_T(\gamma,i)|}{\delta P_T(\gamma,i)}\right)^2 + \left(\frac{|\vec{P}_T(j,k)|}{\delta P_T(j,k)}\right)^2}$$

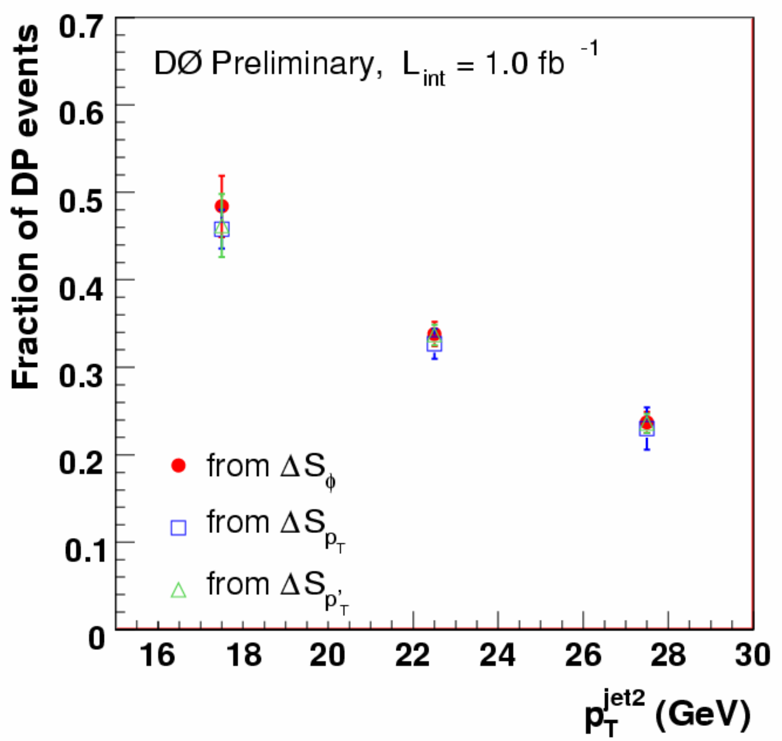
$$\Delta S = \Delta\phi\left(\mathrm{p}_T^{\gamma,jet_i},\ \mathrm{p}_T^{jet_j,jet_k}\right)$$

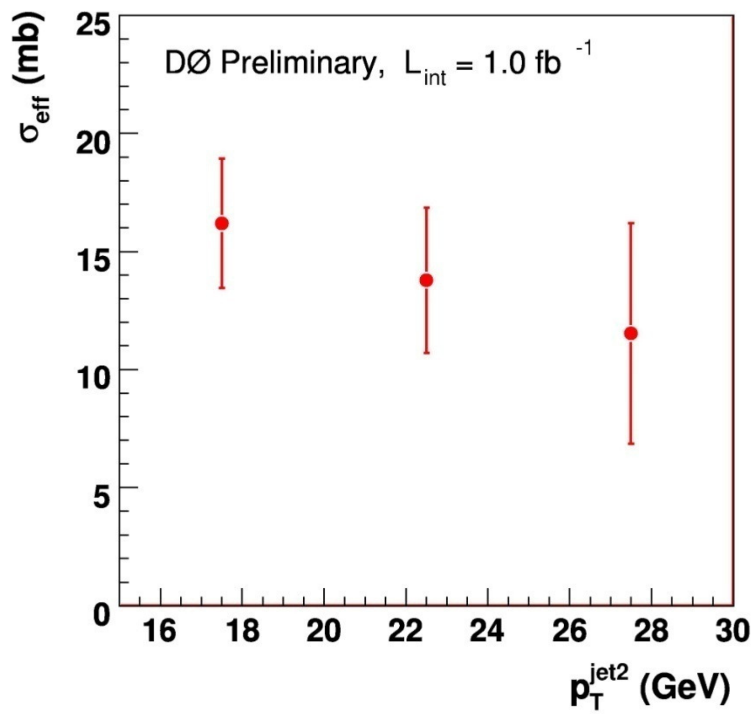
Double Parton Measurement

- The measurement is done in 3 bins depending on the p_T of the 2nd jet:
  - 15-20 GeV
  - 20-25 GeV
  - 25-30 GeV
- Lower p_T should have higher fraction of DP events



DØ Double Parton Results



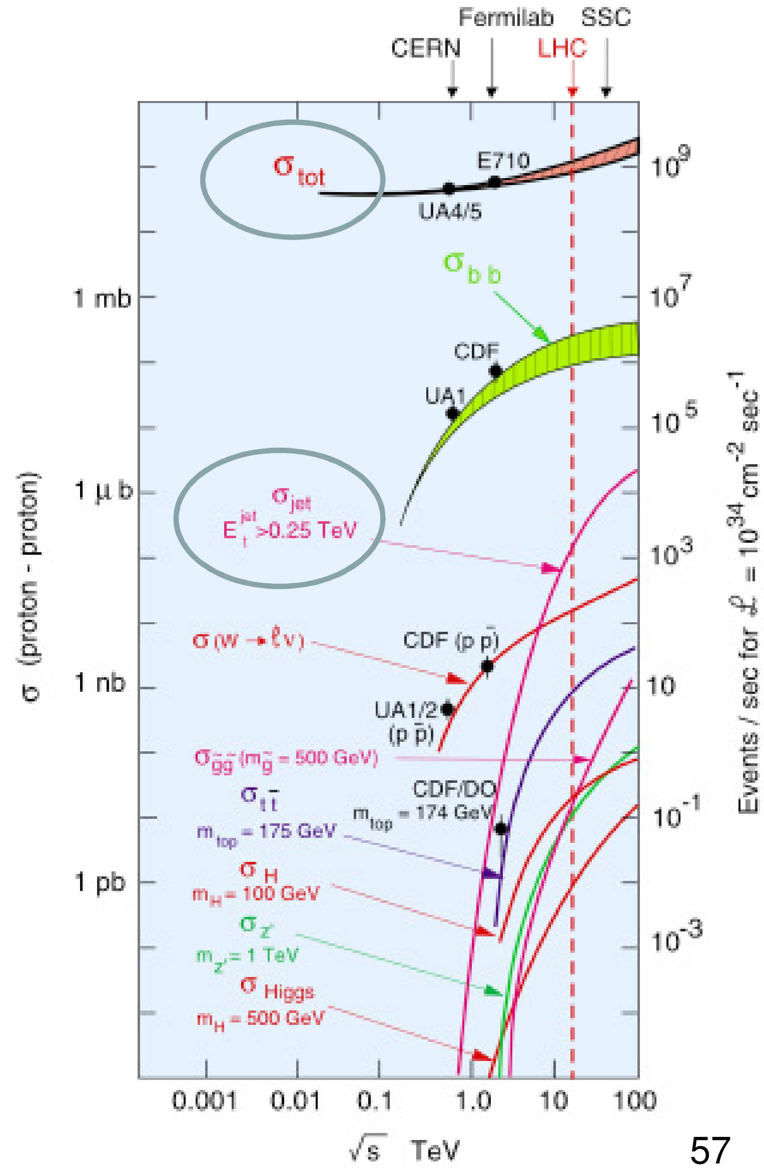


- The measured DP fraction drops from 0.47±0.04 at $15<p_{T2}<20$ GeV to 0.23±0.03 at $25<p_{T2}<30$ GeV
- Effective cross section is approximately the same and averages to σ_{eff} = 15.1±1.9 mb
- Good agreement with previous measurements by CDF

Additional LHC

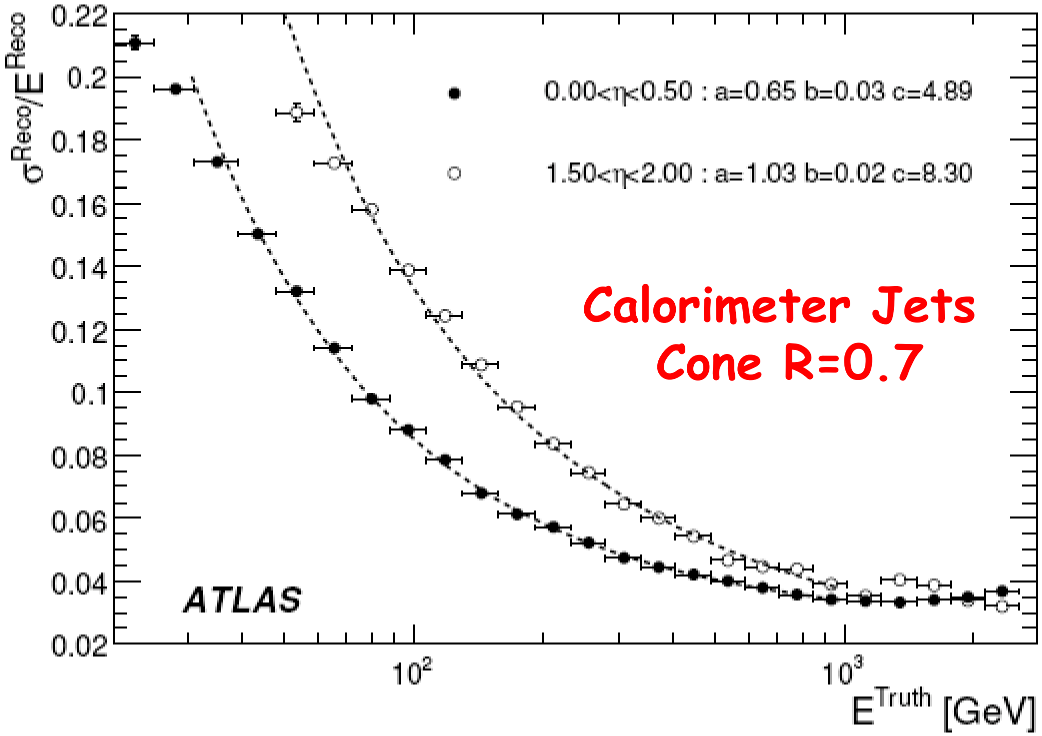
Physics at the LHC

- Total cross section ~100-120 mb
- The goal at startup is to re-establish the standard model (i.e., QCD, SM candles) in the LHC energy regime
  - σ(pT>250 GeV)
    - 100x higher than Tevatron
  - Electroweak
    - 10x higher than Tevatron
  - Top
    - 100x higher than Tevatron
- Jet measurements at LHC are important:
  - confront pQCD at the TeV scale
    - constrain PDFs
    - probe α_s
  - important backgrounds for SUSY and BSM searches
  - sensitive to new physics
    - quark substructure, excited quarks, dijet resonances, etc.
- QCD processes are not statistics limited!



Jet Resolution at ATLAS

CERN-OPEN-2008-020



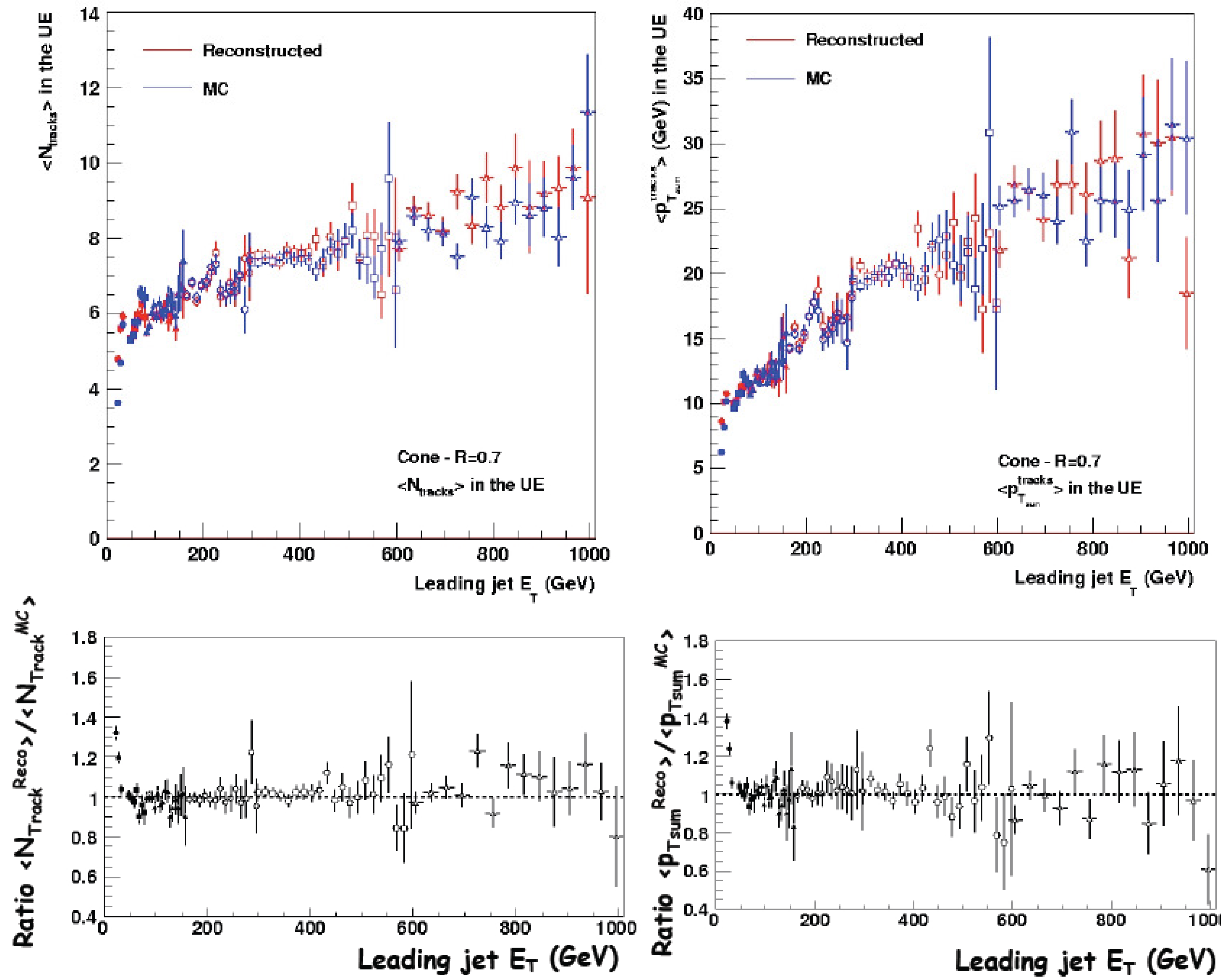
Calorimeter Jets
Cone R=0.7

Jet Energy Resolution from MC Truth

- Energy calibrated using "H1-style" cell signal weighting

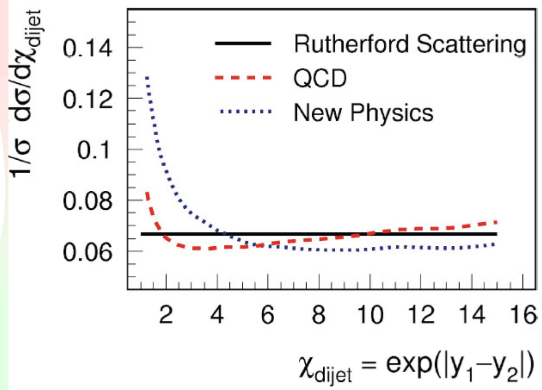
Underlying Event at ATLAS

Good agreement between reconstructed and generated variables

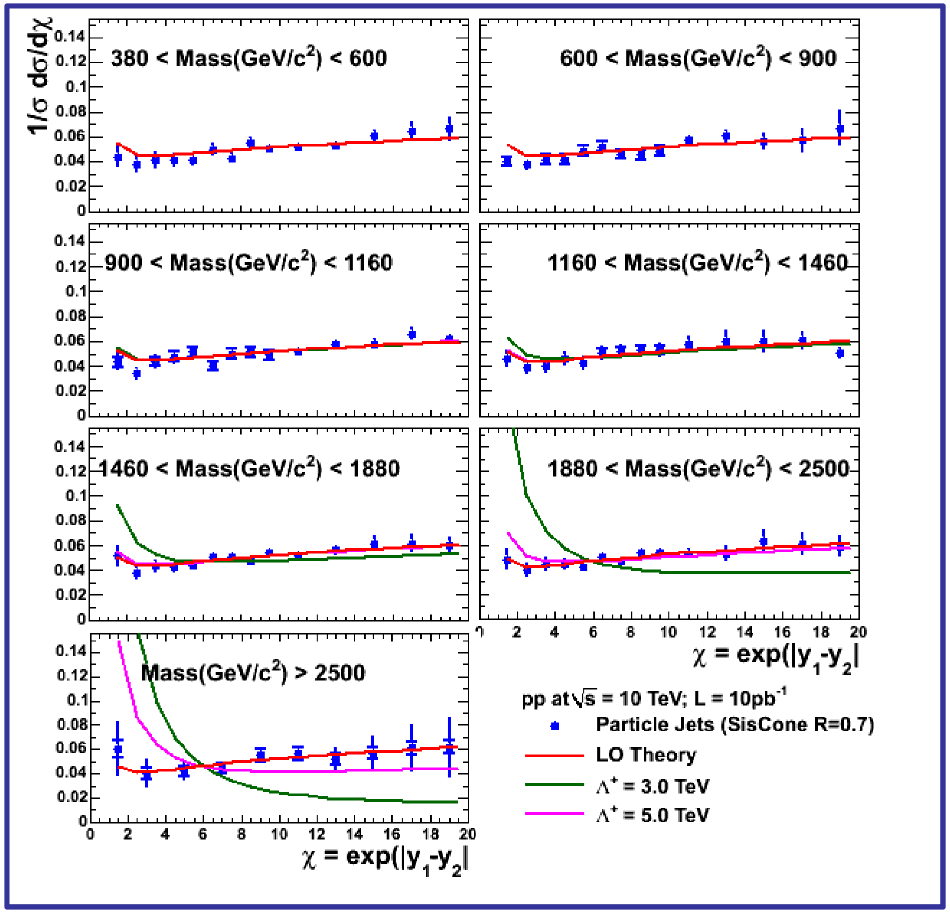


Dijet Angular Distribution

- Angular distributions sensitive to new physics



- Insensitive to PDFs
- Reduced sensitivity to detector effects
- Errors dominated by JES

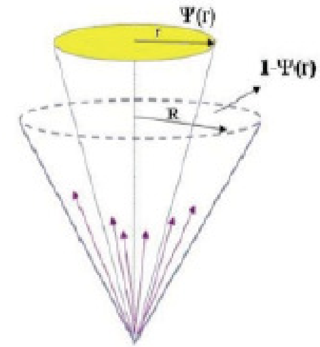


dσ ~ [QCD + Interference + Compositeness]

$$\alpha_s^2(\mu^2)\frac{1}{\hat{t}^2} \qquad \alpha_s(\mu^2)\frac{1}{\hat{t}}\cdot\frac{\hat{u}^2}{\Lambda_c^2} \qquad \left(\frac{\hat{u}}{\Lambda_c^2}\right)^2$$

Integrated Jet Shape

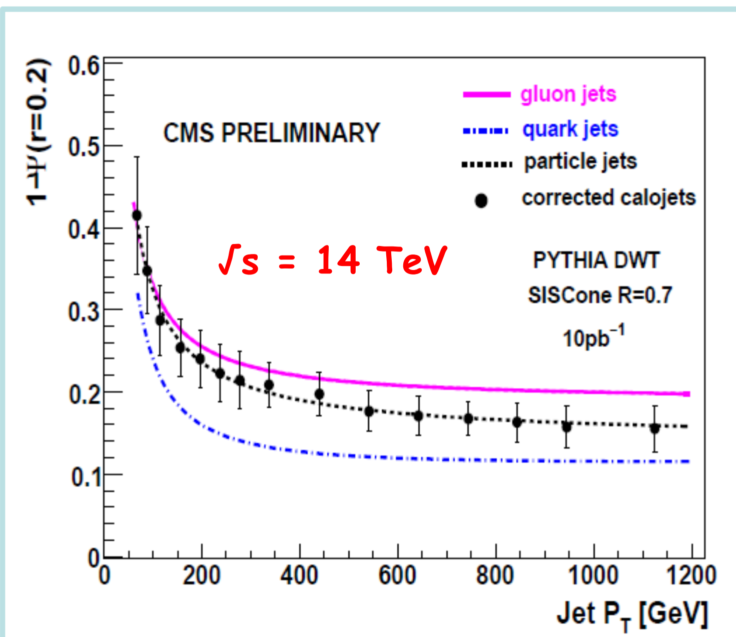
$$\Psi(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{P_T(0,r)}{P_T^{Jet}(0,R)}$$



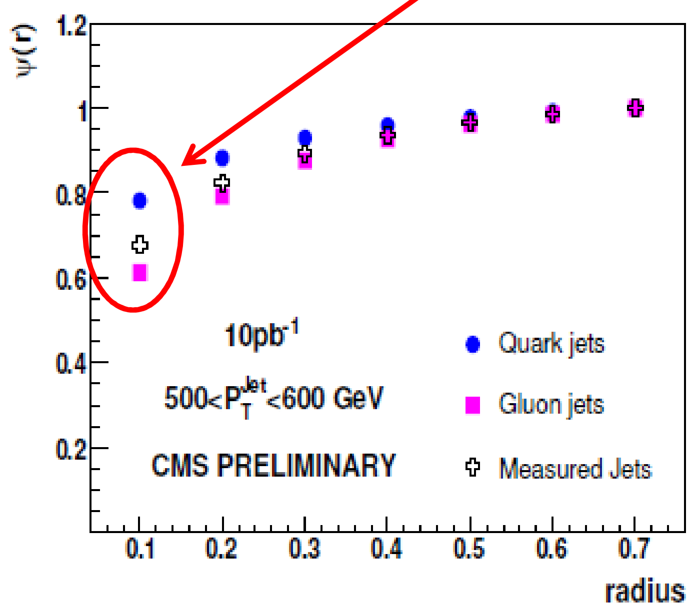
Integrated Jet Shape

CMS PAS QCD-08-005

- Jet shapes probe the transition between a parton produced in the hard process and the observed spray of hadrons
- Sensitive to the quark/gluon jet mixture
- Test of parton shower event generators at non-perturbative levels
- Useful for jet algorithm development and tuning



Quark jets narrower than gluon jets

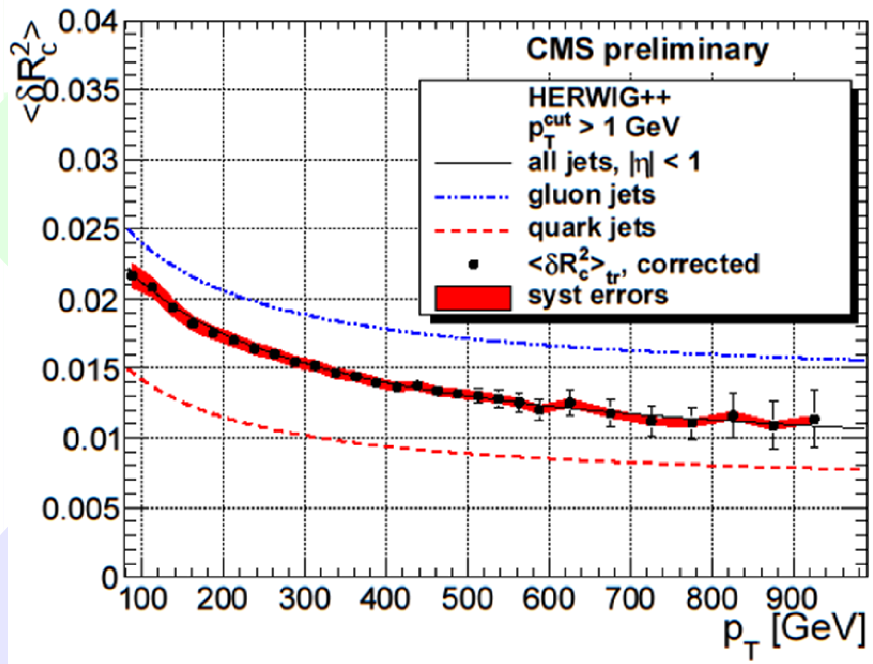


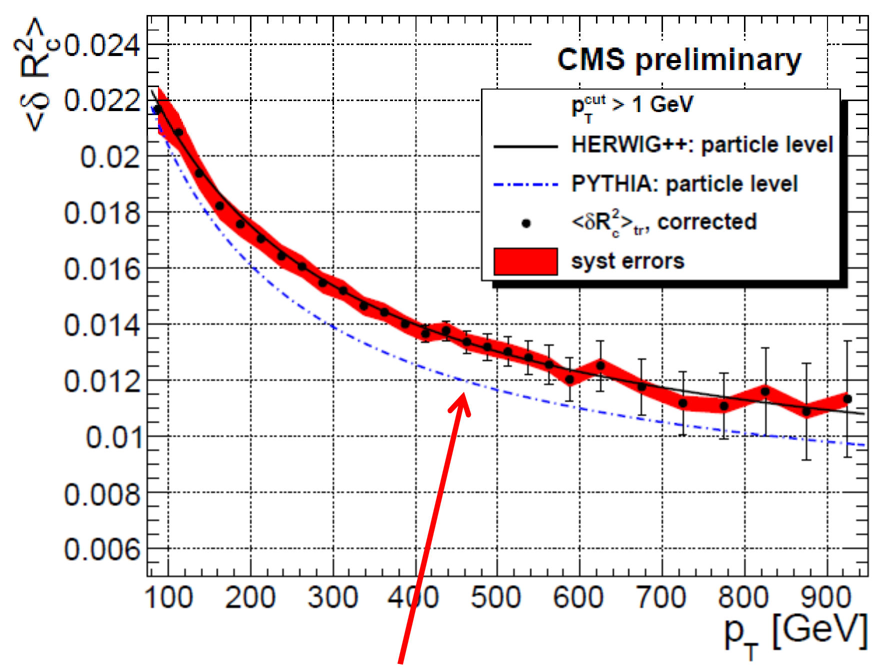
Jet Structure: 2nd Moment of P_T Radial Distribution

CMS PAS QCD-08-002

- Complementary method to study jet structure
- Potentially improved systematic uncertainties
  - Largest uncertainty is from energy scale calibration

$$\delta R^2_{jet}(p_T) = \frac{\sum_{C*} \Delta R^2(C*, jet) * p_T^{C*}}{p_T^{jet}}$$





Differences observed between Herwig and Pythia

Tevatron vs LHC

Tevatron vs LHC

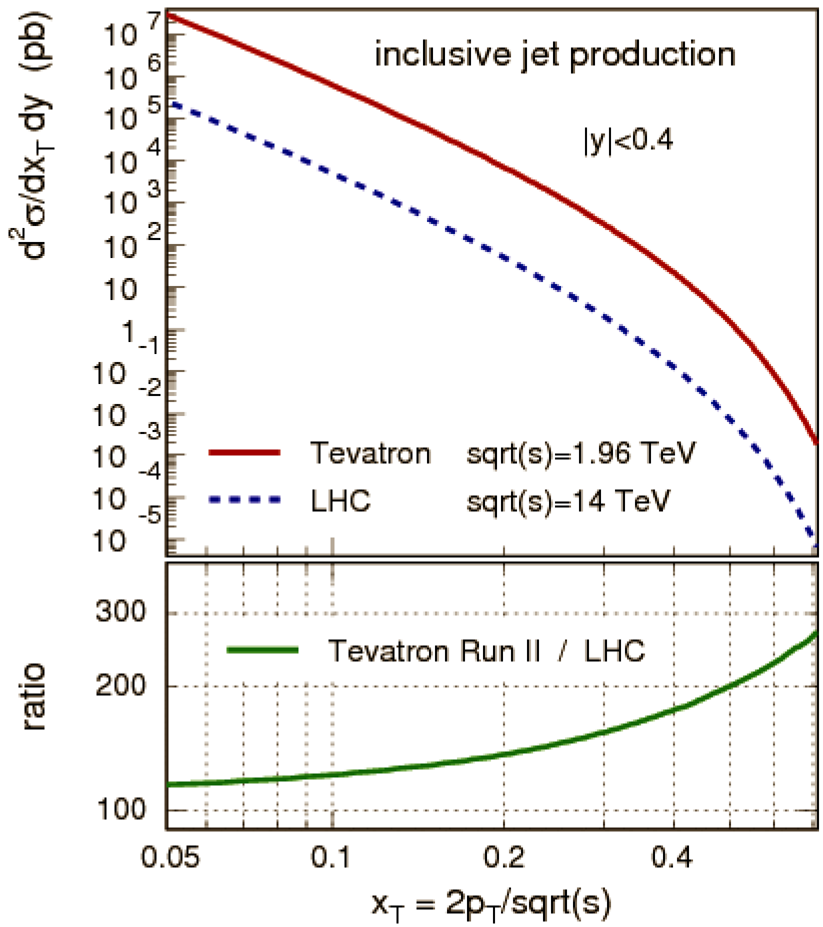
At the LHC:
cross section vs pT obviously much larger

BUT cross section vs x significantly smaller!
e.g. for |y|<0.4, factor of 200 at x = 0.5

D0 results with 0.7 fb^{-1}
→need 140 fb^{-1} at LHC

Further, problem of steeply falling spectrum:
at D0,   1% error on jet energy calibration
→ 5 - 10% error on central σ
→10 - 25% error on forward σ

At LHC:
need excellent jet energy scale
out to very high p_T



Expect Tevatron to dominate high-x gluon for some years!