High E_T Jet Production

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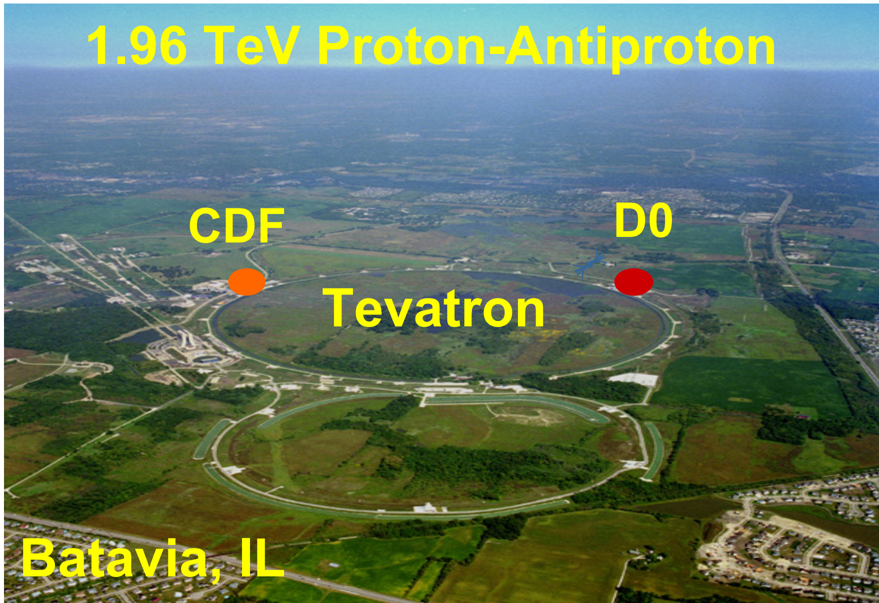
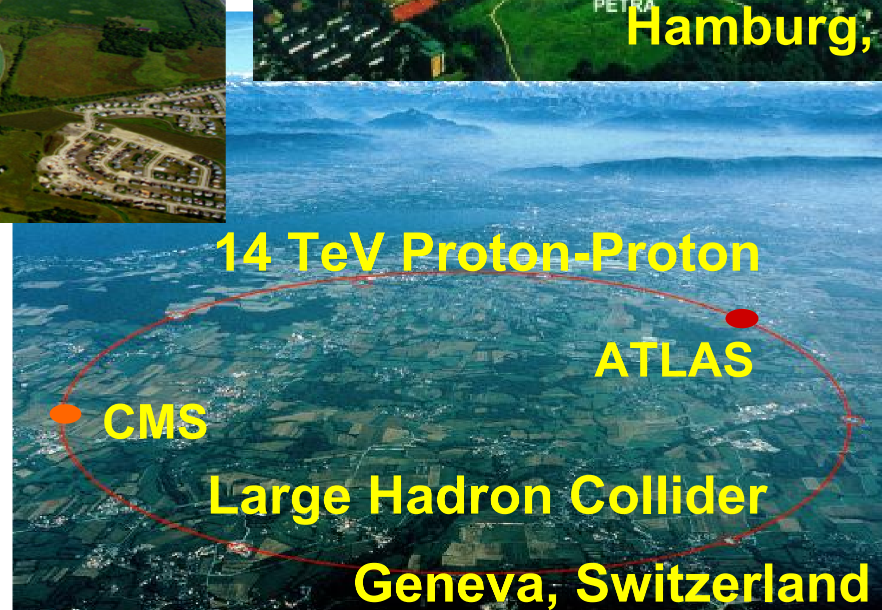
Outline

- Introduction
- Results from HERA and Tevatron
  - Inclusive jets and dijets
  - Inclusive photons, photon+jets, and photon+heavy flavor
  - W/Z+jets and W/Z+heavy flavor
  - Underlying Event and Multiple Parton Interactions
- Expected Results from LHC
- Summary & Remarks

This talk is entitled "High-E_T Jet Production"; however, results on boson+jets and low-Et jets relevant to high Et physics are also discussed.

HERA, Tevatron, and LHC

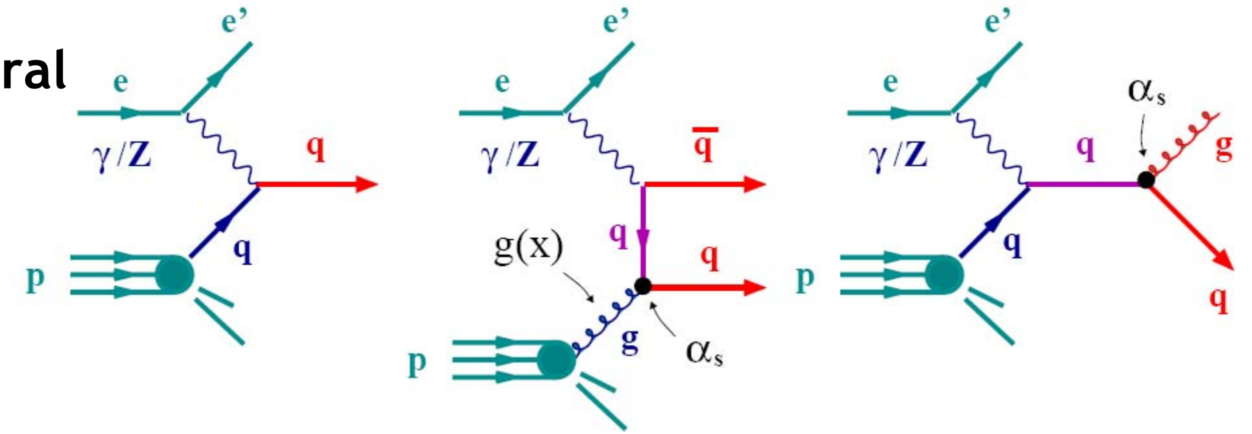




Jet Production at HERA

Jet Production in Neutral Current Deep Inelastic Scattering (NC DIS)

Diagrams up to $O(\alpha_S)$



Born Process | Boson-Gluon Fusion | QCD Compton

Lowest order non-trivial contributions to high-Et jets

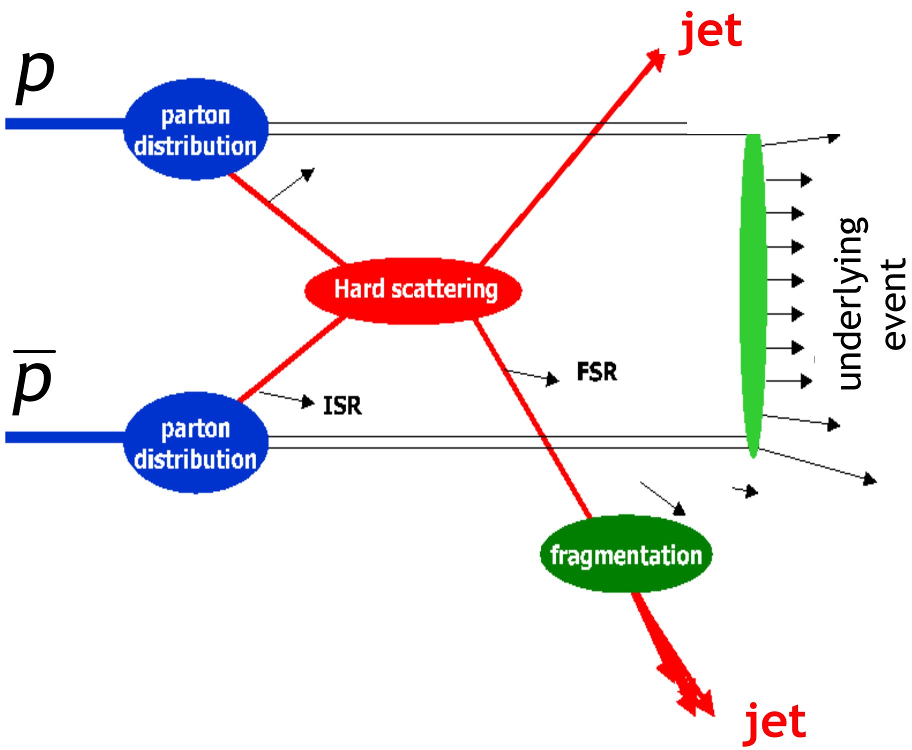
$$d\sigma_{jet} = \sum_{a=g,q,\bar{q}} \underbrace{f_{a/p}(x,\mu_F^2)}_{\text{PDFs}} \underbrace{\hat{\sigma}_{a,m}(x,\alpha_s,\mu_R^2)}_{\text{Hard Scatter}}$$

- Testing pQCD: factorization, universality of PDFs and strong coupling constant (α_s)
- Assuming pQCD: extract PDFs (James's talk) and α_s

- DIS: $Q^2 >> 0$
  Hard collision & No UE.
- Photoproduction (PHP): $Q^2 \approx 0$
  Hadron-hadron like collision (photon behaves like hadron)

Jet Production at the Tevatron

$$d\sigma_{jet} = \underbrace{\sum_a \sum_b \overbrace{f_{a/p}(x_p,\mu_F^2)\, f_{b/\bar{p}}(x_{\bar{p}},\mu_F^2)}^{\text{PDFs}} \otimes \hat{\sigma}_{a,b}(x_p, x_{\bar{p}}, \alpha_s, \mu_R^2)}_{\text{Hard Scatter}}$$



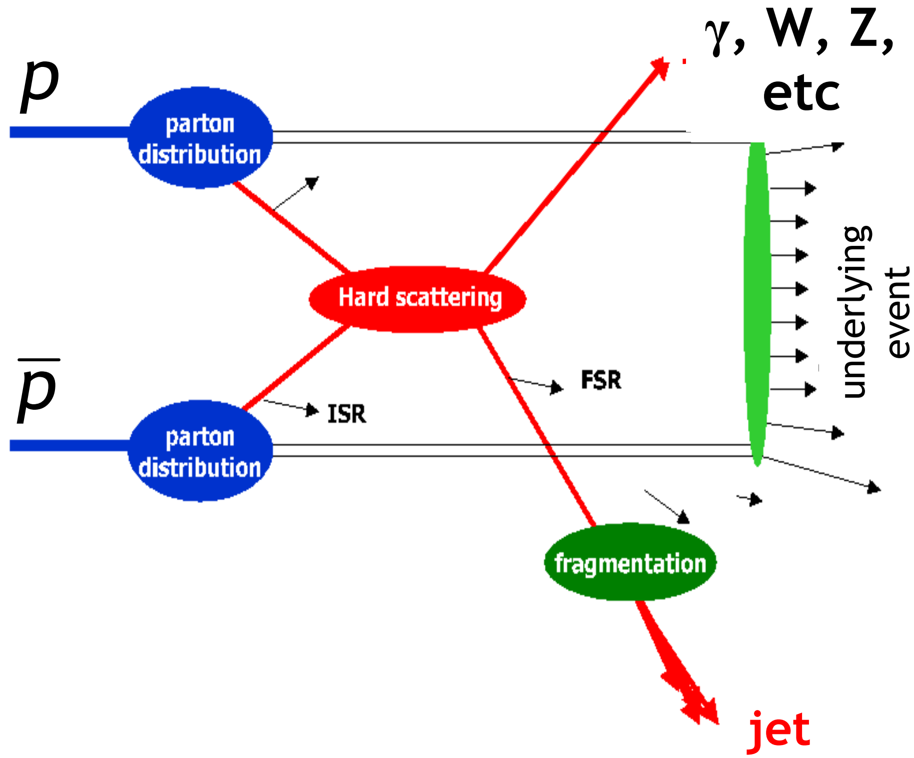
- Test pQCD
- Based on pQCD: extract PDFs and α_s. Study/test matrix element calculations.

- Underlying event makes the measurement complicated
  - Good place to study nature of underlying event
- Wider kinematic ranges than HERA

Boson+Jet Production at the Tevatron

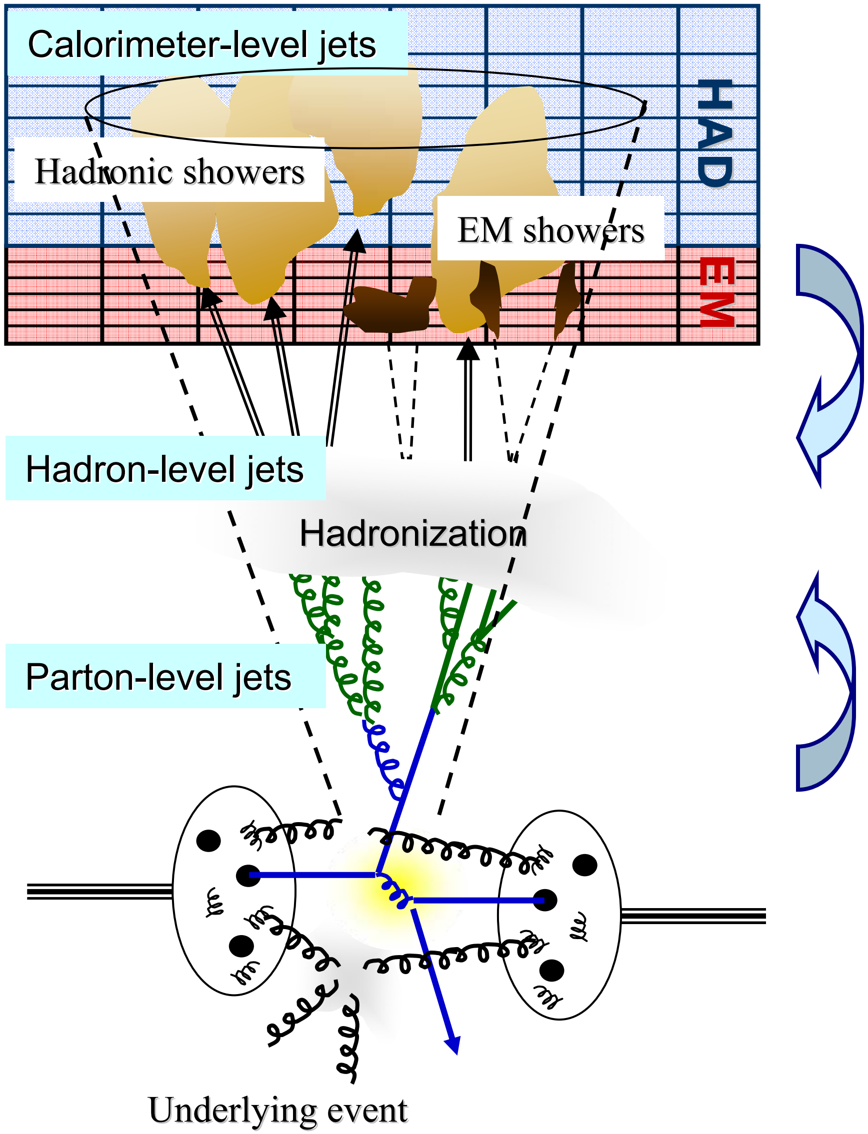
$$d\sigma = \overbrace{\sum_a \sum_b f_{a/p}(x_p, \mu_F^2) f_{b/\bar{p}}(x_{\bar{p}}, \mu_F^2)}^{\text{PDFs}} \otimes \underbrace{\hat{\sigma}_{a,b}(x_p, x_{\bar{p}}, \alpha_s, \mu_R^2)}_{\text{Hard Scatter}}$$

- Testing pQCD
- Assuming pQCD: extract PDFs and α_s. Study/test matrix element calculations.



- Underlying event makes the measurement complicated
  - Good place to study nature of underlying event
- Wider kinematic ranges than HERA

Jet Production and Measuremnt



Unfold measurements to the hadron (particle) level

Correct parton-level theory for non-perturbative effects (hadronization & underlying event)

Inclusive Jets & Dijets

α_s, PDFs,

Physics beyond the Standard Model

Inclusive Jets in Photoproduction

Reanalysis of published measurement

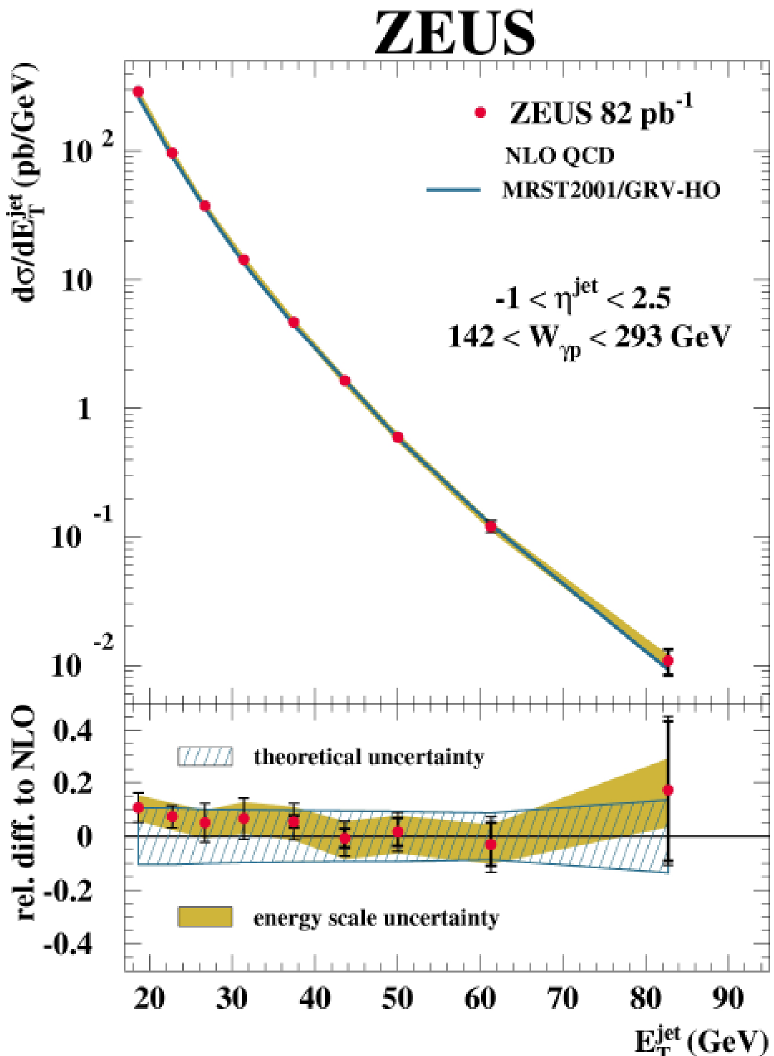
- New NLO calculation by Klasen, Kleinwort, Kramer
- MRST2001 PDF (previously MRST99)

- Parameterize $\alpha_s(M_Z)$ dependence of observable $d\sigma/dE_T$ in bin i by

$$\frac{d\sigma_i}{dE_T} = C1 \cdot \alpha_s(M_Z) + C2 \cdot \alpha_s^2(M_Z)$$

$$\alpha_s(M_Z) = 0.1223 \pm 0.0001(stat) {}^{+0.0023}_{-0.0021}(syst) \pm 0.0030(th.)$$

Total 3.1% uncertainty



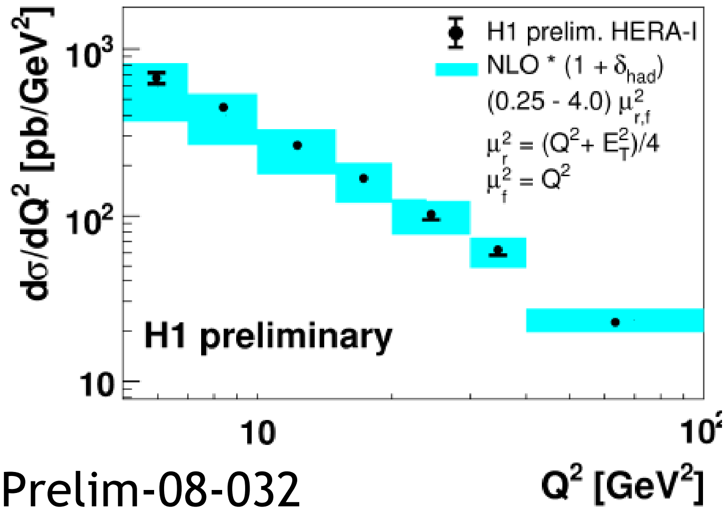
ZEUS-prel-08-008

Inclusive Jets in Low-Q^2 DIS

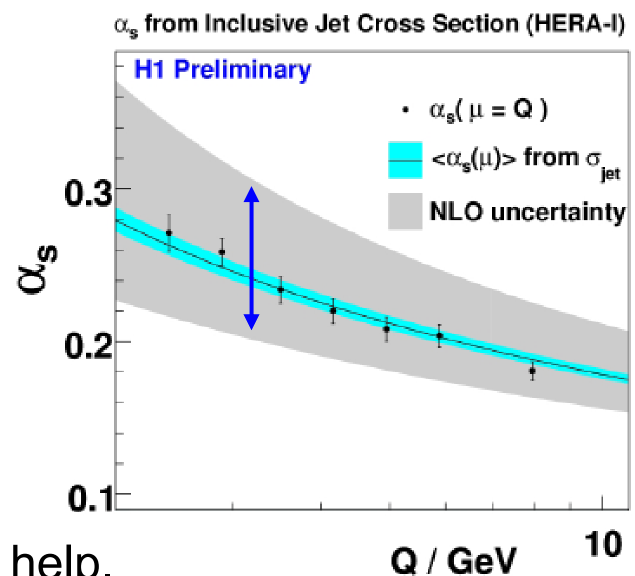
DIS at low Q^2

- Lots of statistics
- Natural region to look first

- $5 < Q^2 < 100\ (\mathrm{GeV}/c)^2$
- $E_{T,\mathrm{Breit}}^{\mathrm{jet}} > 5$ GeV



H1Prelim-08-032



Good data description by NLO pQCD but with a large uncertainty due scale uncertainty

Double differential cross sections yield:

$$\alpha_s(M_Z) = 0.1186 \pm 0.0014(\mathrm{exp})$$
$$\ {}^{+0.0132}_{-0.0101}(\mathit{theory}) \pm 0.0021(\mathit{PDF})$$

≈ 10%. Higher order calculations will help.

Inclusive Jets in High-Q^2 DIS

ZEUS-prel-09-006

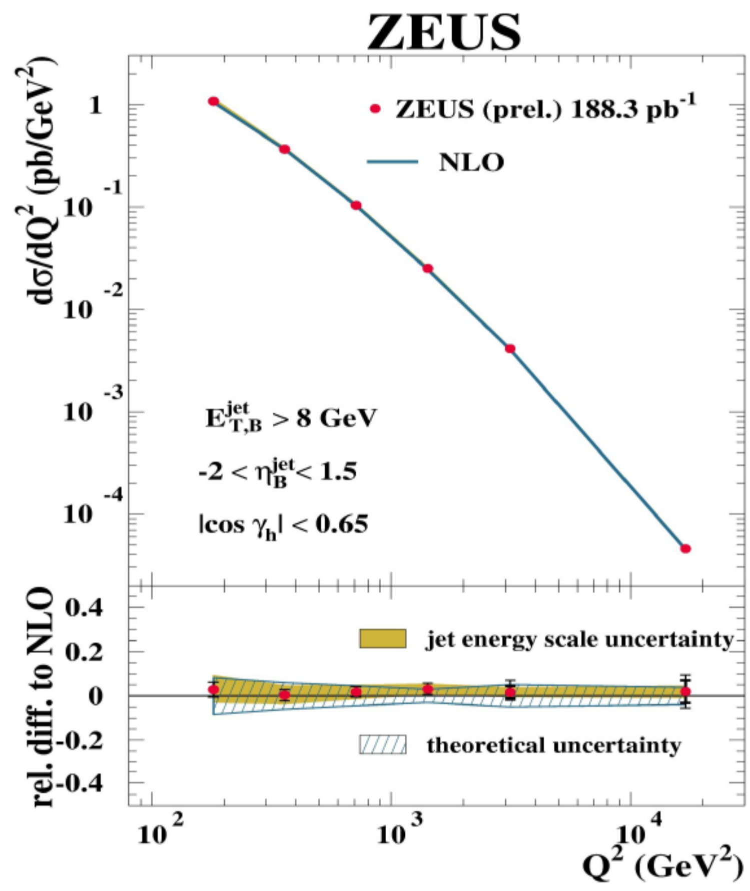
- Good description of data by NLO pQCD over many orders of magnitude in Q^2

- Scale uncertainty much smaller than that at low Q^2, but still dominates the experimental one except at high Q^2.

- α_s from $d\sigma/dQ^2$ at Q^2>500 GeV^2

$$\alpha_s(M_Z) = 0.1192 \pm 0.0009(stat)$$
$$^{+0.0035}_{-0.0032}(exp.)^{+0.0020}_{-0.0021}(th.)$$

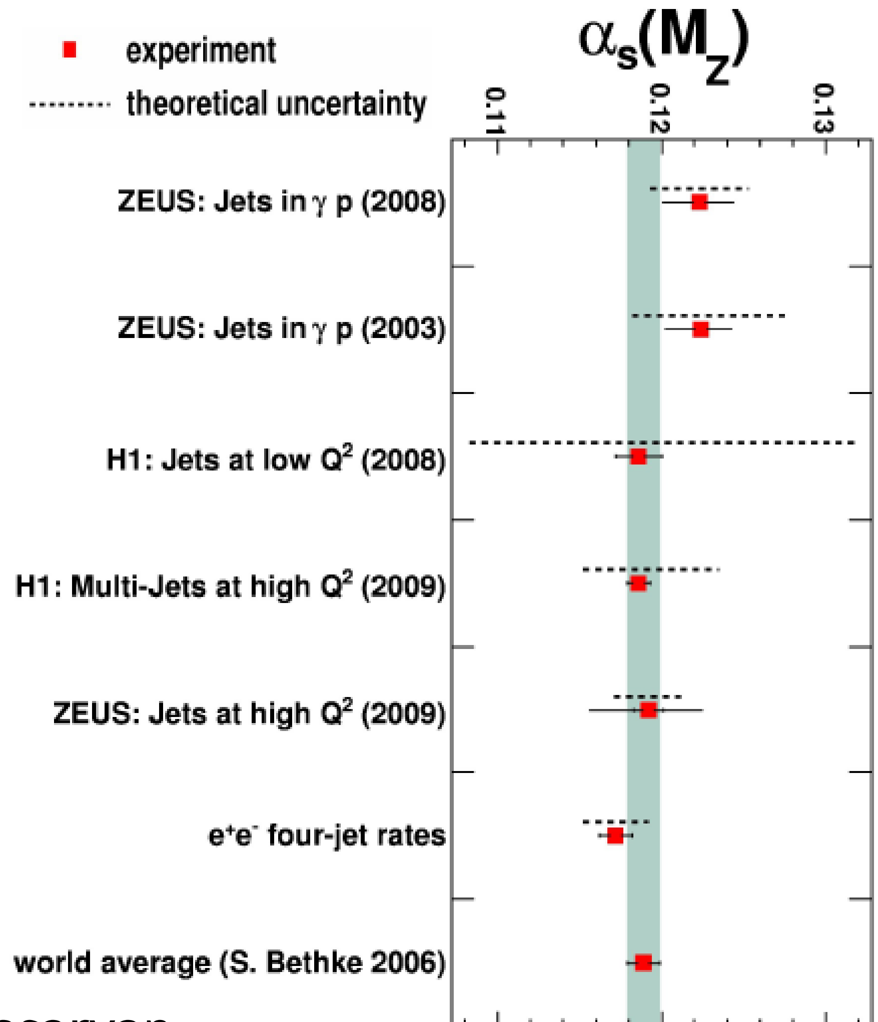
total 3.5% uncertainty



See also James Ferrando's talk.

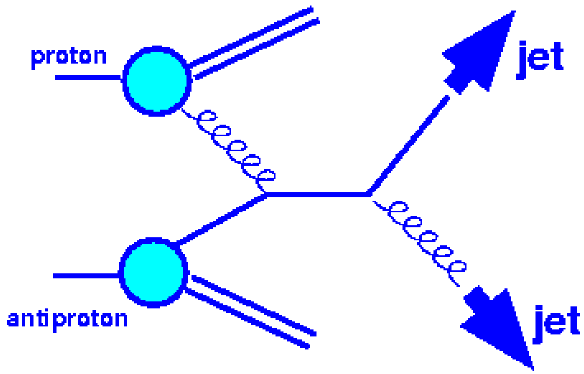
Strong Coupling Constant Summary

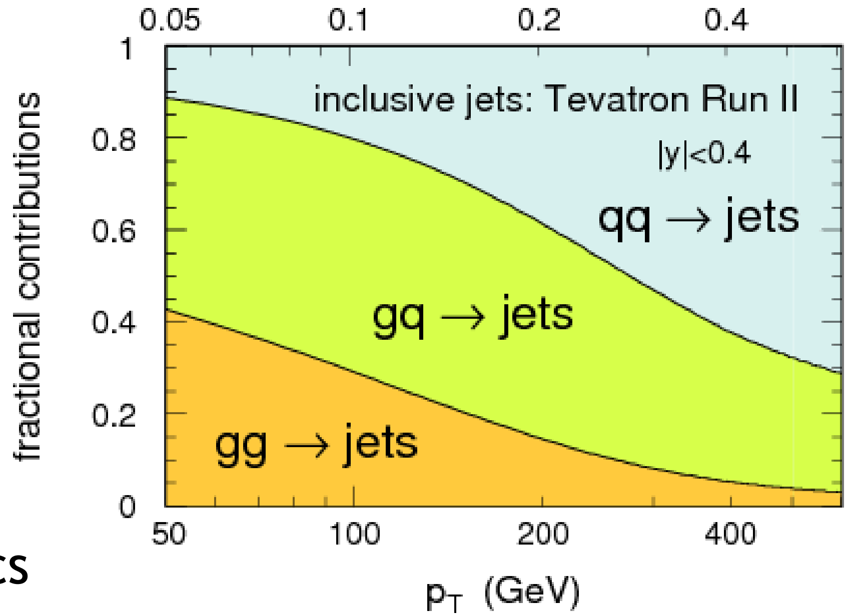
- Extracted α_s values are consistent with the world average
- Consistent between different processes
  - Success of QCD!
  - In many cases, the measurements suffer from sizable theoretical uncertainties (higher order QCD calculations wanted)



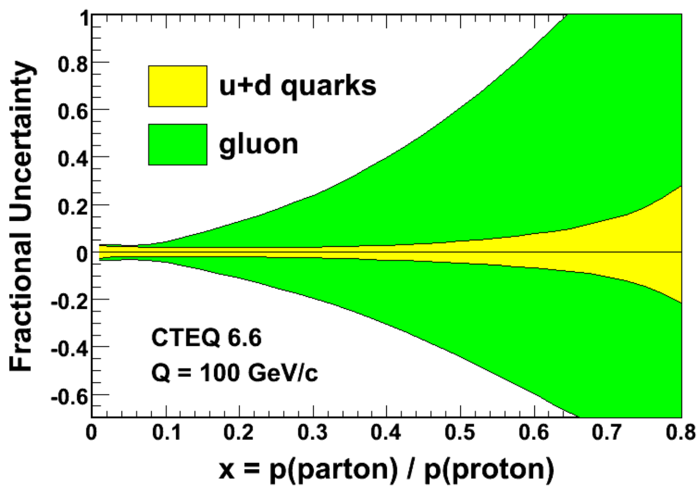
See also:
Inclusive jets, dijets, Multi-jets, H1, DESY 09-032; also a poster by A. Baghdasaryan

Jet Production at the Tevatron

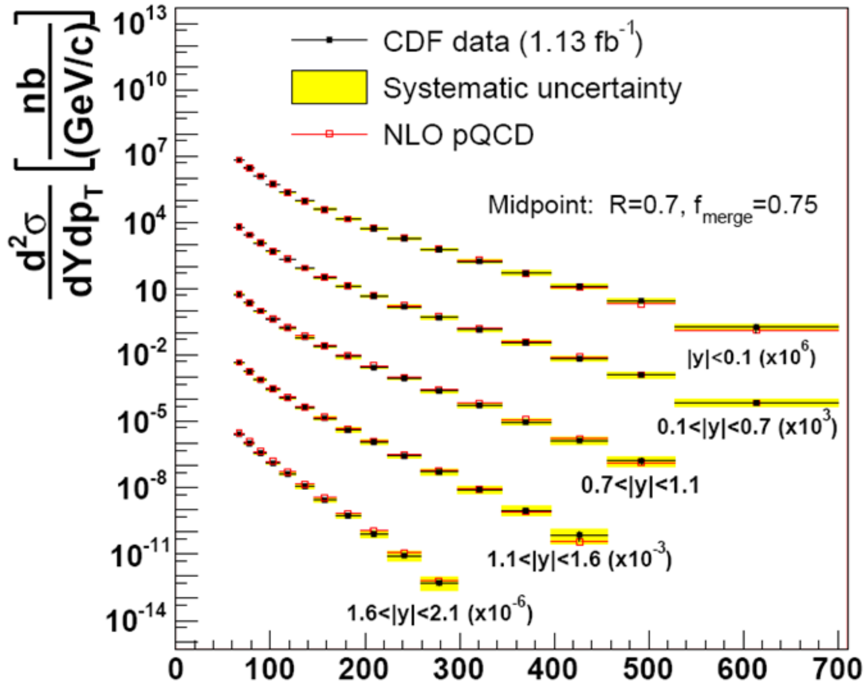




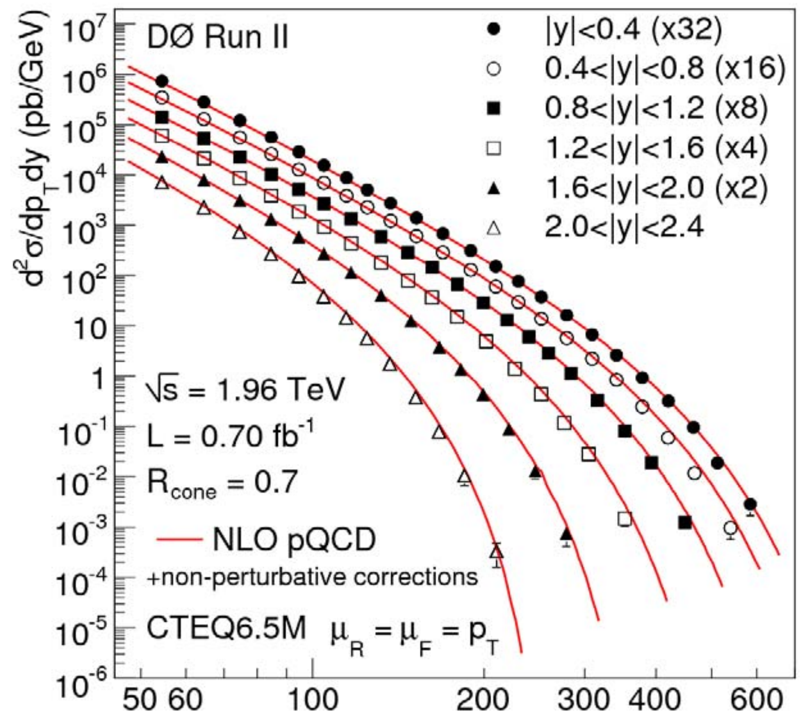
- Test pQCD at highest Q^2.
- Unique sensitivity to new physics
  - Compositeness, new massive particles, extra dimensions, …
- Constrain PDFs (especially gluons at high-x)
- Measure α_s



Inclusive Jet Cross Section



Phys. Rev. D 78, 052006 (2008) p_T (GeV/c)

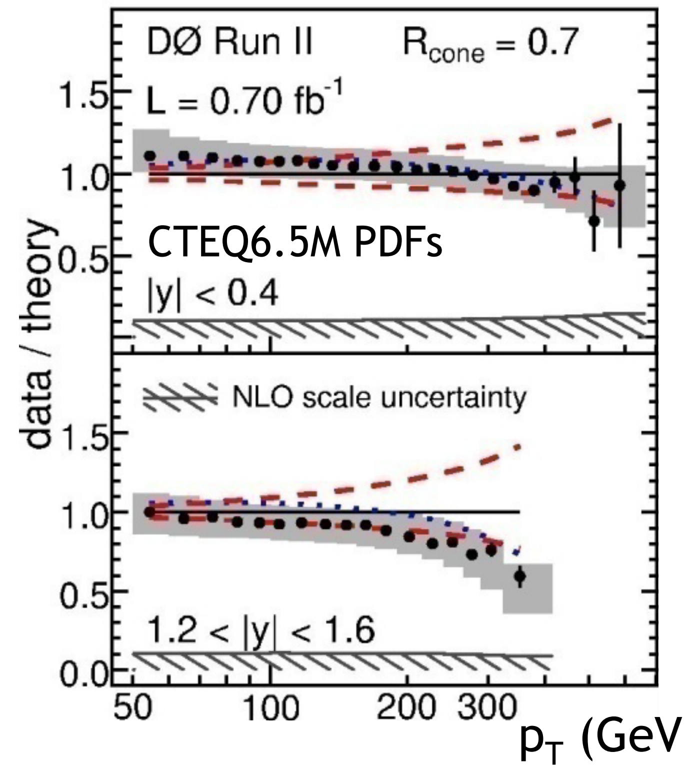


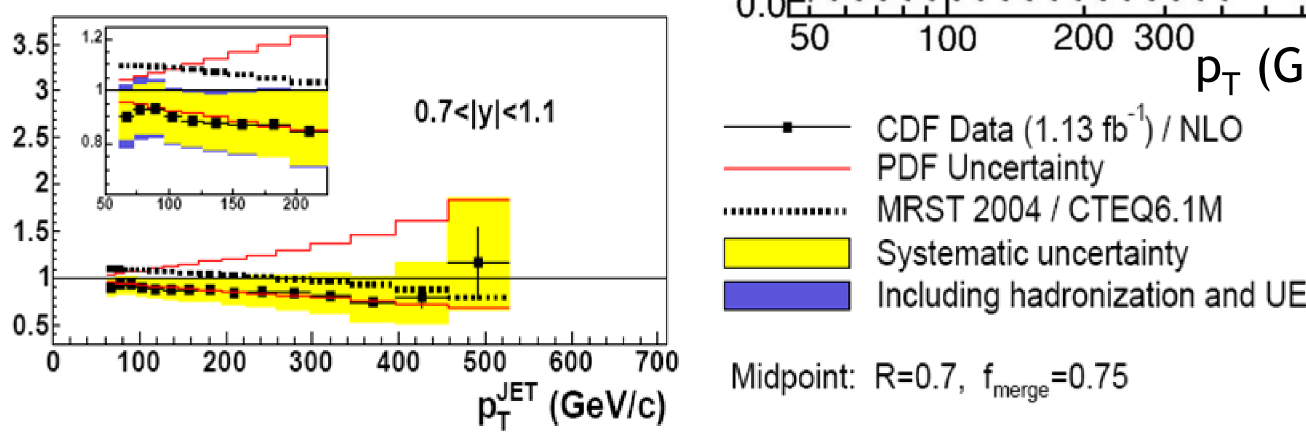
Phys. Rev. Lett. 101, 062001 (2008) p_T (GeV/c)

- Test pQCD over 8 order of magnitude in $d\sigma^2/dp_T dy$
- Highest p_T^{jet} > 600 GeV/c

Inclusive Jet Cross Section

- Both CDF and D0 measurements are in agreement with NLO predictions
  - Both in favor of somewhat softer gluons at high-x
- Experimental uncertainties: smaller than PDF uncertainties

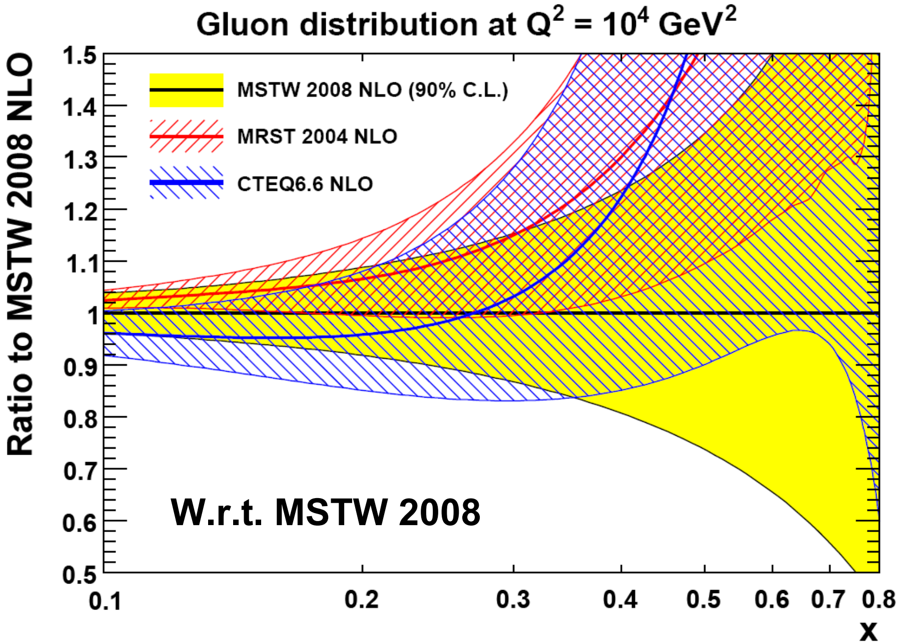




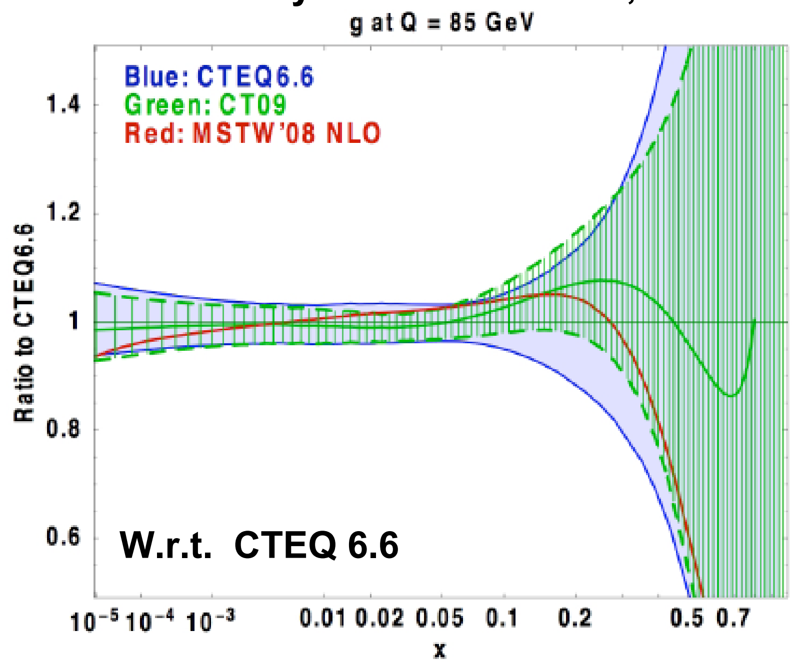
 see also, Inclusive jets with Kt, CDF, Phys. Rev. D, 75, 092006 (2007).

PDF with Recent Tevatron Jet Data

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



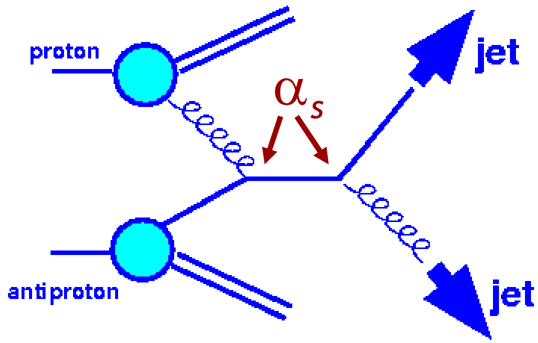
CT09: Phys.Rev.D80:014019,2009.



- Tevatron Run II data lead to softer high-x gluons (more consistent with DIS data) and help reducing uncertainties

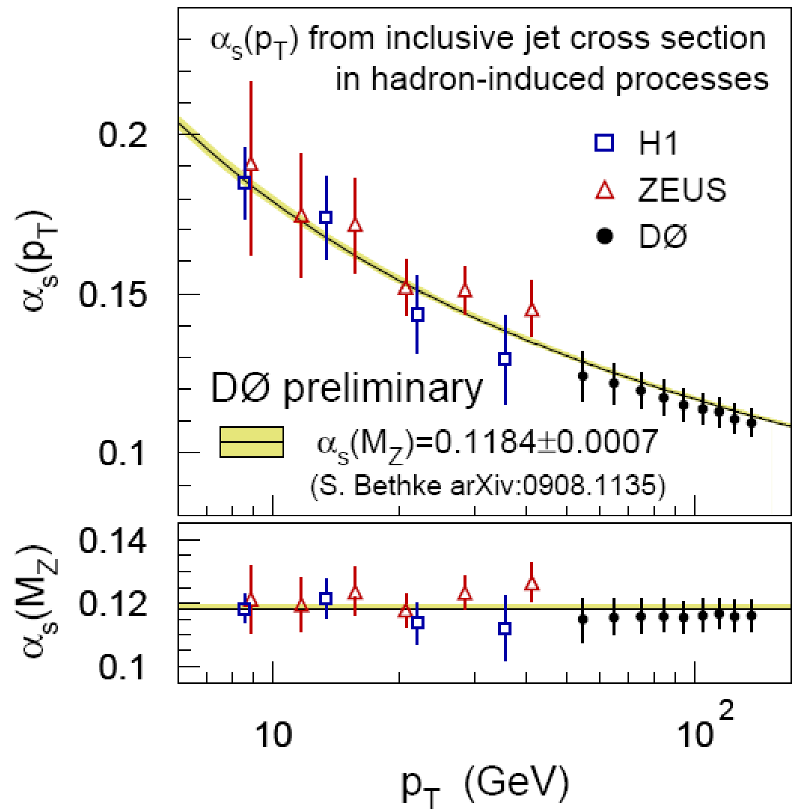
Strong Coupling Constant

D0 Note 5979



$$\sigma_{jet} = (\sum_n \alpha_s^n c_n) \otimes f_1(\alpha_s) \otimes f_2(\alpha_s)$$

From 22 (out of 110) inclusive jet cross section data points at $50 < p_T < 145$ GeV/c



- NLO + 2-loop threshold corrections
- MSTW2008NNLO PDFs
- Extend HERA results to high p_T

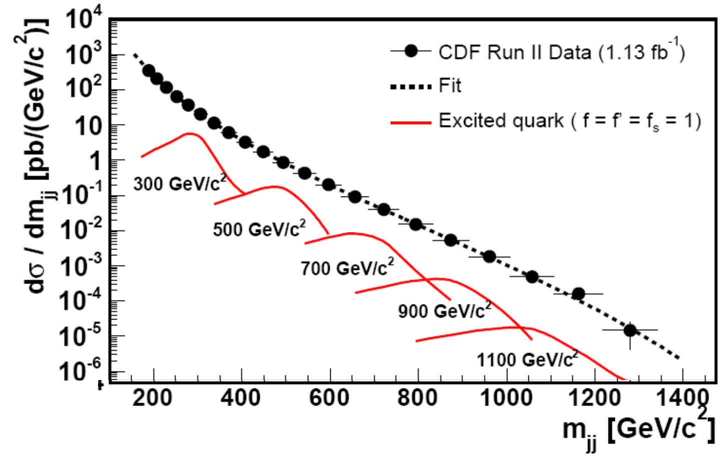
$$\alpha_s(M_Z) = 0.1173^{+0.0041}_{-0.0049}$$

3.5-4.2% precision

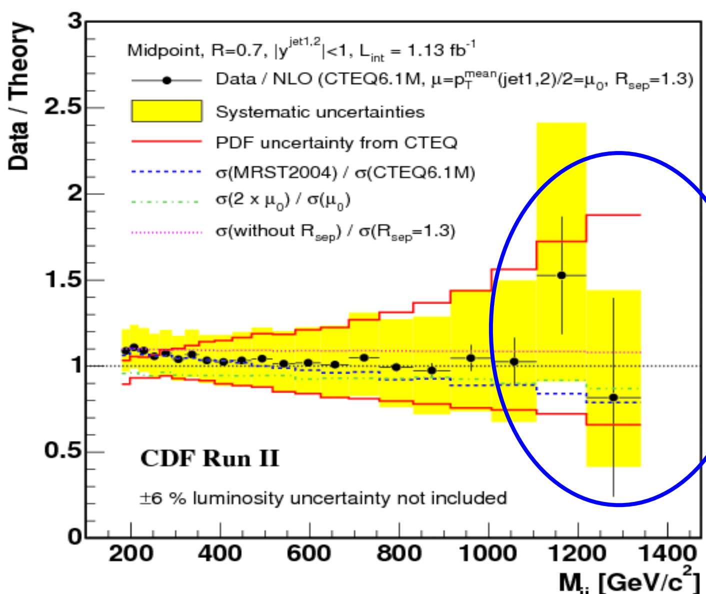
Dijet Mass Spectrum

Phys. Rev. D 79, 112002

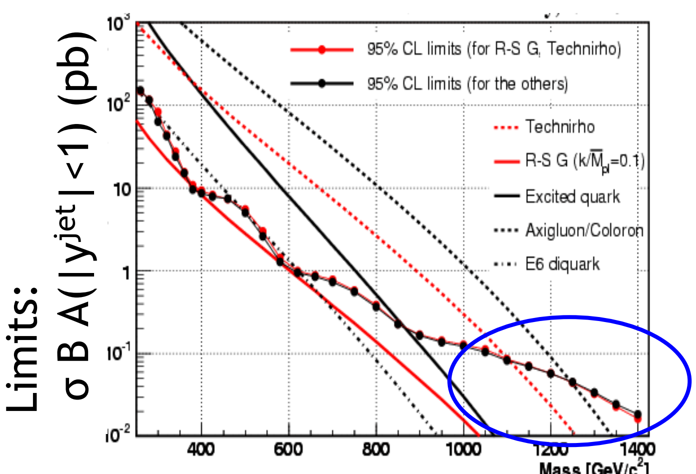
- Test pQCD predictions
- Sensitive to new particles decaying into dijets: excited quarks, heavy gluons, techni-ρ, etc



Dijets with jets $|y^{jet}|<1$



- Consistent with NLO pQCD
- Most stringent limits on many new heavy particles



Mass reach up to ~ 1.2 TeV/c²

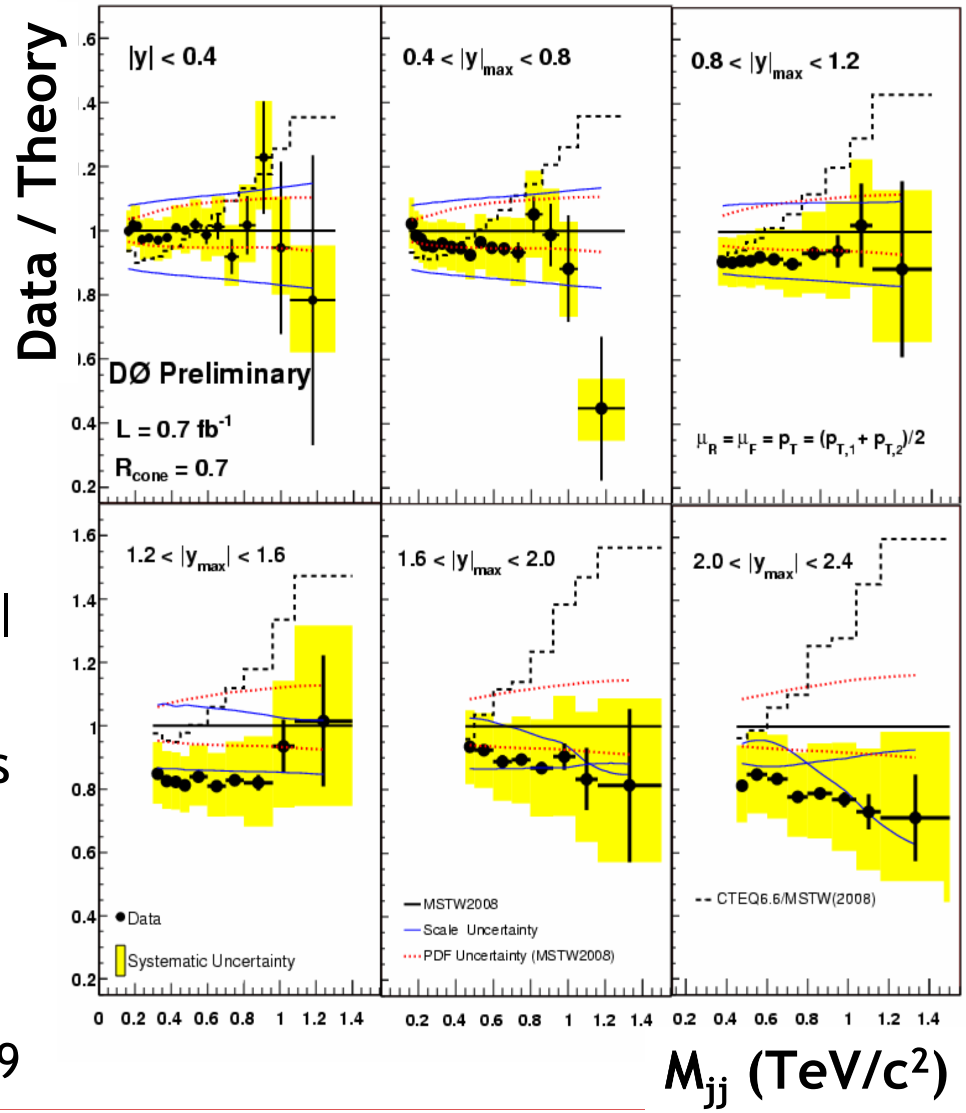
Dijet Mass Spectrum

Extend pQCD test to forward rapidity regions

- six $|y_{max}|$ regions ($0<|y_{max}|<2.4$)

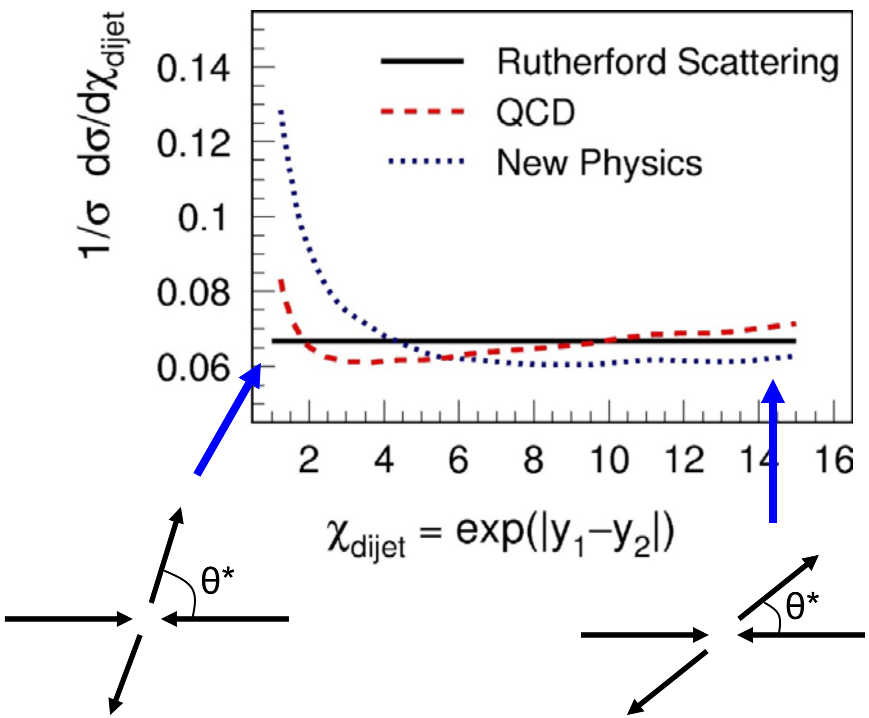
Described by NLO pQCD

- PDF sensitivity at large $|y_{max}|$
- Favor softer high-x gluons
- No indications for resonances



D0 Note 5919

Dijet Angular Distribution



Variable:

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

at LO, related to CM scattering angle

$$\chi_{dijet} = {1+\cos\theta^*}\big/{1-\cos\theta^*}$$

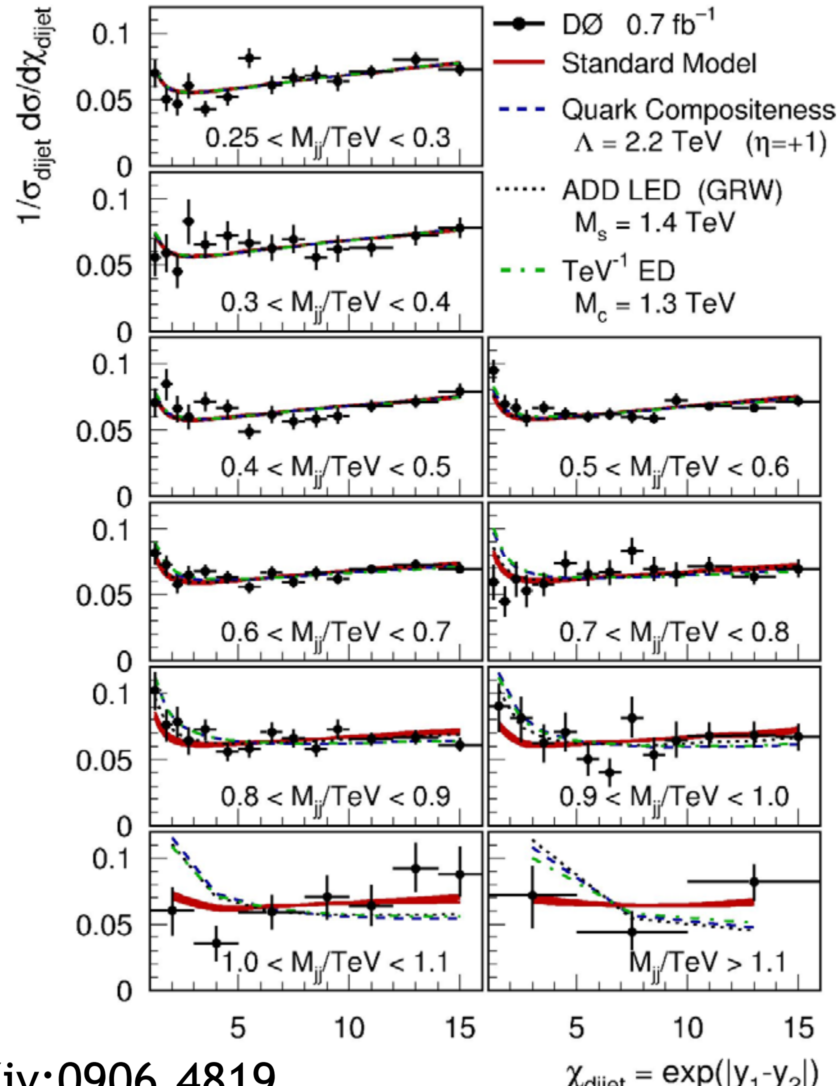
- QCD scattering ~ flat in χ_{dijet}
- New physics, like
  - quark compositeness
  - extra spatial dimensions (LED)
  - → Peak centrally (low χ_{dijet})

$\dfrac{1}{\sigma}\dfrac{d\sigma}{d\chi_{dijet}}$: Normalized distribution (reduce experimental and theoretical uncertainties)

Dijet Angular Distribution

$$\frac{1}{\sigma}\frac{d\sigma}{d\chi_{dijet}}$$: Normalized distribution (reduce experimental and theoretical uncertainties)

- Consistent with NLO pQCD
- Limits on Compositeness & LED
  - Quark Compositeness $\Lambda > 2.9$TeV
  - ADD LED (GRW) Ms > 1.6 TeV
  - TeV-1 ED Mc > 1.6 TeV



arXiv:0906.4819

Photons, +Jets, +Heavy-Flavor

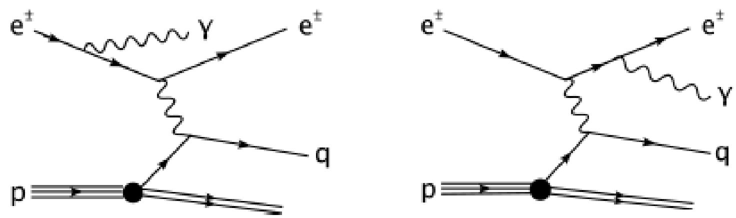
Photons: “direct” probes of hard scattering

Test perturbative QCD, PDFs

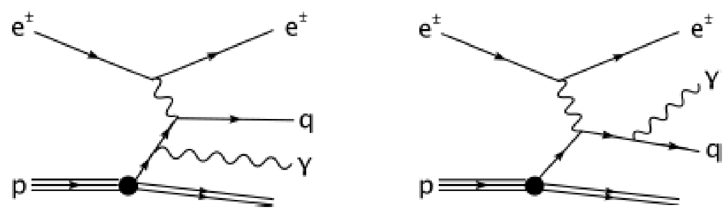
Prompt Photons at HERA

Prompt photons in DIS

Hard radiation from lepton line



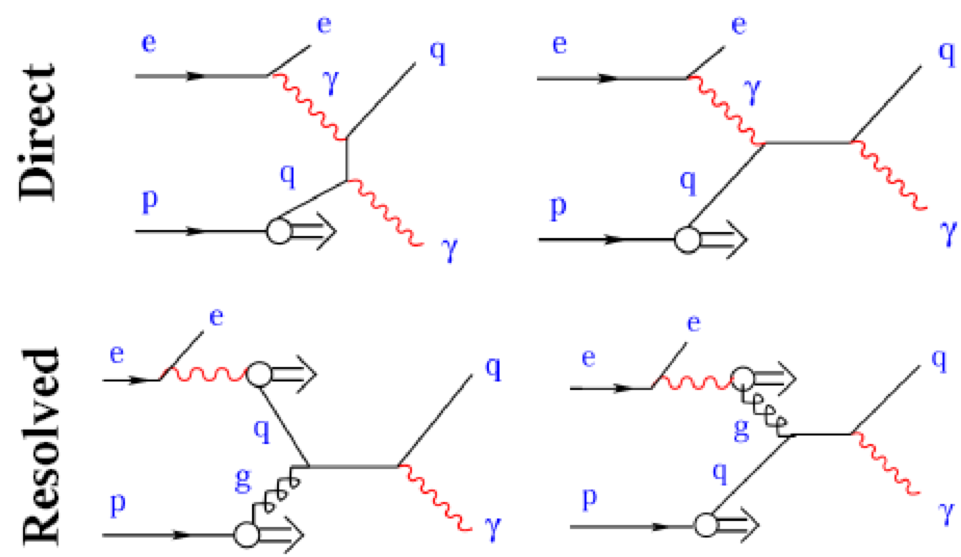
Hard radiation from quark line



See James Ferrando's talk.

Prompt photons in Photoproduction

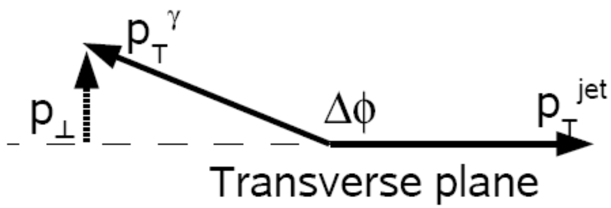
Radiation from lepton line becomes negligible



- Testing QCD models
- Sensitive to proton and photon PDFs

Prompt Photons in Photoproduction

Photon-jet correlations

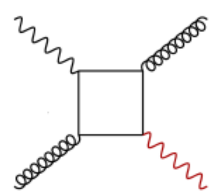


Theoretical models:

FGH (Fontannaz et al): NLO

Including:

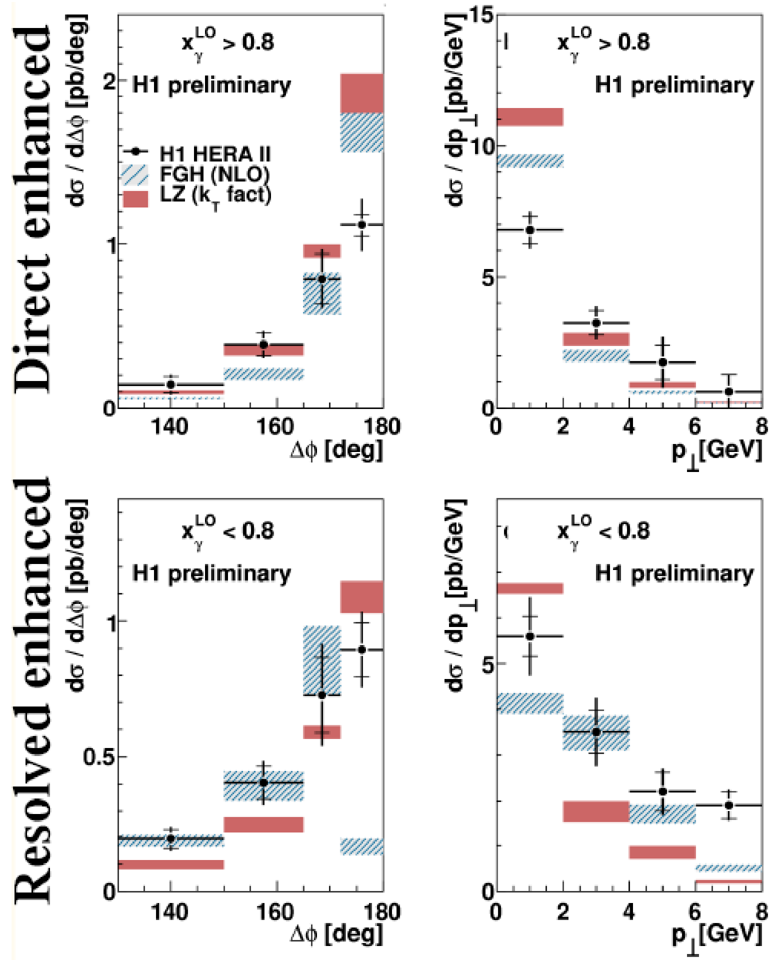
- box diagram
- quark-to-photon fragmentation



LZ (Lipatov, Zotov): Kt factorization

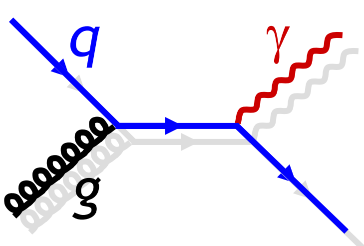
- box diagram and fragmentation neglected
- soft gluons absorbed

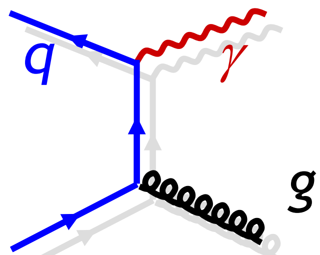
H1Prelim-09-035



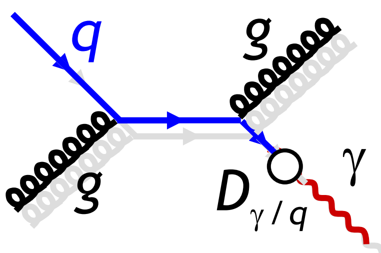
Need more complete theory calculation

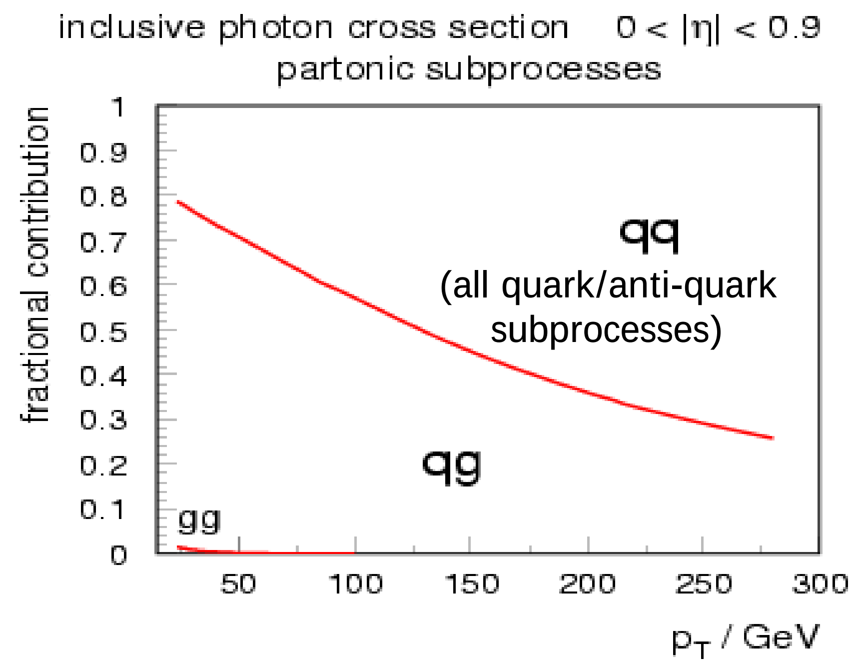
Prompt Photons at the Tevatron





Directly sensitive to hard scatter





Fragmentation contribution:

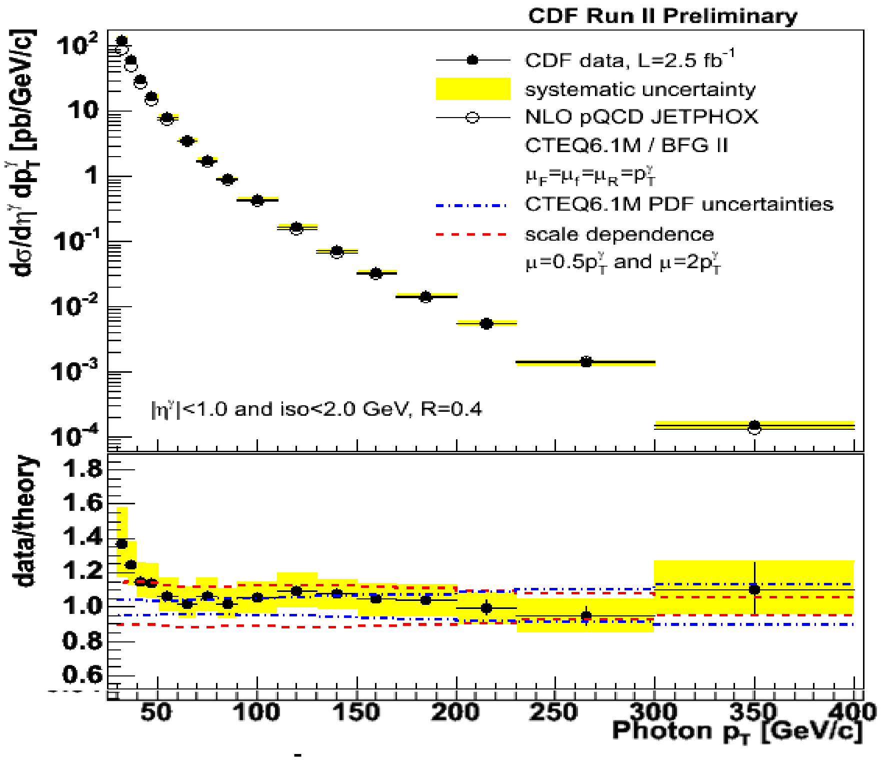
Photons accompanied by other particles.

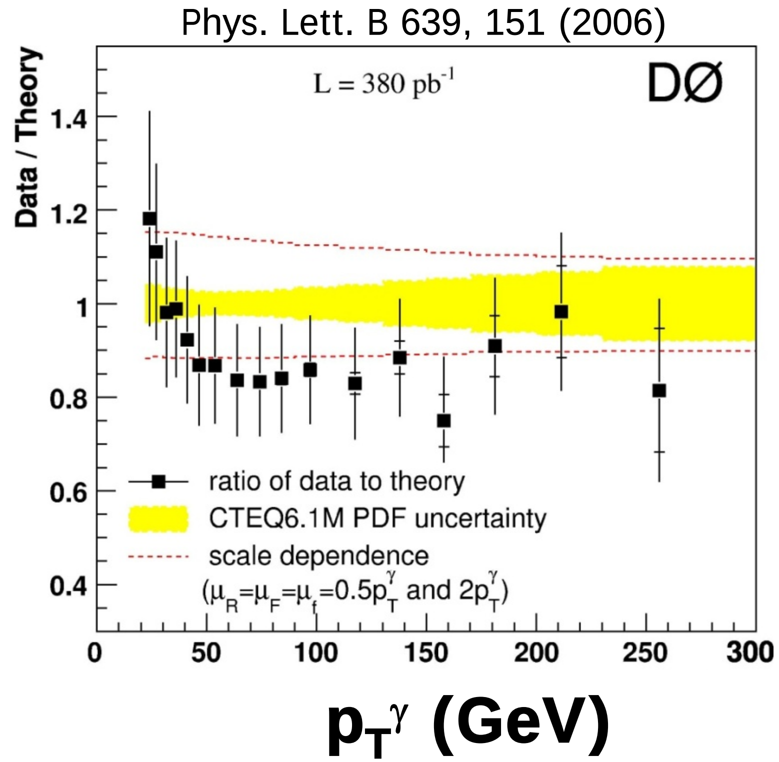
Suppressed by isolation requirement.

Potentially sensitive to PDFs

We measure "isolated" photons (E_T in R=0.4 < 2 GeV for CDF)

Inclusive Photon Cross Sections

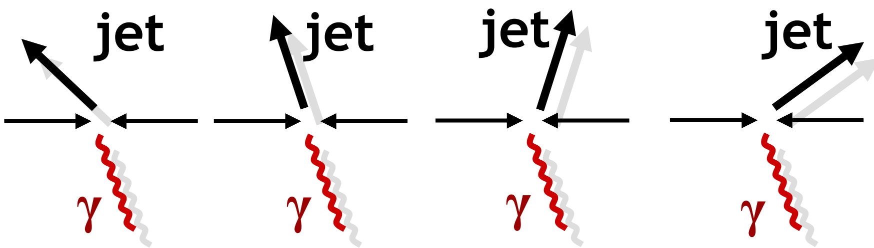




- CDF and D0 measurements show similar trends
- Data/NLO pQCD: In agreement at high p_T, but enhancement at low p_T
  - Similar shape also in Run 1 analyses – need to be understood

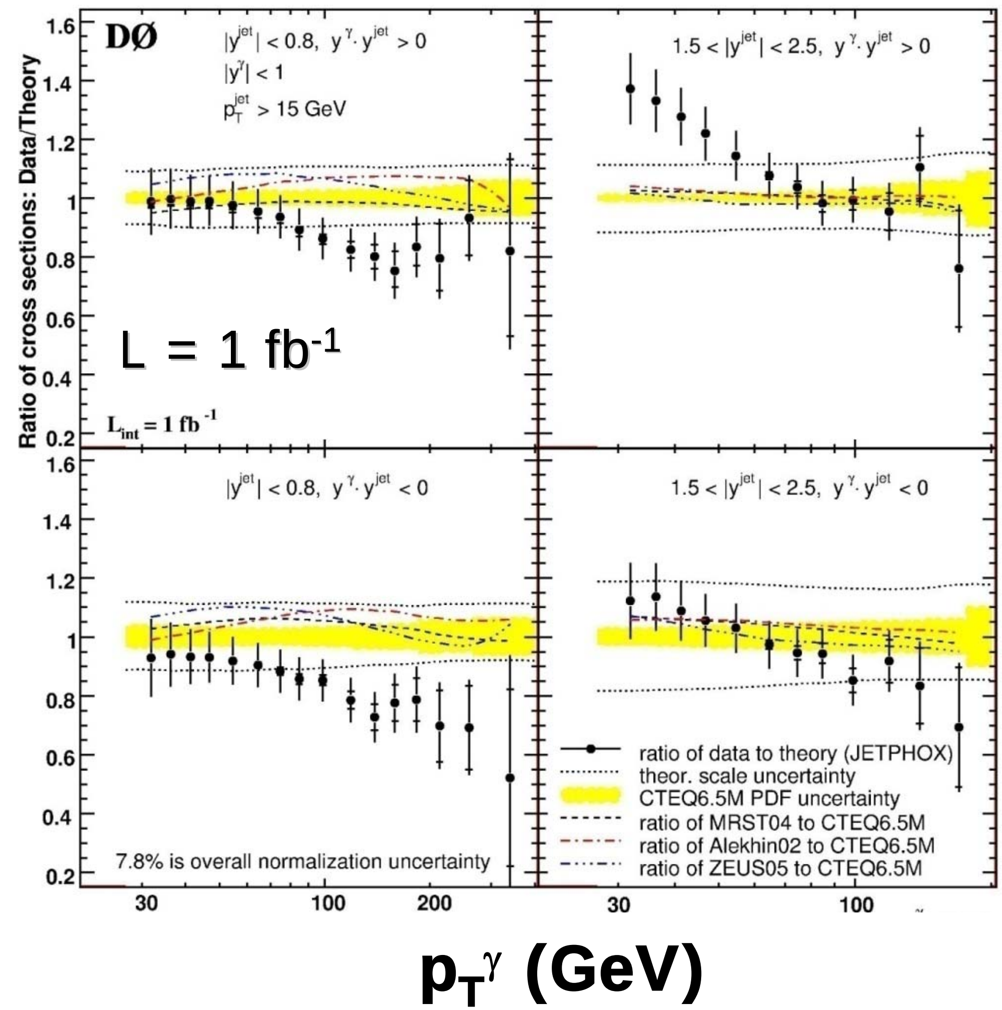
Photon + Jet

- Look at more full hard scatter kinematics

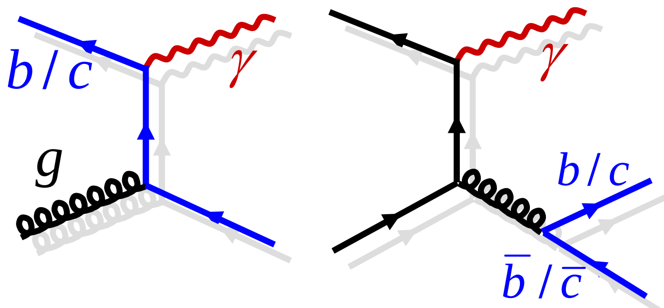


- Data not well described by NLO pQCD
  - Can CDF reproduce this?
  - Intrinsic k_T? Ressumation?

Phys. Lett. B 666, 2435 (2008)



Photon + HF Jet Production



- Sensitive to HF-content of proton
- Bkgd for many BSMs

Photon p_T: 30 – 150 GeV/c
Rapidities: $|y^\gamma|<1.0$, $|y^{jet}|<0.8$

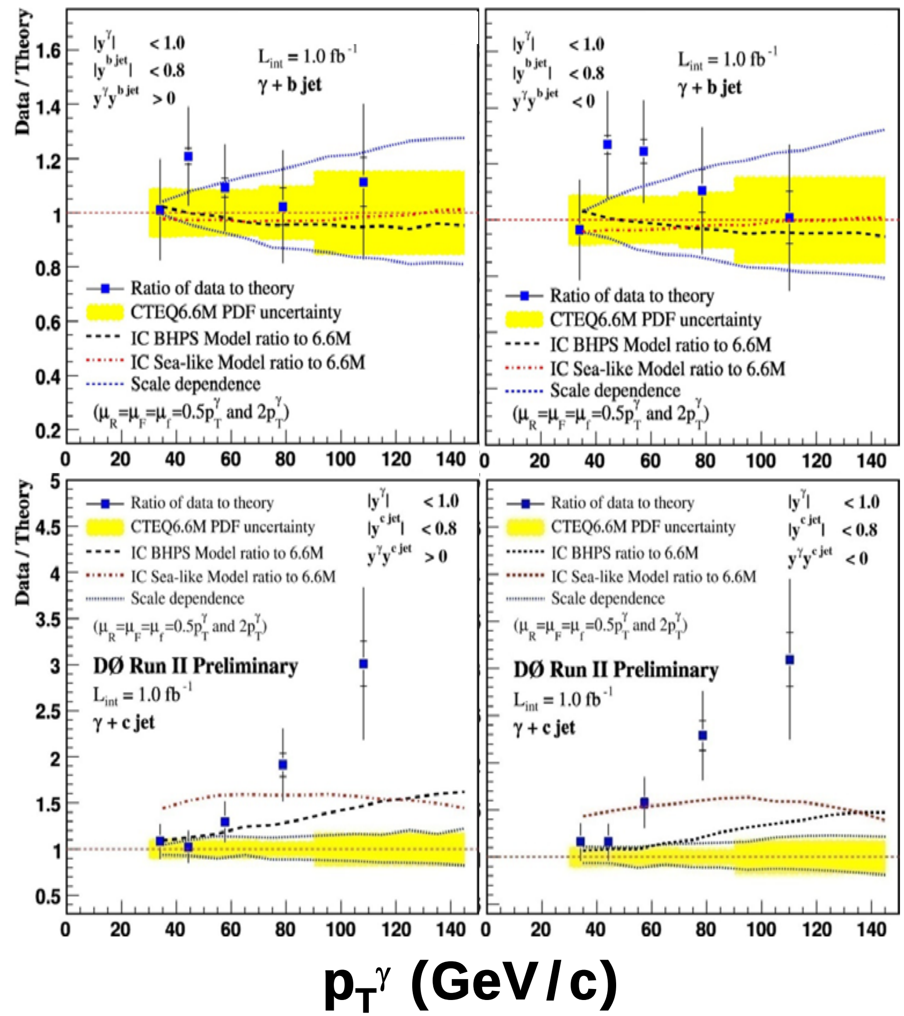
<u>Photon+*b*:</u>

- Agreement over full p_T^γ range

<u>Photon+*c*:</u>

- Agree only at $p_T^\gamma<50$ GeV/c.
- Disagreement increases with p_T^γ.
- Using PDF including the intrinsic charm (IC) improves, but data and theory still not compatible

Phys. Rev. Lett. 102, 192002

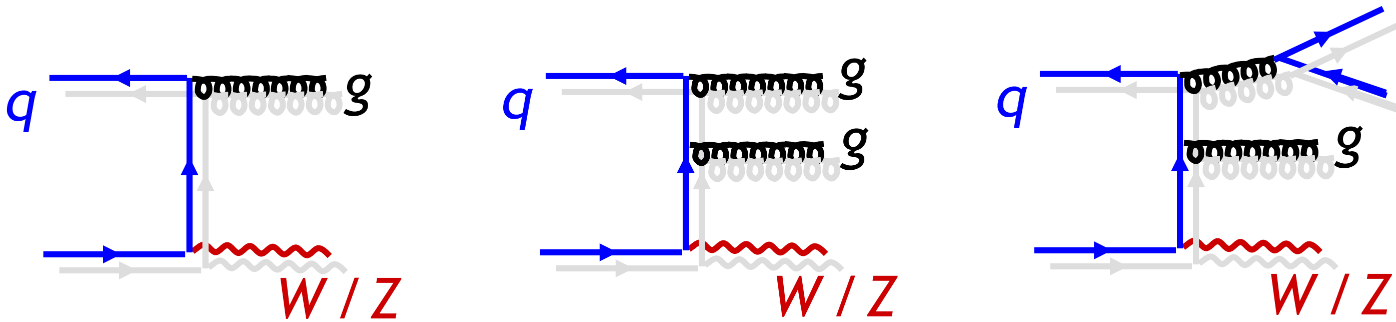


W/Z + Jets, + Heavy-flavor

Prerequisites for top, Higgs, SUSY, BSM

Test perturbative QCD calculations,
Monte Carlo Models

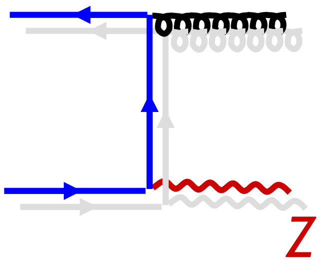
W/Z+Jets Production

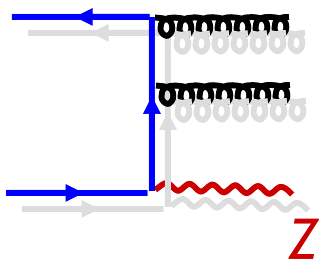


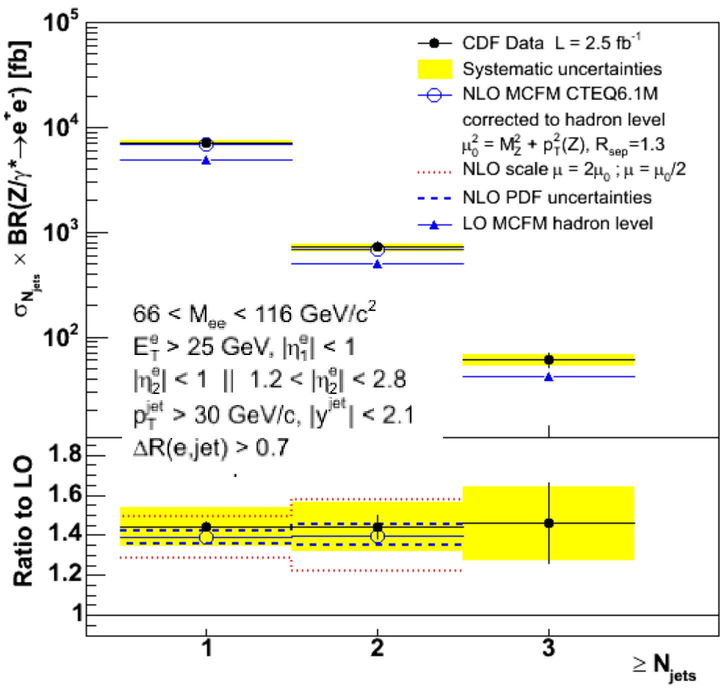
- W/Z+jets are critical for physics at the Tevatron and LHC: top, Higgs, SUSY, and other BSM
- NLO pQCD calculations are available up to >=2(3) jets
- Many Monte Carlo tools are available
  - LO + Parton shower Monte Carlo (Pythia, Herwig,)
  - Matched tree level matrix element + parton shower Monte Carlo (Alpgen, Sharpa,)
- These calculations and tools need “validation” by experimental measurements

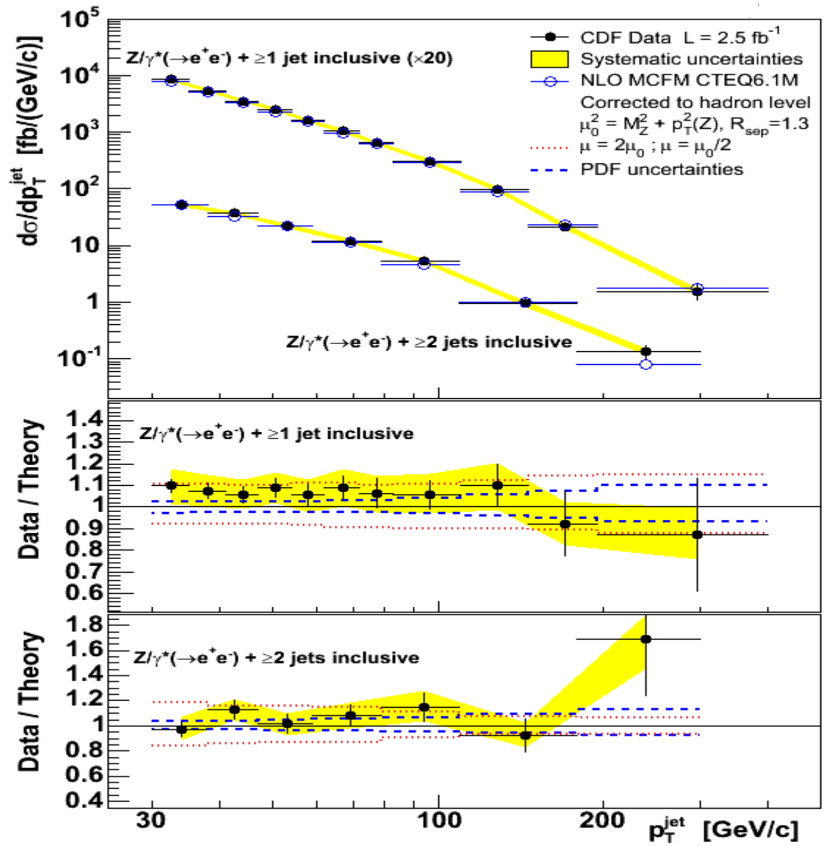
Z+Jets Production

Phys. Rev. Lett 100, 102001 & update









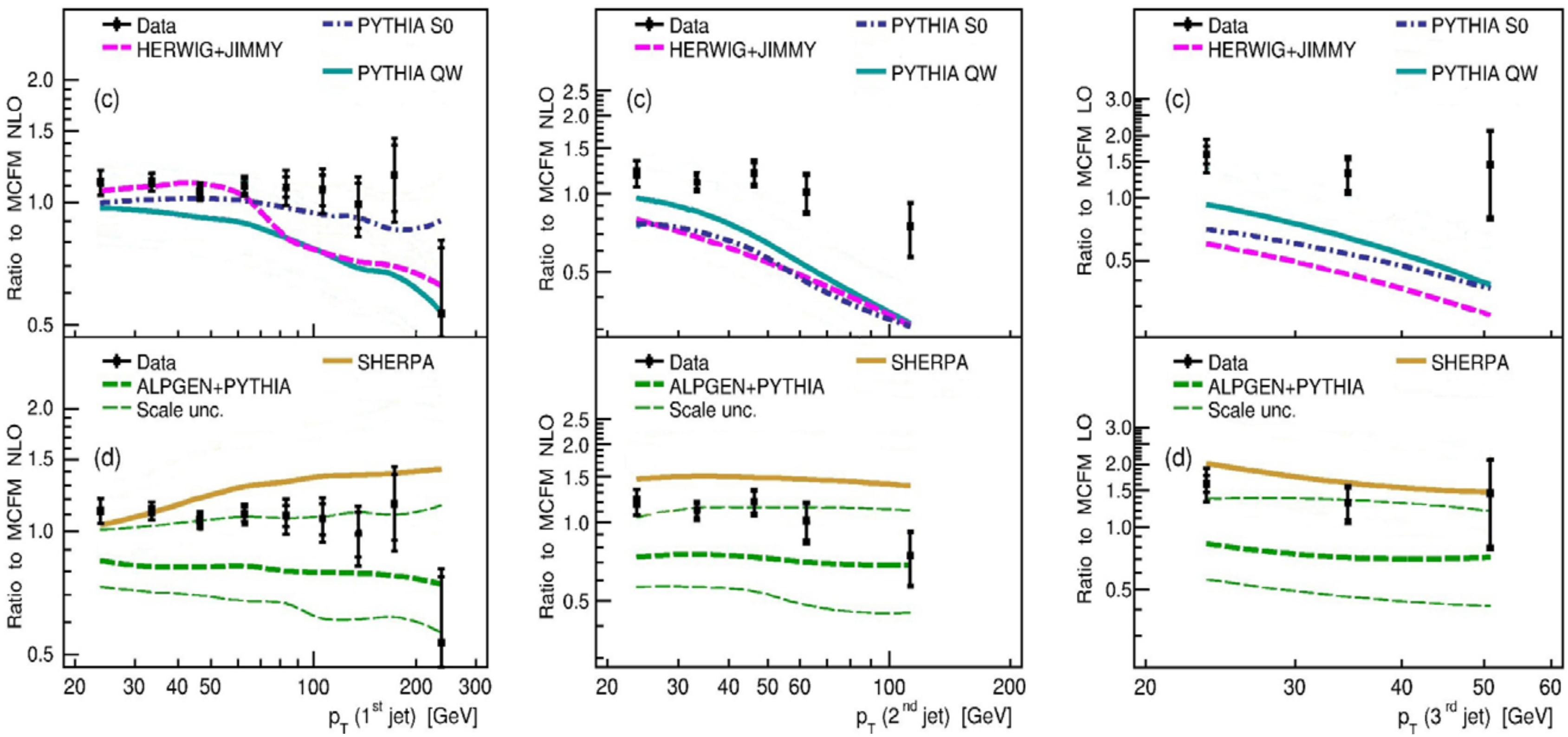
Data and NLO pQCD in agreement

Good control sample for SUSY search

Z + (1, 2, 3) Jets

Testing Monte Carlo Models: favor Alpgen with low scale

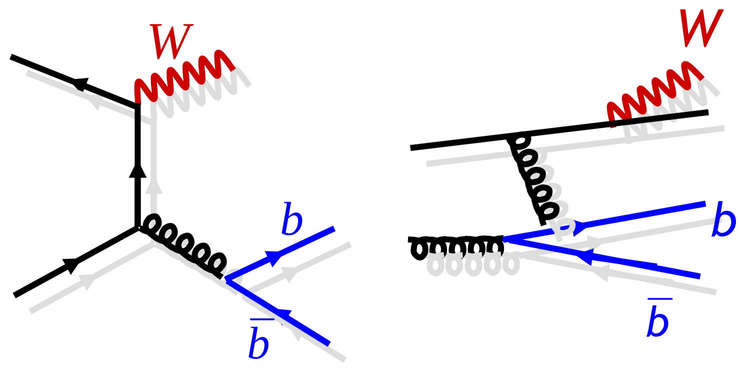
Leading jet in Z + jet + X   Second jet in Z + 2jet + X   Third jet in Z + 3jet + X

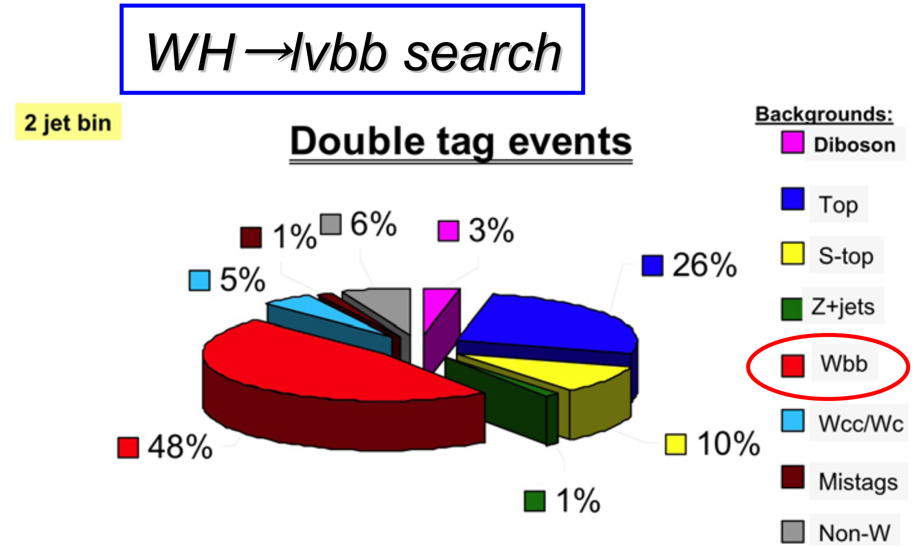


Phys. Lett. B 669, 278 (2008), arXiv:0903.1748, arXiv:0907.4286

See also W+jets, CDF, Phys. Rev. D 77, 011108(R).

W+*b*-jets production





Large bkgd for many analyses

- SM Higgs (WH) production
- Single top quark production
- $t\bar{t}$ production

(See Bernd's and Krisztian's talks.)

Can we better understand this bkgd?

Both electron and muon channels

Jets with Et > 20 GeV and |η| < 1.5

$\sigma \cdot B = 2.74 \pm 0.27(stat) \pm 0.42(syst) pb$

NLO: $2.28 \pm 0.22 pb$

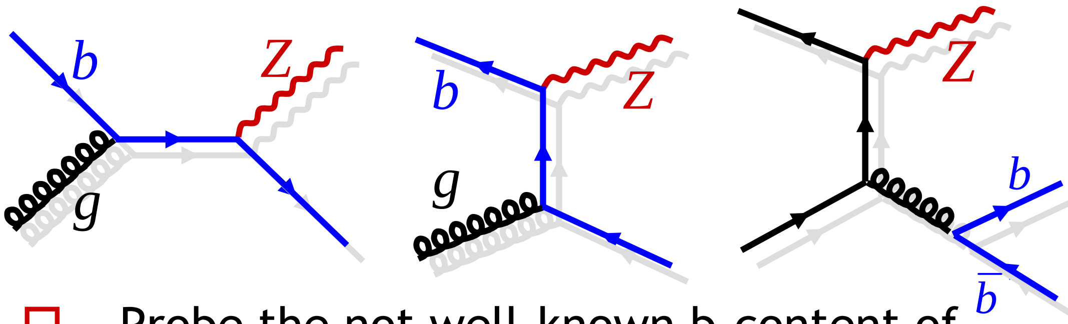
Alpgen: 0.78pb

CDFnote 9321

Success of NLO QCD. Awaiting for differential measurements.

Z+*b*-jets Production

arXiv:0812.4458

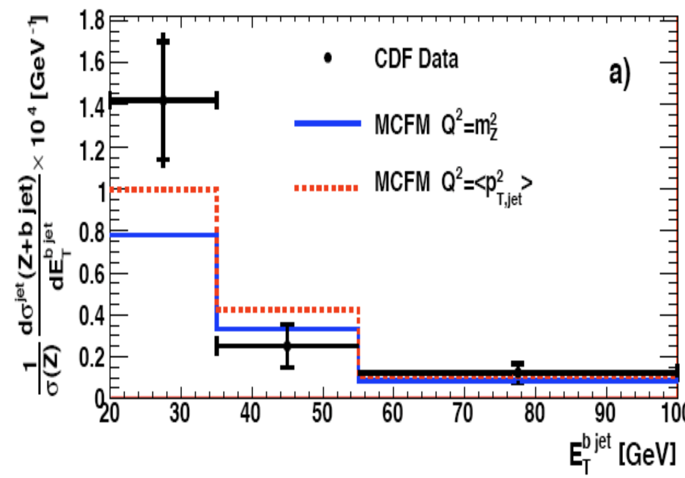


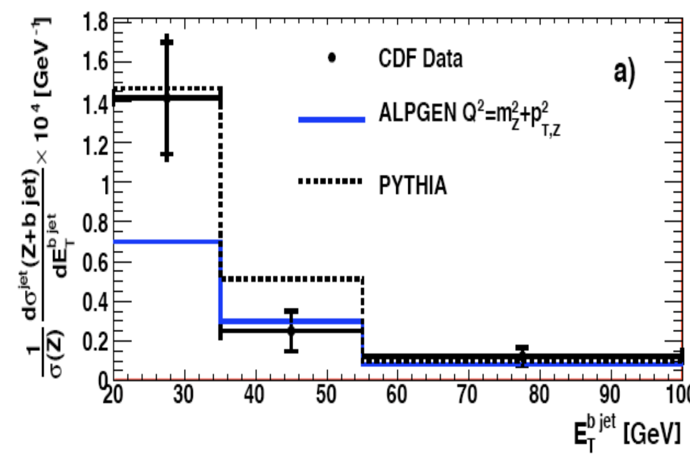
- Probe the not well-known b-content of the proton
- Backgrounds for SM Higgs Search (ZH→ννbb) and SUSY

Both electron and muon channels
Jets with Et > 20 GeV and |η| < 1.5

$$\frac{\sigma(Z+b)}{\sigma(Z+jets)} = 2.08 \pm 0.33 \pm 0.34(\%)$$

$$pQCD(MCFM): 1.8\%\ (Q^2 = M_Z^2 + P_{T,Z}^2)\ ;\ 2.2\%(Q^2 = < P_{T,Jet}^2 >)$$





Data and theory in agreement but both have sizable uncertainties (No complete NLO prediction for Z+bb)

Large variations between MC models (important inputs for tuning)

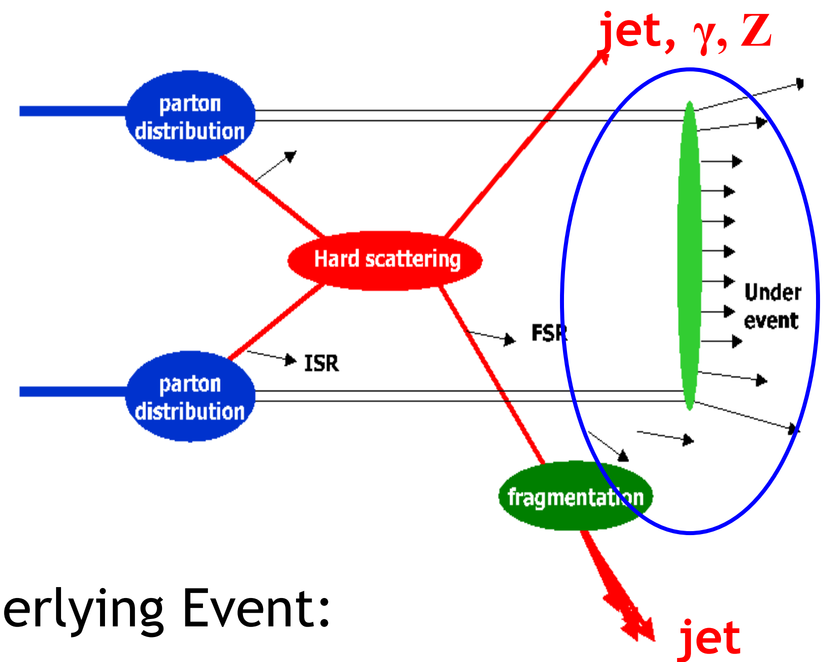
Underlying Event (UE) & Multiple Parton Interactions

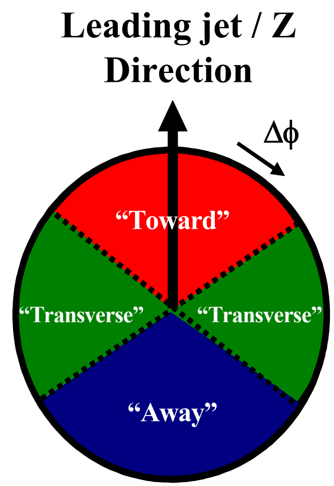
Prerequisites for High Pt Physics

Low-p_T Soft QCD, Monte Carlo Tuning

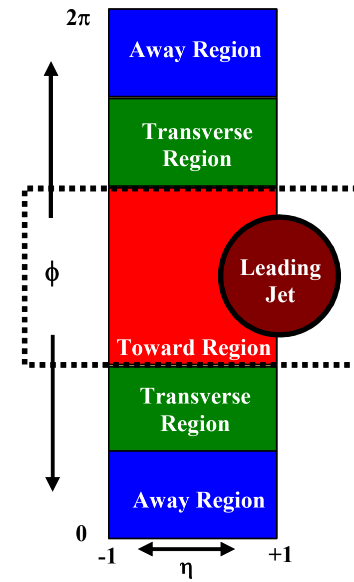
See also:
Minimum bias measurement, CDF, Phys. Rev. D, 79, 112005 (2009).
Multiple parton interaction, H1prelim-08-036; also a poster by L. Magro.

UE in Jet and Drell-Yan Production





Transverse plane



η-ϕ Plane

Underlying Event:

everything except hard scatter

Jet production:

- Transverse region sensitive to UE
- High statistics jet sample
- Studies in various dijet topologies

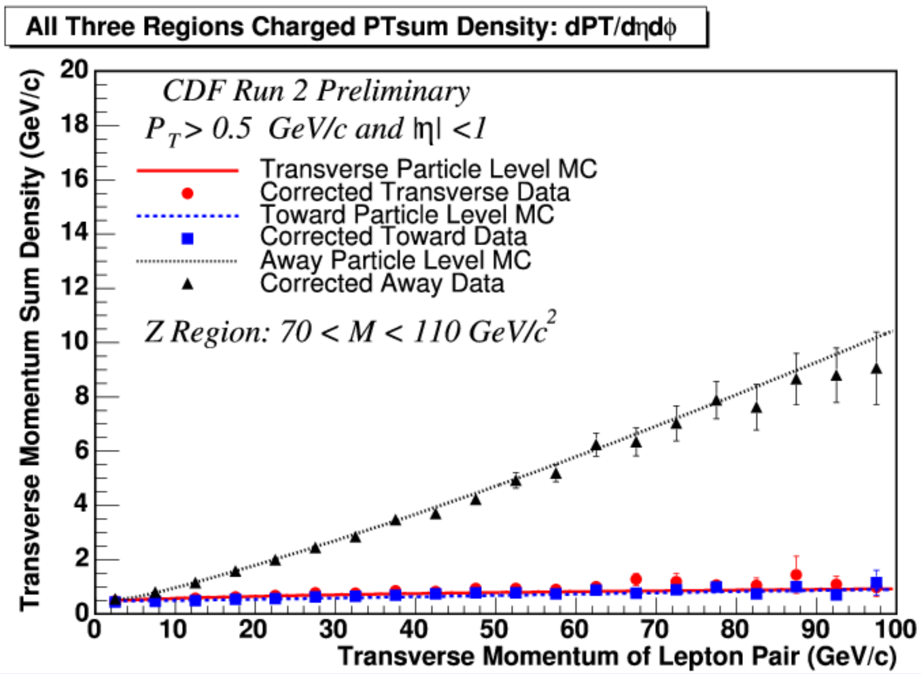
DY production:

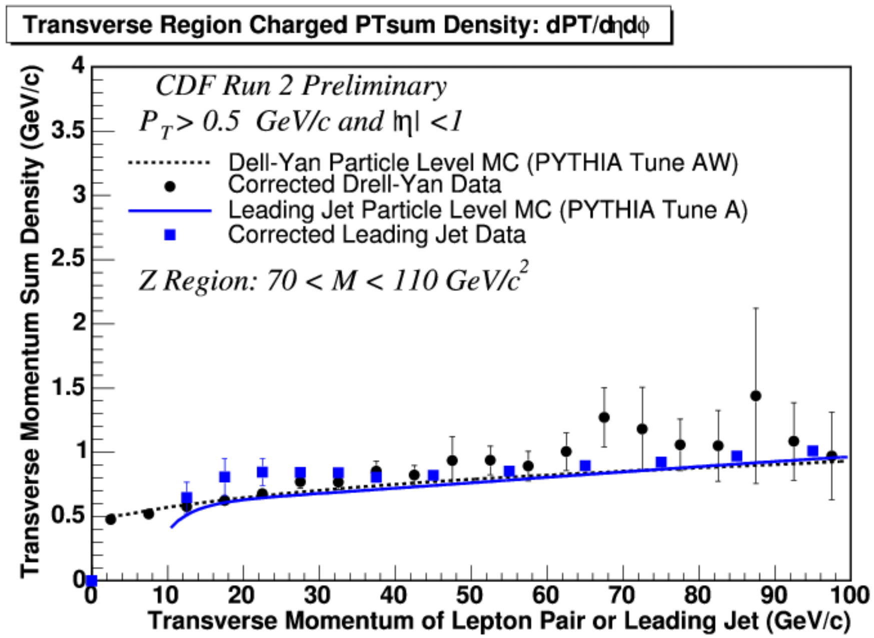
- Transverse and toward regions (excluding lepton-pairs) sensitive to UE
- Cleaner environment (Z/γ^* carries no color)
- Limited statistics

UE in DY and Jet Production

Comparisons of three regions

- Away region p_T density goes up with lepton-pair p_T, while the transverse and toward region p_T densities are mostly flat with lepton-pair p_T



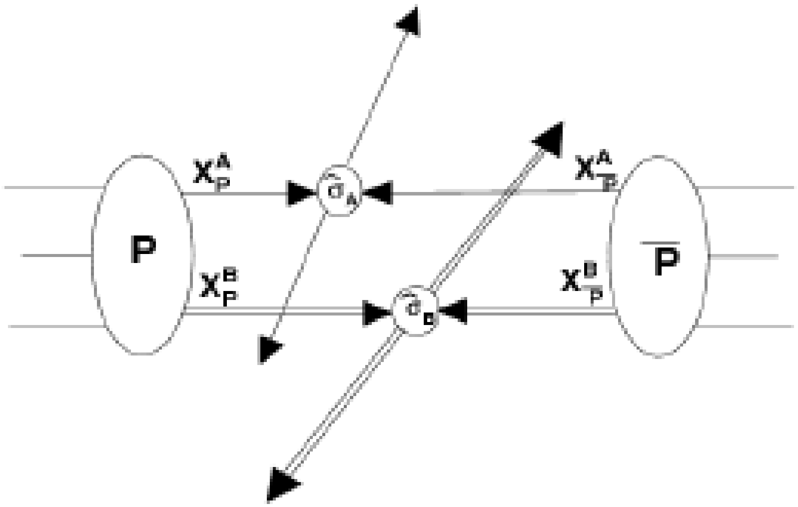


Comparisons between jet and DY

- Similar trend in jet and DY events: UE universality?
- Tuned Pythia describe data reasonably well.

There are many more plots for UE in jet and Drell-Yan production corrected to hadron level: Very important for MC generator tuning/development

Double Parton using γ+3 Jets

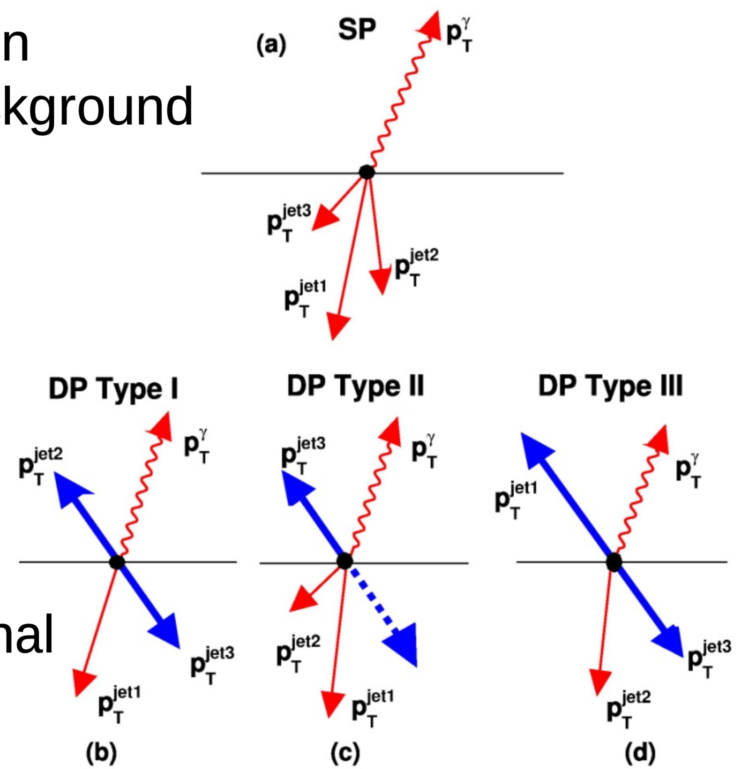


$$\sigma_{DP} = \sigma_{\gamma j}\, \sigma_{jj} / \sigma_{eff}$$

σ_{eff} : effective interaction region
(Large σ_{eff}: partons more uniformly distributed)

Main background

signal



- Study interactions of two parton pairs in single proton:
  - Insight to parton spatial distributions in the proton
  - Background to other process especially at high luminosities

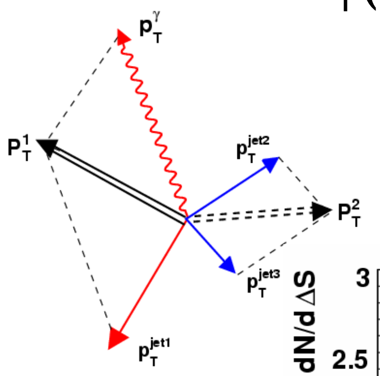
Double Parton Scattering

- Calculated for the pair that gives the minimum value of S:

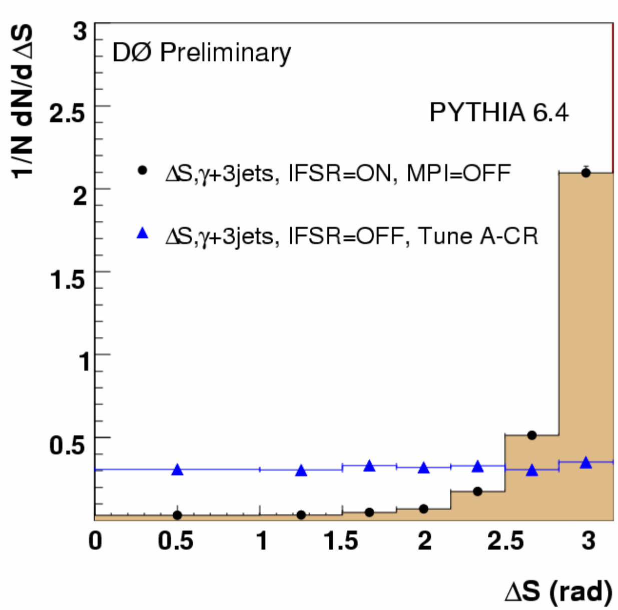
$$S_{\varphi} = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{\Delta\varphi(\gamma,i)}{\delta\varphi(\gamma,i)}\right)^2 + \left(\frac{\Delta\varphi(j,k)}{\delta\varphi(j,k)}\right)^2}$$

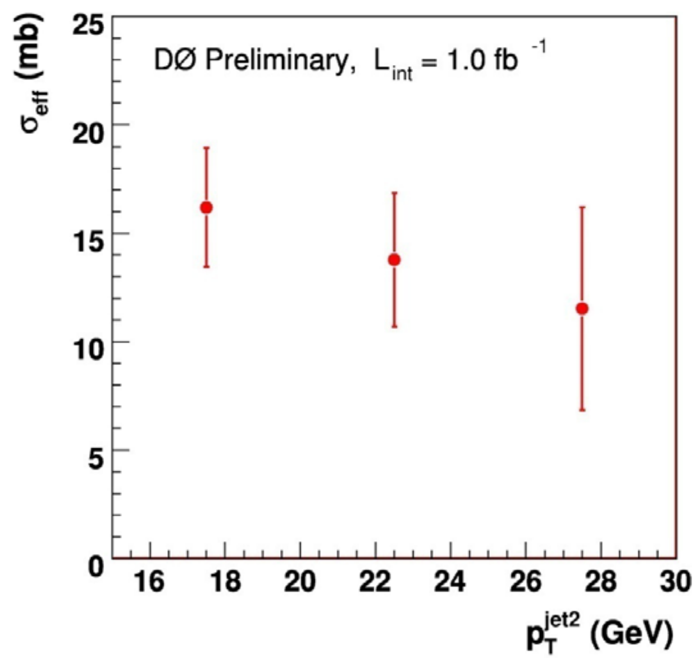
$$S_{p_T} = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{|\vec{p}_T(\gamma,i)|}{\delta p_T(\gamma,i)}\right)^2 + \left(\frac{|\vec{p}_T(j,k)|}{\delta p_T(j,k)}\right)^2}$$

$$\Delta S = \Delta\phi(p_T^{\gamma,jet-i}, p_T^{jet-j,jet-k},)$$



D0 Note 5910

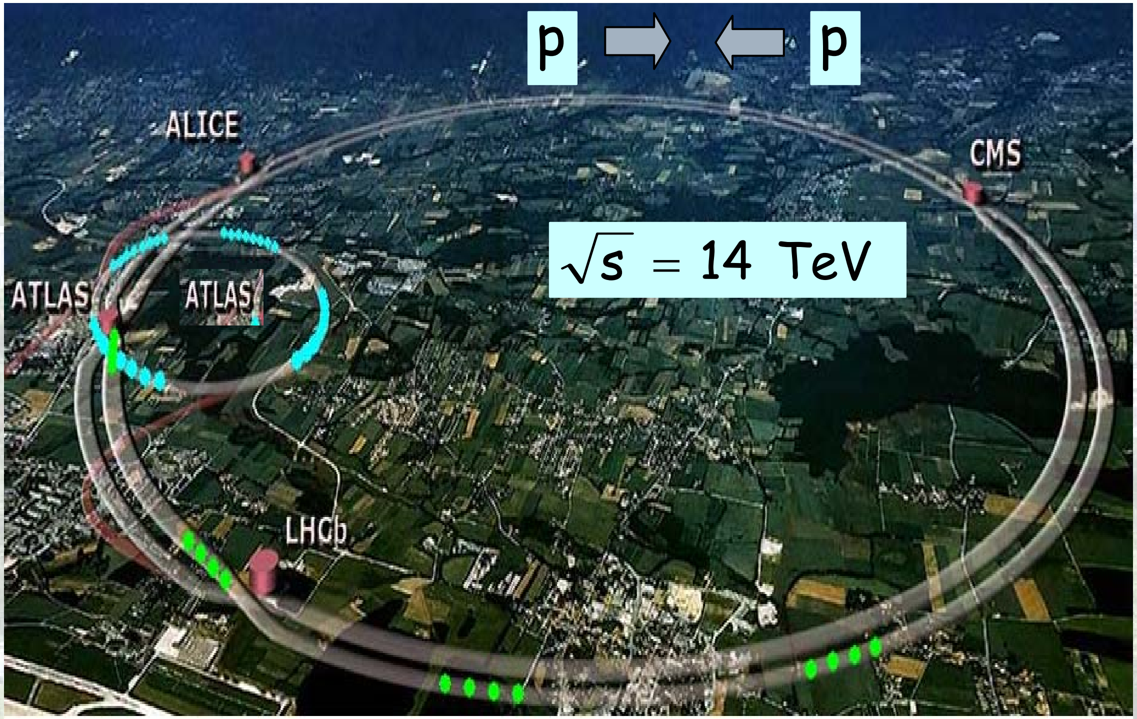




σ_{eff} = 15.1±1.9 mb

(consistent with previous CDF results.)

Early Results from LHC

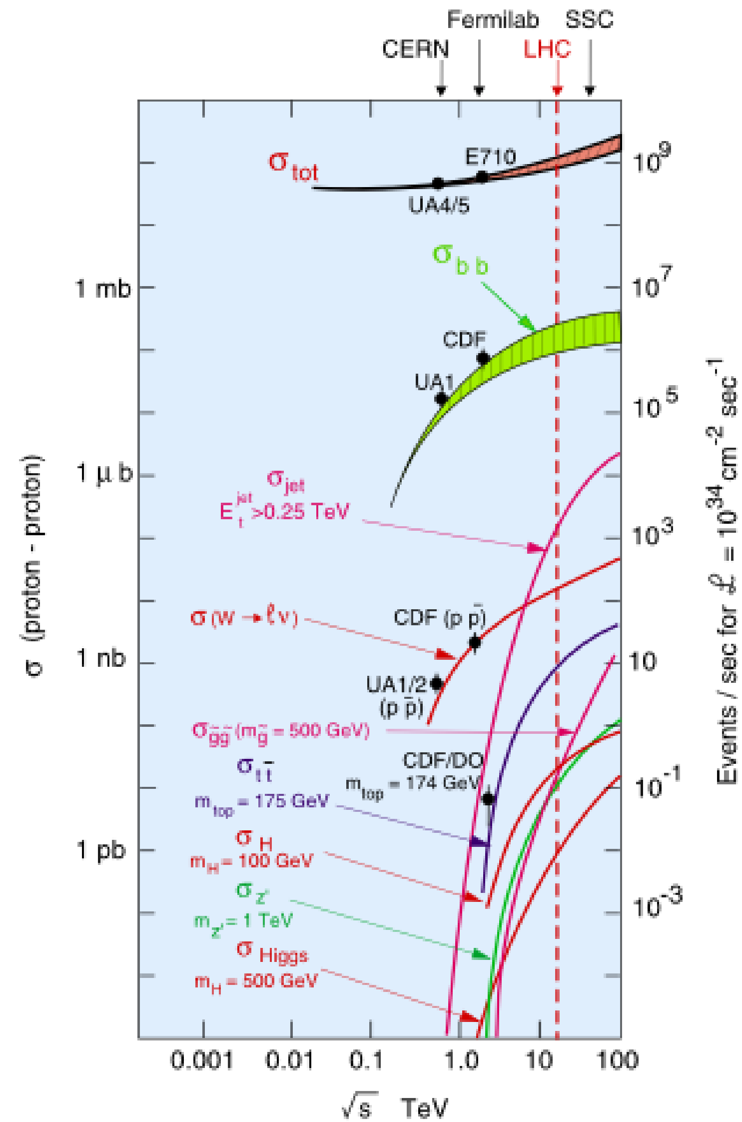


Jet and QCD Physics at the LHC

- Minimum Bias / Underlying Event Measurements
  - Scaling from lower energy experiments to LHC
  - Basis for high p_T physics program
- Jet Physics:

  Inclusive jets, dijet mass, dijet angle, jet structure, …
  - New physics beyond QCD?
  - Monte Carlo Tuning
  - Constraints on PDFs and α_s at unprecedentedly-high Q^2

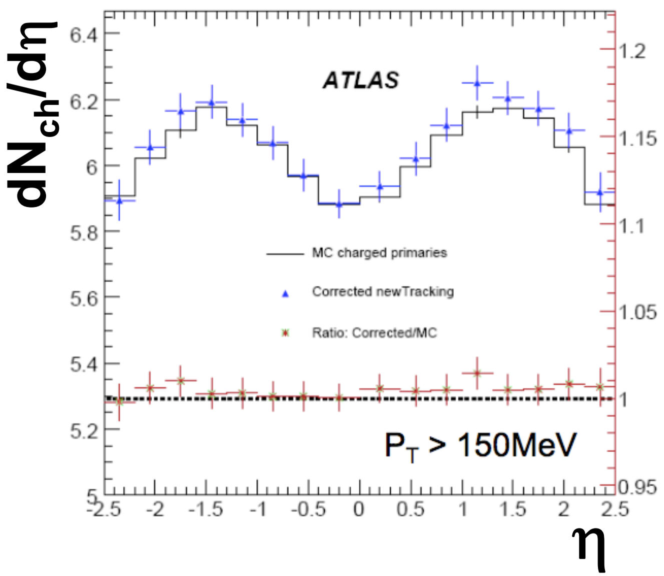
  Boson + Jets
  - Prerequisites for top/Higgs/SUSY/BSM
  - Monte Carlo Tuning

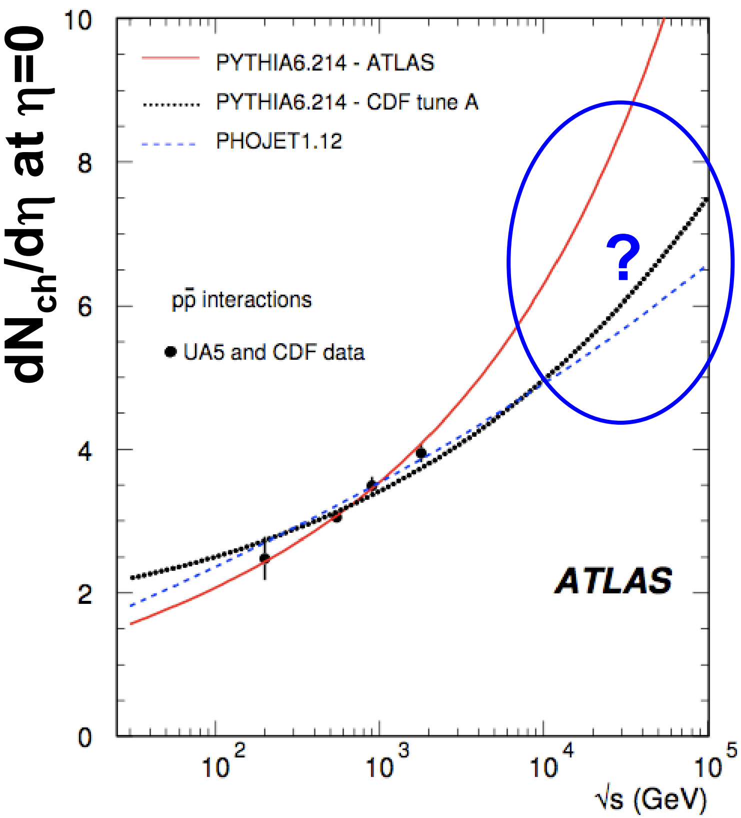


Measurement of Minimum Bias

- Minimum bias is major "background" to all physics processes
  - LHC will run at high luminosities. Pileups.
- One of the important first measurements to be made at LHC.

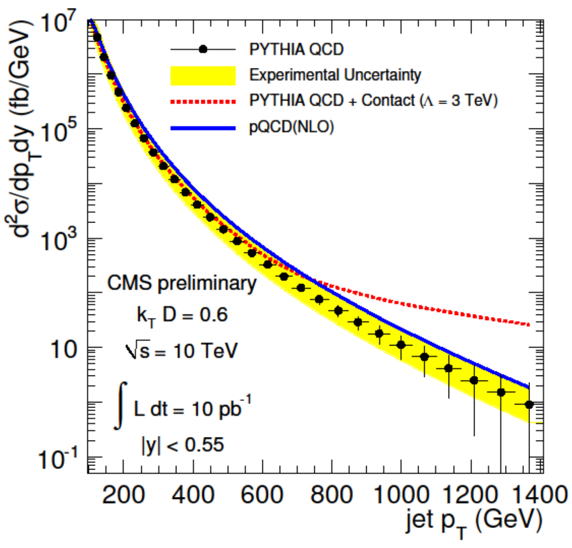
$$\sigma_{tot} = \sigma_{el} + \sigma_{sd} + \sigma_{dd} + \sigma_{nd}$$





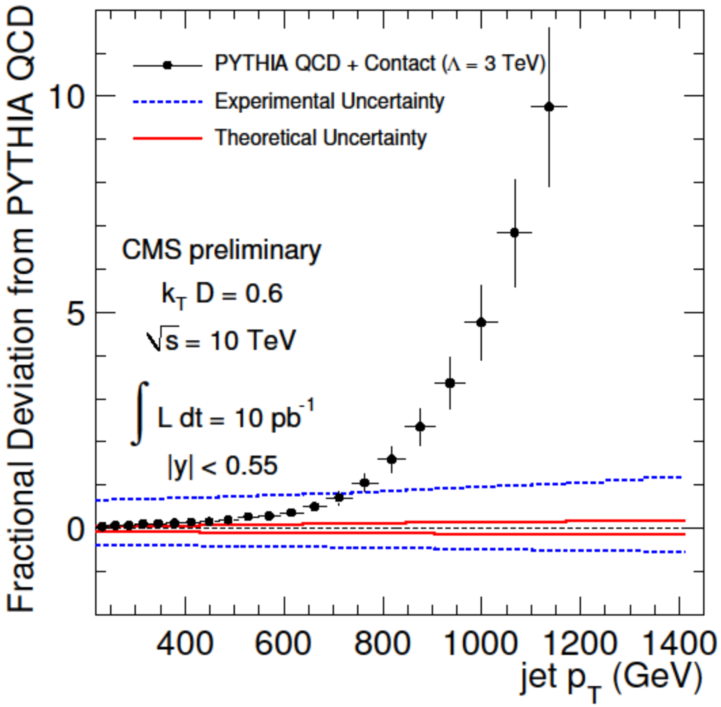
Inclusive Jets at the LHC

- Test perturbative QCD
- Sensitive to new physics in new energy regime (compositeness, new heavy particles, …)



- Assume 10% jet energy scale uncertainty on day 1 (factor ~2 in cross section)

CMS PAS QCD-08-001



- Can probe contact interactions beyond Tevatron reach.
- Constrain PDFs and extract α_s at high Q^2 later.

Summary & Remarks

Tremendous effort has been made to advance understanding of QCD with jets (+X, X= γ, W, Z) at HERA and Tevatron

- Determination of α_s and PDFs from jet x-section measurements
  - Precise α_s from HERA and Tevatron
  - Stringent constraints on gluons at high-x
- Photon-jets measurements challenge theorists
- Z/W+jet(s) measurements test pQCD, help MC modeling, set basis for Higgs/BSM searches
- Underlying event measurements important for MC tuning
- Much more to come - Tevatron expects 12 fb^{-1} by 2011

First results from LHC expected next year

- Rediscover QCD (commissioning detectors)
- Test QCD at unprecedented high Q^2
- Physics beyond QCD?

A "jet" in Geneva, Switzerland.

Acknowledgement

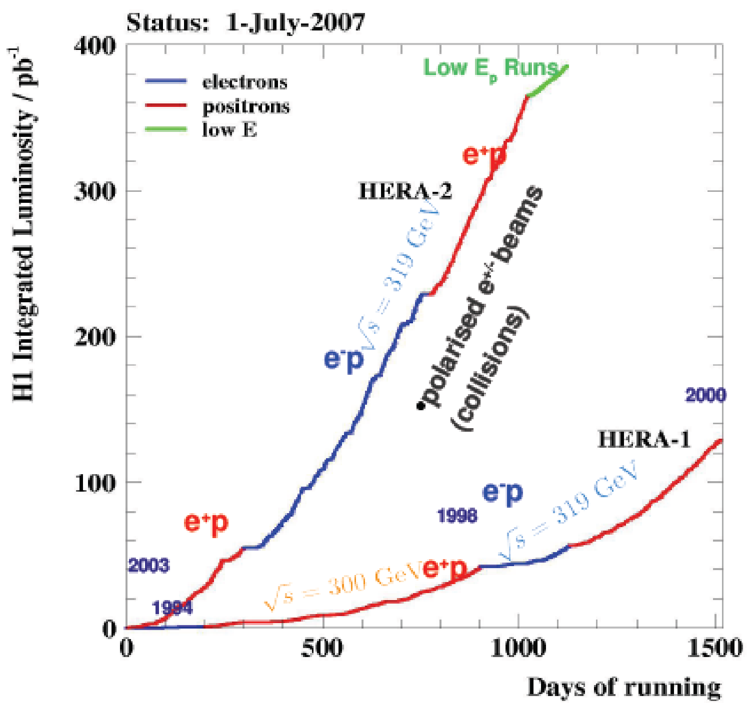
- Many thanks to:

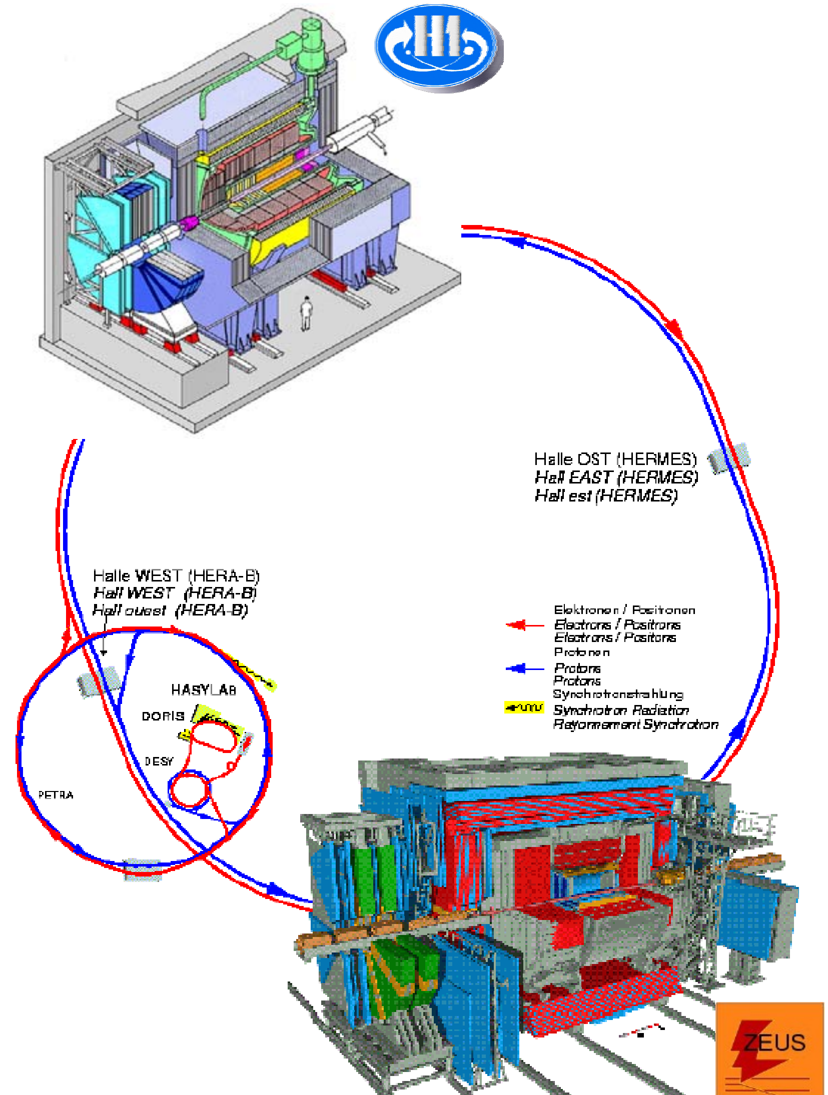
  S. Pronko, C. Mesropian, A. Bhatti, J. Dittmann, M. Wobisch, D. Lincoln, G. Hesketh, C. Glasman, G. Grindhammer, J. Ferrando, S. Tapprogge, …

Backup

HERA - ZEUS and H1

- HERA 1: 1992-2000, ~120 pb-1/expt
- HERA 2: 2003-2007
  - ~200 pb-1 e-p, ~300 pb-1 e+p
  - June 30, 2007: Last day of HERA after tremendous success

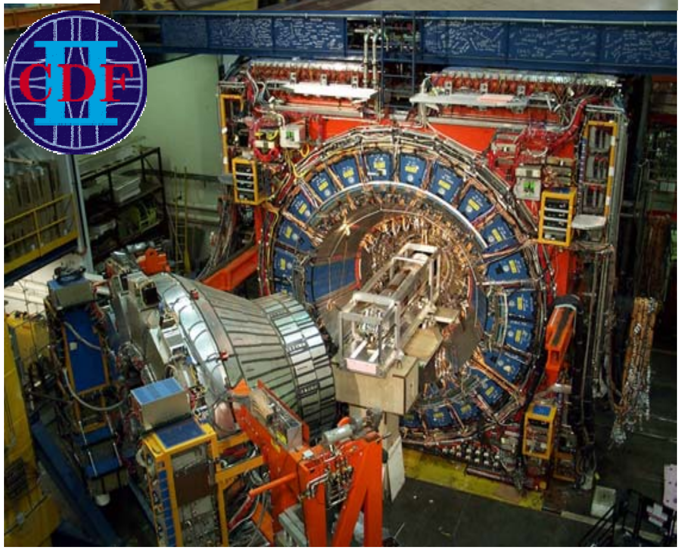




Tevatron in Run II, CDF and DØ

Tevatron:

- Proton-antiproton collider
- Run I (1992-1996)
  - $\sqrt{s}$ = 1.8 TeV, ~100 pb^{-1}
- Run II (2001-)
  - $\sqrt{s}$ = 1.96 TeV
  - 36 bunches: crossing time = 396 ns
  - Delivered luminosity ~6.8 fb-1
  - Current expectation: ~12 fb-1 by 2011

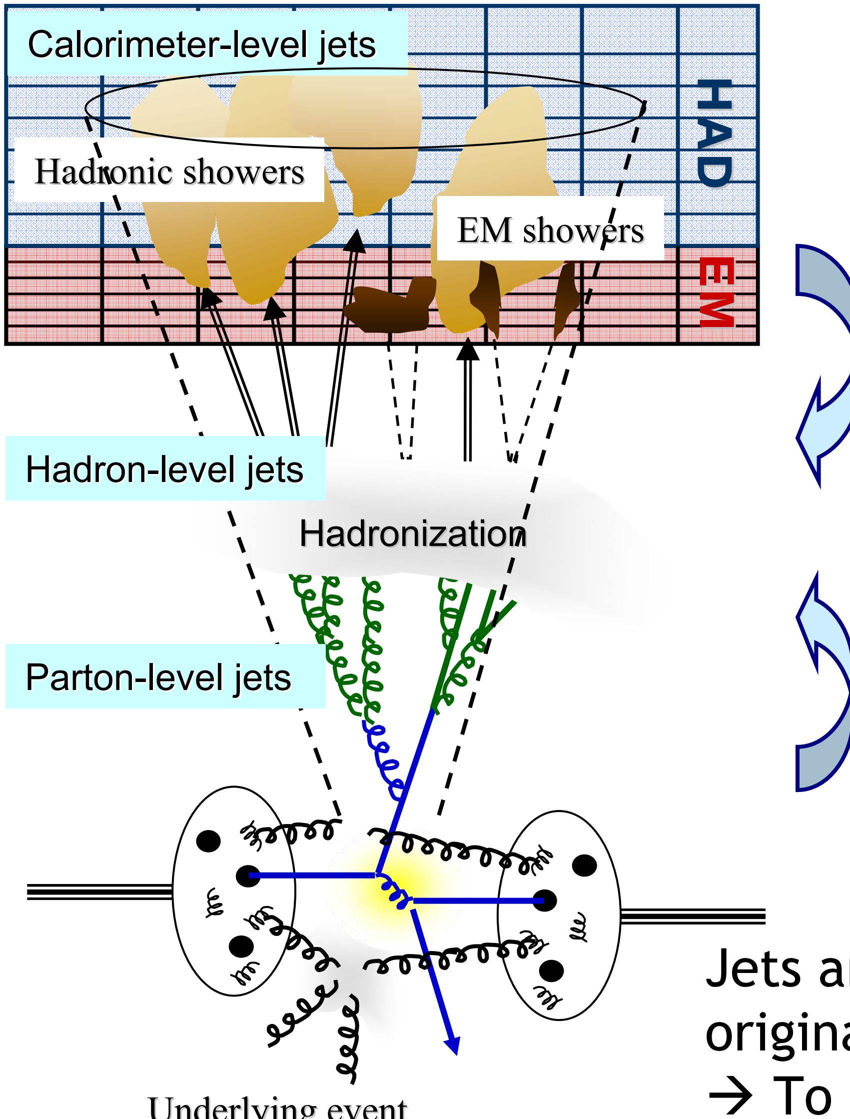


CDF and DØ:

Two general-purpose detectors:

- Silicon microvertex detector
- Solenoid magnet
- Calorimeters
- Muon chambers
- …

Jet Production and Measuremnt



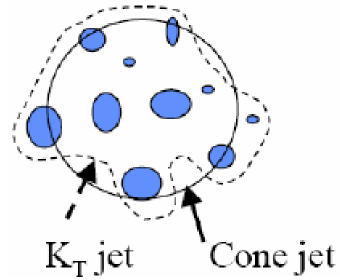
Unfold measurements to the hadron (particle) level

Correct parton-level theory for non-perturbative effects (hadronization & underlying event)

Jets are collimated spray of particles originating from parton fragmentation.
→ To be defined by an algorithm

Jet Algorithms

Two main categories of jet algorithms



- Cone Algorithms
  - E.g. Midpoint Algo.: Extensive use at Tevatron in Run II (as suggested in Run II workshop in 1999, **hep-ex/0005012**)
  - Cluster objects based on their proximity in y(η)-ϕ space
  - Identify "stable" cones (kinematic direction = geometric center)
  - Pros: simpler for underlying-event and pileup corrections
    Cons: infrared-unsafe in high order pQCD & overlapping stable cones.
- Successive Combination Algorithms
  - E.g. Kt Algorithm: Extensive use at HERA. A few Tevatron analyses.
  - Cluster objects based on a certain metric. Relative Kt for Kt algorithm.
  - Pros: Infrared-safe in all order of perturbative QCD calculations.
    Cons: Jet geometry can be complicated. Complex corrections.

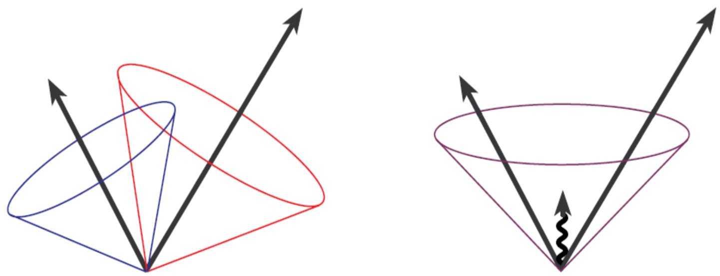
A lot of developments in recent years.

- SISCone, Cambridge-Aachen, Anti-Kt, etc.
- Extensively studied in LHC experiments. Will benefit future studies.

Jet "Definitions" - Jet Algorithms

Midpoint cone-based algorithm

Infrared unsafety:
soft parton emission changes jet clustering



- Cluster objects based on their proximity in y-ϕ space
- Starting from seeds (calorimeter towers/particles above threshold), find stable cones (kinematic centroid = geometric center).
- Seeds necessary for speed, however source of infrared unsafety.
- In recent QCD studies, we use "Midpoint" algorithm, i.e. look for stable cones from middle points between two adjacent cones
- Stable cones sometime overlap
  → merge cones when p_T overlap > 75%

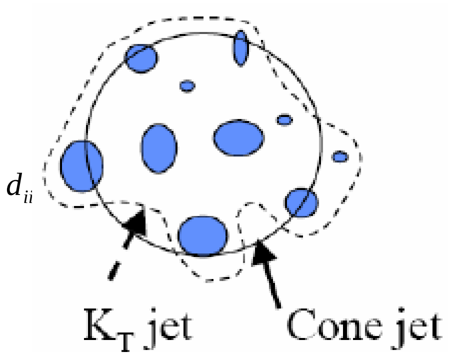
More advanced algorithm(s) available now, but negligible effects on this measurement.

Jet "Definitions" – Jet Algorithms

k_T algorithm

- Cluster objects in order of increasing their relative transverse momentum (k_T)
  - $$d_{ii} = p_{T,i}^2, \quad d_{ij} = \min(p_{T,i}^2, p_{T,j}^2)\, \frac{\Delta R^2}{D^2}$$

  until all objects become part of jets
- D parameter controls merging termination and characterizes size of resulting jets



- No issue of splitting/merging. Infrared and collinear safe to all orders of QCD.
- Every object assigned to a jet: concerns about vacuuming up too many particles.
- Successful at LEP & HERA, but relatively new at the hadron colliders
  - More difficult environment (underlying event, multiple $p\bar{p}$ interactions…)

Inclusive & Multi-jets in High-Q^2 NC DIS

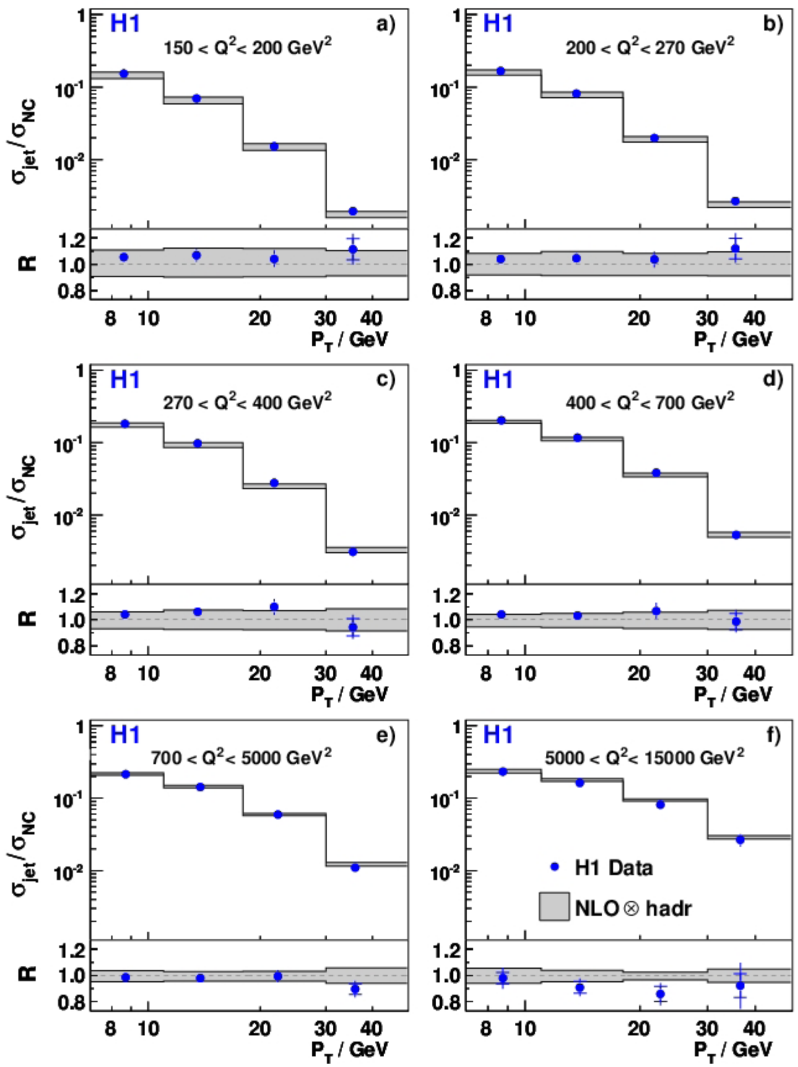
- $150 < Q^2 < 15000$ GeV^2
- Inclusive jets, 2-jet, and 3-jet cross sections are measured

- α_s from inclusive, 2-jet, and 3-jet cross sections and combined

$$\alpha_s(M_Z) = 0.1168 \pm 0.0007(\text{exp.})\,{}^{+0.0046}_{-0.0030}(th.) \pm 0.0016(PDF)$$

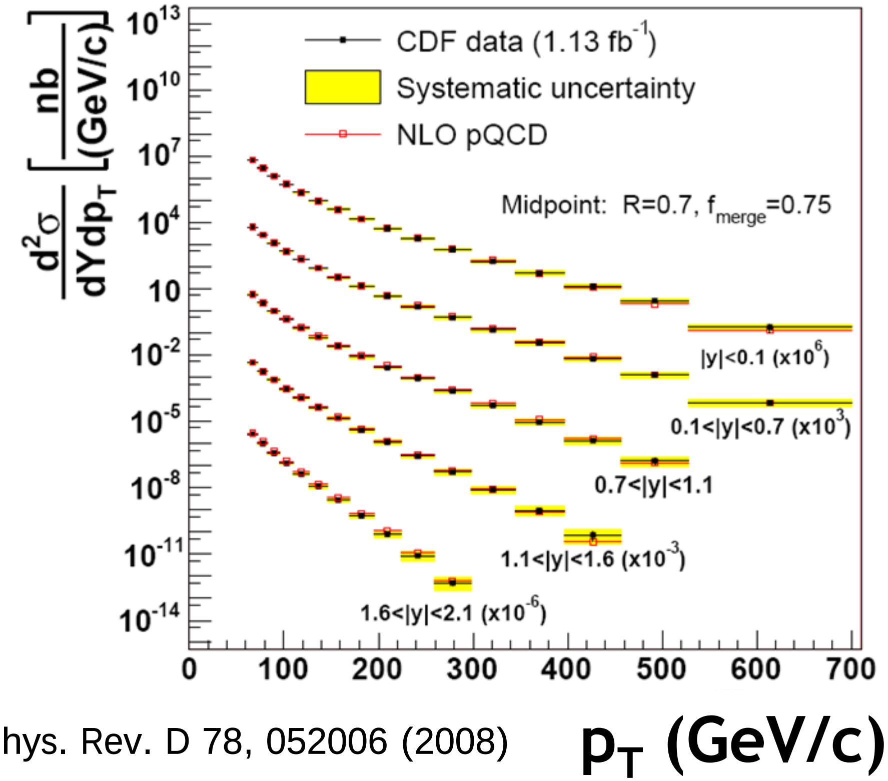
+4.2-3.0% uncertainty

Normalised Inclusive Jet Cross Section

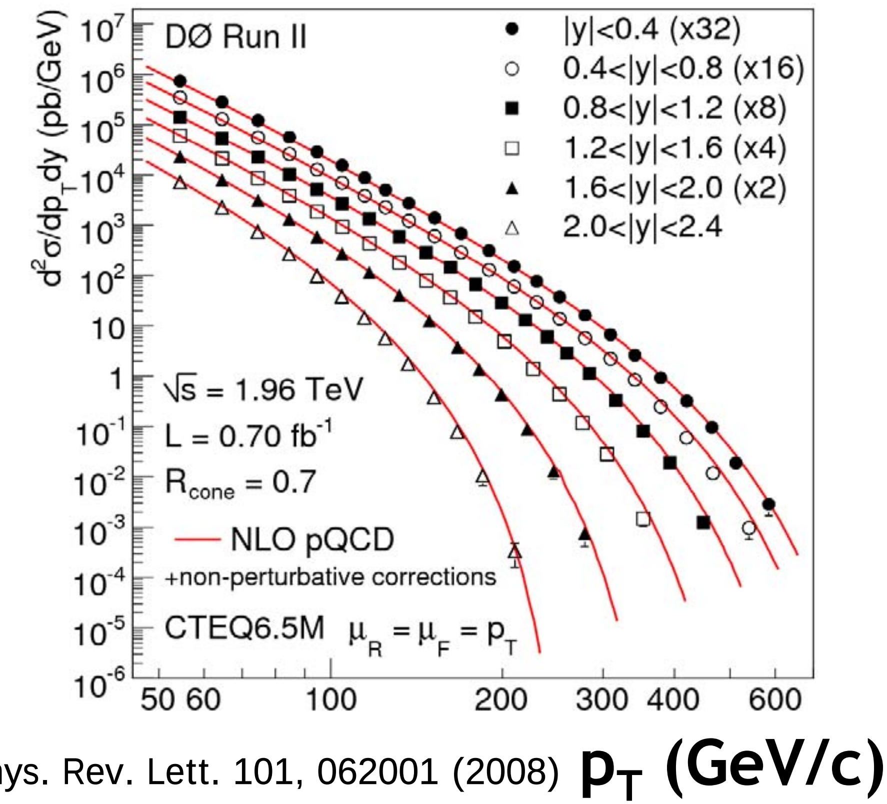


DESY 09-032

Inclusive Jet Cross Section



Phys. Rev. D 78, 052006 (2008)



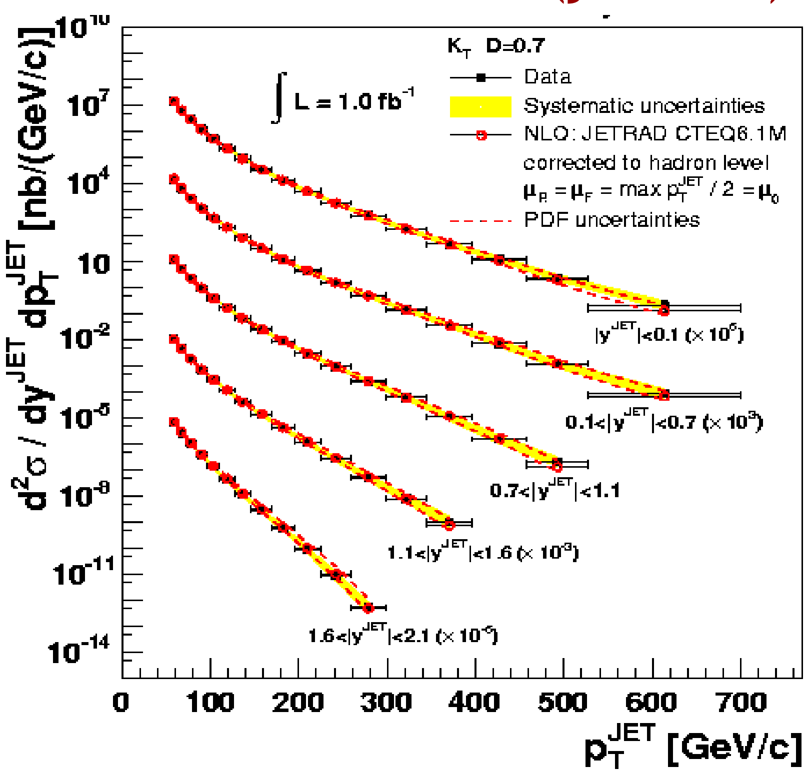
Phys. Rev. Lett. 101, 062001 (2008)

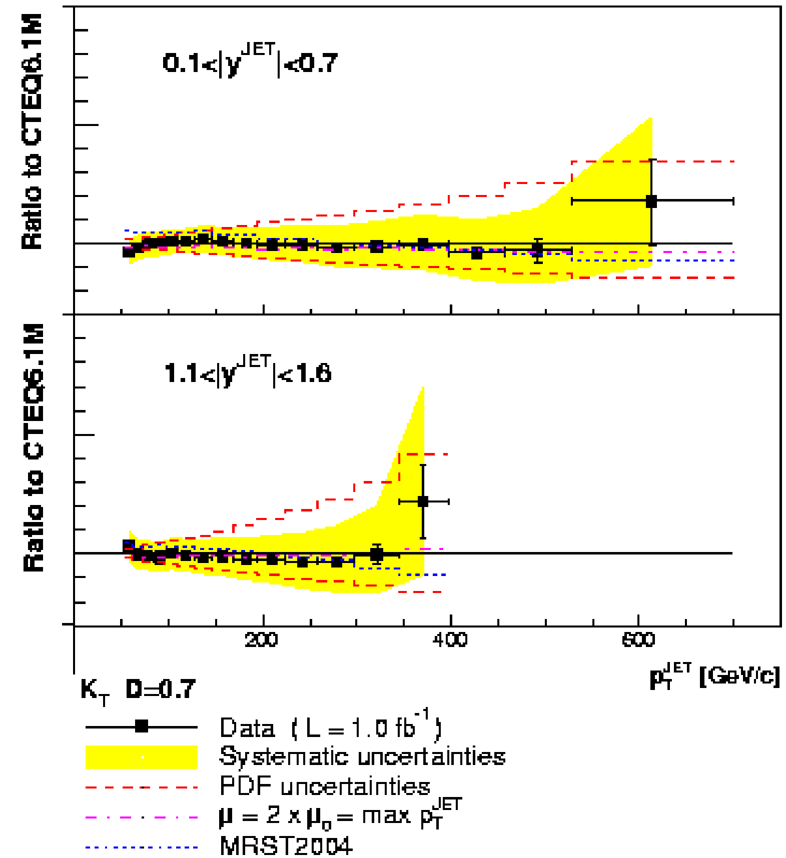
- Test pQCD over 8 order of magnitude in $d\sigma^2/dp_Tdy$
- Highest p_T^{jet} > 600 GeV/c
- Jet energy scale (JES) is dominant uncertainty: CDF (2-3%), D0 (1-2%)
- Spectrum steeply falling: 1% JES error → 5—10% (10—25%) central (forward) x-section

Inclusive Jets with Kt Algorithm

- Data/theory comparison consistent between measurements with cone and Kt algorithms and with different D values (jet sizes)

Phys. Rev. D 75, 092006 (2007)

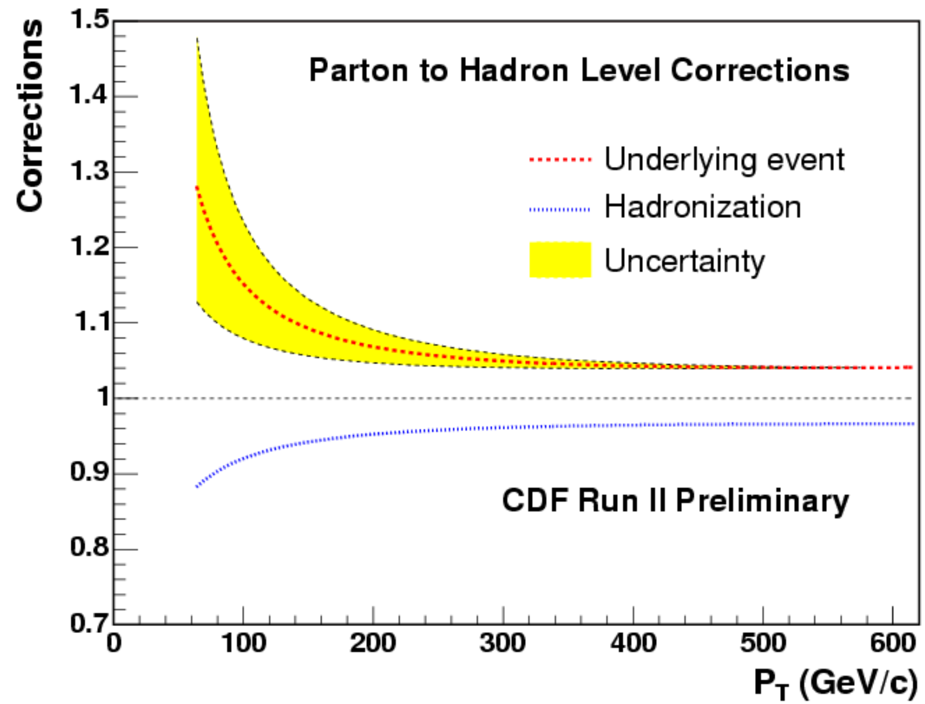




From Particle to Parton Level

use models to study effects
of non-perturbative processes
(PYTHIA, HERWIG)
- hadronization correction
- underlying event correction

CDF study for cone R=0.7
for central jet cross section

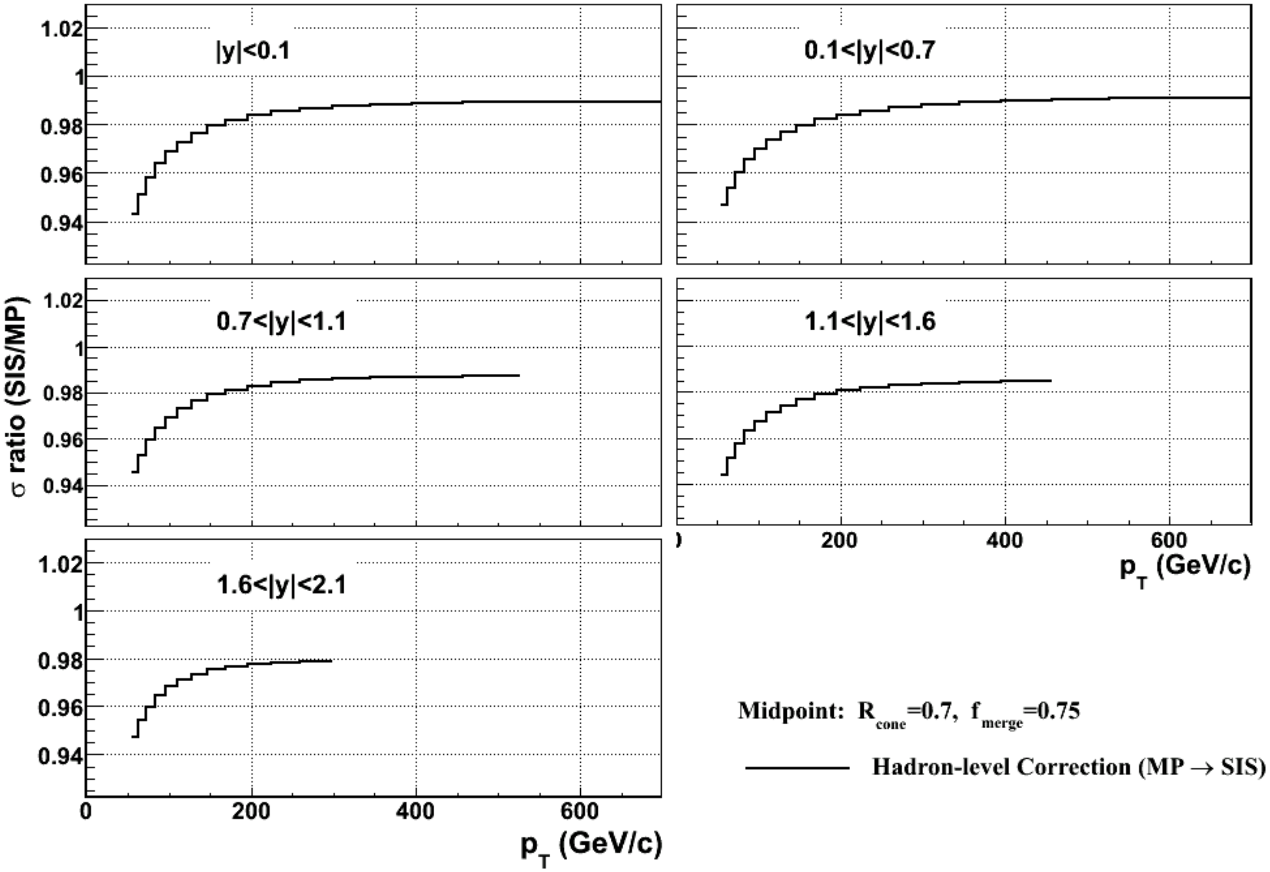


→ apply this correction to the pQCD calculation
→ to be used for future MSTW/CTEQ PDF results
→ first time consistent theoretical treatment of jet data in PDF fits

new in Run II !!!

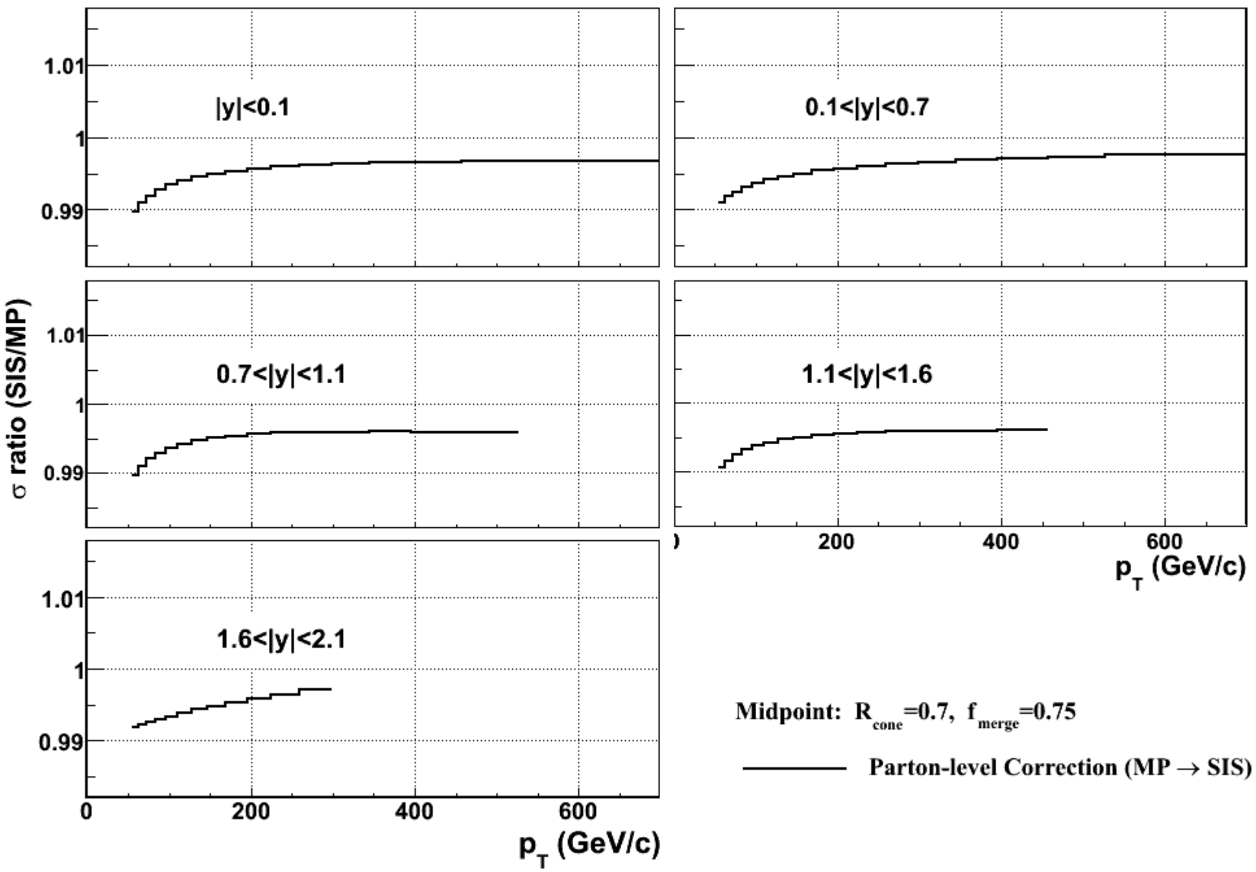
Midpoint vs SIScone: hadron level

- Differences between the currently-used Midpoint algorithm and the newly developed SIScone algorithm in MC at the hadron-level.



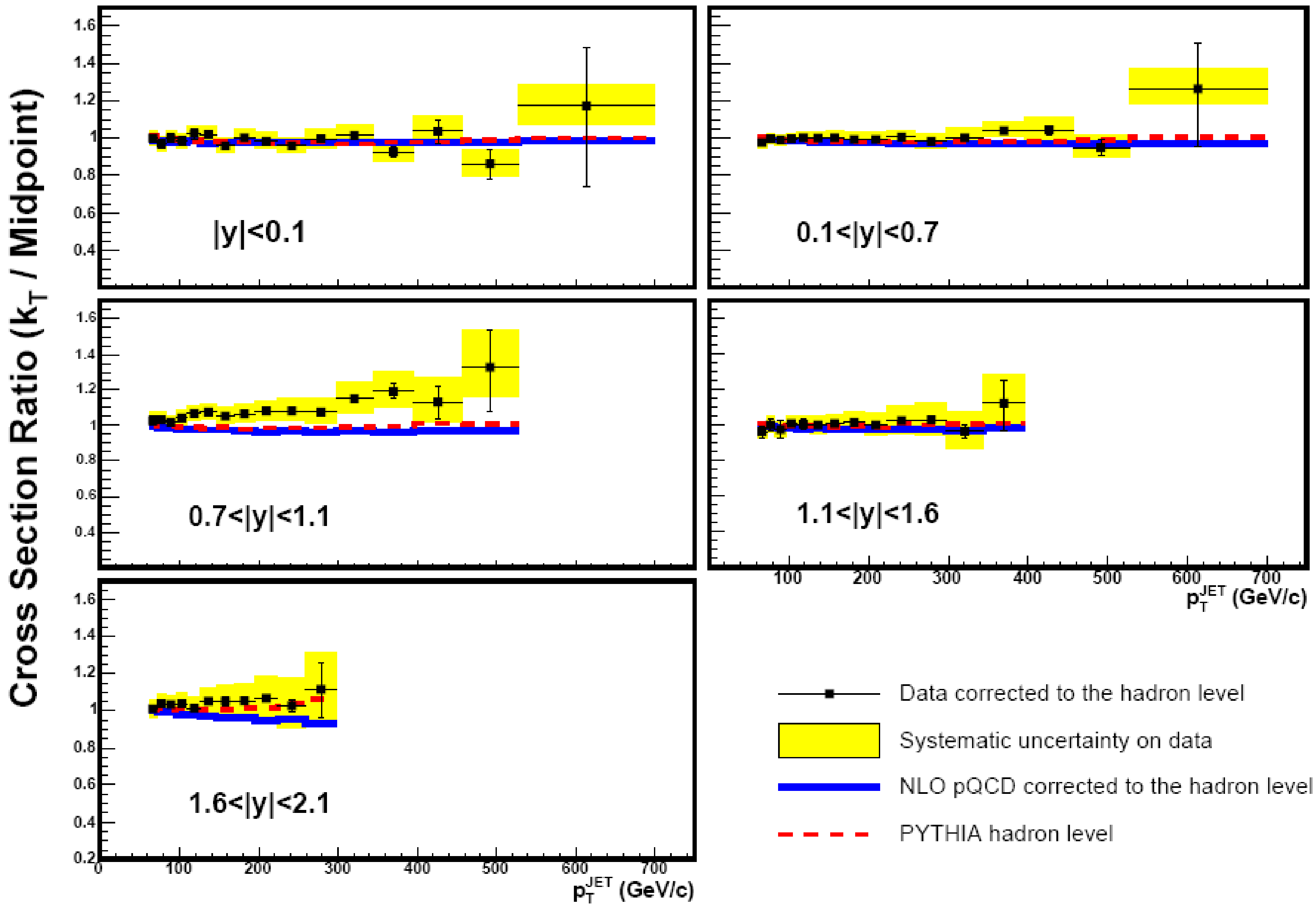
Midpoint vs SIScone: parton level

- Differences between the currently-used Midpoint algorithm and the newly developed SIScone algorithm at the parton-level.



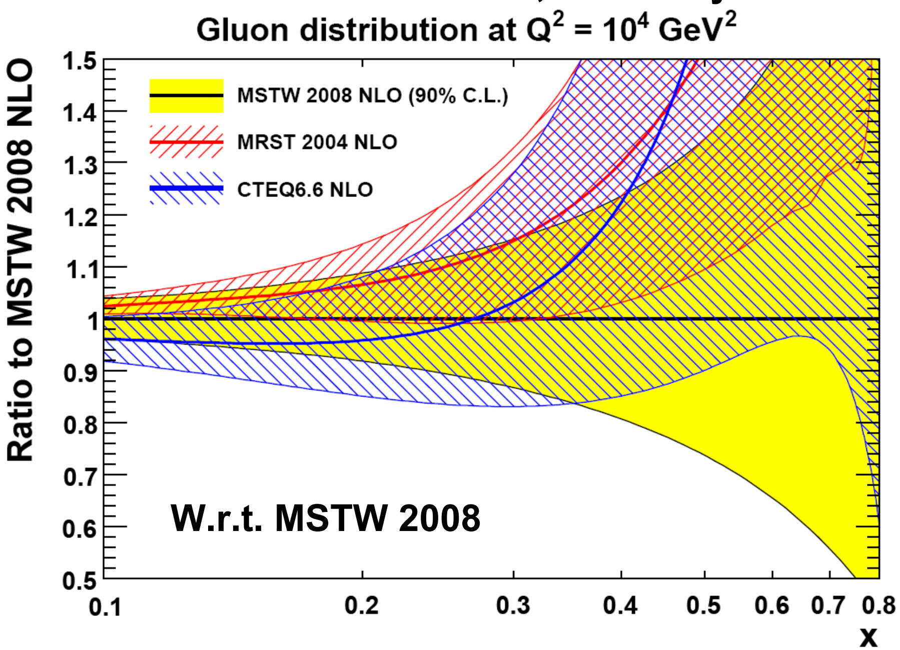
Differences < 1% → negligible effects on data-NLO comparisons

Inclusive Jets: Cone vs Kt Algorithms

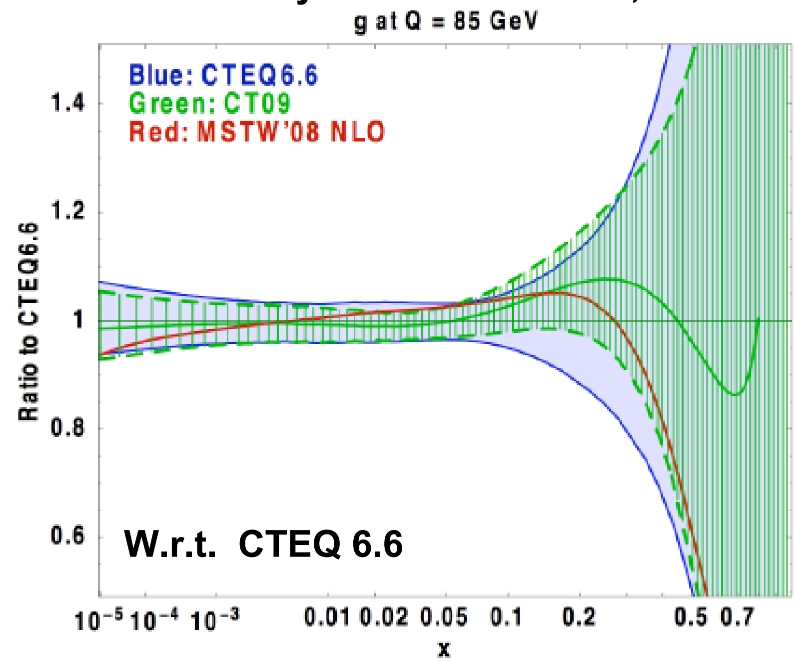


PDF with Recent Tevatron Jet Data

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



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

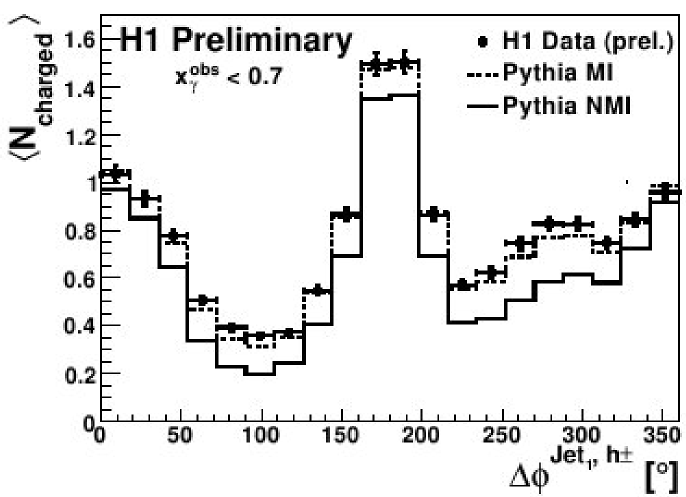


- Tevatron Run II data lead to softer high-x gluons (more consistent with DIS data) and help reducing uncertainties
- MSTW08 does not include Tevatron Run 1 data any longer while CT09 (CTEQ TEA group) still does, which makes MSTW08 high-x even softer (consistent within uncertainty)

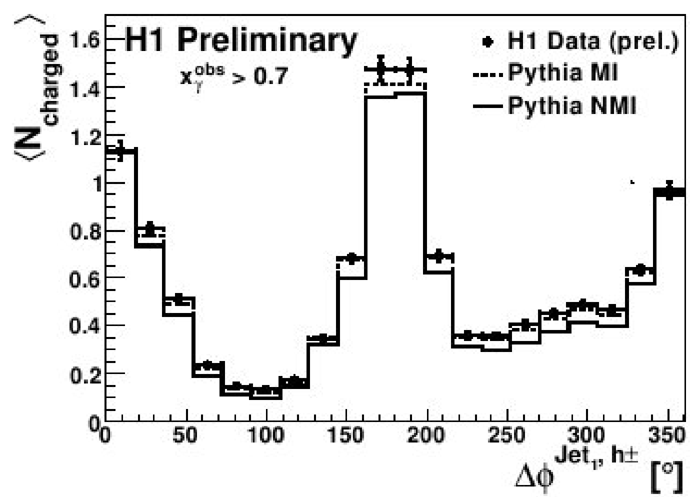
Underlying Event Study at HERA

- Dijet Photoproduction (PHP)
  - Photon either point-like ($x_\gamma \approx 1$) or hadronic (resolved γ, x_γ<1)
- Multi-parton interactions are expected for x_γ<1 but not for $x_\gamma \approx 1$

Resolved

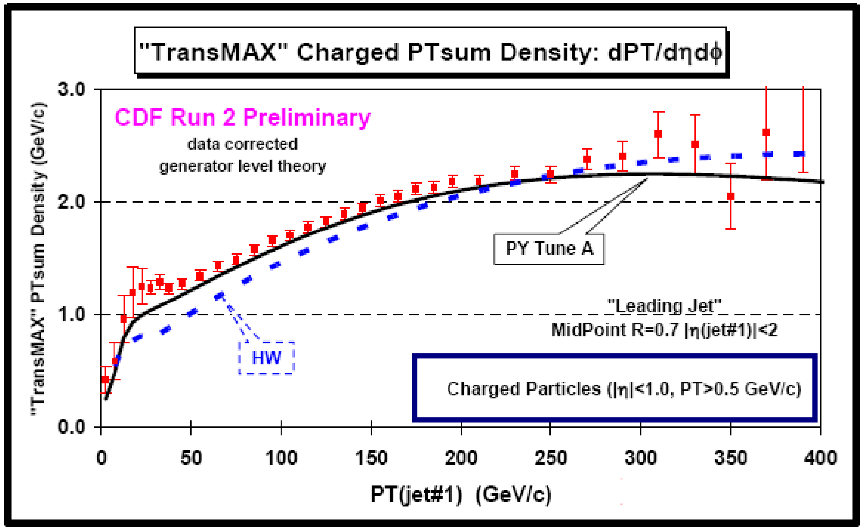


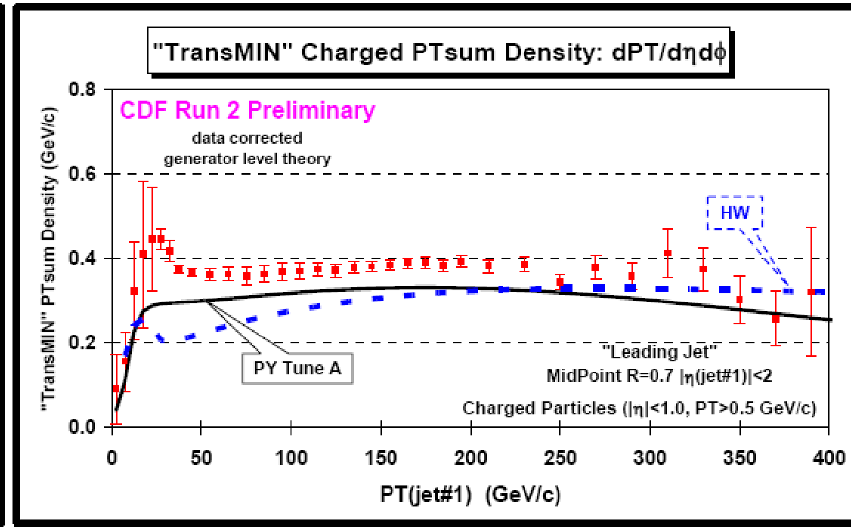
Direct



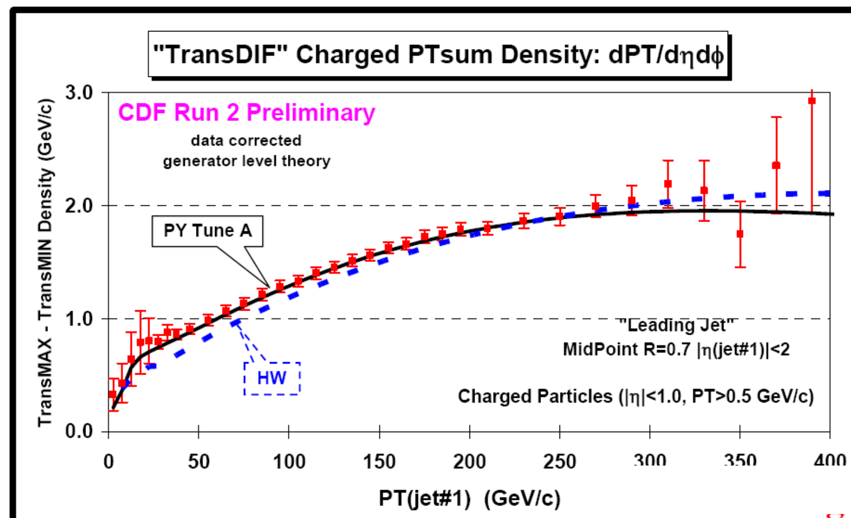
Strong Indication of Multiple Parton Interactions in PHP

Underlying Event in Jet Events

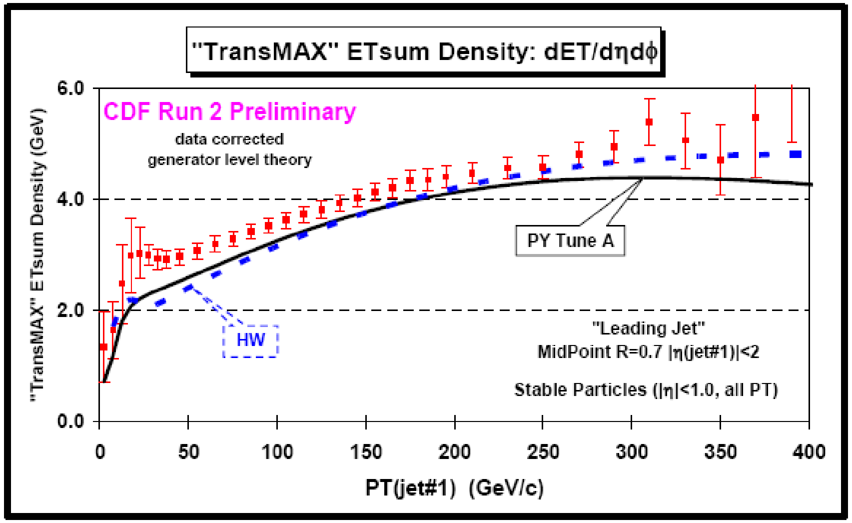


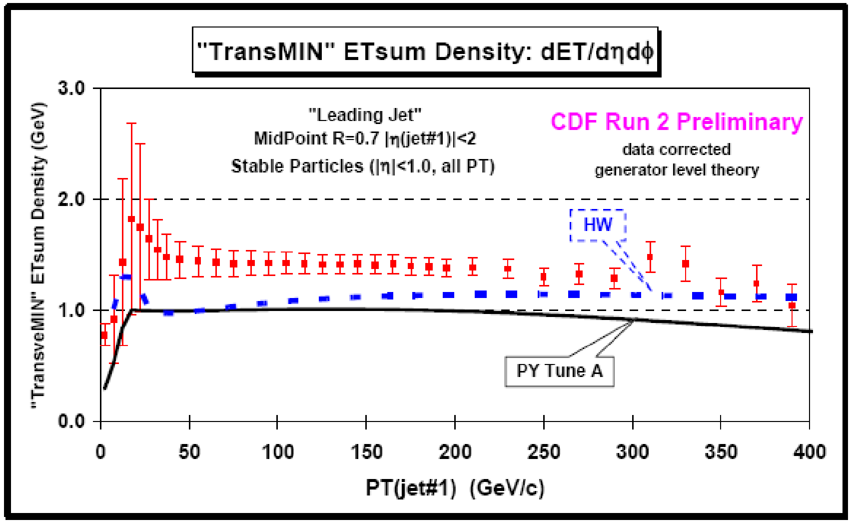


- Tuned PYTHIA (Tune A) doing reasonable job but not quite perfect
- TransDIF = TransMAX-TransMIN is sensitive to the semi-hard component of UE. Well described by Tuned PYTHIA (w/ multiple parton interactions)

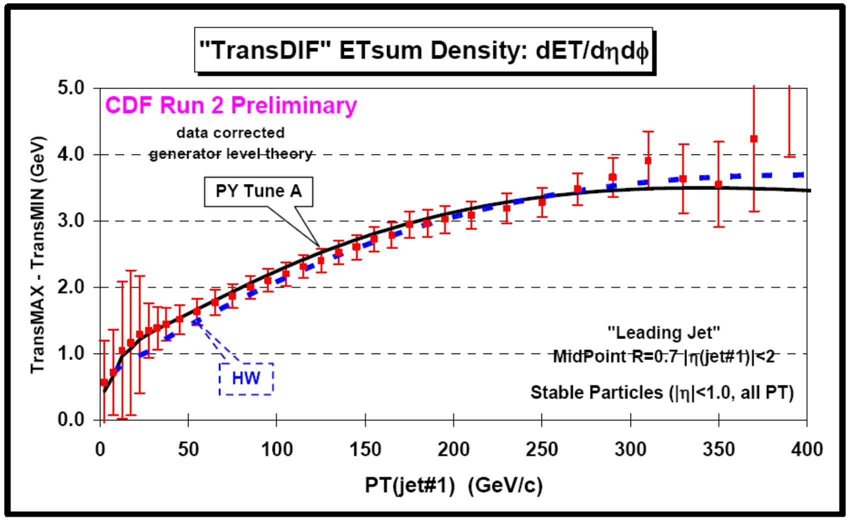


Underlying Event in Jet Events





- Now, looking at all particles including neutrals (instead of charged particles only with p_T>0.5 GeV/c)
- Similar trend observed



W + Single *c* Production

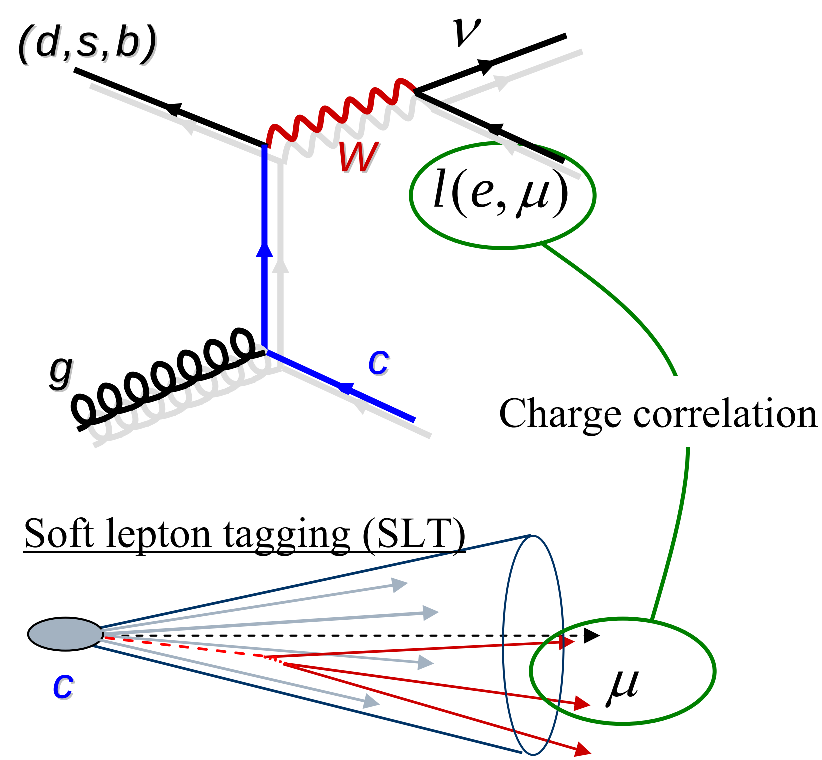
Motivation:

- Probe *s*-content of proton at high Q^2
  - *g*+*s* ~ 0.9, *g*+*d* ~ 0.1.
- Important BG for top quark studies, searches for Higgs, stop…

Strategy:

- W→ l+ν selected by high p_T *e*,*μ* + MET
- Charm-jet identified by the soft lepton (muon) tagging (SLT) algorithm.
- Utilize charge correlation between W lepton and SLT muon.
  - In W+c production, opposite sign (OS) > same sign (SS).
  - In W+bb(cc), same sign (SS) ~ OS.

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

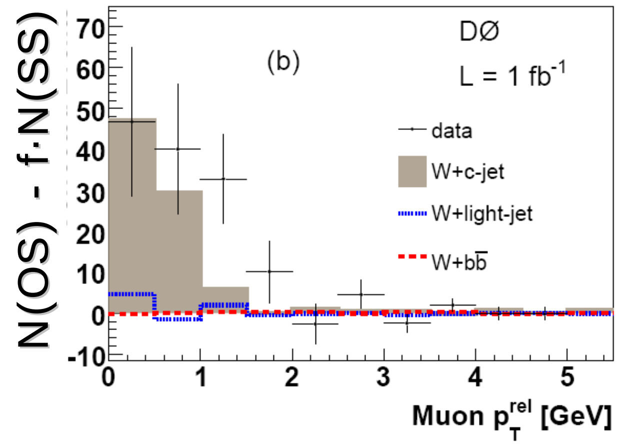


Main OS-SS backgrounds

- Fake W
- W+light jets
- Drell-Yan

W + Single c Production

- Measure the ratio $\sigma_{W+c}/\sigma_{W+jets}$. Many systematic uncertainties cancel.
- Measurement made as function of jet p_{T}.



- **Measurement** (p_T^{jet}>20 GeV/c, $|\eta_{jet}|$<2.5) :

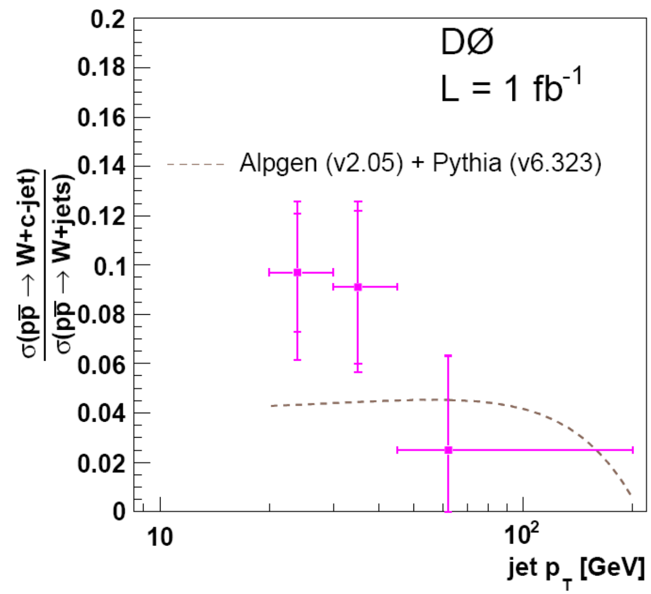
$$\frac{\sigma_{W+c}}{\sigma_{W+jets}} = 0.074 \pm 0.019(stat.)^{+0.012}_{-0.014}(syst.)$$

Alpgen+Pythia prediction:

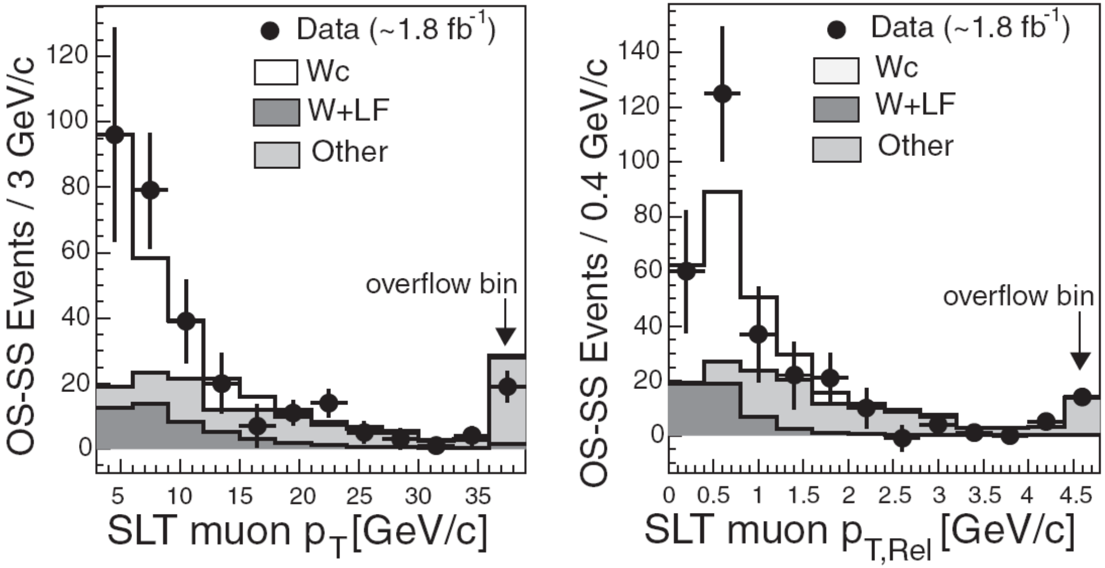
0.040 ± 0.003 (PDF)

In reasonable agreement

arXiv:0803.2259 [hep-ex]



W + Single *c* Production



Total: 298 events, W+c = 149 ± 42 ± 15 events.

Measurement (p_T^c>20 GeV , $|\eta_c|$<1.5) **:**

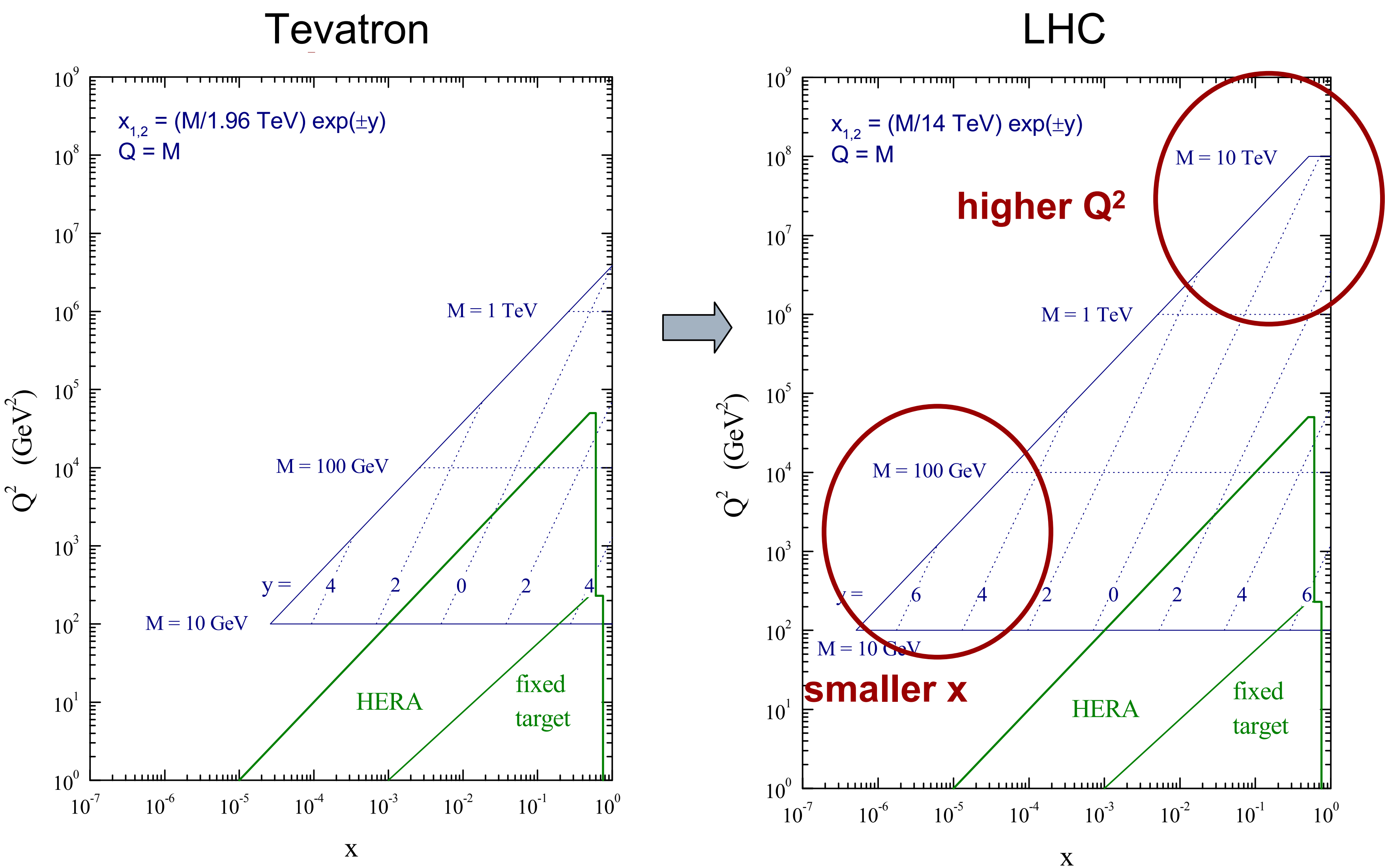
$\sigma_{W+c} \cdot BR(W \to l\nu)$ = 9.8 ± 2.8 (stat) $^{+1.4}_{-1.6}$ (syst) ± 0.6 (lum) pb

NLO pQCD prediction:
11.0 $^{+1.4}_{-3.0}$ pb

In good agreement

Phys. Rev. Lett. 100, 091803 (2008).

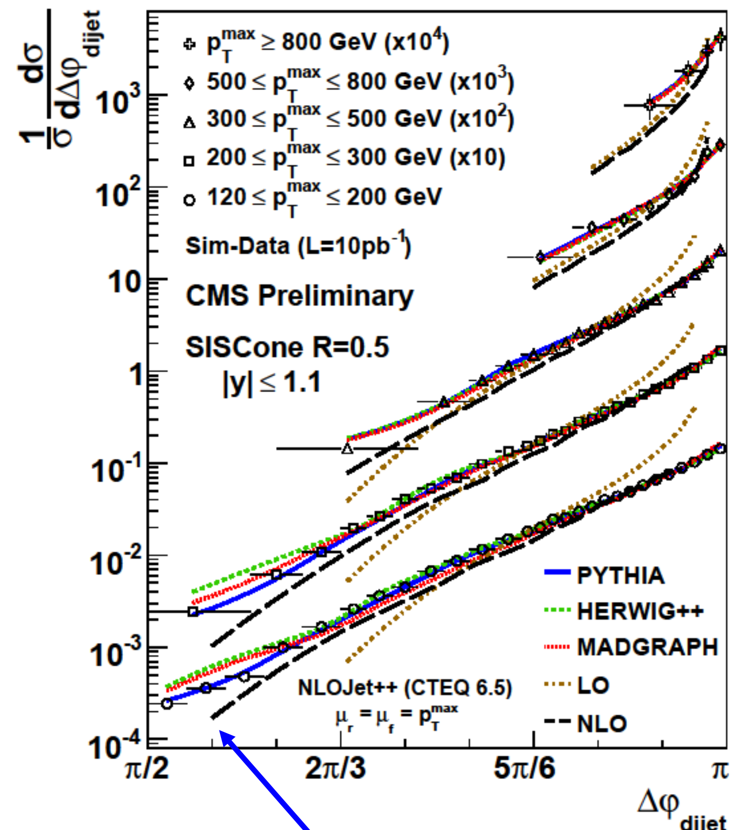
Tevatron → LHC Parton Kinematics

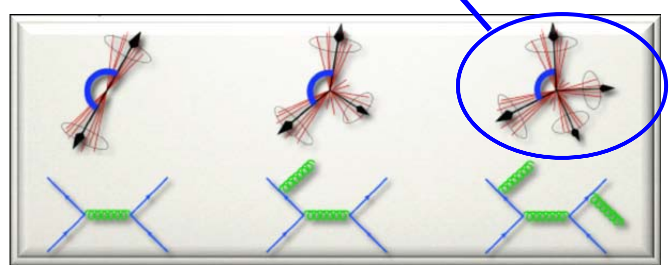


From J. Stirling (U. Durham)

Dijet Angular Distribution

- Azimuthal angle between the two leading jets
  - Sensitive to higher order radiation w/o explicitly measuring radiated jets
- Shape Analysis: $\frac{1}{\sigma_{dijet}} \frac{d\sigma}{d\Delta\varphi}$
  - Less sensitive to theoretical (hadronization, underlying event) and experimental (JEC, luminosity) uncertainties
- Useful for e.g. tuning MC parameters (ISR)





LO for $\Delta\phi$, NLO for $\Delta\phi$