Recent QCD Measurements at the Tevatron

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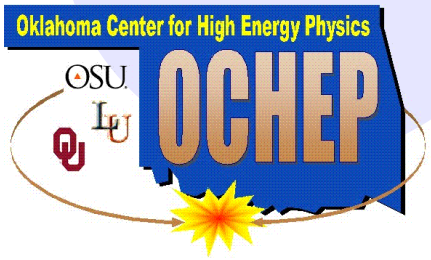
for the

CDF and DØ Collaborations

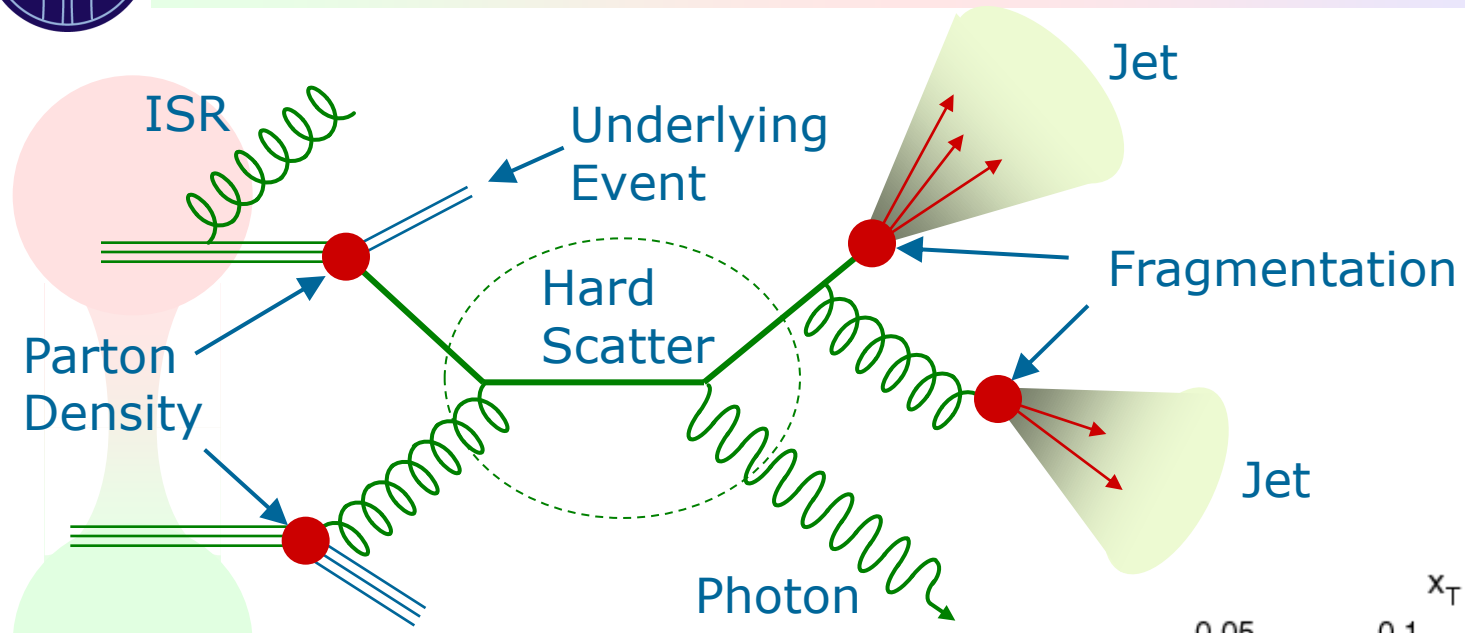


Rencontres de Blois 2010

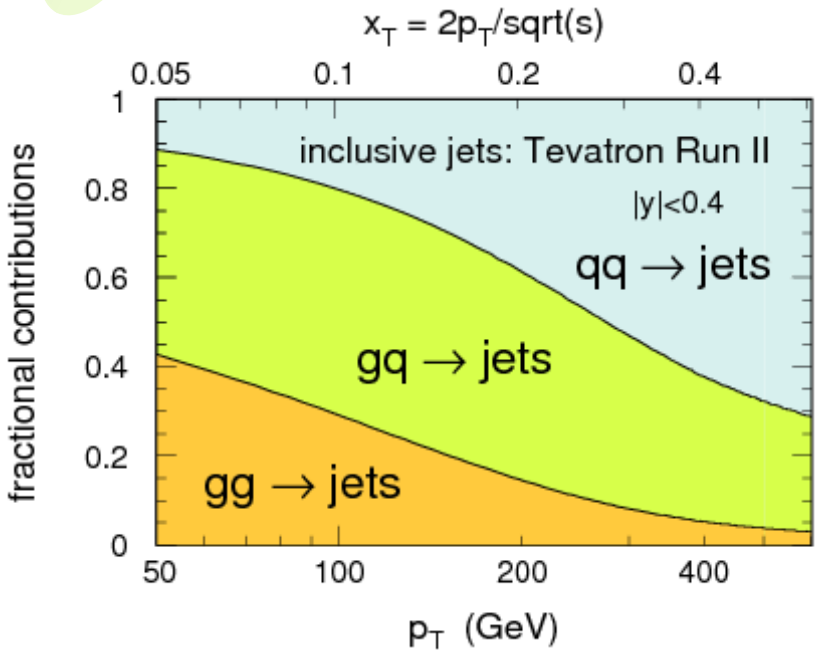
Preamble and Outline

- Preamble
  - Many very nice results
  - Apologies to those whose results aren't shown
  - Results shown are new or published within ~9 months
  - Minimize overlap with plenary QCD talk by Nikos Varelas
- Introduction: QCD physics
- Results
  - All Jet Final States
    - Dijet (DØ and CDF) and Trijet mass (DØ)
  - Photons and Photons plus Jets
    - Diphotons (CDF and DØ)
    - Double Parton (DØ)
  - Bosons plus Jets
    - Z plus jets angles and Z + b jets (CDF and DØ)
    - W plus b jets (CDF)

QCD Scattering Processes

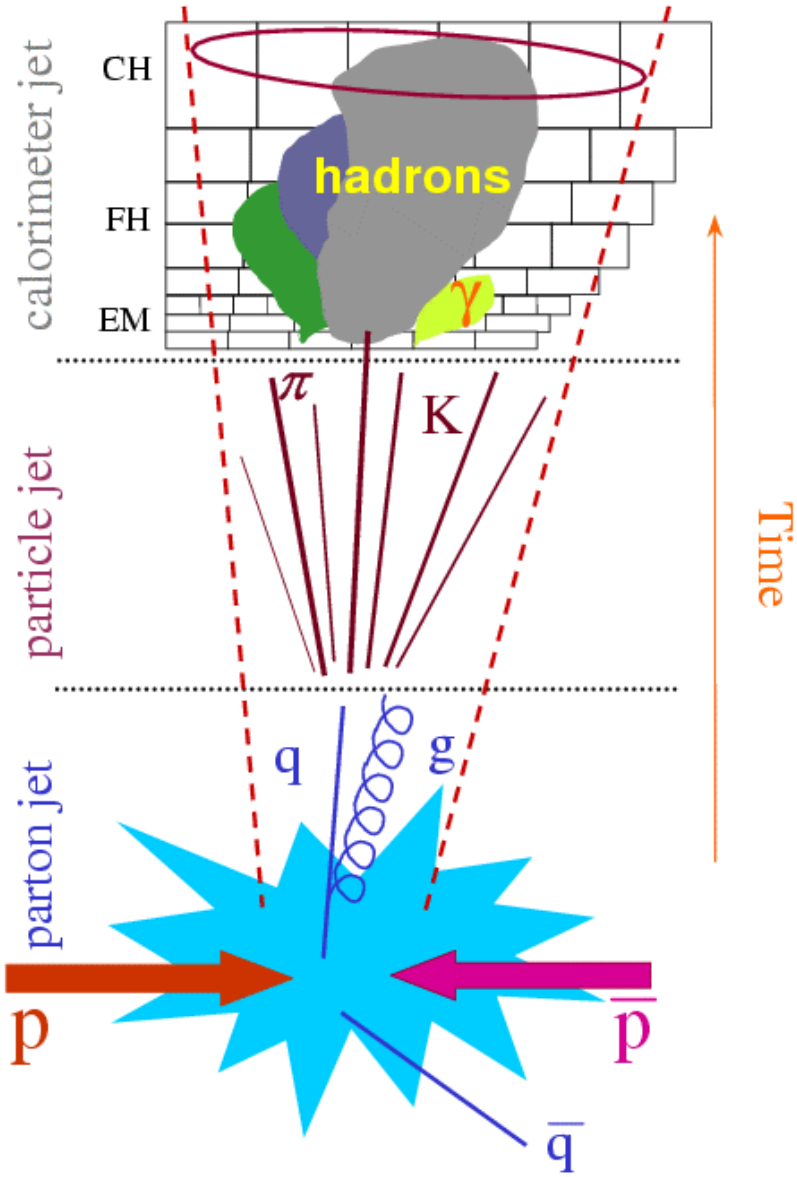


- Jets of particles originate from hard collisions between quarks and gluons
- Quark and gluon density described by Parton Distribution Functions (PDFs)
- Proton remnants form underlying event



Jets, Particles, and Partons

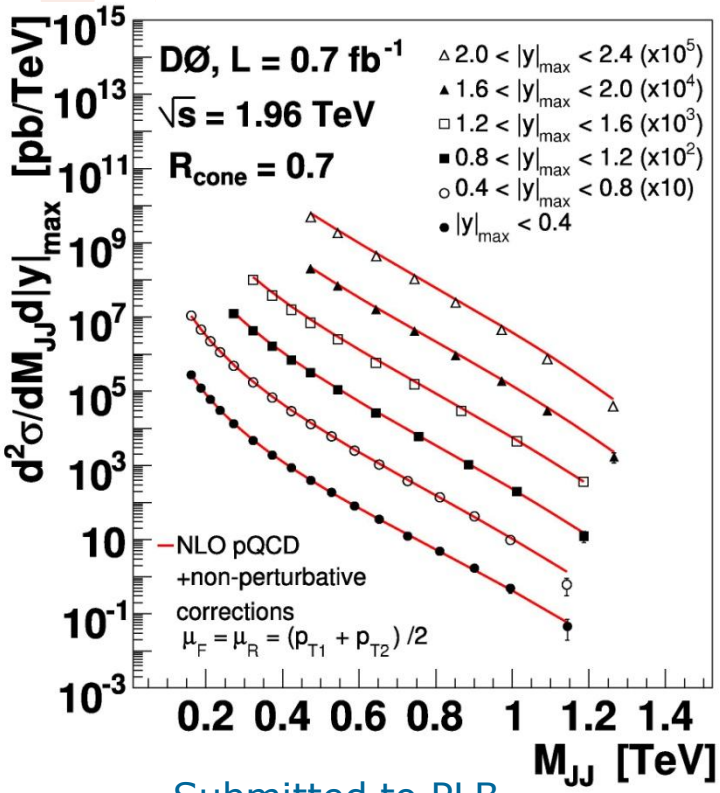
- We do not see partons or particles
- Calorimeter ADC counts are corrected to the particle level using the Jet Energy Scale (JES)
- Calibrate using *Z*+jets, *γ*+jets, dijets
- JES can include
  - Energy Offset (energy not from the hard scattering process)
  - Detector Response
  - Out-of-Cone showering
  - Resolution
- Energy scale uncertainties typically are the largest systematic errors in jet measurements.
- Correction to parton level requires fragmentation model



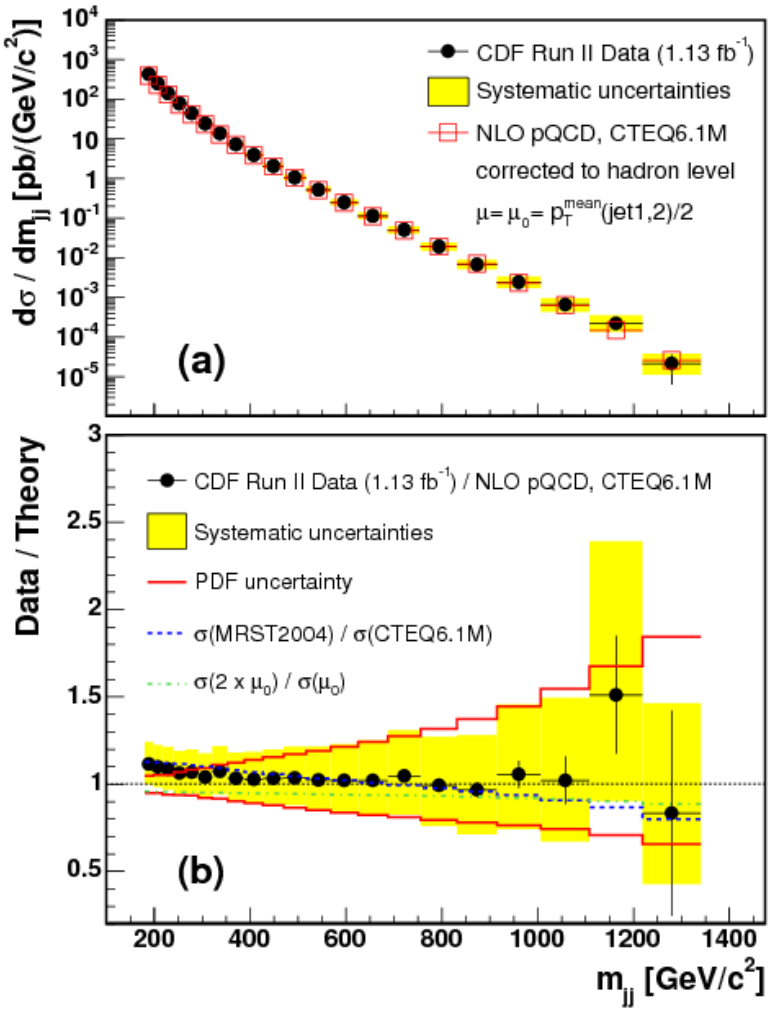
All Jet Final States

Dijet Mass Cross Section

- $E_{jet} = \Sigma E_i$, $\mathbf{p}_{jet} = \Sigma \mathbf{p}_i$
- $M_{jj}^2 = (E_{j1}+E_{j2})^2 - (\mathbf{p}_{j1}+\mathbf{p}_{j2})^2$
- Sensitive to heavy particle resonances and PDFs



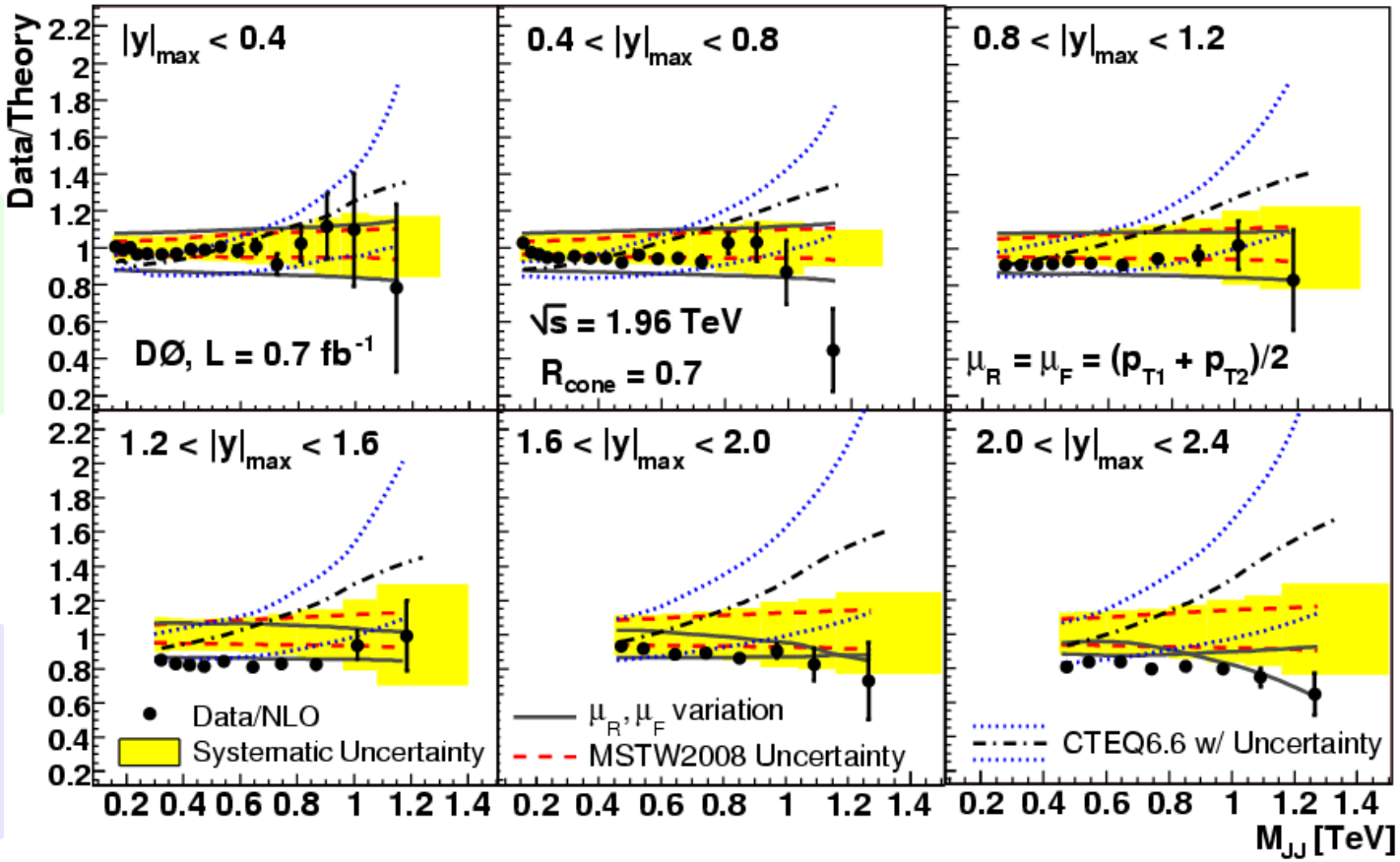
Submitted to PLB



PRD 79, 112002 (2009)

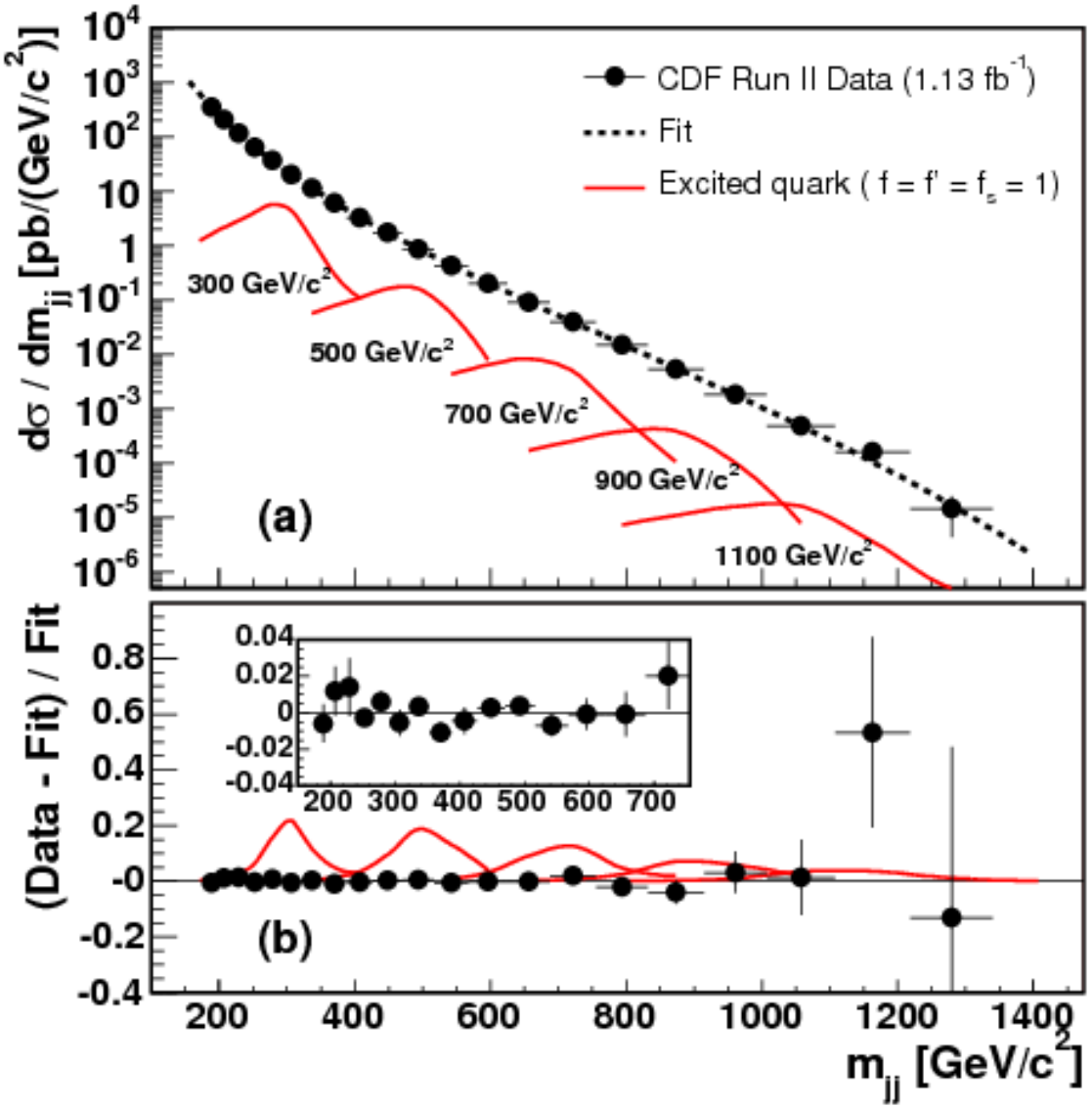
DØ Dijet Data/Theory

Data agrees with MSTW2008 and CTEQ 6.6 within pdf and scale uncertainties, though closer to MSTW central value



Dijet Resonance Search

- Select jets with $|\eta|<1.0$
- Use midpoint cone algorithm with $R=0.7$
- Select M_{jj} > 180 GeV
  - M_{jj} up to 1.3 TeV!
- Fit spectrum with parameterized model shape
  - Described by NLO pQCD
  - No indications for resonances
  - Set limits using Bayesian approach

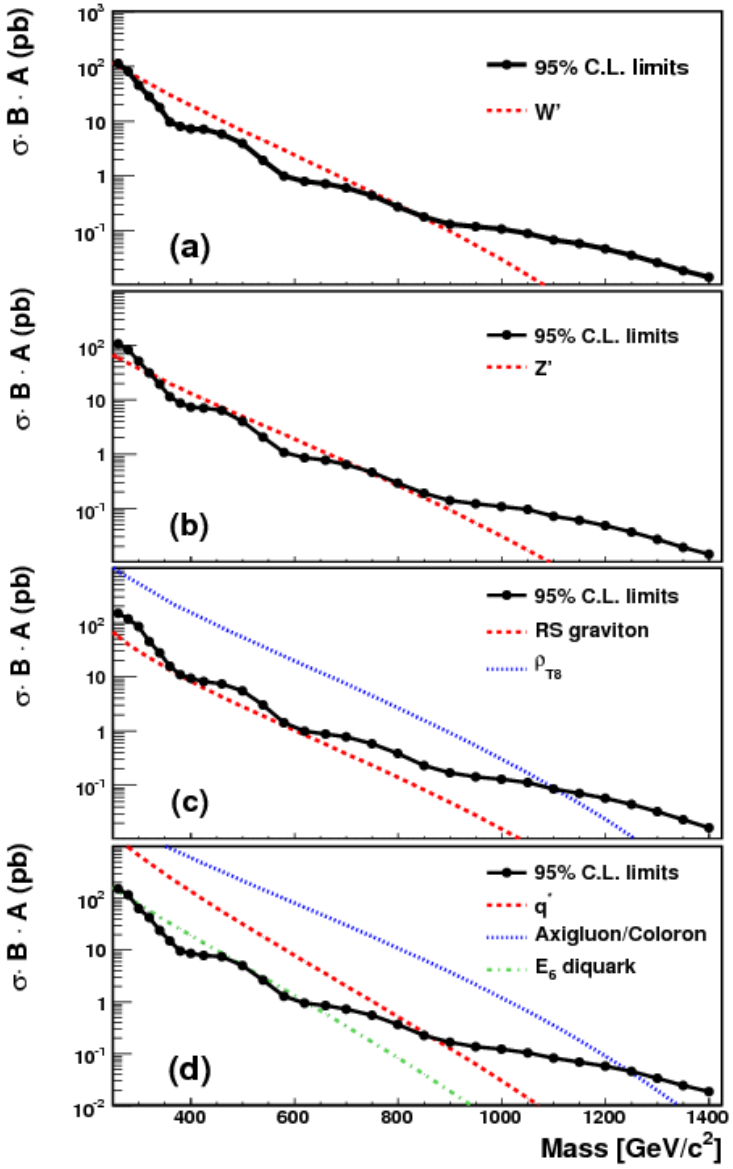


Limits from CDF Dijet Mass

Exclusion (GeV)	Model
280–840	*W′* (SM couplings)
320–740	*Z′* (SM coupling)
260–870	Excited quark (SM couplings)
260–1100	Color-octet techni-rho
260–1250	Axigluon & flavor-universal color
290–630	E_6 diquark

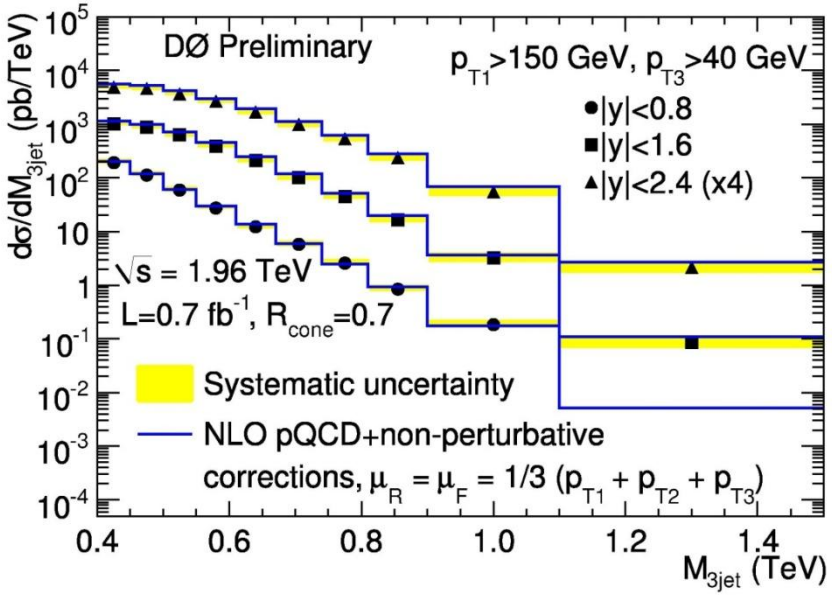
Most Stringent limits except for *W′* and *Z′*

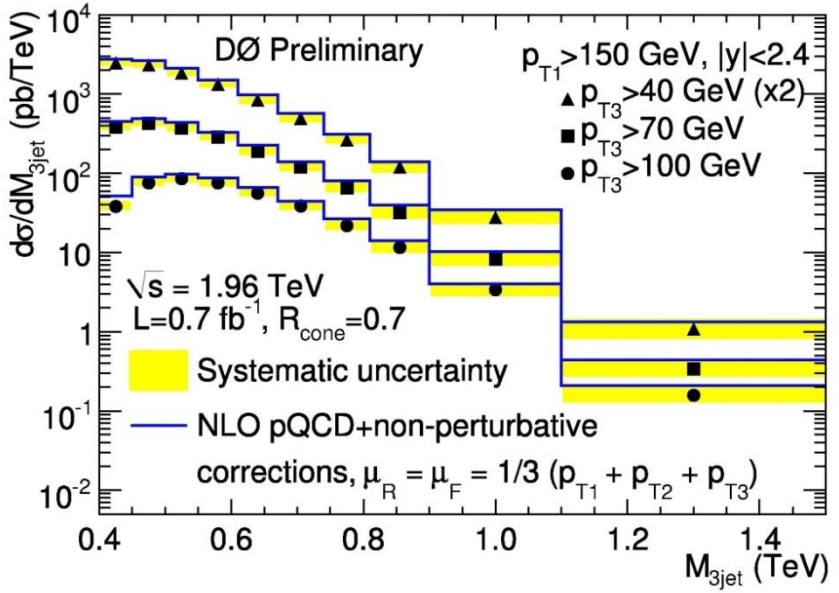
No exclusion for RS Graviton



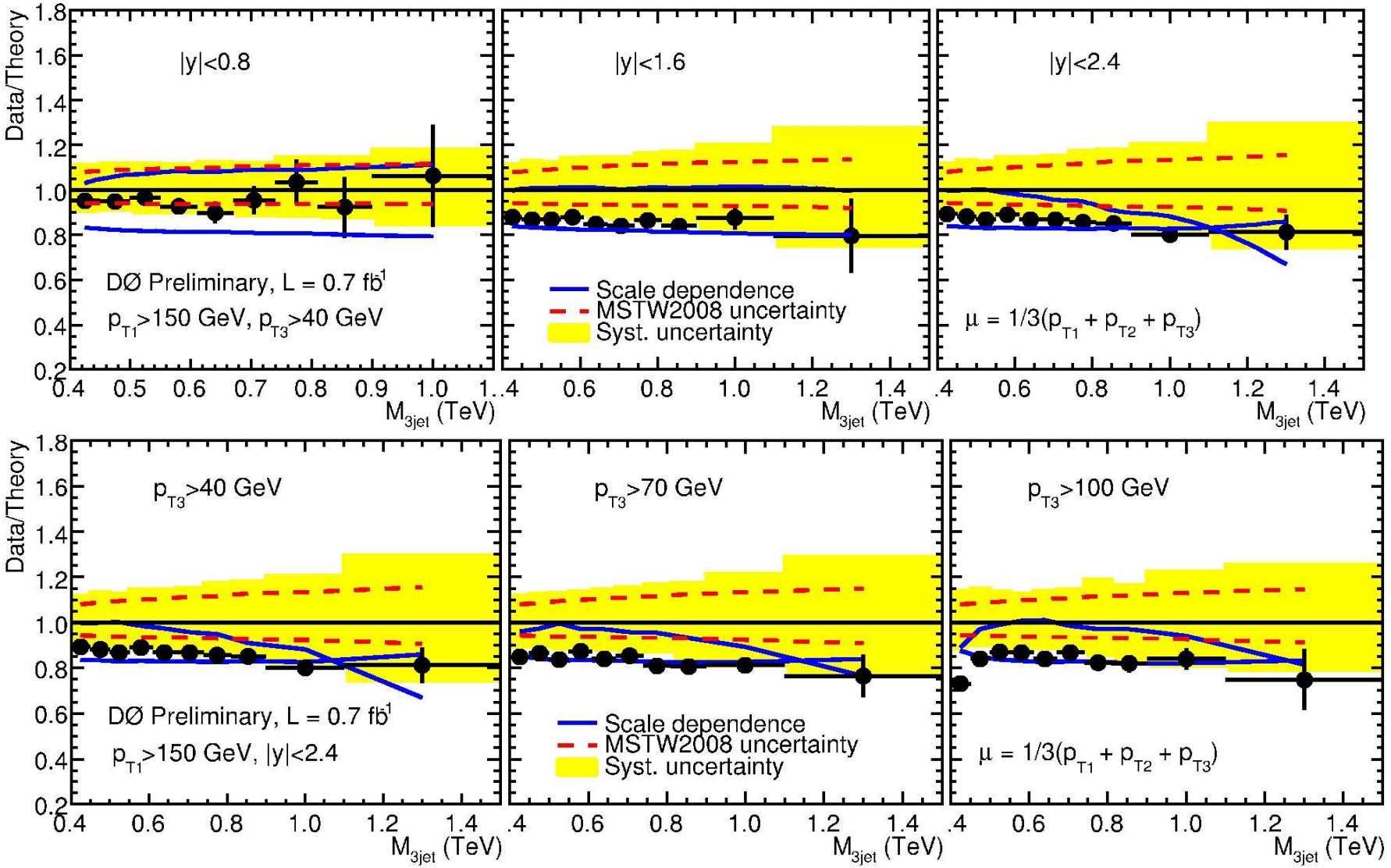
Trijet Mass Cross Section

- 1st measurement of trijet cross section at Tevatron
- Constrains PDFs
- Can be used to look for new physics
- Sensitive to jet clustering algorithms
- Analysis in
  - 3 rapidity regions
  - 3 minimum p_{T3} cuts





DØ Trijet Mass Cross Section

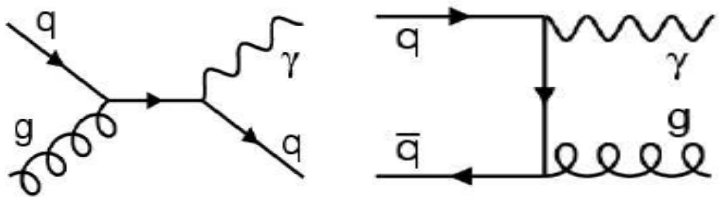


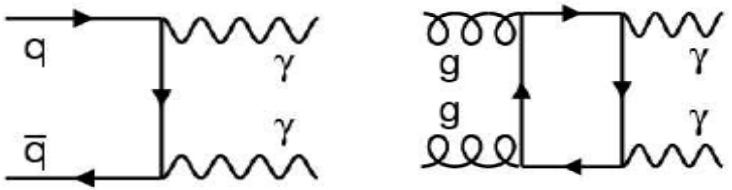
Well described by pQCD

Photon Final States

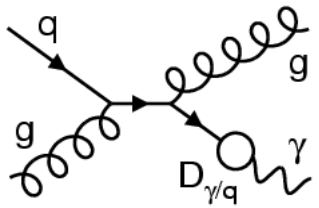
Photon Production

- Direct photons come unaltered from the hard scattering
  - Allows probe of hard scattering dynamics with fewer soft QCD effects
  - Probes gluon PDFs
  - Diphotons are a signal for some BSM processes



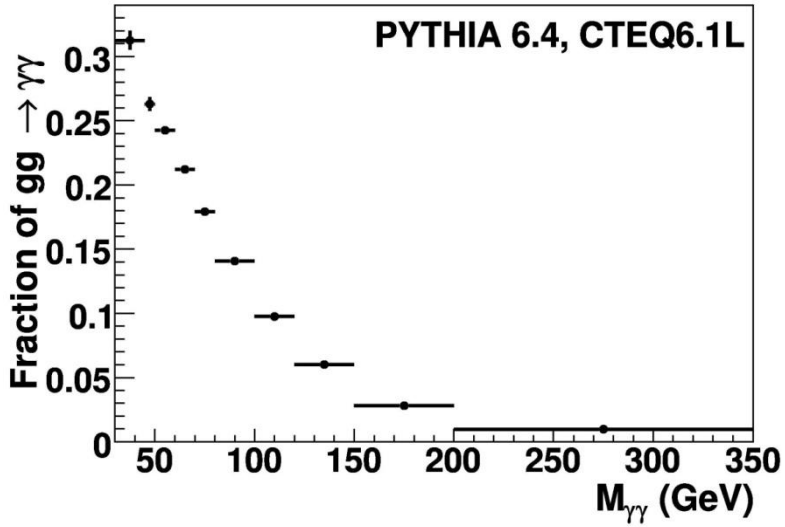


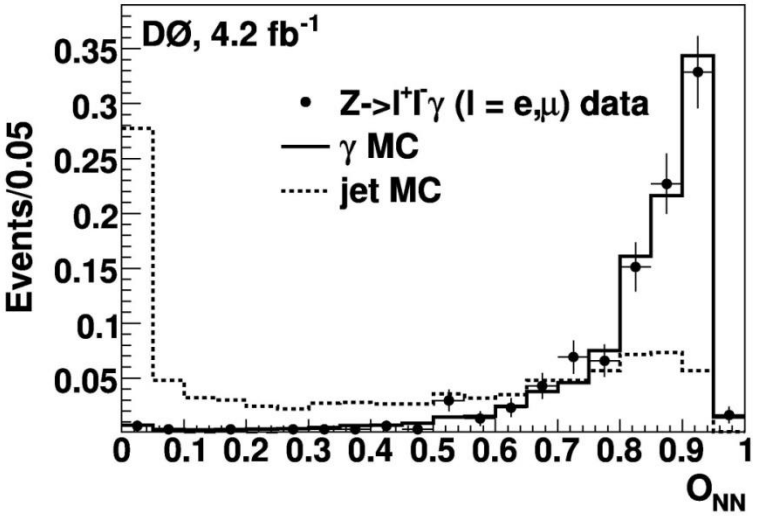
plus some fragmentation effects



DØ Diphoton Production

- Photons identified with kinematic cuts and NN
  - NN checked with Z decays
- Prompt photons identified with track isolation and angular separation cuts
- Compared with three models
  - LO Pythia
  - Fixed NLO Diphox
  - Resummed NLO ResBos
- Look at kinematic variables sensitive to production mechanism





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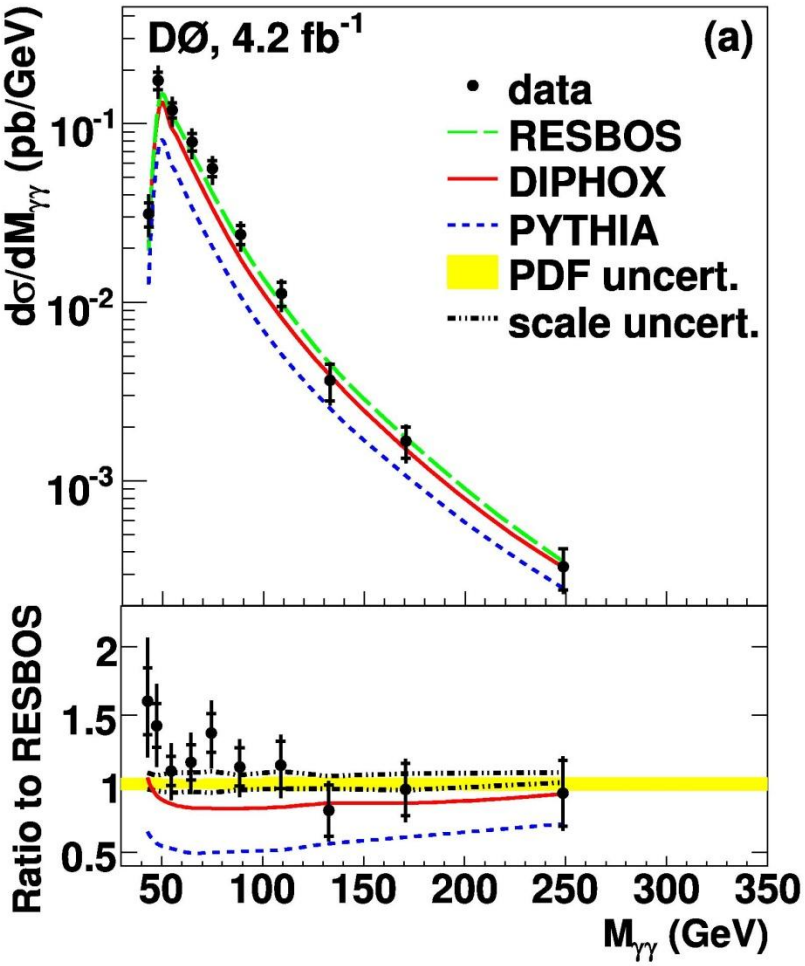
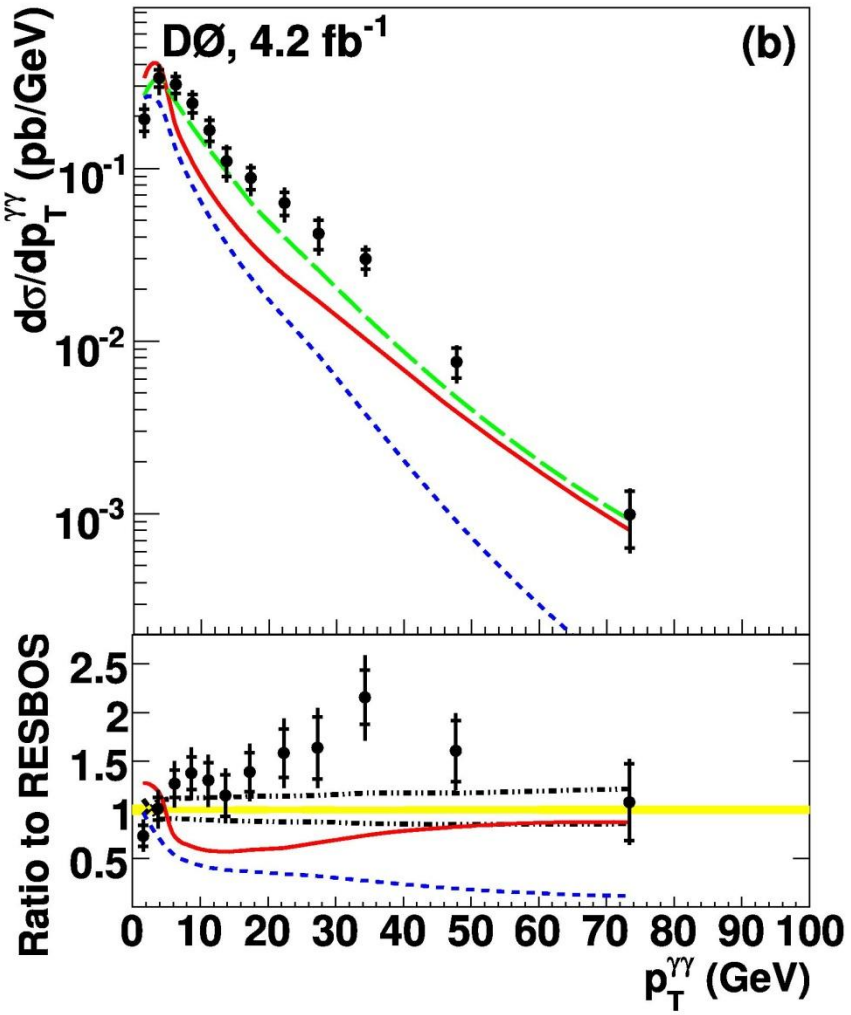
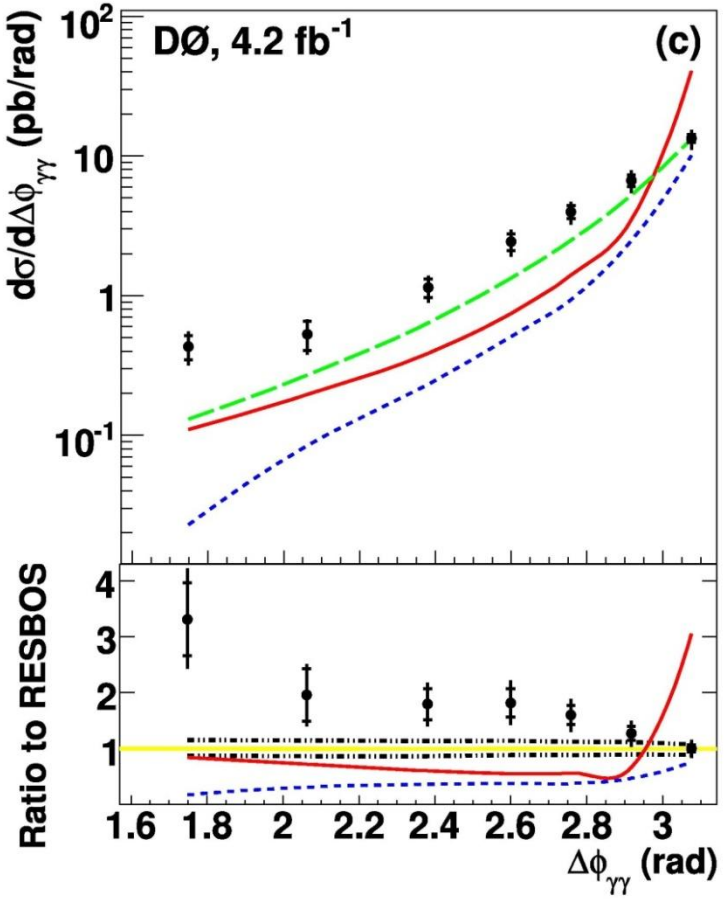
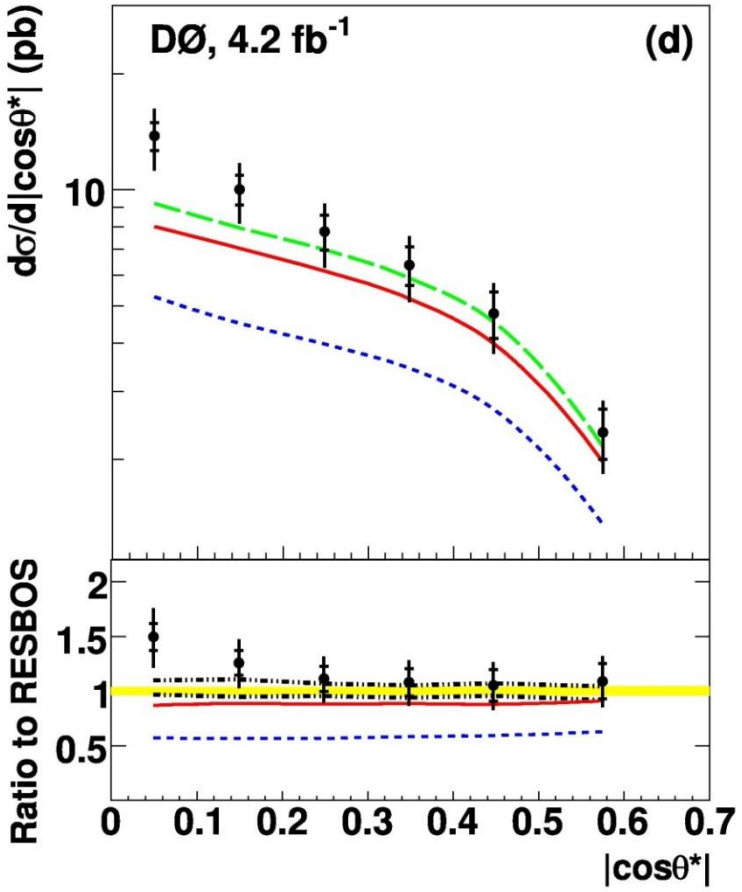
Diphoton Production





Diphoton Production



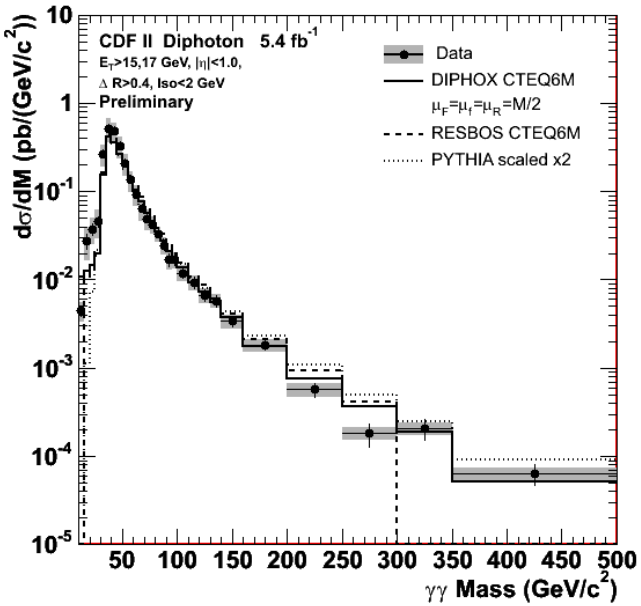


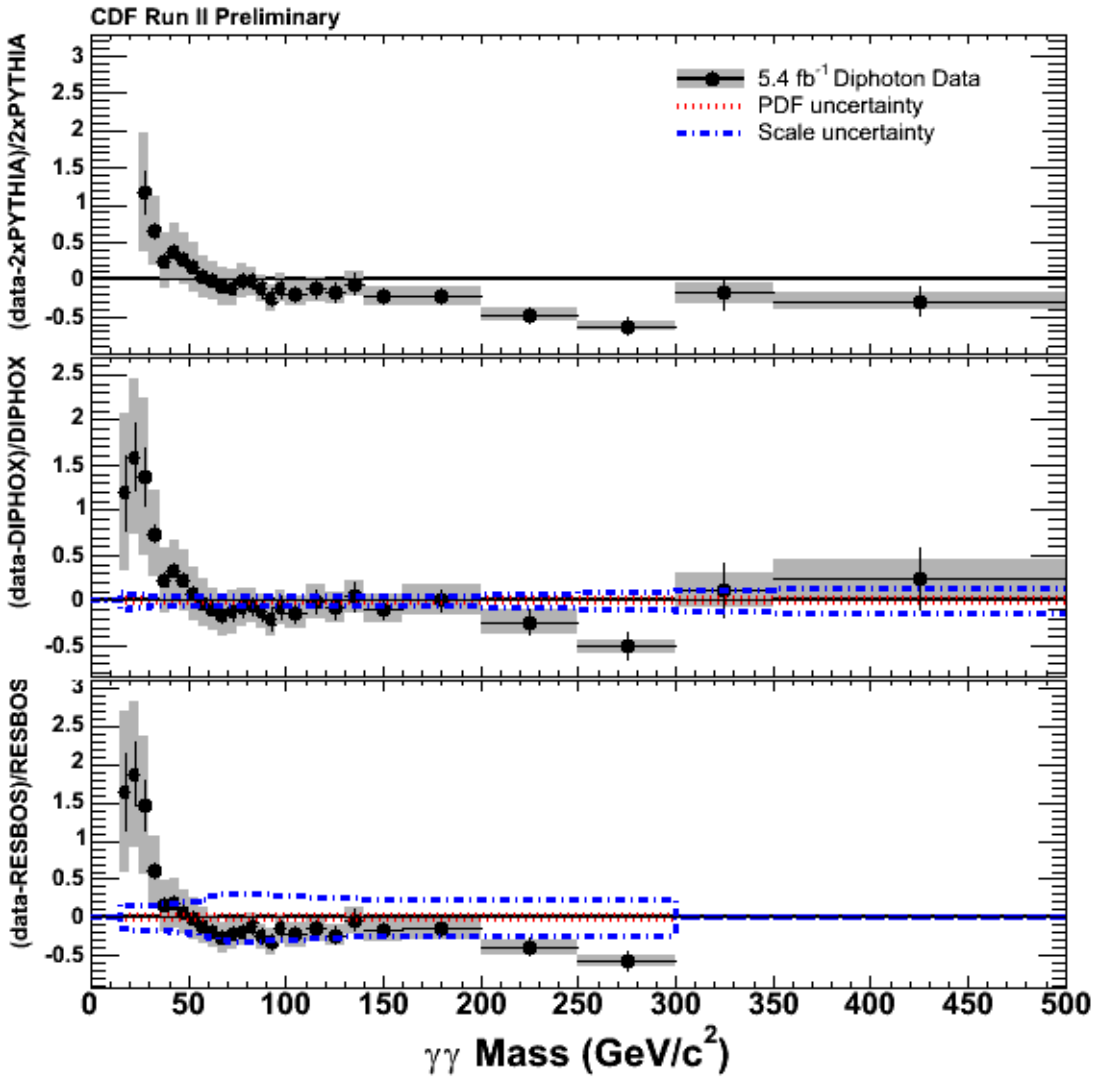
$\cos\theta^* = \tanh[(\eta_1 - \eta_2)/2]$,

ResBos describes the data best, but no model describes the data over all kinematic variables

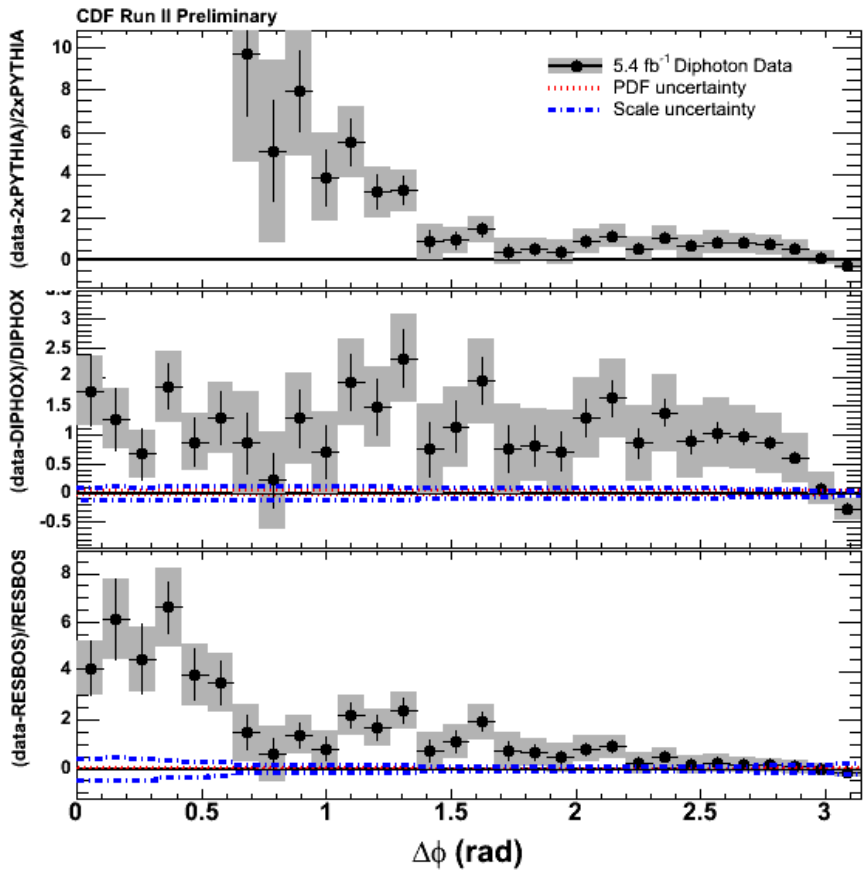
CDF Diphoton Production

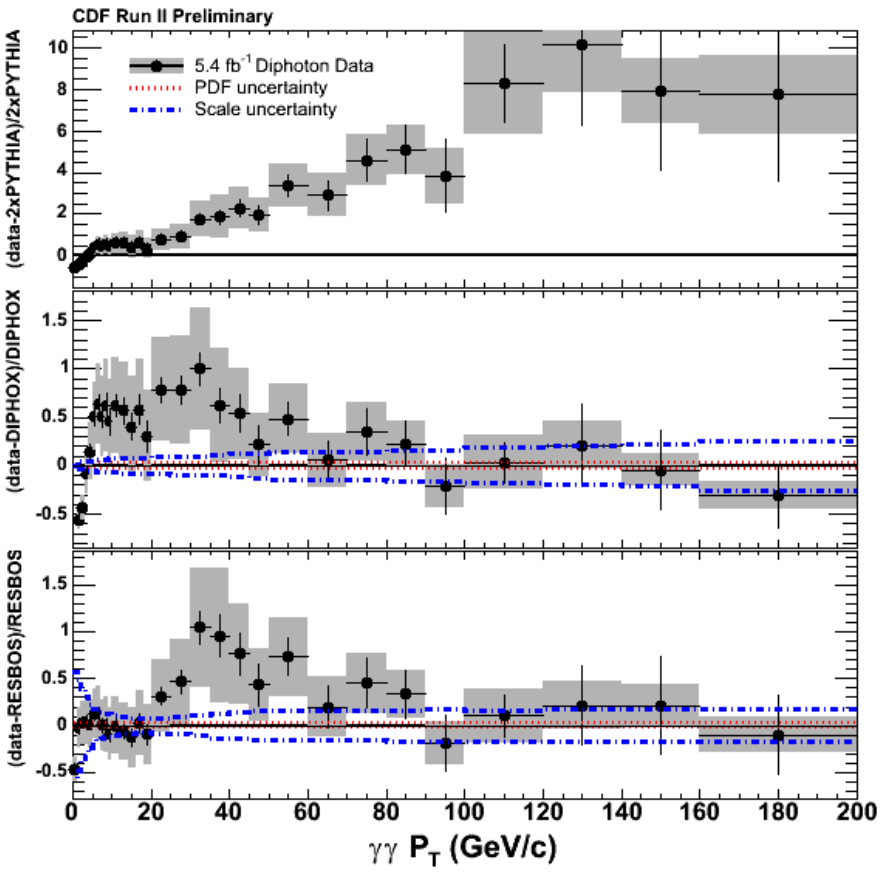
- Chose prompt photons based on track isolation
- Look at kinematic variables sensitive to the production mechanism.
- Compare with three models
  - LO Pythia
  - Fixed NLO Diphox
  - Resummed NLO ResBos





CDF Diphoton





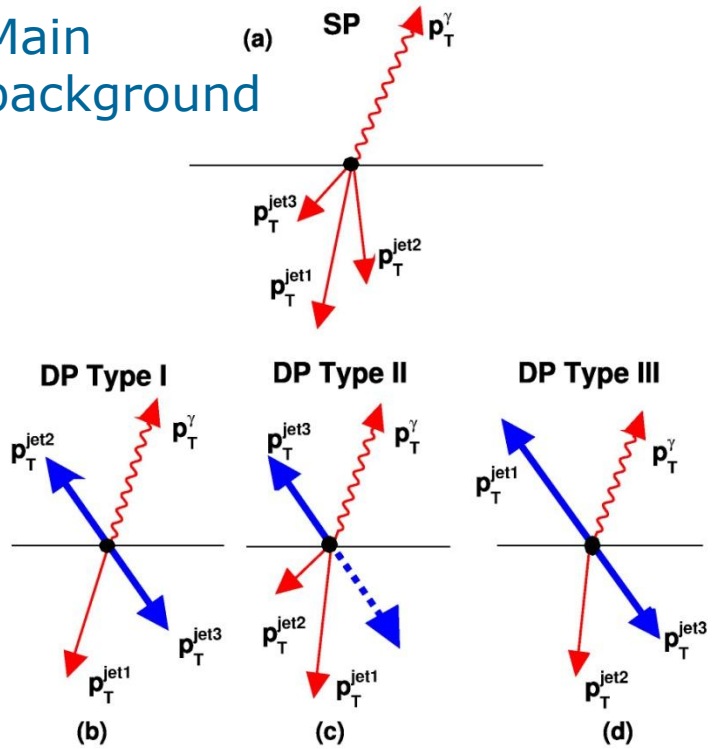
No model accurately describes the data over all regions.

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
- σ_{eff}: a measure of effective size of interaction region
  - Contains information on the spatial distribution of partons
  - Uniform → Large σ_{eff}
  - Clumpy → Small σ_{eff}

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

Main background



signal

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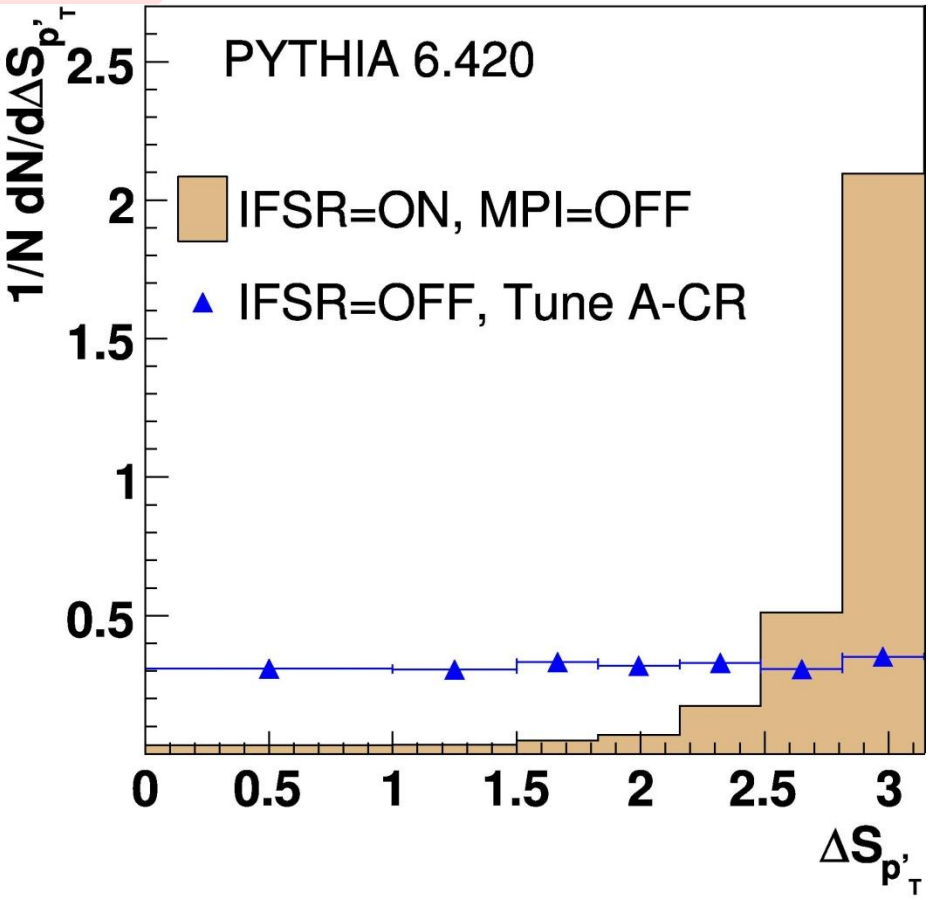
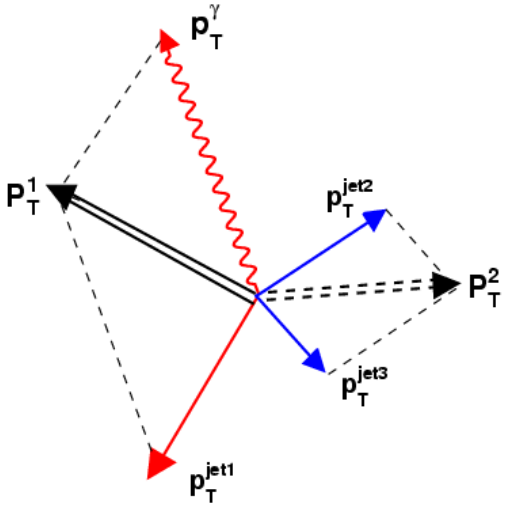
Double Parton Signal Variables

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





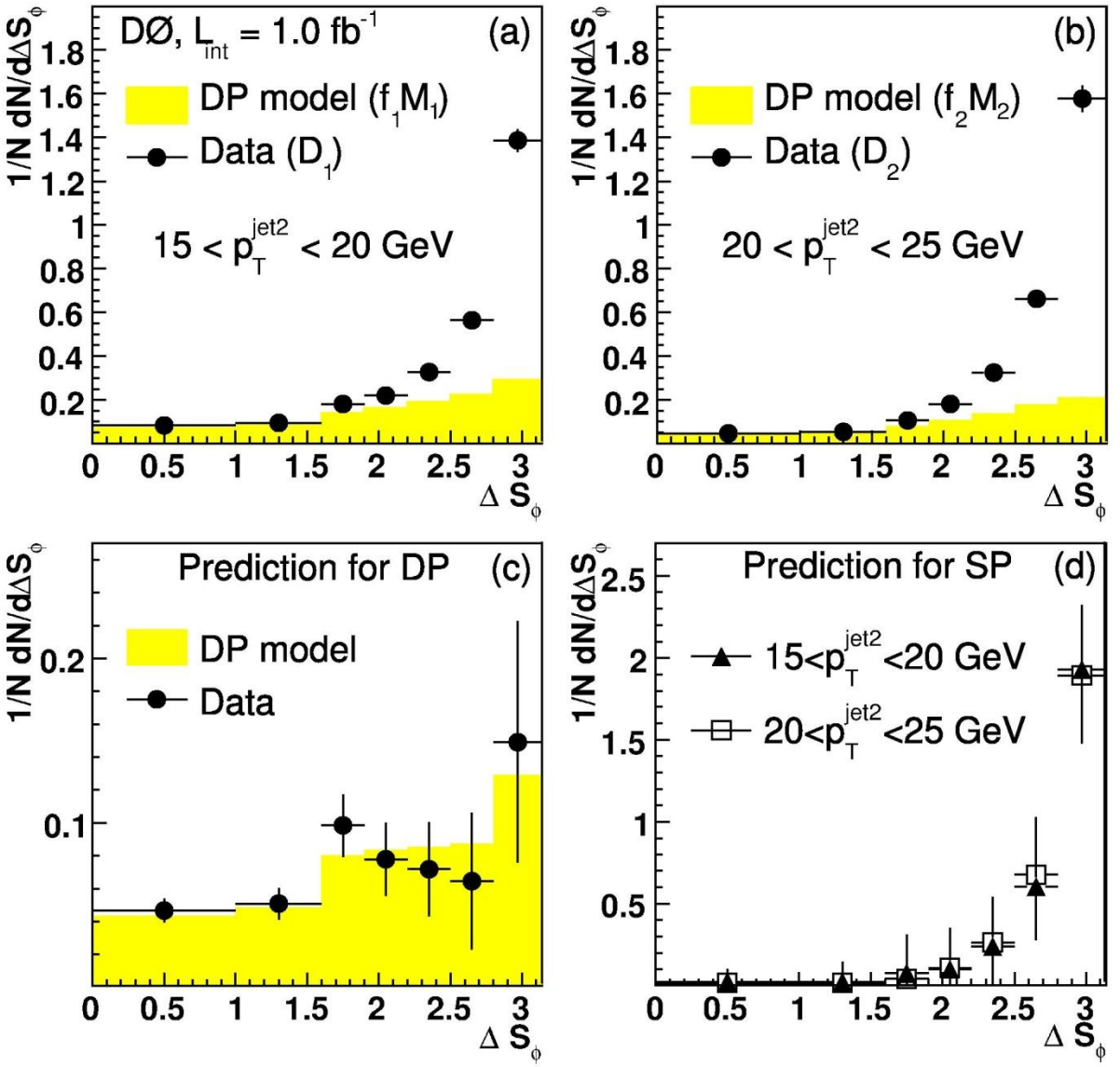
$$S_{\phi} = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{\Delta\phi(\gamma,i)}{\delta\phi(\gamma,i)}\right)^2 + \left(\frac{\Delta\phi(j,k)}{\delta\phi(j,k)}\right)^2}$$

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

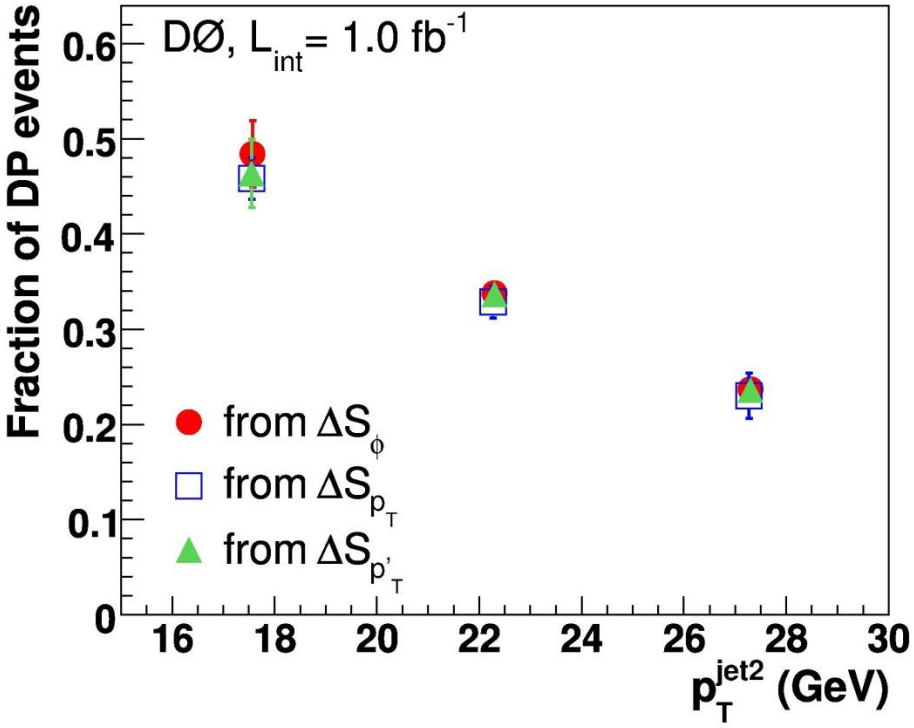
$$\Delta S = \Delta\phi\left(\mathrm{p_T}^{\gamma,jet_i},\ \mathrm{p_T}^{jet_j,jet_k}\right)$$

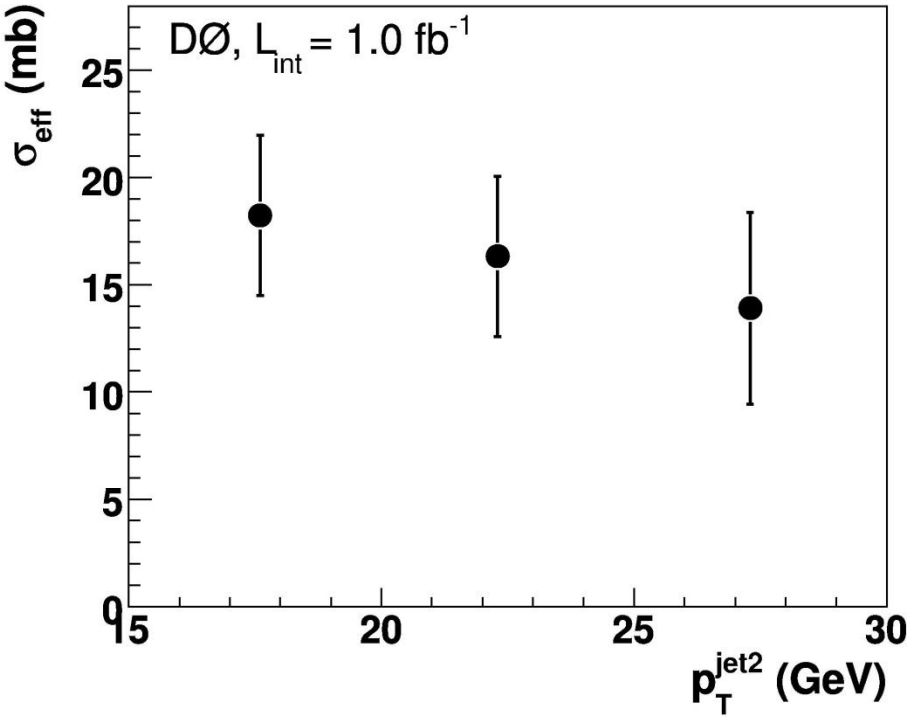
Double Parton Measurement

- 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

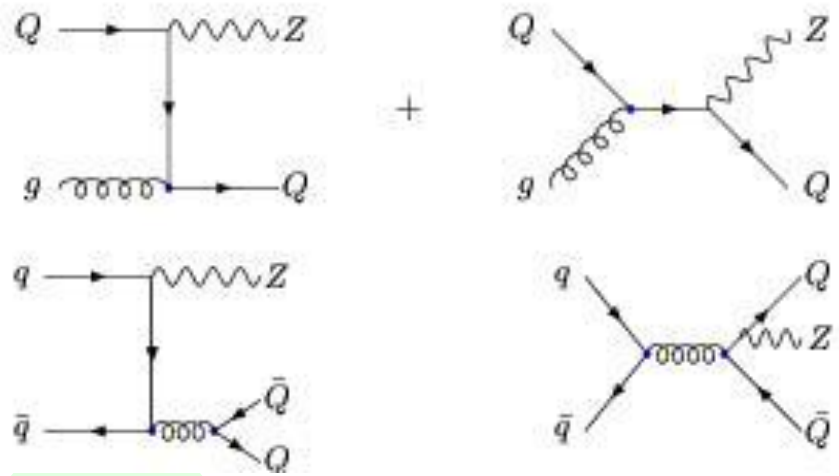


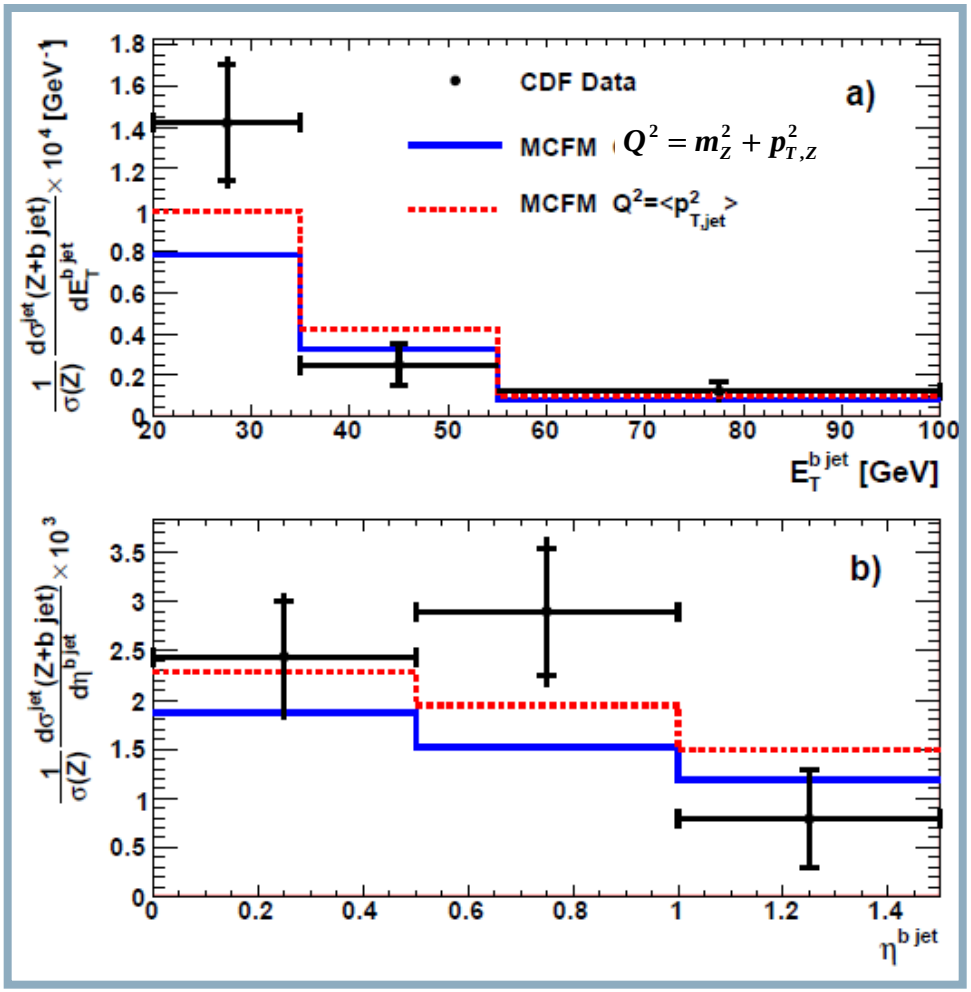


- Average σ_{eff} = 16.4 ± 0.3 (stat) ± 2.3 (syst) mb
- Good agreement with previous measurements by CDF

Boson plus Jets Final States

CDF Z + b Jet





- Z + b probes b-quark PDFs and provides an important test of pQCD
- Background for many channels including ZH, top, SUSY…
- Uses Z→ee and Z →μμ

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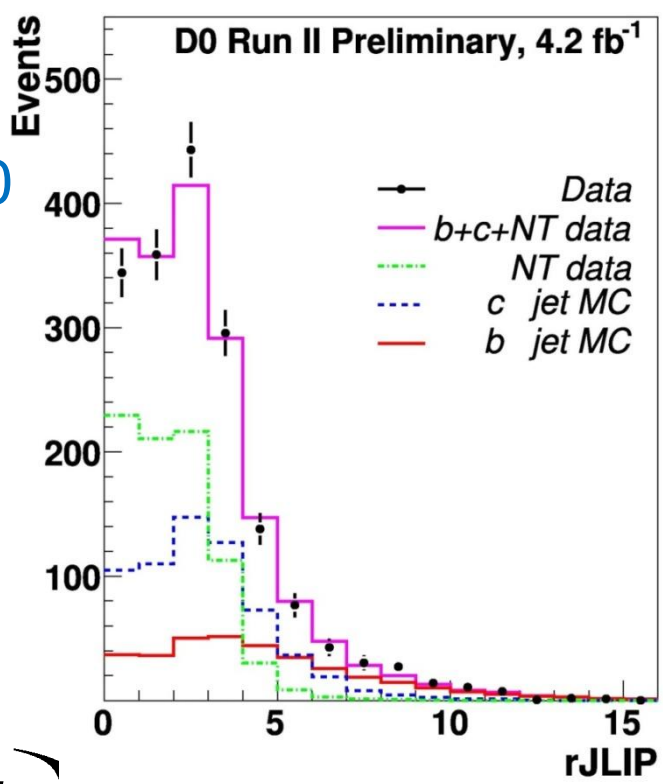
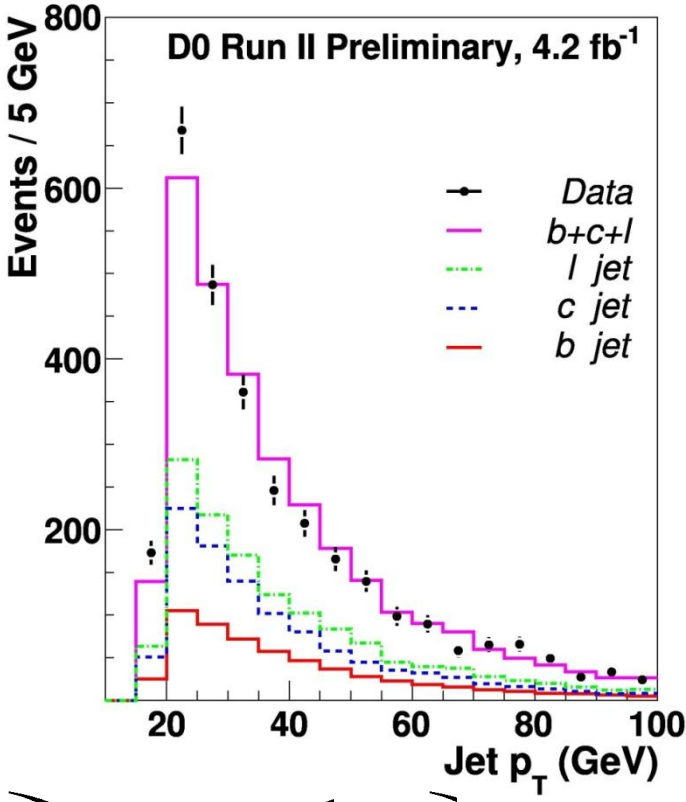
Data in general agreement with NLO pQCD

DØ Z+b/Z+jet

- Combines Z→ee and μμ channels
- At least one jet with p_T>20 GeV, |η|<1
- 2 electrons (muons)
  - p_T>15 GeV (10 GeV), |η|<2.5 (2.0)
- b jets tagged with NN
- NLO QCD: 0.018±0.004

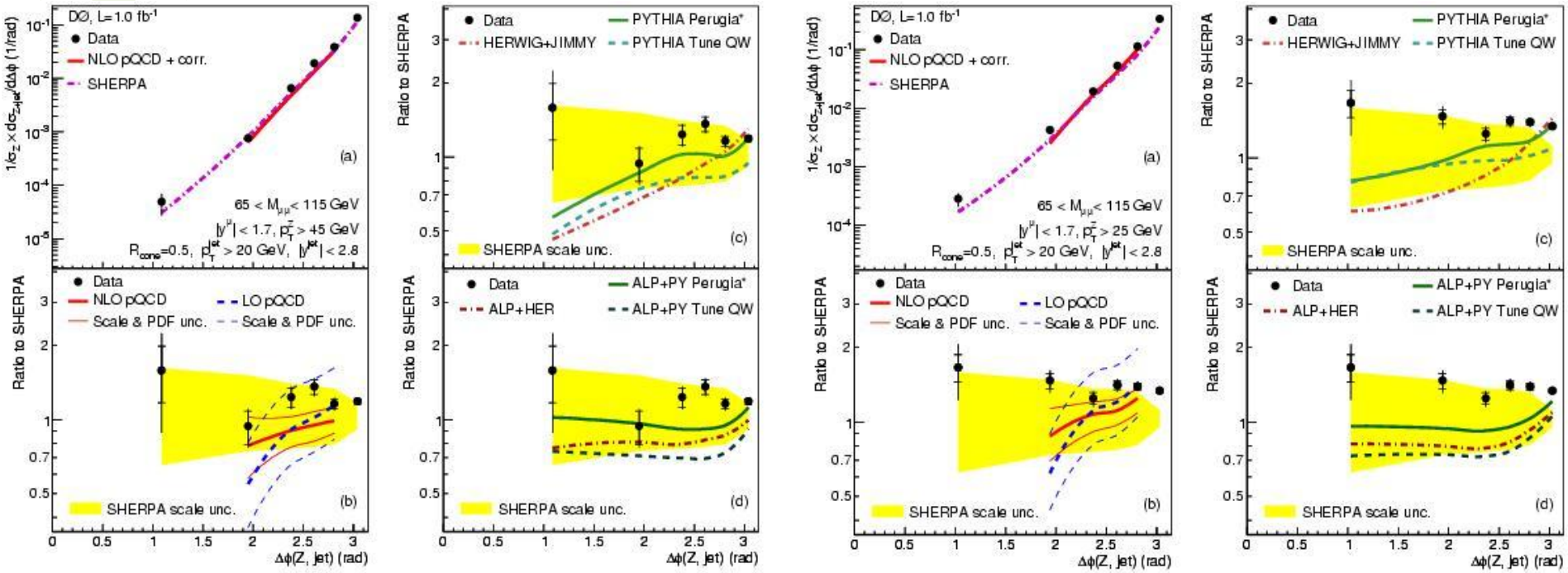




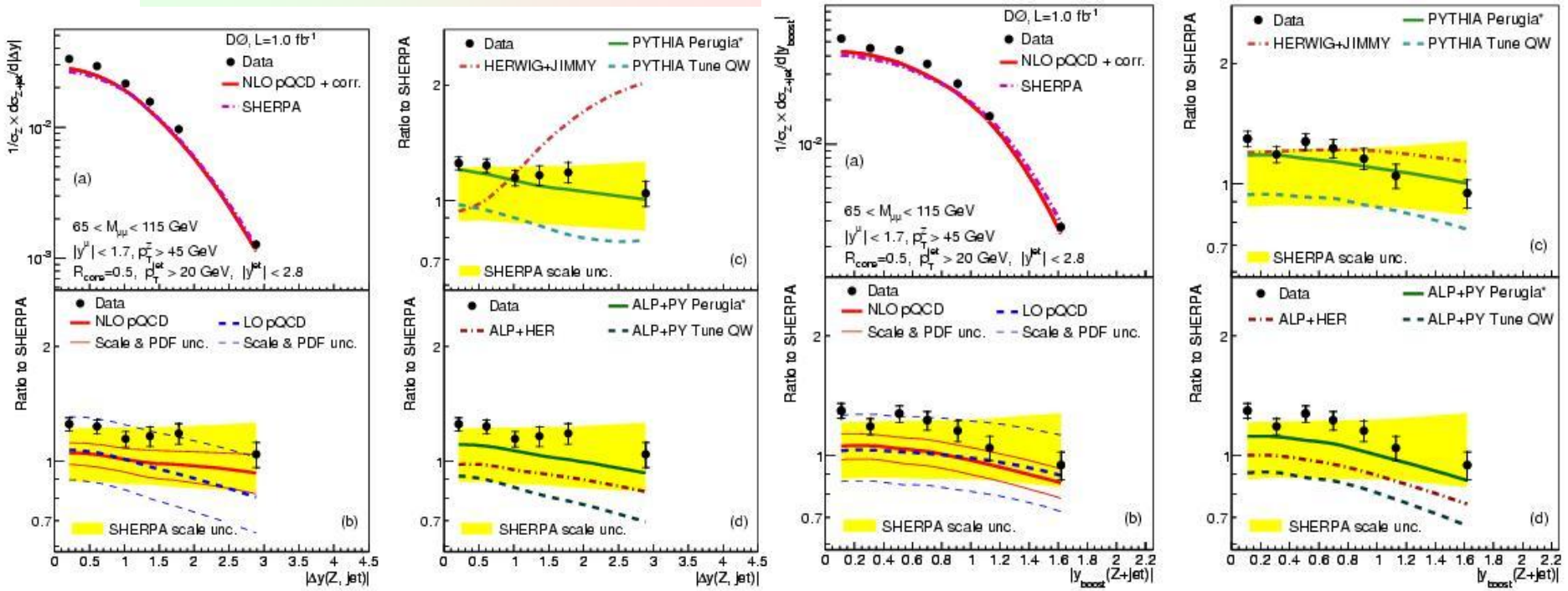
$$\frac{\sigma(Z+b\ jet)}{\sigma(Z+jet)} = 0.0176 \pm 0.0024\,(\text{stat.}) \pm 0.0023\,(\text{syst.})$$

Z/γ + jets angular distribution

- DØ measures angular variables $\Delta\phi$(Z, jet), Δy(Z jet), $|y_{boost}(Z, jet)|$
- Normalize to inclusive Z/γ
- Measure for $p_T(Z)>25$ GeV and $p_T(Z)>45$ GeV



DØ Z + jets angular distribution



- NLO describes data fairly well where applicable
- No model describes data over all kinematic regions
- SHERPA tends to be describe the shape of the data but not normalization
- ALPGEN provides good description of some shapes

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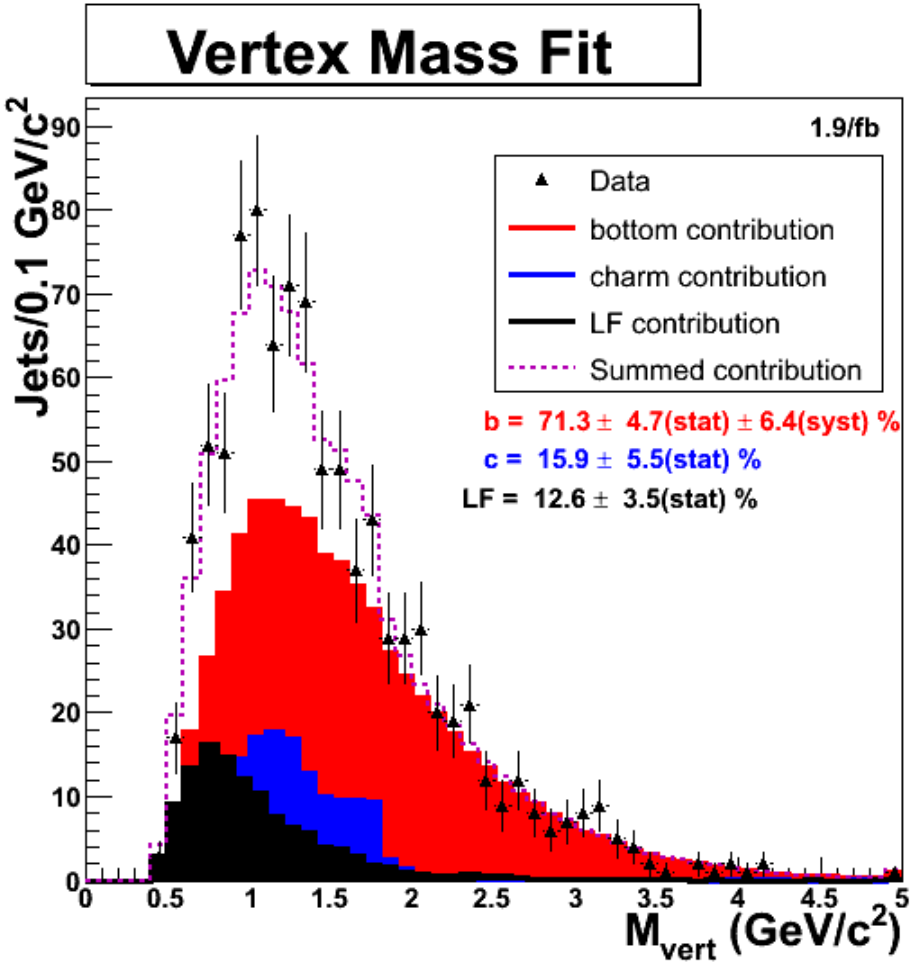
CDF W+b jets

- First measurement of W+b jets at Tevatron
- Measurement of cross section with
  - Jets with E_T>20 GeV and $|\eta| < 2.0$
  - e or μ with p_T >20 GeV and $|\eta| < 1.1$
  - ν with p_T>25 GeV
- Predictions are a factor of 2.5 to 3.5 below measured value.



$$\sigma_{b\ \mathrm{jets}} \times \mathrm{B}(W \to \ell\nu) = 2.74 \pm 0.27(\mathrm{stat}) \pm 0.42(\mathrm{syst})$$

Phys. Rev. Lett. 104, 131801 (2010)

Conclusions

- The Tevatron is operating extremely well at $\sqrt{s}$ = 1.96 TeV with very high luminosity
- QCD measurements are probing higher energy scales than ever before
- More measurements of jets plus bosons
- Current PDFs model most processes quite well though improvement is needed to match some measurements
- No evidence from QCD measurements of any physics beyond the standard model
- QCD will continue to be a rich field of study and extremely important in the LHC era


CDF


DØ


OSU
OU
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