W/Z + jets at the Tevatron

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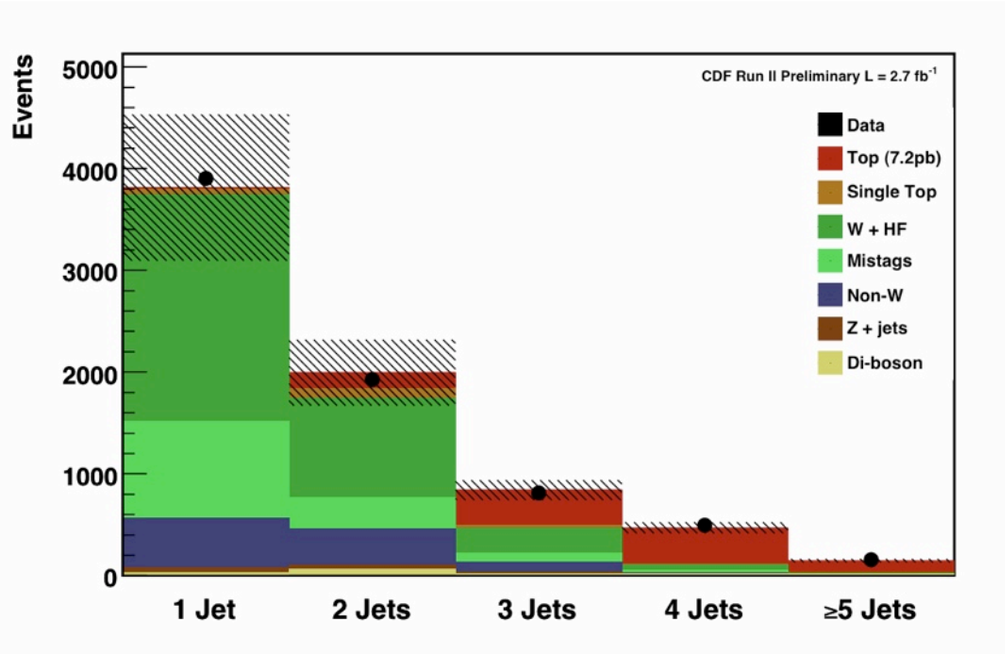
On behalf of the CDF and D0 collaborations

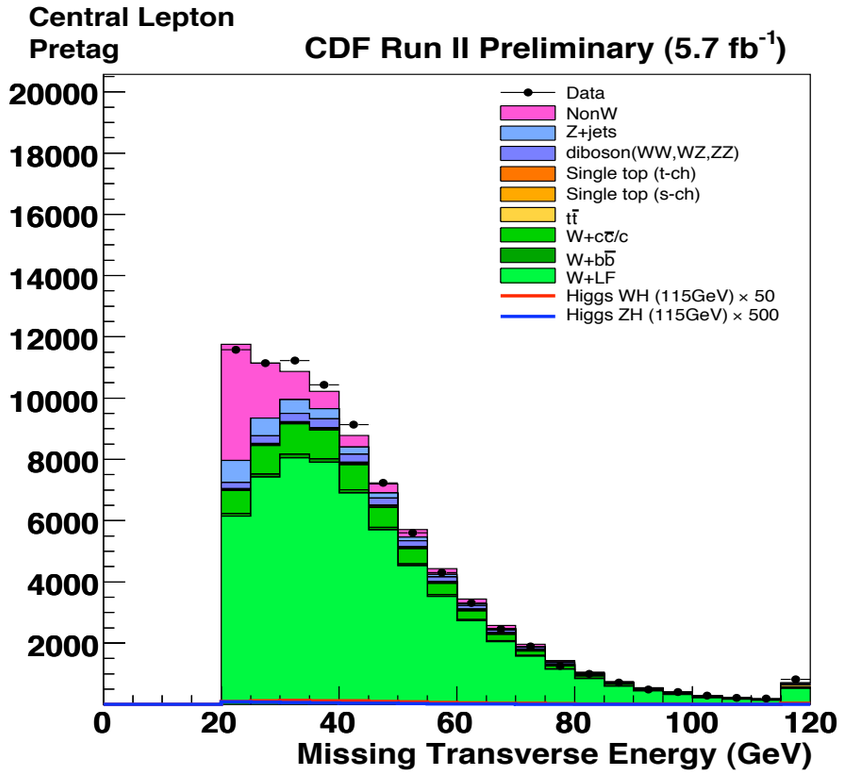
XXIII Rencontres de Blois

MOTIVATION

- Test of pQCD predictions
- Backgrounds to other SM process of interest and to many searches for new physics



- ❖ test/tune different MC models
- ➡ dedicated measurements on W/Z + jets



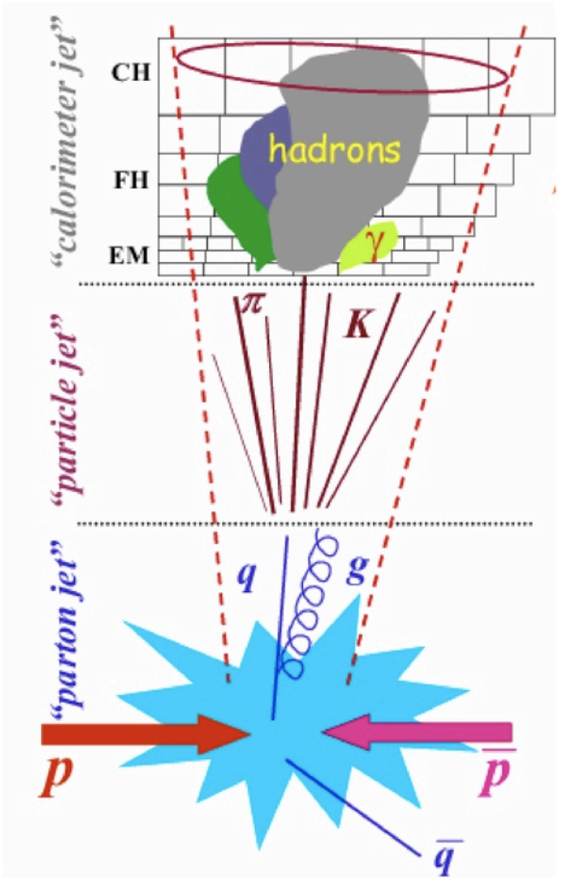
$Z/\gamma^* (\rightarrow e^+e^-)$ + jets

6 fb^{-1}

1.7 fb^{-1} : PRL 100, 102001 (2008)

Measurements defined for

- $66 < M_{ll} < 116$ GeV , with ℓ an electron
  - $E_T > 25$ GeV and CC (both $|\eta| < 1.$) or CF ($|\eta| < 1.$ and $1.2 < |\eta| < 2.8$)
- Jets reconstructed with midpoint algorithm with R=0.7, $p_T > 30$ GeV and $|\eta| < 2.1$



Measurements corrected for detector effects back to hadron level

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

inclusive jet multiplicity, differential XS as function of jet p_T and rapidity

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

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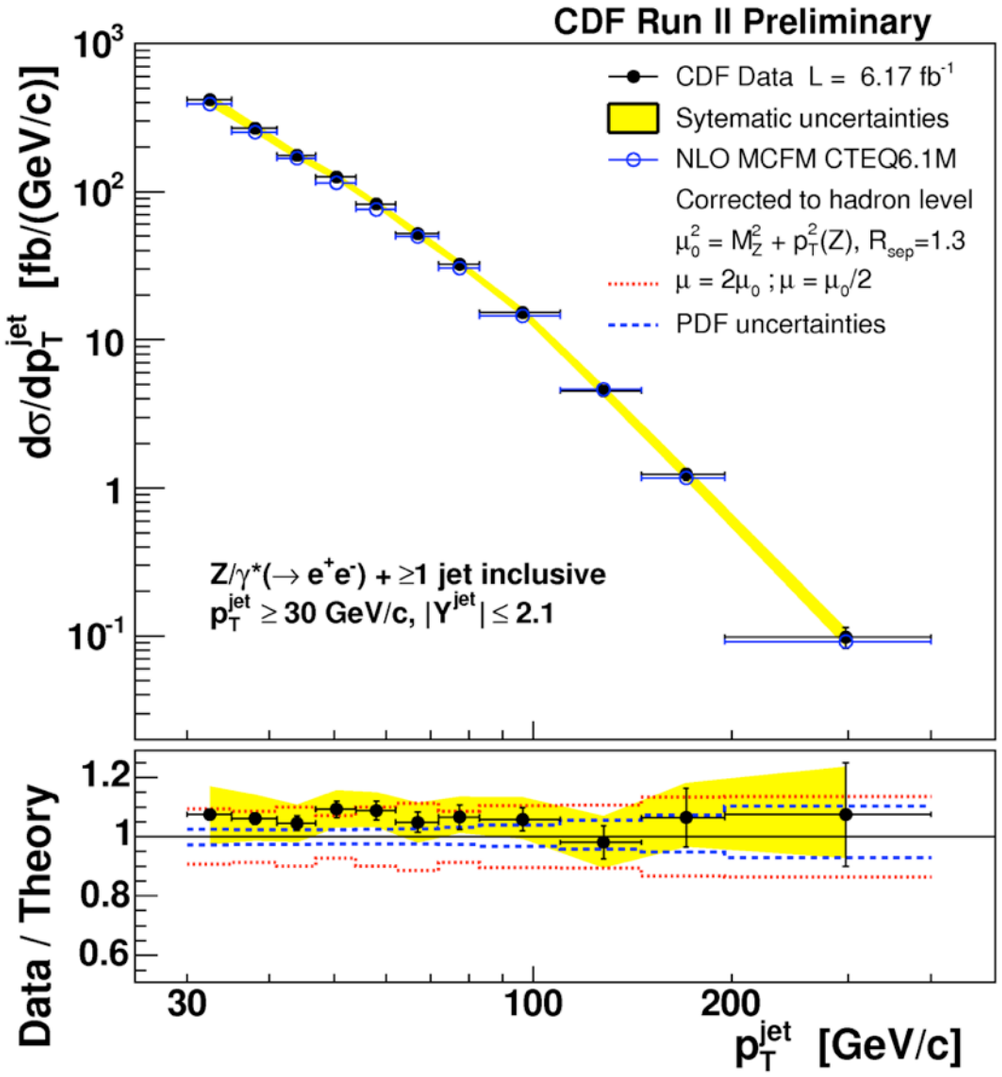
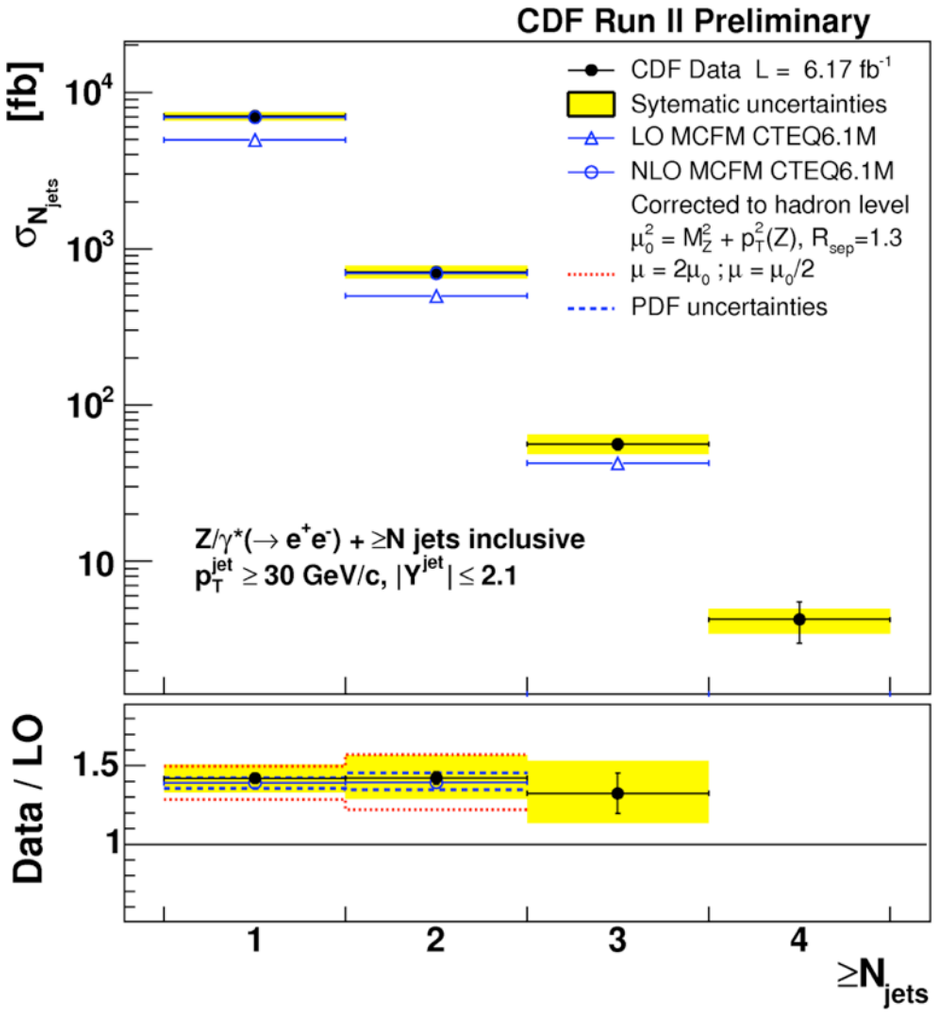


Systematics dominated by Jet Energy Scale uncertainties



Theory prediction corrected for non-pQCD effects

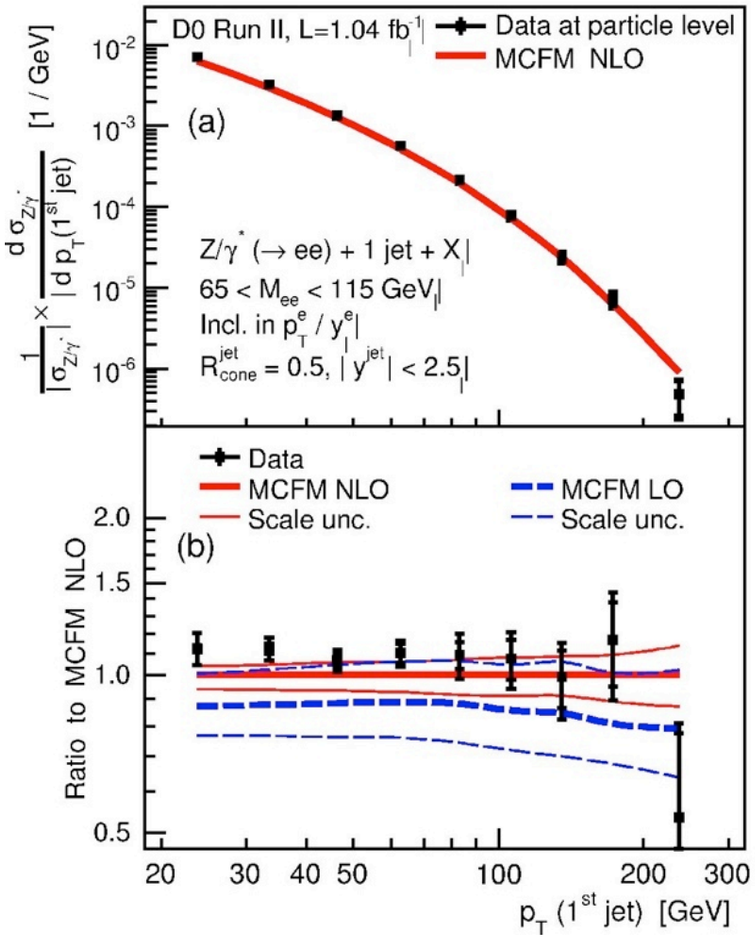
Good agreement with NLO pQCD

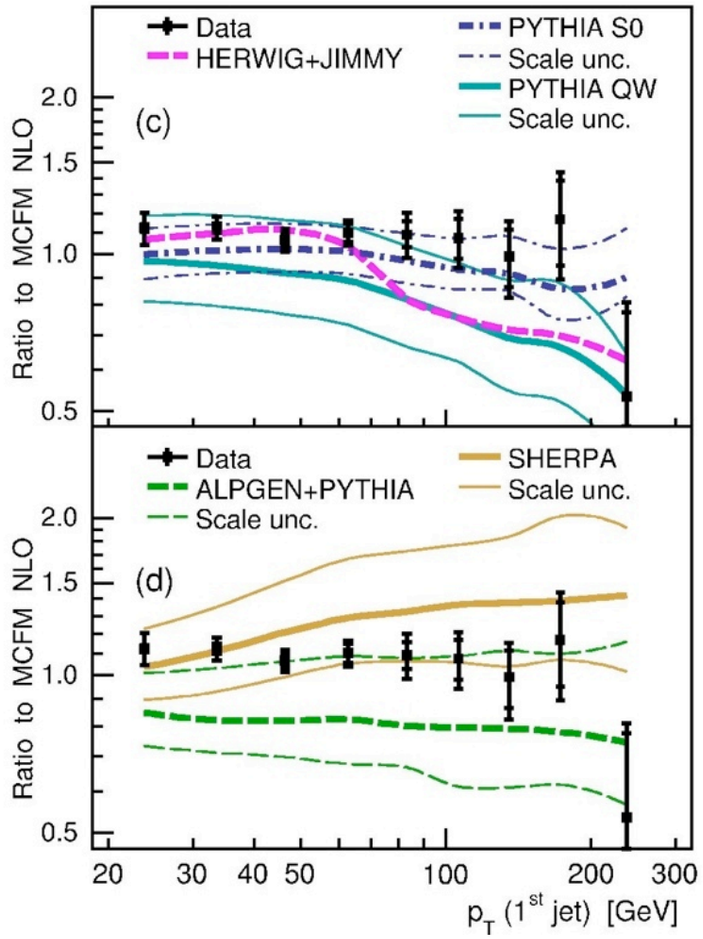
$Z/\gamma^* (\rightarrow e^+e^-)$ + jets

1 fb^{-1}

PLB 678, 45 (2009)

- $65 < M_{ll} < 115$ GeV
- $p_T > 25$ GeV and $|y| < 1.1$ and $1.5 < |y| < 2.5$
- Jets reconstructed with midpoint algorithm with R=0.5, $p_T > 20$ GeV and $|\eta| < 2.5$





Measurements normalized to inclusive Z XS and MCFM prediction corrected for non-pQCD effects

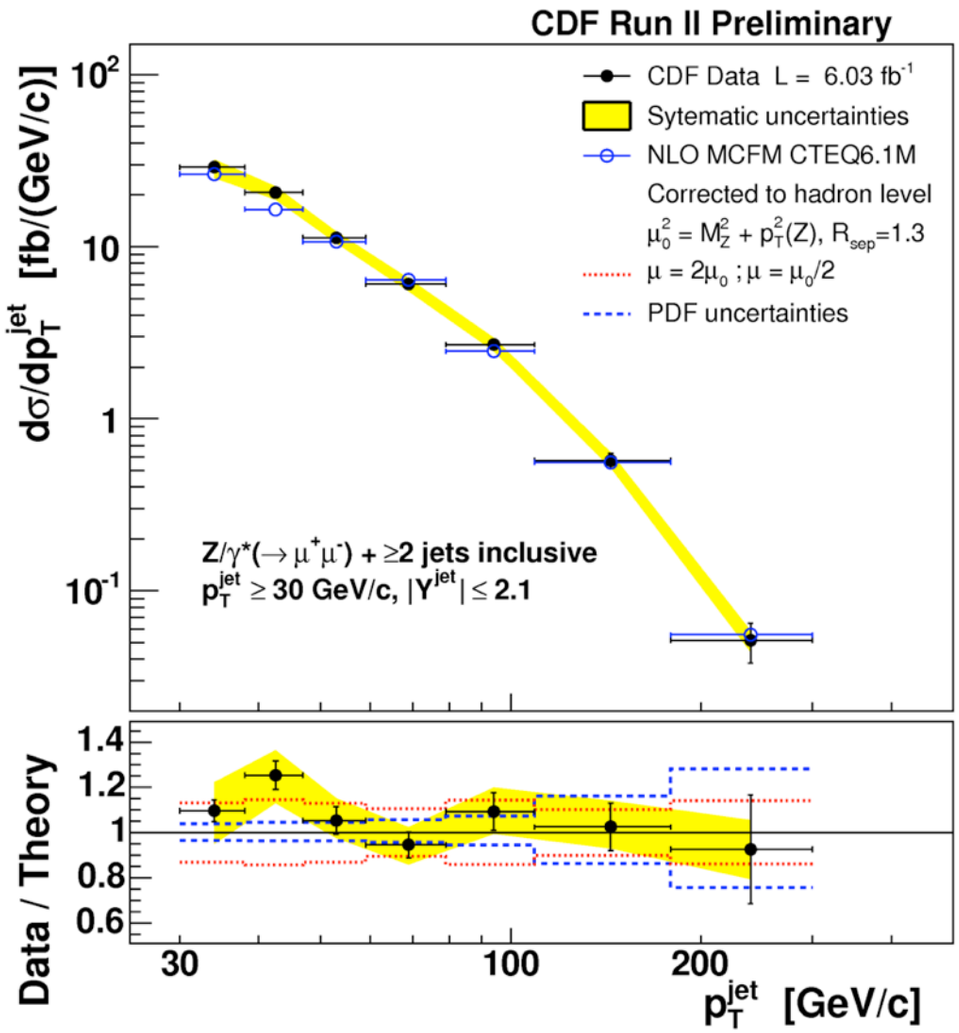
Similar as in the CDF case, NLO pQCD well described the data
Compared to event generators, ME+PS MC show reasonable description of shapes but large scale uncertainties

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

6 fb^{-1}

Measurements defined for

- $66 < M_{\ell\ell} < 116$ GeV , with ℓ a muon
- $E_T > 25$ GeV and CC (both $|\eta| < 1.$)
- Jets reconstructed with midpoint algorithm with R=0.7, $p_T > 30$ GeV and $|\eta| < 2.1$



Measurements defined for similar kinematic region as electrons. Working on combination and exploring distributions for higher ($\geq$3) jet multiplicity

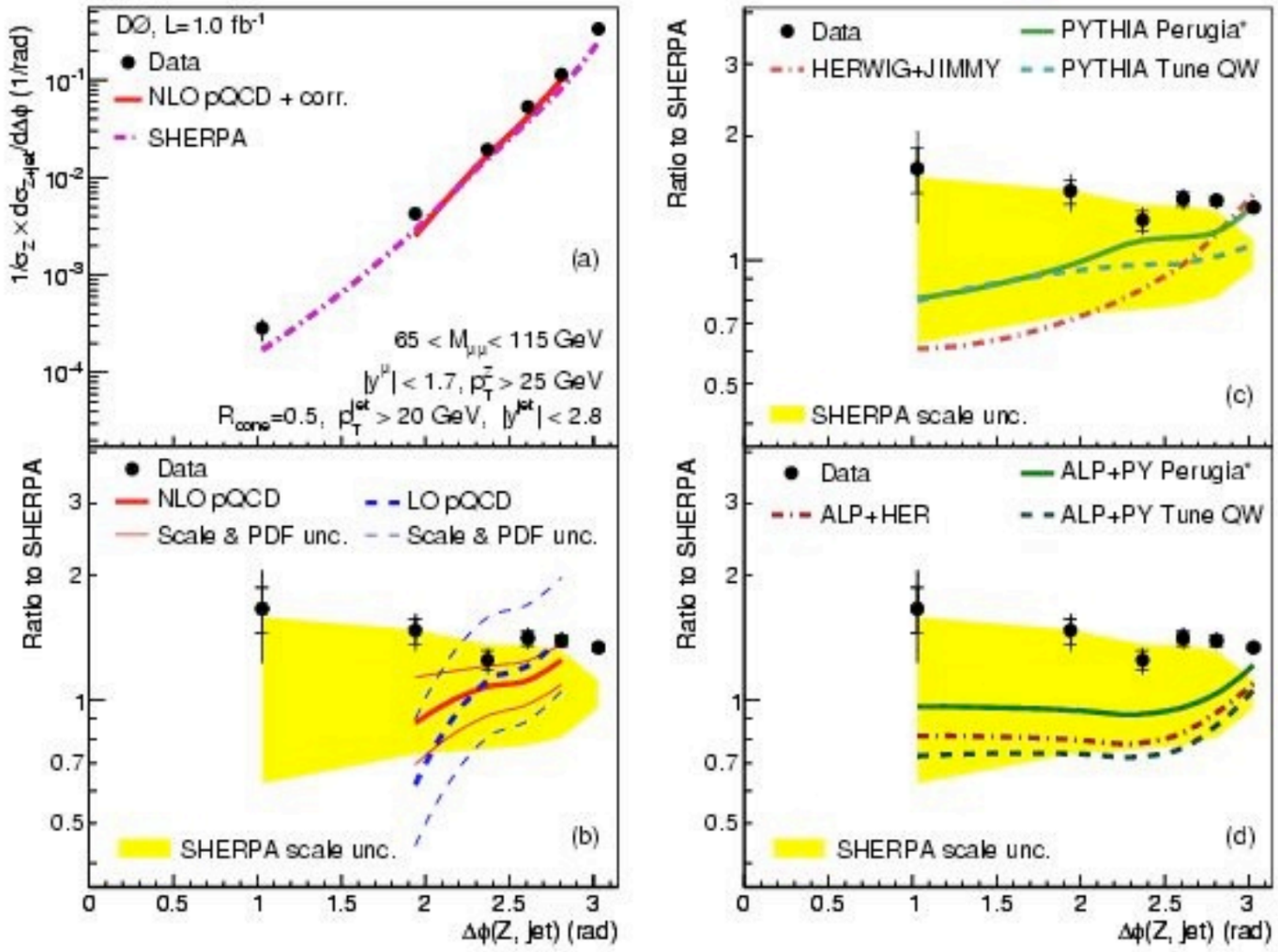
$Z/\gamma^* (\rightarrow \mu^+\mu^-)$ + jets

1 fb^{-1}

PLB 682, 370 (2010)

Angular Distributions

- $65 < M_{\ell\ell} < 115$ GeV
- $p^Z_T > 25$ GeV and $|y| < 1.7$
- Jets reconstructed with midpoint algorithm with R=0.5, $p_T > 20$ GeV and $|\eta| < 2.8$



Sensitive to QCD radiation
→ excellent for MC tuning

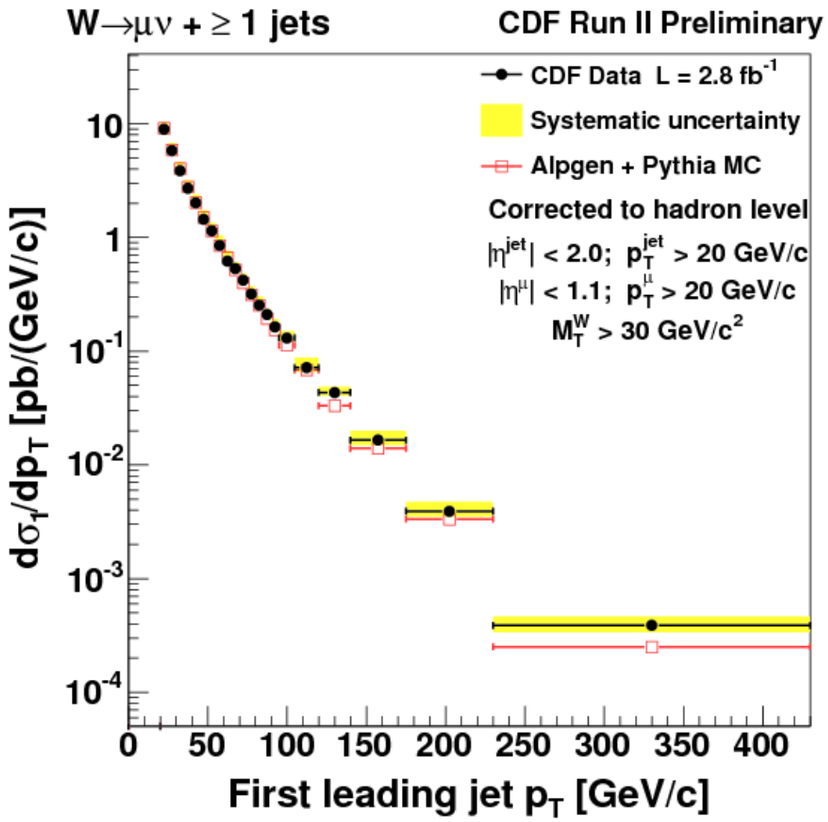
SHERPA provides good description of the shapes though large scale uncertainties

W + jets

2.8 fb^{-1}

Selection

- electron and muon channels
- XS defined for
  - Leptons: p_T > 20 GeV and $|\eta|$ < 1.1
  - M^W_T > 40 GeV (30 for muons)
  - Jets (Midpoint R=0.4): p_T > 20 GeV and $|\eta|$ < 2.0

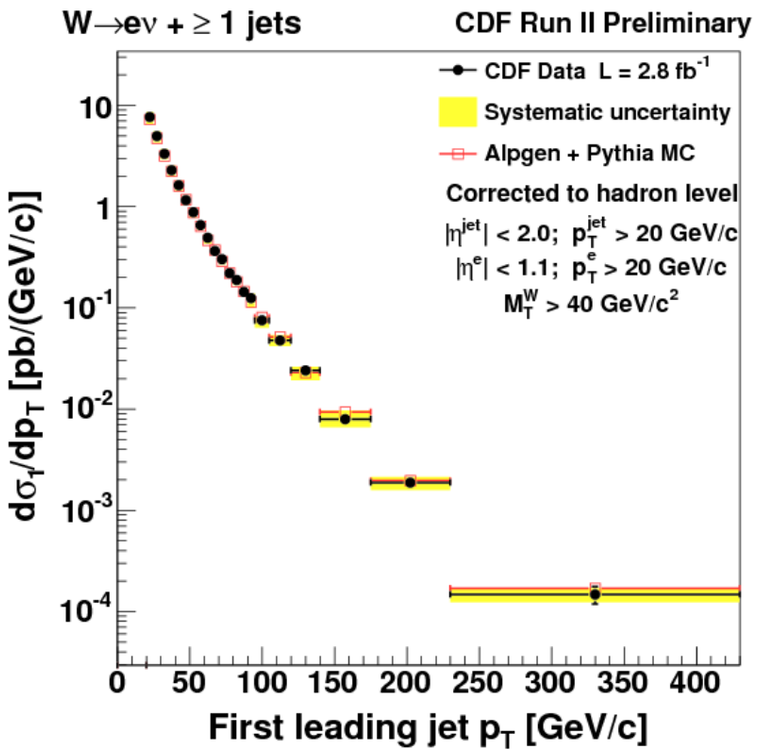


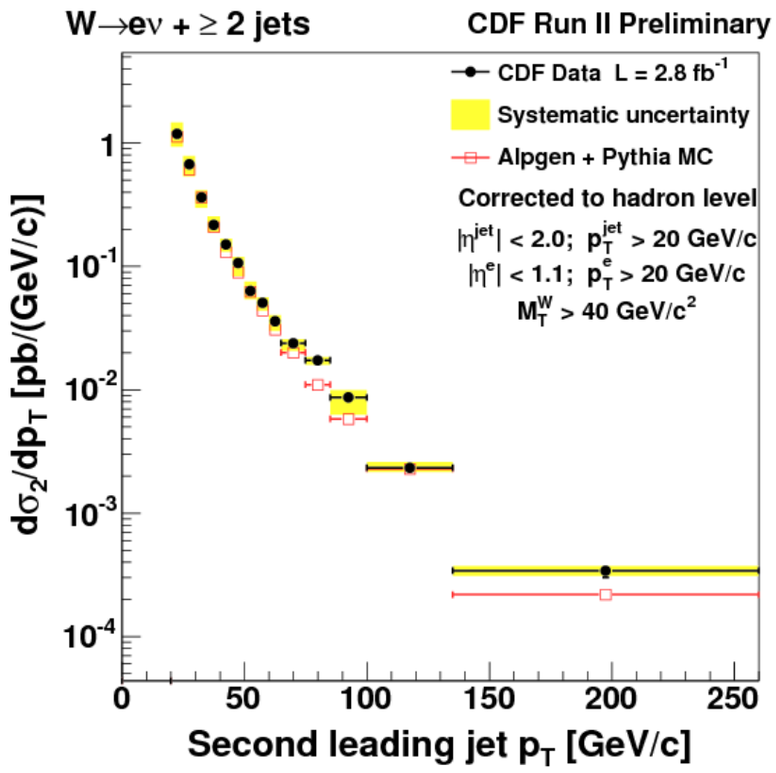
Measured differential XS in various kinematic variables for ≥ n jets (up to 4):

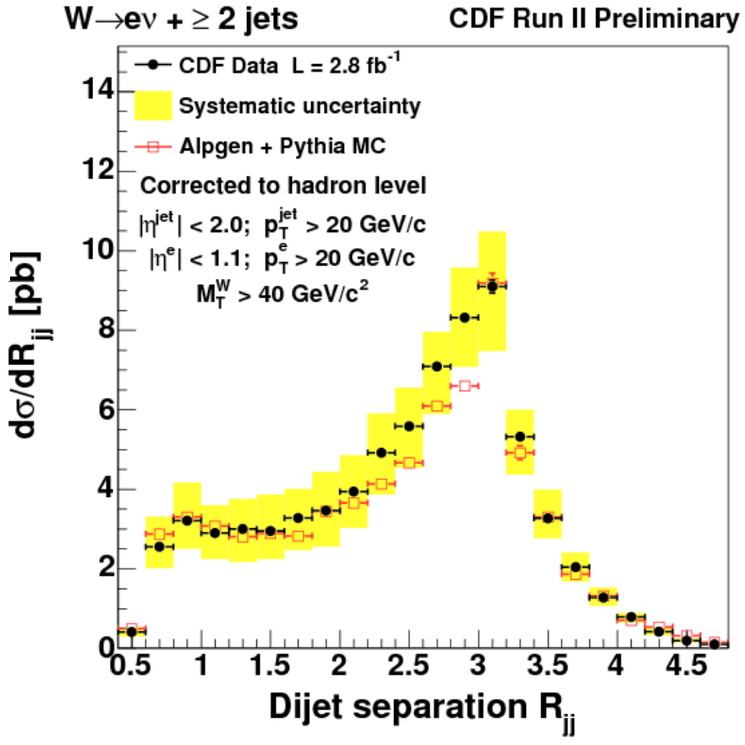
- cross section ratios, n^{th} leading jet pt, angular distributions, etc

W + jets

2.8 fb^{-1}



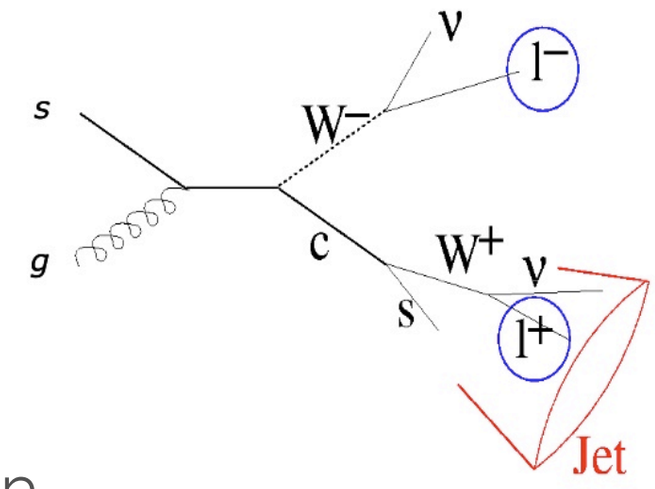




- Comparison with Alpgen+Pythia normalized to control region, i.e $M^W_T > 20$ GeV
- Backgrounds derived from M^W_T fit
- Comparison to NLO pQCD to be available soon

W/Z + HF

W + c



Selection

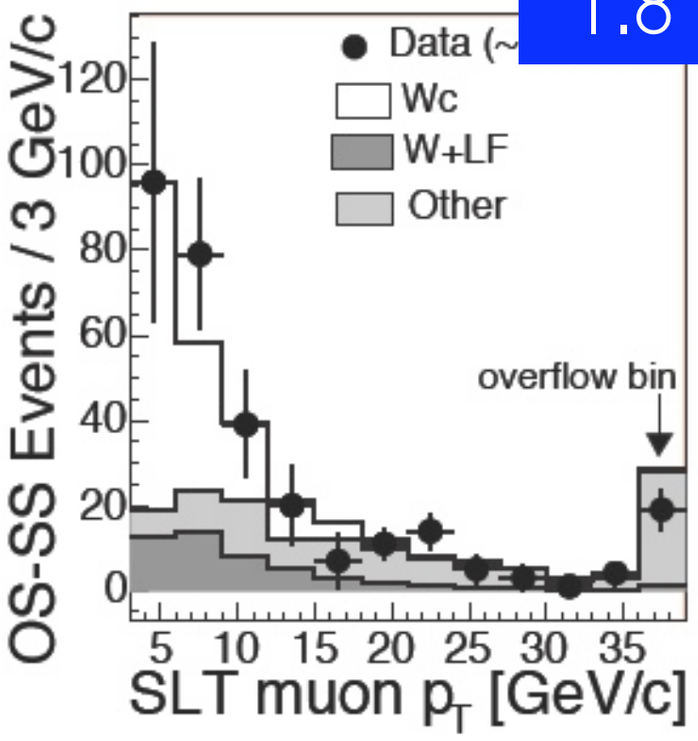
- electron and muon channels
- identify charm jets by Soft Lepton Tagging
  - both Muons and Electrons

Methodology

- use charge correlation between primary and secondary lepton
- expect mainly OS events from Wc
- backgrounds , primarily W +lightflavor, Drell-Yan and multijets, will show smaller asymmetry
- measure Wc XS from excess of OS-SS events

W + c

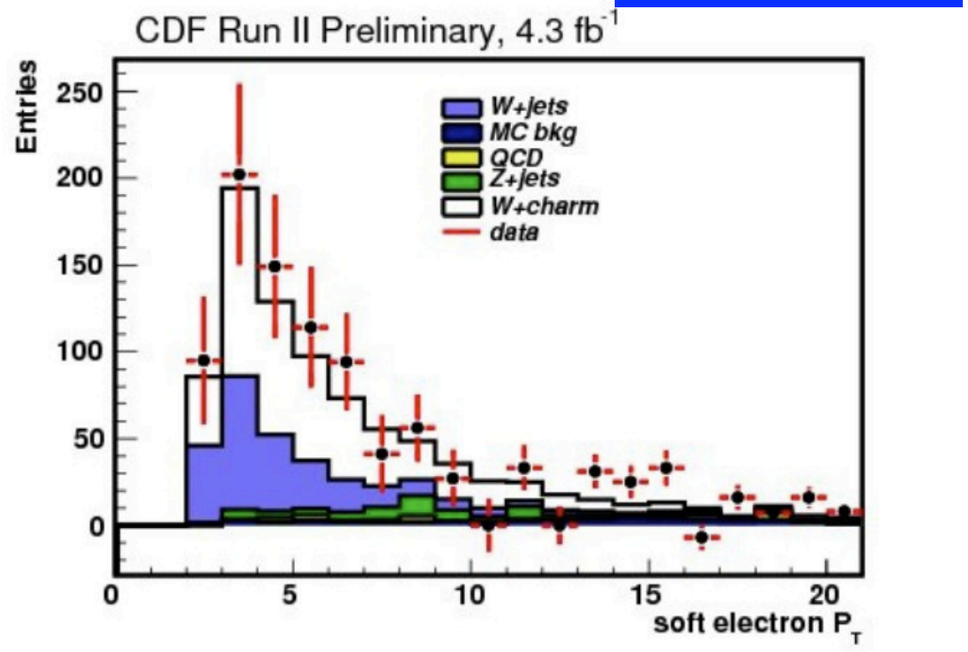
1.8 fb^{-1}



PRL 100, 091893 (2008)

$\sigma_{Wc} \times BR(W \to l\nu) = 9.8 \pm 2.8$ (stat) $^{+\,1.4}_{-\,1.6}$ (syst) $\pm$ 0.6 (lum) pb

4.3 fb^{-1}



$\sigma_{Wc} \times BR(W \to l\nu) = 21.1 \pm 7.1$ (stat) $\pm$ 4.6 (syst) pb

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

$p_T > 20$ GeV and $|\eta| < 1.5$

Measurements in agreement with NLO pQCD (within large experimental uncertainties)

1. fb^{-1}

$\sigma_{Wc} / \sigma_{Wjets} = 0.074 \pm 0.019$ (stat) $^{+\,0.012}_{-\,0.014}$ (syst) pb

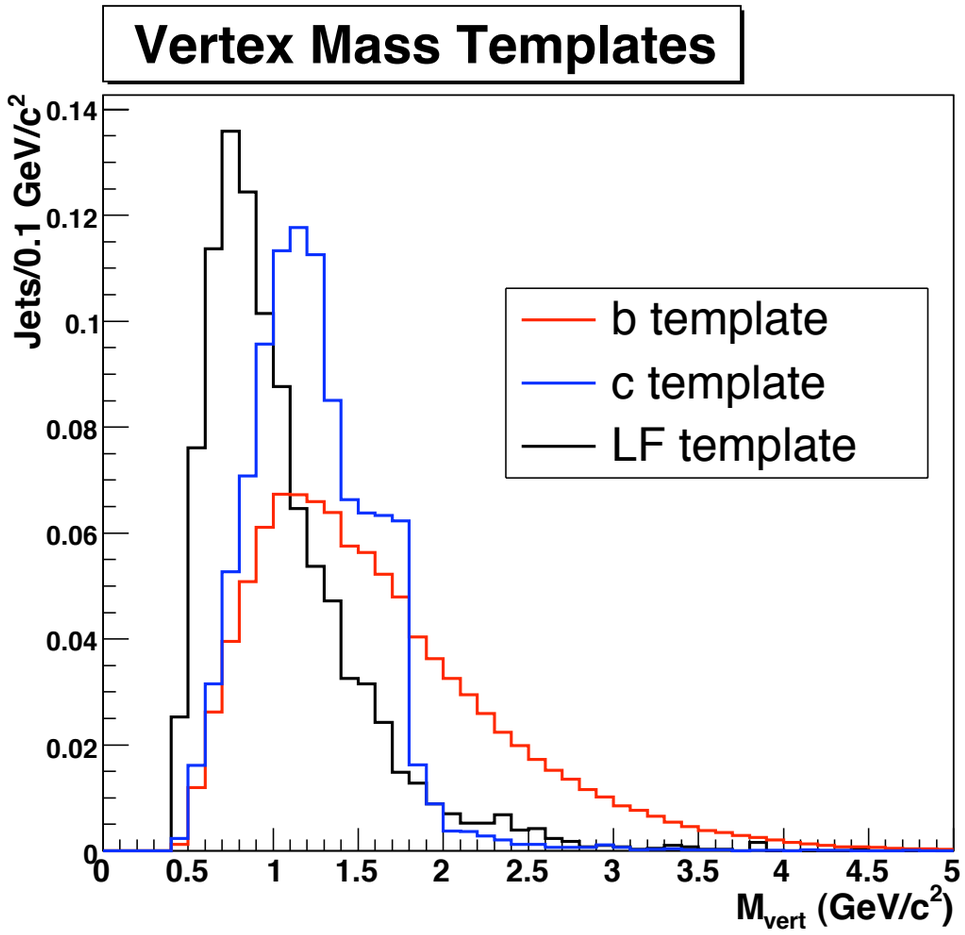
in agreement with LO pQCD predictions

PLB 666, 23 (2008)

W + b-jets

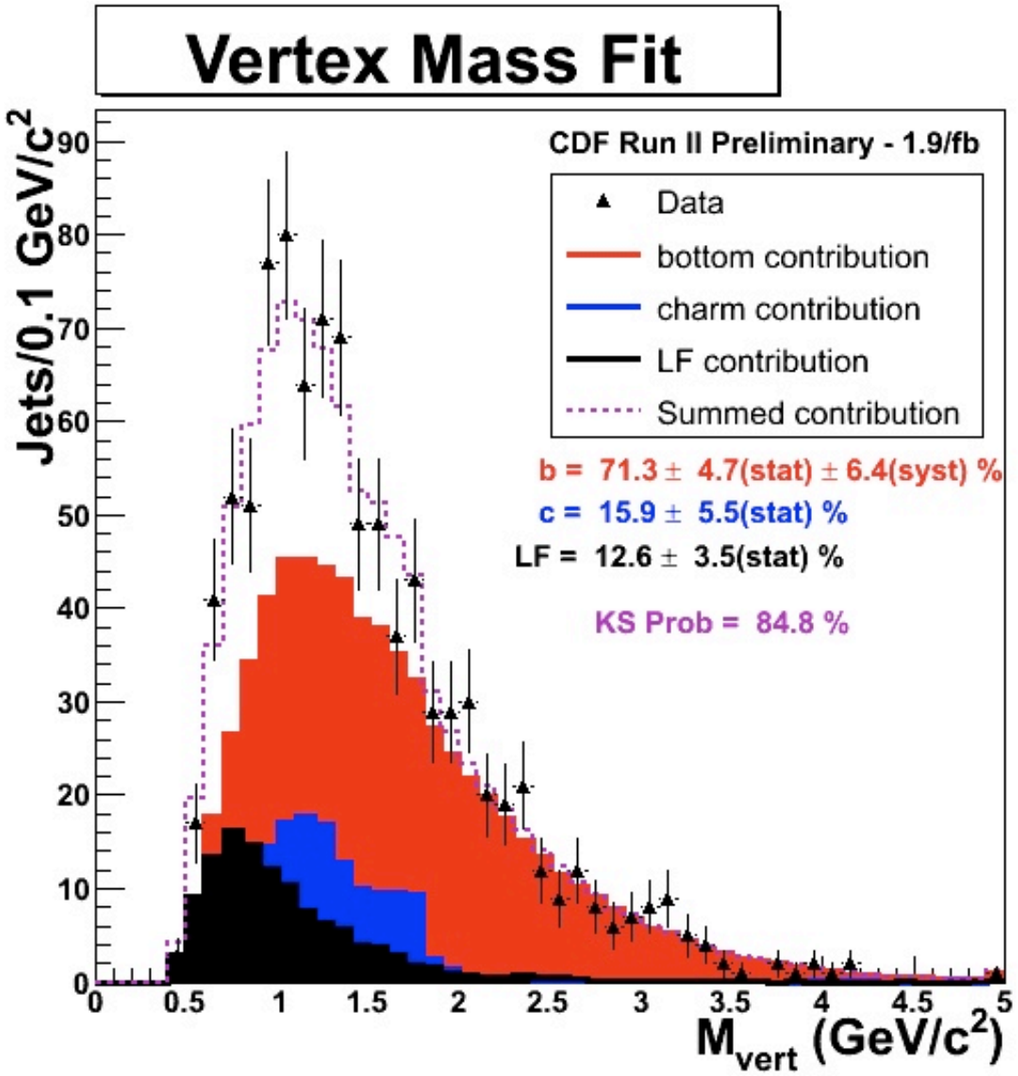
1.9 fb^{-1}

- Restricted phase space to:
  - Electron and muon channels
    - pt > 20 GeV and $|\eta|$< 1.1 , MET > 25 GeV
  - one or two jets, reconstructed with a cone algorithm with R=0.4
    - E_T > 20 GeV and $|\eta|$< 2.0
- Methodology
  - events with at least one b-tagged (ultra-tight secondary vertex requirements)
  - Use vertex mass to discriminate between b, c and light jets.



- Templates obtained from MC (Alpgen+Pythia)
- Backgrounds from data (multijets) and MC

W + b-jets



1.9 fb^{-1}

PRL 104, 131801 (2010)

Systematics

- dominated by vertex mass model (8%), b-tagging efficiency uncertainty (6%) and Luminosity (6%)

Alpgen prediction

- $Q^2 = m^2_W + p^2_{T,W}$, 0.78 pb

NLO pQCD = 1.22 ± 0.14 (syst)

$\sigma_{bjets} \times BR(W \rightarrow l\nu) = 2.74 \pm 0.27\ (stat) \pm 0.42\ (syst)$ pb

Z/γ^* + b-jets

2 fb^{-1}

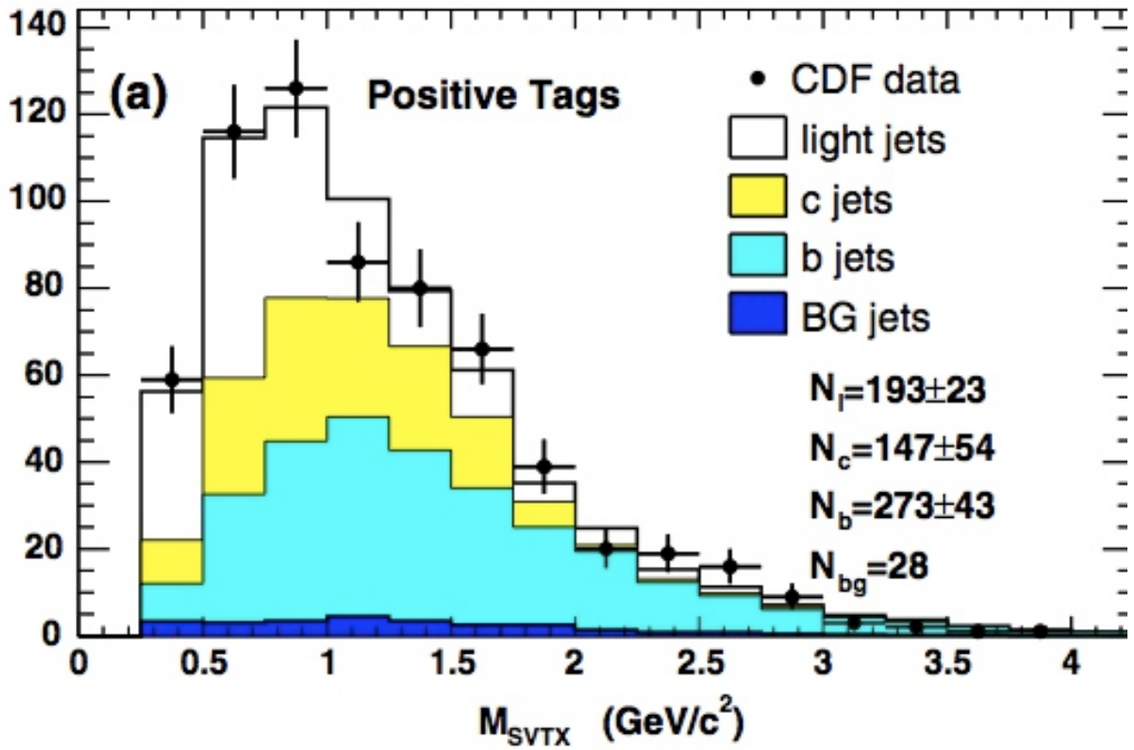
PRD 79, 052008 (2009)

Selection

- $76 < M_{\ell\ell} < 106$ GeV , with ℓ an electron or muon
- Jets reconstructed with cone algorithm with R=0.7, $E_T > 20$ GeV and $|\eta| < 1.5$.

Methodology

- At least 1 b-tagged (tight secondary vertex)
- Use vertex mass to discriminate between b, c and light jets.
- Templates obtained from MC (Alpgen +Pythia)
- Backgrounds from data (multijets) and MC



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

Systematics due to modeling, i.e template shapes and b-tagged efficiency uncertainty

Z/γ* + b-jets

2 fb^{-1}

PRD 79, 052008 (2009)

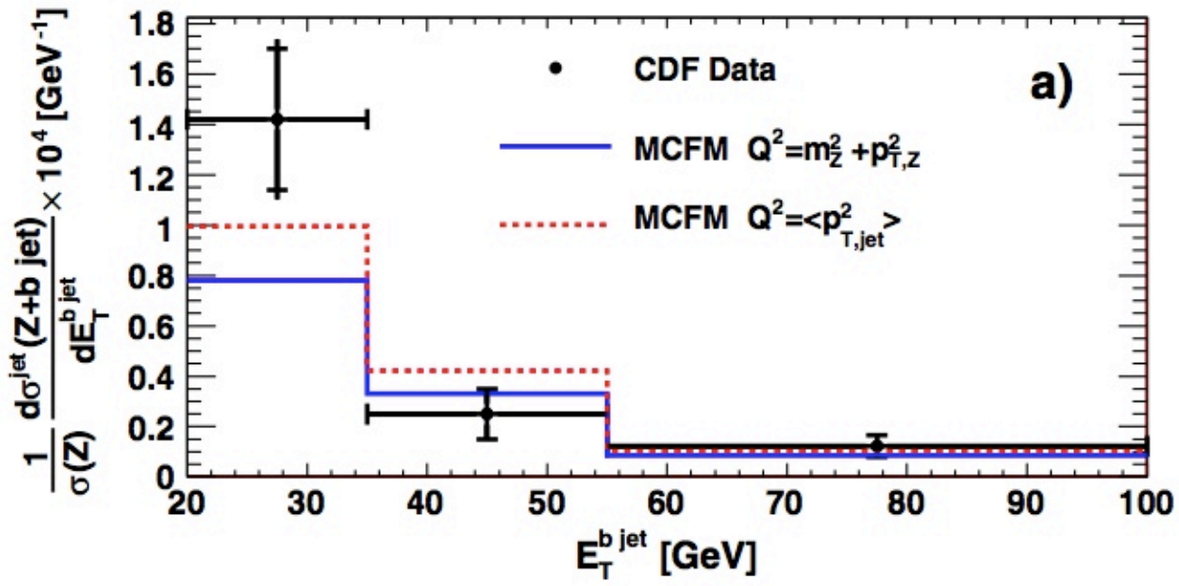
$$\frac{\sigma^{\text{jet}}(Z + b\,\text{jet})}{\sigma(Z)} = (3.32 \pm 0.53(\text{stat}) \pm 0.42(\text{syst})) \times 10^{-3}.$$

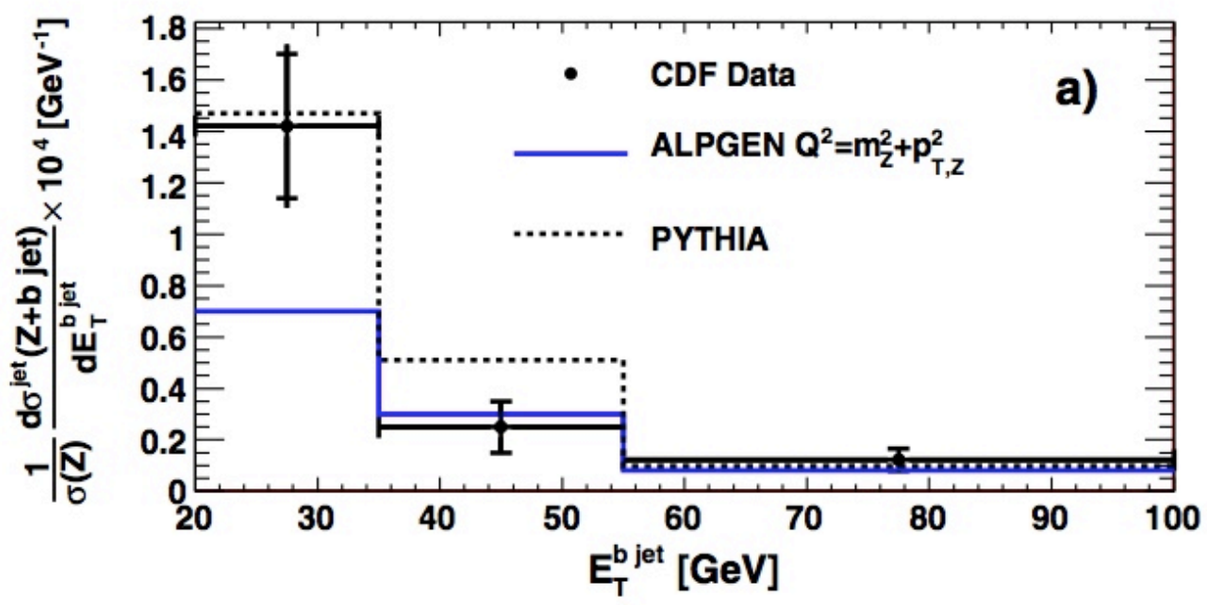
MCFM prediction

$Q^2 = m^2_Z + p^2_{T,Z}$	2.3 x 10^{-3}
$Q^2 = \langle p^2_{T,\text{jet}} \rangle$	2.8 x 10^{-3}

Non-pQCD corrections of order of 8%

- Measurements in agreement with predictions
- Though large variation on both, theory and data



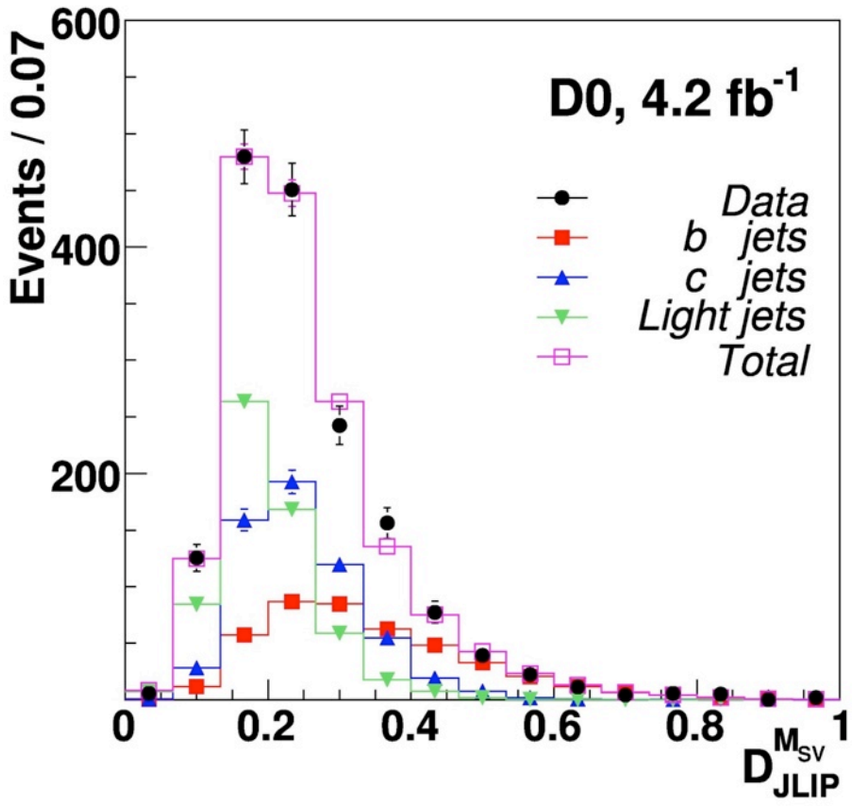


Z/γ^* + b-jets

4.2 fb^{-1}

- $70 < M_{\ell\ell} < 110$ GeV , with ℓ an electron or muon
- Jets reconstructed with midpoint algorithm with R=0.5, $p_T > 20$ GeV and $|\eta| < 2.5$
- At least 1 b-tagged (NN based)
- Build discriminant using vertex mass and track probability to originate from primary vertex
- Templates obtained from MC (Alpgen +Pythia) and negatively tagged data (for light jets)
- Backgrounds estimate from data (fakes coming from multijets) and MC

PRD 83, 031105(R) (2011)



$\sigma(Z + b\ jet) / \sigma(Z + jet) = 0.0193$
$\pm$ 0.0022 (stat) $\pm$ 0.0015 (syst)

In agreement with

MCFM prediction

$Q^2 = m^2_Z$ 0.0192 $\pm$ 0.0022

SUMMARY

- Presented a large suite of W/Z+jets measurements from Tevatron
- General good agreement with NLO pQCD predictions
- Available larger datasets that allow to

  ➡ achieve better precision, challenging that of theory predictions

  ➡ explore higher jet multiplicity and provide variety of distributions to test MC models

    - expect soon Z+jets distributions for njet ≥3 (electron and muon channel combination) and updates on W+jets, Wc and Zb measurements

Details at CDF and D0 web pages:

- http://www-cdf.fnal.gov/internal/physics/qcd/qcd.html
- http://www-d0.fnal.gov/Run2Physics/WWW/results/qcd.htm