Z/γ^*+Jets and photon+b/c Measurements at DØ

Murilo Rangel

on behalf of the DØ collaboration

OUTLINE:

- **INTRODUCTION**
- **ANALYSIS / RESULTS**
- **CONCLUSION**

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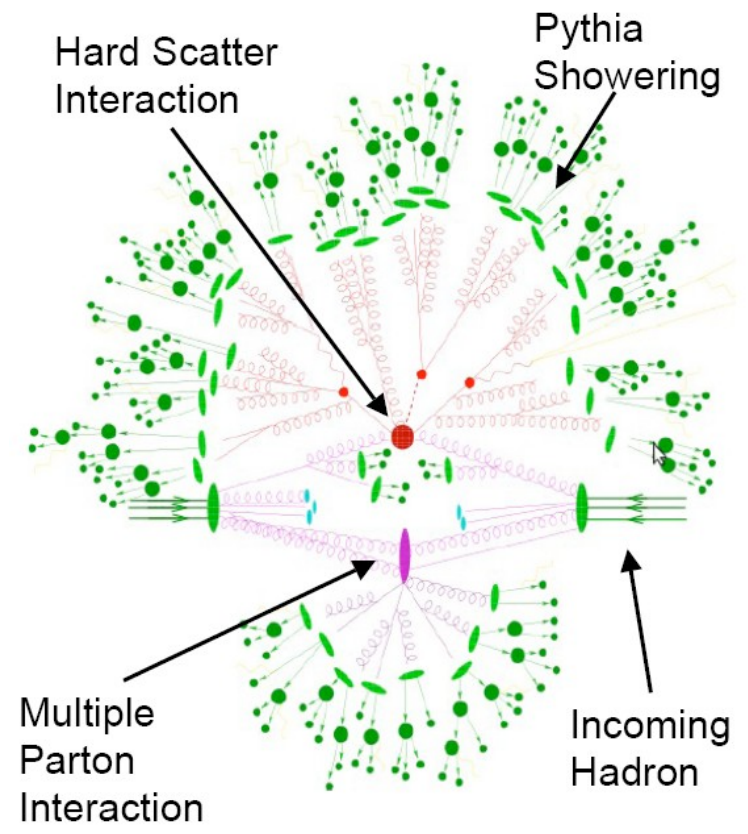
MOTIVATION

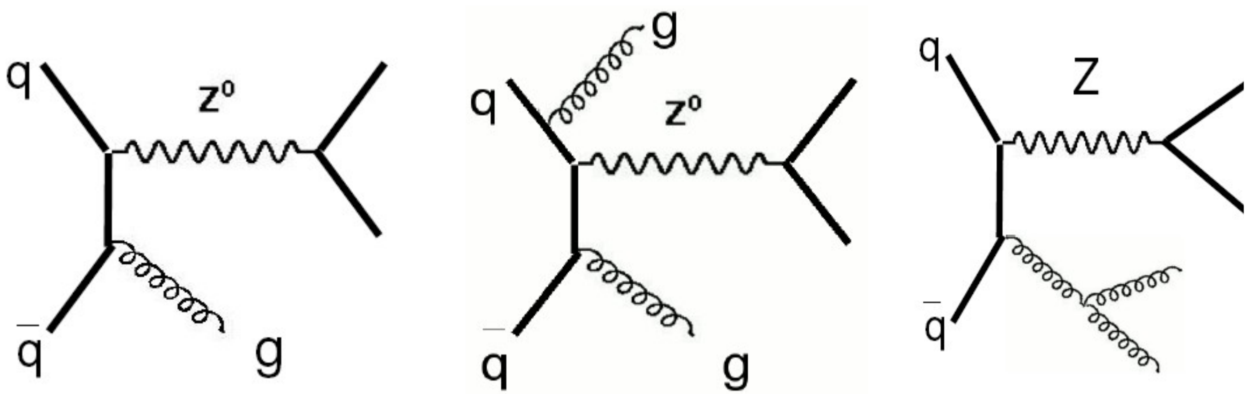
Z+Jets

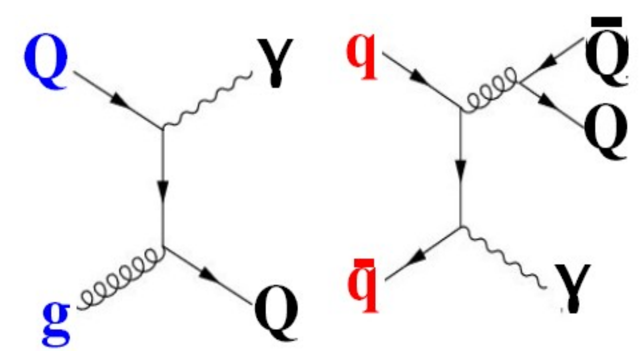
- Test perturbative QCD and parton shower models
- Comparison with different event generators
- It is a major background for small cross section processes
- Clean signature and high purity

Photon+heavy flavor

- Probe of heavy flavor and gluon contents of hadrons
- Probe gluon splitting to heavy flavor quark pairs
- Small cross section productions benefit from this knowledge
- High statistics and good energy measurement of the photon

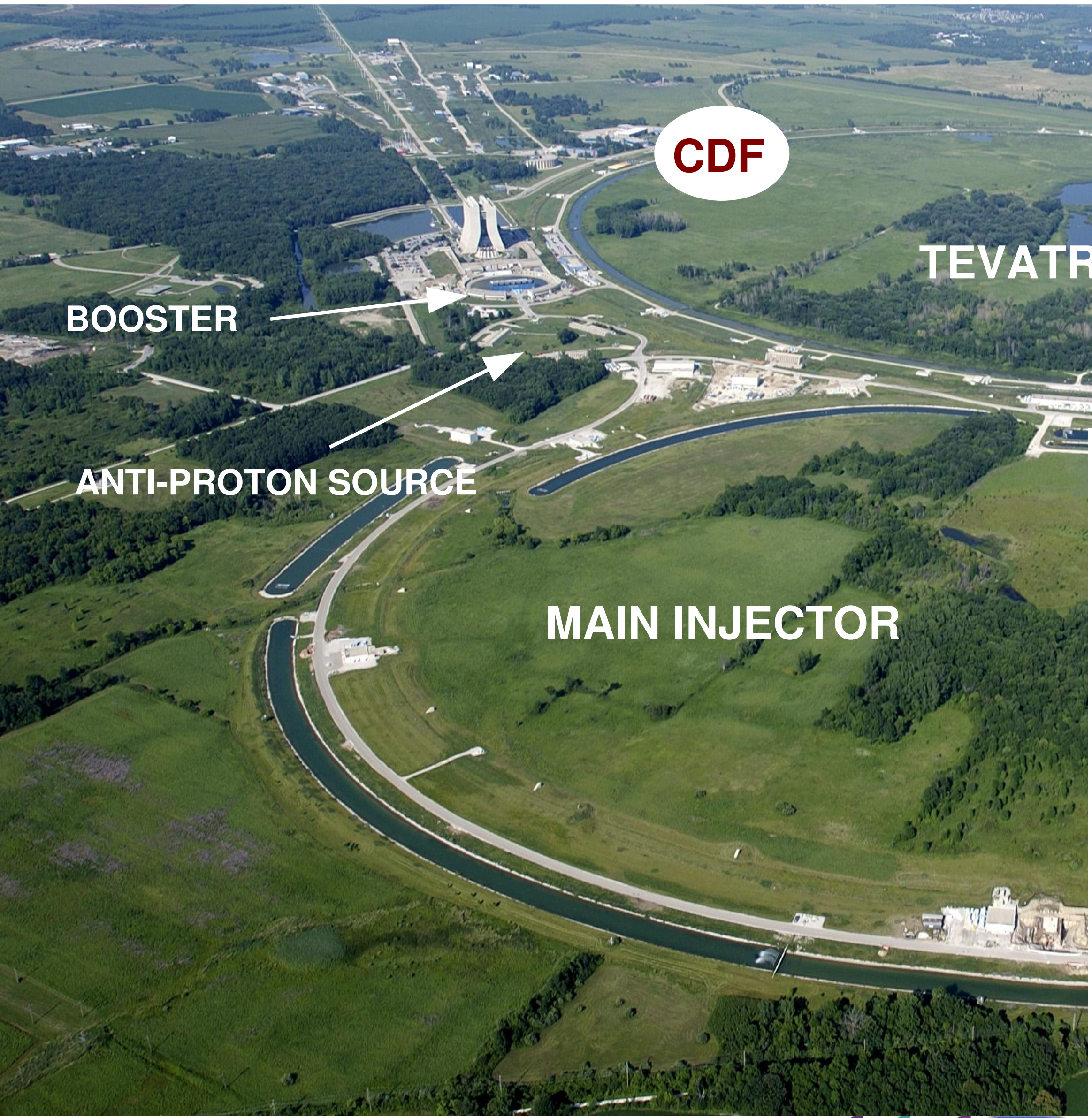


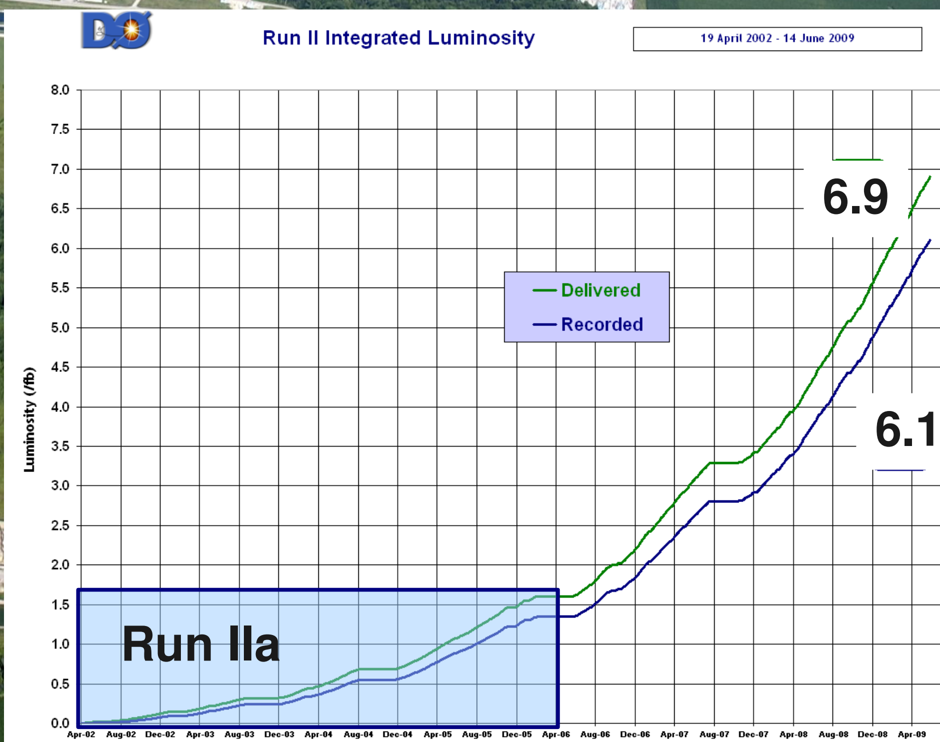




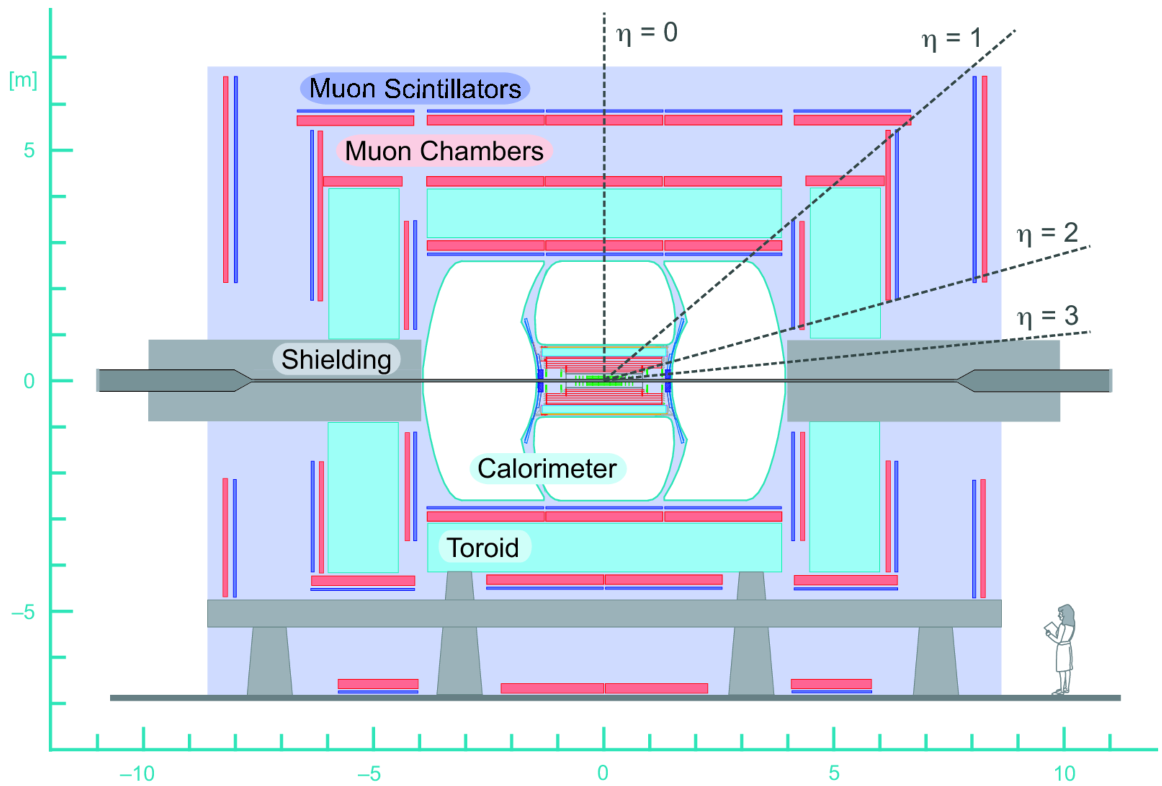
TEVATRON

Currently taking DATA of proton-antiproton collisions at 1.96 TeV
70/pb per week and already 6/fb in tape
DØ Run IIa jet physics well understood





DØ DETECTOR



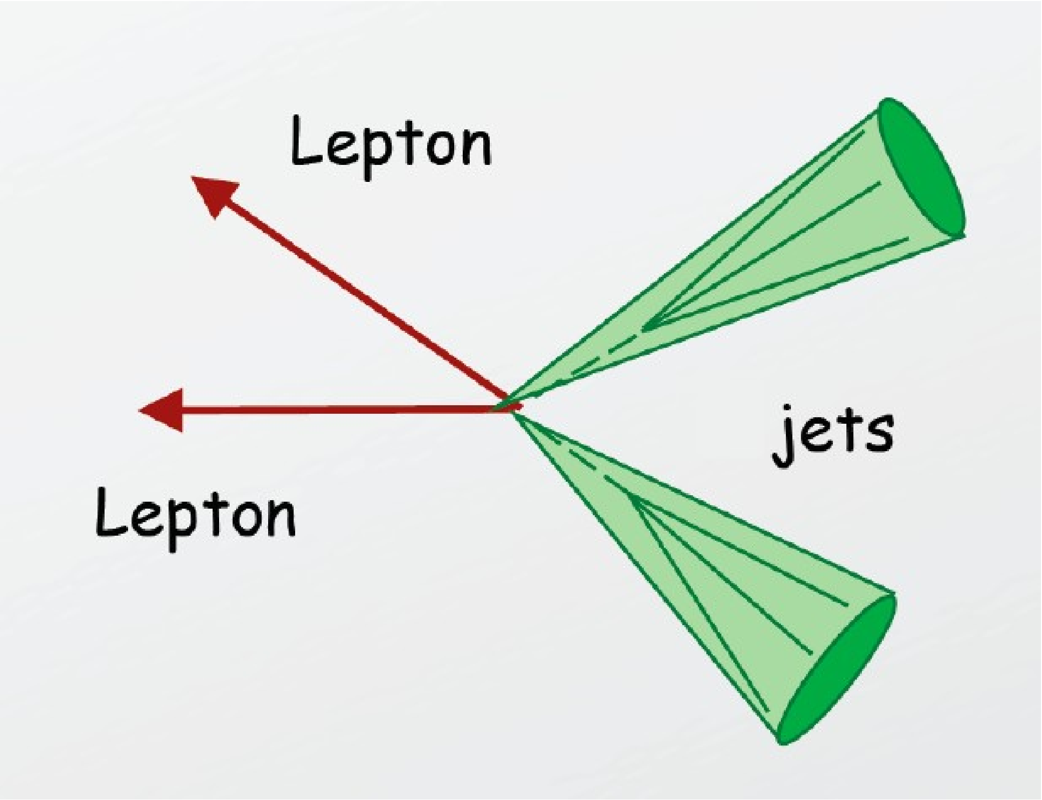
- Fiber and Silicon detectors for tracking in 2T superconducting solenoid magnet - $|\eta| < 2.5$

- Liquid Ar calorimeter (fine segmentation) + Ur calorimeter - $|\eta| < 4$

- Muon spectrometers using 1.8 T toroidal iron magnets - $|\eta| < 2.0$

Muons

- p_T > 15 GeV
- $|\eta|$ < 1.7
- Matched track
- ΔR(jet,muon) > 0.5
- 65 GeV < $M(\mu,\mu)$ < 115 GeV



Electrons

- p_T > 25 GeV
- $|\eta|$ < 1.1 and 1.5 < $|\eta|$ < 2.5
- Matched track
- 65 GeV < $M(e,e)$ < 115 GeV

Jets

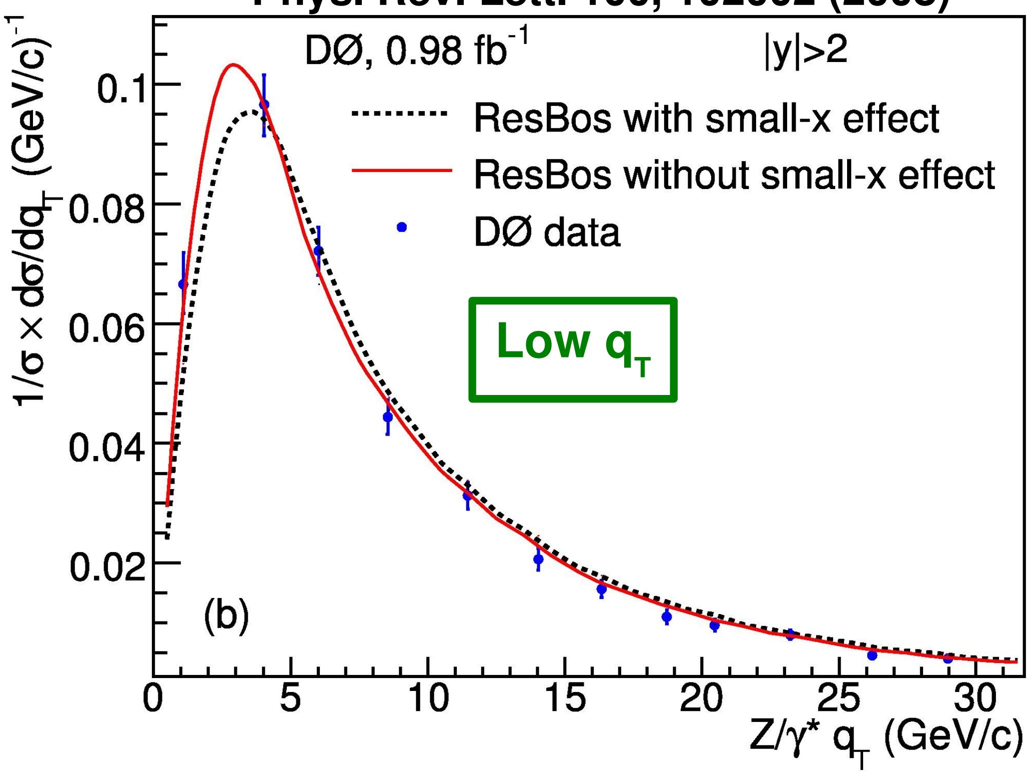
- reconstructed by D0 RunII iterative seed-based algorithm $\Delta R = 0.5$
- p_T > 20 GeV
- $|\eta|$ < 2.5 (ee)
- $|\eta|$ < 3.2 ($\mu\mu$)

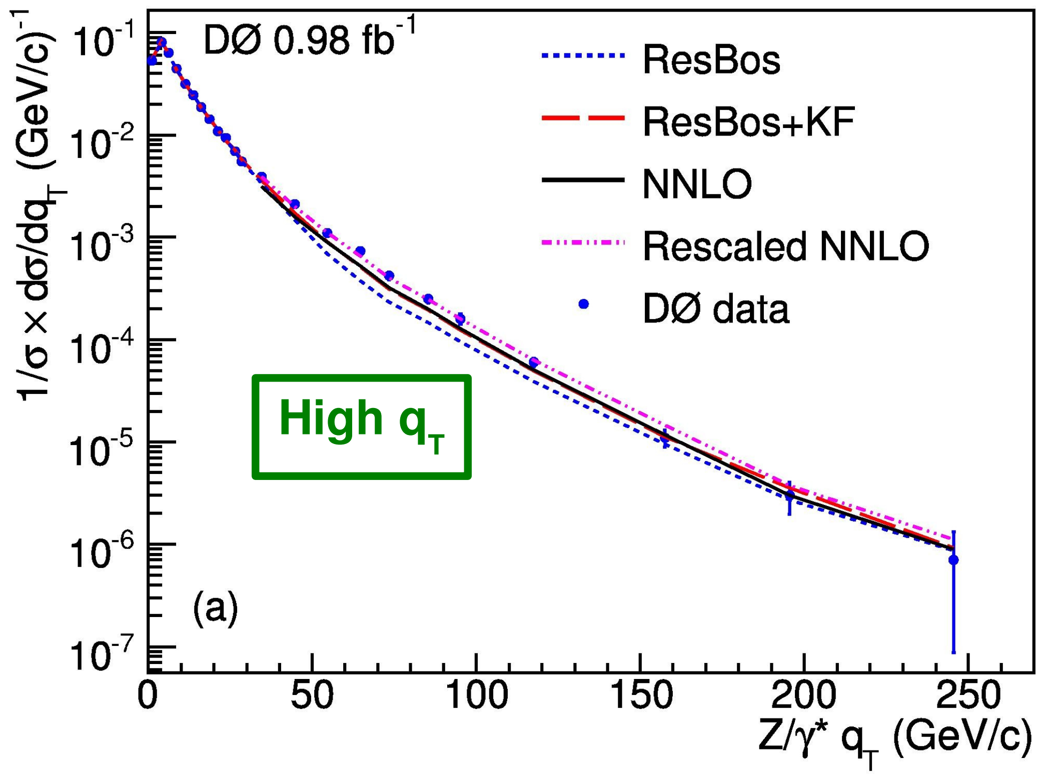
DATA is unfolded to particle level

- **low q_T high |y|** : small-x non-perturbative test (BLNY) with and without modified form factors from small-x DIS data

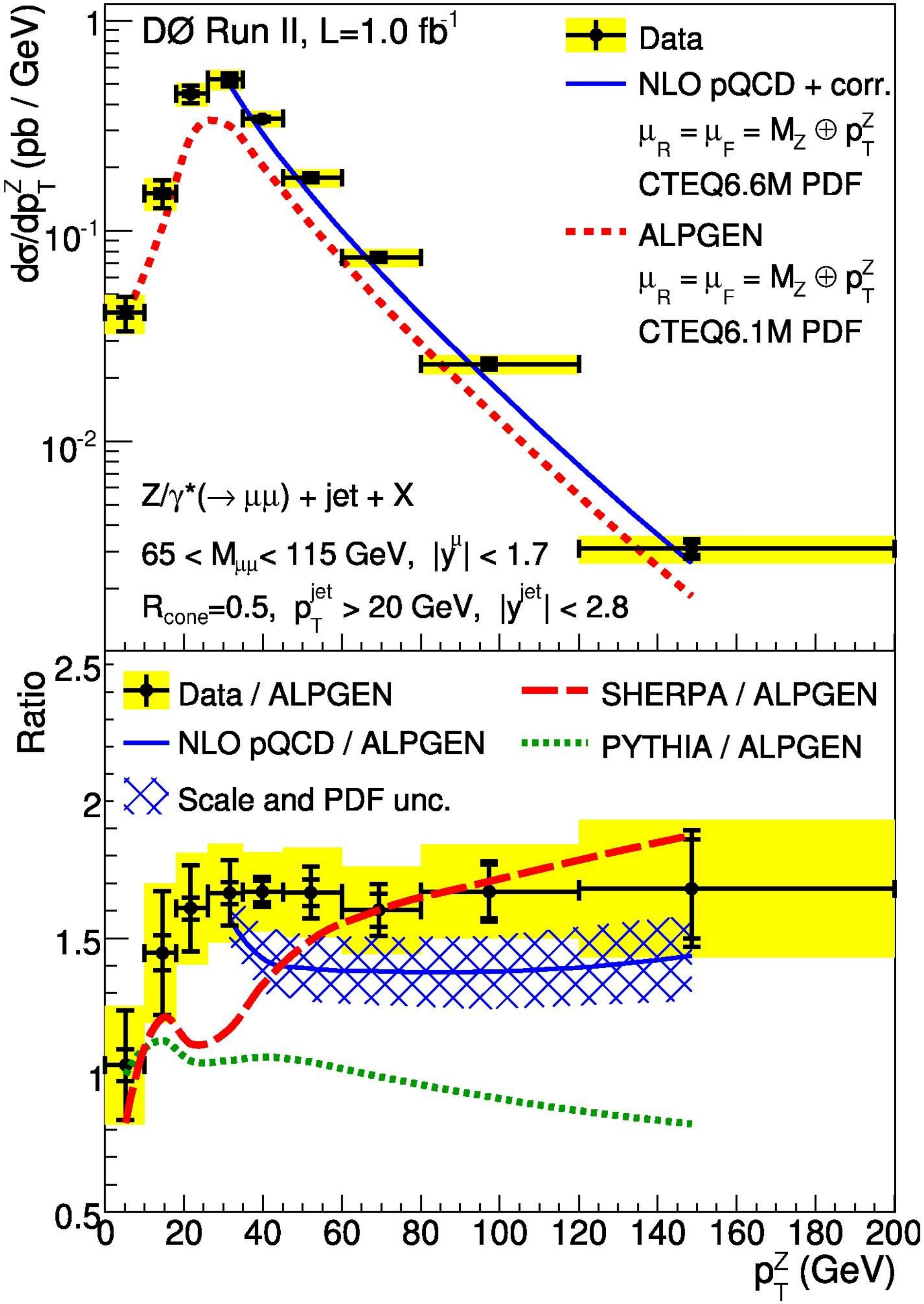
- **high q_T**: perturbative calculation test. NNLO is off by a factor of 1.25

Phys. Rev. Lett. 100, 102002 (2008)





Z/γ^* AND JET MEASUREMENTS (pp → Z/γ^* (→ $\mu\mu$) + jet + X)



DATA is corrected to particle level

Non-perturbative effects at low p_T not well described

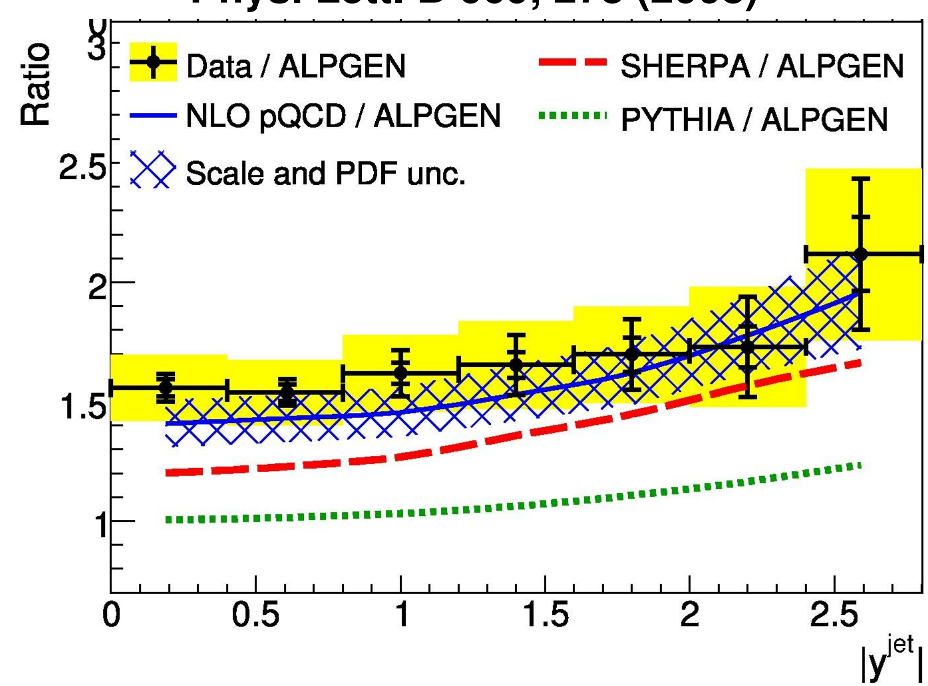
NLO agrees within errors

Event generators predict lower cross sections

Alpgen has more central jets

High p_T slope differences in SHERPA and PYTHIA

Phys. Lett. B 669, 278 (2008)



ANGULAR MEASUREMENTS (pp → Z/γ* (→μμ) + jet + X)

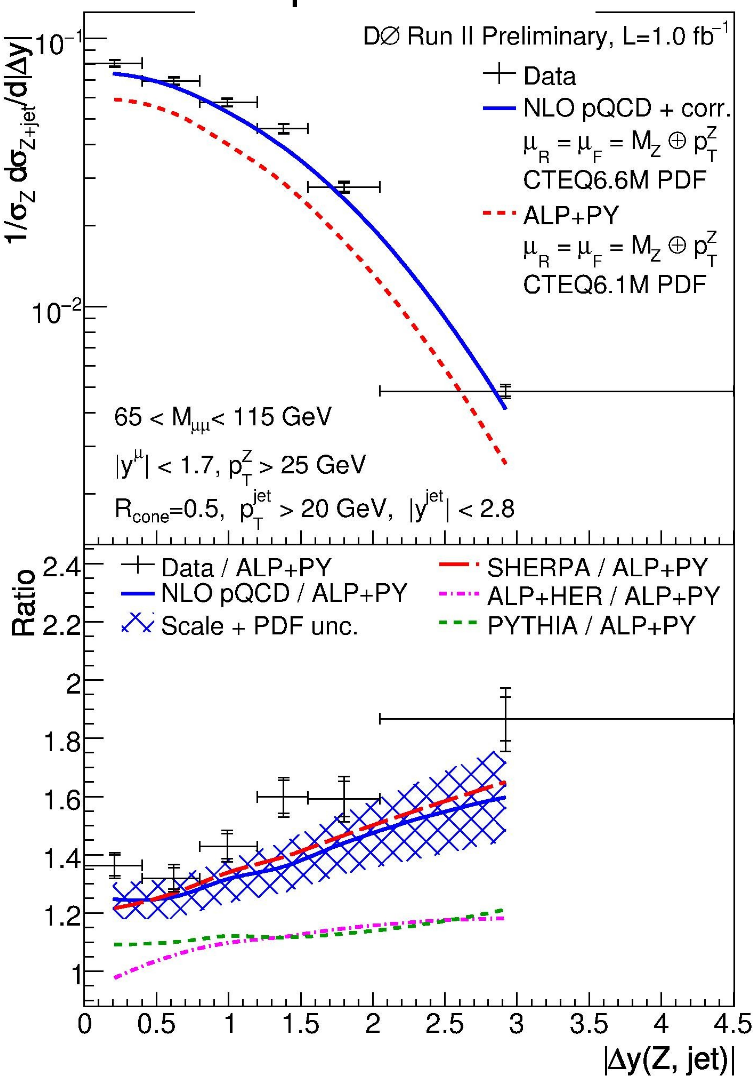
Measurements for 2 different Z p_T thresholds

NLO is in fair agreement with DATA

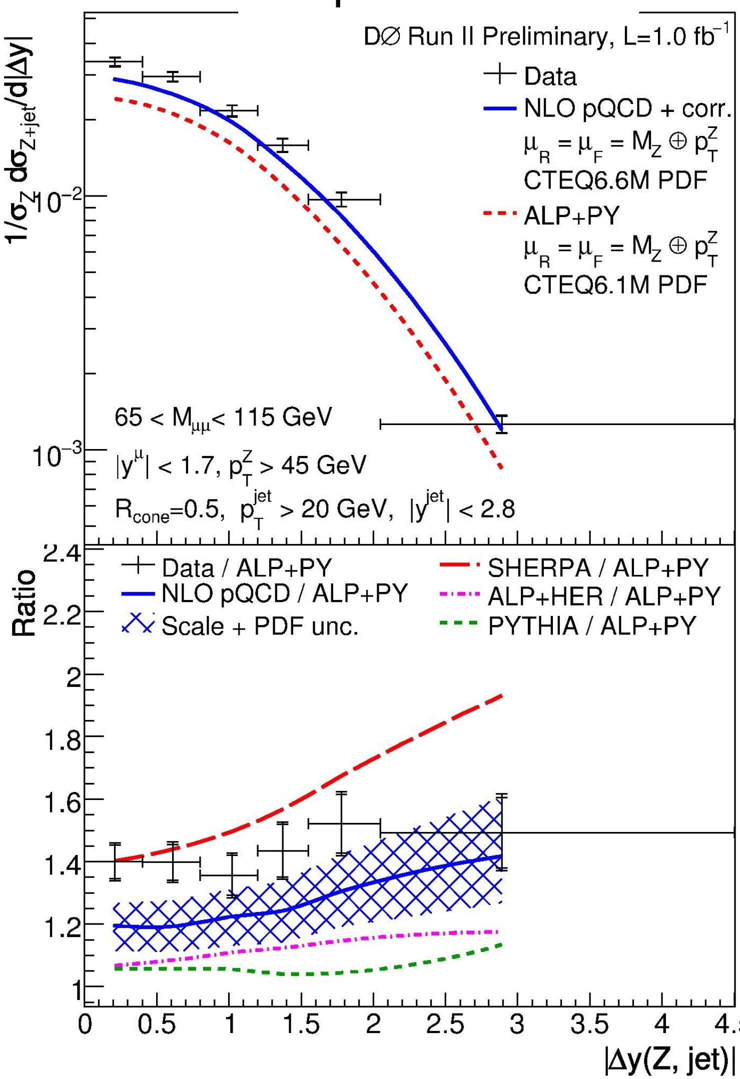
Sherpa agrees with DATA Z p_T > 25 GeV and has shape difference for Z p_T > 45 GeV

Other event generators have the correct shape

Z p_T > 25 GeV



Z p_T > 45 GeV



Scale discrepancy

Alpgen and Pythia

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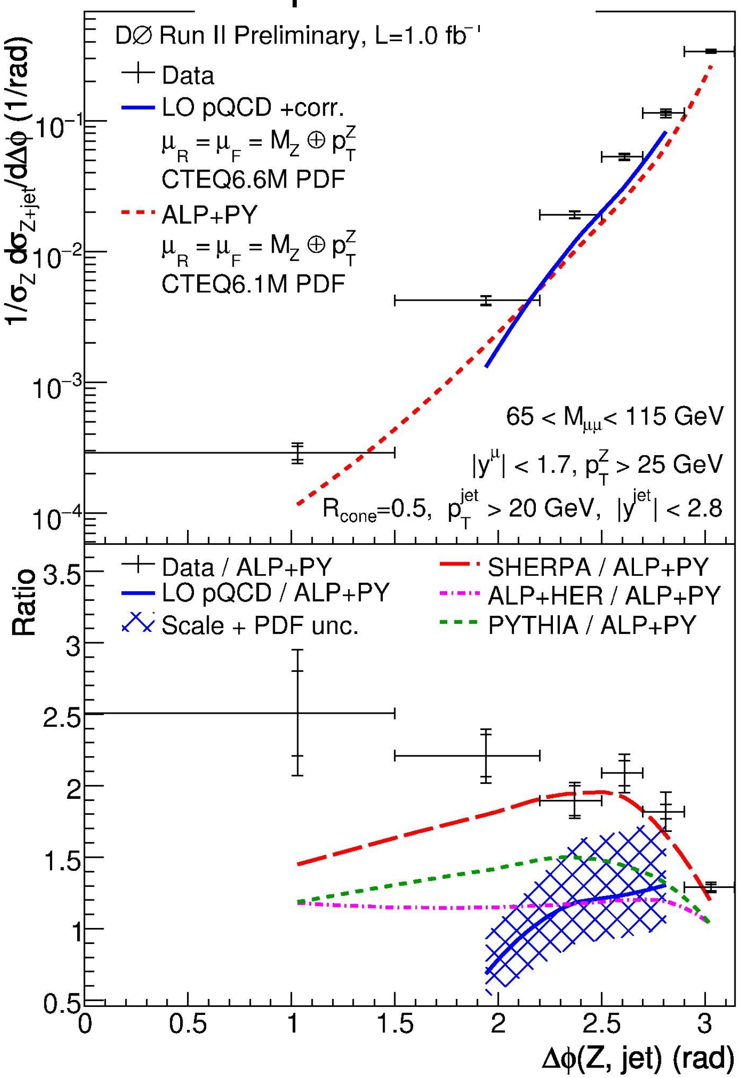
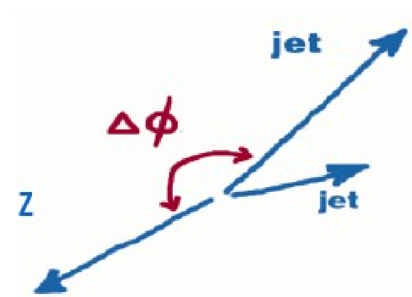
ANGULAR MEASUREMENTS $(pp \rightarrow Z/\gamma^* (\rightarrow \mu\mu) + jet + X)$

Measurements for 2 different Z p_T thresholds

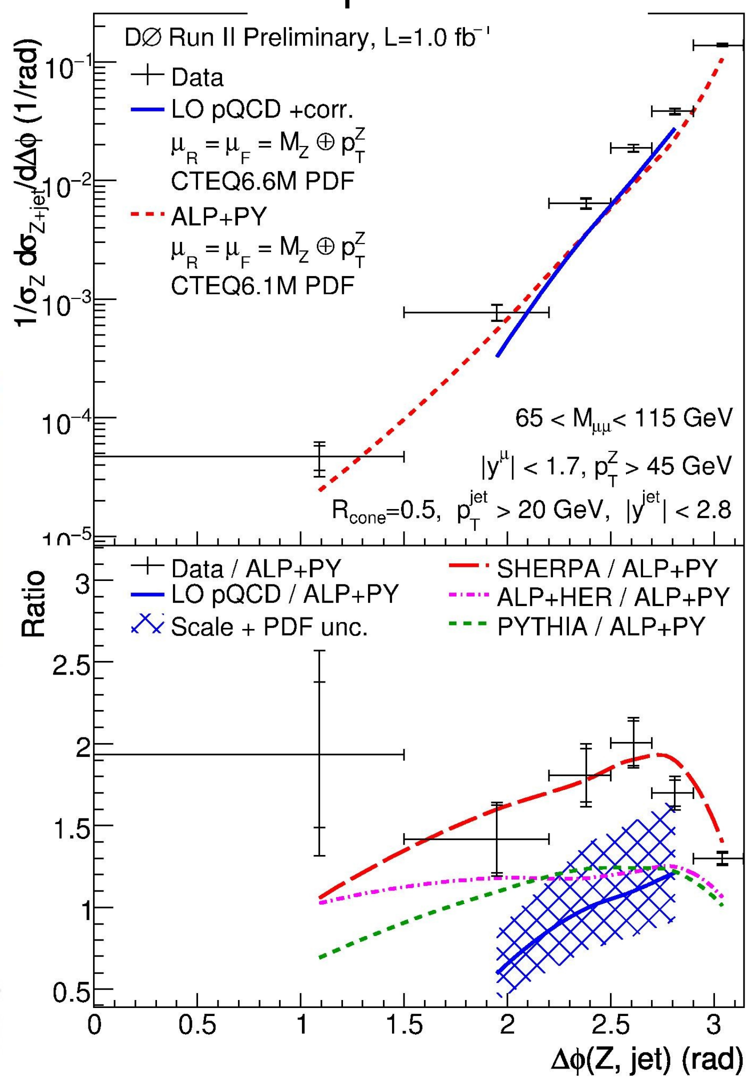
LO is shown (NLO not available by publication)
Sherpa provides a good description while other event generators have a normalization differences

Z p_T > 25 GeV





Z p_T > 45 GeV



JET MEASUREMENTS (pp → Z/γ* (→ee) + jet + X)

NLO improves over LO

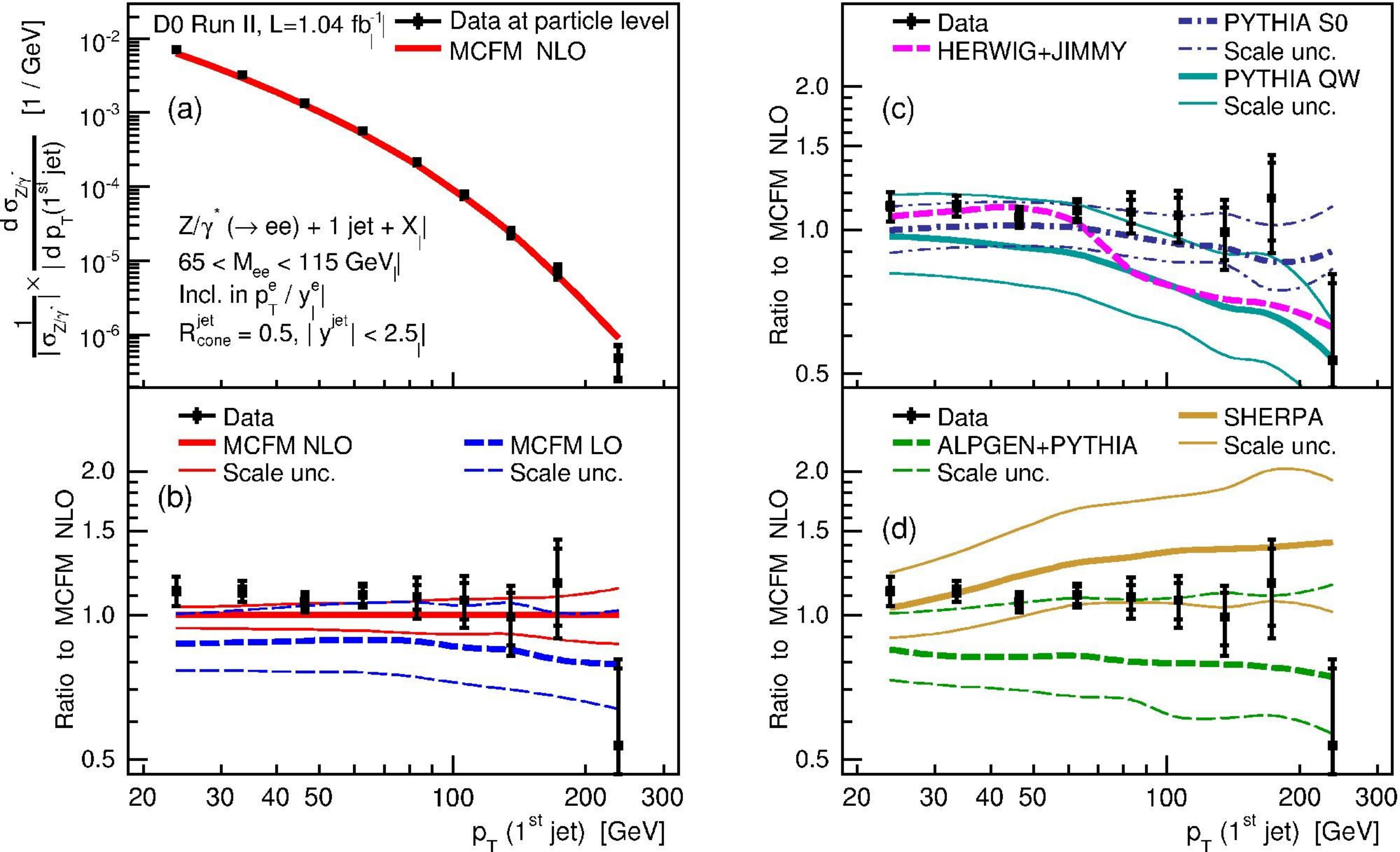
Pythia with p_T ordered (tune S0) has better agreement

Alpgen+Pythia agrees in shape but not in normalization

Herwig disagrees for p_T > 50 GeV

Sherpa predicts a less steeply falling spectrum

Phys. Lett. B 678, 45 (2009)



JET MEASUREMENTS (pp → Z/γ* (→ee) + jet + X)

NLO improves over LO

Both Pythia tunes (tune S0, tune QW) and Herwig do not agree in shape

Alpgen+Phytia and Sherpa agree in shape but not in normalization

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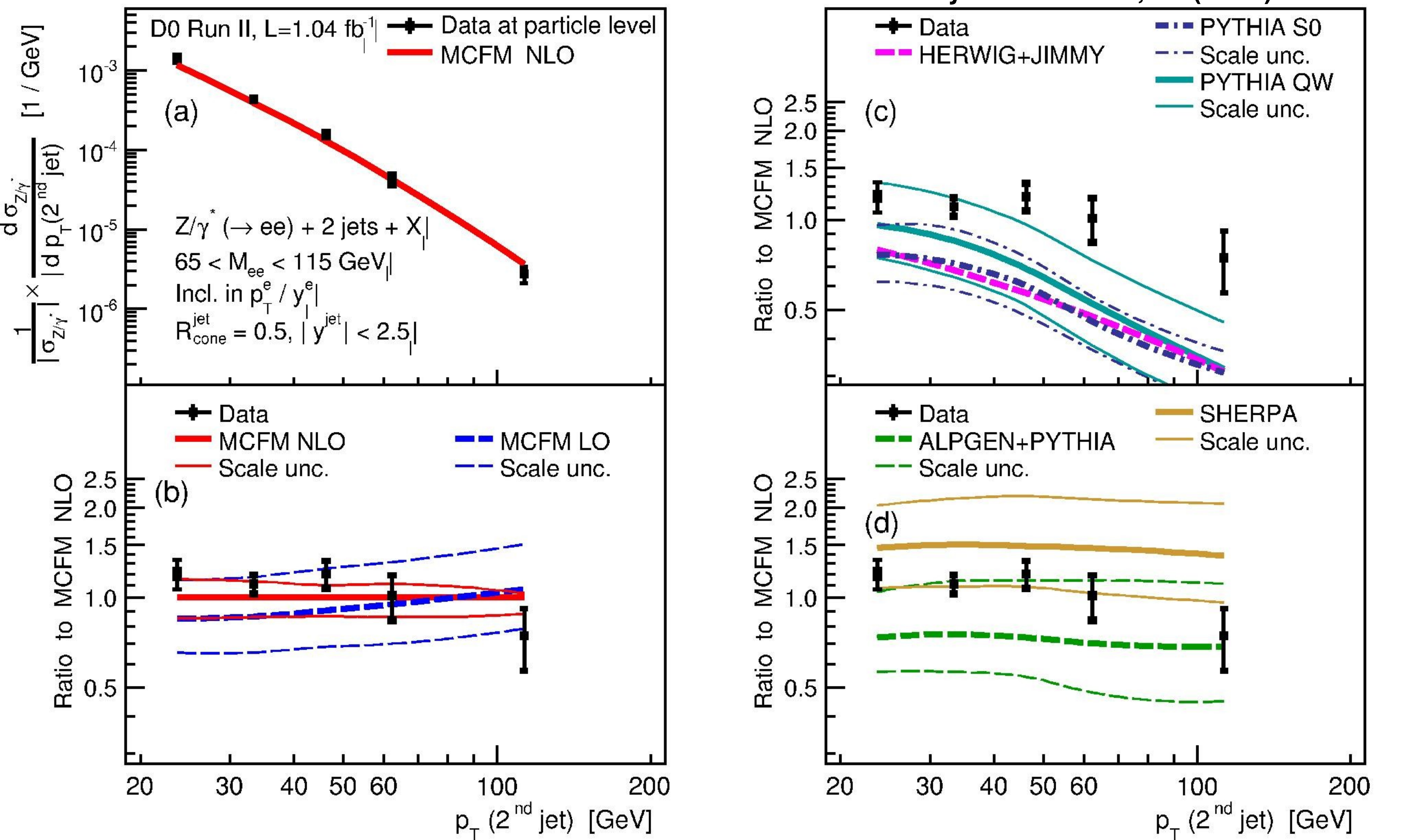

JET MEASUREMENTS (pp → Z/γ* (→ee) + jet + X)

LO is in good agreement with DATA

Both Pythia tunes (tune S0, tune QW) and Herwig do not agree in shape

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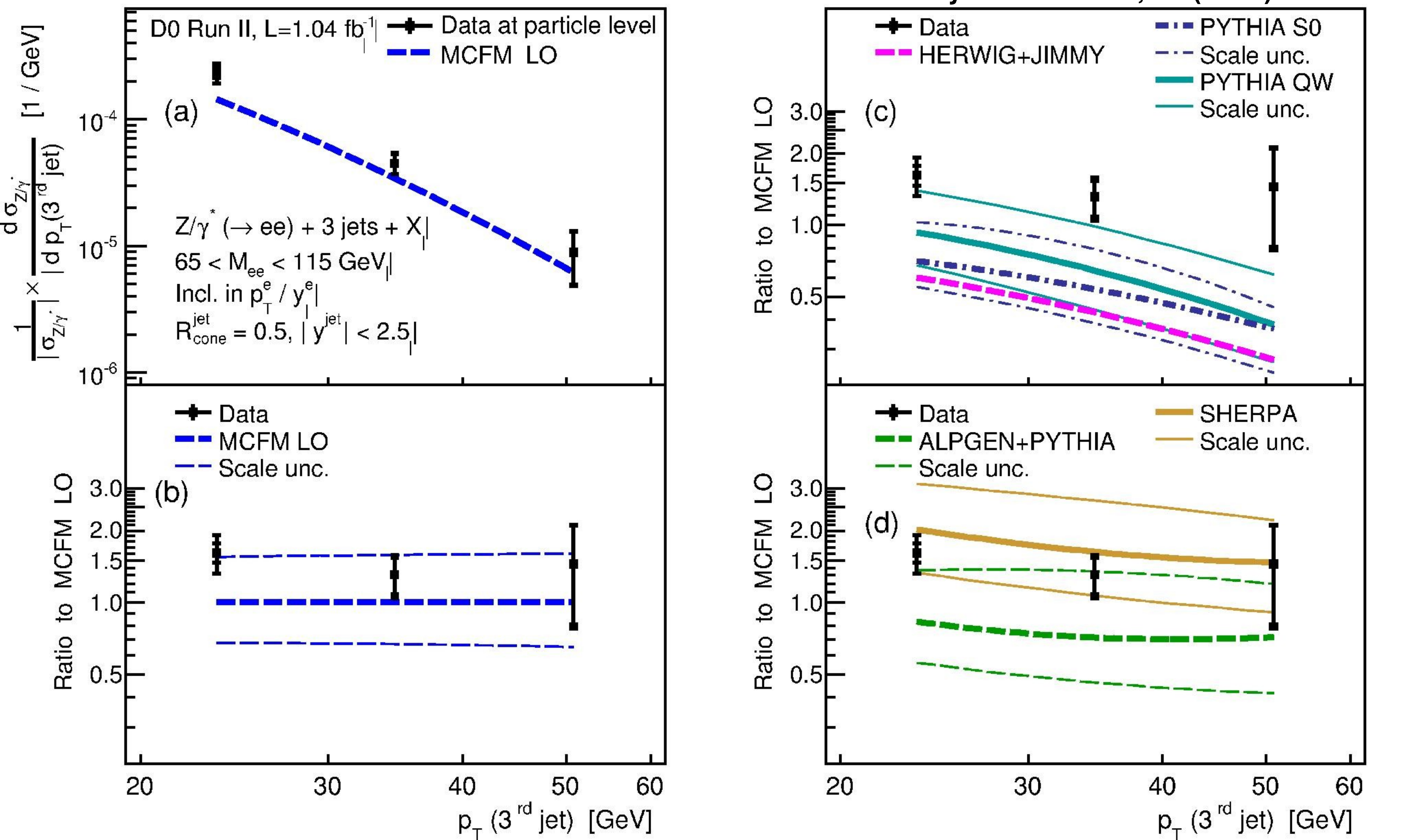
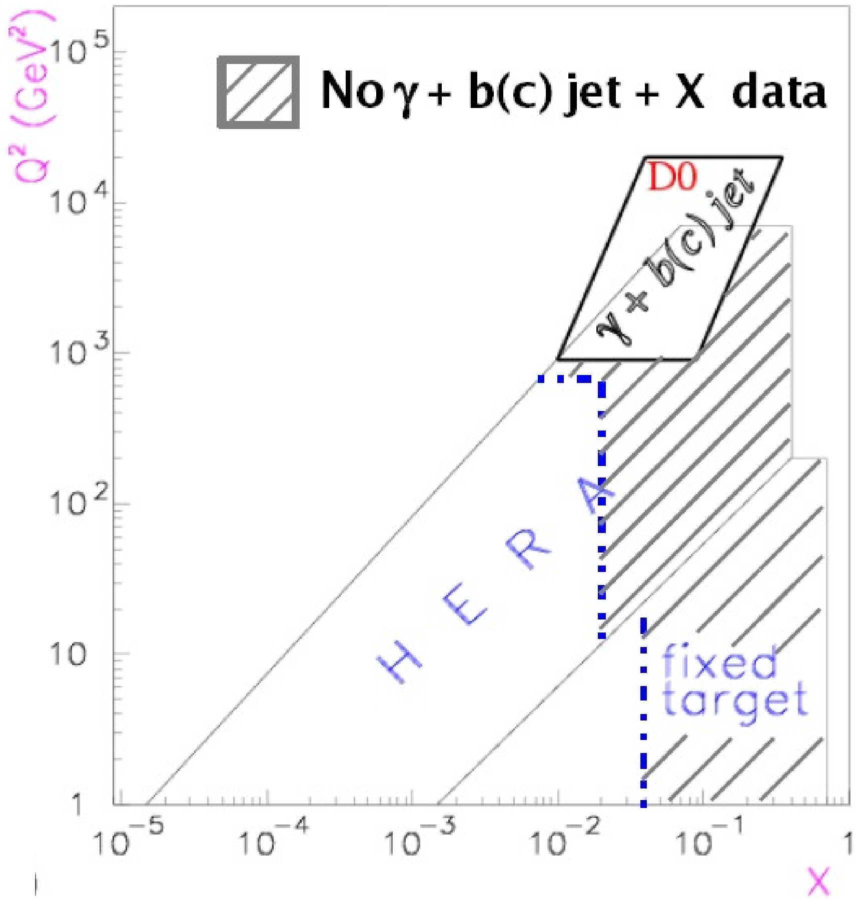


Photon

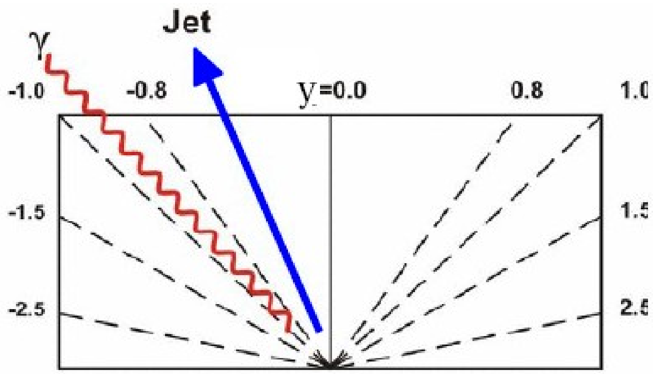
- $p_T > 30$ GeV
- $|y| < 1.0$
- Clusters of $\Delta R = 0.4$
- Isolation criteria required
- NN to reject di-jet background

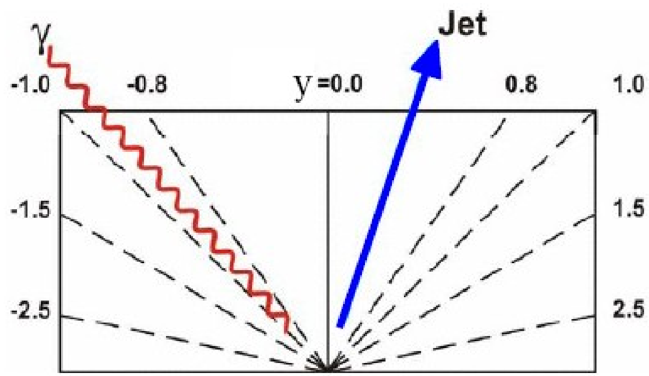
Jets

- reconstructed by D0 RunII algorithm $\Delta R = 0.5$
- $p_T > 15$ GeV
- $|y| < 0.8$



Two rapidity regions $y^{\gamma}y^{jet} > 0$ and $y^{\gamma}y^{jet} < 0$ ⇒ different intervals x accessed.





Steps

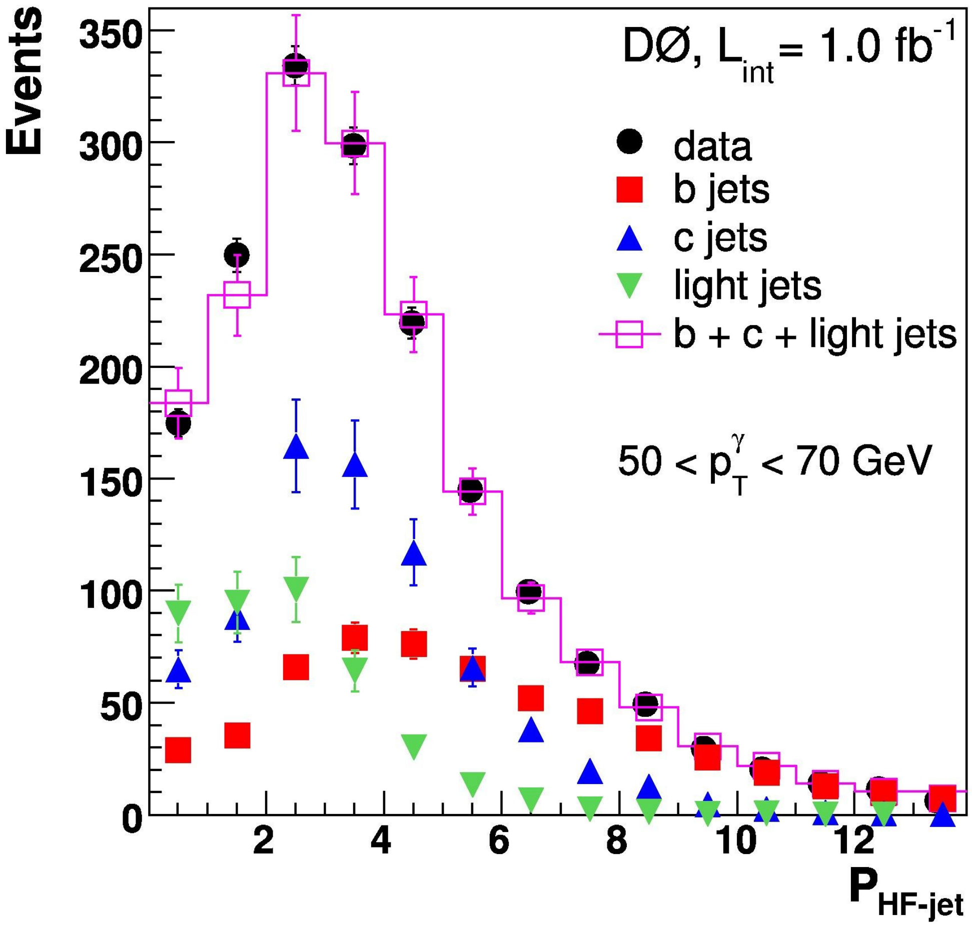
1- Determine photon purity fitting MC photon ID NN templates to DATA
2- Use a b-tagging NN to enhance heavy flavor content
3- Perform a template fitting procedure to estimate the heavy flavor fractions

Use templates of a heavy flavor sensitive variable:

$$P_{\text{HF-jet}} = -\ln \prod_i P^i_{\text{track}}$$

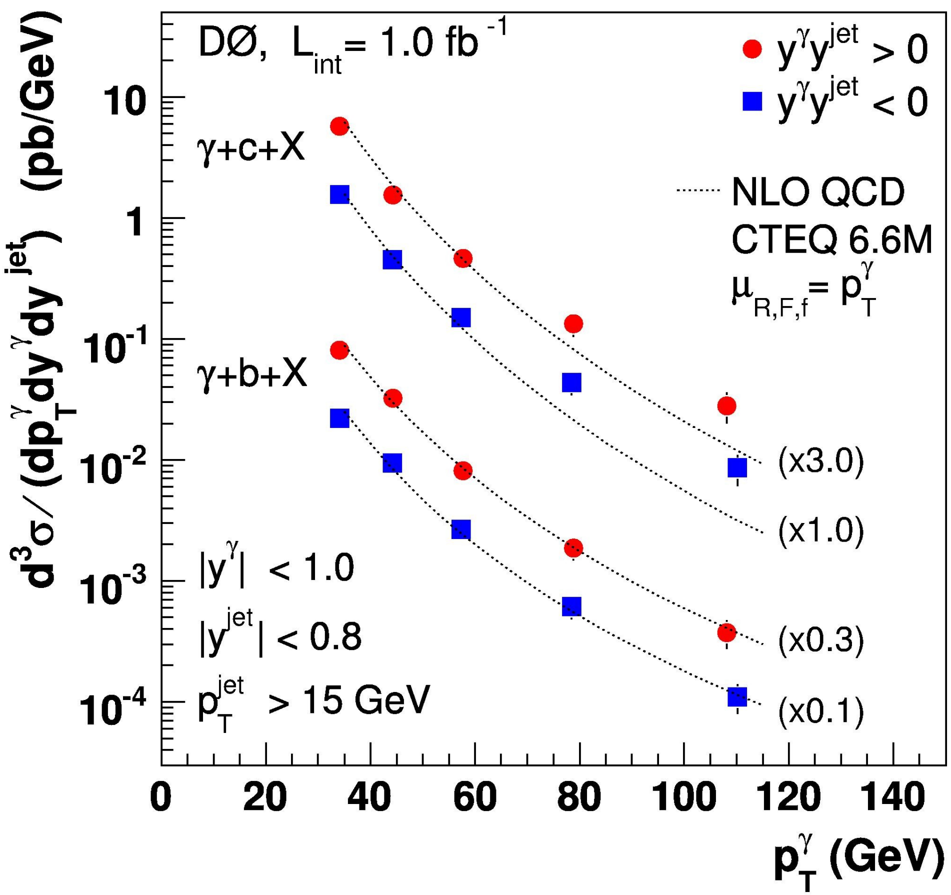
Light flavor template from DATA
Heavy flavor template from MC
fit constraint (light + c + b) = 1

Many consistency checks showed the method is very robust.

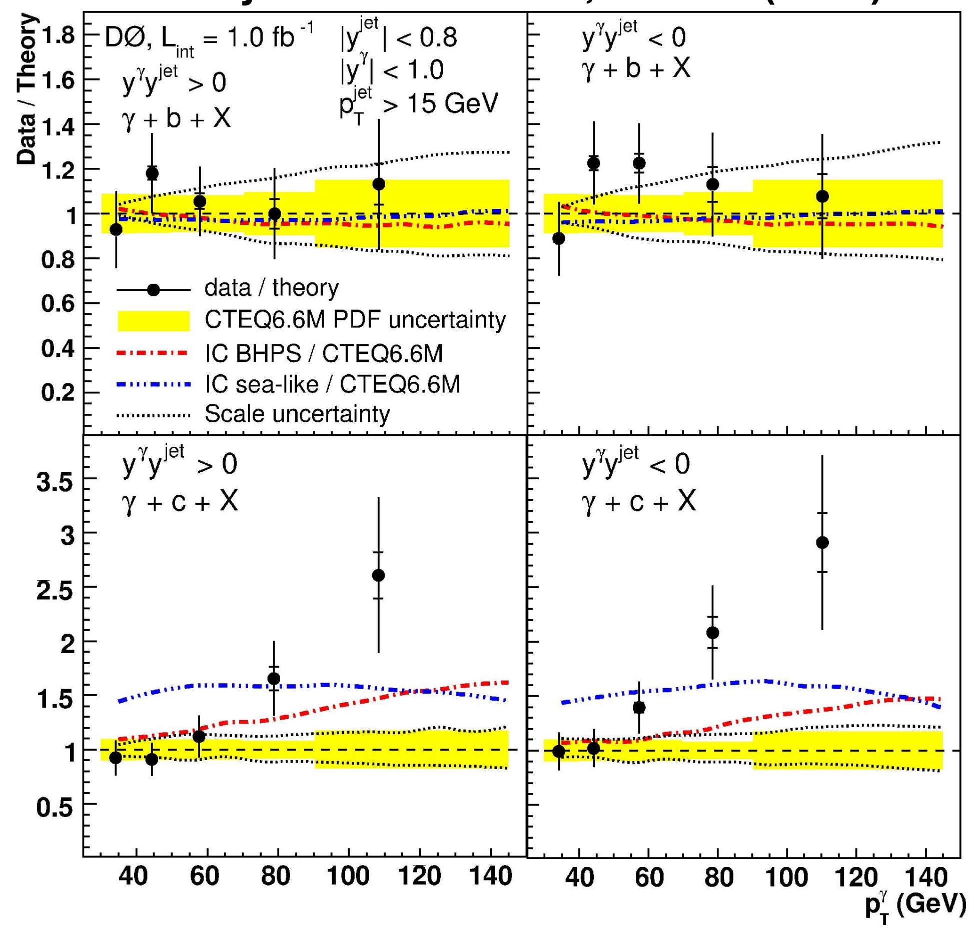


Photon + b ⇒ Good agreement

Photon + c ⇒ Discrepancy in both rapidity regions for $p_T > 70$ GeV



Phys. Rev. Lett. 102, 192002 (2009)



Two intrinsic charm parametrization included in CTEQ BHPS and sea-like

CONCLUSIONS

- Important tests of QCD and Electroweak predictions.

- Comparisons with event generators will improve physics background modeling and help to find undiscovered physics.

- **Z+jets**
  - NLO describes DATA, but not everywhere.
  - SHERPA is the best generator for angles, but not for transverse momentum.
  - All generators have large scale uncertainties.

- **Photon+heavy flavor**
  - Theory predictions work for photon+b, but not for photon+c.

REFERENCES

Phys. Rev. Lett. 100, 102002 (2008)

Phys. Rev. Lett. 102, 192002 (2009)

Phys. Lett. B 678, 45 (2009)

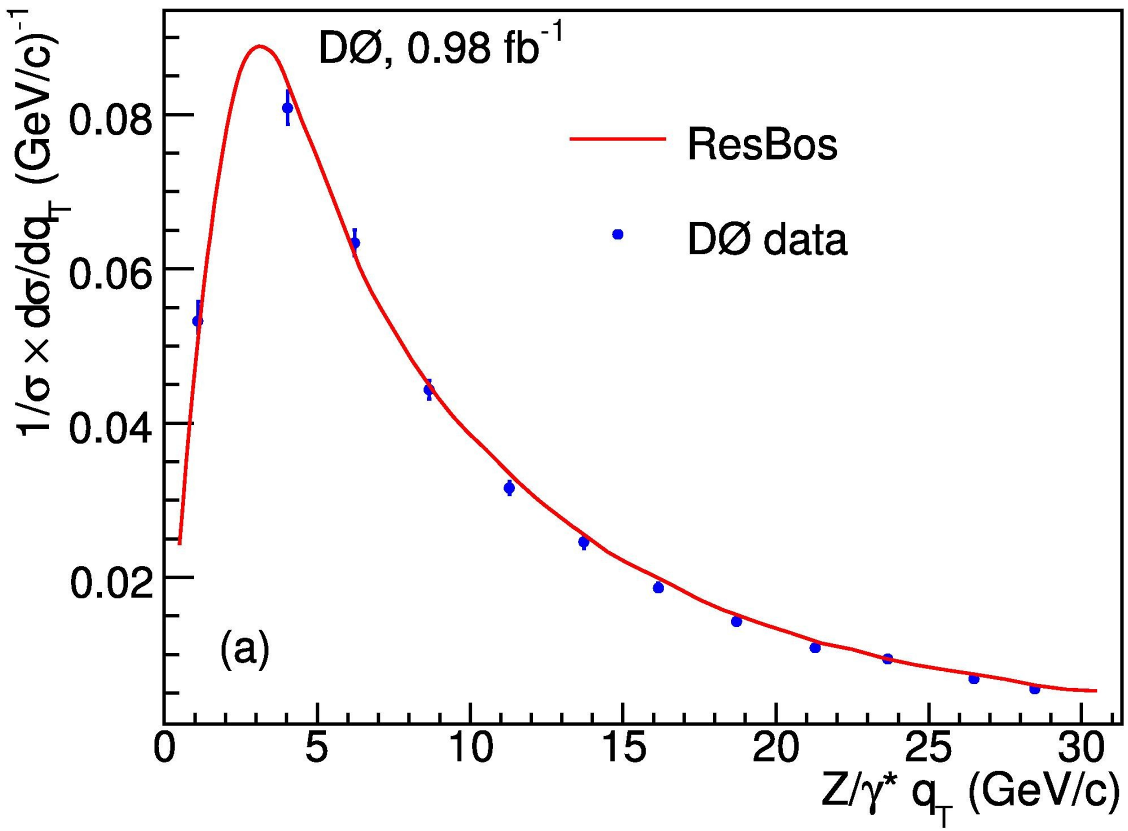
Phys. Lett. B 669, 278 (2008)

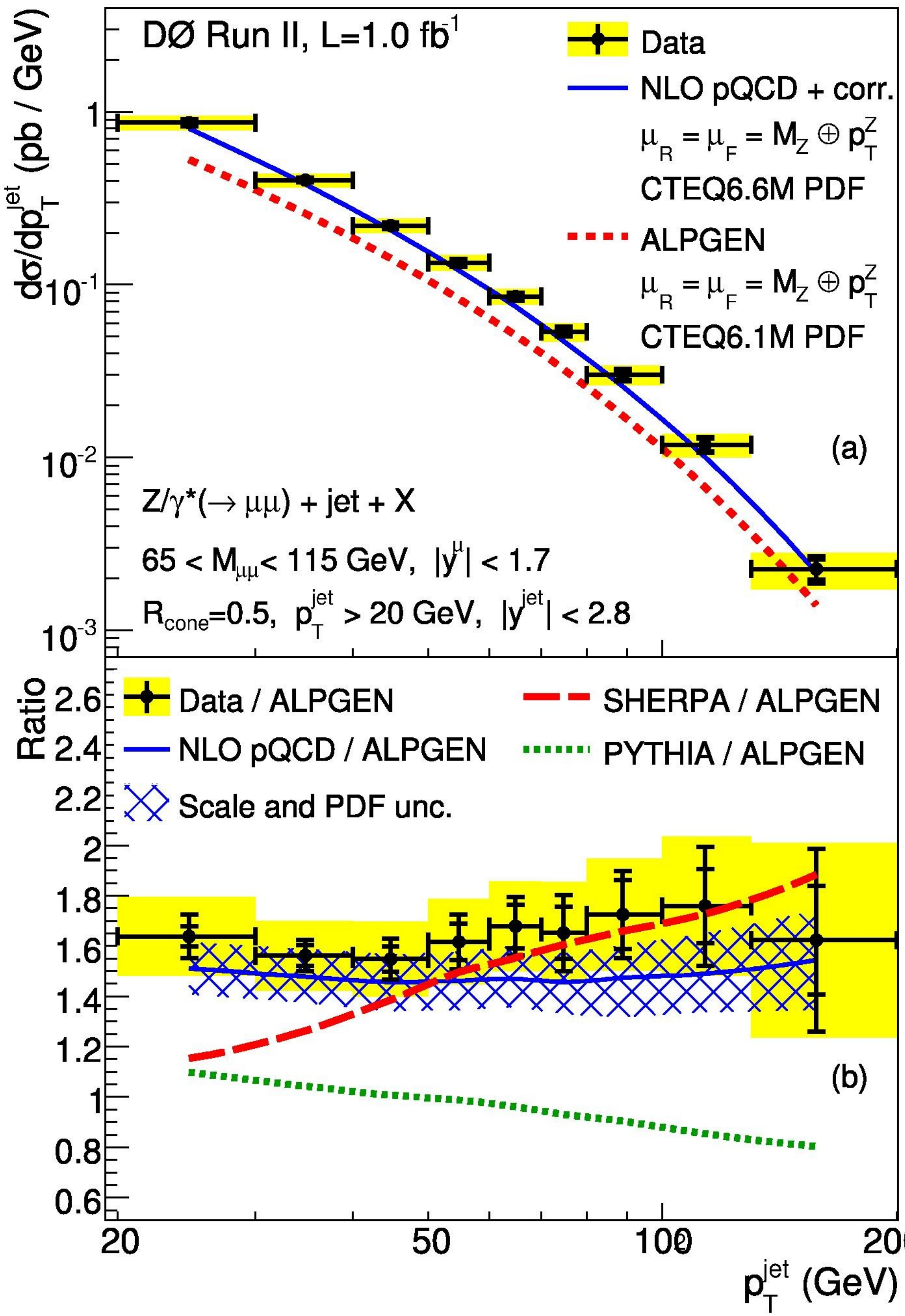
http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/QCD/Q12/

BACK UP SLIDES

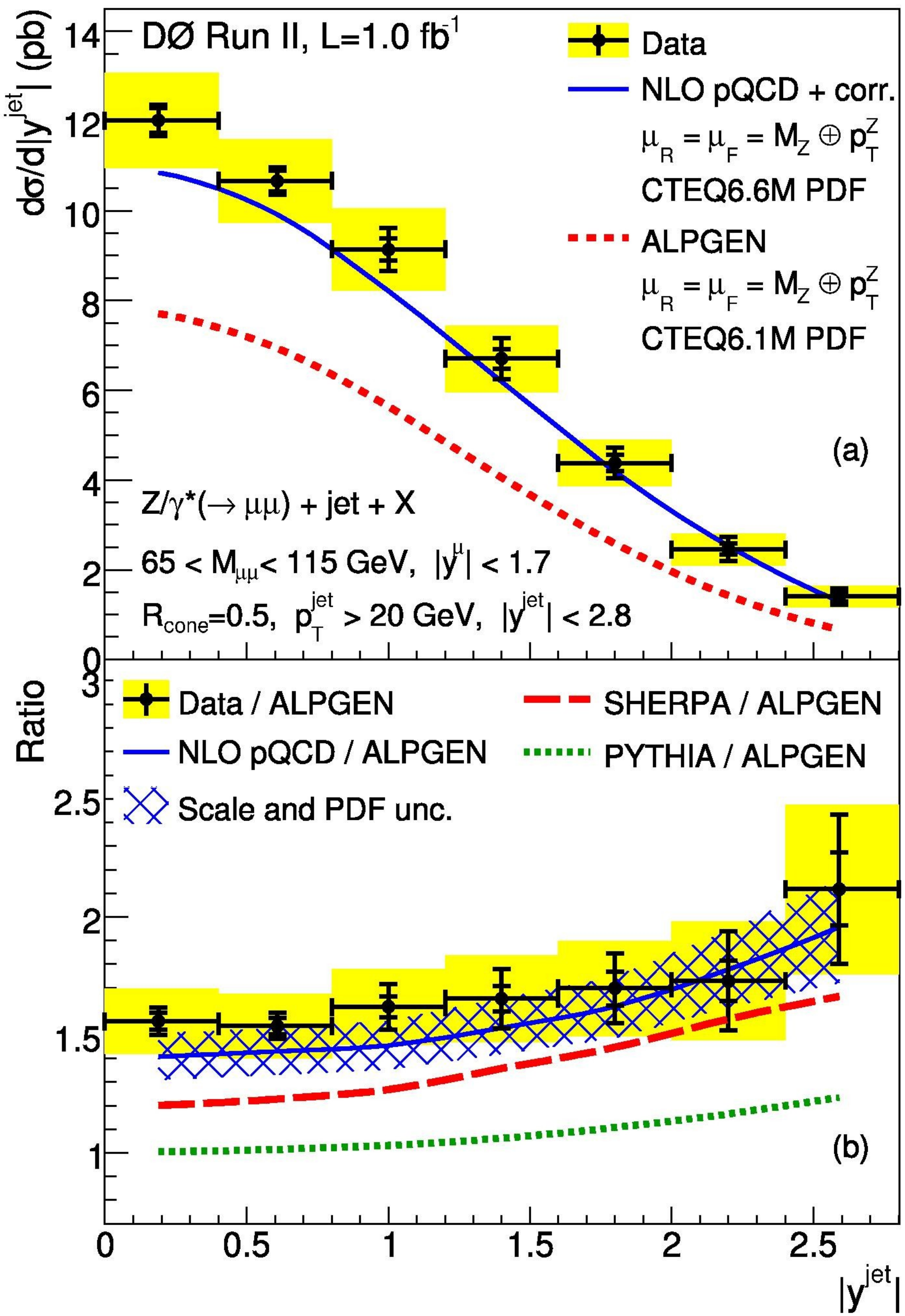
EVENT GENERATORS

Z+Jet muon:
MCFM + CTEQ6.6M
Alpgen v2.13 + Phythia tune QW + CTEQ6.1M
Sherpa v1.1.1 + APACIC + AMISIC + CTEQ6.1M
Phythia v6.418 tune QW + CTEQ6.1M
Z+Jet electron:
Pythia v6.416 Tune QW and Tune S0 (pT ordered) + CTEQ6.1M
Herwig v6.510 + Jimmy v4.31 + CTEQ6.1M
MCFM v5.3 + non-perturbative corrections + CTEQ6.1M
Alpgen v2.13 + Pythia v6.325 + CTEQ6.1M
Sherpa v1.1.1 + CTEQ6.1M
Z+Jet angular:
Pythia v6.420 Tune QW + CTEQ6.1M
Pythia v6.420 Tune P (pT ordered) + MRST 2007 modified L0 PDFs
Herwig v6.510 + Jimmy v4.31 + CTEQ5L
MCFM v5.4 + MSTW2008
Alpgen v2.13 + Pythia v6.420 tune QW and tune P + CTEQ6.1M
Sherpa v1.1.3 + CTEQ6.1M
Photon+h.f
preliminary theory predictions + CTEQ6.6M


DØ, 0.98 fb^{-1}
ResBos
DØ data
(a)
$1/\sigma \times d\sigma/dq_T$ (GeV/c)$^{-1}$
Z/γ^* q_T (GeV/c)
0.02
0.04
0.06
0.08
0
5
10
15
20
25
30



DØ Run II, L=1.0 fb-1
Data
NLO pQCD + corr.
μR = μF = MZ ⊕ pTZ
CTEQ6.6M PDF
ALPGEN
μR = μF = MZ ⊕ pTZ
CTEQ6.1M PDF
(a)
Z/γ*(→ μμ) + jet + X
65 < Mμμ< 115 GeV, |yμ| < 1.7
Rcone=0.5, pTjet > 20 GeV, |yjet| < 2.8
dσ/dpTjet (pb / GeV)
Ratio
Data / ALPGEN
SHERPA / ALPGEN
NLO pQCD / ALPGEN
PYTHIA / ALPGEN
Scale and PDF unc.
(b)
pTjet (GeV)



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dσ/d|yjet| (pb)
Ratio
Data / ALPGEN
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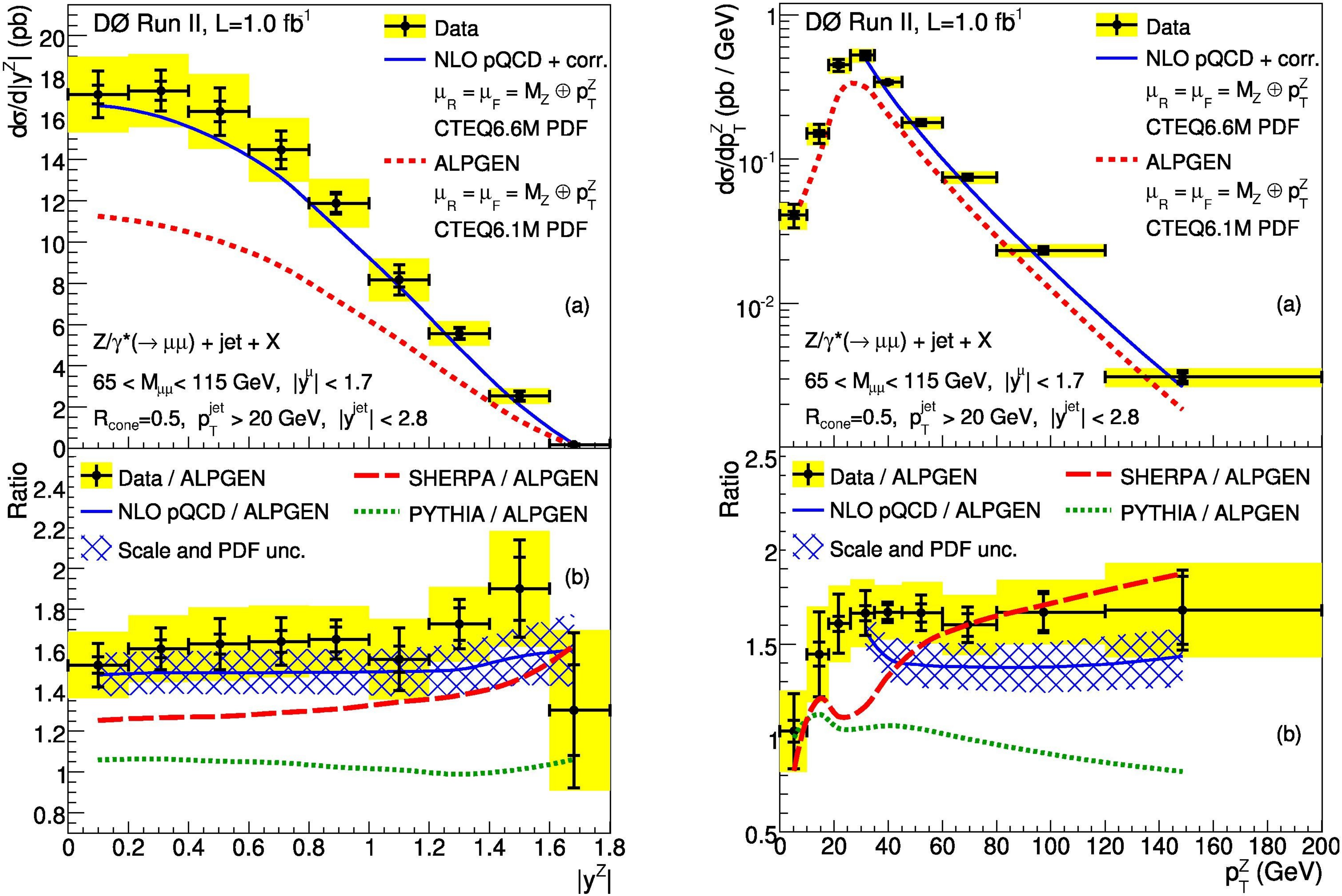
PYTHIA / ALPGEN
Scale and PDF unc.
(b)
|yjet|



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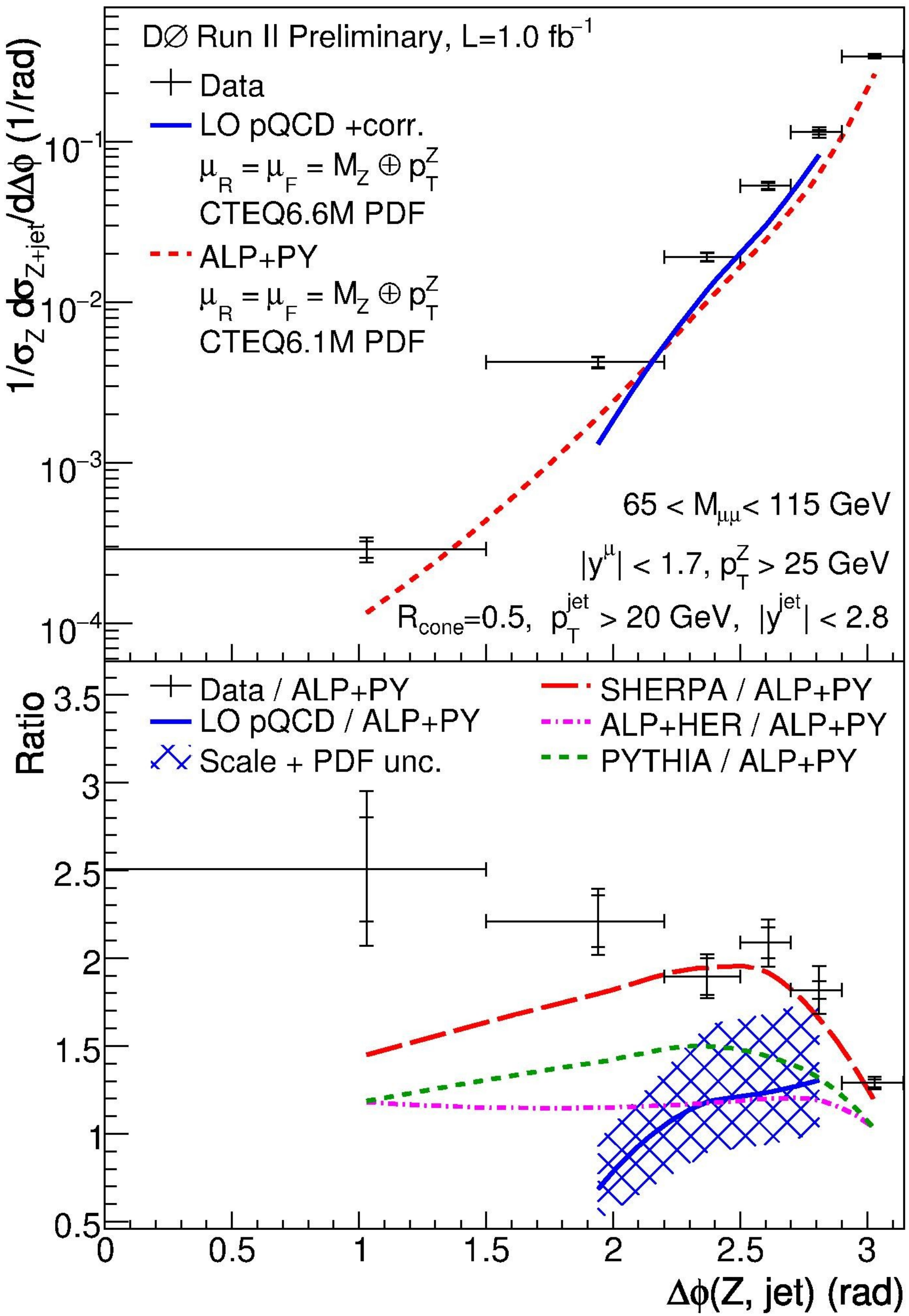
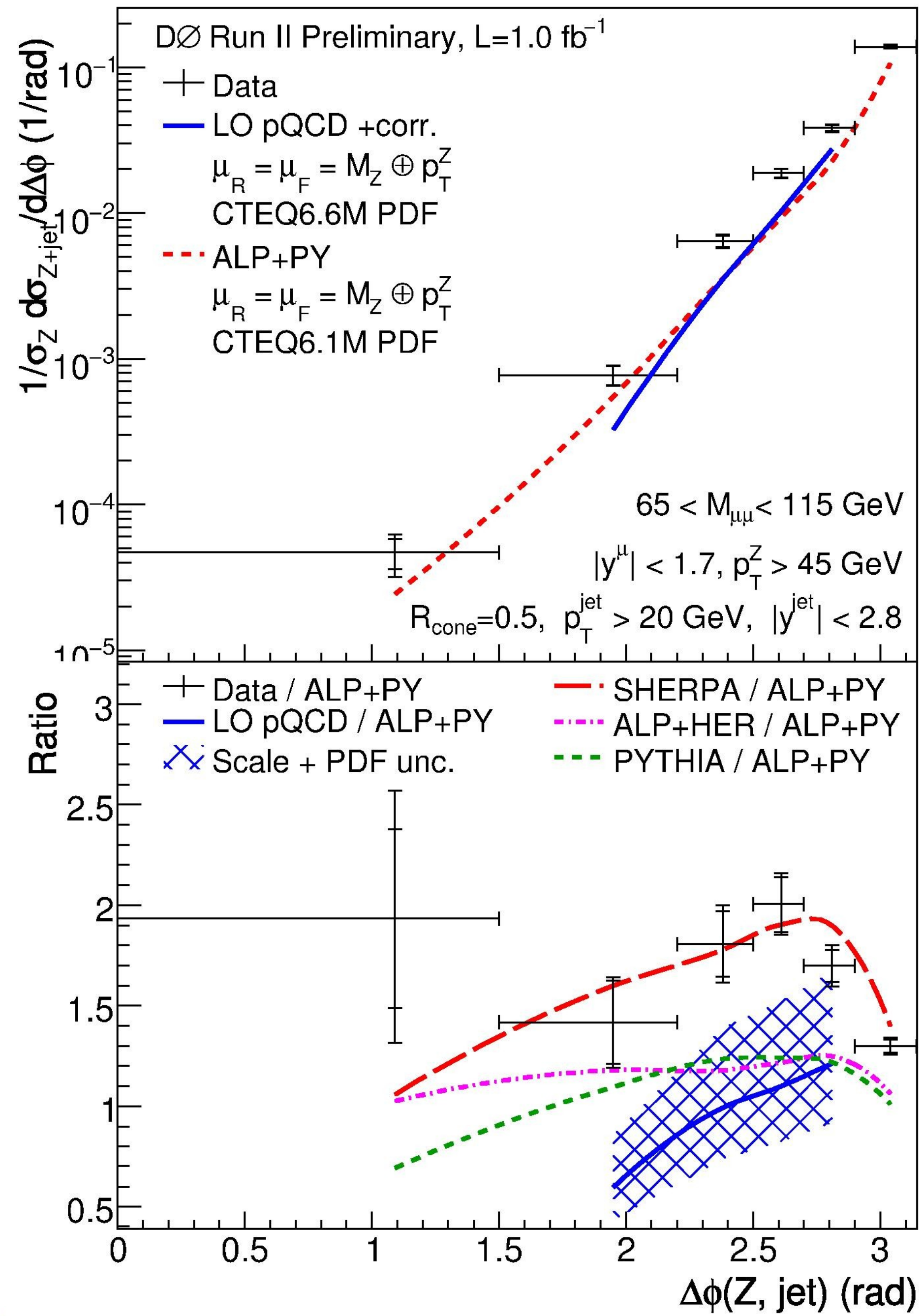
Ratio
Data / ALPGEN
SHERPA / ALPGEN
NLO pQCD / ALPGEN
PYTHIA / ALPGEN
Scale and PDF unc.
(b)
|yZ|
dσ/dpTZ (pb / GeV)
pTZ (GeV)


DØ Run II Preliminary, L=1.0 fb^{-1}
Data
LO pQCD +corr.
$\mu_R = \mu_F = M_Z \oplus p_T^Z$
CTEQ6.6M PDF
ALP+PY
$\mu_R = \mu_F = M_Z \oplus p_T^Z$
CTEQ6.1M PDF
$65 < M_{\mu\mu} < 115$ GeV
$|y^{\mu}| < 1.7$, $p_T^Z > 25$ GeV
R_{cone}=0.5, $p_T^{jet} > 20$ GeV, $|y^{jet}| < 2.8$
$1/\sigma_Z\ d\sigma_{Z+jet}/d\Delta\phi$ (1/rad)
Data / ALP+PY
LO pQCD / ALP+PY
Scale + PDF unc.
SHERPA / ALP+PY
ALP+HER / ALP+PY
PYTHIA / ALP+PY
Ratio
$\Delta\phi$(Z, jet) (rad)


DØ Run II Preliminary, L=1.0 fb^{-1}
Data
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$\mu_R = \mu_F = M_Z \oplus p_T^Z$
CTEQ6.6M PDF
ALP+PY
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Data / ALP+PY
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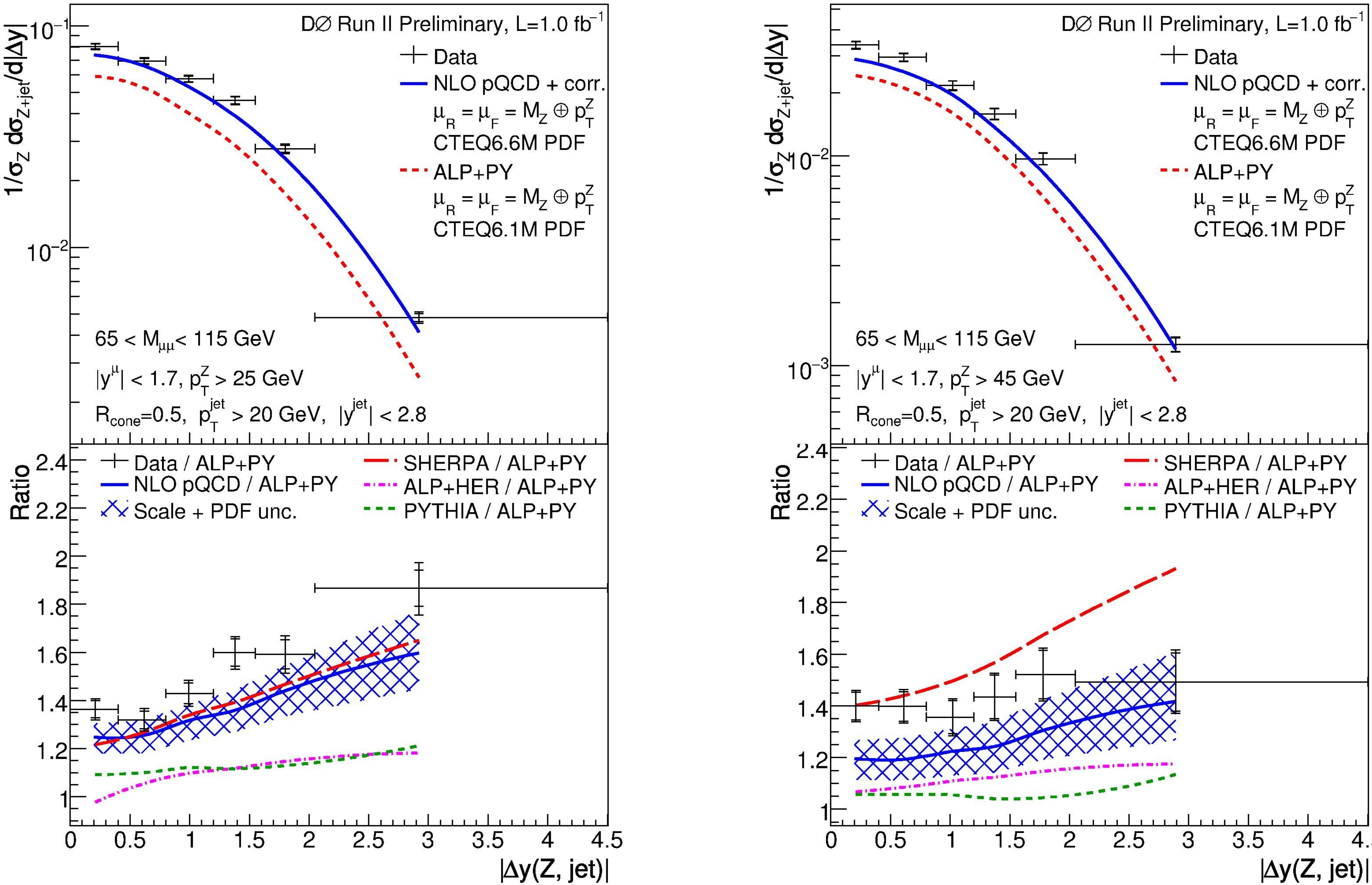
Scale + PDF unc.
SHERPA / ALP+PY
ALP+HER / ALP+PY
PYTHIA / ALP+PY
Ratio
$\Delta\phi$(Z, jet) (rad)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μR = μF = MZ ⊕ pTZ
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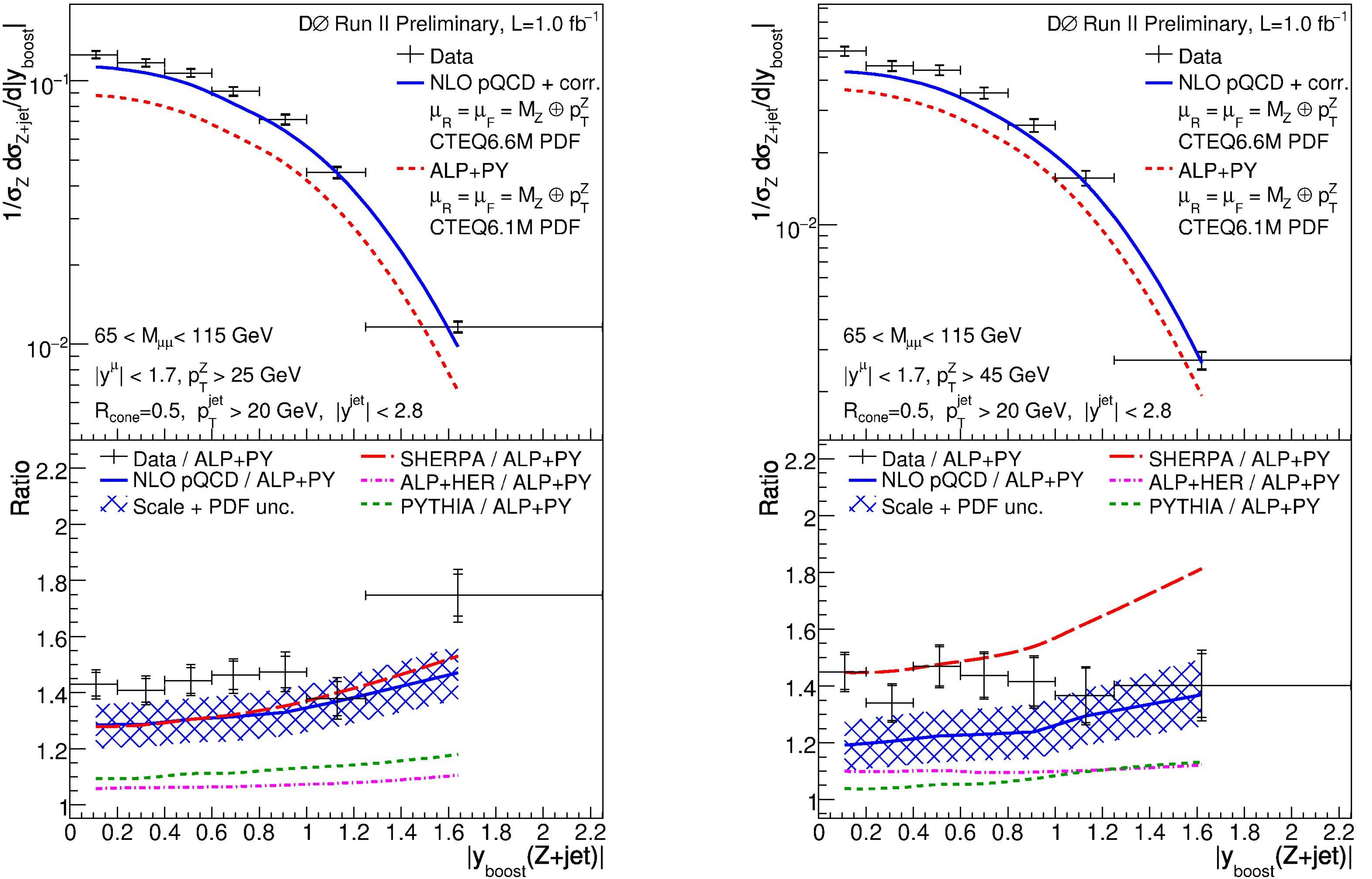
SHERPA / ALP+PY
ALP+HER / ALP+PY
PYTHIA / ALP+PY
1/σZ dσZ+jet/d|Δy|
Ratio
|Δy(Z, jet)|


DØ Run II Preliminary, L=1.0 fb^{-1}
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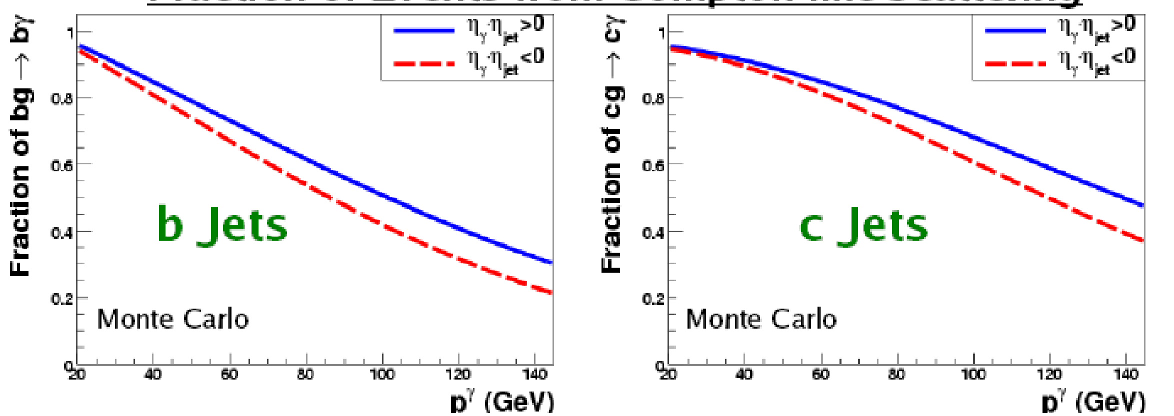
$|y^\mu| < 1.7$, $p_T^Z > 25$ GeV
R_{cone}=0.5, $p_T^{jet} > 20$ GeV, $|y^{jet}| < 2.8$
$1/\sigma_Z\, d\sigma_{Z+jet}/d|y_{boost}|$
Ratio
Data / ALP+PY
NLO pQCD / ALP+PY
Scale + PDF unc.
SHERPA / ALP+PY
ALP+HER / ALP+PY
PYTHIA / ALP+PY
$|y_{boost}(Z+jet)|$
DØ Run II Preliminary, L=1.0 fb^{-1}
$65 < M_{\mu\mu} < 115$ GeV
$|y^\mu| < 1.7$, $p_T^Z > 45$ GeV
R_{cone}=0.5, $p_T^{jet} > 20$ GeV, $|y^{jet}| < 2.8$

Phase Space: 9x102 < Q2 < 2E4 GeV2 and 0.01 < x < 0.3

At Hera: Q2 < 650 GeV2 and x < 0.02

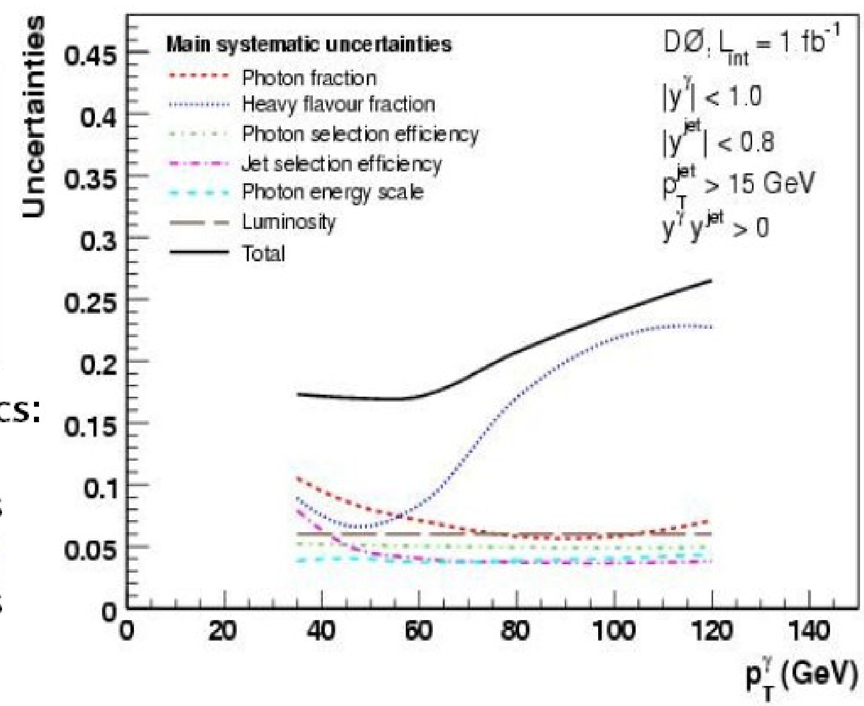
$$x_{1,2} = p_T^{\gamma}/\sqrt{s} \cdot (\exp(\pm y^{\gamma}) + \exp(\pm y^{\text{jet}}))$$

Fraction of Events from Compton-like scattering

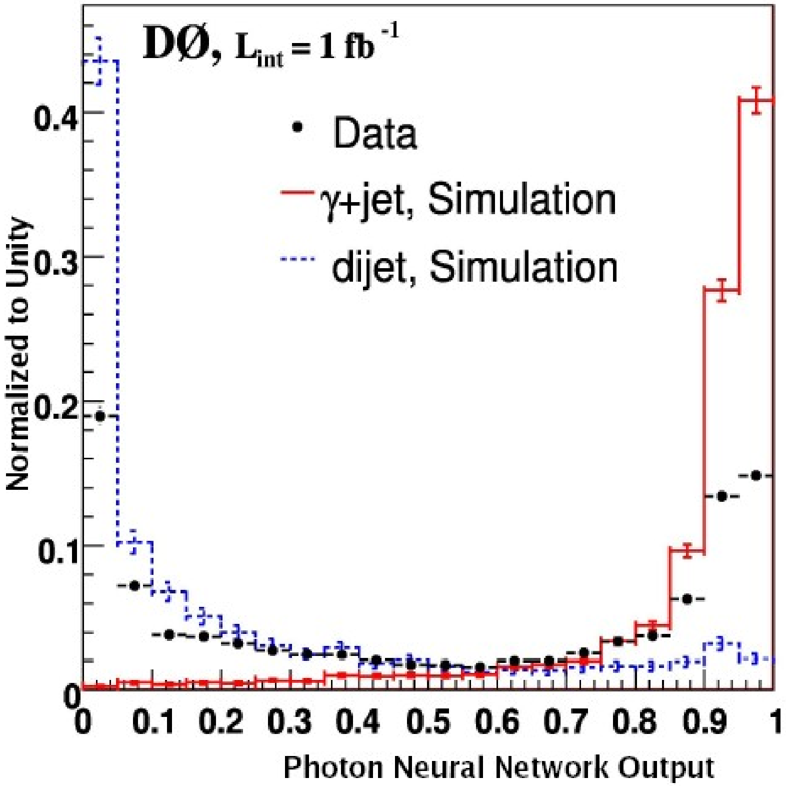


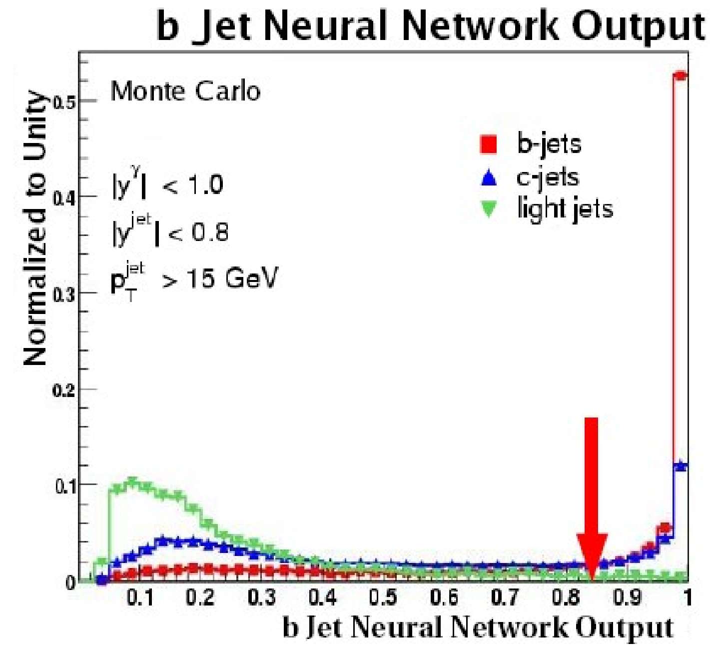
Main systematic uncertainties

- Photon fraction
- Heavy flavour fraction
- Photon selection efficiency
- Jet selection efficiency
- Photon energy scale
- Luminosity
- Total

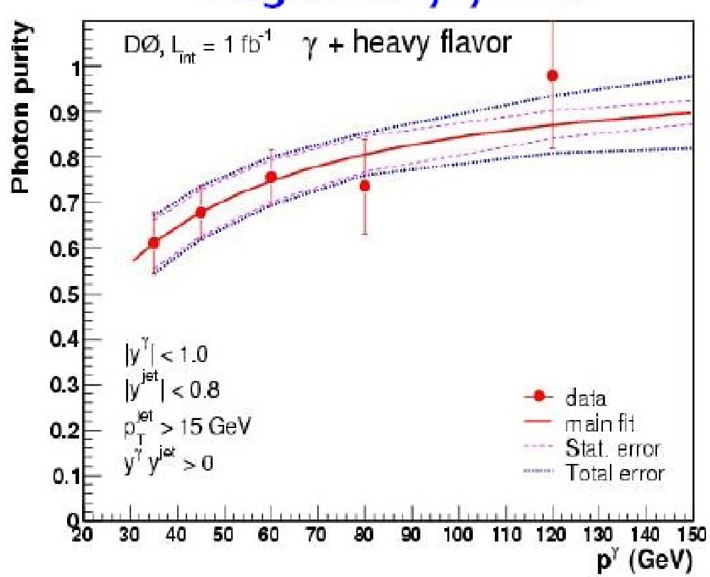


- The two dominant systematics:
  - At low p^γ_T, the photon fitting fraction dominates
  - At high p^γ_T, the jet flavor fraction fitting dominates





Region 1: $y^{\gamma} y^{jet} > 0$



Region 2: $y^{\gamma} y^{jet} < 0$