Z/γ*+jets Differential Cross Section Measurements at D0

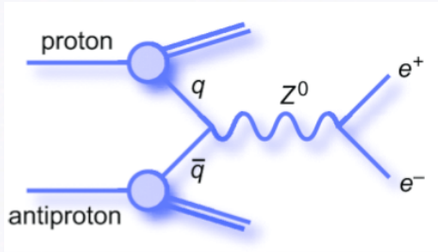
187 - Measurement of Differential Z/gamma+jet+X Cross Sections with the D0 Detector

Presenter: SOLDNER-REMBOLD, Stefan (University of Manchester); JUSTE, Aurelio (Fermilab); WAHL, Horst (Florida State University)

We present measurements of differential cross sections in inclusive Z/gamma plus jet production in a data sample of 1fb-1 collected with the D0 detector in proton antiproton collisions at sqrt(s)=1.96TeV. Measured variables include the Z/gamma transverse momentum (pT-Z), and rapidity (y-Z), the leading jet pT (pT-jet), and rapidity (y-jet), as well as various angles of the Z+jet system. We compare the results to different Monte Carlo event generators and to next-to-leading order perturbative QCD (NLO pQCD) predictions, with non-perturbative corrections applied.

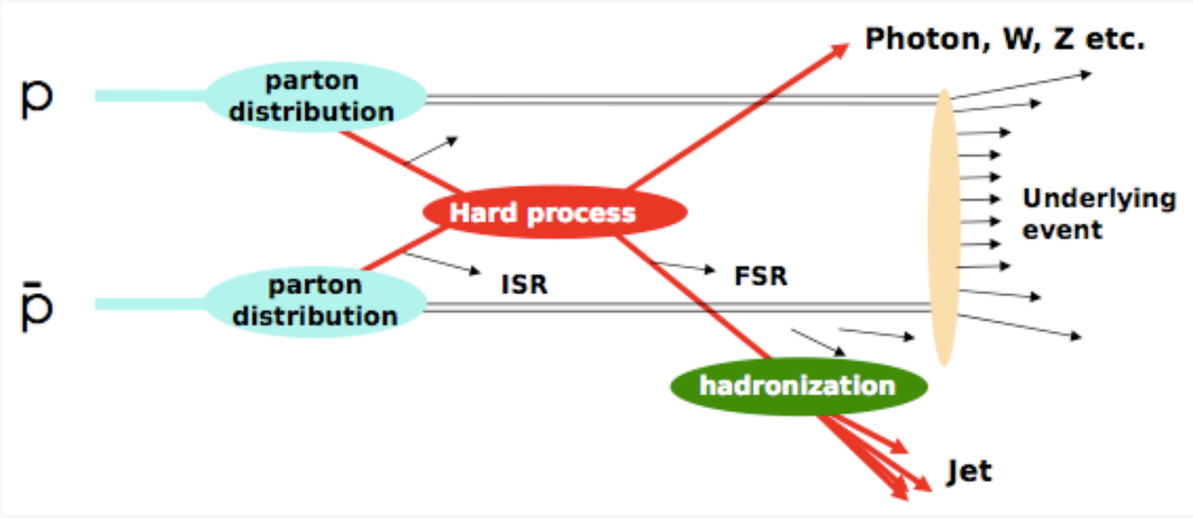
Sabine Lammers
on behalf of D0 Collaboration
Indiana University
July 30, 2009

Motivation



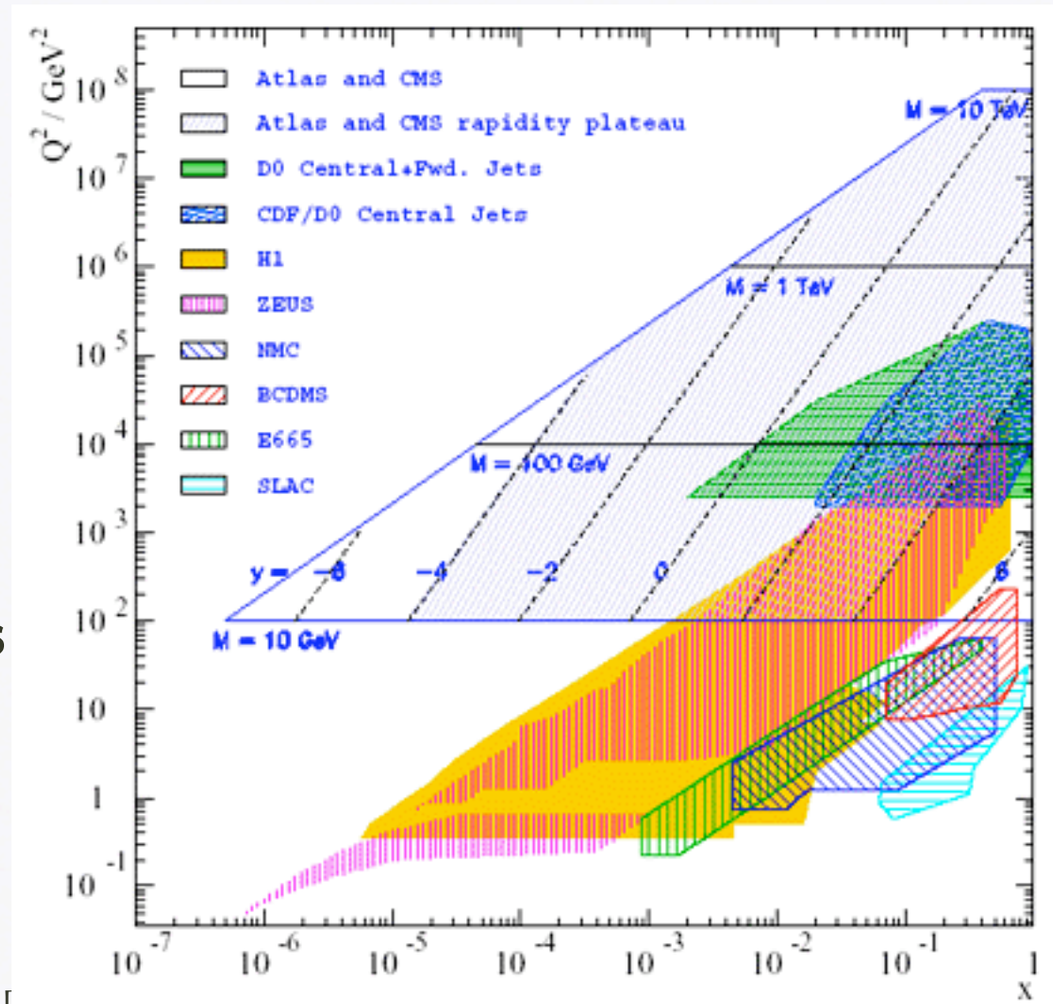
Precision tests of pQCD

- complementary kinematic regime to HERA, fixed target
- parton distributions
- ISR/FSR - gluon radiation
- p_T spectra



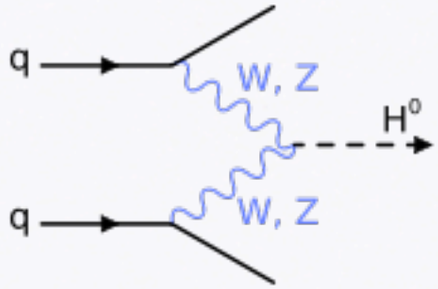
Important measurements for tuning MC models

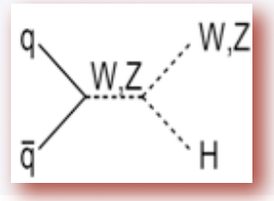
- Tevatron dataset is now large enough and systematics are constrained well enough to use data to vet ME+PS models
- unique kinematic overlap with LHC and expected SM Higgs mass range

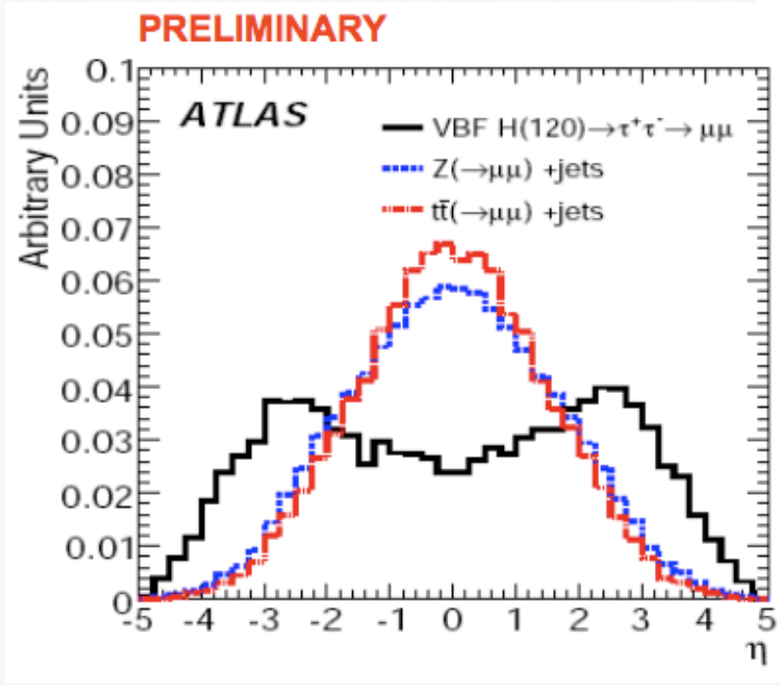


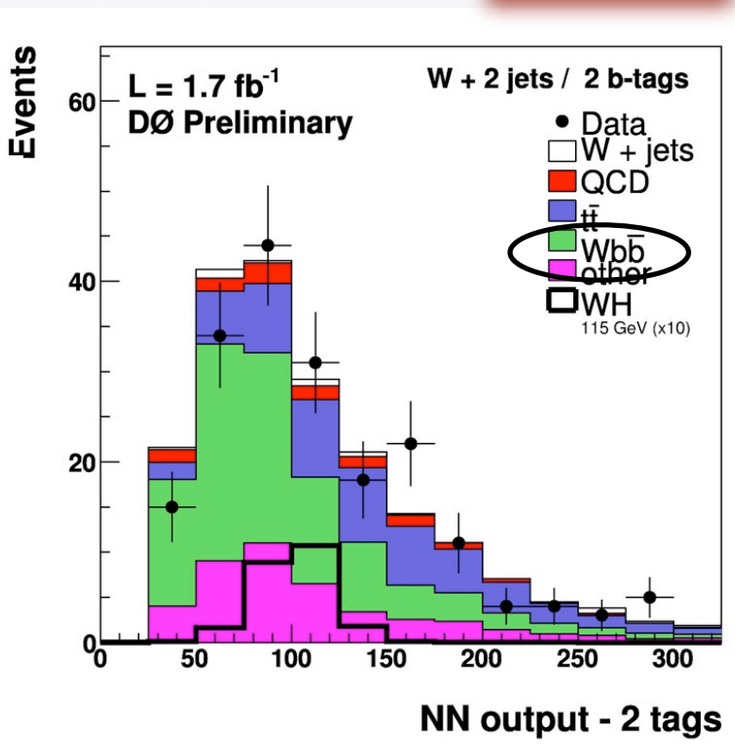
Backgrounds to New Physics

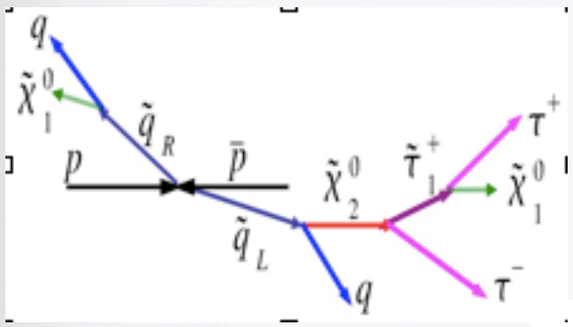
- New physics signatures with large vector boson +jets backgrounds rely heavily on accurate simulation!
- Use Tevatron W/Z+jets to tune Monte Carlos

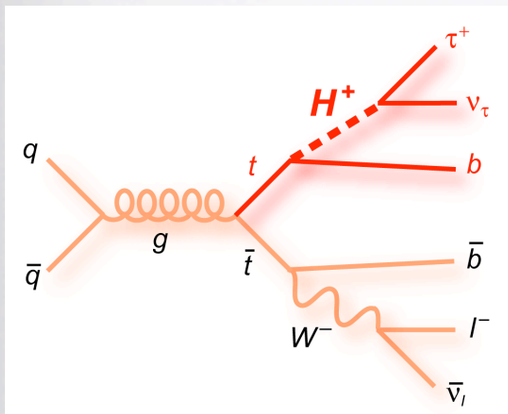


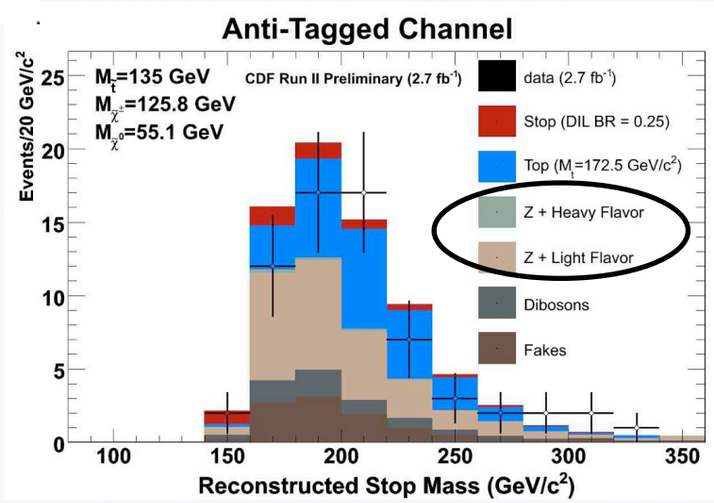


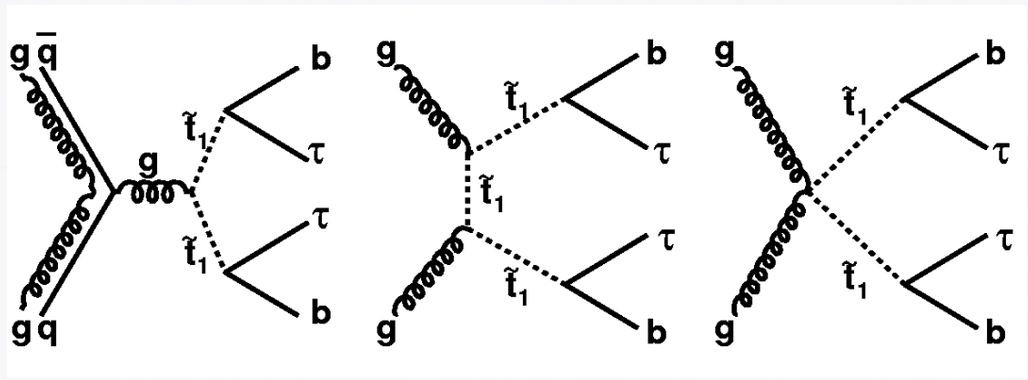






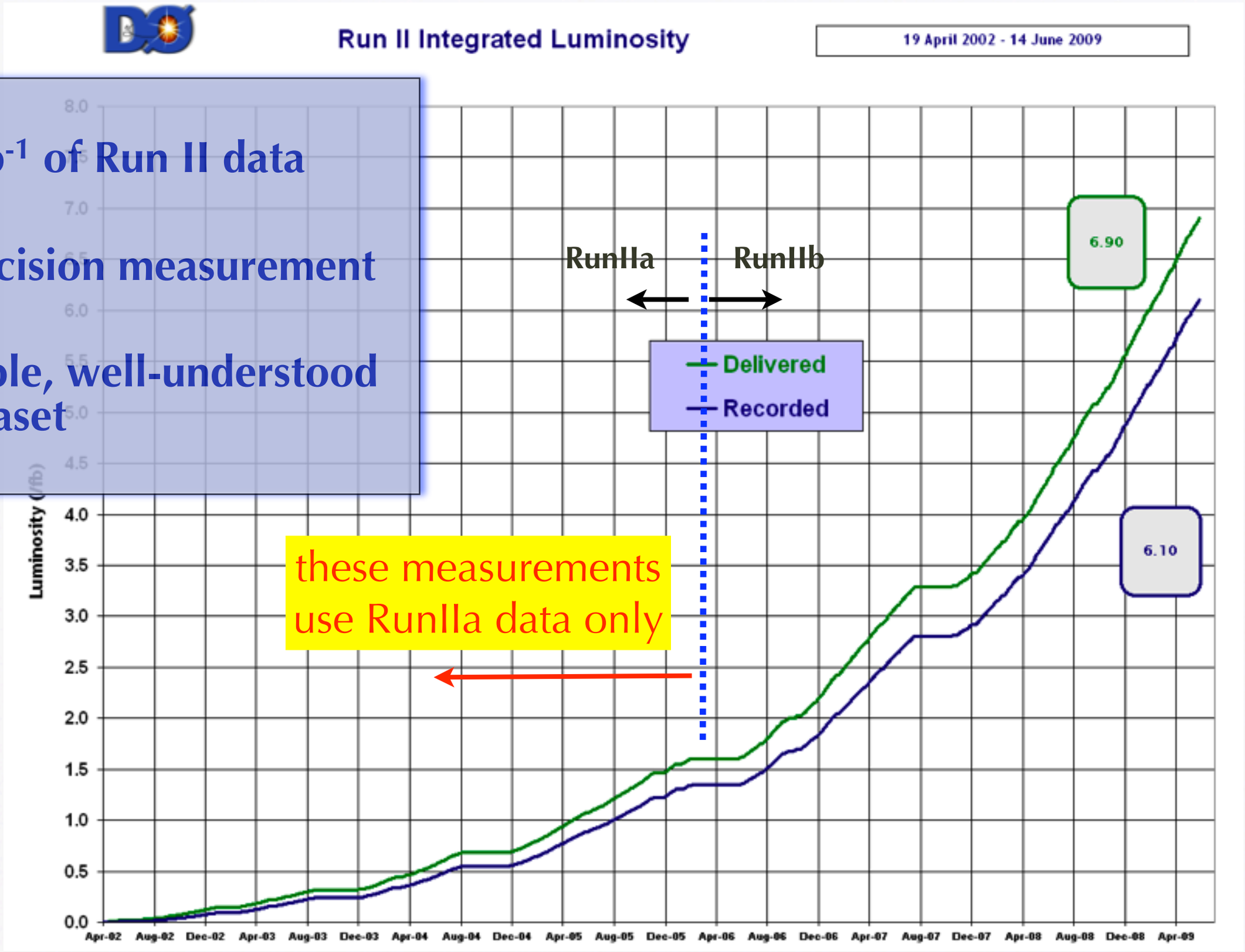






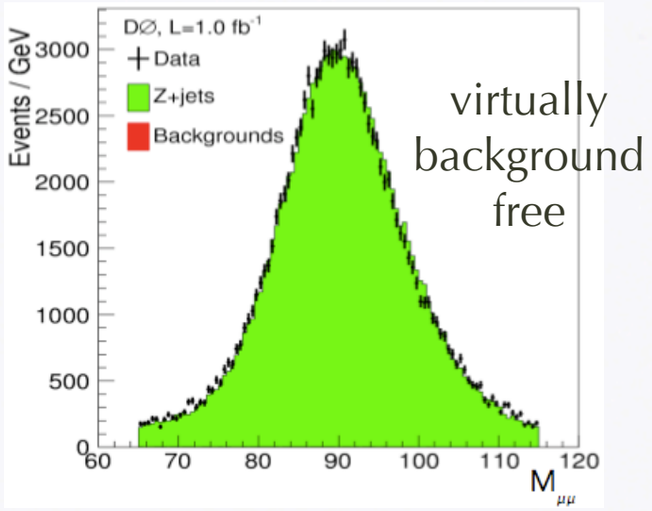
Dataset

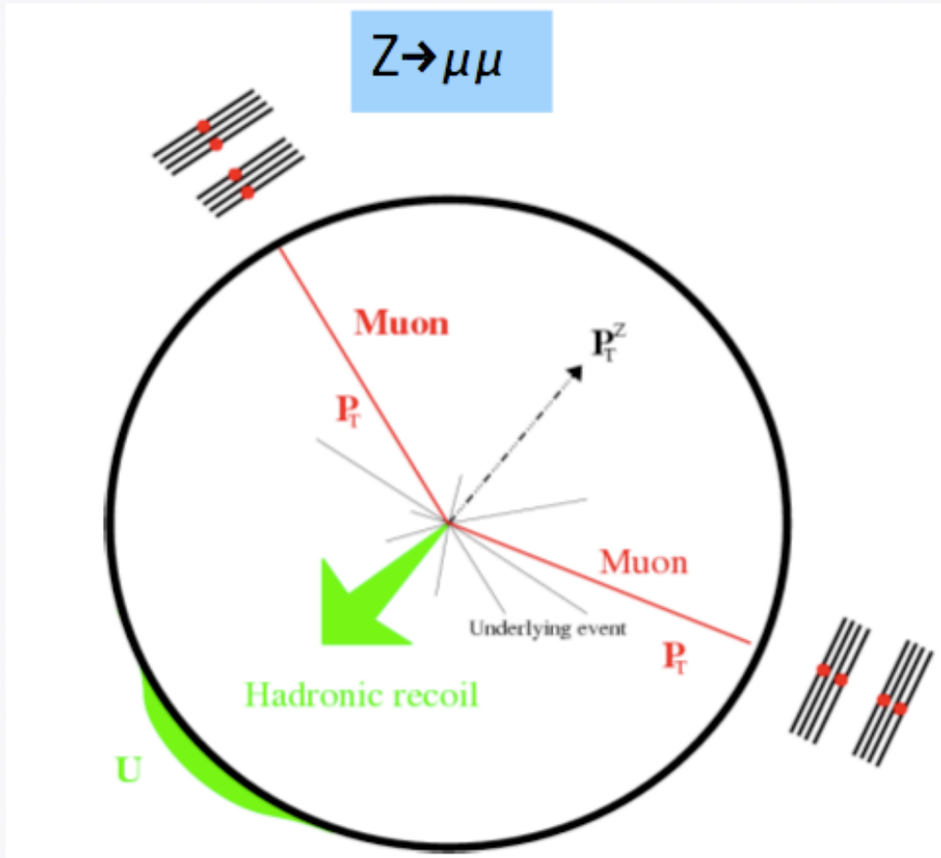
- 1 fb^{-1} of Run II data
- precision measurement
- stable, well-understood dataset



Measurement Strategy

- Z boson decay products (leptons) and jets measured, calibrated
- corrections applied for acceptance, trigger losses
- data unfolded to particle level
  - accounts for detector resolution and efficiency
- comparisons to predictions
  - NLO pQCD via MCFM
    - Pythia hadronization corrections applied
  - LO ME-PS models - ALPGEN, SHERPA
  - LO PS models - PYTHIA, HERWIG





MC Models

- **MCFM** - partonic NLO predictions for Z+1,2 jets, LO predictions for Z +1,2,3 jets
- **PYTHIA, HERWIG** : **2->1,2 LO PS models**
- **SHERPA** - CKKW : **2->1,2,3,4,5,6 LO ME+PS model**
  - the separation of ME and PS for different multijet processes is achieved through a k_T-measure
  - undesirable jet configurations are rejected through reweighting of the matrix elements with analytical Sudakov form factors and factors due to different scales in α_s
- **ALPGEN** - MLM : **2->1,2,3,4,5,6 LO ME+PS model**
  - matching parameters chosen, ME and PS jets matched in each n-parton multiplicity, events vetoed which do not have complete set of matched jets
  - further suppression required to prevent double counting of n and n+1 samples (replaces Sudakov reweighting in CKKW)

Z, jets Reconstruction

- Event Selection:

  rapidity y = 1/2 ln(E+p_z/E-pz)

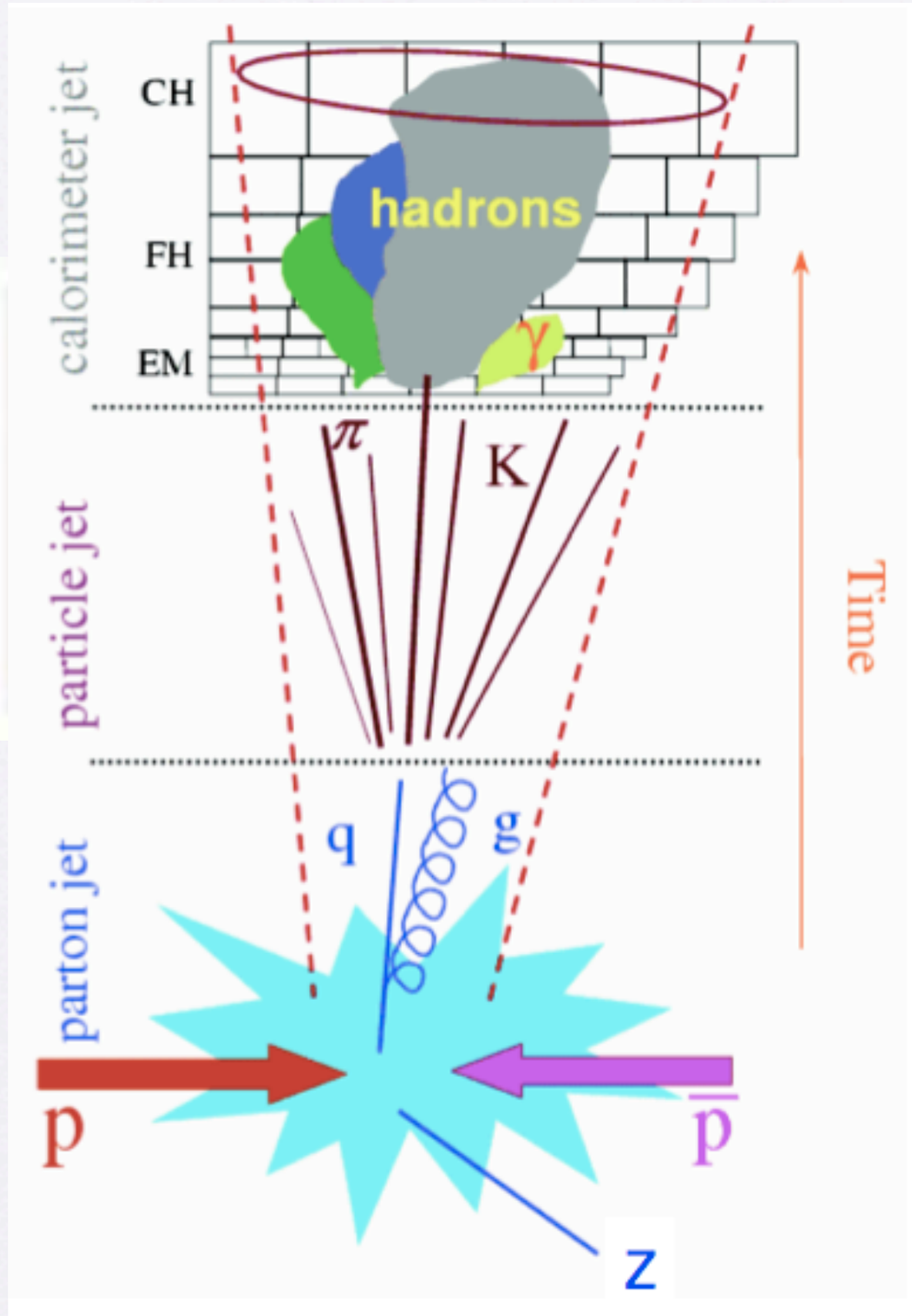
  $\eta = -\ln(\tan\Theta/2)$

  - electron, muon p_T > 25,15 GeV
  - electron, muon $|\eta|$ < 2.5, 2
  - 65< $M_{Z->ll}$ < 115
  - ≥1 jet with p_T> 20 GeV, |y| < 2.8

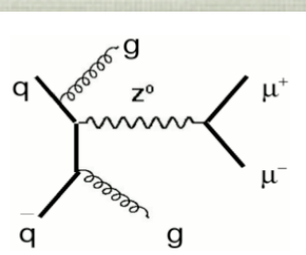
- Electron Reconstruction
  - EM fraction > 0.9
  - shower shape requirement
  - cone isolation requirements
  - EM deposit matched to 5 GeV track
  - likelihood requirement

- Muon Reconstruction
  - hits in all layers of muon system
  - scintillator hits
  - track matching between central tracking and muon systems
  - isolation requirements

- Jet Reconstruction
  - D0 seeded midpoint cone algorithm R=0.5
    - JES corrections computed with this algorithm



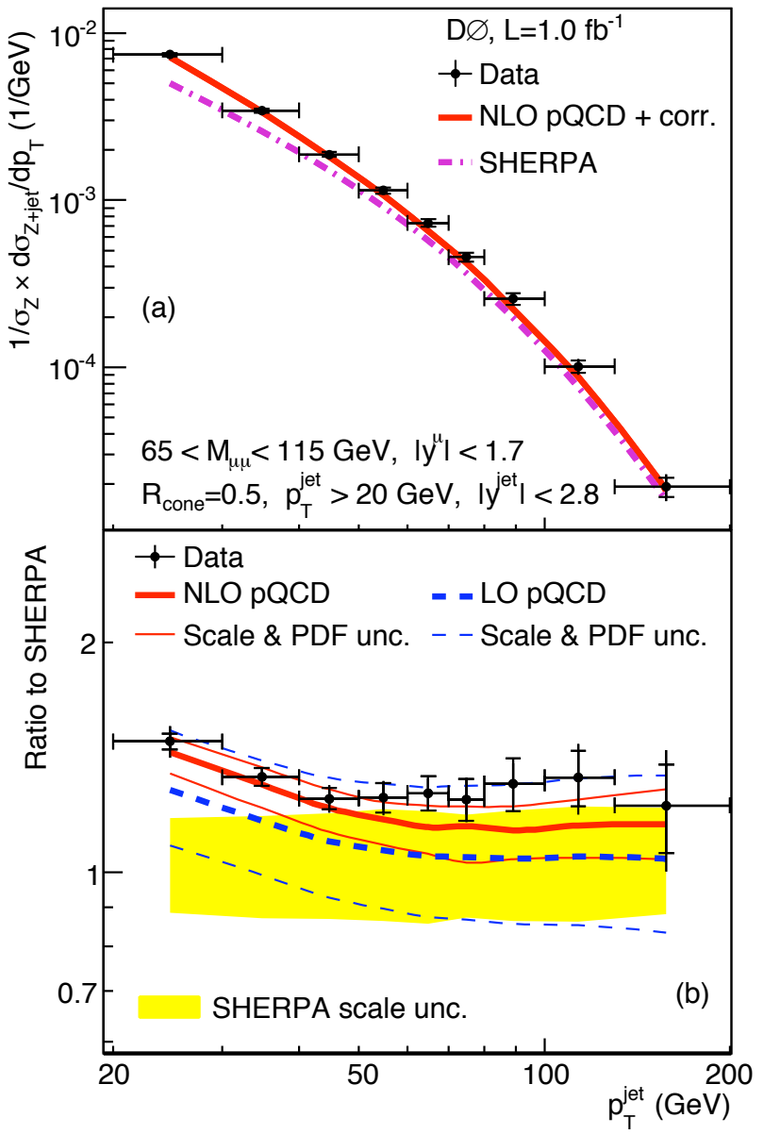
Z->μμ + jet + X - p_T spectra

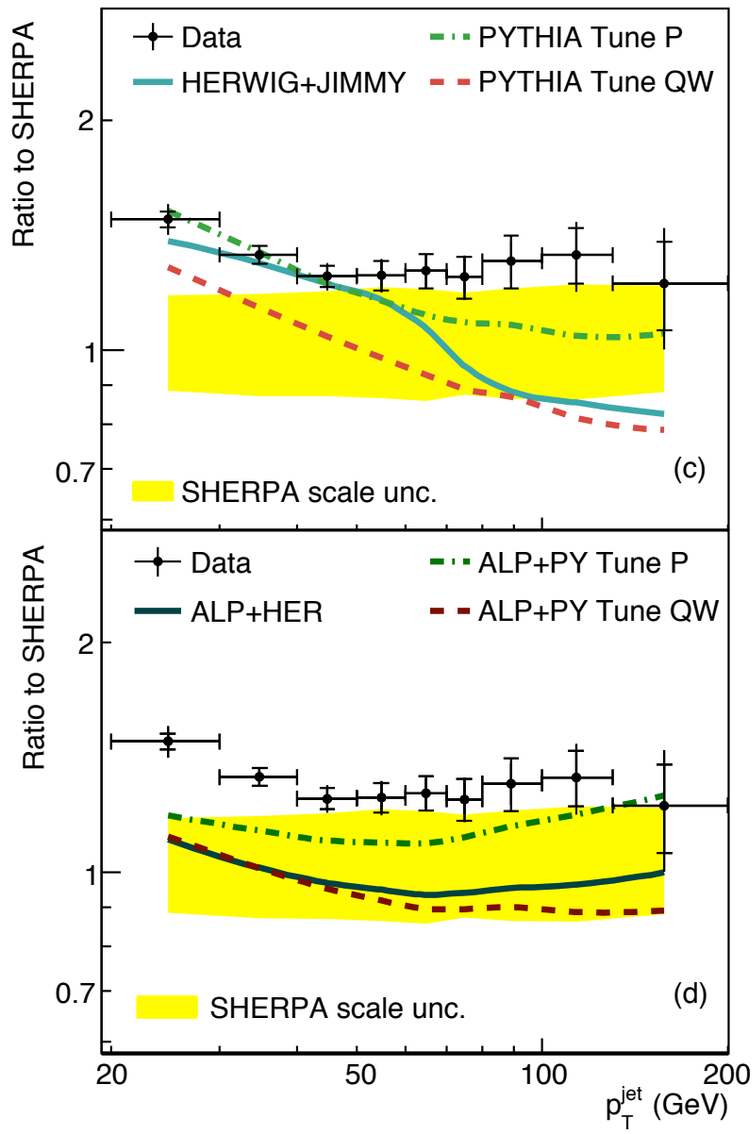


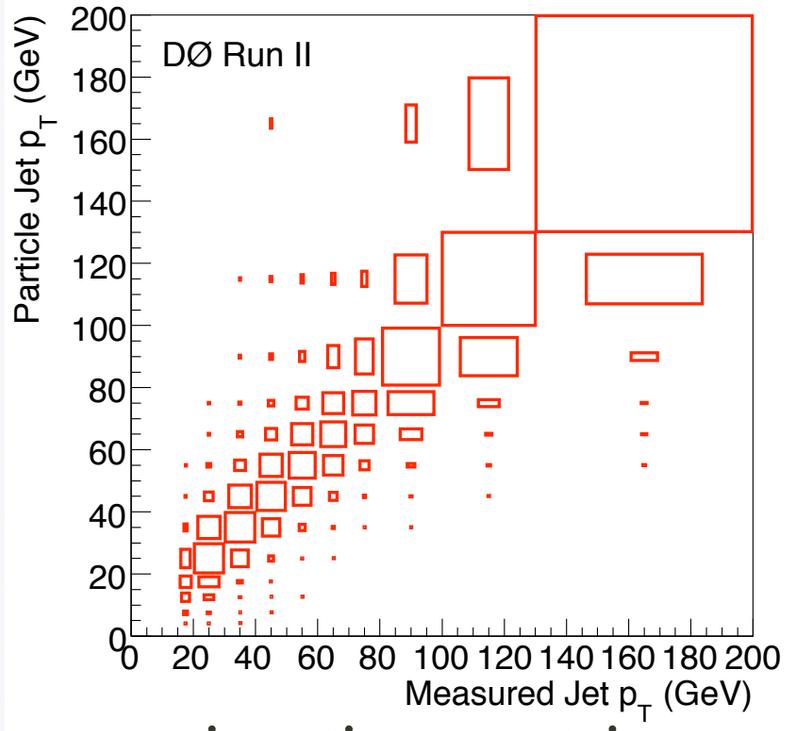
Particle level phase space:
65 GeV< $M_{\mu\mu}$ < 115 GeV,
D0 midpoint R_{cone}=0.5, p_T^{jet} > 20 GeV
$|y^{jet}| < 2.8$, $|y^{\mu}| < 1.7$

theory predictions updated since publication

ratios relative to Sherpa 1.1.3







migration matrix
-> used to unfold data
large migrations,
especially at low p_T

MCFM v5.4 PDF: MSTW2008
$\mu_r^2 = \mu_f^2 = p_{T,Z}^2 + M_Z^2$

PYTHIA v6.420
Pythia Tune P
Pythia Tune QW
HERWIG v6.510 + JIMMY v4.31
ALPGEN v2.13+PYTHIA v6.420
ALPGEN v2.13+HERWIG v6.510

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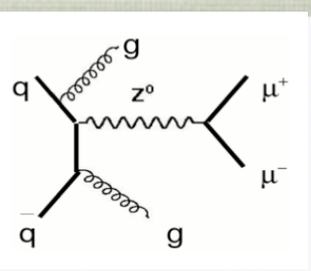
Z->μμ + jet + X - p_T spectra



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theory predictions updated since publication

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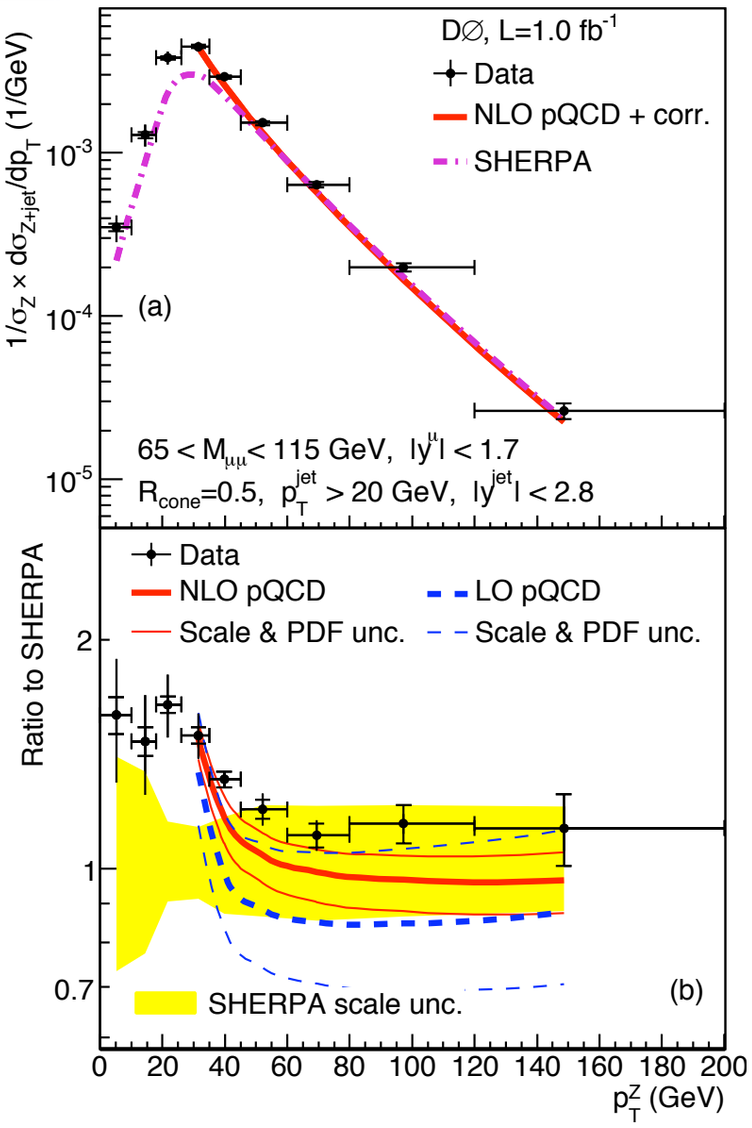

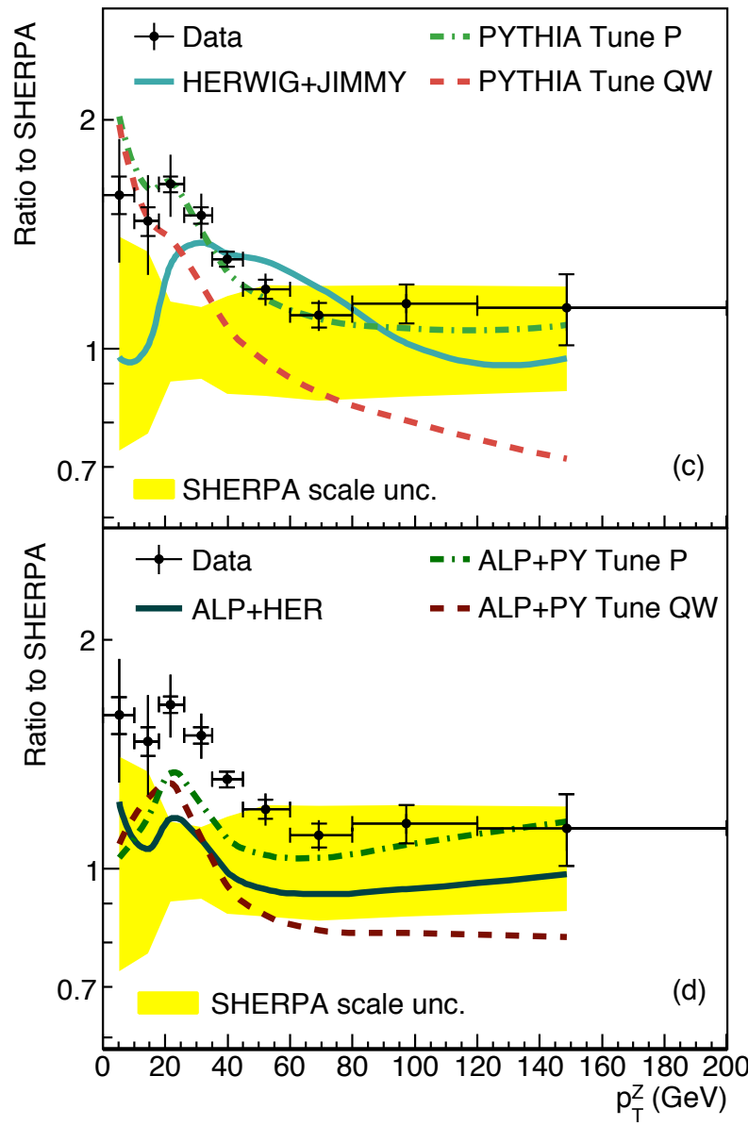

- NLO prediction with Z p_T<30 GeV sensitive to underlying event
- All LO predictions underestimate data normalization
- Pythia can be tuned to reproduce data

MCFM v5.4 PDF: MSTW2008
$\mu_r^2 = \mu_f^2 = p_{T,Z}^2 + M_Z^2$

PYTHIA v6.420
Pythia Tune P
Pythia Tune QW
HERWIG v6.510 + JIMMY v4.31

ALPGEN v2.13+PYTHIA v6.420
ALPGEN v2.13+HERWIG v6.510

All cross sections normalized to inclusive Z production to reduce systematic errors

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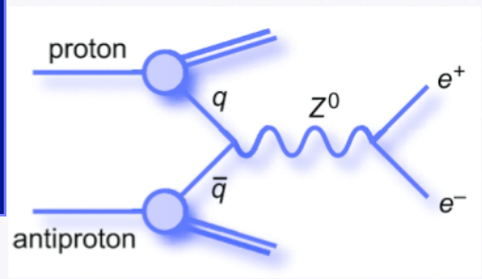
Z->ee + jet + X - p_T spectra

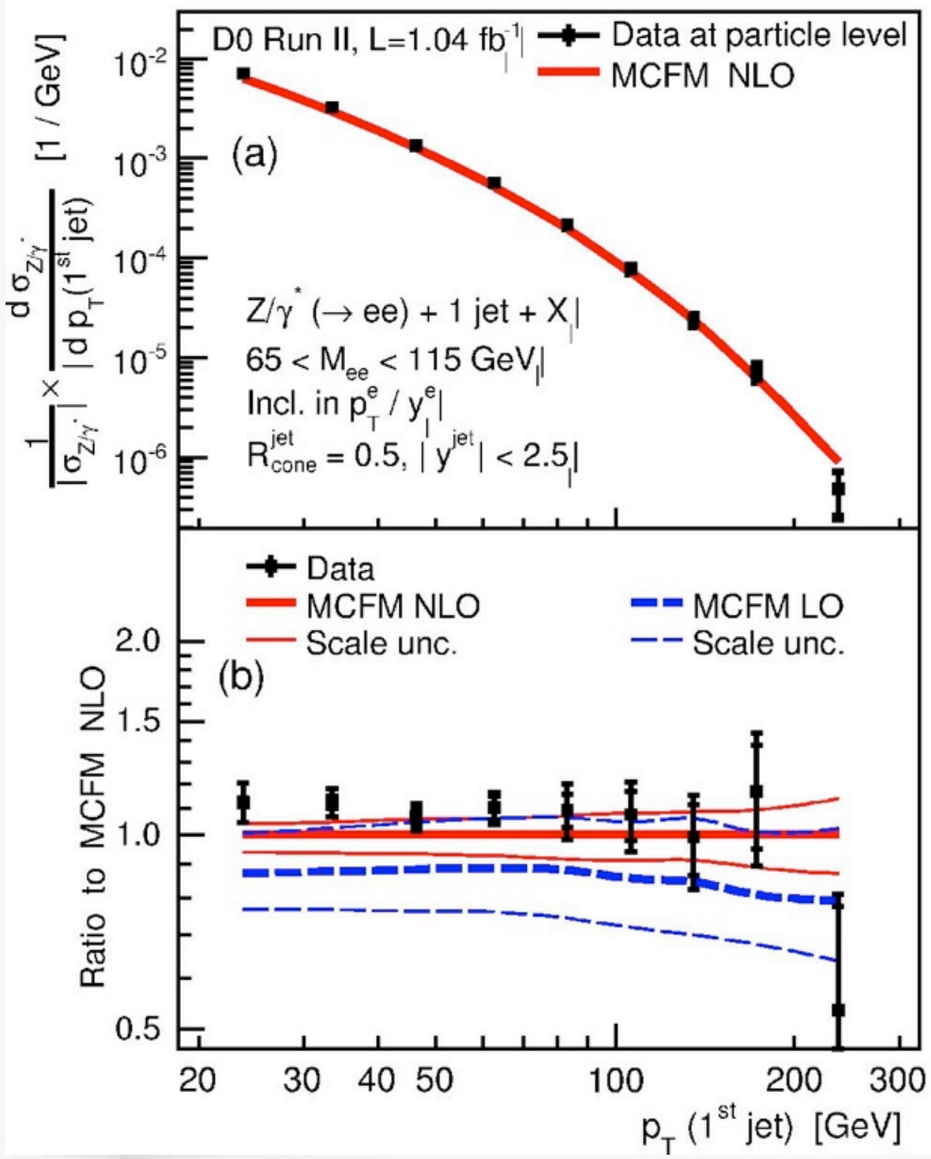


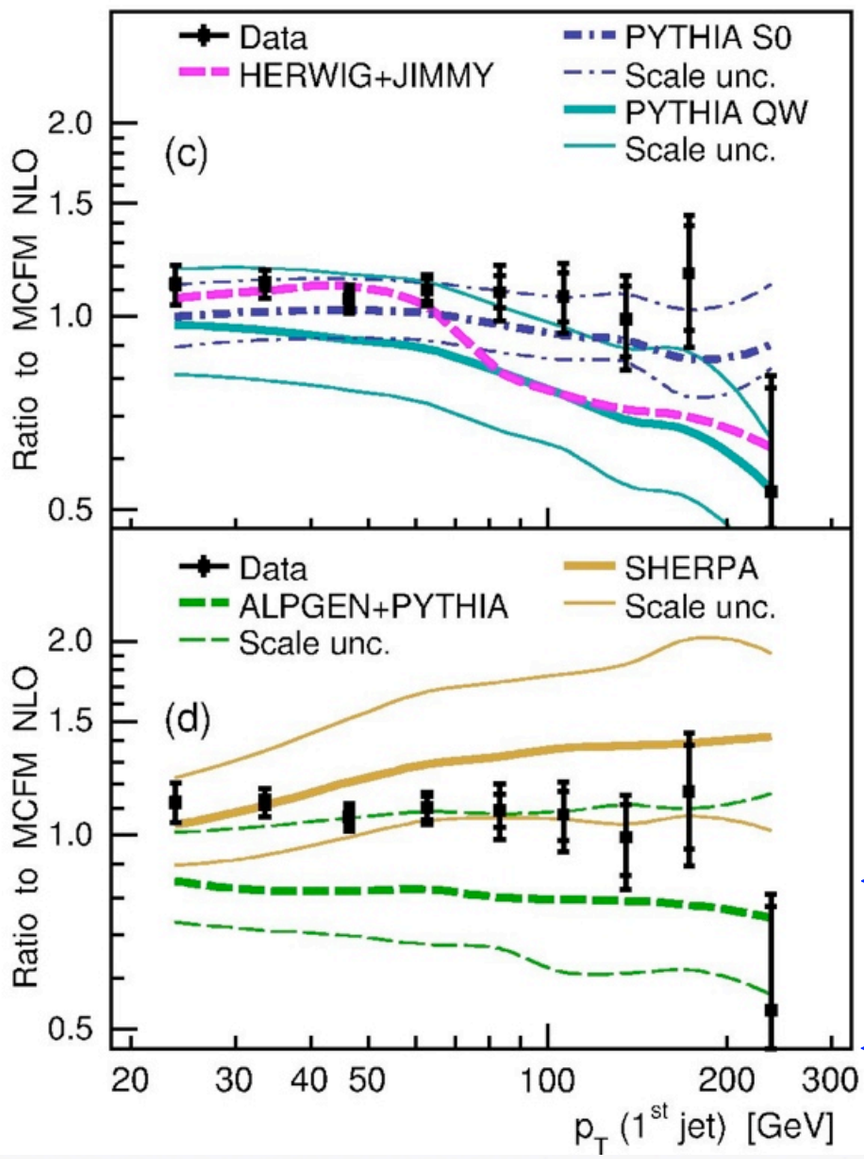
Particle level phase space:
65 GeV< M_{ee} < 115 GeV,
D0 midpoint R_{cone}=0.5, p_T^{jet} > 20 GeV
$|y^{jet}|$ < 2.5, Incl in $p_T^e/|y^e|$

normalized to
inclusive Z production

ratios relative to MCFM NLO

MCFM v5.3 PDF: CTEQ6.6M
$\mu_r^2 = \mu_f^2 = p_{T,Z}^2 + M_Z^2$





PYTHIA v6.416
Pythia Tune SO
Pythia Tune QW
HERWIG v6.510
+JIMMY v4.31

ALPGEN v2.13
+PYTHIA v6.325
SHERPA v1.1.1

- Large differences between models
- Small experimental errors

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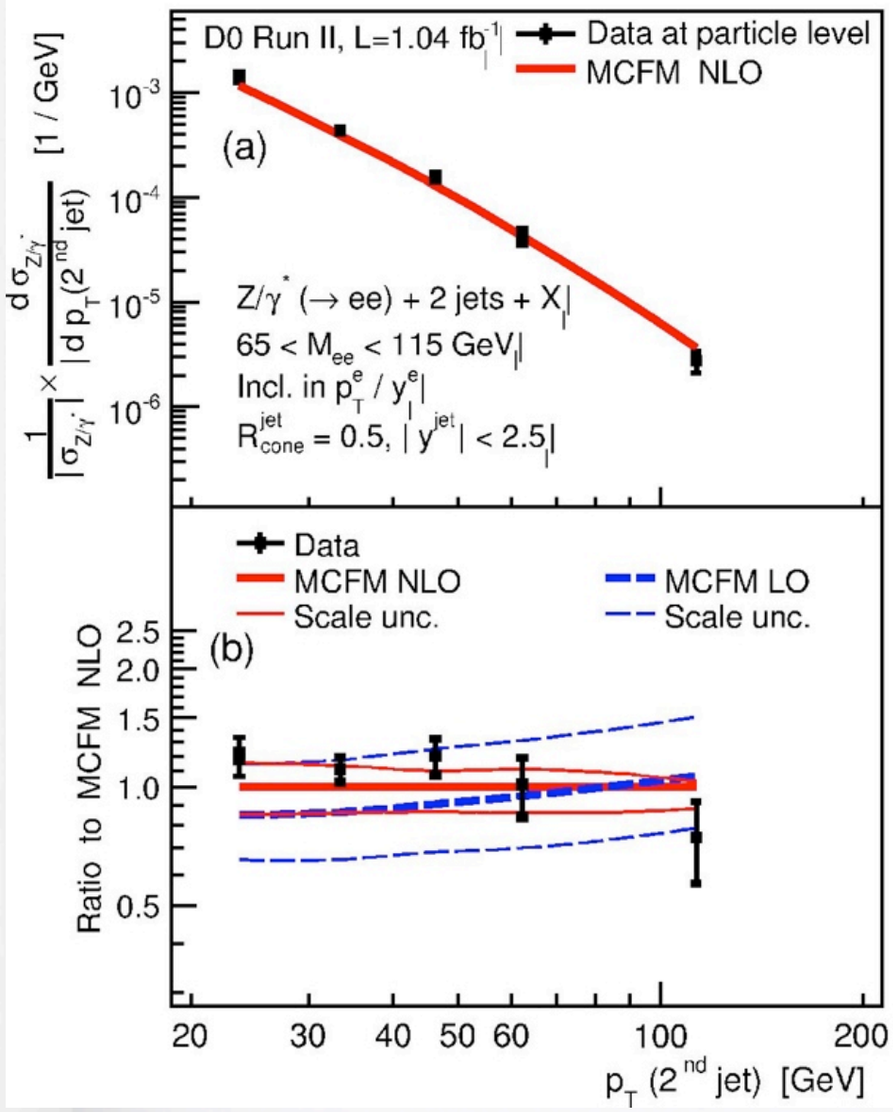
Z->ee + **2jets** + X - p_T spectra

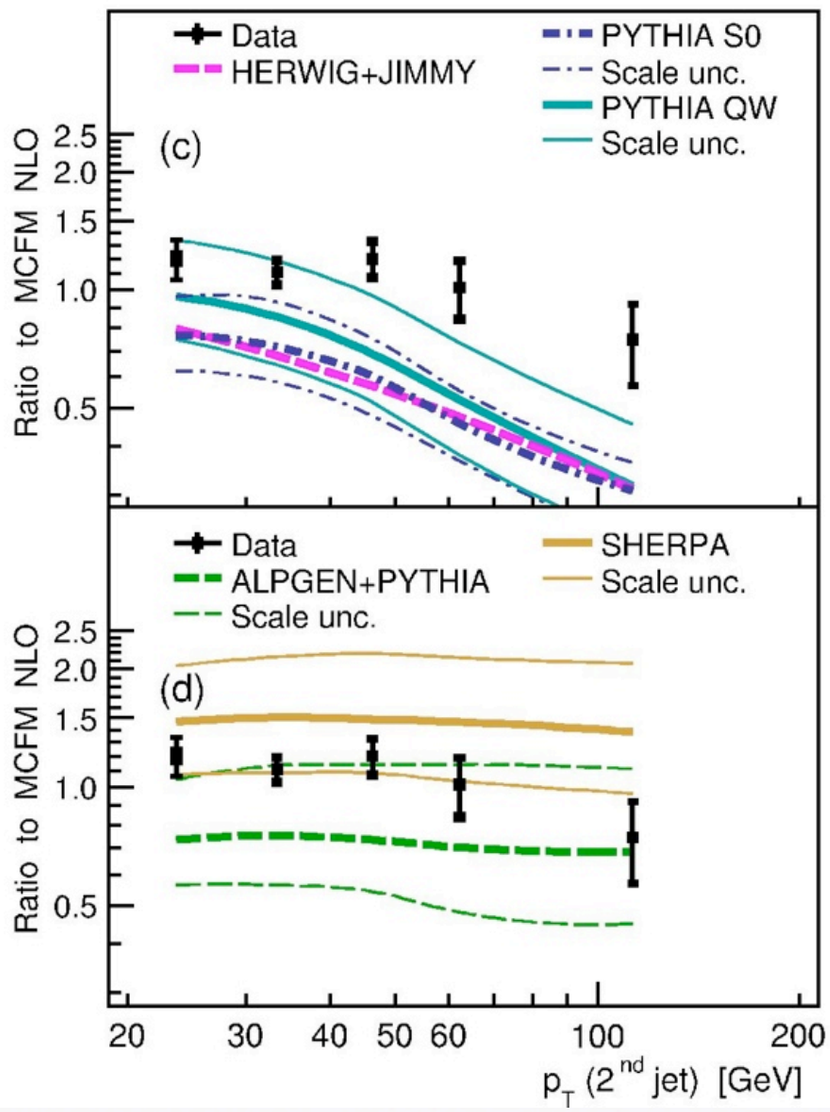
Particle level phase space:
65 GeV< M_{ee} < 115 GeV,
D0 midpoint R_{cone}=0.5, p_T^{jet} > 20 GeV
$|y^{jet}|$ < 2.5, Incl in $p_T^e/|y^e|$

normalized to
inclusive Z production

ratios relative to MCFM NLO

MCFM v5.3 PDF: CTEQ6.6M
$\mu_r^2 = \mu_f^2 = p_{T,Z}^2 + M_Z^2$





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HERWIG v6.510
+JIMMY v4.31

ALPGEN v2.13
+PYTHIA v6.325
SHERPA v1.1.1

- Large differences between models
- Small experimental errors, dominated by statistics

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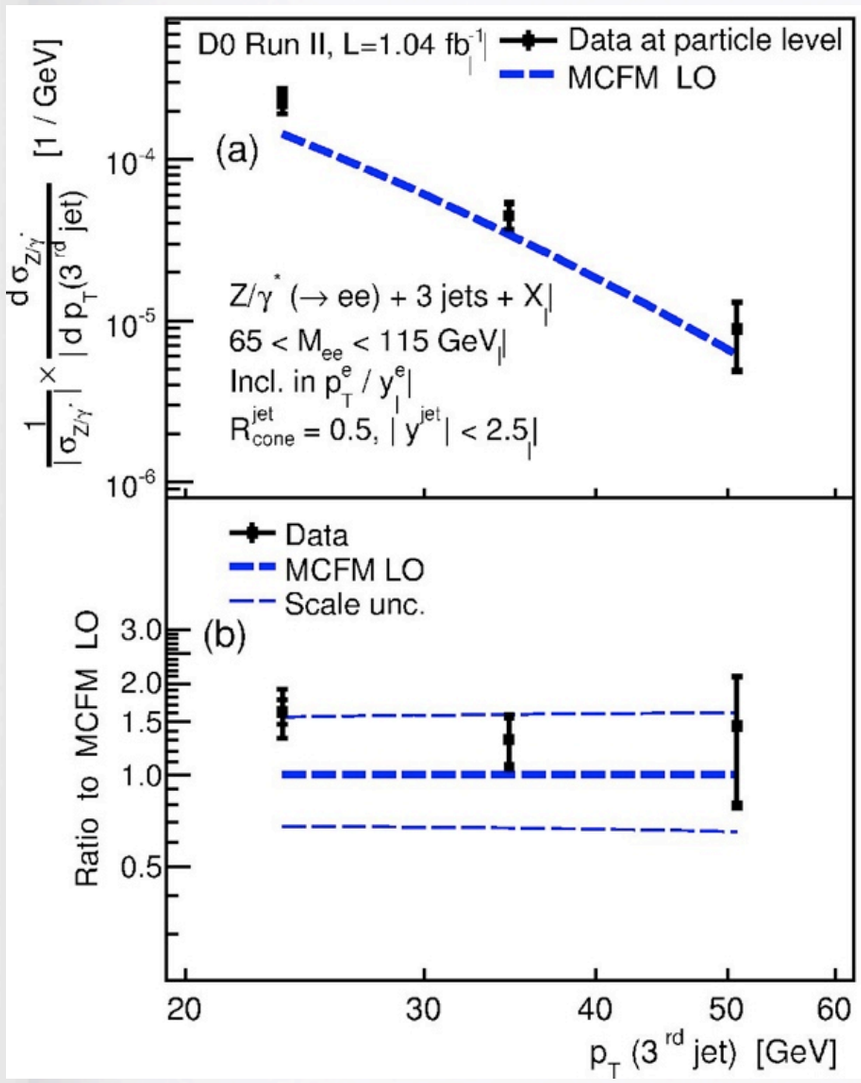
Z->ee + **3jets** + X - p_T spectra

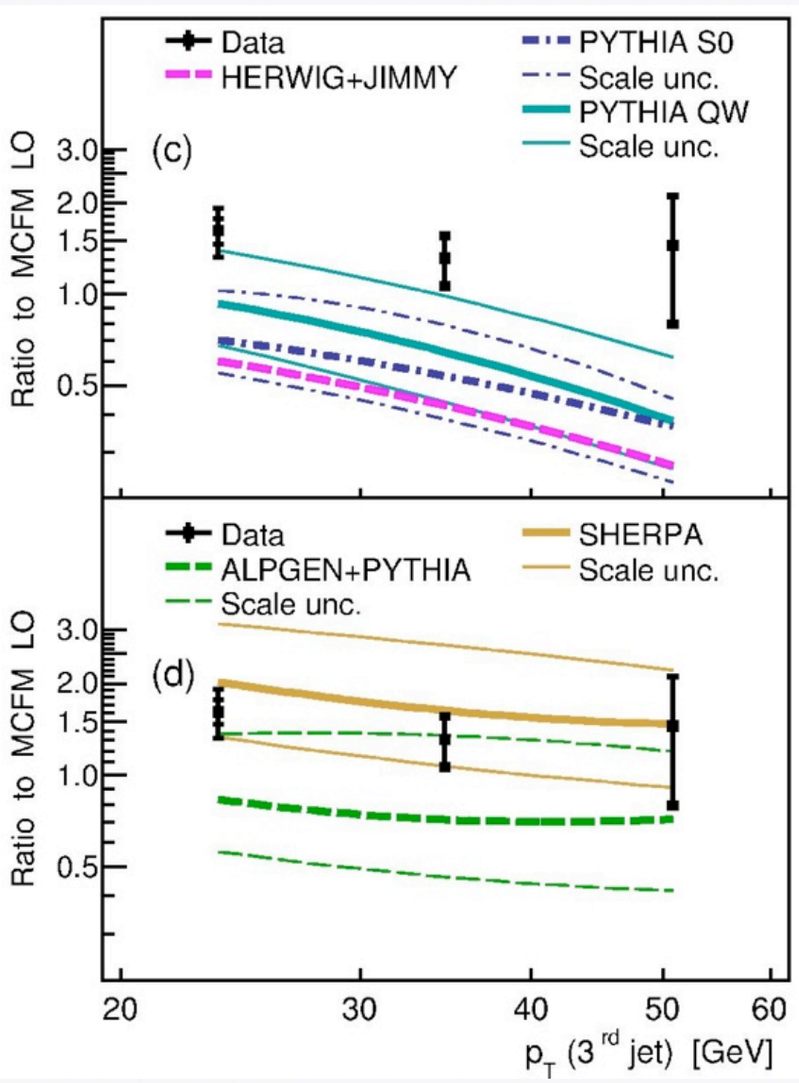
Particle level phase space:
65 GeV< M_{ee} < 115 GeV,
D0 midpoint R_{cone}=0.5, p_T^{jet} > 20 GeV
$|y^{jet}|$ < 2.5, Incl in $p_T^e/|y^e|$

normalized to
inclusive Z production

ratios relative to MCFM LO

MCFM v5.3 PDF: CTEQ6.6M
$\mu_r^2 = \mu_f^2 = p_{T,Z}^2 + M_Z^2$





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✦ Large differences between models
✦ Small experimental errors, dominated by statistics

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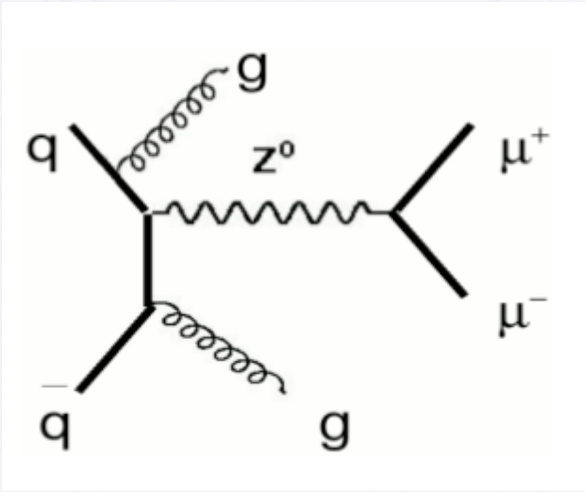
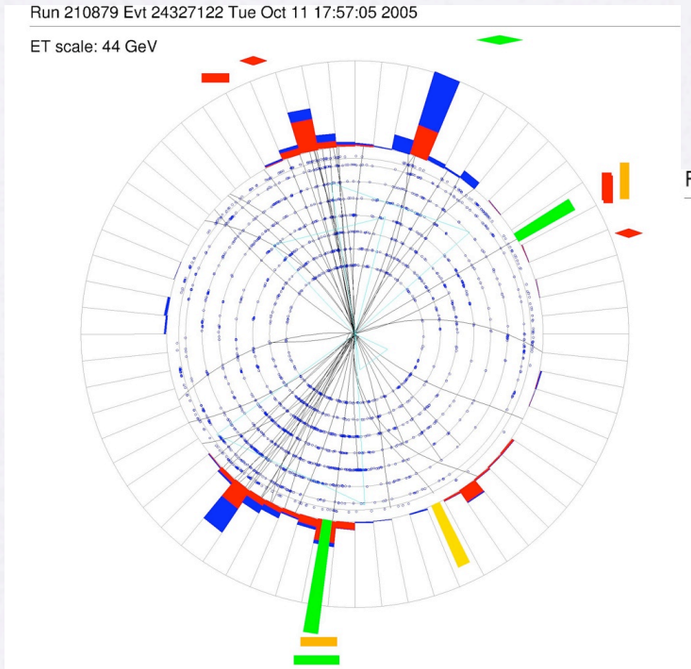
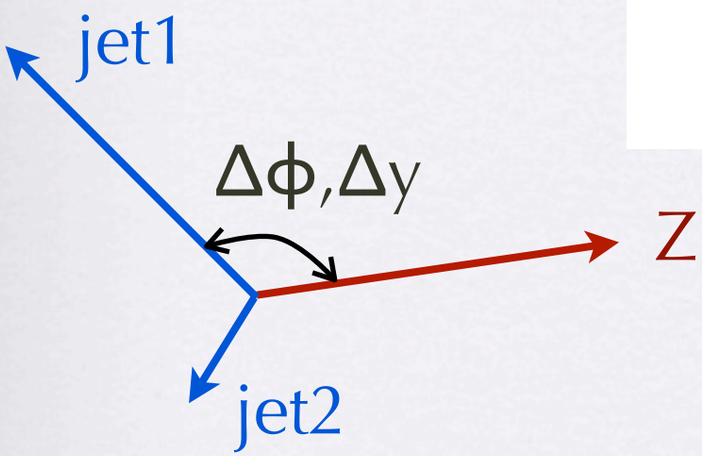
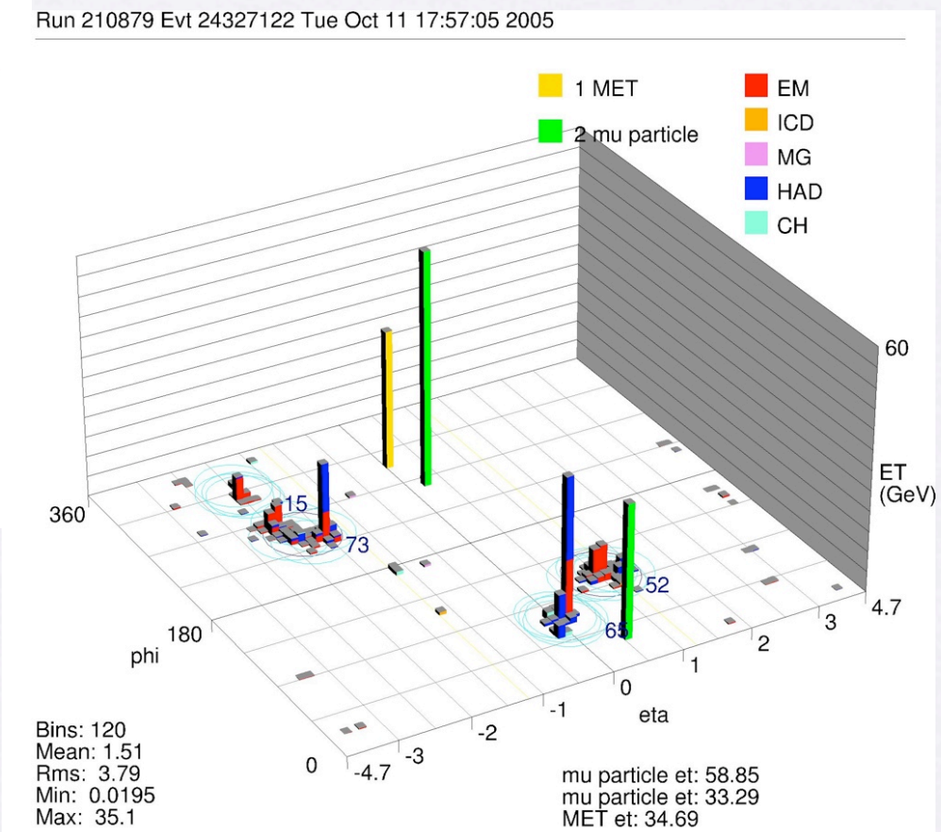
Z+jets - angular variables

- further constrains kinematics
- test of PS model assumptions
- first measurements at hadronic collider of
  - $\Delta\phi$(Z,leading jet)
  - Δy(Z,leading jet)
  - $y_{boost} = 1/2(y_Z+y_{jet})$



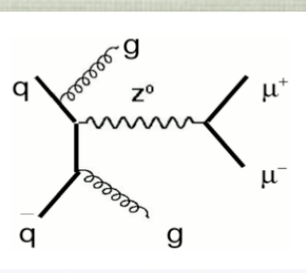






Z->μμ + jet + X -- jet rapidity

rapidity $y = 1/2 \ln(E+p_z/E-pz)$
$\eta = -\ln(\tan\Theta/2)$



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D0 midpoint R_{cone}=0.5, $p_T^{jet} > 20$ GeV
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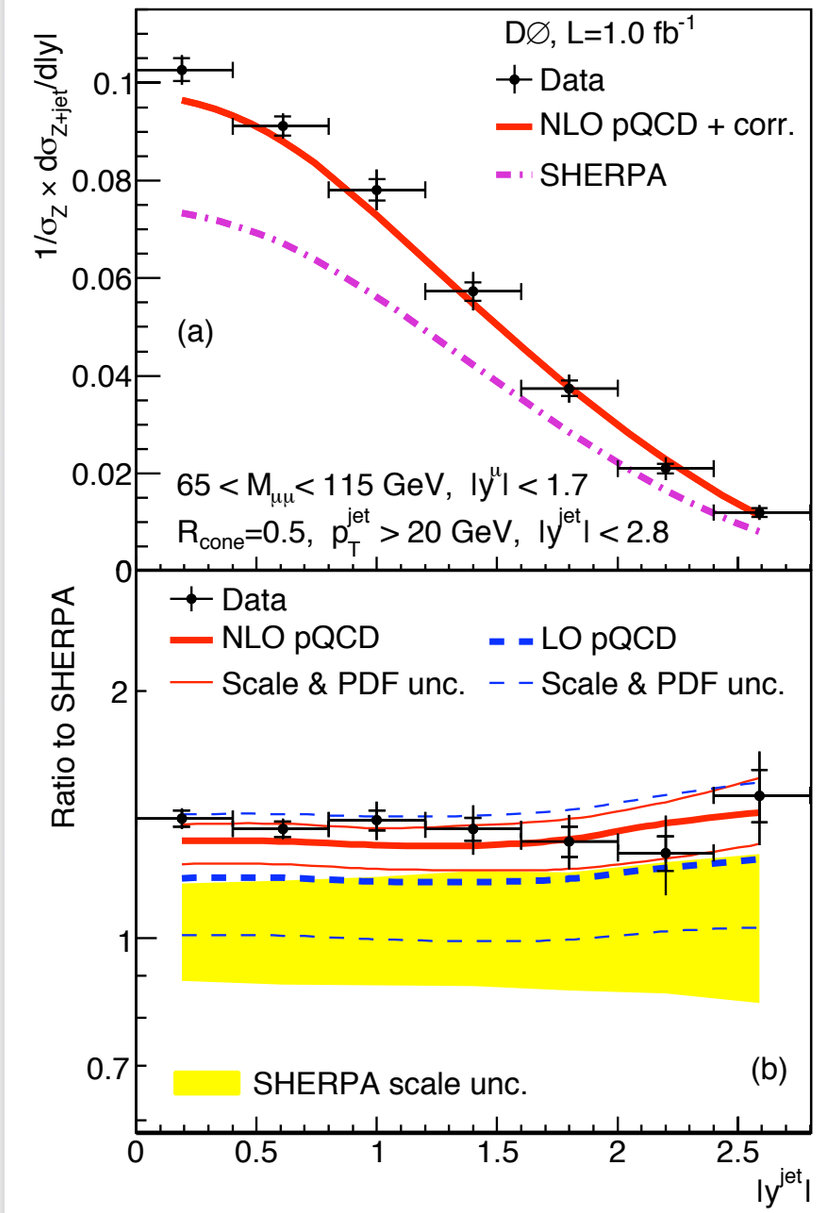
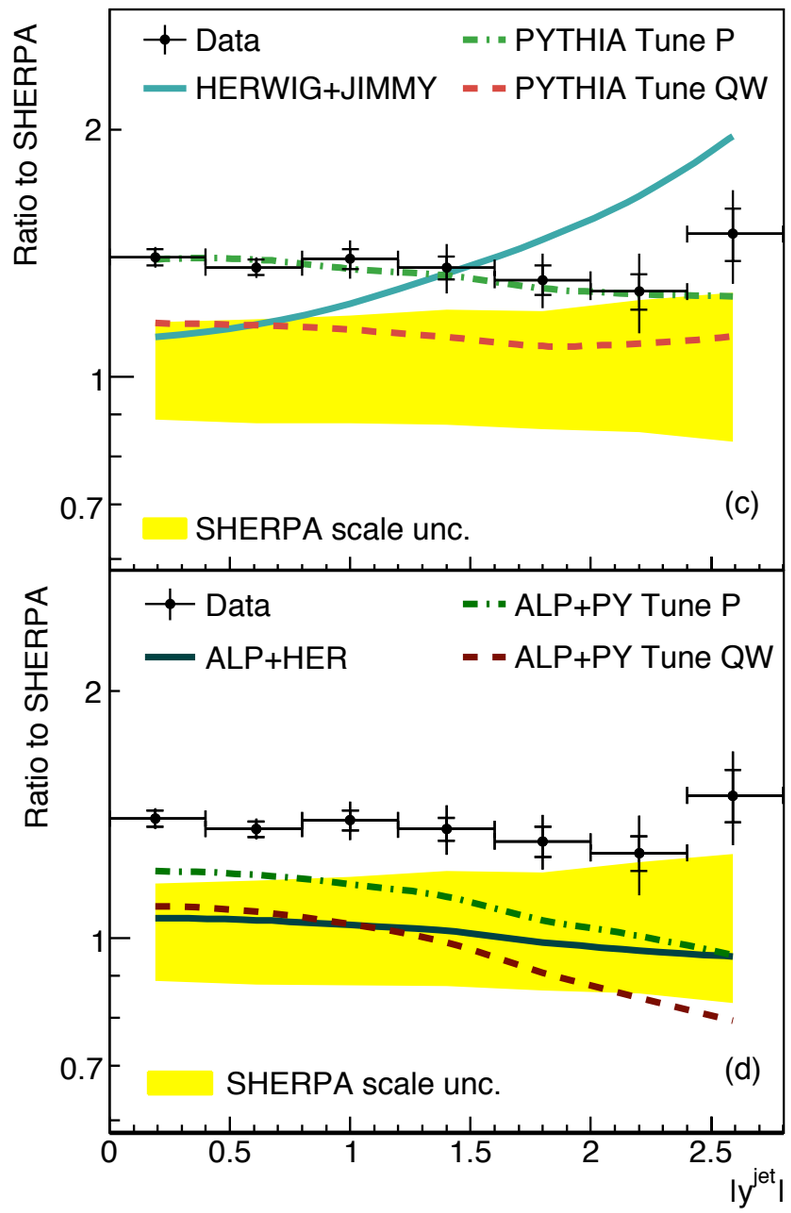
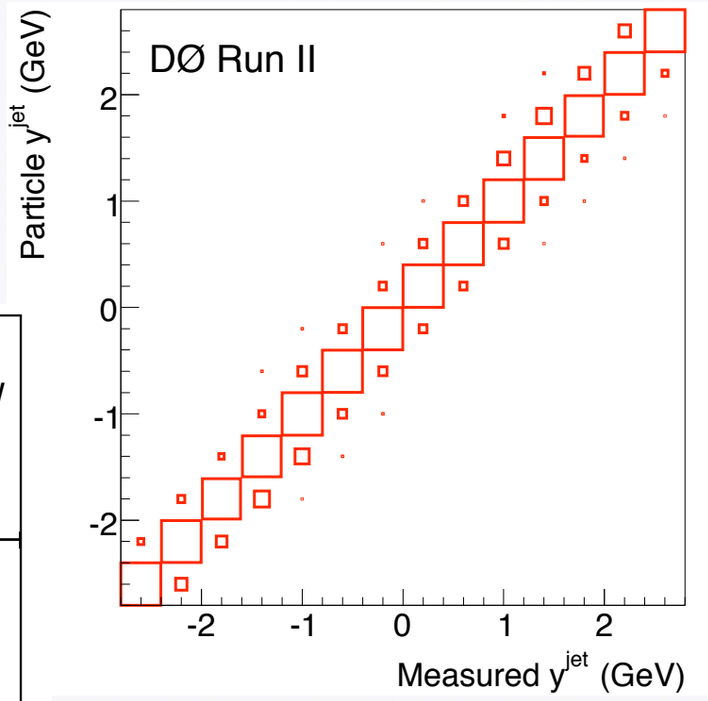
theory predictions updated since publication

ratios relative to Sherpa v1.1.3







migrations much reduced in y^{jet}

- MCFM,Sherpa describe y^{jet} shape well
- Alpgen+Pythia predicts narrower y^{jet} than data
- LO programs underestimate data normalization

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Z->μμ + jet + X -- Z rapidity

rapidity $y = 1/2 \ln(E+p_z/E-pz)$
$\eta = -\ln(\tan\Theta/2)$

Particle level phase space:
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D0 midpoint R_{cone}=0.5, $p_T^{jet} > 20$ GeV
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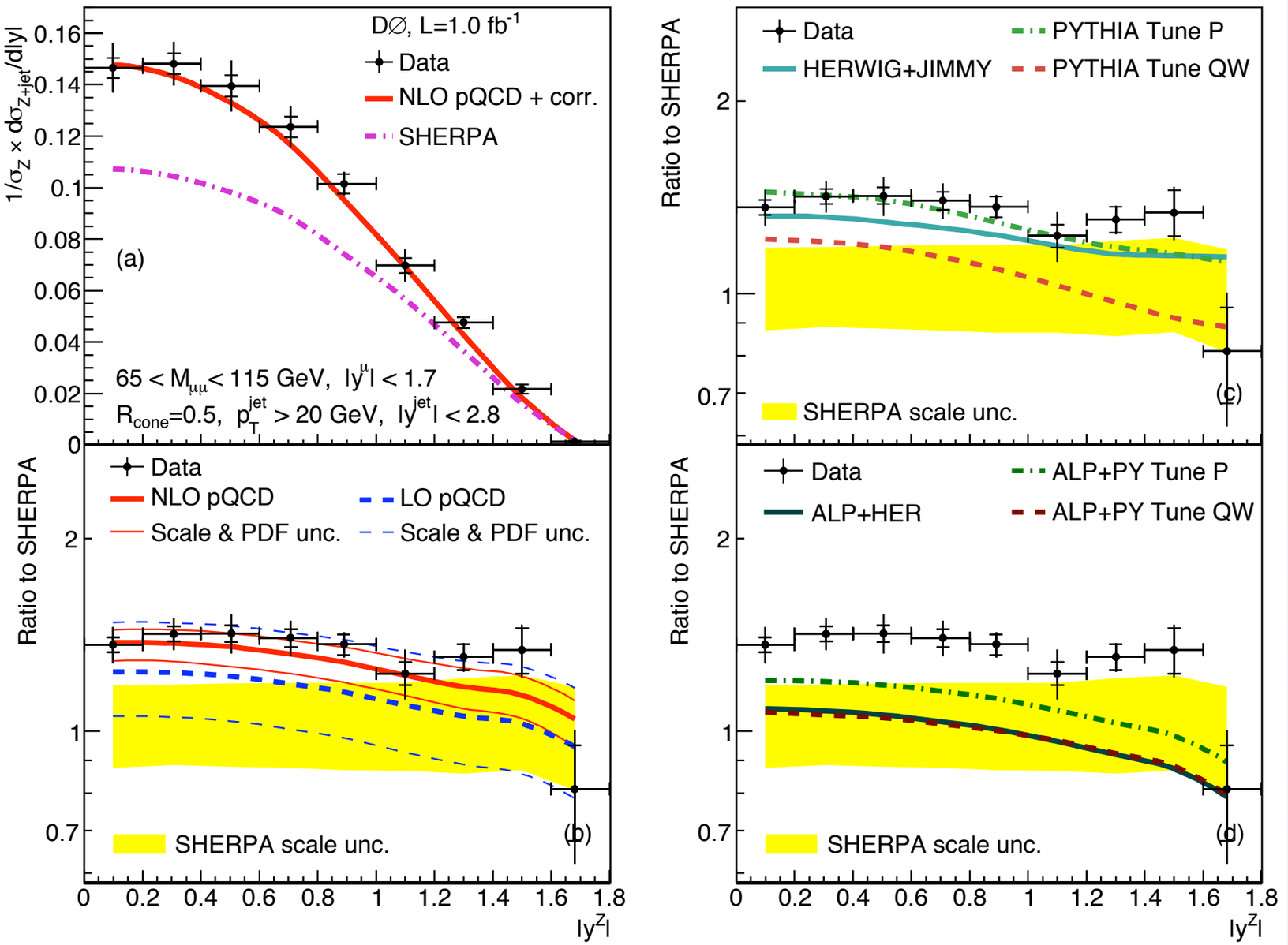

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$\mu_r^2 = \mu_f^2 = p_{T,Z}^2 + M_Z^2$

PYTHIA v6.420
Pythia Tune P
(p_T ordered shower)
Pythia Tune QW
(Q^2 ordered shower)
HERWIG v6.510
+JIMMY v4.31

ALPGEN v2.13
+PYTHIA v6.420
ALPGEN v2.13
+HERWIG v6.510
CTEQ6.1M PDFs

✦ All predictions describe y_Z shape

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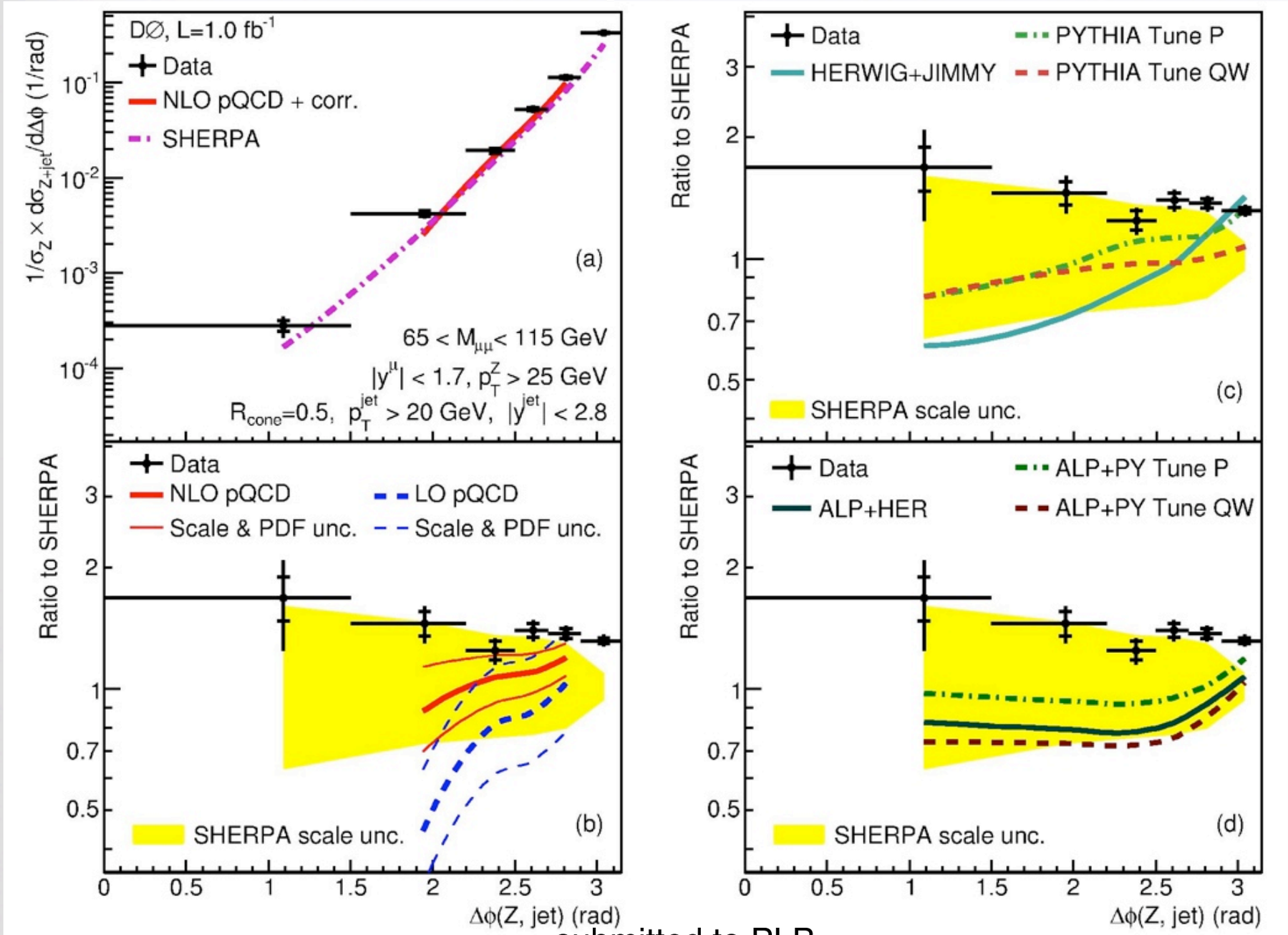
Z->μμ + jet + X -- Δφ

First measurement at a hadron collider!

ratios relative to Sherpa v1.1.3

MCFM v5.4 PDF: MSTW2008
$\mu_r^2 = \mu_f^2 = p_{T,Z}^2 + M_Z^2$

Z p_T > 25 GeV



PYTHIA v6.420
Pythia Tune P
(p_T ordered shower)
Pythia Tune QW
(Q^2 ordered shower)
HERWIG v6.510
+JIMMY v4.31

ALPGEN v2.13
+PYTHIA v6.420
ALPGEN v2.13
+HERWIG v6.510
CTEQ6.1M PDFs

✦ Sherpa describes Δφ

arXiv:0907.4286 [hep-ex] submitted to PLB

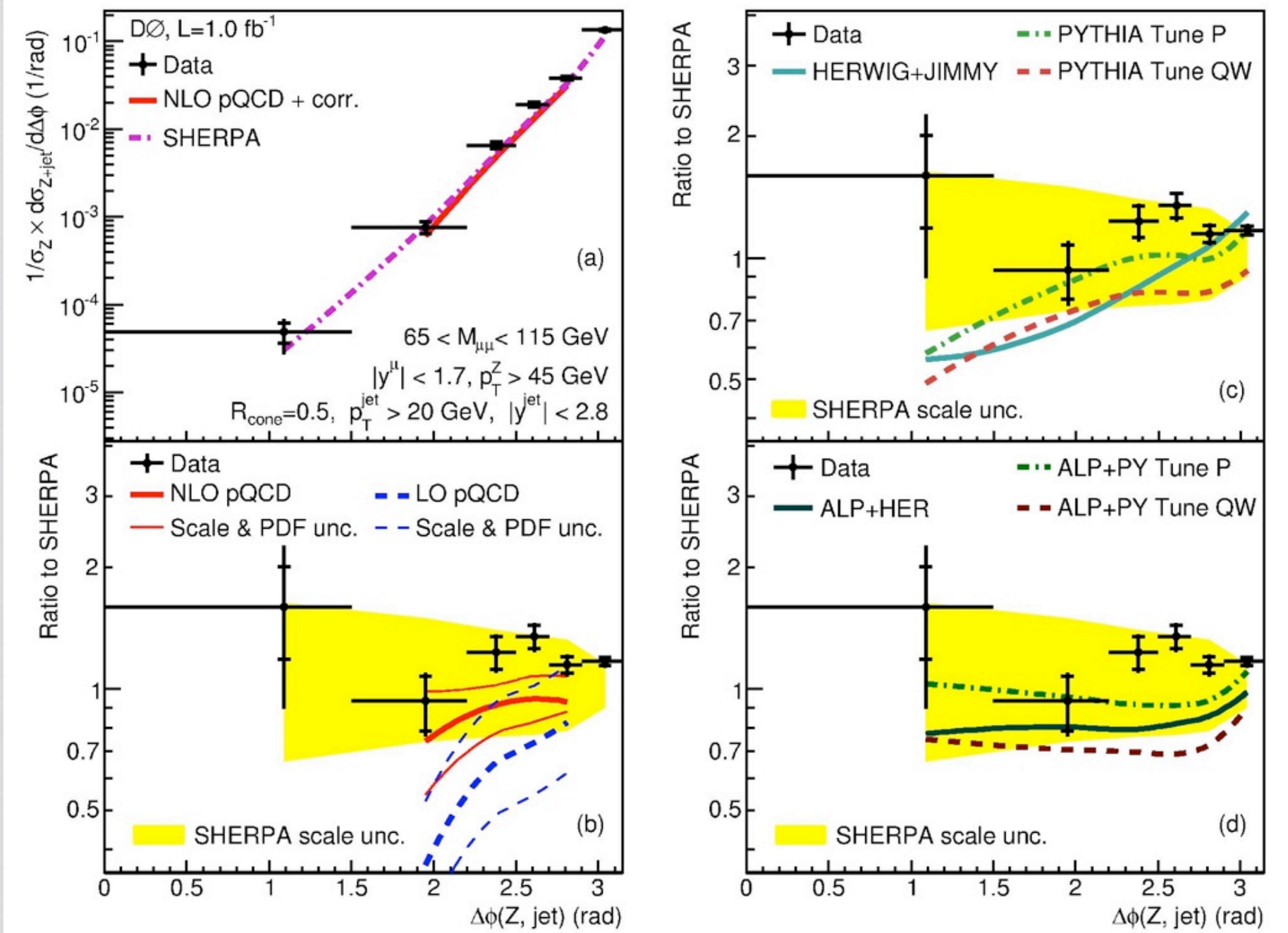
Z->μμ + jet + X -- Δφ

First measurement at a hadron collider!

Z p_T > 45 GeV

ratios relative to Sherpa v1.1.3

MCFM v5.4 PDF: MSTW2008
$\mu_r^2 = \mu_f^2 = p_{T,Z}^2 + M_Z^2$



PYTHIA v6.420
Pythia Tune P
(p_T ordered shower)
Pythia Tune QW
(Q^2 ordered shower)
HERWIG v6.510
+JIMMY v4.31

ALPGEN v2.13
+PYTHIA v6.420
ALPGEN v2.13
+HERWIG v6.510
CTEQ6.1M PDFs

✦ Sherpa describes Δφ

arXiv:0907.4286 [hep-ex]

submitted to PLB

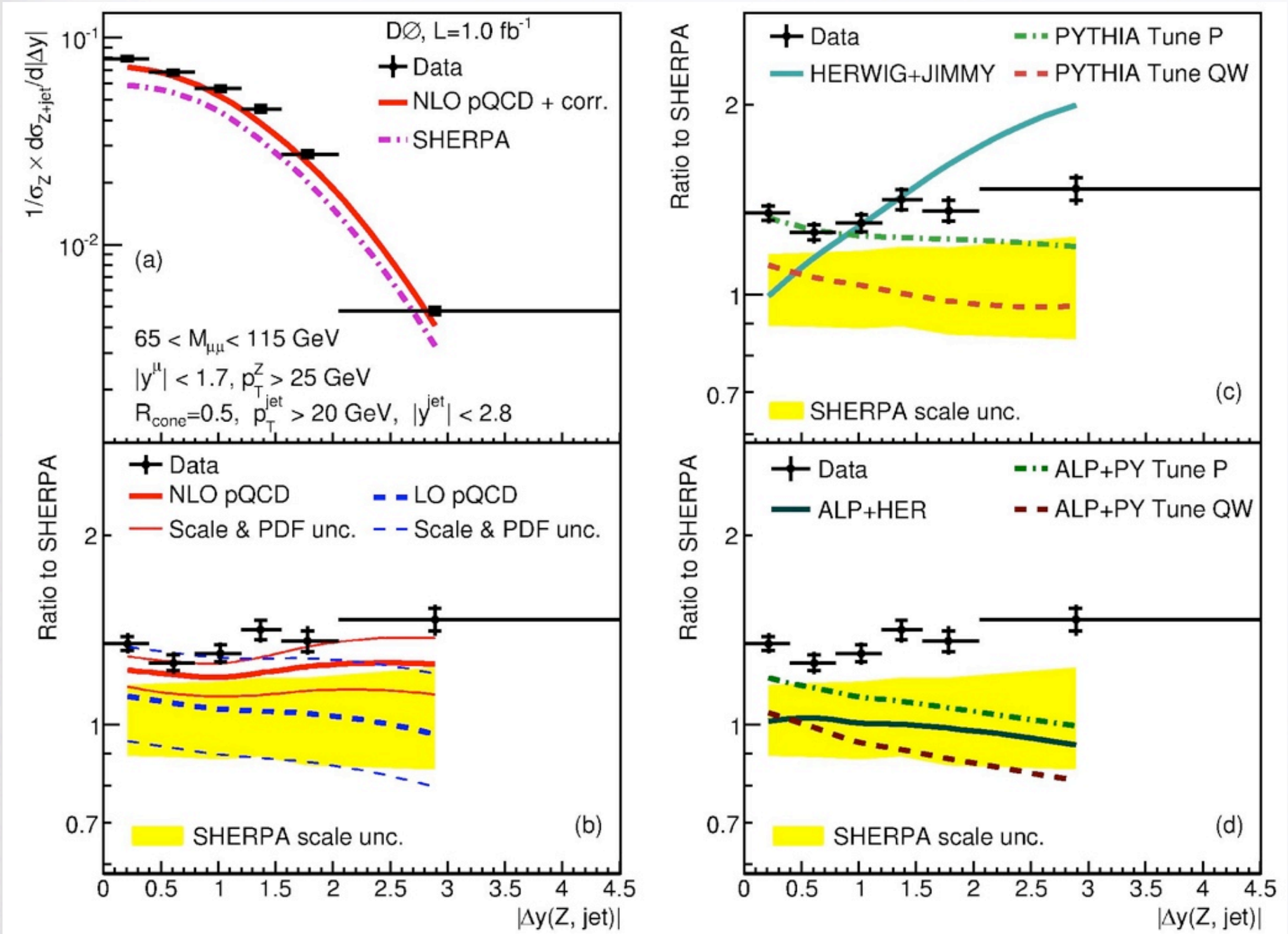
Z->μμ + jet + X - Δy

First measurement at a hadron collider!

Z p_T > 25 GeV

ratios relative to Sherpa v1.1.3

MCFM v5.4 PDF: MSTW2008
$\mu_r^2 = \mu_f^2 = p_{T,Z}^2 + M_Z^2$



PYTHIA v6.420
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HERWIG v6.510
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ALPGEN v2.13
+PYTHIA v6.420
ALPGEN v2.13
+HERWIG v6.510
CTEQ6.1M PDFs

✦ Sherpa, NLO describe Δϕ

arXiv:0907.4286 [hep-ex]

submitted to PLB

Z->μμ + jet + X -- y_{boost}

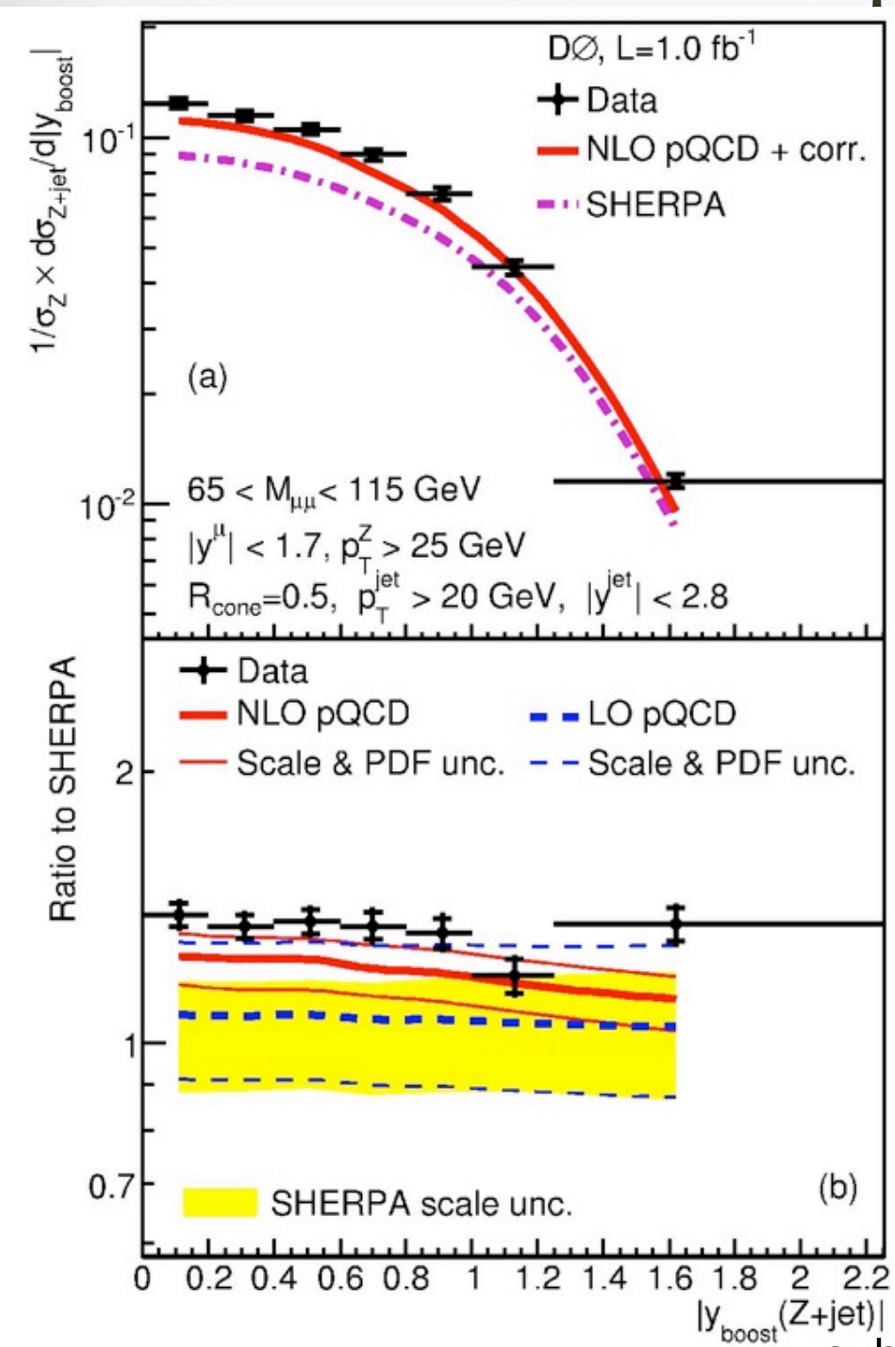
$y_{boost} = 1/2(y_Z + y_{jet1})$

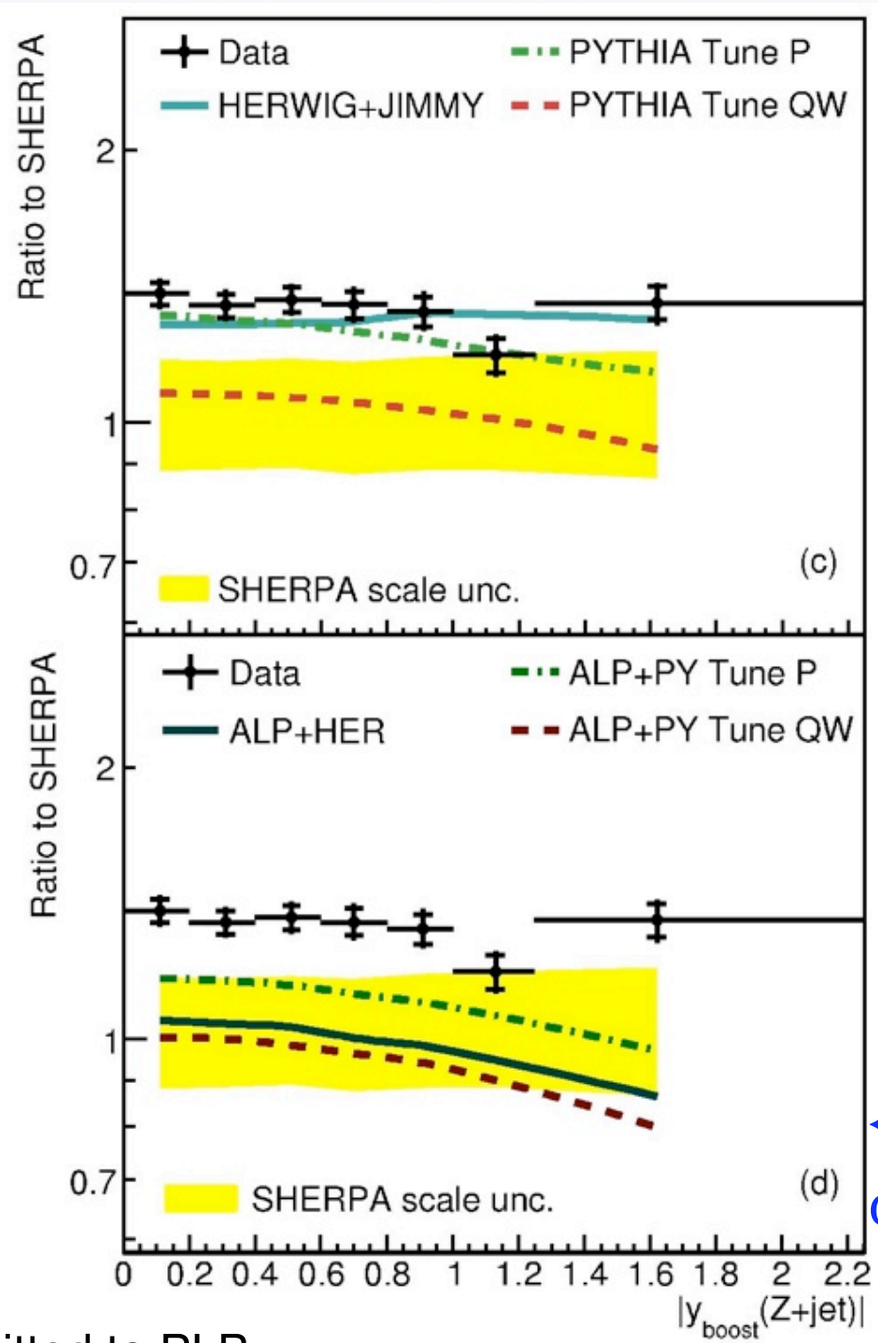
First measurement at a hadron collider!

Z p_T > 25 GeV

ratios relative to Sherpa v1.1.3

MCFM v5.4 PDF: MSTW2008
$\mu_r^2 = \mu_f^2 = p_{T,Z}^2 + M_Z^2$





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ALPGEN v2.13
+PYTHIA v6.420
ALPGEN v2.13
+HERWIG v6.510
CTEQ6.1M PDFs

✦ All predictions describe y_{boost} shape

arXiv:0907.4286 [hep-ex] submitted to PLB

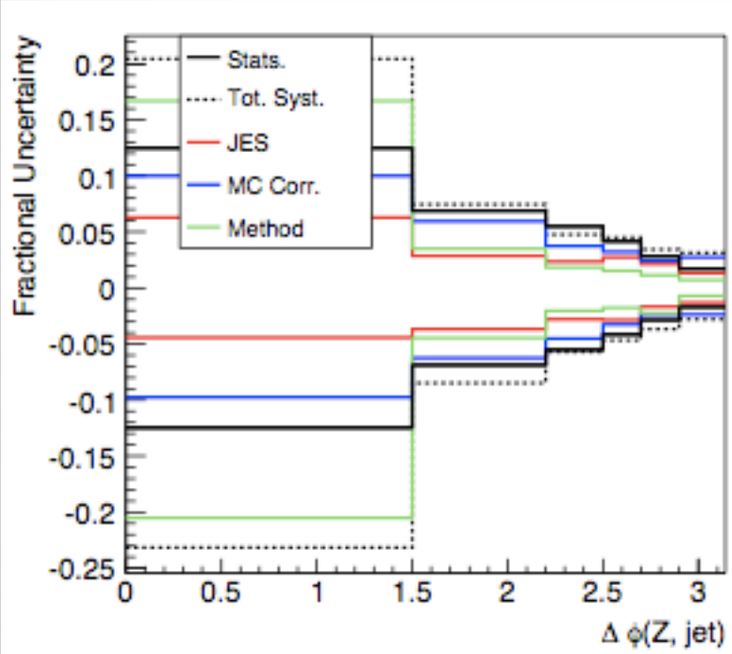
Uncertainties

- Jet Energy Scale (JES)
- MC Corrections: lepton resolution, jet resolution, efficiency
- Method: unfolding, model/simulation uncertainties

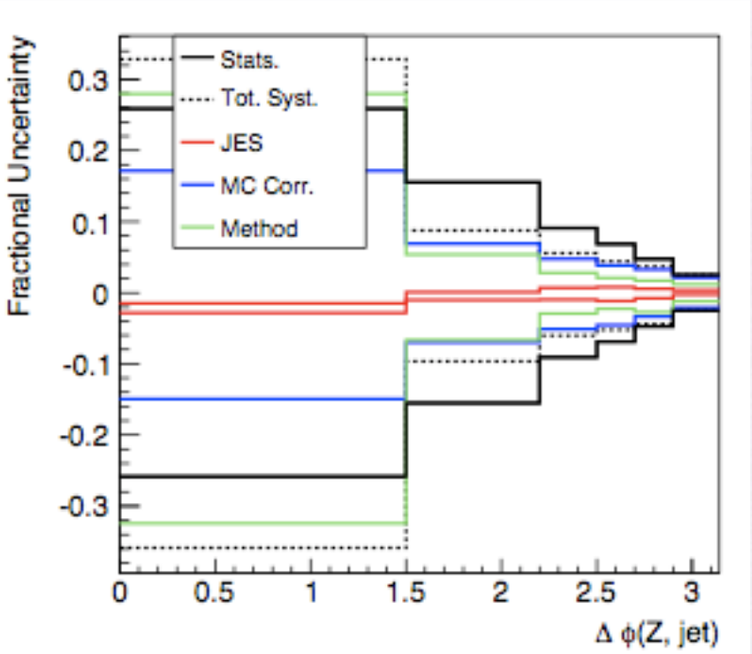
Z p_T > 25 GeV
Statistical, systematic errors are comparable

Z p_T > 45 GeV
Statistical error dominates in most bins

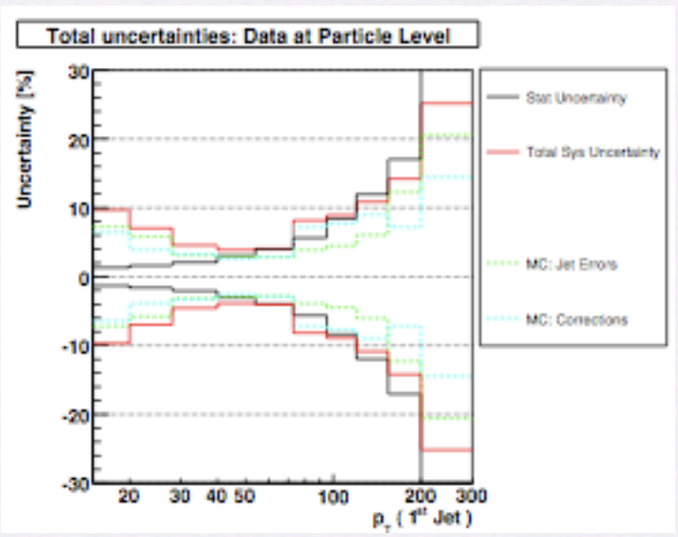
Systematic errors < 10% in bulk of data



muon channel



muon channel



electron channel

Summary and Outlook

Plethora of new measurements

- NLO pQCD describes data
- ME+PS outperform PS programs, need tuning

V+jets measurements - now a pillar of core D0 program

- W+jets cross section measurements underway
- Z+b/c, W+b/c under study
- multi-dimensional differential cross sections

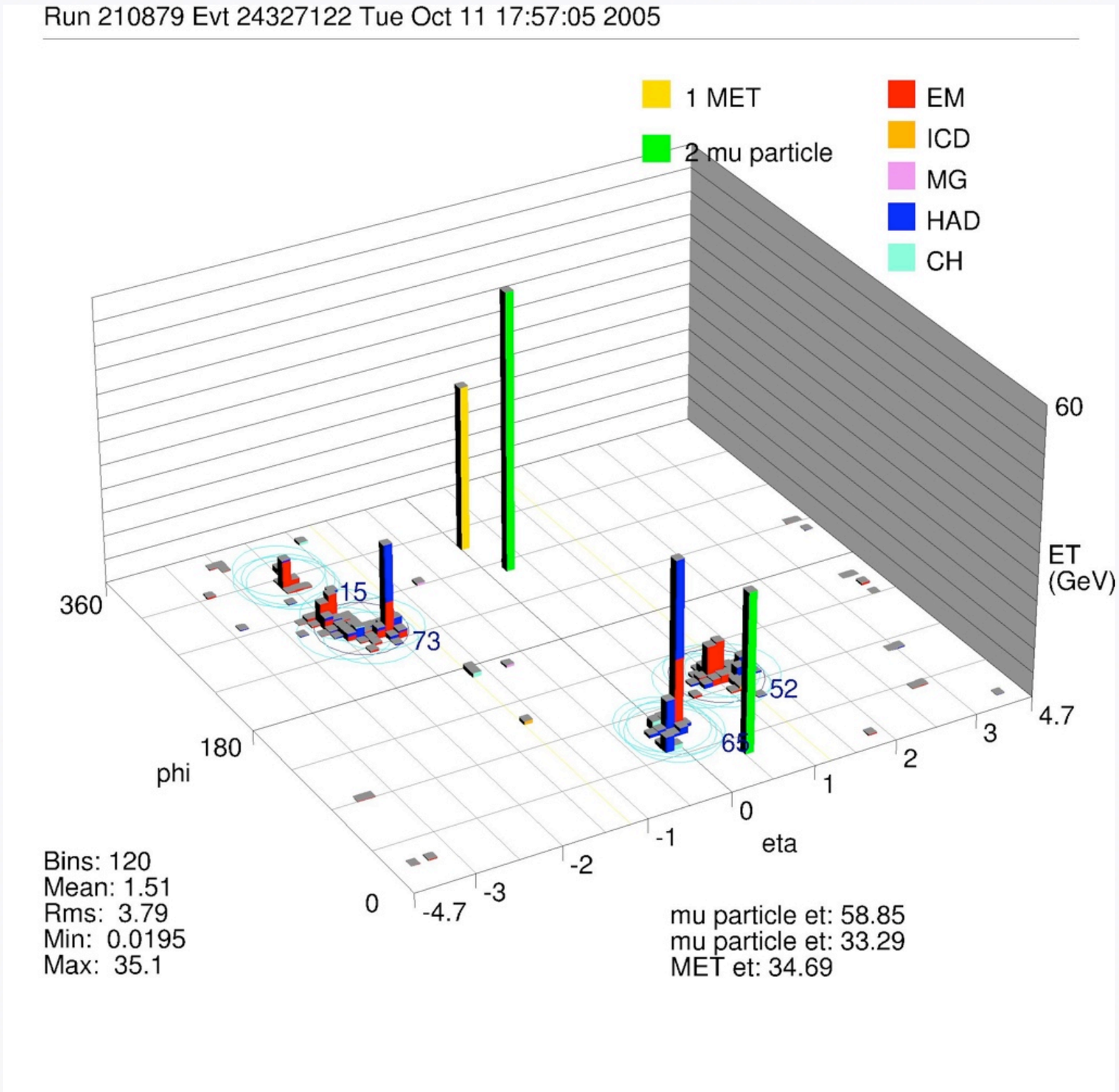
Z+jets measurements are pushing the boundary of theory predictions!

Precision comparisons will continue with larger dataset, W/Z+3 jet NLO calculations

Performance by	Z+jet normalization	Z+jet angles	Z+jet p_T
MCFM NLO	✔	✔	✔
Alpgen/MLM + Pythia			✔
Alpgen/MLM + Herwig			✔
Sherpa/CKKW		✔	
HERWIG			
PYTHIA			

Additional Slides

Event Display

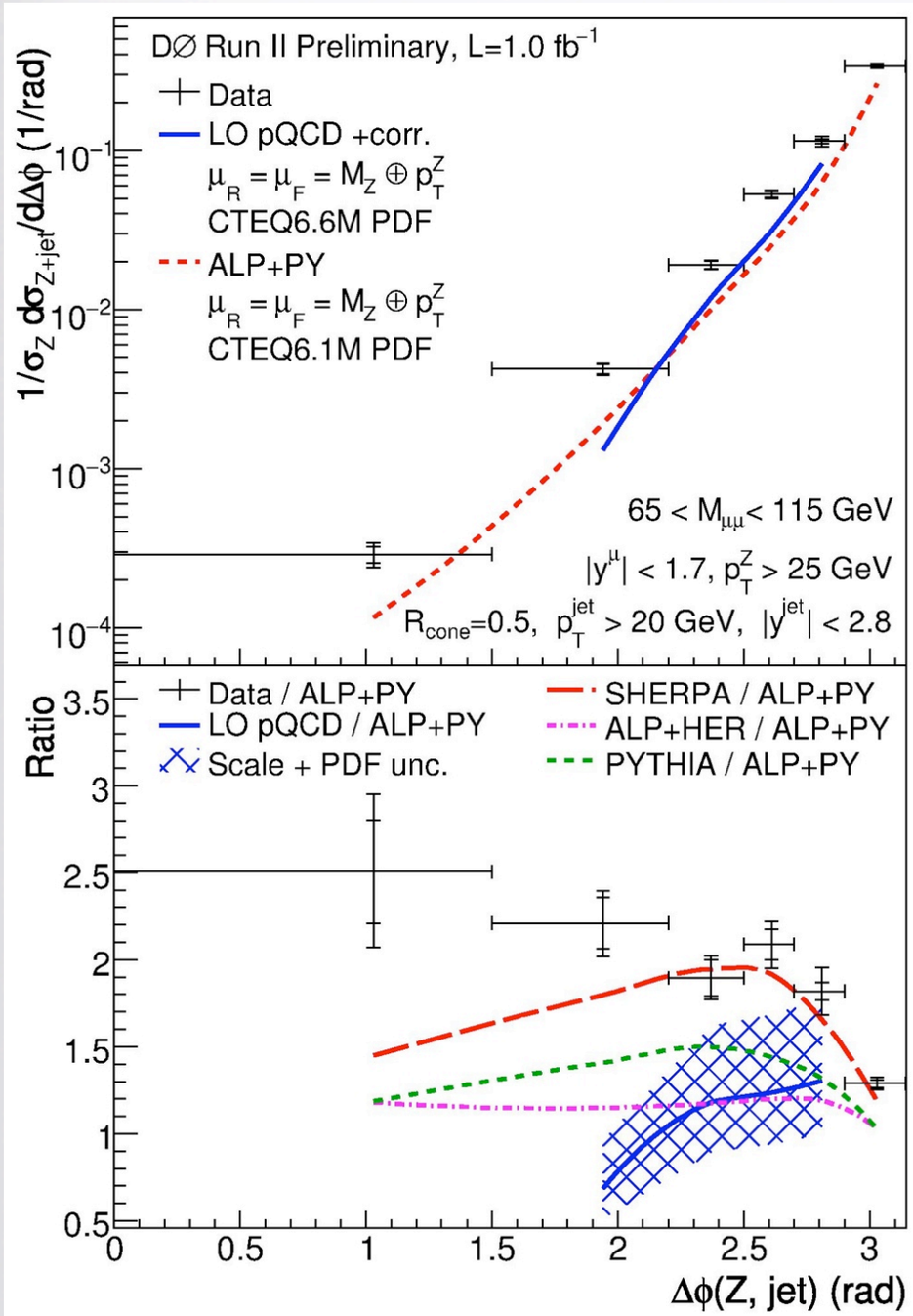


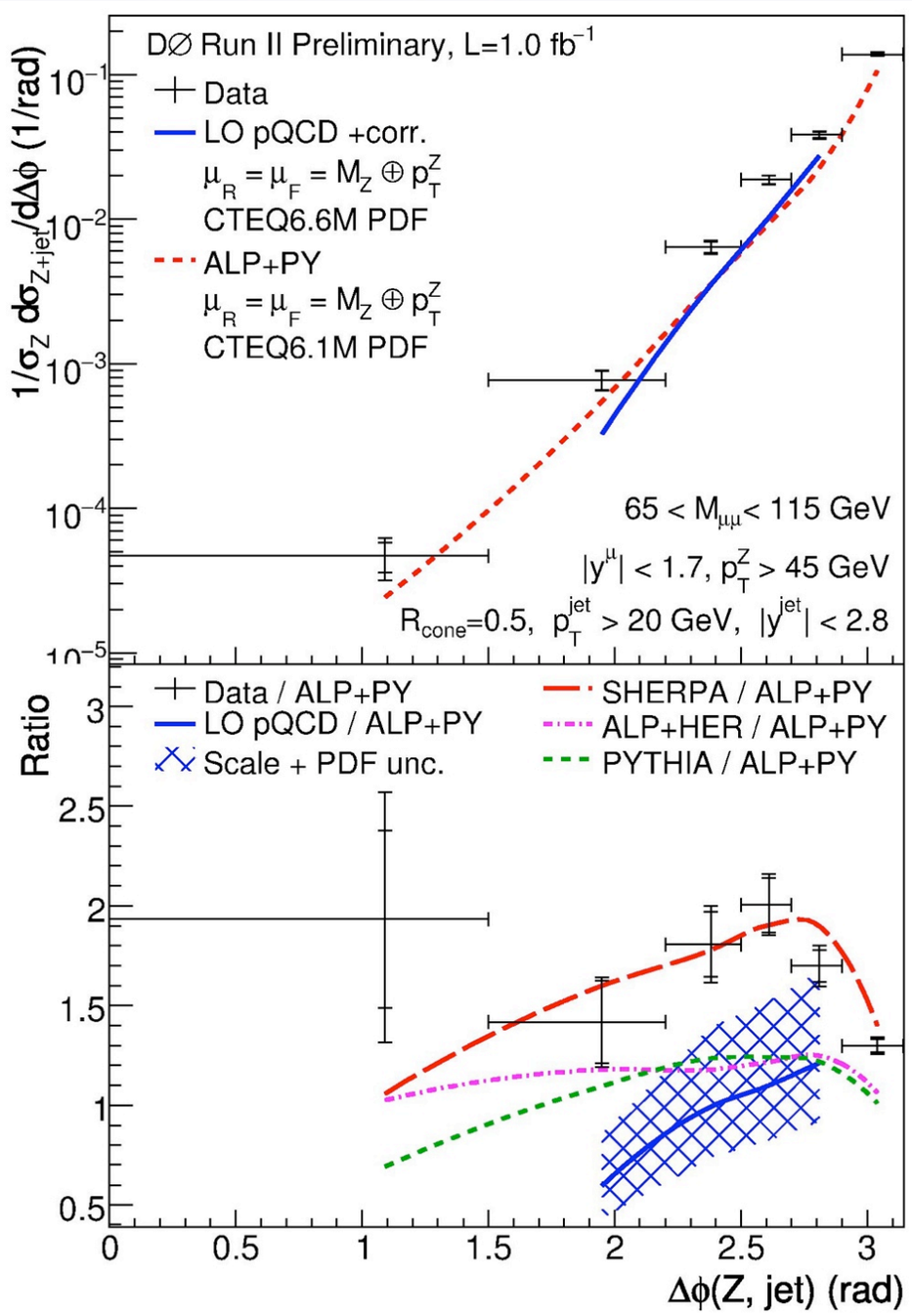
Z->μμ + jet + X - angles

Z p_T > 25 GeV

Z p_T > 45 GeV

First measurement at a hadron collider!



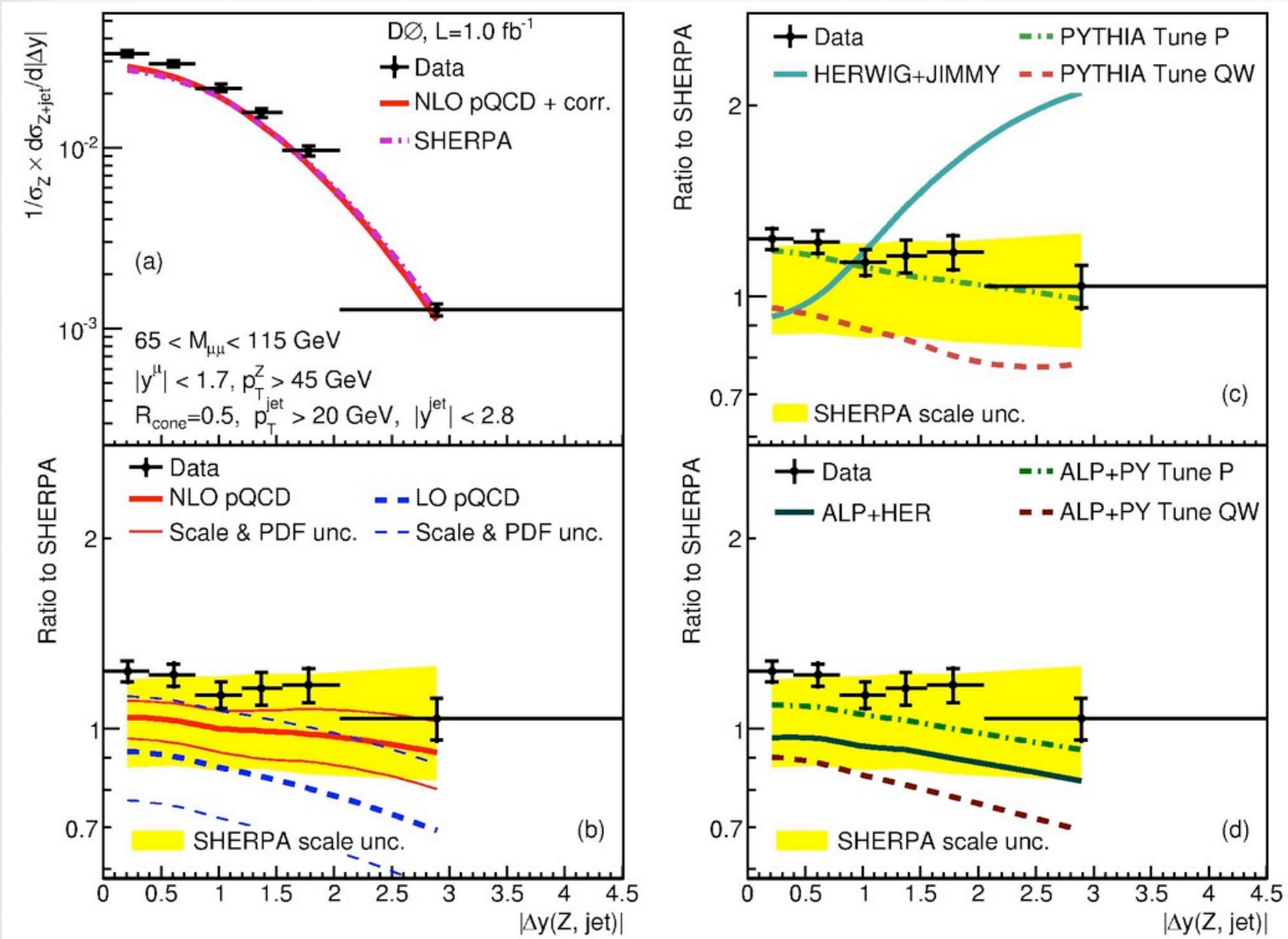


ratios relative to Alpgen+Pythia

Z+jets

Z p_T > 45 GeV

First measurement at a hadron collider!

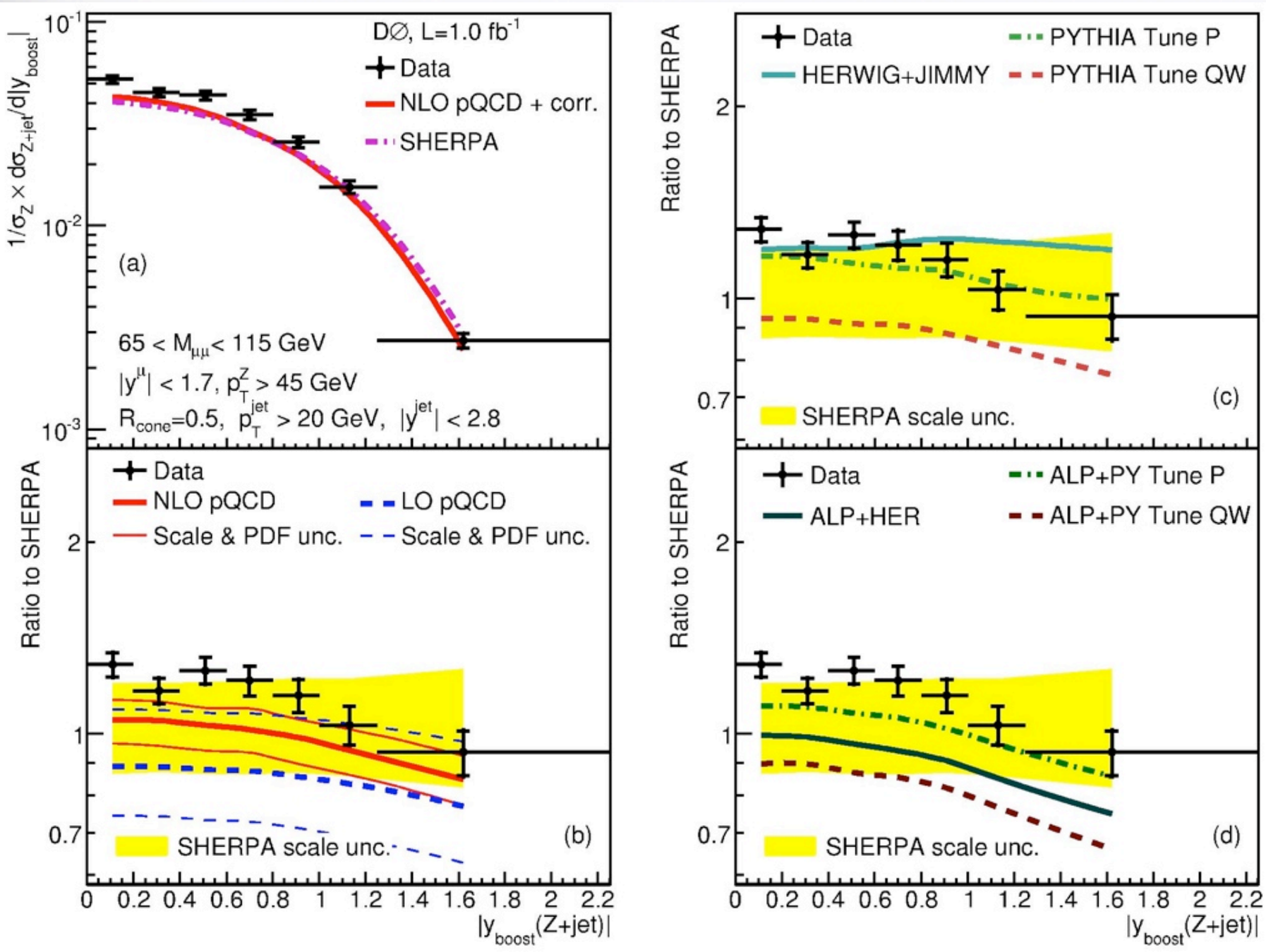


ratios relative to Sherpa

Z+jets

Z p_T > 45 GeV

First measurement at a hadron collider!



Sherpa does not describe shape

ratios relative to Sherpa