ME-PS Comparisons to Tevatron Data

Sabine Lammers
Indiana University
(formerly Columbia University)
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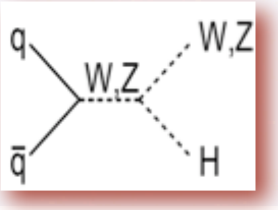
Motivation

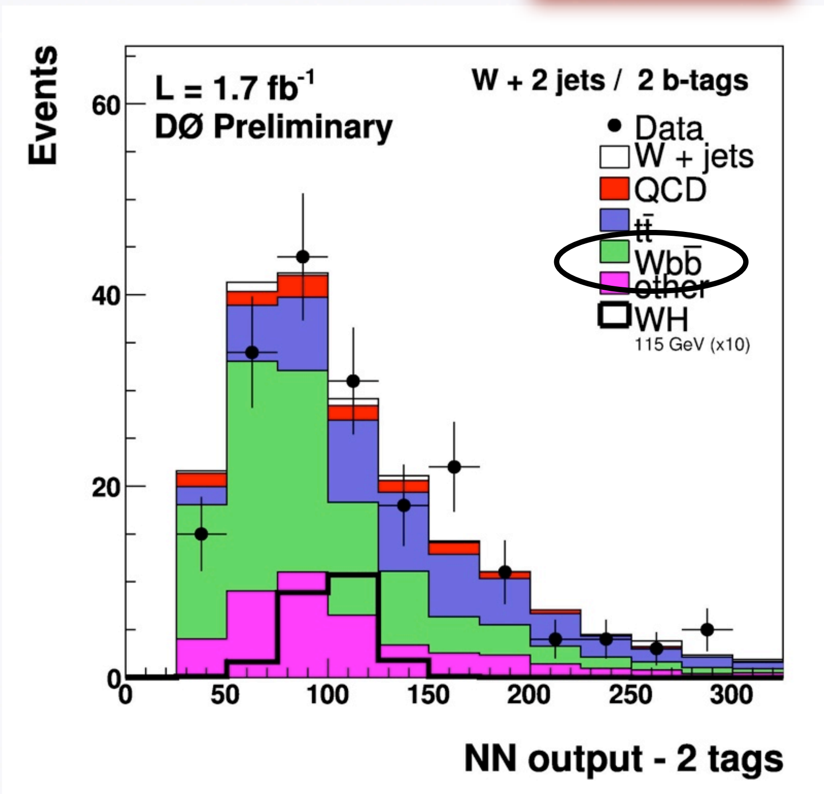
- N(N)LO predictions not available for many processes of interest, particularly those with large jet multiplicities and heavy flavor components.
- ME+PS models are used extensively to simulate signal and backgrounds, particularly for multijet topologies.
- Parton shower models can vary and are constantly being improved thanks to our phenomenologist friends.
- Experimentalists massage (calibrate to data) simulations through reweighting and empirically derived k-factors.
- Tevatron dataset is now large enough and systematics are constrained well enough to use data to vet ME+PS models.

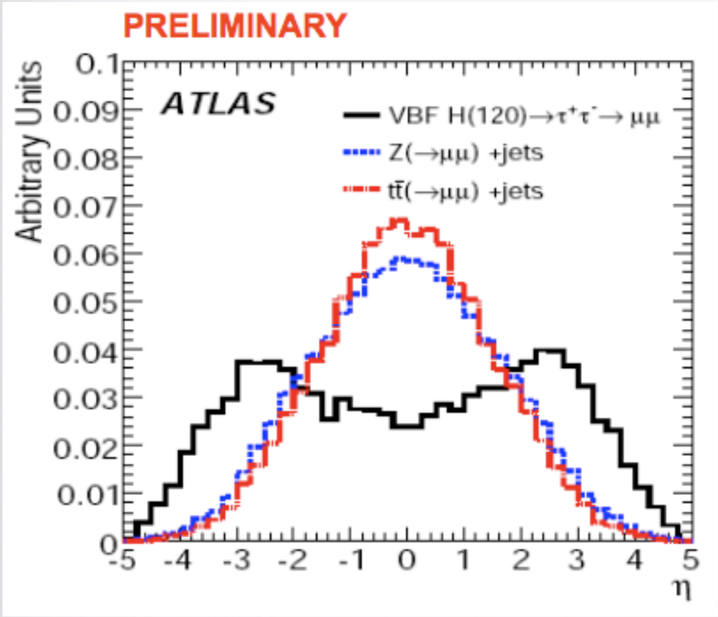
New Physics signals

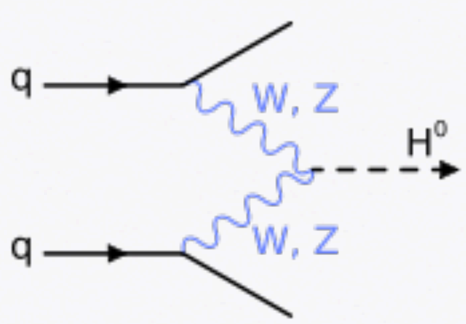
- New physics share signatures with TeV backgrounds that are currently being pinned down.

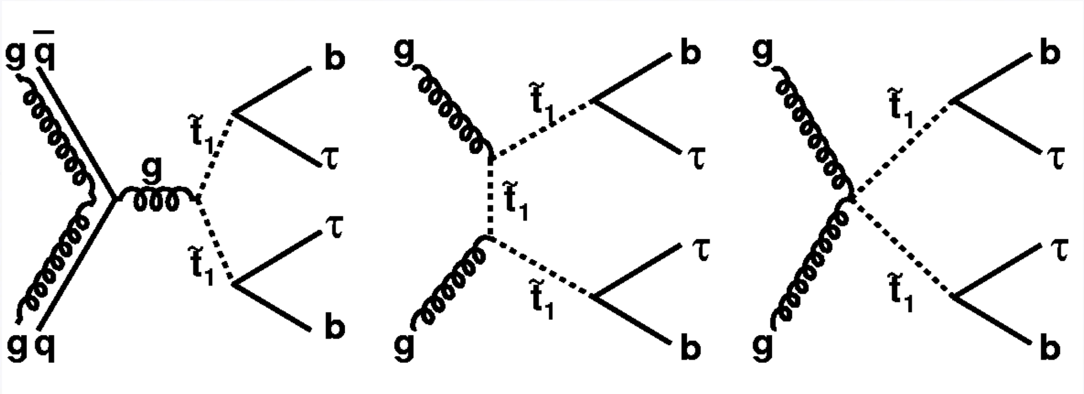
- Estimating background with data has its own set of challenges.











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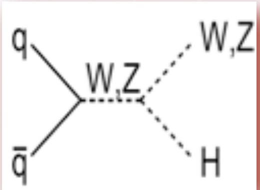
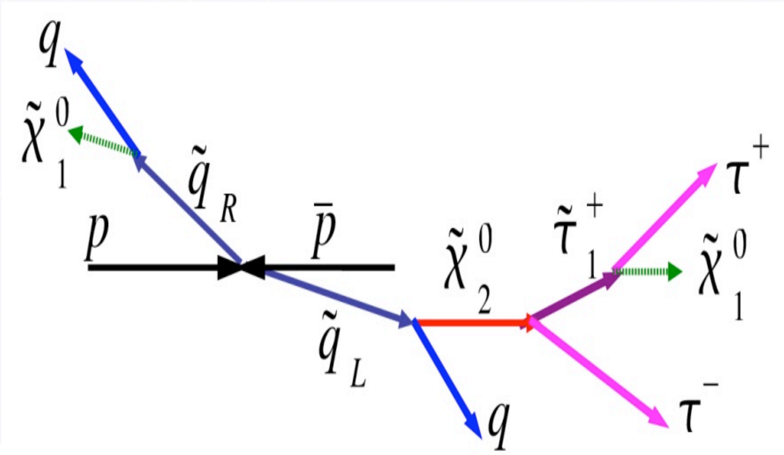
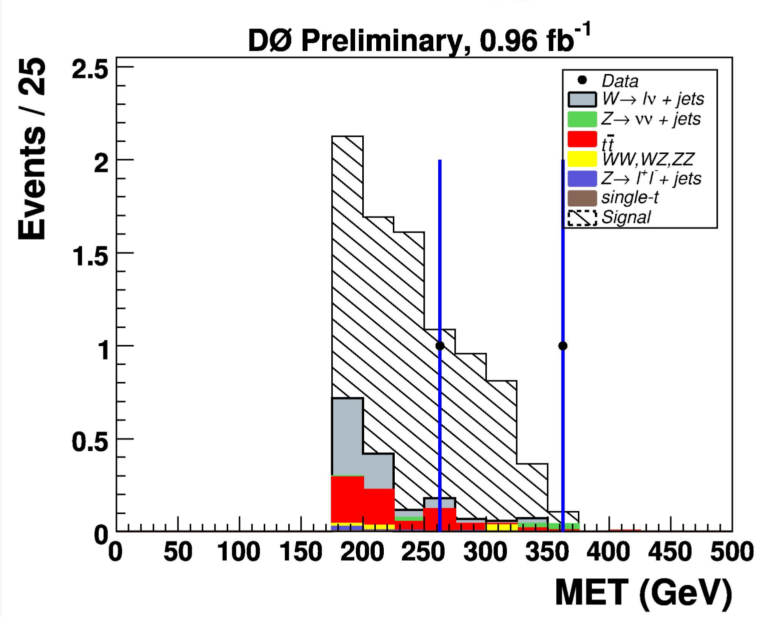
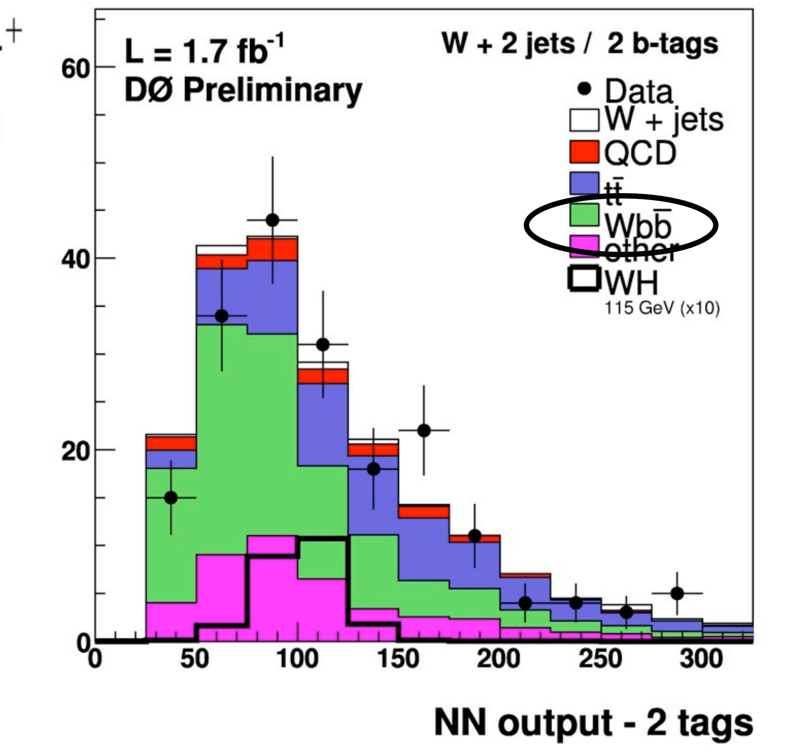
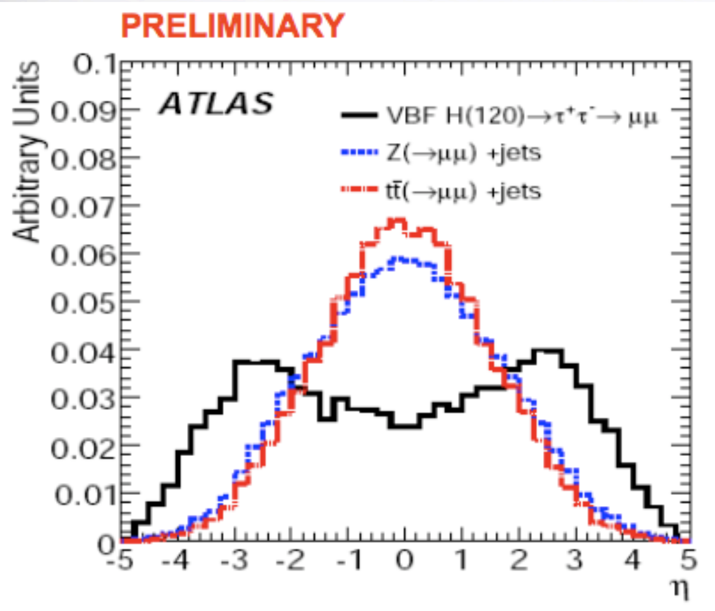
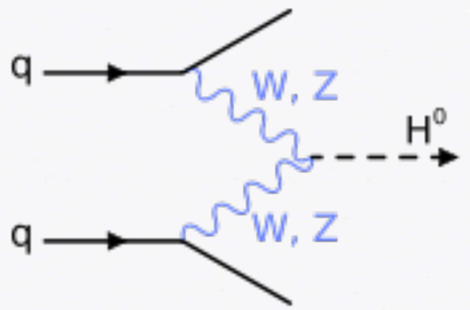


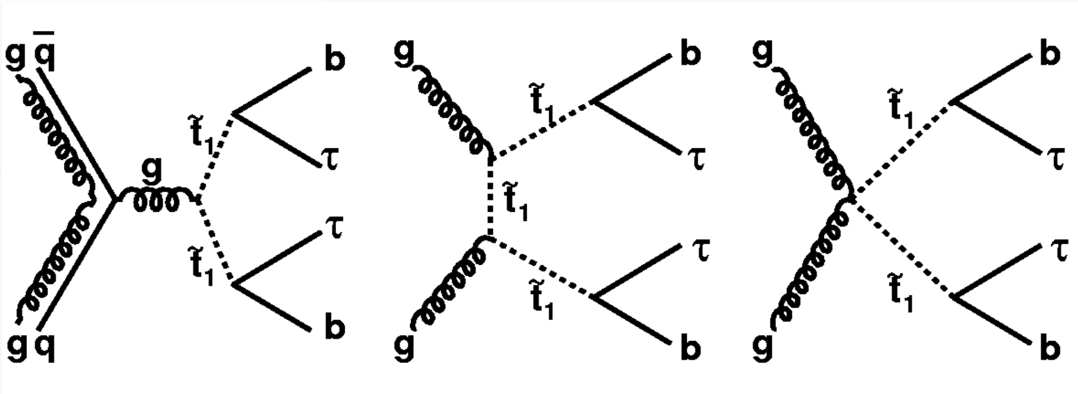










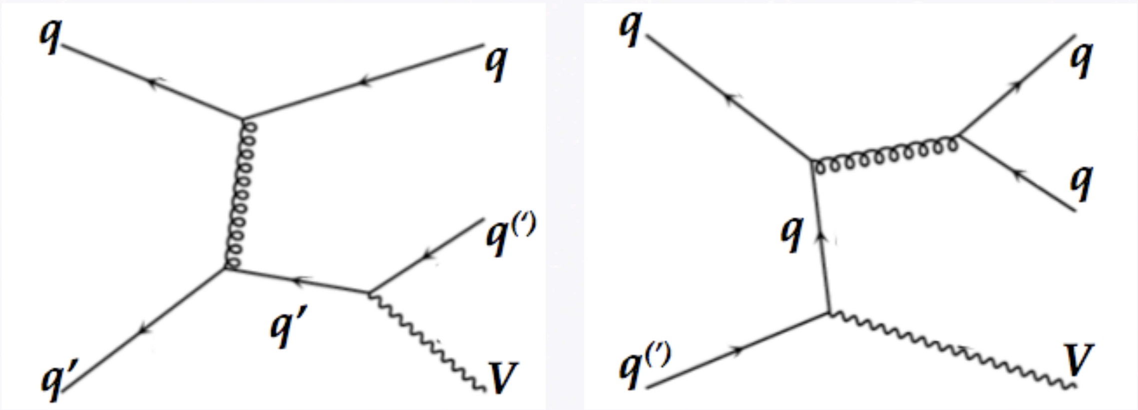


Final States

- W/Z + light flavor jets
- W/Z + heavy flavor jets

Result(1/fb)	DØ	CDF
W+jets	--	0.32
Z+jets	1.0/0.95	2.5/1.7
W+b-jets	0.38	1.9
Z+b-jets	0.18	2.0/0.33
W+c-jets	1.0	1.8

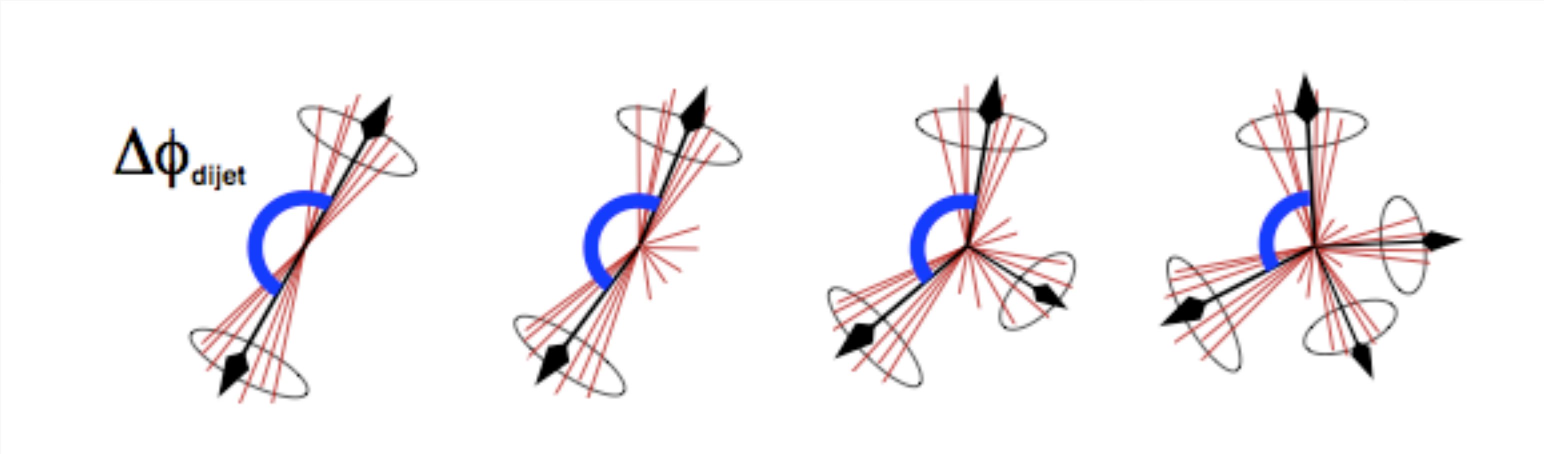
in red = published



V = W or Z/ϒ*

This talk will focus on results with comparisons to ME+PS models

- dijet azimuthal decorrelations
- Inclusive vs. Exclusive states



ME-PS Models

- Many programs on the market: Alpgen, Sherpa, MC@NLO, Madgraph, Helac, Ariadne, Madevent, ...
- This talk will focus on MLM vs. CKKW inspired models, where we have most comparisons to data
- CKKW
  - 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
- MLM
  - 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)

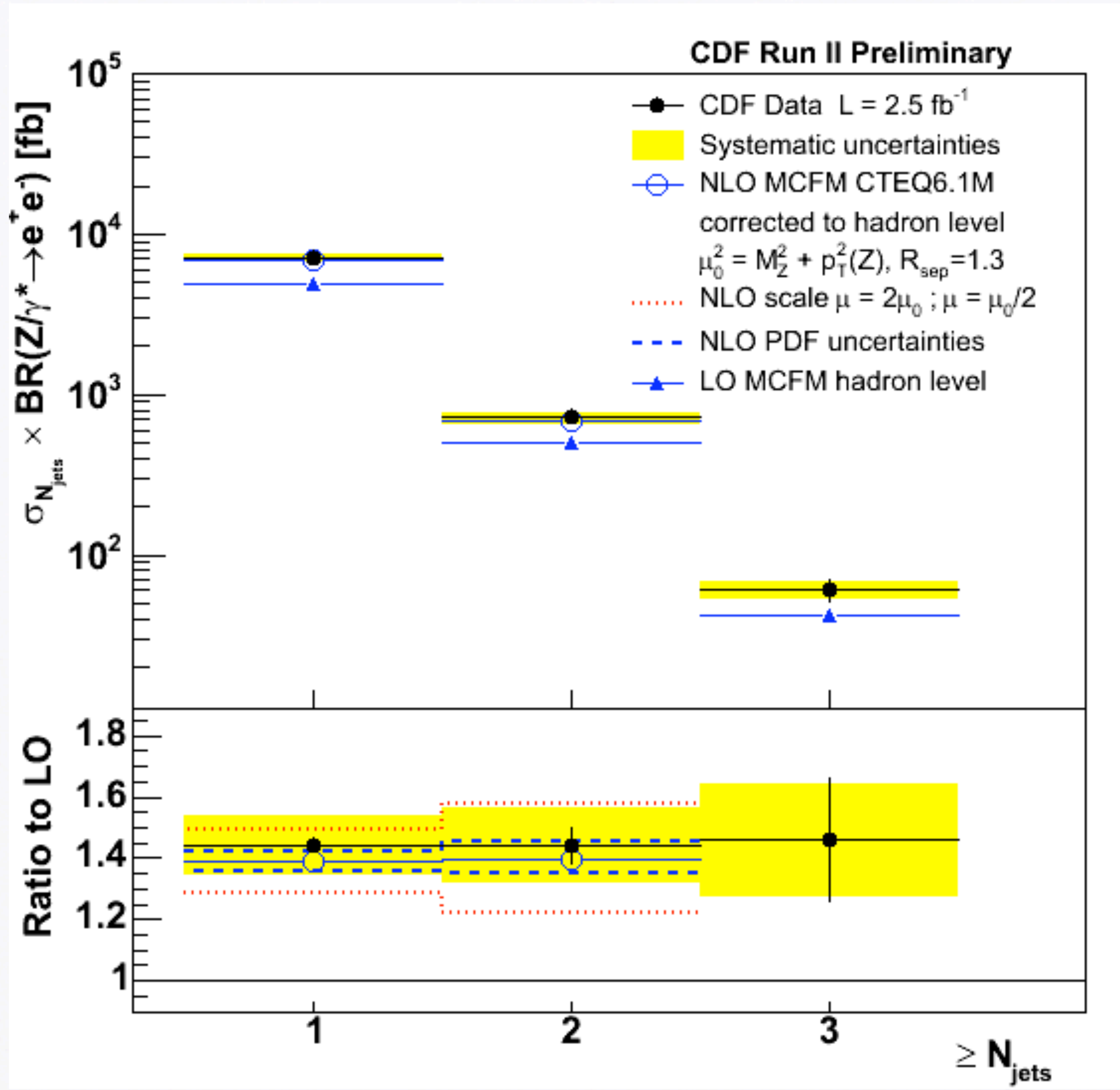
Z+ light flavor jets

$\mathcal{L} = 2.5/\text{fb}$

Z/Υ* → e⁺e⁻+jets

Corrected to hadron level with phase space:

- $p_T^{jet} > 30$ GeV
- $|y^{jet}| < 2.1$
- R = 0.7 cone jets
- $\Delta R_{(e,jet)} < 0.7$



MCFM corrected for hadronization

- NLO predicts correct normalization, with K-factor ~1.4

Z+ light flavor jets

data w/stat error
data w/stat & sys error
Pythia range stat
Pythia range stat & sys

$\mathcal{L} = 0.95/\text{fb}$

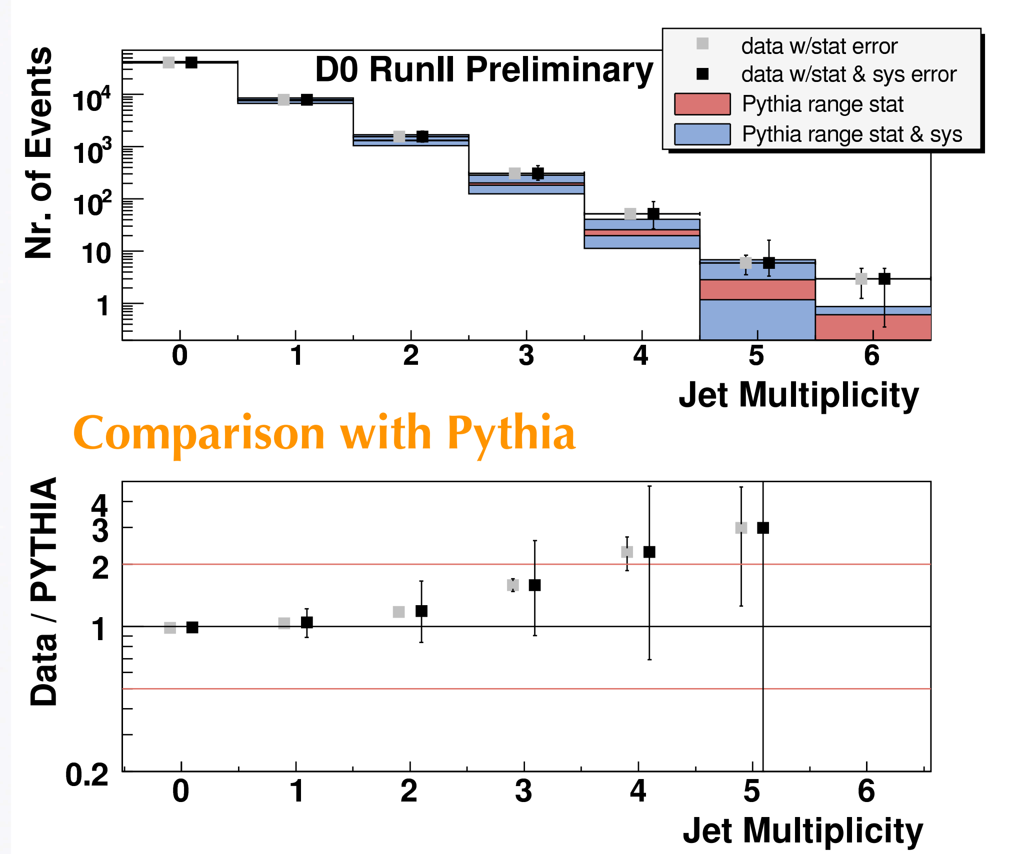
PYTHIA v6.314
SHERPA v1.0.6

Z->ee selection with

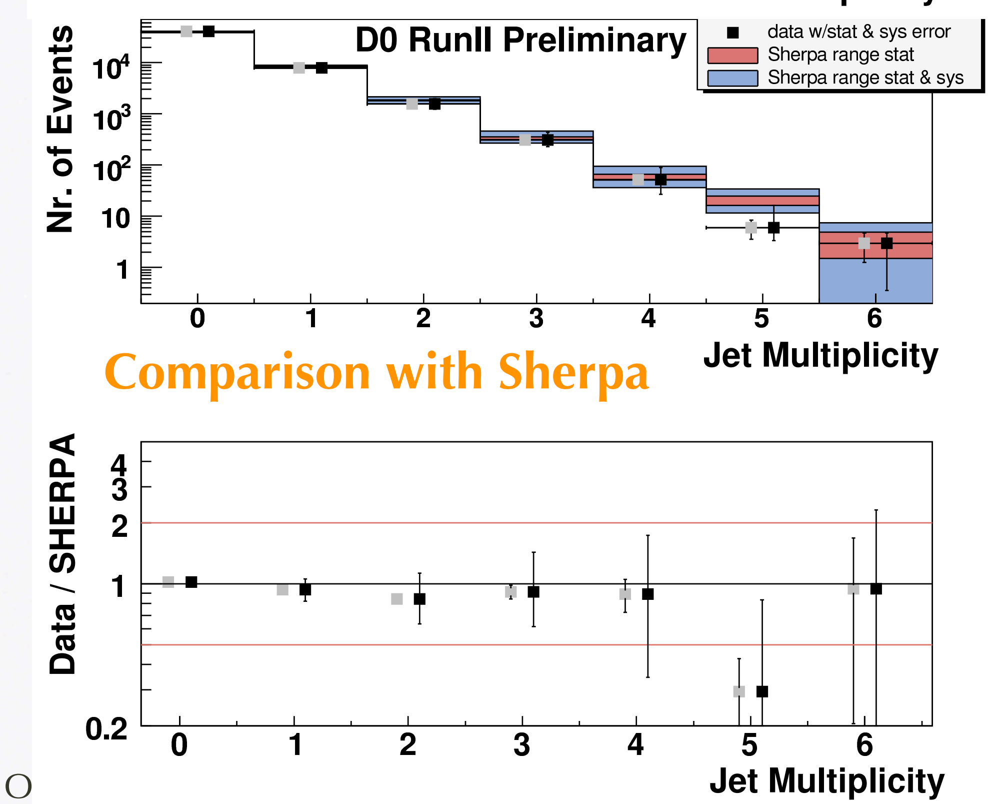
- electron $p_T > 25$ GeV
- 70 GeV < M_{ee} < 100 GeV
- cone jet $p_T > 15$ GeV, R=0.5, $|\eta| < 2.5$

MC predictions normalized to #Z/γ events in data

systematic uncertainties dominated by Jet Energy Scale and Jet resolution



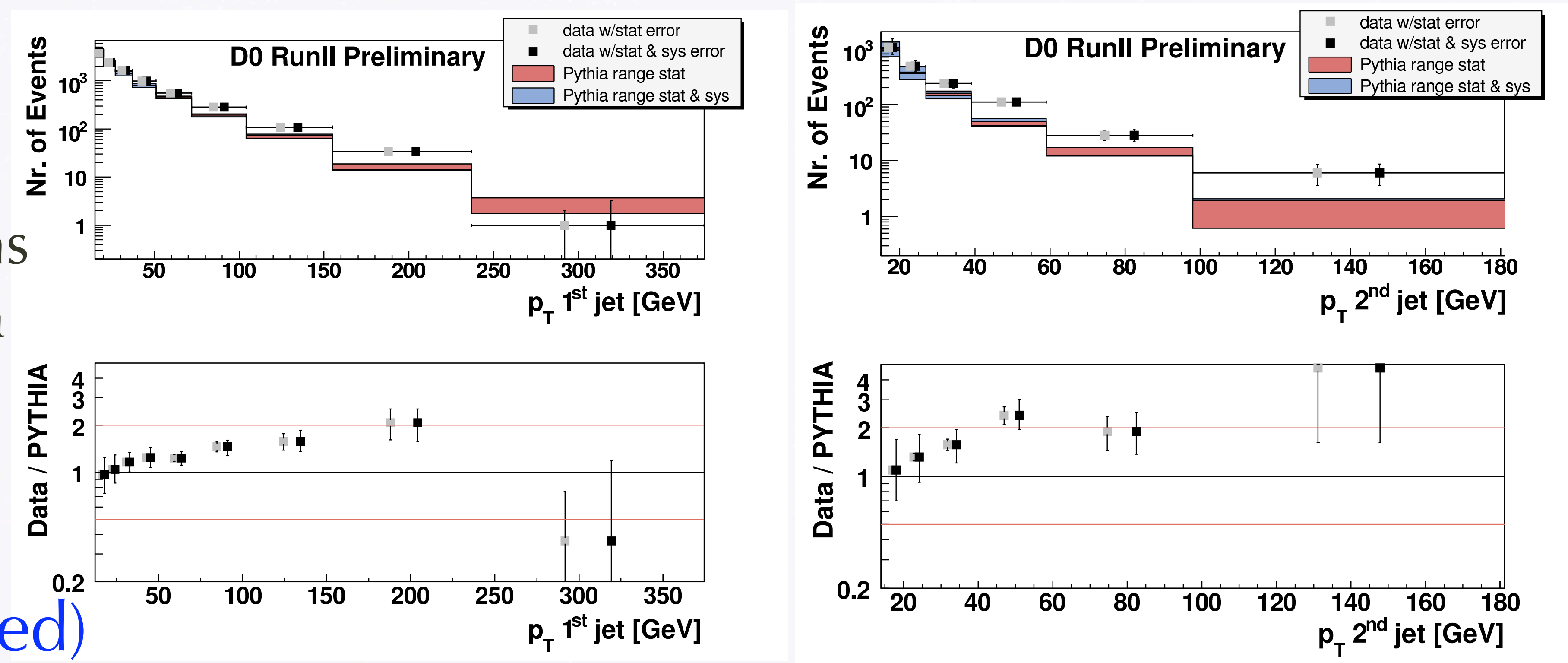
- Sherpa - implementation of CKKW
  - tree level diagrams
  - phase space cut to avoid soft/ collinear divergences
  - reweighting of ME to consistently match with PS
- Although errors are large, Sherpa accurately predicts jet multiplicity



Z+light flavor jets

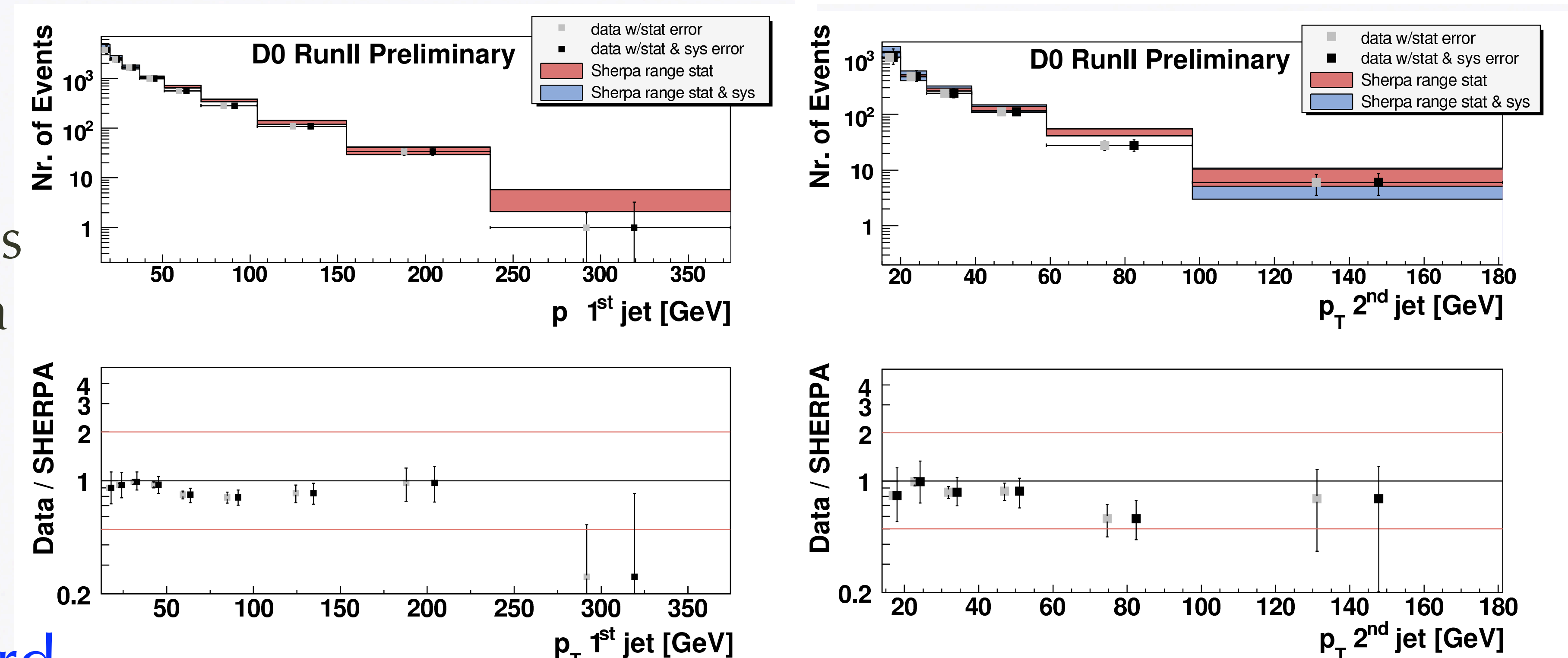
p_T 1[st] jet p_T 2[nd] jet

Comparisons with Pythia



Pythia p_T spectra too soft (as expected)

Comparisons with Sherpa



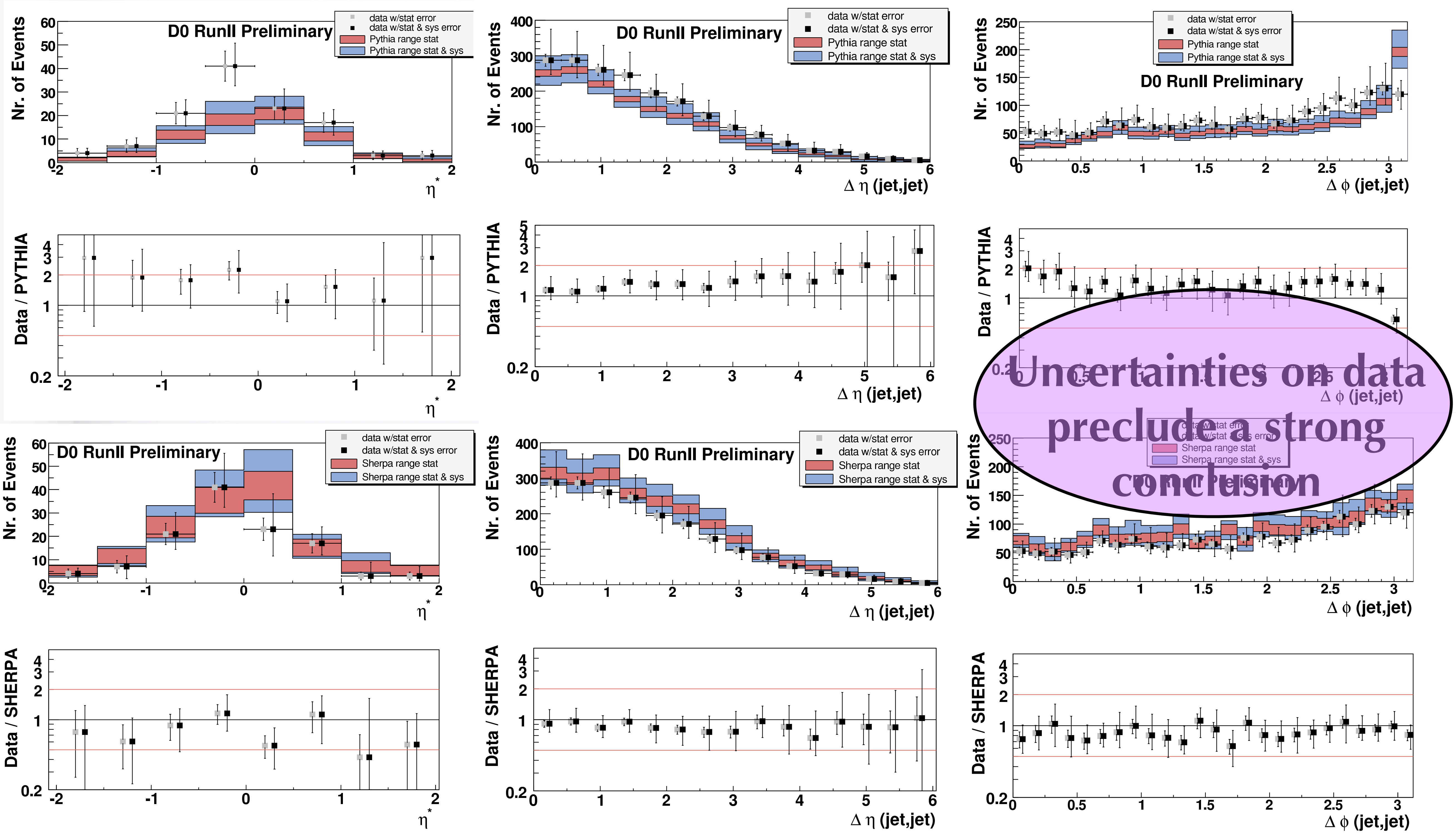
Suggests Sherpa spectra slightly hard

Z+light flavor jets

$p_T^1 > p_T^2 > p_T^3$

$\eta 1 < \eta 3 < \eta 2$ or $\eta 2 < \eta 3 < \eta 1$

$\eta^* = \eta_3 - (\eta_2+\eta_1)/2$ | $\Delta\eta$(jet,jet) | $\Delta\Phi$(jet,jet)



Uncertainties on data preclude a strong conclusion

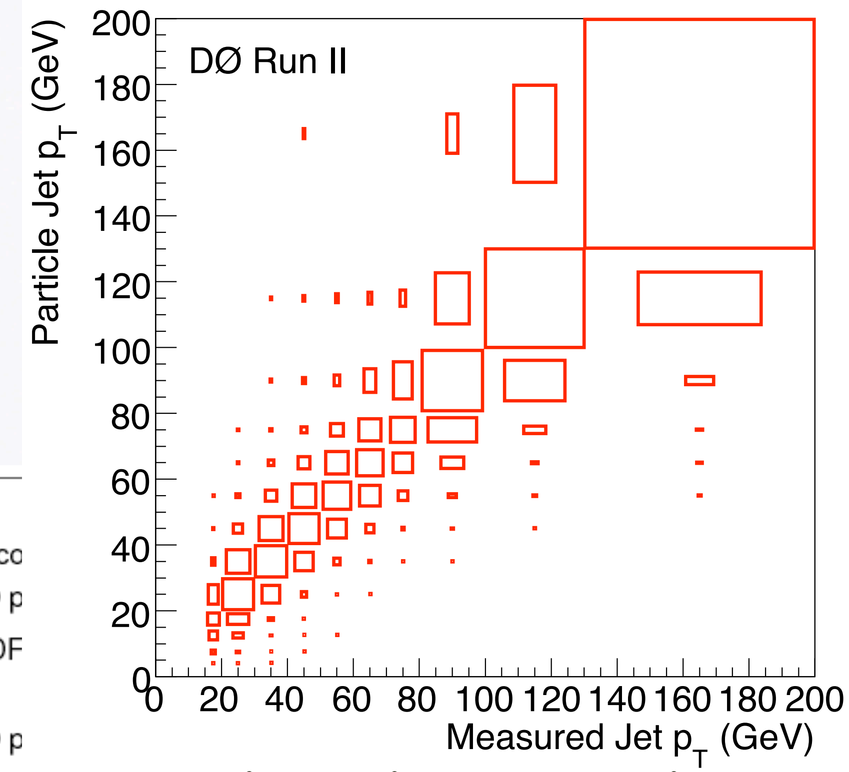
Z+light flavor jets

$\mathcal{L} = 1.0$/fb

Z->μμ + jet + X

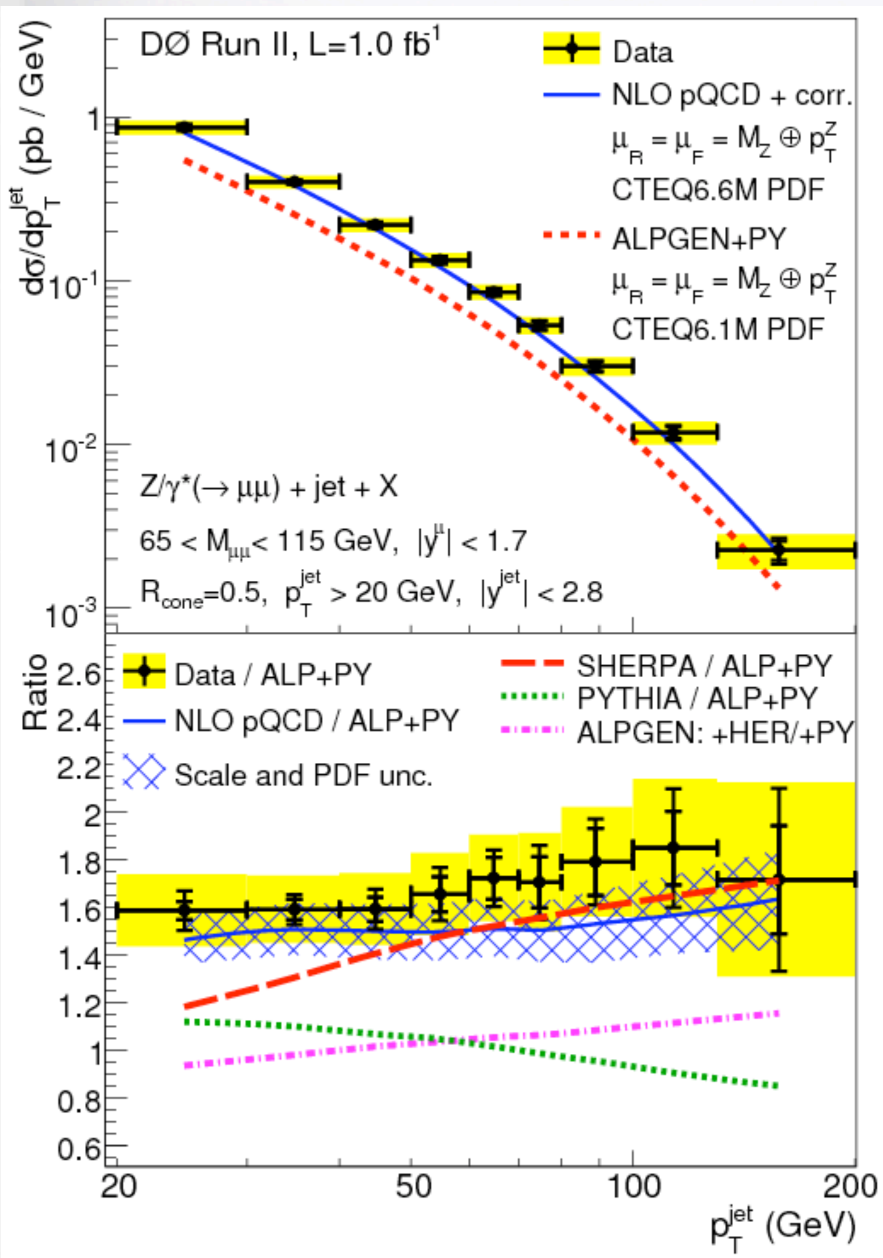
data corrected to particle level - can be used to tune MCs

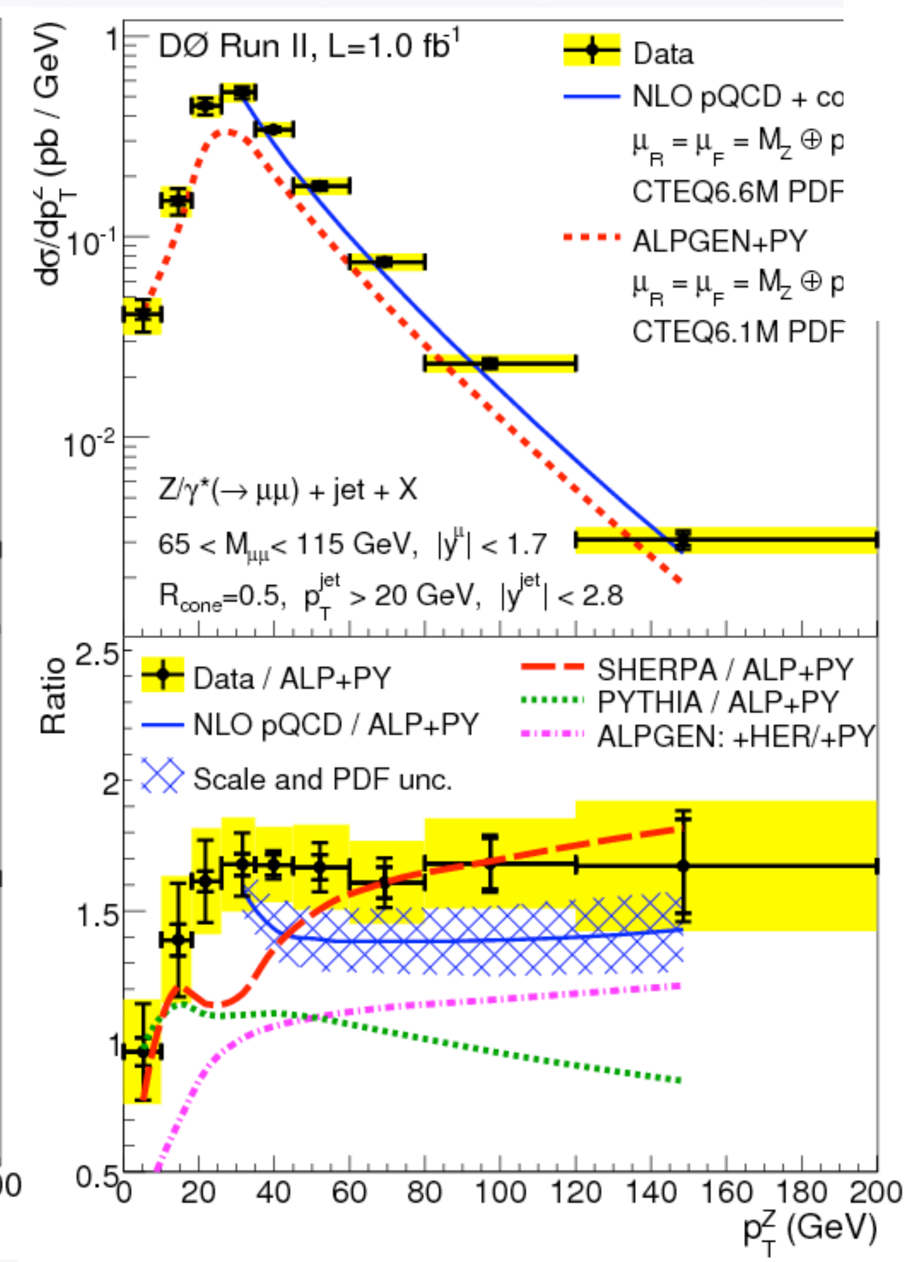
Phase space:
65 GeV< $M_{\mu\mu}$ < 115 GeV,
R_{cone}=0.5, p_T^{jet} > 20 GeV
$|y^{jet}|$ < 2.8, $|y^{\mu}|$ < 1.7



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

ratios relative to Alpgen+Pythia





- Alpgen+Pythia accurately predicts shape of p_T^{jet}

PYTHIA v6.418
ALPGEN v2.13+PYTHIA v6.323
ALPGEN v2.13+HERWIG v6.510
SHERPA v1.1.1(native showering)

Z+light flavor jets

Z->μμ + jet + X

data corrected to particle level - can be used to tune MCs

Phase space:

65 GeV< $M_{\mu\mu}$ < 115 GeV,

R_{cone}=0.5, p_T^{jet} > 20 GeV

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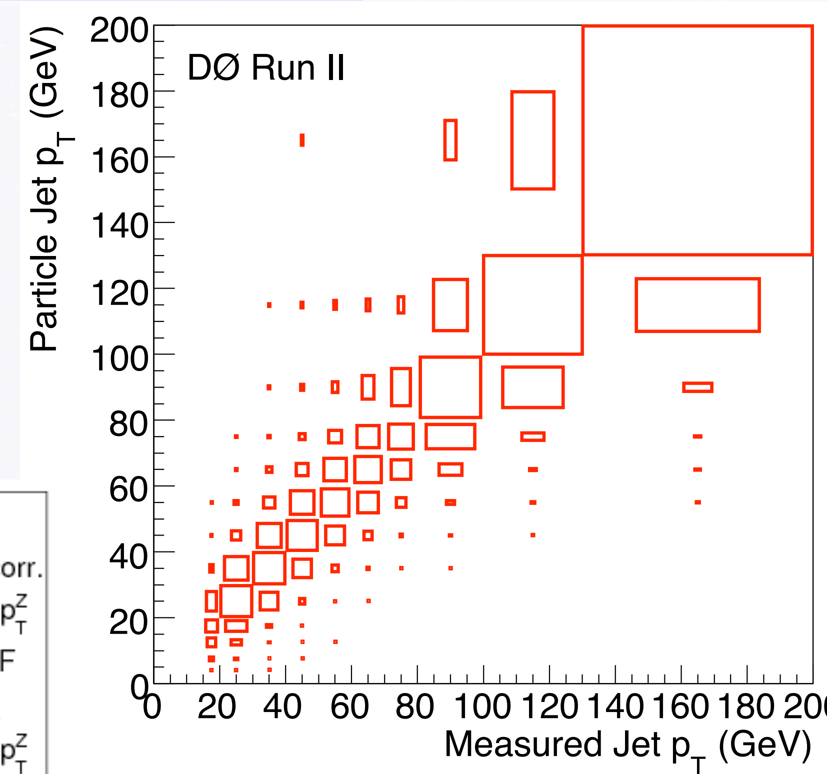
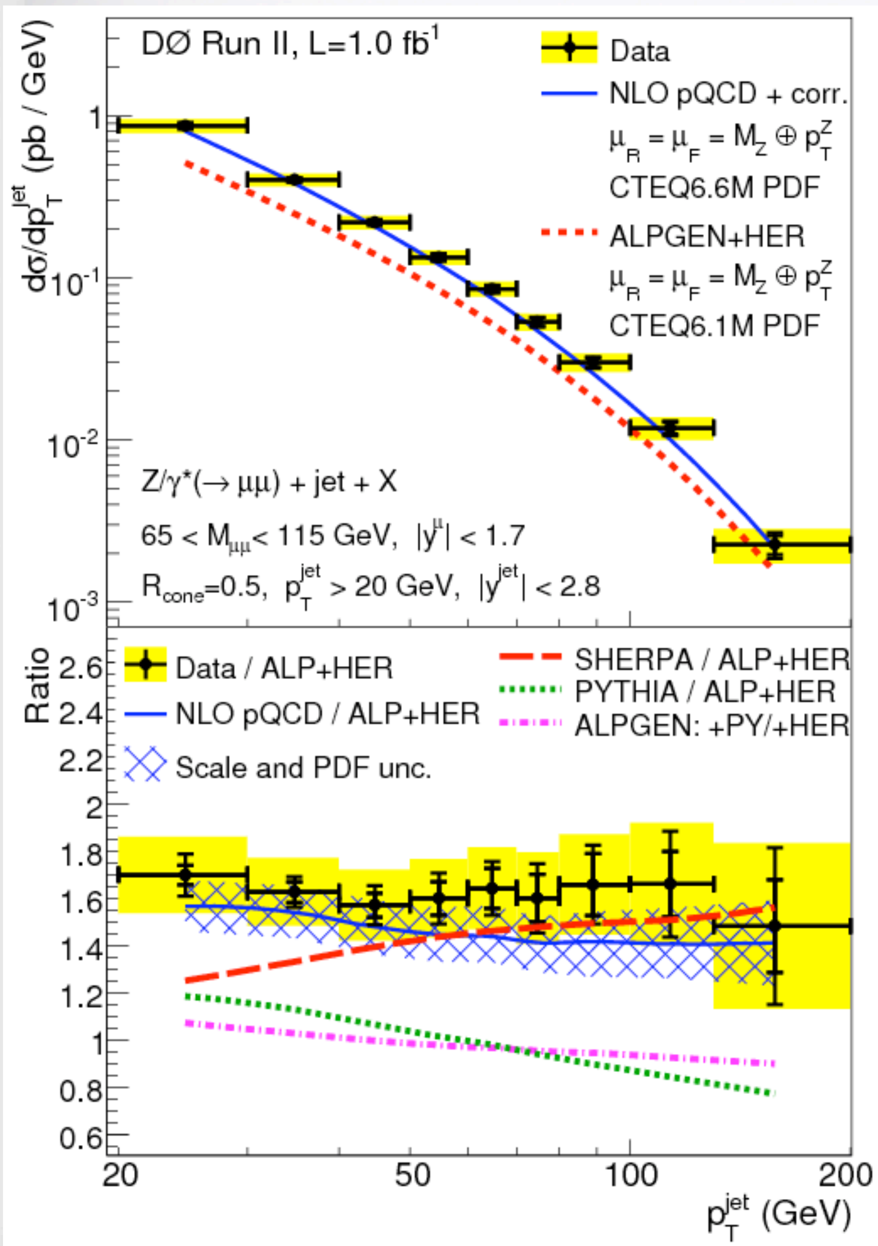
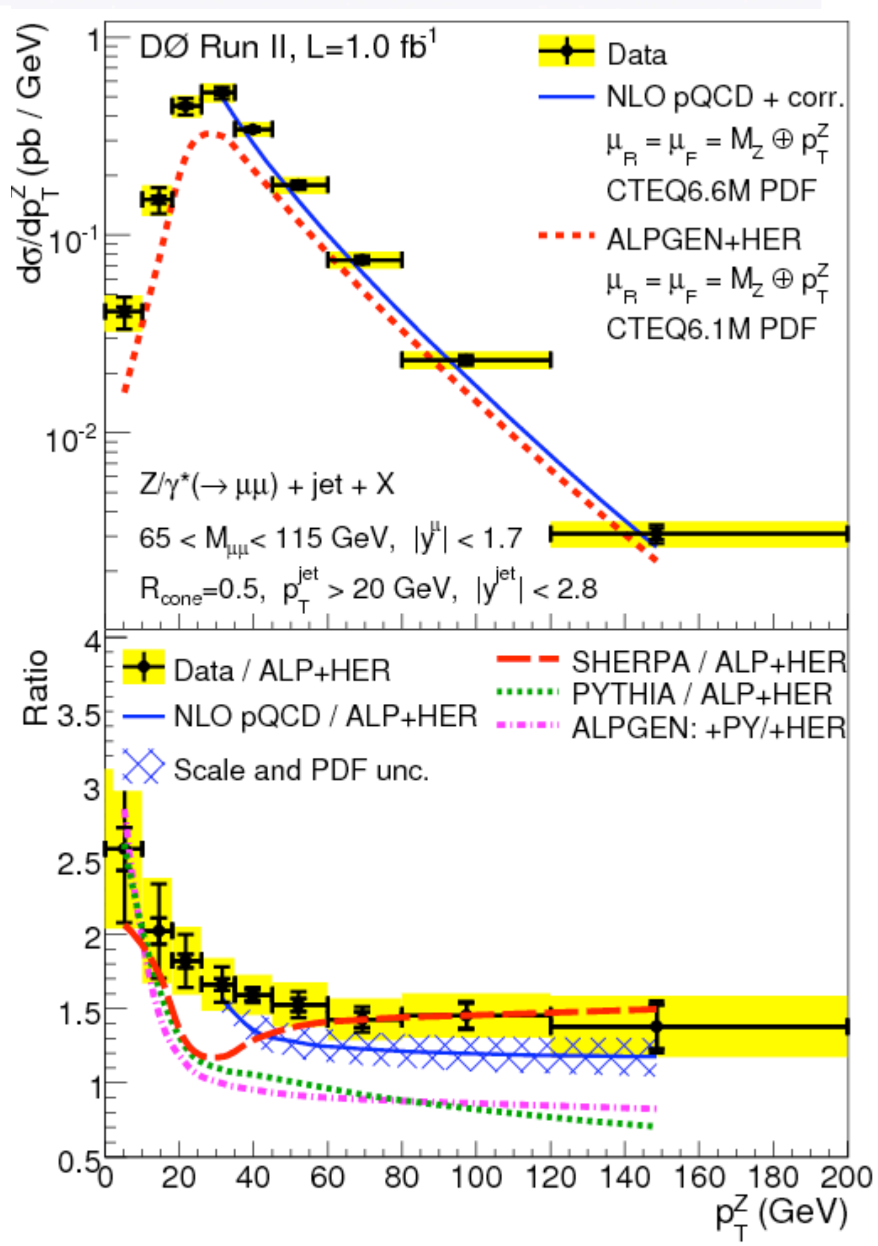


ratios relative to Alpgen+Herwig



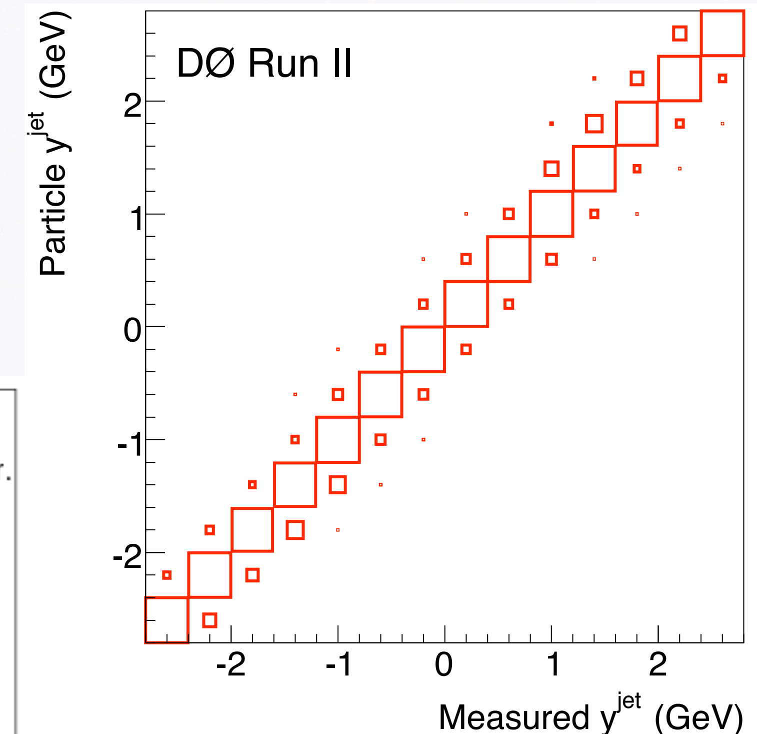


- Dramatic difference with Alpgen+Herwig at low Z p_T
- p_T^{jet} shape described very well
- All LO predictions underestimate data normalization

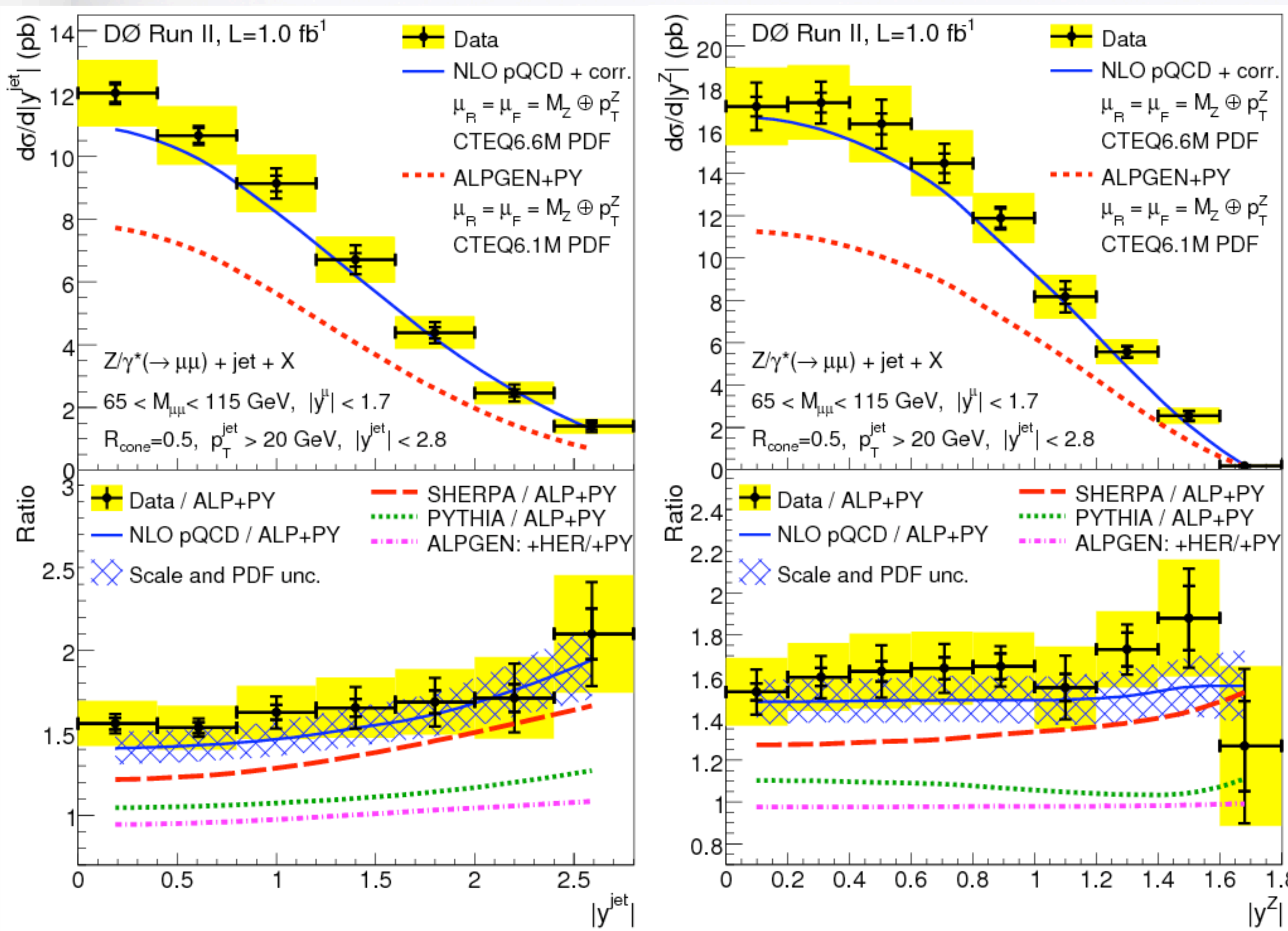
Z+light flavor jets

Z->μμ + jet + X

particle jets: D0RunII midpoint algorithm (for particle an detector jets) with R=0.5



ratios relative to Alpgen+Pythia



migrations much reduced in y^{jet}

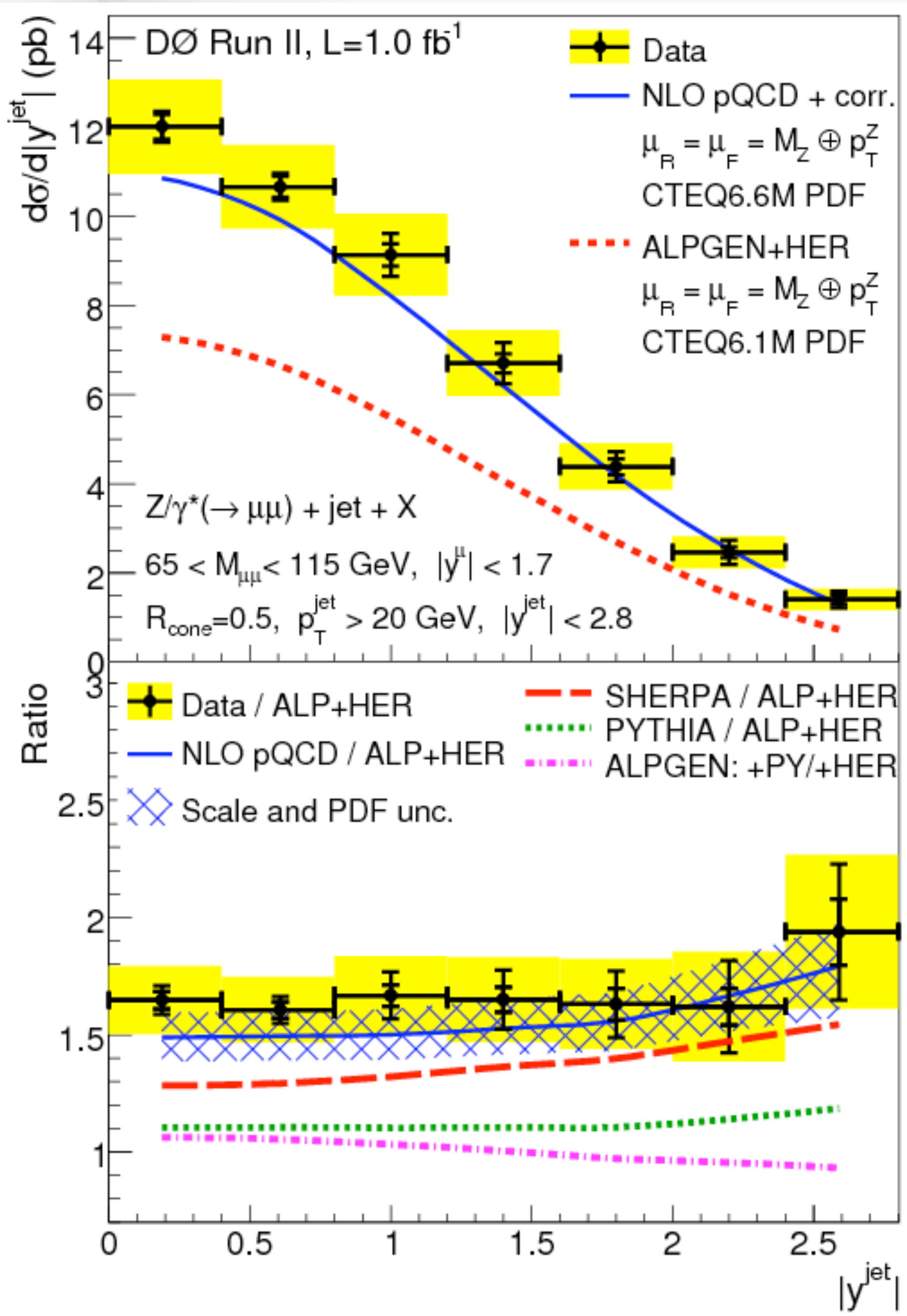
- Alpgen+Pythia predicts narrower y^{jet} than data
- Sherpa describes y^{jet} shape well.
- Both underestimate data normalization

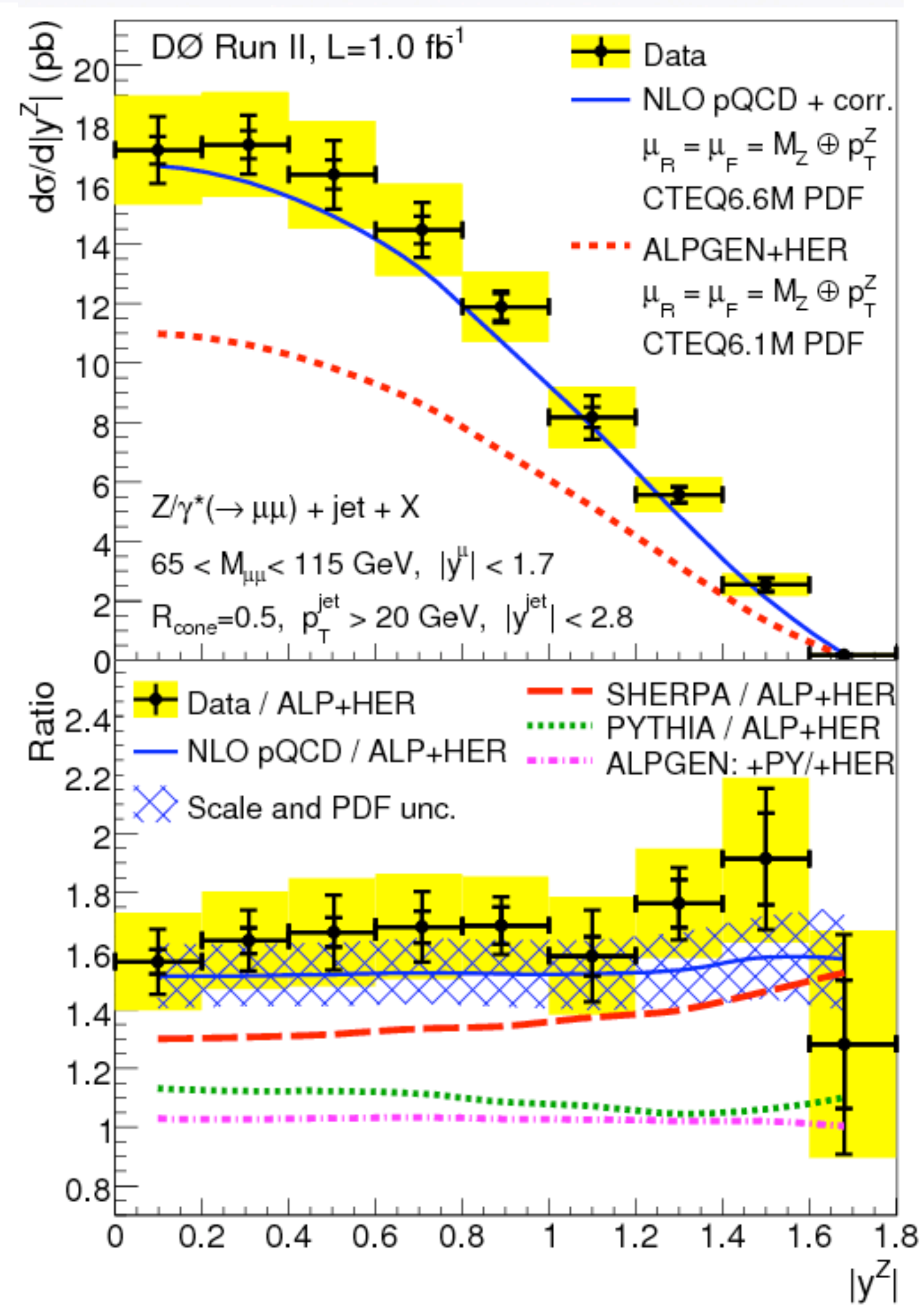
Z+light flavor jets

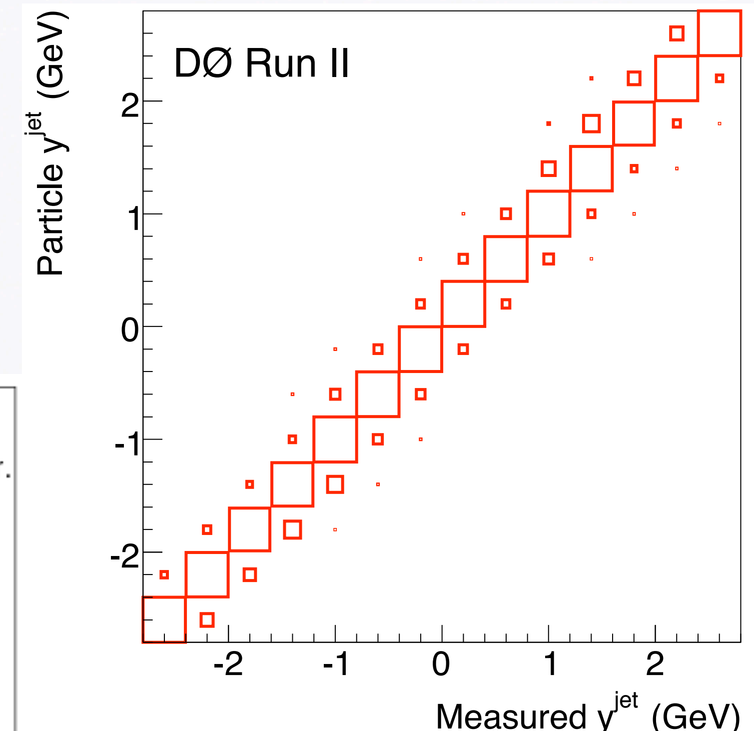
Z->μμ + jet + X

particle jets: D0RunII midpoint algorithm
(for particle an detector jets) with R=0.5

ratios relative to Alpgen+Herwig







migrations much reduced in y^{jet}

- Alpgen+Herwig and Sherpa provide good modeling of y^{jet}.
- Both underestimate data normalization.

Z+heavy flavor jets

Z->ee/μμ + b + X
jet p_T > 20 GeV
jet |η| < 1.5
secondary vertex tagging

R=0.7 cone jets
data is corrected to hadron level
statistics limited analysis

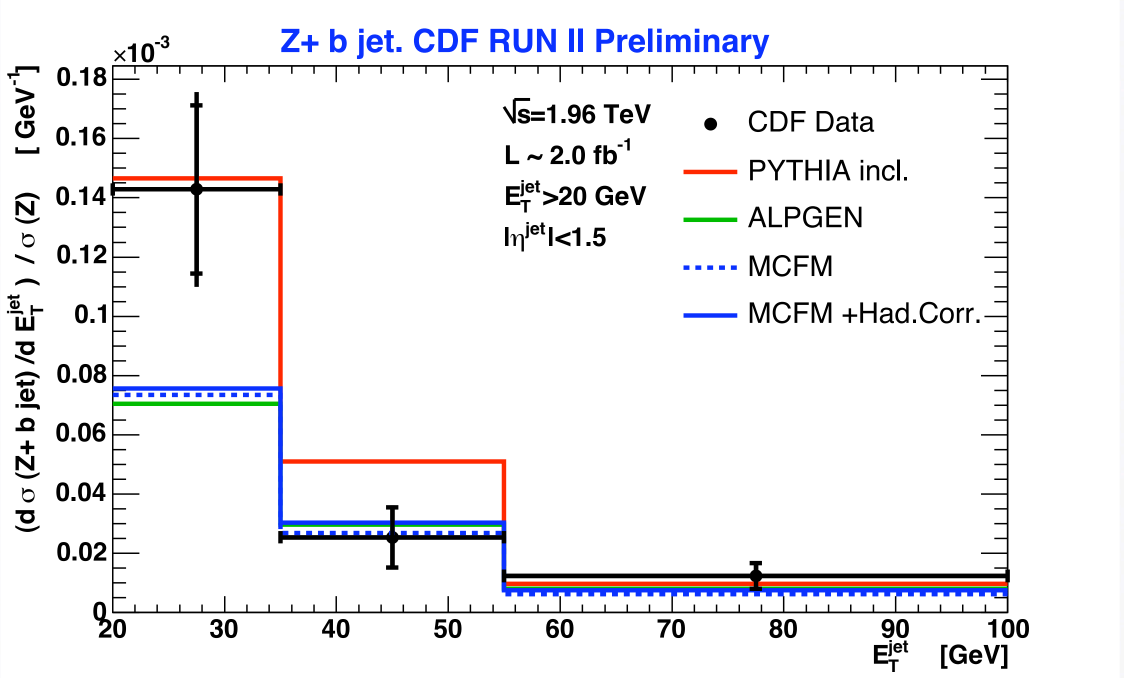
PYTHIA v6.2
ALPGEN v2.13

$\mathcal{L}$ = 2.0/fb

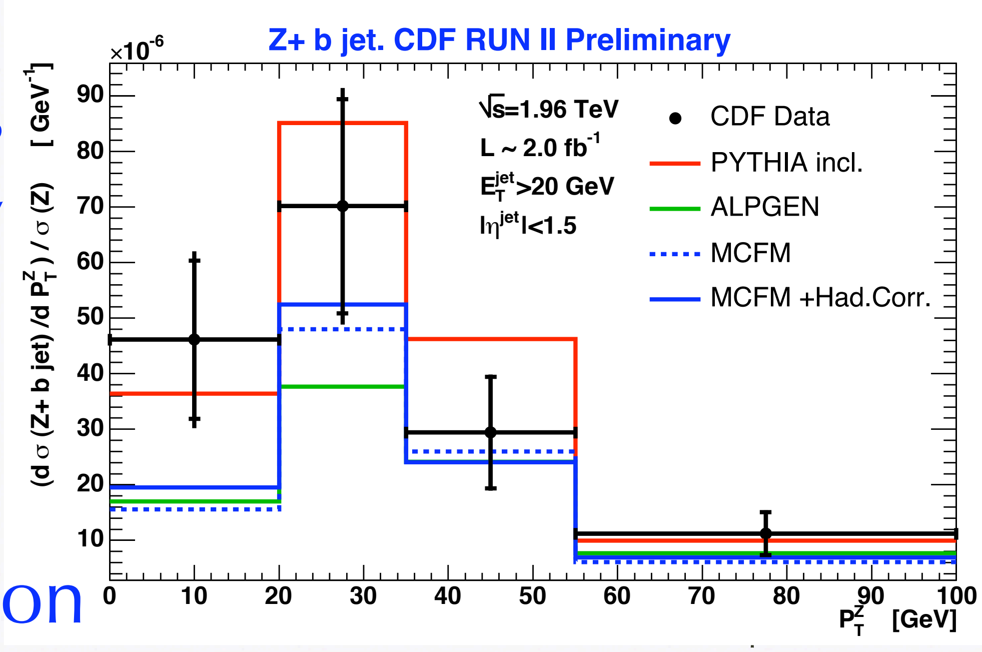
Measure:

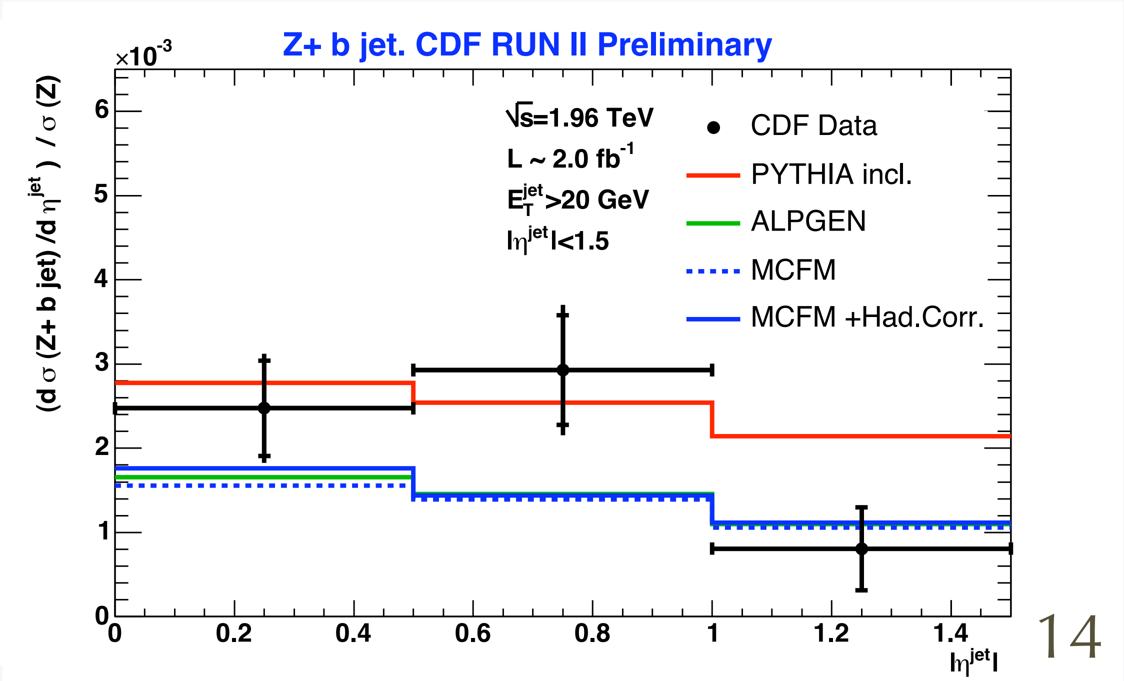
$$\frac{\sigma(Z+b\ jets)}{\sigma(Z)}$$

Source of Uncertainty	Uncertainty (%)
jet energy scale	2.4
MC η^{jet} dependence	2.8
MC E_T^{jet} dependence	8.0
b tagging efficiency	4.1
single/double b/c quark in jet	3.8
track reconstruction efficiency	5.7
b hadron multiplicity	0.8
fake lepton background	1.8
other backgrounds	0.8
Z selection efficiency	1.8
luminosity	5.8
total	14



Pythia does surprisingly well in describing overall normalization



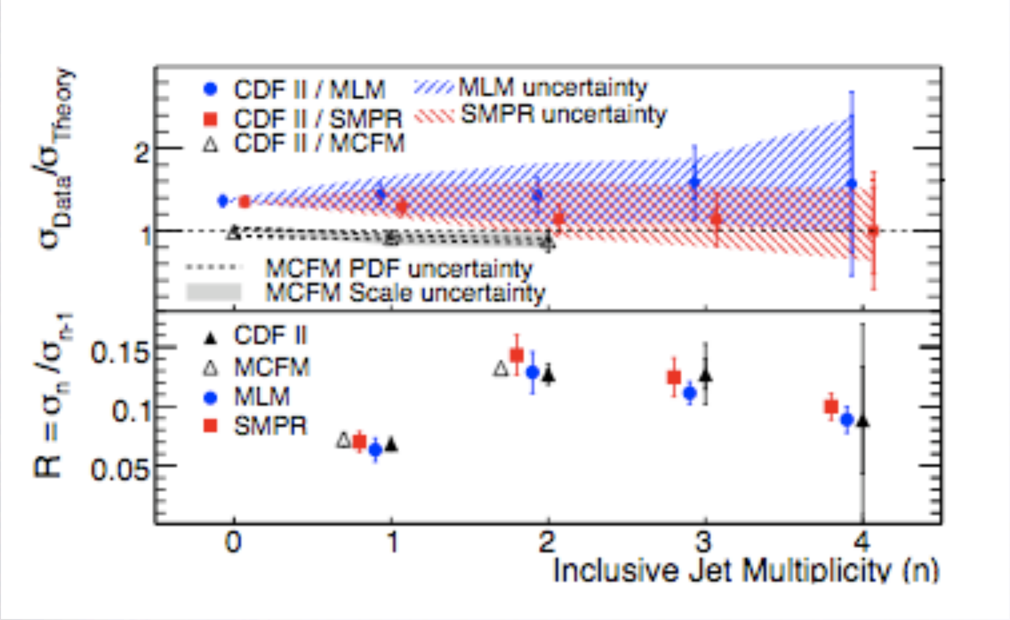


W+light flavor jets

$\mathcal{L}$ = .32/fb

W->eν + jets

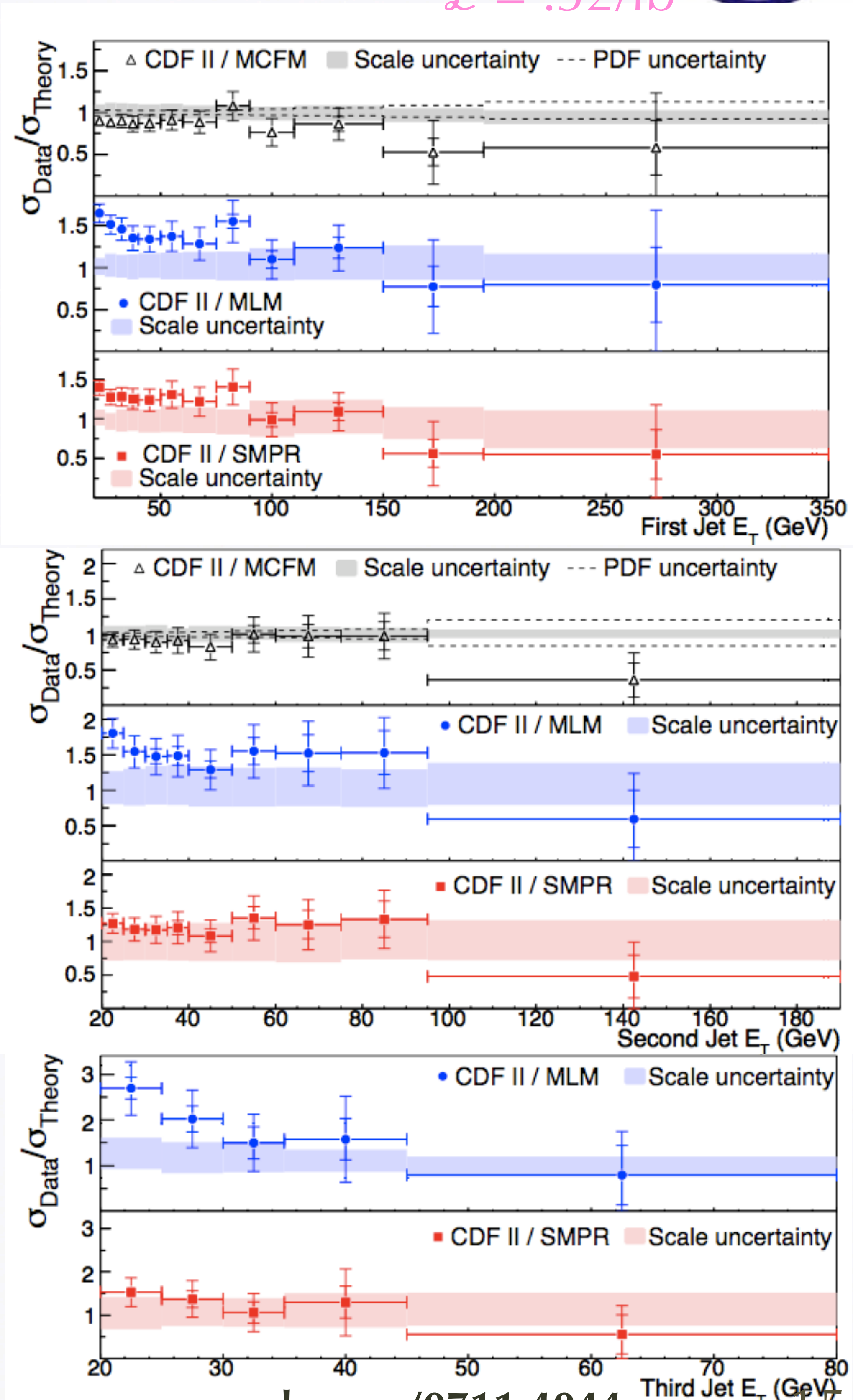
All distributions corrected to particle level with:
lepton $E_T^e > 20$ GeV, $|\eta^e|<1.1$
$E_T^\nu > 30$ GeV, $m_T^W > 20$ GeV/c^2
jet $p_T > 20$ GeV, R=0.4, $|\eta| < 2.0$



- MCFM: NLO, no shower
- MLM: Alpgen v2.12+Herwig v6.5, MLM matching
- SMPR: Madgraph v4+Pythia v6,3, CKKW matching

NLO does excellent job of modeling jet p_T shape and normalization for <=2 jets

MLM fails, especially at low pT
SMPR does better job at high n-jet

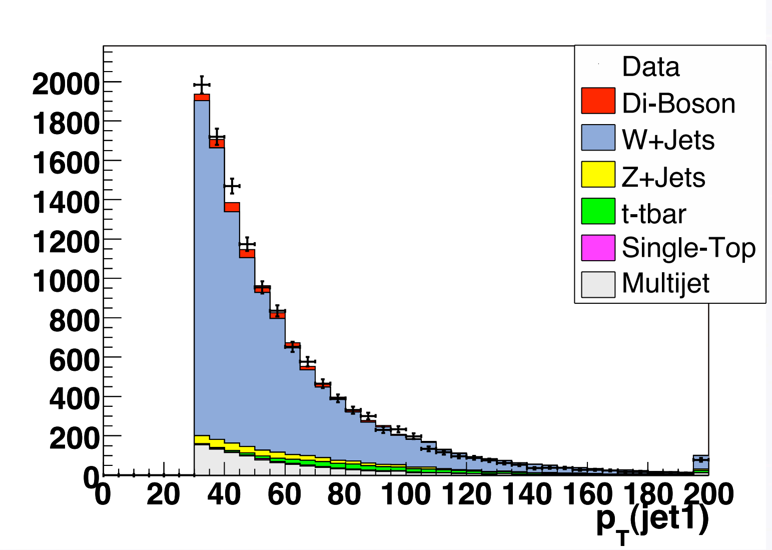


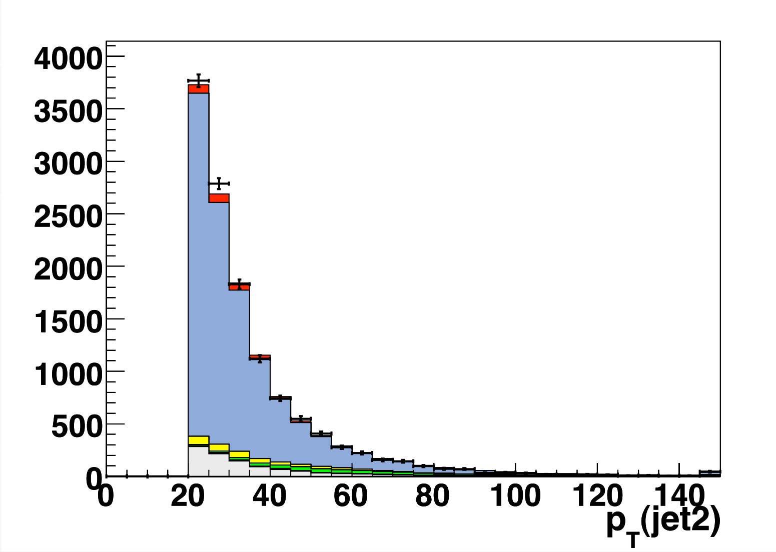
hep-ex/0711.4044

W+light flavor jets

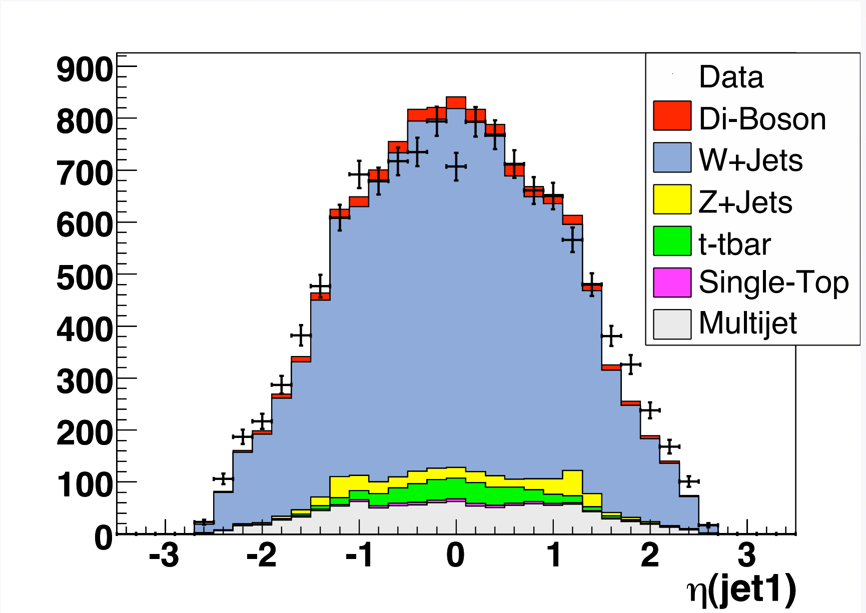
WV->eν+2jets+X

electron p_T > 20 GeV
missing E_T > 20 GeV
jet p_T > 20 GeV
leading jet p_T > 30 GeV
jet $|\eta|$ < 2.5

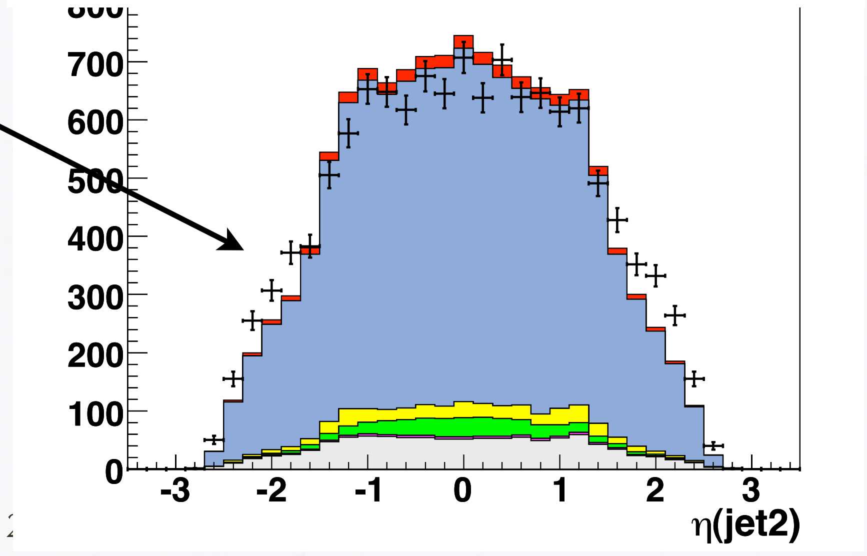




detector level distributions



- p_T spectra well modeled by Alpgen
- Data jet η distribution is broader than Alpgen



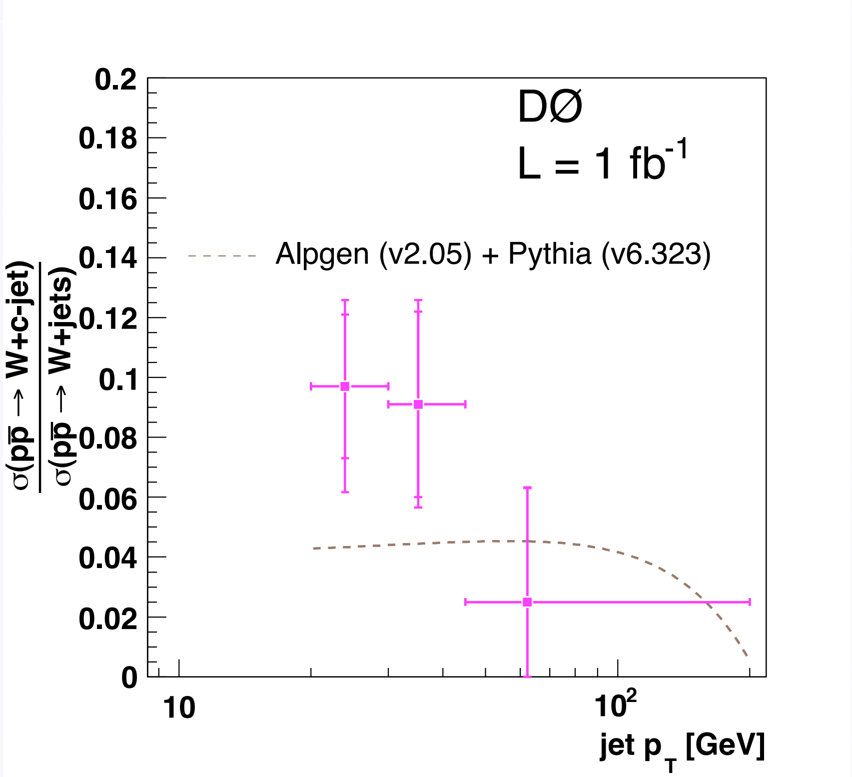
DØ work in progress

W+heavy flavor jets

$\mathcal{L}$ = 1/fb

- Measure ratio W+c-jets/W+jets to cancel uncertainties

Alpgen prediction: 0.04 pb
Result: measure σ(W+cjets)/σ(W+jets) = 0.071 ± 0.017 (stat)

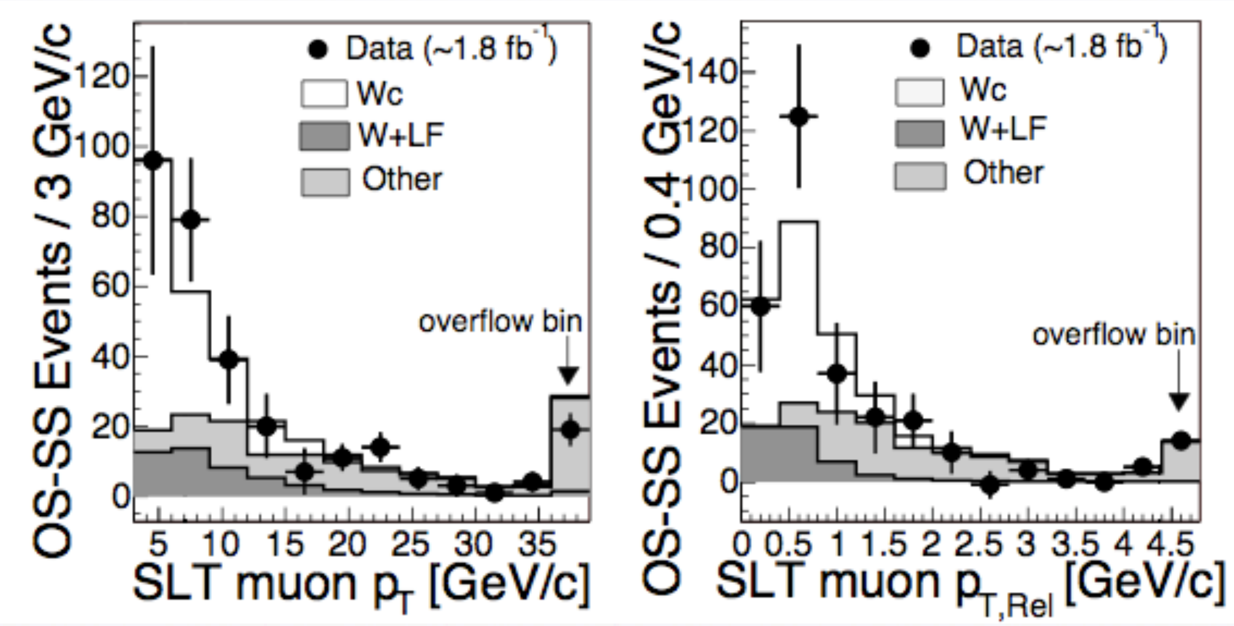


Alpgen v2.05 + Pythia v6.323

$\mathcal{L}$ = 1.8/fb

$$\sigma_{Wc} \times \mathrm{BR}(W \to \ell\nu) = \frac{N^{OS-SS}_{\mathrm{tot}} - N^{OS-SS}_{\mathrm{bkg}}}{Acc \cdot \int L\, \mathrm{d}t}$$

NLO prediction: 11.0 pb
Result: measure σ(W+cjets)xBR(W->lν) = 9.8 ± 2.8 (stat)$^{+1.4}_{-1.6}$ (sys) + 0.6(lumi) pb.



W+heavy flavor jets

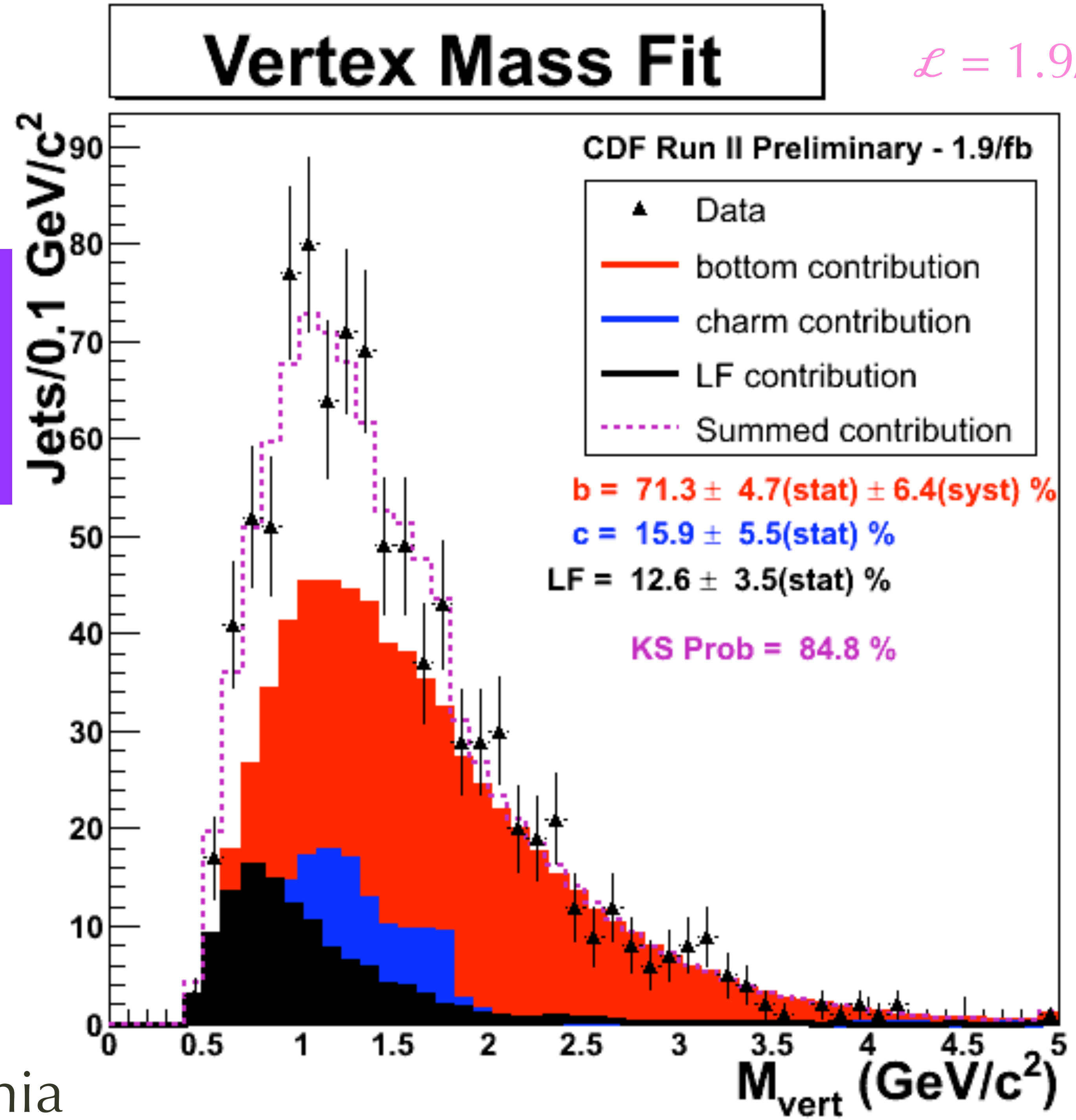
Phase space:

- a truth level electron or muon with $p_T > 20$ GeV/c, $|\eta| < 1.1$
- a truth level neutrino with $p_T > 25$ GeV/c
- 1 or 2 total truth level jets with $E_T > 20$ GeV/c^2, $|\eta| < 2.0$

Backgrounds:
ttbar (40%), single top (30%), fake W (15%), WZ (5%)

Alpgen prediction: 0.78 pb
Result: measure σ(W+bjets)xBR(W➛lν)
σxBR = 2.74 ± 0.27 (stat) ± 0.42 (sys) pb.
→ 3.5x bigger!

$\mathcal{L}$ = 1.9/fb



much larger difference than seen in W+c-jets

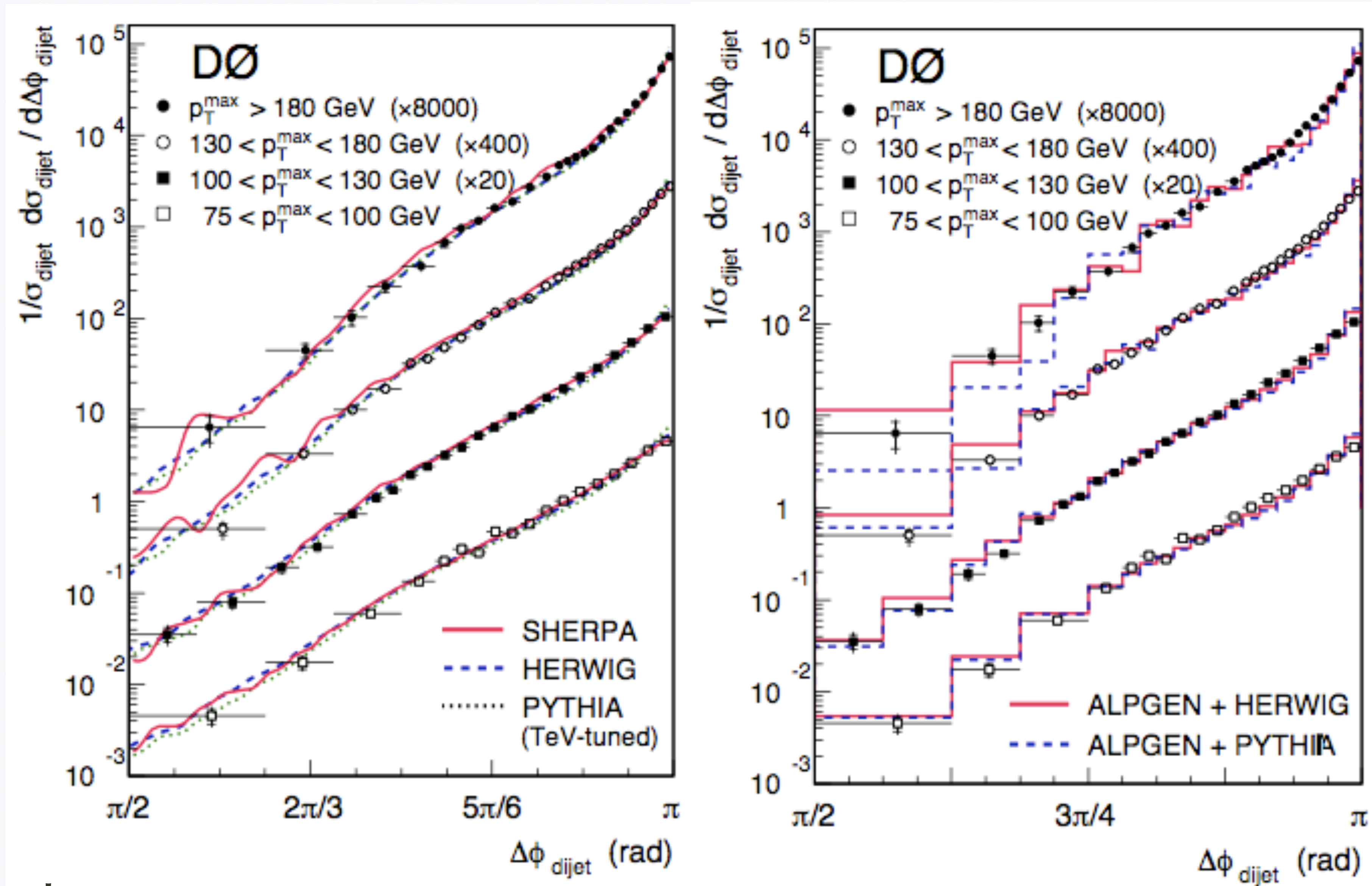
Still to come:

- differential distributions
- comparisons to Sherpa, Pythia

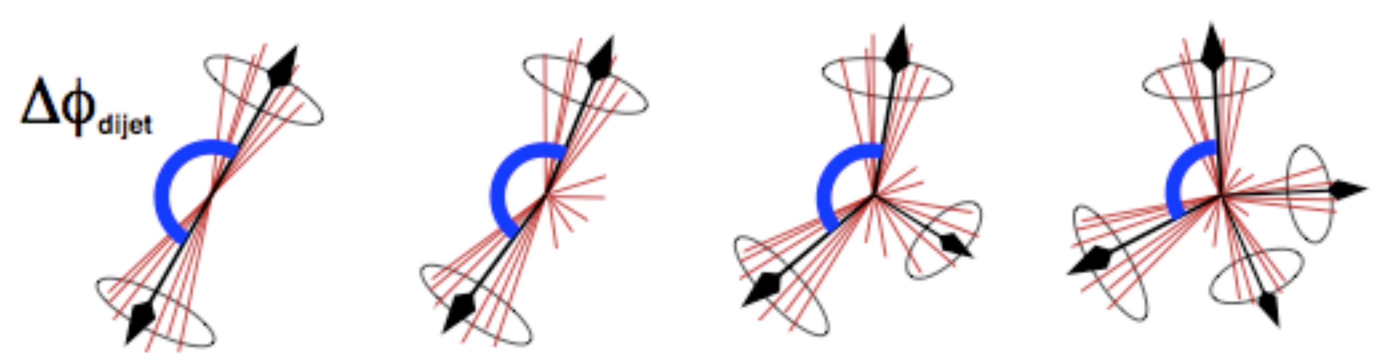
Dijets

$\mathcal{L}$ = 1.0/fb

Allows to study transition from soft to hard QCD processes in single variable



- Sherpa, Herwig and TeV-tuned Pythia perform well.
- Alpgen+Herwig and Alpgen+Pythia perform reasonably well.



arXiv: hep-ph/0610012

Summary

Performance in **normalization** and **shape**	W+jet	Z+jet	W+hf jet	Z+hf jets	Dijet $\Delta\phi$
Alpgen/MLM + Pythia		✘ ? (energy) ✘ (angles)	✘	✘ ✘	✔
Alpgen/MLM + Herwig	✘ ✘ (energy) ✘ (angles)	✘ ? (energy) ✔ (angles)			✔
Sherpa/CKKW		✘ ✘ (energy) ✔ (angles)			✔
Madgraph/ CKKW	✘ ✘ (energy) ✔ (angles)				
Pythia		✘ ✘		✔ ✔	

✔ - good
✘ - problematic
? - jury is still out

These are indications from what has been measured so far, and should be taken somewhat lightly ...
... picture is still evolving

Further Studies

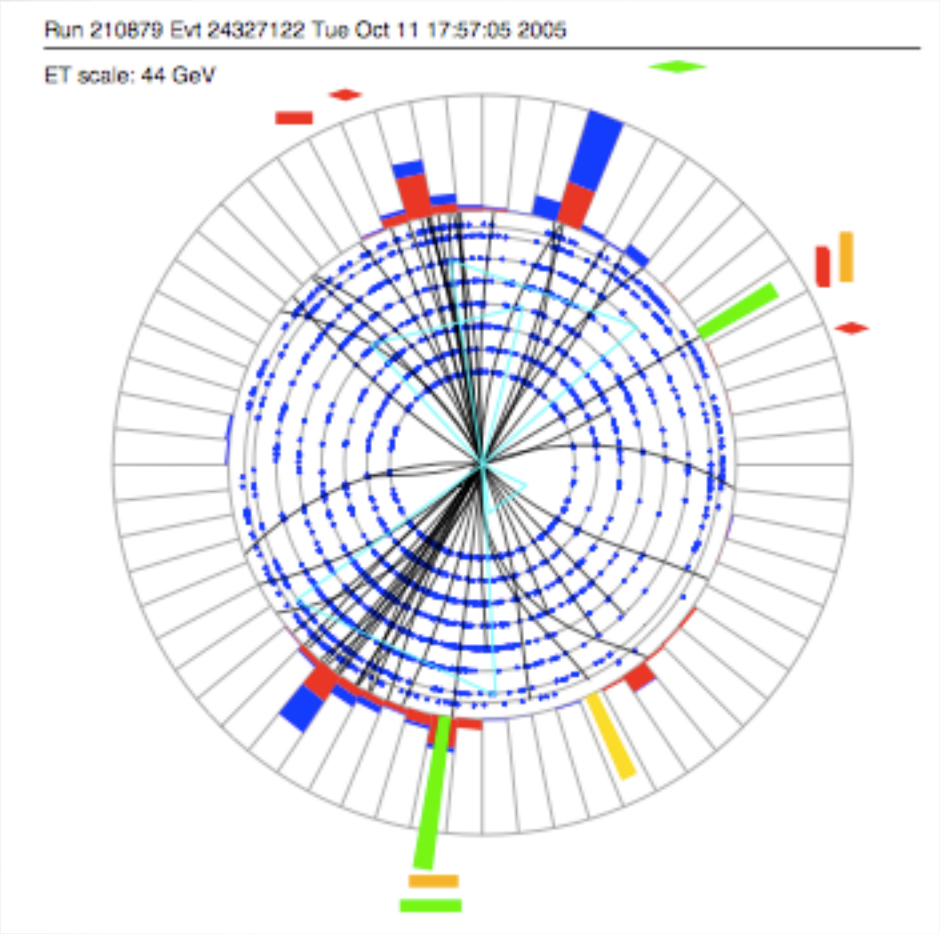
- Similar studies of Z+jets ongoing for Z->ee decays @ DØ
  - analysis with unfolded with **n-jet exclusive** jet p_T in 1, 2, 3-jet events coming
- Unfolding Angular distributions between Z boson and jets from DØ
- Comparisons between W+jets data and Alpgen, Sherpa from DØ
- Differential distributions, comparisons to Sherpa, Pythia in W+b-jets from CDF
- Publication of WV analysis

Conclusions

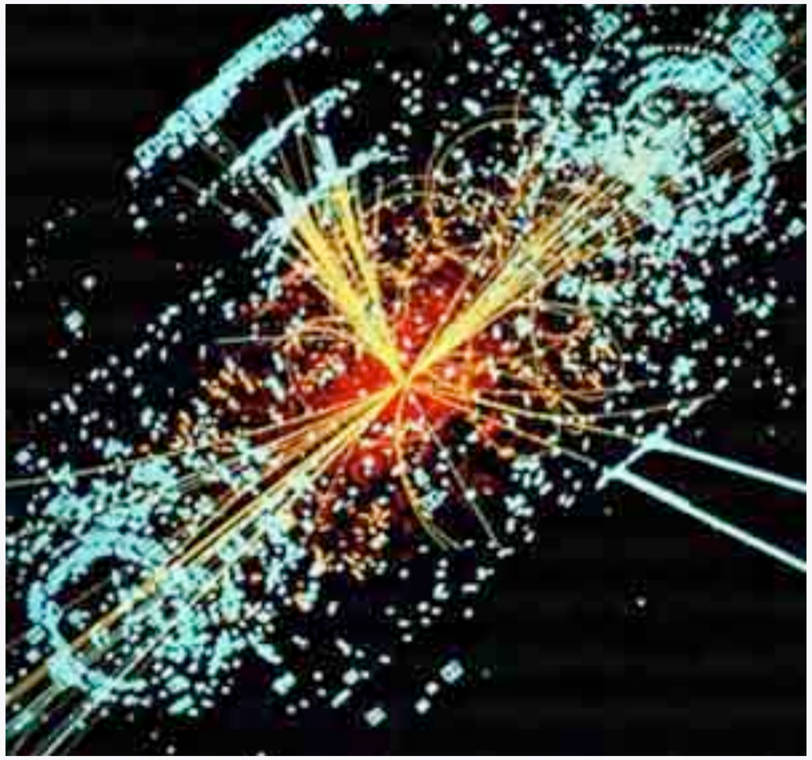
- With ~$3x10^4$/fb Z and ~$6x10^5$/fb W events on tape, Tevatron dataset is now large enough and adequately understood to vet ME-PS models for many final states involving vector bosons.
- A complete picture is still forming.
- ME-PS models are generally superior to Pythia in predicting higher jet multiplicity events and their distributions.
- ME-PS models are not able to predict correct normalization of many final states.
- Some indications that Alpgen/MLM can describe p_T distributions, Sherpa/CKKW can describe angular distributions in W/Z+jets.
- Distinguishing between models of W/Z + heavy flavor jets will require more data or increased experimental acceptance.

Final Thought

A concerted effort by experimentalists and theorists is needed to resolve existing puzzles and improve predictions of ME-PS programs which are critical for NP searches at both the Tevatron and LHC. Tuning to Tevatron data is a good opportunity.



TeV-->LHC

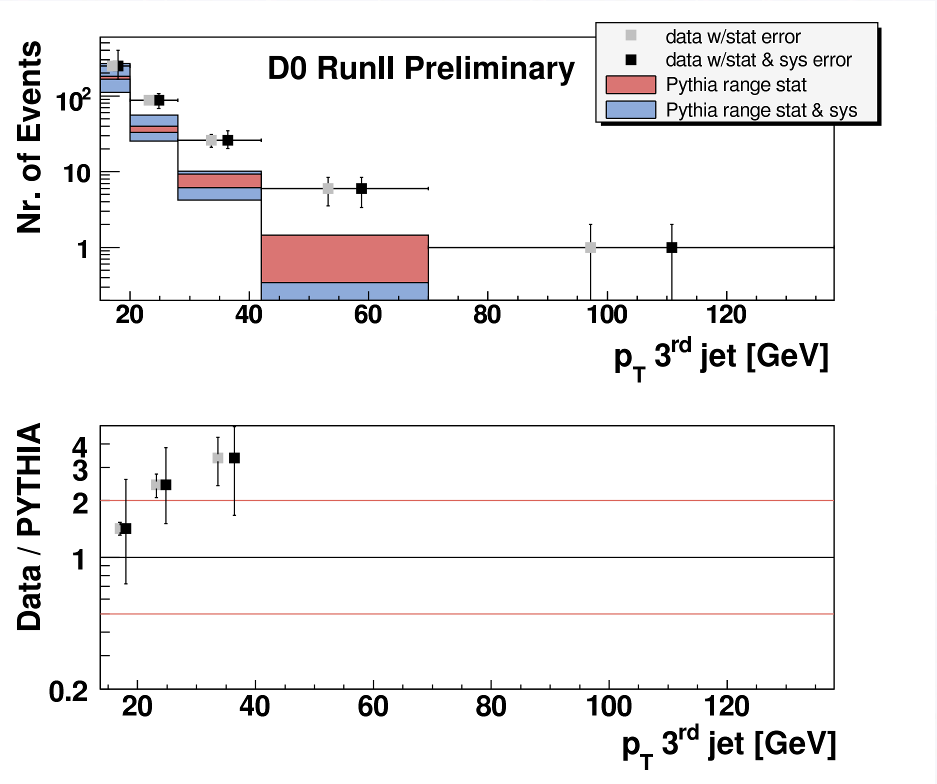


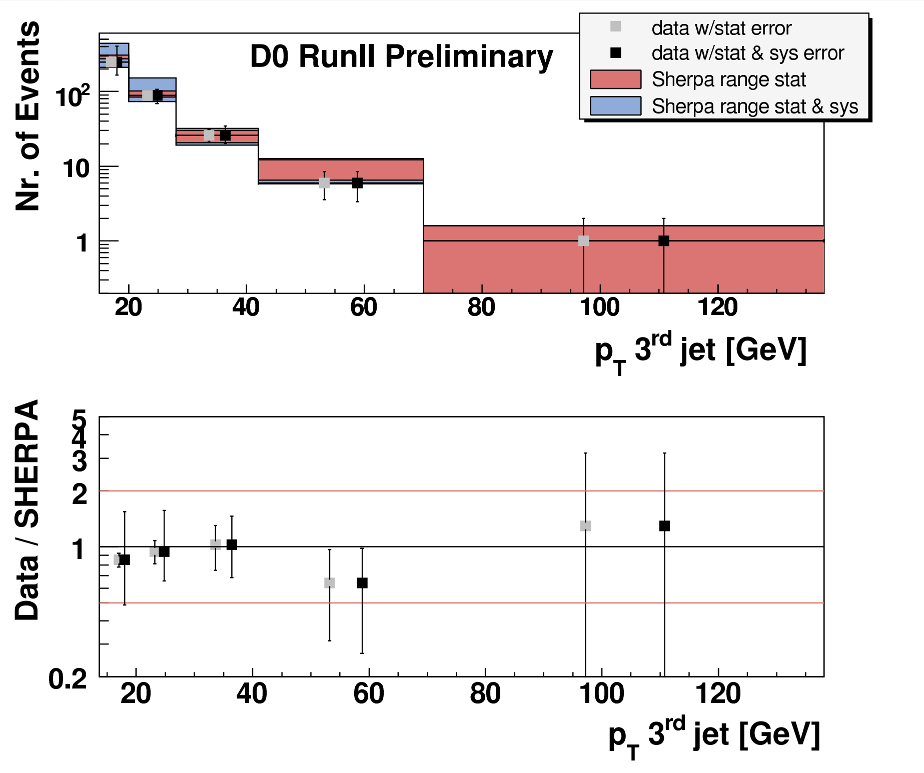
Acknowledgements:
- Thanks to Gavin Hesketh for producing all Z+jets predictions on Slides 10-14

Backup

Z+ light flavor jets

- Trends for 3rd jet similar to 1st and 2nd





Status of TeV and the experiments