W / Z + Jets and W / Z + Heavy Flavor Jets at the Tevatron

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University of Freiburg

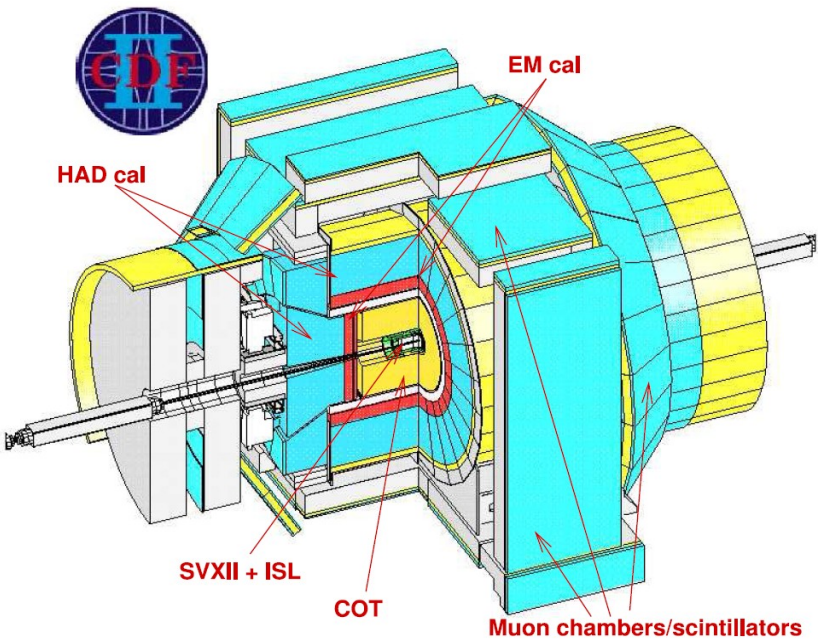
on behalf of the CDF and D0 Collaborations

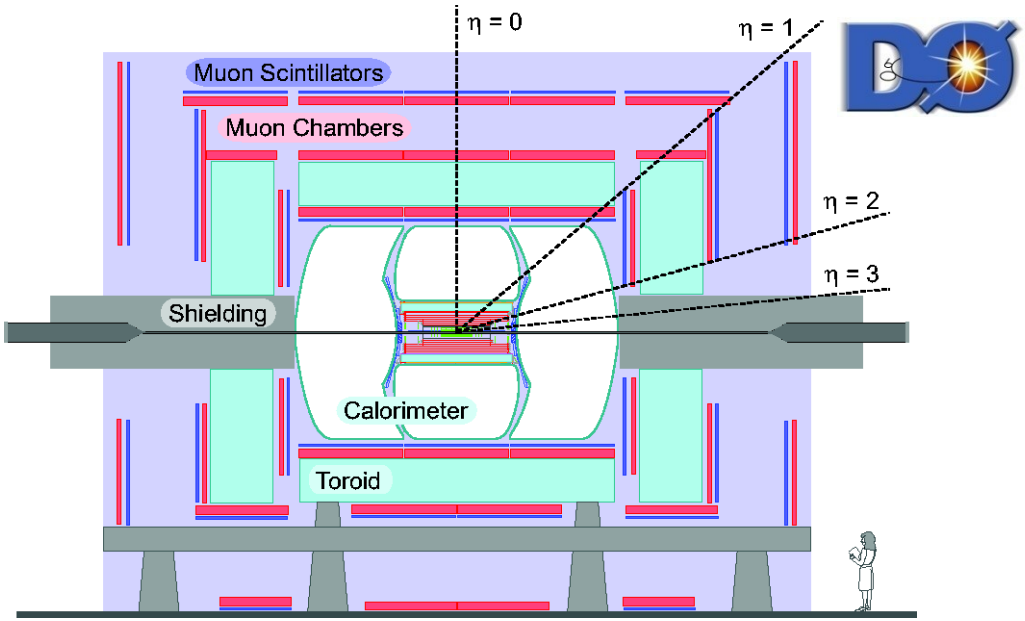
XLIVth RENCONTRES DE MORIOND

QCD and High Energy Interactions

18th of March 2009

Tevatron: CDF & D0

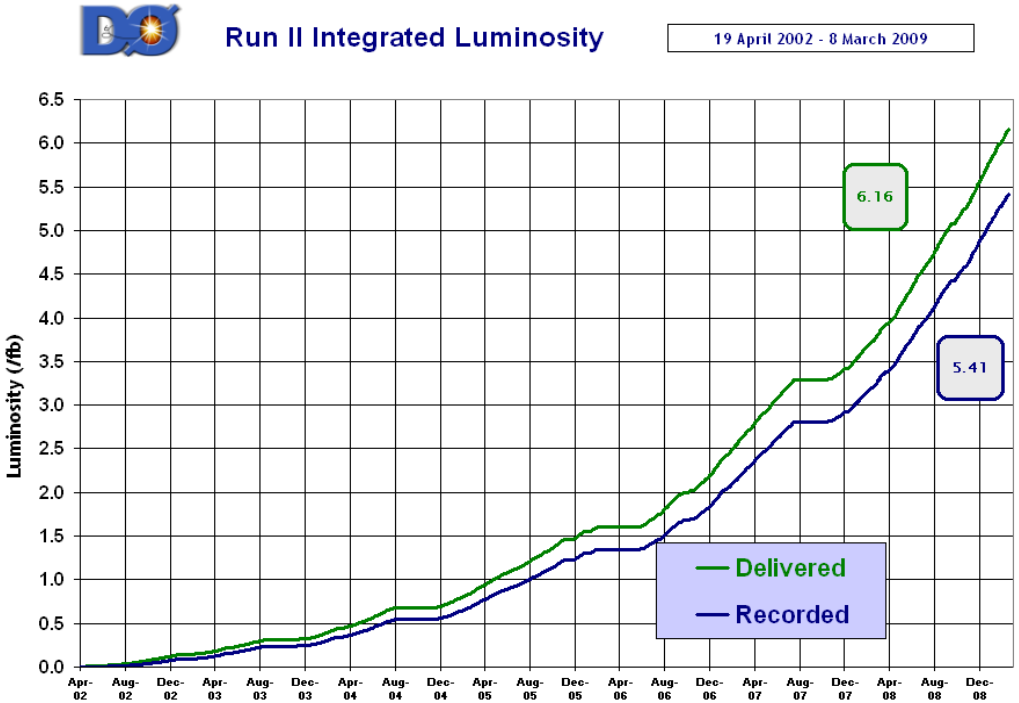




- Both experiments have 5 fb^{-1} on tape
- ~ 2 fb^{-1} registered in 2008 alone
- Current data-taking efficiency ~ 90%

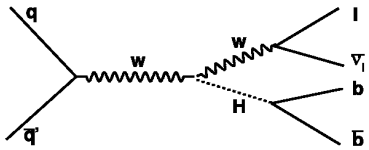
Results presented here: 1.0 – 2.5 fb^{-1}

All results corrected to the particle level



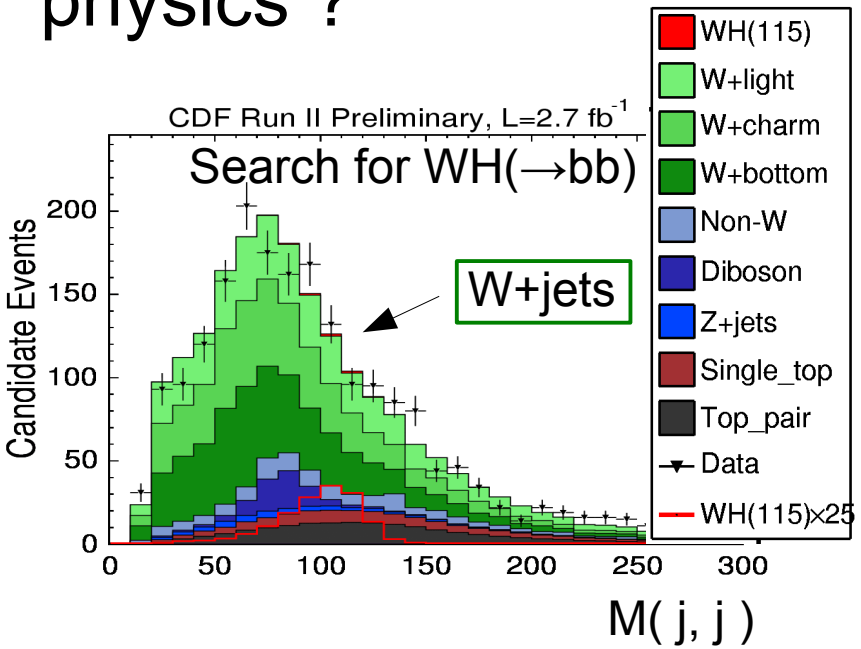
Why study W / Z + jet physics ?

- Important test of QCD
- Major background to many measurements & searches:
  - single top, ttbar
  - low-mass Higgs & SUSY



- Challenging to accurately simulate

→ important to validate tools using experimental data



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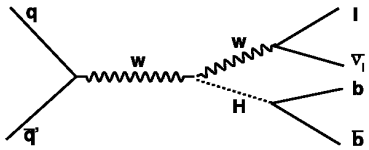

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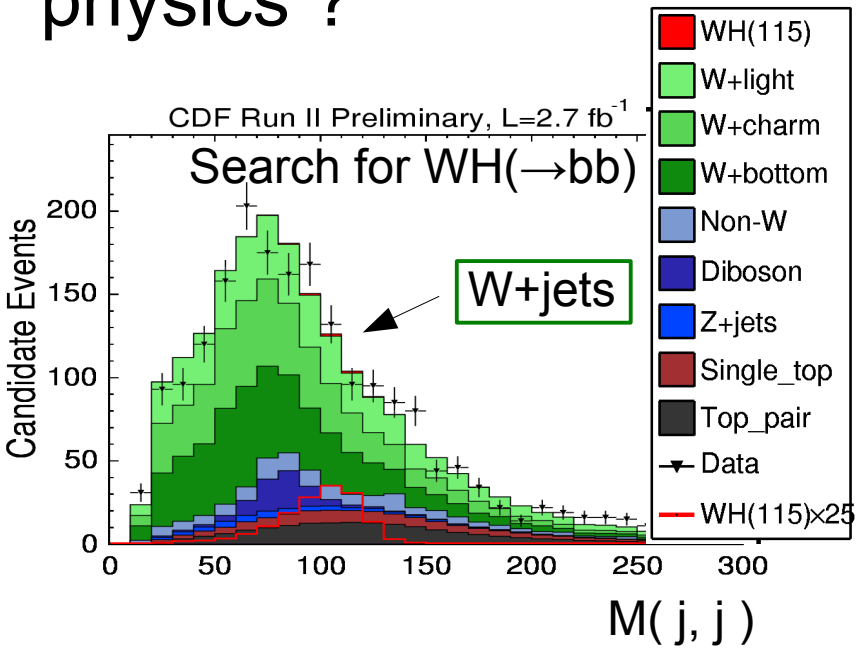
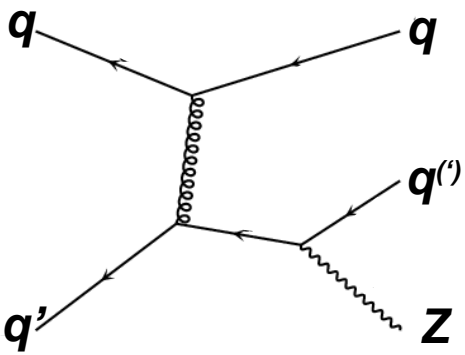


<u>Theoretical descriptions appearing later:</u>

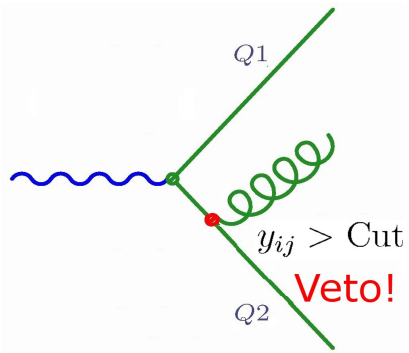
- pQCD (+ corrections for underlying event & hadronization)
  - LO for N_{parons} = 1, ..., 6
  - NLO for $N_{partons}$ = 1, 2



- LO 2 → 2 + parton shower
  - PYTHIA
  - HERWIG

  } (reweighted to Z+parton matrix element)

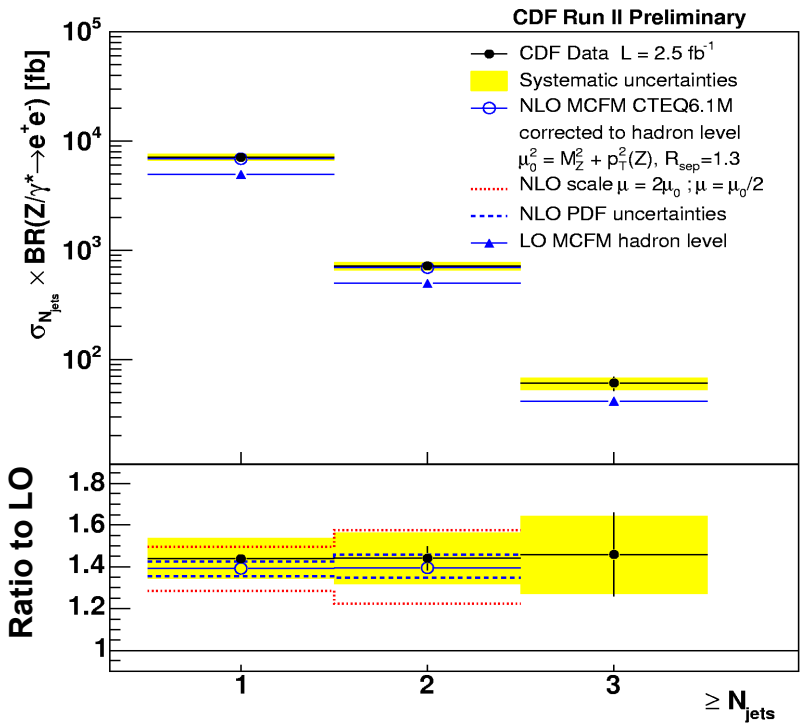
- LO 2 → N + vetoed parton shower
  - SHERPA (CKKW matching)
  - ALPGEN + PYTHIA / HERWIG (MLM matching)



PRL **100**, 102001 (2008)
hep-ex/0711.3717

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

- Test validity of pQCD + non-pQCD corrections
- Electrons: E_T>25 GeV, 66 < M_{ee}< 116 GeV
- Jets: R = 0.7, p_T > 30 GeV, |y| < 2.1



- NLO pQCD: good agreement with data !
- LO pQCD: ~30% below data

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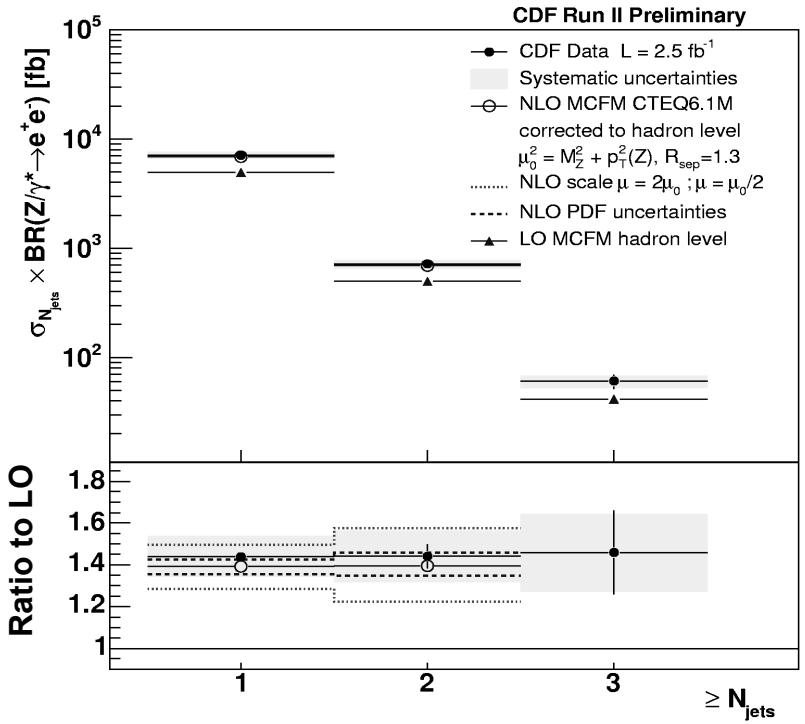

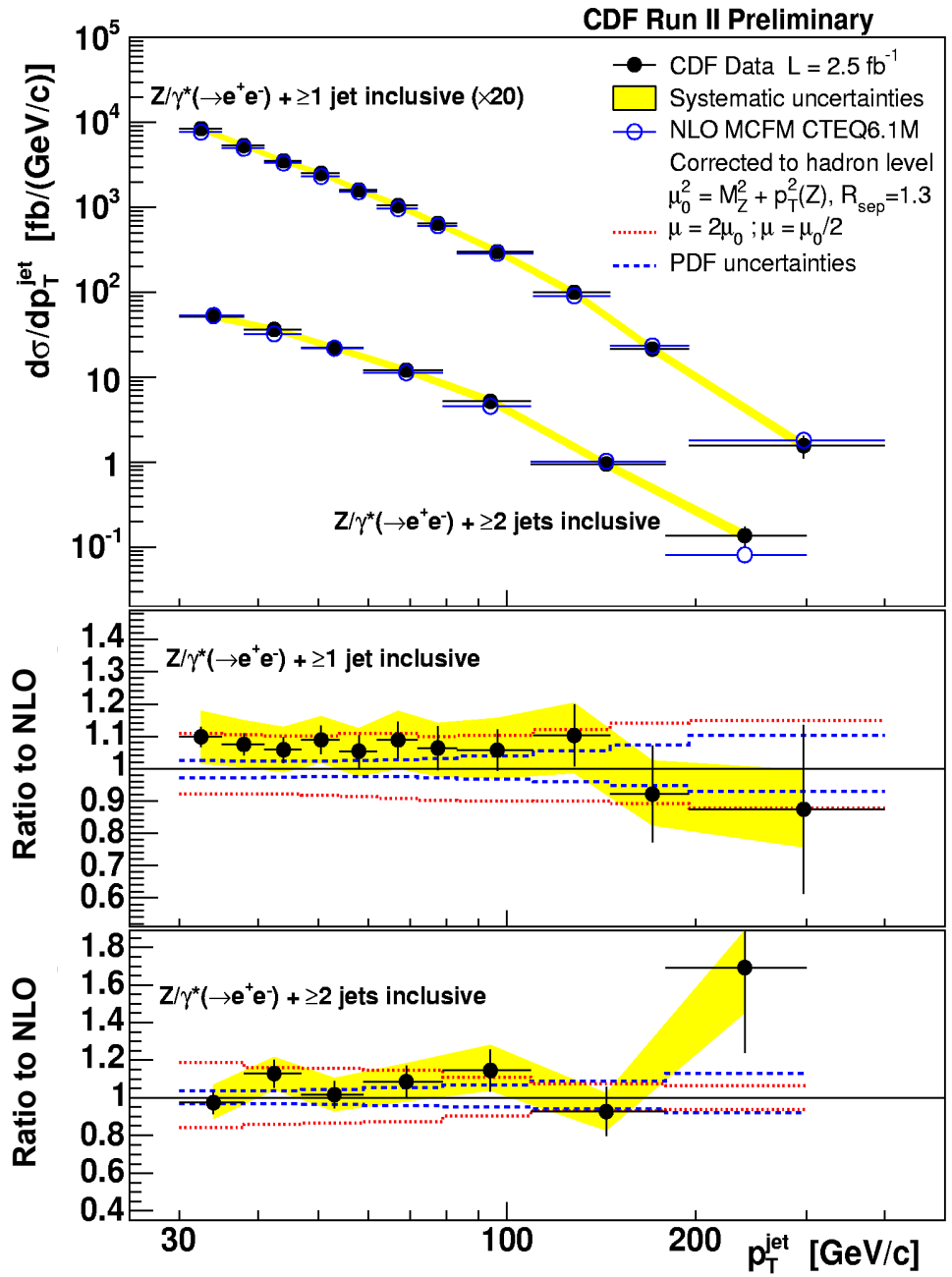

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Submitted to PLB,
hep-ex/0903.1748

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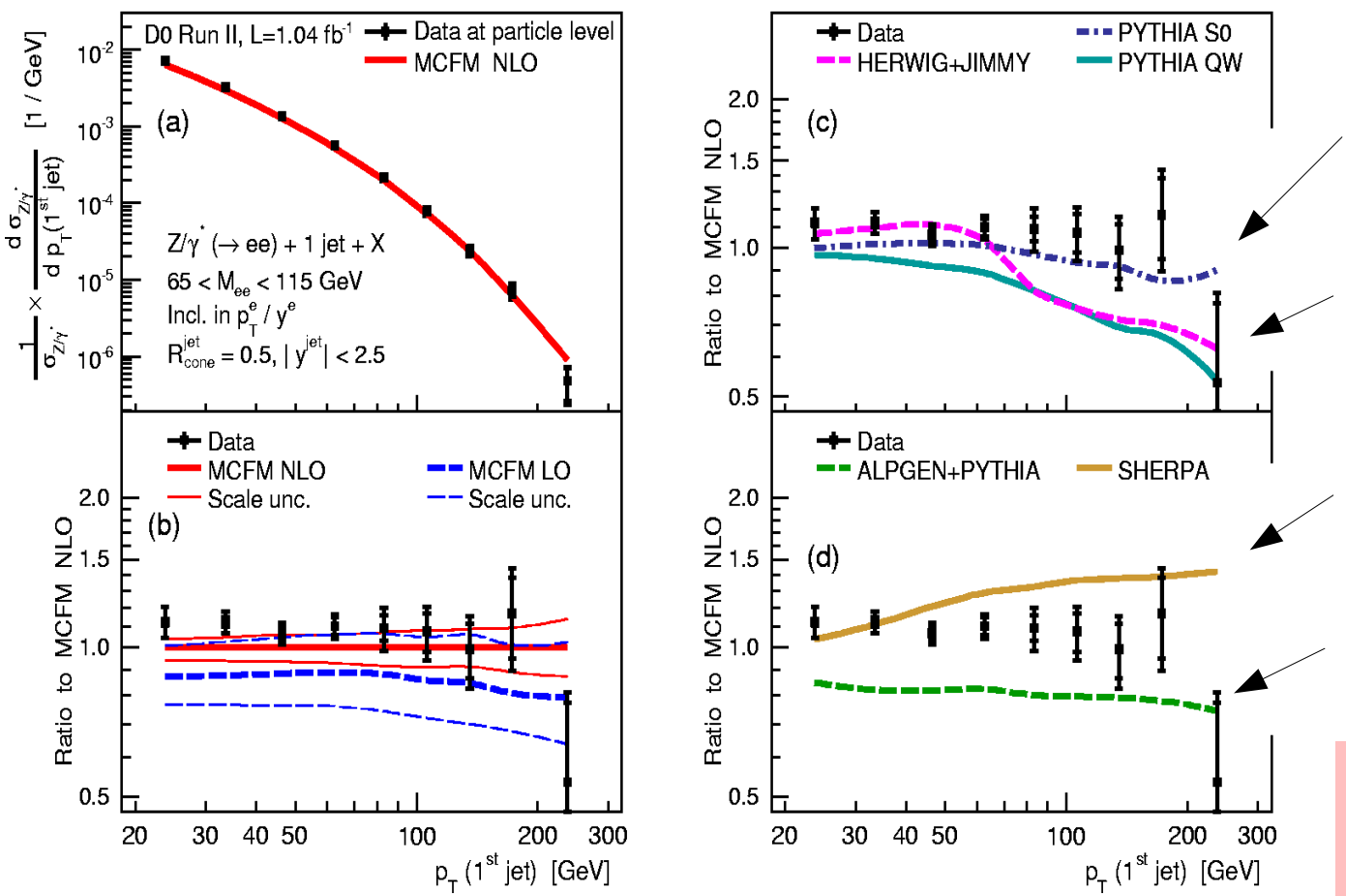
- Normalized with $\sigma(Z)^{-1}$

$p_T(1^{st}$ jet)



- NLO pQCD large improvement over LO
- PYTHIA „p_T-ordered“: ≈ data / NLO pQCD
- HERWIG+JIMMY &
- PYTHIA „Q^2-ordered“: too low at high p_T
- SHERPA: harder spectrum than data
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Consider scales as tunable parameter
→ correct normalization

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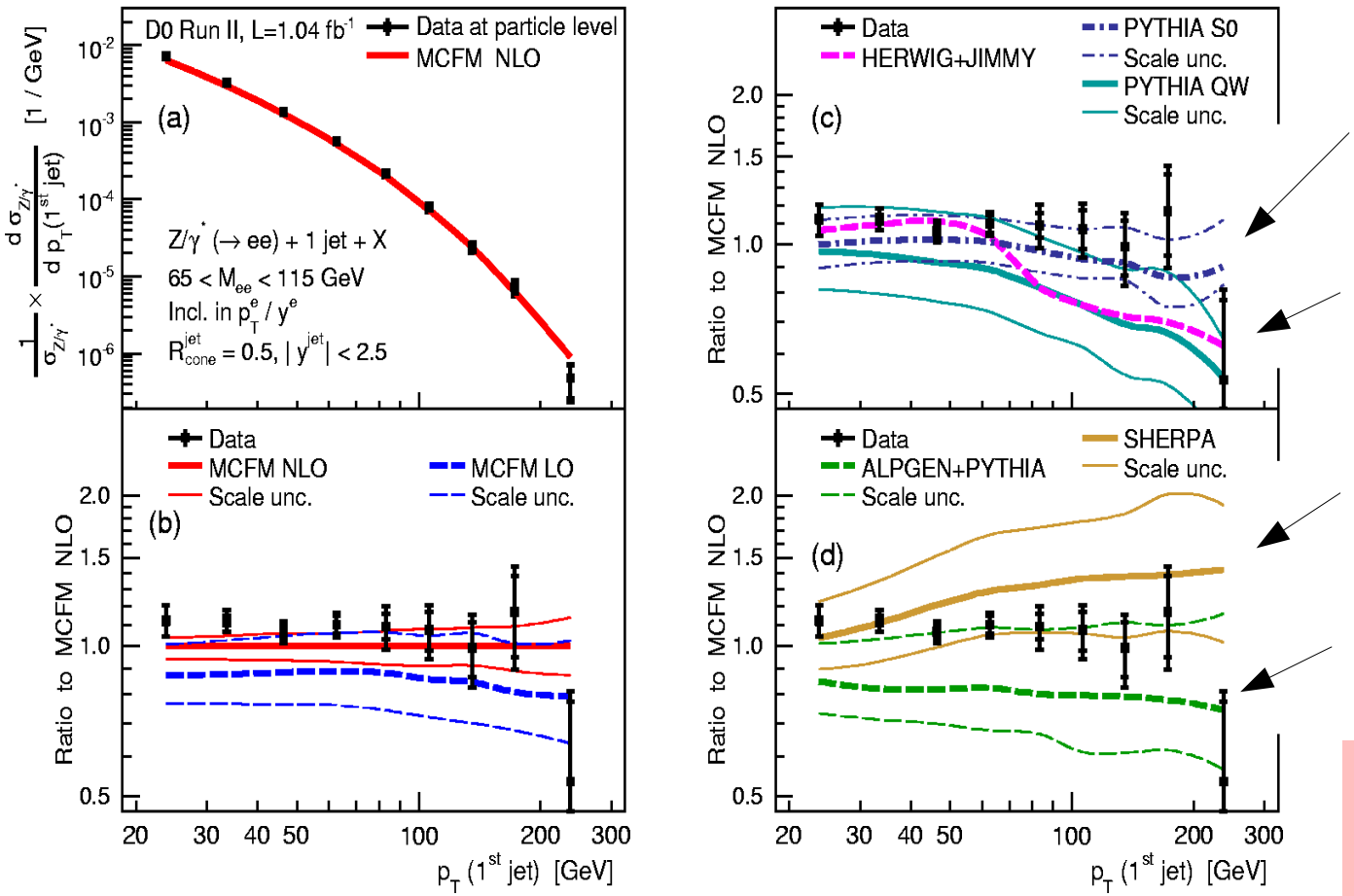

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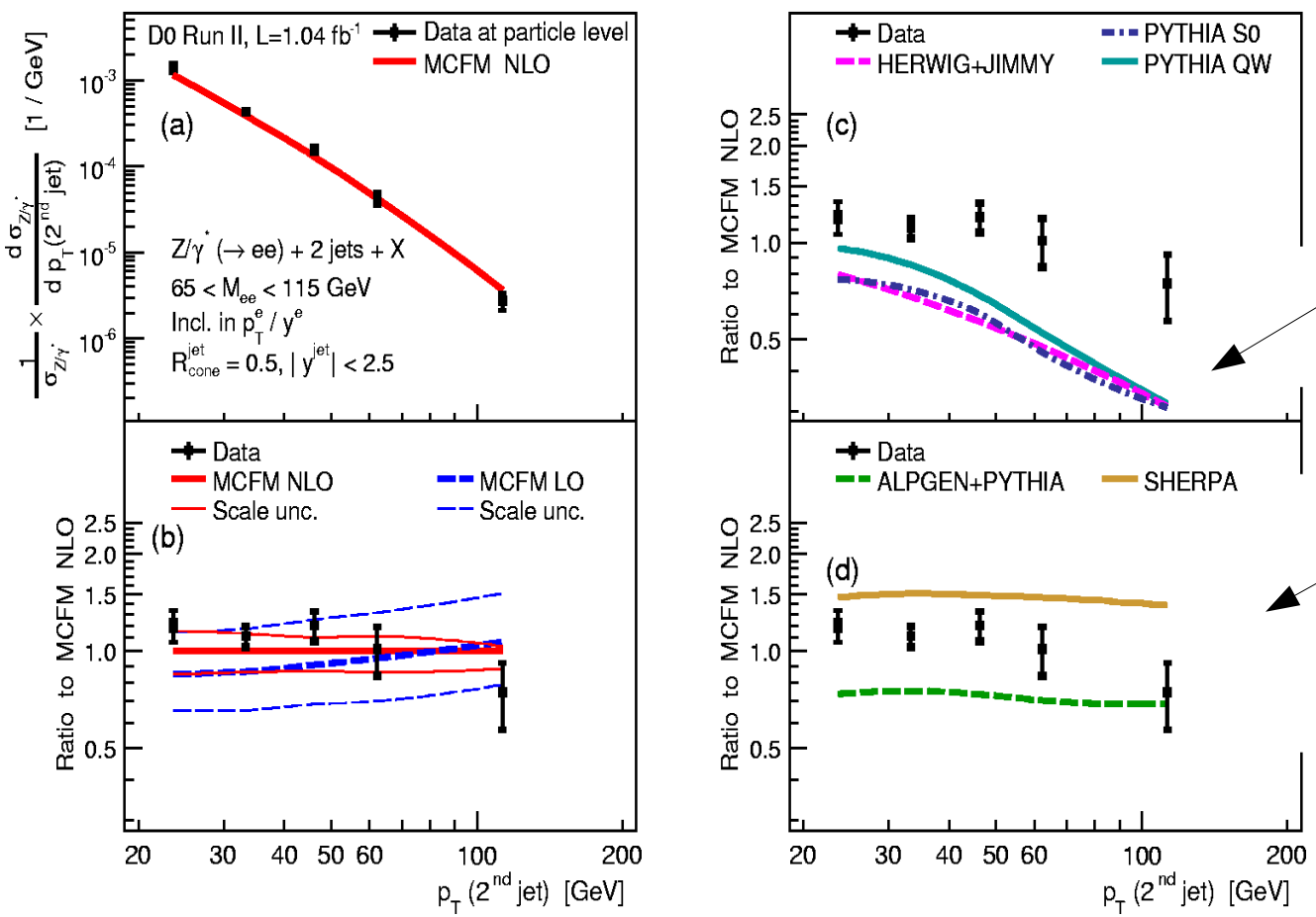

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- Shower-based generators: consistently too low tails
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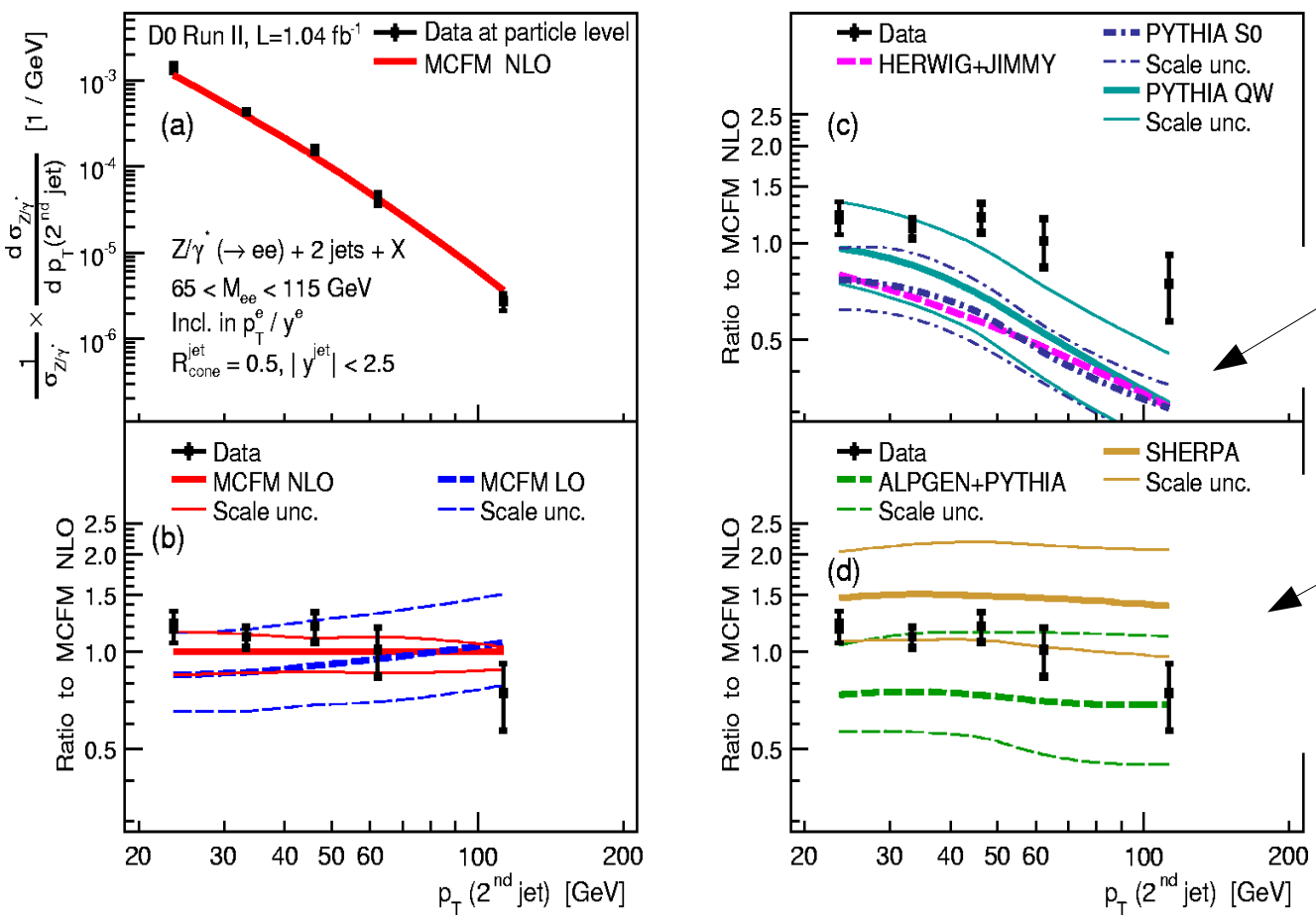

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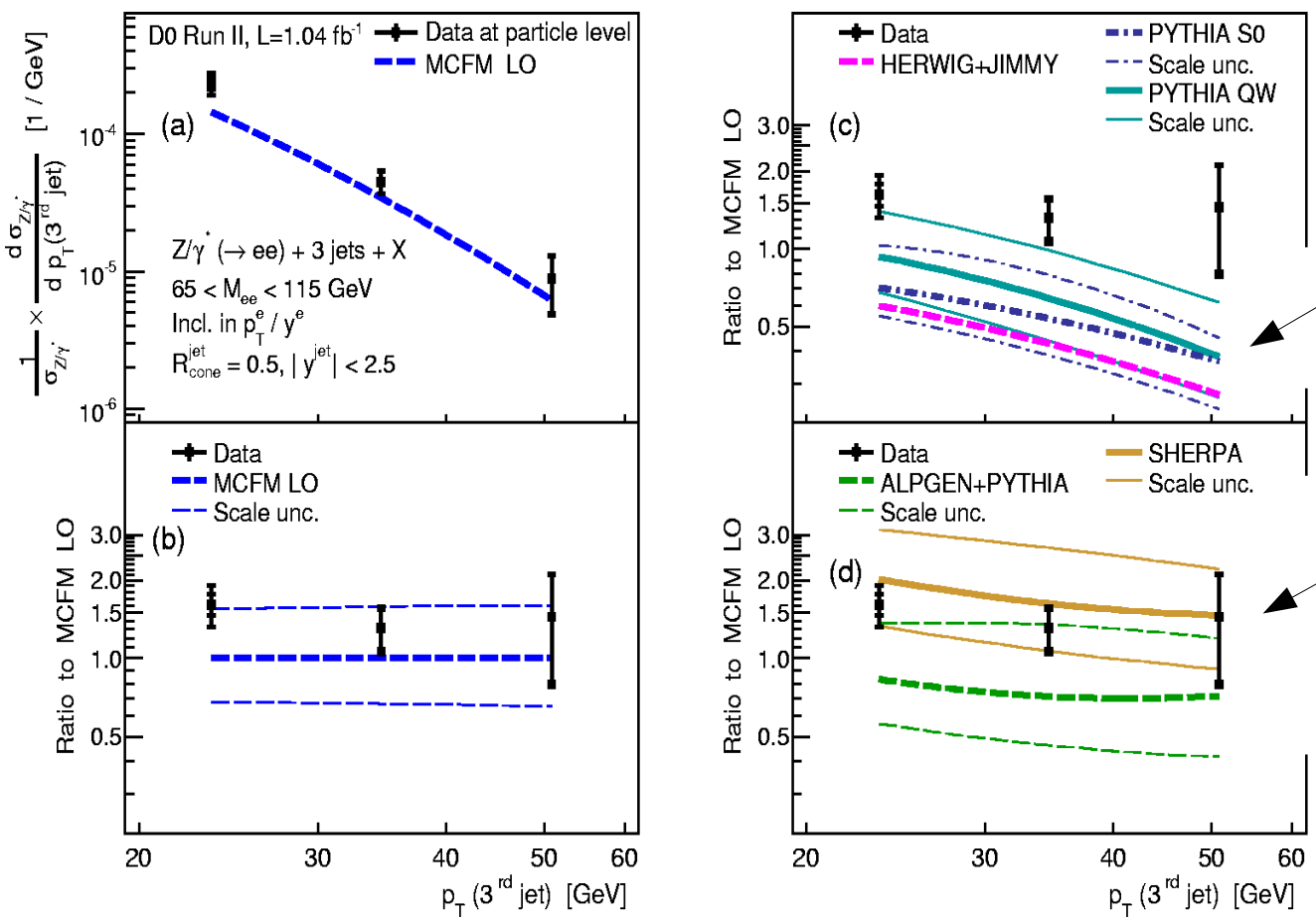
$p_T(3^{rd}$ jet)



- LO pQCD only
  (new 2009: approximate NLO for W+3-jets !)
- Shower-based generators: consistently too low tails
- Matched generators: correct shapes, uncertain normalizations

ALPGEN: nominal scales x0.5
→ simultaneous agreement for all 3 leading jets

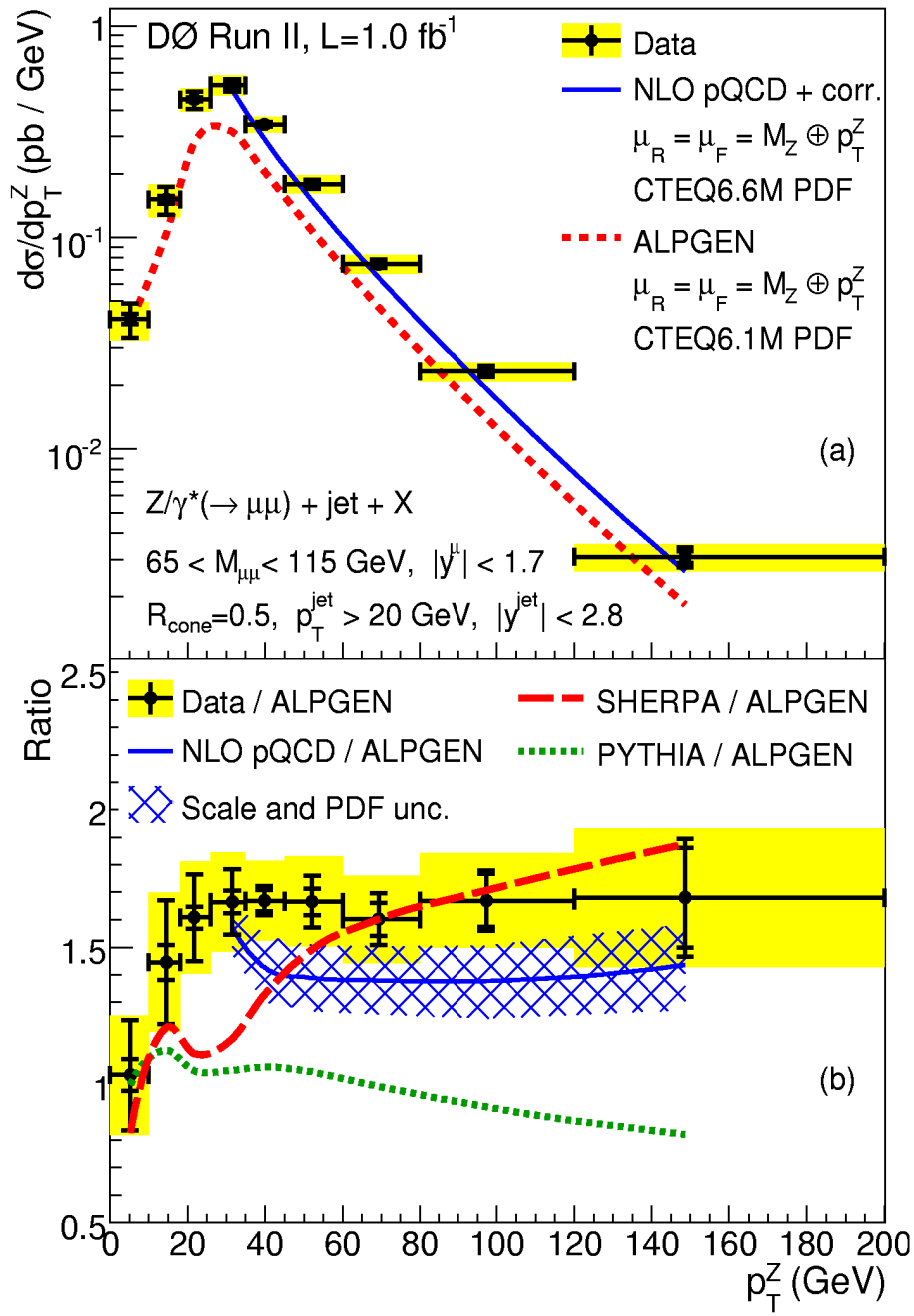
PLB **669,** 278 (2008)
hep-ex/0903.1748

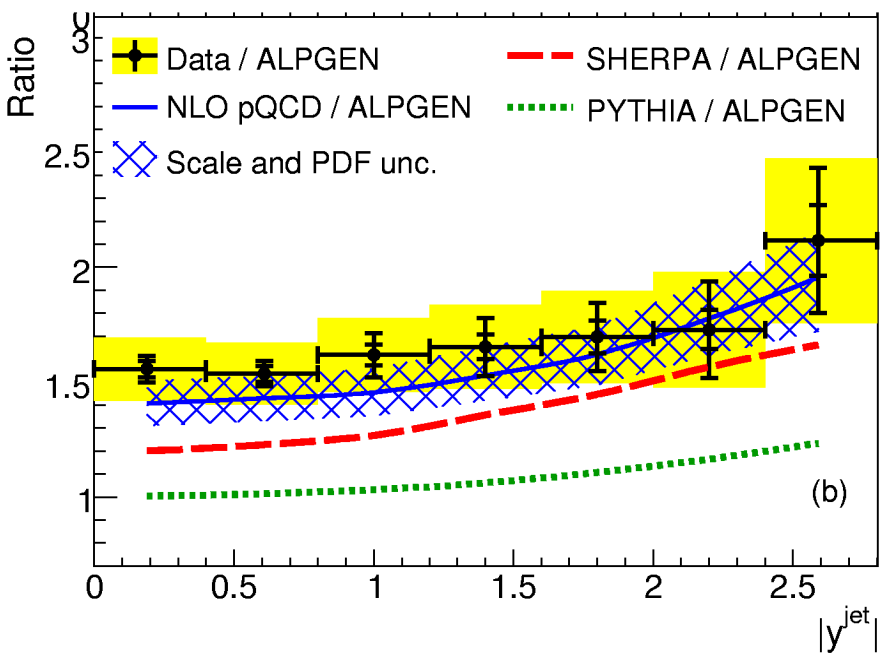
$Z/\gamma^* (\rightarrow \mu\mu)$ + jets

- 1st jet – including angular distributions
- Jets: R = 0.5, p_T > 20 GeV, |y| < 2.8

$p_T(Z)$ underlying event dominates at low p_T
→ tuning might be needed

$|y^{jet}|$ ALPGEN more central than data / SHERPA / PYTHIA





Preliminary,
D0 Note 5903-CONF

Z/γ* (→ μμ) + jets

Δφ(Z, jet)

SHERPA gives reasonable description

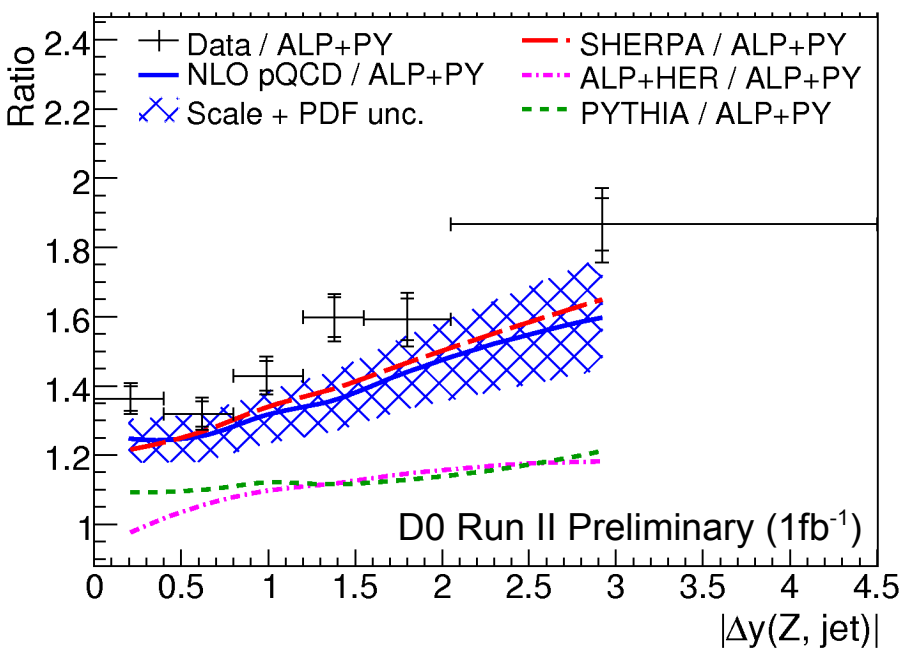
~π : multiple soft emissions important

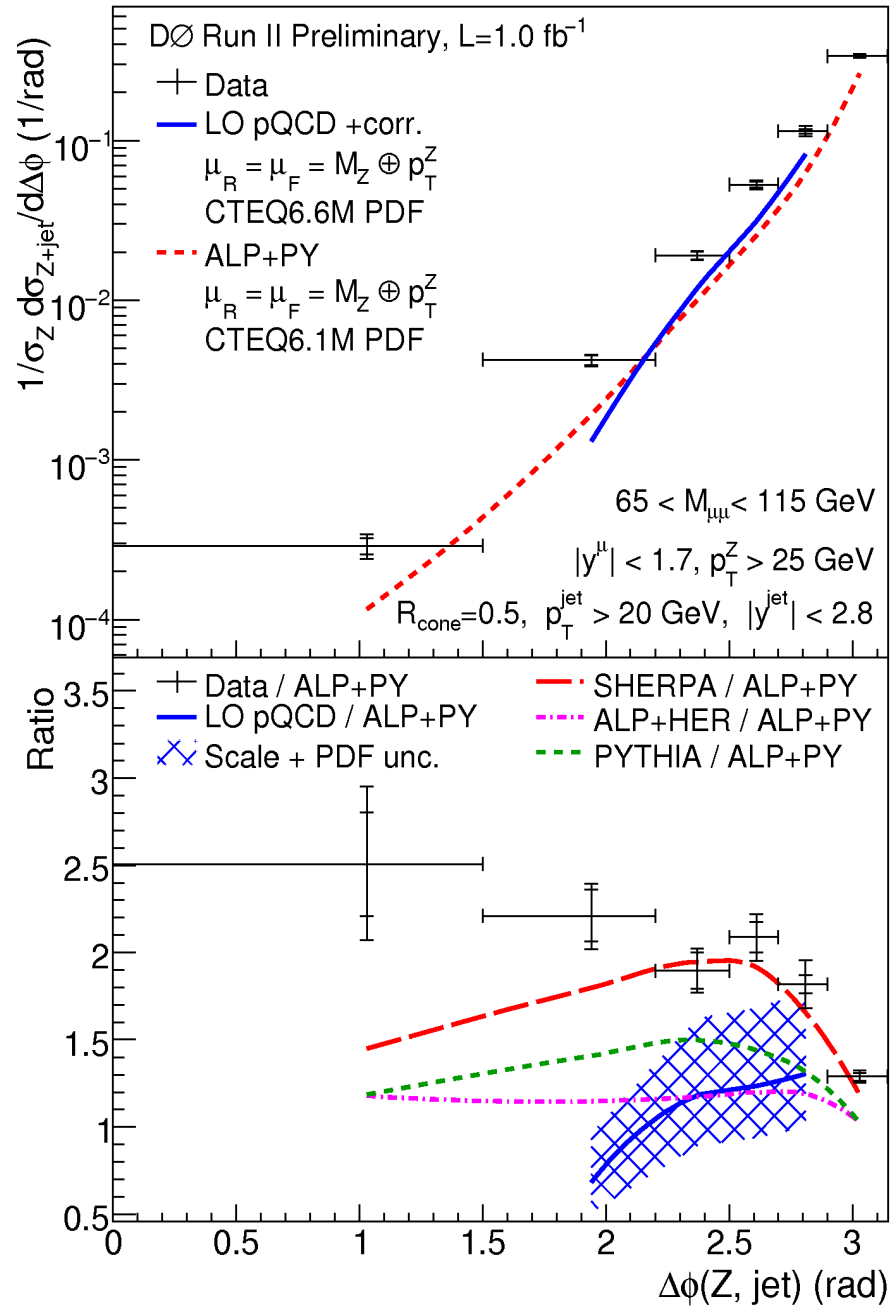
<2: underlying event dominates

→ only limited range described by fixed-order pQCD

|Δy(Z, jet)|

NLO pQCD and SHERPA agree with data





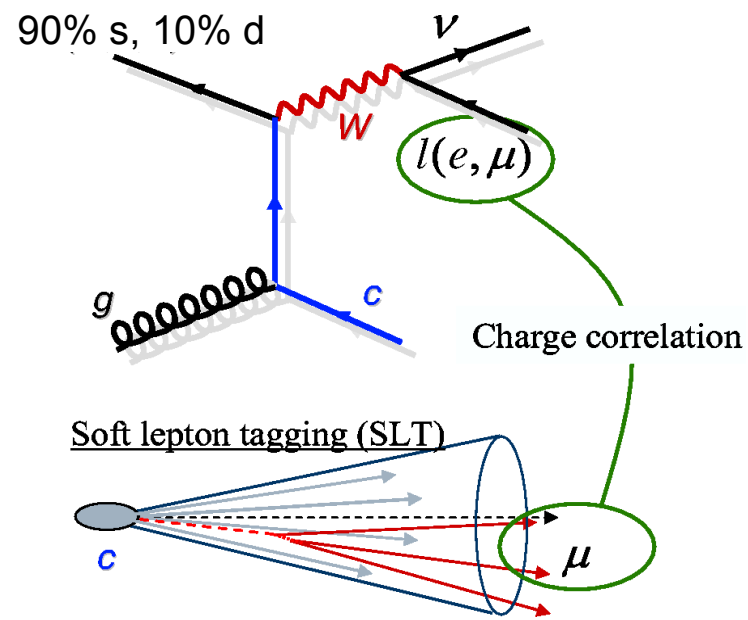
PRL **100**, 091803 (2008)
hep-ex/0711.2901

W + single c-jet

PLB **666**, 23 (2008)
hep-ex/0803.2259

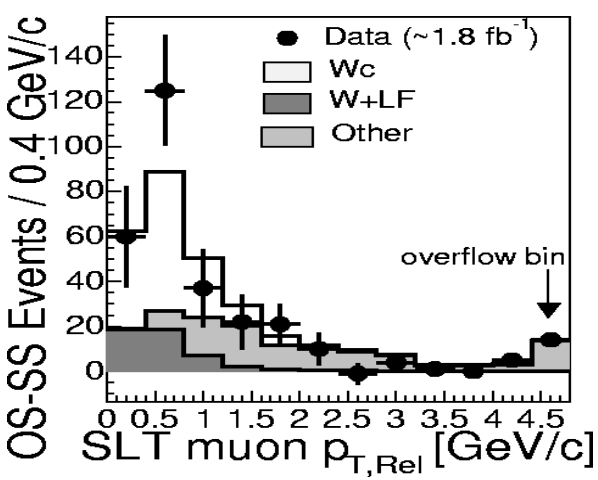
- Sensitive to s-quark content of protons at high Q^2
- Background to top quark, Higgs and SUSY
- W selection: high-p_T e or μ and missing E_T
- For multijet, DY, W+bb / cc : OS ≈ SS

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

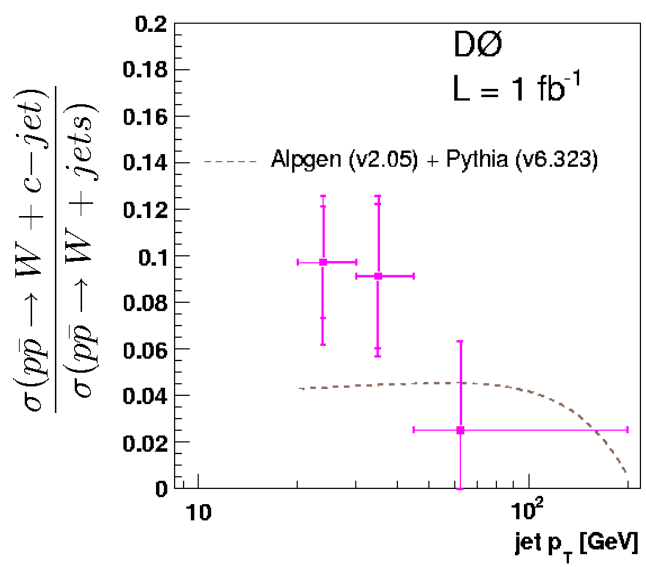


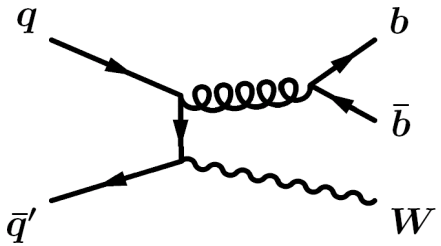
Measured: $\sigma \times \mathrm{BR} = 9.8 \pm 2.8(\mathrm{stat})^{+1.4}_{-1.6}(\mathrm{sys})$ pb

Theory: NLO pQCD : $11.0^{+1.4}_{-3.0}$ pb



W+c / W+jets: agrees with ALPGEN+PYTHIA





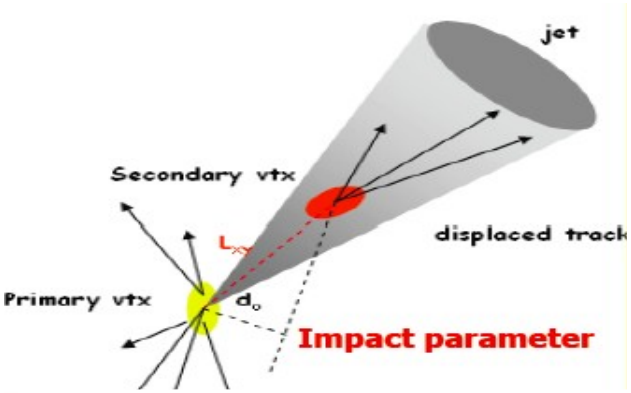
W + b-jets

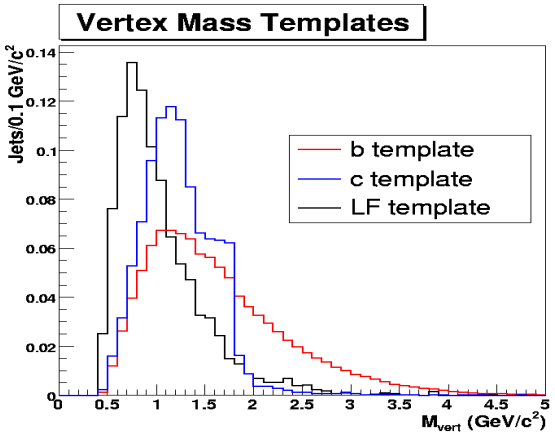
Preliminary,
CDF Note 9321

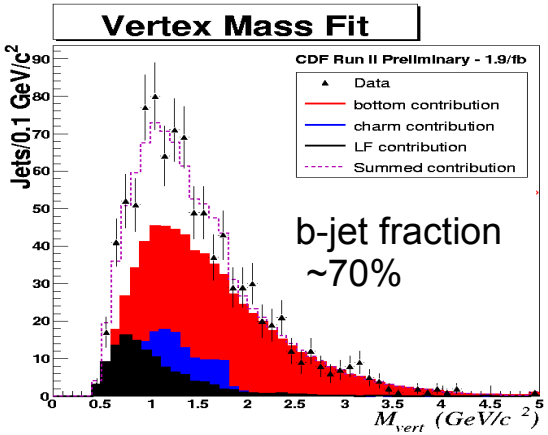
- Major background to:
  - Single-top & ttbar measurements
  - low-mass Higgs, WH(→bbar)
- b-tagging using secondary-vertex tag
- Vertex mass template fit → extract b-jet signal
- Selection: high-p_T e / μ + missing E_T
- Jets: E_T > 20, R=0.4

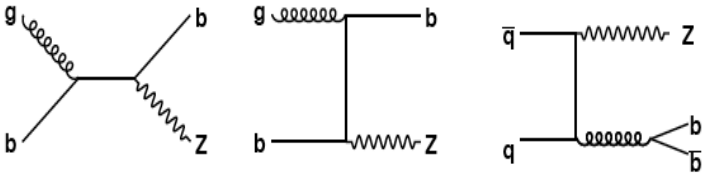
Prediction	$\sigma_{b-\text{jets}}(W + b\text{–jets}) \times BR(W \to \ell\nu)(\text{pb})$
ALPGEN	0.78
Data	$2.78 \pm 0.27\ (\text{stat}) \pm 0.42\ (\text{syst})$

- Factor of 3 difference data ↔ ALPGEN
- Under study / waiting for comparisons with more models





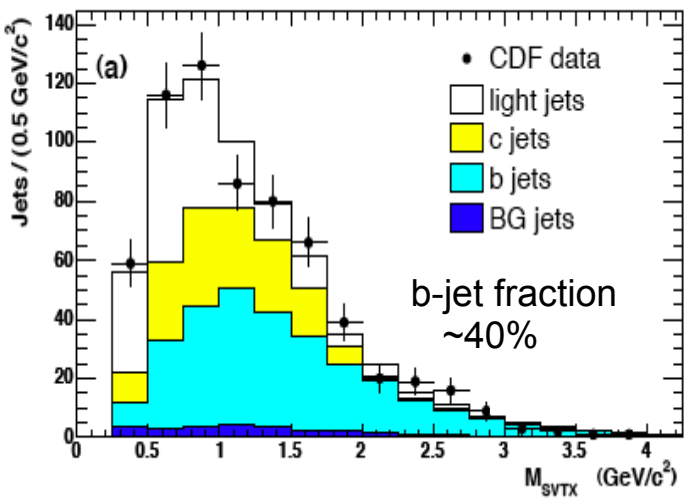


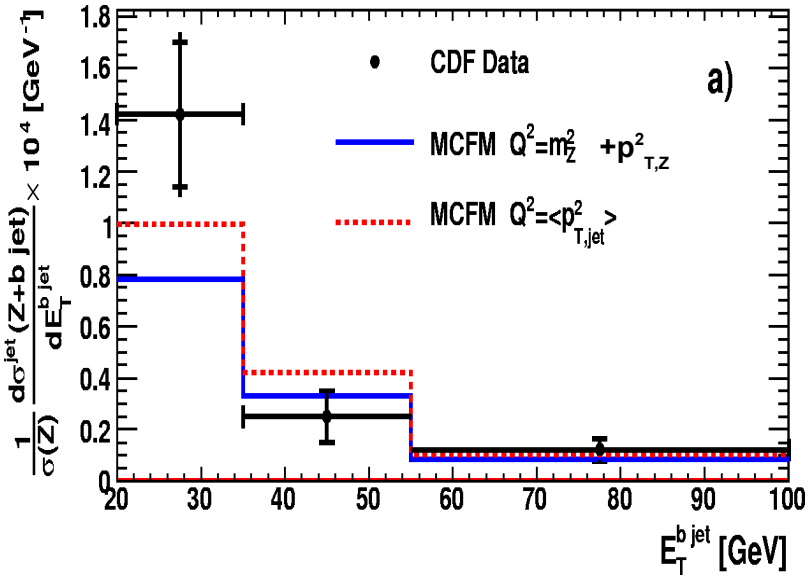


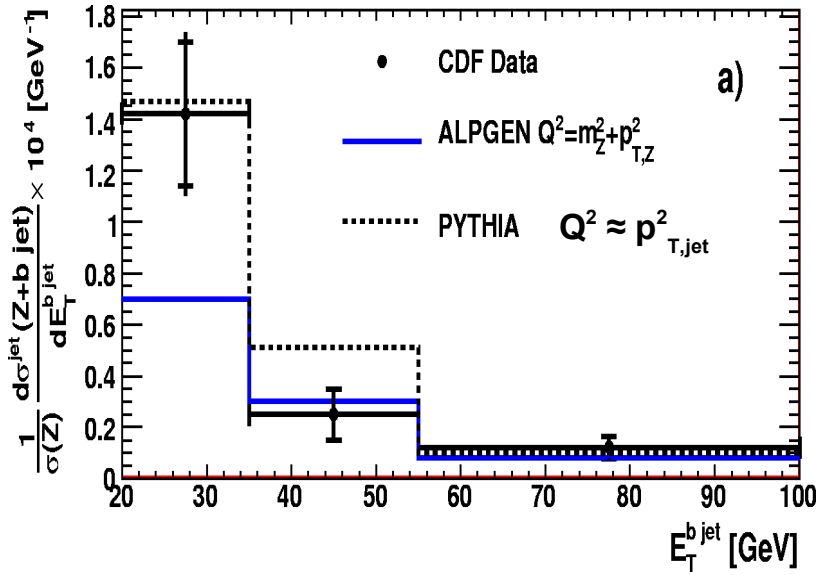
Z/γ* + b-jets

Submitted to PRD, hep-ex/0812.4458

- Similar b-tagging / mass fit as for W + b-jet
- Using both ee and μμ
- Jets: E_T > 20, R=0.7
- Differential distributions: $E_T^{b\text{-jet}}$, $\eta^{b\text{-jet}}$, p_T^Z, N_{jets}, $N_{b\text{-jets}}$







- Agreement with pQCD within large uncertainties
- Factor of 2 difference PYTHIA ↔ ALPGEN probably related to different scale choices

Summary

- Boson + jets: important background to many measurements and searches
- Wide range of CDF and D0 measurements available – fully corrected for detector effects

Flavor-inclusive measurements:

p_T(jet):

- Good agreement data ↔ NLO pQCD for both experiments
- ALPGEN / SHERPA :
  - Reasonable shapes, uncertain normalizations
  - Agreement with data after tuning μ_R and μ_F

p_T(Z) / angles / angular correlations:

- Varying agreement between models and data
- $\Delta\varphi$(Z, jet) & p_T(Z): sensitive to underlying event and soft emissions – tuning needed

Heavy-flavour measurements:

- Theory in agreement with data within uncertainties – W+b a possible exception
- First differential distributions available