W/Z+jets properties at the DØ experiment

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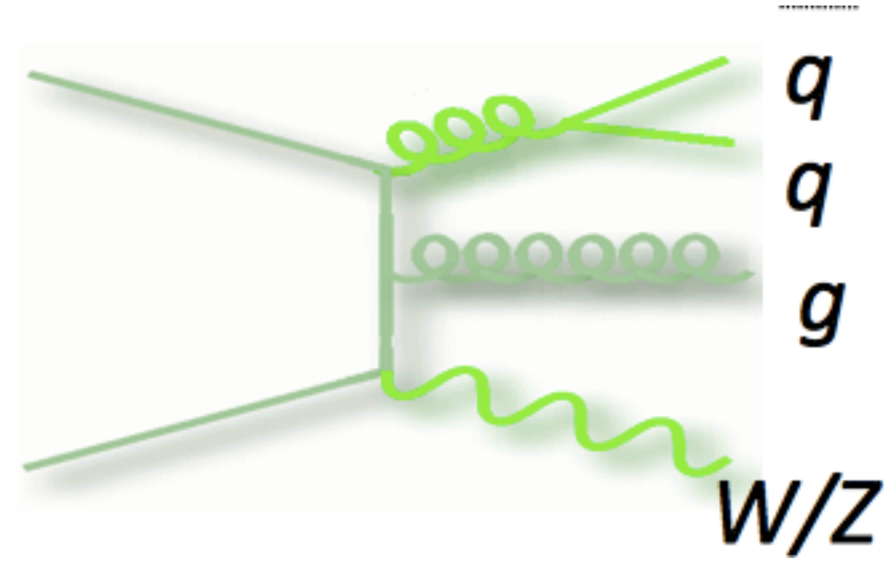
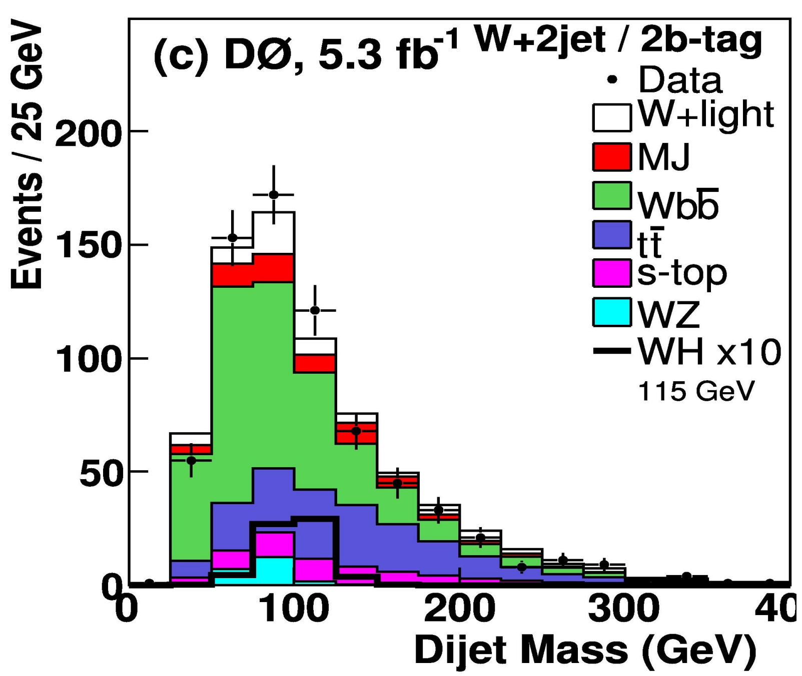
on behalf of the DØ Collaboration

V+Jets Results

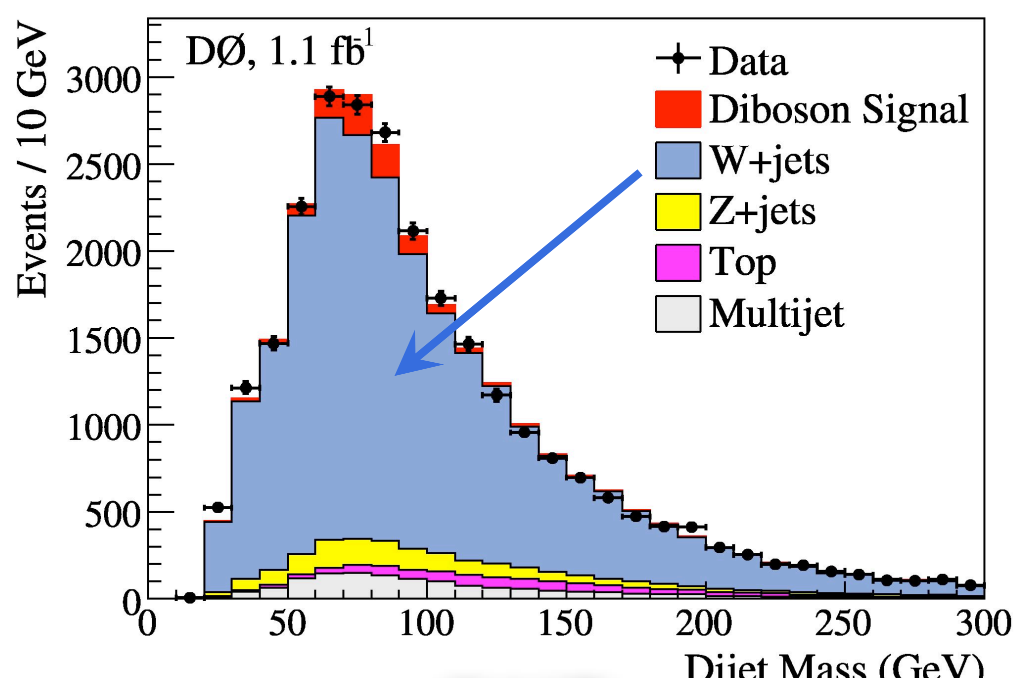
- **Test of perturbative QCD calculations:**
  recent high jet multiplicity calculations available, appropriate scale choice not always clear



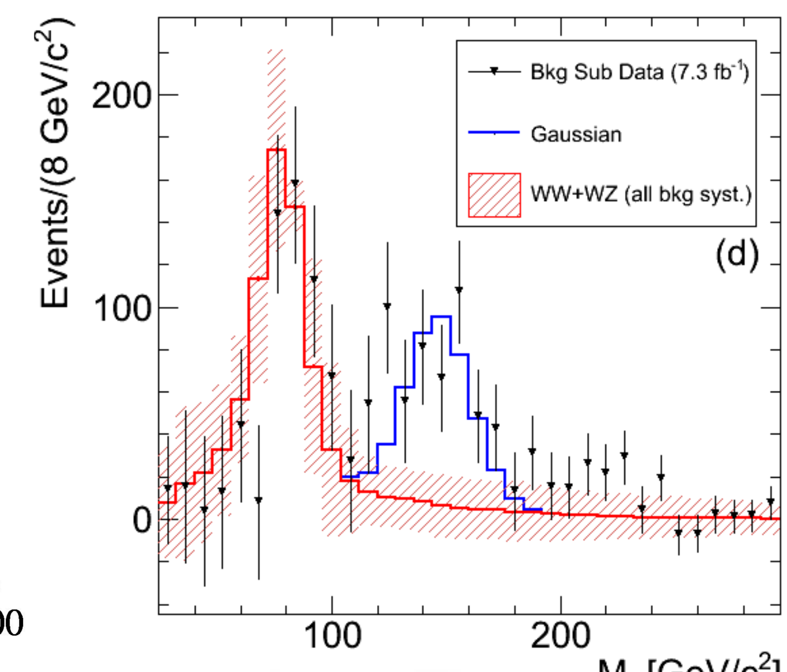
- **Monte Carlo modeling:**
  Parton Shower (PS) and Matrix Element (ME) approaches need tests/tuning
- **Experimental measurements:**
  Bkgd to precision SM measurements and searches for NP



Higgs

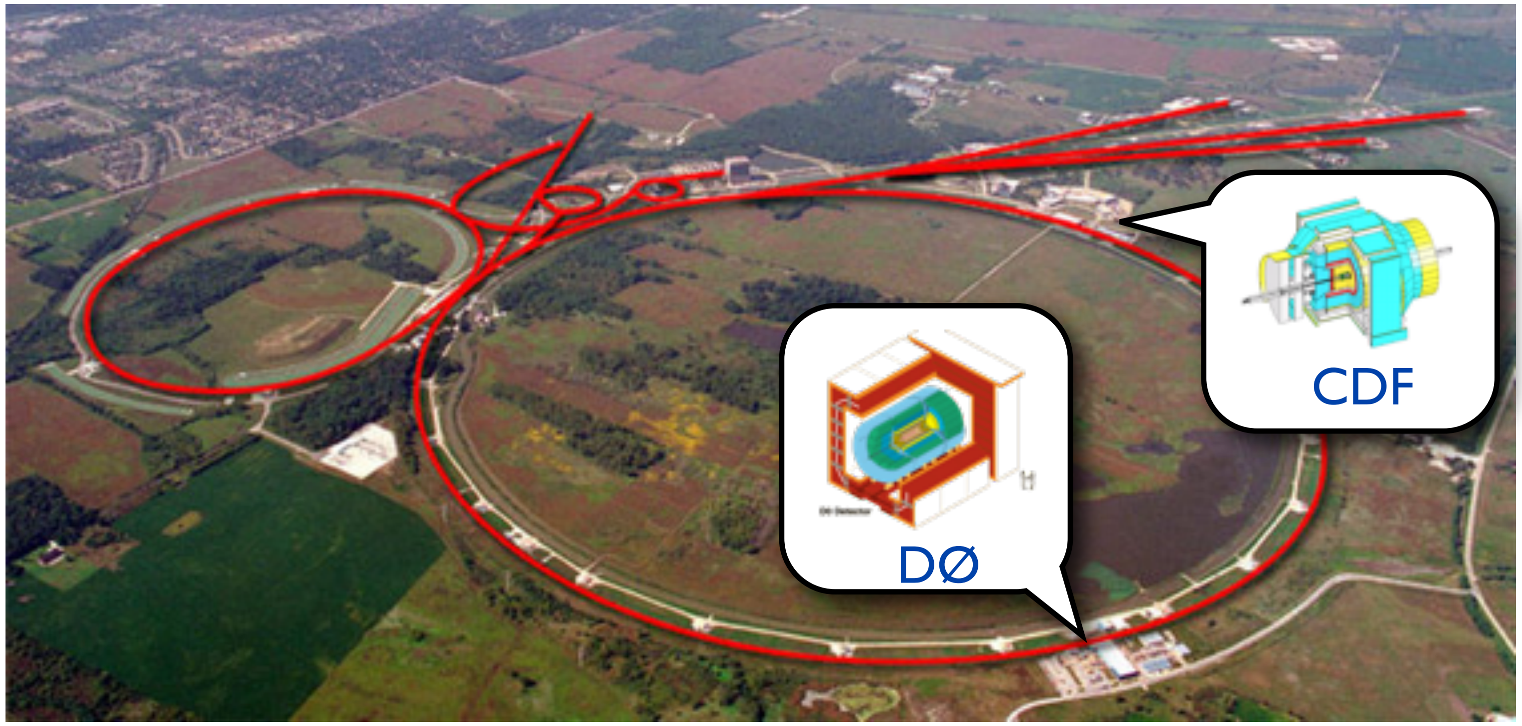


EW/Top



New Phenomena

The Tevatron & DØ



Tevatron

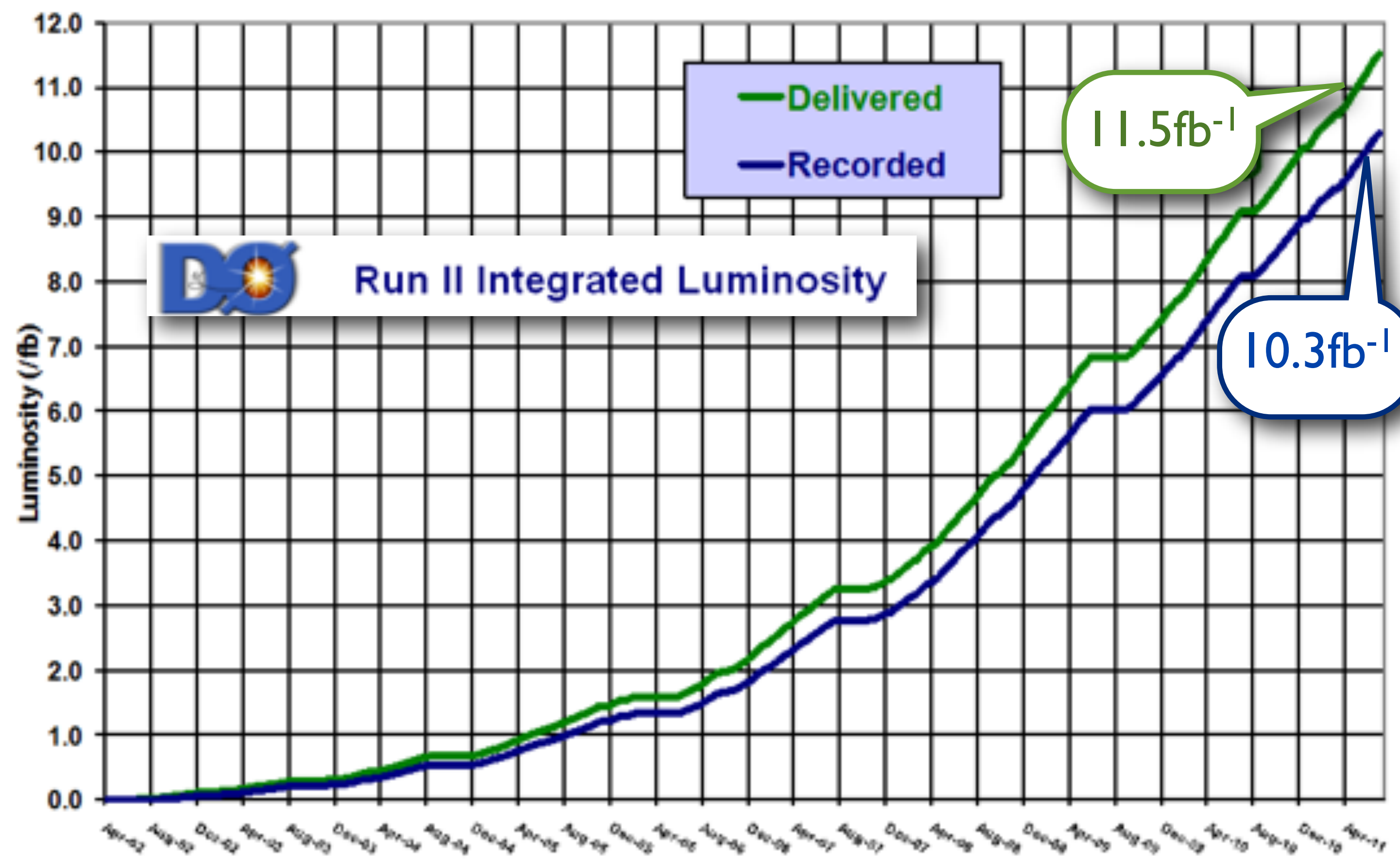
- $\sqrt{s} = 1.96$ TeV
- $\Delta t = 396$ ns
- RunII: 2001-2011: Typical average luminosity:

  >400x10^{30} cm^{-2} sec^{-1}

  ~70pb^{-1} per week

DØ Detector

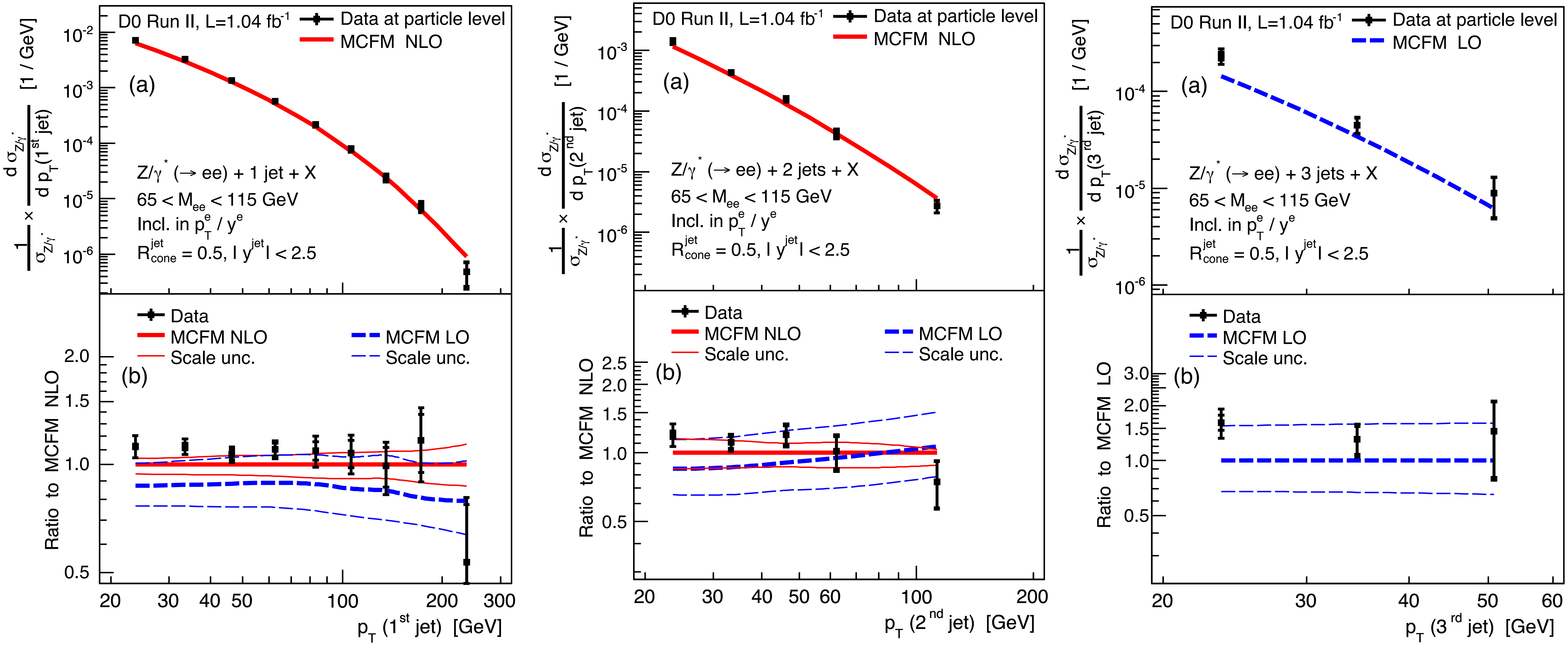
- Central Tracking:
  Silicon vertex detector and fibre tracker in 2T field tracker and
- Calorimeter:
  Hermetic coverage |η|<3.6, LAr calorimeter
- Muon System:
  Excellent purity and coverage: |η|<2



Z+jets Production

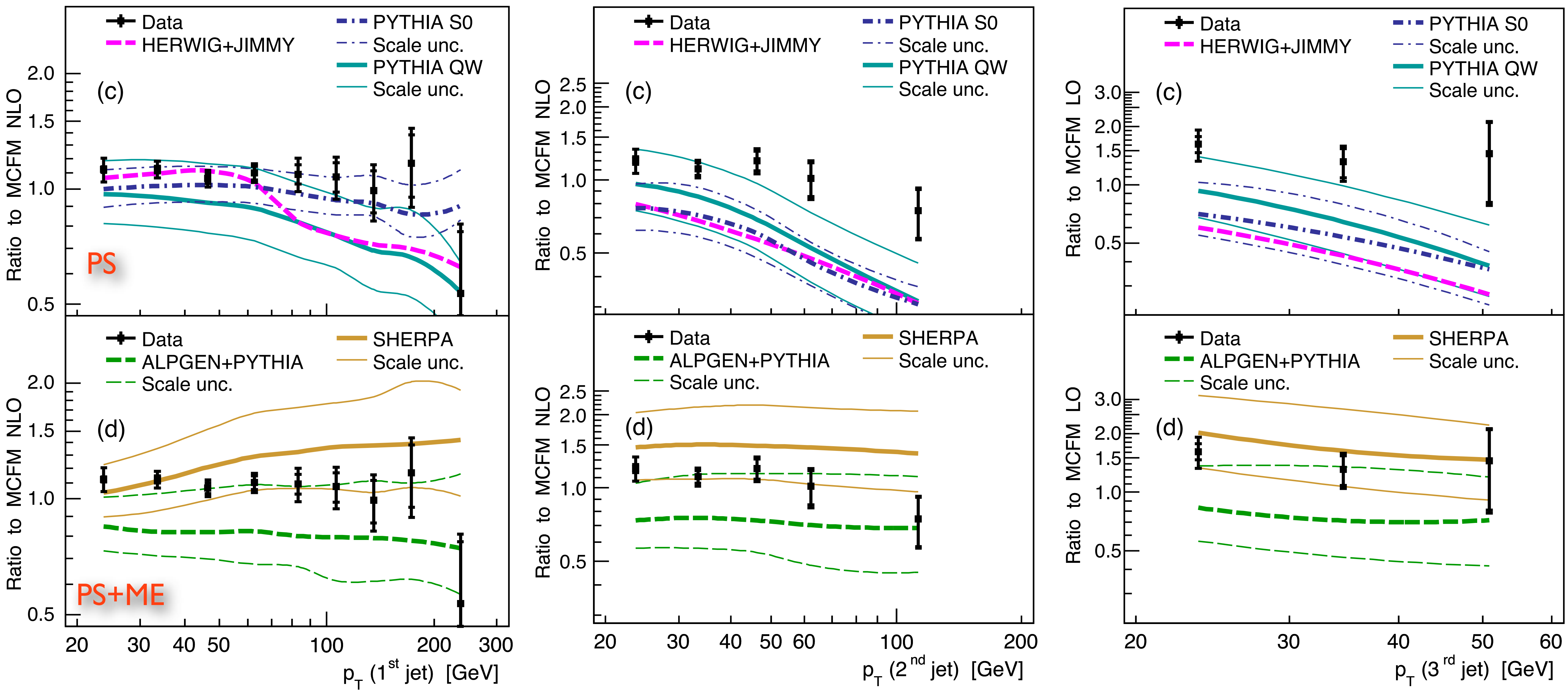
Phys. Lett. B **678**, 45 (2009)

- Measurement of 1st, 2nd, 3rd jet p_T in Z events
- Selection: Z→ee: |y(μ)|<2.4, m(Z)>65-115 GeV, p_T(j)>20 GeV, |y(j)|<2.8



- Normalized to inclusive σ(Z) in data
- Corrected for efficiencies, resolution effects and acceptance

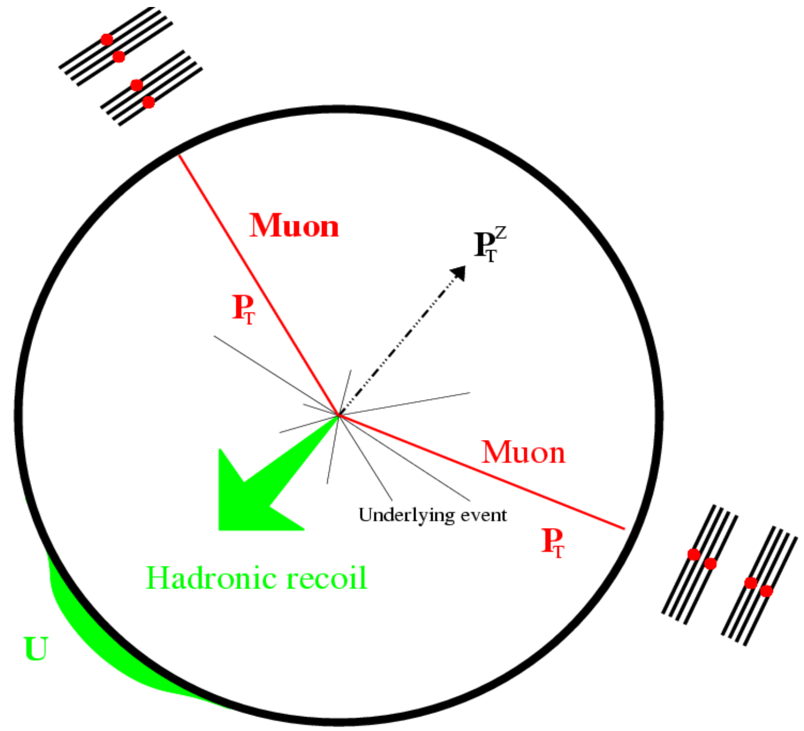
Z+jets Production

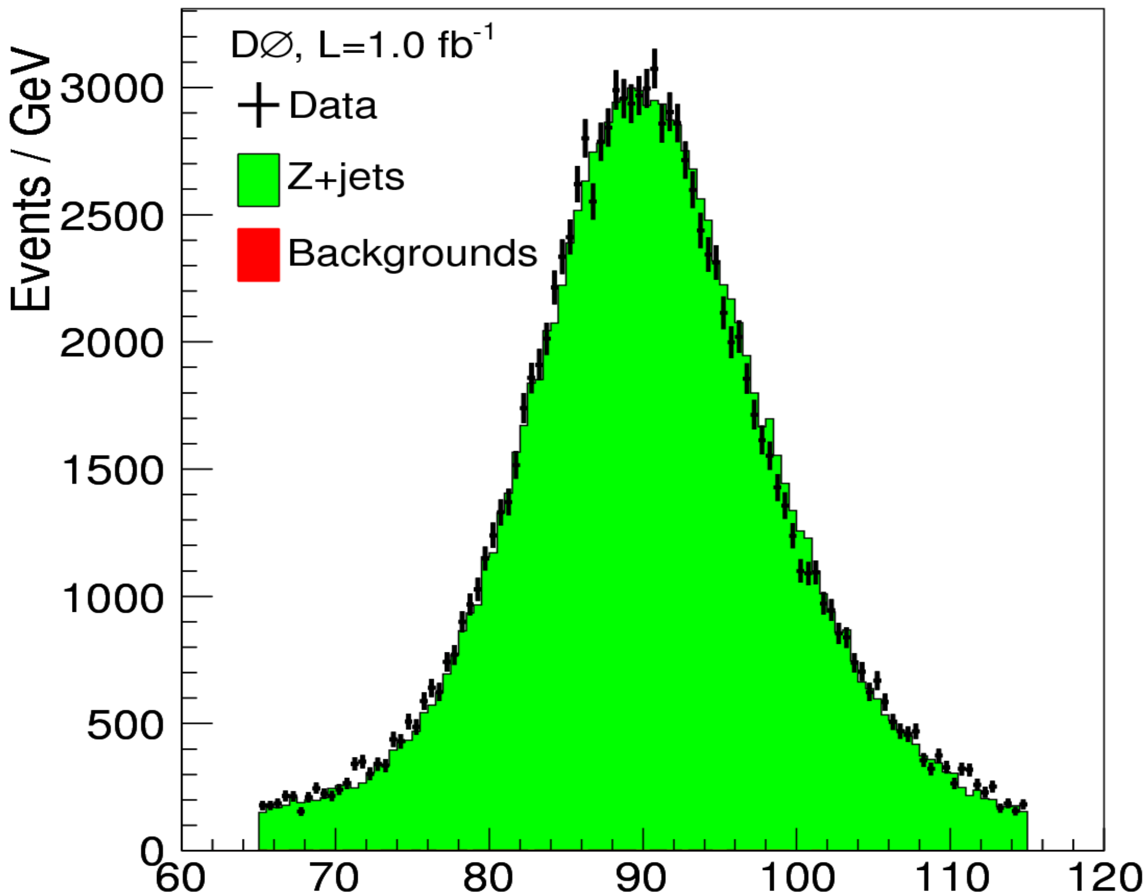


- Newer Pythia (v6.325) with p_T ordered showering (S0) shows improved performance
- Alpgen (v2.13) + Pythia predicts lower rates but shapes described well
- Sherpa (v1.1.1) generally well described, some deviations for p_T>40 GeV
- Herwig(v6.510) + Jimmy(v.4.31)

Phys. Lett. B **682**, 370 (2010)

- Z+jets σ measured as function of angular correlation between leading jet and Z boson
- Provide test of pQCD sensitive to effects not probed e.g. in p_T distributions, e.g. additional QCD radiation
- Z→μμ, very clean signature:
  Physics Bkgds: 0.5-1%
  Instrumental: ~1%

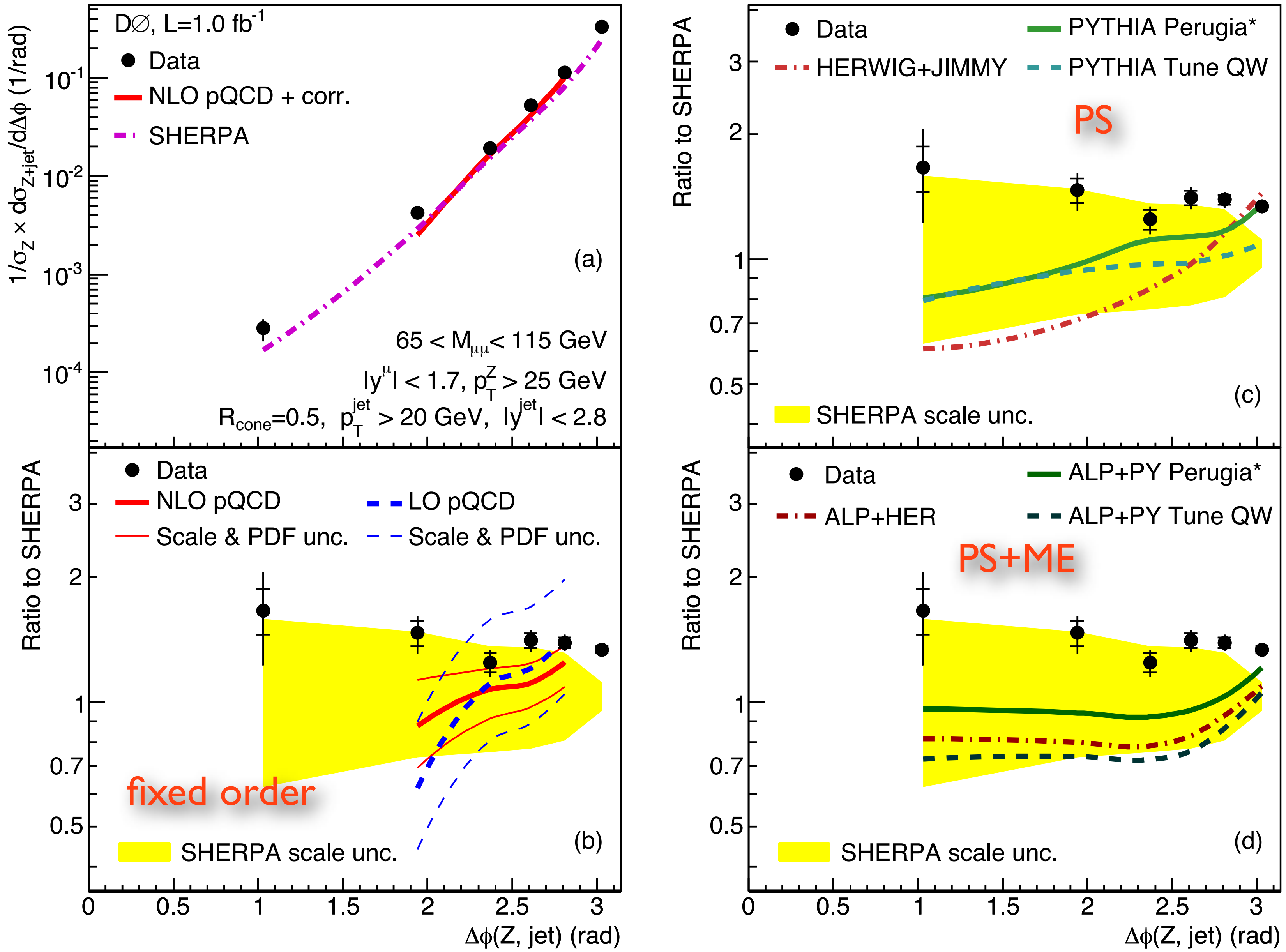




- Correct to particle level to account for detector resolution and efficiencies
- Compare to:
  - NLO pQCD with MCFM
  - LO ME+PS (Alpgen/Sherpa)
  - LO PS (Pythia/Herwig)

Z+jets Angular Correlation

- Selection: $Z \to \mu\mu$: $|y(\mu)|<1.7$, $p_T(Z)>25$ GeV, $p_T(j)>20$ GeV, $|y(j)|<2.8$



Δφ(Z,j)

- Measurement performed for Δφ(Z, jet), Δy(Z,j) and $|\Delta y_{boost}(Z,j)|$
- NLO pQCD calculations describe data well
- Sherpa performs best
- Pythia does well in Δy, Alpgen+Pythia both
- Herwig performs not as well

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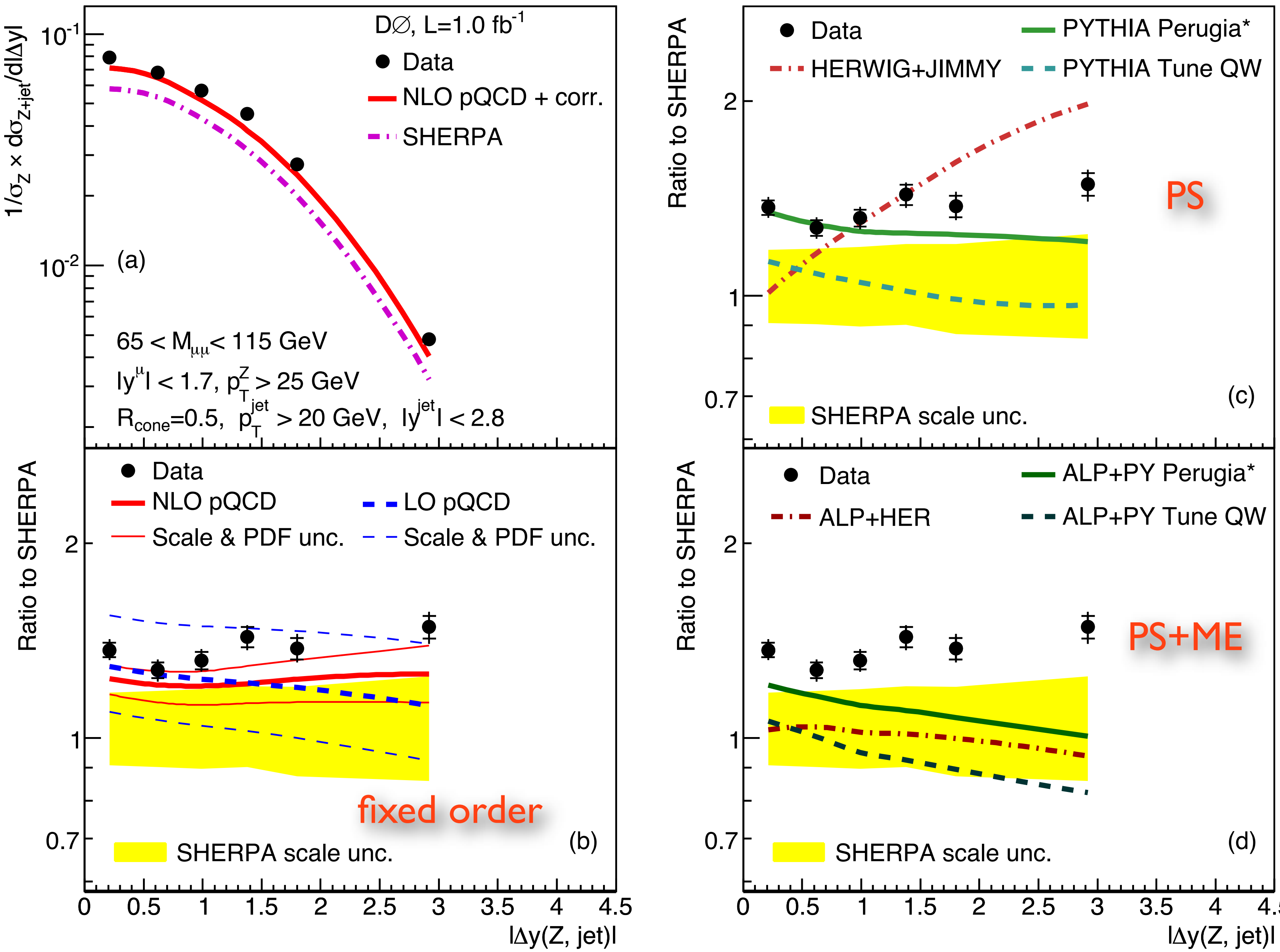

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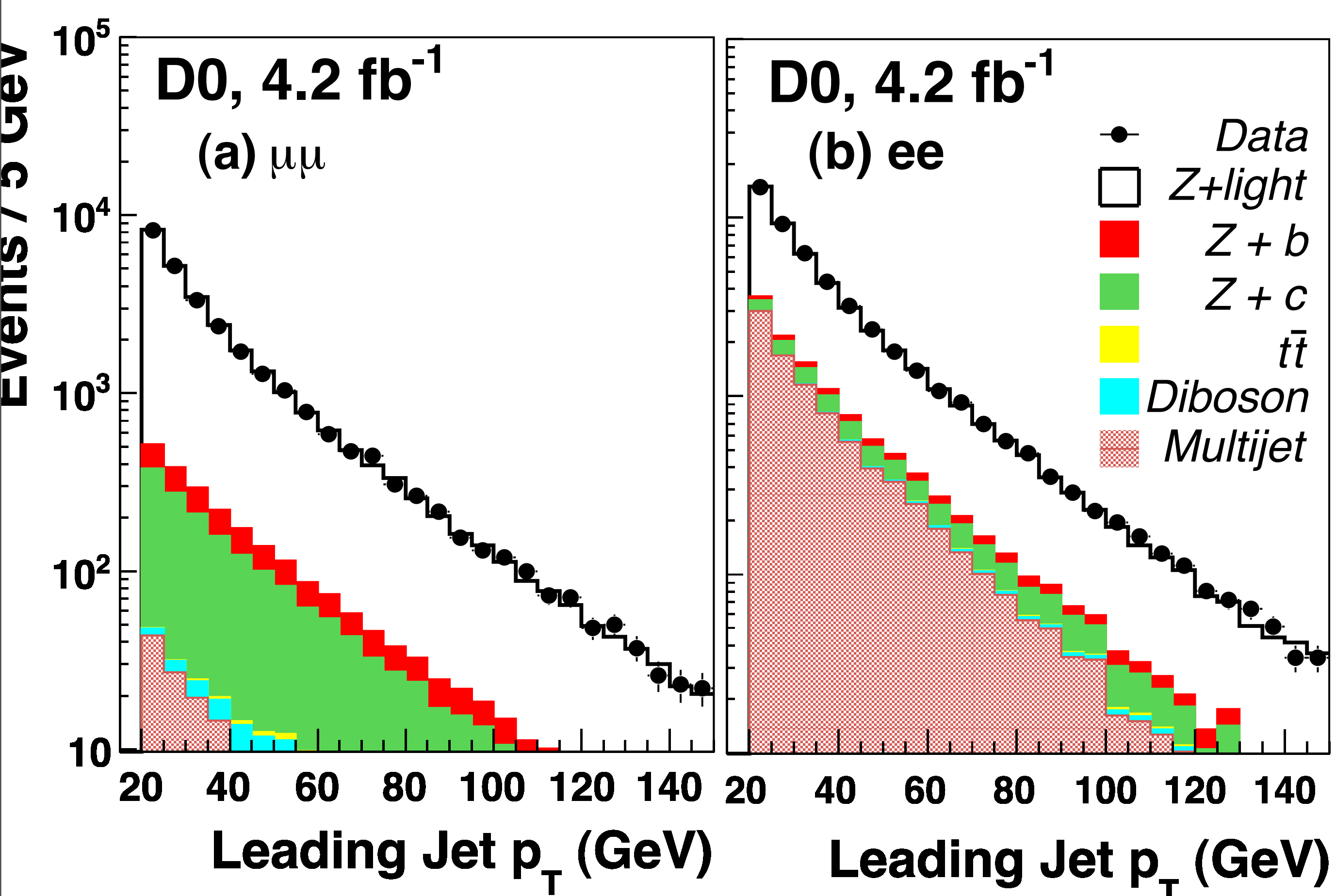
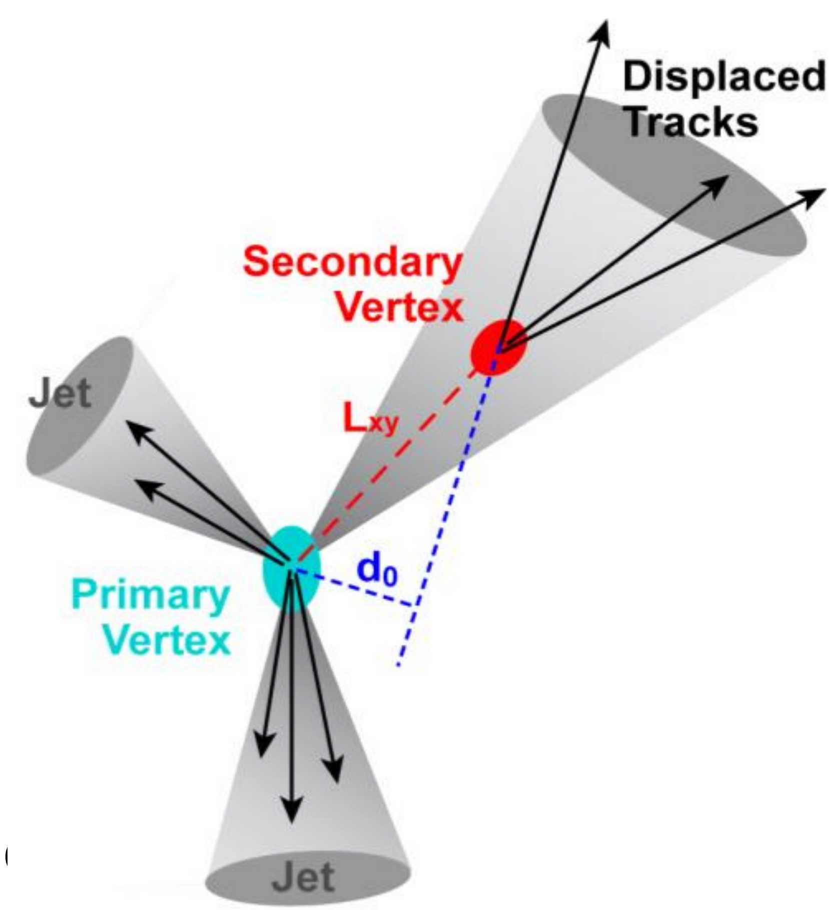
σ(Z+b)/σ(Z+jet incl)

Phys. Rev. D **83**, 031105 (2011)

- Probe of pQCD and b-quark fragmentation
- Z+b is important background to Single-Top, ZH, NP
- Measurement of ratio cancels uncertainties





- Sele
  - Z → ll: 70<m(Z)<110 GeV
  - $p_T(l)>15$ GeV,
  - $p_T(j)>20$ GeV, $|\eta(j)|<2.5$
- Apply tight cut on b-jet algorithm

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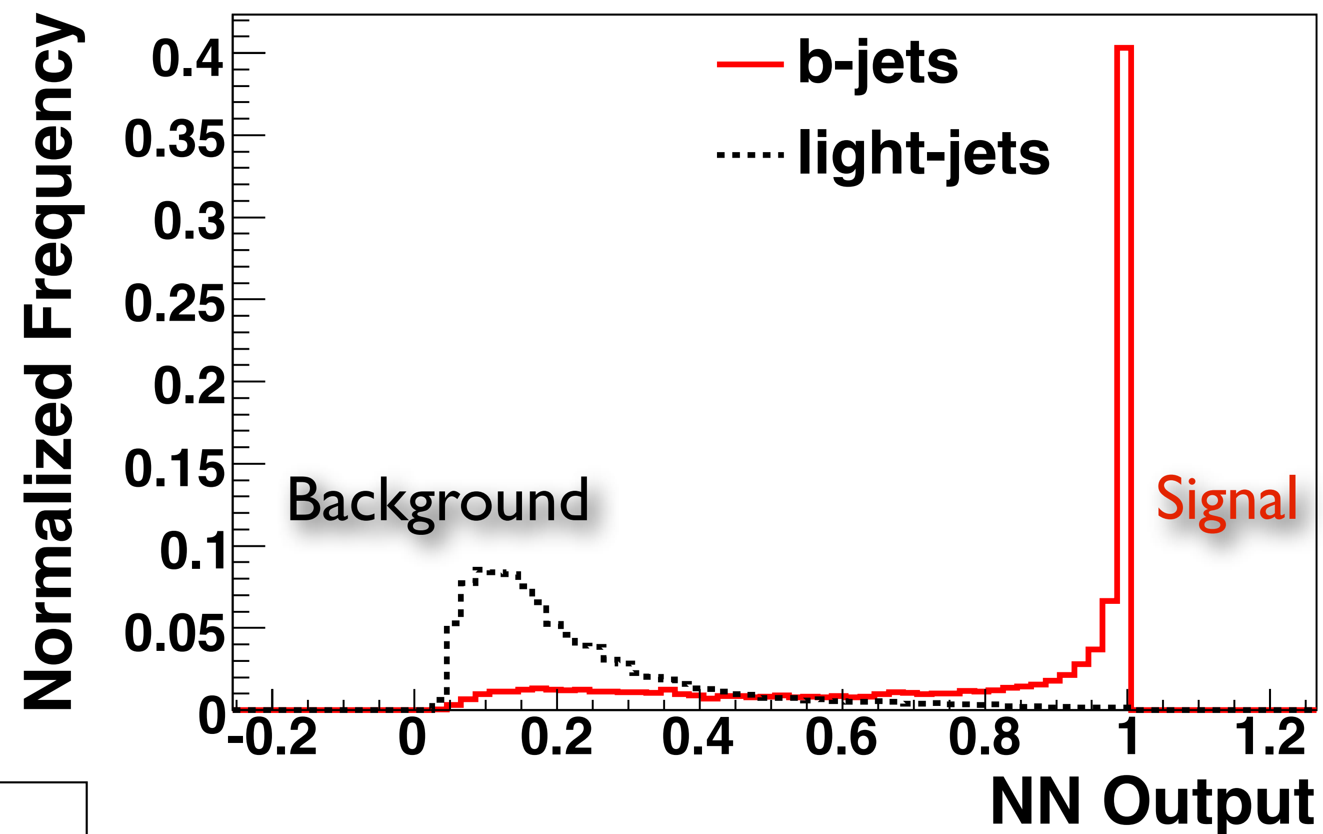
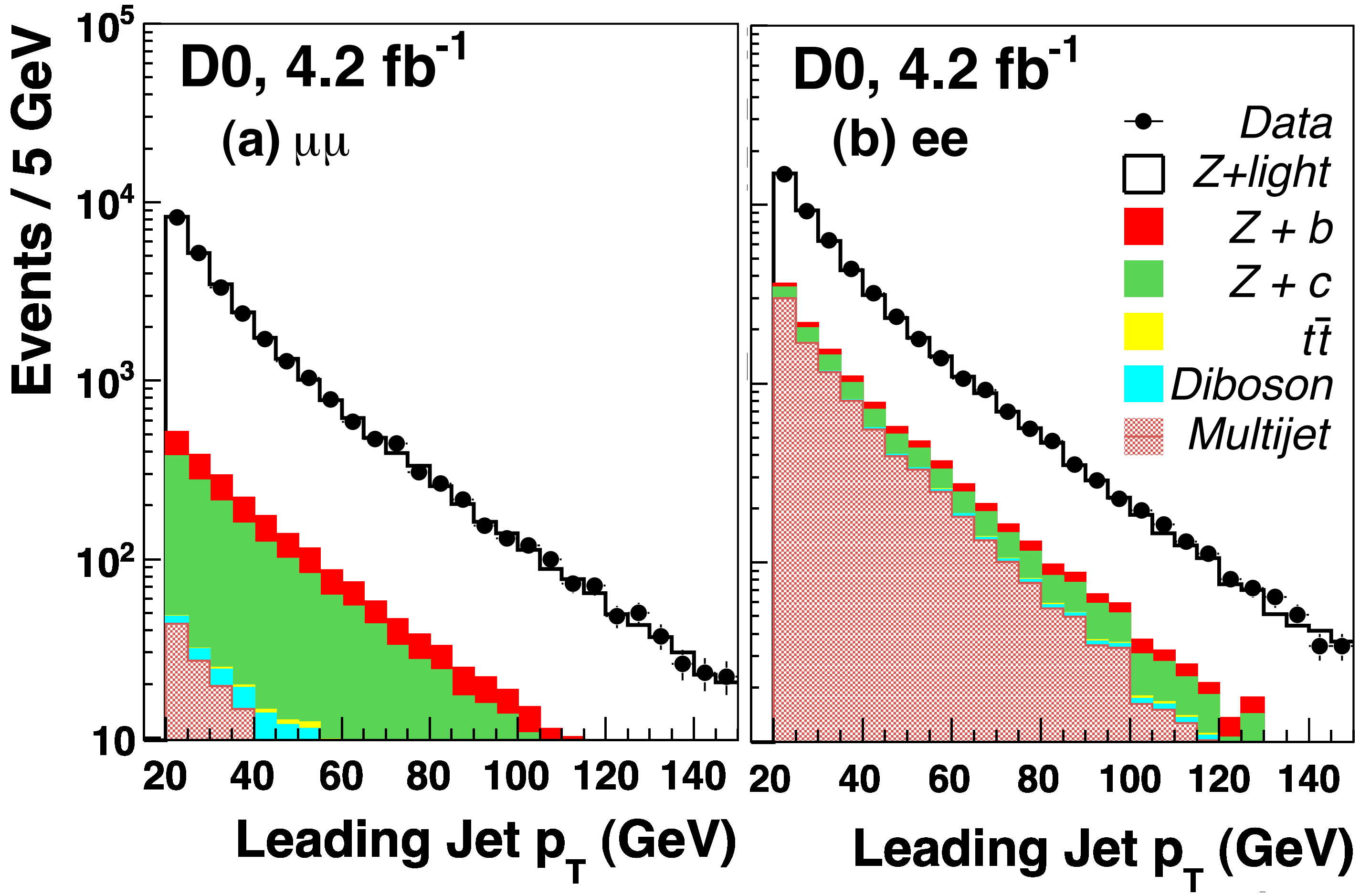
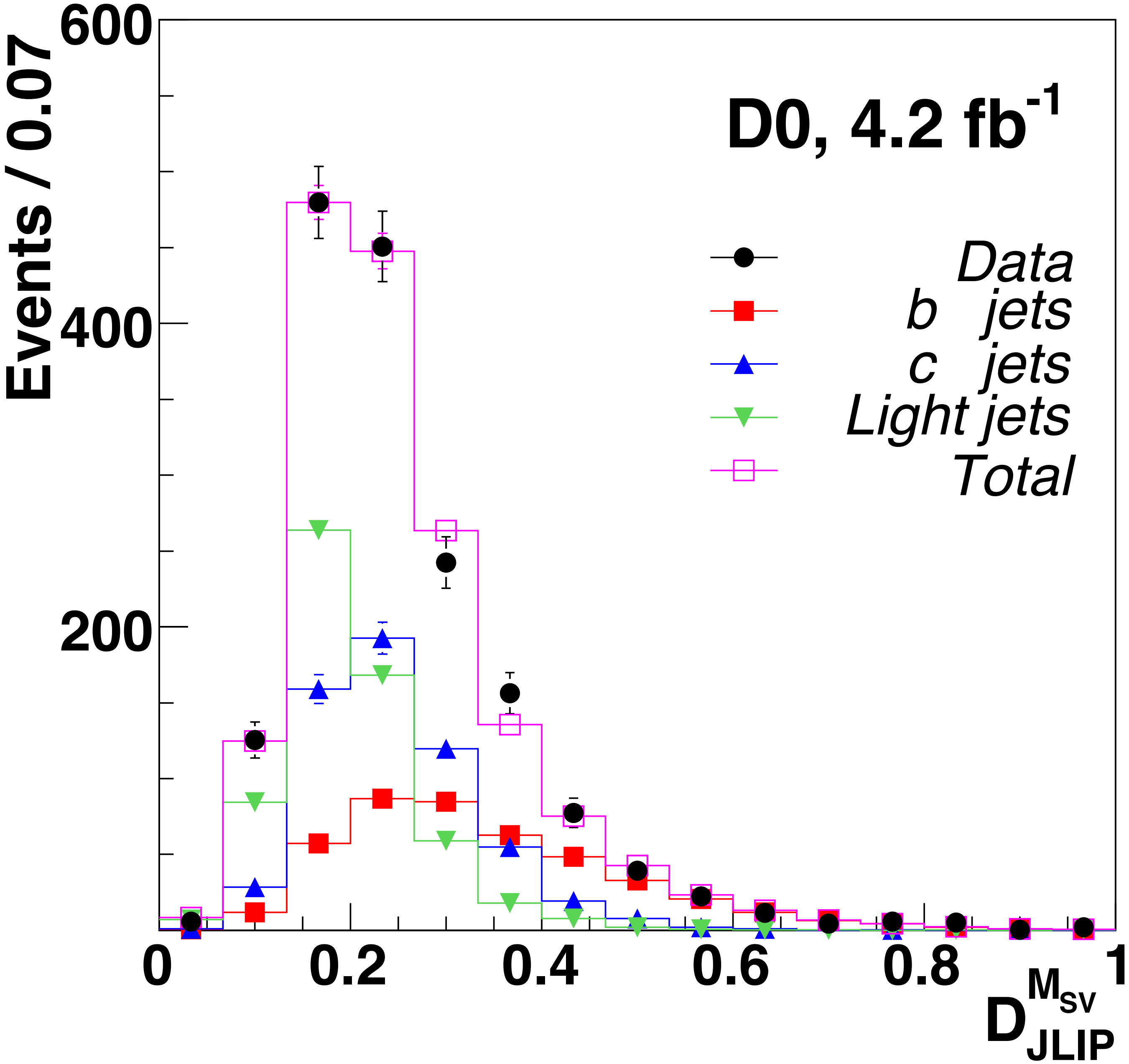




- Selection:
  - $Z \to ll$: $70 < m(Z) < 110$ GeV
  - $p_T(ll) > 15$ GeV,
  - $p_T(j) > 20$ GeV, $|\eta(j)| < 2.5$
- Apply tight cut on b-jet NN
  → Eff: ~57%, fakes ~2%

Zb/Zc ratio

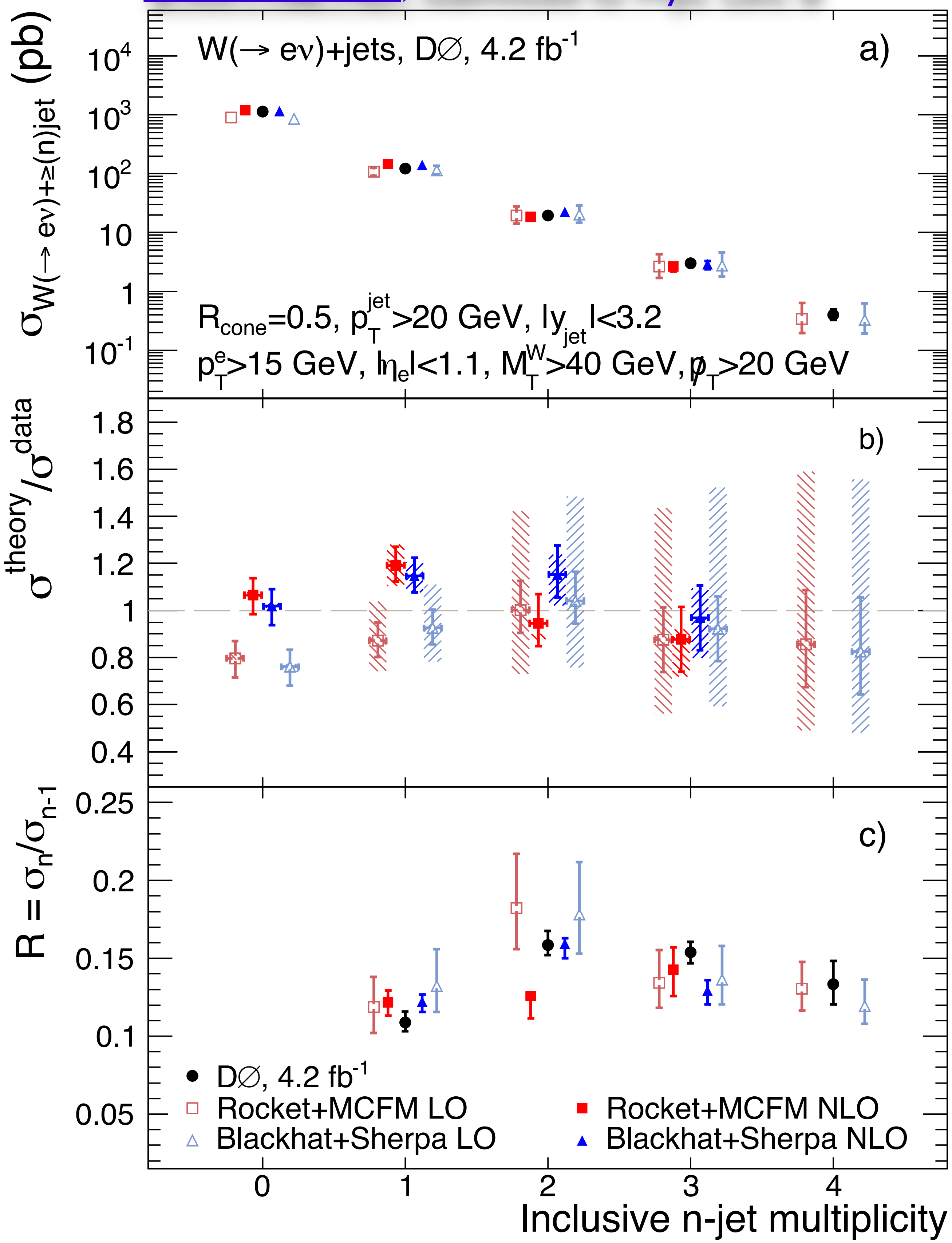


Measurement:

$$\frac{\sigma(Z + b\,\text{jet})}{\sigma(Z + \text{jet})} = 0.0193 \pm 0.0022(\text{stat}) \pm 0.0015(\text{syst})$$

- Most precise measurement of 'Z+b' to date
- Consistent with NLO theory: 0.0192 +/- 0.0022
- renormalization and factorization scales: $Q^2_R = Q^2_F = m^2_Z$

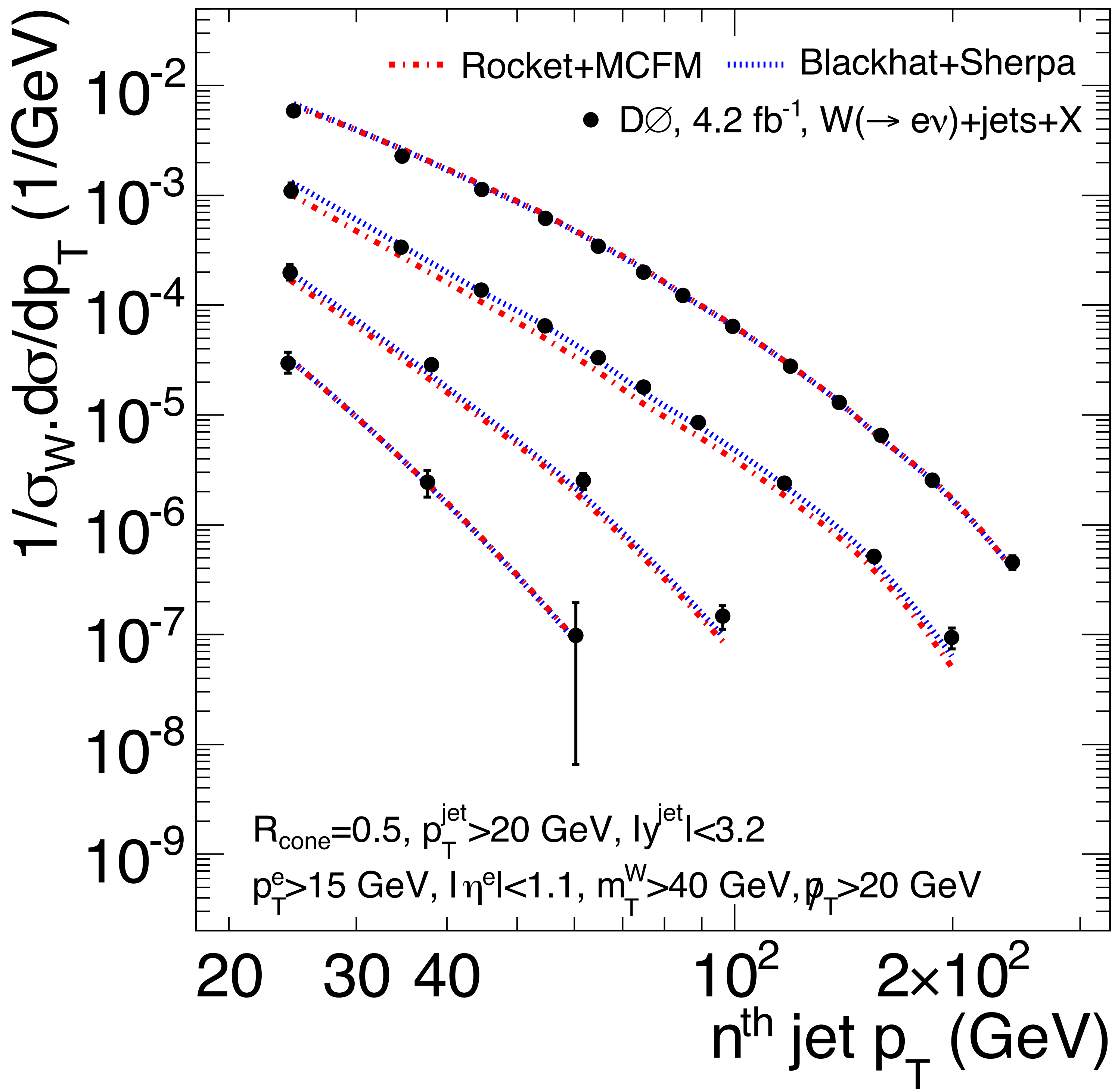
arXiv:1106.1457, submitted to Phys. Lett. B



- Fundamental test of pQCD & bkgd for many measurements
- Test of W+≤4j production
- Measurement of diff. cross-section of n^{th} $p_T(j)$ in inclusive n^{th} jet mult. bin
- Unfolding to particle level using GURU matrix rather than traditional bin-by-bin method
- Compared to
  - Blackhat+Sherpa $\mu = \sqrt{M_W^2 + \frac{1}{4}(\Sigma p^{\rm jet})^2}$
  - Rocket+MCFM $\mu = \frac{1}{2}\hat{H}_T$
- UE + hadronization particle level corrections derived from Sherpa

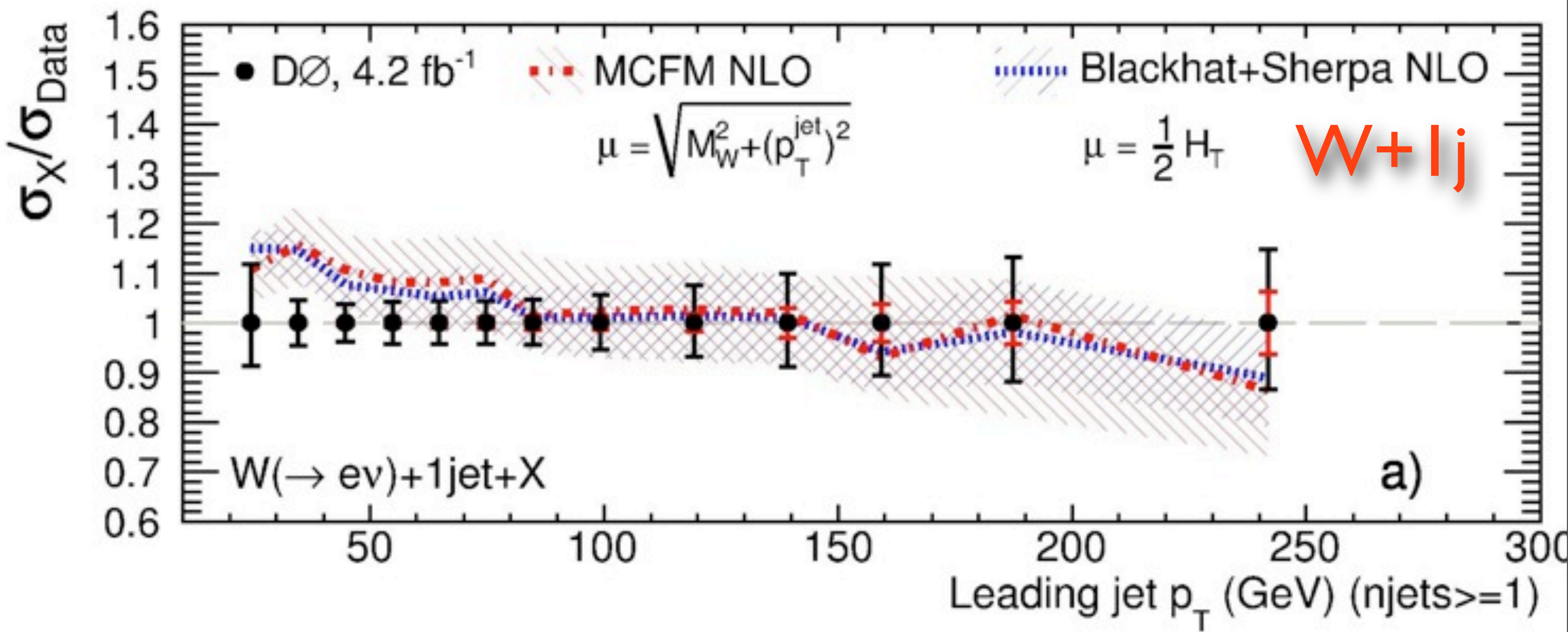
W+jets production

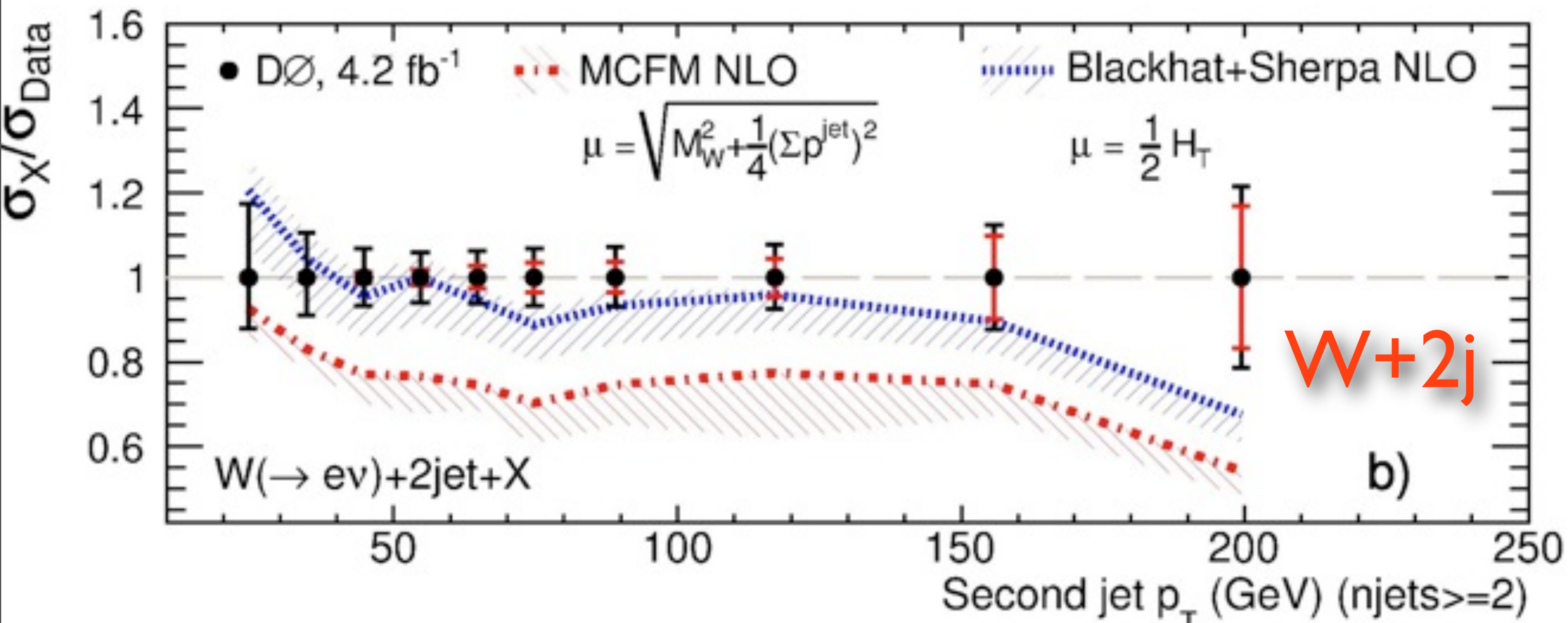
- Normalized to W+jet σ from data
- Largest uncertainties: JES (4-16)%, JER (2-10)%, Jet-Vertex-Conf. (2-8)%
- Data precision greater than pQCD predictions in a wide range of the phase space
- Let's have a detailed comparison by looking at the ratio
- Many uncertainties cancel in ratio



W+jets production

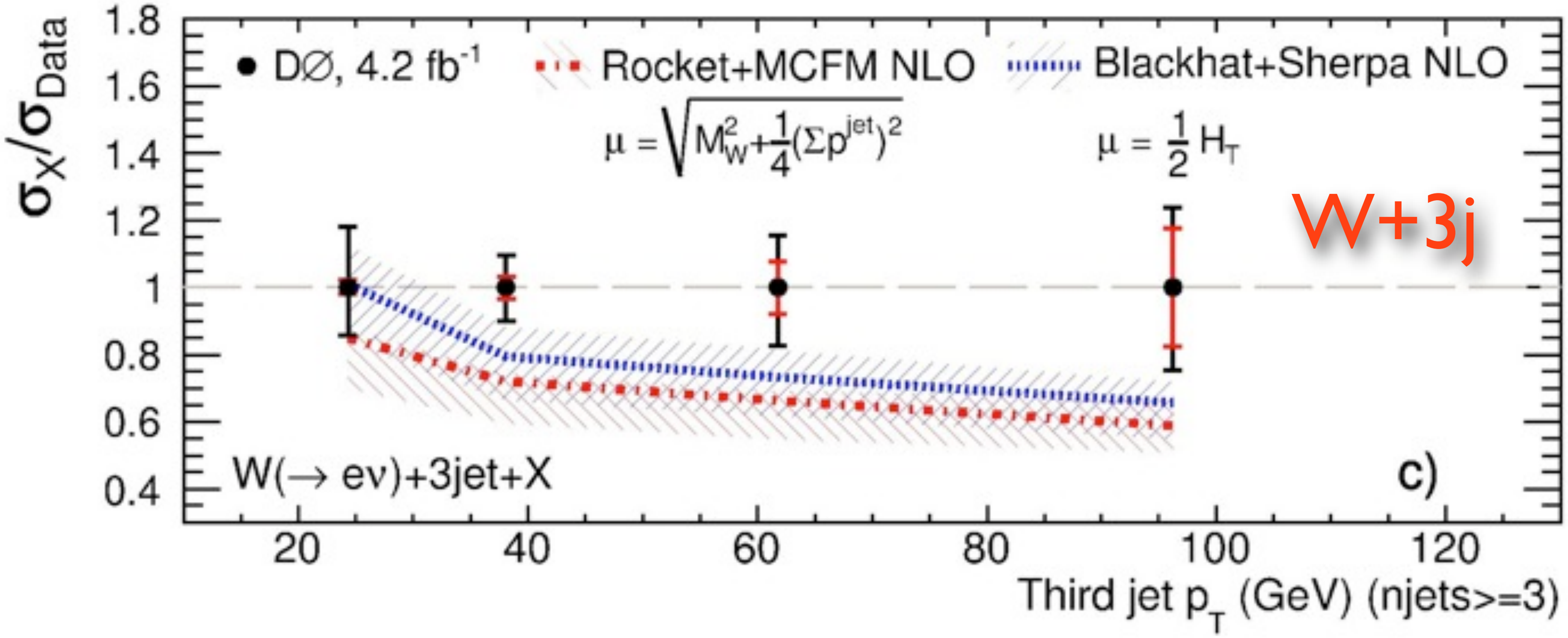
- NLO prediction performs well
- Caveats at low p_T

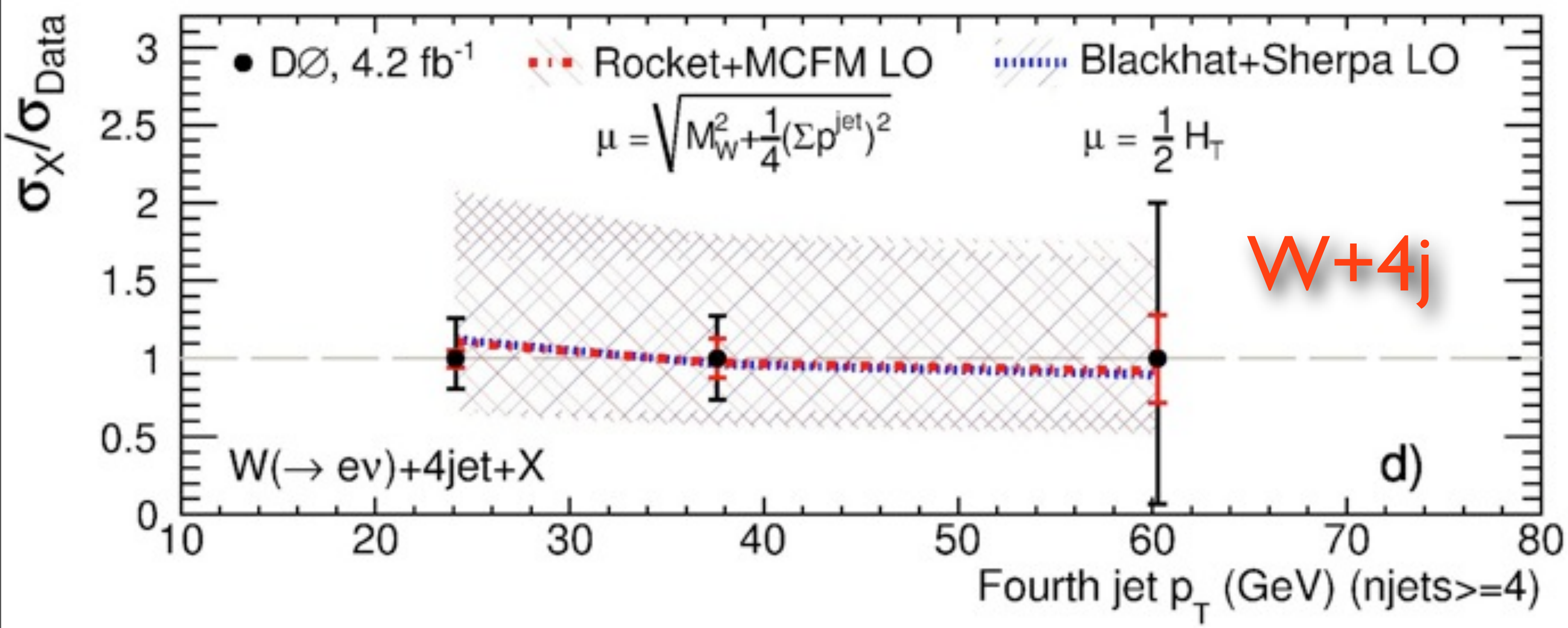




- Disagreements between scale choices appear in 2nd jet bin

- Deviations in shape and rate appear
- Partly due to non-pertubative corr.





- Only LO available, need NLO Tevatron calc.
- Good agreement but large uncertainties
- First diff. σ for 4jet

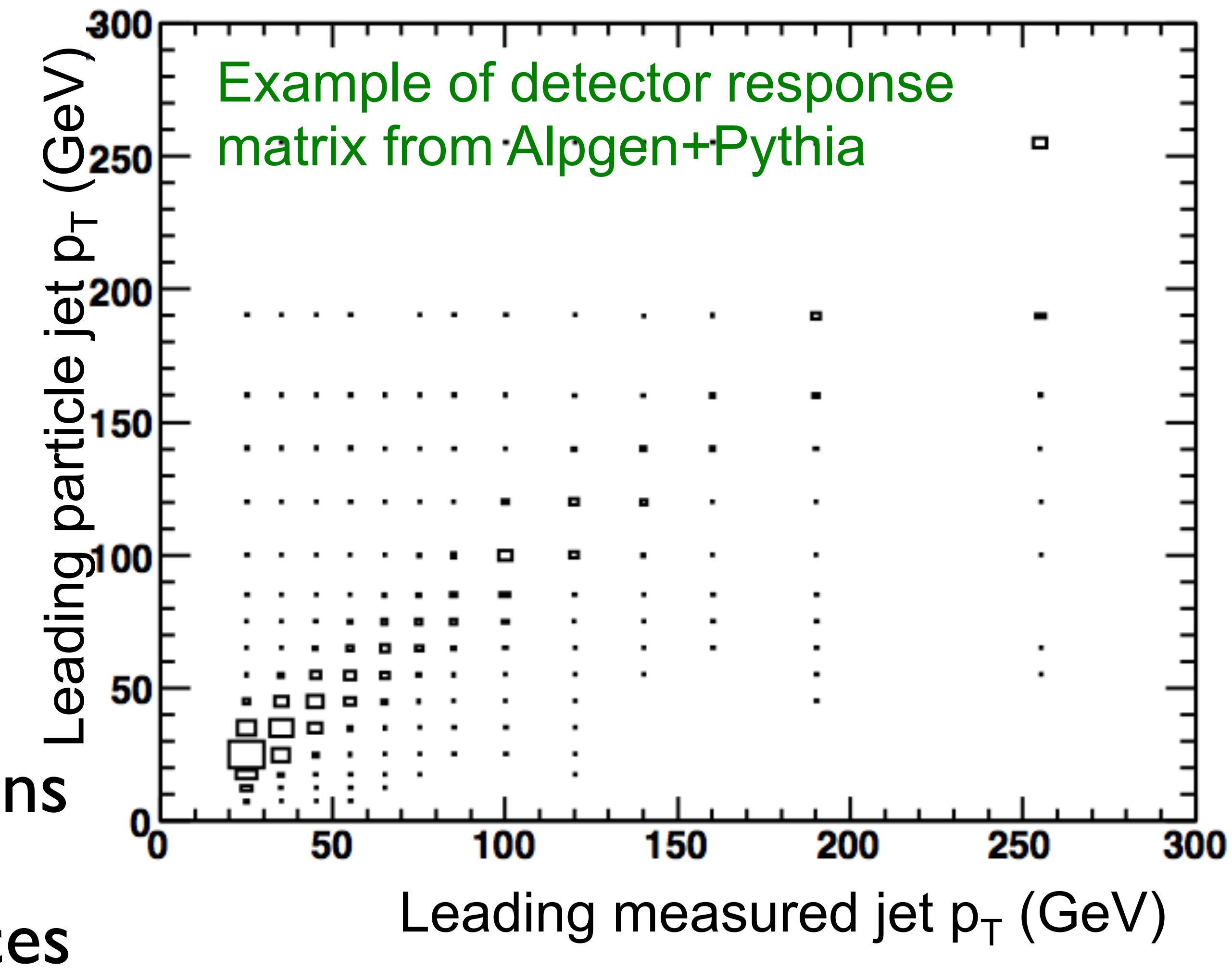
Summary

- Precise knowledge of DØ object IDs, energy scales and systematics lead to experimental uncertainties comparable or lower than theoretical uncertainties
- V+jets results:
  - Generally good agreement with data, but some discrepancies observed, as well *between* theoretical approaches
  - Results precise enough to provide input in these cases
- More available: http://www-d0.fnal.gov/Run2Physics/qcd/
  e.g: extraction of α_s, jet algorithm studies, jet substructures, underlying/double parton events here

Backup

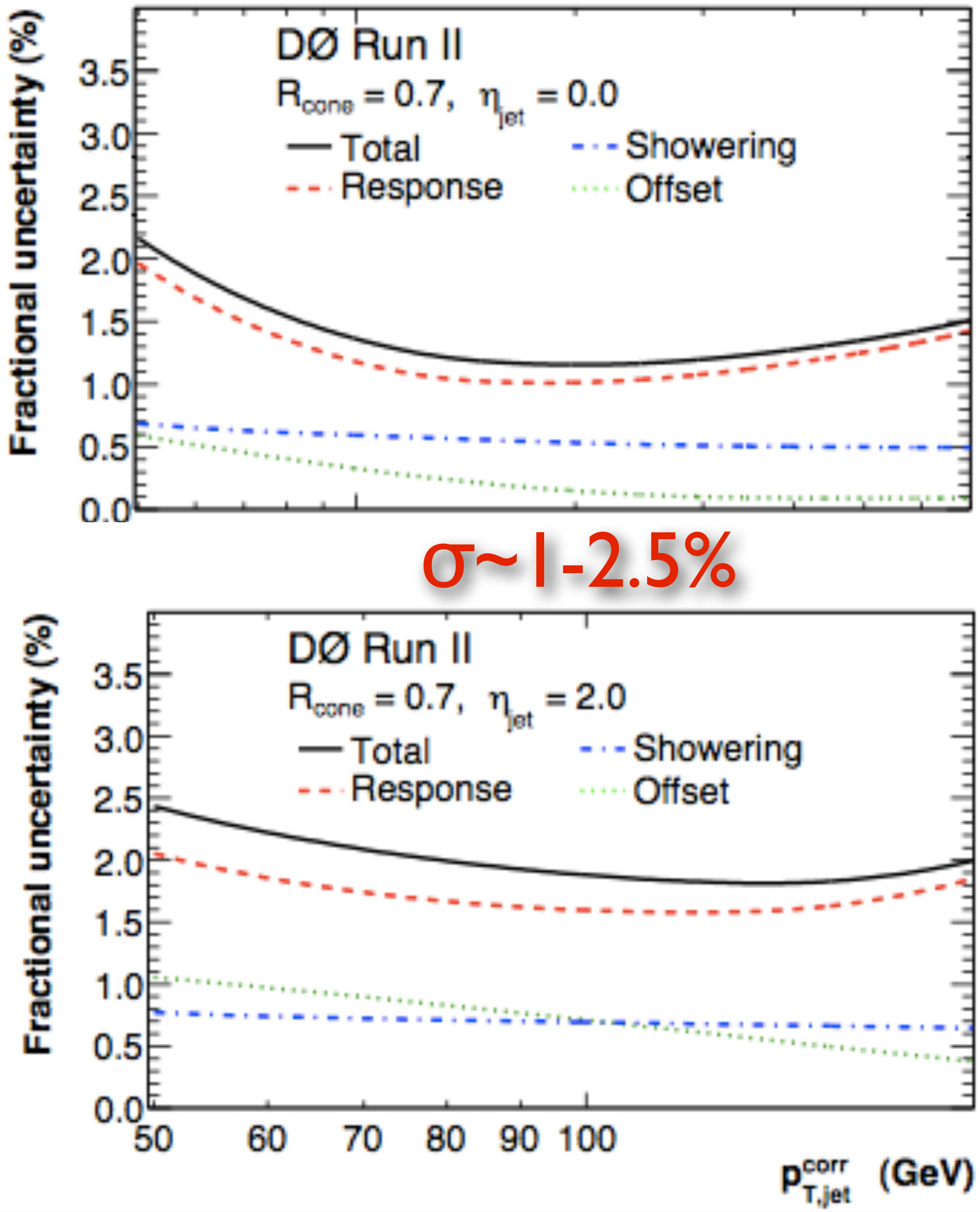
W+jets production

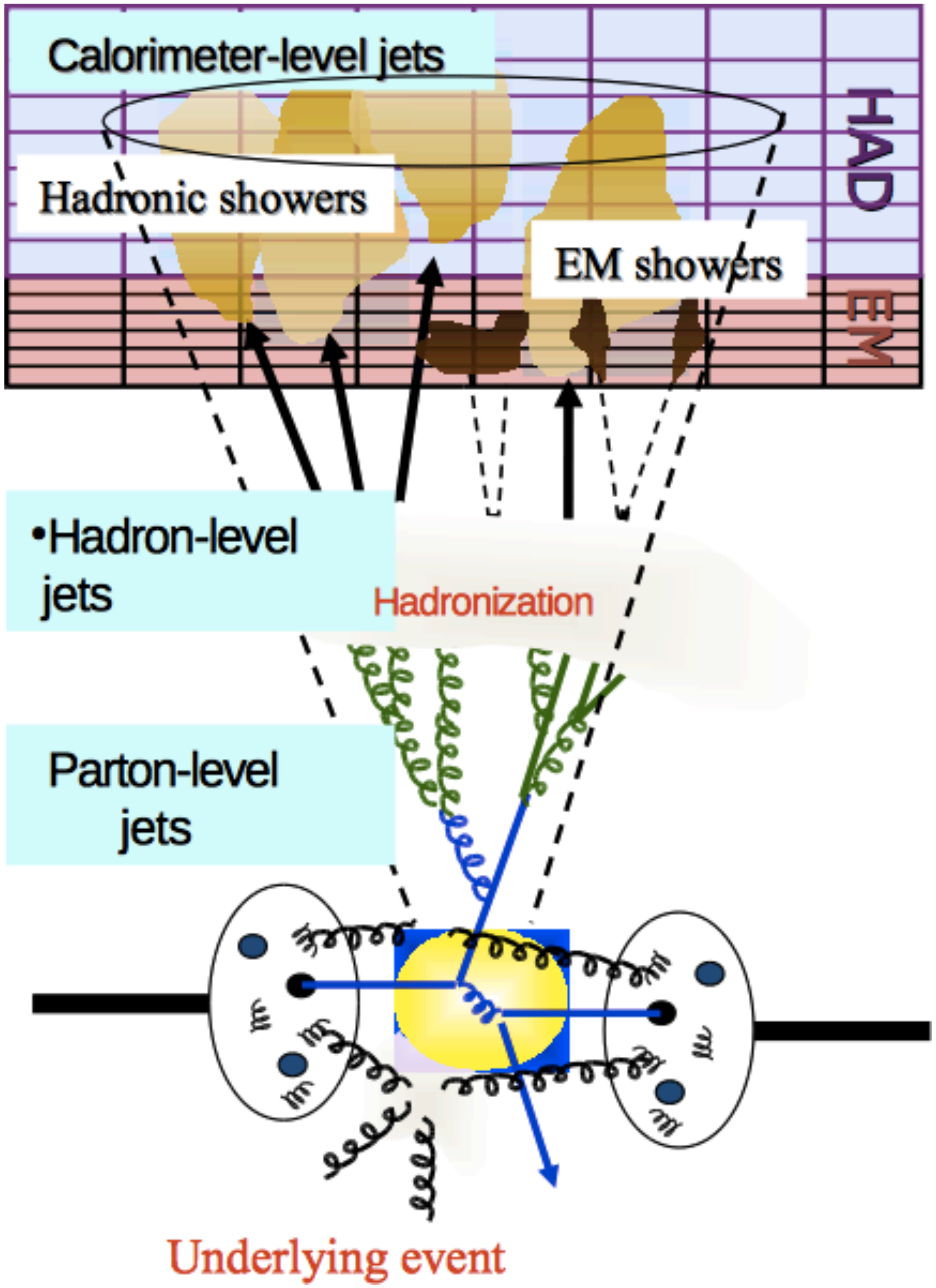
- Unfolding done using Singular Value Decomposition technique (NIM A 372, 469; hep-ph/9509307)
- Inputs are:
  - Background subtracted data distributions
  - Monte Carlo Reco Level Distributions
  - MC based detector response matrices



- SVD significantly reduces dependence on MC description of signal/background over bin-by-bin corrections

- What we call 'GeV' in the detector are actually ADC counts
  → translate to cell energies
- RunII jet cone algorithm with
  $\Delta R = \sqrt{(\Delta y^2 + \Delta \Phi^2)} < R_{cone}$
- Jet Energy Scales (JES) corrected to the particle level:
  - Calibrated using γ+jets (dijets and Z+jets)
  - JES includes: Energy Offset (energy not from the main hard scattering process); Detector Response, Out-of-Cone showering; Resolution
  - Different response for quark and gluon jets





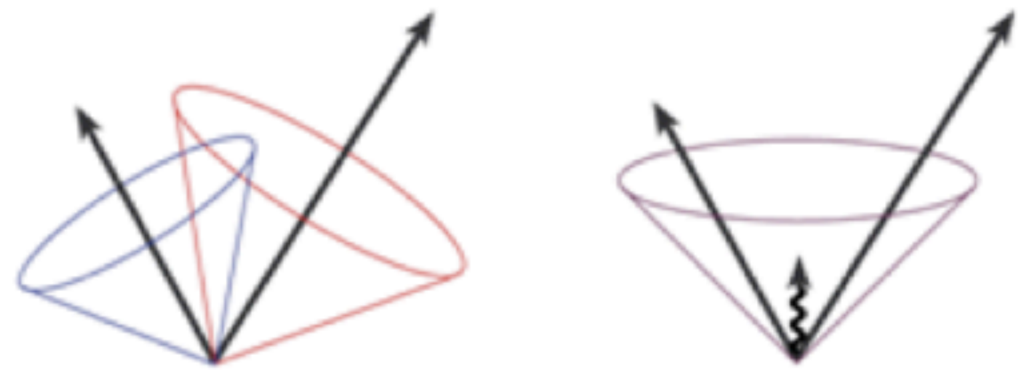
- In RunII jet results, in most cases:
  - Data are corrected to particle level
  - Particle level measurements are compared to NLO theory
  - NLO theory is corrected to particle level using parton shower MC
- Corrections for the underlying events (UR) and hadronization.

Midpoint cone-based algorithm

- Cluster objects based on their proximity in y-ϕ space
- Starting from seeds (calorimeter towers/particles above threshold), find stable cones (kinematic centroid = geometric center).
- Seeds necessary for speed, however source of infrared unsafety.
- In recent QCD studies, we use "Midpoint" algorithm, i.e. look for stable cones from middle points between two adjacent cones
- Stable cones sometime overlap
  → merge cones when p_T overlap > 75%

Infrared unsafety:

soft parton emission changes jet clustering

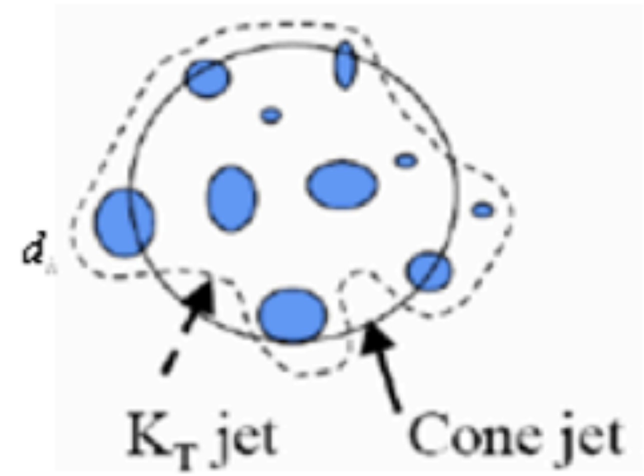


More advanced algorithm(s) available now, but negligible effects on this measurement.

k_T algorithm

- Cluster objects in order of increasing their relative transverse momentum (k_T)
  - $d_{ii} = p^2_{T,i}, \quad d_{ij} = \min(p^2_{T,i}, p^2_{T,j}) \dfrac{\Delta R^2}{D^2}$

  until all objects become part of jets
- D parameter controls merging termination and characterizes size of resulting jets



- No issue of splitting/merging. Infrared and collinear safe to all orders of QCD.
- Every object assigned to a jet: concerns about vacuuming up too many particles.
- Successful at LEP & HERA, but relatively new at the hadron colliders
  - More difficult environment (underlying event, multiple *pp* interactions...)