W/Z+Multi-Jet Production at the LHC with BlackHat

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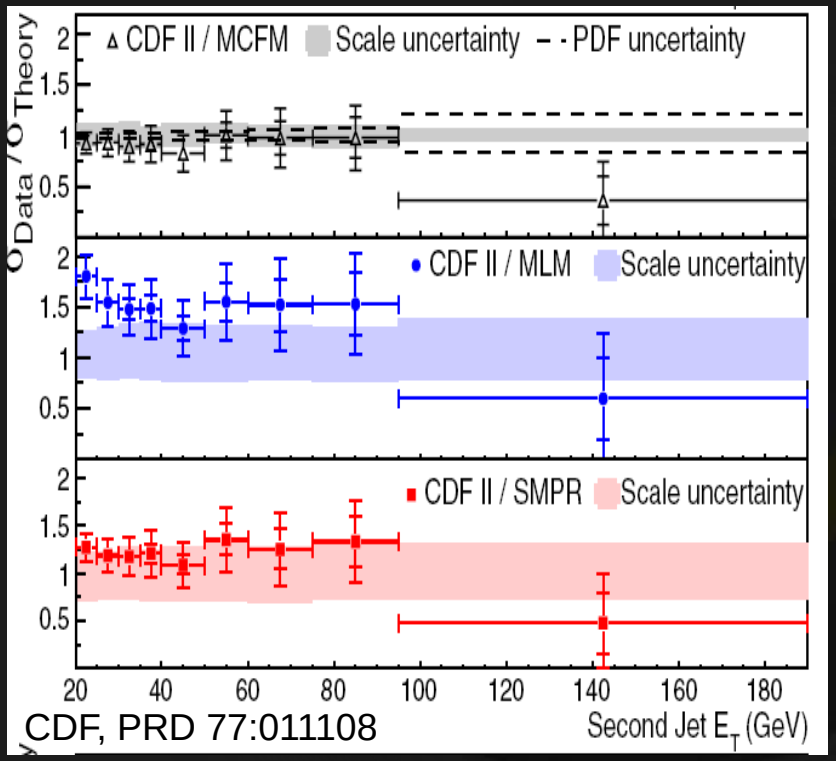
Why NLO?

W+2 jets



← NLO (MCFM)

← PS+LO matching

← PS+LO matching

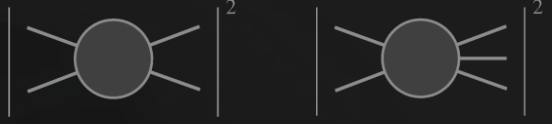
QCD at LO is not quantitative: large dependence on unphysical renormalization scale

NLO: reduced dependence, first quantitative prediction

…want this for *W*+more jets too

Ingredients for NLO Calculations

- Tree-level matrix elements for LO and real-emission terms
  known since '80s ✓



- Singular (soft & collinear) behavior of tree-level amplitudes, integrals, initial-state collinear behavior *known since '90s* ✓
- NLO parton distributions *known since '90s* ✓
- General framework for numerical programs *known since '90s* ✓

  Catani, Seymour (1996); Giele, Glover, DAK (1993); Frixione, Kunszt, Signer (1995)

- Automating it for general processes

  Gleisberg, Krauss; Seymour, Tevlin; Hasegawa, Moch, Uwer; Frederix, Gehrmann, Greiner (2008); Frederix, Frixione, Maltoni, Stelzer (2009)

- Bottleneck: one-loop amplitudes

- *W*+2 jets (MCFM) → *W*+3 jets → → →

Bern, Dixon, DAK, Weinzierl (1997–8); Campbell, Glover, Miller (1997)

BlackHat

- New technologies for one-loop computations: numerical implementation of on-shell methods
- Automated implementation ⇒ industrialization

- SHERPA for real subtraction, real emission, phase-space integration, and analysis
- Other groups using on-shell methods: Ossola, Papadopoulos, Pittau, Actis, Bevilacqua, Czakon, Draggiotis, Garzelli, van Hameren, Mastrolia, Worek;
  Ellis, Giele, Kunszt, Lazopoulos, Melnikov, Zanderighi;
  Giele, Kunszt, Winter;
  Anastasiou, Britto, Feng, Mastrolia; Britto, Feng, Mirabella

Recent Developments in BlackHat

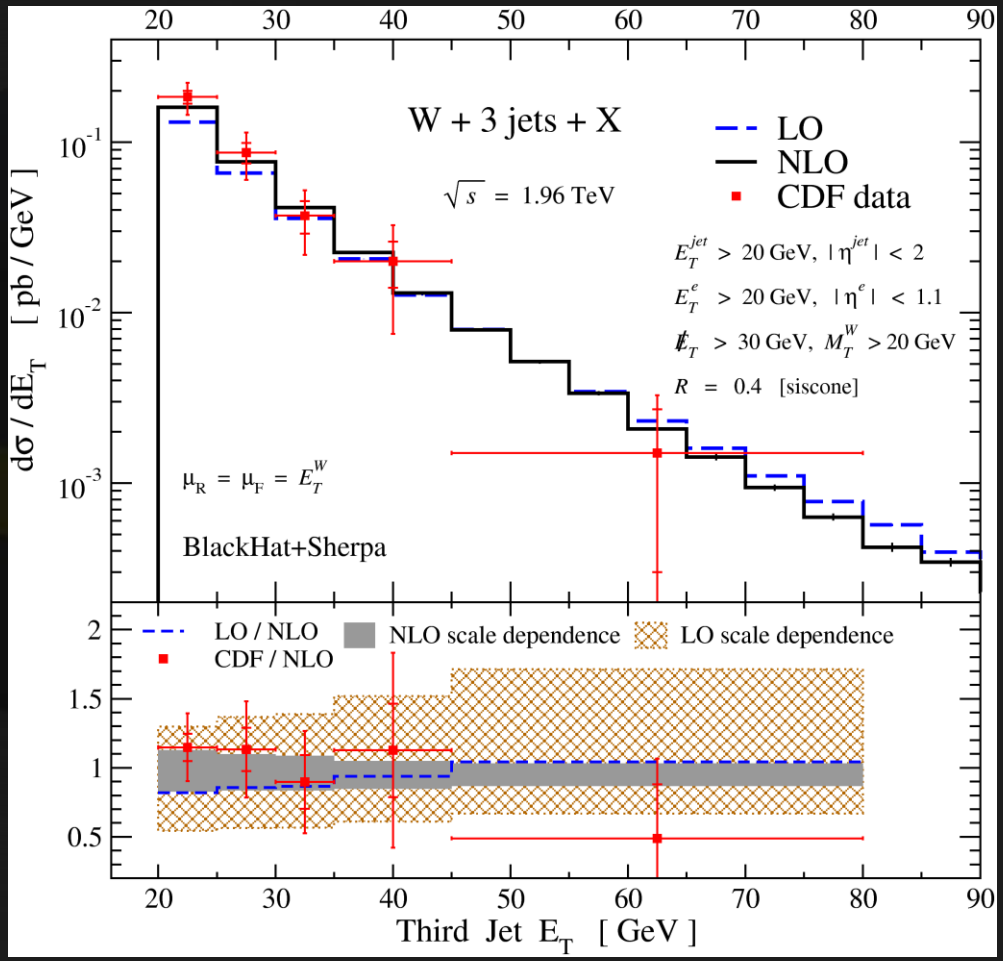
- Generation of ROOT tuples
- Re-analysis possible
- Distribution to experimenters

- Flexibility for studying scale variations
- Flexibility for computing error estimates associated with parton distributions

- More processes

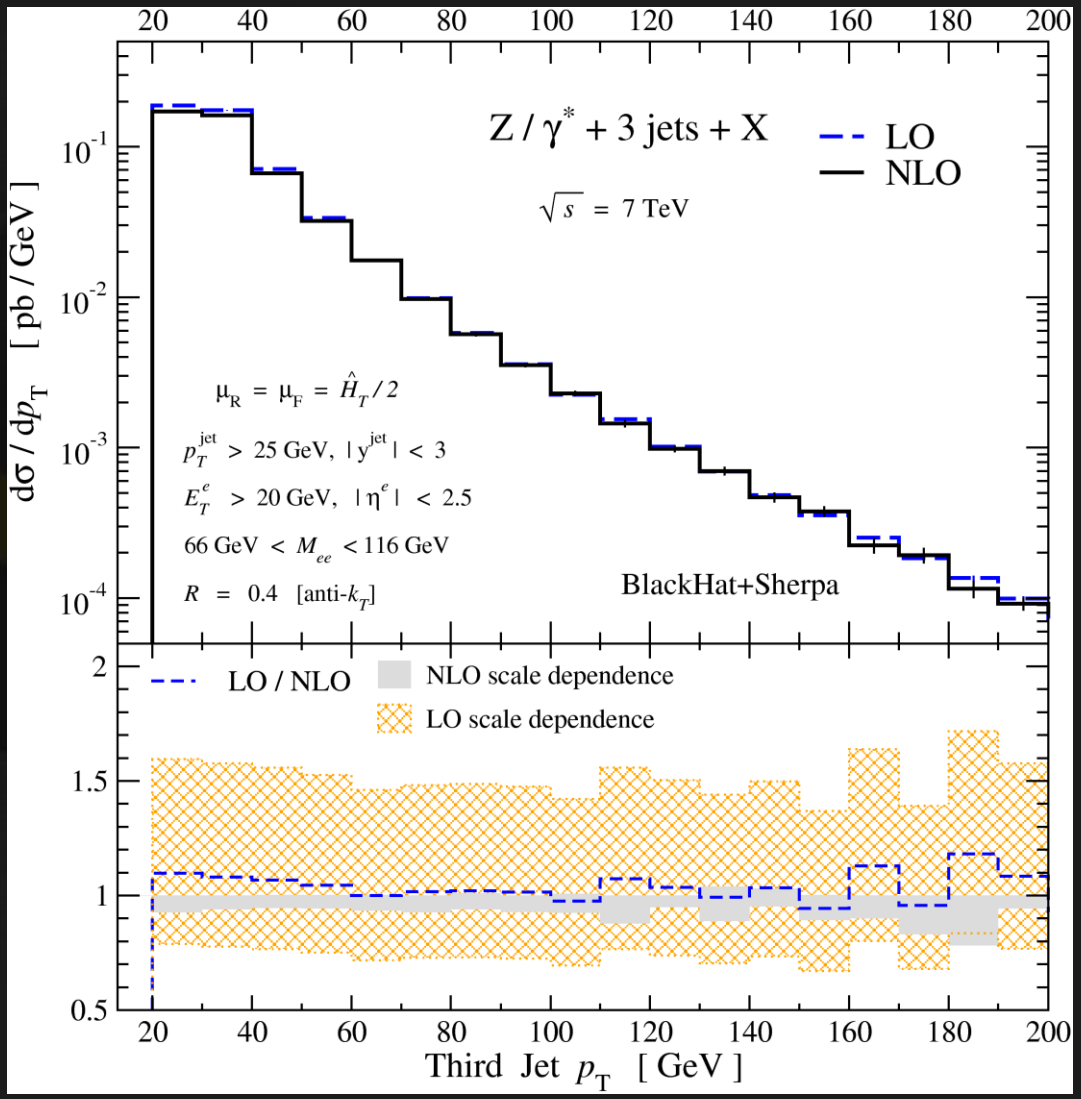
The Tevatron is Still Producing Ws…

- Third jet in W+3 jets [0907.1984]
- Reduced scale dependence at NLO
- Good agreement with CDF data [0711.4044]
- Shape change small compared to LO scale variation
- SISCone (Salam & Soyez) vs JETCLU



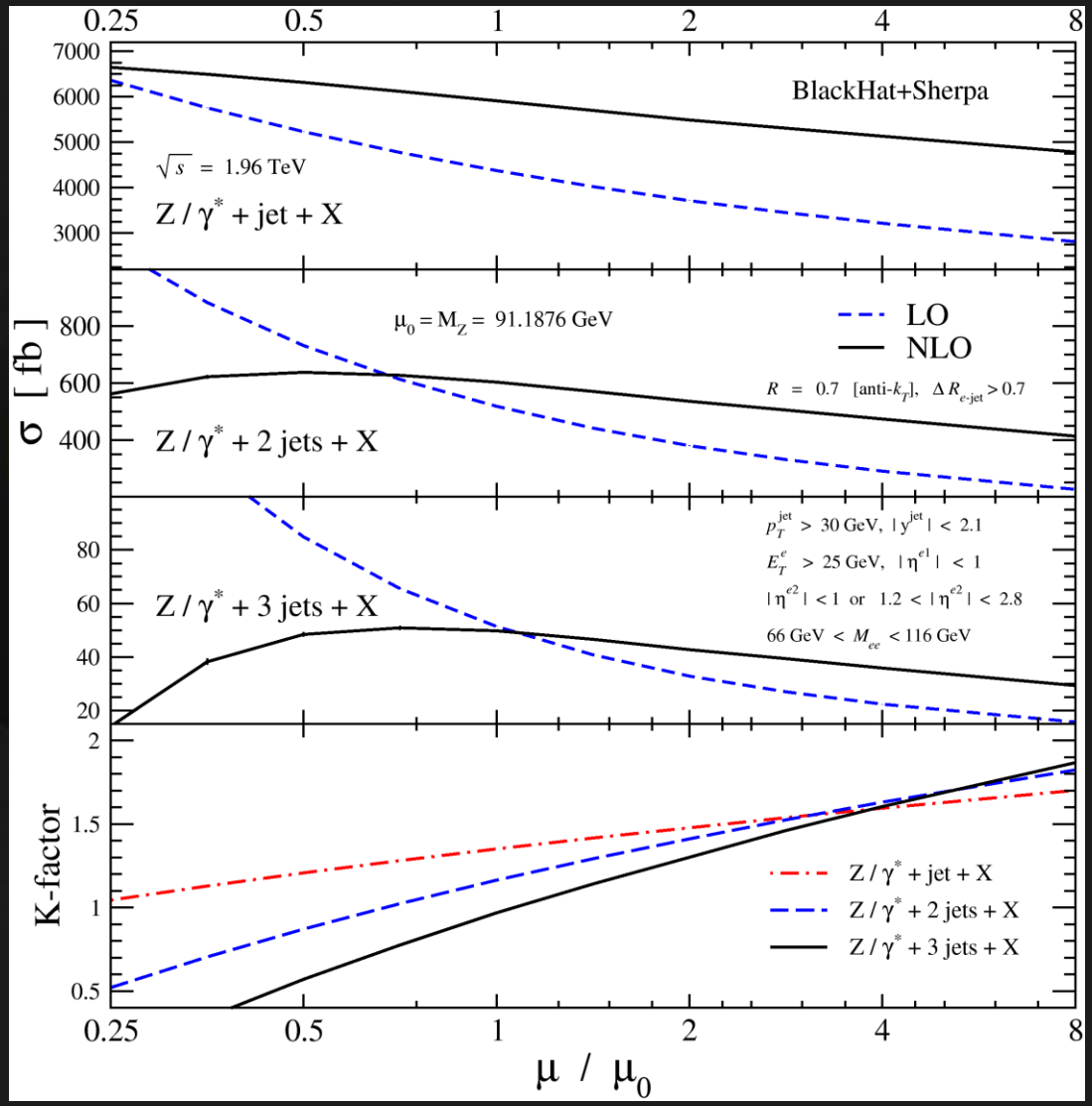
Z+3 Jets at the LHC

- Z+3 jets: new
- NLO scale uncertainty smaller than LO (band accidentally narrow given central choice — but would in any case be much improved)
- Shape change mild
- Scale choice $\hat{H}_T/2$ (half total partonic E_T)
- Anti-k_T

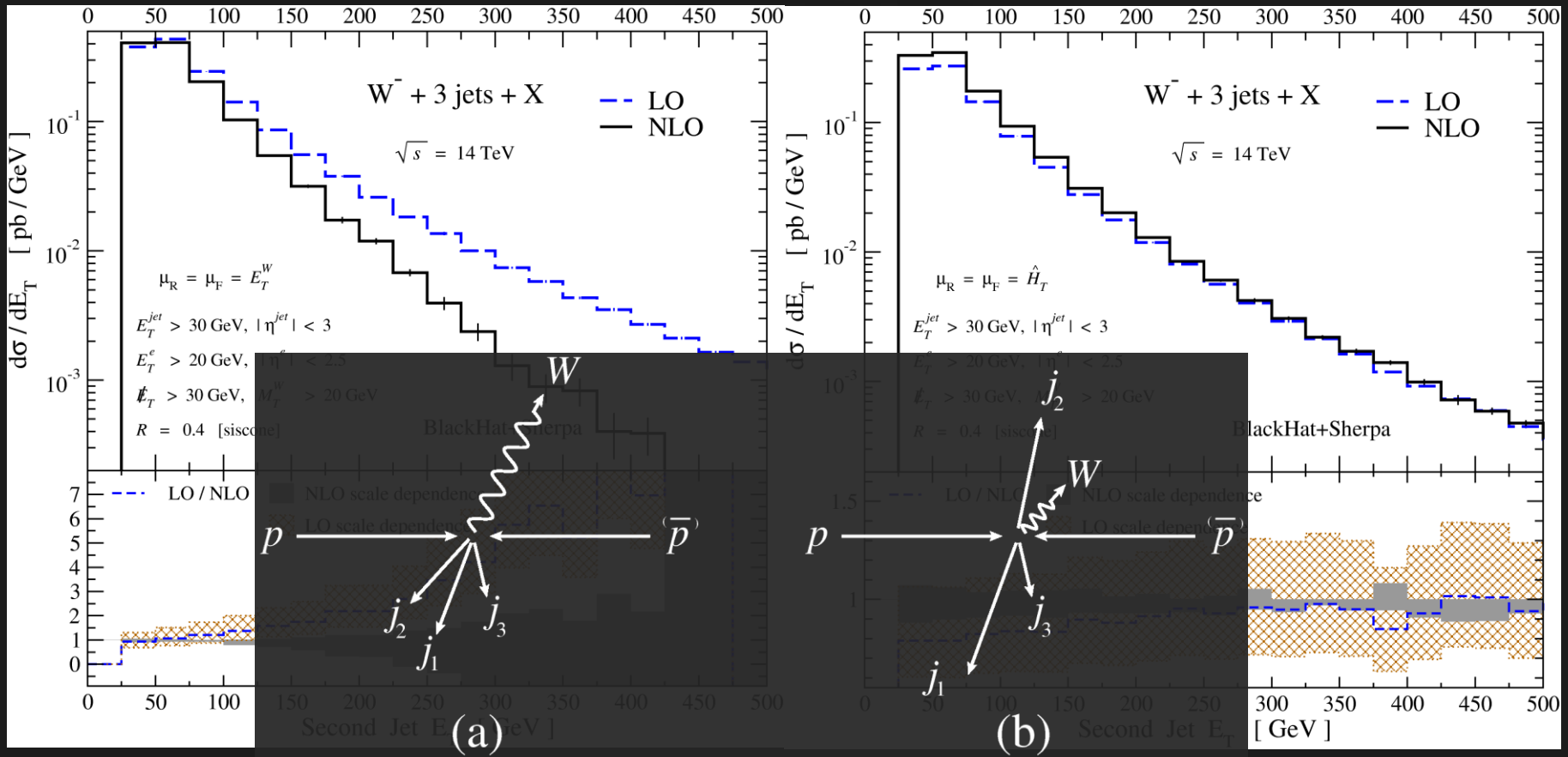


Reduced Scale Dependence

- Anti-k_T @ Tevatron (CDF cuts)
- Reduction of scale dependence
- NLO importance grows with increasing number of jets

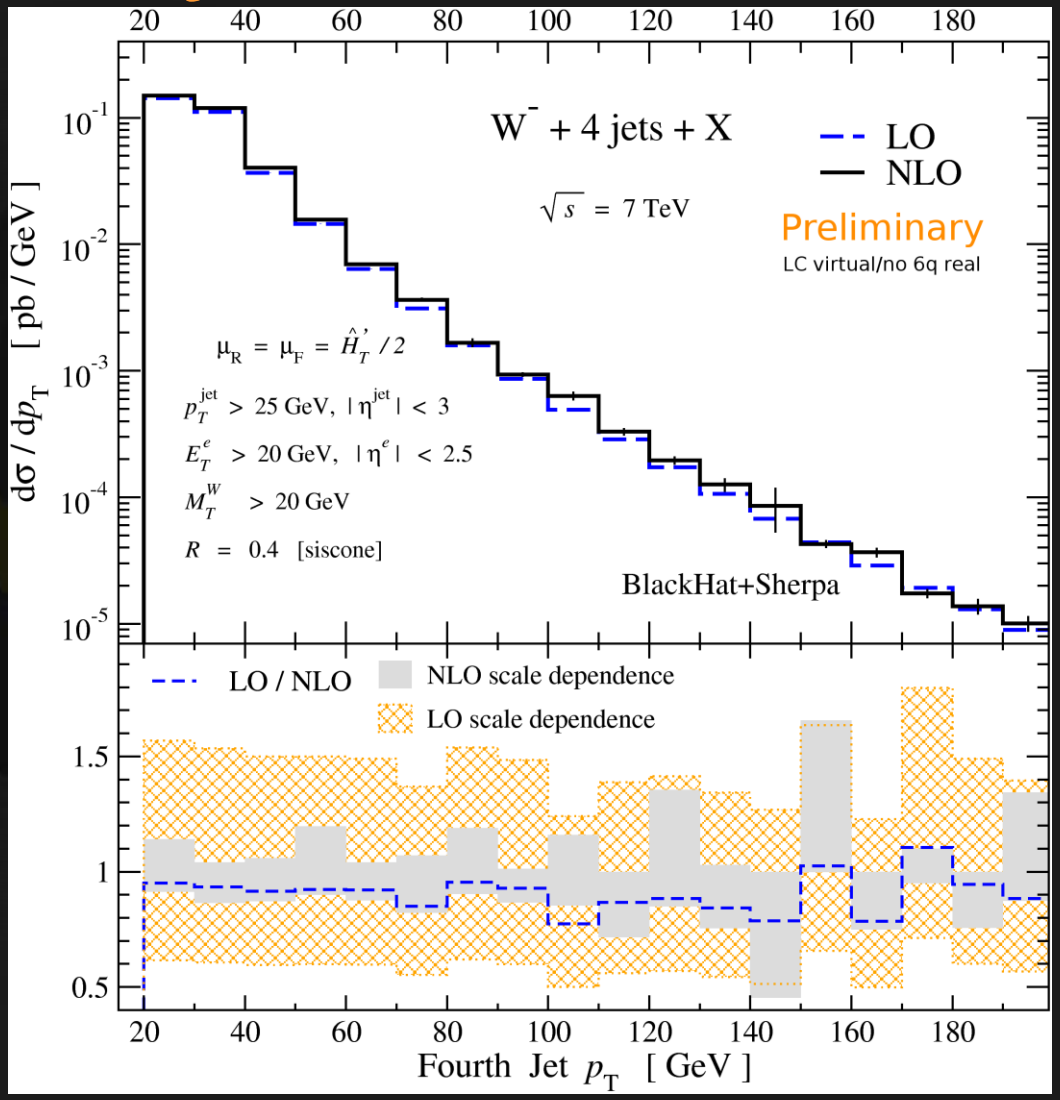


Scale Choices

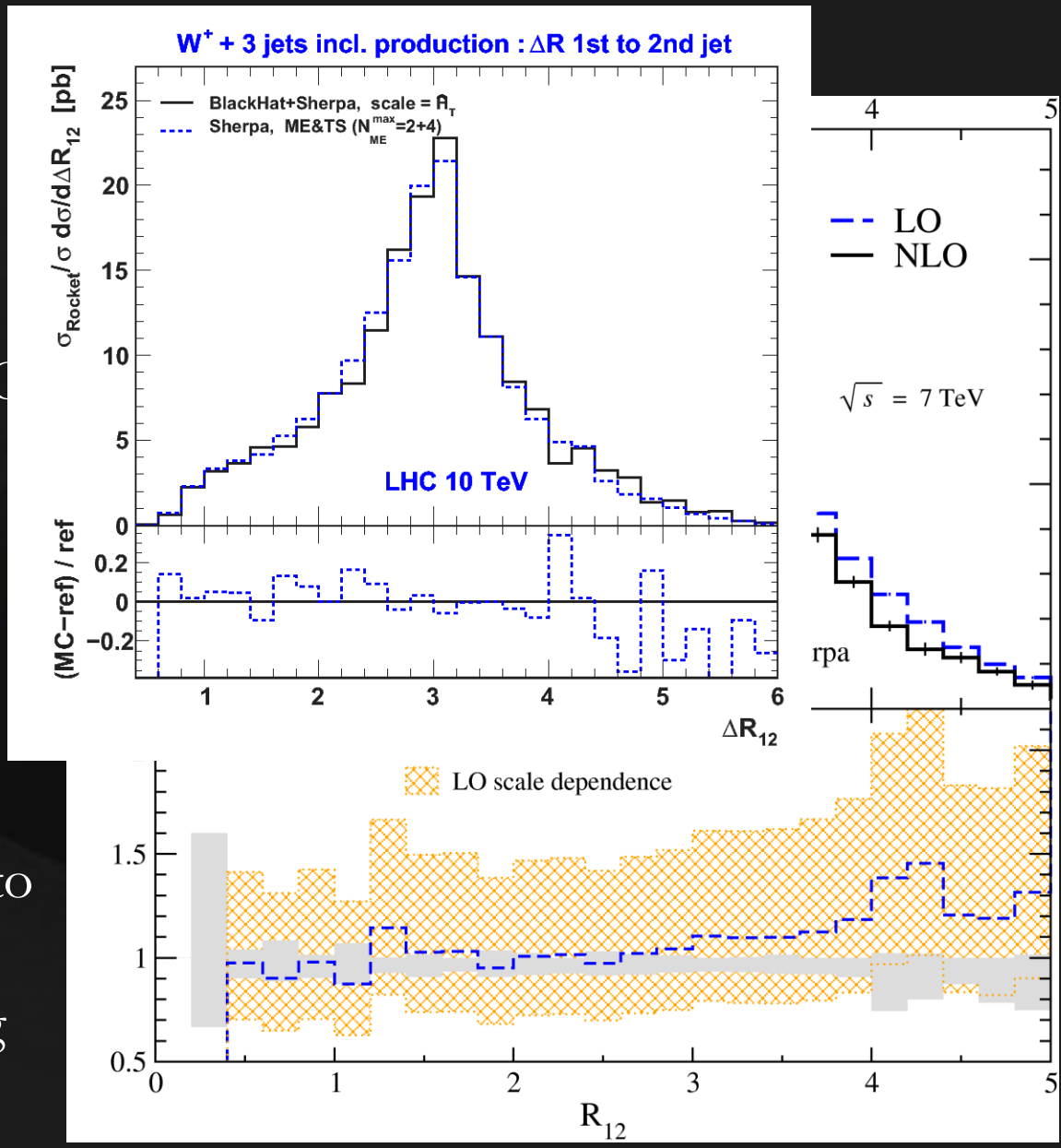


W^- + 4 Jets

- Background to top quark studies
- Background to new physics searches
- High-multiplicity frontier

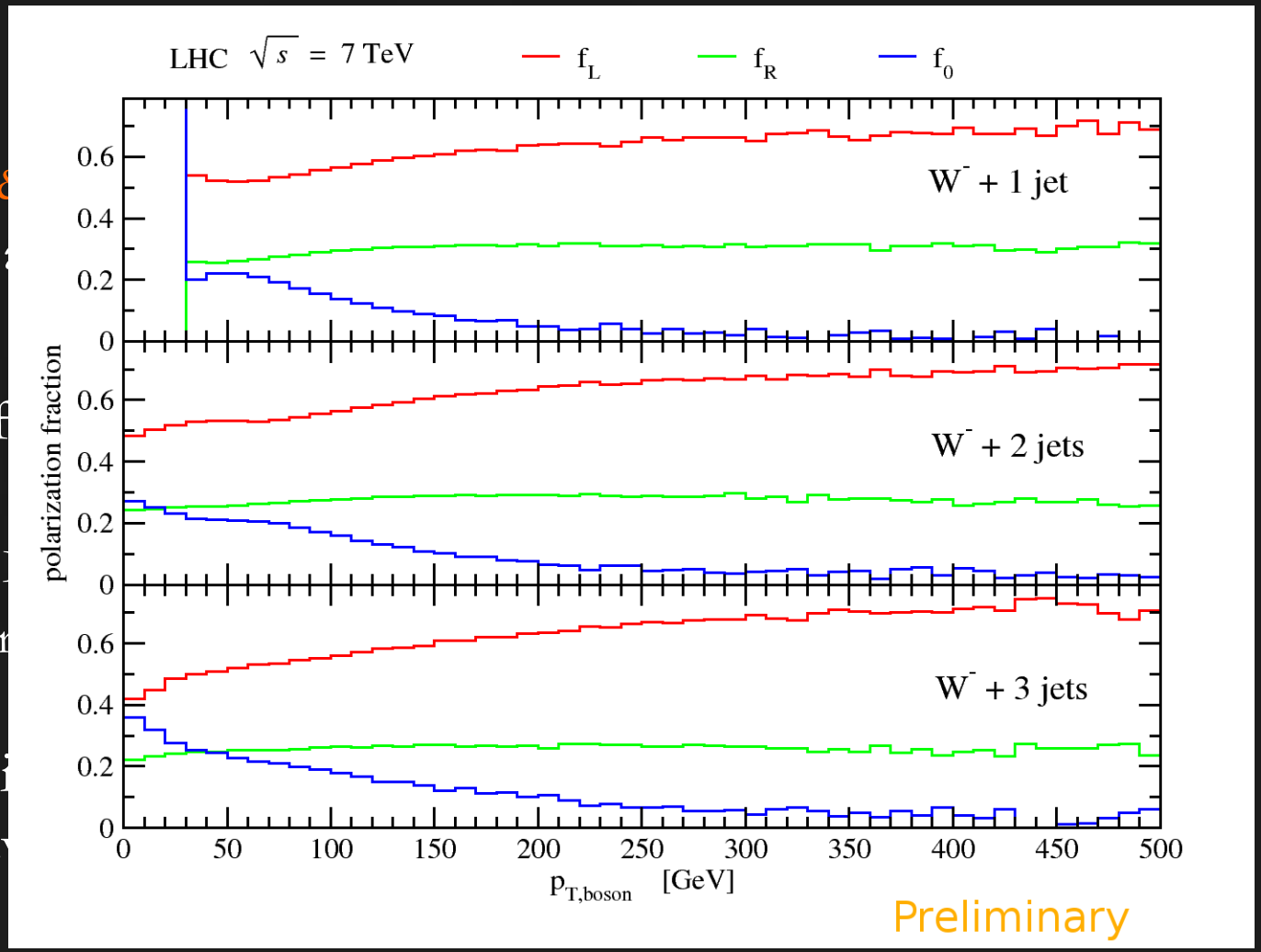


- $\Delta R(1^{st},2^{nd})$ jet
- Shapes can change!
- Physics of leading jets not modeled well at LO; additional radiation allows jets to move closer
- Cf Les Houches study [in 1003.1241] (Hoche, Huston, Maitre, Winter, Zanderighi) comparing to SHERPA w/ME matching & showering

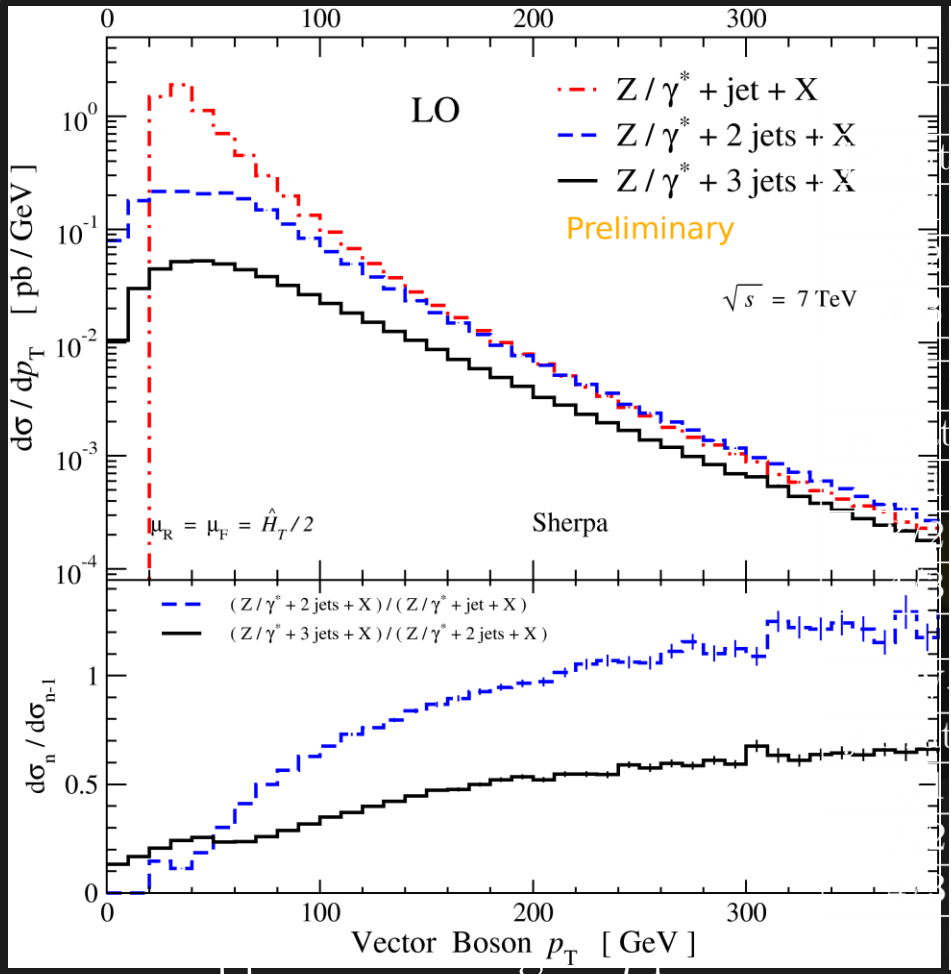


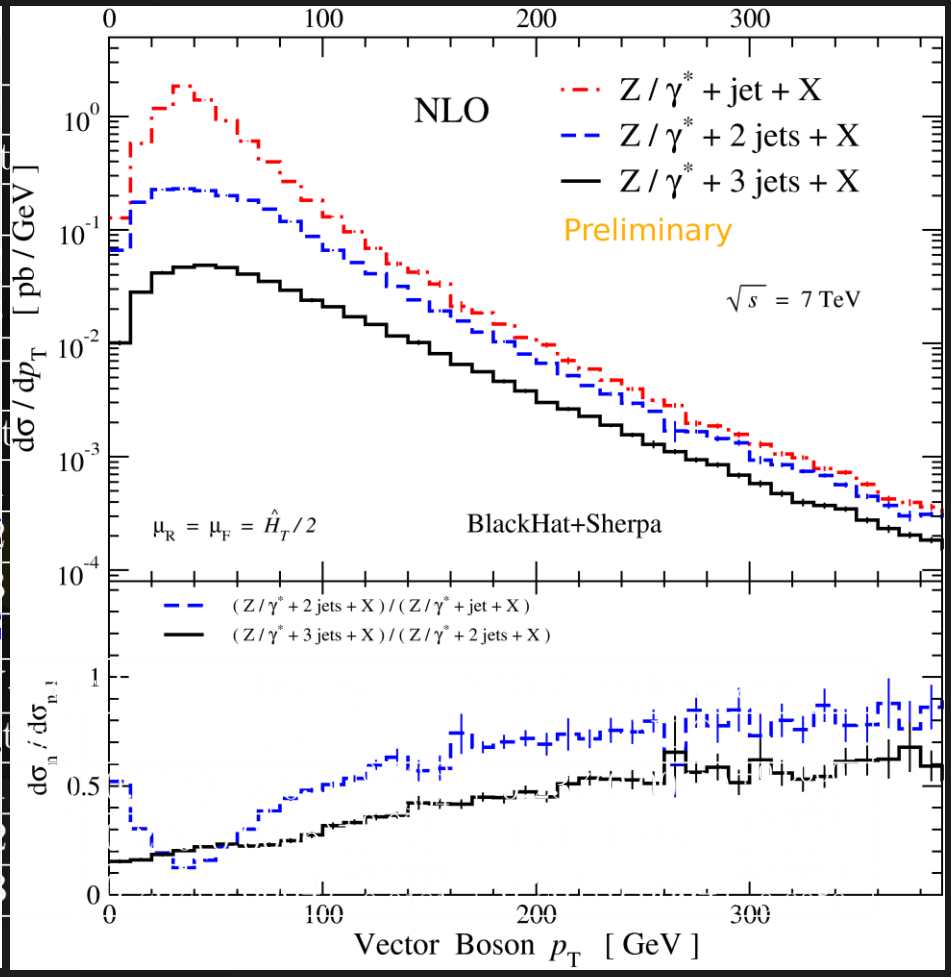
High-E_T W Polarization

- Polarization
  (Ellis, Stirling &
  distribution
- This is a diff
  dependence
  - Present at
  - Present for
- Useful for di
  decay (or ne



Jet-Production Ratio in *W*,Z+Jets



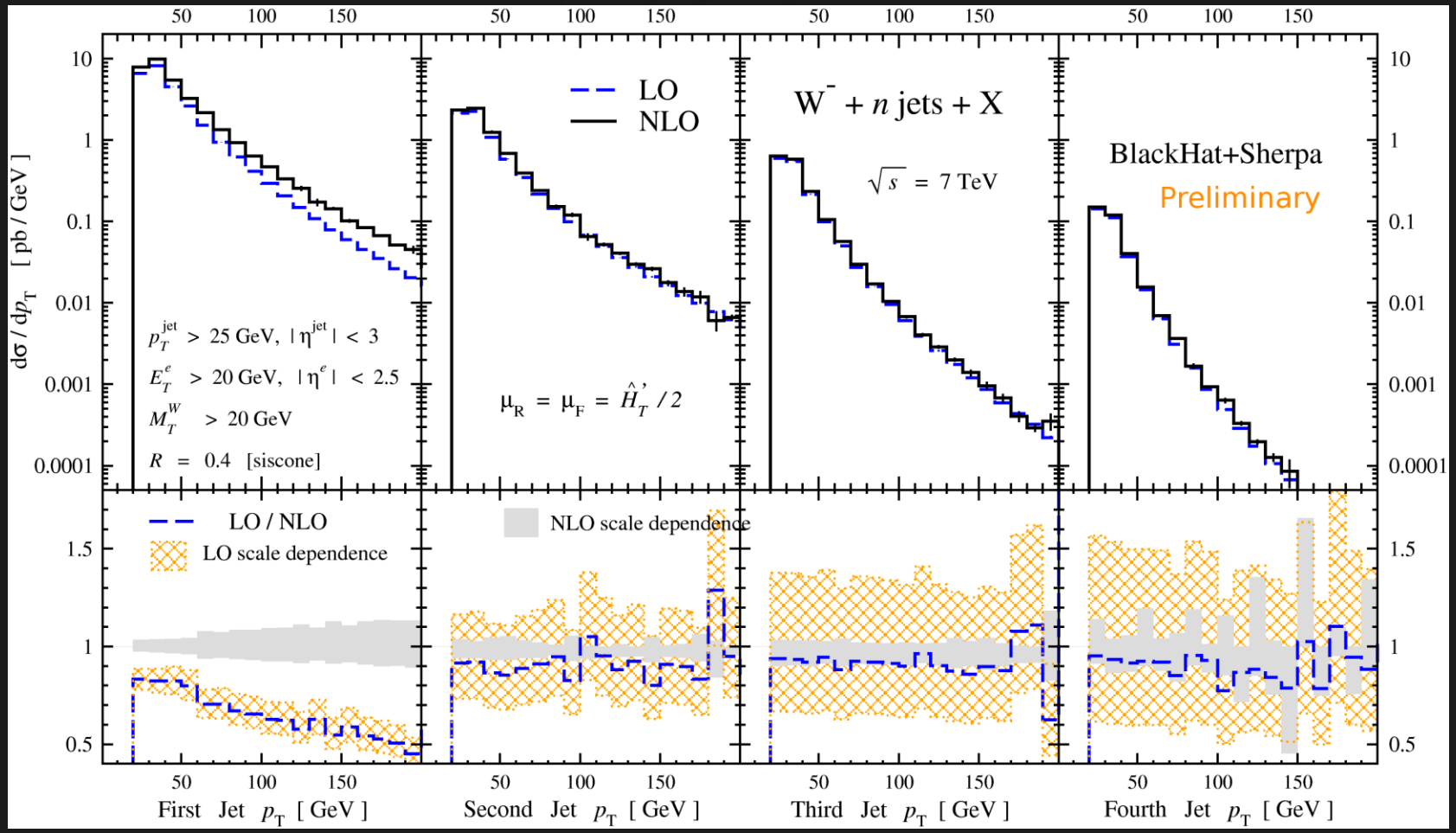


Summary

- NLO calculations required for reliable QCD predictions at the Tevatron and LHC
- On-shell methods are maturing into the method of choice for these QCD calculations

- BlackHat: automated seminumerical one-loop calculations

- Phenomenologically useful NLO parton-level calculations:
  - *W*+3 jets at Tevatron and LHC
  - Z+3 jets at Tevatron and LHC
  - First results for *W*+4 jets at LHC
  - Broad variety of kinematical configurations probed


LO
NLO
W⁻ + n jets + X
√s = 7 TeV
BlackHat+Sherpa
Preliminary
dσ / dp_T [pb / GeV]
p_T^jet > 25 GeV, |η^jet| < 3
E_T^e > 20 GeV, |η^e| < 2.5
M_T^W > 20 GeV
R = 0.4 [siscone]
μ_R = μ_F = Ĥ_T' / 2
LO / NLO
LO scale dependence
NLO scale dependence
First Jet p_T [GeV]
Second Jet p_T [GeV]
Third Jet p_T [GeV]
Fourth Jet p_T [GeV]