V+Jets at Next-to-Leading Order with BlackHat

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on behalf of the BlackHat Collaboration

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MC4LHC Readiness, CERN
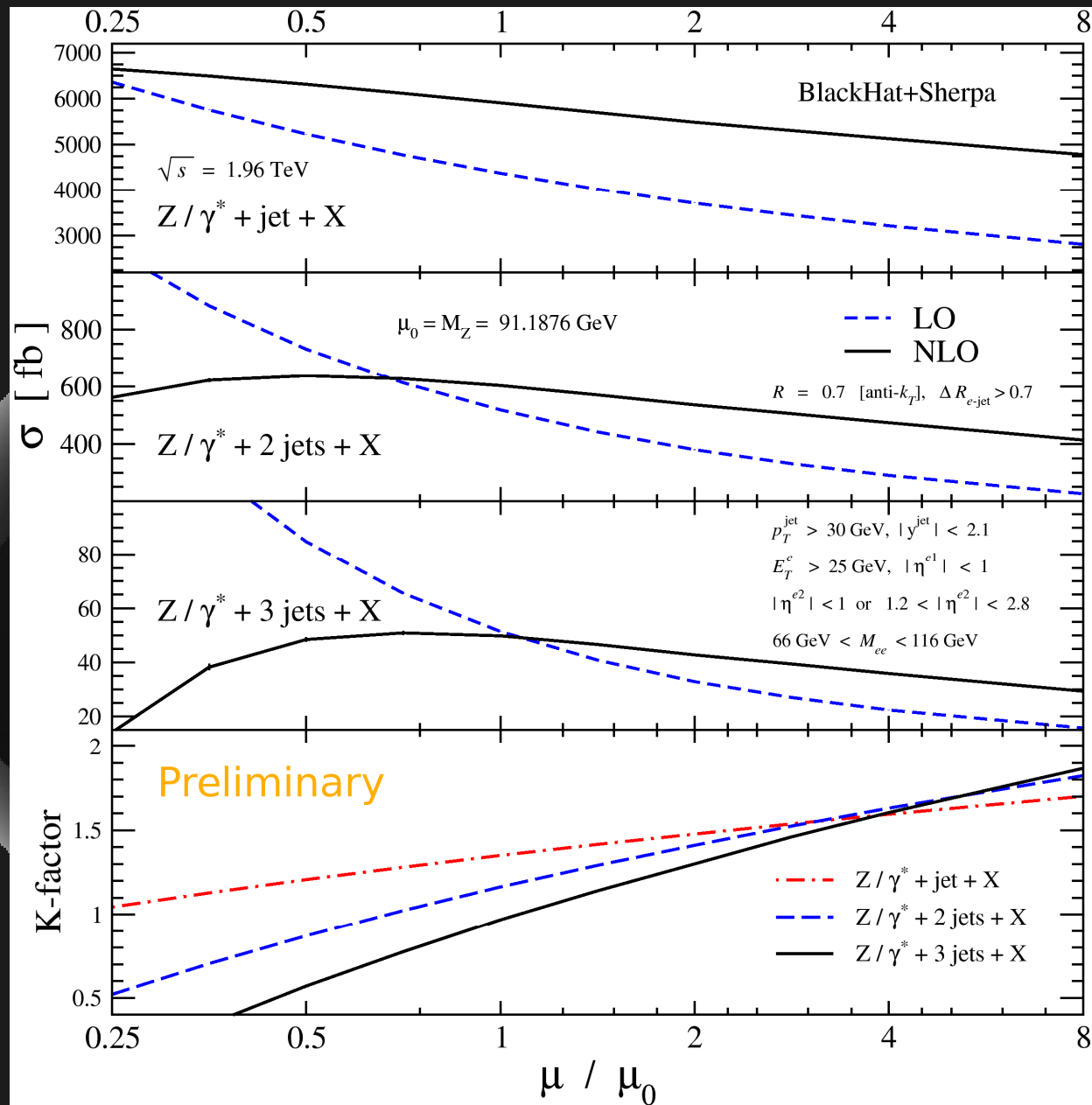
March 29–April 1, 2010

BlackHat

- On-shell methods $\Rightarrow$ Darren Forde's talk

- Numerical implementation

- Automated implementation $\Rightarrow$ industrialization

- C++ framework for automated one-loop calculations: organization, integral basis, spinor products, residue extraction, tree ingredients, caching

- 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
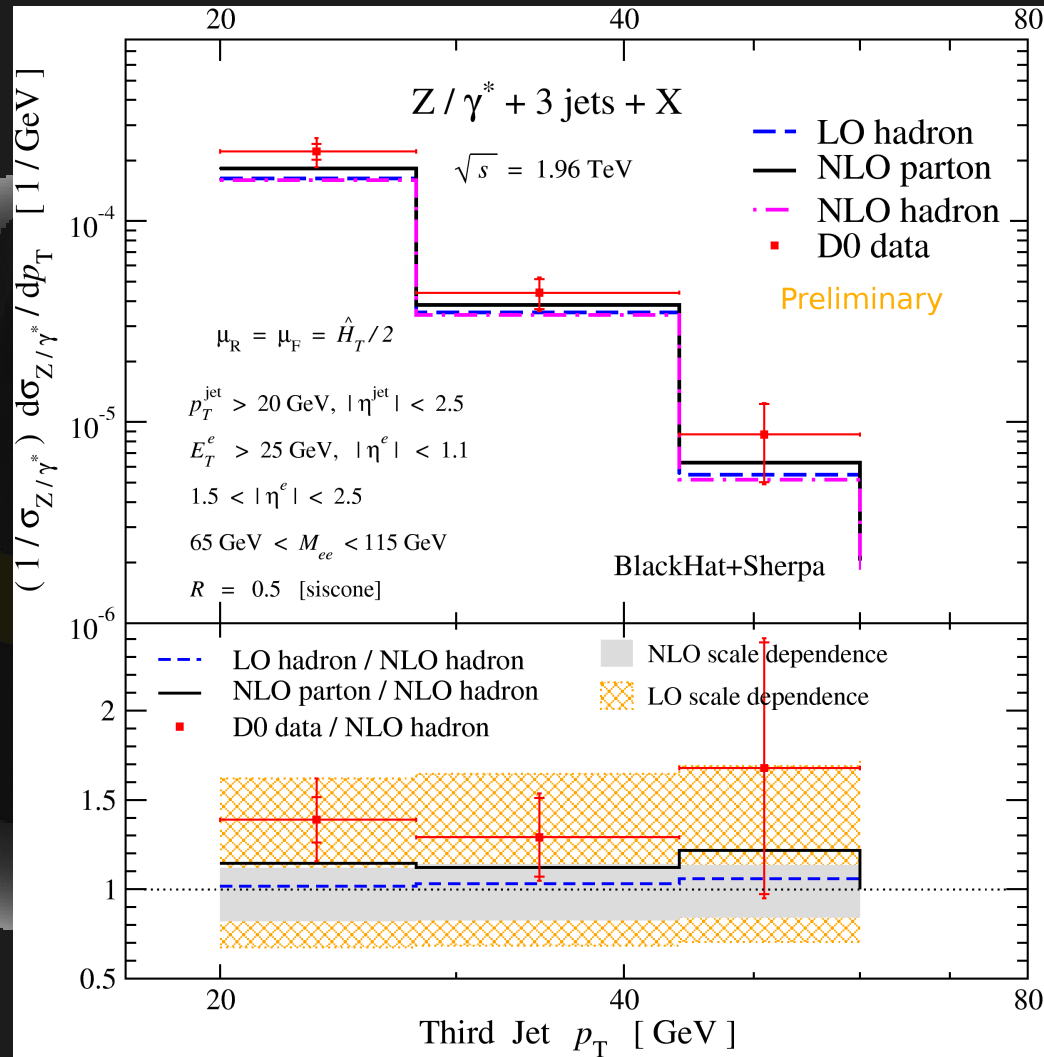
The Tevatron is Still Running…

- 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
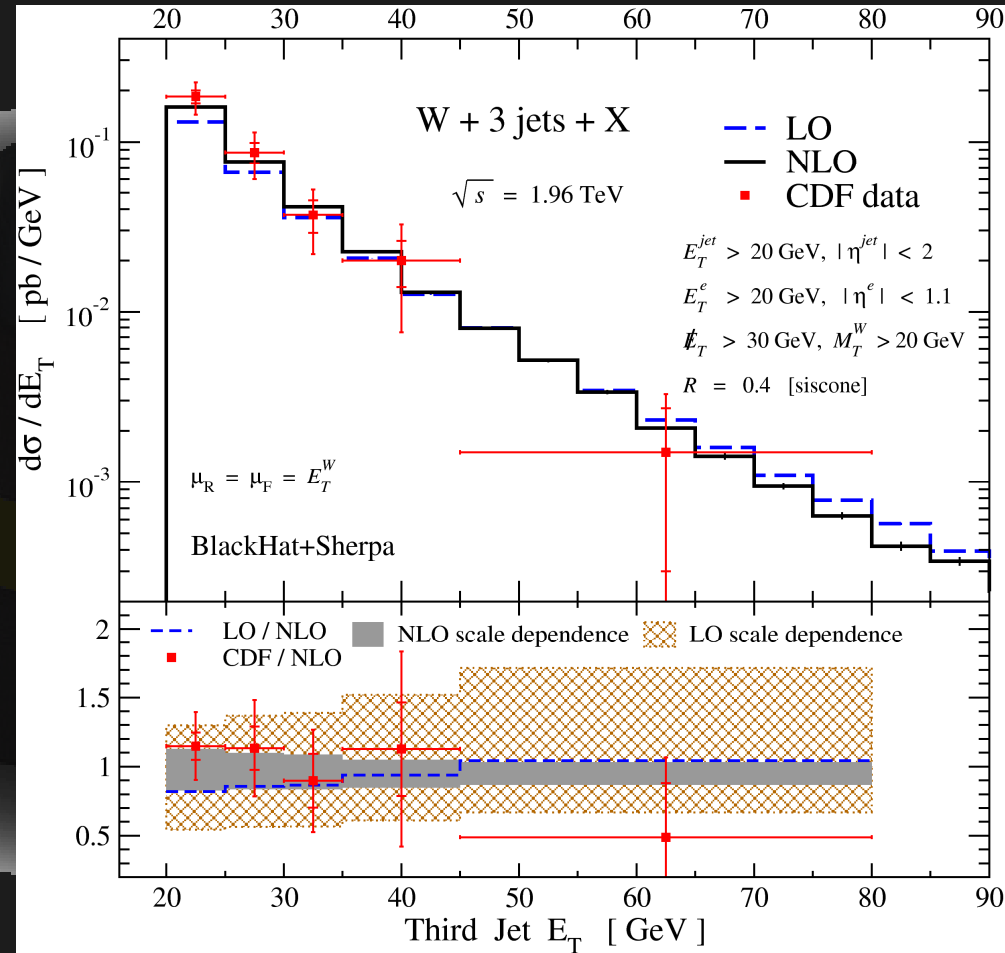
- Anti-k_T

- Reduction of scale dependence

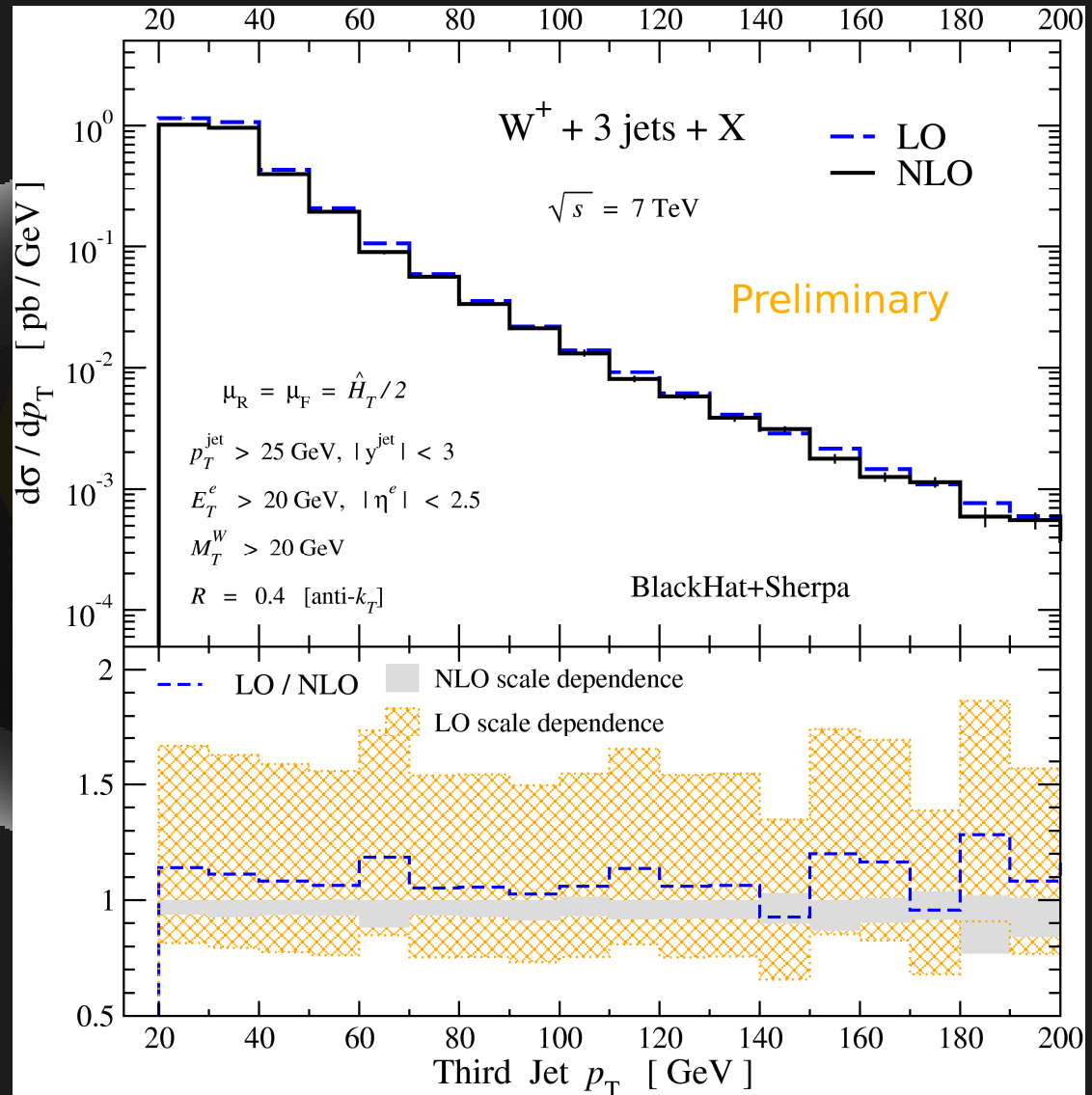- NLO importance grows with increasing number of jets

$\sqrt{s} = 1.96$ TeV

$Z / \gamma^* + $ jet $ + X$

BlackHat+Sherpa

$\mu_0 = M_Z = 91.1876$ GeV

LO

NLO

$R = 0.7$ [anti-k_T], $\Delta R_{e\text{-jet}} > 0.7$

$Z / \gamma^* + 2$ jets $+ X$

$Z / \gamma^* + 3$ jets $+ X$

$p_T^{jet} > 30$ GeV, $|y^{jet}| < 2.1$
$E_T^e > 25$ GeV, $|\eta^{e1}| < 1$
$|\eta^{e2}| < 1$ or $1.2 < |\eta^{e2}| < 2.8$
66 GeV $< M_{ee} < 116$ GeV

Preliminary

σ [fb]

K-factor

$Z / \gamma^* + $ jet $+ X$
$Z / \gamma^* + 2$ jets $+ X$
$Z / \gamma^* + 3$ jets $+ X$

μ / μ_0

- Z+3 jets: new

- Reduced scale dependence

- Parton calculation corrected to hadron level using experiment-provided table

- Reasonable agreement with D0 data [0903.1748]
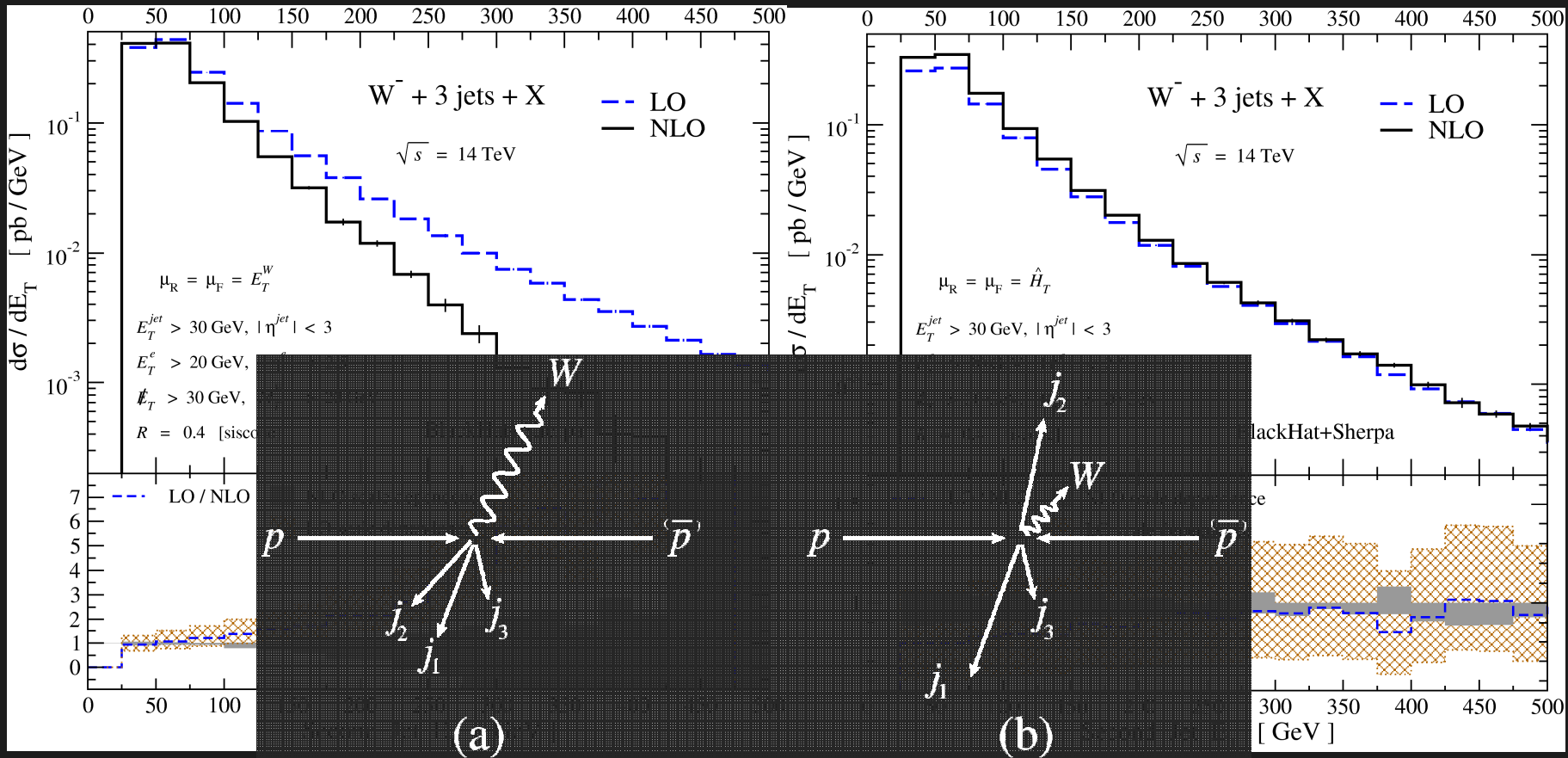
- SISCone (Salam & Soyez) vs D0 midpoint

$Z/\gamma^* + 3$ jets + X

$\sqrt{s} = 1.96$ TeV

- - - LO hadron
—— NLO parton
- · - NLO hadron
■ D0 data

Preliminary

$\mu_R = \mu_F = \hat{H}_T/2$

$p_T^{jet} > 20$ GeV, $|\eta^{jet}| < 2.5$

$E_T^e > 25$ GeV, $|\eta^e| < 1.1$

$1.5 < |\eta^e| < 2.5$

65 GeV $< M_{ee} < 115$ GeV

$R = 0.5$ [siscone]

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$(1/\sigma_{Z/\gamma^*})\ d\sigma_{Z/\gamma^*}/dp_T\ $ [1 / GeV]

- - - LO hadron / NLO hadron
—— NLO parton / NLO hadron
■ D0 data / NLO hadron

▨ NLO scale dependence
▨ LO scale dependence

Third Jet p_T [GeV]

…and so is the LHC

- Third jet in W+3 jets @ 7 TeV

- NLO scale uncertainty smaller than LO (band accidentally narrow given central choice — but would in any case be much improved)

- Shape change mild

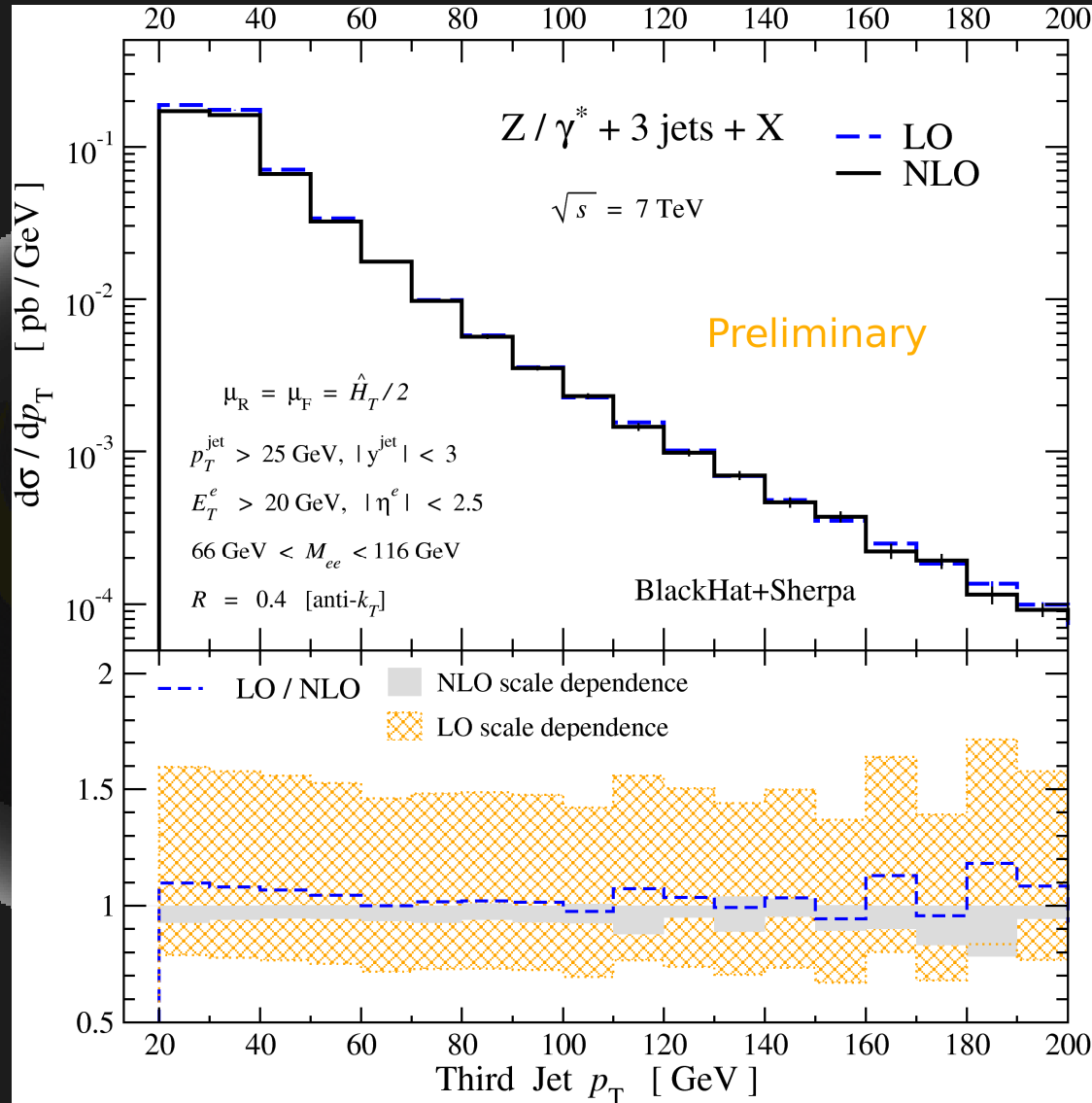- Scale choice $\hat{H}_T/2$ (half total partonic E_T)

V + Jets at Next-to-Leading Jet Physics with BlackHat, MC4LHC, CERN, March 30–April 1, 2010

Scale Choices
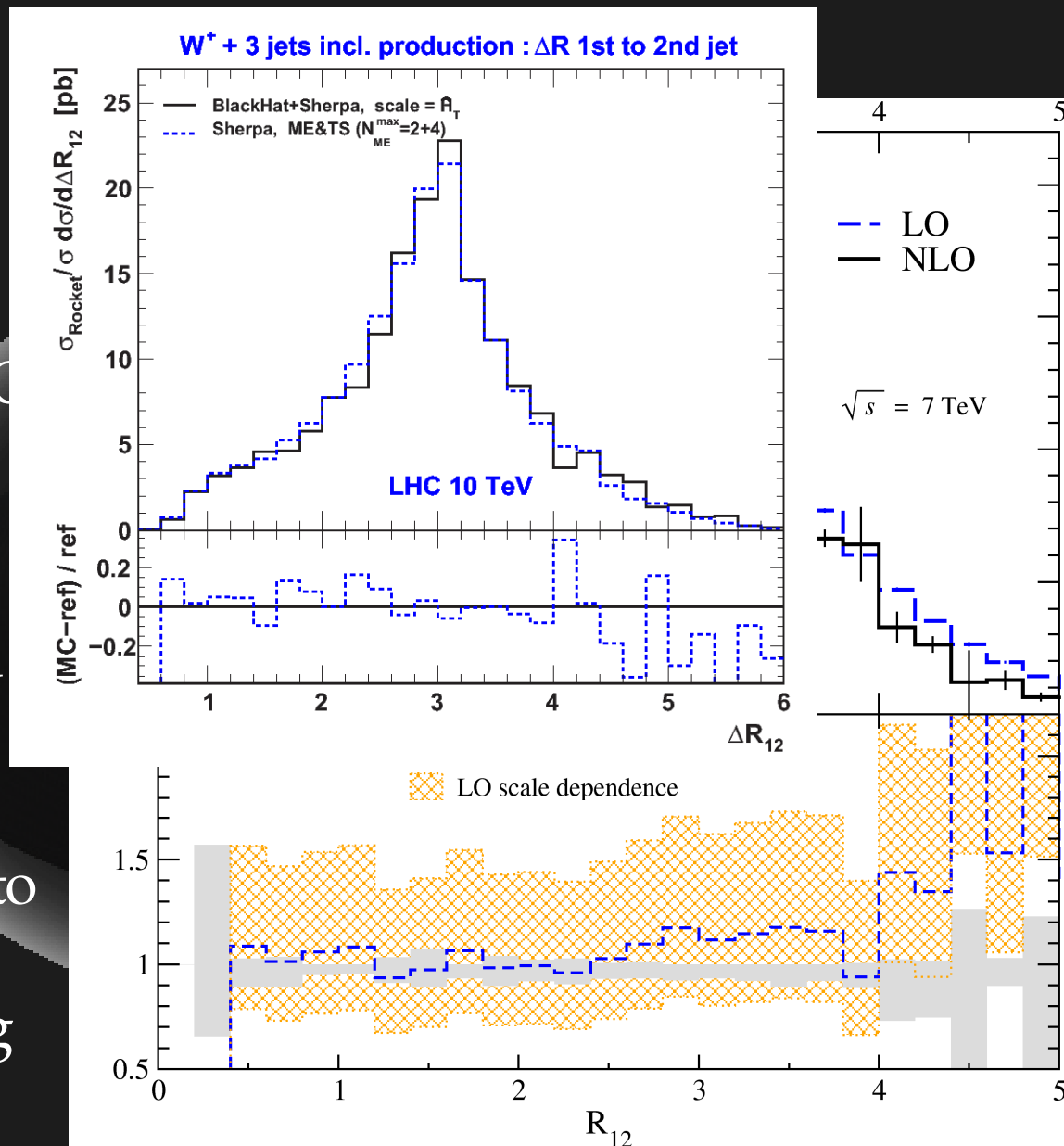
- Third jet in Z+3 jets @7TeV

- Shape similar at LO to NLO, slightly closer than for W+3 jets

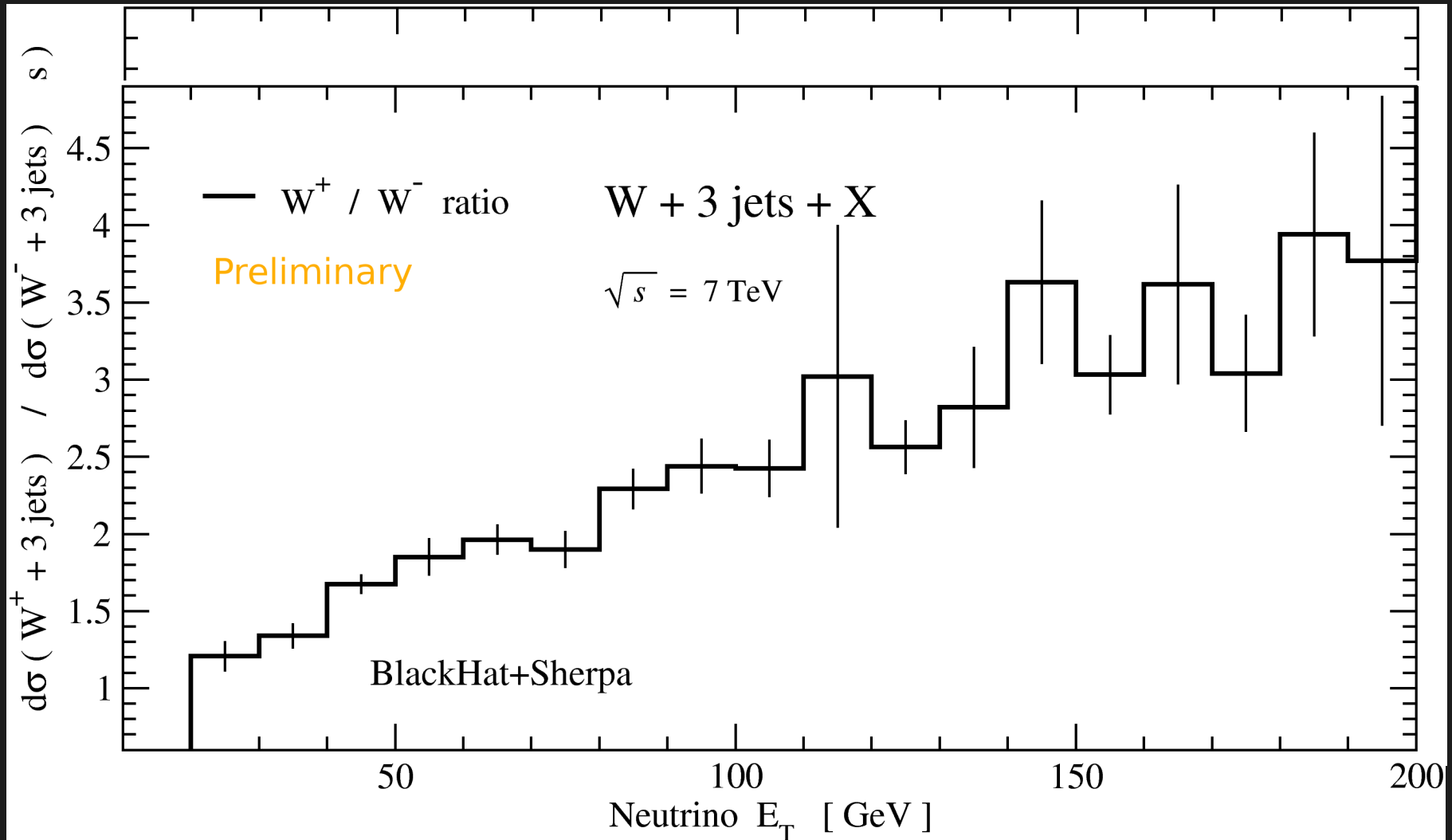- NLO band is accidentally narrow, but would in any case be much improved compared to LO

$\Rightarrow$ predictions for W+3/Z+3 ratios, handle on missing-E_T + 3 jets

$Z/\gamma^* + 3$ jets + X

-- LO
— NLO

$\sqrt{s} = 7$ TeV

Preliminary

$\mu_R = \mu_F = \hat{H}_T / 2$

$p_T^{jet} > 25$ GeV, $|y^{jet}| < 3$

$E_T^e > 20$ GeV, $|\eta^e| < 2.5$

66 GeV $< M_{ee} < 116$ GeV

$R = 0.4$ [anti-k_T]

BlackHat+Sherpa

$d\sigma / dp_T$ [pb / GeV]

-- LO / NLO   NLO scale dependence
LO scale dependence

Third Jet p_T [GeV]

- $\Delta R(1^{st}, 2^{nd})$ 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 1103.1241] (Hoche, Huston, Maitre, Winter, Zanderighi) comparing to SHERPA w/ME matching & showering
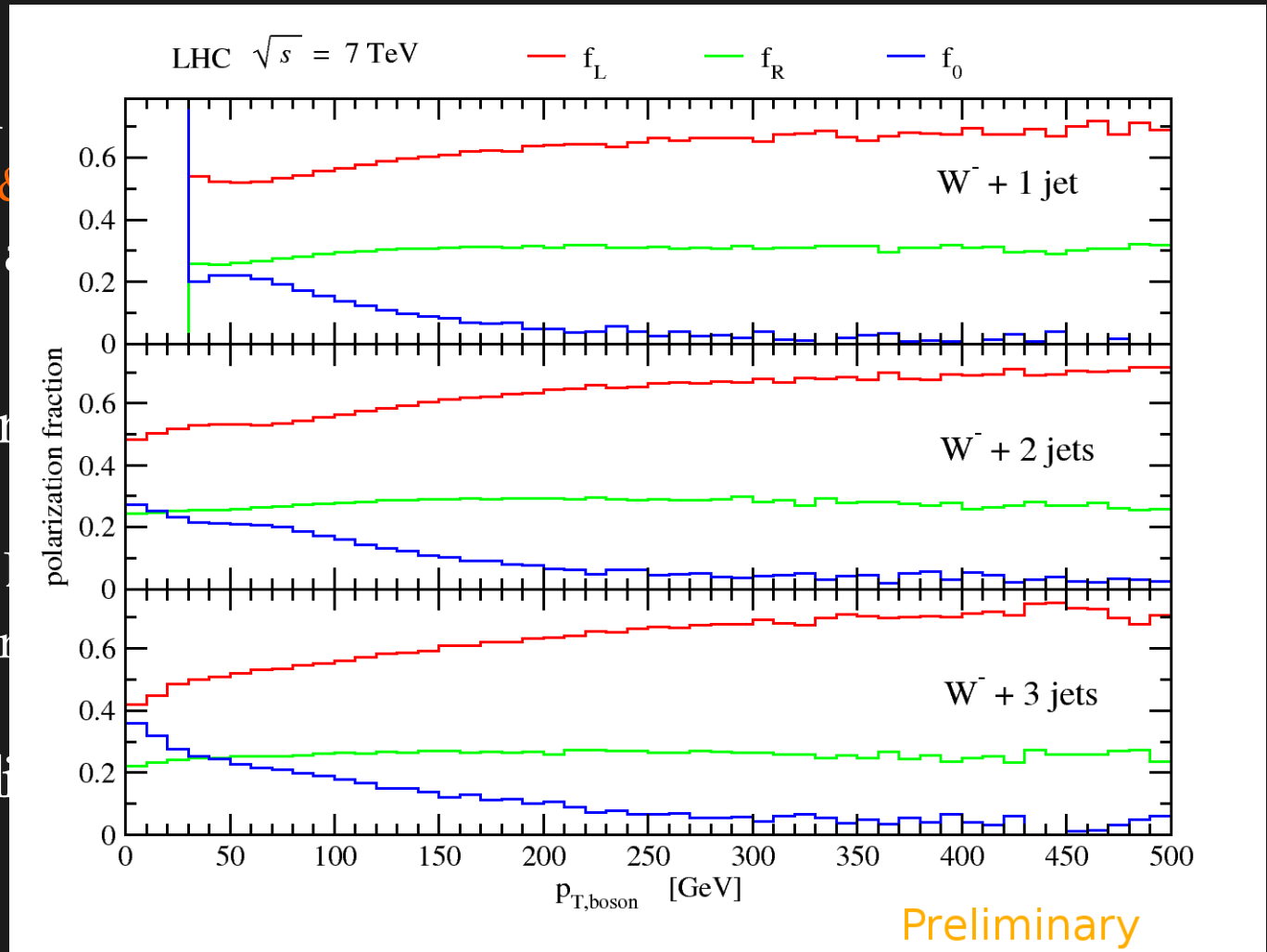

W^+ + 3 jets incl. production : ΔR 1st to 2nd jet
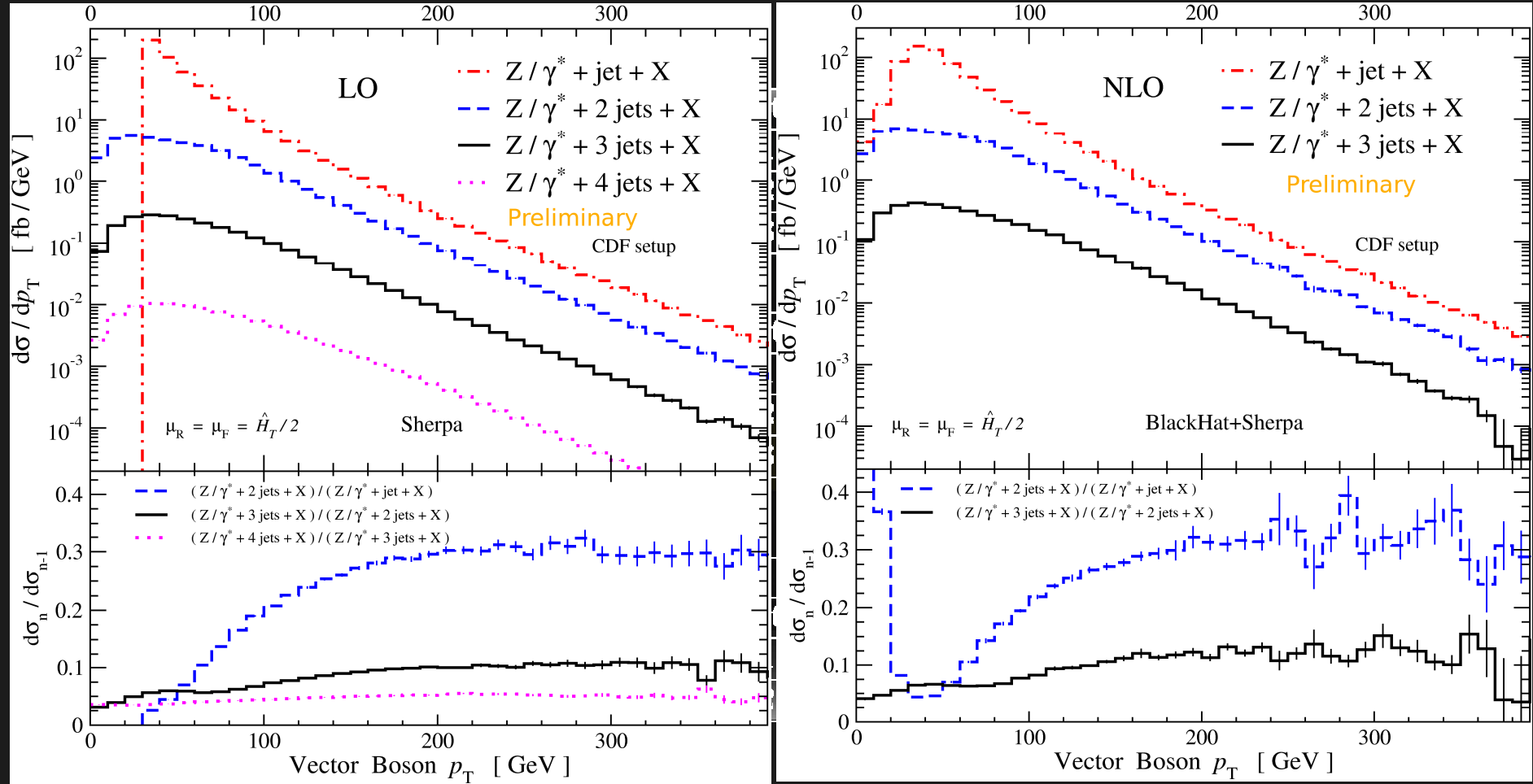
BlackHat+Sherpa, scale = $\hat{H}_T$
Sherpa, ME&TS (N_{ME}^{max}=2+4)

LHC 10 TeV

LO
NLO

$\sqrt{s}$ = 7 TeV

LO scale dependence

W+3 jets at the LHC: W^+/W^- Ratio

W Polarization

- Polarization
  (Ellis, Stirling &
  distribution a

- This is differ
  dependence
  - Present at
  - Present for

- Useful for di
  decay!

Jet-Production Ratio in Z+Jets

Summary

- On-shell methods are maturing into the method of choice for QCD calculations for colliders

- 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
  - Broad variety of kinematical configurations probed