Vector boson+jets with BlackHat and Sherpa

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in collaboration with

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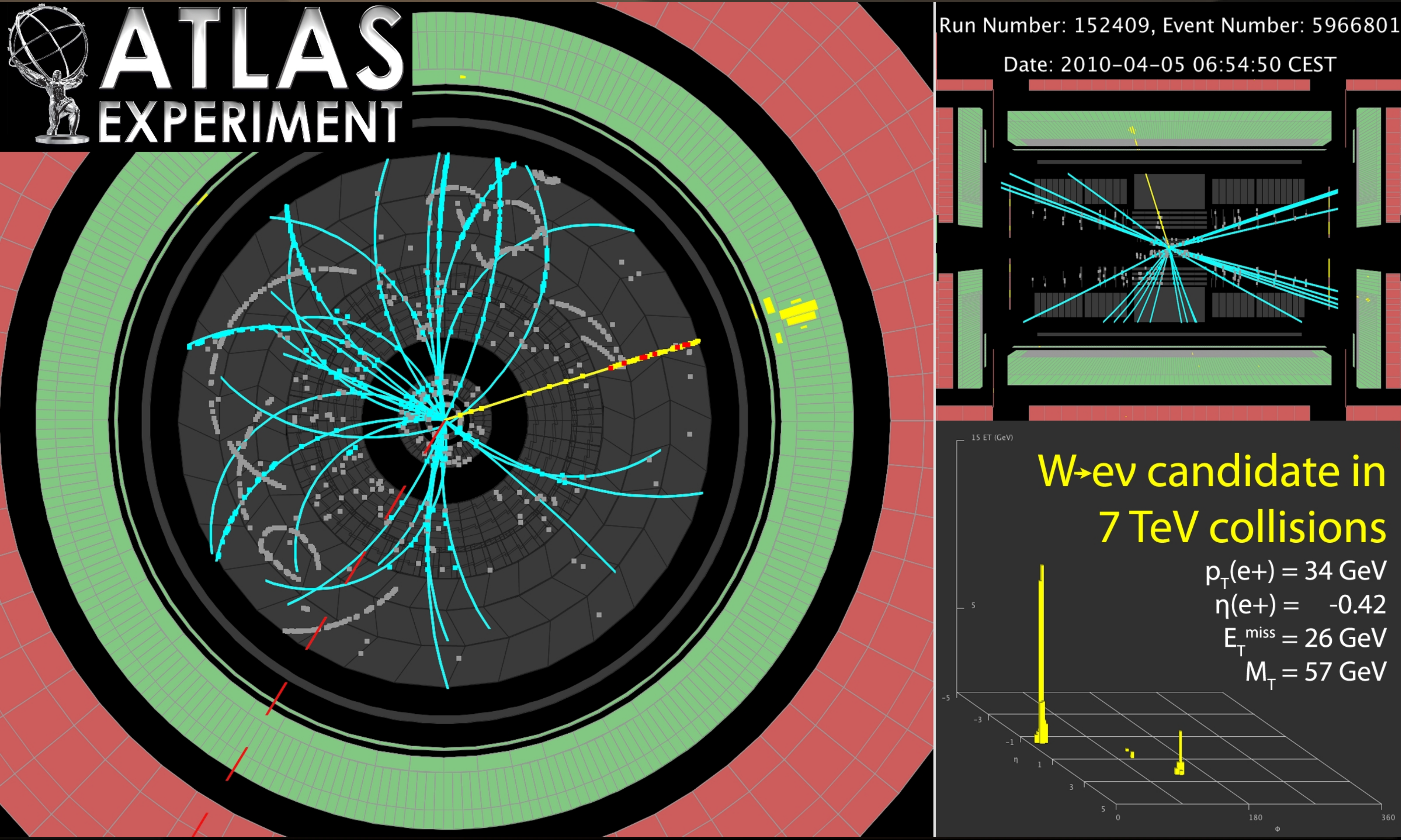
Loops and Legs 2010, Woerlitz, 27 March

First W events are coming in



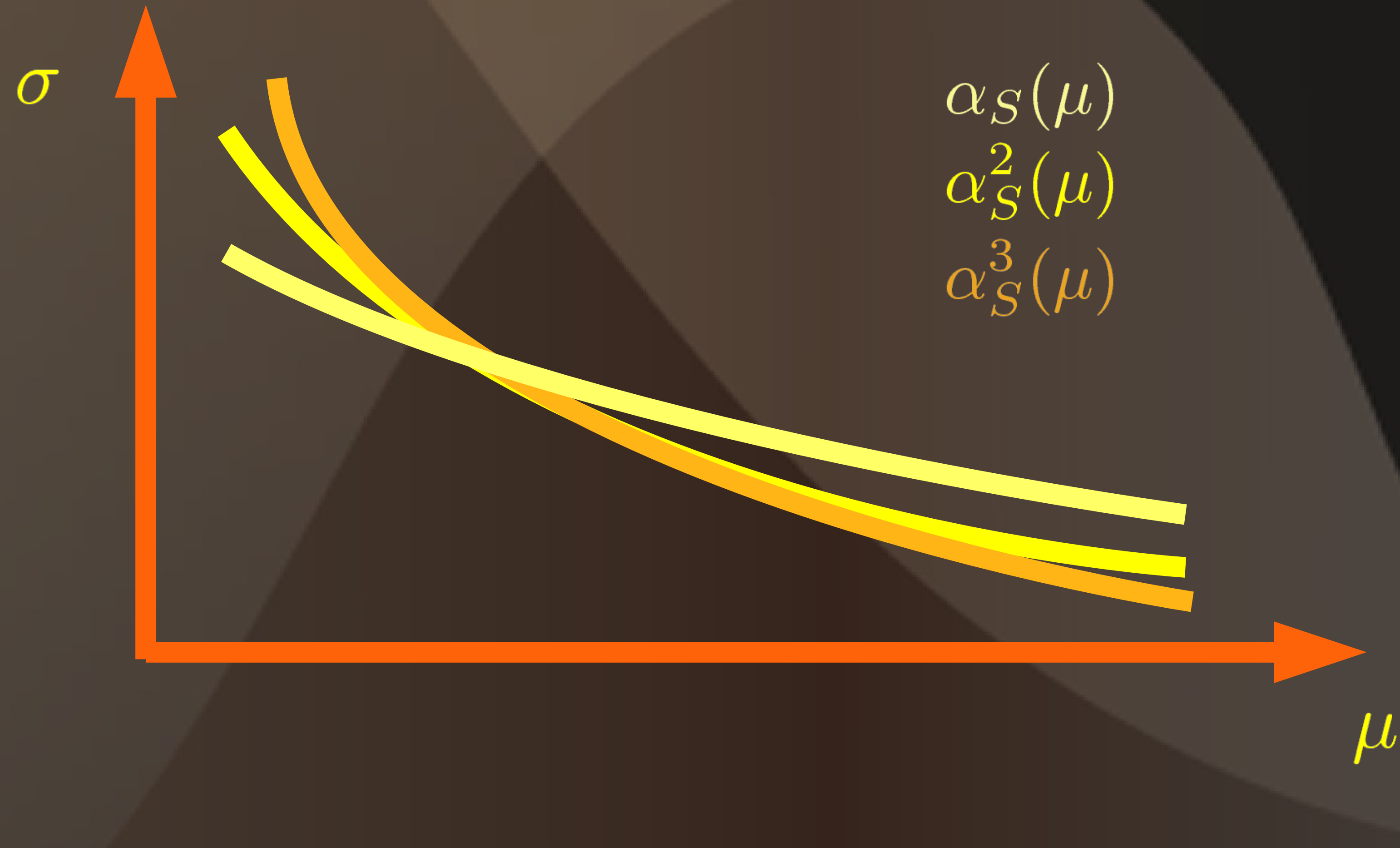
Motivation

Vector Boson + jets processes are very important at the LHC and Tevatron

- As a signal
- As a background
  - For SM physics (Higgs, $t\bar{t}$, single top)
  - For BSM physics
- Luminosity determination
- Need the best possible theory prediction!
  - Extrapolate to signal region

Renormalization scale dependence

- The scale dependence increases with number of jets



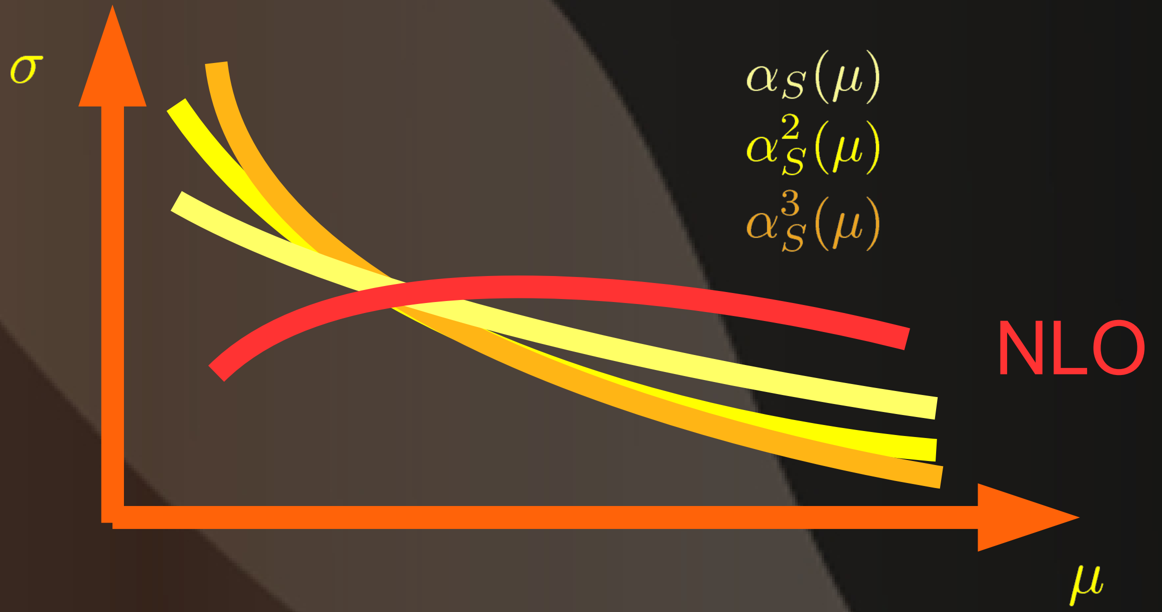
NLO Corrections

NLO corrections are needed for a good theoretical understanding of QCD processes

Improve theory prediction for

- Absolute normalization
- Reduce renormalization scale dependency

Number of jets	LO	NLO
1	16%	7%
2	30%	10%
3	42%	12%



- Corrections can be very large
- Shape of distributions

NLO with BlackHat+Sherpa

NLO cross section

$$\sigma_n^{NLO} = \int_n \sigma_n^{tree} + \int_n \left(\sigma_n^{virt} + \Sigma_n^{sub}\right) + \int_{n+1} \left(\sigma_{n+1}^{real} - \sigma_{n+1}^{sub}\right)$$

BlackHat

Sherpa

Sherpa

[Gleisberg,Hoeche,Krauss,Schoenherr,Schumann,Siegert,Winter]

Provides

- Efficient phase space integration (now even better)
- Analysis framework
- Automated dipole subtraction for the real part [Catani,Seymour] [Gleisberg,Krauss]
- (and much more)
- Is written in C++

BlackHat

[Berger, Bern, Dixon, Febres Cordero, Forde, Ita, Kosower, DM]

- C++ library for the computation of virtual 1-loop amplitudes for QCD processes
- Uses new progress in the unitarity techniques, spinor formalism, complex momenta

  [Ossola,Papadopoulos,Pittau;Forde]
- Cut containing part: 4 Dim, using Forde's method
- Rational part:
  - 1- loop recursion (reuse of lower point results)

    [Berger,Bern,Dixon,Forde,Kosower]
  - Rational extraction using D-dim unitarity

    [Giele,Kunszt,Melnikov;Badger]

Z vs W

- Z
  - Cleaner signal in the leptonic channel
  - Smaller cross section
  - Missing energy
- W
  - Larger cross section
  - Less clean signal
  - lepton+missing energy
- Underlying QCD dynamics is the same
  → Can use Z/W to calibrate W/Z

W+jets @ Tevatron

CDF Collaboration

$320pb^{-1}$

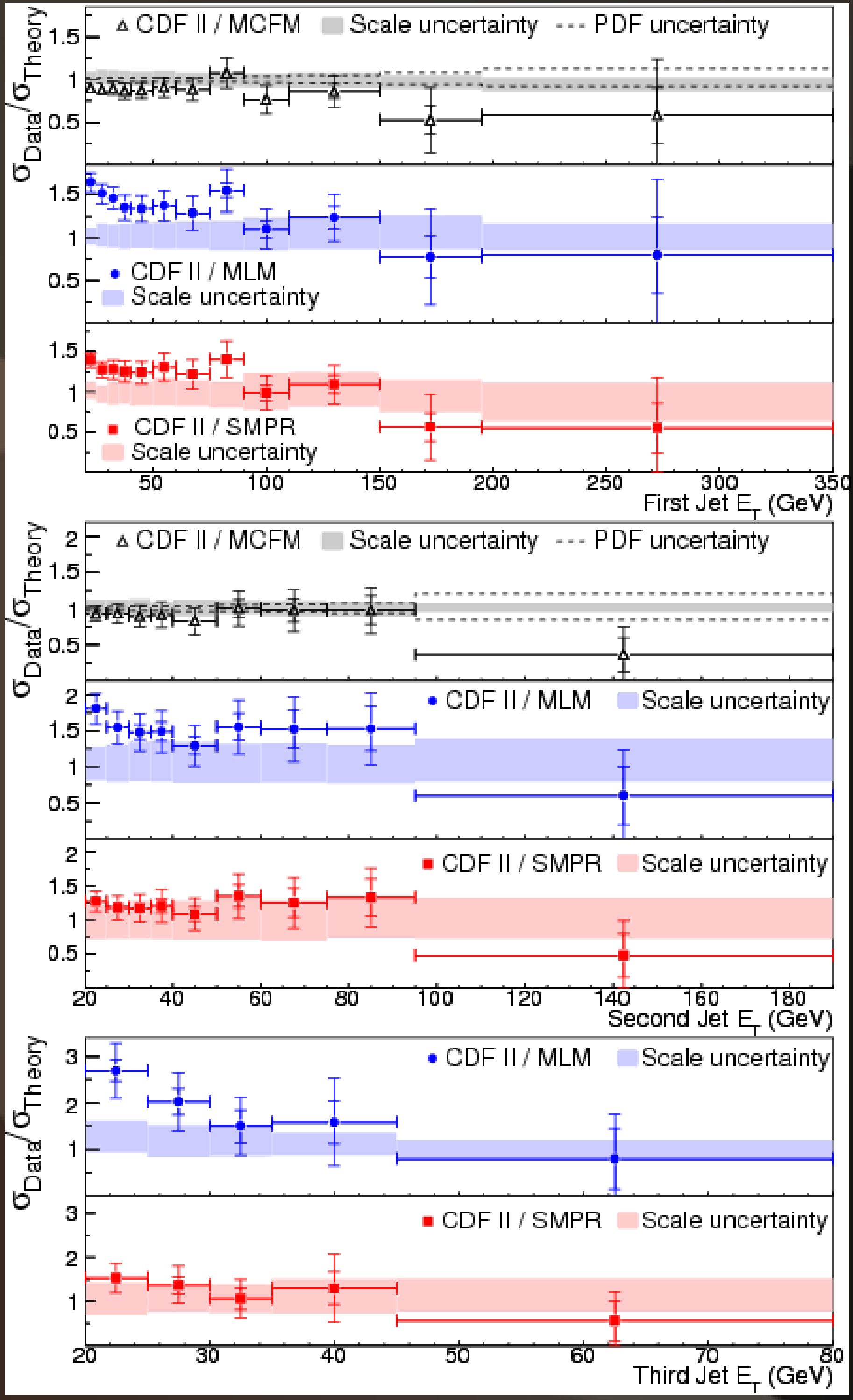
- Corrected for comparison with particle level
- Comparison with
- NLO: MCFM
- MLM = Alpgen+Herwig
- SMPR = Madgraph+Pythia

$E_T^e > 20$ GeV $\quad E_T^{\rm jets} > 20$ GeV

$|\eta^e| < 1.1 \quad \not{E}_T > 30$ GeV

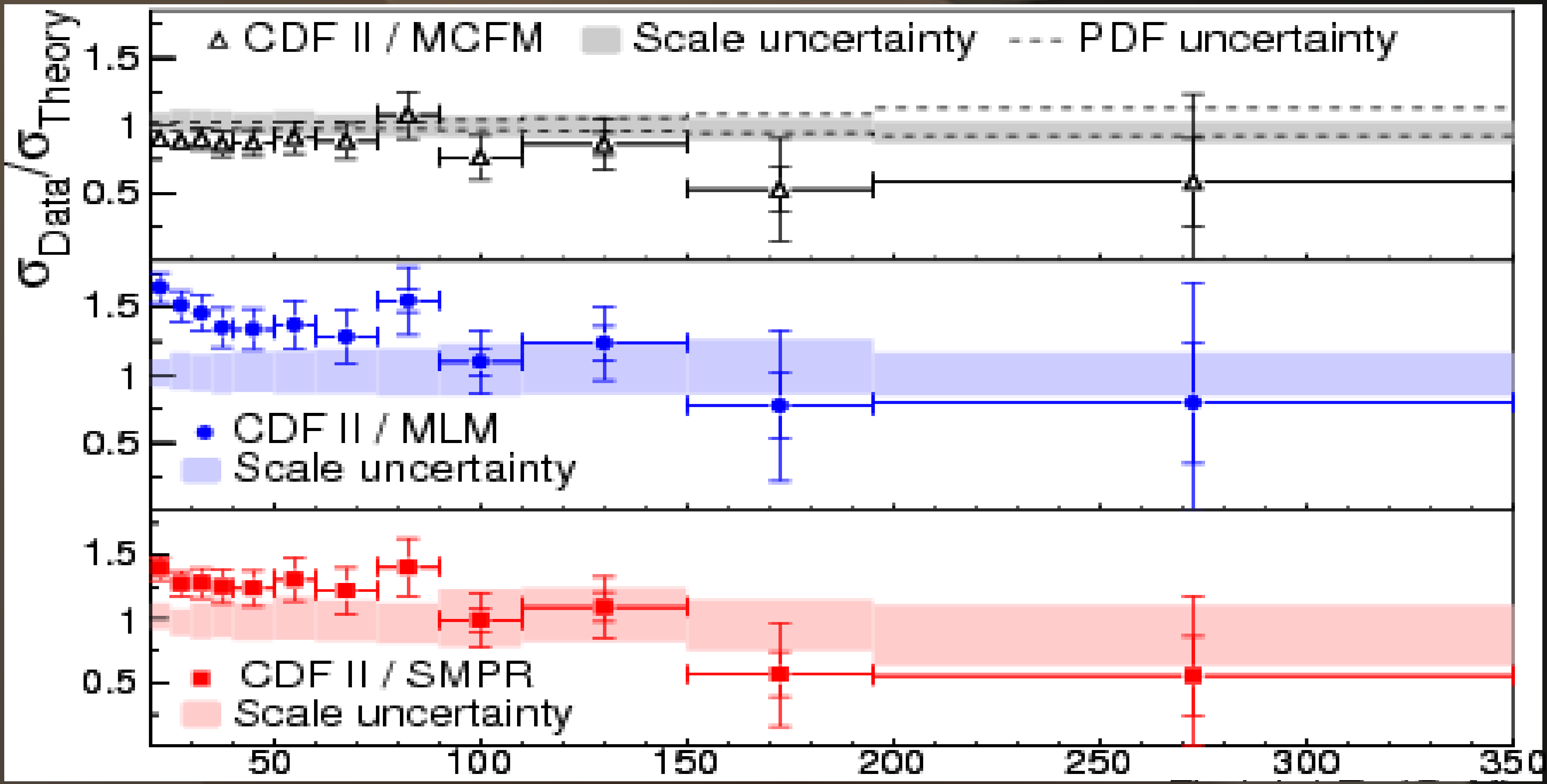
$|\eta^{\rm jets}| < 2 \quad E_T^{\rm jets} > 20$ GeV

$M_T^W > 20$ GeV

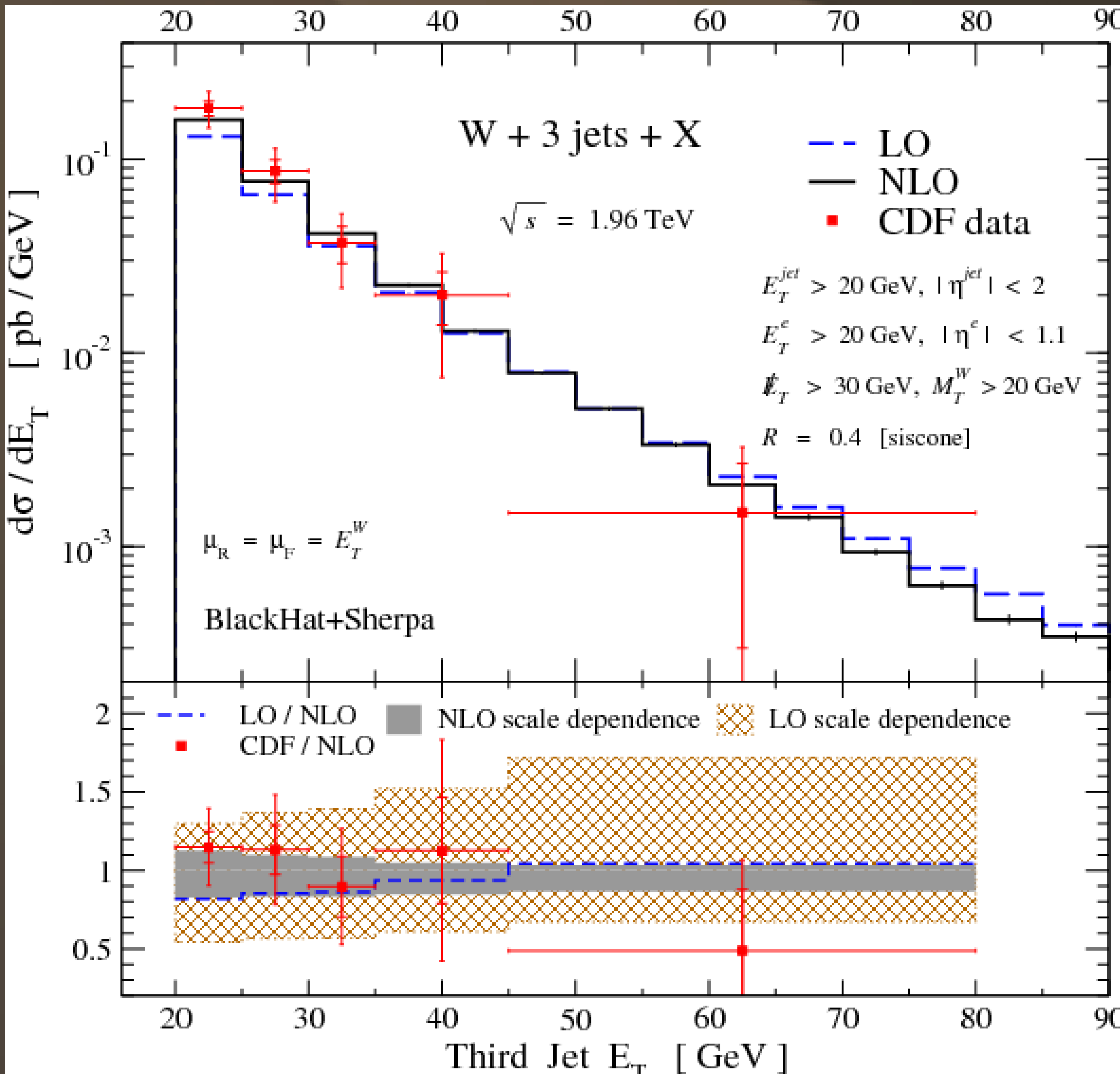


[CDF Collaboration PRD 77 011108, Arxiv:0711.4044]

W+1 Jet at Tevatron



W+3 jets @ Tevatron



$$\mu = \sqrt{m_W^2 + p_T^2(W)}$$

PDF: CTEQ6M

Jet algorithm: SISCone [Salam,Soyez]

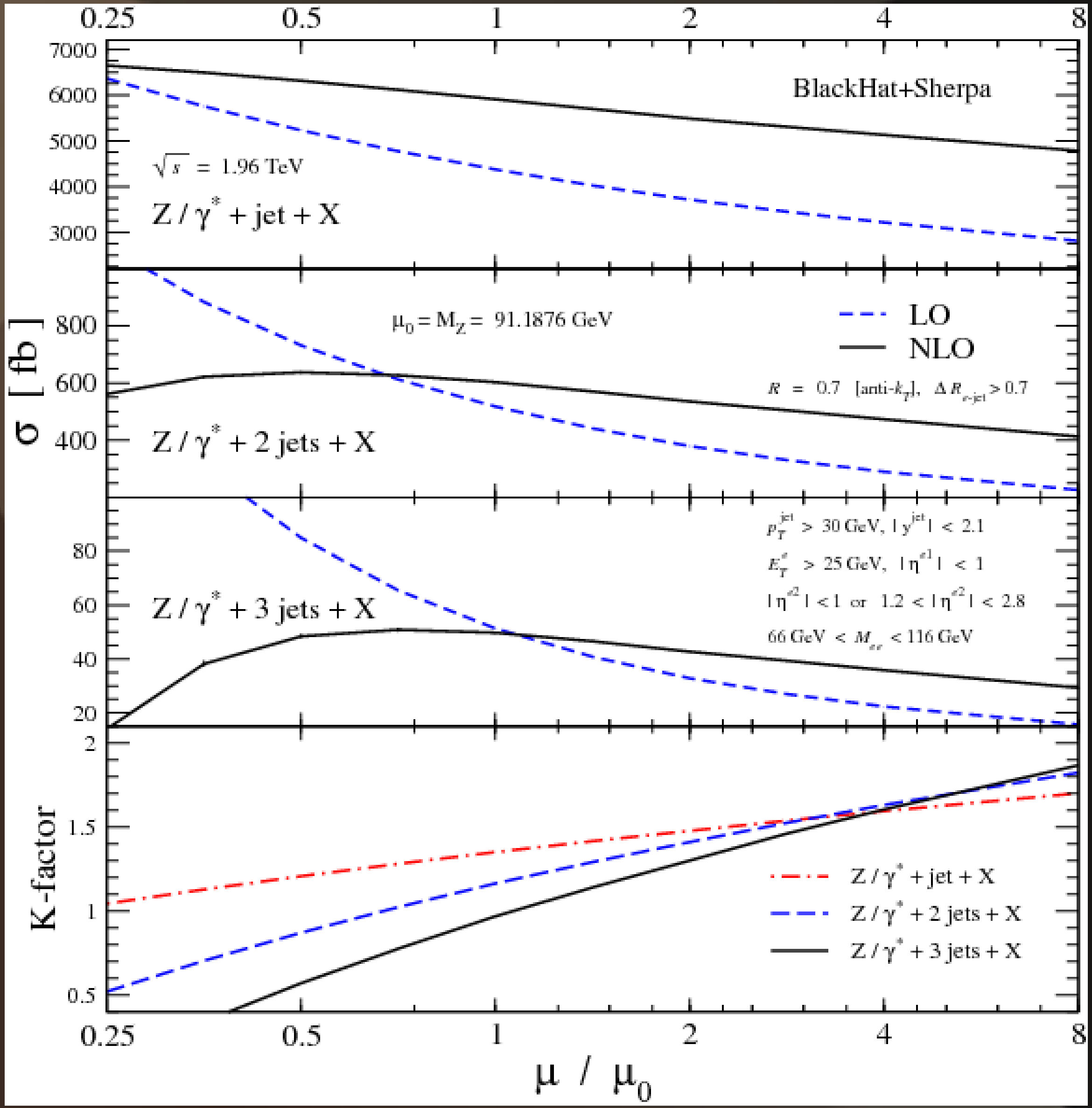
Z/γ^* + jets at the Tevatron

- Measured by both CDF and D0
- e^+e^- final state
  - Include γ^* and Z/γ interference
  - Massless electron
  - Take width of Z into account
  - Full color
  - Neglect top quarks
  - Neglect fermion loops attached directly to the vector boson

Z + jets @ Tevatron

Z(e+ e-) +1,2,3 jets

- NLO has a reduced scale dependence
- Scale dependence increases with the number of jets



Z + jets @ Tevatron

- CDF collaboration ArXiv 0711.3717
- Midpoint jet algorithm $1.7\ \mathrm{fb}^{-1}$

$P_T^{\mathrm{jet}} > 30\ \mathrm{GeV}\,,$

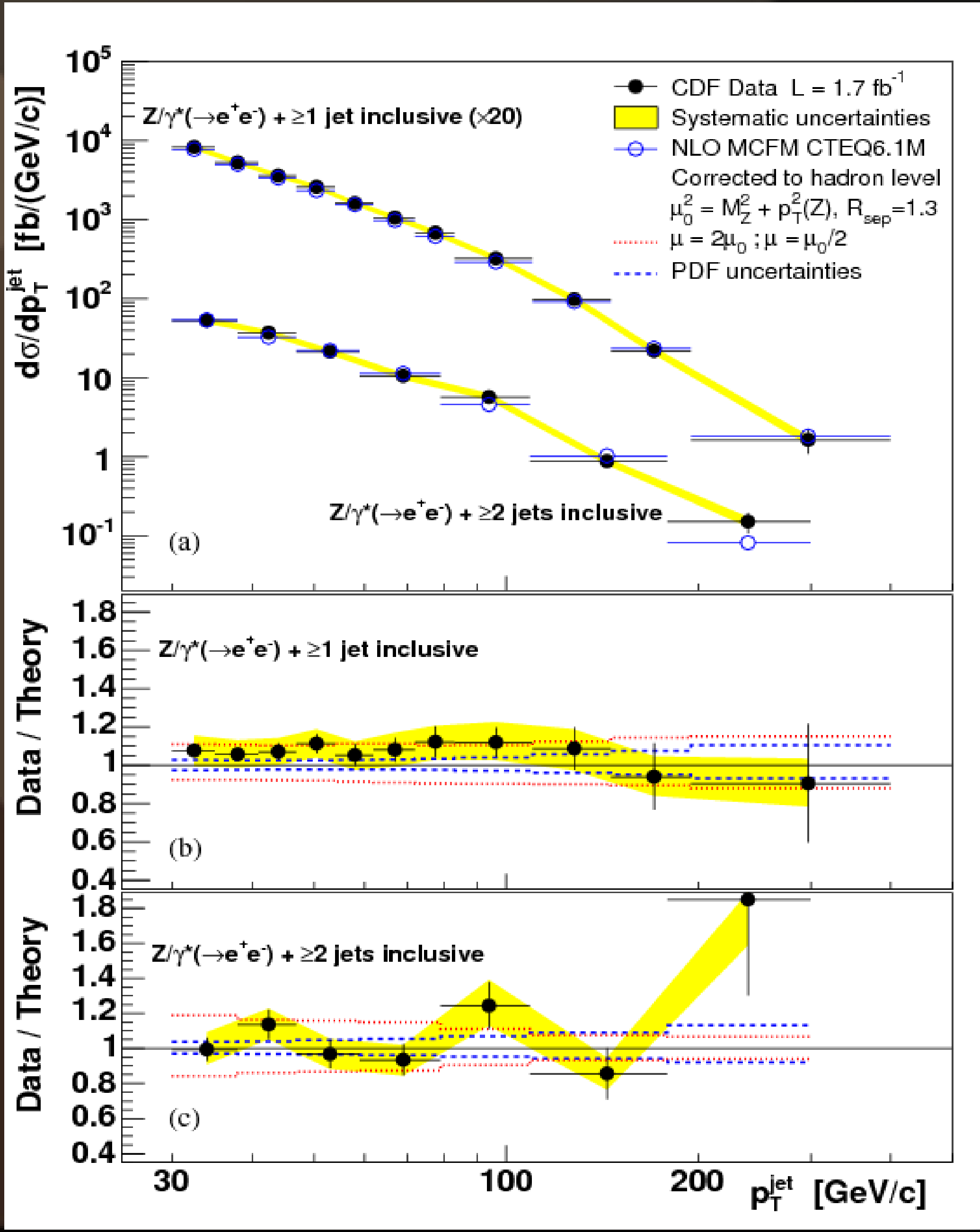
$E_T^e > 25\ \mathrm{GeV}$

$\Delta R_{e-\mathrm{jet}} > 0.7\,,$

$66 < M_{e^+e^-} < 116\ \mathrm{GeV}\,,$

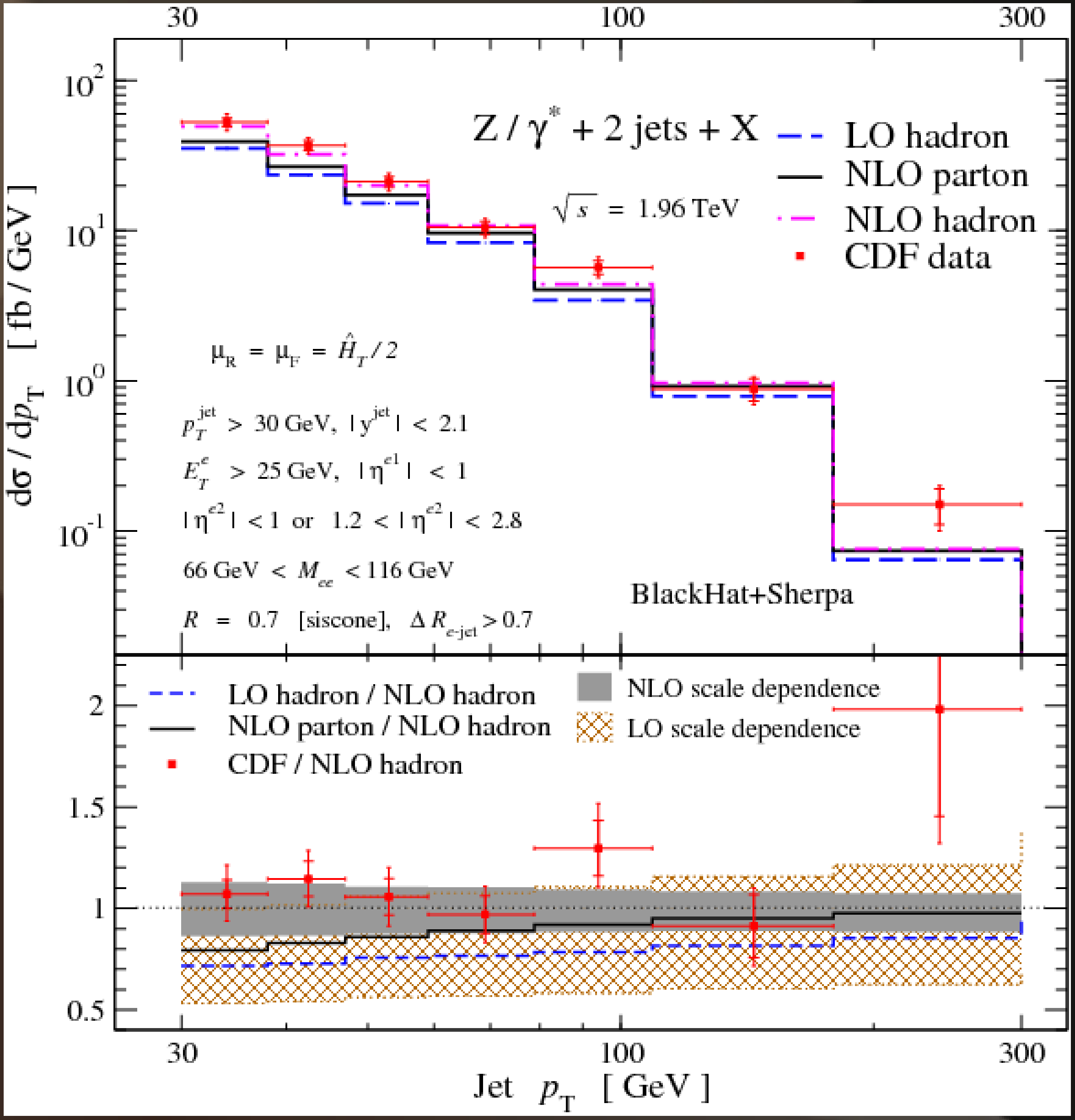
$|\eta^{\mathrm{jet}}| < 2.1 \qquad |\eta^{e_1}| < 1$

$|\eta^{e_2}| < 1 \quad \text{or} \quad 1.2 < |\eta^{e_2}| < 2.8$



Z+2 jets @ CDF

- Hadronic corrections from CDF



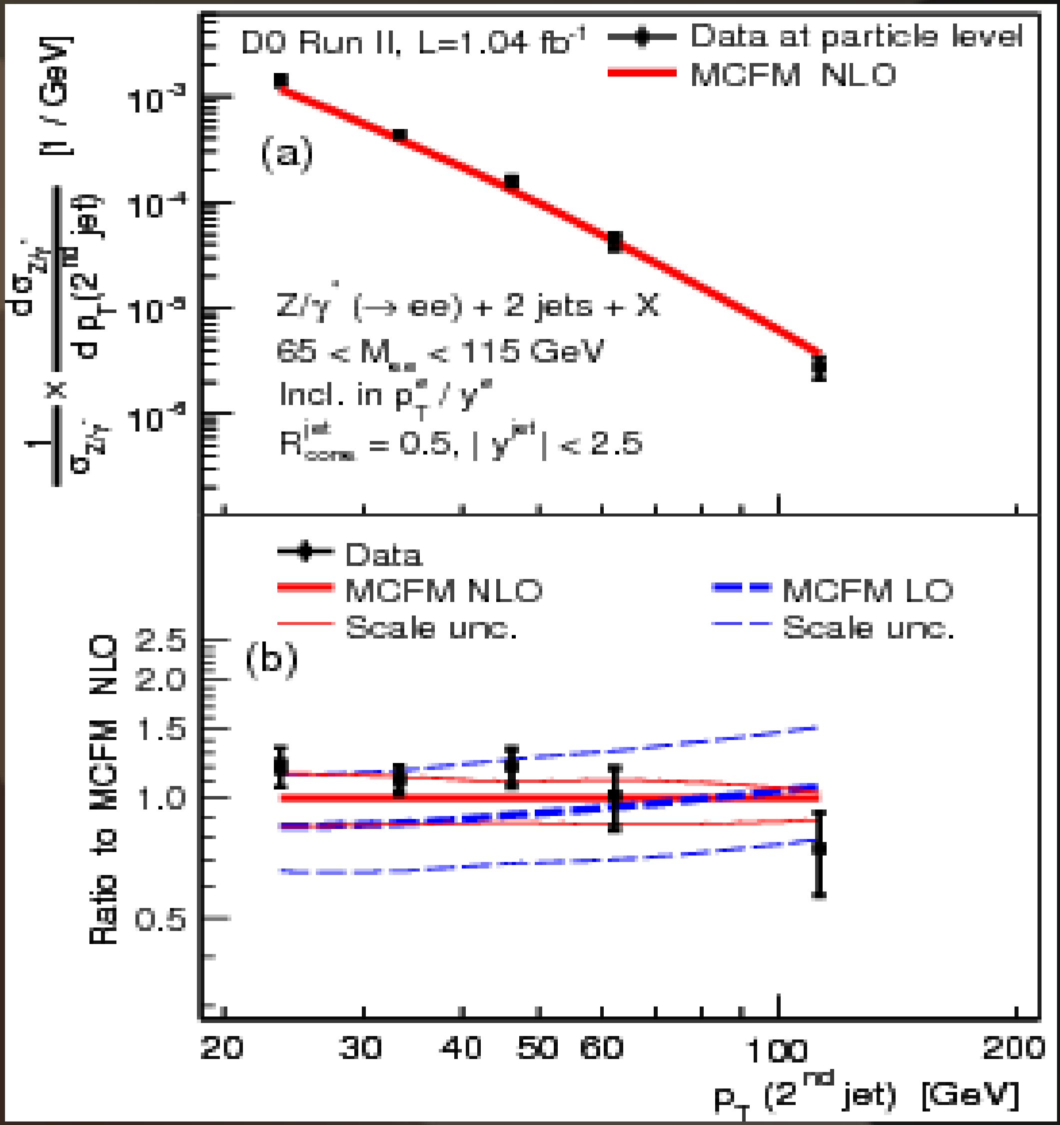
Z+jets @ D0

- ArXiv 0903.1748
- 1 fb^{-1}

$$65 < M_{e^+e^-} < 115 GeV$$

$$R^{jet}_{\text{cone}} = 0.5$$

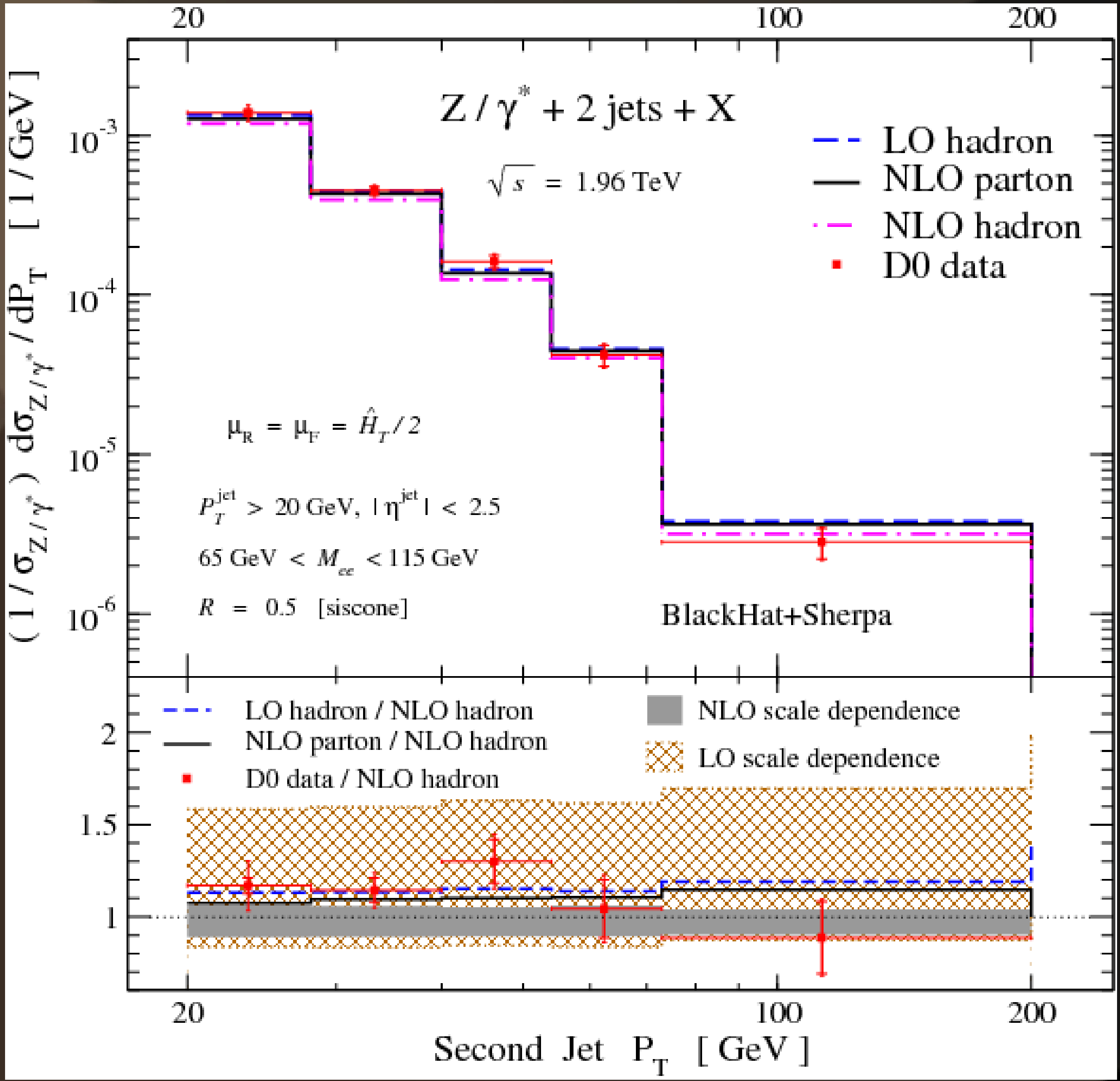
$$p_T^{\text{jet}} > 20\, GeV\ |y^{\text{jet}}| < 2.5$$



$$E_T^e > 25\, GeV\ |y^e| < 1.1 \text{ or } 1.5 < |\text{y}^e| < 2.5$$

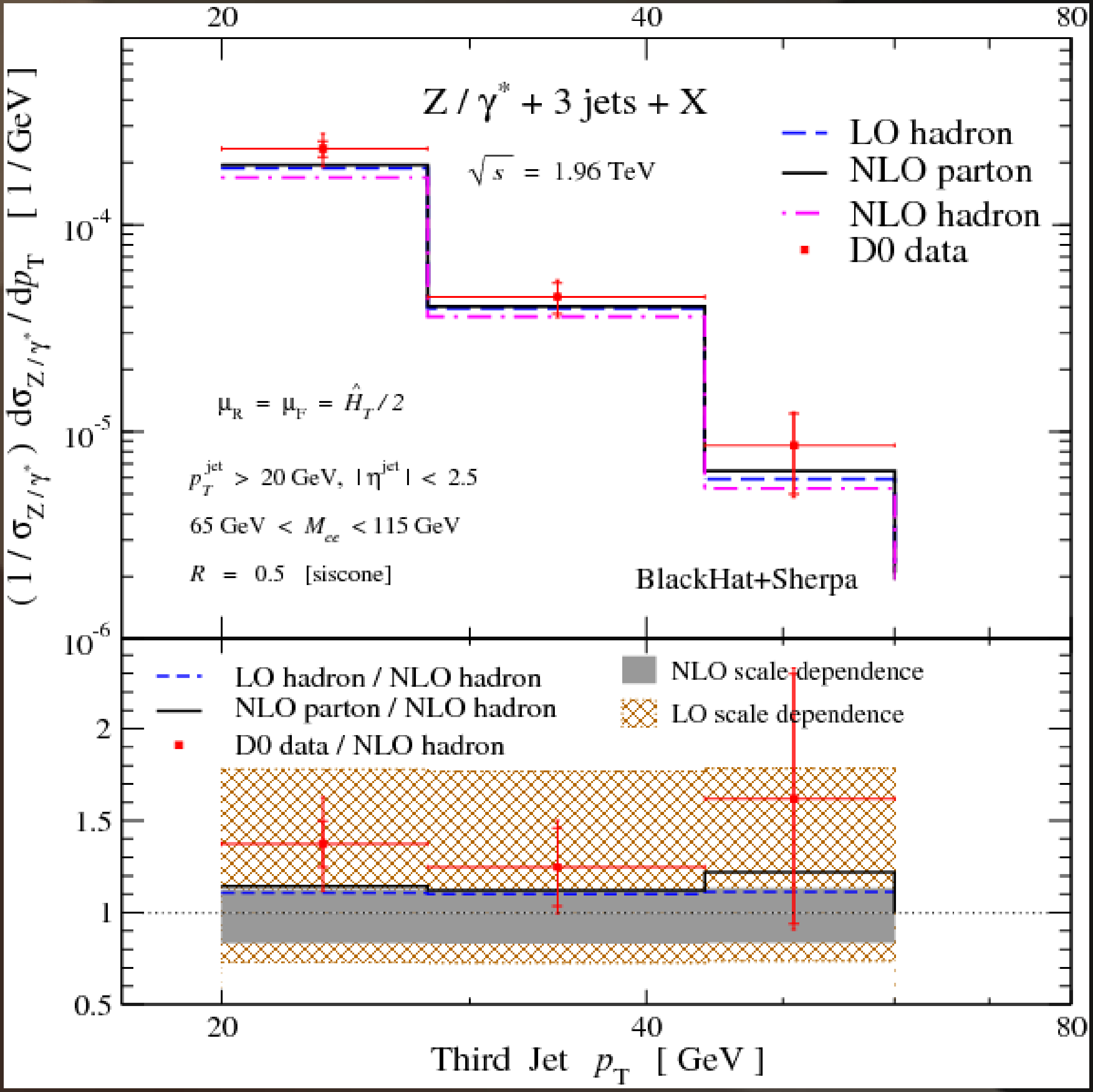
Z+2 jets at D0

- Used hadronic corrections supplied by D0
- Scale $\hat{H}_T/2$



Z+3 jets @ D0

- Used hadronization corrections from D0
- Scale $\hat{H}_T/2$



Towards W+4 jets

- Start with leading color approximation
- Check numerical stability
- Check speed
- Integrate
- Produce distributions

Towards W+4 jets

- Same technology for virtual part
- Real part is very challenging
  - Matrix elements are supplied by BlackHat (BCFW recursion)

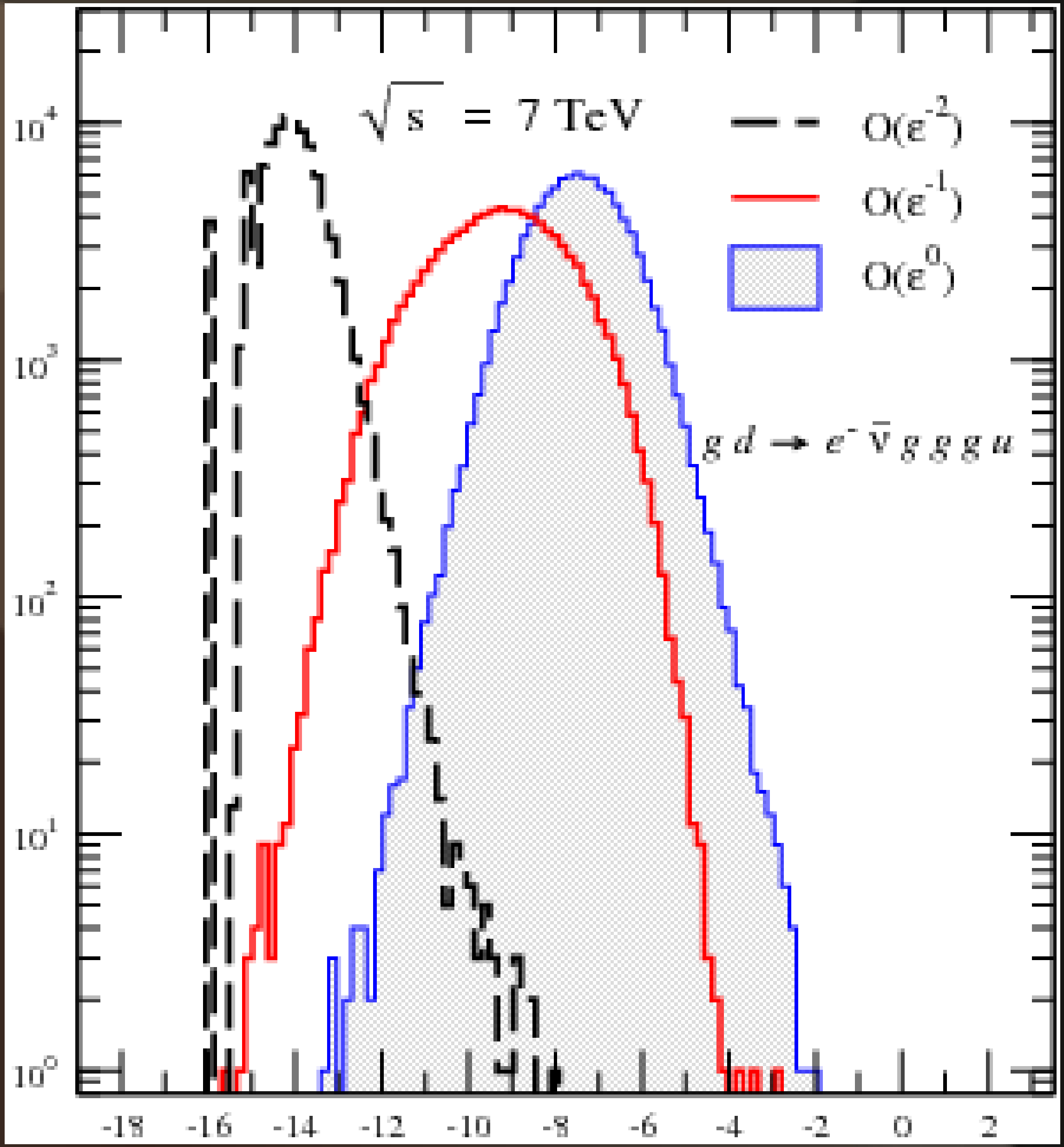
$$\sigma_n^{NLO} = \int_n \sigma_n^{tree} + \int_n \left(\sigma_n^{virt} + \Sigma_n^{sub}\right) + \int_{n+1} \left(\sigma_{n+1}^{real} - \sigma_{n+1}^{sub}\right)$$

Stability for W+4 jets

- Numerical stability is under control
- Accuracy

$$\log\left(\frac{d\sigma_V^{\mathrm{BH}} - d\sigma_V^{\mathrm{target}}}{d\sigma_V^{\mathrm{target}}}\right)$$

$$g\,d \to e^-\,\bar{\nu}_e\,g\,g\,g\,u$$

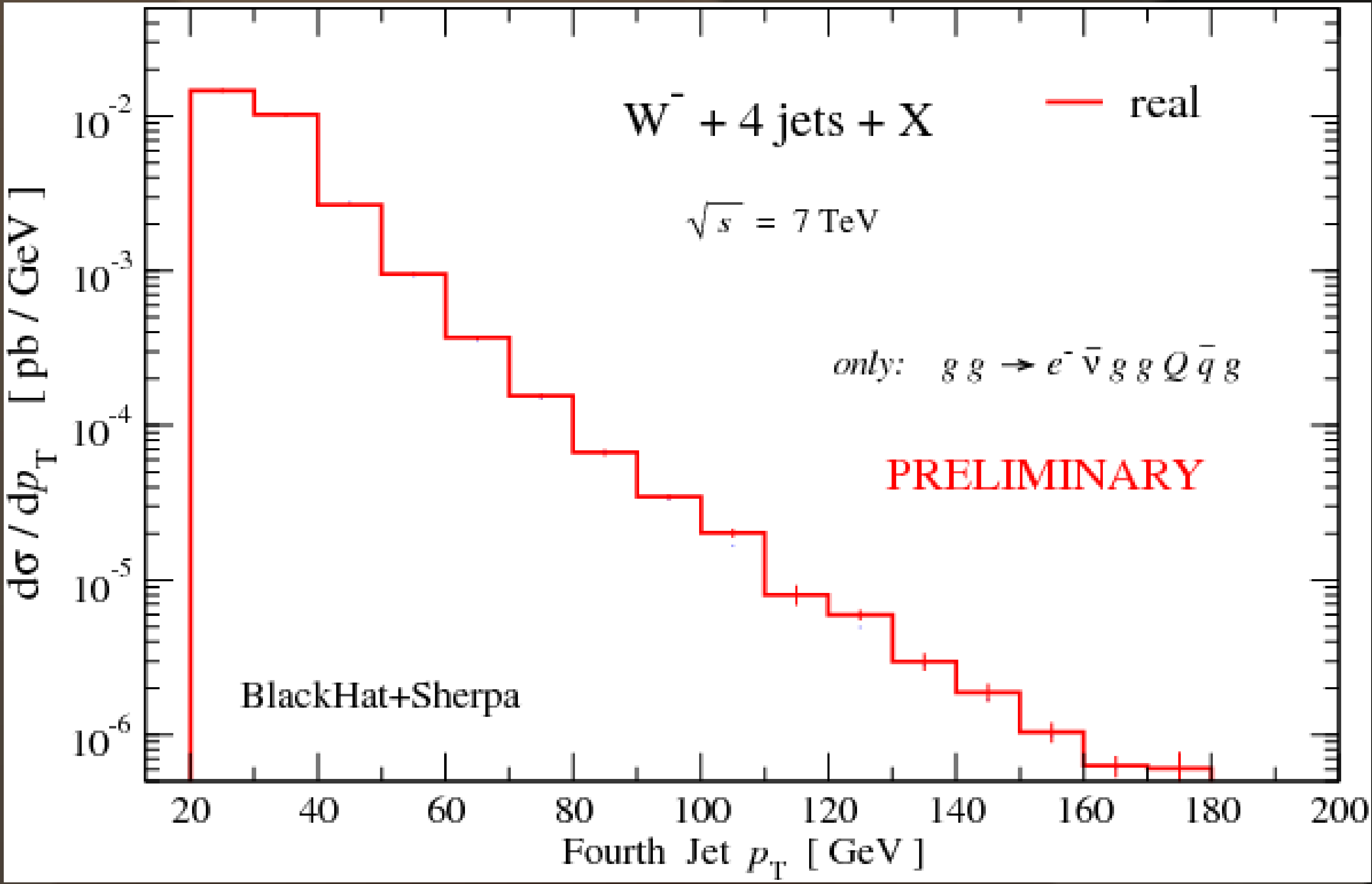


“Proof of principle” plots

- Show that a reasonable integration accuracy can be obtained
- Show numerical stability for real part
- Not all checks performed → PRELIMINARY

Real part

- Uses tree ME from BlackHat



- 200'000'000 PS points

Still a lot to do

- Checks, checks, checks, …
- Accumulate statistics
- …

- But we see the light at the end of the tunnel

Conclusion

- Showed comparison of NLO W/Z+ 3 jets and experimental data from the Tevatron
- Presented progress towards NLO results for W+4 jets

Outlook

- Public version of BlackHat
- W/Z+4 jets, ...
- Merging with parton shower
- NLO as the standard theory prediction at the LHC