NLO QCD prediction for W+3 jets

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in Collaboration with

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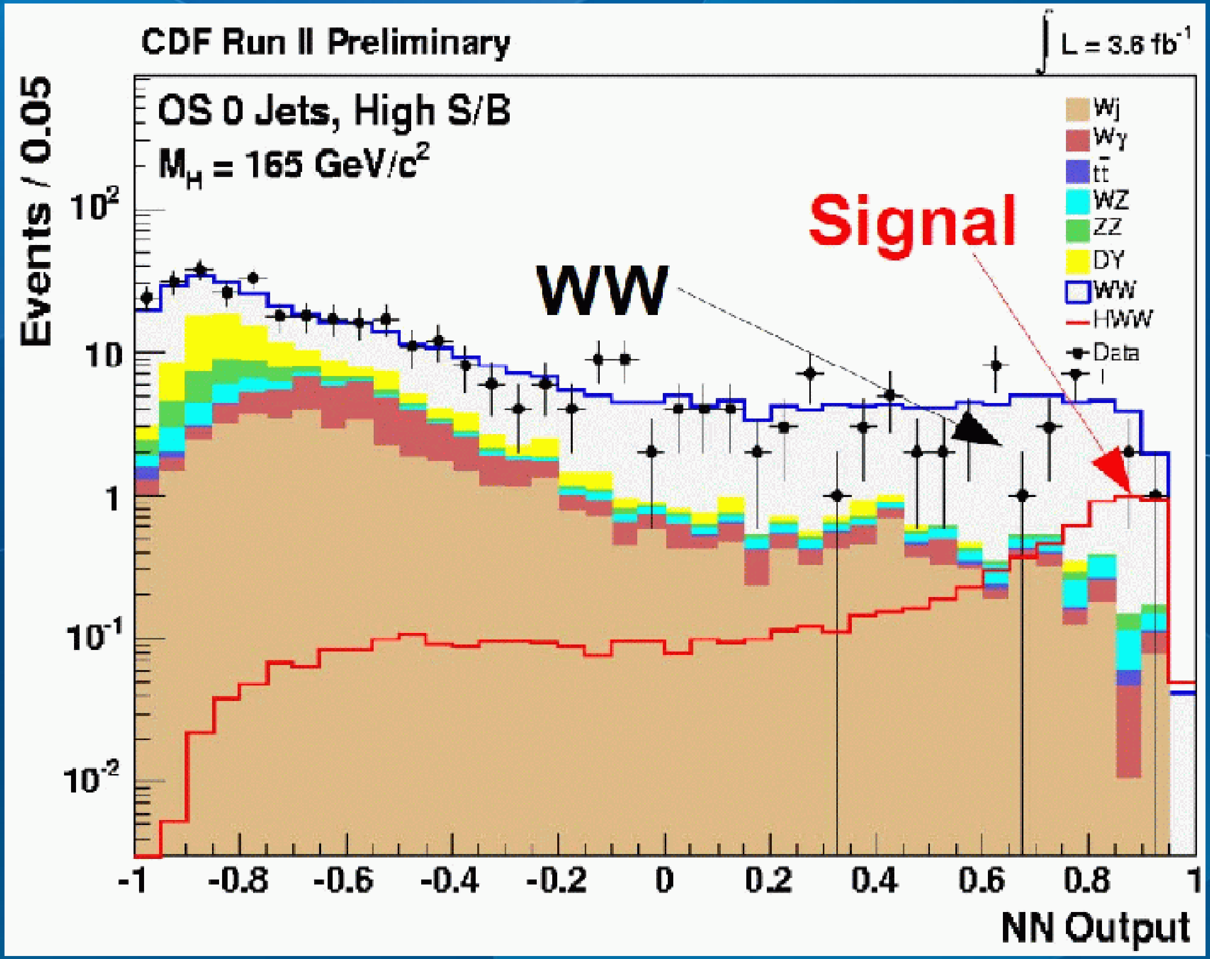
Based on arXiv:0907.1984

Motivation

- Theoretical predictions for QCD processes are crucial for the physics program at a hadron collider
  - Signal
  - Background
- Many measurements are limited by uncertainties from theory prediction

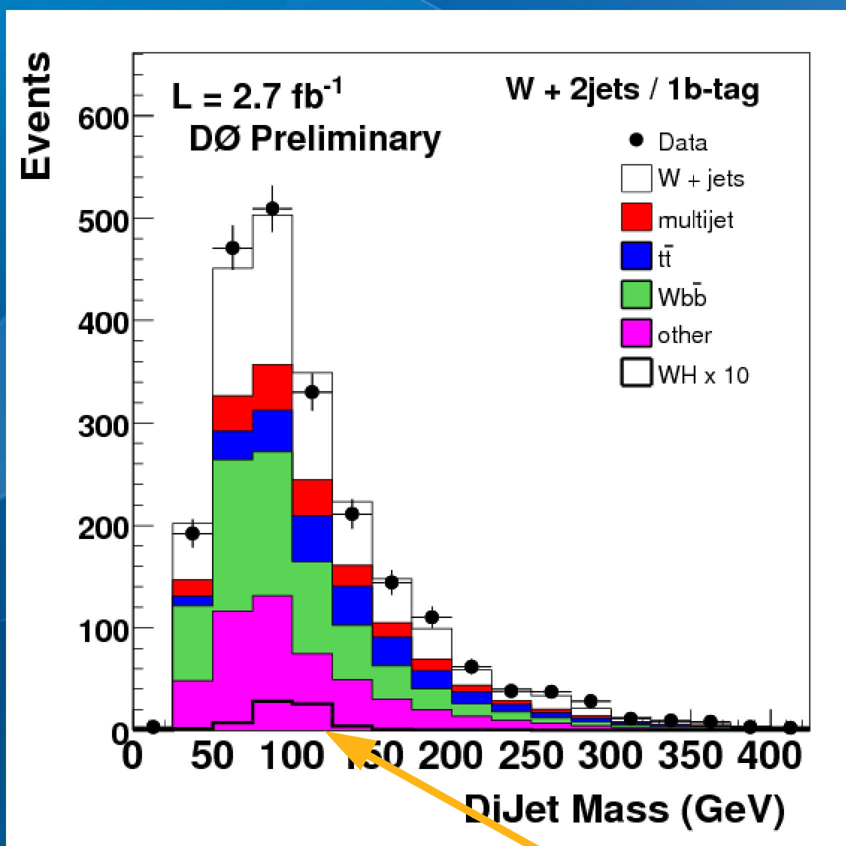
Motivation

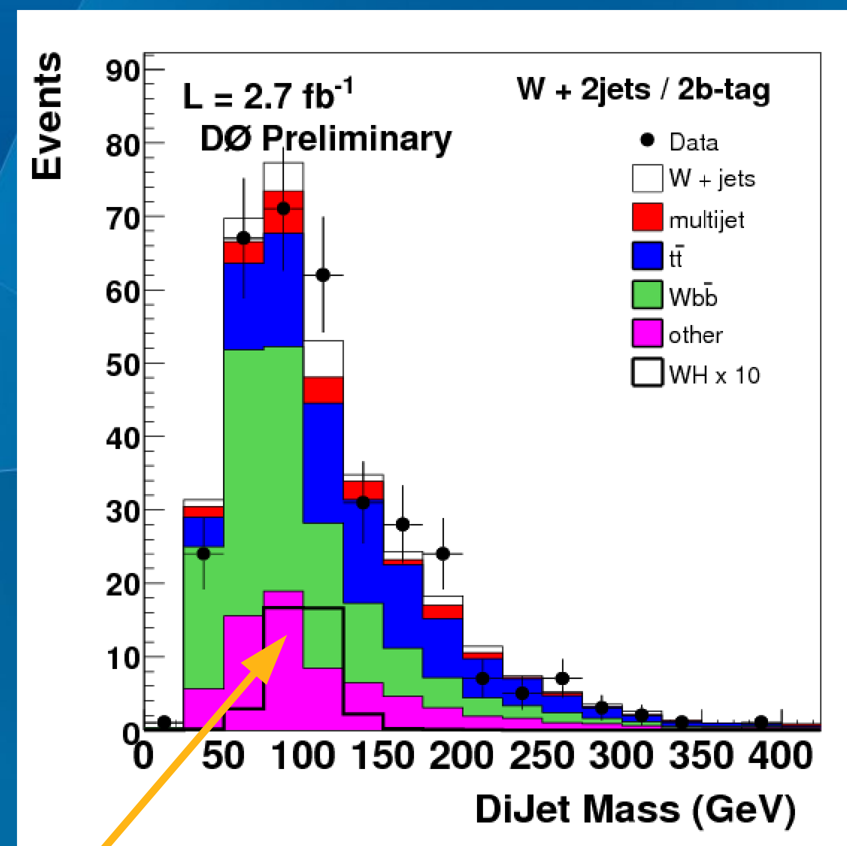
- Higgs →WW search @ CDF



Motivation

- Higgs associated production WH ($H \rightarrow b\bar{b}$)





Signal x 10

Leading order

- Lots of good general tools for leading order cross sections (Madgraph, Herwig, Sherpa, Alpgen, Whizard, Pythia, …)
- Large factorisation/renormalisation scale dependence
- Possible improvements
  - Parton shower
  - Resummation (N....LL)
  - More orders in perturbation theory (N....LO)

NLO Corrections

- Consider (infrared safe) observable

- Add contributions that have an higher order in perturbation theory, but yield the same value for an observable
  - Virtual

  - Real

NLO Corrections

- NLO corrections are needed for a good theoretical understanding of QCD processes
- Improve theory prediction for
  - Absolute normalization
    - Corrections can be very large
    - Reduce renormalization scale dependency
  - Shape of distributions

NLO with BlackHat+Sherpa

- BlackHat

  - Virtual part

- Sherpa

  - Leading order
  - Real part
  - Integration of the virtual part

Sherpa

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

Provides

- Efficient phase space integration
- Event generation
- Analysis framework
- Automated dipole subtraction for the real part
- (and much more)
- Is written in C++

[Catani,Seymour]

[Gleisberg,Krauss]

BlackHat

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

- Goal : automate computation of virtual 1-loop amplitudes for QCD processes
- C++ framework
- 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
    [Ellis,Giele,Kunszt;Badger]

W+jets @ Tevatron and LHC

- W/Z+jets processes are important
  - For SM physics (Higgs, $t\bar{t}$, single top)
  - Background to new physics
  - Luminosity determination

So far

- MCFM [John Campbell, Keith Ellis]
  - NLO W+1 jet (Feynman diagrams)
  - NLO W+2 jets (amplitudes from unitarity methods)
- Amplitudes
  - Leading color primitive amplitudes (2q3gW) [BlackHat]
  - All primitive amplitudes [Ellis,Giele,Kunszt,Melnikov,Zanderighi; van Hameren,Papadopoulos,Pittau]
- Cross section
  - Leading color W+3 jets (2q3gW) [Ellis,Melnikov,Zanderighi]
  - Leading color W+3 jets (all subprocesses) [BlackHat]
  - Leading color W+3 jets (with rescaling to account for subleading color) [Ellis,Melnikov,Zanderighi]
  - Full color W+3 jets (all subprocesses) [BlackHat]

W+jets @ Tevatron

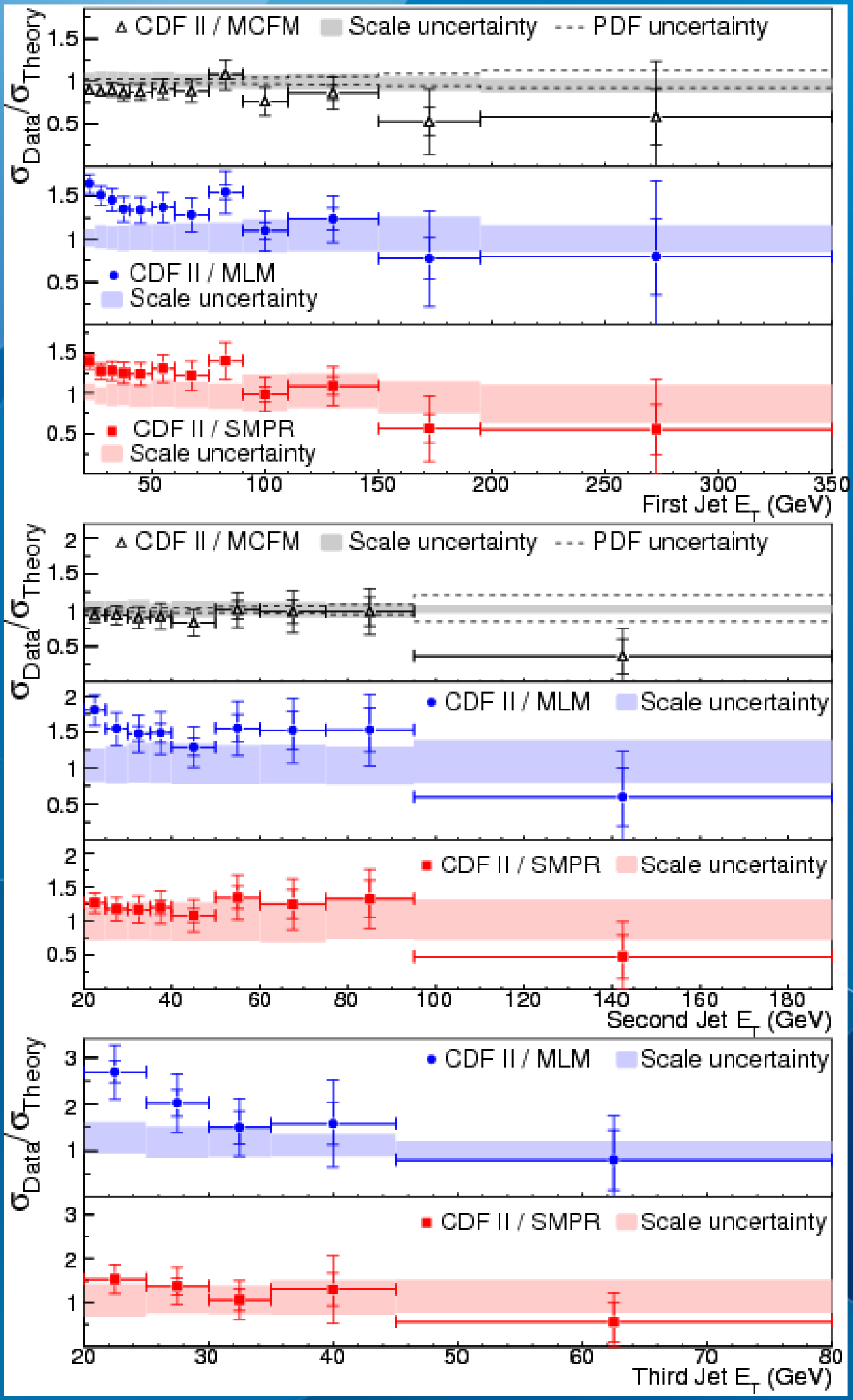
- CDF Collaboration
  - $320pb^{-1}$
  - Corrected for comparison with particle level
  - Comparison with
    - NLO: MCFM
    - MLM = Alpgen+Herwig
    - SMPR = Madgraph+Pythia

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

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

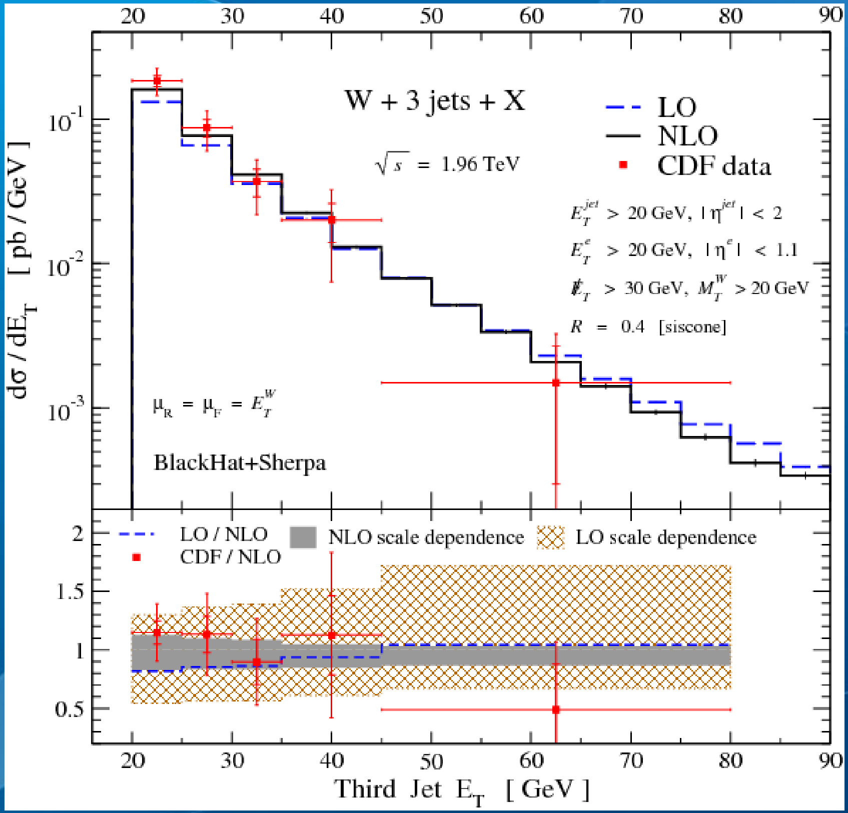
$|\eta^{\text{jets}}| < 2 \quad E_T^{\text{jets}} > 20$ GeV

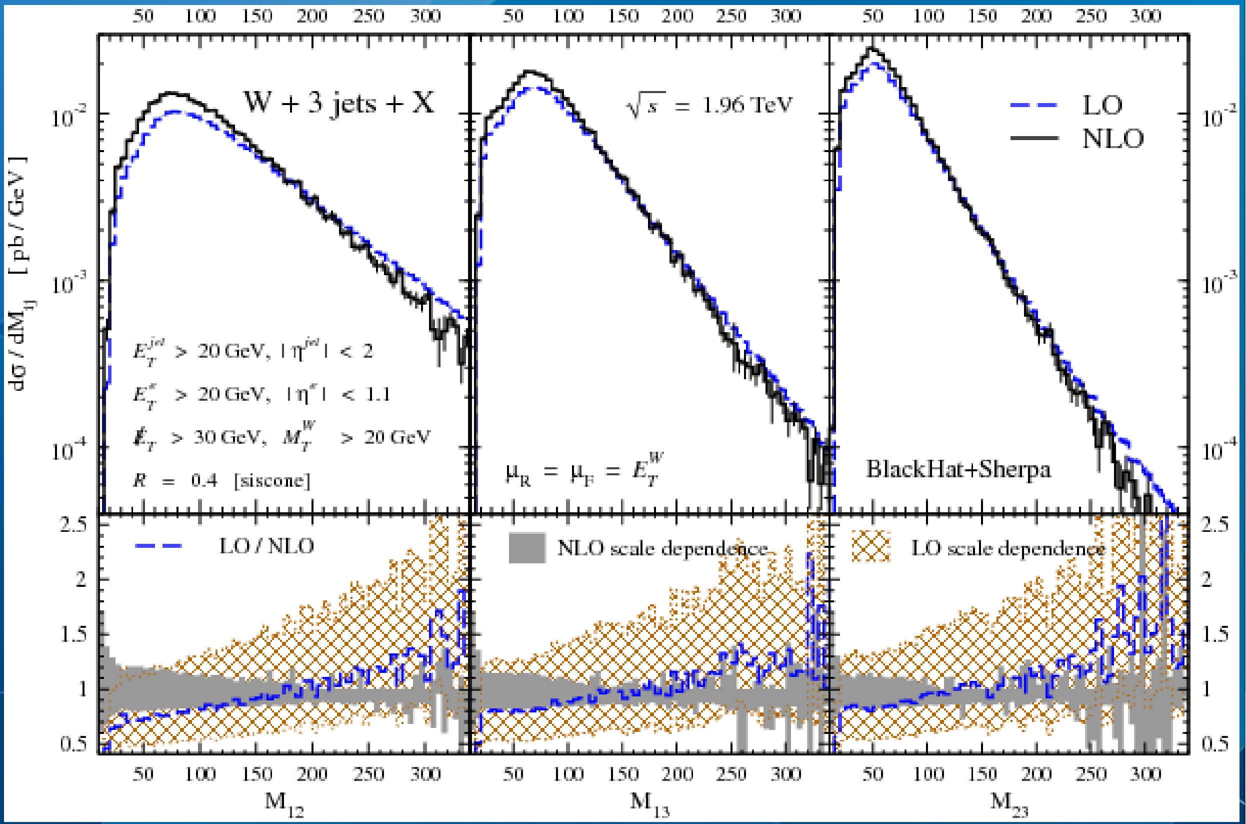
$M_T^W > 20$ GeV



[CDF Collaboration PRD 77 011108, Arxiv:0711.4044]

W+3 jets @ Tevatron





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

PDF: CTEQ6M

Jet algorithm: SISCone [Salam,Soyez]

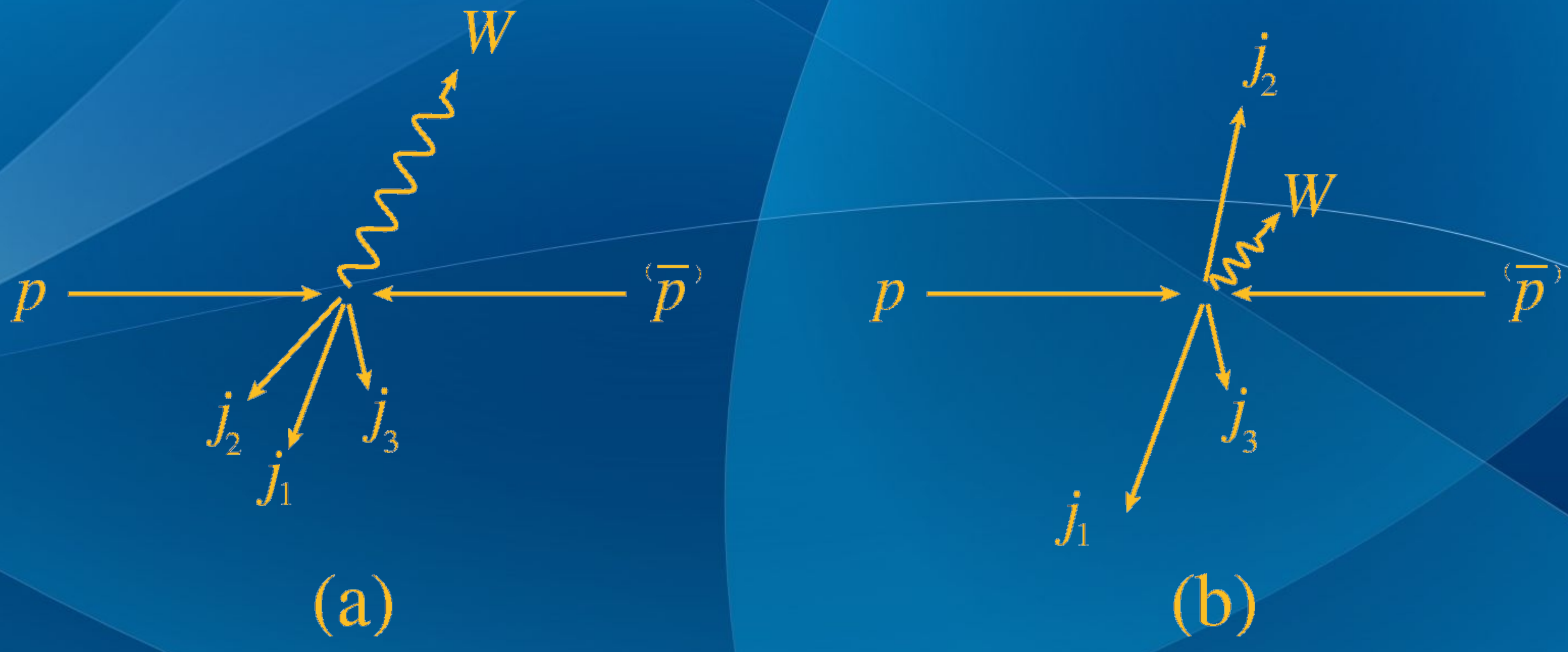
Scale Choice

- Theory predictions depend on two unphysical scales
  - Renormalization scale
  - Factorization scale
- Due to the truncation of the perturbation series
- Want to choose a scale “typical” for the process
- Complicated processes have many scales
- Good choice of scale
  - Cross sections and distributions should be positive
  - LO has a shape close to the NLO one

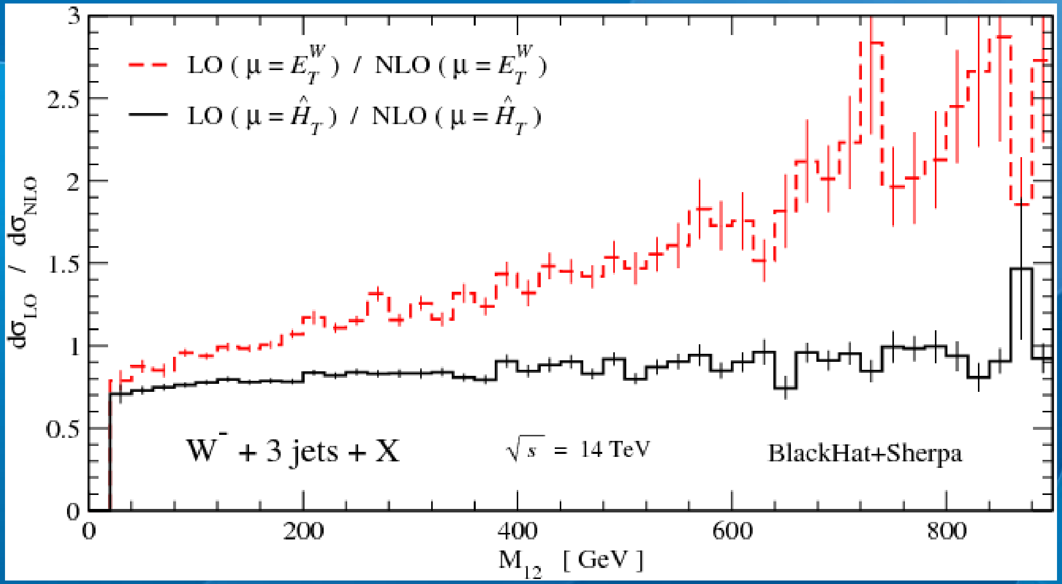
Scale choice

- Possible scale choices:

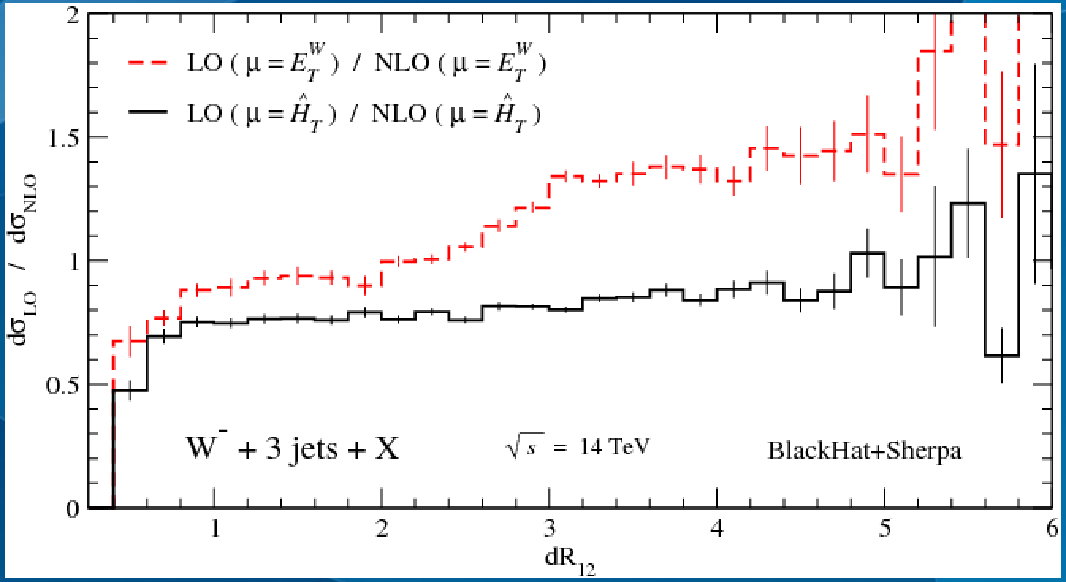
$$E_T^W = \sqrt{m_W^2 + p_T^2(W)} \qquad H_T = \sum_{j=1,2,3} E_{T,j}^{\text{jet}} + E_T^e + \not{E}_T$$



Scale choice



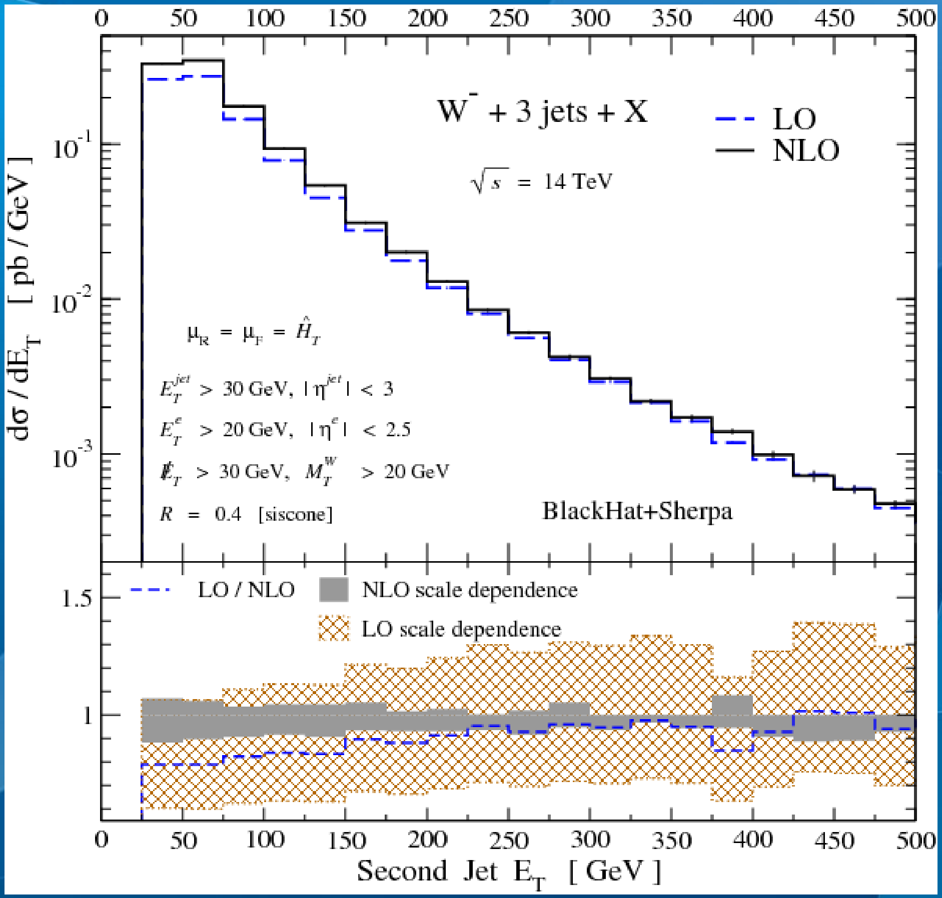
$$M_{ij}^2 = (p_i^{\text{jet}} + p_j^{\text{jet}})^2$$

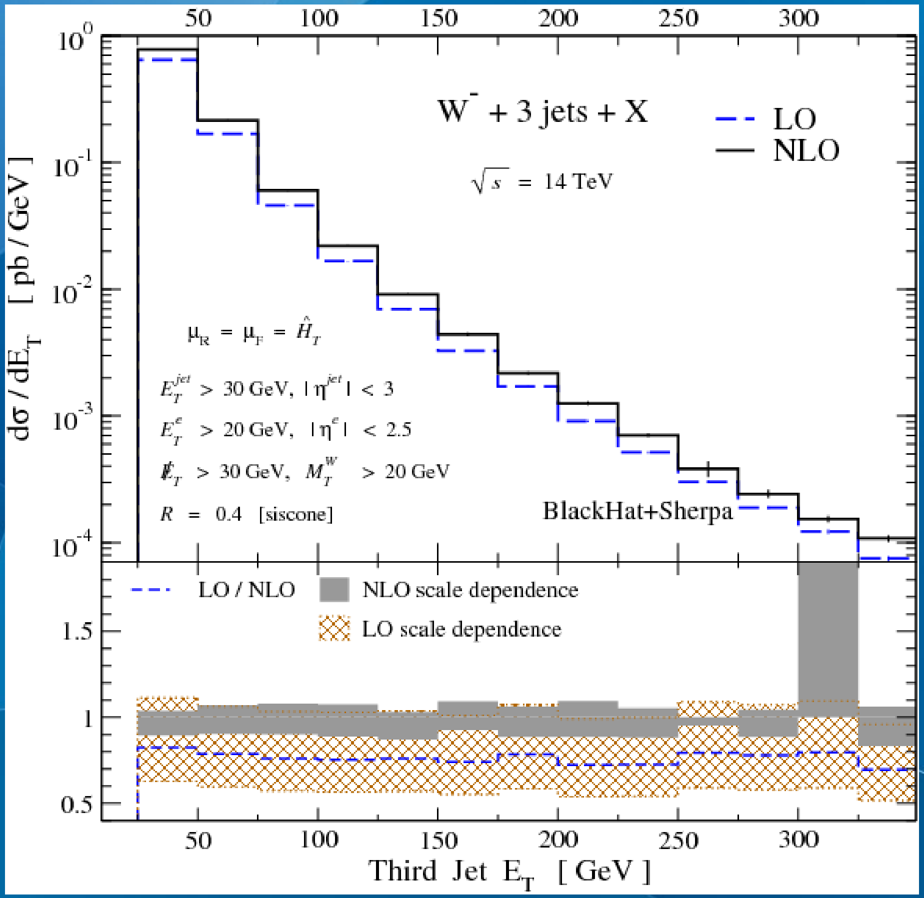


- Does not work for all distributions!
- Distributions that are specifically sensitive to the W
- Choice of scale has more effect at LHC, but visible at Tevatron

$$\Delta R_{12} = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$$

LHC



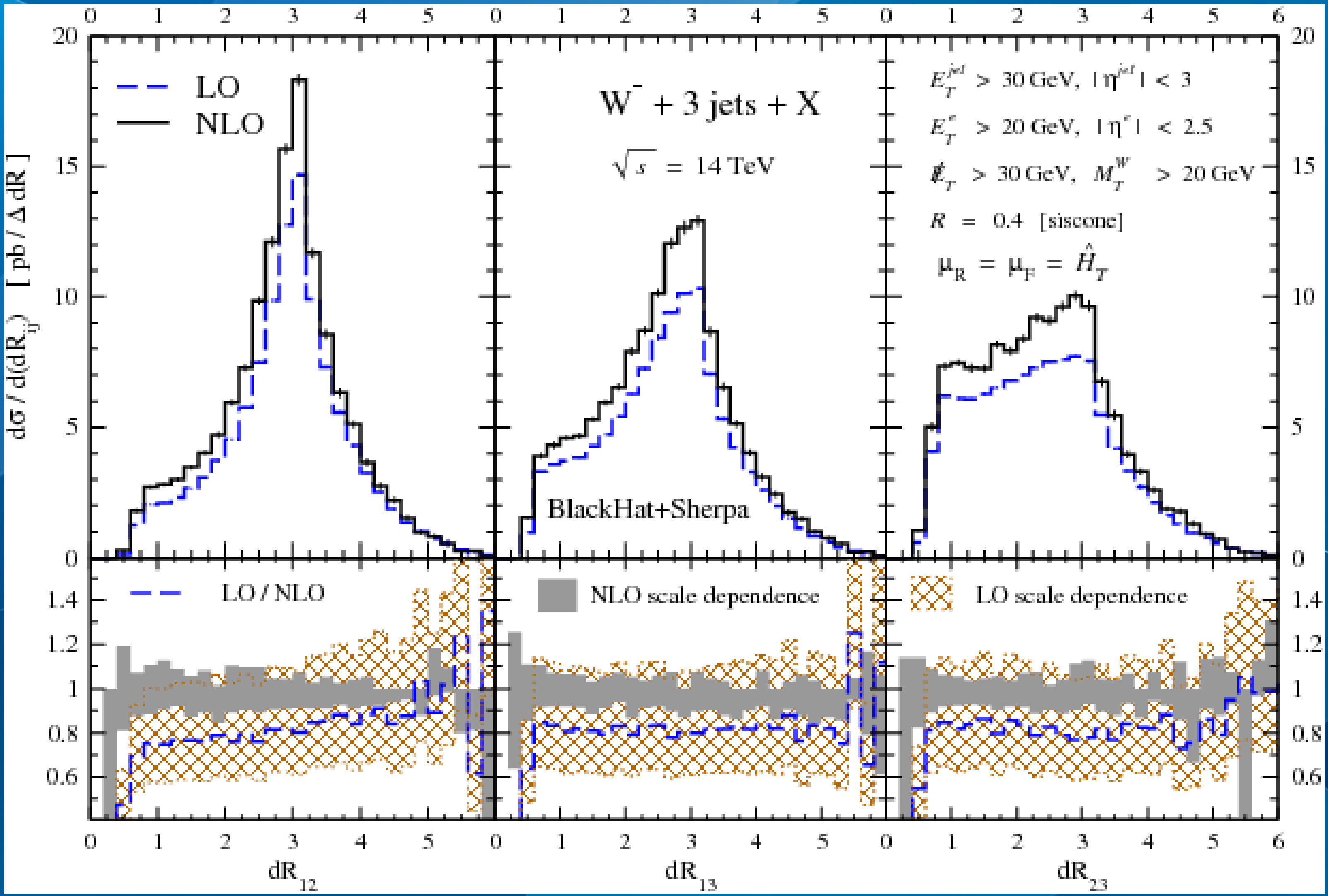


$\sqrt{s} = 14\,\mathrm{TeV}$ $\mu = H_T$

$E_T^e > 20\,\mathrm{GeV}$ $E_T^{\mathrm{jet}} > 30\,\mathrm{GeV}$ $|\eta^{\mathrm{jet}}| < 3$ $|\eta^e| < 2.5$

$E_T^\nu > 30\,\mathrm{GeV}$ $R = 0.4$ $M_T^W > 20\,\mathrm{GeV}$

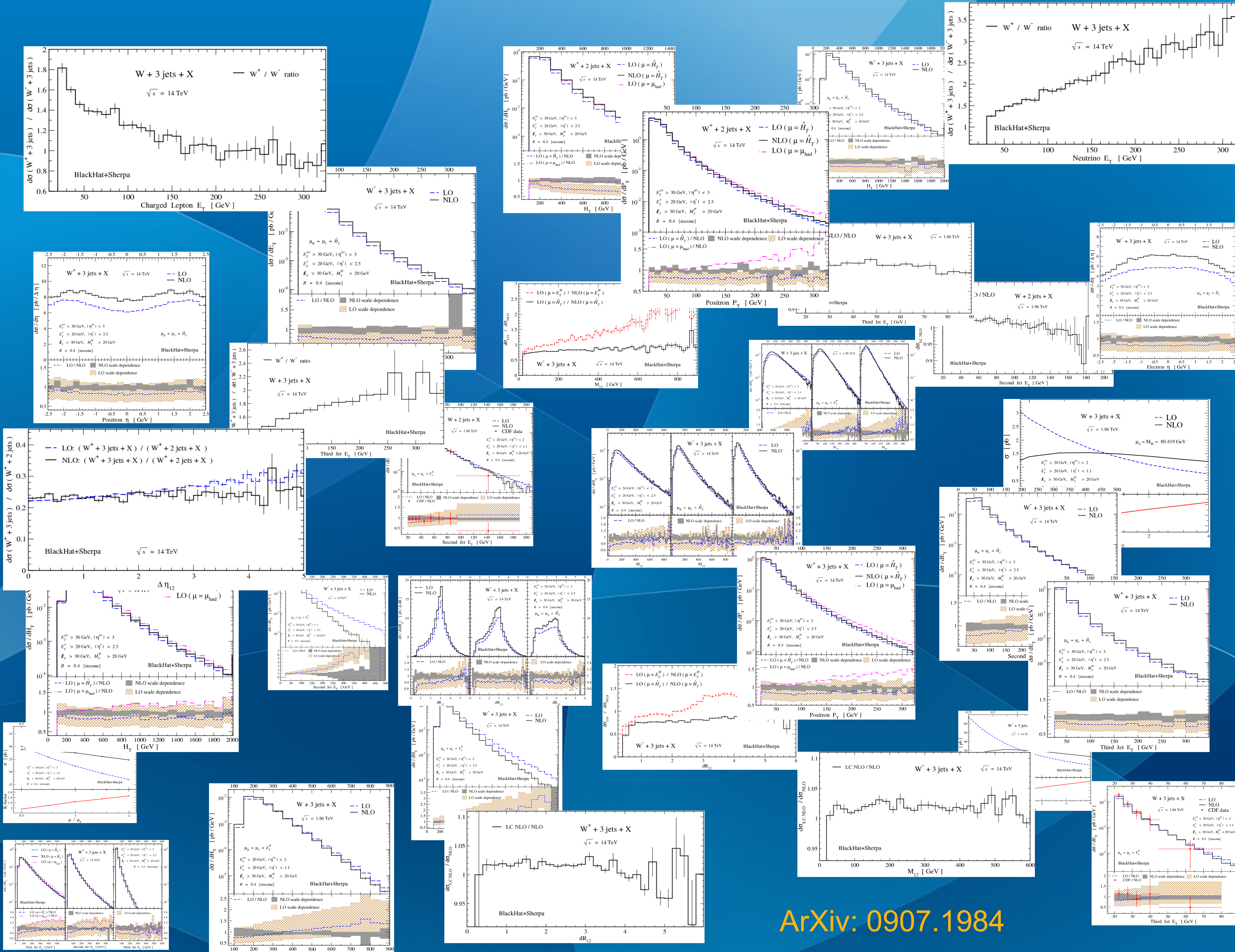
W+3 jets @LHC



LO
NLO
$W^- + 3$ jets + X
$\sqrt{s}$ = 14 TeV
E_T^{jet} > 30 GeV, $|\eta^{jet}|$ < 3
E_T^e > 20 GeV, $|\eta^e|$ < 2.5
$\not{E}_T$ > 30 GeV, M_T^W > 20 GeV
R = 0.4 [siscone]
$\mu_R = \mu_F = \hat{H}_T$
BlackHat+Sherpa
dσ / d(dR$_{ij}$) [pb / Δ dR]
LO / NLO
NLO scale dependence
LO scale dependence
dR$_{12}$
dR$_{13}$
dR$_{23}$

Conclusions

- Presented first full color NLO results for W+3jets @ Tevatron and LHC
- Show potential of unitarity techniques for phenomenology



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