NLO QCD prediction for W+3 jets

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in Collaboration with


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 ($H \rightarrow b\bar{b}$)
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 a 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++
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, $tt\bar{t}$, 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
- 320\(pb^{-1}\)
- Corrected for comparison with particle level
- Comparison with
  - NLO: MCFM
  - MLM = Alpgen+Herwig
  - SMPR = Madgraph+Pythia

\[ E_T^e > 20 \text{ GeV} \quad E_T^{\text{jets}} > 20 \text{ GeV} \]
\[ |\eta^e| < 1.1 \quad E_T^e > 30 \text{ GeV} \]
\[ |\eta^{\text{jets}}| < 2 \quad E_T^{\text{jets}} > 20 \text{ GeV} \]
\[ M_T^W > 20 \text{ GeV} \]

[CDF Collaboration PRD 77 011108, Arxiv:0711.4044]
W+3 jets @ Tevatron

\[ \mu = \sqrt{m_W^2 + p_T^2} \]

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:

\[ E_T^W = \sqrt{m_W^2 + p_T^2(W)} \]

\[ H_T = \sum_{j=1,2,3} E_{T,j}^{\text{jet}} + E_T^{e} + E_T^{\nu} \]

(a) [Diagram showing two particles, one with a W boson and three jets, and the other with a W boson and two jets.]

(b) [Diagram showing two particles, one with a W boson and three jets, and the other with a W boson and two jets.]
Scale choice

- 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

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

\[
\Delta R_{12} = \sqrt{(\Delta \phi)^2 + (\Delta \eta)^2}
\]
\[ \sqrt{s} = 14 \text{ TeV} \quad \mu = H_T \]

\[ E_T^e > 20 \text{ GeV} \quad E_T^{\text{jet}} > 30 \text{ GeV} \quad |\eta^{\text{jet}}| < 3 \quad |\eta^e| < 2.5 \]

\[ E_T^\nu > 30 \text{ GeV} \quad R = 0.4 \quad M_T^W > 20 \text{ GeV} \]
W+3 jets @LHC

\[ \sqrt{s} = 14 \text{ TeV} \]

- \( E_T^{\text{jet}} > 30 \text{ GeV} \)
- \( 1 \eta_{\text{jet}} < 3 \)
- \( E_T^e > 20 \text{ GeV} \)
- \( 1 \eta^e < 2.5 \)
- \( \hat{E}_T > 30 \text{ GeV} \)
- \( M_W > 20 \text{ GeV} \)
- \( R = 0.4 \) [siscone]
- \( \mu_R = \mu_F = \hat{H}_T \)

\( \frac{d\sigma}{dR} \) [pb/\( \Delta R \)]
Conclusions

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