NLO predictions for multi-leg processes with BlackHat and Sherpa

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DIS 2013, Marseille, 24 April 2013

Outline

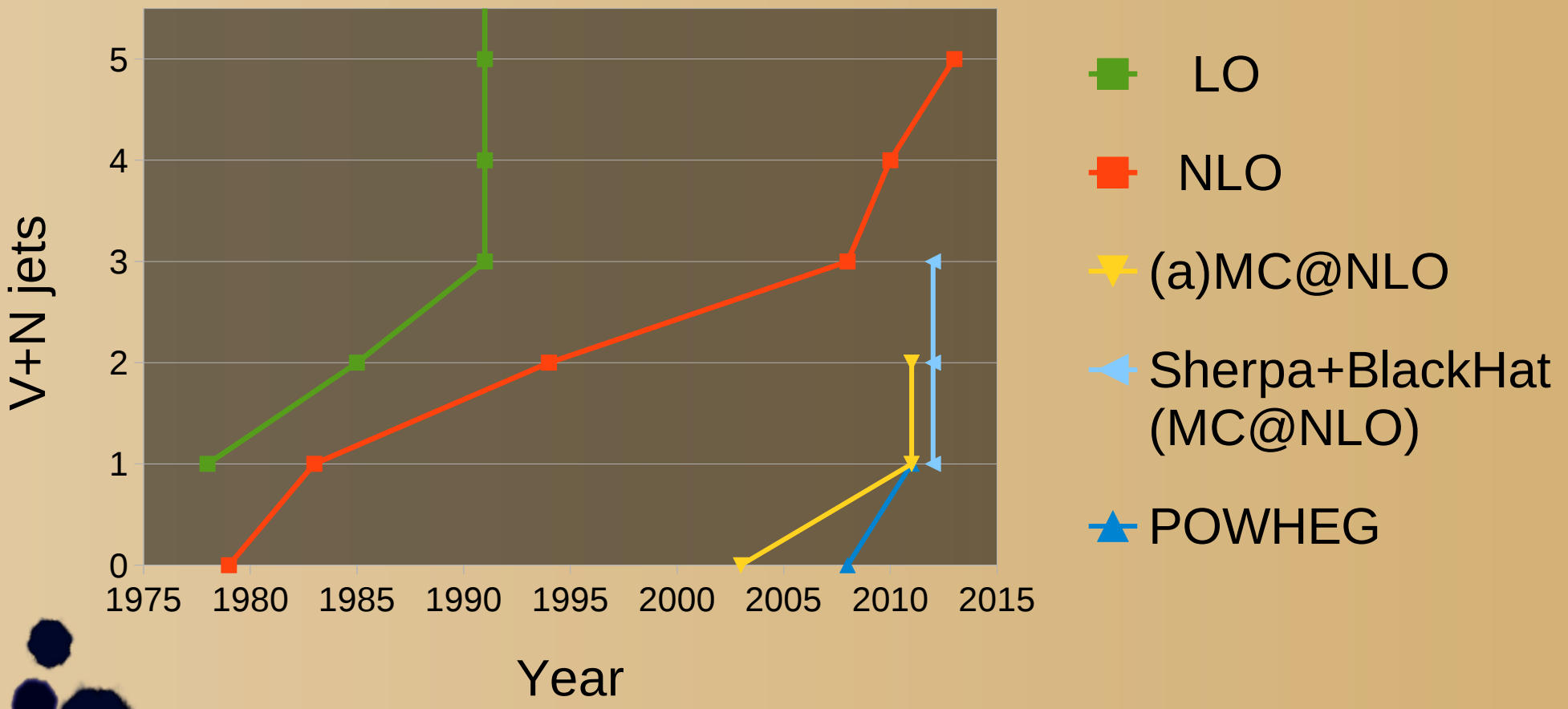
- NLO calculation
- Applications (W+5j)
- “Exclusive sums”

Precise predictions

- Precise predictions are needed
  - Signal
  - Background
  - Also for data-driven methods
    - Extrapolation from control to signal region
    - Transfer of information from one process to another
- NLO improves
  - Absolute normalisation
  - Shapes of distributions
  - Scale dependence

Recent progress

- Number of jets in addition to the vector boson



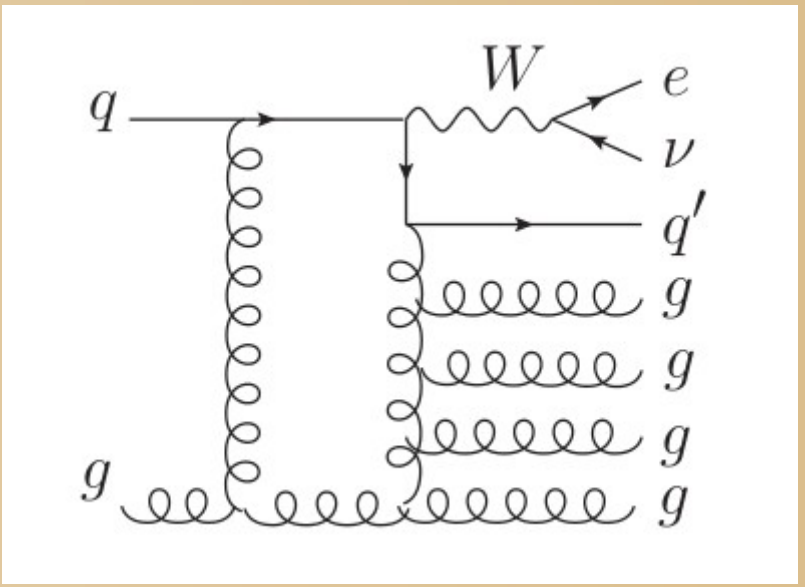
W/Z+jets with Blackhat and Sherpa

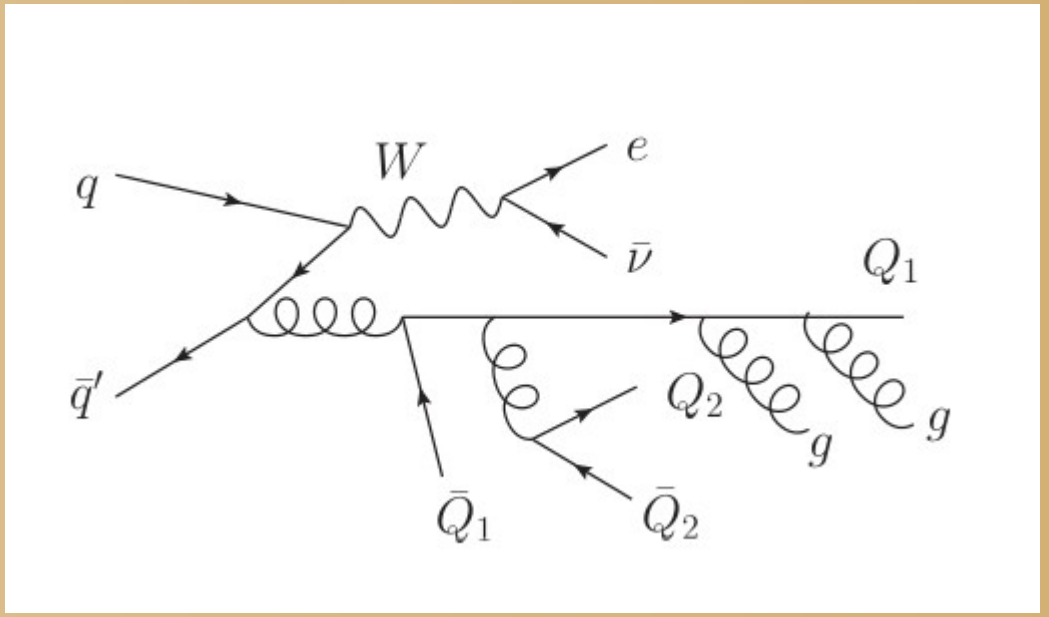
- Use BlackHat for the virtual part
- Real part is very challenging
- For W+4j the real matrix elements were supplied by BlackHat (BCFW recursion+analytic formulae [arXiv:1010.3991])

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

W+5 jets at NLO

- First NLO corrections for a 2 → 6 hadron collider process calculated

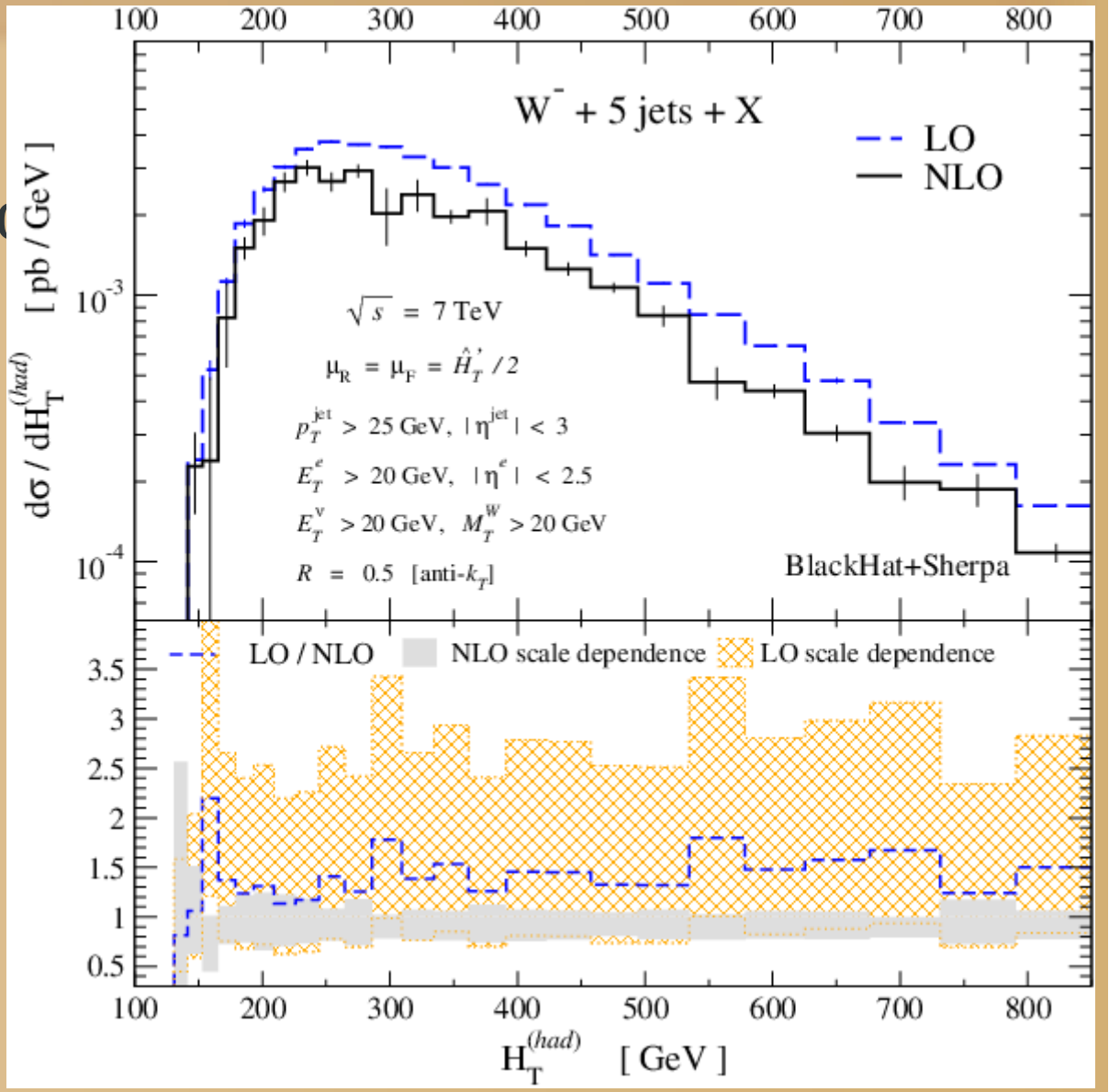




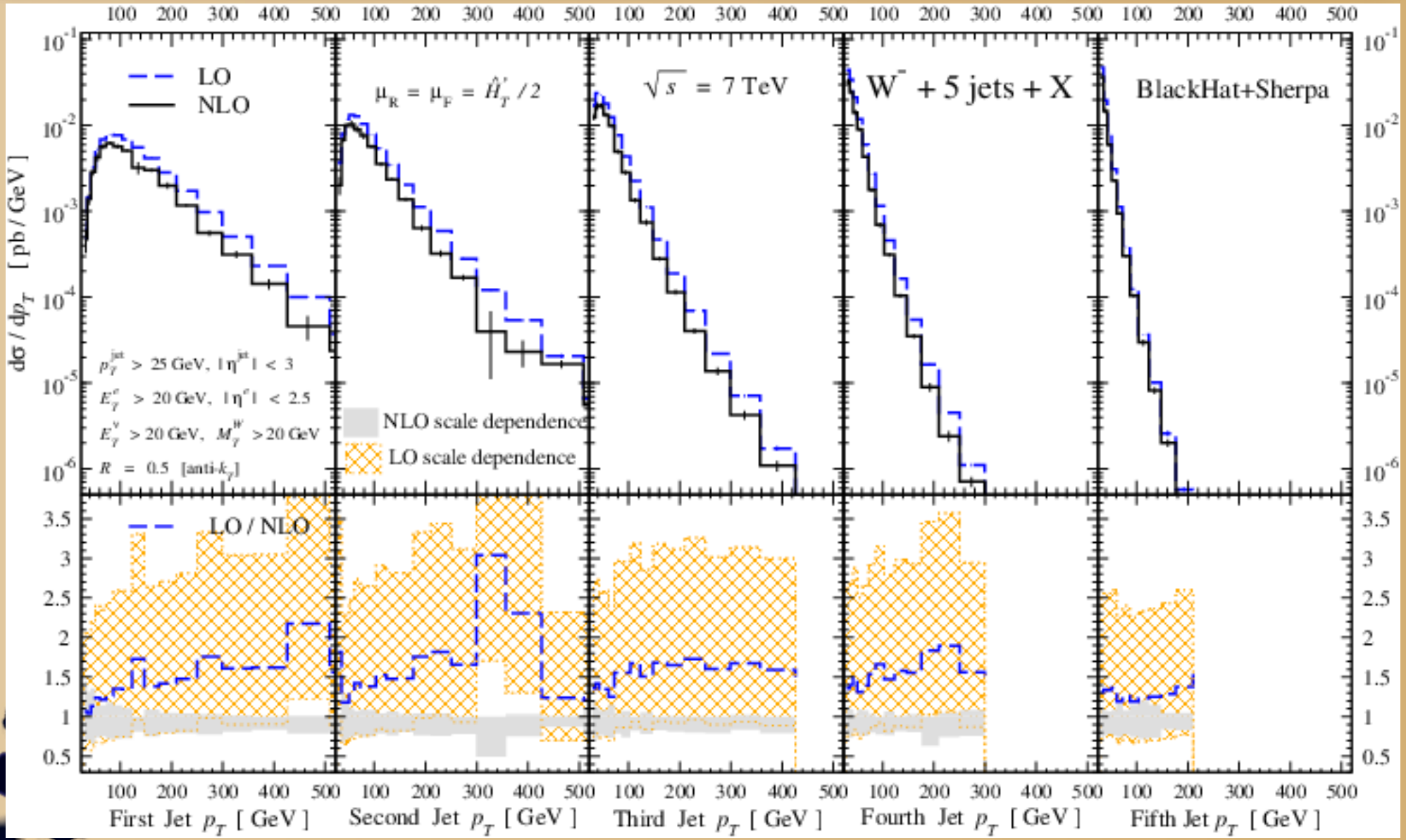
W+5 jets

- Leading color approximation for loo part
- Scale $\hat{H}'_T$
- $\hat{H}'_T \equiv \sum_m p_T^m + E_T^W$

$$E_T^W \equiv \sqrt{M_W^2 + (p_T^W)^2}$$

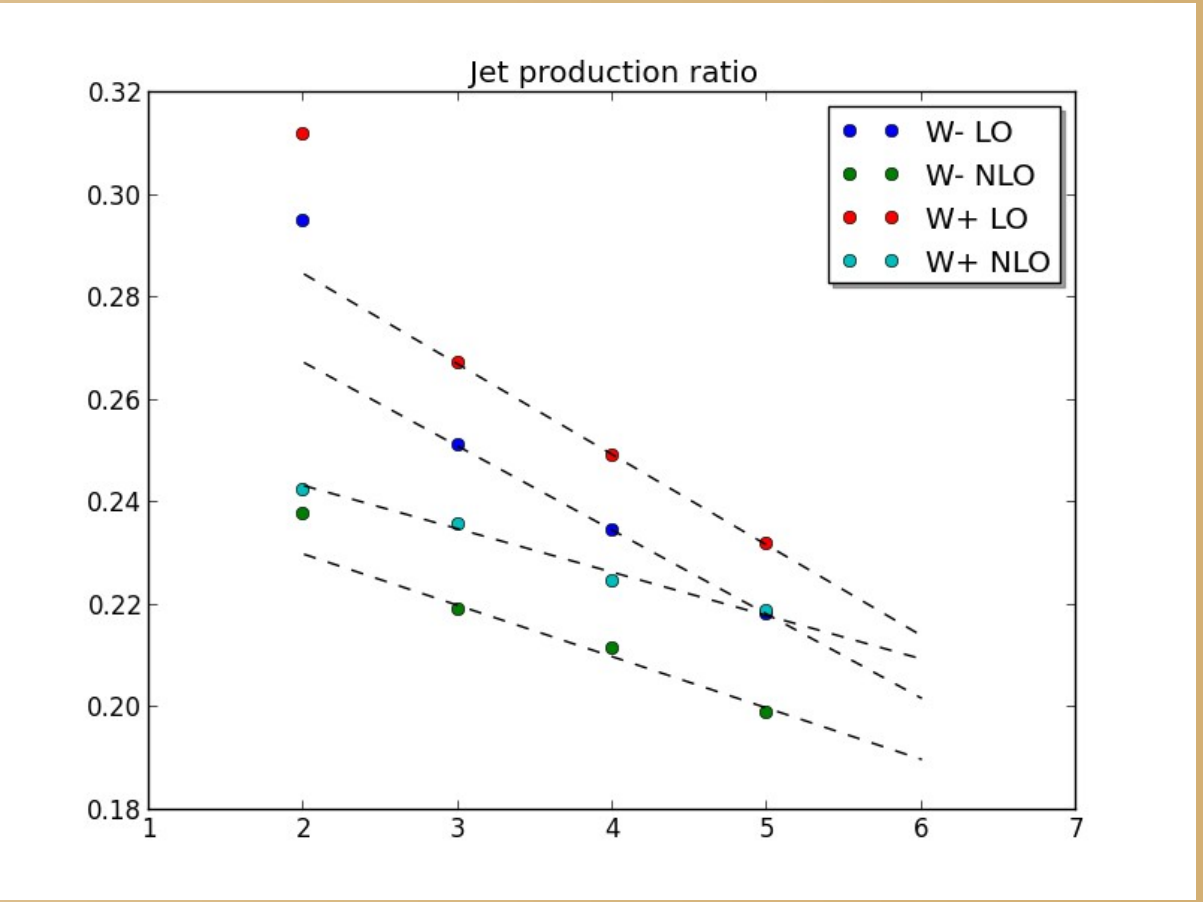


W+5 jets


LO
NLO
$\mu_R = \mu_F = \hat{H}_T' / 2$
$\sqrt{s}$ = 7 TeV
W^- + 5 jets + X
BlackHat+Sherpa
$p_T^{jet} > 25$ GeV, $|\eta^{jet}| < 3$
$E_T^e > 20$ GeV, $|\eta^e| < 2.5$
$E_T^\nu > 20$ GeV, $M_T^W > 20$ GeV
$R = 0.5$ [anti-k_T]
NLO scale dependence
LO scale dependence
LO / NLO
$d\sigma / dp_T$ [pb / GeV]
First Jet p_T [GeV]
Second Jet p_T [GeV]
Third Jet p_T [GeV]
Fourth Jet p_T [GeV]
Fifth Jet p_T [GeV]

Extrapolation for ratios

- Ratio n jets/(n-1 jets)
- Use extrapolation for 6 jets:
- W− : 0.15 ± 0.01 pb
- W+ : 0.30 ± 0.03 pb
- Consistent with extrapolation of charge asymmetry



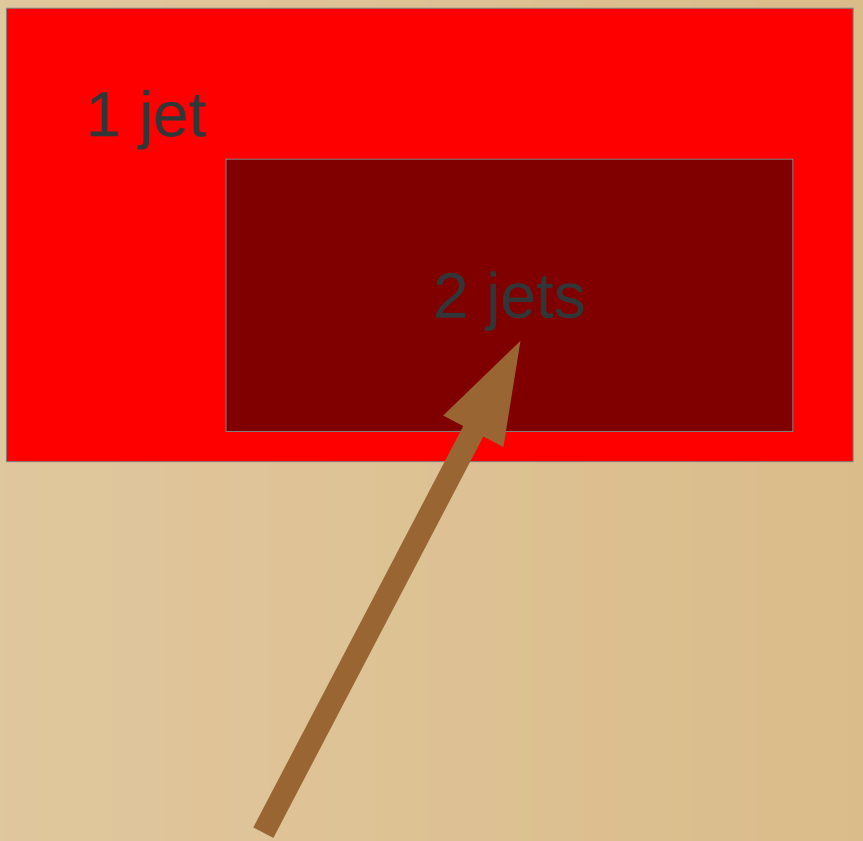
“Exclusive sums”

Exclusive sums

- Combine NLO event samples of different multiplicity
- Justified (if at all) for observables where higher multiplicities are important
- Avoid double counting by restricting the samples to a fixed multiplicity
- Formally not better than a NLO calculation
- No systematic study of uncertainties/stability
  - In preparation

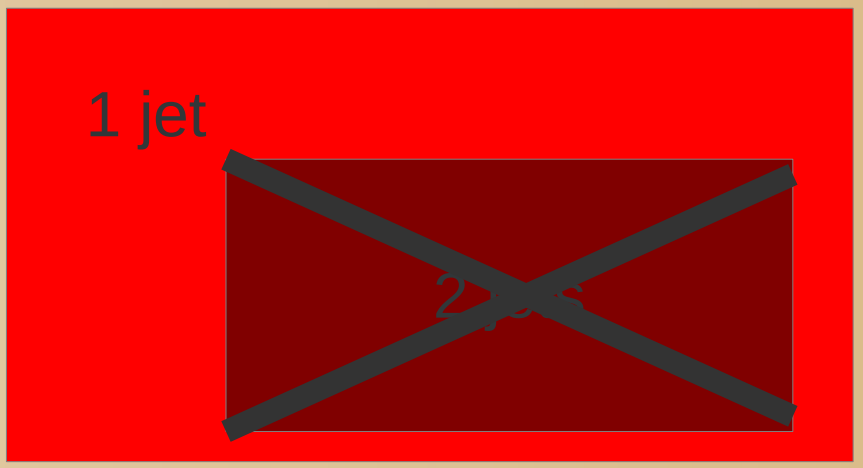
Exclusive sums

- W+1 jet at NLO



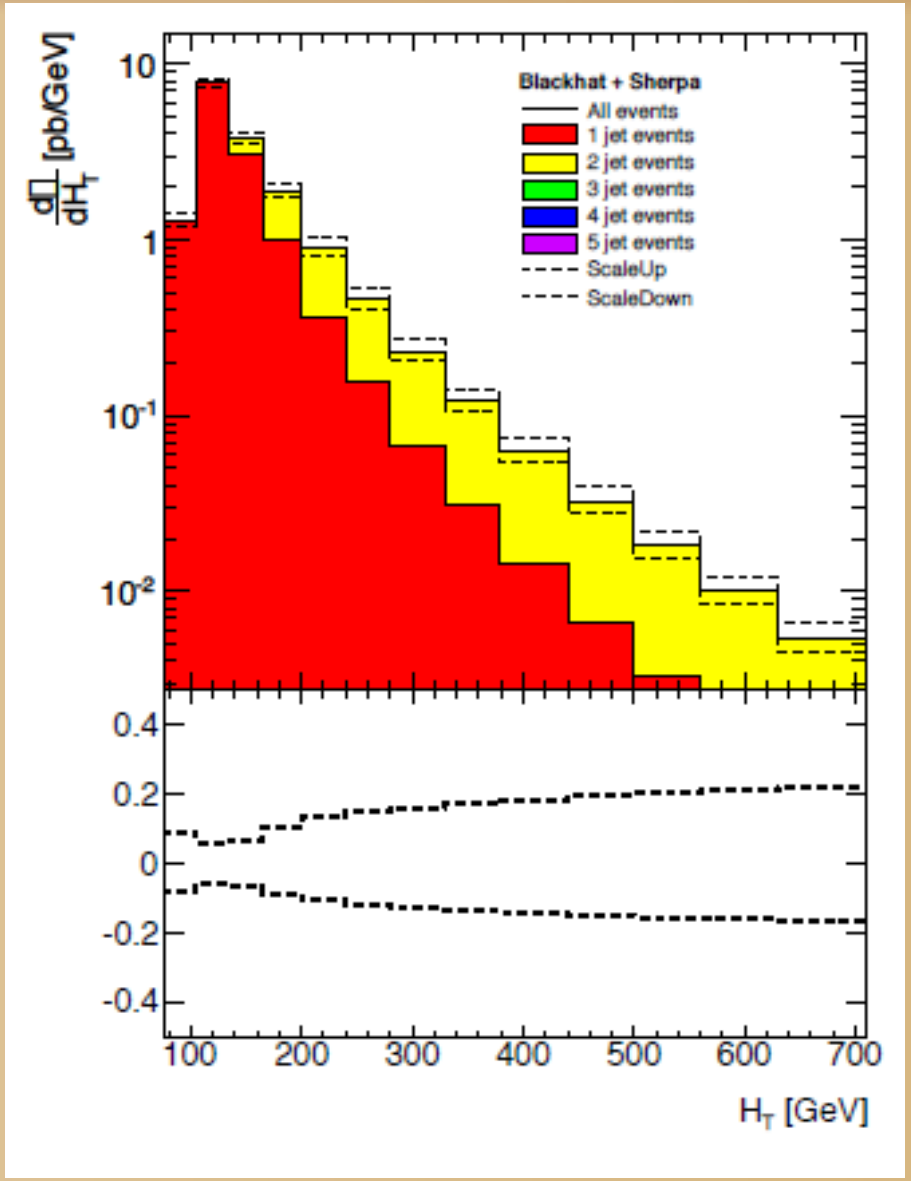
Exclusive sums

- W+1 jet at NLO



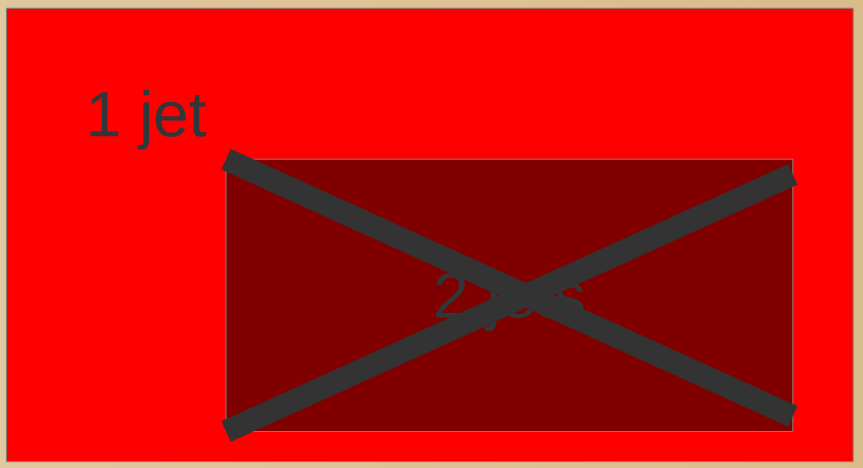
W+2 jets at NLO

W+1 jet


Blackhat + Sherpa
All events
1 jet events
2 jet events
3 jet events
4 jet events
5 jet events
ScaleUp
ScaleDown
$\frac{d\sigma}{dH_T}$ [pb/GeV]
10
1
10^{-1}
10^{-2}
0.4
0.2
0
-0.2
-0.4
100
200
300
400
500
600
700
H_T [GeV]

Exclusive sums

- W+1 jet at NLO

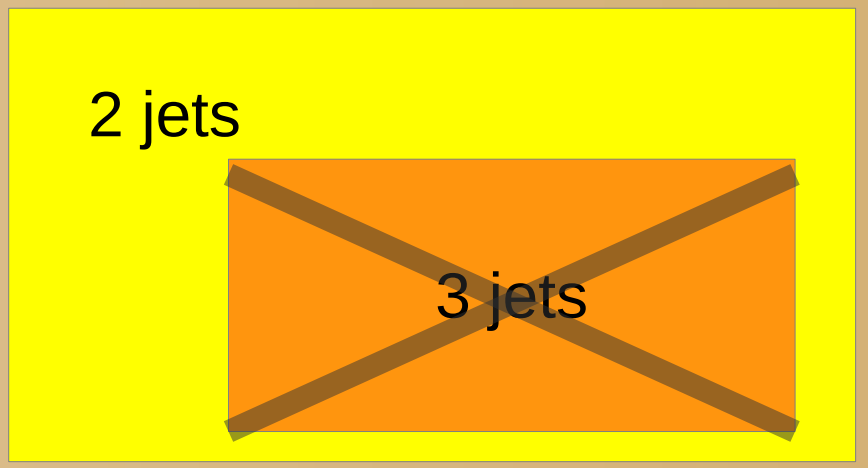


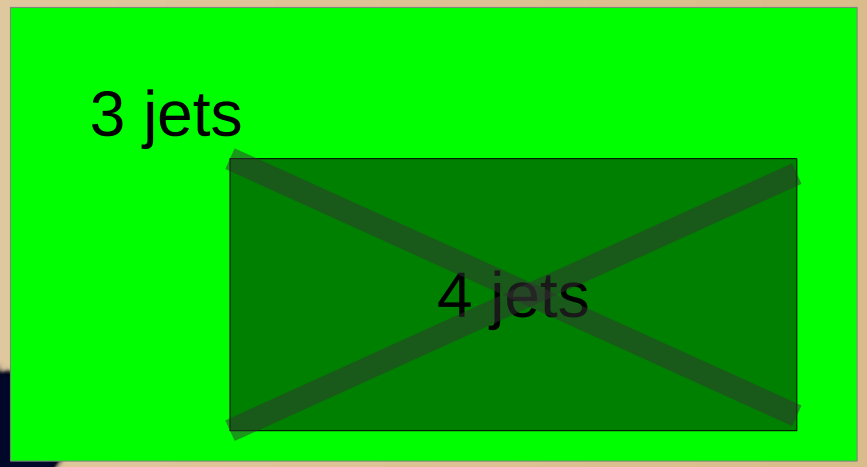
W+2 jets at NLO

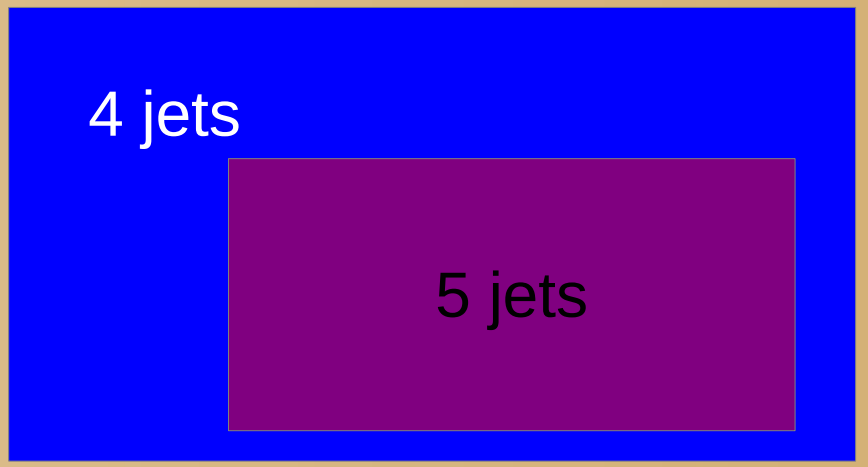
Exclusive sums

- W+1 jet at NLO

W+2 jets at NLO

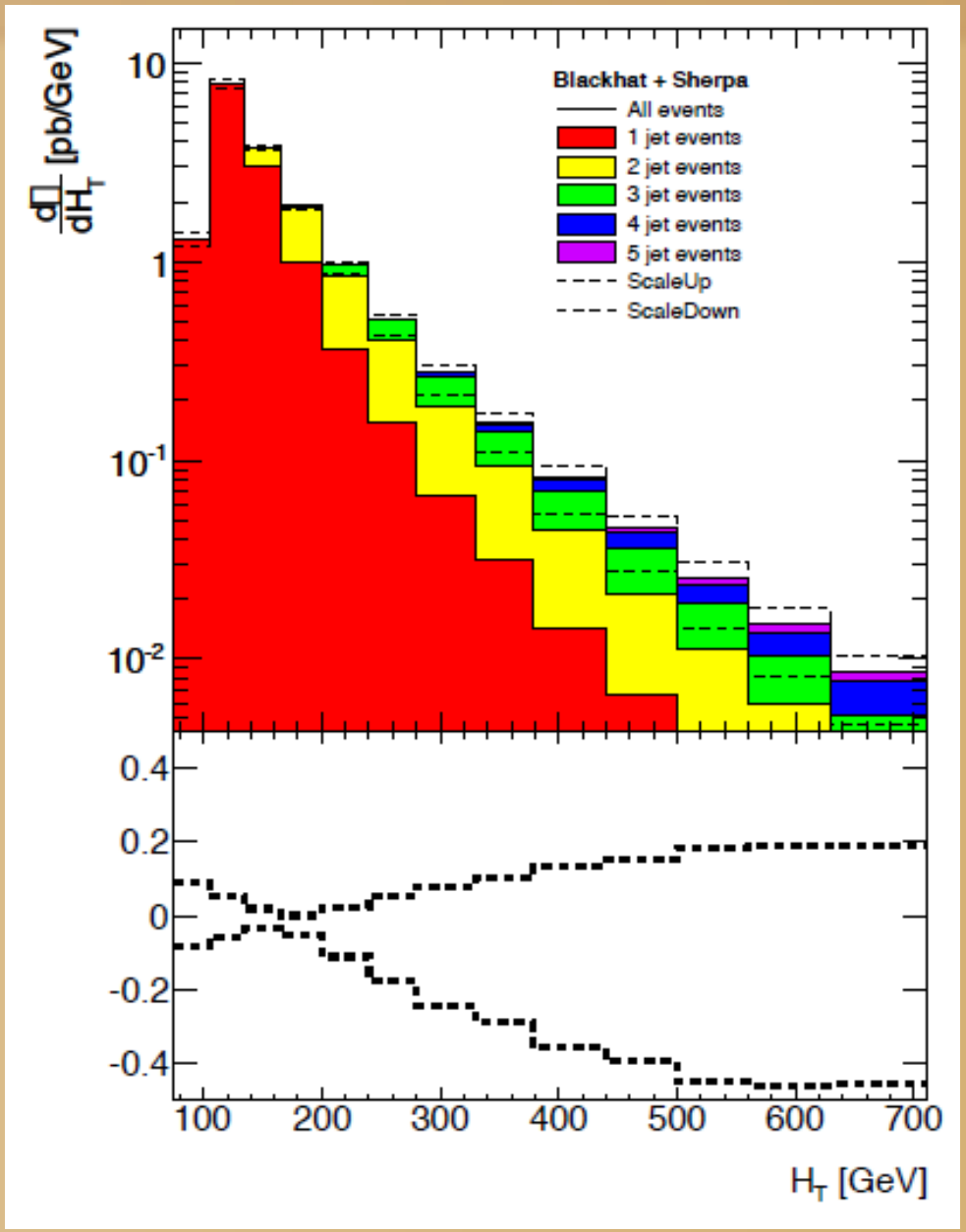






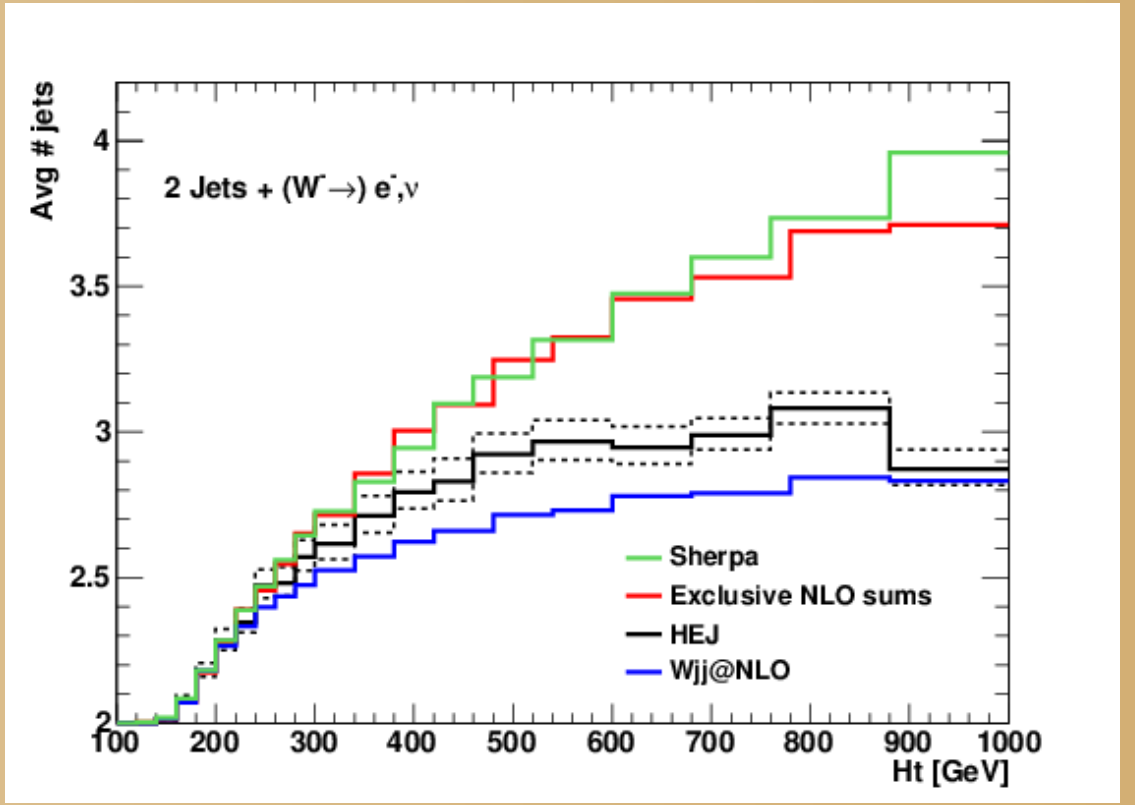
W+1j

- Scale variation much larger than at NLO
- Need to be investigated more precisely
- Combination can be made 'official' using LoopSim [Rubin,Salam,Sapeta] (under investigation)
- Better : 'ME+PS'-type merging



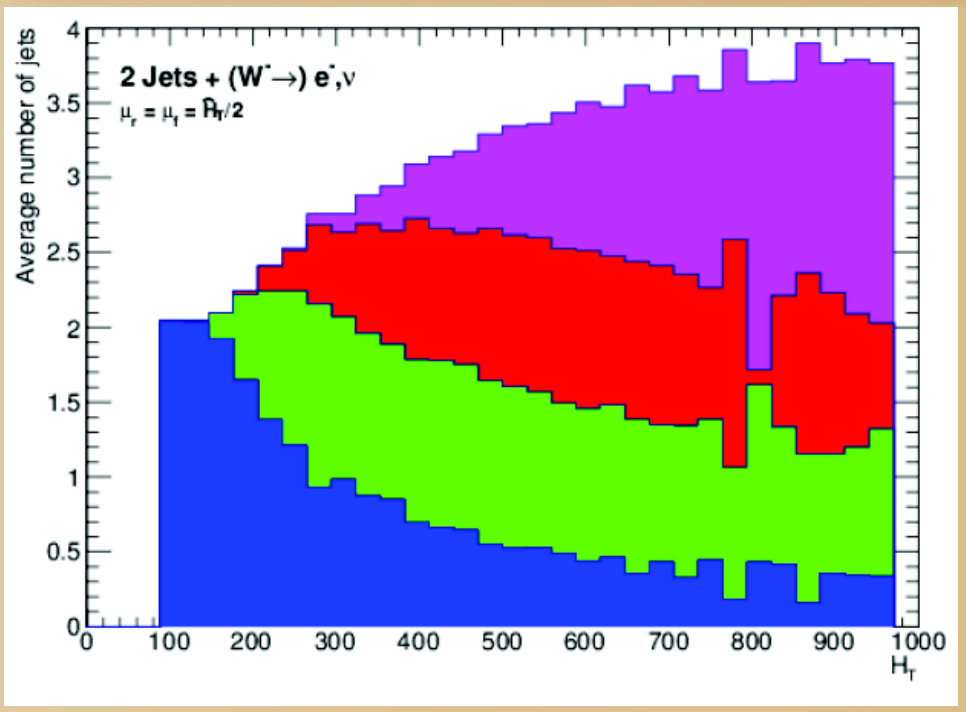
Average number of jets

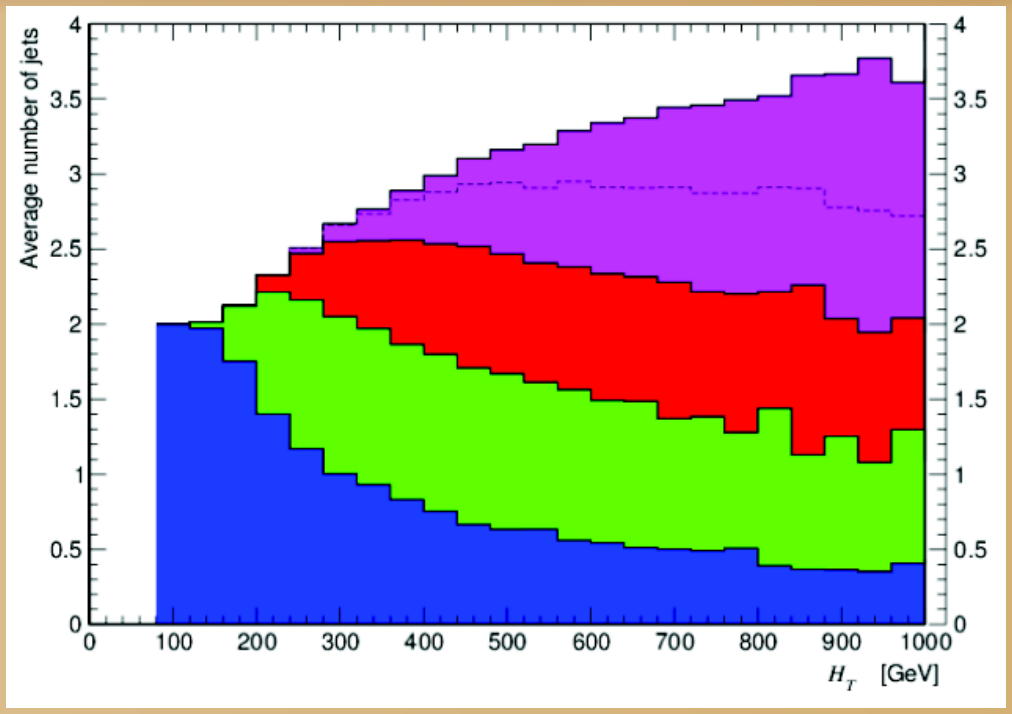
- Good agreement between Sherpa ME+PS and BH+S exclusive sum
- Clear difference with HEJ and pure NLO
- Looking forward to have data points on this plot !



Les Houches 2011 Proceedings
Andersen,Maître,Smilie,Winter

Number of jets in W + >= 2 jets





BH+S exclusive sum

Only first order of Sudakov

Sherpa ME+PS

Sudakov suppression

Les Houches 2011 Proceedings
Andersen,Maître,Smilie,Winter

Conclusions

- There has been a lot of progress in recent years in the calculation of NLO predictions
  - State-of-the-art moved from $2 \to 3/4$ to $2 \to 5/6$
- Different multiplicities can be combined for some observables
  - More work on validity/uncertainty estimation

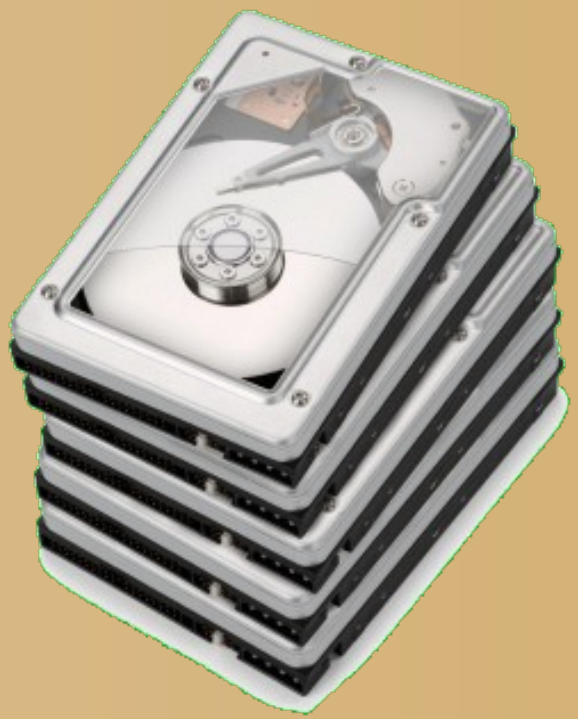
BlackHat+Sherpa Ntuples

BlackHat+Sherpa ntuples

- NLO predictions are CPU expensive
- While generating events for a NLO computation, save in files
  - Parton information (momenta, flavor)
  - Weight
  - Factorisation and renormalisation scales
  - Additional information for scale and pdf change
- Can share these files

BlackHat+Sherpa ntuples

- Advantages:
  - No need for the end user to run a complicated NLO setup
  - Can produce many plots from the same run
  - Can change scales/pdf, including pdf errors
- Disadvantages
  - Large files



Z+4 jets @ NLO

Ita, Bern, Dixon, Febres Cordero, Kosower, Maître
[ArXiv:1106.1423]

- Z/gamma* interference included (but small because of mass window for the lepton pair)
- Leading color for virtual part → 3% error
- Compare with W+4j
- Allows transfer from control region to signal region or from Z ↔ W

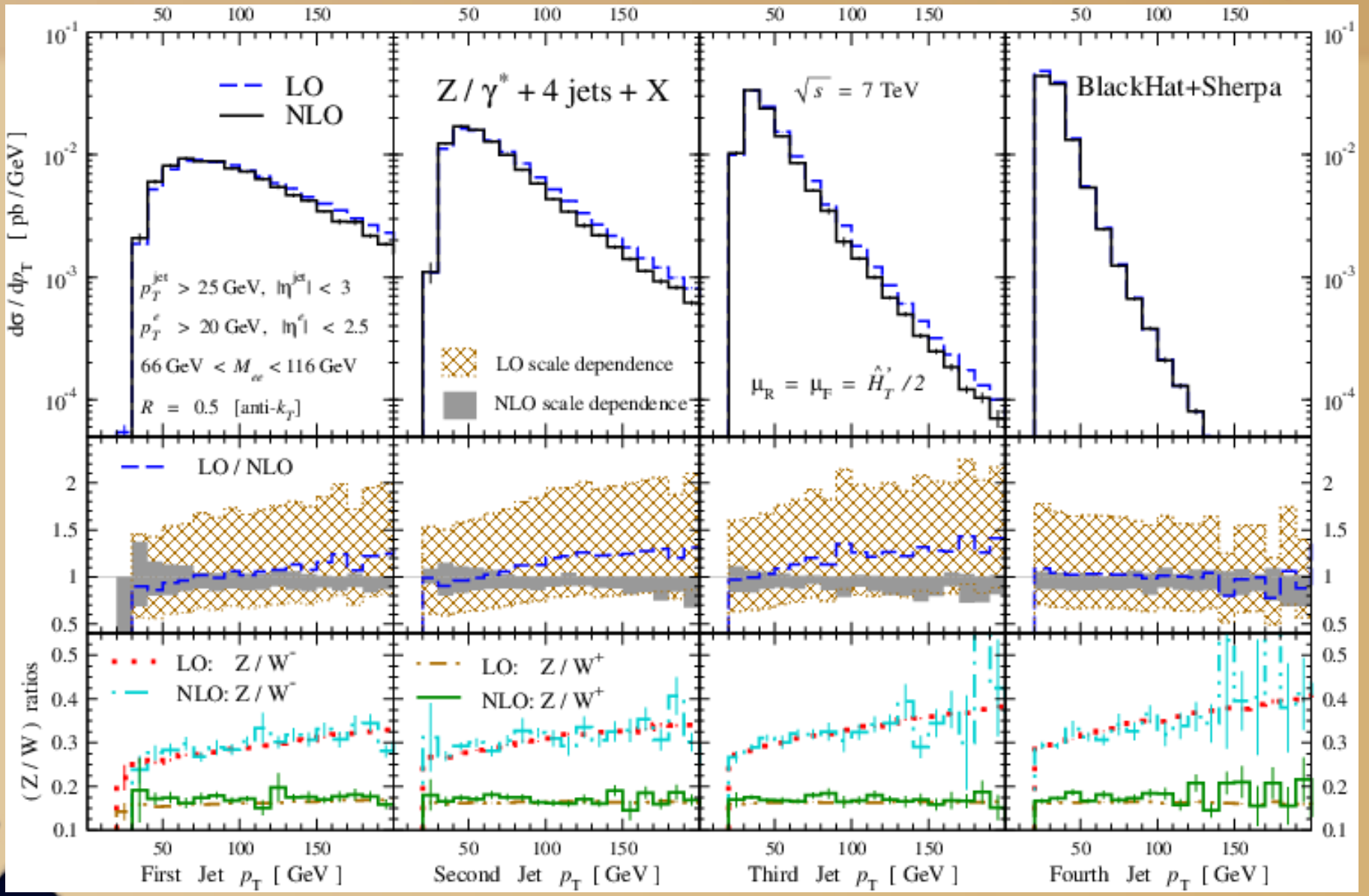
Z+jets

- Scale $\hat{H}'_T = E_T^Z + \sum_{\text{jets}} p_T \qquad E_T^Z = \sqrt{M_Z^2 + \left(p_T^{e^+e^-}\right)^2}$
- Cuts :
  - $p_T^e > 20$ GeV
  - $|\eta^e| < 2.5$
  - $p_T^{\text{jet}} > 25$ GeV
  - $\left|\eta^{\text{jet}}\right| < 3$
  - $66\ \text{GeV} < M_{e^+e^-} < 116\ \text{GeV}$
  - Anti-Kt, R=0.5 ; CTEQ6m

no. jets	Z LO	Z NLO
0	$323.1(0.1)^{+39.3}_{-44.3}$	$428.6(0.3)^{+6.2}_{-4.1}$
1	$66.69(0.04)^{+5.59}_{-5.30}$	$82.1(0.1)^{+3.3}_{-2.6}$
2	$19.10(0.02)^{+5.32}_{-3.82}$	$20.25(0.07)^{+0.31}_{-1.02}$
3	$4.76(0.01)^{+2.18}_{-1.35}$	$4.73(0.03)^{+0.05}_{-0.35}$
4	$1.116(0.002)^{+0.695}_{-0.390}$	$1.06(0.01)^{+0.05}_{-0.14}$

ArXiv:1108.2229

Z+4 jets



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