QCD and precision SM calculations for colliders

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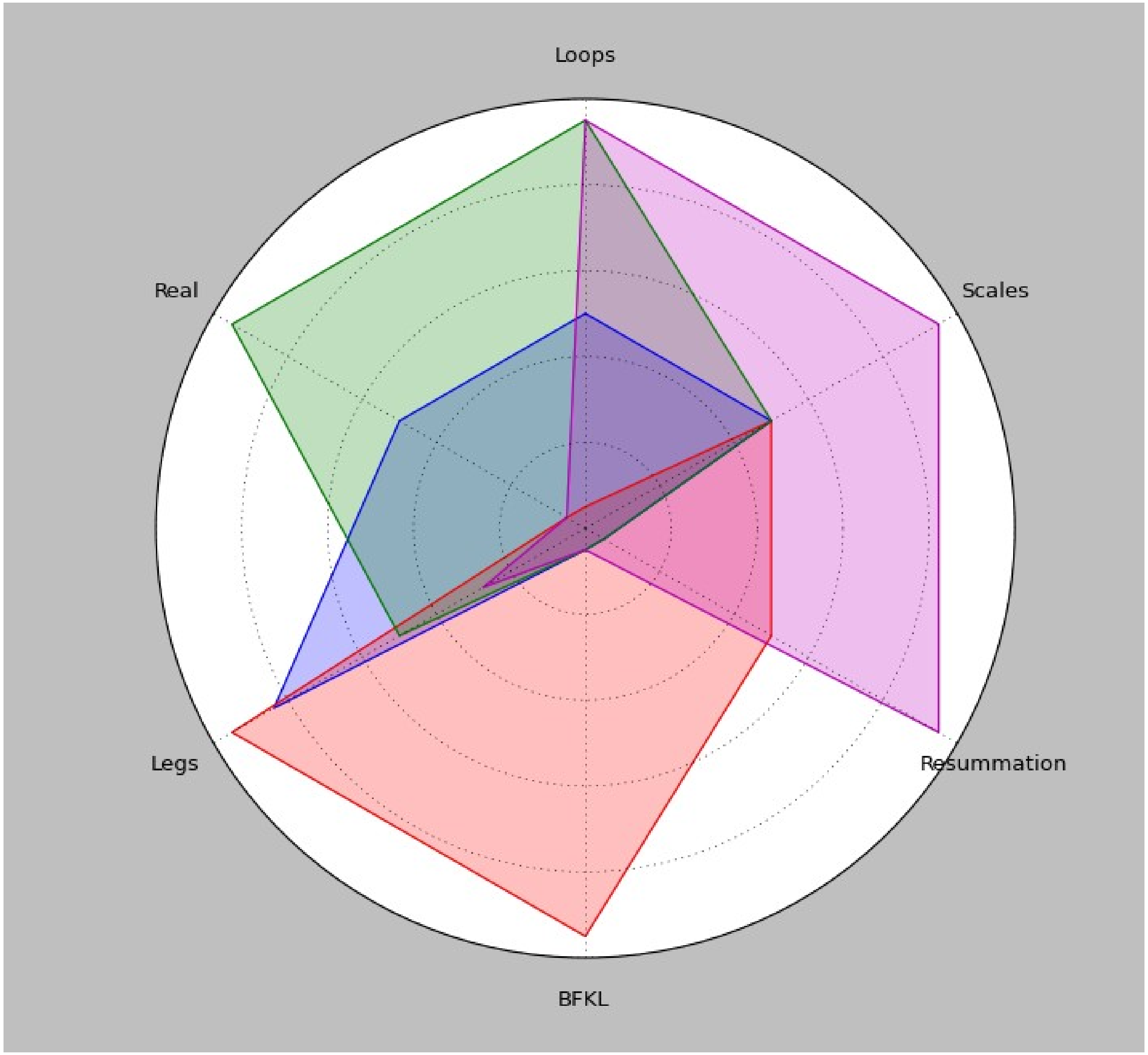
Precision SM @ IPPP

- We need good precision predictions for large number of high multiplicity processes, and enhanced precision for a few selected processes (H+j,W+j,tt,Z/W+j,...)
- Precision can be increased by
  - Increasing the order in the perturbation theory/theories
  - Resumming divergent behaviour in phase-space regions where perturbation theory fails.
  - Using fewer approximations (massless light quarks, heavy top approximation, narrow resonance approximations)

Precision SM @ IPPP

- Jeppe Andersen
  - Helen Brooks
  - Tuomas Hapola
- Nigel Glover
  - Xuan Chen
  - James Currie
  - Thomas Morgan
- Daniel Maître
  - Simon Armstrong
- Ben Pecjak
  - Rhorry Gauld
  - Darren Scott



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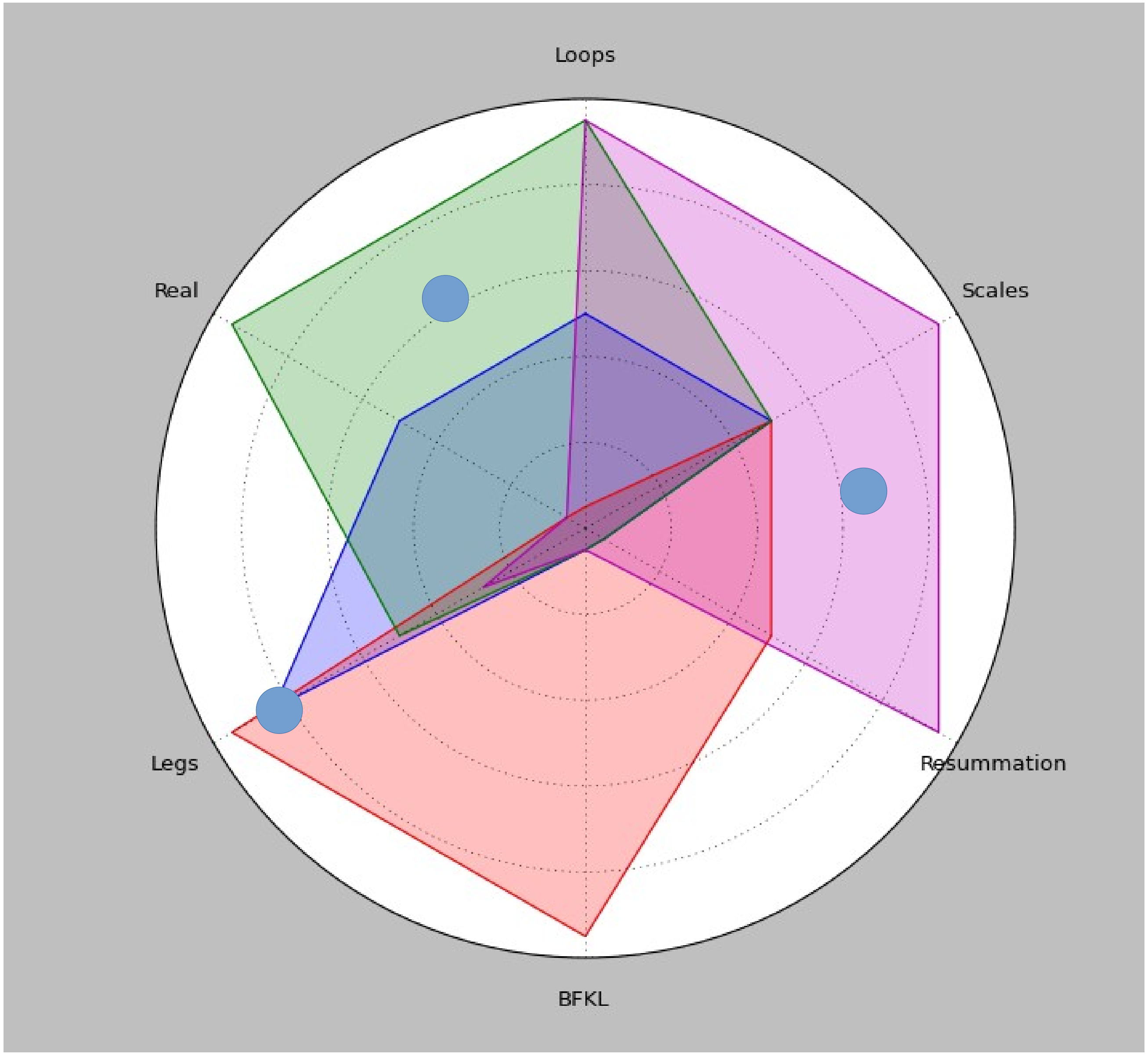
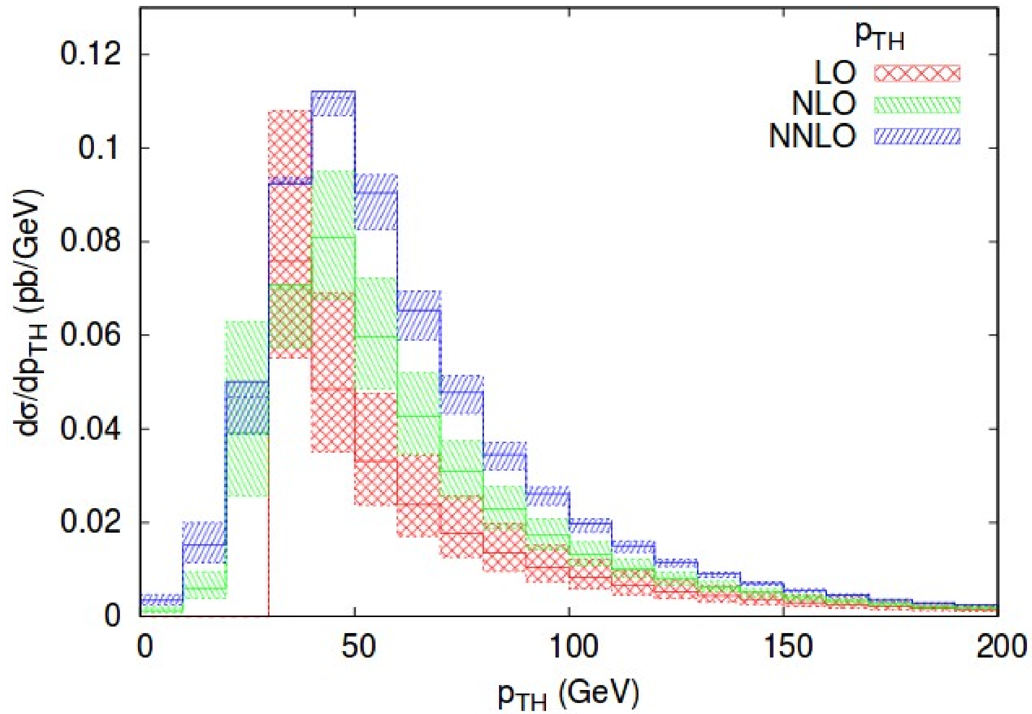
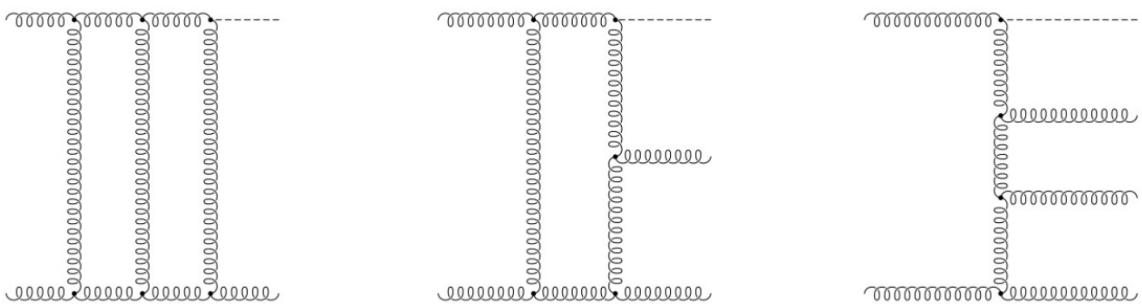


H+jet @ NNLO

- Nigel Glover with Xuan Chen, James Currie and Thomas Morgan
- The production of a Higgs boson in association with a jet is an important part of the total Higgs production
- Its understanding is crucial to determine the Higgs boson properties





ArXiv:1408.5325

Higgs

- One of the main background in Higgs event selections is top pair
- We need to understand top pair production as well as we can, not only for the Higgs, it is a background to most BSM searches
- To reduce the top background jet vetoes are applied, the effect of these vetoes is an important line of studies

Boosted top quark production

- Project of Ben Pecjak with Darren Scott
- Consider highly boosted Top pair (relevant for new physics searches)
- Two types of logarithms can arise:
  - Soft logs $\frac{\log(1-z)}{1-z}\,, \qquad z \equiv M_{tt}^2/\hat{s}$
  - Collinear logs $\log \frac{m_t}{M_{t\bar{t}}}$
- Resum both types of logs
- Need to understand factorisation in the soft and small mass limit

Boosted top quark production

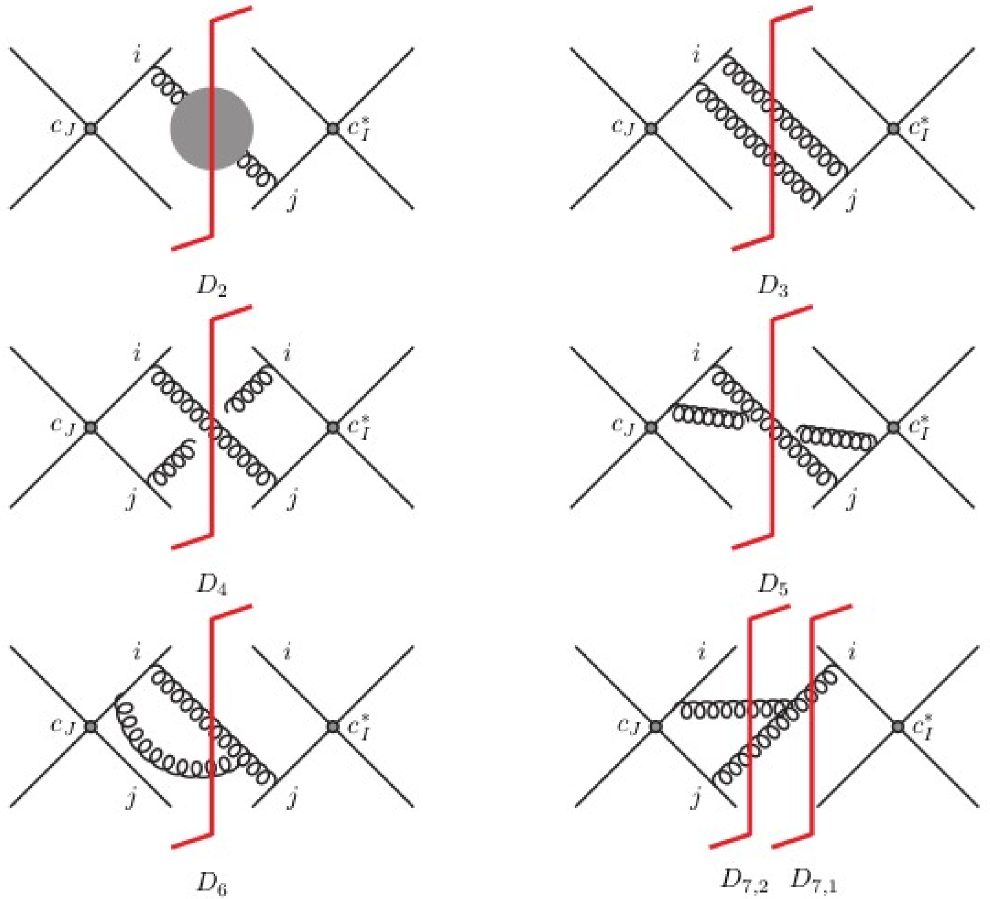
- Factorisation at NNLO:

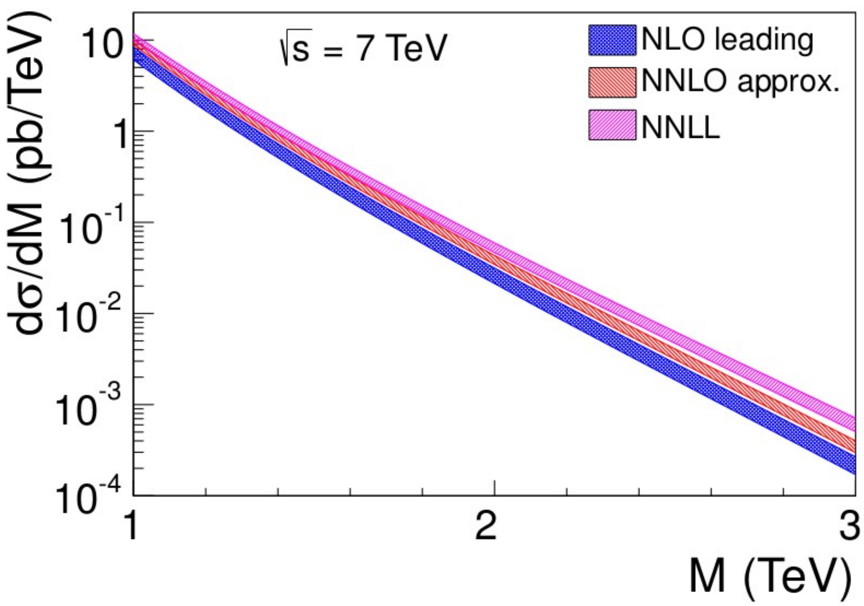
$$\frac{d\hat{\sigma}}{dM} \sim \mathrm{Tr}[\mathbf{H}(M,\mu)\mathbf{S}(M(1-z),\mu)] \otimes C_D^2(m_t,\mu)S_D^2(m_t(1-z),\mu) + \mathcal{O}(1-z) + \mathcal{O}\left(\frac{m_t^2}{M^2}\right)$$

Hard function

Soft gluon

Fragmentation functions





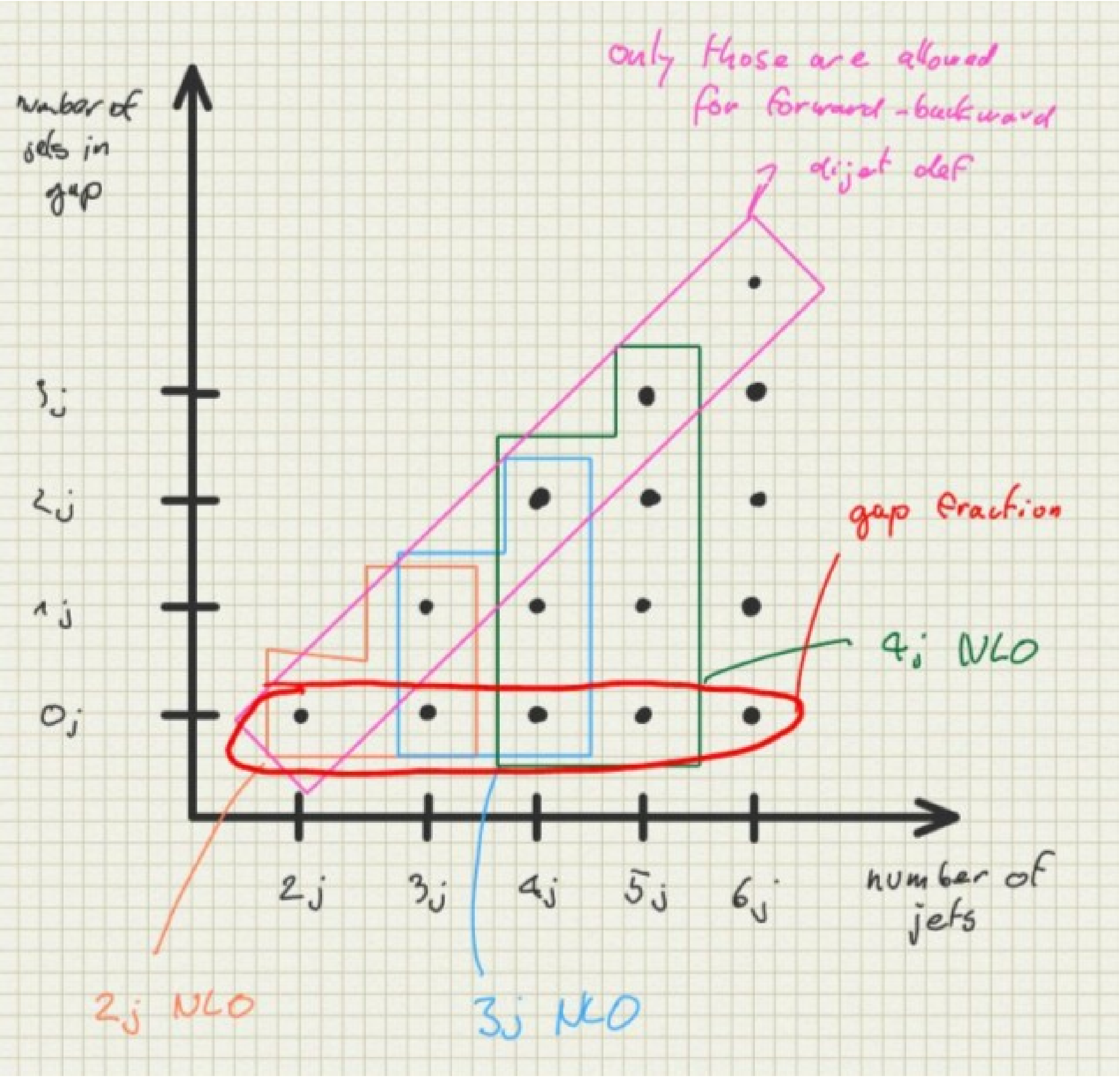
Gap fraction

- Project with Jeppe Andersen
- The gap fraction is defined as the fraction of events with no jets with transverse momentum above Q_0 between the two tagging jets
- The tagging jets can be either the hardest jets or the most forward/backward jets

$$g = \frac{\sigma_{Y/pt}(Q_0)}{\sigma_{tot}}$$

- Different ways to compute it

Gap fraction



Gap fraction

- “fixed order”

$$g = \frac{\sigma_{g=0}}{\sigma_{tot}} = 1 - \frac{\sigma_{g\geq 1}}{\sigma_{tot}}$$

$$= 1 - \frac{\sigma_{g\geq 1}^{\mathrm{nlo},j\geq 3}}{\sigma^{\mathrm{nlo},j\geq 2}} = 1 - \frac{\sigma^{\mathrm{nlo},j\geq 3} - \sigma_{g=0}^{\mathrm{nlo},j=3} - \sigma_{g=0}^{\mathrm{lo},j=4}}{\sigma^{\mathrm{nlo},j\geq 2}}$$

- “mixed order”

$$g = \frac{\sigma_{g=0}}{\sigma_{tot}} = \frac{\sigma_{g=0}^{\mathrm{nlo},j=2} + \sigma_{g=0}^{\mathrm{nlo},j=3} + \sigma_{g=0}^{\mathrm{nlo},j\geq 4}}{\sigma^{\mathrm{nlo},j=2} + \sigma^{\mathrm{nlo},j=3} + \sigma^{\mathrm{nlo},j\geq 4}}$$

Gap fraction

- Compare experimental results from ATLAS [arXiv:1107.1641] with the two fixed order formula using BlackHat+Sherpa nTuples and the HEJ resummation [Andersen,Smilie]
- Gap fraction as a function of the rapidity difference for various slices in the average transverse momentum of the tagging jets (two hardest jets)
- Limited statistics so far
- Not striking differences between “fixed” and “mixed”

Gap fraction

- Pt slices:

240 GeV < $\bar{p}_T$ < 27

210 GeV < $\bar{p}_T$ < 24

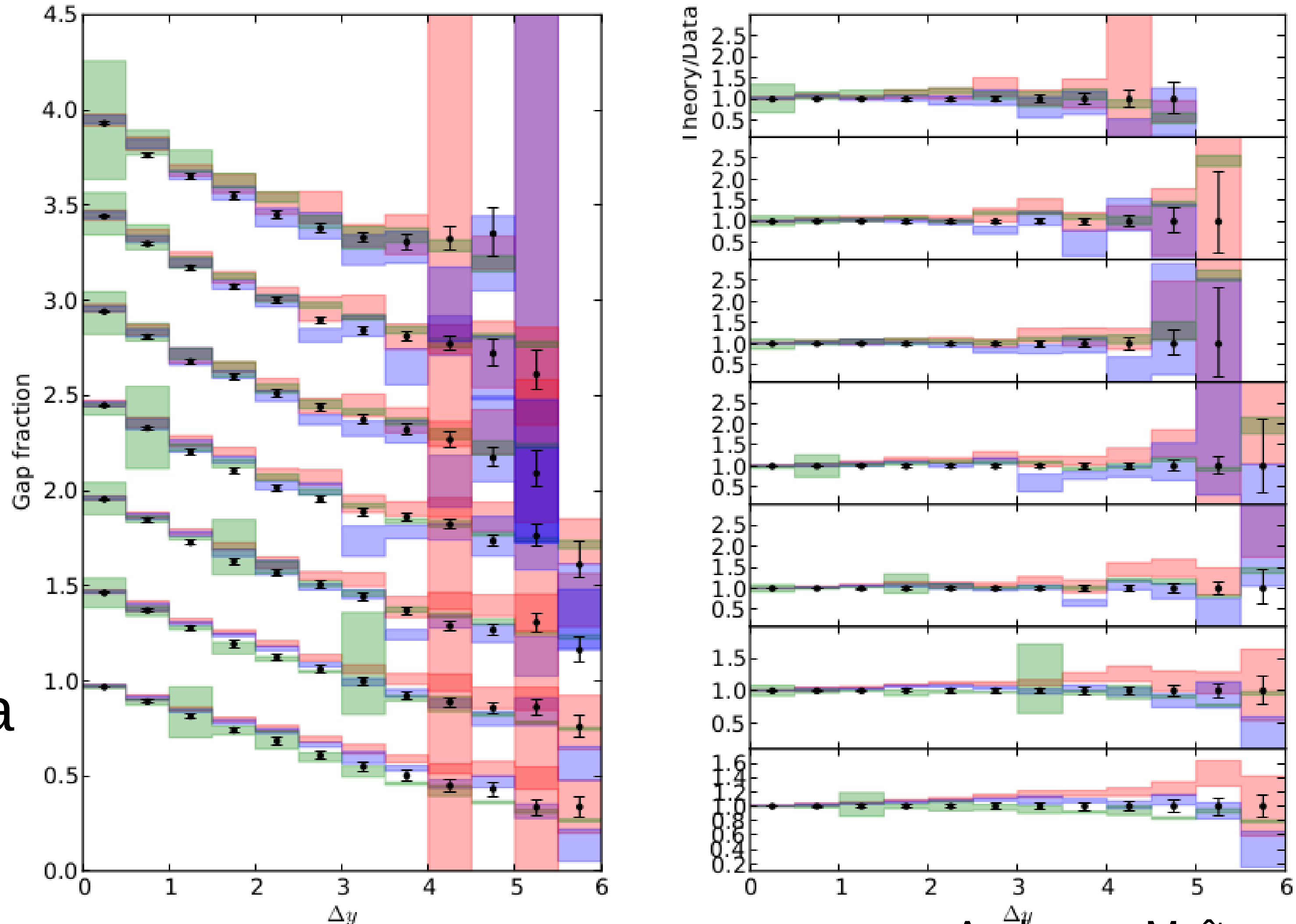
180 GeV < $\bar{p}_T$ < 21

150 GeV < $\bar{p}_T$ < 18

120 GeV < $\bar{p}_T$ < 15

90 GeV < $\bar{p}_T$ < 12

70 GeV < $\bar{p}_T$ < 90

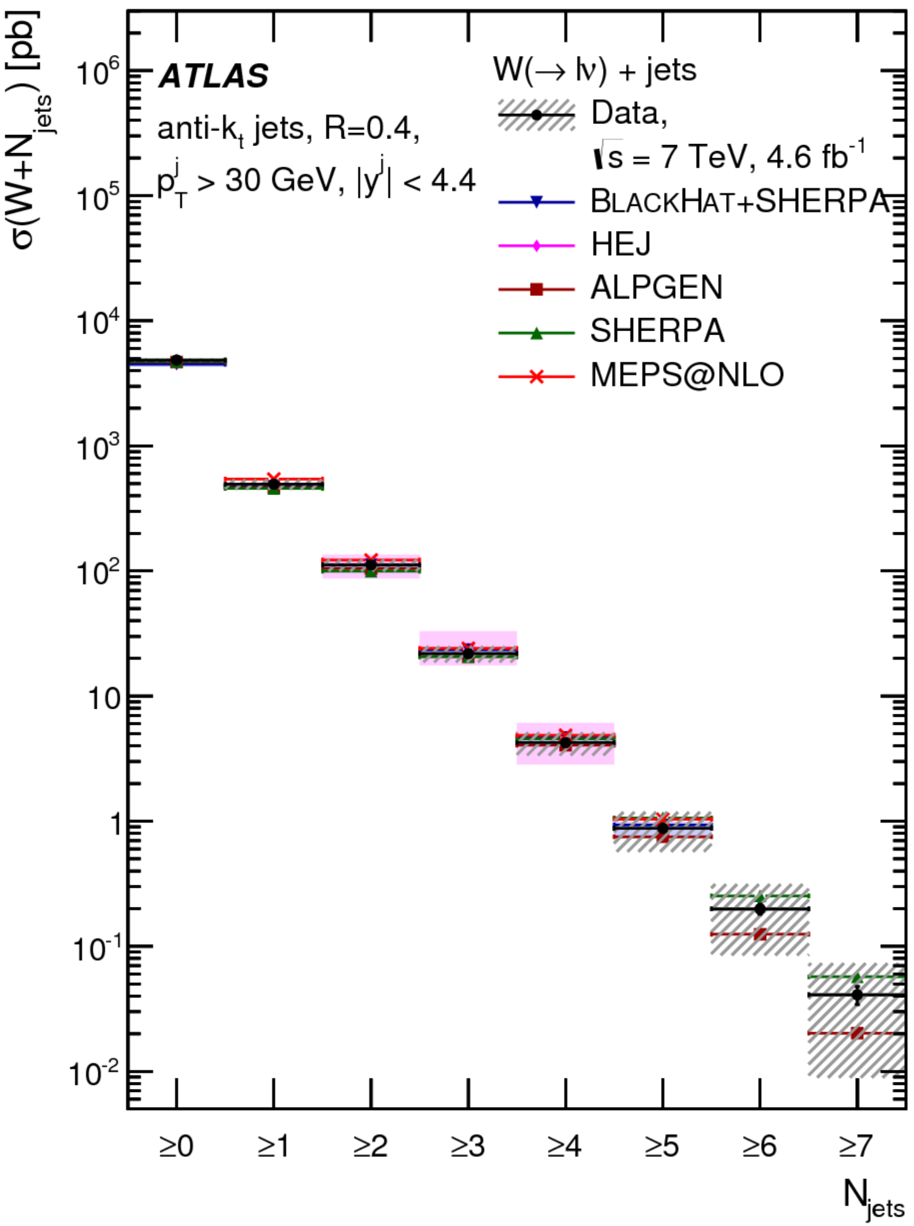


Andersen,Maître

- ATLAS data
  HEJ
  fixed
  mixed

W+jets

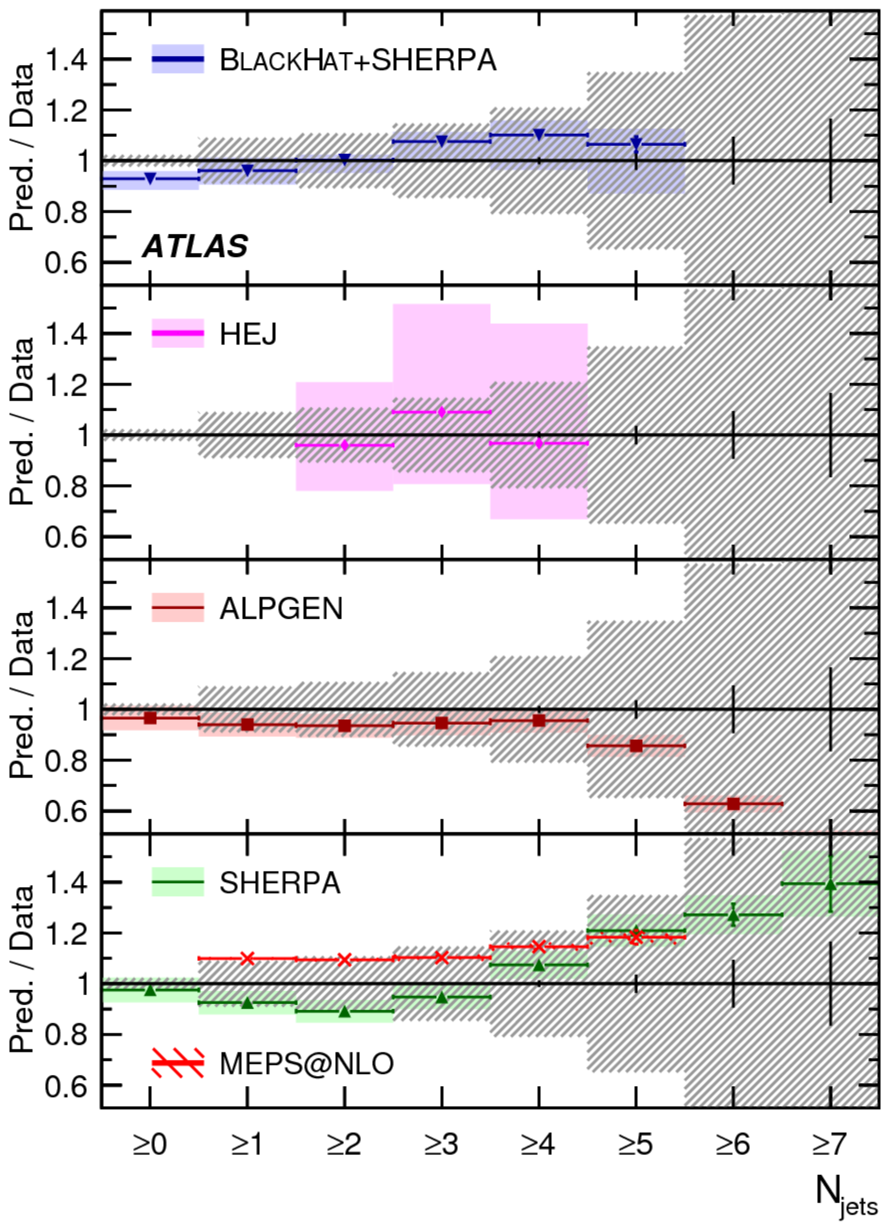
- Look at W+jets inclusive cross section for several jet multiplicity
- Compare Atlas data with
  - NLO (BlackHat+Sherpa)
  - HEJ
  - Alpgen
  - Sherpa
  - MEPS@NLO (Sherpa)



[ArXiv:1409.8639, Eur. Phys. J. C (215) 75:82]

W+jets

- All theory predictions are doing quite well
- The large uncertainty band for the HEJ prediction is due the scale variation



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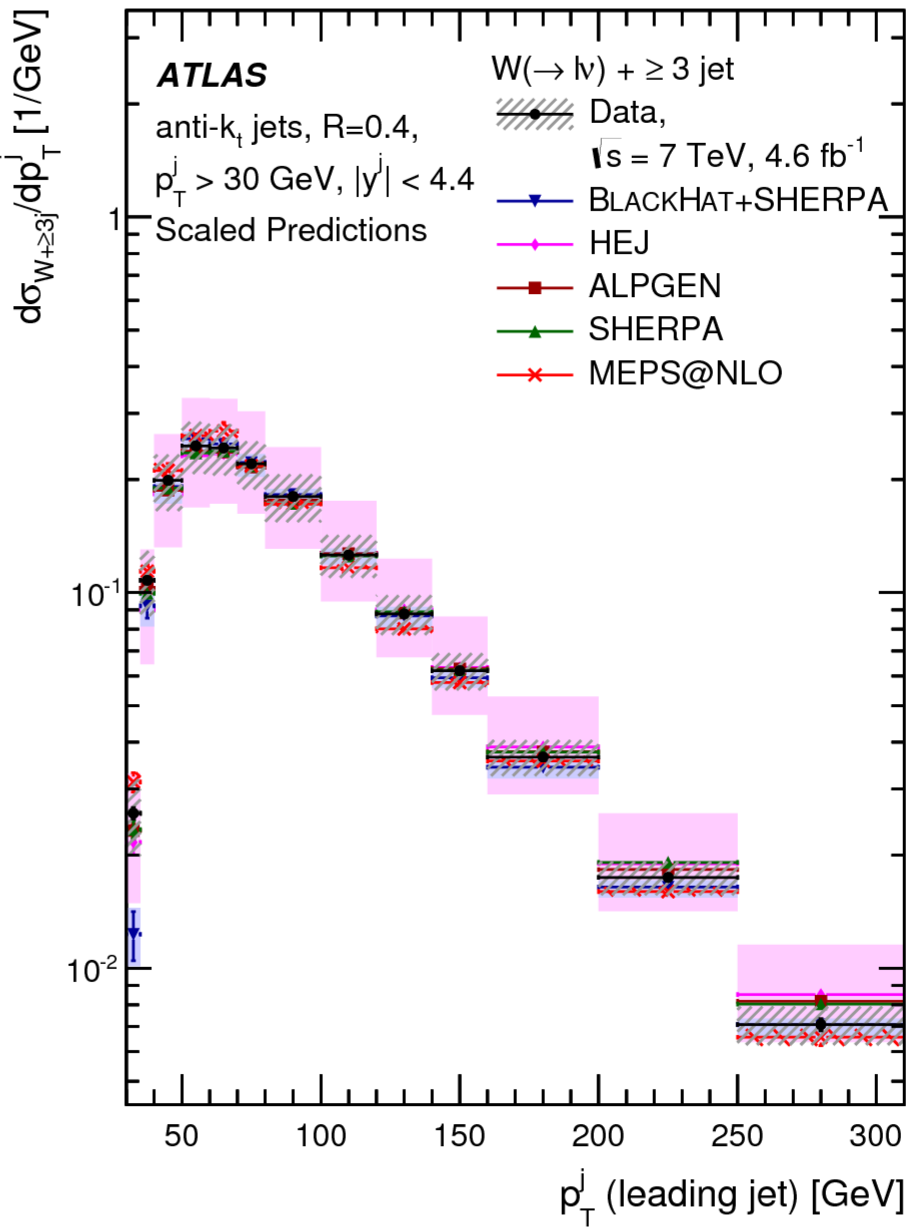
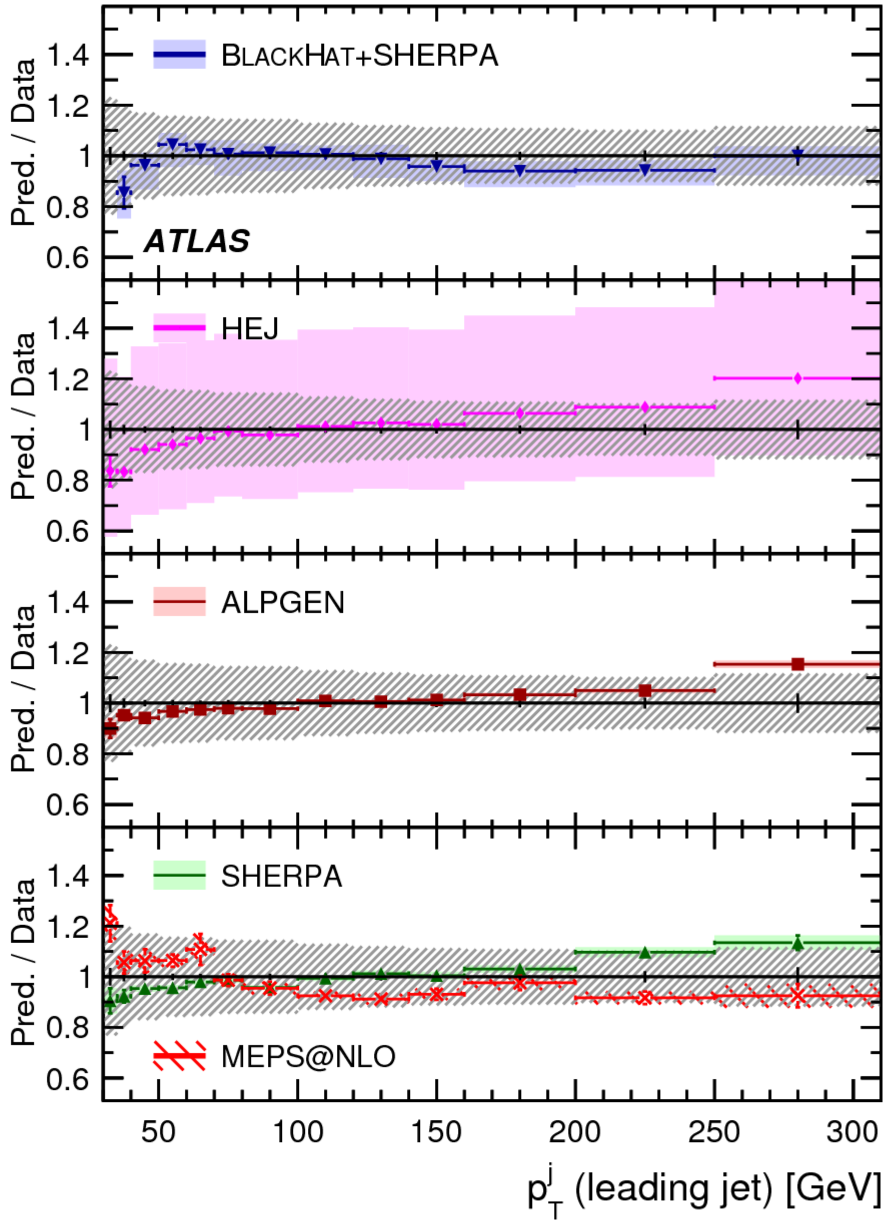
W+jets

- First jet transverse momentum
- NLO and parton shower predictions are expected to give a good descrition



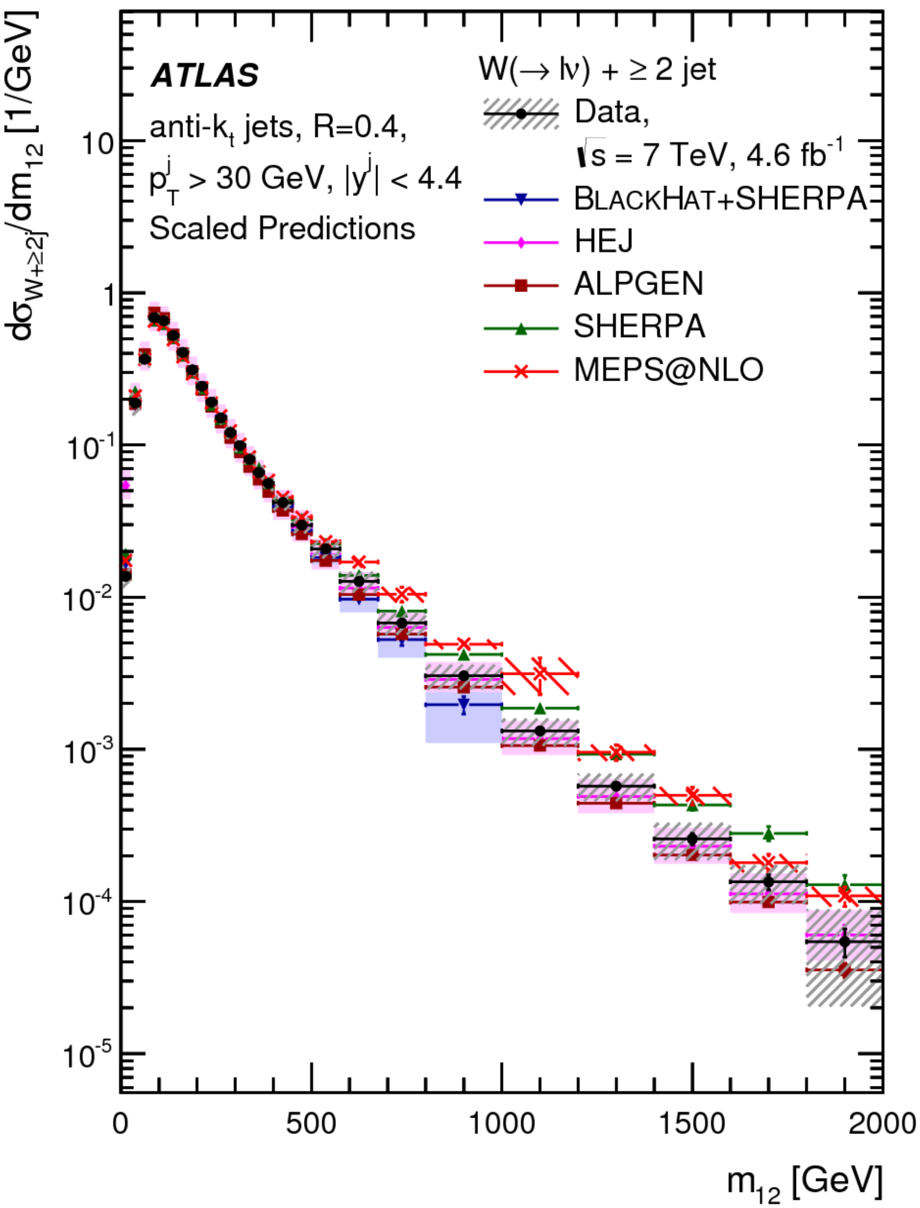
W+jets

- All prediction agree reasonably well where they are expected to
- The comparatively large uncertainty of the HEJ prediction is due to uncertainty in the normalisation and not in the shape



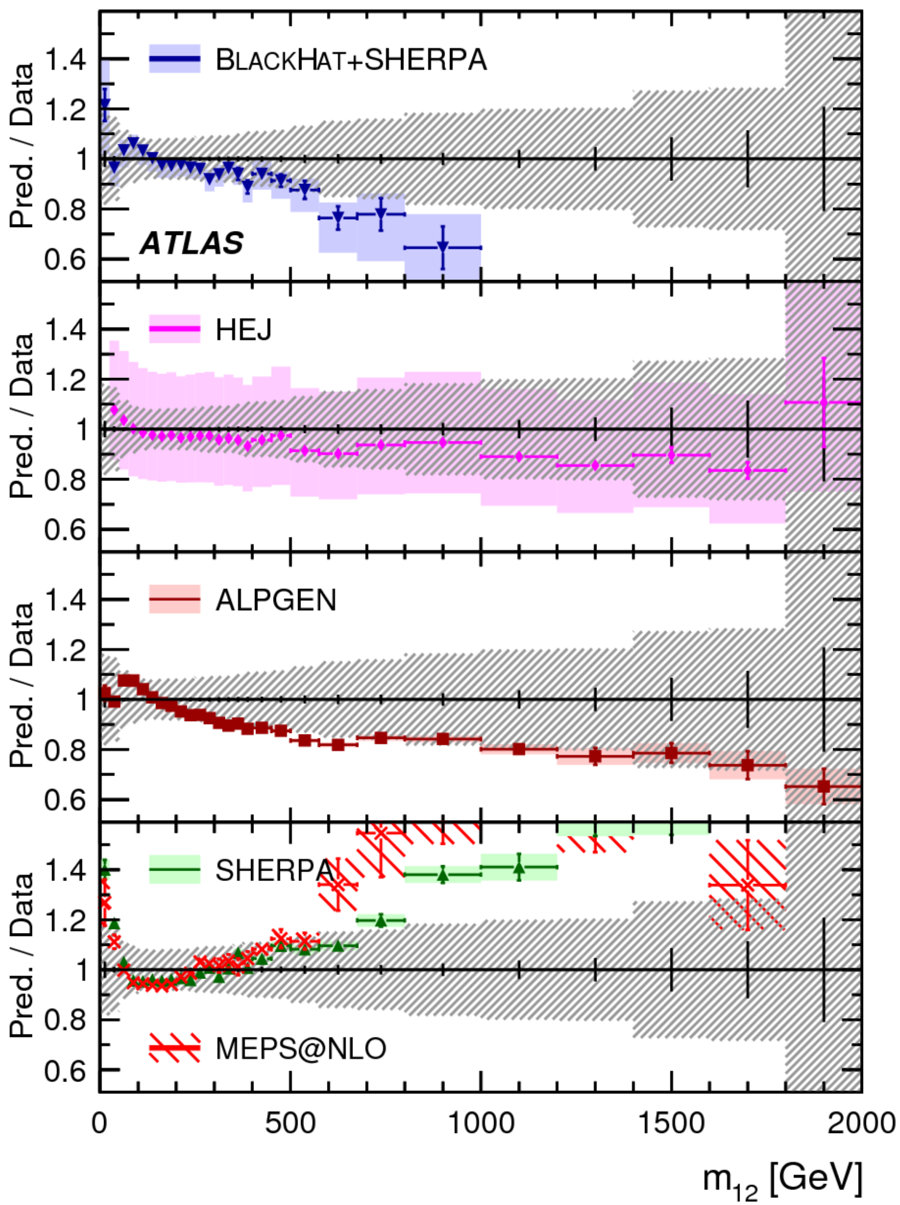
W+jets

- The dijet mass is more sensitive to emissions between the two jets
- Parton shower and NLO are not expected to do as well as for the jet transverse energy observable
- HEJ is resumming jets emission in wide rapidity gaps, it should be well suited for this observable



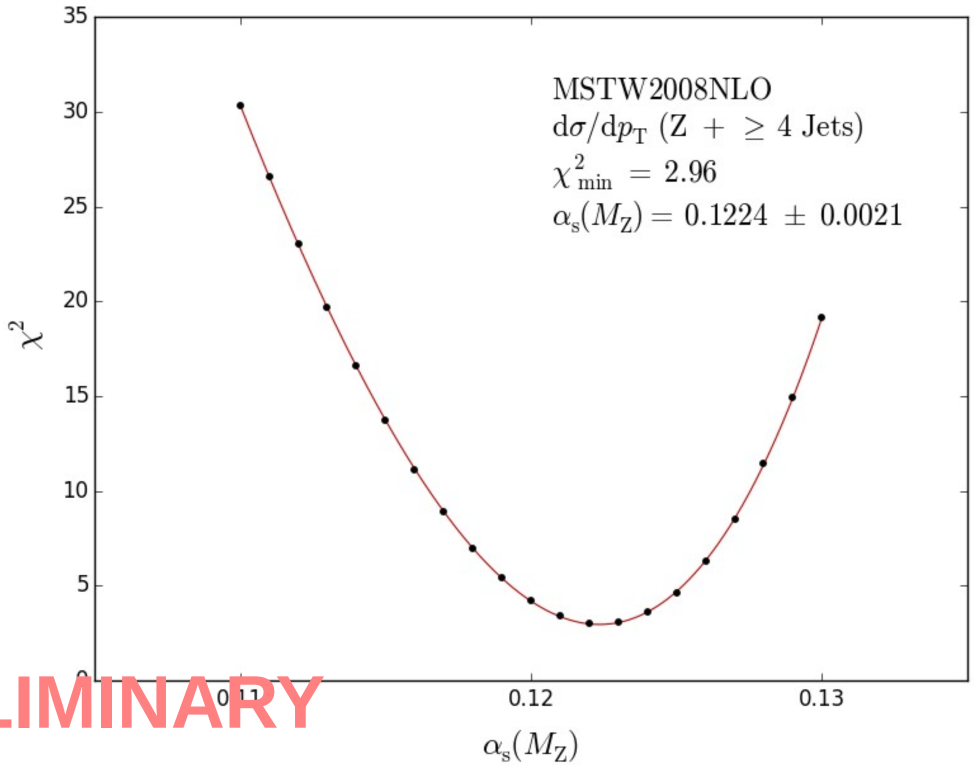
W+jets

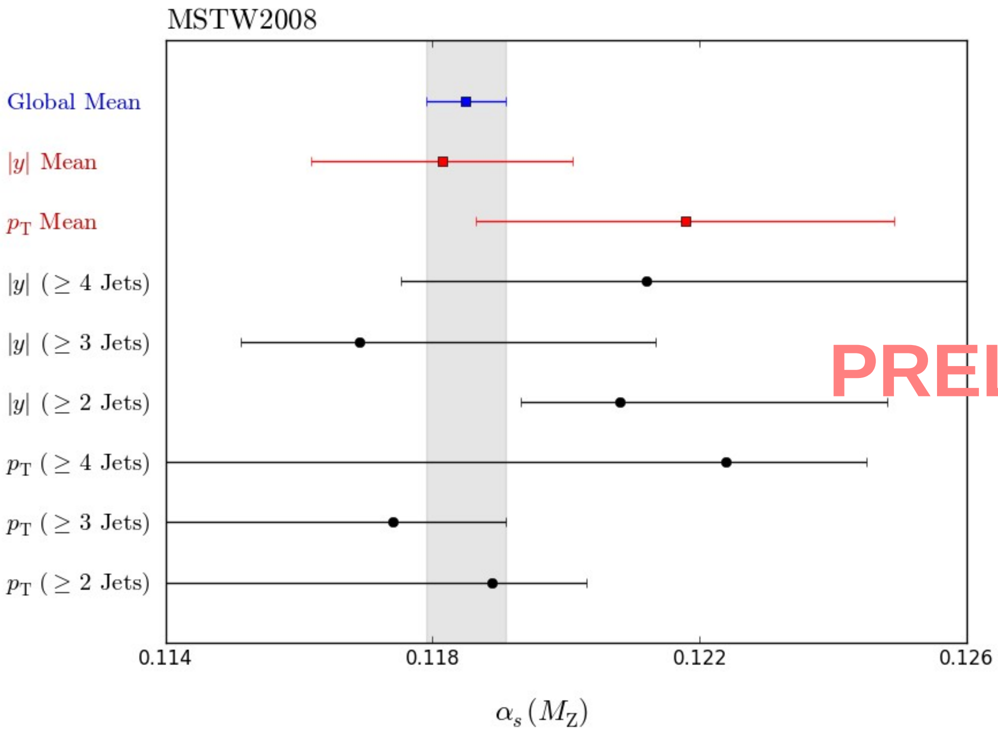
- Indeed HEJ provides the best description
- Project:
  - Matching to NLO high-multiplicity samples
  - Inclusion of sub-leading corrections
  - H+Jets (also with full top-mass dependence)



Strong coupling determination

- Use Atlas Z+2,3,4 jets data to extract the value of the strong coupling constant
- Use PDF fit for various values of *α(M$_Z$)*





PRELIMINARY

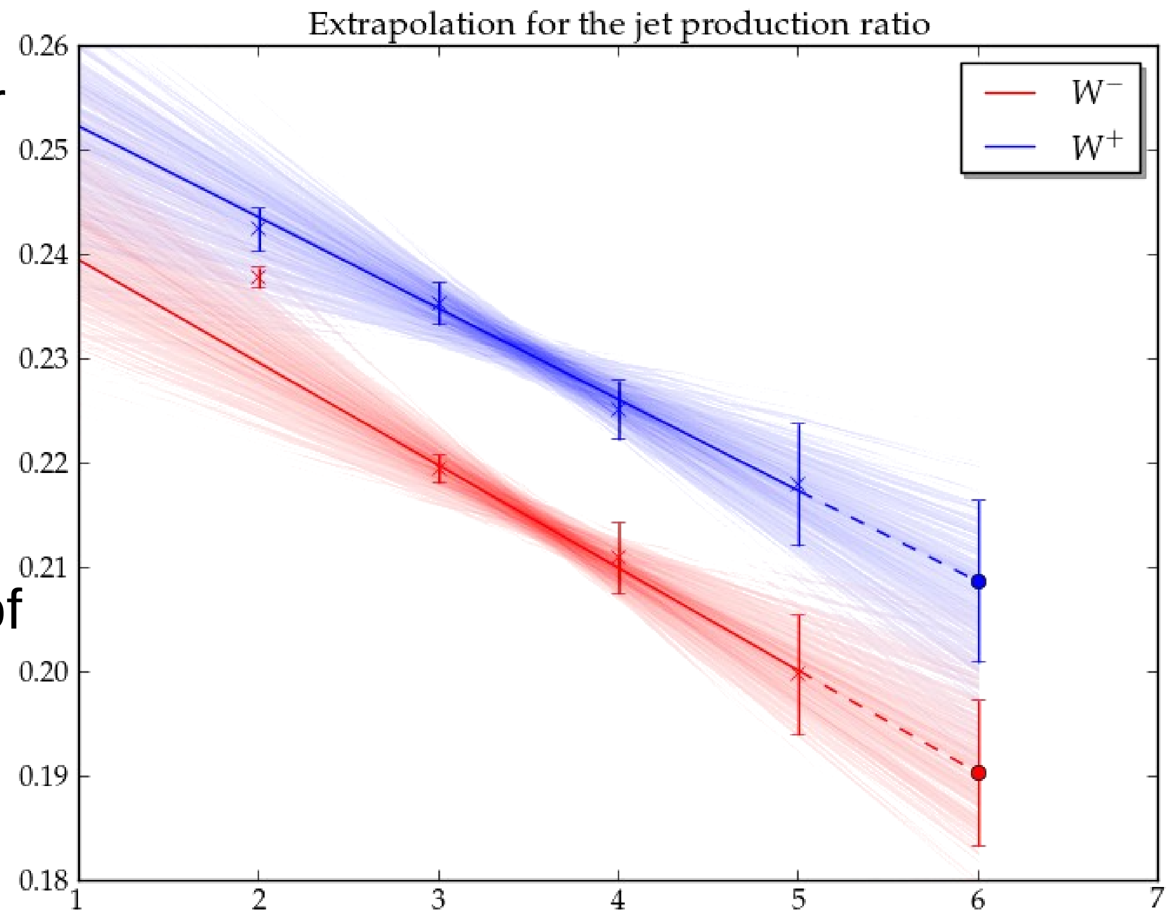
[Plot from Mark Johnson's L4 project]

Towards higher multiplicities?

- We have a lot of prediction for high multiplicity processes at NLO
- We can try to find 'universal' properties/features
- Usually need to discard 0-jet and 1-jet because new partonic channels open
- Usually these features are more easily seen in ratios between multiplicities

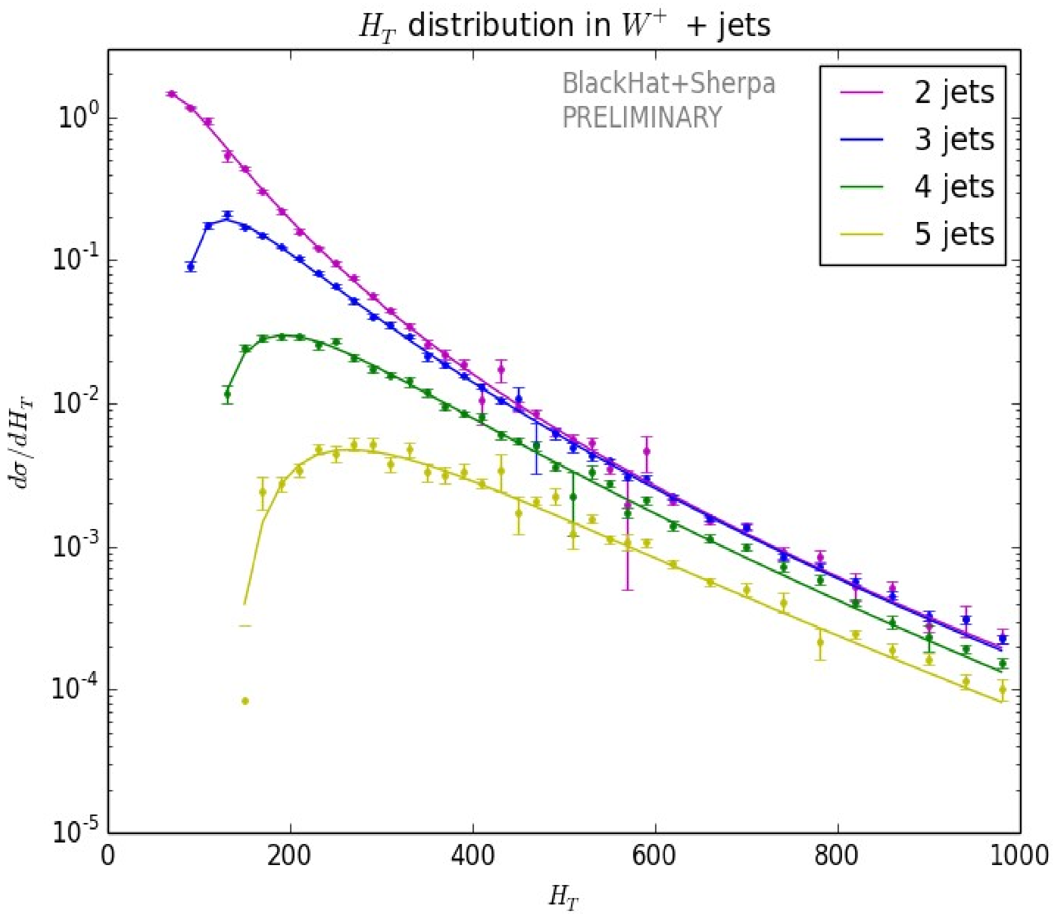
Extrapolation for ratios

- Ratio V+n jets/(V+n-1 jets)
- Consistent with straight line for n>2
- Use extrapolation for 6 jets:
- W^- : 0.15 ± 0.01 pb
- W^+ : 0.30 ± 0.03 pb
- Consistent with extrapolation of charge asymmetry
- Error estimates through Monte Carlo method



Distributions

- What about distributions?
- Look at sum of transverse energies of the jets (HT)
- Cannot extrapolate the value of each bin separately
  - Statistical errors are too large
  - Different thresholds
  - Different peak positions



HT Distribution

- Instead find a parametrisation and extrapolate the parameters of the parametrisation
- Ansatz for the HT distribution:

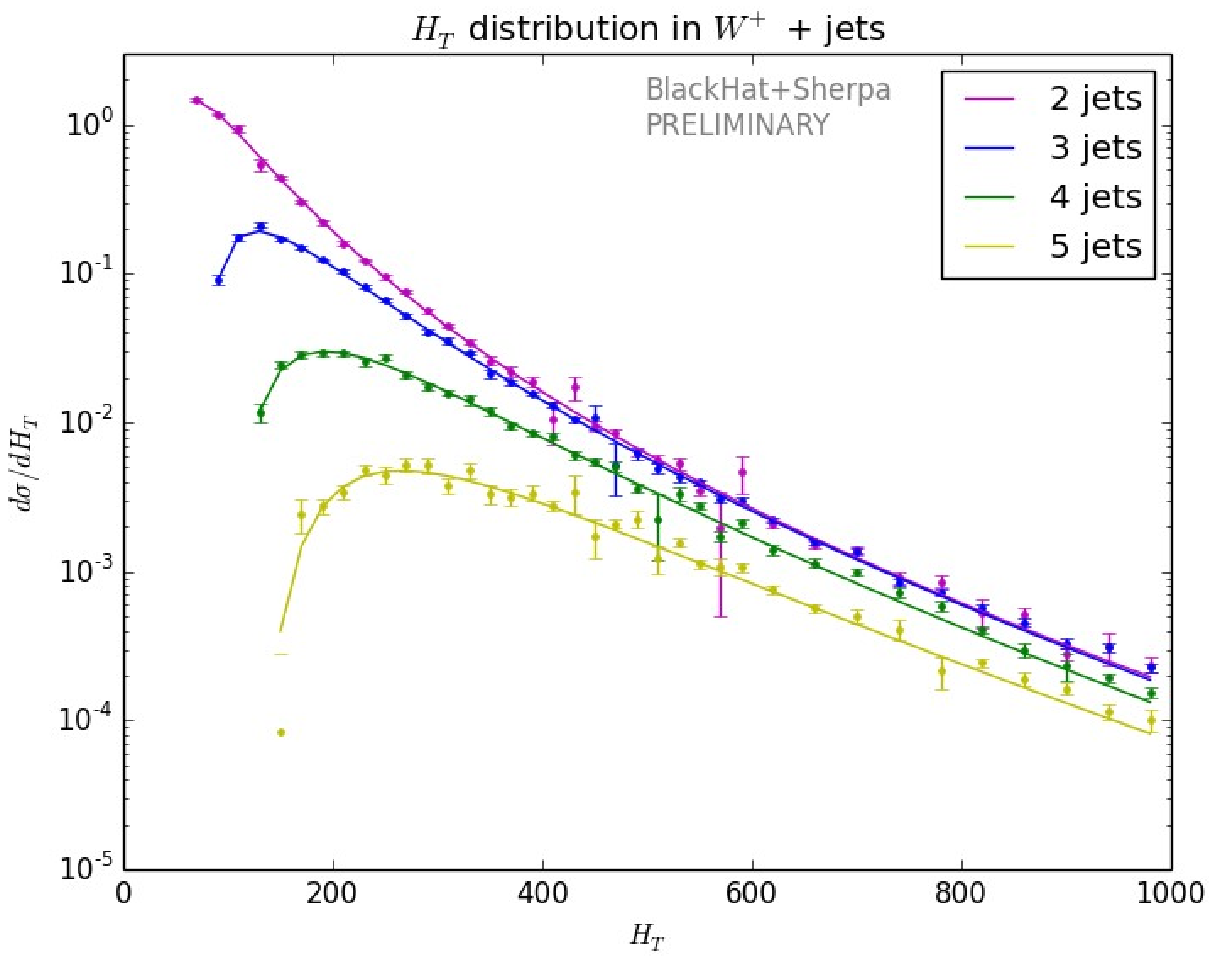
$$\frac{d\sigma_{V+n}}{d\,H_T} = \left(\frac{N_C \alpha_s}{2\pi}\right)^n f(H_T)\mathcal{N}_n \ln^{\tau_n} \rho_{H,n} \left(1 - H_T/H_T^{\max}\right)^{\gamma_n}$$

parameters

Independent of *n*

$$\rho_{H,n} = H_T/(np_T^{min})$$

HT distribution



Distributions

- Extrapolated HT distribution
- Uncertainty bands are estimated using a MC method