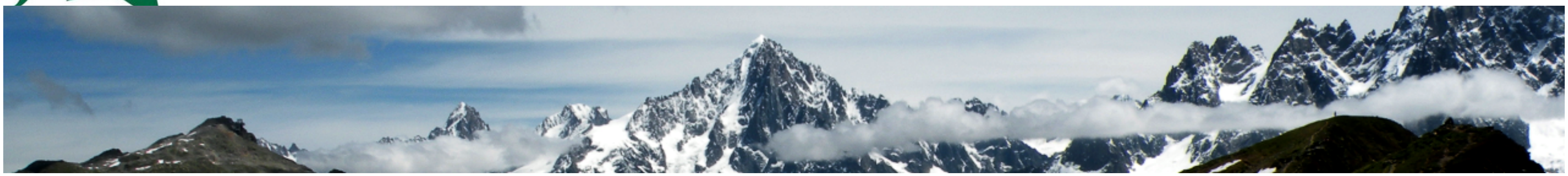


NLM Working Group Summary …from an experimentalist perspective

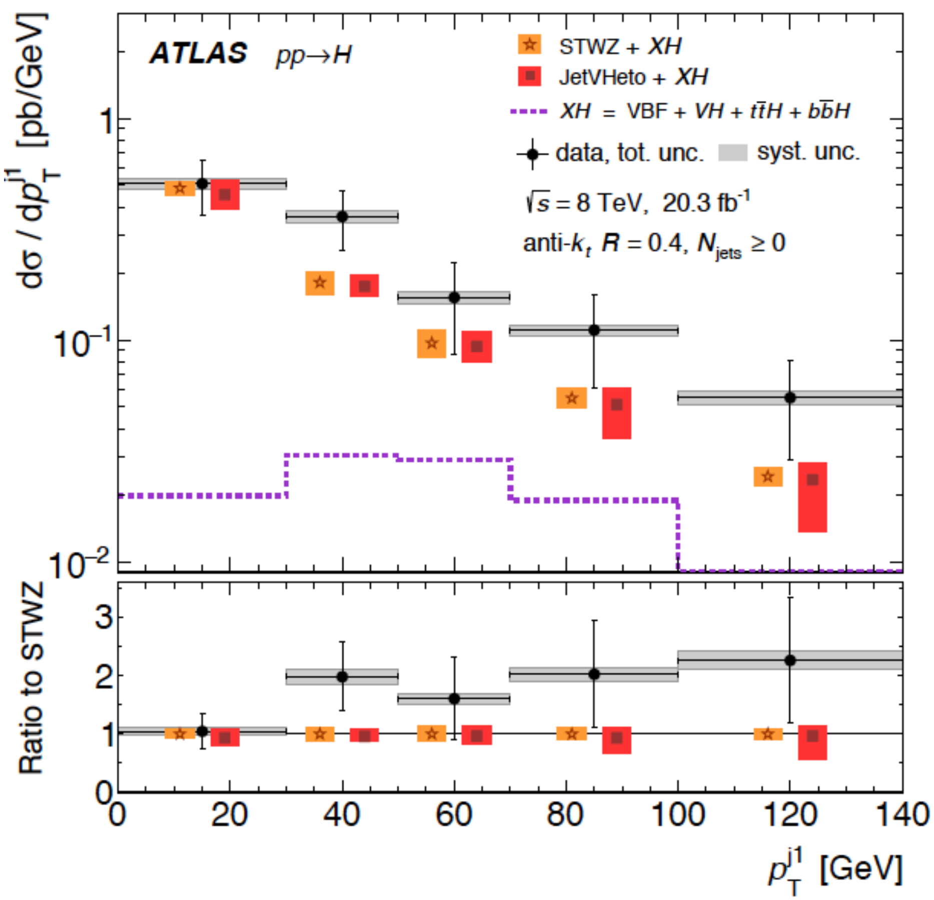
J. Huston

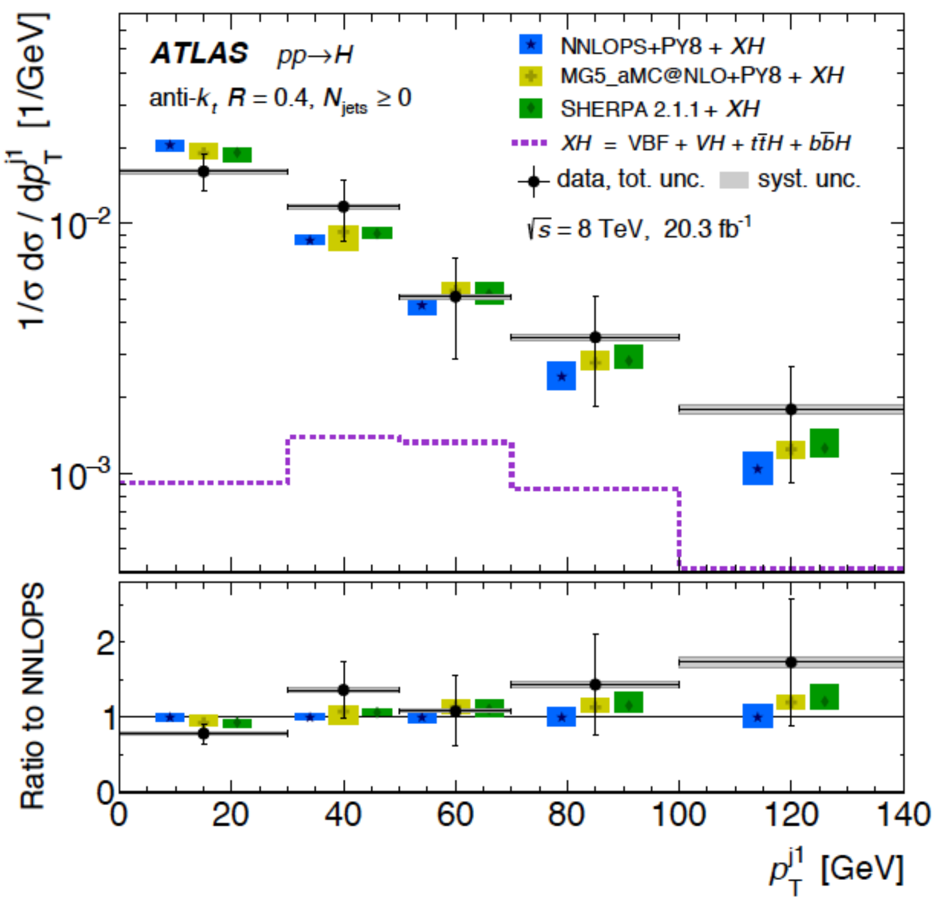
Michigan State University/IPPP

for Simon Badger, Ansgar Denner and the NLM group

ATLAS Higgs+>=1 jet

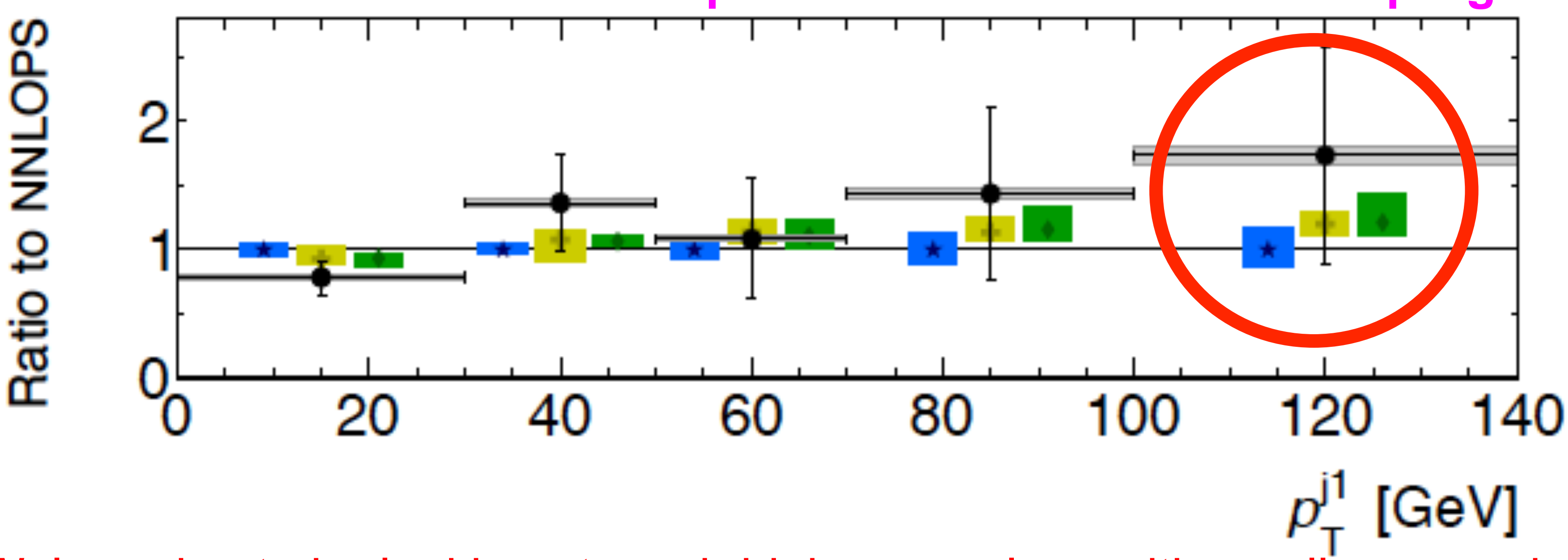
- Comparisons to a wide number of resummation/ME+PS predictions…**but not to fixed order**!





ATLAS Higgs+>=1 jet

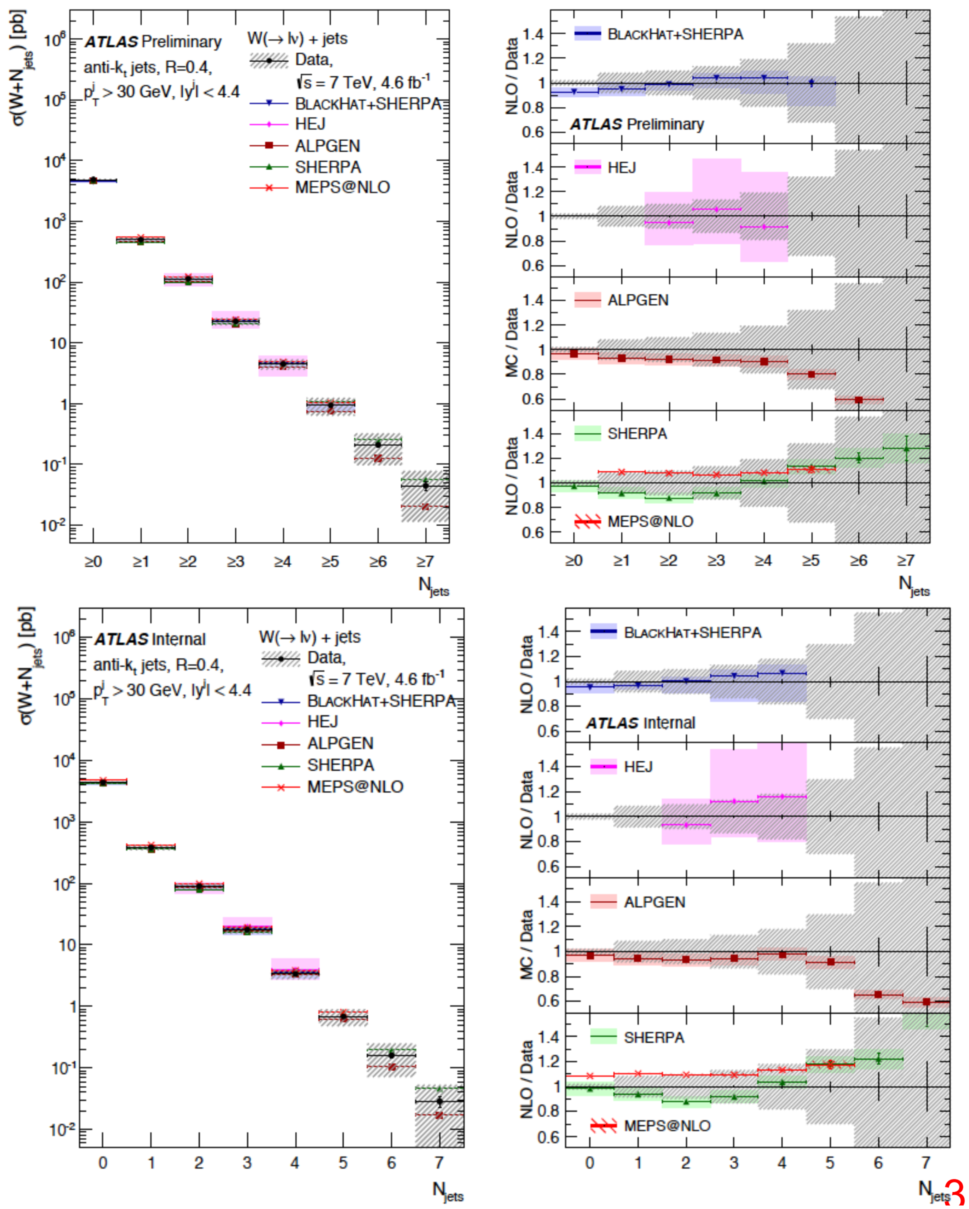
- Comparisons to a wide number of resummation/ME+PS predictions…**but not to fixed order**!
- **Les Houches:compare each prediction to each other, to fixed NLO/NNLO in detailed framework→see MC summary talk for more details**
- **How well do the resummation calculations anticipate/reproduce the NNLO results**? **Comparison with F. Tackmann in progress**



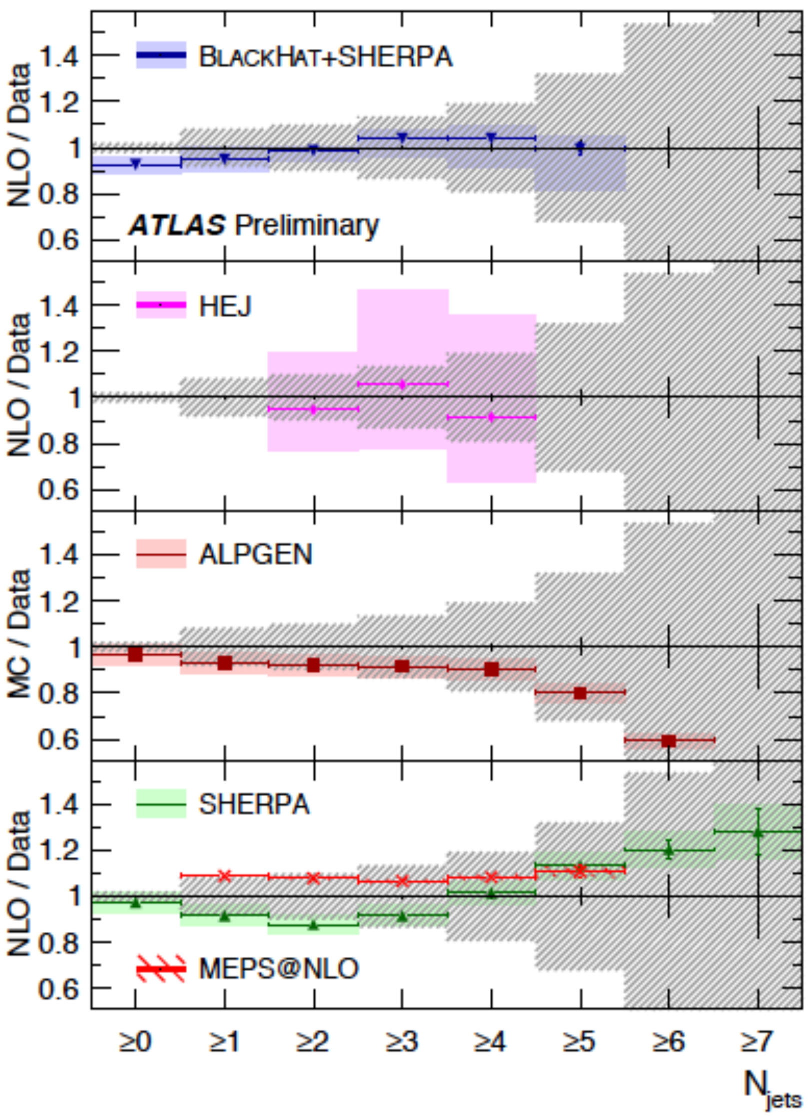
We're going to be looking at much higher p_T values with smaller errors in Run 2. We need to have a better quantitative handle on this.

W+jets

- ATLAS has measured up to 7 jets in the final state
  - both inclusive and exclusive final states
  - good agreement with Blackhat+Sherpa in general
    - with non-perturbative corrections

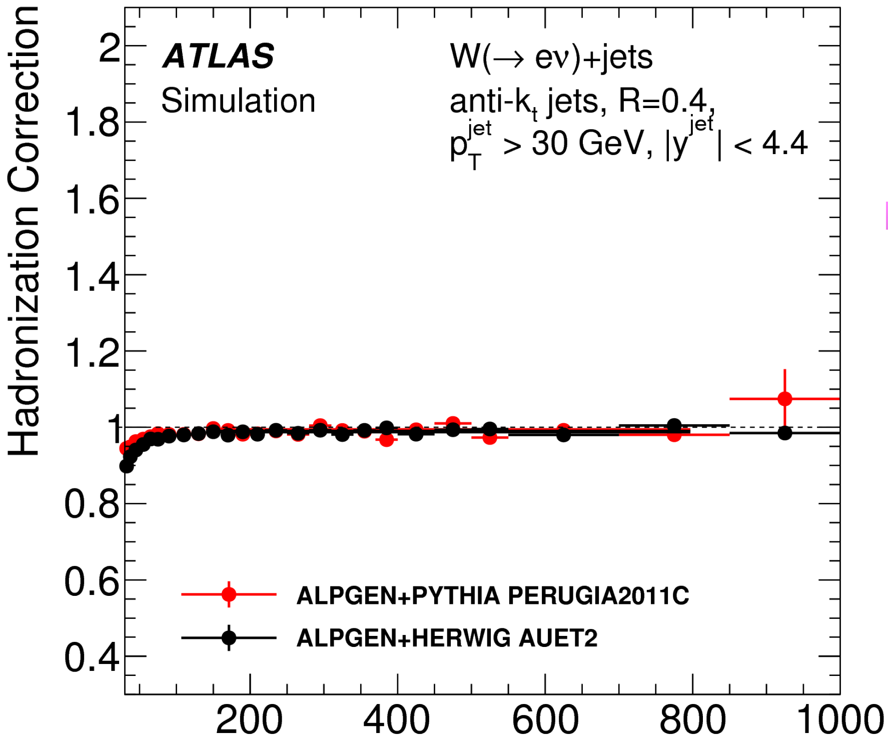


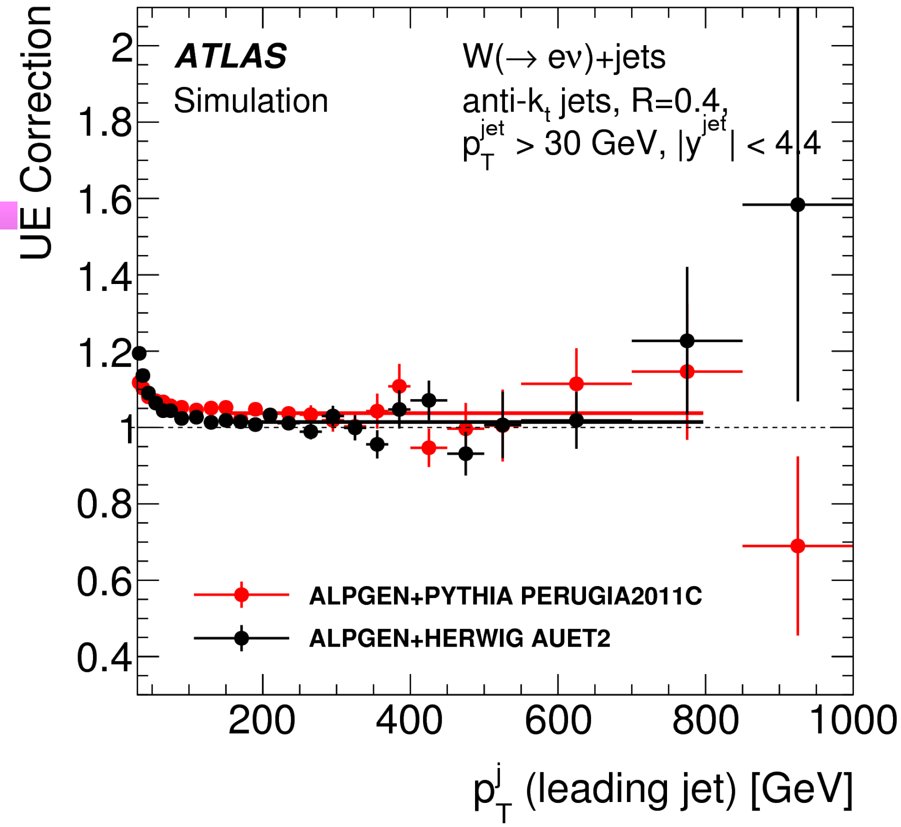
W+jets comparisons

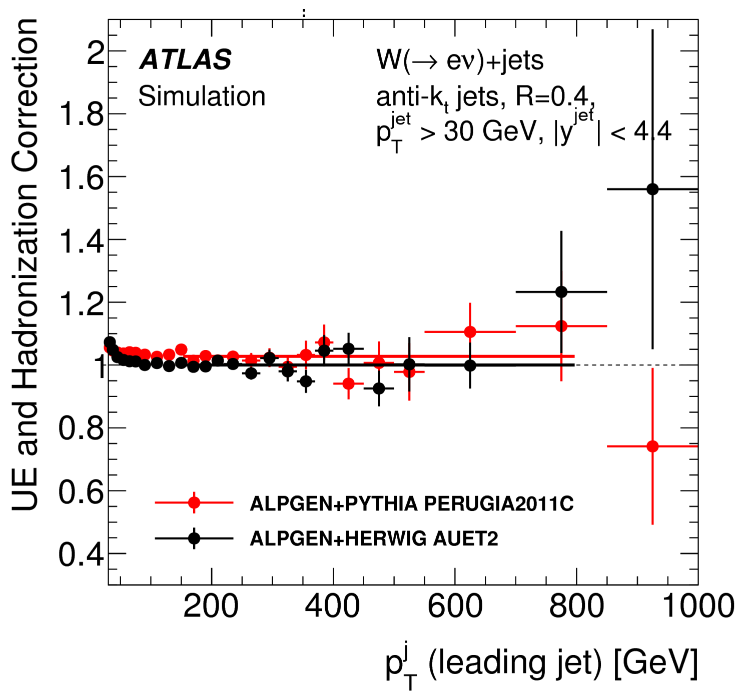


*fixed order with non-perturbative corrections
*describes jet multiplicity distribution well

*LO ME+PS along with NLO ME+PS
*problems when ME information runs out





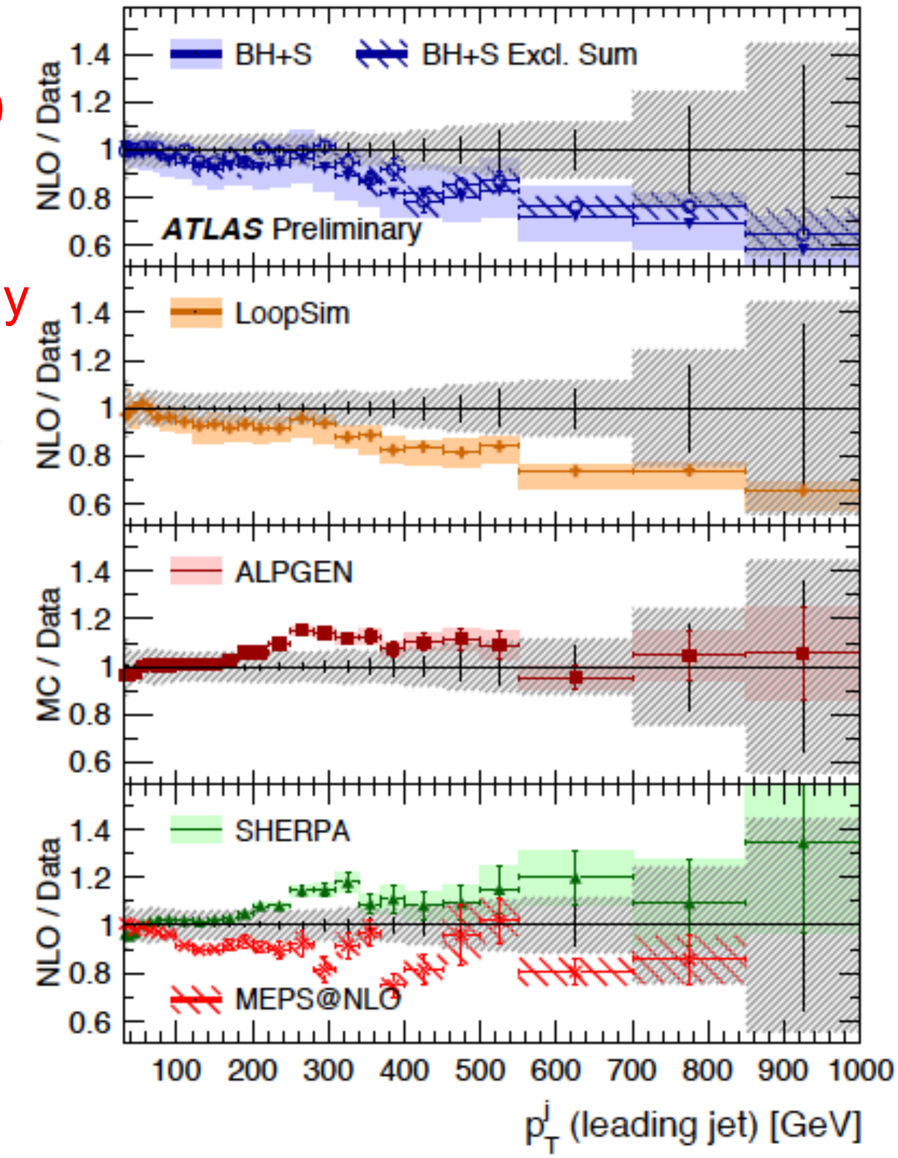


*The net correction is small and dies away quickly with increasing p_T, as expected for power corrections.

*Non-perturbative corrections for higher multiplicity final states are separately (UE and hadronization) but still cancel.

Leading jet p_T

*TeV dynamic range
*fixed order (+augmented fixed order) falls below the data at high p_T
*ALPGEN agrees at high p_T?
  -curious given that ALPGEN arguably has 'less physics in it'
*Sherpa and MEPS@NLO somewhat different behaviors?
  -MEPS@NLO 'tames' high p_T behavior of Sherpa?
*each type of comparison adds to physics interpretation
companion W+jets precision benchmark tests to accompany Higgs+jets
*now have W+jets at NNLO to compare to
NB: absolute normalization for NLO



Scale determination (and uncertainty)

- We (almost universally) use a scale of $H_T/2$ for complex fixed order calculations, and the scale seems to work well, with variations a factor of 2 up and down to give uncertainties
- However, the optimal scale choice depends on kinematics and factors such as the jet size/algorithm
- **Can we understand this scale choice better for example through an implementation of the MINLO procedure in fixed order ntuples?**
  - **implementation in progress (S. Badger and D. Maitre)**
- **Can we adapt LoopSim to provide ~NNLO predictions for final states for which such calculations are not available?**
  - **implementation available for NLO ntuples (S. Badger)**
  - **how well does it work for states for which NNLO is available?**
    - **comparison with NNLO numbers from F. Petriello in progress**

Ntuple discussion

- As mentioned in the introductory talk, B+S ntuple format now universal among fixed order NLO calculations
- Want to be able to pipe Ntuples into Rivet, keeping track of correlated weight information; allows comparisons, for example Higgs+>=1 jet

New in twiki

Rivet for correlated weights

David Grellscheid and Daniel Maitre tested the feature of the new Rivet version that allows correlated weights to be taken into account correctly in Rivet analyses. This new feature allows to pipe nTuples directly into Rivet. An example implementation and the updated nTupleReader library is attached.

nTuple2Rivet program

nTupleReader library

The program can be called with

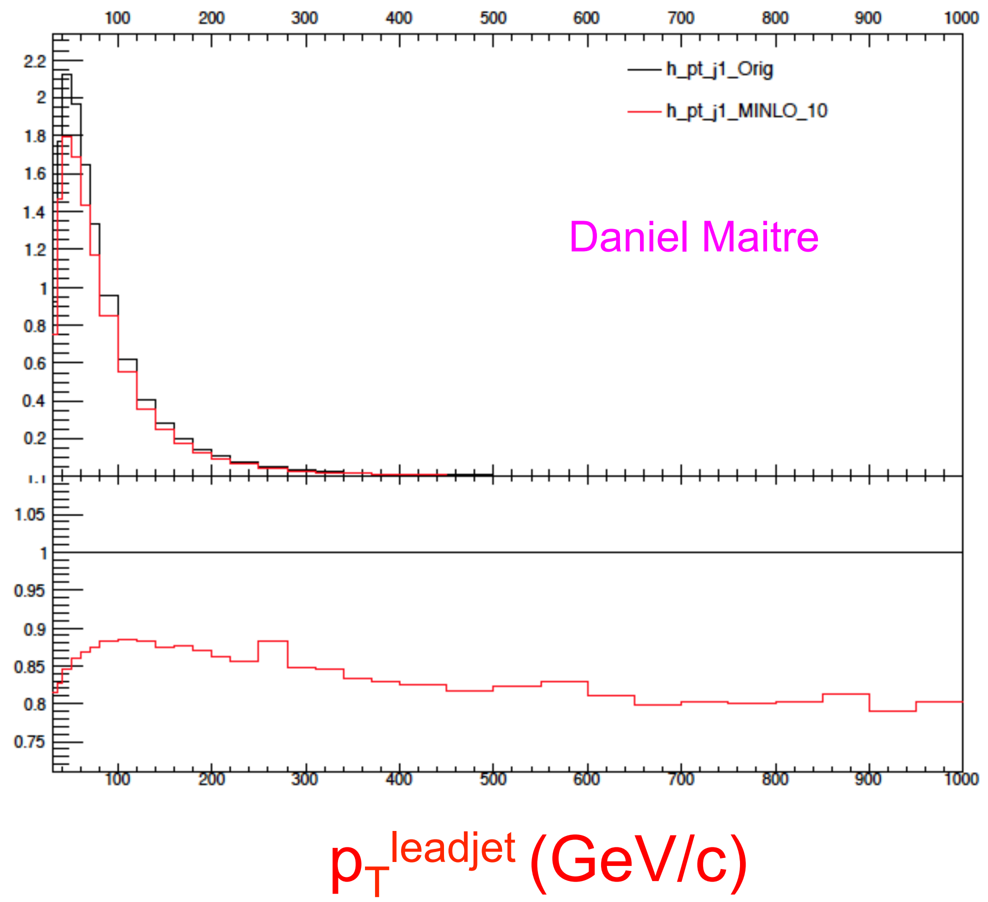
```
nTuple2Rivet RIVET_ANALYSIS_NAME nTupleFile1.root nTupleFile2.root ....
```

and will create a RIVET_ANALYSIS_NAME.yoda file with the analysis histograms.

This only works for a new version of Rivet.

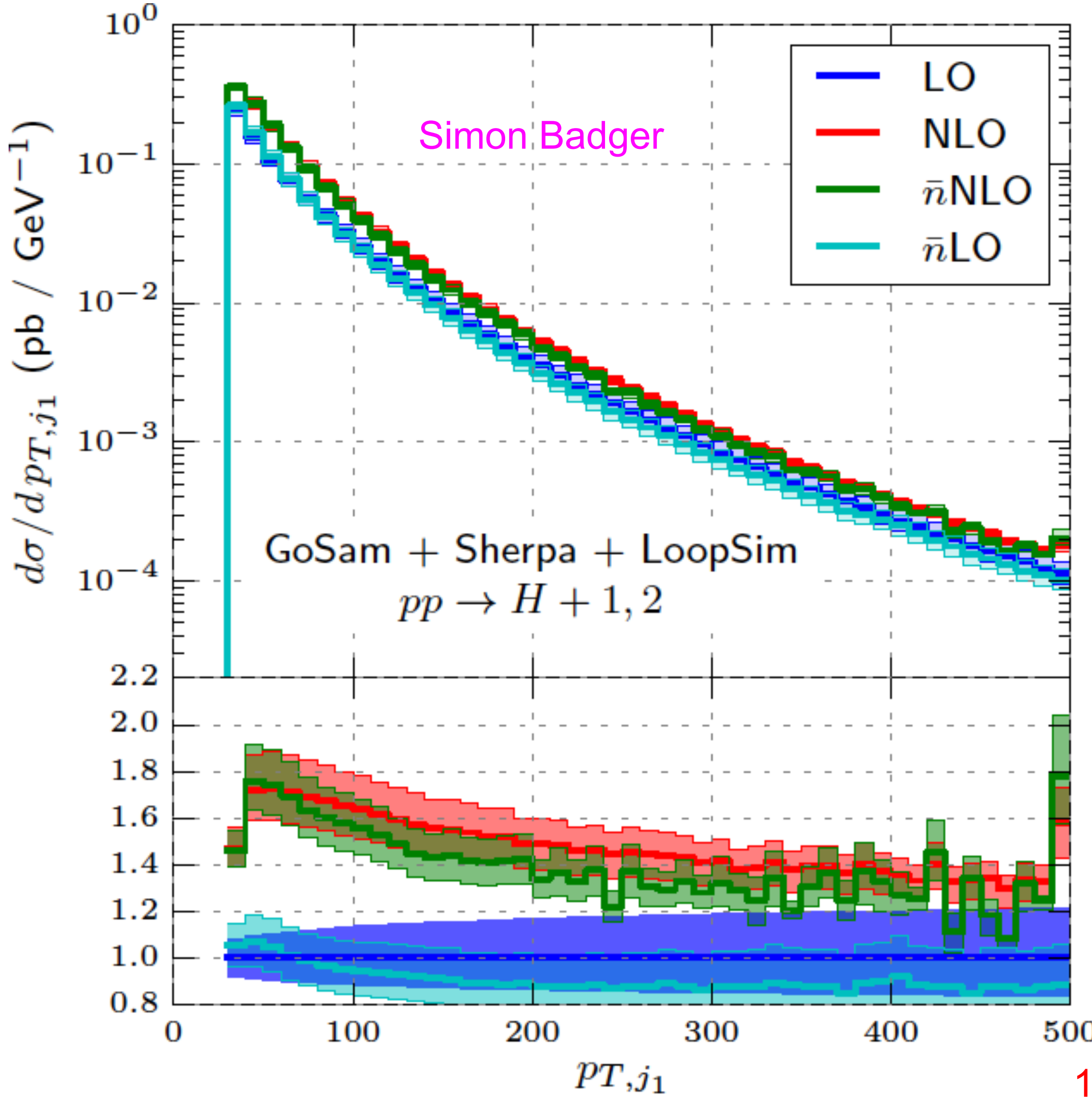
MINLO for W+2 jet ntuples

- Scale setting (and Sudakov form factors) in fixed order calculations similar to what CKKW does in ME+PS
- So far Born level only
- Proof of principle
- Can't conclude anything until have complete NLO



LoopSim for Higgs+>=1 jet

- Again, LoopSim approximates NNLO (nNLO) contributions
- Works best for processes in which real corrections are very large
  - for example, W +>=1 jet at high p_T
- Applied here to Higgs +>=1 jet, using Gosam ntuples

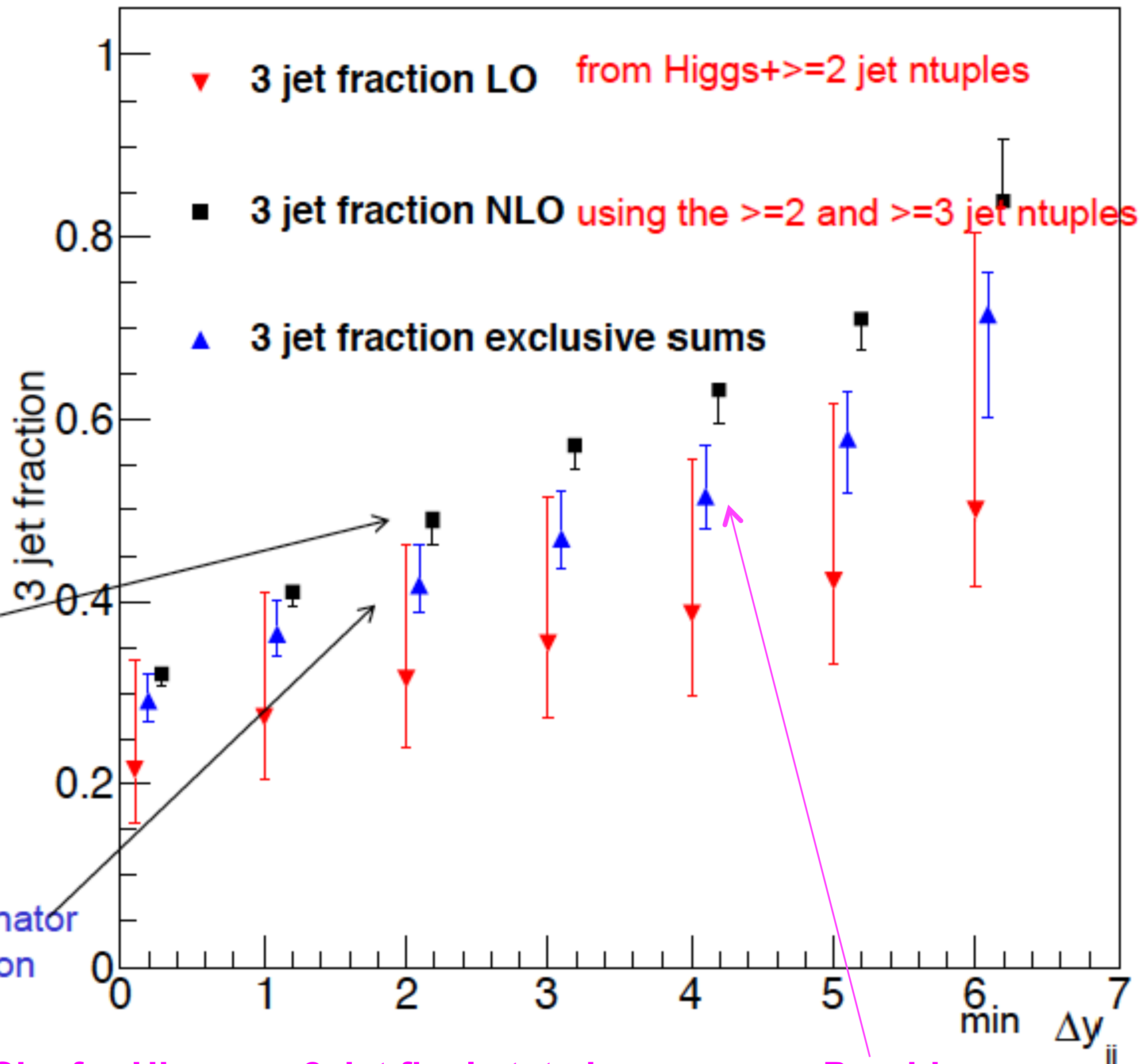


An example

fraction of Higgs+>=2 jet events with a 3rd jet as a function of the minimum rapidity separation between the two most forward-backward jets.

note the small scale dependence for the 3 jet fraction NLO; fractions are larger since >=3 jet cross section is at NLO

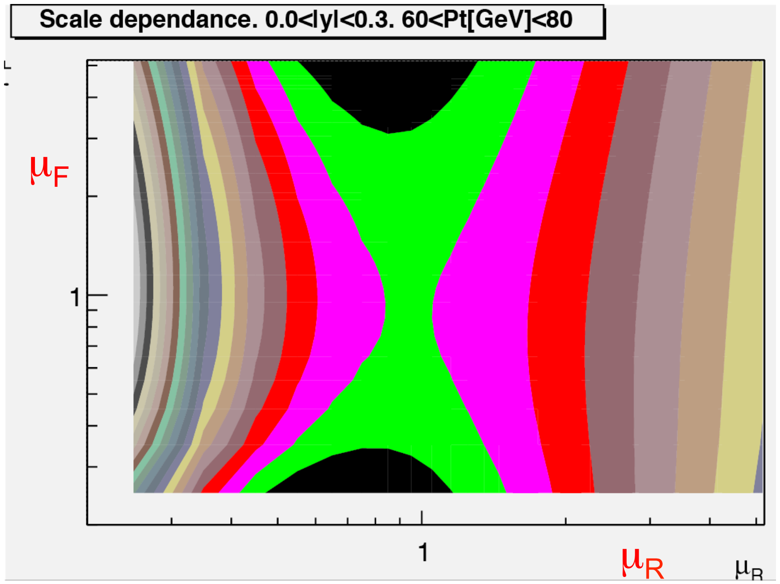
exclusive sums fractions are somewhat smaller since >=2 jets in denominator gets increased contribution

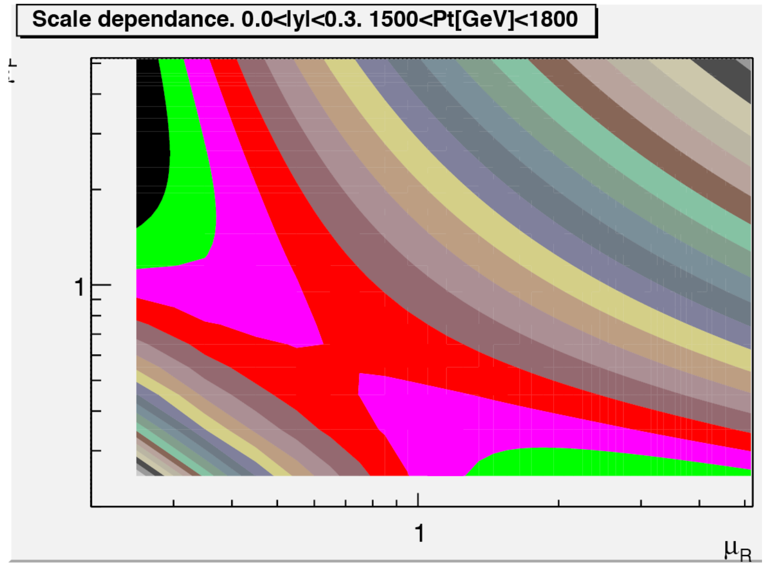


Calculation with LoopSim for Higgs+>=2 jet final state in progress. Provide nNLO for Higgs_>=2 jets. Compare to/replace exclusive sums.

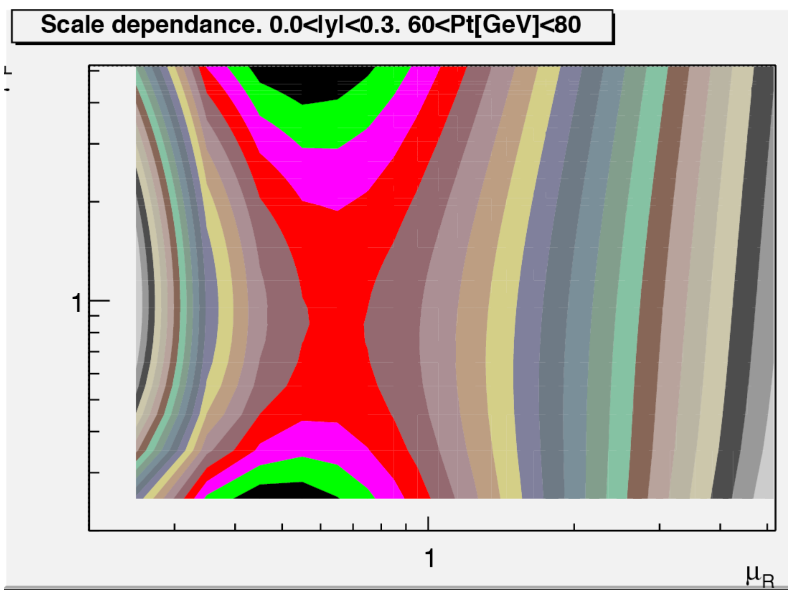
Scale dependence also depends on jet size, pT,y; inclusive jets at 7 TeV

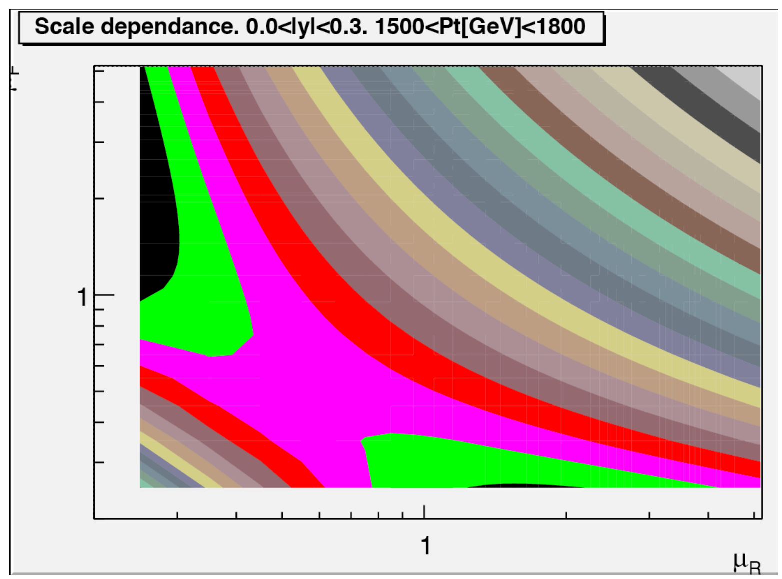
R=0.4
antikT



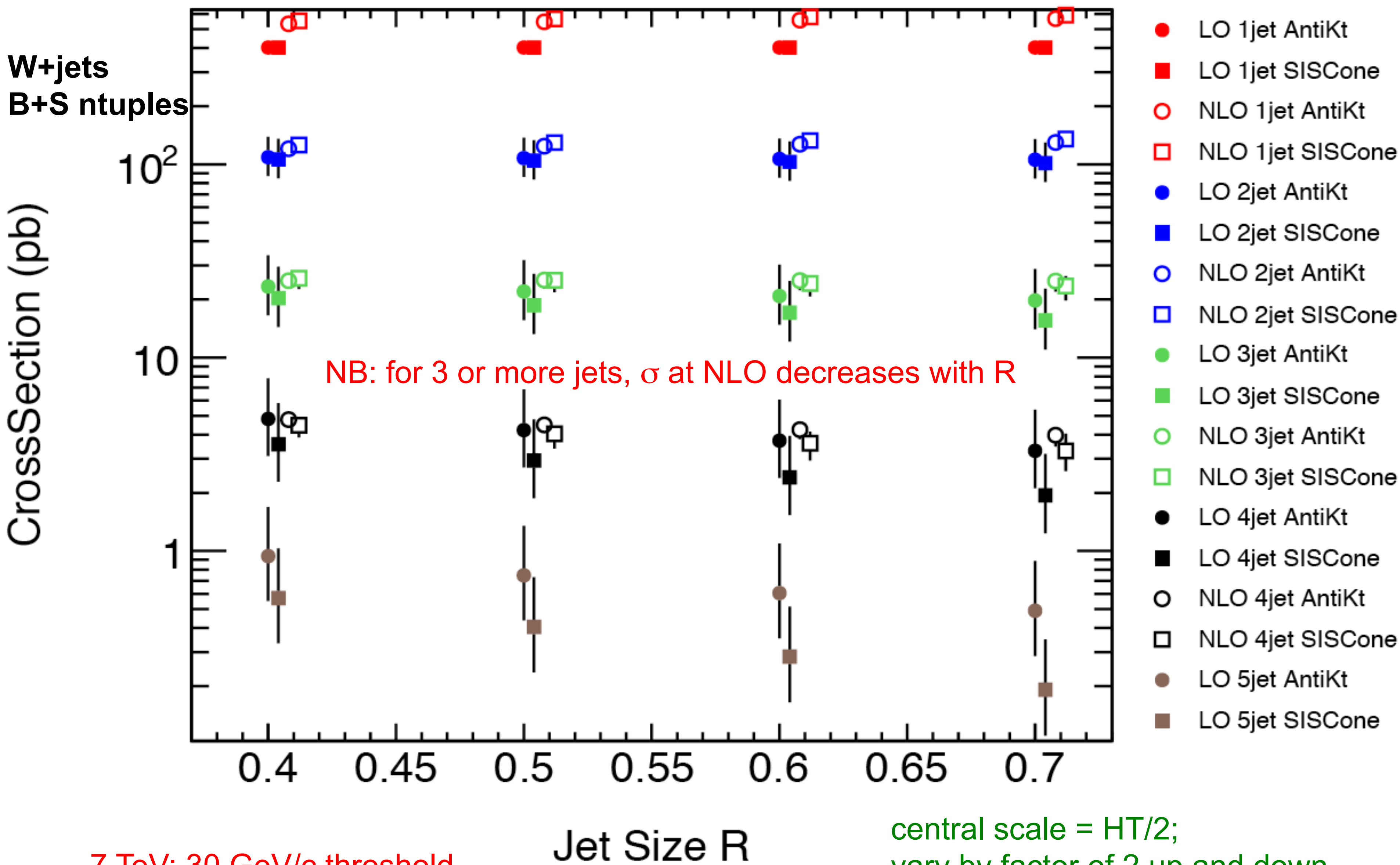


R=0.6
antikT





Look at jet size, algorithm dependences; scale uncertainty

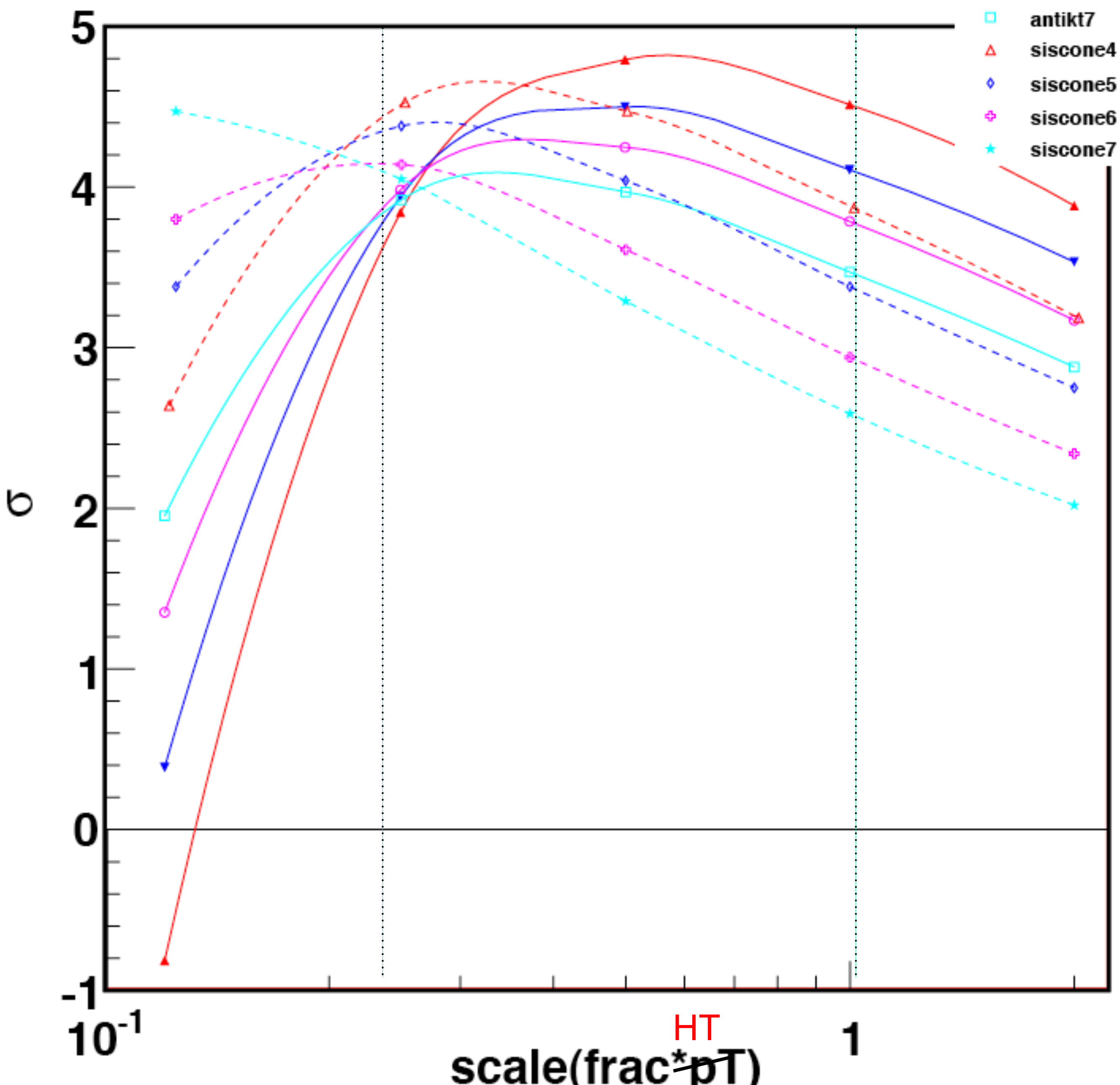


7 TeV; 30 GeV/c threshold

central scale = HT/2;
vary by factor of 2 up and down

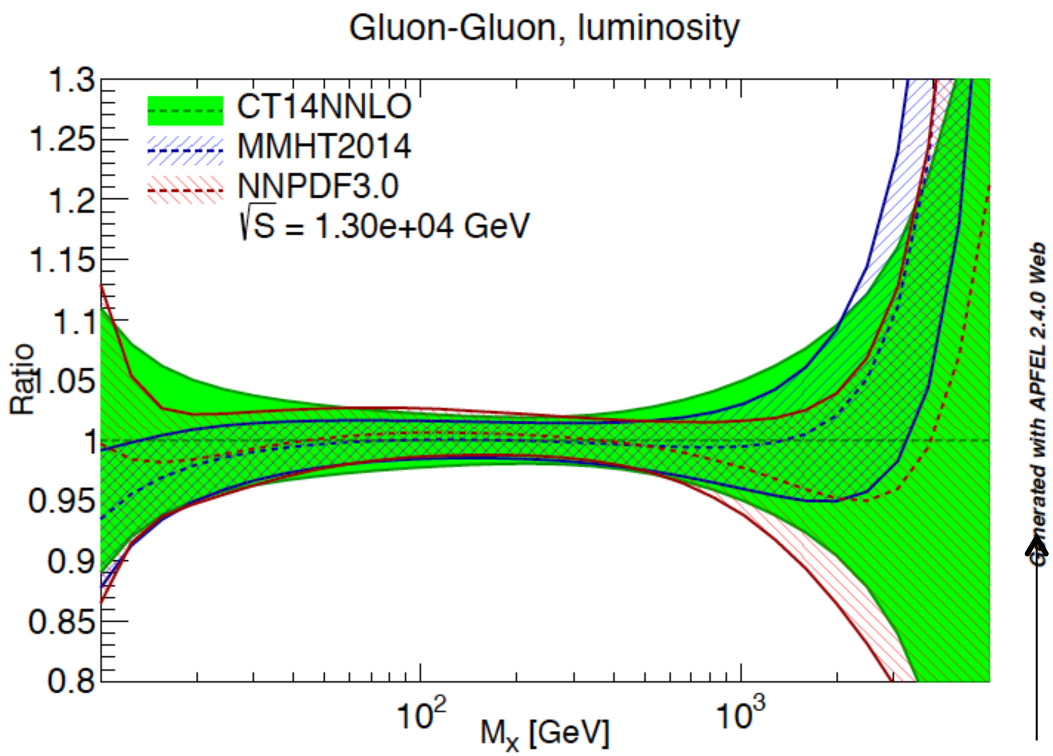
W+4 jets scale dependence

- A scale of HT/2 is ~ the peak for antikt4; so all deviations are negative
- Siscone peaks around HT/3
- Moves to smaller scales for larger R
- @HT/4, all antikt R give same result; that scale seems to be around HT/5 for siscone
- it is difficult to make conclusions about the uncertainty of any particular W + n jet cross section without understanding the scale dependence as the jet size/algorithm is varied



PDFs: the next generation

- NNPDF3.0 (arXiv:1410.8849)
- MMHT14 (arXiv:1412.3989)
- CT14 (on LHAPDF, archive soon)
- HERAPDF2.0 (soon)
- The gg PDF luminosities for the first three PDFs are in good agreement with each other in the Higgs mass range
- PDF uncertainty using the CT14, MMHT14, CT14 PDFs would be 2-2.5%, comparable to new scale dependence at NNNLO, and comparable to the as uncertainty



A very useful tool

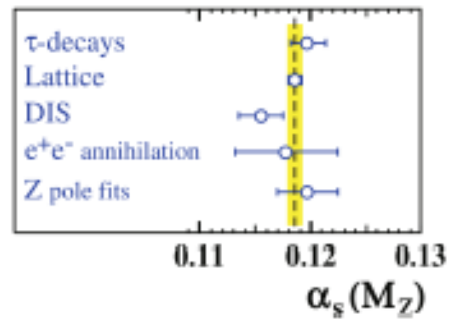
THE VALUE OF α_s

PDG VALUE (AUGUST 2014): $\alpha_s(M_Z) = 0.1185 \pm 0.0006$

to account for perturbative truncation errors

COMMENTS (S.F.)

- LATTICE UNCERTAINTY CURRENTLY ESTIMATED BY FLAG (arXiv:1310.8555) TO BE TWICE THE PDG VALUE (± 0.0012)
- IT IS AN AN AVERAGE OF AVERAGES
- SOME SUB-AVERAGES (E.G. DIS) INCLUDE MUTUALLY INCONSISTENT/INCOMPATIBLE DATA/EXTRACTIONS



- SOME SUB-AVERAGES (E.G. τ OR JETS) INCLUDE DETERMINATIONS WHICH DIFFER FROM EACH OTHER BY EVEN FOUR-FIVE σ
- AVERAGING THE TWO MOST RELIABLE VALUES (GLOBAL EW FIT & τ, BOTH $\mathrm{N^3LO}$, NO DEP. ON HADRON STRUCTURE) GIVES

$$\alpha_s = 0.1196 \pm 0.0010$$

NEW PDF4LHC AGREEMENT

- PDG UNCERTAINTY CONSERVATIVELY MULTIPLIED BY 2
- CENTRAL VALUE & UNCERTAINTY ROUNDED: PDF SETS USUALLY GIVEN IN STEPS OF $\Delta\alpha_s(M_z) = 0.001$

$$\alpha_s(M_Z) = 0.118 \pm 0.001$$

-PDFs all evaluated at same value of α_s (0.118).
-α_s uncertainty added in quadrature with PDF uncertainty
-α_s uncertainty is one of the dominant errors now

S. Forte Higgs XSWG meeting June 8, 2015

Updating the PDF4LHC prescription

- We are working on an updated prescription, at NNLO and NLO, using information from CT14, MMHT14, NNPDF3.0, that have similar theoretical treatments/data sets
- We are currently examining two techniques for reducing the number of error PDFs needed
  - Hessian
    - META PDFs
    - MC2Hessian
  - Compression
    - CMC PDFs

Note that measurements should be compared to individual PDFs. Error PDFs derived in this way are useful when a more general definition of the PDF uncertainty is required.

Specialized PDFs can also be made available, i.e. to look at directions sensitive to Higgs physics, W mass, etc.

- See for example the presentation and discussion from PDF4LHC meeting in April
  - https://indico.cern.ch/event/355287/
- …and the one here last Thursday
  - https://indico.cern.ch/event/399439/
- Followup meeting later this month at CERN; paper in preparation

Scale uncertainties for PDFs

- PDFs are almost always determined using fixed scales for ME's used in global fit, i.e. $\mu_R=\mu_F=p_T^{jet}$ for jet production
- Experimentalists calculate scale uncertainties for predictions by varying the scales for the ME's for those processes, assuming that scales in processes are uncorrelated with scales in PDF fits
  - and/or scale uncertainties in PDF fits are small compared to uncertainties for processes of interest at the LHC
- PDF uncertainties are essentially the same at NLO and NNLO, as they are derived from the errors on the experimental data

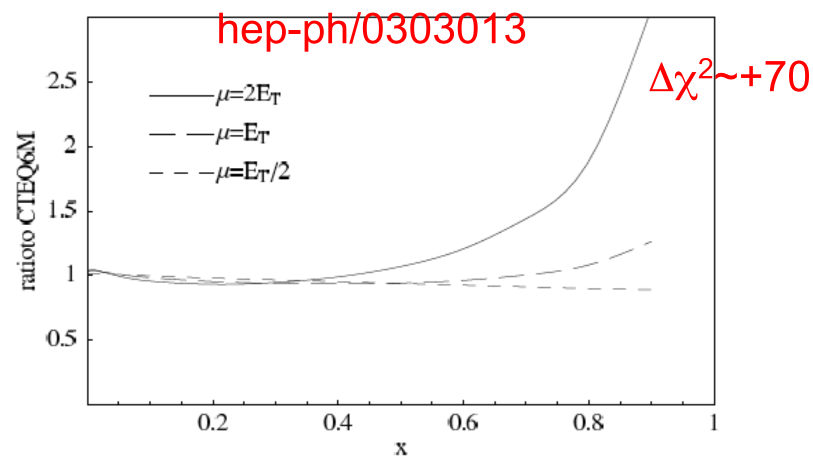
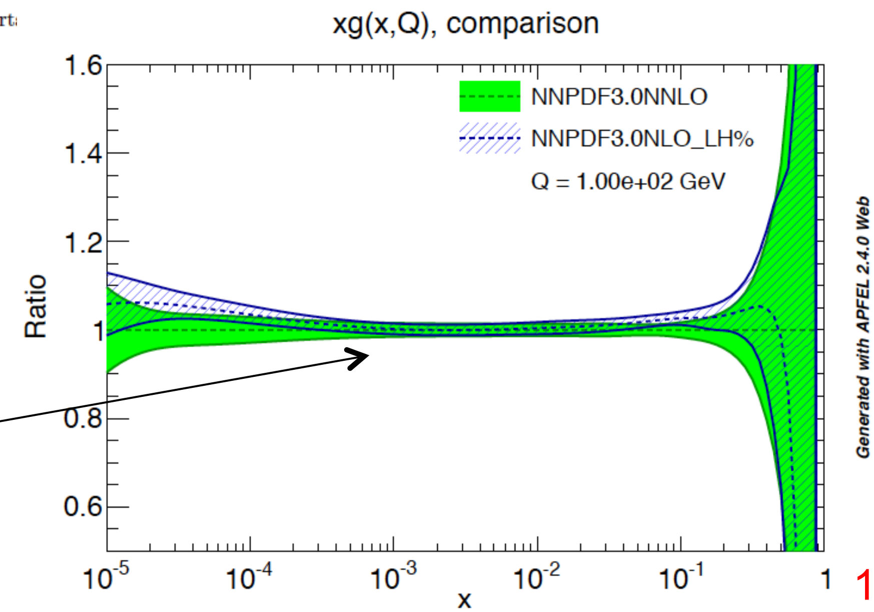


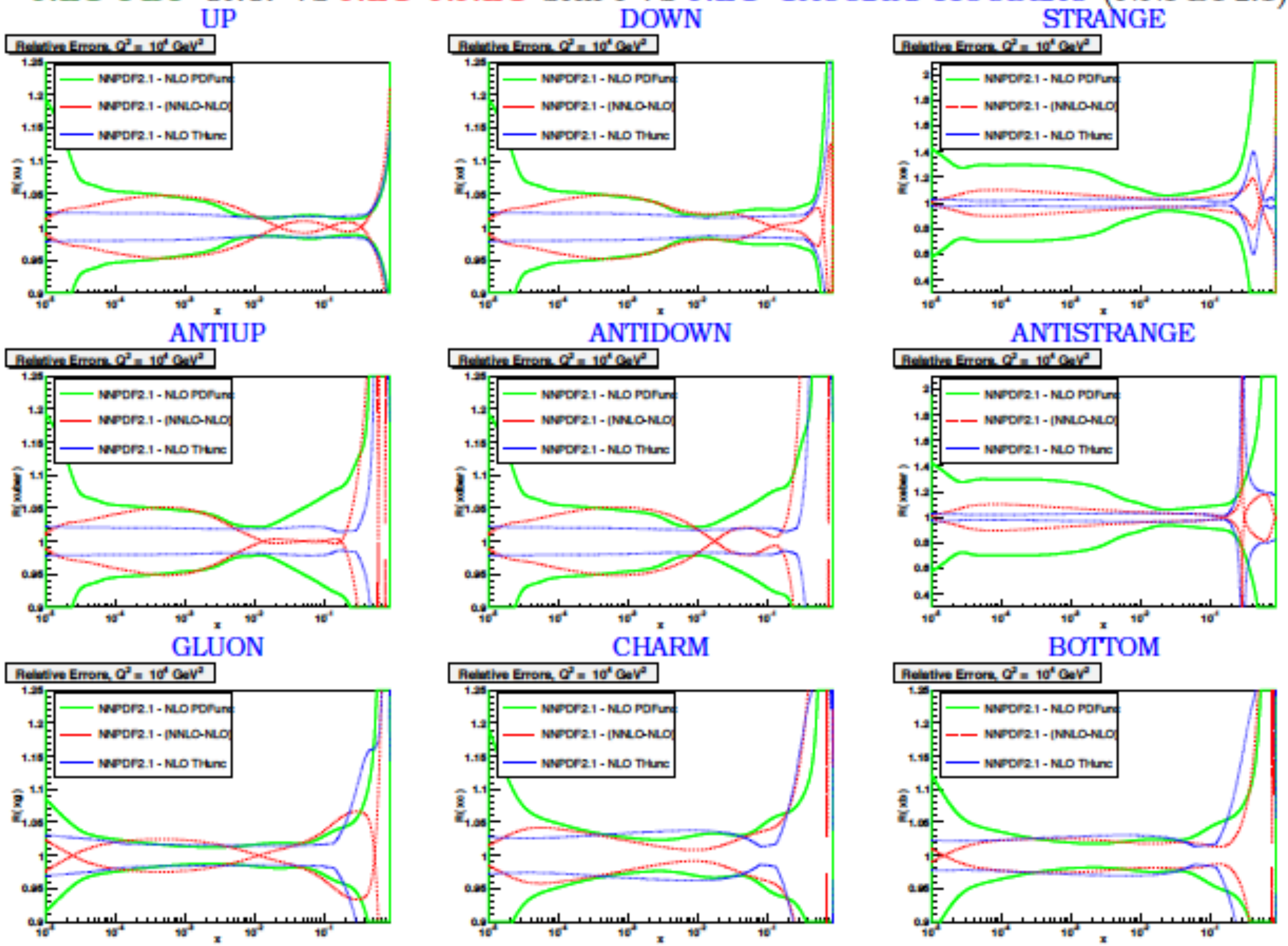
FIG. 18: Comparison of fitted gluon distributions for fits made with different scale choices for the jet cross section. Comparison to Fig. 6 shows that this theoretical error is smaller than the uncert



THEORETICAL UNCERTAINTIES

S. Forte

NLO PDF UNC. VS NLO-NNLO SHIFT VS NLO CACCIARI-HOUDEAU (NNPDF2.1)



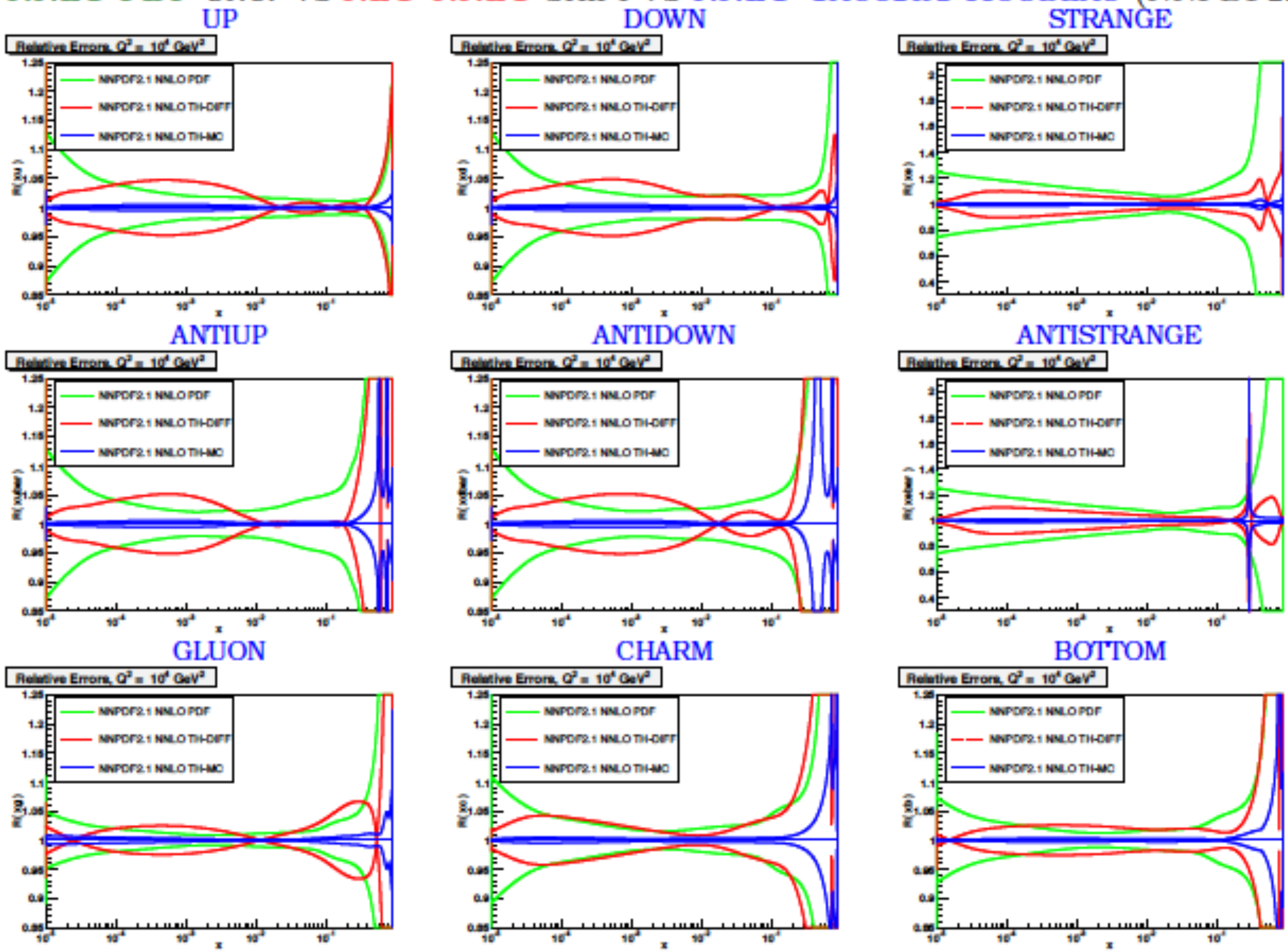
'Theory error' at NLO similar in size to PDF error, and to Cacciari-Houdeau estimate. Perhaps consider this as a validation of Cacciari-Houdeau.

Another test: compare NLO ME + NNLO evolution with NNLO ME + NLO evolution.

THEORETICAL UNCERTAINTIES

S. Forte

NNLO PDF UNC. VS NLO-NNLO SHIFT VS NNLO CACCIARI-HOUDEAU (NNPDF2.1)



Cacciari-Houdeau estimate of uncertainty at NNLO much smaller.

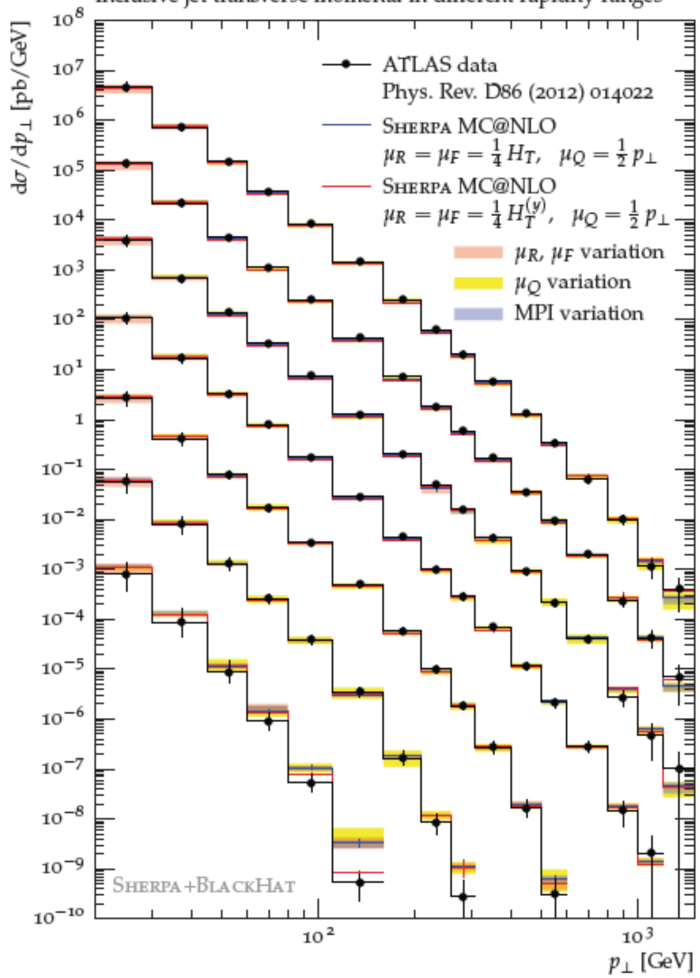
Inclusive jet production

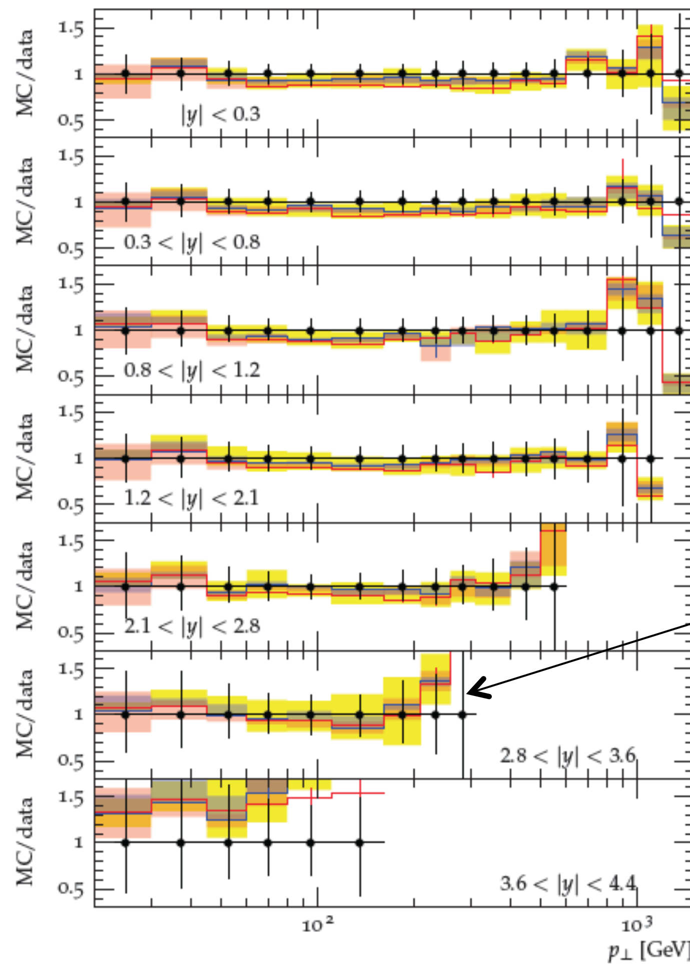
- **We also need a better understanding of the impact of parton showers on the fixed order cross section**

Sherpa MC@NLO seems to do a good job in describing ATLAS data (but PDF dependent statement)

Compare to fixed order with same PDF

Inclusive jet transverse momenta in different rapidity ranges





S. Hoeche, Marek Schoenherr for Sherpa; would be useful for other MC's as well

resummation scale uncertainties seem small except at extremes of phase space (as expected)

Topics discussed for direct photon measurements*

1. Isolation criteria for measurement of processes including photons and comparison to theoretical predictions

LH2013: 'Tight photon Isolation accord' (Cieri, de Florian):
*Experimental measurement: (Hollow) cone isolation, R<Rmax Etcone<epsilonX Etgamma OR Etcone<Etmax
*Theoretical predictions: Smooth Frixione cone with same R and Etmax
*Validity: Agreement O(1%)if contribution from the fragmentation component does not exceed ~15-20% of total cross section.
*Demonstrated on inclusive gamma gamma

LH2015: Valid for other processes containing photons? (gamma + jet, gamma gamma + jet, tri/quadri-photon, Vgamma)

2. Fragmentation: FO calculators (PHOX family, MCFM, GoSam) integrate out non-longitudinal components of fragmentation,

how much do these contribute and how?

*Coordinated by Susan Gascon-Shotkin

Topics discussed for direct photon measurements

3. Observed unphysical behaviour in inclusive gamma gamma under 'mismatch' of fragmentation and ME orders (Cieri, de Florian LH2013)
LH2015: Also observed in other processes (gamma + jet, gamma gamma + jet, W/Zgamma)?

- study various processes trying to find universal behaviour
- investigate fragmentation component at
  - ∗ LO ME's with LO fragmentation functions
  - ∗ LO ME's with NLO fragmentation functions
  - ∗ NLO ME's with NLO fragmentation functions (where available)

$\gamma\ \gamma$	DiPhox, 2gammaNNLO	Leandro
$\gamma + jet$	JetPhox	Gudrun, Jean-Philippe
$\gamma\gamma + jet$	GoSam	Gudrun, Nicolas Greiner
$\gamma\gamma + jet ; \gamma\ \gamma\ \gamma ; 4\,\gamma$	MCFM	Ciaran

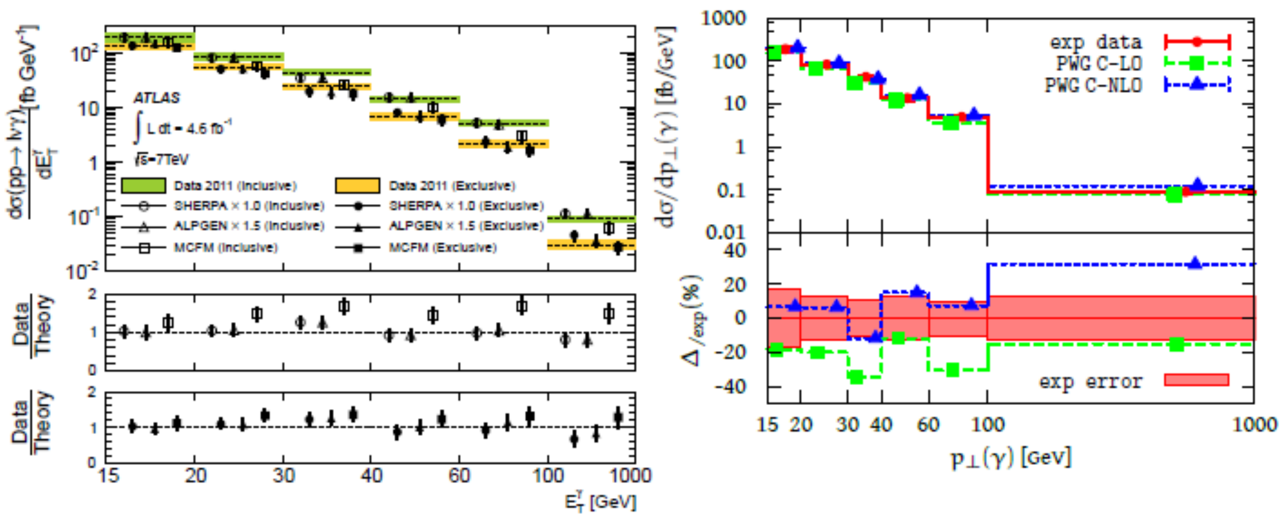
New LO fragmentation function possible in time for proceedings (Guillet, Fontannaz)

Topics discussed for direct photon measurements

LH2015: New formalism for Vgamma (Wgamma now, Zgamma coming, perhaps other direct photon processes) with POWHEG + MiNLO, NLO QCD normalization with exclusive generation of the final state particles, hadronized events (L. Barzé et al. JHEP 1412, 039 (2014))

$pp \to V\gamma$ at NLO+PS accuracy with POWHEG+MiNLO

$pp \to W\gamma,\ p_T^{\gamma},\ N_{\mathrm{jet}} \geq 0$ JHEP **1412**, 039 (2014)



No q/γ separation cuts at the generator level: directly comparable with experimental isolation

Topics discussed for direct photon measurements

4. Experimental Survey:
--size and character (hollow/solid, Fixed Et or normalized) of cones used/planned for use in CMS + ATLAS
--Survey of direct photon measurements esp. Vgamma
(Delmastro, Gascon et al)

References:
Greiner, Gehrmann, Heinrich, JHEP 1306 (2013) 058
Campbell & Williams, Phys. Rev. D 89, 113001 (2014)
Dennen & Williams, Phys. Rev. D 91, 054012 (2015)

Summary

- The data taken in Run 2 requires the best phenomenology technology
- The theory developed for the Run 2 data requires the best phenomenology technology
- Data from Run 2 is in progress.
- Theory development continues
- **Don't wait.**

Wu Ki Tung Award for Early Career Research on QCD

- See information at

http://tigger.uic.edu/~varelas/tung_award/

- Contribute at

https://www.givingto.msu.edu/gift/?sid=1480

- **MSU will match any donations**
- The 2015 winner was Stefan Hoeche