

HIGH-PT QCD AT THE LHC

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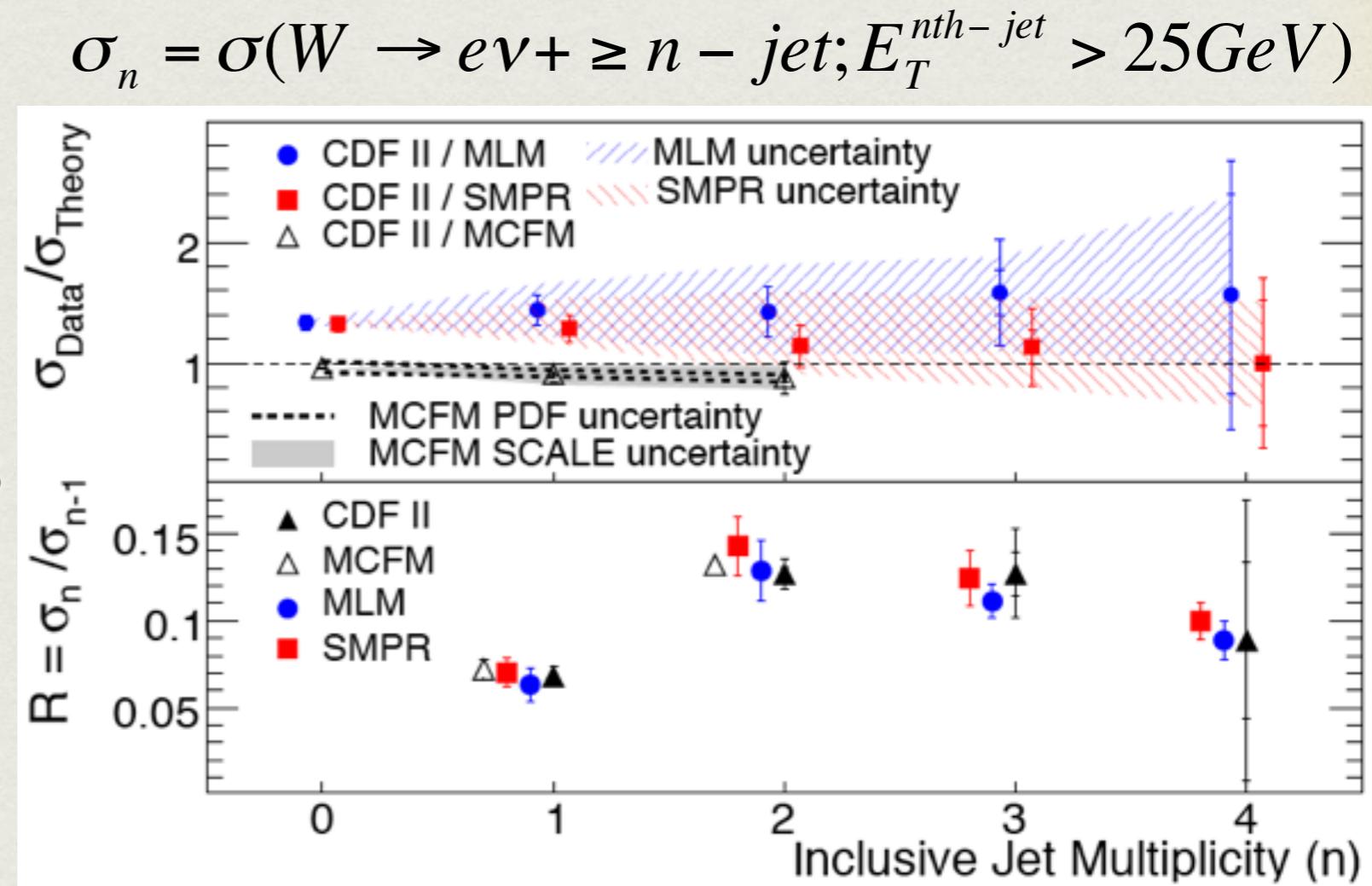
On behalf of the ATLAS and CMS collaborations

IMPORTANCE OF QCD STUDIES TODAY

- Understanding QCD interactions — and the ability to model them — directly impacts our discoveries and measurements at the LHC
- How well do we know QCD today?
 - *Especially in many different phase spaces*

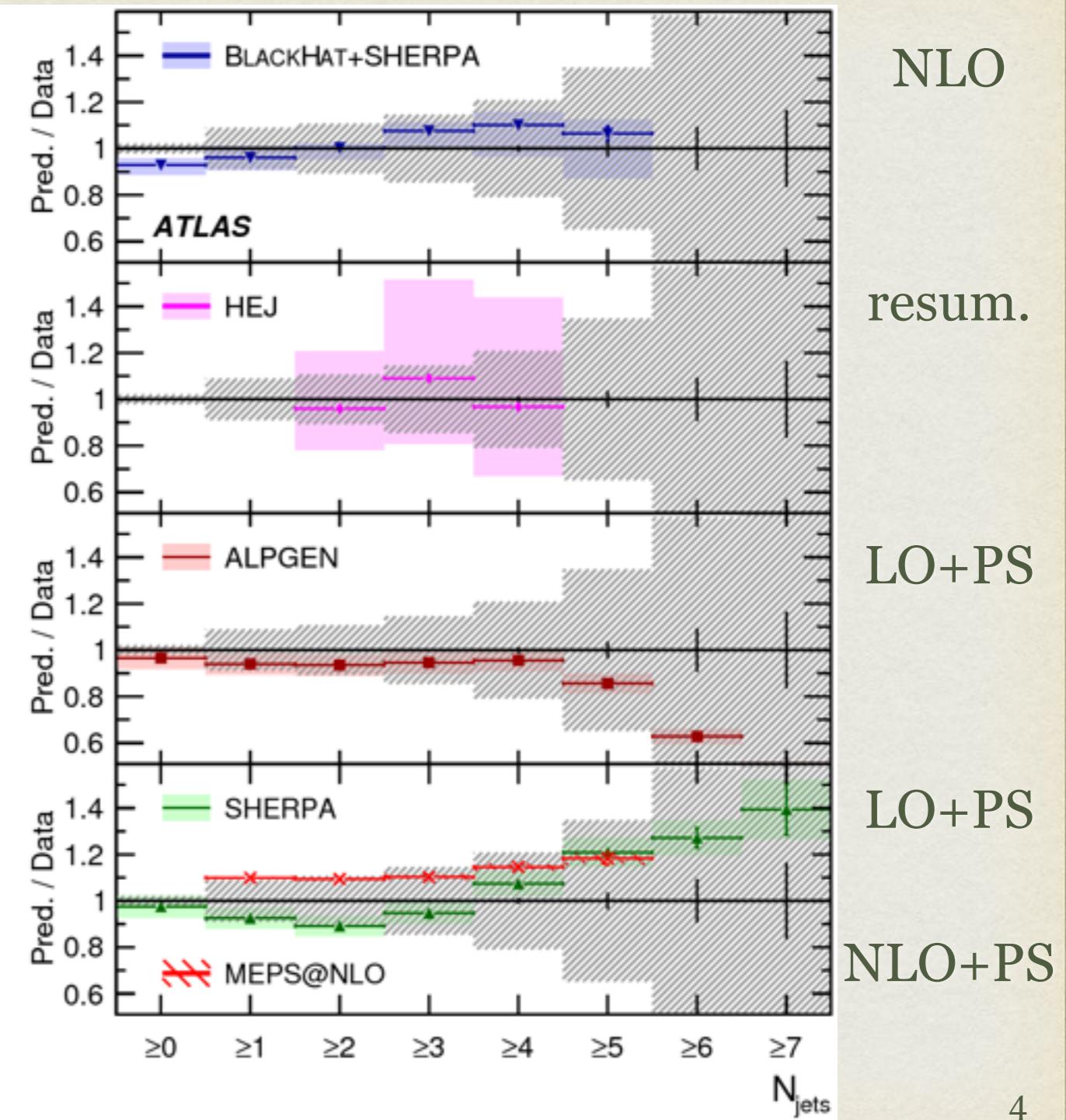
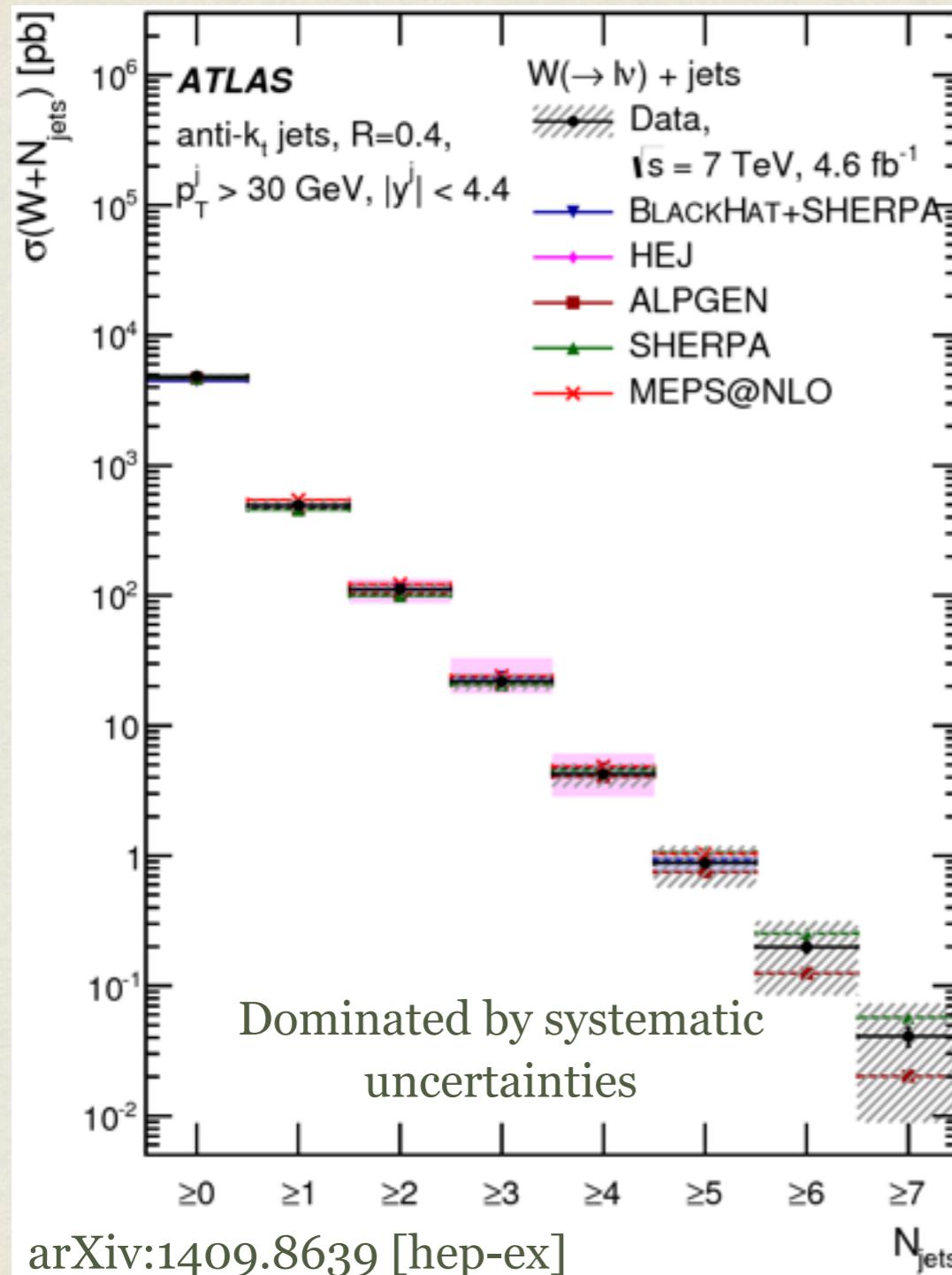
A TRIP DOWN MEMORY LANE: 2008

- Data:
 - At 4-jet large statistical uncertainties
- NLO calculations:
 - Improved uncertainties but limited to 2-jet
- LO calculations:
 - Greater kinematic coverage, include parton showering, large uncertainties



Results from CDF Phy. Rev. D 77 011108 (2008)

THE SAME PLOT TODAY



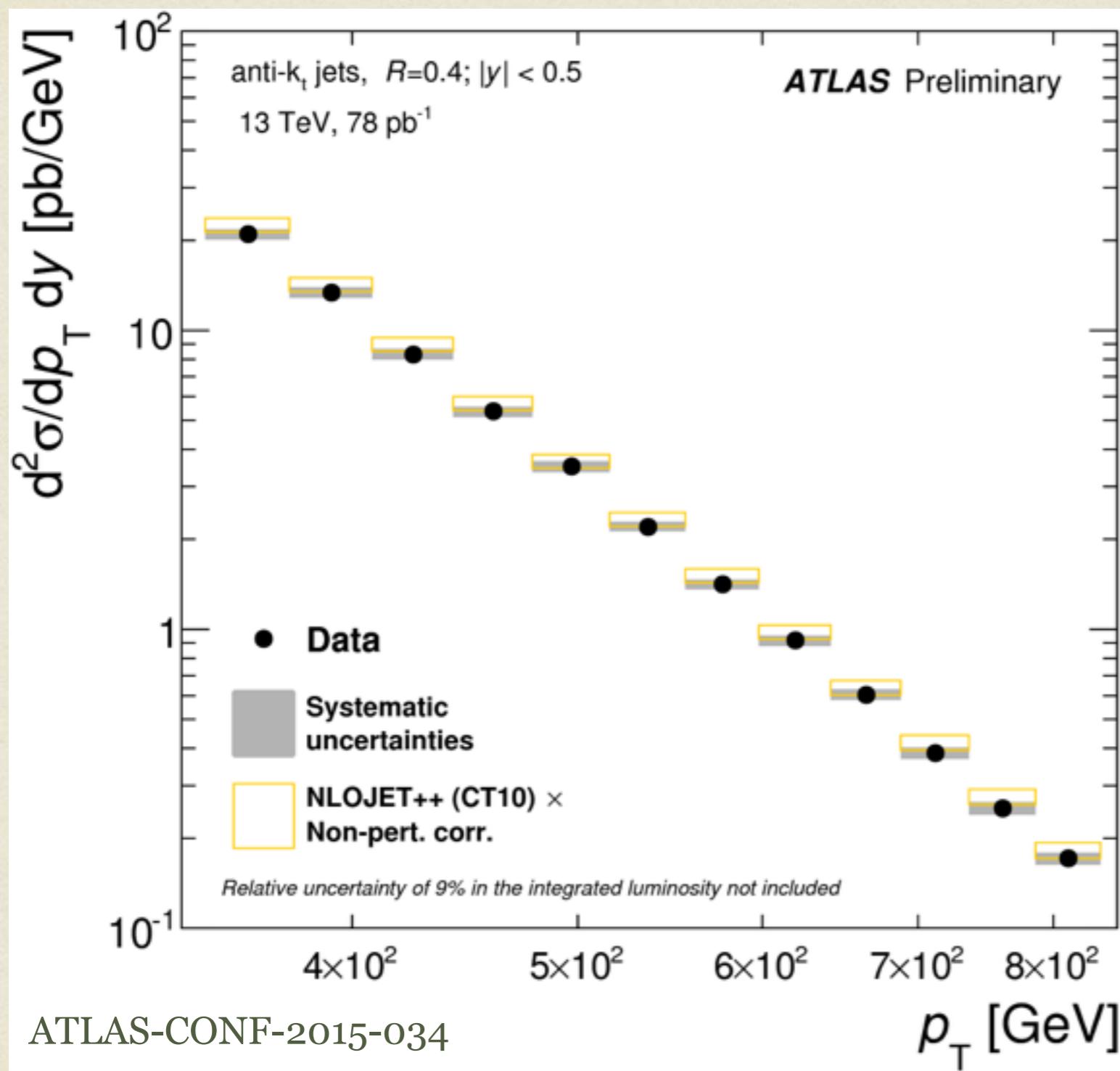
QCD STUDIES TODAY

- What we have achieved
 - Tremendous progress in QCD calculations and modeling
 - Greater precision in QCD measurements
 - Access to lots of data
- What's yet to come
 - Need to go beyond NLO (i.e. NNLO V+1-jet becoming available)
 - More measurements probing the corners of the Standard Model (i.e. energetic objects, forward jets)
 - More measurements of differential cross sections for rare processes (i.e. Z+bb)

JET PRODUCTION

- Jet production cross sections
 - Excellent probes of QCD dynamics over many orders of magnitude
 - Probes perturbative QCD but also its interplay with non-perturbative effects
 - Sensitive to strong coupling constant, PDFs and multi-parton interactions
- Many existing measurements
 - Spanning a range of different center-of-mass energies
 - Using different jet radii to probe this interplay

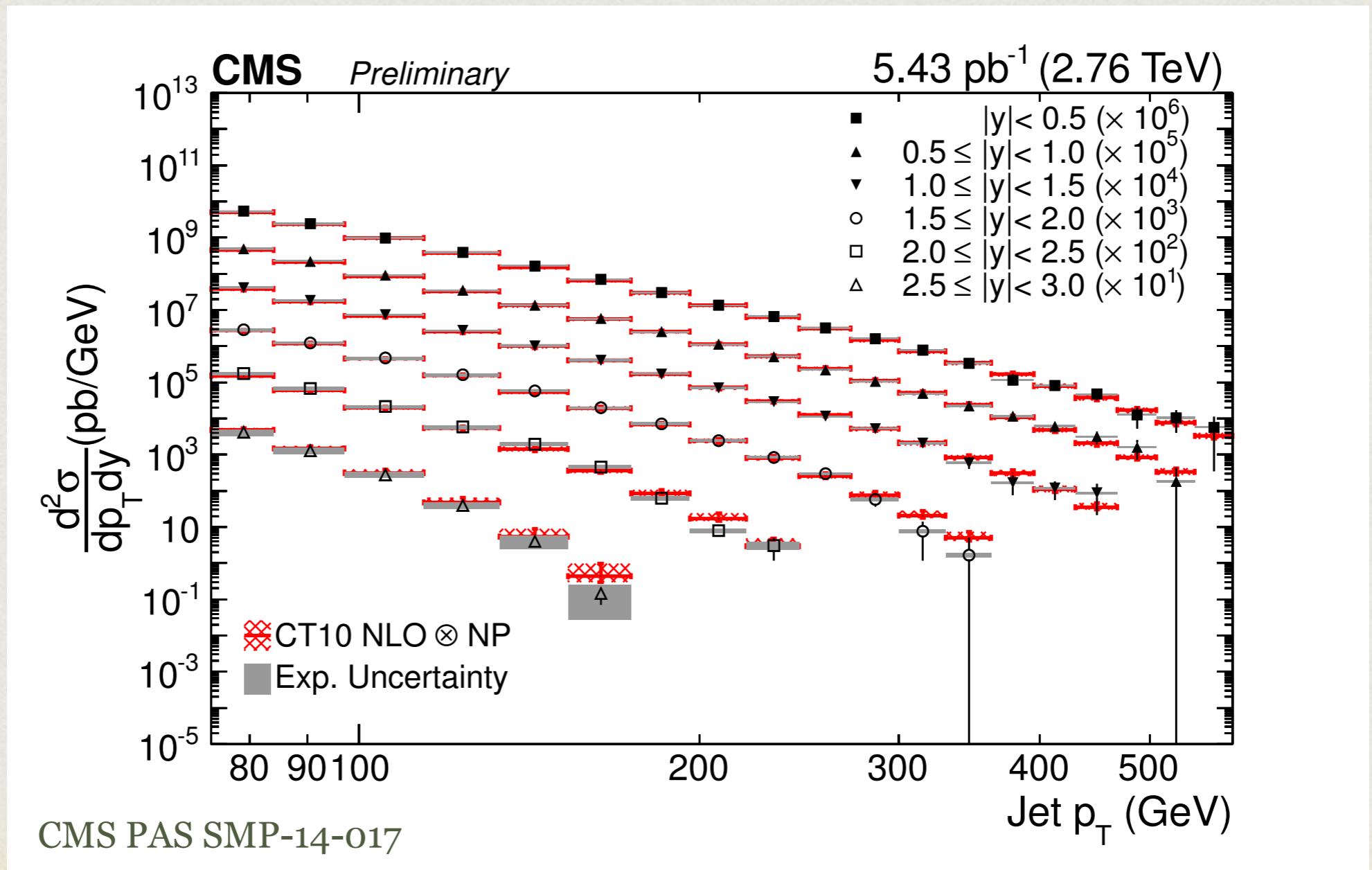
INCLUSIVE JET PRODUCTION



- Inclusive jet production at 13 TeV
- Excellent agreement over full range

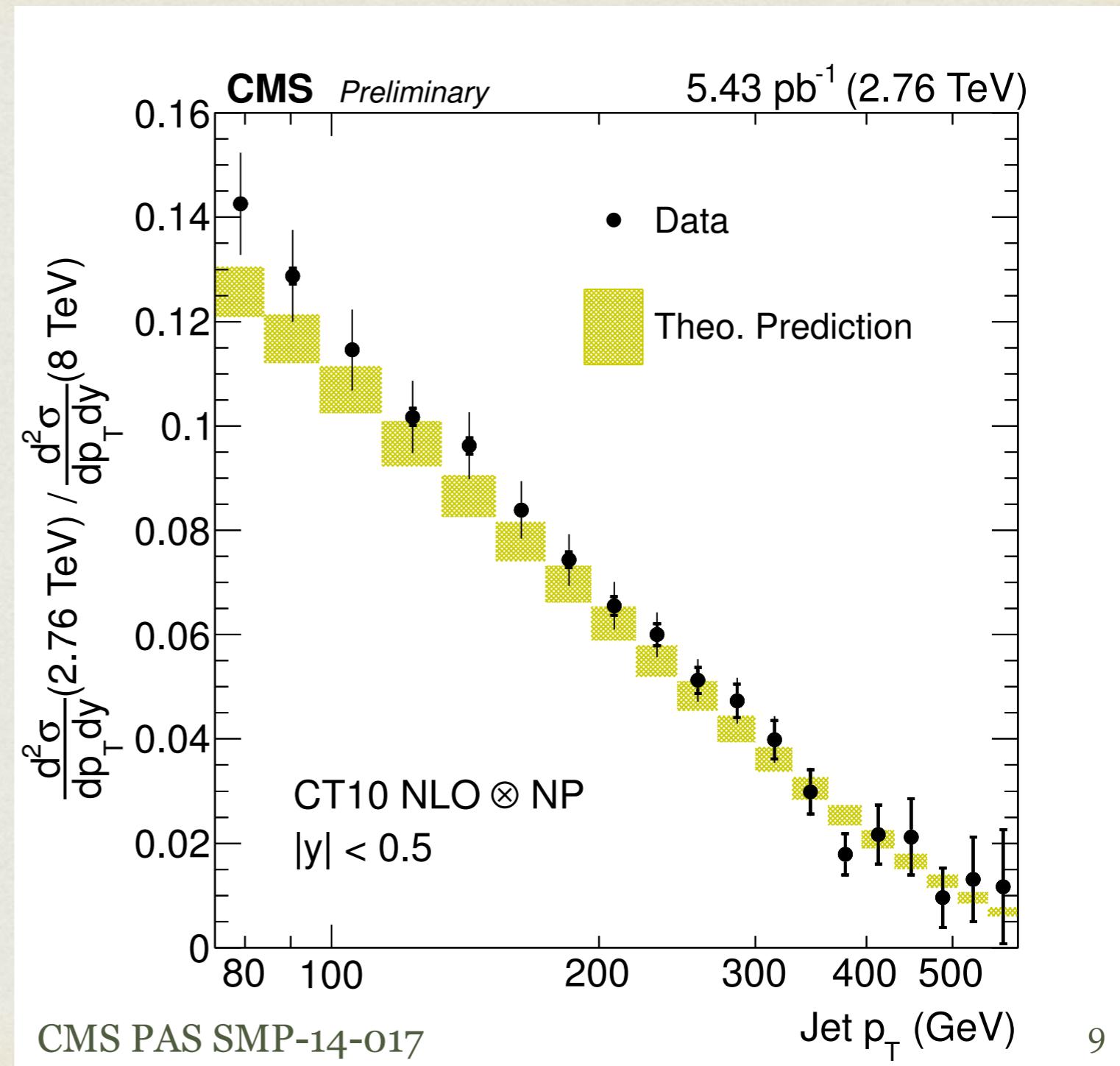
DIFFERENT CENTER-OF-MASS ENERGIES

- Inclusive jet production at **2.76 TeV**
 - Tests QCD at different center-of-mass energies, important for PDF fits



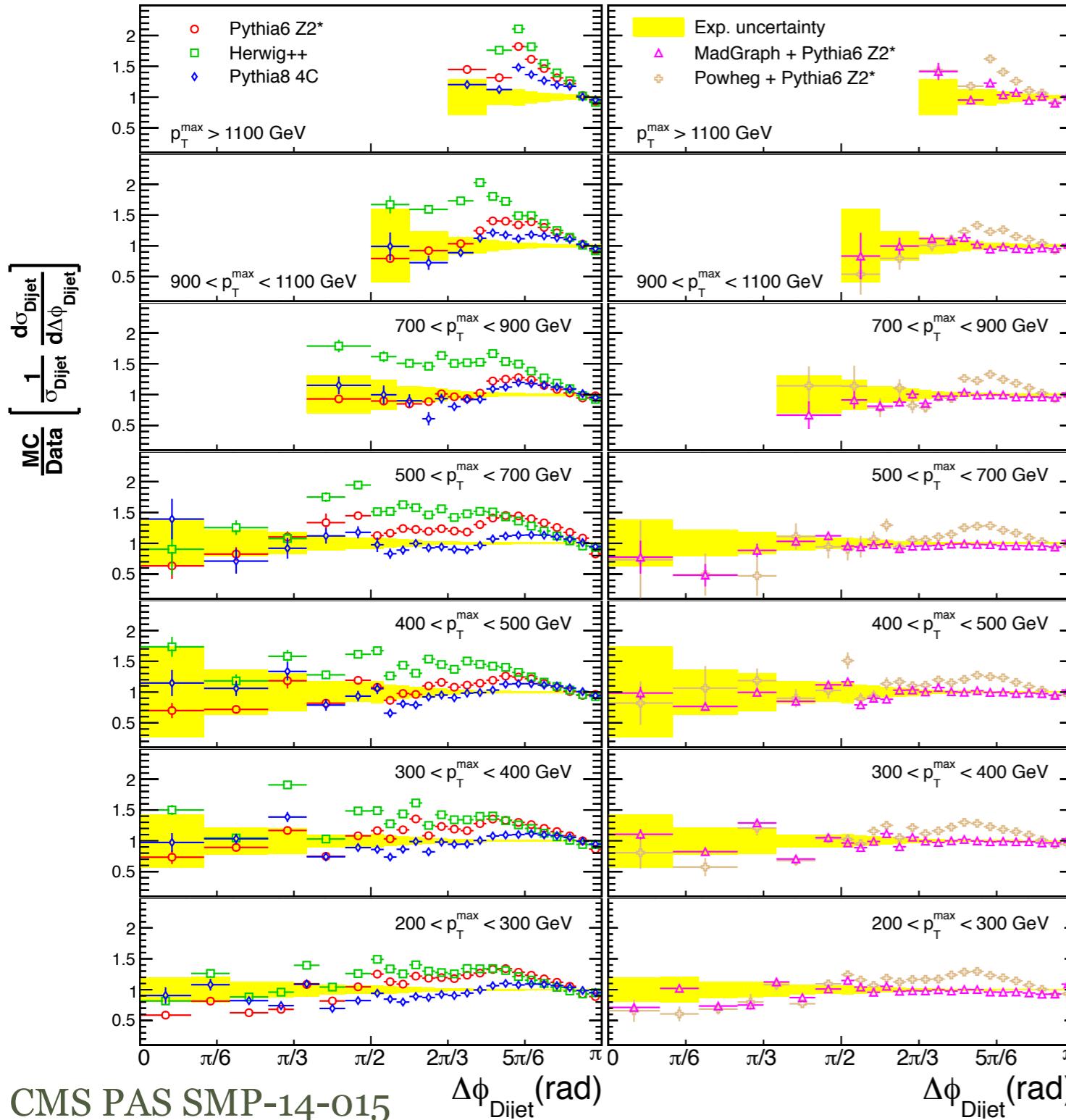
CROSS SECTION RATIOS

- The ratio of **2.76 TeV** to **8 TeV** is a powerful test as many systematic uncertainties cancel

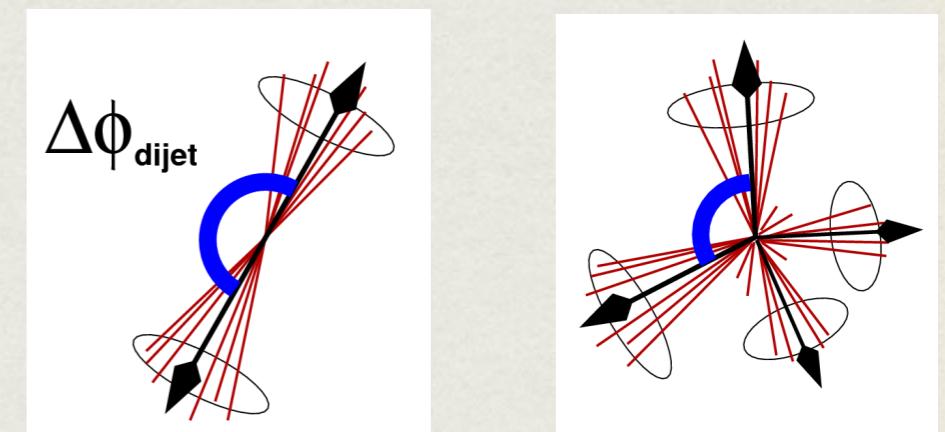


DIJET AZIMUTHAL DECORRELATIONS

CMS Preliminary



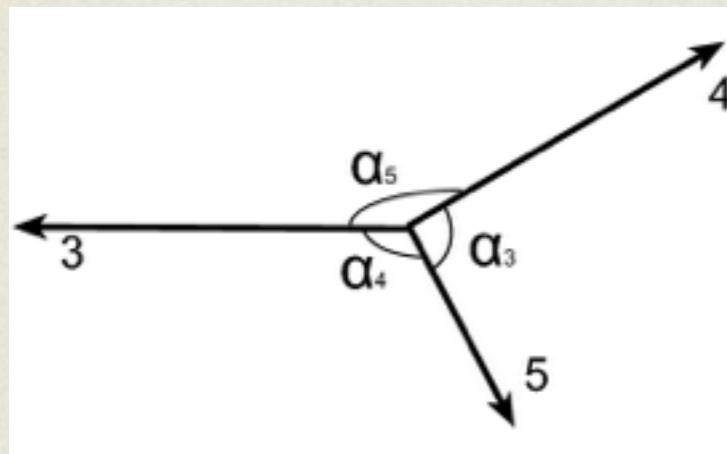
Sensitive to the radiation of additional jets and probes dynamics of multijet production



- For LO, Pythia8 is best
- NLO Powheg+Pythia6 similar to Pythia6
- Multi-jet MC, Madgraph gives best description overall

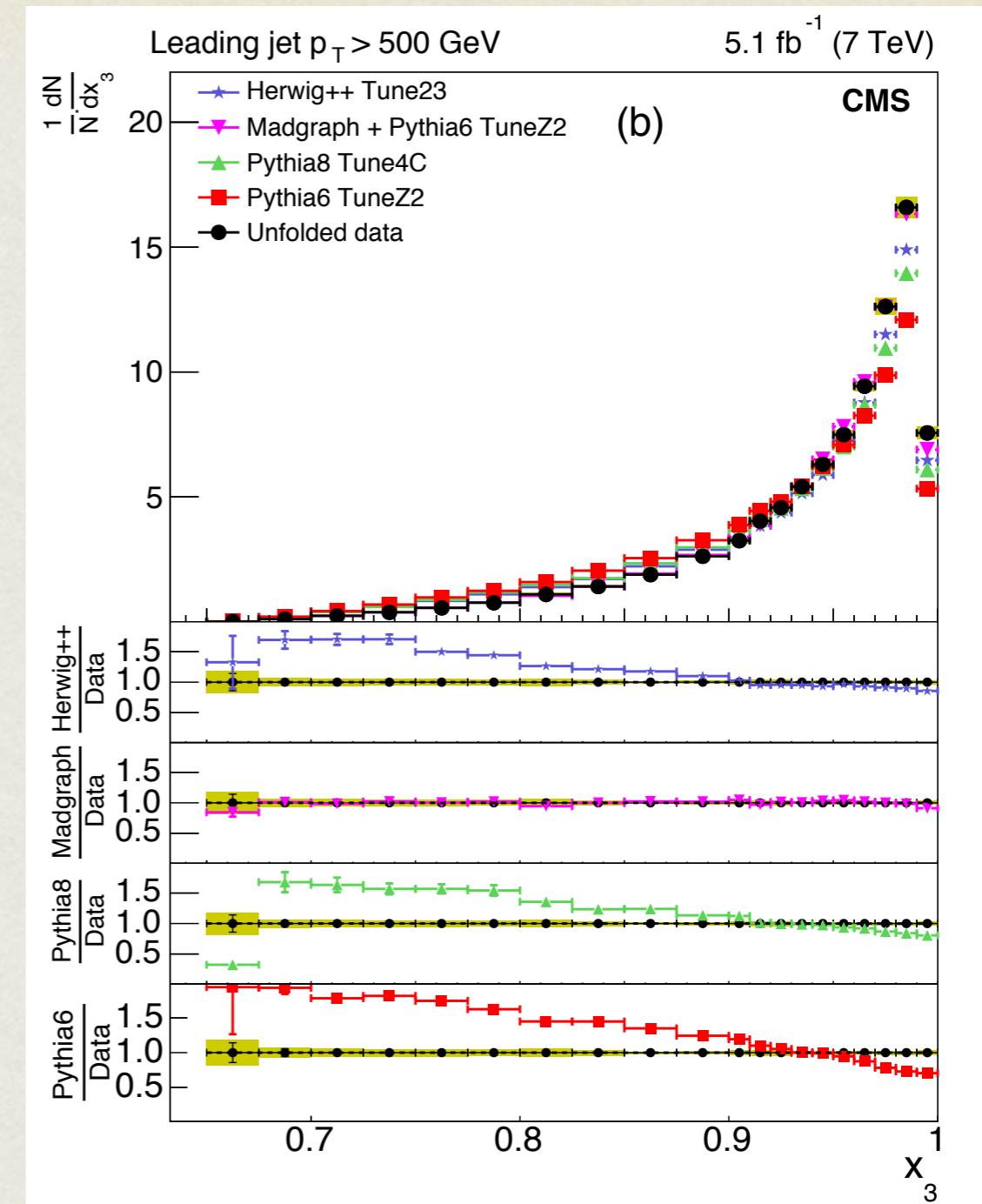
MULTI-JET TOPOLOGIES

- Topological variables sensitive to QCD color factors, gluon spin structure, and hadronization models



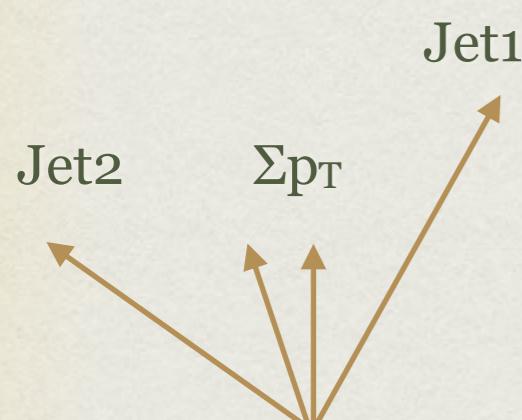
$$x_3 = 2E_3 / \sqrt{\hat{s}_{345}}$$

- Madgraph has best description, other MCs differences possibly due to missing higher multiplicities



4-JET PRODUCTION

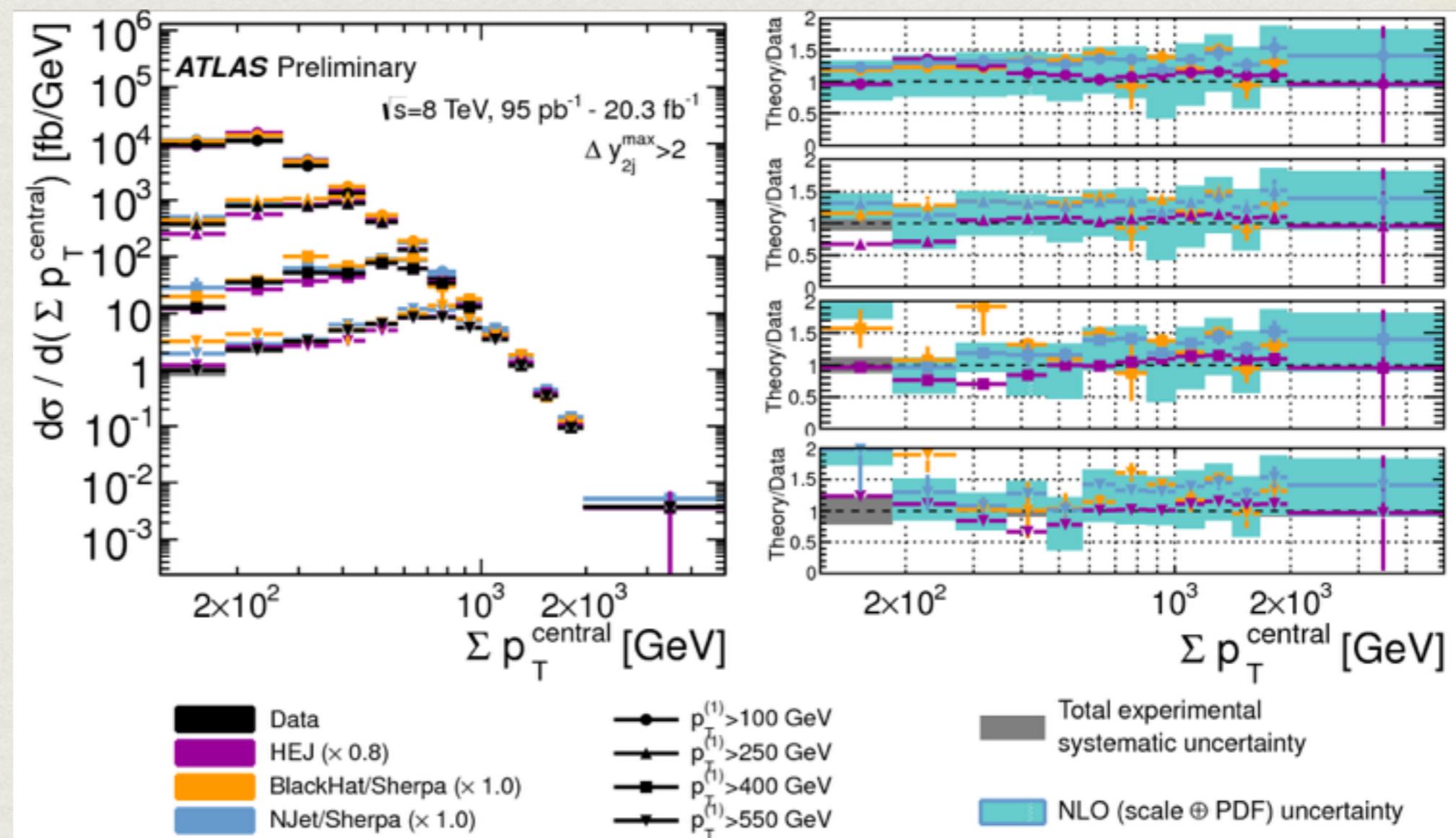
- Extensive study of 4-jet event topologies
- Here, test jets within the rapidity interval of the two leading jets



 Jet1
 Jet2
 Σp_T

 Observable where
 many generators
 have trouble

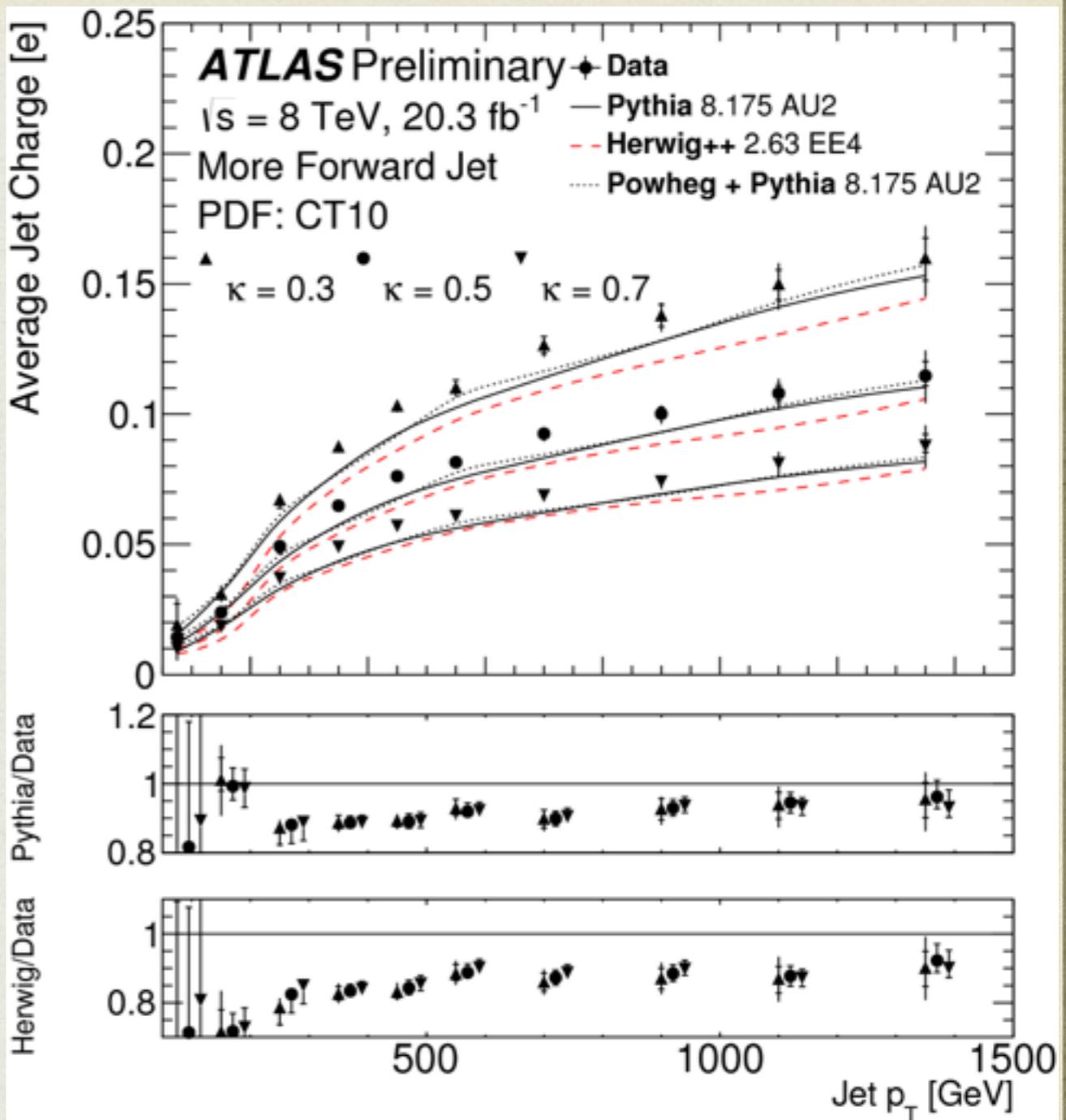
HEJ describes
the data the best



JET CHARGE

- Momentum weighted sum of track charges is sensitive to initial quark or gluon
- Also very sensitive to fragmentation models
- Average charge expected to increase with jet pT (increase in up-flavor jets)

Data is consistently above predictions. Possibly due to fragmentation modeling



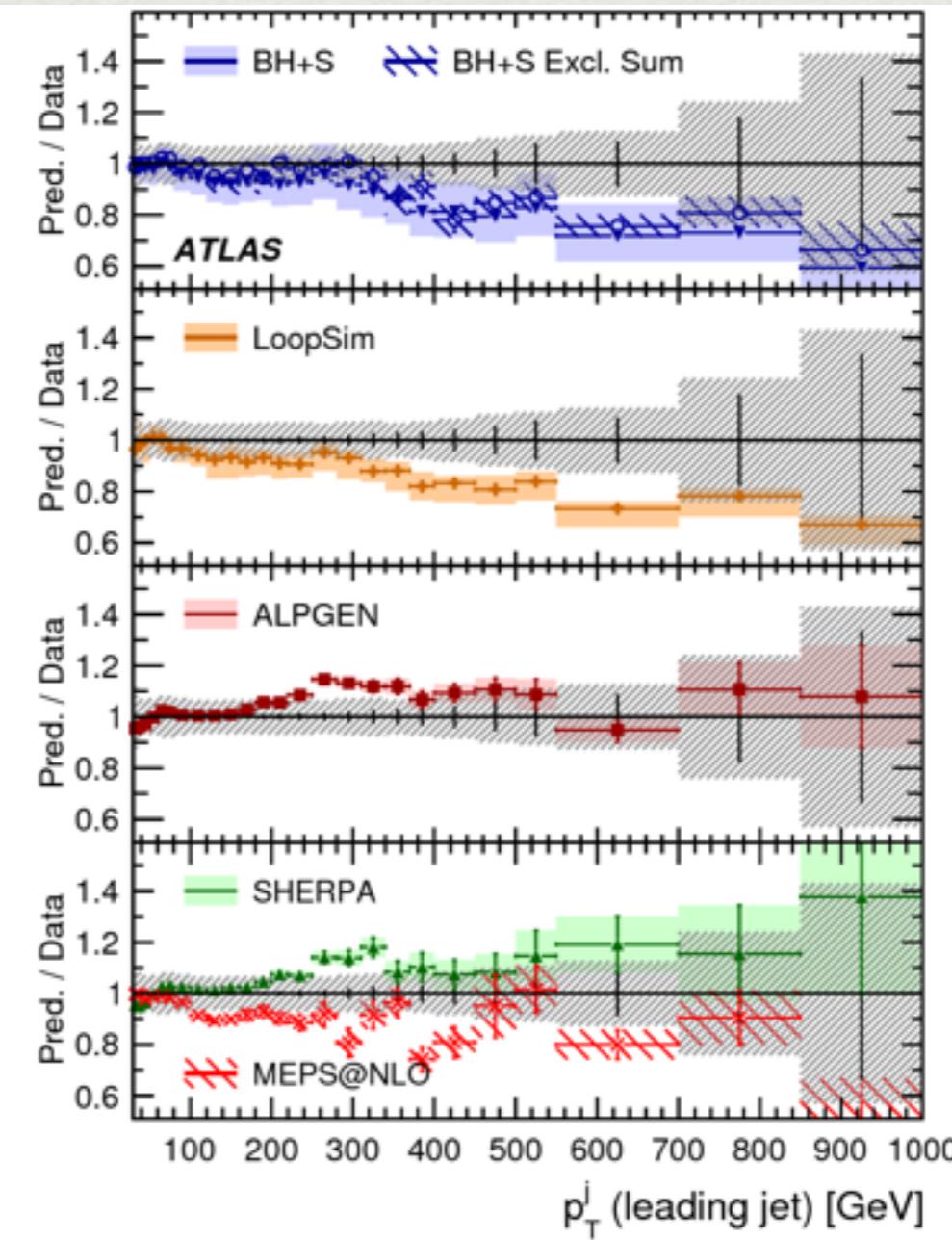
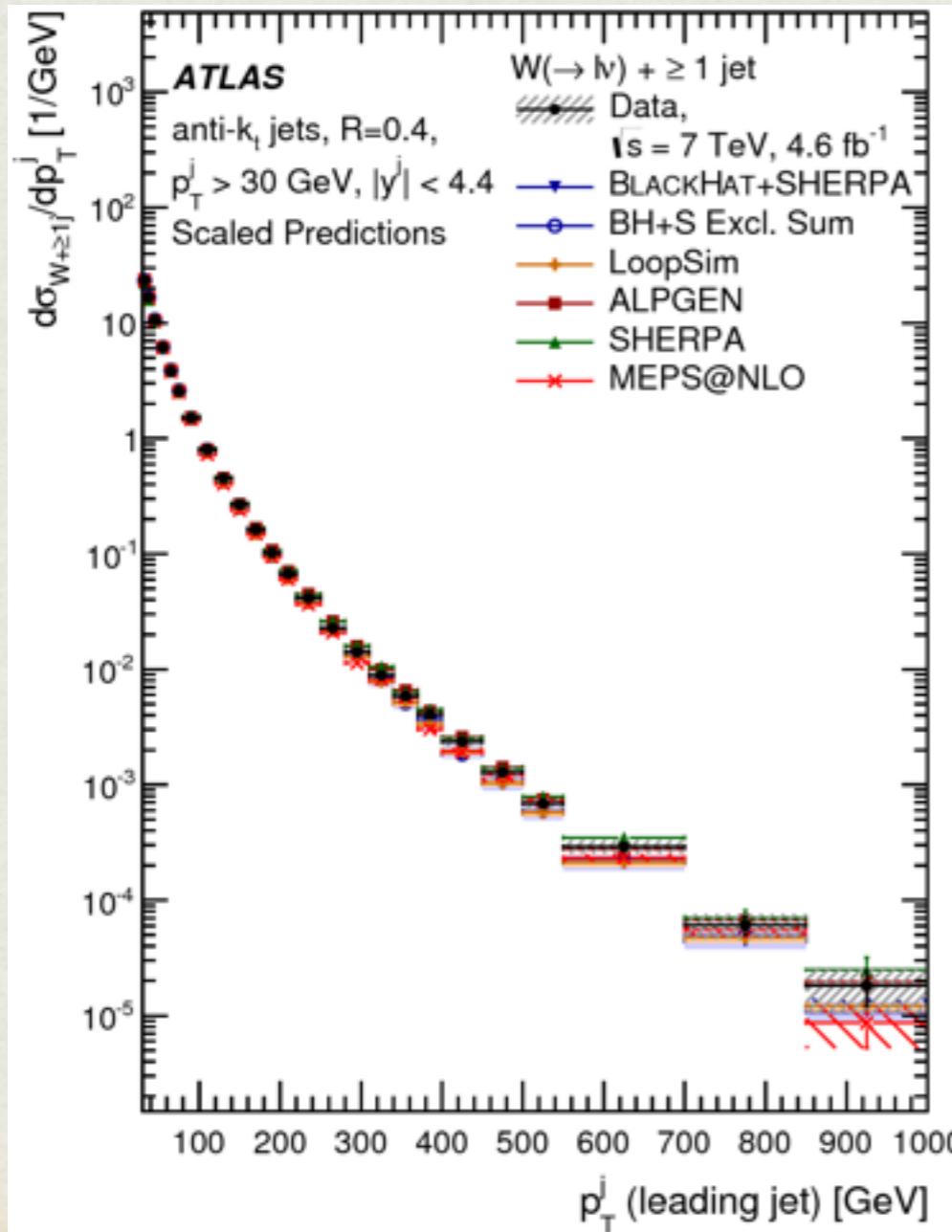
V+JETS

- Light jet measurements
 - Test various aspects of QCD calculations
 - Experimental precision of measurements sufficient to reveal discrepancies in predictions
- Heavy flavor measurements probe
 - Heavy-quark content in the proton
 - Modeling of gluon splitting
 - Massive vs. massless b-quark models

W+JETS: JET PT

- Events with energetic jets interesting for searches
- Expect EW corrections to be large/negative (See S. Pozzorini's talk)

arXiv:1409.8639 [hep-ex]



NLO

approx
NNLO.

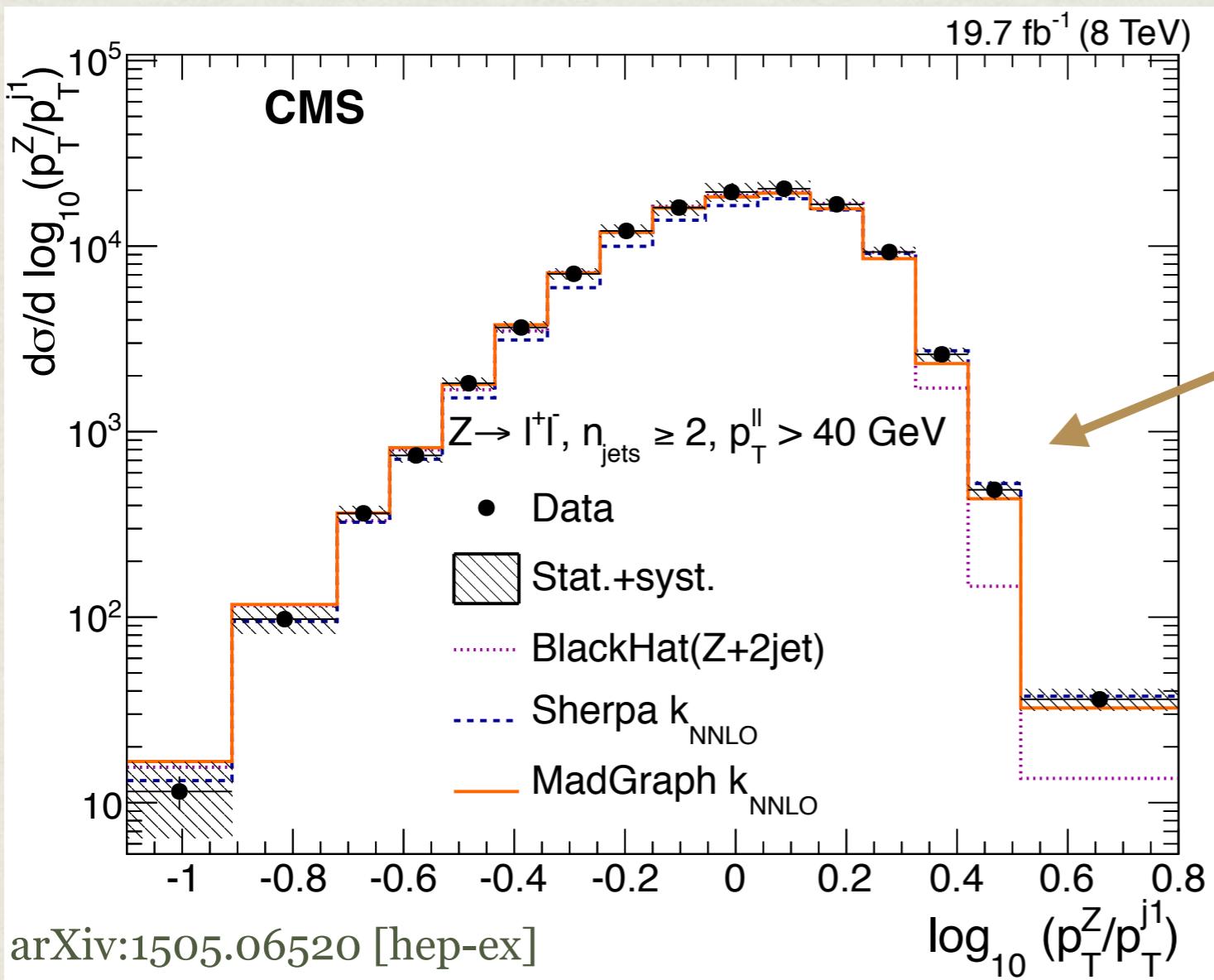
LO+PS

LO+PS

NLO+PS

Z+JETS: PT DISTRIBUTIONS

- The ratio of $p_T^Z/p_T^{1\text{st jet}}$ tests the validity of NLO pQCD calculations
 - Large logs are expected, and reveal missing higher order terms

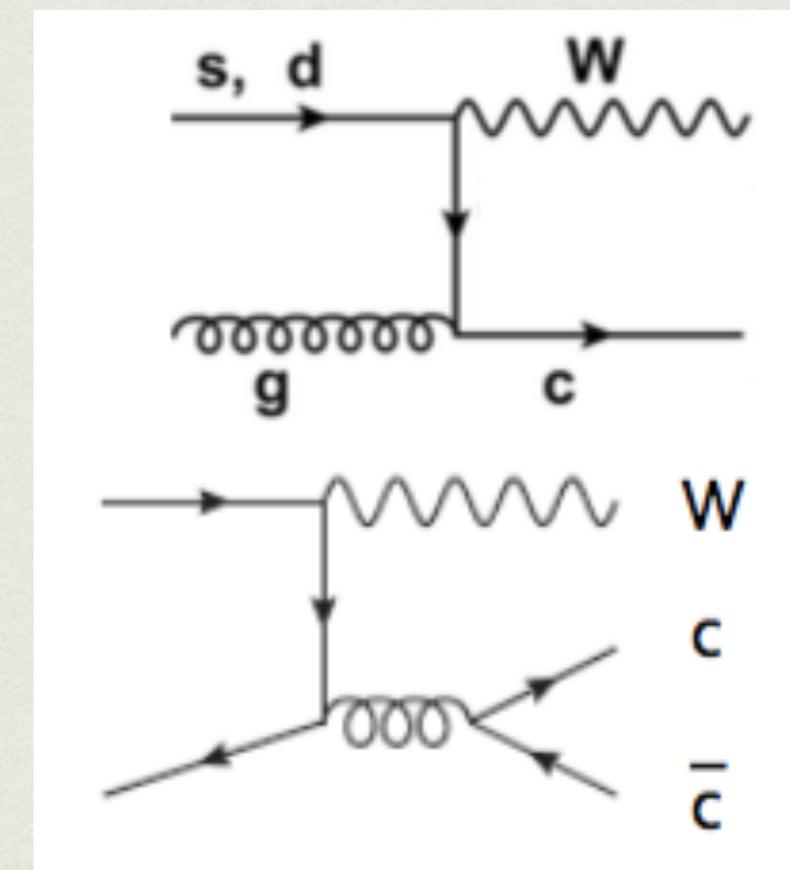
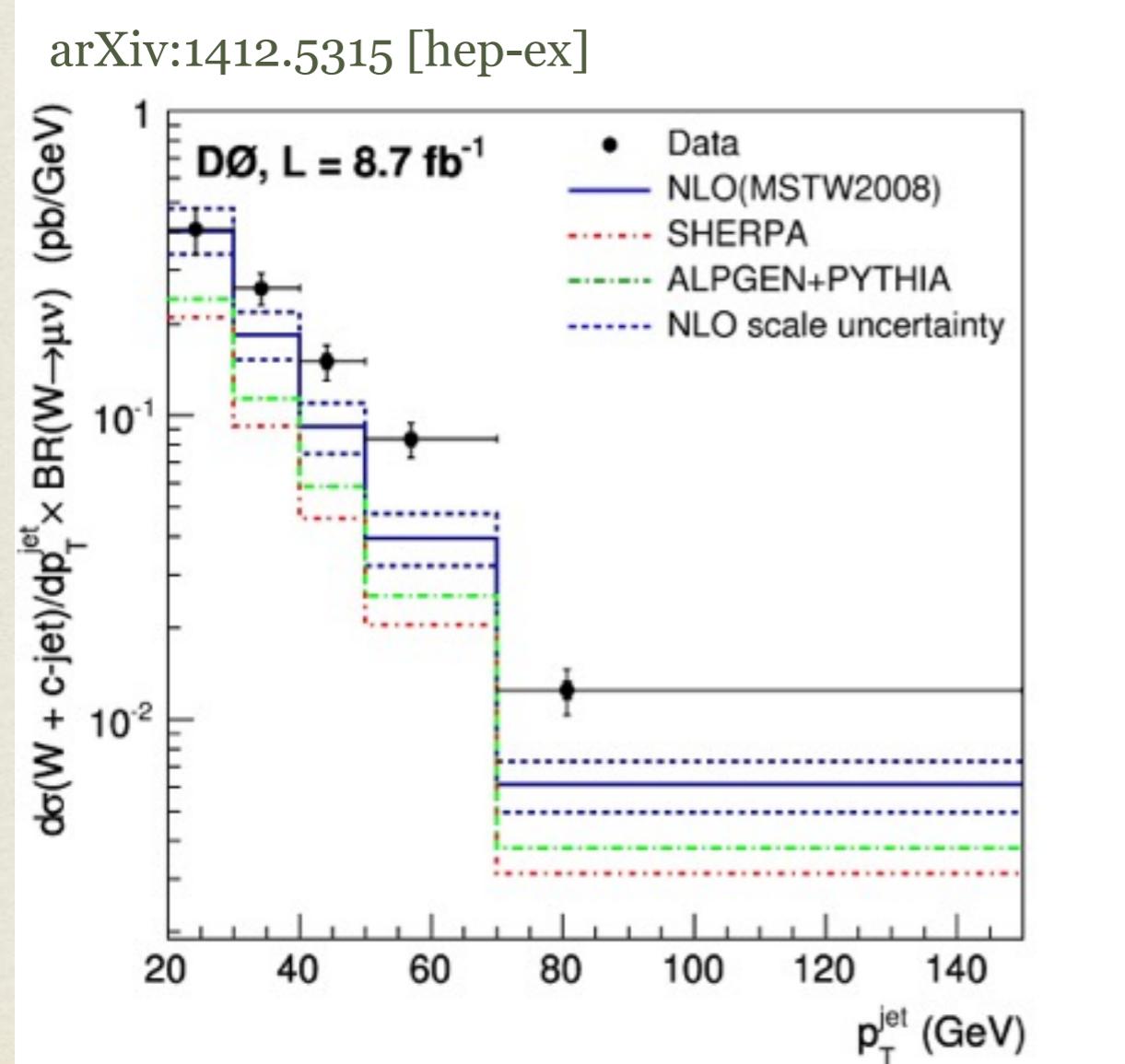


3rd jet becomes
important

Parton shower has
soft jets, provides
better description

V+HEAVY FLAVOR

- Several measurements with sensitivity of gluon splitting
- W+c sensitive to both strange-PDF and gluon splitting



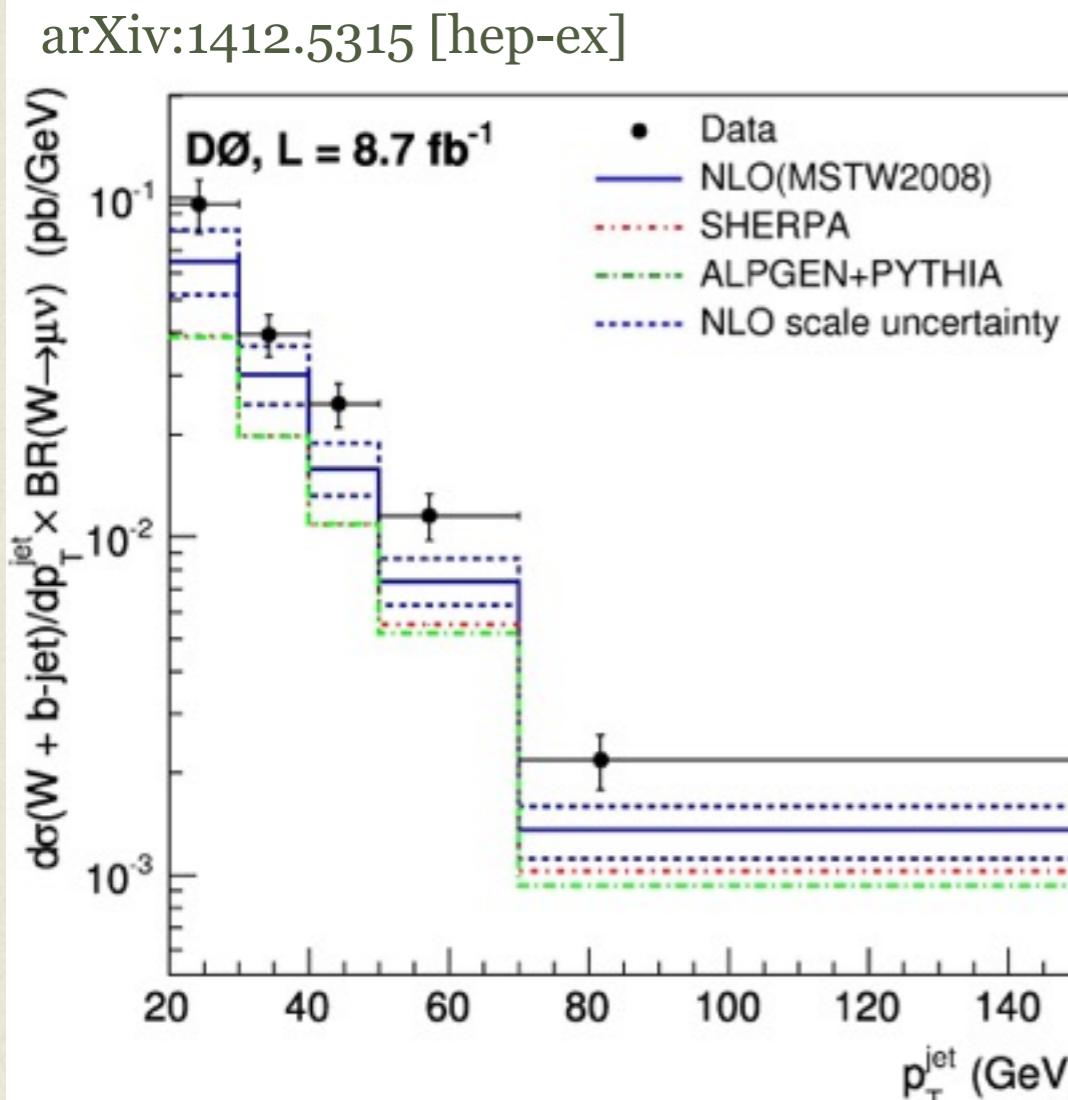
Dominant

More
important at
high jet pt

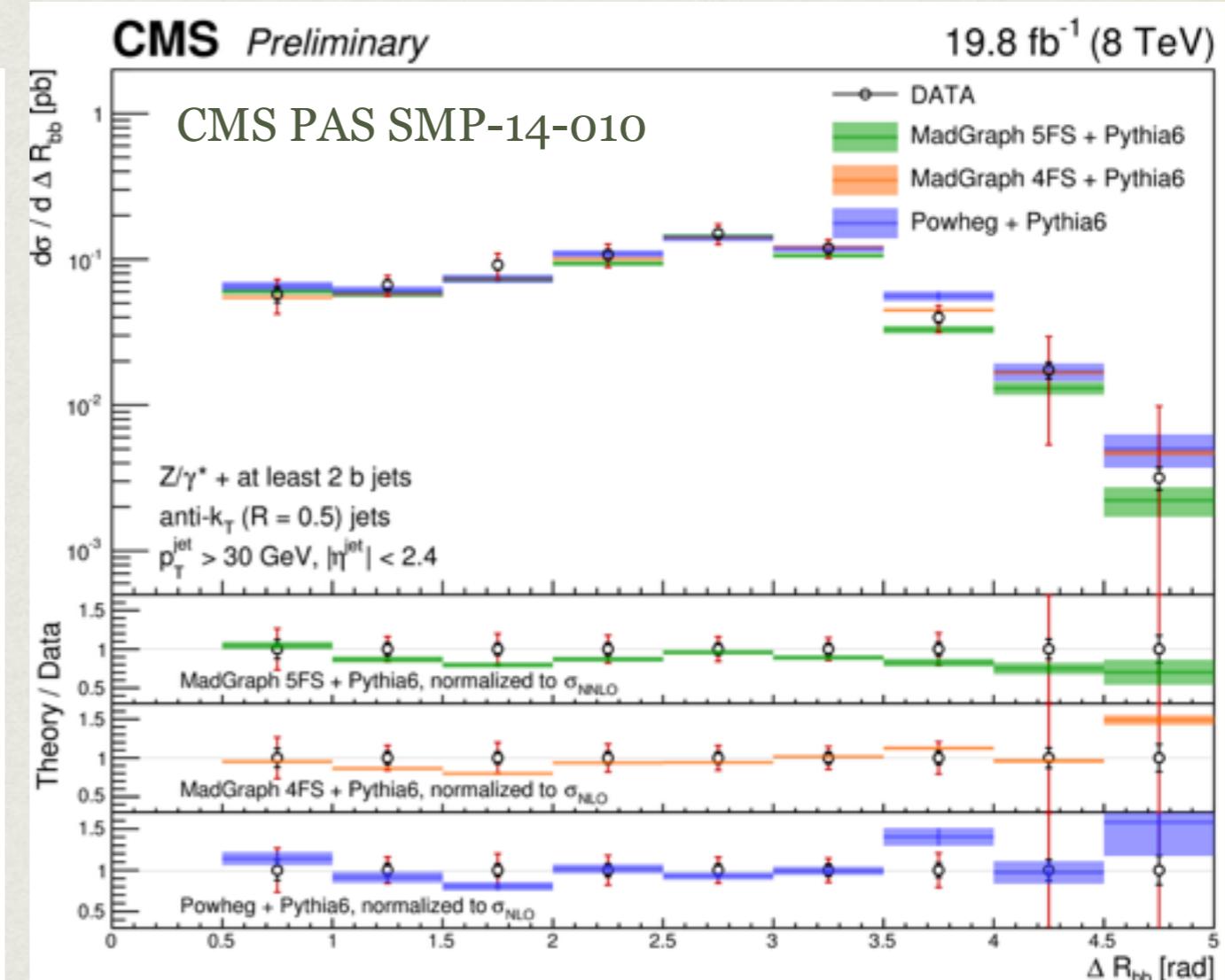
Source of difference? Gluon
splitting? s-quark enhancement?

V+HEAVY FLAVOR

W+b-jet
Dominated by gluon splitting



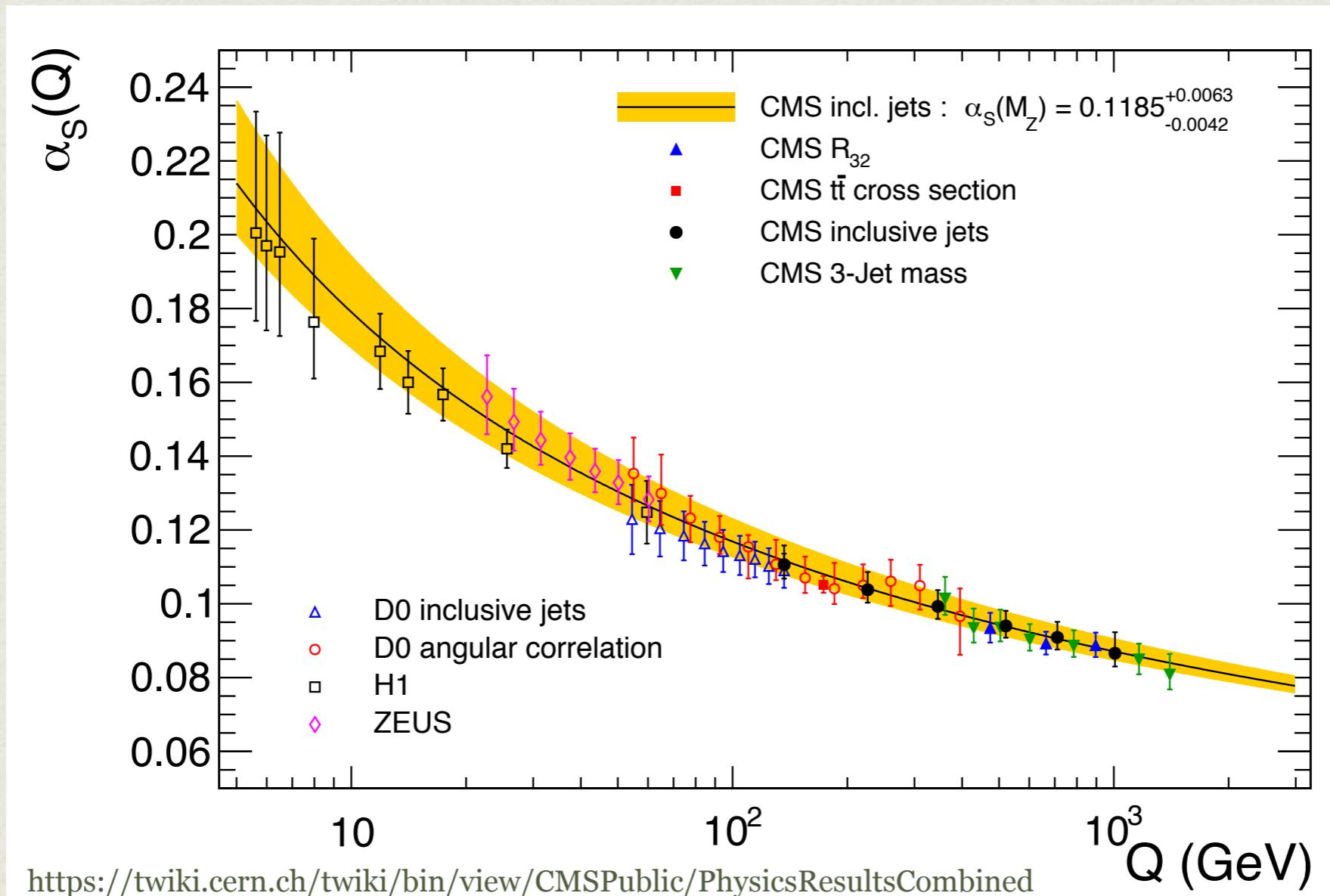
Missing higher-order corrections?



Good agreement: in contrast to
7 TeV results

STRONG COUPLING CONSTANT

- α_s , a fundamental parameter of QCD
- Extensive measurements up to the TeV scale

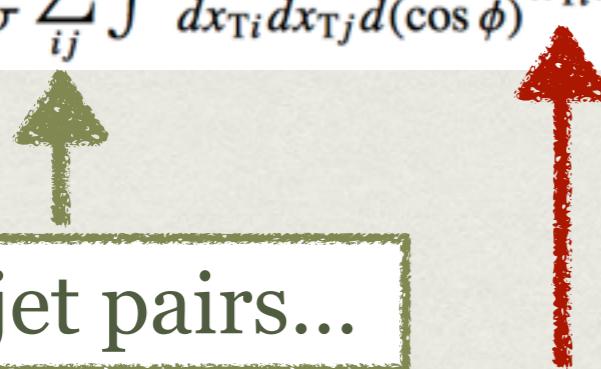


ENERGY-ENERGY CORRELATIONS

- In the style of measurements done at e^+e^- colliders, determine α_s using jet-based transverse energy-energy correlations

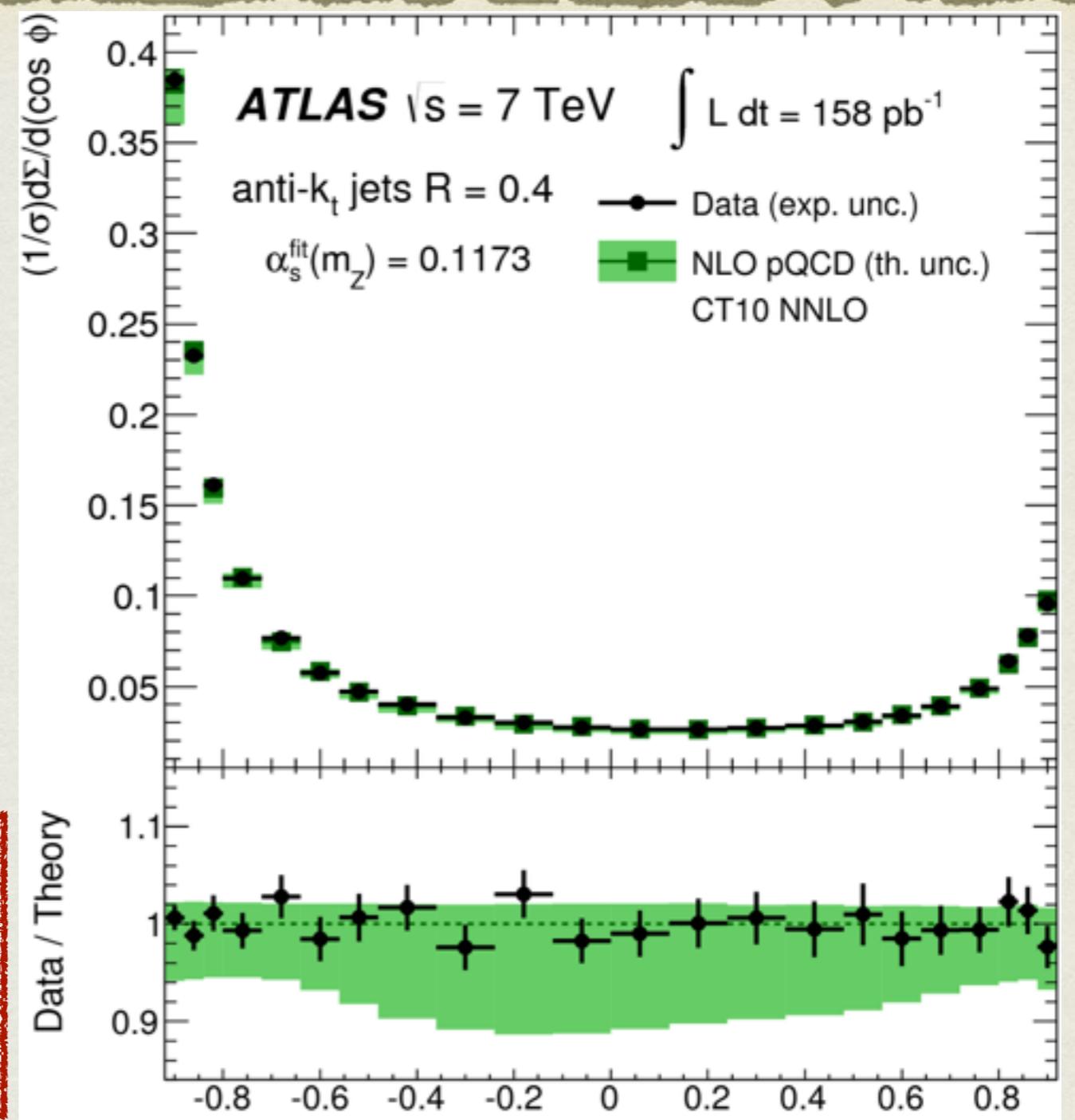
$$\frac{1}{\sigma} \frac{d\Sigma}{d(\cos \phi)} = \frac{1}{\sigma} \sum_{ij} \int \frac{d\sigma}{dx_{Ti} dx_{Tj} d(\cos \phi)} x_{Ti} x_{Tj} dx_{Ti} dx_{Tj}$$

For all jet pairs...

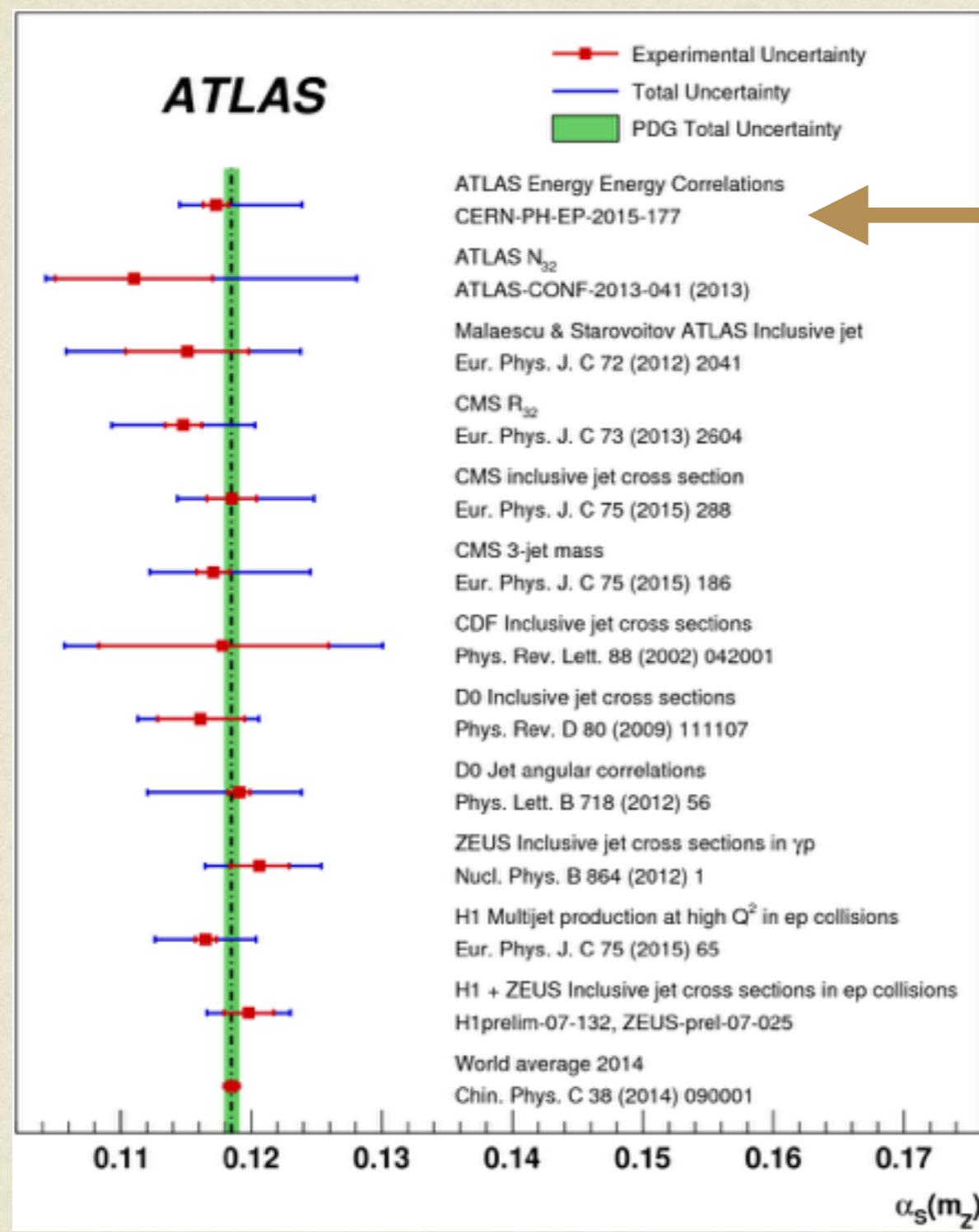


Estimate jet E_T /total E_T

$$x_{Ti} = \frac{E_{Ti}}{E_T} \quad E_T = \sum_i E_{Ti}$$



STRONG COUPLING CONSTANT



- Measurement dominated by theory uncertainties
- Need NNLO calculations to improve precision of α_s at hadron colliders

CONCLUSIONS

- Have made tremendous progress in our understanding of QCD both in calculations and modeling and in the breadth of measurements
- Further improvements include
 - Going to NNLO for QCD calculations (already starting)
 - Exploring and modeling QCD in the corners of the phase space
 - Exploring the new energy regime of the LHC run-2

BACKUP