TOOLS AND MC (exp)

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Les Houches Workshop Series
"Physics at TeV Colliders"   2015

Tools and MC

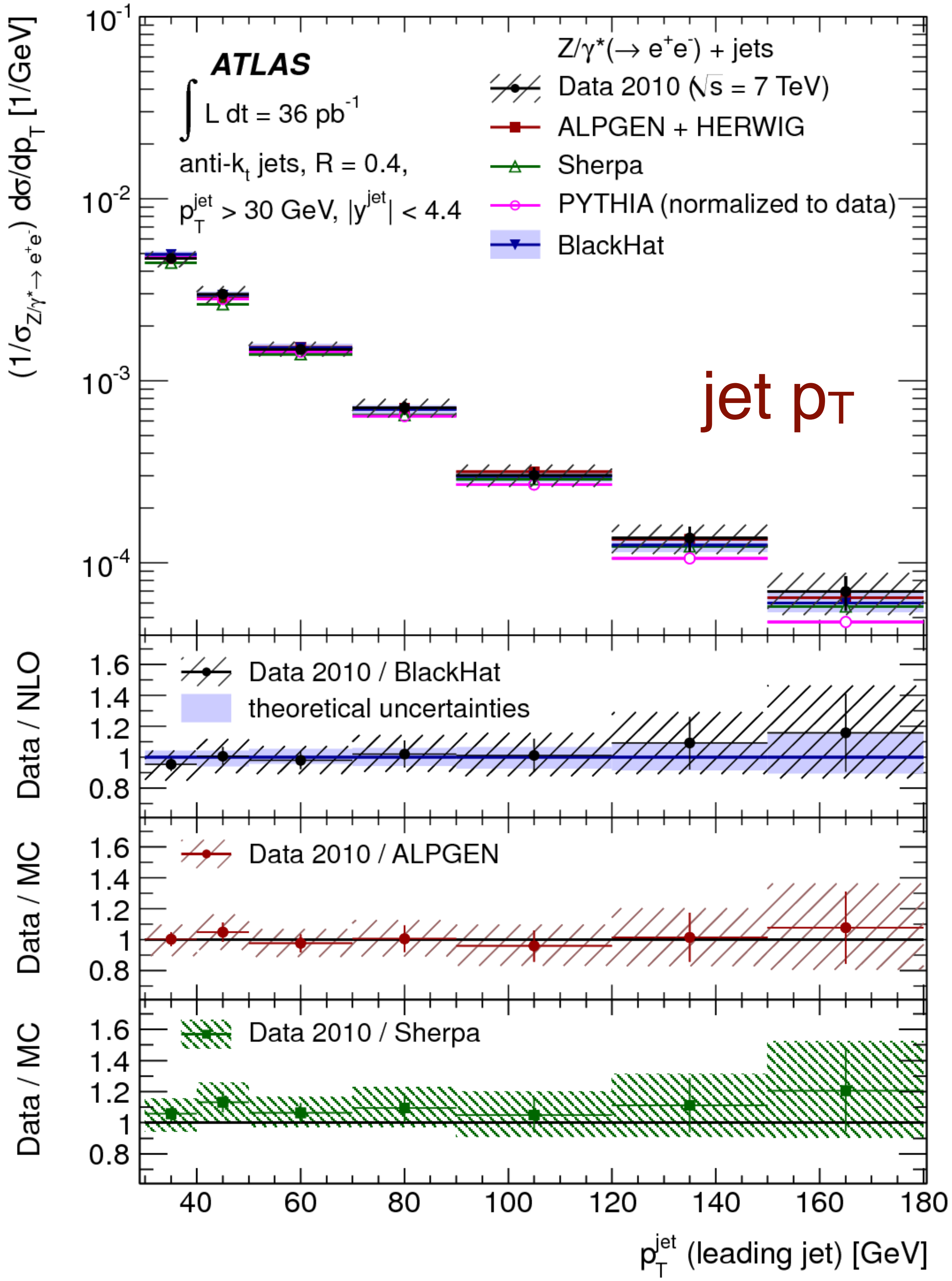
≡ Matrix Element + Parton Shower + Non Perturbative corrections

- I will discuss some recent example of their usage by the experiments
  - not a review!
- In the past a lot of work has been done in the *NP corrections*: tuning of multiparton interactions, the underlying event and hadronization
- In the latest years focus has moved towards the interface between *Matrix Element* calculation (often at NLO) and *Parton Shower*
- What should be done next and what can we do at Les Houches?
  - as usual more ideas are welcomed!

Evolution of MC tools

Looking back at available predictions for V+jets in 2011

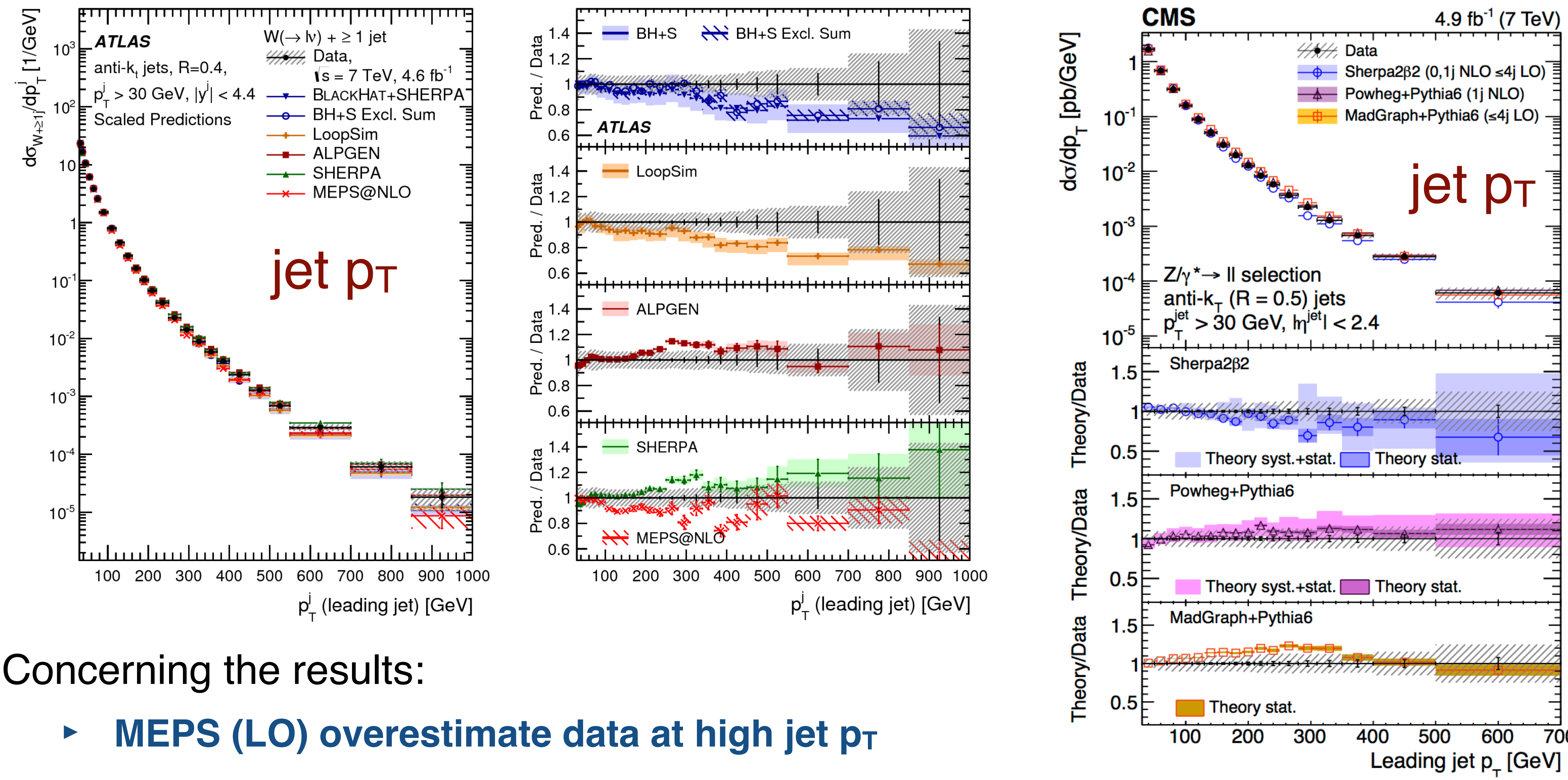
- ME+PS at LO
    - impressively good, but estimate of systematics not available
- Fixed order results at NLO
    - no matching with PS or merging of different multiplicities



Evolution of MC tools

TODAY: NLO-PS matching available up to 2 additional partons with merging of different multiplicity (shorted as **MEPS@NLO**)

- a meaningful scale uncertainty can be evaluated
- PS and UE tune uncertainties on the other hand have been neglected so far



Concerning the results:

- **MEPS (LO) overestimate data at high jet p_T**
- **NLO slightly underestimate data at high jet p_T**

Parton and particle level predictions

As an example, the last ATLAS paper W+jets compares kinematic distributions with a long list of theoretical predictions

Eur. Phys. J. C (2015) 75:82

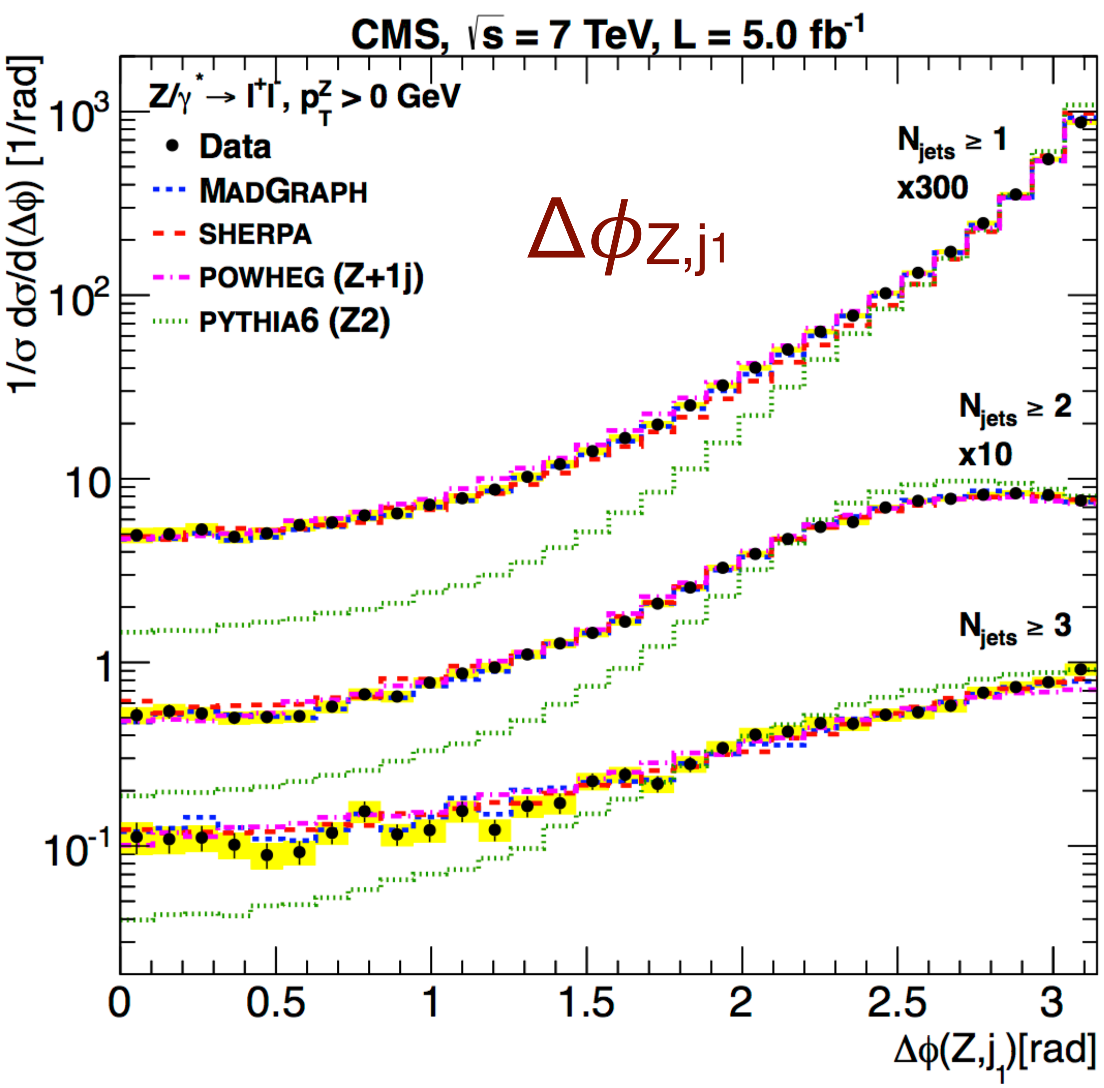
Program	Max. number of partons at			Parton/particle level	Distributions shown
	Approx. NNLO ($\alpha_s^{N_{\text{jets}}+2}$)	NLO ($\alpha_s^{N_{\text{jets}}+1}$)	LO ($\alpha_s^{N_{\text{jets}}}$)		
LoopSim	1	2	3	Parton level with corrections	Leading jet p_T and H_T for $W + \geq 1$ jet
BLACKHAT+SHERPA	–	5	6	Parton level with corrections	All
BLACKHAT+SHERPA Exclusive sums	1	2	3	Parton level with corrections	Leading jet p_T and H_T for $W + \geq 1$ jet
HEJ	All orders, resummation			Parton level	All for $W + \geq 2, 3, 4$ jets
MEPS@NLO	–	2	4	Particle level	All
ALPGEN	–	–	5	Particle level	All
SHERPA	–	–	4	Particle level	All

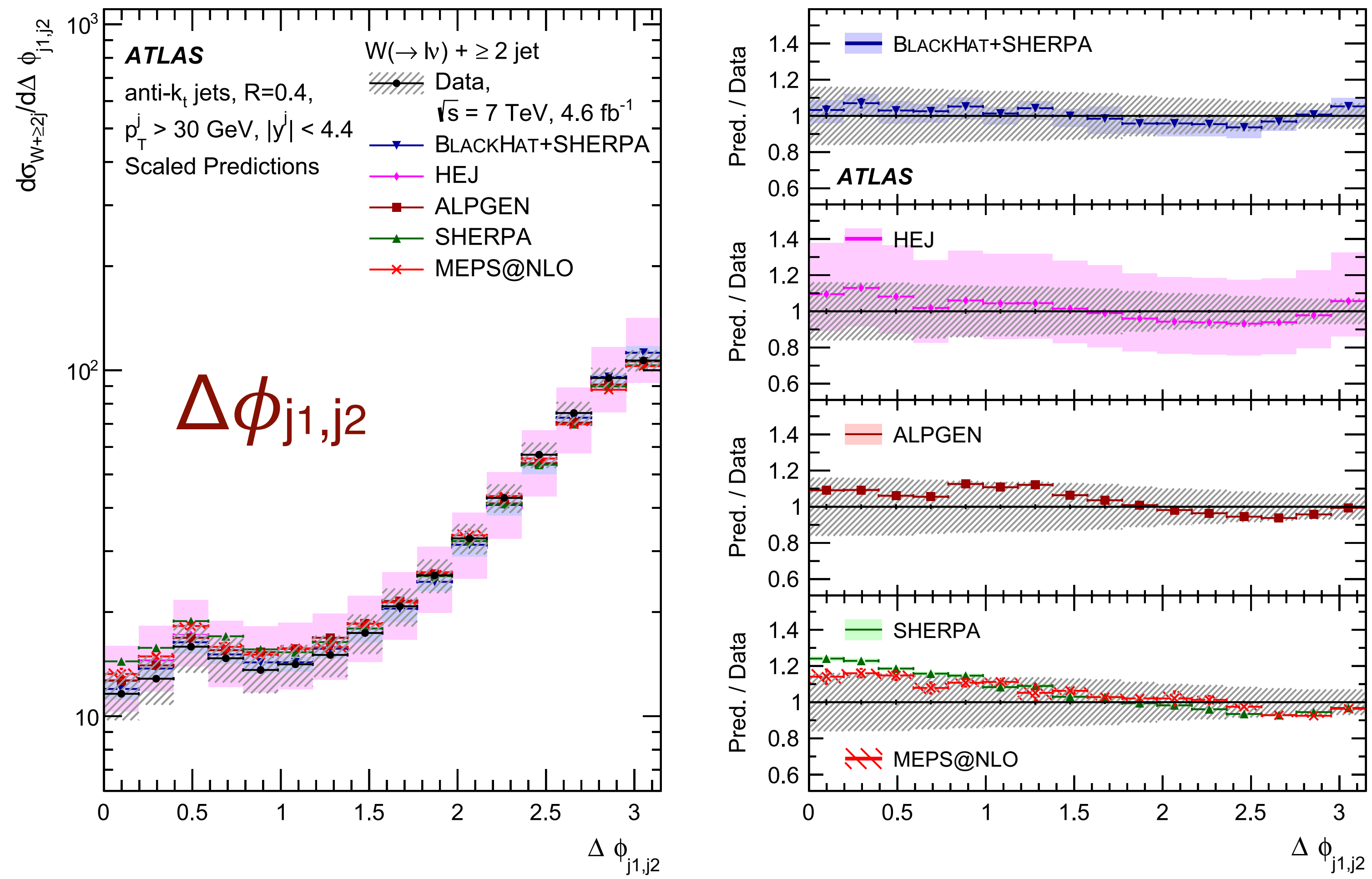
Z+jets, W+jets

Benchmarks for ME-PS matching/merging

All corners of phase space have been, and still are, studied in details:

Angular correlations

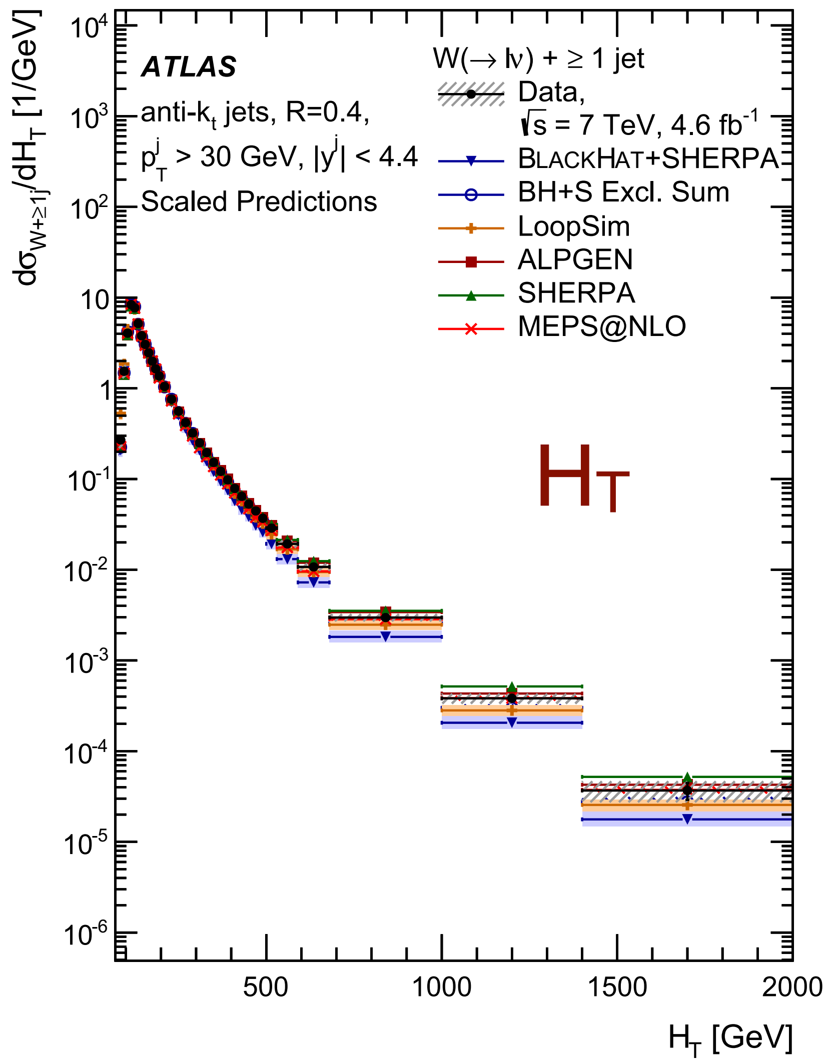


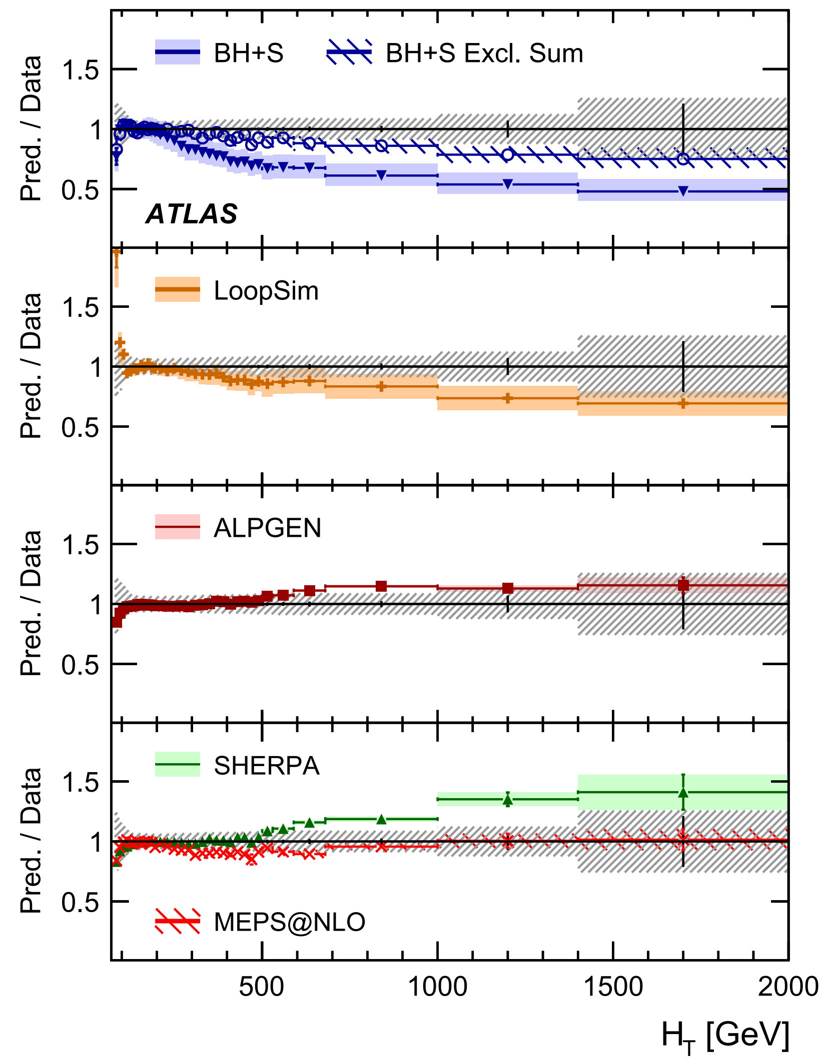


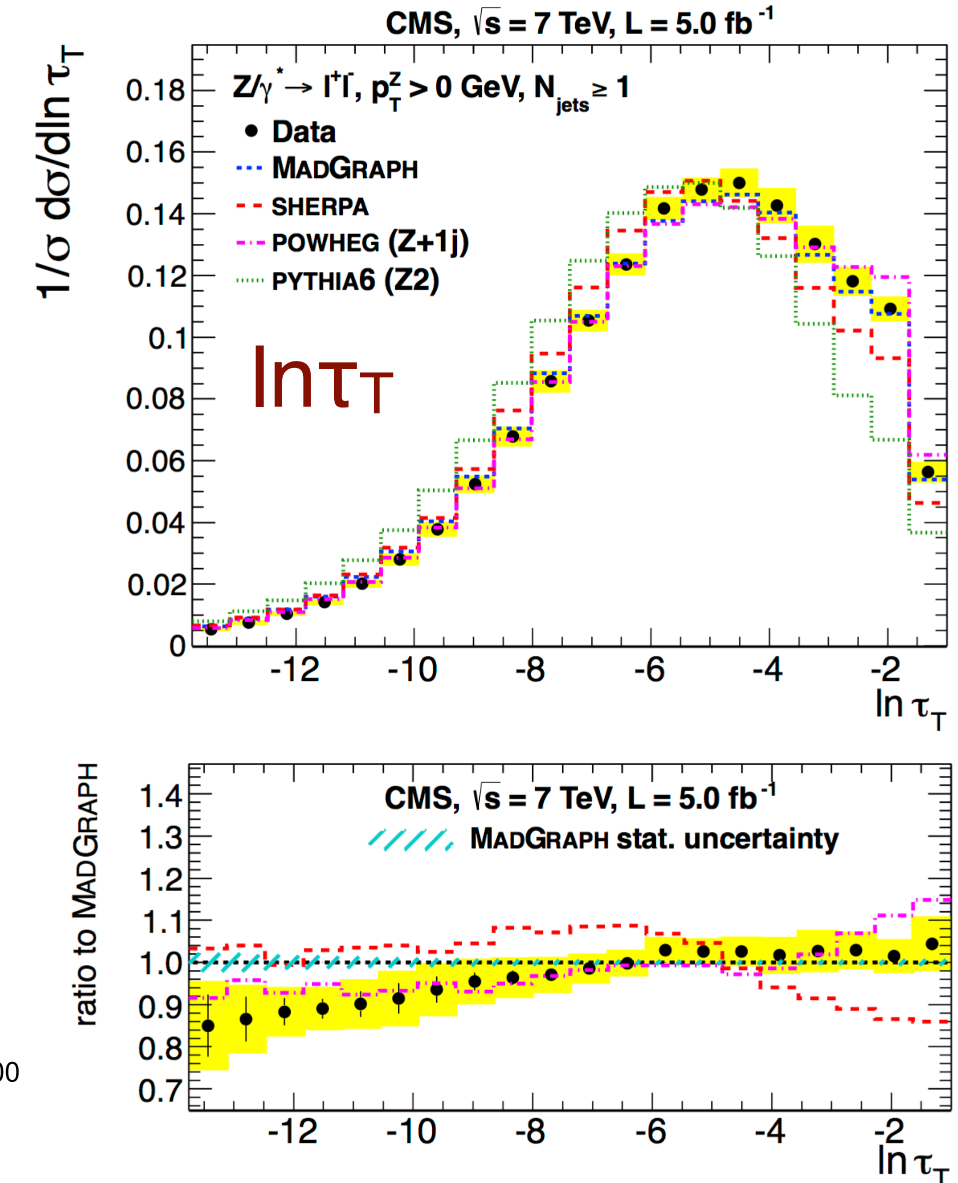
- very good agreement for most theoretical predictions

Z+jets, W+jets

Event shapes: H_T, transverse thrust,…







Similar thrend as observed for jet p_T:

- MEPS at LO above data at high H_T, while (N)NLO fixed-order is below
- MEPS@NLO does an excellent job on H_T

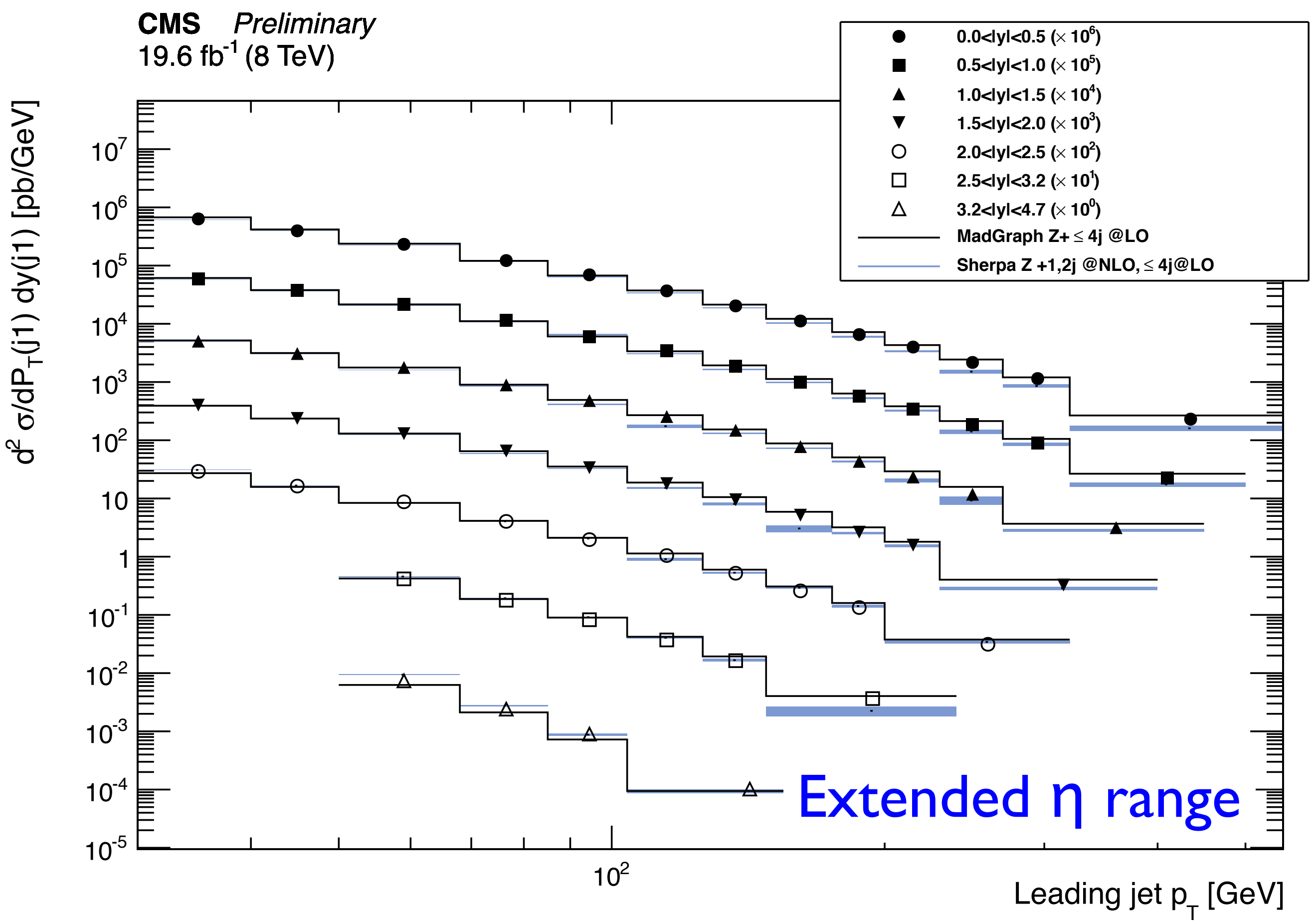
Powheg describes slightly better the transverse thrust

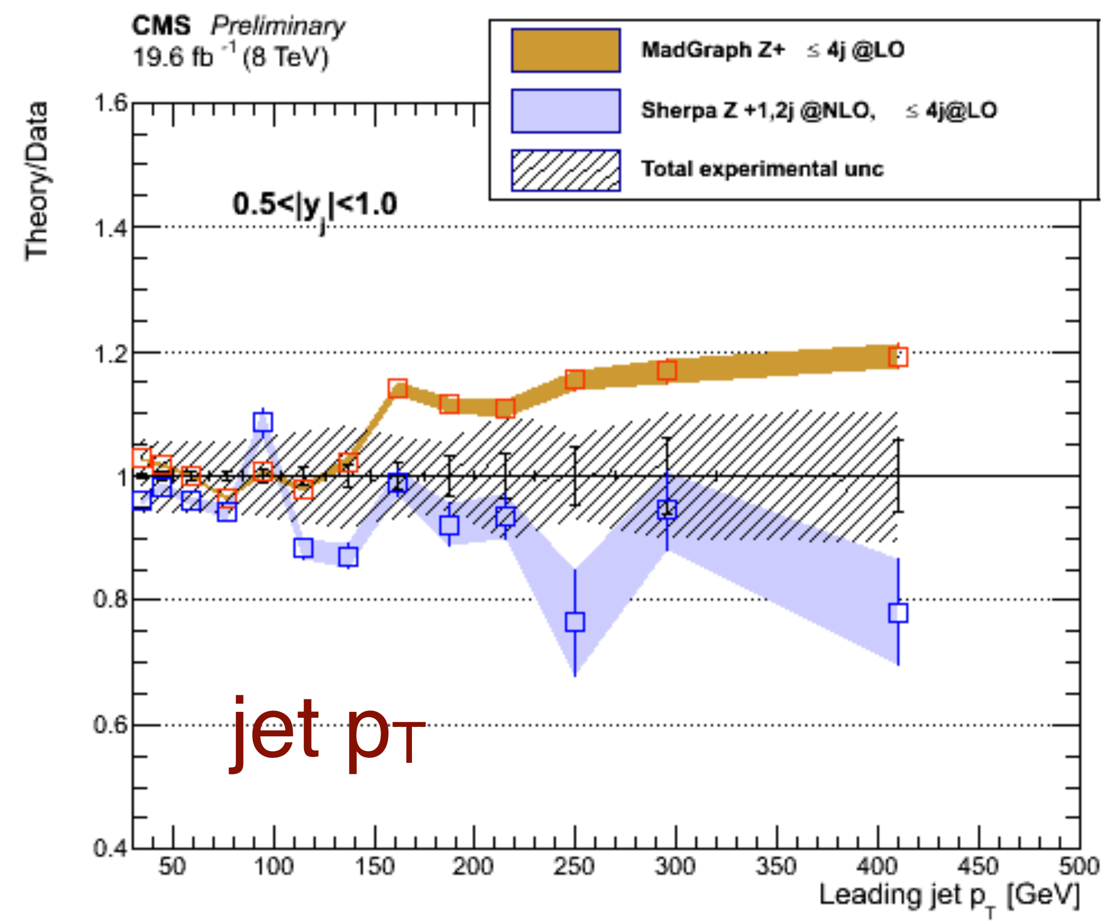
Z+jets, W+jets

Not many results at **8 TeV** yet, but preliminary ones show that the increased statistics allows measurements of double differential x-sec

Double differential x-sec vs jet p_T and rapidity

CMS-PAS-SMP-14-009



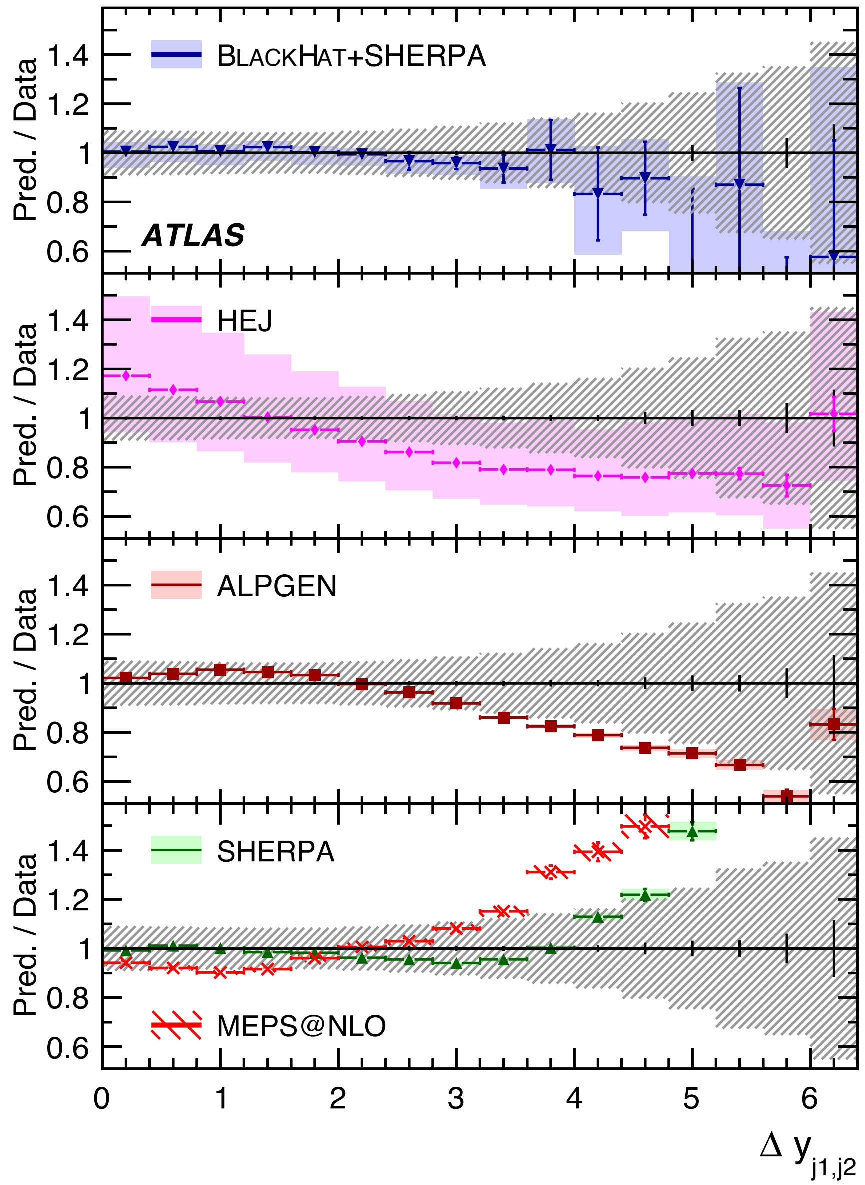


- same behaviour for MEPS and MEPS@NLO vs p_T as before ME+PS overshoot data at high jet pT

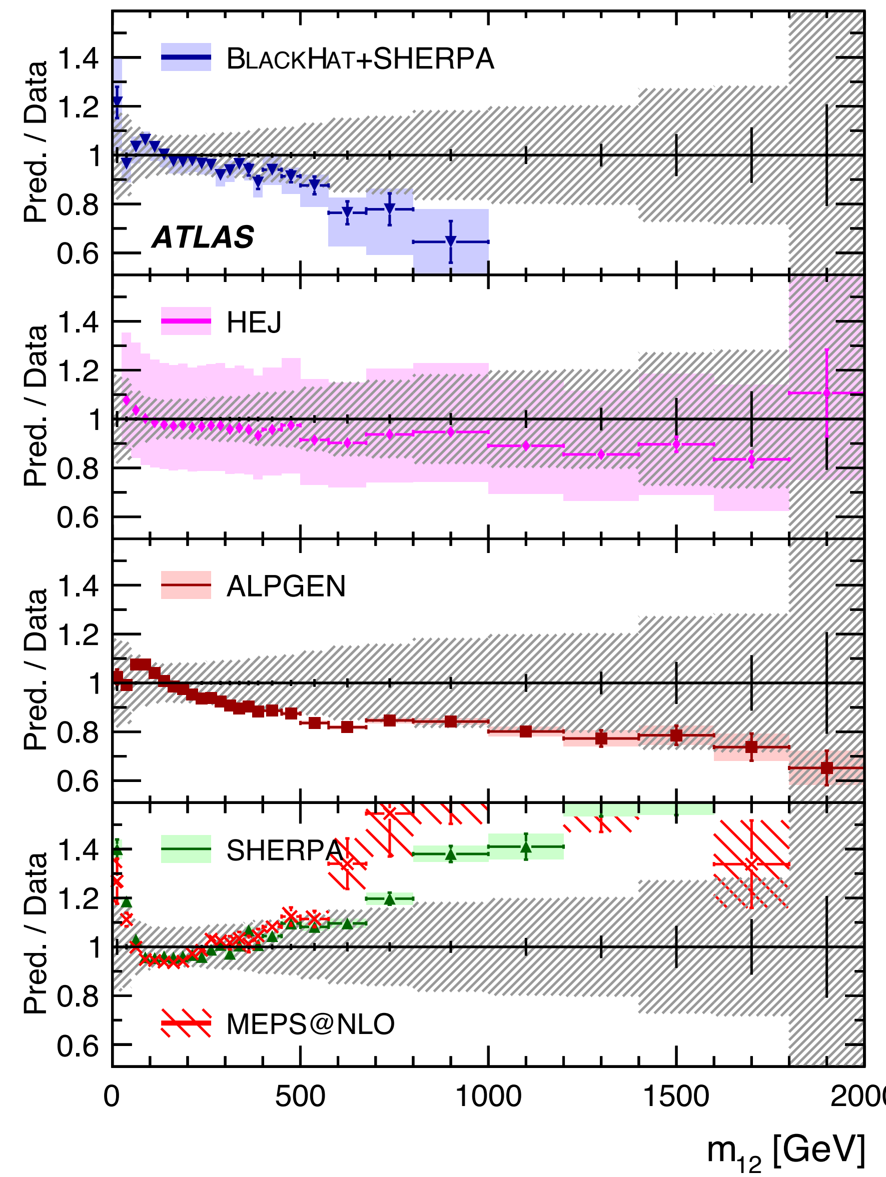
W/Z+jets

Overall there is good agreement with data, but in some case there are important discrepancies

$\Delta y_{j1,j2}$



m_{12}



- only *HEJ* (BFKL approx. for 2 or more partons) describes m_{12}

5-flavour vs 4-flavour in Z+b(b)

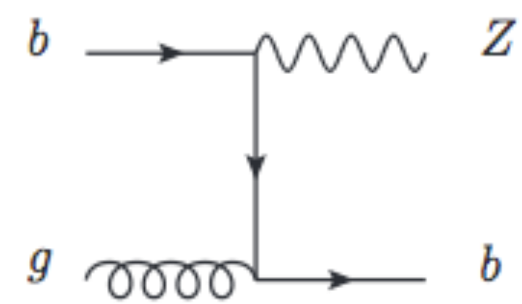
Emerging pattern:

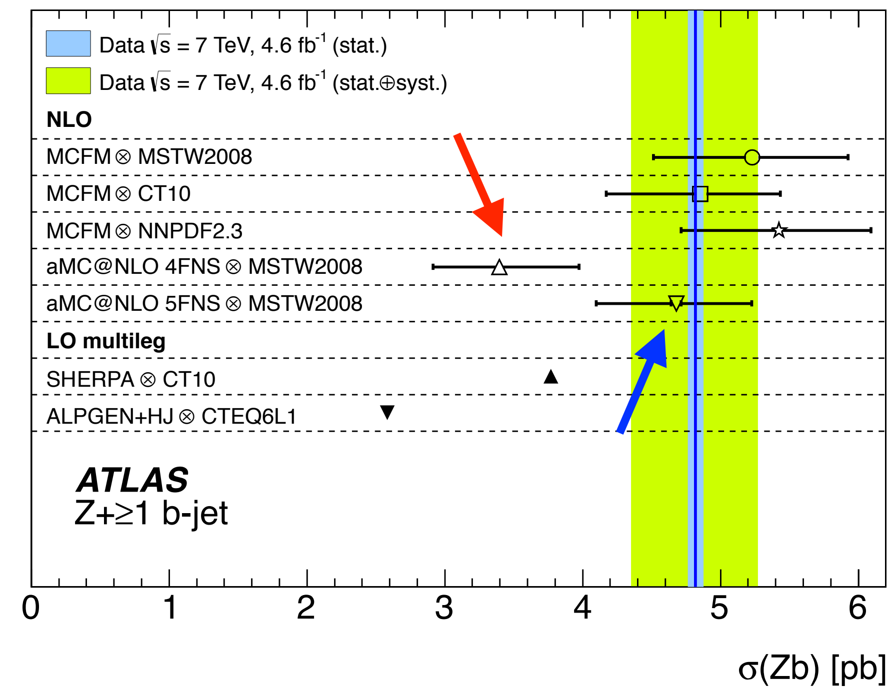
- 5-flavour is better for Z+1b
- 4-flavour is better for Z+2b

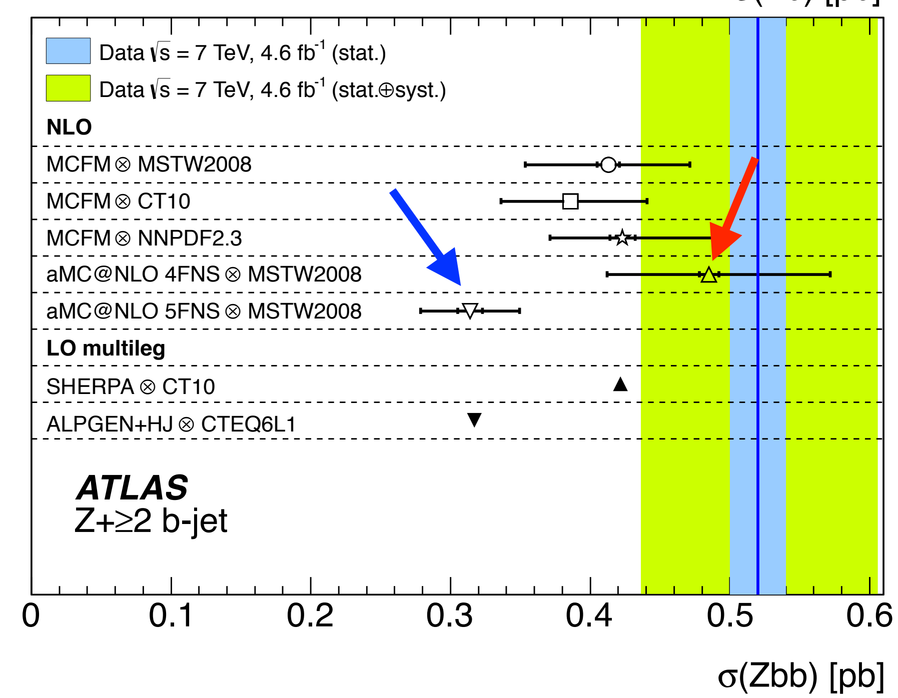
at least for aMC@NLO…

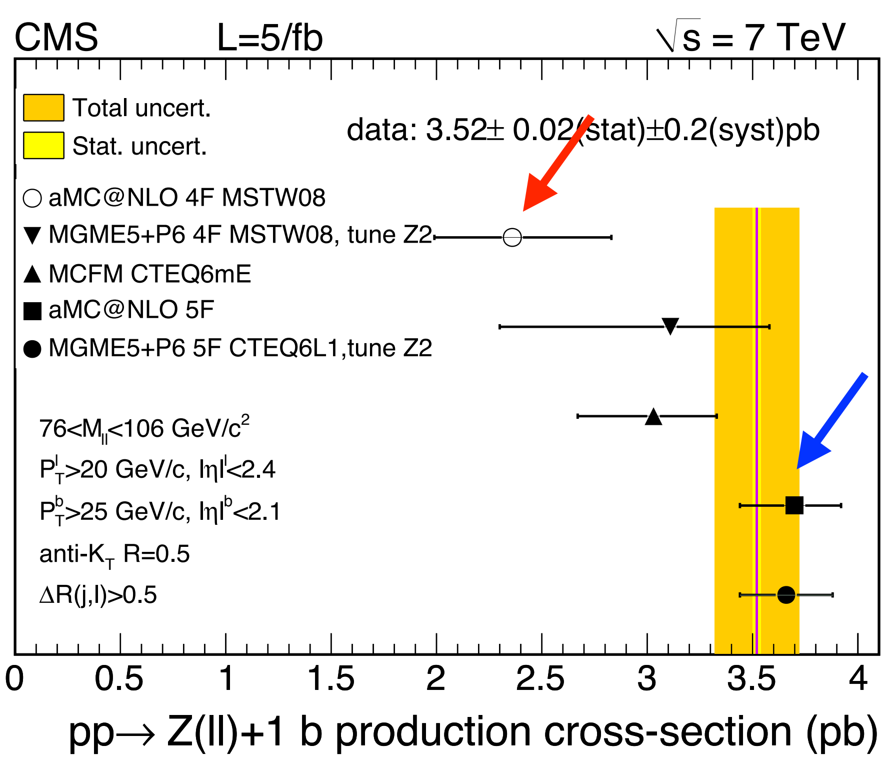
Somewhat reasonable but is it fully understood?

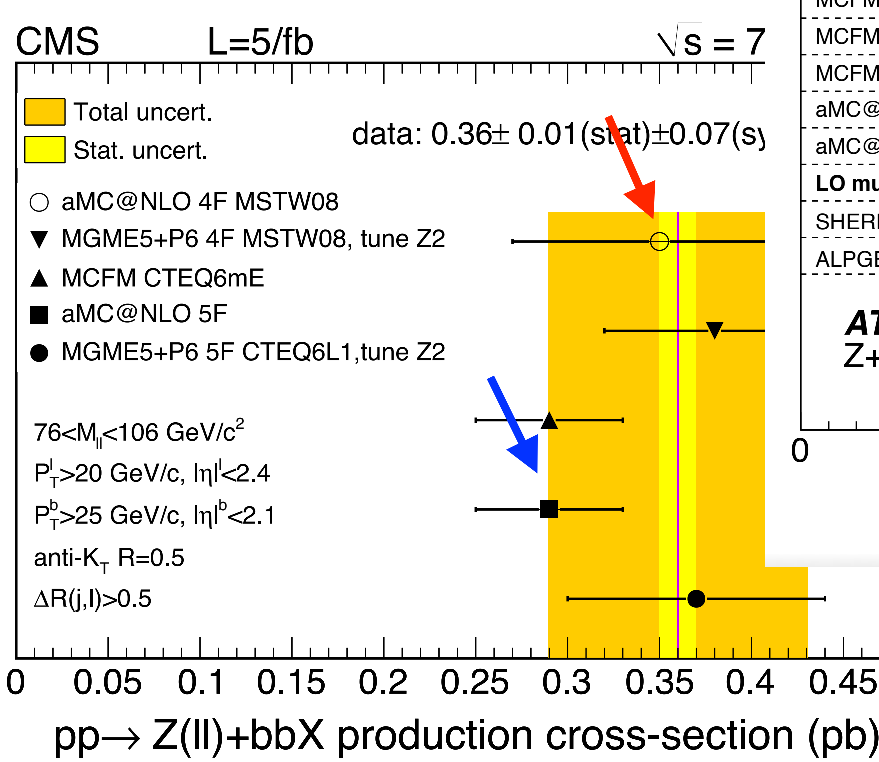
What must be used to evaluate background e.g. for ZH?







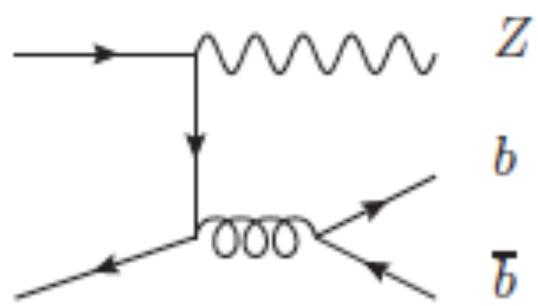


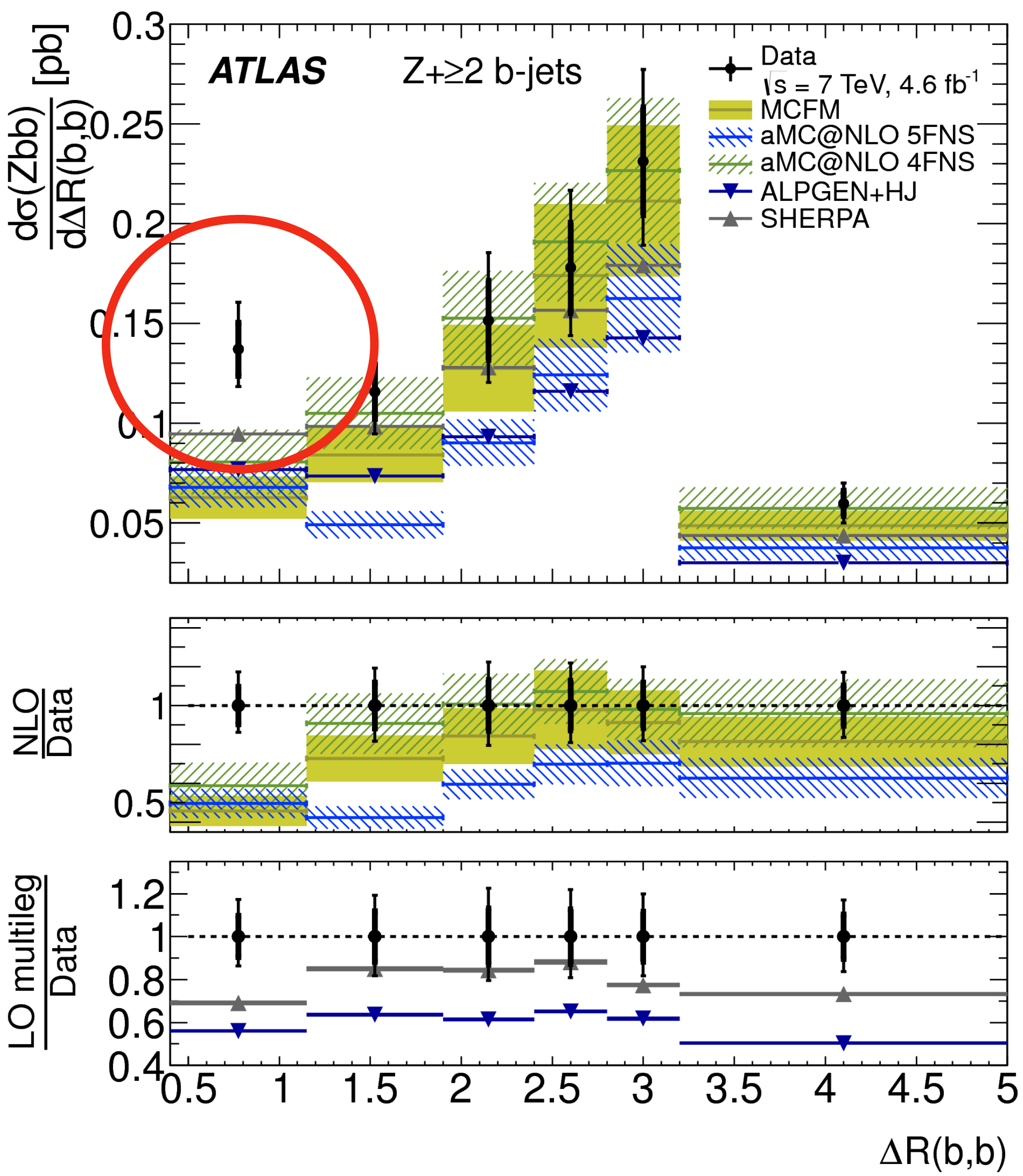


Differential distributions for Z+bb

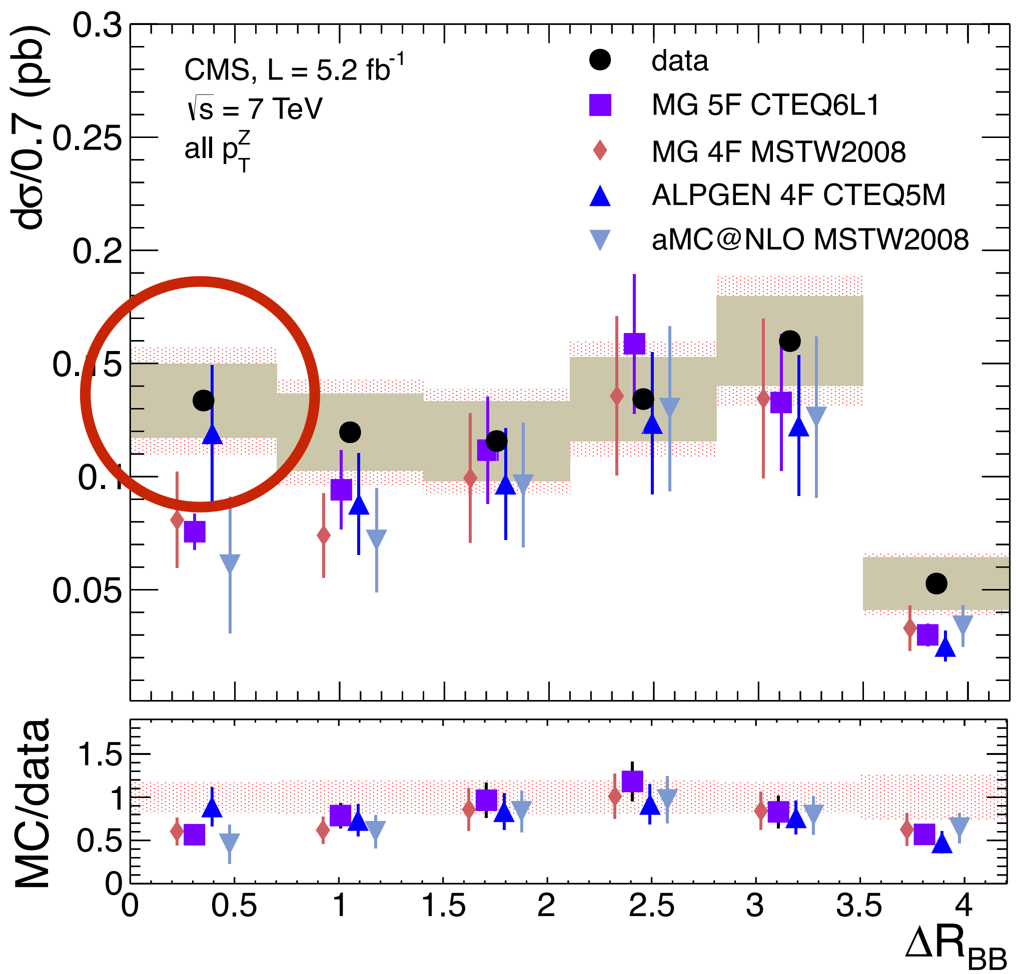
Some hints might come from tension at low ΔR, dominated by gluon splitting → tune?

- B-hadron identified by displaced secondary vertex





ΔR_{BB}

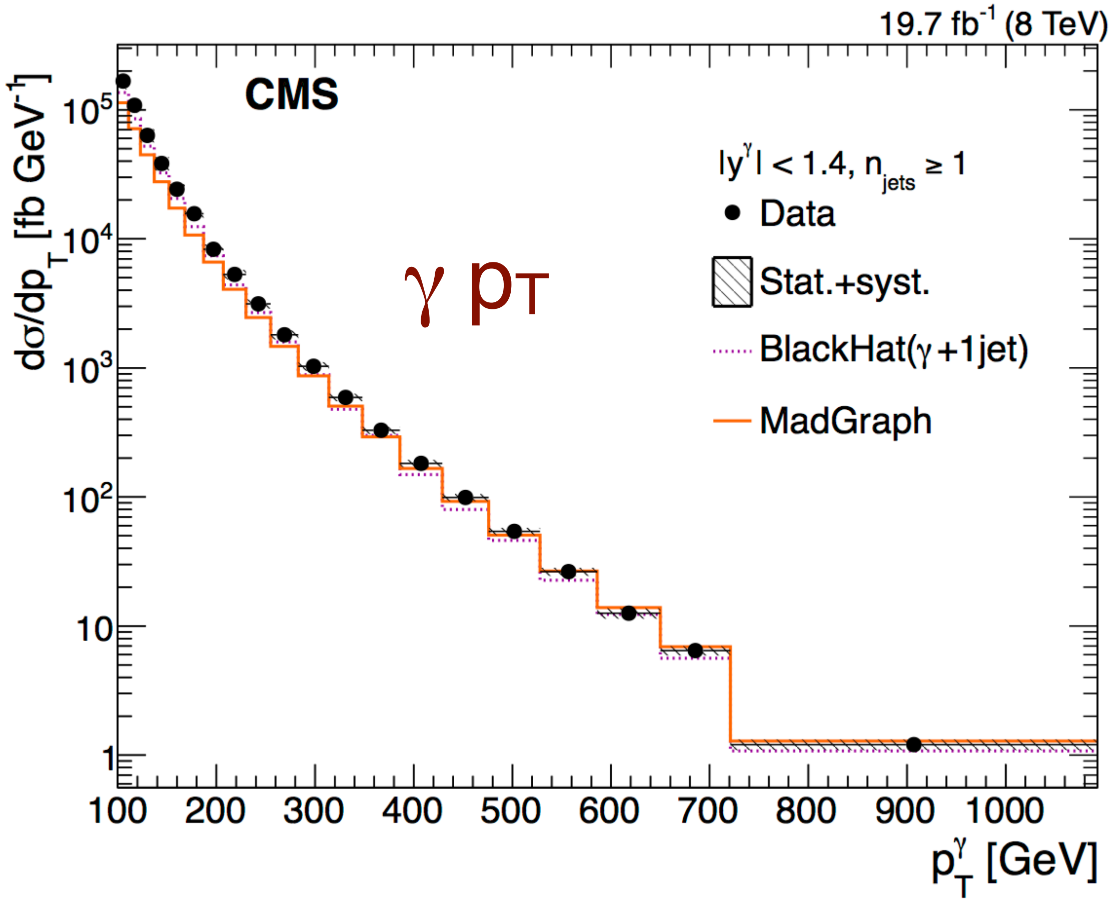


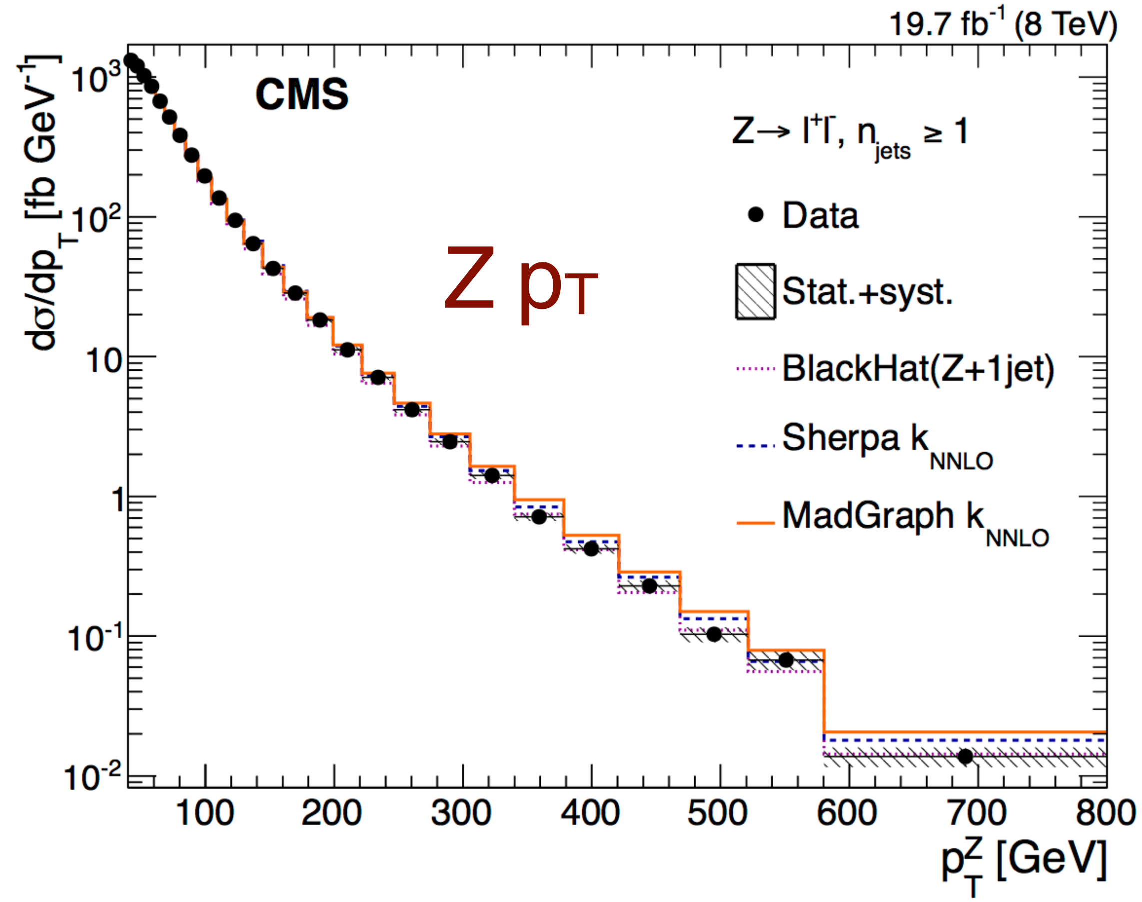
Z+jets/γ+jets

Crucial for searches based on MET because γ+jets is used to estimate $Z \to \nu\nu$ background

Results recently submitted by CMS: arXiv.1505.06250

- measures both Z and γ differential p_T distribution vs number of jets and calculate the ratio





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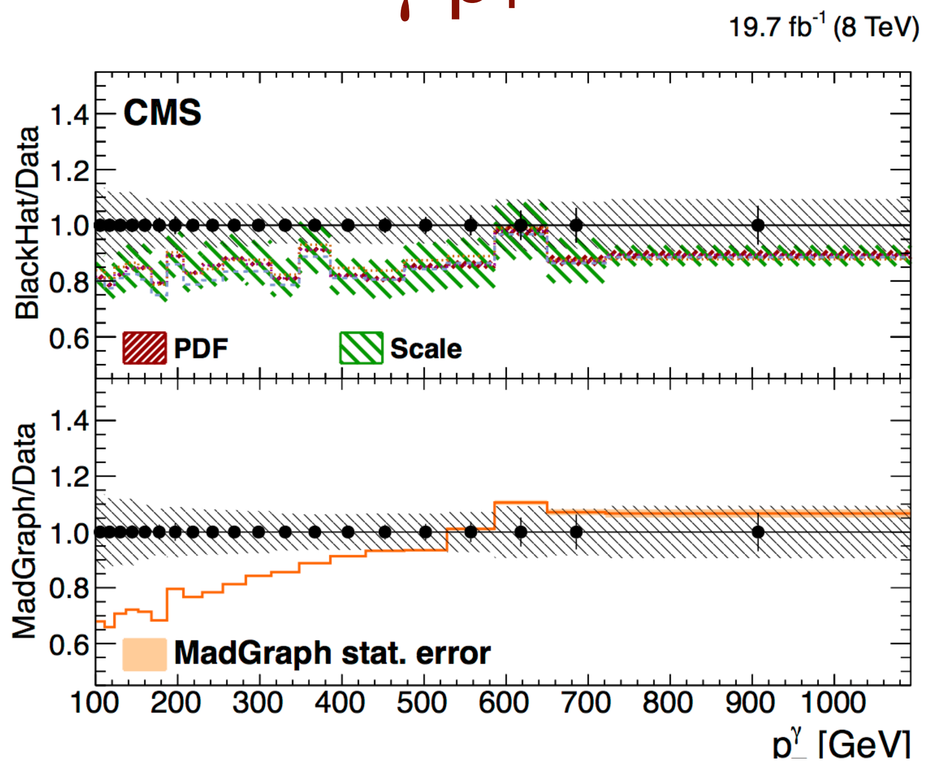
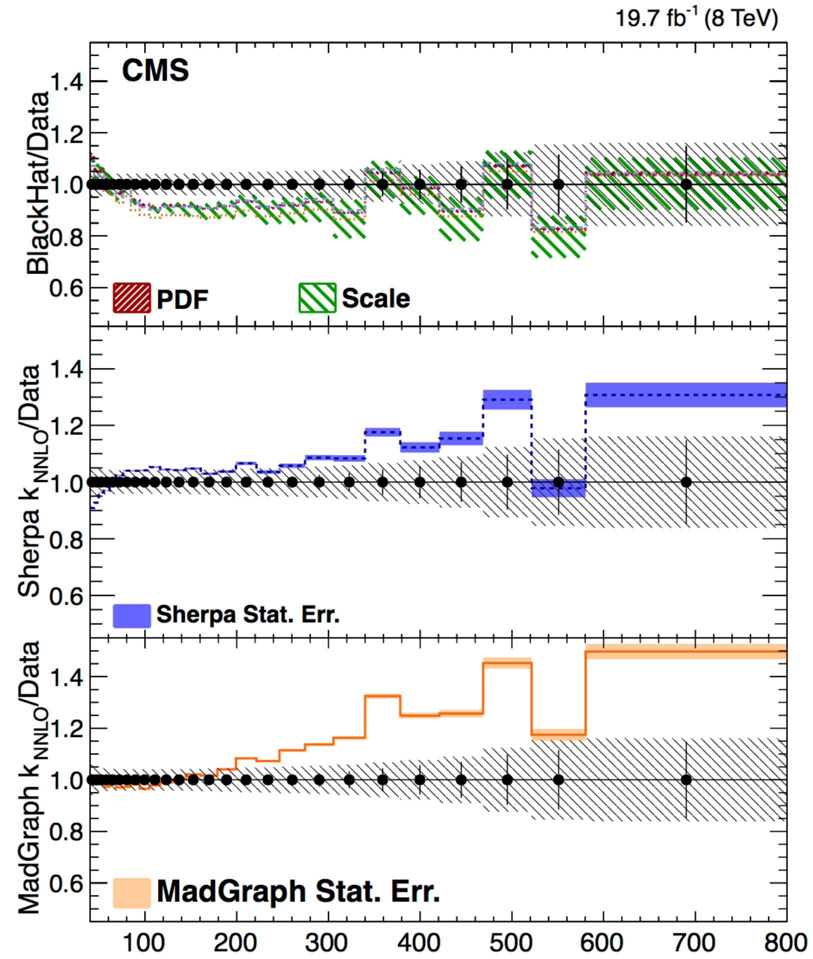
γ p_T





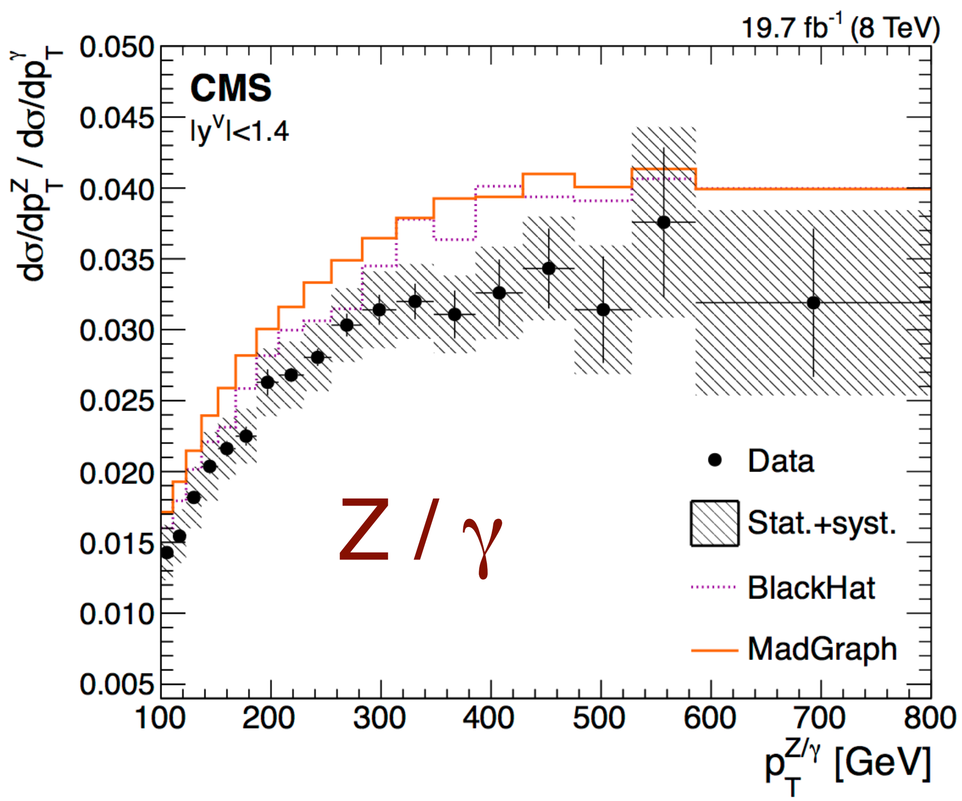
Z p_T

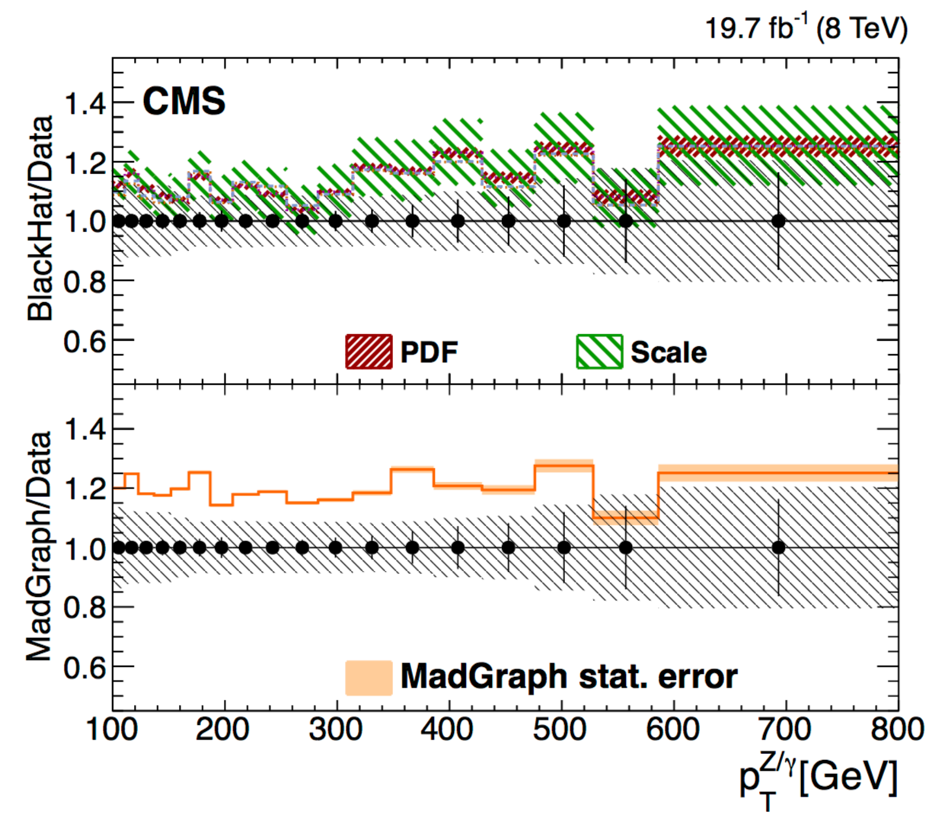
- ME+PS does not correctly describe the p_T of both bosons
- BlackHat+Sherpa (top) flat at high boson p_T but 10%-20% lower

Z+jets/γ+jets

LO predictions for the ratio vs data off by 20% but flat!

BH prediction (NLO for both processes) are also ~10% larger than data





Scale uncertainty of NLO predictions

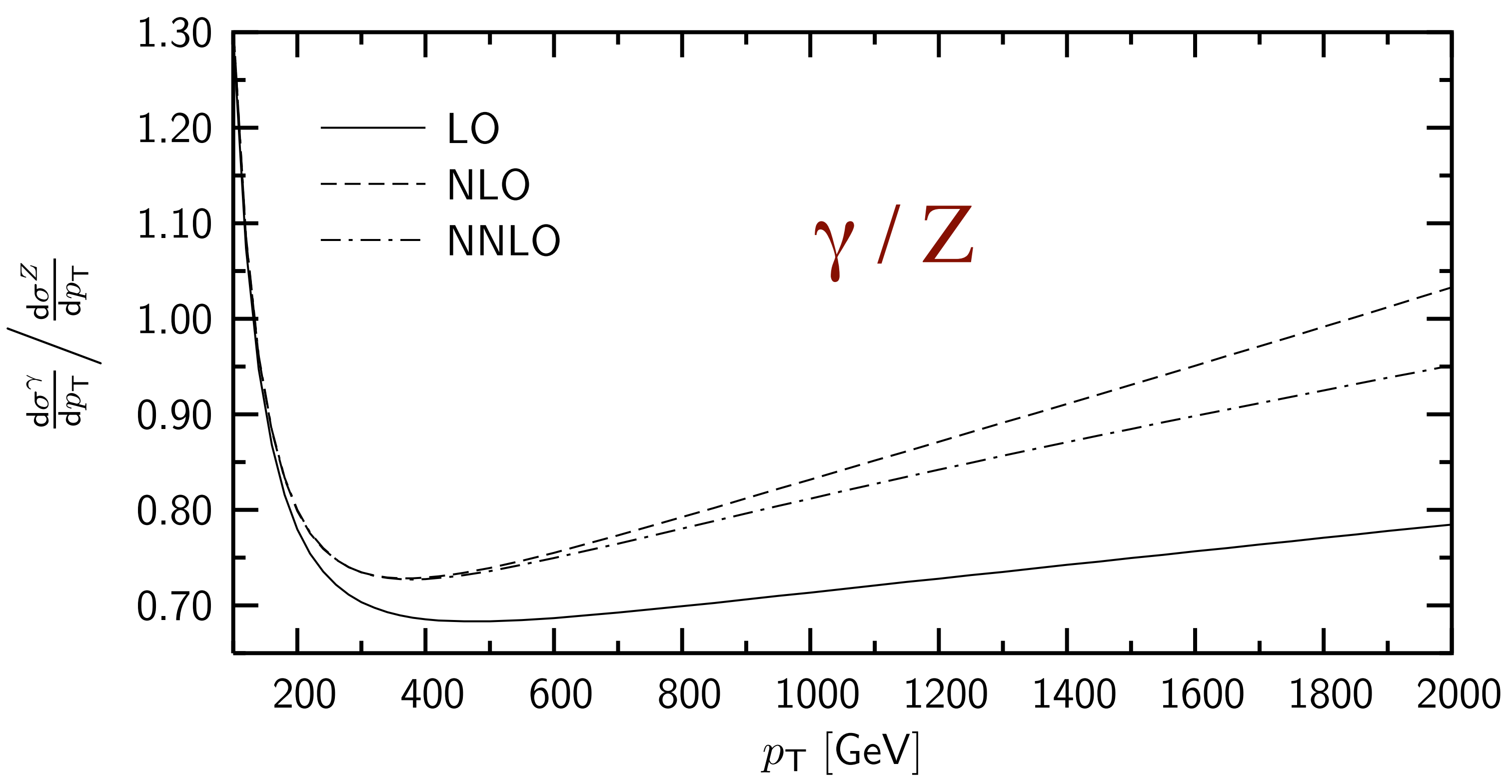
- scale $H_T' = H_T + E_T(Z,\gamma)$
- cancel in the ratio if considered fully correlated between the two processes
- would clearly underestimate the theoretical uncertainty
- largest relative scale uncertainty on each process used for the uncertainty on the ratio
- is there a better suggestion on how to handle these cases?

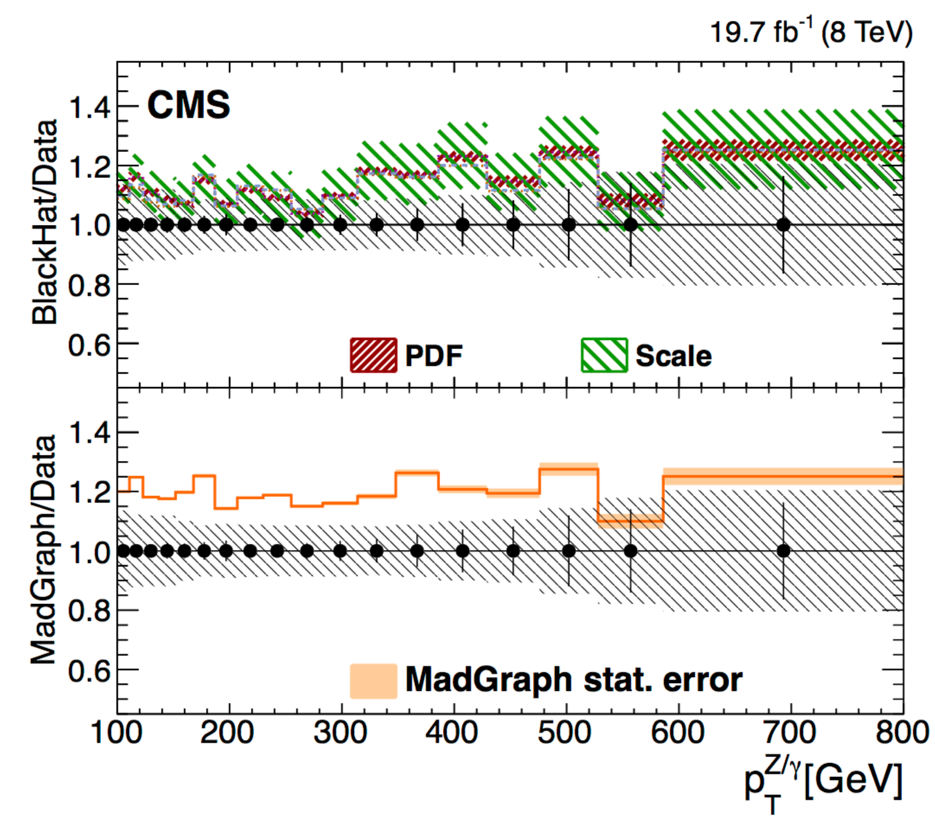
EWK corrections to Z+jets/γ+jets

Khün et al. JHEP0603:059,2006

EWK corrections are ~10% at √s = 14 TeV for up to 1 TeV

- *NNLO here means dominant 2-loop EWK*





Somewhat smaller at 8 TeV but they could explain the difference

- *for √s = 2 TeV corrections are < 5% for up to 400 GeV p_T)*

Will certainly be important at 13 TeV!

tt production

With statistical precision reached at LHC is a **new benchmark process** for MC

- The **modelling of ISR and FSR radiation** in ttbar production is one of the dominant uncertainties in the measurement of the top mass
- A lot of ongoing work to study **systematics uncertainties in MC modelling**

Some ATLAS measurements used to compare/tune MC to data (available in RIVET):

- tt gap fraction - Eur. Phys. J. C72 (2012) 2043
  - The inclusive gap fraction as function of the leading jet pT threshold, Q0
- tt+jets differential xsec — JHEP01(2015)020
  - The distribution of the leading and 5th jet pT and the number of jets for jets with pT>25 and pT>80 GeV
- jet shapes in tt events - Phys. Rev. D 90, 072004 (2014)
  - The distributions of differential jet shapes for jets with 30<pT<150 GeV (5 observables) for light- and b-jets separately.

Gap fraction analysis

Eur. Phys. J. C72 (2012) 2043

Study fraction of $t\bar{t}$ events, that do not contain an additional jet(s):

- Sensitive to the amount of extra radiation
- Use dilepton events with two reconstructed b-quark jets
  → additional (radiated) jets easily to identify

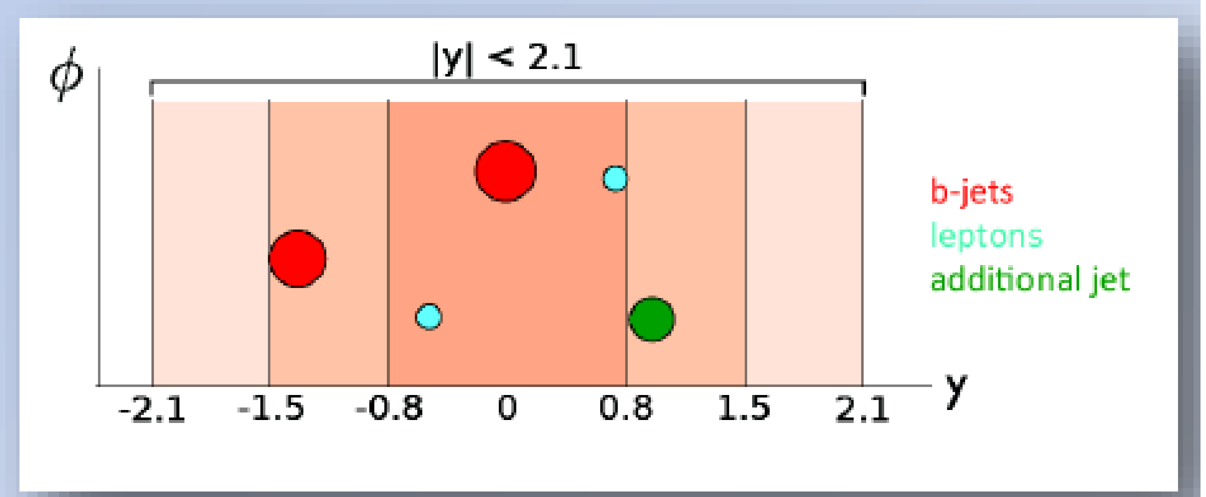
Provided unfolded distributions

- Fraction of events that do not contain an additional jet in a central rapidity region with $p_T > Q_0$:

$$f_{gap}(Q_0) = \frac{n_{gap}(Q_0)}{N_{t\bar{t}}}$$

- Sum of the p_T of the jets falling into each rapidity region

$$f_{gap}(Q_{sum}) = \frac{n_{gap}(Q_{sum})}{N_{t\bar{t}}}$$



Official Rivet routine since Rivet 1.8.1

Similar Analysis from CMS:

- 7 TeV: arXiv:1404.3171
- 8 TeV: CMS-PAS-TOP-12-041

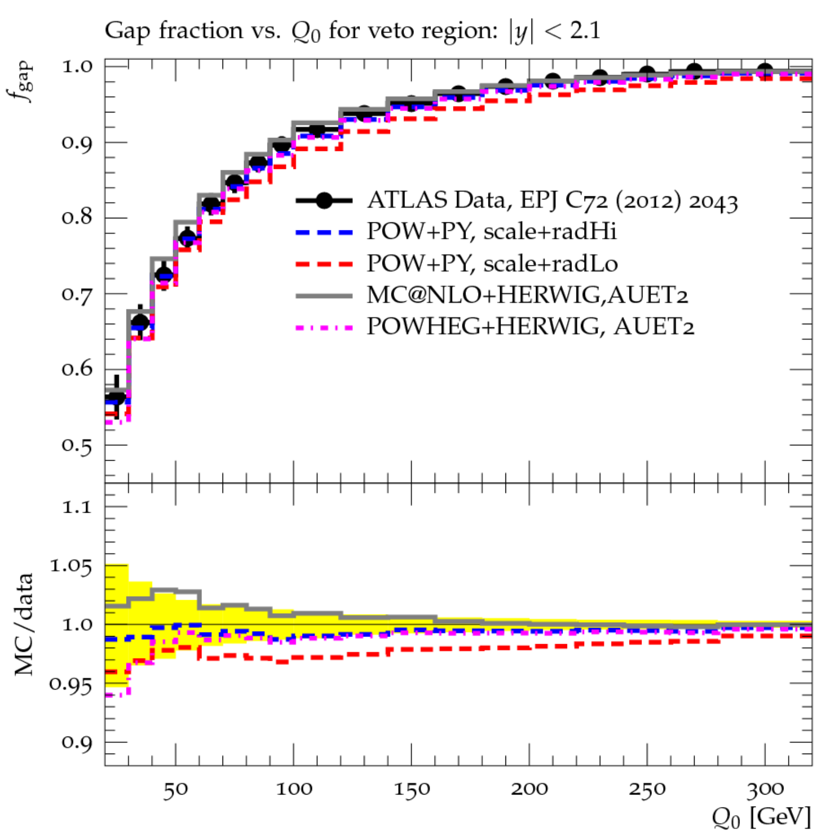
Study of scale uncertainty

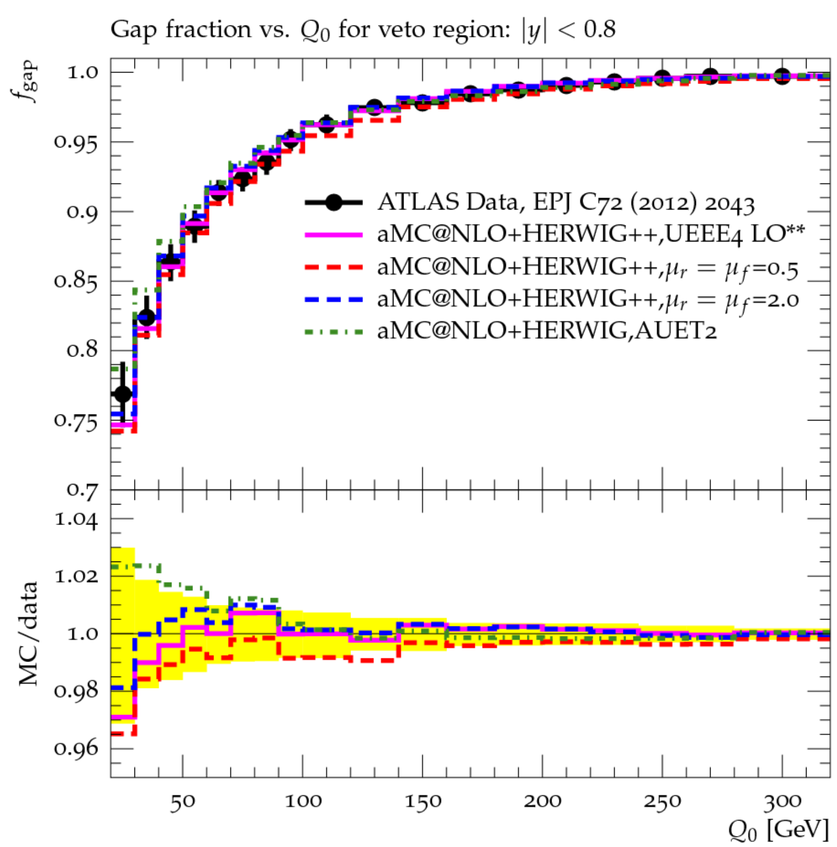
ATL-PHYS-PUB-2014-005 / ATL-PHYS-PUB-2015-011

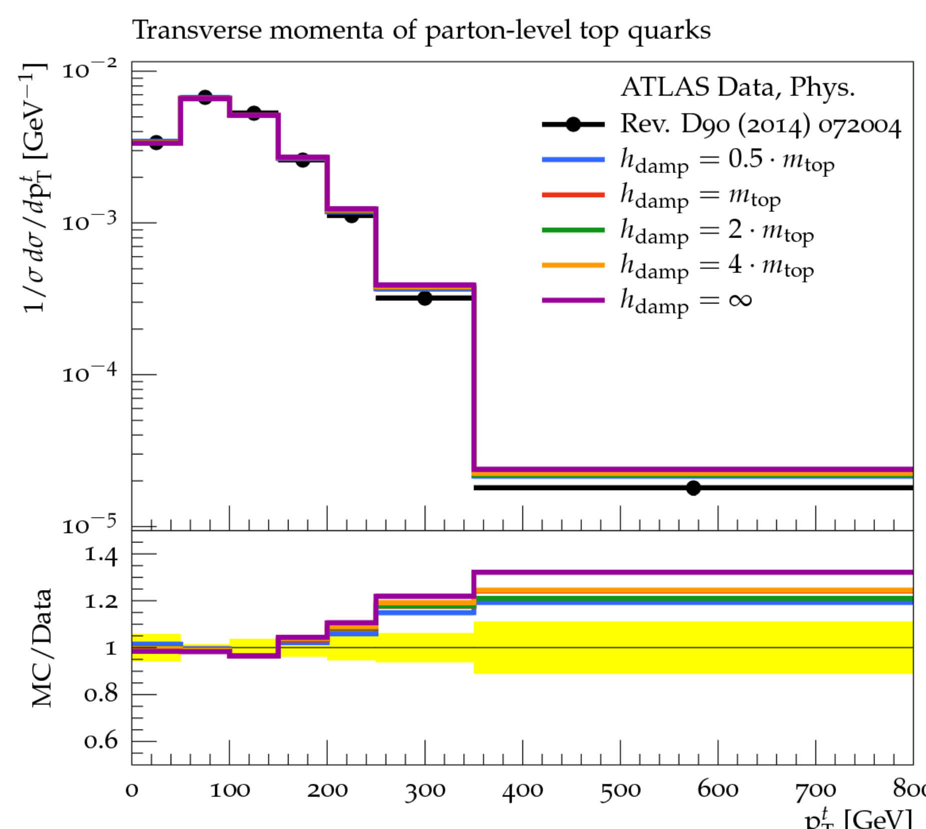
Several generators studied

Main focus on **POWHEG+PYTHIA6/PYTHIA8/Herwig++** compared to **MC@NLO, Madgraph_aMC@NLO+HERWIG++, SHERPA**

- scale/hdamp variations in Powheg have approx. the same size as scale variations in Madgraph5_aMC@NLO
- none of the variations gives good agreement in $p_T(t)$

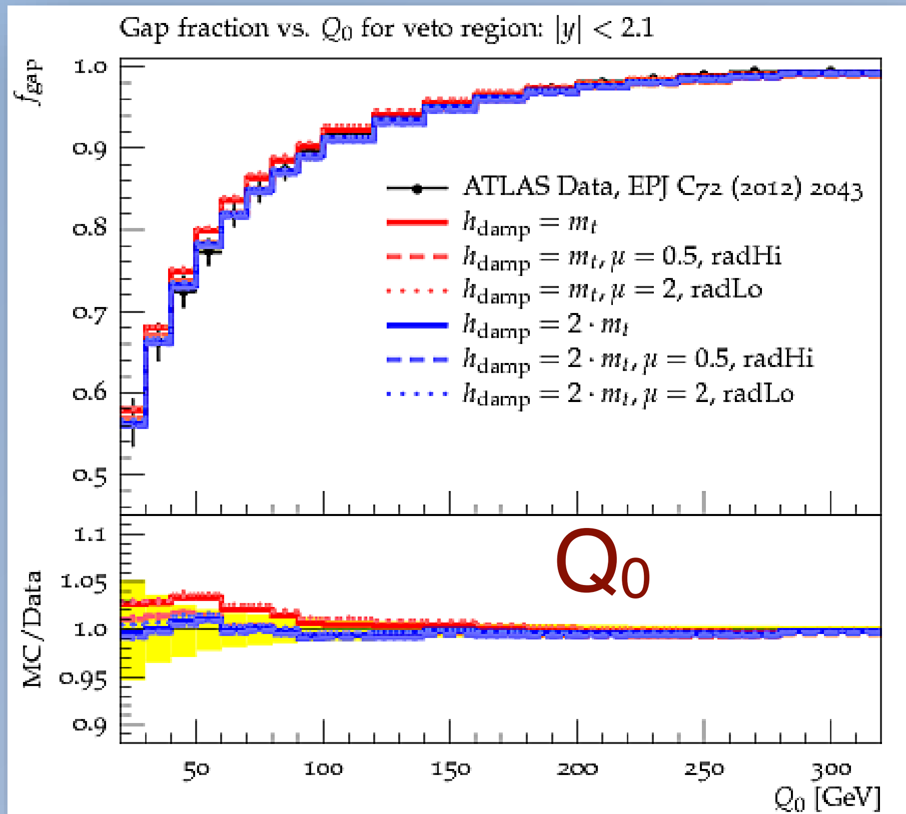


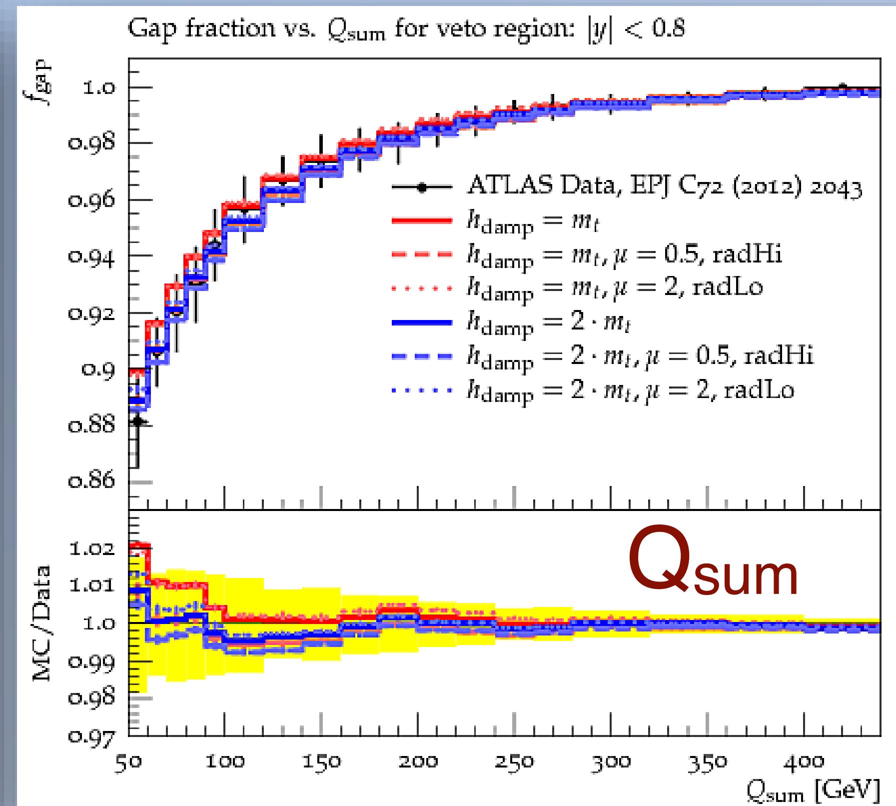


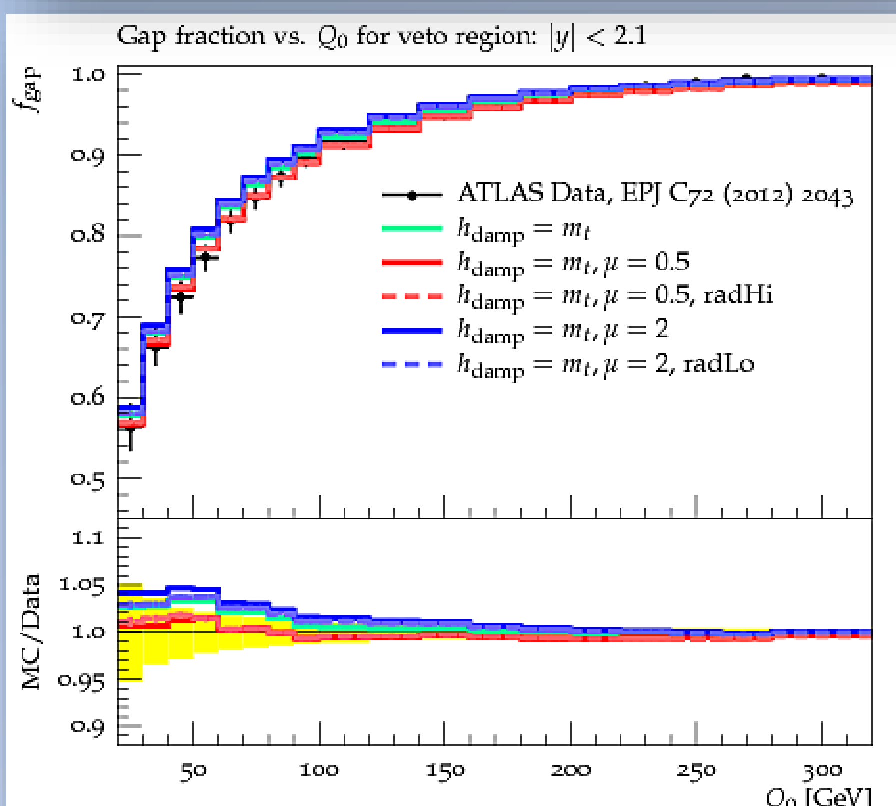


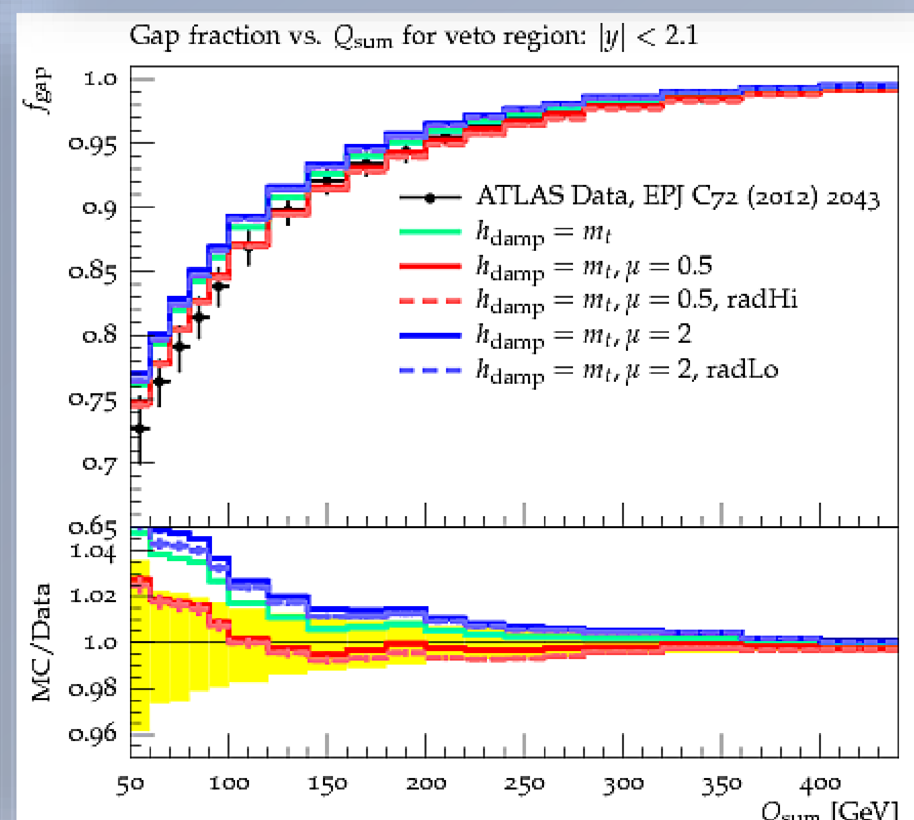
Q_0 $p_T(t)$

Correlated variations of ME and PS scales









No big effect observed by changing PS scale in addition to ME scale

Tuning strategy on tt

ATL-PHYS-PUB-2015-007

List of parameters:

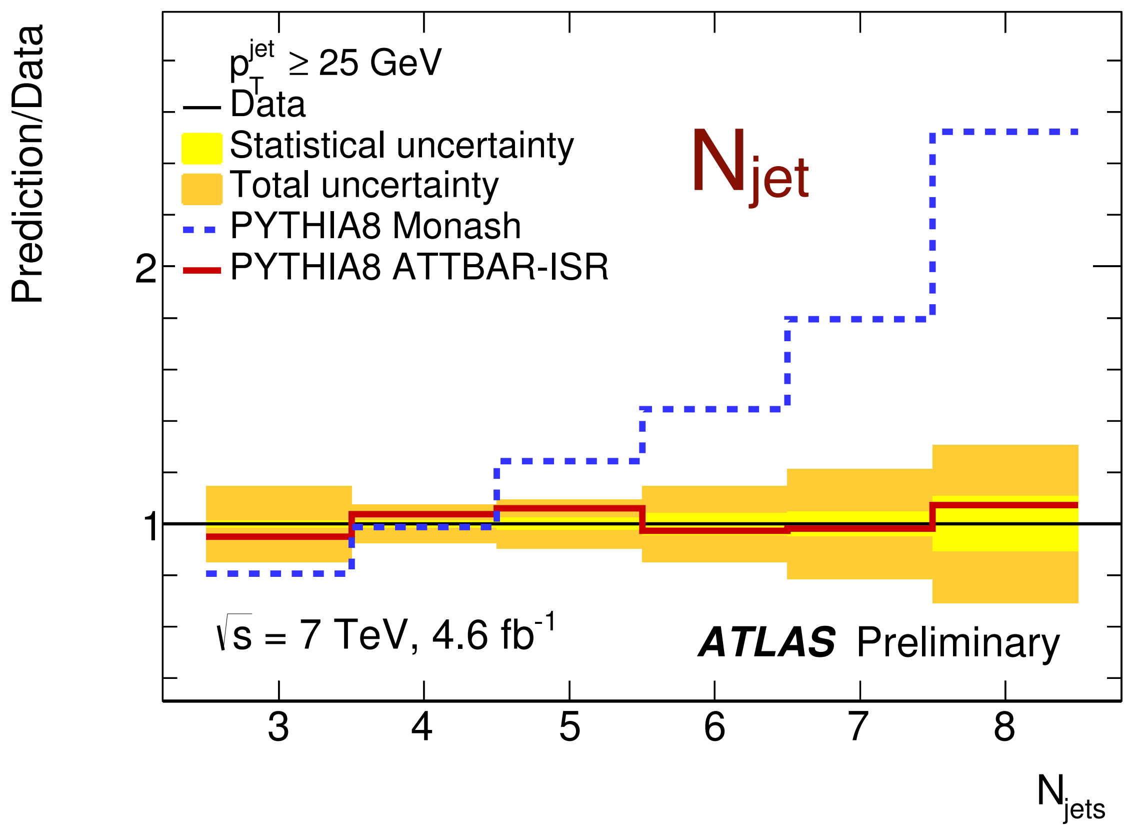
Parameter	Pythia8 setting	Variation range	4C	Monash
$\alpha_s^{\mathrm{ISR}}(m_Z)$	`SpaceShower:alphaSvalue`	0.110 – 0.140	0.137	0.1365
ISR damping	`SpaceShower:pTdampMatch`	1 (fixed)	0	0
$p_{\mathrm{T,damp}}^{\mathrm{ISR}}$	`SpaceShower:pTdampFudge`	0.8 – 1.8	-	-
$\alpha_s^{\mathrm{FSR}}(m_Z)$	`TimeShower:alphaSvalue`	0.110 – 0.150	0.1383	0.1365
$p_{\mathrm{T,min}}^{\mathrm{FSR}}$ [GeV]	`TimeShower:pTmin`	0.1 – 2.0	0.4	0.5

- Tune the **Pythia8 ISR** parameters to the **gap fraction and tt+jets**
- Tune the **Pythia8 FSR** parameters to the **jet shapes in ttbar**
- Combine tune of both ISR and FSR parameters to all the measurements
- Retune the **MPI cut-off** to maintain the description of **UE data**
- Apply the **Pythia8 tune to NLO+PS generators**, tuning additional parameters sensitive to the extra radiation to the **gap fraction** and **tt+jets**

PYTHIA8 ATTBAR tune

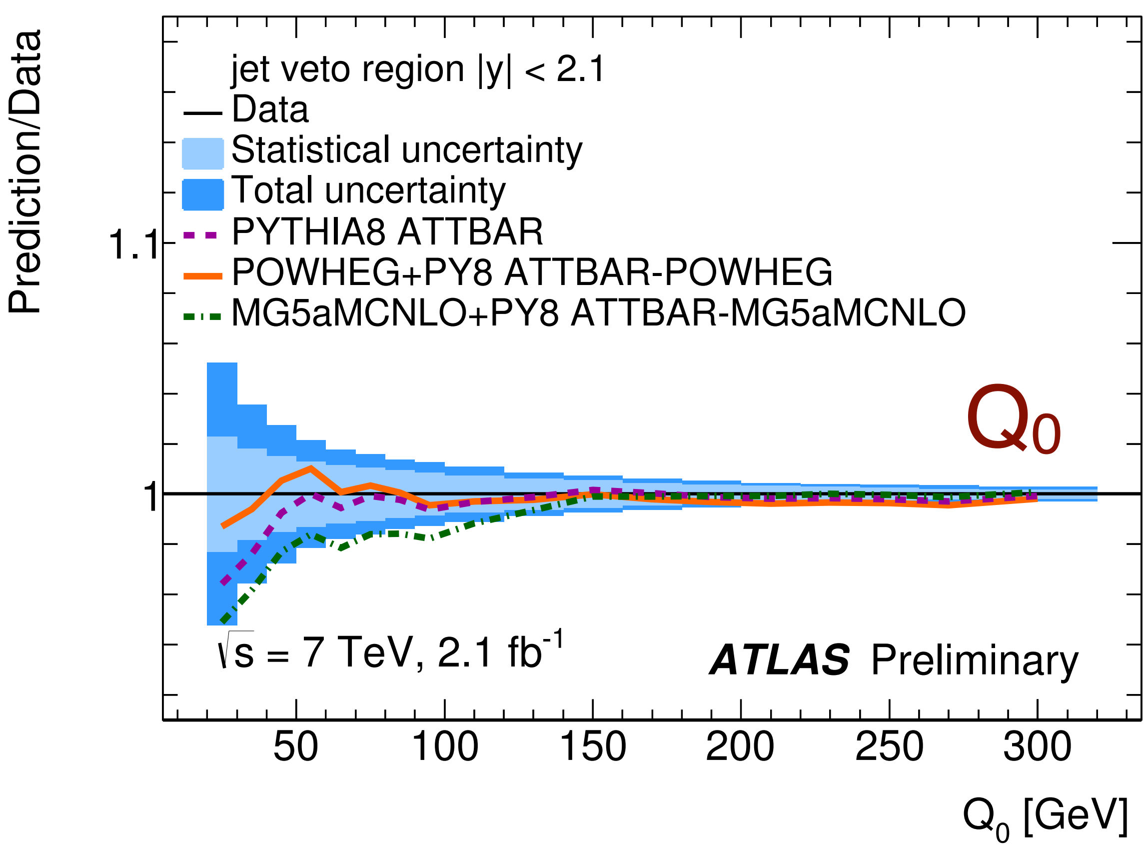
Results for PYTHIA8 standalone

- Can describe extra radiation in ttbar data by adding a damping factor to the ISR emission probability
- The tuned value of α_S^{ISR} is compatible with the Z p_T determinations
- The tuned value of α_S^{FSR} to light-jet shapes is compatible with LEP data

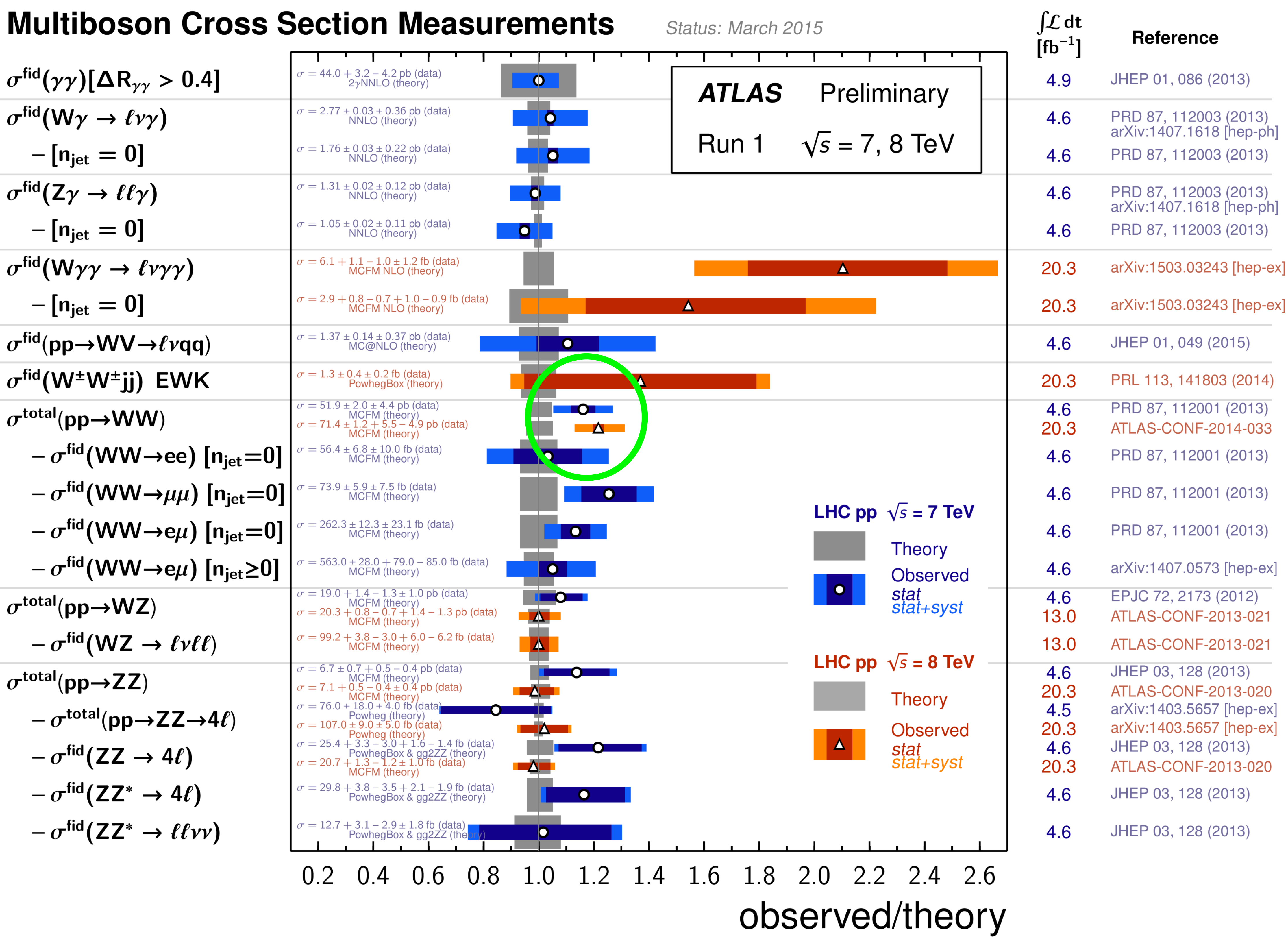


Tune applied to NLO+PS generators Powheg and MadGraph5_aMC@NLO

- additional parameters *hdamp* and *frac_upp/low* have been tuned to data
- a good agreement with data is found for both ME generators



WW cross-section



WW cross-section

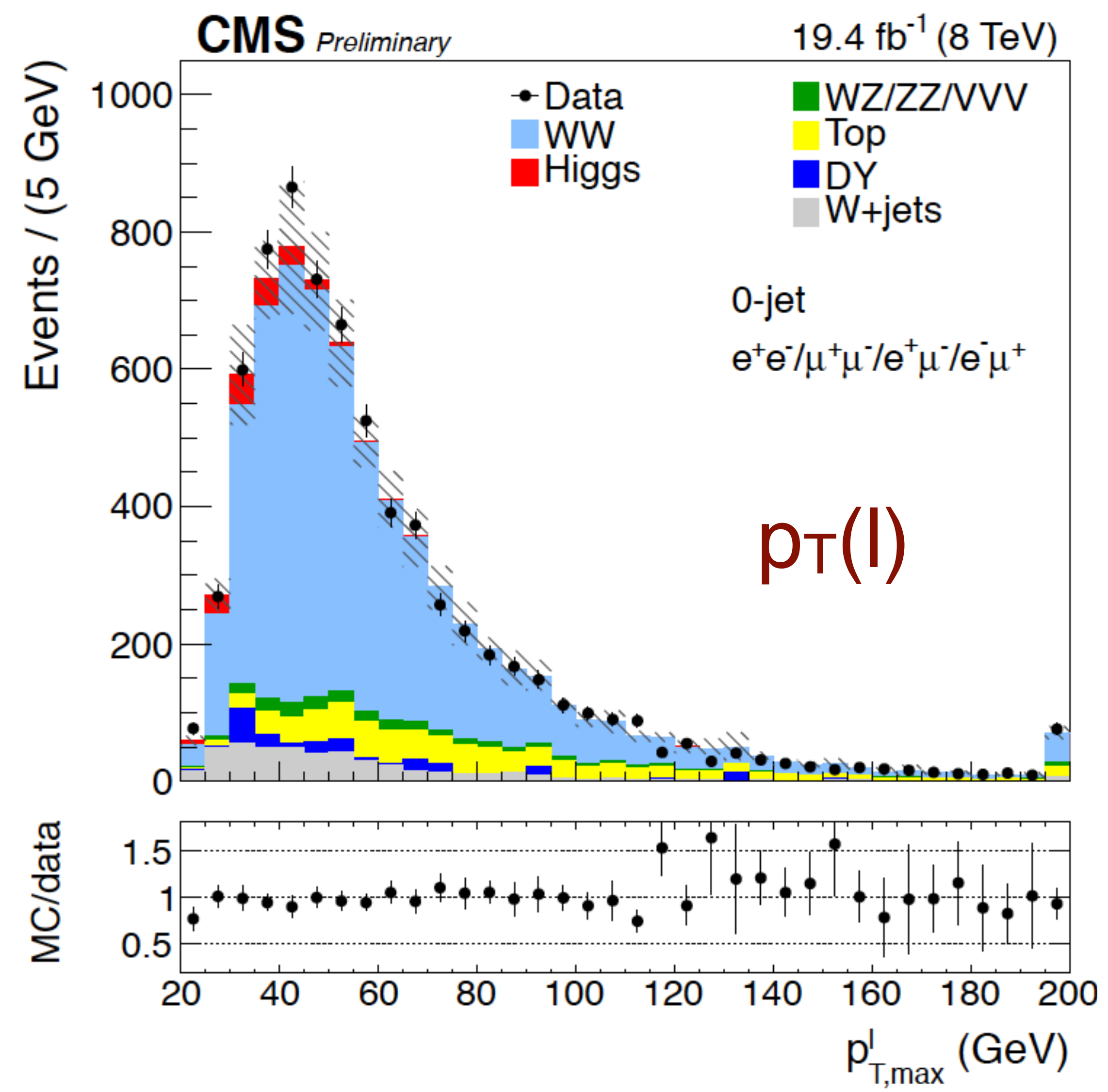
Due to observed discrepancy, raised a lot theoretical interest

Cross-section known at NNLO QCD

- *T. Gehrmann et al. [1408.5243]*
- 7% higher than NLO
- gg→H→WW only 3% of signal yields (considered as a background)

However different categories for 0 and 1 reconstructed jet with pT > 30 GeV and |η| < 4.7

0-jet and 1-jet bin makes the kinematics sensitive to higher-order QCD

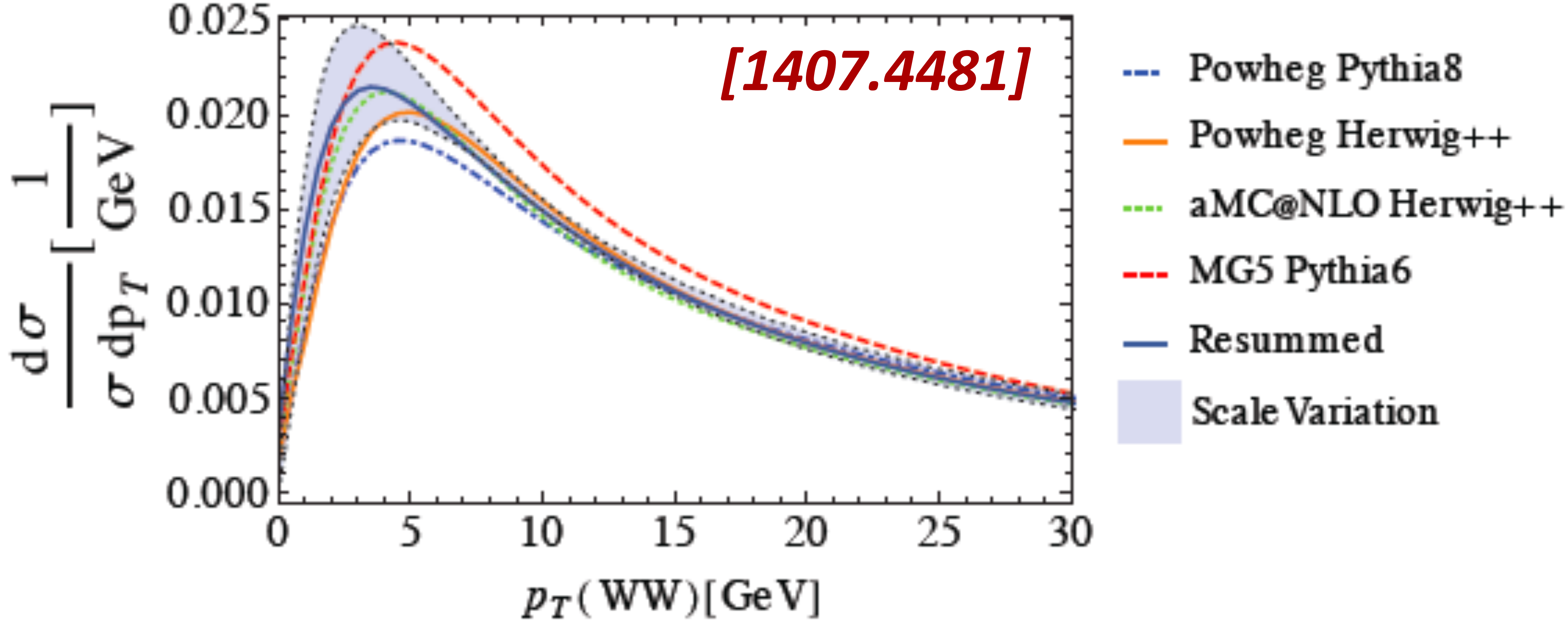


CMS-PAS-SMP-14-016

WW p_T reweighting

Improve modelling by reweighting p_T(WW) of qq → WW to a NLO+NNLL pT resummed calculation

- strongly correlated with jet veto: ~3.5% effect on the 0-jet cross-section
- scale uncertainty of 2.8% (resummation) + 2.5% (renormalization) for 0-jet



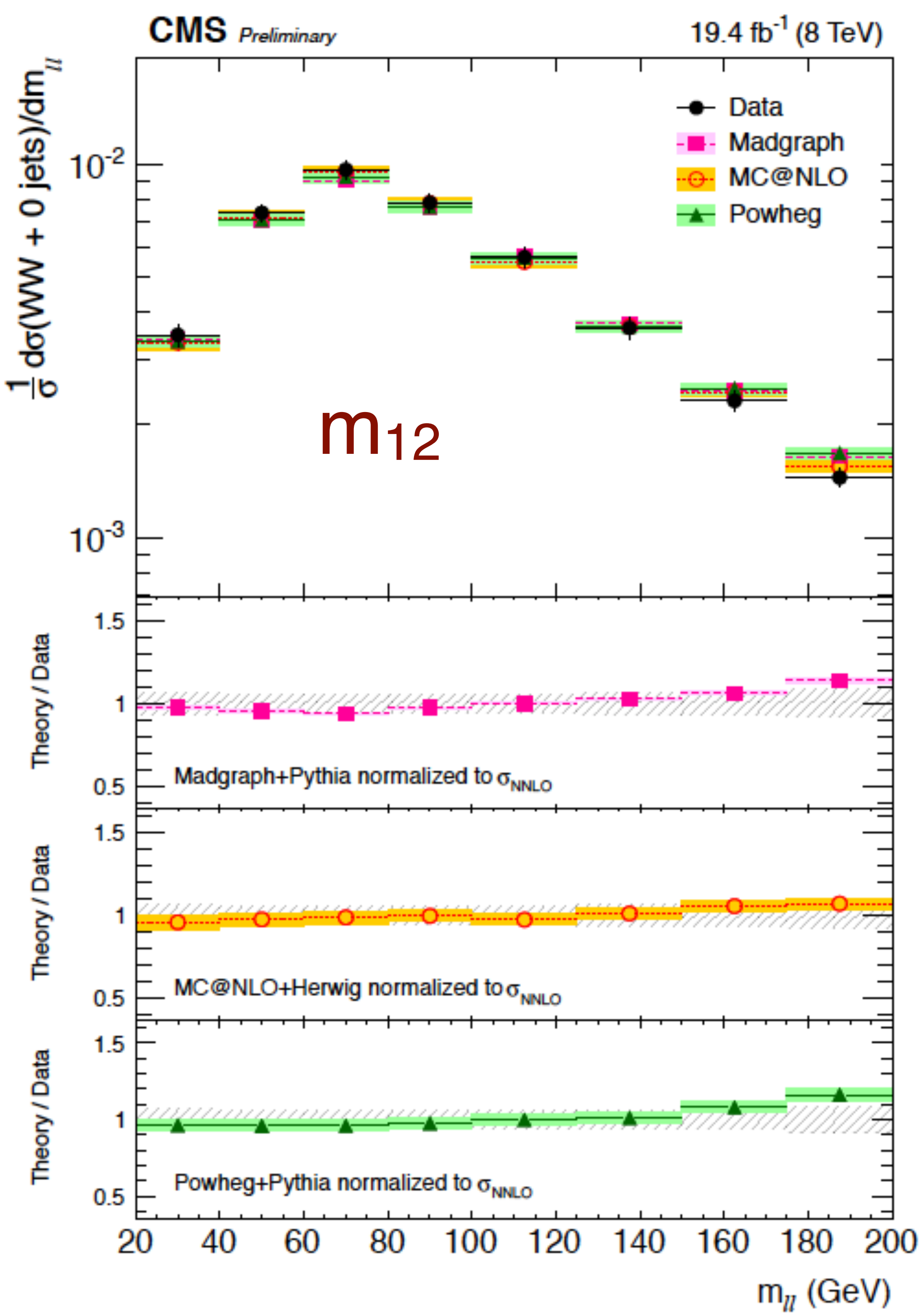
This reweighting procedure raised some discussion

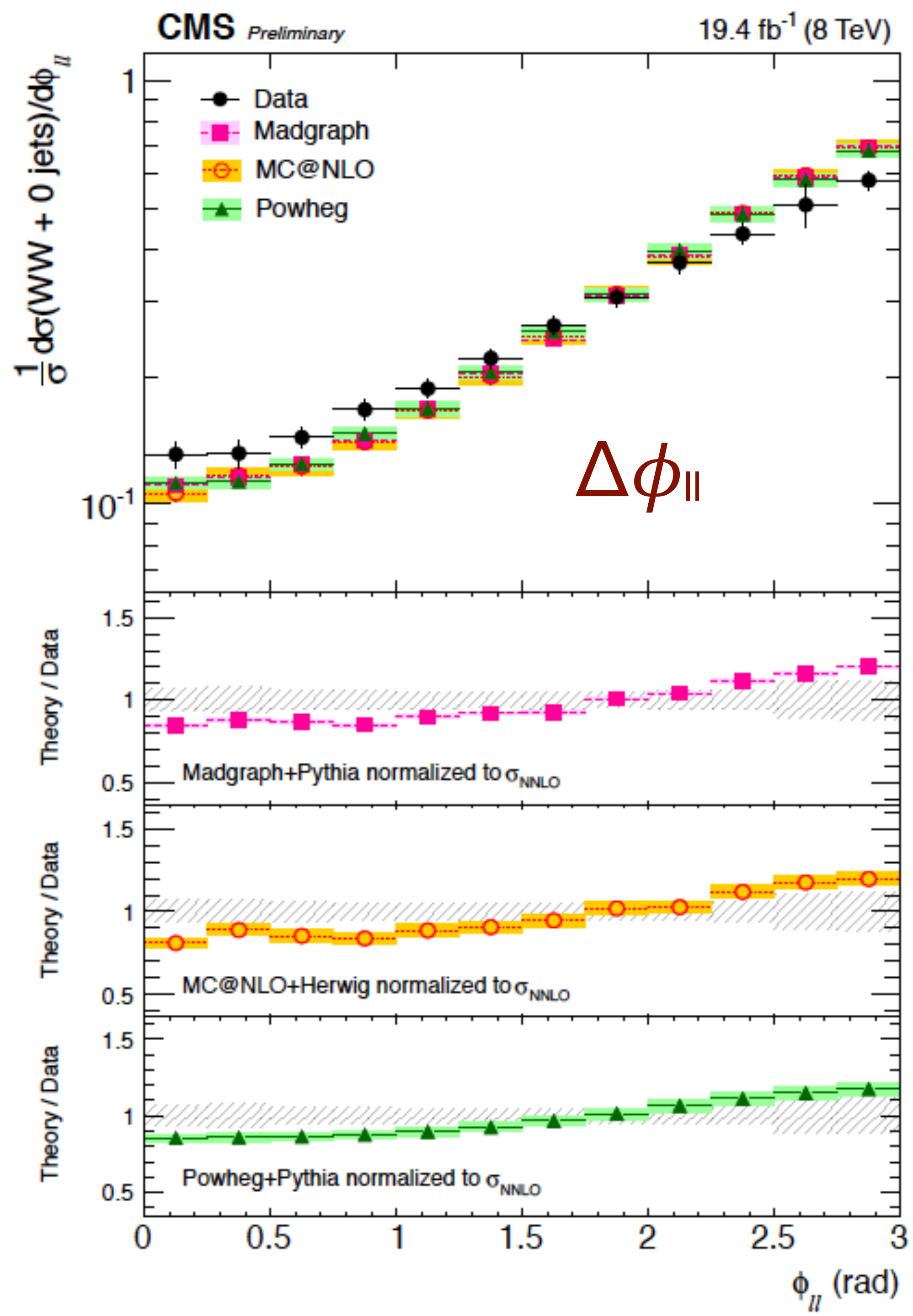
Stronger prescription from theory community needed for further progress!

WW normalized differential cross-sections

New nice set of results for MC comparison:

- Measured in the 0-jet category. Results given in a fiducial phase space.





A list of items to work on

V+jets have been our workhorse

- however treatment of systematics still approximate: PS and UE tune uncertainties not deeply studied

V+b(b): still something to understand here, e.g. 5F vs 4F, tune,…

γ+jets vs Z+jets: treatment of correlated scale systematics

- also important for tt and single-top or Z and W for Mw

EWK corrections: need to tackle them now before 13 TeV data

tt production is the new benchmark for MEPS@NLO

- allows study of systematics uncertainty/tuning of PS

VV+jets, ttV, etc… will become increasingly important:

- are present tools good enough?

Scheduled sessions:

Thu: tt benchmark analysis

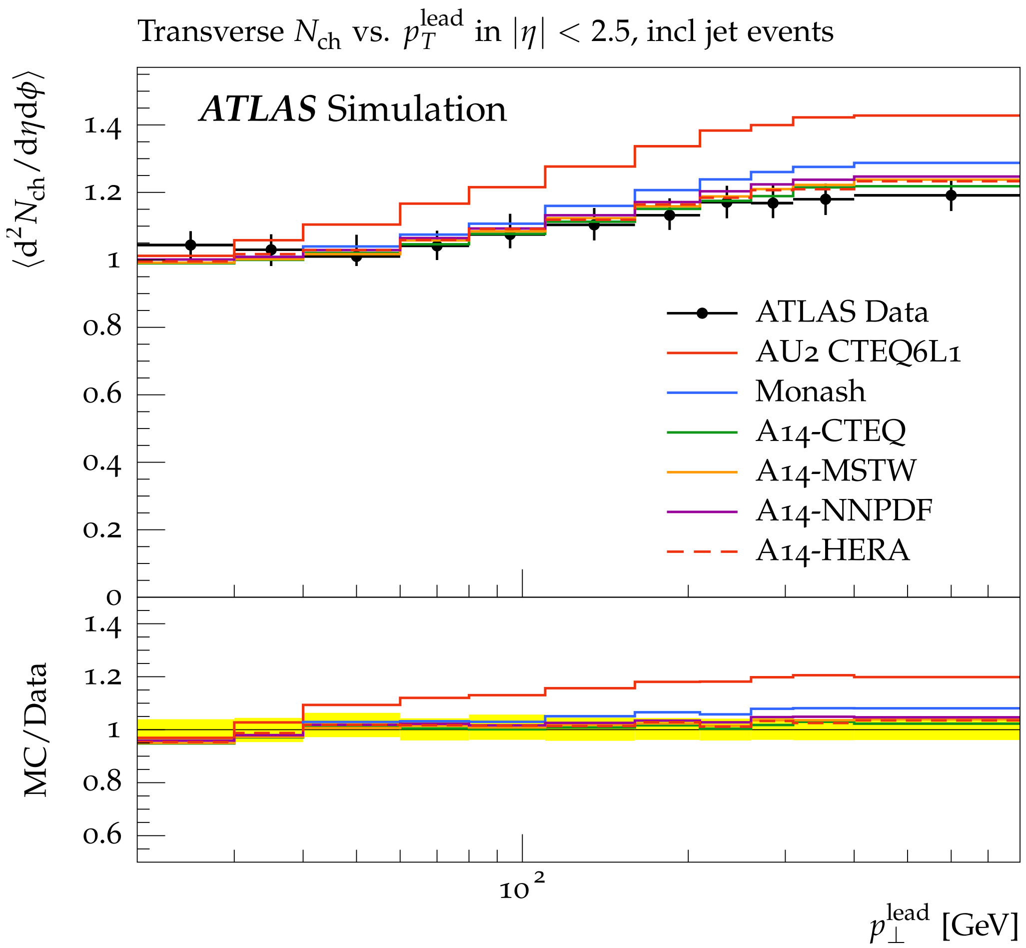
Fri: PS and matching/merging uncertainty

Backup

Underlying Event tunes

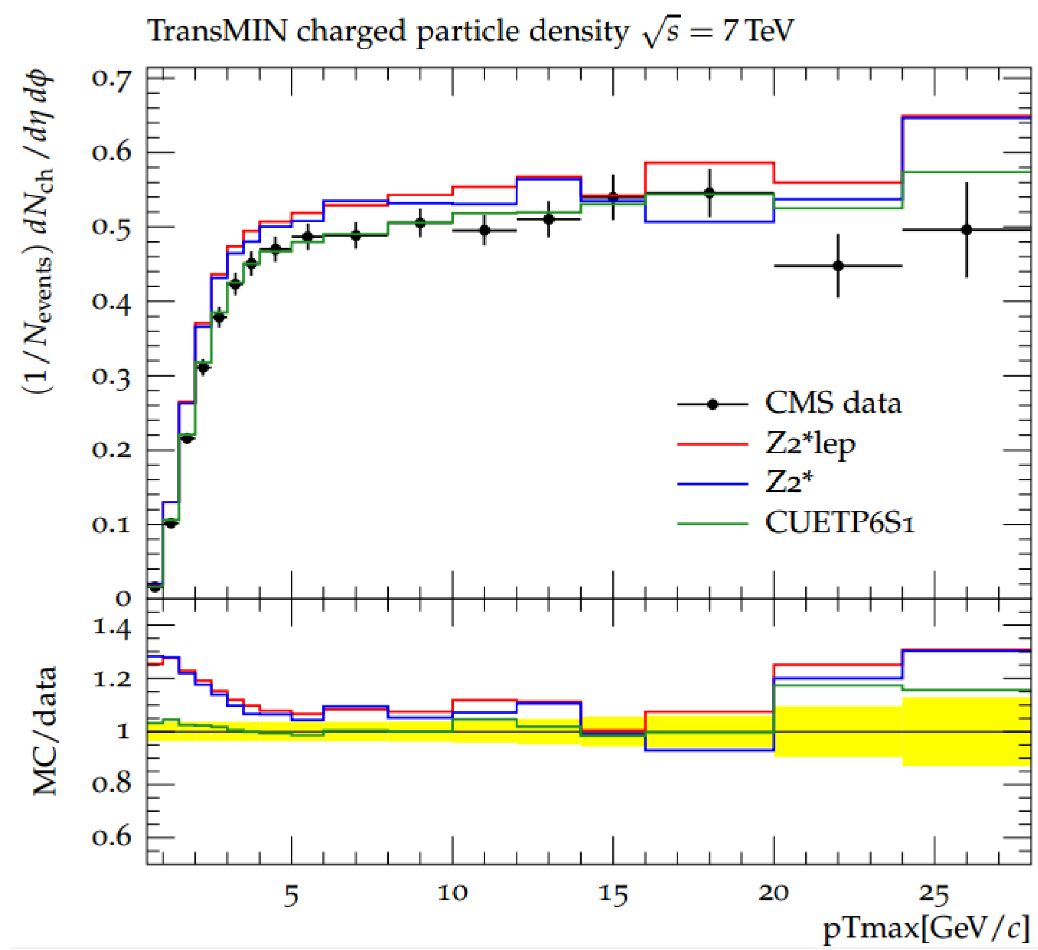
- Family of **A14** full-scale tunes[1] with various PDFs to most ATLAS jet and underlying-event observables.

- Optimized MPI and ISR/FSR parameters.



→ Tunes are suitable for high p_T processes.
→ Improved description of UE data, $t\bar{t}$ gap fractions, and 3-to-2 jet ratios.

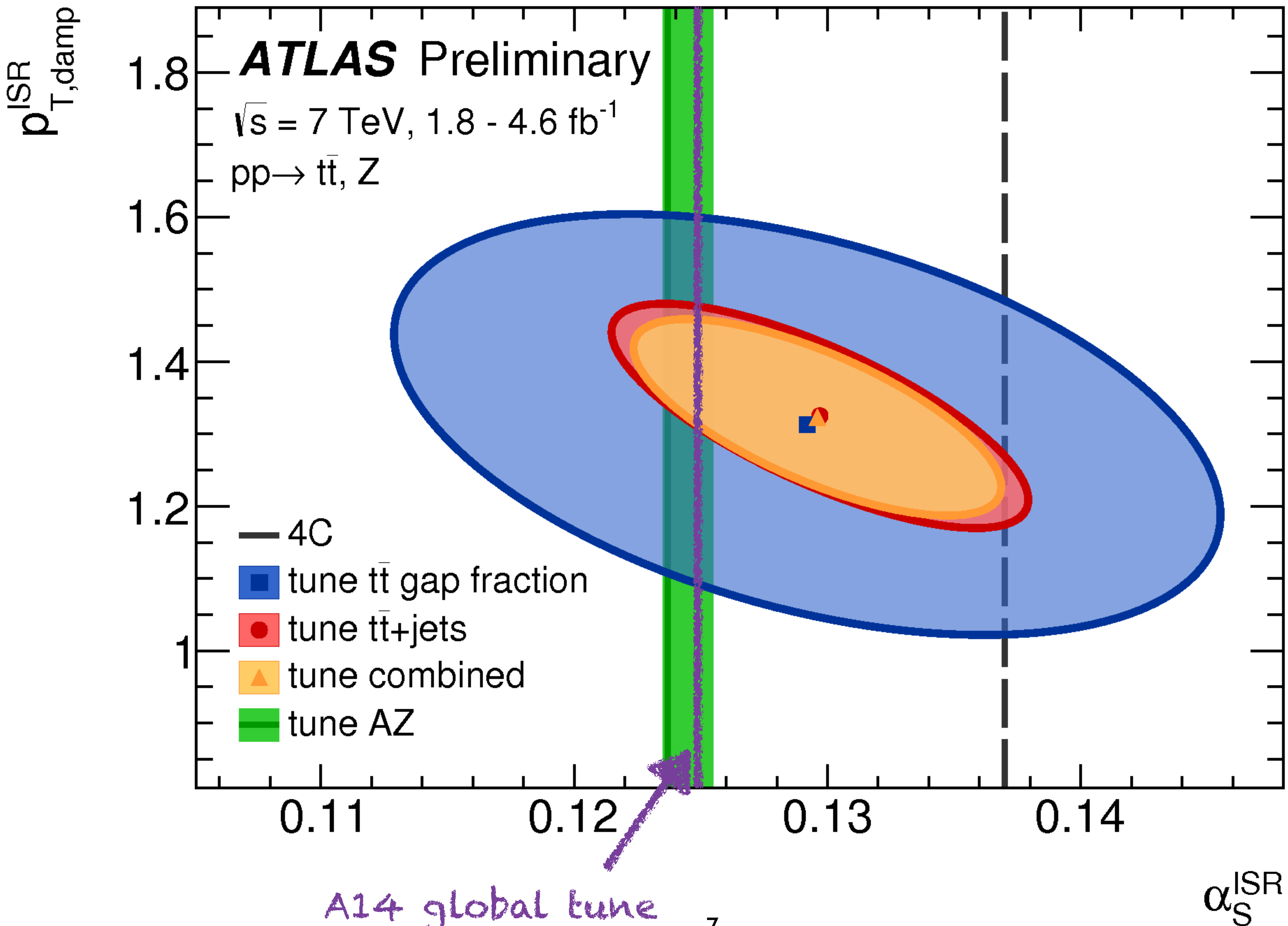
- CUETP8M1 (MonashStar[1]), CUETP8S and CUETP6S - tunes[2,3] with various PDFs, include CDF and CMS UE data at $\sqrt{s} = 0.9$, 1.96 and 7 TeV.



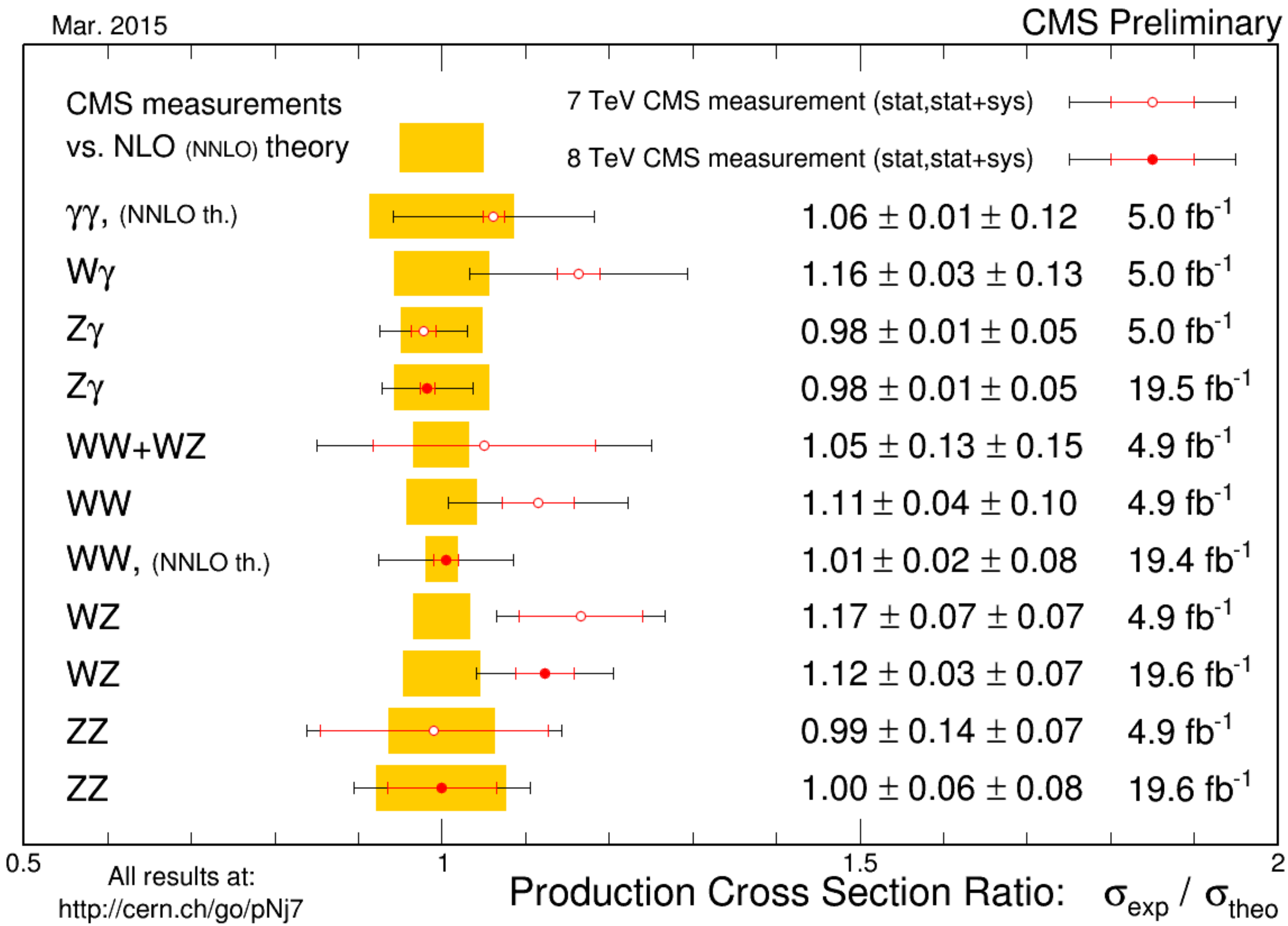
→ Test model of MPI energy dependence.
→ Attempt to describe "soft" and "semi-hard" MPI scatterings.

[1] based on Monash2013 tune: MB+AU
[2] based on 4C tune
[3] based on Z2*-lep tune

ISR Tunes Consistency



Dibosons



Mar. 2015
CMS Preliminary
CMS measurements
vs. NLO (NNLO) theory
7 TeV CMS measurement (stat,stat+sys)
8 TeV CMS measurement (stat,stat+sys)
γγ, (NNLO th.)
Wγ
Zγ
Zγ
WW+WZ
WW
WW, (NNLO th.)
WZ
WZ
ZZ
ZZ
1.06 ± 0.01 ± 0.12 5.0 fb^{-1}
1.16 ± 0.03 ± 0.13 5.0 fb^{-1}
0.98 ± 0.01 ± 0.05 5.0 fb^{-1}
0.98 ± 0.01 ± 0.05 19.5 fb^{-1}
1.05 ± 0.13 ± 0.15 4.9 fb^{-1}
1.11 ± 0.04 ± 0.10 4.9 fb^{-1}
1.01 ± 0.02 ± 0.08 19.4 fb^{-1}
1.17 ± 0.07 ± 0.07 4.9 fb^{-1}
1.12 ± 0.03 ± 0.07 19.6 fb^{-1}
0.99 ± 0.14 ± 0.07 4.9 fb^{-1}
1.00 ± 0.06 ± 0.08 19.6 fb^{-1}
0.5
1
1.5
2
All results at:
http://cern.ch/go/pNj7
Production Cross Section Ratio: $\sigma_{exp} / \sigma_{theo}$

Systematics

- **PDF + α_s**: PDF4LHC prescription, ~ 1.3%(0.8%) for qqWW (ggWW)
- **Higher order corrections *[1407.4481]***
  - reweight Powheg by varying resummation scale at NLO+NNLL by half and twice the nominal value: 2.8%(6.9%) for 0-jet (1-jet)
  - renormalization by half and twice the nominal: 2.5%(6.3%) for 0-jet (1-jet)

  → Same order systematic on the final signal efficiency obtained from Stewart-Tackmann recipe [1107.2117]
- **UE+PS:**
  - three different showering tunes of the UE (CMS tune Z2*, ATLAS tune AUET2, new Tune 64 Z2*-Lep CMS) and two different PS (pythia and herwig). 3.5%

WW particle level definition (1/2)

- Fiducial and differential WW cross sections at **Particle Level** only (not at Parton Level)
- **Particle Level definition:**
  - stable particles from full ME+parton shower generators. **WW results just before Final State Radiation (FSR).**
  - without any simulation of the interaction of these particles with the detector components or any additional proton-proton interactions.
- **Definition of jets** at particle level:
  - define with anti-k_t algorithm, with R= 0.5, built from stable truth particles: electrons, muons, taus and neutrinos are removed from the collection of gen-particles.

WW particle level definition (2/2)

- **Definition of leptons** at particle level:
  - No isolation condition is imposed
  - Leptons just after W decay before FSR (BORN leptons)
  - Parent of the lepton require to be a W boson.
  - Taus considered as background: electrons and muons from tau decays are not considered as part of the signal.

- **Further cuts in the event:**
  - Defined with hard jet veto in particle levels: **No jets** with $|\eta| < 4.7$ and a given maximum jet p_T (nominal value in the analysis is jet $p_T > 30$ GeV)
  - Selected **only eμ events** with leptons=electron/muon are defined as before, and fulfilling:
    - $pT > 20$ GeV and $|\eta| < 2.5$