Double Parton Scattering and UE Tunes

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On behalf of ATLAS and CMS Collaborations

Physics at LHC and Beyond
10-17 August, 2014
Quy Nhon, Vietnam


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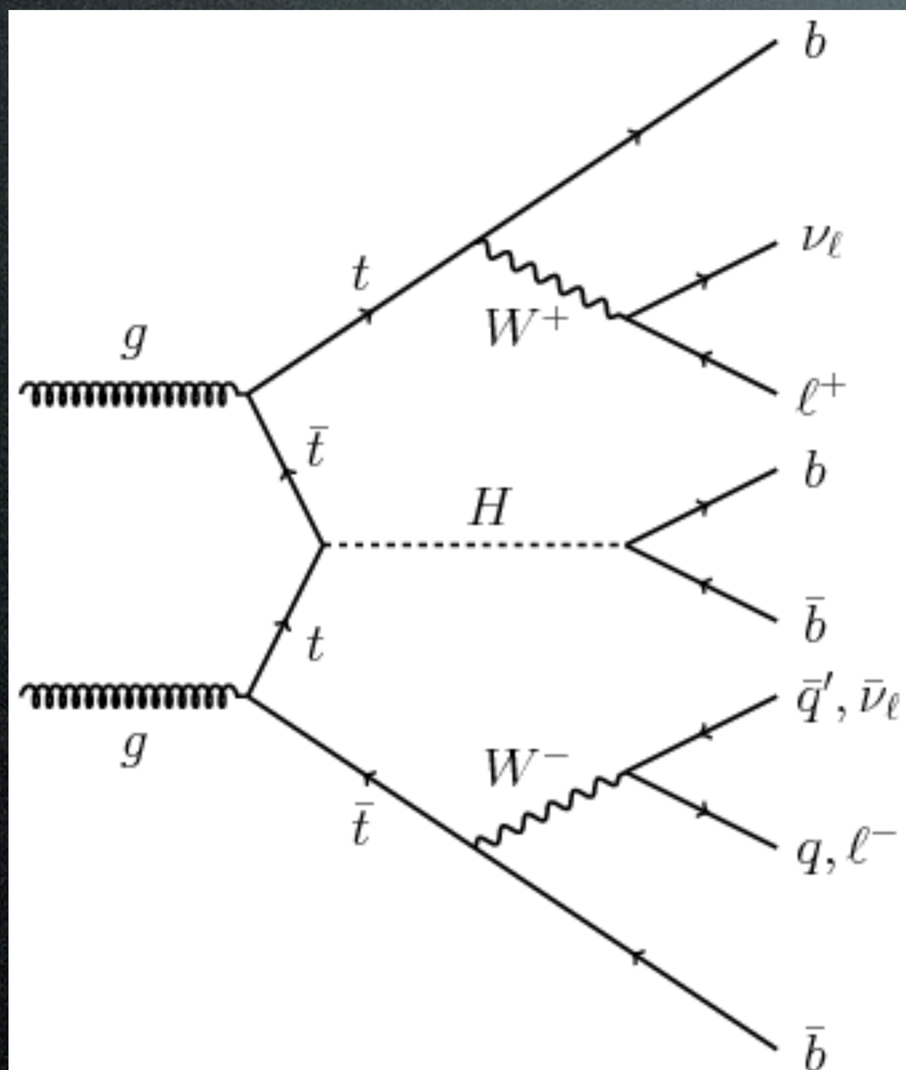
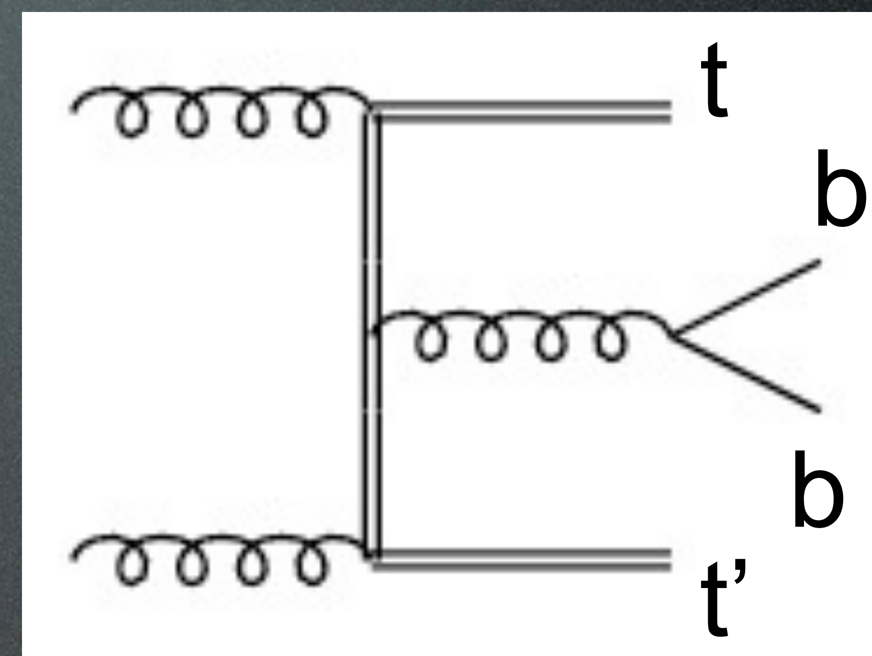
One of the hardest measurements now:



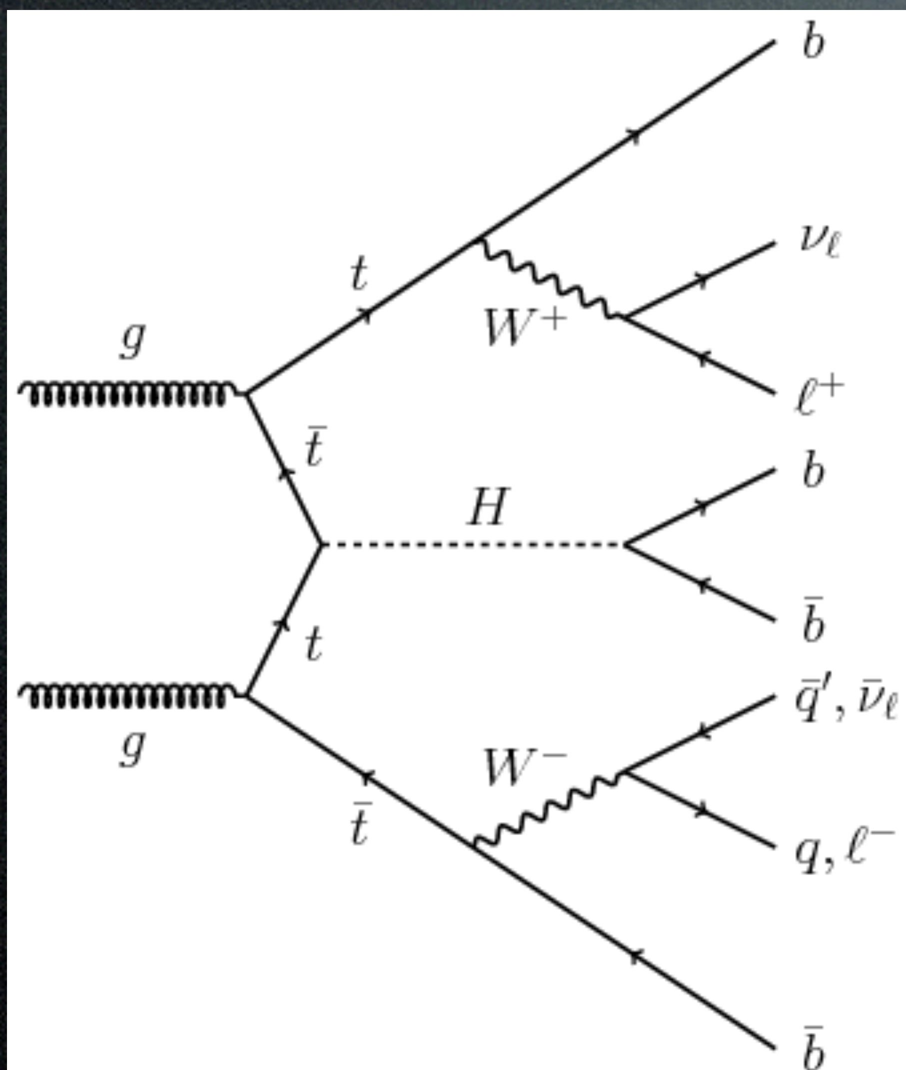
Signal: ttH(bb)

important for measuring Yukawa couplings

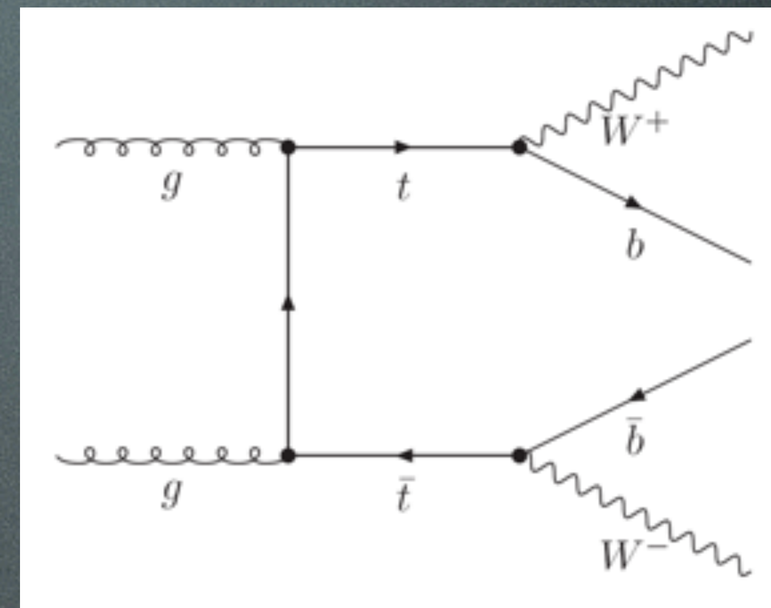


BG: ttbb

One of the hardest measurements now:



Signal: ttH(bb)



tt

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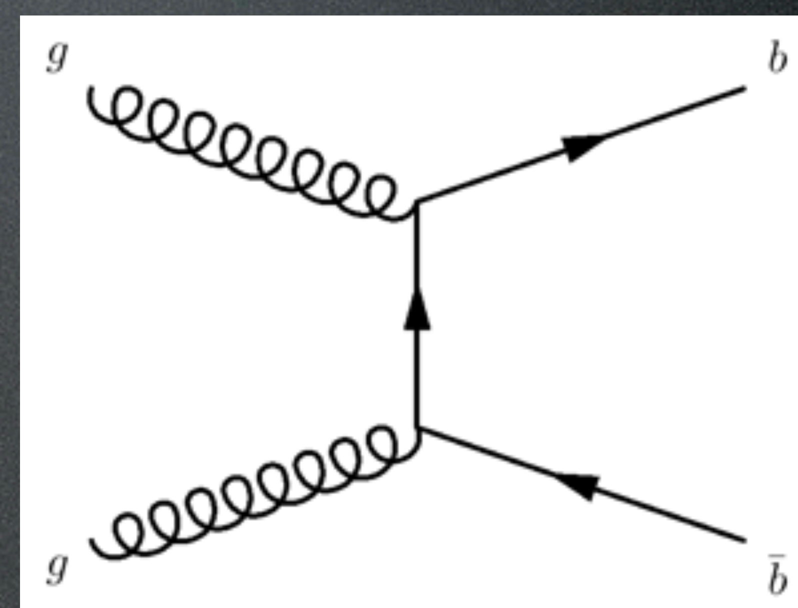
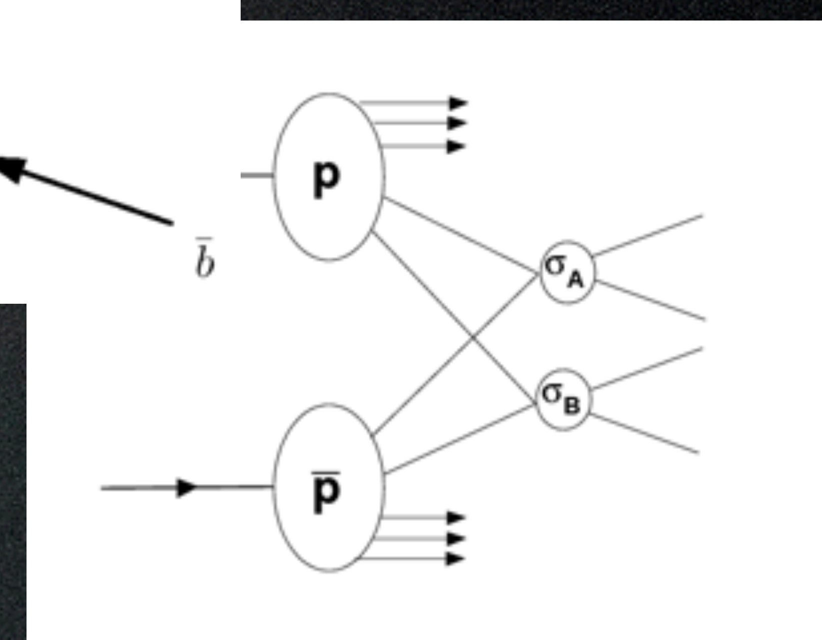
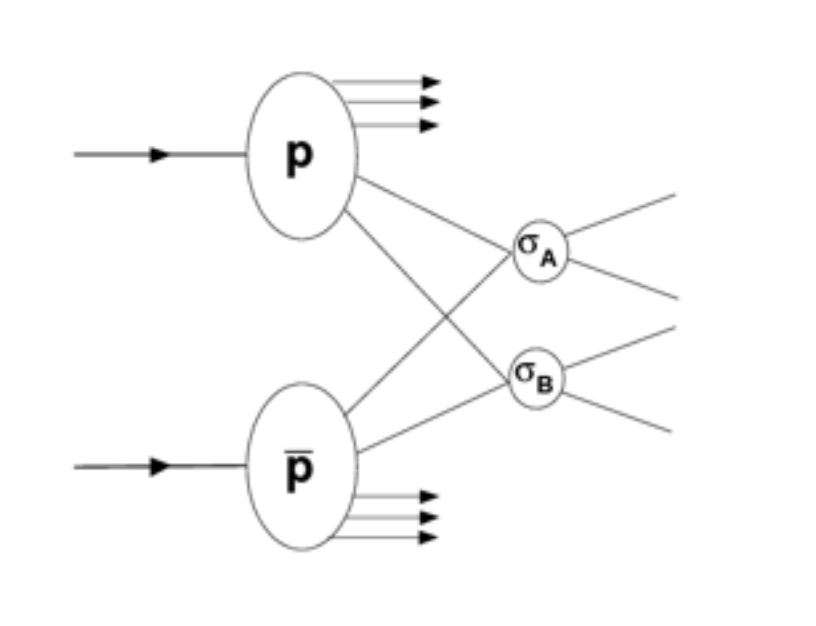


(DPI) bb



Double Parton Interaction

- Two hard parton-parton scattering in the same hard collision:



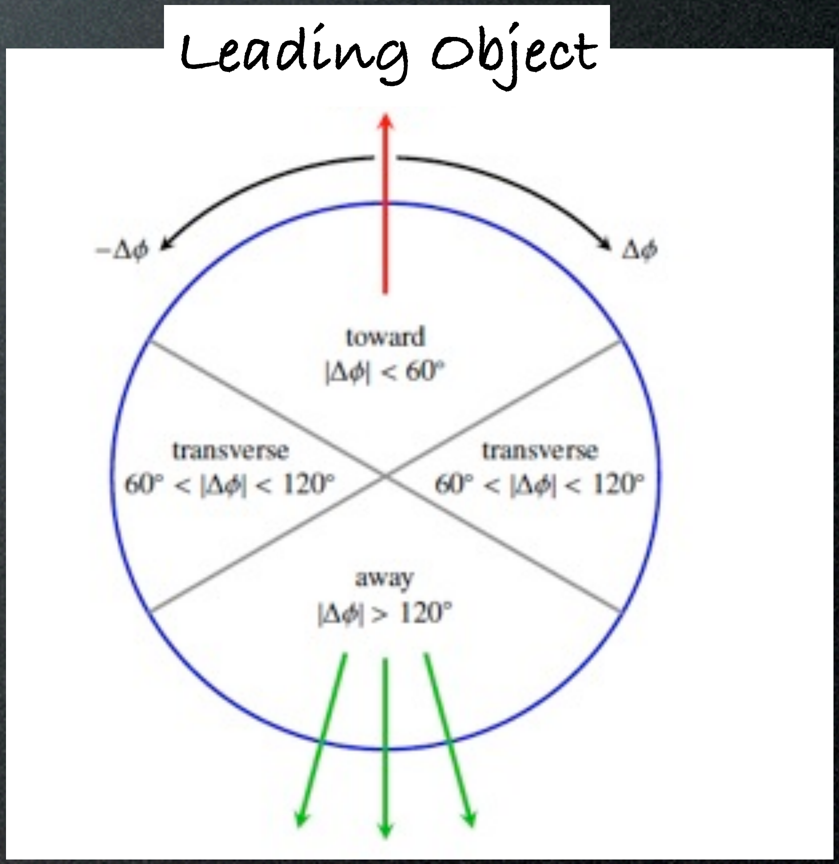
- Described in terms of the effective cross-section:

$$\sigma_{AB} = \frac{\sigma_A \sigma_B}{\sigma_{eff}}$$

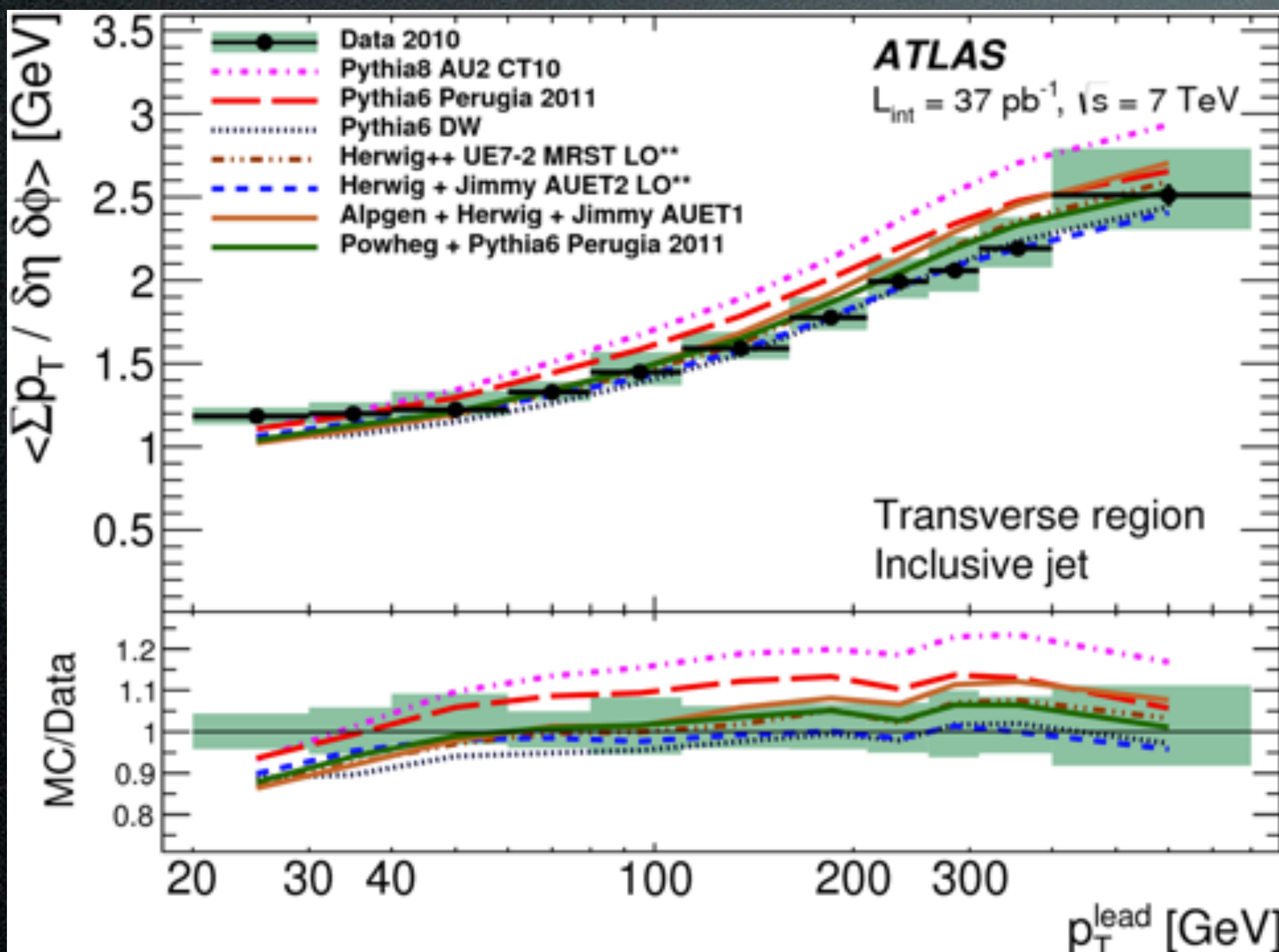
- Assumed: Factorization, and independence of σ_{eff} from hard processes.

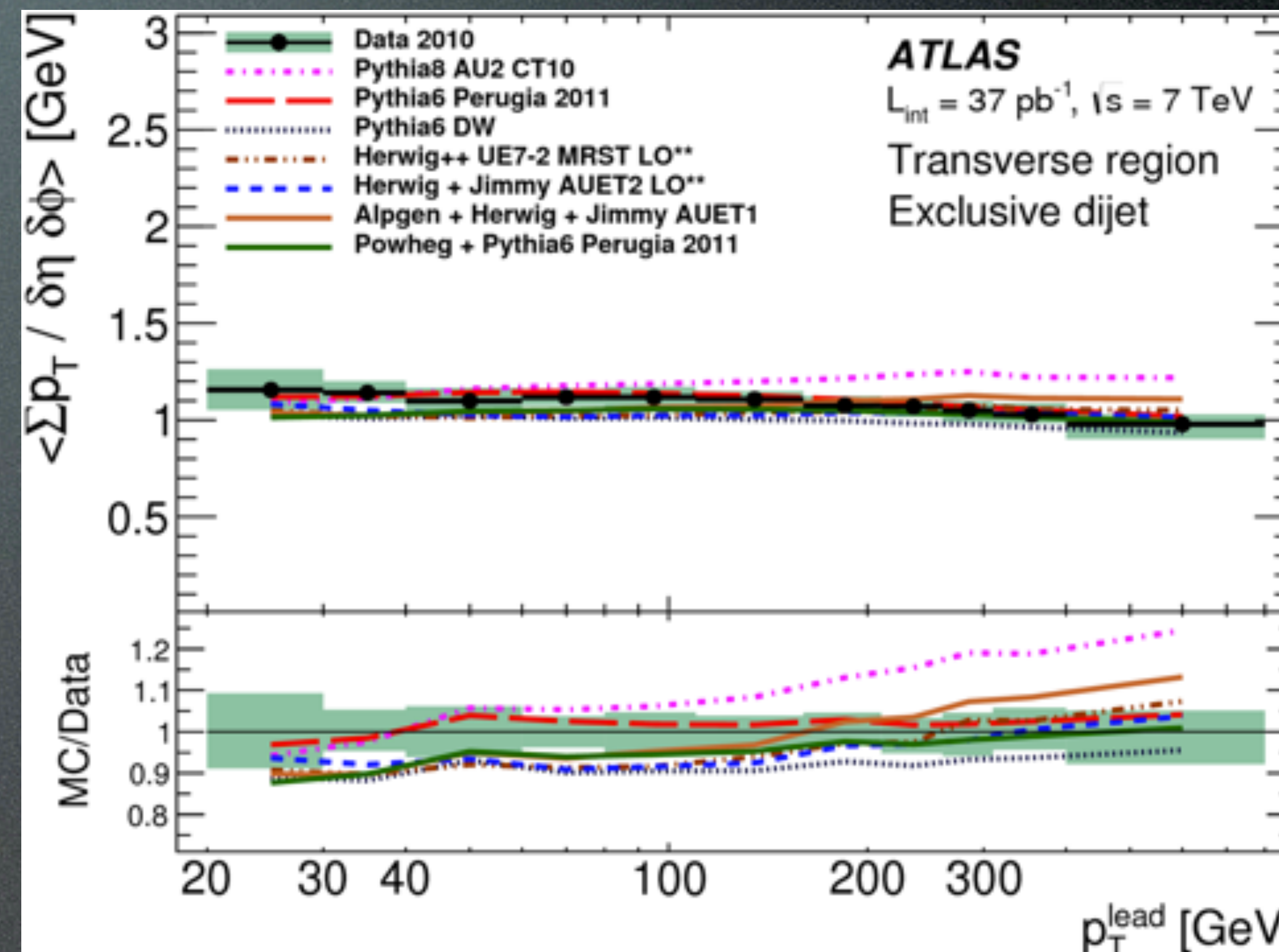
Recent UE Measurements

- Many results from ATLAS and CMS.
- In busy LHC environments, how much of "UE" is UE?
- **Sensitive to DPI contribution.**
- Not just comparing with PS models, but with ME+PS setups too.



ATLAS Jet UE



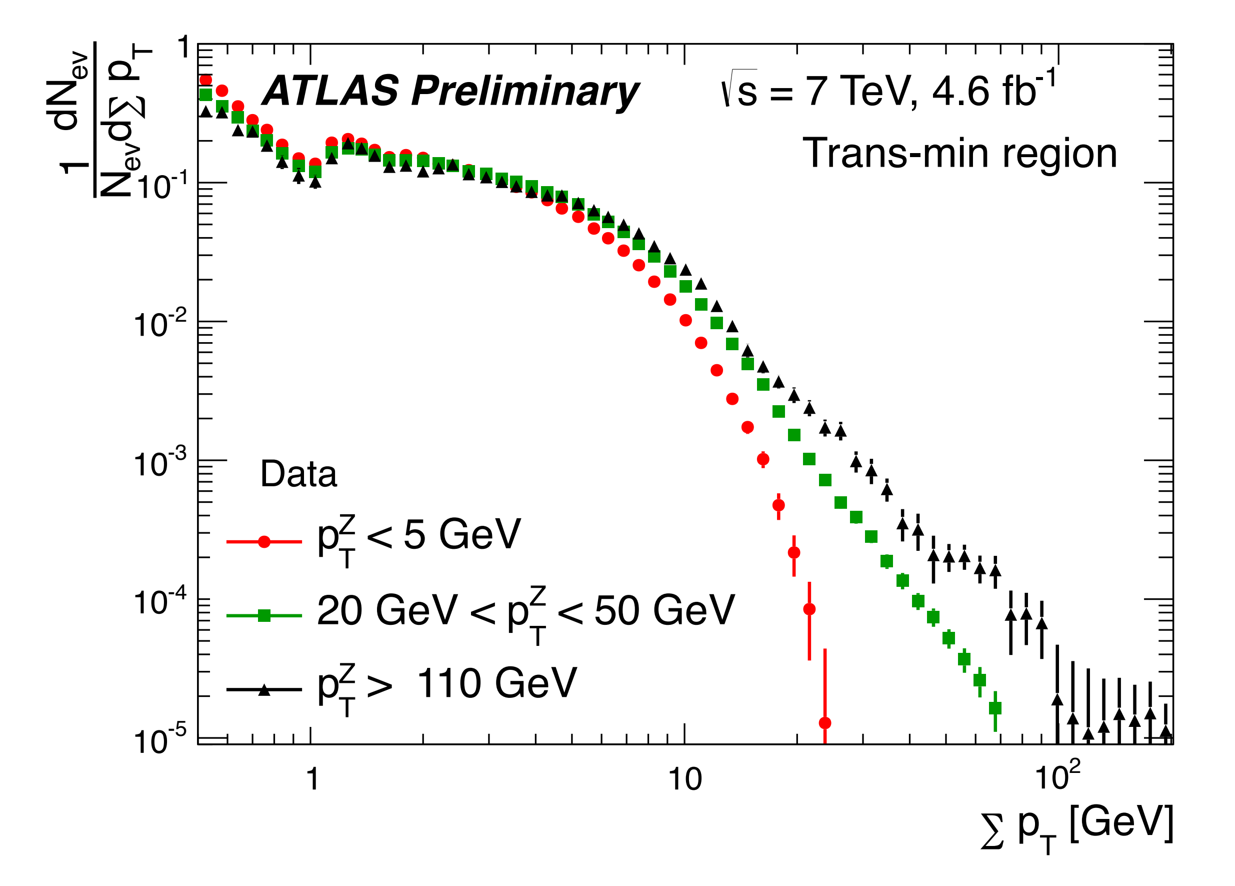


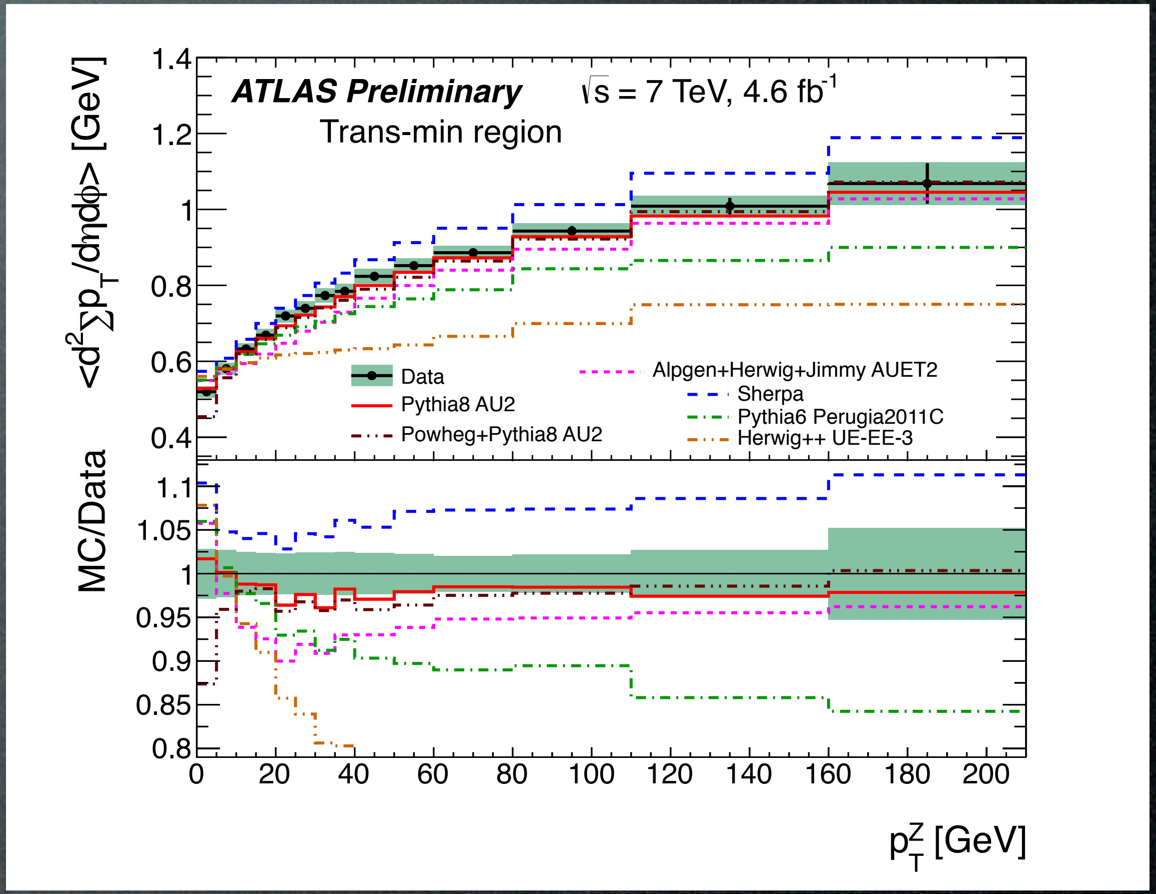
Rise in inclusive, almost flat in when requiring exactly 2 jets .
Models better describe exclusive profile.

arXiv:1406.0392 [hep-ex]

ATLAS Z UE

Also CMS result at Eur.Phys.J. C72 (2012) 2080

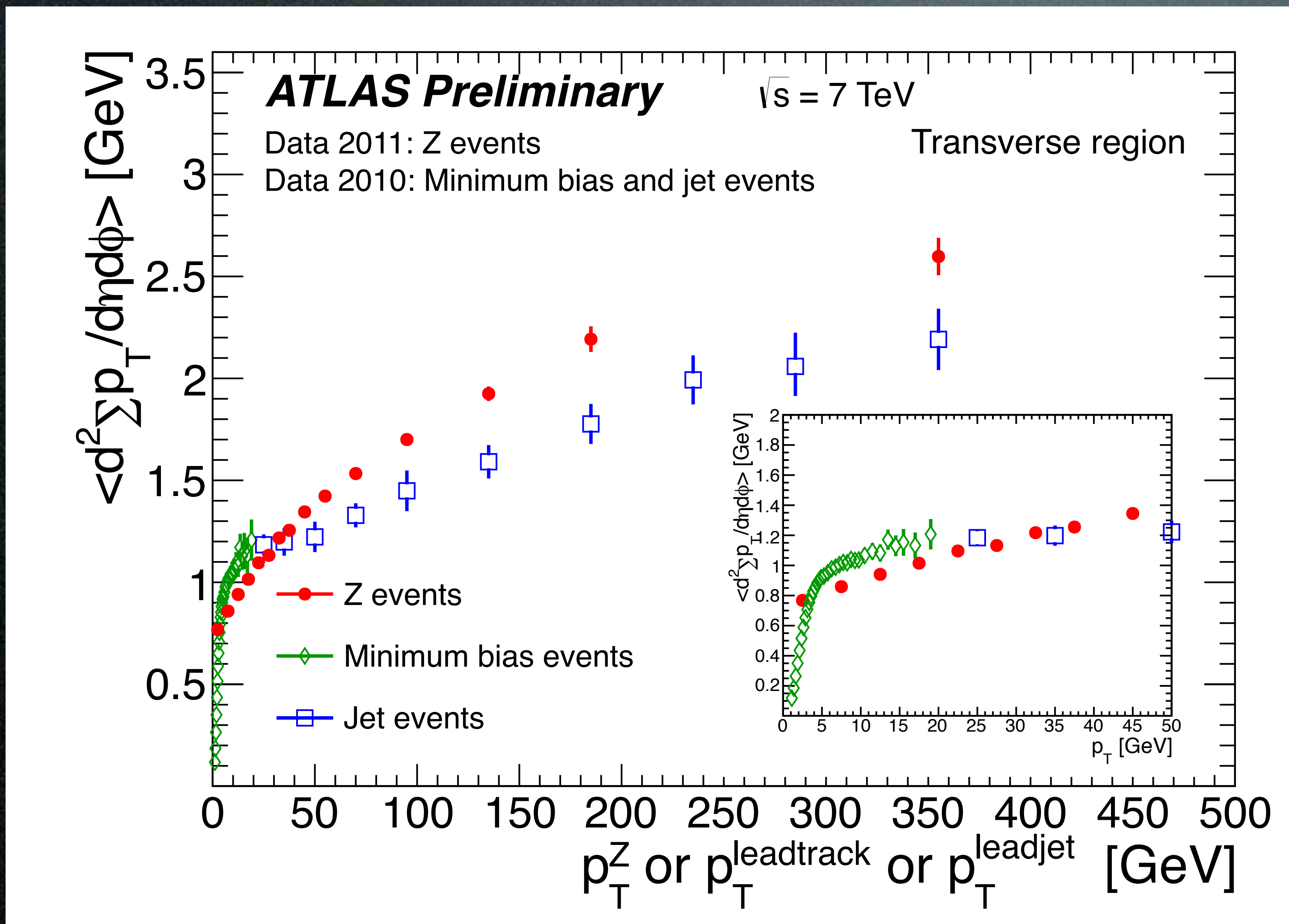


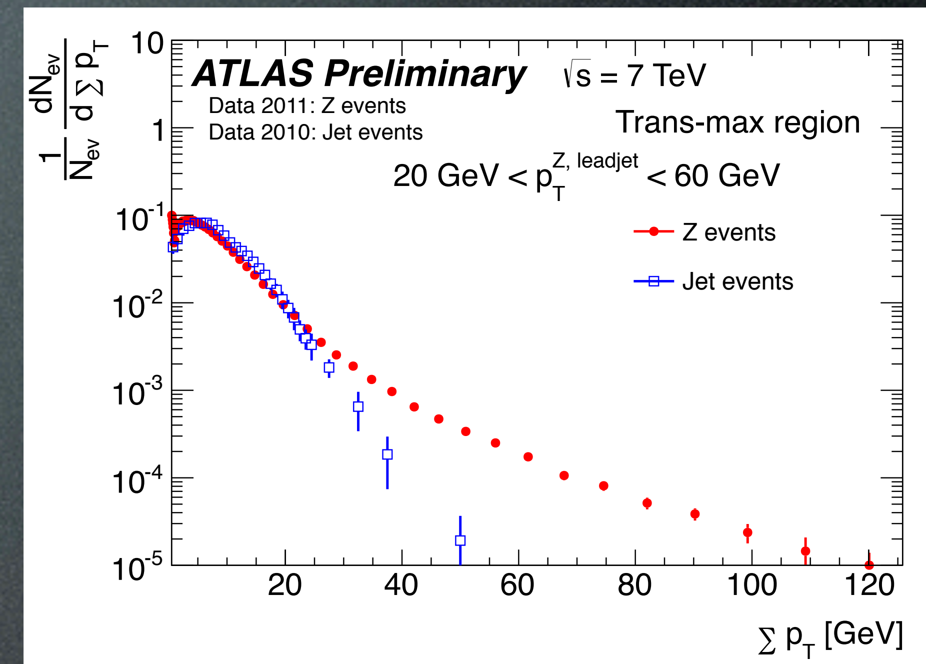


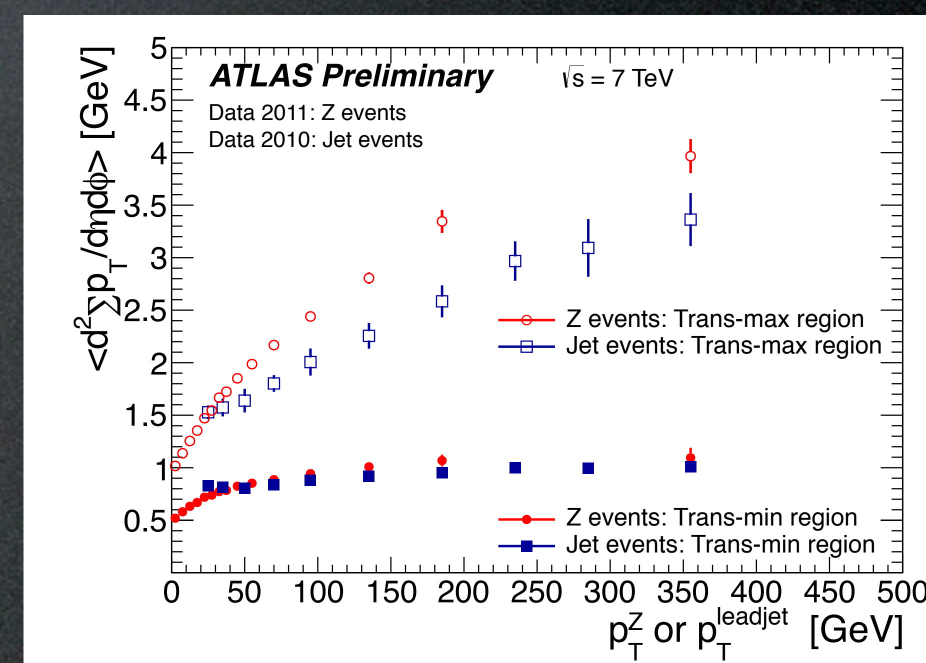
Transmin independent of Z p_T till about 10 GeV, profile best described by Pythia8 and Powheg+Pythia8

However full transverse (or trans-max) regions are described better by NLO or multileg generators than pure LO ones.

Z/Jet UE Comparison

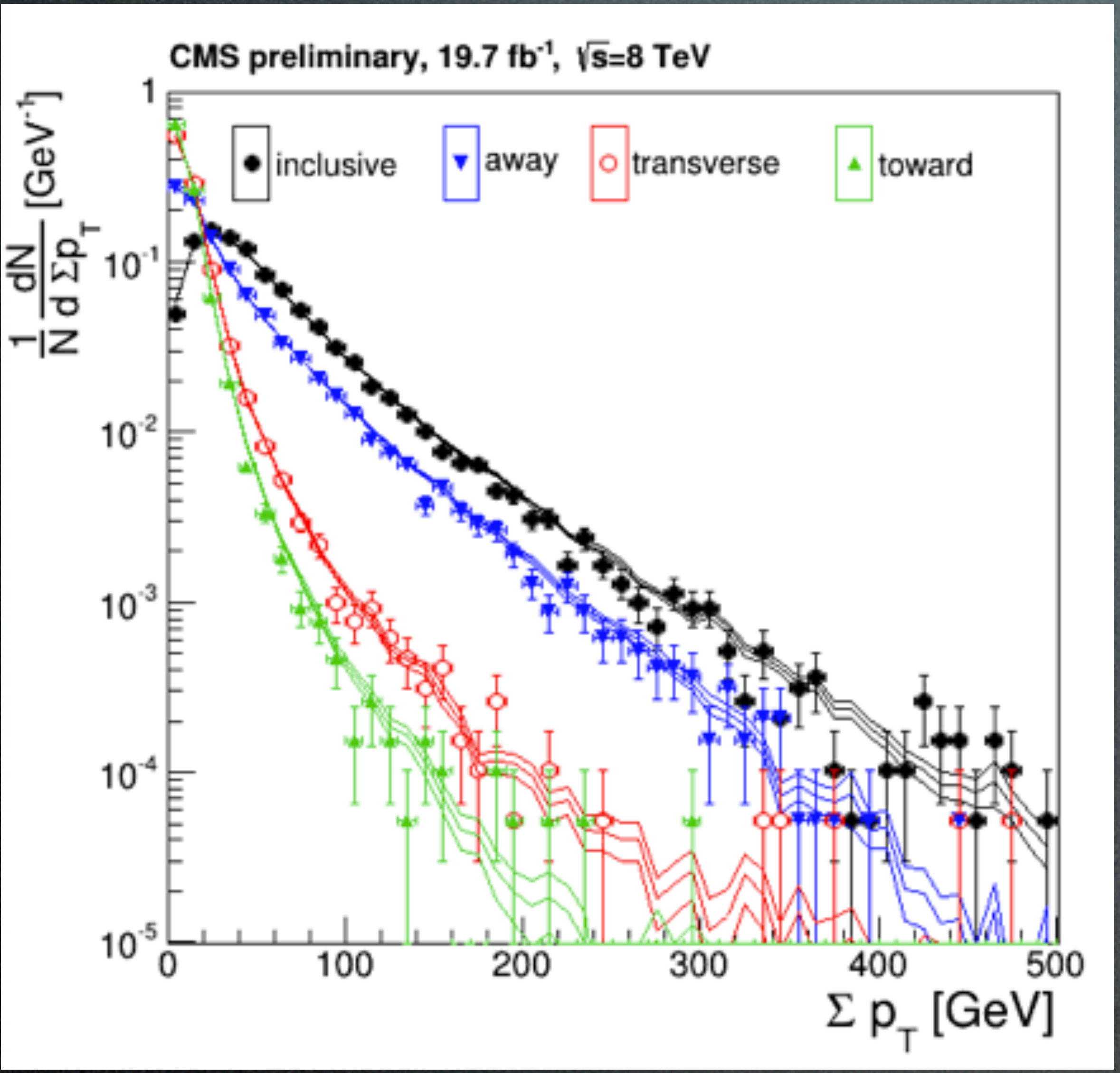


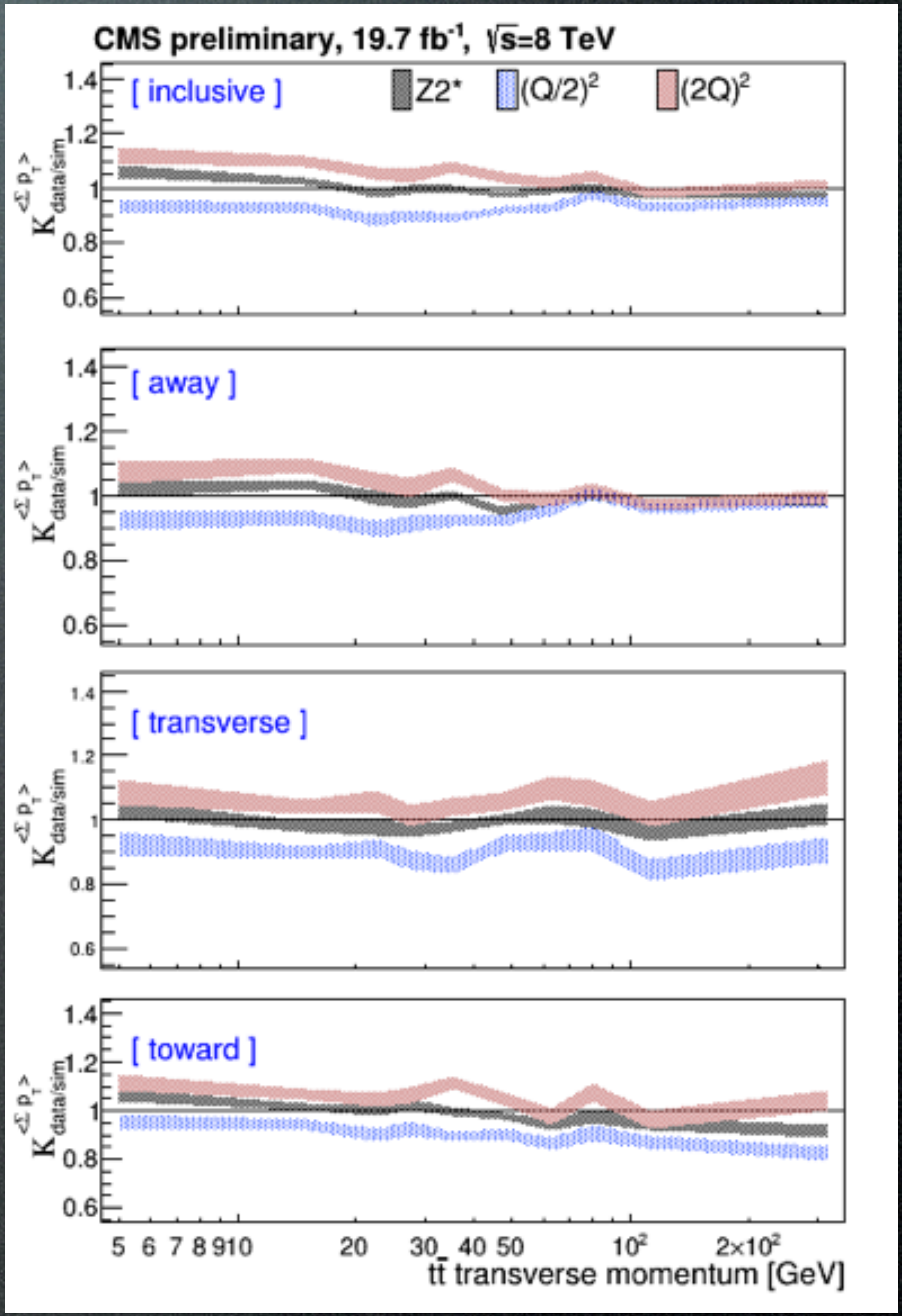




Discrepancy due to selection bias,
trans-min identical.

CMS ttbar UE



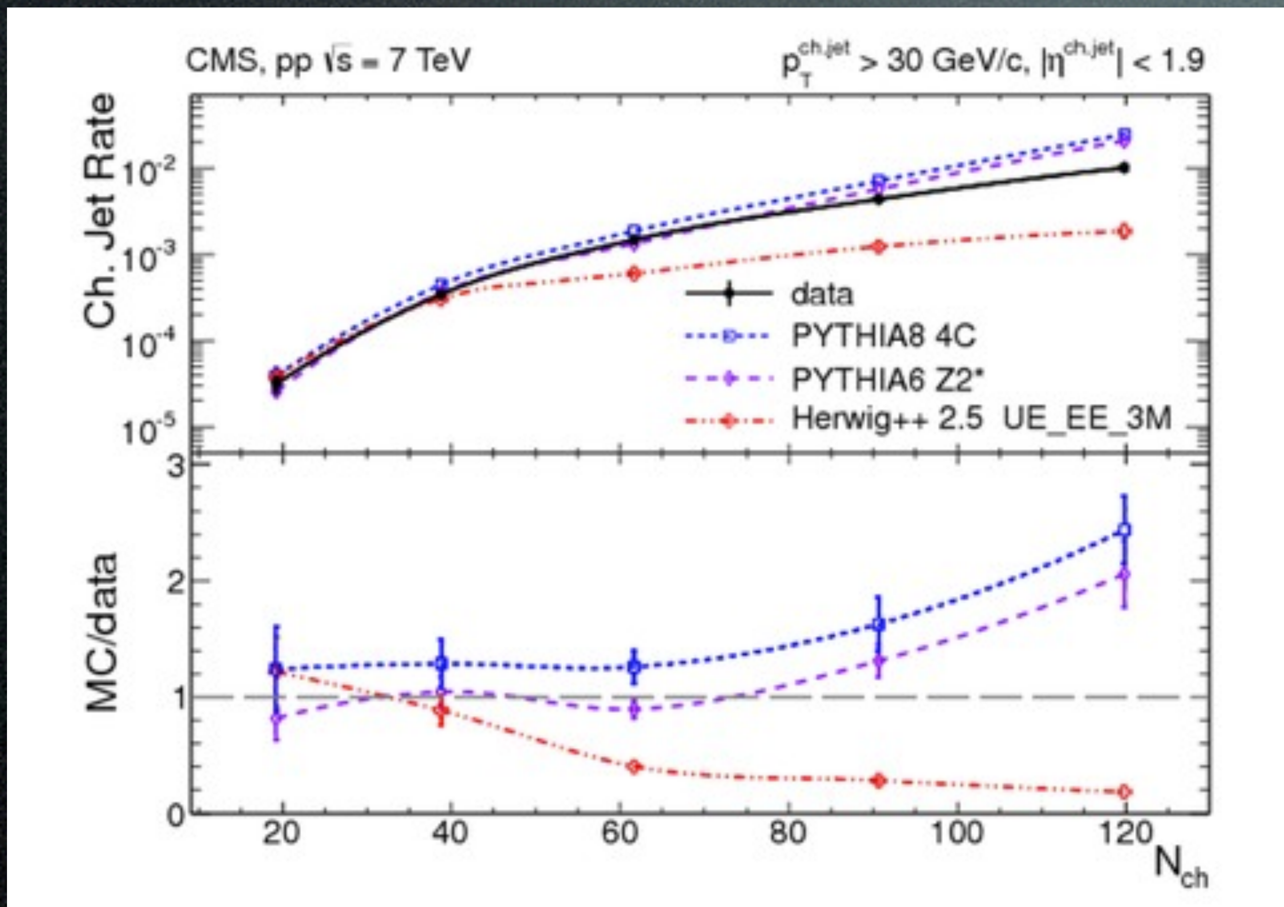


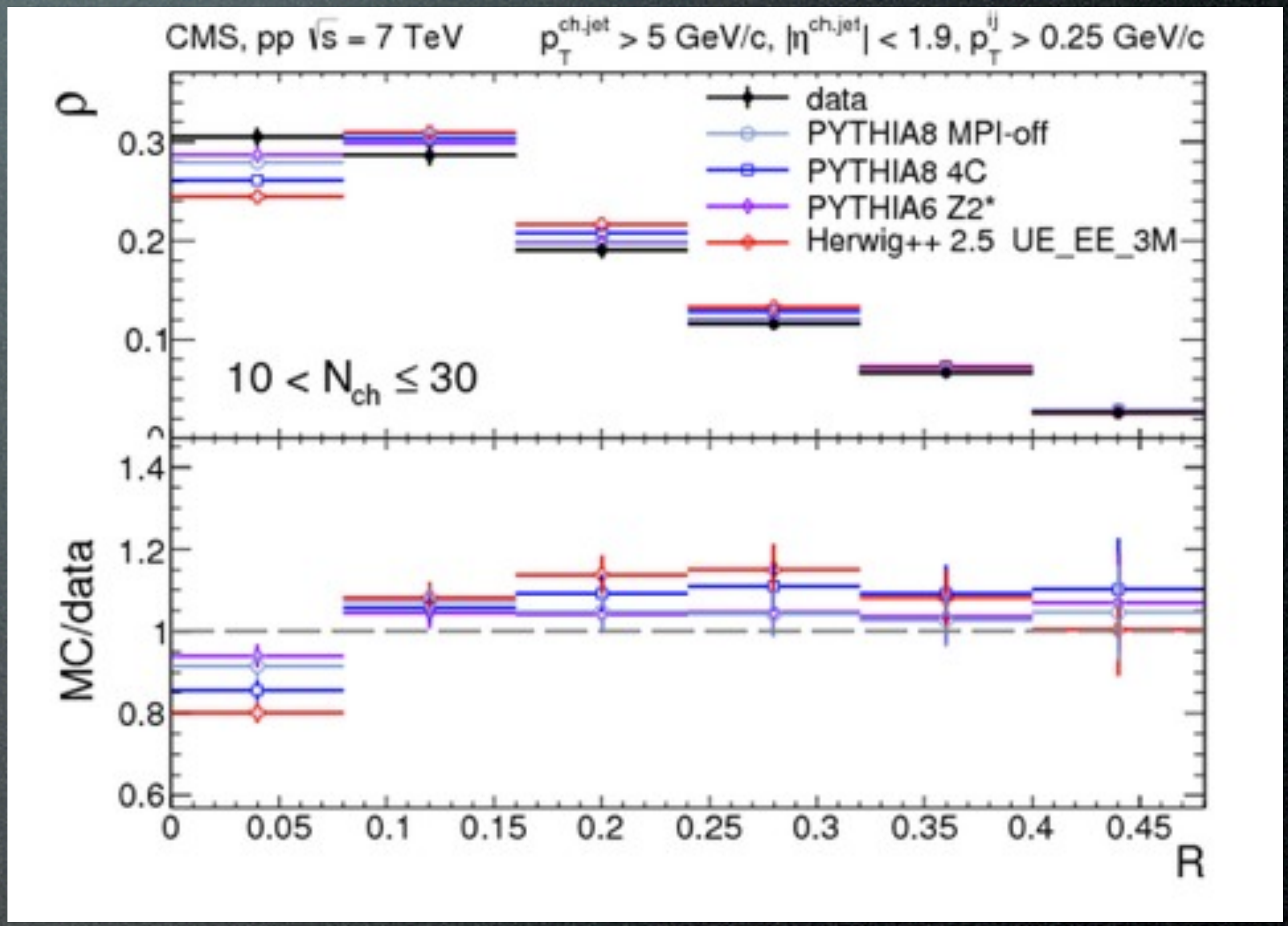
Good agreement with MADGRAPH+PYTHIA 6 Z2*.

Scale variations looked at.

CMS-PAS-TOP-13-007

CMS UE Against Multiplicity



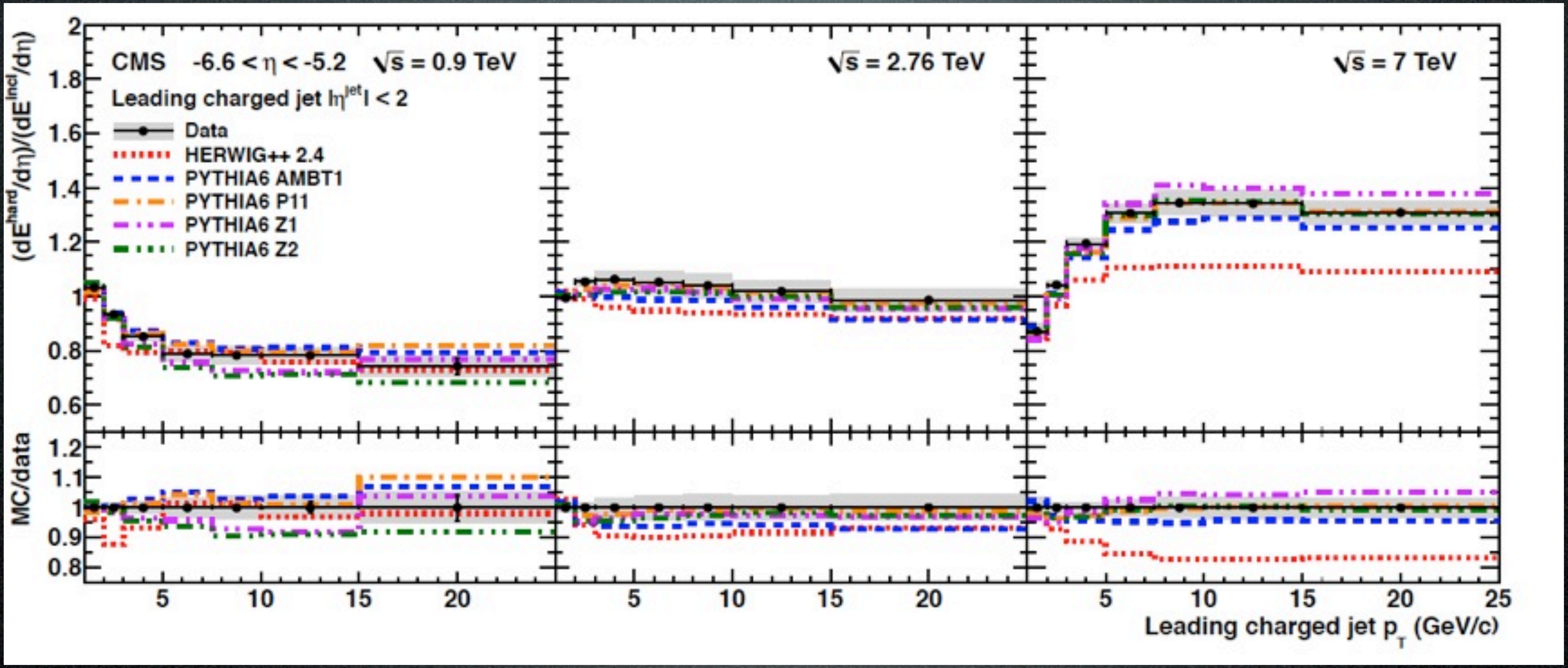


Higher (lower) jet rates with increasing multiplicity by Pythia (Herwig).

In the lowest-multiplicity events, the data show narrower jets (ρ = p_T density in rings) than predicted by both MC generators.

Eur.Phys.J. C73 (2013) 2674

CMS Forward UE

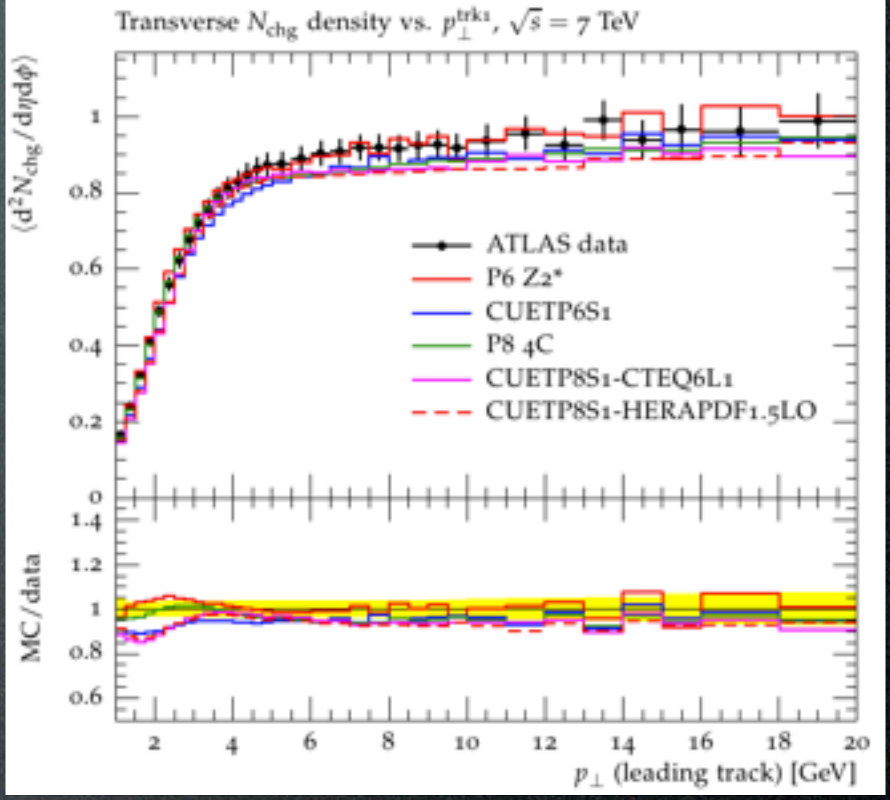


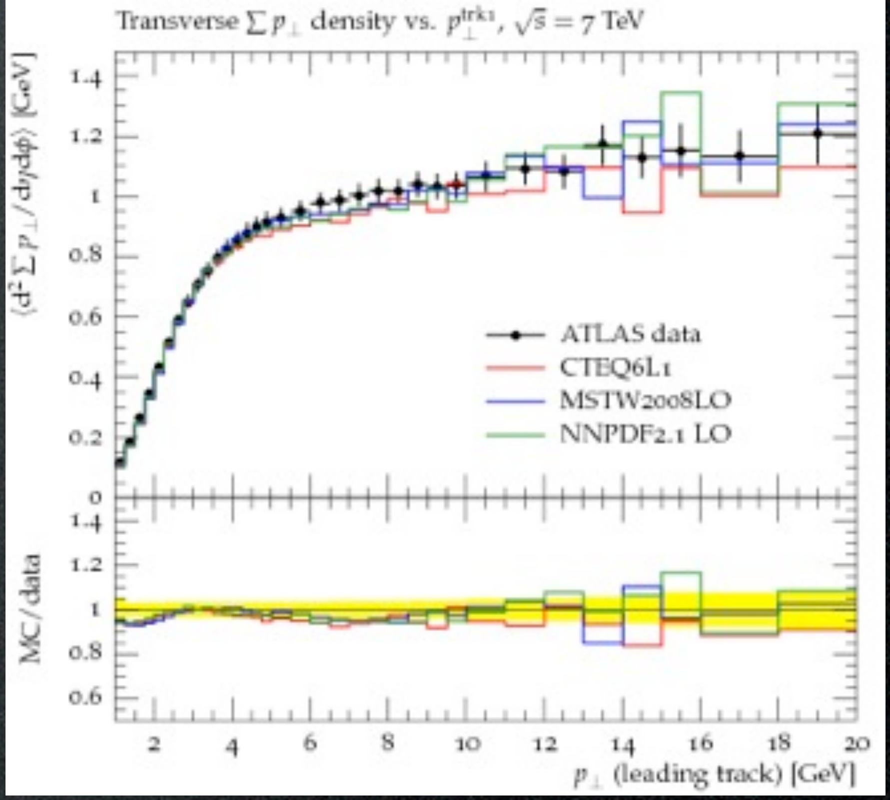
Pythia6 tunes predict Sum E_T well even in far forward region.

JHEP 04 (2013) 072

(Post-LHC) UE Tunes

- Pythia6: ATLAS AMBT*/AUET*, CMS Z1/Z2/Z2*/CUETP6S1. (Author: Perugia2011/2012)
- Pythia8: ATLAS A2/AU2, CMS CUETP8S1. (Author: 4C/4Cx/Monash)
- Tunes depend on PDF used.
- Tuning of shower and matched setups are equally critical and in progress.

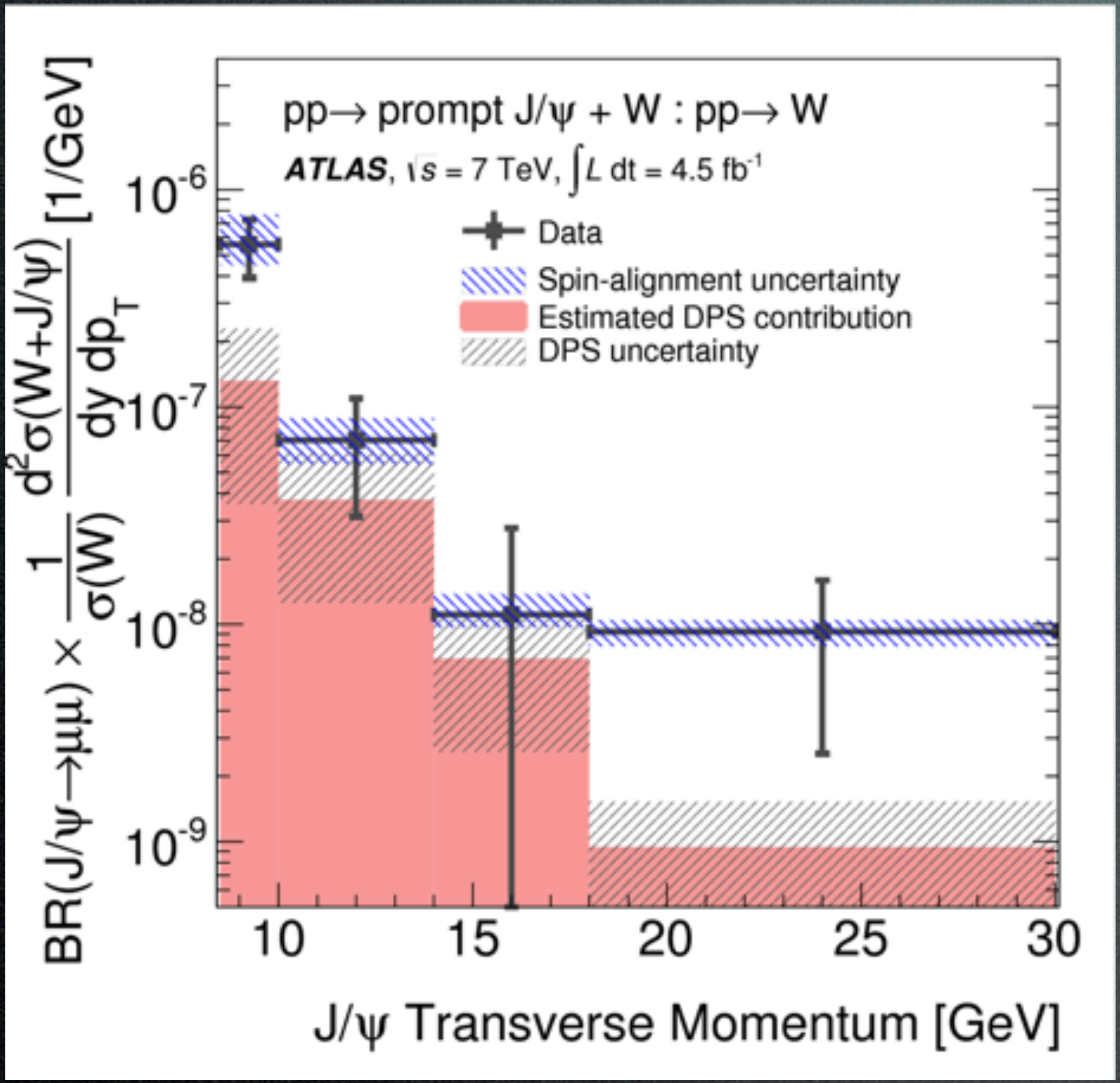




Models are actually doing quite well!

CMS-PAS-GEN-14-001

DPI Measurements at LHC



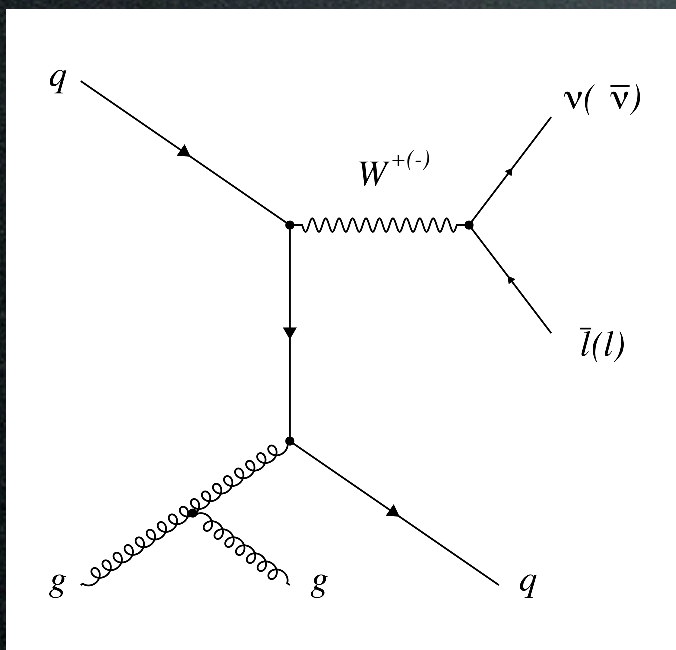
W + J/psi production rate as a ratio to inclusive W production gives DPI contribution.

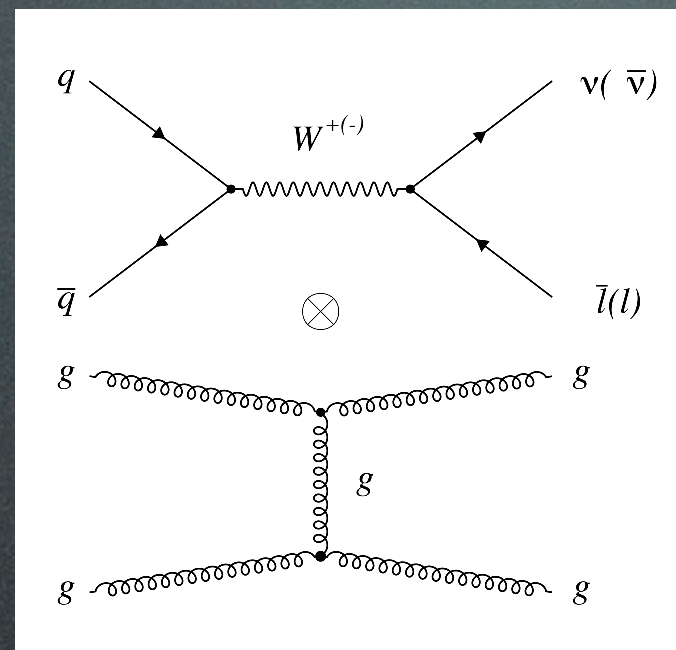
Also measurements in progress with Z+J/psi and di-J/psi final states in ATLAS.

JHEP 1404 (2014) 172

DPI Measurements at LHC

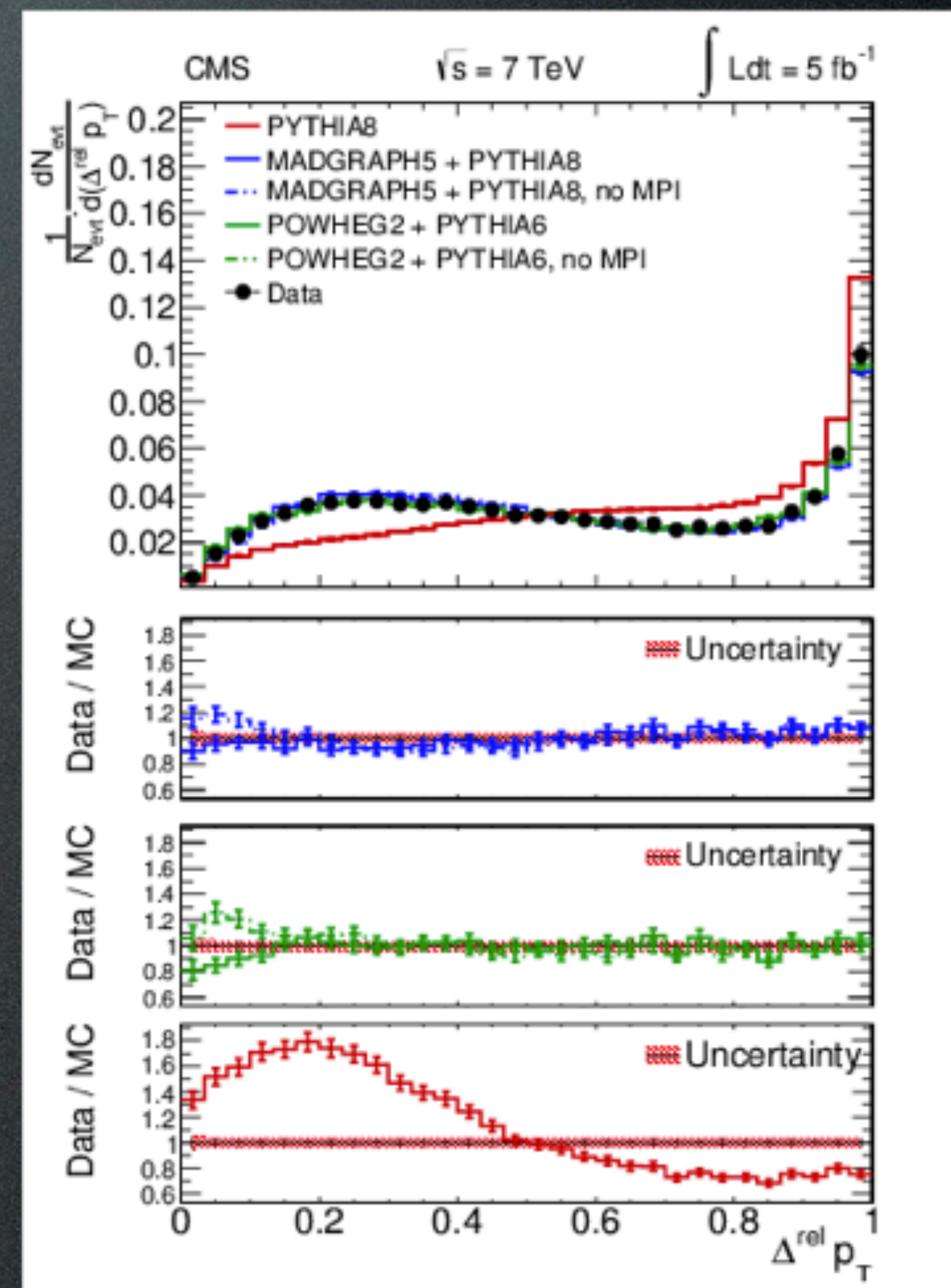
W+dijet Events





$$\Delta S = \arccos\left(\frac{\vec{p}_T(\text{object\#1})\cdot\vec{p}_T(\text{object\#2})}{|\vec{p}_T(\text{object\#1})|\times|\vec{p}_T(\text{object\#2})|}\right)$$

$$\Delta^{\text{rel}} p_T = \frac{|\vec{p}_T^{\,\text{jet\#1}} + \vec{p}_T^{\,\text{jet\#2}}|}{|\vec{p}_T^{\,\text{jet\#1}}| + |\vec{p}_T^{\,\text{jet\#2}}|}$$

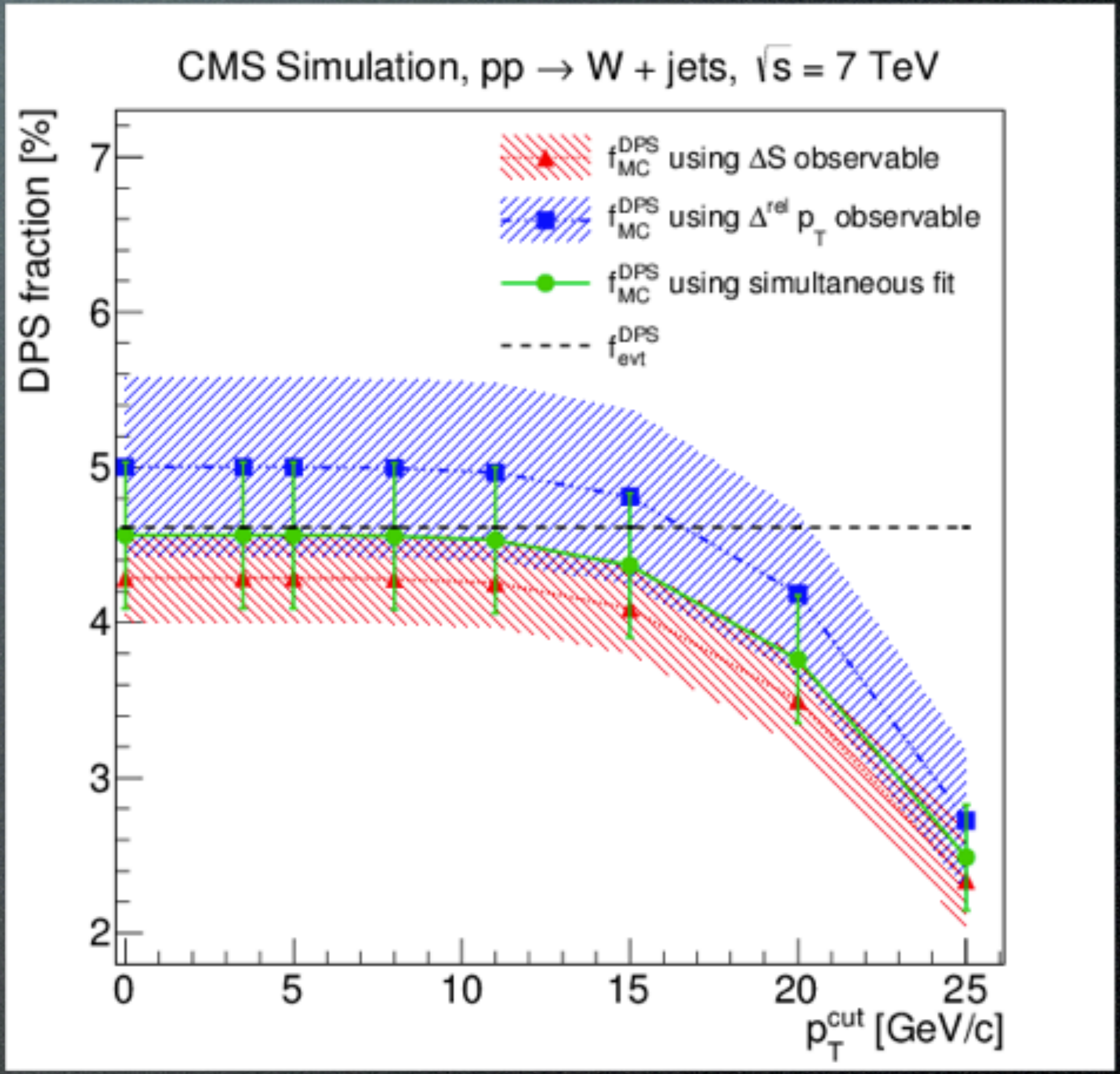


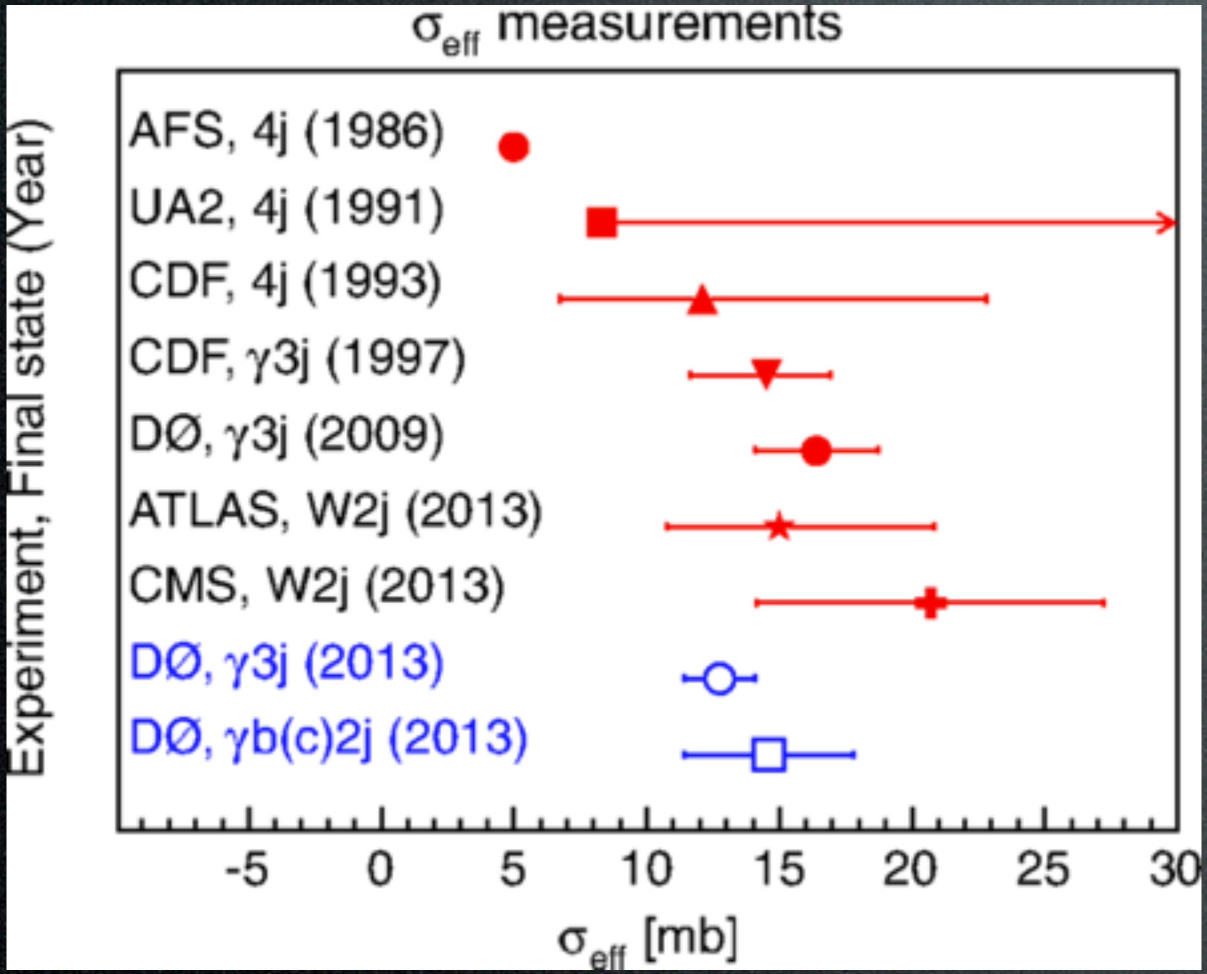
Compare corrected data distributions to MPI on/off predictions

ATLAS:
New J. Phys. 15 (2013) 033038
CMS:
JHEP 03 (2014) 032

DPI Results

Extracted value of the DPS fraction from MADGRAPH5 + PYTHIA8, using different background templates obtained by varying the p_T cutoff for the second hard interaction.

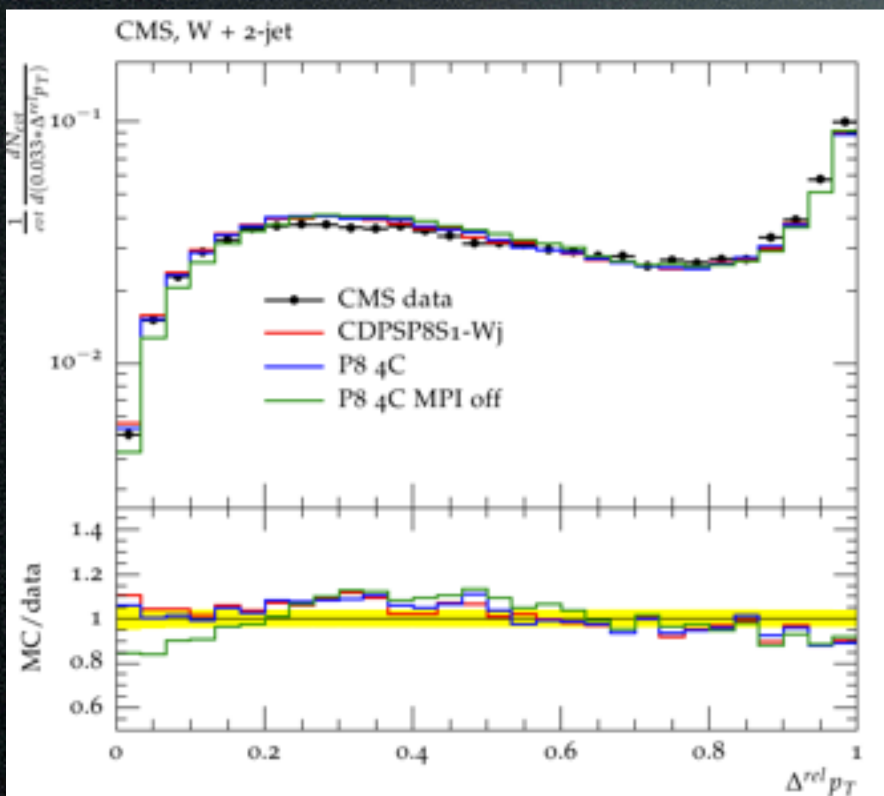


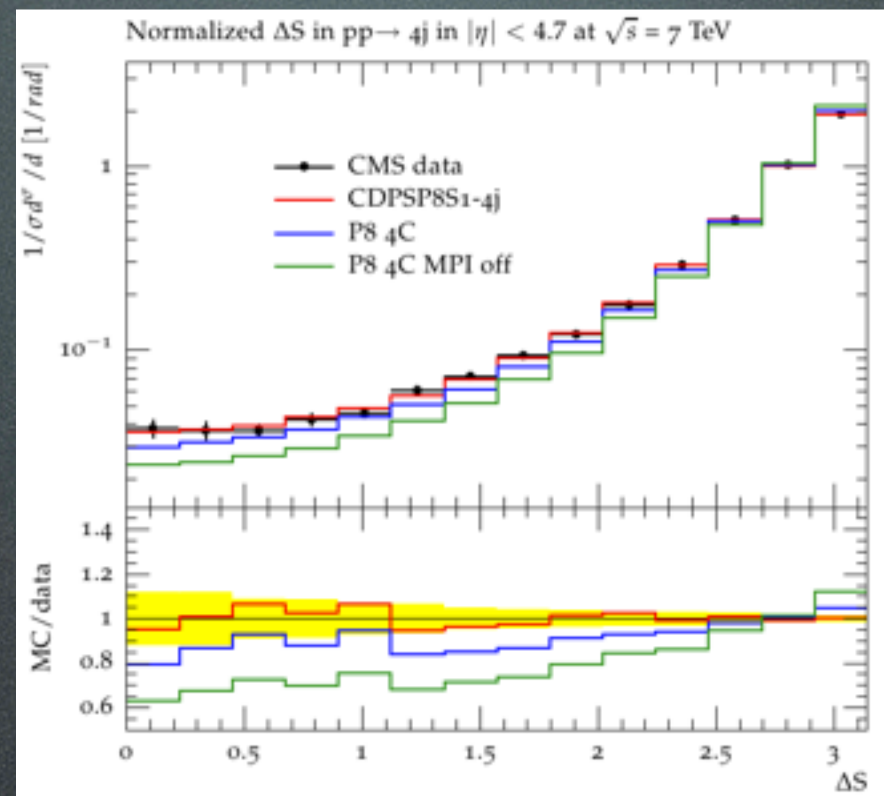


Plot from Phys. Rev. D 89, 072006

Can't prove or rule out of E_{cm} dependence (but large experimental uncertainties)

DPI Sensitive Observables





Reasonable prediction by specific CMS tunes for W+dijet and 4-jets events

Using Pythia8 mode to have to two hard scatter, σ_{eff} was calculated for the CMS (UE) tunes and tune 4C to be 28-30 mb, higher than experimentally measured values.

Tuning to these observables give central values of 19-25 mb, closer to the direct DPI measurements.

CMS-PAS-GEN-14-001

Summary

- The improved modelling of low p_T processes is fed back to full event generation, where it affects high p_T part of the event, especially for precision measurements.
- At Run 2, such measurements will be critical to test the energy extrapolation of the models, and to probe QCD in a new energy domain.
- All these data are useful for tuning the models, but obviously we are constrained by model limitations.
- Many analyses/data are available in Rivet/Hepdata, but experiments should try to have MC-independent final results, and make sure they are included in Rivet/Hepdata.

A Note on the Models

"The predictions of the model are reasonable enough physically that we expect it may be close enough to reality to be useful in designing future experiments and to serve as a reasonable approximation to compare to data. We do not think of the model as a sound physical theory . . . "

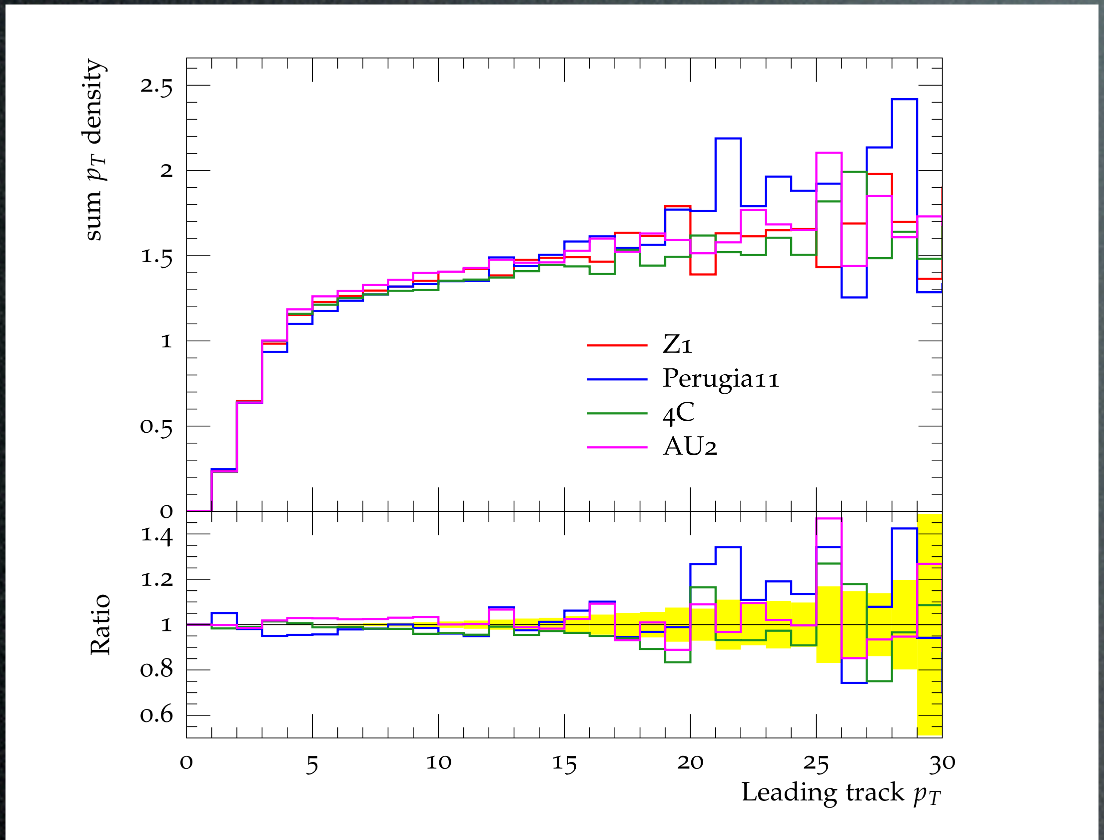
– Richard Feynman and Rick Field, 1978

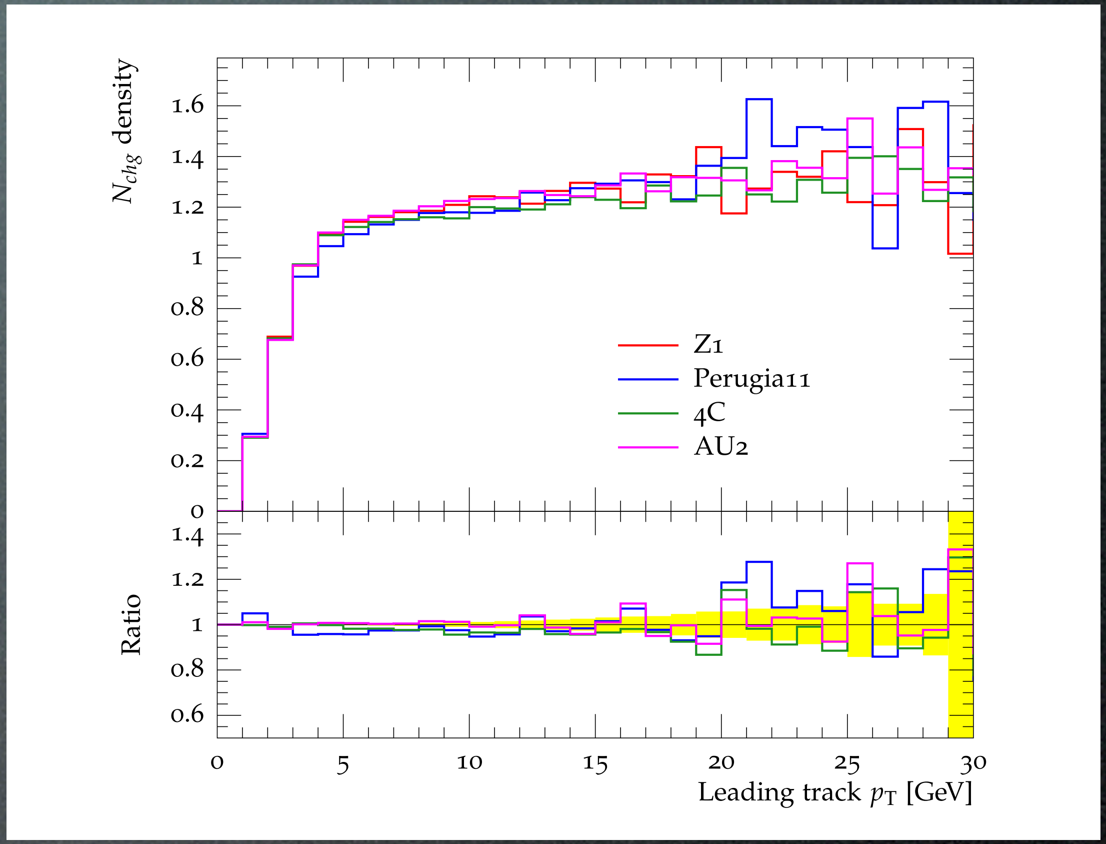
Supporting Material

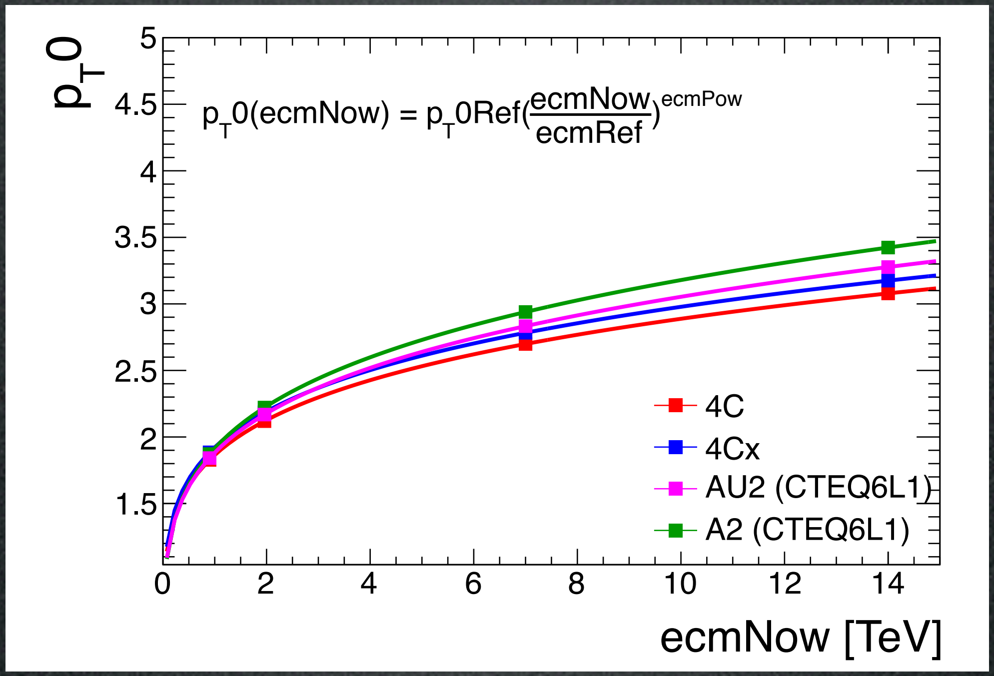
Glossary

- Minimum-bias (MB): Pretty much everything, exact definition trigger dependent.
- Underlying event (UE): background to events with an identified hard scatter (more like the actual interesting events we want to look at)
- Pileup (PU): (uncorrelated) separate collisions within the same/different bunch crossing we can’t differentiate because of our finite detector resolution (more like “isotropic” min-bias events).

14 TeV UE Predictions







Tuning Procedure

- Tuning-by-eye: the classical approach. Stare at a few distributions, think hard, change some parameters, hope those are better, nothing else is broken. Very intuition/experience dependent.
- Automated tuning tool/Professor: pioneered by ATLAS. Essentially generate lot of samples covering the parameter space. Interpolate the generator response, get the best fit by minimization. (and burn a lot of CPU)

PDF Dependence of Tunes

- Changing PDFs change gluon density, so re-tuning is needed.
- ATLAS systematically explored the effect of NLO and modified LO PDFs on the tunes.
- Many matrix element generators use NLO/mLO PDFs, so it is important to understand the effect on matched parton-shower generators.
- LO PDFs generally give the best description, with mLO ones the worst.
- NLO PDFs require less MPI cross-section screening and stronger color reconnection.

MC Models

- Leading order/Parton shower models: Trying to build up a complex 2->N final state by showers.
- Pieces of a Parton-Shower MC Generator: (2->2 hard scattering), ISR, FSR, MPI, Fragmentation, Hadronization.
- Examples: Pythia, Herwig family.
- Higher order/Multileg generators: Sherpa, Alpgen, MC@NLO, Madgraph, Powheg ...
- Generators used mostly for a specific process: Phojet (diffraction), HIJING (heavy ion), AcerMC (top), JHU (spin and polarization information)...

DPI/MPI

- Cross-section for 2->2 interactions is dominated by t channel gluon exchange. Diverges like $1/(p_T)^4$ as (p_T)->0. Regularize by a smooth cutoff, (p_T) ->$(p_T{}^2+p_{T0}{}^2)^2$.

- If average number of interactions $\langle n\rangle(P_T=P_{T0})=\sigma^{integrated}(p_{T0})/\sigma^{total}$, then reconciled.

- Protons are composite objects, physically corresponds to several parton pairs interacting.