


Recent results on forward physics/jets at LHC

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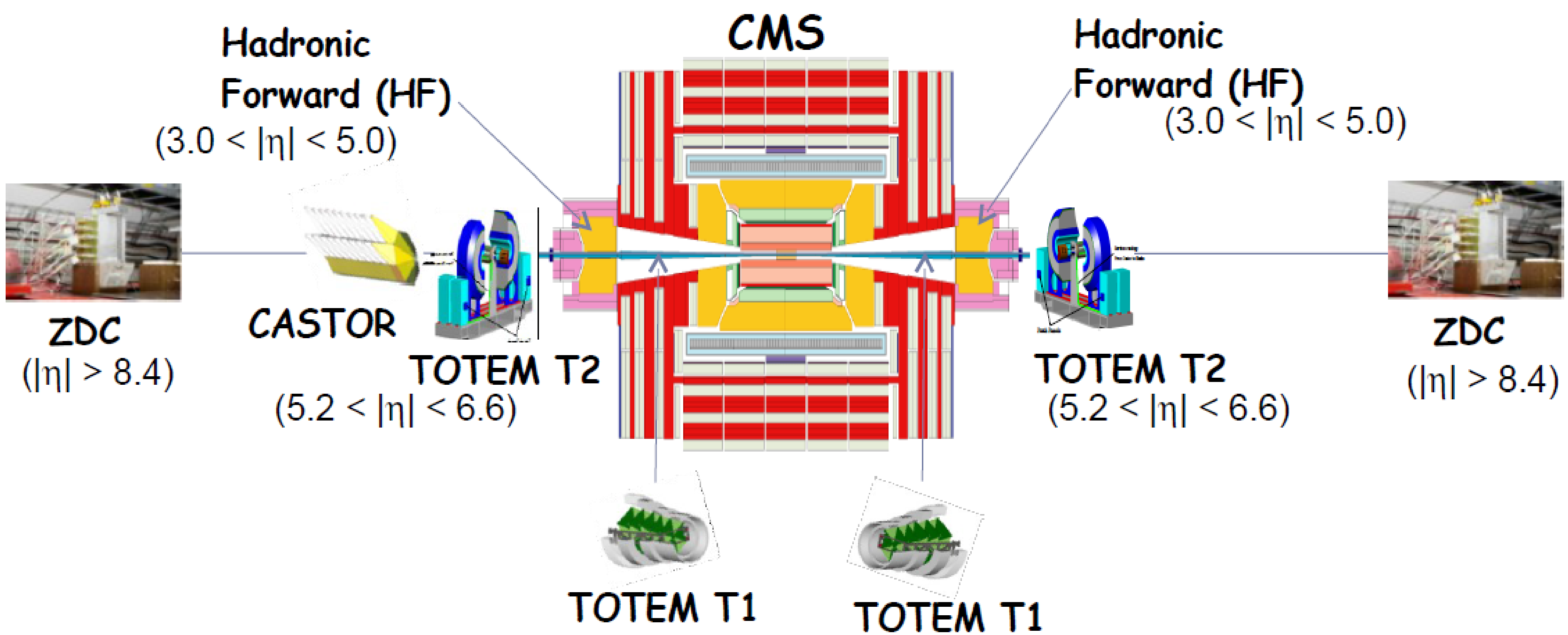
Outline

Selection of „recent results” -> only 13 TeV

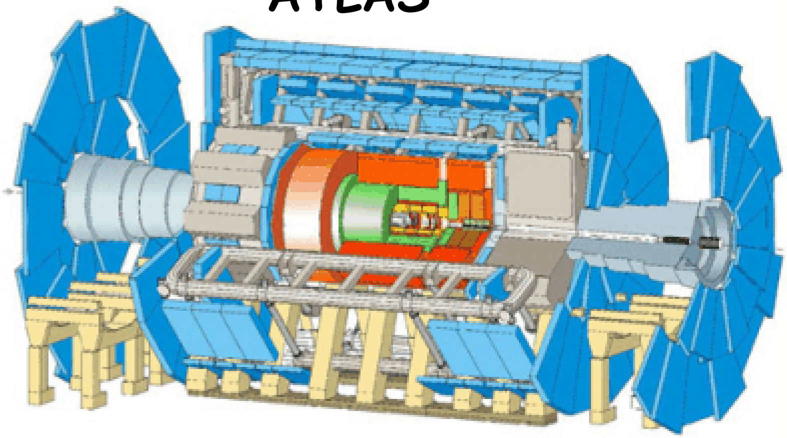
- Forward energy flow [CMS-FSQ-15-006]
- Very forward energy flow [CMS-FSQ-16-002]
- Inclusive jets [Eur. Phys. J. C (2016) 76: 451], [ATLAS-CONF-2016-092]
- Very forward jets [CMS-FSQ-16-003]
- Pseudorapidity spectra of charged particles [CMS-FSQ-15-008], [Phys. Lett. B758 67-88 (2016)], [arXiv:1606.01133]
- Underlying activity with leading track/jet [CMS-FSQ-15-007], [ATL-PHYS-PUB-2015-019]

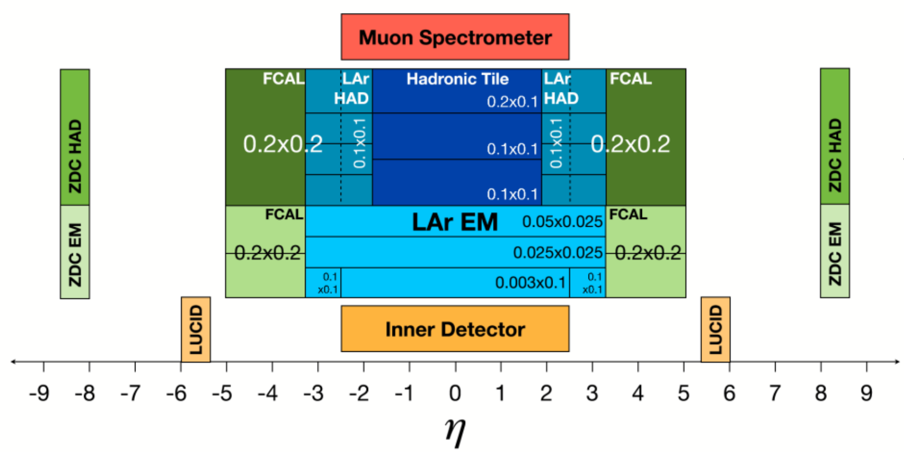
No results on diffraction and total cross section presented – see dedicated talks

Detectors at forward rapidities



ATLAS

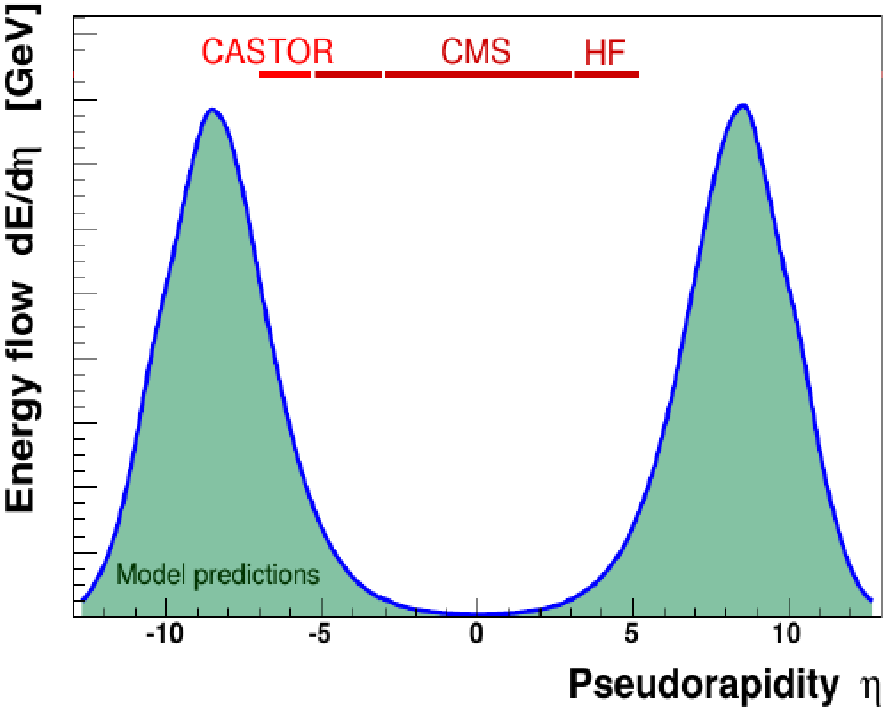




+ ALFA

Forward energy flow

- Underlying activity for hard processes and new physics
- Requirement for precise measurements in QCD and EW sectors
- Better understanding of QCD dynamics
- Input to the models for cosmic ray physics studies
- Previous measurements at 0.9 and 7 TeV for pp



Most of the energy in the forward rapidities in HF or CASTOR.

Different models used for comparison:

- PYTHIA8 Monash
- PYTHIA8 CUETP8
- EPOS
- QGSJETII

Forward energy flow

- Two samples:
  1) HF OR -> at least one HF calorimeter tower above 5 GeV, at at least one side of CMS - inclusive sample

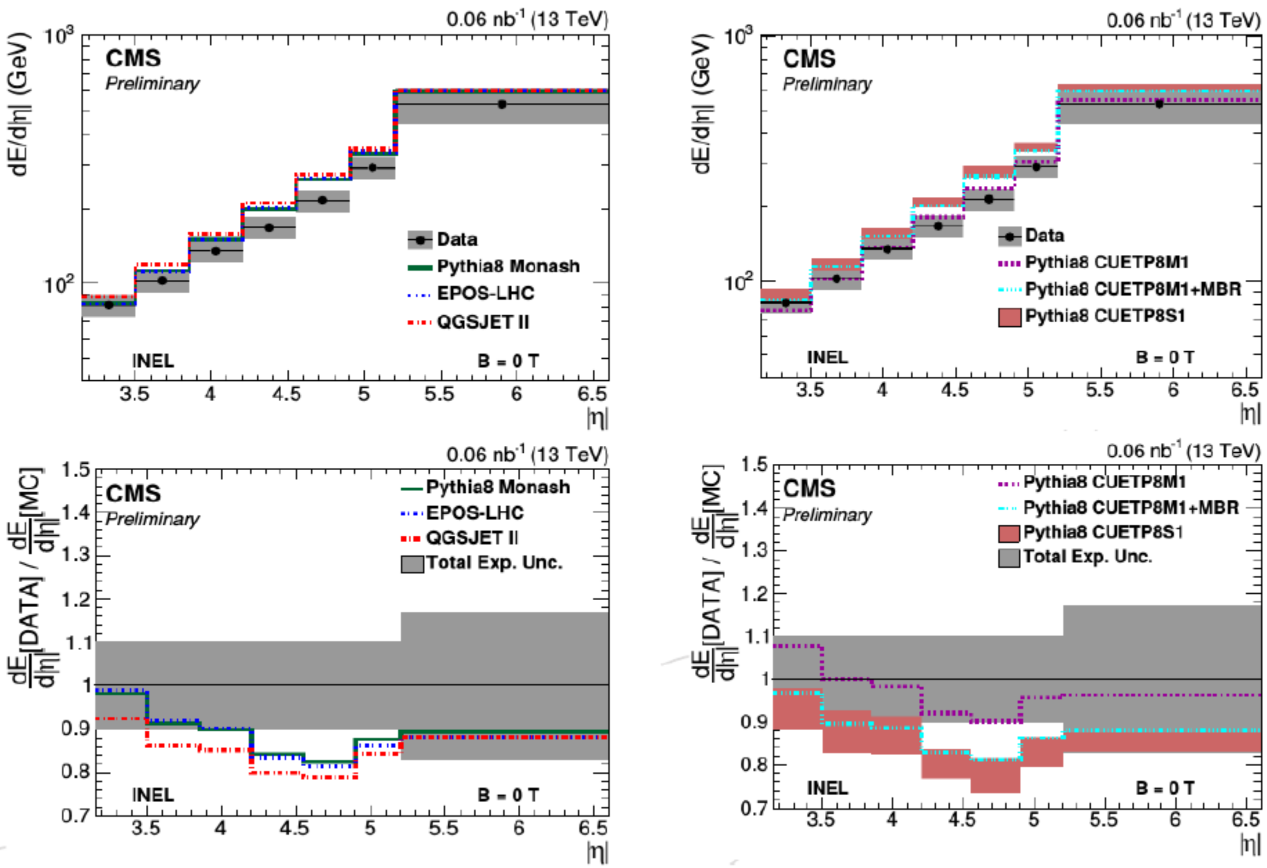
  2) HF AND -> at least one HF tower above 4 GeV at both sides of CMS - non-single diffractive enhanced sample

- Observable: sum over calorimeter towers in η bin

- Corrected for pile-up and noise
- Results corrected to particle level
- Largest uncertainty: calorimeter global energy scale 10-17%

Forward energy flow

The same HF-or data, different MC models



HF-OR

PYTHIA8 Monash and cosmic ray MC provides similar results.

PYTHIA8 CUETP8M1 (Sch.-Sj) and PYTHIA8 CUETP8M1 (MBR) exhibits large variations – different diffraction modeling.

PYTHIA8 CUETP8M1 works the best

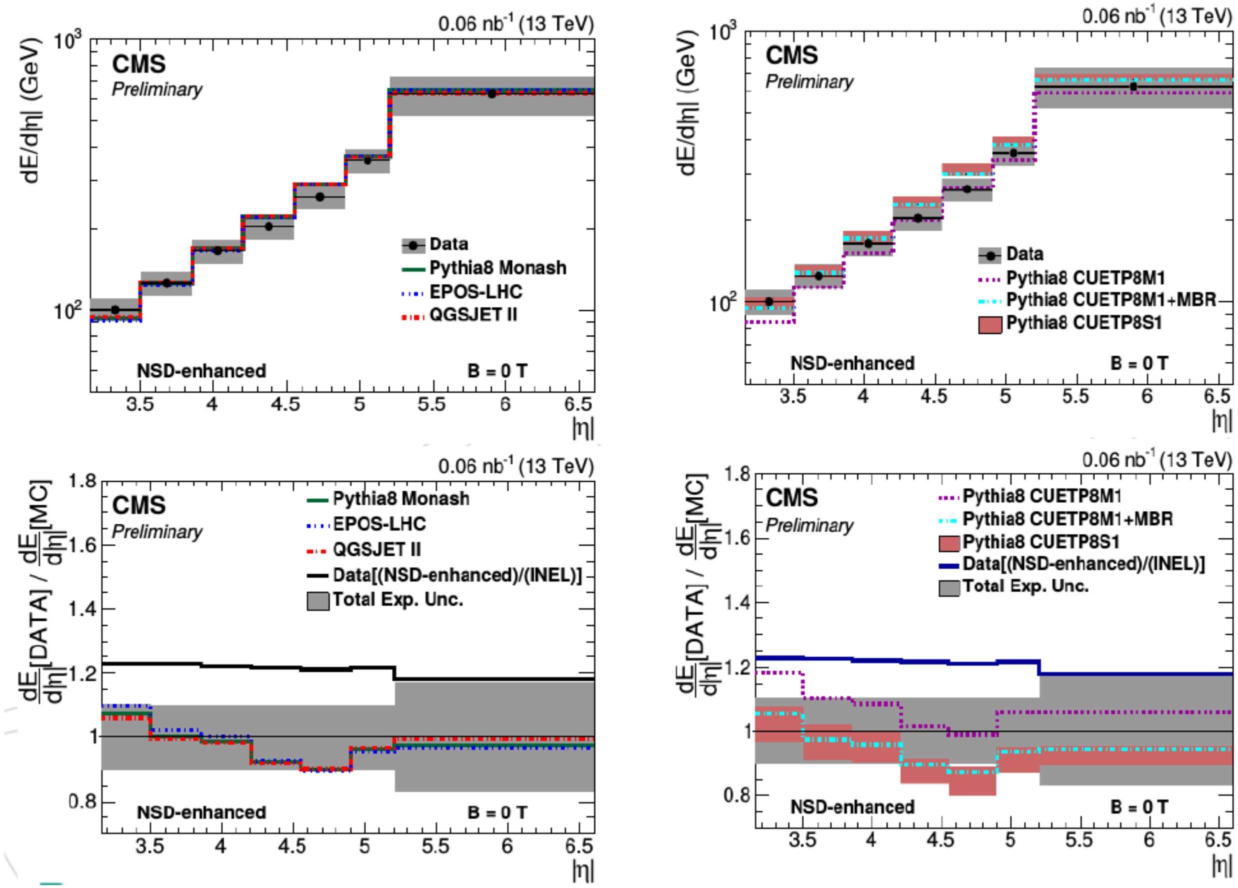
- At lowest η the best agreement
- At higher η bins MC models overestimates the data
- At CASTOR bin the agreement is again better

[CMS-FSQ-15-006]

Forward energy flow

The same HF-and data, different MC models

HF-AND



The spread between models smaller

Cosmic ray MC inside the uncertainities – good description

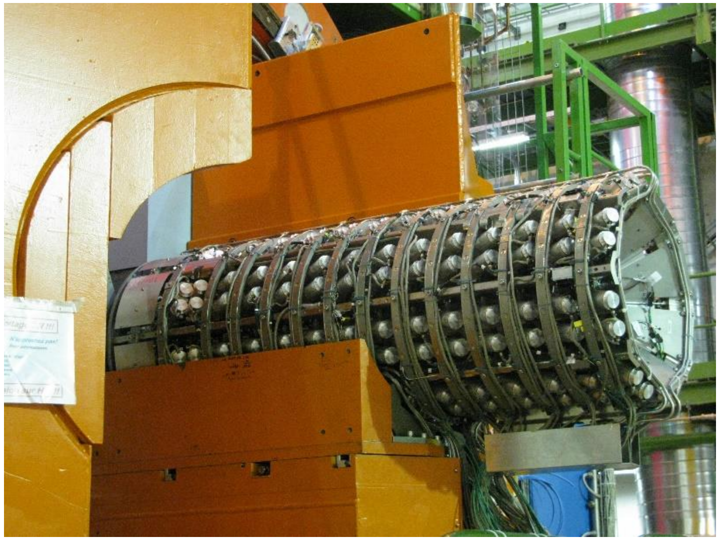
HF-and to HF-or ratio shown – no significant difference in the spectrum shape

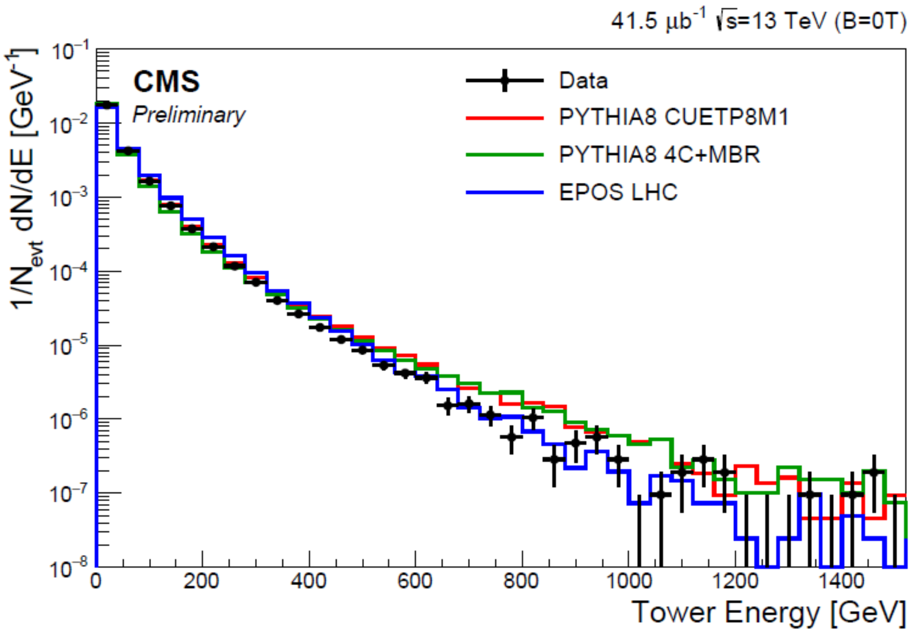
- Good description by PYTHIA8 CUETP8M1 apart from the first bin

Very forward energy flow

- No segmentation in rapidity
- 14 modules in *z* direction:
  - 2 electromagnetic
  - 12 hadronic

- Selection of events via activity in HF (or) above 5 GeV (tower)



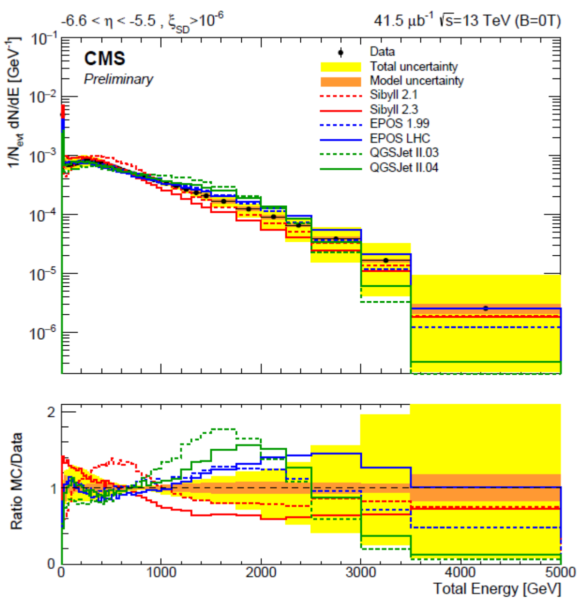


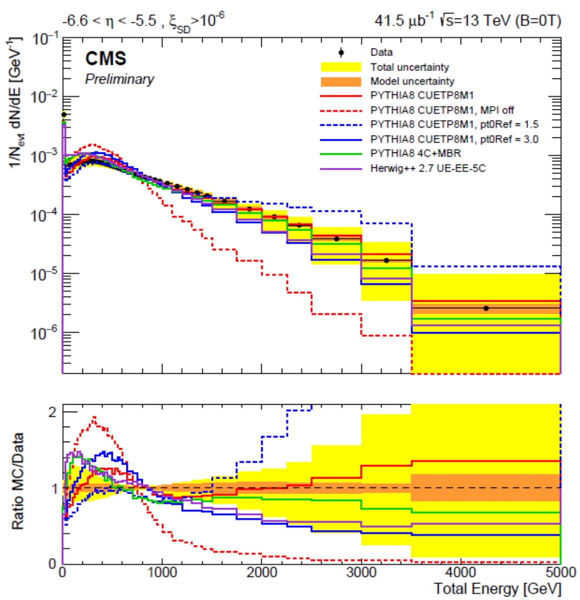
Energy spectrum of single reconstructed CASTOR towers in data well described by MC simulations

The detector level spectra corrected to the stable particle level (with $\xi_{SD}>10^{-6}$ cut)

Very forward energy flow

- Three observables defined:
    1) Total energy in CASTOR per event
    2) Electromagnetic energy (2 modules)
    3) Hadronic energy (12 modules)
- Energy scale uncertainty dominant – 17%





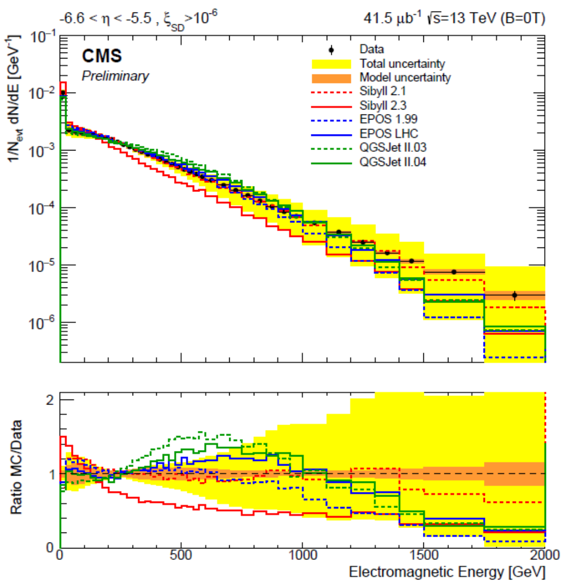
Diffractive events visible as a peak at lowest energies

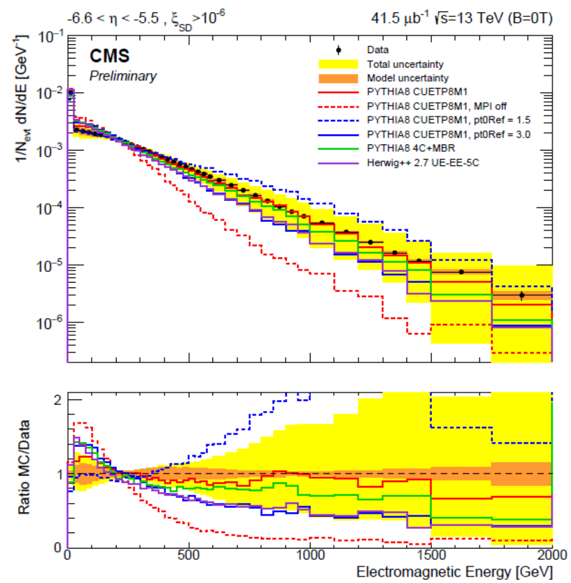
PYTHIA8/HERWIG tend to overestimate the data in the soft part of te spectrum

The data is very sensitive to MPI and the underlying event parameters

[CMS-FSQ-16-002]

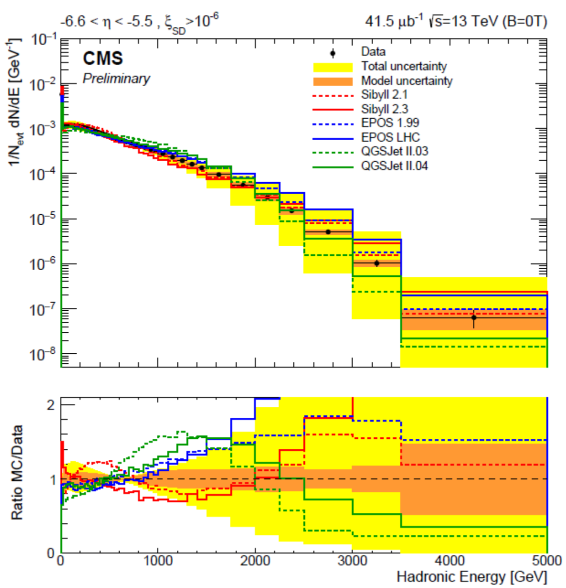
Very forward energy flow

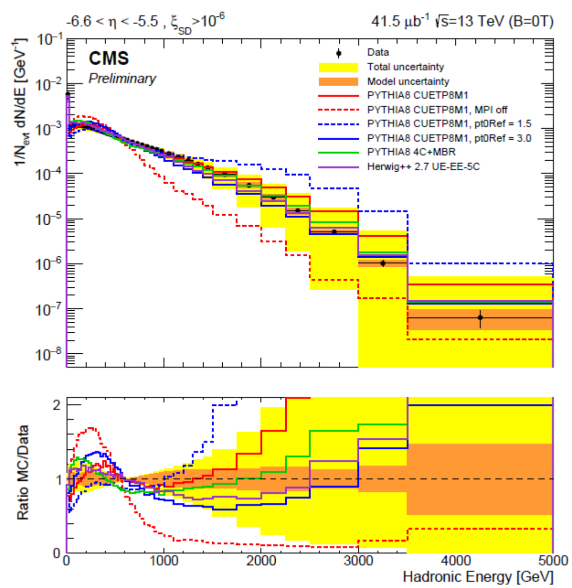




Electromagnetic spectrum better described by all models except for PYTHIA8 4C+MBR and SIBYLL

Sensitivity to the MPI tuning

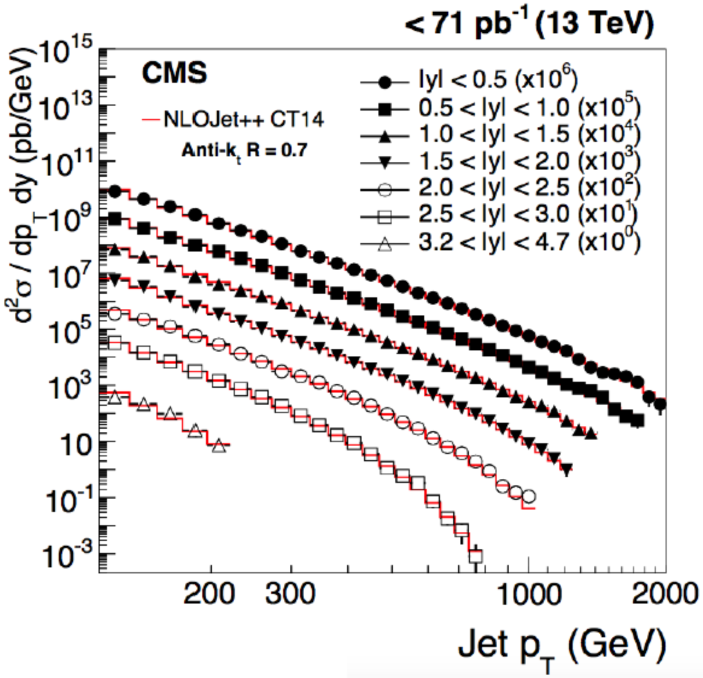


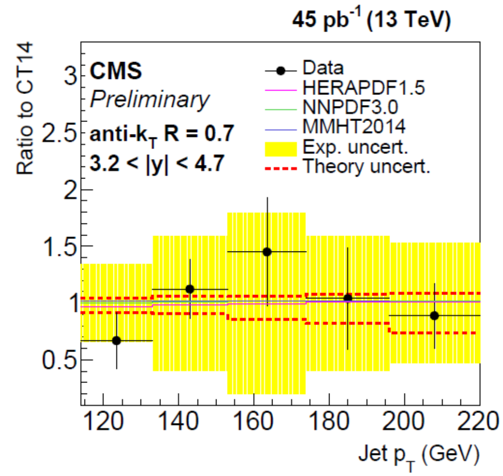


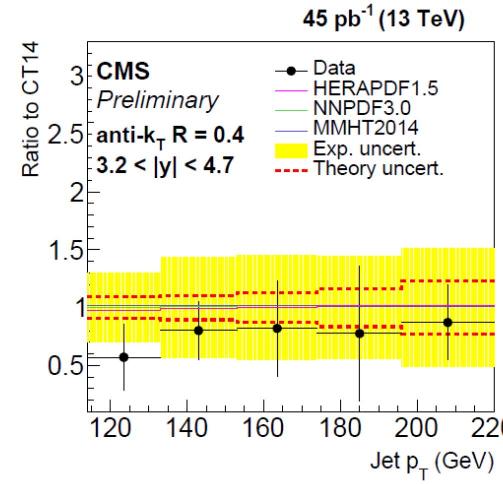
QGSJETII overestimates in 0.5-1.8 TeV range and underestimates at larger values

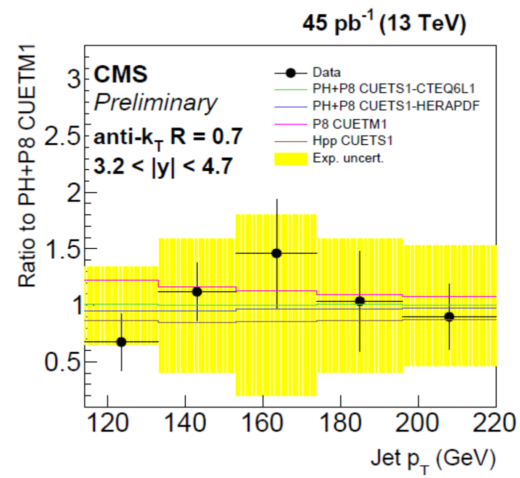
PYTHIA8 tunes overestimate the soft region

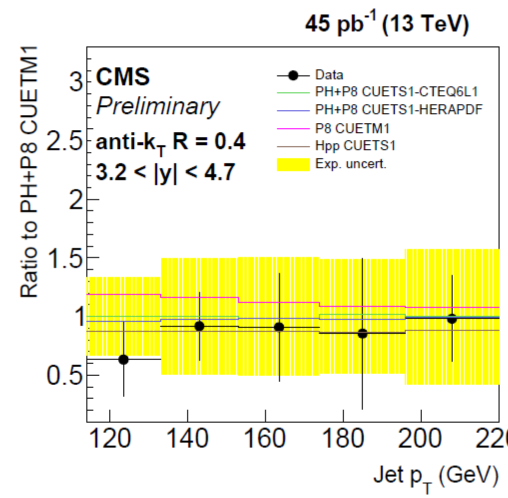
Inclusive jet cross section











Measurement in $|y|<4.7$
Jets reconstruction with R=0.4, R=0.7

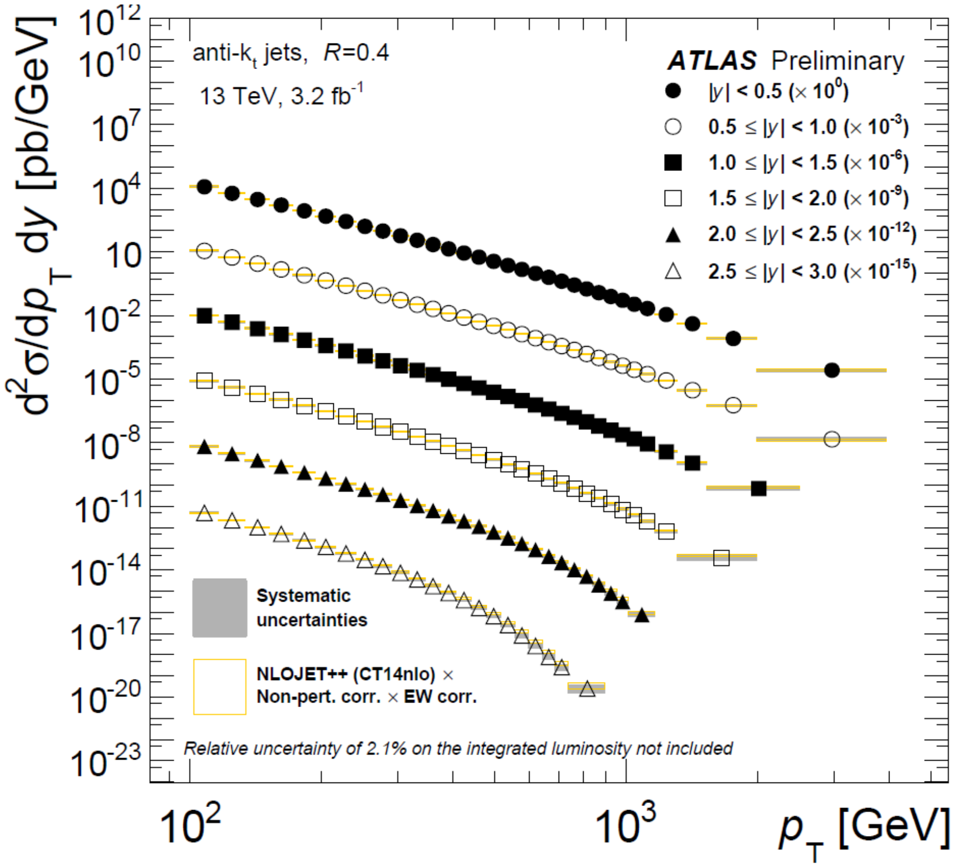
NLO pQCD predictions follow the data
Predictions in agreement with the data in each rapidity bin

In forward rapidities better agreement with R=0.4 (more flat ratio), all models tend to follow the data

[Eur. Phys. J. C (2016) 76: 451]

Inclusive jet cross section

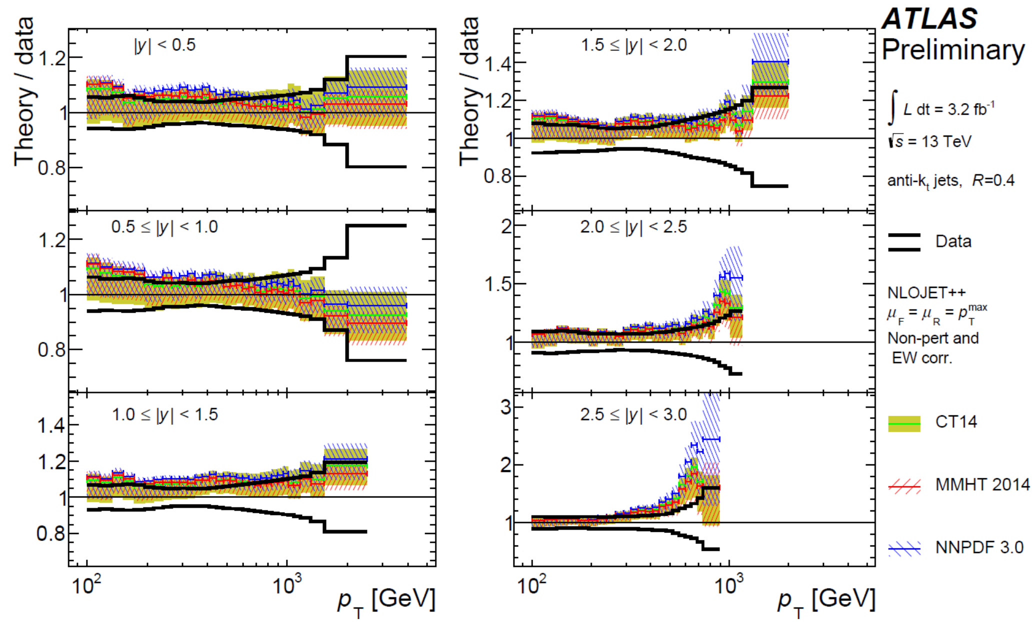
- Measurement in |y|<3.0
- Coverage: 100 < pT < 3200 GeV
- Anti-kT with R=0.4
- pT binning is chosen according to the detector pT resoluton
- 6 bins in |y|
- Comparison of data and NLO predictions (NLOJET++) with different PDF sets (CT14, MMHT2014, NNPDF3.0, CT10, HERAPDF 2.0, ABM12)

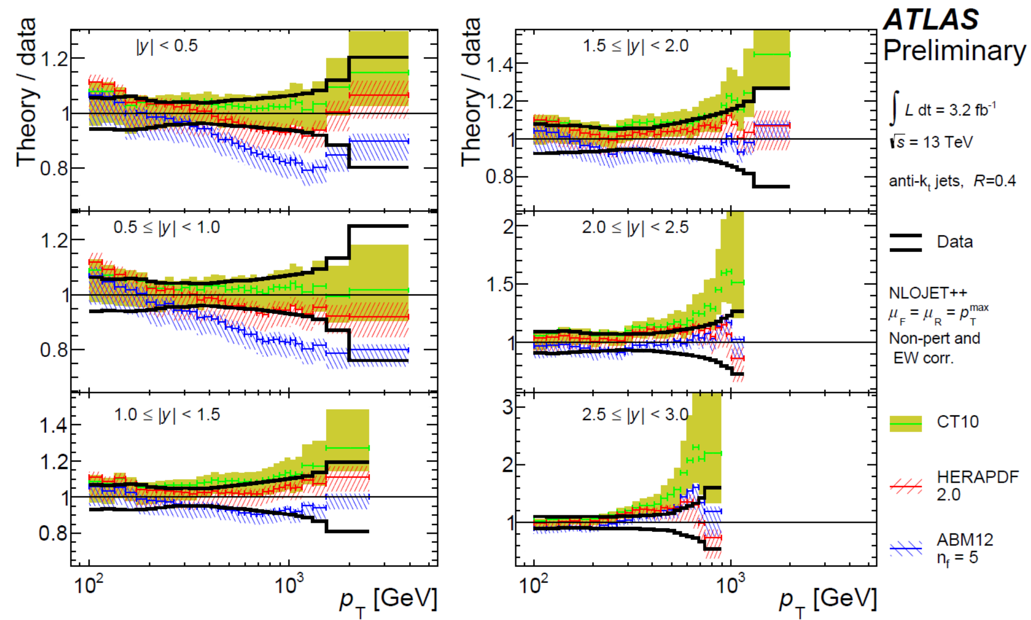


[ATLAS-CONF-2016-092]

Inclusive jet cross section

- All predictions describe the data overall well
- In the forward region at large pT there is a tendency in theoretical approach to overestimate the data
- ABM12 has a tendency to underestimate the data in medium and low rapidity bins

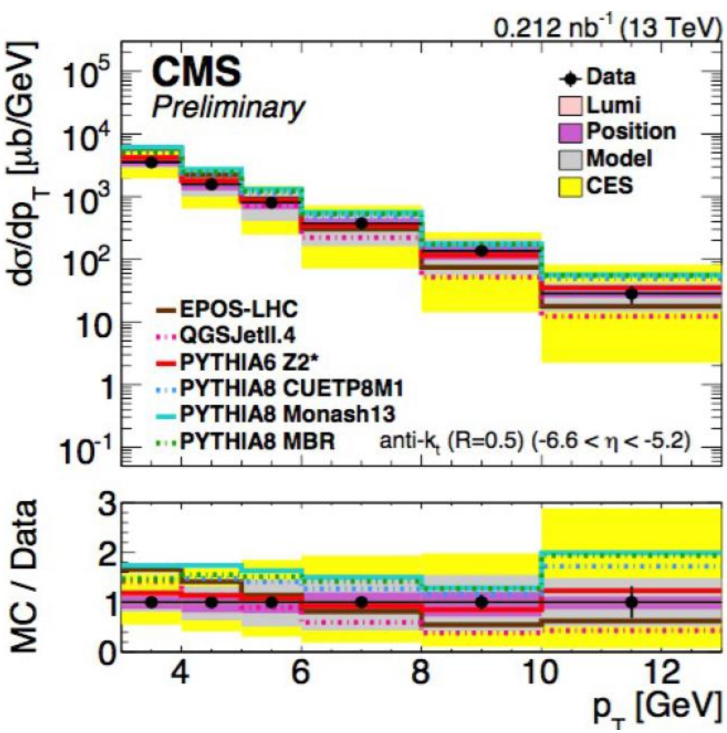




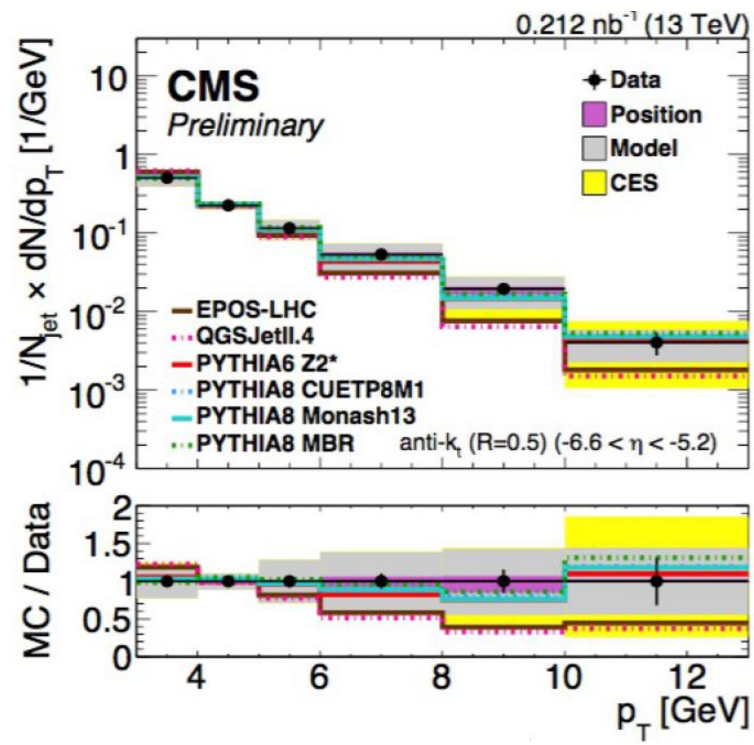
Very forward jet cross section

- Very low pile-up runs from Run2
- -6.6 < η < -5.2 (CASTOR acceptance)
- Jet pT > 3 GeV
- Sensitive to low-x gluon PDF and non-linear effects

Normalized to the luminosity



Normalized to the number of jets

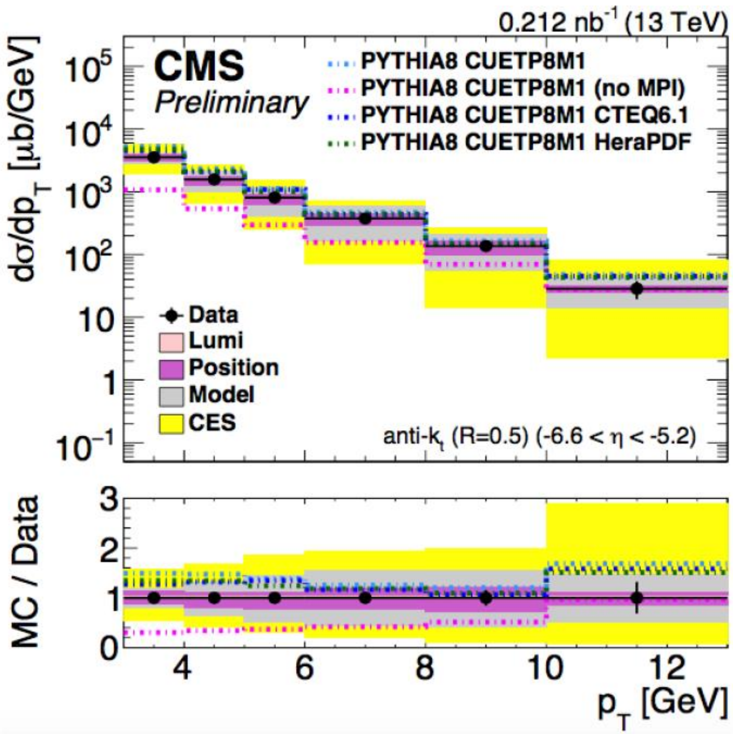


Main systematics: CASTOR energy scale
Agreement with all models

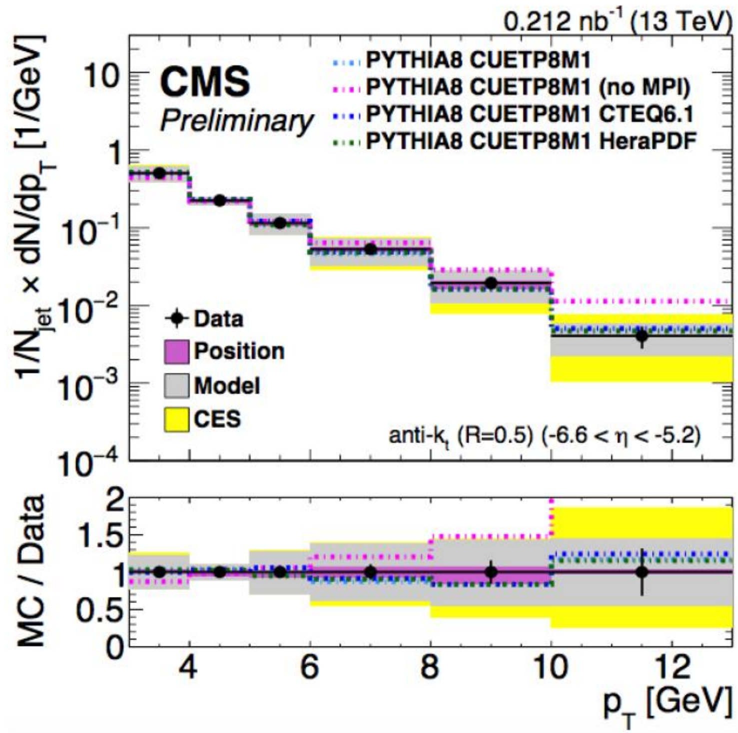
EPOS/QGSJET - faster decrease with pT
PYTHIA tunes in agreement with data

Very forward jet cross section

Normalized to the luminosity



Normalized to the number of jets



Different PDF sets tested – small differences

No MPI scenario tested – large disagreement with the data predictions

[CMS-FSQ-16-003]

Charged particle spectra

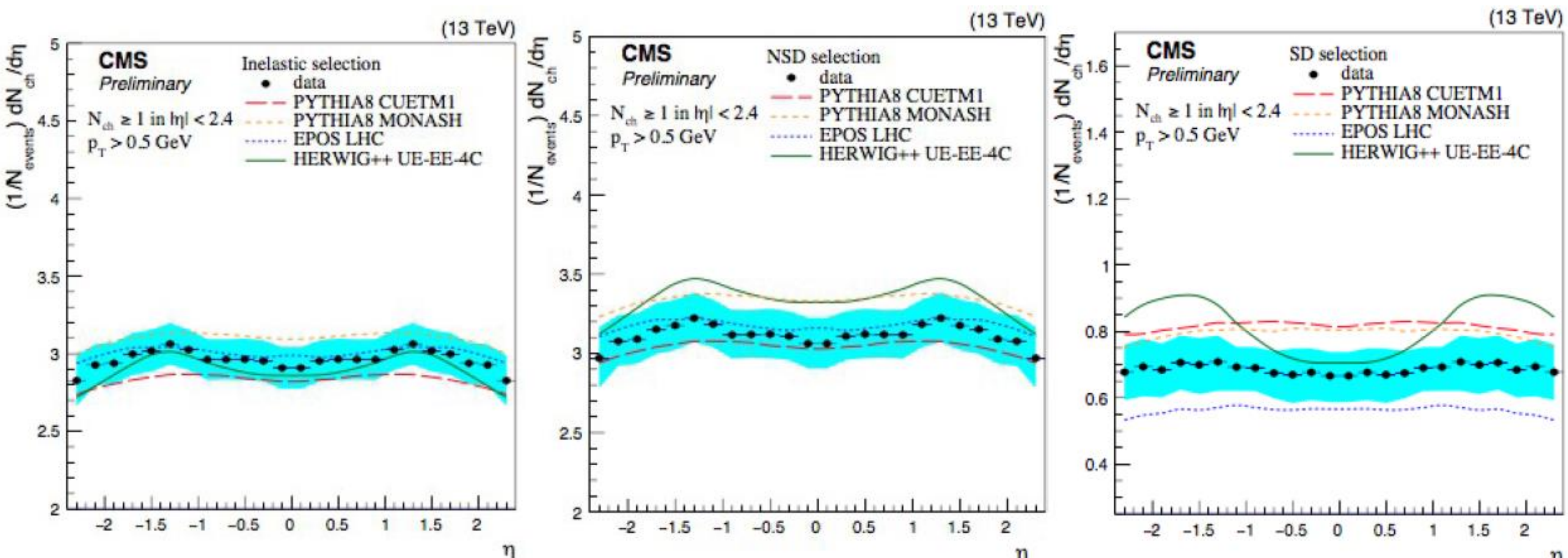
Minimum bias sample: trigger on a beam crossing at IP [CMS-FSQ-15-008]

At least one charged particle with pT>0.5 GeV and |η|<2.4

Inelastic sample: + in at least one forward region at least one particle with E>5 GeV

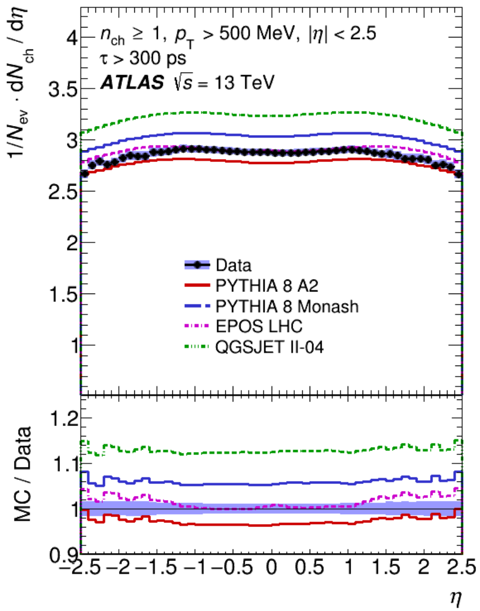
NSD sample: + at least one particle with E>5 GeV in both forward regions

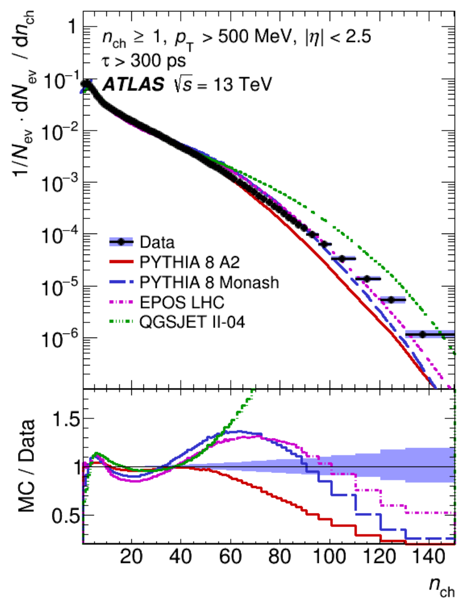
SD sample: + at least one particle with E>5 GeV in one fwd region + veto on opposite side



- EPOS, HERWIG++, PYTHIA8 CUETP8M1 describe the inelastic sample
- PYTHIA8 CUETP8M1 describes the NSD sample best
- EPOS is below SD sample while PYTHIA8 Monash and CUETP8M1 is above

Charged particle spectra

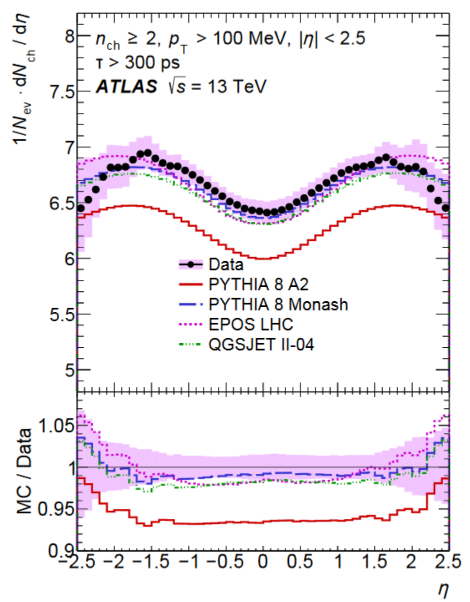


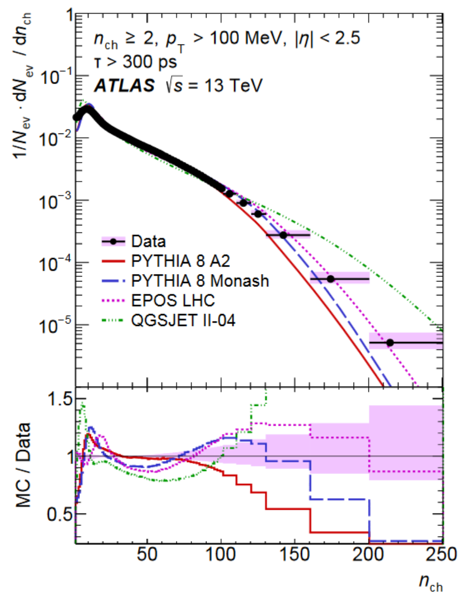


Selections of events with at least 1 (2) charged particles within |η|<2.5 and with pT>500 MeV (100 MeV)

Primary-charged-particle multiplicities as a function of pseudorapidity

Primary-charged-particle multiplicities as a function of the multiplicity, n_{ch}



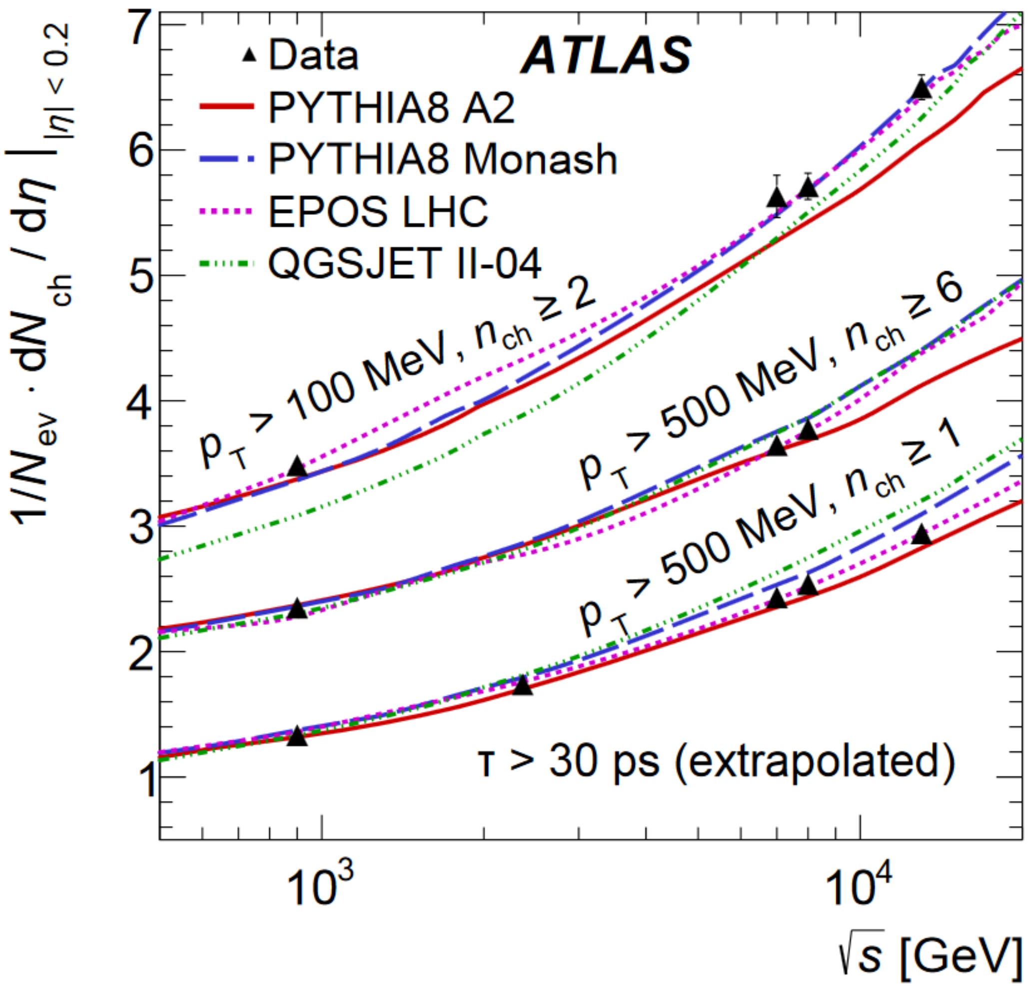


EPOS in an overall picture is the best

All models show large discrepancies for large multiplicities n_{ch}

[Phys. Lett. B758 67-88 (2016)]

Charged particle spectra



Charged particles multiplicity within $|\eta|<0.2$

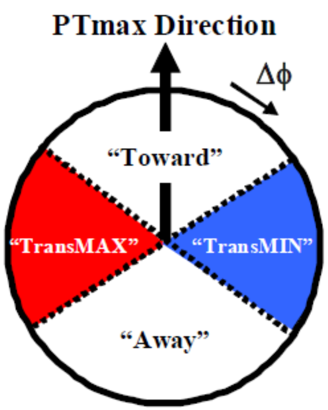
Around 20% increase when moving from 7 TeV to 13 TeV

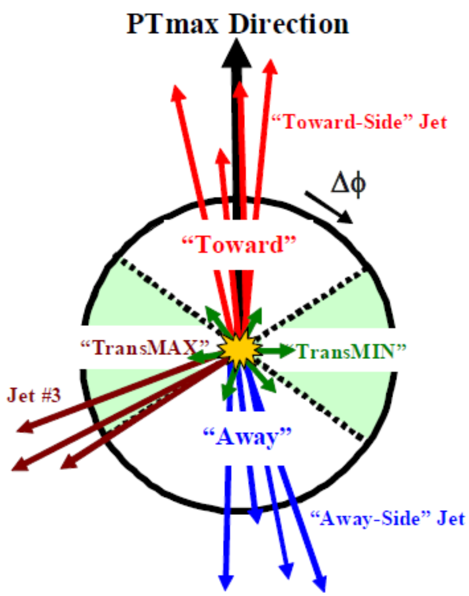
Models follow the data

The best predictions from EPOS

Underlying activity with leading track/jet

Leading object in an event (track, jet)





Transverse region divided:

- TransMIN – lower activity, sensitive to MPI + beam-beam remnants
- TransMAX – higher activity, sensitive to MPI + beam-beam remnants + initial and final state radiation
- TransDIF = TransMAX – TransMIN, sensitive to initial and final radiation

Leading track:

- $p_T > 0.5$ GeV
- $|\eta|<2$

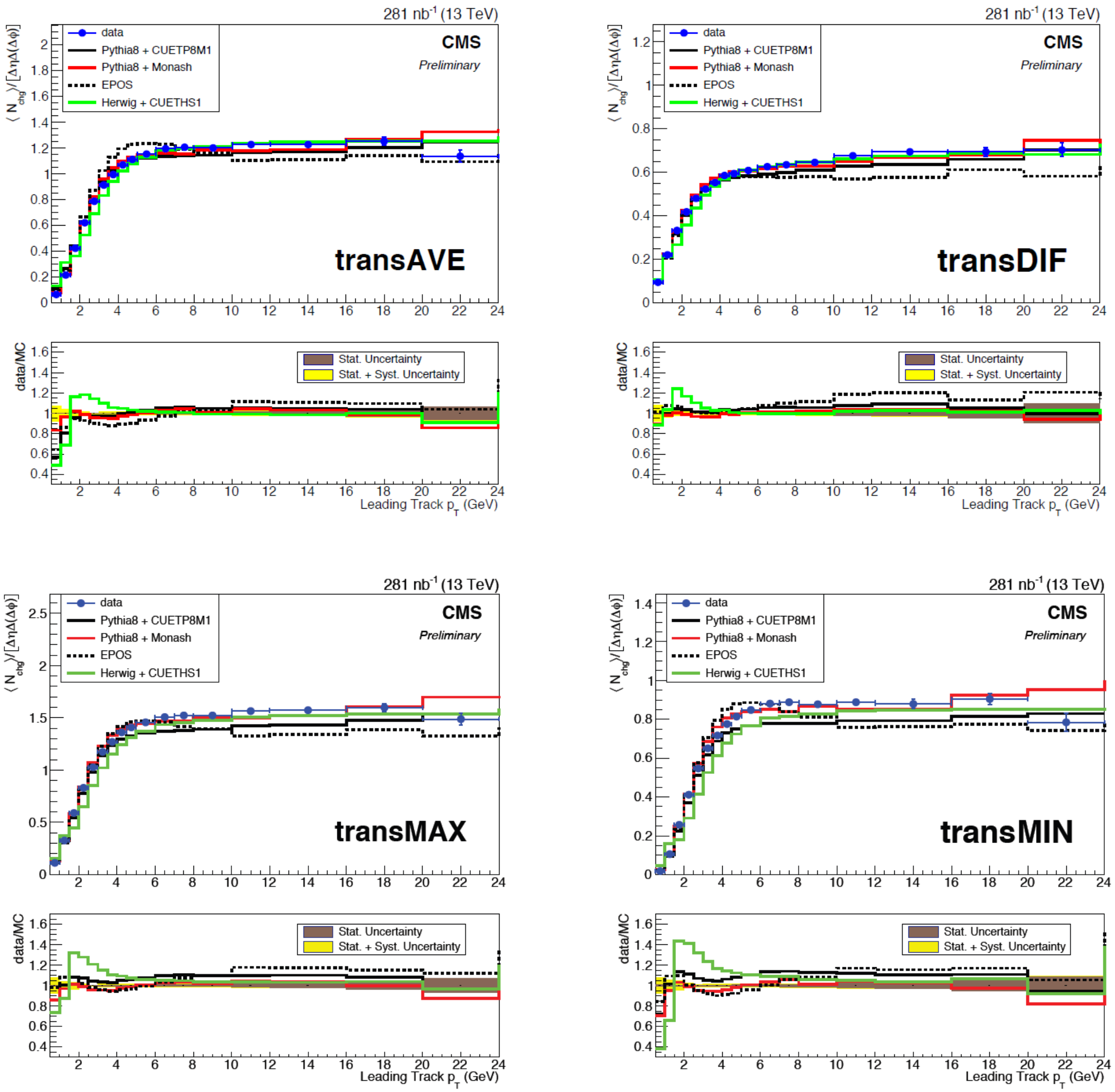
Leading jet:

- $p_T > 1$ GeV
- $|\eta|<2$

Observables:

- The charge density: N_{ch}
- The transverse momentum density: $\sum p_T$

Underlying activity with leading track



Average charged particle multiplicity density

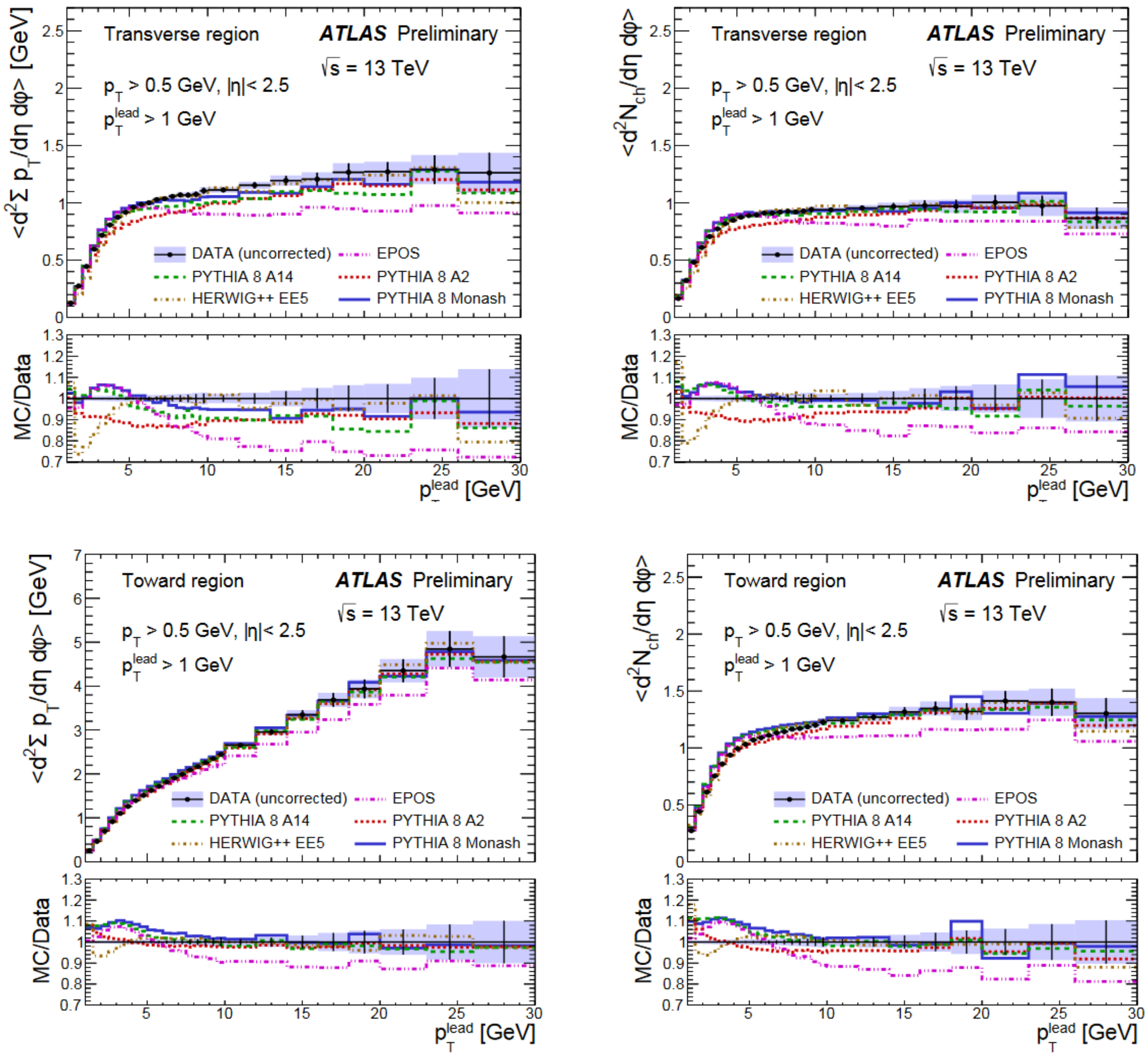
PYTHIA8 Monash, CUETP8M1 are the best

HERWIG does not fit the data at low p_T

EPOS first above then below the data

[CMS-FSQ-15-007]

Underlying activity with leading track



Similar results for ATLAS

p_T (leading track) > 1 GeV

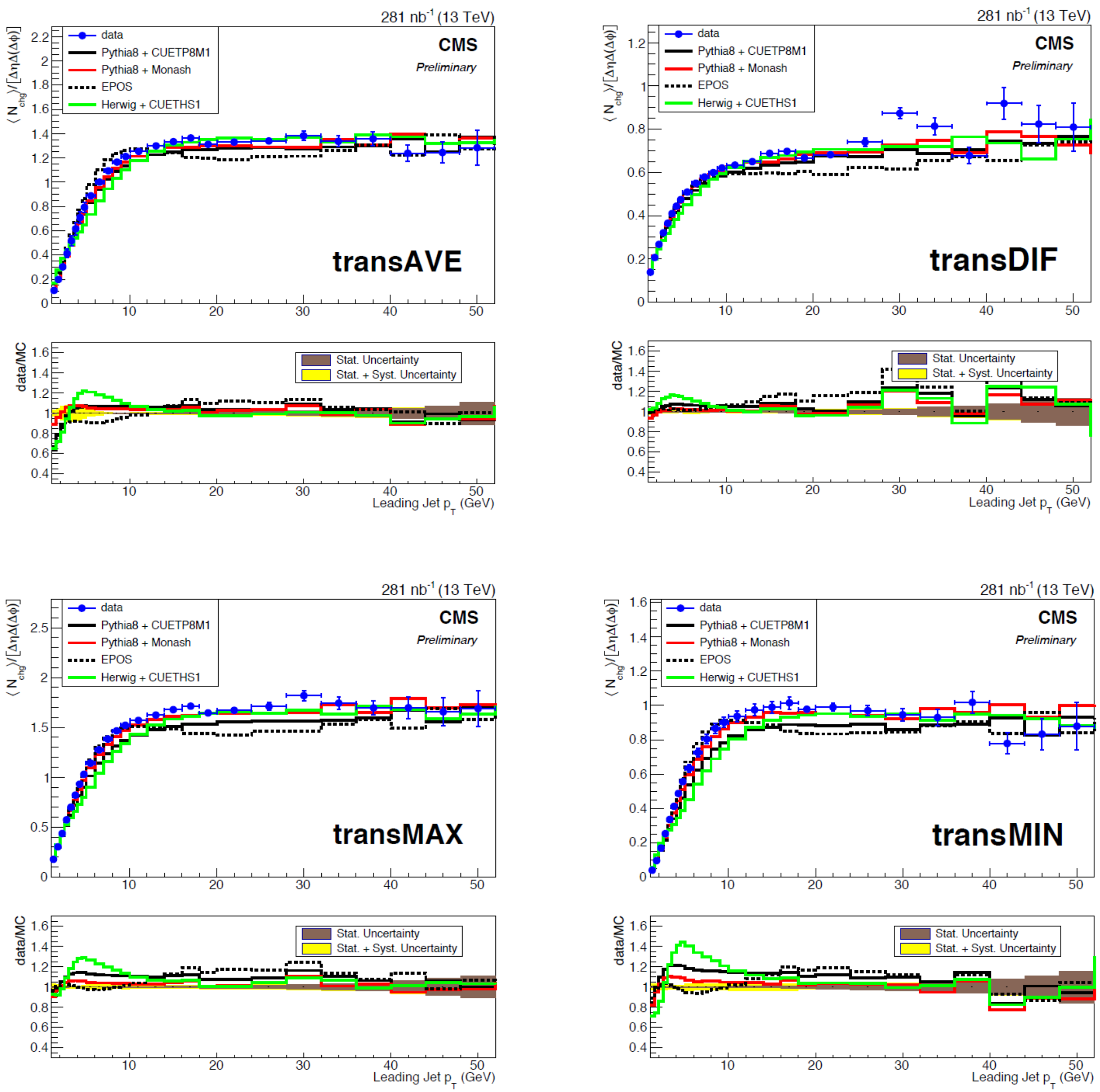
None of the models predict well the initial rise

From ~10 GeV good description by HERWIG++, PYTHIA 8 A14 and Monash

EPOS predicts much less activity in the plateau region

[ATL-PHYS-PUB-2015-019]

Underlying activity with leading jet



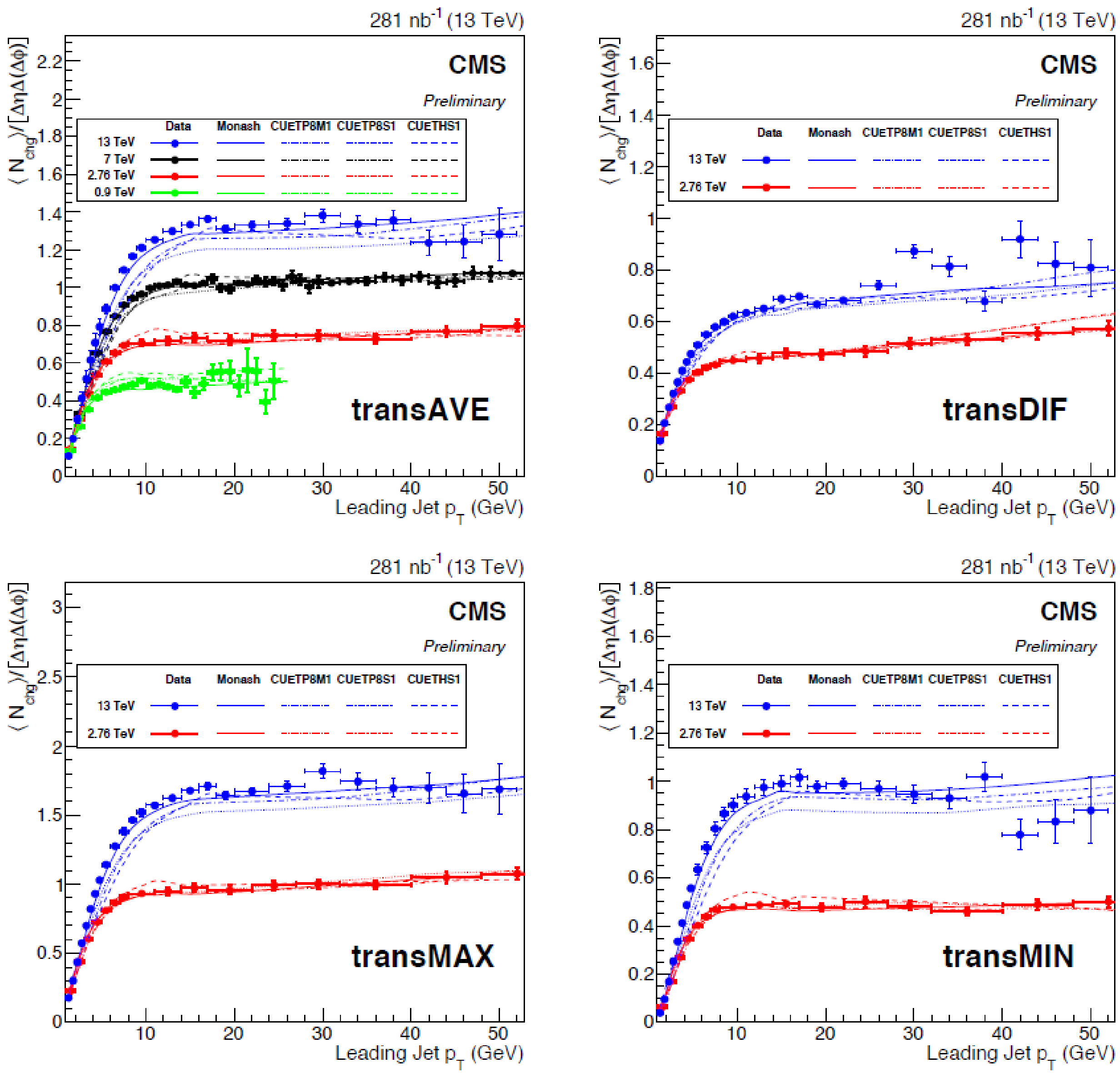
Average charged particle multiplicity density

PYTHIA8 Monash, CUETP8M1 are the best

Higher activity with respect to the leading track spectra

HERWIG again not good at soft region, EPOS underestimates high values

Underlying activity with leading jet



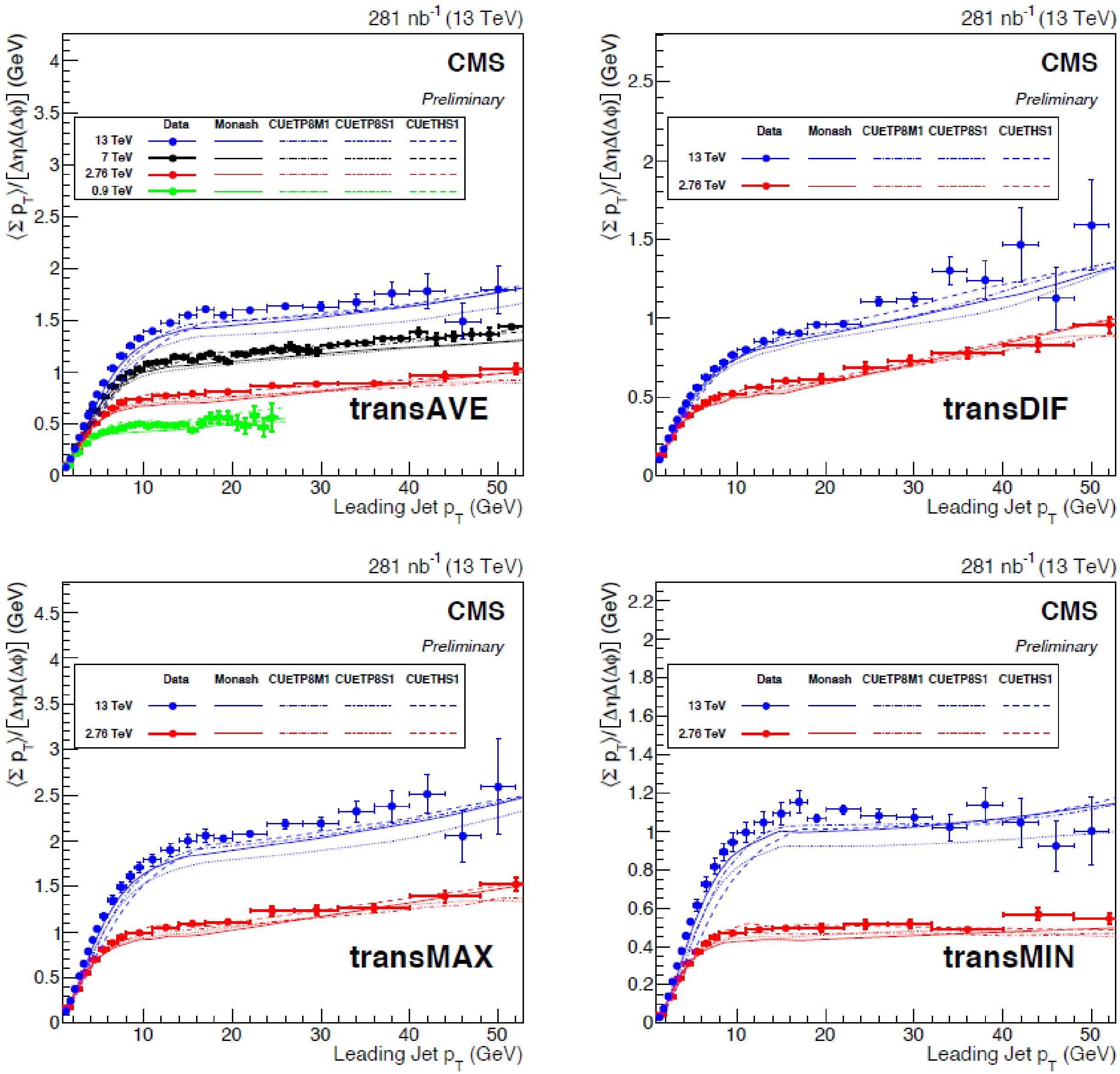
Average charged particle multiplicity density – energy dependence

Rise of UE activity with the rise of the center of mass energy

Rise well described by models

transMIN rise faster than transDIF -> MPI activity rises faster than ISR/FSR activity

Underlying activity with leading jet



Average transverse momentum density – energy dependence

The same observation

PYTHIA8 Monash, CEUTP8M1 are the best

Summary

- Forward energy flow (HF) and very forward energy flow (CASTOR) measured and compared with PYTHIA and cosmic ray models and different tunes
- Inclusive jets spectra in agreement with predictions, smaller jet cone sizes works better
- Very forward jets measured in CASTOR, large systematic uncertainties, small differentiation power betwen models
- Underlying activity with leading track/jet measured, center-of-mass energy dependence obtained, PYTHIA8 Monash, CUTEP8M1 fit the best