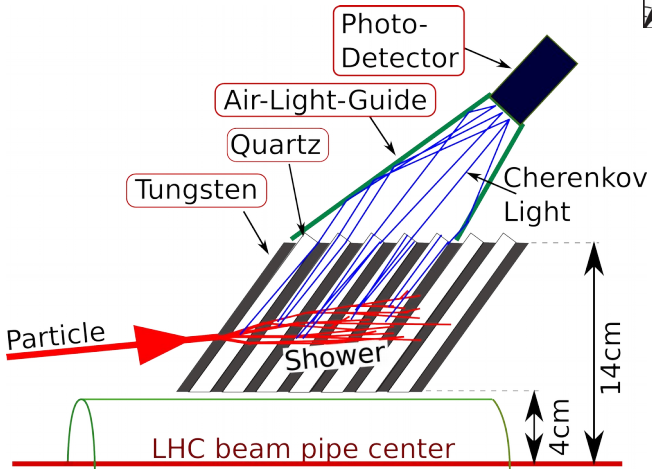
Measurements of the very-forward energy in pp collisions at the LHC and constraints for cosmic ray air showers

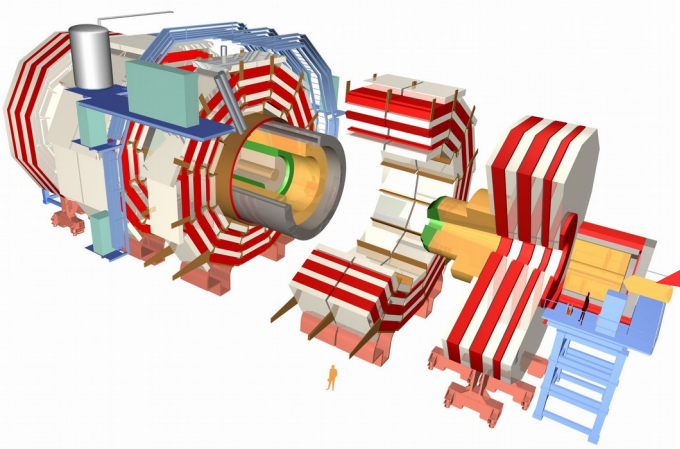
Sebastian Baur and Ralf Ulrich
for the CMS collaboration

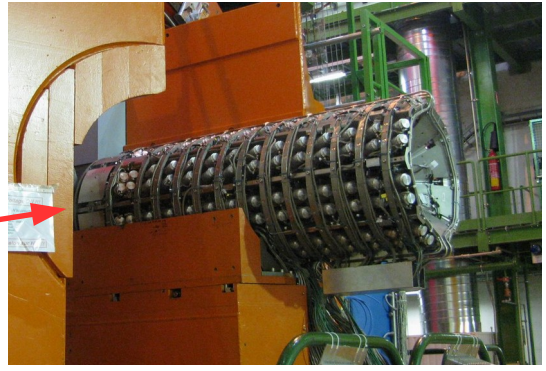
ICRC2019

CASTOR in CMS

- Tungsten-Quartz sampling calorimeter
- Coverage $-6.6 < \eta < -5.2$
- Segmentation in φ and z
- Separated electromagnetic and hadronic sections with depth of $20\ X_0 / 10\ \lambda_{int}$
- Energy scale known to $\pm 17\%$





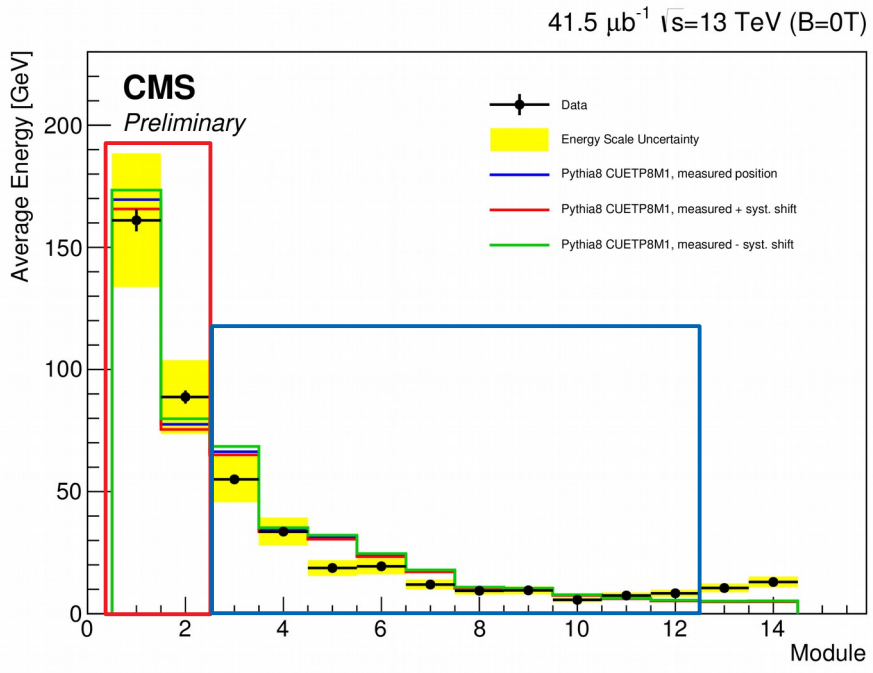


Energy measurements with CASTOR

- Total energy: Sum all calorimeter towers above noise threshold
- Signal in the first two modules of CASTOR is sensitive to the electromagnetic component
- Back part measures the hadronic contribution

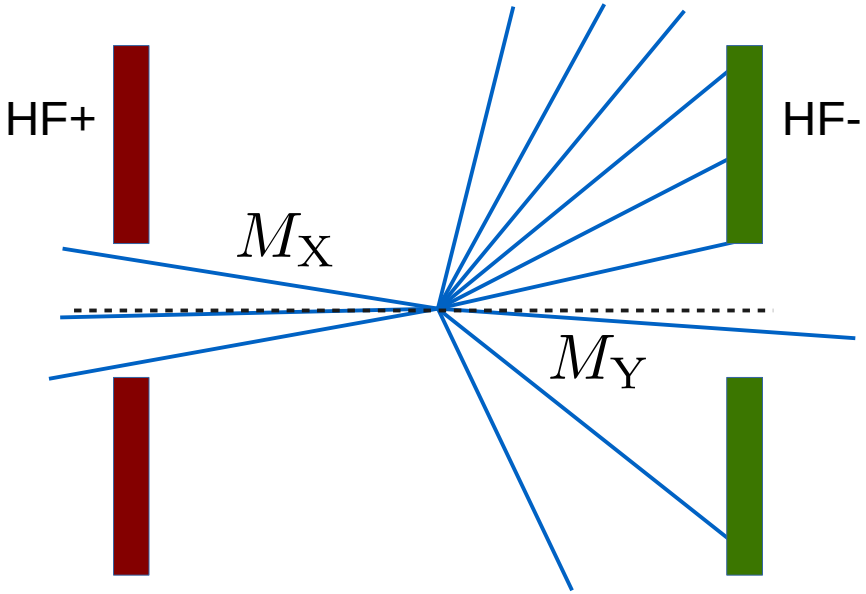
Corresponding particle level energies:

Energy sum of
- all stable particles except μ, ν
- e, γ $(incl.\ \pi^0)$
- all stable particles except μ, ν, e, γ



Consistent analyses with 13 TeV data

- Strong combined effort in CMS to exploit early 13 TeV low pileup data
- Number of analyses with consistent event selections and particle level definitions
- Minimal bias: energy deposit in Hadron Forward calorimeters ($3.15<|\eta|<5.2$)



HF OR

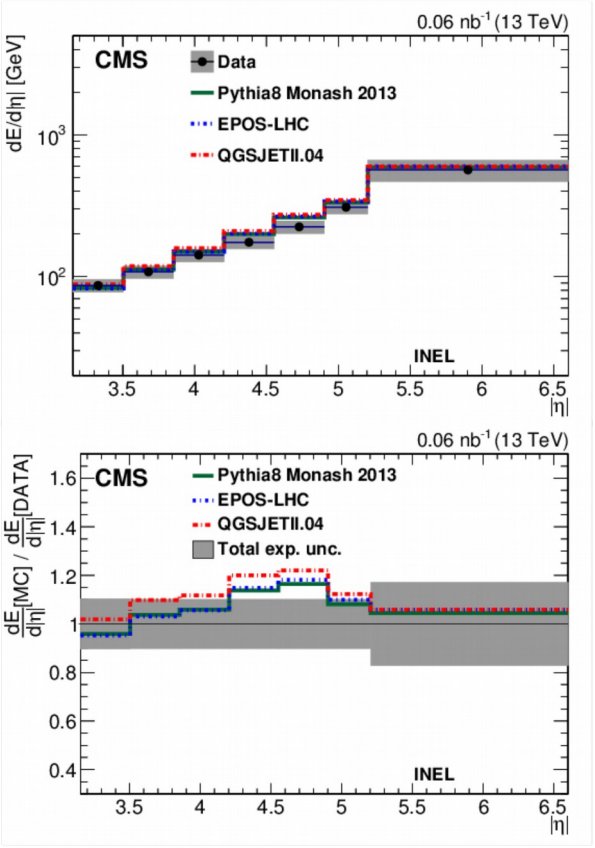
(5 GeV in any HF cell)

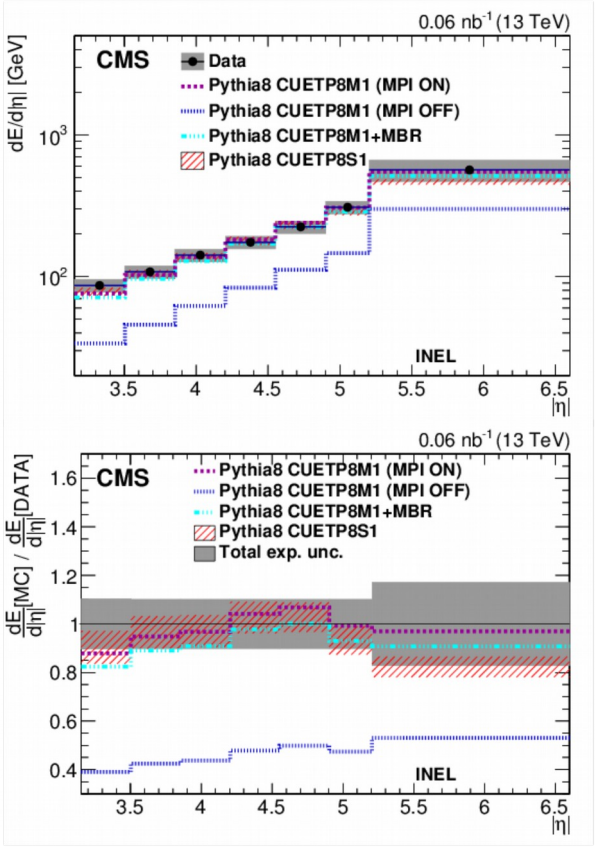
corresponds

$$M_{\mathrm{min}} = \max(\mathrm{M_X}, \mathrm{M_Y}) > 13\,\mathrm{GeV}$$

Forward energy flow [EPJC 79 (2019) 391]

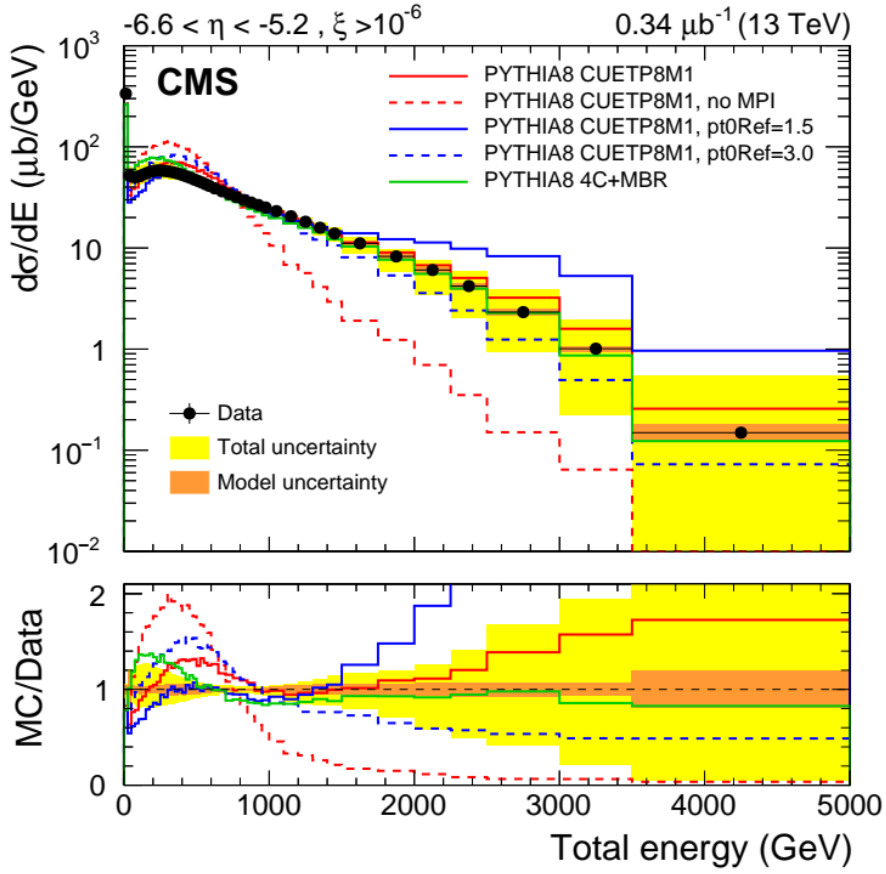
- Combining HF and CASTOR acceptances
  → $3.15 < |\eta| < 6.6$
- Average energy per collision and unit in pseudorapidity
- Model spread still larger than tune uncertainty
- Important benchmark for MPI modeling





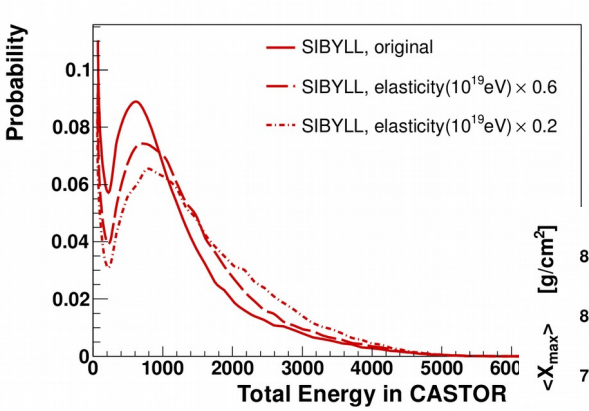
Forward energy spectra [JHEP 08 (2017) 046]

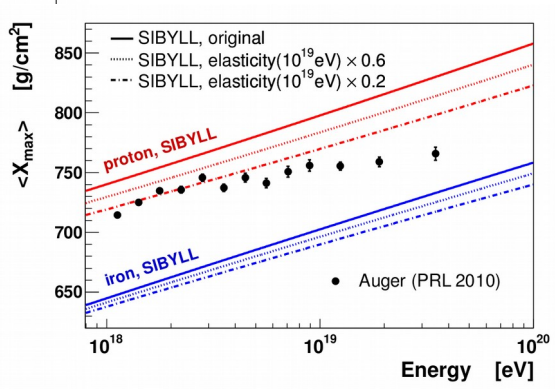
- Detailed energy distribution in CASTOR acceptance
- Differential cross-section as function of total, electromagnetic, hadronic energy
- Sensitive to MPI modeling

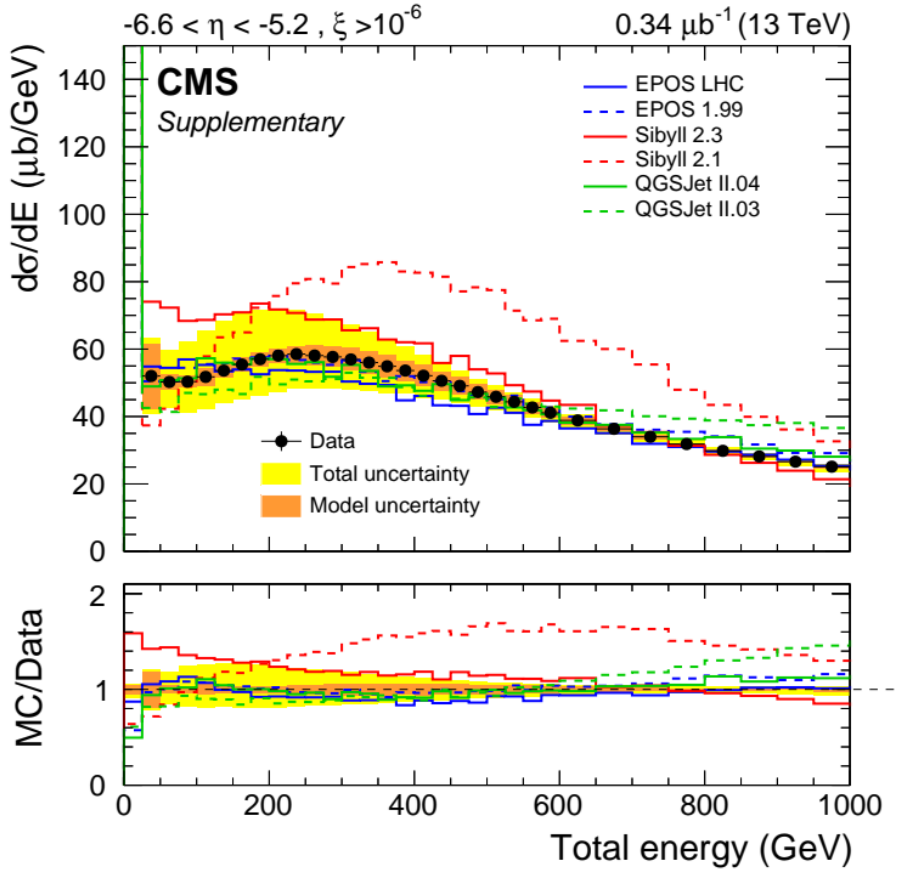


Forward energy spectra [JHEP 08 (2017) 046]

- Bulk of events at low energies: contribution from diffraction (1st bin)
- Sensitive to model elasticity





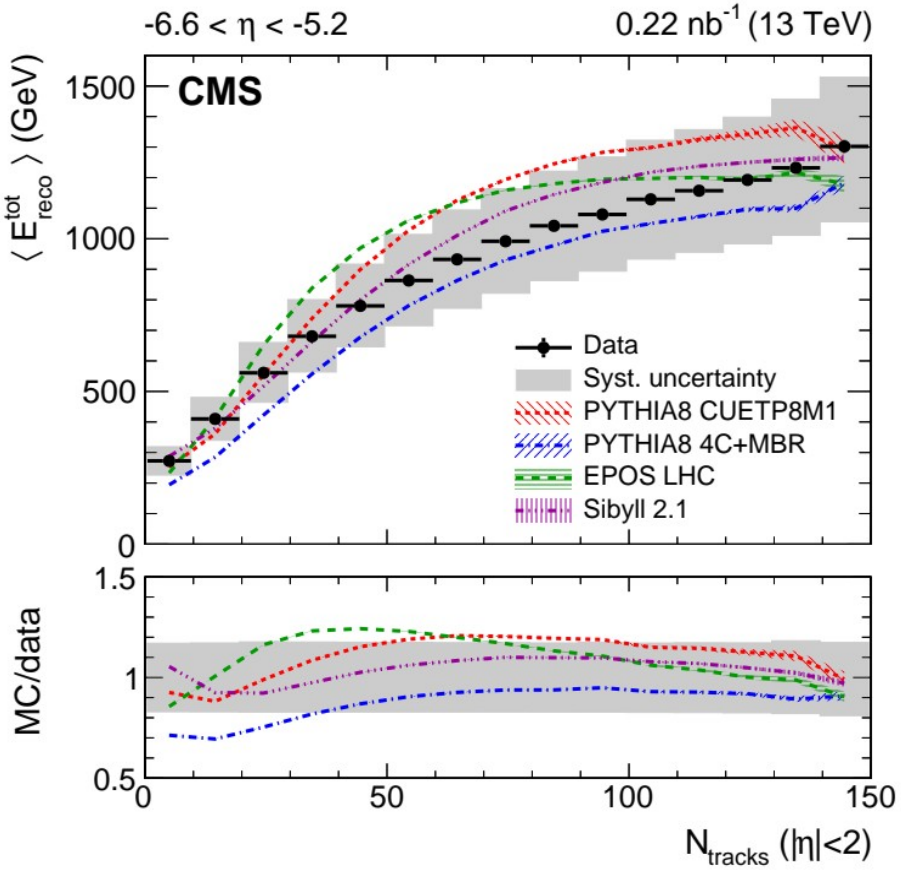


new

Forward-central correlation

- Correlate central particle multiplicity
- No magnetic field → special tracking
- Require HF energy and at least 1 track
  → low influence of diffraction
- No correction to particle level
  → compare on detector level

$$\langle E_{reco} \rangle \left(N_{tracks,|\eta|<2} \right)$$

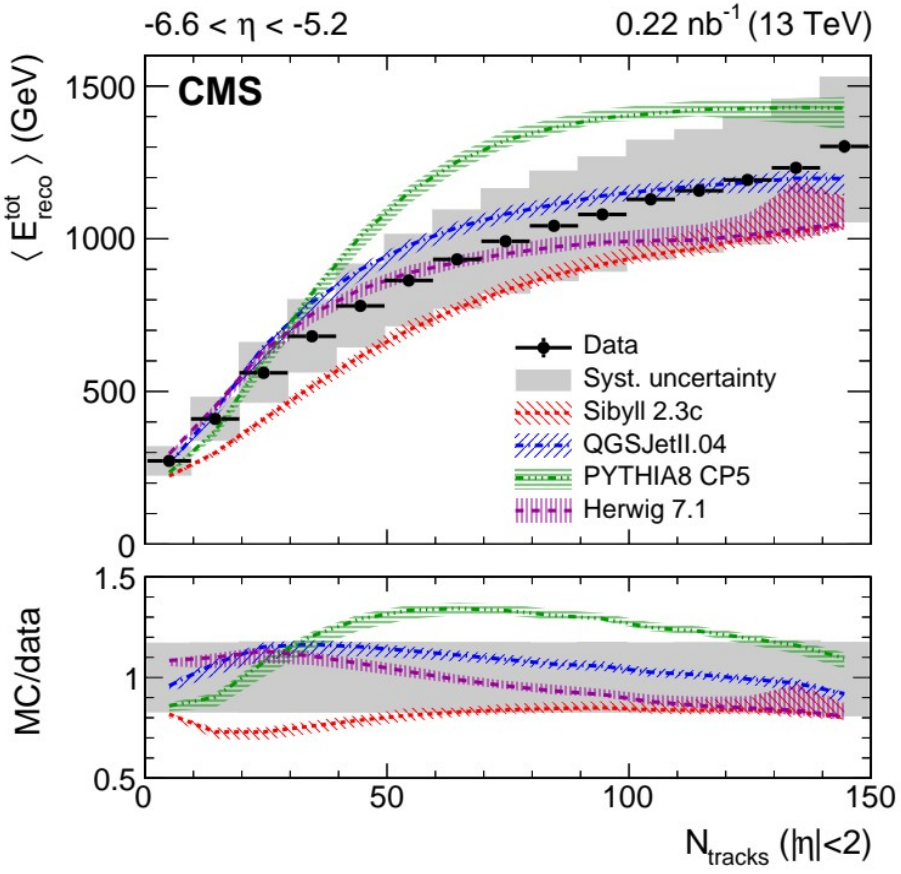


new

Forward-central correlation

- Correlate central particle multiplicity
- No magnetic field → special tracking
- Require HF energy and at least 1 track
  → low influence of diffraction
- No correction to particle level
  → compare on detector level
- Forward-Folding of model predictions
  → includes systematic uncertainties
  → available as rivet plugin very soon

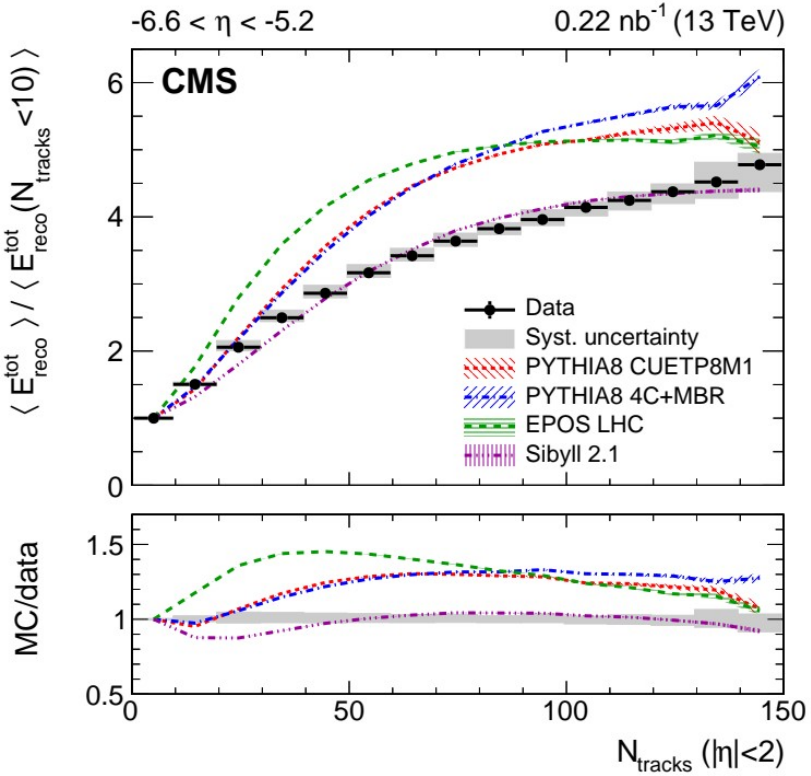
$$\langle E_{reco} \rangle \left(N_{tracks, |\eta|<2} \right)$$

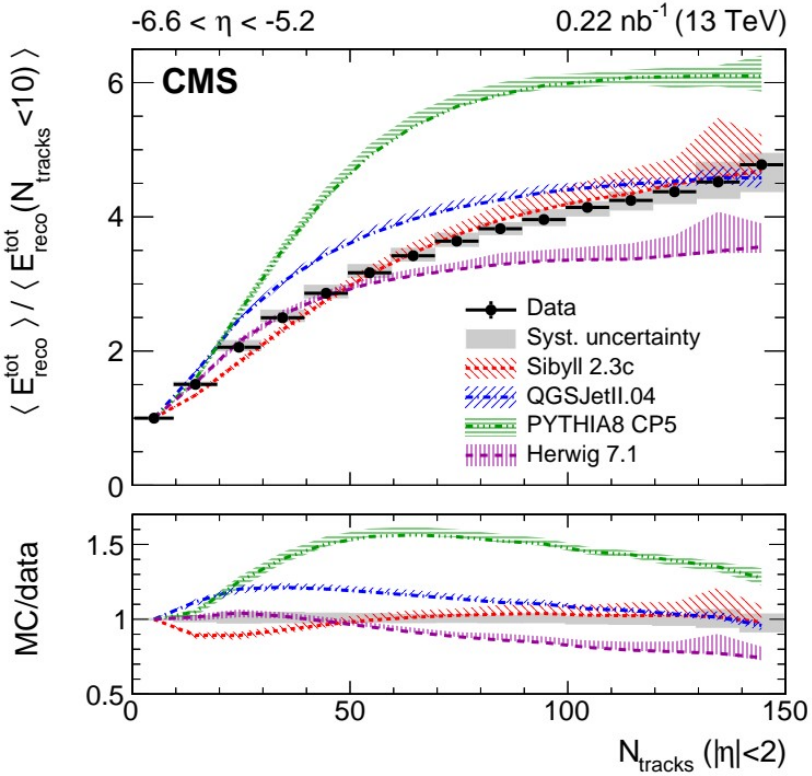


new

Forward-central correlation

- Shape-Analysis: Main systematic uncertainties cancel

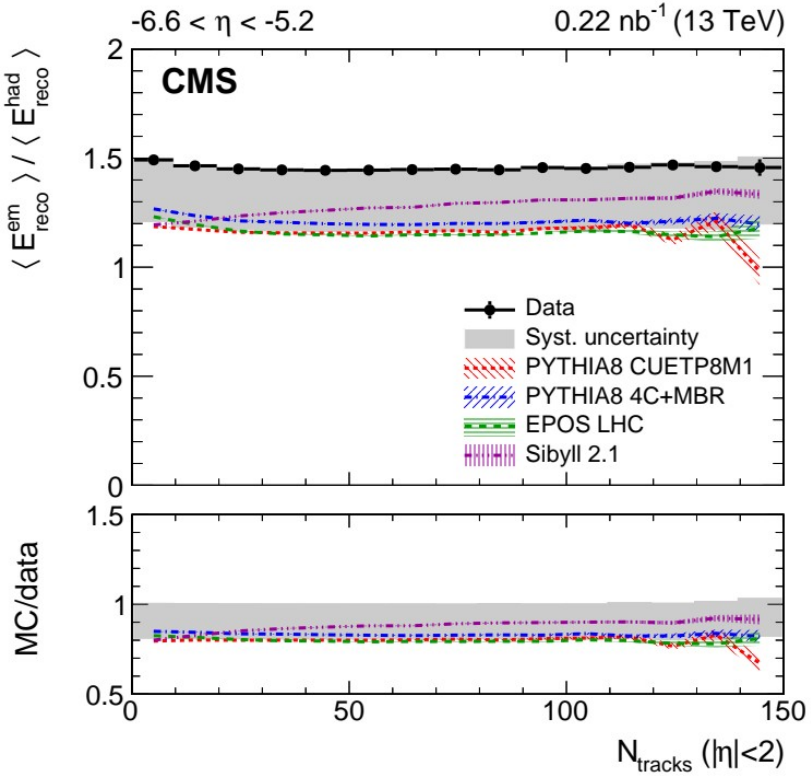


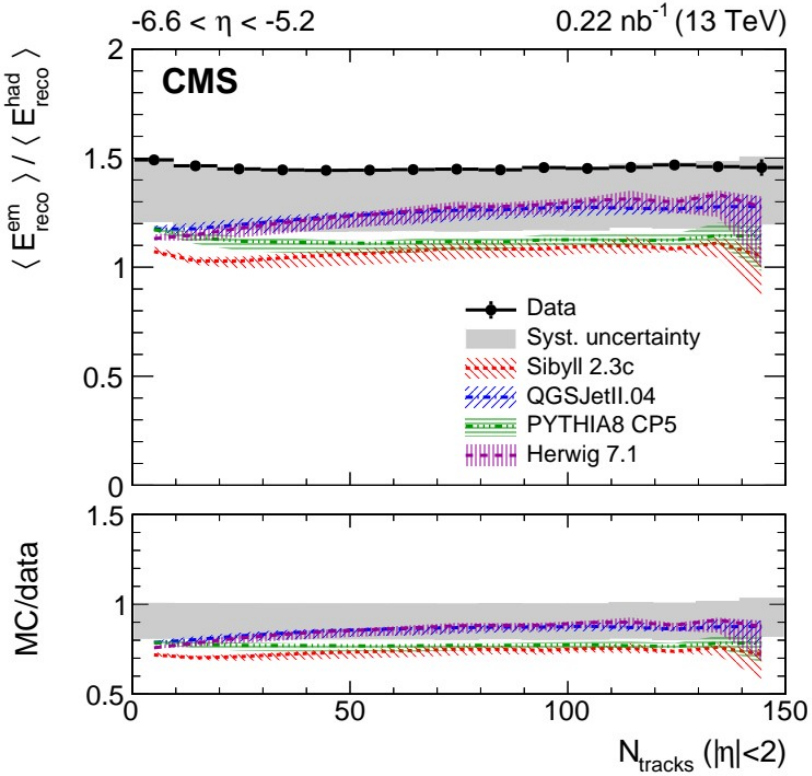


new

Forward-central correlation

- Ratio of electromagnetic to hadronic energy





new

Forward-central correlation

- First correlation of central and very-forward particle production at 13 TeV
- Measurement of underlying event activity in extreme phase space
- Very sensitive to MPI modelling, in combination with proton PDFs

- Reasonably well description of the average energies, but not the shape
- Data show softer rise than predicted by most models (except Sibyll)
- Data shows larger em/had ration than the models

→ energy available for muon production in air showers is strongly constraint!

Summary

- Extensive and consistent set of MinimumBias analyses with CASTOR at 13 TeV
  → complete and diverse picture of the forward energy production
  → first direct comparison of electromagnetic and hadronic energy

- Benchmark tests for event generators, impact for air showers
  → probe MPI modelling, low-x gluon PDF
  → model elasticity
    → impact on shower maxima
  → fraction of hadronic energy
    → constrain possibilities to enhance muon number with QCD tuning

- Example analyses for future efforts (e.g. Dembinski et al. PoS(ICRC2019)235)