Karlsruhe Institute of Technology

Forward energy flow per pseudorapidity and limiting fragmentation with CMS at 13TeV

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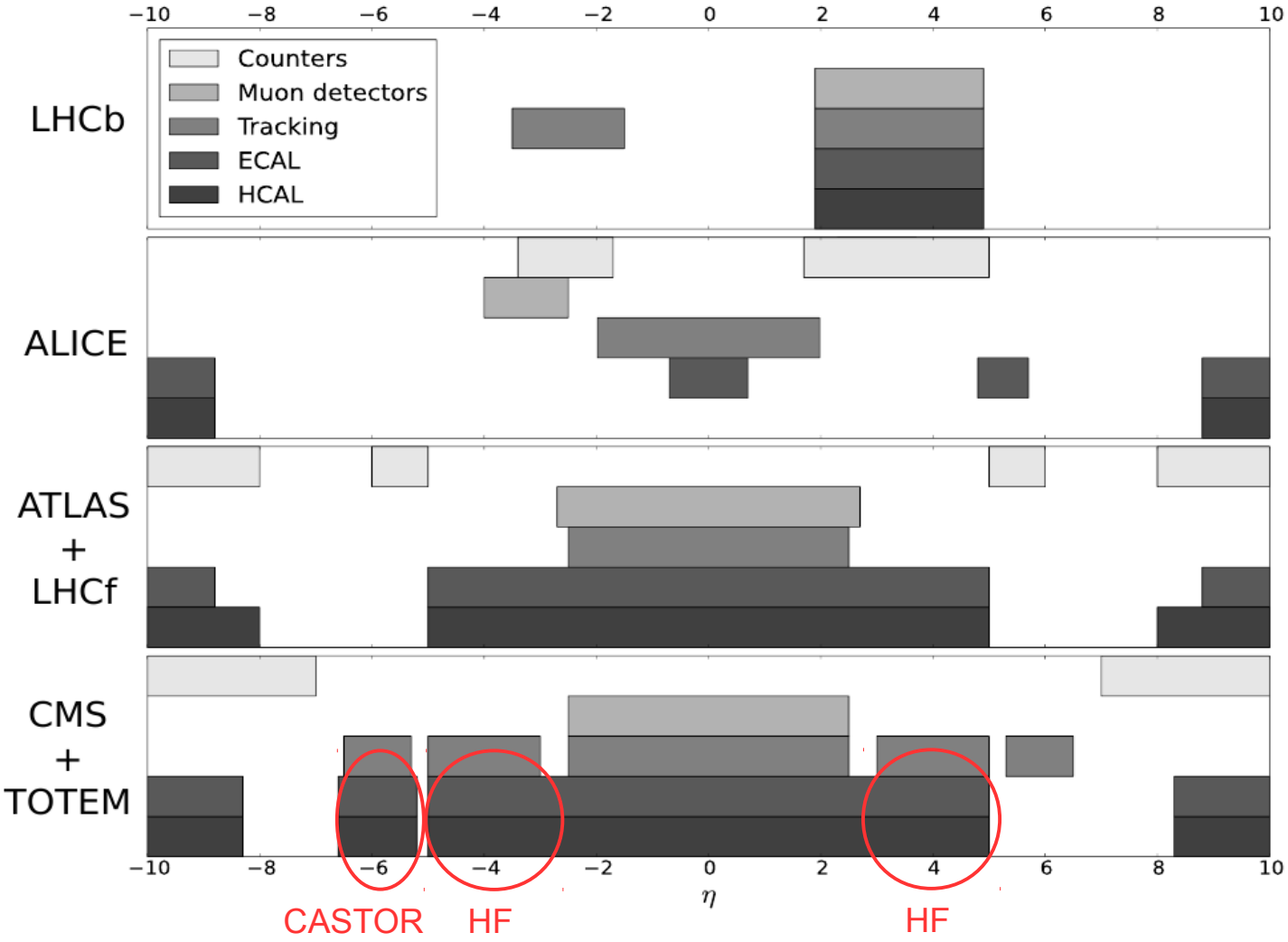
Basic facts and motivation

- LHC operation in 2015
  - Setting the stage for successful Run 2
  - Record center-of-mass energy, 13 TeV
  - Luminosities corresponding to pileup up to ~40 interactions/bx
  - Several periods of low luminosity / low PU running

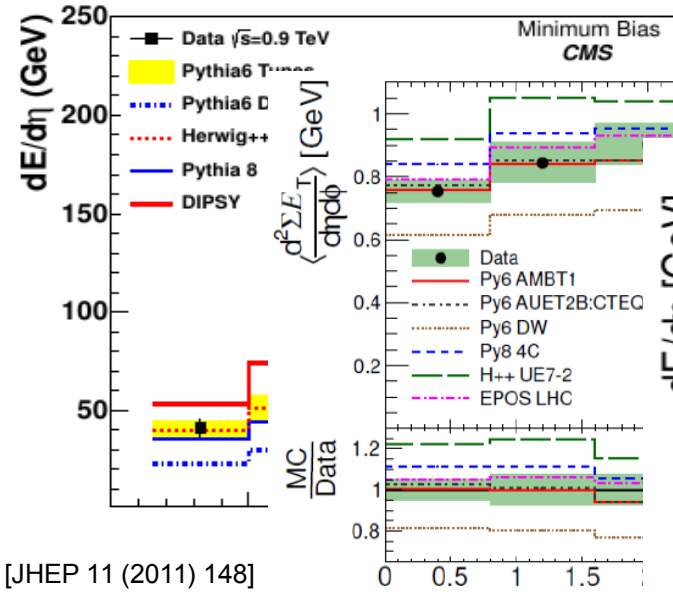
- Physics motivation
  - New exciting physics is always on top of a 'pedestal' of (at least) several soft interactions which we never measured at this energy scale
  - Modeling of soft-inclusive particle production have important consequences for precision high-p_T measurements (example: top mass)
  - Useful input for further tuning of hadronic interaction models
  - Important reference for models used in cosmic ray physics to be able to extrapolate to highest energies



[Thesis C.Baus]

- CMS is nicely equipped for benchmark energy flow measurements

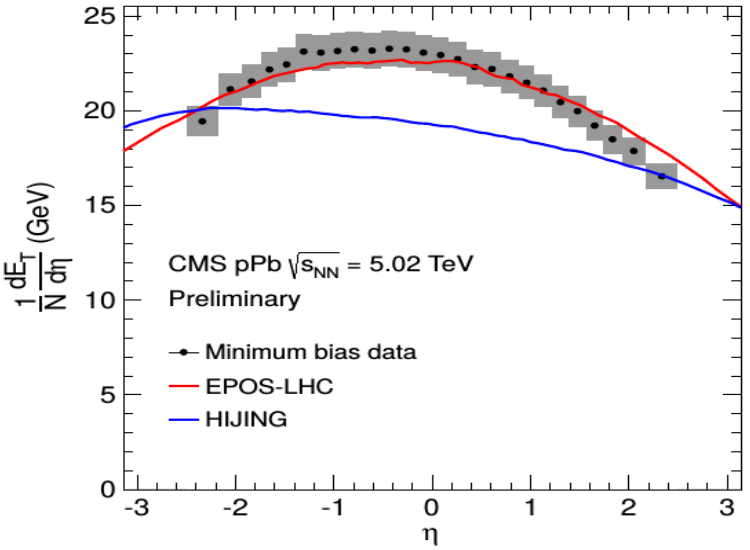
What has been done so far at LHC?



[JHEP 11 (2011) 148]

[JHEP 11 (2012) 033]

[CMS-HIN-12-006]

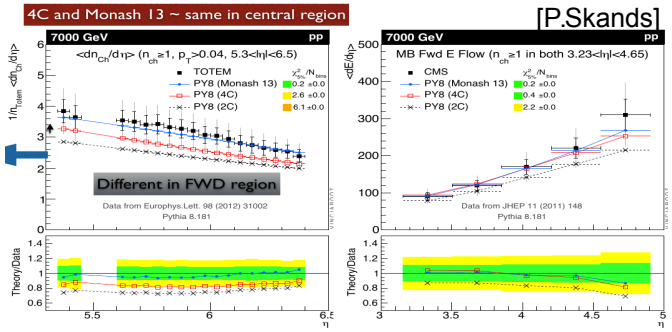


[CMS-HIN-14-014]

- Measurements performed for pp (900 GeV, 7 TeV), pPb (5TeV), PbPb (2.76 TeV)
- We naturally continue along this line and measure at 13TeV as well and focus on the forward region ($3.15 < |\eta| < 6.6$) where most of the energy goes

Hadronic interaction models

- Pythia8, tuned to LHC Run 1 results
  - Hard scattering matrix elements + parton showering + string fragmentation
  - Highly 'tunable': fragmentation, underlying event including/colour reconnections/partonic re-scattering, diffraction
    - Underlying event tune Monash 2013
    - CMS tunes CUETP8M1/CUETP8S1
    - MBR model for diffraction



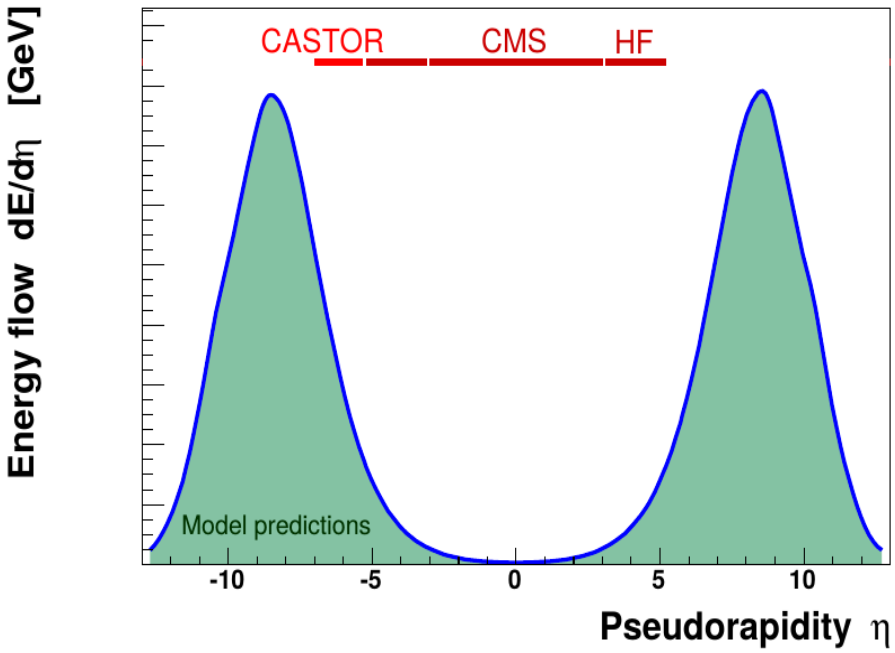
- EPOS-LHC and QGSJET II.04,

  tuned to LHC Run 1 results,

  commonly used in cosmic ray physics,

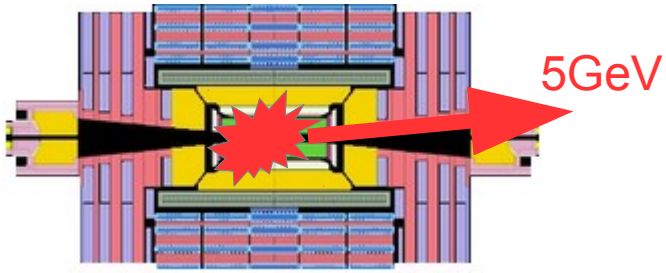
  focus on soft interactions
  - Gribov-Regge multiple scattering + string fragmentation
  - EPOS includes collectivity/hydrodynamic component in a parametrized form
  - EPOS compared to QGSJET is more 'phenomenological'/'tunable'
- There are nice tools to compare corrected results to a large variety of models (example: mcplots.cern.ch); we picked up just a few for to draw basic conclusions

Energy flow in data: sum up calorimeter energies for two events classes

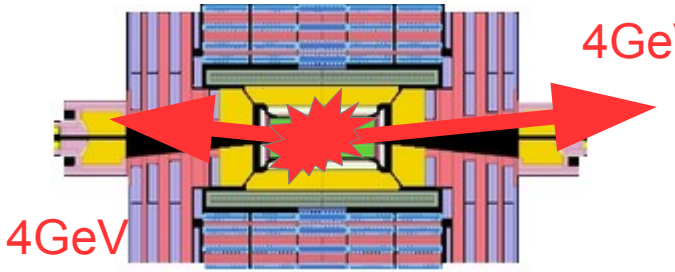


$$\frac{dE}{d\eta}(\eta) = \frac{1}{N}\frac{1}{\Delta\eta}\sum_j E^j \,(\text{if } E^j > noise)\cdot C(\eta)$$

Sum over calorimeter towers per η-bin
PU-corrected (factor ~1.025)
Noise estimated from non-colliding bunches



Single sided collision event activity / 'HF-OR' /
Soft-inclusive-inelastic events



Double sided collision event activity / 'HF-AND' /
Non-single-diffractive-enhanced events

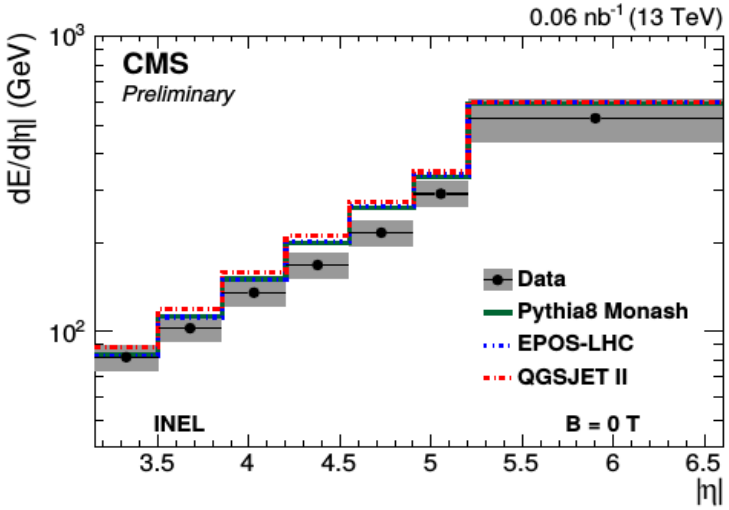
Data corrected to particle level

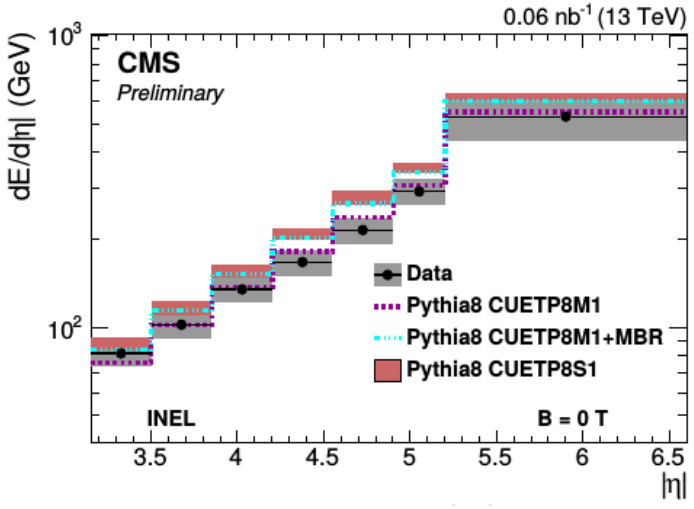
- Count only stable particles, w/o energy threshold (hadrons and leptons with $c\tau > 10$ mm, excluding μ's and ν's)
- Energy in each η-bin: sum of particle energies
- Soft-inclusive-inelastic events: $\xi = M^2_x / \sqrt{s} > 10^{-6}$
- Non-single-diffractive-enhanced events: at least one particle (charged or neutral) in nominal HF acceptance on both sides w.r.t. nominal IP of CMS

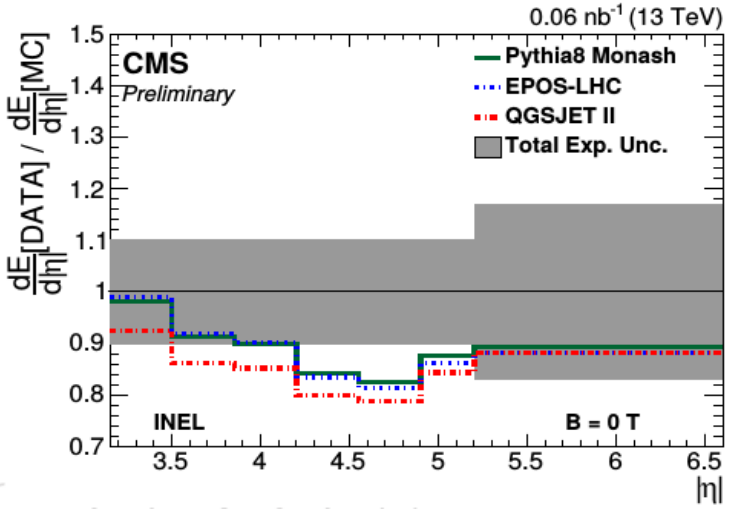
- 4 models used (take average + envelope for uncertainties, correction factor values below 2.5)
  - Pythia8 Monash
  - Pythia 4C+MBR
  - EPOS-LHC
  - QGSJETII.04

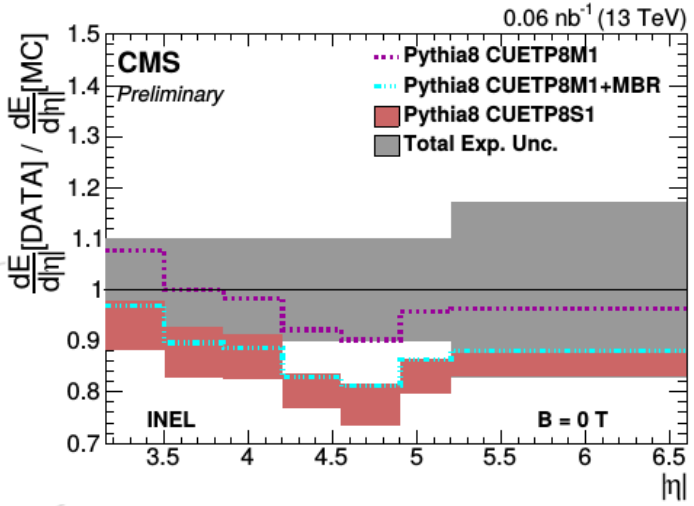
Check of systematic effects

	Soft-inclusive inelastic events	Non-single diffractive events
Model dependence of correction factor	< 3.5%	
Influence of noise on selection	< 1.75%	< 0.5%
Influence of noise on energy sums	< 1.2%	
Calorimeter global energy scale in $3.15 < \|\eta\| < 5.20$	10%	
Calorimeter global energy scale in $5.20 < \|\eta\| < 6.6$	17%	

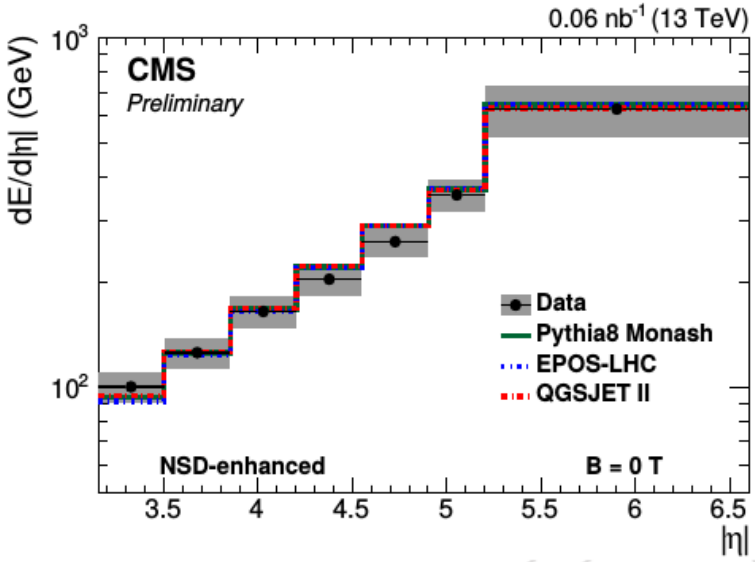


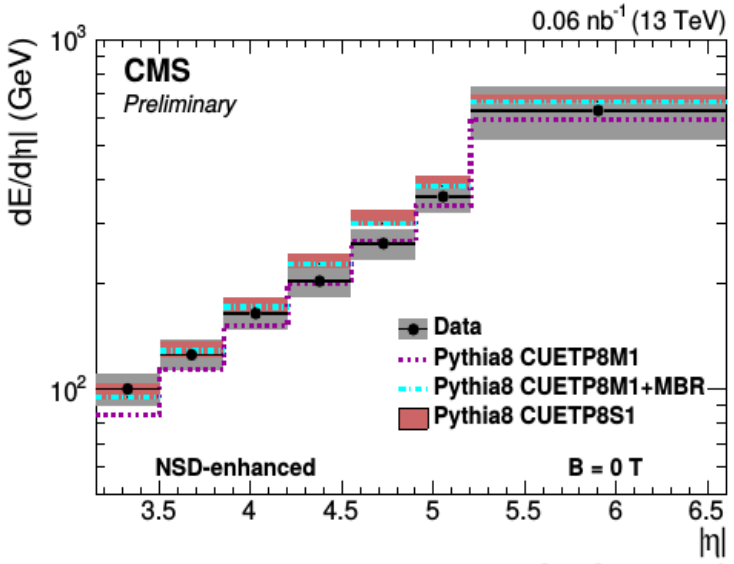


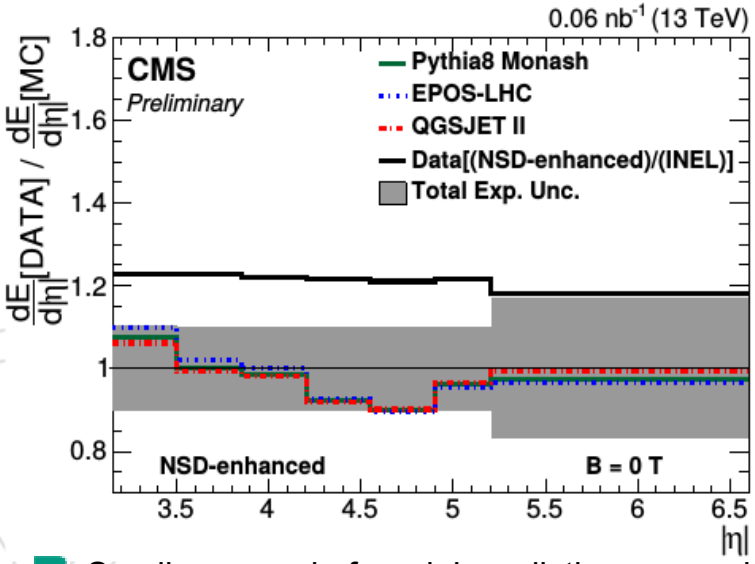


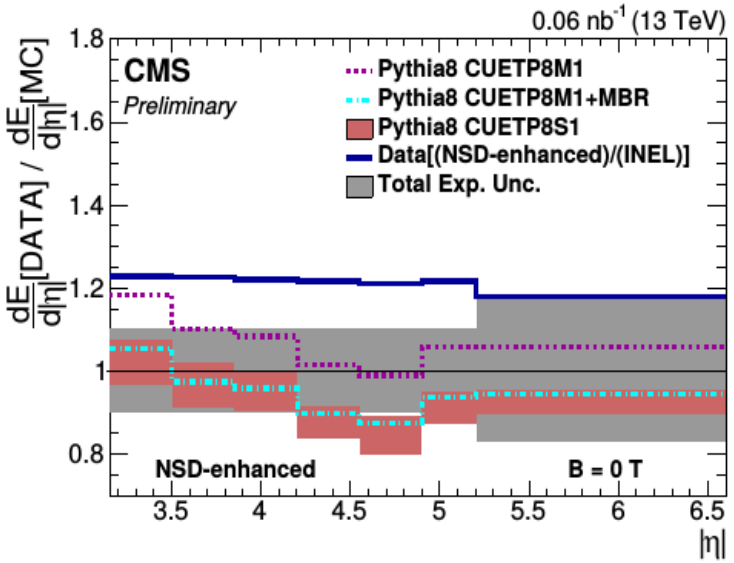


- The spread in the model predictions is large for soft-inclusive-inelastic events (INEL)
- Pythia8 Monash vs EPOS/QGSJET: comparable results
- CUETP8M1 vs CUETP8M1+MBR: effect of variation of diffractive parameters
- CUETP8S1+uncertainties: dominant contribution from color reconnection parameters





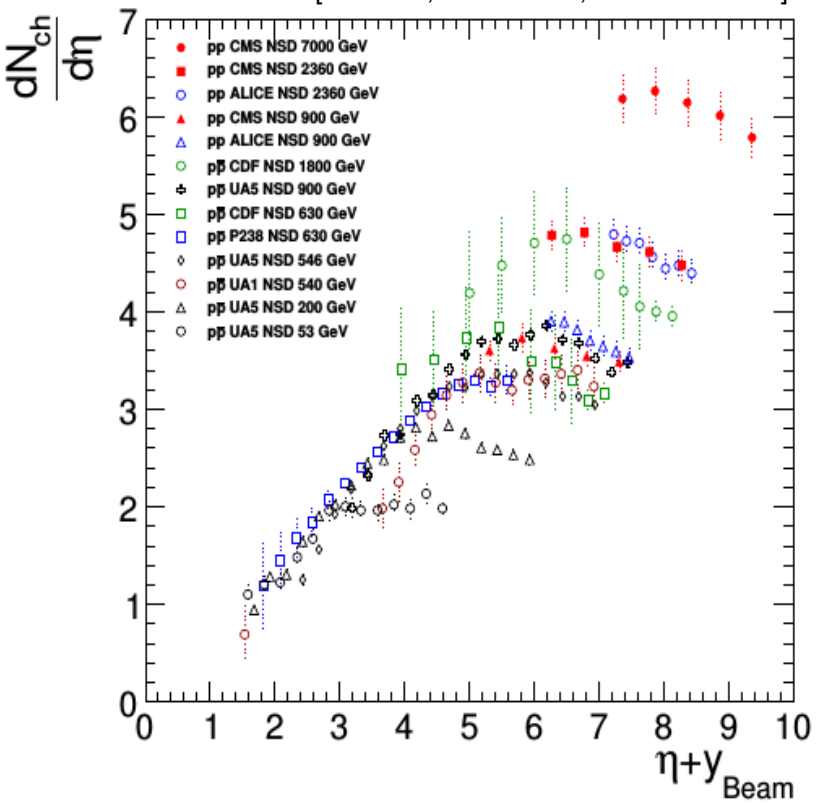




- Smaller spread of model predictions: non-single-diffractive-enhanced (NSD-enhanced) vs soft-inclusive-inelastic (INEL)
- Overall reasonable description of data by predictions given uncertainties of data

Is there a way to compare results obtained at different center-of-mass energies?

[W.Busza, Yen-Jie Lee, arxiv 1102.3921]



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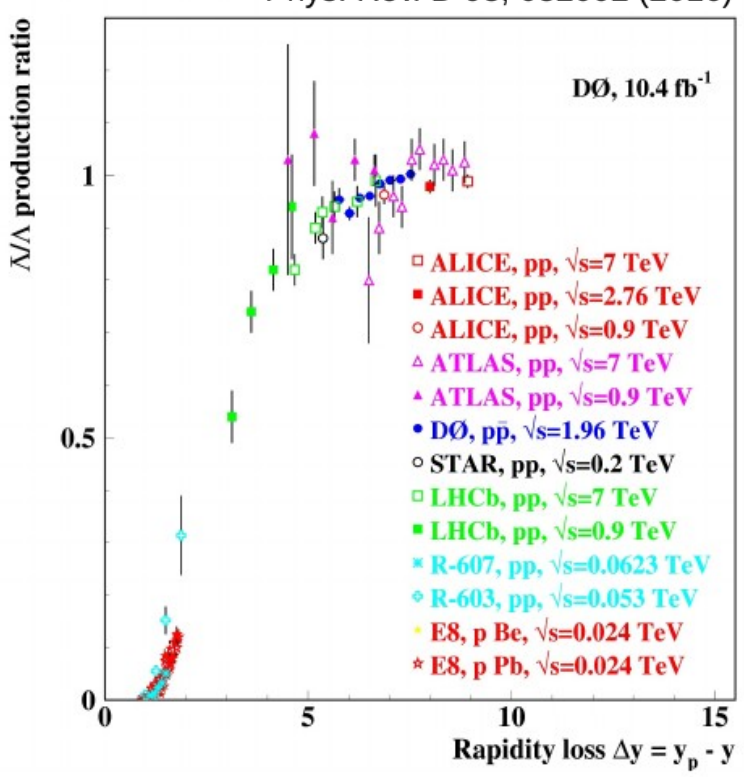
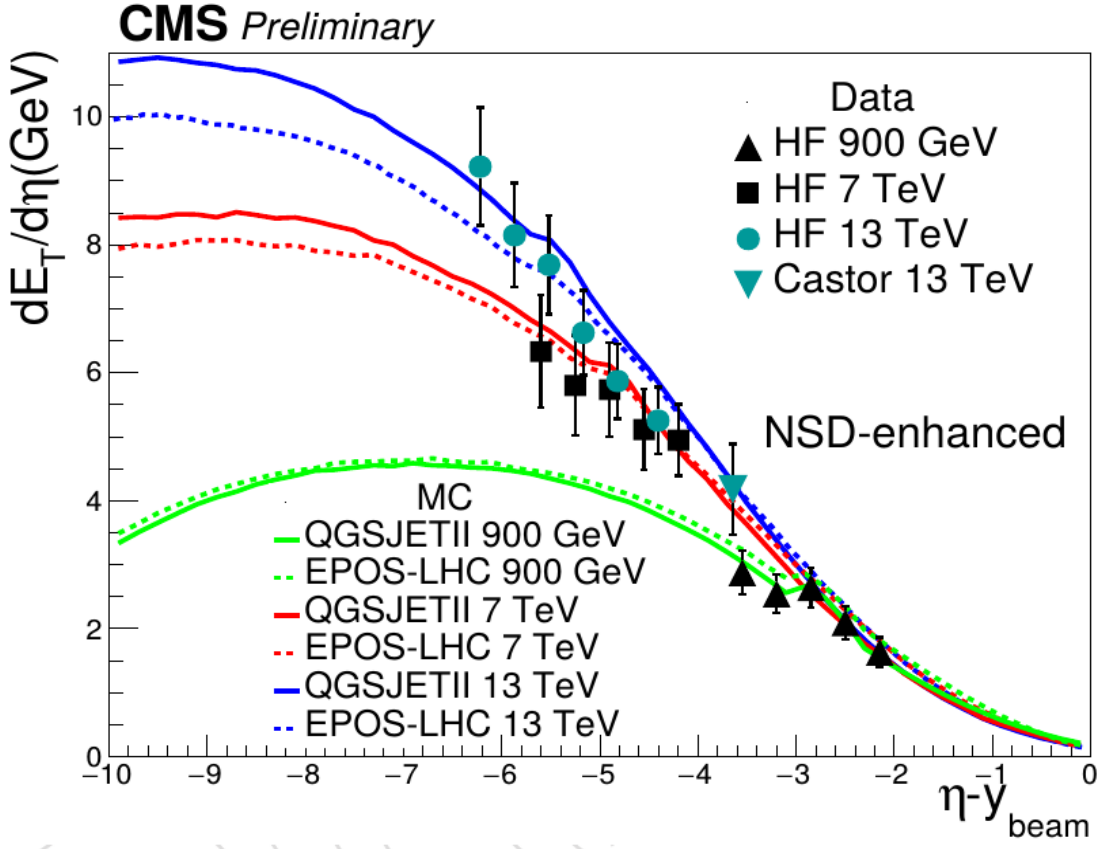


- Hypothesis of limiting fragmentation for high energy hadronic interactions: longitudinal scaling behavior in terms of the, $\eta' = \eta - y_b$, (pseudo)rapidity shifted by beam rapidity; soft particle production in the region close to beam rapidity, $\eta' \sim 0$, becomes independent of center-of-mass energy

Limiting fragmentation



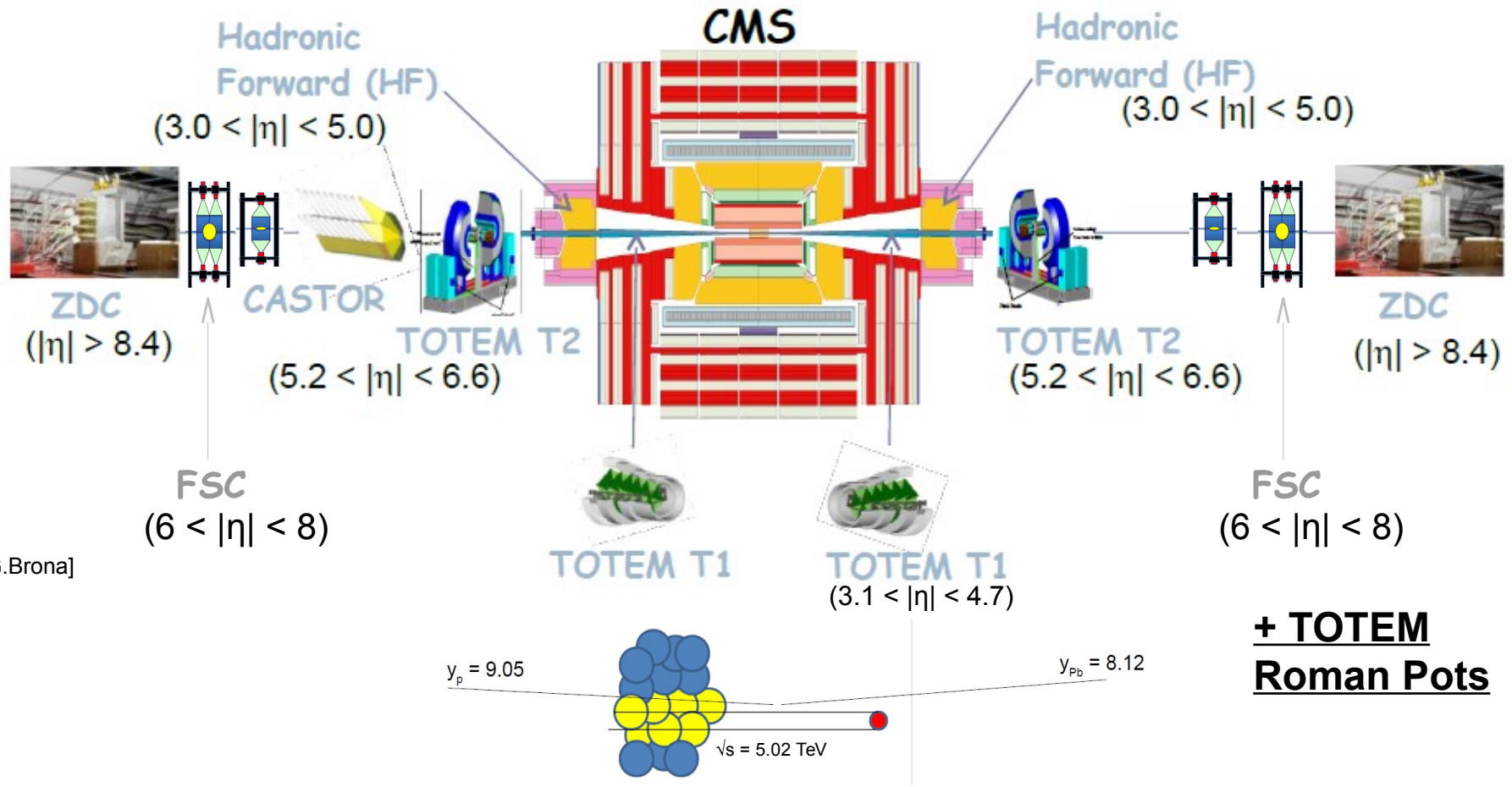
- Simple geometry factors to get E_T from E; particle level definition adjusted to agree with previous data
- Obvious trend on which results obtained at different center-of-mass energies line up

Summary

- We present measurements of energy flow in the forward region, in pseudorapidity range $3.15 < |\eta| < 6.6$, in pp-collisions at 13 TeV
- Energy flow as a function of pseudporapidity is studied for two event classes, soft-inclusive-inelastic and non-single-diffractive
- We compared our data to several hadronic interaction models: Pythia8, EPOS-LHC, QGSJETII.04
- The spread in model predictions is large, in general models provide reasonable description of data, given the uncertainties
- Results are studied in terms of shifted pseudorapidity variable, $\eta - y_b$, and compared to earlier data at 900 GeV and 7 TeV
- Overall consistency with hypothesis of limiting fragmentation is found

BACKUP

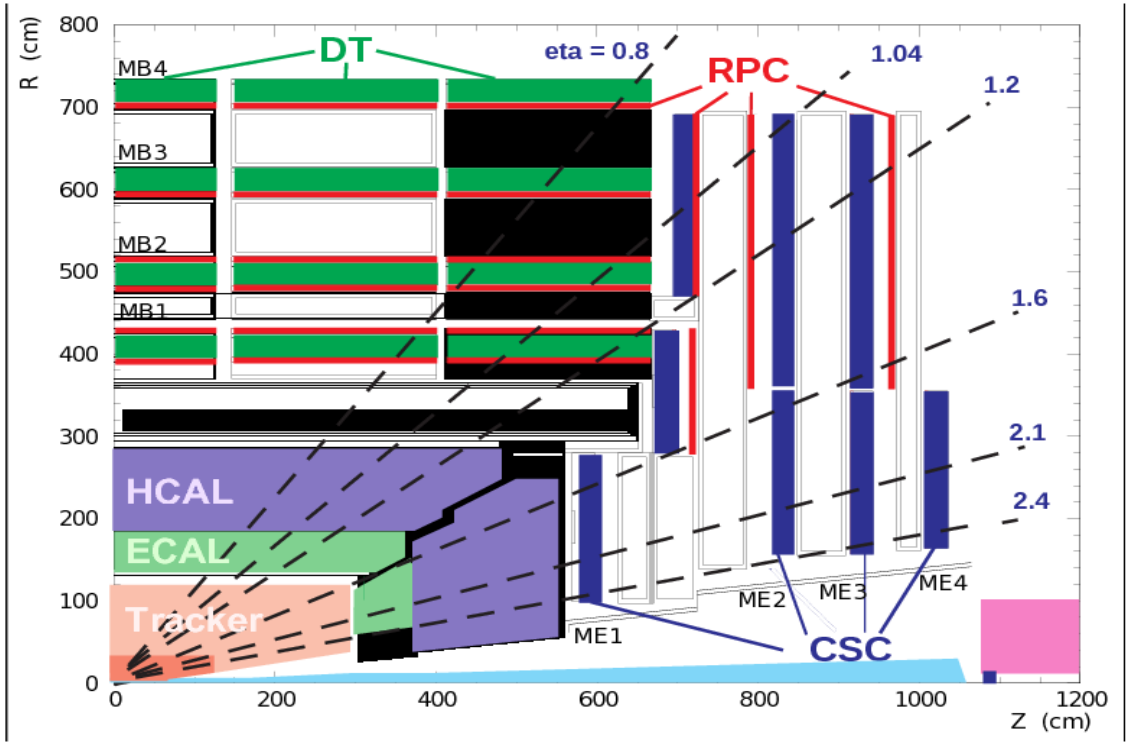
Rich forward instrumentation around common interaction region of CMS and TOTEM experiments



[G.Brona]

+ TOTEM Roman Pots

Central region of CMS detector

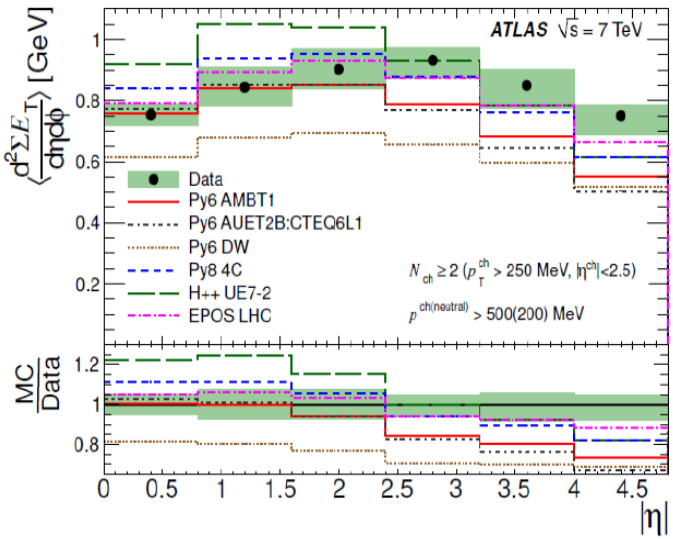


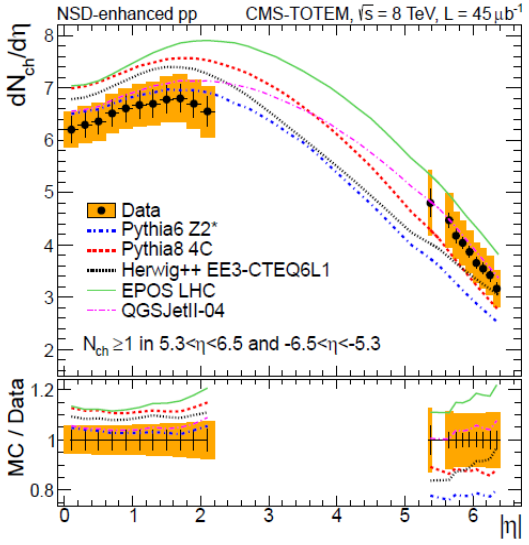
[JINST 7 (2012) P10002]

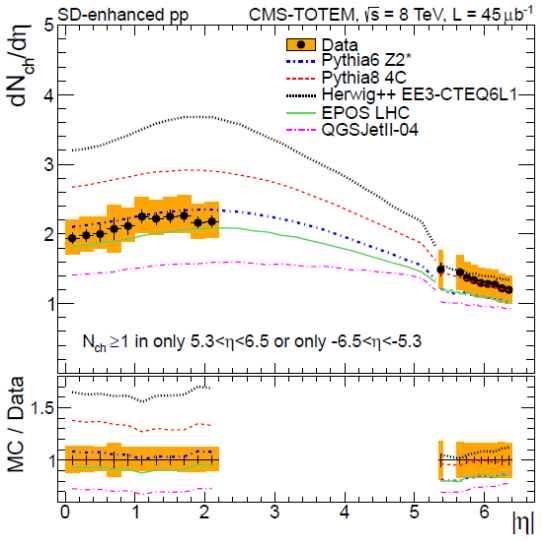
Pseudorapidity density: central vs forward, non-diffractive vs diffractive

[JHEP 11 (2012) 033]

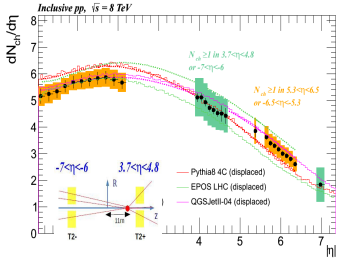
[arXiv:1405.0722, EPJC 74 (2014) 2053]







- Collider experiments forward region very important for understanding of high energy hadronic interactions
- Central-forward correlations
- Spread of model predictions for SD-enhanced sample



[K. Österberg, arXiv:1411.4963]