Forward energy flow and jet measurements with CMS

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on behalf of the **CMS** collaboration

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Why study forward energy flow?

- Study QCD and its (low x parton) dynamics

- Kinematic range relevant for cosmic air showers

-> use to test and/or tune cosmic ray air shower models

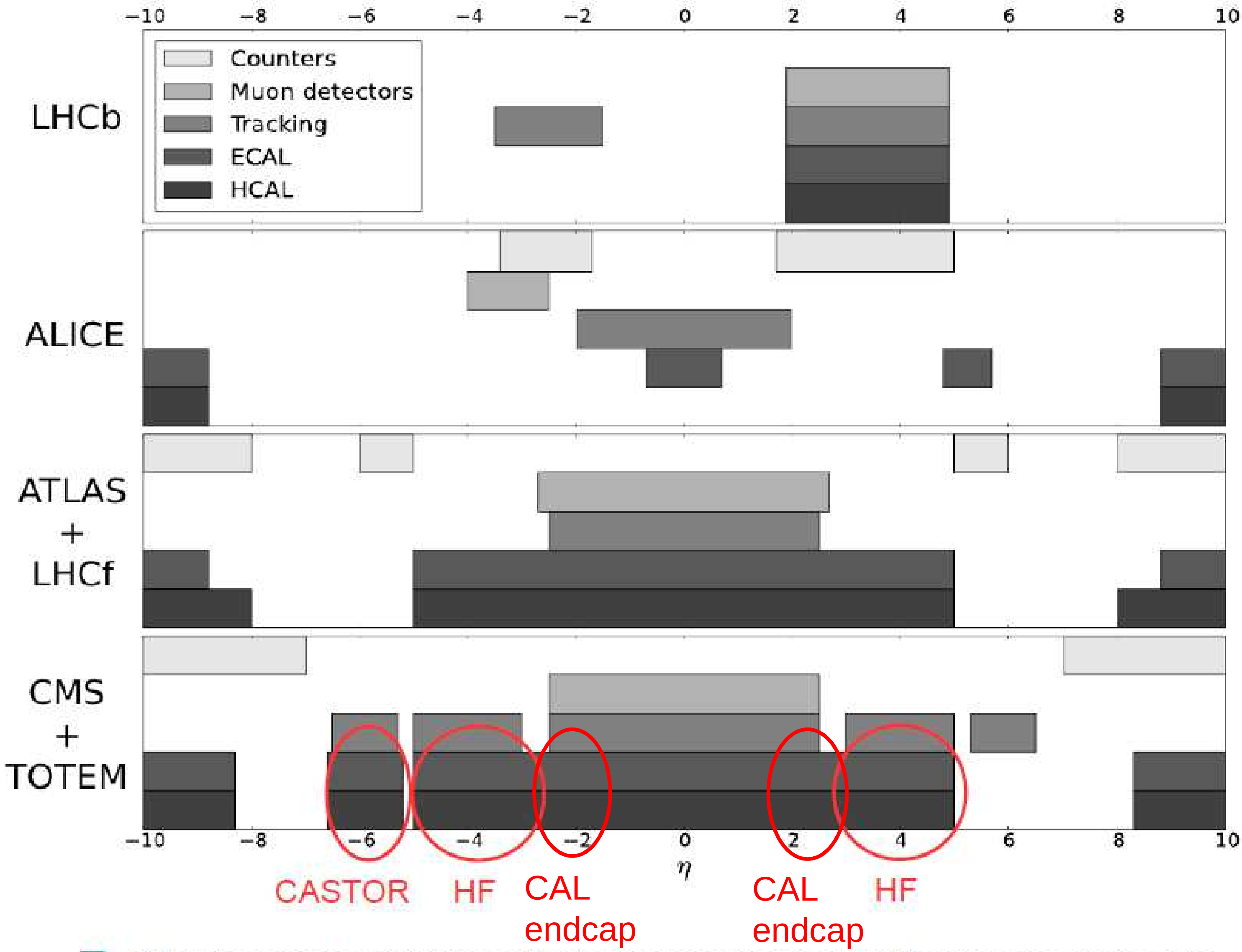
- In most LHC interactions, most of energy goes forward

-> good coverage for total inelastic cross section measurement

- Wide rapidity coverage

-> good coverage of large rapidity gaps,
test colour singlet exchange

How to do this in CMS?



[Thesis C.Baus]

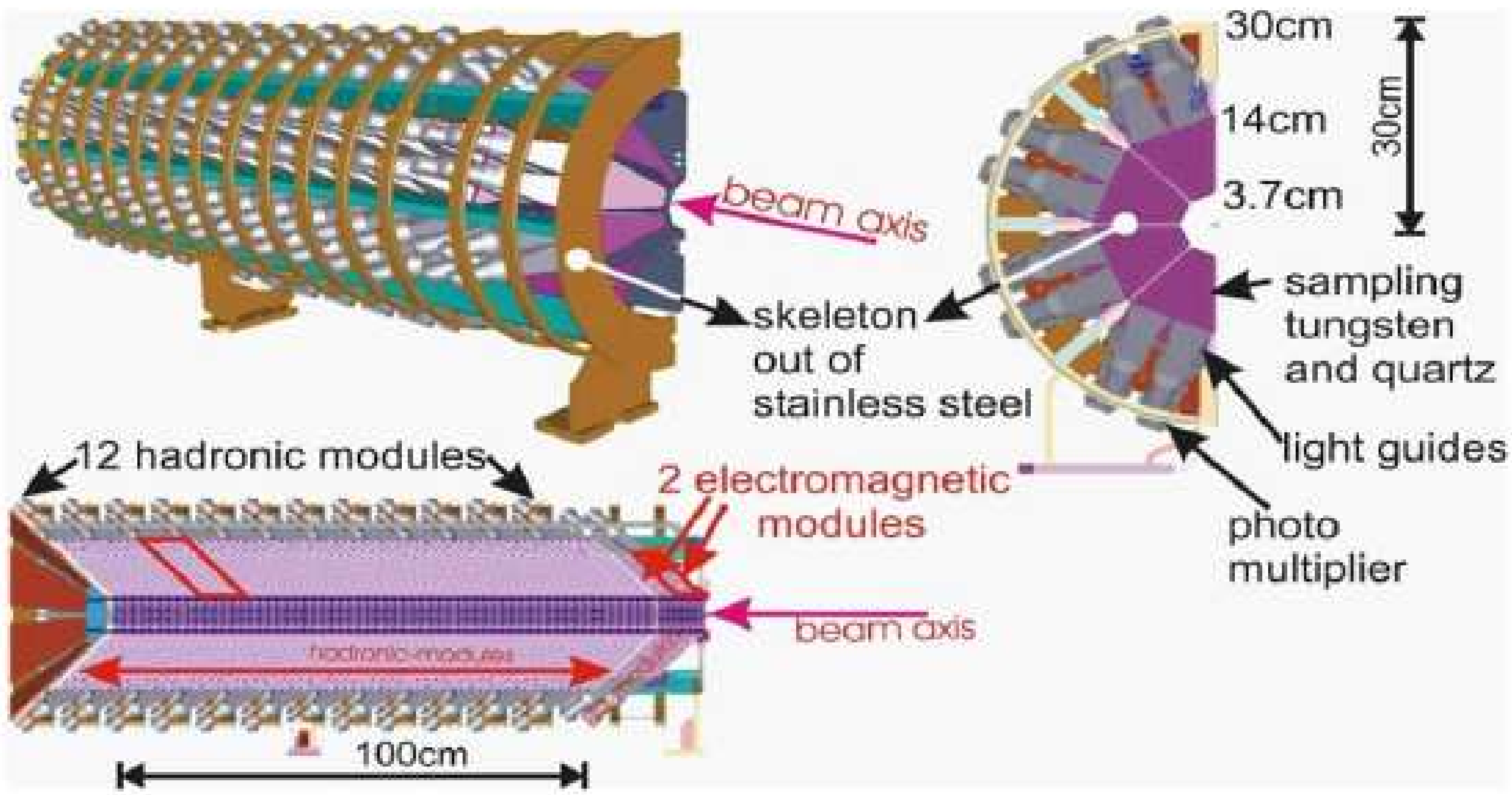
- CMS is nicely equipped for benchmark energy flow measurements

Measurements with CASTOR

very forward energy measurement: $-6.6 < \eta < -5.2$

14-fold segmentation in z,   16-fold segmentation in ϕ,

no segmentation in η

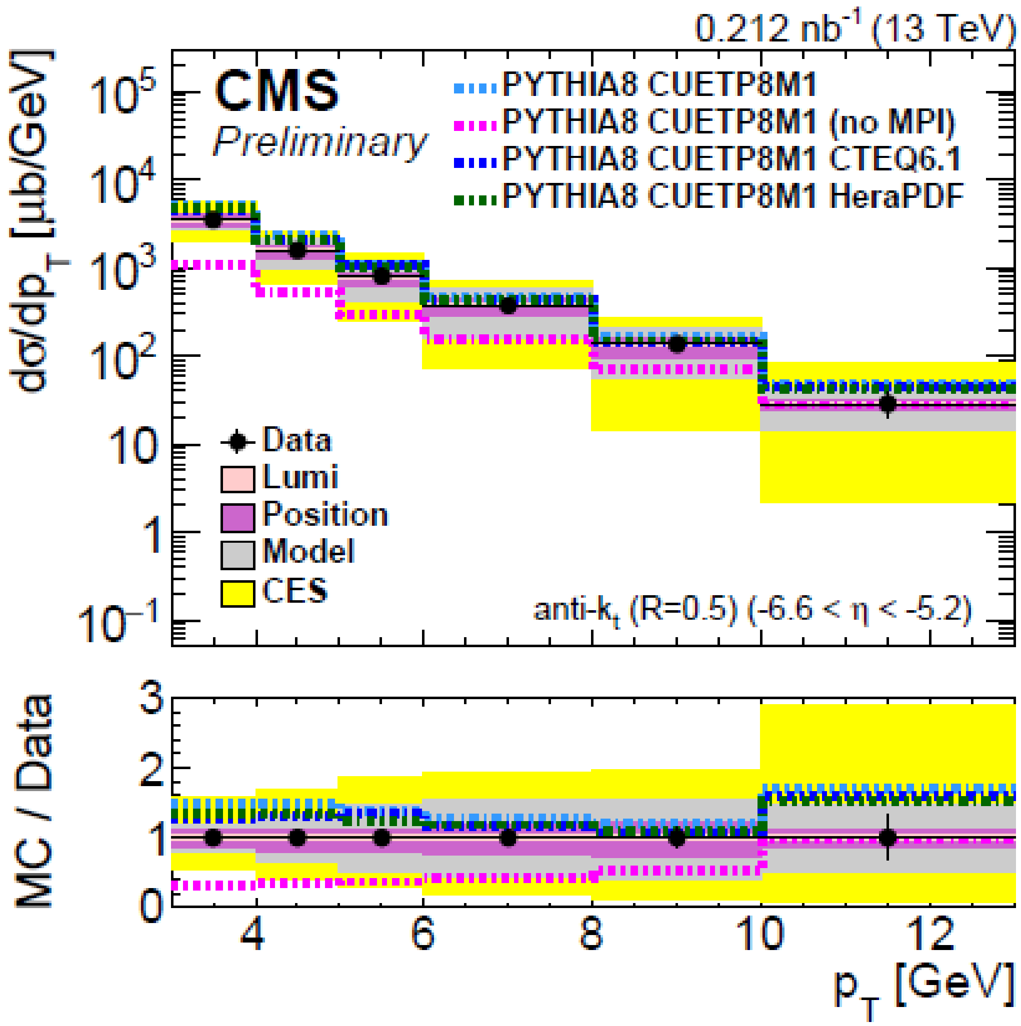


Forward jet p_T spectrum @ 13 TeV

CMS PAS FSQ-16-003

jet p_T

0T runs



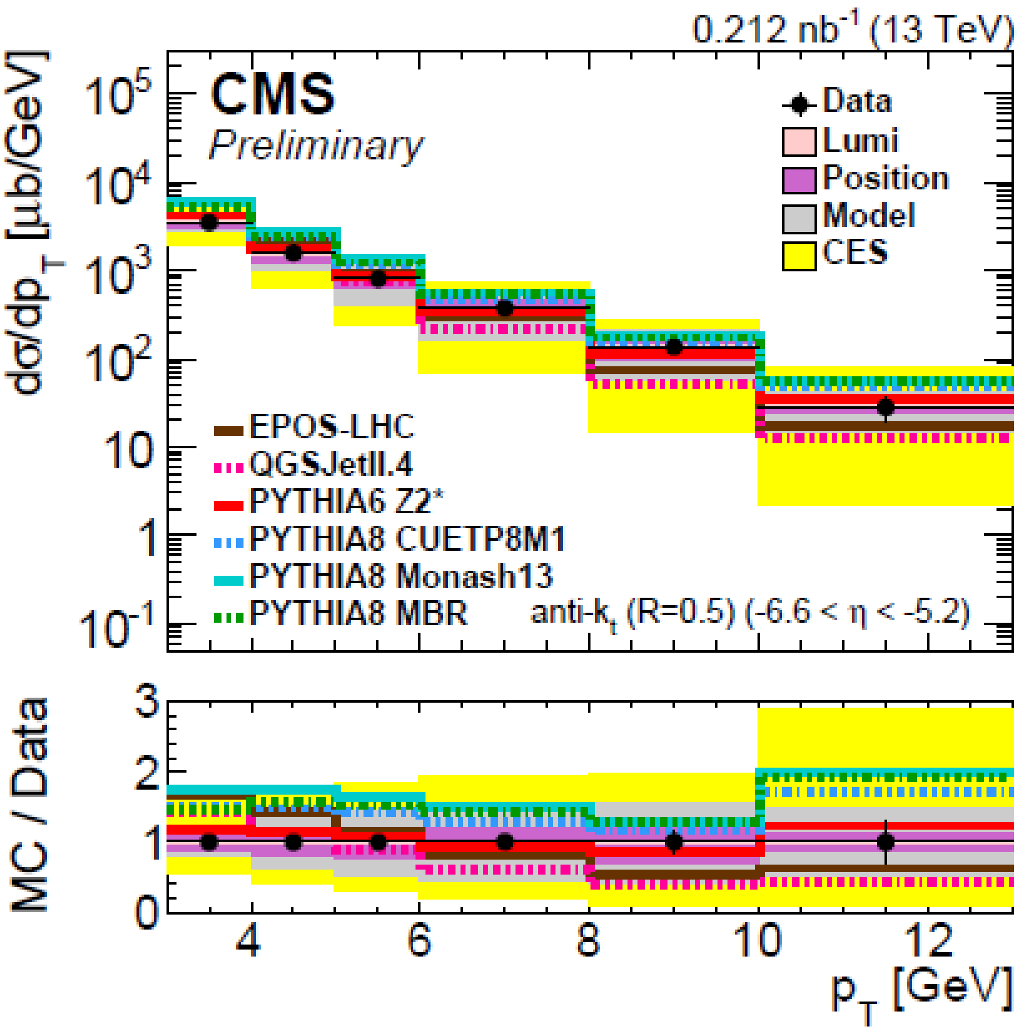
PYTHIA8 (CUETP8M1) gives consistent description

Multi-Parton-Interactions important

Forward jet p_T spectrum @ 13 TeV

CMS PAS FSQ-16-003

jet p_T



cosmic ray shower generators

EPOS and QGSJetII

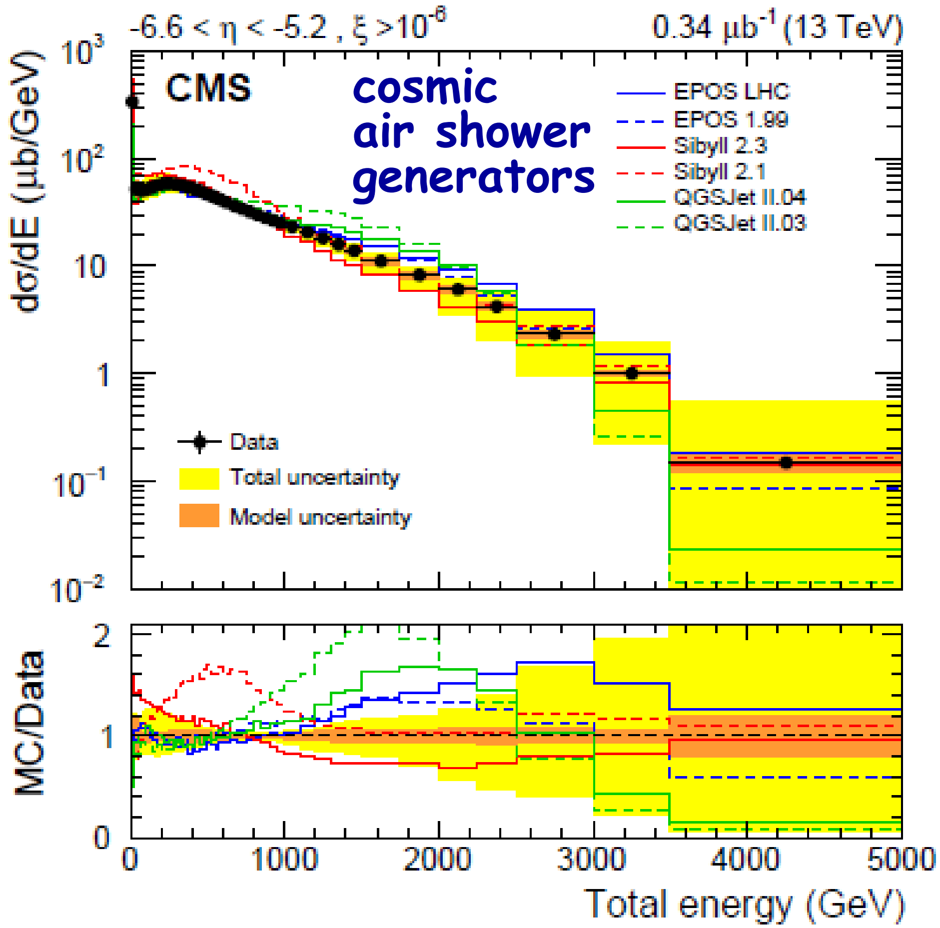
give reasonable description

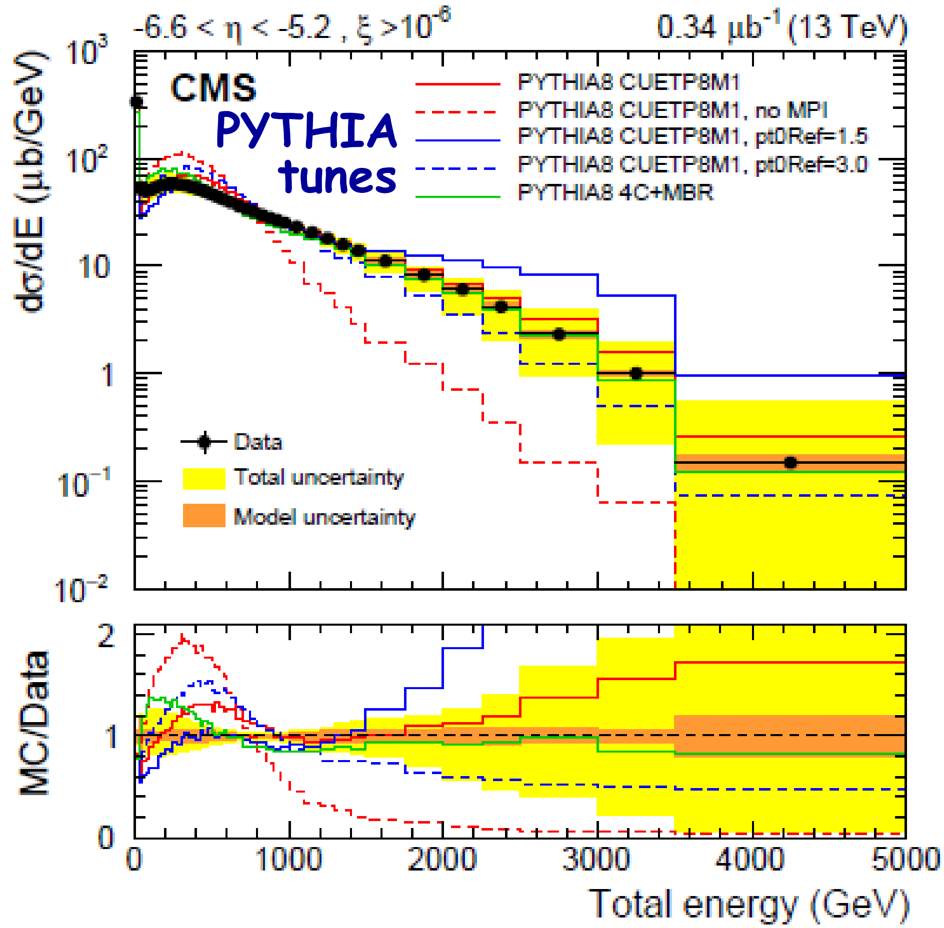
Forward particle production @ 13 TeV

CMS-FSQ-16-002, arXiv:1701.08695, JHEP 1708 (2017) 046

0T runs

total energy of all particles





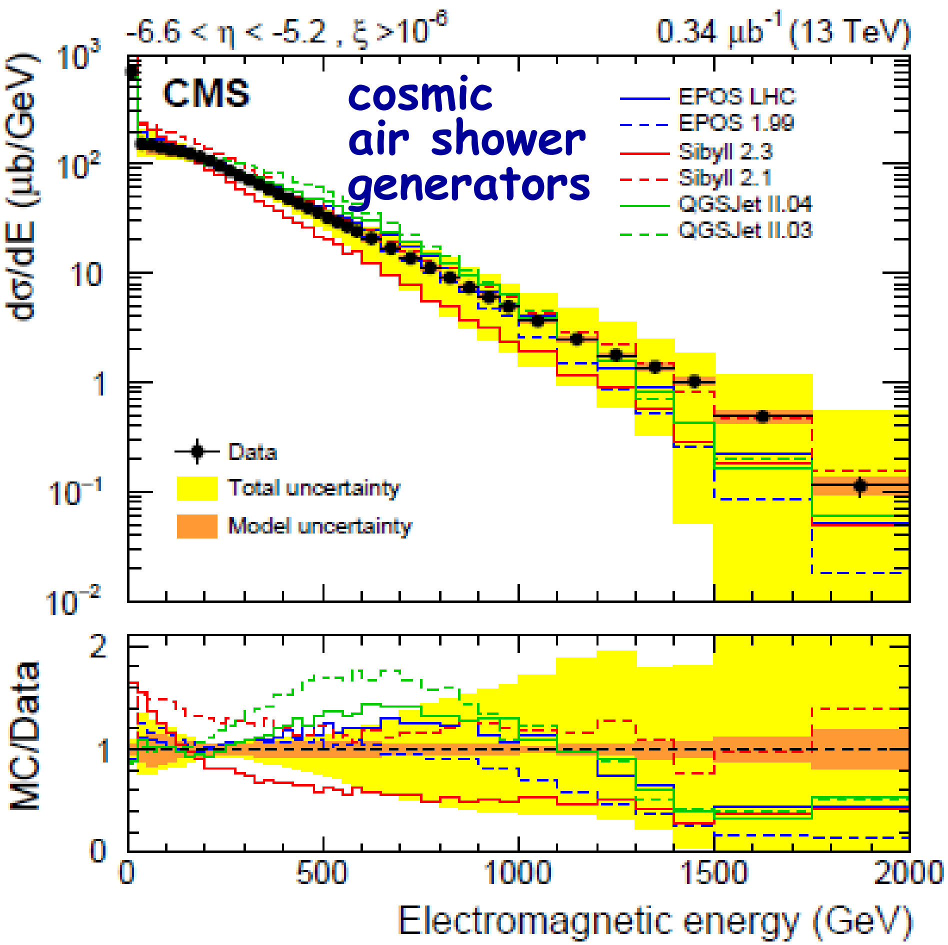
significant check of performance of different generators and tunes

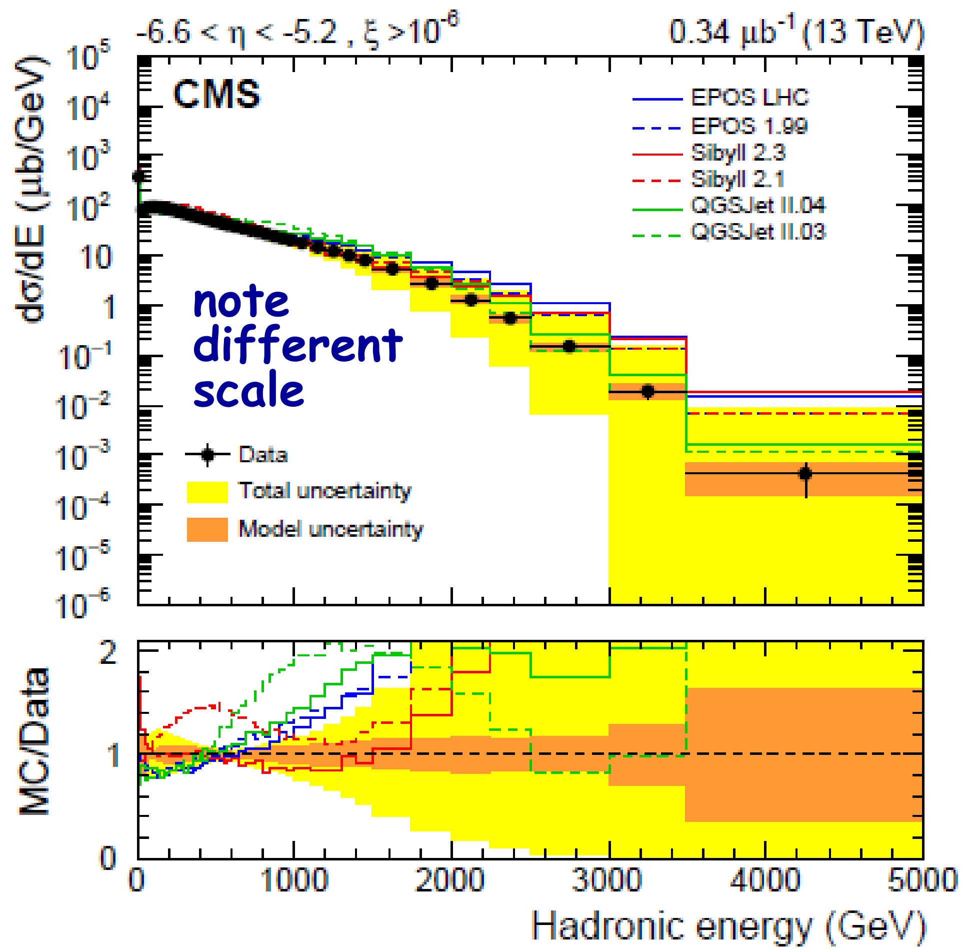
none reproduces all features

Forward particle production @ 13 TeV

CMS-FSQ-16-002, arXiv:1701.08695, JHEP 1708 (2017) 046

electromagnetic (mainly π^0) hadronic (mainly $\pi^{\pm}$)



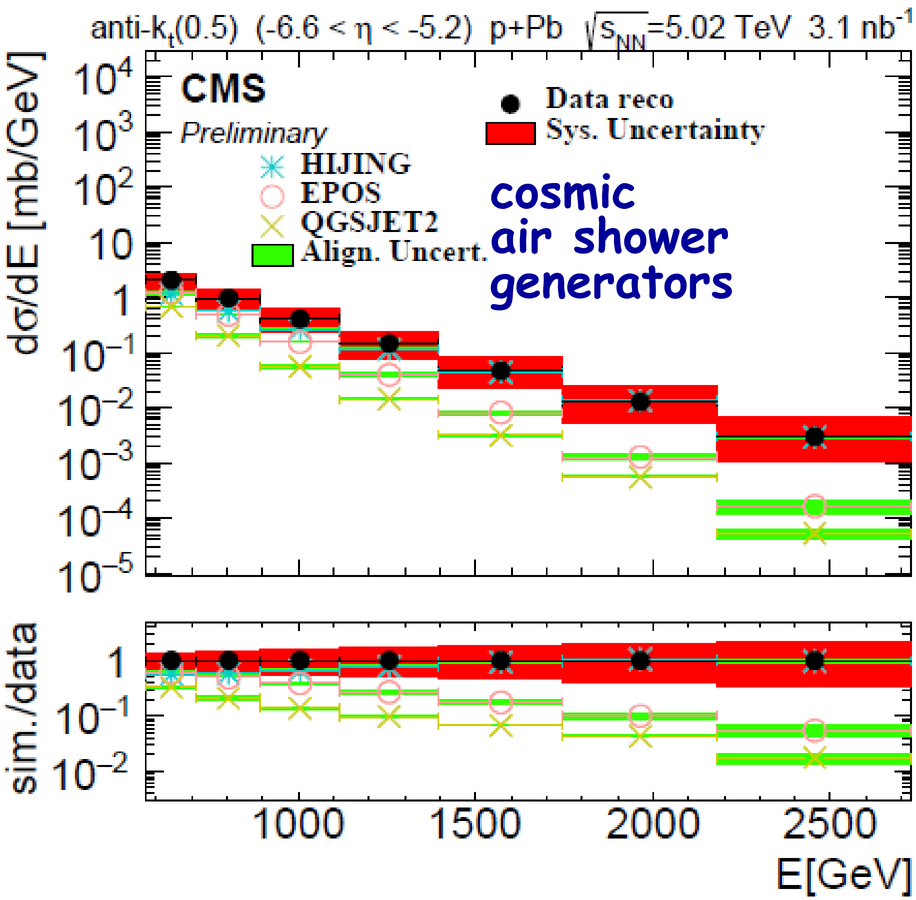


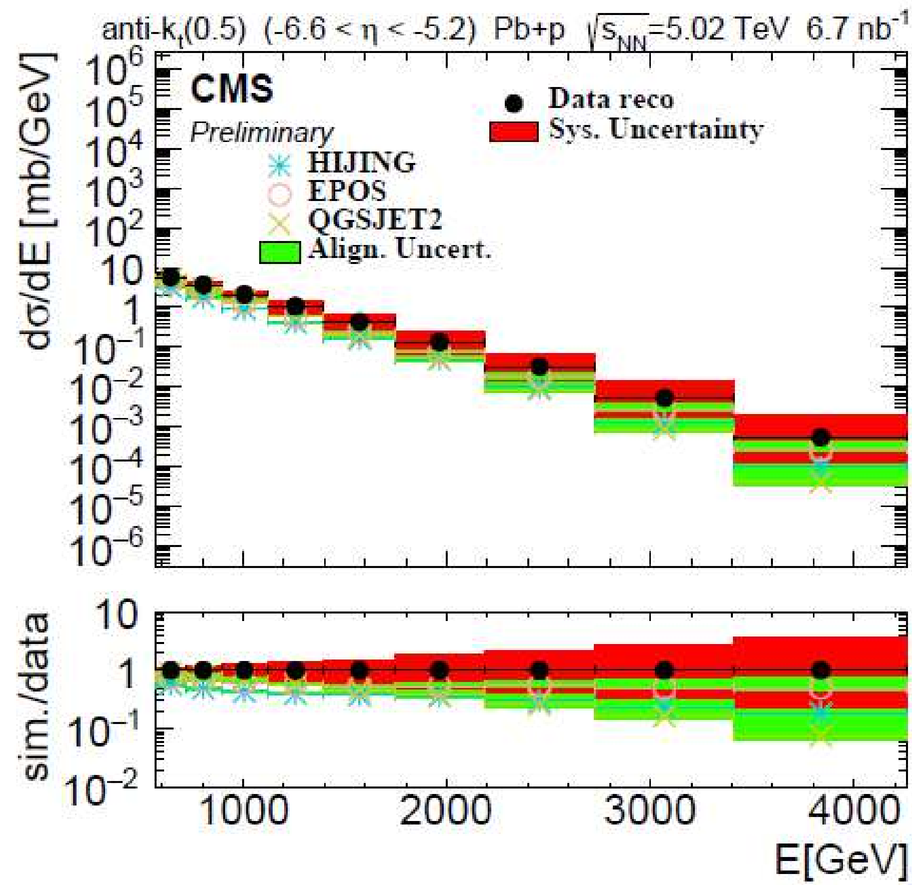
overall, EPOS seems to do best for electromagnetic (π^0) and hadronic ($\pi^{\pm}$) energy fractions

Forward jet production in pPb and Pbp @ 5 TeV

CMS PAS FSQ-17-001, to be published soon

p+Pb (p -> CASTOR) | Pb+p (lead -> CASTOR)





distributions at RECO level (norm. to cross section); **test "saturation"**

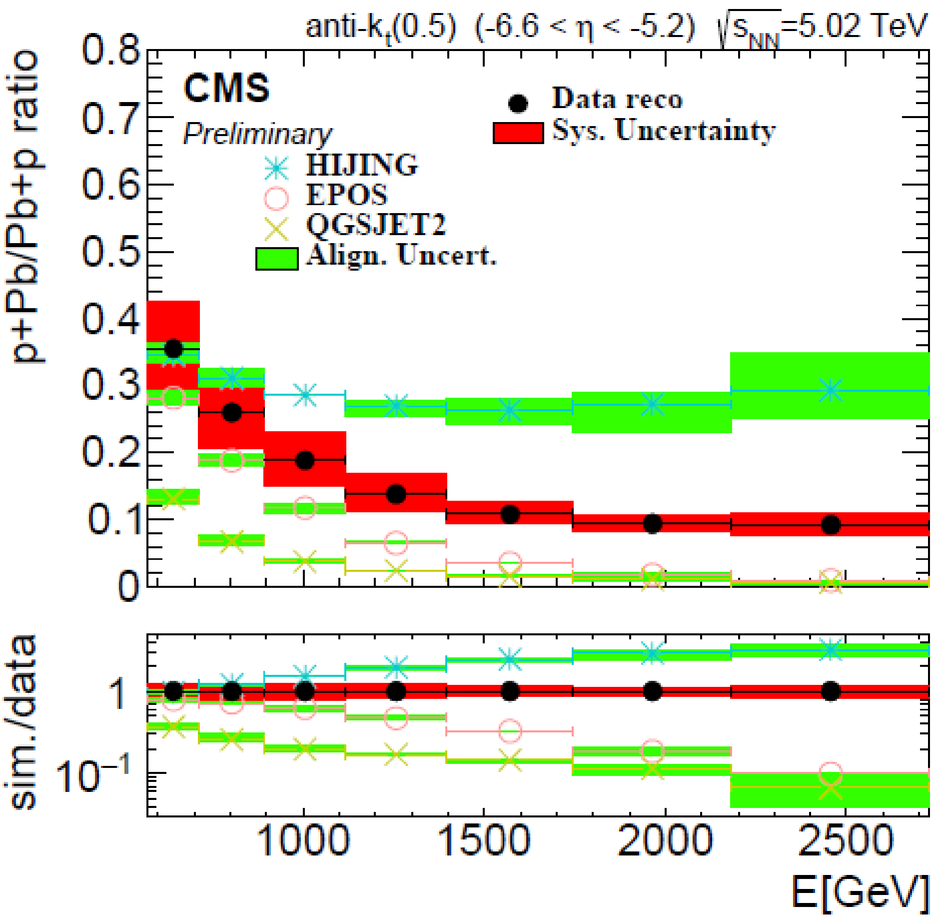
data slope for p->CASTOR not well described by models

Forward jet production in pPb and Pbp @ 5 TeV

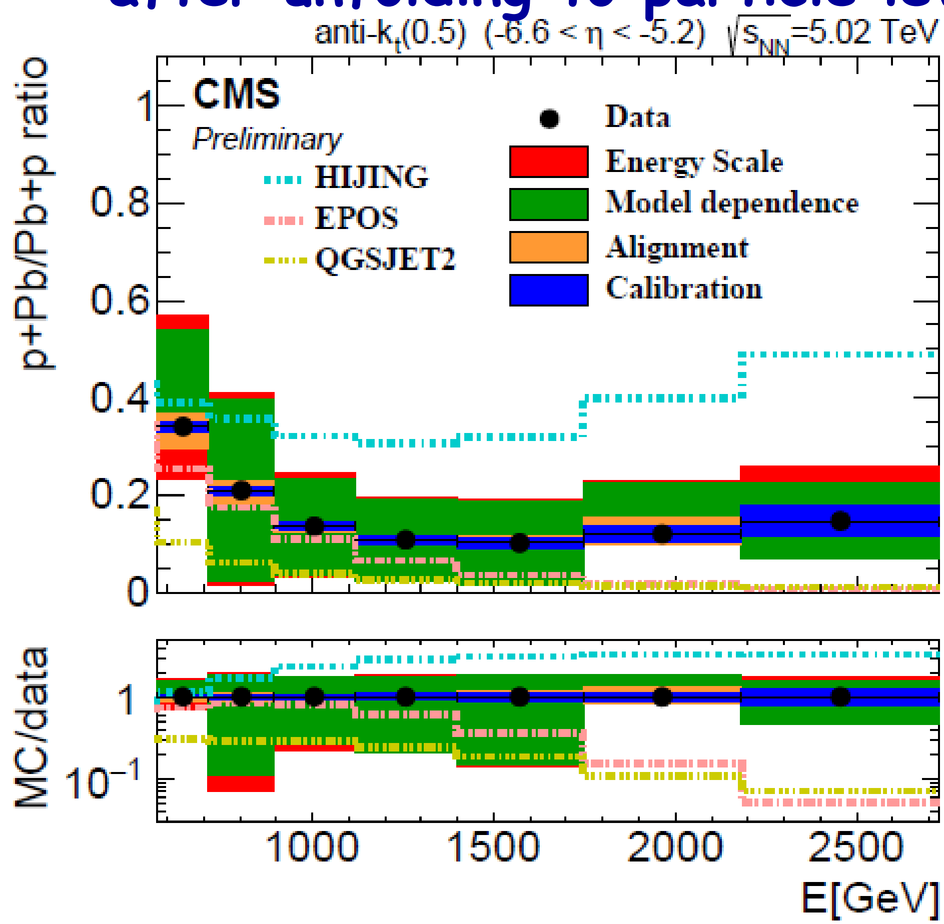
CMS PAS FSQ-17-001, to be published soon

ratio p+Pb/Pb+p

before



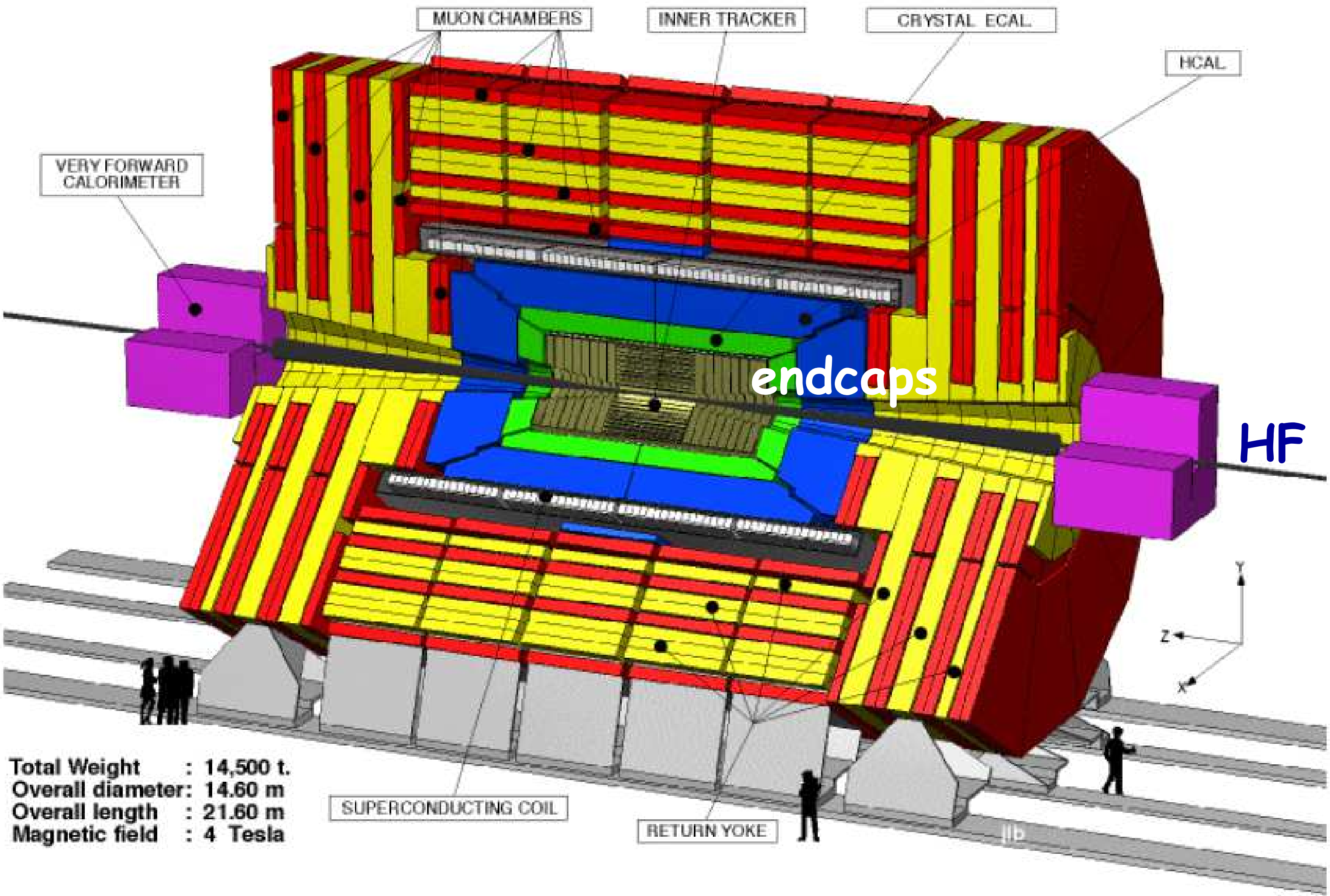
after unfolding to particle level



none of generators performing well,

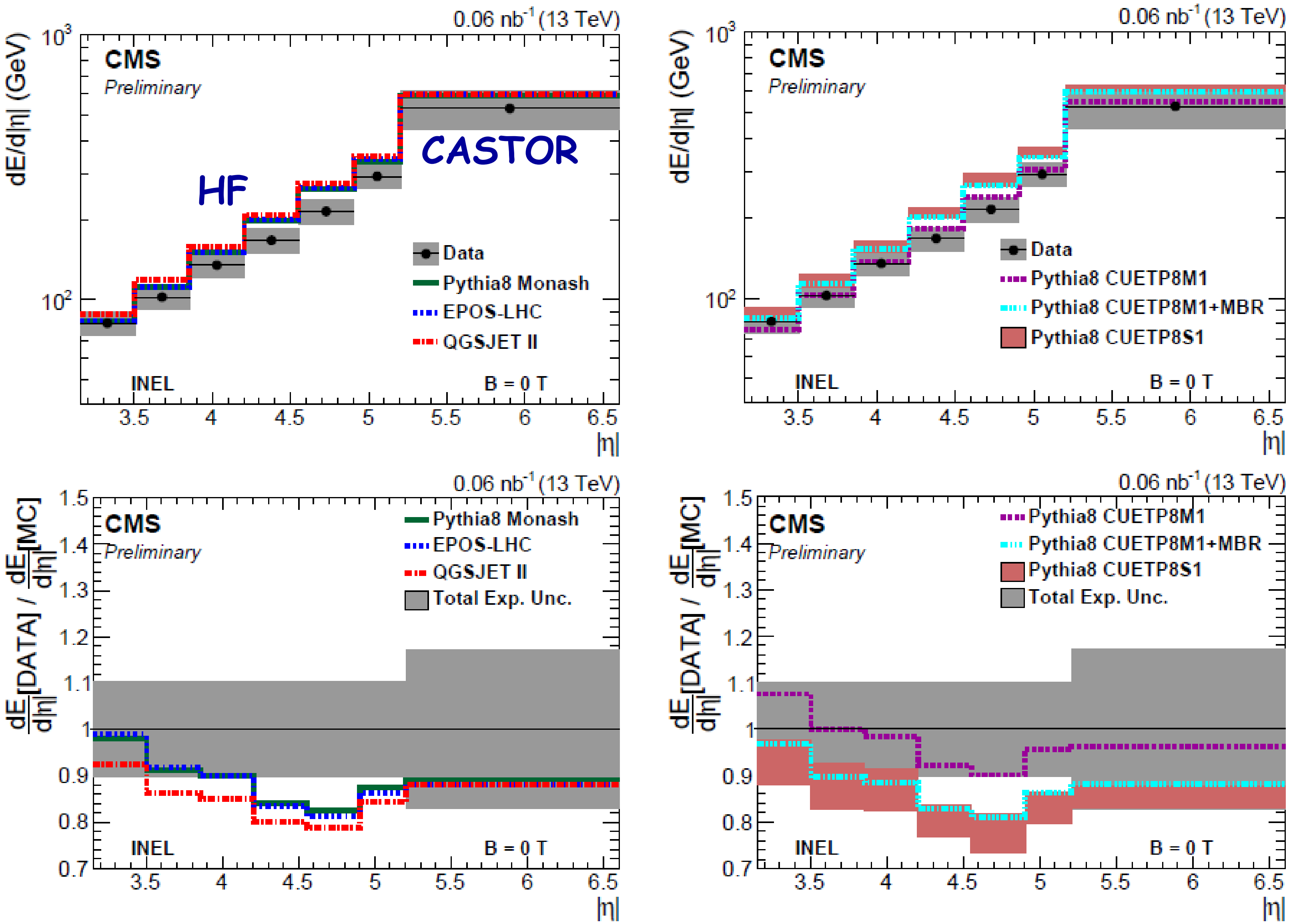
can use unique data to improve !

Measurements with HF (and CAL endcaps)



Forward energy/unit rapidity in pp @ 13 TeV

CMS PAS FSQ-15-006



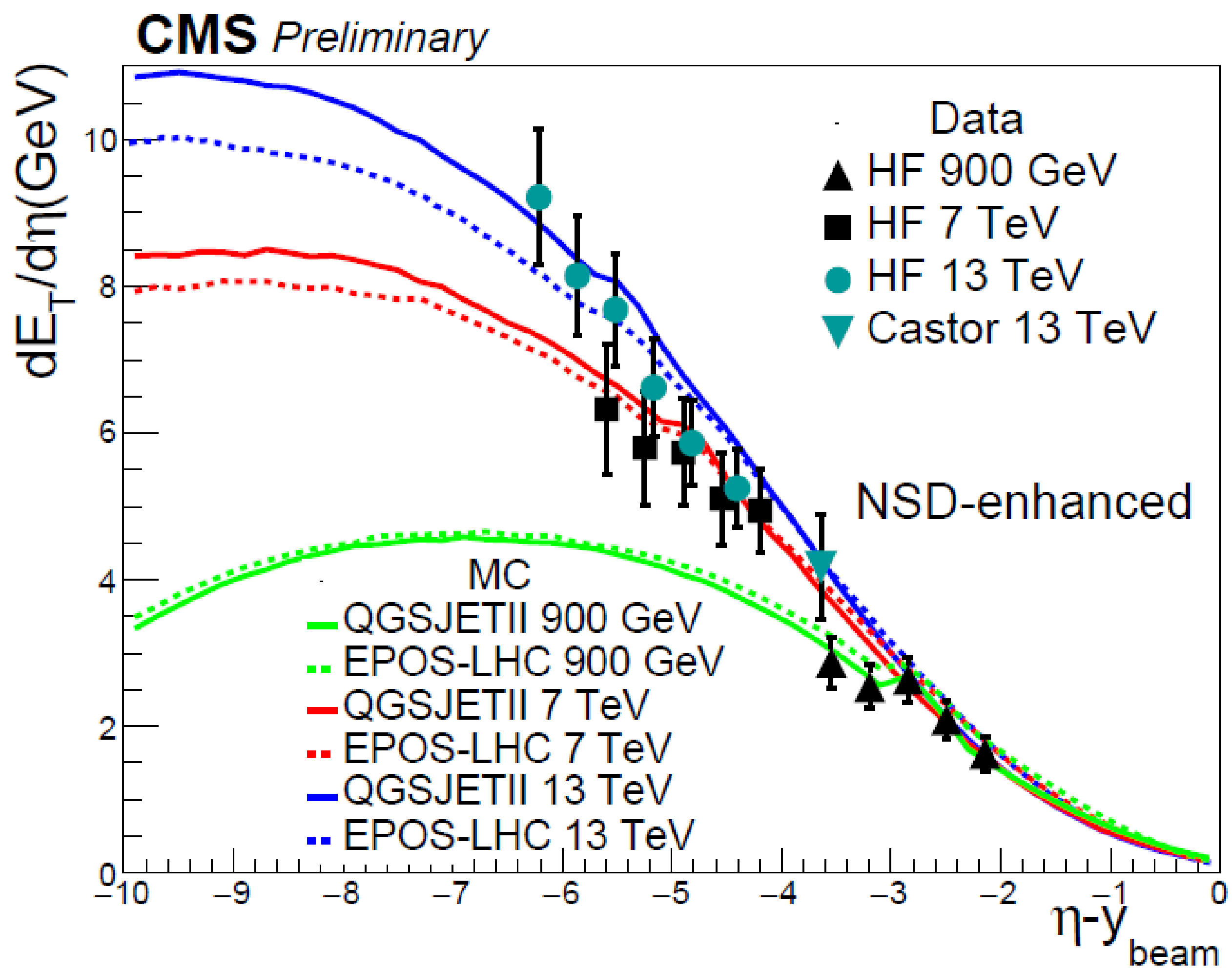
inelastic events

(>= one side HF)

reasonably described by predictions

Forward energy/unit rapidity in pp @ 13 TeV

CMS PAS FSQ-15-006



Non-Single-Diffractive enhanced events

(both sides HF)

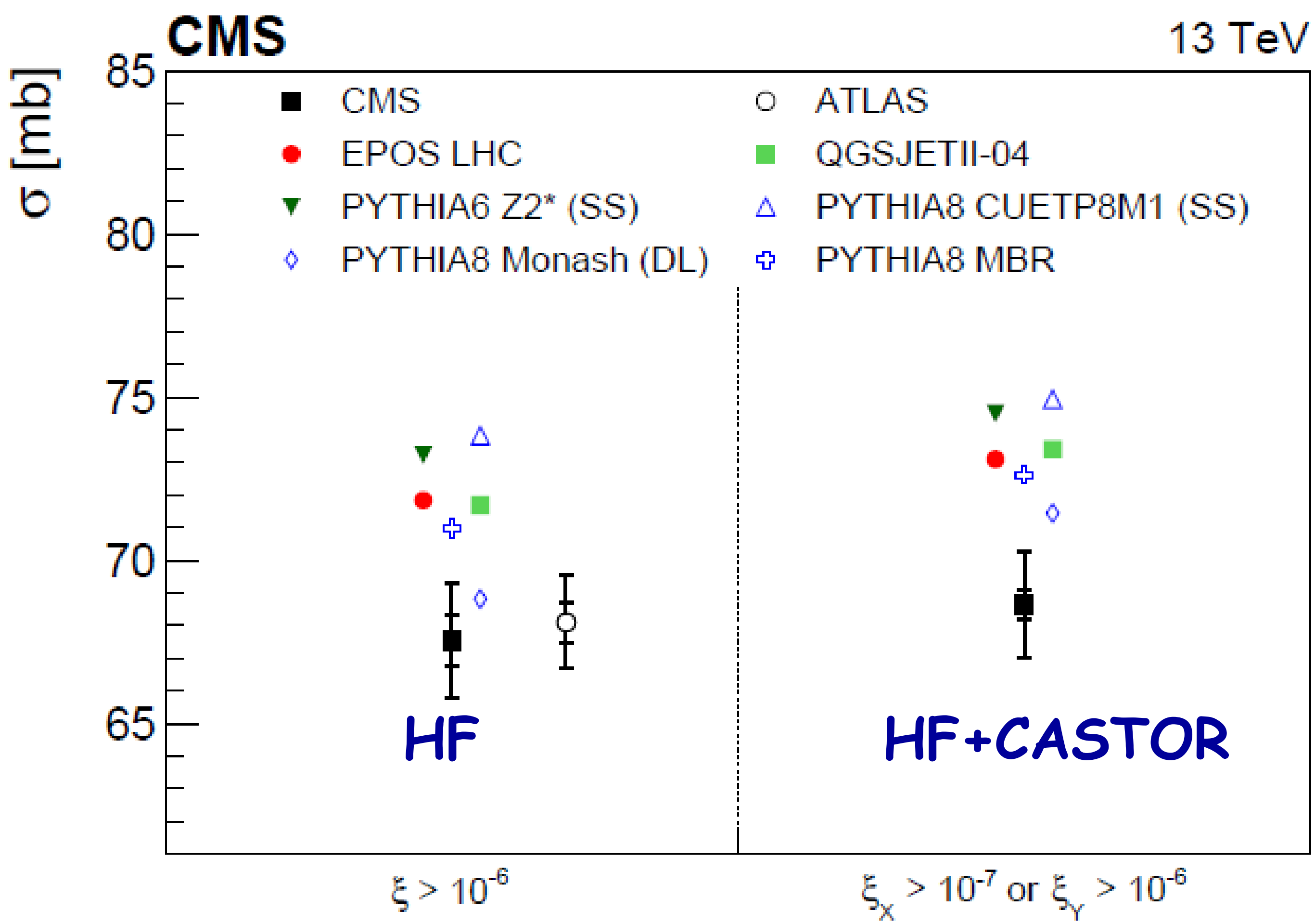
center-of-mass energy dependence well described,

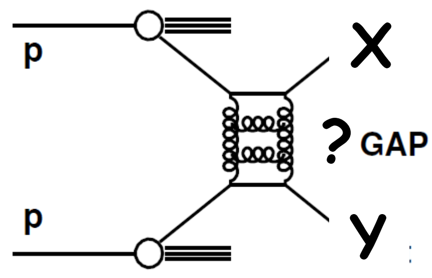
consistent with limiting fragmentation hypothesis

Total inelastic cross section @ 13 TeV

CMS-FSQ-15-005, arXiv:1802.02613, Eur.Phys.J. C78 (2018) 242

use HF and/or CASTOR to define inelastic events





$\xi_X = M_X^2/s$

$\xi_Y = M_Y^2/s$

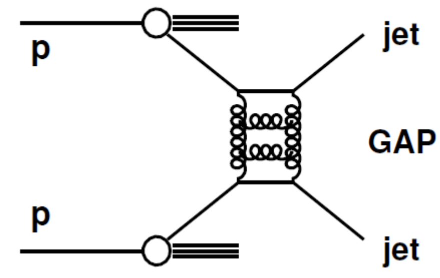
$\xi = \max(\xi_X, \xi_Y)$

results from HF and HF+CASTOR are consistent

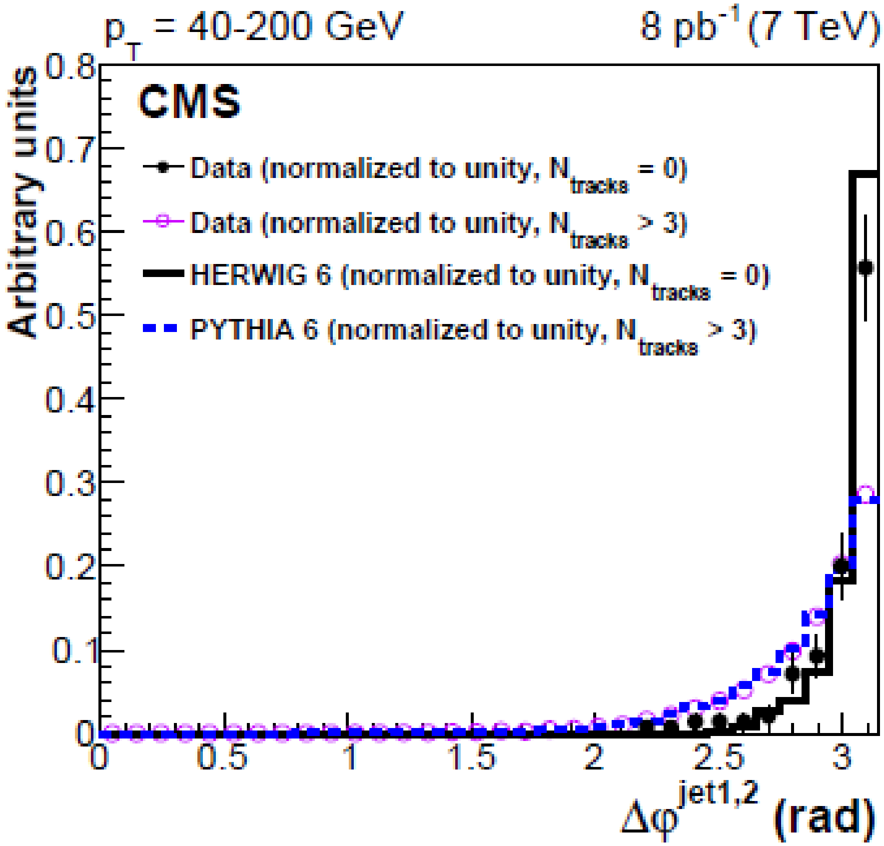
CMS and ATLAS results are consistent

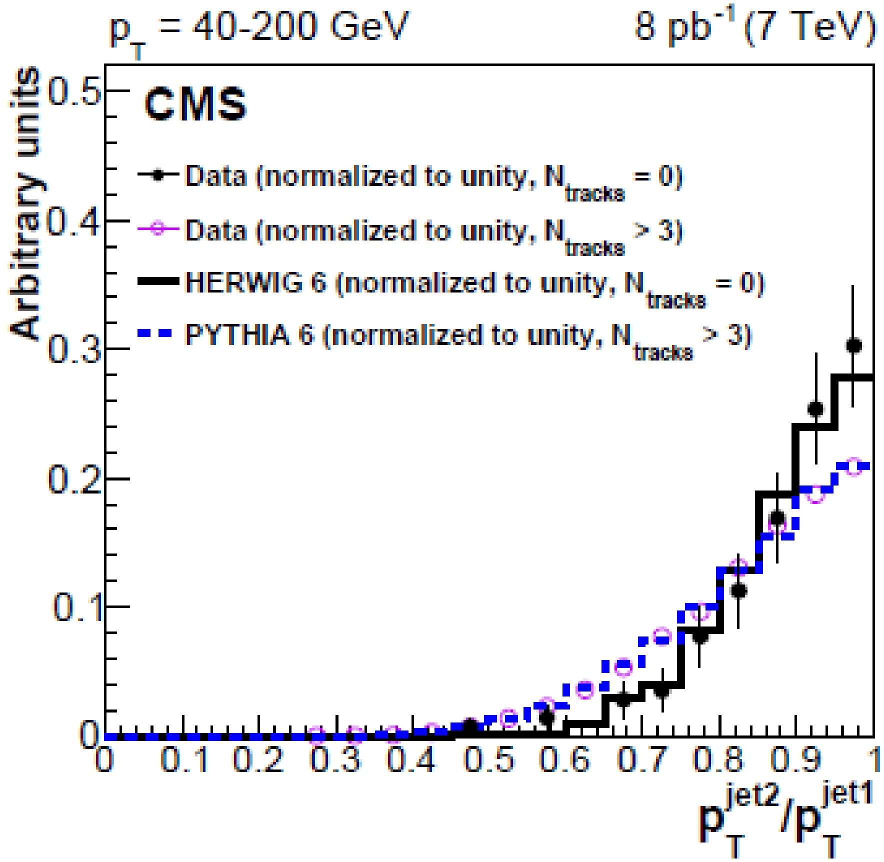
Dijet events with large rapidity gaps

CMS-FSQ-12-001, arXiv:1710.02586, Eur.Phys.J. C78 (2018) 242



@ 7 TeV jet 1: $-4.7<\eta<-1.5$ no tracks
jet 2: $1.5<\eta<4.7$ $-1<\eta<1$ (GAP)



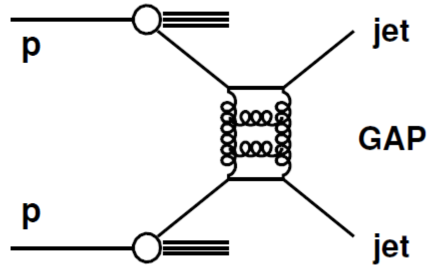


HERWIG 6 describes data with gap (includes colour-singlet exchange)

PYTHIA 6 describes data w/o gap (no colour-singlet simulation)

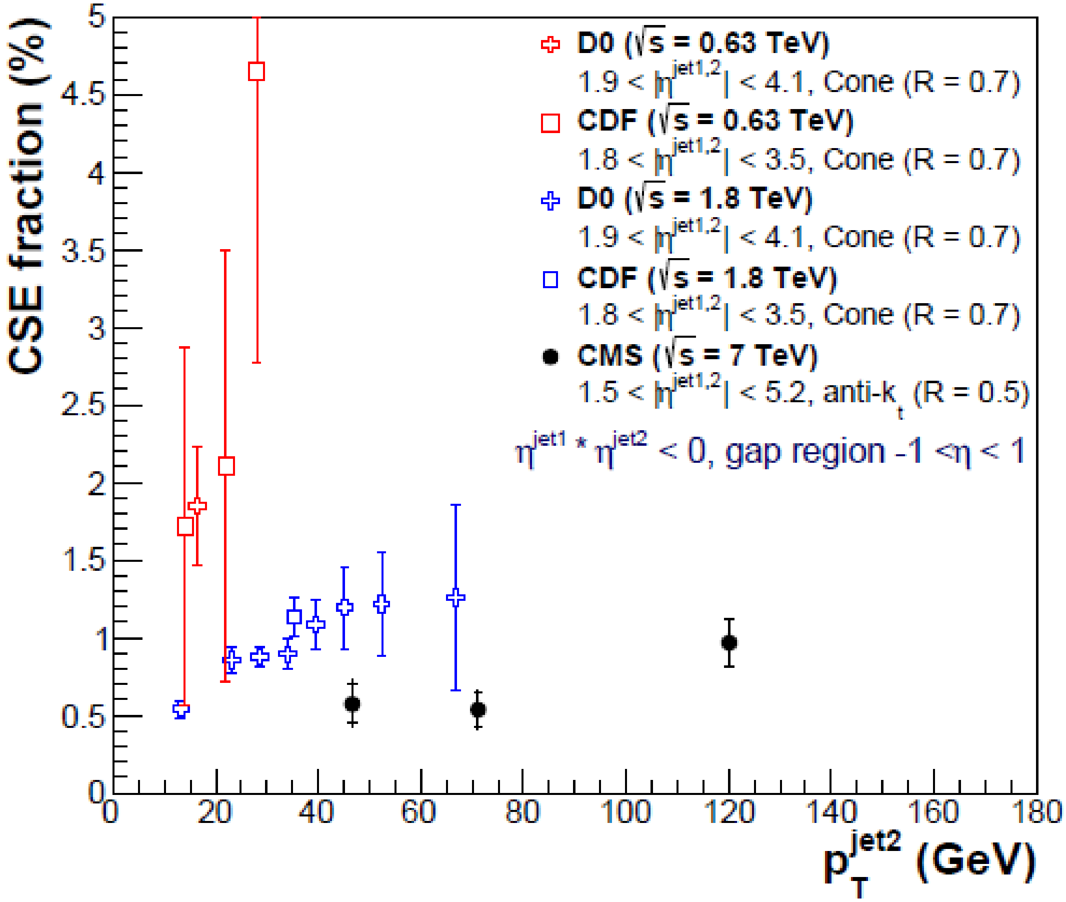
Dijet events with large rapidity gaps

CMS-FSQ-12-001, arXiv:1710.02586, Eur.Phys.J. C78 (2018) 242



Colour-Singlet-Exchange fraction

comparison to Tevatron



trend 0.63 -> 1.8 TeV confirmed by

trend 1.8 -> 7 TeV

consistent with rapidity gap suppression models

Dijet events with large rapidity gaps

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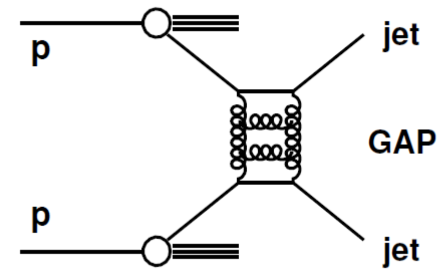
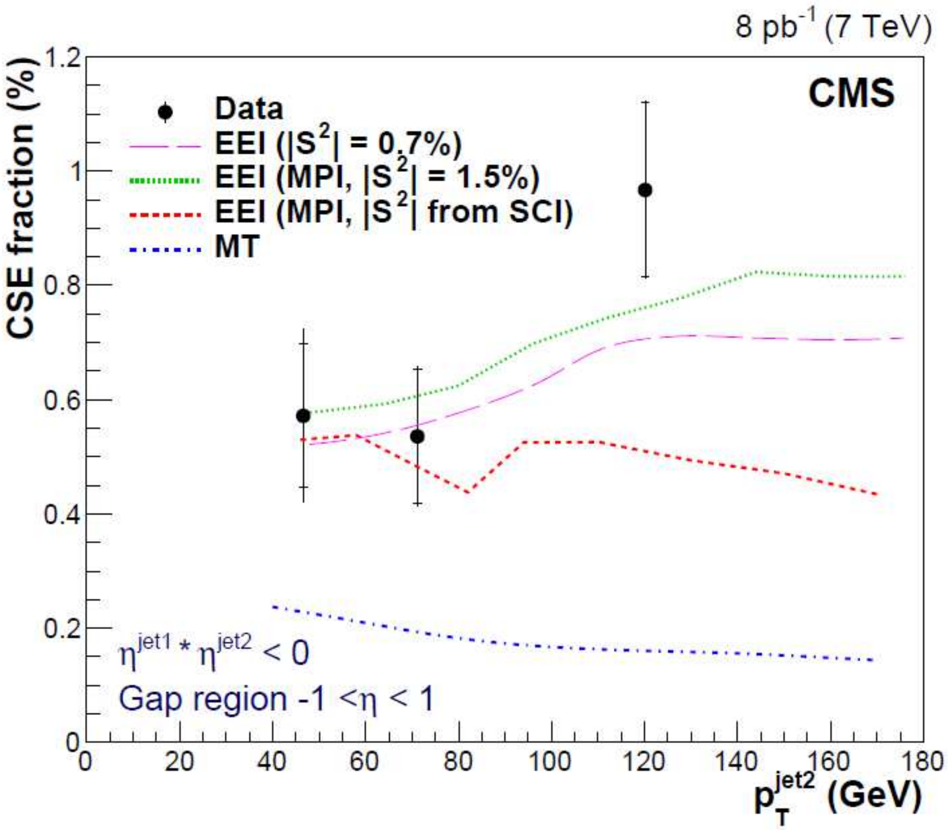
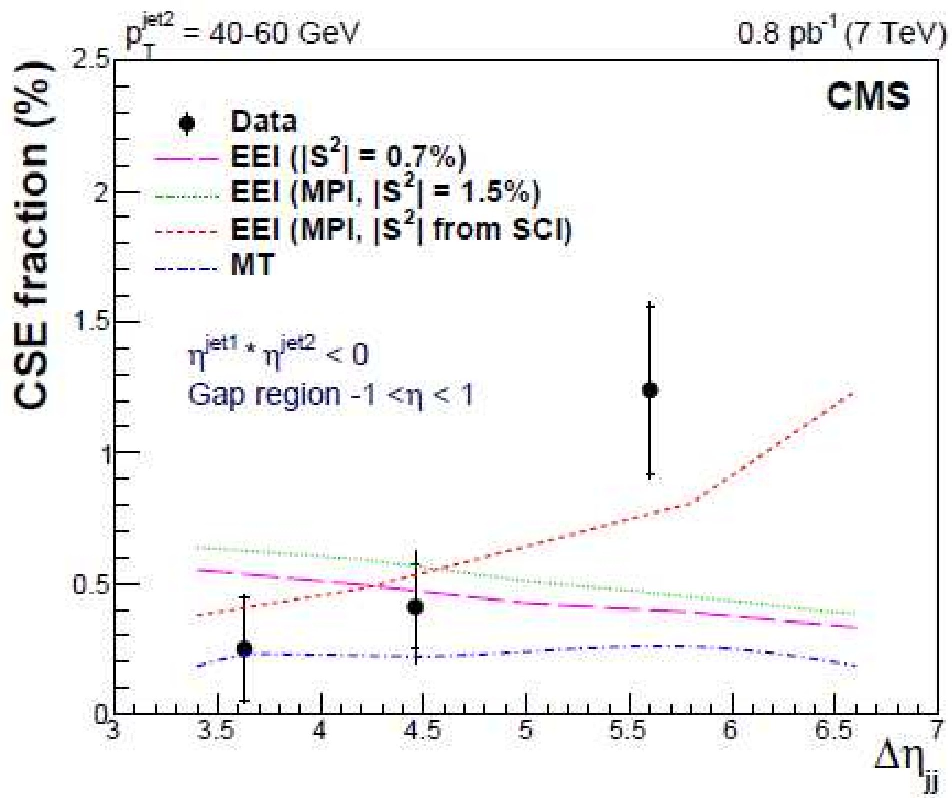


Colour-Singlet-Exchange fraction





EEI model (Ekstedt, Enberg and Ingelmann) (NLL BFKL+gap suppr.) works better than MT model (Mueller and Tang) (LL)

Conclusions

- Measurements of forward energy or jet production at LHC are great tool to test QCD and its dynamics, and to calibrate cosmic ray air shower simulations

- Measurements in CASTOR rapidity range $-6.6 < \eta < -5.2$ in both pp and pPb unique to CMS. Reasonably described by QCD. Discriminate between different "air shower" models and PYTHIA tunes. Significant room for improvement of proton+lead interaction simulations.

- Conclusions consistent with differential measurements in "more central" calorimeters (HF and endcaps). Also give access to total inelastic cross section, consistent with ATLAS and dijets with large rapidity gap, first LHC measurement, checks BFKL-based colour singlet exchange and gap suppression models