Studies of the nuclear stopping power in PbPb collisions at 2.76 TeV with CMS

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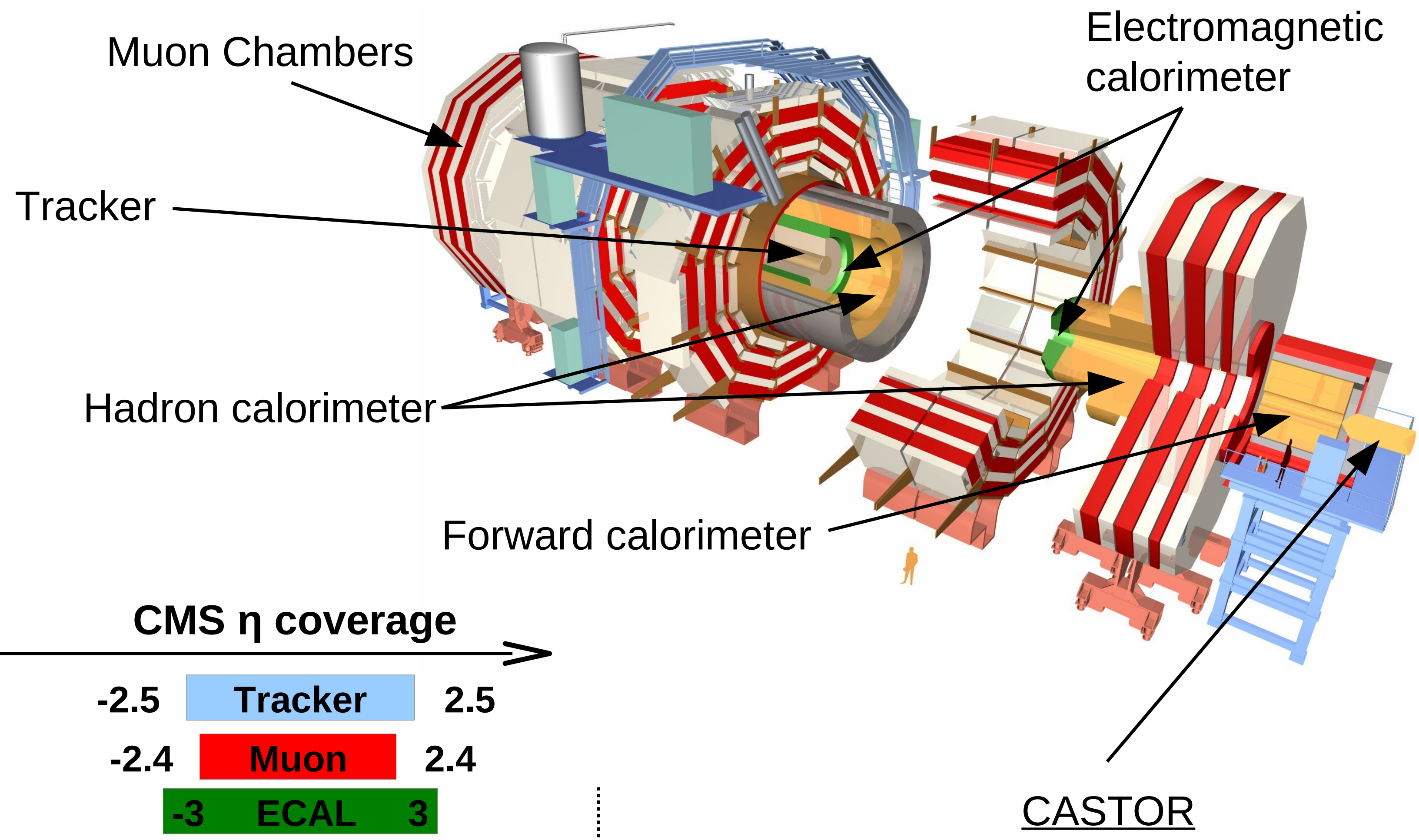
Motivation

- CMS has almost complete η coverage, $-6.6 < \eta < 5.2$
- Forward coverage is essential to study parton structure for small fractional parton momentum x
- Pseudorapidity of the very forward calorimeter CASTOR (|η| up to 6.6) is very close to y_{beam} (~8 at 2.76 TeV)
  - Therefore we expect CASTOR near the peak of dE/dη
- Study the centrality dependence of the energy deposit at different pseudorapidities
- Determine the average energy-weighted relative pseudorapidity for different centralities and compare it with stopping data

The CMS Detector

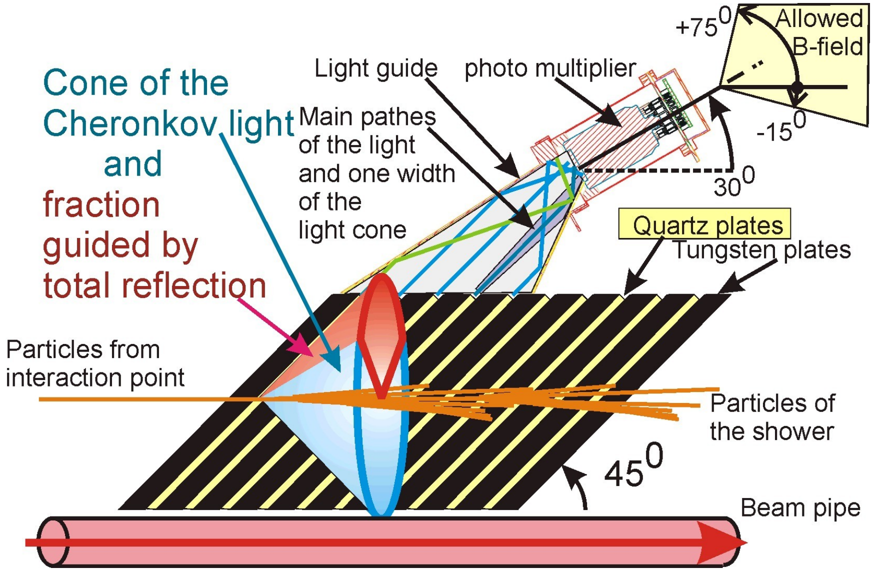


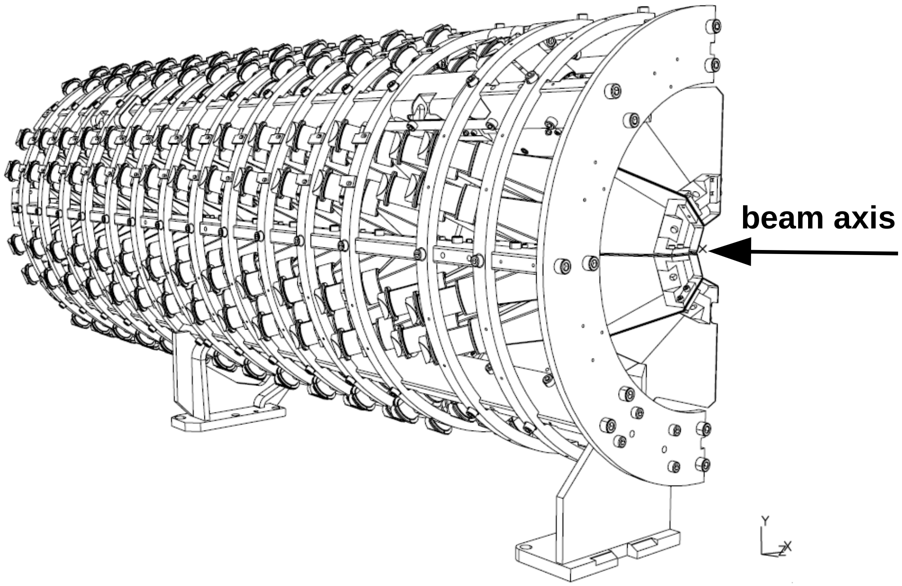
CMS η coverage

Tracker	-2.5	2.5
Muon	-2.4	2.4
ECAL	-3	3
HCAL	-3	3
HF	-5.2 to -3	3 to 5.2
CASTOR	-6.6 to -5.2	

used detectors in this analysis (ECAL, HCAL, HF, CASTOR)

CASTOR calorimeter design





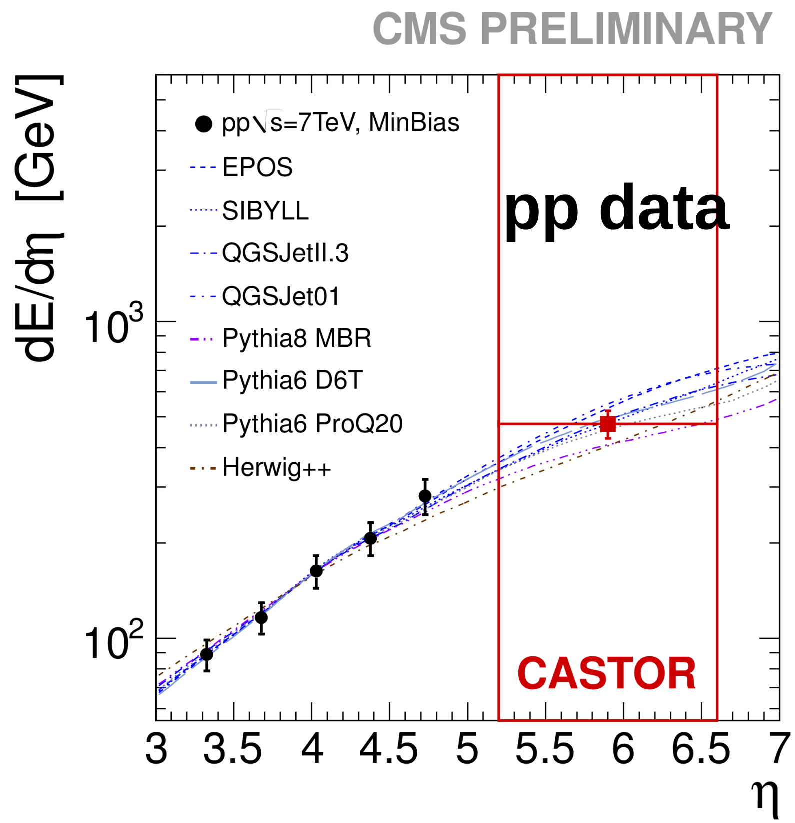
- Cherenkov quartz-tungsten sampling calorimeter for CMS with quartz plates as active medium and tungsten as absorber
  → compact, radiation hard and fast
- 16 azimuthal sectors (semi-octants/towers) mechanically organised in two half calorimeters
- EM = 0.7λ = 20X_0; HAD = 12 x 0.7 = 9.24λ ; overall depth = 10λ

CASTOR cross-calibration to HF using pp minimum bias data @ 7 TeV

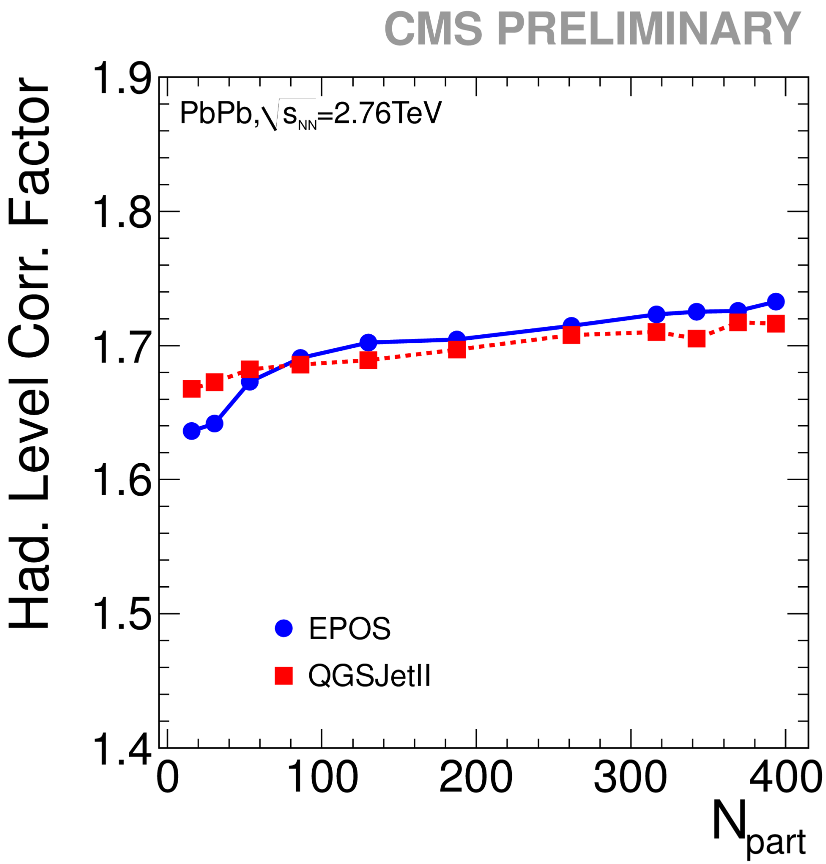
- Energy measured in HF & model dependent extrapolation using shape of model predictions

Systematic uncertainties

HF energy scale	10%
Extrapolation + model dependence	10%
CASTOR non-compensation	5%
CASTOR alignment	16%
Total	**22%**



Correction factors: $C(PbPb)=E_{gen}/E_{det}$



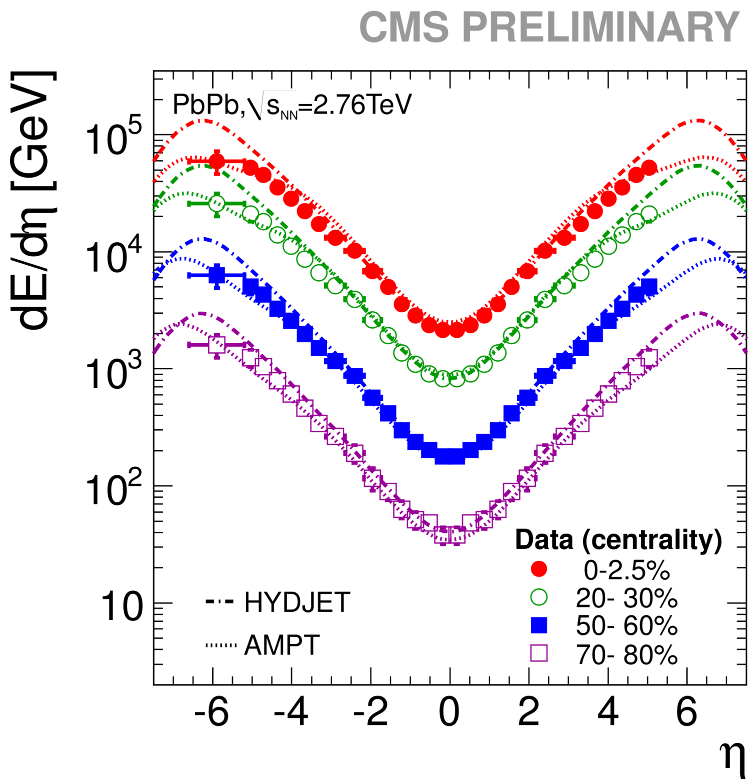
Cosmic Ray models used for correction:

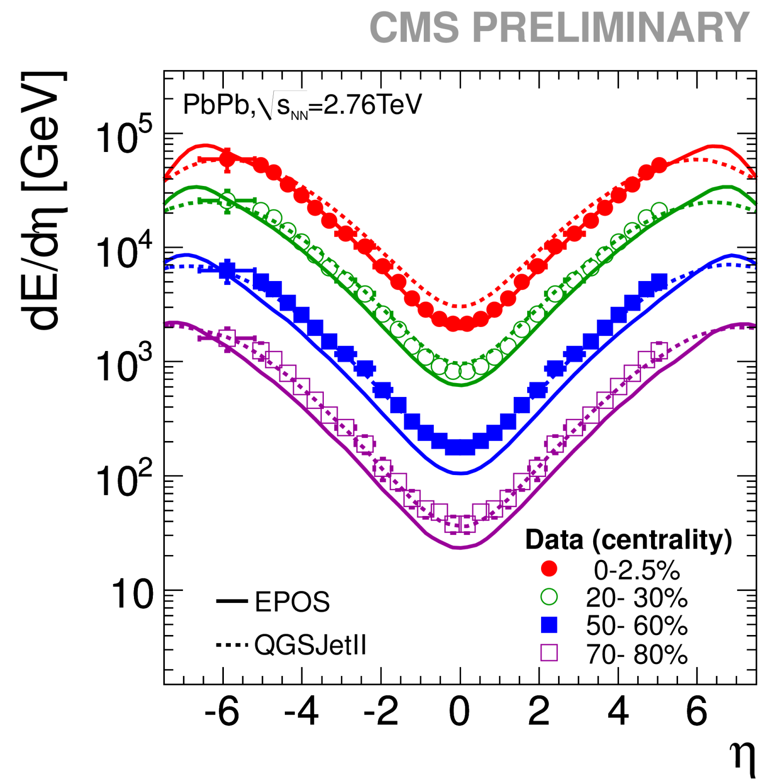
- QGSJetII:
  - Gibov-Regge with pomeron net and loop corrections to all orders
  - The pomeron-pomeron coupling produces saturation effects
- EPOS 1.99 (retuned to LHC):
  - Gribov-Regge with energy sharing on parton level
  - Includes collective hydrodynamic effects for high energy densities
  - Implements a phenomenological model of gluon saturation

Correction factors to hadron level:

- **EPOS vs QGSJetII → 2% difference**
- **Variation of correction factors with centrality: within ± 3%**

Energy η-density $dE/d\eta(\eta, N_{part})$



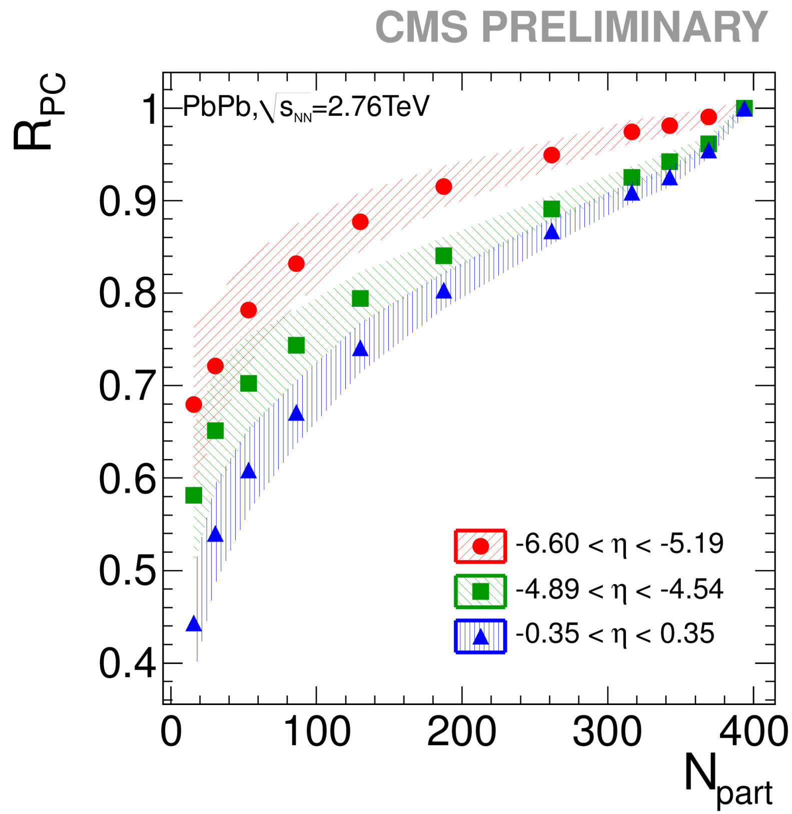


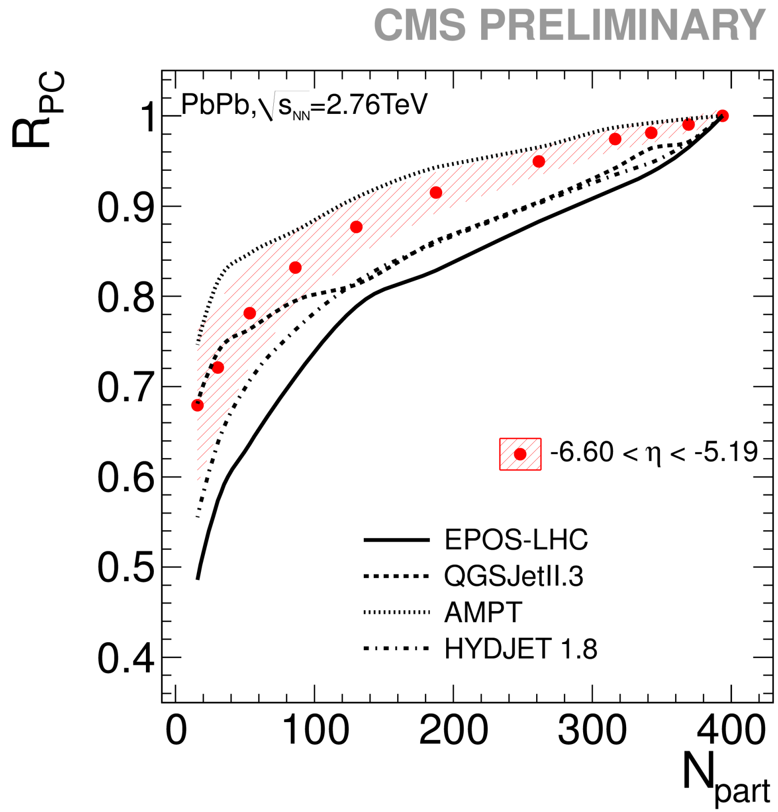
Data for $|\eta|<5.2$ is from arXiv:1205.0206 (CMS E_T measurement)

- HYDJET 1.8 is very well tuned to the central rapidities.
- AMPT has a qualitative agreement to the data
- EPOS-LHC has good agreement for central data
- QGSJetII.3 describes peripheral data better

Energy η-density ratio R_{PC} peripheral vs. central

$$R_{PC} = \frac{\langle E\rangle(\eta, N_{\mathrm{part}})}{\langle E\rangle(\eta, N_{\mathrm{part}}^{\mathrm{max}})} \cdot \frac{N_{\mathrm{part}}^{\mathrm{max}}}{N_{\mathrm{part}}}$$



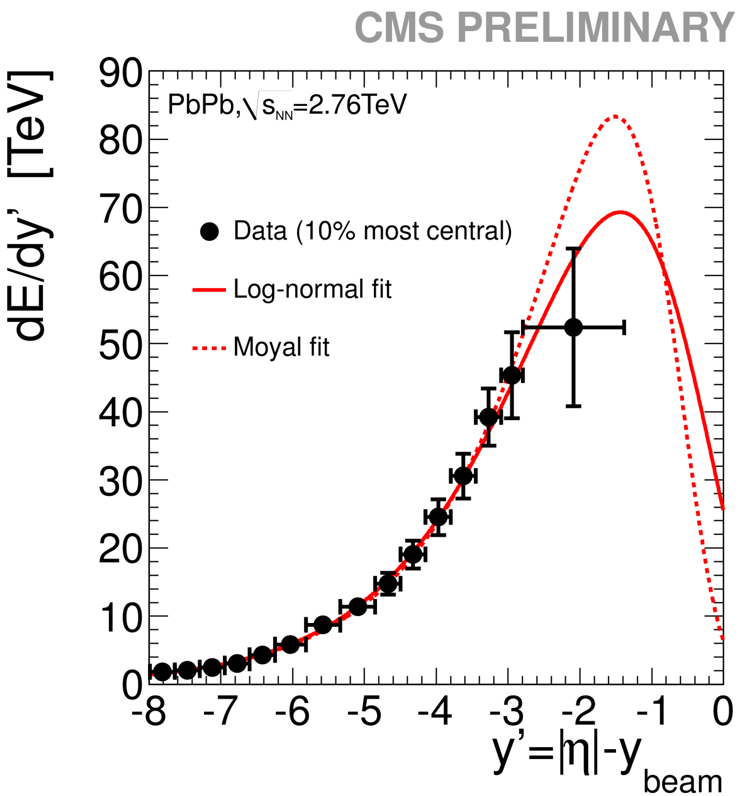


- Shape changes significantly in forward region
- Flattening region for central events at high pseudorapidity
- Data is challenging for models

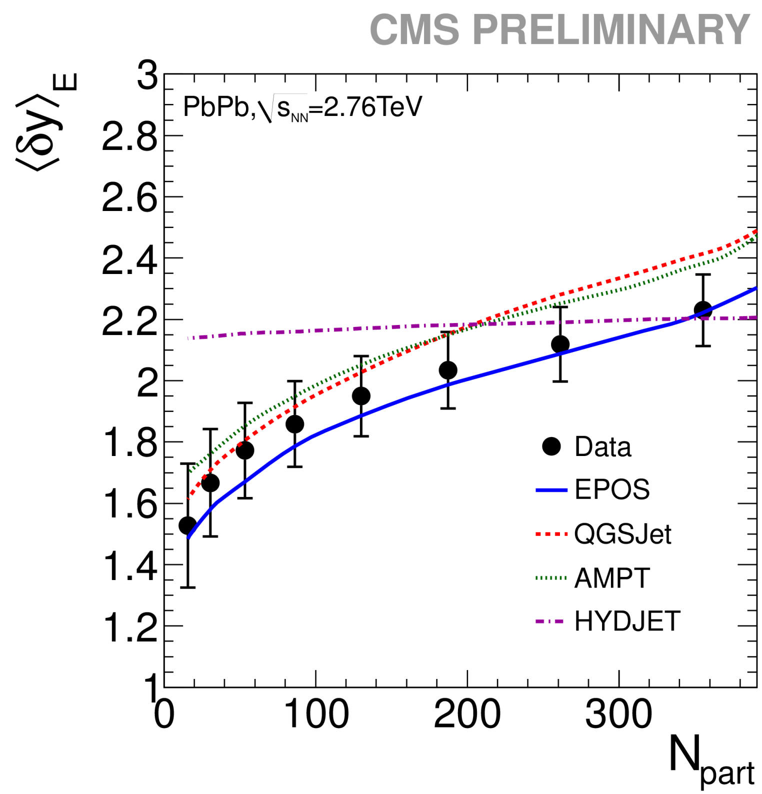
Average energy-weighted relative pseudorapidity

$$\langle \delta y \rangle_E = \frac{2}{E_N N_{part}} \int_{\infty}^{-y_{beam}} y' \frac{dE}{dy'} \, dy'$$

(E_N: kinetic Energy per Nucleon =1.38 TeV)



For 0 – 10% centrality



- EPOS describes the data
- QGSJetII & AMPT describe the shape
- HYDJET is flat

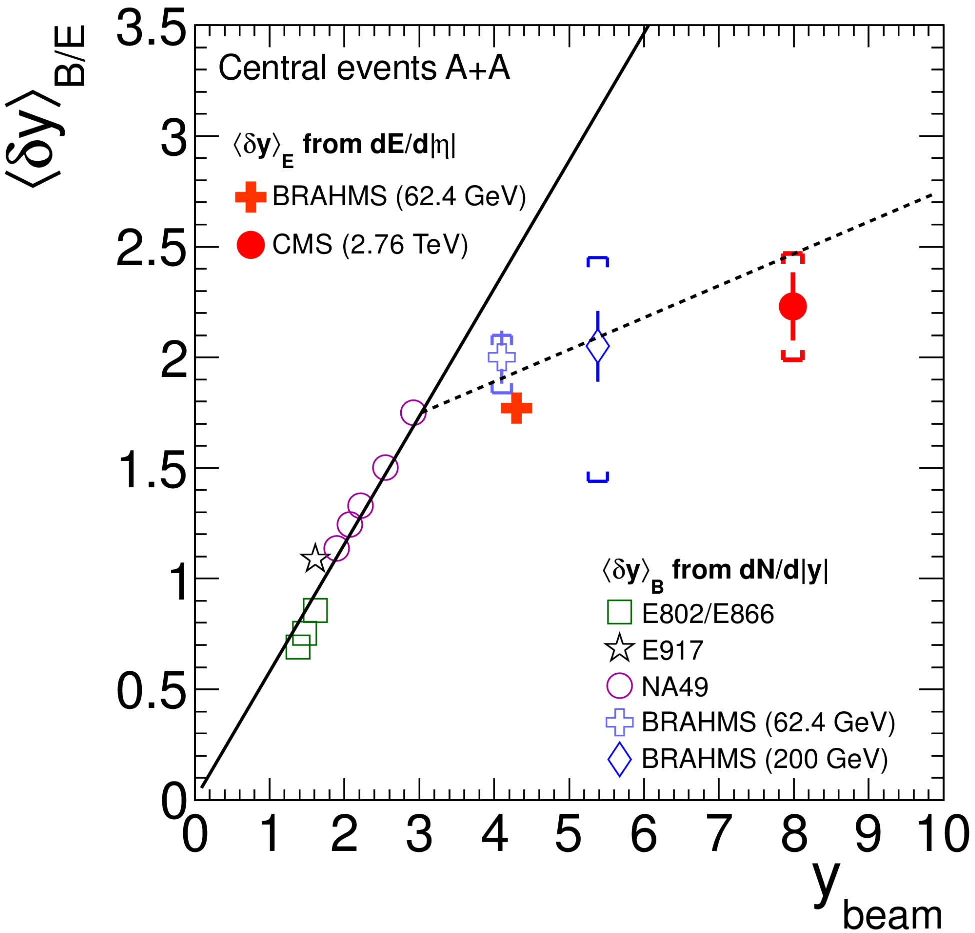
Comparison to lower energy stopping power data

- Different observables:
  <δy>$_E$: energy-weighted relative η (**filled red** Markers)
  <δy>$_B$: mean net baryon production (**open** Markers)

- Solid line:
  fit by BRAHMS to low energy stopping data
- Dashed line:
  parameterization by BRAHMS for RICH data

- CMS data consistent with BRAHMS parameterization

CMS PRELIMINARY



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Summary

- First CASTOR results with heavy ion data, used full set of CMS calorimetry
- Measured **dE/dη** over 11.8 units of pseudorapidity
- The **$R_{PC}(\eta, N_{part})$** ratio for dE/dη changes shape with η and may hint at interesting physics at small-x
- First results on **average energy-weighted relative pseudorapidity** from CMS/LHC; nicely on track with observations at low energies in the context of stopping

BACKUP

CASTOR response

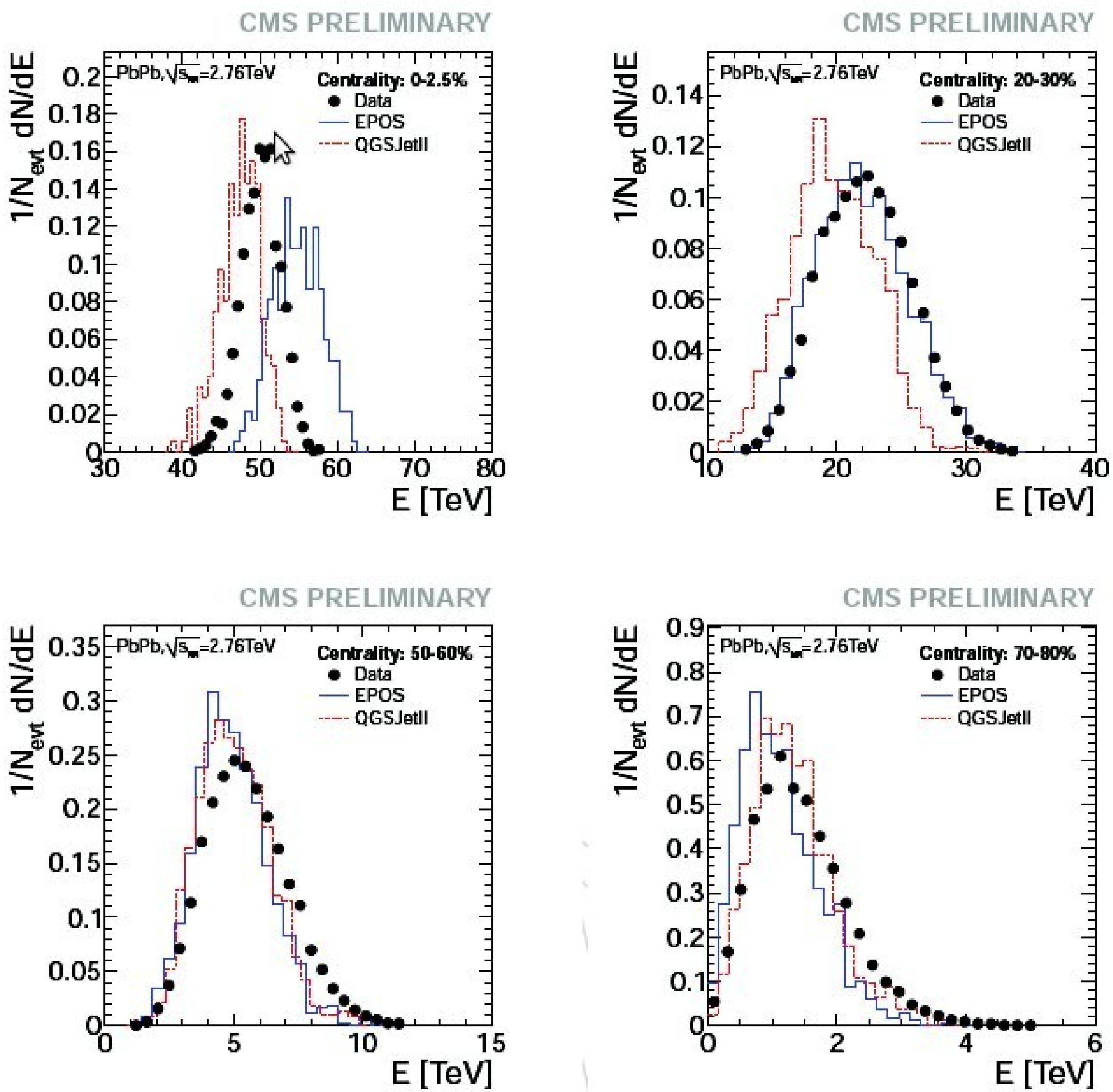
- Using first 5 front modules (10λ → 3.2λ)
  - No bad channels
  - Same configuration as for pp measurement
- CASTOR energy: E = S(PbPb)C(PbPb)*K
  - S = signal
  - C = E_{gen}/E_{det} = hadron level correction factor
  - K = absolute calibration factor obtained via cross-calibration to HF
- CASTOR uncertainty
  - Energy scale: 22%
  - PbPb hadron level correction factor: 2%
  - Vertex distribution: 2%
  - Calorimeter noise: <1%
  - **Total: 22%**

CMS preliminary

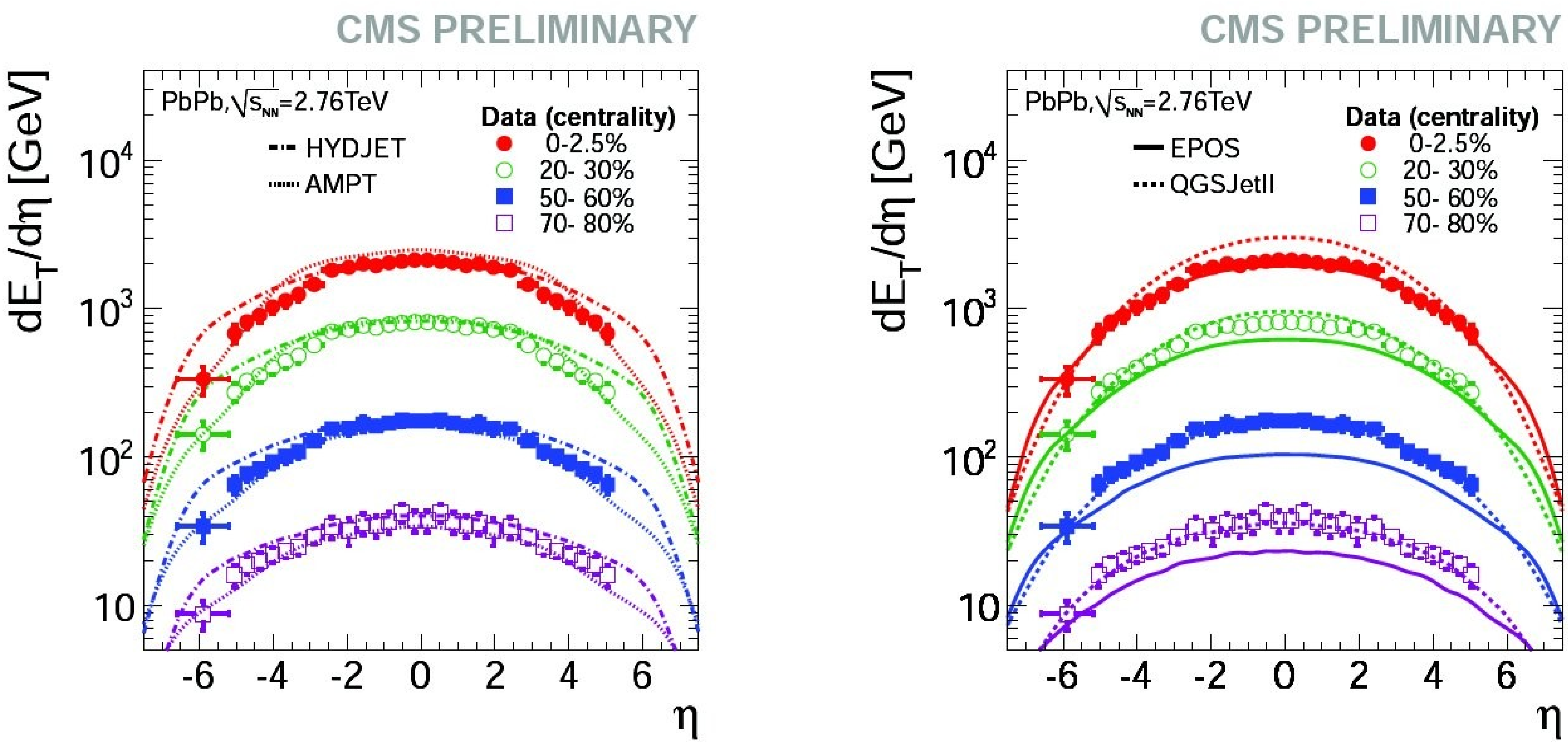
φ ↑ \ Z →	1	2	3	4	5	6	7	8	9	10	11	12	13	14
16	0.85	0.91	0.92	0.98	1.31	0.33			0.68	0.81	0.91	1.01	0.99	0.97
15	0.98	0.91	0.94	1.01	1.27	1.32			0.79	0.93	0.92	0.97	1.06	1.00
14	0.84	0.92	0.94	0.97	1.20	0.42			0.65	0.81	0.96	1.02	1.15	1.30
13	0.89	0.93	0.96	1.04	1.34	0.11			X	0.73	0.94	1.02	X	1.07
12	0.94	0.94	0.98	0.98	1.03	0.10			0.46	0.74	0.94	1.03	1.10	1.13
11	0.96	0.94	0.93	1.00	1.21	0.24			0.68	0.84	0.93	0.97	1.08	1.03
10	0.97	0.89	0.88	0.93	0.96	0.27		0.43	0.87	0.94	0.95	0.88	0.91	1.18
9	0.92	0.88	0.89	0.99	0.92	0.29		0.62	0.70	0.85	0.89	0.91	0.97	0.93
8	0.95	0.69	0.83	0.90	0.86	1.09		0.41	0.66	0.82	0.76	0.79	0.85	0.85
7	0.95	0.81	0.83	0.90	0.87	0.12		0.27	0.71	0.71	0.71	X	0.81	0.94
6	X	1.03	0.81	0.75	1.07	0.29			0.30	0.71	0.69	0.57	0.80	0.76
5	X	0.89	0.81	0.84	1.06	0.49				X	0.68	0.50	0.97	0.88
4	0.84	0.91	0.84	0.88	0.79	0.60				0.59	0.80	0.84	0.83	0.96
3	0.89	0.88	0.85	0.81	0.98	0.50			0.16	0.62	0.76	0.83	0.99	0.84
2	0.84	0.76	0.90	0.86	1.01	1.35		0.08	0.73	0.72	0.80	0.84	0.88	0.85
1	1.02	0.86	0.89	0.96	0.92	2.15		0.49	0.69	0.81	0.85	0.85	0.92	0.94

Minimum bias data: run 133046 (Nominal B-field) / run 133239 (B = 0 T)

Control plots: CASTOR energy vs centrality



Transverse energy η-density $dE_T/d\eta(\eta, N_{part})$



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