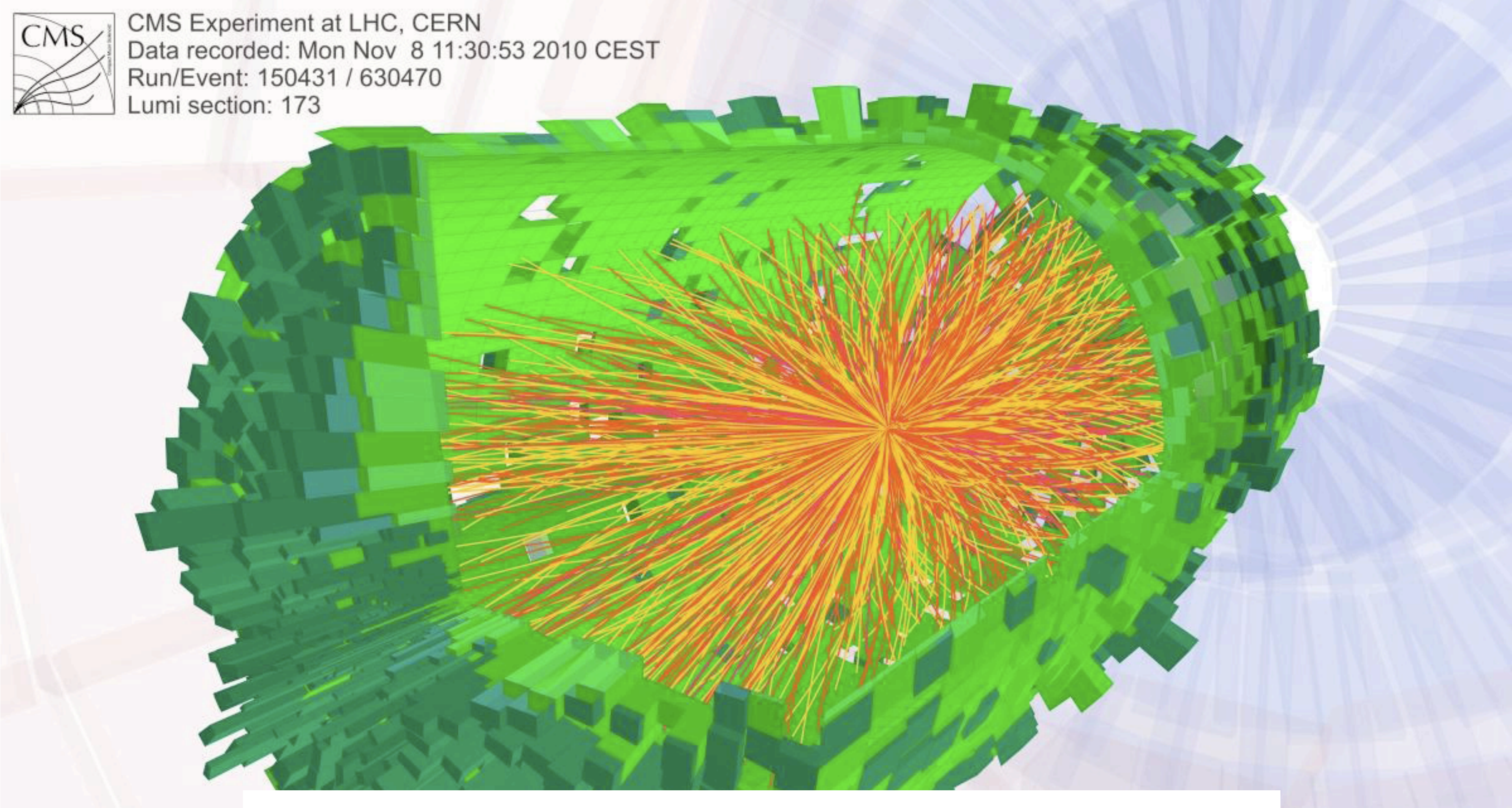
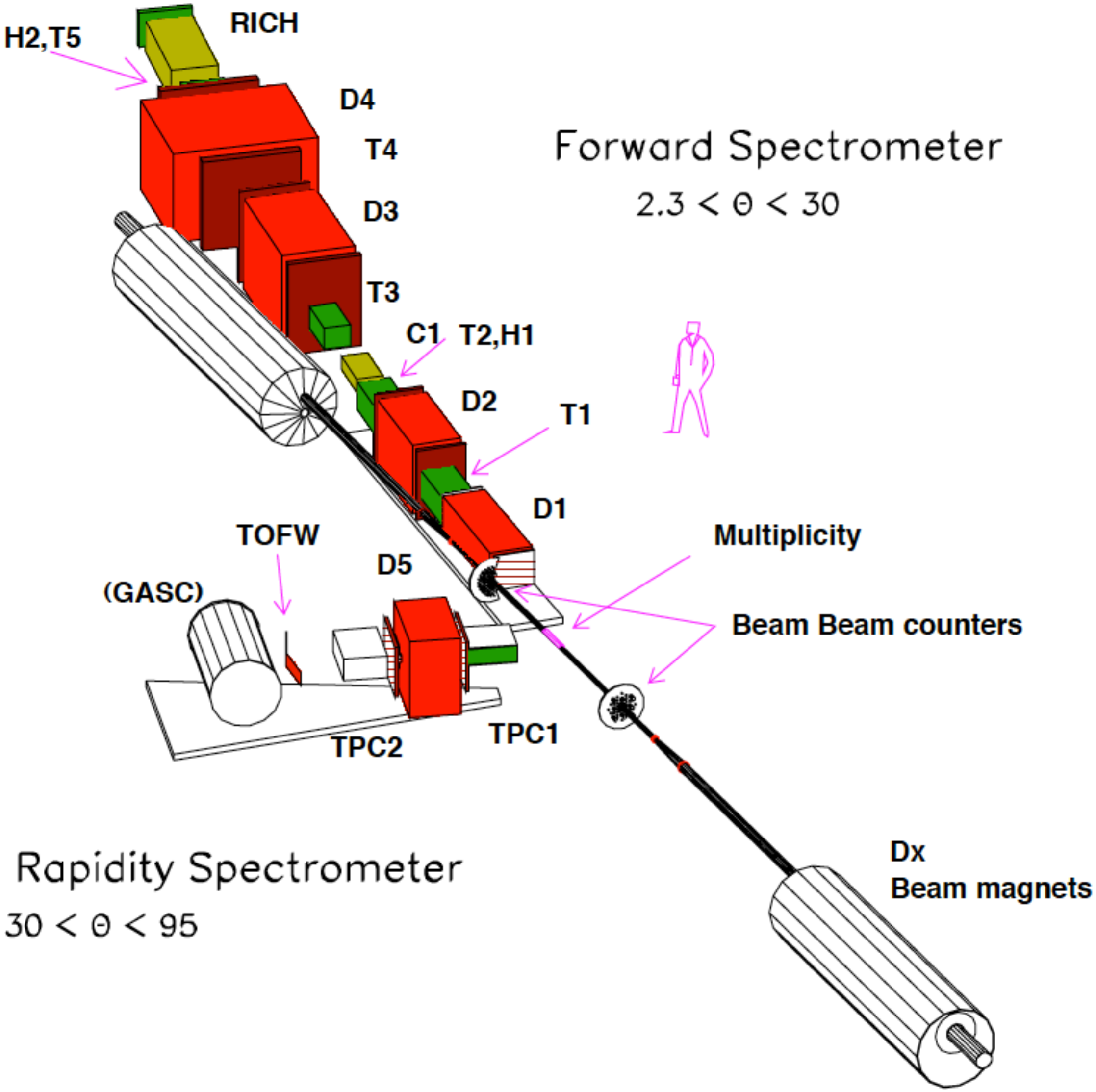
Longitudinal Dynamics in CMS



Michael Murray, University of Kansas, on behalf of CMS

ICFP 2012, Creta, June 2012

BRAHMS at RHIC



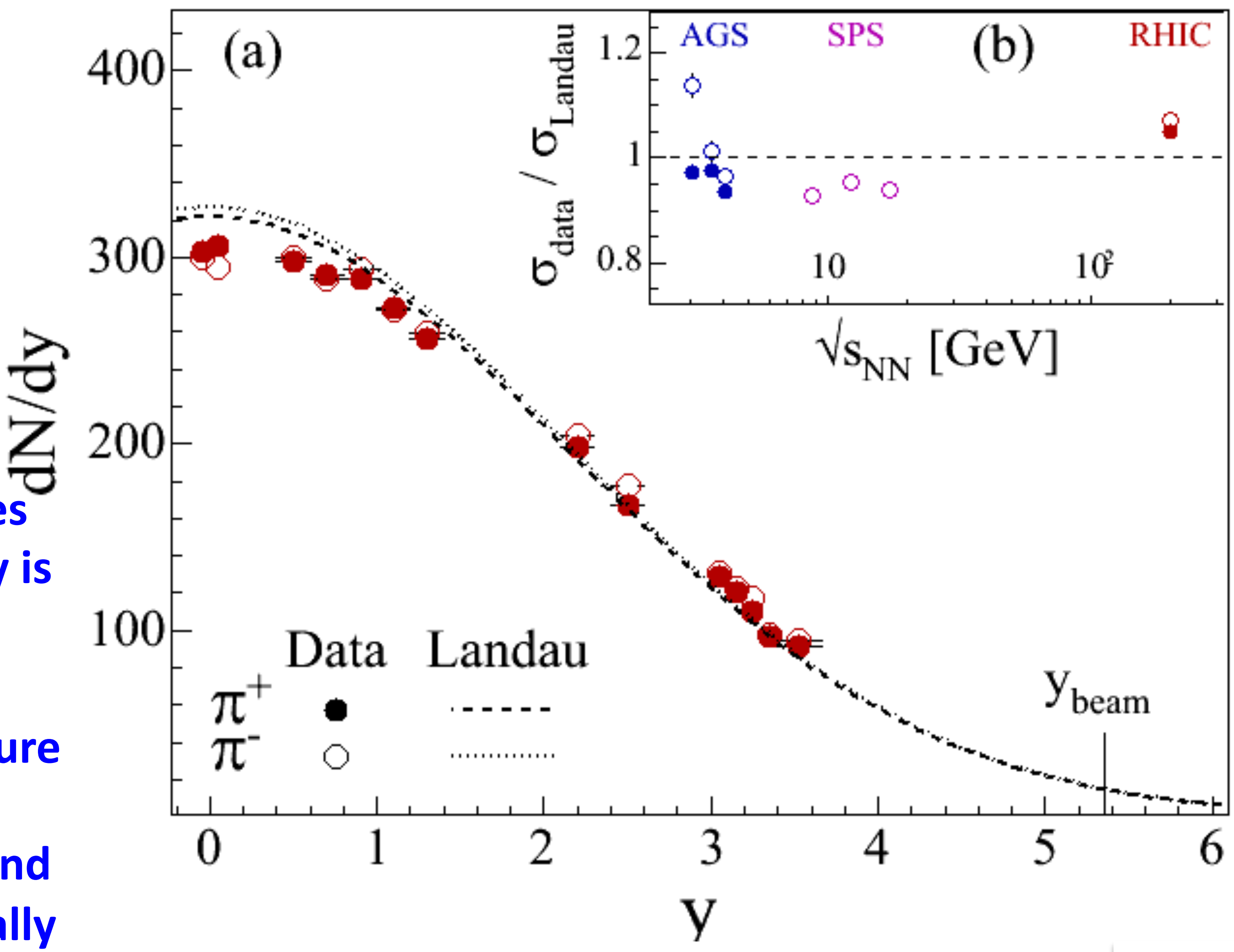
Forward Spectrometer

$2.3 < \Theta < 30$

Mid Rapidity Spectrometer

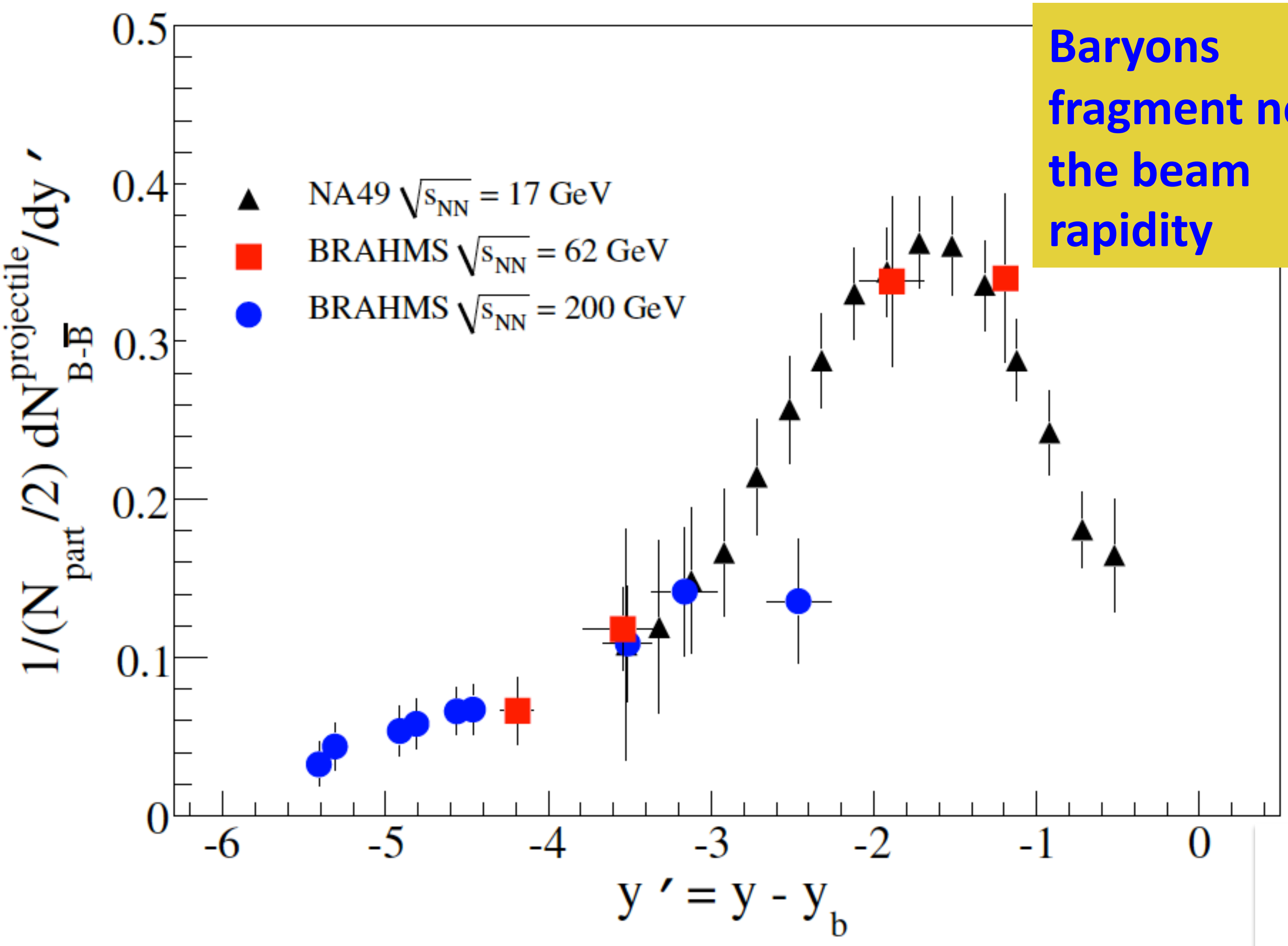
$30 < \Theta < 95$

Longitudinal dynamics at RHIC



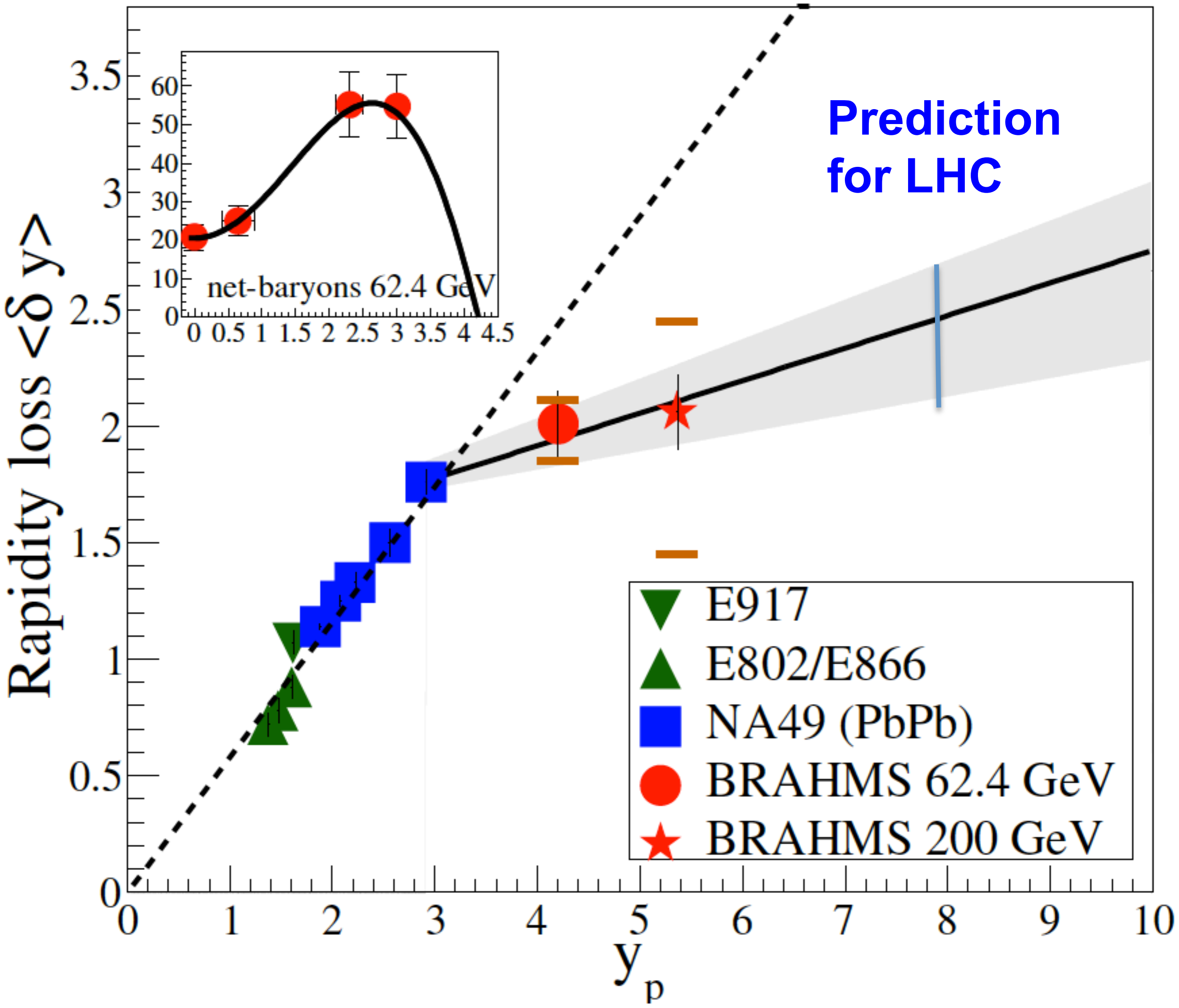
Landau assumes that all entropy is created at the moment of collision. Pressure then causes system to expand hydrodynamically

Limiting Fragmentation



Baryons fragment near the beam rapidity

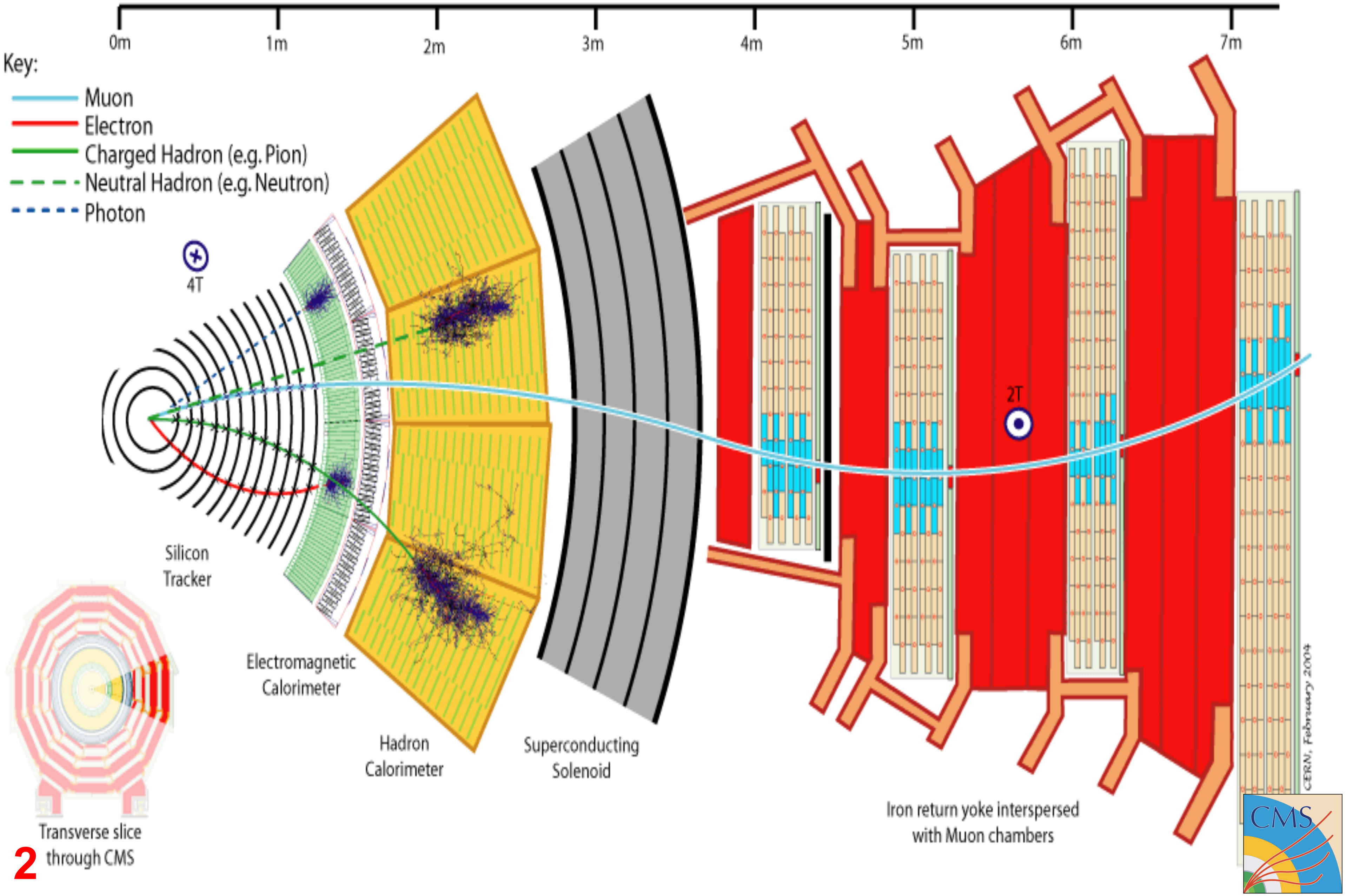
Stopping: Baryons lose 75% of momentum



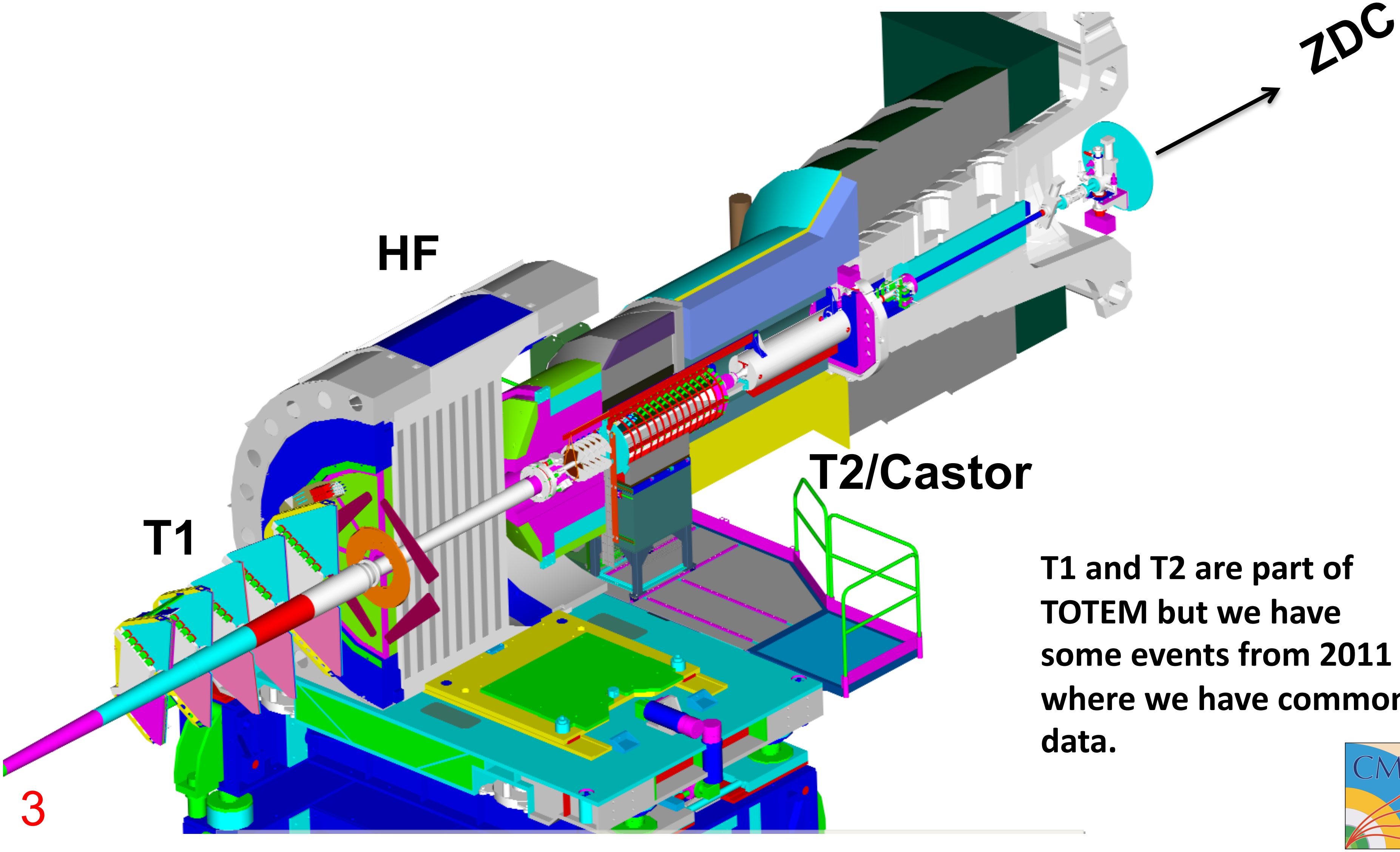
Prediction for LHC

An alternative way to measure stopping is to measure the E_T distribution of all particles

A slice through CMS



Forward detectors



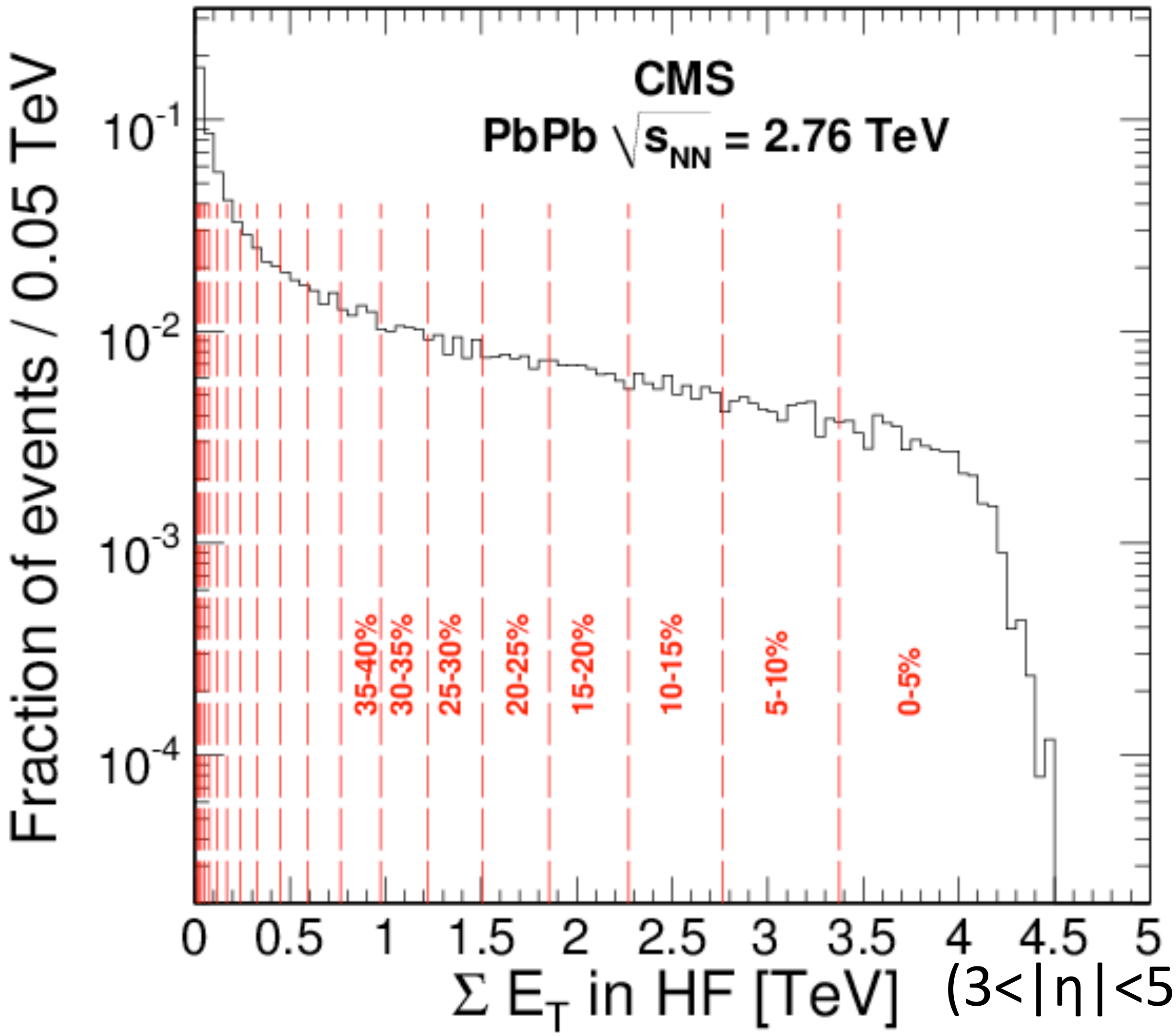
T1 and T2 are part of TOTEM but we have some events from 2011 where we have common data.

Why multiplicity & transverse energy?

- Both are sensitive to the entropy of the system, combining both tells us the energy/particle
- $dE_T/d\eta$ gives a rough estimate of the energy density
- Looking over a large pseudo-rapidity range we can test models of longitudinal expansion, such as Landau flow
- At very forward pseudo-rapidity we should be probing the density of soft low x partons which may be interesting for saturation studies.

This talk is based upon JHEP 07 (2011) 076 for multiplicity and arXiv:1205.2488 for E_T

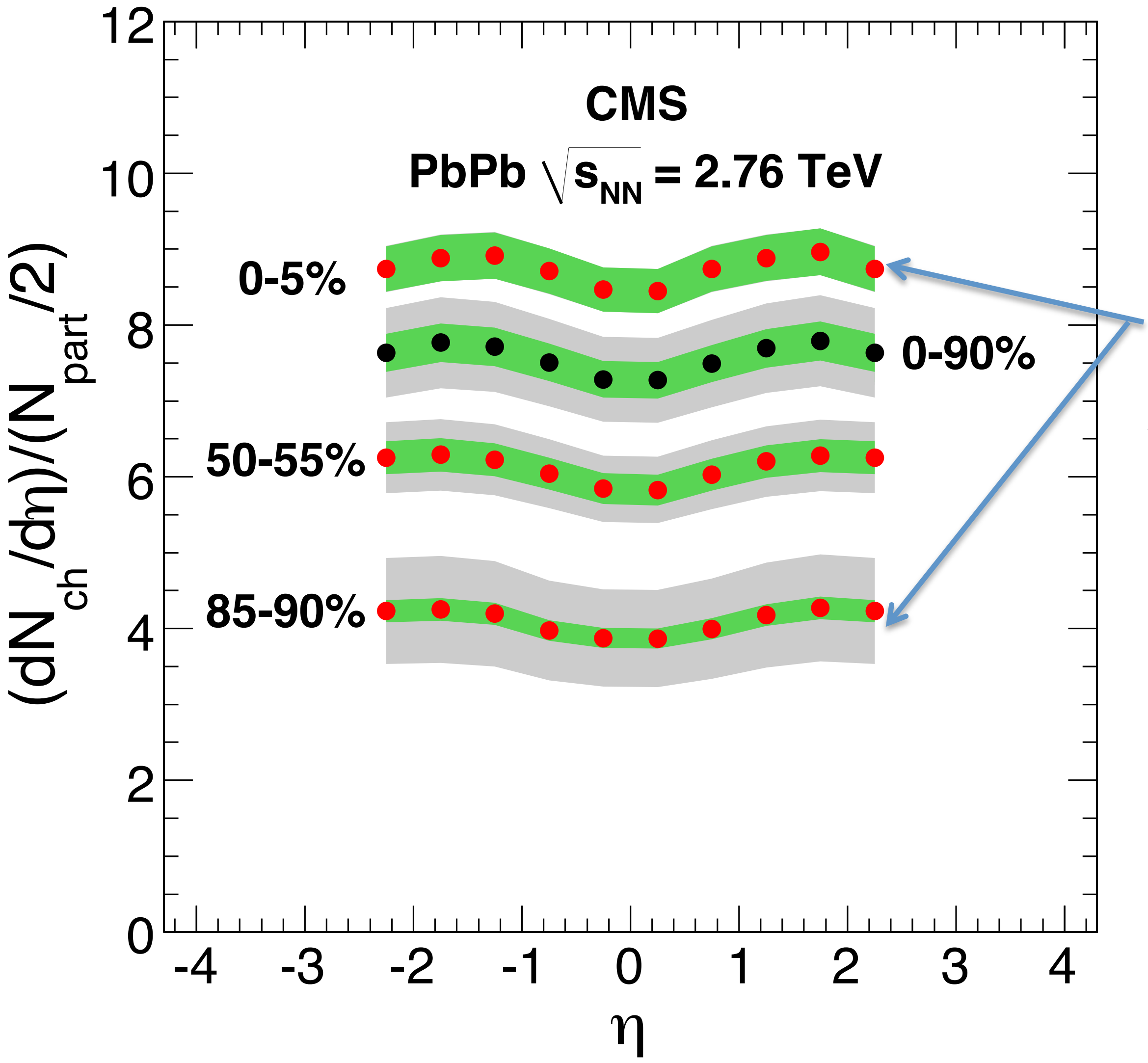
Centrality defined by forward calorimeters



(3<|η|<5)

$dN_{ch}/d\eta$ vs η for various centralities

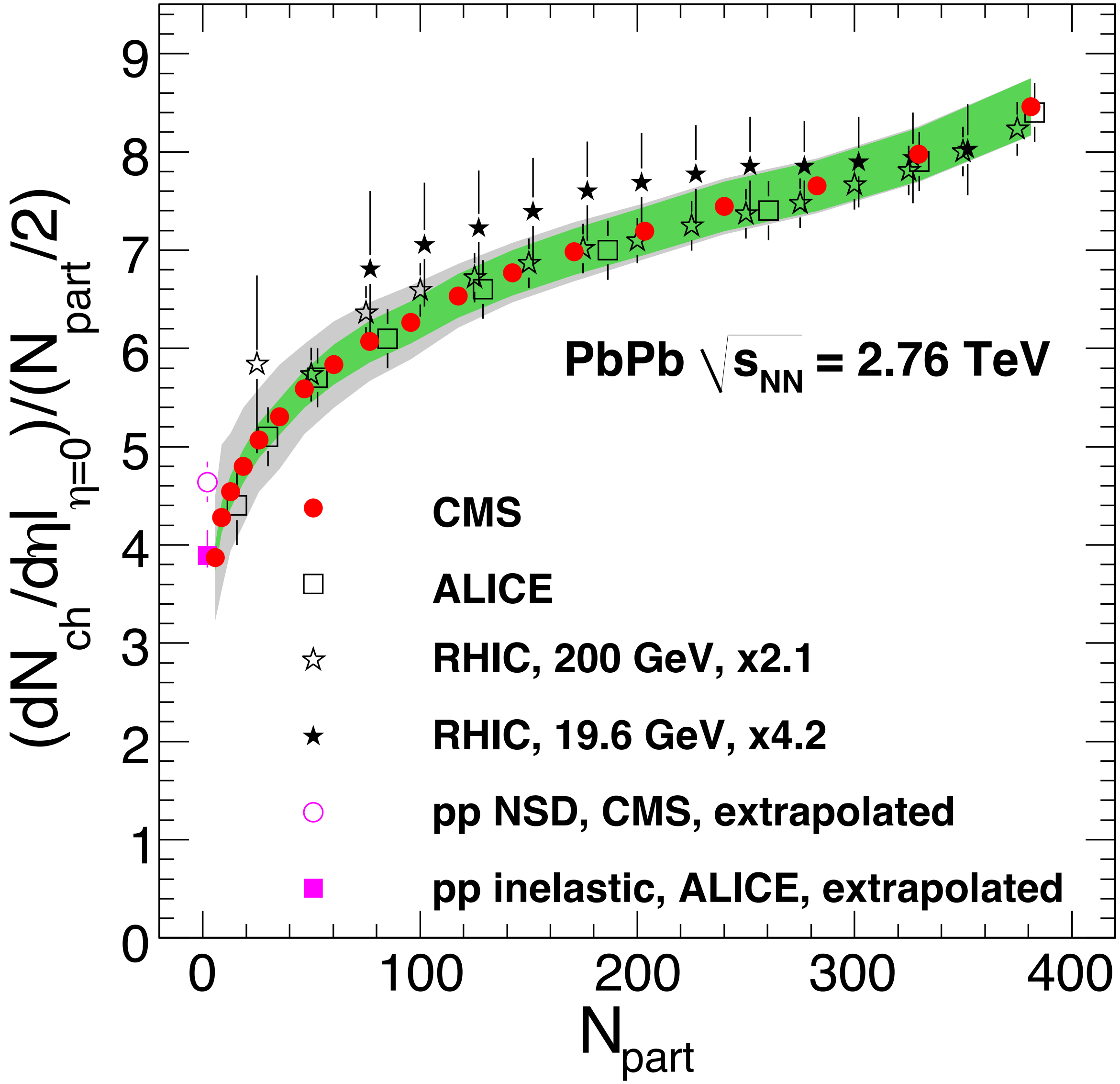
$dN_{ch}/d\eta$ is rather flat for $|\eta| < 2$.



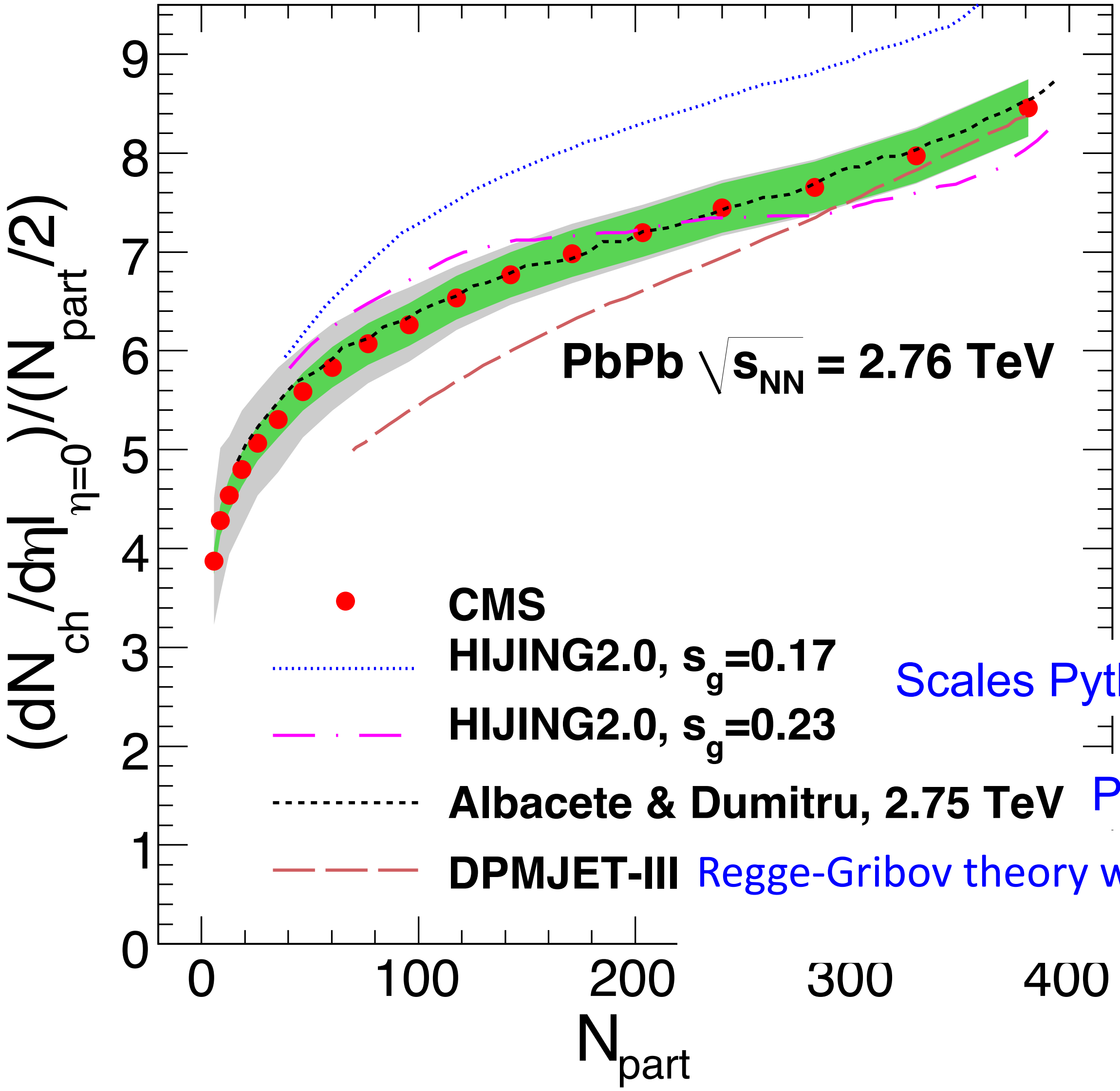
Multiplicity per participant rises with centrality. The yield of charged particles is not simply proportional to the volume of the collision.

$dN_{ch}/d\eta$ vs N_{part} and RHIC data

Shape is strikingly similar from 19.6 GeV to 2.76 TeV



$dN_{ch}/d\eta$ vs N_{part} for data & models

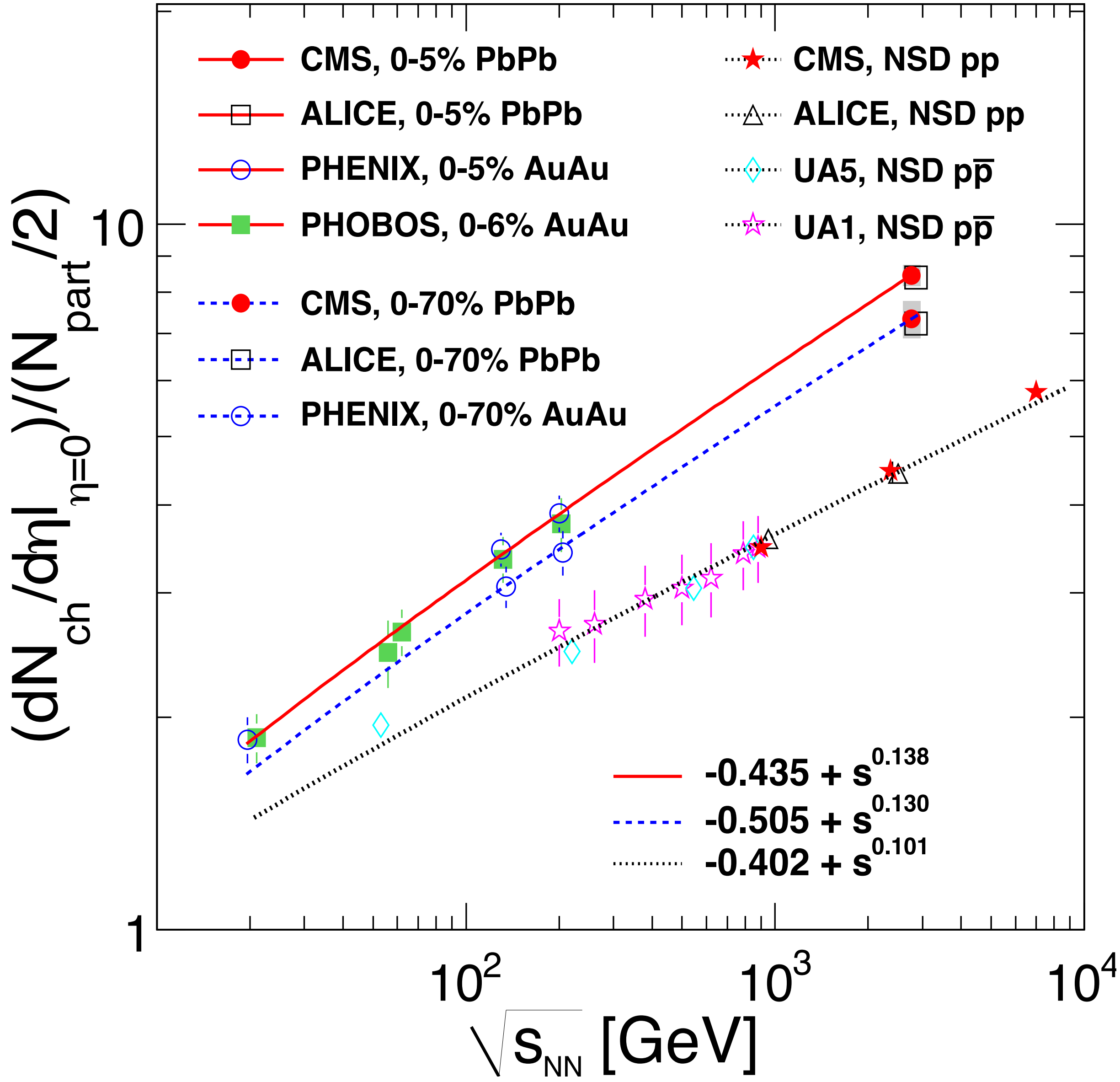


Scales Pythia by N_{coll}, + shadowing

Parton saturation

Regge-Gribov theory with pomeron fusion

Multiplicity vs beam energy for A+A, pp



Multiplicity rises as a power law for both heavy ion and pp collisions but more quickly for heavy ions

Measuring transverse energy

$$\frac{\mathrm{d}E_\mathrm{T}}{\mathrm{d}\eta}(|\eta|) = \frac{C_1(|\eta|)}{C_2(|\eta|)} \cdot \frac{\sum_j E_{\mathrm{T},j}(|\eta|)}{N \times (2 \times \Delta\eta)}$$

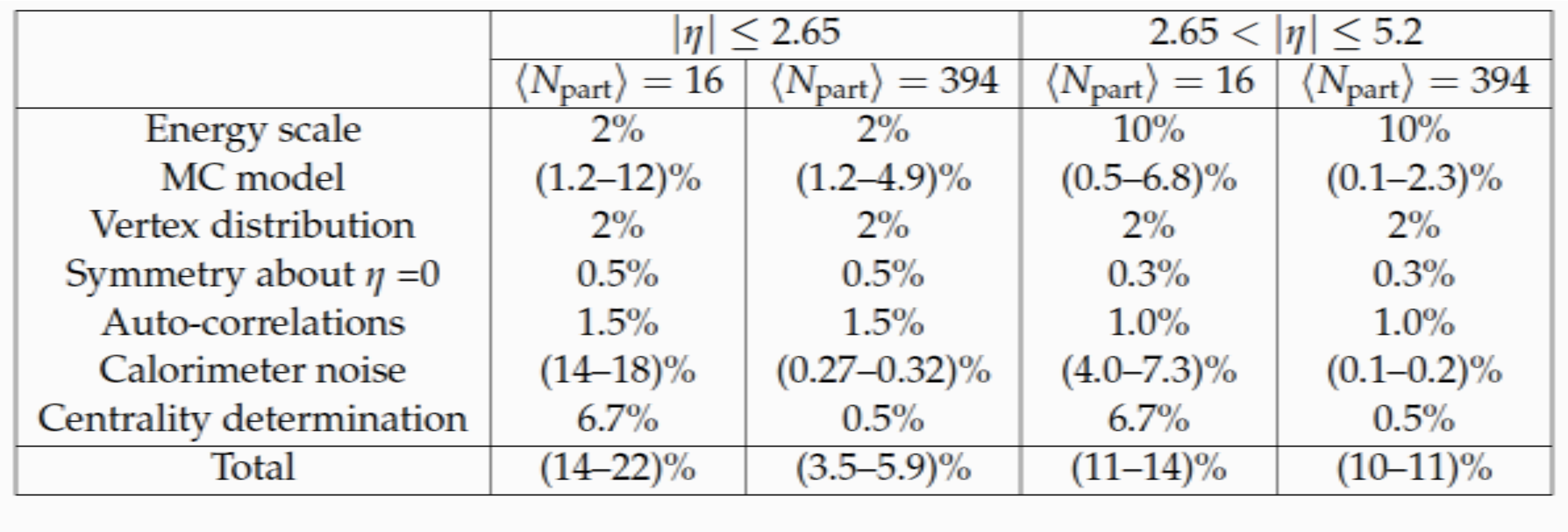
$E_{T,j}$ is the energy in a given calorimeter cell and we sum over all calorimeter cells j within a given Δη region.

$$C_1(\eta\ ) = \frac{\text{MC energy into the } \Delta\eta \text{ region}}{\text{MC energy reconstructed in calorimeters}}$$

$C_1(\eta) \approx 1.6$ for $\eta<2$ falling to ≈ 1.1 by $\eta = 4$ rising to 2 at $\eta=5$
C_1 depends only weekly on centrality.

C_2 accounts for dead areas of the forward calorimeter that are not in GEANT. C_2 varies 0.98 at $\eta=3$ to 0.85 at = 0.98 at $\eta=5$

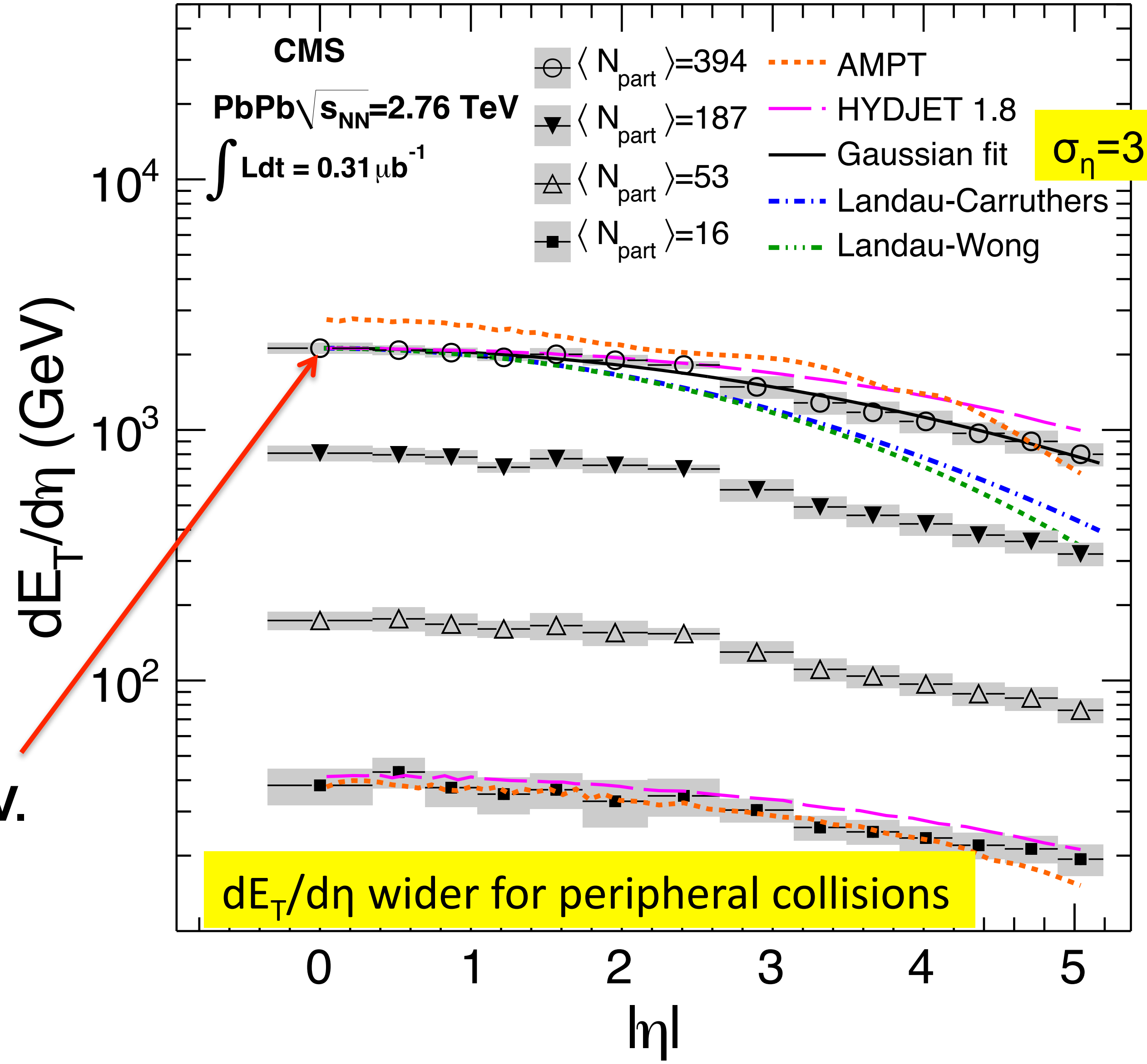
Systematic errors for E_T measurement



	$\lvert\eta\rvert \leq 2.65$		$2.65 < \lvert\eta\rvert \leq 5.2$	
	$\langle N_{\text{part}} \rangle = 16$	$\langle N_{\text{part}} \rangle = 394$	$\langle N_{\text{part}} \rangle = 16$	$\langle N_{\text{part}} \rangle = 394$
Energy scale	2%	2%	10%	10%
MC model	(1.2–12)%	(1.2–4.9)%	(0.5–6.8)%	(0.1–2.3)%
Vertex distribution	2%	2%	2%	2%
Symmetry about η =0	0.5%	0.5%	0.3%	0.3%
Auto-correlations	1.5%	1.5%	1.0%	1.0%
Calorimeter noise	(14–18)%	(0.27–0.32)%	(4.0–7.3)%	(0.1–0.2)%
Centrality determination	6.7%	0.5%	6.7%	0.5%
Total	(14–22)%	(3.5–5.9)%	(11–14)%	(10–11)%

The understanding of energy scale and calorimeter noise produce the largest systematic errors. The energy scale was initially set with test beam data and radioactive sources and for the central calorimeters this was checked by comparing the energy isolated hadrons to the momenta of charged tracks. For the forward region we used Z➔e^+e-. The noise was studied by comparing zero bias with very peripheral events. Statistical errors are negligible in all cases.

$dE_T/d\eta$ vs η



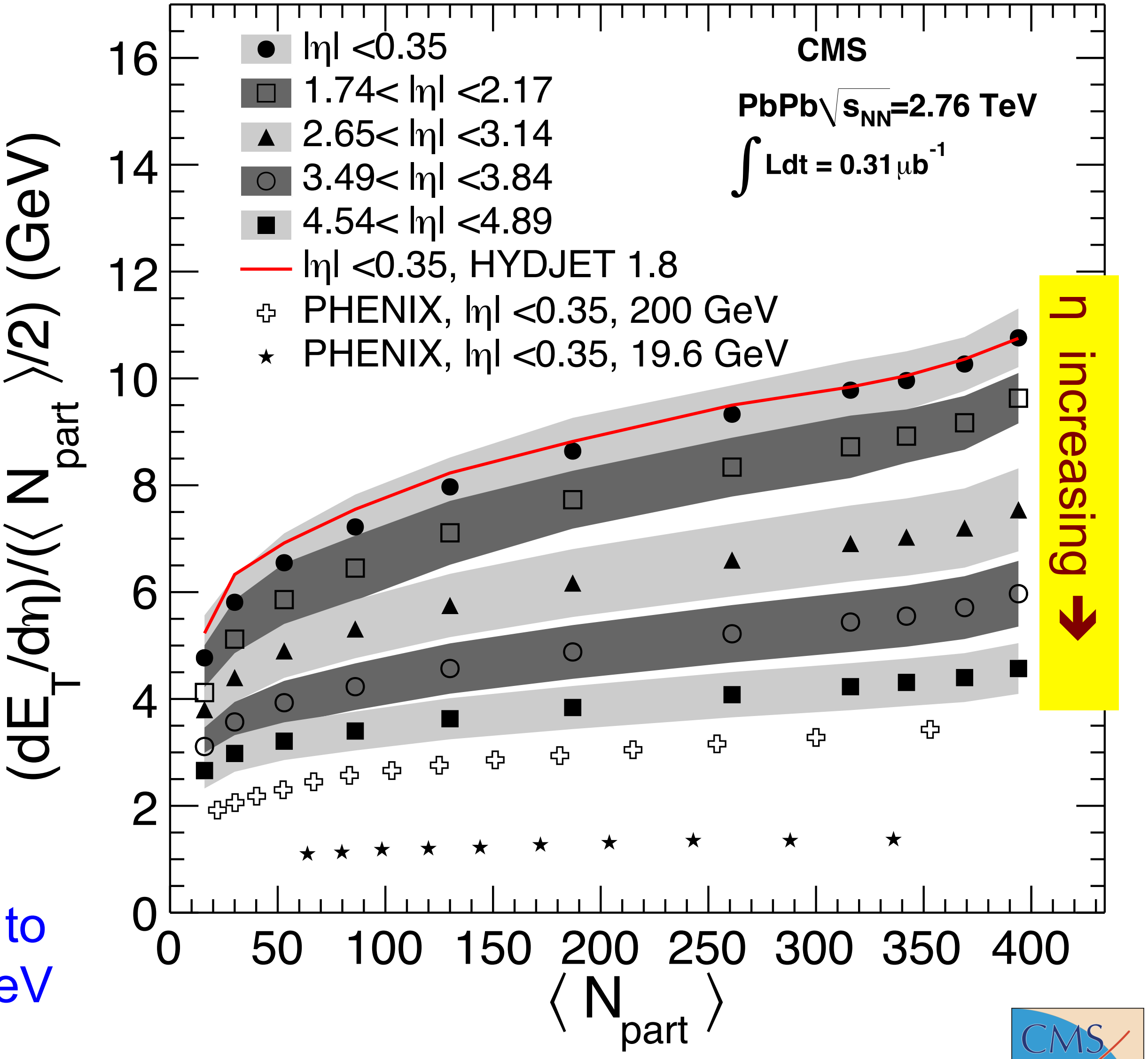
σ_η=3.6±0.1

$dE_T/d\eta$ wider for peripheral collisions

$dE_T/d\eta$ = 2.1 TeV.
Energy density
$\varepsilon \approx 15$ GeV/fm^3

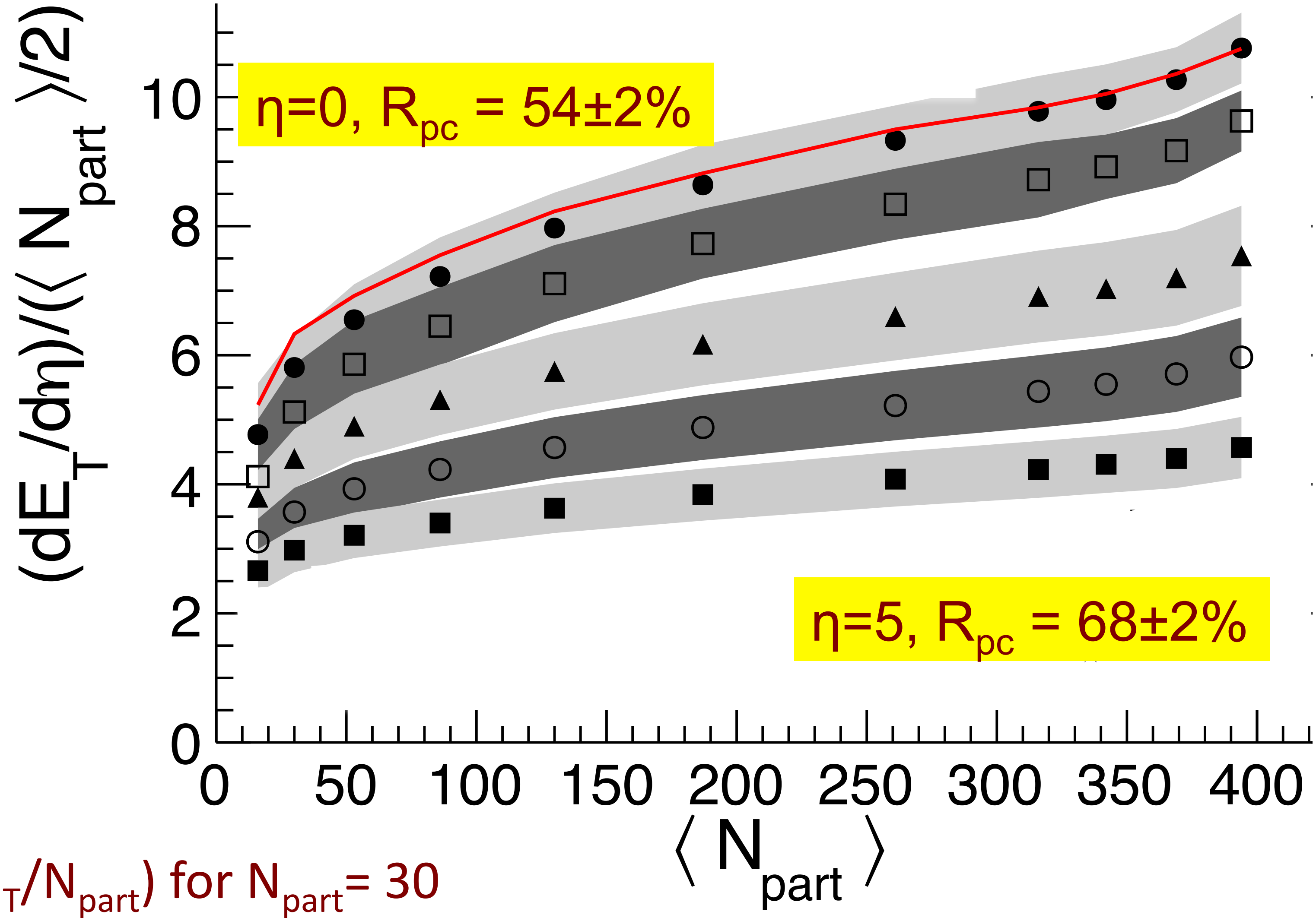
$dE_T/d\eta$ vs N_{part} and η

For all η the distribution rises rapidly at low N_{part} and then more slowly



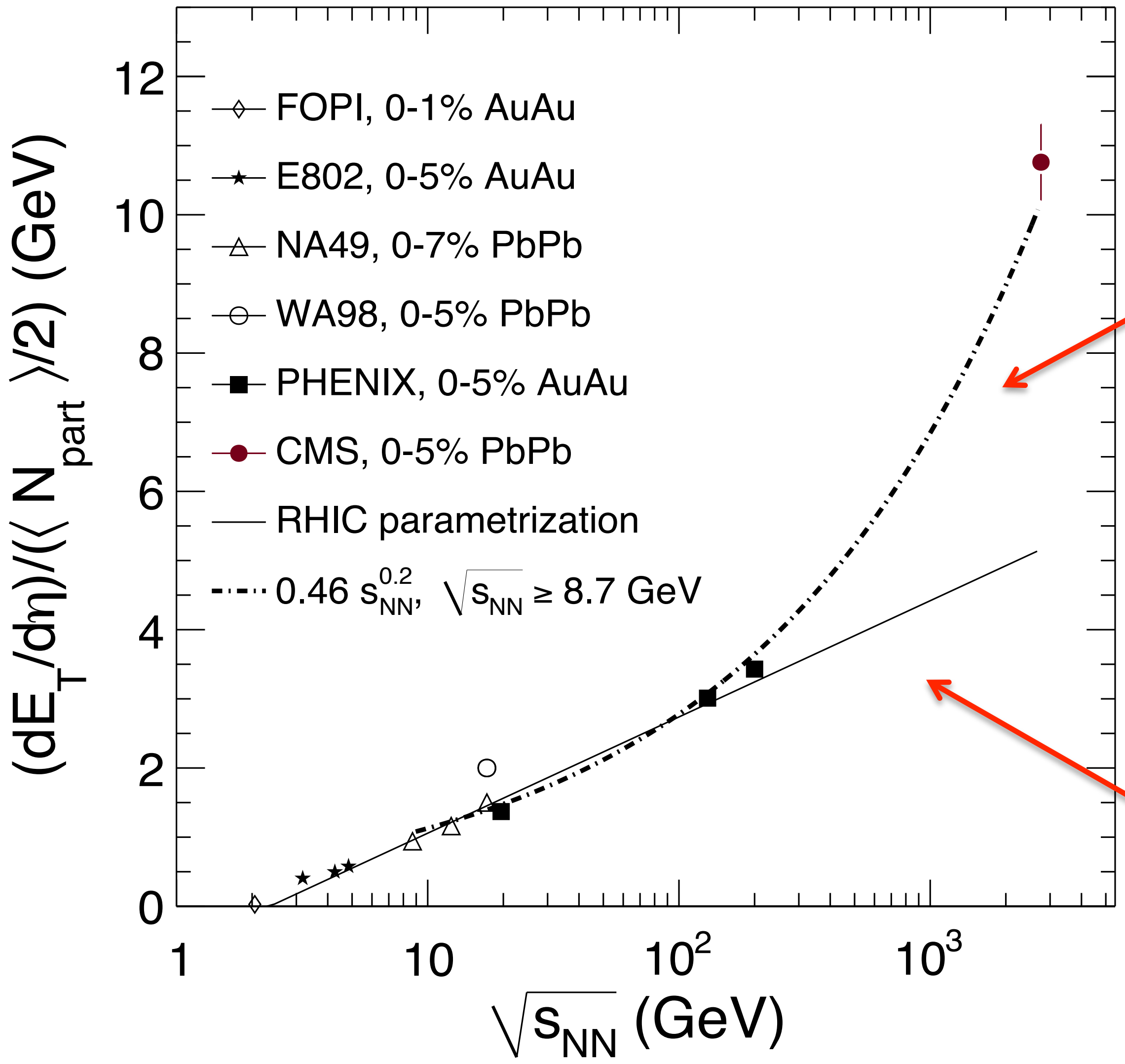
As N_{part} changes from 64 to 336 $dE_T/d\eta/N_{part}$ for $\sqrt{s_{NN}}$ =19.6 GeV rises by a factor 1.25±0.17 compared to 1.47±0.13 at $\sqrt{s_{NN}}$ = 2.76 TeV

E_T/N_{part} is flatter at forward η



$$R_{pc} = \frac{(E_T/N_{part})\text{ for }N_{part} = 30}{(E_T/N_{part})\text{ for }N_{part} = 387}$$

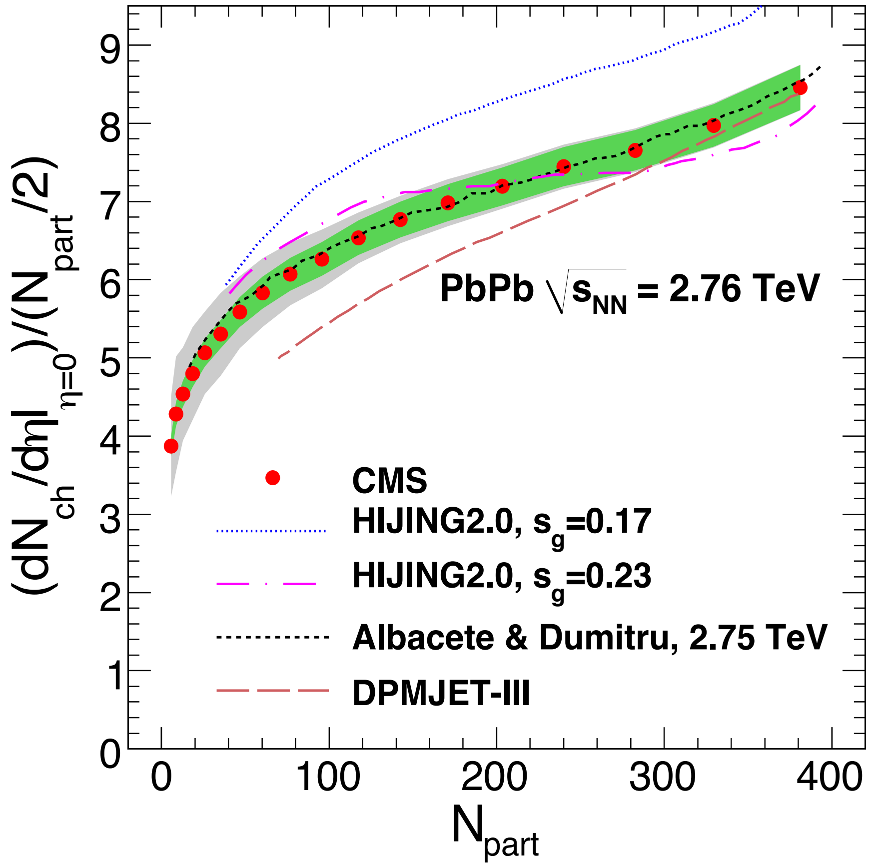
$dE_T/d\eta$ at η=0 versus $\sqrt{s}$

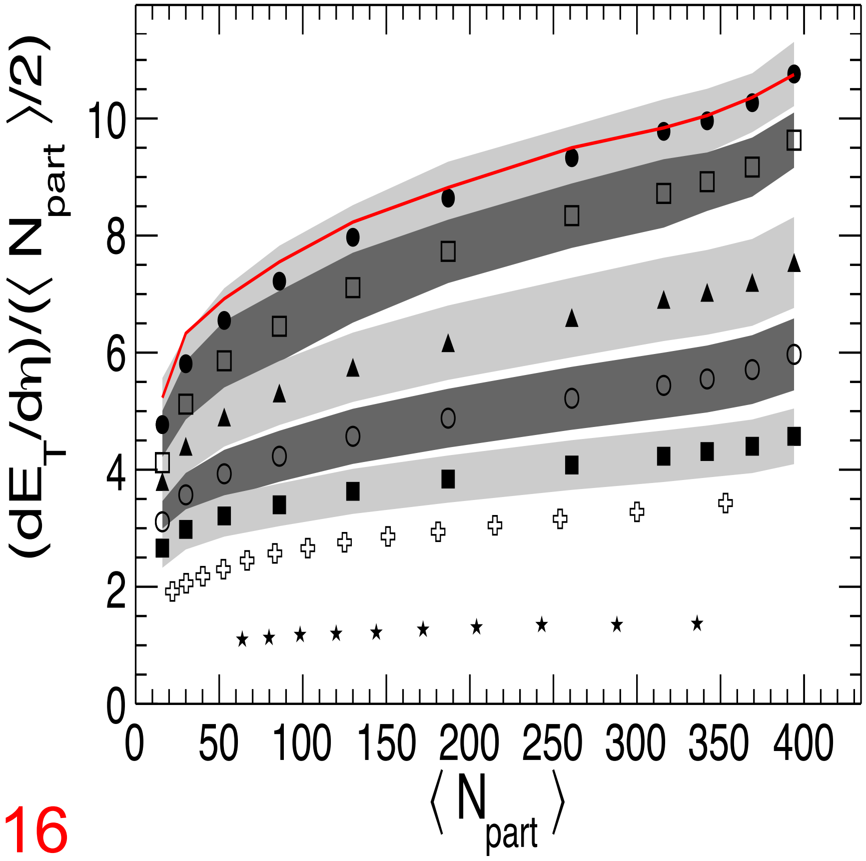


Power law works for $\sqrt{s_{nn}} \geq$ 8GeV

Logarithmic parameterization that worked from $\sqrt{s_{NN}}$ = 1.5 to 200 GeV breaks down for TeV energies

E_T and multiplicity vs N_{part}

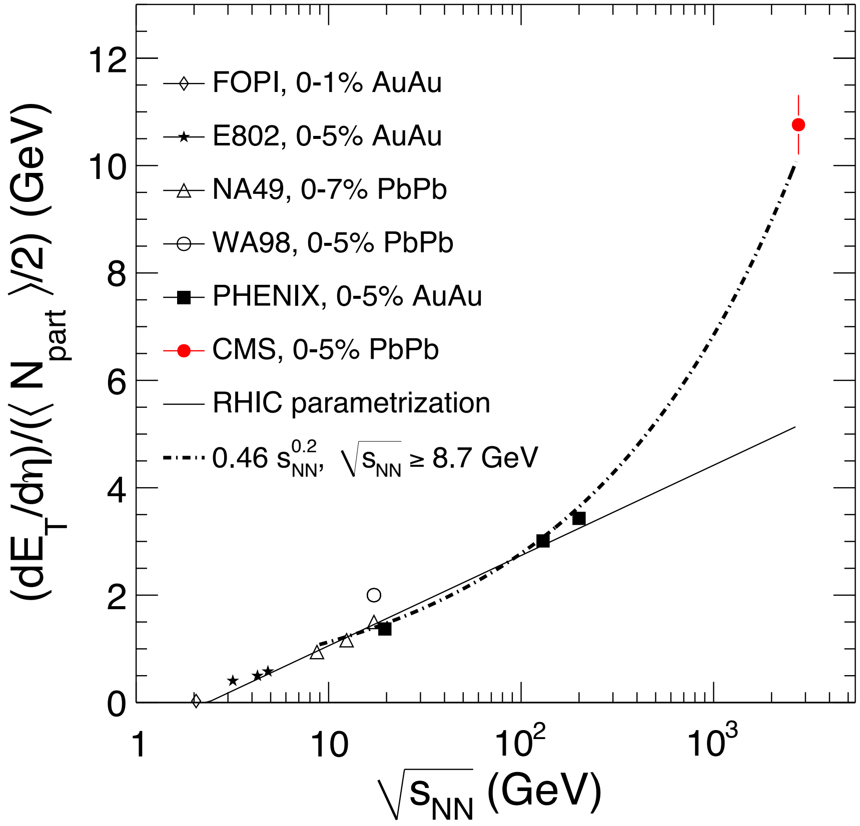




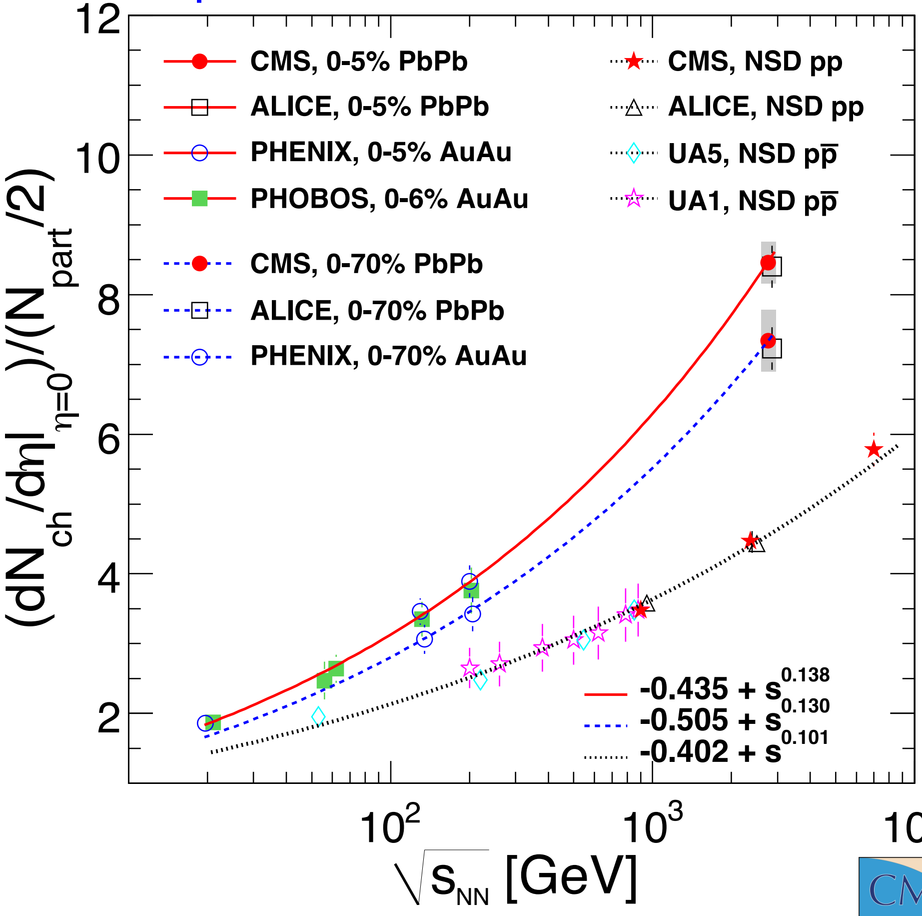
As N_{part} changes from 16 to 381 E_T/N_{ch} at η=0 increases by ≈ 40%

E_T rises faster with $\sqrt{s}$ than multiplicity

E_T/N_{part} rises by factor of 3.2 from RHIC



E_T/N_{part} rises by factor of 2.2 from RHIC



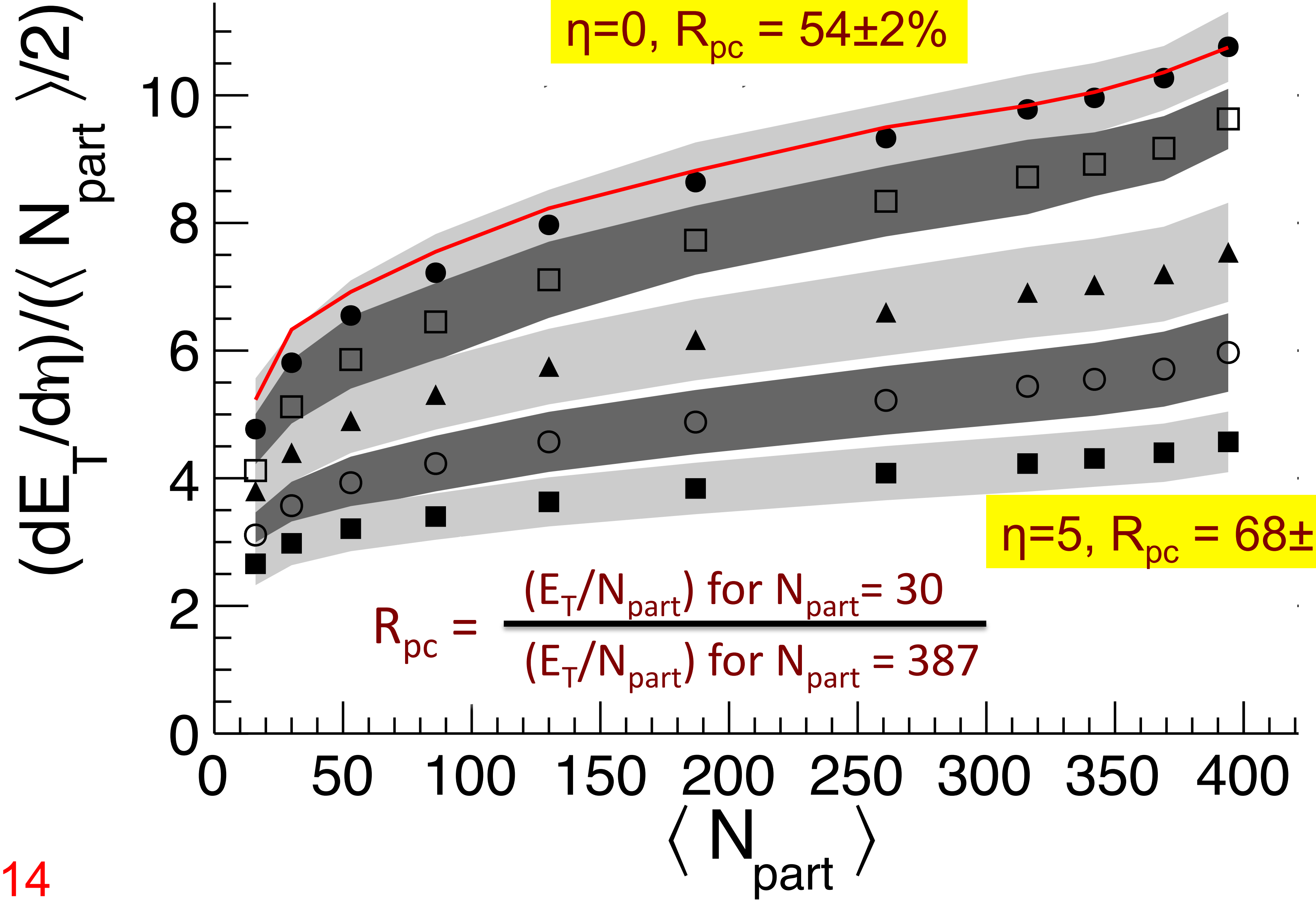
E_T/N_{ch} increases from
0.88 ± 0.07 at $\sqrt{s_{NN}}$=200 GeV
to
1.32 ± 0.08 at $\sqrt{s_{NN}}$=2.76 TeV

Conclusions and outlook

- $dE_T/d\eta$ vs η is wider than predicted by Landau flow and is wider for peripheral than central events
- Both N_{ch} and E_T increase as a power law in s from $\sqrt{s_{NN}}$~8 GeV to 2.76 TeV but E_T increases faster
- E_T/N_{ch} increases with both $\sqrt{s_{NN}}$ and N_{part}.
- $dE_T/d\eta = 2.1$ TeV ➔ energy density ≈ 15 GeV/fm^3
- We are working to extend our η coverage to 6.6 using CASTOR to estimate stopping at 2.76 TeV.
- Forward (and backward) detectors will give unique information on pPb collisions in November.

Backup

E_T/N_{part} is flatter at forward η



η=0, R_{pc} = 54±2%

η=5, R_{pc} = 68±2%

$$R_{pc} = \frac{(E_T/N_{part}) \text{ for } N_{part} = 30}{(E_T/N_{part}) \text{ for } N_{part} = 387}$$