Pseudorapidity and centrality dependence of transverse energy flow in PbPb collisions at 2.76 TeV from CMS

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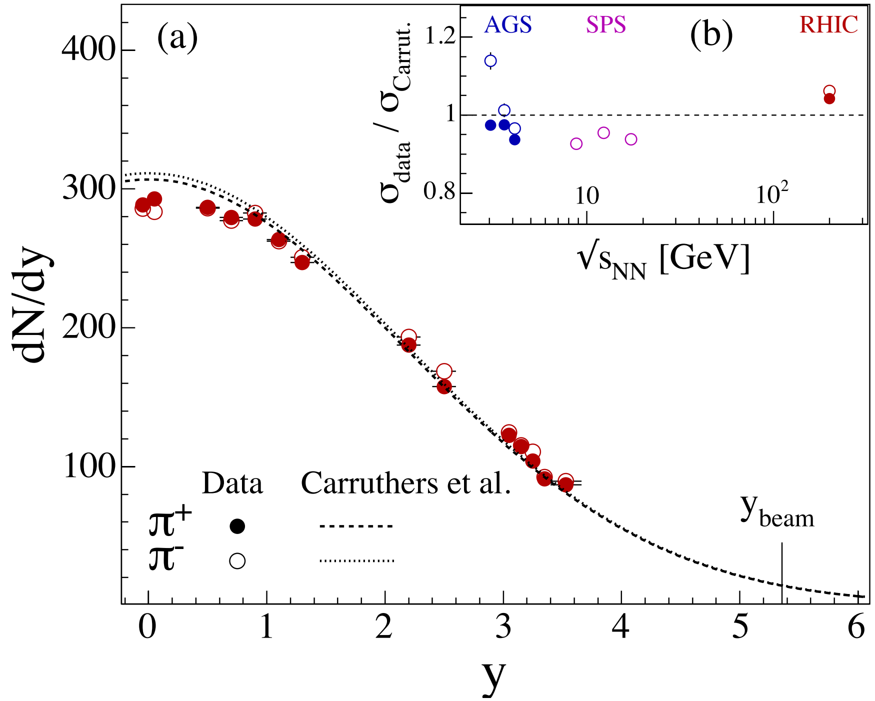
Motivation to study $dE_T/d\eta$ vs η and centrality

- Global observable used to characterize an AA event
  - total entropy produced in the event
  - longitudinal dynamics from pseudorapidity dependence
  - at forward pseudorapidity the centrality dependence may be sensitive to initial distribution of partons

- Central energy density via Bjorken approach

$$\epsilon_{\mathrm{BJ}} = \frac{dE_T}{dy} \cdot \frac{1}{\tau_0 \pi R^2}$$

- BRAHMS pion multiplicity: Gaussians with $\sigma_y = \sqrt{\ln \gamma}$

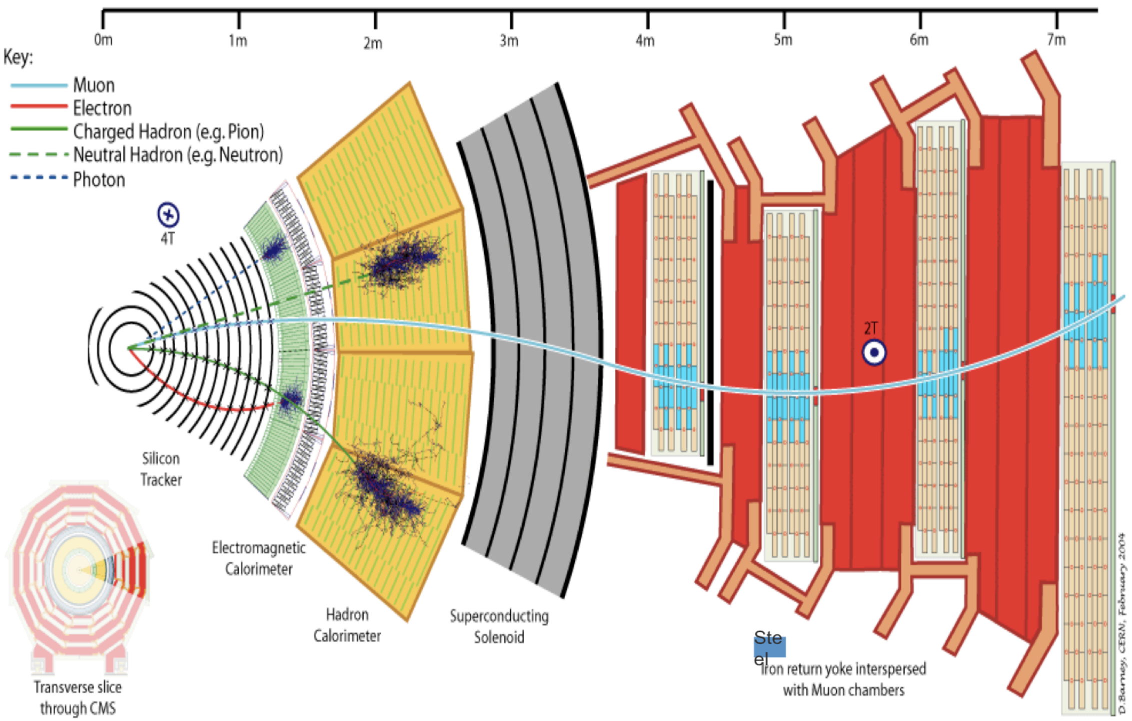


Phys.Rev.Lett. 94 (2005) 162301

CMS

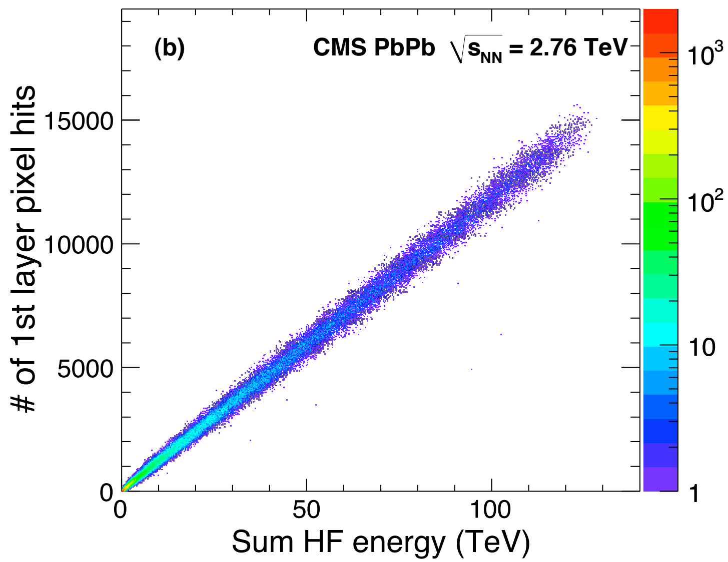
- CMS detector
  - large acceptance tracker, hermetic calorimetry, excellent muon system, forward detectors
- Calorimeters: ECAL, HCAL for $|\eta|<3$ and HF: $2.9 < |\eta| < 5.2$

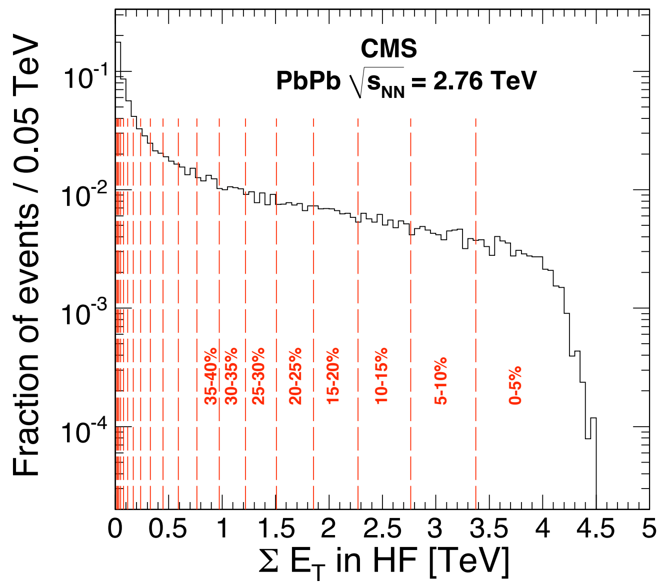
- Note for calorimeters:
  - non-linear response at low energies
  - low-p_T (<1GeV) charged particles don't reach the detector



Event selection and centrality determination

- Min bias data with B=3.8 T
  - double sided HF or BSC coincidence, primary vertex, pixel cluster length compatibility with vertex, beam halo filter
  - min bias trigger efficiency of 97%
- Collision centrality
  - determined from the total energy deposited in HF
  - N_{part} obtained from Glauber model





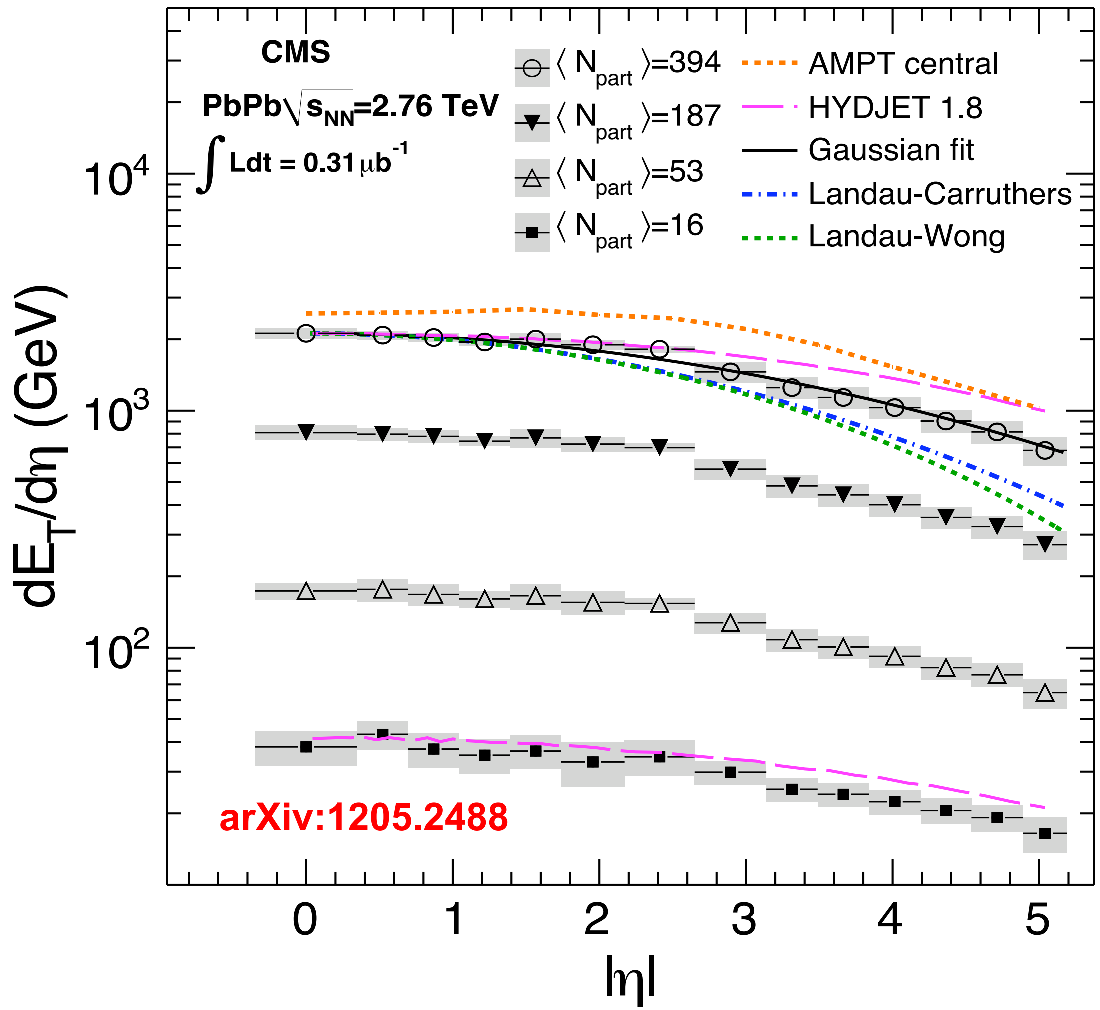
$dE_T/d\eta$: measurement method

- Data: 0.31 μb^{-1} minimum bias data with B=3.8 T from 2010
  - sum over all calorimeters cells (without threshold) within $\Delta\eta$ range
  - correction for detector acceptance and inefficiencies from MC. Correction factor is $C(|\eta|) \approx 1.6$; 1.1 ; 2 for $|\eta|<2$; $|\eta| \approx 4$; $|\eta| \approx 5$
  - muons and neutrinos not considered
- Simulation:
  - HYDJET 1.8 tuned to ALICE spectra and particle yields
    - fraction of E_T carried by charged π, K, p and antiprotons is 0.62
    - weak decays ON
  - HYDJET 1.6: for systematic check

η		Hydjet 1.8	Hydjet 1.6
$\eta=0$	K+-/pi+-	0.15	0.16
	p+-/pi+-	0.045	0.045
	<pT_ch>	0.66 GeV/c	0.57 GeV/c
$3<\eta<5$	K+-/pi+-	0.20	0.19
	p+-/pi+-	0.51	0.54
	<pT_ch>	0.62	0.53

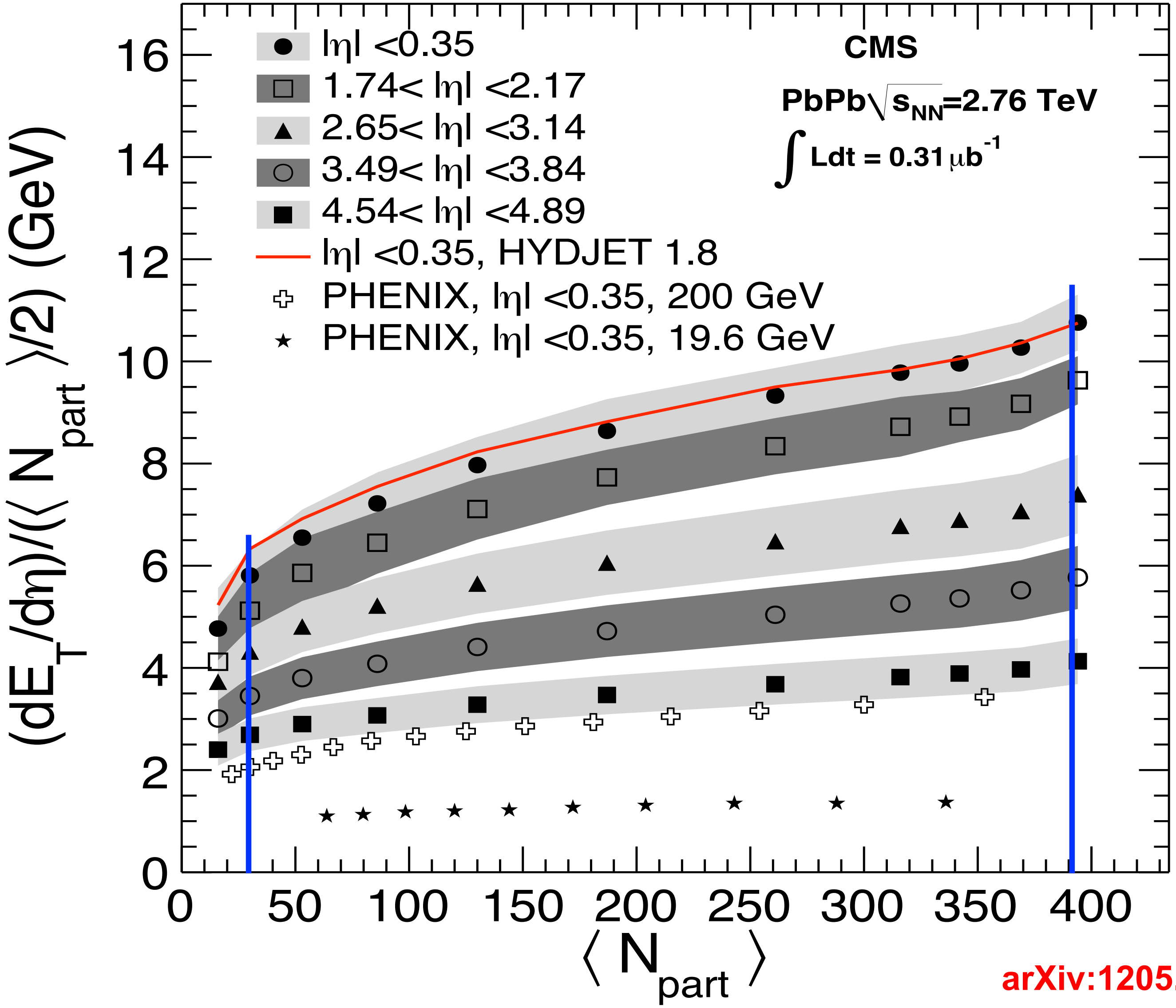
HYDJET 1.8: Eur.Phys.J.C45:211-217,2006

$dE_T/d\eta$: η dependence



- 2.1 TeV at η=0; Gaussian with σ=3.4±0.1; ε_{Bj} =14 GeV/fm^3 (τ_0=1 fm/c, R=7 fm)
- Total E_T per pair of participating nucleons: 91±5 GeV

$dE_T/d\eta$: N_{part} dependence



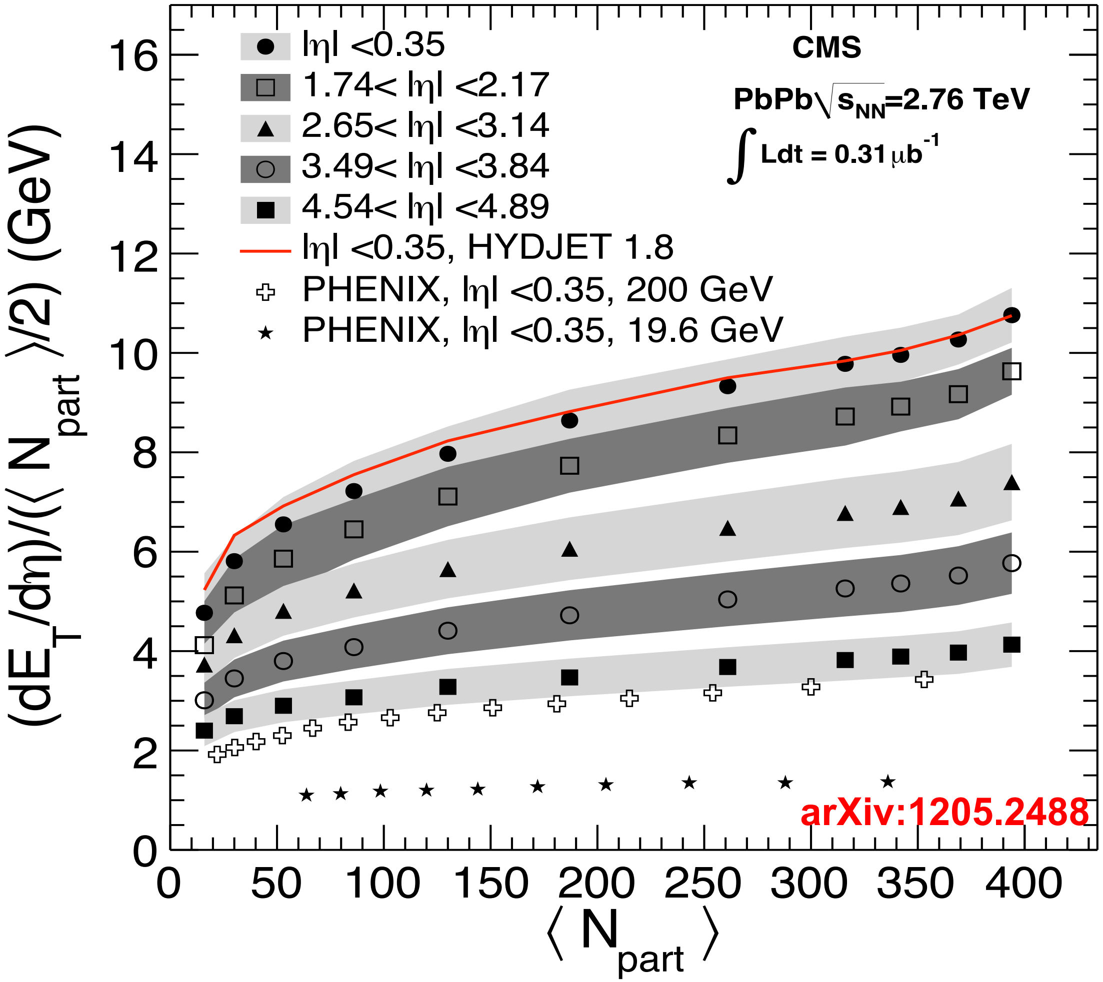
arXiv:1205.2488

R_{pc}

η=0; 54±2%

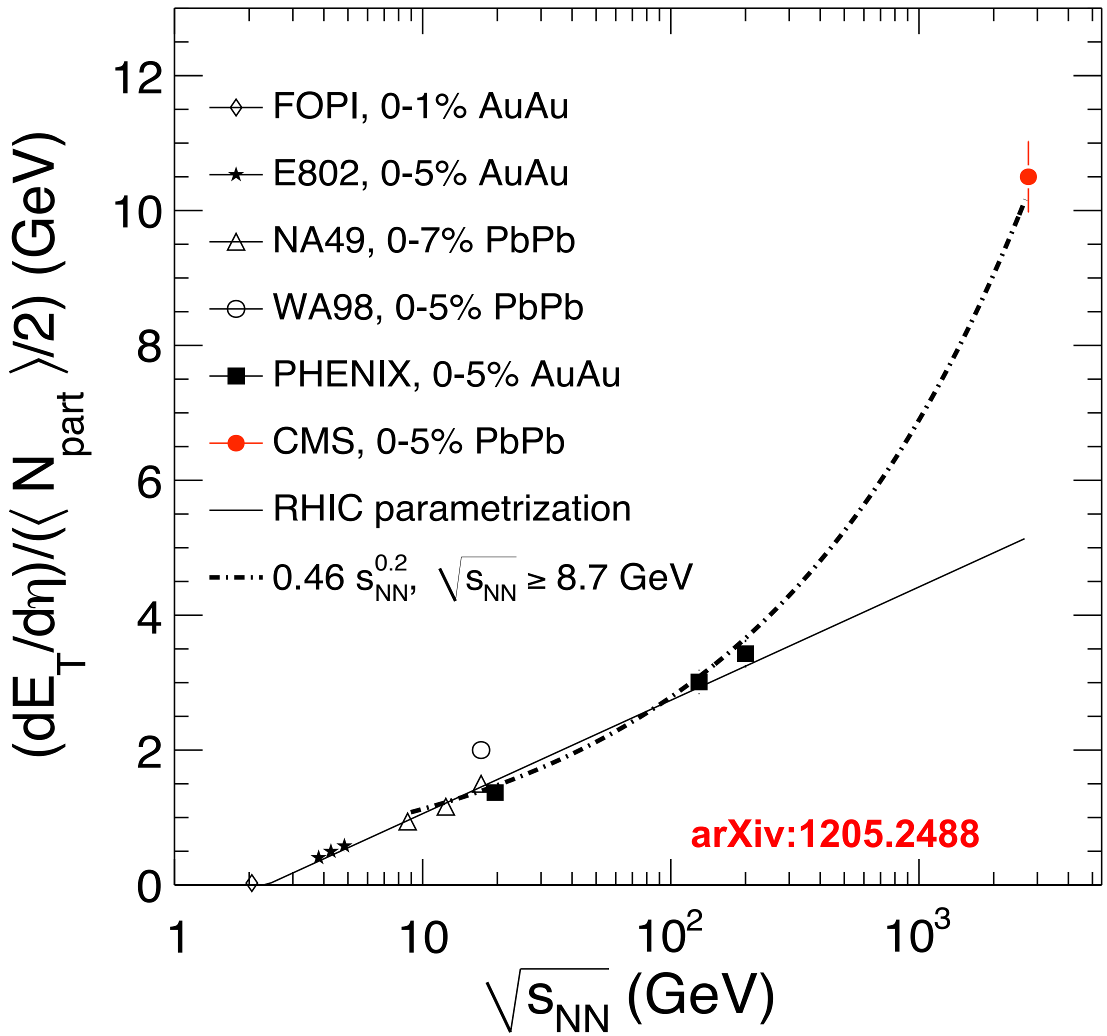
η=5; 68±2%

$dE_T/d\eta$: N_{part} dependence



- Increases with N_{part}, $dE_T/d\eta/(N_{part=30}/2)/dE_T/d\eta/(N_{part=394}/2)$: 54±2%[68±2%] for η=0[5]
- At $\sqrt{s_{NN}}$=19.6 GeV[2.76 TeV] for η=0: $dE_T/d\eta/(N_{part}/2)$ increases by 1.25[1.47] when N_{part} goes from 63.8 to 336

$dE_T/d\eta$: $\sqrt{s_{NN}}$ dependence for $\eta \approx 0$



- Rises faster than log dependence, in accordance with $s_{NN}^{0.2}$ dependence
- From $\sqrt{s_{NN}}$= 0.2 to 2.76 TeV the $dE_T/d\eta/(N_{part}/2)$ increases by a factor of 3.07±0.24

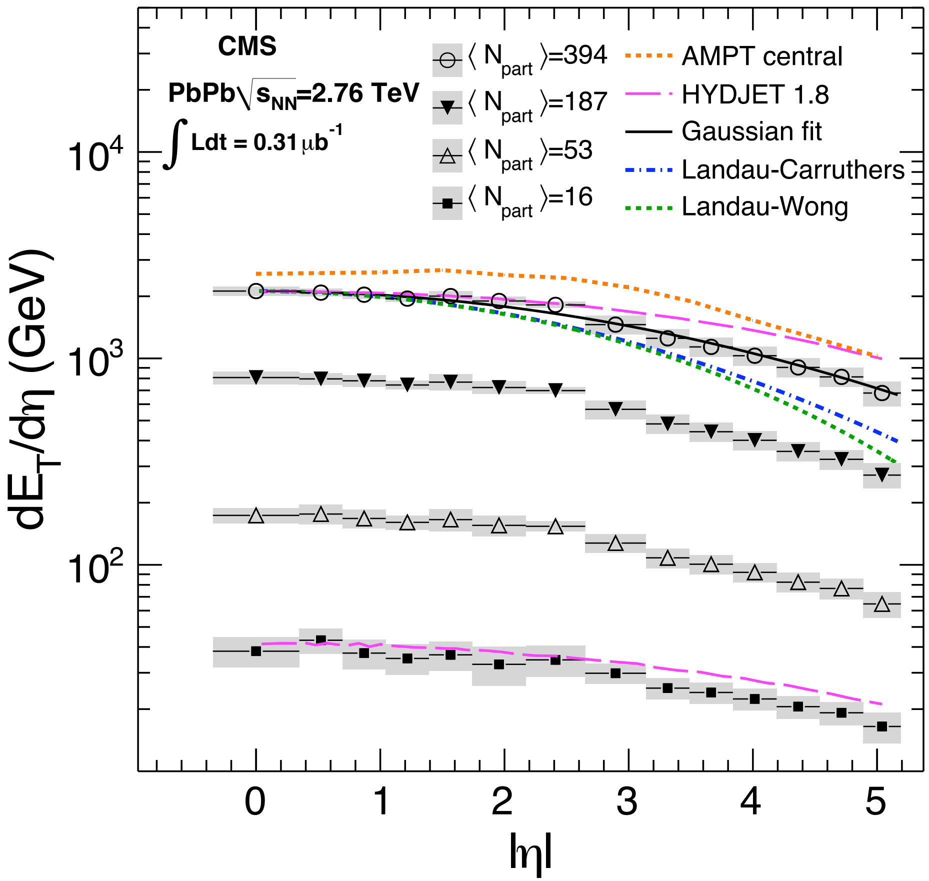
$dE_T/d\eta$: systematic uncertainties*

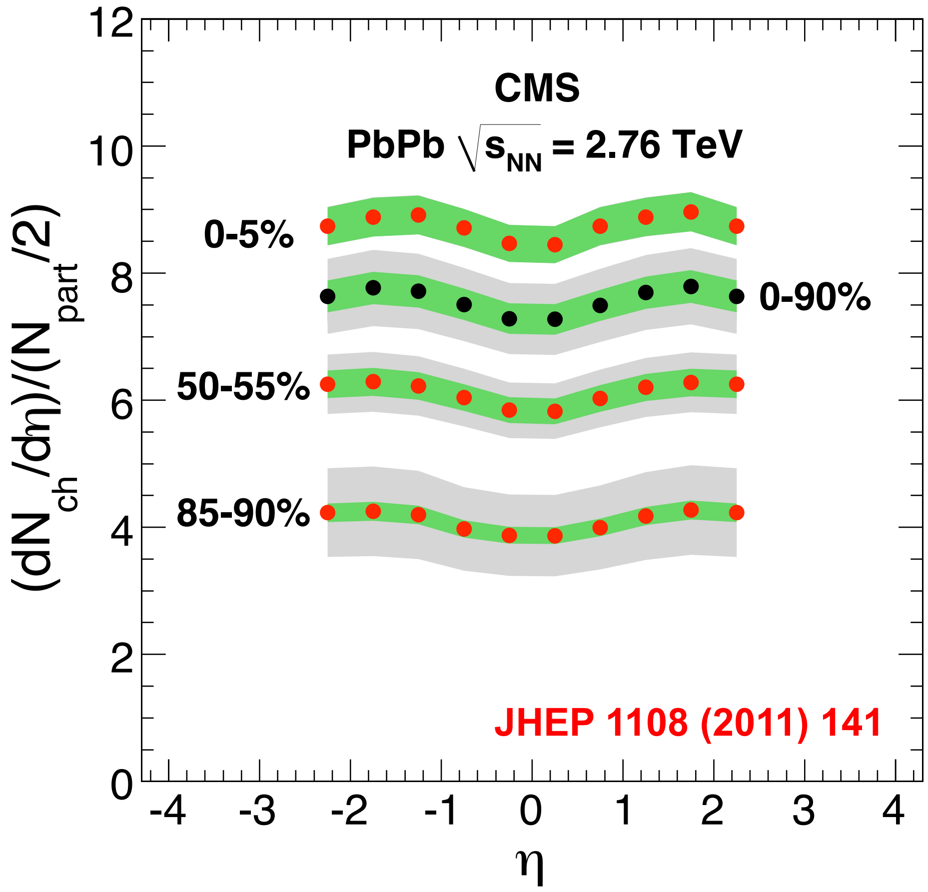
- For $|\eta| \leq 2.65$ uncertainties smaller near $\eta=0$ and maximal for η between 1.4 and 2.1
- For $|\eta| > 2.65$ uncertainties increase with $|\eta|$

	$\lvert\eta\rvert \leq 2.65$		$2.65 < \lvert\eta\rvert \leq 5.2$	
	$\langle N_{part} \rangle = 16$	$\langle N_{part} \rangle = 394$	$\langle N_{part} \rangle = 16$	$\langle N_{part} \rangle = 394$
Energy scale	2%	2%	10%	10%
MC model	(1.2–12)%	(1.2–4.9)%	(1.0–6.8)%	(1.0–2.3)%
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)%	0.3%	(4.0–7.3)%	(0.1–0.2)%
HF MC description	–	–	(1.5–9)%	(1.5–9)%
Centrality determination	6.7%	0.5%	6.7%	0.5%
Total	(14–22)%	(3.5–5.9)%	(11–17)%	(10–14)%

* Statistical uncertainties are negligible

$dE_T/d\eta$ vs $dN_{ch}/d\eta$





- N_{ch} rises faster than log dependence: described by $s_{NN}^{0.13}$ dependence
- From $\sqrt{s_{NN}}$= 0.2 to 2.76 TeV the $dN_{ch}/d\eta/(N_{part}/2)$ increases by a factor of 2.17±0.15
- For η=0 E_T/charged particle is 1.25±0.08 [0.88±0.07] GeV for 2.76 [0.2] TeV

Conclusions

- Maximum $dE_T/d\eta$ of 2.1 TeV for $\eta=0$: ~3 times larger than at RHIC
- Shape of $dE_T/d\eta$ consistent with Gaussian of $\sigma_\eta=3.4\pm0.1$ for 0-2.5% collisions
  - larger than predicted by Landau hydrodynamics but narrower than given by HYDJET; AMPT overestimates $dE_T/d\eta$
- $dE_T/d\eta$ is narrower in η for central events
- $(dE_T/d\eta)/(\langle N_{part}/2\rangle)$ increases with N_{part} for all η
- $dE_T/d\eta$ and $dN_{ch}/d\eta$ have a power-law dependence on s_{NN} but E_T grows faster
- Significant increase of the mean E_T per particle compared to lower energy data

For η range extended up to -6.6 see C. WOHRMANN, 15/08 (8:30 AM, Parallel 3D)

Back up

Remarks/cross-checks (E_T/N_{ch})

- From data E_T/N_{ch} = 1.25+-0.08 (E_T_weak_on/N_{ch}_weak_off), for ALICE ~1.05 (|y|<0.6)
- Consistent with
  - results from B=0 T data. The correction factor only accounts for the material budget before the calorimeters.
  - results from particle flow (match tracks to energy clusters in the calorimeter). Use hadron calorimeter to measure neutrals.
  - results from HYDJET that gives 1.28
- Transverse energy sums over both charged and neutral particles and is sensitive to the number of particles, mix of particle types and momentum spectra.
  - CMS: measures mostly neutrals and correct for charged from MC. Fraction of energy carried by charged pions, kaons, p and pbar is 60-62% (depend on hydjet version)
  - ALICE: measures charged and suppose neutrals. Fraction of energy carried by charged pions, kaons, p and pbar is 55%. What about strangeness enhancement?
- N_{ch} from PHENIX and PHOBOS (difference of 6%)
  - PHENIX $dN_{ch}/d\eta$ = 687 for $|\eta|<0.3$; (E_T/N_{ch} = 0.88) ; so from 0.2 to 2.76 TeV we have 42% increase in E_T/N_{ch}
  - PHOBOS $dN_{ch}/d\eta$ = 649 for $|\eta|<1$; (E_T/N_{ch} = 0.93): 34% increase
- Jacobian: taking an average $dN_{ch}/d\eta$ over $|\eta|<2.2$; our E_TNch changes to 1.12.
- We compare the top 5% of PbPb <Npart>=381 to PHENIX AuAu 353 (E_T increases with N_{part}).

Few words about HYDJET

- tuned using mainly the following LHC ALICE and CMS data for mid-rapidity:
  - dN/d(η) of charged hadrons vs. centrality;
  - p_T-spectrum of charged particles for central events;
  - p_T-integrated K/pi & p/pi ratios for central events (use ALICE only. Remark: More differential results like p_T-spectra of pi, K and p came from ALICE later)
  - elliptic flow coefficient v2 of charged hadrons vs. p_T and centrality;
  - plus CMS data on dN/d(η) of charged particles vs. η.