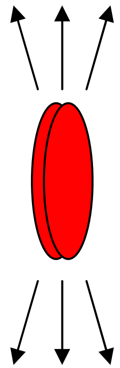
Lecture 08: transverse energy, nuclear stopping and energy density

- Last lecture:
  - Nuclear geometry, centrality, N_{part}, N_{coll}
  - Multiplicity:
    - Energy dependence
    - Pseudo-rapidity dependence and scaling
      - at mid-rapidity
      - Total multiplicity
      - fragmentation region
- Today: nuclear stopping, transverse energy and energy density – i.e. get a more detailed picture of particle production and energy flow

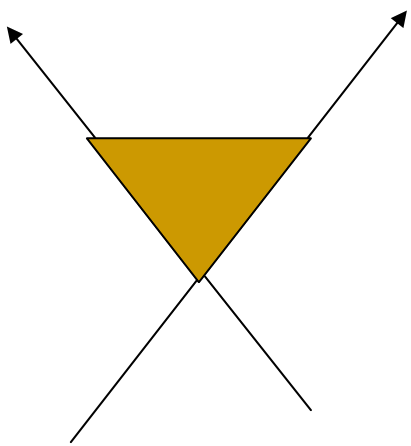
Consider 2 pictures of the AA collisions

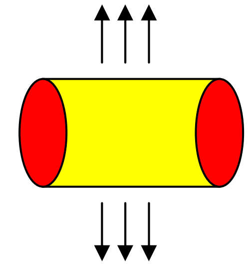
- Colliding nuclei stop and convert all of their kinetic energy into particles (Landau)
- Colliding nuclei are transparent to each other. They “pass-through” stretching strings between the colliding partons. As the strings break – particles are produces. Only a fraction of the initial kinetic energy is lost and available for particle production. (Bjorken)

Landau vs Bjorken picture

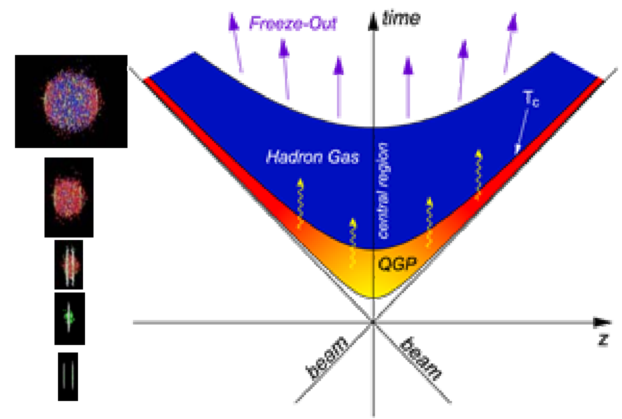


Landau





Bjorken



Gaussian rapidity distribution.

Rapidity plateau, or
“boost invariance”.

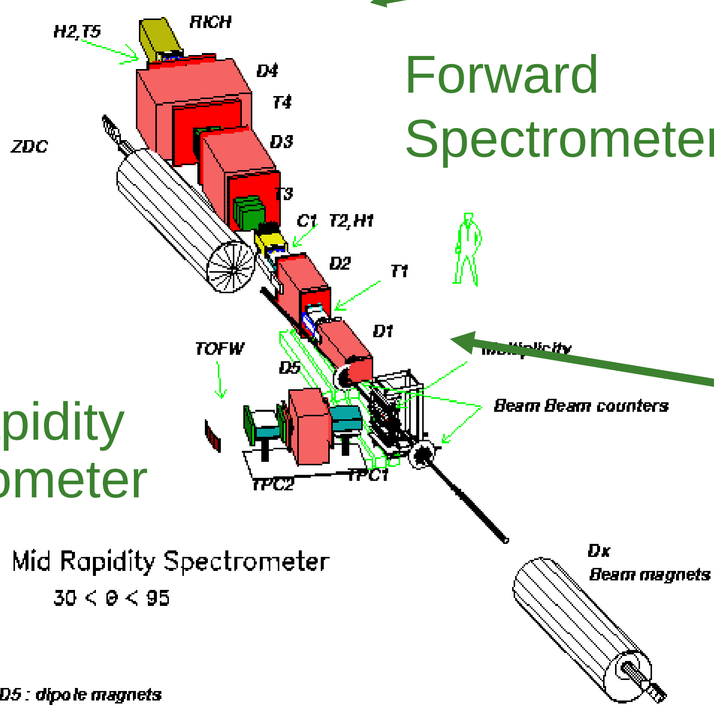
Let’s measure where the initial baryons go – then we’ll know which picture is correct

The Brahms detector

Two Arm Spectrometer
with Variable Setting

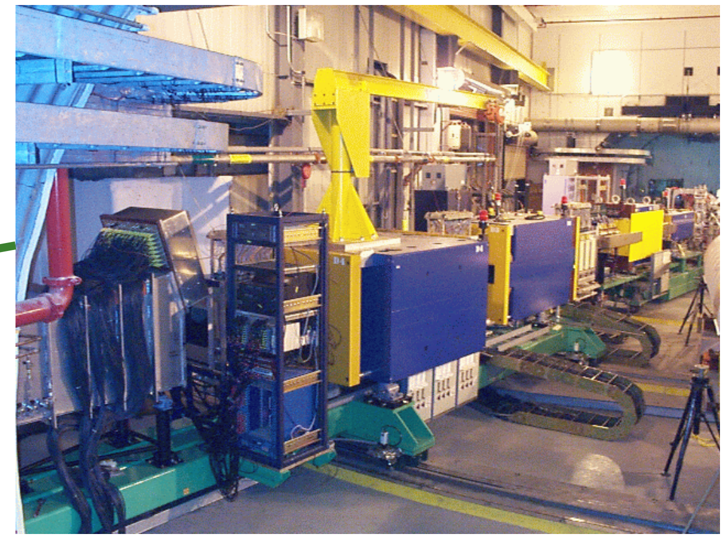
Good Particle ID

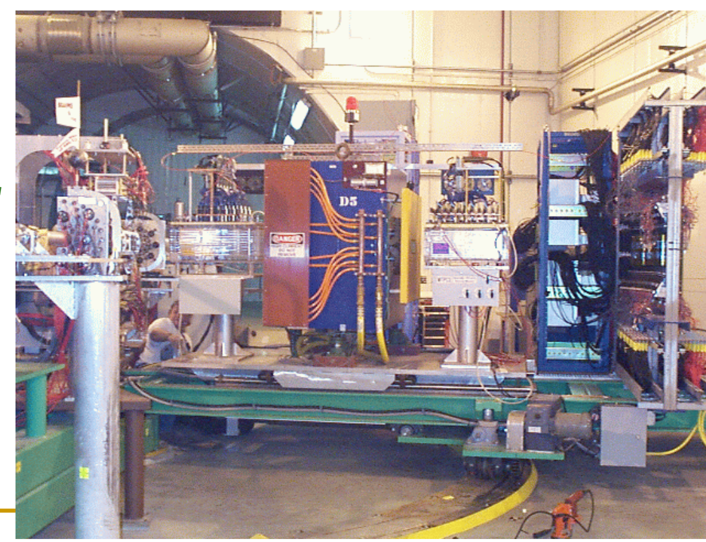
Forward
Spectrometer



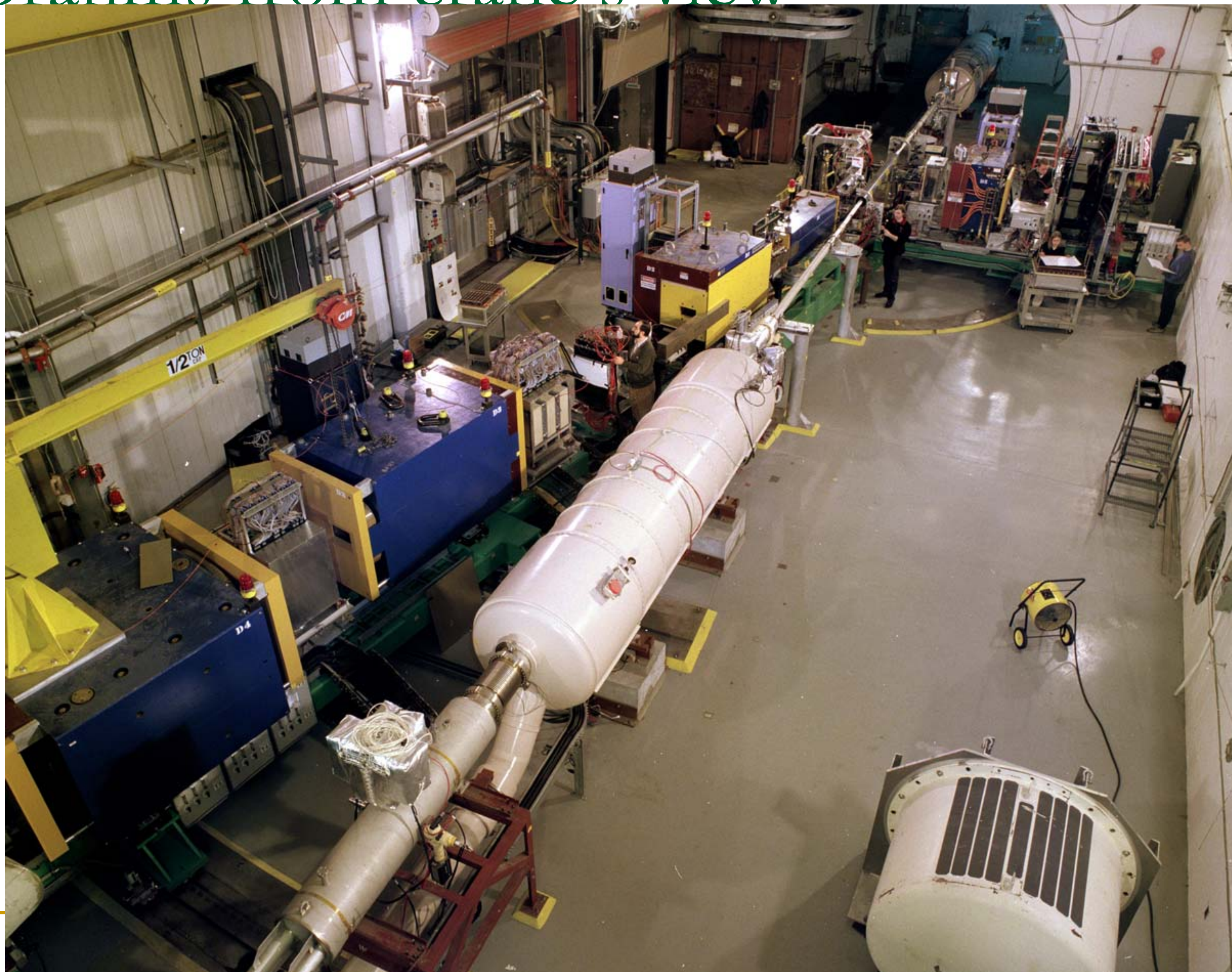
Mid-Rapidity
Spectrometer

D1,D2,D3,D4,D5 : dipole magnets
T1,T2,T3,T4,T5, TPC1 TPC2: tracking detectors
H1,H2, TOFW : Time-of-flight detectors
RICH, GASC : Cherenkov detectors

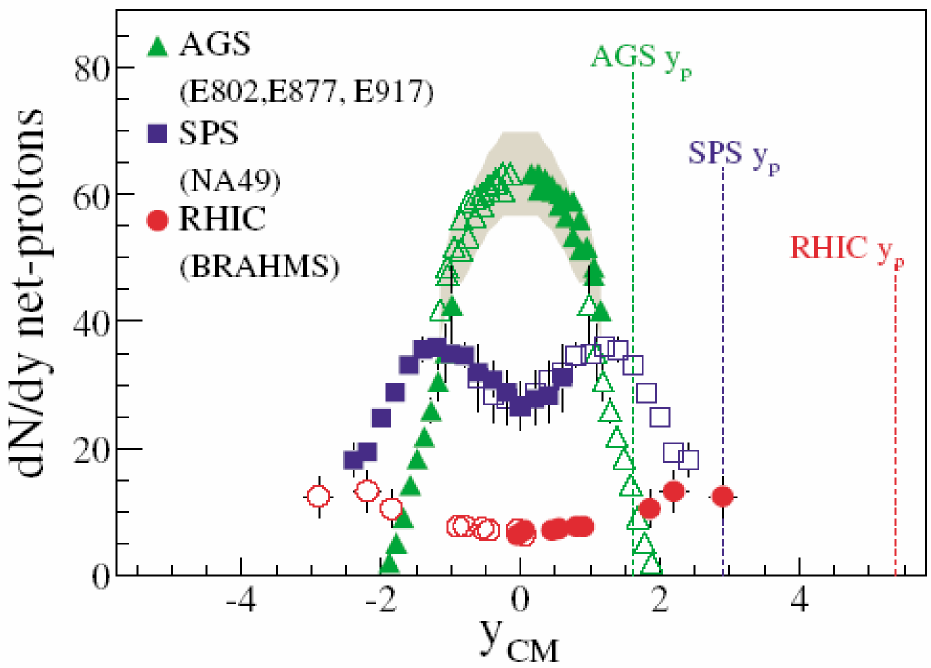




Brahms from crane's view



Net baryon (these are the transported particles) rapidity distributions



BRAHMS Collaboration (I. G. Bearden et al.)
"Nuclear Stopping in Au+Au Collisions at sqrt(sNN)=200 GeV"
Phys. Rev. Lett. 93, 102301 (2004)

FIG. 3 (color online). The net-proton rapidity distribution at AGS [8,21,22] (Au + Au at $\sqrt{s_{NN}} = 5$ GeV), SPS [23] (Pb + Pb at $\sqrt{s_{NN}} = 17$ GeV), and this measurement ($\sqrt{s_{NN}} = 200$ GeV). The data are all from the top 5% most central collisions and the errors are both statistical and systematic (the light gray band shows the 10% overall normalization uncertainty on the E802 points, but not the 15% for E917). The data have been symmetrized. For RHIC data black points are measured and gray points are symmetrized, while the opposite is true for AGS and SPS data (for clarity). At AGS weak decay corrections are negligible and at SPS they have been applied.

Net proton rapidity distributions

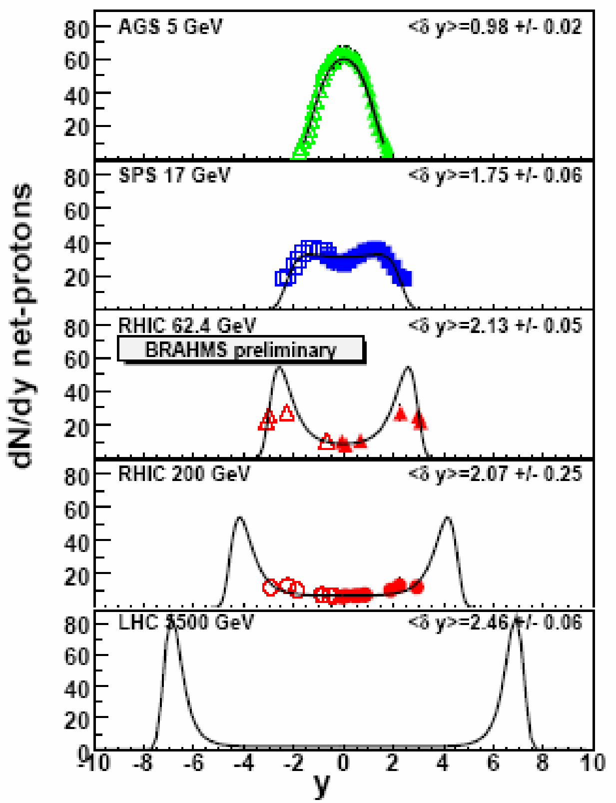


Fig. 3. $\frac{dN}{dy}$ of protons from AGS[5], SPS[9] and RHIC[5]. Errors include systematic errors. Bottom panel shows extrapolation to LHC.

Since baryon number is conserved, We can extrapolate the net baryon distributions in the unmeasured region.
Then measure the average rapidity loss to quantify the stopping:

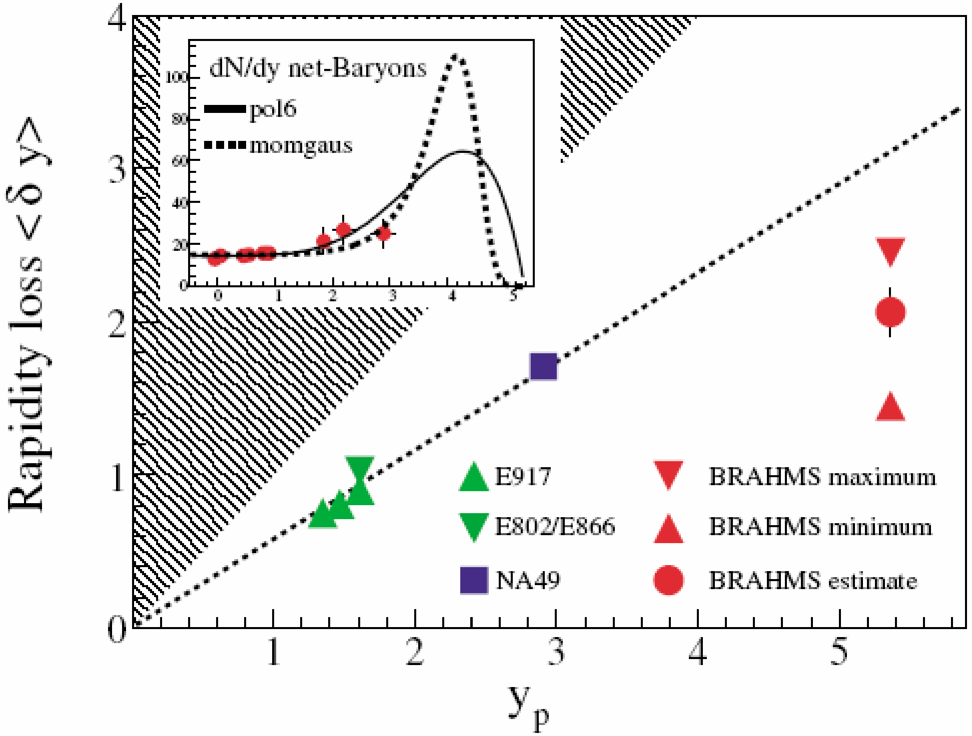
$$\langle \delta y \rangle = y_p - \langle y \rangle$$

Here, y_p is the rapidity of the incoming projectile and <y> is the mean net-baryon rapidity after the collision:

$$\langle y \rangle = \frac{2}{N_{\text{part}}} \int_0^{y_p} y \frac{dN_{(B-\bar{B})}(y)}{dy} dy$$

Poster by H.H.Dalsgaard at QM06

Nuclear stopping from AGS to LHC



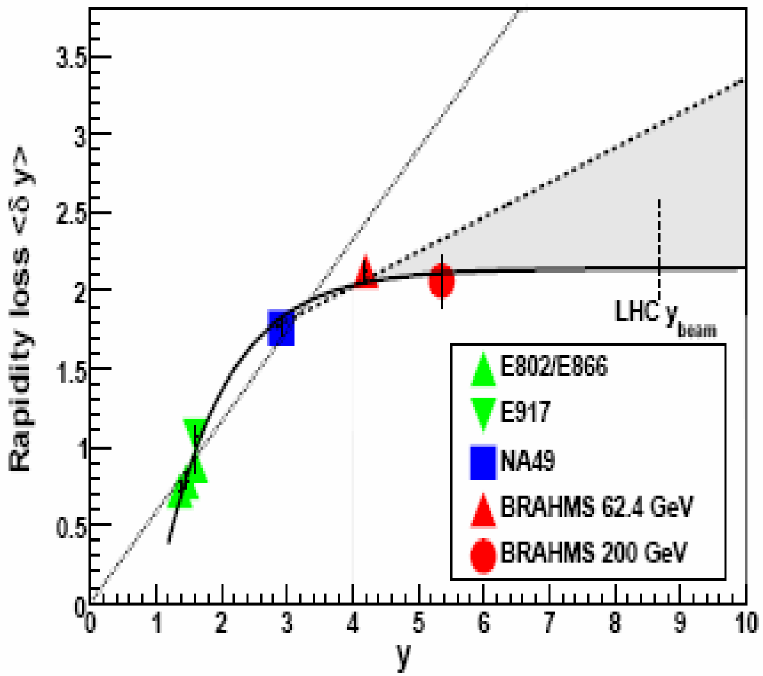
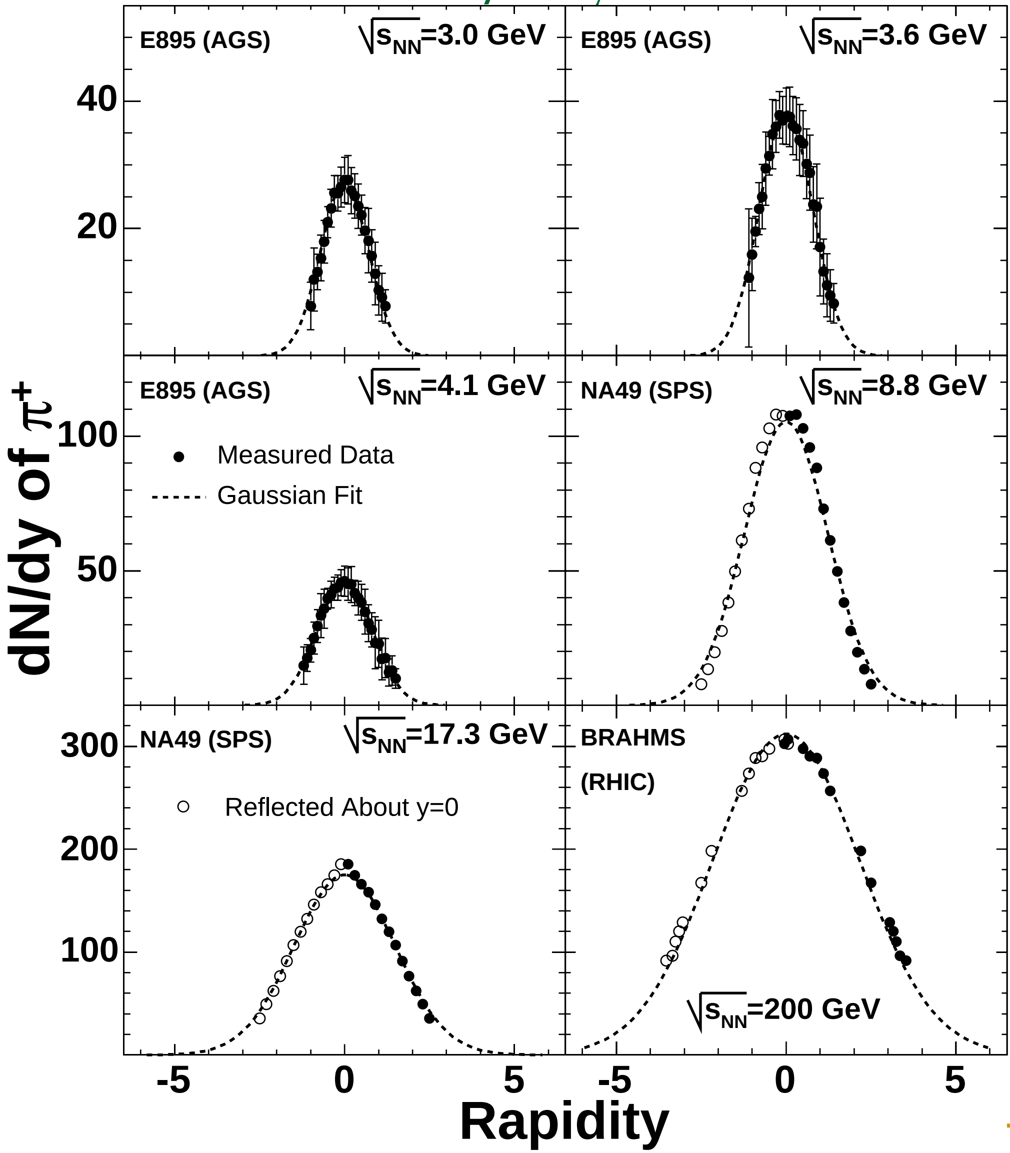


FIG. 4 (color online). The inset plot shows the extrapolated net-baryon distribution (data points) with fits (represented by the curves) to the data; see text for details. The full figure shows the rapidity loss, obtained using Eq. (1), as a function of projectile rapidity (in the CM). The hatched area indicates the unphysical region, and the dashed line shows the phenomenological scaling $\langle \delta y \rangle = 0.58 y_p$. The data from lower energy are from [6,8].

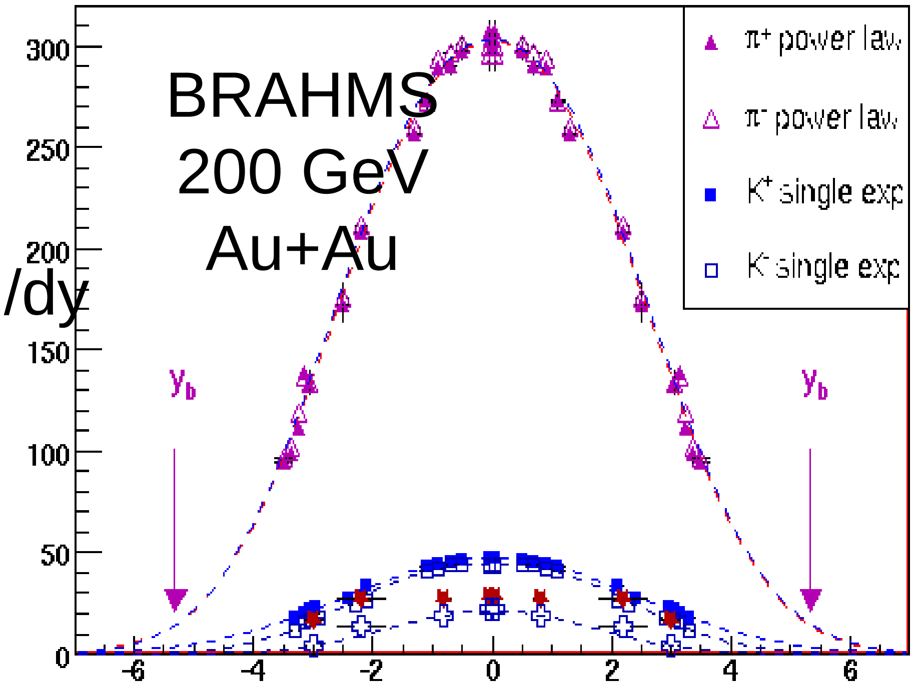
Look at dN/dy – no boost invariance



- No plateau is present in the dN/dy distributions of pions

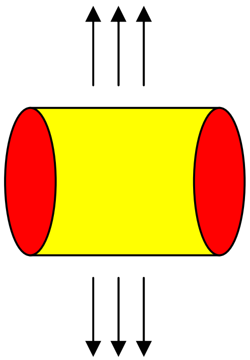
Boost invariant?

dn/dy



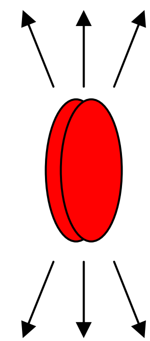
rapidity, y

(not pseudorapidity, η)



Bjorken

The “truth” is in-between.



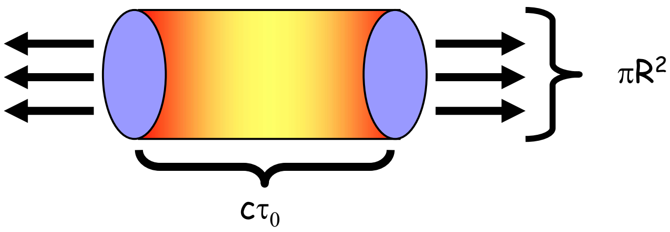
Landau

Now go on and estimate the energy density in the collisions

This will let us find out if we have exceeded the critical energy density for the phase transition.

energy density = ΣE/volume

Colliding system expands:



Energy ⊥ to beam direction

$$\varepsilon_{Bj} = \frac{1}{\pi R^2} \frac{1}{c\tau_0} \left(\frac{dE_T}{dy} \right)$$

per unit velocity || to beam

$$\varepsilon_{Bj} = \frac{1}{\pi R^2} \frac{1}{c\tau_0} \frac{dN}{dy} \langle m_T \rangle$$

Question:

What is the relevant time during the collision at which we need to calculate the energy density ?

Note: Lattice calculations predict critical energy density ε_C ~ 0.3-1.0 GeV/fm^3 .

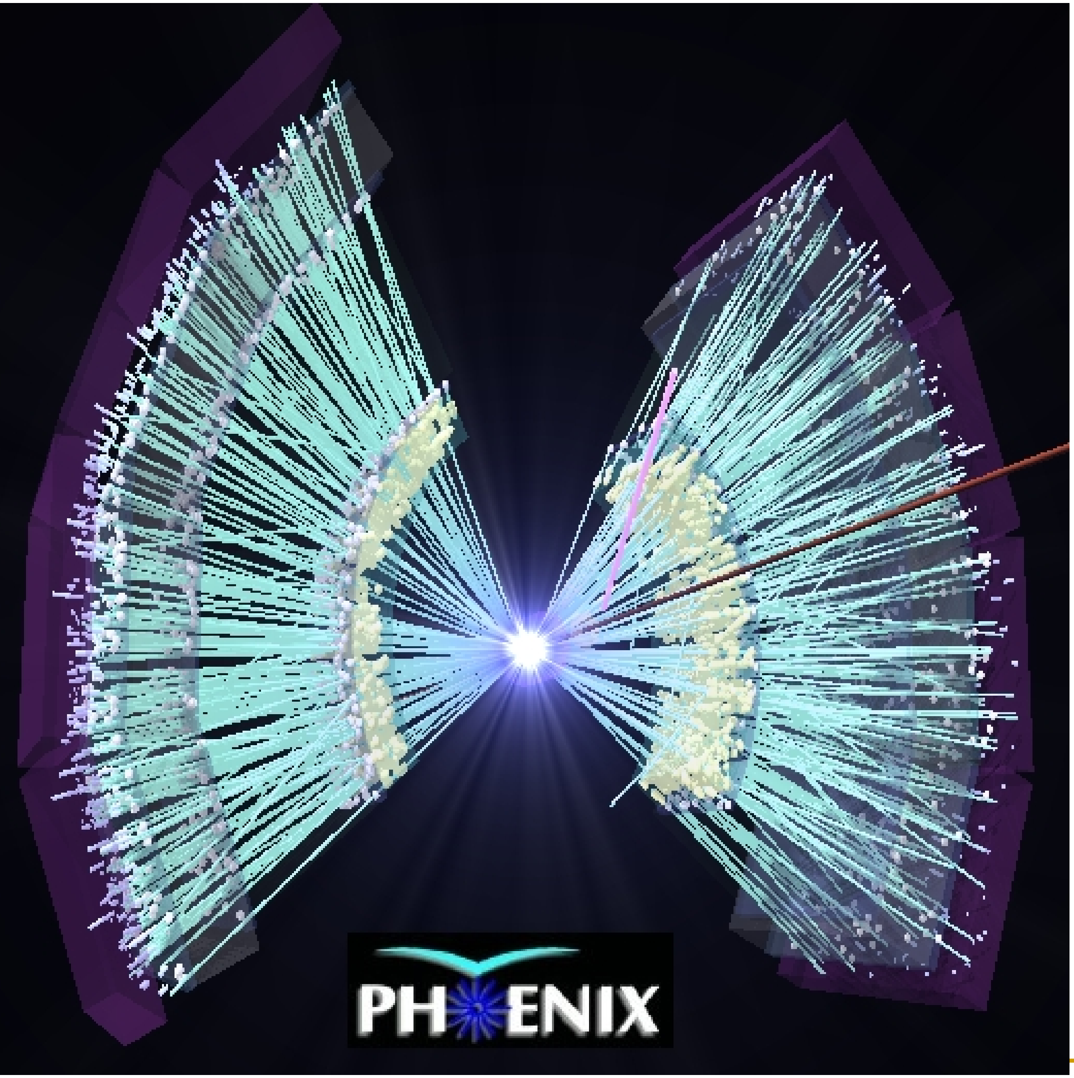
Estimating energy density

- Time less than the time needed for the nuclei to pass through doesn't make sense , because ε becomes unphysically large trivially (just by overlap mass), so we need:

$$\tau \gg \frac{2R}{\gamma}$$

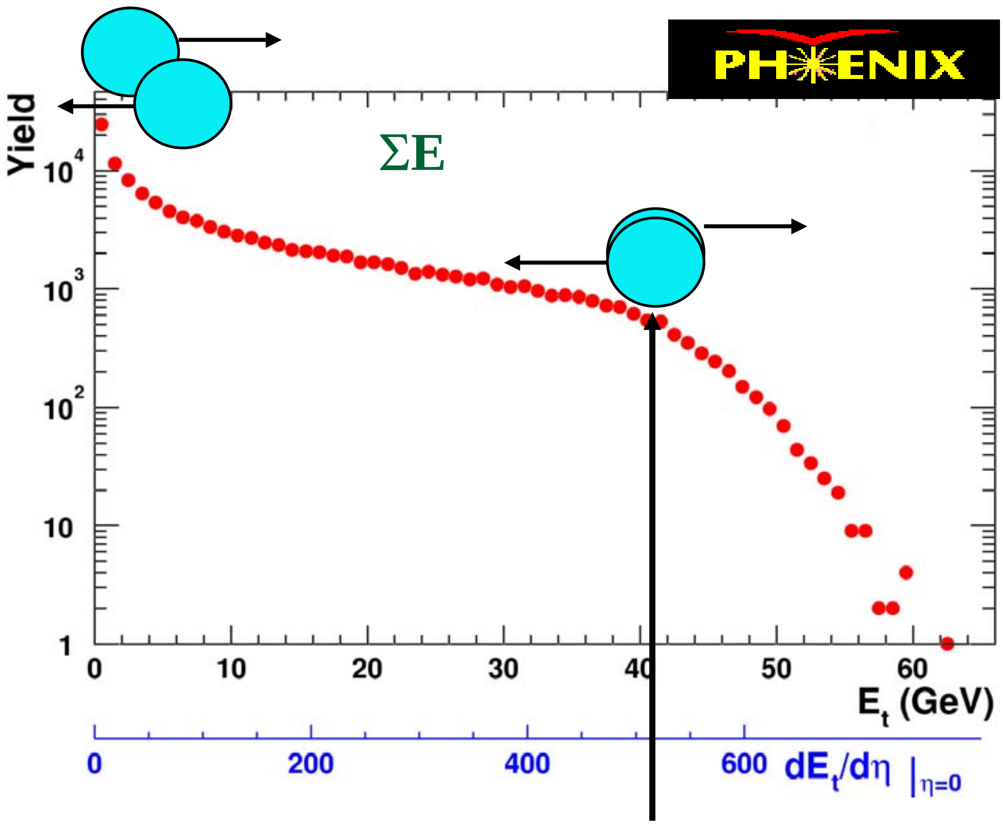
- For RHIC full energy $\gamma = 106$ => $\tau_{\text{pass through}}$ ~ 0.13 fm/c
- We need to consider "formed" or secondary particles – following Bjorken (PRD 27 (1983) 140) – τ_{form} ~ 1 fm/c
- So, let's measure the transverse energy and get the energy density
- We also need to know how to define centrality (to get the volume), and we discussed this already

How do we measure E_T ?

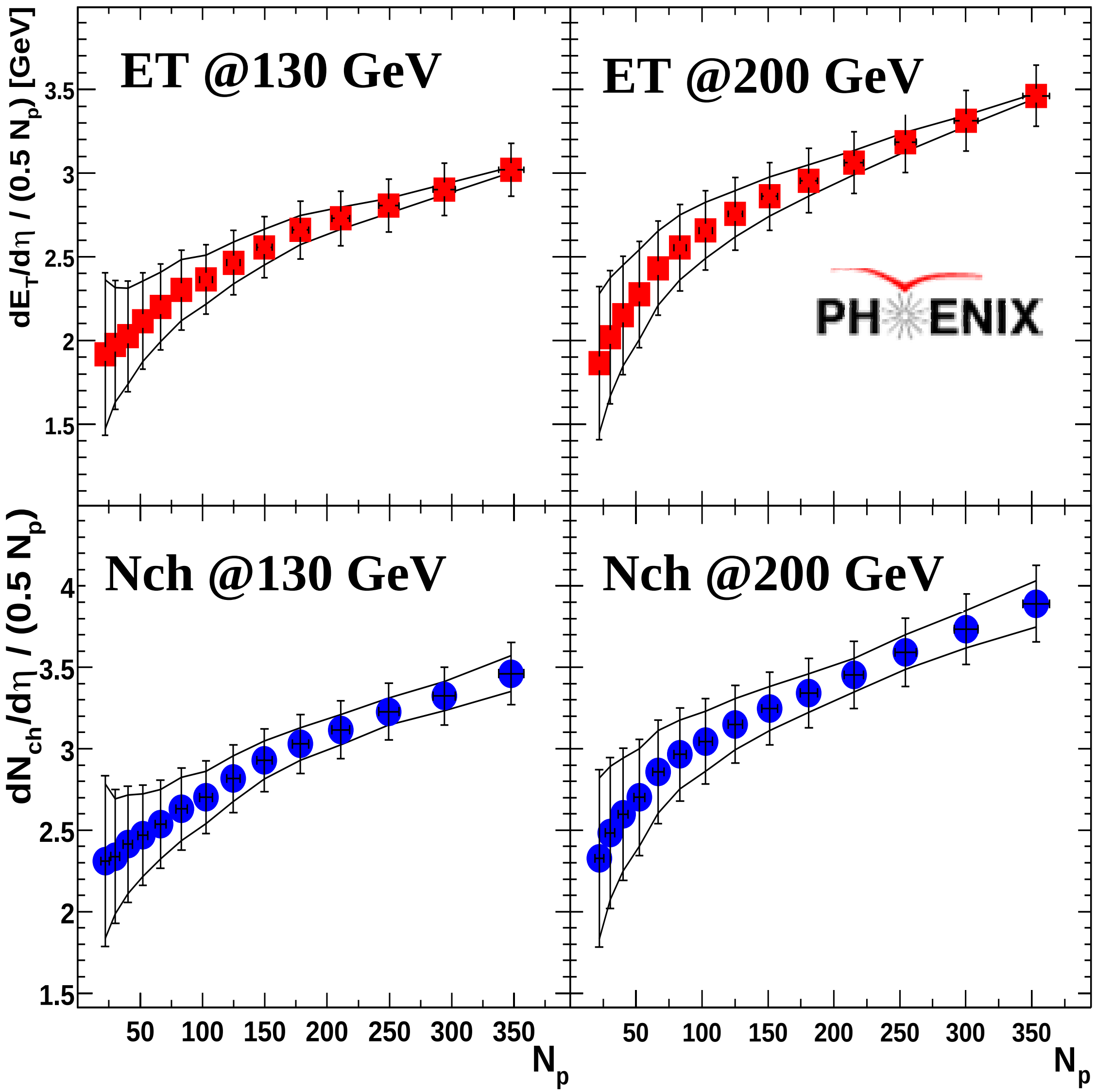


We measure the particles coming out, so add up their energy.
Put a calorimeter detector (measures energy) – sum it up for all particles.

Transverse energy at mid-rapidity



Results for E_T and N_{ch} : centrality dependence



Stat. errors

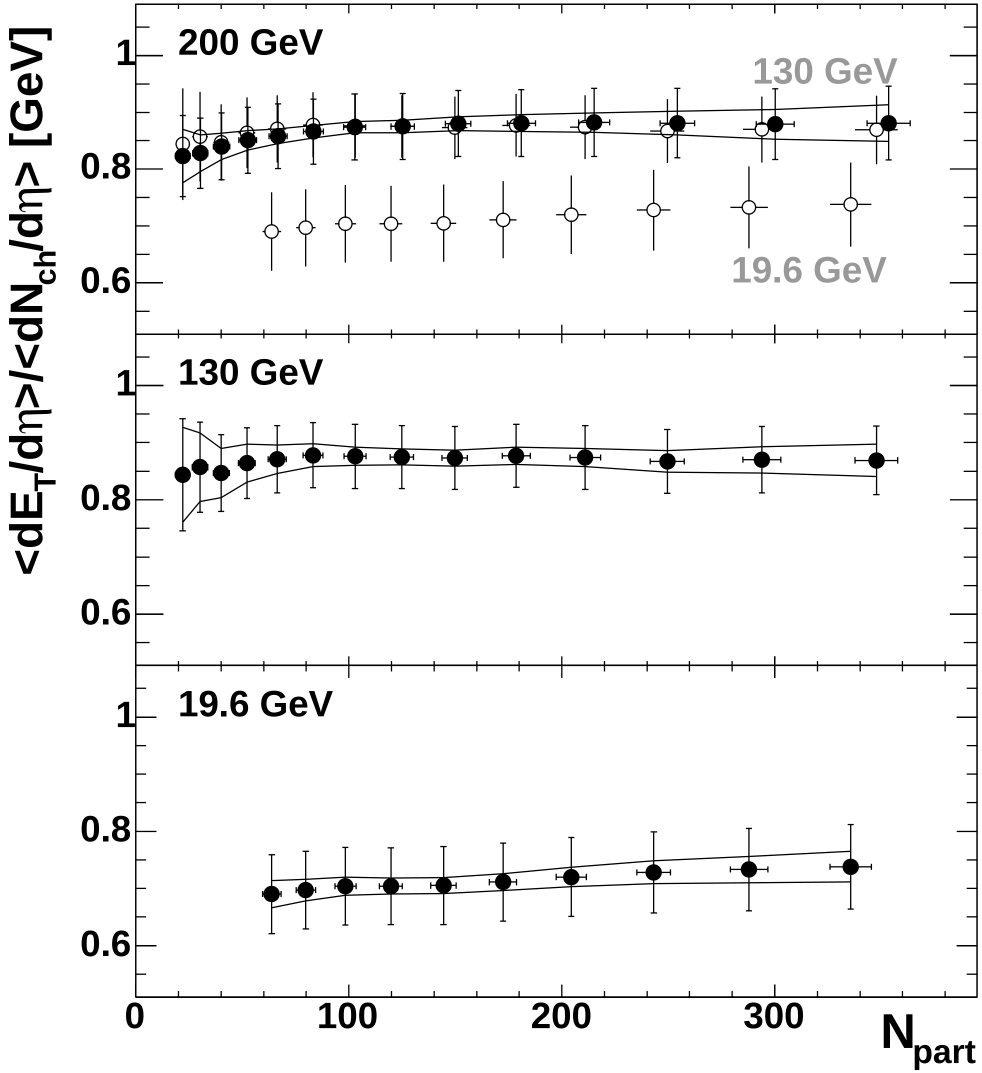
Negligible

Syst. errors

Band: possible common tilt

Bars: total syst. error

E_T / N_{ch}



- Remarkably,
  $dE_T/d\eta$ / $dN_{ch}/d\eta$
  does not change much with sqrt (s)
- The extra energy goes into particle production
- From

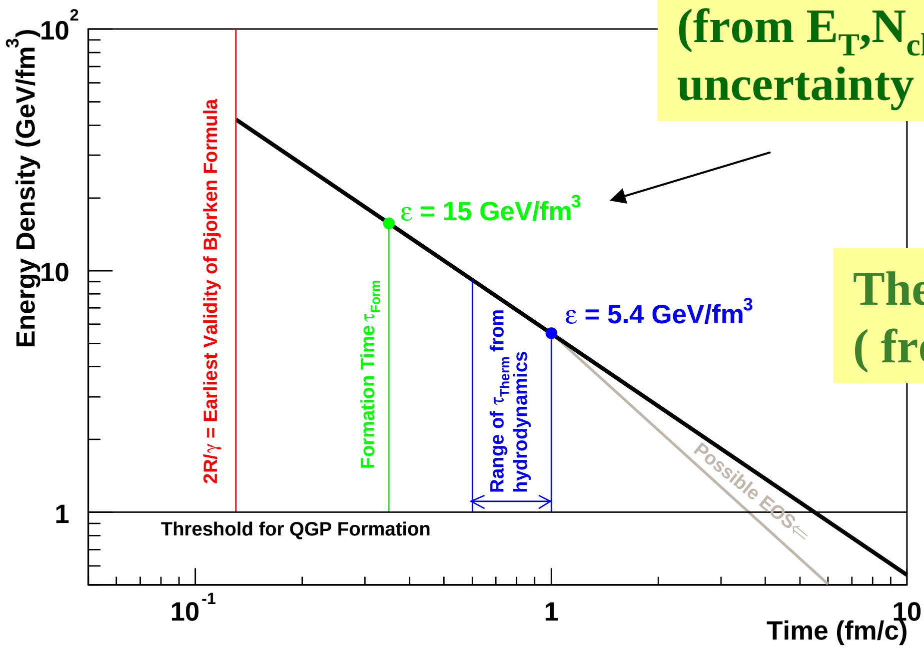
$dE_T/d\eta$ / $dN_{ch}/d\eta = 0.85$ GeV after converting to dN/dy , we get $\langle m_T \rangle \sim 0.57$ GeV

- If we assume that

$$\tau_{form} \simeq \hbar / \langle m_T \rangle$$

We get $\tau_{form} \sim 0.35$ fm/c . This is smaller than the “nominal” , but larger than $2R/\gamma$

Now … estimate ε



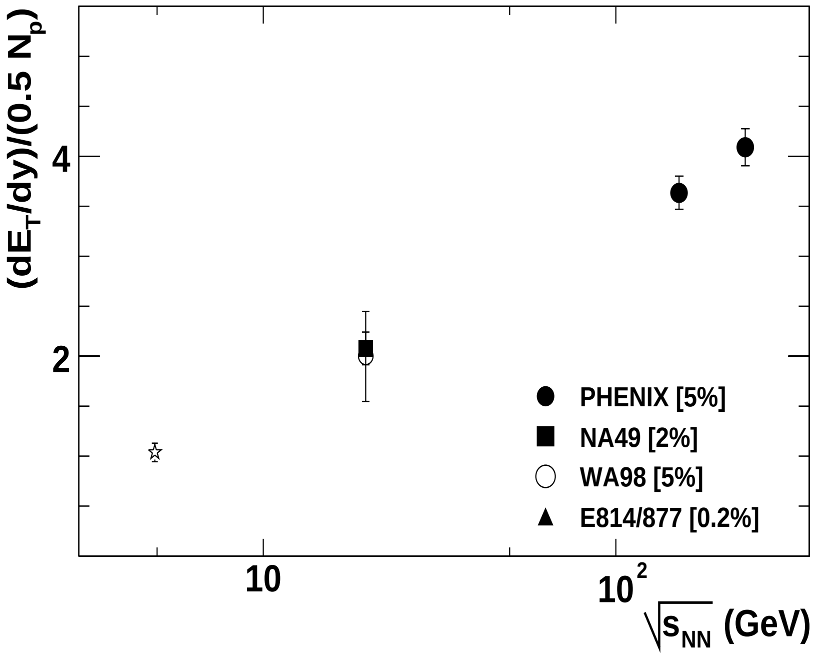
Peak energy density (from E_T,N_{ch} and uncertainty principle

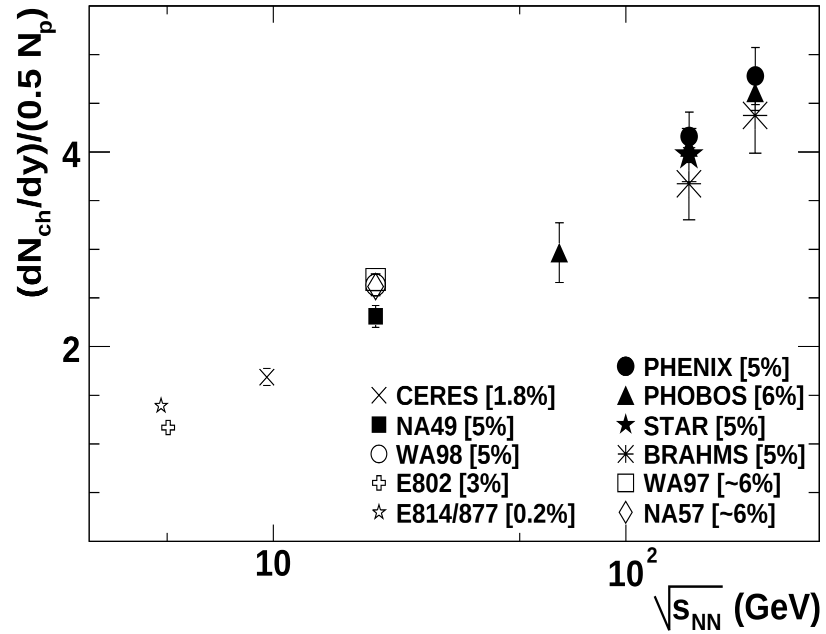
Thermalized energy density (from hydro+ data)

- With the " nominal " τ_{form} = 1 fm/c,
  - ***$\varepsilon \geq$ 5.5 GeV/fm^3* (200 GeV Au+Au)**
- With the uncertainty principle limit: τ_{form} = 0.35 fm/c,
  - ***$\varepsilon \geq$ 15 GeV/fm^3* (200 GeV Au+Au)**

→ ***well above predicted transition!***

Energy dependence of energy density





- **Both $dN_{ch}/d\eta$ and $dE_T/d\eta$ show logarithmic growth with sqrt (s_{NN})**
- **At LHC expect ~ factor 20 increase in ε. $dN_{ch}/d\eta \sim 1200$**

Extra slide on E_T

Transverse Energy Measurements

PHENIX

Convention: $E_T = \sum_i E_i \sin\theta_i$

$E_i = E_i^{tot} - m_N$ for baryons

$E_i = E_i^{tot} + m_N$ for antibaryons

$E_i = E_i^{tot}$ for others

EMCal is "almost" hadronic calorimeter (depth 18 radiation lengths, or 0.85 interaction lengths)

$E_{EMC} = 1.0 \cdot E_{tot}$ for γ, π^0

$E_{EMC} = 0.7 \cdot E_{tot}$ for $\pi^{\pm}$

$E_{EMC} \rightarrow E_T$ transformation:

$E_T = 1.23 \cdot E_{EMC}$

Do a MC simulation with realistic particle composition

EMCal absolute energy calibration

MIP peak

E/p matching peak for $e^{\pm}$

π^0 mass peak