Charged Particle Multiplicity and Transverse Energy in Au+Au Collisions at $\sqrt{s_{NN}}$ = 130 GeV

Alexander Milov — *Weizmann Institute, Israel*
Alexander Bazilevsky — *RIKEN BNL Research Center , USA*
Klaus Reygers — *University of Münster, Germany*
for the PHENIX Collaboration

Nucl-exp/0012008 (submitted to PRL)
QM2001 poster P179

Outline

- **Introduction:**
  - Importance of N_{ch} and E_t measurements
- **The PHENIX detector.**
- **Experimental results:**
  - $dN_{ch}/d\eta$ distribution at mid-rapidity
  - $dE_t/d\eta$ distribution at mid-rapidity
  - Centrality determination
- **Results and discussion:**
  - Comparison to model predictions
  - Comparison to CERN and AGS data
- **Summary.**

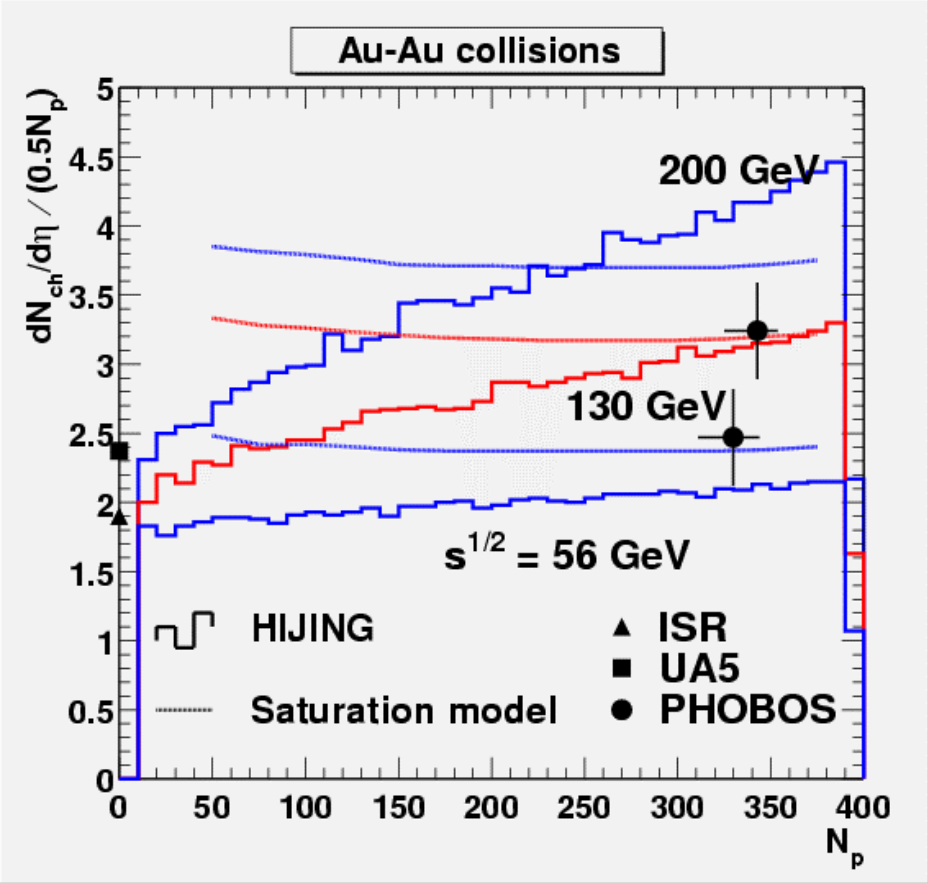
PHENIX

Global variables: E_t and N_{ch}

- **Initial conditions, energy density of the system.**
- **Scaling with $\sqrt{s}$.**
- **Mechanism of particle production, soft vs hard?**
  - Soft: $N_{ch} \propto N_{part}$
  - Hard: $N_{ch} \propto N_{coll}$
- **Constrain theoretical predictions.**

PHENIX

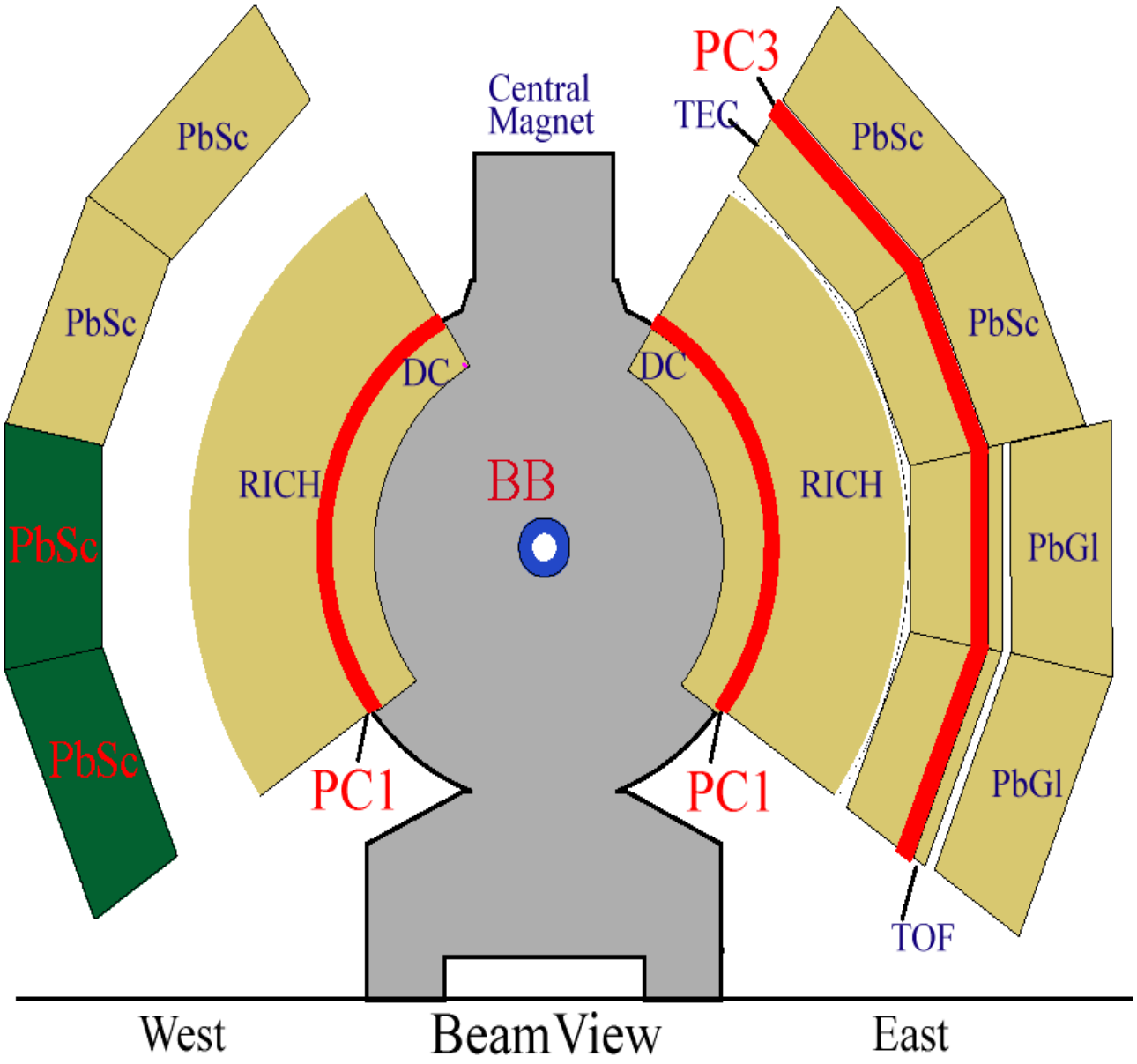
Theoretical Predictions



- **Various models predict different trends for $(dN_{ch}/d\eta)/N_{part}$ vs N_{part}:**
  - HIJING: (Wang, Gyulassy, nucl-th/0008014)
    $(dN_{ch}/d\eta)/N_{part}$ increases with N_{part}
  - Saturation model: (Eskola, Kajantie, and Tuominen hep-ph/0009246)
    $(dN_{ch}/d\eta)/N_{part}$ constant vs N_{part}

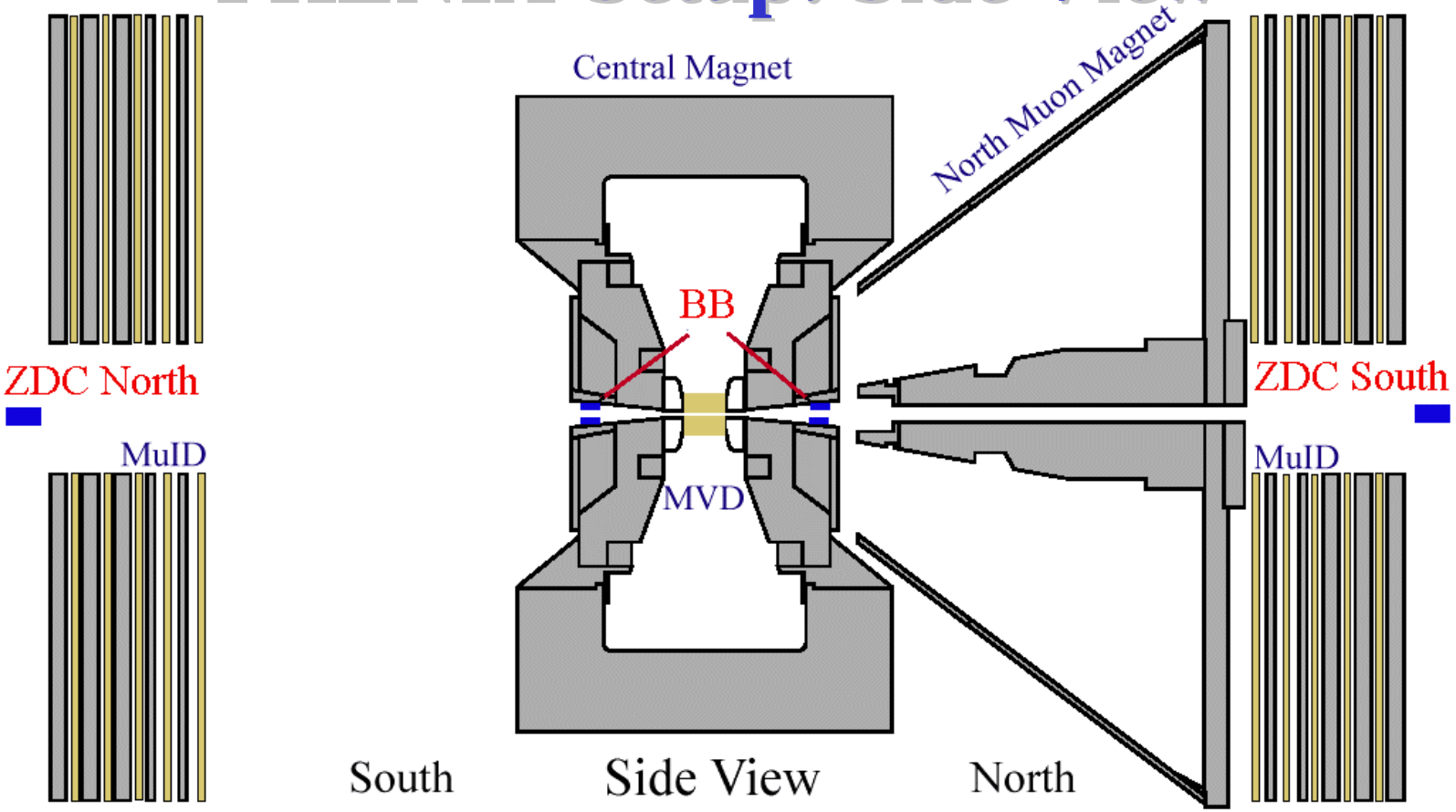
PHENIX

PHENIX-Setup: Beam View



- **Pad Chambers:**
  - R_{PC1} = 2.5 m
    R_{PC3} = 5.0 m
  - $|\eta| < 0.35$, $\Delta\phi = 90^o$
  - 8 x 4320 pads.
  - $\varepsilon > 99\%$, $\sigma \sim 2$ mm
- **Lead Scintillator EMCal.**
  - R_{EMCal} = 5.1 m.
  - $|\eta| < 0.38$, $\Delta\phi = 45^o$
  - 2 x 2592 PMT
  - $18X_0$, $\sigma \sim 8\%$ for 1GeV γ-quanta

PHENIX-Setup: Side View



- **Zero Degree Calorimeters**
  - Spectator neutrons with $|\eta| > 6$
  - $|Z|=18.25$ m
- **Beam Beam Counters**
  - 64 Cherenkov quartz counters with PMT readout
  - $3.0 < |\eta| < 3.9$ $\Delta\phi = 360^{o}$

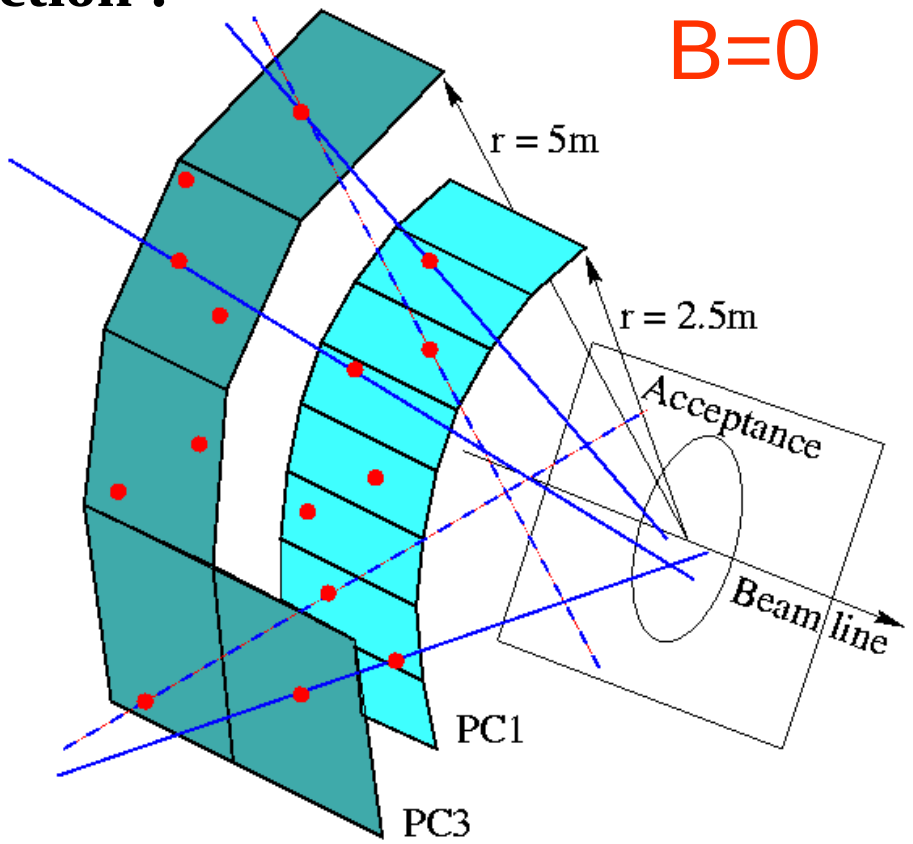
Trigger and event selection

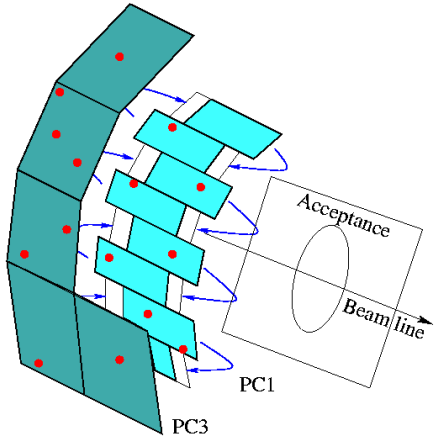
- **BBC trigger:**
  - Coincidence of both BBC (at least two photomultipliers fired in each BBC).
  - Corresponds to (92 ± 2)% of the geometrical Au-Au cross section ($\sigma_{geo.}$ = 7.2 b).
- **ZDC trigger:**
  - Coincidence of both ZDC (E > 10 GeV)
  - Includes mutual Coulomb dissociation processes
  - 97.8% of the BBC trigger events also satisfy ZDC trigger condition.
- **Event vertex restriction:**
  - |Z| < 20 cm around centre of interaction region.

PHENIX

Charged Multiplicity Determination

- **Procedure: count tracks on a statistical basis, no explicit track reconstruction :**
  - Combine all hits in PC3 with all hits in PC1.
  - Project resulting lines onto a plane through the beam line.
  - Count tracks within a given radius.
  - Determine combinatorial background by event mixing

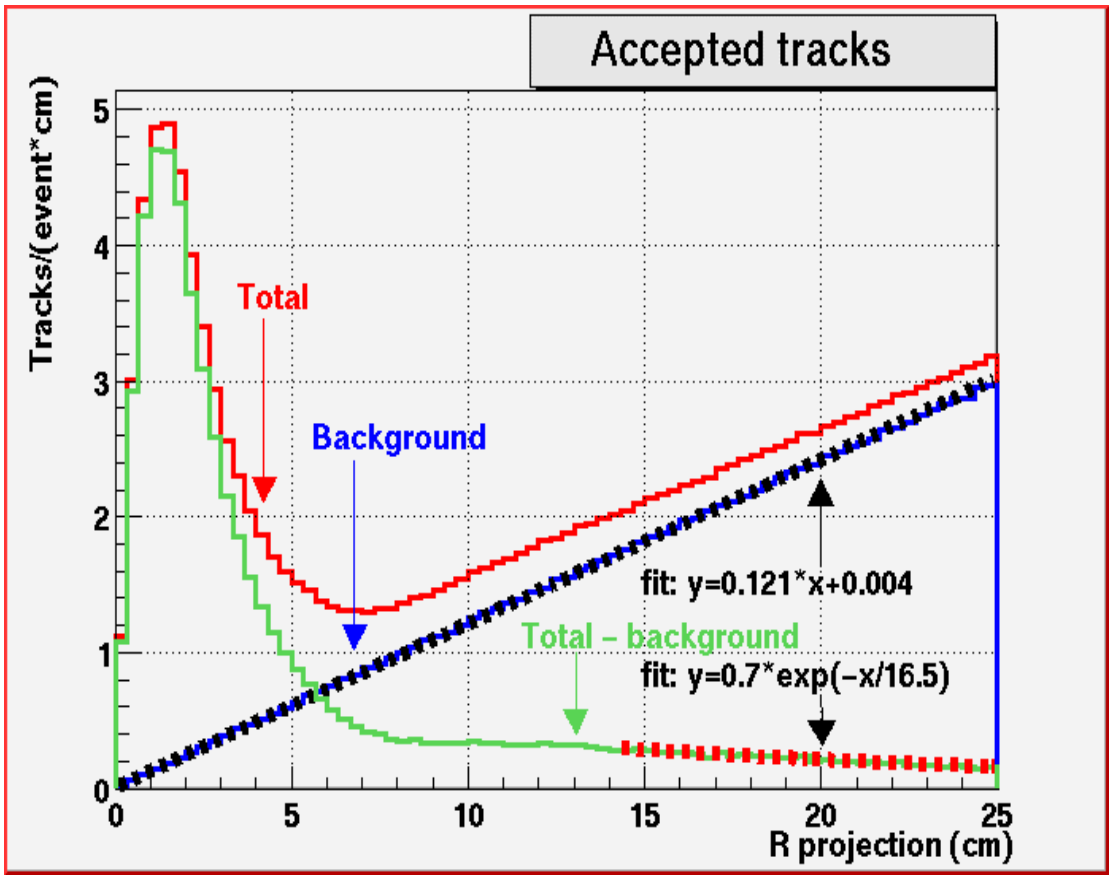




PHENIX

Track Vertex Distribution

- **3 contributions:**
  - Peak at low R:
    primary particles coming
    from the event vertex
  - Combinatorial background:
    $dN_B/dR \propto R$
  - Exponential tail:
    in-flight decays



- **Number of tracks per event:**
  - Subtract average background on an event-by-event basis
  - Count all tracks within R=25 cm
    (=> 95.9% of all tracks)

PHENIX

Corrections

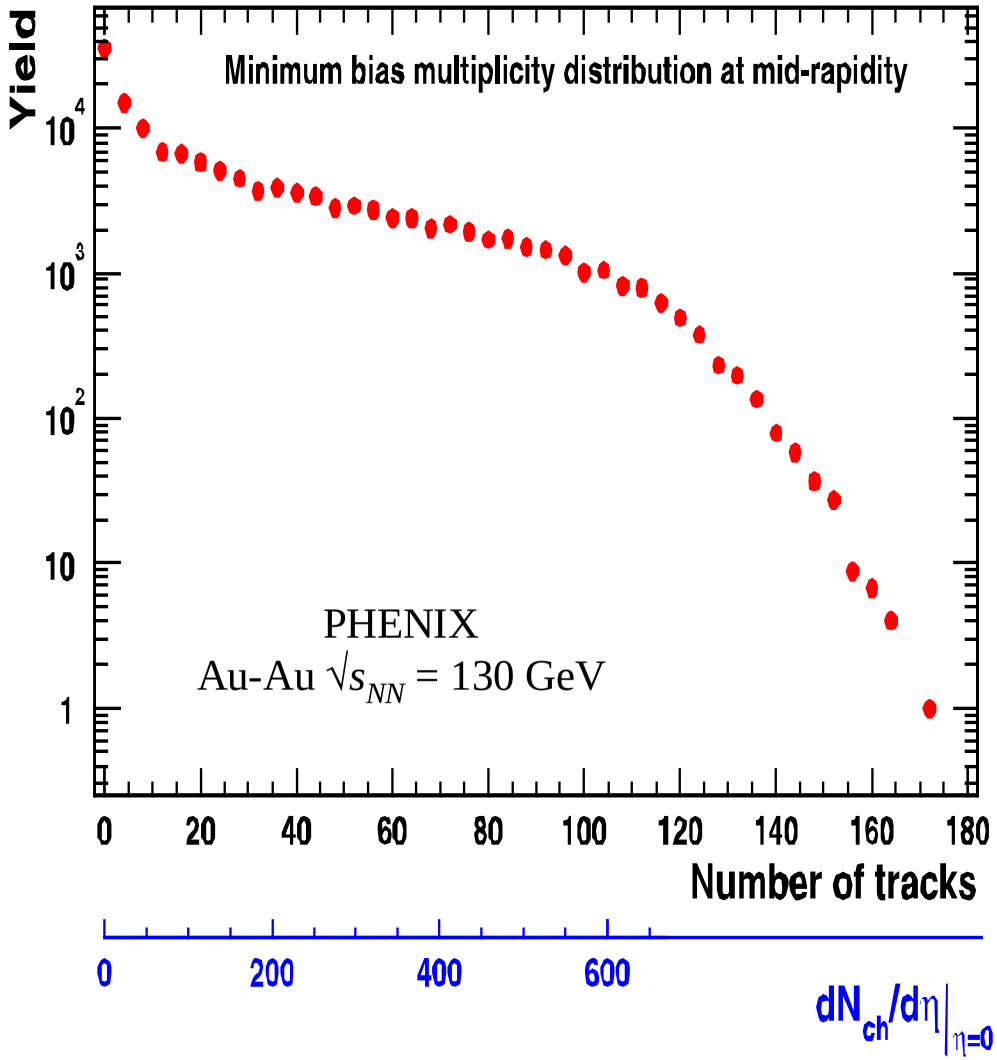
- **Tracks outside acceptance window: 4.3%**
- **Pad Chamber inactive regions: 15.3%**
- **Double hit resolution:**
  - 13.6% for most central events
  - 3.6% to the subtracted background
- **Correction due to particle decays**
  - Primary charged particles ($\pi^{\pm}$) decays in-flight,
  - Neutral (K^0, π^0…) particles feed-down:

  .

  Net correction: 2.8% based on HIJING

PHENIX

Minimum-bias multiplicity distribution at $\sqrt{s_{NN}}$ = 130 GeV

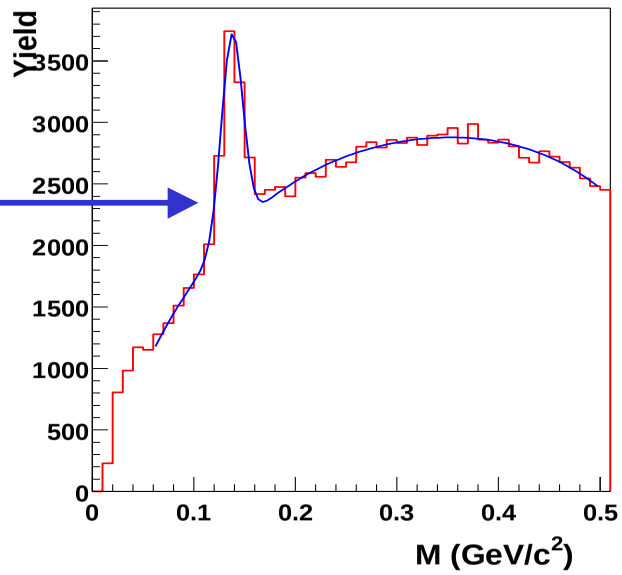


- 92% of σ_{geo} (Missing events are all in the lowest bins)
- Shape at high multiplicities determined by fluctuations due to limited acceptance.
- Scaling factor (geometry) to one unit of rapidity 5.82 (lower axis).

PHENIX

EMCal energy response

- **Energy scale:**
  - EMCal measures full energy of γ and $e^{\pm}$
  - Slow hadrons are absorbed in EMCal
  - Relativistic hadrons produce MIP peak

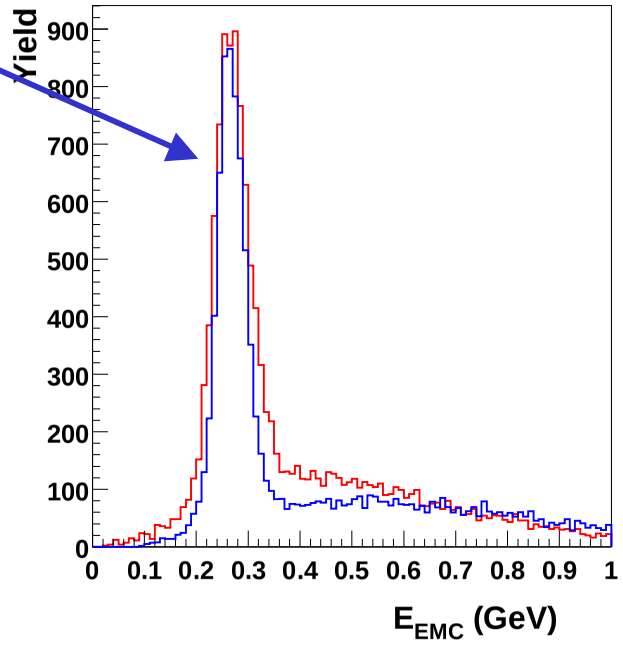


π^o peak at 136.7 MeV/c^2

- **EMCal energy response proportional to E_t:**

$$E_t = 1.17 \pm 0.05\ E_t^{EMCal}$$

  - EMCal energy resolution not important for the E_t measurement



Red curve: Au-Au data. MIP peak at 270 MeV

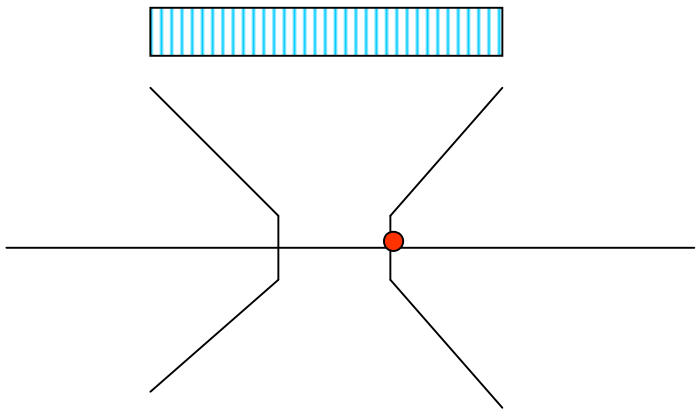
Blue curve is AGS test beam data with π^+

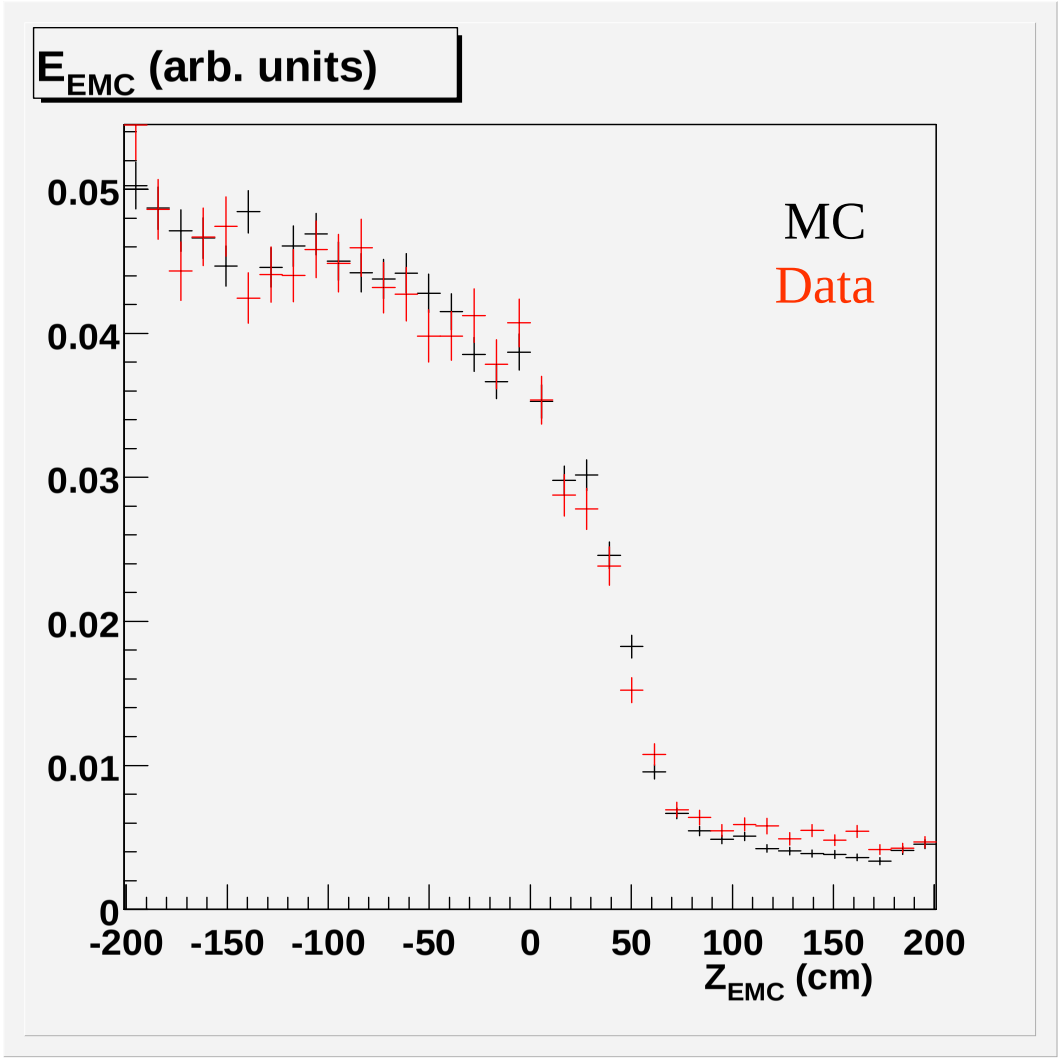
PHENIX

Background sources

- **Background from albedo**
- **Background from decays**
  - From simulations
  - From events with displaced vertex.

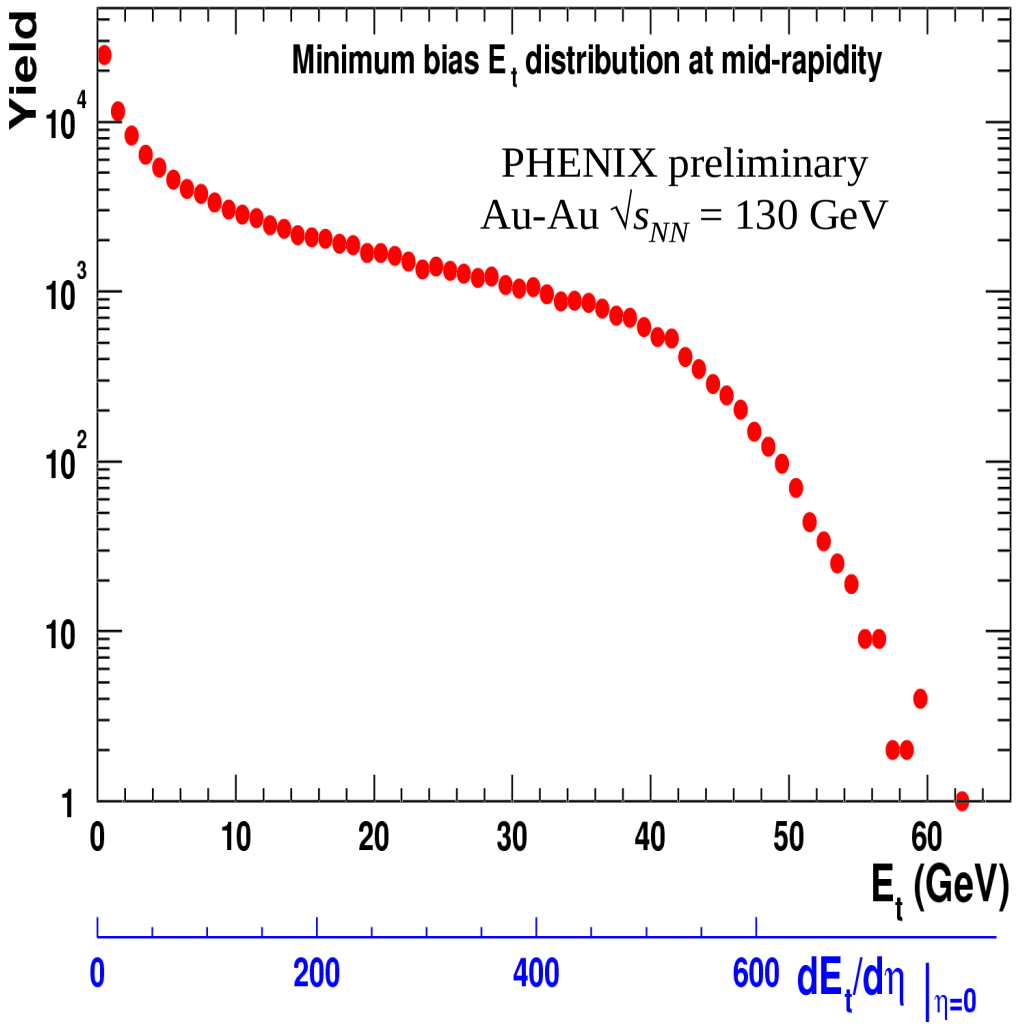
$$\frac{E_{EMC}\left(|\eta| > 0.38\right)}{E_{EMC}} \approx 0.25$$





PHENIX

Minimum-bias transverse energy distribution at $\sqrt{s_{NN}}$ = 130 GeV



x **92% of σ_{geo} (Missing events are all in the lowest bins)**

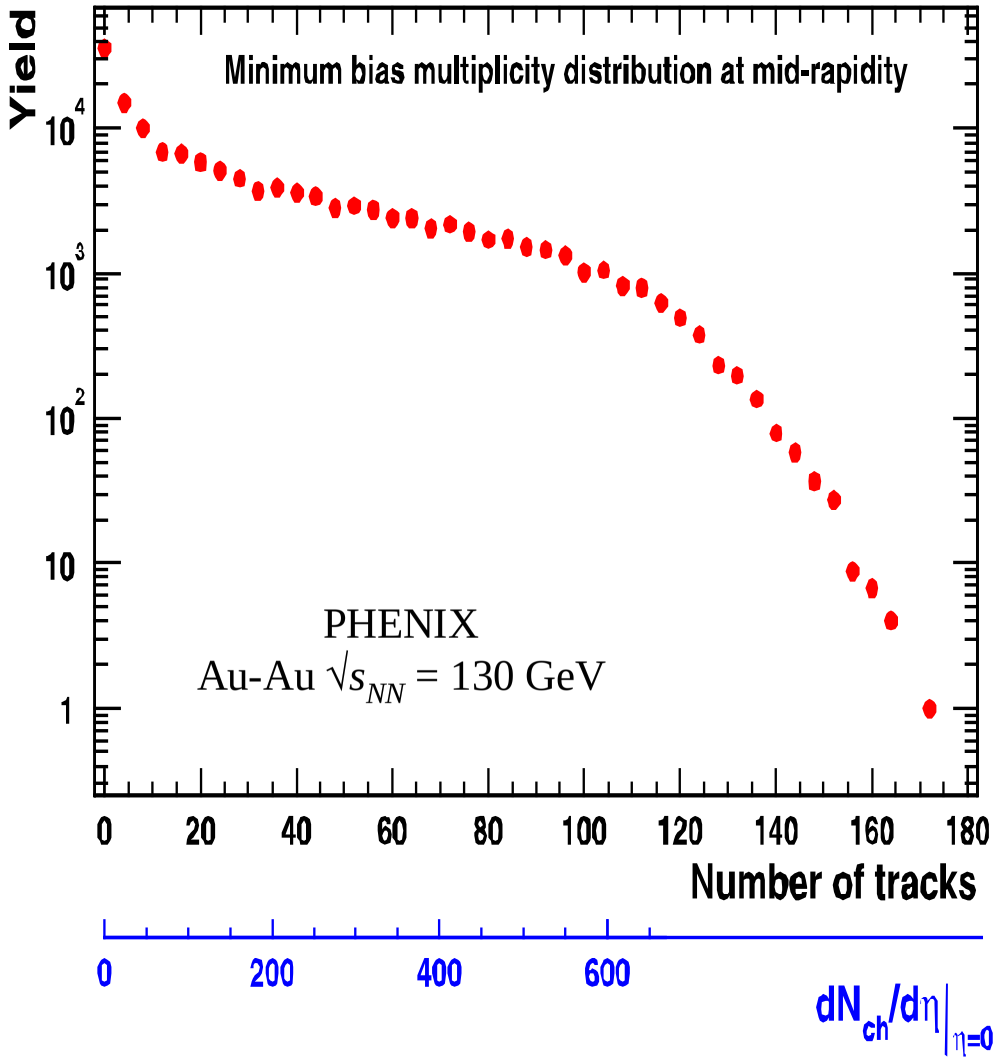
x **Shape at high multiplicities determined by fluctuations due to limited acceptance.**

x **Scaling factors:**

- Transformation 1.17
- Dead areas 1.03
- Geometry 10.6

PHENIX

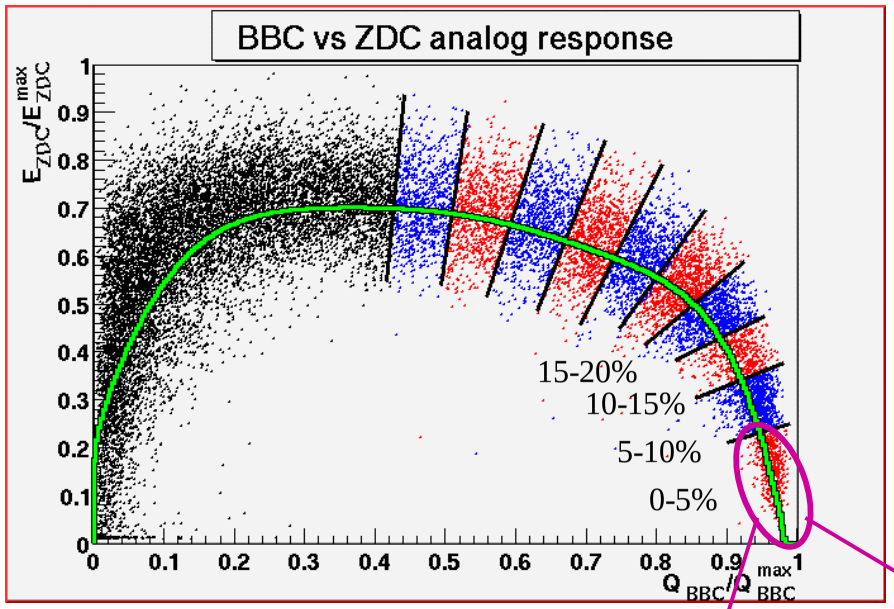
Minimum-bias multiplicity distribution at $\sqrt{s_{NN}}$ = 130 GeV



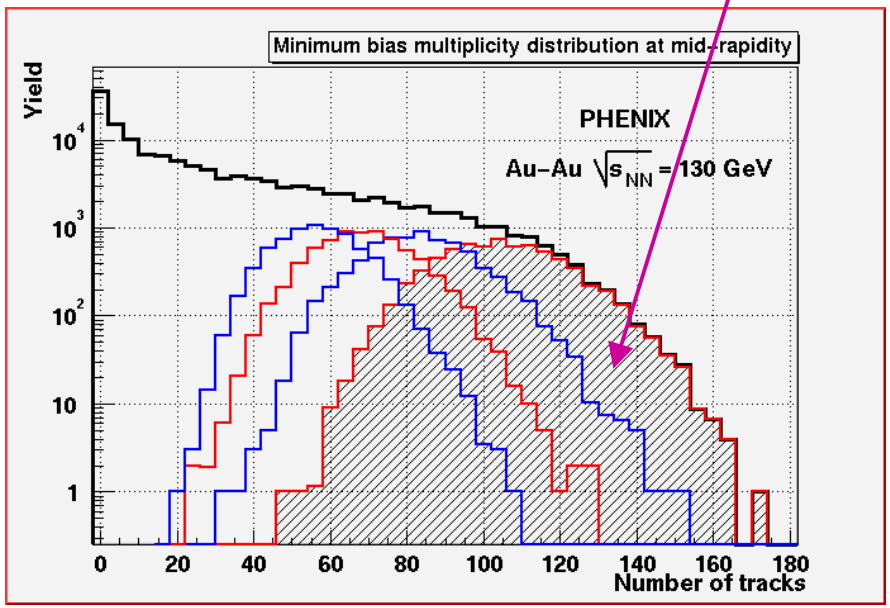
- 92% of σ_{geo} (Missing events are all in the lowest bins)
- Shape at high multiplicities determined by fluctuations due to limited acceptance.
- Scaling factor (geometry) to one unit of rapidity 5.82 (lower axis).

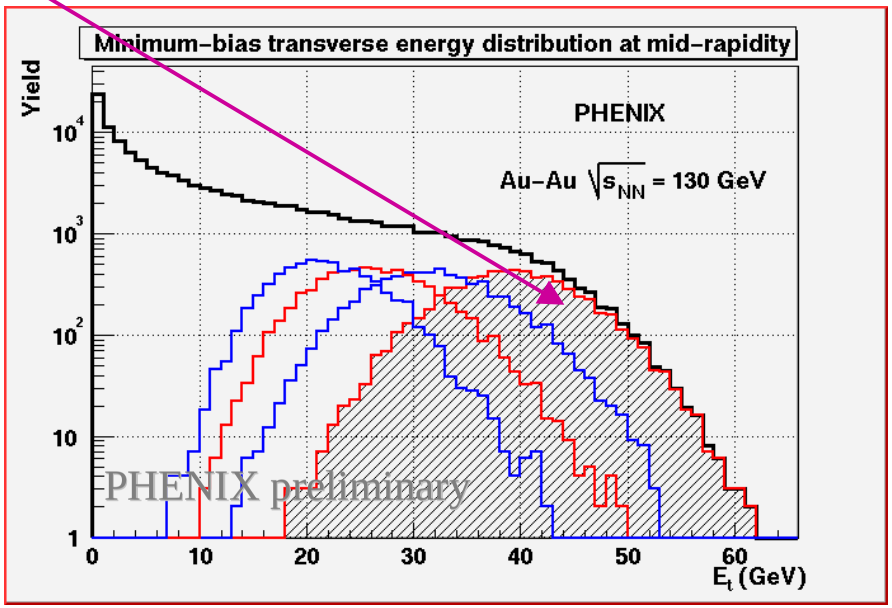
PHENIX

Centrality dependence



- **Use BBC – ZDC response to define centrality cuts (in 5% bins of σ_{geo})**
- **Determine $\langle dN_{ch}/d\eta \rangle$ and $\langle dE_t/d\eta \rangle$ vs centrality**





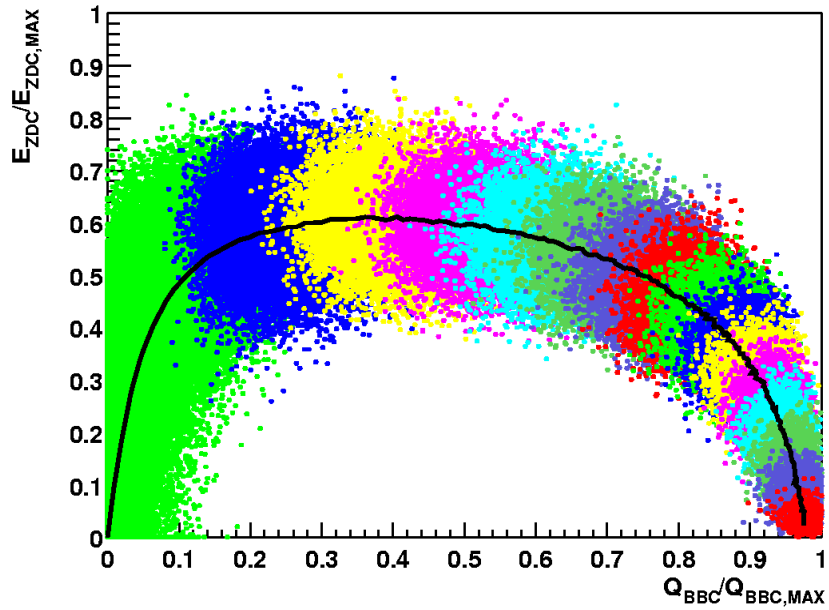
Calculation of N_{part} and N_{coll}

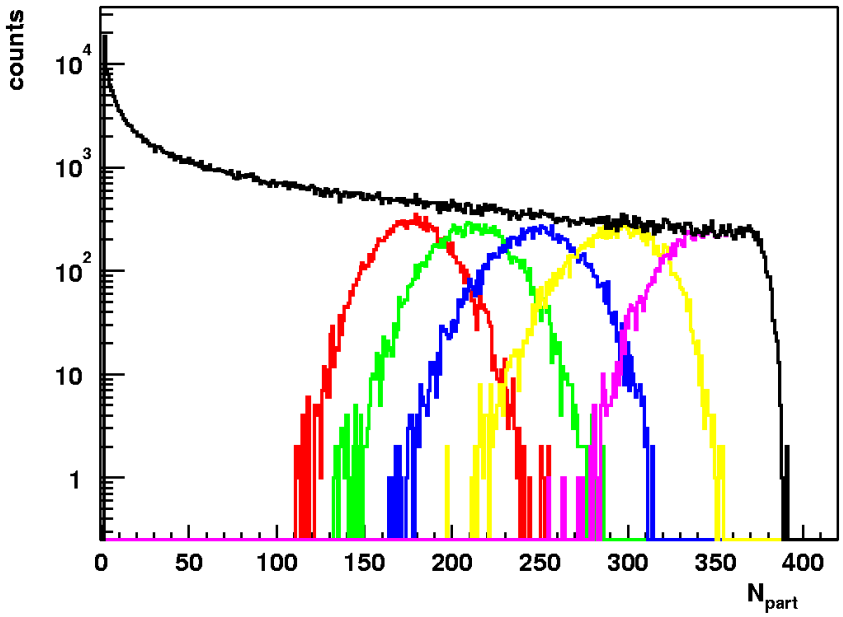
- **Use simulated BBC – ZDC response to define centrality cuts.**
- **Relate them to N_{part} and N_{coll} using Glauber model.**
  - Straight-line nucleon trajectories
  - Constant $\sigma_{NN}=(40 \pm 5)mb$.
  - Woods-Saxon nuclear density:

$$\rho(r)=\rho_o \cdot \frac{1}{1+\exp\left(\frac{r-R}{d}\right)}$$

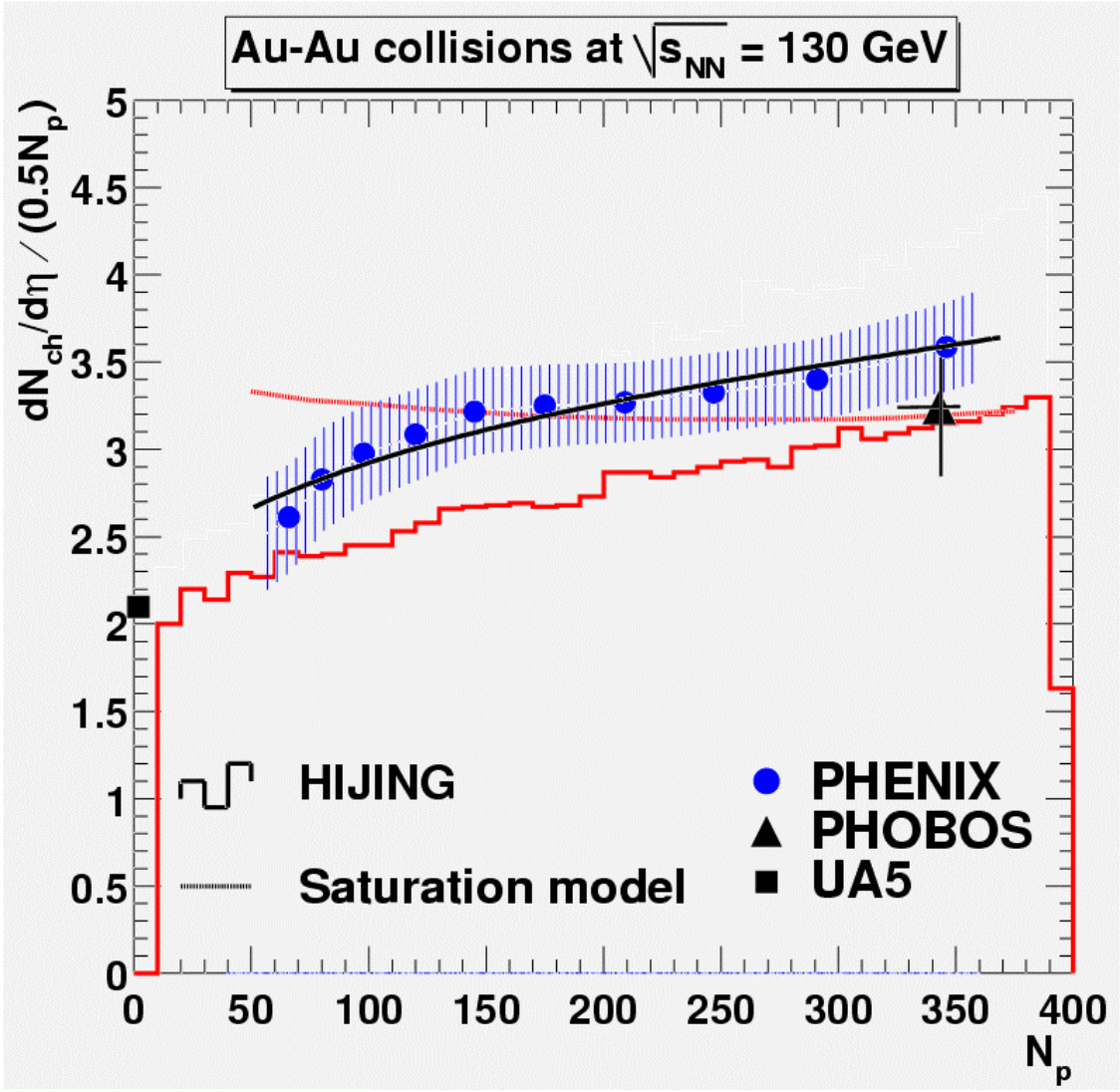
$$R=1.19A^{1/3}-1.61A^{-1/3}=(6.65\pm0.03)\,fm$$

$$d=(0.54\pm0.01)\,fm$$





Centrality dependence



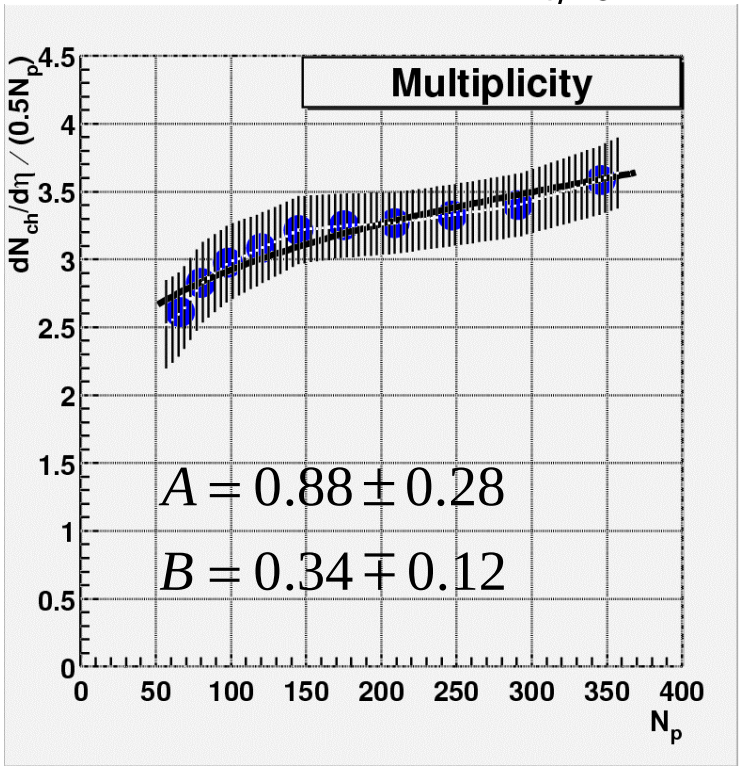
- **Data shows clear increase of $dN_{ch}/d\eta$ per participant vs N_{part}**

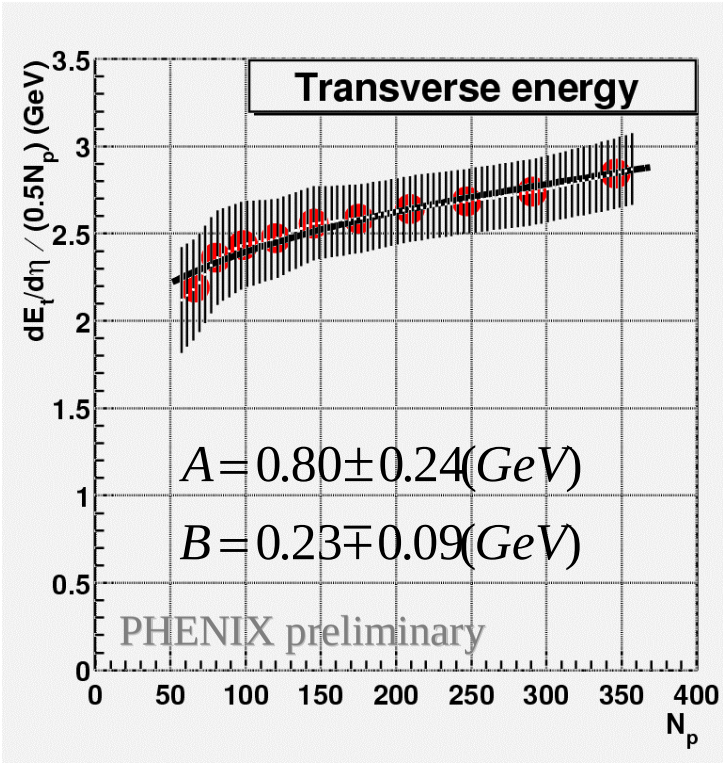
- In contrast with EKRT saturation model
- Similar to HIJING (although data ~15% higher)

PHENIX

Particle production mechanism

$$dX/d\eta\big|_{\eta=0} = A \times N_{part} + B \times N_{coll}$$





- **Consistent results:**

  $B/A = 0.38 \pm 0.19$ $\qquad$ $B/A = 0.29 \pm 0.18$

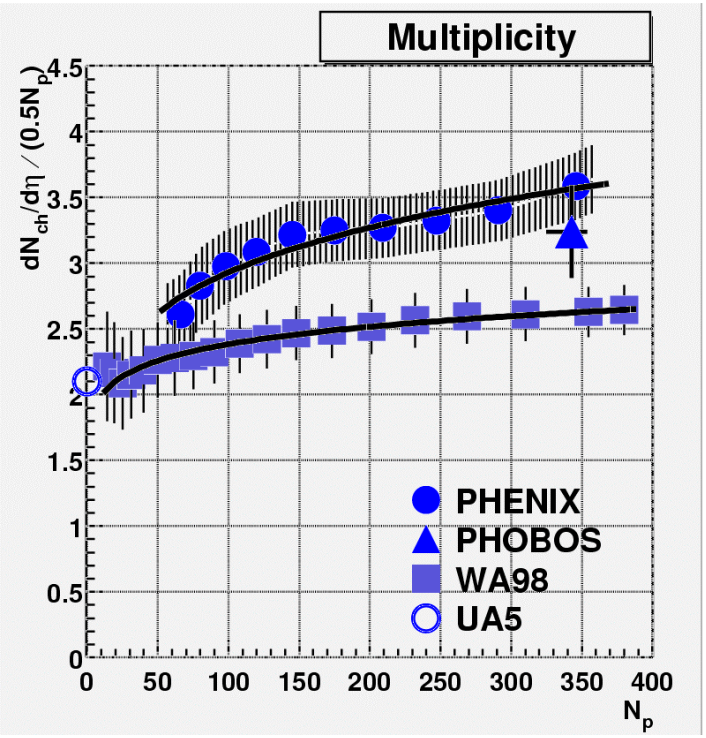
- **Hard processes contribution increases with centrality:**

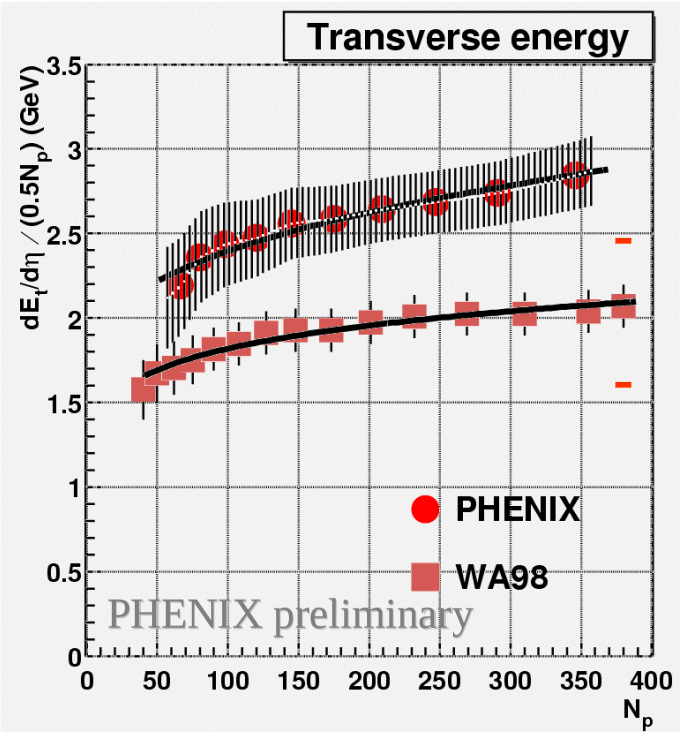
  from ~30% mid-central to ~50% most central

PHENIX

Comparison to CERN results

$$dX/d\eta\big|_{\eta=0} \propto N_{part}^{\alpha}$$

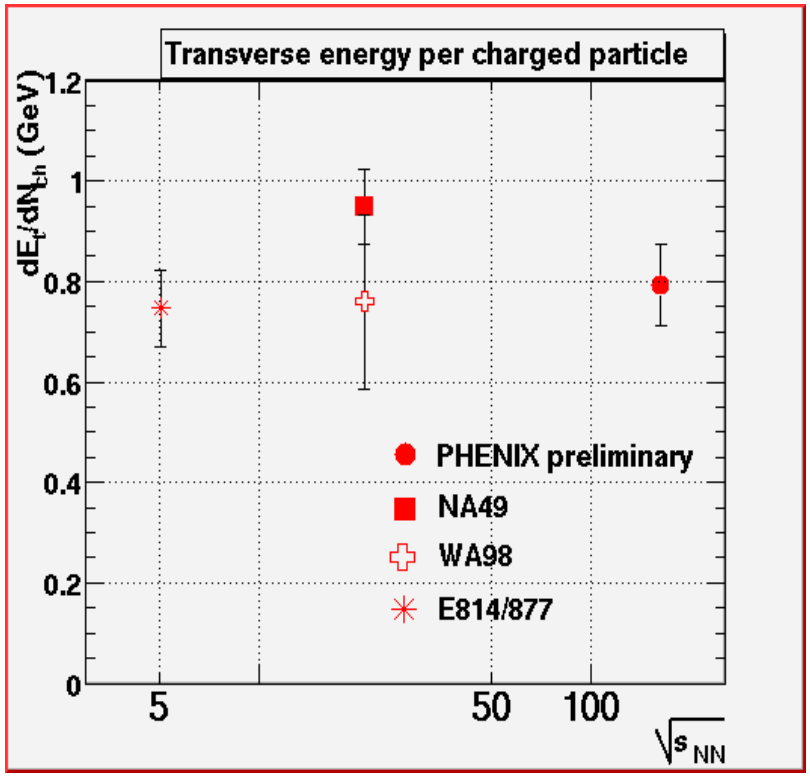


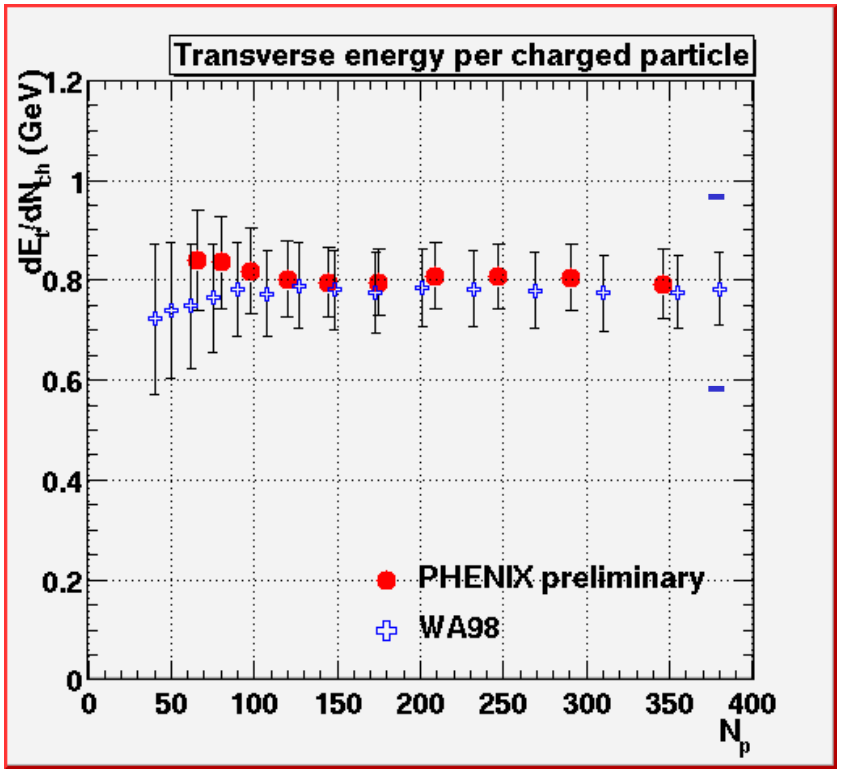


α-value	Multiplicity	Transverse energy
PHENIX	1.16 ± 0.04	1.13 ± 0.05
WA98	1.07 ± 0.04	1.08 ± 0.06
WA97	1.05 ± 0.05	

PHENIX

Transverse energy per charged particle

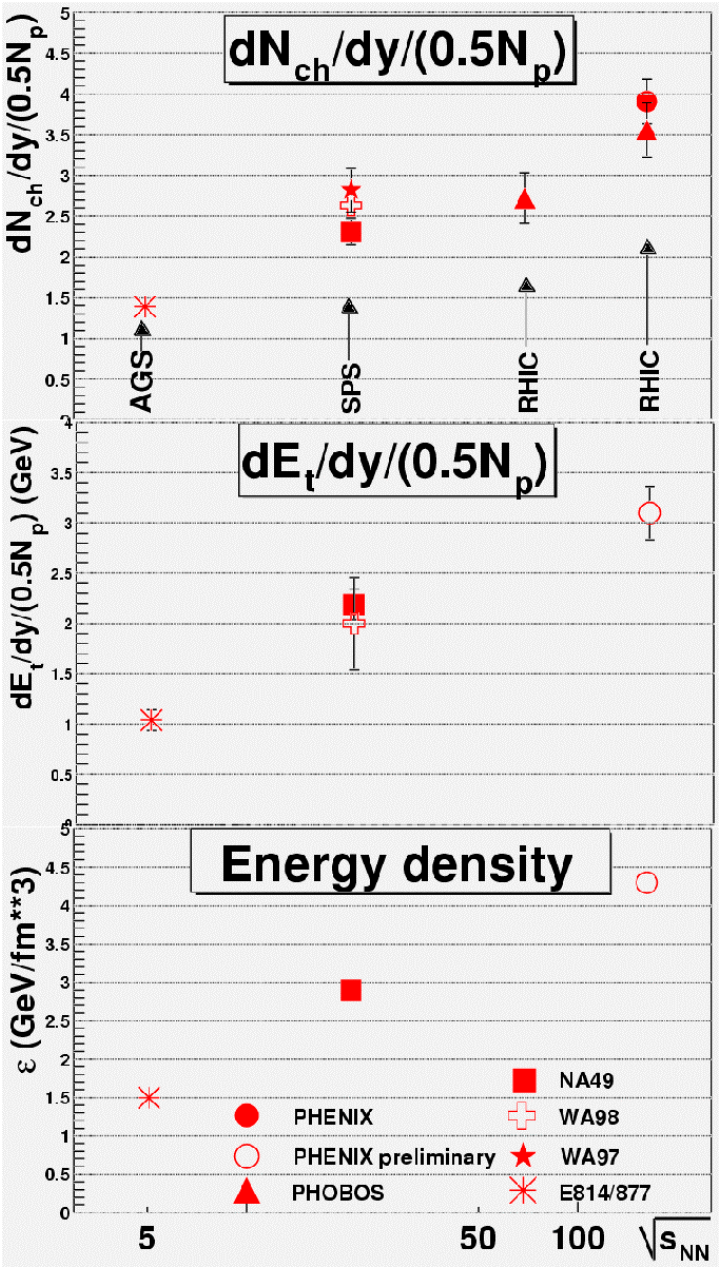




dE_t/dN_{ch} **independent of** $\sqrt{s_{NN}}$

dE_t/dN_{ch} **independent of** N_{part}

$\sqrt{s_{NN}}$ dependence



- **Assumptions:**

  in Lab: $\frac{dX}{dy} \approx \frac{dX}{d\eta}$

  in C.M.: $\frac{dX}{dy} \approx 1.1\frac{dX}{d\eta}$

- **Energy density (Bjorken):**

$$\varepsilon = \frac{1}{\pi R^2 \tau}\frac{dE_t}{dy} \qquad R = 1.12A^{1/3} \qquad \tau = 1\,fm/c$$

- **From SPS to RHIC**
  - ~50% increase in dN_{ch}/dy
  - ~50% increase in dE_t/dy
  - at least 50% increase in ε

PHENIX

Summary

- **Centrality dependence of particle $dN_{ch}/d\eta$ and $dE_t/d\eta$ have been measured in $\sqrt{s_{NN}}$ = 130 GeV Au+Au collisions.**
- **Both $dN_{ch}/d\eta$ and $dE_t/d\eta$ per participant increase with centrality:**
  - in qualitative agreement with HIJING
  - in contrast to EKRT saturation model prediction
  - the increase is stronger than at SPS
- **dE_t/dN_{ch} is independent of centrality and of $\sqrt{s_{NN}}$.**

PHENIX