Global observables in the PHENIX experiment

Hirschegg, January 13-19, 2002

David Silvermyr
Lund Univ.

Outline

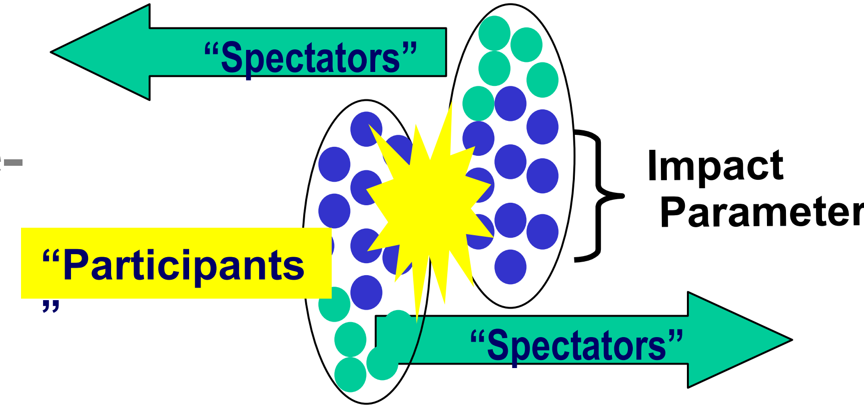
- $dN_{ch}/d\eta$ analysis at mid-rapidity for 200 GeV and 130 GeV.
- $dE_T/d\eta$ at 130 GeV at mid-rapidity
  - E_T per charged particle
- Net-charge fluctuations at 130 GeV
- Event-by-event fluctuations in Mean p_t and Mean e_t fluctuations at 130 GeV

Global Observables

- **WHAT ?**

  * $dN_{ch}/d\eta$, $dE_T/d\eta$

  * **Reflect conditions well after freeze-out and resonance decays**



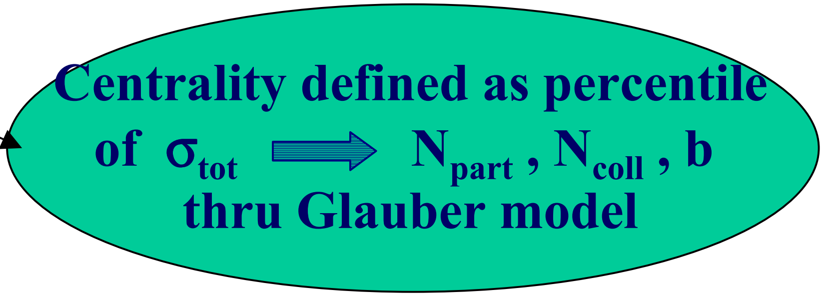
- **WHY ?**

  * **"Easy" measurements**

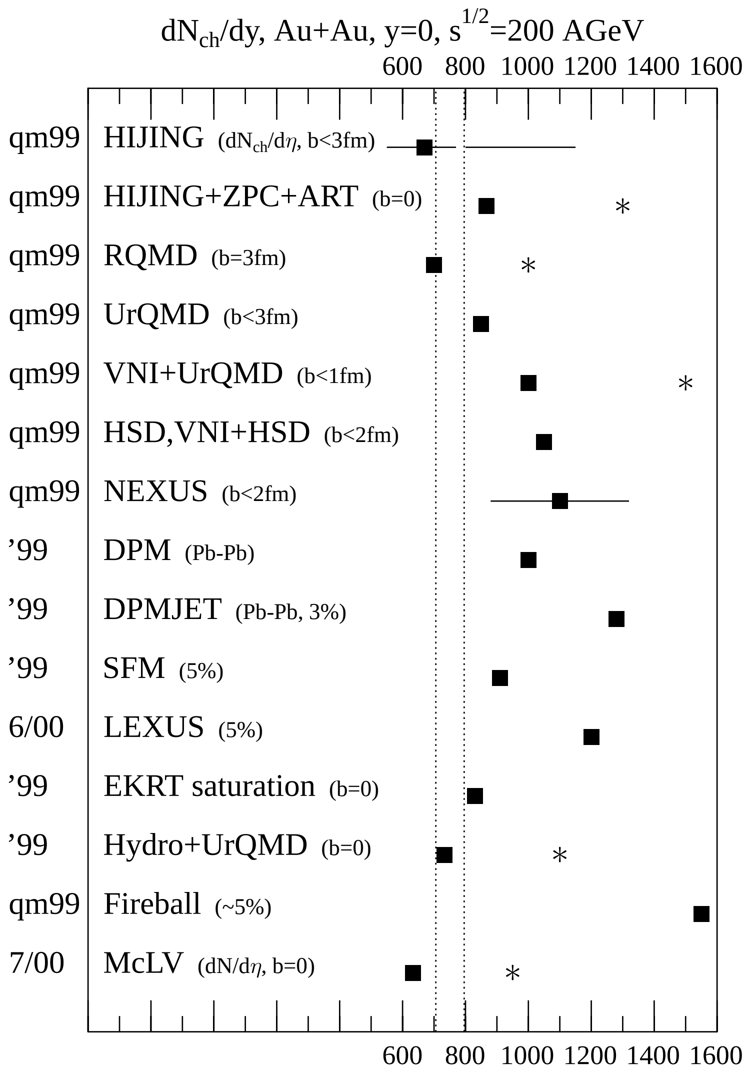
  * **Characterize collision geometry**

  * **Constrain models**

  * **Initial conditions**



dN_{ch}/dy Predictions



Charged particle multiplicity at midrapidity is an essential global variable for characterizing high-energy heavy-ion collisions.

Before data-taking the range in predictions was large..

Year 2000 Configuration

Calorimetry -

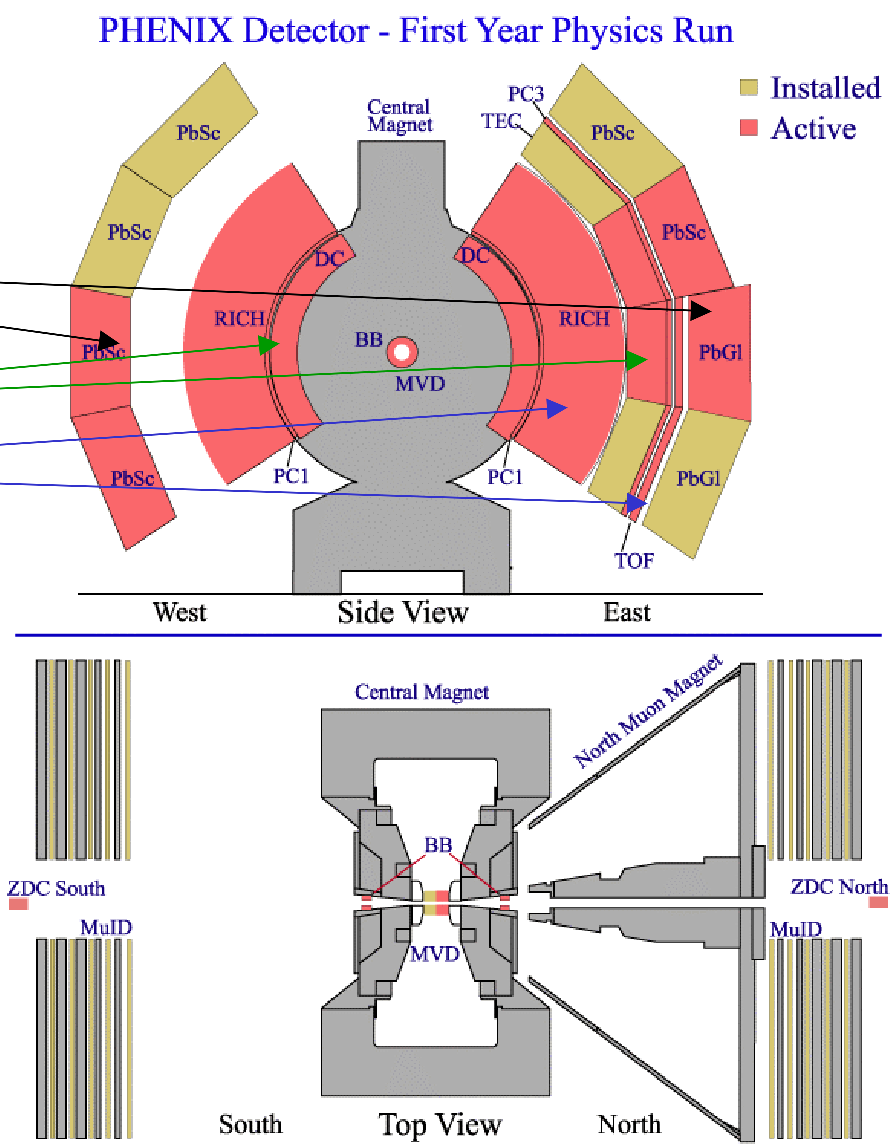
Pb-glass, Pb-scint.

Tracking

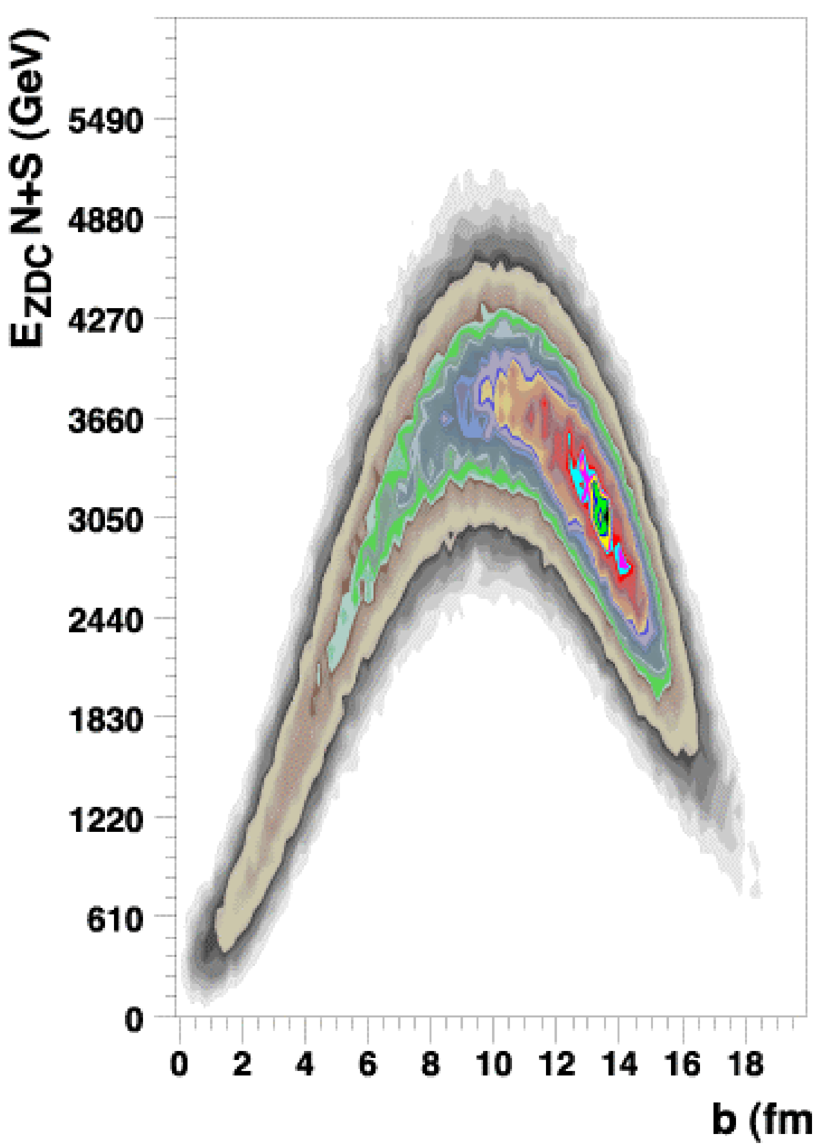
Drift, Pad, Time Exp.

PID - RICH, TOF

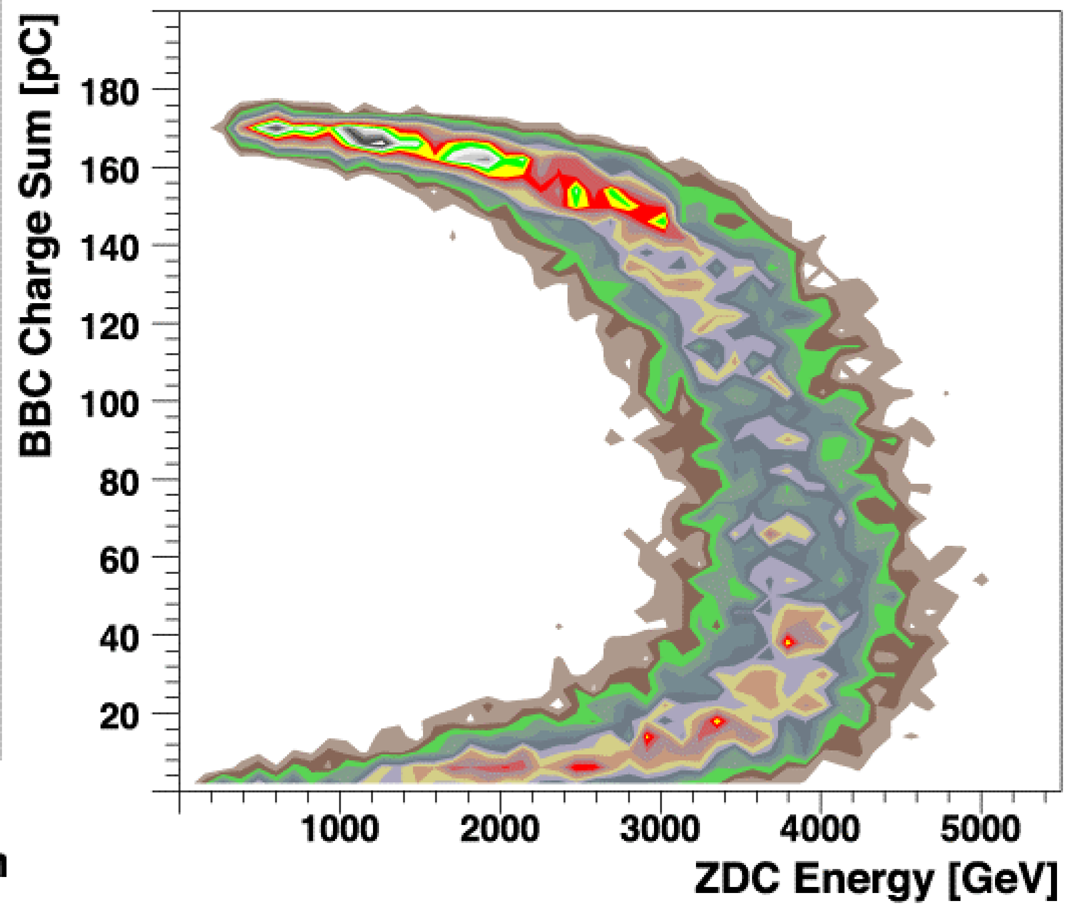
Global - MVD, Beam-Beam, Zero-Deg.



Trigger



Glauber model reproduces ZDC spectrum reasonably, which gives a possibility to estimate # of participant nucleons.



The Pad Chambers in PHENIX

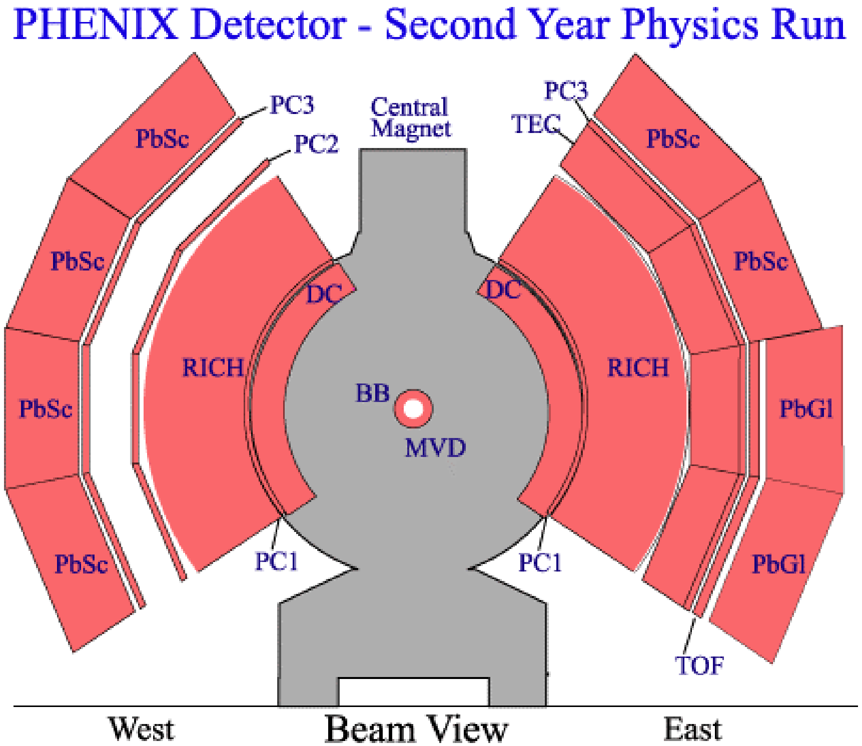
* Three layers: **PC1**, **PC2** and **PC3**. Provide 3D coord. for charged tracks in field-free

* Ensure reliable pattern recognition in the high-multiplicity environment.

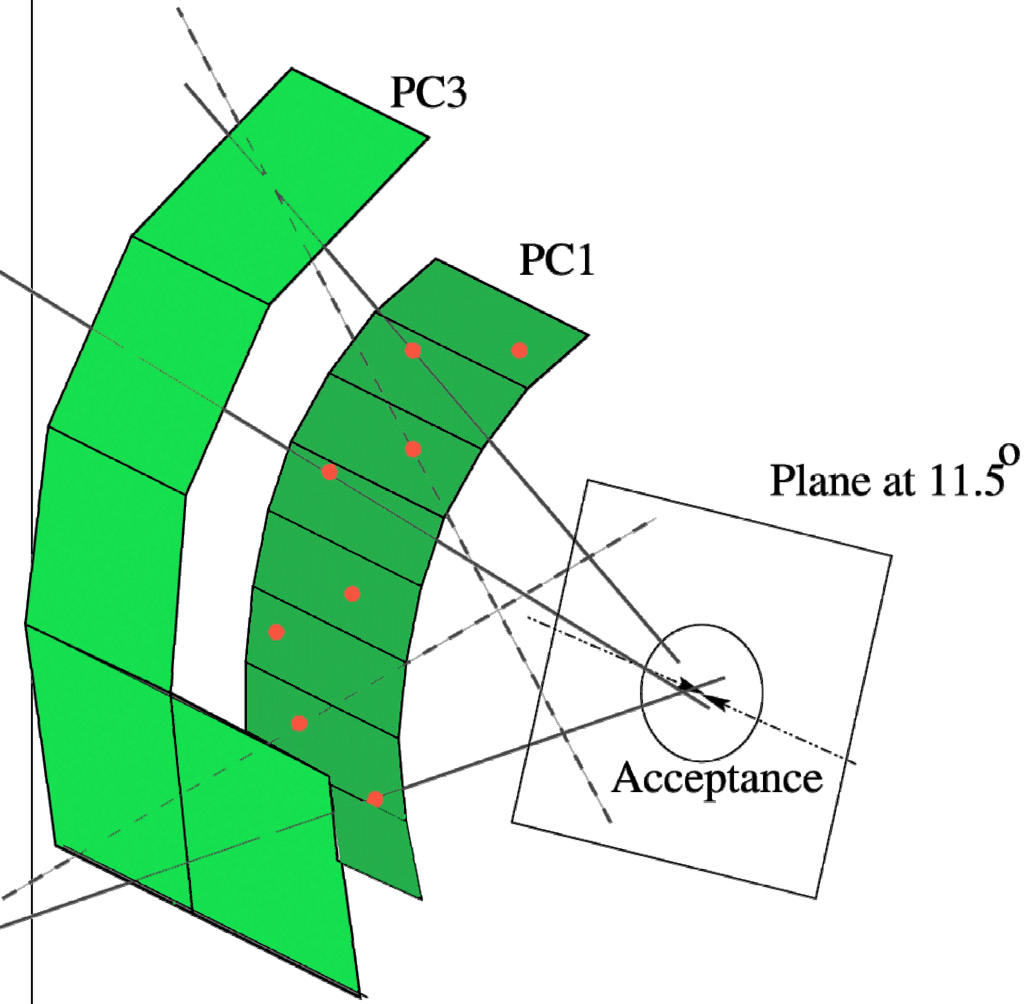
* MWPC with a total of 172 800 Yes/No readout channels.

* 88 m^2 total active detector area.

BNL - Lund University - McGill University - ORNL - Stony Brook - Vanderbilt University - Weizmann Institute



Hit Matching Procedure



The analysis presented here was performed with field off runs only and using PC1 and PC3 in the East arm. (For year-2: also West arm)

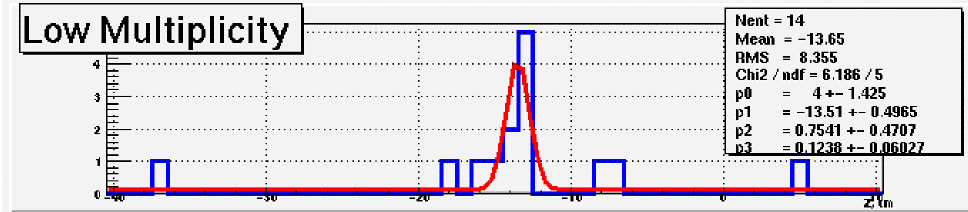
The background contribution is determined by a mixed event technique of exchanging each PC1 sector with its neighbour.

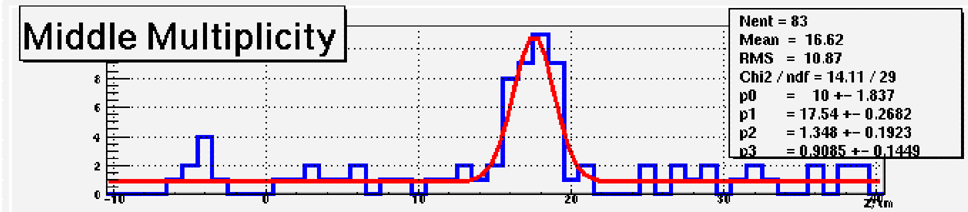
Vertex reconstruction is done by PC/BBC.

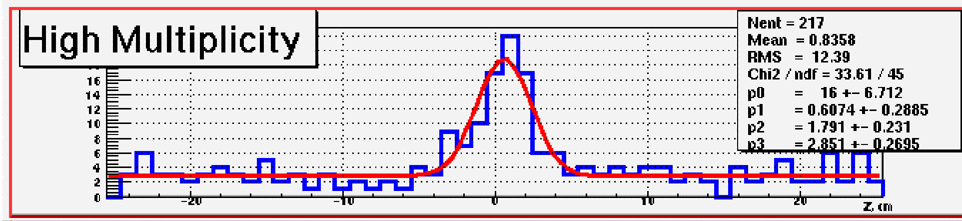
Vertex Reconstruction

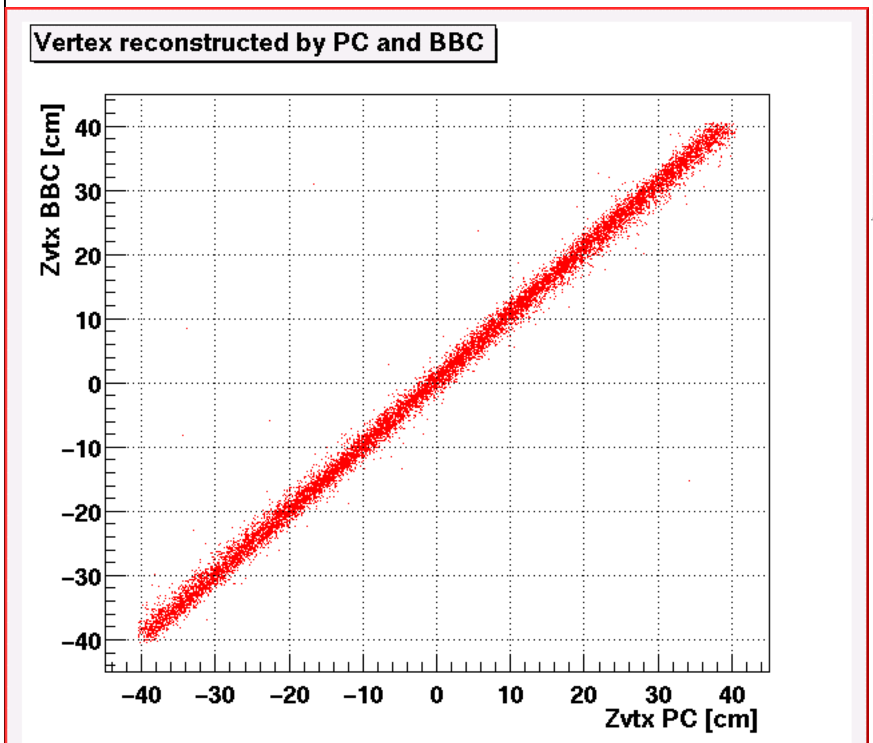
The vertex position is determined by

1) Combining all PC1 and PC3 hits to lines
2) Project the lines to the plane and save all within an appropriate X and Y window.
3) Calculate the peak position of the Z distribution.







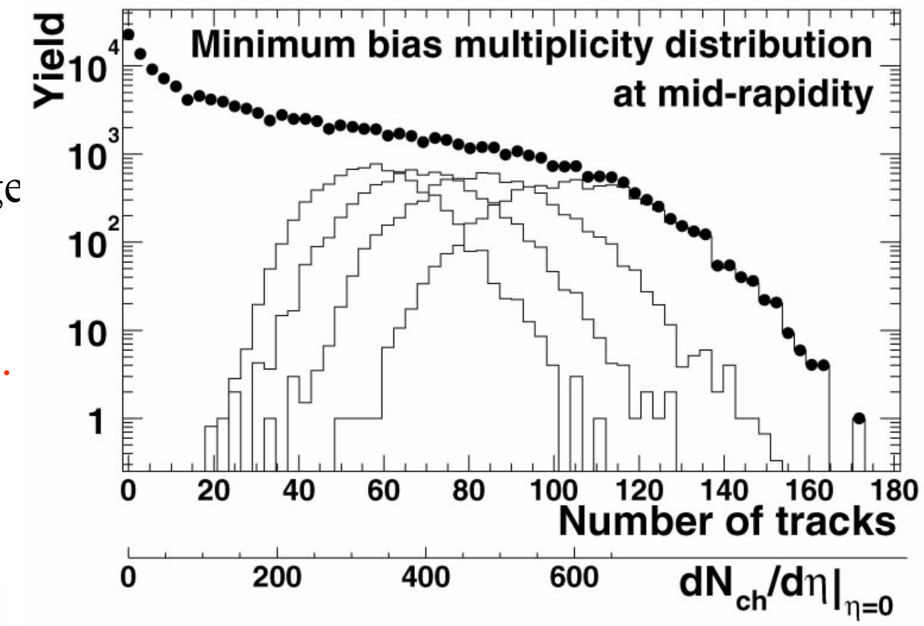


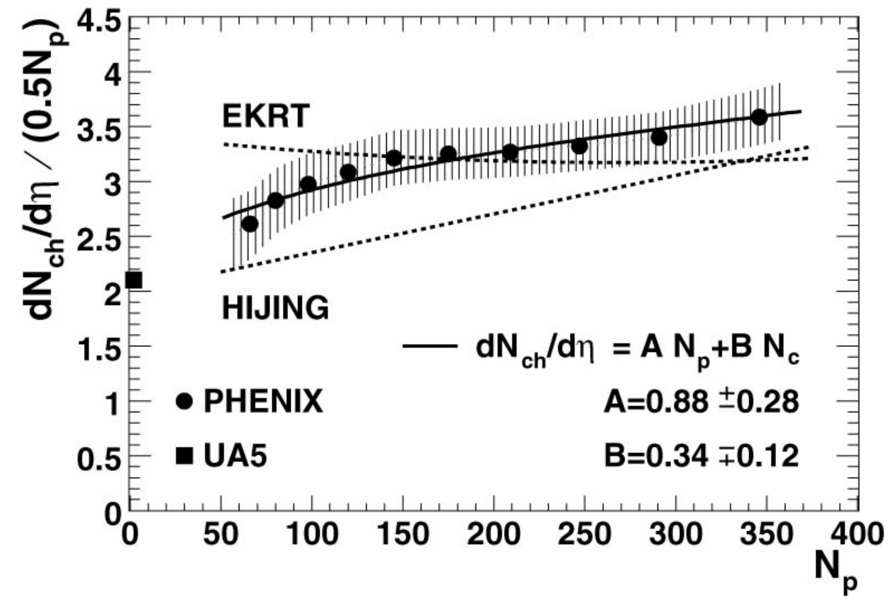
The vertices found by PC and BBC agree nicely. By repeating the procedure with a tighter cut placed around the found vertex, one can estimate the number of tracks in the collision.

Multiplicity distribution @ 130 GeV

Distribution has been scaled by the known correction factors, to correspond to a coverage of ± 0.5 in η and 2π in ϕ.

Width of high N_{ch} roll-off is a function of e.g. finite aperture.





First results on centrality dependence of charged particle multiplicity at RHIC energies.

RHIC : $dN_{ch}/d\eta$ at $\sqrt{s_{NN}} = 130$ GeV

PHOBOS: $|\eta|<1$, $\Delta\Phi \approx 1\%$?

2 layers of Si detectors close to vertex (B=0)

$dN_{ch}/d\eta$ = 555 ± 12 ± 35 (6% most central) PRL

$dN_{ch}/d\eta$ = 579 ± 1 ± 22 (6% most central)

PHENIX: $|\eta|<0.35$, $\Delta\Phi = 90^o$

2 layers of PC at 2.5 and 5 m from vertex (B=0)

$dN_{ch}/d\eta$ = 622 **± 1 ± 41 (5% most central)**

STAR: $|\eta|<1.8$, $\Delta\Phi = 2\pi$

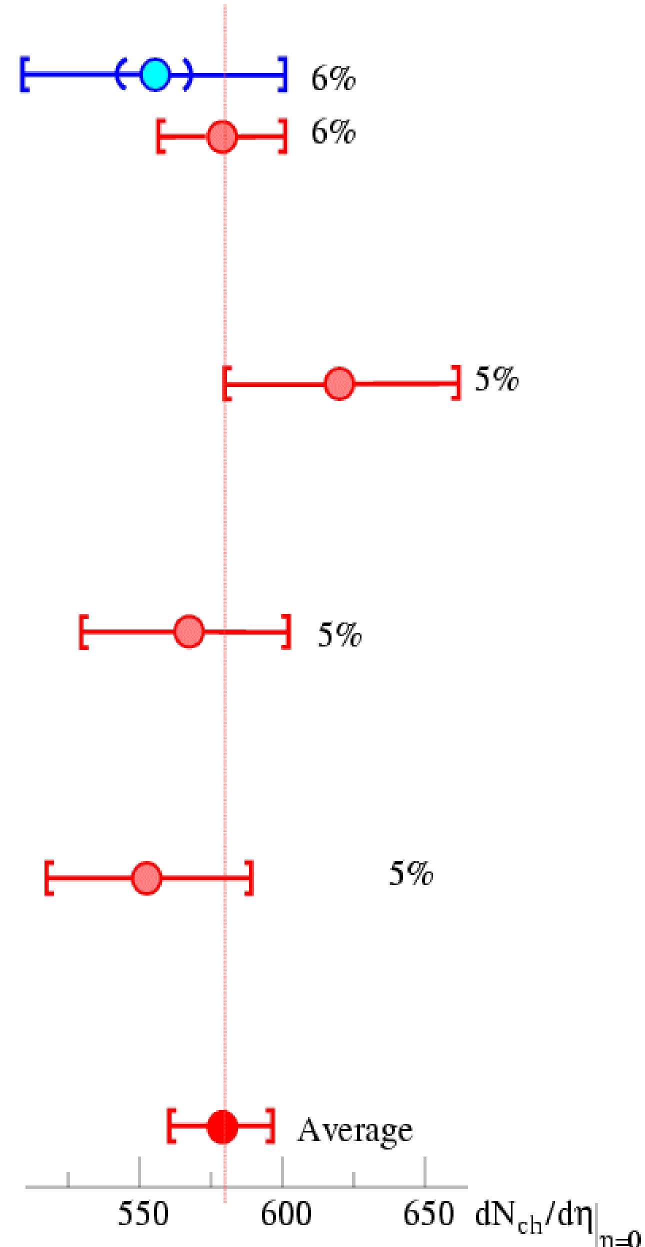
Tracking in TPC, p_t>100 MeV (B#0)

$dN_{ch}/d\eta$ = 567 **± 1 ± 38 (5% most central)**

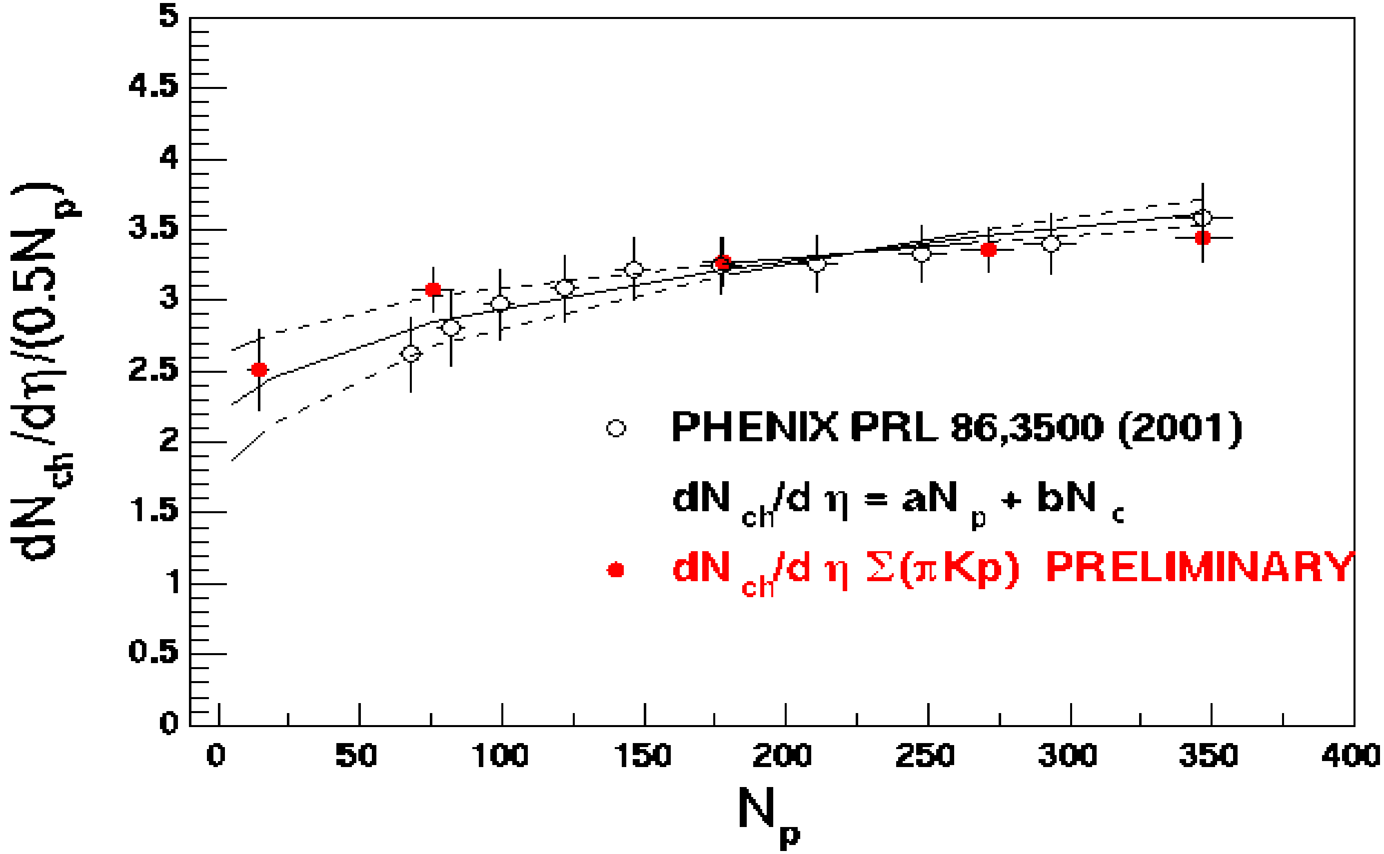
BRAHMS $|\eta|<4.7$

Si strips, scintillators and Cherenkov counters

$dN_{ch}/d\eta$ = 553 **± 1 ± 36 (5% most central)**



PHENIX internal consistency on yields



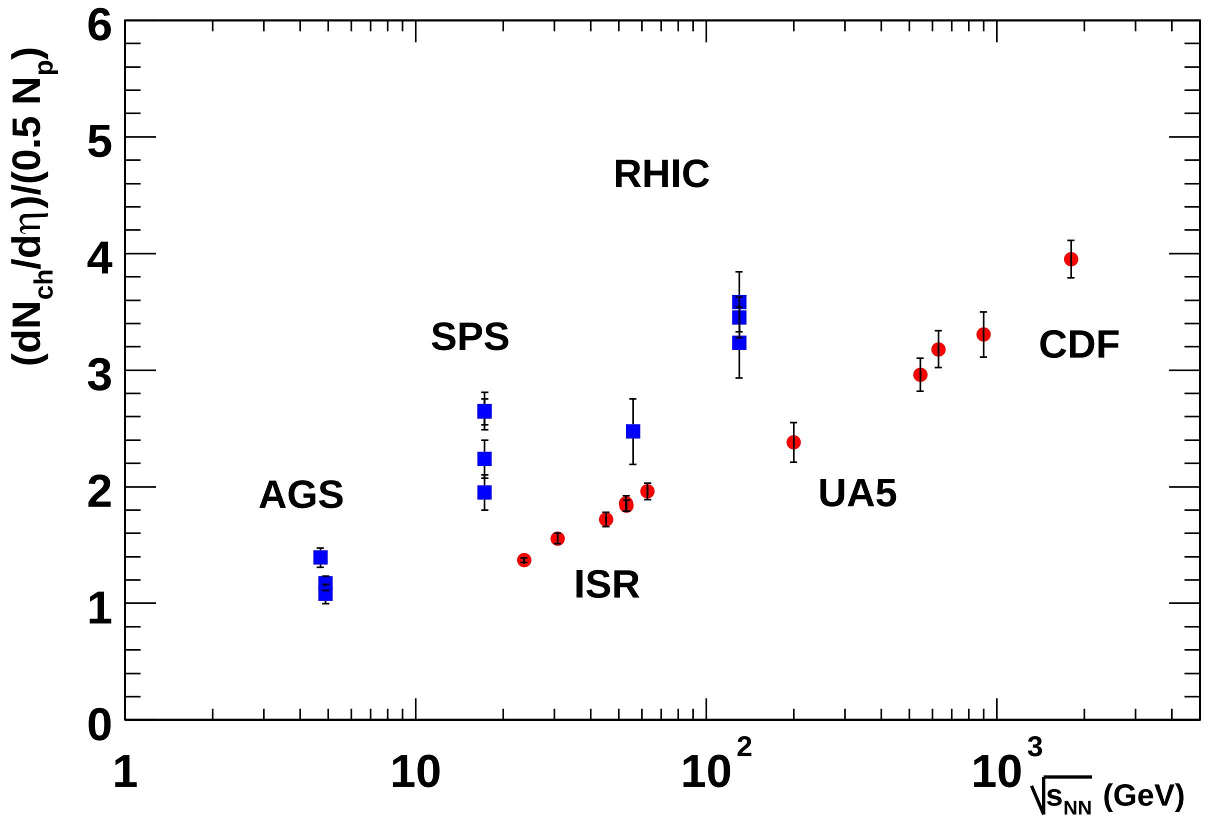
- Sum of dN/dη from integration of identified particle spectra are consistent with the published dN/dη results.

Energy Scaling of $dN_{ch}/d\eta$: pp and AA

Collection of data points from pp and AA experiments.

AA Fixed-target:
$dN_{ch}/d\eta$ approx. equal to dN_{ch}/dy

AA Collider:
$dN_{ch}/d\eta$ not equal to dN_{ch}/dy

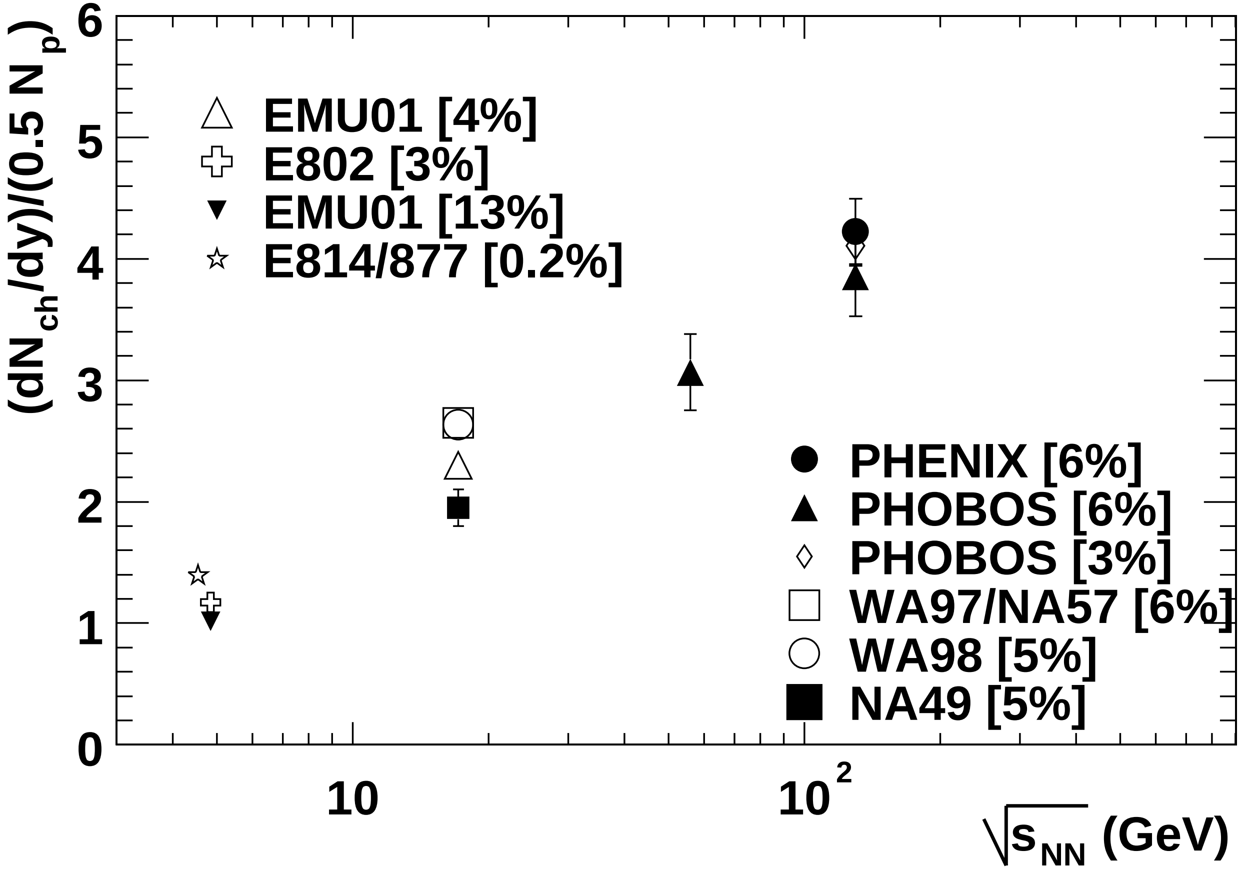


Energy Scaling of dN_{ch}/dy: AA

AA points only. Collider data scaled to correspond to dNch/dy.

Scale-factor (model-dependent):
1.24 @ 56 GeV
1.19 @ 130 GeV

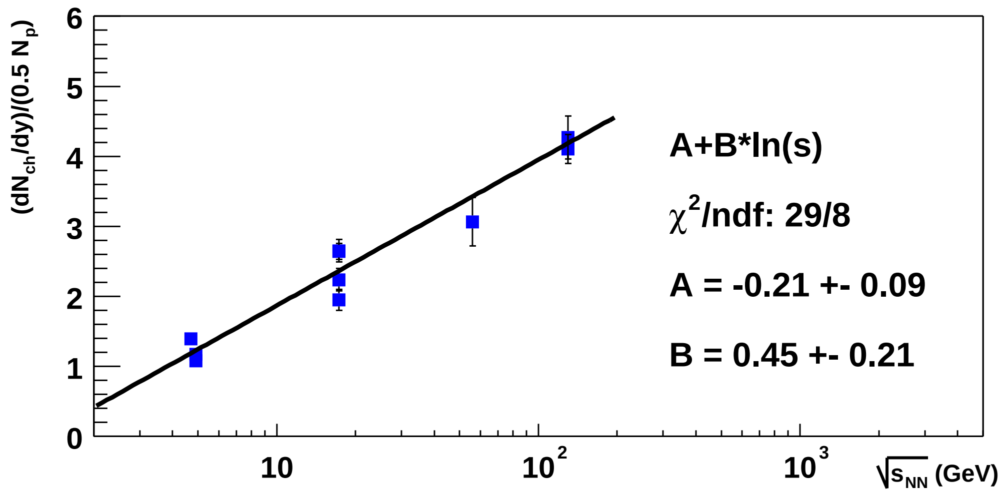
Note the large spread between points at SPS.



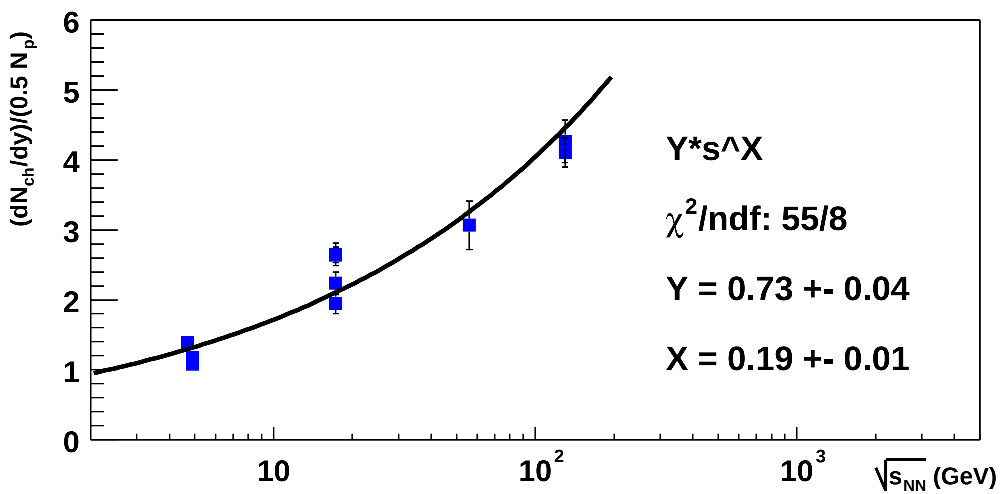
dN_{ch}/dy Fits: AA

Two simple functional forms:

Log: A+B*ln(s)



Pow: Y*s^X

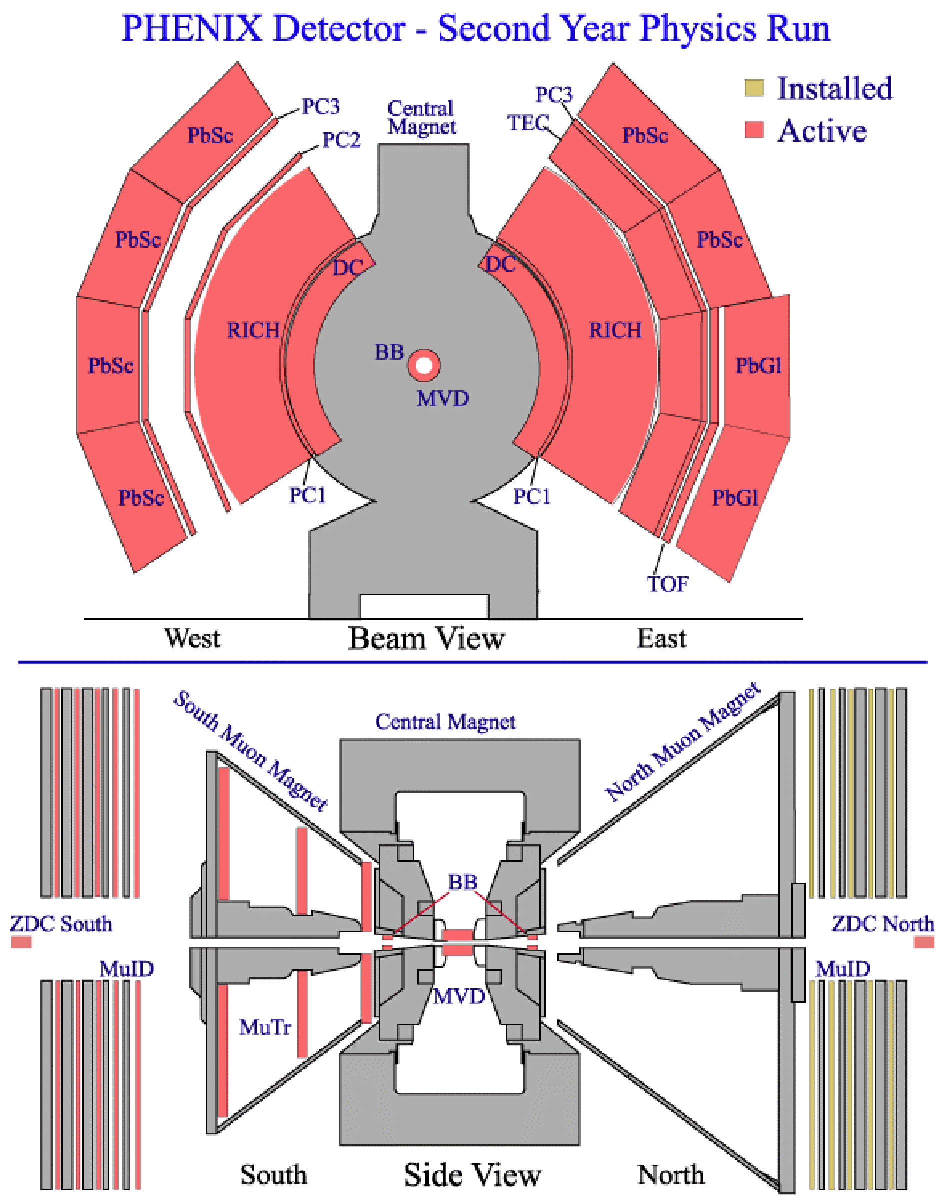


Both describe data reasonably well.

200 GeV is next..

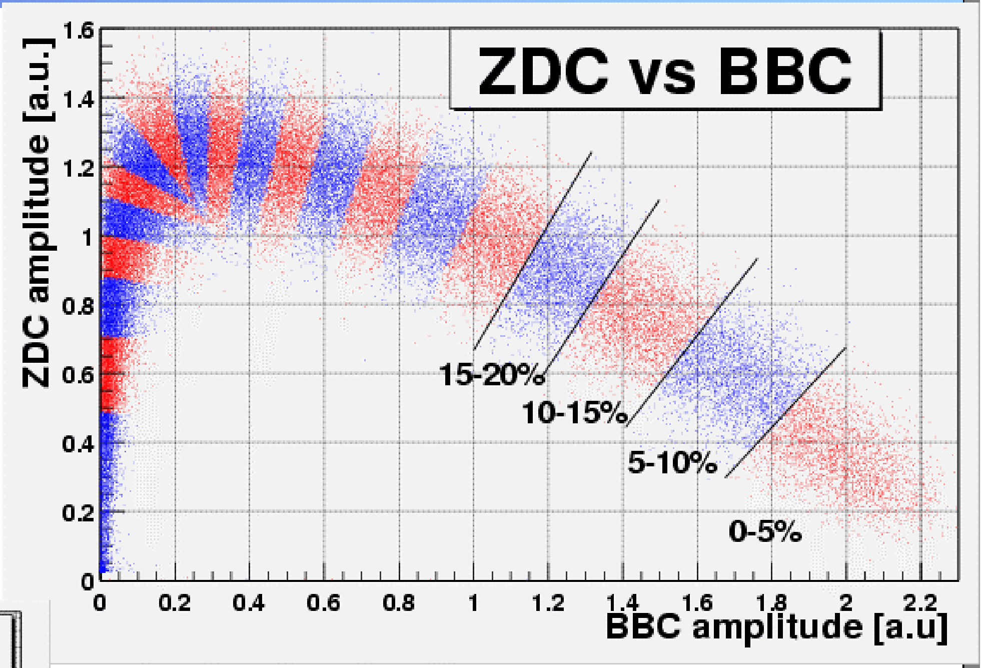
Year 2001 Configuration

* EMCal coverage extended
* South Muon Arm added
* PC2 and PC3 West added

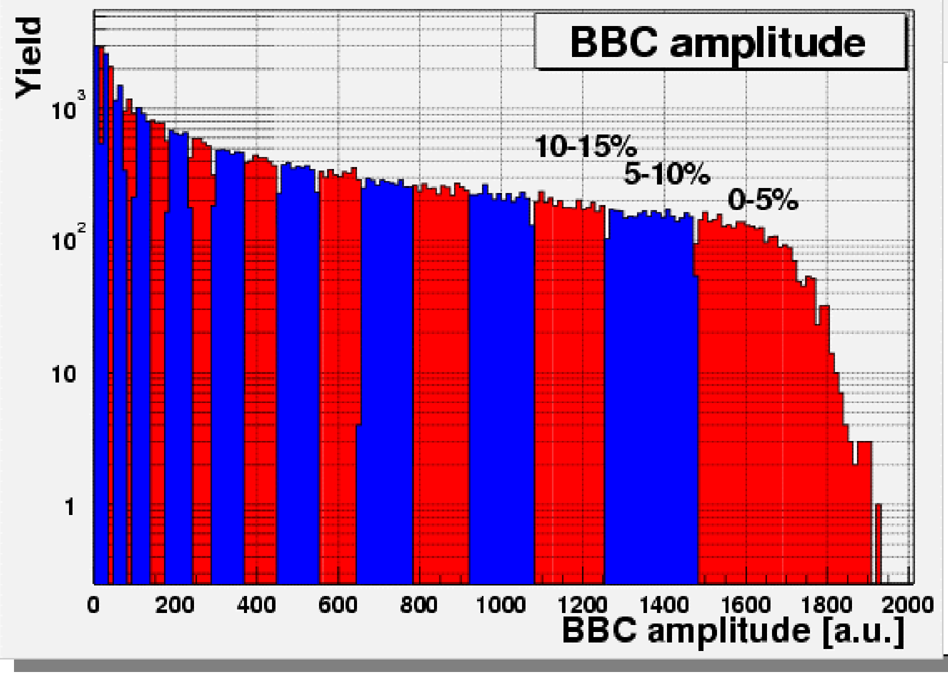


Centrality determination: Year 2001

Two dimensional cut in the same way as in first year analysis.



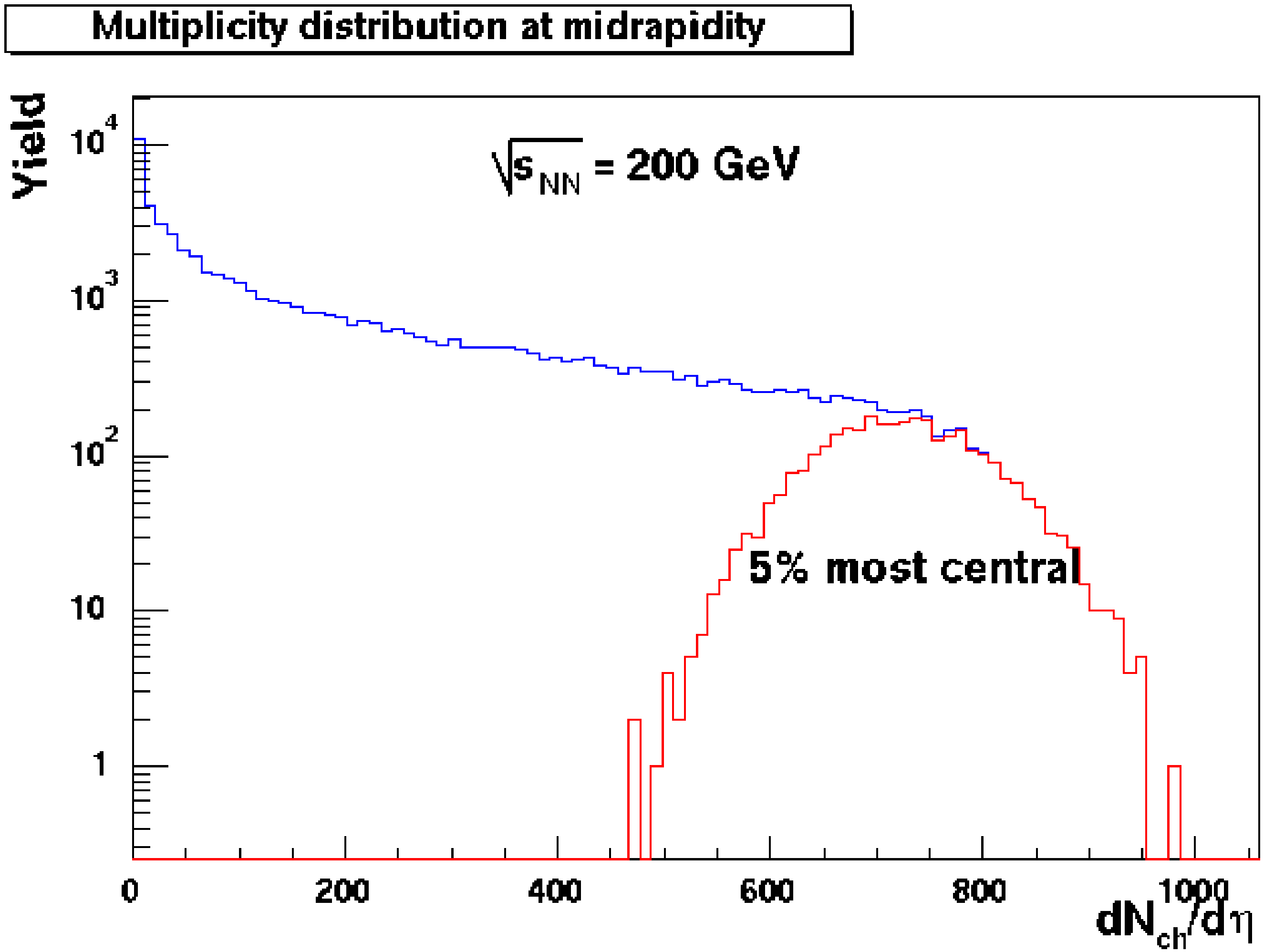
Can also do one-dimensional cut.



Both methods are in good agreement for centrality < 60 % (most central).

Multiplicity distribution @ 200 GeV

For the 5 % most central collisions, an increase of 1.15 ± 0.04, relative to 130 GeV, in $dN_{ch}/d\eta$ per participant pair is observed.



Extrapolations to 200 GeV and LHC

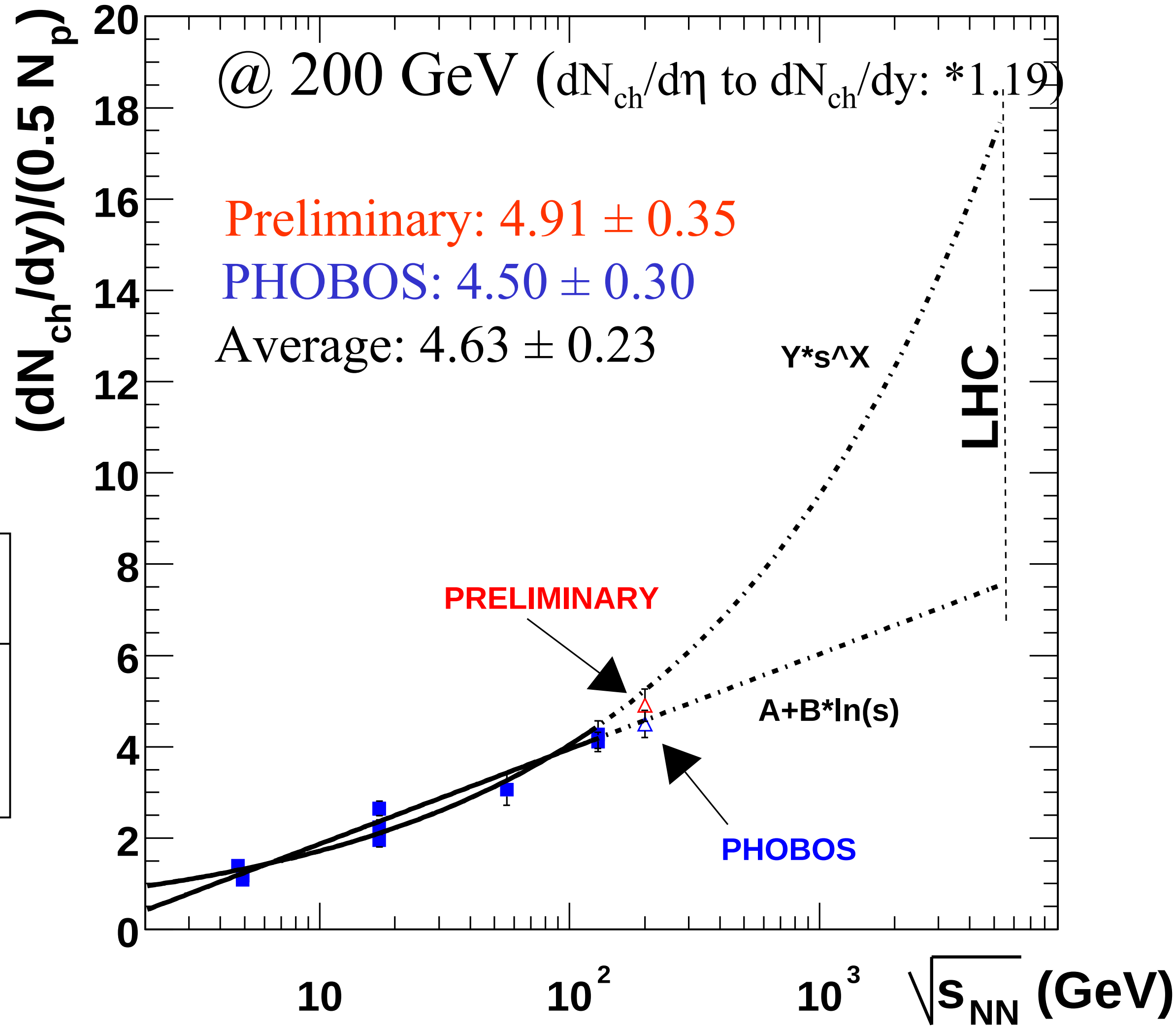
Predictions @ 200 GeV from data up to 130:

Log: A+B*ln(s): 4.58

Pow: Y*s^X: 5.23

At LHC:

Fit	dN_{ch}/dy	N_{ch}
Log	1 400	13 000
Pow	3 400	30 000

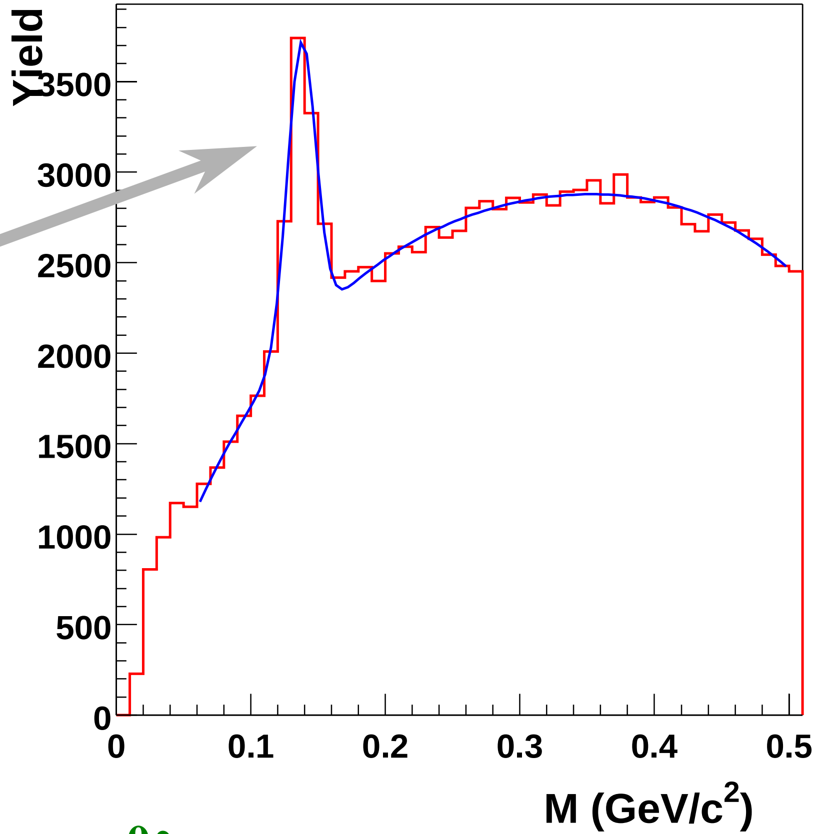


N_{ch} obtained assuming that the shape is invariant in y/y_{max}

Transverse Energy

- ❑ Well-understood response to soft charged hadrons
- ➨ Reliable measurement of total transverse energy

$E_T = (1.17 \pm 0.05)\ E_{EMCal}$

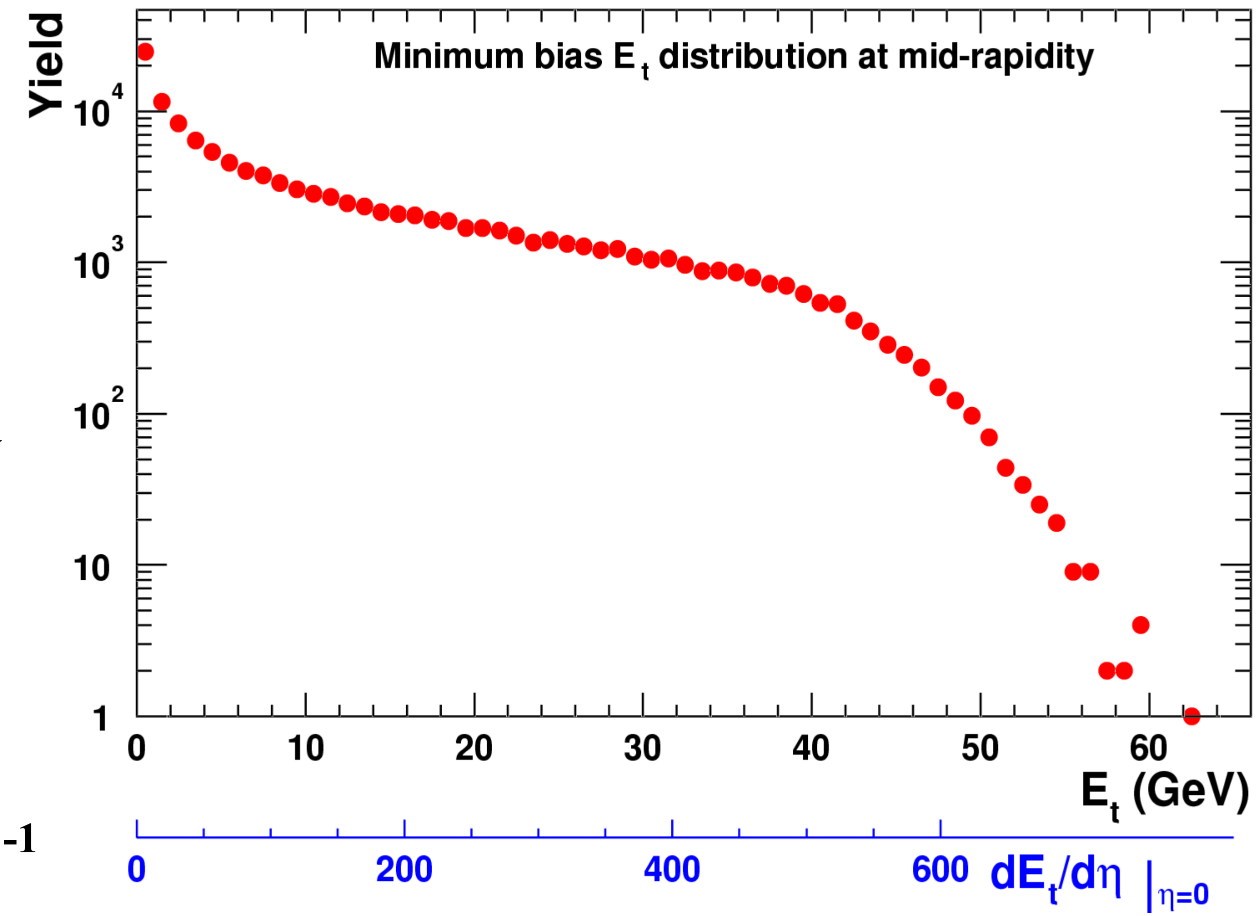


π^0's

$p_T > 2$ GeV, asym<0.8

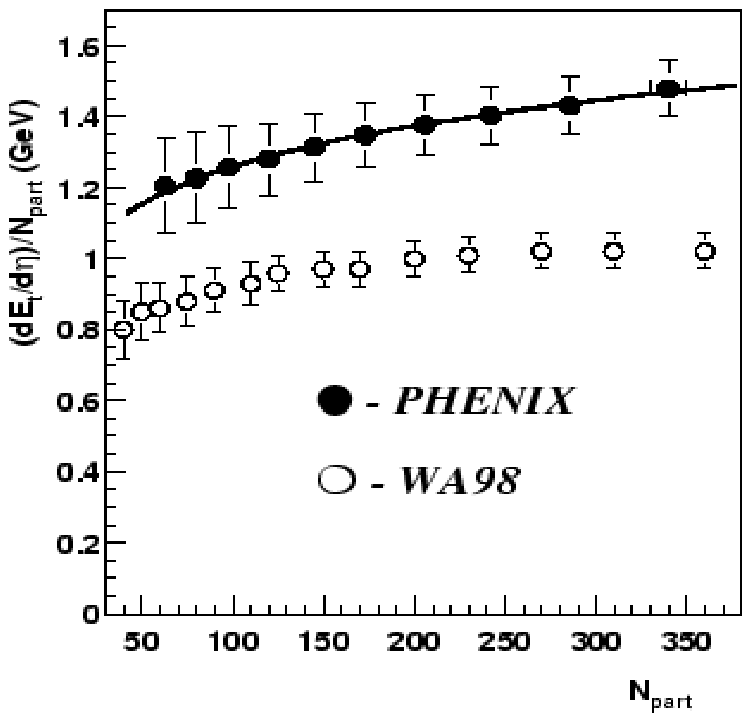
Transverse Energy Distribution

- Measured for
  - $|\eta| < 0.35$
    $\Delta\phi = 45^o$
- Studied versus
  - Charged multiplicity
  - N participants

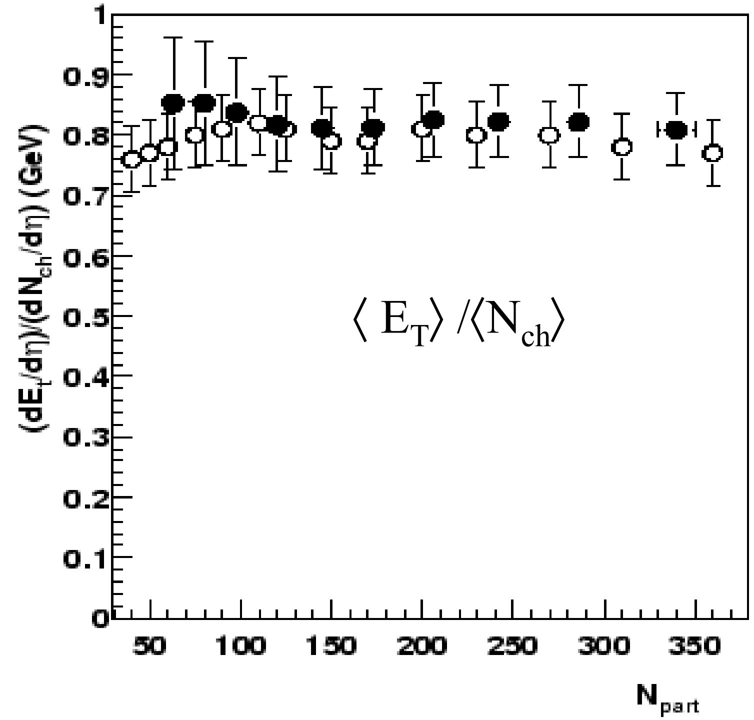


Phys.Rev.Lett.87(2001)052301-1

- E_T increases faster than number of participants
- E_T/N_{Part} larger than at CERN
- $\langle E_T \rangle / \langle N_{ch} \rangle \sim 0.8$ independent of centrality

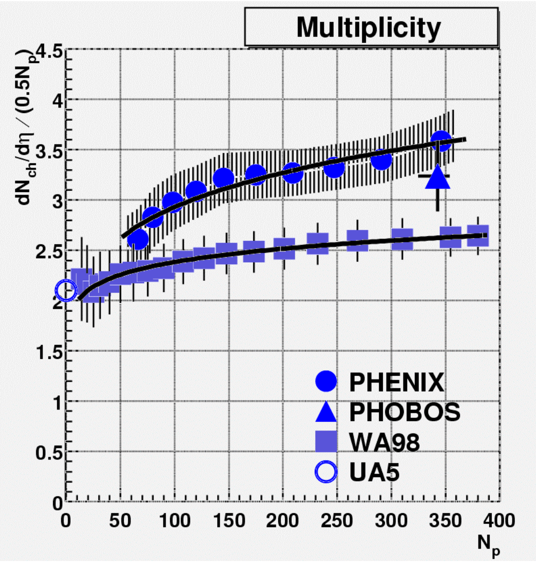


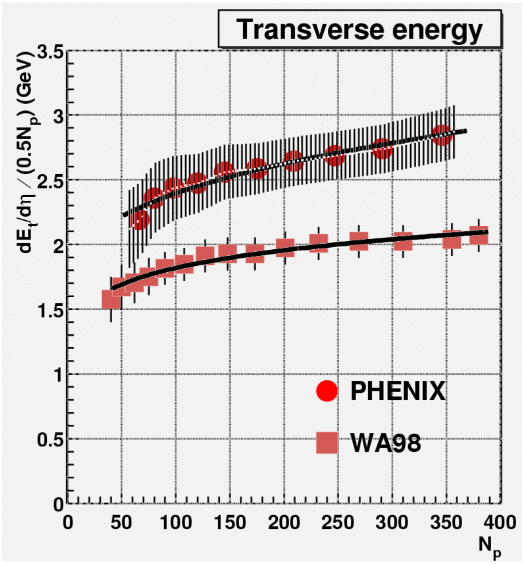
(PHENIX excludes baryon mass, WA98 includes baryon mass)

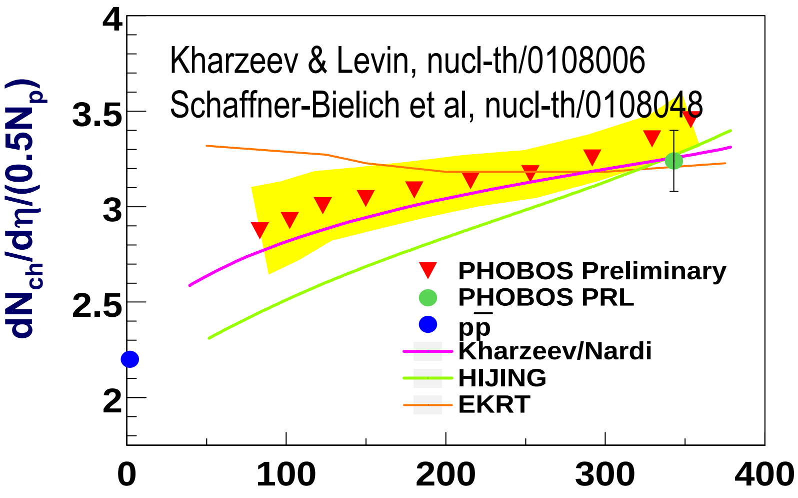


PRL 87, 52301 (2001)

Centrality Dependence : Comparison to CERN Results and Models







Evidence of hard processes?

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

soft (A) hard (B)

Hard processes contribution increases with centrality:

~50% for most central collisions

Saturation models reproduce the scaling with centrality and energy dependence!

New regime at RHIC?

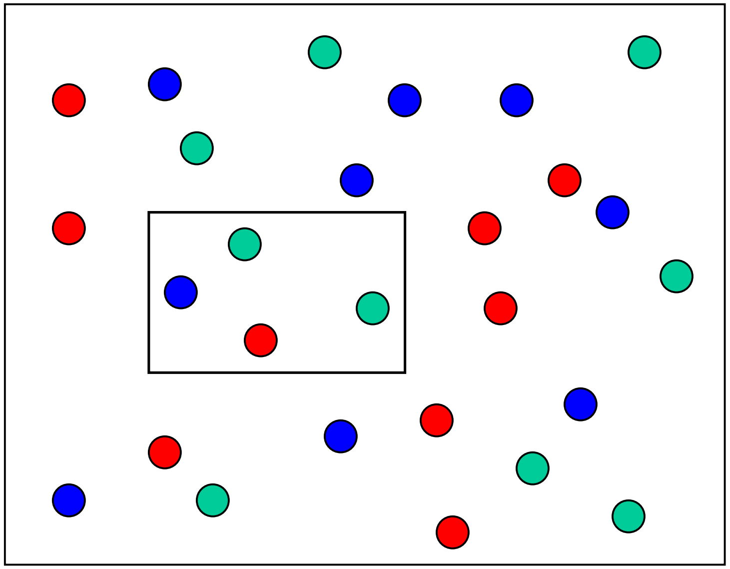
Net charge fluctuations

Proposed ~ 1½ year ago: Fluctuations in net charge and net baryon number significantly reduced if a QGP is formed in the collisions

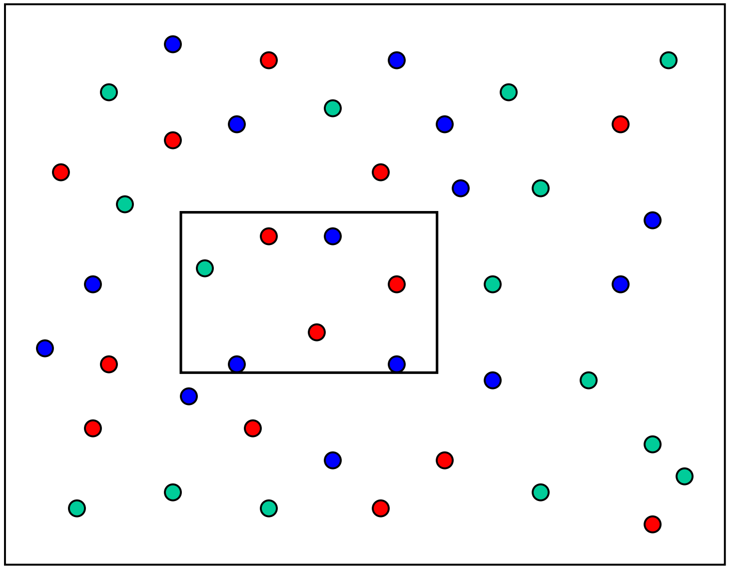
Asakawa, Heinz, Müller PRL 85(2000)2072; Jeon&Koch PRL 85(2000)2076

Several theoretical investigations since then

Shuryak&Stephanov PRC 63(2000)064903; Bleicher, Jeon, Koch PRC62(2000) 061902; Fialkowski&Wit Europhys. Lett. 55(2001)184; Heiselberg&Jackson PRC 63(2001)116003; Lin&Ko PRC64(2001)041901; Bopp&Ranft Eur.Phys.J. C22 (2001) 171 …



"hadron-gas"



"quark-gluon plasma"

Fractional charges (q = ± 1/3, 2/3) of the quarks ==> Charges more evenly spread in a plasma ==> reduced net charge fluctuations in a small region of phase-space

Charged particle tracks defined by Drift Chamber + matching Pad Chamber hit. The charge determined from the deflection in the magnetic field (Magnet ON).

Study the fluctuations in

$$Q = N+ - N-$$

or

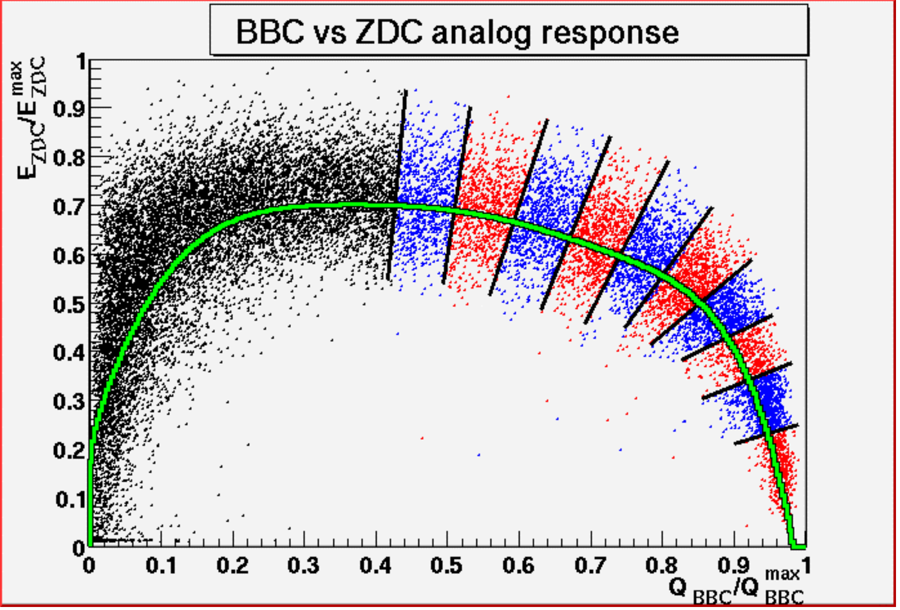
$$R = N+/N-$$ (Koch,Jeon PRL 85(2000)2076)

Define

$v(Q) = var(Q)/\langle n_{ch}\rangle$ $v(R) = \langle nch\rangle \, var(R)$

Asymptotically, $v(R) = 4\, v(Q)$

For stochastic emission, $v(Q) = 1.0$; $v(R) = 4.0$
but the value for R depends on the fraction of + and – particles, n_{ch} (and thus centrality) etc.

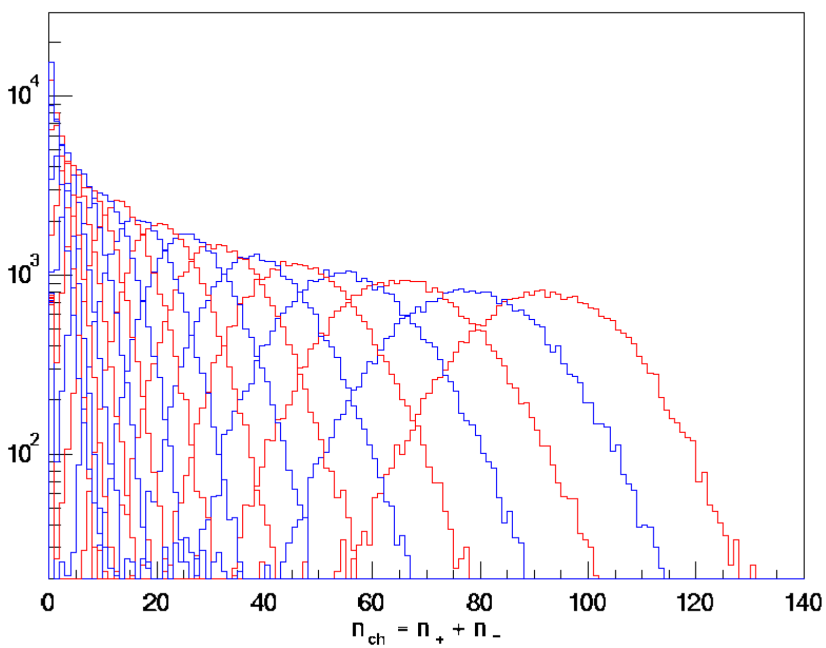


Centrality Selection

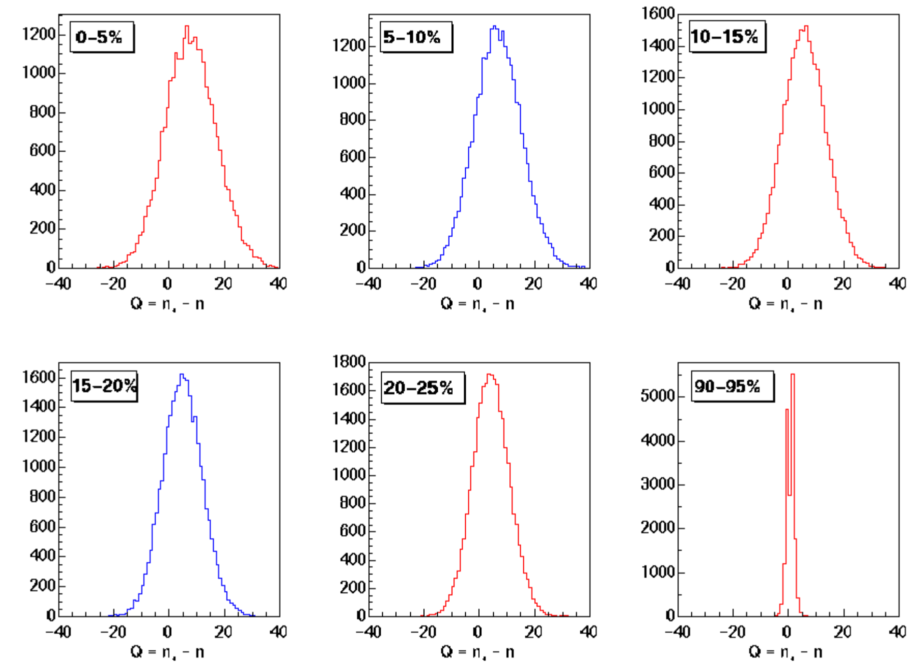
Select events based on ZDC and BBC information.

Charge and net charge distributions for centrality classes (5% bins).

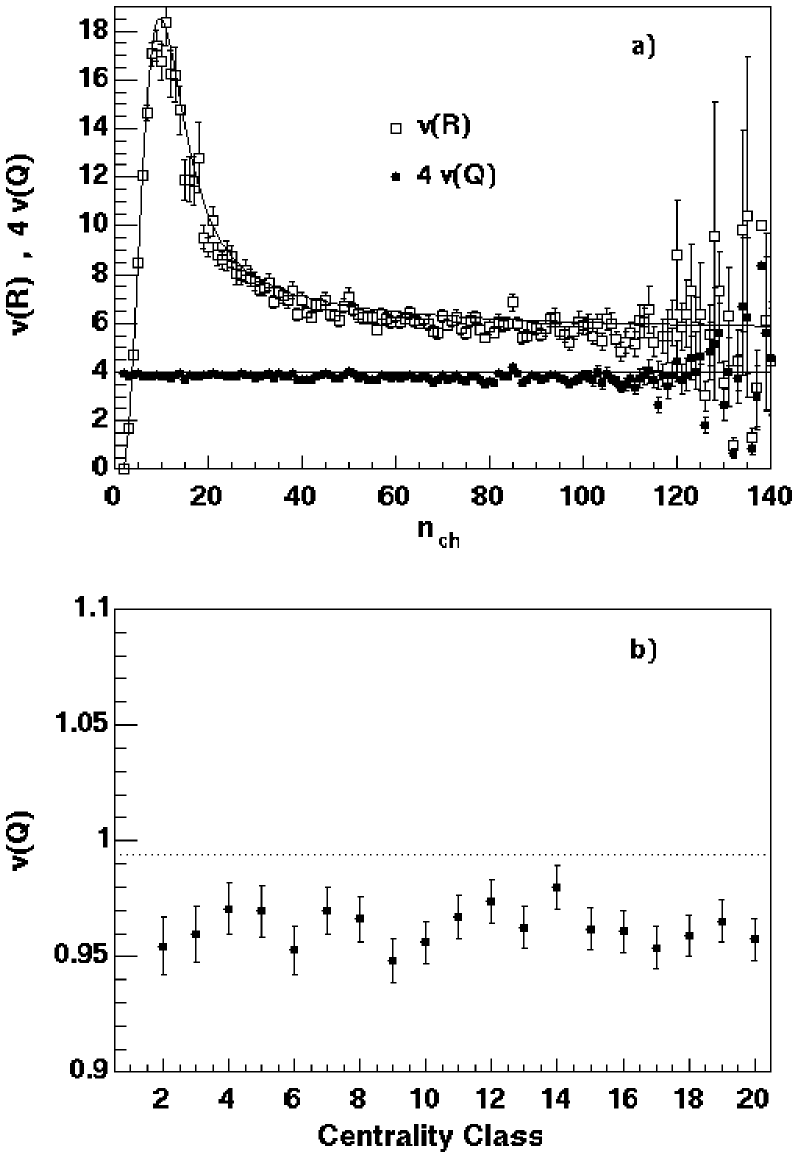
$$n_{ch} = n_+ + n_-$$



$$Q = n_+ - n_-$$



What do we see?



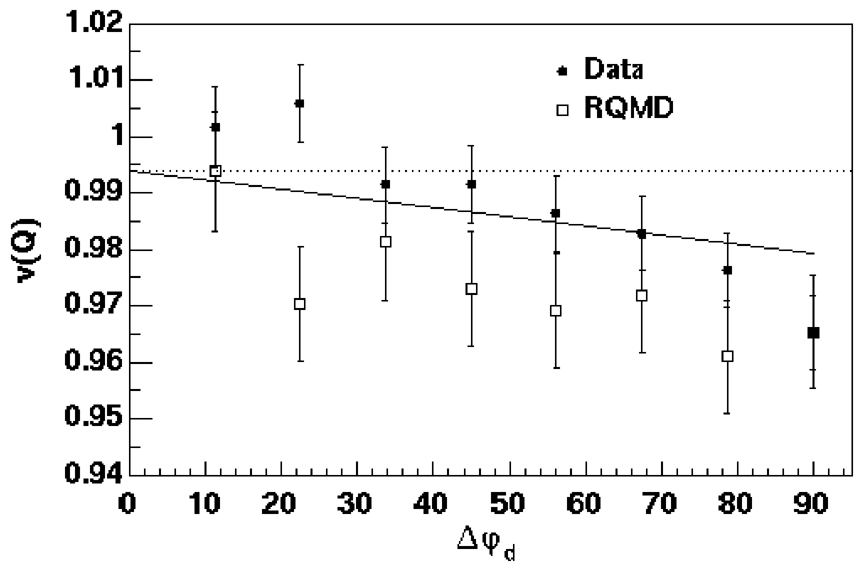
v(R) and v(Q) for two centrality measures:
a) n_{ch} and
b) BBC/ZDC.

v(Q) is close to what one expects for purely stochastic emission.

v(R) shows a complicated behaviour, but this can be understood (solid curve).

Small deviations from 1.0 (stochastic emission) can be seen for v(Q).

Systematics for v(Q)



The fluctuations scale with geo. acceptance.

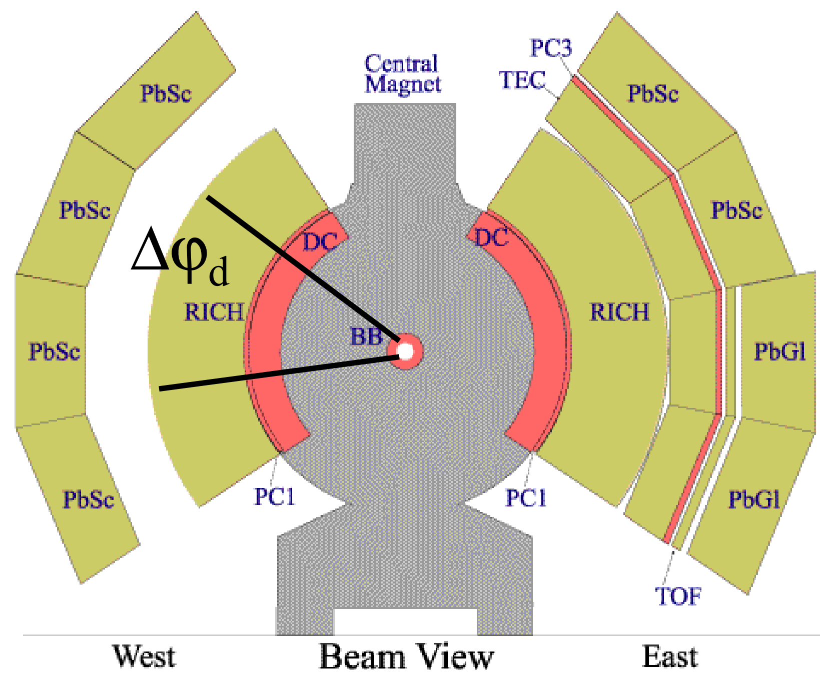
Do the analysis using only a part of the detector.

Expected variation from global charge conservation:

(1 – p)

where p is the fraction of the produced particles inside the acceptance. $p \propto \Delta\varphi$

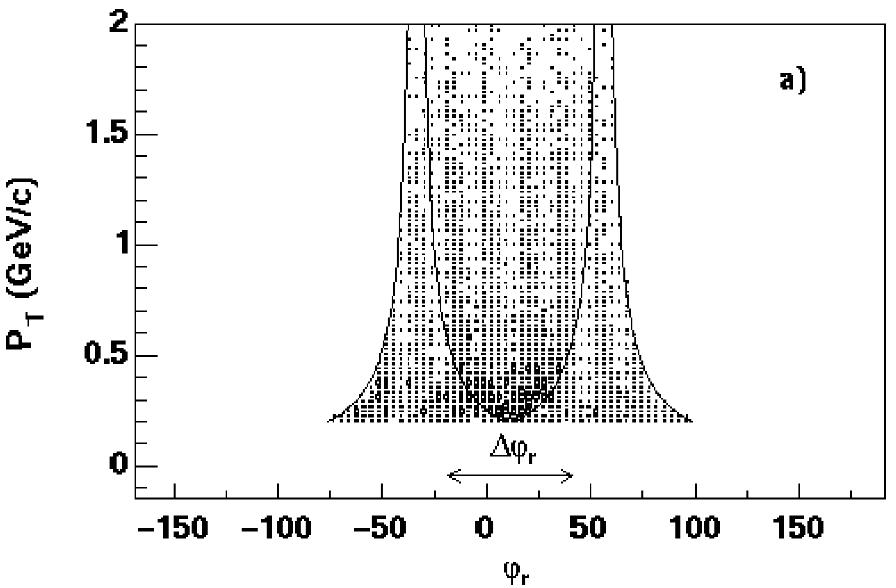
RQMD contains charge conservation + resonances.



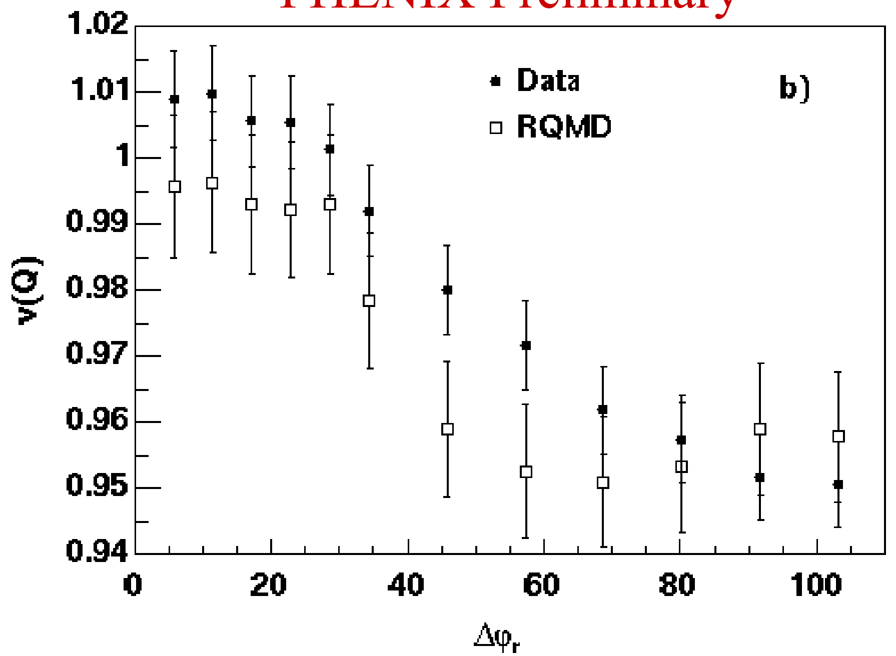
The reduction in v(Q) increases with increased acceptance, as expected.

By cutting on the reconstructed
φ = atan(py/px)
phase space regions with over-lapping coverage for + and - particles can be selected.

Again, data is in very good agreement with RQMD.



PHENIX Preliminary



Result for v(Q)

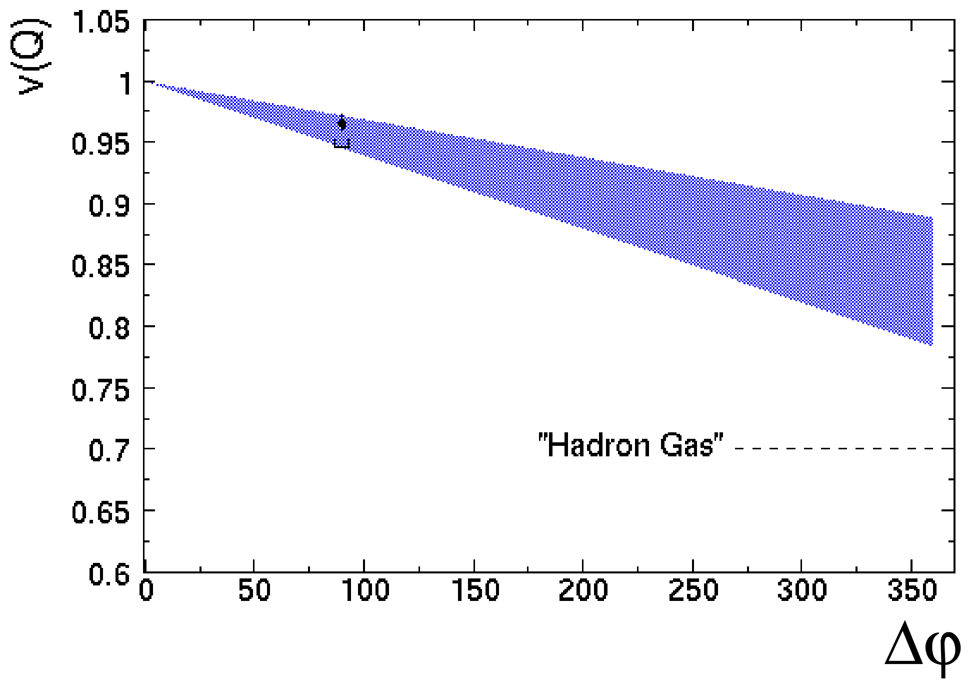
For $|\eta|<0.35$, p_T > 200 MeV/c, $\Delta\varphi=\pi/2$ (PHENIX preliminary):

$$v(Q) = 0.965 \pm 0.007(\text{stat.}) \pm 0.019\ (\text{syst.})$$

Systematical error estimated from geant simulations (reconstruction efficiency and contribution from background tracks).

Extrapolating to $\Delta\varphi= 2\pi$ (linearly) gives a value consistent with or slightly above that of a hadron gas.

Data does not support the predicted signal for a QGP, $v(Q) \approx 0.25$. It would require a very abrupt change in the behaviour of v(Q) vs. $\Delta\varphi$ in the region $\pi/2$ to 2π.



Analysis Details...

Data:

• The mean p_t and e_t are determined on an event-by-event basis:

$$Mp_t = \Sigma\, p_{t,\,i}/N_{pt} \quad Me_t = \Sigma\, e_{t,\,i}/N_{et}$$

200 MeV/c < p_t < 1.5 GeV/c, ***225 MeV < e_t < 2.0 GeV***

• *An event must have at least 10 tracks/clusters per event to be included in the mean distribution.*

Mixed Events:

• Mixed event distributions are built from reconstructed tracks/clusters in real events from the same centrality/multiplicity class.

• *No 2 tracks/clusters from the same real event are allowed in the same mixed event.*

• *The number of tracks/clusters distribution, N_{pt} or N_{et}, in mixed events are sampled from the data N distribution.*

Dataset Statistics

Small apertures in the PHENIX central arm spectrometers, but particles are plentiful in RHIC Collisions…

Acceptance: $\eta<|0.35|$, $\Delta\phi \sim 45^0$

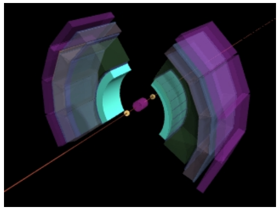
NOTE: Distributions are left uncorrected for static acceptance/efficiency

Statistics for the 0-5% centrality class:

Mean p_t analysis:

$N_{events} = 72692$, $\langle N_{tracks}\rangle = 59.6$, $\sigma_{Ntracks} = 10.8$

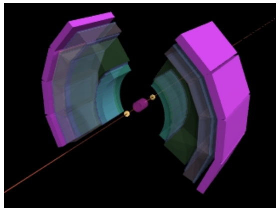
$\langle M_{pt}\rangle = 523$ MeV/c, $\sigma_{Mpt} = 38.6$ MeV/c, $\sigma_{pt} = 290$ MeV/c



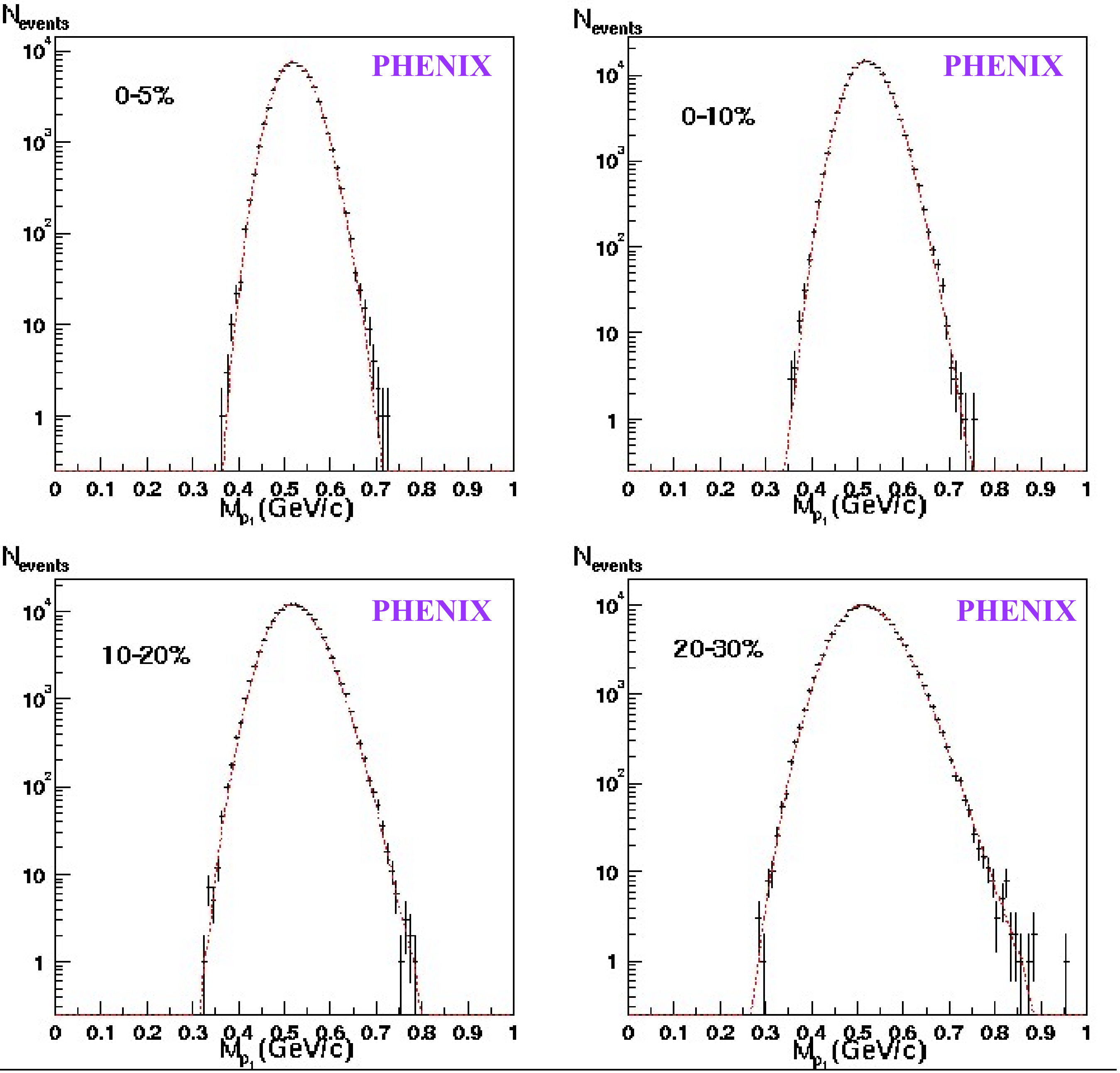
Mean e_t analysis:

$N_{events} = 69224$, $\langle N_{clusters}\rangle = 68.6$, $\sigma_{Nclusters} = 11.6$

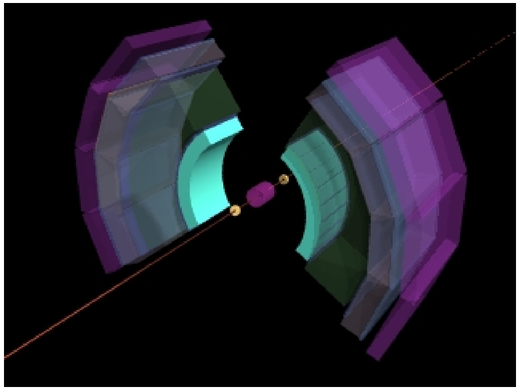
$\langle M_{et}\rangle = 466$ MeV, $\sigma_{Met} = 34.1$ MeV, $\sigma_{pt} = 267$ MeV



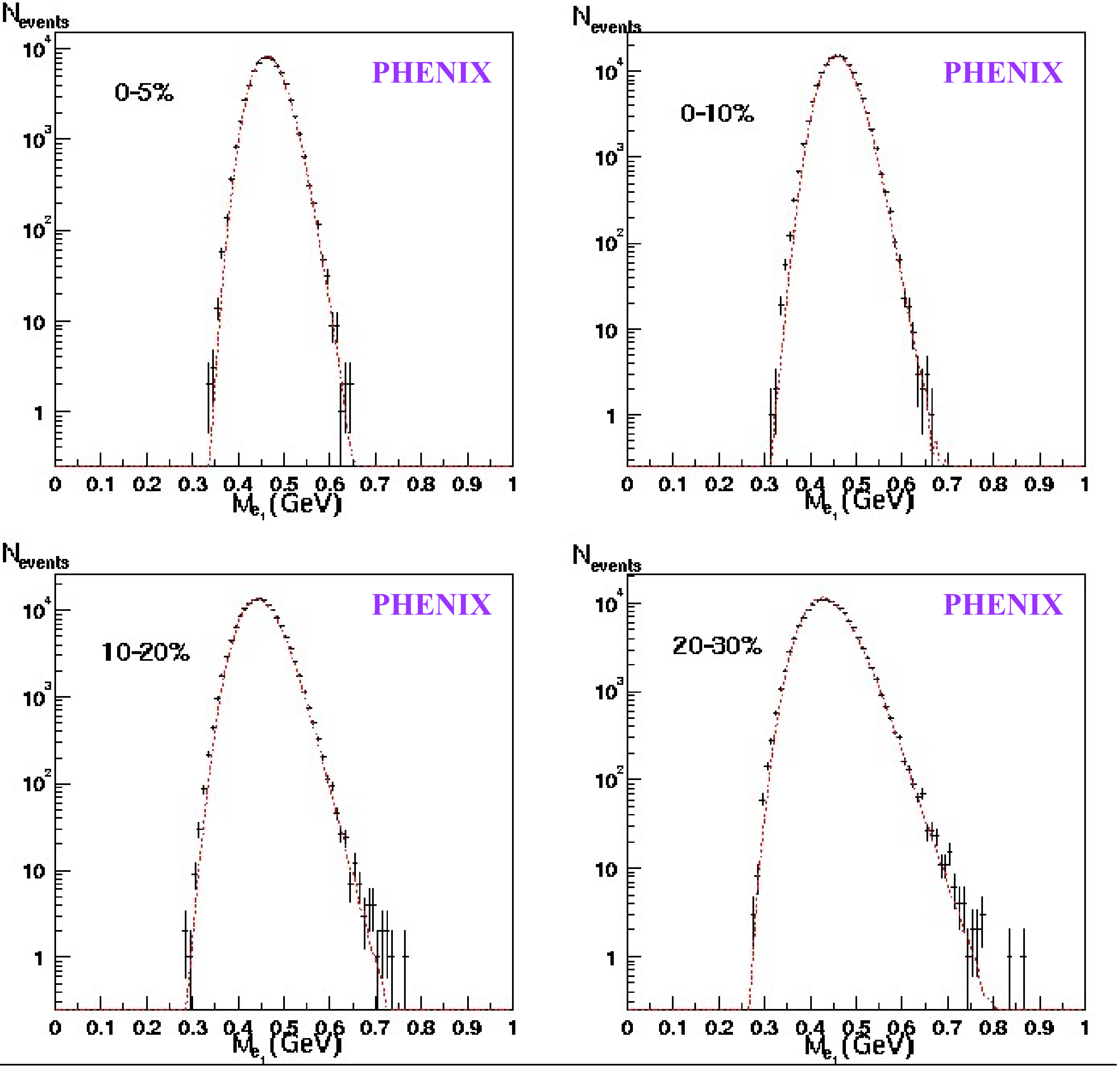
Mean p_t Distributions



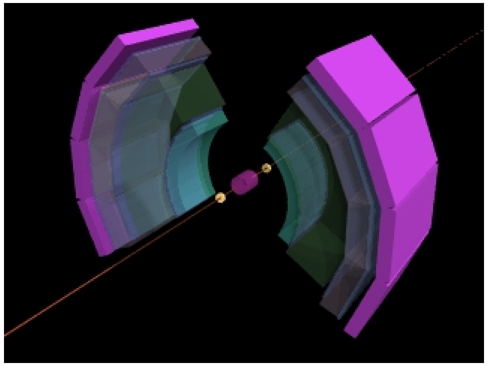
Mixed Event Distribution



Mean e_t Distributions



Mixed Event Distribution



Quantifying the Fluctuations

Define the magnitude of a fluctuation, ω_t:

$$\omega_t = \frac{\sqrt{<X^2> - <X>^2}}{<X>} \times 100\% = \frac{\sigma_{M_X}}{\mu_{M_X}} \times 100\%$$

Define the fractional fluctuation difference from random, F_t:

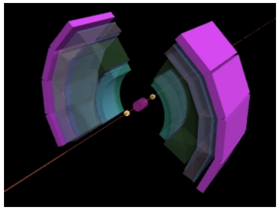
$$F_t = \frac{(\omega_{data} - \omega_{random})}{\omega_{random}}$$

F is related to the fluctuation variable ϕ via:

$$\phi = \sqrt{n}\left(\sigma_{data} - \sigma_{random}\right) = F_t \times \sigma_{inclusive}$$

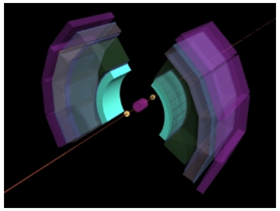
PHENIX Fluctuation Results

Centrality class	$\omega_{(t,\ data)}$ (%)	F_t (%)	ϕ_{p_t} (MeV/c)
0 - 5 %	7.37 ± 0.10	1.9 ± 2.1	5.65 ± 6.02
0 - 10 %	7.85 ± 0.13	2.0 ± 2.5	6.03 ± 7.28
10 - 20 %	9.52 ± 0.14	2.1 ± 2.2	6.11 ± 6.63
20 - 30 %	11.7 ± 0.21	1.8 ± 3.0	5.47 ± 9.16



Mean P_t

Centrality class	$\omega_{(t,\ data)}$ (%)	F_t (%)	ϕ_{e_t} (MeV)
0 - 5 %	7.32 ± 0.07	4.3 ± 1.3	11.5 ± 3.59
0 - 10 %	7.84 ± 0.08	5.0 ± 1.6	13.6 ± 4.23
10 - 20 %	9.58 ± 0.17	4.2 ± 2.2	11.1 ± 5.75
20 - 30 %	11.8 ± 0.26	3.5 ± 2.8	9.28 ± 7.34



Mean E_t

Summary

- **dN_{ch}/dy , dE_T/dy:** ln($\sqrt{s_{NN}}$) **dependence from AGS to RHIC → ~ 90% increase from SPS at $\sqrt{s_{NN}}$= 17.2 GeV to RHIC at $\sqrt{s_{NN}}$= 200 GeV**

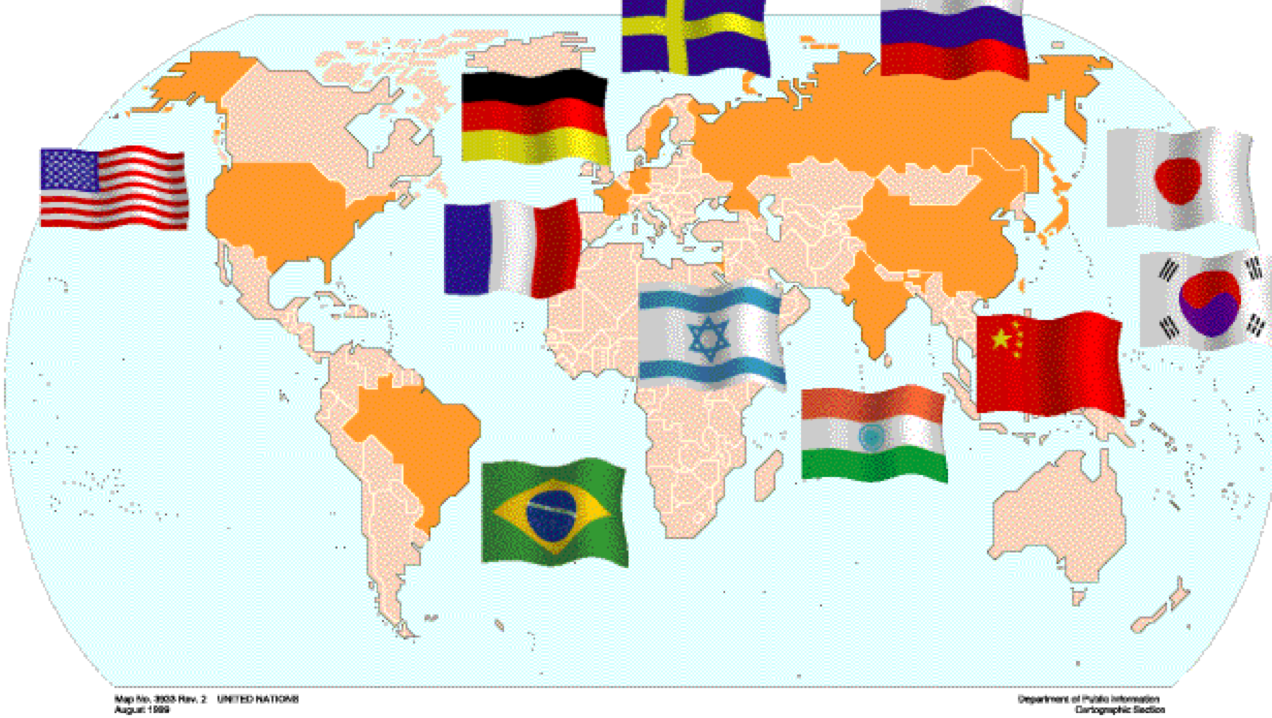
- **Systematic study of $dE_T/d\eta$ and $dN_{ch}/d\eta$ vs. N_{part}:**
  *** Stronger increase than at the CERN SPS**

- E_T per N_{ch} ~ independent of centrality and of energy
  - consistent with moderate increase in $\langle p_T \rangle$

- The net-charge fluctuations, v(Q), shows a reduction from what is expected for stochastic emission. Still above what was expected for QGP.

- No *significant* non-random fluctuations in Mean p_t or Mean e_t over the most 30% central γ = 130 Au+Au collisions within the PHENIX acceptance.

PHENIX



University of São Paulo, São Paulo, Brazil
Academia Sinica, Taipei 11529, China
China Institute of Atomic Energy (CIAE), Beijing, P. R. China
Laboratoire de Physique Corpusculaire (LPC), Universite de Clermont-Ferrand, 63170 Aubiere, Clermont-Ferrand, France
Dapnia, CEA Saclay, Bat. 703, F-91191, Gif-sur-Yvette, France
IPN-Orsay, Universite Paris Sud, CNRS-IN2P3, BP1, F-91406, Orsay, France
LPNHE-Palaiseau, Ecole Polytechnique, CNRS-IN2P3, Route de Saclay, F-91128, Palaiseau, France
SUBATECH, Ecole des Mines at Nantes, F-44307 Nantes, France
University of Muenster, Muenster, Germany
Banaras Hindu University,Banaras, India
Bhabha Atomic Research Centre (BARC),Bombay, India
Weizmann Institute, Rehovot, Israel
Center for Nuclear Study (CNS-Tokyo), University of Tokyo, Tanashi, Tokyo 188, Japan
Hiroshima University, Higashi-Hiroshima 739, Japan
KEK, Institute for High Energy Physics,Tsukuba, Japan
Kyoto University, Kyoto, Japan
Nagasaki Institute of Applied Science, Nagasaki-shi, Nagasaki, Japan
RIKEN, Institute for Physical and Chemical Research, Hirosawa, Wako, Japan
University of Tokyo, Bunkyo-ku, Tokyo 113, Japan
Tokyo Institute of Technology, Ohokayama, Meguro, Tokyo, Japan
University of Tsukuba, Tsukuba, Japan
Waseda University, Tokyo, Japan

Cyclotron Application Laboratory, KAERI, Seoul, South Korea
Kangnung National University, Kangnung 210-702, South Korea
Korea University, Seoul, 136-701, Korea
Myong Ji University, Yongin City 449-728, Korea
System Electronics Laboratory, Seoul National University, Seoul, South Korea
Yonsei University, Seoul 120-749, KOREA
Institute of High Energy Physics (IHEP-Protvino or Serpukhov), Protovino, Ru
Joint Institute for Nuclear Research (JINR-Dubna), Dubna, Russia
Kurchatov Institute, Moscow, Russia
PNPI: St. Petersburg Nuclear Physics Institute, Gatchina, Leningrad, Russia
Lund University, Lund, Sweden
Abilene Christian University, Abilene, Texas, USA
Brookhaven National Laboratory (BNL), Upton, NY 11973
University of California - Riverside (UCR), Riverside, CA 92521, USA
Columbia University, Nevis Laboratories, Irvington, NY 10533, USA
Florida State University (FSU), Tallahassee, FL 32306, USA
Georgia State University (GSU), Atlanta, GA, 30303, USA
Iowa State University (ISU) and Ames Laboratory, Ames, IA 50011, USA
LANL: Los Alamos National Laboratory, Los Alamos, NM 87545, USA
LLNL: Lawrence Livermore National Laboratory, Livermore, CA 94550, USA
University of New Mexico, Albuquerque, New Mexico, USA
New Mexico State University, Las Cruces, New Mexico, USA
Department of Chemistry, State University of New York at Stony Brook (USB), Stony Brook, NY 11794, USA

Deviations in $v(Q)$ from purely stochastic particle emission:

Global charge conservation: $v(Q) = (1-p)$
(p - fraction of detected particles)

Hadron-gas (hadronic resonances): $v(Q) = (1-p) \times 0.75$
Plasma: $v(Q) = (1-p) \times 0.25$

How should one interpret the behaviour of v(R) ?

p_+ and p_- are the probabilities for a particle to be pos. or neg.

Purely stochastic particle emission ⇒ n_+ and n_- follow binomial distributions.

v(R) can be calculated for fixed n_{ch} :

$$\langle R \rangle = \frac{1}{A} \sum_{i=1}^{nch-1} \frac{n_{ch}-1}{i} \binom{n_{ch}}{i} p_+^{nch-i}\, p_-^{\,i}$$

$$\langle R^2 \rangle = \frac{1}{A} \sum_{i=1}^{nch-1} \left(\frac{n_{ch}-1}{i} \right)^2 \binom{n_{ch}}{i} p_+^{nch-i}\, p_-^{\,i}$$

Obviously, events with $n_+ = 0$ or $n_- = 0$ have to be excluded.
$A = 1 - p_+^{nch} - p_-^{nch}$ constant of normalization.

For other centrality measures, the variation of v(R) will be more complicated, and cannot be calculated analytically.

Modelling a fluctuation

Goal: Produce a fluctuation that does not change the mean or variance of the final inclusive distribution.

- We consider two models of this type:
  - Fluctuation Model A: *The inclusive distributions of the two event classes have the same mean, but different variance.*
  - Fluctuation Model B: *The inclusive distributions of the two event classes have the same variance, but different means.*
- After applying the constraints for each model, two event classes are defined with differing inverse slope parameters.

Define $\Delta T = T_{class\ 1} - T_{class\ 2} > 0$

Mean p_t fluctuation Sensitivity: Experimental Comparison, Model B