Global Observables and Identified Hadrons in the PHENIX Experiment

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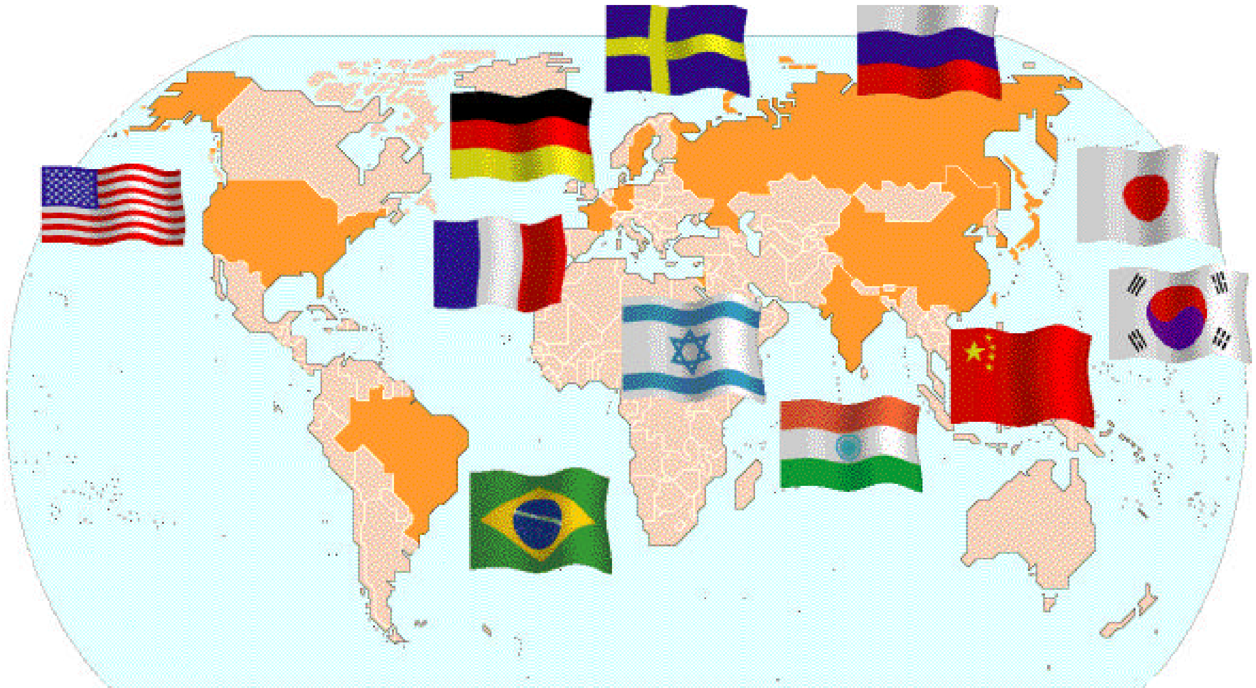
for the PHENIX Collaboration

PHENIX



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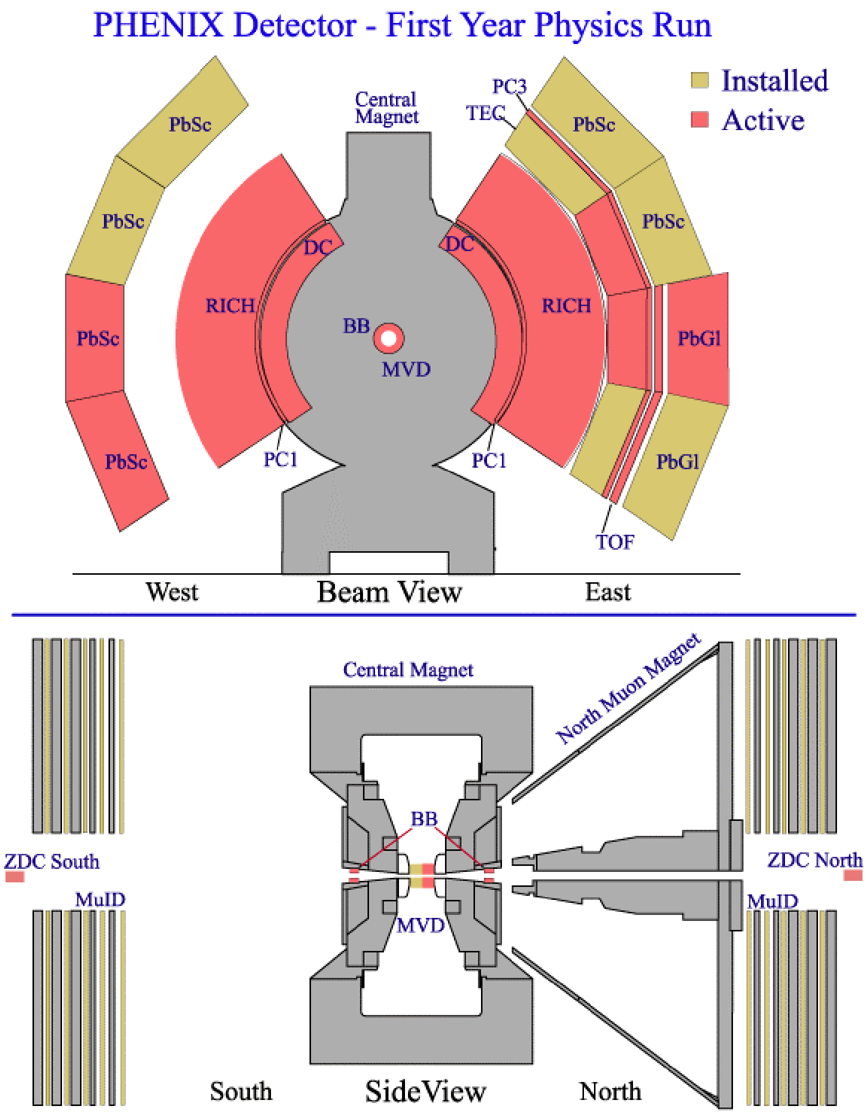
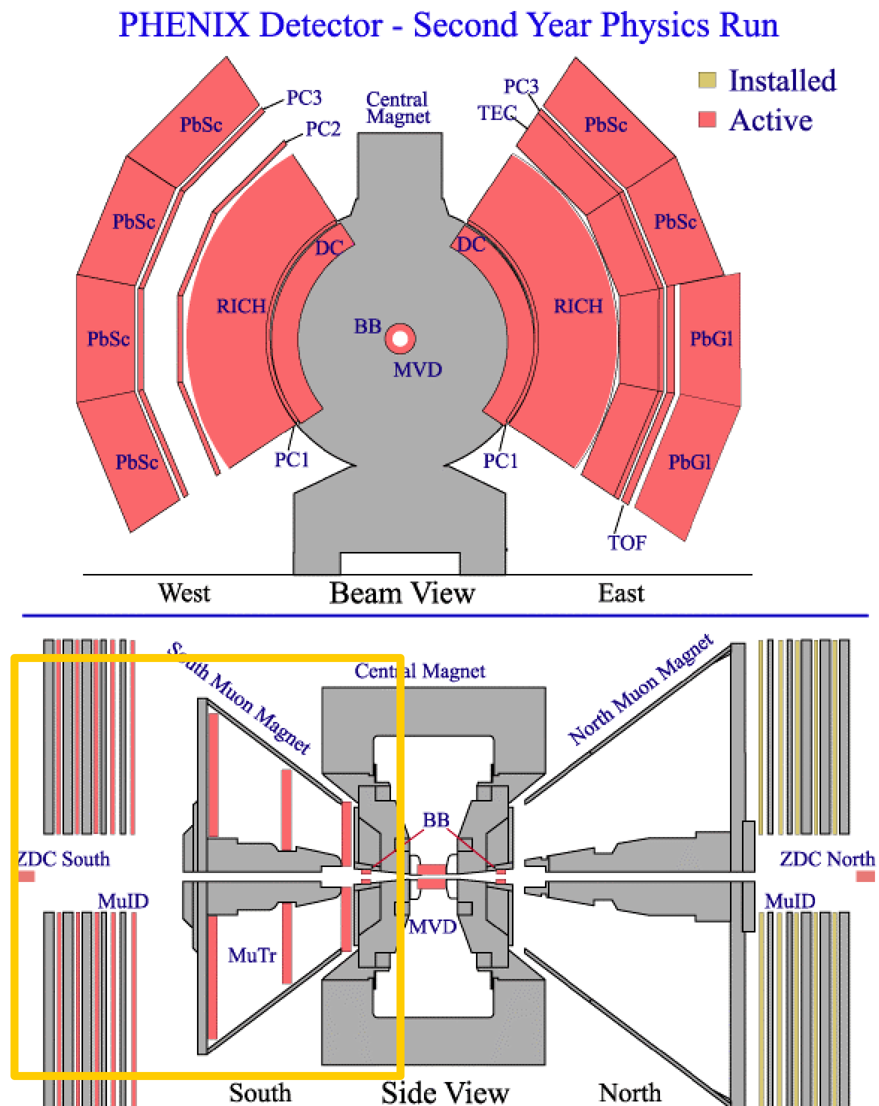
Outline

- Global variables:
  - Mean Multiplicity (previous talk by David Silvermyr)
  - Mean E_T
  - Elliptic flow
  - P_T, E_T fluctuations
  - charge fluctuations
- Some particle ratios
- Two pion correlations
- Some consistency checks

PHENIX detector, years 1 and 2





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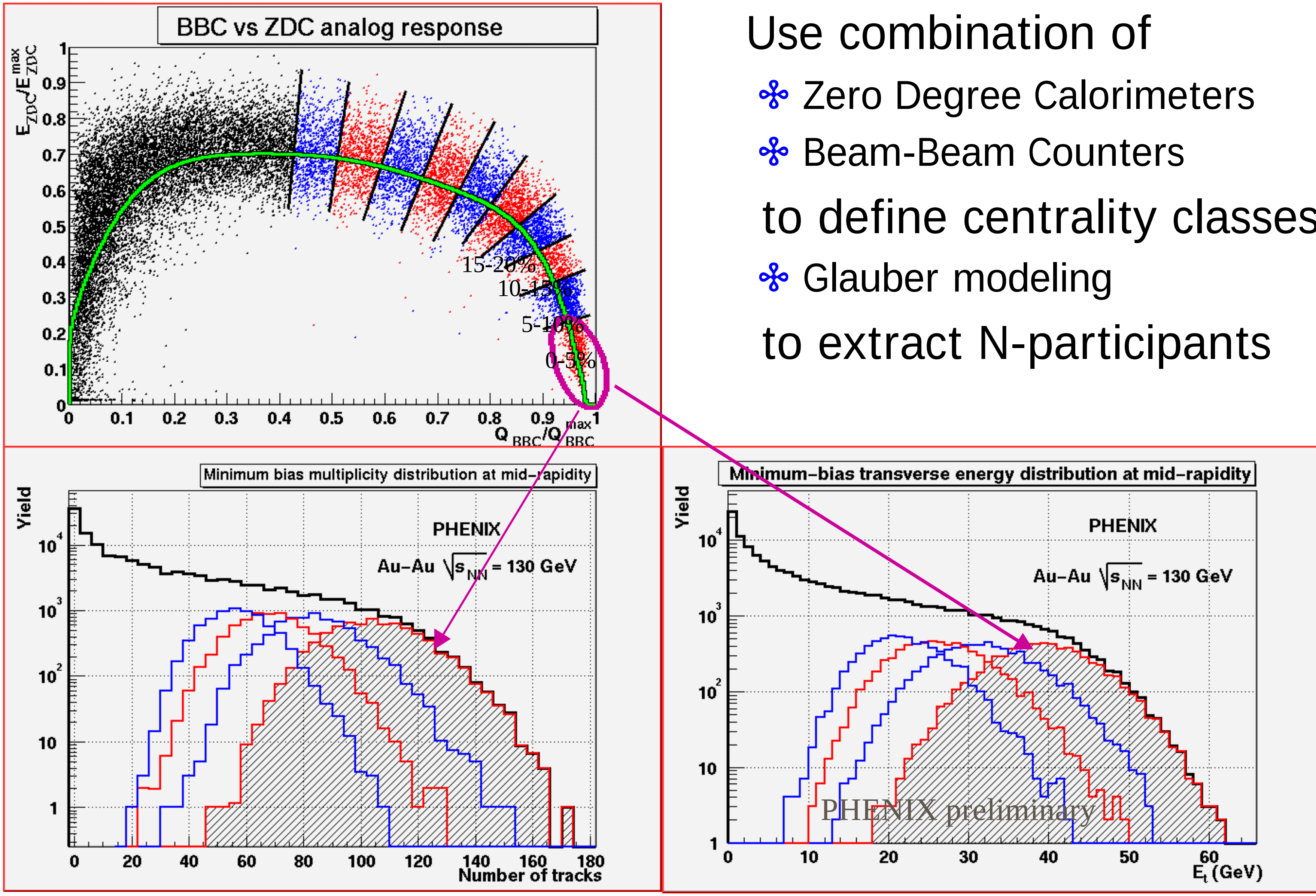
Determining N(participants)



Use combination of

- Zero Degree Calorimeters
- Beam-Beam Counters

to define centrality classes

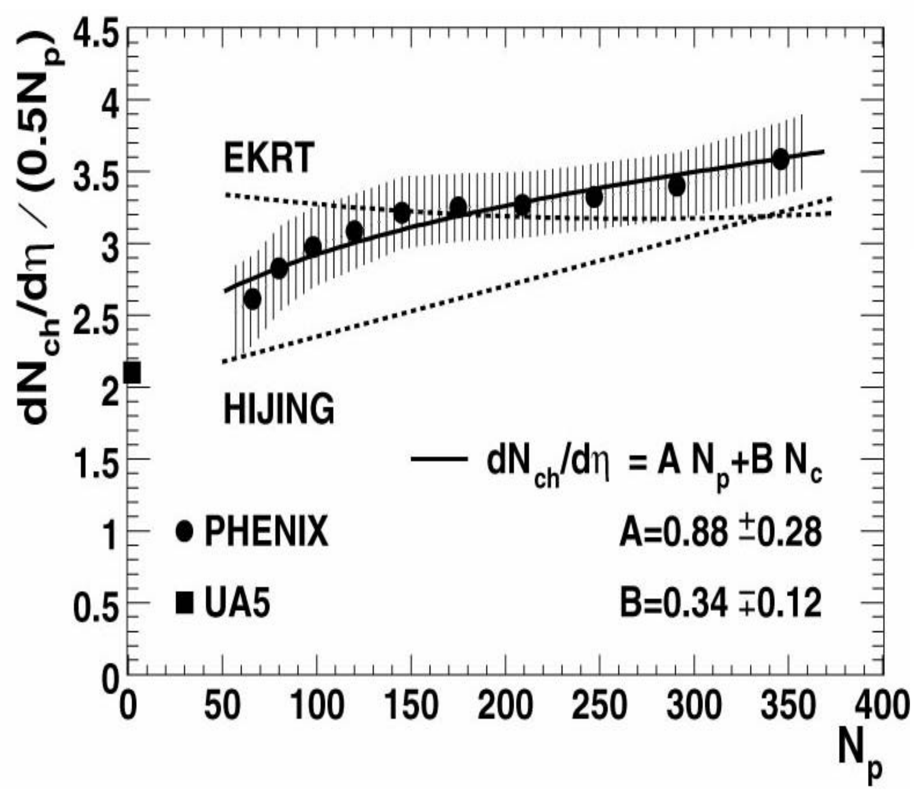
- Glauber modeling

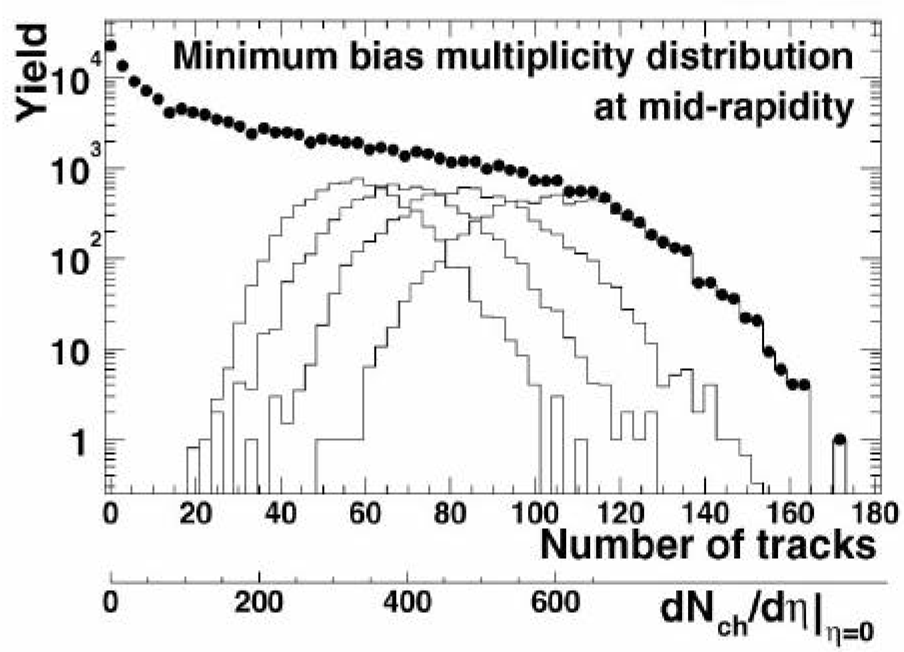
to extract N-participants

Multiplicity distribution @ 130 GeV

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

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





Assume:

Hard: scales with Ncollisions

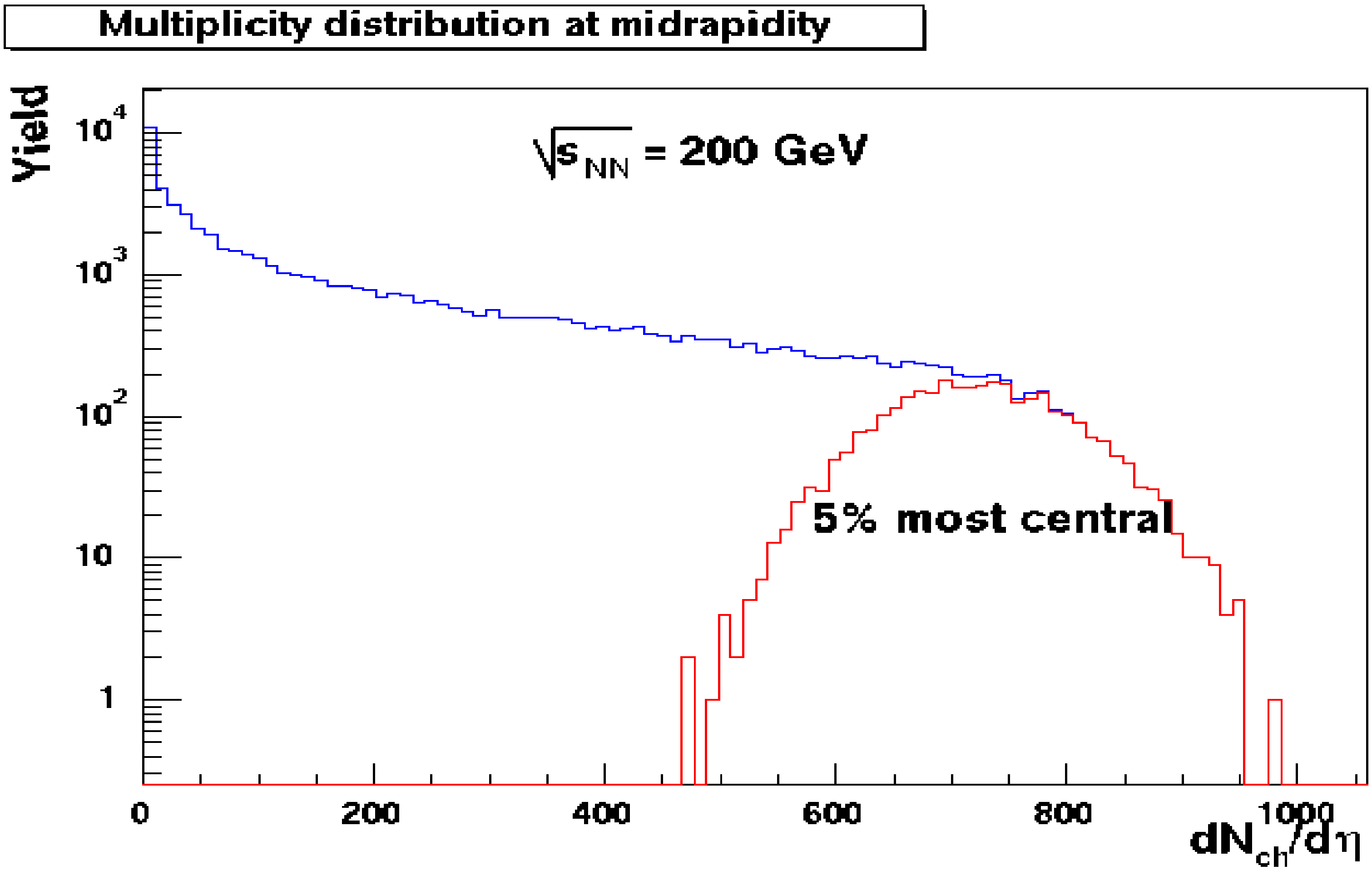
Soft: scales with Nparticipants

Conclude:

Hard collisions are important

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.



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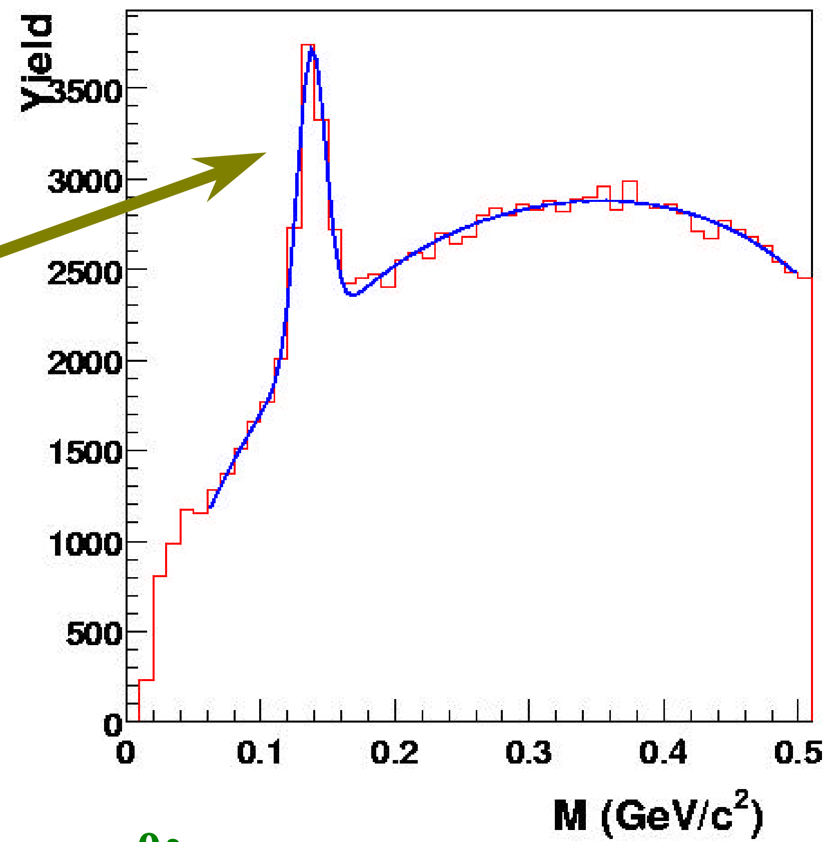
Transverse Energy

Measured with EM calorimeter

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

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

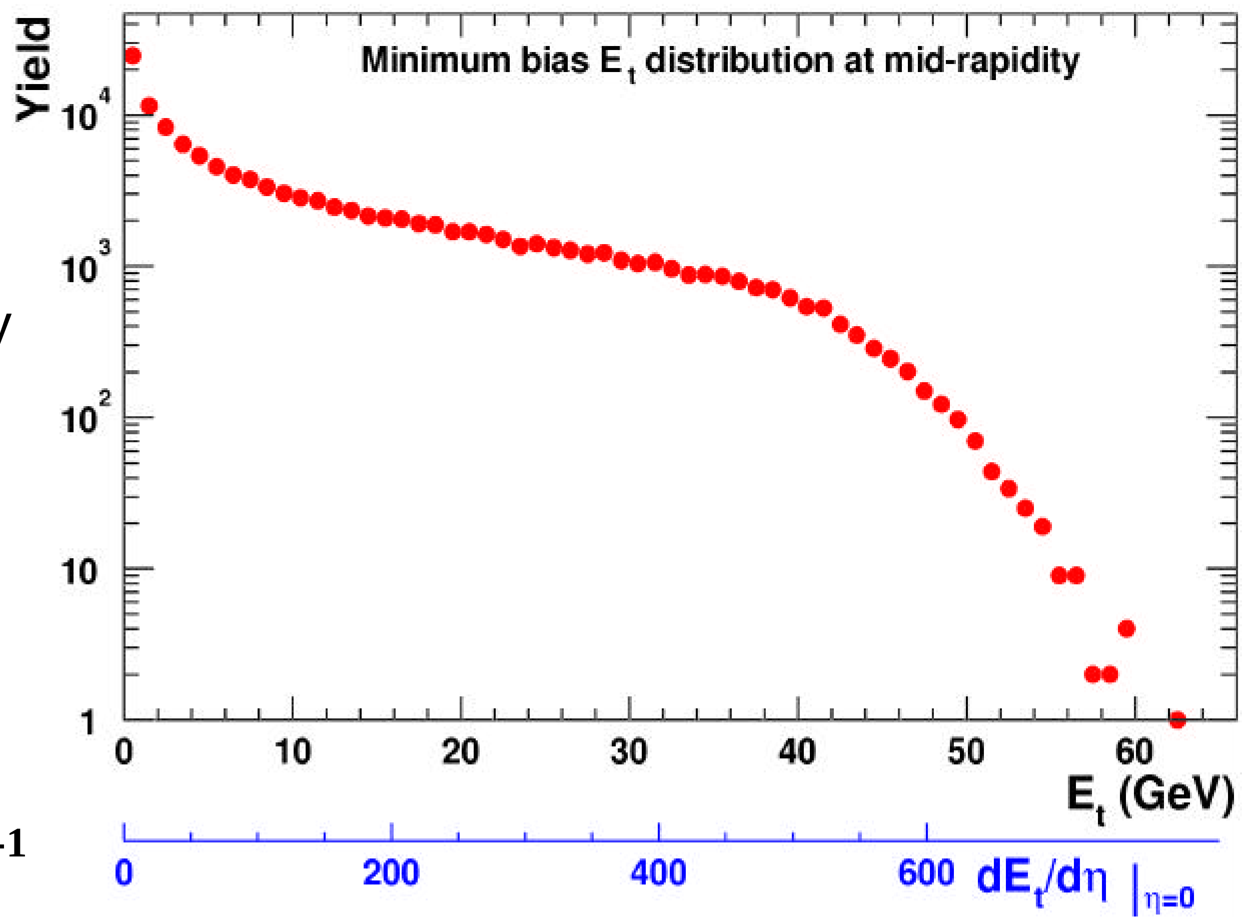


π^0's

$p_T > 2$ GeV, asym<0.8

Transverse Energy Distribution

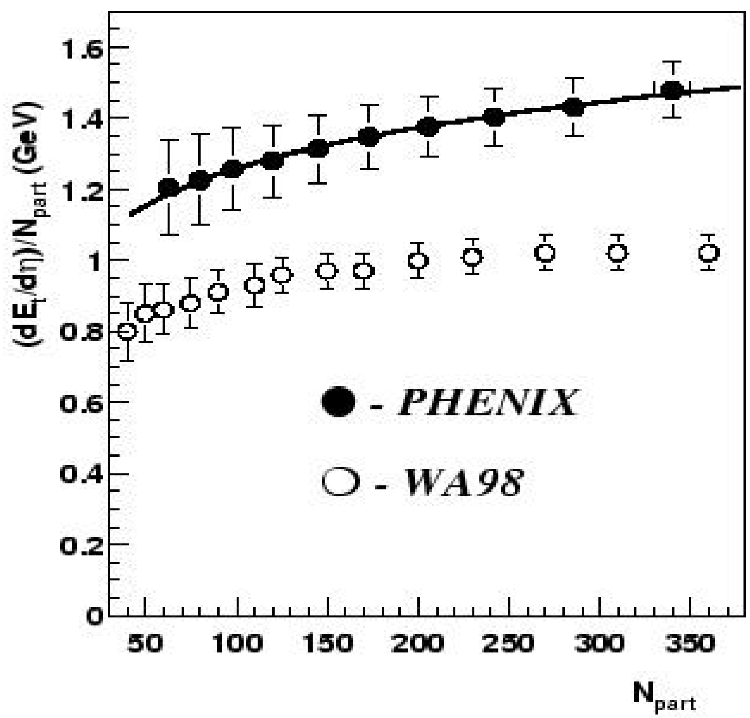
- Measured for
  - $|\eta| < 0.35$
  - $\Delta\phi = 45^o$
- Studied versus
  - Charged multiplicity
  - N participants



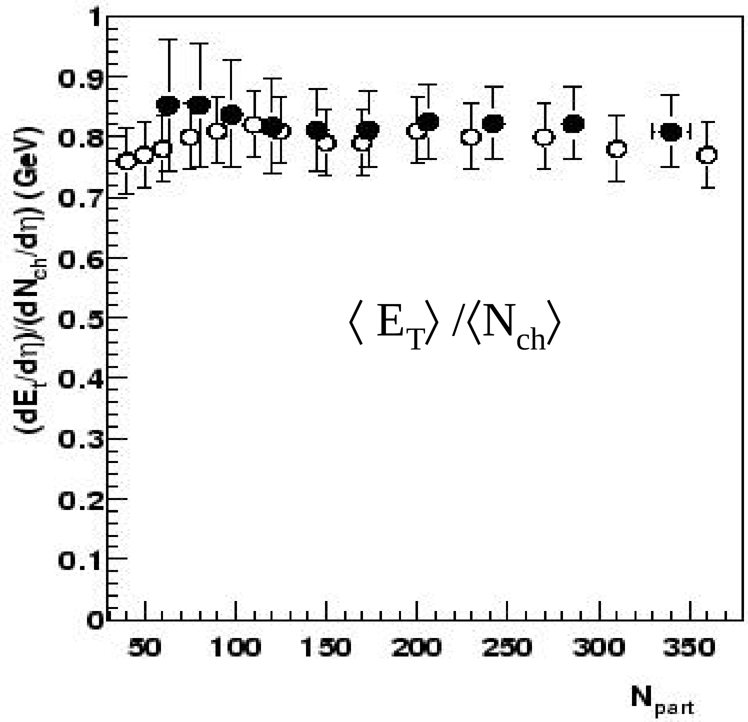
Phys.Rev.Lett.87(2001)052301-1

E_T vs. Nparticipants

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



(PHENIX excludes baryon mass, WA98 includes baryon mass)



PRL 87, 52301 (2001)

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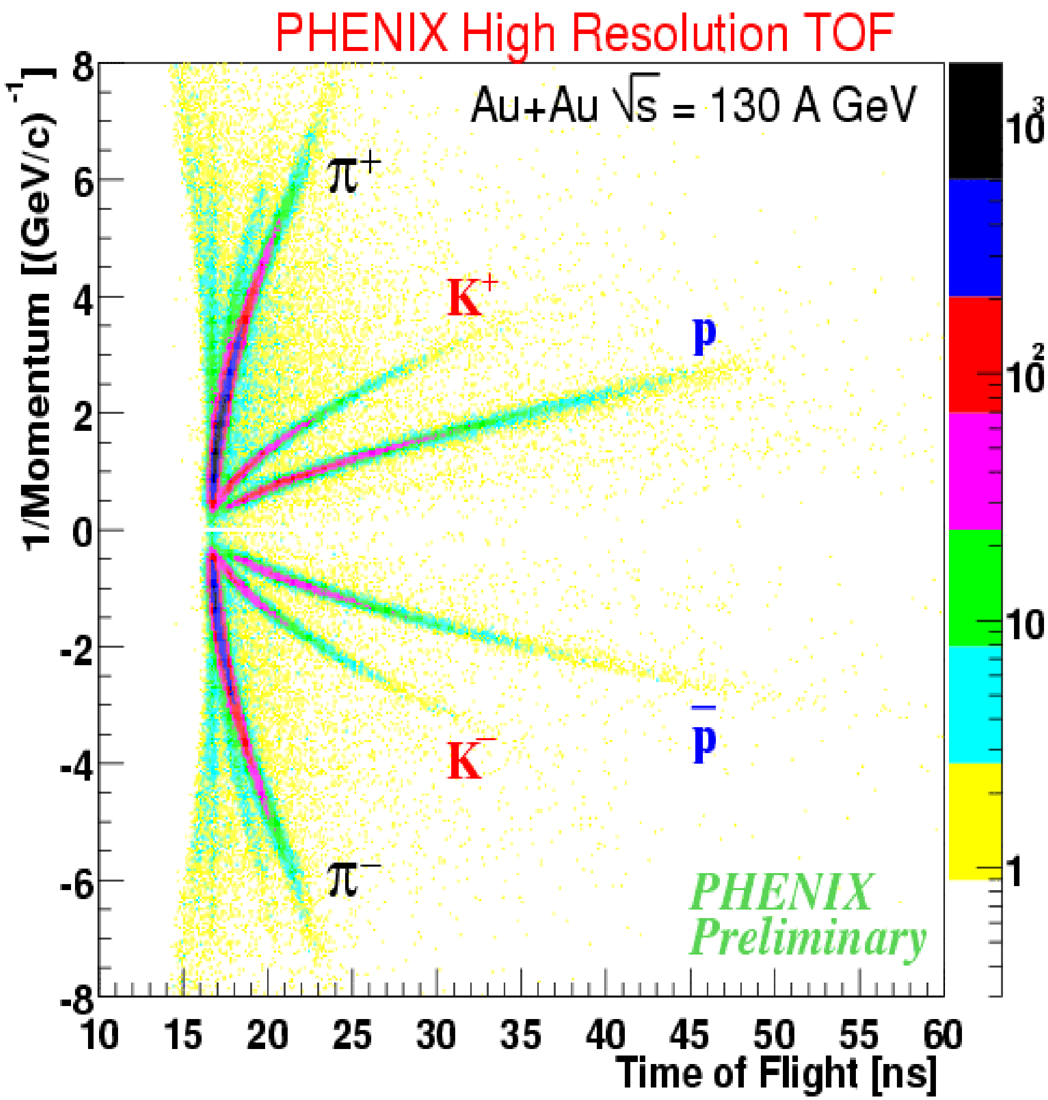
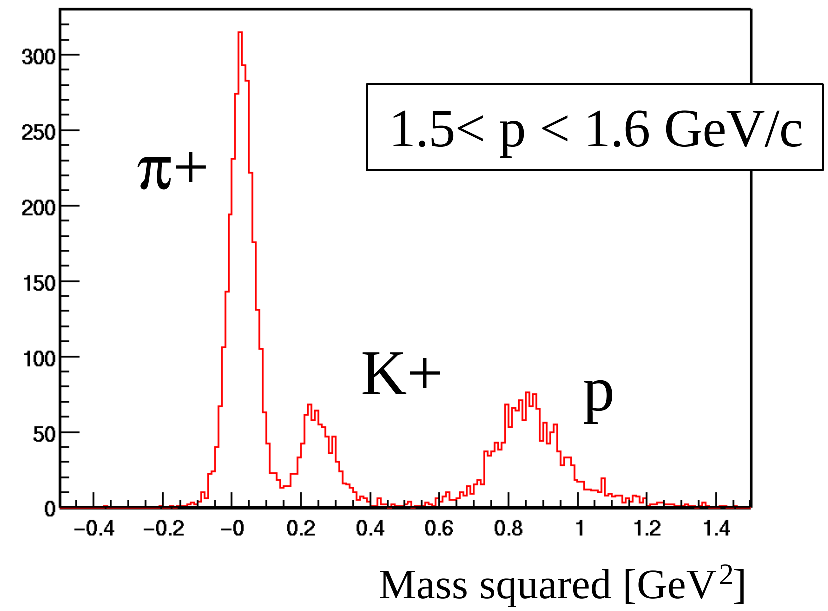
Particle identification via TOF





π/K separation < 1.6 GeV/c
Proton separation < 3.5 GeV/c

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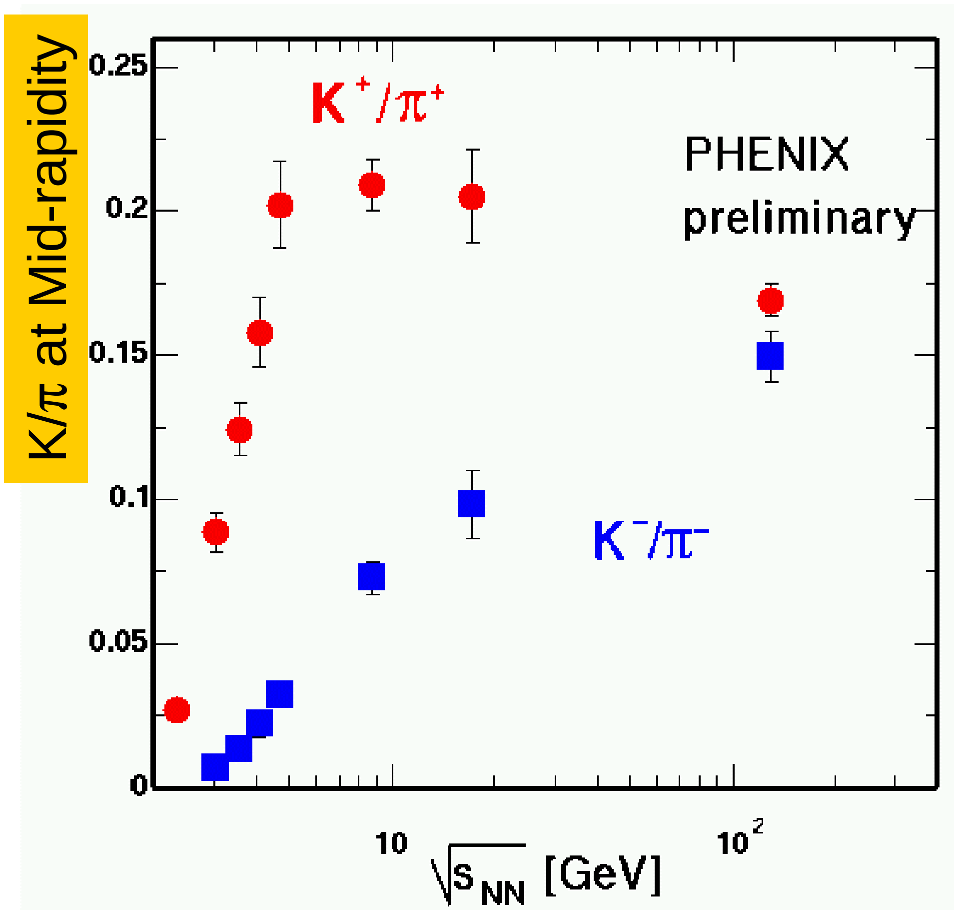
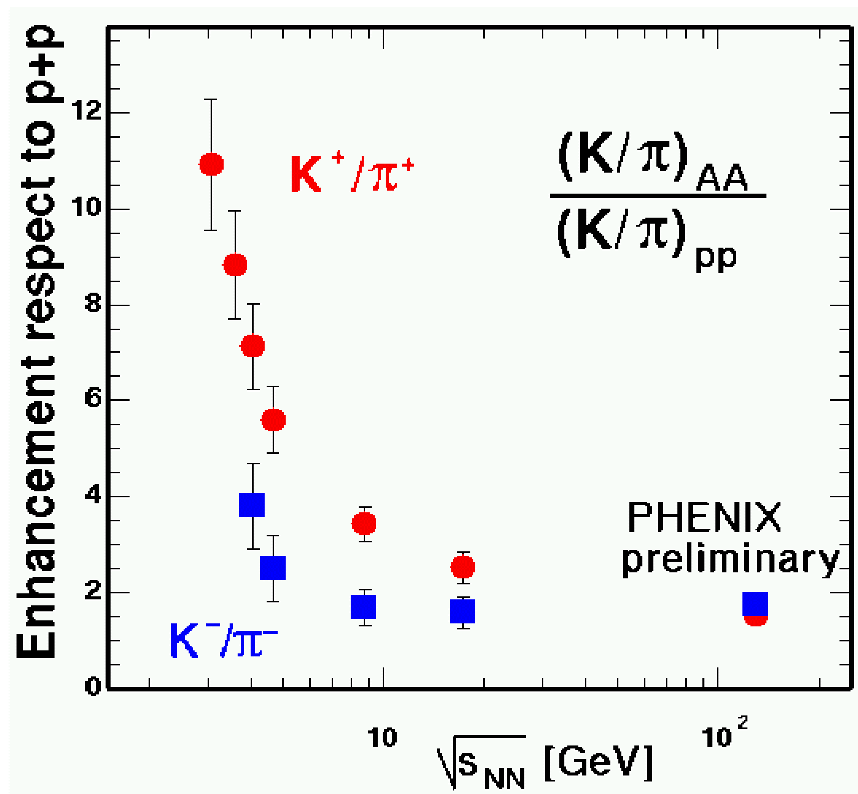
K/π ratio in central collisions vs $\sqrt{s_{NN}}$



- Strangeness enhancement with respect to p+p collisions



- **K+/p+ : Slightly decreases from top SPS energy.**
- **K-/p- : monotonically increases from AGS/SPS**

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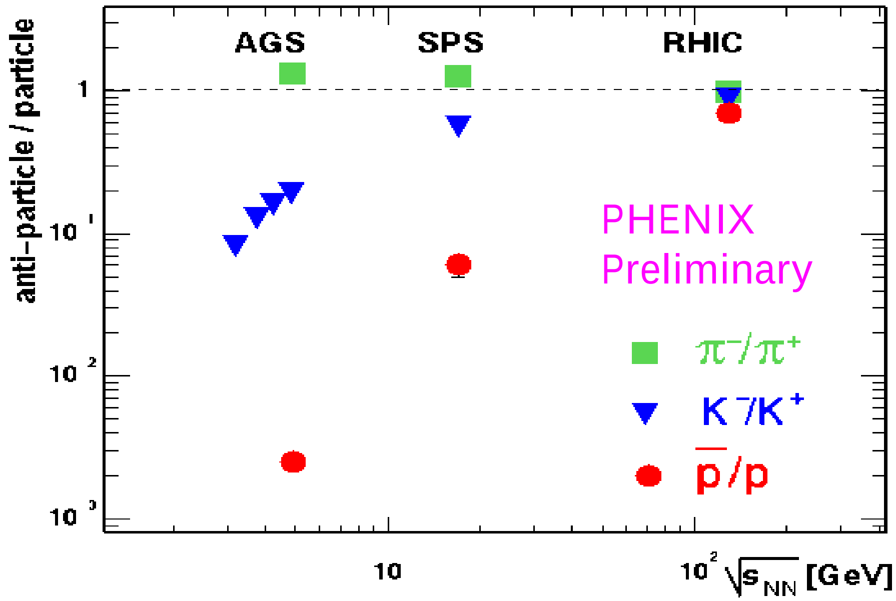
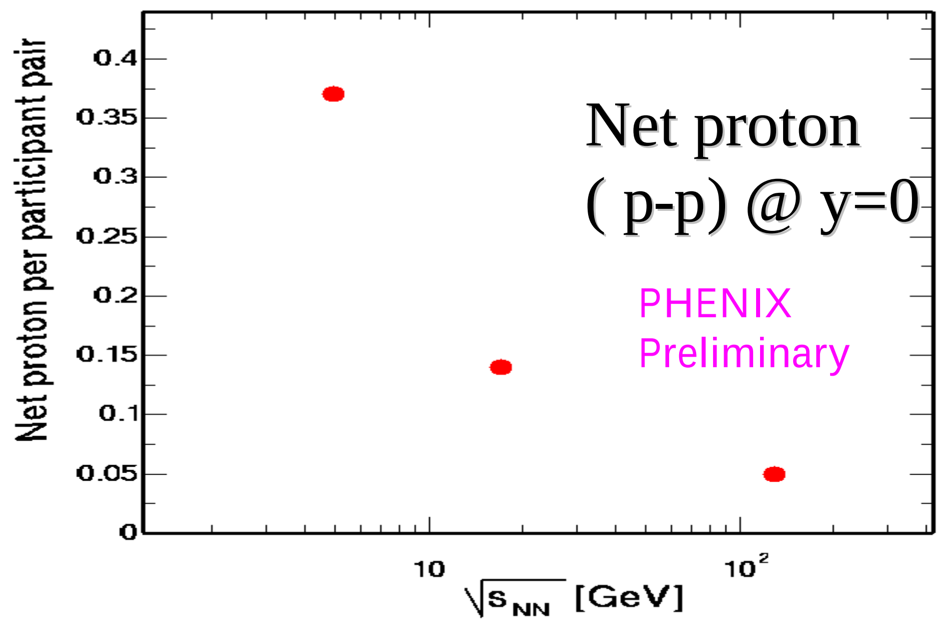
Collision energy dependence

- p-/p+, K-/K+ and pbar/p vs. collision energy.
  - anti-particle/particle ratios are dramatically increasing from SPS and AGS energies and approaching unity.



- (p-p)/(Npart pair) is dramatically decreasing from AGS and SPS energy

  RHIC : factor 7 smaller than AGS energy.



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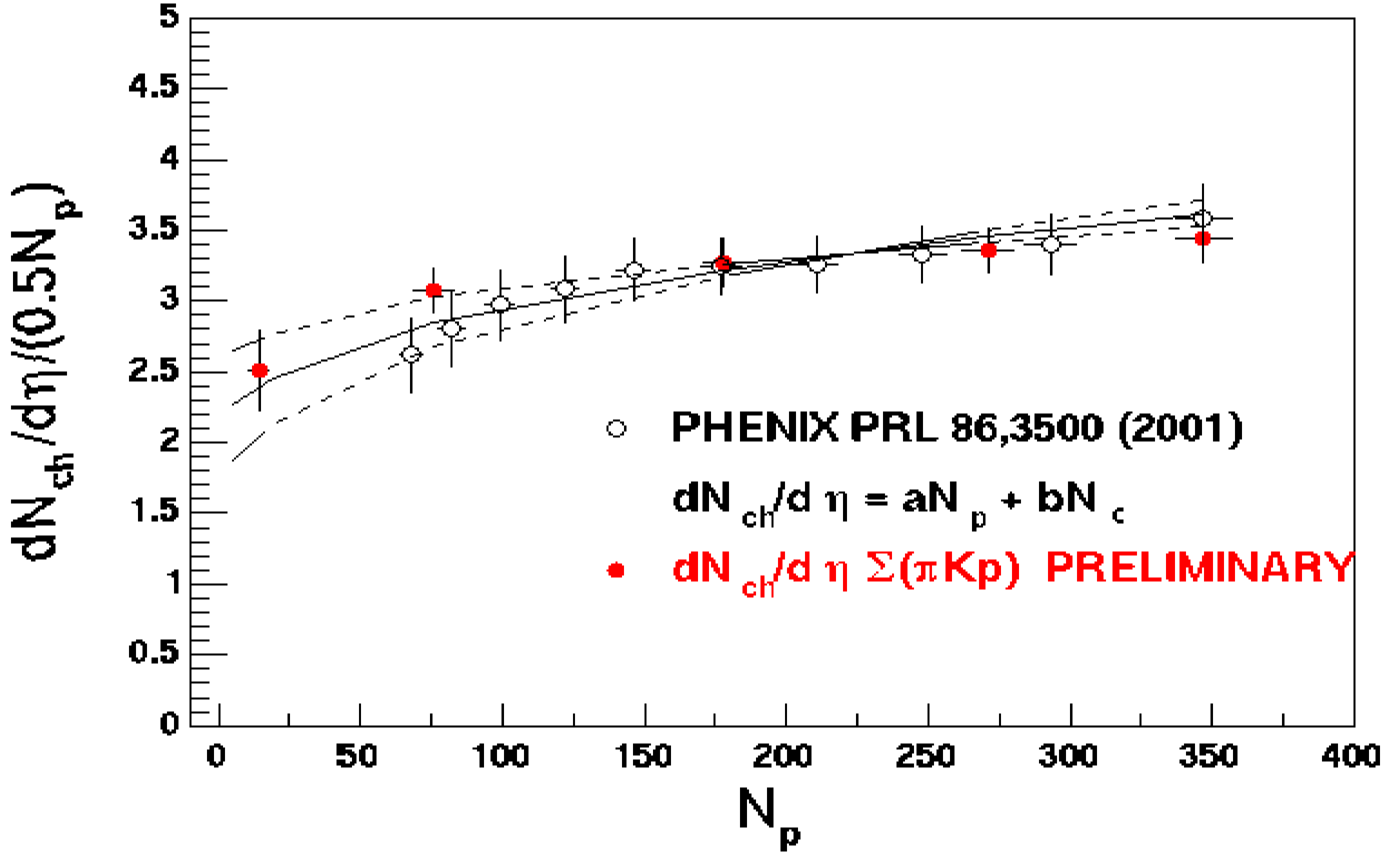
PHENIX internal consistency on yields



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

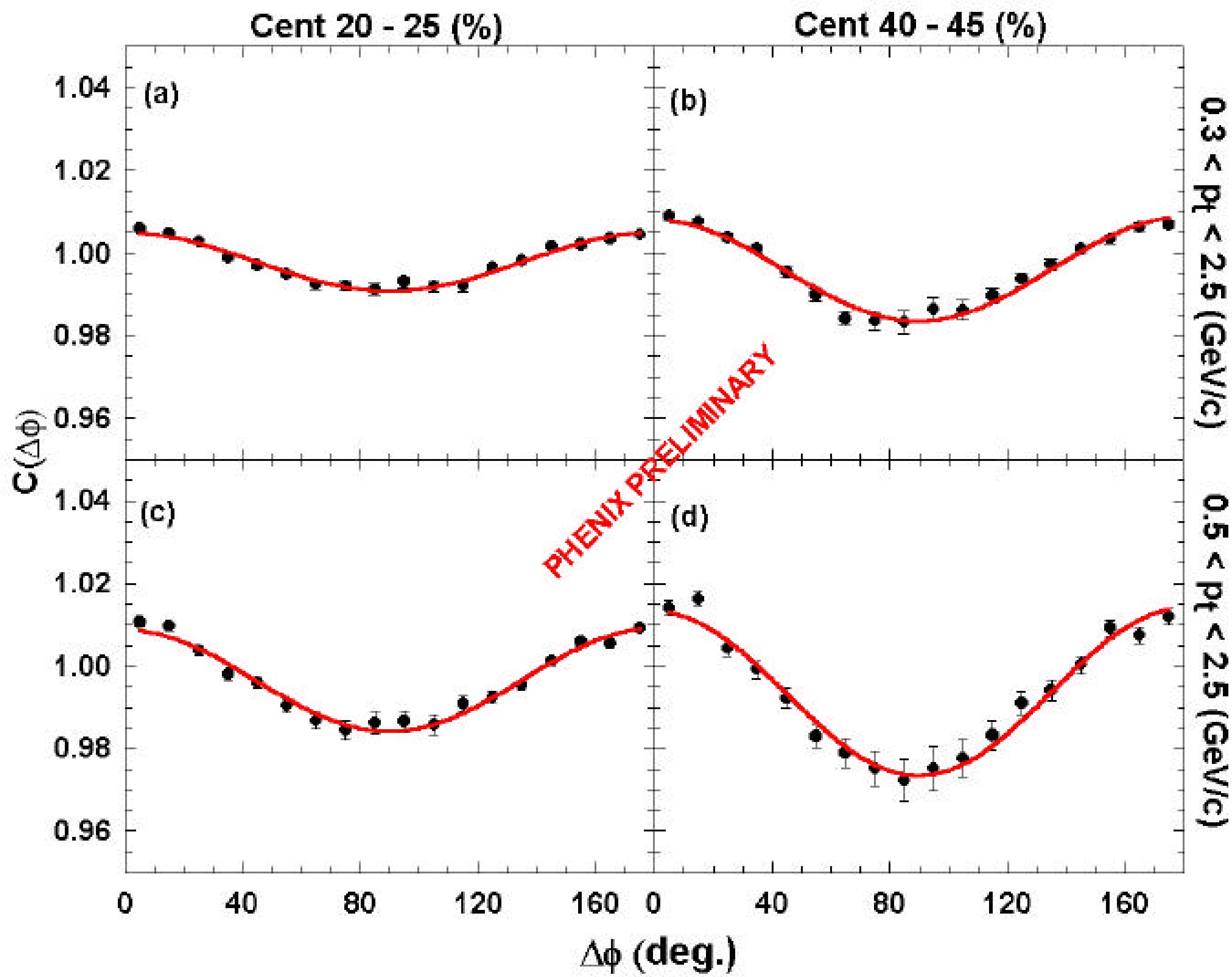
Elliptic Flow calculation

- Determine via a correlation function method $C(\Delta\phi) = R(\Delta\phi)/B(\Delta\phi)$

$$dN/d\phi \sim 1 + 2v_1\cos(\phi) + 2v_2\cos(2\phi)$$

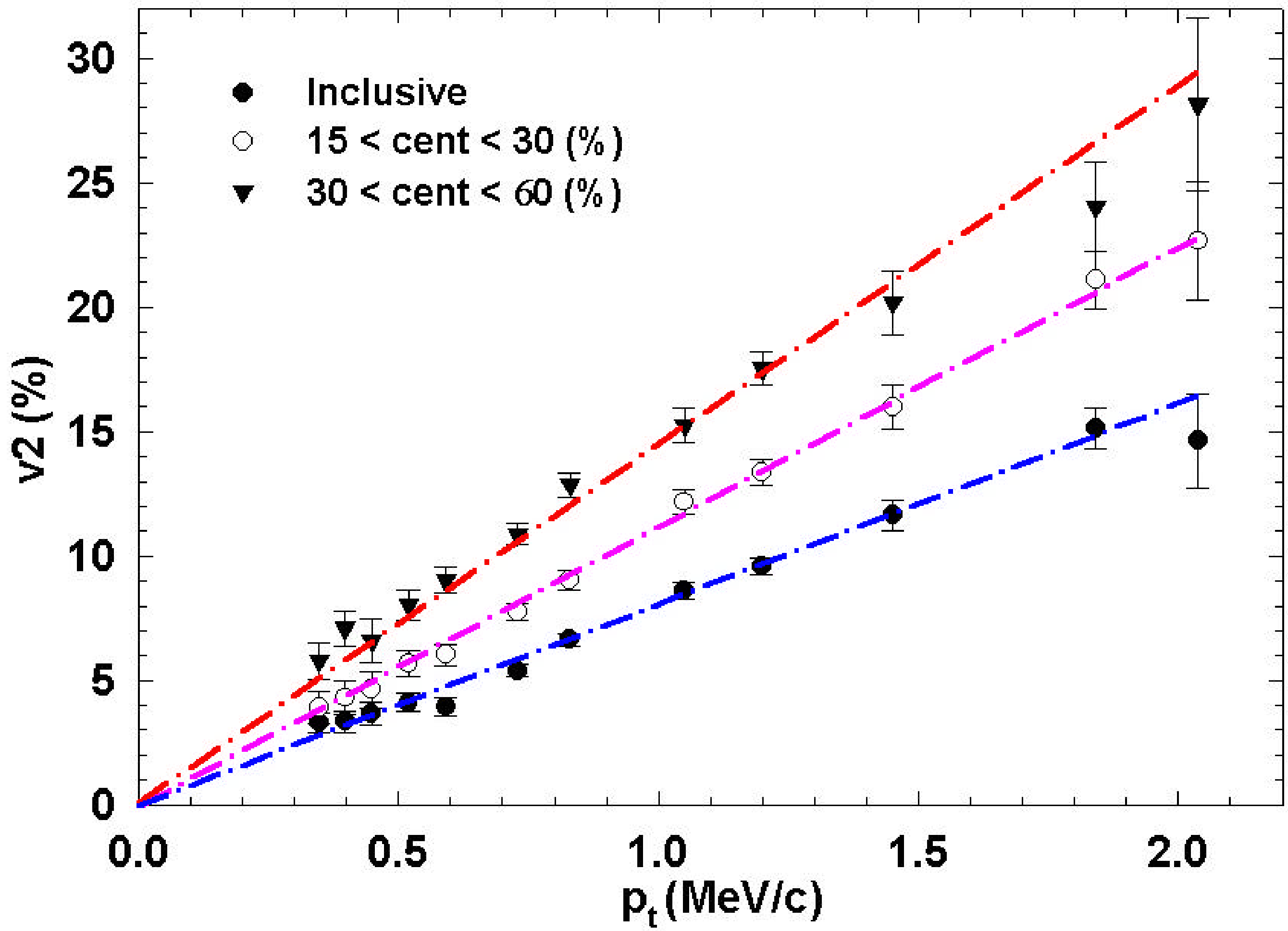
- Study versus
  - Centrality
  - p_T

Correlation Functions



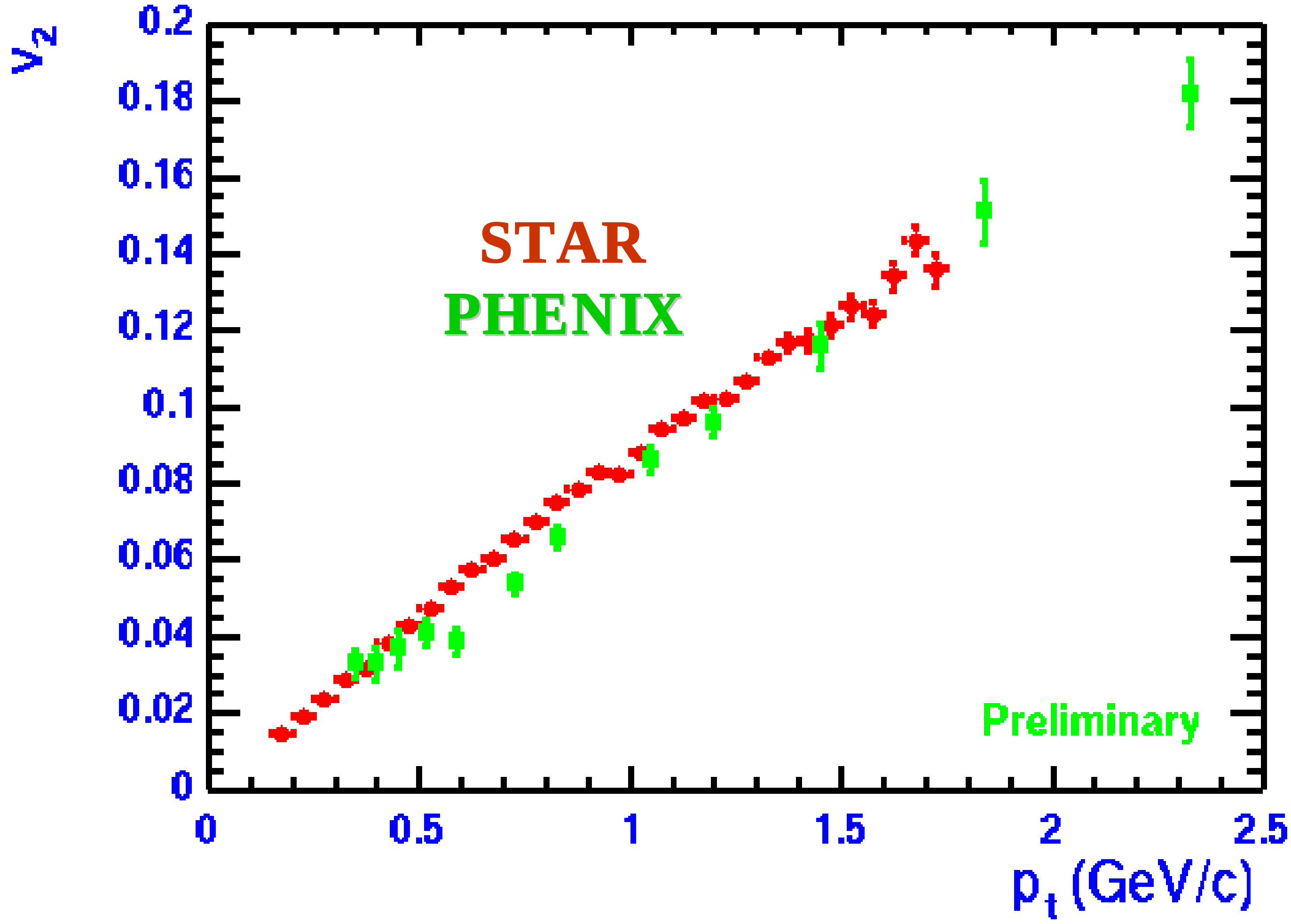
V_2 shows clear centrality and p_T dependence

V_2 vs. p_T (PHENIX preliminary)



Strong pt Dependence

V_2 from PHENIX and STAR



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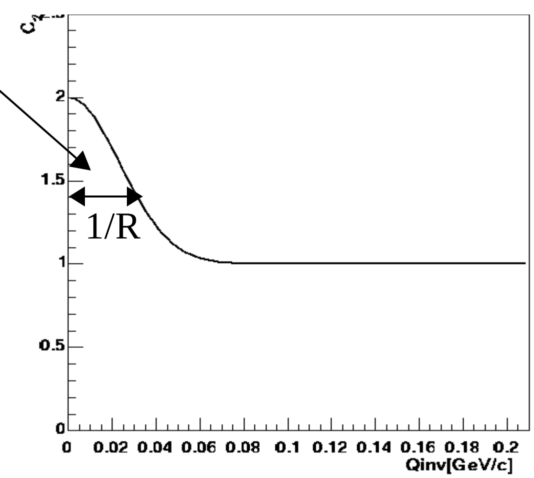
HBT measurements

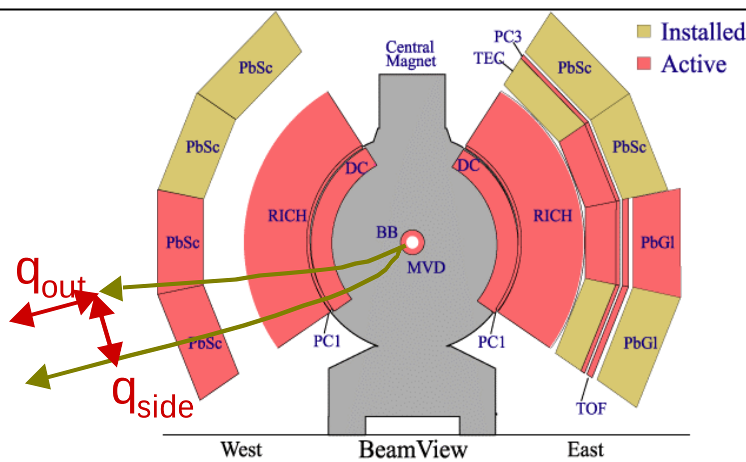
$$C_2 = P_2(p_1, p_2) / P(p_1)P(p_2)$$
$$= 1 + \lambda \exp\left(-q_{inv}^2 R_{inv}^2\right)$$
$$= 1 + \lambda \exp\left(-q_X^2 R_X^2 - q_Y^2 R_Y^2 - q_Z^2 R_Z^2 - q_t^2 \sigma_t\right)$$
$$= 1 + \lambda \exp\left(-q_{side}^2 R_{side}^2 - q_{out}^2 R_{out}^2 - q_{long}^2 R_{long}^2\right)$$

Assuming a source density is a Gaussian distribution

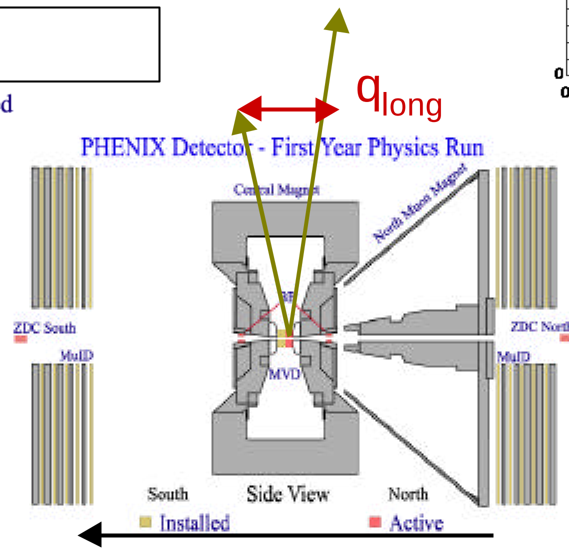
1D correlation function



Bertsch-Pratt parameterization scheme



⊗ Beam direction



Beam direction

If we use LCMS frame…

The duration time

$$\Delta\tau = \sqrt{R_{To}^2 - R_{TS}^2} / \beta$$

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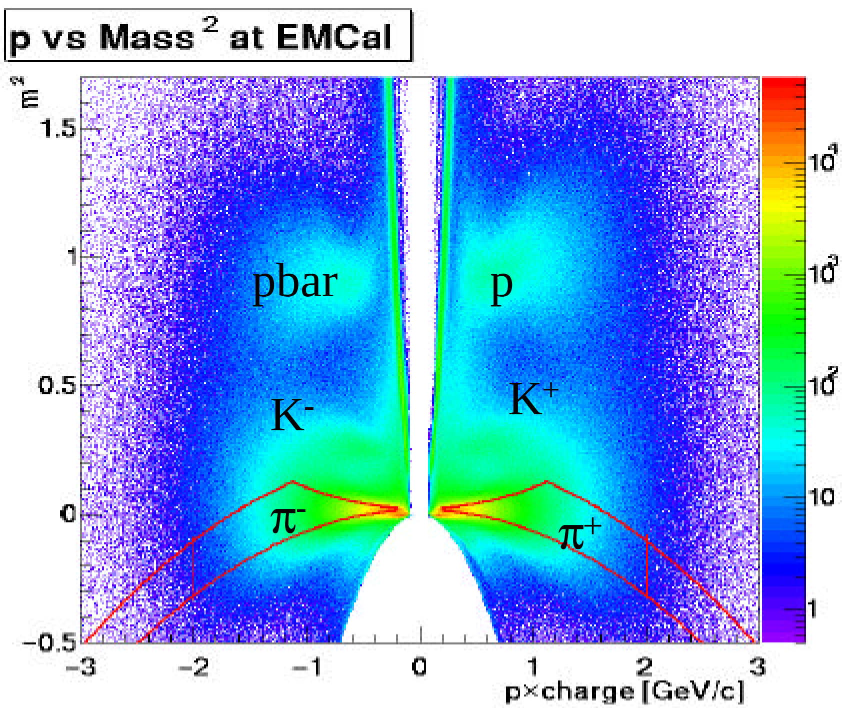
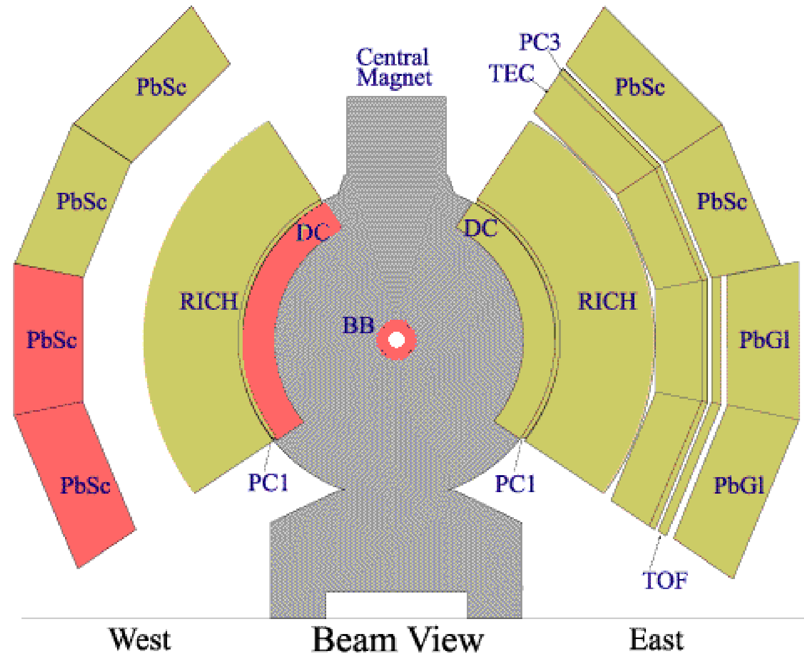
Particle Identification (EMCal TOF)

- BBC (Beam-Beam counter), ZDC
- DCH (Drift chamber), PC1(Pad chamber)
- EMCAL (Electro-magnetic calorimeter)
- EMC Time-of-flight σ_T~800psec





- Z-vertex < 30cm
- centrality in the top 30%
- $0.2 < p_T < 1.0$ GeV/c

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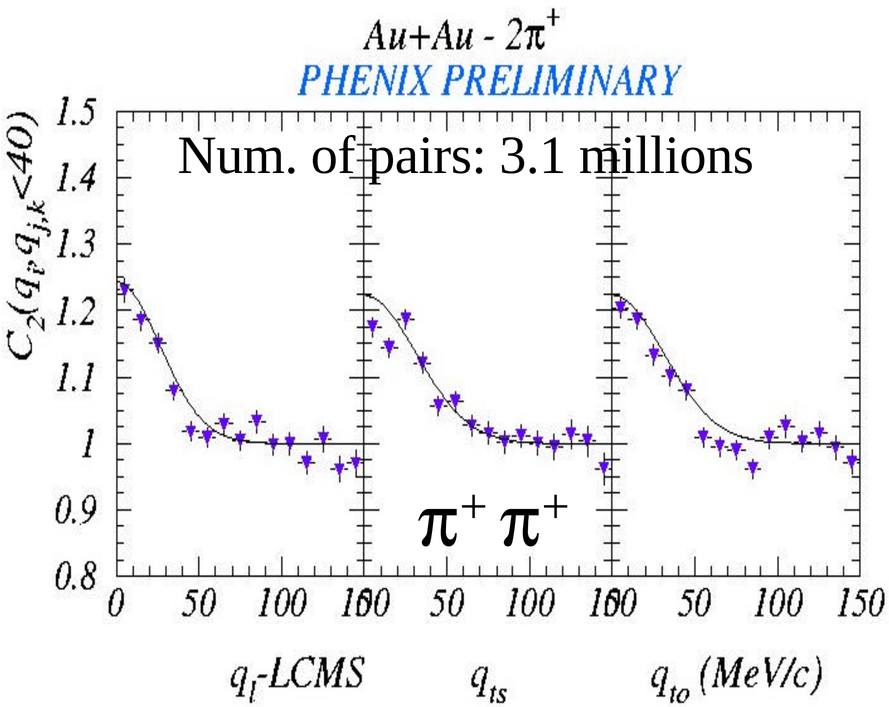
3-D correlation result

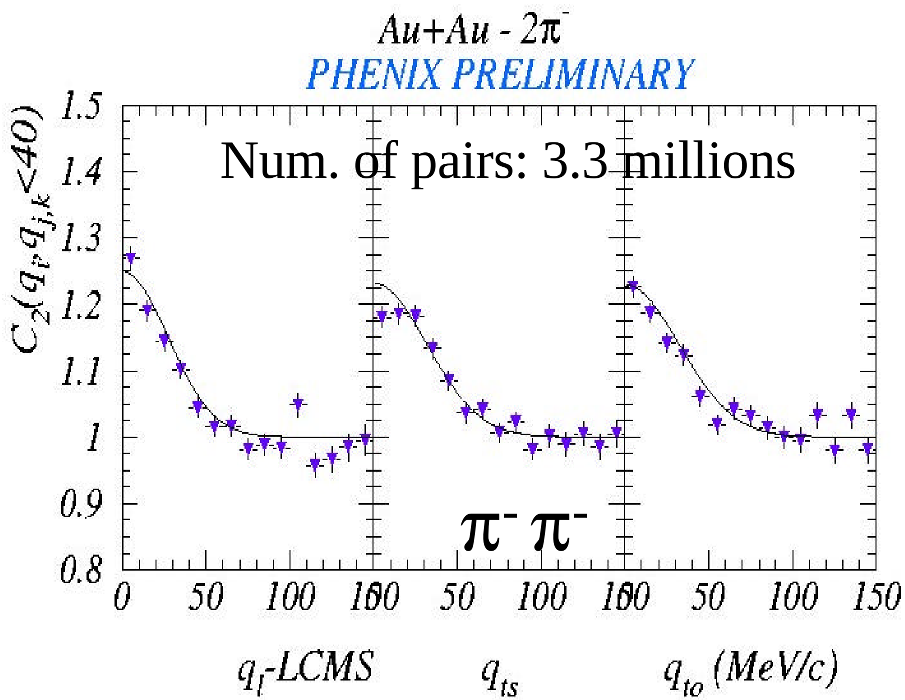


$\lambda = 0.395 \pm 0.026$

$R_{side} = 4.42 \pm 0.22$

$R_{out} = 4.45 \pm 0.22$ [fm]

$R_{long} = 5.28 \pm 0.32$



$\lambda = 0.399 \pm 0.026$

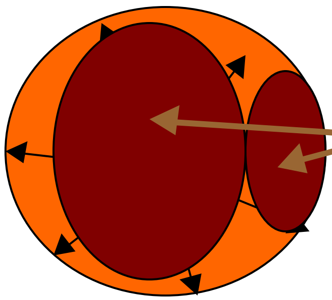
$R_{side} = 4.41 \pm 0.22$

$R_{out} = 4.30 \pm 0.24$ [fm]

$R_{long} = 5.13 \pm 0.26$

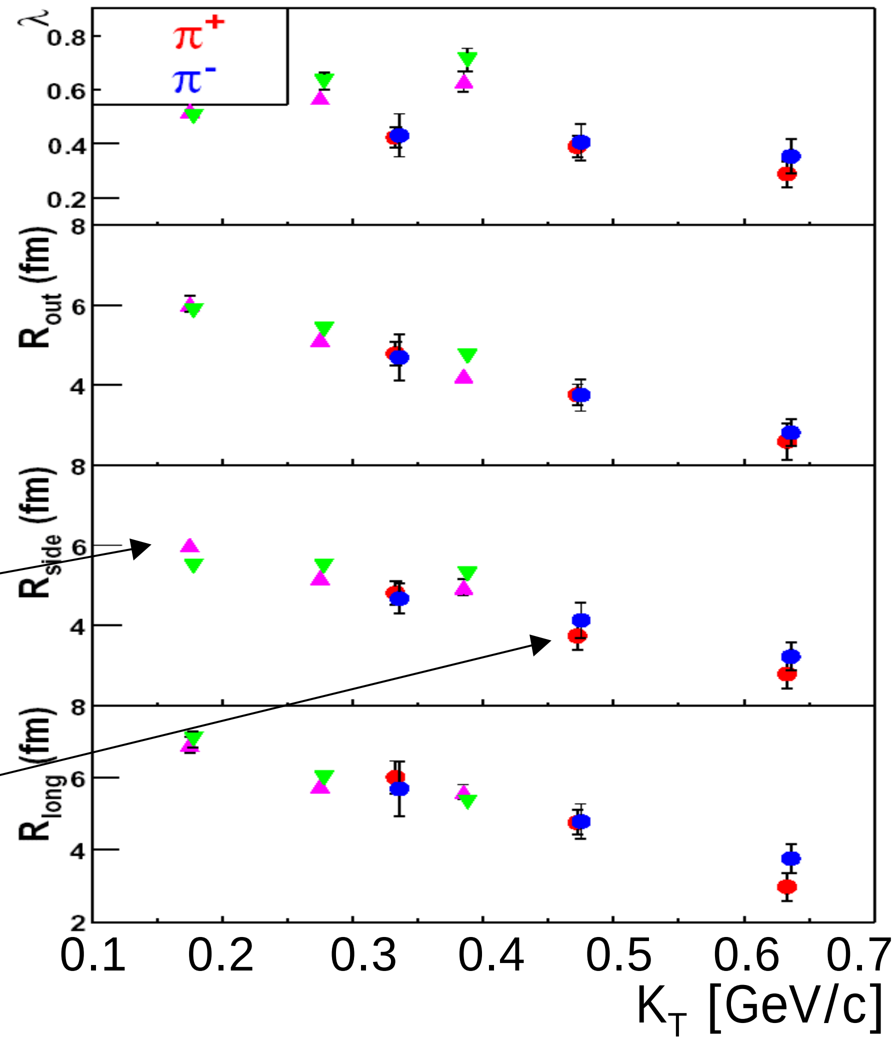
(Errors are statistical only)

K_T dependence of radius parameters



$$k_T = (p_{T1} + p_{T2})/2$$

We can see
"x-p correlation"
if there is collective
expansion of the source



STAR's result (▲ π^+ ▼ π^-)

PRL 87 982301(2001)

PHENIX's result (● π^+ , ● π^-)

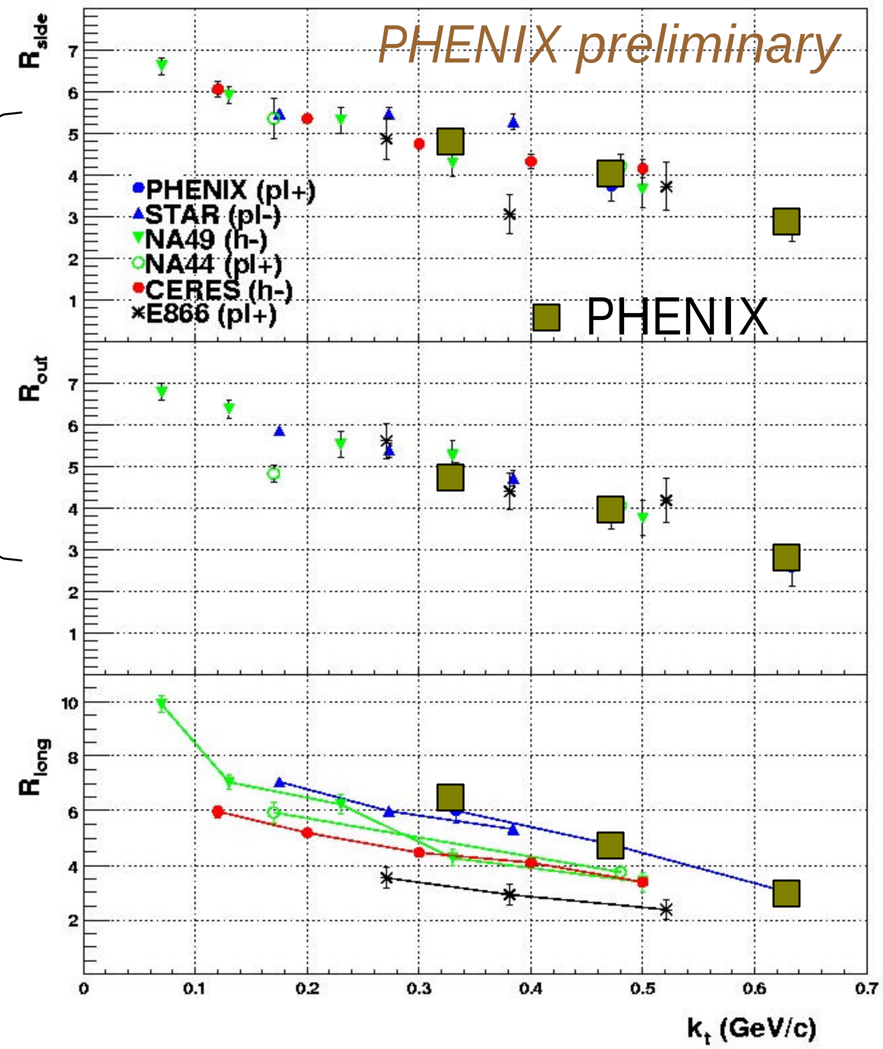
Comparison with other experiments

	$\sqrt{s_{NN}}$
PHENIX,STAR	130GeV
NA44,NA49,CERES	17.2GeV
AGS-E866	4.6GeV

Radii parameters depend on K_T

• Transverse radii (R_{side} and R_{out}) have very little dependence on beam energy

• Almost all energy dependence is in longitudinal radius (R_{long})



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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:

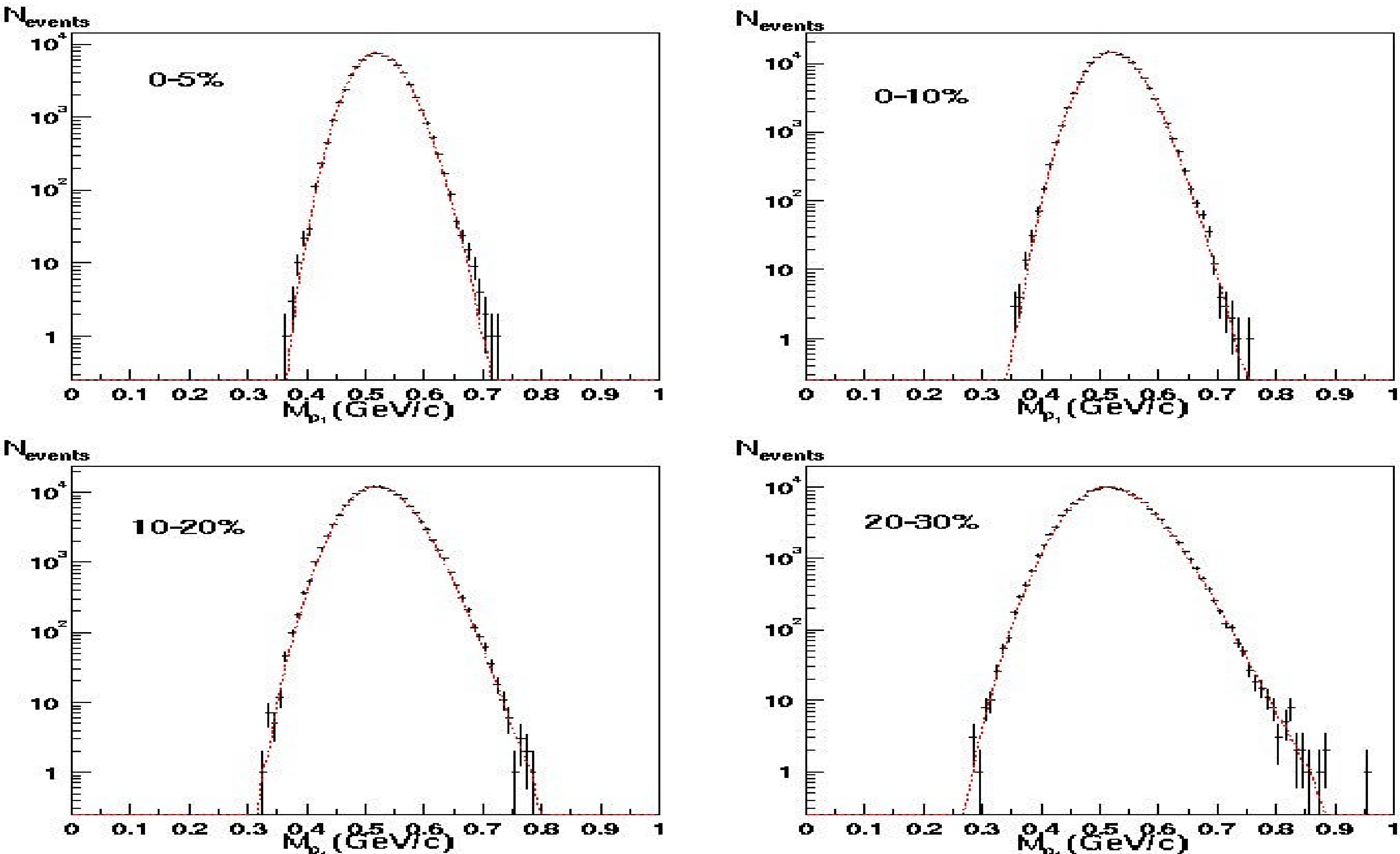
• Mixed event distributions are built from reconstructed tracks/clusters in real events.

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

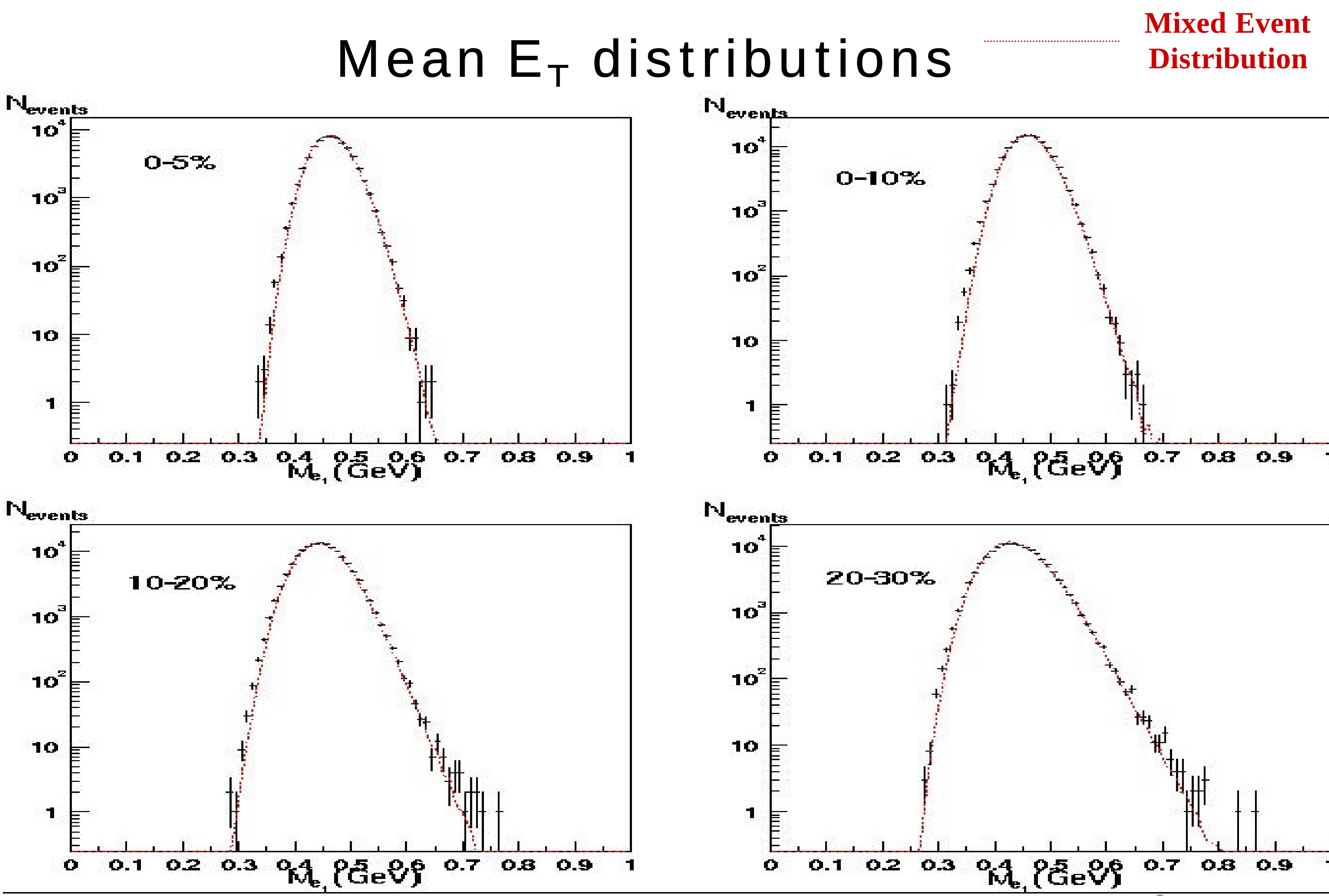
• *The number of tracks/clusters distribution, N_{pt} or N_{et}, in mixed events are sampled from the data N distribution.*

Mean p_T distributions

Mixed Event Distribution



Mean E_T distributions



Quantifying the fluctuations

Define the magnitude of a fluctuation, ω:

$$\omega = (\langle X^2\rangle - \langle X\rangle^2)^{1/2}/\langle X\rangle = \sigma/\mu$$

Define the fractional fluctuation difference from random, d:

$$d = \omega_{\delta ata} - \omega_{\ random}$$

Also commonly used is the variable, ϕ_{pt}:

$$\phi_{pT} = \mathrm{sqrt}(\langle N\rangle)(\sigma_{data} - \sigma_{random}) = d\mu\ \mathrm{sqrt}(\langle N\rangle)$$

Fluctuation Results

Fluctuation Quantities for the M_{p_t} analysis.

Centrality class	ω (%)	d (%)	ϕ_{p_t} (MeV/c)
0 - 5 %	7.37 ± 0.10	0.14 ± 0.15	5.65 ± 6.02
0 - 10 %	7.85 ± 0.13	0.16 ± 0.19	6.03 ± 7.28
10 - 20 %	9.52 ± 0.14	0.19 ± 0.21	6.11 ± 6.63
20 - 30 %	11.7 ± 0.21	0.21 ± 0.35	5.47 ± 9.16

Fluctuation Quantities for the M_{e_t} analysis.

Centrality class	ω (%)	d (%)	ϕ_{e_t} (MeV/c)
0 - 5 %	7.32 ± 0.07	0.30 ± 0.09	11.5 ± 3.59
0 - 10 %	7.84 ± 0.08	0.37 ± 0.12	13.6 ± 4.23
10 - 20 %	9.58 ± 0.17	0.38 ± 0.20	11.1 ± 5.75
20 - 30 %	11.8 ± 0.26	0.40 ± 0.32	9.28 ± 7.34

Net charge fluctuations: QGP signal?

(S. Jeon & V. Koch PRL 85(2000)2076)

(M. Asakawa, U. Heinz, B. Müller, PRL 85(2000)2072)

Expected fluctuations in net charge, Q (= N_+ - N_-) :

Hadron gas : $$\frac{\langle Q^2 \rangle}{\langle N_{ch} \rangle} = 1$$

(A reduction is expected due to global charge conservation and resonances, depending on the acceptance.)

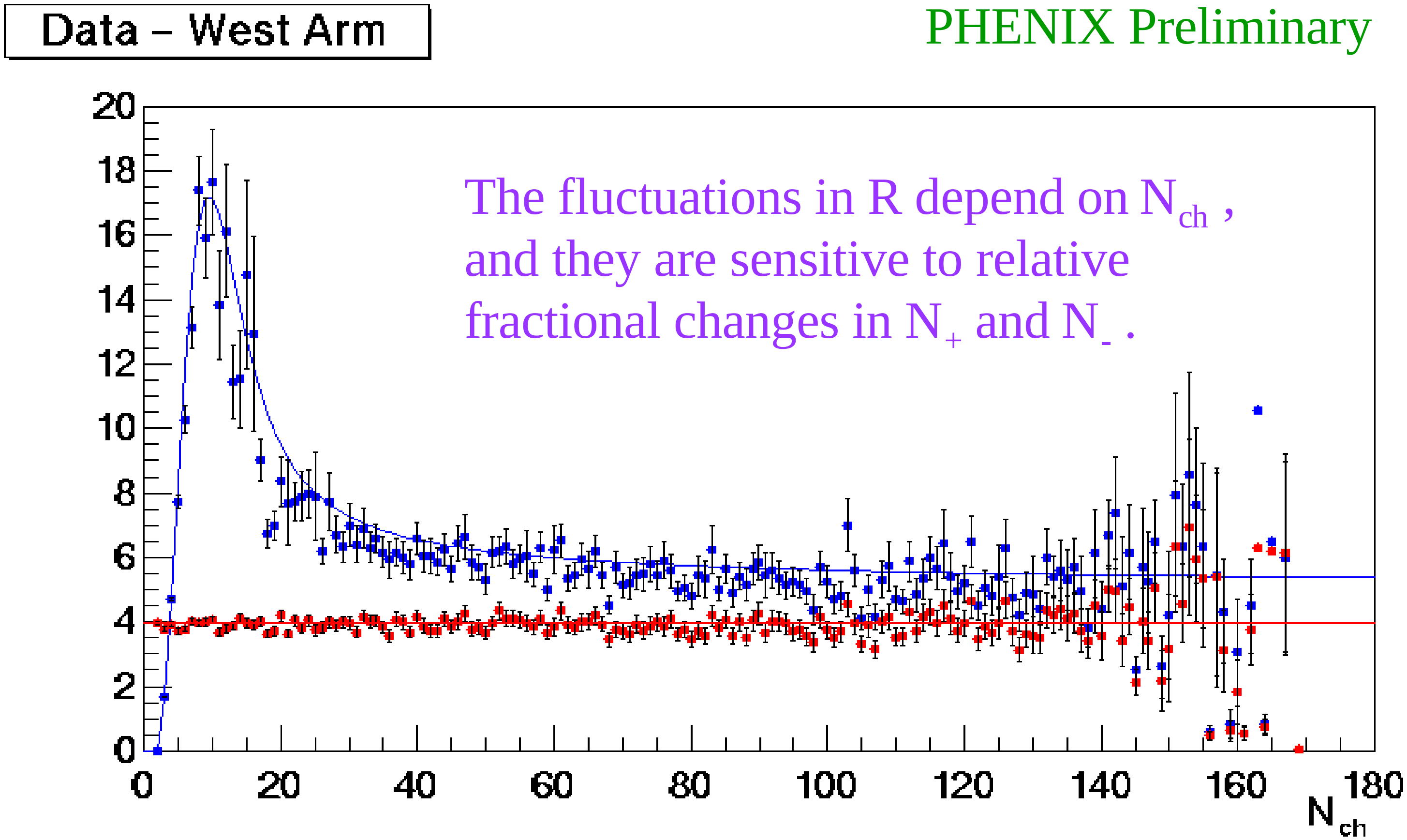
QGP : $$\frac{\langle Q^2 \rangle}{\langle N_{ch} \rangle} \approx 0.20 - 0.25$$ (S. Jeon & V. Koch PRL 85(2000)2076)

The use of $R = N_+ / N_-$ is proposed.

Asymptotically, for large N_{ch} :

$$\langle N_{ch} \rangle \langle R^2 - \langle R \rangle^2 \rangle \approx 4 \frac{\langle Q^2 \rangle}{\langle N_{ch} \rangle}$$

PHENIX Charge Fluctuations



$(<R^2> - <R>^2) * N_{ch}$ $\qquad$ $(R = N_+/N_-)$

$4 (<Q^2> - <Q>^2) / N_{ch}$ $\qquad$ $(Q = N_+ - N_-)$

Summary (1)

- dN/dη increases steadily with Nparticipants
- E_T increase is similar to dN/dη increase
- Constant Et/(charged particle) ~ 0.8 implies increase in energy density from AGS, SPS is from increased particle production
- Anti-particle/particle ratios approaching 1
- Net baryons at mid-rapidity small, but non-zero
- Elliptic flow results: initial spatial asymmetry translates to similar asymmetry in momentum

Summary (2)

- HBT: transverse radii consistent with AGS, SPS results, R_{LONG} increases with sqrt(s), $R_{OUT} \sim R_{SIDE}$
- Mean pT fluctuations consistent with no fluctuations beyond random, but all are positive (HBT?)
- Mean ET fluctuations have a non-statistical component, most is attributed to cluster merging, the remainder sets an upper limit
- Net charge fluctuations are consistent with statistical fluctuations in a hadron gas