Event-by-Event Fluctuations in 40, 80, and 158AGeV/c Pb+Au Collisions

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Quark Matter 2004
Oakland, Jan 11-17, 2004

- Goals
- Mean p_T fluctuations
- Net-charge fluctuations
- Conclusions

Goals of mean p_T fluctuations

– Search for the critical point and the phase transition

Non-monotonic variation and enhancement as a function of collision energy

– *M. Stephanov et al, PRD60 (1999)14028*

– *A. Dumitru et al, PLB 504 (2001) 282*

– How does thermalization/rescattering modify the fluctuations with respect to the superposition of N+N collisions?

$\Rightarrow$ Comparison with p+p extrapolation as a function of centrality

Goals of net charge fluctuations

– Search for the deconfined phase transition

Suppressed fluctuations due to small charge unit of (anti-) quarks

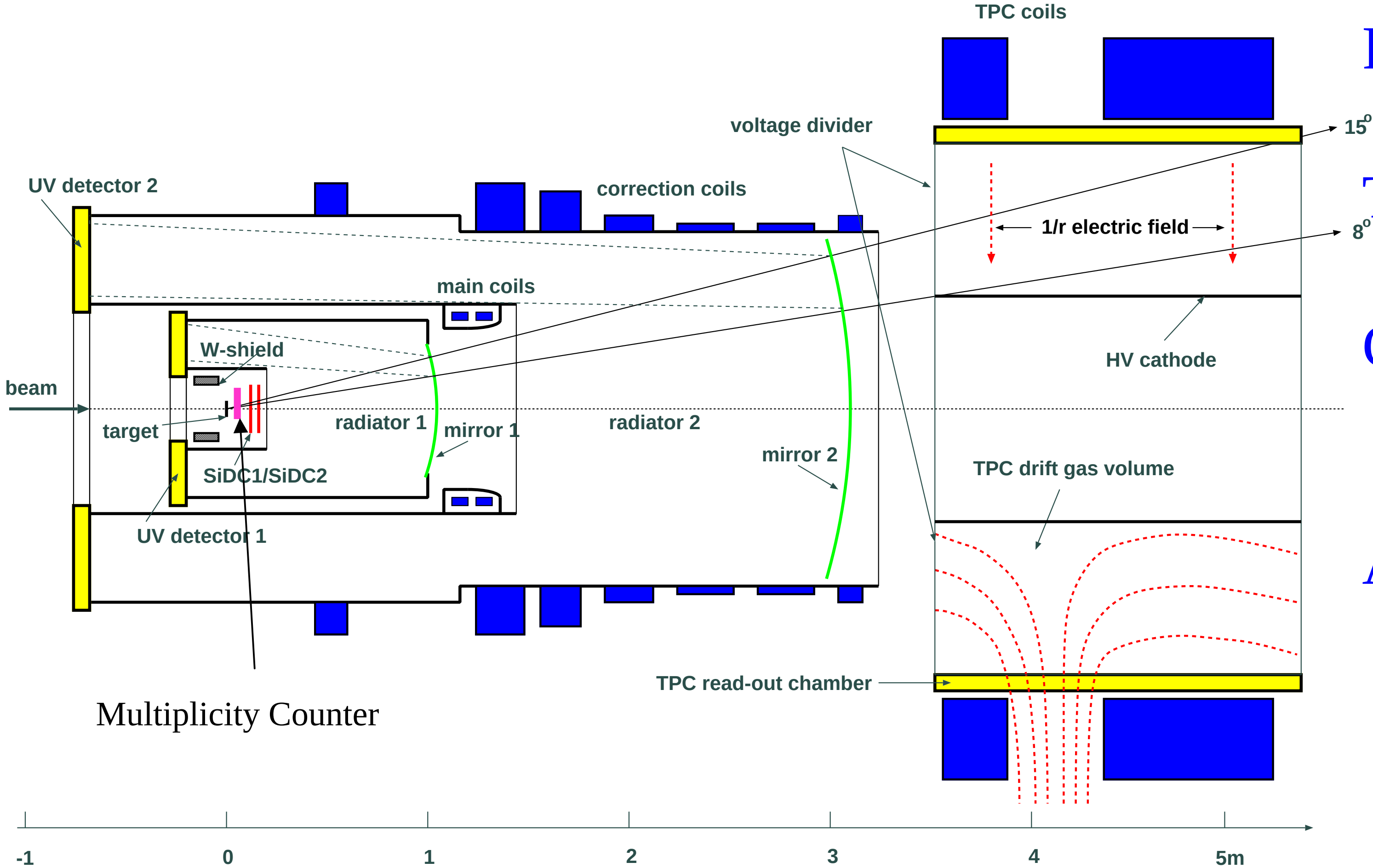
- *Jeon, Koch, PRL 85 (2000) 2076*
- *Asakawa, Heinz, Muller, PRL 85 (2000) 2072*

– Are observed fluctuations described by the resonance gas models?

$\Rightarrow$ Comparison with RQMD/UrQMD

CERES Experiment

Hadron measurement near mid-rapidity in Pb+Au collisions



Primary vertex

SIDC1+SIDC2

Track/momentum

TPC

Centrality

SIDCs

Multiplicity Counter

Acceptance

$\Delta\phi=2\pi$ (80/158GeV)

$\sim 1.3\pi$ (40 GeV)

$2.0<\eta<2.9$

(near mid-rapidity)

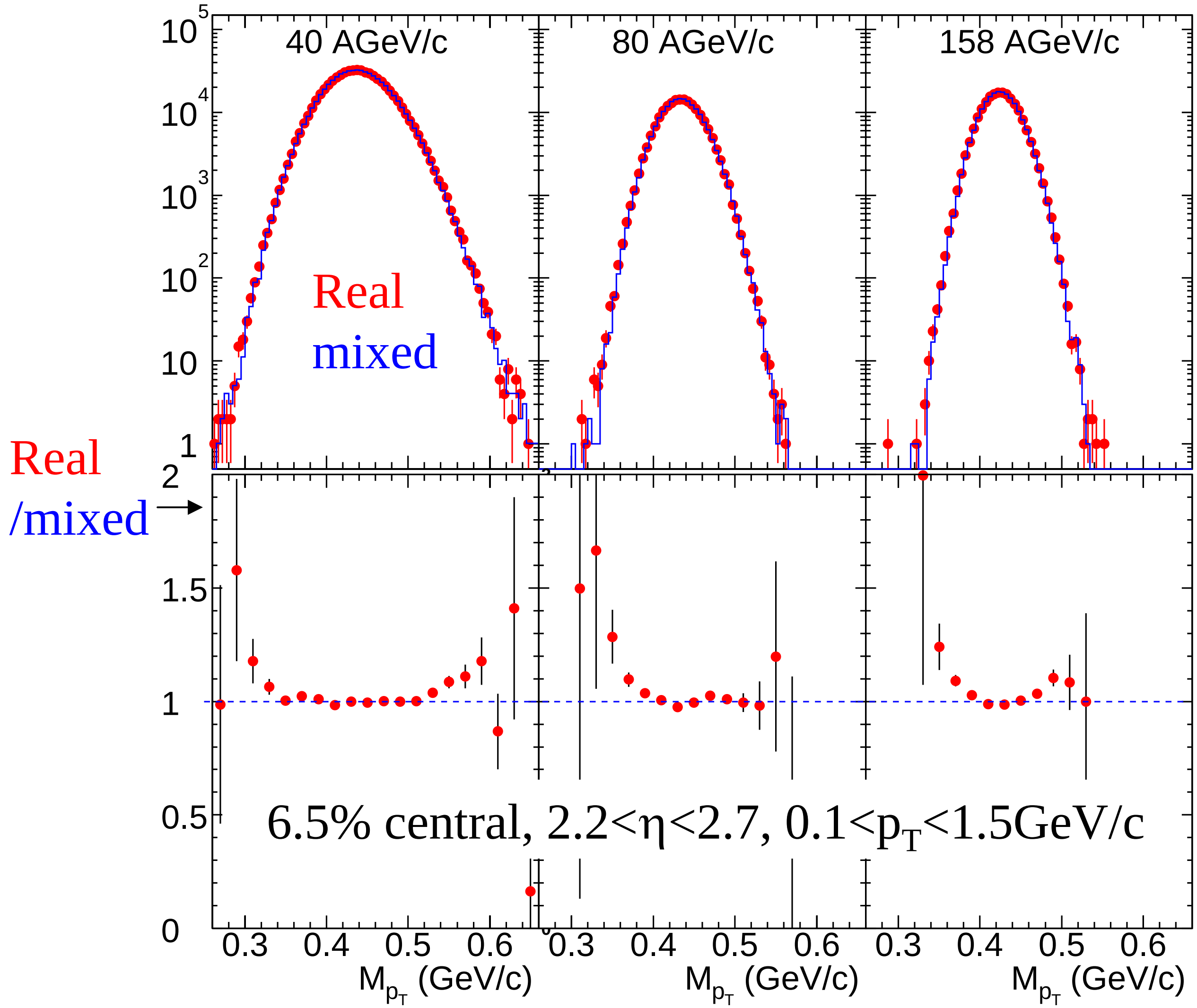
Mean p_T Fluctuations

(D. Adamova, *et al*, CERES collaboration,
Nucl. Phys. A727(2003)97-119)

Event-by-event mean p_T distributions

Event-by-event M_{pT} distributions in real events are slightly wider than those in mixed events

⇒Evidence for the non-statistical (dynamical) mean p_T fluctuations



M_{p_T} : Mean p_T of all charged particles per event

Measures of mean p_T fluctuations

- CERES

$$\Sigma_{p_T}^2 \equiv \frac{\sigma_{M_{p_T}}^{\ 2} - \sigma_{M_{p_T}}^{stat\ 2}}{\overline{p_T}^2}$$

Proportional to mean covariance of all particle pairs / event

- PHENIX (S.Adler, nucl-ex/0310005)

$$F_{p_T} \equiv \frac{\sigma_{M_{p_T}}}{\sigma_{M_{p_T}}^{stat}} - 1$$

- Statistical distribution
  - The 2 measures $\to 0$
- Multiplicity dependence

$$\Sigma_{p_T}^{\ 2} \propto \frac{F_{p_T}}{\langle N \rangle}$$

$\sigma_{M_{p_T}}$: r.m.s. of M_{p_T} dist.

$\sigma_{M_{p_T}}^{stat} = \frac{\sigma_{p_T}}{\sqrt{\langle N \rangle}}$: $\sigma_{M_{p_T}}$ for statistical dist.

σ_{p_T} : r.m.s. of inclusive p_T dist.

$\langle N \rangle$: mean multiplicity

$\overline{p_T}$: mean p_T

Dependence of mean p_T fluctuations on pseudo-rapidity interval ($\Delta\eta$)

- Σ_{pT} decreases only 30% with $\Delta\eta$ and saturates at $\Delta\eta$>0.4

  ⇔ F_{pT} increases by factor of 3~5 in $\Delta\eta$=0.05-0.8

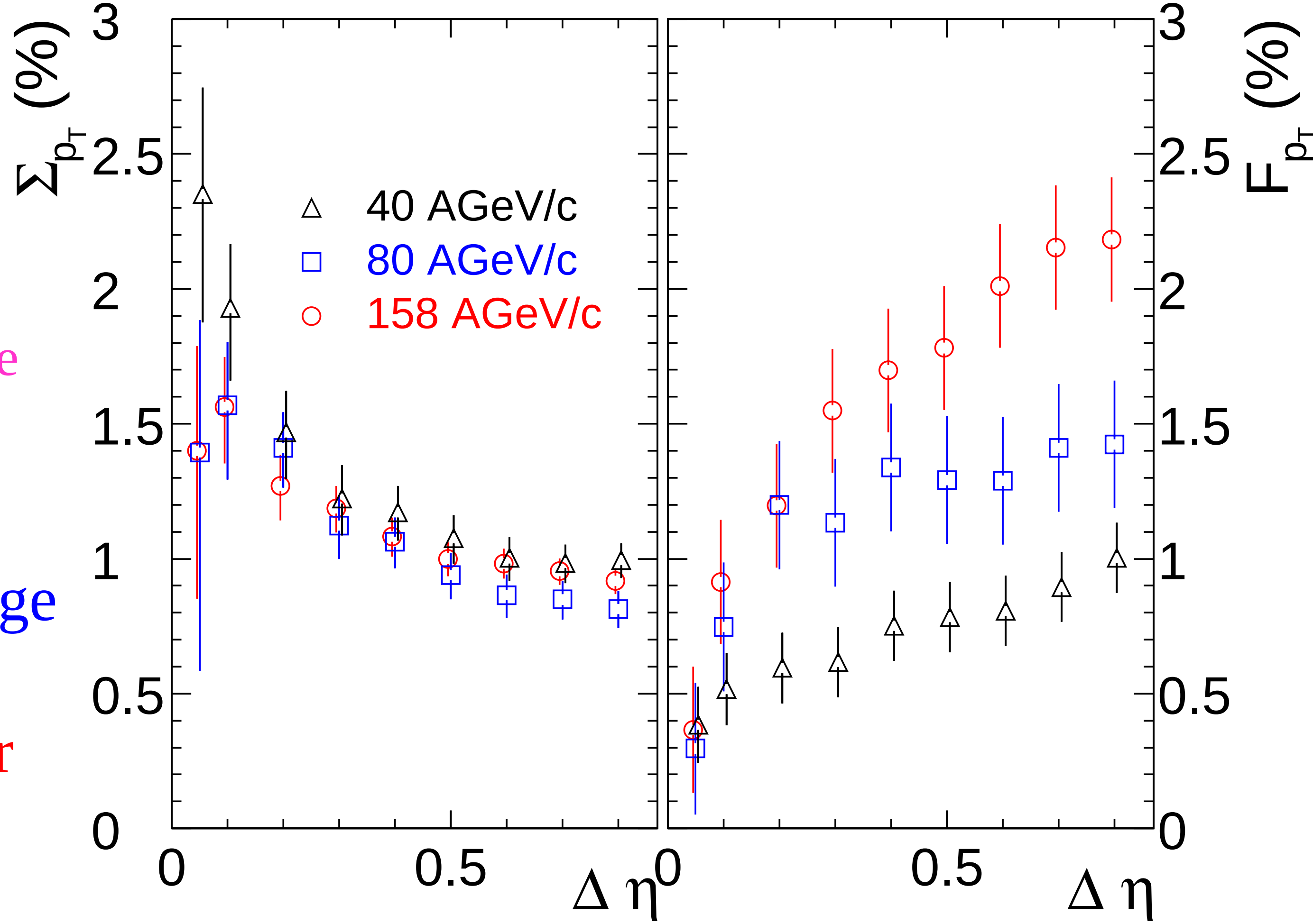
- Σ_{pT} at each $\Delta\eta$ is similar at 3 energies

  ⇔ F_{pT} has large difference due to multiplicity difference

Σ_{pT} is robust under change of multiplicity and $\Delta\eta$

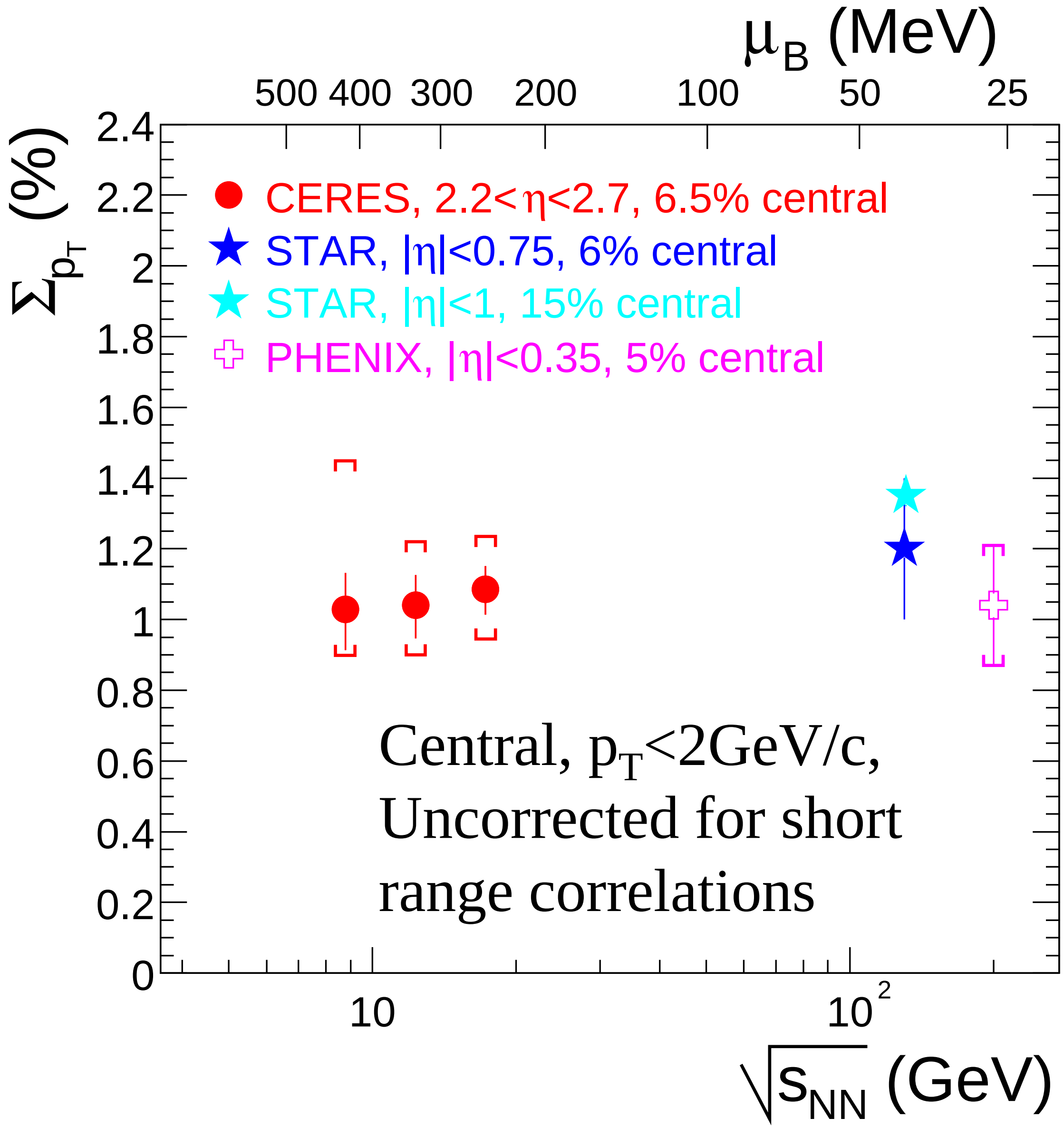
⇒Use Σ_{pT} to compare our data to RHIC data with wider $\Delta\eta$

$0.1<p_T<1.5$GeV/c, 6.5% central
$|\eta-2.45|<\Delta\eta/2$ at each bin



Collision energy dependence

- Fluctuations of ~1% similar at SPS and RHIC
- No indication for non-monotonic dependence or enhanced fluctuations at the critical point
  (~2% at SPS,
 Stephanov, PRD60 (1999) 14028)



Refs.

J.Adams (STAR), nucl-ex/0308033

S.Voloshin (STAR), nucl-ex/0109006

S.Adler (PHENIX), nucl-ex/0310005

Centrality dependence at 158 AGeV/c

- Baseline:extrapolation from p+p measurement

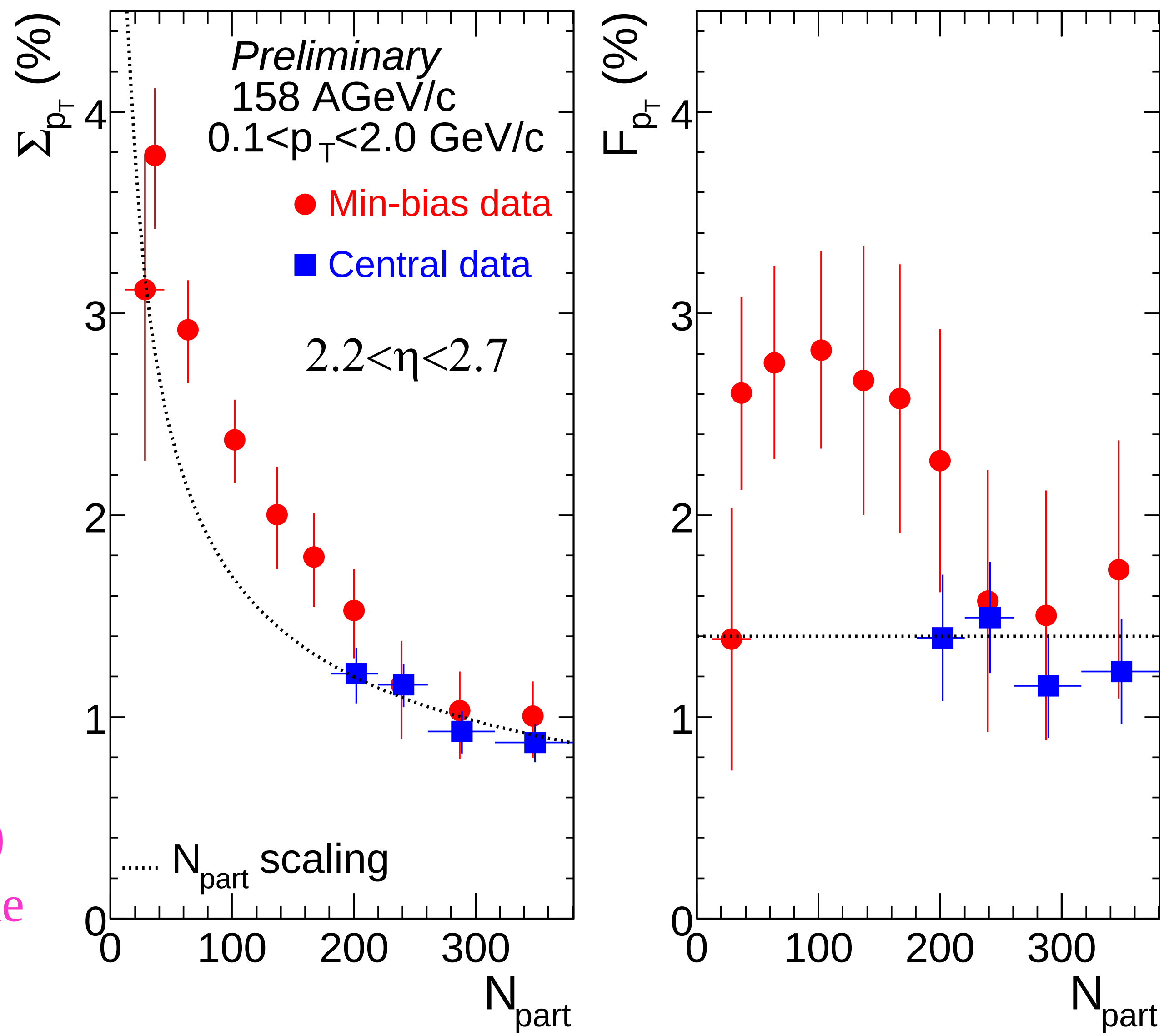
$$\Sigma_{p_T}^{AA} = 12\% \cdot \left(\left\langle N_{part} \right\rangle / 2 \right)^{-1/2}$$

12% measured in p+p at ISR (*Braune, PLB123(1983)467*)

$$F_{pT} = 1.4\% \text{ (const)}$$

- Non-monotonic dependence and enhancement of F_{pT} in semi-central events
  - Maximum of 2.8 % at N_{part}~100 (30-40% central)
  - Consistent with the baseline in central and peripheral

Corrected for short range correlations



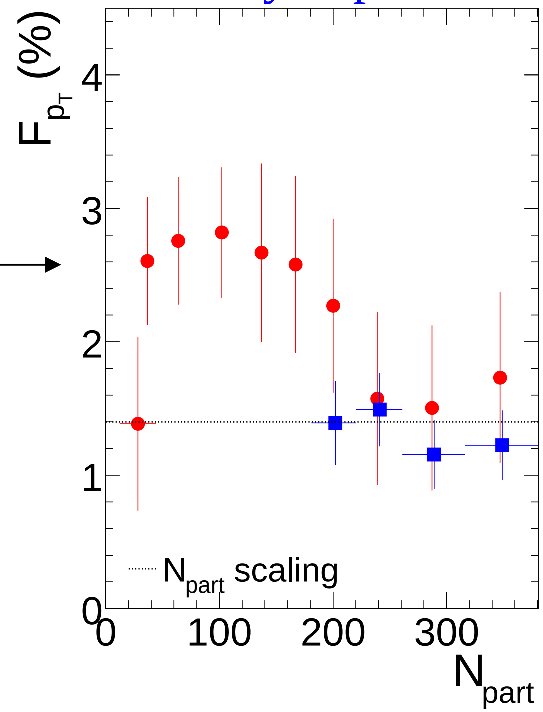
Comparison with PHENIX data

Similar dependence of F_{pT} to PHENIX data

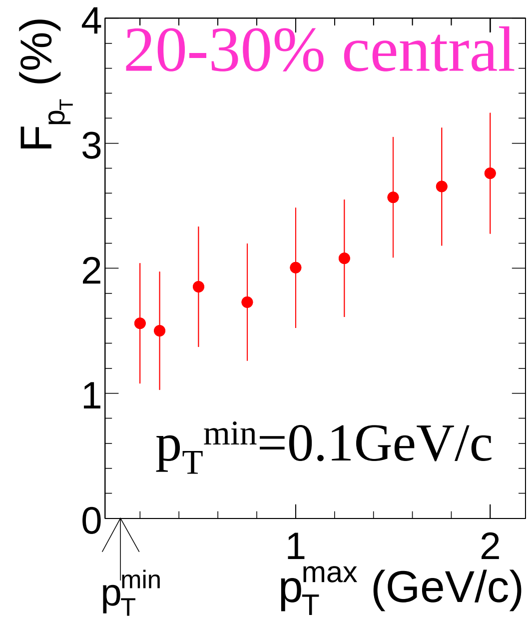
- Non-monotonic dependence of F_{pT} as a function of N_{part}
- Increase in F_{pT} as a function of upper p_T cut
- Indication of same production mechanism?

Centrality dependence

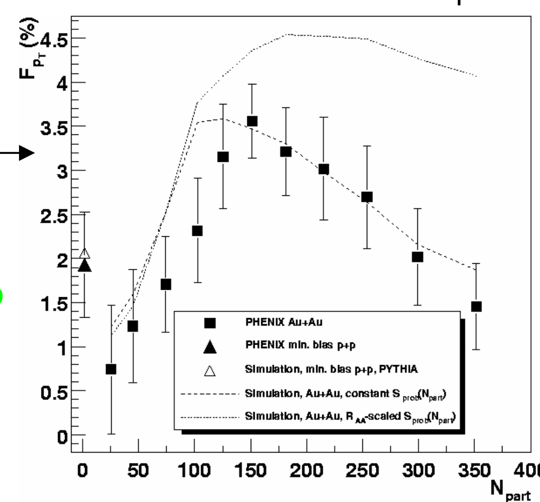
CERES →



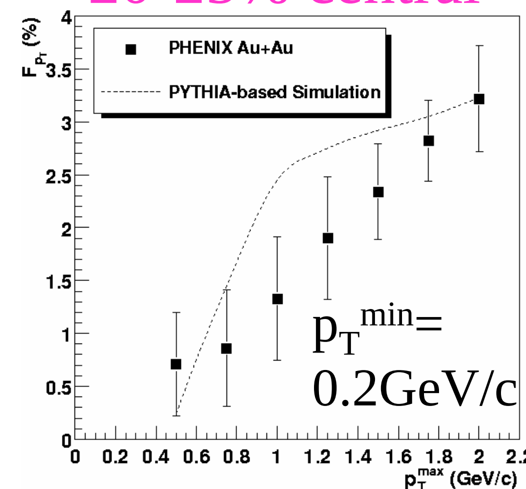
Upper p_T cut dependence



PHENIX → ($s^{1/2}$=200GeV) nucl-ex/031005



20-25% central

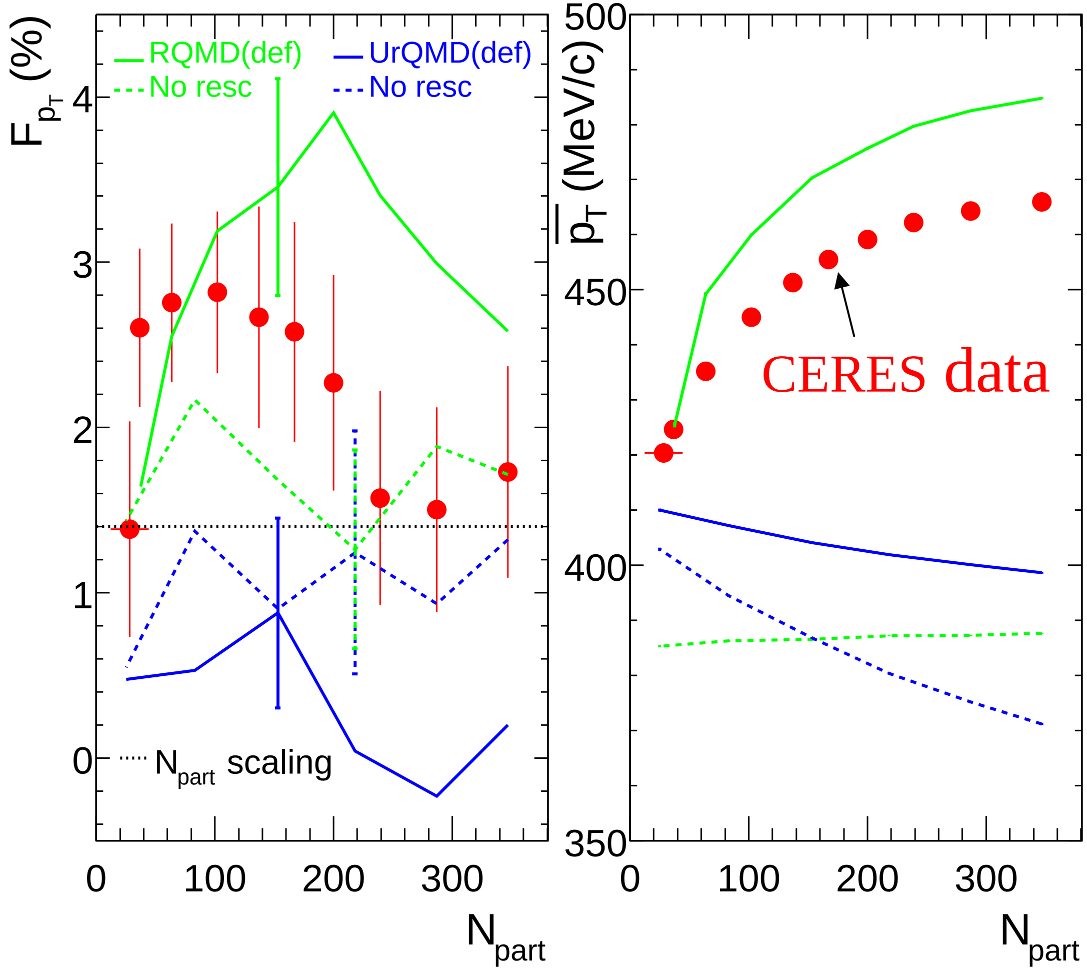


Comparison with RQMD and UrQMD

- Without rescattering
  - Fluctuations agree with p+p
- RQMD w/ rescattering
  - Enhanced fluctuations in semi-central
  - Increase of mean p_T
  - Qualitatively reproduces data
- UrQMD w/ rescattering
  - Reduced fluctuations
  - Flat mean p_T

⇒ Strong connection between centrality dependence of fluctuations and $\langle p_T \rangle$?

(c.f. S. Gavin, talk in this session, nucl-th/0308067)



Net Charge Fluctuations

Measures of net charge fluctuations

- Measure ν_{dyn} (C. *Pruneau et al, PRC66 (2002) 044904*)

$$\nu_{dyn} \equiv \left\langle \left(\frac{N_+}{\langle N_+ \rangle} - \frac{N_-}{\langle N_- \rangle} \right)^2 \right\rangle - \left(\frac{1}{\langle N_+ \rangle} + \frac{1}{\langle N_- \rangle} \right)$$

$N_\pm$: positive(negative) particle multiplicity
$\langle \ \rangle$: average over events

= Dynamical fluctuations of difference between normalized multiplicity of positive particles and that of negative particles

= 0 for statistical distribution

- – Neutral resonance decay into a positive and a negative particles
  $\rightarrow$decreases ν_{dyn}

- Advantages of ν_{dyn}
  - – Correction for the global charge conservation is constant and additive

$$\tilde{\nu}_{dyn} = \nu_{dyn} - C$$

$$C \equiv -\frac{4}{\langle N \rangle_{4\pi}} : \text{charge conservation limit}$$

  - – Insensitive to detector inefficiency

Centrality dependence of net charge fluctuations

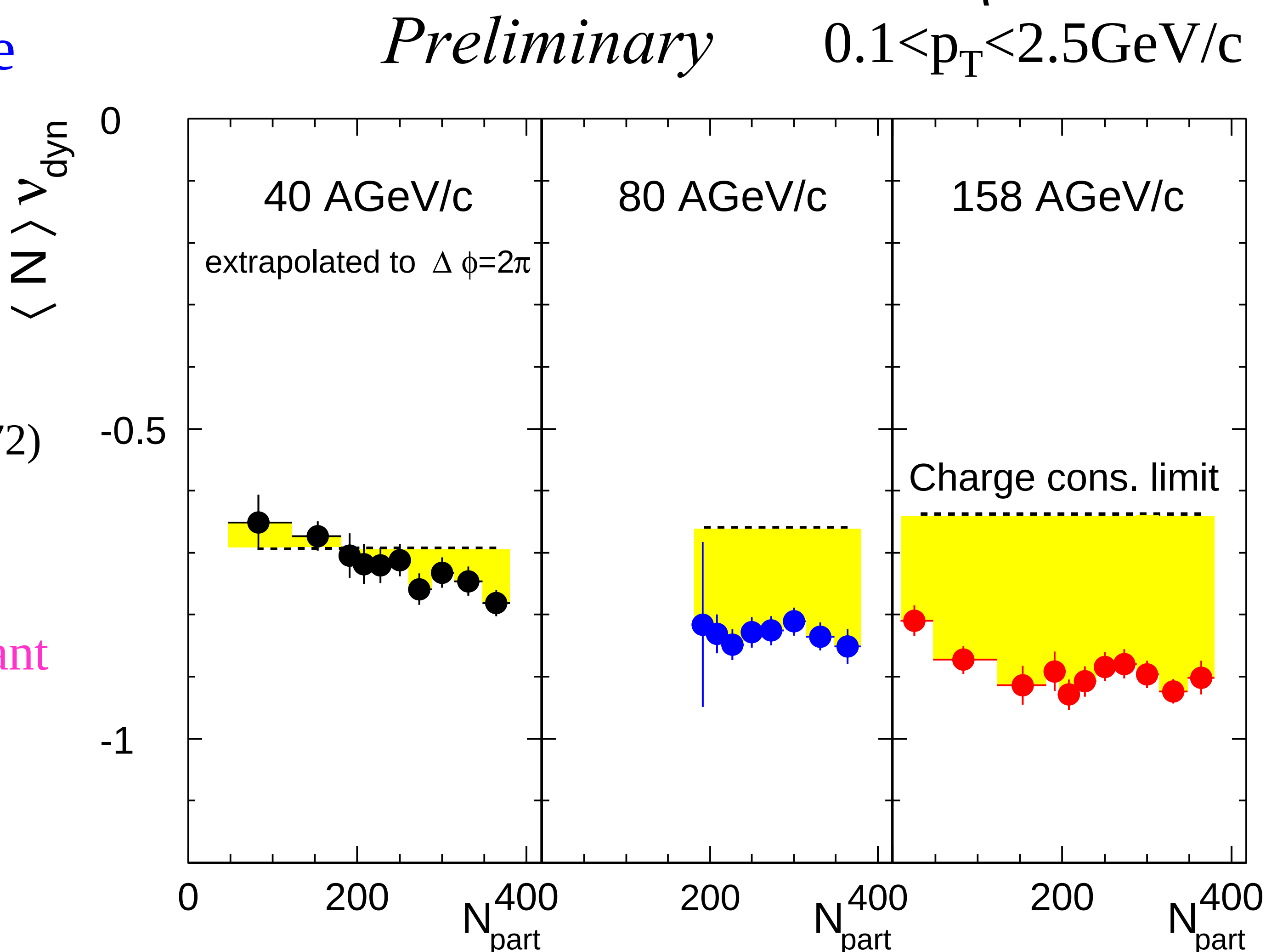
- Fluctuations lower than charge conservation limit
- Fluctuations far above the QGP models of ~ –3.5
  - No indication for phase transition

  (Jeon, PRL85 (2000) 2076,

  Asakawa, PRL85 (2000) 2072)
- Slight decrease with centrality
  - Deviation from constant with superposition of sub-collisions

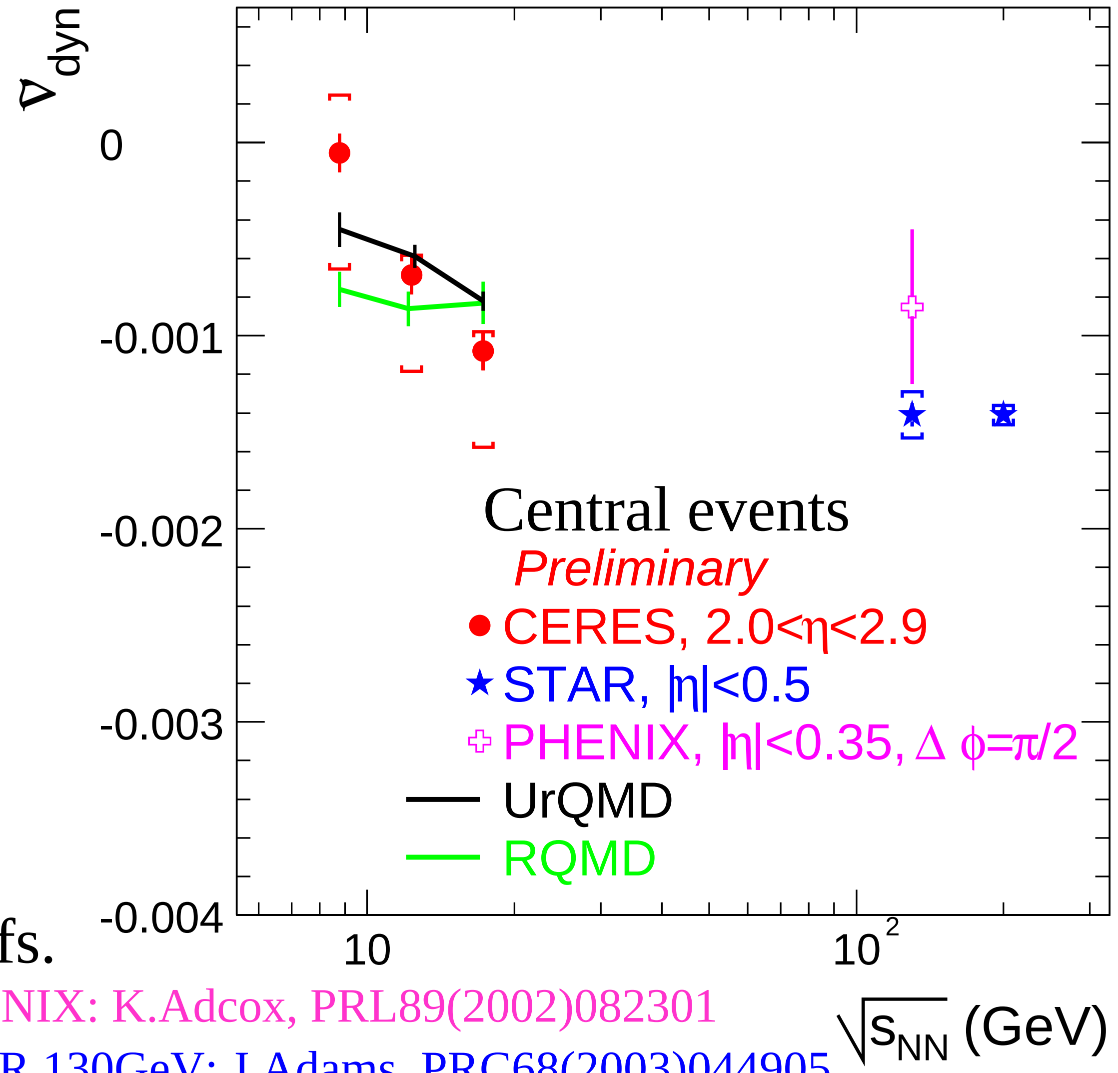
    Rescattering and resonance effects ?

Charge conservation limit
NA49 collaboration,
PRC66(2002)054902



Collision energy dependence of net charge fluctuations

- ν_{dyn} corrected for charge conservation
  - Decrease at SPS
  - Little decrease from SPS top energy to RHIC
- UrQMD and RQMD are consistent with the observed fluctuations



Refs.

PHENIX: K.Adcox, PRL89(2002)082301

STAR 130GeV: J.Adams, PRC68(2003)044905

STAR 200GeV:C.Pruneau, nucl-ex/0304021

Conclusions

Mean p_T fluctuations

- Dynamical fluctuations of ~ 1 % are observed at SPS, which are similar to RHIC data. No indication for the critical point or phase transition.
- Fluctuations show non-monotonic dependence on centrality with enhancement over p+p extrapolation in semi-central
- Dependence on the centrality and upper p_T cut is similar to PHENIX data

Net-charge fluctuations

- Dynamical fluctuations smaller than charge conservation limit are observed at SPS
- No indication for suppressed fluctuations in QGP
- ν_{dyn} corrected for charge conservation decreases at SPS energies but changes little from the SPS top energy to RHIC. At SPS UrQMD and RQMD reproduce the data.

CERES/NA45 Collaboration

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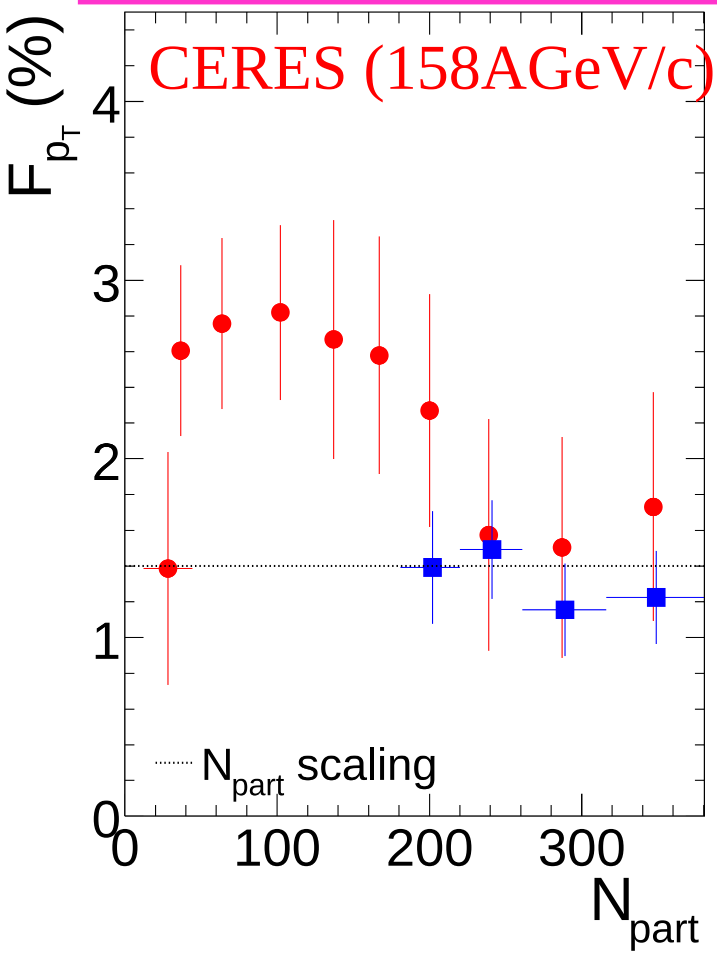
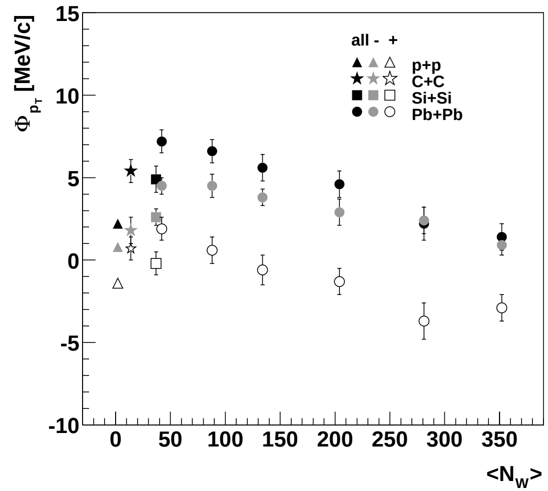
Comparison to other SPS and RHIC experiments

Fluctuations at SPS and RHIC show similar non-monotonic dependence

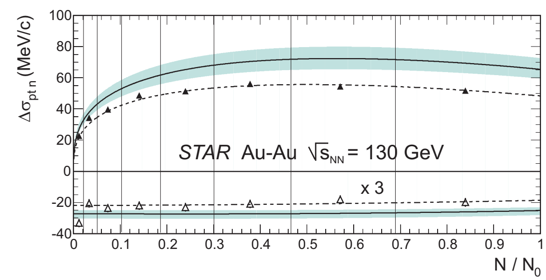
CERES (158AGeV/c)



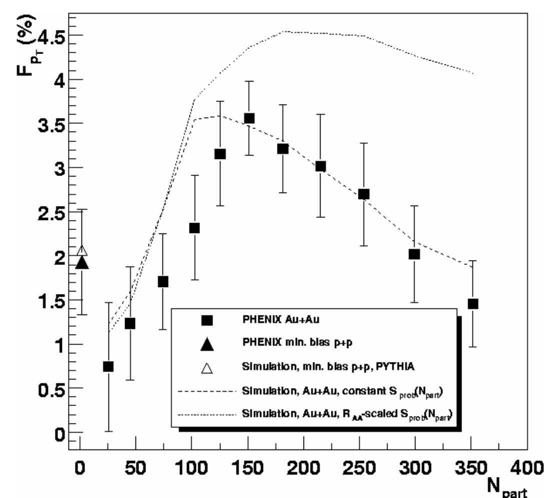
NA49 (158AGeV/c)
hep-ex/0311009



STAR ($s^{1/2}$=130GeV)
nucl-ex/0308033

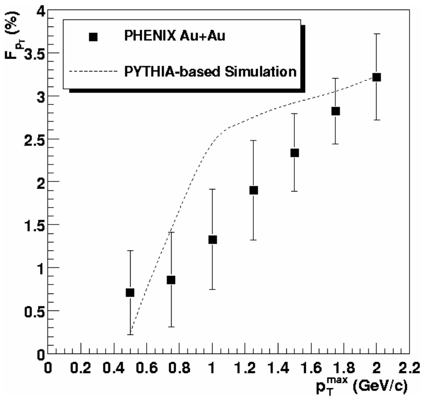


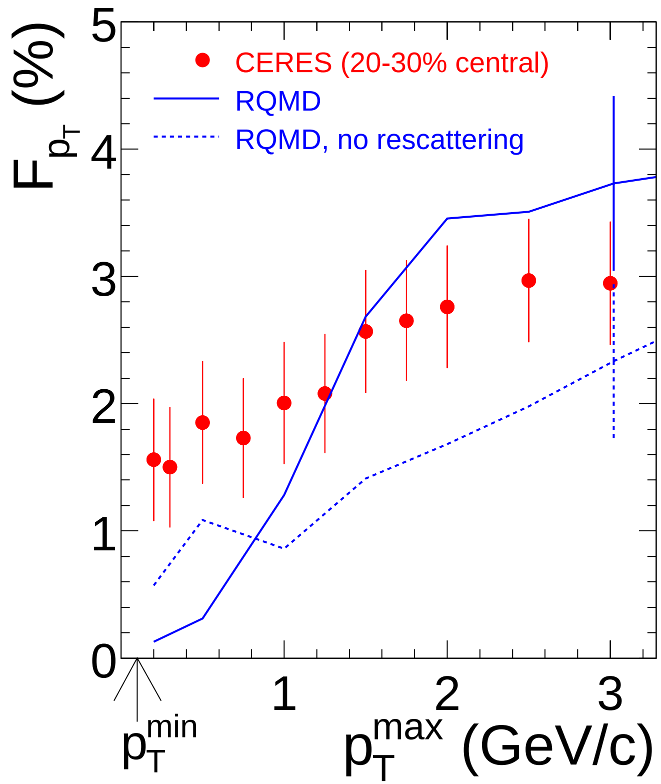
PHENIX ($s^{1/2}$=200GeV)
nucl-ex/031005



Dependence of mean p_T fluctuations on upper p_T cut

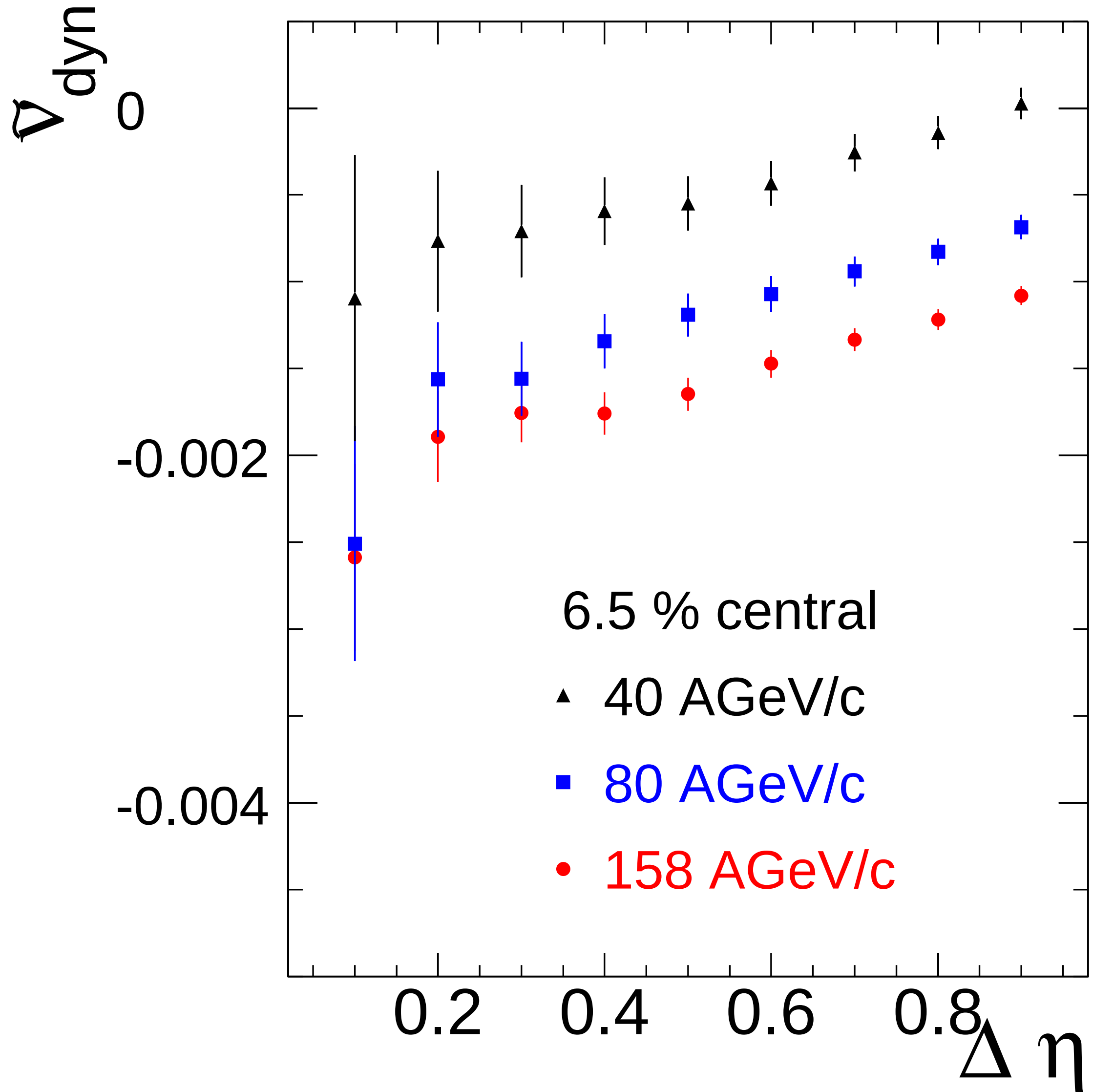
PHENIX
($s^{1/2}$=200GeV)
nucl-ex/031005





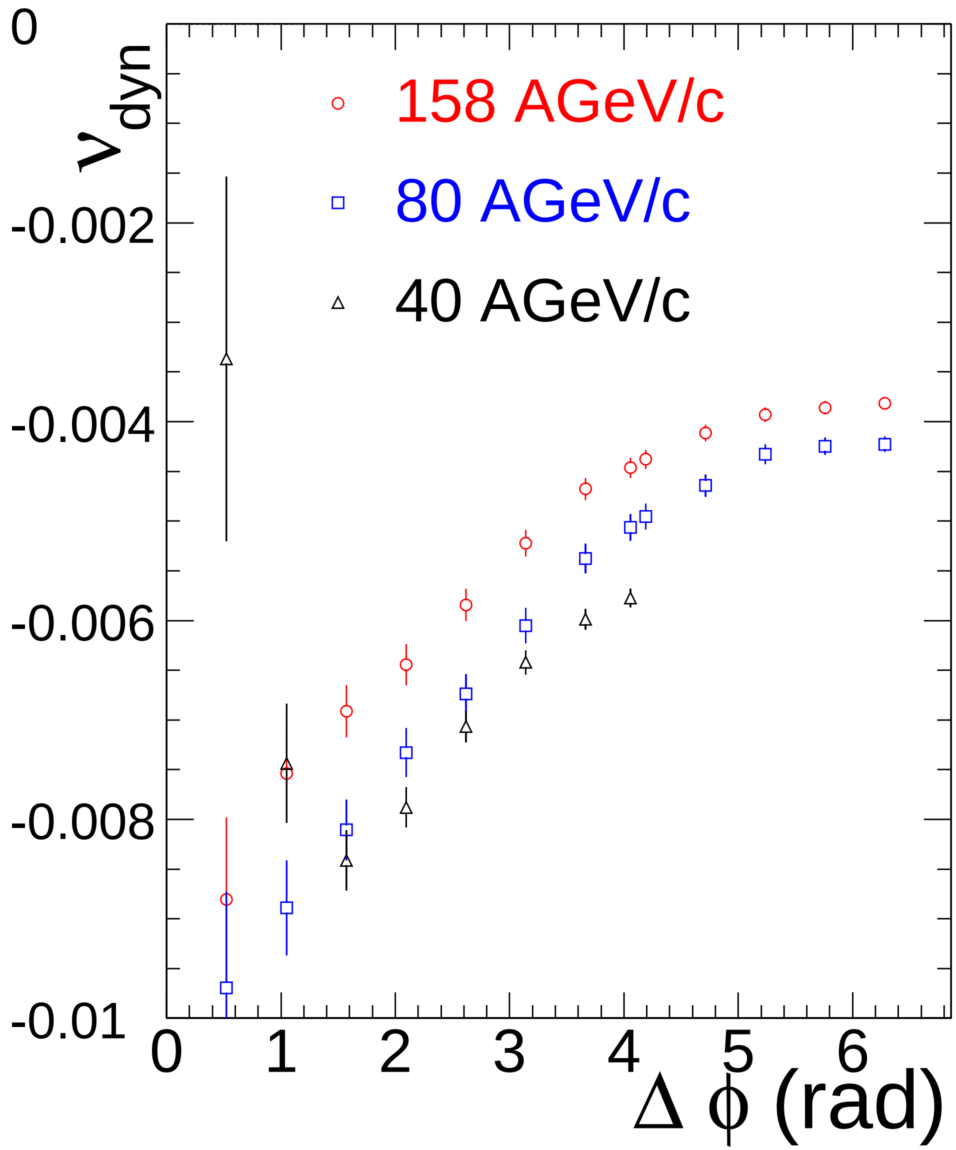
Pseudo-rapidity dependence of net-charge fluctuations

- ν_{dyn} corrected for charge conservation increases as a function of $\Delta\eta$
- To compare energy dependence, we need to use similar $\Delta\eta$ acceptance



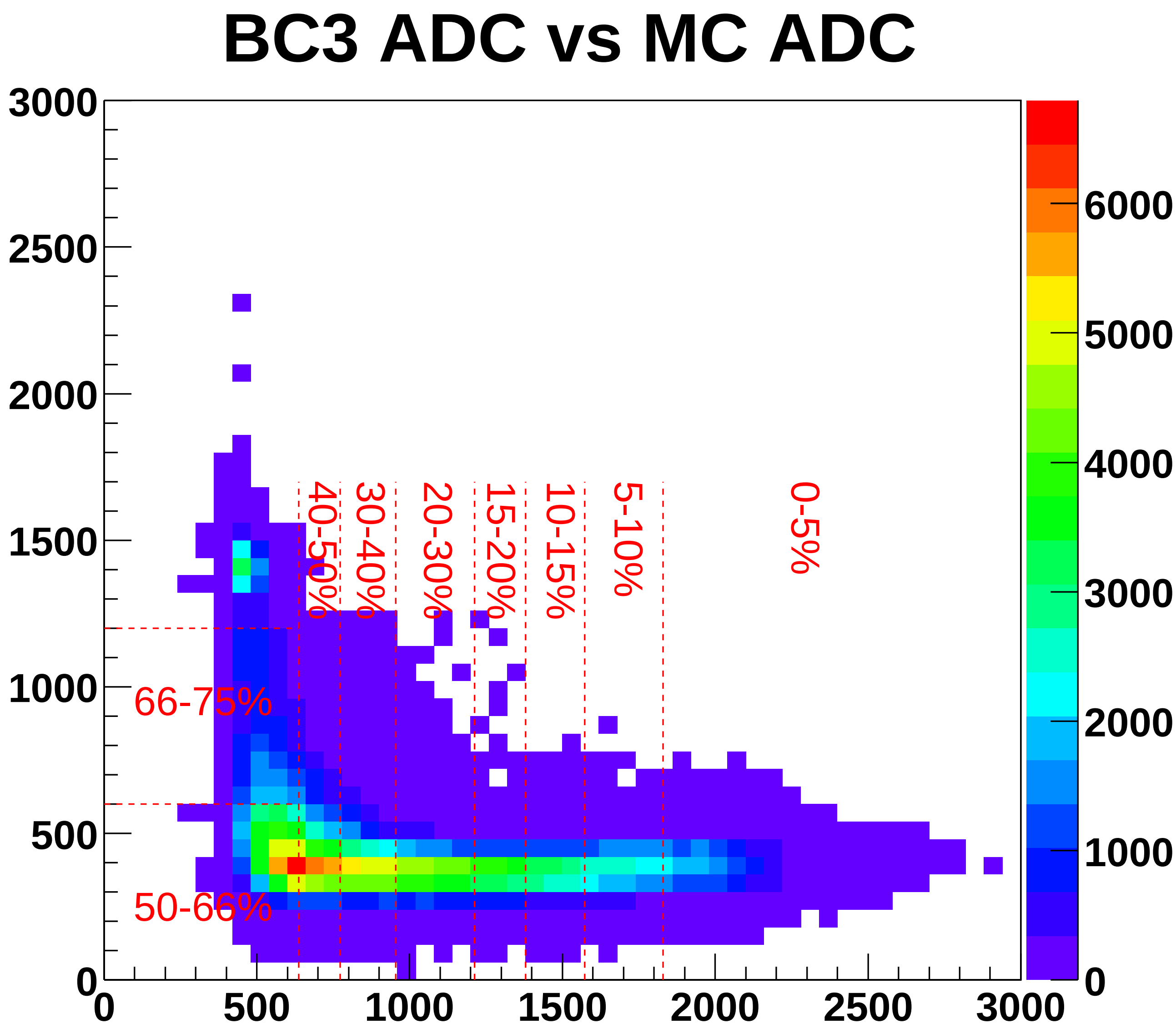
Φ acceptance dependence of net-charge fluctuations

- Use 80 and 158 AGeV/c data to extrapolate 40 AGeV data to $\Delta\phi = 2\pi$

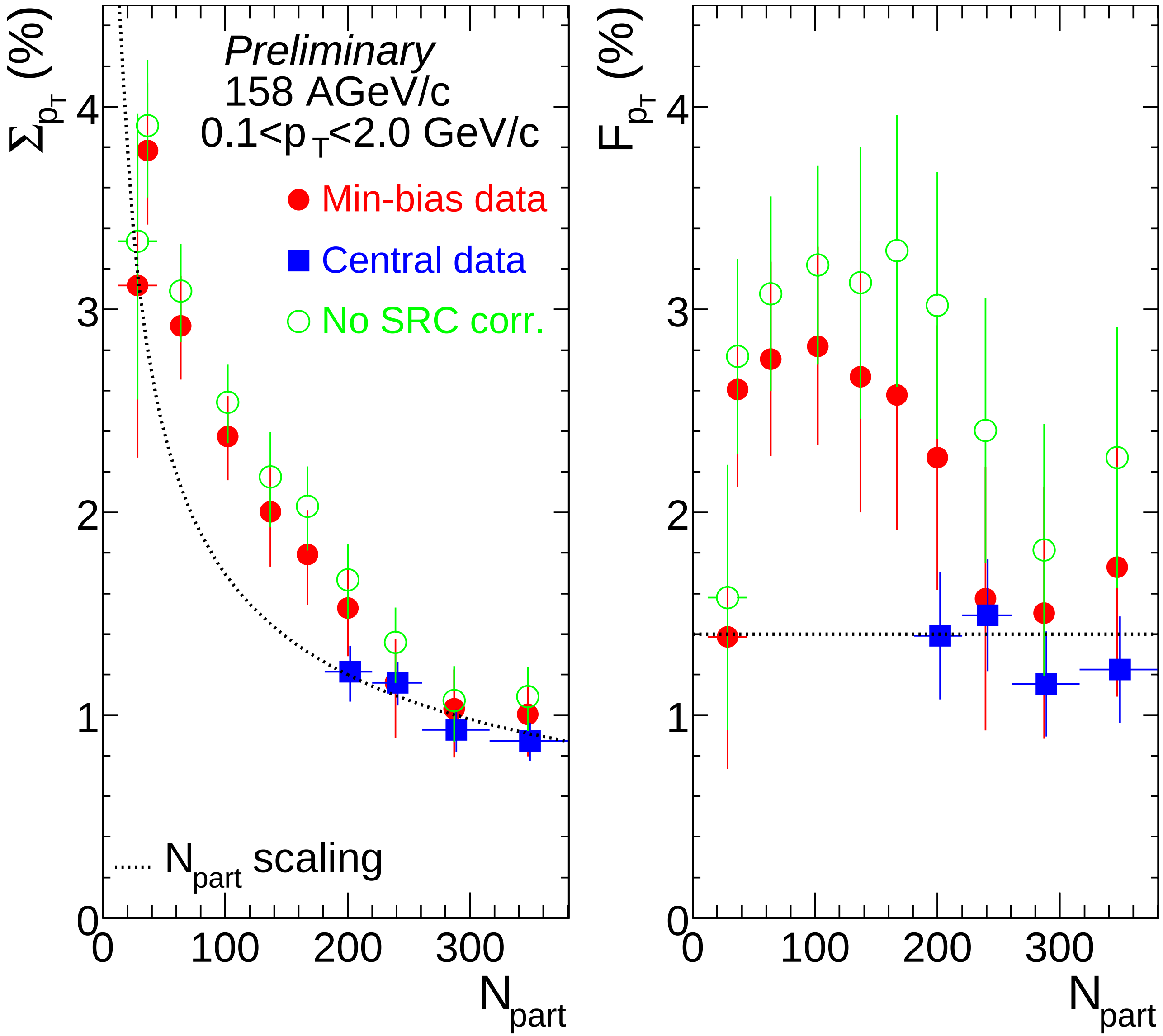


Centrality cut

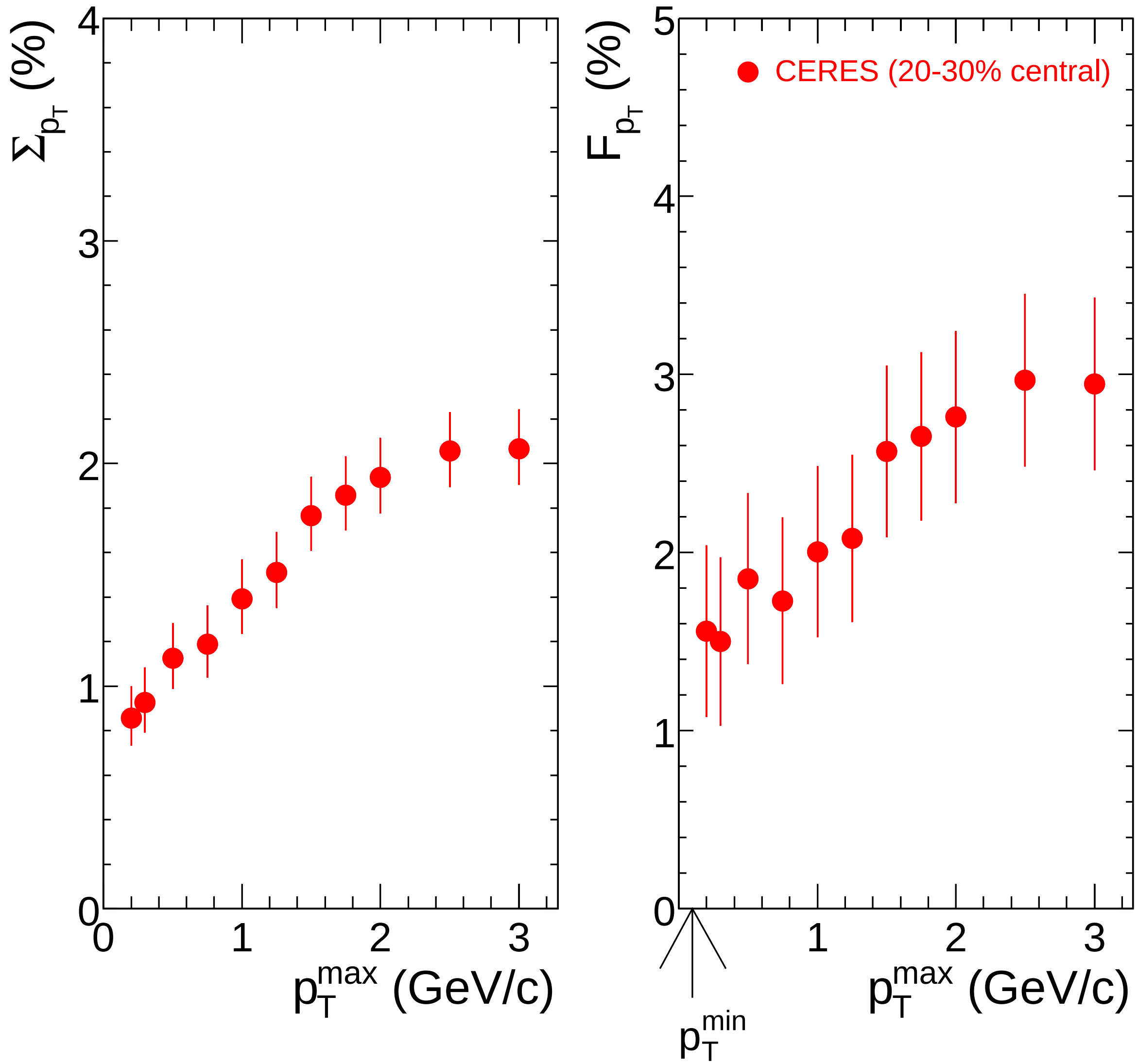
- Multiplicity Counter vs BC3 (measurement of beam spectator)



Uncorrected centrality dependence

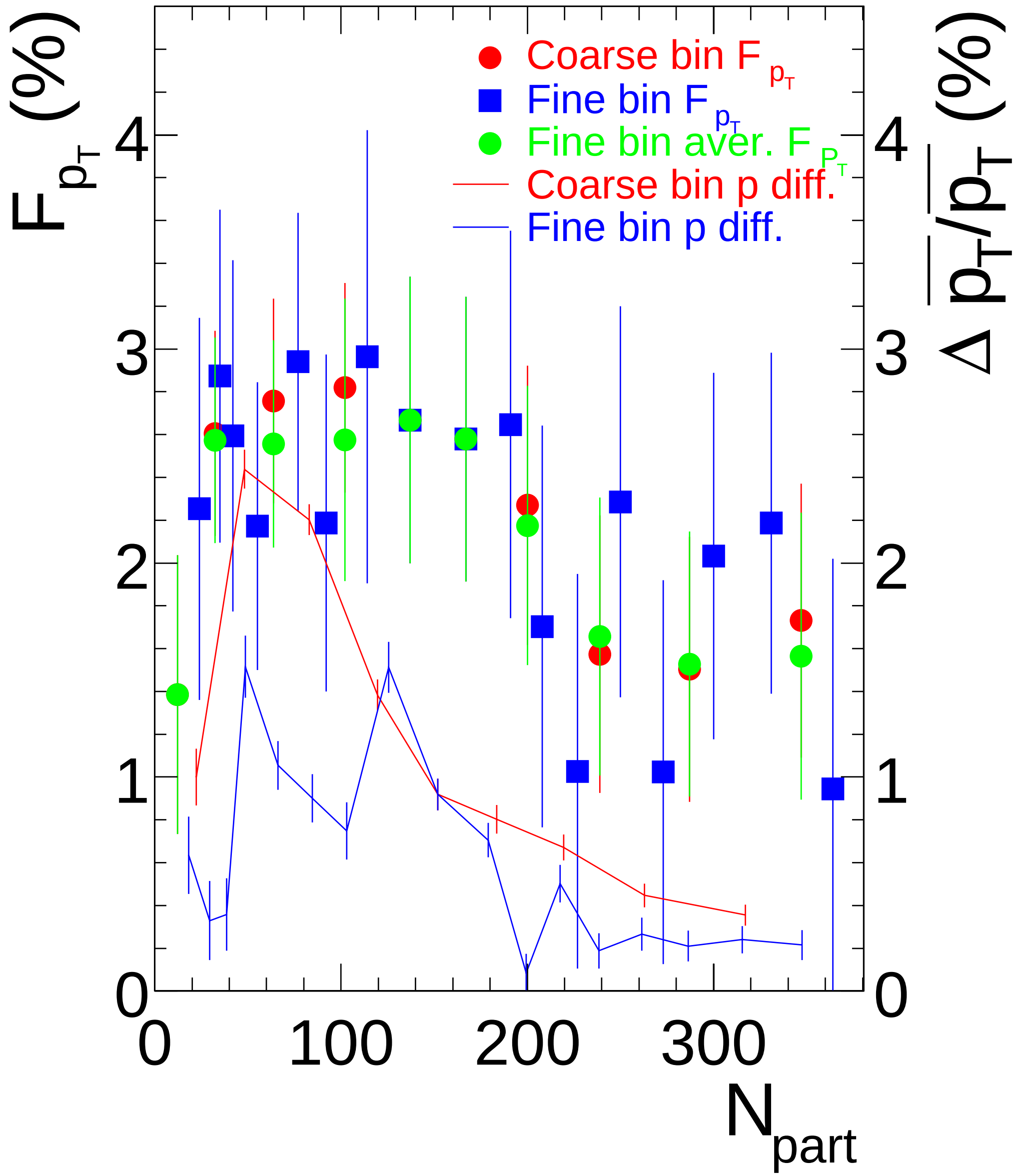


Σ_{pT} vs N_{part}

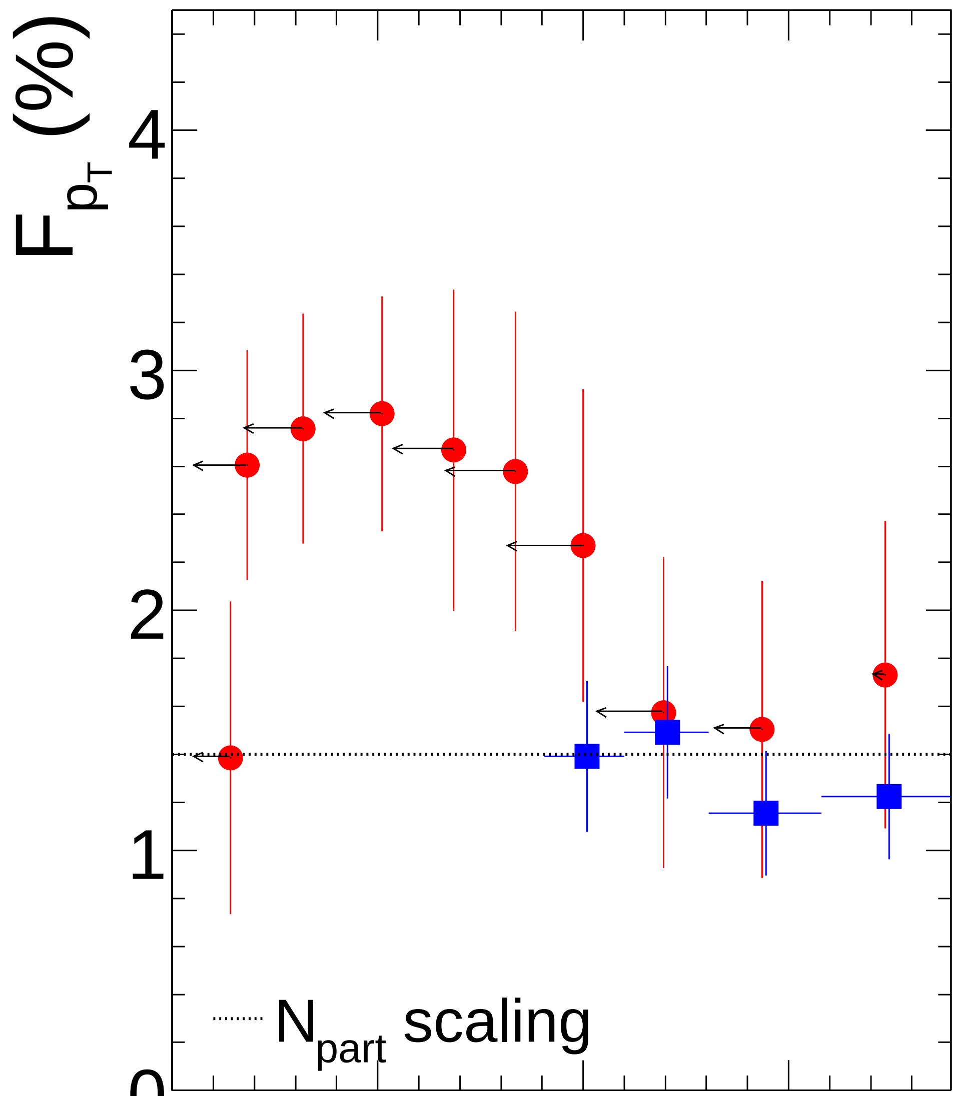


Centrality bin dependence

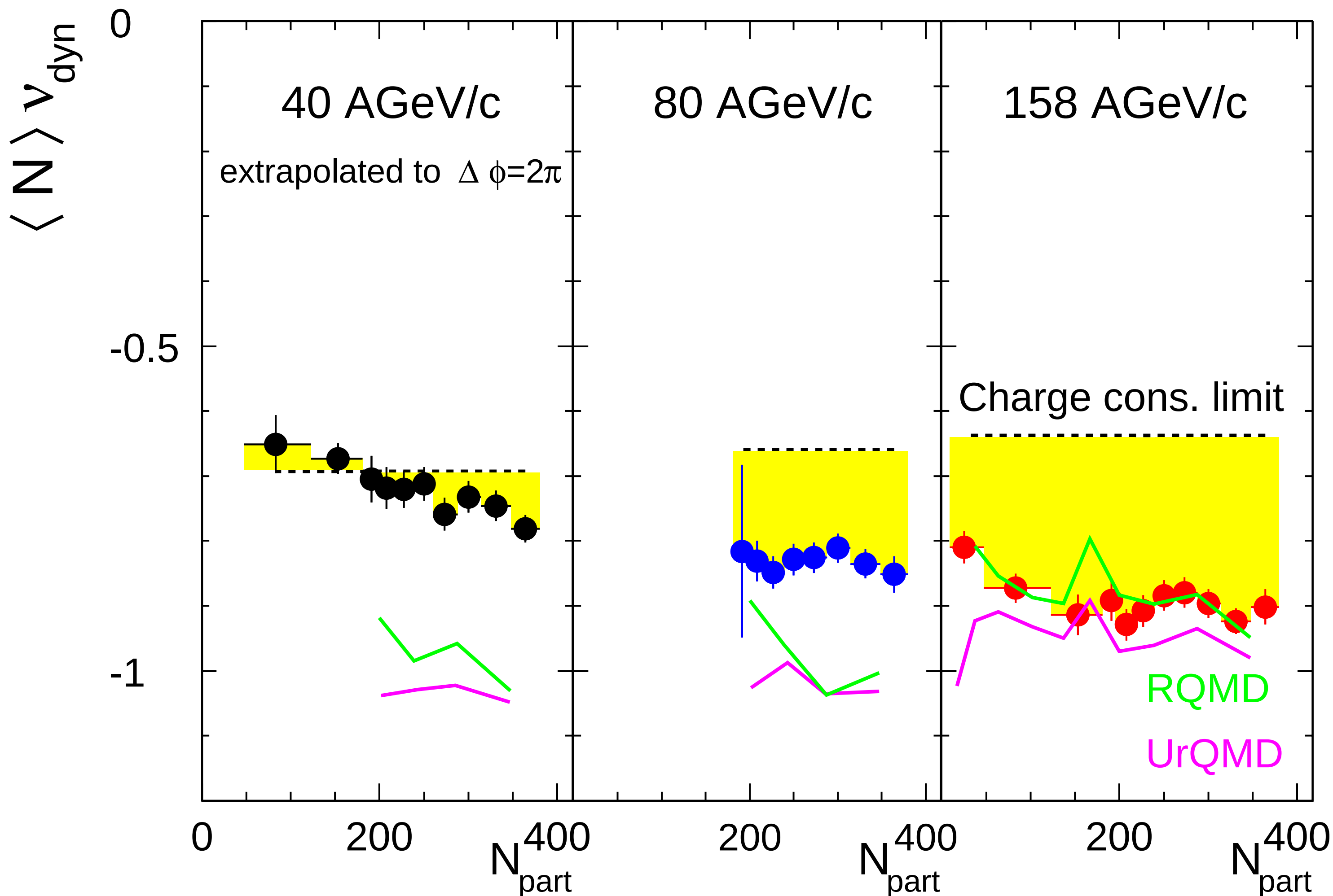
- Sys error due to finite centrality bin-size
  - Maximum of ~ -0.4% at 30-50% central
- From dp/p slope
  - Estimated contribution ~ -0.4%



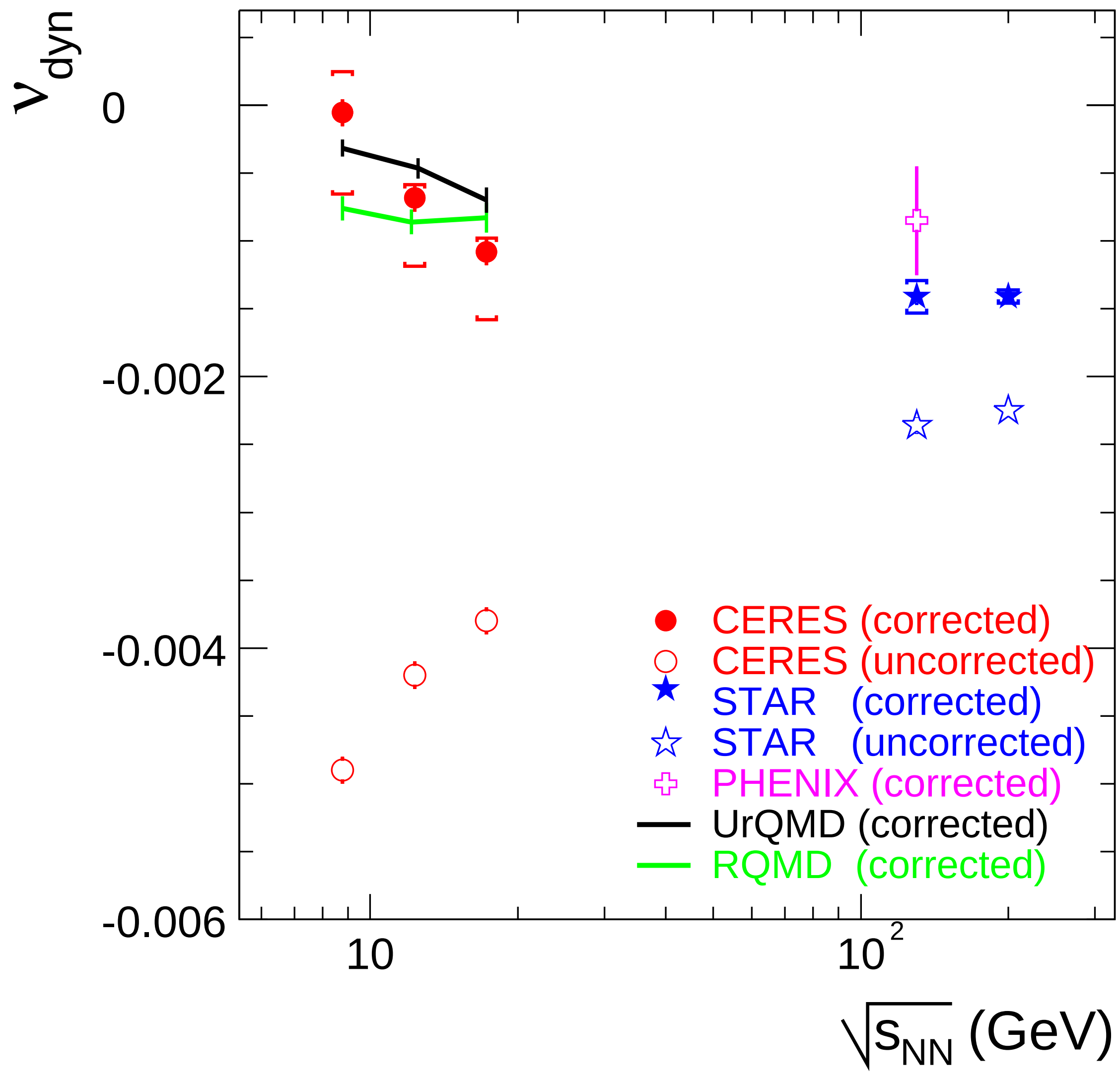
Sys error of Npart



Centrality dependence of net charge fluctuations with RQMD/UrQMD



Uncorrected ν_{dyn} vs sqrt(s)



Multiplicity dependence of p_T fluctuations

- Superposition of elementary sources whose number is proportional to the multiplicity
- Σ_{pT}^2 is proportional to probability *p* to select a correlated pair

$$p = \frac{N_s \cdot n(n-1)}{N(N-1)} \propto \frac{1}{N_s}$$

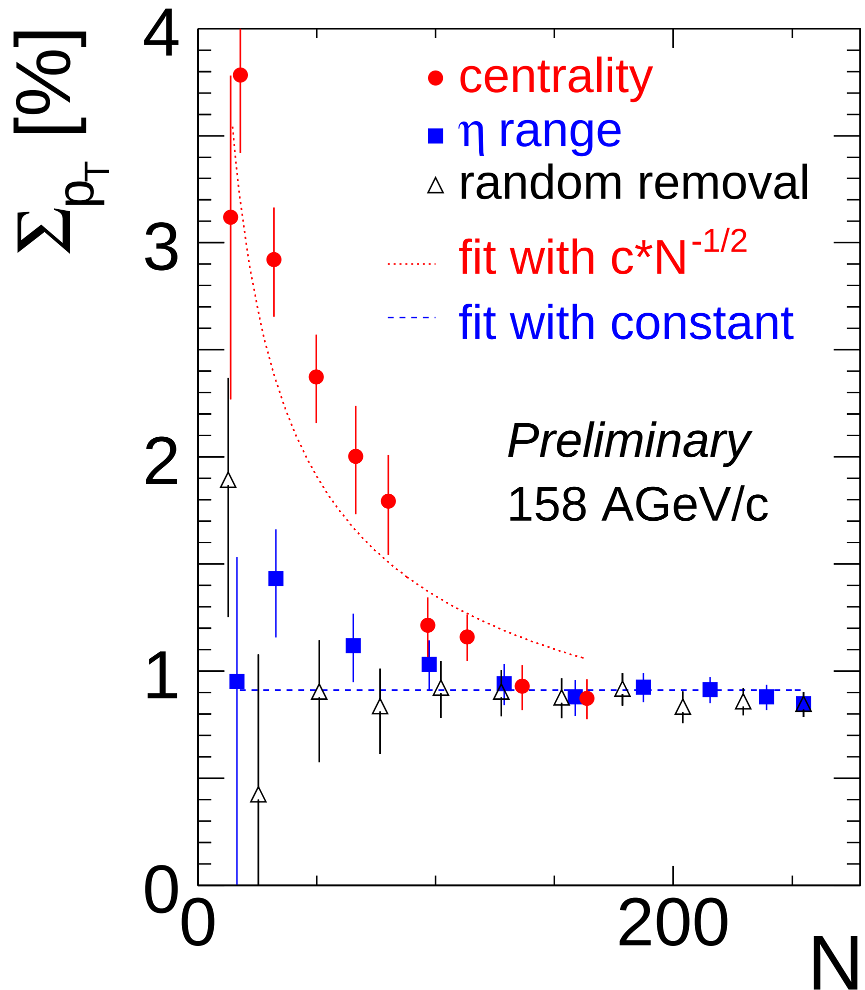
$N = N_s n$: particle multiplicity in acceptance

N_s : number of elemental sources

n : emitted particles from a source

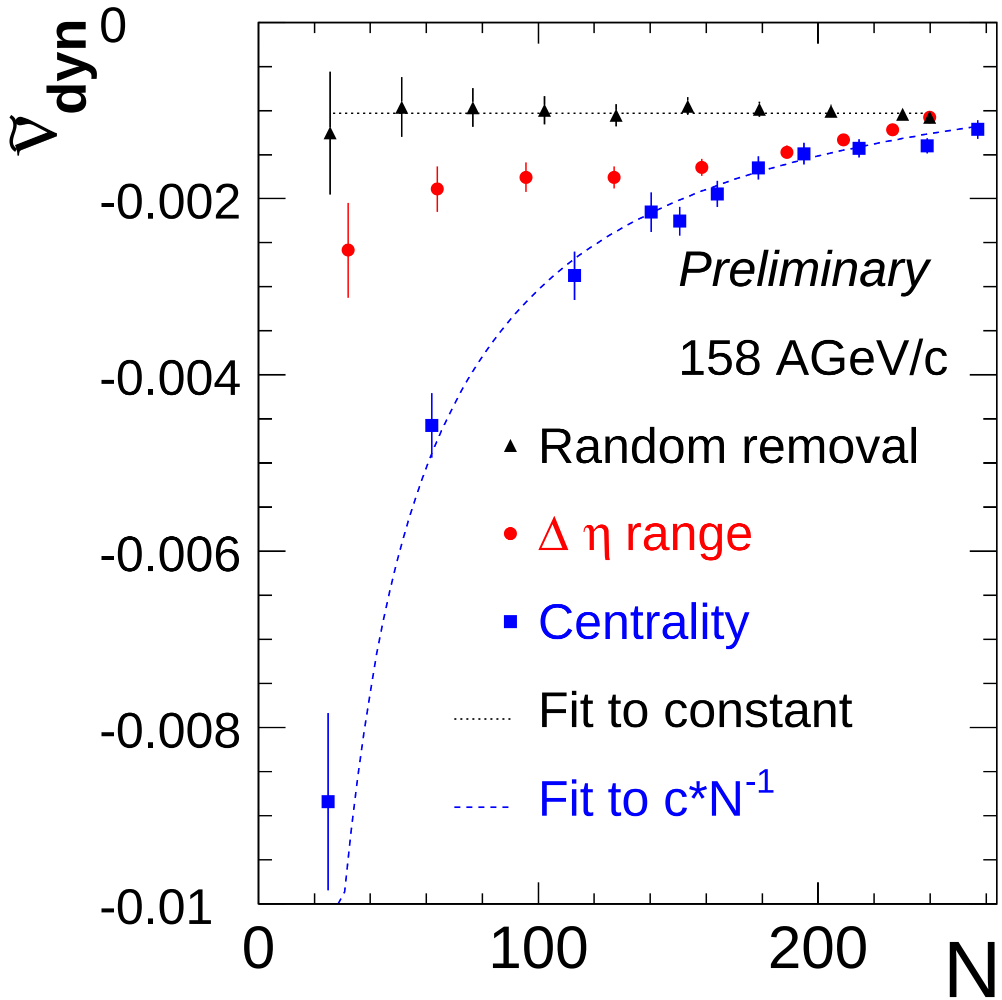
  - Centrality dependence
    - Change N_s, fix n, $\Sigma_{pT}^2 \sim N^{-1}$, $F_{pT} \sim$ const
  - Long range correlations, with $\Delta\eta$ cut
    - Fix N_s, change n, $\Sigma_{pT}^2 \sim$const, $F_{pT} \sim N$
    - Σ_{pTis} is good to compare data with different y acceptance

0.1<p_T<2.0GeV/c
Corrected for SRC



Multiplicity dependence of net-charge fluctuations

- Similar discussions with mean p_T fluctuations apply
- Just replace Σ_{pT}^{2} -> ν_{dyn}
  - Centrality dependence
    - $\nu_{dyn} \sim N^{-1}$
  - Long range correlations, with $\Delta\eta$ cut, random removal of tracks
    - ν_{dyn} ~const
  - Deviation from constant for $\Delta\eta$ range dependence may be due to correlations of daughters from a resonance



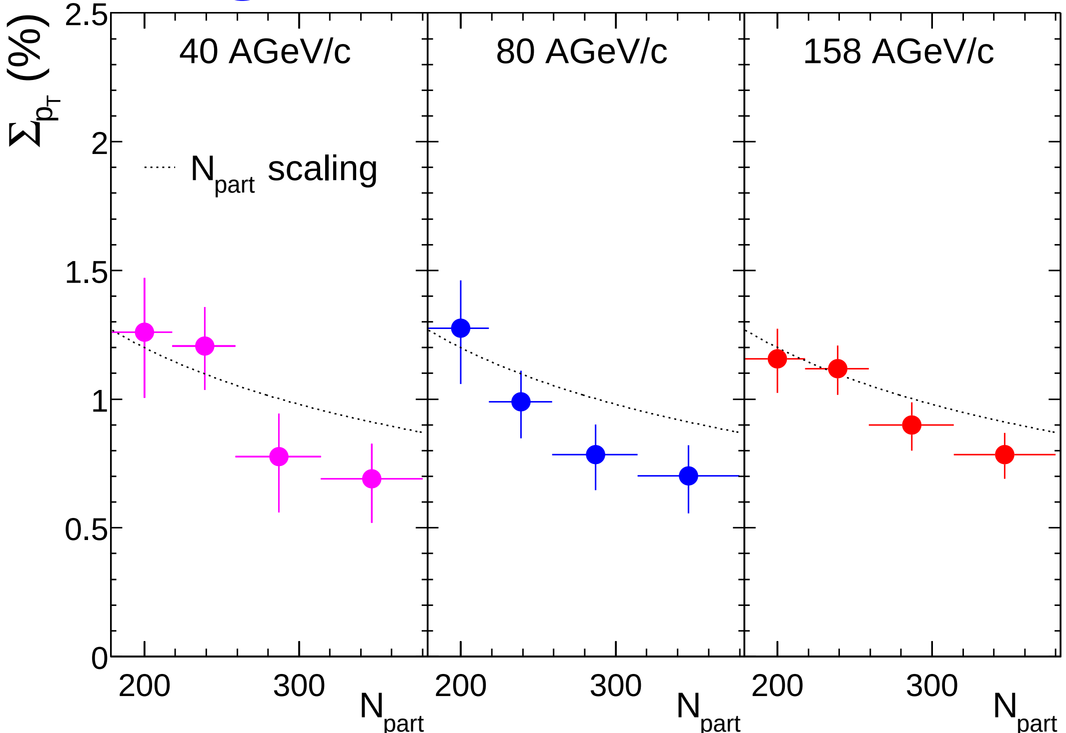
Comparison to p+p collisions

- Consistent with p+p superposition with N_{part} scaling in 20% central events

$$\Sigma_{p_T}^{AA} = \Sigma_{p_T}^{pp} \cdot \left(\left\langle N_{part} \right\rangle / 2 \right)^{-1/2}$$

$$\Sigma_{p_T}^{pp} = 0.12 \text{ at ISR (K.Braune, PLB 123 (1983) 467)}$$

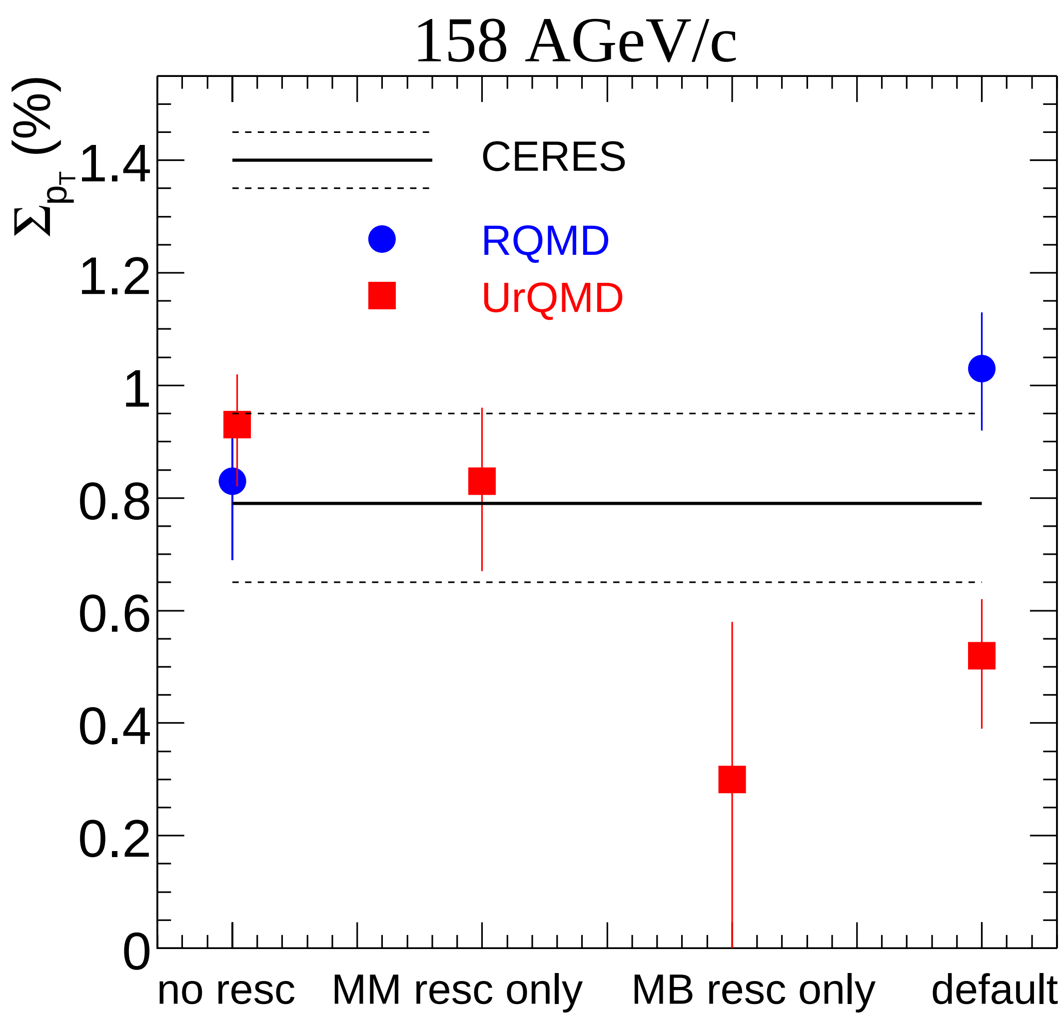
- Rescattering effect is weak.



NPA727(2003)97

Effect of rescattering

- Rescattering effect is opposite between RQMD and UrQMD
- Measured fluctuations are consistent with both models without rescattering

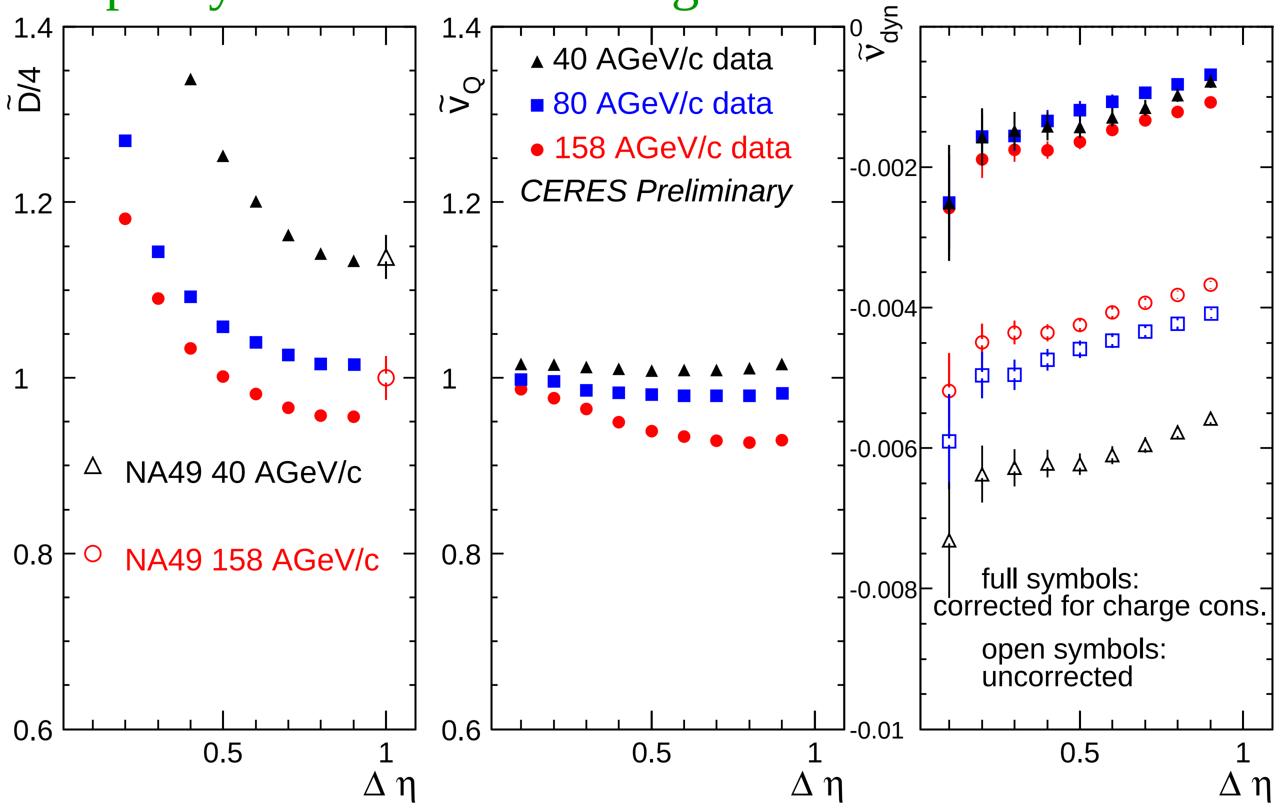


NPA727(2003)97

η range dependence of net-charge fluctuations

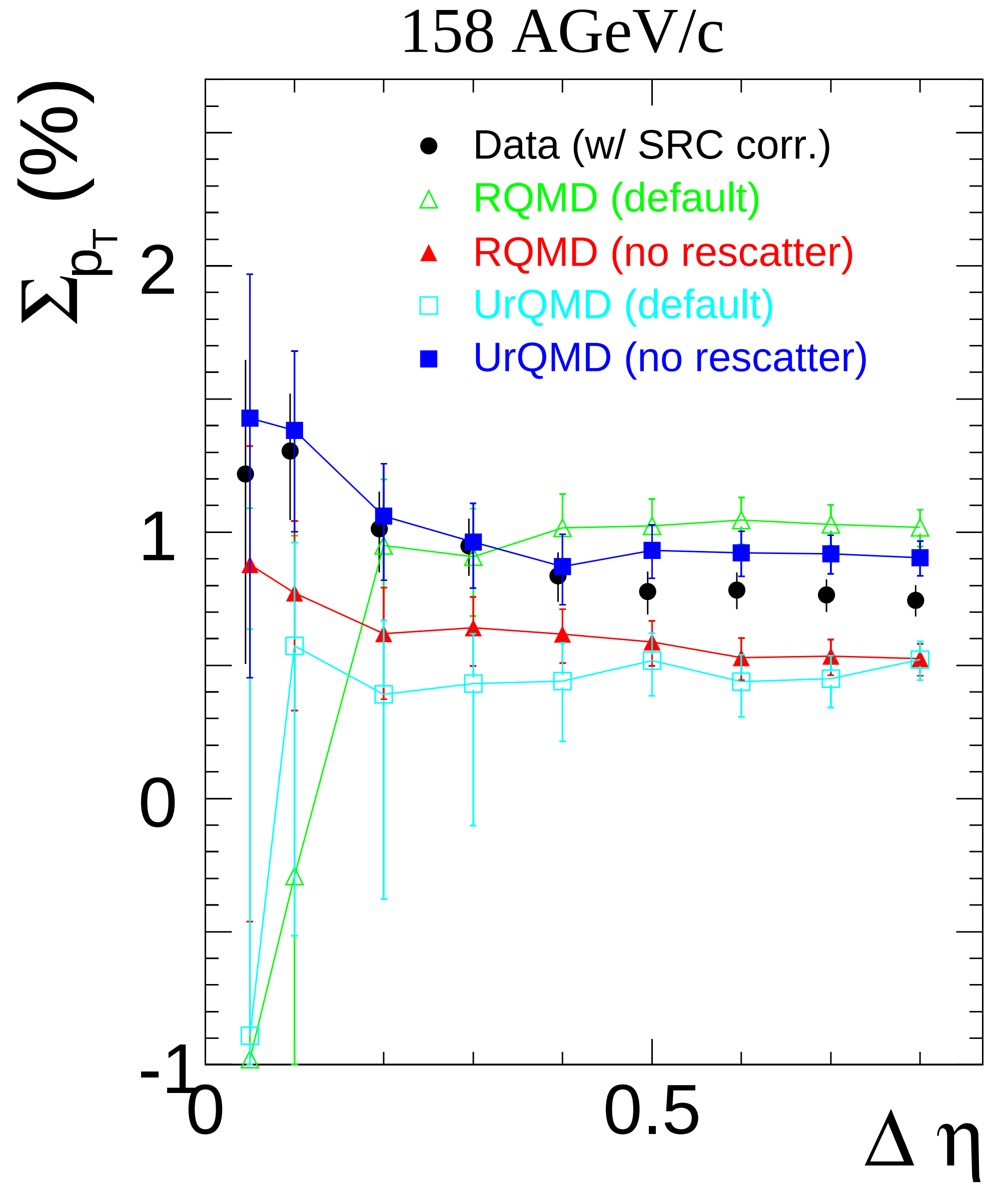
- Consistent with NA49 data at 40 and 158 AGeV/c
- Small difference of v_{dyn} in collision energies after correction for the charge conservation
- Decrease of $|v_{dyn}|$ as a function of $\Delta\eta$
  - Rapidity correlations of daughters from a resonance decay?

Δ η



Pseudo-rapidity range dependence

- Enhanced fluctuations at $\Delta\eta$<=0.4
- Similar trend in RQMD/UrQMD without rescattering
- Enhancement disappears in RQMD/UrQMD with rescattering



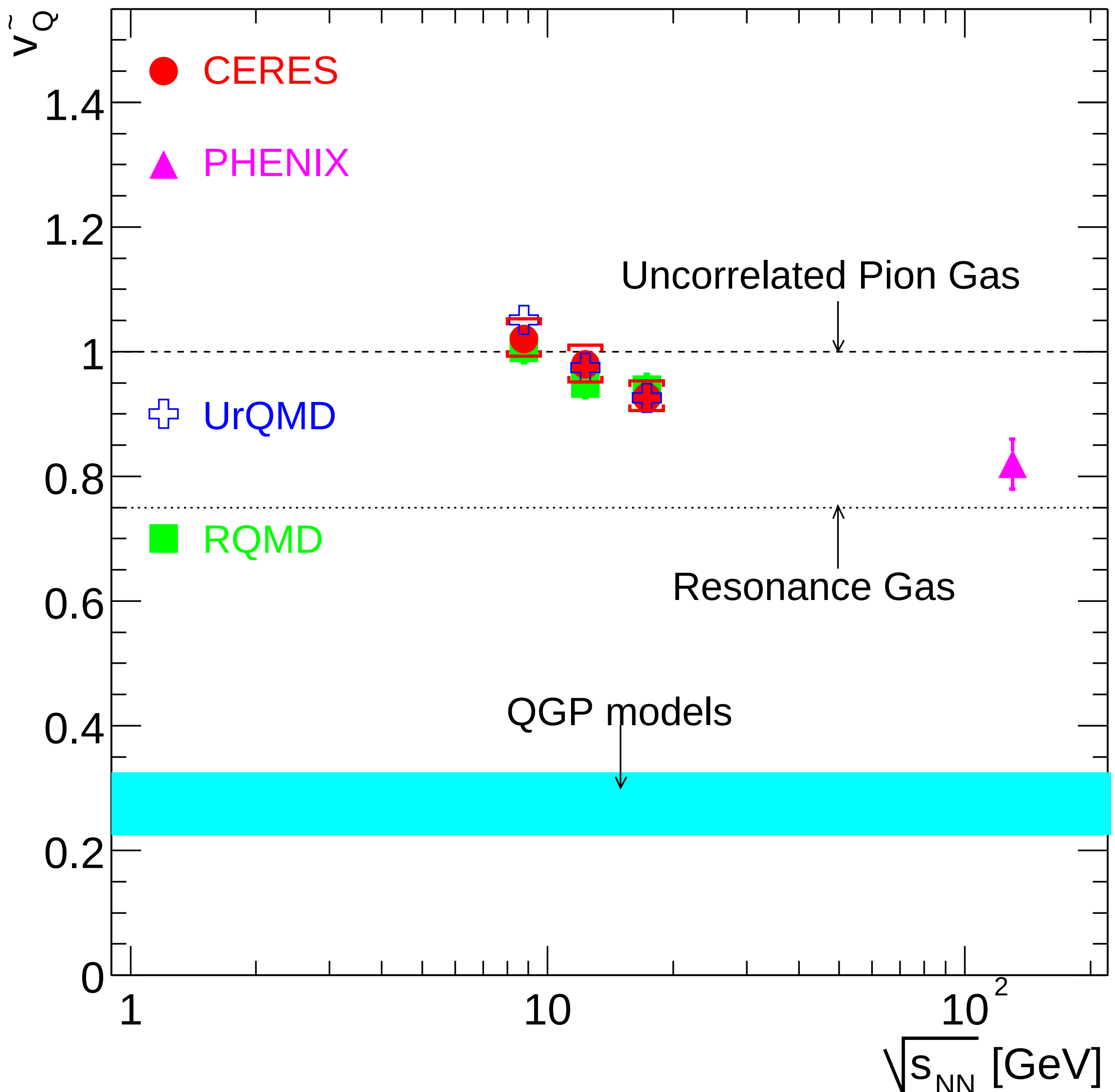
Net Charge Fluctuations

- Net-charge: $Q = N_+ - N_-$
- Measure

$$\tilde{v}_Q \cong \frac{\sigma^2_{real}}{\sigma^2_{stat}}$$

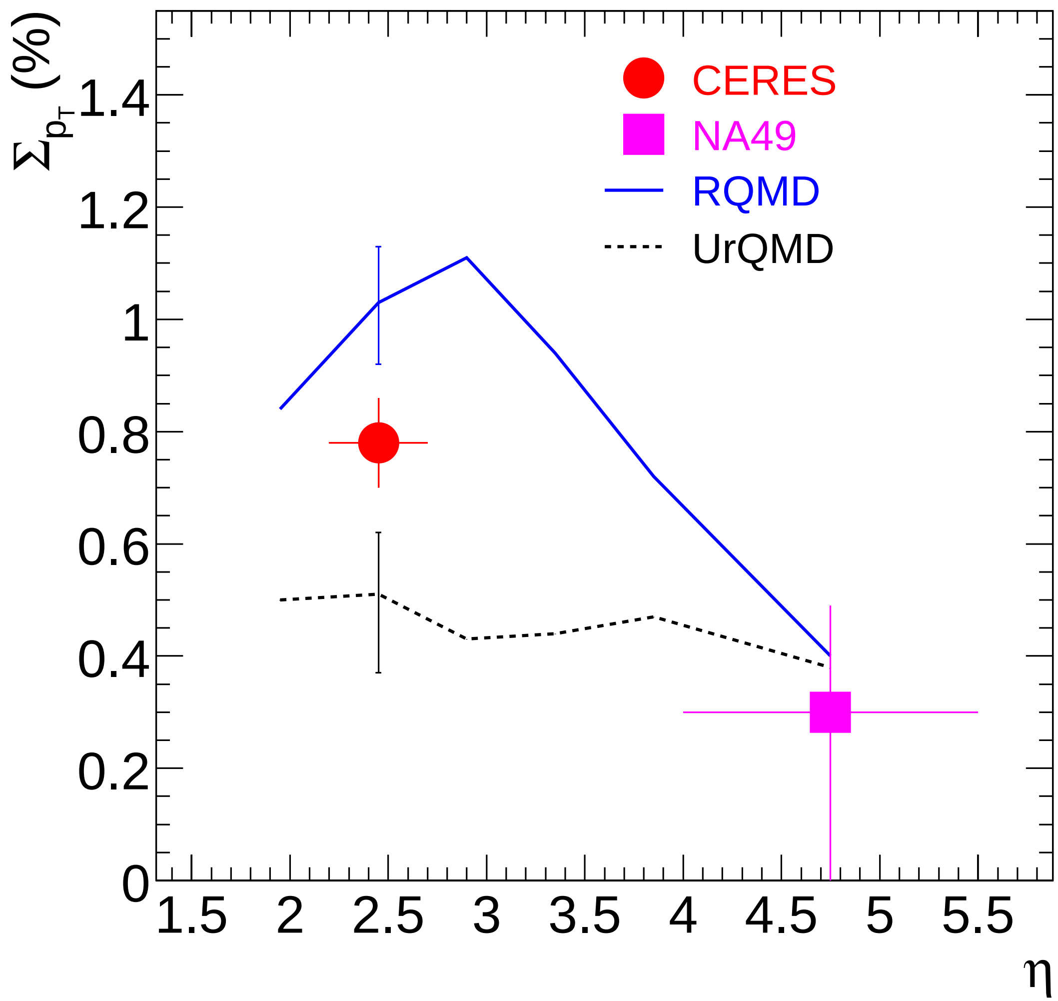
$$(\sigma^2_{stat} = (\langle N_+ \rangle + \langle N_- \rangle) C_y C_\mu)$$

- Fluctuations decrease 1 ~ 0.85 as a function of $s^{1/2}$
  - Increasing fraction of resonances?
- RQMD/UrQMD models reproduce SPS data
- No indication for QGP fluctuations
  - Hadron diffusion in y larger than the Δy_{acc}?



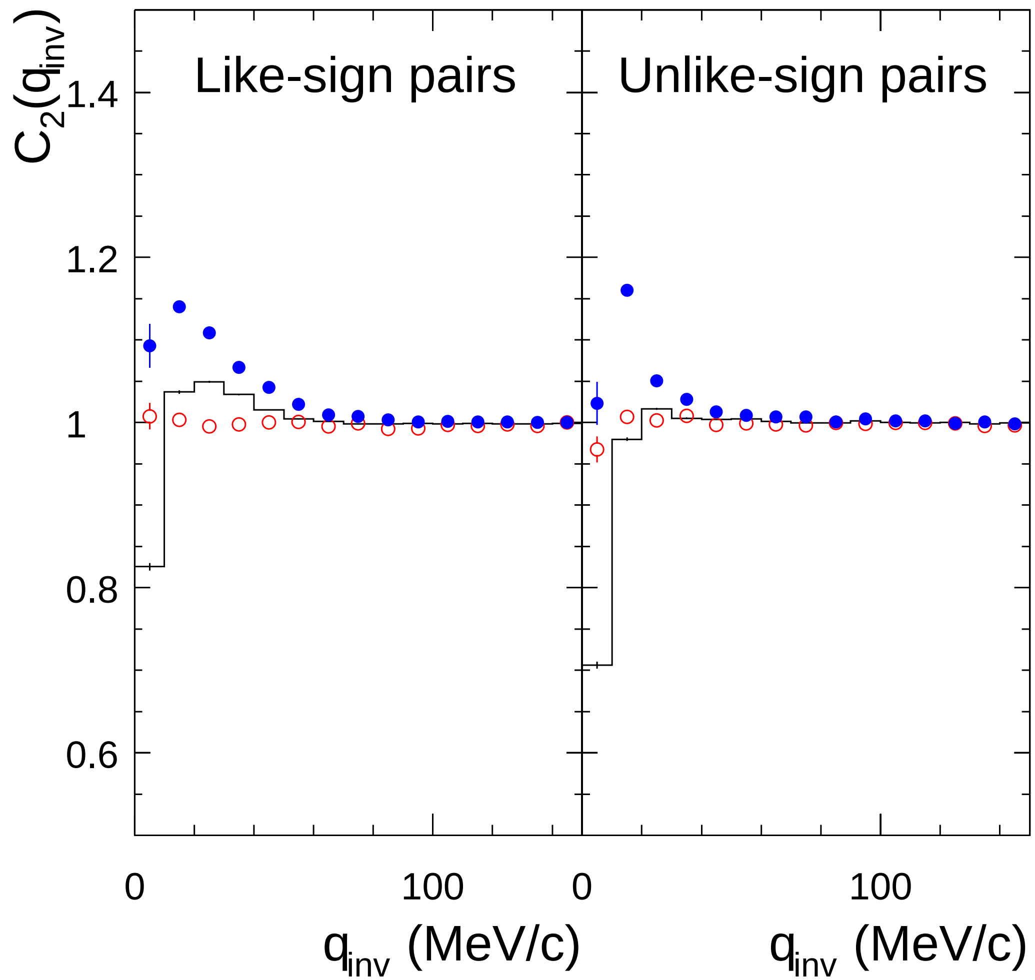
Pseudo-rapidity dependence of p_T fluctuations

- Data show higher fluctuations in mid-rapidity
- RQMD reproduces this tendency
- UrQMD has no η dependence



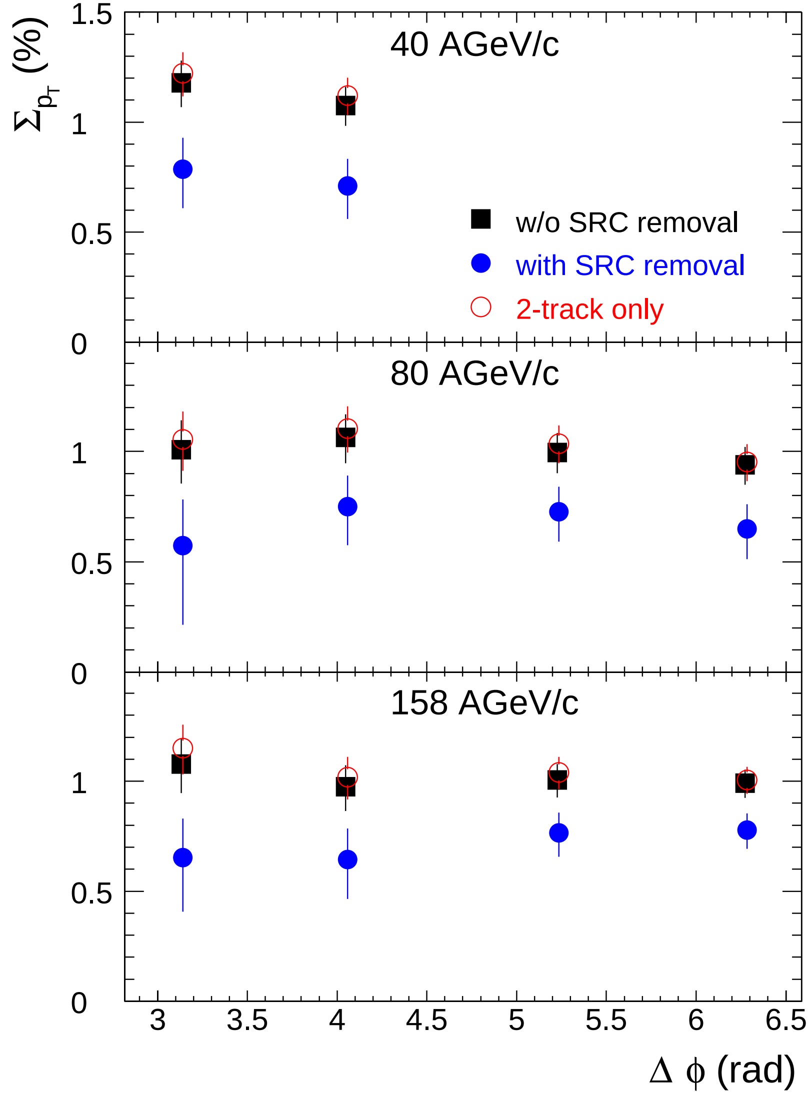
Corrections for HBT/Coulomb correlations and two-track resolution

- Method
  1. Remove tracks with small q to another track with a probability
  2. Add tracks from another event with close opening angles to a real track to correct for lost tracks due to two-track resolution
  3. Repeat 1. and 2. until the resulting correlation function is flat as a function of q

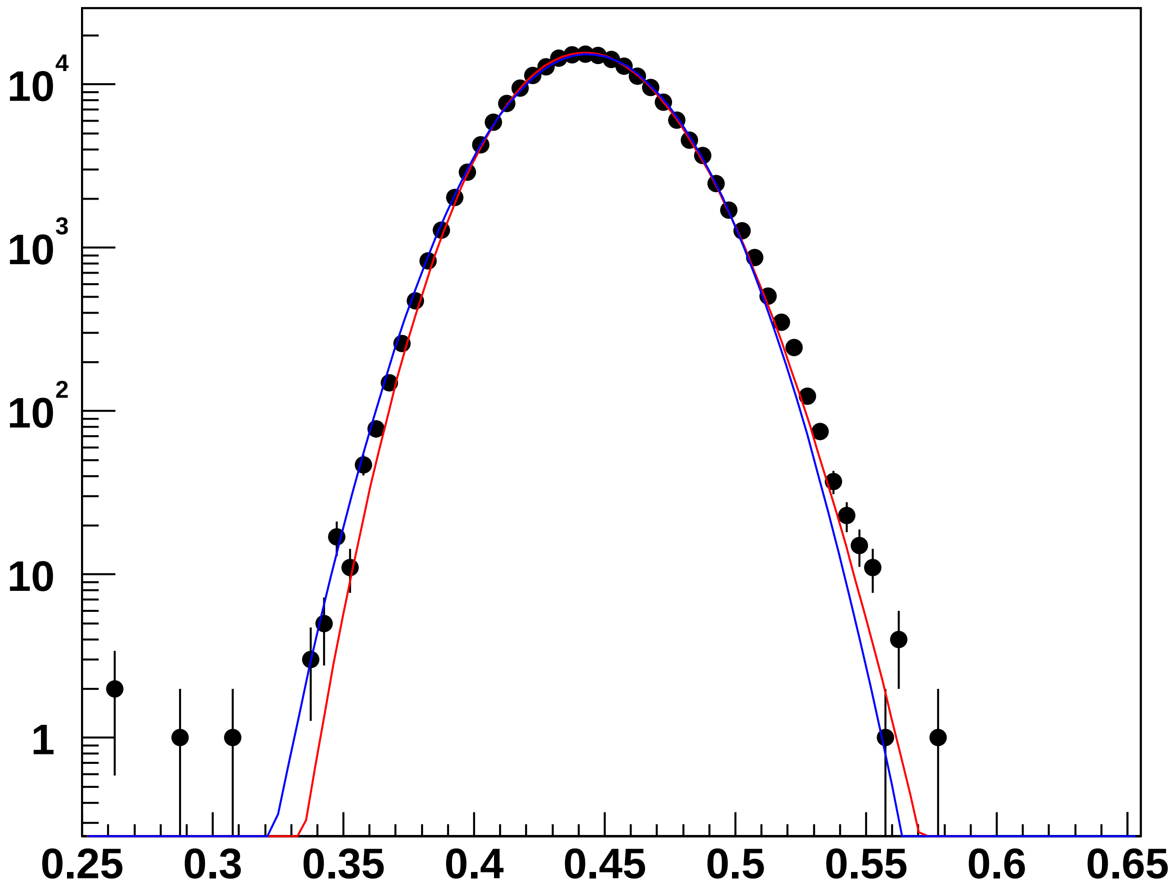


P_T fluctuation after corrections for HBT and two-track resolutions

- After SRC removal, fluctuations reduce by ~ 30%
- Weak $\Delta\phi$ dependence from $\pi/2$ to 2π.



Gamma fit



Statistics and centrality selection

No. of Pb+Au events

P_{beam}	#event
40 AGeV/c	1.4M
80 AGeV/c	0.5M
158 AGeV/c	0.5M

Centrality selection

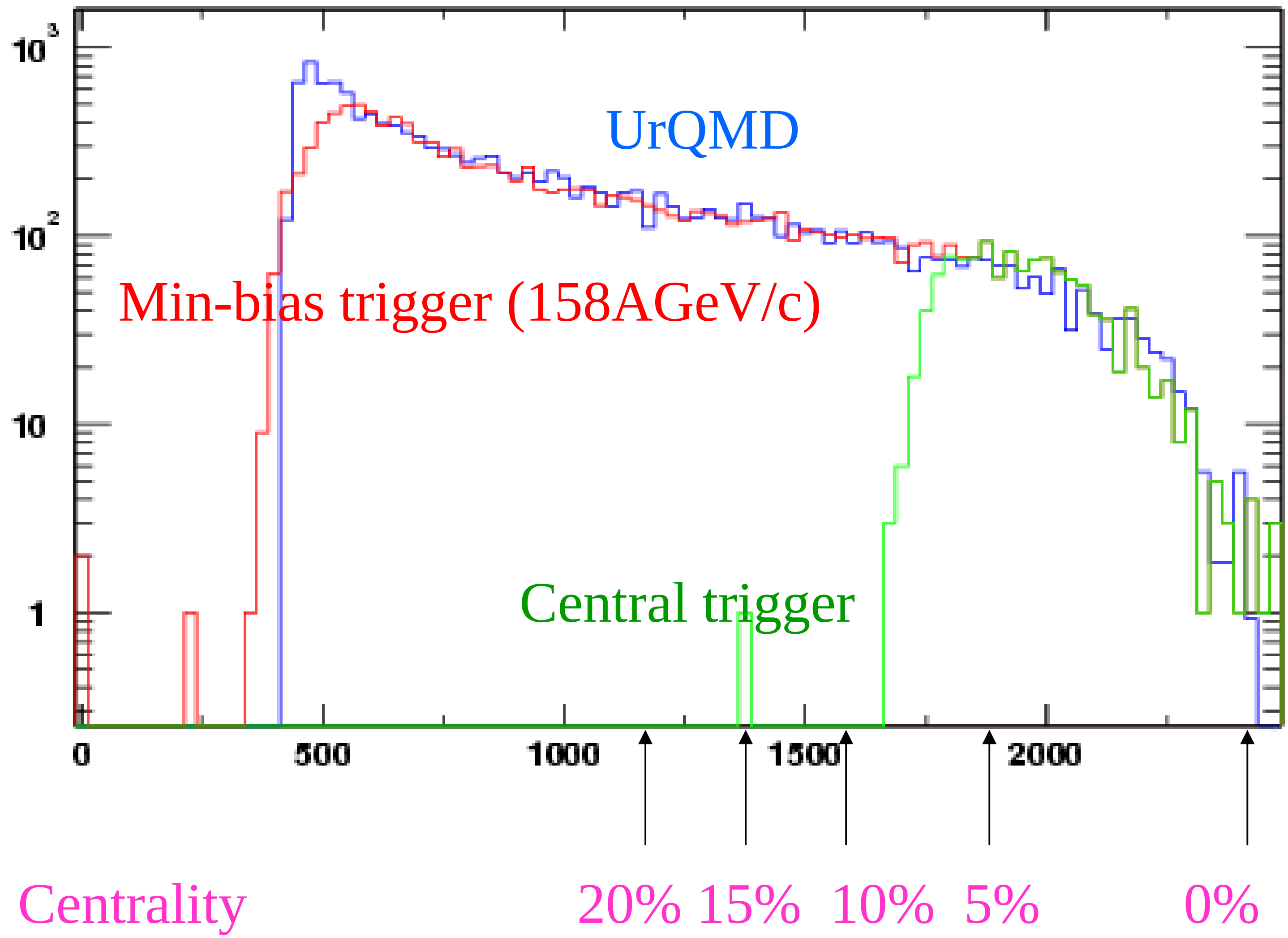
- Multiplicity in SDDs (40 GeV) Multiplicity Counter (80/158 GeV)
- Number of participant nucleons is estimated with a geometric nuclear overlap (Glauber) model

σ/σ_{geo}	b	$\langle N_{part} \rangle$
0-5%	0-3.3 fm	358
5-10%	3.3-4.7 fm	289
10-15%	4.7-5.8 fm	240
15-20%	5.8-6.6 fm	200

Centrality determination

- Determination of centrality
  - 0%-100% of the total Pb+Au inelastic cross section
  - 0% -> impact parameter=0

Multiplicity Counter gain distribution



Systematic errors (6.5% most central)

P_T fluctuation

	40GeV	80GeV	158GeV
Tracking efficiency	+-0.11%	+-0.11%	+-0.06%
Pile-up events	+-0.03%	+-0.03%	+-0.03%
Momentum scale	$^{+0.08}_{-0.03}$%	$^{+0.05}_{-0.07}$%	$^{+0.02}_{-0.07}$%
Fiducial cut	+-0.01%	-	-
SDD-TPC assoc.	+-0.02%	+-0.02%	+-0.02%
χ^2,vertex cut	$^{+0.39}_{-0.04}$%	$^{+0.13}_{-0.01}$%	<+- 0.01%
Total	**$^{+0.41}_{-0.23}$%**	**$^{+0.18}_{-0.13}$%**	**$^{+0.12}_{-0.13}$%**

Net-charge fluctuation

	40GeV	80GeV	158GeV
Pile-up events	+-0.0001	+-0.0001	+-0.0001
ϕ extrapolation	+-0.0003	-	-
SDD-TPC assoc.	$^{+0.0000}_{-0.0005}$	$^{+0.0000}_{-0.0004}$	$^{+0.0000}_{-0.0004}$
χ^2,vertex cut	$^{+0.0001}_{-0.0001}$	$^{+0.0000}_{-0.0003}$	$^{+0.0001}_{-0.0002}$
Total	**$^{+0.0006}_{-0.0006}$**	**$^{+0.0001}_{-0.0005}$**	**$^{+0.0004}_{-0.0005}$**

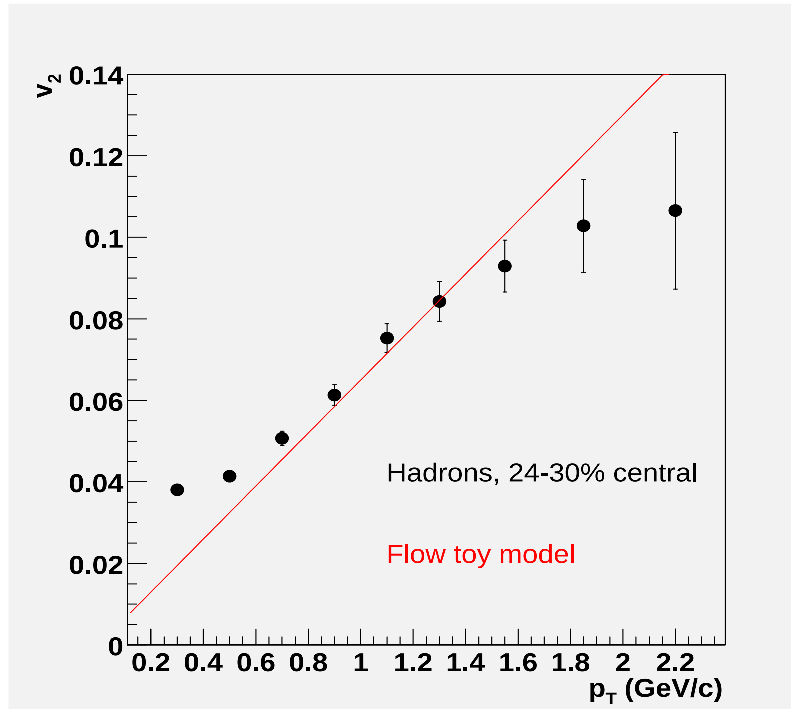
Flow toy model

- Pt and multiplicity distributions from the real data (158AGeV)
- Flow input
  - Reaction plane angle changes randomly

$$\frac{dN}{d(\phi-\Phi)} = A[1+2v_2\cos(2(\phi-\Phi))]$$

$$v_2 = 0.065\times p_T$$

  - No pt fluctuations produced (track efficiency 80-100%, ebe v2 fluctuations 0-50%),
    - Σpt <0.3% in and Fpt <0.2%

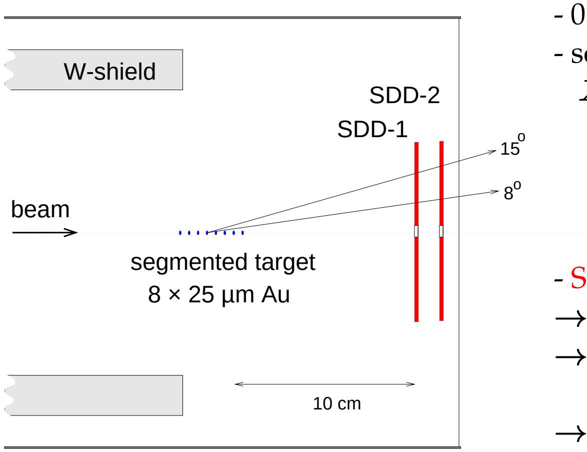


Tracking selection and parameters

- Track Selection
  - TPC tracks (no. of hits >= 11-14 out of 20)
  - Target cut (projection of TPC track on the primary vertex < 4cm)
- Momentum resolution
  - $\Delta p/p = \mathbf{(0.024^2+(0.036p)^2)^{1/2}}$ at 40 AGeV
  - $= \mathbf{(0.015^2+(0.016p)^2)^{1/2}}$ at 80, 158 AGeV
- Acceptance
  - ~ 60% of TPC at 40 AGeV
  - >90% at 80, 158 AGeV
- Tracking efficiency
  - Better than 85% at p_T>0.05GeV/c
- 2-particle resolution
  - ~5 mrad in TPC

Target area

Target Area

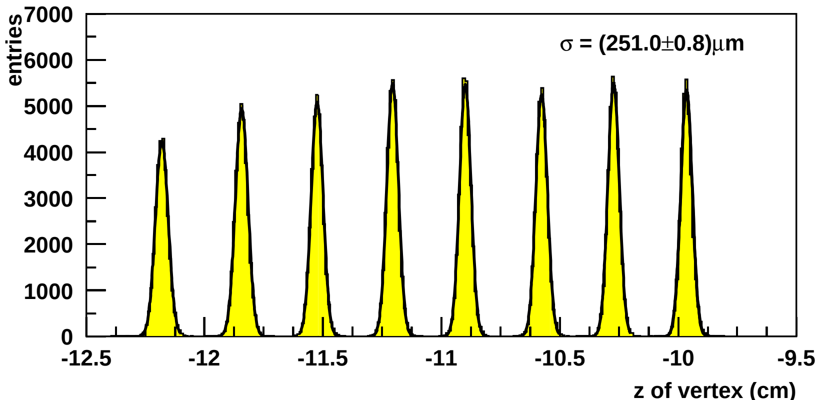


- 0.83% interaction length
- segmented micro-target $X/X_0 \approx 0.3\,\%$

- Silicon Drift Detectors
$\rightarrow N_{ch}(\eta = 1.9 - 3.9)$
$\rightarrow$ vertex, tracking to RICH
$\rightarrow$ conversion and Dalitz rejection (dE/dx)

vertex resolution for $\langle N_{ch} \rangle \approx 165$

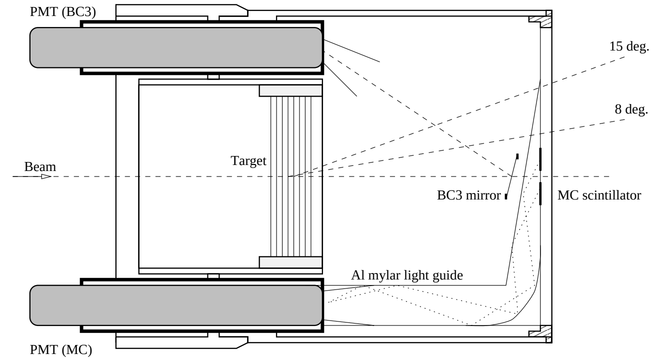
$\sigma_z = 251\ \mu m \qquad \sigma_{x,y} = 28\ \mu m$



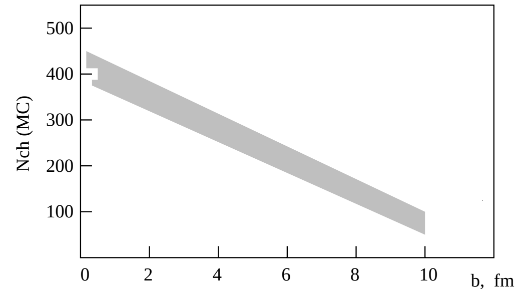
Scintillation Counter for a Measurement of Charged Particle Multiplicity in Angular Acceptance of 2-6 deg. in the Target Area as a Part of the Detector System of the First Level Trigger

FLT = BC1 ⊕ BC2 ⊕ $\overline{\text{BC3}}$ ⊕ MC ⊕ MD

1. The new counter, MC, layout (1-mm scintillator with 4.9-mm inner and 14.7-mm outer diameters, 2.95< η <4.05).



2. Result of Simulation - a dependence of charged particle multiplicity (or the pulse height of the counter) on an impact parameter of 160-GeV/n Pb-Au collisions.



3. Results of test measurements with the β– source at MPI (1-mip response).