Correlations and fluctuations from CERES

Dariusz Miskowiec, GSI Darmstadt

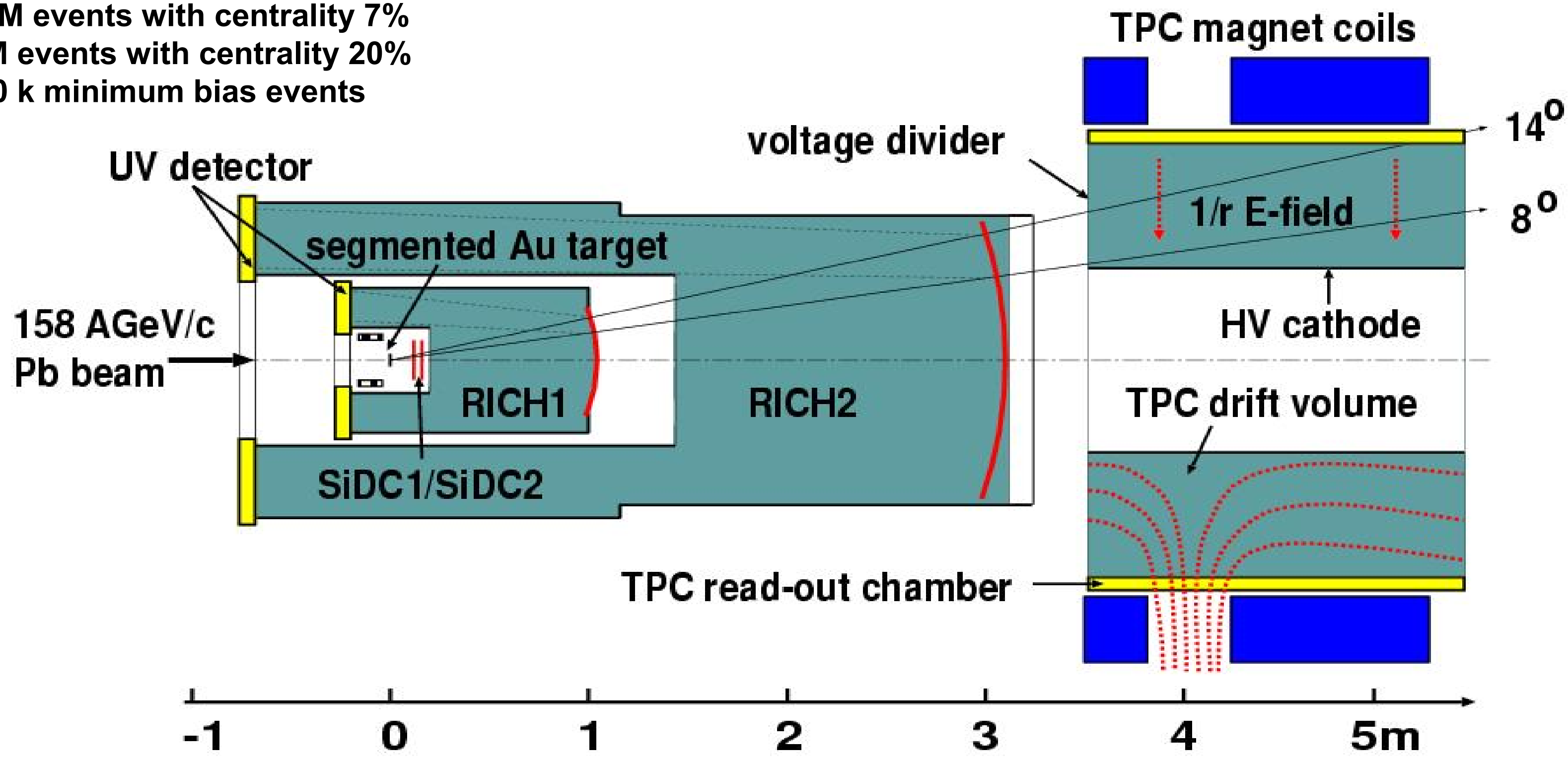
Critical Point and Onset of Deconfinement, Darmstadt, July 2007

CERES run history

1990	installation	
1991	completed	
1992	200 GeV S+Au	4M central 445 open pairs
1993	450 GeV p+Be 450 GeV p+Au	10M pairs 3M pairs
1995	160 GeV Pb+Au	10M central
1996	160 GeV Pb+Au	50M central 2700 open pairs
1997	upgrade	
1998	upgrade	
1999	40 GeV Pb+Au	10M central 185 open pairs
2000	80 GeV Pb+Au 160 GeV Pb+Au	1M central 30M central

setup with TPC: 1999 and 2000

run 2000: 30 M events with centrality 7%
2 M events with centrality 20%
500 k minimum bias events



CERES built and upgraded for leptons; but also good for...

pt spectra, elliptic flow, two-particle correlations of hadrons

this talk

- azimuthal dependence of pion HBT radii
- pt fluctuations

this talk

- ***azimuthal dependence of pion HBT radii***
  (Dariusz Antonczyk, Ph.D. work)
- ***pt fluctuations***
  (Georgios Tsiledakis, Ph.D. work)

azimuthal dependence of two-pion correlations (HBT) in central Pb+Au at 158 GeV per nucleon

pion-pion correlation function

correlation function
= pair distribution,
normalized to event mixing

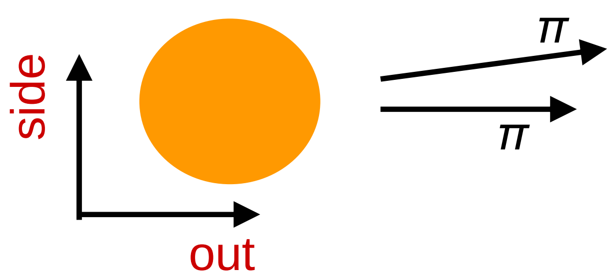
$$C_2(\mathbf{P},\mathbf{q}) = \frac{n(\mathbf{p}_1,\mathbf{p}_2)}{n(\mathbf{p}_1)\, n(\mathbf{p}_2)}$$

with mean momentum $\mathbf{P} = (\mathbf{p}_1 + \mathbf{p}_2) / 2$

and momentum difference $\mathbf{q} = \mathbf{p}_2 - \mathbf{p}_1$

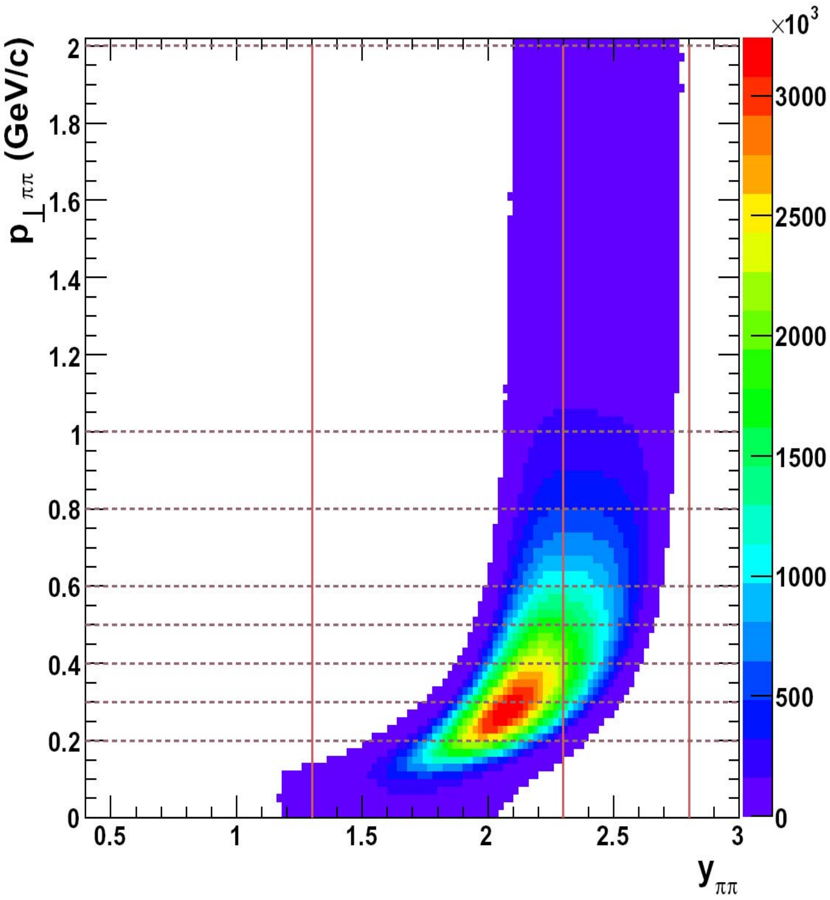
Bertsch-Pratt coordinates
LCMS frame

$\mathbf{q} = (q_{out}, q_{side}, q_{long})$

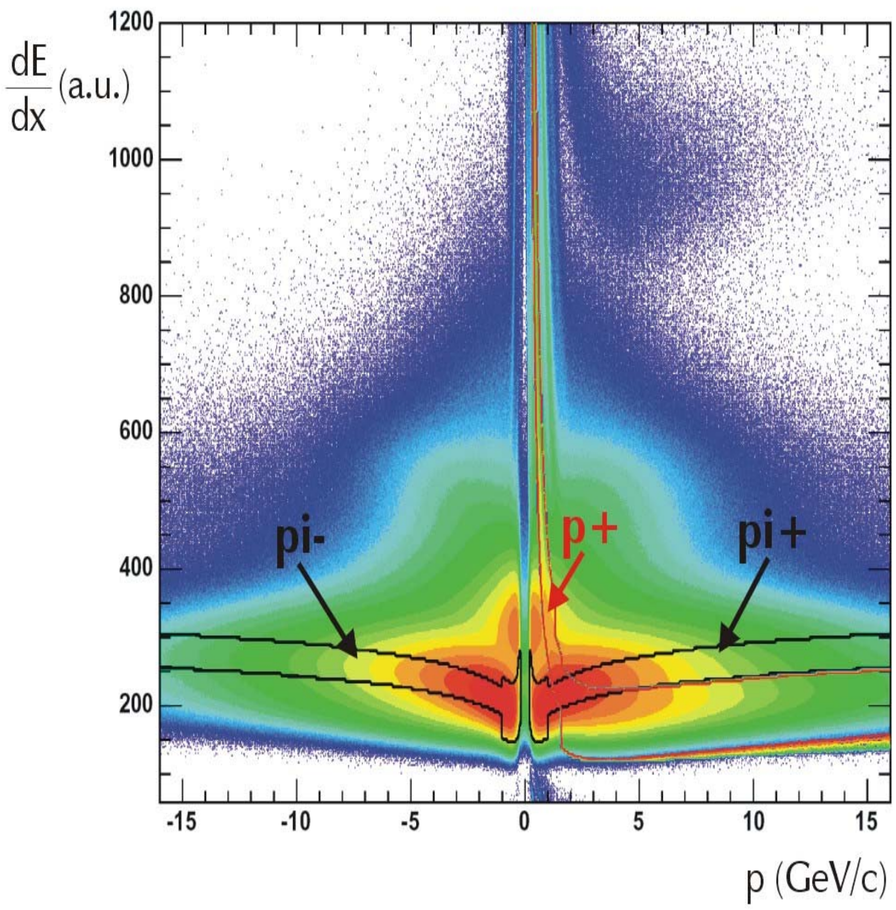


acceptance and particle id

Pb+Au at 158 AGeV

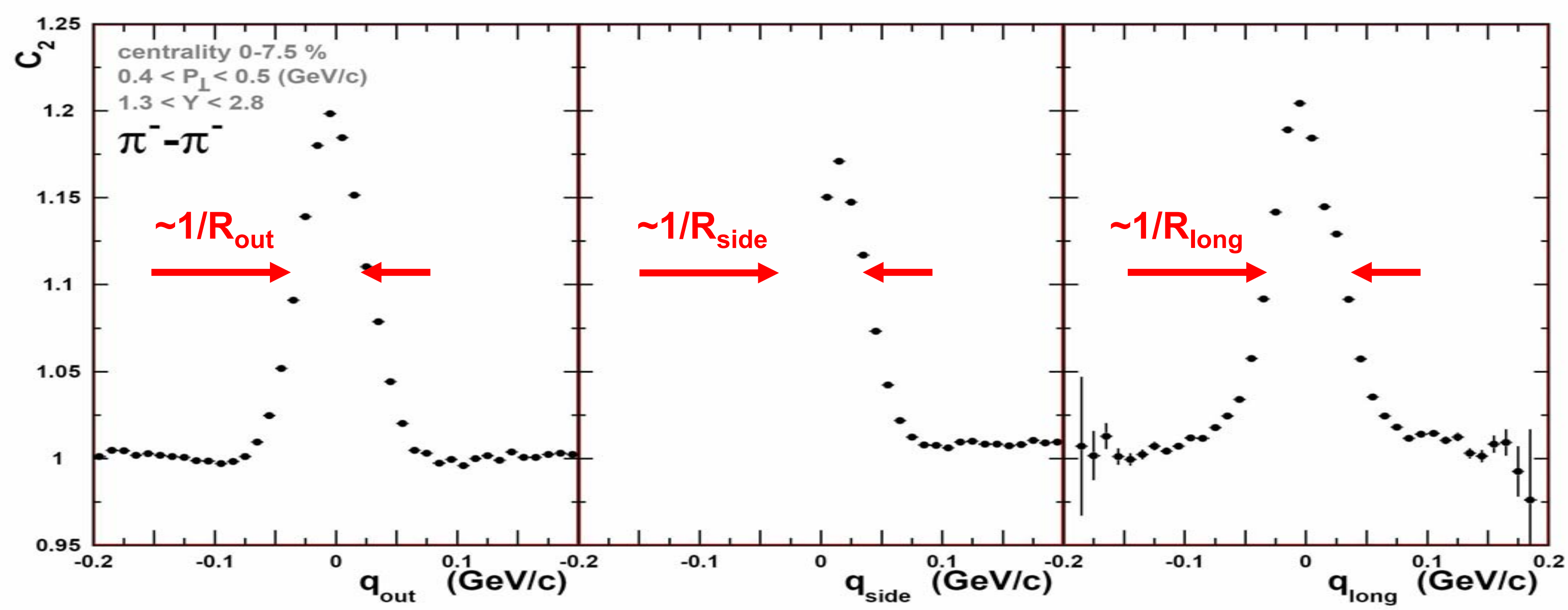


midrapidity: y=2.91



two-pion correlation function

Pb+Au at 158 AGeV ***D. Antonczyk***



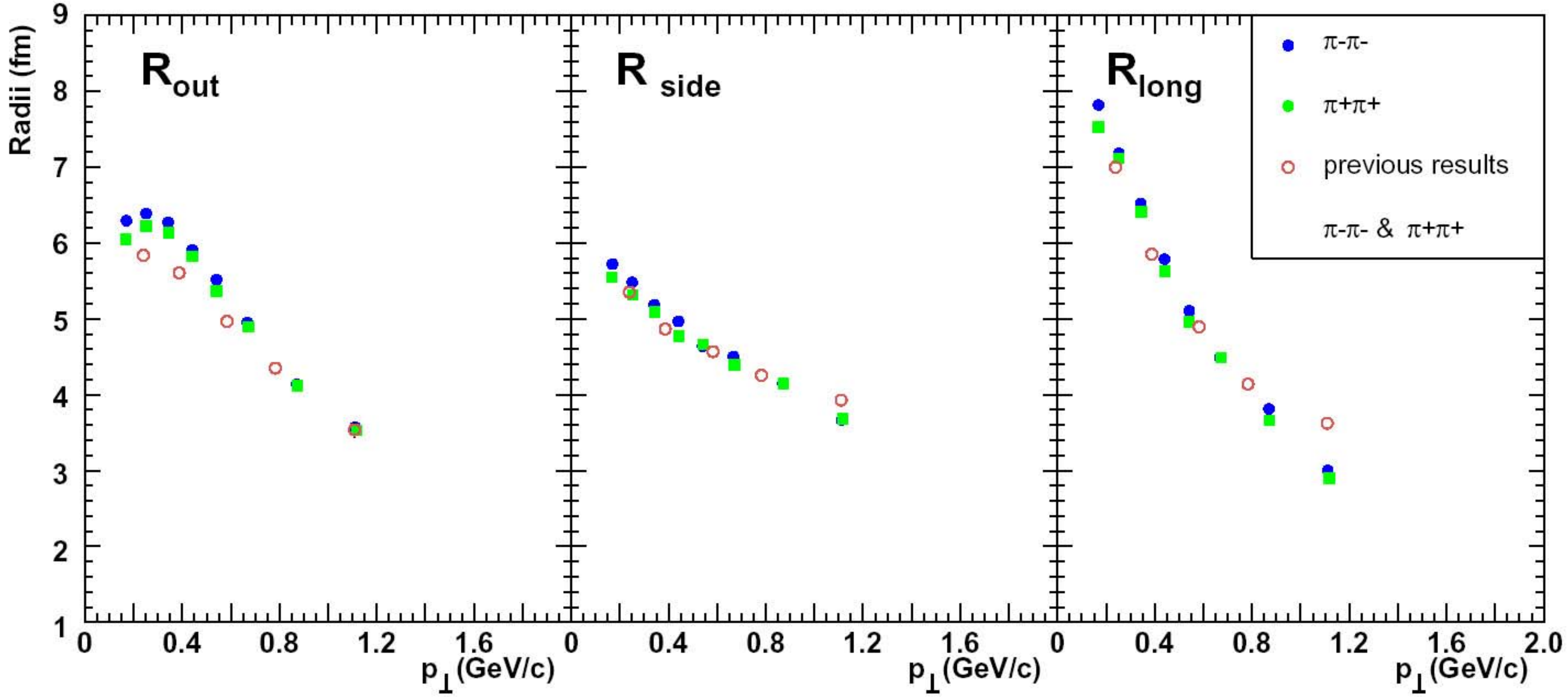
fit with $$C_2(q) = 1 + \lambda \exp\left\{ \sum_{i,j} R_{i,j}^2 q_i q_j \right\}$$ *with i,j = out, side, long*

correct for Coulomb and finite momentum resolution

HBT radii: pt dependence

Pb+Au at 158 AGeV
centrality 5%

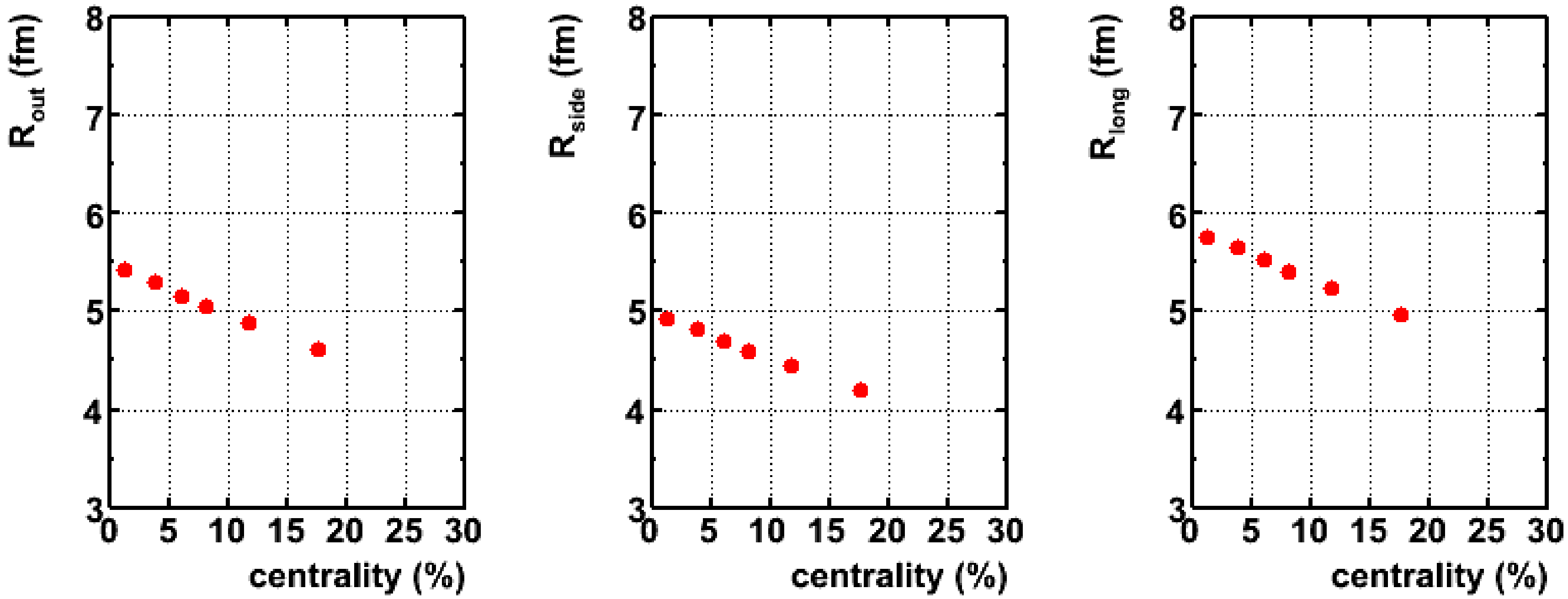
D. Antonczyk



HBT radii: centrality dependence

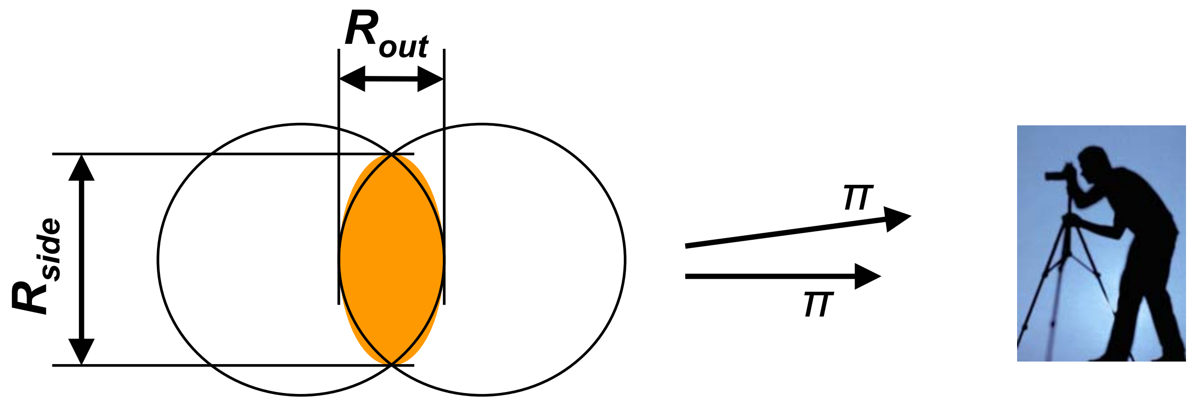
Pb+Au at 158 AGeV
< p_t > = 0.47 GeV/c

D. Antonczyk

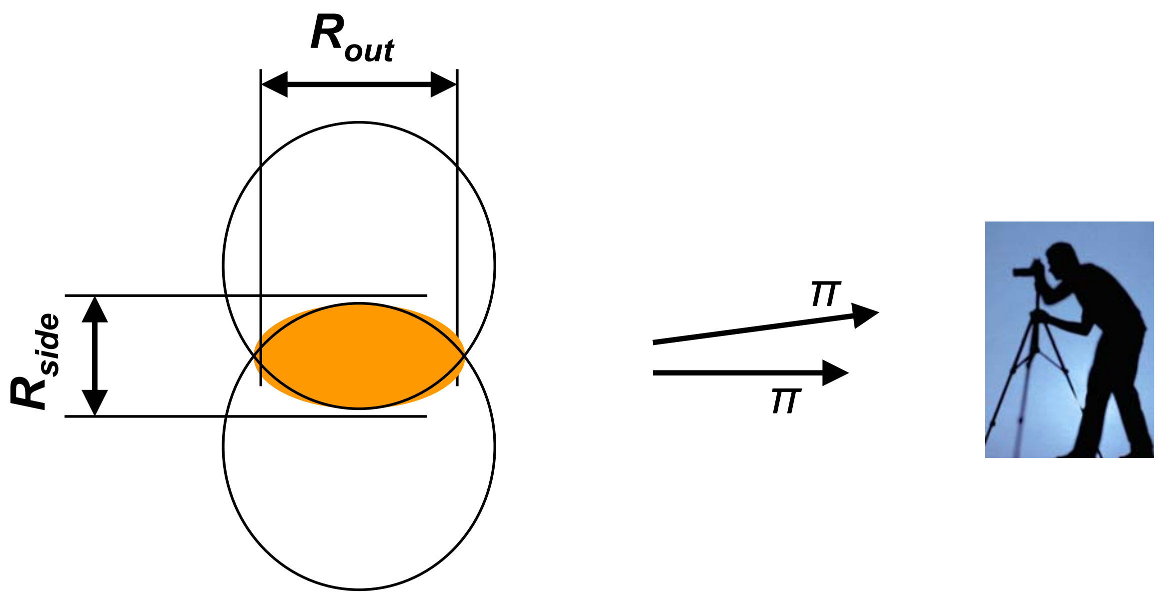


centrality – fraction of σ_{GEOM} = 6.94 b

HBT radii vs azimuthal pion angle - expectation

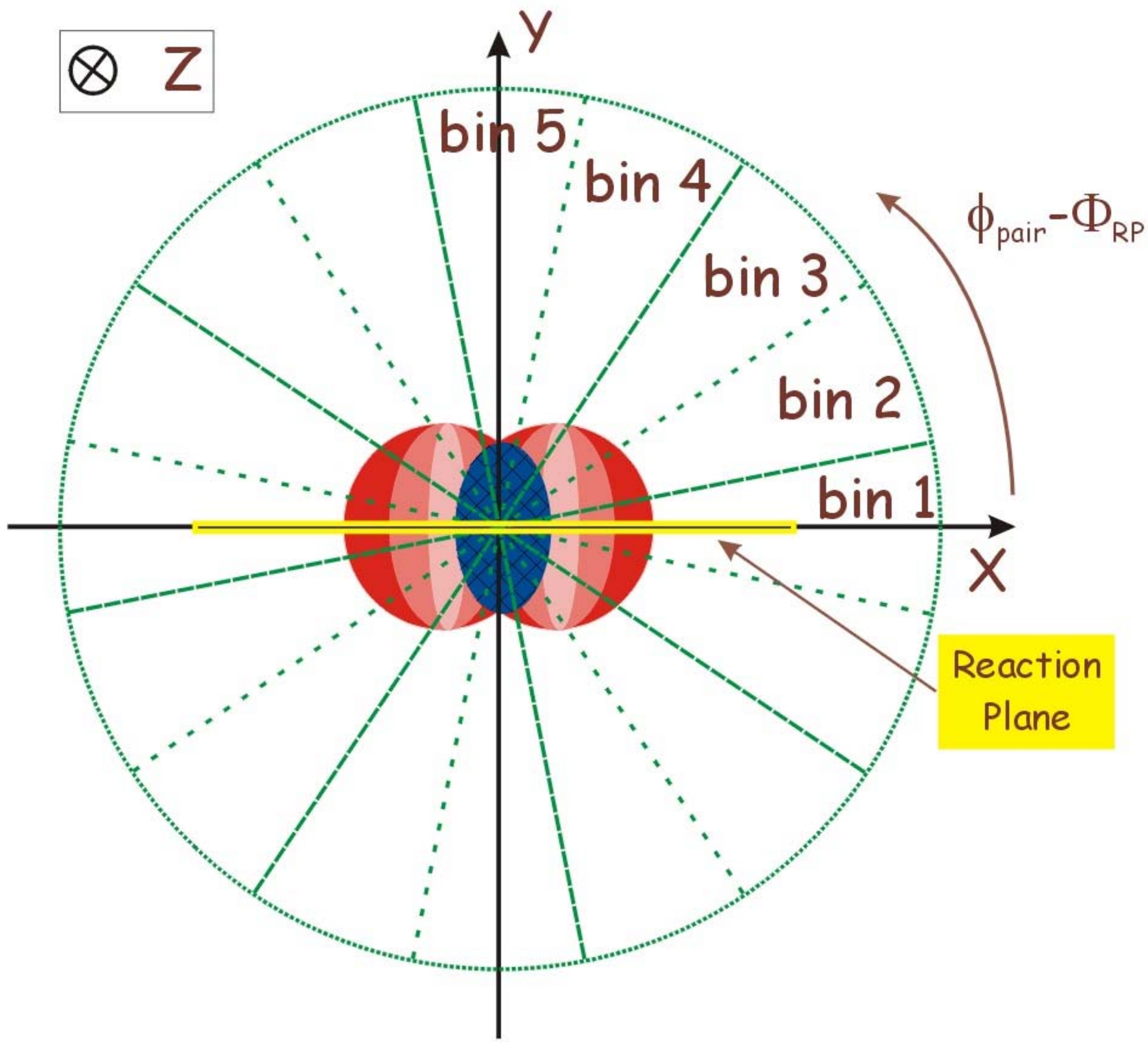


in-plane

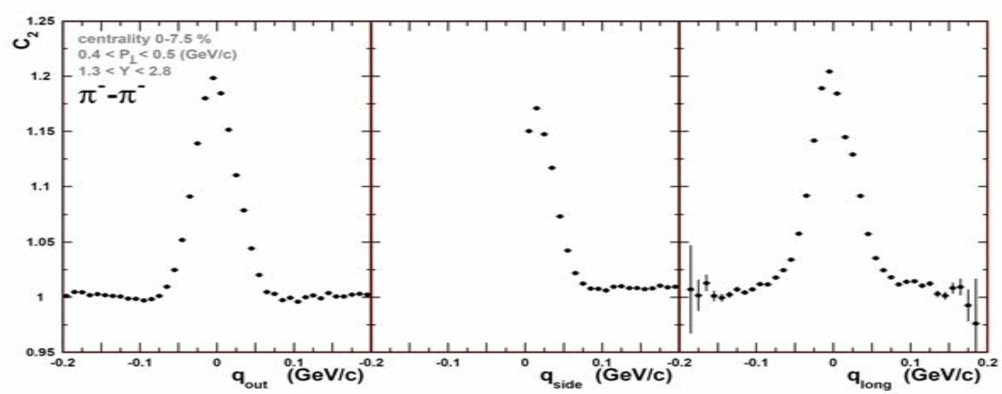


out-of-plane

HBT radii in bins of the azimuthal pair angle



pion-pion correlation function



3-dimensional fit to C_2 performed
R_{out}, R_{side}, R_{long}, R_{ol}, R_{os}, R_{sl} extracted

*separately in each **Φ**-bin*

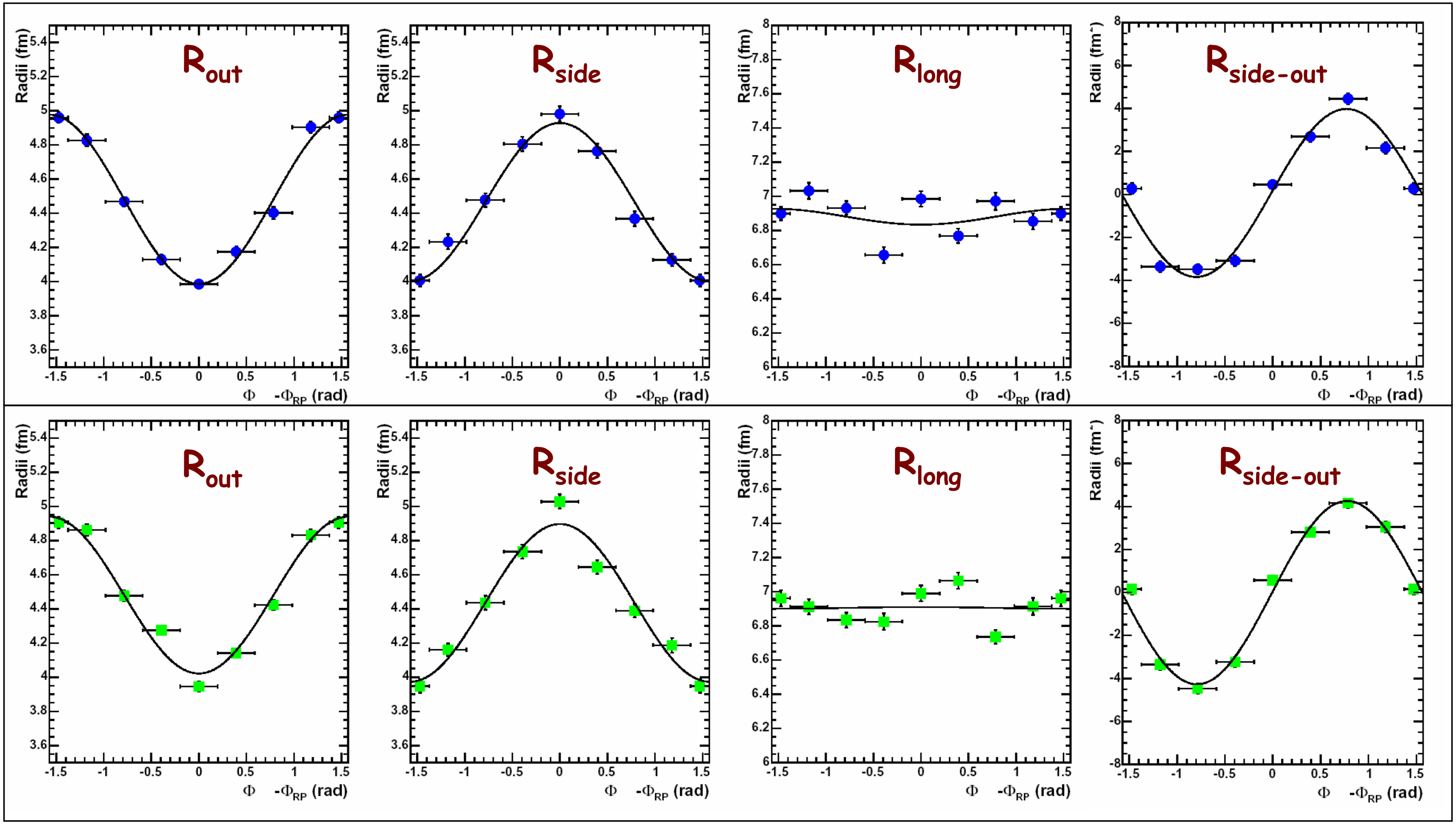
$\boldsymbol{\Phi = \Phi_{\pi\pi} - \Phi_{RP}}$
azimuthal pair angle with respect to RP

azimuthal angle dependence of the HBT radii - simulation

D. Antonczyk

- $\pi^-\pi^-$
- $\pi^+\pi^+$

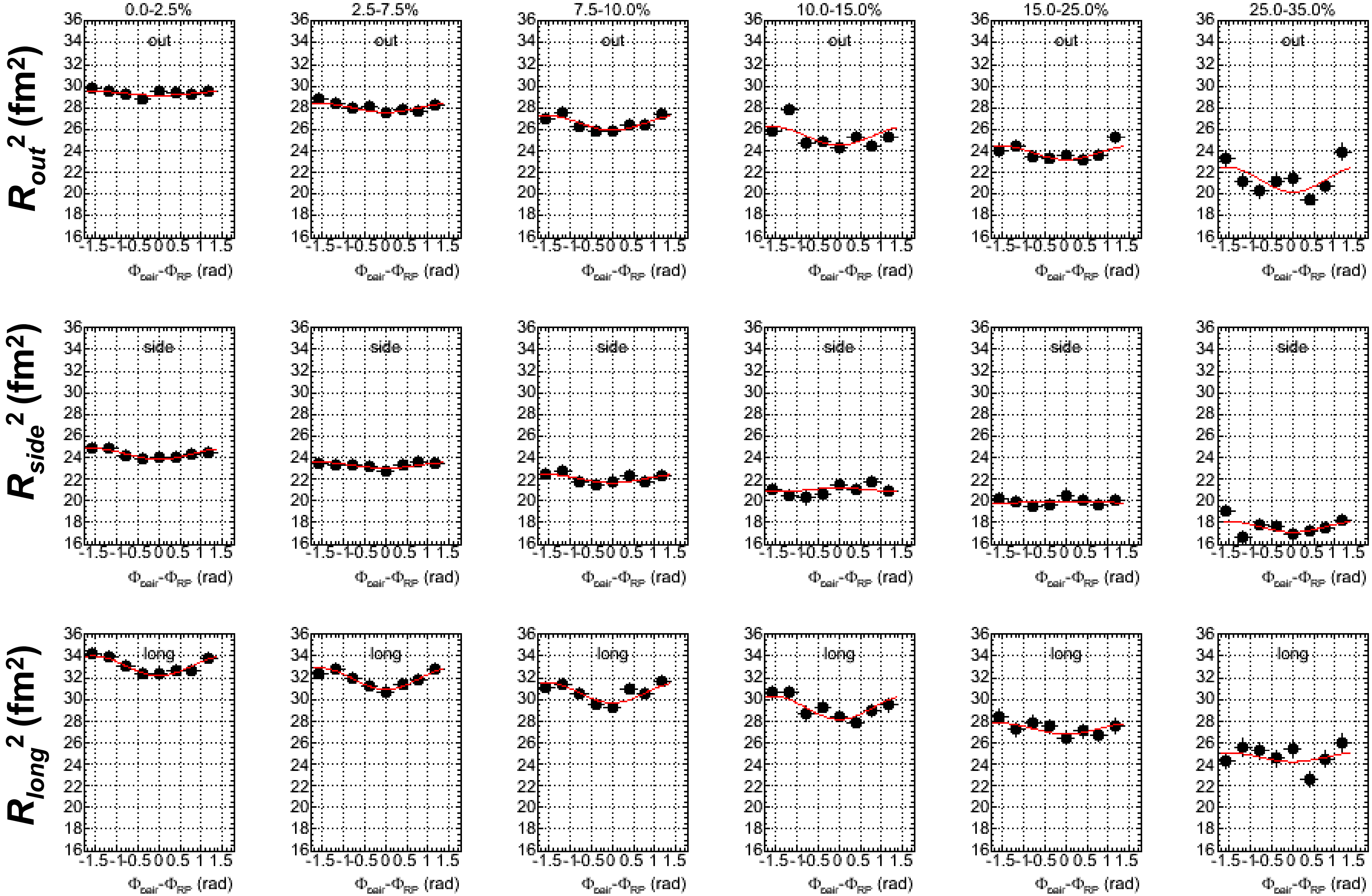
Gaussian source parameterization with R_x = 4 (fm), R_y = 5 (fm), R_z = 7 (fm)



azimuthal angle dependence of HBT radii

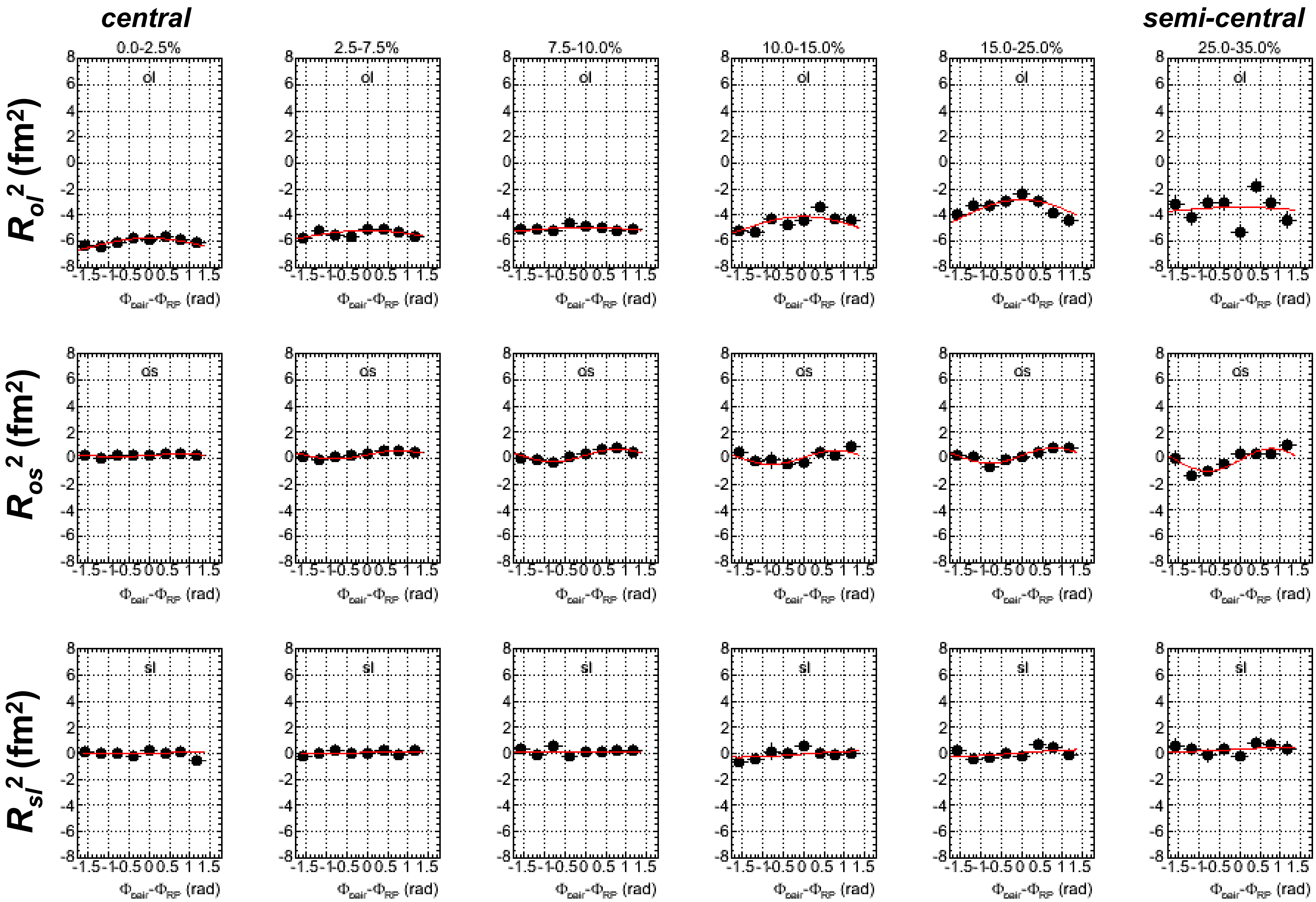
Pb+Au at 158 AGeV ***D. Antonczyk***

central ***semi-central***



azimuthal angle dependence of HBT radii

Pb+Au at 158 AGeV ***D. Antonczyk***

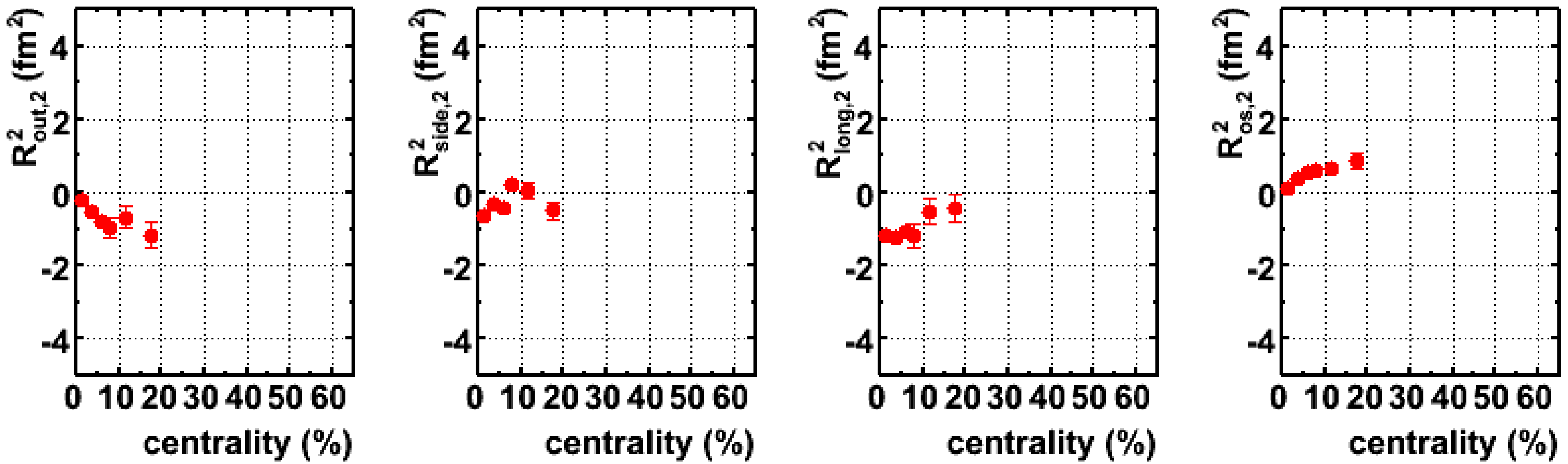


pion source size anisotropy

Pb+Au at 158 AGeV
preliminary

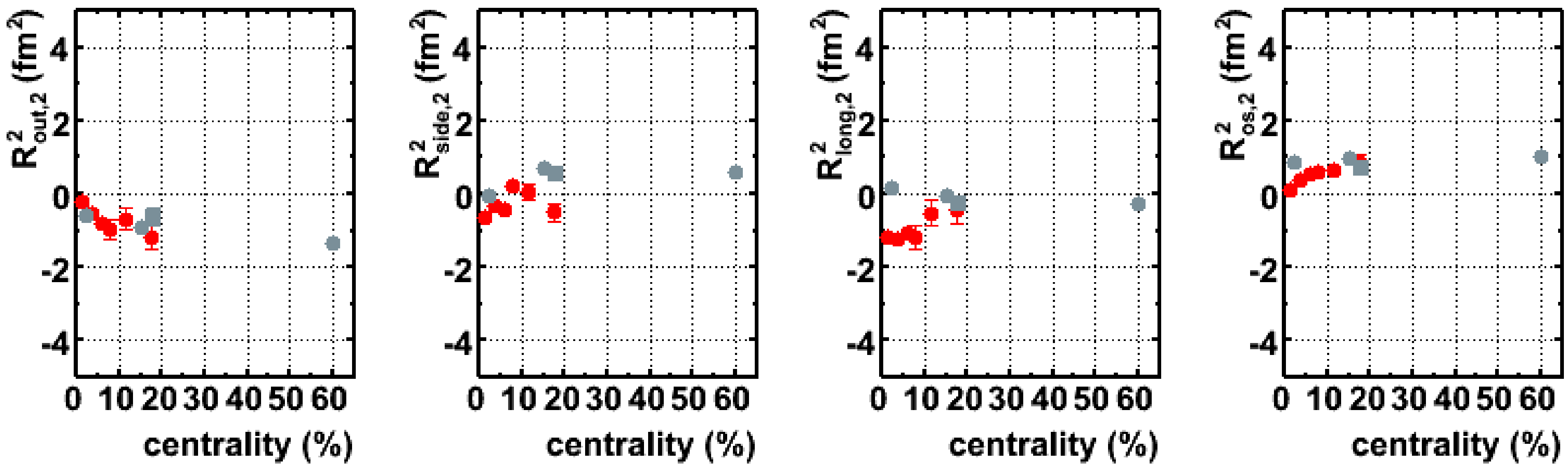
D. Antonczyk

parametrize the oscillation with $R_i^2 = R^2_{i,0} + 2\,R^2_{i,2} \cos[2(\Phi_{\pi\pi}-\Phi_{RP})]$ →



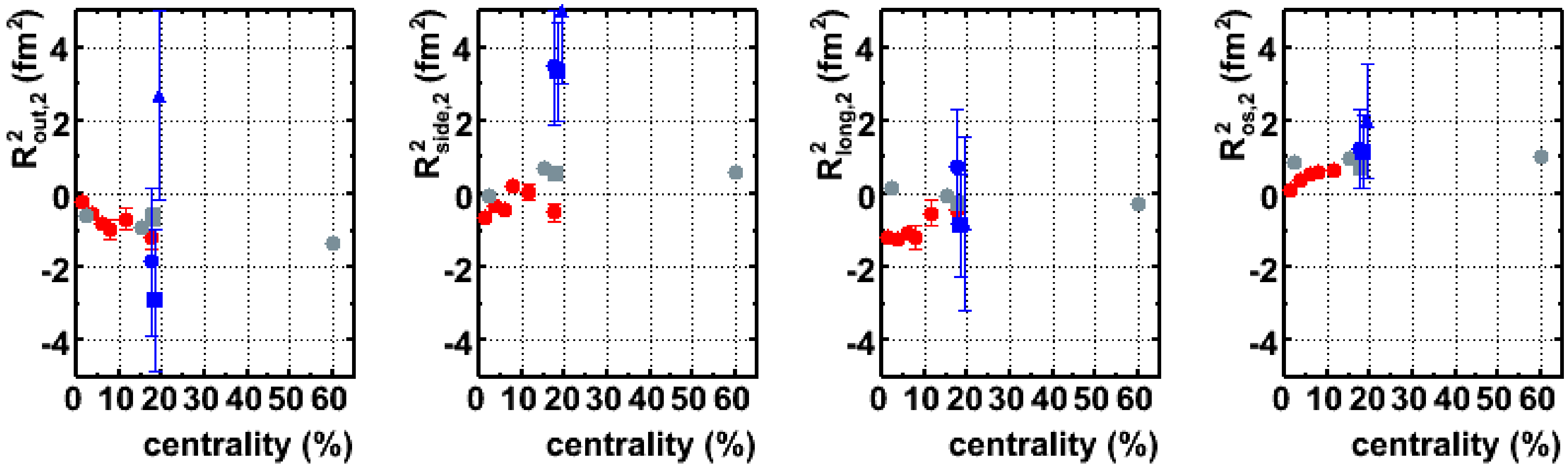
⇧ suggests an out-of-plane elongation	⇧ no effect -- inconsistent with R_{out}	⇧ significant -- against expectation and symmetry	⇧ consistent with R_{out}

...compared to RHIC



● *CERES*	*158 AGeV*	*<pt> = 0.47 GeV/c*	*D. Antonczyk, Ph.D.*
■ *STAR*	*sqrt(s) = 130 GeV*	*0.125<pt<0.45 GeV/c*	
● *STAR*	*sqrt(s) = 200 GeV*	*0.15<pt<0.6 GeV/c*	*PRL 93 (2004) 012301*

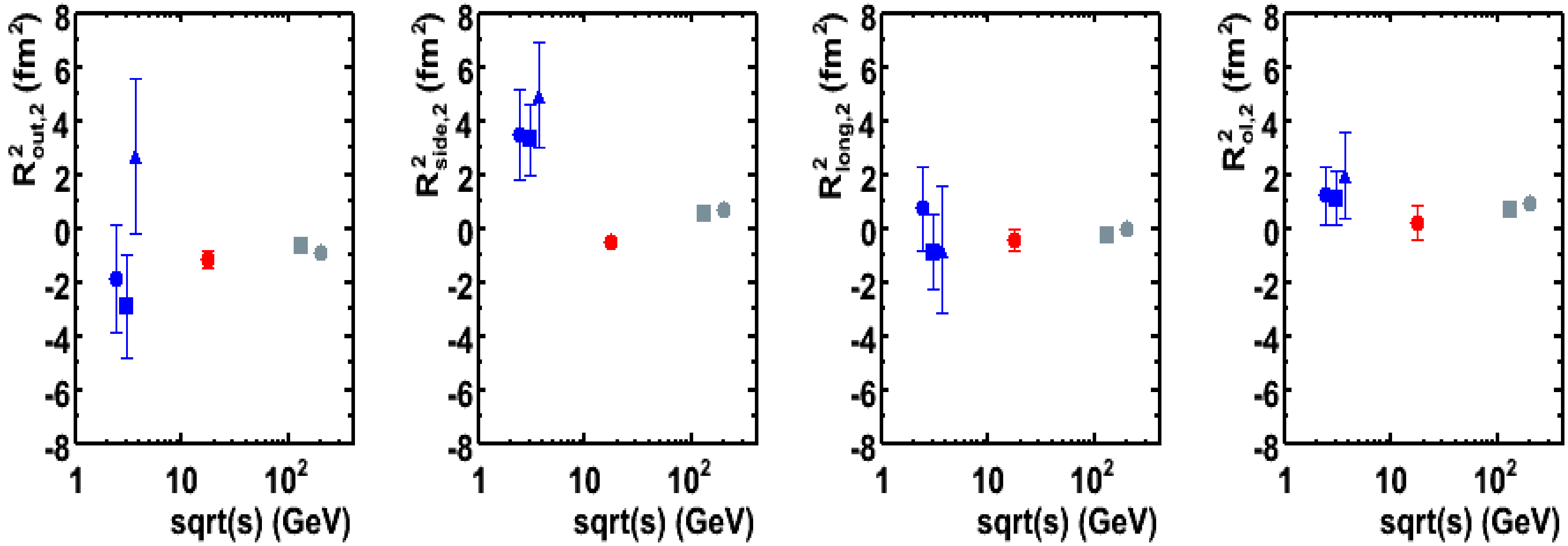
... and AGS



● E895	●2,■4,▲6 AGeV	<pt> = 0.11 GeV/c	Phys. Lett. B 496 (2000) 1
● CERES	158 AGeV	<pt> = 0.47 GeV/c	D. Antonczyk, Ph.D.
■ STAR	sqrt(s) = 130 GeV	0.125<pt<0.45 GeV/c	
● STAR	sqrt(s) = 200 GeV	0.15<pt<0.6 GeV/c	PRL 93 (2004) 012301

source anisotropy vs sqrt(s)

Pb+Au, Au+Au
centrality 15-20%



- ***non-monotonic behavior of R_{side}***
- ***R_{side} inconsistent with R_{out} → different freeze-out times in-plane and out-of-plane?***

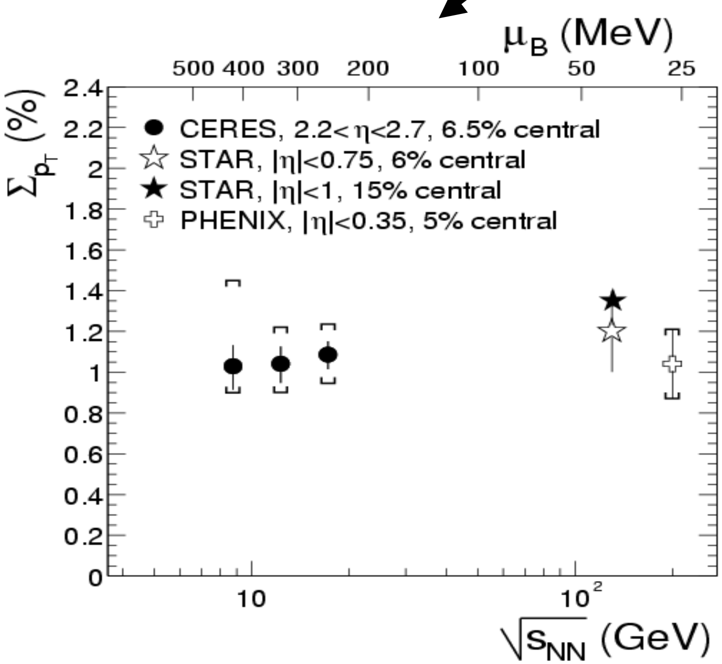
transverse momentum fluctuations in Pb+Au at 158 and 80 GeV per nucleon

pt fluctuations

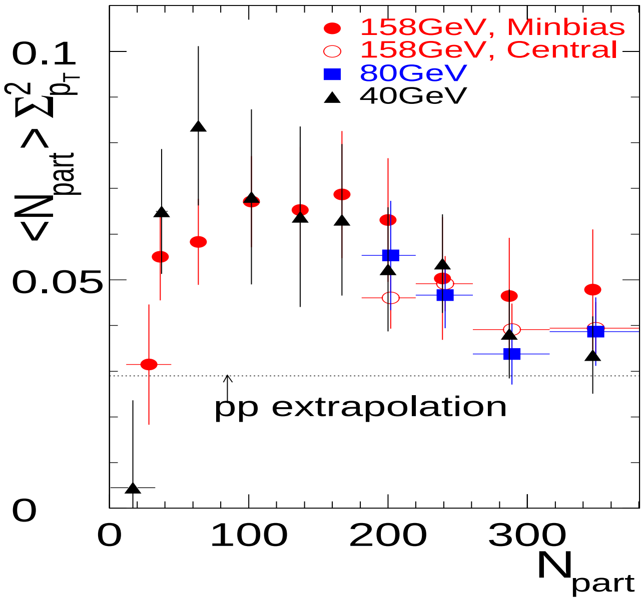
motivation:
enhanced fluctuations at critical point

difficulty:
distinguish from trivial fluctuations (statistical, centrality, HBT, elliptic flow...)

observation:
non-statistical fluctuations exist, indeed
flat vs beam energy
non-monotonic vs centrality



(CERES collaboration, Nucl. Phys. A727(2003)97, J.Phys.G30(2004)S1376)



pt fluctuations strategy: analyze pt-pt correlations as a function of $\Delta\eta$ and $\Delta\varphi$

measures of fluctuations

$\sigma_{pt\ dyn}^2$	**difference between the variances of pt and mean pt**
Σ_{pt}^2	**same divided by mean pt**
$\langle \Delta pt_i, \Delta pt_j \rangle$	**pt covariance**
Φ_{pt}	**difference between the standard deviations of pt and mean pt**

relations

$$\sigma_{pt\ dyn}^2 = \sigma_{\langle pt \rangle}^2 - \sigma_{pt}^2 / \langle M \rangle$$

$$\Sigma_{pt} = \sigma_{pt\ dyn} / \langle pt \rangle$$

$$\langle \Delta pt_i, \Delta pt_j \rangle \cong \sigma_{pt\ dyn}^2$$

$$\Phi_{pt} \cong \langle M \rangle\, \sigma_{pt\ dyn}^2 / 2\sigma_{pt}$$

pt fluctuations

Pb+Au at 158 AGeV

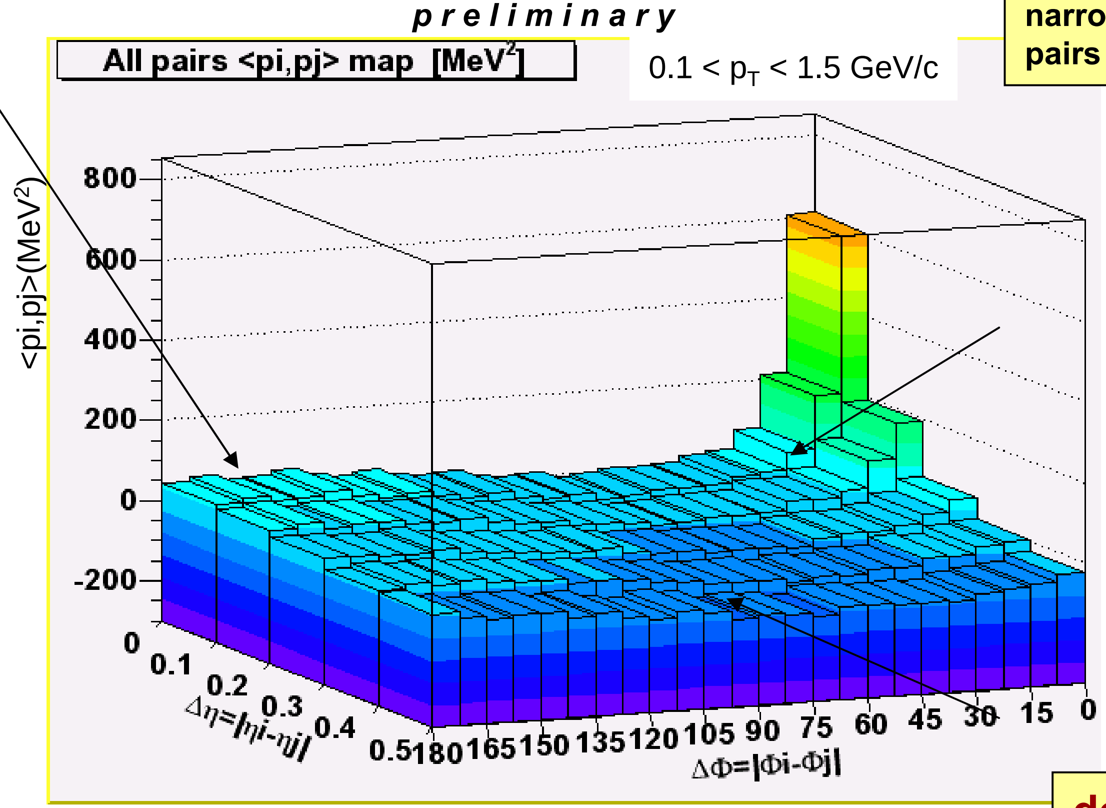
Harry Appelshaeuser
Georgios Tsiledakis

away-side correlations

elliptic flow, jets?

short range correlations

confined to Q_{INV}<70 MeV
narrower and weaker for unlike pairs → HBT and Coulomb?



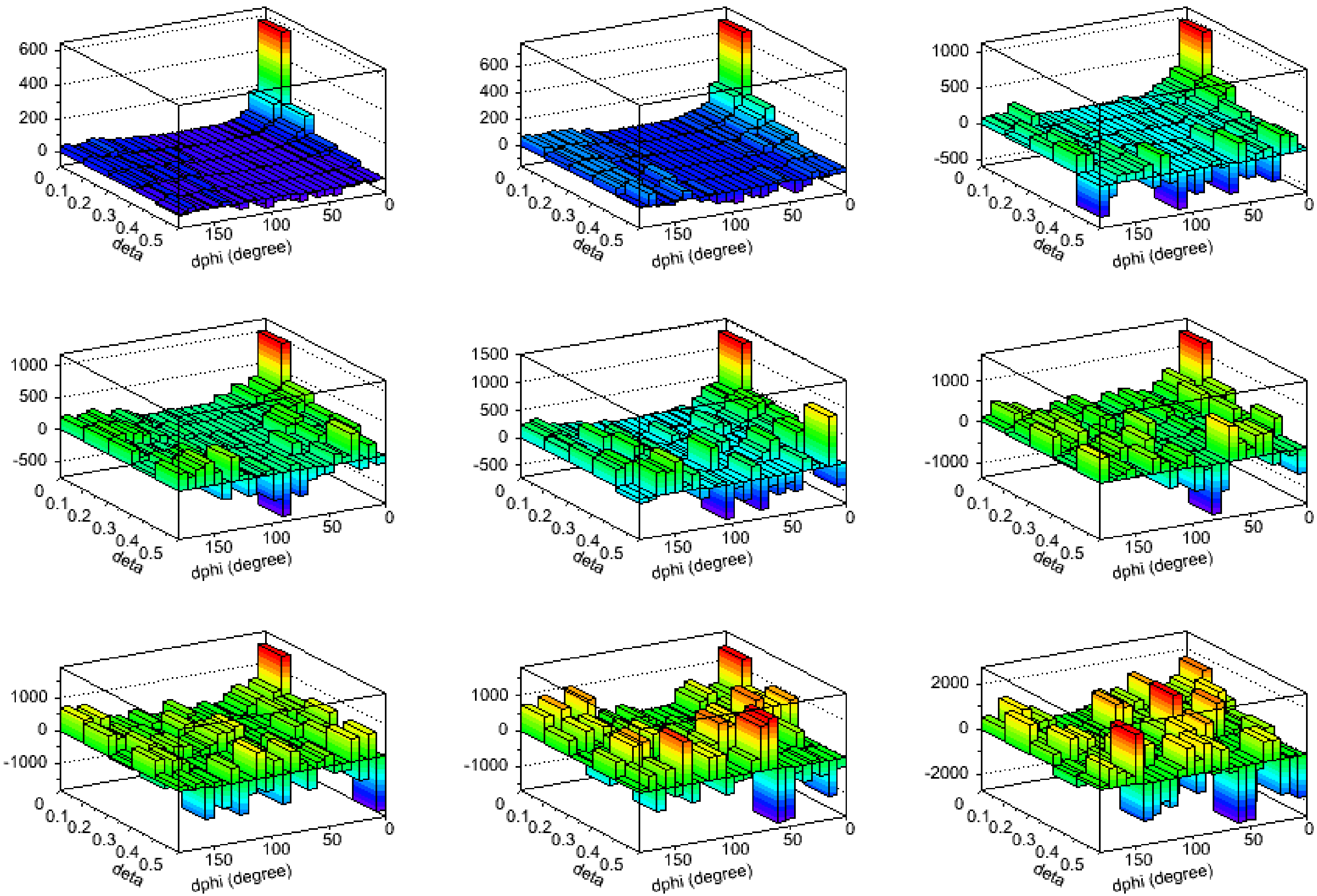
decline with Δη

reproduced with event mixing
trivial effect of pt(η) dependence?

rich structure → averaging over Δφ and Δη is not good

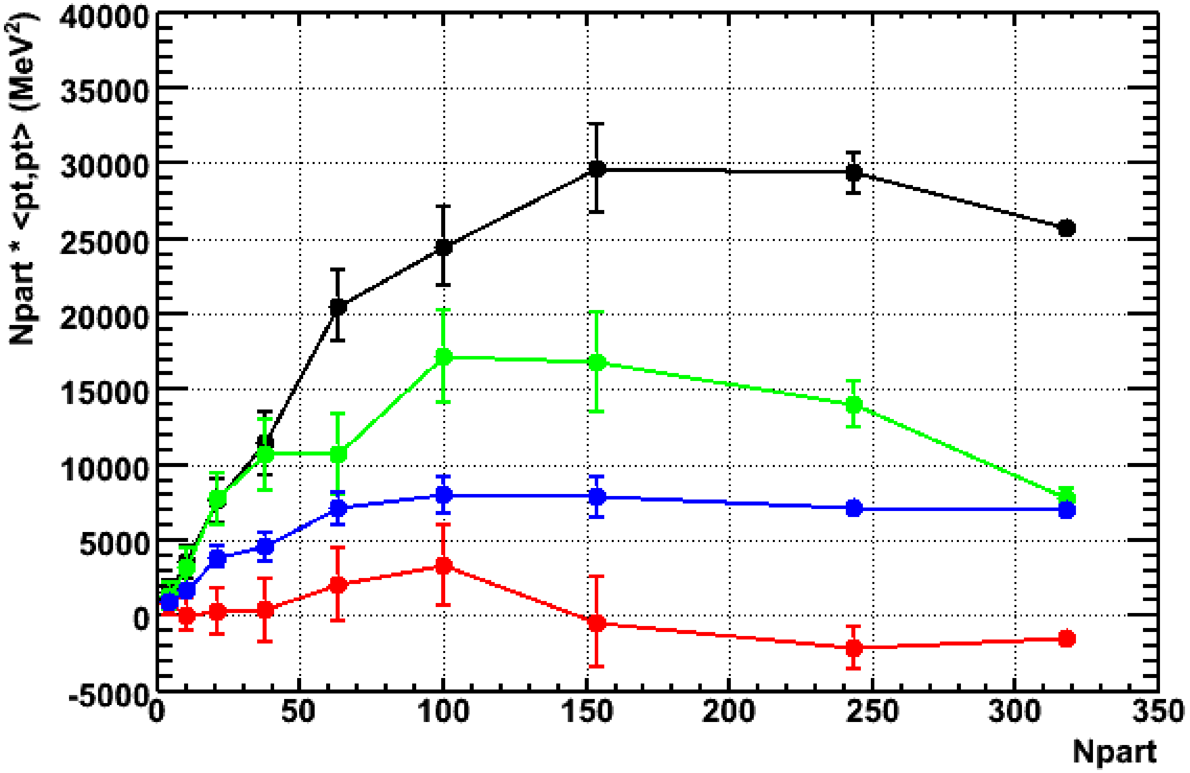
pt covariance at 158 GeV: centrality dependence

Pb+Au at 158 AGeV
preliminary



pt covariance at 158 GeV: centrality dependence

Pb+Au at 158 AGeV
preliminary



0°<Δφ<30°
short range

150°<Δφ<180°
away side

0°<Δφ<180°
all inclusive

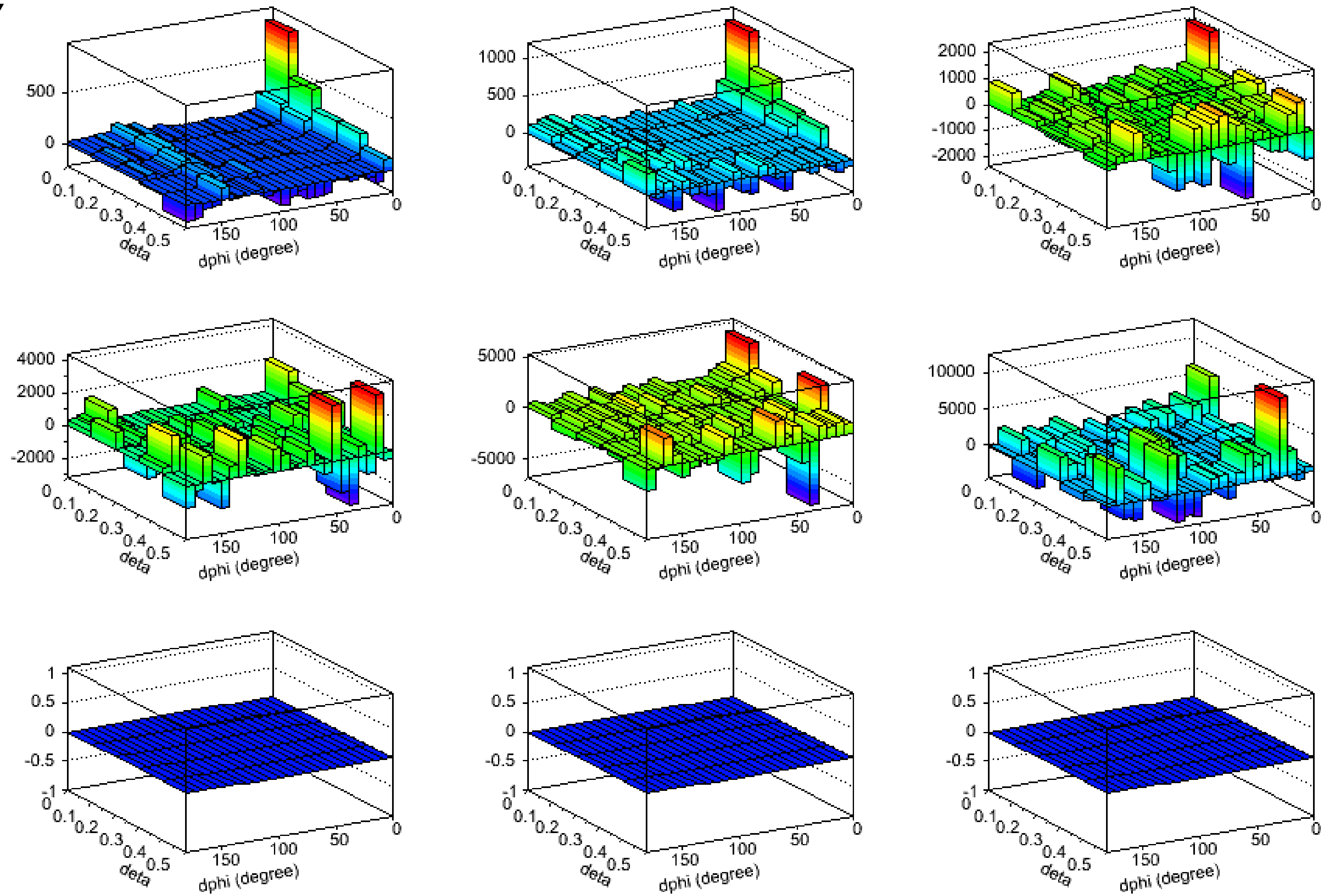
30°<Δφ<60°
best suited for
critical point

the observed centrality dependence comes from the short-range and the away-side correlations

30°<Δφ<60° region, which is free of these effects and of elliptic flow, shows no signal

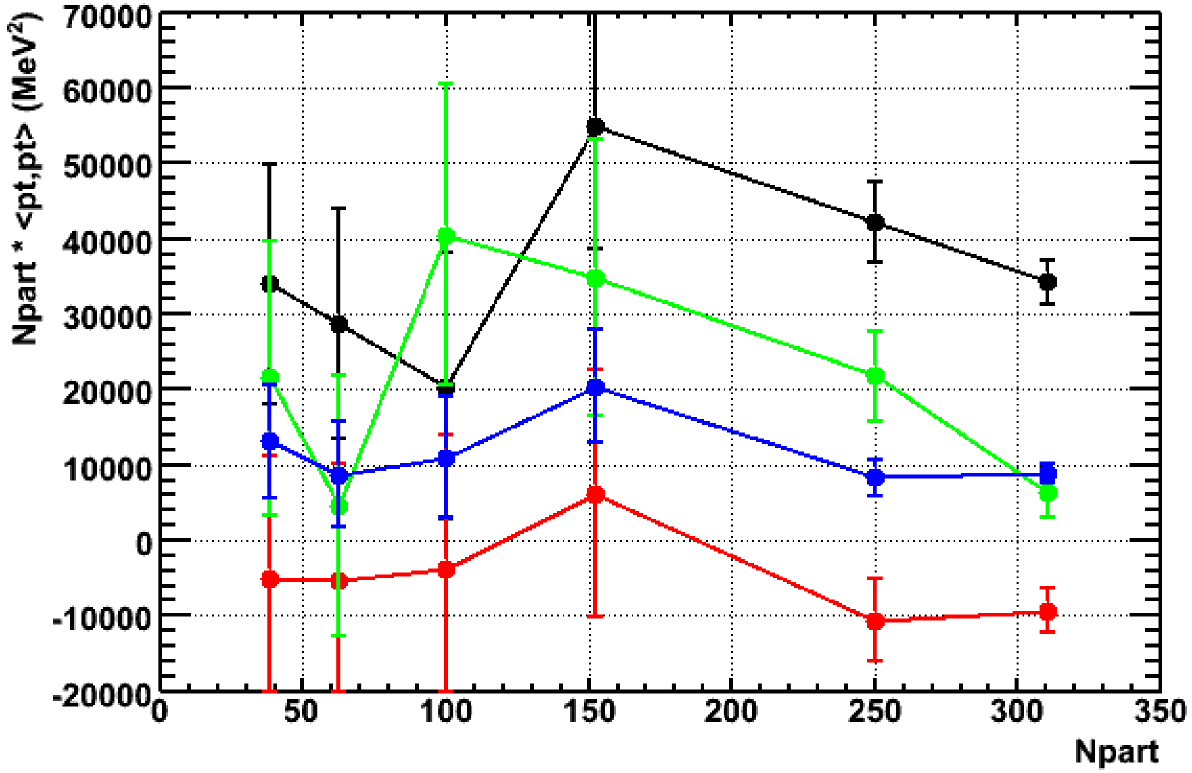
pt covariance at 80 GeV: centrality dependence

Pb+Au at 80 AGeV
preliminary



pt covariance at 80 GeV: centrality dependence

Pb+Au at 80 AGeV
preliminary



0°<Δφ<30°
short range

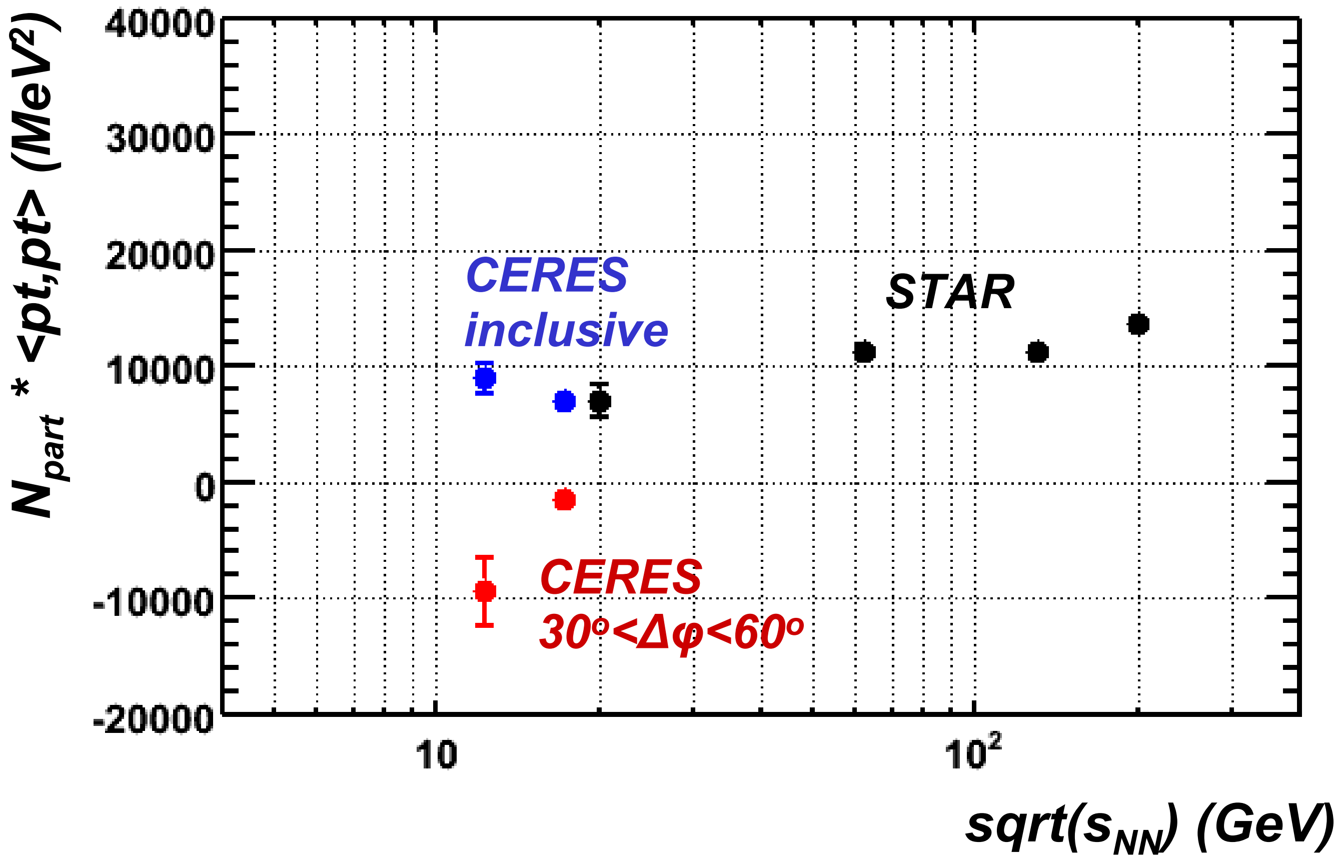
150°<Δφ<180°
away side

0°<Δφ<180°
all inclusive

30°<Δφ<60°
best suited for critical point

pt covariance: beam energy dependence

CERES Pb+Au 158 AGeV preliminary
STAR Au+Au 20-200 GeV PRC 72 (2005) 044902



the 30°<Δφ<60° region is suited for critical point, easy to analyze, and gives results different from the inclusive analysis

summary

- anisotropy of R_{out} as expected
- unexpectedly small anisotropy of R_{side}
  non-monotonic collision energy dependence

- pt covariance for pairs with $30^o < \Delta\varphi < 60^o$ is well suited for the critical point search
- pt-fluctuations in this region are rather small

CERES Collaboration

D. Adamova, G. Agakichiev, D. Antonczyk, A. Andronic, H. Appelshäuser, V. Belaga, J. Bielcikova, P. Braun-Munzinger, O. Busch, A. Cherlin, S. Damjanovic, T. Dietel, L. Dietrich, A. Drees, S. Esumi, K. Filimonov, K. Fomenko, Z. Fraenkel, C. Garabatos, P. Glässel, G. Hering, J. Holeczek, M. Kalisky V. Kushpil, B. Lenkeit, W. Ludolphs, A. Maas, A. Marin, J. Milosevic, A. Milov, D. Miskowiec, R. Ortega, Yu. Panebrattsev, O. Petchenova, V. Petracek, A. Pfeiffer, M. Ploskon, S. Radomski, J. Rak, I. Ravinovich, P. Rehak, W. Schmitz, J. Schukraft, H. Sako, S. Shimansky, S. Sedykh, J. Stachel, M. Sumbera, H. Tilsner, I. Tserruya, G. Tsiledakis, T. Wienold, B. Windelband, J.P. Wessels, J.P. Wurm, W. Xie, S. Yurevich, V. Yurevich

quark-gluon plasma paradox

QGP paradox: statement of the problem

converting large volume of QGP into hadrons proceeds...

simultaneously in the whole volume

↓

no way to synchronize regions separated by space-like interval so single quarks may remain between hadronization domains

one region after another ("burning log")

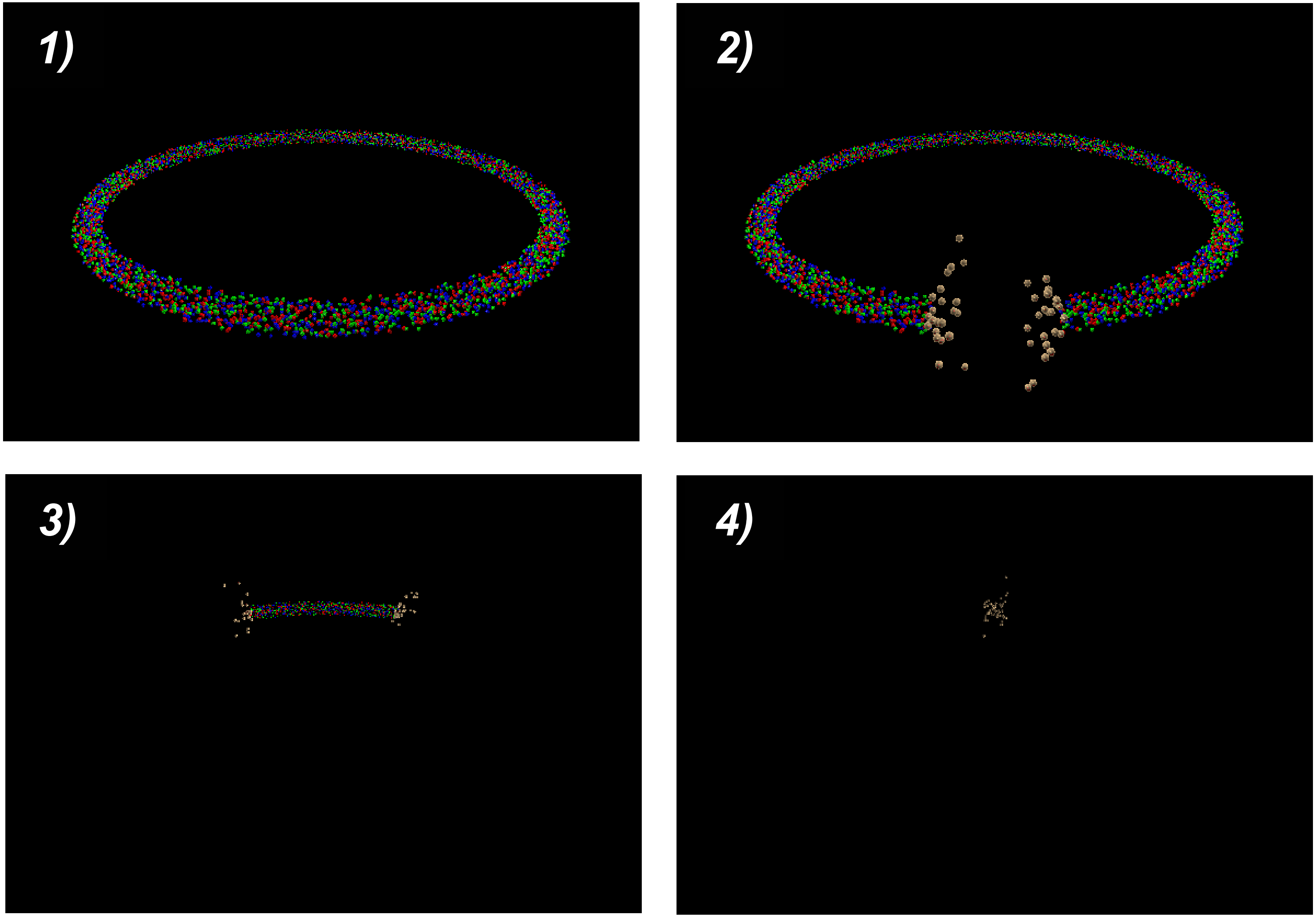
↓

terribly slow!

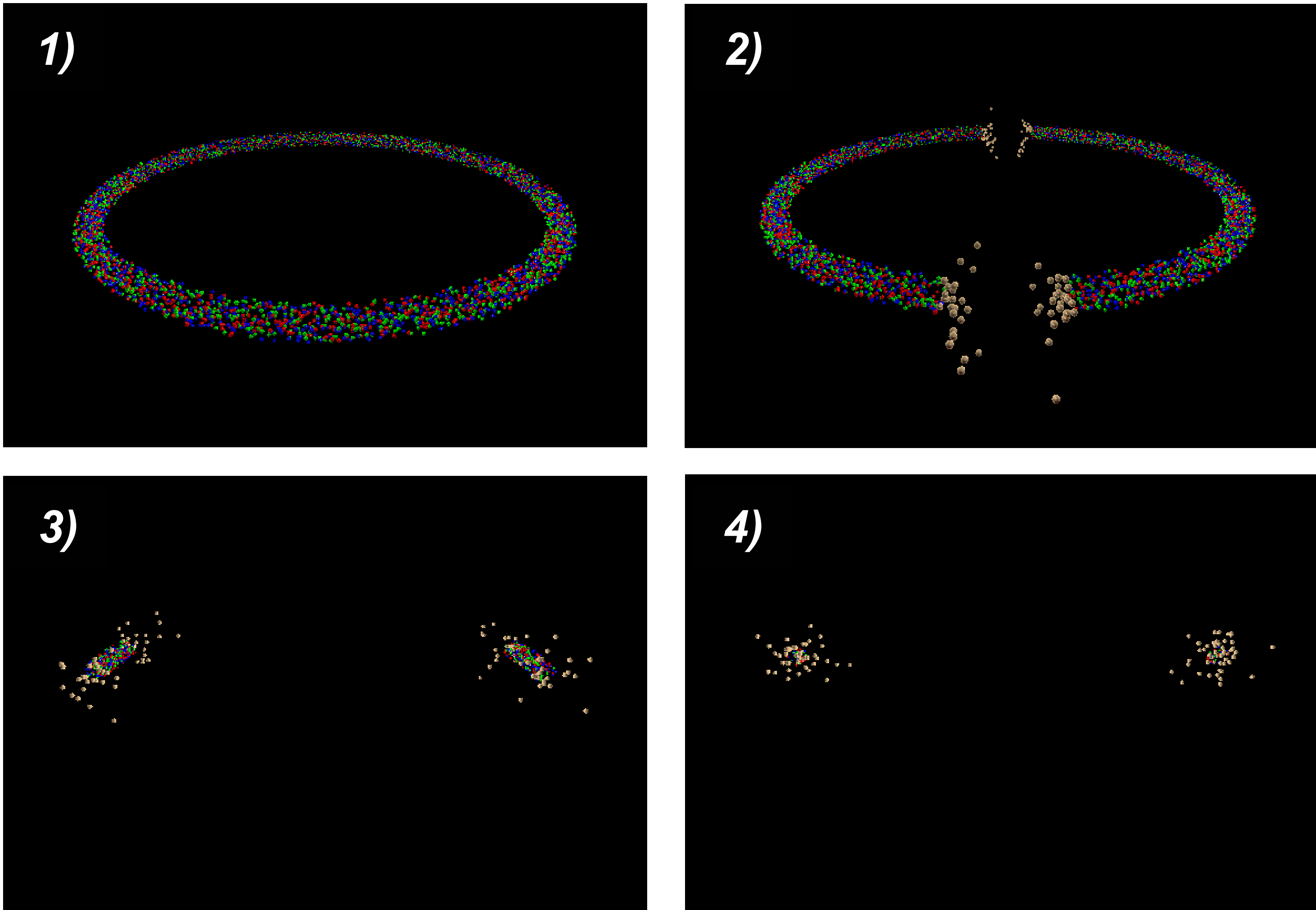
QGP paradox demonstrated

- *I will start from an allowed state (1 mm^3 of QGP)*
- *I will never violate any physics law*
- *I will end up in a not allowed state (with single quarks)*

QGP paradox: experiment 1



QGP paradox: experiment 2



QGP paradox: 3 ways out

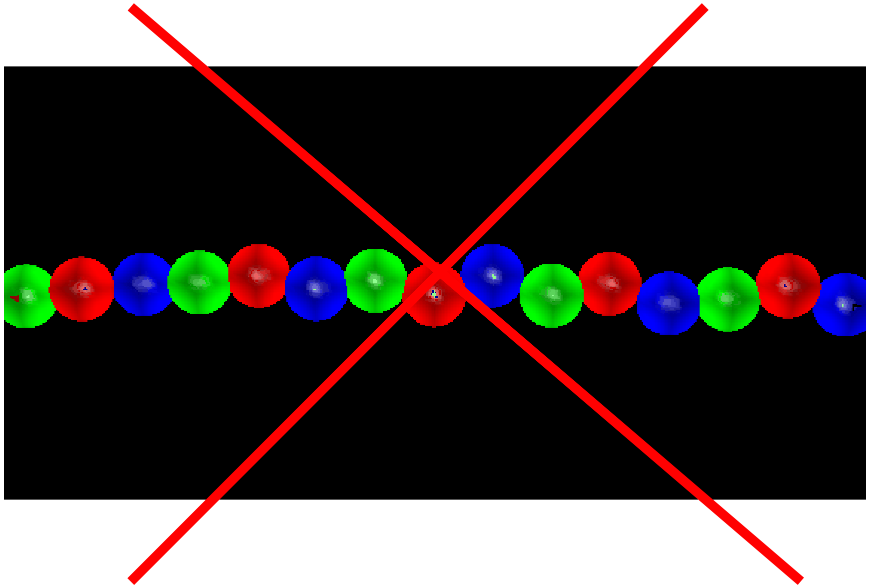
1) fast (volume) hadronization

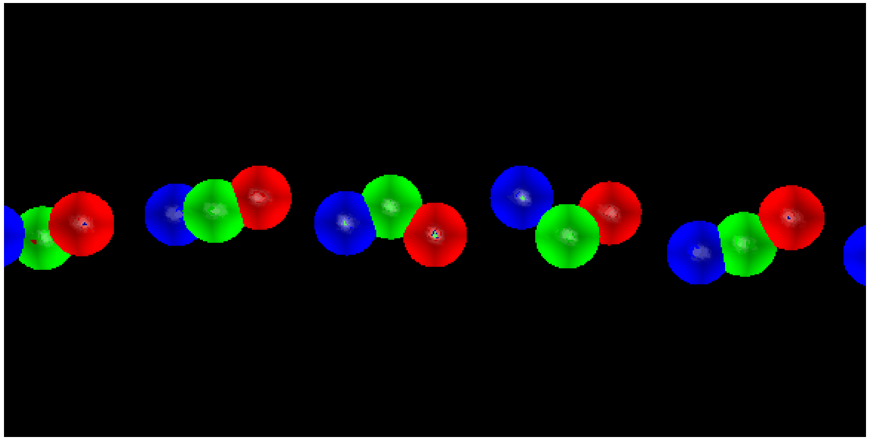
- single quarks can exist, or
- baryon number not conserved, or
- superluminal information transfer is possible

2) slow (surface) hadronization

- too slow: Early Universe at least couple of minutes
- holes in QGP not allowed (infinite surface tension)

QGP paradox: 3 ways out





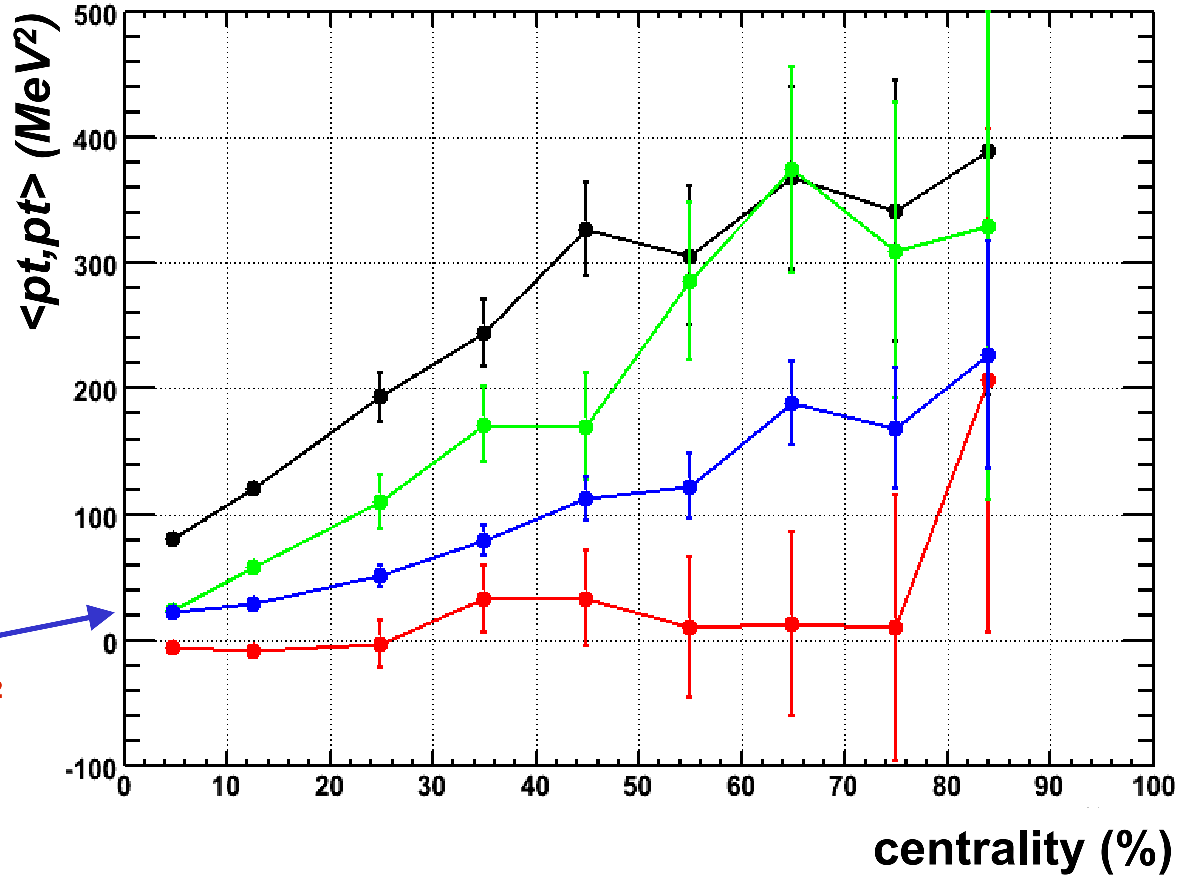
3) true QGP does not exist

- *quarks are in clusters*
- *the ring can be cut only between two such clusters*
- *no problem with hadronization*

backup slides

pt covariance at 158 GeV: centrality dependence

Pb+Au at 158 AGeV
preliminary



published inclusive analysis value 22 MeV^2

0°<Δφ<30°
short range

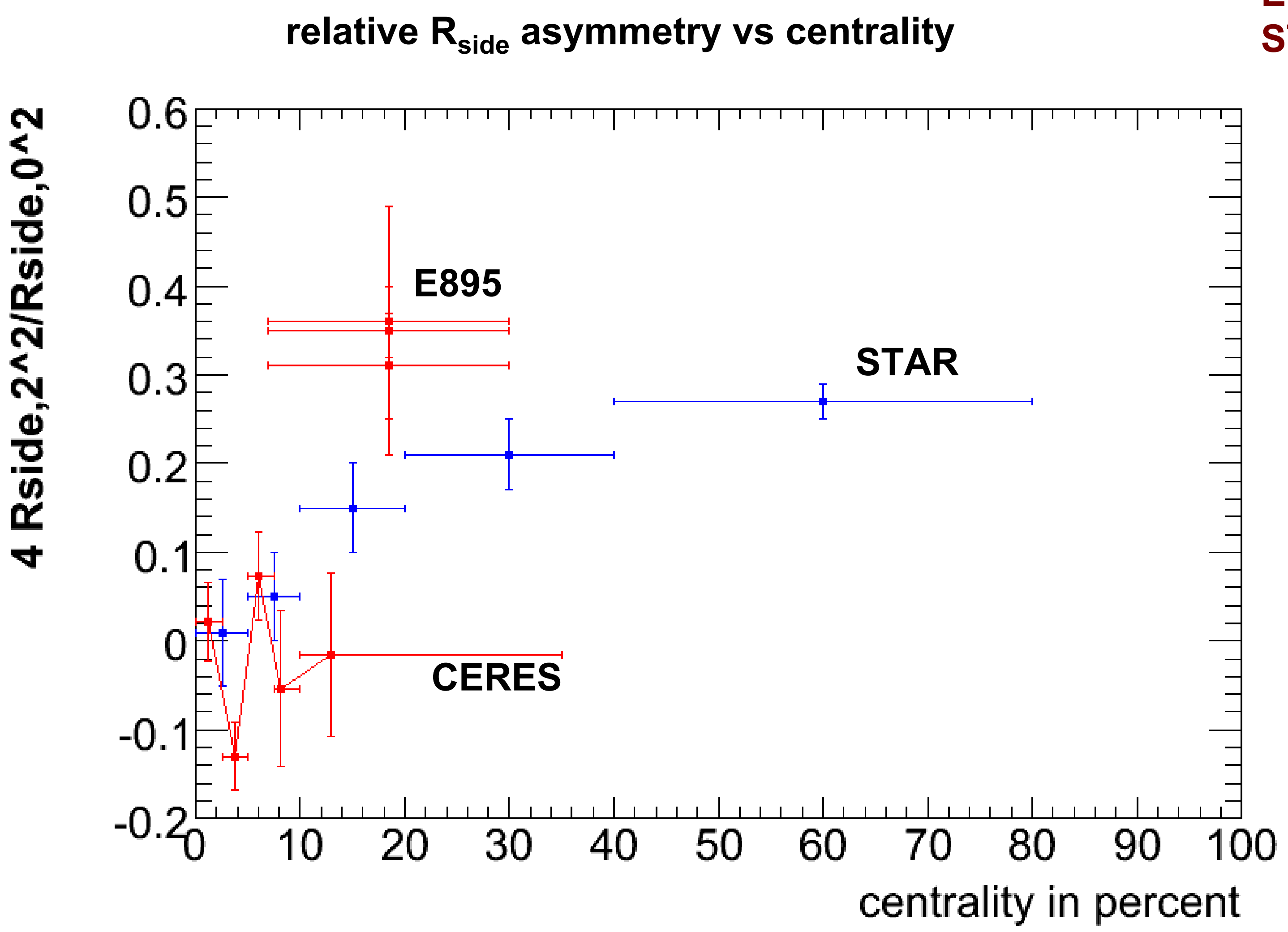
150°<Δφ<180°
away side

0°<Δφ<180°
all inclusive

30°<Δφ<60°
best suited for critical point

Source anisotropy from HBT

E895 PLB 496 (2000) 1
STAR nucl-ex/0312009

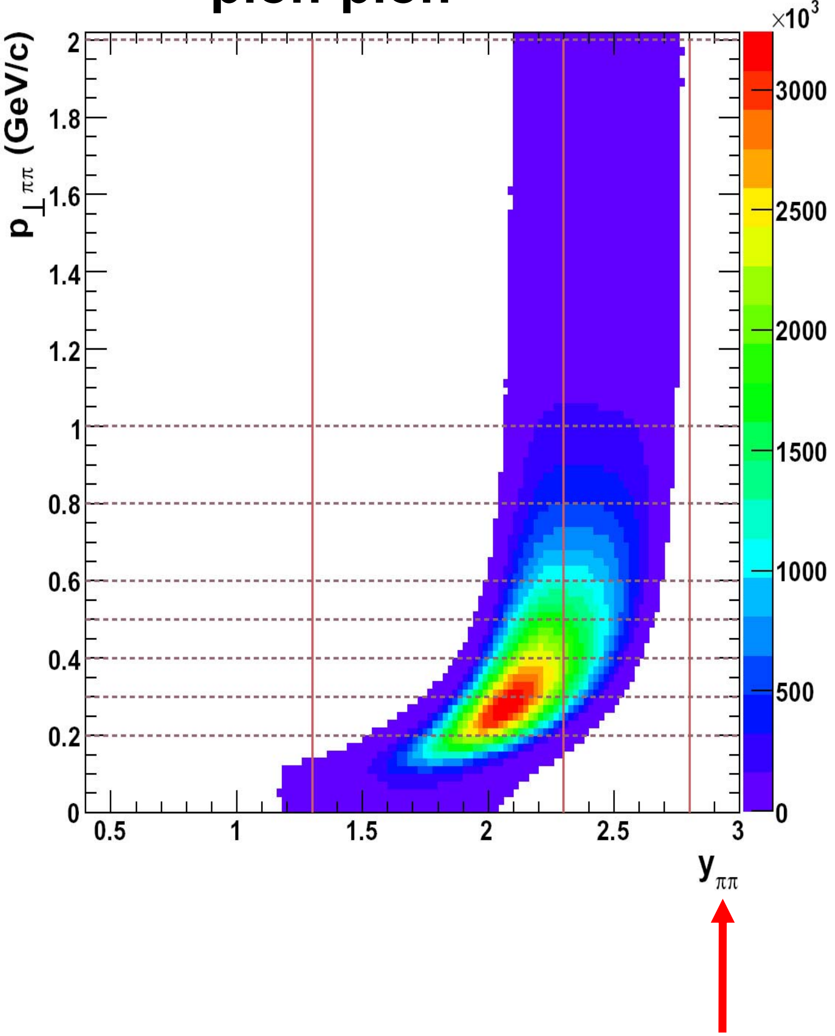


pion-proton correlations
central Pb+Au
158 GeV per nucleon

pair acceptance

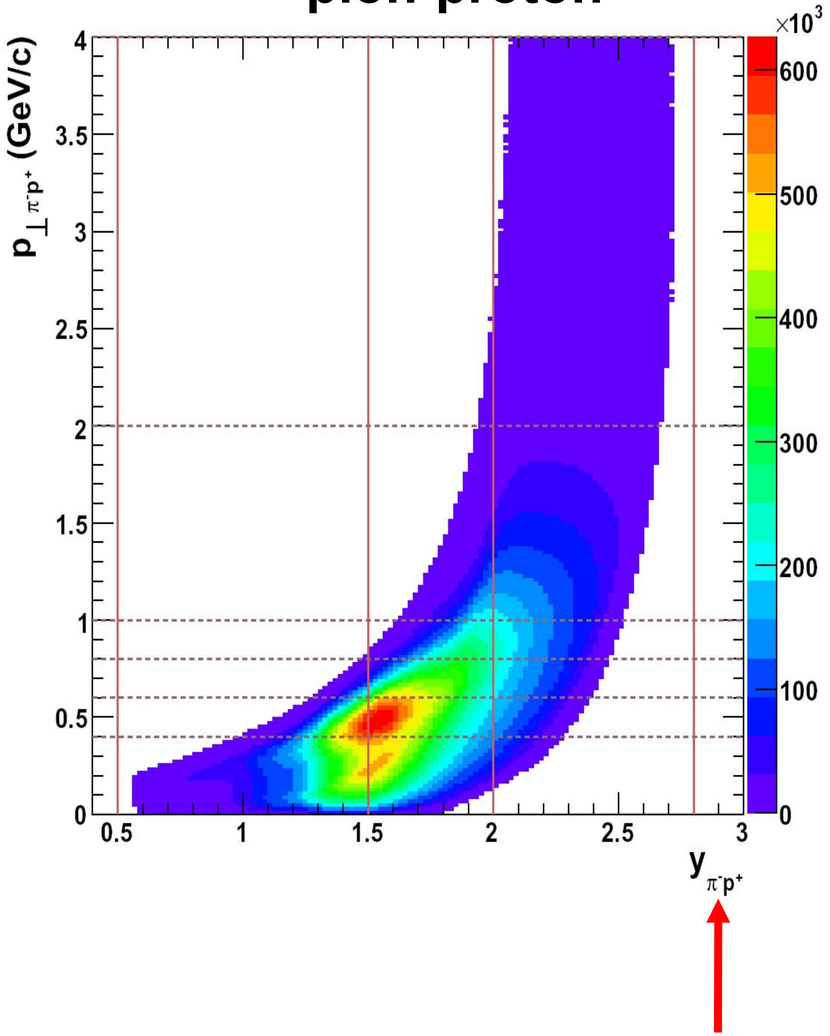
central Pb+Au at 158 AGeV

pion-pion



midrapidity: y=2.91

pion-proton

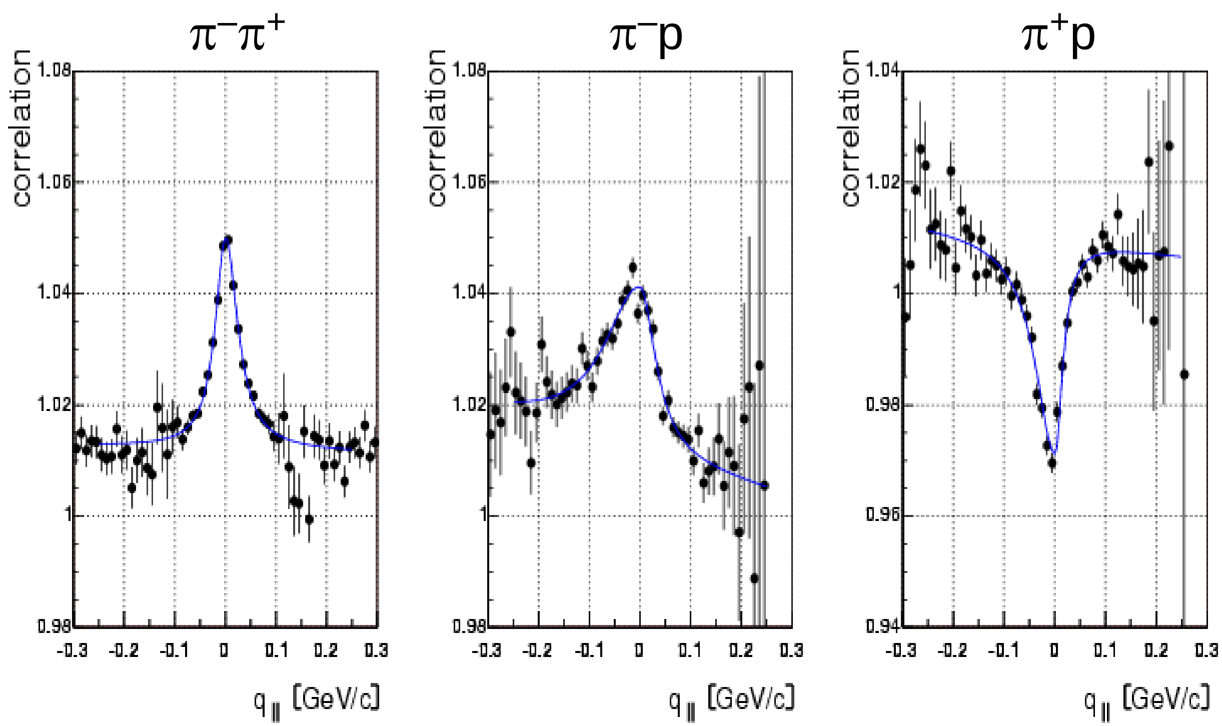


midrapidity

pion-proton correlations

central Pb+Au at 158 AGeV

Dariusz Antonczyk, Ph.D. thesis



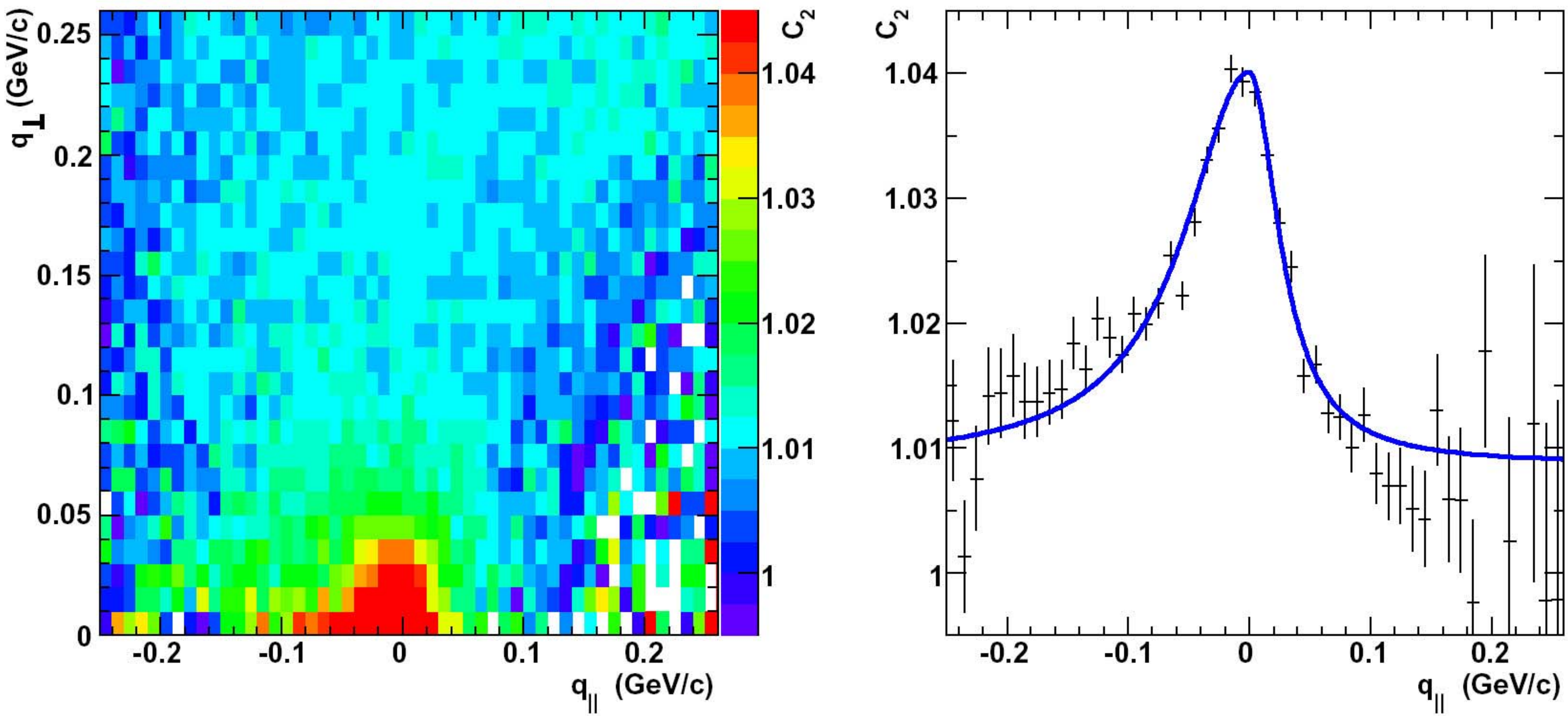
idea:
asymmetry of correlation function is related to the asymmetry of the relative source distribution (Lednicky, Phys.Lett.B373(96)30)

analysis:
pair c.m.s.
$q = p_{proton} - p_{pion}$
$C(q_{||}, q_{\perp})$
$q_{||}$ **is parallel to the pair** $P_{\perp}$

result :
the proton source is located at a larger transverse radius than the pion source

parametrizing the peak asymmetry

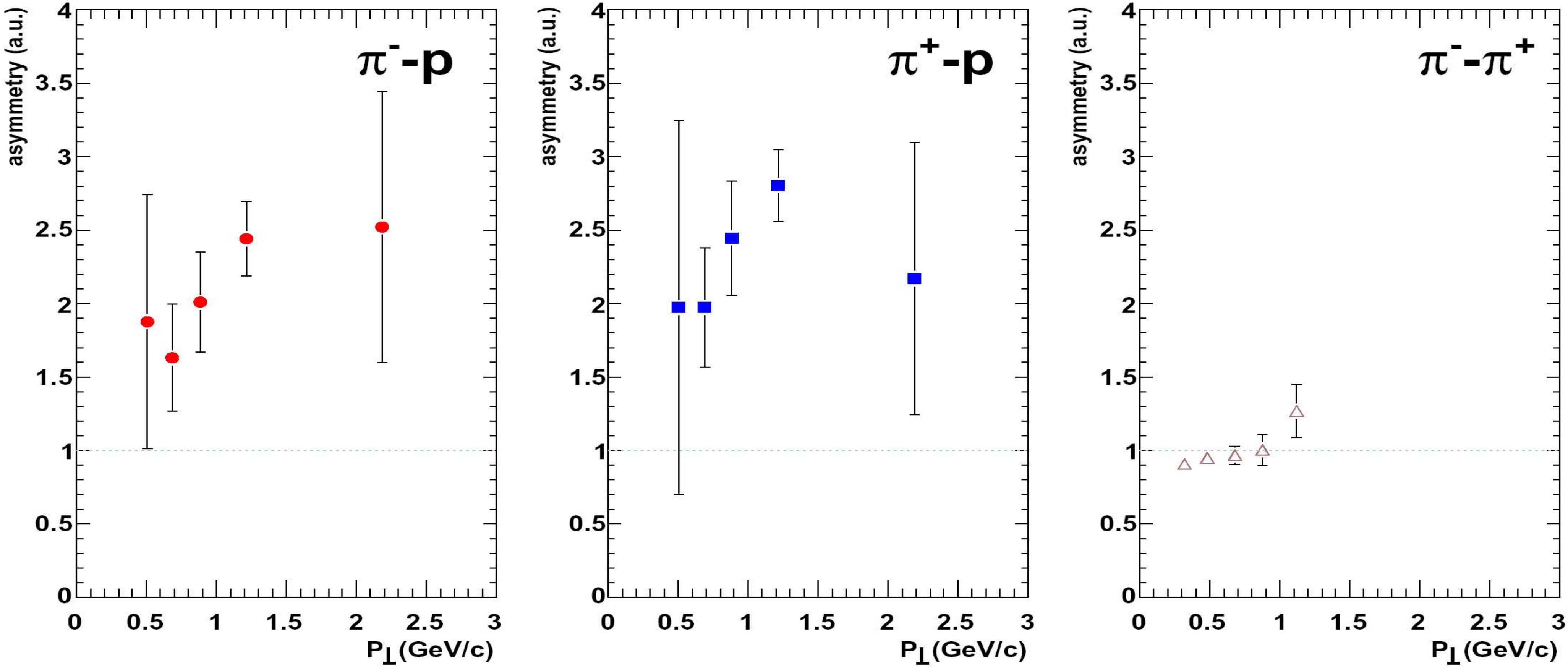
π^- - proton correlation



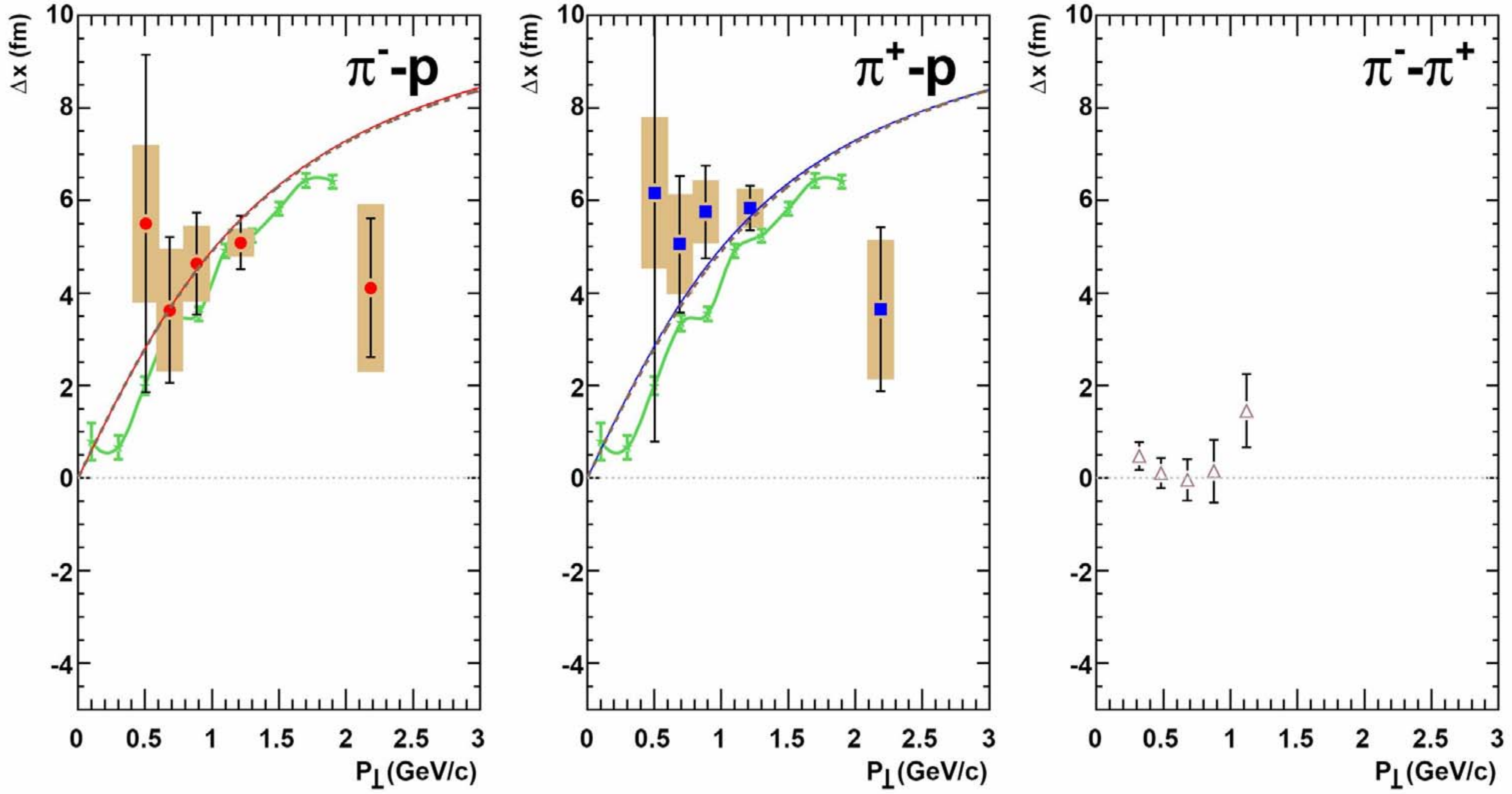
take a slice and project on $q_{||}$
fit each half separately with……… $C\ \ q\ \ = 1\ \ \frac{A}{1\ \ q\ _2 / B^2}$
require same A
B is HWHM
asymmetry = B_{left}/B_{right}

peak asymmetry: pt-dependence

centrality 7%, 1.5<y<2.8 **Pt is pair pt!**



pion-proton displacement: pt-dependence

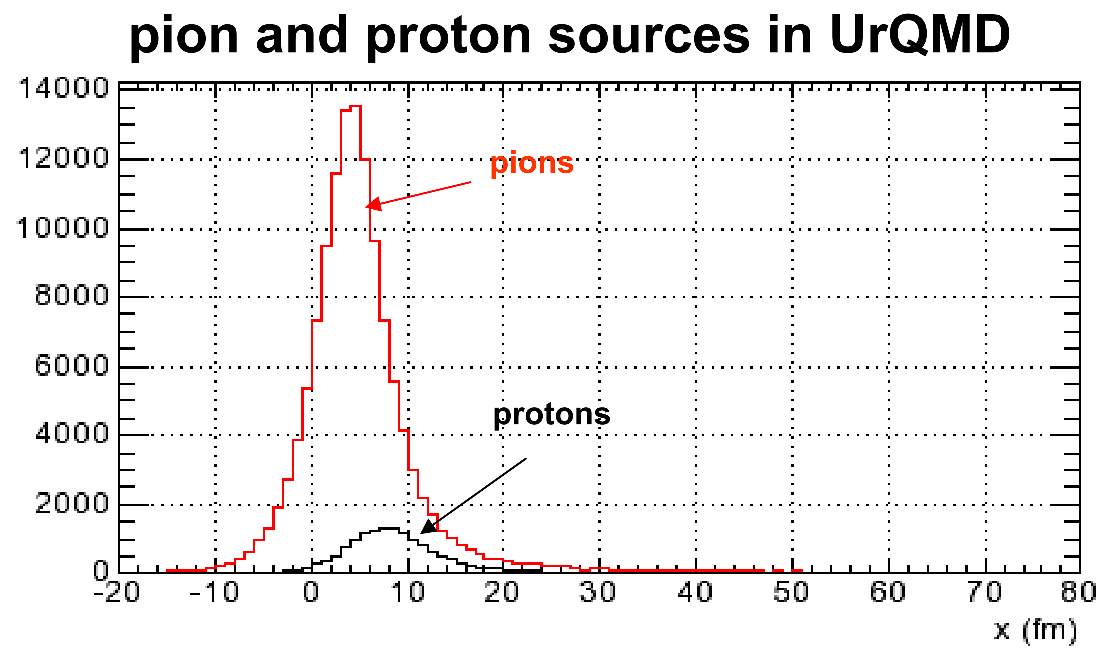


green: UrQMD (only Δx, not Δt!)
blue and red: fit to Δx (see next slide)

Δx is the average displacement between protons and pions at freeze-out in the out-direction. Positive Δx – protons outside

pion-proton correlations conclusion

- *protons freeze-out at larger radii than pions*
- *quantitatively consistent with transverse flow*

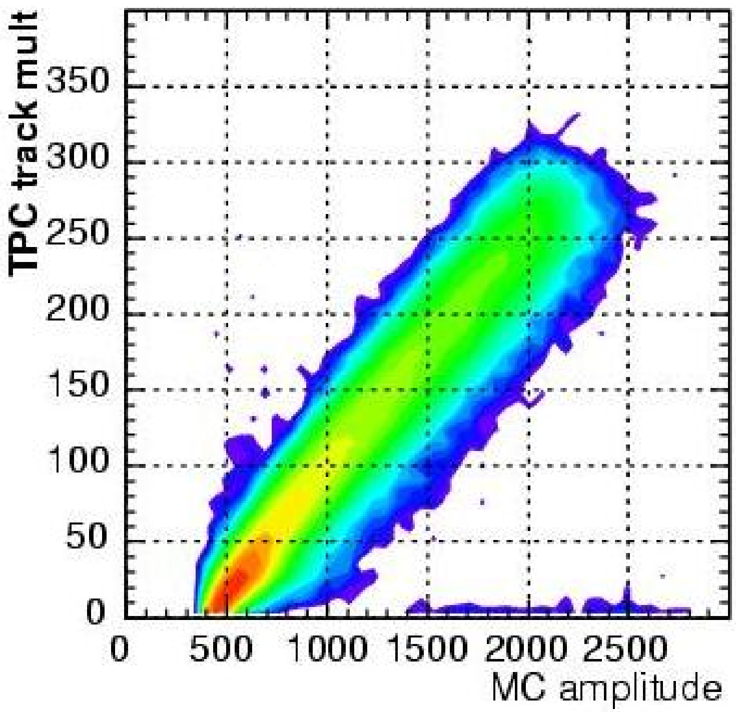


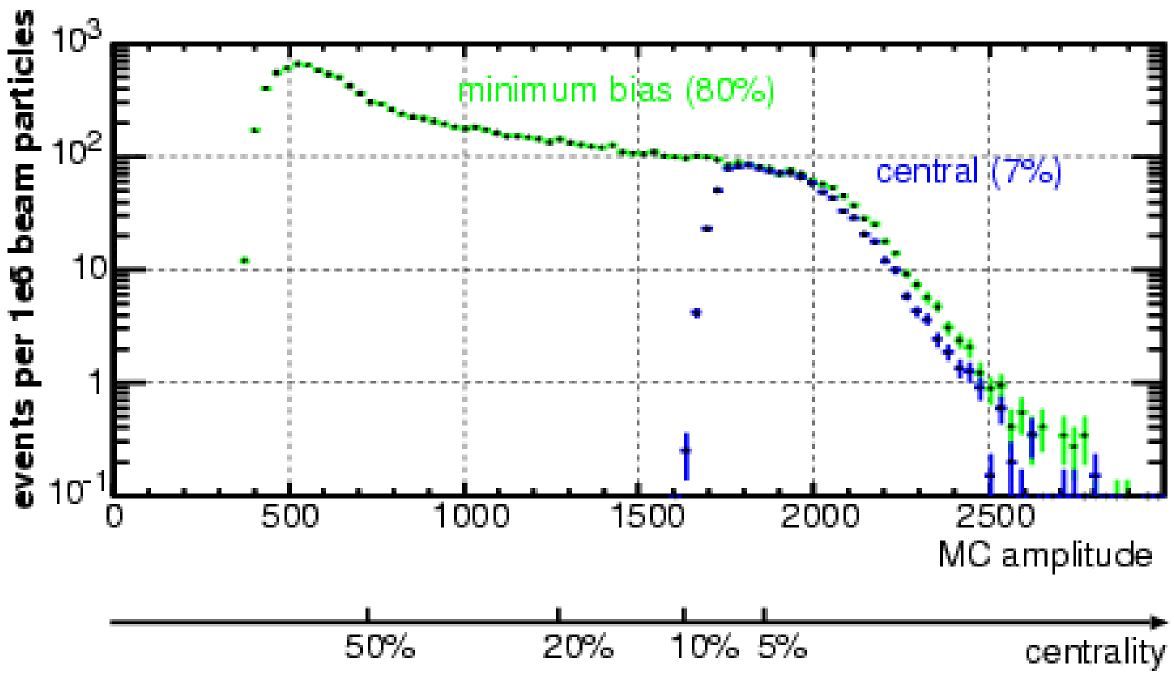
centrality determination

Pb+Au at 158 GeV per nucleon

centrality deduced from the multiplicity of charged particles around mid-rapidity

MC scintillator amplitude 2.95 < η < 4.05
TPC track multiplicity 2.10 < η < 2.80
mid-rapidity y = 2.91

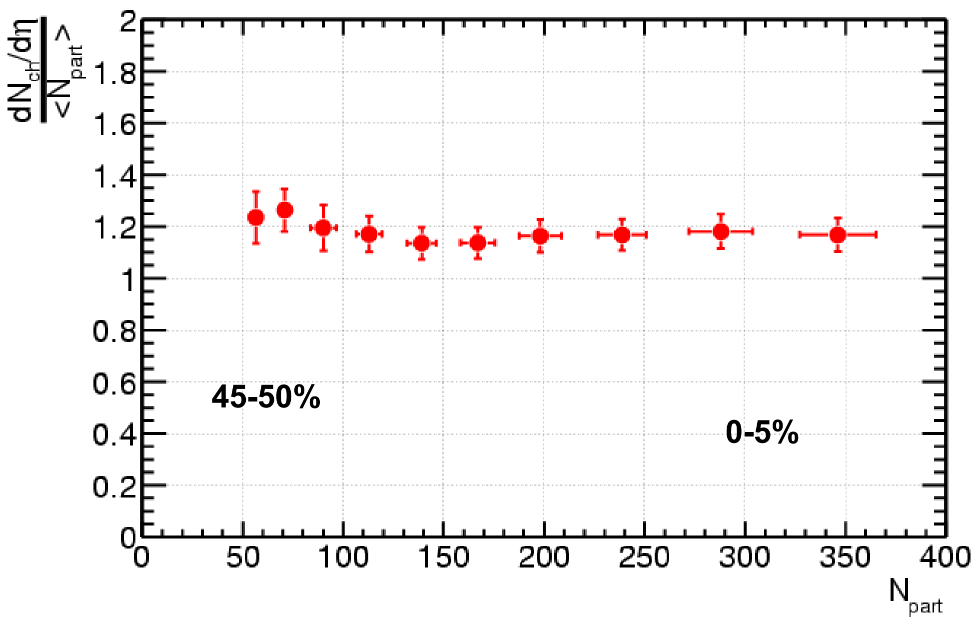




charged particle multiplicity

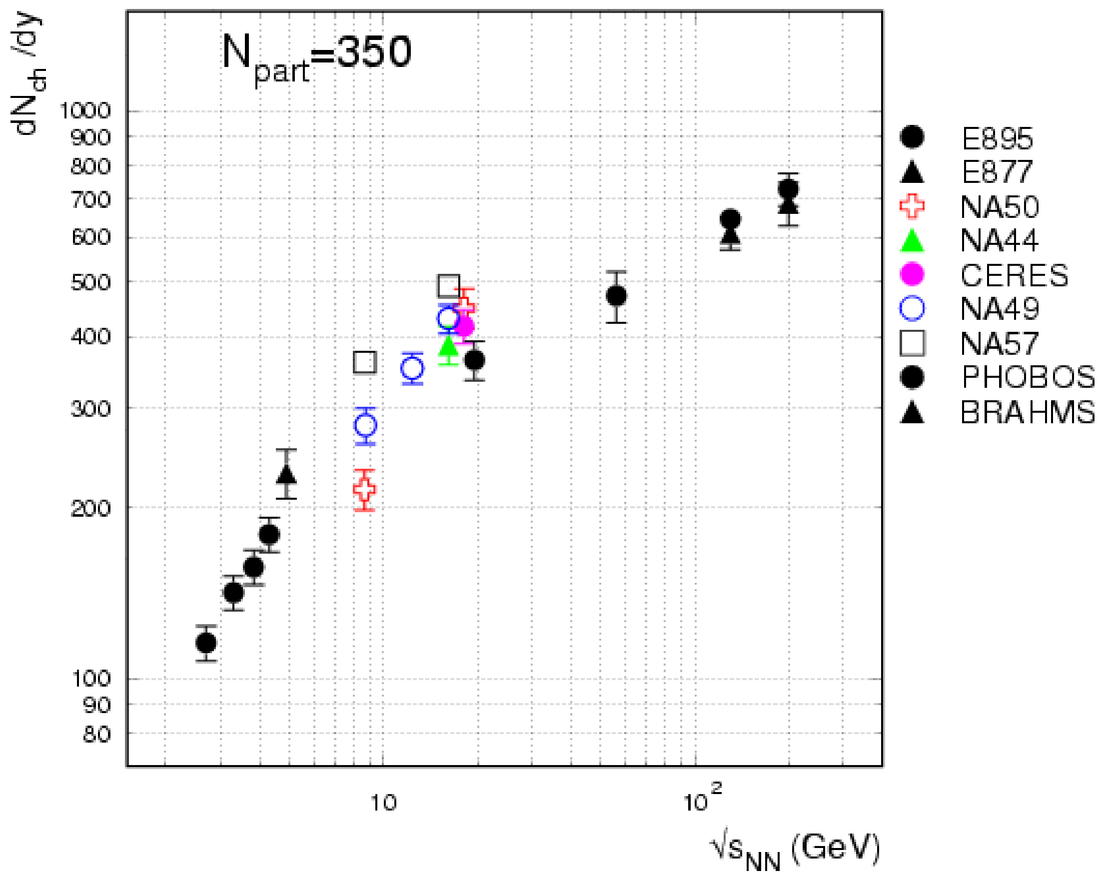
Pb+Au at 158 GeV per nucleon

charged particle multiplicity determined from hits in the two silicon detectors



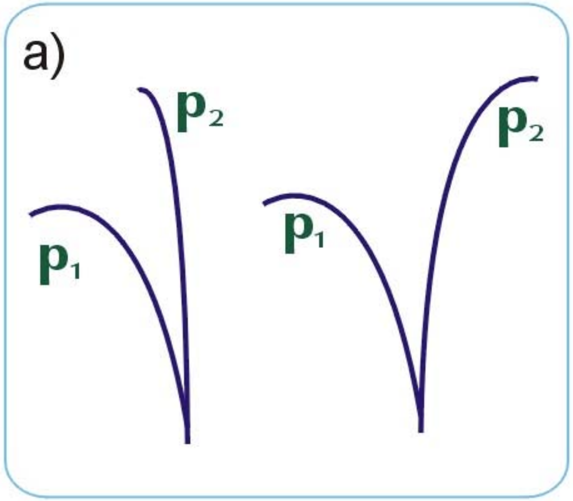
flat N_{ch} per participant

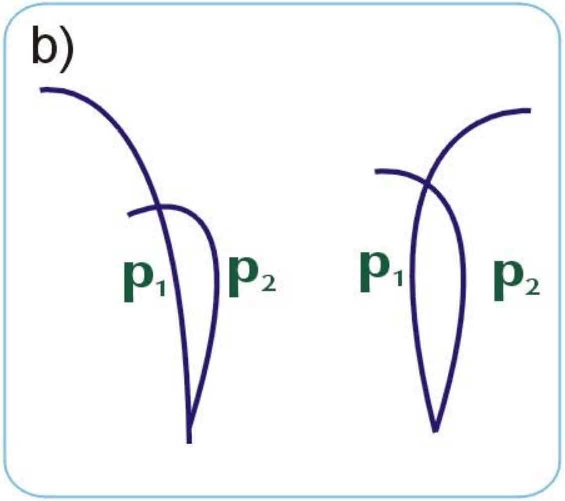
dNch/dη in central collisions of Au or Pb compilation by A. Andronic



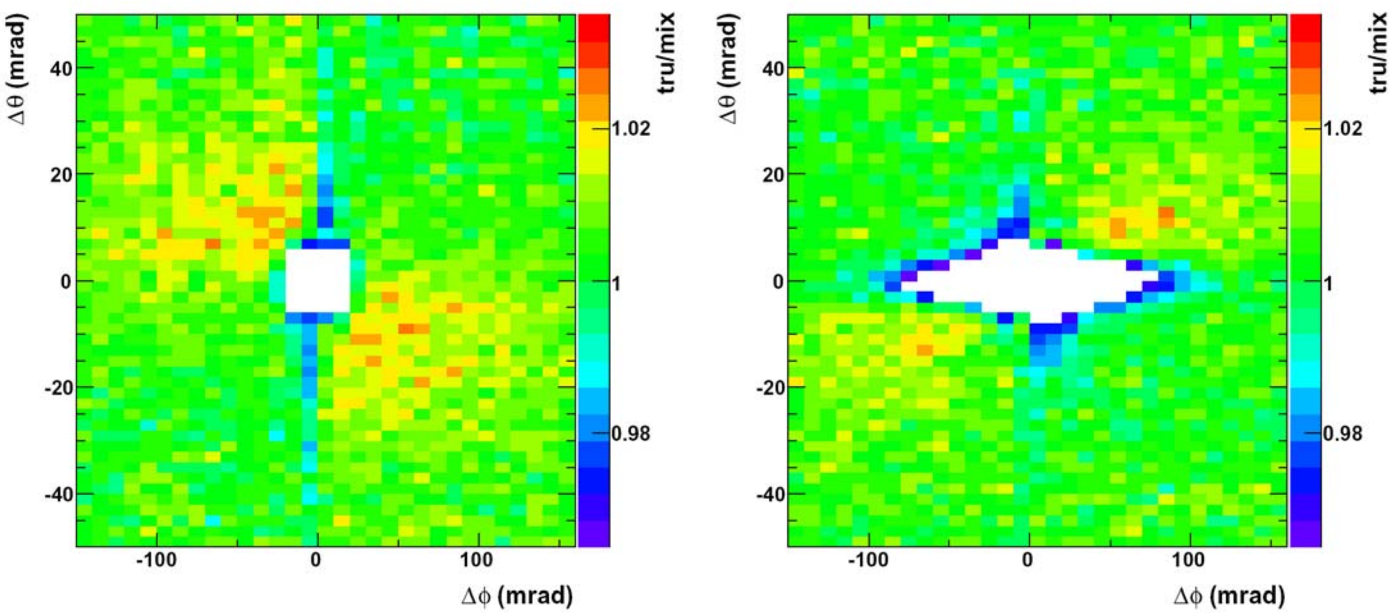
good agreement in dNch/dη between CERES, NA49, NA50, and NA44

two-track cut

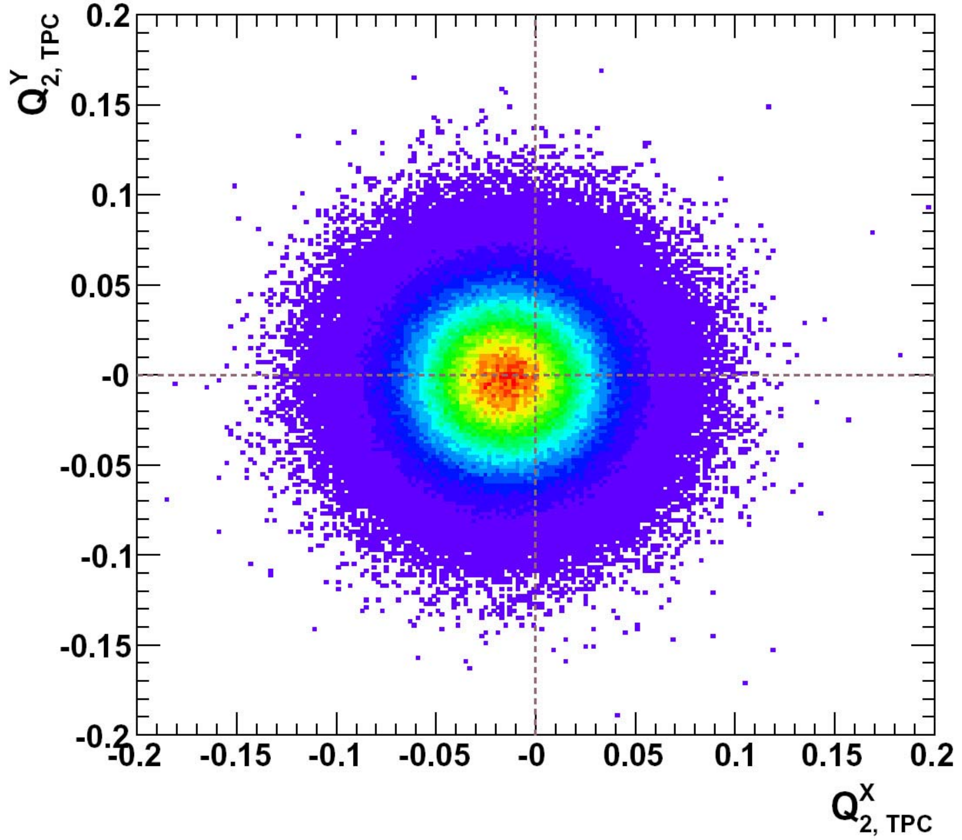




Different cuts needed for the two topologies: sailor and cowboy



determination of the reaction plane



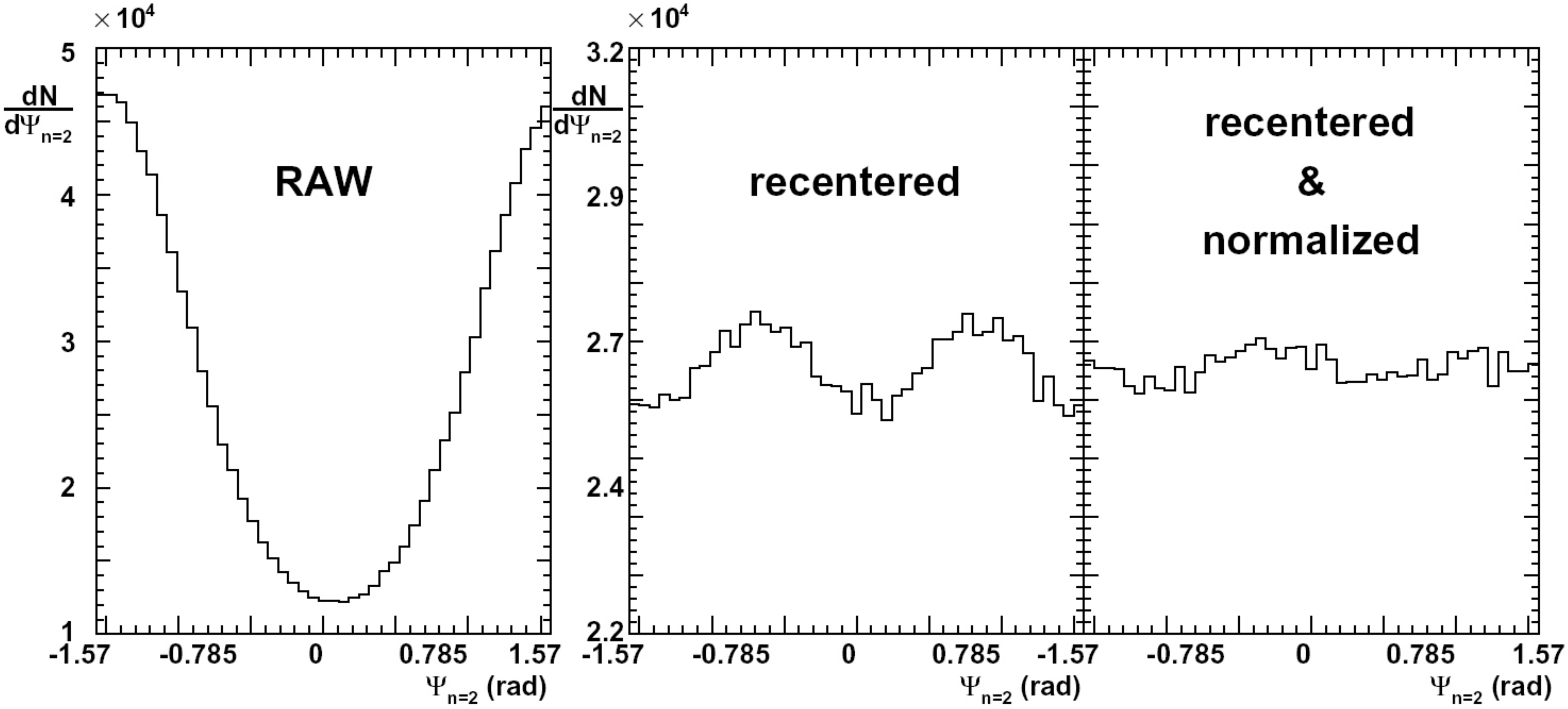
$$Q_2^X = \sum_i p_t \cdot \cos(2\varphi_i)$$

$$Q_2^Y = \sum_i p_t \cdot \sin(2\varphi_i)$$

$$\Phi_{RP} = \frac{1}{2}\arctan\left(\frac{Y_2}{X_2}\right)$$

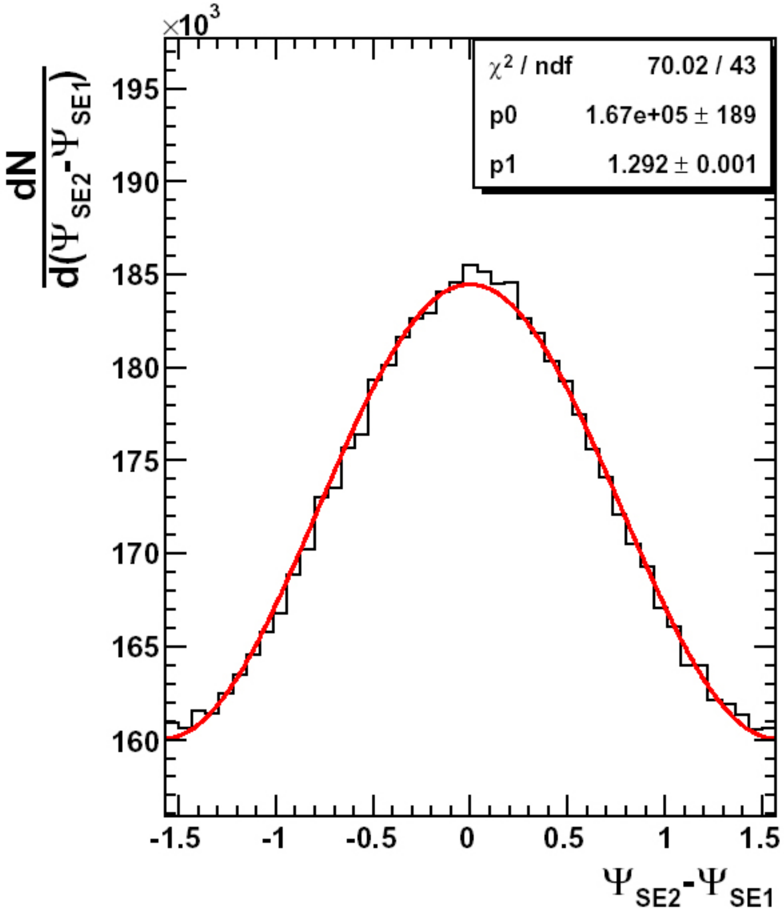
distribution of the reaction plane angle

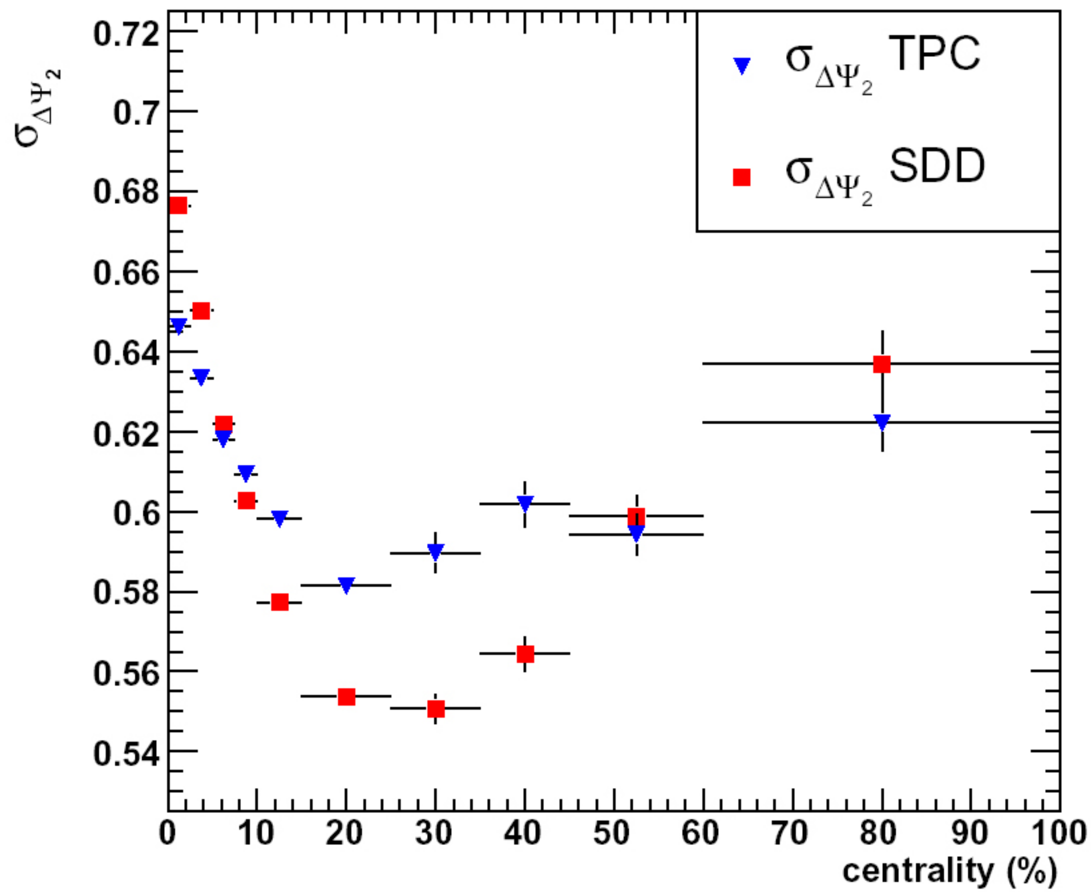
D. Antonczyk



resolution of the reaction plane

D. Antonczyk

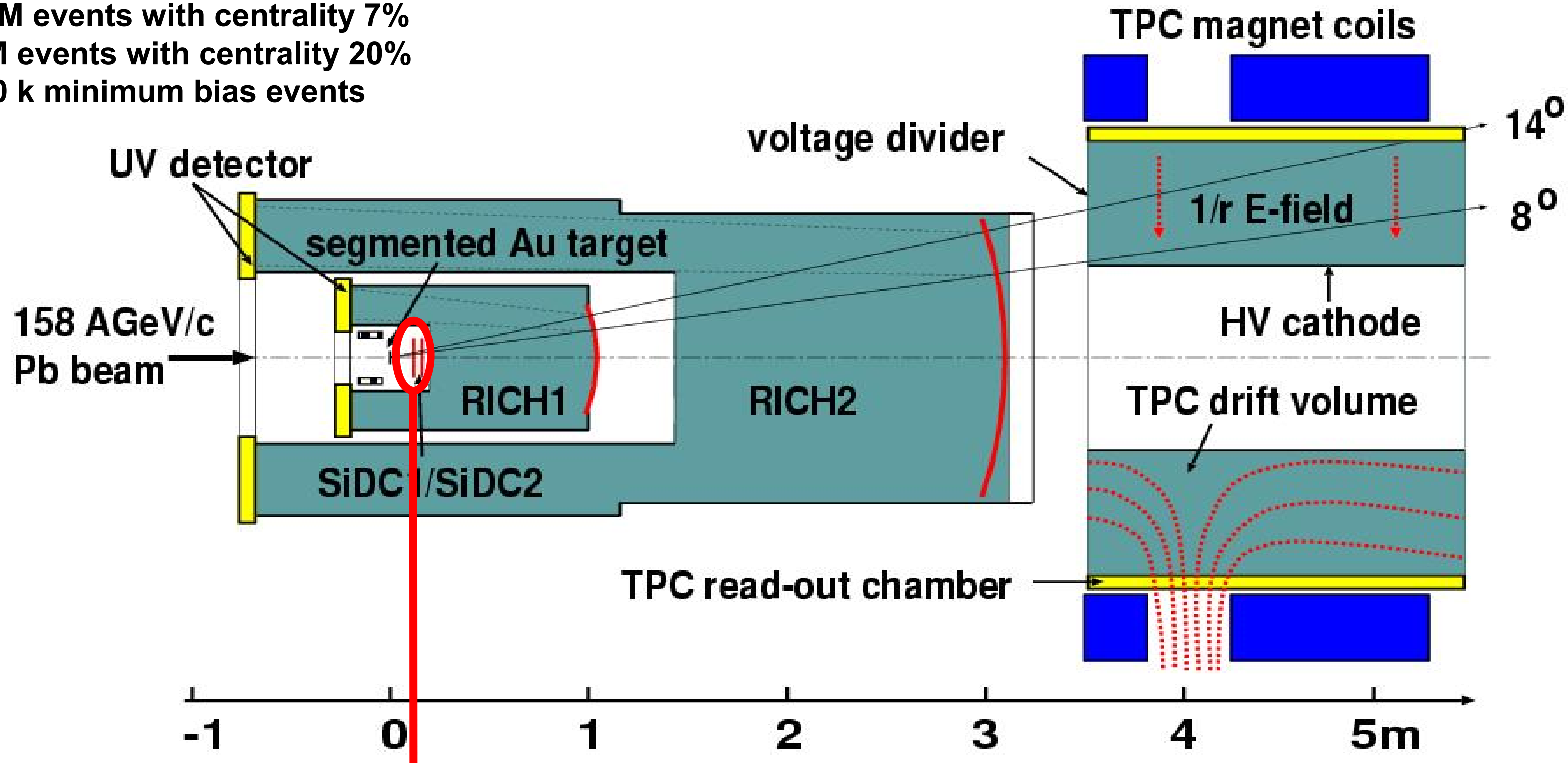




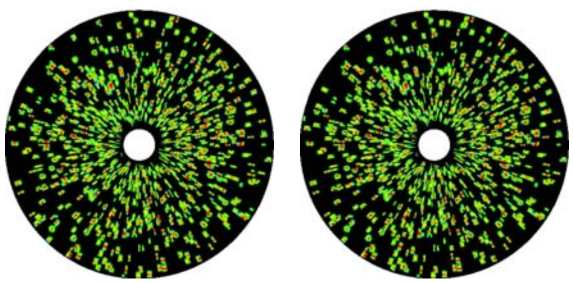
resolution 31°-38° (depending on centrality)

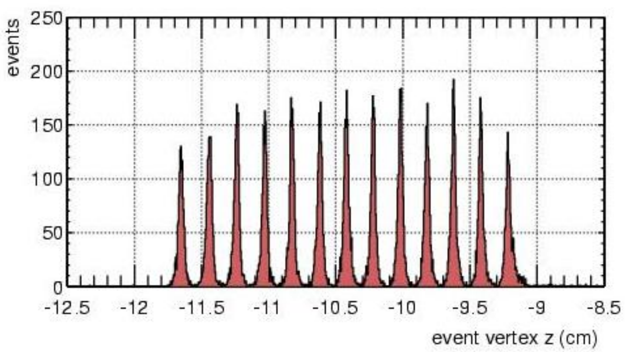
setup with TPC: 1999 and 2000

run 2000: 30 M events with centrality 7%
2 M events with centrality 20%
500 k minimum bias events



SD: event vertex, track vertex and angle

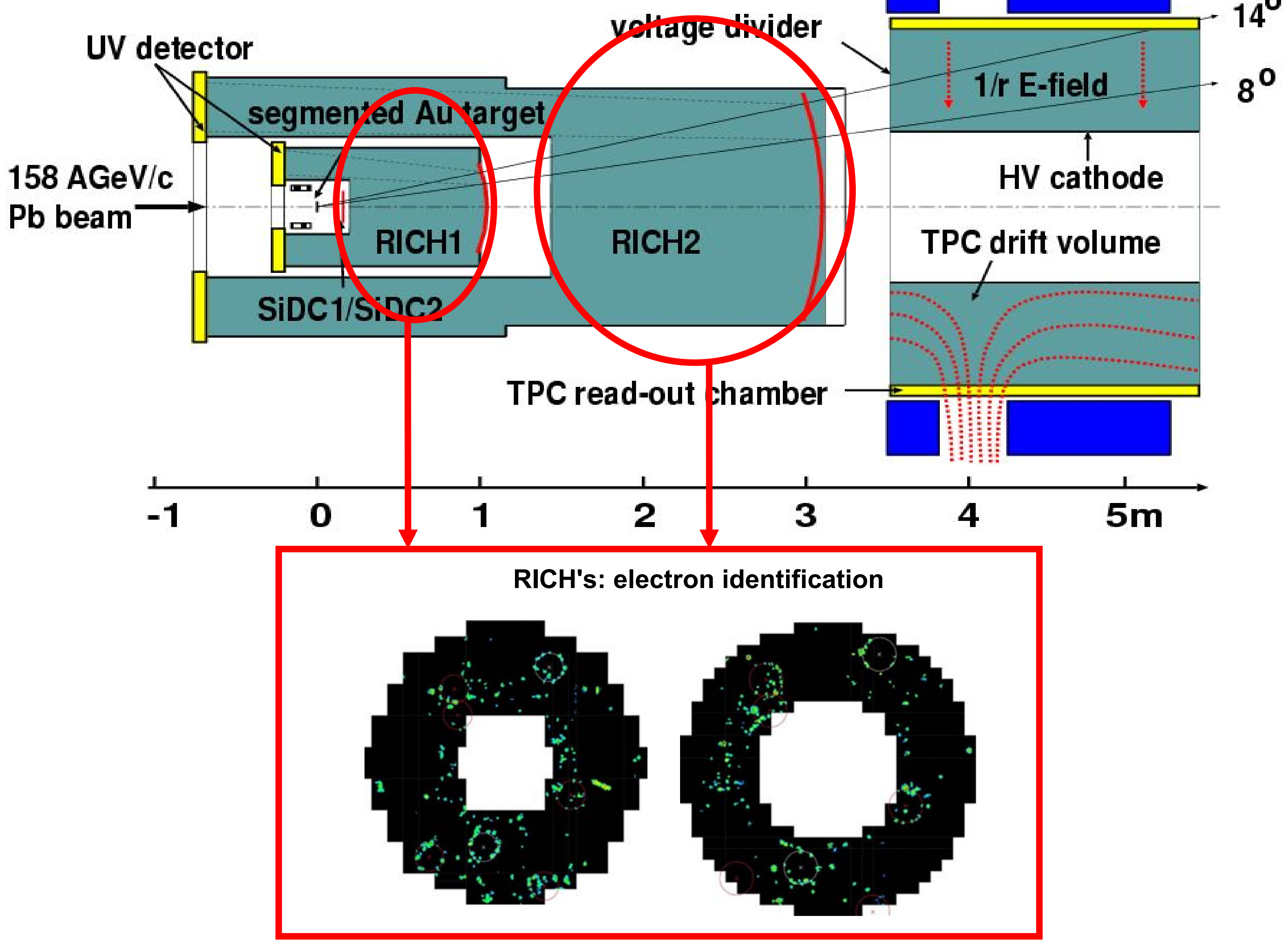




event Δz = 0.2 mm
track $\Delta\theta$ = 0.2 mrad
$\Delta\varphi$ = 2 mrad

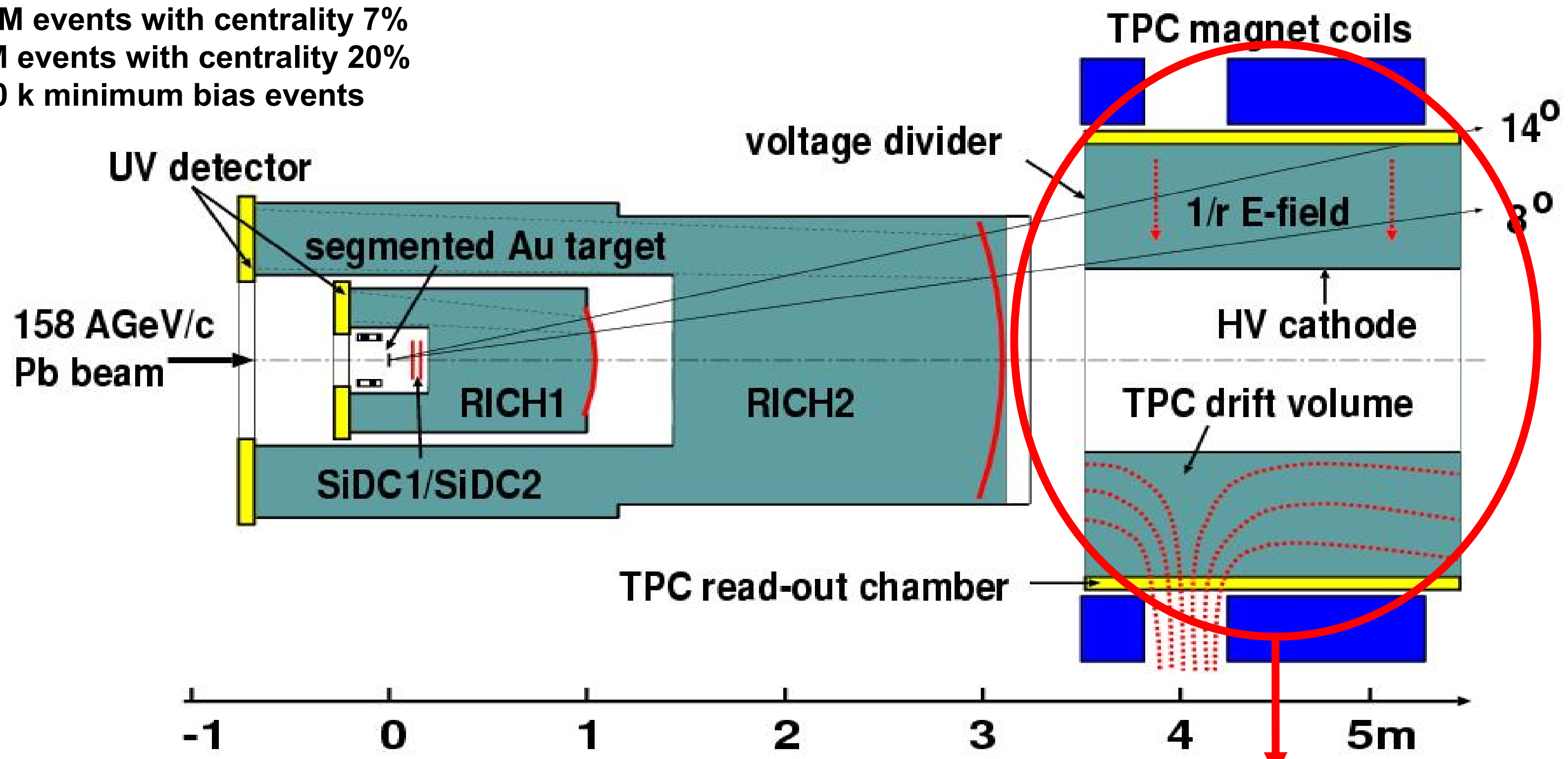
setup with TPC: 1999 and 2000

run 2000: 30 M events with centrality 7%
2 M events with centrality 20%
500 k minimum bias events

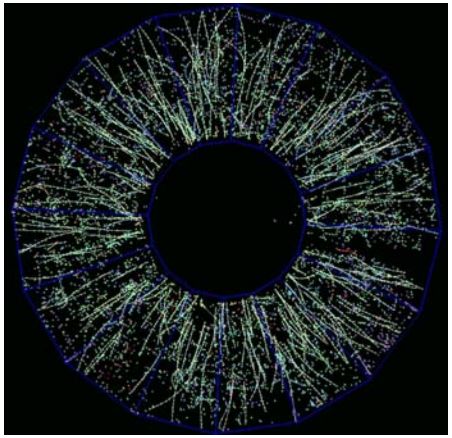


setup with TPC: 1999 and 2000

run 2000: 30 M events with centrality 7%
2 M events with centrality 20%
500 k minimum bias events



radial drift TPC: momentum and energy loss



$\Delta p/p = 2\% \oplus 1\% * p/GeV$

$\Delta m/m = 3.8$ % for ϕ

$\delta dEdx = 10\%$