Femtoscopic results in Au+Au & p+p from PHENIX at RHIC

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Topics:
- Bose-Einstein correlations of charged kaons in 200 GeV Au+Au collisions
  - comparisons (π -s, K^0-s of STAR)
  - m_t and N_{part} scaling of 3d HBT radii
  - 1d imaging and tails
- Bose-Einstein correlations of charged pions in 200 GeV p+p collisions
  - comparisons with Au+Au
  - m_t and N_{part} scaling of 3d HBT radii
  - 1d imaging and tails
- Squeezed particle-antiparticle correlations
  - (see M. Nagy's WPCF'09 talk for details)

HBT nomenclature

$$C_2(\mathbf{q}) = A(\mathbf{q})/B(\mathbf{q})$$

$$\mathbf{q} = \mathbf{p_1} - \mathbf{p_2}$$

$$= 1 + \int d\mathbf{r} K(\mathbf{q},\mathbf{r}) S(\mathbf{r})$$

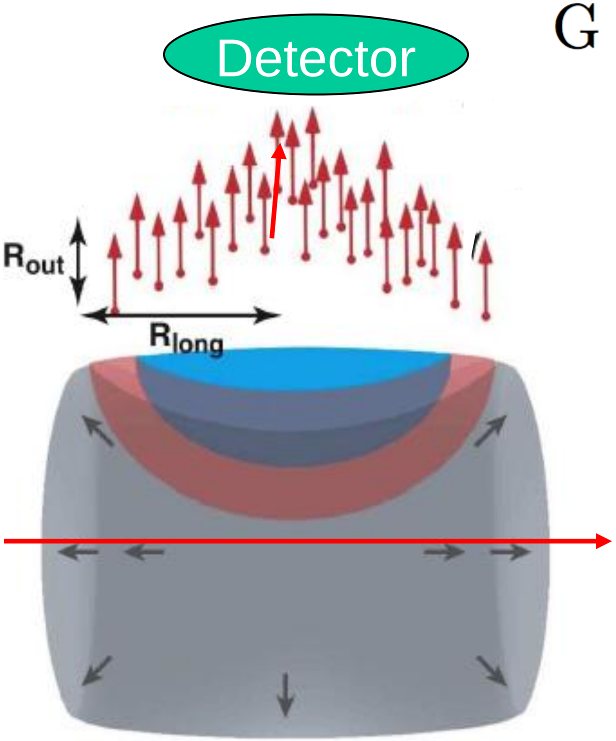
The source *S* can be directly recovered with imaging

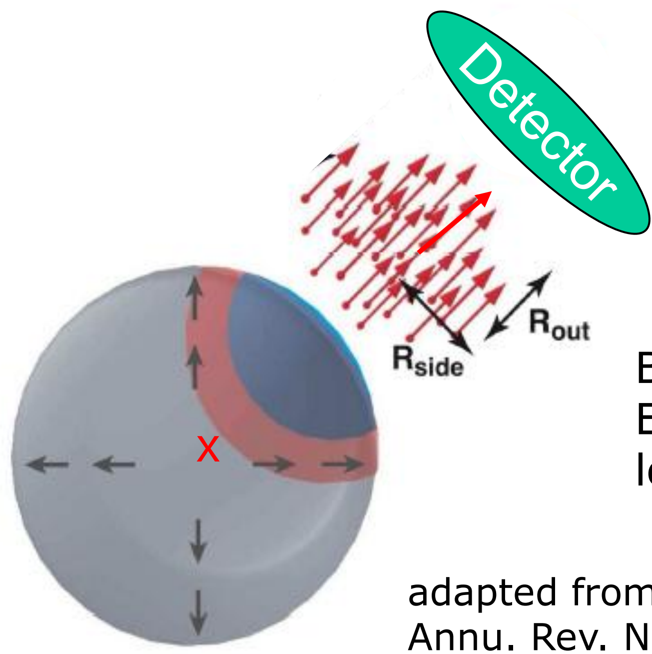
or

Make assumptions about the source

$$= \lambda(1 + \mathrm{G})\mathrm{F_C} + 1 - \lambda$$

$$\mathrm{G} = exp(-R^2_{side}q^2_{side} - R^2_{out}q^2_{out} - R^2_{long}q^2_{long})$$

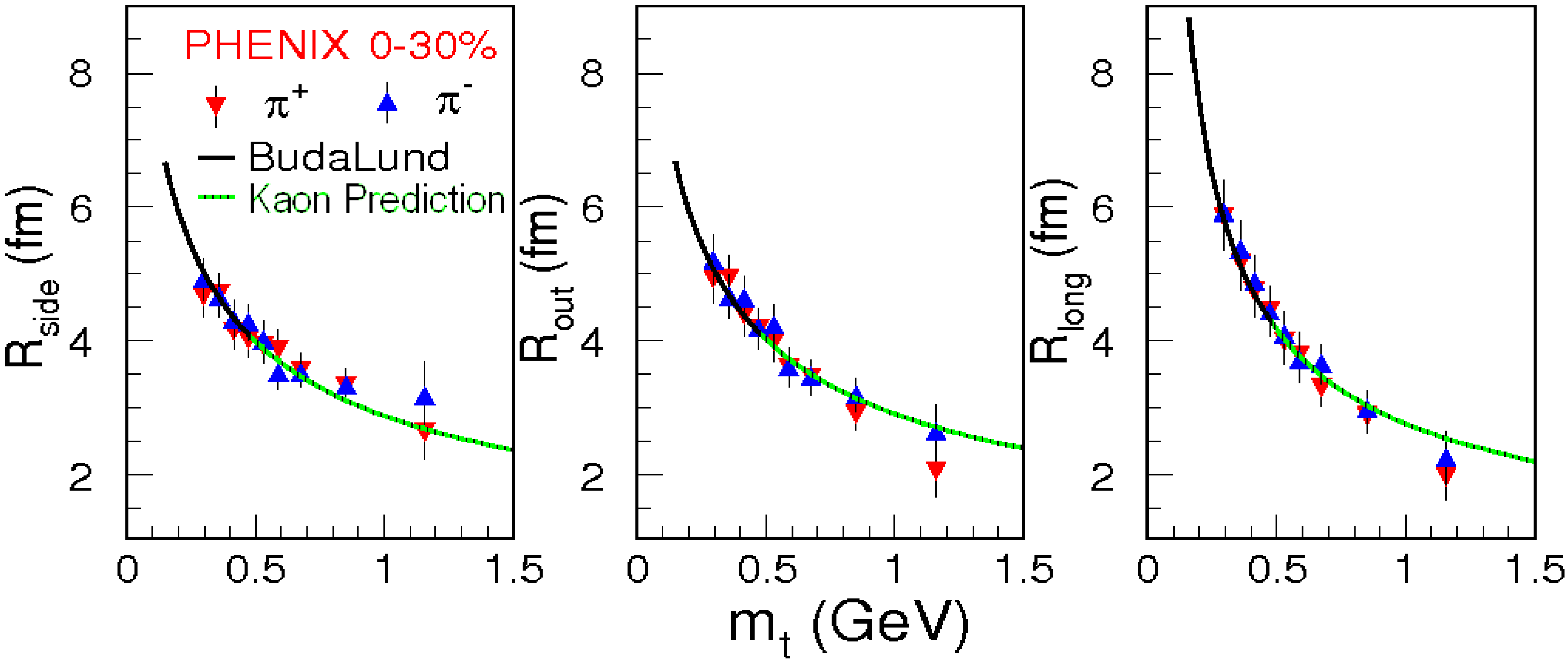




Bose-Einstein Enhancement at low relative momentum q

adapted from Annu. Rev. Nucl. Part. Sci. 2005. 55:357-402

Why kaon HBT in Au+Au at RHIC?



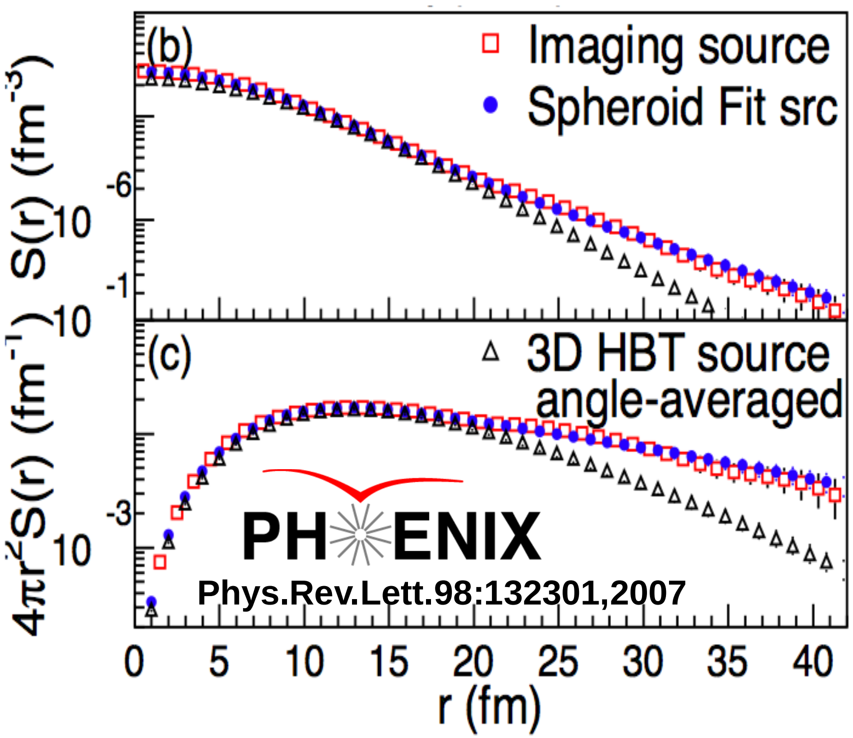
From M. Csana'd, T. Cs., Acta Phys.Polon.Supp.1:521-524,2008

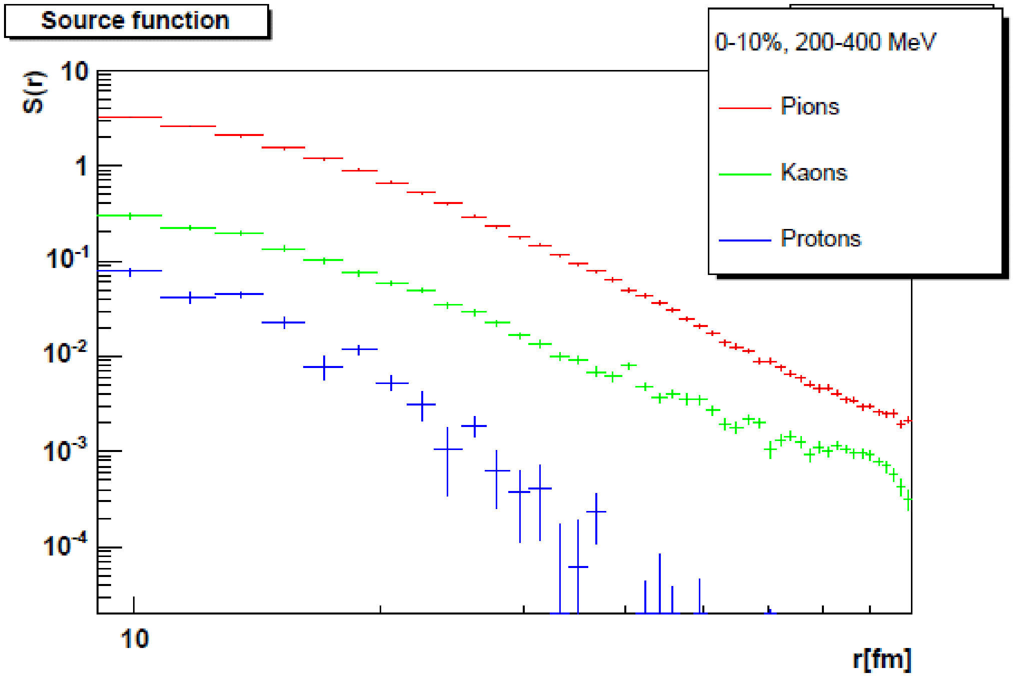
Kaon interferometry: M. Gyulassy, Sandra S. Padula, PRC 41, R21 (1990)

- Kaons less effected by decays of long lived resonances, than pions.
- A clearer distinction between QGP formation and resonance dynamics

But kaons follow m_T scaling at CERN SPS: NA44 Collab, PRL 87:112301, (2001)

Why kaon imaging in Au+Au?





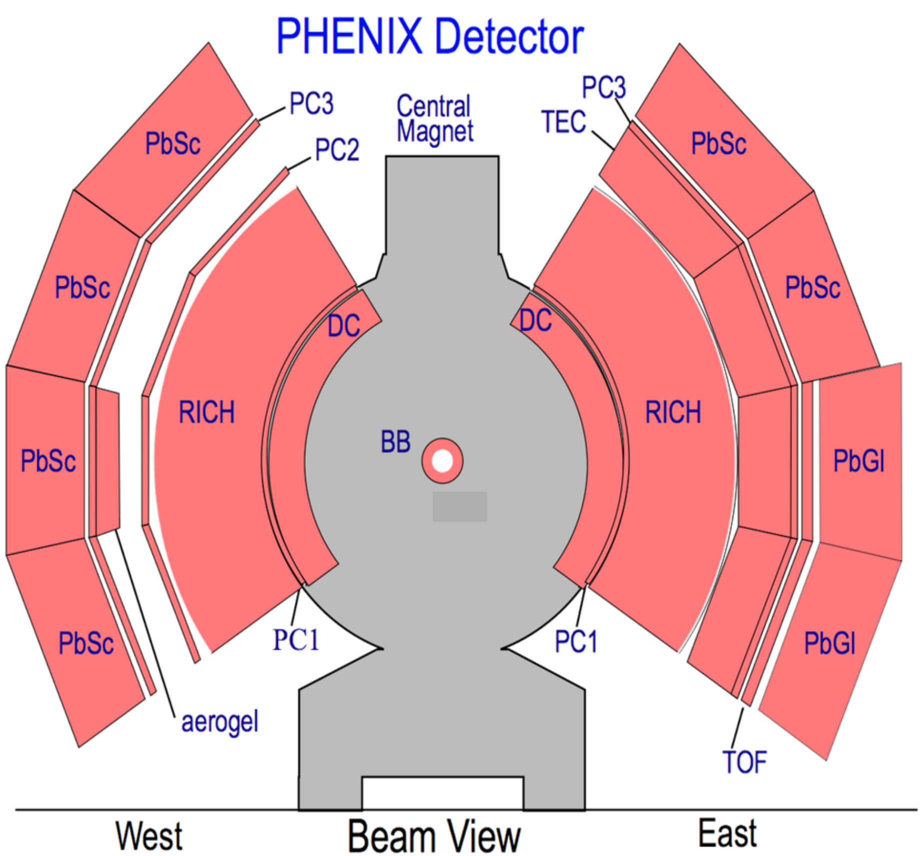
M. Csana'd et al., Braz.J.Phys.37:1002-1013,2007

FIG. 20: Source distribution of pion, kaon and proton pairs with 0.2 GeV/c < p_t < 0.4 GeV/c and 0-10% centrality.

First imaging data: extended tail of pion emission in S(r)

- Long lived resonances? Pions have longer tail, than kaons.
- Hadronic rescattering? Pions larger cross sections, than kaons.
- Anomalous diffusion in HRC simulation: kaon's tail is longer, than pions!(?)

Analysis details



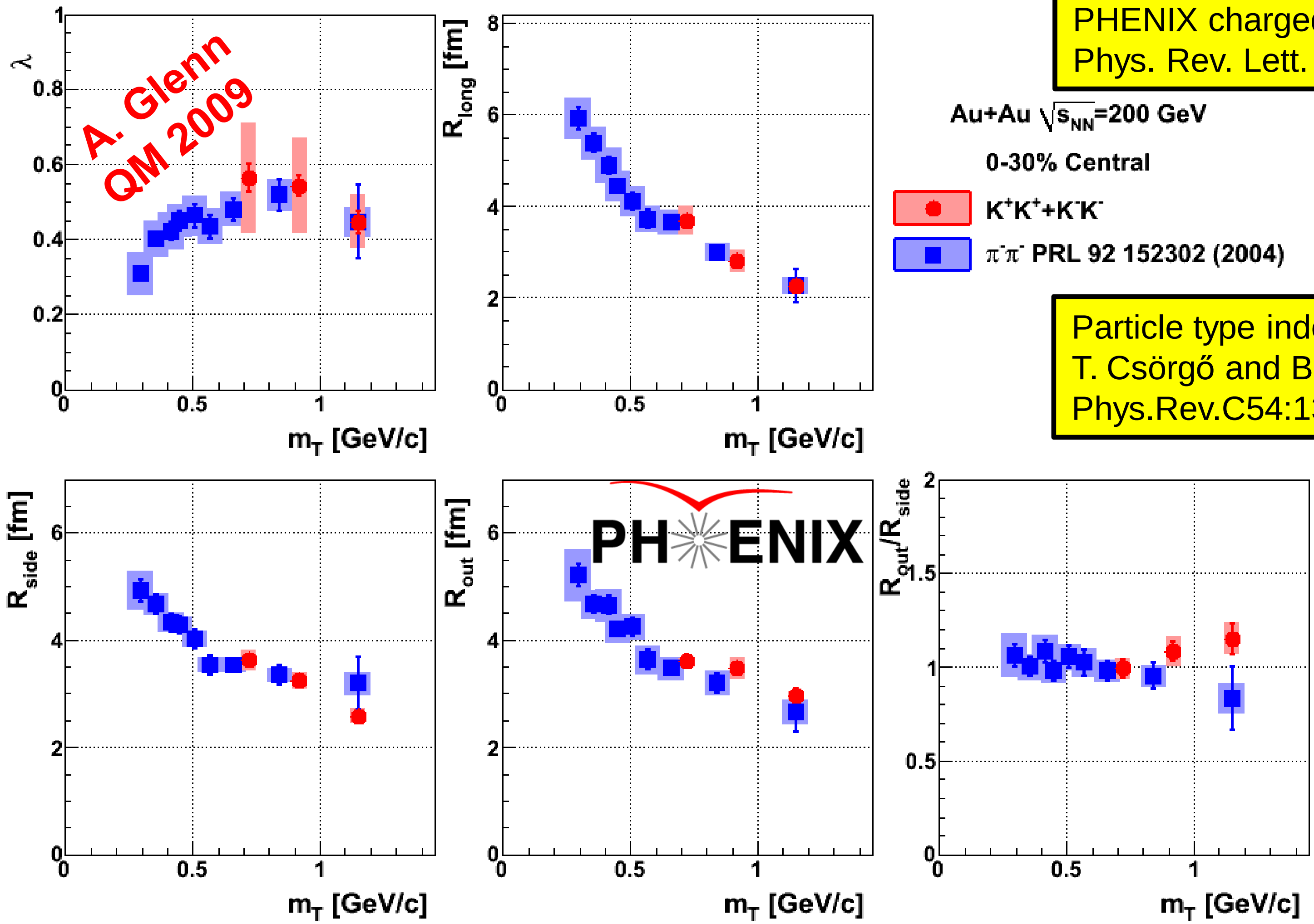
600M events, Au+Au 200 GeV minimum bias dataset of 2004 (~30M like sign kaon pairs)

Charged kaons tracked by DC, PC1, PC3, identified by time of flight from PbSc

$|\eta| < 0.35$, $\Delta\pi = \pi/2(\pi/4)$
in West(East) arm

Matching cuts reduce backgrounds
Pair selection cuts to remove merging and splitting
Monte Carlo based corrections to extend into regions with reduced pair efficiency

Transverse mass scaling



PHENIX charged kaon HBT data:
Phys. Rev. Lett. 103, 142301 (2009)

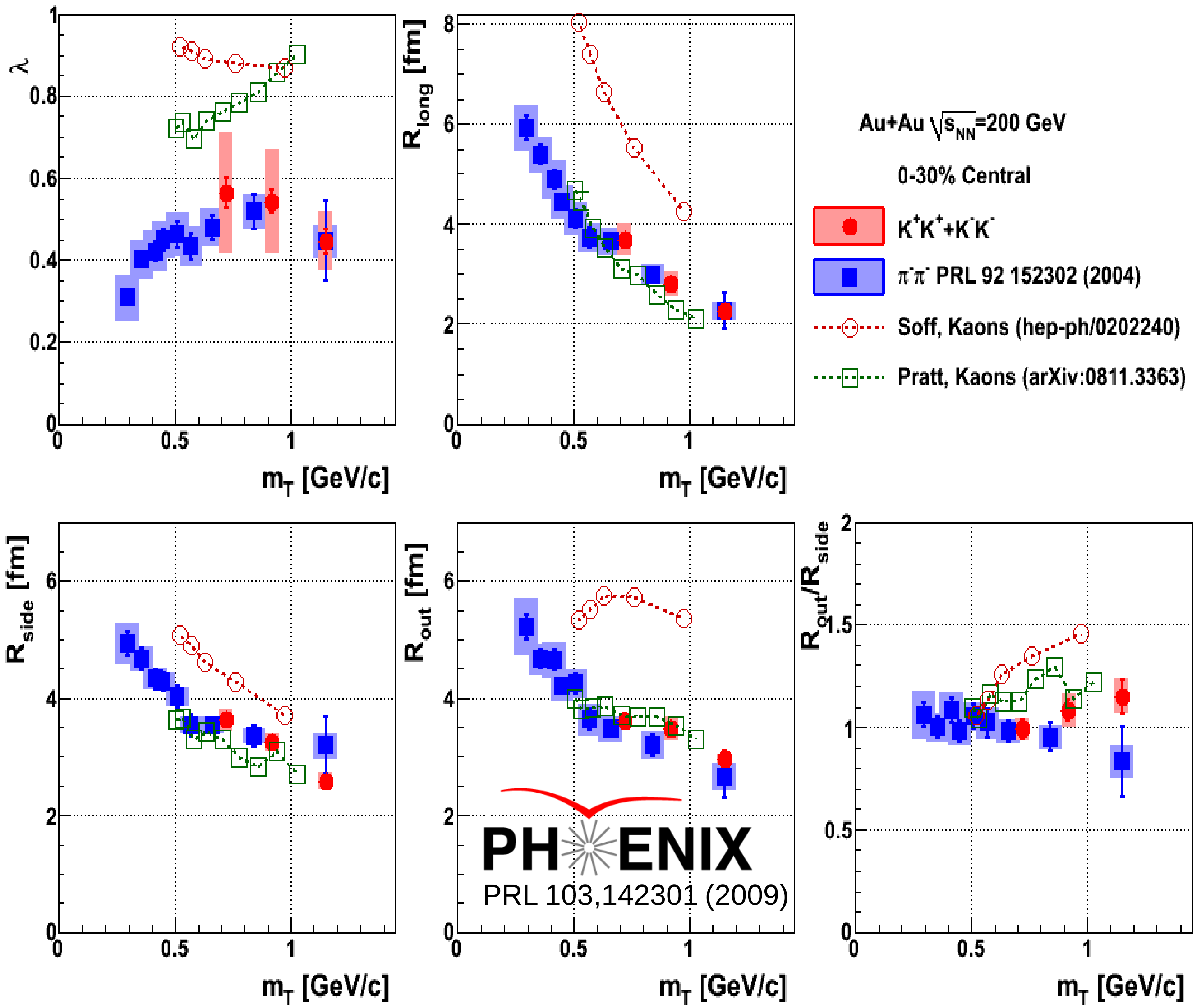
Particle type independent m_T scaling :
T. Csörgő and B.Lörstad
Phys.Rev.C54:1390-1403 (1996)

$$m_T = \sqrt{k_T^2 + m^2}$$

$$k_T = (p_{1T} + p_{2T})/2$$

In 200 GeV Au+Au, m_T dependent HBT radii for charged kaons and pions follow the same universal m_T scaling curve

More theory comparisons



S. Soff, hep-ph/0202240:

2 d +1 hydro+UrQMD
Example of "HBT puzzle"

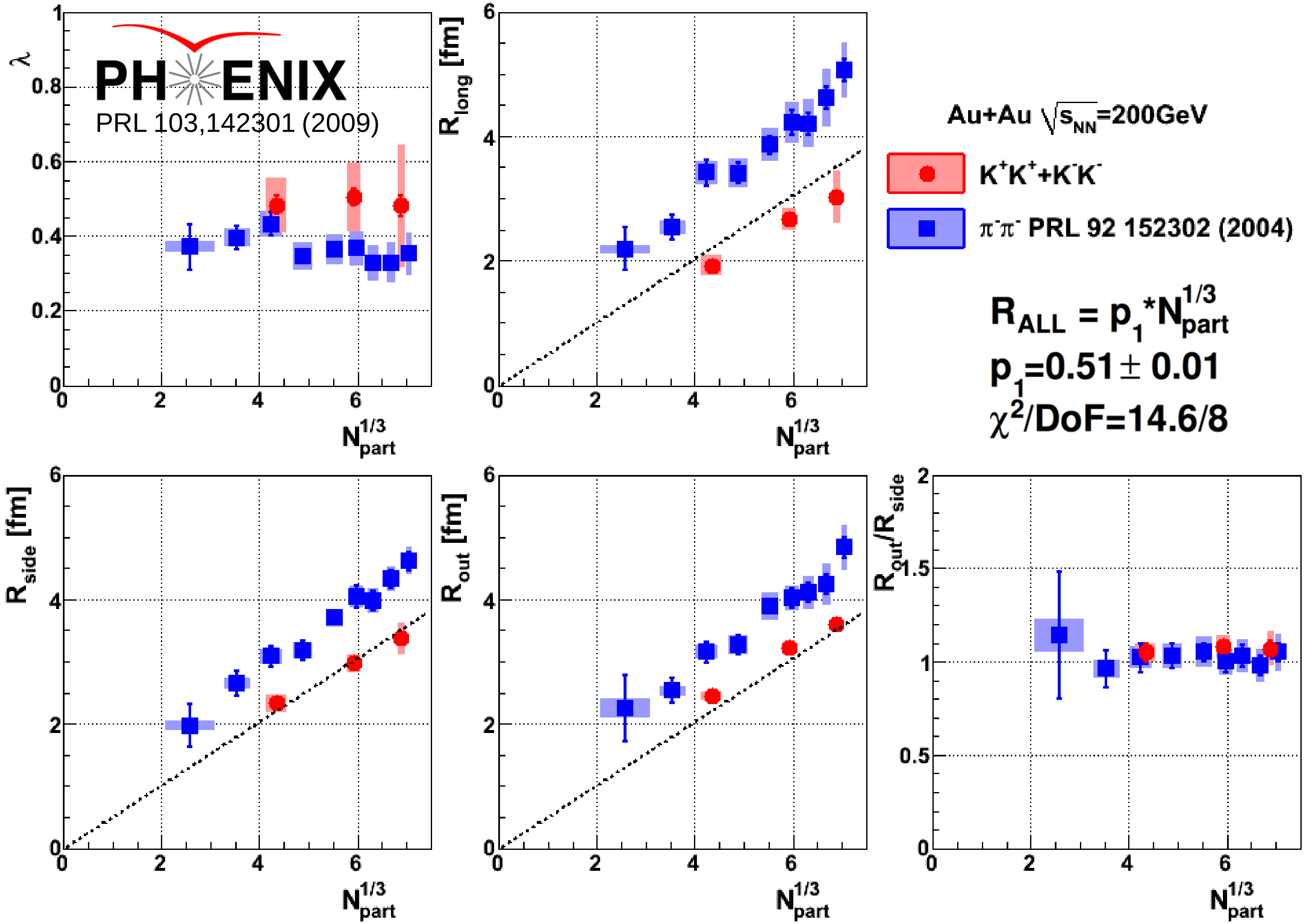
S. Pratt,
nucl- th/0811.3363
& private comm. for kaons: ~ m_T scaling

1 d +1 hydro+cascade with.pre-equilibrium flow & lattice inspired equation of state.

not tuned to kaons!

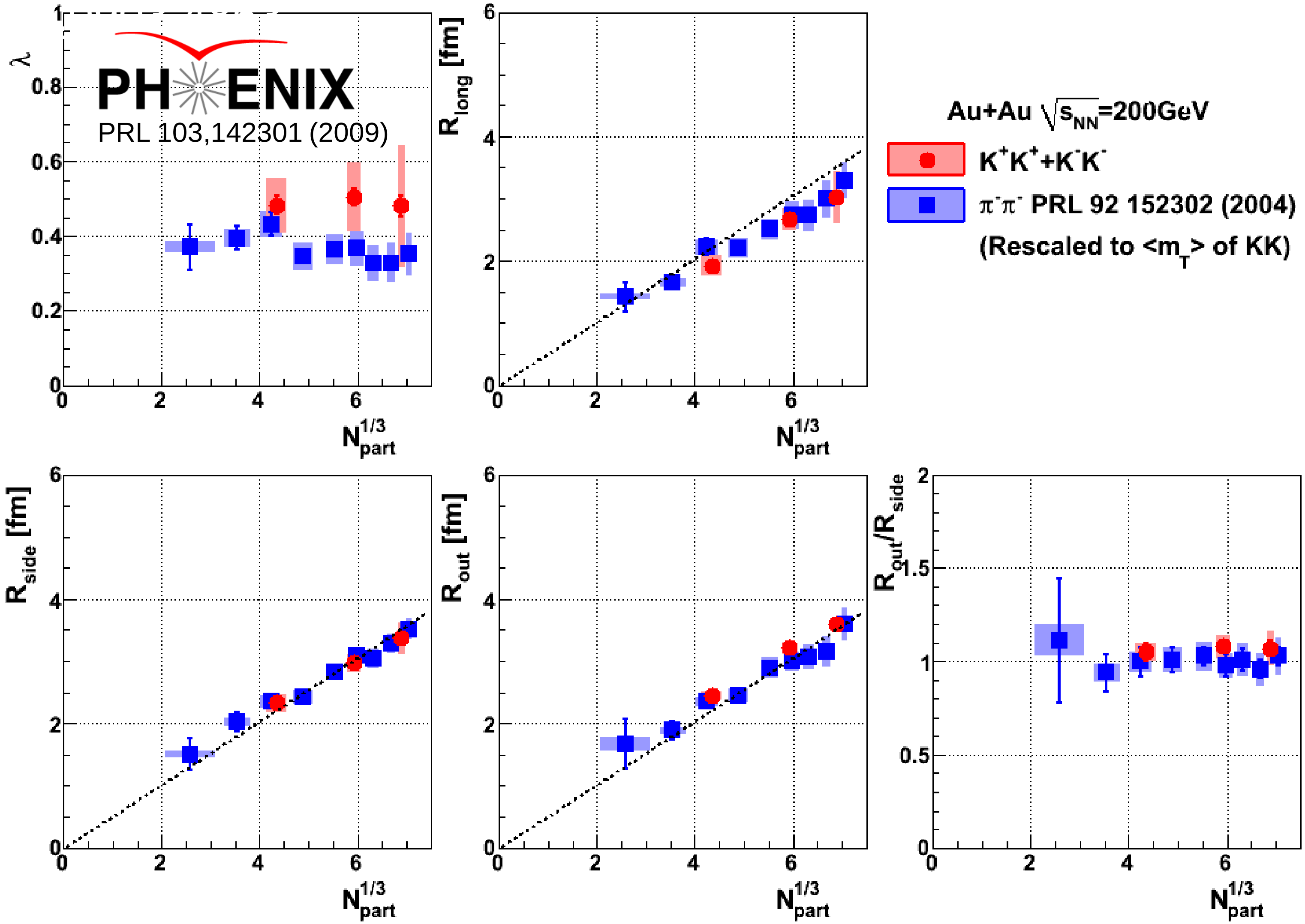
Can 3D+1 implementation reproduce elliptic flow?

Centrality Dependence



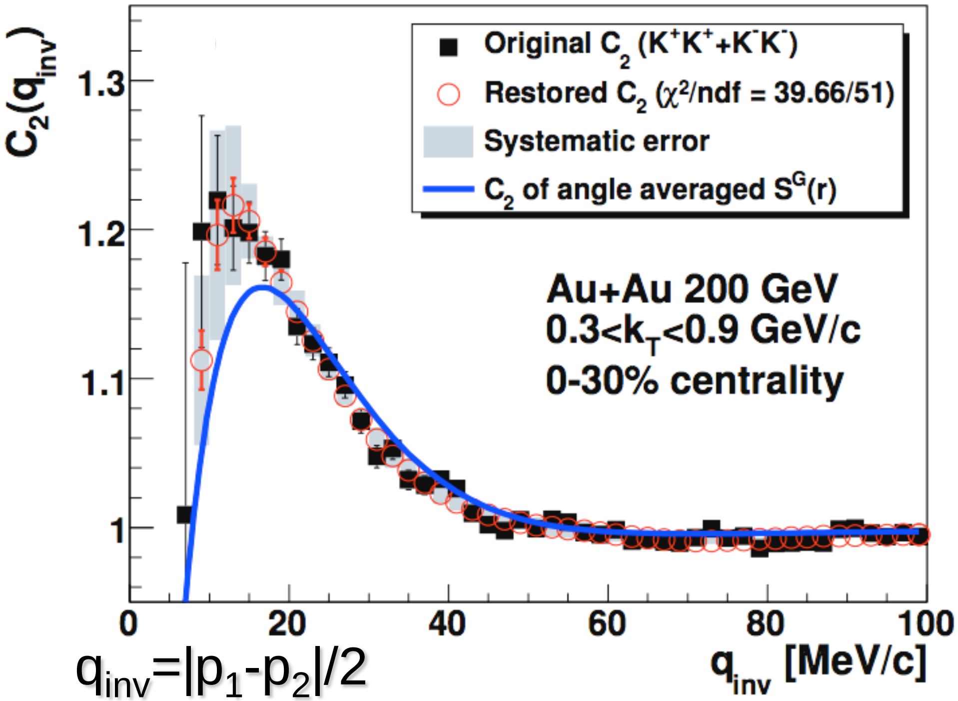
Similar slope as π-s, agrees well with linear extrapolation, R=0 for N_{part}=0

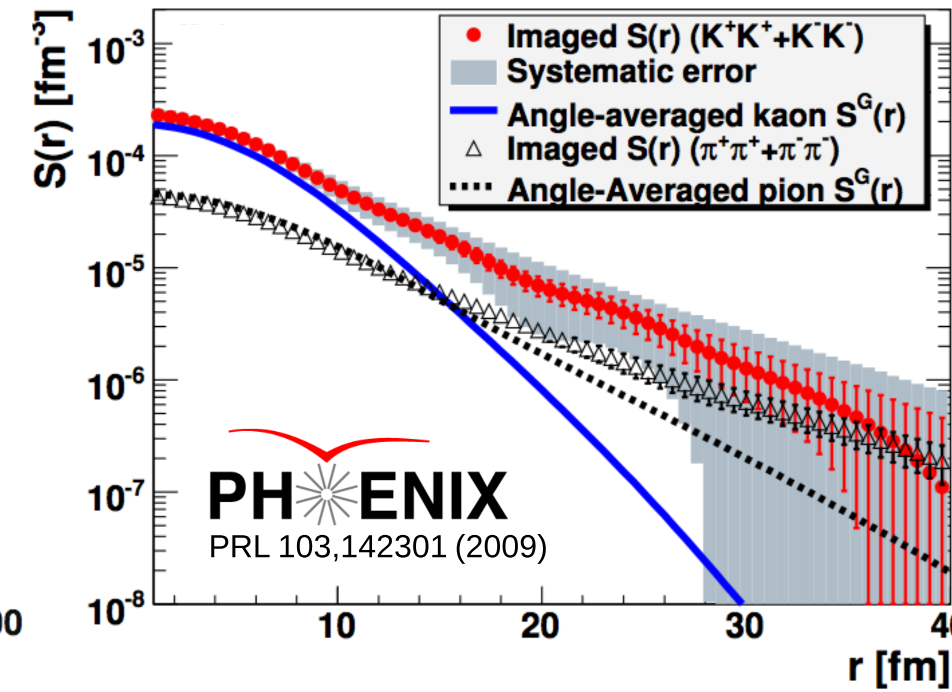
Compared to rescaled pions



Consistent with previous pion measurement

Source Imaging





Significant tail for r>10 fm for kaon source
Pion source is not only from long lived resonance (ω) decays
Larger kaon tail consistent with hadronic resonance cascade models
M. Csanad et al, hep-ph/0702032, T. Csörgő et al, nucl-th/051206.0298

Pions in p+p

Baseline measurement

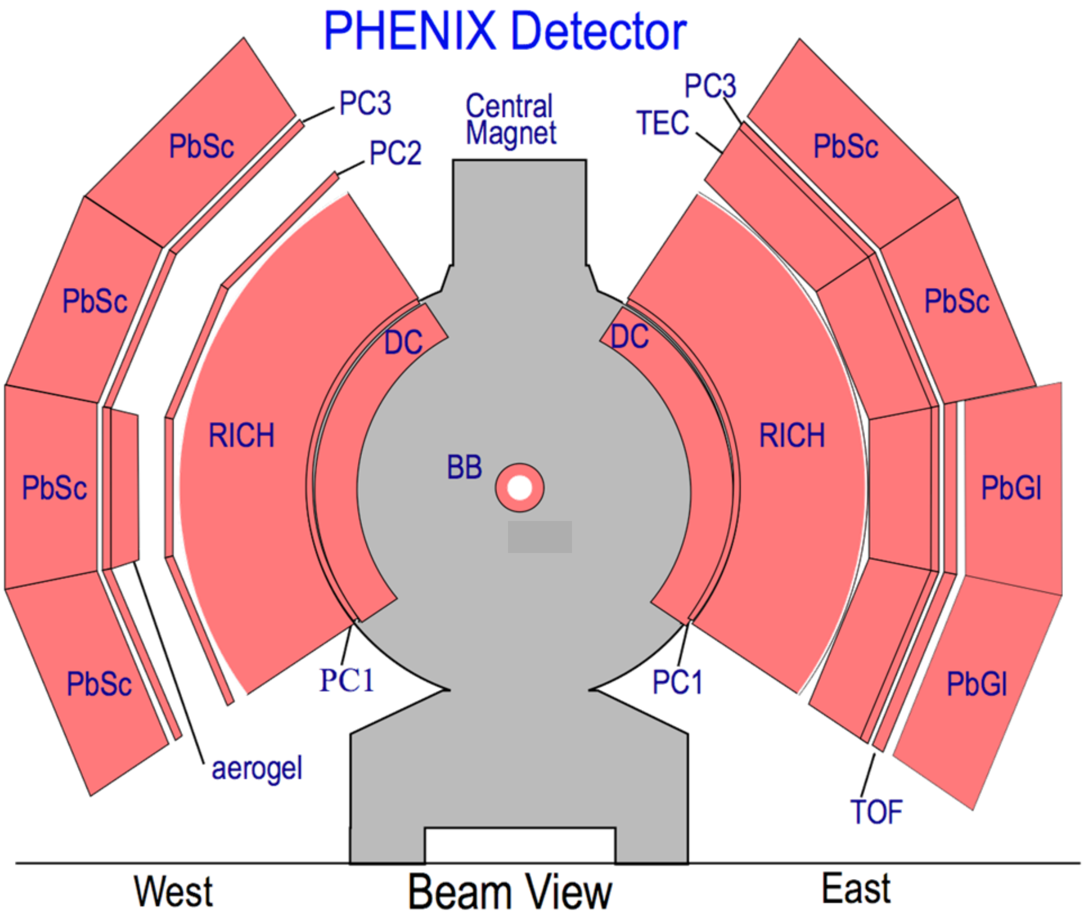
Proving ground for understanding and dealing with non-HBT contamination

- Event selection
- Relative to jet
- Multiplicity
- …

Phys.Rev.C78:064903,2008

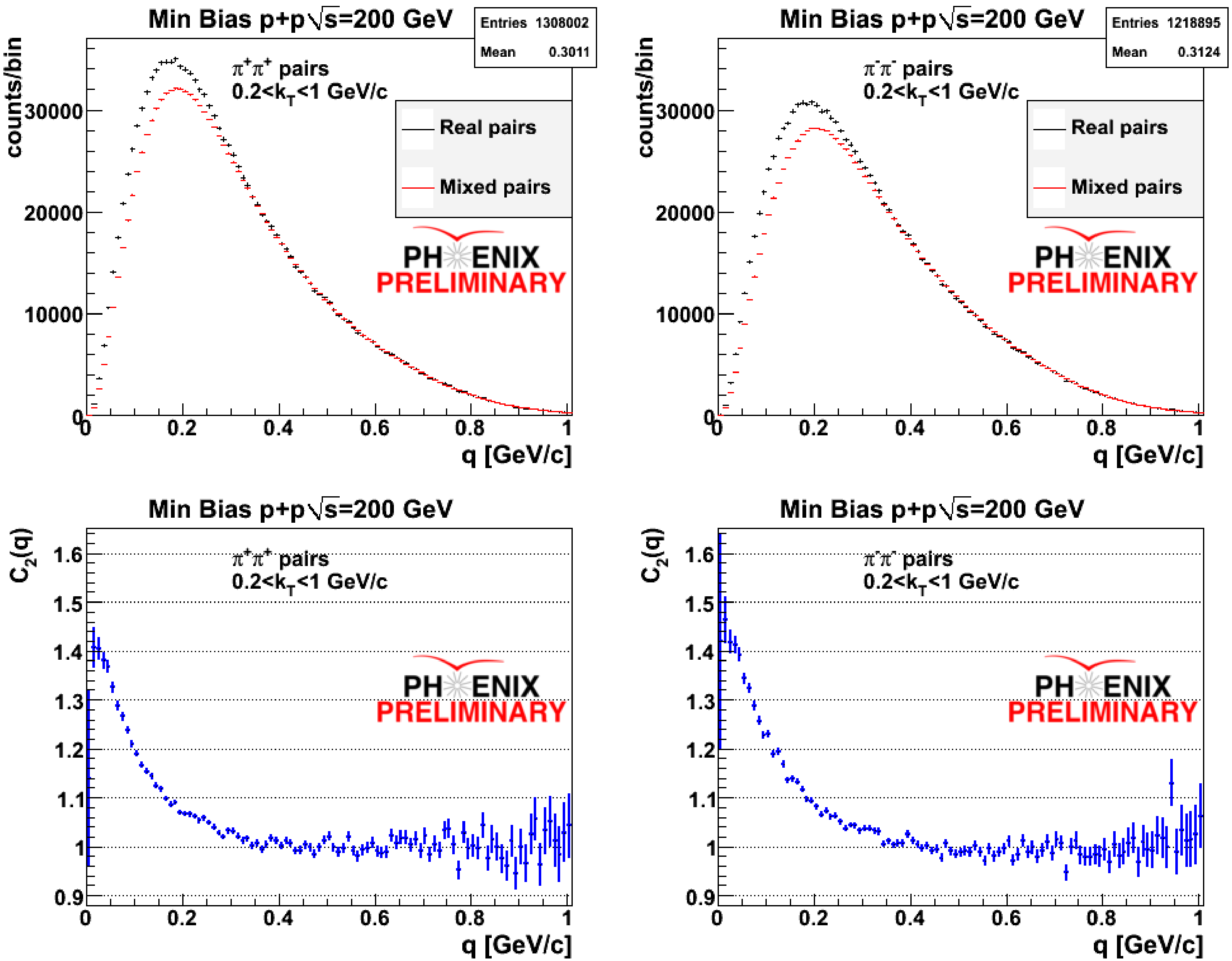
Capability likely needed: future heavy ion analyses relative to jet axis…

A few analysis details for p+p



- Run5 p+p minimum biased (~2.5M like sign pion pairs)
- Charged pions identified by time of flight from West PbSc
- Matching cuts reduce backgrounds
- Pair selection cuts to remove merging and splitting
- No Monte Carlo based corrections so more selective pair cuts

1-D Correlations



Slices of 3-D Correlation

$$\text{Bowler-Sinyukov: } C_2 = [\lambda(1+G)]F_c(q_{inv}) + [1+\lambda]$$

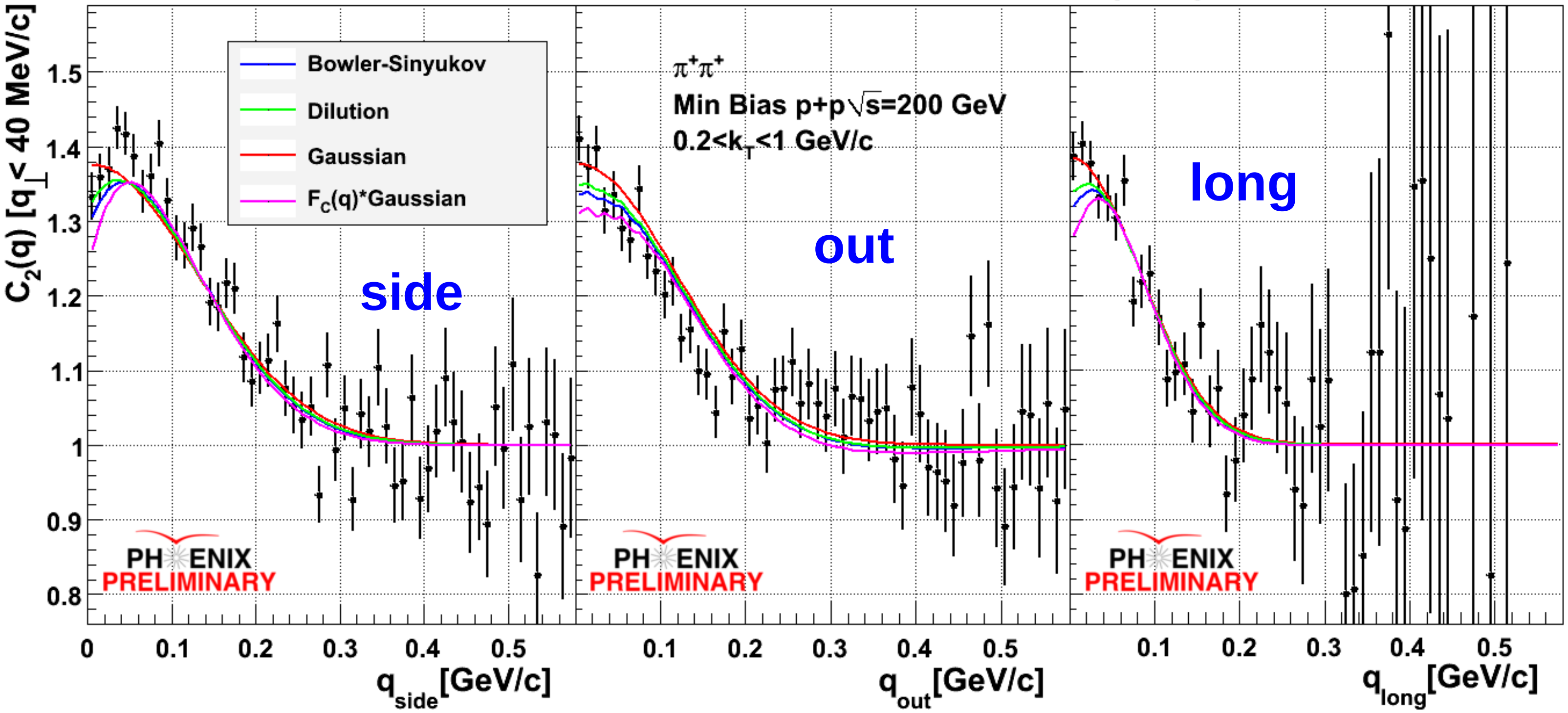
$$\text{Dilution: } C_2 = [\lambda(1+\lambda G)]F_c(q_{inv}) + [1+\lambda]$$

$$\text{Coulomb corrected Gaussian: } C_2 = (1+\lambda G)F_c(q_{inv})$$

$$\text{Gaussian: } C_2 = 1+\lambda G$$

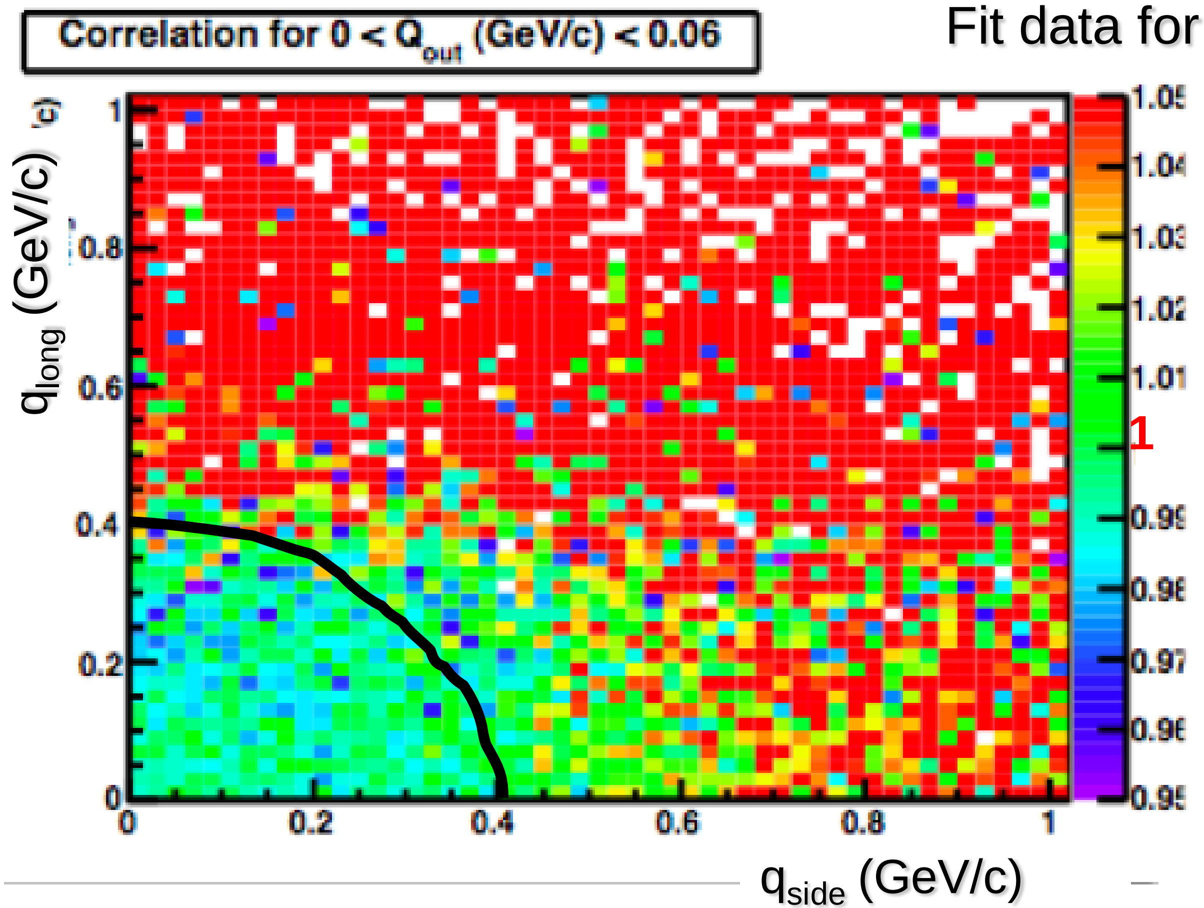
$$\text{where } G = \exp(R^2_{side}q^2_{side} + R^2_{out}q^2_{out} + R^2_{long}q^2_{long})$$

A. Glenn
QM 2009



A few words on fitting

PYTHIA used as sanity check to limit fit range
and help minimize impact of non-HBT correlations

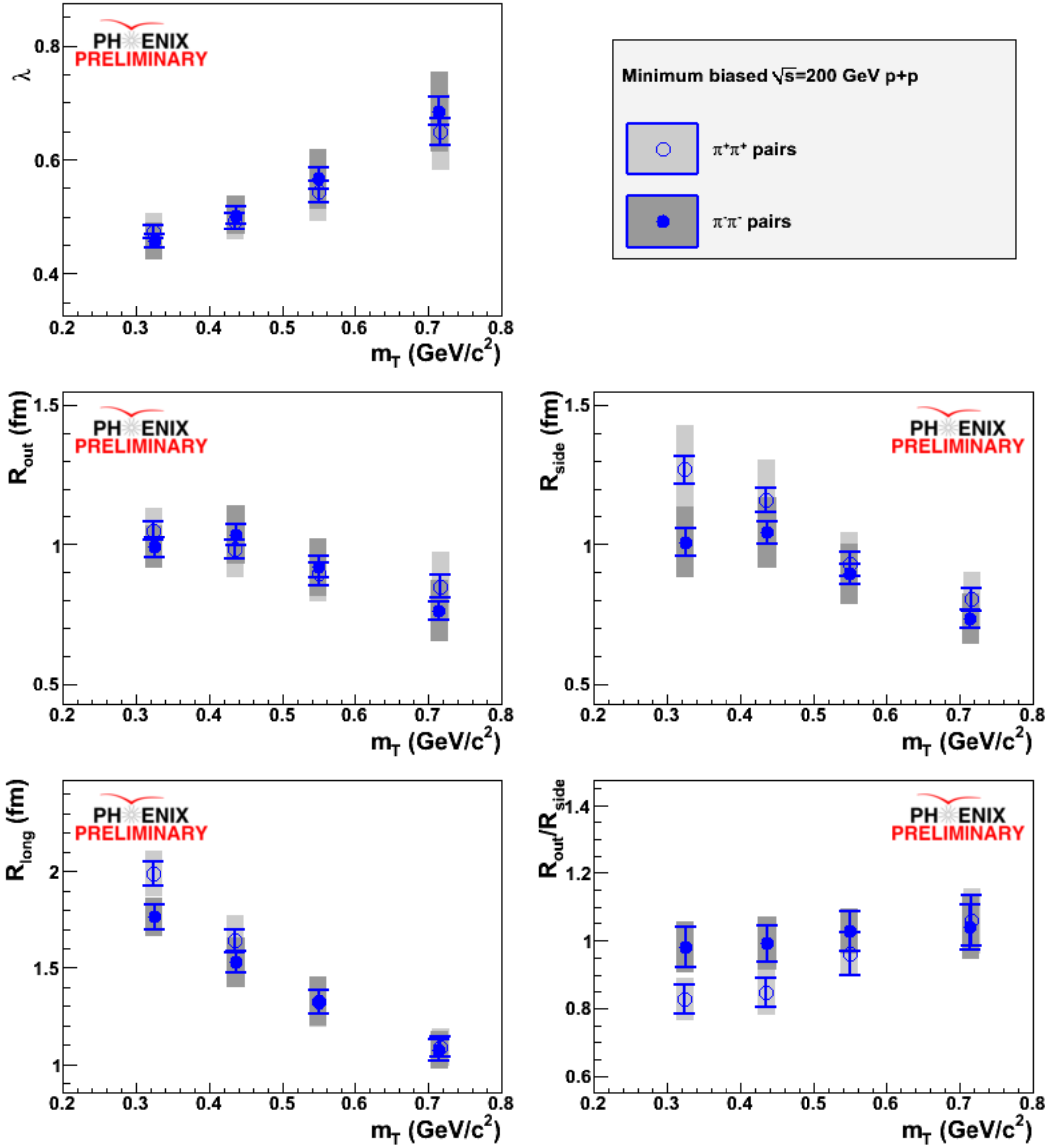


Fit data for $q_o^2+q_l^2+q_s^2<(0.4\text{GeV/c})^2$

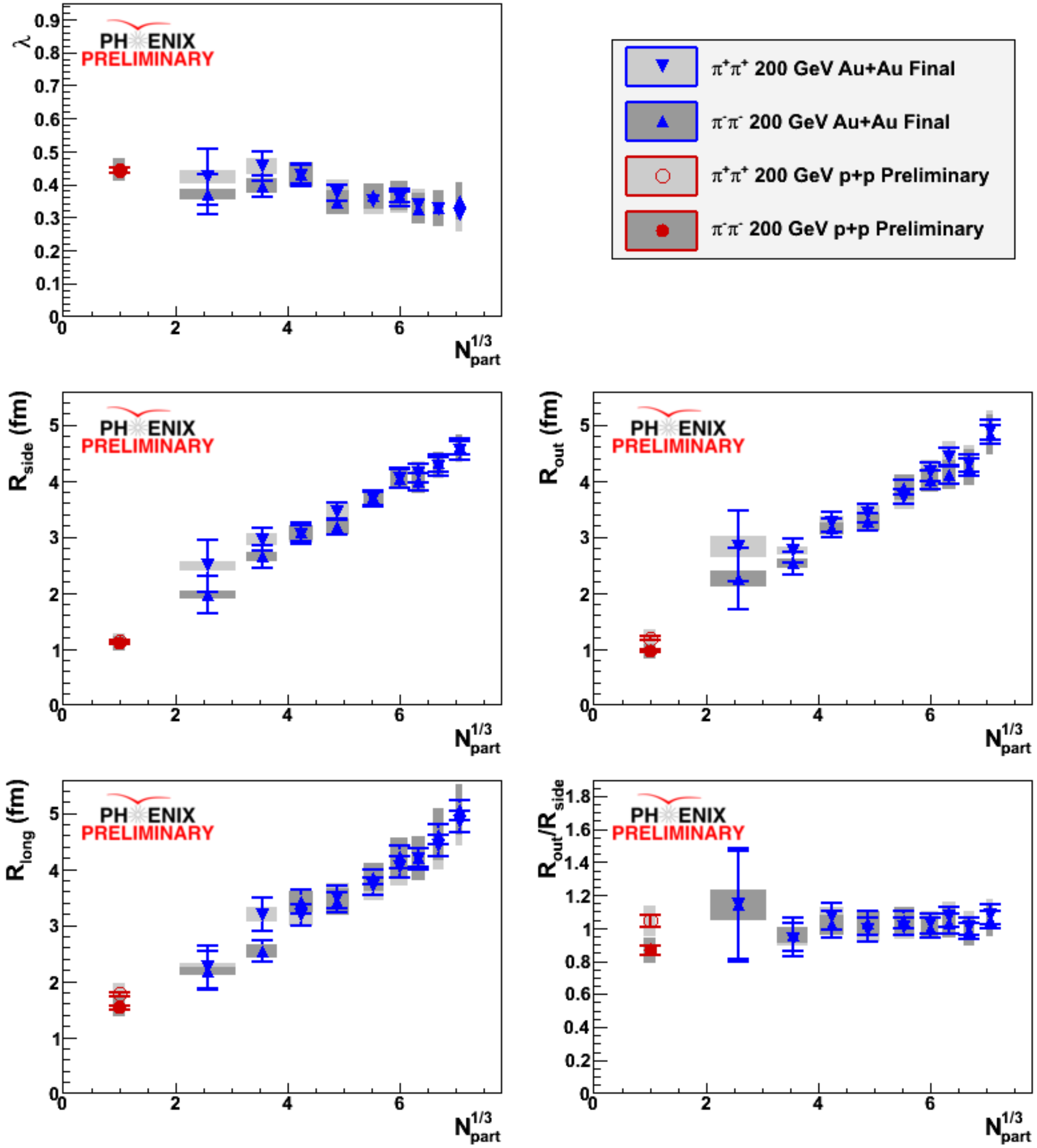
one example of
many slices

Transverse Mass Dependence

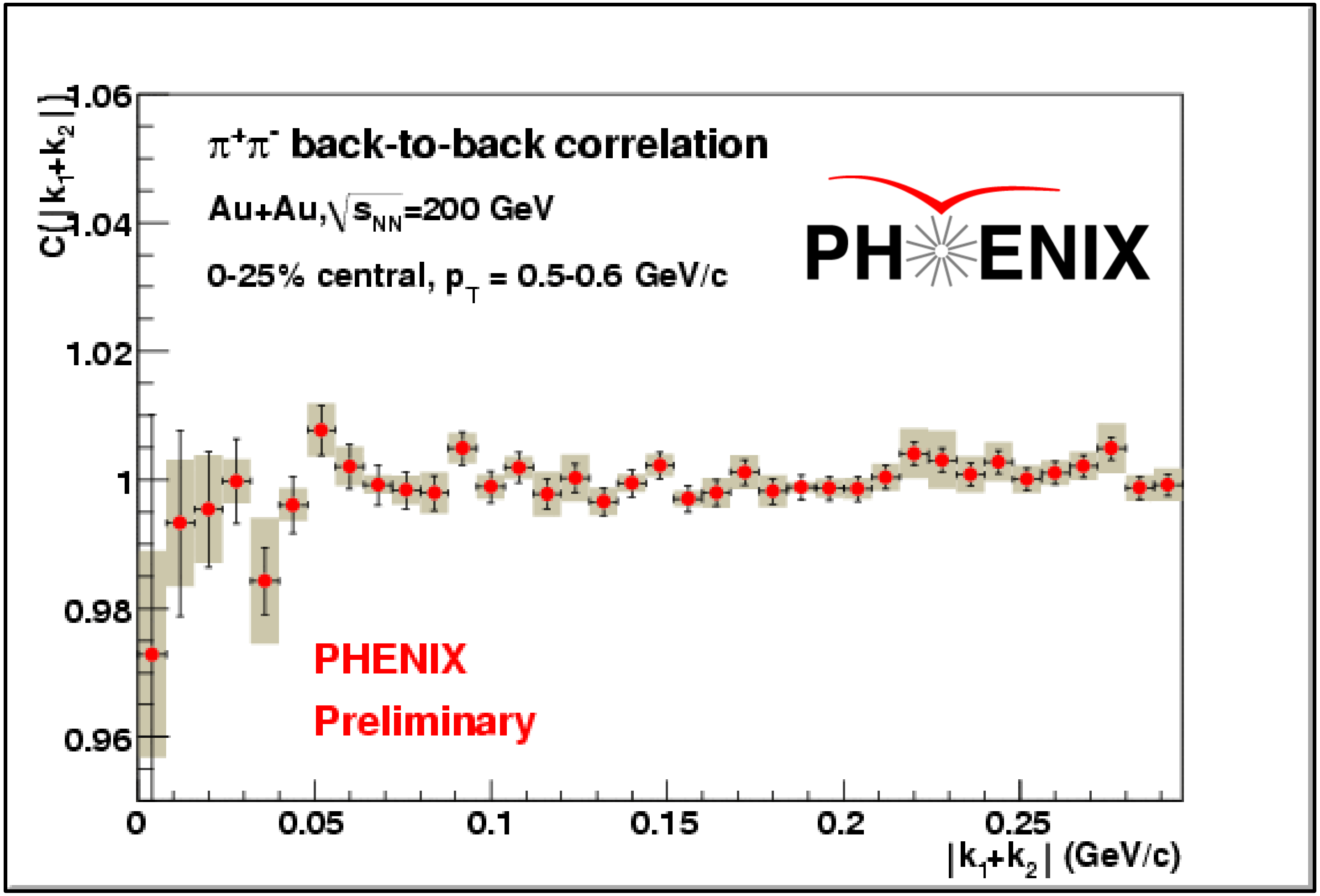
A. Glenn
QM 2009



p+p and Au+Au comparison



Squeezed particle-antiparticle correlations



Back-to-back particle-antiparticle correlations: first measurements
Expected to signal in-medium mass modification of hadrons
For more details, see the talk of M. Nagy at WPCF 2009

Summary, K K in Au+Au

Kaon m_T and m_T scaled centrality dependence consistent with pions.

Kaon HBT radii scale as $R_{HBT} = p_1 N_{part}^{1/3}$

i.e. $R_{HBT}=0$ at $N_{part}=0$

Bulk production in agreement with predictions on m_T scaling, and with a promising 1+1D+hydro+cascade with initial flow

Significant tail in imaged K source for r>10fm

- Tail stronger for kaons than for pions !
- Tail in pions not just from resonances!
- Further checks needed for other particles (protons)!

Summary: $\pi\pi$ in p+p

Pion correlations in min. bias collisions for PHENIX west arm acceptance do not show significant energy momentum contamination.

Measured radii: consistent with centrality extrapolation from Au+Au

Plenty to look at

(multiplicity dependence, jets…)

In Au+Au, the first preliminary back-to-back particle-antiparticle correlations were measured. See M. Nagy's WPCF 2009 talk.

Back-up slides

Charged kaon analysis details

Momentum resolution:
$\delta p/p = 0.7\ \% \oplus 1\ \% \times p$ (GeV/c)

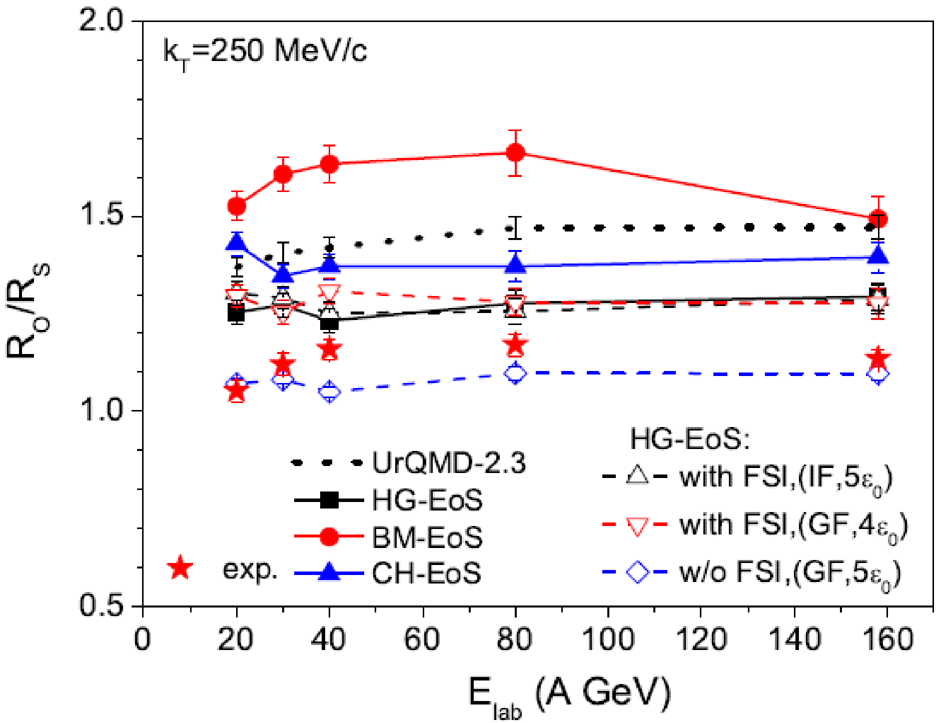
Matching cuts for tracking:
2 σ position match in PbSc
3 σ position match in PC3

Kaon identification based on BBC and PbSc timing signals for $p_t < 0.9$ GeV/c. For $p_t > 0.9$ GeV/c, kaons accepted if $< 2\sigma$ close to the invariant mass peak and $> 3\sigma$ from the invariant mass peak of pions and (anti)protons.

At $p_t \sim 1.5$ GeV/c,
contamination from pions: 4 %, from (anti)protons: 1 %.

After track selection and merging cuts:
1.5×10^7 K^+K^+ and 1.4×10^7 K^-K^- pairs

HBT signal of 1st order phase transitions, uses $R_{out}/R_{side}(m_t, \sqrt{s_{NN}})$



H. Petersen, QM 2009 talk:
HG= hadron gas EoS +hydro
BM= bag model EoS + hydro
CH= chiral EoS with CP+hydro
arXiv: 0812.0375

Comment:
Rischke's hydro <-> NA49
HBT puzzle is not RHIC specific
R_{out}/R_{side} sensitive to the EoS