RHIC, PHENIX, HBT, and other acronyms

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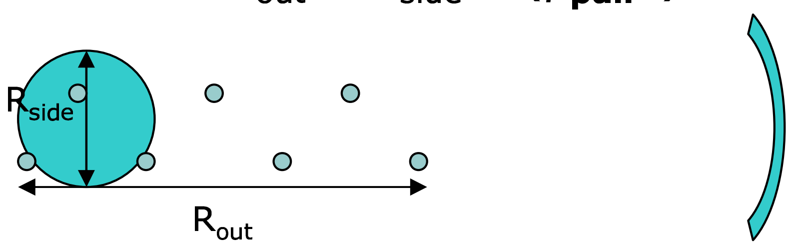
for the PHENIX Collaboration

HBT and the QGP

- "Naïve" picture:
  - $R_{out}^2 = R_{side}^2 + (\beta_{\mathbf{pair}}\tau)^2$



- One step further:
  - Hydro calculation of Rischke & Gyulassy expects $R_{out}/R_{side} \sim$ 2->4 @ k_t = 350 MeV.
  - Result robust to T_{freeze}, d_Q/d_H, 1st order vs. rapid cross-over.
- Response: can hadronic rescattering mask this prediction?

D.H. Rischke, M. Gyulassy/Nuclear Physics A 608 (1996) 479-512

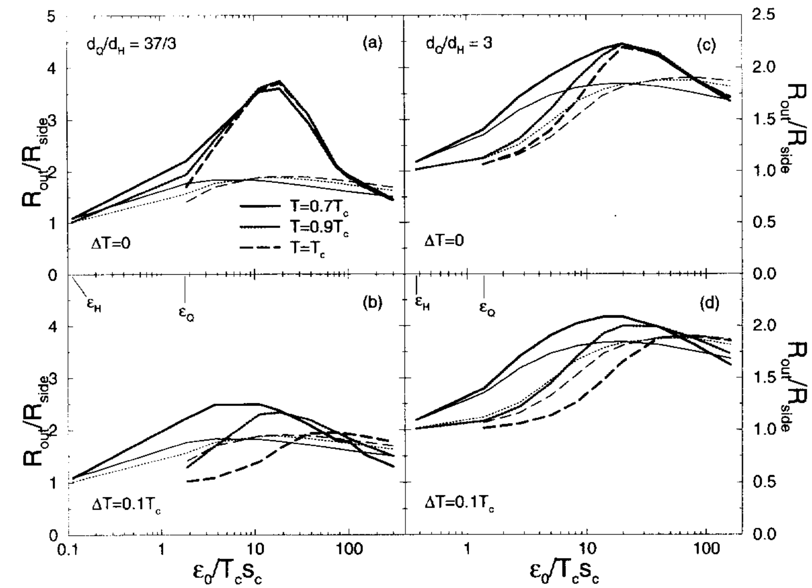
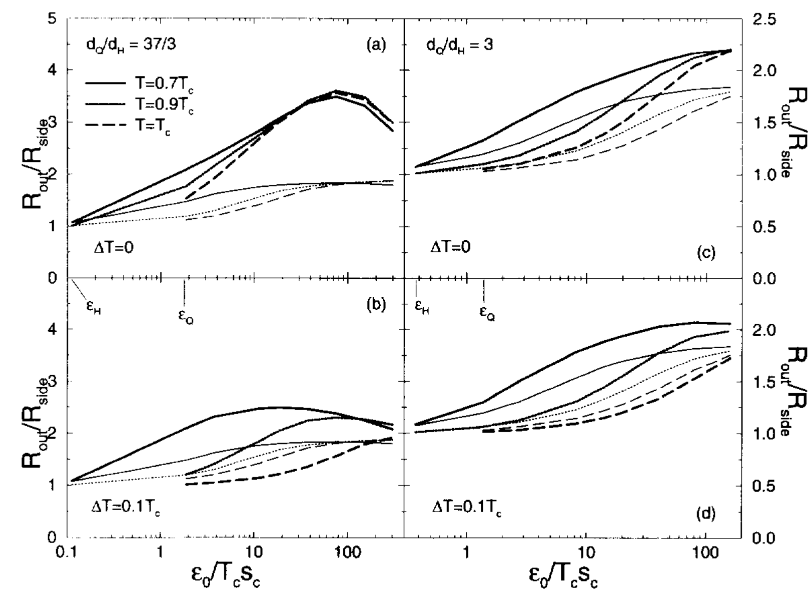


Fig. 17. The same as in Fig. 12, but for the ratio R_{out}/R_{side}.



One step closer

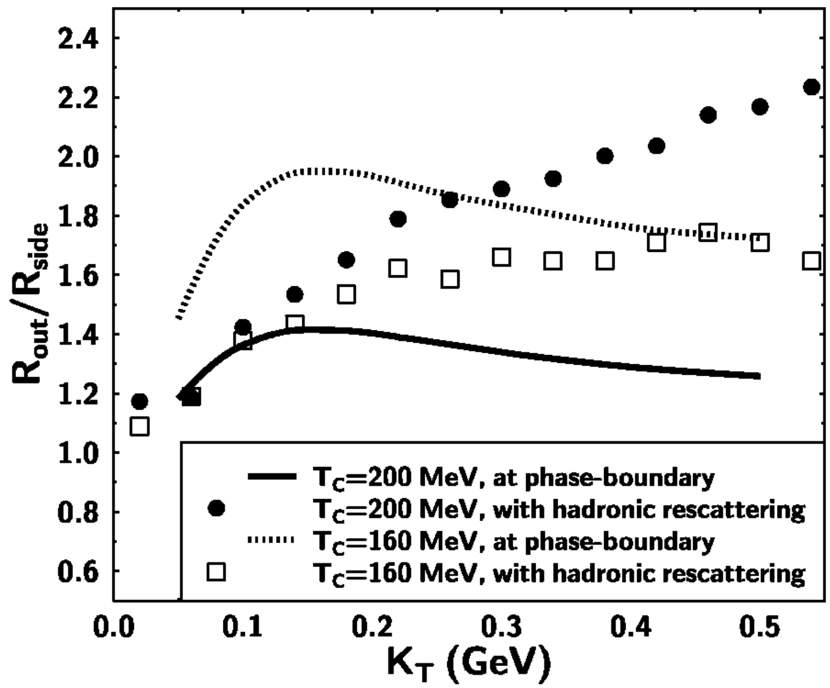


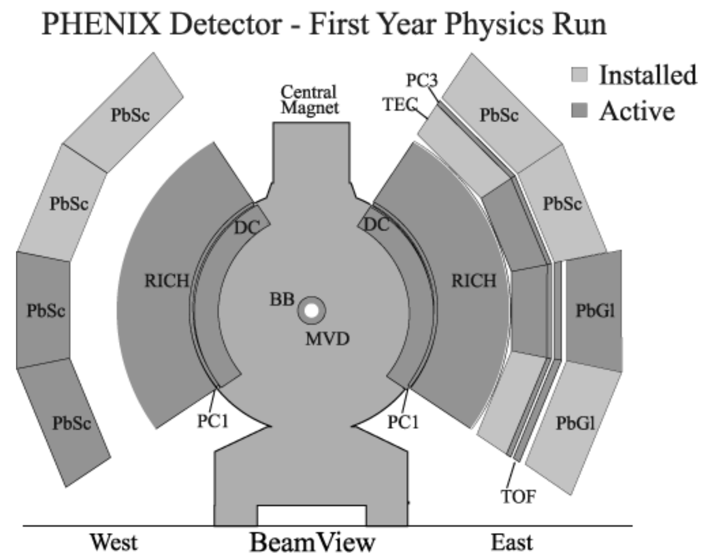
FIG. 3. R_{out}/R_{side} for RHIC initial conditions, as a function of K_T at freeze-out (symbols) and at hadronization (lines).

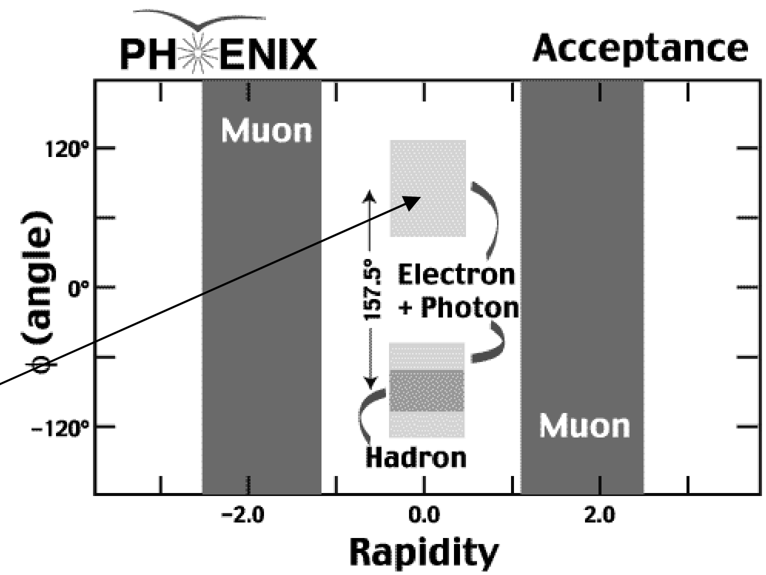
- Soff, Bass, Dumitru (PRL 86)
  - Couple microscopic transport to hydro with phase transition
  - Still expect $R_{out}/R_{side}>1$ ➔ measurements at high k_t are very interesting.

PHENIX – Year 1 Configuration

- Both arms provide hadron PID (contrary to popular belief)
- East:
  - DC + TOF (~100 ps)
  - π/K separation to 2 GeV/c
- West:
  - DC + PbSc (~600 ps)
  - π/K separation to 1 GeV/c
- B-field + geometry limits lower k_t bound to 200 MeV.

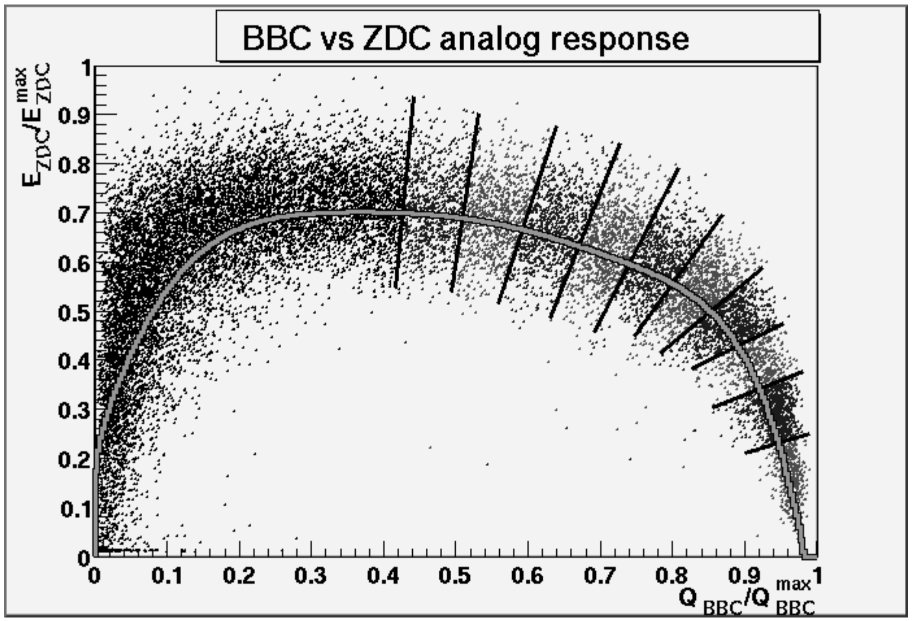
$$\frac{\partial p}{p} = 0.6\% \oplus 3.6\% \, p$$



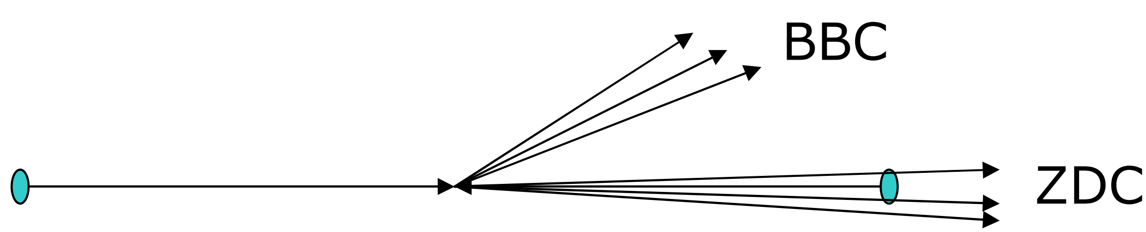


I use 'electron' acceptance for this hadron analysis

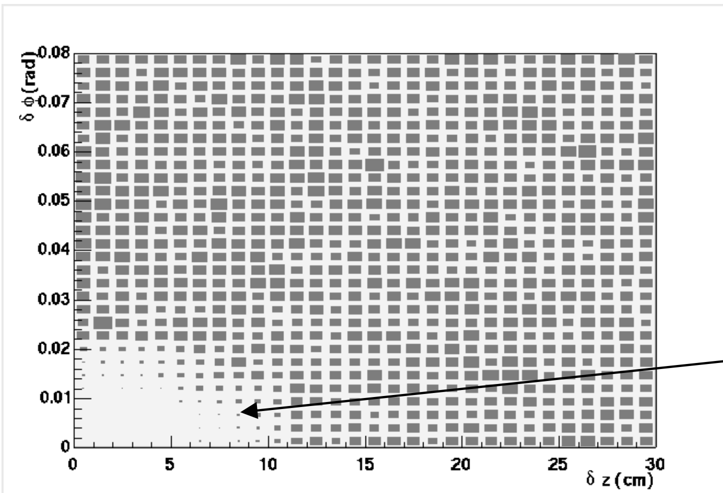
Centrality definition and sample

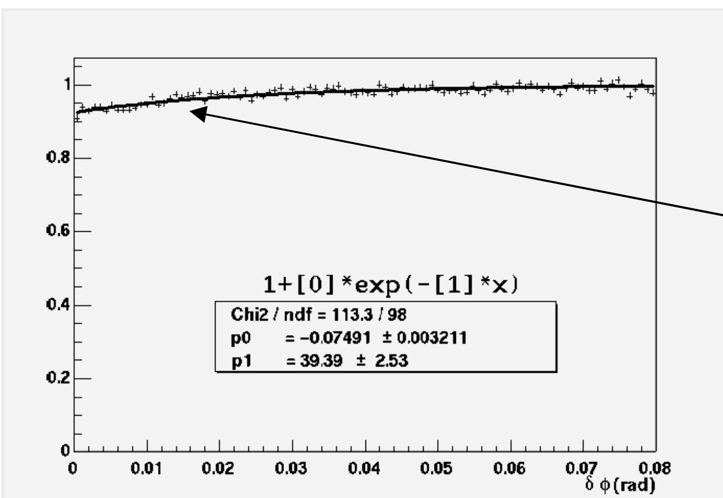


- This data sample uses the 30% most central collisions
  - $<cent_{pairs}> = 10\%$
  - 493k events
- After all analysis cuts:
  - 3.1M π^+ pairs
  - 3.3M π^- pairs



Pair acceptance and corrections





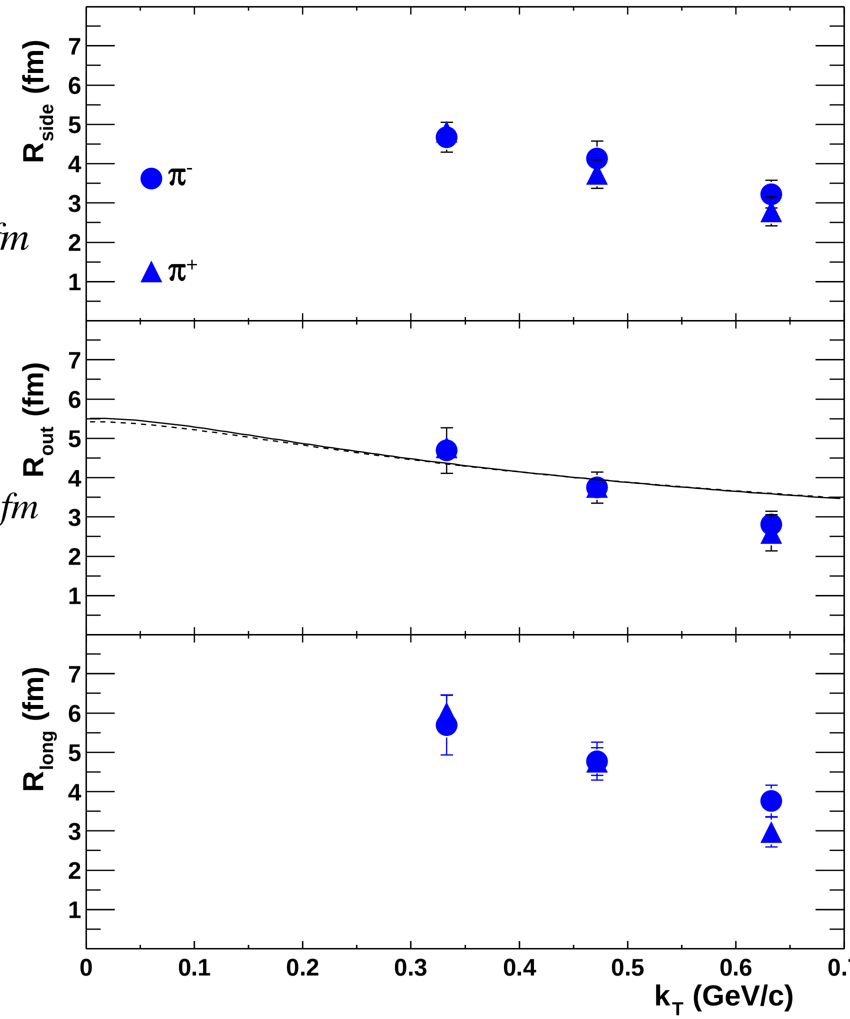
- π definition ➔ $<1.5\sigma$ from π peak && $>2.5\sigma$ from K peak
- Remove pairs within 2cm in drift chamber
  - Ghosting
- Remove tracks with EMC clusters within 12cm of each other in both real and mixed sample
  - Shower + tower size in EMC
- Require pairs from mixed events to have reconstructed vertices within 1cm
  - Acceptance varies as a function of vertex position
- Correct for two track inefficiencies at low relative ϕ in the drift chamber.
- Full Coulomb Correction
  - Partial correction changes radii results minimally

Systematic Errors:
R_{long} & R_{side}: 8%
R_{out}: 4.5%

Results:

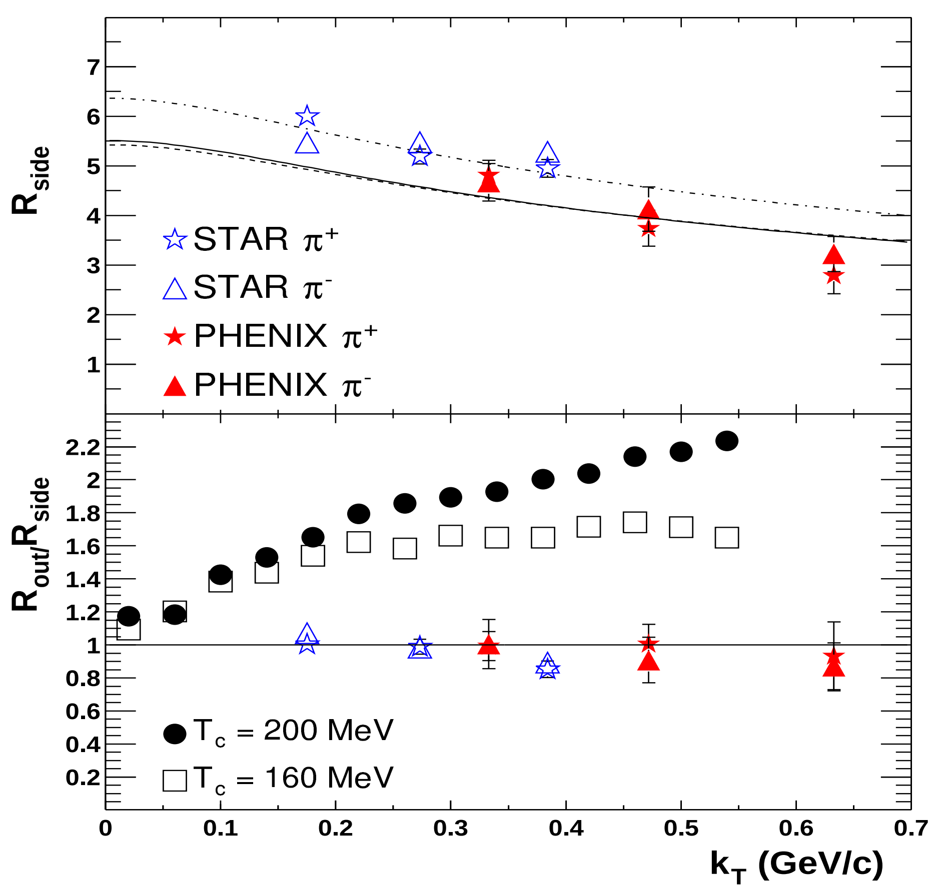
- Theoretical hydro-inspired fits.
  - $R_{side}{}^2(m_T) = \dfrac{R_{geom}{}^2}{1+\beta_f^2\left(\dfrac{m_T}{T}\right)} \Rightarrow R_{geom} = 6.7 \pm 0.2\,fm$
  - Chapman, Nix, Heinz PRC 52, 2694
  - $R_{side}{}^2(m_T) = \dfrac{R_{geom}{}^2}{1+\eta_f^2\left(\dfrac{1}{2}+\dfrac{m_T}{T}\right)} \Rightarrow R_{geom} = 8.1 \pm 0.3\,fm$
  - Wiedemann, Scotto, Heinz PRC 53, 918
- Much larger than comparable 1D RMS Au radius of 3.07fm

Assume T = 125 MeV, β_f = .69/η_f=.85
From fits to singles spectra (J. Burward-Hoy)



Systematic Errors:
R_{long} & R_{side}: 8%
R_{out}: 4.5%

Compared to STAR



Soff, Bass, Dumitru (PRL 86)

Well described by hydro model if consider datasets separately.

- But they indicate a much higher flow/temp ratio when taken together
- Need to be careful about systematics between different measures.
- Both experiments should be able to sort this out in the next dataset.

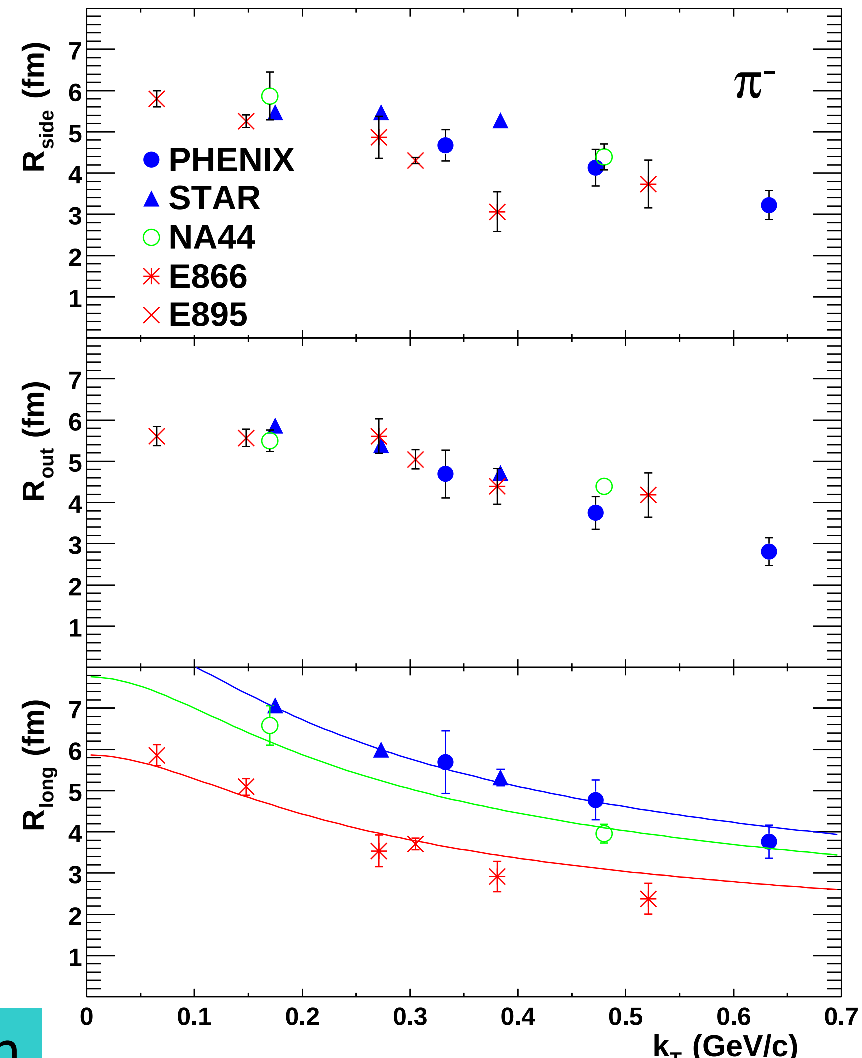
Inconsistent with models of QGP that include an hadronic rescattering phase.

Energy dependence …

M. Lisa *et al.*, PRL **84**, 2798 (2000)
R. Soltz *et al.*, to be sub PRC
C. Adler *et al.*, PRL **87**, 082301
I.G. Bearden *et al.*, EJP **C18**, 317 (2000)

- R_{out} and R_{side} are energy independent within error bars.
- Smooth energy dependence in R_{long}
- No immediate indication of very different physics
- Fit R_{long} to: $\dfrac{A}{\sqrt{m_T}}$

- AGS: A = 2.19 +/- .05
- SPS: A = 2.90 +/- .10
- RHIC: A = 3.32 +/- .03

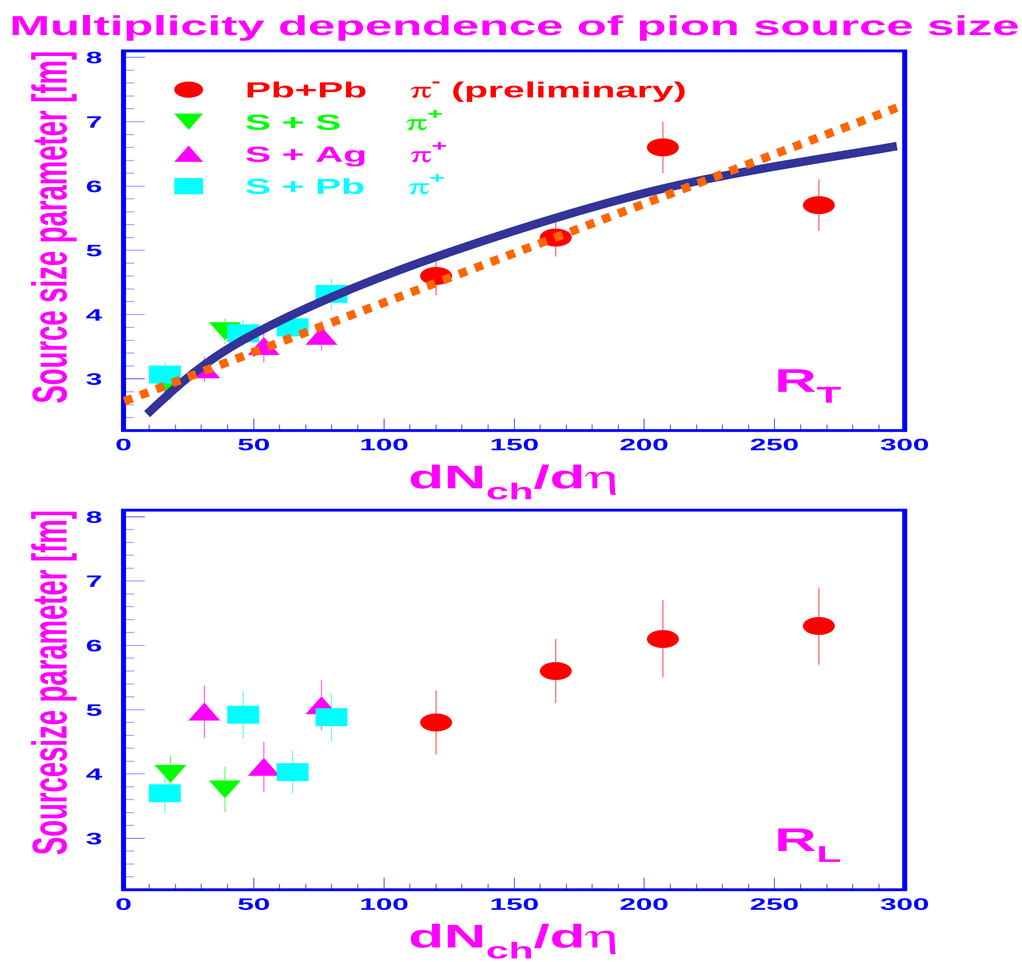


A = τ_0T in 1st order T/m_T calculation

τ_0 = average freeze-out proper time

Even an experimentalist can't predict this

- "A prognostication"
  - Local PHENIX HBT expert keeps his predictions on the web.
- Zajc at Nucleus-Nucleus 97 showed this slide
- Extrapolation to RHIC multiplicities?
  - $(dN/dy)^{1/3}$ => R ~ 9 fm
  - (dN/dy) => R ~20 fm
- Neither.
- What is happening here?
- **



** To be fair: Bill's radii predictions are way off. His guess at the charged particle multiplicity in the extrapolations…bang on

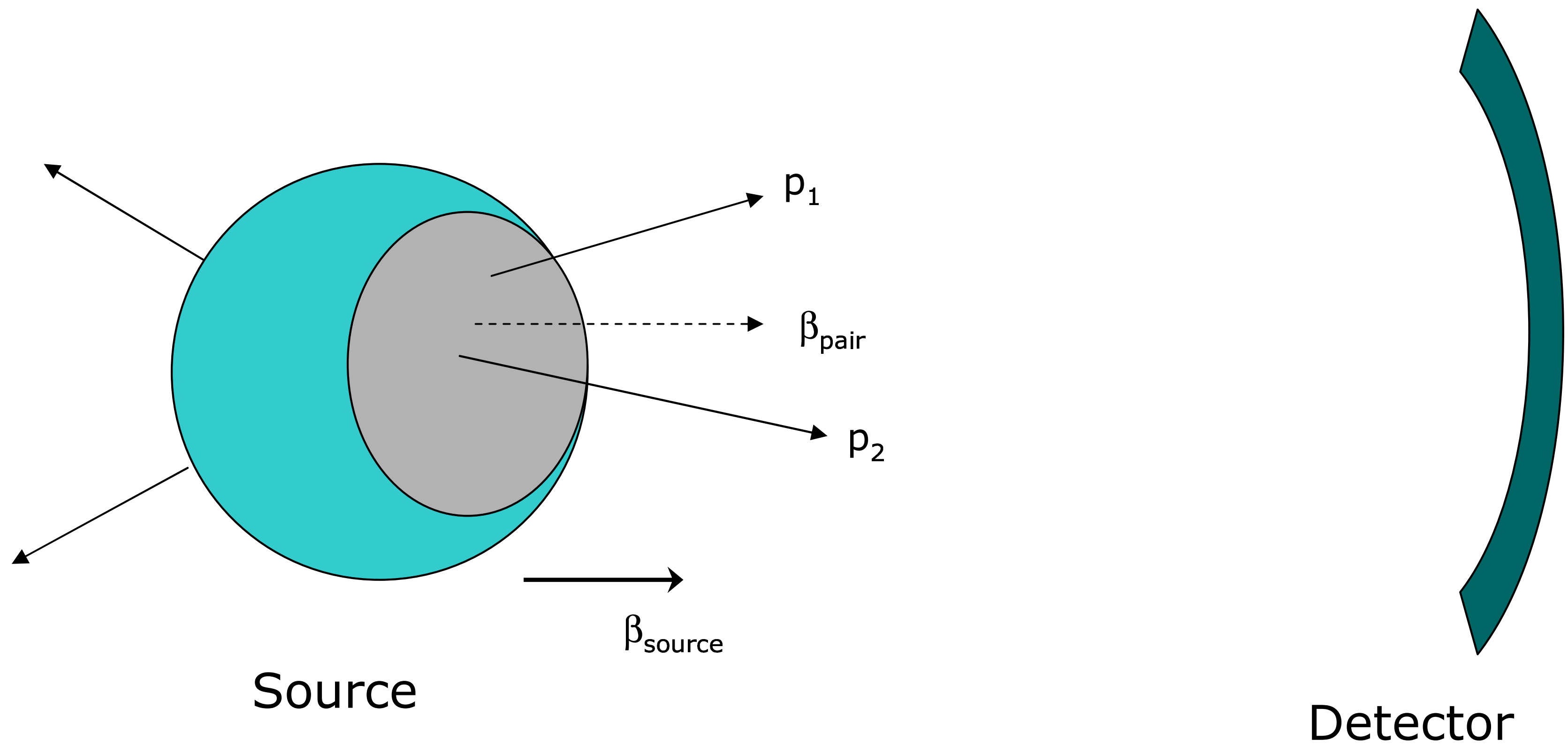
Q & A

- Why are R_{out} and R_{side} ~identical over an order of magnitude of beam energy?
  - There is ample evidence at AGS and SPS of dependence of radii on # target+projectile nucleons
    - Even though the larger nuclei have larger flow the radii follow a simple scaling
    - Why no multiplicity/energy dependence?
  - Q: Flow higher at RHIC leads to smaller radii?
  - A: Not born out by k_t dependence of radii.
  - Q: Higher opacity at RHIC energies?
  - A: Why would opacity be higher at RHIC than at AGS?
    - $\pi n \rightarrow \Delta \rightarrow \pi n$ ➔ $\pi\pi \rightarrow \rho \rightarrow \pi\pi$
    - And why would size and opacity effects identically cancel?
  - Total multiplicity (pions + nucleons) changes by only a factor of 3…
    - Why is it only changing in the longitudinal direction?

Switching frames

- Problem: radii extracted depend on the frame in which you measure
- Historically we have used:
  - Q_{inv} (1D pair rest frame)
  - Collision Center of Mass
    - AGS
  - LCMS (longitudinally co-moving frame)
    - Longitudinally boost invariant sources
    - SPS(?), RHIC
  - Jet frame
    - p-p collisions.
  - PCMS (pair center-of-mass – 3D version of Q_{inv})
  - …
- What is the 'correct' frame?? (= the frame in which the source is not moving)
- Can we bound it experimentally?

Our source??



Pair rest frame != source rest frame

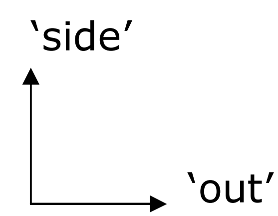
What is the β_{source}?

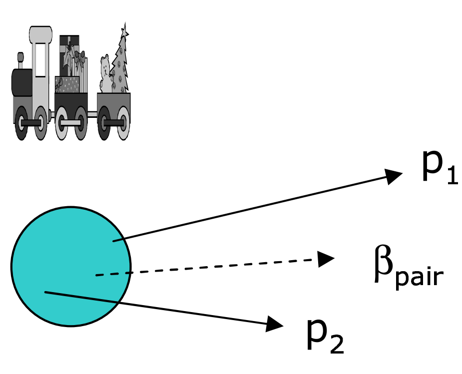
We don't know, but we can bound it:

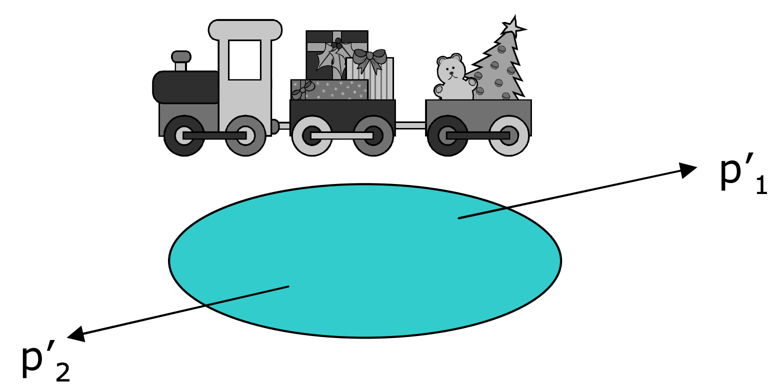
>0

$<\beta_{pair}$

LCMS vs. PCMS







$$R_{PCMS} = \gamma_{pair} R_{LCMS}$$

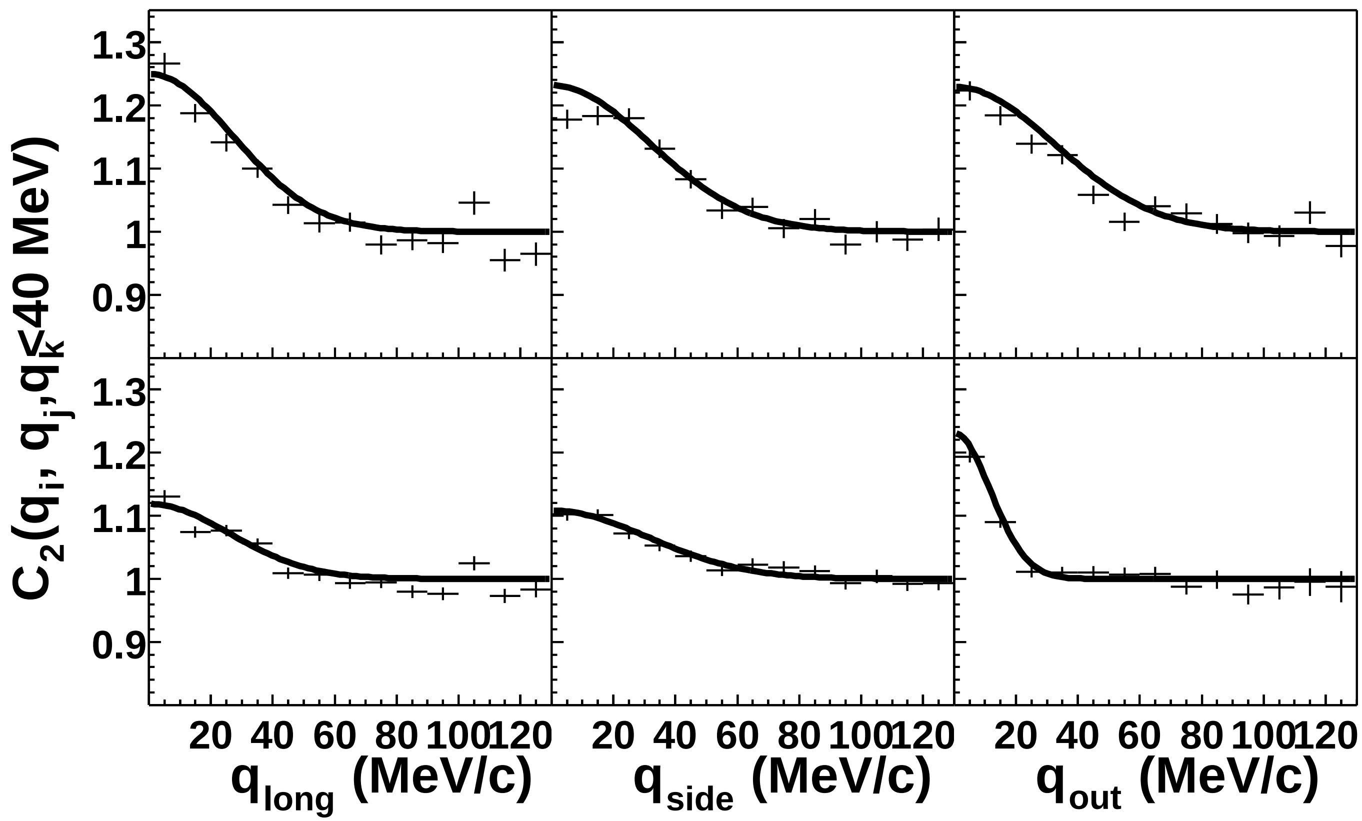
- LCMS
  - A Lorentz contracted measurement of the frame
- PCMS
  - A measurement of the length of the train in the train frame

unphysical

True frame

unphysical

Fits to entire dataset (π^-)



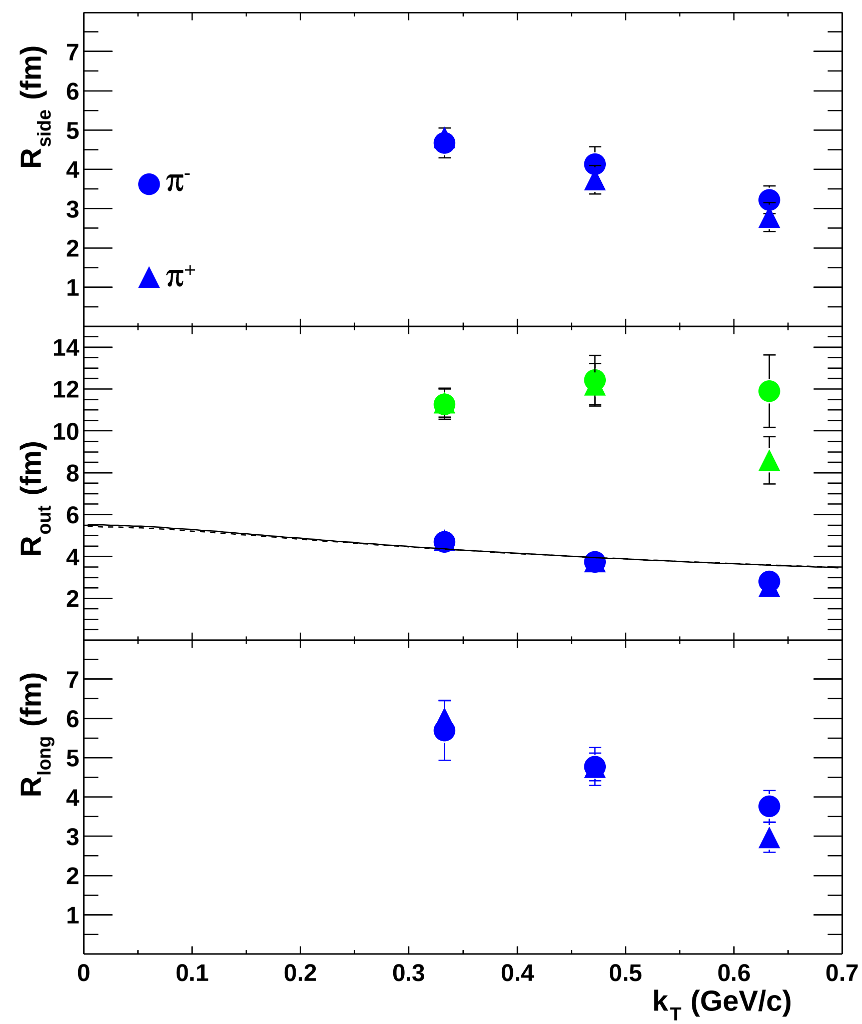
LCMS

PCMS*

*PCMS = Pair Center of Mass System

PCMS results

- R_{side} and R_{long} unchanged
  - And not plotted
- R_{out}^{PCMS} differs by $<\gamma_{pair}>$ from R_{out}^{LCMS}
- Be careful about deducing a lifetime from $R_{out}^2 = R_{side}^2 + (\beta_{\mathbf{pair}}\tau)^2$
  - $\beta_{pair} = 0$



A taste of the future

- For year-1 we wrote ~5 million min. bias events.
  - 1/2 million events in this analysis after all cuts
- In the past run we wrote ~90 million min. bias events (+14 million rare event triggers)
- Therefore, for the year-2 pion correlations:
  - easily 10 high statistics bins in k_t from .2 to 1.0 GeV + a few bins from 1.0 to 2.0 GeV
    - Capability to exclude detailed theories
    - Systematic errors start to become the real problem
- Beyond pions:
  - 1D and 3D(?) proton and kaon (?) correlations
  - π^0 and anti-neutron correlations using the PbSc

The scientists that make me look good*

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*or at least better than I normally do