HBT Interferometry with STAR

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for the STAR Collaboration

- Au+Au Collisions at STAR
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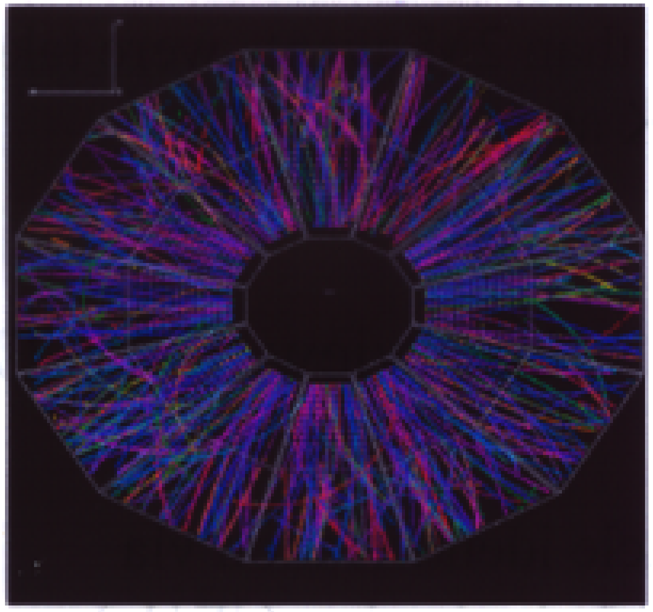
- Bread and Butter … - Pion HBT
  - Centrality
  - Transverse Momentum (p_T,k_T)
  - The HBT Excitation Function
- … and beyond
  - E-by-E HBT
  - Pion Phase Space Density
  - K^0_S
- Summary
- Future Plans

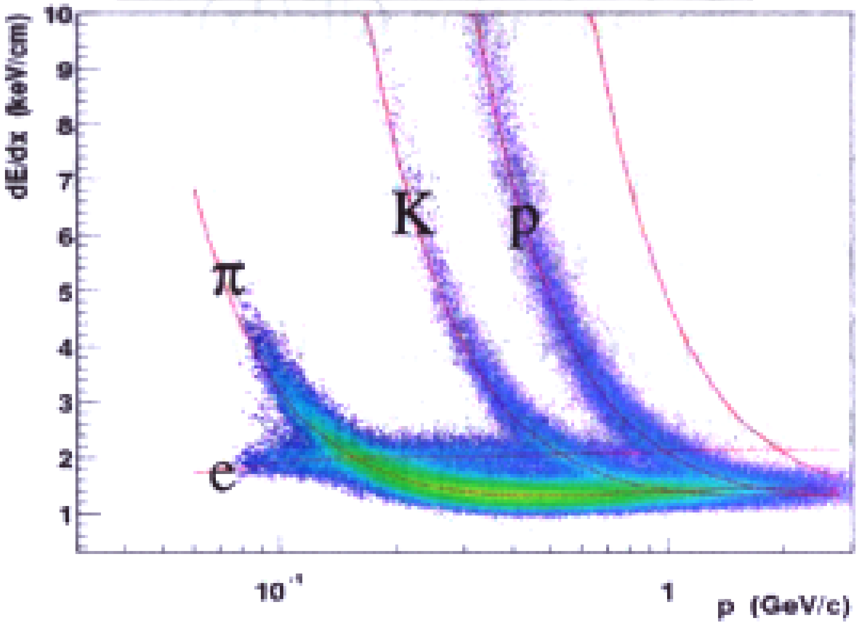
Au+Au Collisions as seen from STAR

•More than 2M events were taken in Y2K at $\sqrt{s_{NN}} = 130 GeV$



Front view of the TPC

Particle identification via specific ionisation (dE/dx):



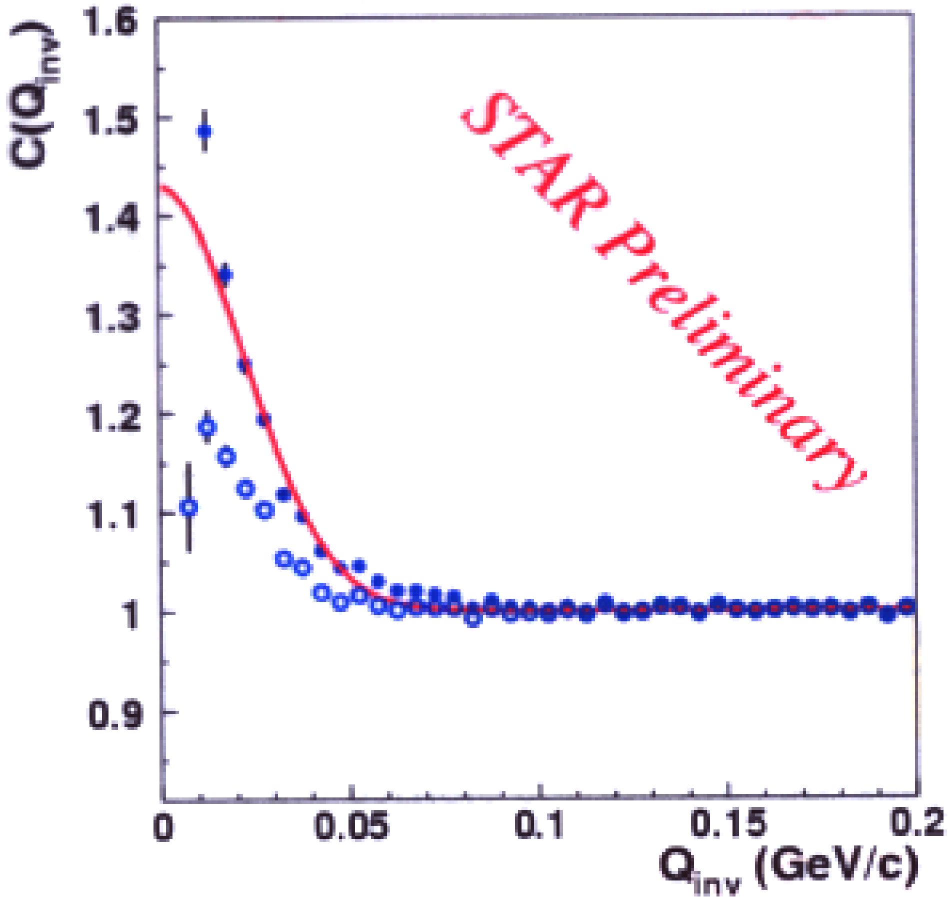
Optimum performance for HBT:
$-0.5 < y < +0.5$
$0.125 < p_T/(GeV/c) < 0.450$
π : electron contamination<10%

Two Particle Interferometry

Two particle correlations are sensitive space-time geometry

$$C(p_1, p_2) = \frac{P(p_1, p_2)}{P(p_1)P(p_2)} = \frac{N_{real}}{N_{mixed}} = 1 + |\tilde{\rho}(q)|^2$$

$\pi^-\pi^-$: $|y|<0.5$
$0.125 < p_T(\text{GeV}/c) < 0.225$



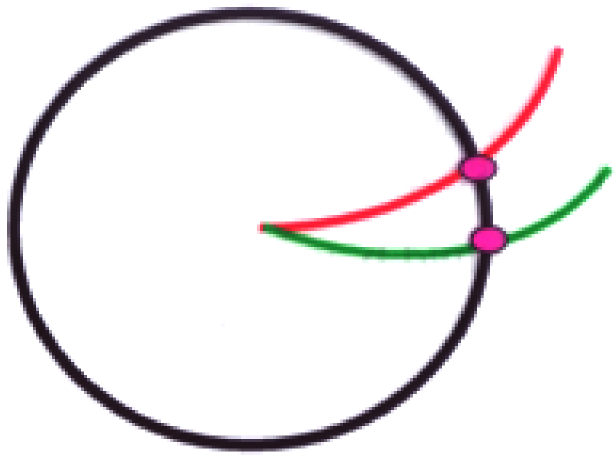
The simplest parameterization:

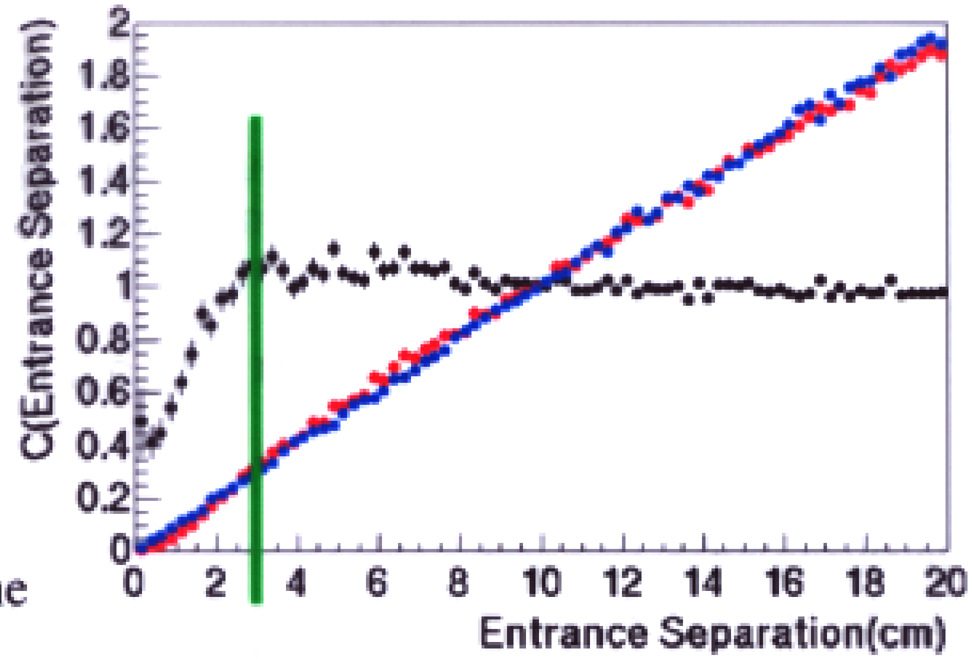
$$C(Q_{inv}) = 1 + \lambda \cdot e^{-Q_{inv}^2 R_{inv}^2}$$

$$Q_{inv} = \sqrt{(p_1 - p_2)^2 - (E_1 - E_2)^2}$$

$$R_{inv} = (6.3 \pm 0.5)\, fm$$
$$\lambda = 0.5 \pm 0.1$$

A Technical Issue: Track Merging





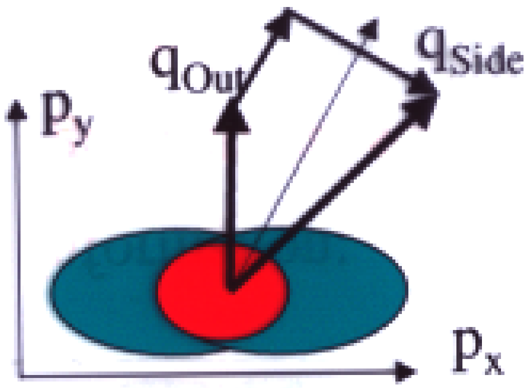
Close tracks can be reconstructed as one
→ artificial suppression of low-q pairs

- Cutting on the entrance separation of the TPC removes the merging effect, but de-emphasizes low-q pairs.
- For non-Gaussian sources this leads to a residual effect on the HBT parameters requiring correction ~10% in λ and ~4% in the radii.

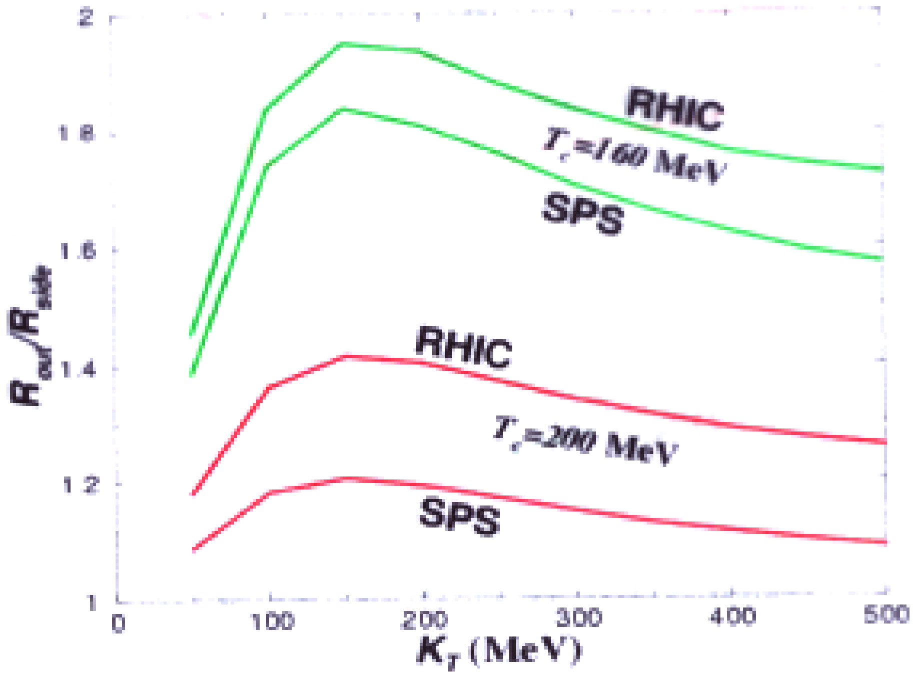
3Dimensional - HBT

Pratt-Bertsch Parameterization (measured in the LCMS frame; $(p_1 + p_2)_z = 0$)

$$C(q_{Out}, q_{Side}, q_{Long}) = 1 + \lambda e^{-(q_{Out}^2 R_{Out}^2 + q_{Side}^2 R_{Side}^2 + q_{Long}^2 R_{Long}^2)}$$



Soff et al. nucl-th/0012085



Information:

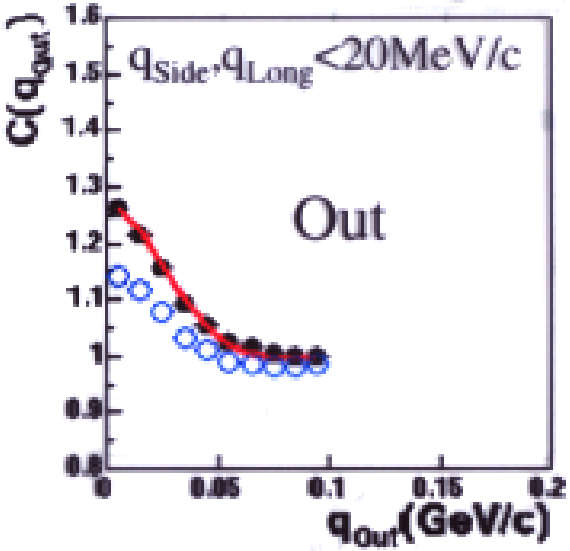
- geometrical source size
- lifetime $\tau = \sqrt{R_{Out}^2 - R_{Side}^2} / \beta_T$

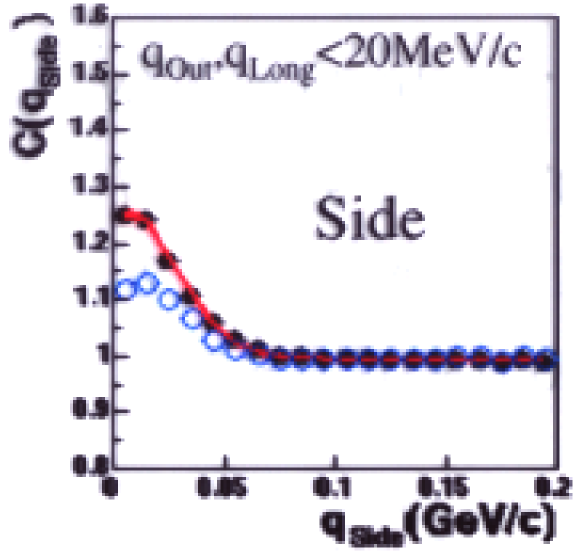
(for transparent sources)

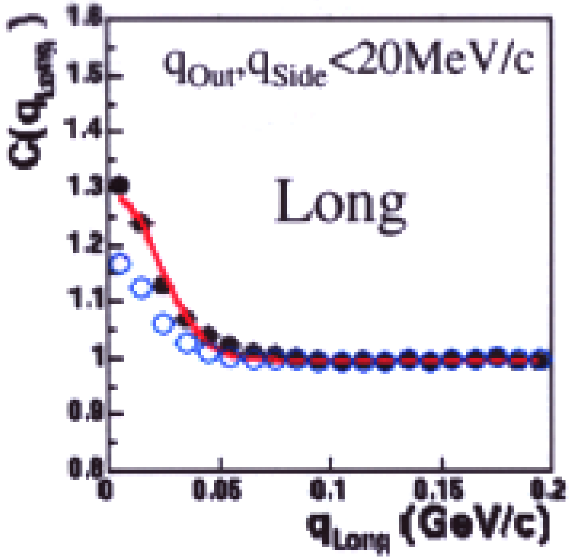
$$K_T = (p_1 + p_2)_T / 2$$

3 Dimensional - $\pi^- \pi^-$ HBT

1D Projections of the 3D Pratt-Bertsch Parameterization







12% most central events

Pion tracks:
$0.125<p_T/(GeV/c)<0.225$;
$|y|<0.5$

- **Coulomb corrected with a 5 fm source**
- **No Coulomb correction**

$$\lambda = 0.50 \pm 0.01 \pm 0.03$$

$$R_{Out} = (5.86 \pm 0.11 \pm 0.23)\ fm$$

$$R_{Side} = (5.47 \pm 0.09 \pm 0.16)\ fm$$

$$R_{Long} = (7.07 \pm 0.12 \pm 0.21)\ fm$$

sys. error result from the pair cuts (merging) and Coulomb correction

Coulomb Correction

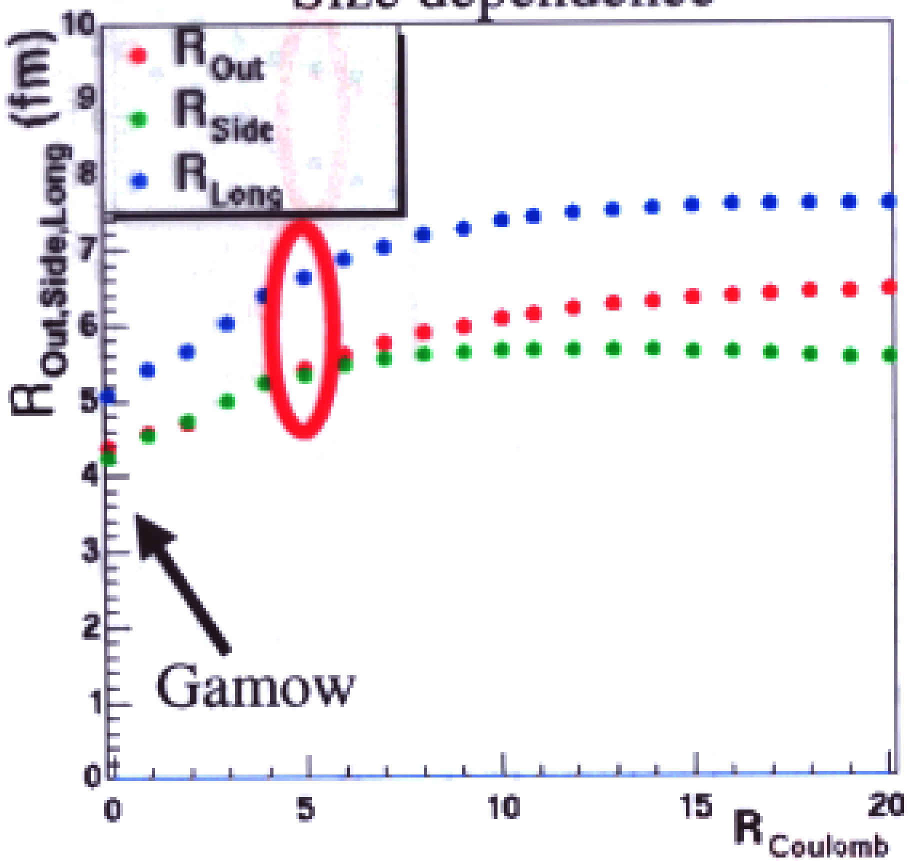
Standard Coulomb

5-dimensional Monte-Carlo integration of Coulomb wave functions over a spherical source {S.Pratt et al.,Phys.Rev. C42(1990)2646}

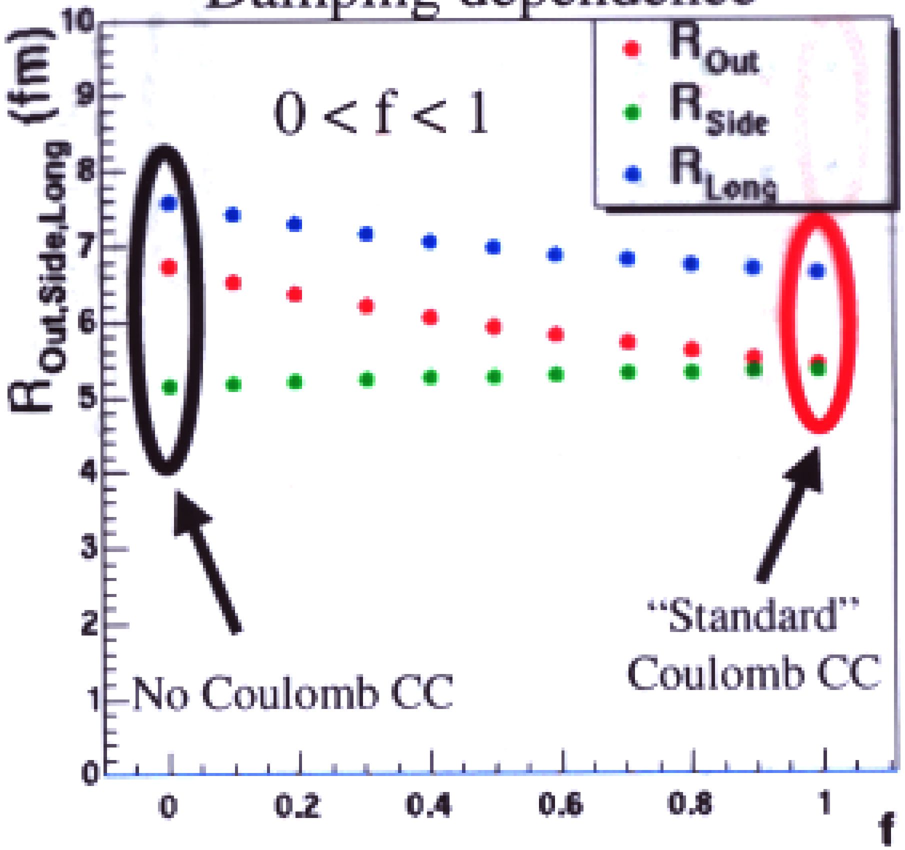
Damped Coulomb (λ<1)

- particle misidentification
- long lived resonances

Size dependence



Damping dependence



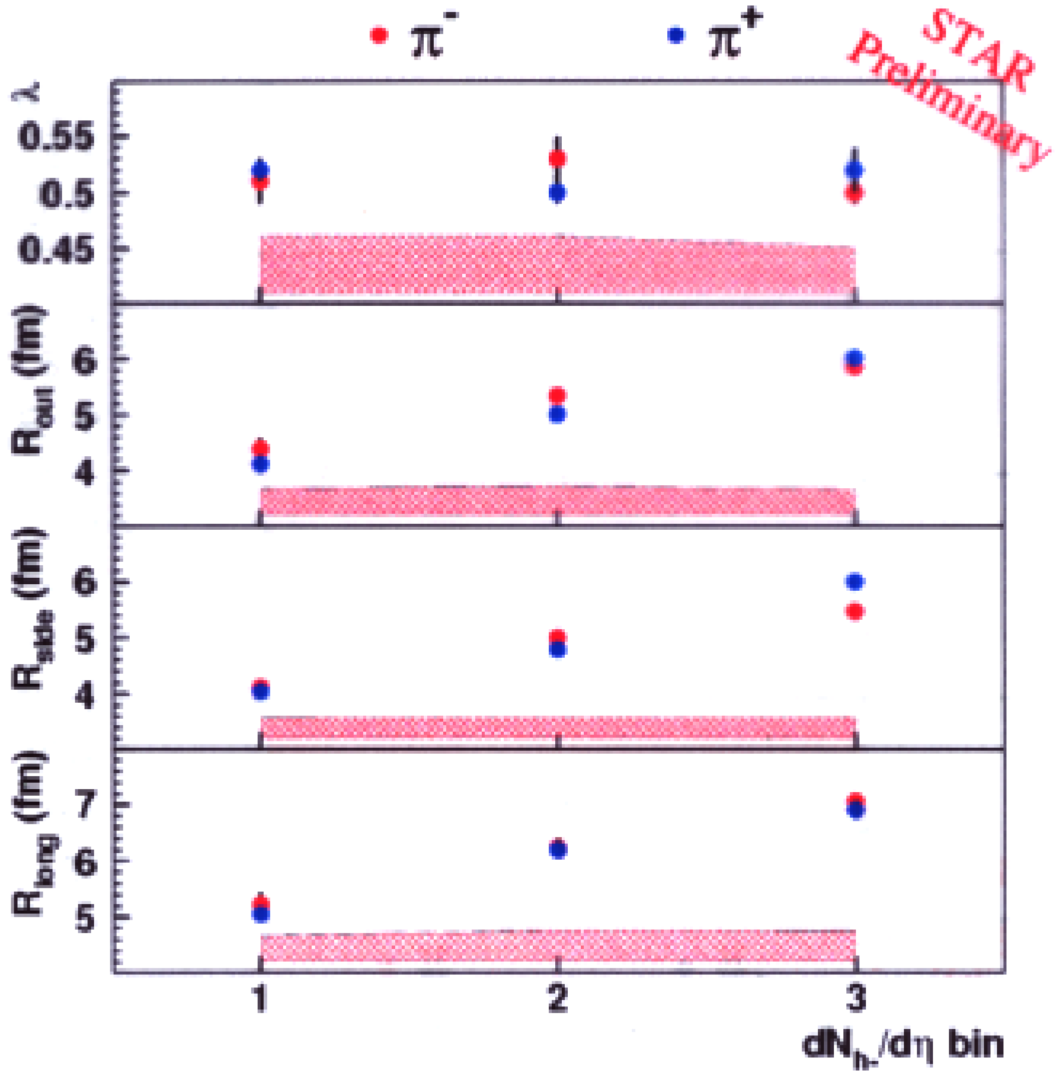
Centrality Dependence

- $\pi^+\pi^+$, $\pi^-\pi^-$, parameters similar
- λ`s don't change with mult.
- radii increase with multiplicity
- roughly similar to AGS/SPS

Comparison with AGS/SPS
- parameters roughly same
- similar increase in R_{Out}, R_{Side} (geometric effect)

•R_{Long} - increase not seen at AGS/SPS

0.125 GeV/c < p_T <0.225 GeV/c



$\sigma_{tot:}$ 32-72% 12-32% 0-12%

m_T Dependence - sensitivity to flow

- $\pi^+\pi^+$, $\pi^-\pi^-$ HBT parameters similar

  With increasing m_T

  - λ increases → fewer resonances
  - radii decrease → position-momentum correlations

Comparison with AGS/SPS

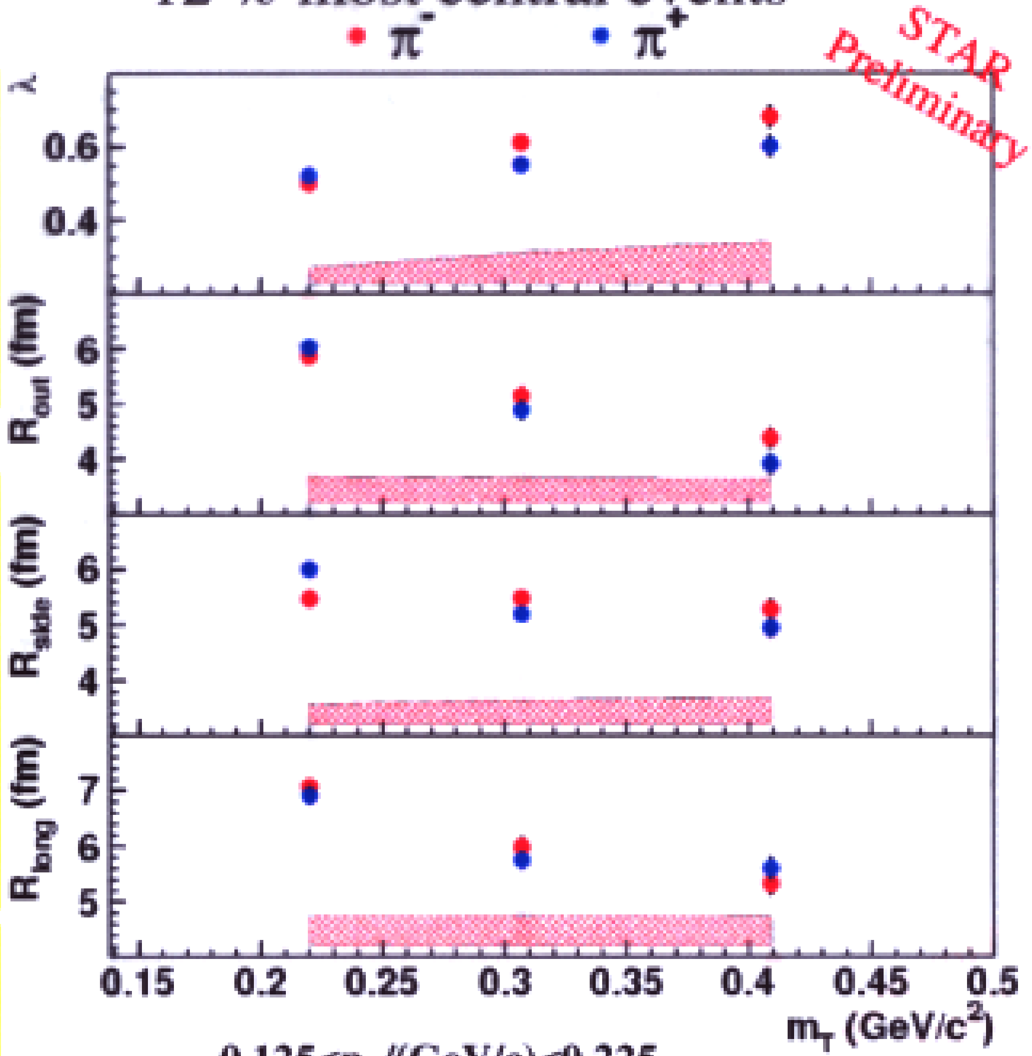
- parameters roughly similar to AGS/SPS

  With increasing m_T

  - similar increase in λ
  - similar decrease of radii

- stronger effect in R_{Out} than at AGS/SPS

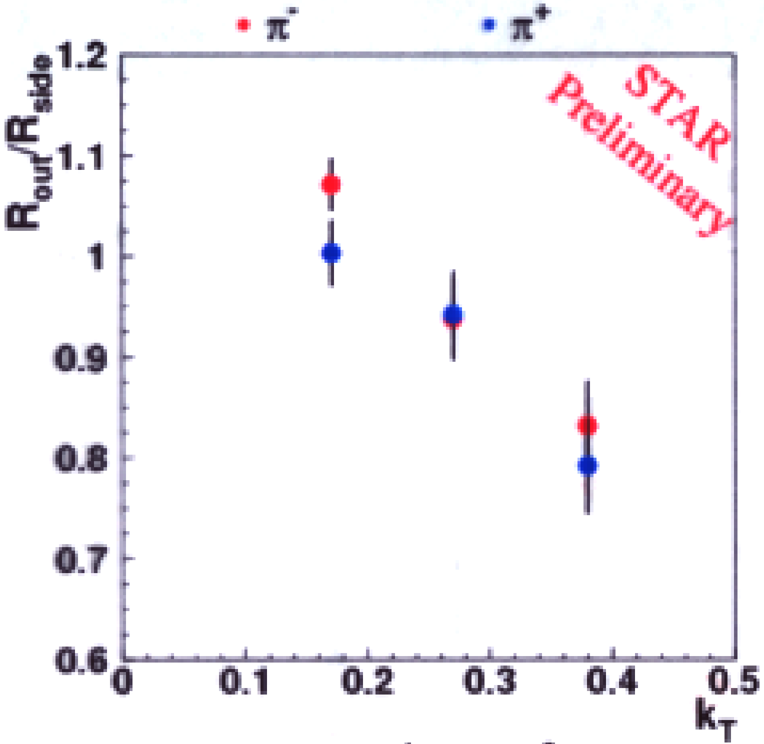
12 % most central events



0.125<p_T/(GeV/c)<0.225
0.225<p_T/(GeV/c)<0.325
0.325<p_T/(GeV/c)<0.450

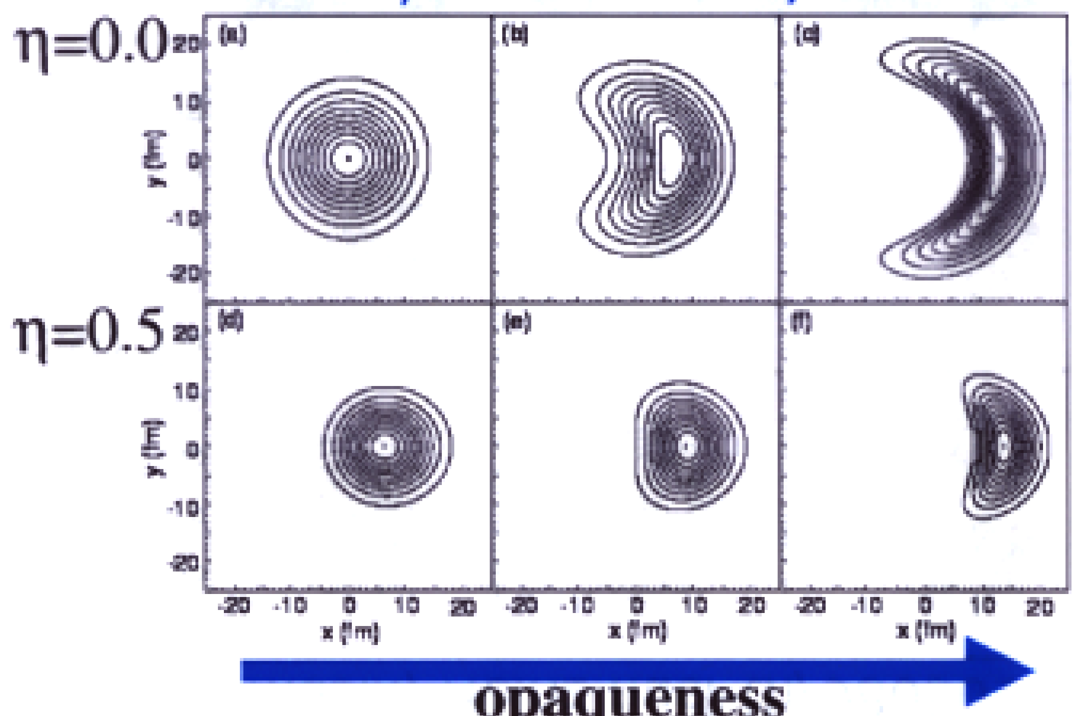
The R_{Out}/R_{Side} Ratio

emission duration for transparent sources: $\tau = \sqrt{R_{Out}{}^2 - R_{Side}{}^2} \,/\, \beta_T$



$K_T = (p_T^1 + p_T^2)/2$

Tomášik, Heinz nucl-th/9805016

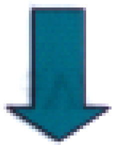


x-p correlations (flow / opaqueness) might change the homogeneity length

Note: extremely strong flow at RHIC (close to hydro)

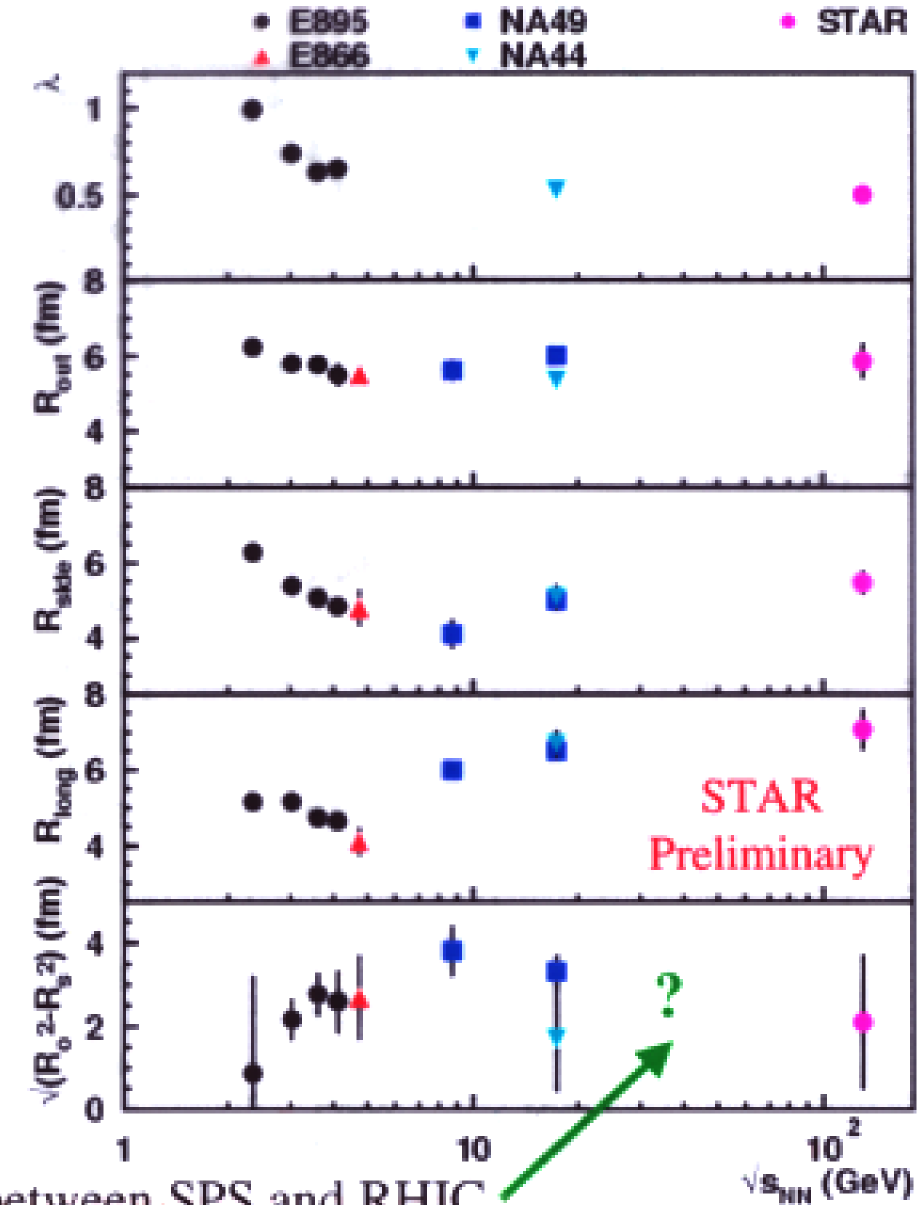
The HBT Excitation function

Compilation of world BP 3D $\pi\pi$-HBT parameters as a function of $\sqrt{s}$



- ~10% Central AuAu(PbPb) events
- $y \sim 0$
- $k_T \approx 0.17$ GeV/c

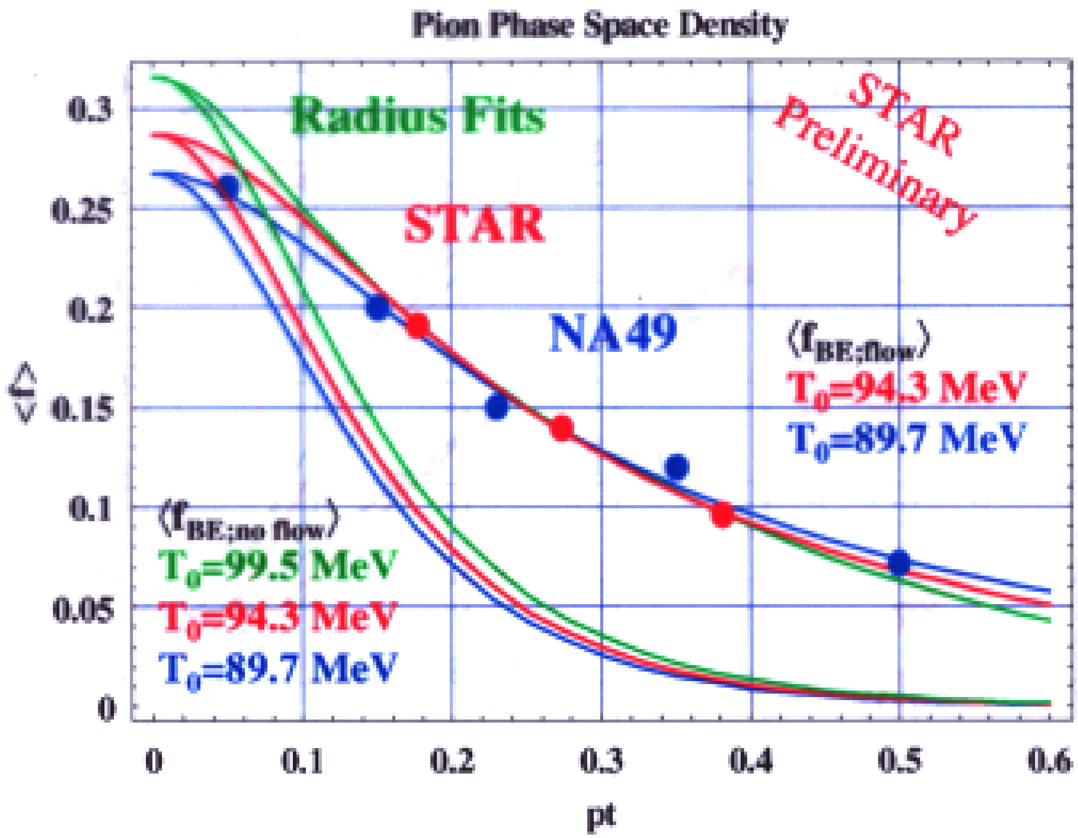
no significant rise in spatio-temporal size of the π emitting source



close the gap between SPS and RHIC

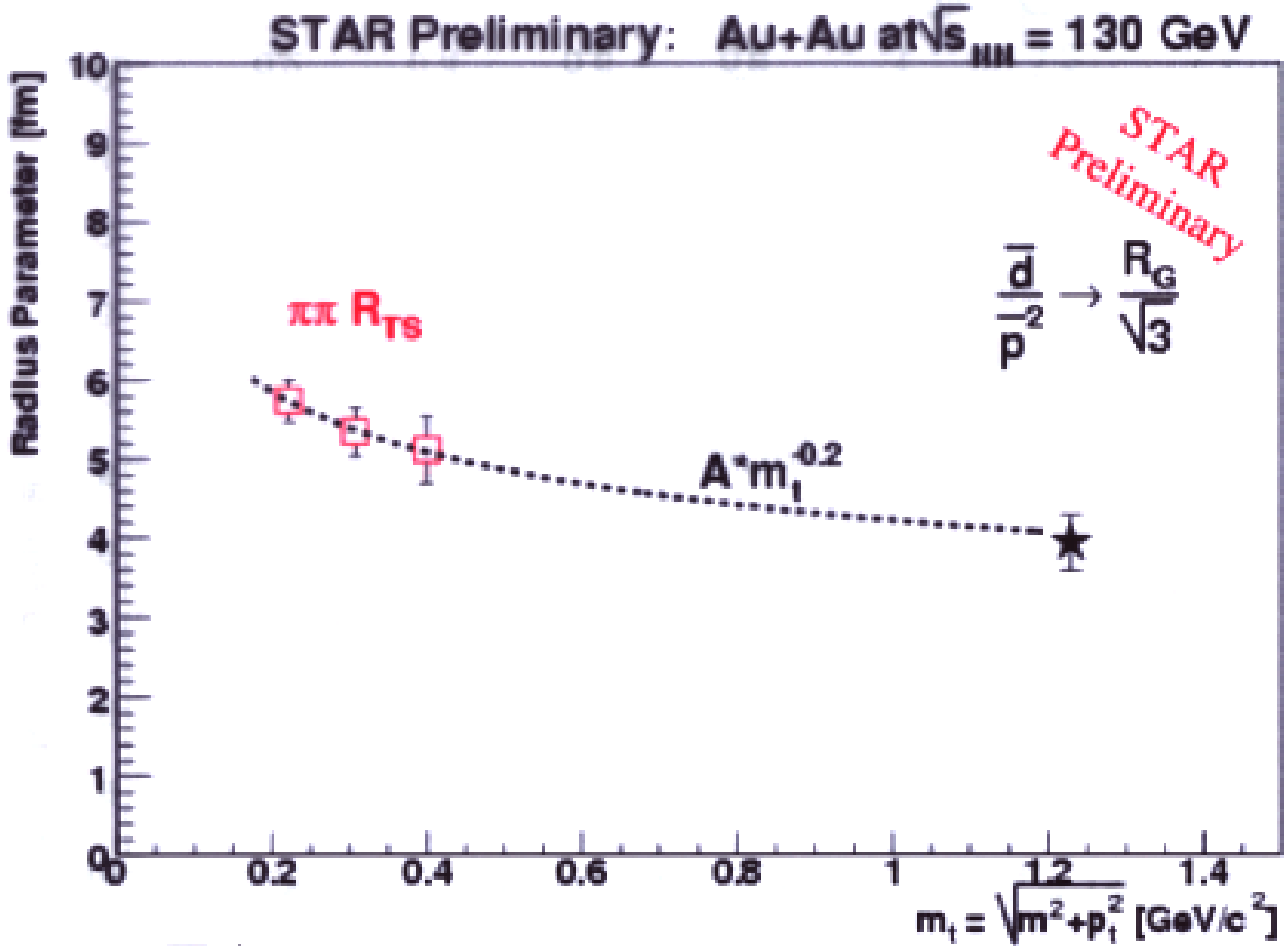
The π Phase Space Density (Poster by J.Cramer)

pion occupation of cell in coordinate⊗momentum space: $$\langle f\rangle(m_T) = \frac{(\hbar c)^3}{2\,E_\pi\, m_T}\,\frac{d^2N}{dy\,dm_T}\,\frac{(\lambda\,\pi)^{1/2}}{R_O\,R_S\,R_L}$$



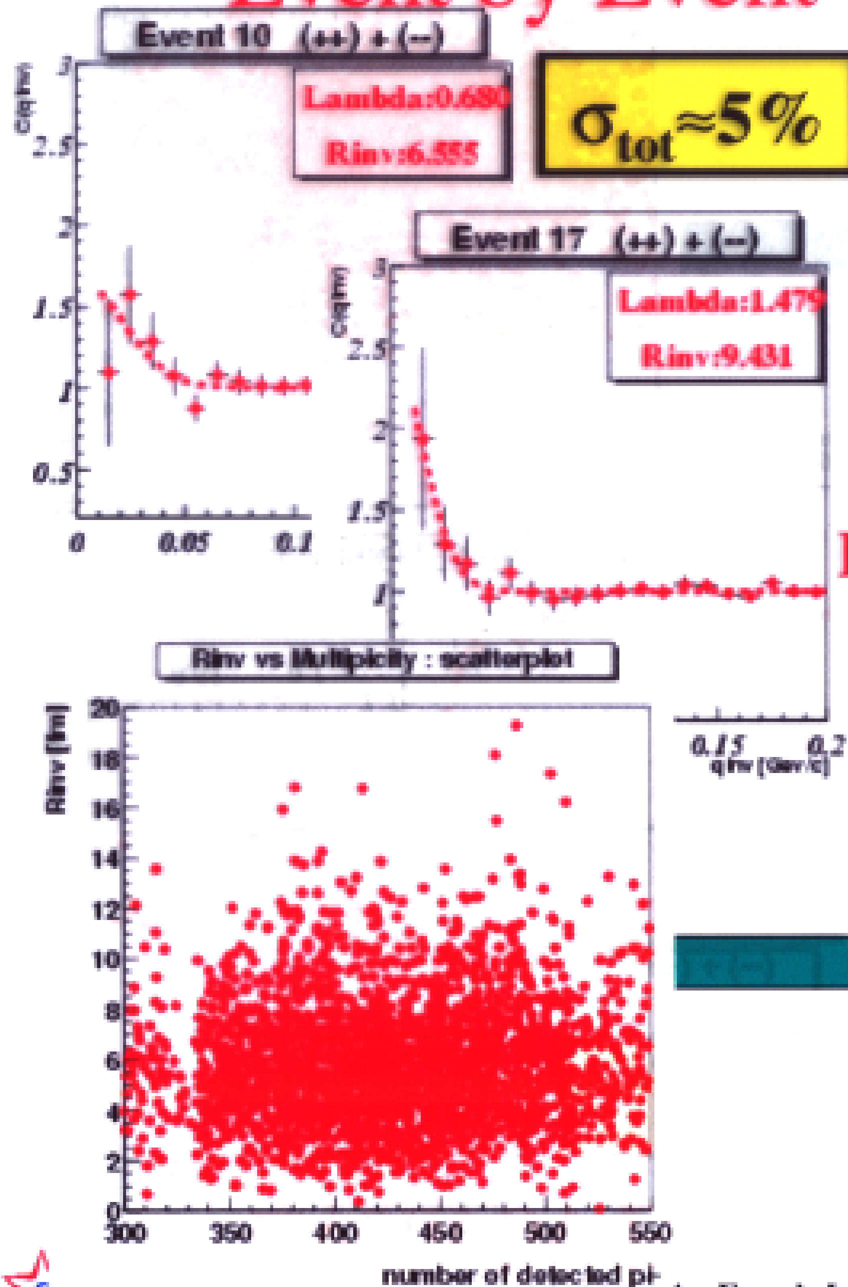
- "Universal" phase space density observed at SPS appears to hold at RHIC as well
- Consistent with thermal distribution (T=94MeV) and strong collective flow (β =0.58)
- Fundamental phase space saturation may relate increases in geometry, temperature, multiplicity

m_T systematics ($\pi\pi$, $\bar{d}/\bar{p}$)



$\bar{d}/\bar{p}$ - Talk by D.Hardtke

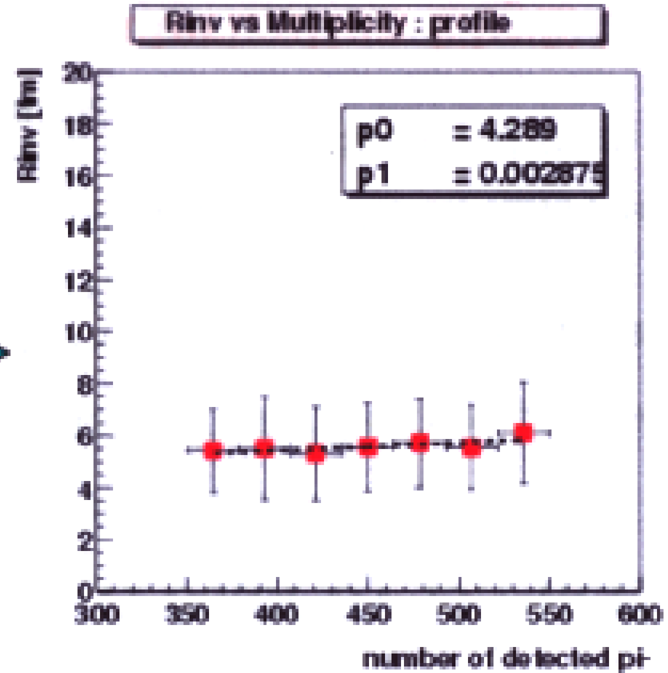
Event by Event - HBT (Poster by D.Flierl)



$\sigma_{tot} \approx 5\%$

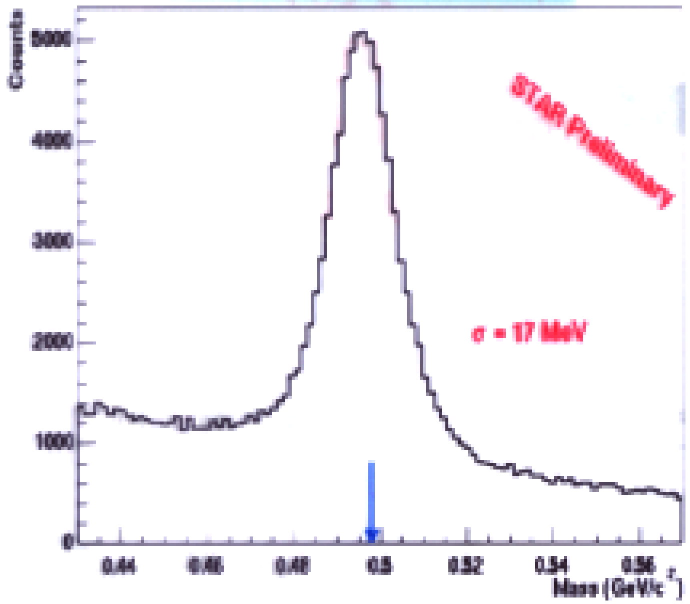
- Numerator from one event only
- Denominator from 10 mixed events
- Numerators and Denominators from $\pi^+ \pi^+$ and $\pi^- \pi^-$ HBT added
- for 50% of all events the fit fails ($0<\lambda<1$)
  - these events are excluded from further analysis

Event characterization EbyE ? almost



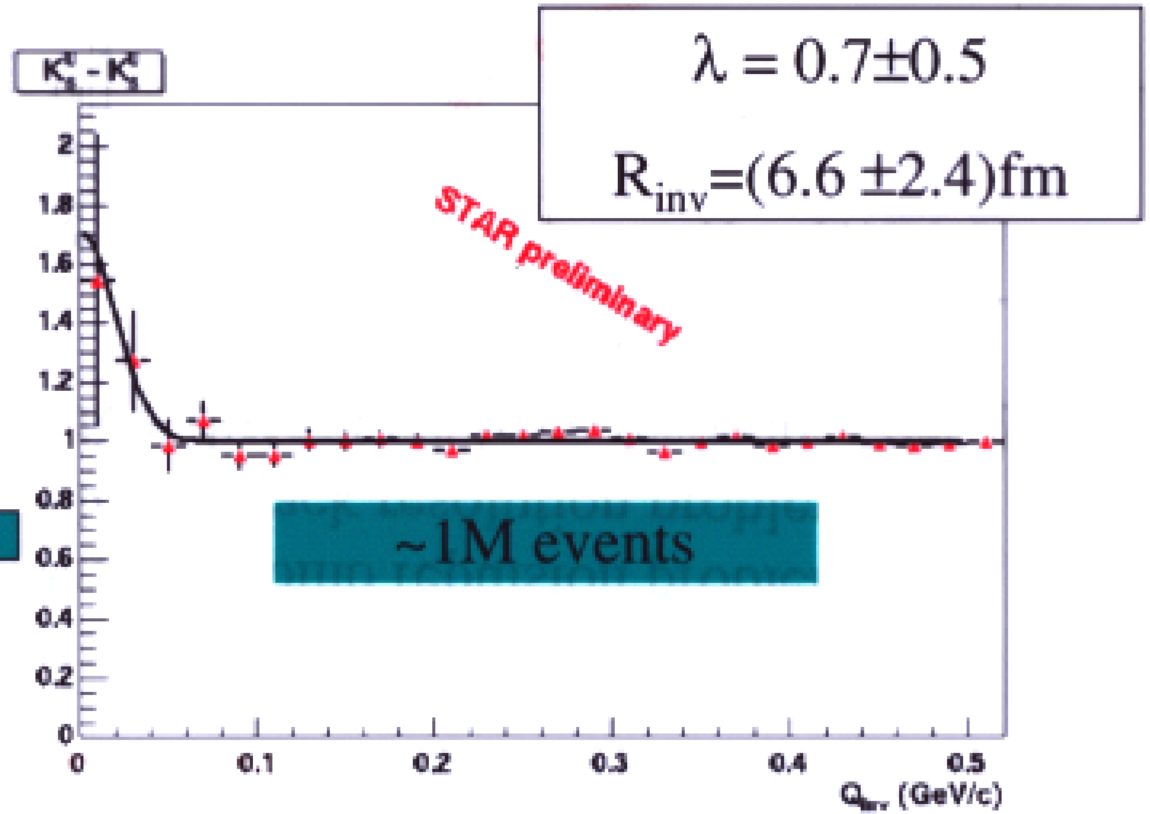
$K^0_S K^0_S$ - Correlations (Poster by T.Humanic)

1.3 K^0/event



- no coulomb repulsion problems
- less 2 track resolution problems
- few distortions from resonance decays

  → ideal for HBT



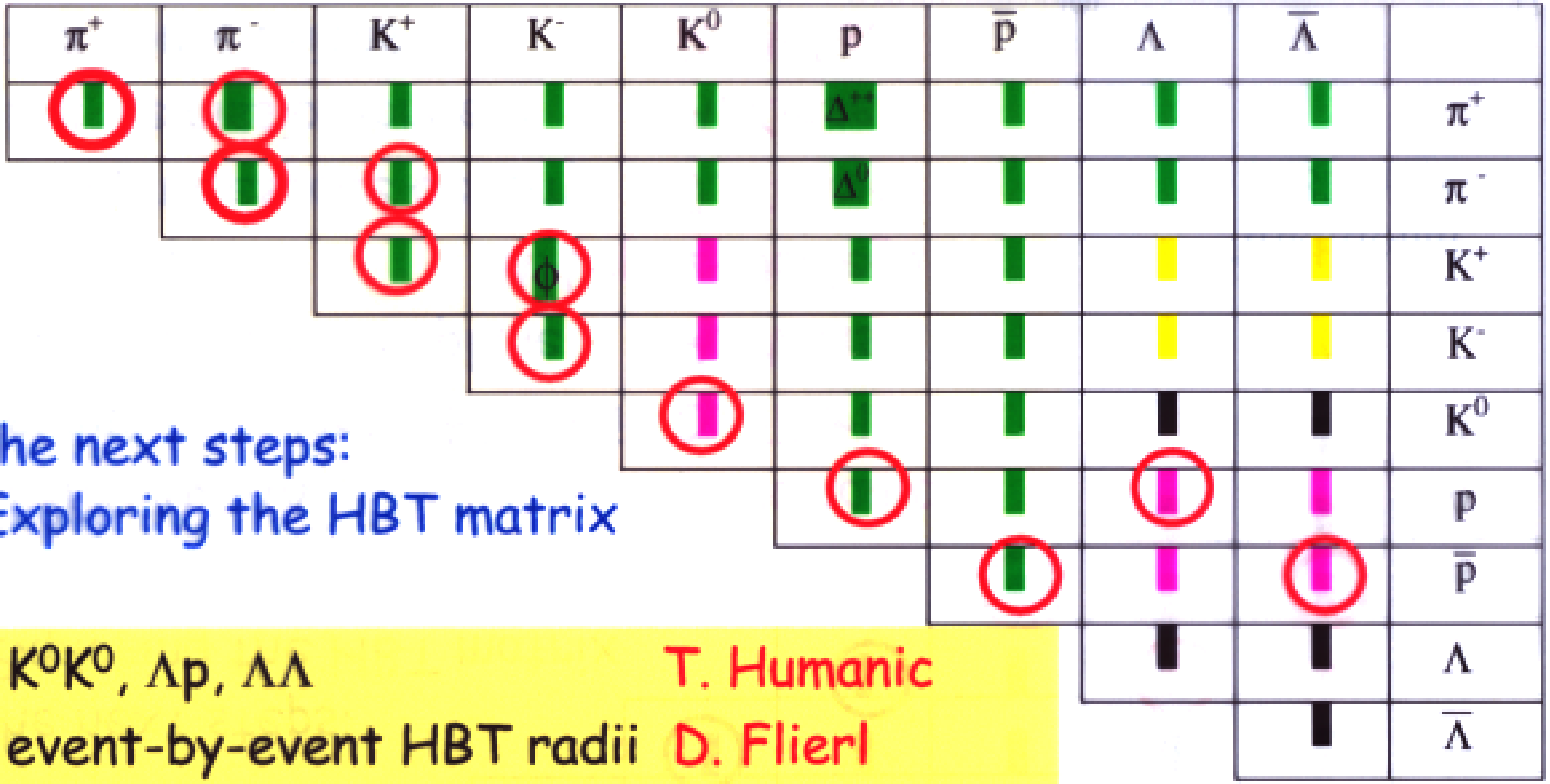
K^0_S Correlation will become statistically meaningful once we have 10M events

Summary

- first $\pi\pi$ interferometry at RHIC
  - source sizes roughly same as at AGS/SPS (< 10fm)
  - radii increase with centrality (expected for R_{Out},R_{Side})
  - radii decrease with increasing k_T (flow)
  - $R_{Out}/R_{Side} \sim 1$ (explosive source)
  - The "universal" phase space density observed at SPS holds at RHIC
- promising novel analyses
  - event characterisation E-by-E: almost
  - K^0 interferometry

Future Plans

- improved Coulomb correction
- other particle combinations
- different collision systems
- energy scan



"traditional" HBT axis

The next steps: Exploring the HBT matrix

- K^0K^0, Λp, $\Lambda\Lambda$ — T. Humanic
- event-by-event HBT radii — D. Flierl
- HBT vs. reaction plane — R. Wells
- $\bar{p}$-$\bar{p}$, p-p — M. Lopez-Noriega
- 6-D phasespace density — J. Cramer
- $K^+\pi^-$ (emission-order) — A. Kiesel
- 3-π correlations — R. Willson