Bose-Einstein Correlation (BEC)

A brief Introduction and Results Review

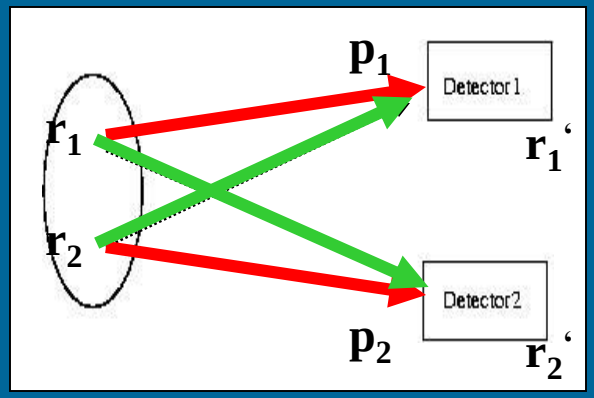
In-Kwon YOO (yoo@pusan.ac.kr)

- HBT Effect
- Bose-Einstein Correlation
- Results Discussion

HBT Effect

- In 1950s, Hanbury-Brown and Twiss
- For Improving of Resolution Power of Michelson Interferomertry [Phil.Mag.45, 663 (1954)]
- Astronomical Application
  - Radio Source [Phil.Mag.45,663 (1954)]
  - Visible Source (Photon) [Nature 178, 1046 (1956)]
- Application to Particle Physics [Phys.Rev.120, 300 (1960)]
  - G.Goldhaber, S.Goldhaber, Lee and Pais
  - GGLP Effect : Bose-Einstein Correlation

Bose-Einstein Correlation (1)



$A(p_1,r_1)e^{i\varphi(r1)}e^{ip1(r1-r'1)}A(p_2,r_2)e^{i\varphi(r2)}e^{ip2(r2-r'2)} = \Psi_d$

$A(p_1,r_2)e^{i\varphi(r2)}e^{ip1(r2-r'1)}A(p_2,r_1)e^{i\varphi(r1)}e^{ip2(r1-r'2)} = \Psi_c$

$$\frac{1}{\sqrt{2}}\{\Psi_d + \Psi_c\} = e^{i\varphi(r1)}e^{i\varphi(r2)}\Phi(p_1p_2{:}r_1r_2 \Rightarrow r_1'r_2')$$

$q = p_1 - p_2$

$K = 0.5(p_1 + p_2)$; $r = r_1 - r_2$

$$P(p_1,p_2) = \int dr_1dr_2\rho(r_1)\rho(r_2)|\Phi|^2 = P(p_1)P(p_2) + \left|\int dre^{iqr}\rho(r)A^2(K,r)\right|^2$$

Bose-Einstein Correlation Function

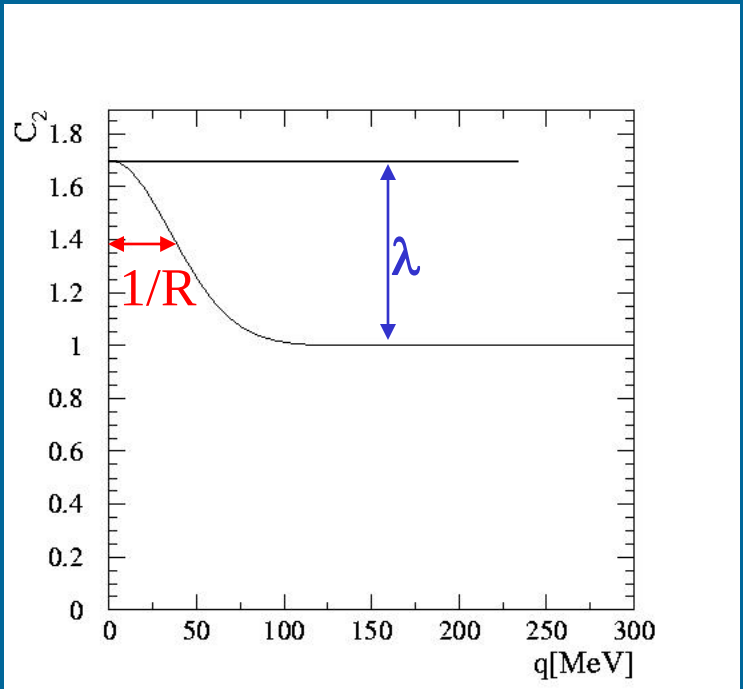
$$C_2 = \frac{P(p_1,p_2)}{P(p_1)P(p_2)} = 1 + \frac{\left|\int drS(K,r)e^{iqr}\right|^2}{\left|\int drS(K,r)\right|^2}$$

Bose-Einstein Correlation (2)

- For Gaussian Source Function :

$$S(r) \sim \exp(-r^2/2R^2) \longrightarrow \tilde{S}(q) \sim \exp(-q^2R^2/2)$$

$$\longrightarrow \quad C_2 = 1 + \lambda \exp(-q^2R^2)$$



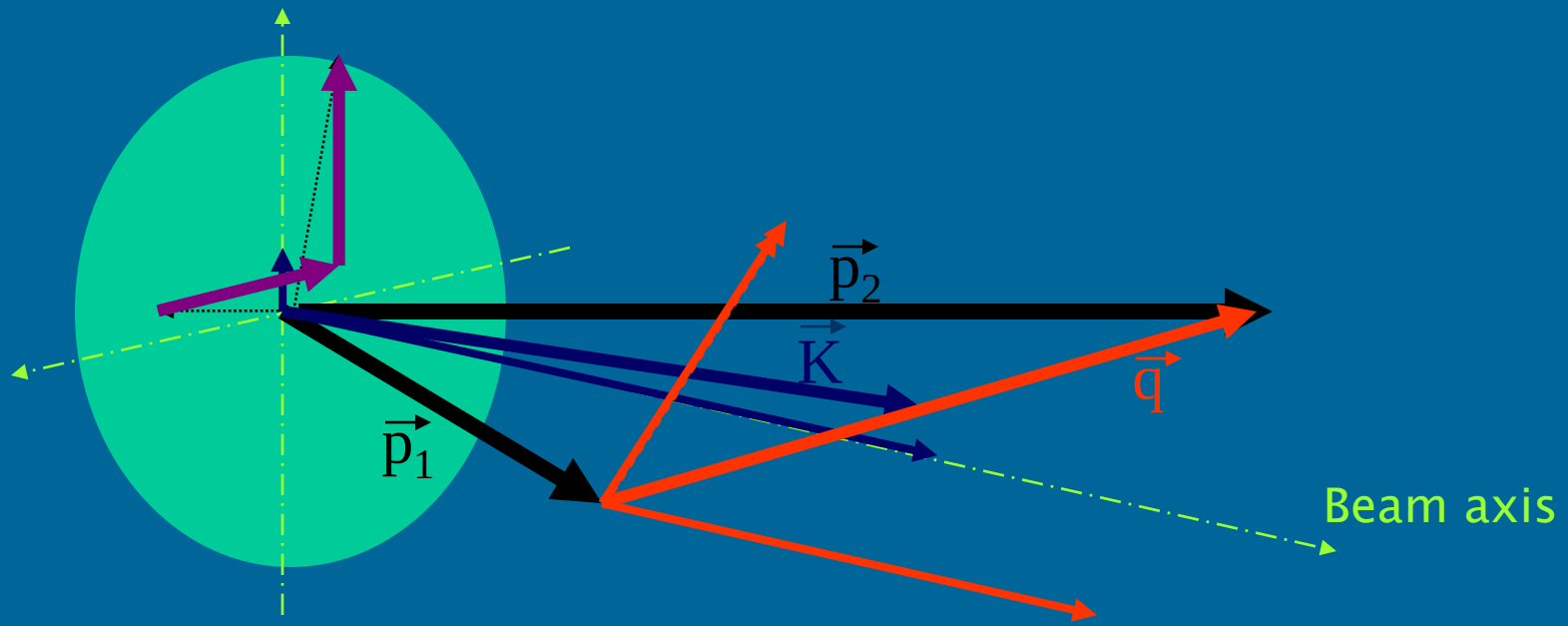
- λ : Chaoticity Parameter
  - λ =1 for a chaotic source
  - λ = 0 for a coherent source
- R : Source Extension

Parameterization of BEC

- 1D Parameterization : $C_2 = 1 + \lambda \exp(-Q_{inv}^2 R_{inv}^2)$

$$Q_{inv} = \sqrt{(\vec{p}_1 - \vec{p}_2)^2 - (E_1 - E_2)^2}$$

- 3D YKP-Parameterization : q_0, $q_{||}$, $q_{\perp}$
- 3D BP-Parameterization : q_{out}, q_{side}, q_{long}



What we expect from BEC radii ?

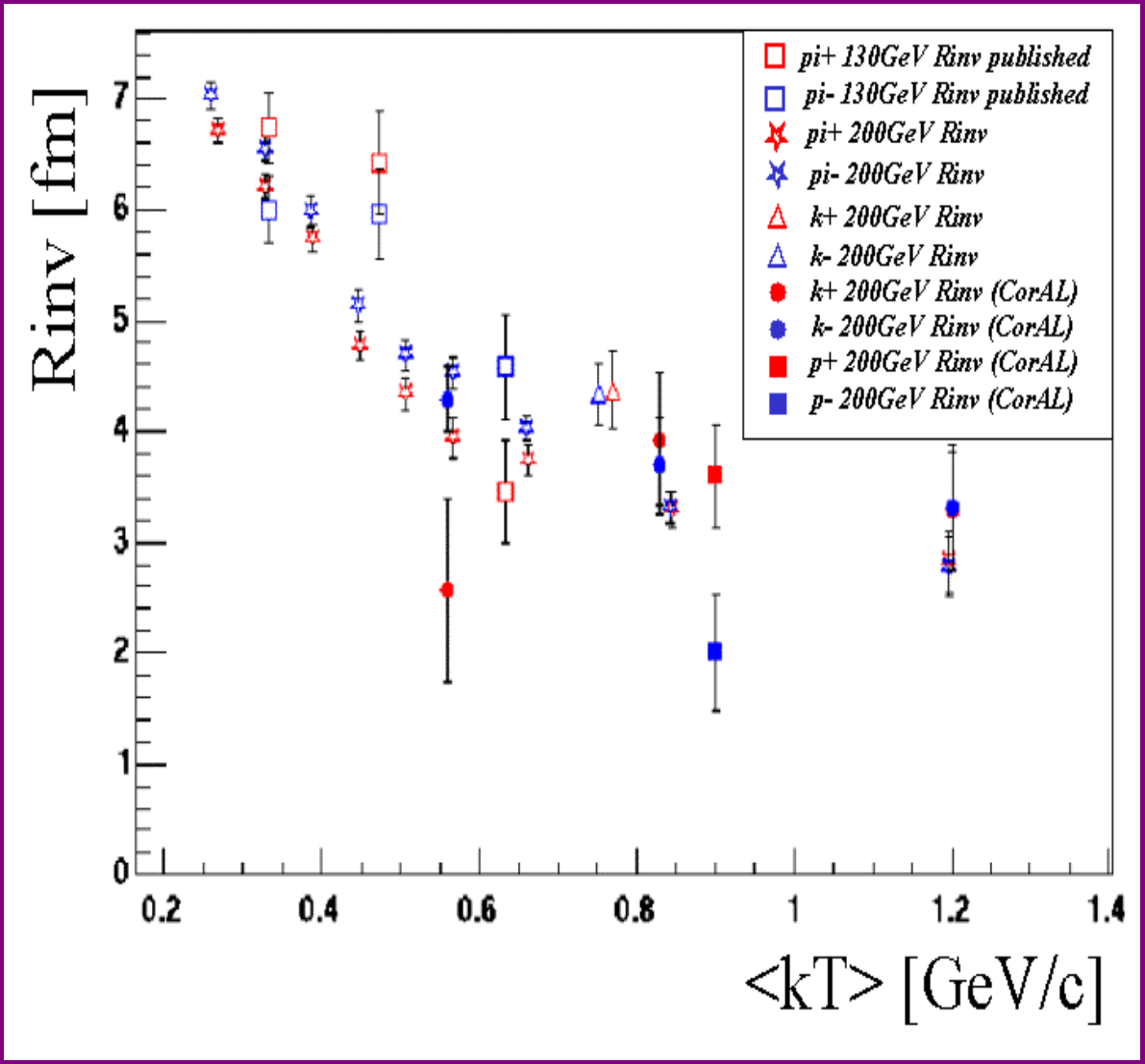
- Source Sizes for
  - particle species : π, K, p ..
  - dynamic region of fireball : K_T (p_T), Φ
- Source Evolution
  - emission duration : R_0, R_{out}/R_{side}
  - lifetime : $\mathbf{dr = R_L = \tau_f \sqrt{\frac{T}{m_T}}}$
- Varying $s^{1/2}$, System size : Any Signal ?

What we expect from BEC radii ?

- Source Sizes for
  - particle species : π, K, p ..

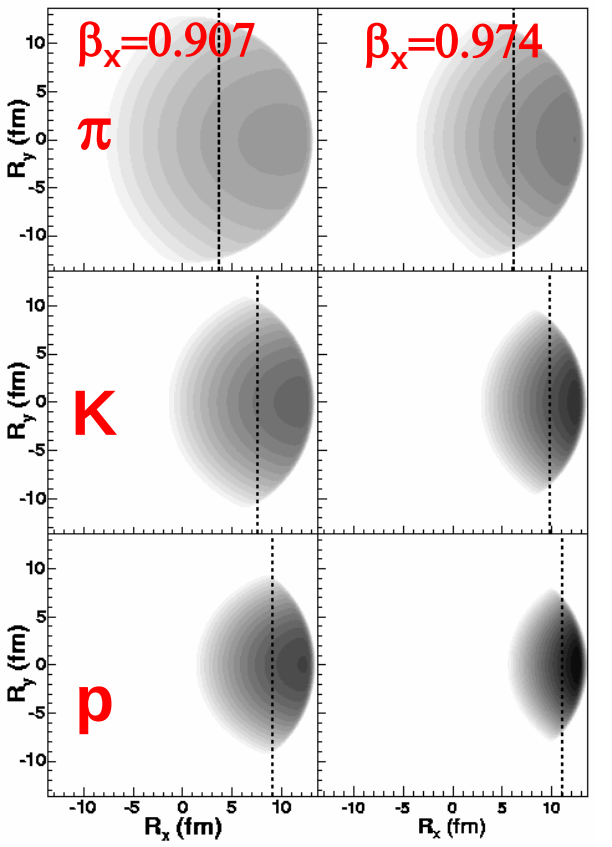
Source Size for identified particles

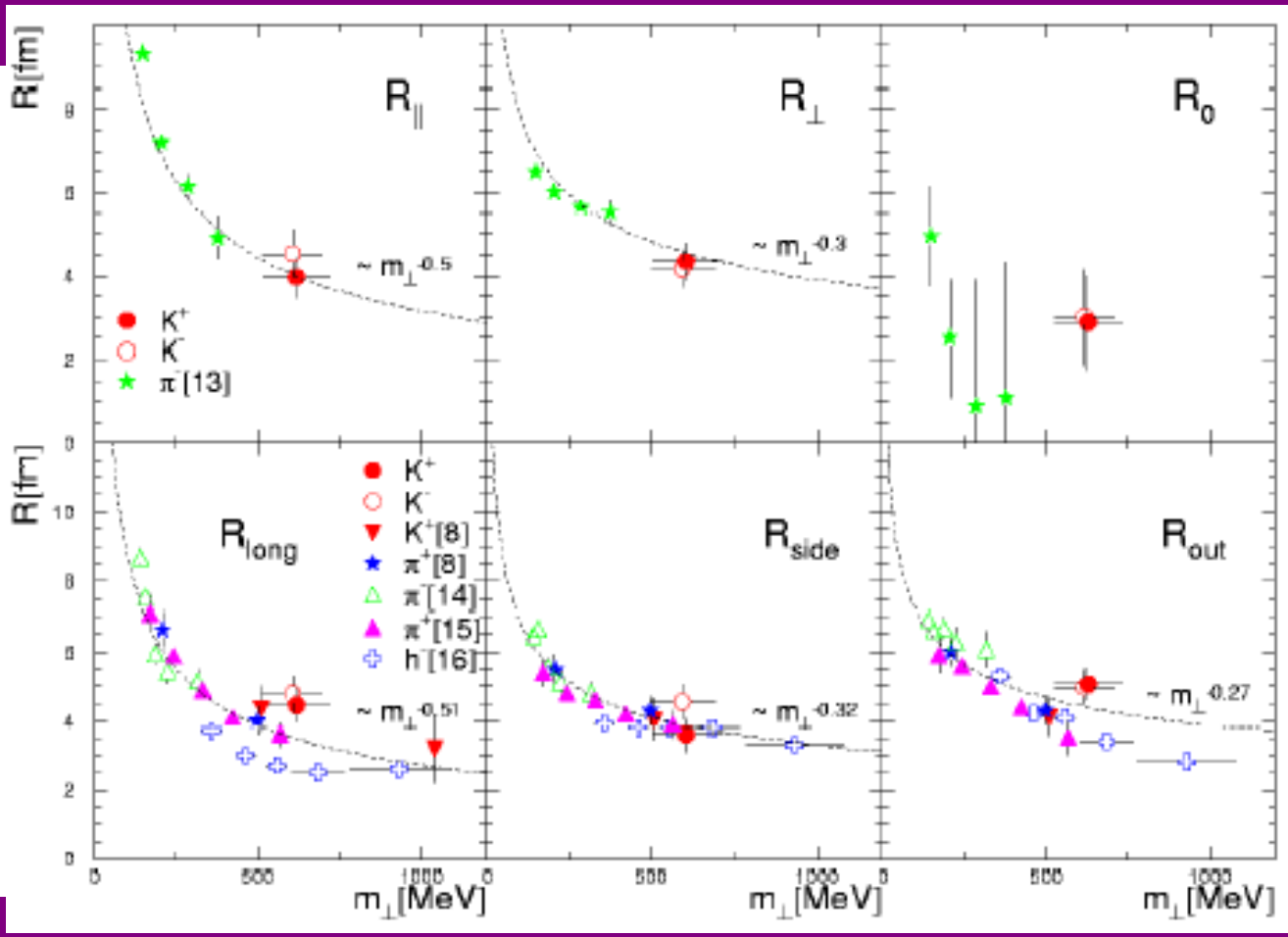
$Rp < R_K < R_\pi$?



Source Size for identified particles

$R_p < R_K < R_\pi$?





Flow Effect !

What we expect from BEC radii ?

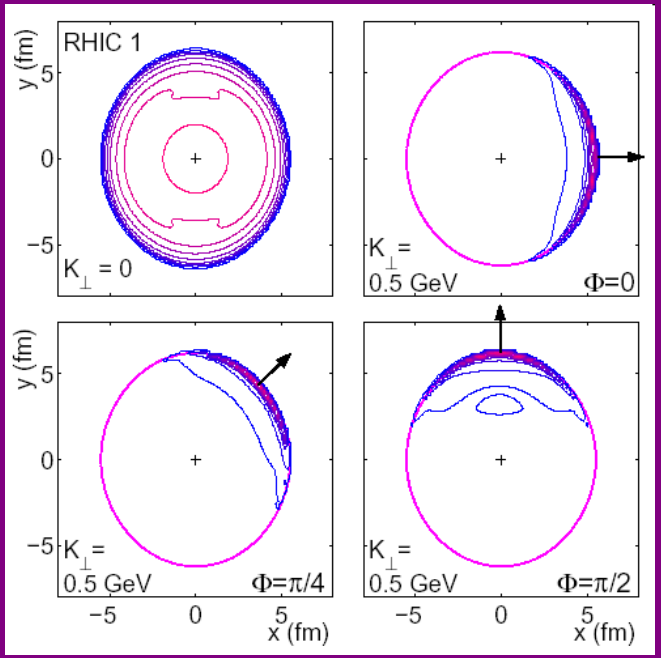
- Source Sizes for
  - particle species : π, K, p .. ✓
  - dynamic region of fireball : K_T (p_T), Φ

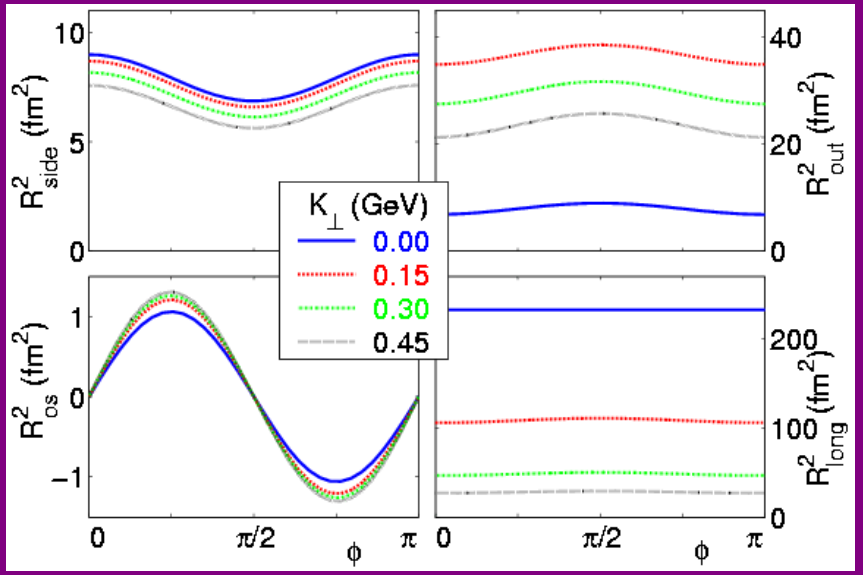
Azimuthal BEC

Measure HBT-Radii relative to the reaction plane in non-central collisions

U. Wiedemann a.m.m.

- out-side crossterm
- characteristic oscillations

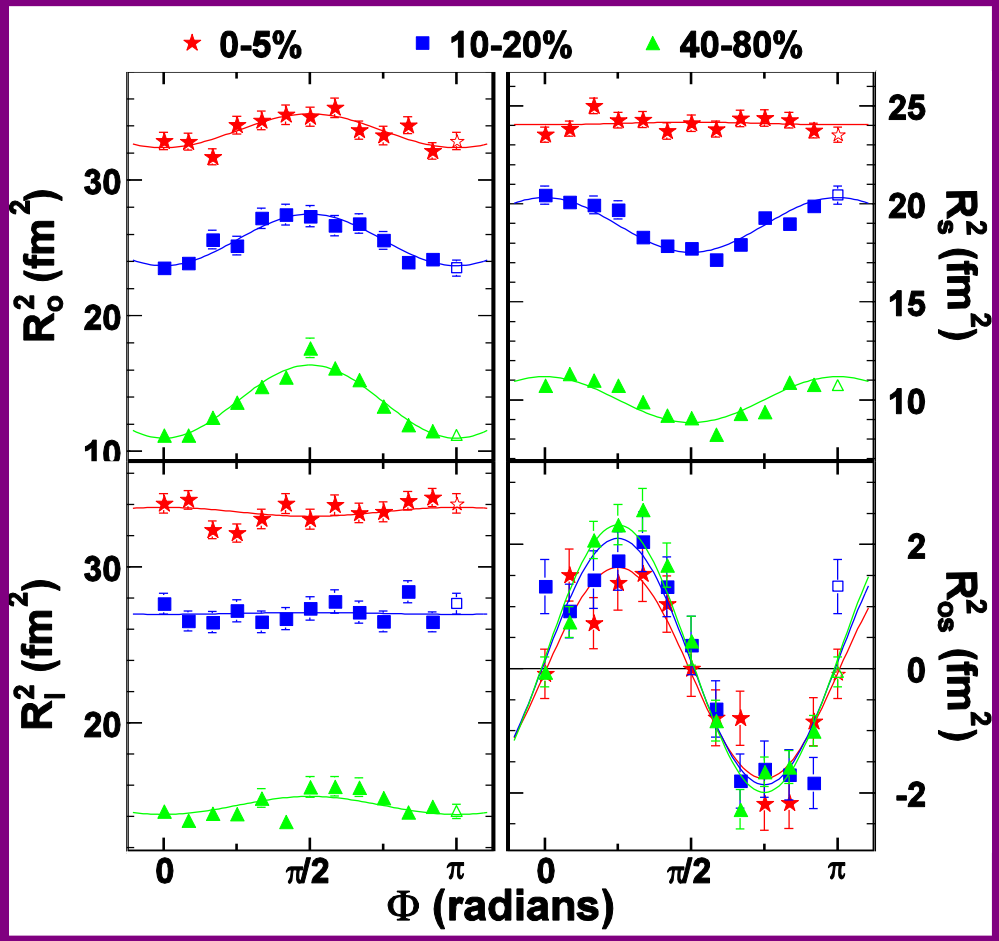




Heinz, Kolb PLB 542 (2002)

➡ *spatial* anisotropy of the pion source at freeze-out!

Azimuthal BEC

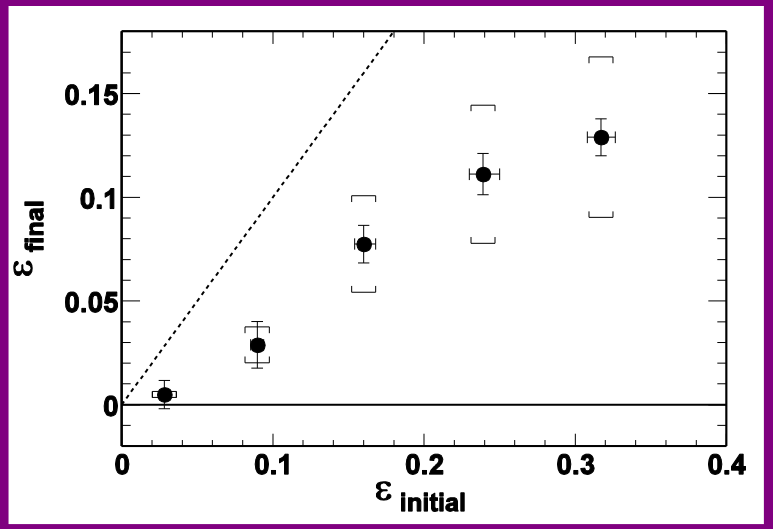


D. Magestro (STAR)

Source eccentricity:

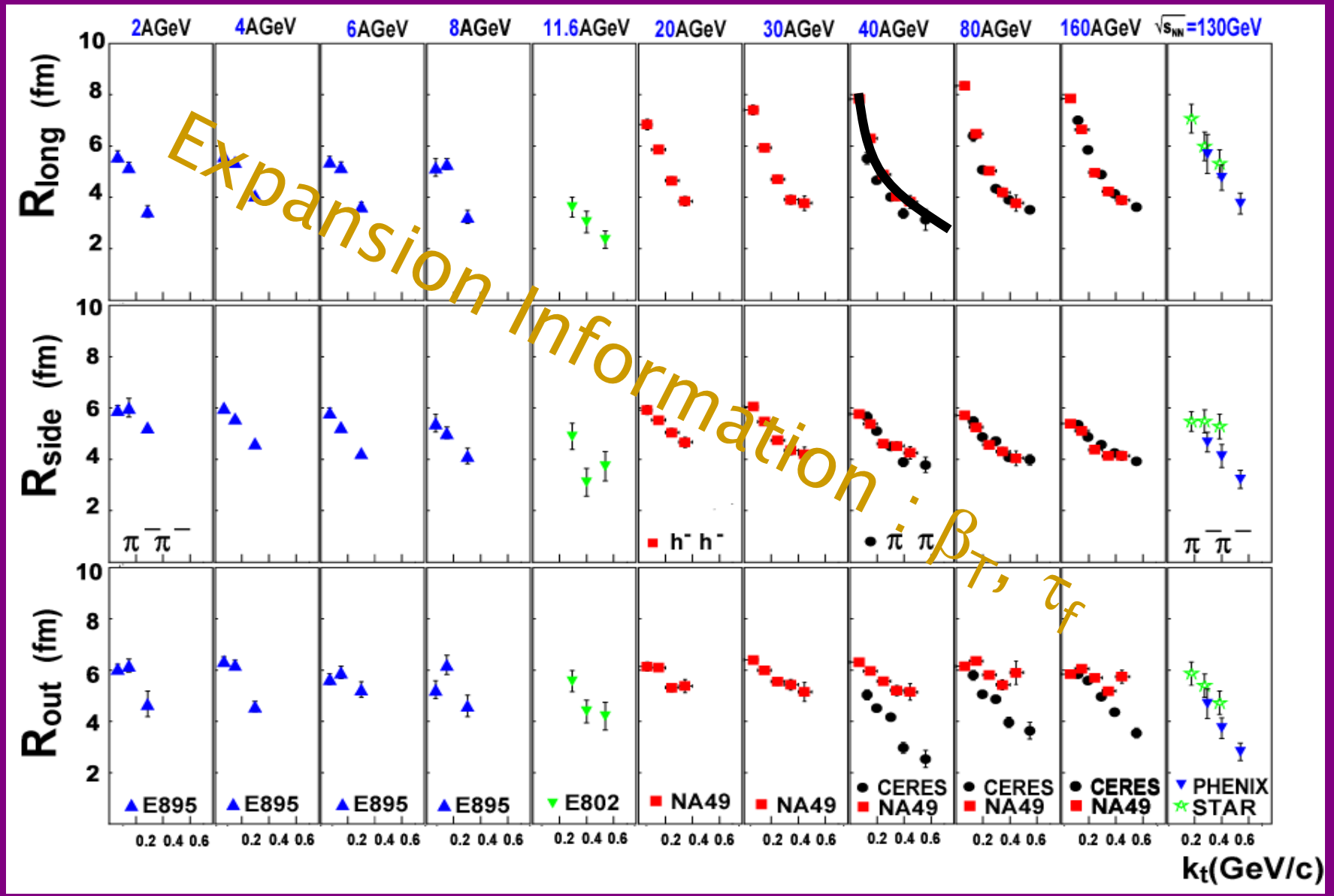
$$\varepsilon_{initial} \equiv \left(R_y^2 - R_x^2\right) / \left(R_y^2 + R_x^2\right)$$

$$\varepsilon_{final} \approx 2R_s^2 / R_o^2$$



...source retains initial orientation!

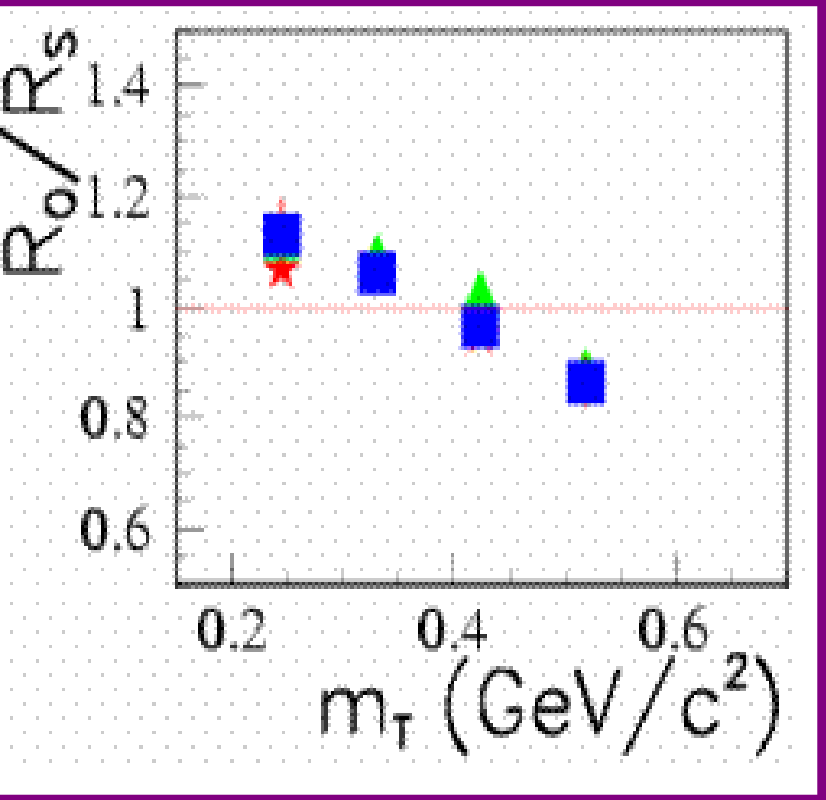
BEC Radii in k_T-bin

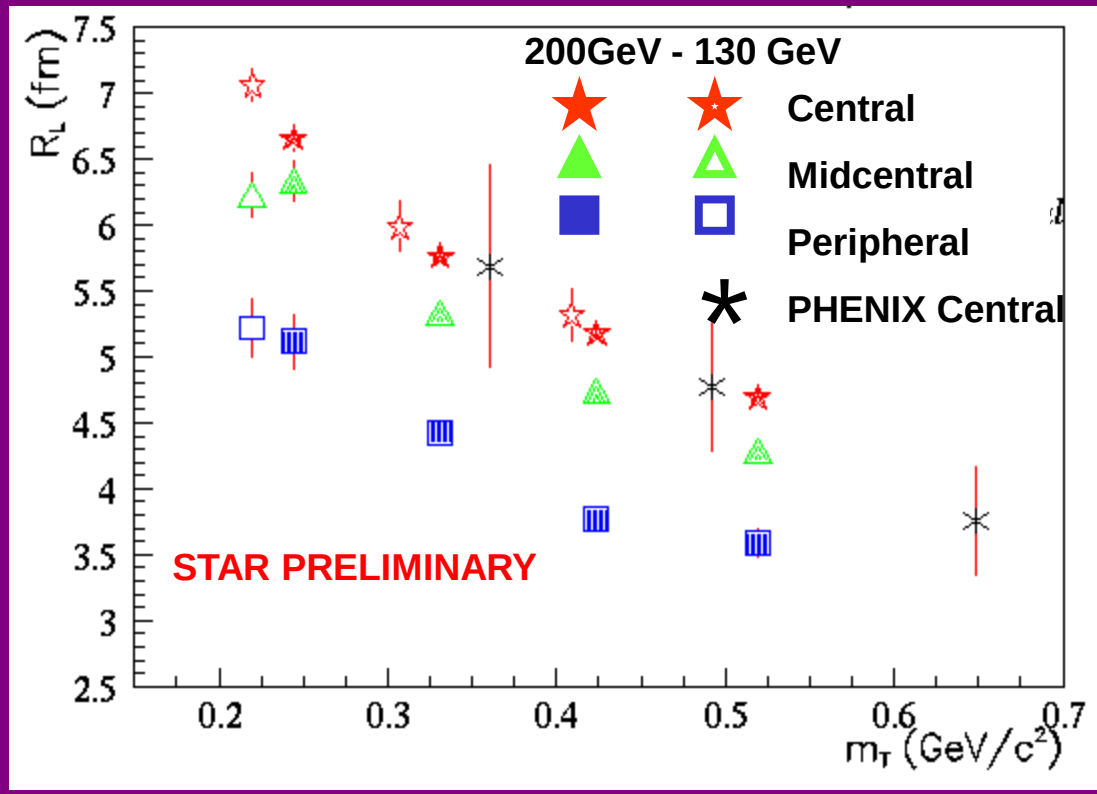


What we expect from BEC radii ?

- Source Sizes for
  - particle species : π, K, p .. ✓
  - dynamic region of fireball : K_T (p_T), Φ ✓
- Source Evolution
  - emission duration : R_0, R_{out}/R_{side}
  - lifetime : $\mathbf{dr = R_L = \tau_f \sqrt{\frac{T}{m_T}}}$

Source Evolution





$R_O/R_S \sim 1$
(short emission time)

Longitudinal radius:
at 200GeV identical to 130 GeV

Source Evolution

Simple Mahklin/Sinyukov fit (assuming boost-invariant longitudinal flow)

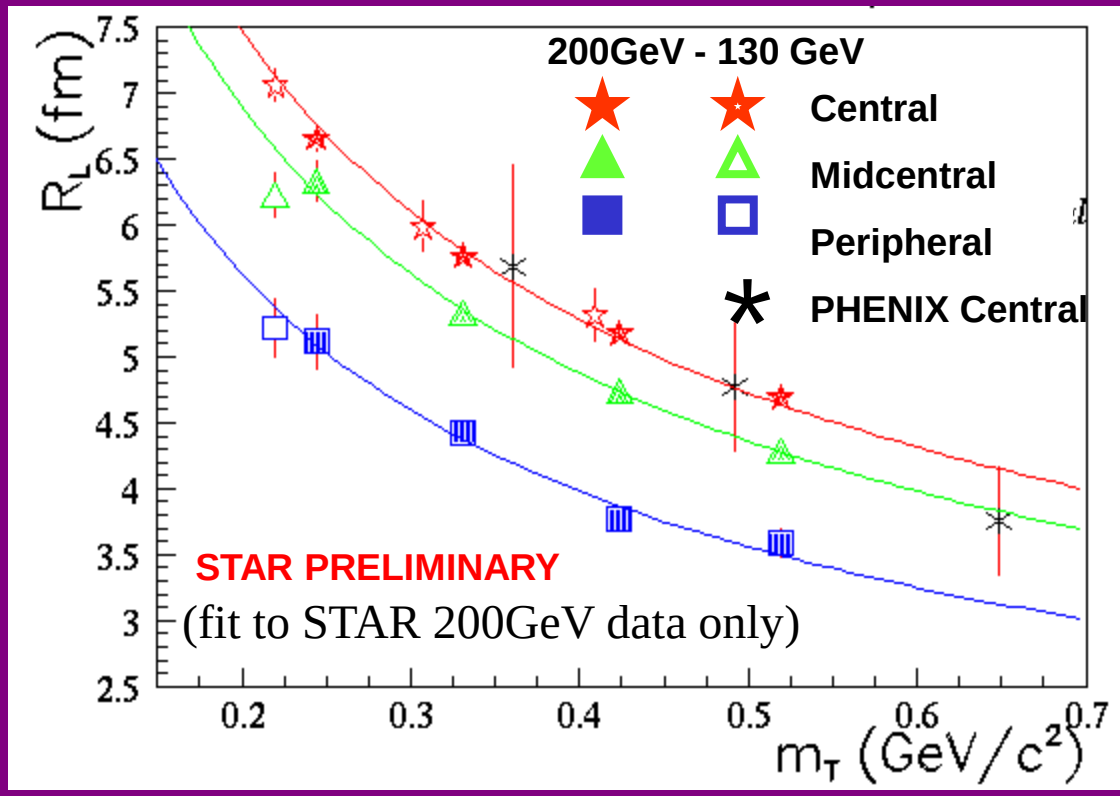
$$R_L = \langle t_{fo} \rangle \sqrt{\frac{T_K}{m_T}}$$

Makhlin and Sinyukov,
Z. Phys. C 39 (1988) 69

Assuming T_K=110 MeV (from spectra at 130 GeV)

$$\langle \tau_f \rangle_{central} \approx 10 \text{ fm/c}$$

$$\langle \tau_f \rangle_{periph} \approx 7.6 \text{ fm/c}$$



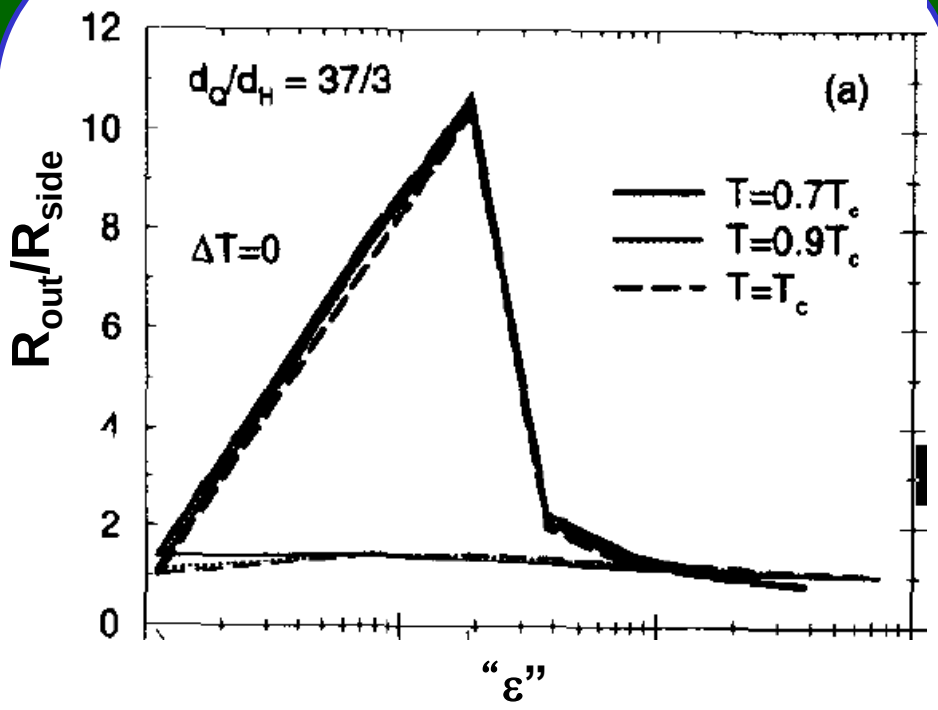
Longitudinal radius:
at 200GeV identical to 130 GeV

rapid evolution!!!

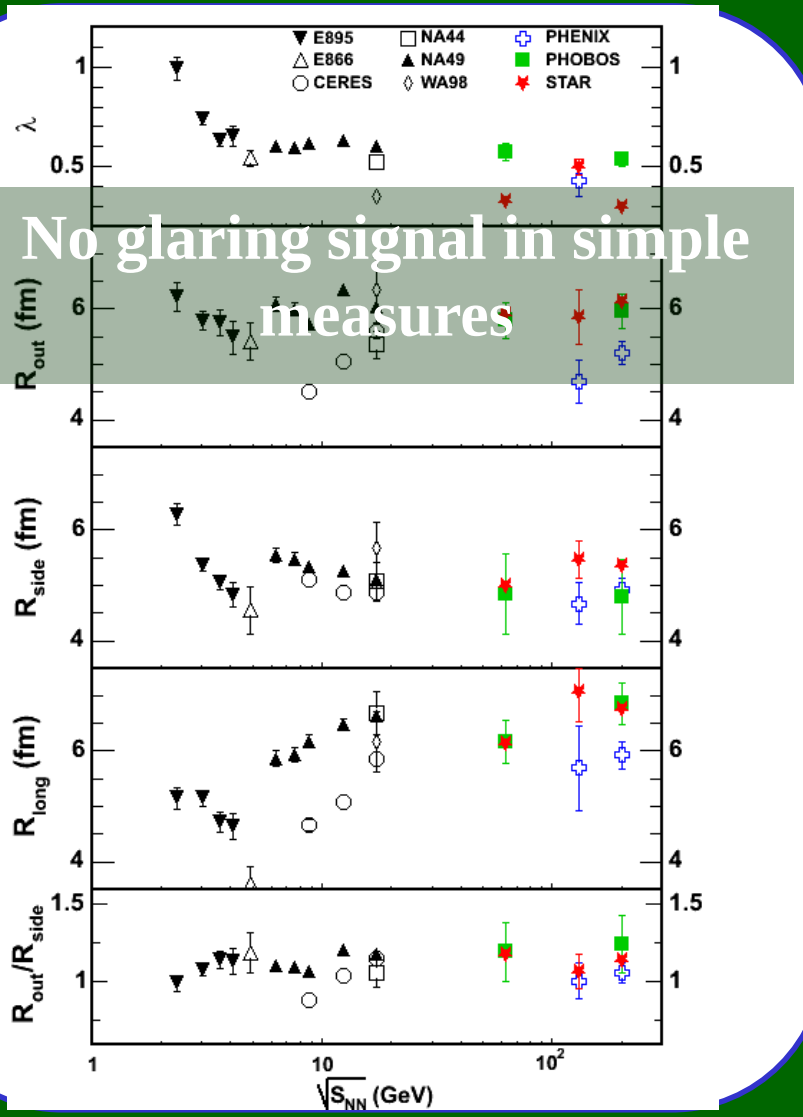
What we expect from BEC radii ?

- Source Sizes for
  - particle species : π, K, p .. ✓
  - dynamic region of fireball : K_T (p_T), Φ ✓
- Source Evolution
  - emission duration : R_0, R_{out}/R_{side} ✓
  - lifetime : $\mathbf{dr = R_L = \tau_f\sqrt{\frac{T}{m_T}}}$ ✓
- Varying $s^{1/2}$, System size : Any Signal ?

R($\sqrt{S_{NN}}$, m_T, b, N_{part}, PID …)



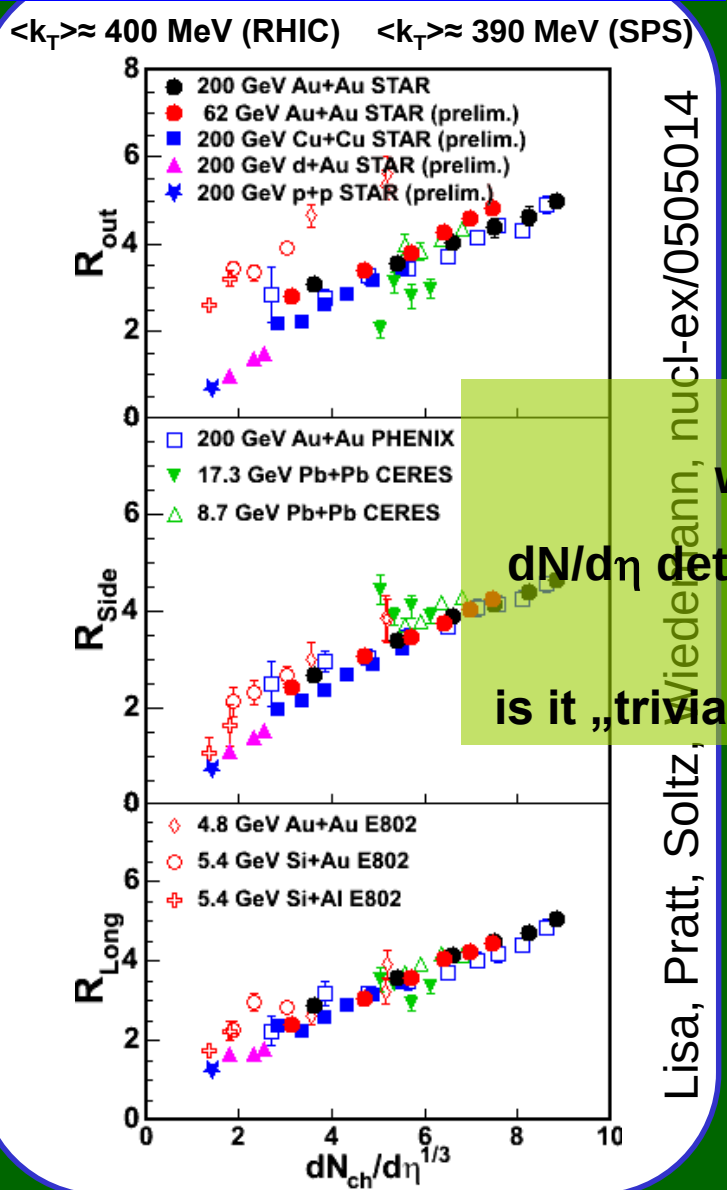
Rischke, Gyulassy, NP A 608 (1996) 479



No glaring signal in simple measures

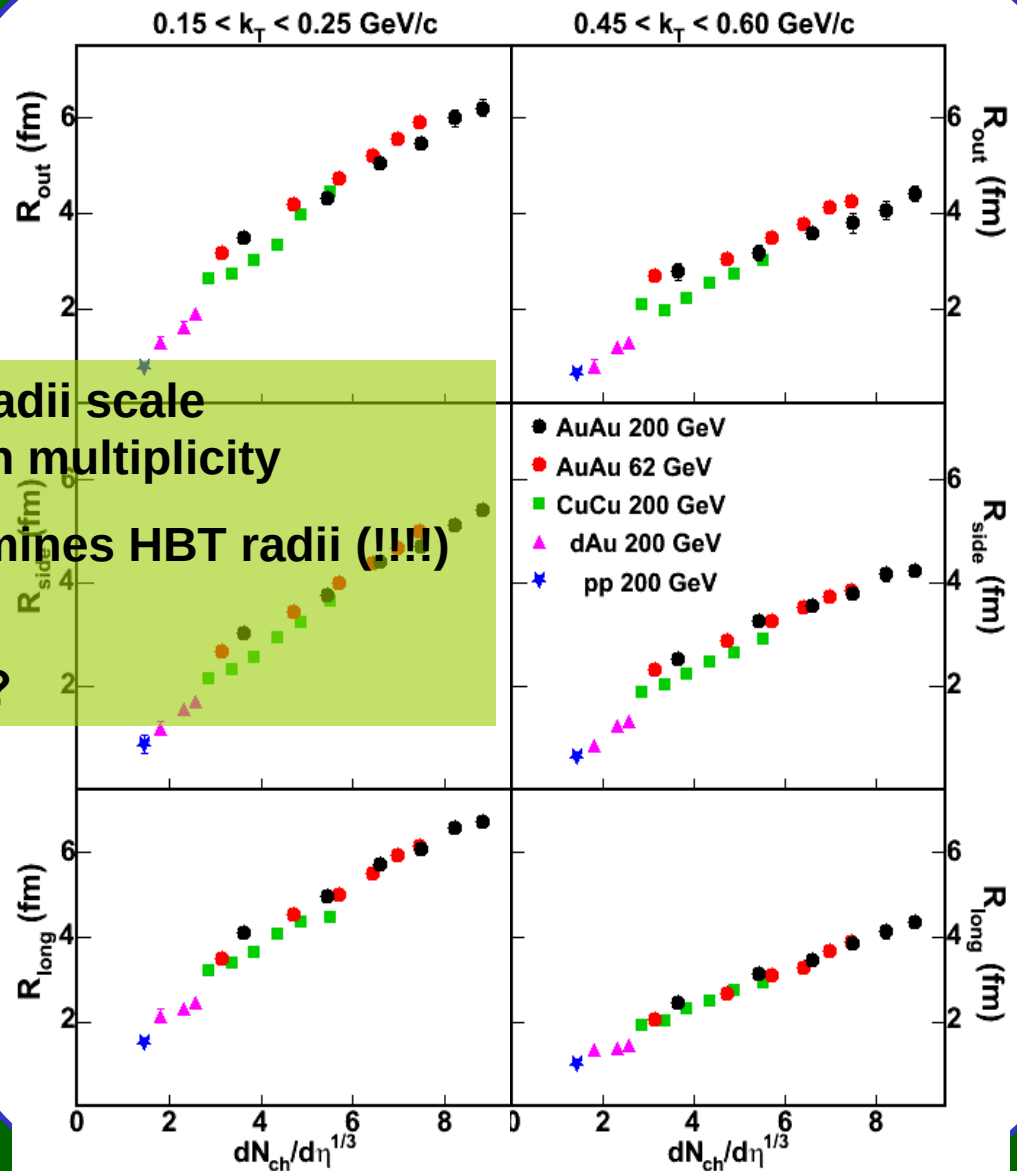
„Universal" scaling ?

RHIC/AGS/SPS Systematics



Lisa, Pratt, Soltz, Wiedemann, nucl-ex/0505014

STAR DATA
(pp,dAu,CuCu,AuAu@62GeV - prelim.)



Radii scale with multiplicity

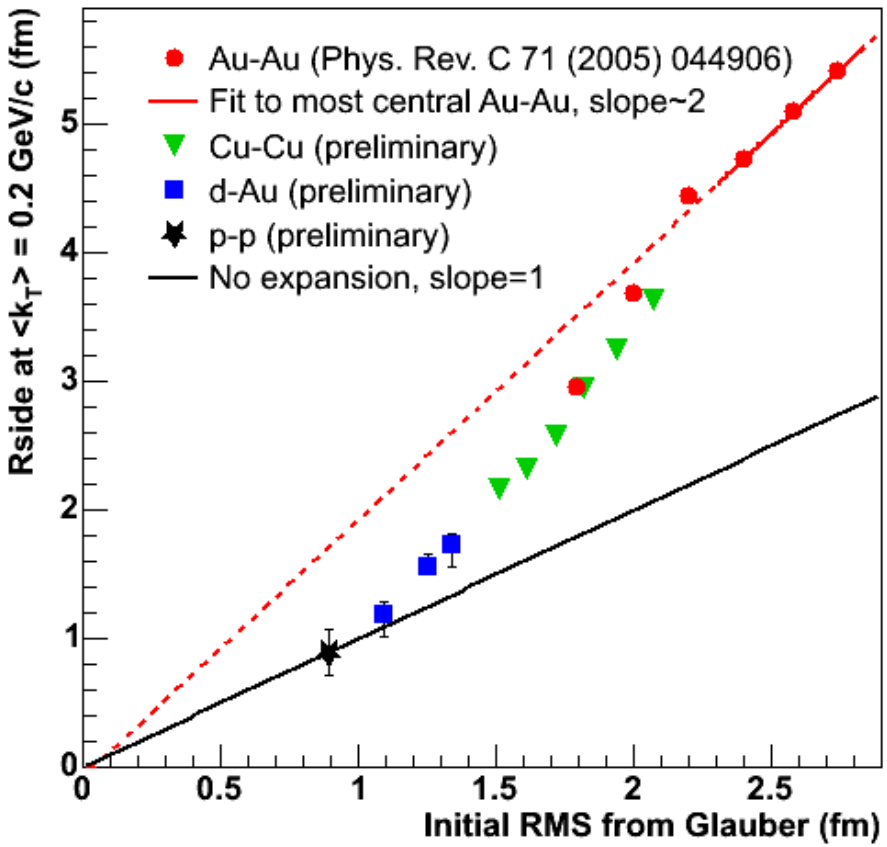
dN/dη determines HBT radii (!!!)

is it „trivial" ?

System expansion: Initial vs Final Size

Smooth expansion of the system from p+p to Au+Au

Collisions at 200GeV only



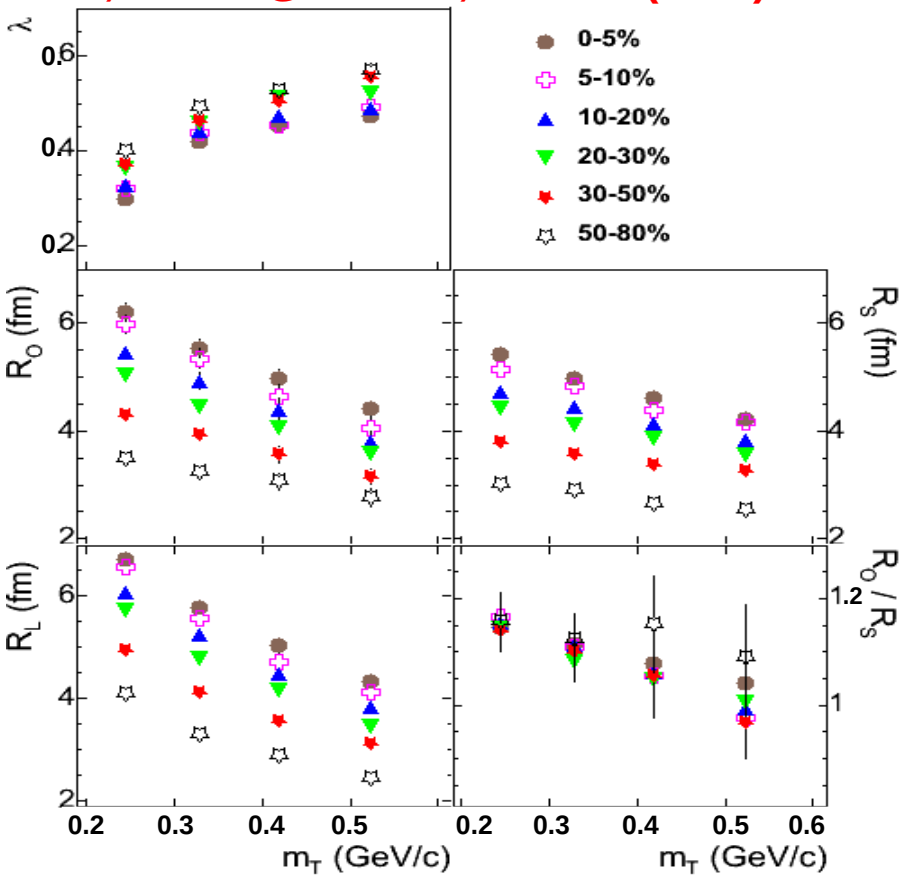
Proton initial size = 0.89 fm
from e-scattering

AuAu: system expands

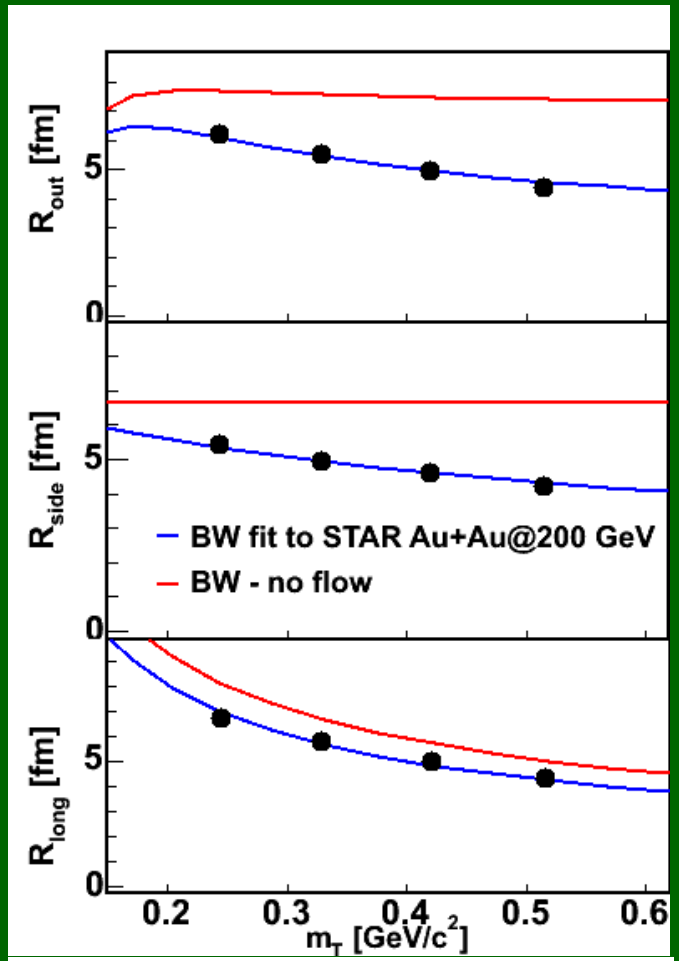
pp (dAu): no or less expansion

Transverse mass dependence in Au+Au

STAR, Au+Au@200GeV, PRC 71 (2005) 044906

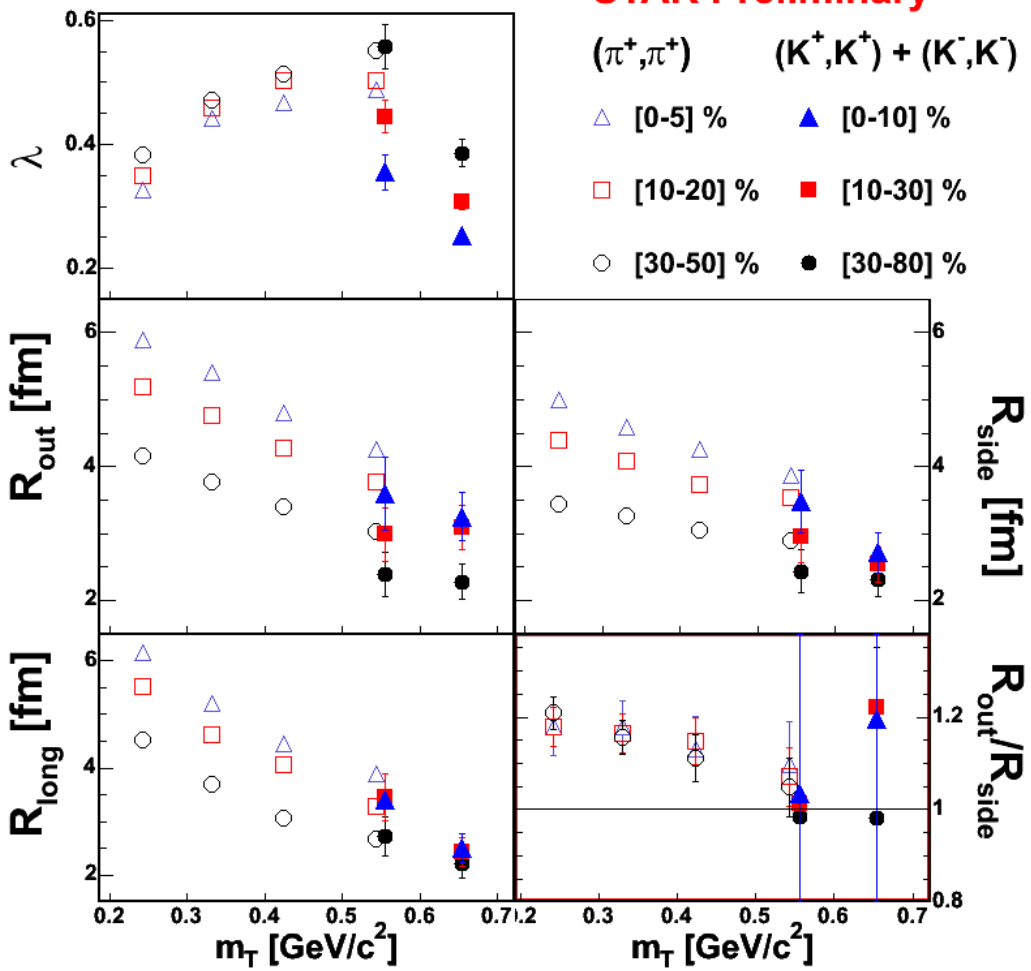


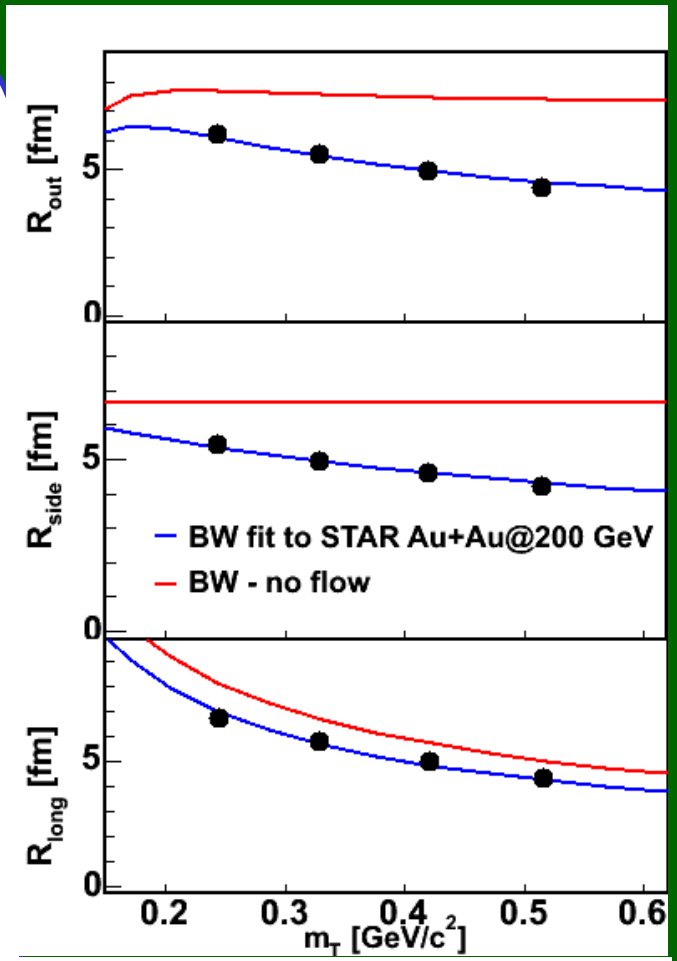
In Au+Au p_T (m_T) dependence attributed to collective expansion of the source



Calc. with Blast-Wave - Retiere, Lisa, PRC 70 (2004) 044907

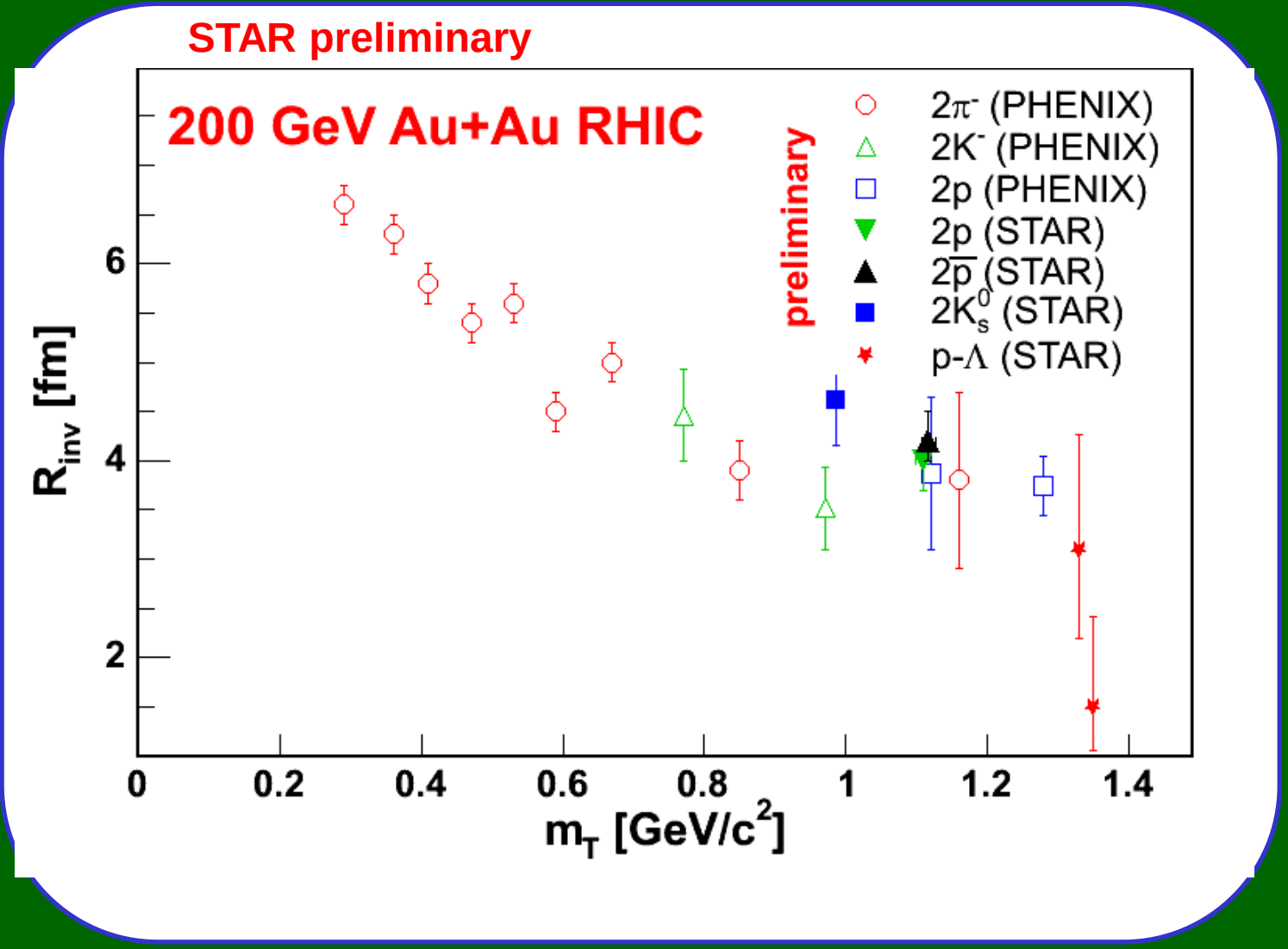
Consistency Check with Kaons





Calc. with Blast-Wave -
Retiere, Lisa, PRC 70 (2004) 044907

More confirmations



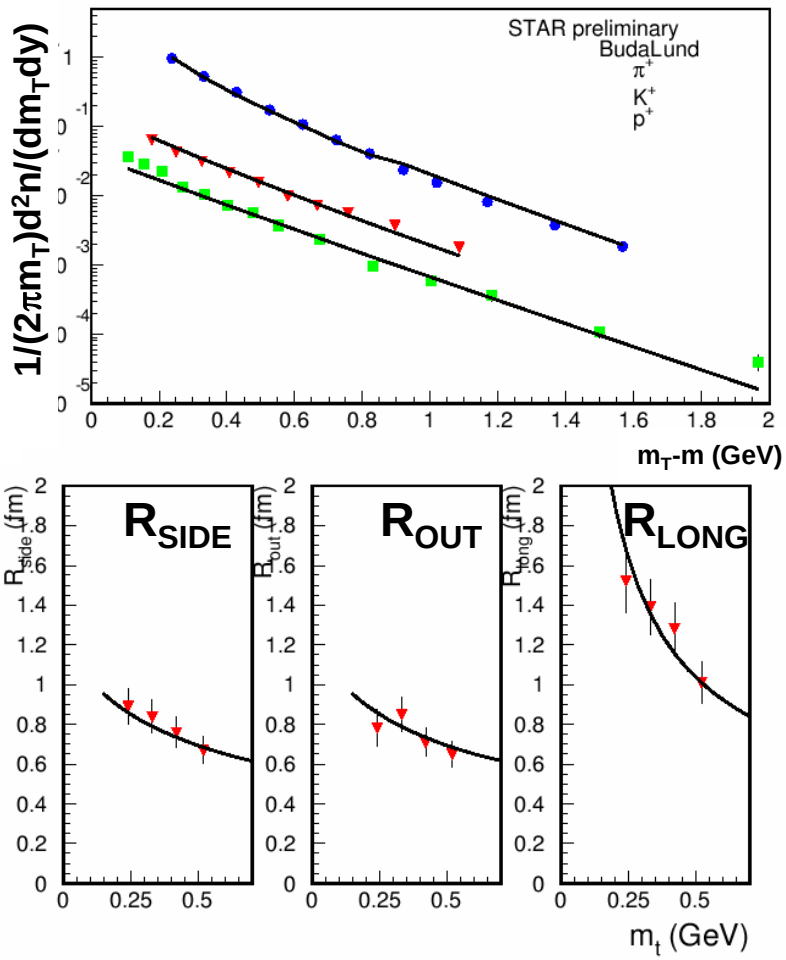
Transverse mass dependence: p+p, d(p)+Au

Hydrodynamical expansion in such small systems?

flow not expected in such a small system as p+p

see e.g. Shuryak: ***hep-ph/0405066***

- **Csorgo *et al.***: m_T dependence of HBT radii in pp is not generated by the transverse flow, but by the transverse temperature inhomegeneities of hadron-hadron collisions due to the freezing scale – ***hep-ph/0406042***



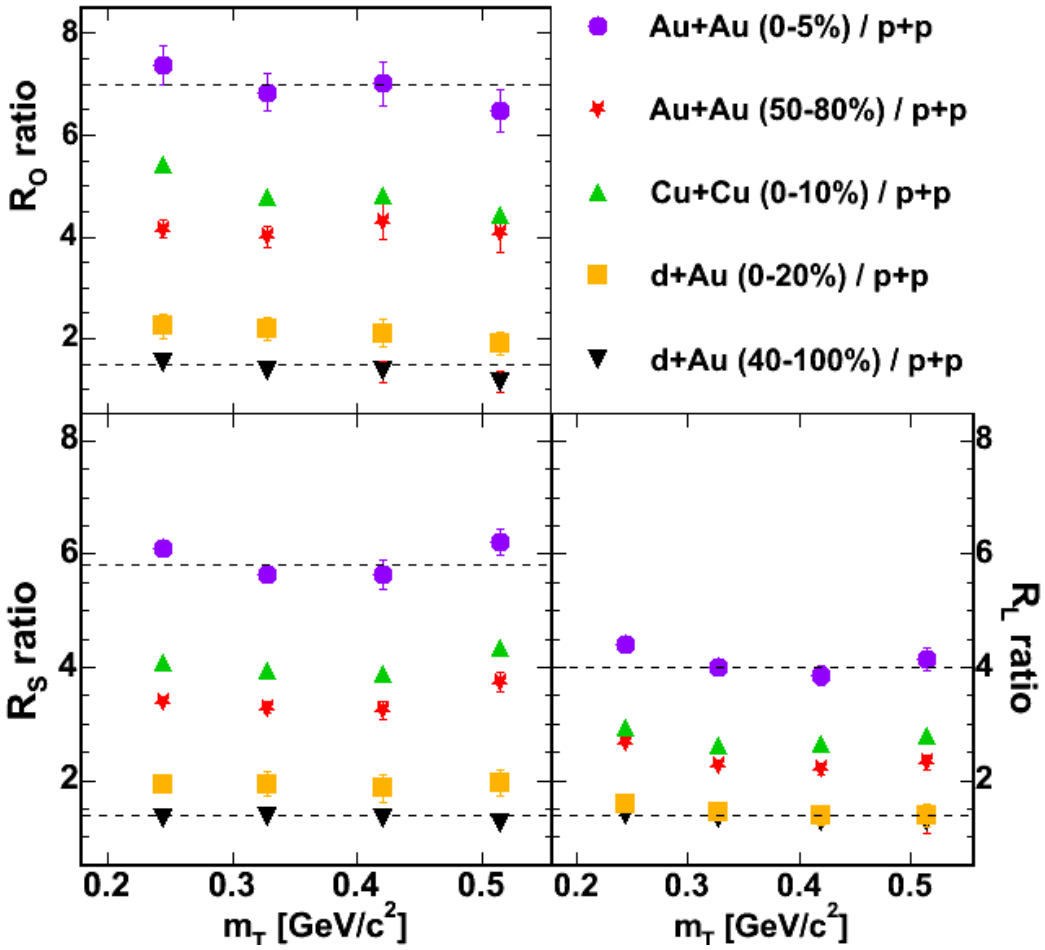
Surprising („puzzling”) scaling

- All $p_T(m_T)$ dependences of HBT radii observed by STAR scale with pp although it’s expected that different origins drive these dependences

HBT radii scale with pp

Scary coincidence or something deeper?

Ratio of (AuAu, CuCu, dAu) HBT radii by pp



pp, dAu, CuCu - STAR preliminary

BEC Epilogue

- Some nice Reconstructions of our spatial-temporal imagination
- No dramatic Change from SPS to RHIC
- What can we do more with HBT / BEC ?
  - Technical Problems (correction for FSI) ?
  - Philosophical Problem (homogeneity, etc) ?

Thanks to