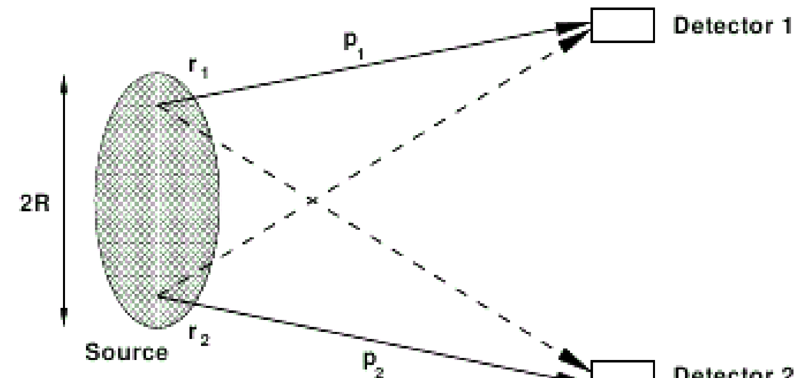
Two Particle Interferometry – Determination of 'Size' of Fireball

The method: **Pion HBT interferometry**

When phase space volume smaller than $\Delta p_x \Delta x \approx \hbar$ is considered, chaotic system of identical non-interacting particles exhibits quantum fluctuations following Bose-Einstein or Fermi statistics

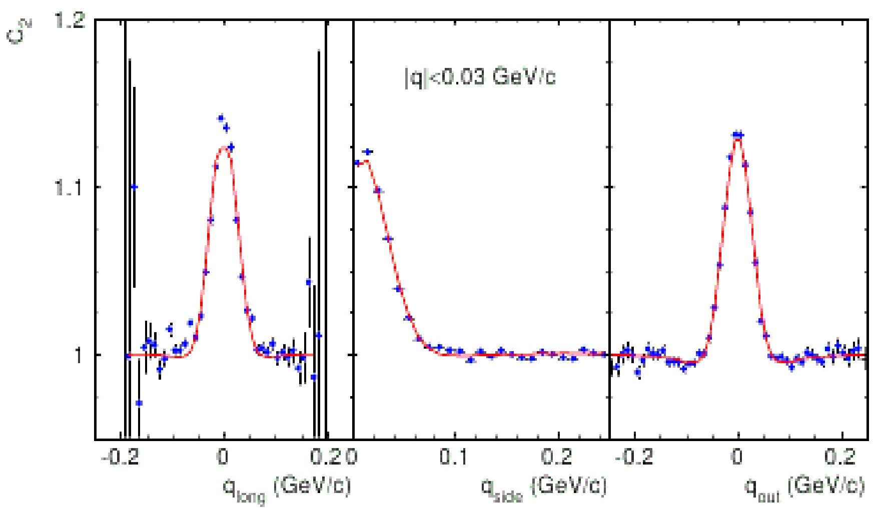


First application in astrophysics (Hanbury Brown and Twiss) $\rightarrow$ size of stars

$$C_2 \propto \frac{P_2(\vec{p_1},\vec{p_2})}{P_1(\vec{p_1})P_2(\vec{p_2})} = 1 \pm \chi(\vec{p_1} - \vec{p_2})$$

$$\Delta r = \frac{\hbar c}{q} = \frac{197\mathrm{MeV}}{q}\mathrm{fm}$$

in heavy ion physics typical dimensions 1-10 fm $\rightarrow$ momentum differences of 20-200 MeV/c



more complications, but also more information for non-static source:
duration of emission, space-momentum correlations due to expansion, strong & EM interaction, decays of resonances ...
measure C_2 as function of
Δp_x, Δp_y, Δp_z for all y, p_t, m

The two particle correlation function is related via Fourier transformation to source emission function

e.g. a Gaussian source profile in x direction leads to a two boson correlation function $C(p_x^{\,1}, p_x^{\,2}) = 1 + \exp(-q_x^{\,2}/2\sigma_x^{\,2})$

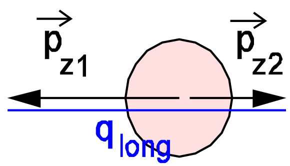
typically there is also correlation due to Coulomb repulsion, data need to be corrected before fitting correlation function to extract geometry of source

The vector momentum difference as analyzed in terms of its 3 components:

Bertsch-Pratt Parametrization $p_1 - p_2 = q = (q_{long}, q_{side}, q_{out}) \rightarrow R_{long}, R_{side}, R_{out}$

$$C(\vec{q},\vec{P}) = \frac{\{n_{\vec{p}_1} n_{\vec{p}_2}\}}{\{n_{\vec{p}_1}\}\{n_{\vec{p}_2}\}} = 1 + \lambda e^{-\left(q_{\text{out}}^2 R_{\text{out}}^2 + q_{\text{side}}^2 R_{\text{side}}^2 + q_{\text{long}}^2 R_{\text{long}}^2 + 2 q_{\text{out}} q_{\text{long}} R_{\text{ol}}^2\right)}$$

longitudinal:

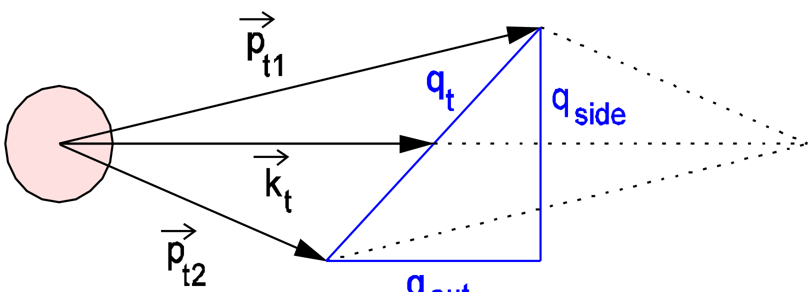


$q_{long} = \vec{p}_{z1} - \vec{p}_{z2}$

in LCMS:

$p_{z,1} + p_{z,2} = 0$

transverse:



$$\vec{k}_t = \frac{1}{2}(\vec{p}_{t1} + \vec{p}_{t2})$$

$$q_t = \vec{p}_{t1} - \vec{p}_{t2}$$

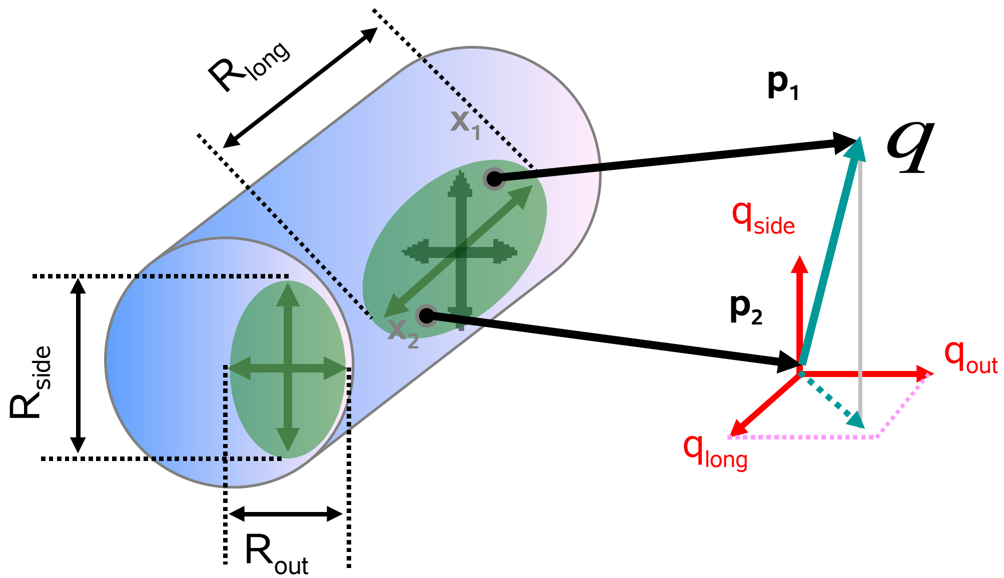
$$q_{side} \perp \vec{k}_t, \quad q_{out} \parallel \vec{k}_t$$

R_{long} : longitudinal expansion and lifetime τ_f

R_{side} : transverse size, radial expansion

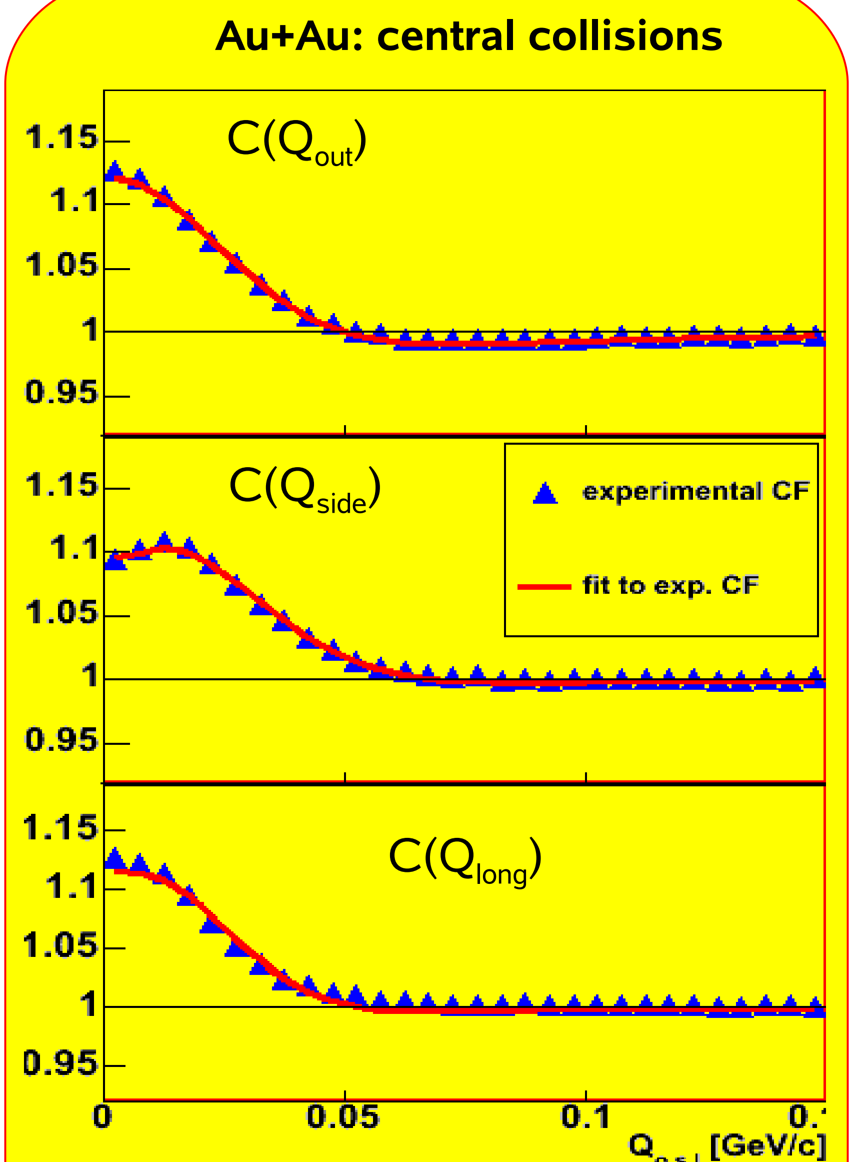
R_{out} : as R_{side} but also duration of emission $\Delta\tau$

3D information



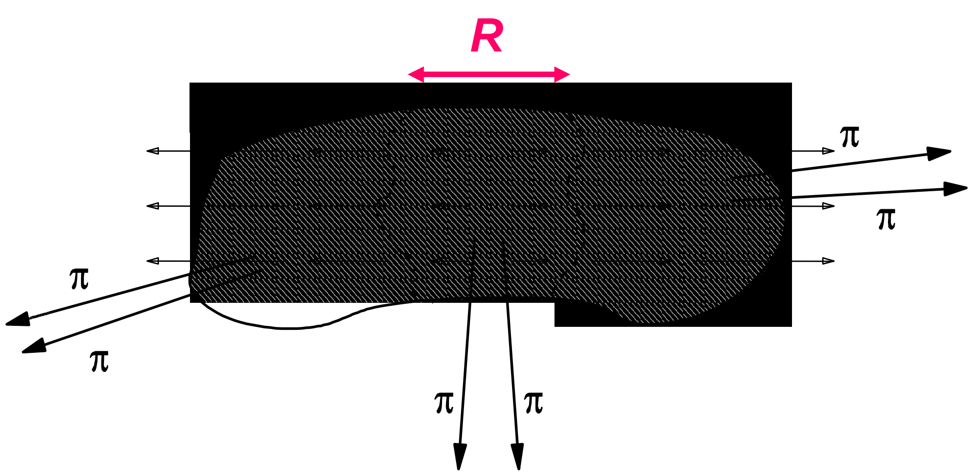
$$\vec{k} = \frac{1}{2}\left(\vec{p}_2 + \vec{p}_1\right)$$

$$q = p_2 - p_1$$



3 “radii” by using 3-D vector **q**

HBT in expanding systems



space-momentum correlations:
pions with similar momenta (small q) are preferentially emitted from close-by regions
→ length of homogeneity: (smaller than geometrical dimension of system)

$$\Delta v_{coll} \approx \sqrt{\frac{T_f}{m_t}}, \qquad m_t = \sqrt{m_\pi^2 + k_t^2}$$

Łthermal vs. geometrical length scale

$$R_{HBT} = \min(R_{geo}, R_{therm})$$

→ HBT radius parameters depend on m_t

→ differential HBT-analysis as function of m_t contains information about source expansion

R_{long} – longitudinal expansion and lifetime

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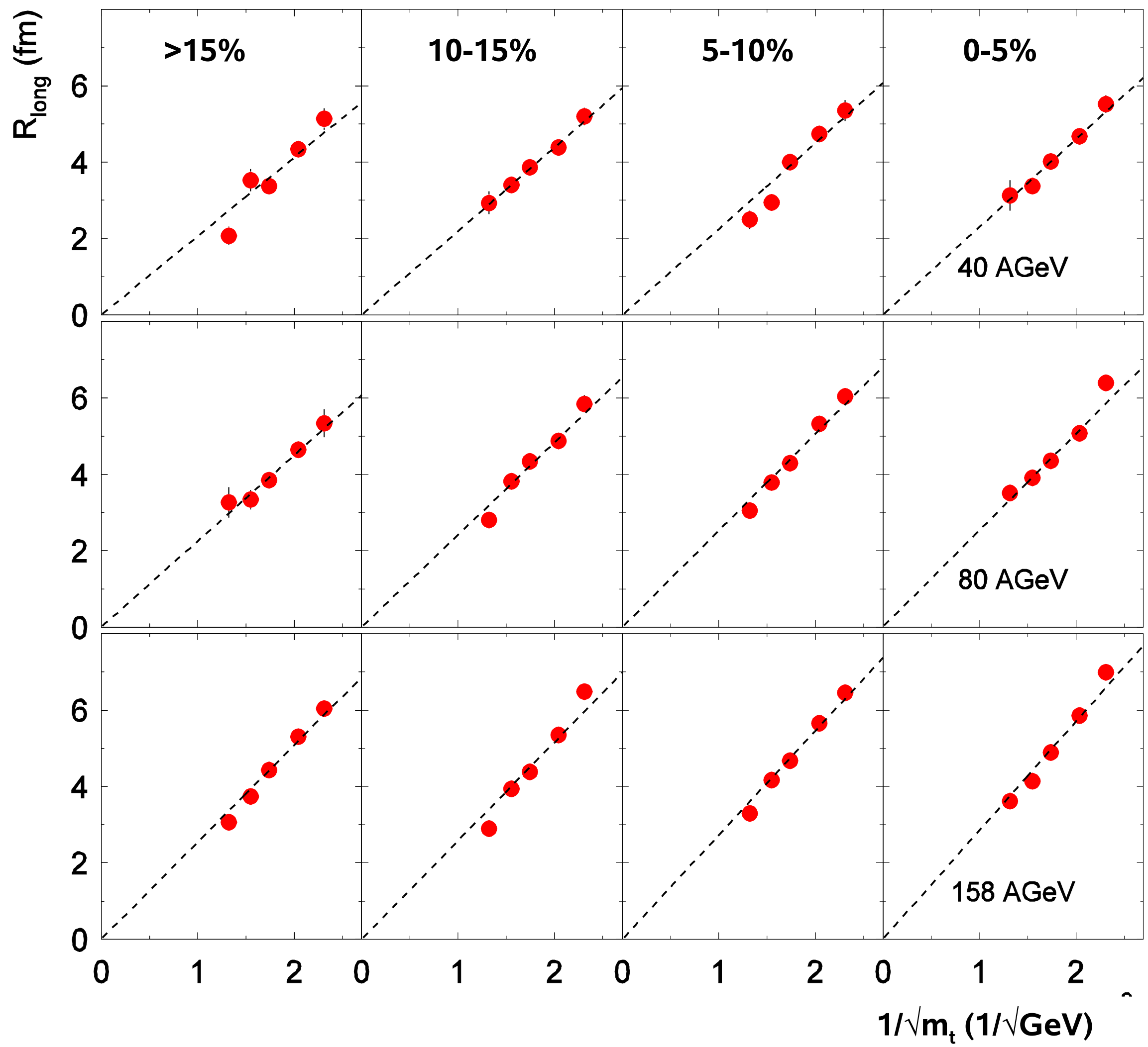
$$R_{long} = \tau_f \cdot \sqrt{\frac{T_f}{m_t}}$$ (Y. Sinyukov)

duration of expansion

thermal velocity



¸ Hubble-Expansion

$$H_{LB} = 1{,}4 \cdot 10^{42} \frac{km}{s \cdot Mpc}$$

$$\tau = \frac{1}{H_{LB}} = 6 - 8\ fm/c \approx 2 \cdot 10^{-23} s$$

for T_f = *160 – 120* MeV

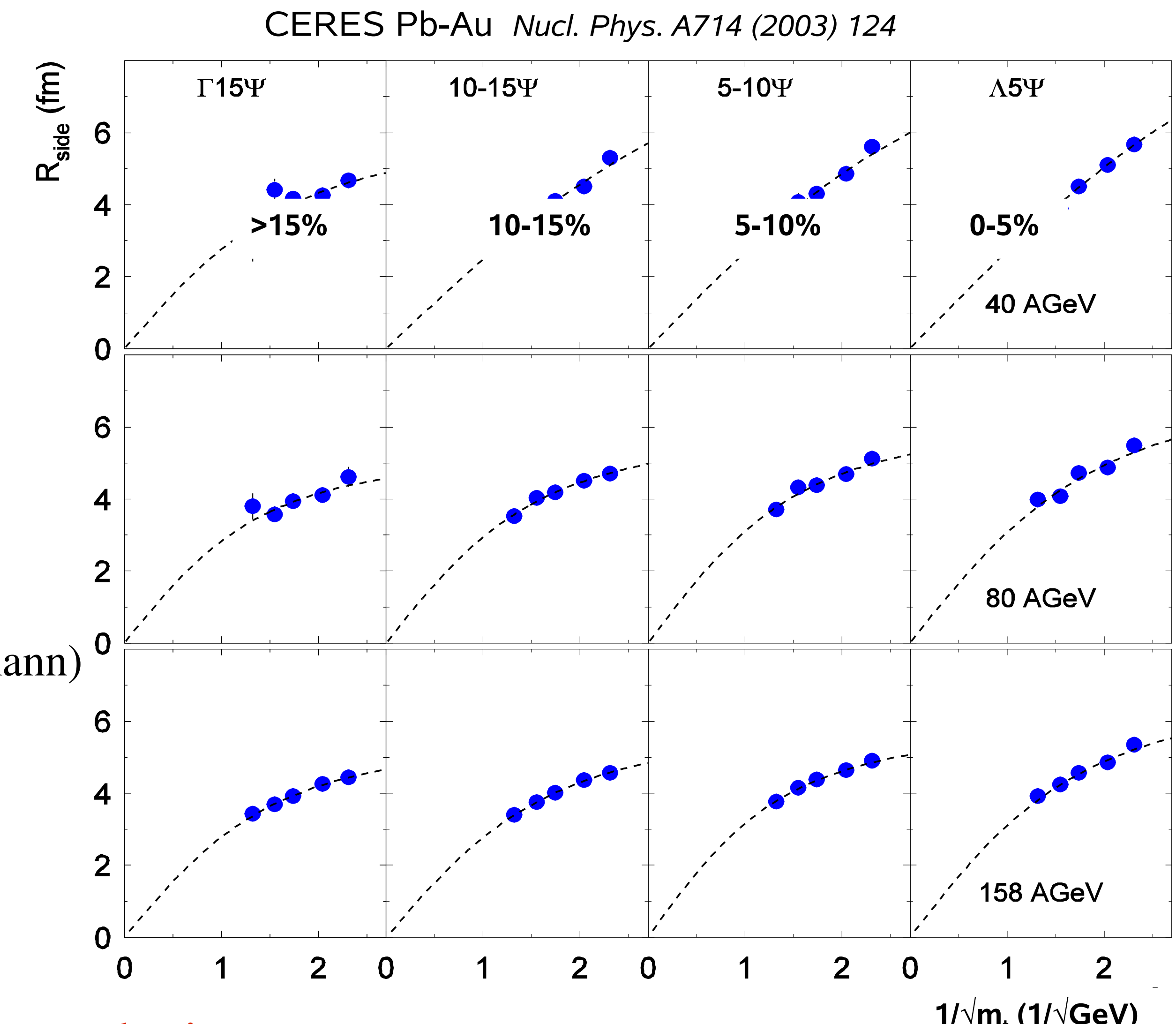
R_{side} – transverse expansion and geometry

in hydrodynamic model:

$$R_{side} = \frac{R_{geo}}{\sqrt{1+\eta_f^2 m_t / T_f}}$$

η_f^2 : rapidity of transverse expansion

(U. Heinz, B. Tomasik, U. Wiedemann)



average transverse expansion velocity

$< v_t > = 0.5\text{-}0.6c$ for $T_f = 160 - 120$ MeV

R_{out} – duration of emission

Generally:

$$R_{out} \approx R_{side}$$

At 158 AGeV:
Short but finite duration of emission

$$\Delta\tau \approx 2 \text{ fm/c}$$

from

$$\Delta\tau^2 \frac{1}{\beta_t^2} \cdot (R_{out}^2 - R_{side}^2)$$

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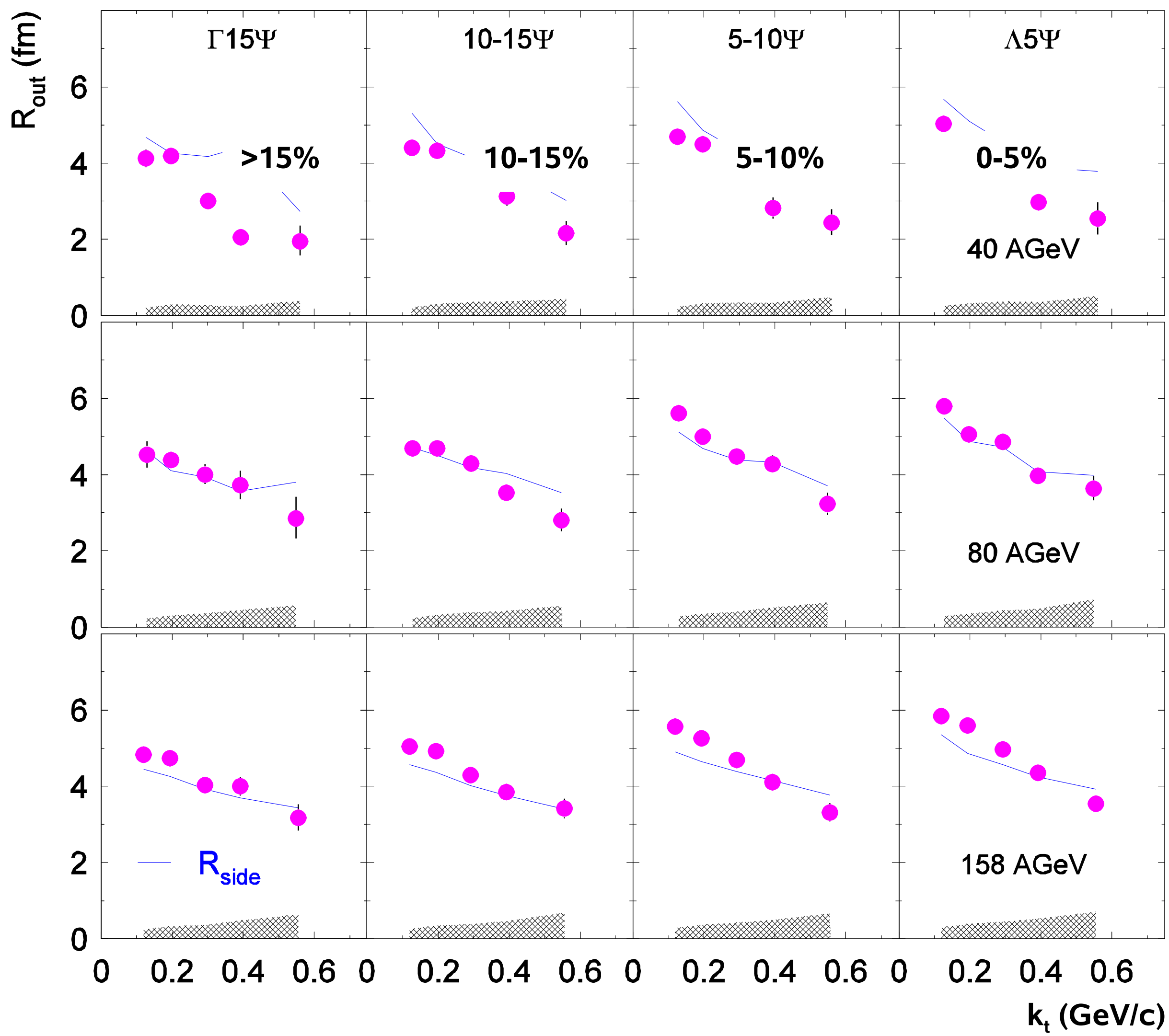

HBT radius parameters: AGS – SPS – RHIC

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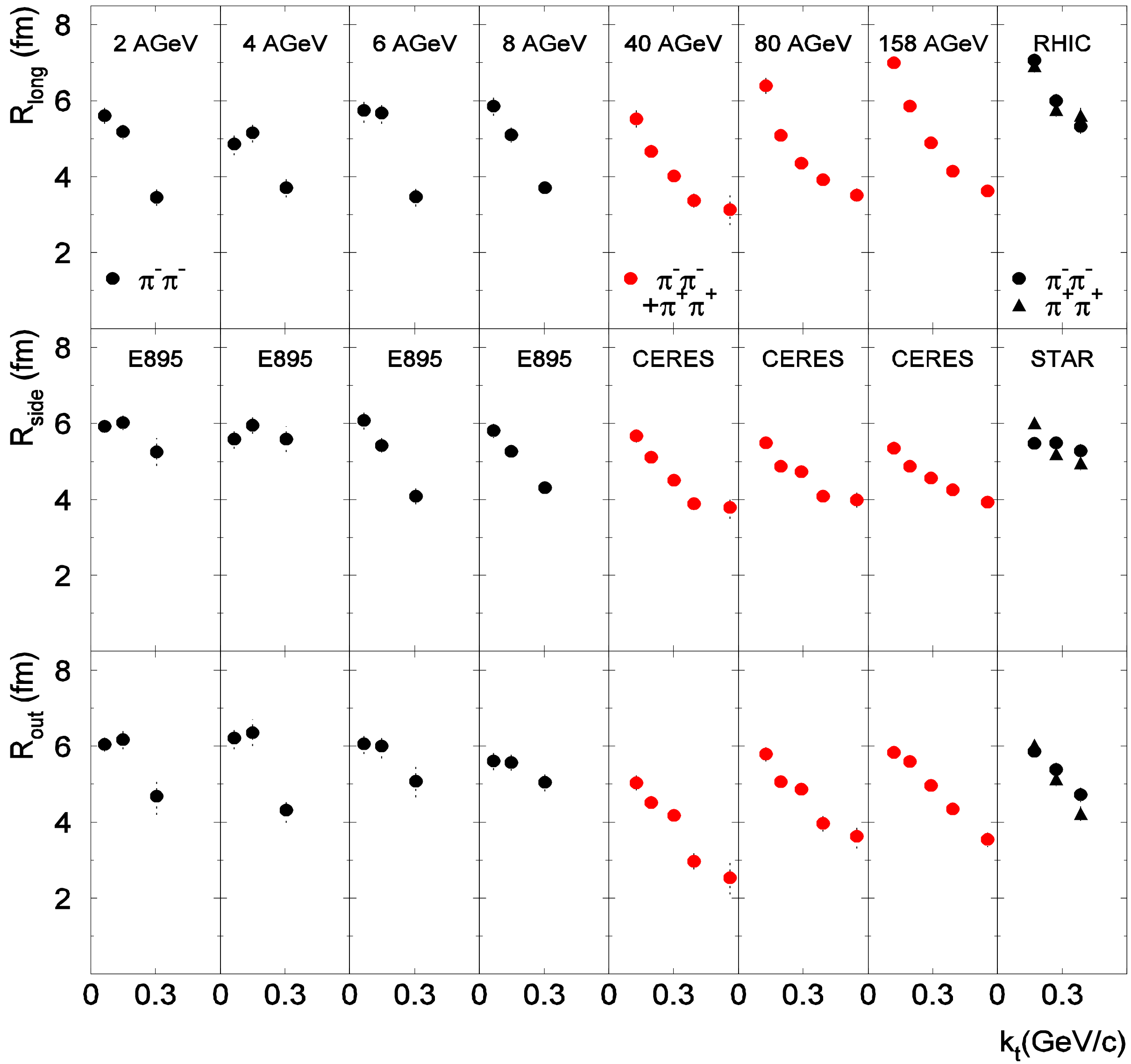
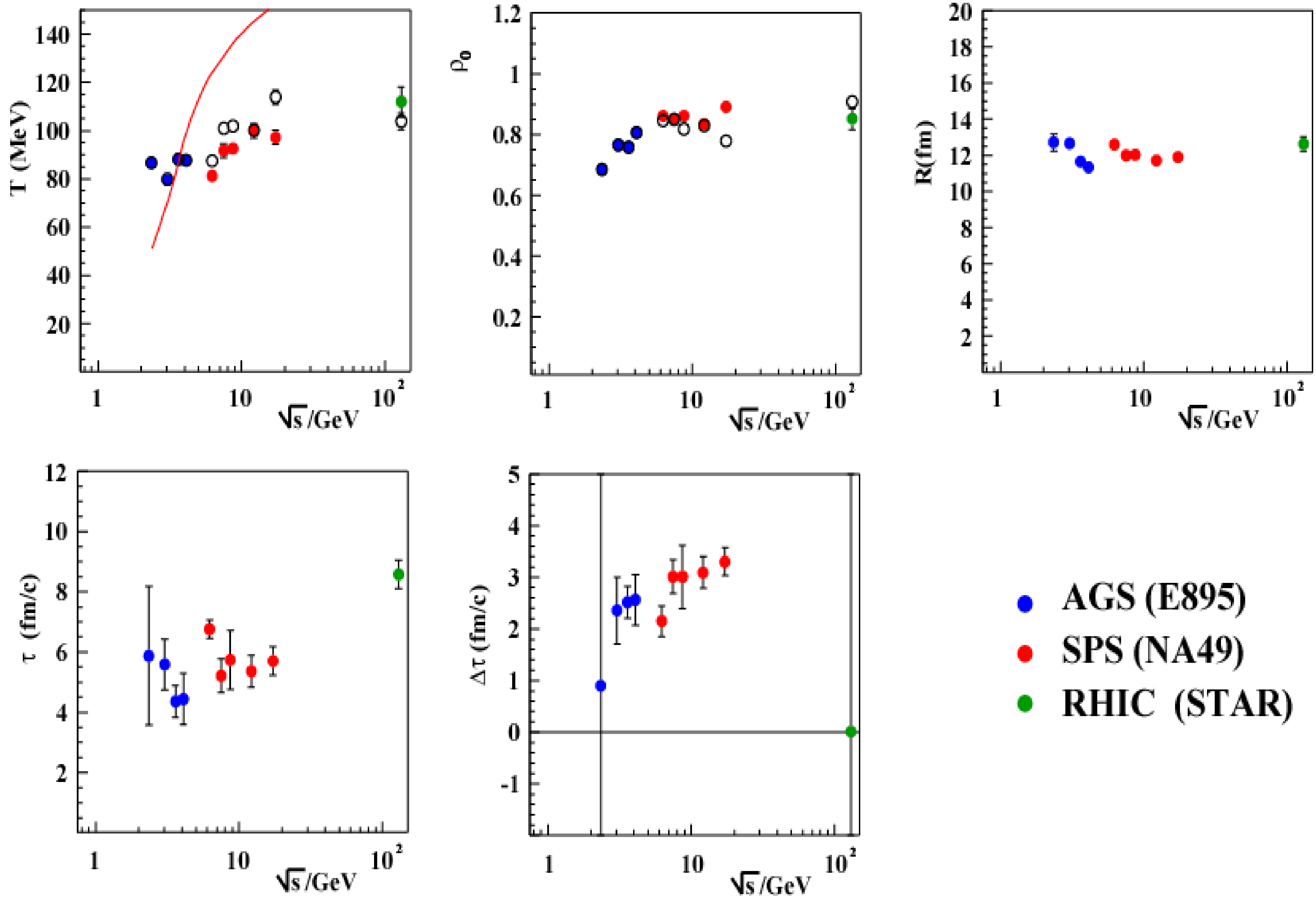


R_{long}:
increase SPS ->>RHIC?

…but by and large a weak E_{beam} dependence

→ is there a universal freeze-out criterion?



Fit of particle spectra and 2 particle correlations using socalled blast wave model - Retiere/Lisa nucl-th/0312024

how can one understand very short duration of pion emission?

one possibility: as system hadronizes simultaneously chemical freeze-out (hadron abundancies are fixed) and thermal freeze-out (spectra and momentum correlations are fixed)
Broniowski, Baran, Florkowski, nucl-th/0212053

assuming T_f = 160 MeV and linear transverse velocity profile with radius and $<\beta_t>$ = 0.47 β_{max} = 0.64