Hanbury-Brown Twiss Results from UrQMD

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in collaboration with
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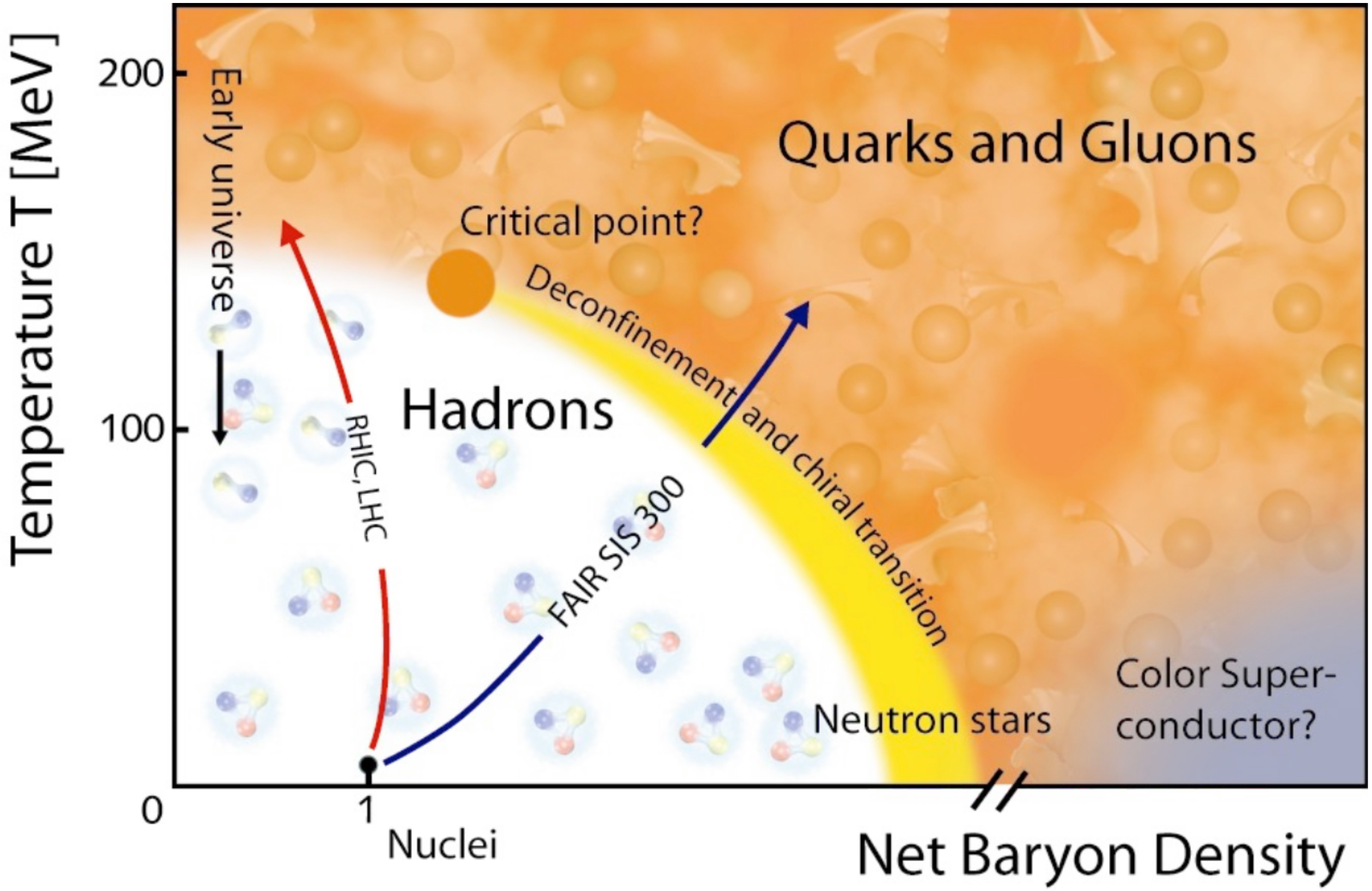
FIAS Frankfurt Institute for Advanced Studies
GOETHE UNIVERSITÄT FRANKFURT AM MAIN
HIC for FAIR Helmholtz International Center
H-QM Helmholtz Research School Quark Matter Studies

Outline

- General introduction to HBT
- Results & Techniques
  - Hadron formation time
  - Particle emission duration
  - Multiplicity scaling
  - Measuring a twisted emission geometry

The strong interaction

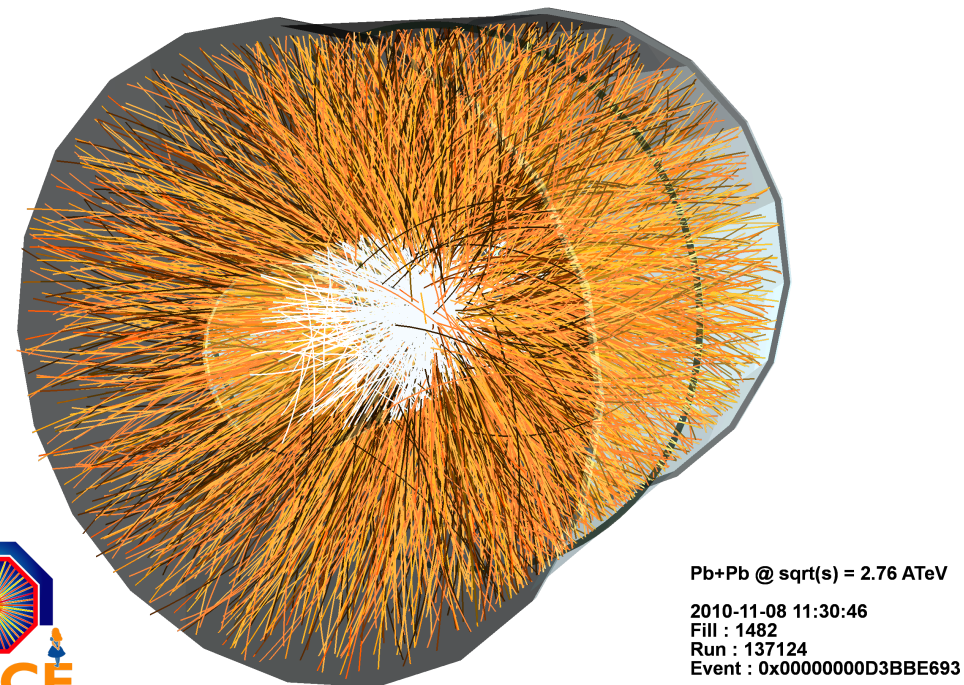


Our probes

Momentum space and multiplicity observables:

- Flow (v_1,v_2, ... , v_n)
- R_{AA}
- Rapidity spectra
- $p_\perp$ spectra
- Particle ratios

  ⋮

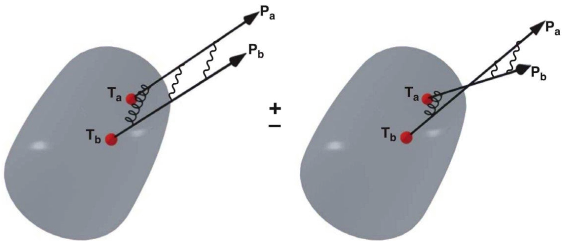


- Shape & Time ↔ HBT interferometry

Hanbury-Brown Twiss technique

HBT connects momentum space to position space

$$C(q) = \frac{\int d^4x_1 d^4x_2 S(p_1,x_1)S(p_2,x_2)|\psi_{12}|^2}{\int d^4x_1 d^4x_2 S(p_1,x_1)S(p_2,x_2)}$$



$$\psi_{12} = \frac{1}{\sqrt{2}}\left[e^{ip_1(x_1'-x_1)}e^{ip_2(x_2'-x_2)} + e^{ip_2(x_2'-x_1)}e^{ip_1(x_1'-x_2)}\right]$$

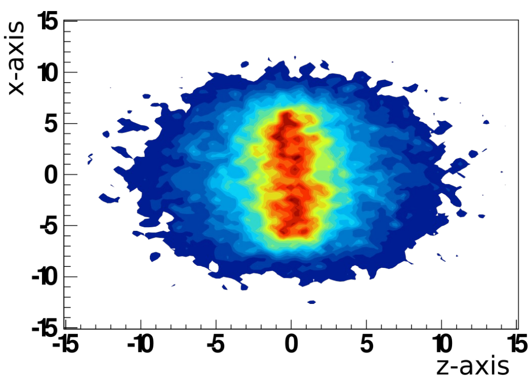
$$C(q) = 1 + \langle\cos(x_\mu q^\mu)\rangle \qquad q^\mu = p_1^\mu - p_2^\mu \qquad x^\mu = x_1^\mu - x_2^\mu$$

Gaussian shape

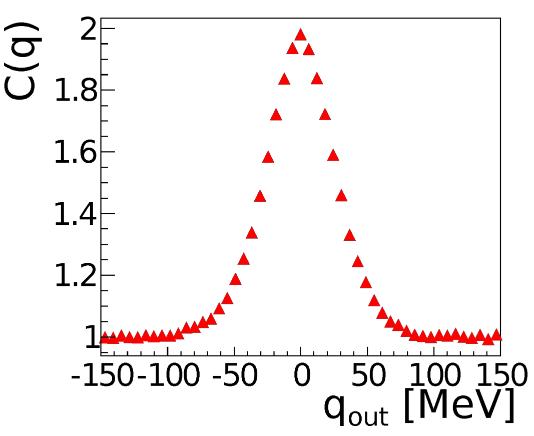
$$S(p,x) = S(p)e^{-\frac{x_\mu x_\nu}{2R_{\mu\nu}^2}}$$

$$C(q) = 1 + \lambda e^{-q_\mu q_\nu R^{\mu\nu 2}}$$

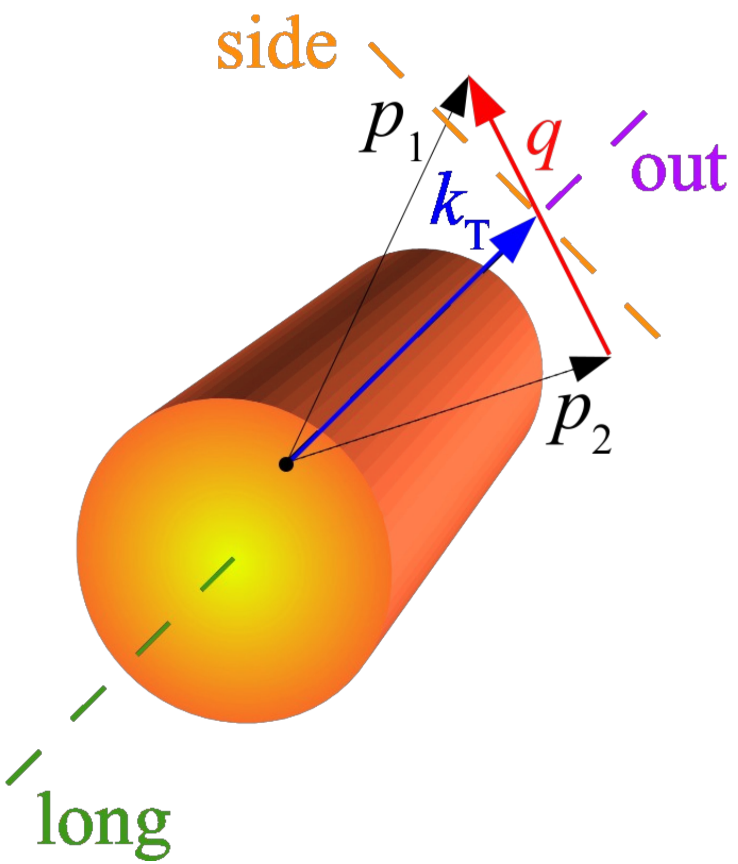
Freeze-out distribution



Correlation function



The Out-Side-Long system



Out: In transverse momentum direction
Long: Along the beam axis
Side: Orthogonal to the other directions

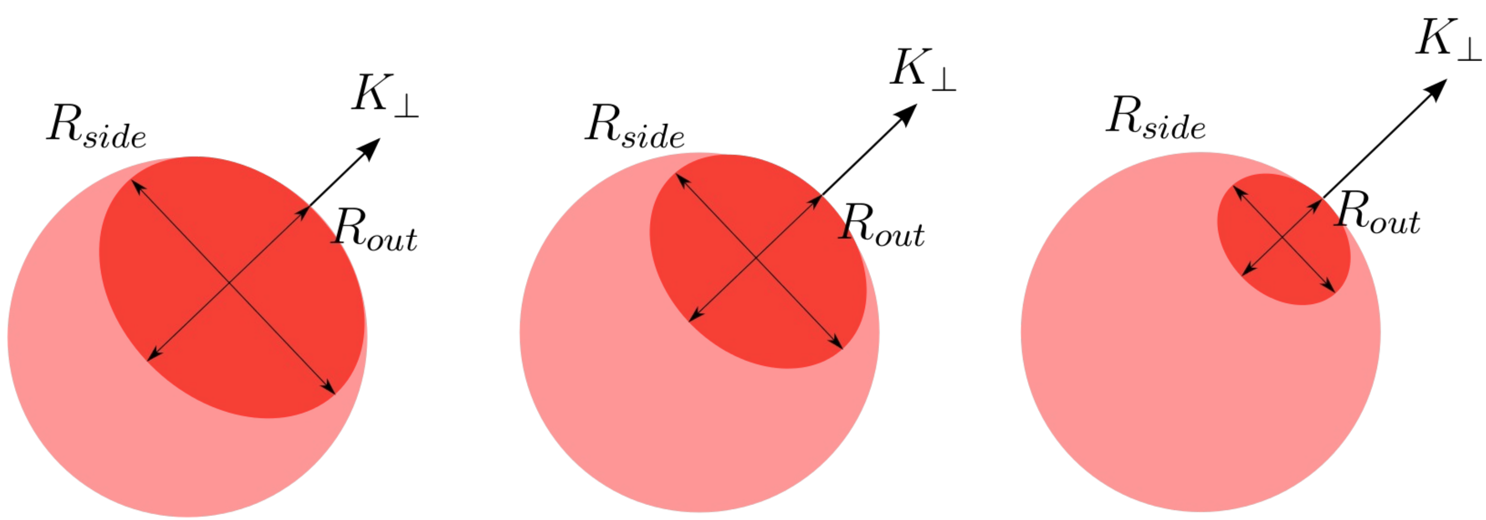
K_T: Transverse pair momentum
q: Pair momentum difference

$$R_o^2 = \left\langle (x_o - \beta_o t)^2 \right\rangle$$
$$= \left\langle x_o^2 \right\rangle - 2 \left\langle \beta_T t x_o \right\rangle + \left\langle \beta_T^2 t^2 \right\rangle$$
$$R_s^2 = \left\langle x_s^2 \right\rangle$$
$$R_l^2 = \left\langle x_l^2 \right\rangle$$

Region of homogeneity

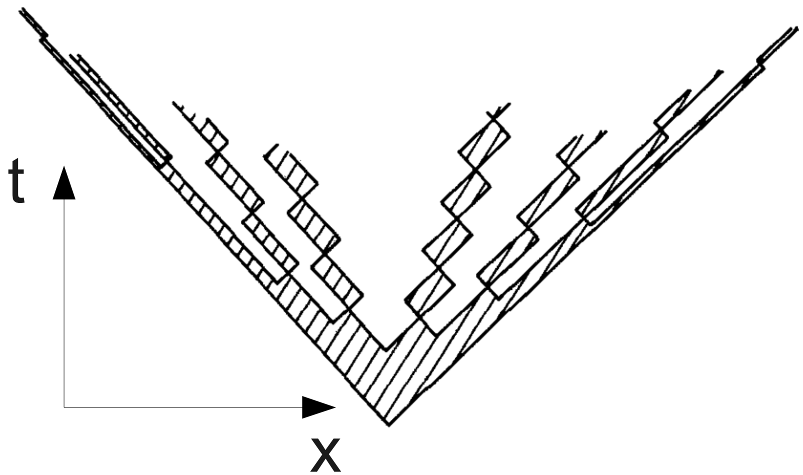
$$C(q) = 1 + \langle \cos(x_\mu q^\mu) \rangle$$

- Oscillations → q and x need to be small for C≠1
- Radial flow
  - Close in momentum → close in space
  - Big pair momentum → small emission region



Hadron formation time

String fragmentation



Formation time

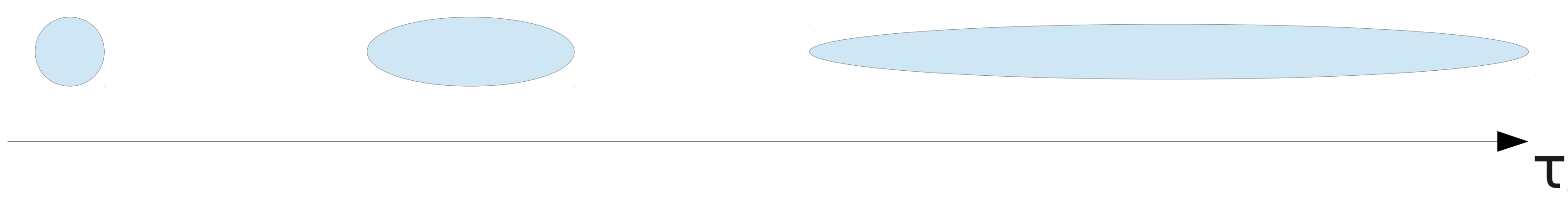
[C.-Y. Wong, Introduction to High-Energy HICs]

Assuming constant τ_f and the formation of two strings

$$\sqrt{s_{\mathrm{pp}}} = 62.3\ \mathrm{GeV}$$

$$\tau_f \approx 0.6\ \mathrm{fm/c}$$

τ_f dependence of the longitudinal source size



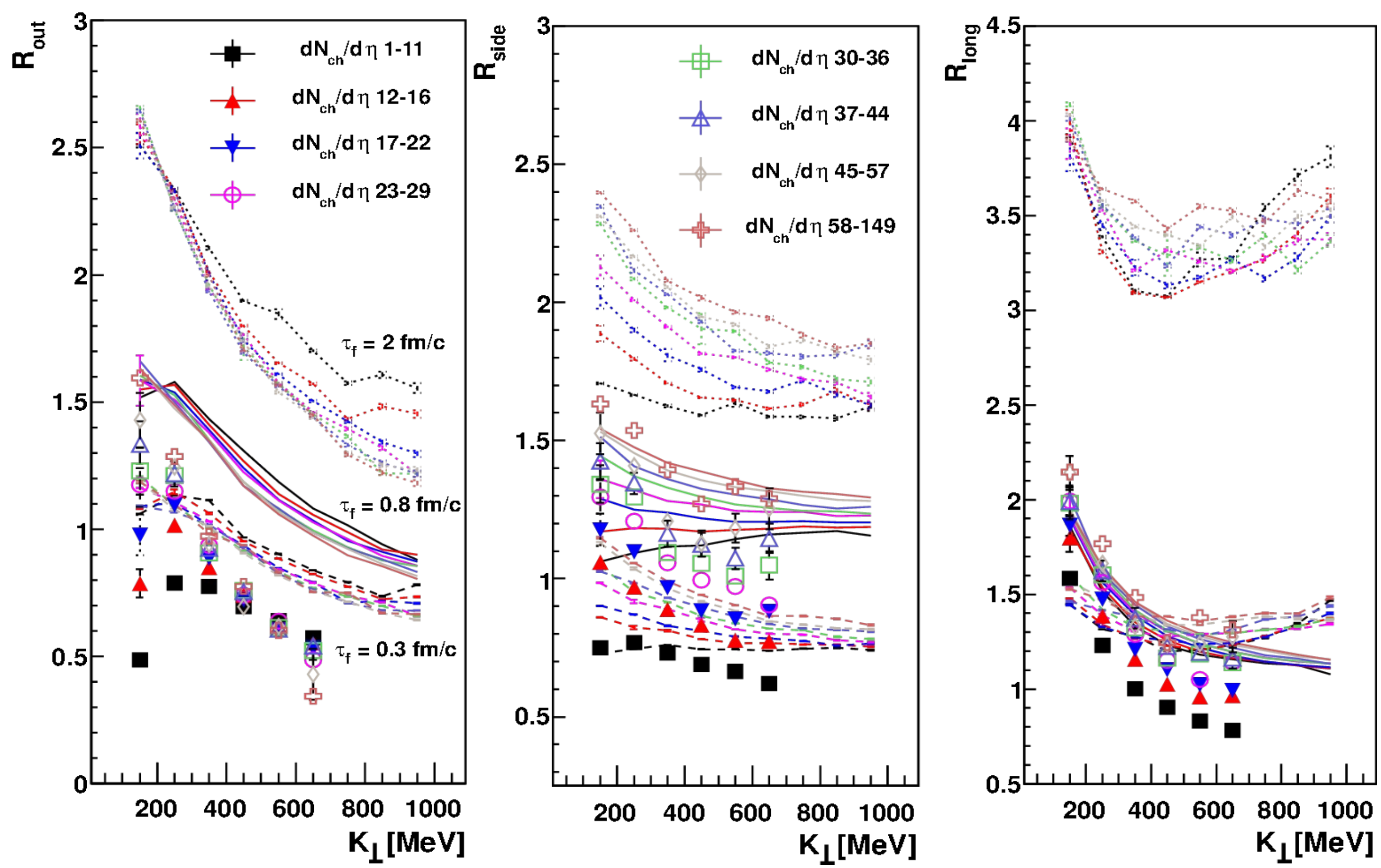
Small source

Big source

τ_f from p+p at LHC

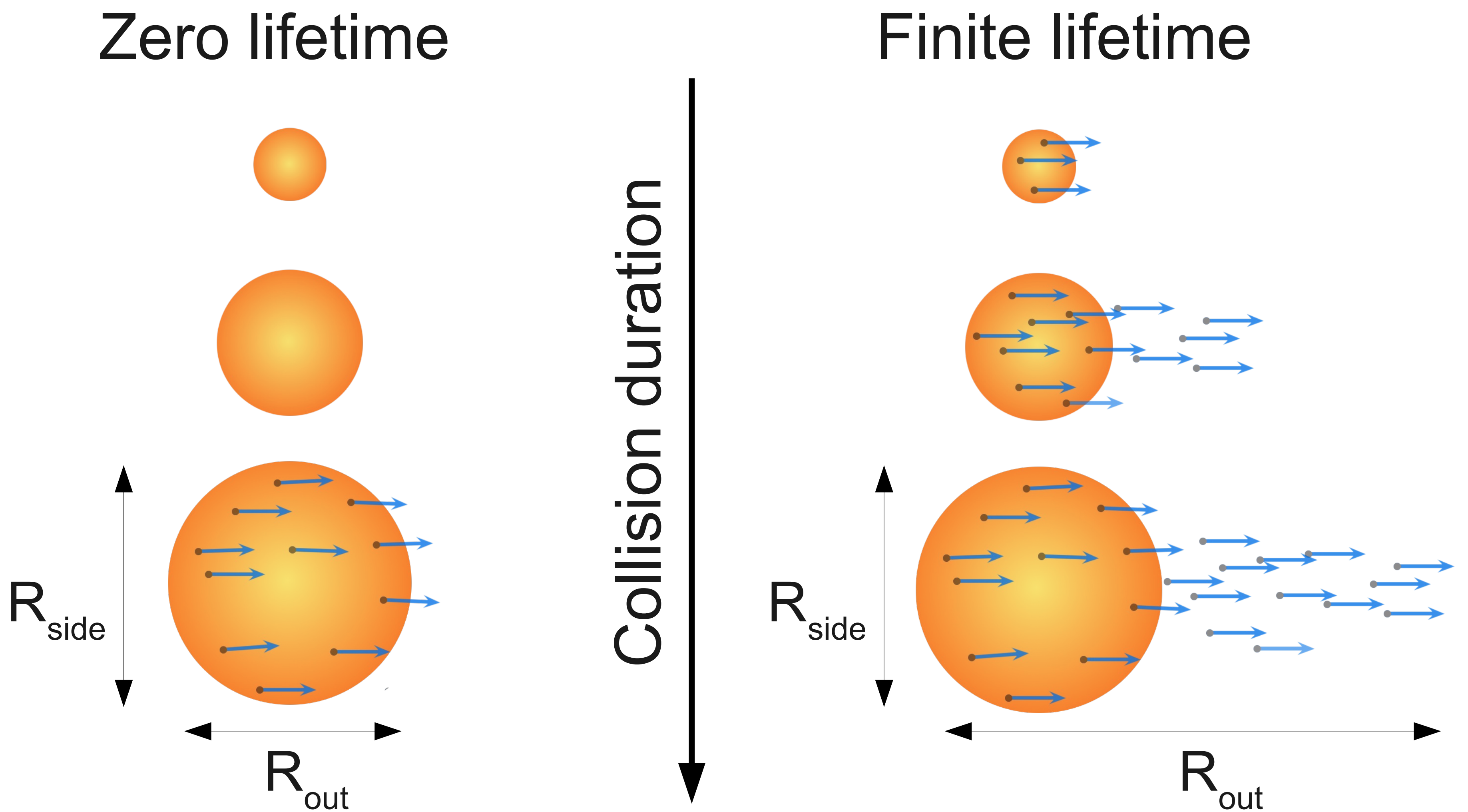
[ALICE, PRD84 (2011) 112004]

[G. G. et al., J.Phys. G39 (2012) 065101]



- Size of the radii scales with τ_f
- Comparison with data yields τ_f<0.8 fm/c

Source lifetime ≠ Collision duration

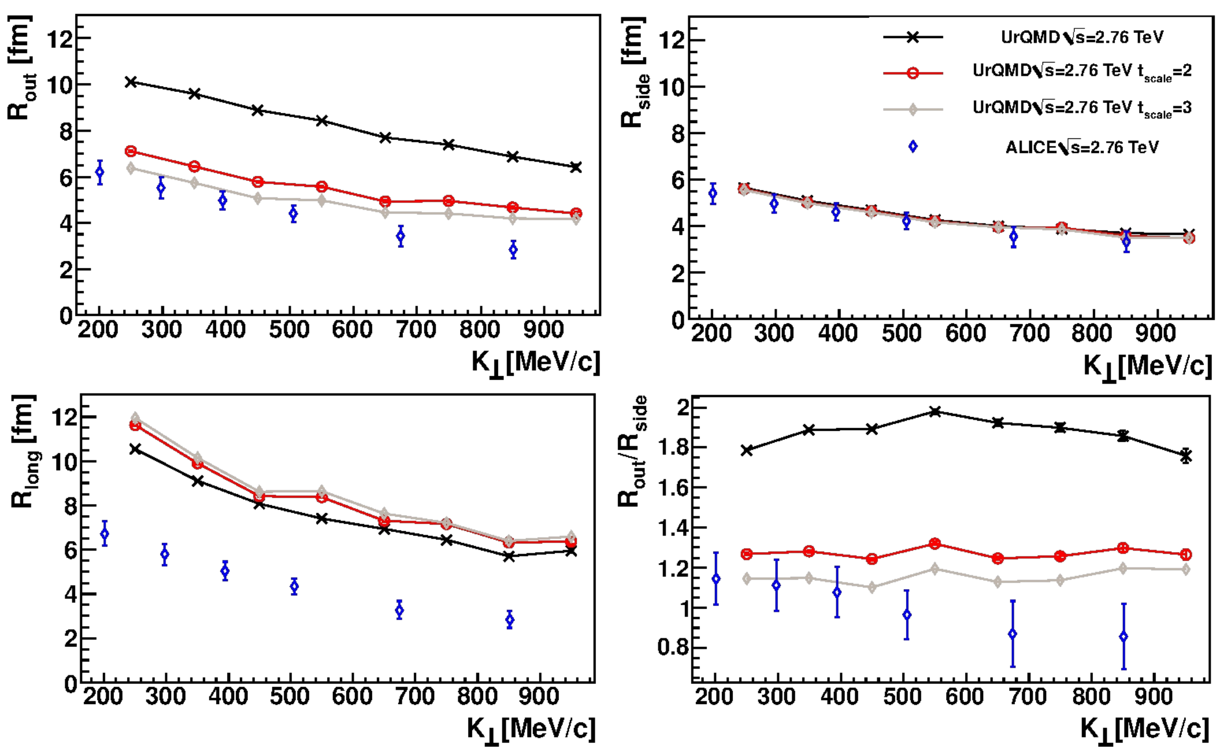


$$R_o^2 = \left\langle (x_o - \beta_o t)^2 \right\rangle = \left\langle x_o^2 \right\rangle - 2\left\langle \beta_T t x_o \right\rangle + \left\langle \beta_T^2 t^2 \right\rangle \qquad R_s^2 = \left\langle x_s^2 \right\rangle \qquad R_l^2 = \left\langle x_l^2 \right\rangle$$

t from Pb + Pb at LHC

[ALICE, PLB696 (2011) 328]

[Q. Li, G. G., M. Bleicher, PRC85 (2012) 034908]



- R_{out} and R_{long} are overestimated by the calculations
- The lifetime is too long by a factor of ≈ 3
- We attribute this to the missing partonic interactions

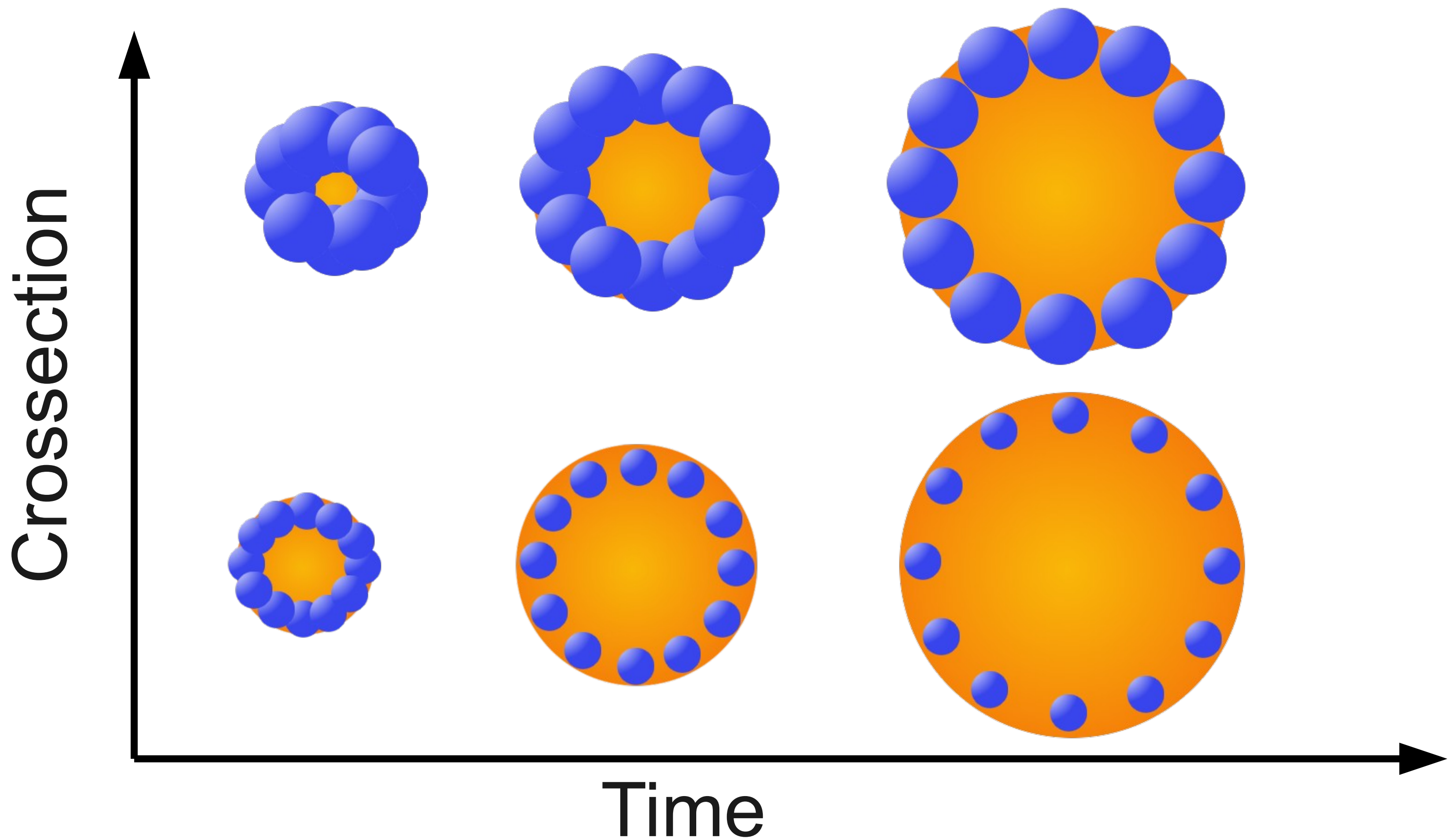
$$t = t_i - \bar{t} \rightarrow t' = (t_i - \bar{t})/t_{scale}$$

$$R_O'^2 = \langle (x - \beta_T t')^2 \rangle = \langle x^2 \rangle - 2\frac{\langle \beta_T t x \rangle}{t_{scale}} + \frac{\langle \beta_T^2 t^2 \rangle}{t_{scale}^2}$$

Decoupling

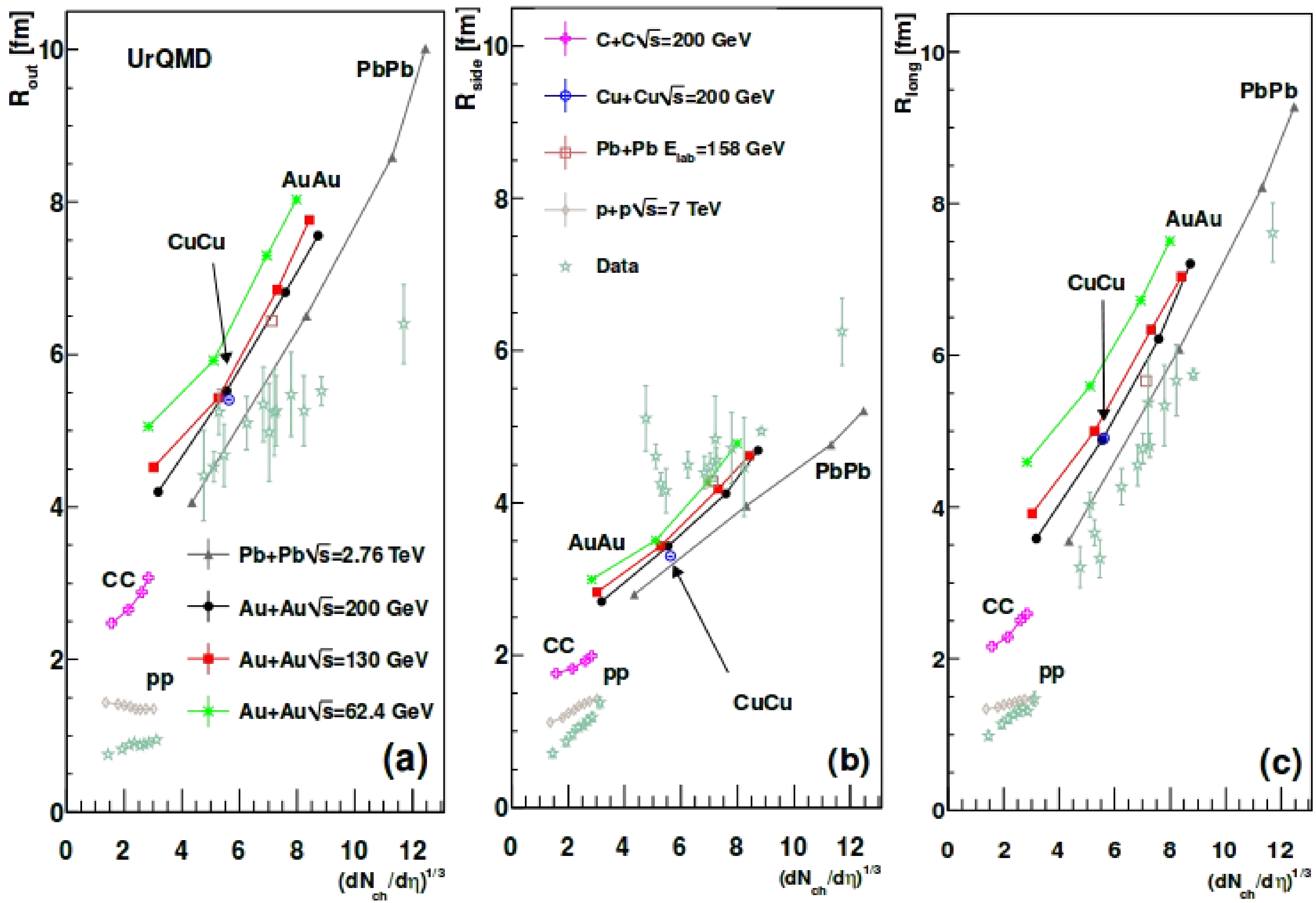
Same decoupling density → HBT radii scale with $\left(\frac{dN_{ch}}{d\eta}\right)^{\frac{1}{3}}$

Different crossection → Different decoupling density



Scaling of the HBT radii

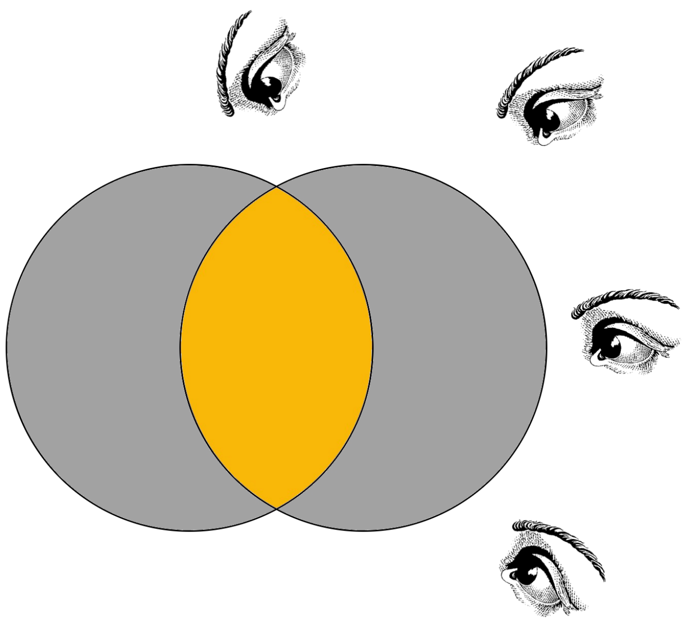
[G. G., M. Bleicher, Q. Li, PRC85 (2012) 044901]

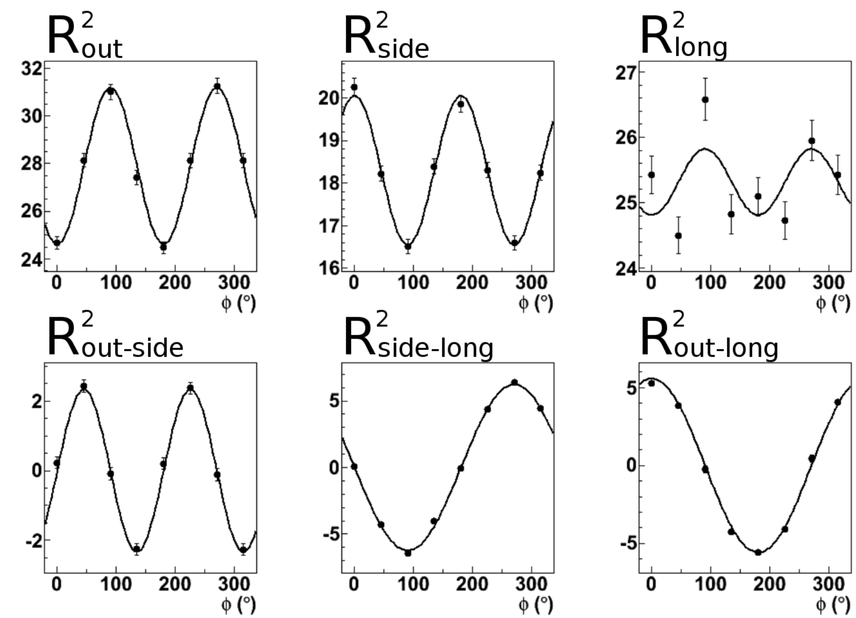


Radii dependent on: Chemical composition and density

Azimuthally sensitive HBT

Source looks different from different directions



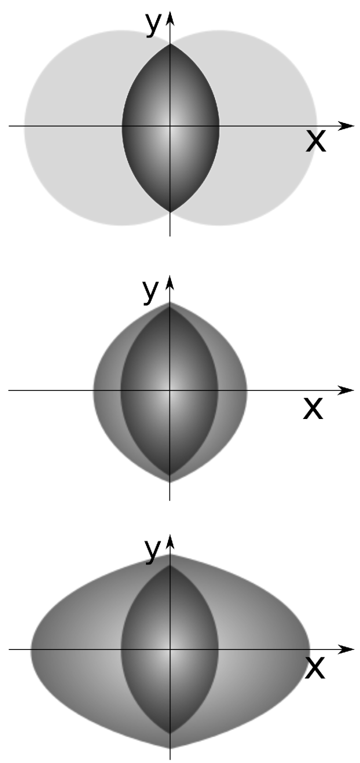


Fourier coefficients of the radii yield information about the source

[E. Mount, G.G., et al., Phys.Rev. C84 (2011) 014908]

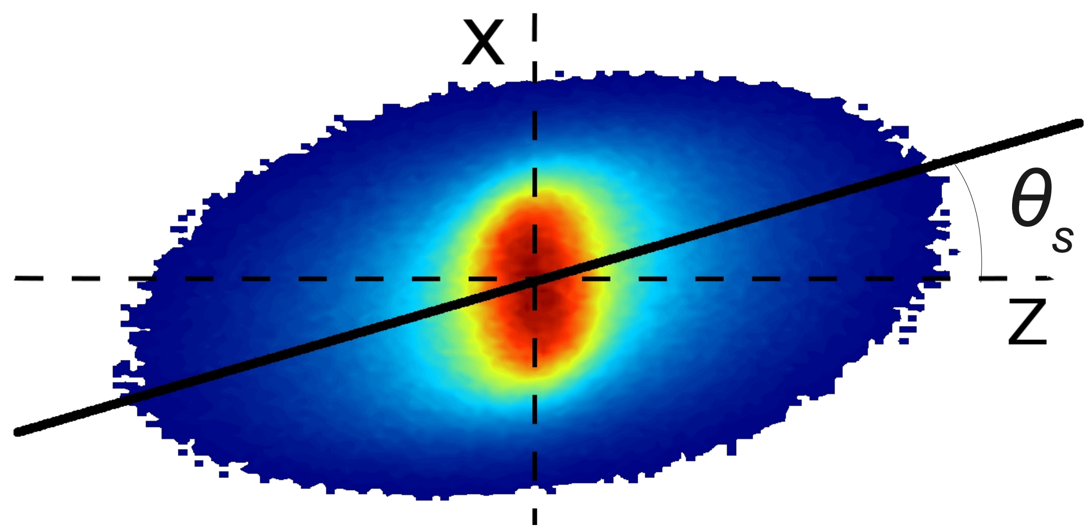
Non-central collisions

Eccentricity



$$\epsilon = 2\frac{R^2_{s,2}}{R^2_{s,0}}$$

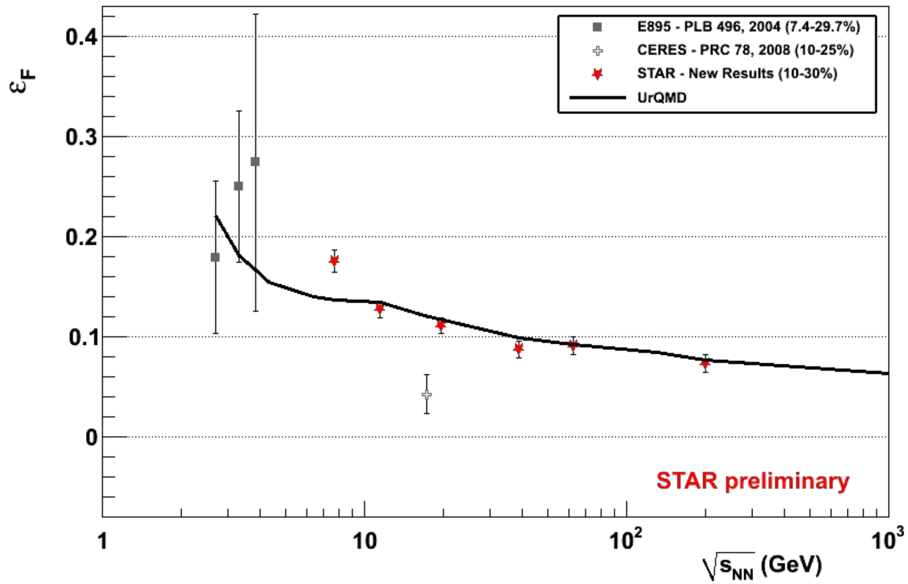
Tilt



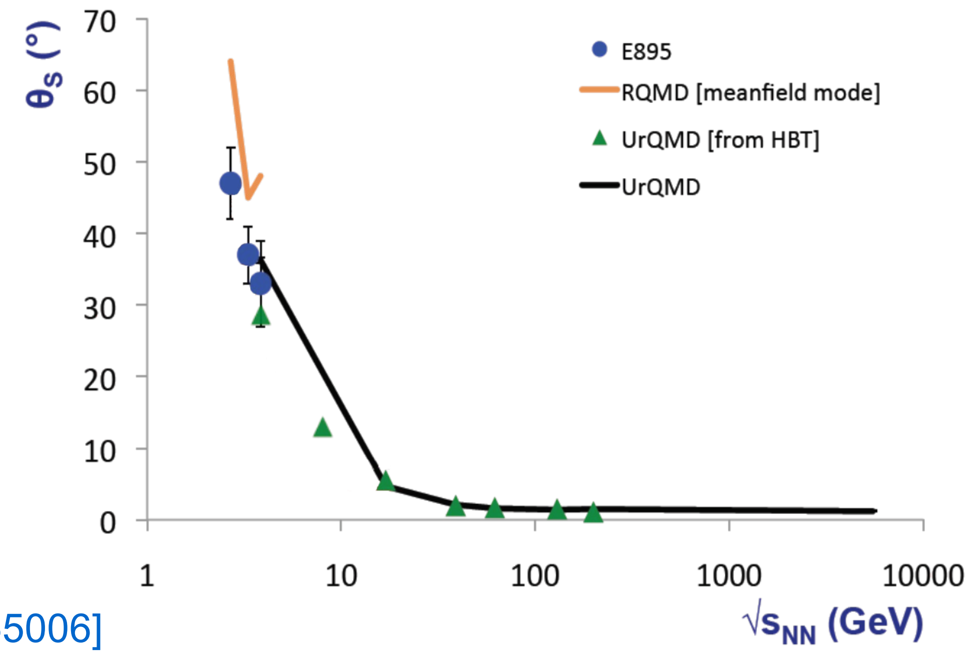
$$\theta_s = \frac{1}{2}\tan^{-1}\left(\frac{-4R^2_{sl,1}}{R^2_{l,0} - R^2_{s,0} + 2R^2_{s,2}}\right)$$

Energy dependence

Eccentricity



Tilt



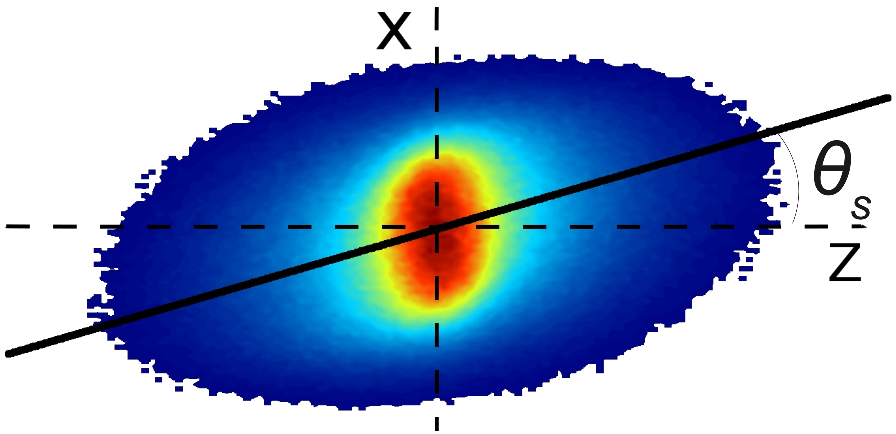
[M. Lisa, G.G., et al., New J.Phys. 13 (2011) 065006]

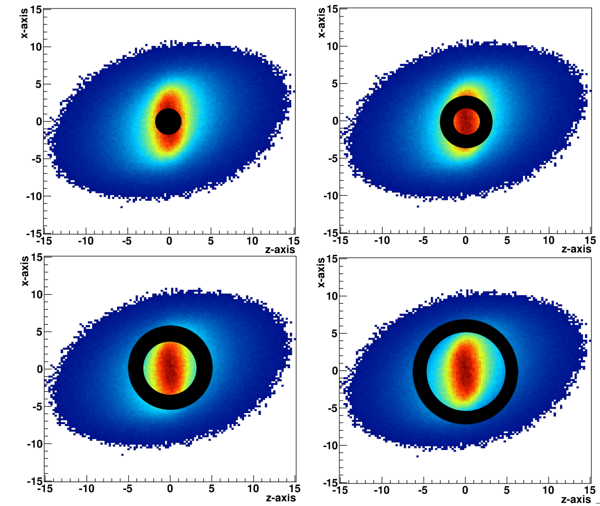
[A. Schmah for STAR, Central Eur.J.Phys. 10 (2012) 1238]

- ε_F and θ_s decrease with increasing energy
- Longer collision duration → rounder source → smaller ε_F
- Higher energy → elongation in beam direction → smaller θ_s

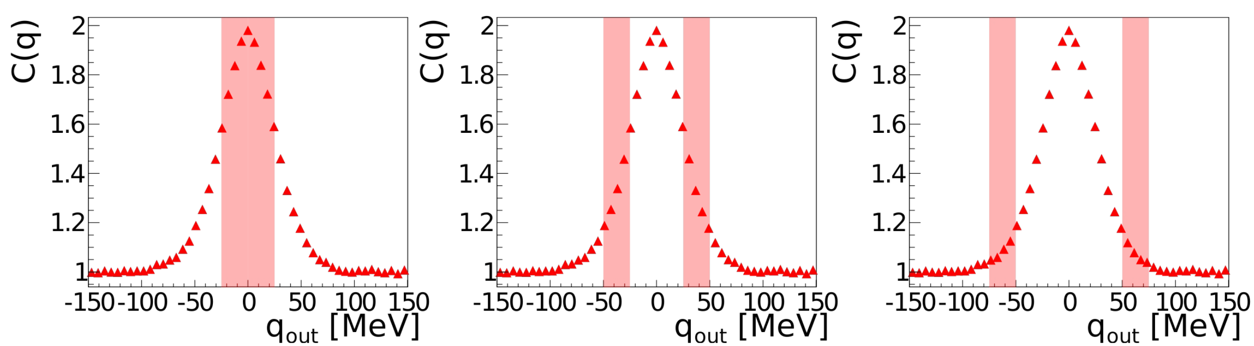
Tilt substructure – Twist

E_{lab} = 8 AGeV, b = 3.4 - 6.8 fm, p_T < 0.4 GeV





$$f(x,y,z) \propto exp\left(-\frac{(x\cos\theta_s - z\sin\theta_s)^2}{2\sigma_{x'}^2} - \frac{y^2}{2\sigma_y^2} - \frac{(x\sin\theta_s + z\cos\theta_s)^2}{2\sigma_{z'}^2} \right)$$

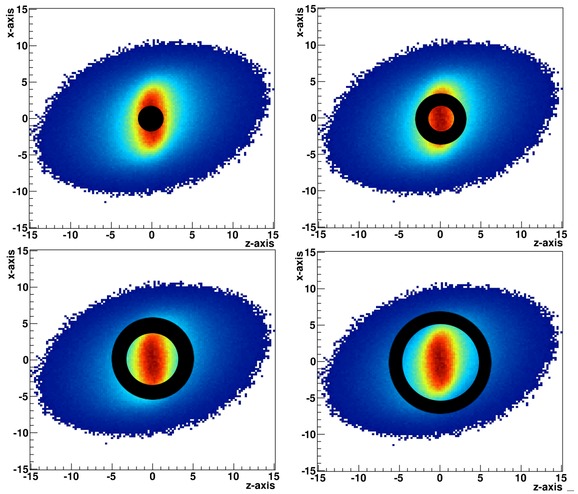


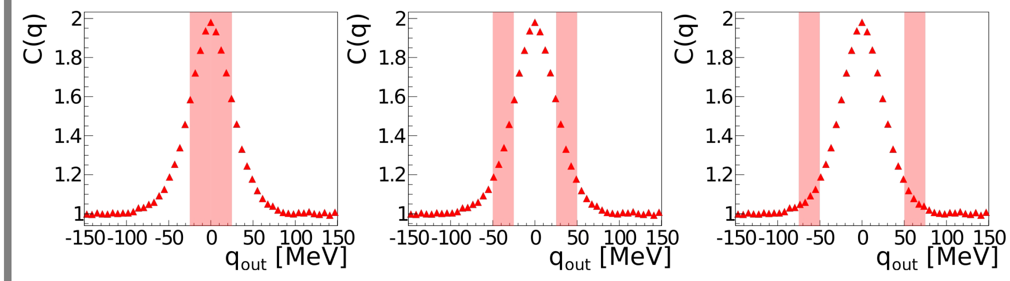
Twist – Two techniques

Freeze-out fit

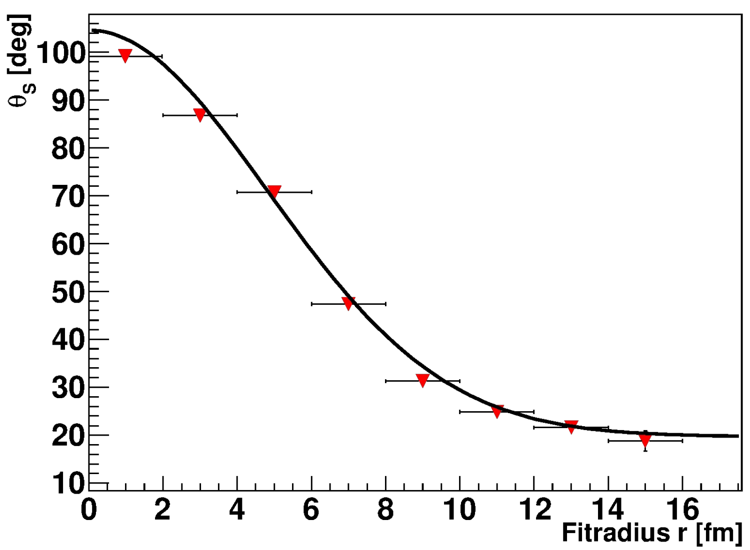
HBT fit

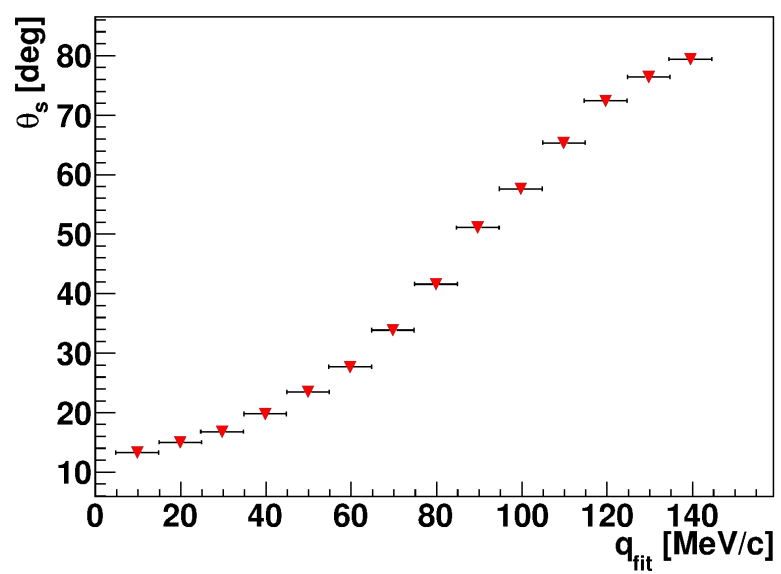
Method





Result

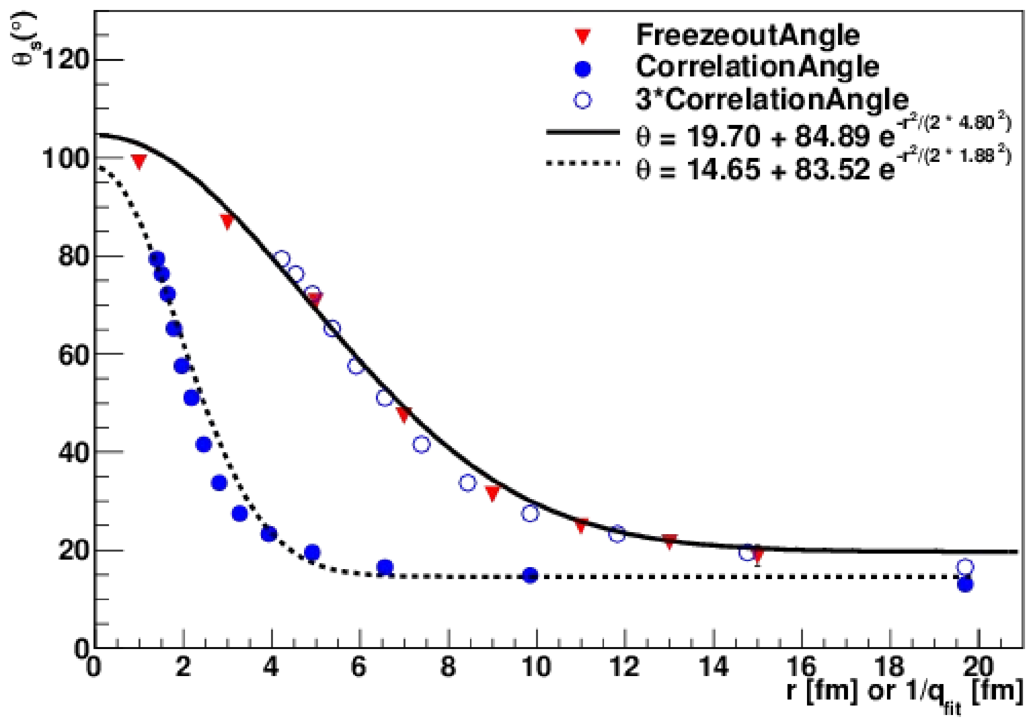




Twist – The results

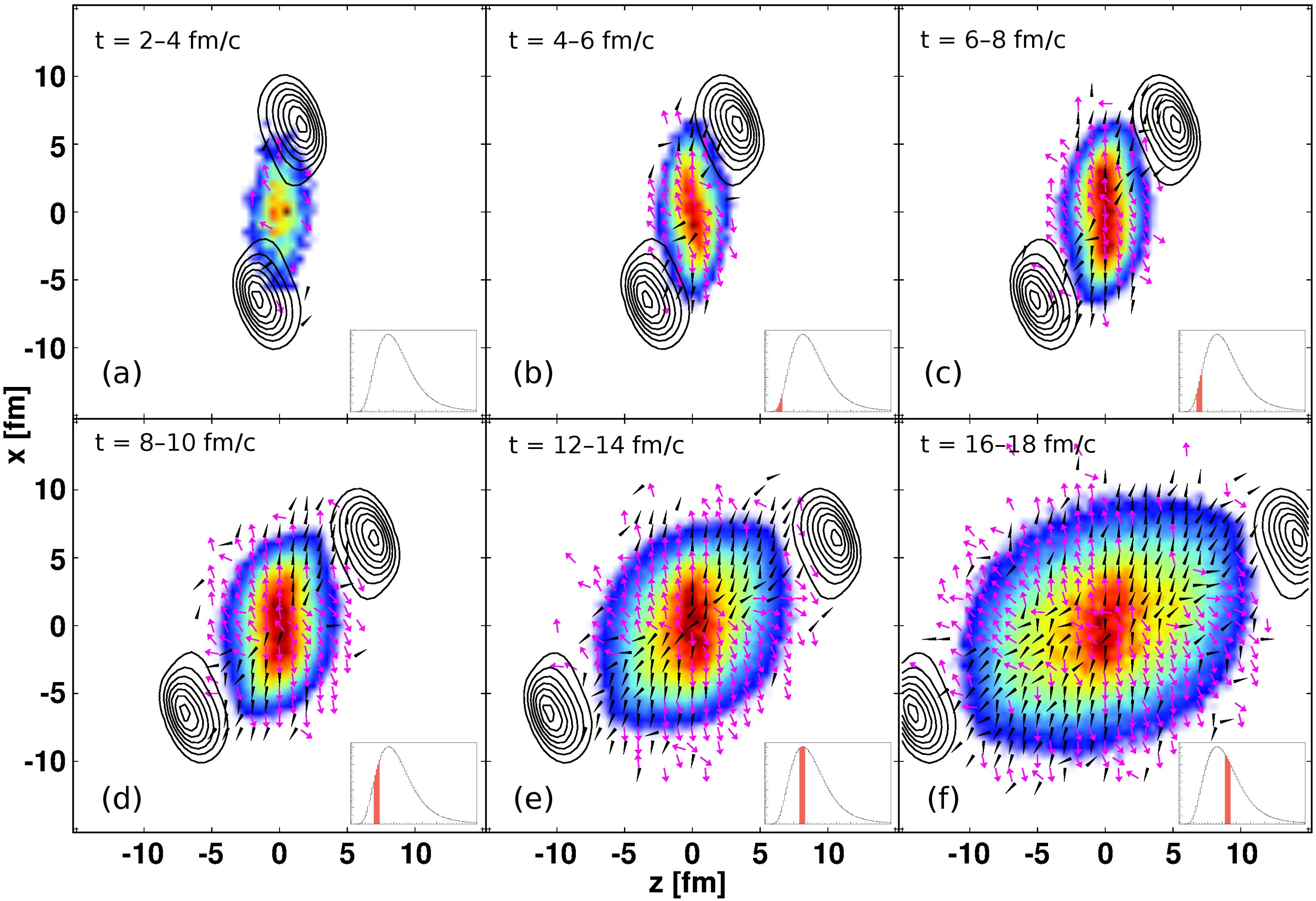
Transformation $r = \frac{1}{q_{fit}}$

- Measurable via asHBT
- Twist caused by Shadowing and Squeeze-out
- Most prominent at FAIR energies



[G. G., M. Lisa, M. Bleicher, arXiv:1302.3408, submitted to PRC]

Shadowing,Flow, Squeeze-out



[G. G., M. Lisa, M. Bleicher, arXiv:1302.3408, submitted to PRC]

Summary

- p+p at LHC suggests τ_f<0.8 fm/c
- Scaling depends on energy as well
- Eccentricity well described, decreases with energy
- Tilt is biggest at FAIR energies
- New observable: Twist

➔ Measure the Twist in experiment at FAIR

➔ Analyse LHC results with partonic phase