# HBT Radii from UrQMD


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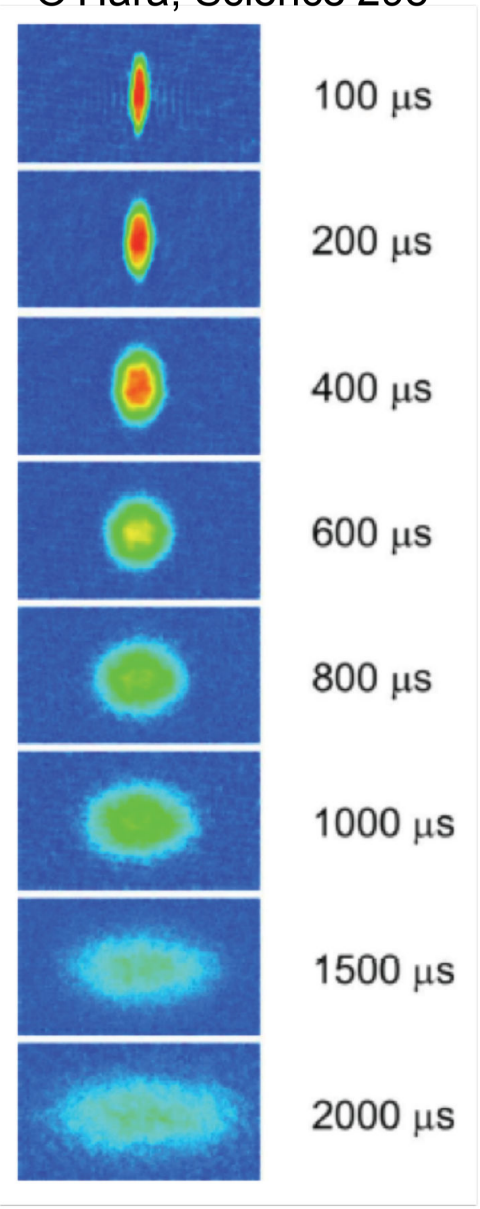
# Outline

- Motivation: geometry vs momentum
- What is HBT?
- Transport model predictions / $k_t$-dep.
- Hybrid model prediction / $k_t$-dep.
- Source eccentricity and tilt
- Summary

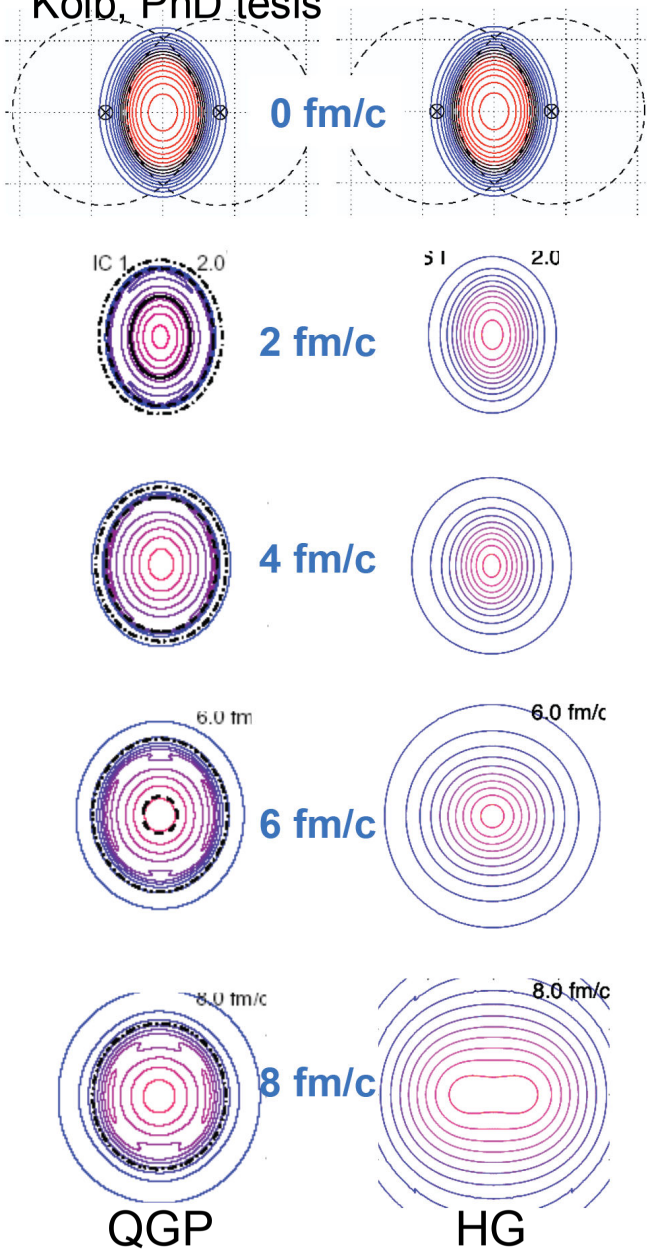
# Expansion patterns

- Usually one measures momenta (or momentum anisotropies) that come spacial anisotropies
- HBT allows to infer the geometry from the final state momentum spectra

Cold Quantum gas,
O'Hara, Science 298

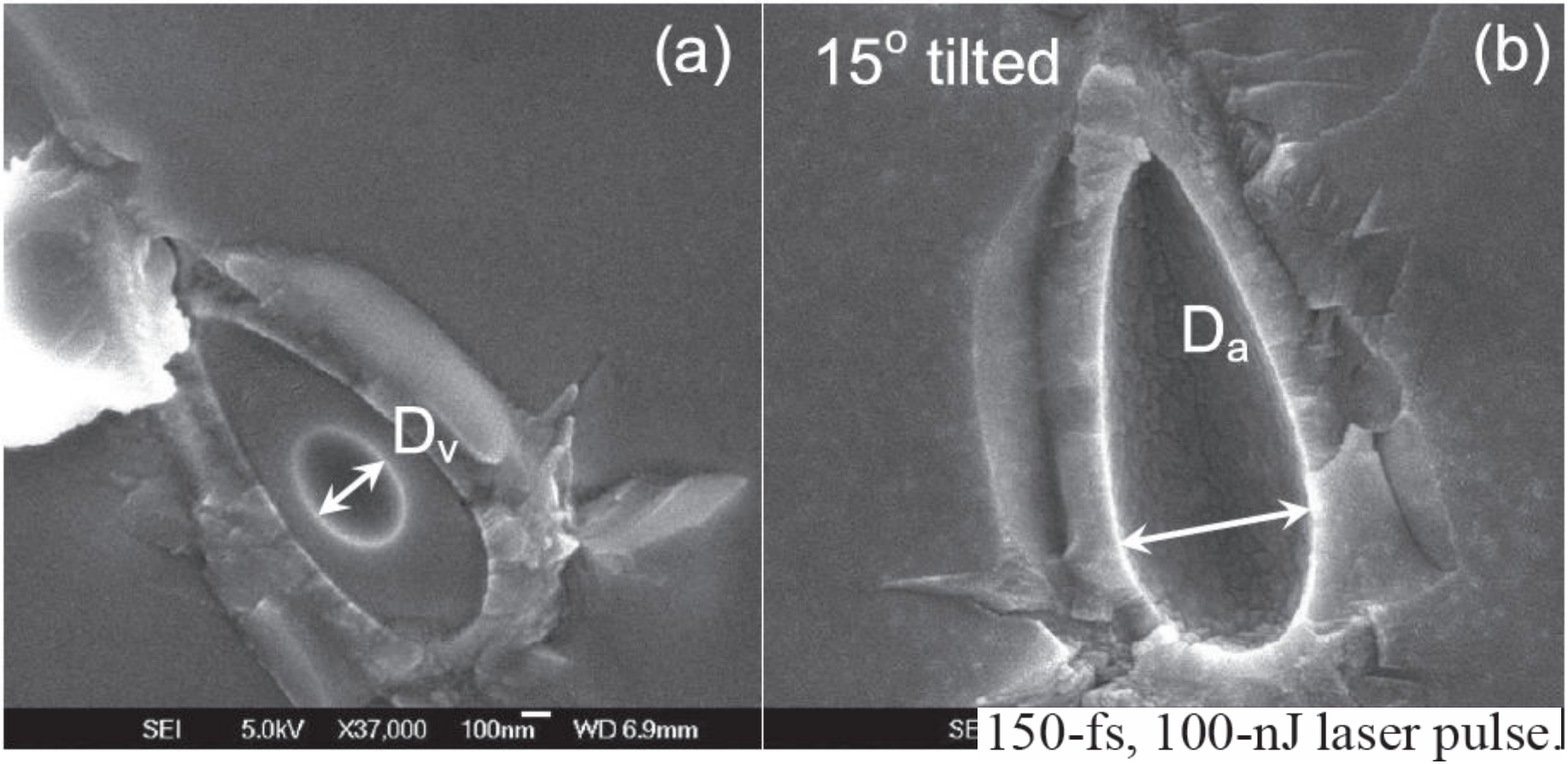



QCD hydrodynamics,
Kolb, PhD tesis



# Micro explosions

Laser induced explosion at National Ignition Facility in Sapphire




→Infer the momentum spectrum from geometry

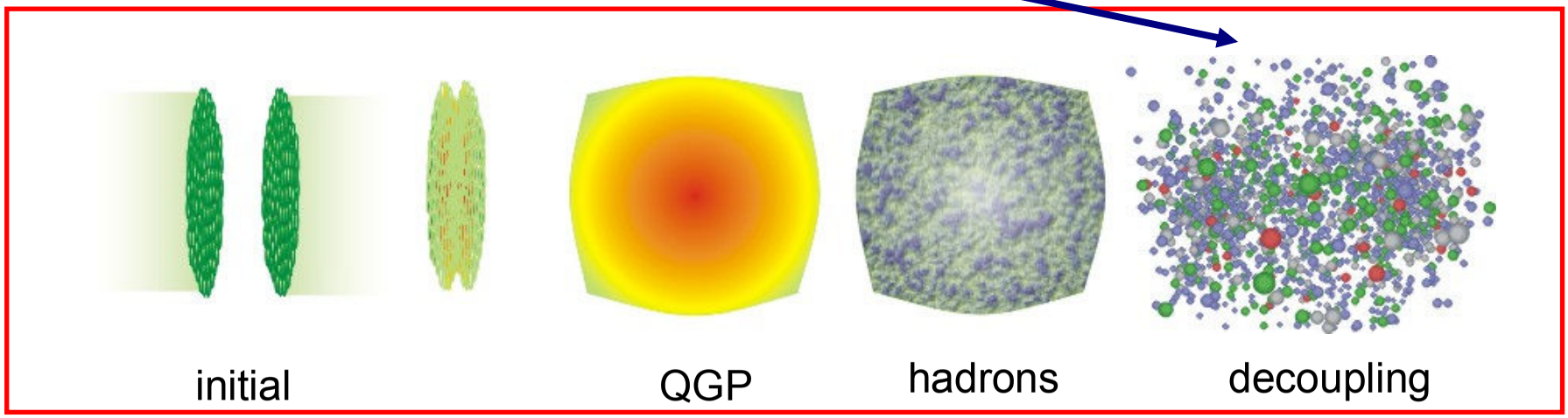
# Motivation for HBT studies

Extremely small
Extremely fast

➡

No direct
observation

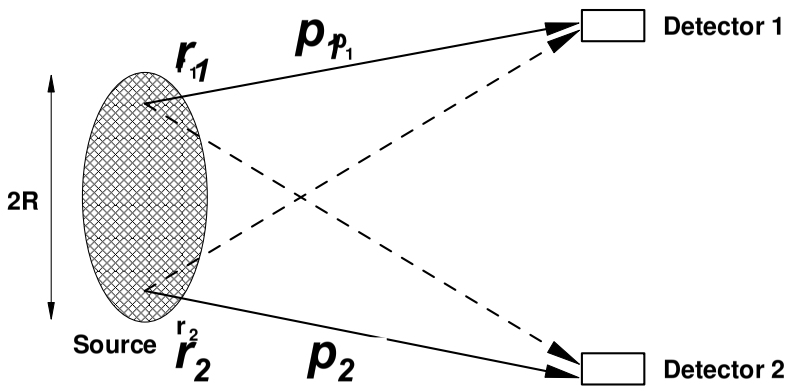
Here: deduce geometry from observed momenta



# HBT: Die Idee

(R. Hanbury-Brown, R.Q. Twiss, 1956)

Bose-Einstein-Statistics leads to short range correlations of Bosons in momentum space

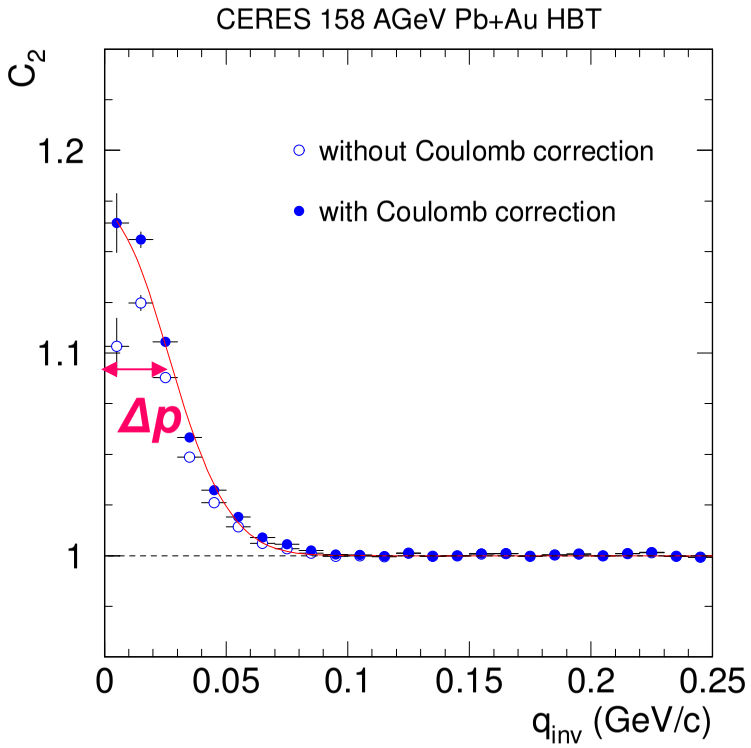



$$C_2(\vec{p}_1,\vec{p}_2) = \frac{P_2(\vec{p}_1,\vec{p}_2)}{P_1(\vec{p}_1)\cdot P_1(\vec{p}_2)} = 1 + \chi(\vec{p}_2 - \vec{p}_1)$$

From $\chi$ one can deduce the features of the source (Imaging, Gauss-Source)

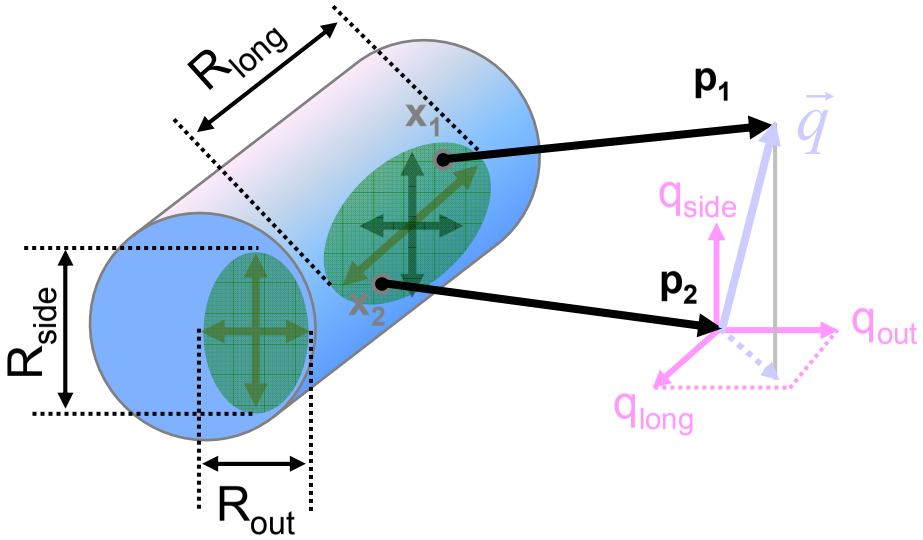
In heavy ion reactions: Pions, Kaons, …

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

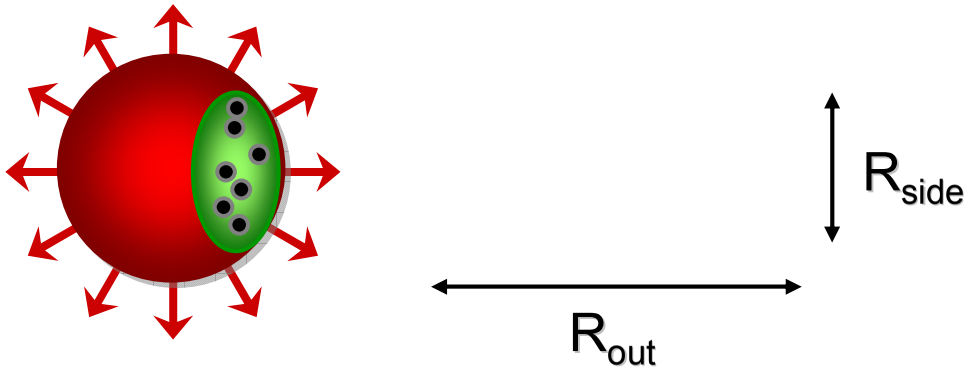


# Meaning of the components

- Two-particel interferometry: Photo and duration of the reaction



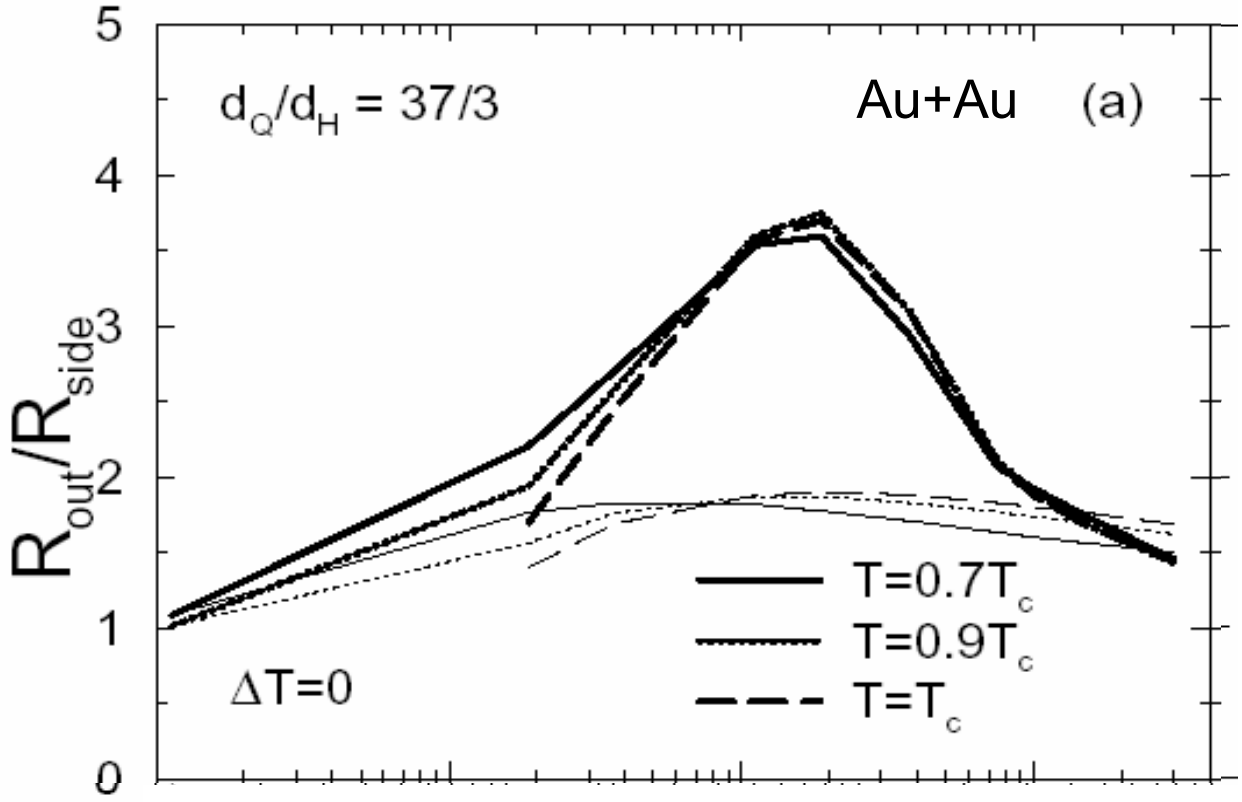

$R_{out}/R_{side}$-ratio is related to the emission duration of the system (no flow, etc)




Pratt-Bertsch ("out-side-long") coordinates are used to extract space and time information of the source

# A predicted feature

Drastic increase of the lifetime due the existence of a mixed phase ($c_s \sim 0 \rightarrow$ long life time)




**~ beam energie**

- 10 fold increase of the lifetime in comparison to a calculation w/o phase transition
- Factor 2 increased $R_{out}/R_{side}$ ratio

**Aus: Rischke, Gyulassy, Nucl.Phys.A608:479-512,1996**

# The UrQMD model

UrQMD=Ultra-relativistic quantum molecular dynamics
[H.Petersen et al. , arXiv:0805.0567v1 (2008)]

Non-equilibrium transport model

All hadrons and resonances up to 2.2 GeV

String excitation and fragmentation

Cross sections are fitted to available data, parametrized via AQM or calculated by detailed balance

Generates full space-time dynamics of hadrons and strings

Hybrid option to explore various Equations of State

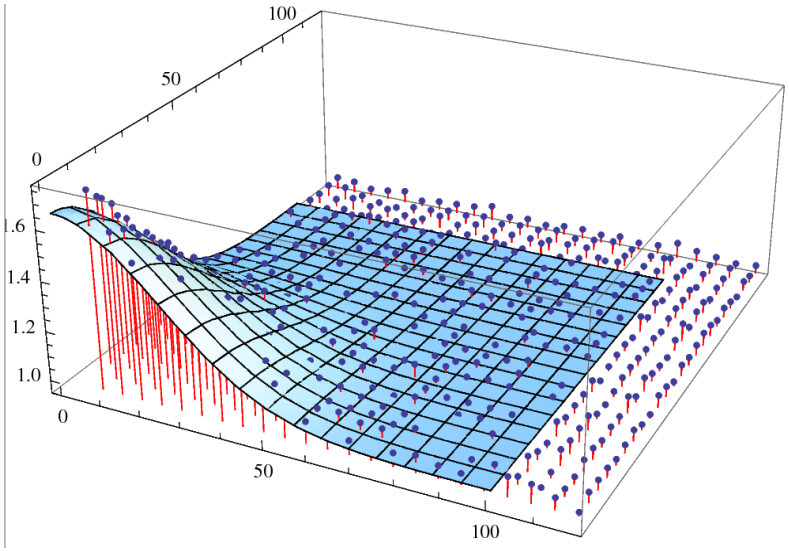
# Correlations functions

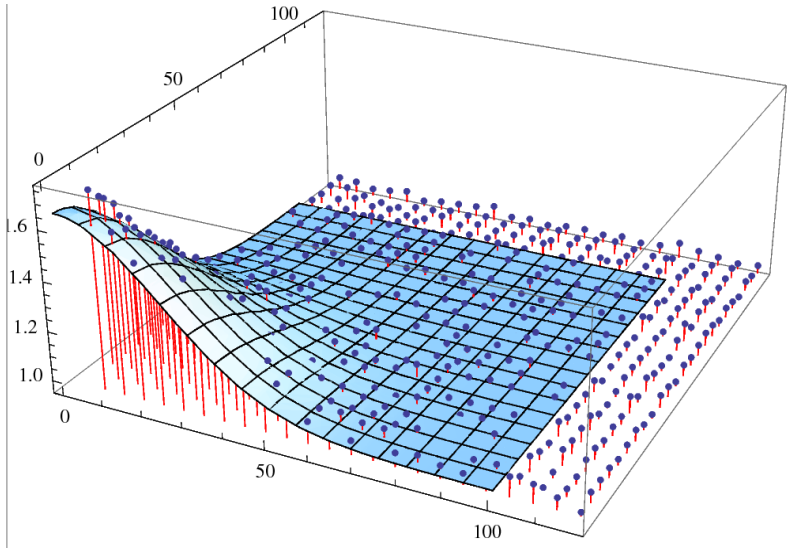
Generate freezeout phasespace-distribution

Apply Correlation Afterburner (CRAB) [Scott Pratt]

CRAB calculates quantum weigths => correlation functions

Correlation functions → HBT radii



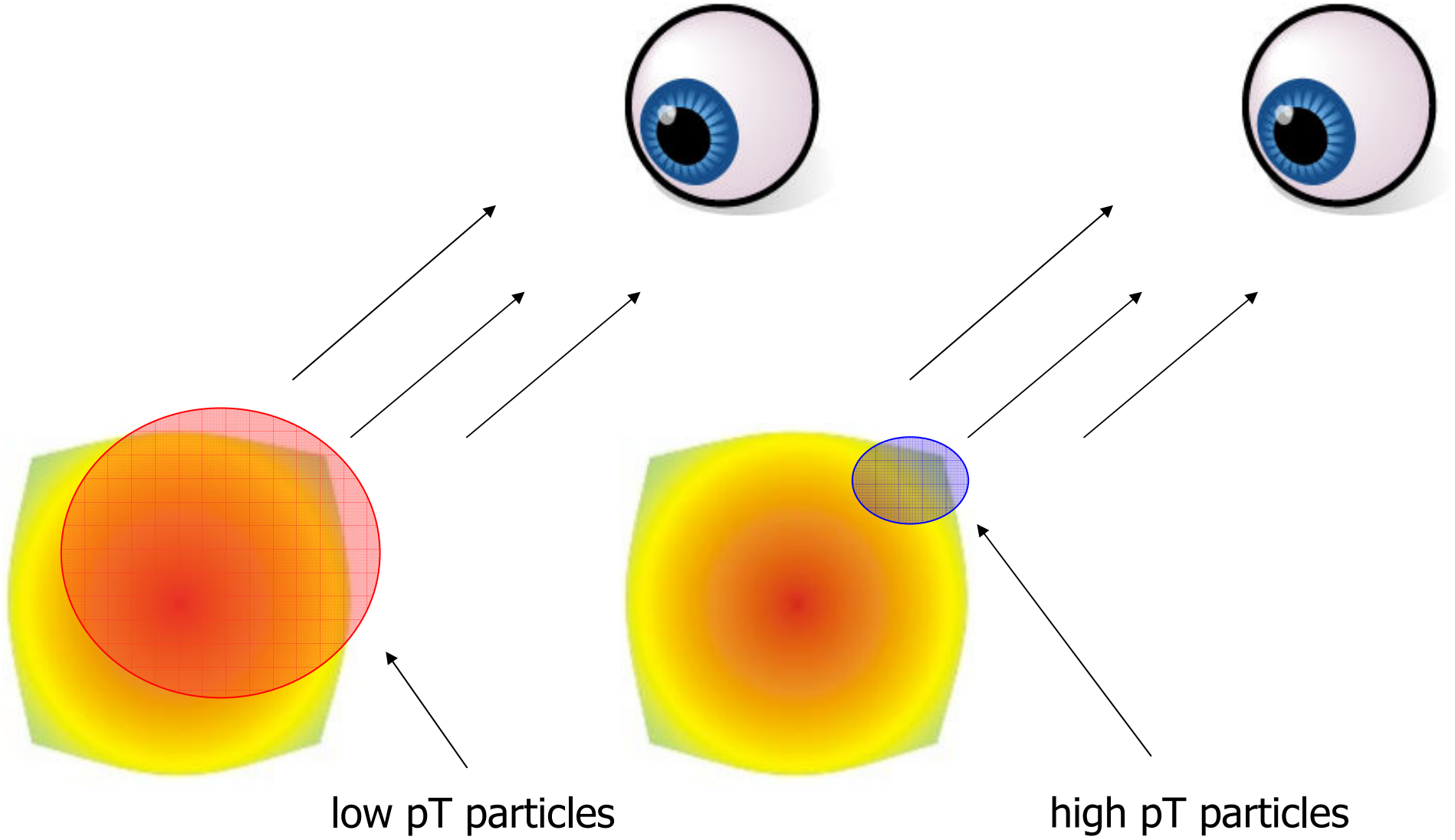




$$C(q,K)=1+\lambda\exp(-R_o^2 q_o^2-R_s^2 q_s^2-R_l^2 q_l^2-R_{os}^2 q_o q_s-R_{ol}^2 q_o q_l-R_{sl}^2 q_s q_l)$$

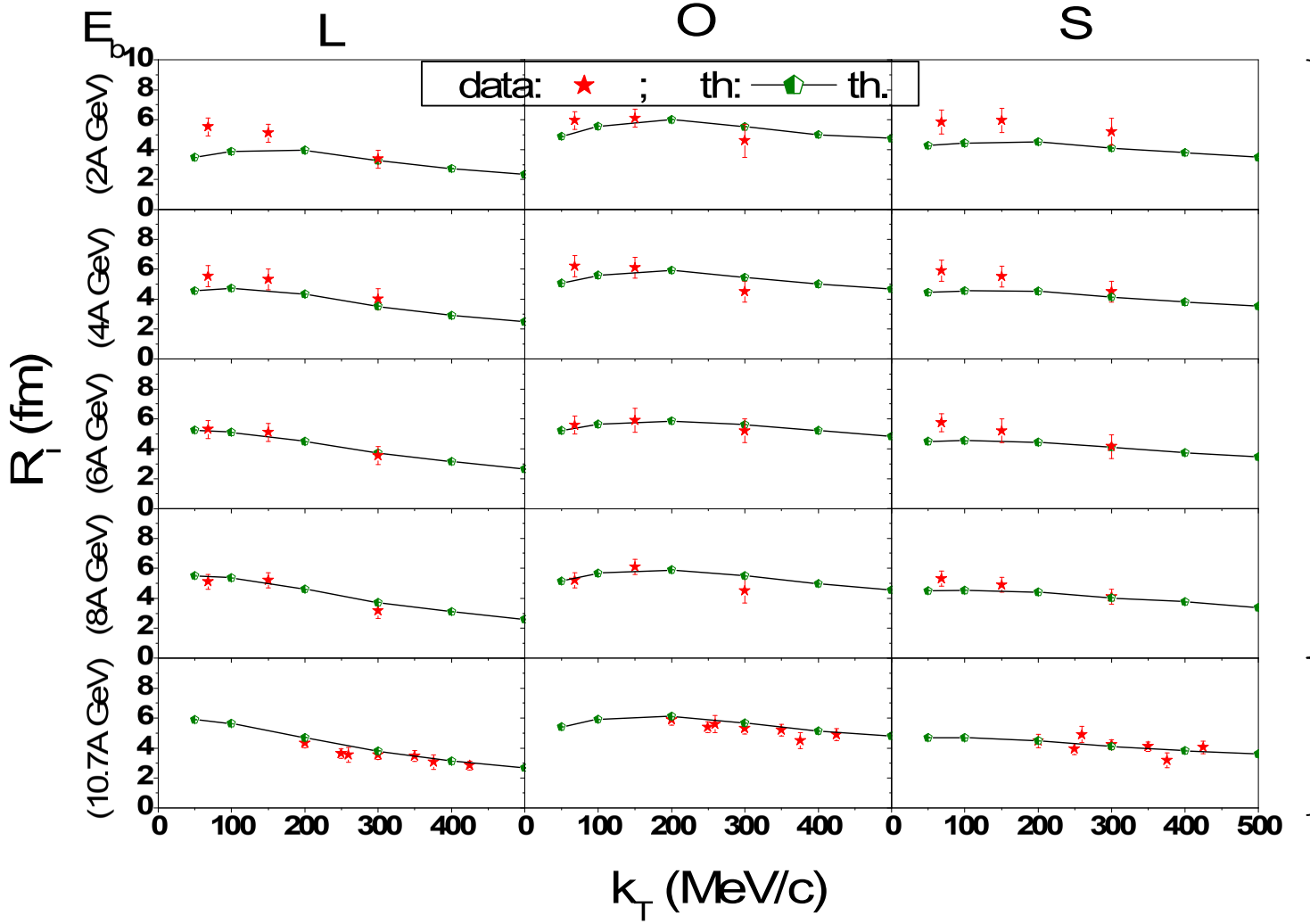
# UrQMD results for FAIR/SPS energies

- kt- dependence

# Region of homogeneity: Expectation



# UrQMD vs. data @ AGS/FAIR



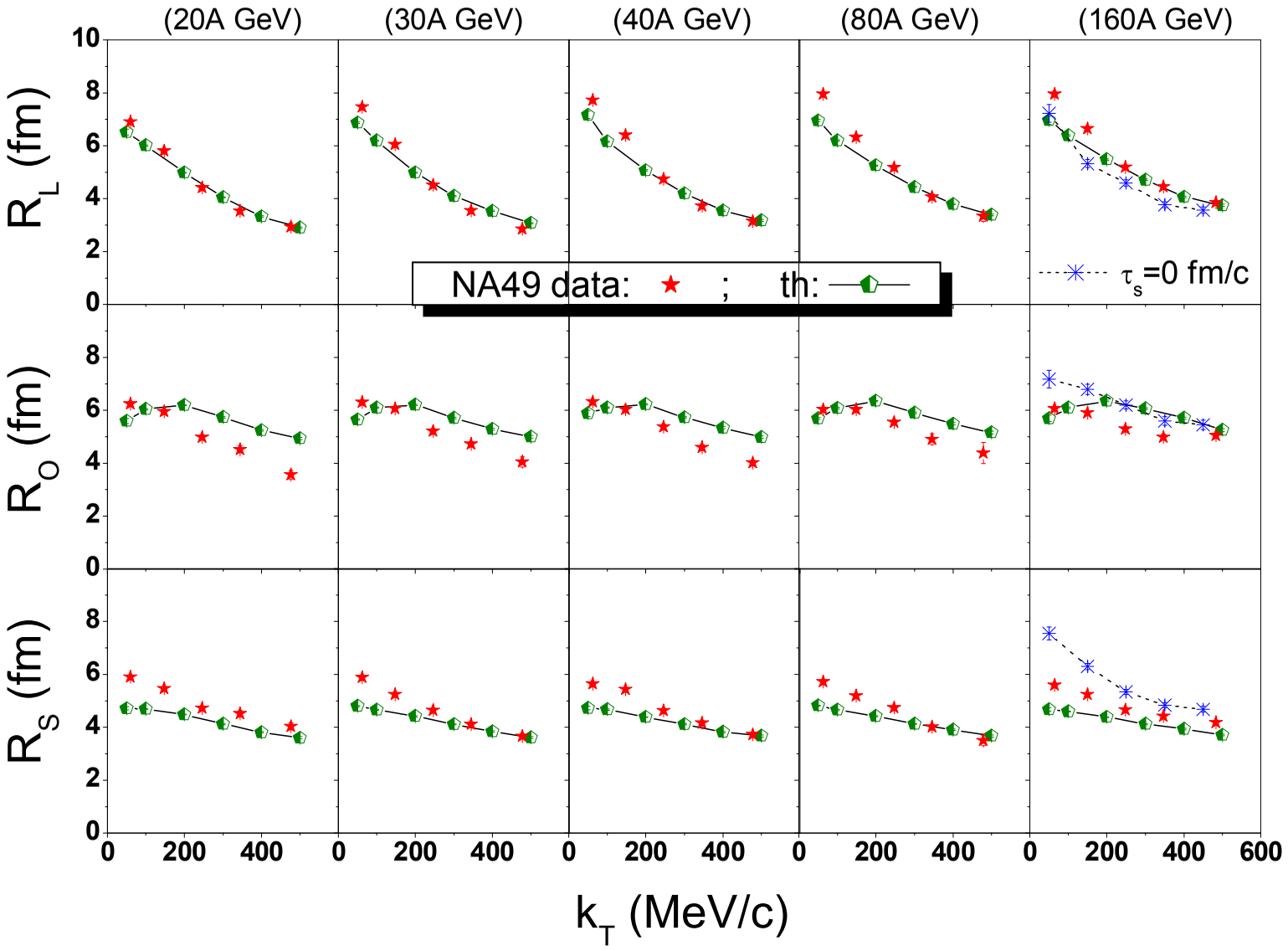

- Good agreement
- Deviations at small $k_T$ for $R_L$ and $R_S$

<11%$\sigma_T$

<5% $\sigma_T$

$$K_T = (p_{T1} + p_{T2})/2$$

# UrQMD @ SPS-NA49



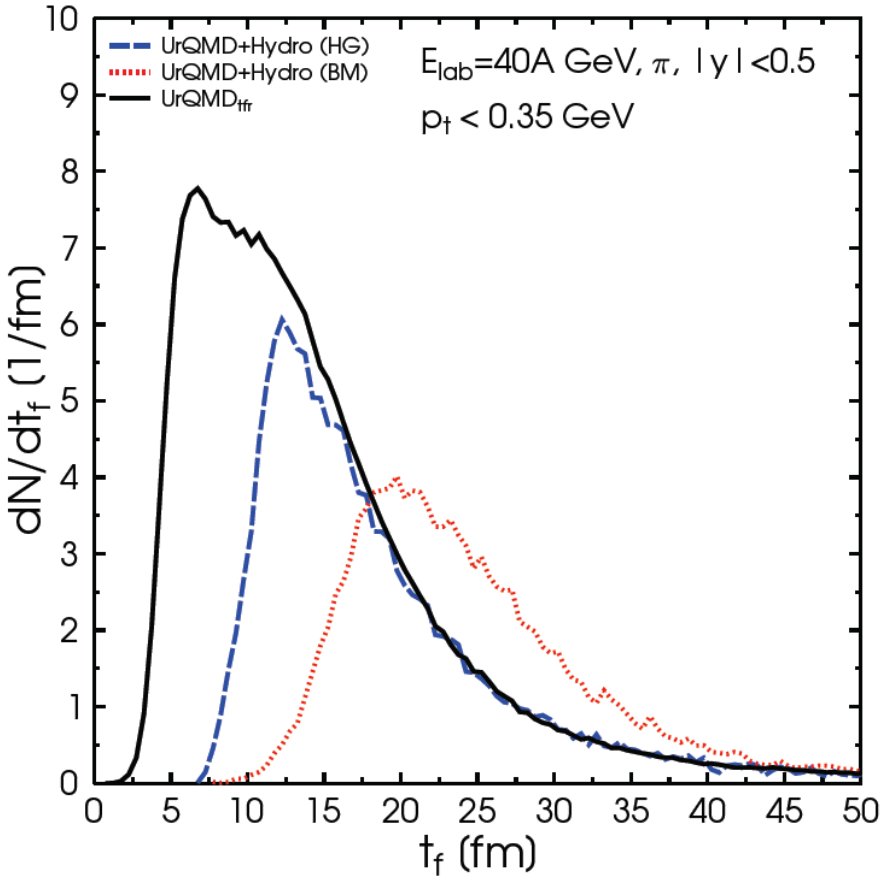

Note the effect of short formation times: more early pressure

<7.2% $\sigma_T$

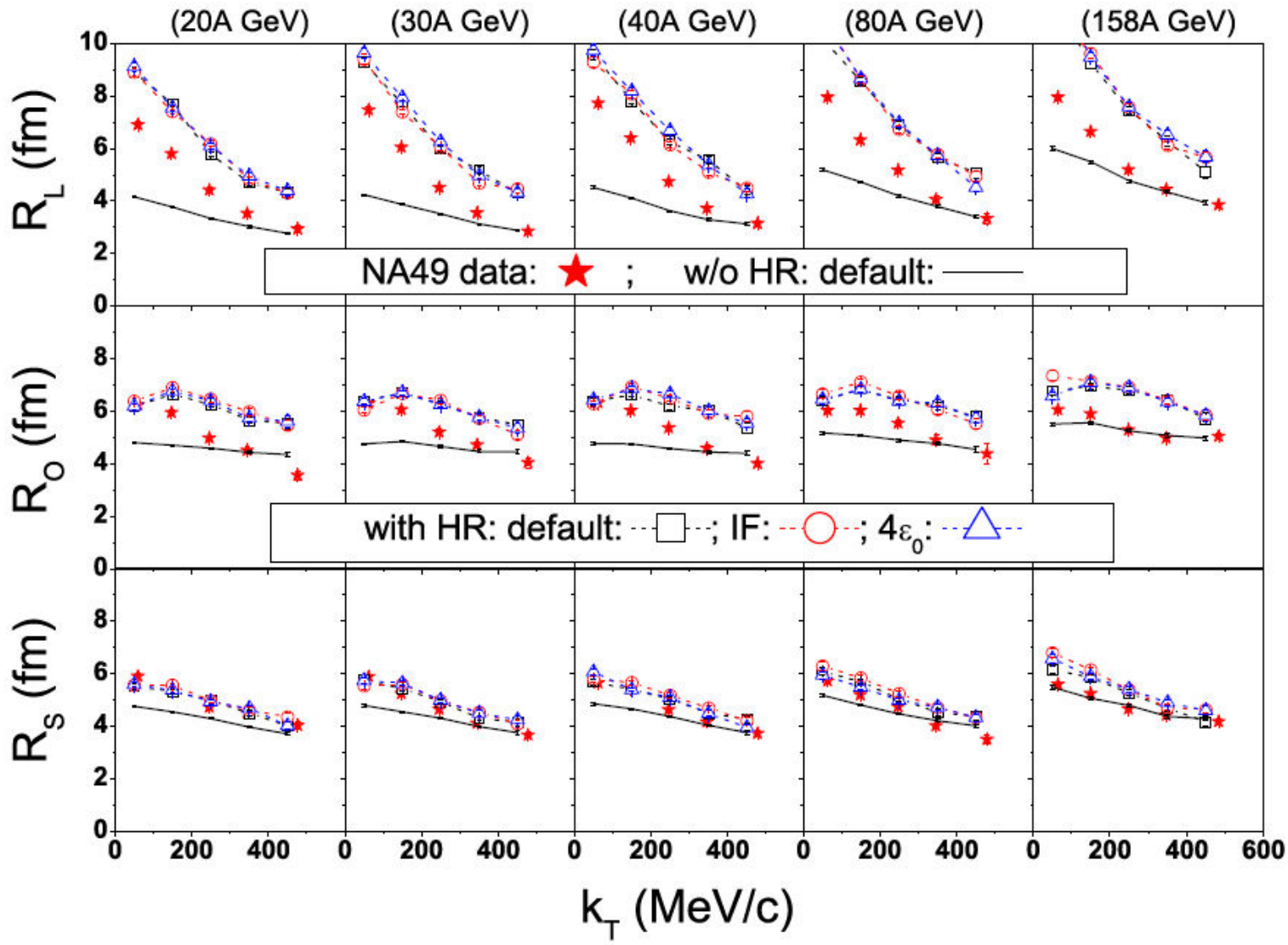
# **Hybrid** Model results

# Emission times: hybrid model

- Shift in emission times for different equations of state
- Later emission in the Bag model scenario
- However, here lifetime increases less than factor 2.



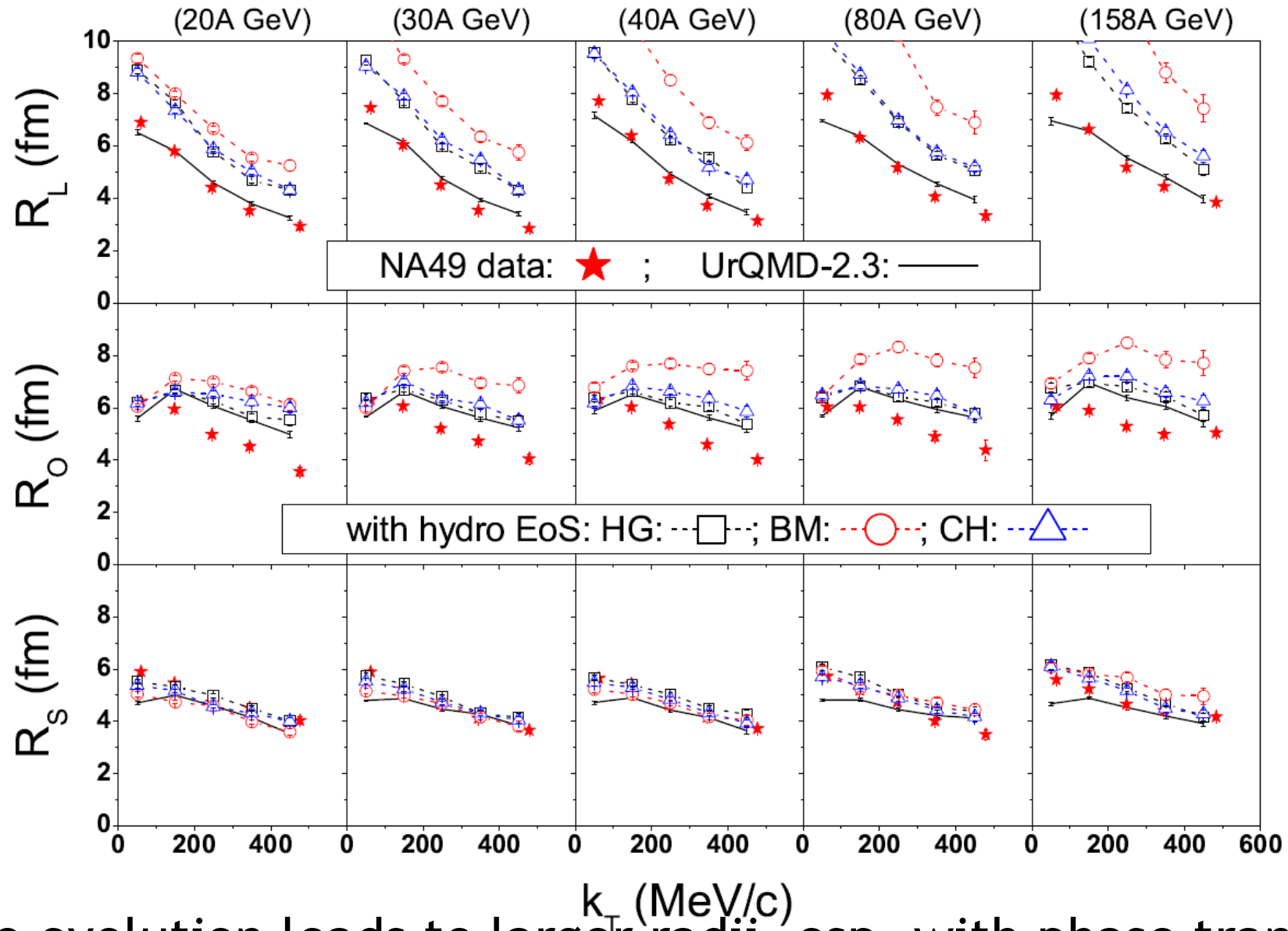
# HBT radii (freeze-out effects)




(Q. Li et al., arXiv: 0812.0375, PLB in print)

Freeze-out effects are small, if hadronic rescattering is included

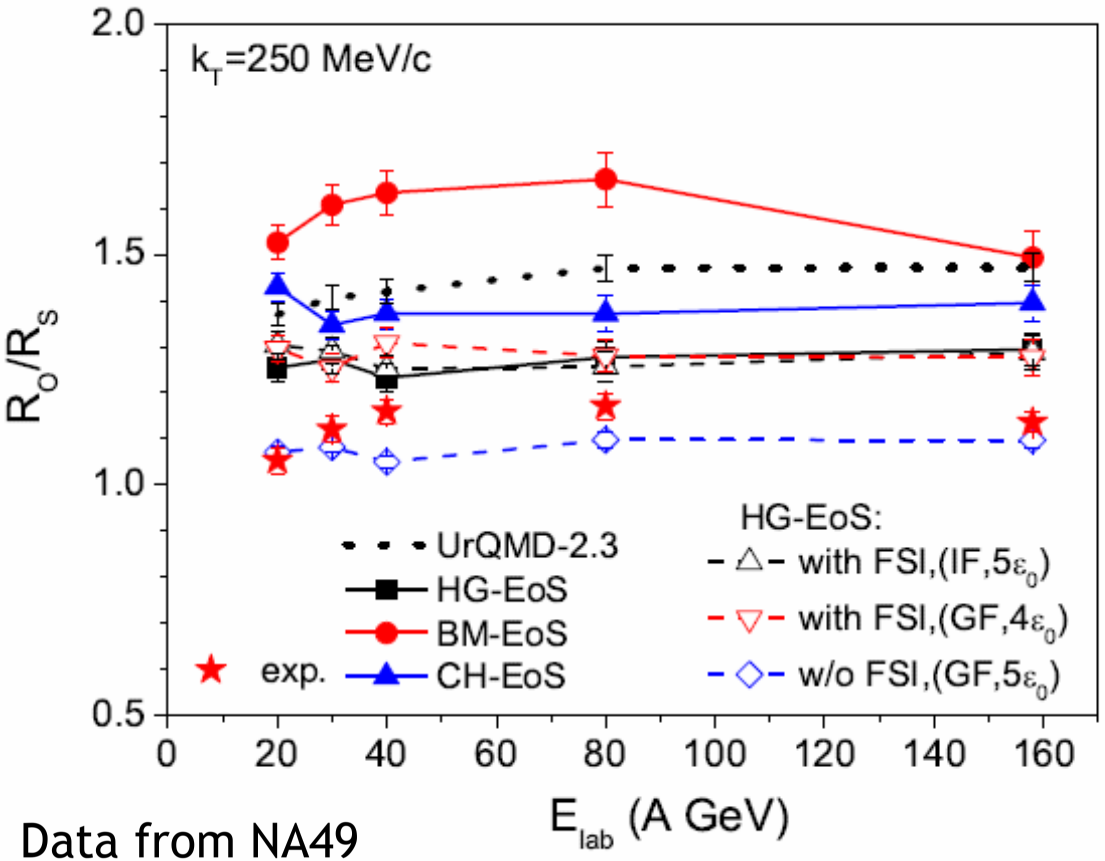
# HBT radii (EoS effects)




(Q. Li et al., arXiv: 0812.0375, PLB in print)

Hydro evolution leads to larger radii, esp. with phase transition

# $R_O/R_S$ Ratio




Data from NA49

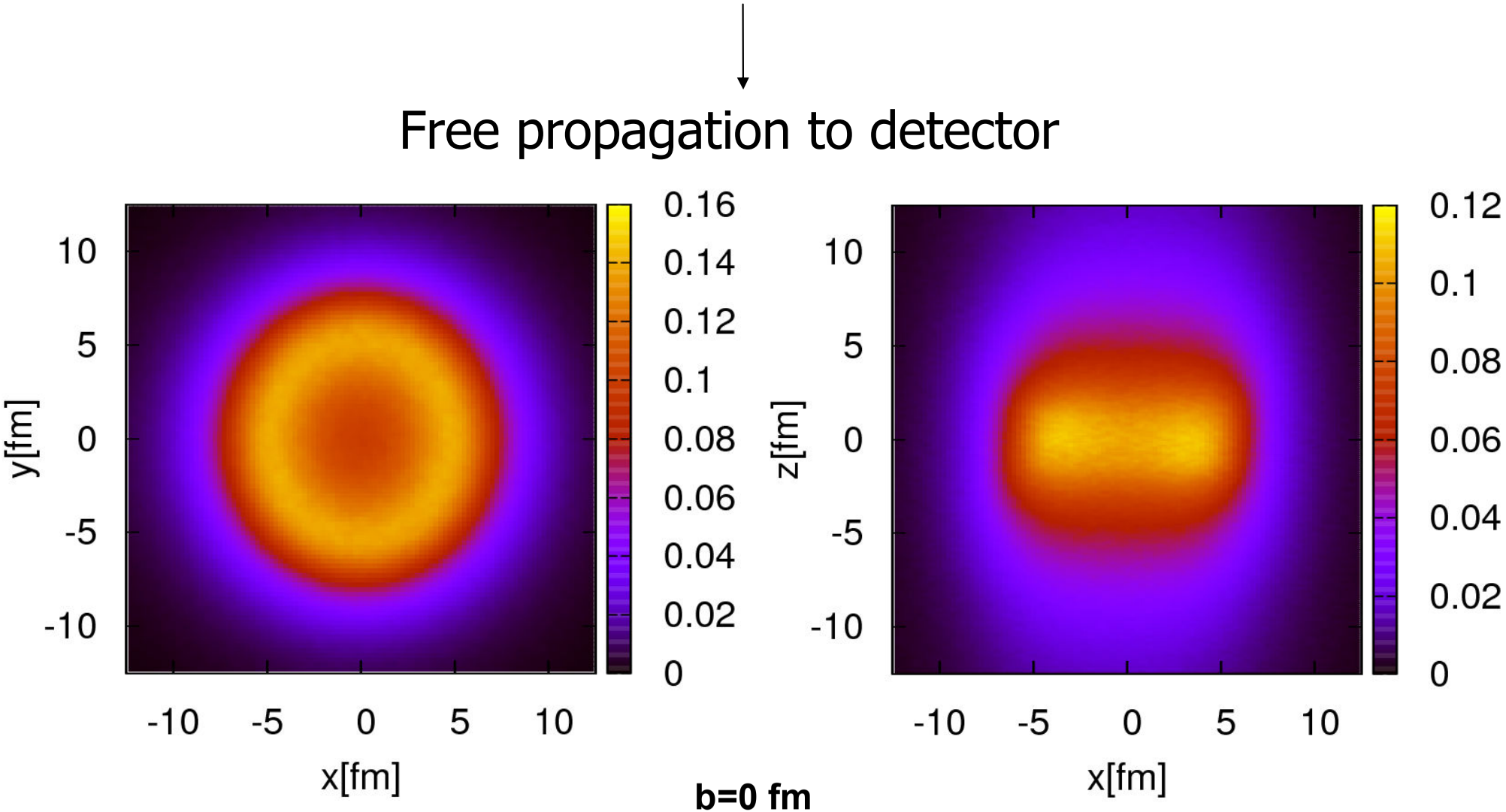
- Hydro phase leads to smaller ratios
- Hydro to transport transition does not matter, if final **rescattering** is taken into account
- **EoS dependence** is visible, but not as strong as previuosly predicted (factor of 5)

(Q. Li et al., PLB 674, 111, 2009)

# Asymmetries

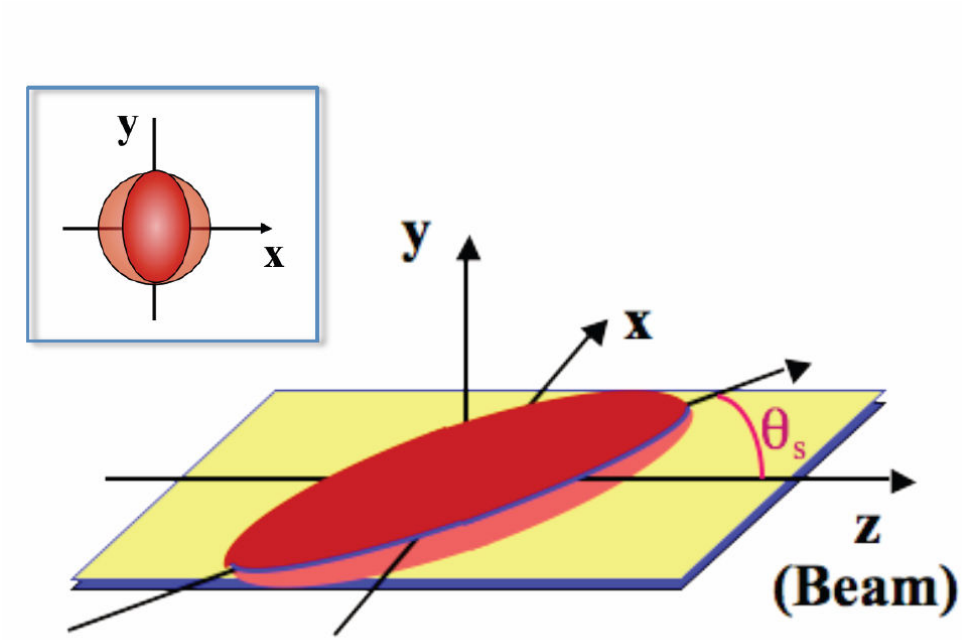
# Kinetic Freezeout

Point of last interaction or production

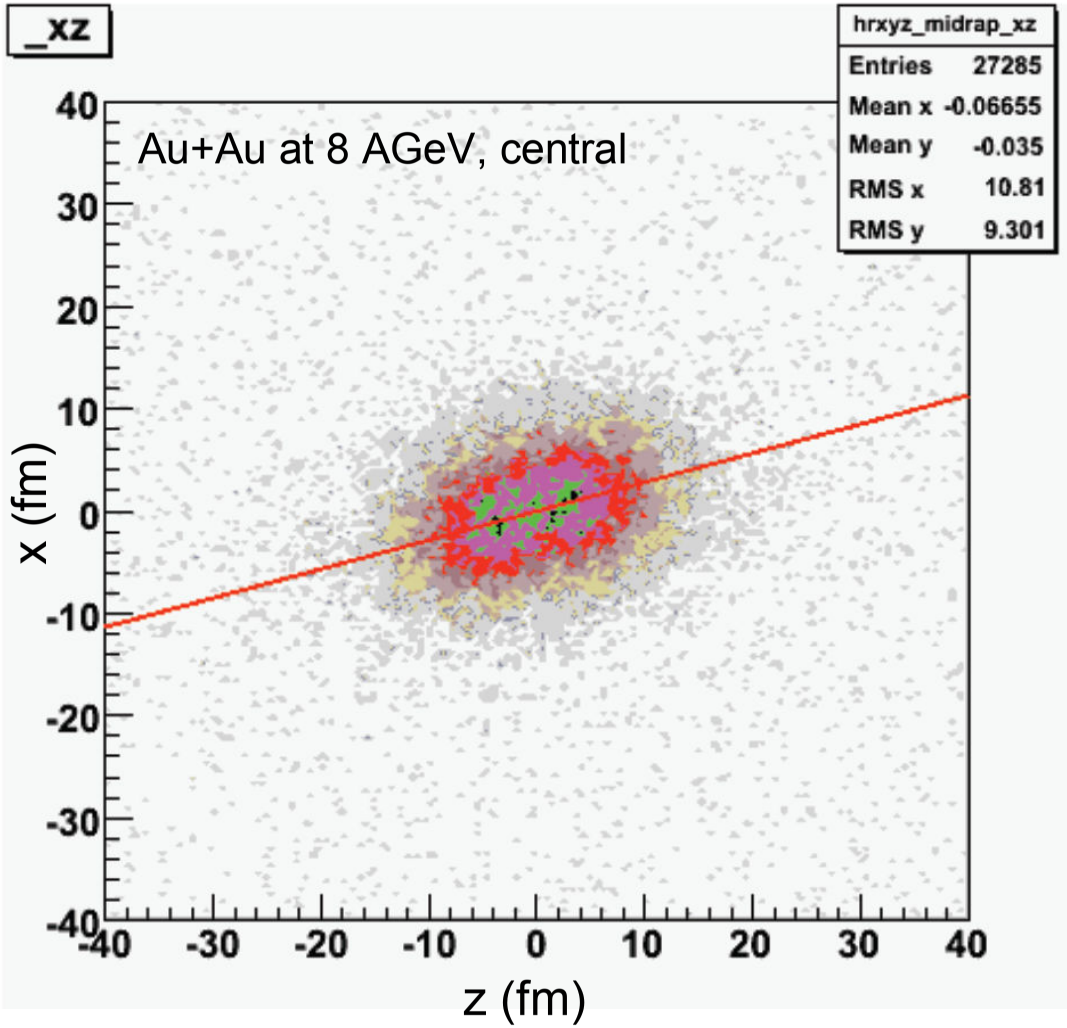



Free propagation to detector

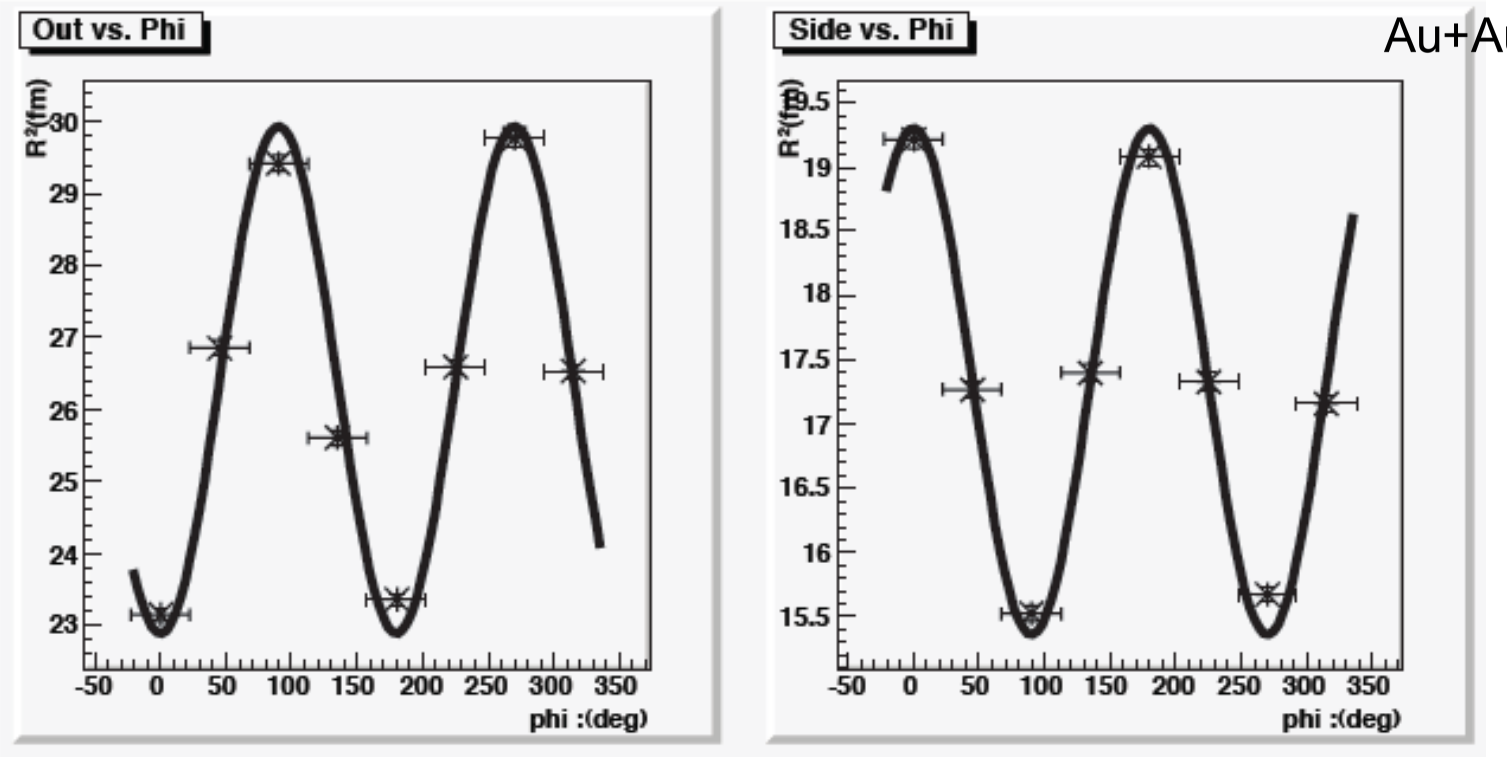
# The tilt angle




Obtain tilt angle directly from fit to freeze-out data



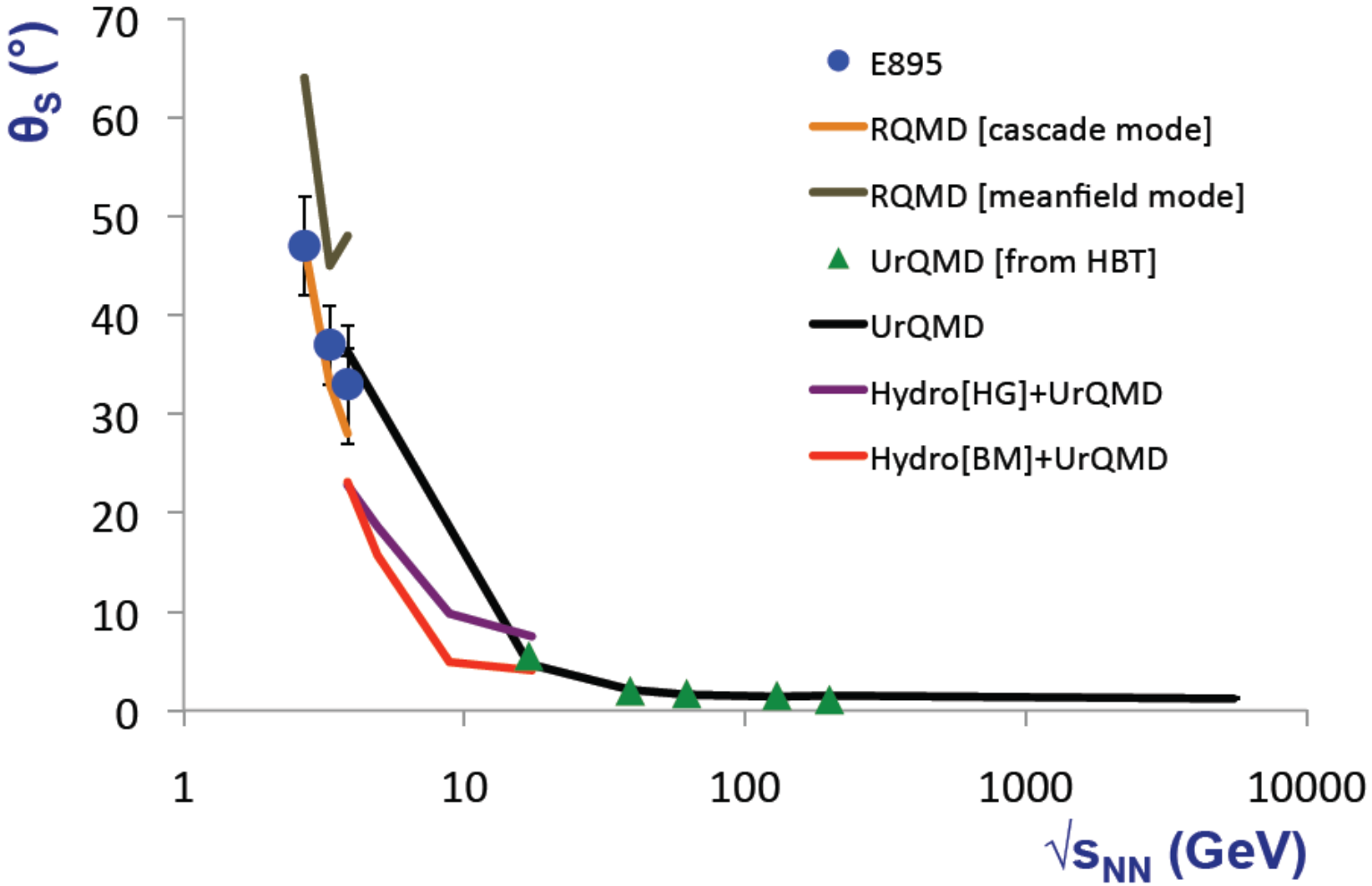
# Azimuthal HBT




Au+Au, 8 GeV

- Tilt angle and eccentricity can be extracted from the model 'directly' or using the correlation function
  (done by Elliot Mount, Mike Lisa)

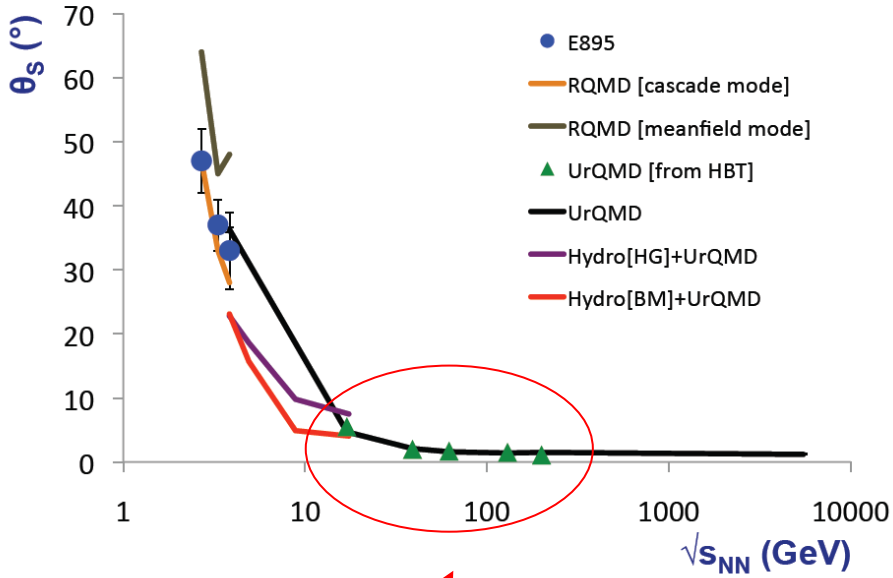
# Tilt angle




Lisa, Graef, Mount, Petersen, Bleicher, in prep.

# Tilt angle - discussion

- Tilt angle drops with increasing energy (increase in longitudinal extension of source)
- Consistency of RQMD vs UrQMD
- Hybrid model deviates where no data is available
- Consistency between direct extraction and HBT method (green triangles vs line)



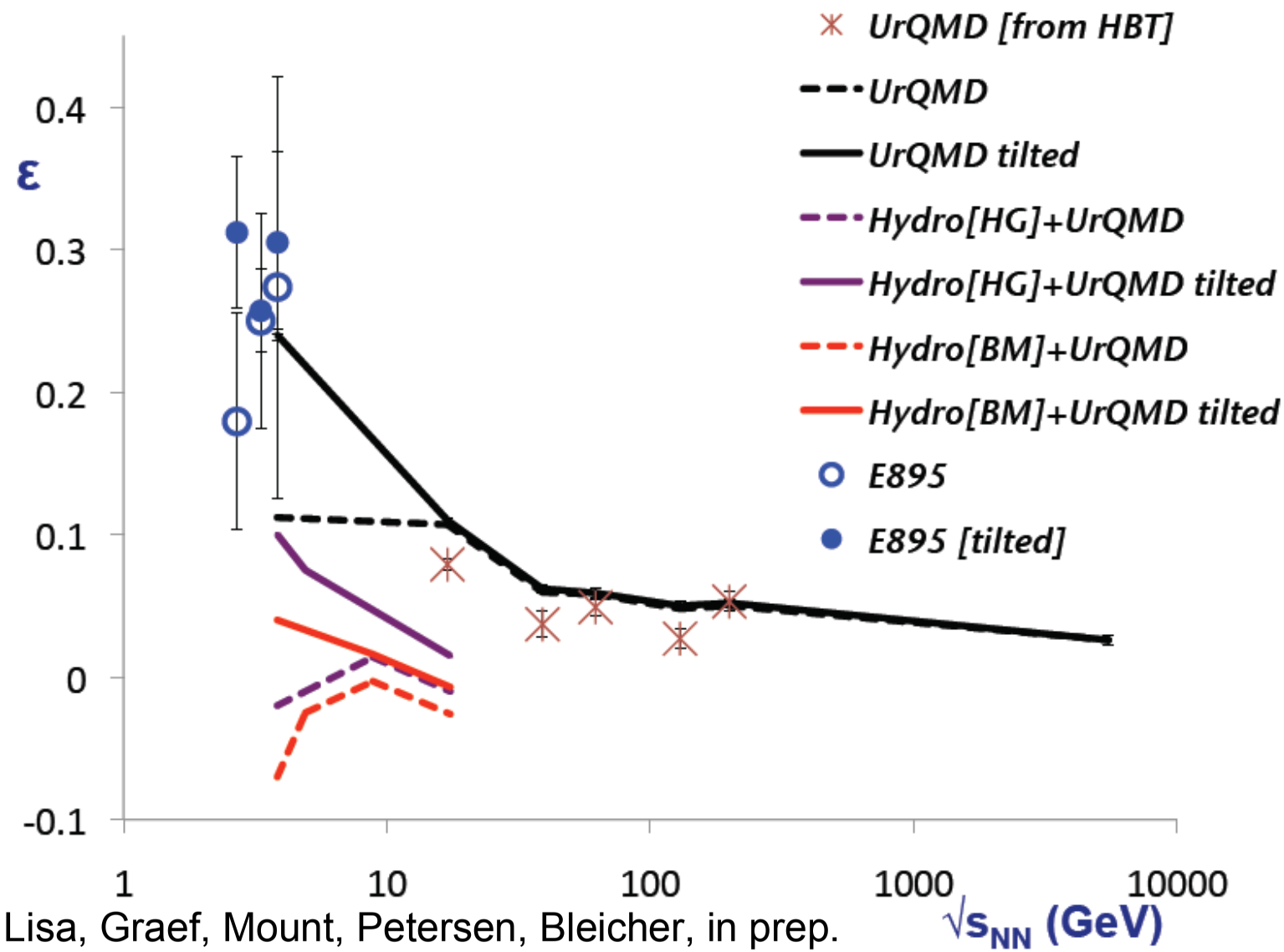
# Freeze-out eccentricity

Calculate eccentricity directly from the freeze-out coordinates of pions:

$$\text{eccentricity } \varepsilon = \frac{\sigma_y^2 - \sigma_x^2}{\sigma_y^2 + \sigma_x^2}$$

$$\sigma_x^2 = \langle x^2 \rangle - \langle x \rangle^2 \text{ and } \sigma_y^2 = \langle y^2 \rangle - \langle y \rangle^2$$

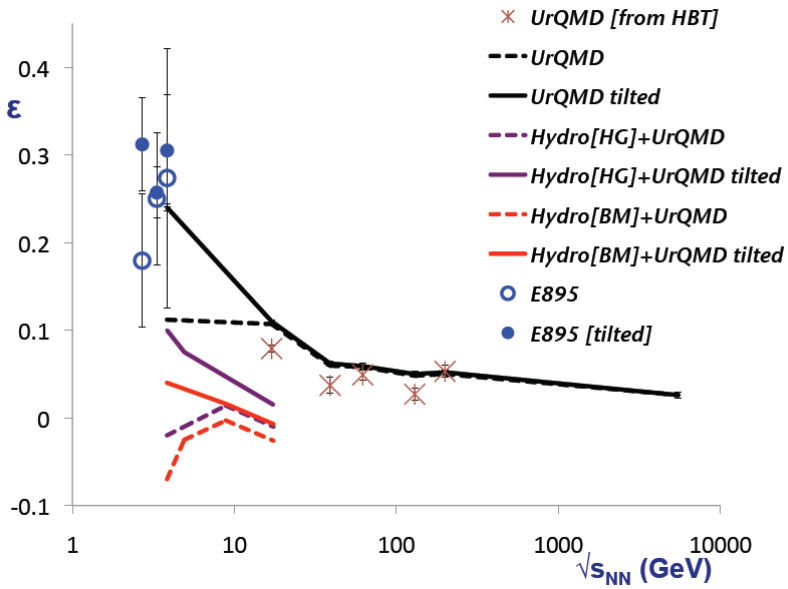
# Eccentricities




Lisa, Graef, Mount, Petersen, Bleicher, in prep.

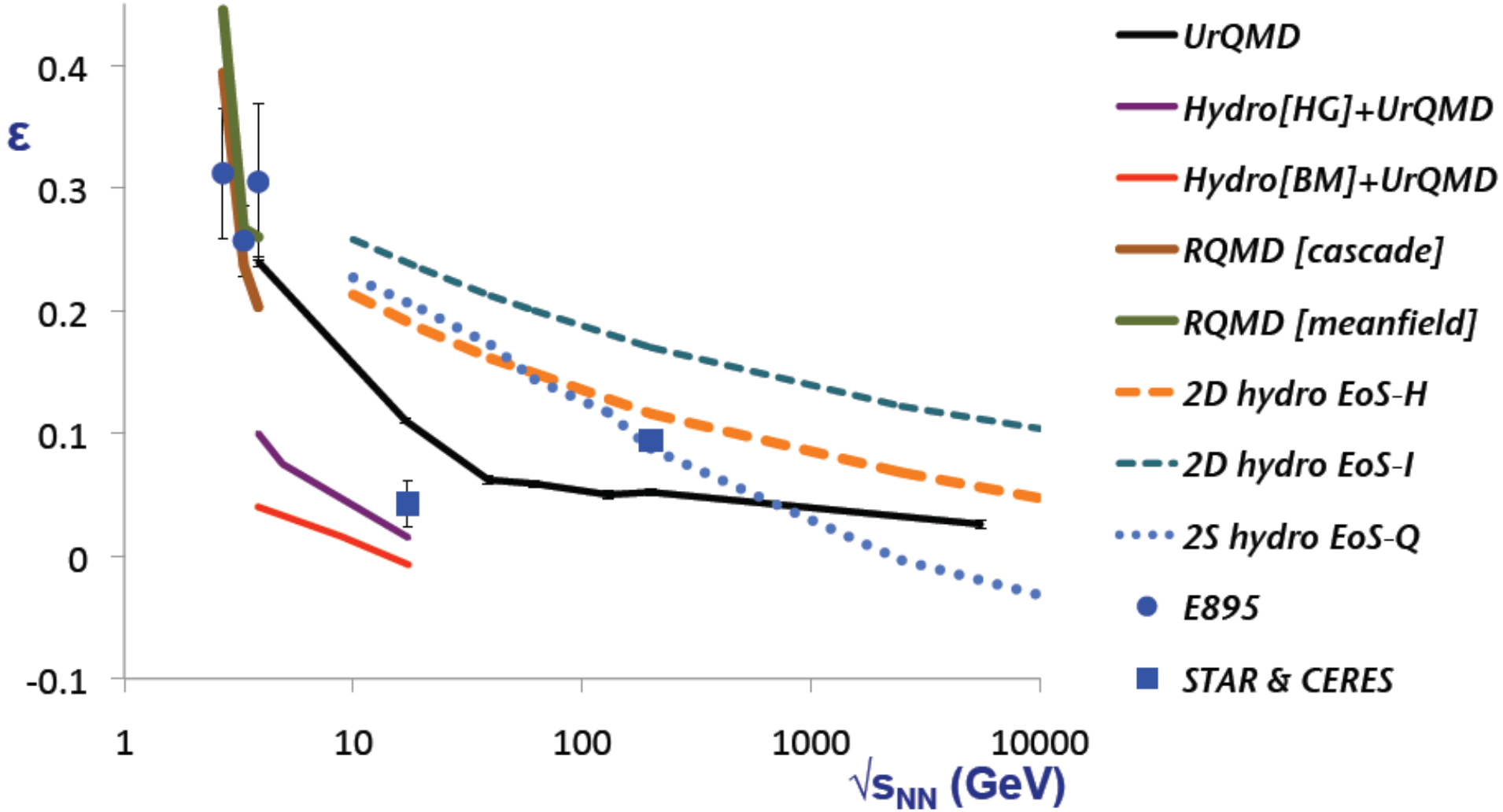
# Eccentricities: Tilted frame…

- Effect of tilt is only important at low energies
- Eccentricities are lower in the hybrid approach




- Comparison between ‘direct’ extraction and the HBT analysis yields good agreement (cf. crosses vs. lines)

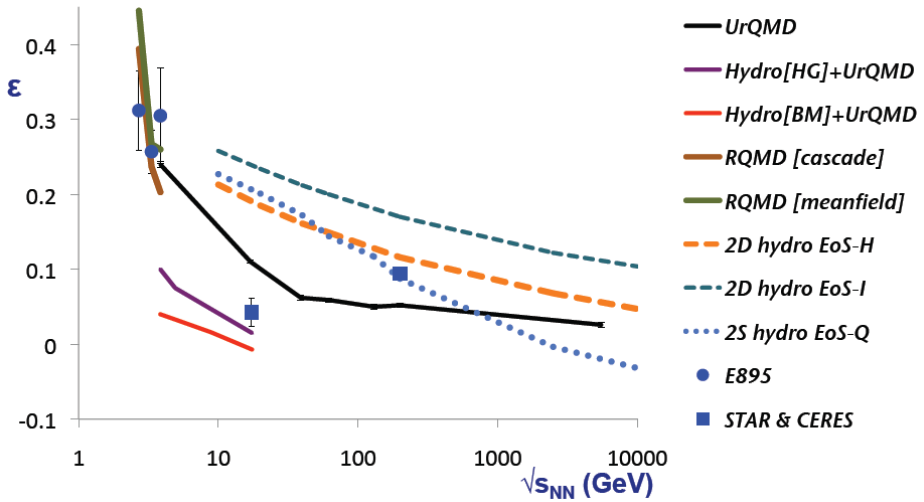
# Model comparison (tilted frame)




Lisa, Graef, Mount, Petersen, Froderman, Bleicher, in prep.

# Discussion

- All models follow expectations (decrease of ε with E)




- However…
  data suggests an increase from SPS to RHIC
  →soft expansion, $c_s$~0 →less spherical system (after same time)
- If this is supported by RHIC low energy data it might indicate a soft point!

# Summary

- UrQMD and the hybrid model where compared to data at AGS/FAIR/SPS/RHIC
- Good agreement was found (however, QGP scenario not supported from $R_o/R_s$)
- Eccentricity and source tilt were discussed
- Surprising non-monotonous behavior found in the eccentricity data
  → possible signal for softening!?
  → needs confirmation by STAR data