Heavy Ion Collisions at LHC in a Multiphase Transport Model

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- A multi-phase transport (AMPT) model
- Heavy ion collisions at RHIC
- Heavy ion collisions at LHC

A multiphase transport (AMPT) model

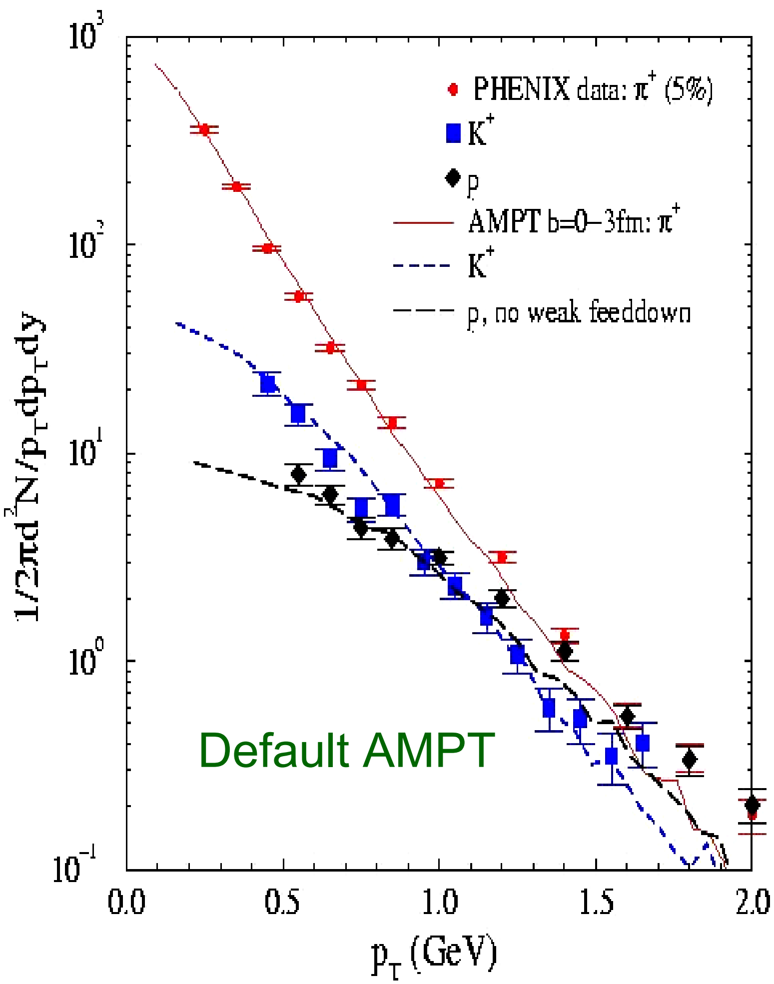
Default: Lin, Pal, Zhang, Li & Ko, PRC 61, 067901 (00); 64, 041901 (01); 72, 064901 (05); http://www-cunuke.phys.columbia.edu/OSCAR

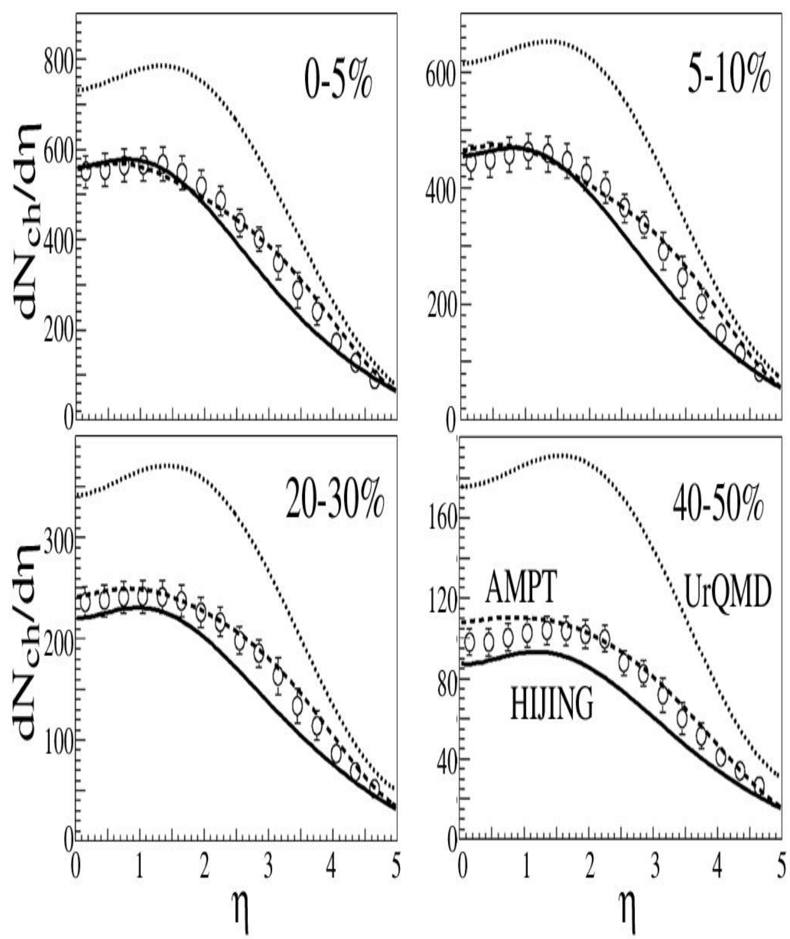
- Initial conditions: HIJING (soft strings and hard minijets)
- Parton evolution: ZPC
- Hadronization: Lund string model for default AMPT
- Hadronic scattering: ART

String melting: PRC 65, 034904 (02); PRL 89, 152301 (02)

- Convert hadrons from string fragmentation into quarks and antiquarks
- Evolve quarks and antiquarks in ZPC
- When partons stop interacting, combine nearest quark and antiquark to meson, and nearest three quarks to baryon (coordinate-space coalescence)
- Hadron flavors are determined by quarks' invariant mass

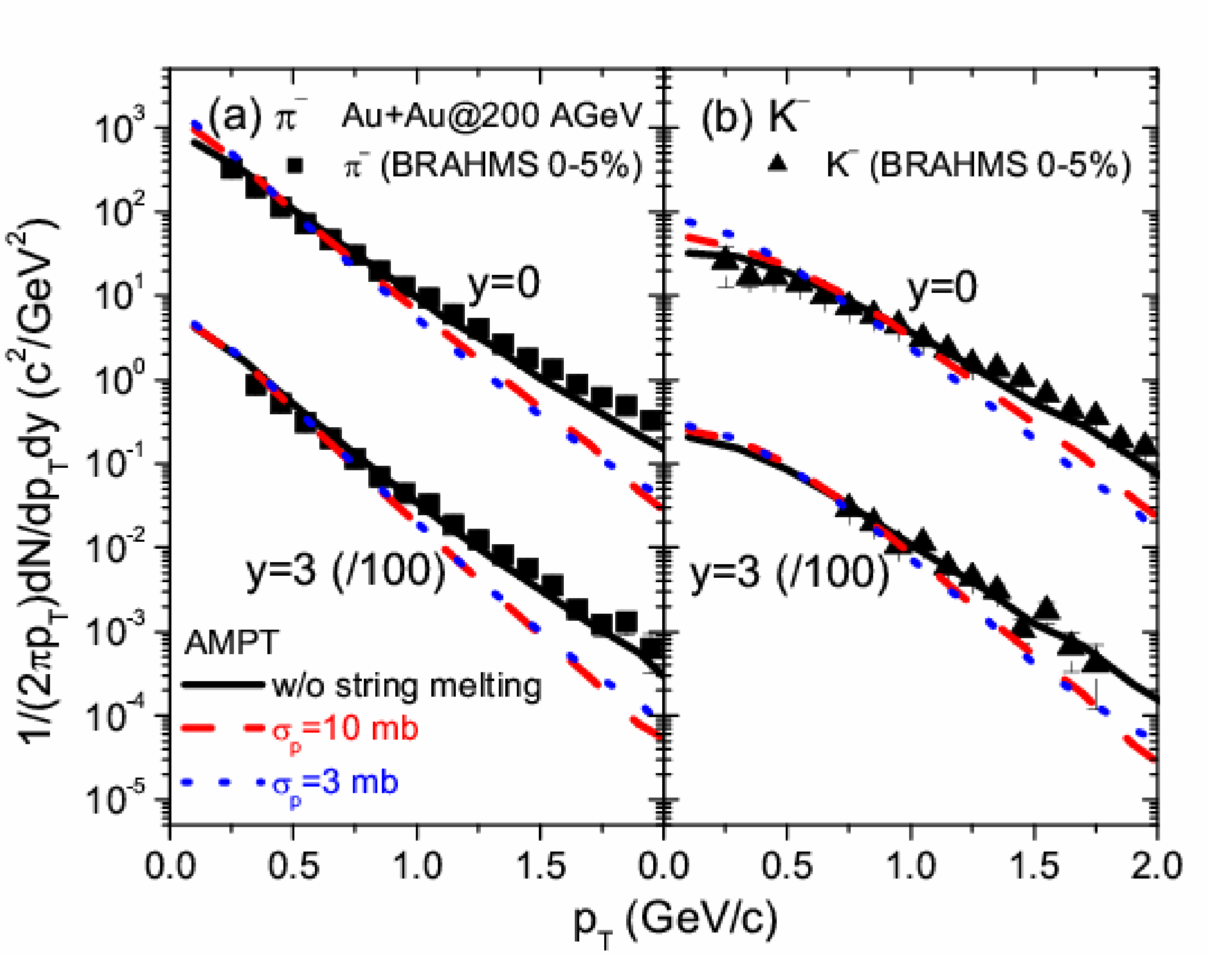
Transverse momentum and rapidity distribution from default AMPT





BRAHMS Au+Au @ 200 GeV

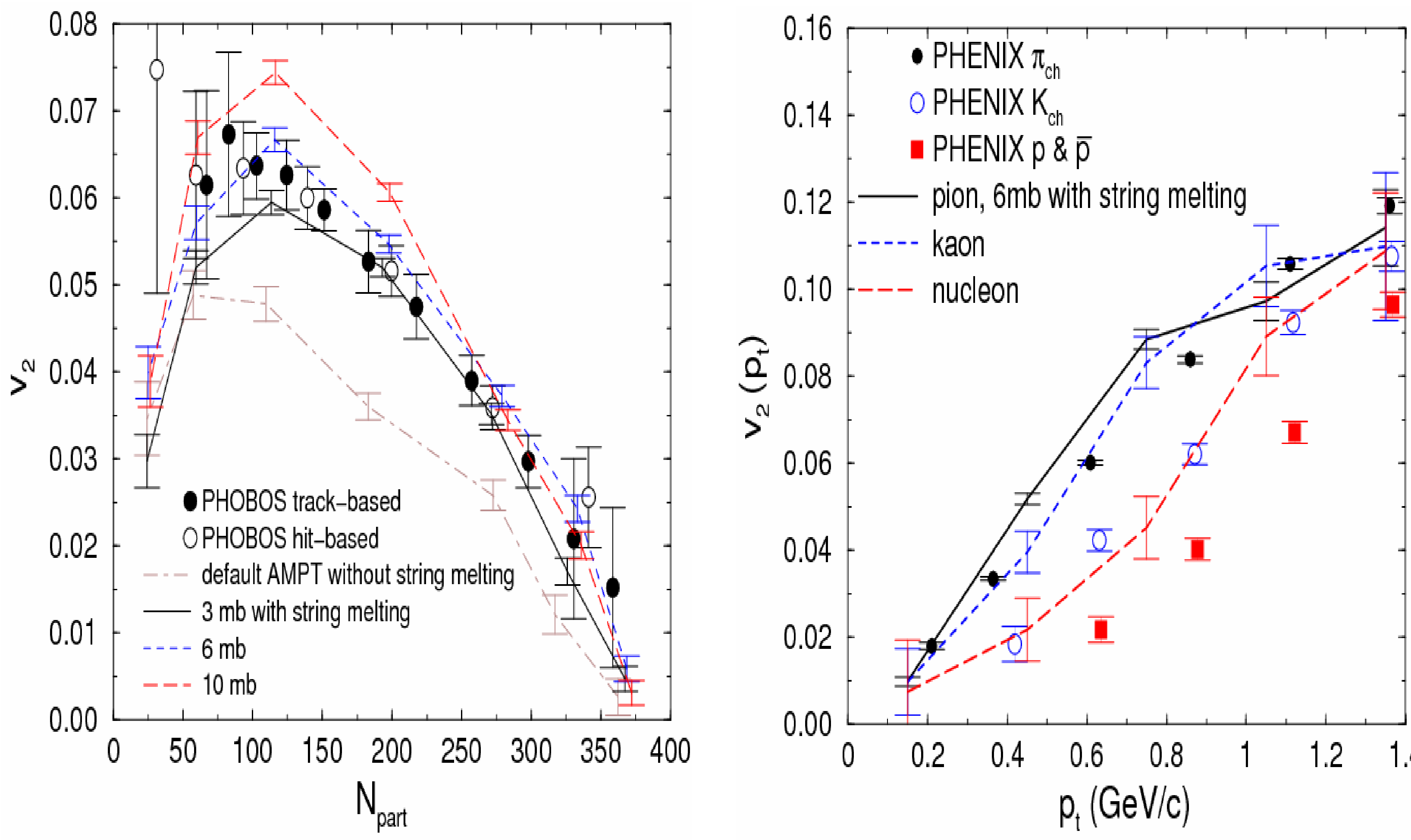
Transverse momentum spectra from AMPT with string melting



- Spectra are softer than in default AMPT as current quark masses are used, whose spectra are less affected by collective radial flow

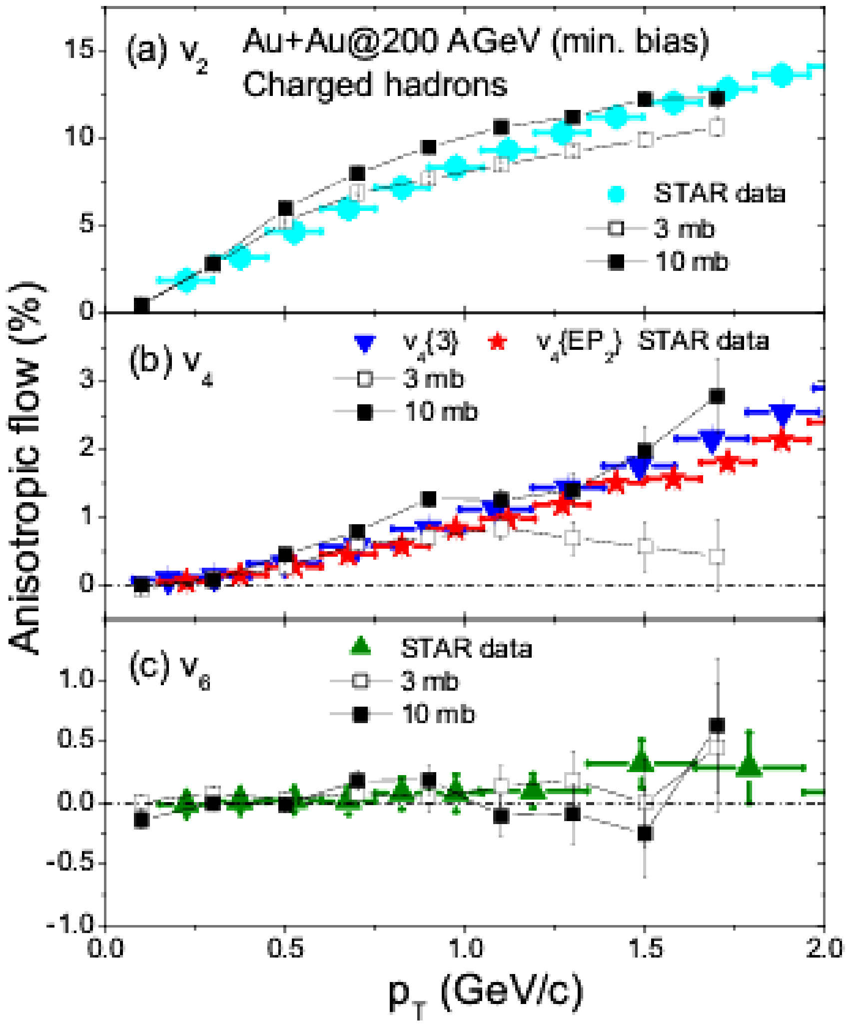
Elliptic flow from AMPT

Minimum bias Au+Au @ 200 AGeV

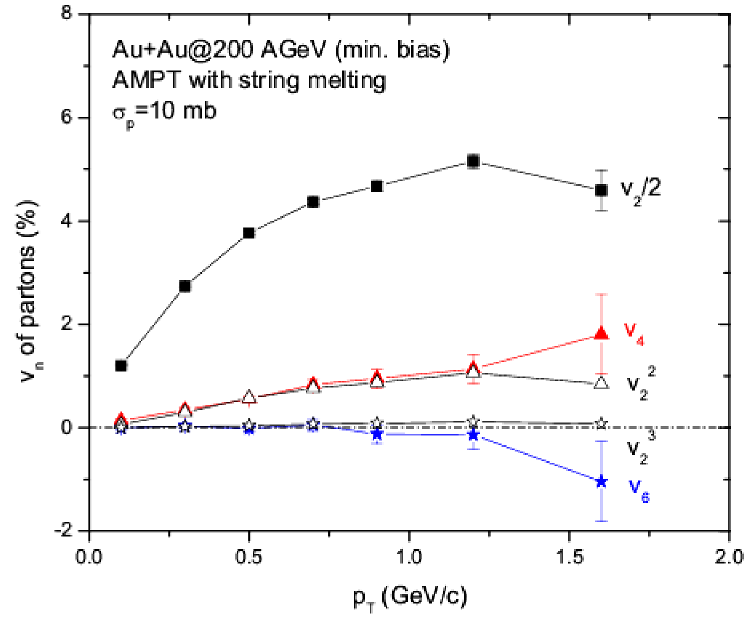


- Need string melting and large parton scattering cross section to reproduce data
- Mass ordering of v_2 at low p_T as in ideal hydrodynamic model

Higher-order anisotropic flow



Chen, Ko & Lin, PRC 69, 031901(R) (2004)



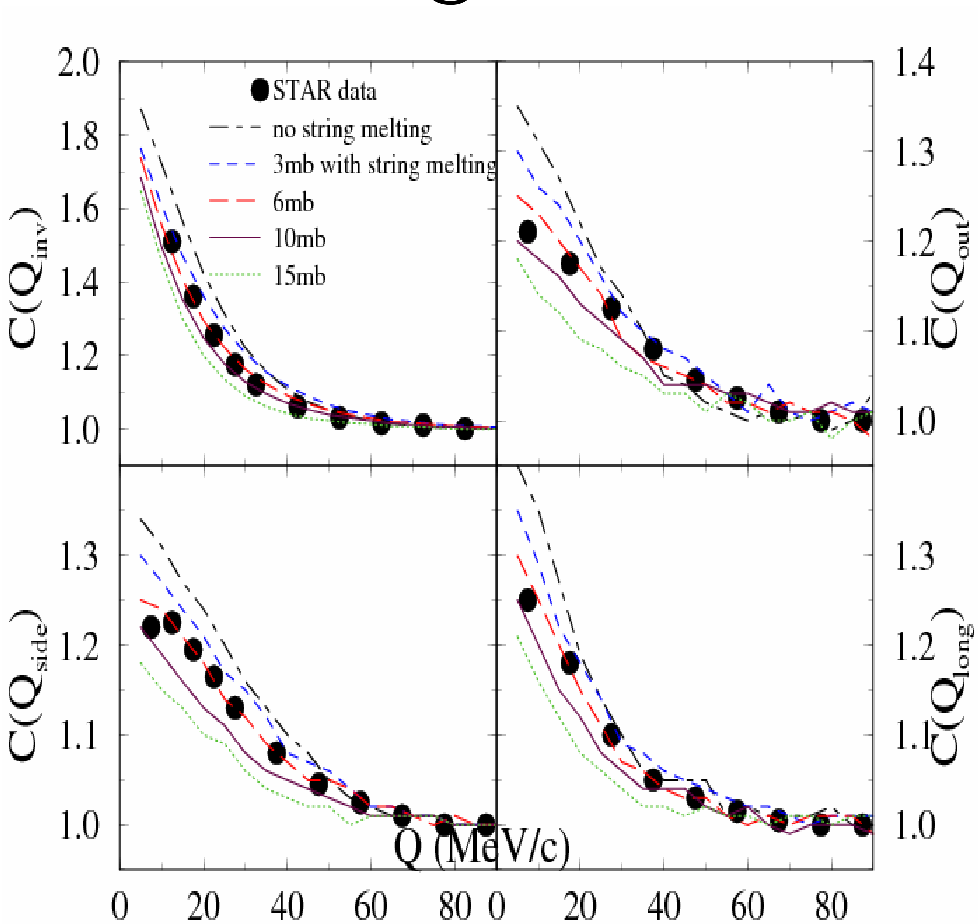
Parton cascade $v_{4,q} \approx v_{2,q}^2$

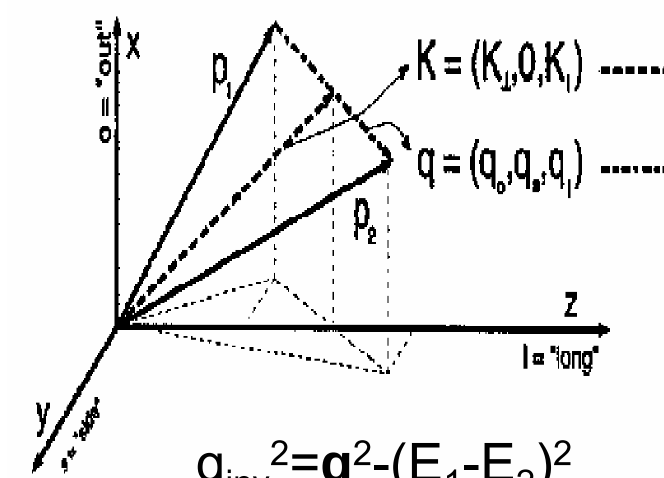
naïve coalescence model

Data $\dfrac{v_4}{v_2^2} \approx 1.2 \Rightarrow v_{4,q} \approx 2v_{2,q}^2$ ← $\dfrac{v_4}{v_2^2} \approx \dfrac{1}{4} + \dfrac{1}{2}\dfrac{v_{4,q}}{v_{2,q}^2}$

Two-pion correlation functions from AMPT

Au+Au @ 200 AGeV



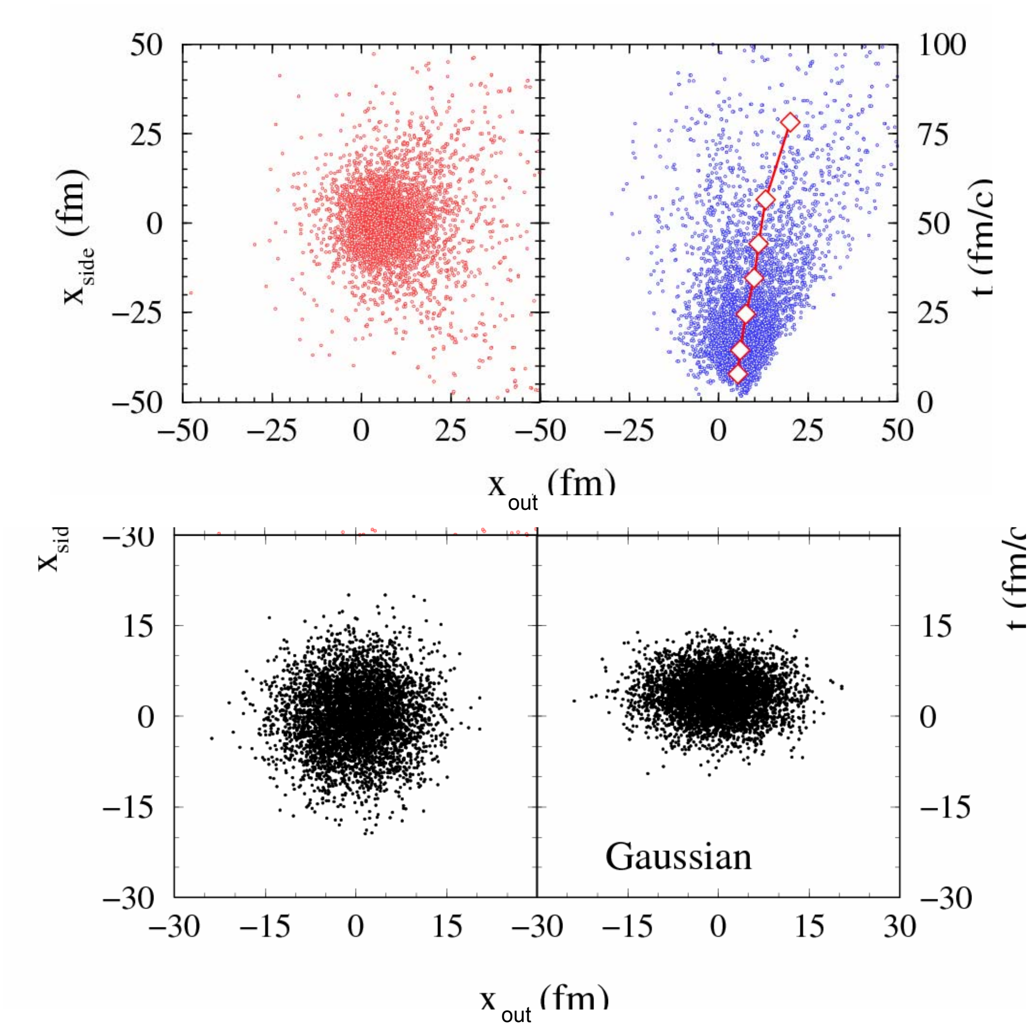


$$q_{inv}^2 = \mathbf{q}^2 - (E_1 - E_2)^2$$

- For pions with -0.5< y < 0.5 and 125 < p_T < 225 MeV/c in central collisions
- Projected correlation functions evaluated with other two Q components integrated from 0 to 35 MeV/c

- Need string melting and large parton scattering cross section to reproduce data

Emission function for pions



- Upper: emission source from AMPT
  - Shift in out direction
  - Strong correlation between out position and emission time
  - Large halo due to resonance (ω) decay and explosion
  - → non-Gaussian source
- Lower: Gaussian source fitted to correlation functions

Source radii from emission function

Pratt showed in ’84 $C(\vec{K},\vec{q}) \cong 1 + \left| \left\langle \exp\left[i\vec{q} \cdot (\vec{x} - \vec{\beta} t) \right] \right\rangle \right|^2$

with β=K/(E_1+E_2) and averaging over emission function S(x,p)

Source radii $R_{ij}^2 = -\frac{1}{2} \frac{\partial^2 C(\vec{K},\vec{q})}{\partial q_i \partial q_j}\Big|_{q=0} \square \left\langle \left(\tilde{x}_i - \beta_i \tilde{t} \right) \left(\tilde{x}_j - \beta_j \tilde{t} \right) \right\rangle$

$$= D_{x_i,x_j} - D_{x_i,\beta_j t} - D_{\beta_i t, x_j} + D_{\beta_i t, \beta_j t}$$

with $\tilde{x} = x - \langle x \rangle, \quad D_{x,y} = \langle xy \rangle - \langle x \rangle \langle y \rangle$

Source radii from Gaussian fit to correlation function

$$C(\vec{K},\vec{q}) = 1 + \lambda \exp\left[-\sum_{i,j} R_{ij}^2 \left(\vec{K} \right) q_{ij}^2 \right]$$

Similar radii only for a Gaussian emission function without strong space-momentum correlation

Source radii in the out-side-long coordinates

$$R^2_{out} = D_{x_{out},x_{out}} - 2D_{x_{out},\beta_\perp t} + D_{\beta_\perp t,\beta_\perp t}$$

$$R^2_{side} = D_{x_{side},x_{side}}$$

$$R^2_{long} = D_{x_{long},x_{long}} + D_{\beta_{\|} t,\beta_{\|} t}$$

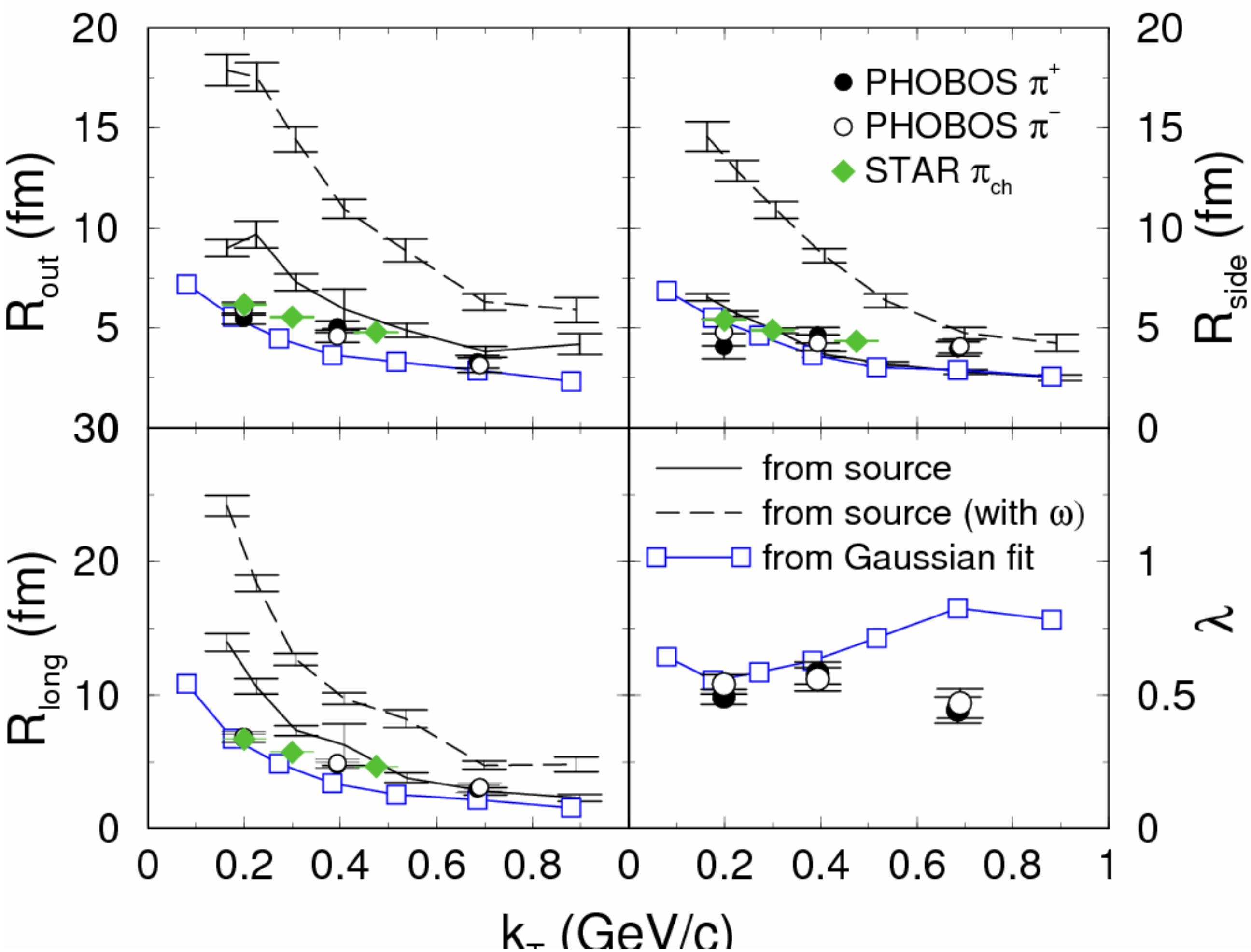
For pion pairs with K_T~200 MeV/c, AMPT gives

$$R_{out} \approx 17\ \text{fm}, \quad D_{x_{out},x_{out}} \approx 185\ \text{fm}^2,$$

$$D_{x_{out},\beta_\perp t} \approx 168\ \text{fm}^2, \quad D_{\beta_\perp t,\beta_\perp t} \approx 431\ \text{fm}^2$$

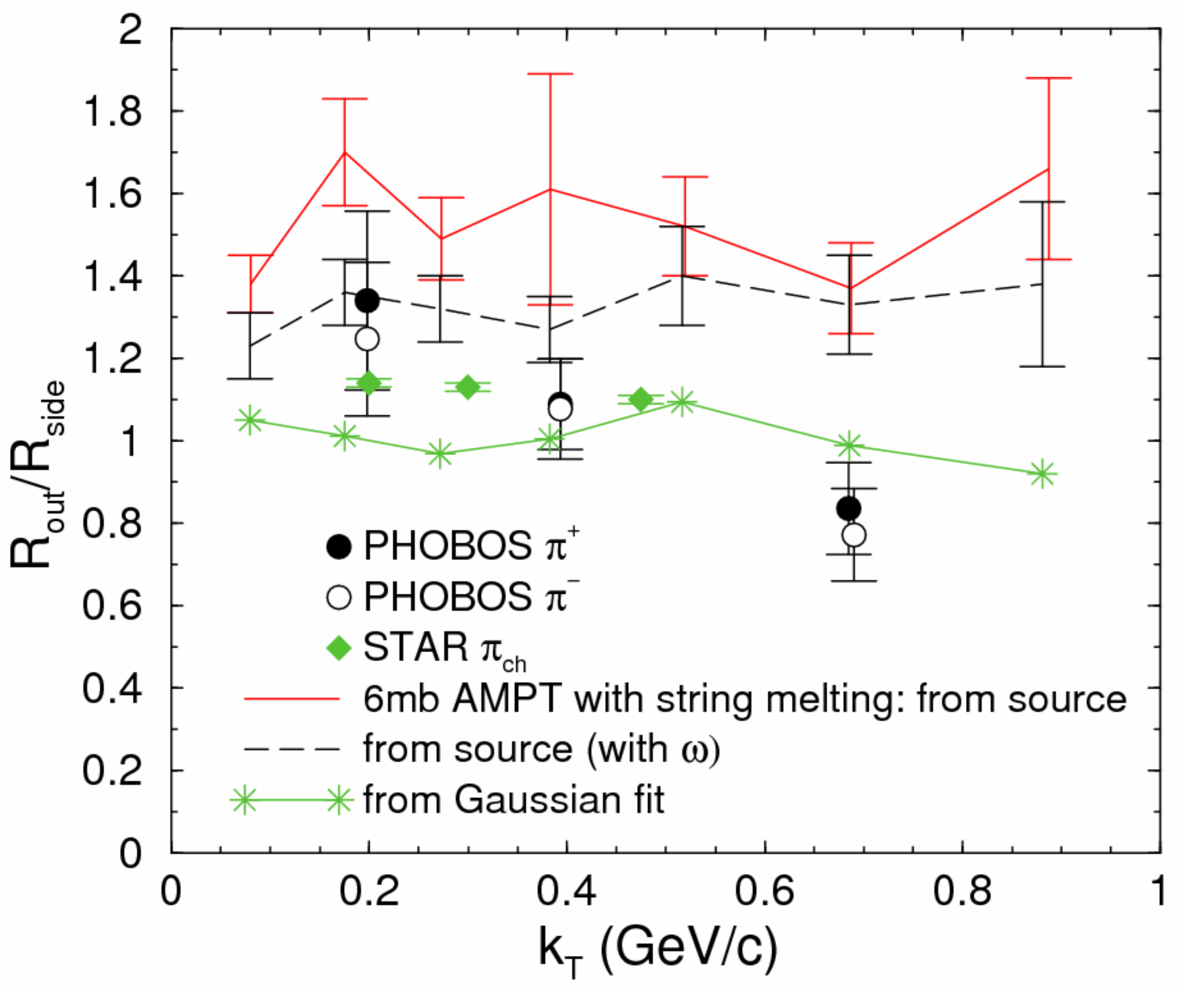
- Large positive out position and emission time correlation reduces out radius
- Without x_{out}-t correlation, R_{out}/R_{side}~1.5 instead 1

Radii of pion emission source



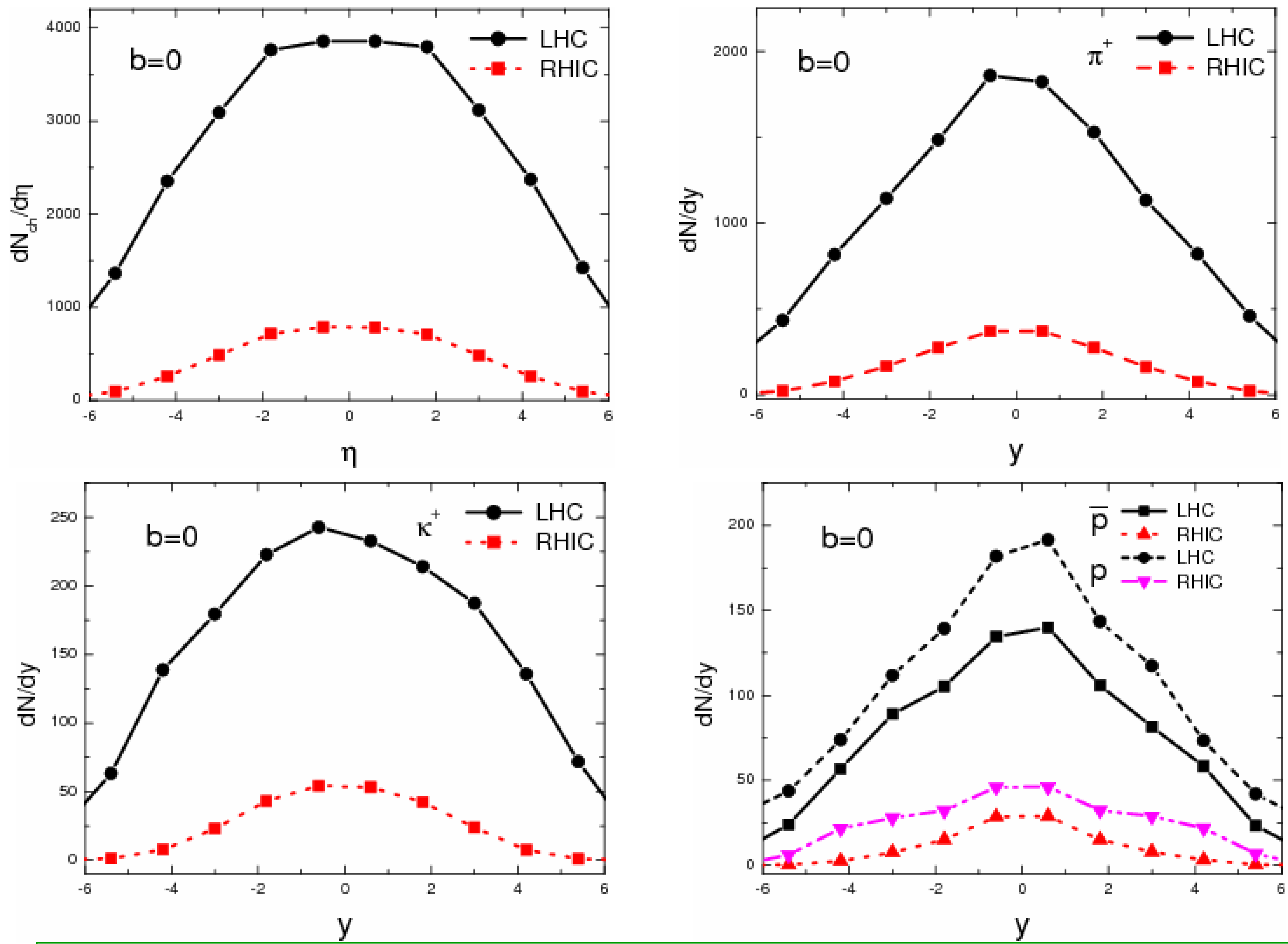
- Radii from emission function > radii from Gaussian fit
- Including ω decay leads to larger radii

Ratio of source radii from AMPT at RHIC



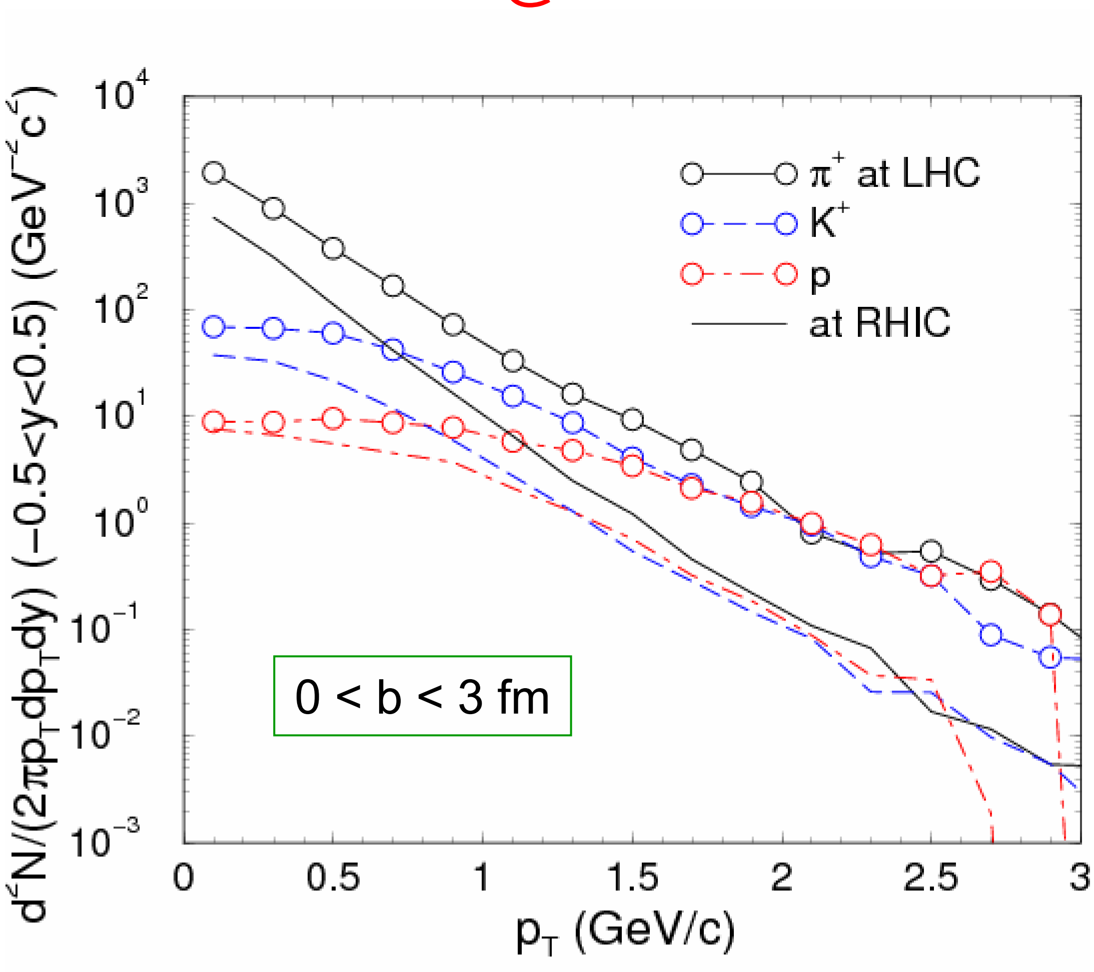
- R_{out}/R_{side} >1 is larger from emission function than from Gaussian fit

Rapidity distributions at LHC: Pb+Pb @ 5.5 ATeV



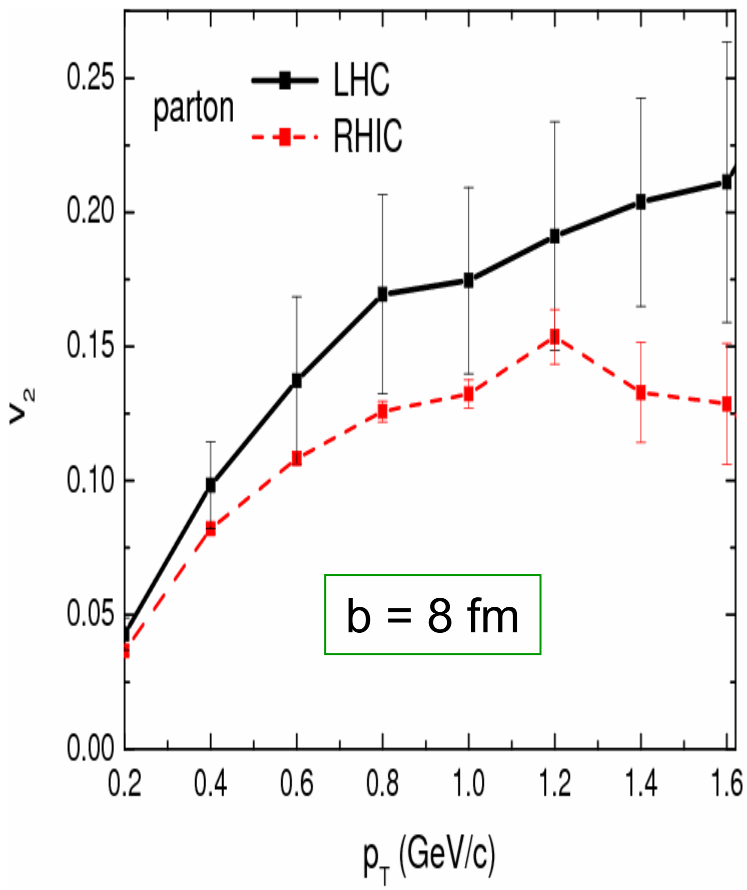
- Particle multiplicity at LHC increases by a factor of about 4 from that at RHIC

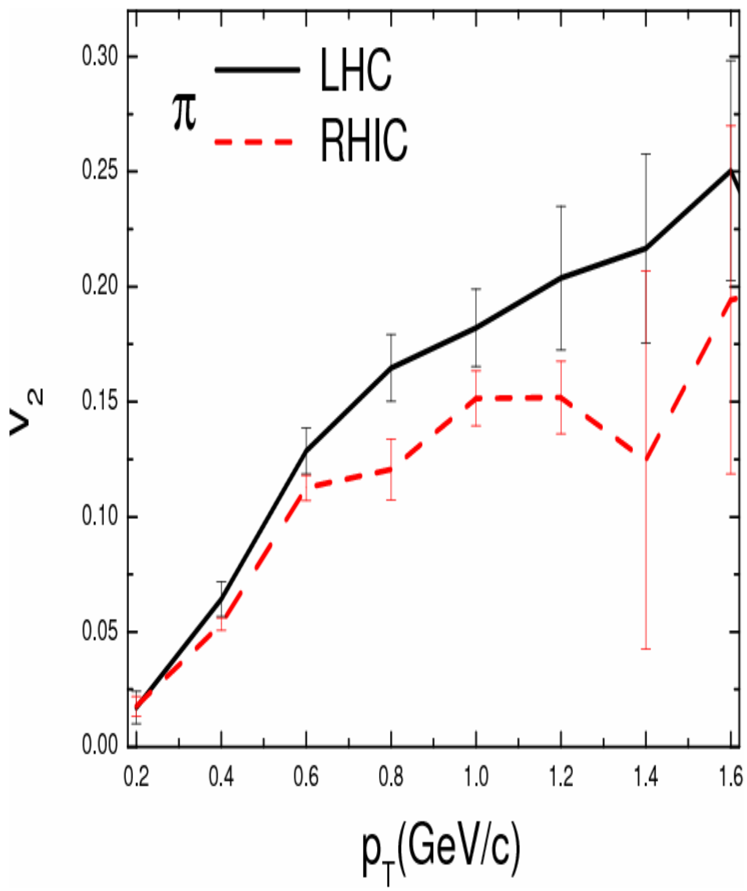
Transverse momentum distributions at LHC: Pb+Pb @ 5.5 ATeV



- Particle transverse momentum spectra is stiffer at LHC than at RHIC → larger transverse flow

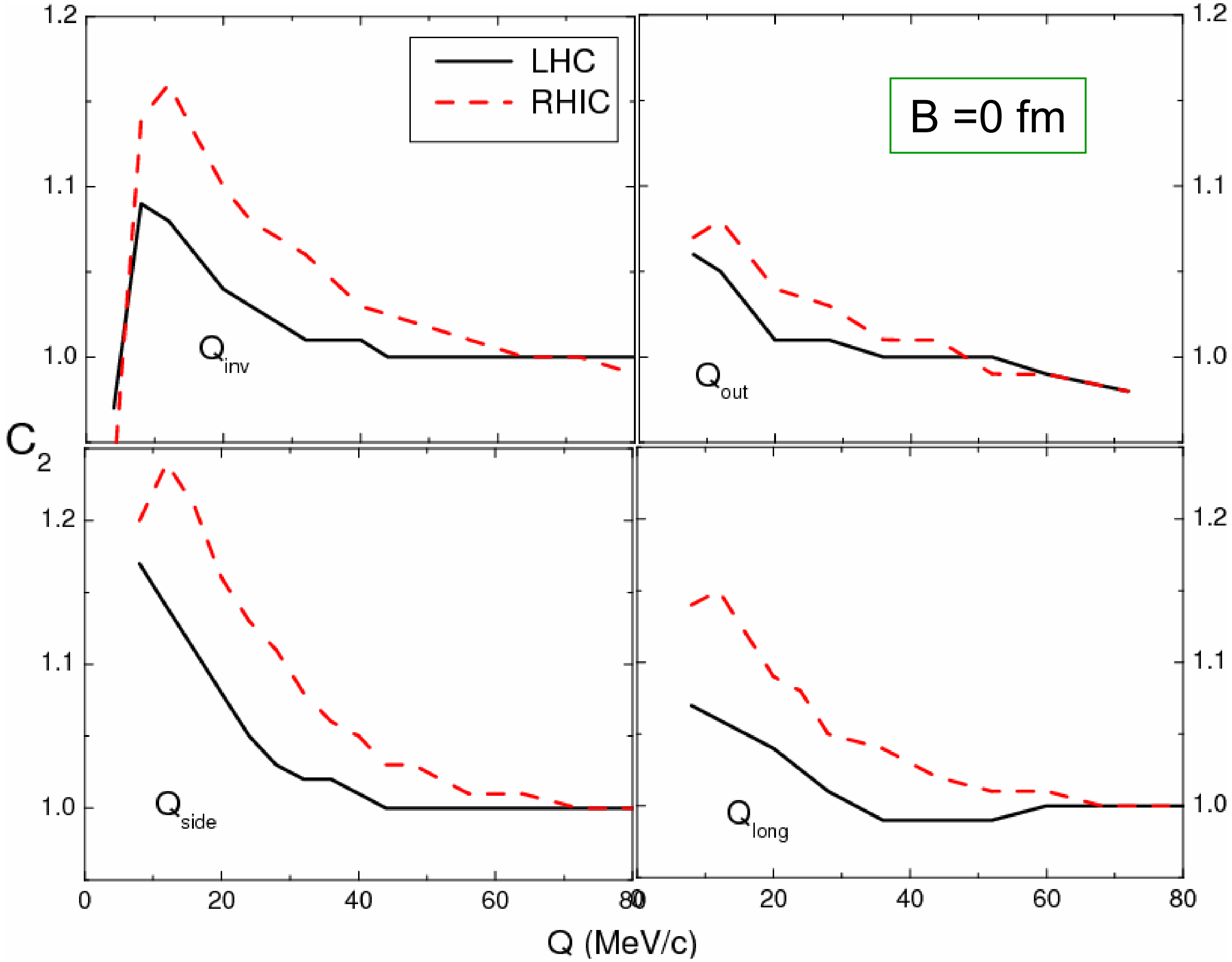
Elliptic flow at LHC: Pb+Pb @ 5.5 ATeV





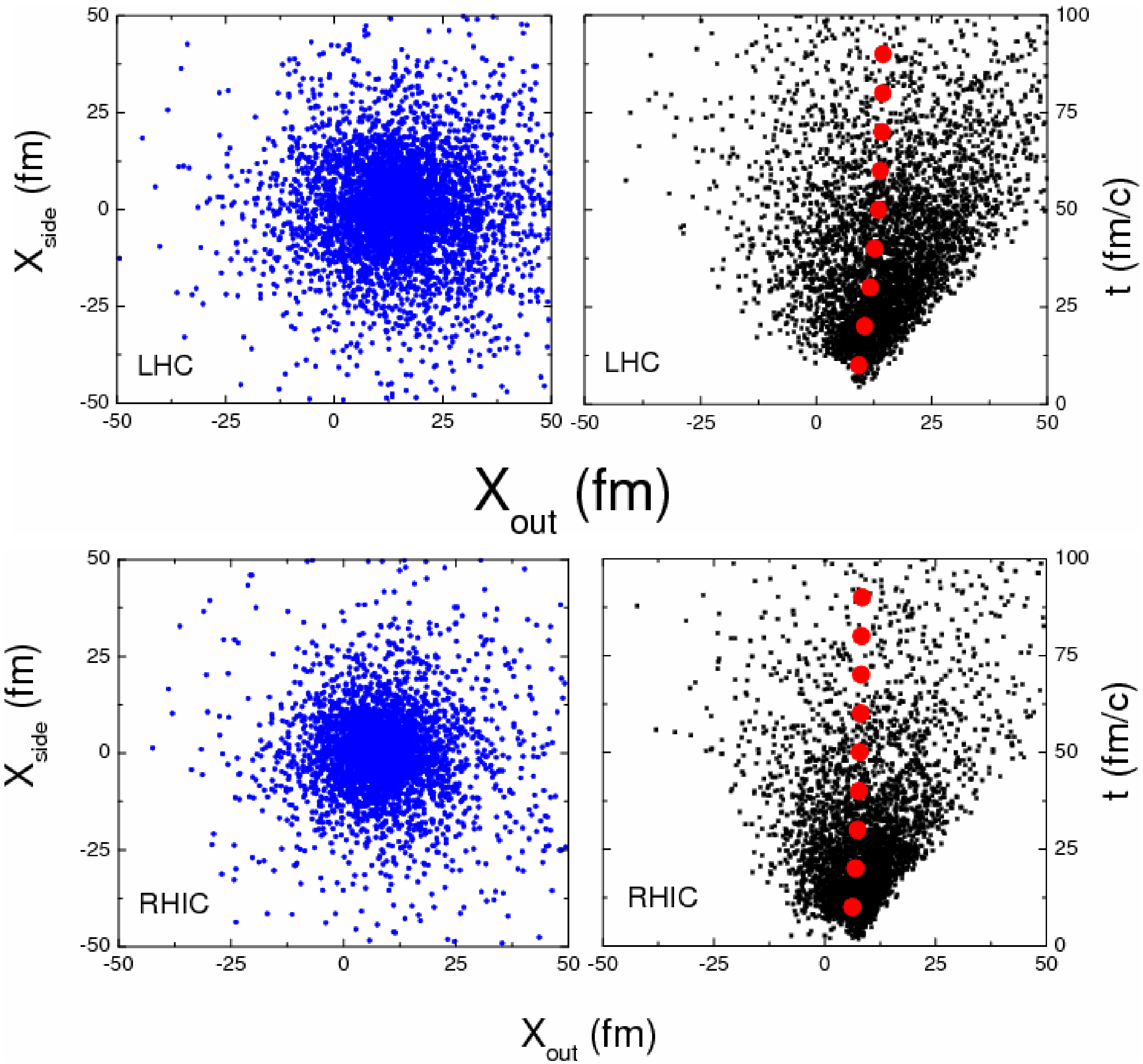
- Larger parton and pion elliptic flows at LHC than at RHIC

Two-pion correlation functions at LHC: Pb+Pb @ 5.5 ATeV



- Smaller correlations at LHC than at RHIC

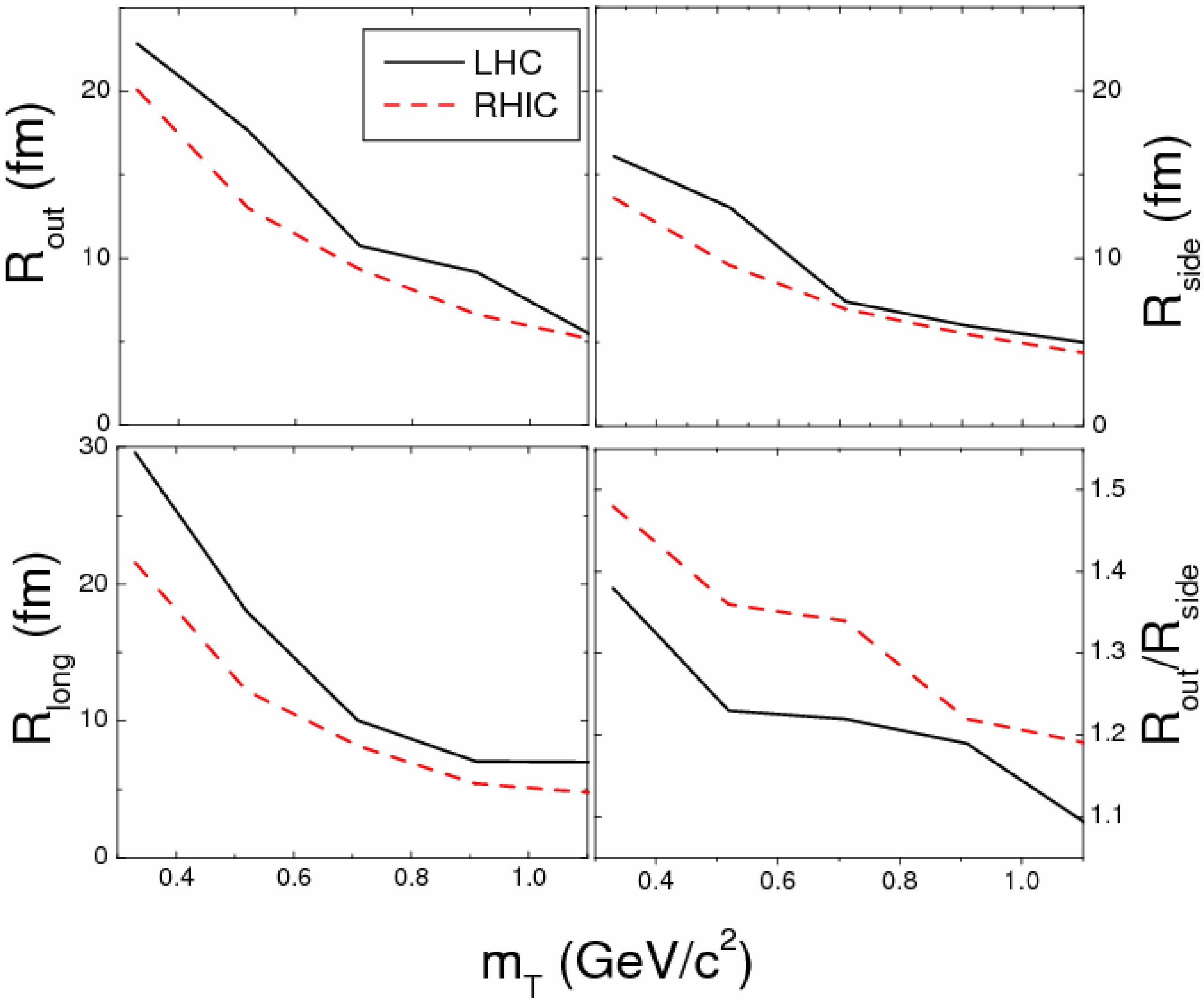
Emission source functions at LHC: Pb+Pb @ 5.5 ATeV



R_{out} = 26 fm
$D_{xo,xo}$ = 356 fm^2
$D_{xo,\beta t}$ = 233 fm^2
$D_{\beta t,\beta t}$ = 756 fm^2

R_{out} = 21 fm
$D_{xo,xo}$ = 232 fm^2
$D_{xo,\beta t}$ = 164 fm^2
$D_{\beta t,\beta t}$ = 556 fm^2

Source raddi at LHC: Pb+Pb @ 5.5 ATeV



- Larger source radii at LHC than at RHIC

Summary

- The AMPT model with string melting and large parton cross section reproduces reasonably at RHIC observed
  - Rapidity distributions and transverse momentum spectra
  - large elliptic flow and mass ordering at low p_T
  - scaling of hadron anisotropic flows $v_4 \approx 1.2 v_2^2$
  - two pion correlation functions
- Emission function in AMPT
  Pions:
  - non-Gaussian with large halo due to resonance decay and explosion
  - shift in out direction
  - strong correlation between out position and time
- Heavy ion collisions at LHC
  - Multiplicity is ~4 times larger
  - Larger trasverse flow, elliptic flow, source radii, and out-time correlation
  - Smaller two-pion correlation functions