Predictions for Heavy Ion Collisions at LHC

Che-Ming Ko
Texas A&M University

- ❑ A multi-phase transport (AMPT) model
- ❑ Rapidity and transverse momentum distributions
- ❑ Anisotropic flows: elliptic & hexadecupole
- ❑ Two-pion and two–kaon interferometries
- ❑ Thermal charm production
- ❑ Jet flavor conversions
- ❑ Charm exotics

Collaborators: L.W. Chen (Shanghai Jiao Tong Univ.), S.H. Lee (Yosei Univ.), Z.W. Lin (East Carolina Univ.), W. Liu & Y.S. Oh (Texas A&M Univ.), B.W. Zhang (Huazhong Normal Univ.), B. Zhang (Askasas State University), ……

Work supported by NSF and Welch Foundation

A multiphase transport (AMPT) model

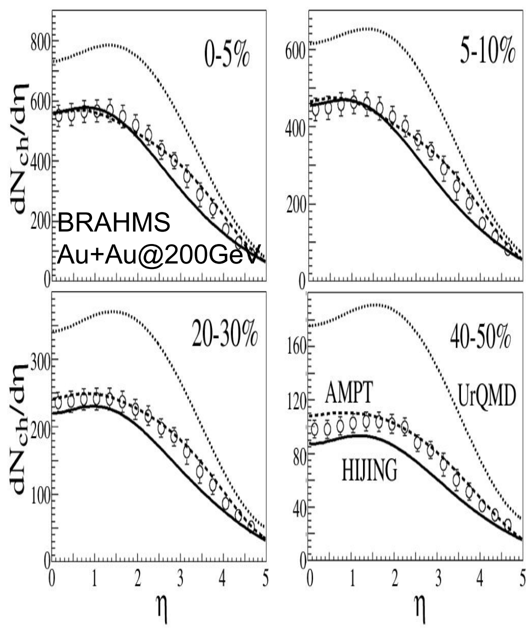
Default: Lin, Pal, Zhang, Li & Ko, PRC 61, 067901 (00); 64, 041901 (01); 72, 064901 (05); http://www-cunuke.phys.columbia.edu/OSCAR

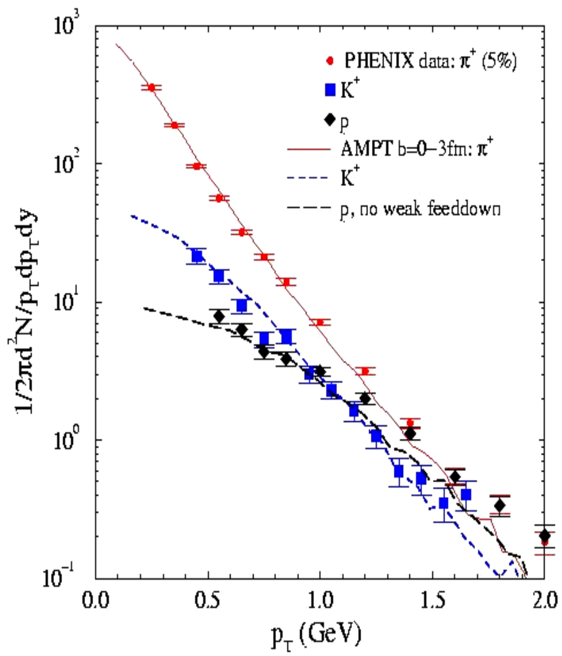
- Initial conditions: HIJING (soft strings and hard minijets)
- Parton evolution: ZPC
- Hadronization: Lund string model for default AMPT
- Hadronic scattering: ART

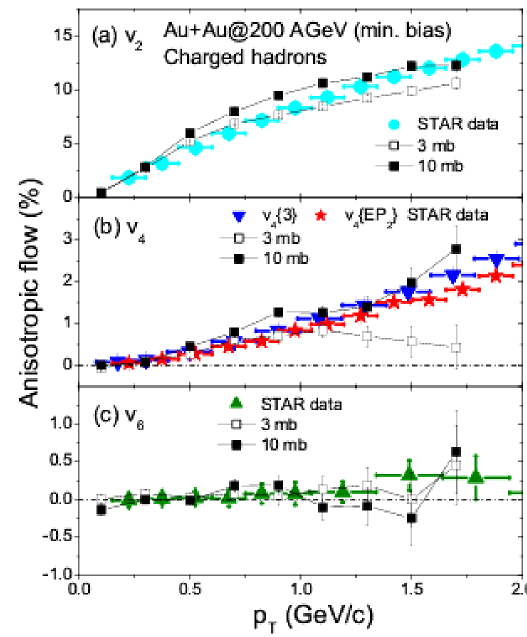
String melting: PRC 65, 034904 (02); PRL 89, 152301 (02)

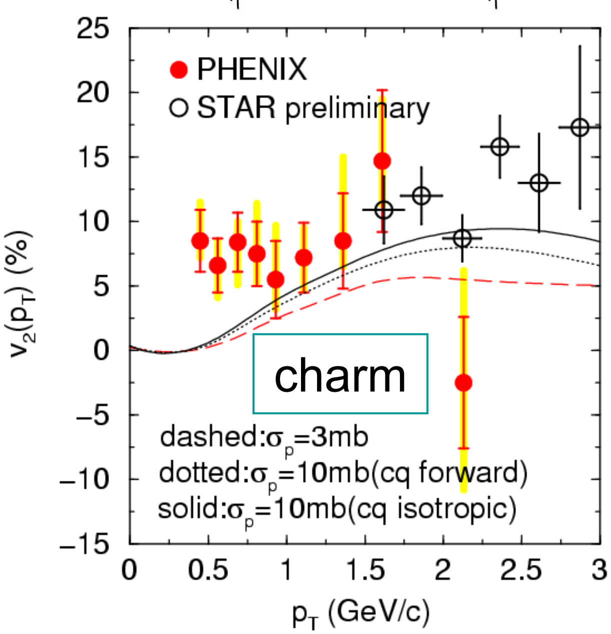
- Convert hadrons from string fragmentation into quarks and antiquarks
- Evolve quarks and antiquarks in ZPC
- When partons stop interacting, combine nearest quark and antiquark to meson, and nearest three quarks to baryon (coordinate-space coalescence)
- Hadron flavors are determined by quarks' invariant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

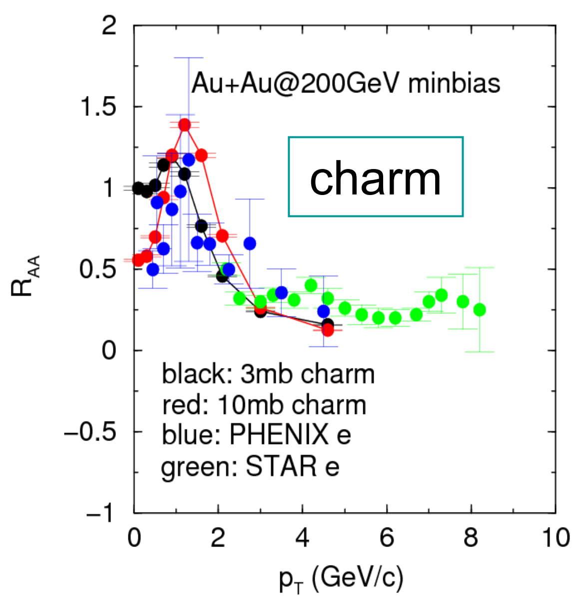
Past results from AMPT for RHIC

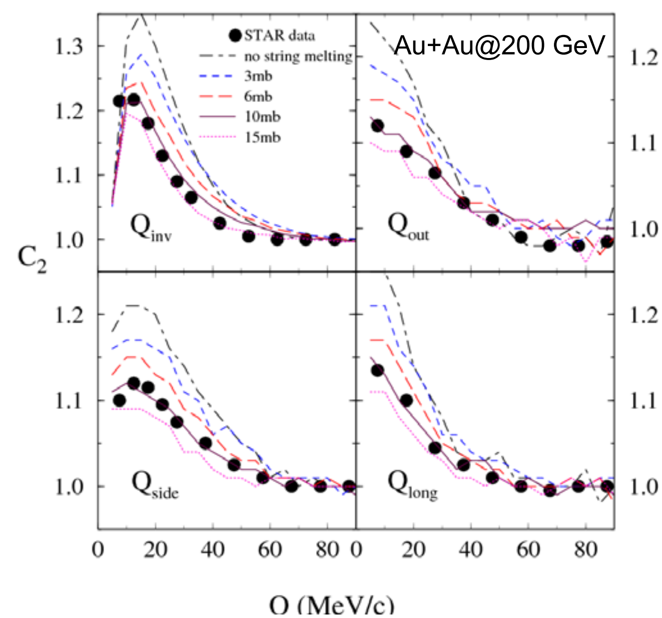




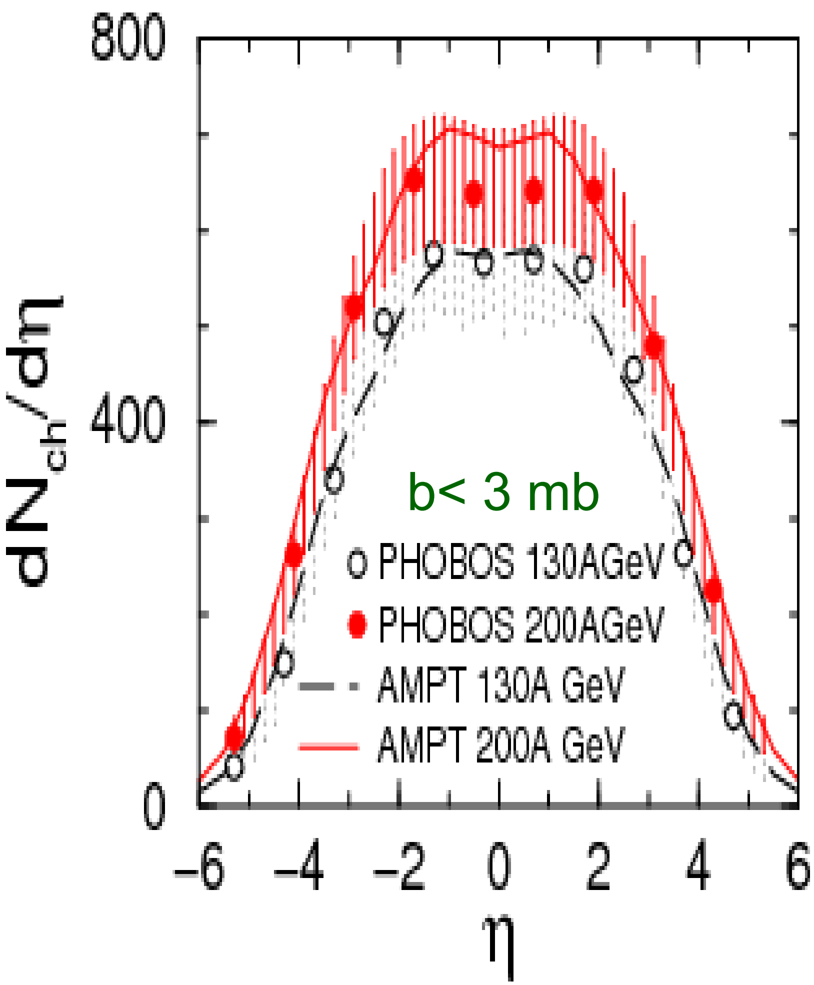


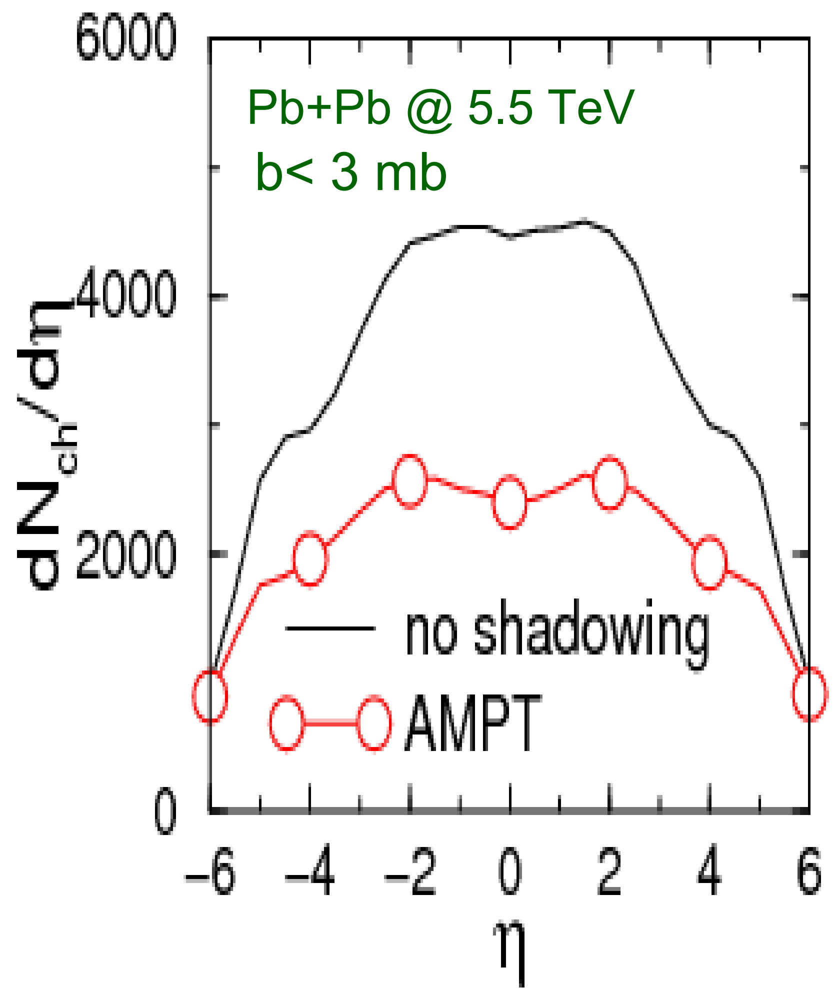






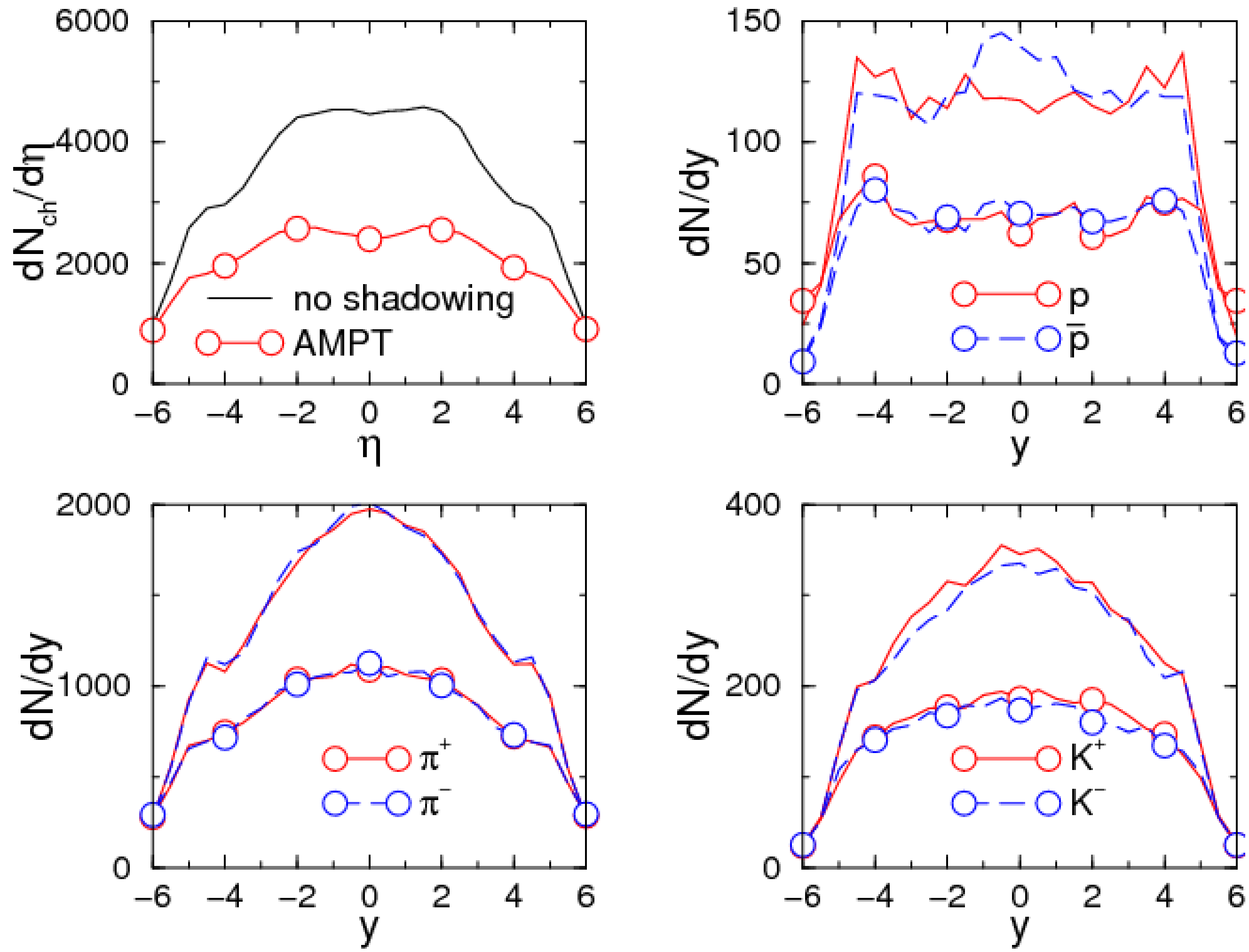
Rapidity distributions at LHC





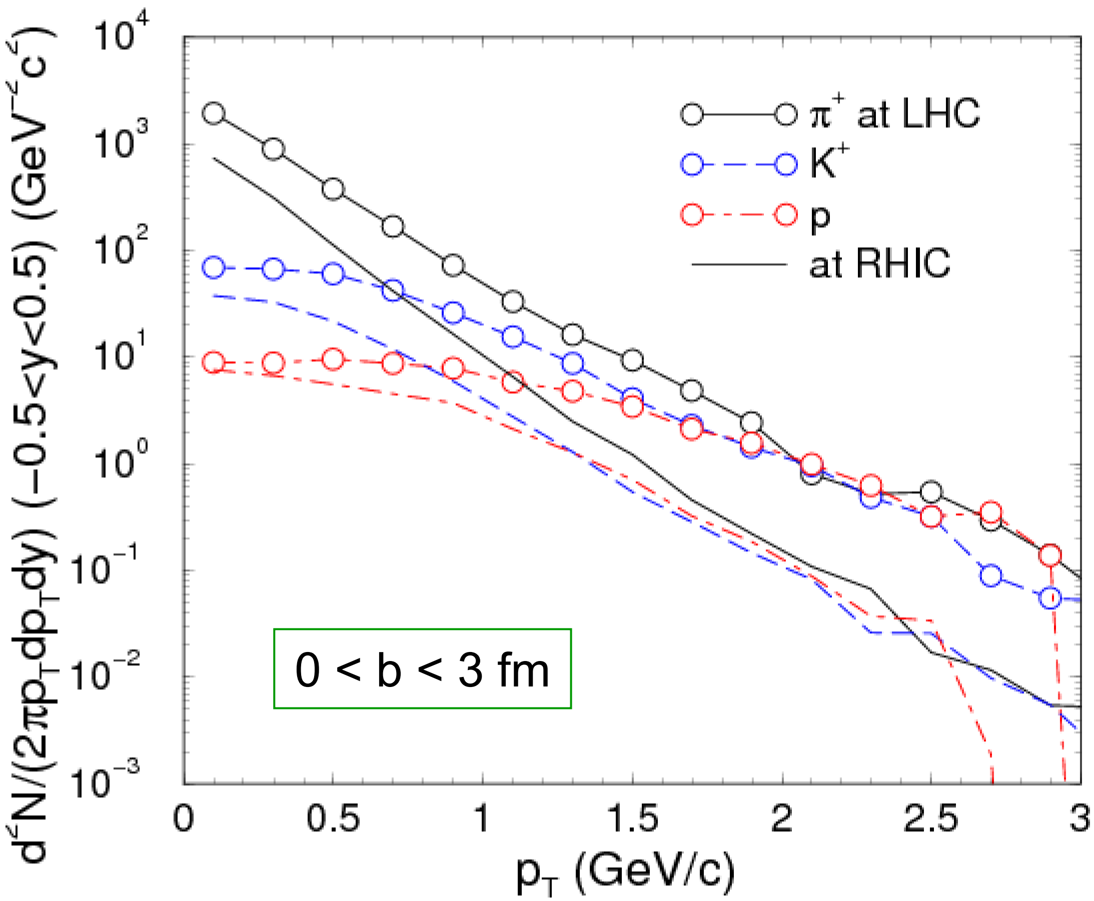
Particle multiplicity at LHC increases by a factor of ~ 4 from that at RHIC

Identified hadron rapidity distributions at LHC



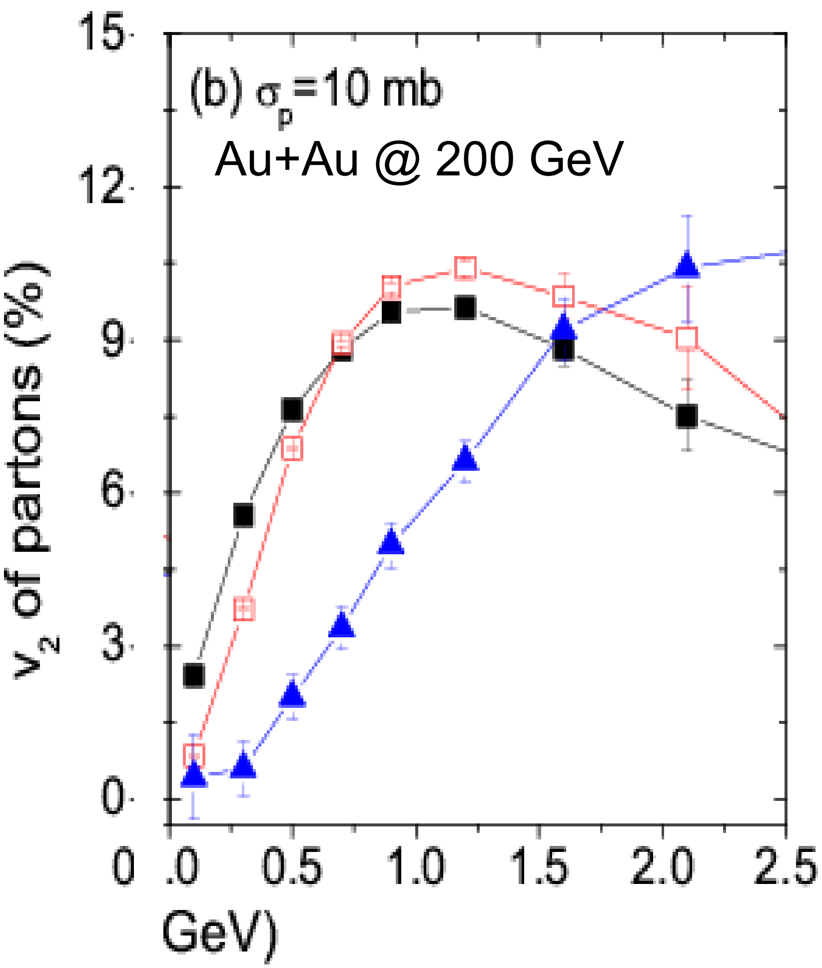
At midrapidity, $N_\pi \approx 5\ N_K \approx 14\ N_p$

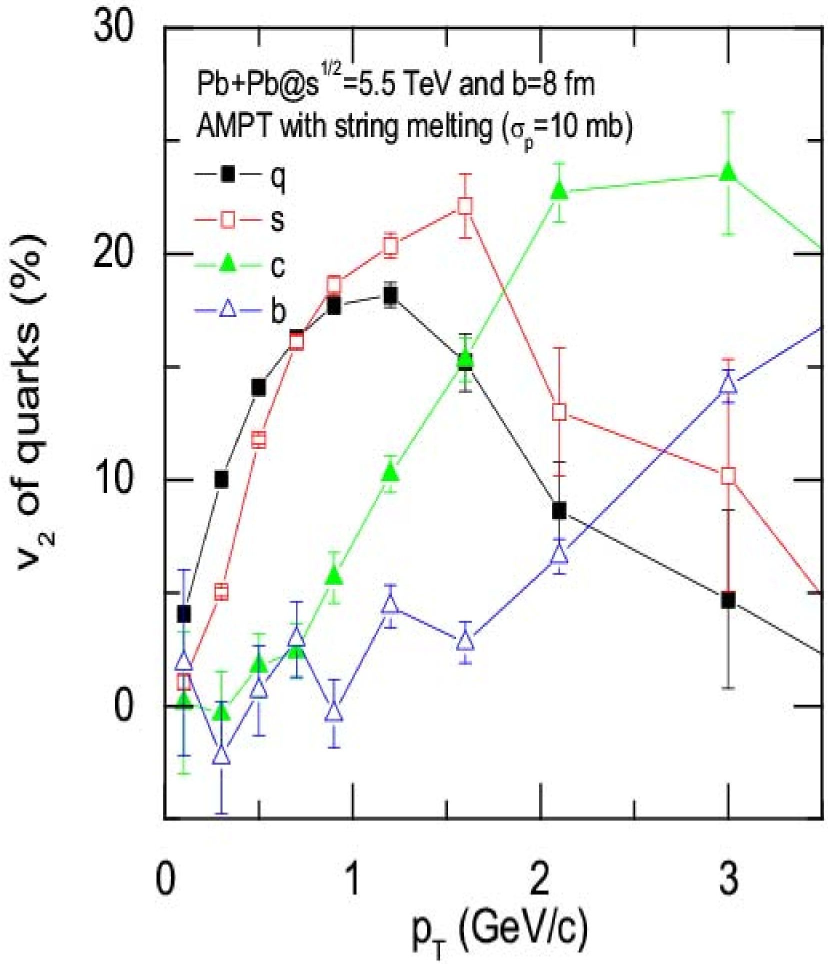
Transverse momentum distributions



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

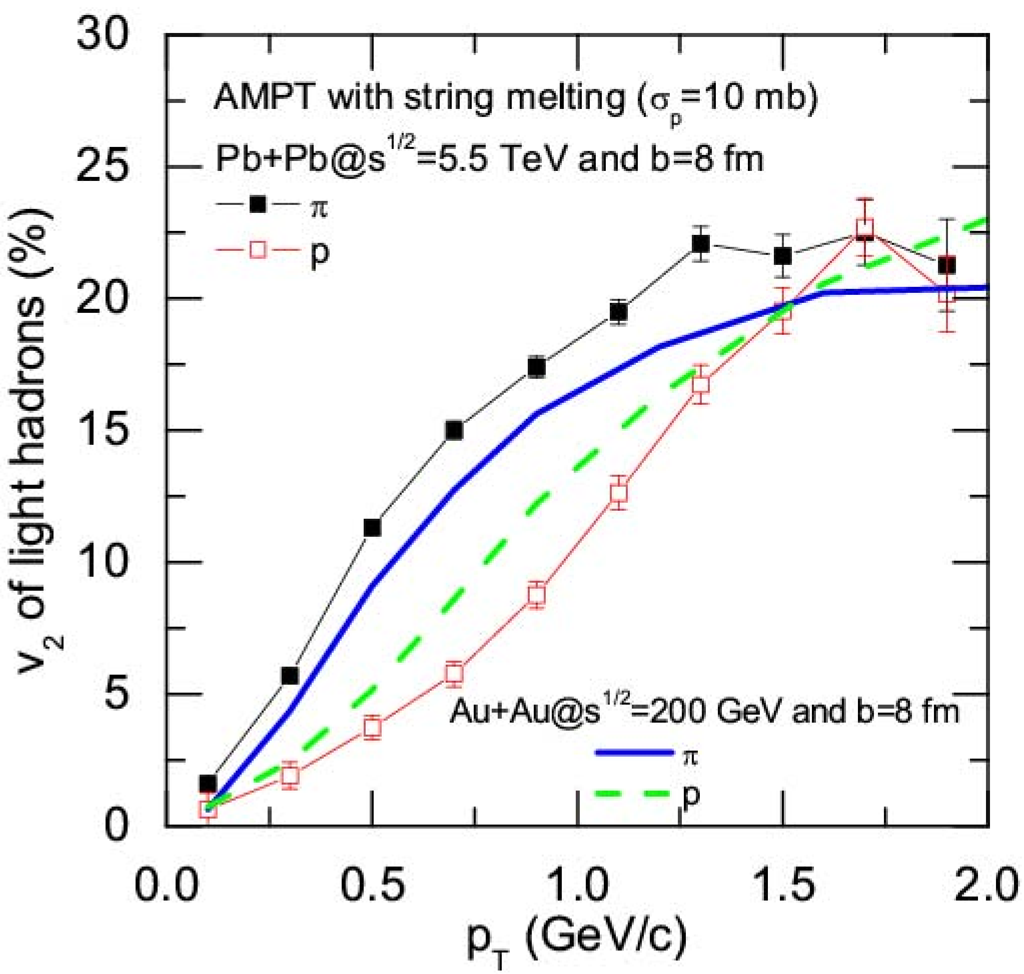
Quark elliptic flows





Quark elliptic flows are larger at LHC than at RHIC, reaching ~ 20%

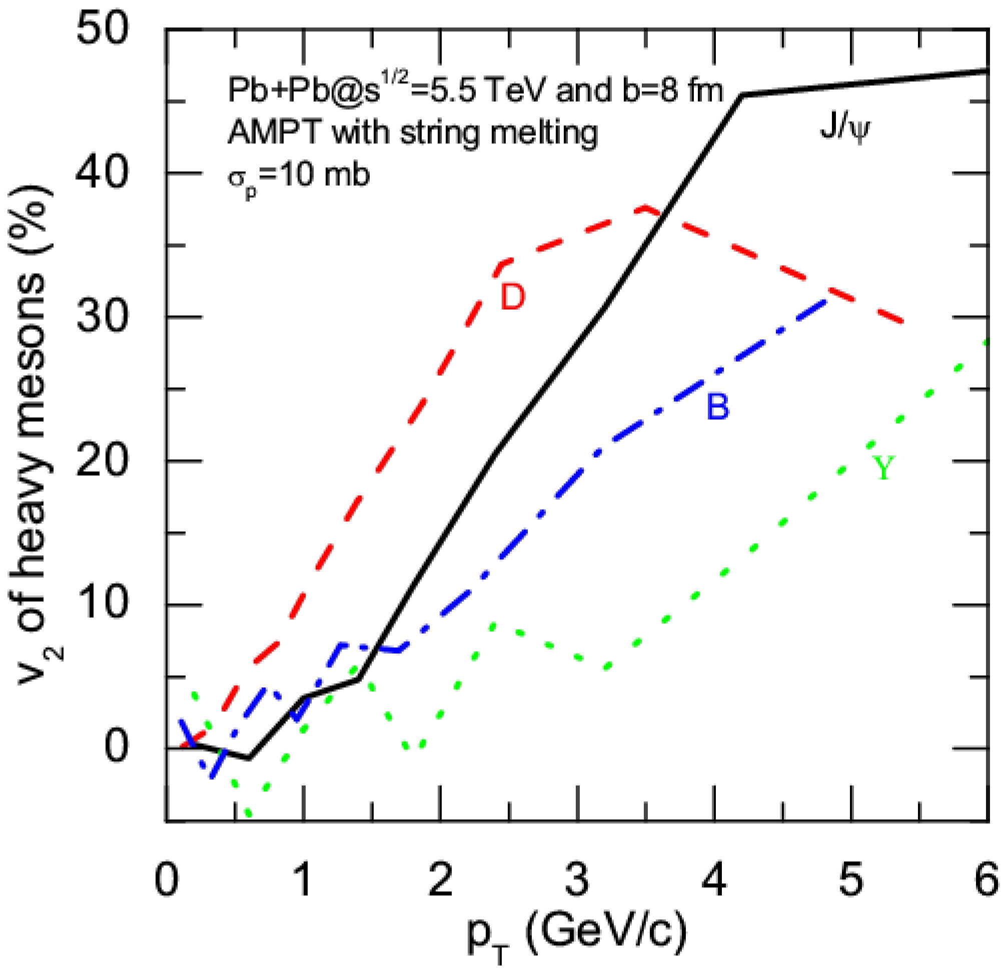
Pion and proton Elliptic flow at LHC



Elliptic flow is larger for pions but smaller for protons at LHC than at RHIC

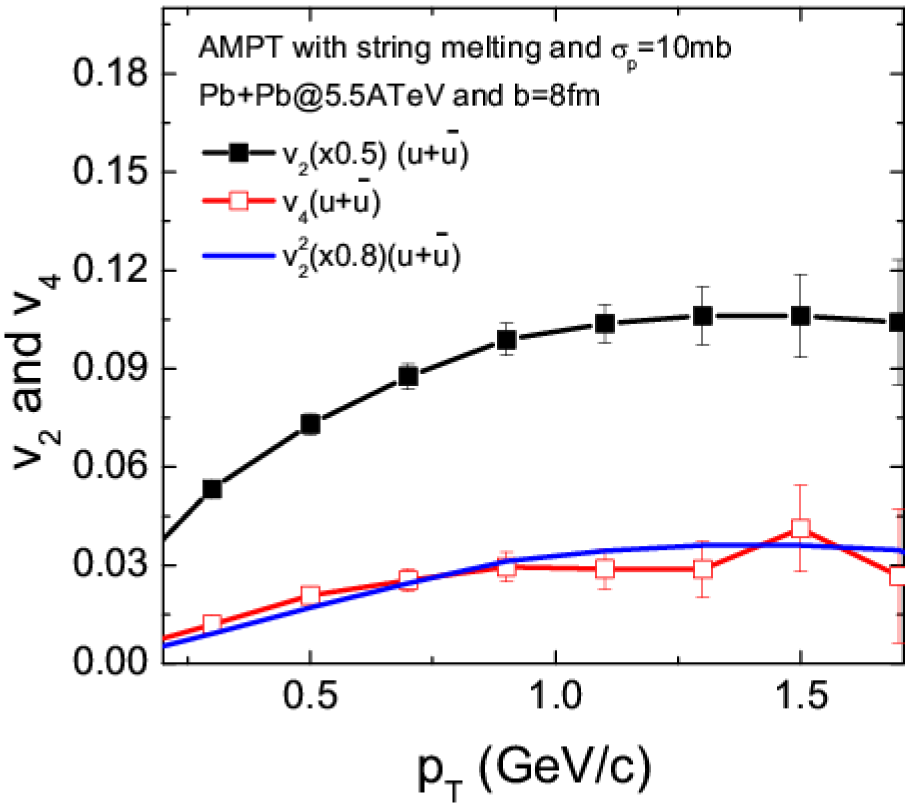
Heavy meson elliptic flows at LHC

Quark coalescence model

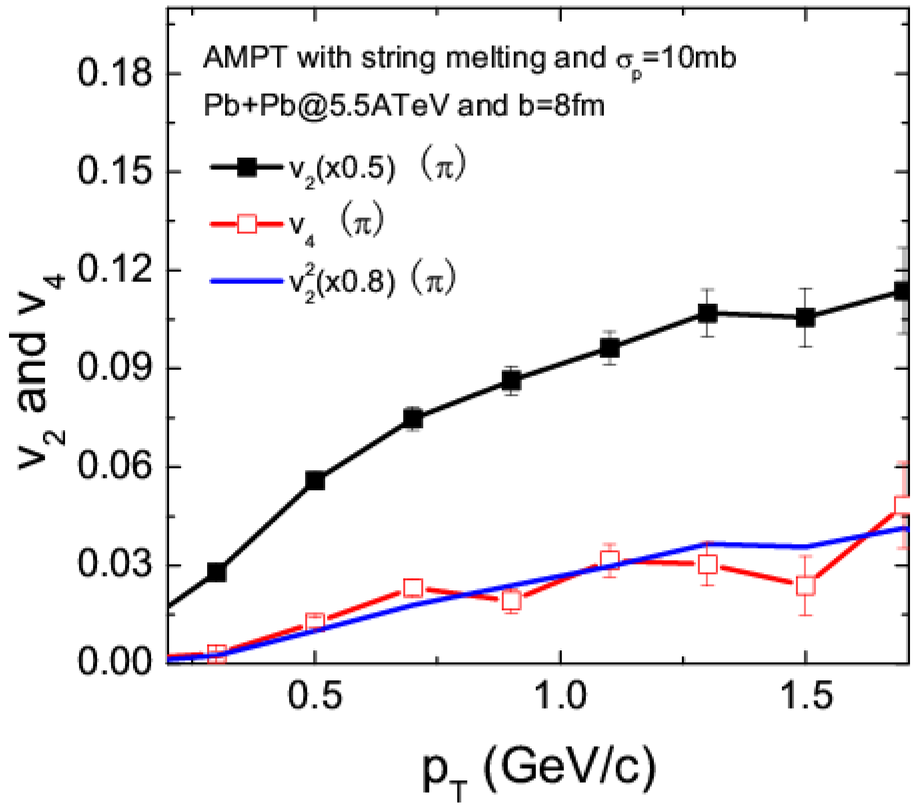


$$v_{2M}(p_T) \cong v_{2,q_1}((m_{q_1}/m_M)p_T) + v_{2,q_2}((m_{q_2}/m_M)p_T)$$

Light quark and pion hexadecupole flows at LHC



naïve coalescence model



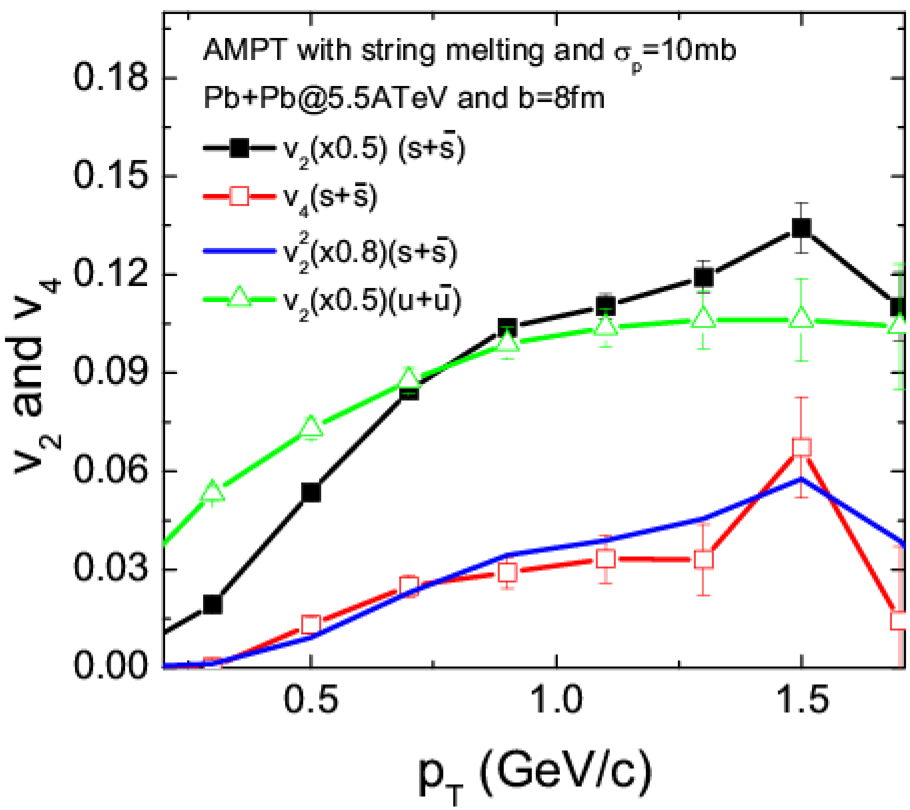
AMPT model

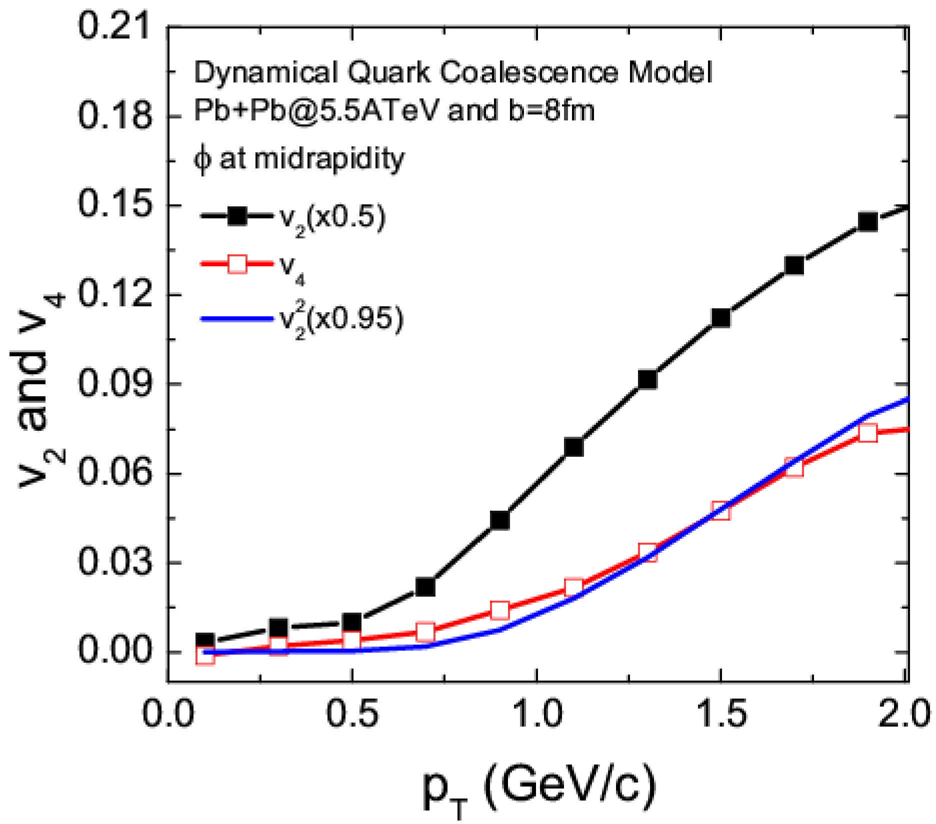
$$\frac{v_{4,M}}{v_{2,M}^2} \cong \frac{1}{4} + \frac{1}{2}\frac{v_{4,q}}{v_{2,q}^2} \approx 0.65$$

$$\frac{v_{4,M}}{v_{2,M}^2} \approx 0.8$$

~1.2 at RHIC

Strange quark and phi hexadecupole flows at LHC





Coalescence model

$$\frac{v_{4,\varphi}}{v_{2,\varphi}^2} \cong \frac{1}{4} + \frac{1}{2}\frac{v_{4,s}}{v_{2,s}^2} \approx 0.65$$

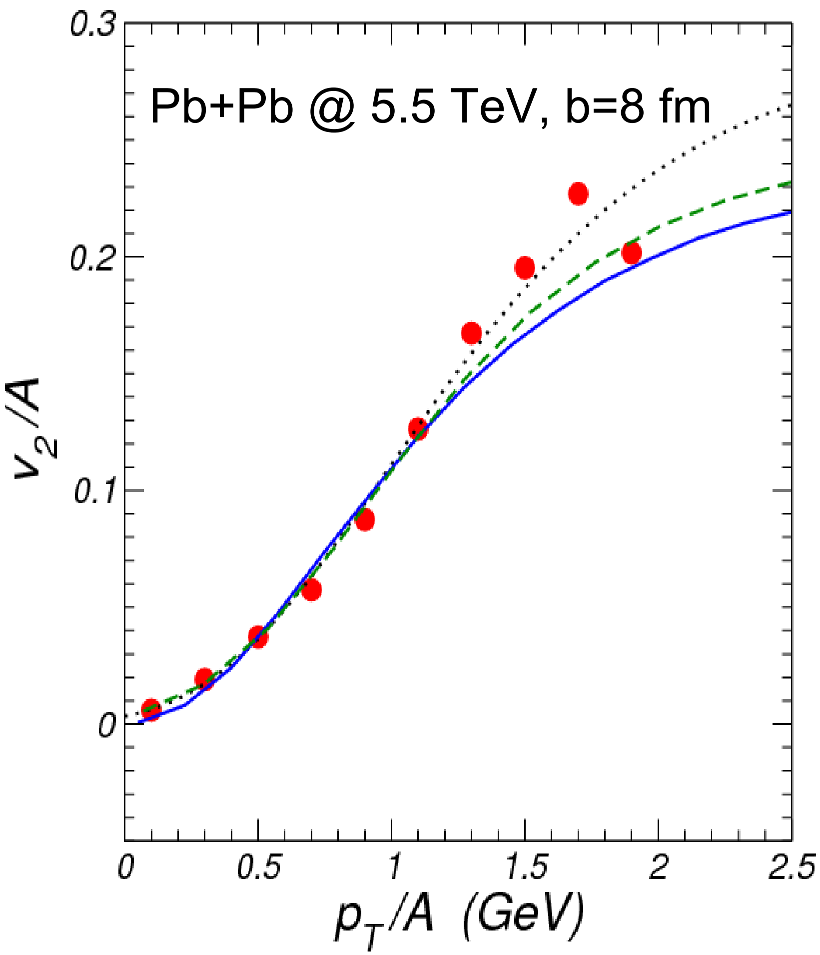
AMPT model

$$\frac{v_{4,\varphi}}{v_{2,\varphi}^2} \approx 0.95$$

~1.2 at RHIC

Deuteron elliptic flow at LHC

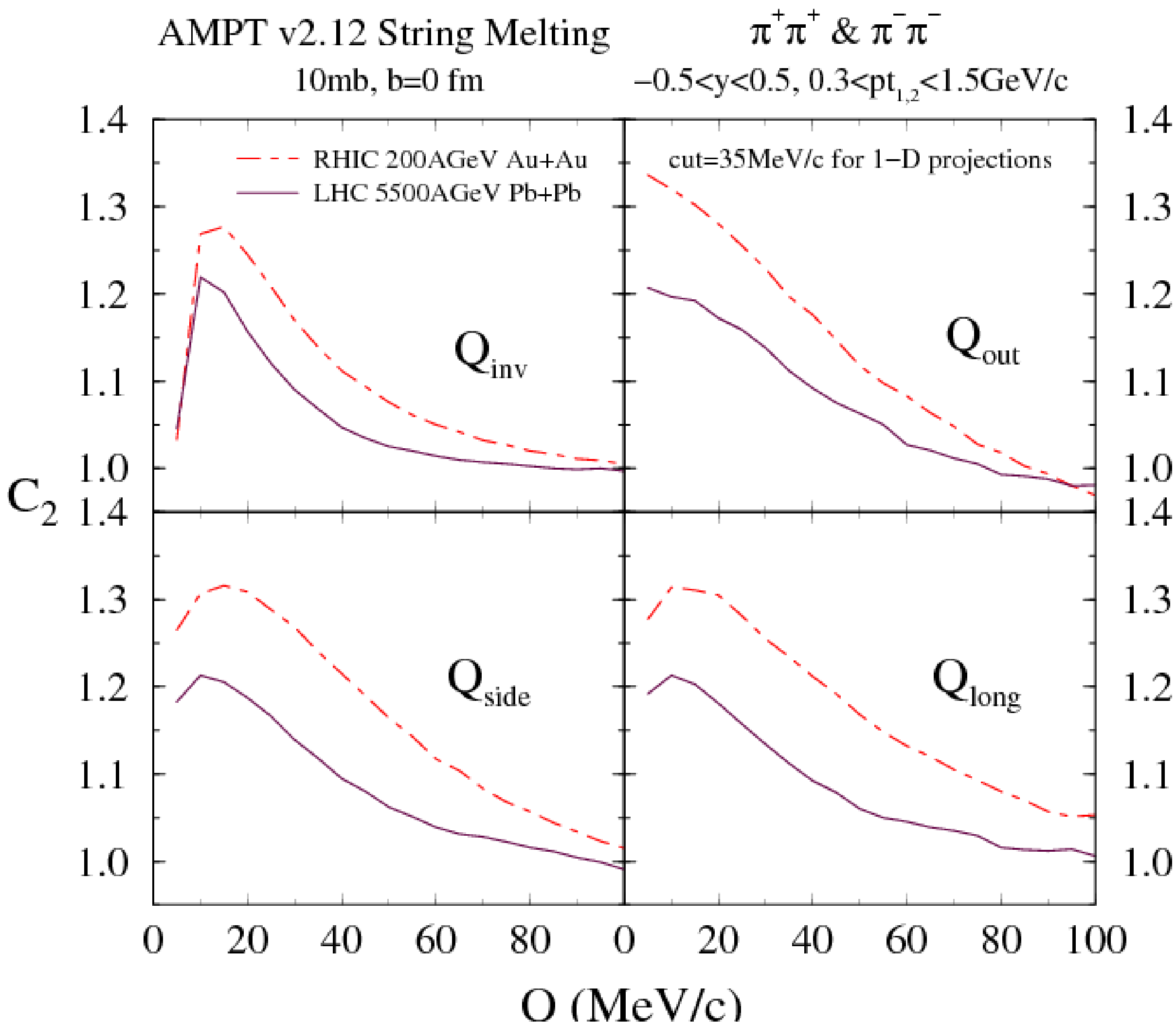
Oh & Ko, PRC 76, 054910 (08)



- Filled circles: proton v_2 from AMPT
- Dotted line: fitted proton v_2
- Dashed line: deuteron v_2 from coalescence model including deuteron wave function effect
- Solid lines: deuteron v_2 from a dynamic model based on reactions $NN \rightarrow d\pi$, $NN\pi \rightarrow d\pi$ and $NNN \rightarrow dN$

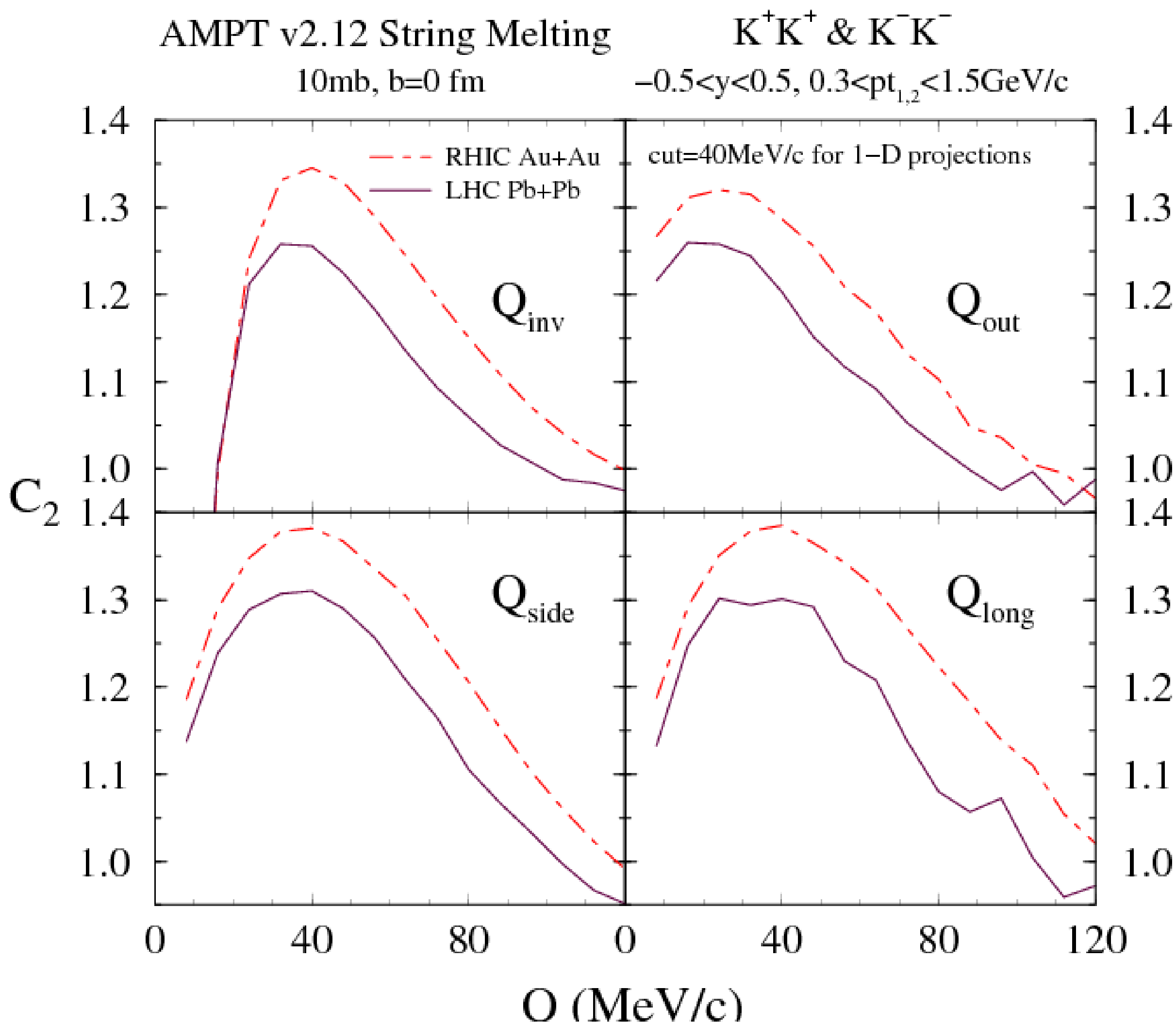
Coalescence model is a very good approximation for weakly bound particles

Pion interferometry



Two-pion correlation functions narrower at LHC than at RHIC

Kaon interferometry



Two-kaon correlation functions narrower at LHC than at RHIC

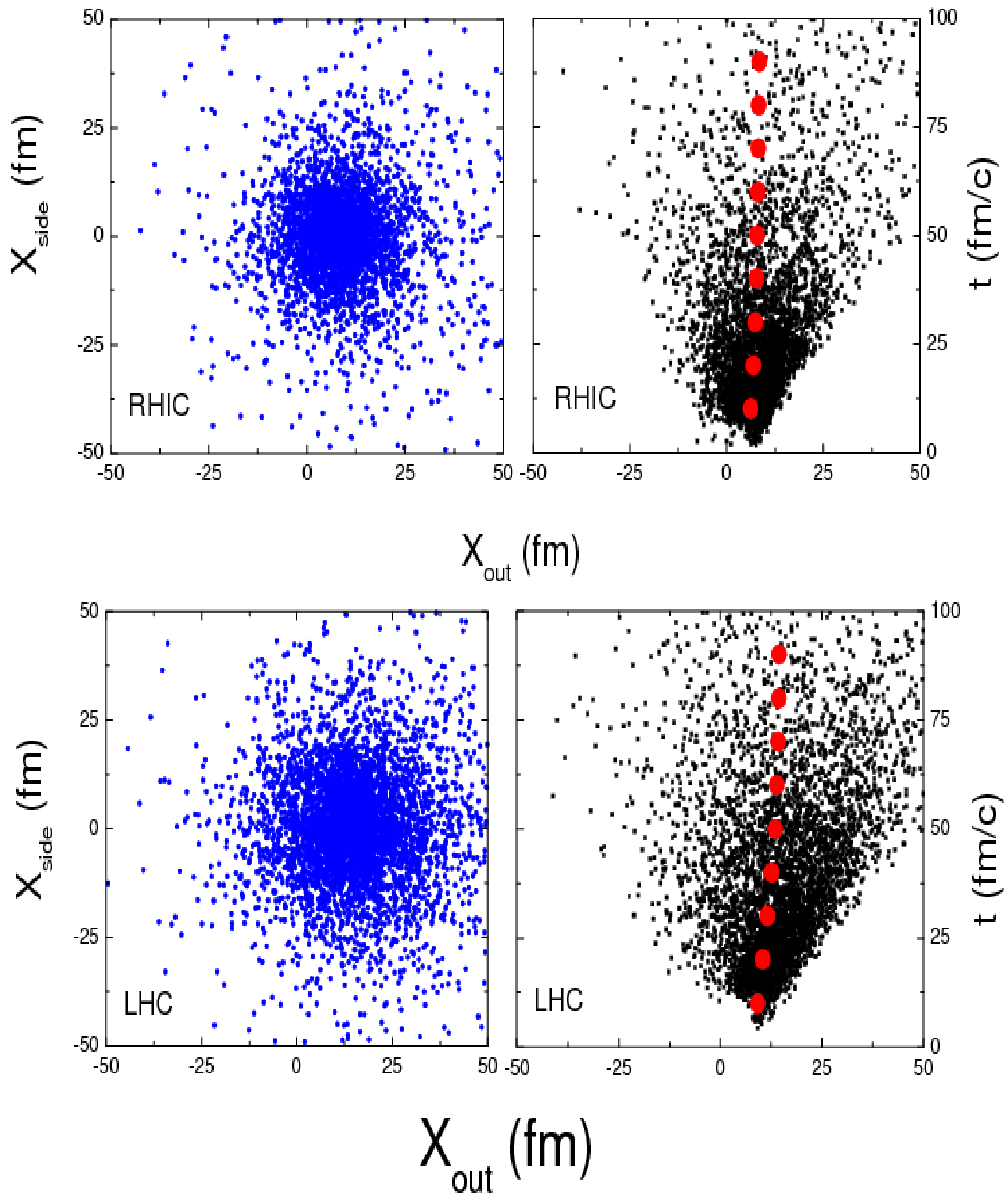
Radii from Gaussian fit to correlation functions

$$C_2(\vec{Q},\vec{K}) = 1 + \lambda \exp\left(-\sum_{i=1}^{3} R_{ii}^2(K) Q_i^2 \right)$$

	R_{out} (fm)	R_{side} (fm)	R_{long} (fm)	λ	R_{out}/R_{side}
RHIC (π)	3.60	3.52	3.23	0.50	1.02
LHC (π)	4.23	4.70	4.86	0.43	0.90
RHIC (K)	2.95	2.79	2.62	0.94	1.06
LHC (K)	3.56	3.20	3.16	0.89	1.11

Source radii for pions are larger than for kaons and both are larger at LHC than at RHIC

Emission source functions



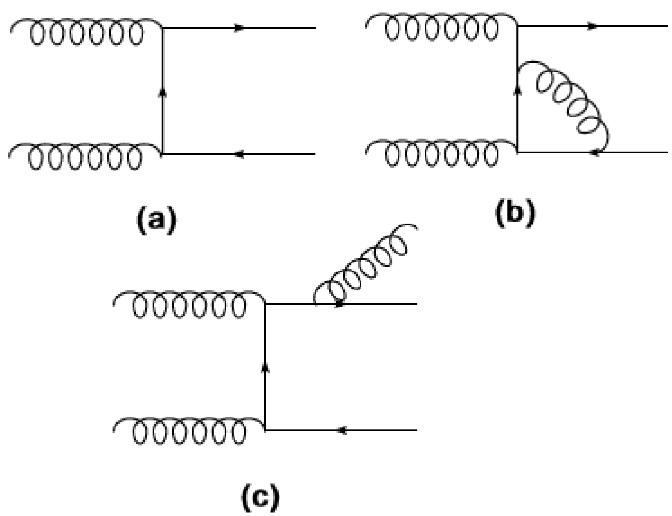
Shift in out direction

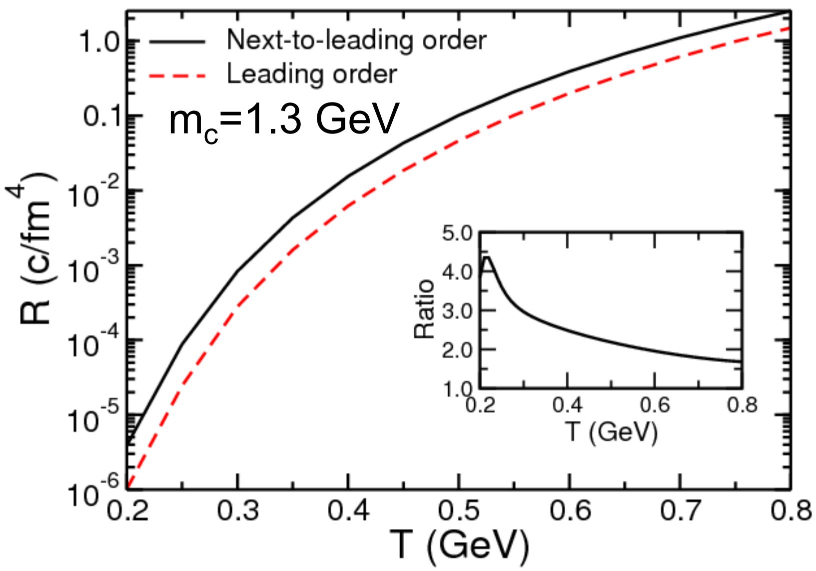
- Strong correlation between out position and emission time
- Large halo due to resonance (ω) decay and explosion

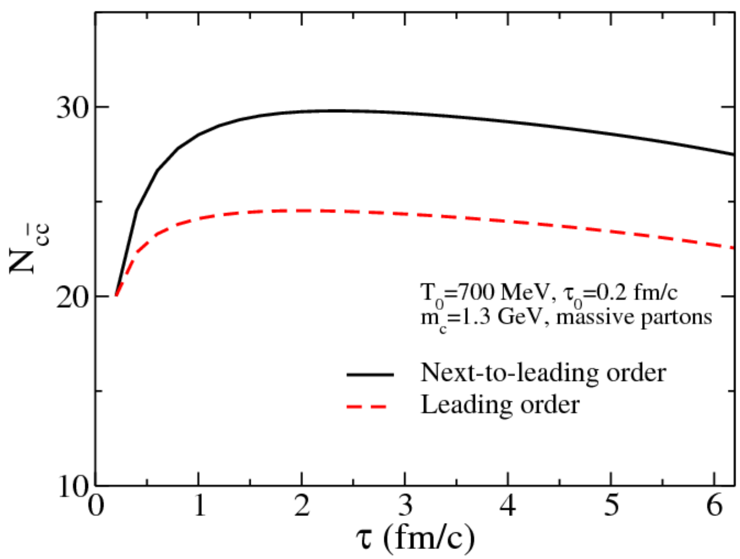
→ non-Gaussian source

Thermal charm production in QGP

Zhang, Liu & Ko,
PRC 77, 024901 (08)







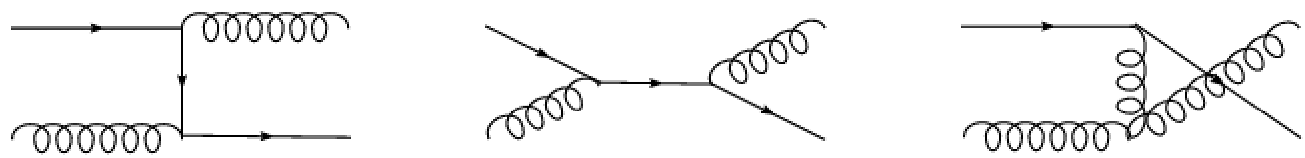
- Thermal production non-negligible
- Next-leading order and leading order contributions are comparable
- Insensitive to gluon masses
- Effect increases by about 2 for initial temperature T_0=750 MeV but decreases by ~ 2 for m_c=1.5 GeV

Jet conversions in QGP

Liu, Zhang & Ko,
PRC 75, 051901 (R) (08)

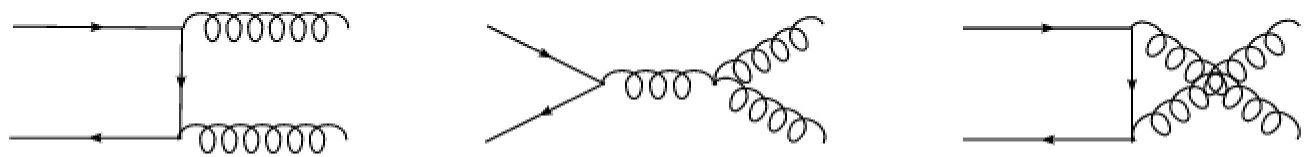
- Quark jet conversion

Elastic process: qg→gq



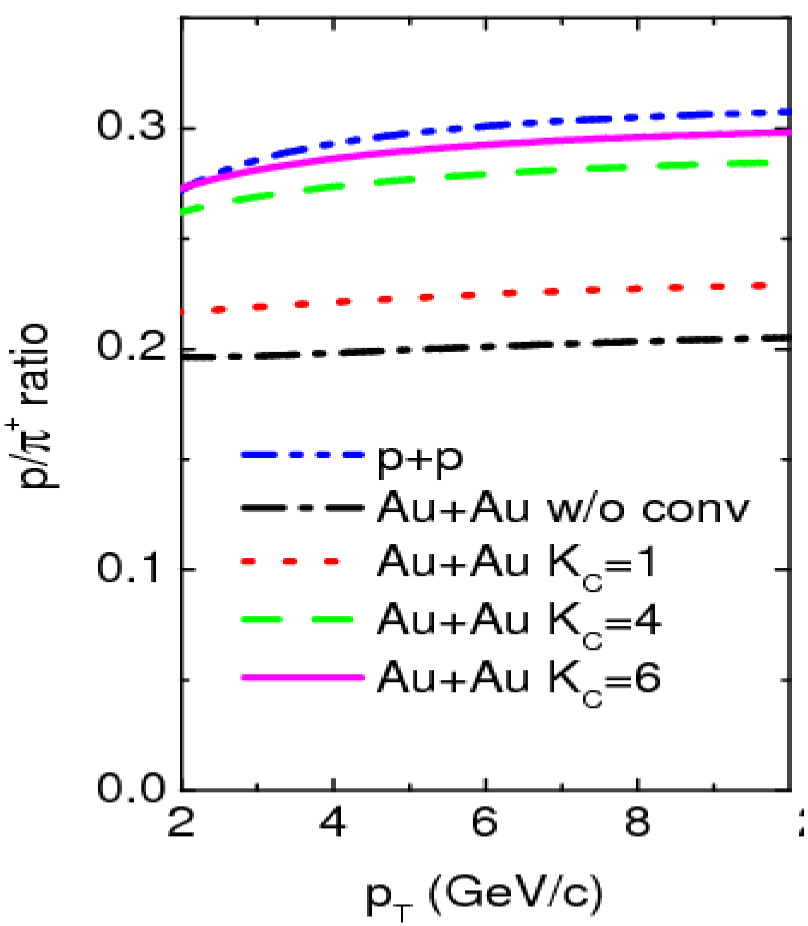
Gluon is taken to have a larger momentum in the final state

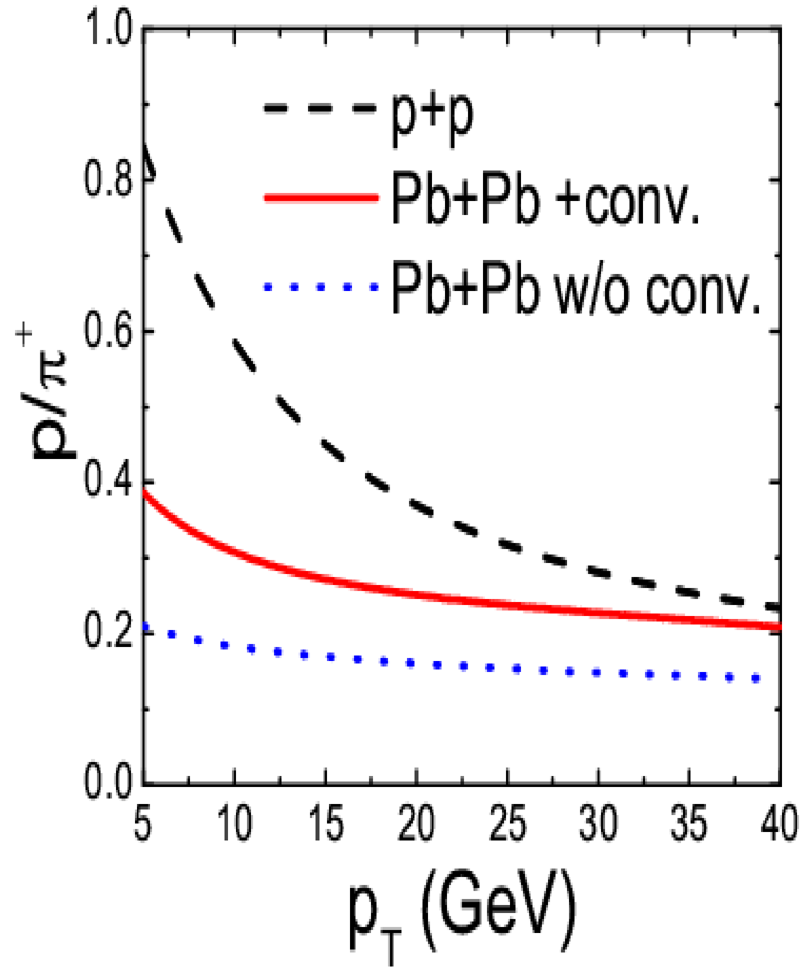
Inelastic process: $q\bar{q} \to gg$



- Gluon jet conversion: similar to above via inverse reactions

Proton to π^+ ratio at high transverse momenta





p/π ratio similar to that in p+p collisions at RHIC when quark and gluon conversion widths are multiplied by K_C~4-6. It is lower than p+p at LHC.

Diquark in sQGP and Λ_c enhancement

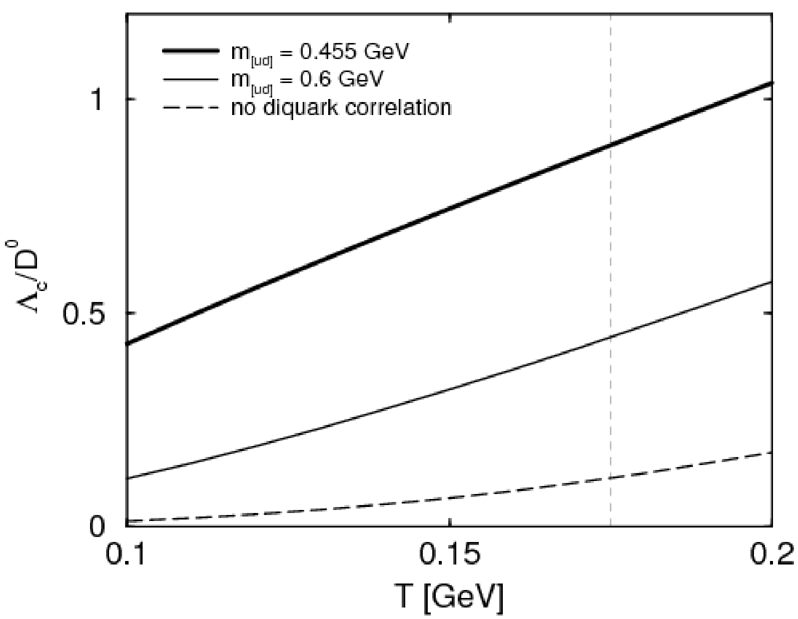
Lee, Yasui, Ohnishi, Yoo & Ko, PRL, in press

Diquark mass due to color-spin interaction:

$$m_{[ud]} \approx m_u + m_d - C\,\vec{s}_u \cdot \vec{s}_d \frac{1}{m_u m_d} \approx 450\,\mathrm{MeV}$$

for $m_u = m_d = 300$ MeV and $C/m_u^2 \sim 195$ Me V from $m_\Delta - m_N$

Coalescence model



Statistical model

$$\frac{\Lambda_c}{D_0} \approx 2\left(\frac{m_{\Lambda_c}}{m_{D_0}}\right)^{3/2} e^{-\left(m_{\Lambda_c} - m_{D_0}\right)/T_c} \approx 0.24$$

- Enhanced by a factor of 4-8
- Similar for Λ_B/B_0

Charm exotics production in HIC

Lee, Yasui, Liu & Ko
Eur. J. Phys. C 54, 259 (08)

- Charm tetraquark mesons
  - T_{cc} ($ud\bar{c}\bar{c}$) is ~ 80 MeV below D+D* according to quark model
  - Coalescence model predicts a yield of ~5.5×10^{-6} in central Au+Au collisions at RHIC and ~9×10^{-5} in central Pb+Pb collisions at LHC if total charm quark numbers are 3 and 20, respectively
  - Yields increase to 7.5×10^{-4} and 8.6×10^{-3}, respectively, in the statistical model

- Charmed pentaquark baryons
  - Θ_{cs}($uds\bar{c}$) is ~ 70 MeV below D+Σ in quark model
  - Yield is ~1.2×10^{-4} at RHIC and ~7.9×10^{-4} at LHC from the coalescence model for total charm quark numbers of 3 and 20, respectively
  - Statistical model predicts much larger yields of ~4.5×10^{-3} at RHIC and ~2.7×10^{-2} at LHC

Summary

Compared to RHIC, heavy ion collisions at LHC have:

- ~ factor of 4 larger charged particle multiplicity
- larger transverse flow
- larger elliptic flow for pion and smaller one for protons
- large heavy quark and meson elliptic flows
- smaller v_4/v^2_2 ratios for both quarks and hadons
- narrower two-pion and two-kaon correlation functions and larger source radii
- enhanced thermal charm production
- smaller p/pi ratio at high p_T than in p+p
- similar enhancement of heavy baryons
- possible factory for charm exotics