Partonic transport description of heavy ion collisions

Che-Ming Ko
Texas A&M University

- Introduction
- The parton cascade model
- Anisotropic flow
- HBT
- Mach-cone
- Charge fluctuation
- Elliptic flow at FAIR and LHC
- Summary

Chronology of parton transport model

- PCM: Geiger & Muller (1992)
- ZPC: Zhang (1998)
- MPC: Molnar (2000)
- AMPT: Zhang, Lin, Li, Pal, & Ko (2000)

  HIJING+ZPC+ART
- PACIAE: Sa (2004)

  PYTHIA+PC+LUCIAE
- Xu & Greiner (2005)

  Include gg$\rightarrow$ggg and its inverse

Zhang's parton cascade (ZPC)

Bin Zhang, Comp. Phys. Comm. 109, 193 (1998)

$$p^{\mu}\partial_{\mu}f_1(x,p,t) \propto \int dp_2 d\Omega \left|\vec{v}_1 - \vec{v}_2\right| (d\sigma/d\Omega)(f_1'f_2'-f_1f_2)$$

$$\frac{d\sigma}{dt} \cong \frac{9\pi\alpha_s^2}{2(t-\mu^2)^2}, \quad \sigma \cong \frac{9\pi\alpha_s^2}{2\mu^2}\frac{1}{1+\mu^2/s}$$

- Using α_s=0.5 and screening mass μ=gT≈0.6 GeV at T≈0.25 GeV, then $\langle s\rangle^{1/2}$≈4.2T≈1 GeV, and pQCD gives σ≈2.5 mb and a transport cross section

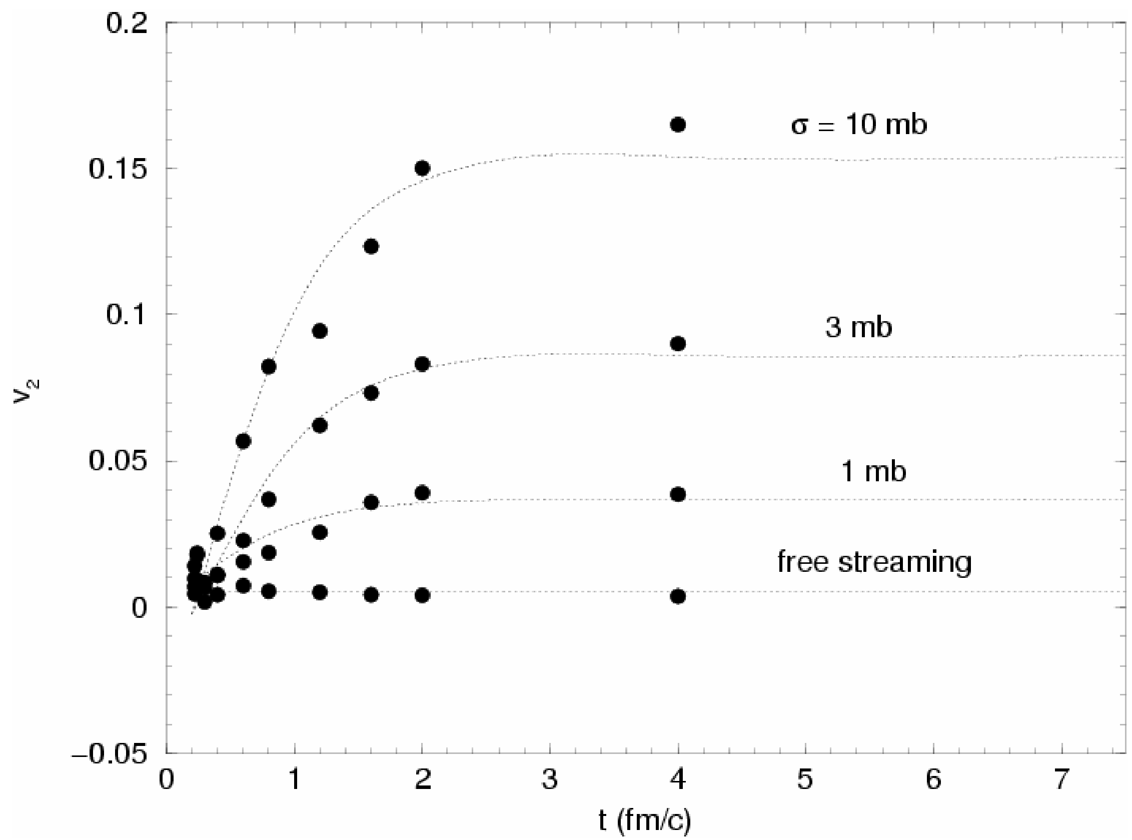
$$\sigma_t \equiv \int d\Omega \frac{d\sigma}{d\Omega}(1-\cos\theta) \approx 1.5\text{mb}$$

- σ=6 mb → μ≈0.44 GeV, σ_t≈2.7 mb
- σ=10 mb → μ≈0.35 GeV, σ_t≈3.6 mb

Elliptic flow from Zhang's parton cascade

Zhang, Gyulassy & Ko, PLB 455, 45 (1999)

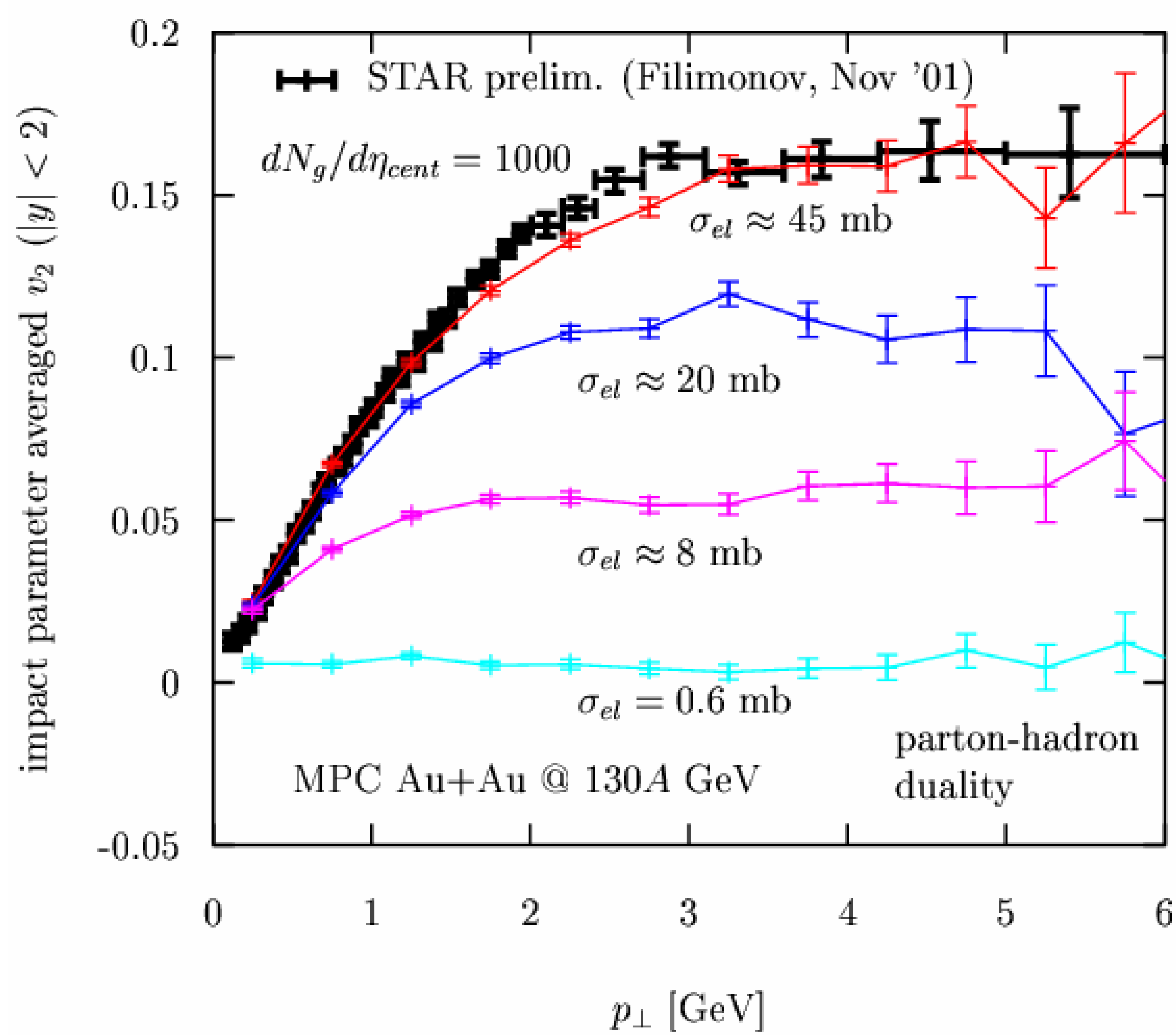
Based on Zhang's parton cascade (ZPC) (CPC 109, 193 (1998)), using minijet partons from HIJING for Au+Au @ 200 AGeV and b=7.5fm



v_2 of partons is sensitive to their scattering cross section

Elliptic flow from Molnar's parton cascade

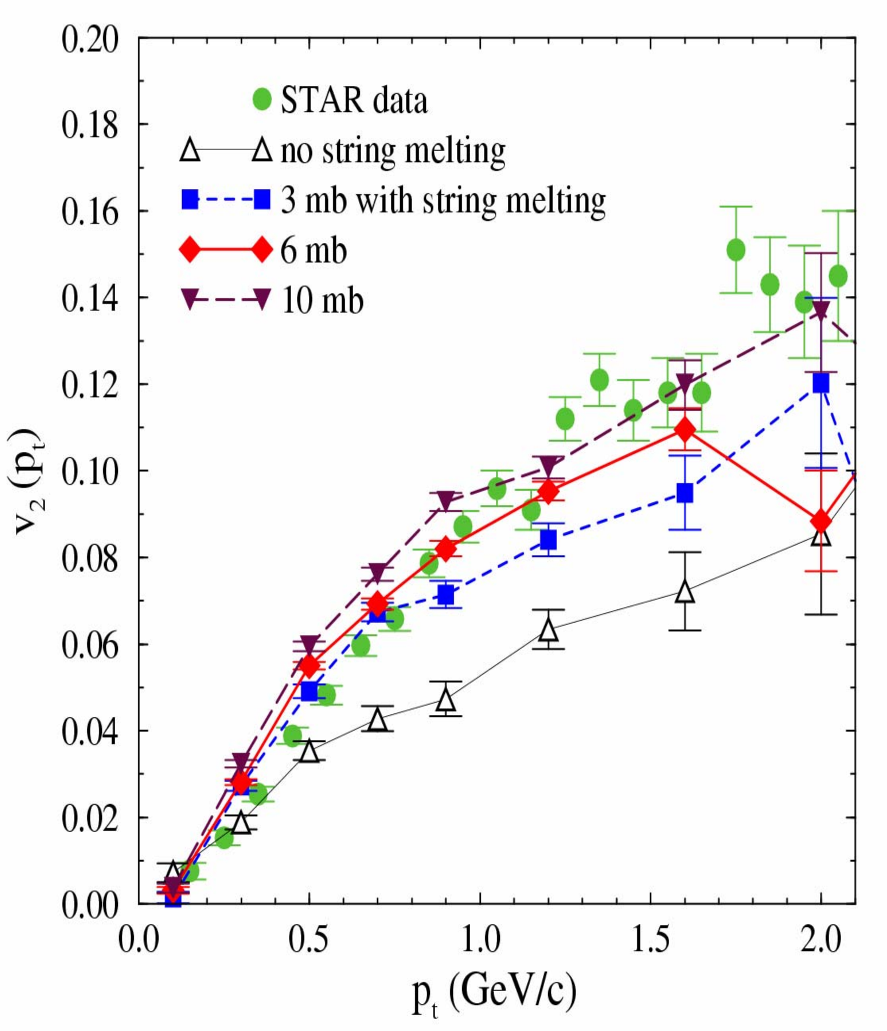
Molnar,
NPA 774, 257 (2006)

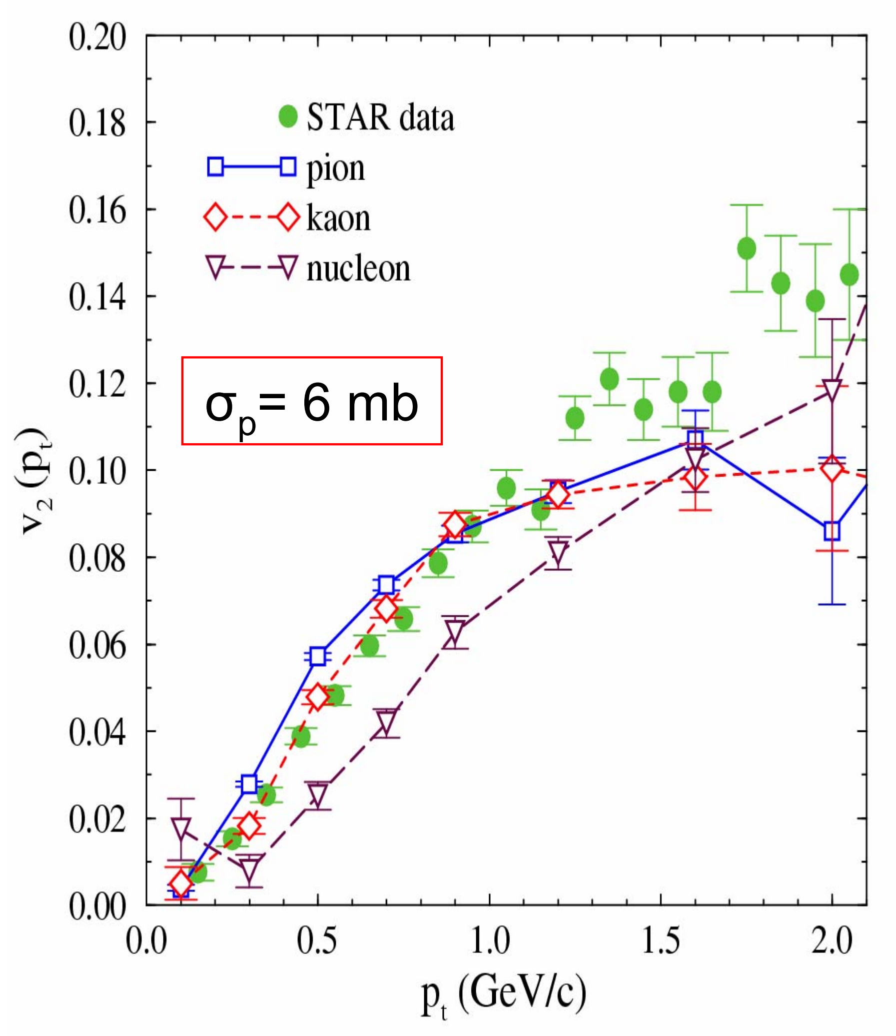


Very large parton cross section is needed to generate the observed elliptic flow.

Elliptic flow from AMPT

Lin & Ko, PRC 65, 034904 (2002)

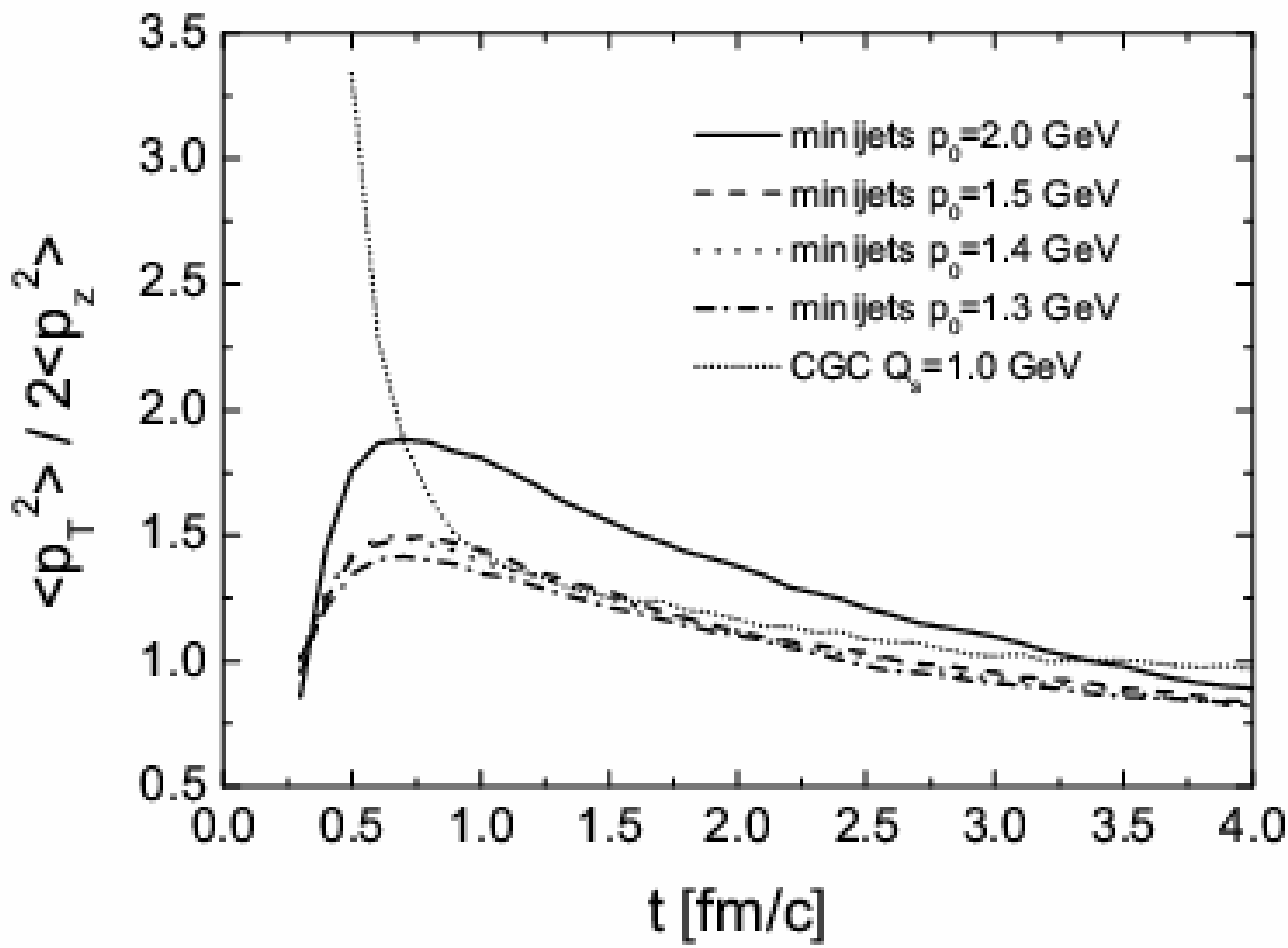




- Based on coordinate-space coalescence
- Need string melting and large parton scattering cross section
- Mass ordering of v_2 at low p_T as in hydrodynamic model

Effect of two-body radiative scattering

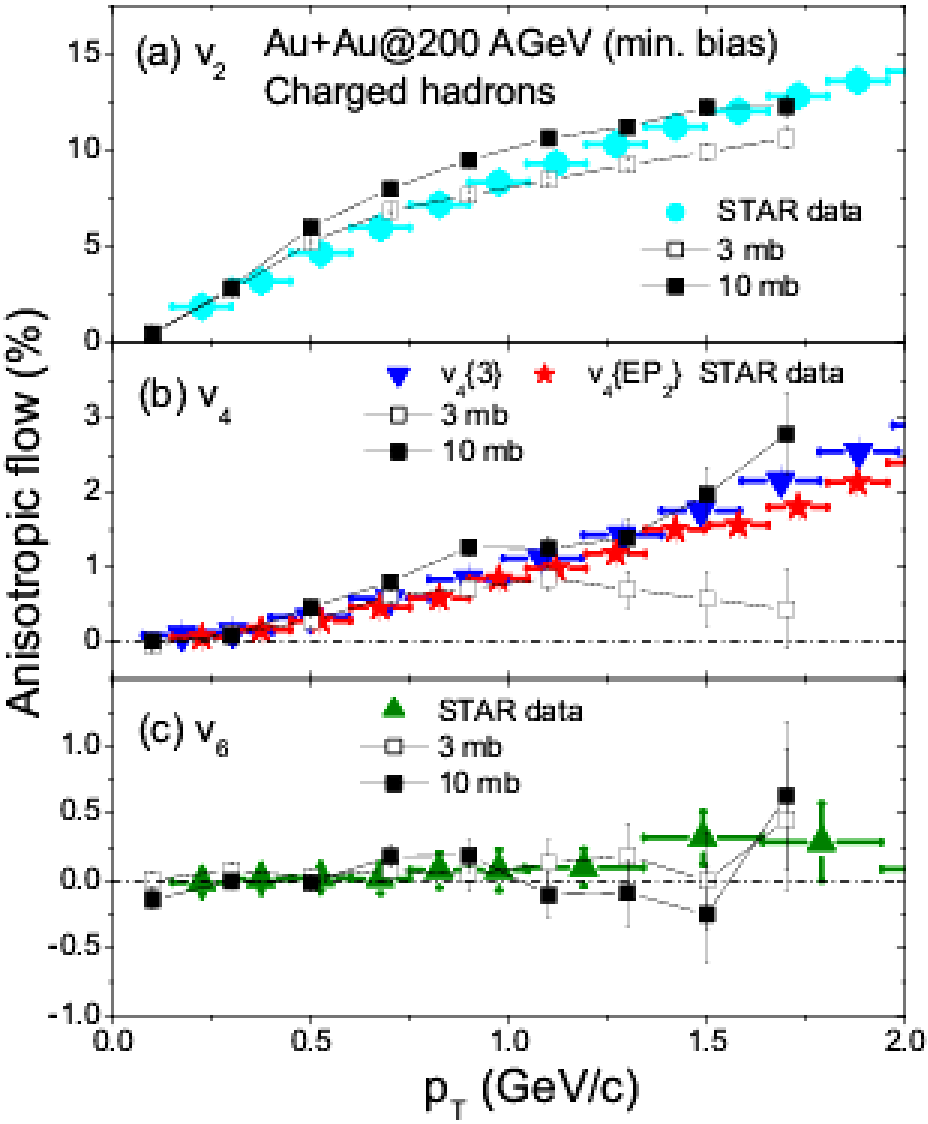
Xu & Greiner
PRC 71, 064901 (2005)



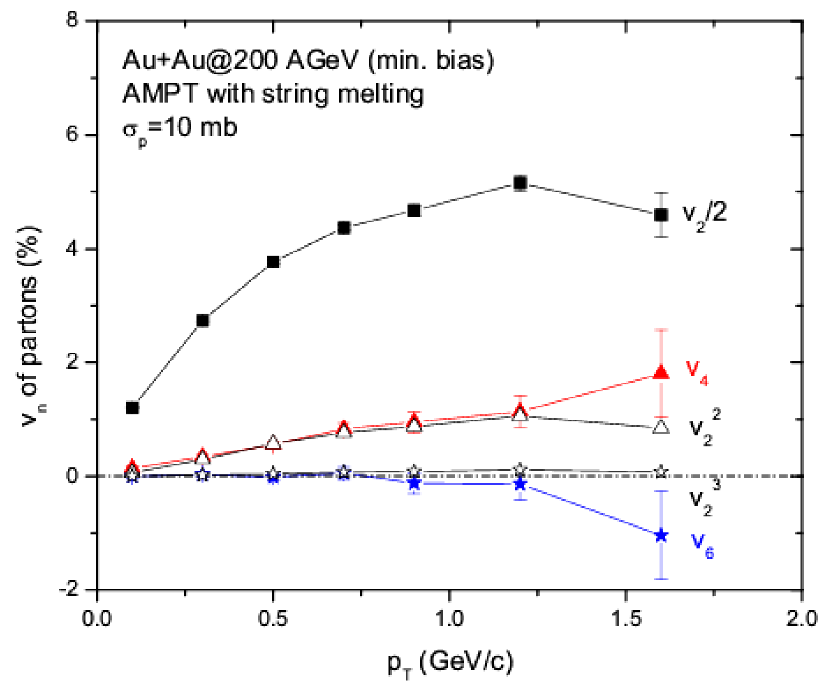
Radiative scattering leads to fast equilibration → effectively taking into account by large elastic scattering cross section needed for describing observed large elliptic flow.

Higher-order anisotropic flow

Chen, Ko, & Lin, PRC 69, 031901 (04)



Data can be described by a multiphase transport (AMPT) model



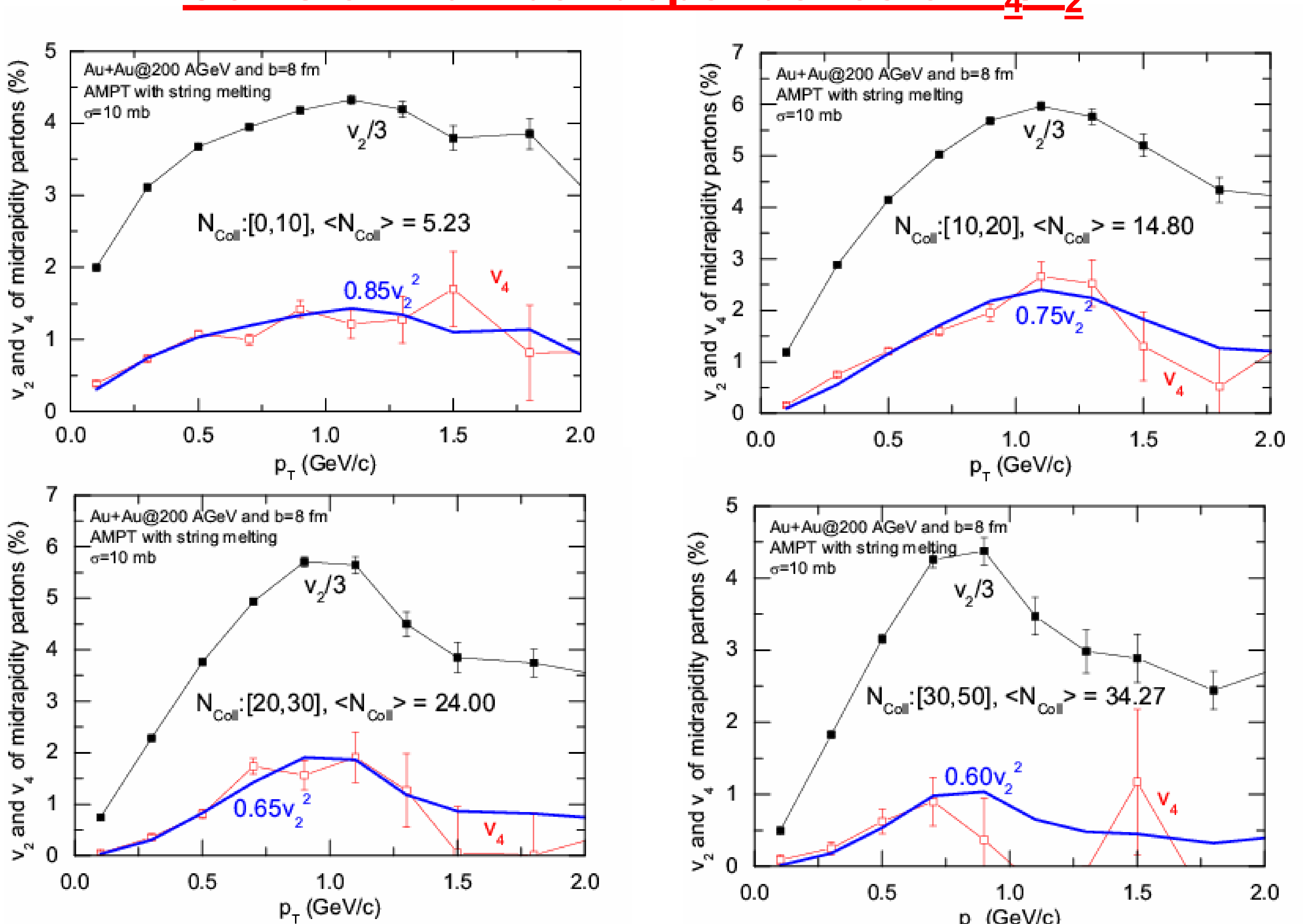
Parton cascade

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

Coalescence model

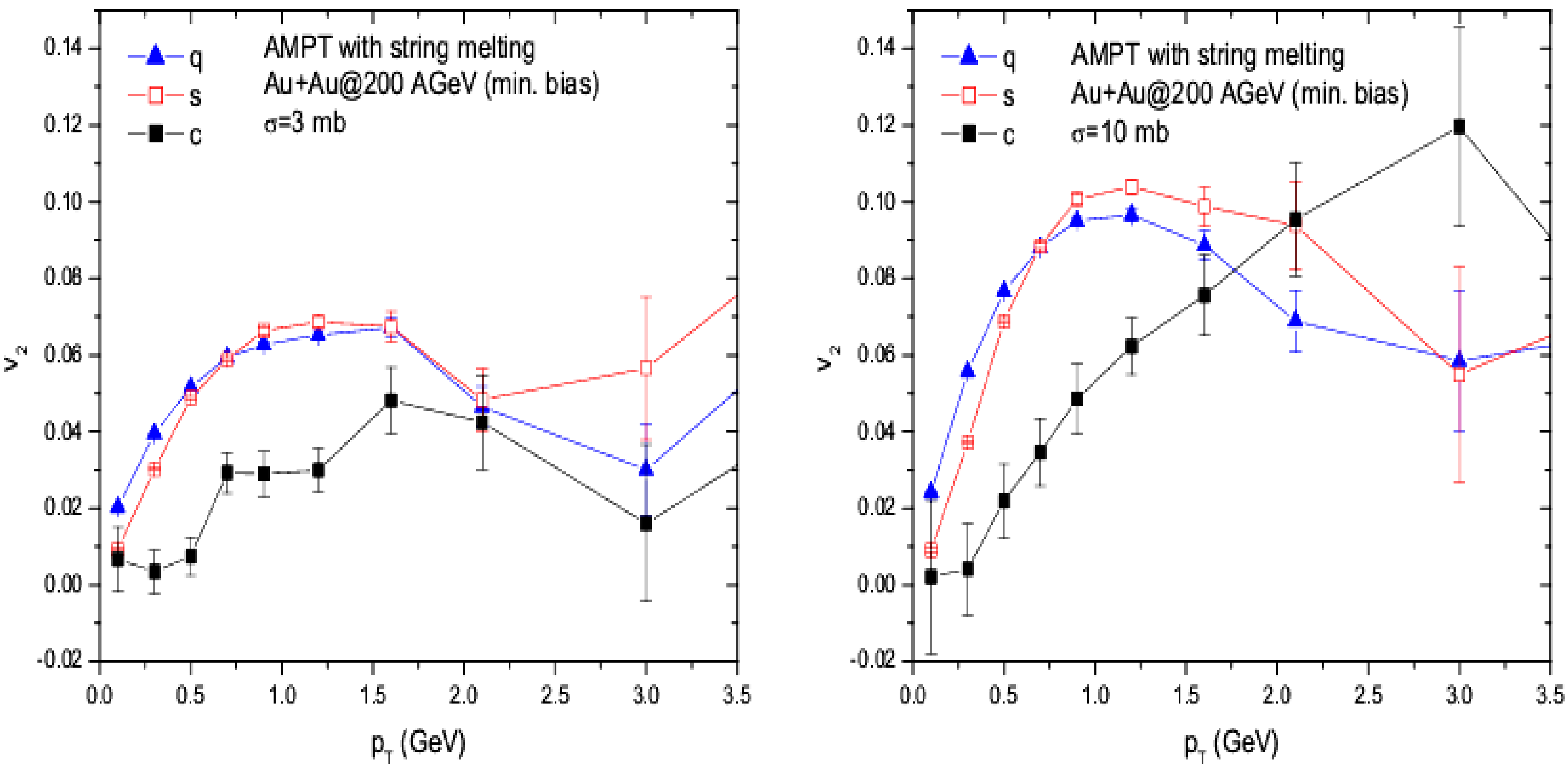
$$\frac{v_{4,M}}{v_{2,M}^2} = \frac{1}{4} + \frac{1}{2}\frac{v_{4,q}}{v_{2,q}^2} \approx 1.2 \Rightarrow v_{4,q} \approx 2v_{2,q}^2$$

Collision number dependence of v_4/v_2^2



v_4/v_2^2 decreases with parton collision number and approaches the ideal hydro limit of 0.5 (Borghini & Ollitrault; Kolb)

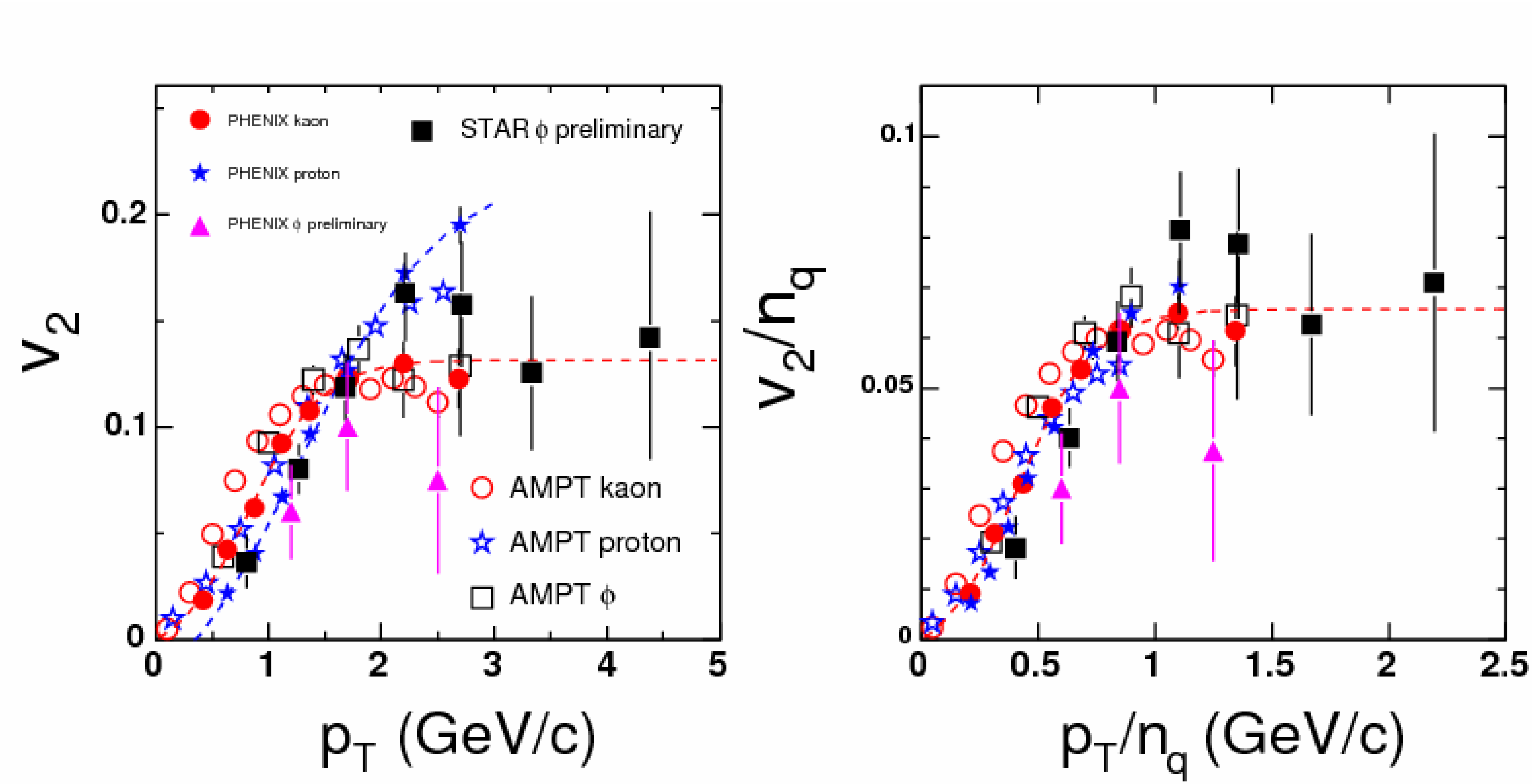
Mass ordering of quark elliptic flow from AMPT



- P_T dependence of charm quark v_2 is different from that of light quarks.
- At high p_T, charm quark has similar v_2 as light quarks.
- Charm elliptic flow is also sensitive to parton cross sections

Phi flow from AMPT

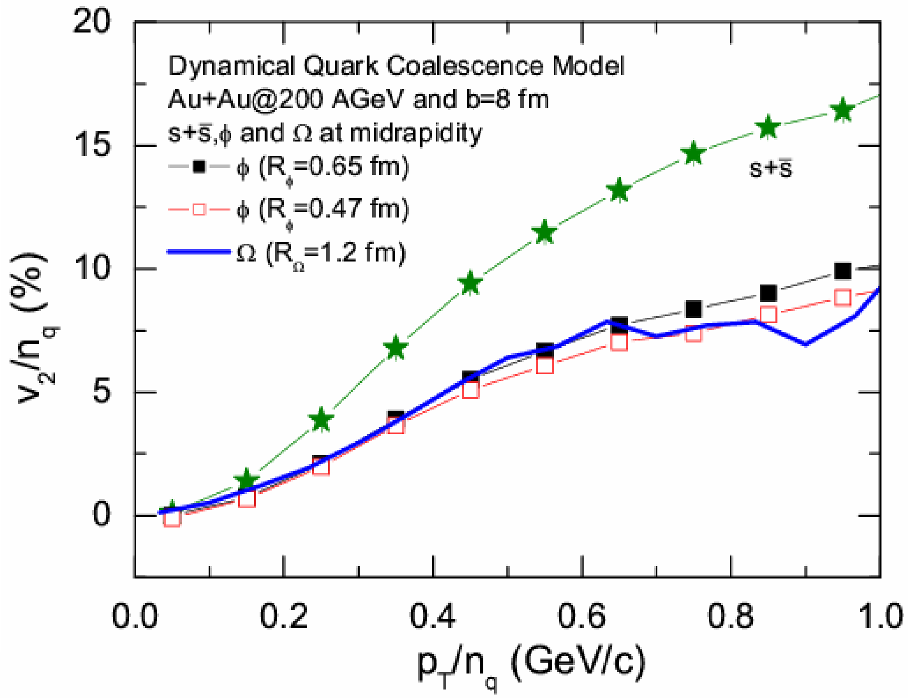
J.H. Chen & Ma et al., nucl-th/0504055, PRC



Phi meson v_2 is similar to that of kaon → quark number scaling

Phi & Omega flows

L.W. Chen & Ko, PRC 73, 044903 (2006)

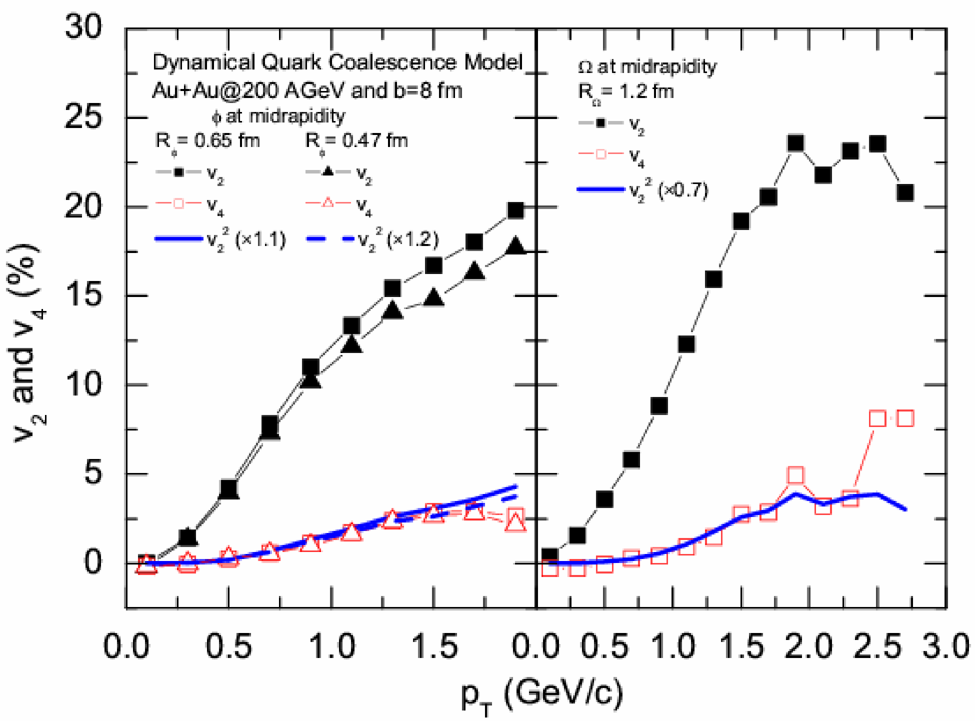


$$v_{2,M}(p_T) = \frac{2v_{2,q}(p_T/2)}{1+2v_{2,q}^2(p_T/2)} \approx 2v_{2,q}(p_T/2)$$

$$v_{2,B}(p_T) = \frac{3v_{2,q}(p_T/3)}{1+6v_{2,q}^2(p_T/3)} \approx 3v_{2,q}(p_T/3)$$

$$\frac{1}{n}v_2(p_T/n)$$

same for phi & Omega but different from quark



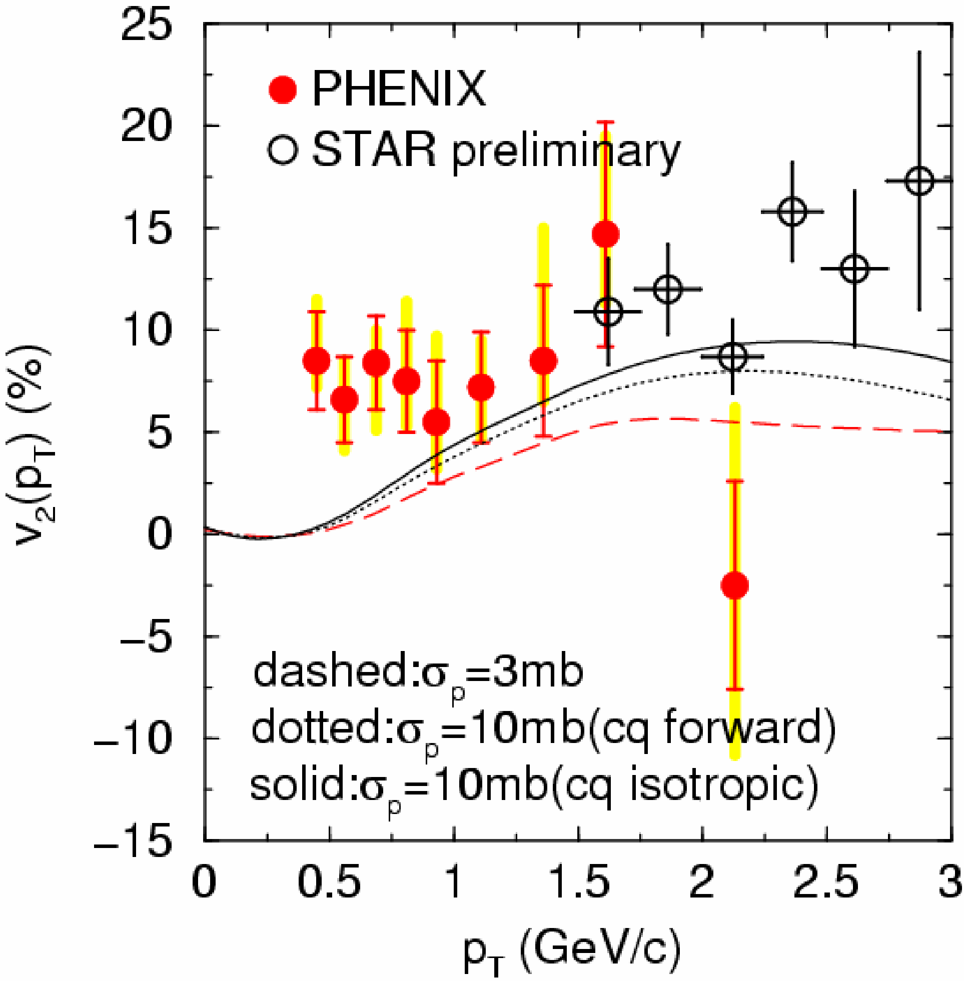
$$\frac{v_{4,\varphi}}{v_{2,\varphi}^2} = \frac{1}{4} + \frac{1}{2}\frac{v_{4,s}}{v_{2,s}^2}, \quad \frac{v_{4,\Omega}}{v_{2,\Omega}^2} = \frac{1}{3} + \frac{1}{3}\frac{v_{4,s}}{v_{2,s}^2}$$

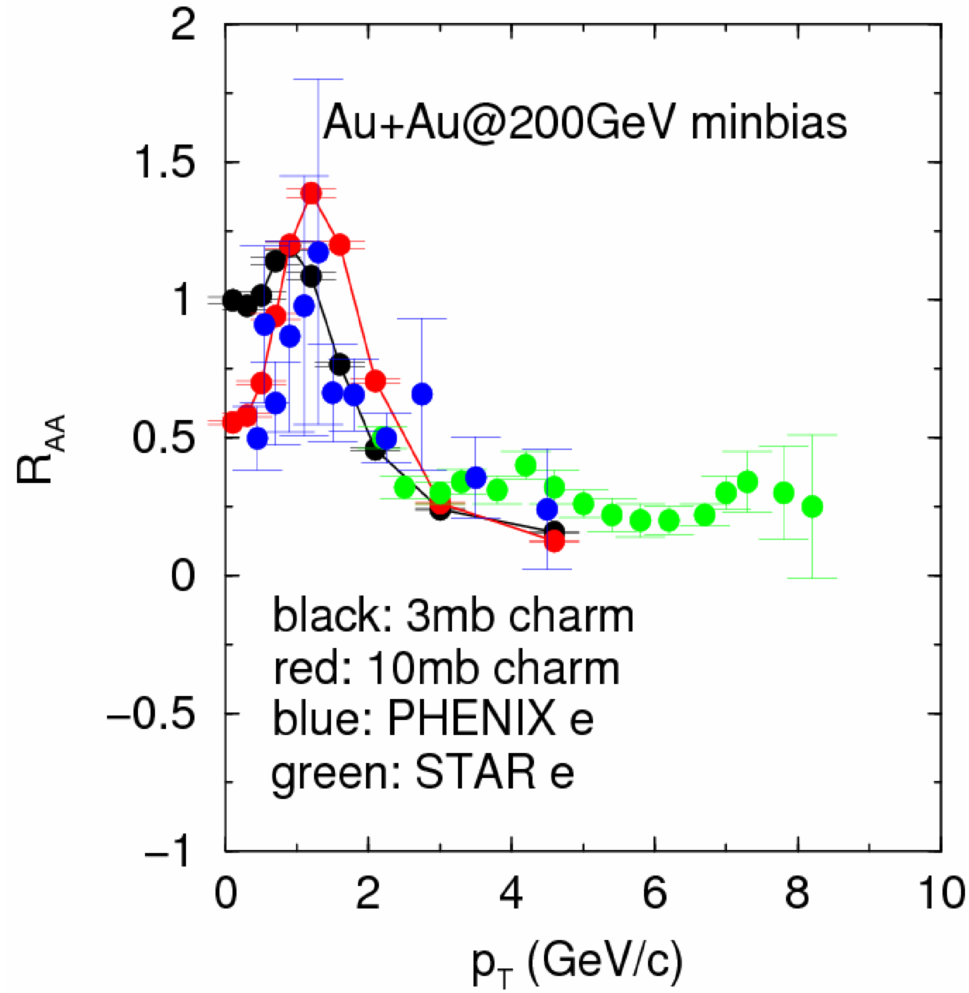
$$\frac{v_{4,s}}{v_{2,s}^2} \approx 0.85 \Rightarrow \frac{v_{4,\varphi}}{v_{2,\varphi}^2} \approx 0.67, \quad \frac{v_{4,\Omega}}{v_{2,\Omega}^2} \approx 0.61$$

instead of 1.1 and 0.7 from dynamical coalescence model

Charm R_{AA} and elliptic flow from AMPT

Zhang, Chen & Ko, PRC 72, 024906 (05)

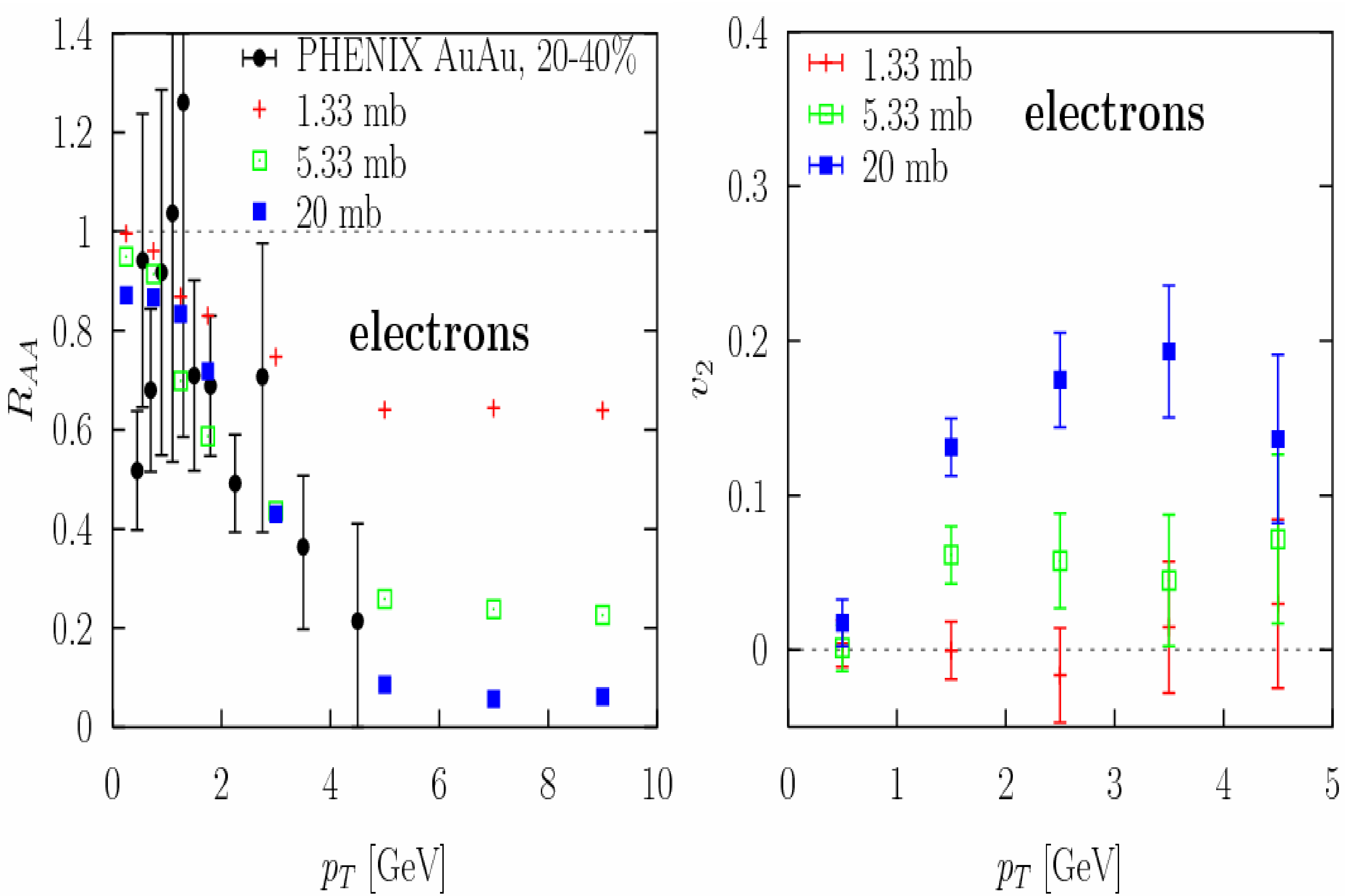




- Need large charm scattering cross section to explain data.
- Smaller charmed meson elliptic flow is due to use of current light quark masses.

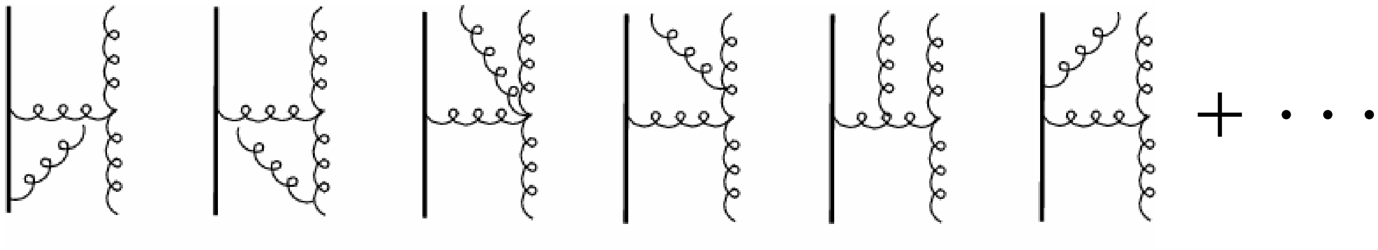
Charm suppression and elliptic flow

D. Molnar
Nucl-th/0608069

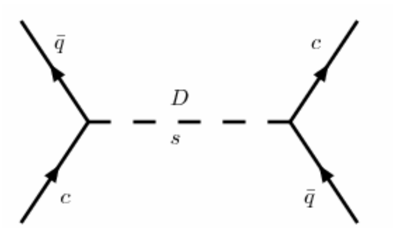


Possible origin of large charm scattering cross section

- Radiative scattering (Amesto et al.; Djodejevic et al.; Zhang et al.)

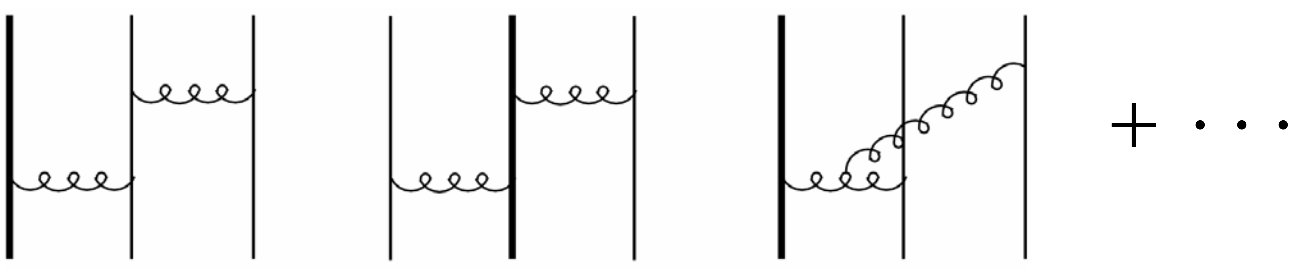


- Resonance scattering (van Hees, Greco & Rapp, PRC 73, 034913 (06))



$\sigma(s_{1/2}=m_D) \approx 6$ mb and isotropic

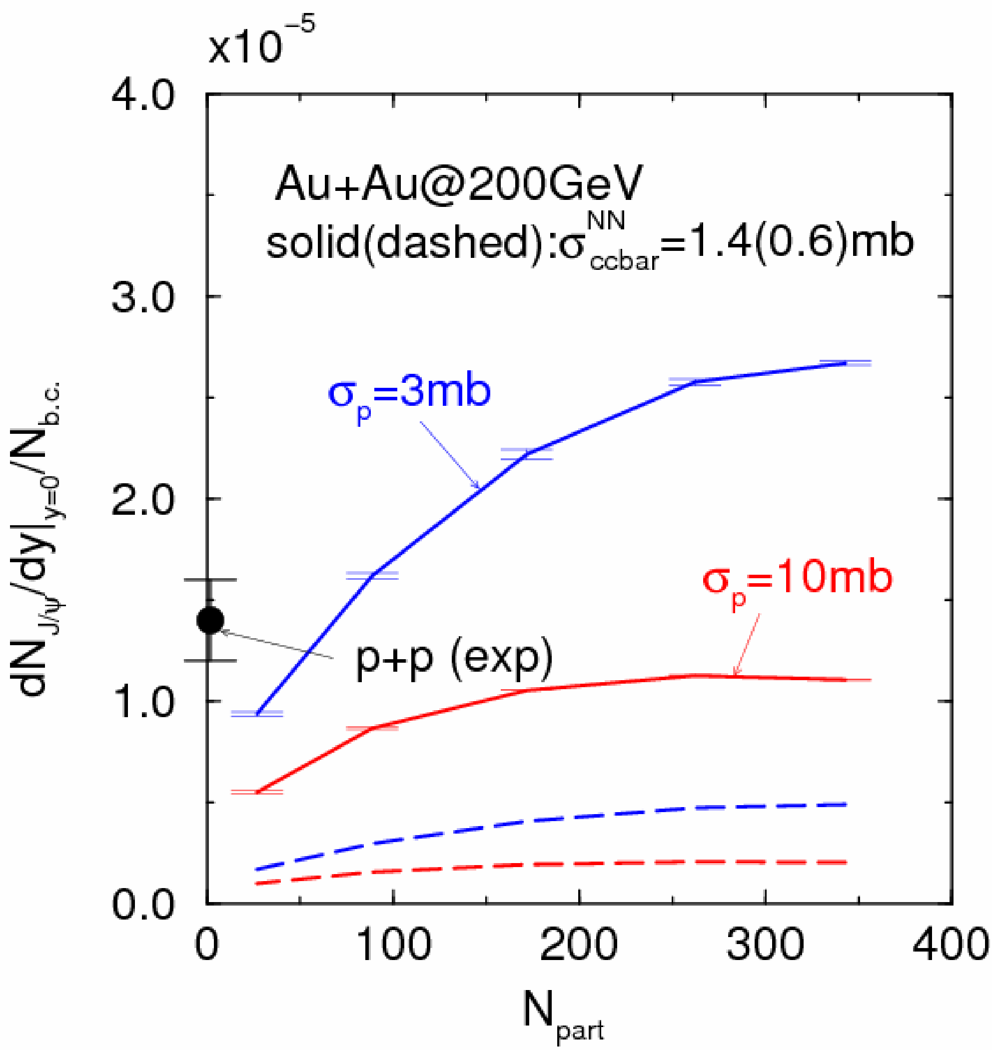
- Three-body elastic scattering (Liu & Ko, nucl-th/0603004)

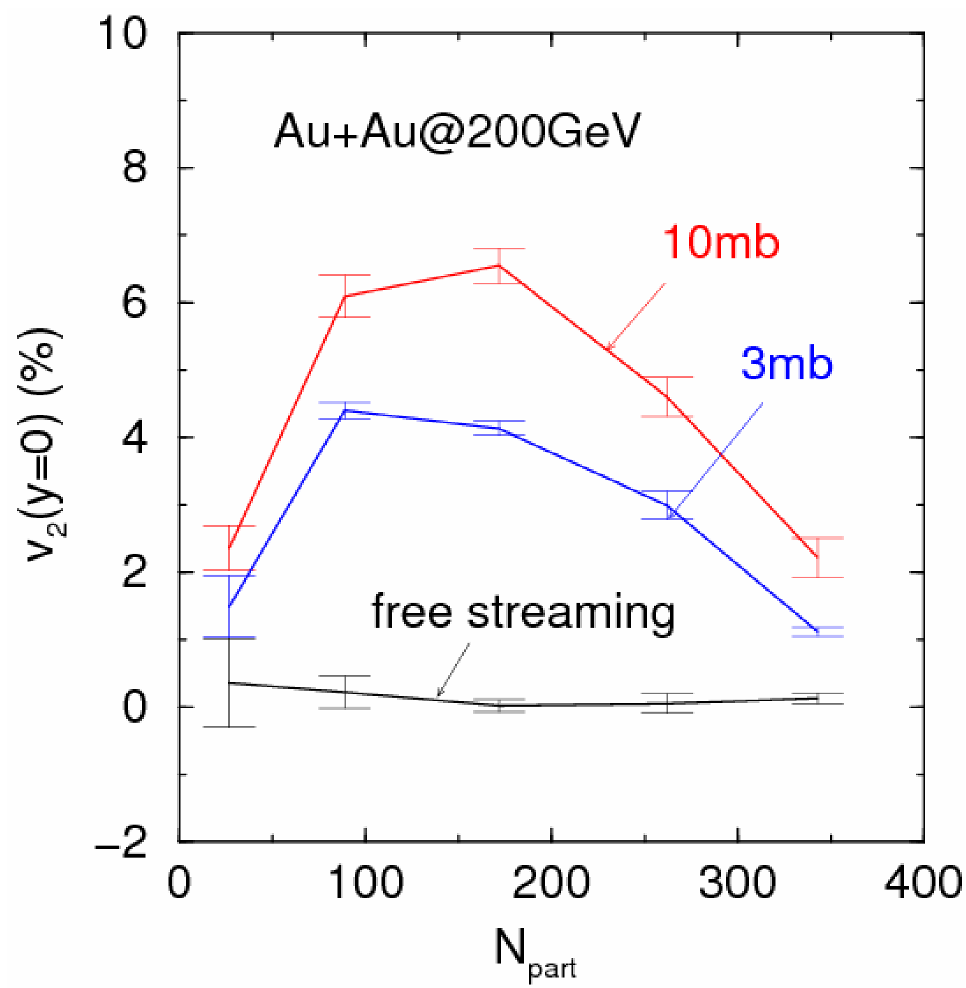


Important as interparton distance ~ range of parton interaction
At T=300 MeV, N_g~(N_q+N_{qbar})~ 5/fm^3, so interparton distance ~ 0.3 fm
Screening mass m_D=gT~600 MeV, so range of parton interaction ~0.3 fm

J/ψ production from charm quark coalescence

Zhang, nucl-th/0606039

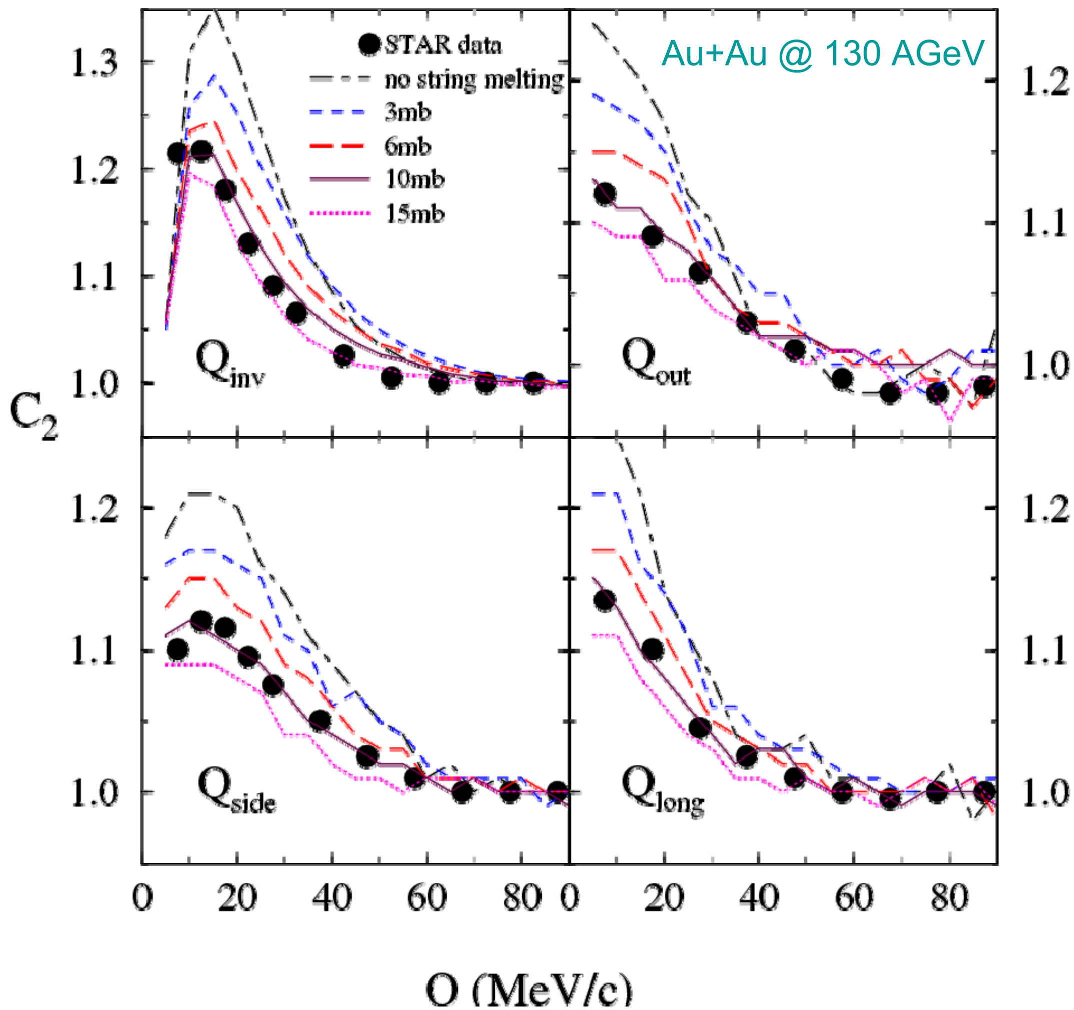


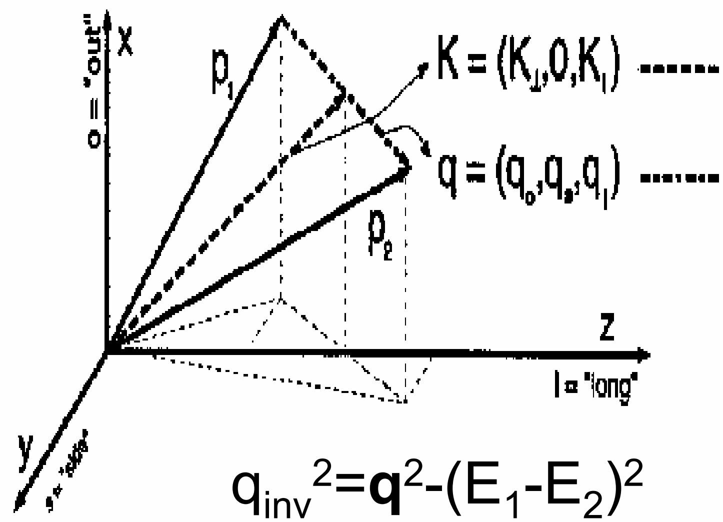


Large (small) charm quark scattering cross section leads to suppressed (enhanced) yield but larger (smaller) elliptic flow.

Two-pion correlation functions

Lin, Ko & Pal, PRL 89, 152301 (2002)



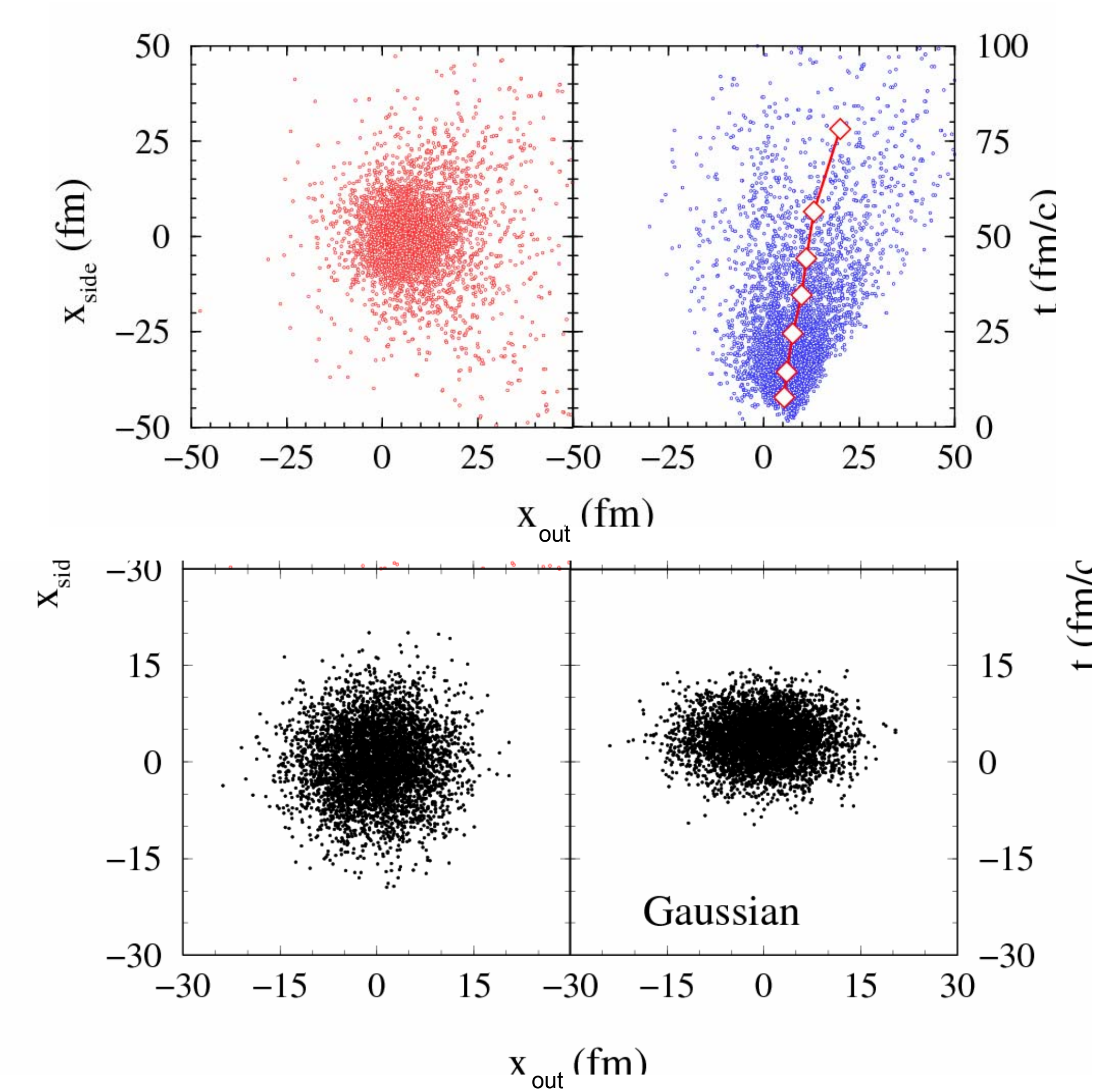


$q_{inv}^2 = \mathbf{q}^2 - (E_1 - E_2)^2$

- 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

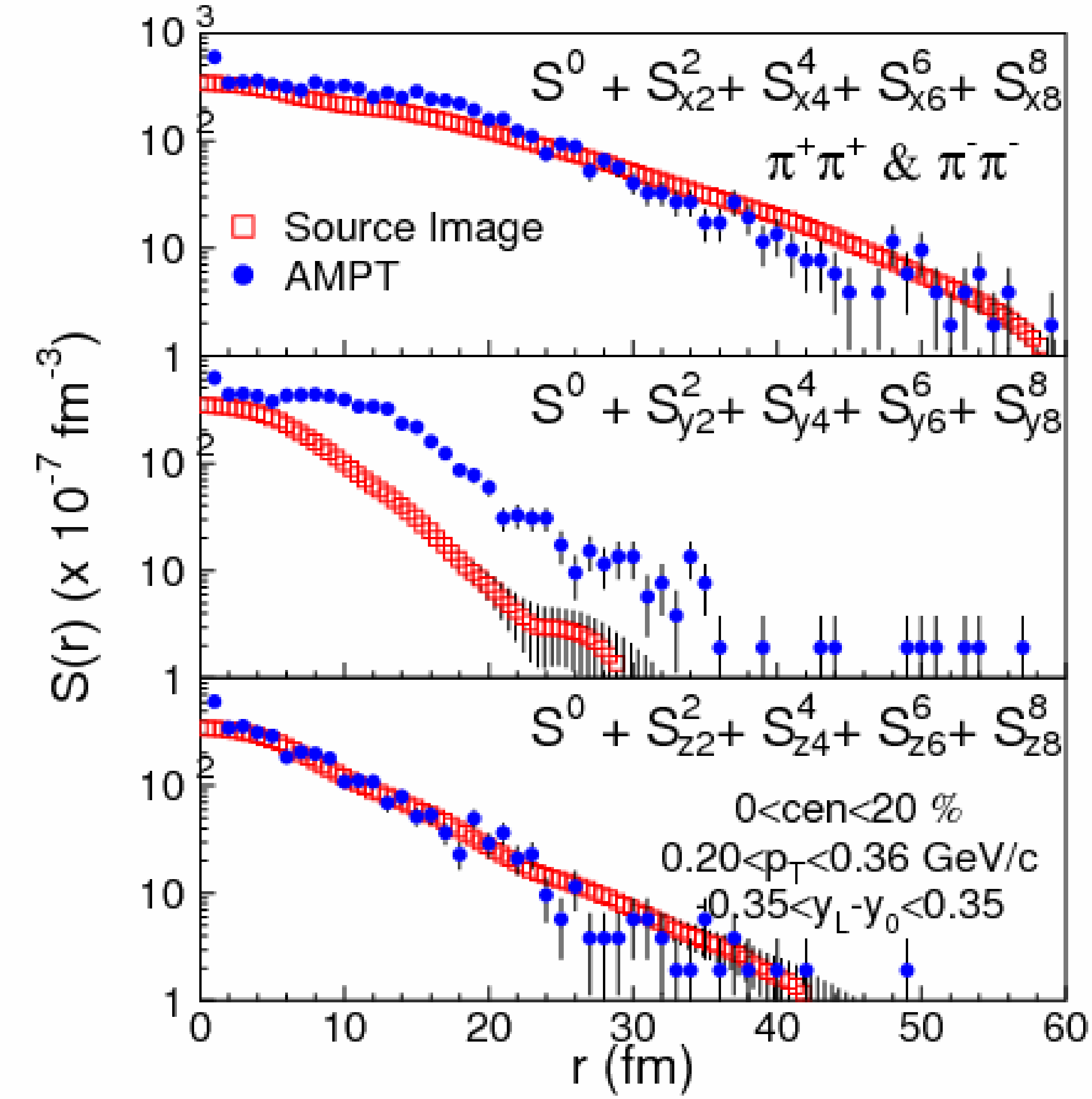


- Upper: emission source from AMPT
  - Shift in out direction
  - Strong correlation between out position and emission time
  - Large halo due to resonance (ω) decay and explosion

  → non-Gaussian source
- Lower: Gaussian source fitted to correlation functions

Emission source function

Paul Chung and Roy Lacey



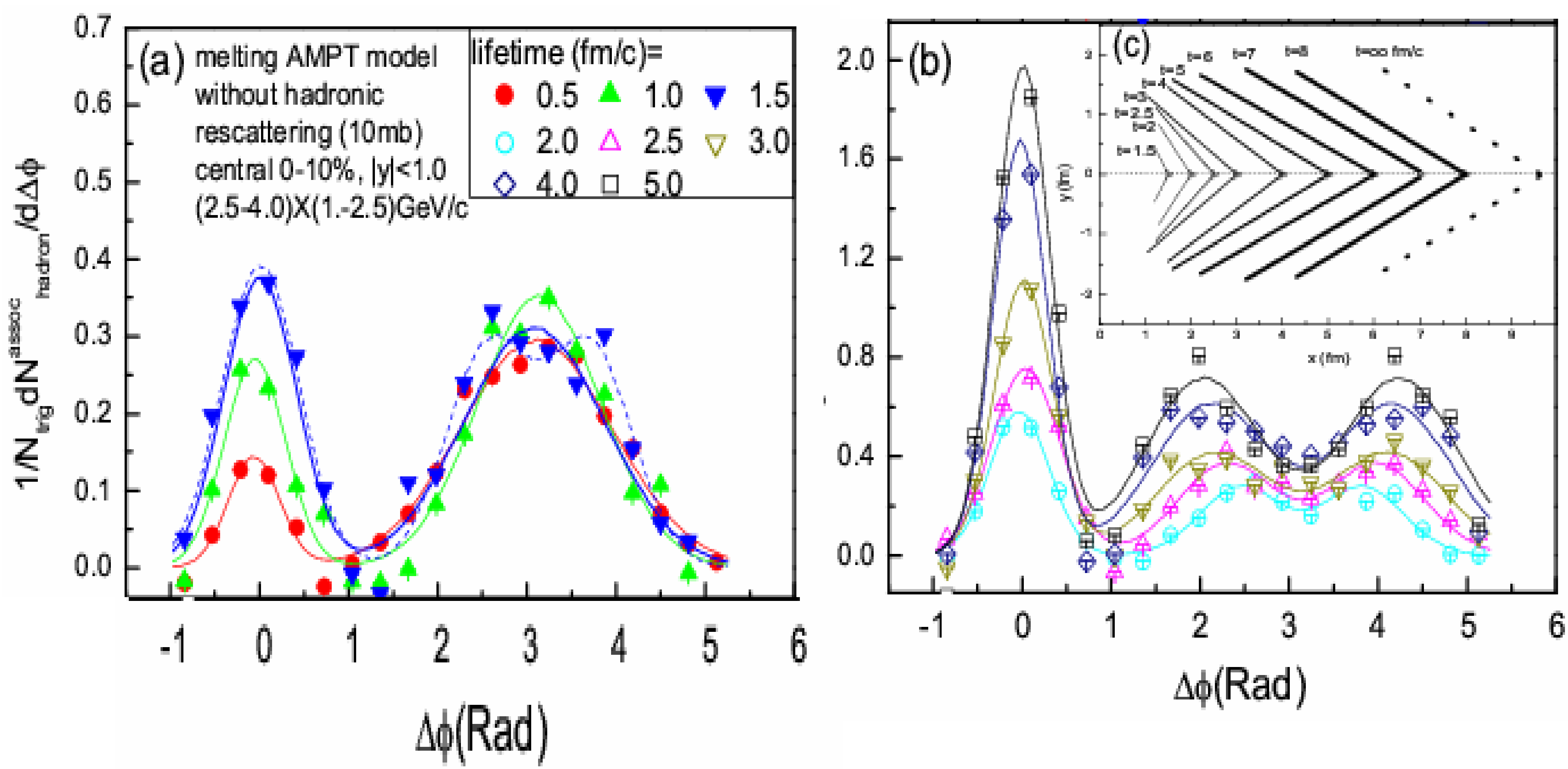
Data from imaging method of Danielewicz and Pratt (PLB 618, 60 (2005))

$$C(q)-1=\int d^3r[|\phi_q(r)|^2-1]S(r)$$

- Long tails are seen in both data and AMPT
- Agrees with data for the out and long directions
- Larger in side direction?

Mach-cone structure from parton cascade

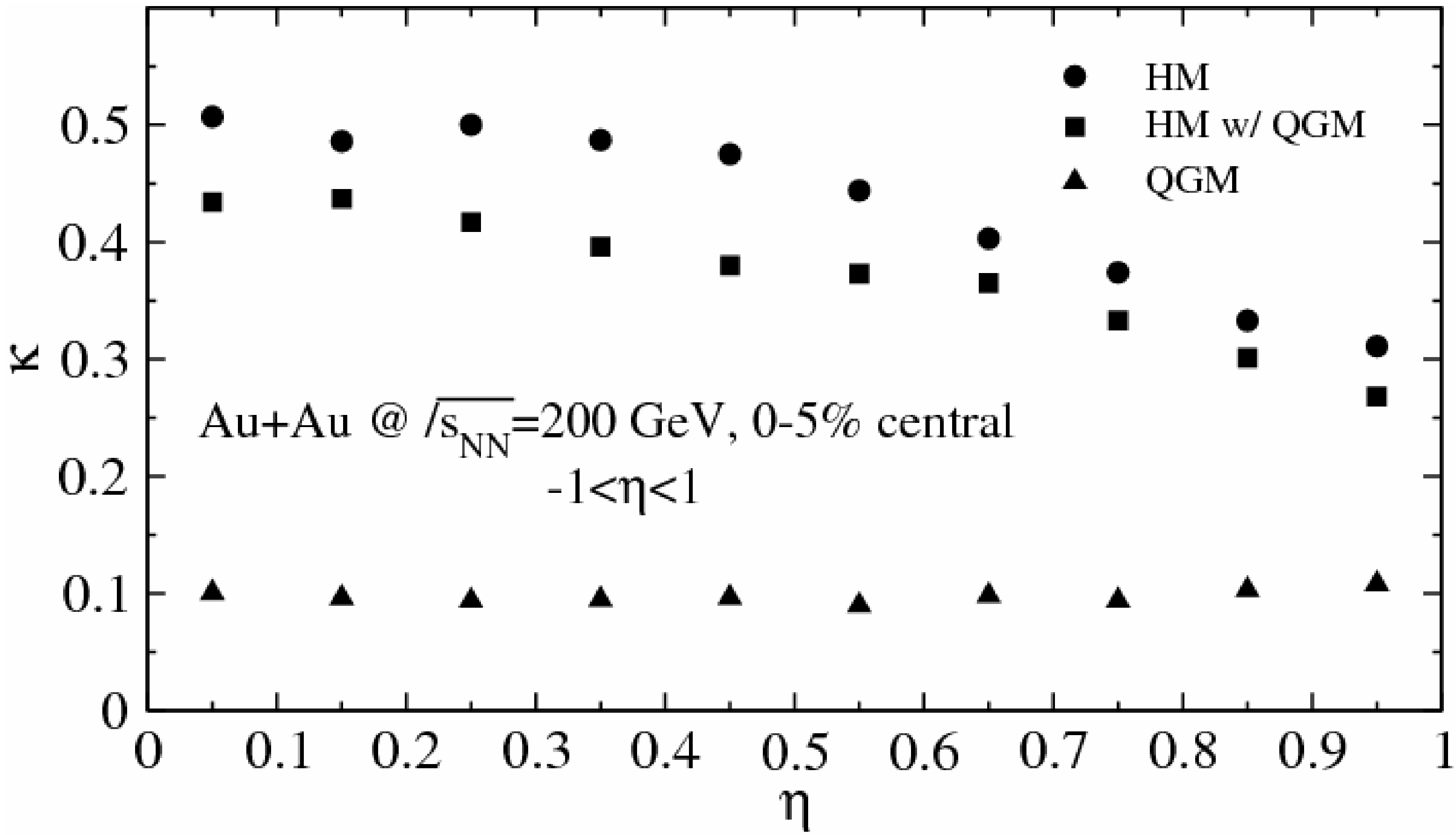
Ma et al.
nucl-th/0610088



Both splitting parameter and number of associated particles increase with time and parton scattering cross section

Charge transfer fluctuation

Zhou, Li, Dong & Sa, PLB 638, 461 (2006)

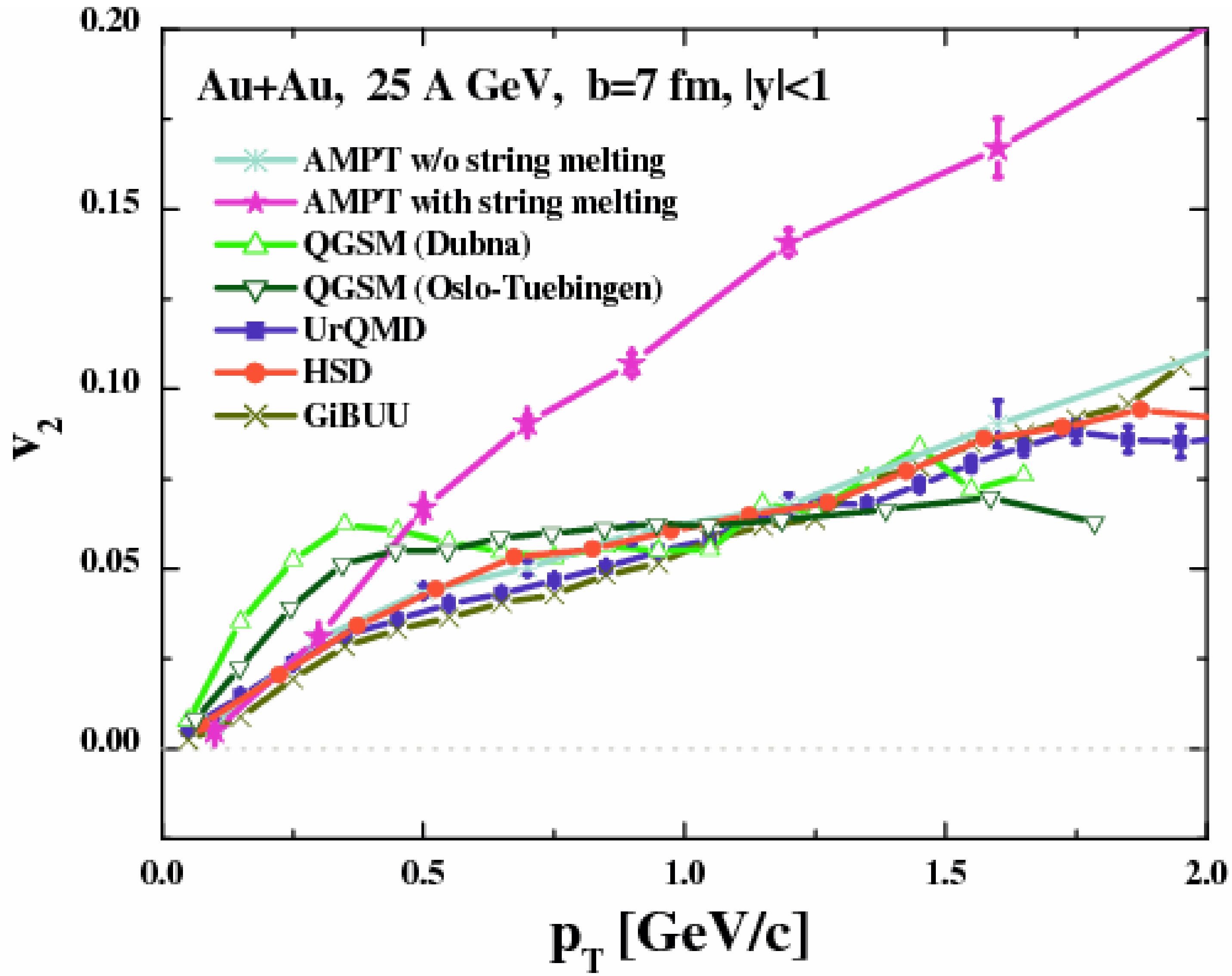


$$\kappa(\eta) = \langle u(\eta)^2 \rangle - \langle u(\eta) \rangle^2$$

$$u(\eta) = [Q_F(\eta) - Q_B(\eta)]/2$$

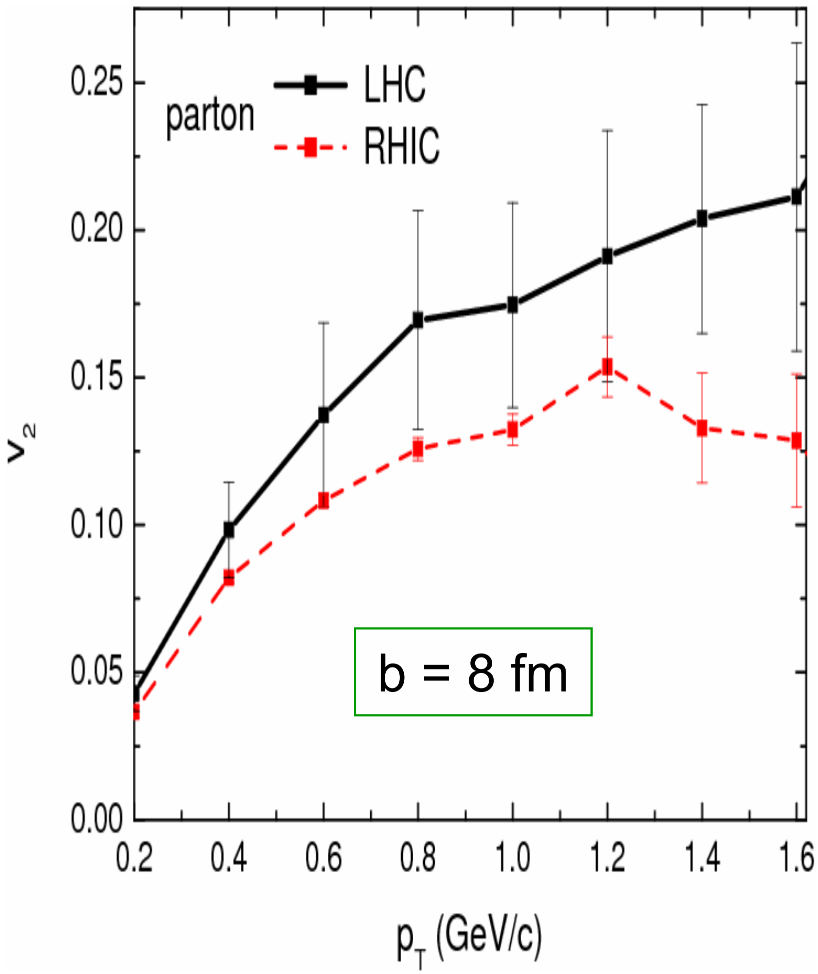
Effect of QGP is present at about 20% level after hadronic evolution.

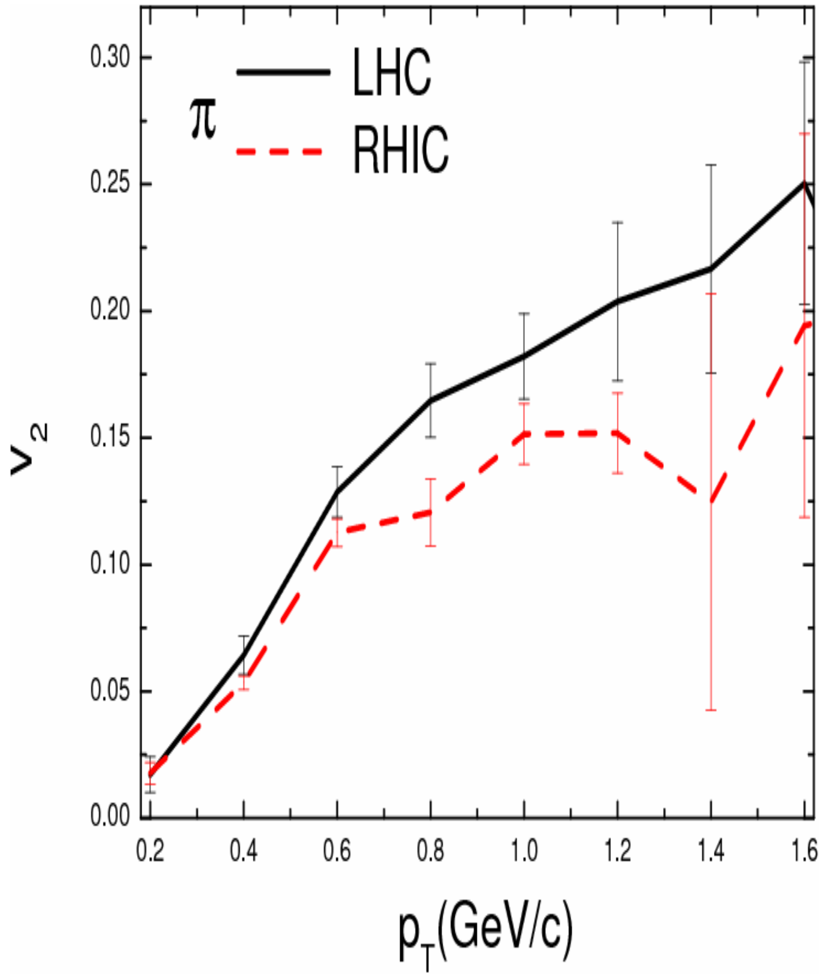
Elliptic flow at FAIR



Partonic scattering enhances elliptic flow

Elliptic flow at LHC: Pb+Pb @ 5.5 ATeV





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

Summary

- Elliptic flow is sensitive to parton scattering cross section
- Observed large elliptic flow and mass ordering at low p_T can be explained with large parton cross section (sQGP?)
- Observed hadron $v_4 \approx 1.2 v_2^2$ is reproduced with parton $v_4 \approx v_2^2$
- Phi and Omega flow follow CQN scaling
- Observed large charmed meson flow requires large charm quark scattering cross section (resonance effect and/or multi-body scattering?)
- Mach-cone structure is seen in parton cascade
- Large elliptic flow predicted for both FAIR and LHC
- Color mean-field effect? (Asakawa, Bass & Muller)