APS April Meeting, Feb. 13-16, Washington, D. C.

ϕ meson production and cold nuclear matter effect in *d*+Au collisions at $\sqrt{s_{NN}} = 200$ GeV in STAR

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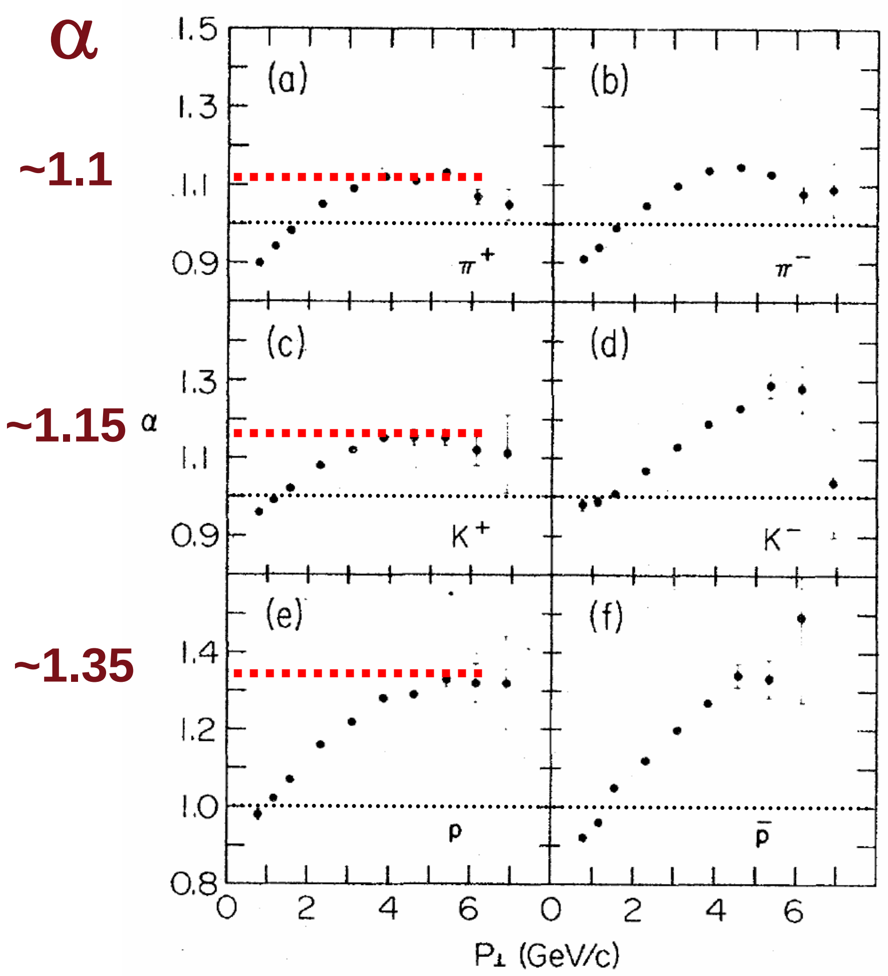
For the STAR Collaboration

- Cronin effect
- ϕ meson measurements and nuclear modification factor
- Summary and outlook

Introduction: Cronin effect in p+A collisions



$\sqrt{s}$ = 27.4 GeV

Phys. Rev. D 11, 3105 (1975)

Phys. Rev. D 19, 764 (1979)

➢Enhanced production of high p_T hadrons in proton-nucleus collisions

$$I_i(p_\perp, A) = I_i(p_\perp, 1) A^{\alpha_i(p_\perp)}$$

✓α is larger than 1 at high p_T

✓Indicating the cold nuclear matter has extra effect on particle production

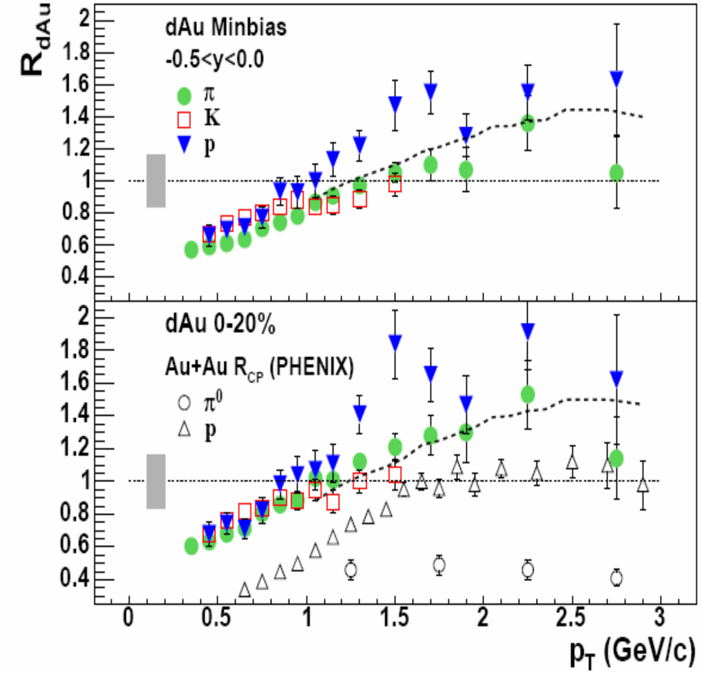
✓**Enhancement: proton > kaon > pion**

Cronin effect in d+Au collisions at RHIC

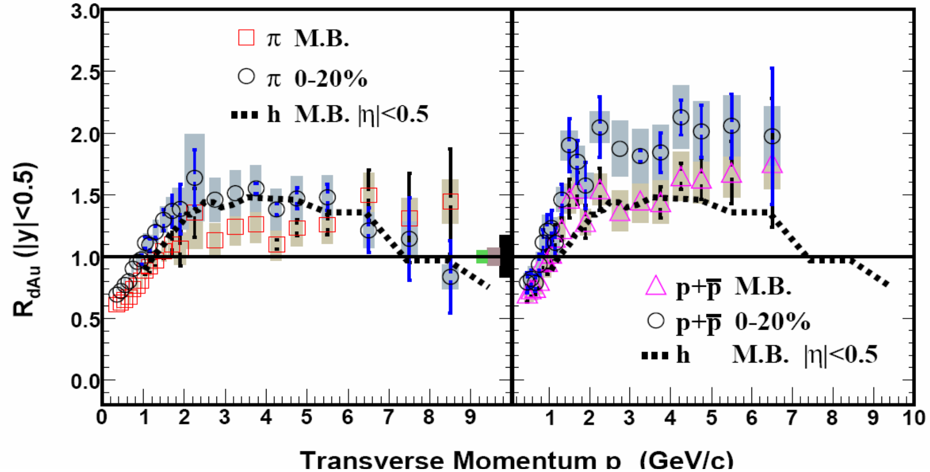
Mid-rapidity && √s =200 GeV:

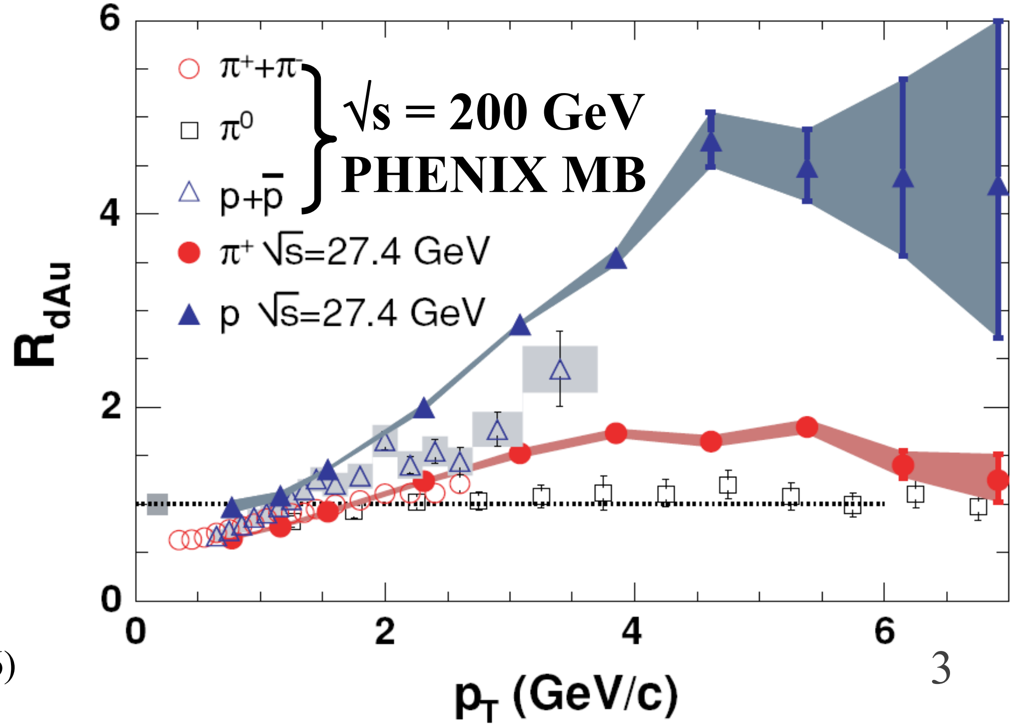
- ➢ Intermediate p_T hadron production enhanced relative to p+p collisions
- ➢ **R_{dAu} (p) > R_{dAu} (π)**
- ➢ **The enhancement depends on collision energy**

STAR √s = 200 GeV



STAR 200 GeV high p_T





Phys. Lett. B 616, 8 (2005); Phys. Lett. B 637, 161 (2006)
Phys. Rev. C 74, 024904 (2006)

Initial state and final state effect

➢Traditional models: initial state effect before hard scattering

● partonic multiple rescatterings with target nucleons

● transverse momentum broadening of the projectile parton

● **particle species dependence not understood**

To exactly infer the initial conditions of collisions we need to know

➢Final state effects: after hard scattering

● *partonic interactions*

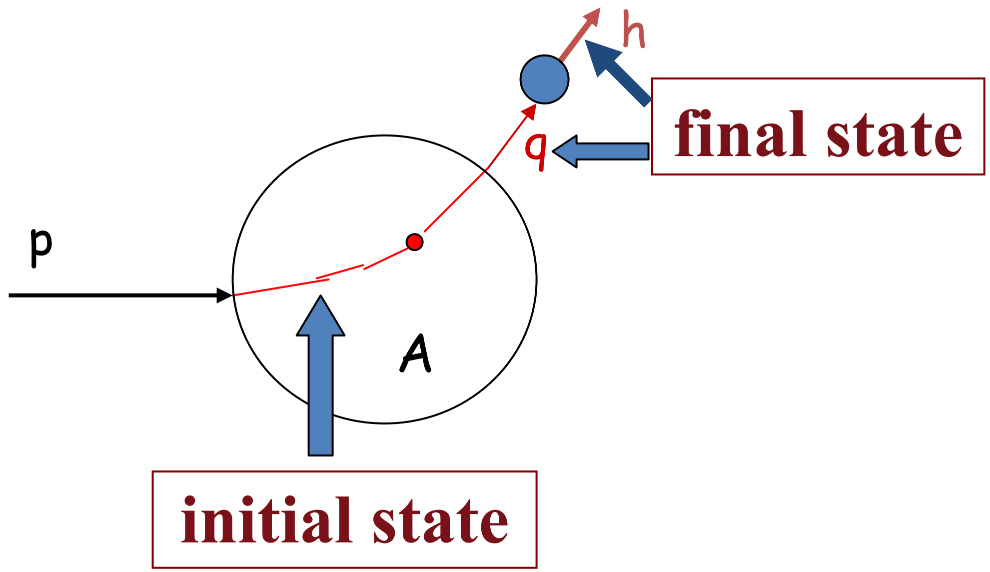
● *hadronization mechanisms*

● *hadronic rescatterings*

Particle species dependence

Can be measured

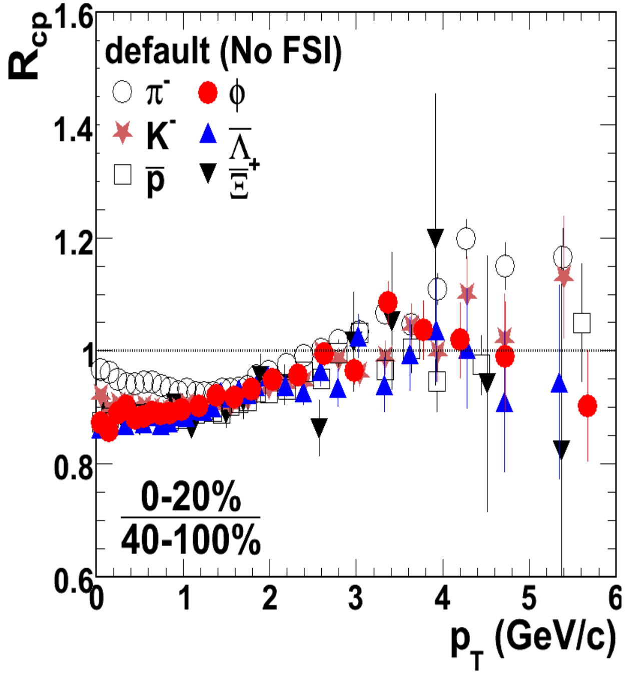
ϕ meson: good probe



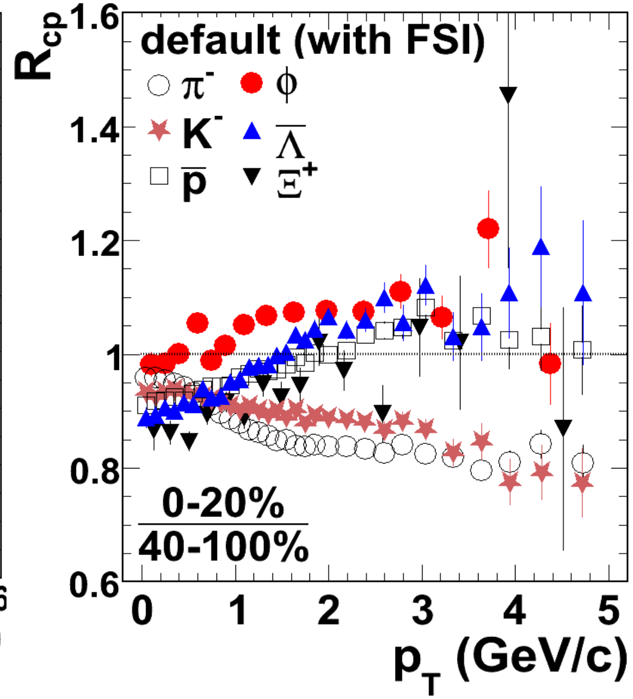
X.N. Wang, Phys. Rev. C 61, 064910 (2000)
R.C. Hwa et al., Phys. Rev. Lett. 93, 082302 (2004)

Implications from transport model (AMPT)

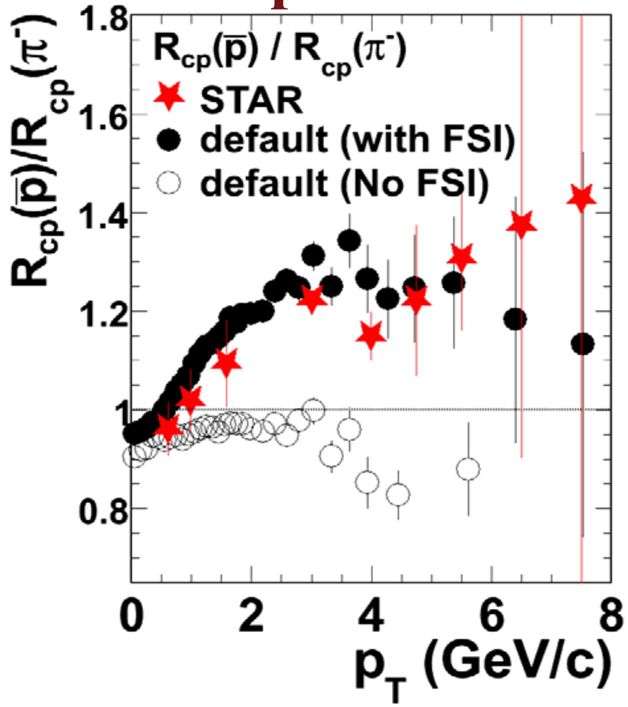
without FSI



with FSI



Comp. with data



- ✓ **What is the effect of final state interactions (FSI) on observables?**
- ✓ Hadronization: Lund string fragmentation
- ✓ **Without FSI, no obvious particle species dependence for $p_T > 1$ GeV/c**
- ✓ **Final-state hadronic rescatterings lead to hadron mass dependent R_{CP}**
- ✓ With FSI included, AMPT can reproduce the R_{CP} ratio between antiproton and π^-

X. Zhang et al., arXiv:1001.4734

Why ϕ meson?

✓AMPT calculations:

Final-state hadronic interactions important!

Hadron mass dependent R_{CP}

✓Another possibility: meson/baryon dependence

✓**ϕ meson: unique probe to distinguish mass effect or meson/baryon effect**

Mass: $\phi \sim p, \Lambda$ Meson v.s. Baryon

✓**Decouples early, provides early time information**

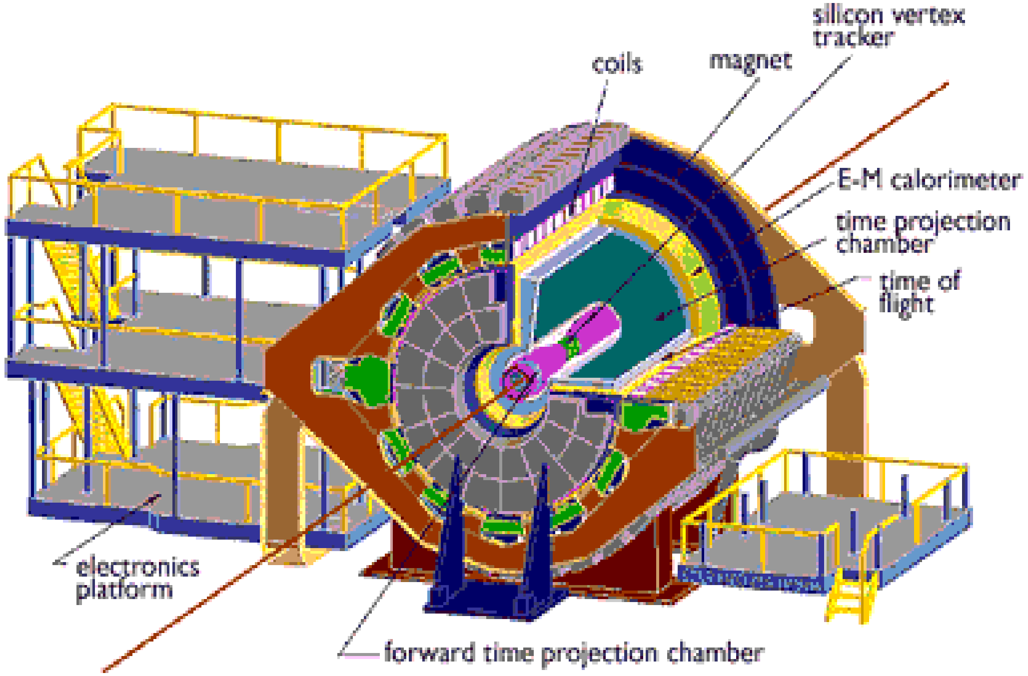
Small hadronic cross section with other non-strange particles

✓Dataset: STAR year 2008 d+Au 200 GeV run

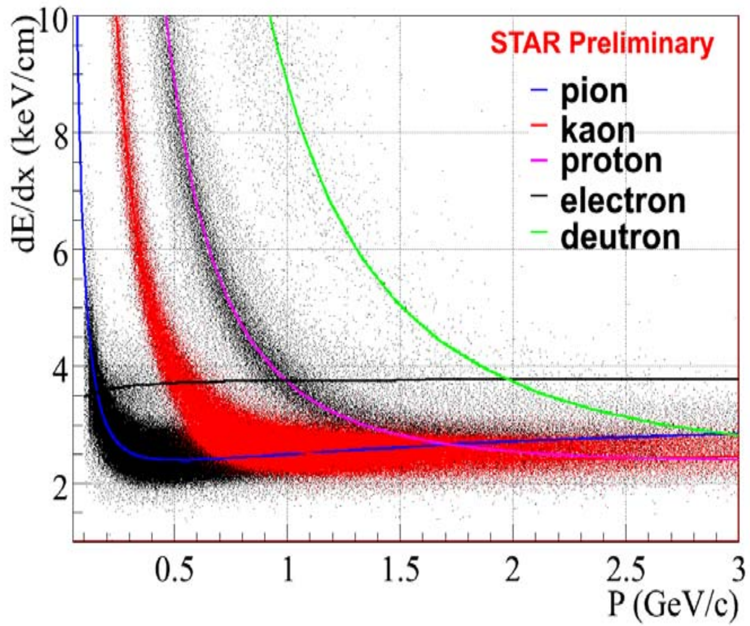
A factor of 3 higher statistics compare to year 2003 run

H. van Hecke, et al., Phys. Rev. Lett. 81, 5764 (1998)
STAR, Phys. Rev. Lett. 99, 112301 (2007)
X. Zhang et al., arXiv:1001.4734

$\phi \rightarrow K^+K^-$ measurements
— Detector and Particle Identification



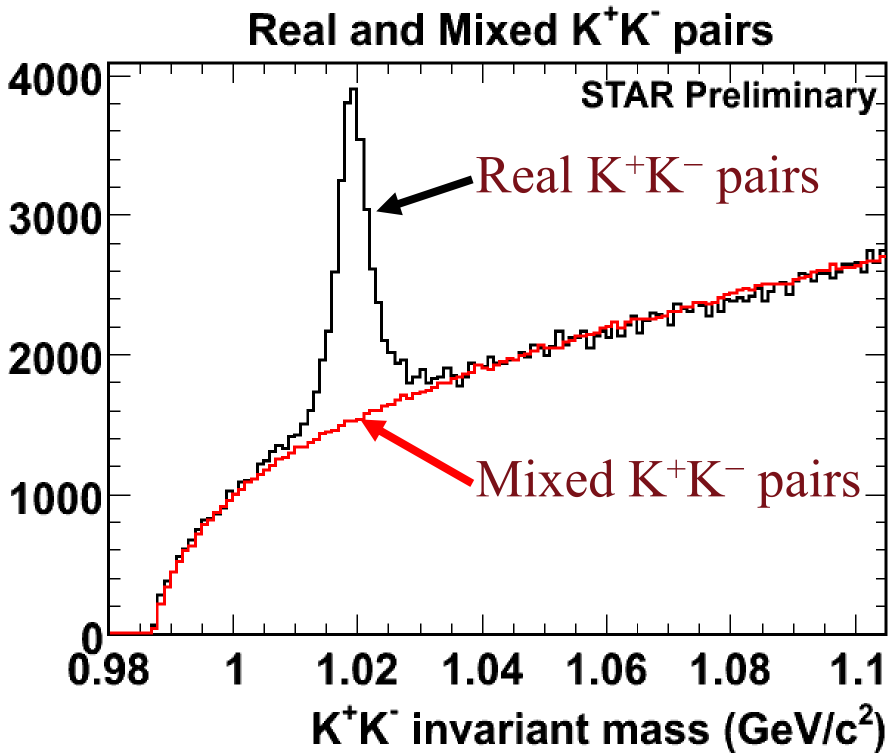
d+Au 200 GeV

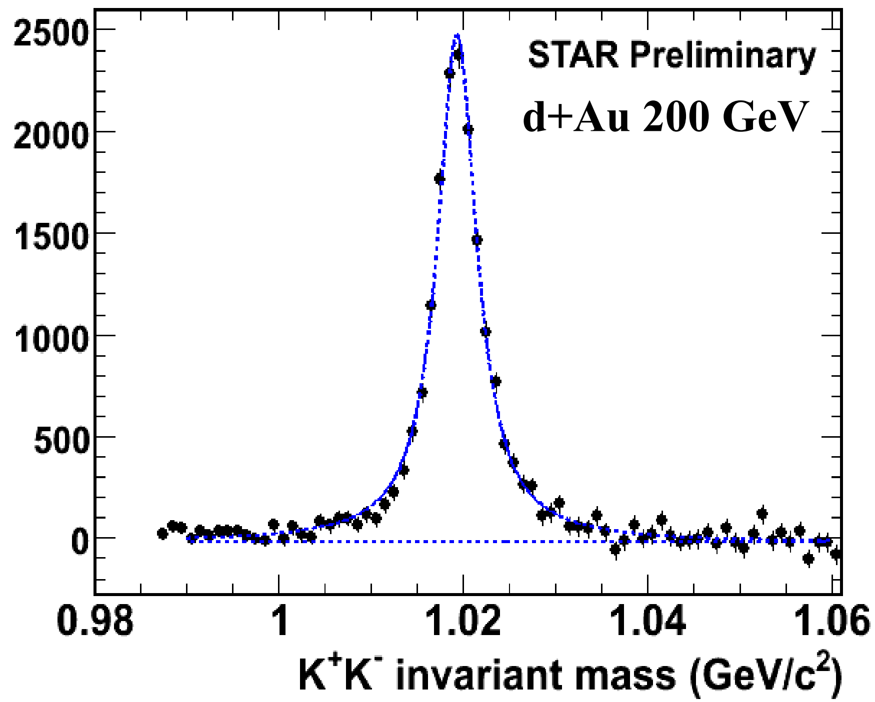


Particle identification: ($\phi \rightarrow K^+K^-$ decay, branching ratio 49.2%)
Measure the momentum v.s. energy loss of particles with Time Projection Chamber
Identification of pion, kaon, proton and electron etc.
Large acceptance: 2 π azimuthal coverage, $-1.5 < \eta < 1.5$
Reduced material: inner tracker removed, lower γ conversion background

ϕ meson reconstruction

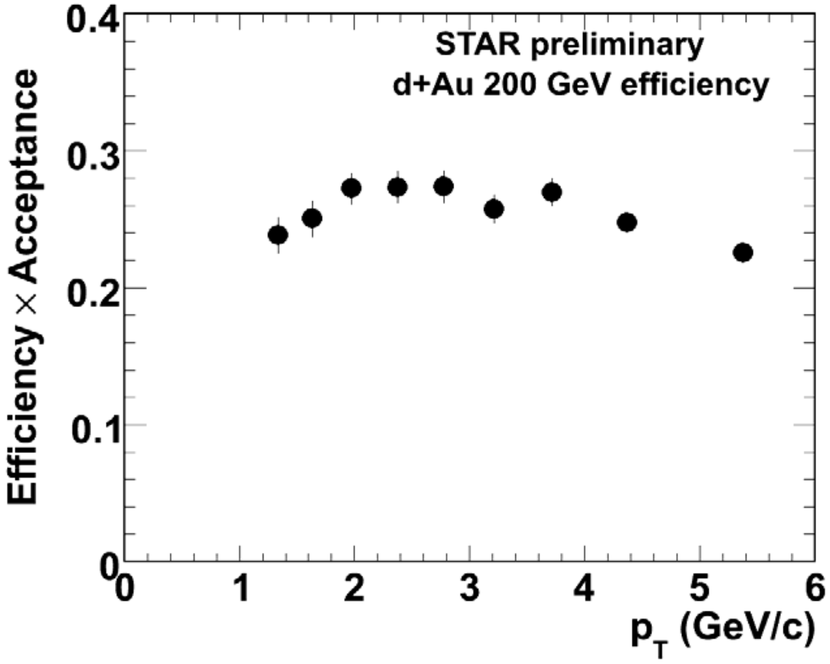
Reconstruct background by mixed event method

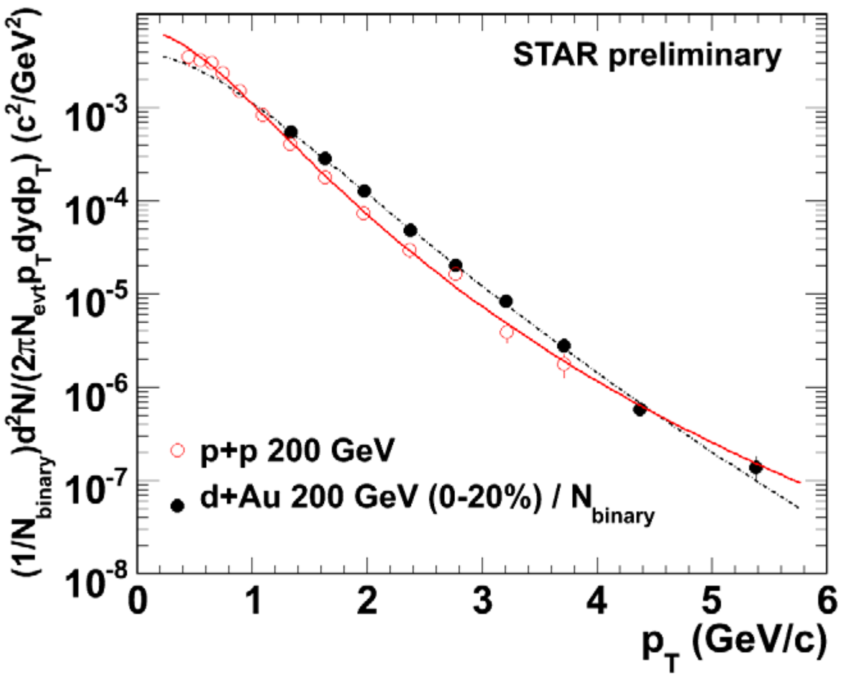




Breit-Wigner + linear function is used to fit ϕ invariant mass distribution after background subtraction

ϕ meson reconstruction efficiency and spectra

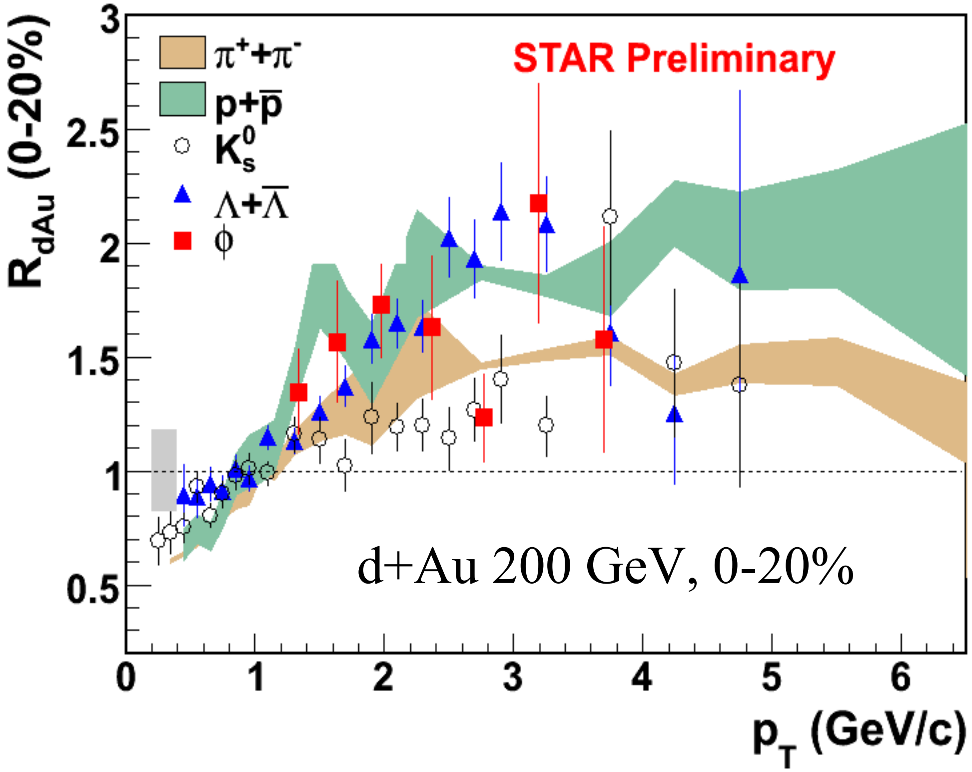




Statistical error only

- Spectra scaled by number of binary collisions
- **Compared to p+p collisions, enhanced ϕ meson production at large p_T in d+Au central collisions.**

Nuclear modification factor R_{dAu}



π , p data: STAR, Phys. Lett. B616, 8 (2005);
Phys. Lett. B637, 161 (2006);
K^0_s , Λ : STAR preliminary data, QM09, statistical error only

- Mid-rapidity (|y|<0.5), statistical error only
- **$p_{T:}$ 2.5 – 4 GeV/c R_{dAu} (Λ , p) > R_{dAu} (K^0_s, π) consistent with AMPT**
- **ϕ meson: enhancement at large p_T**
- Large uncertainty to distinguish mass dependence or meson-baryon separation (due to large error bar in p+p reference)

Summary

- STAR preliminary results of ϕ meson production in 200 GeV d+Au collisions are presented.

- Enhanced ϕ meson production at large p_T in most central d+Au collisions.

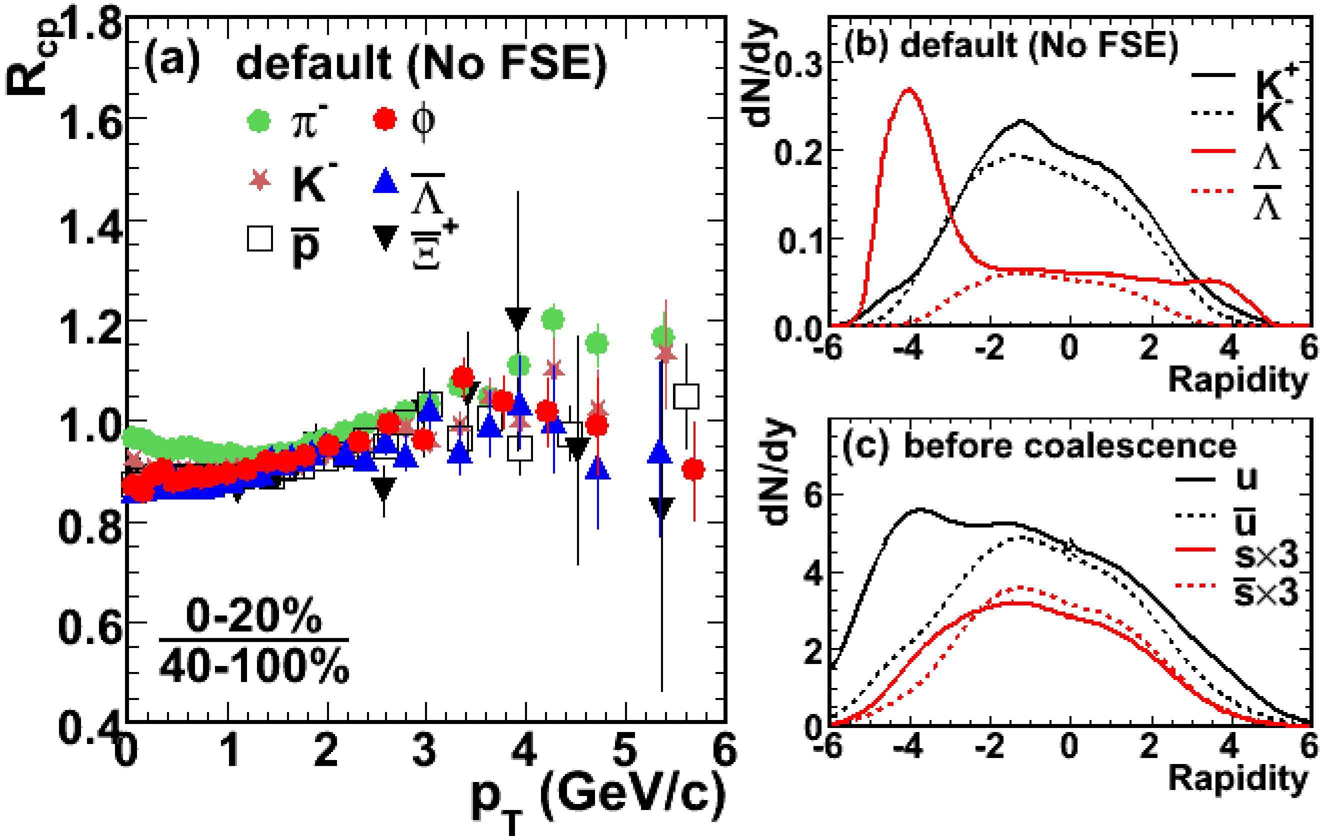
- The particle species dependence of nuclear modification factor R_{dAu} for proton, Λ, K^0_s and π is consistent with the default AMPT calculations which includes hadronic rescatterings in the final state.

  Large uncertainty on Φ meson R_{dAu} prevents decisive conclusion on mass dependent or meson-baryon separation.

- Outlook: rapidity asymmetry of hadron production will provide further information.

Backup

R_{CP} without final state interactions (AMPT)



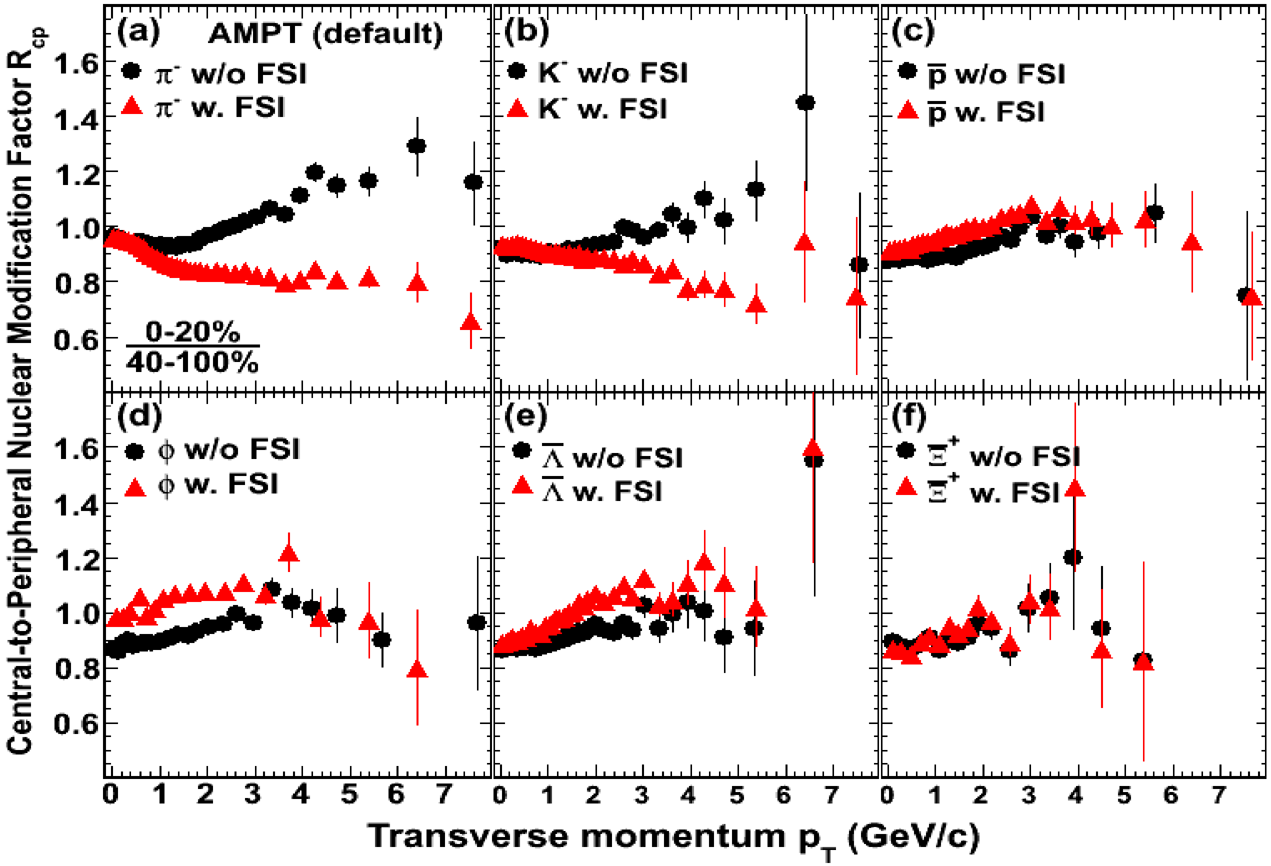
No obvious particle species dependence for $p_T > 1$ GeV/c

Associate production NN→N Λ K+ in initial state

sbar > s at mid-rapidity

X. Zhang et al., arXiv:1001.4734

AMPT model: final-state hadronic rescatterings



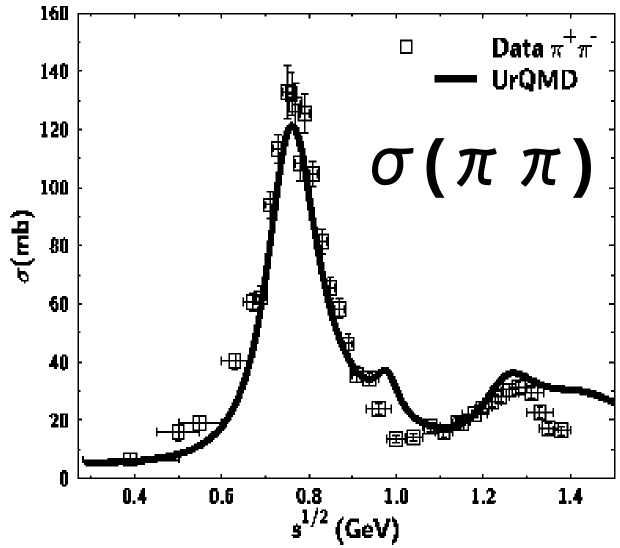
Final-state hadronic rescatterings modify R_{CP}

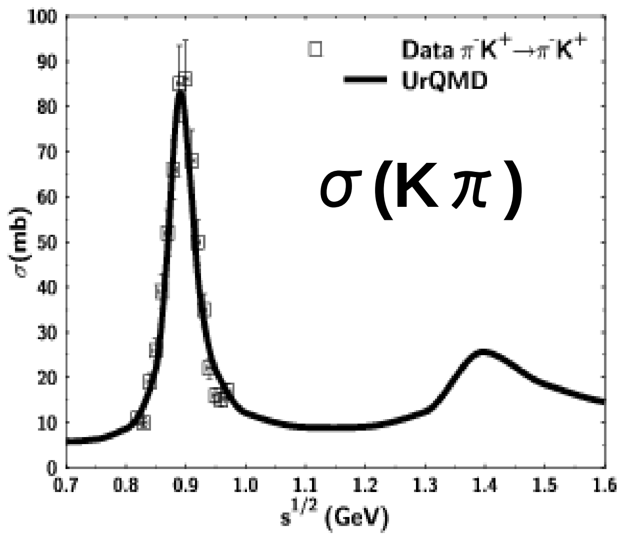
At large p_T, the differences of R_{CP} with/without **final state hadronic rescatterings depend on the rest masses** of different hadrons.

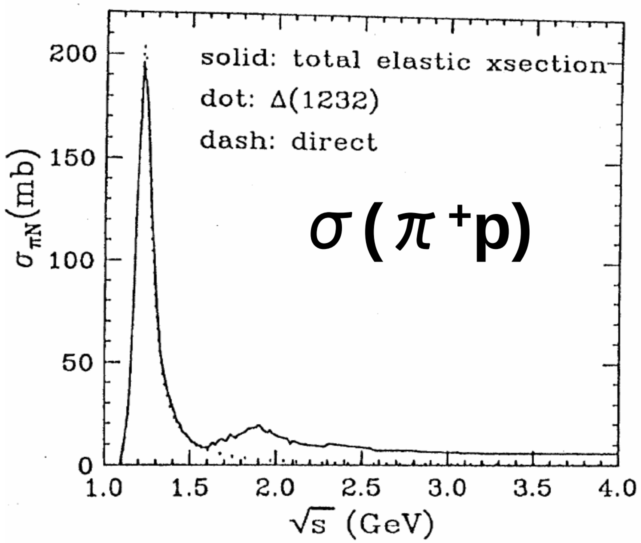
Lighter hadrons (π, K), larger contribution

X. Zhang et al., arXiv:1001.4734

Mass effect in hadronic rescatterings







M. Bleicher *et al.* J. Phys. G 25 (1999) 1859

B. Li et al. Phys. Rev. C 52, 2037 - 2063 (1995)

- ✓ **Cross-section v.s. center of mass energy**
- ✓ E_{cm}=[$(E_1+E_2)^2-(p_1+p_2)^2]^{0.5}$
- ✓ The probable outgoing particles which might have rescatterings will go in the similar direction, open angle between them is small
- ✓ For example, $\pi^+ \pi^-$ scatterings, open angle is chosen to be 5 degree, in our p_T and rapidity range, p increases, E_{cm} is more close to resonance peak
- ✓ Mass effect is important in calculating center of mass energy

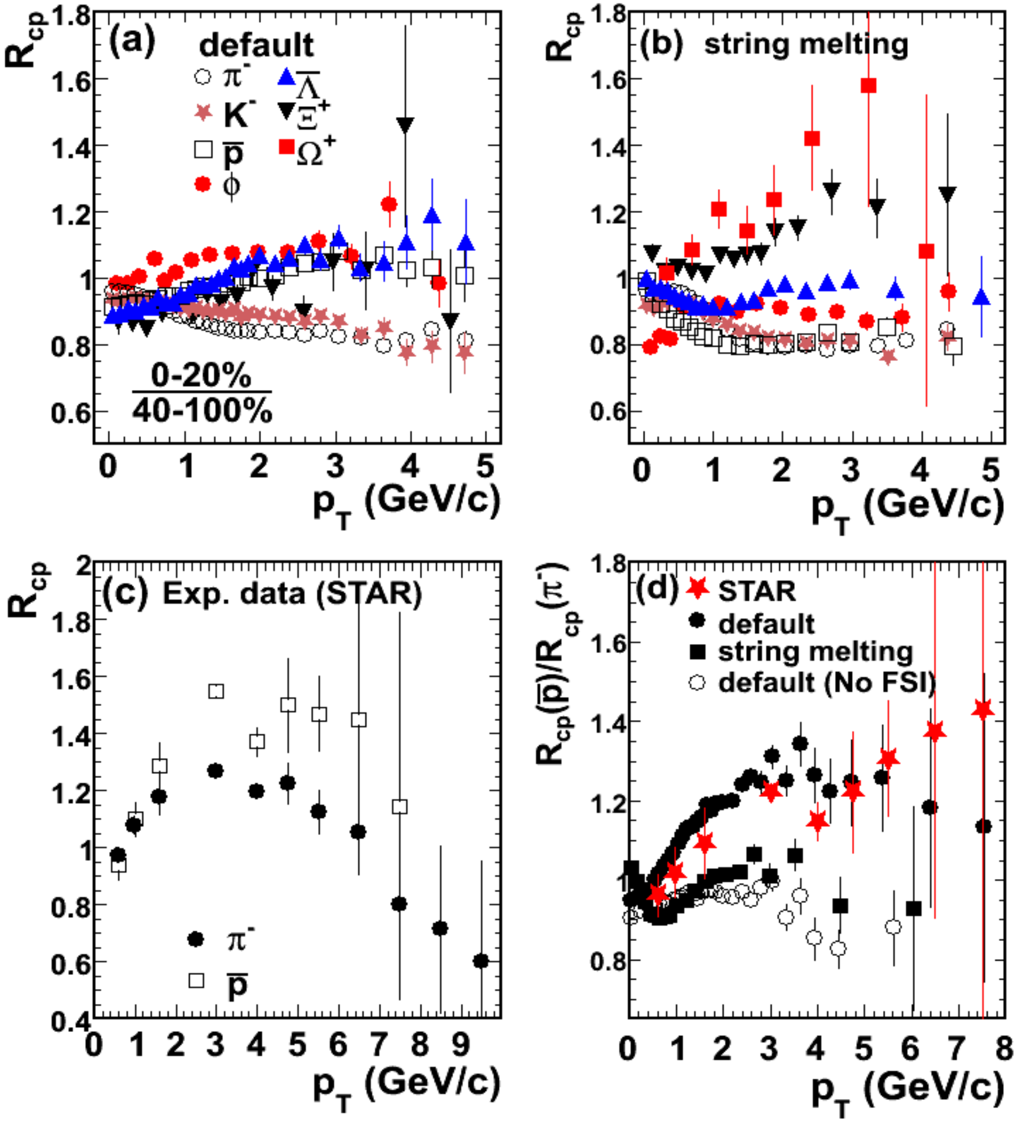
After including final state effects (AMPT)

✓String fragmentation + hadronic rescatterings: **mass dependence**

✓**Other particles? ϕ?**

Mass ϕ ~ p, Λ

Meson v.s. baryon



X. Zhang et al., arXiv:1001.4734