Multi-strange hadrons as Penetrating probes

Shiori Takeuchi
(Sophia University)

Collaborator :
Koichi Murase (Univ. of Tokyo), Tetsufumi Hirano (Sophia Univ.)
Pasi Huovinen (Goethe Univ.), Yasushi Nara (Akita international Univ.)

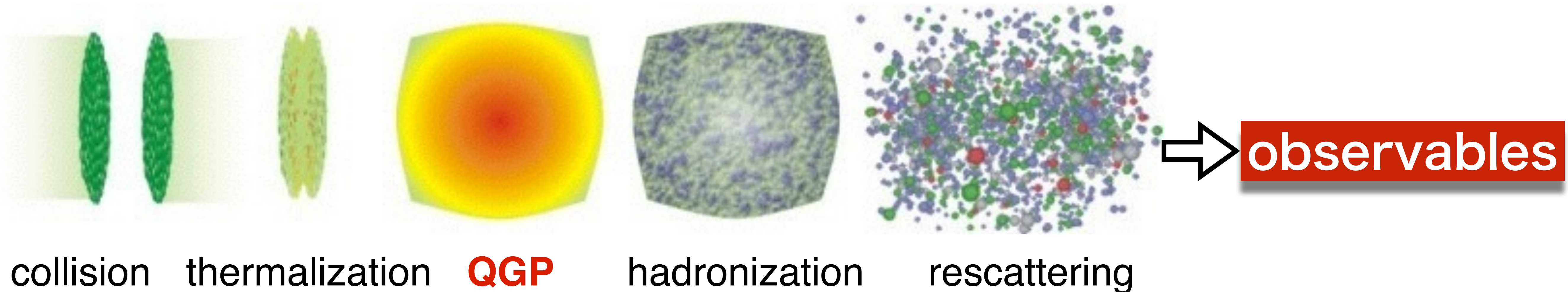
ATHIC2014 OSAKA
The 5th Asian Triangle Heavy Ion Conference 2014
In Osaka, Japan on August 5-8, 2014

Outline

- Introduction
- Integrated dynamical model
- Results
  - p_{T} distributions and $v_2(p_{\mathrm{T}})$
  - Hadronic rescattering effects
- Summary

Introduction

Quark Gluon Plasma in relativistic heavy ion collisions



How to extract the information about QGP from final observables?

Multi-strange hadrons*

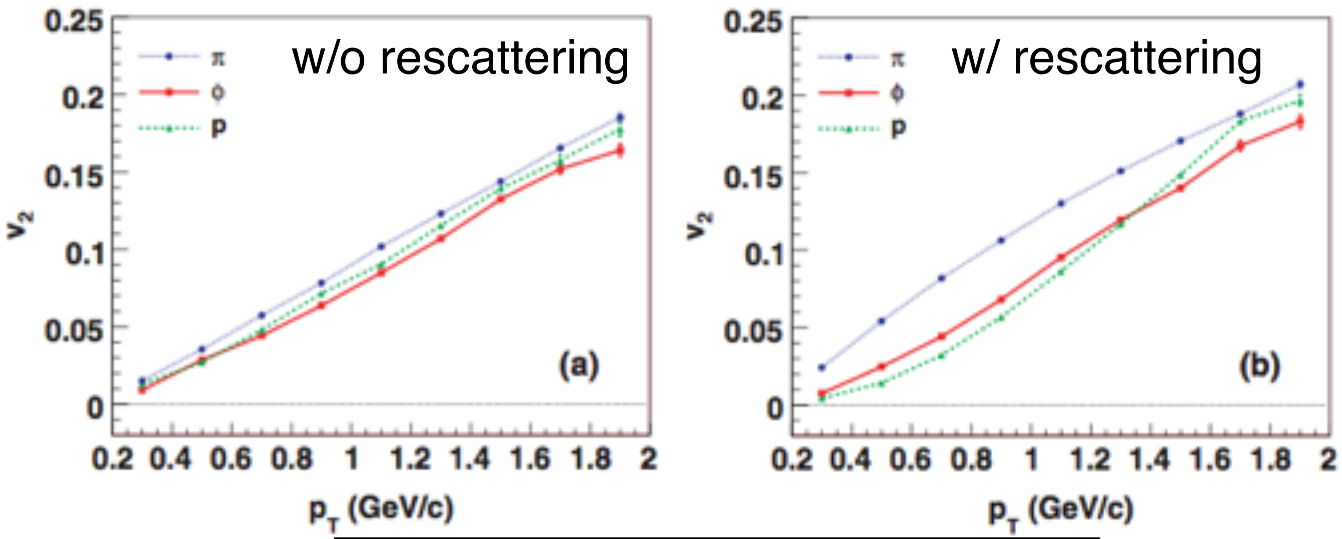
→ small cross section

→ less rescattering

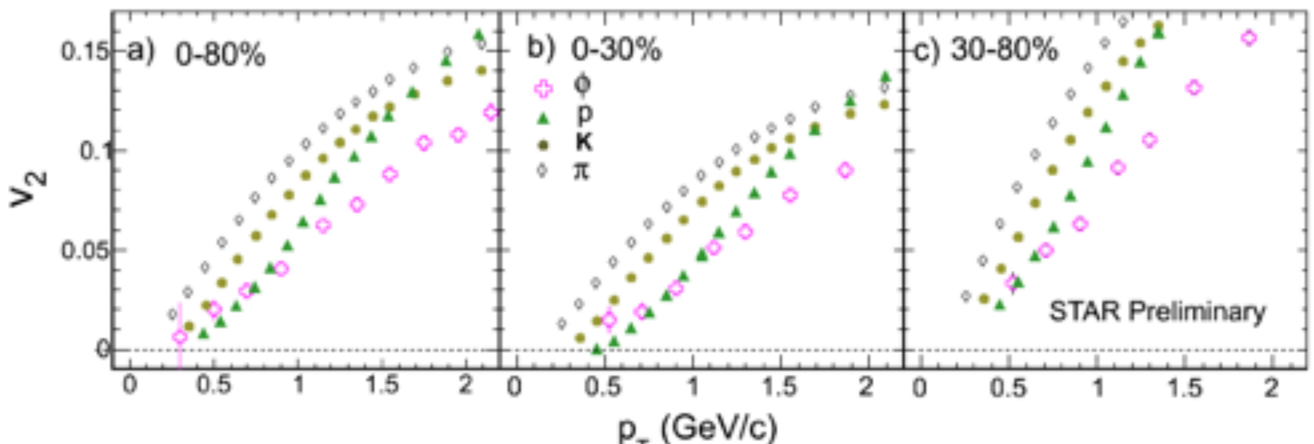
→ direct information about QGP !?

* A. Shor, Phys. Rev. Lett. 54, 1122 (1985)
H. van Hecke, H. Sorge, and N. Xu, Phys. Rev. Lett. 81, 5764 (1998)
Y. Cheng, F. Liu, Z. Liu, K. Schweda, and N. Xu, Phys. Rev. C 68, 034910 (2003)

Introduction



T. Hirano et al., Phys. Rev. C 77, 044909 (2008)



Md. Nasim [STAR Collaboration], Nucl, Phys. A 904-905 (2013) 413c-416c

Small cross section of ϕ meson

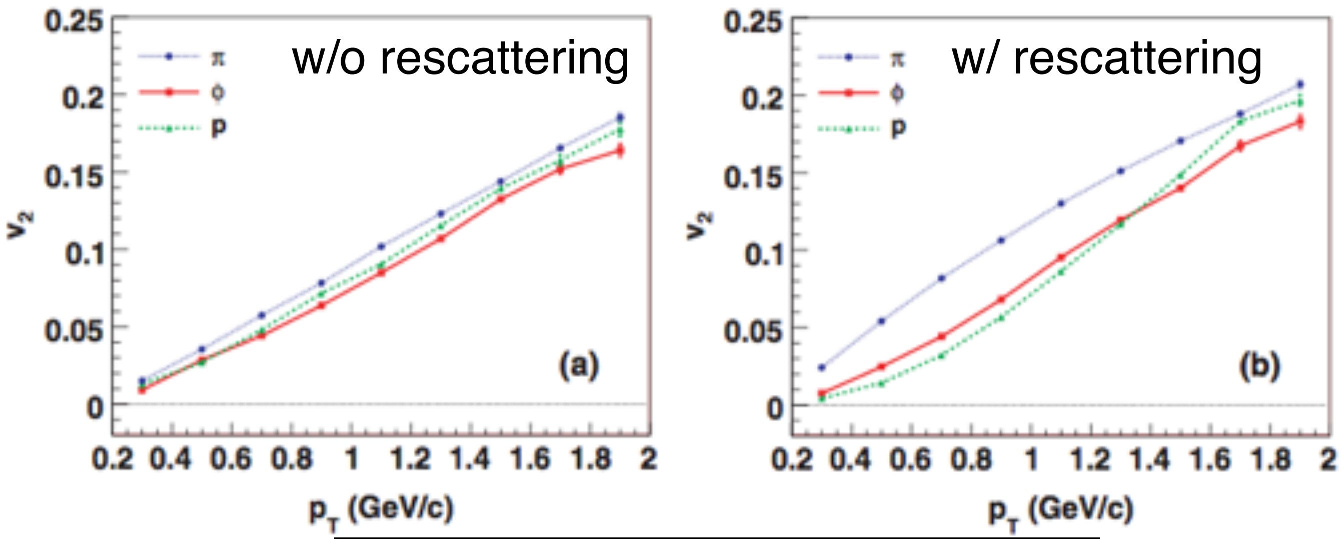
→ less rescattering

→ violation of mass ordering

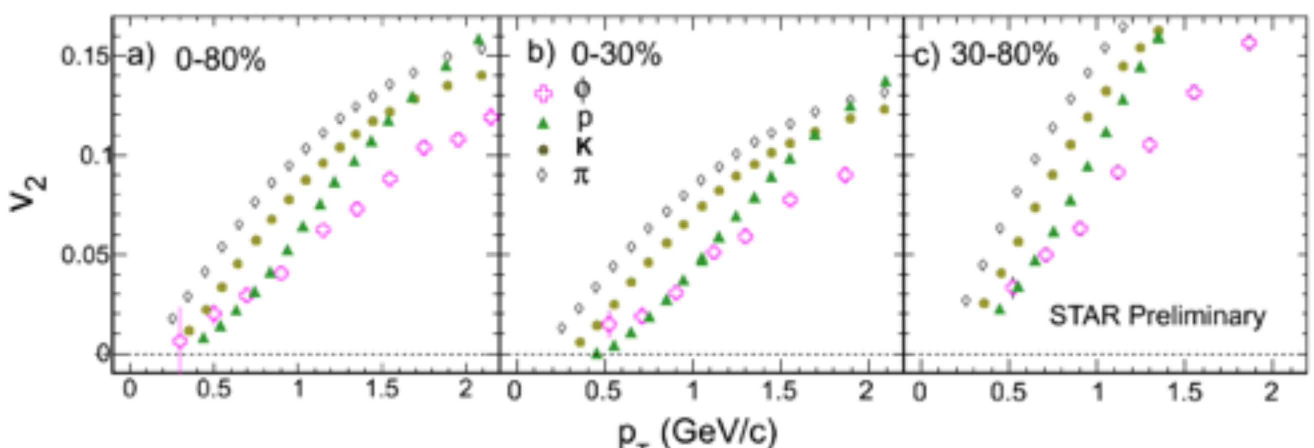
$$v_2^p(p_\mathrm{T}) < v_2^\phi(p_\mathrm{T})$$

- predicted by hydro + cascade model
- observed by STAR Collaboration

Introduction



T. Hirano et al., Phys. Rev. C 77, 044909 (2008)



Md. Nasim [STAR Collaboration], Nucl, Phys. A 904-905 (2013) 413c-416c

Small cross section of ϕ meson

$\rightarrow$ less rescattering

$\rightarrow$ violation of mass ordering

$$v_2^p(p_\mathrm{T}) < v_2^\phi(p_\mathrm{T})$$

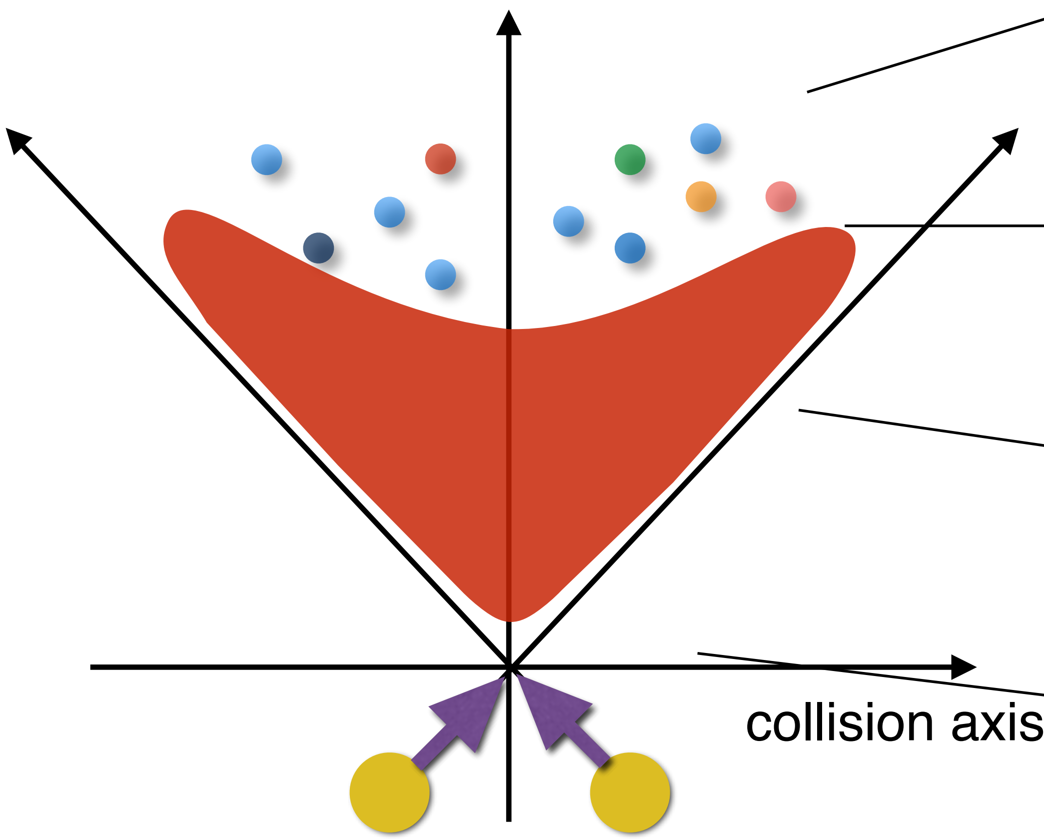
- ◆ predicted by hydro + cascade model
- ◆ observed by STAR Collaboration

<u>Purpose of this study</u>

Investigating the effects of the hadronic rescatterings on observables of **multi-strange hadrons** systematically and quantitatively

Integrated dynamical model

T. Hirano, P. Huovinen, K. Murase and Y. Nara, Prog. Part. Nucl. Phys. **70**, 108 (2013)



Au+Au 200 GeV
event-by-event simulation

Kinetic transport model (JAM)

$T_{\rm sw} = 155\ \mathrm{MeV}$

Cooper-Frye formula

Lattice EoS (s95p-v1.1)

(3+1)D ideal hydro model

Initial condition: MC-Glauber

Option in JAM

Case 1 (default): full calculation

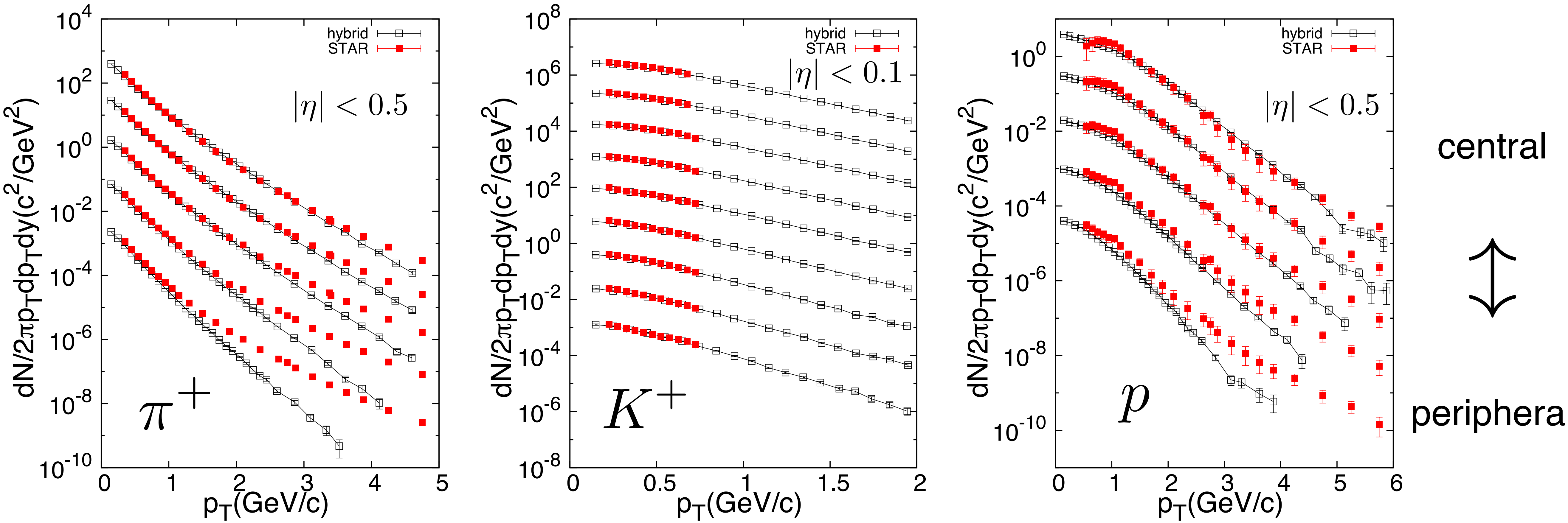
Case 2: switch off the hadronic rescatterings

Results

- Comparison with STAR data
  - p_{T} distributions
  - $v_2(p_{\mathrm{T}})$
- Hadronic rescattering effects

Results - p_{T} distributions

■ Centrality dependences of p_{T} distributions for π, K and p



Integrated dynamical model well reproduces STAR data

◆ in particular in low p_{T} region

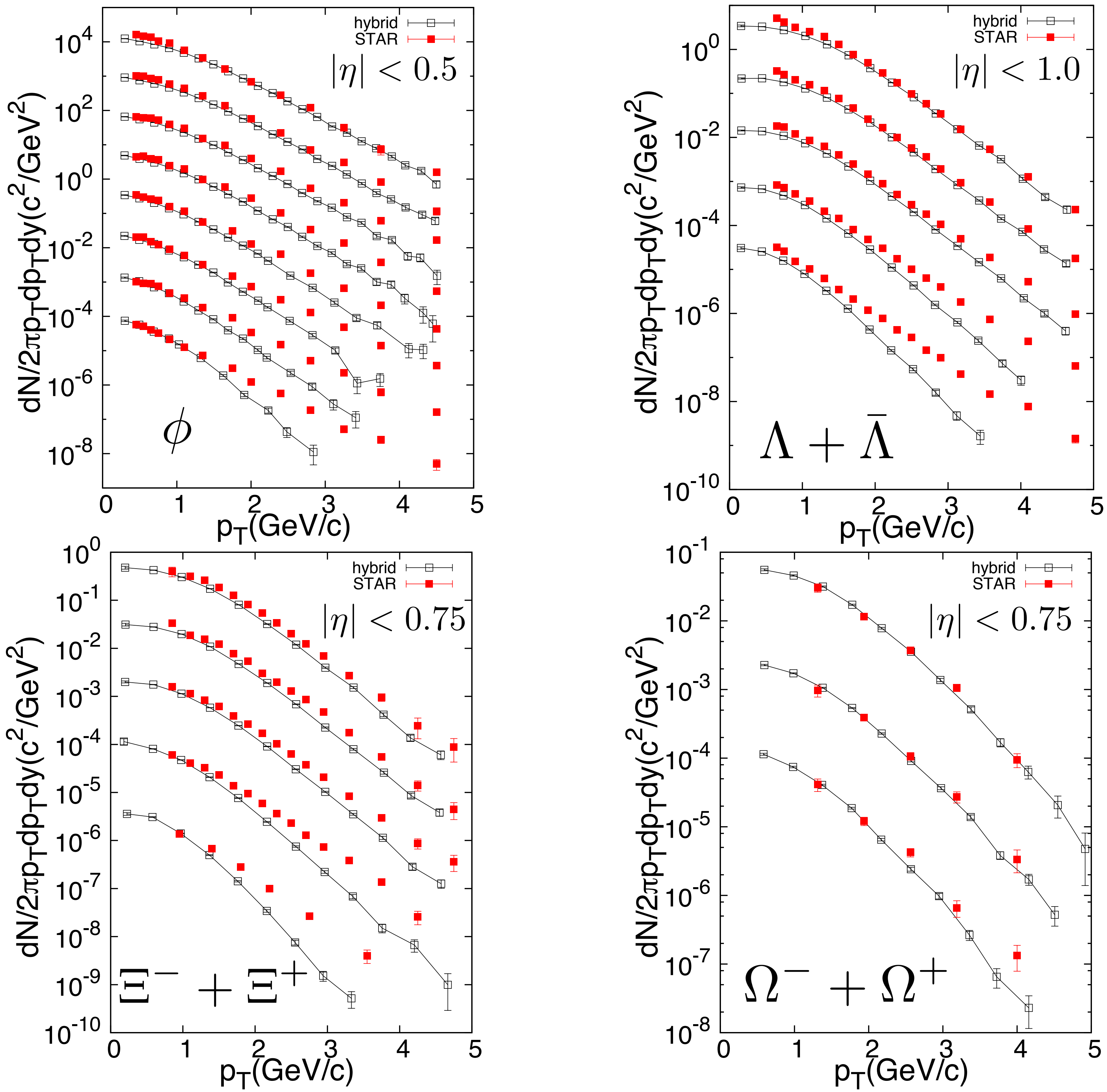
◆ deviation in high p_{T} region due to absence of components for mini-jets/recombination

B.I. Abelev et al., Phys. Rev. Lett. 97, 153201 (2006)

J. Adams et al., Phys. Rev. Lett. 92, 112301 (2004)

Results - p_{T} distributions

- Centrality dependences of p_{T} distributions for ϕ, Λ, Ξ and Ω

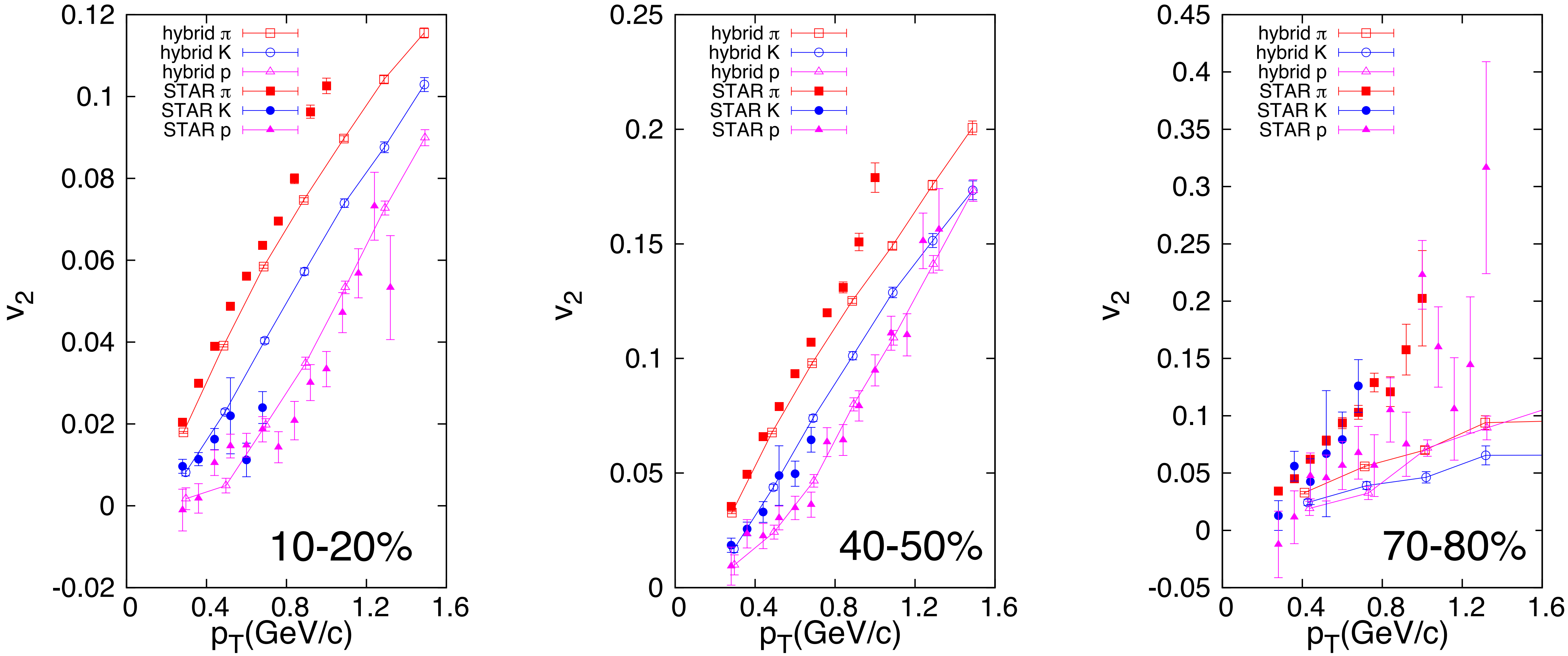


B.I. Abelev et al., Phys. Rev. Lett. 99, 112301 (2007)

J. Adams et al., Phys. Rev. Lett. 98, 62301 (2007)

Results - elliptic flow

- $v_2(p_\mathrm{T})$ compared with STAR data for π, K and p



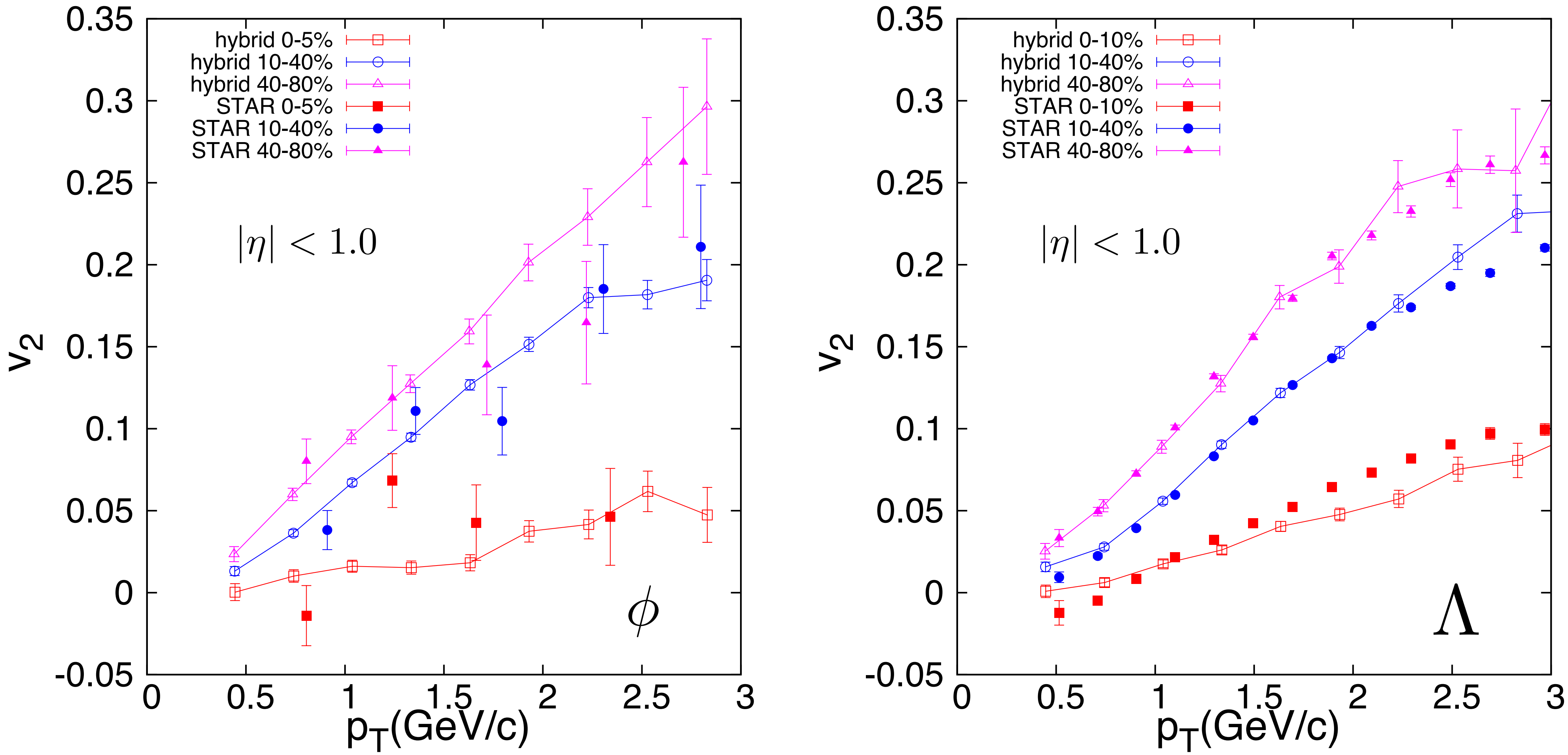
$|\eta| < 1.0$ Reaction plane method

- mid central collisions → well reproduced
- peripheral collisions → smaller than STAR data due to reaction plane method

J. Adams et al., Phys. Rev. C 72, 14904 (2005)

Results - elliptic flow

- $v_2(p_\mathrm{T})$ compared with STAR data for ϕ and Λ

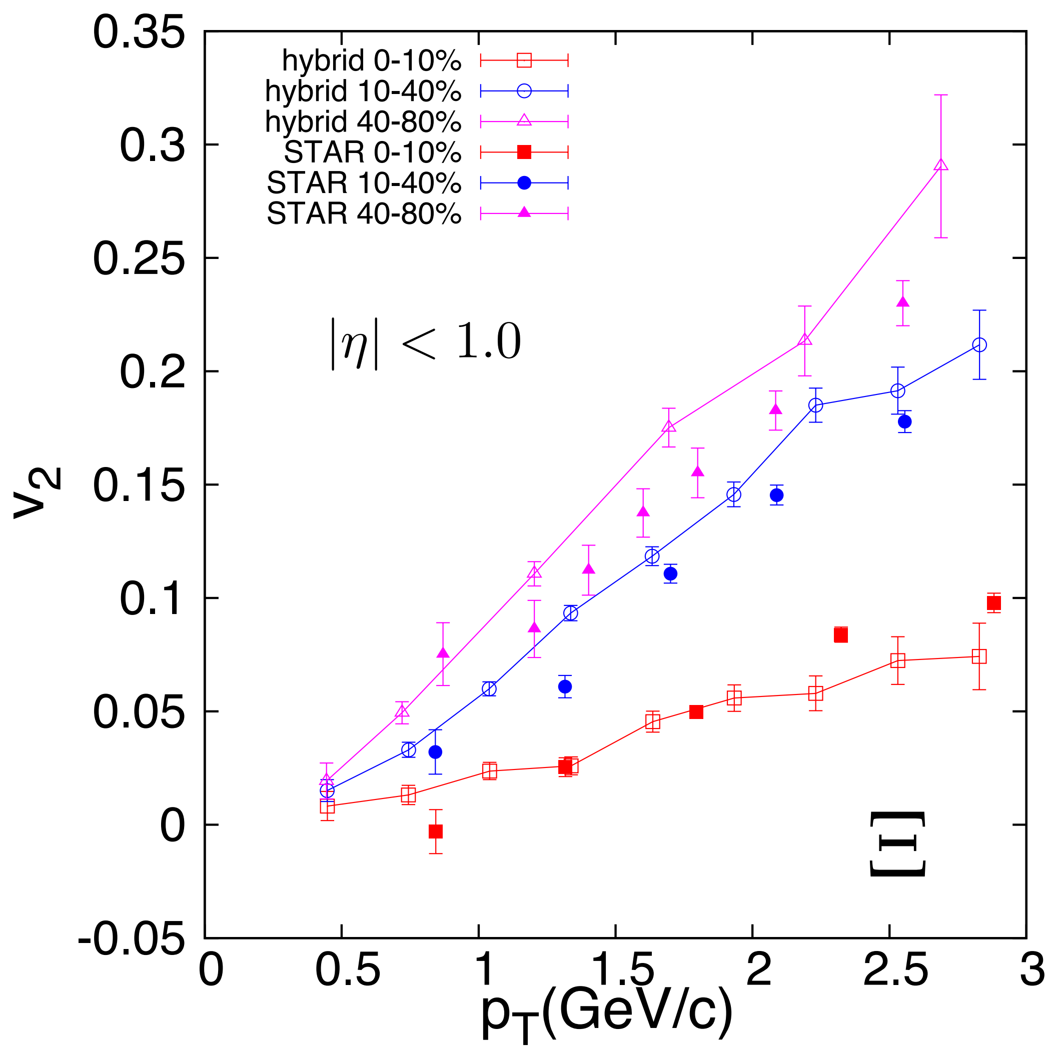


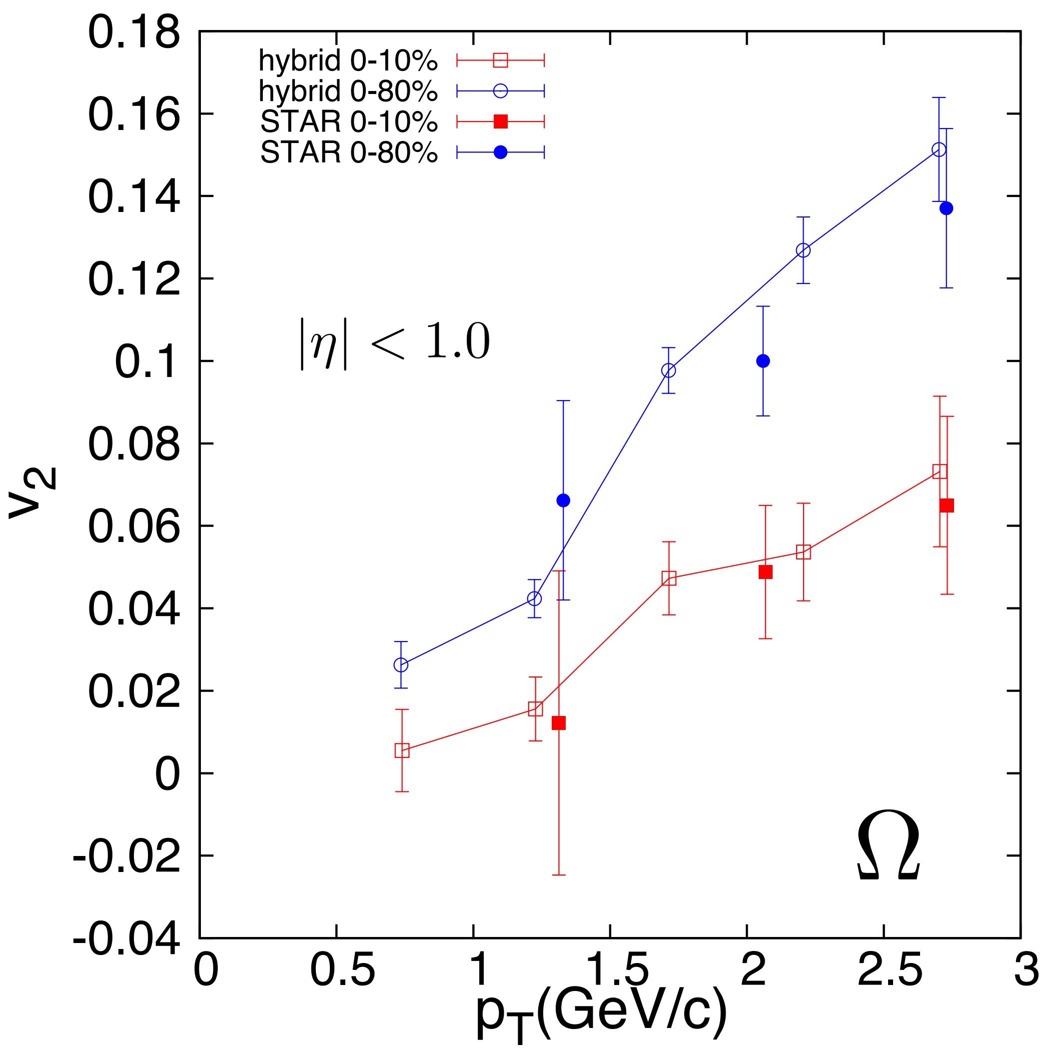
B.I. Abelev et al., Phys. Rev. Lett. 99, 112301 (2007)

B.I. Abelev et al., Phys. Rev. C 77, 54901 (2008)

Results - elliptic flow

- $v_2(p_{\mathrm{T}})$ compared with STAR data for Ξ and Ω





B.I. Abelev et al., Phys. Rev. Lett. 99, 112301 (2007)

B.I. Abelev et al., Phys. Rev. C 77, 54901 (2008)

Results

- Comparison with STAR data
  - p_{T} distributions
  - $v_2(p_{\mathrm{T}})$

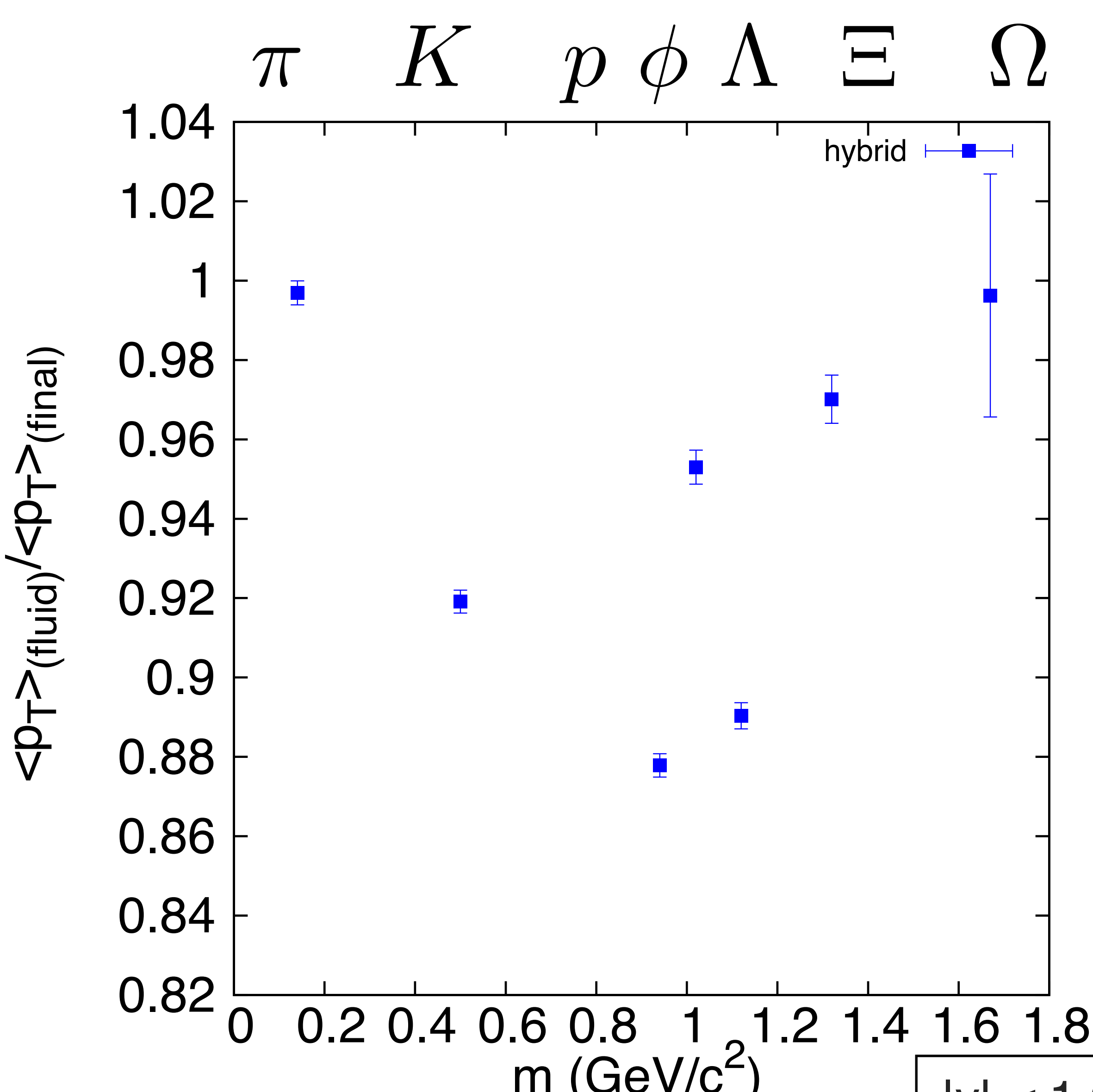
- Hadronic rescattering effects

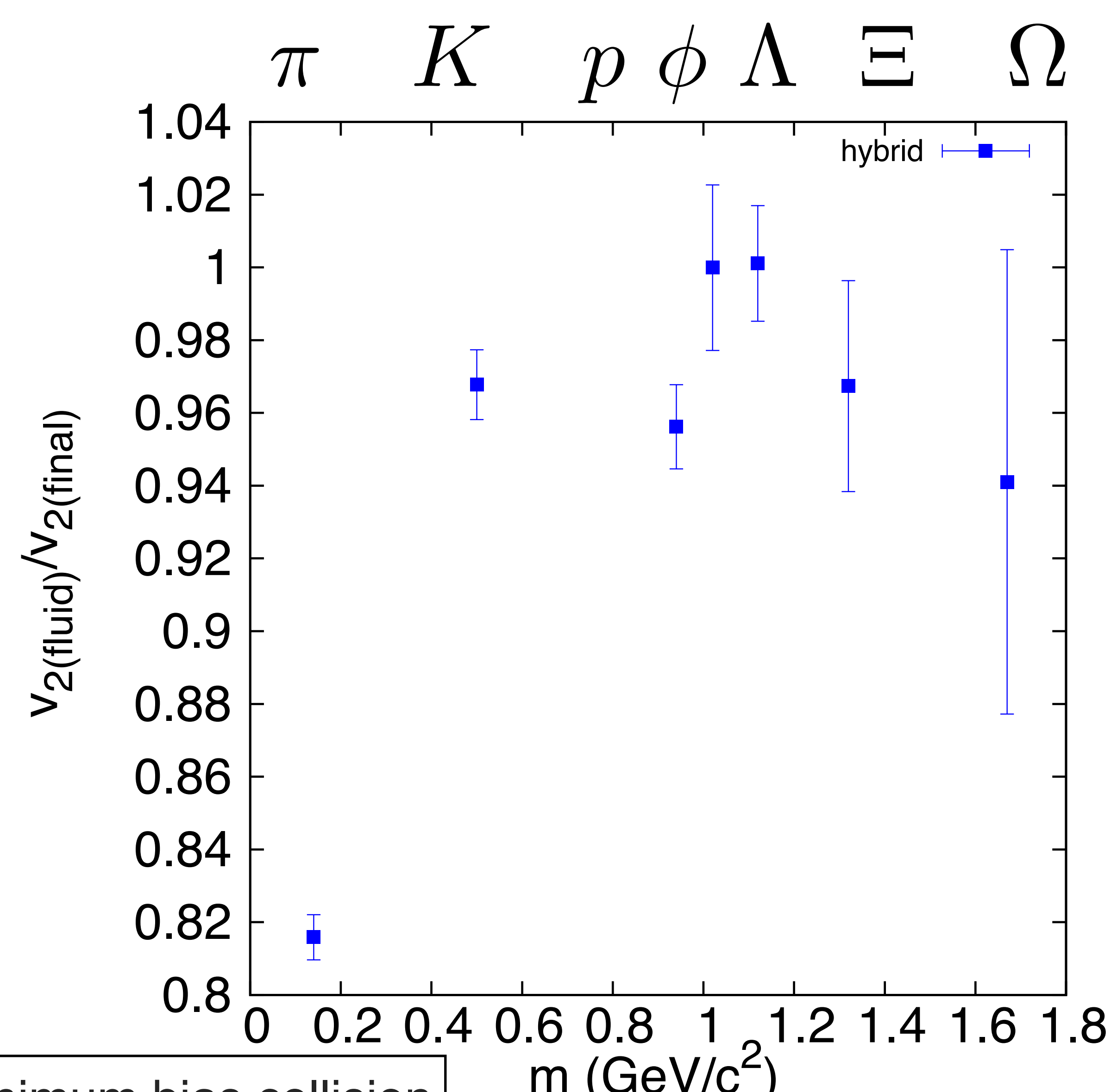
Results - Hadronic rescattering effects

- $\mathcal{O}_{(\mathrm{fluid})}/\mathcal{O}_{(\mathrm{final})}$

  The ratios of observables at the fluid stage to final ones

  $\longrightarrow$ How much does **the space-time evolution of QGP** contribute to final observables?

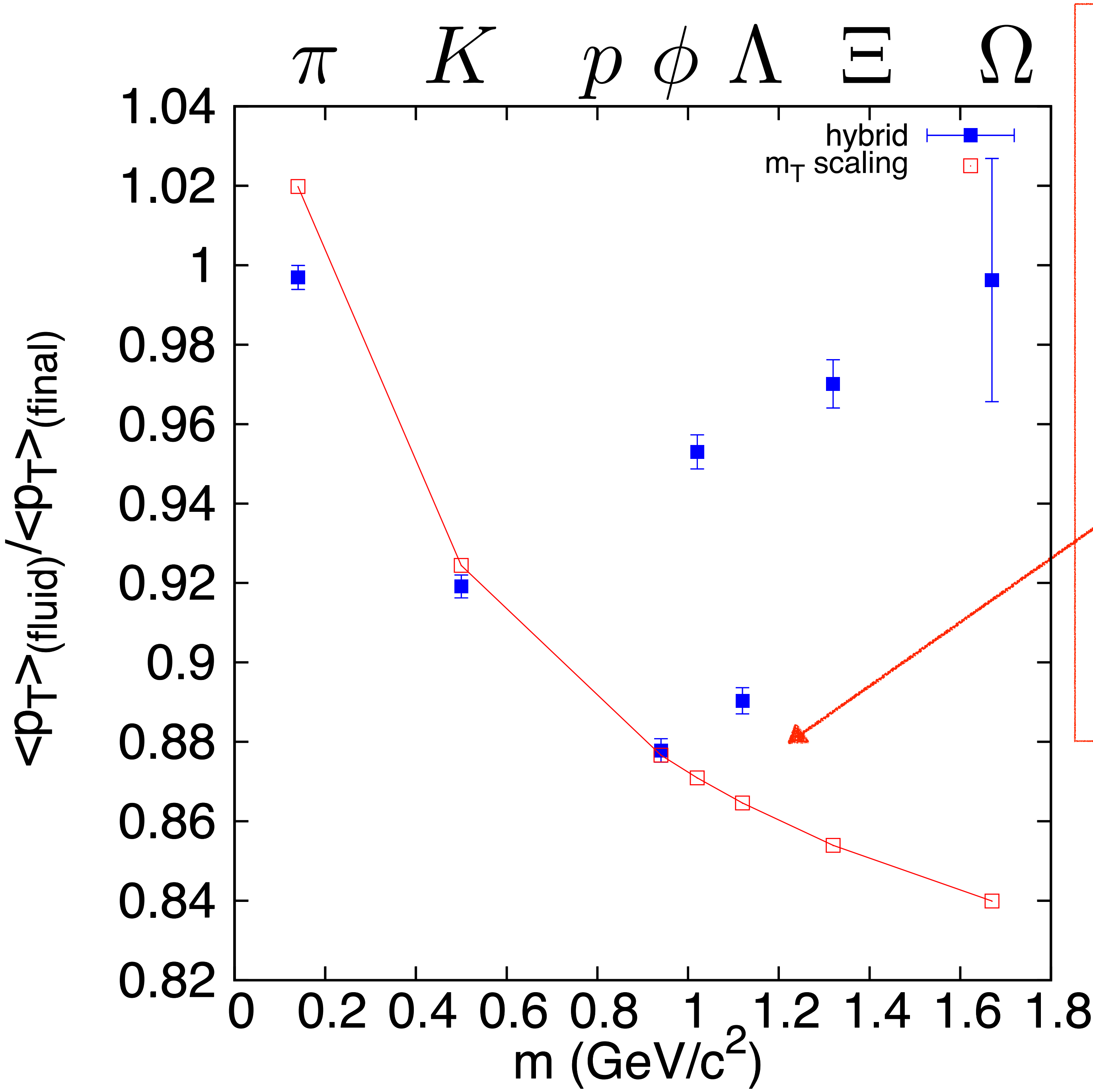




|y| < 1.0, minimum bias collision

Results - Hadronic rescattering effects

- $p_{\mathrm{T}\,(\mathrm{fluid})}/p_{\mathrm{T}\,(\mathrm{final})}$



|y| < 1.0, minimum bias collision

m_{T} scaling

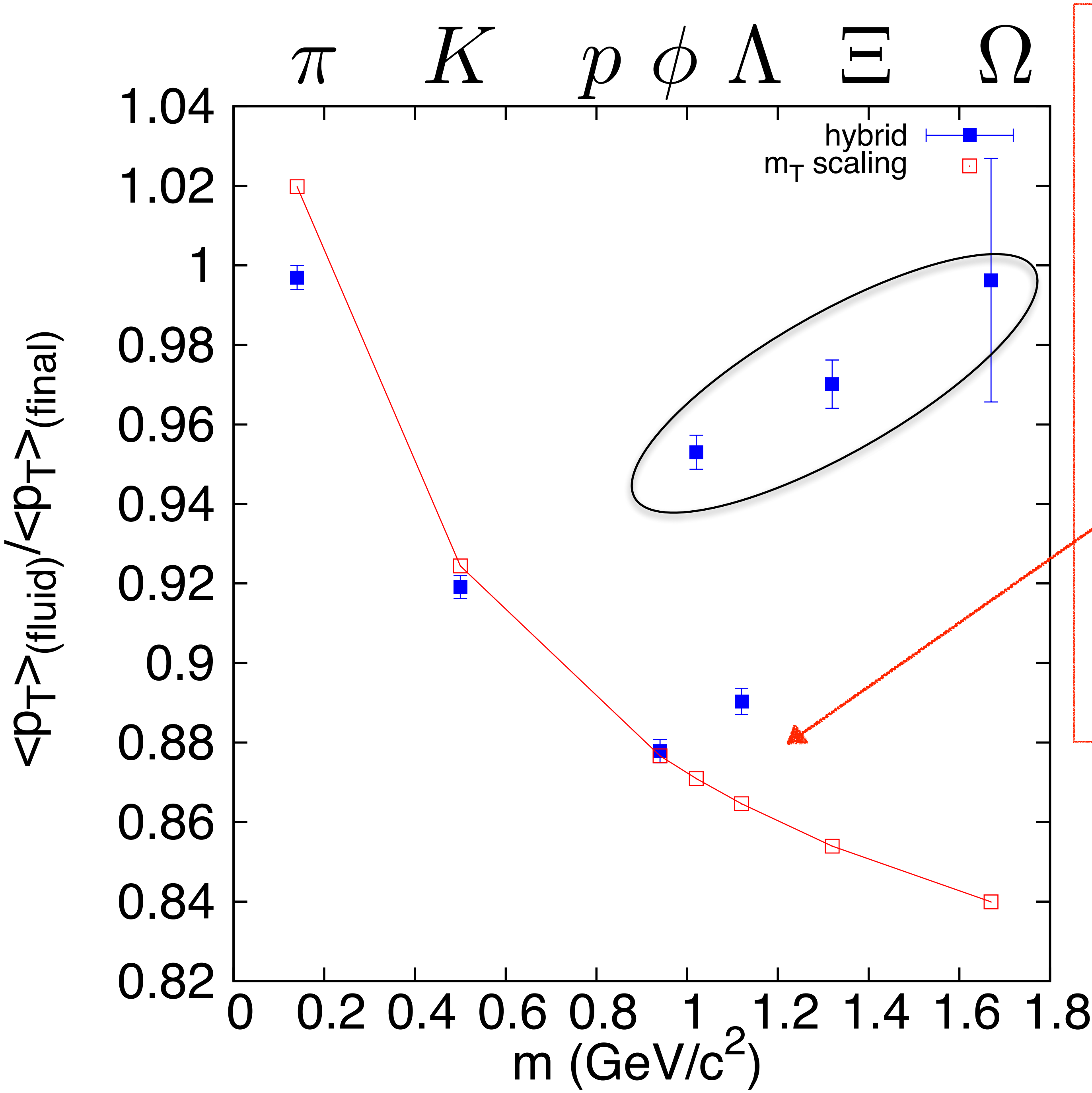
If all the particles
- move with common flow velocity v_{f}
- freeze out at T_{fo}

$$\frac{dN}{p_{\mathrm{T}}dp_{\mathrm{T}}} \propto \exp\left(-\frac{m_{\mathrm{T}}}{T_{\mathrm{eff}}}\right)$$

$$T_{\mathrm{eff}} = T_{\mathrm{fo}} + \frac{1}{2}mv_{\mathrm{f}}^2$$

Results - Hadronic rescattering effects

- $p_{\mathrm{T\,(fluid)}}/p_{\mathrm{T\,(final)}}$



|y| < 1.0, minimum bias collision

m_{T} scaling

If all the particles
- move with common flow velocity v_{f}
- freeze out at T_{fo}

$$\frac{dN}{p_{\mathrm{T}}dp_{\mathrm{T}}} \propto \exp\left(-\frac{m_{\mathrm{T}}}{T_{\mathrm{eff}}}\right)$$

$$T_{\mathrm{eff}} = T_{\mathrm{fo}} + \frac{1}{2}mv_{\mathrm{f}}^2$$

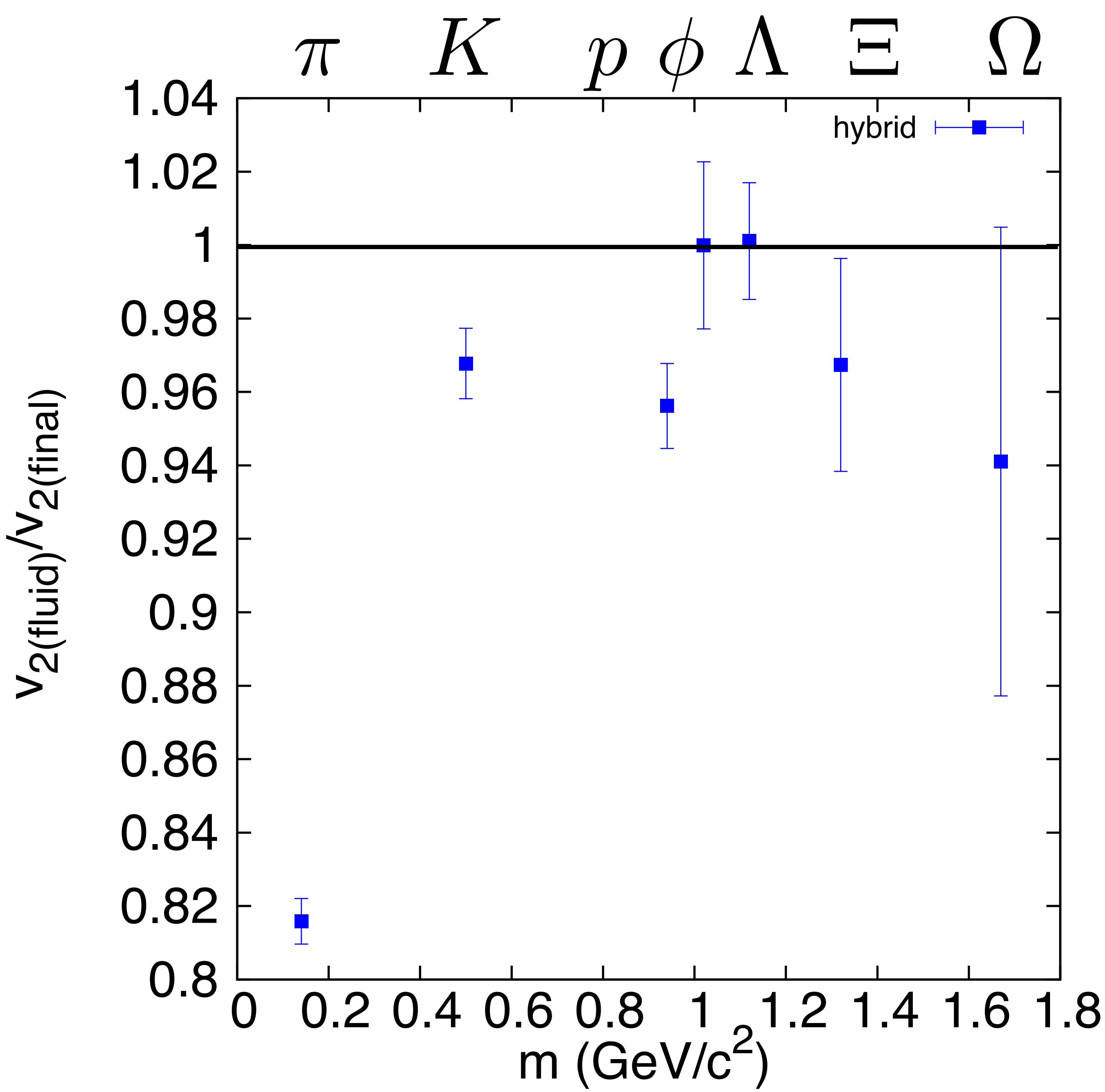
Multi-strange hadrons (ϕ, Ξ and Ω)

→ deviation from m_{T} scaling

→ little rescattering effects on $\langle p_{\mathrm{T}} \rangle$

Results - Hadronic rescattering effects

- $v_{2\,(\mathrm{fluid})}/v_{2\,(\mathrm{final})}$



|y| < 1.0, minimum bias collision

◇ π

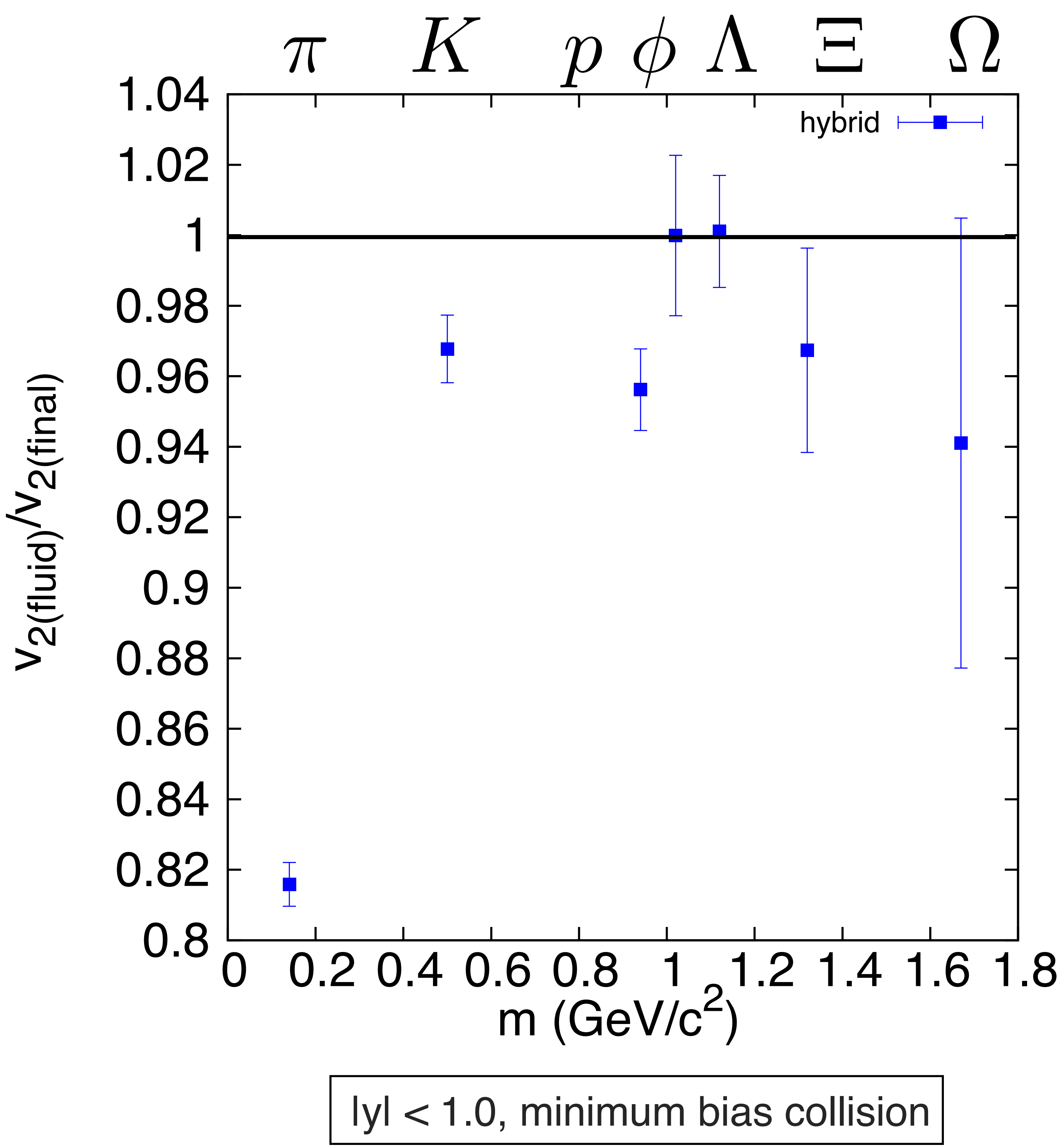
~ 20% of total v_2 is developed in the hadronic stage

◇ the others

hadronic rescattering less contributes to v_2

Results - Hadronic rescattering effects

- $v_{2\,(\mathrm{fluid})}/v_{2\,(\mathrm{final})}$



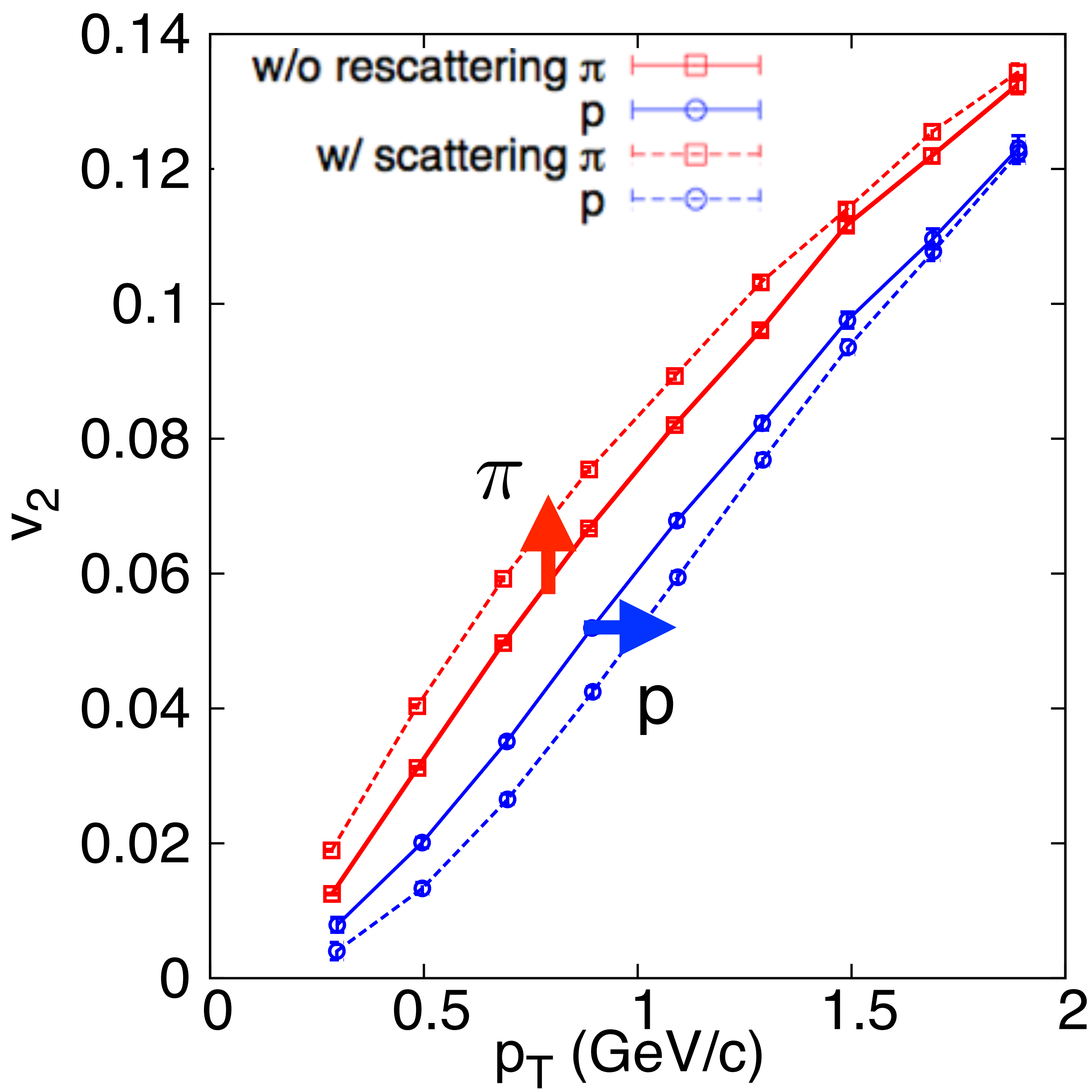
◇ π
~ 20% of total v_2 is developed in the hadronic stage

◇ the others
hadronic rescattering less contributes to v_2

Multi strange hadrons
→ little rescattering effects
→ **<u>penetrating probes</u>**

Results - Hadronic rescattering effects

- $v_2(p_\mathrm{T})$ for π and p
  - switch on/off hadronic rescatterings



$|\eta| < 1.0$, minimum bias collision

Slope of $v_2(p_\mathrm{T})$

$$\longrightarrow \frac{dv_2}{dp_\mathrm{T}} \sim \frac{v_2}{\langle p_\mathrm{T} \rangle}$$

T. Hirano and M. Gyulassy, Nucl. Phys. **A769**, 71 (2006)

After hadronic rescattering

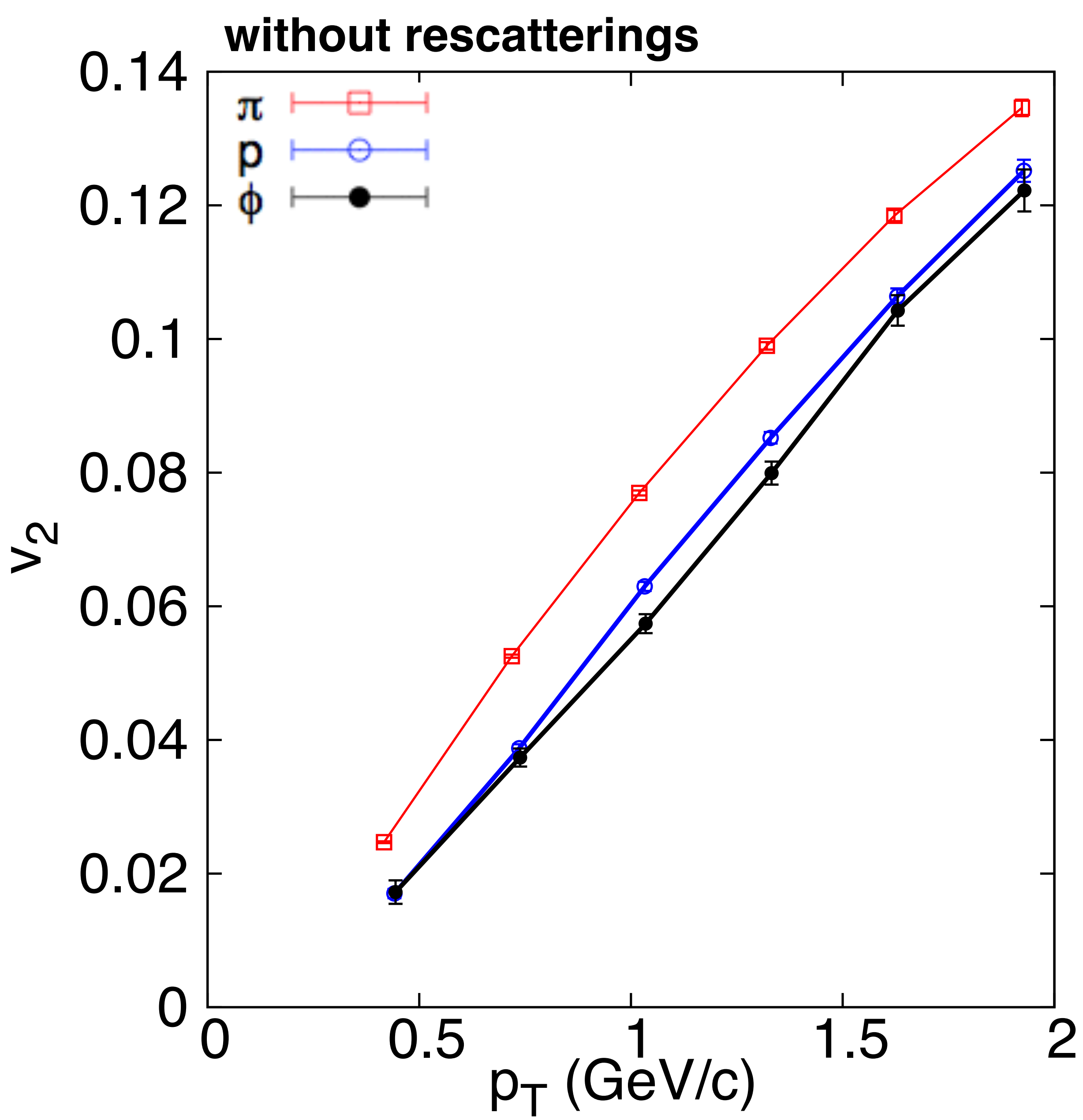
π : $v_2/\langle p_\mathrm{T} \rangle$ → increase

p : $v_2/\langle p_\mathrm{T} \rangle$ → decrease

→ remarkable mass ordering

Results - Hadronic rescattering effects

- $v_2(p_\mathrm{T})$ for π, p and ϕ
  - switch on/off hadronic rescatterings



$|\eta| < 1.0$, minimum bias collision

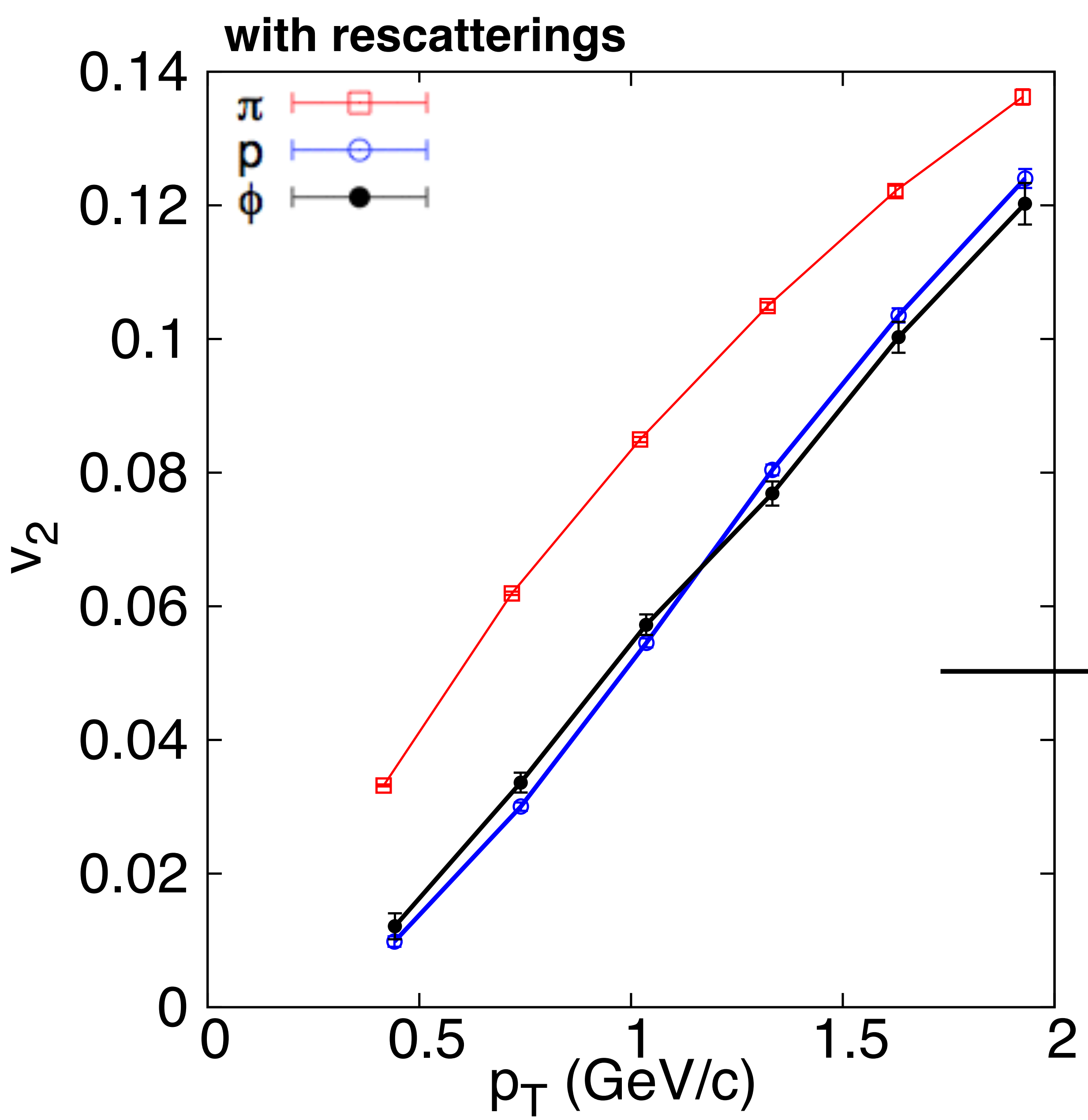
$$m_\pi < m_p < m_\phi$$

$$\rightarrow v_2^\pi(p_\mathrm{T}) > v_2^p(p_\mathrm{T}) > v_2^\phi(p_\mathrm{T})$$

Mass ordering

Results - Hadronic rescattering effects

- $v_2(p_\mathrm{T})$ for π, p and ϕ
  - switch on/off hadronic rescatterings



$|\eta| < 1.0$, minimum bias collision

$m_\pi < m_p < m_\phi$

$\rightarrow \cancel{v_2^\pi(p_\mathrm{T}) > v_2^p(p_\mathrm{T}) > v_2^\phi(p_\mathrm{T})}$

Mass ordering

$$\boxed{v_2^\pi(p_\mathrm{T}) > v_2^\phi(p_\mathrm{T}) > v_2^p(p_\mathrm{T})}$$

Violation of mass ordering

→ due to less rescatterings of ϕ

Summary

Hadronic rescattering effects are studied within the integrated dynamical approach

- The p_{T} distributions and $v_2(p_{\mathrm{T}})$ are well reproduced by default model.

- Multi-strange hadrons are affected little by the hadronic rescattering in the late stage

→ less rescattering and freeze-out earlier

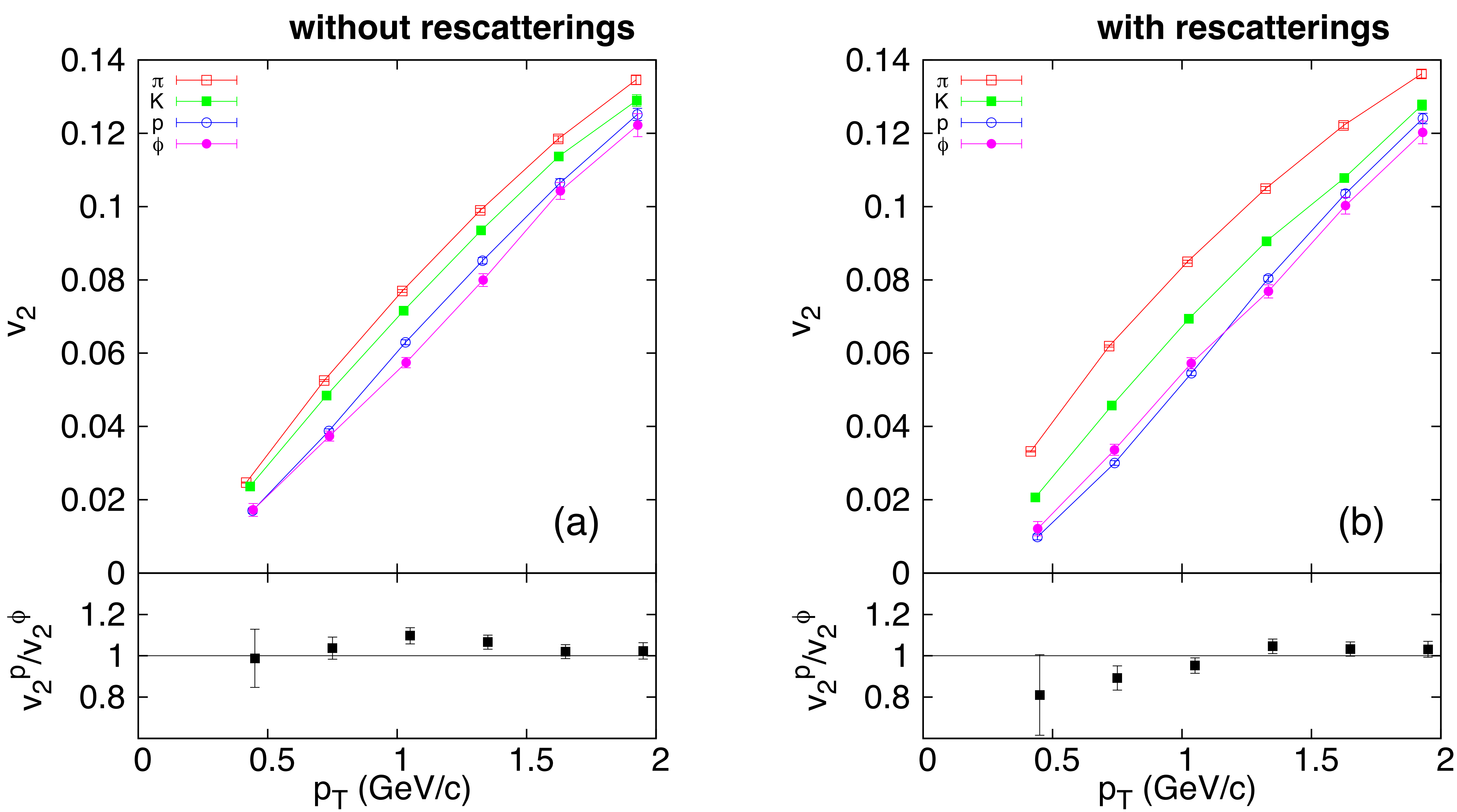
→ keeping the information just after fluid stage

→ **“penetrating” probes!**

Back up

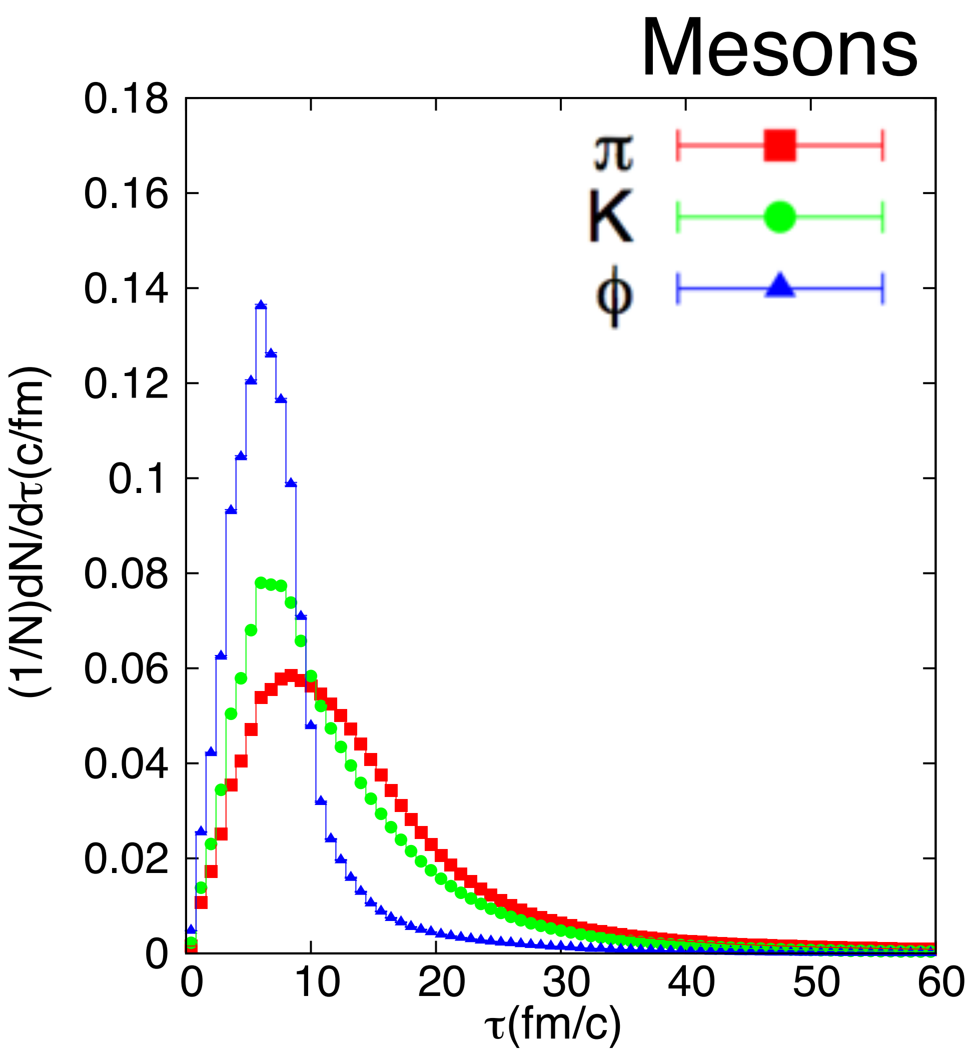
Back up

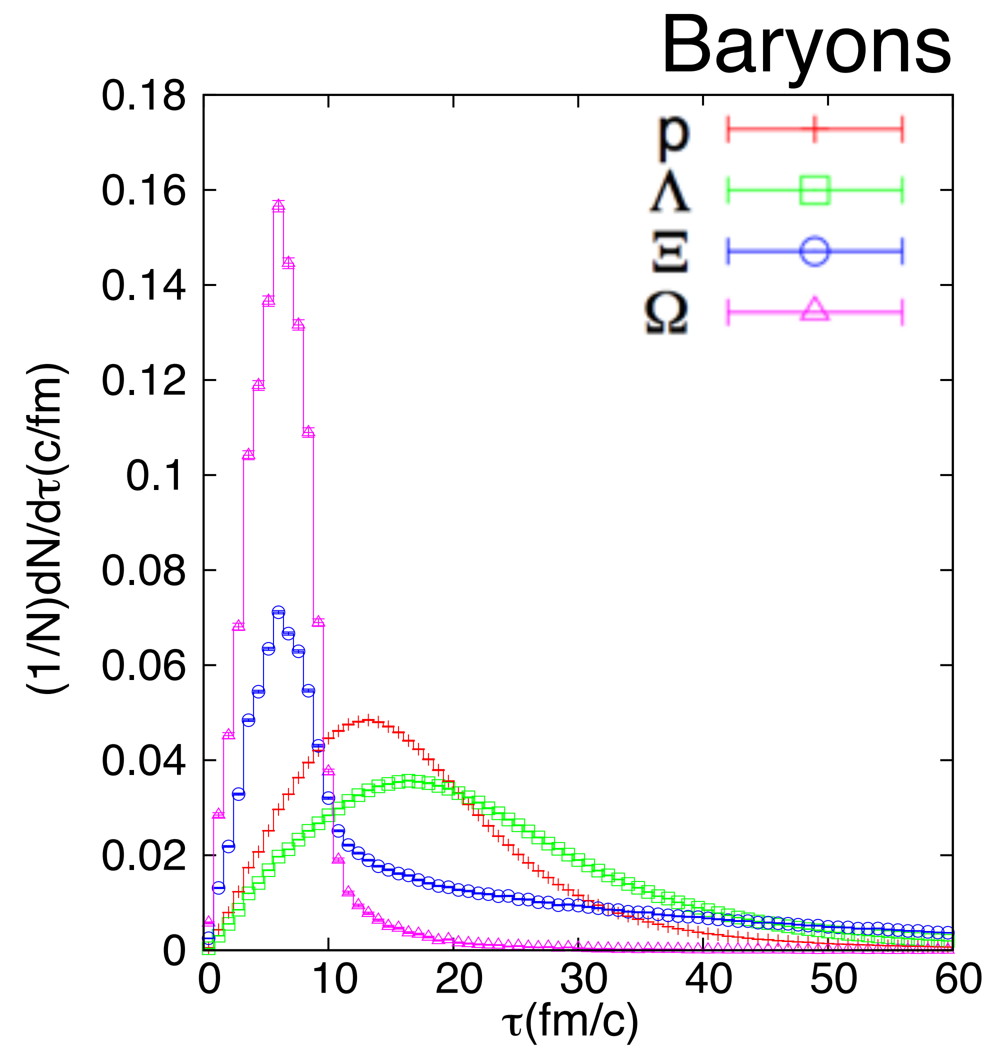
- $v_2(p_\mathrm{T})$ for π, K, p and ϕ
  - switch on/off hadronic rescatterings
  - ratio of v_2^p to v_2^ϕ



Back up

■ Freeze-out time (τ) distributions





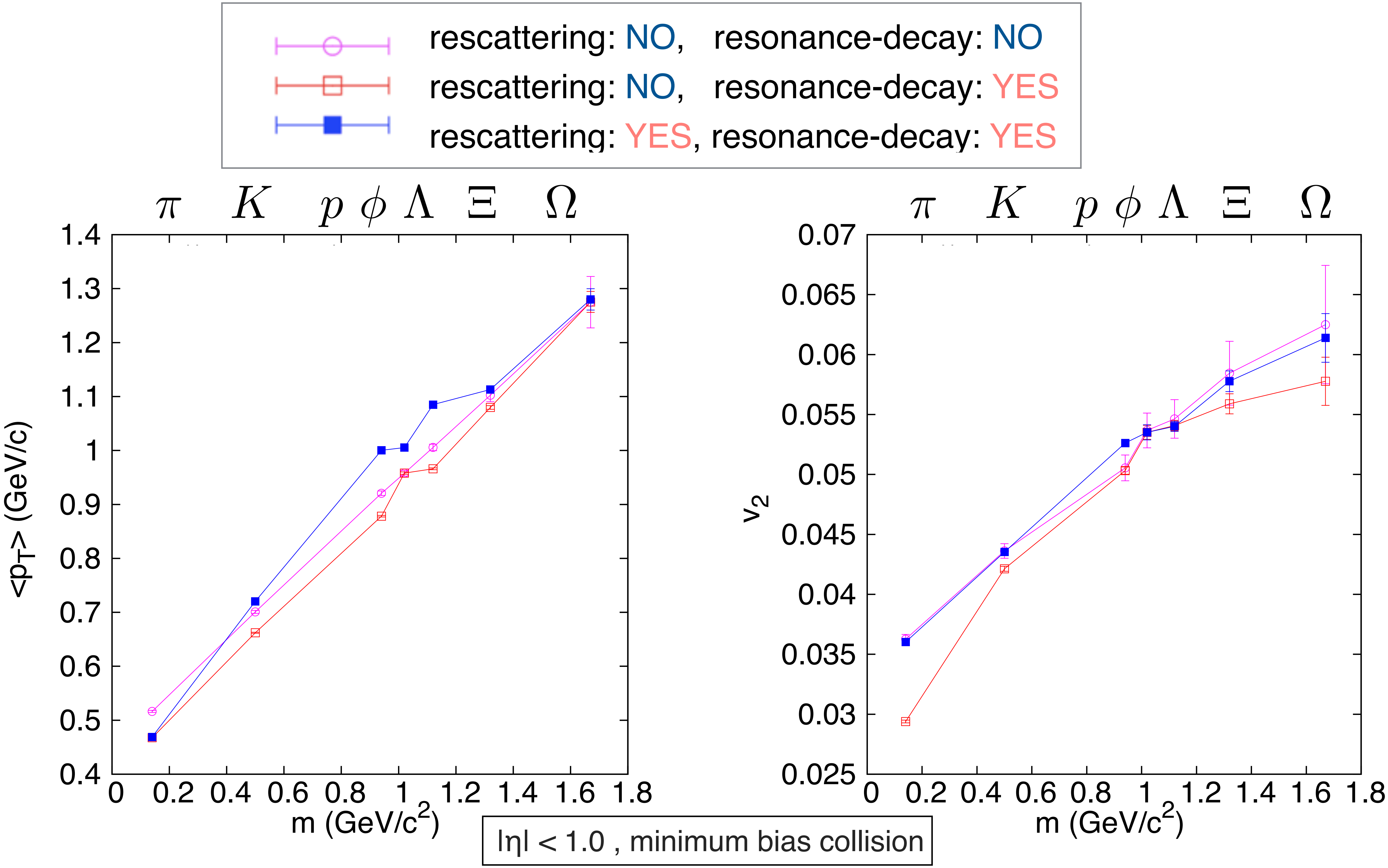
Multi-strange hadrons

→ little rescattering in the late stage

→ <u>freeze-out earlier than non-strange hadrons</u>

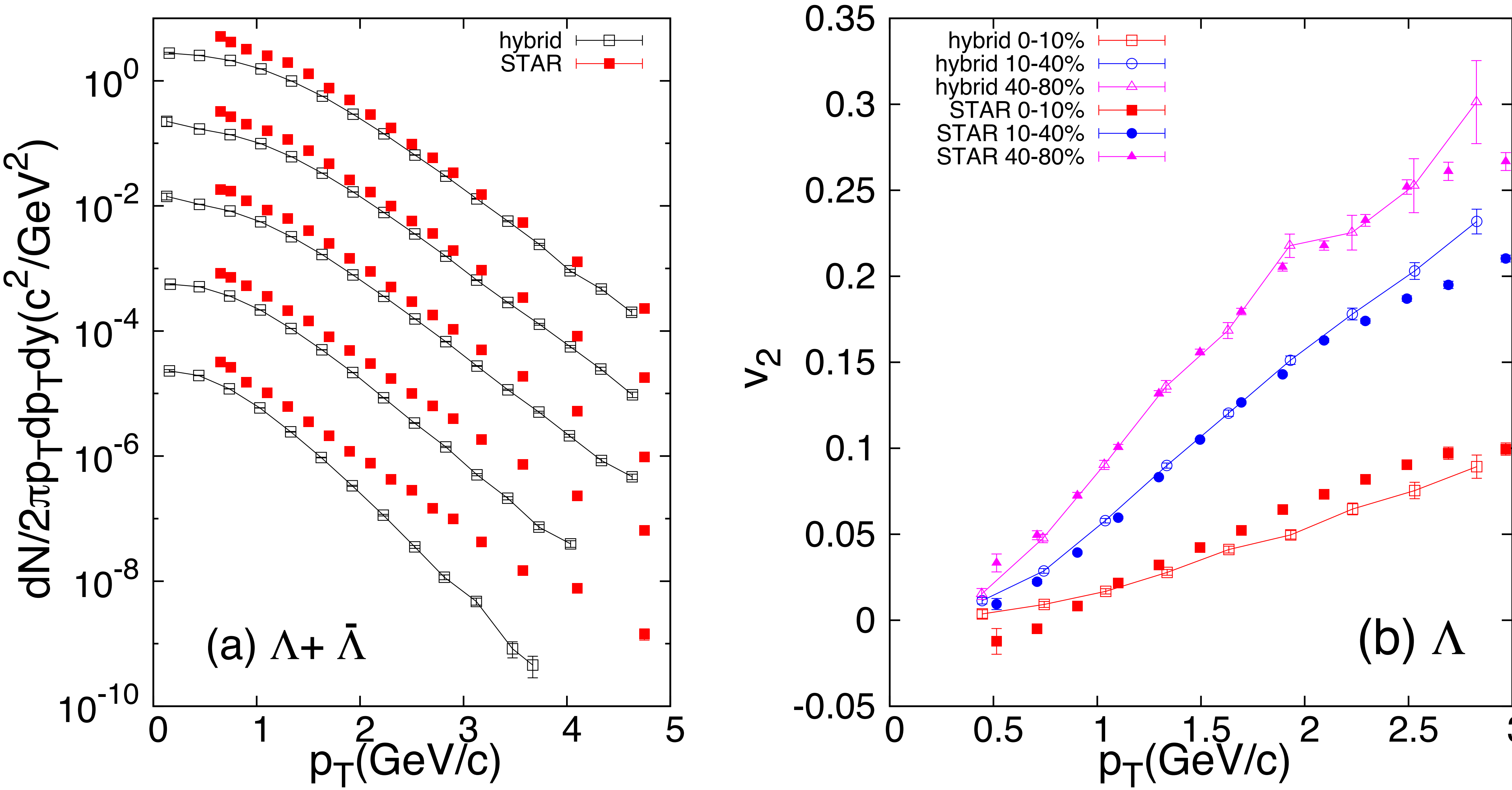
Back up

■ $\langle p_{\mathrm{T}} \rangle$ and v_2 vs hadron mass



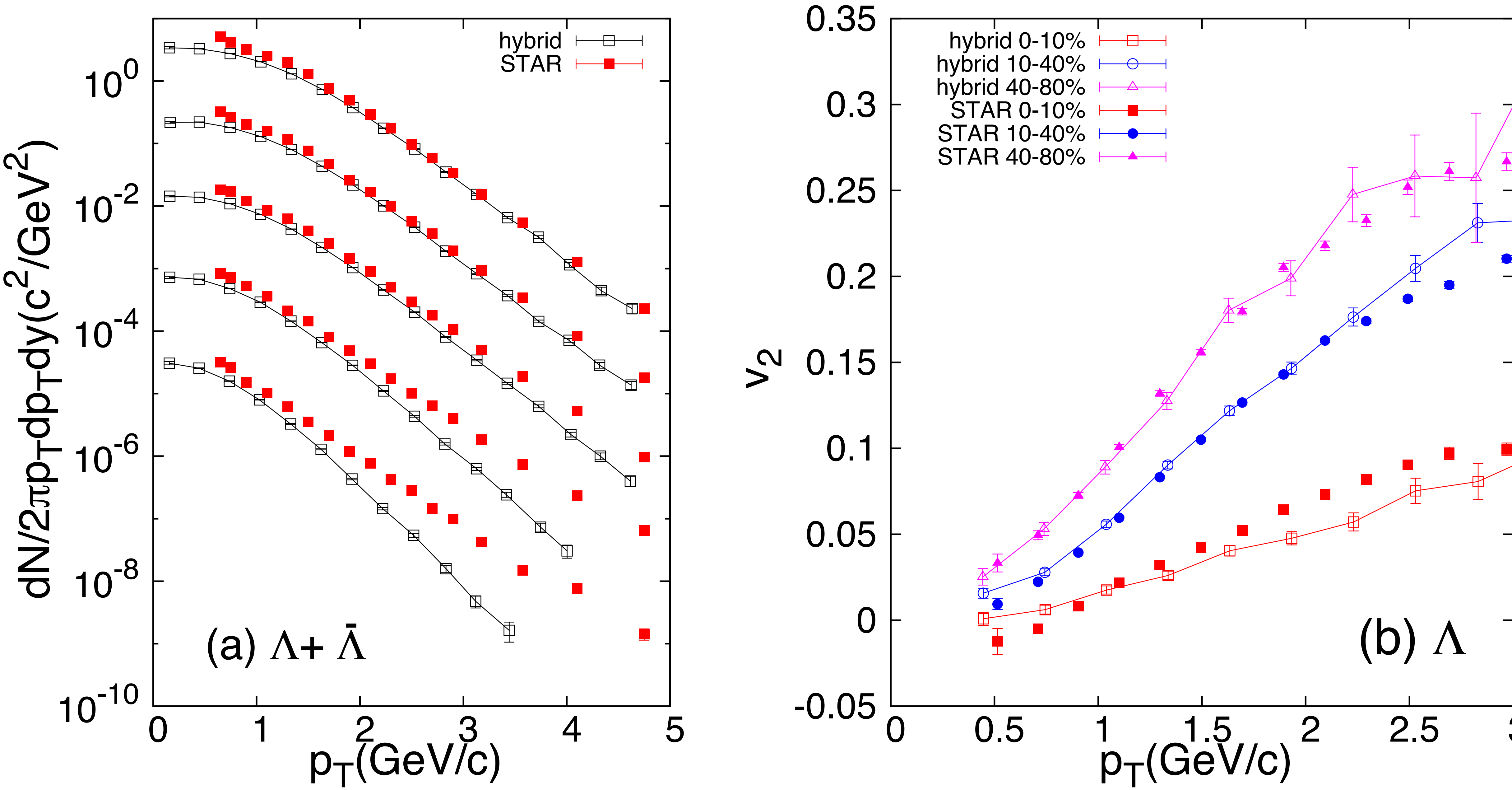
Back up

■ primordial Λ



Back up

- primordial Λ and Σ^0 decay ($\Sigma^0 \to \Lambda + \gamma$)

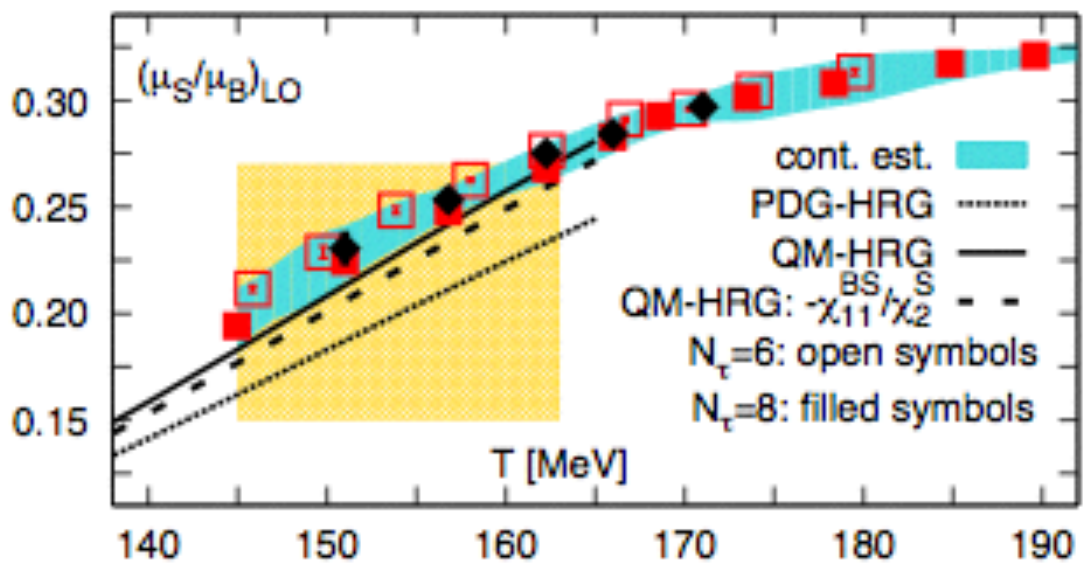


Σ^0 contributes to about 20% of total yield of Λ in our calculation!

Back up

A.Bazavov et al., arxiv:1404:6511[hep-lat]

■ More strange hadrons?



Two hadron resonance gas model (HRG) with strange hadron from

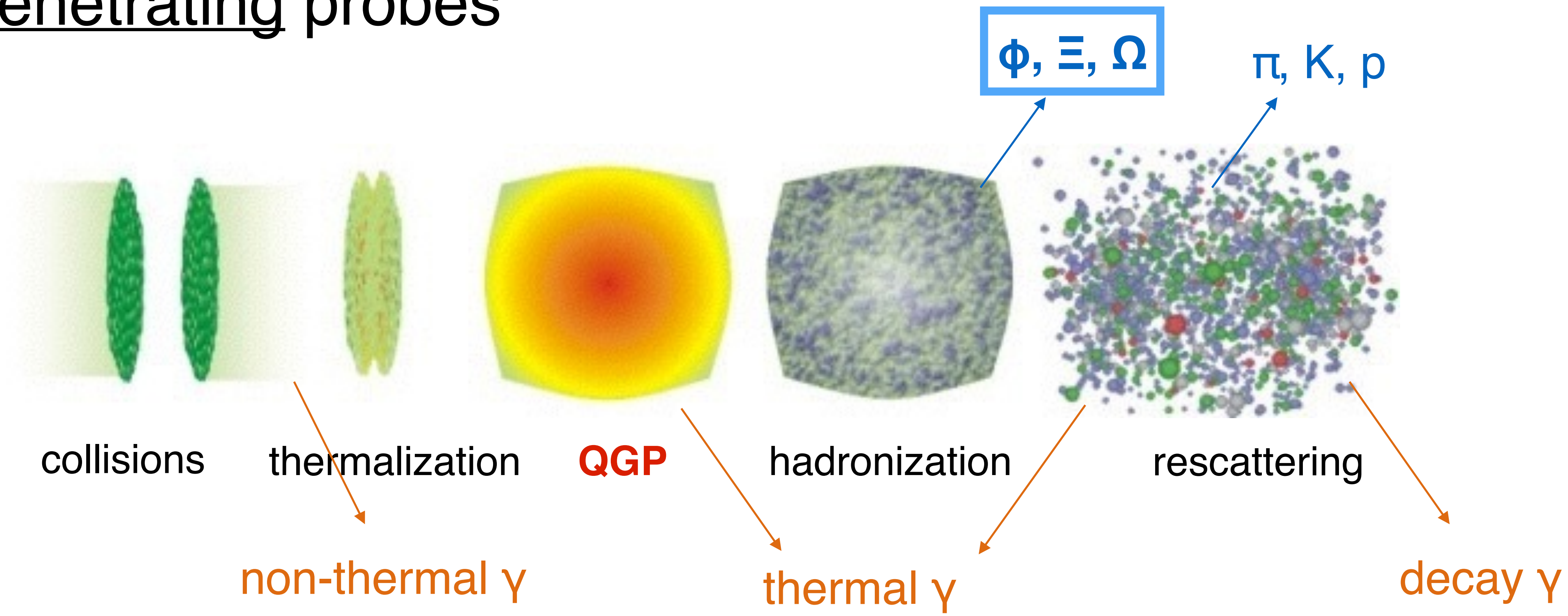
- □ <u>particle data group (PDG)</u>
  - → experimentally established
- □ <u>quark model (QM)</u>
  - → including **predicted but not observed strange hadrons**

<u>QM-HRG</u> well describe the lattice QCD results

→ Additional unobserved strange hadrons exist and contribute to yields of the ground state strange hadrons?

Back up

■ Penetrating probes



▶ EM probes (photons, leptons)
- go through the hadronic rescatterings
- come from different stages of collisions

▶ Multi-strange hadrons
- go through the hadronic rescatterings
- come <u>just after the hadronization</u>