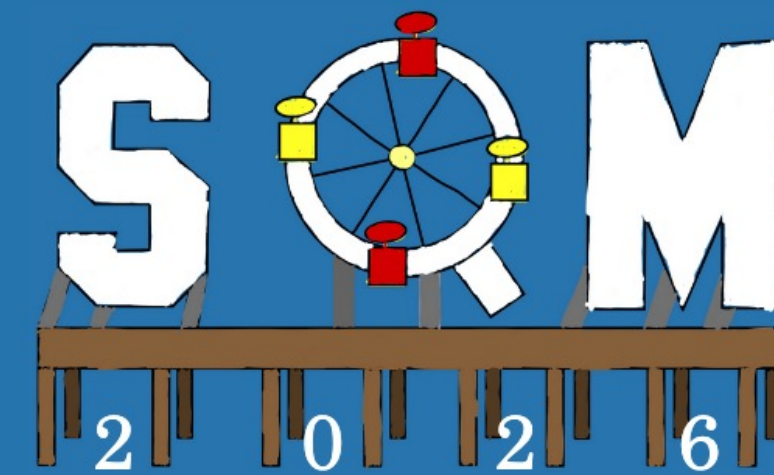




清华大学  
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The 22<sup>nd</sup> International Conference on  
Strangeness in Quark Matter  
22-27 March, 2026, Los Angeles, CA



# Exploring strangeness production across Beam Energies in Au+Au Collisions at STAR

*Weiguang Yuan, Xiongxiang Xu (for the STAR Collaboration)  
Tsinghua University*

- Motivation
- STAR detector and strange hadron reconstruction
- Results
  - ✓  $p_T$  and rapidity spectra
  - ✓ Energy dependence of  $R_{CP}$  and  $\bar{B}/B$
  - ✓  $\Omega/\phi$  ratios
- Summary

Supported in part by



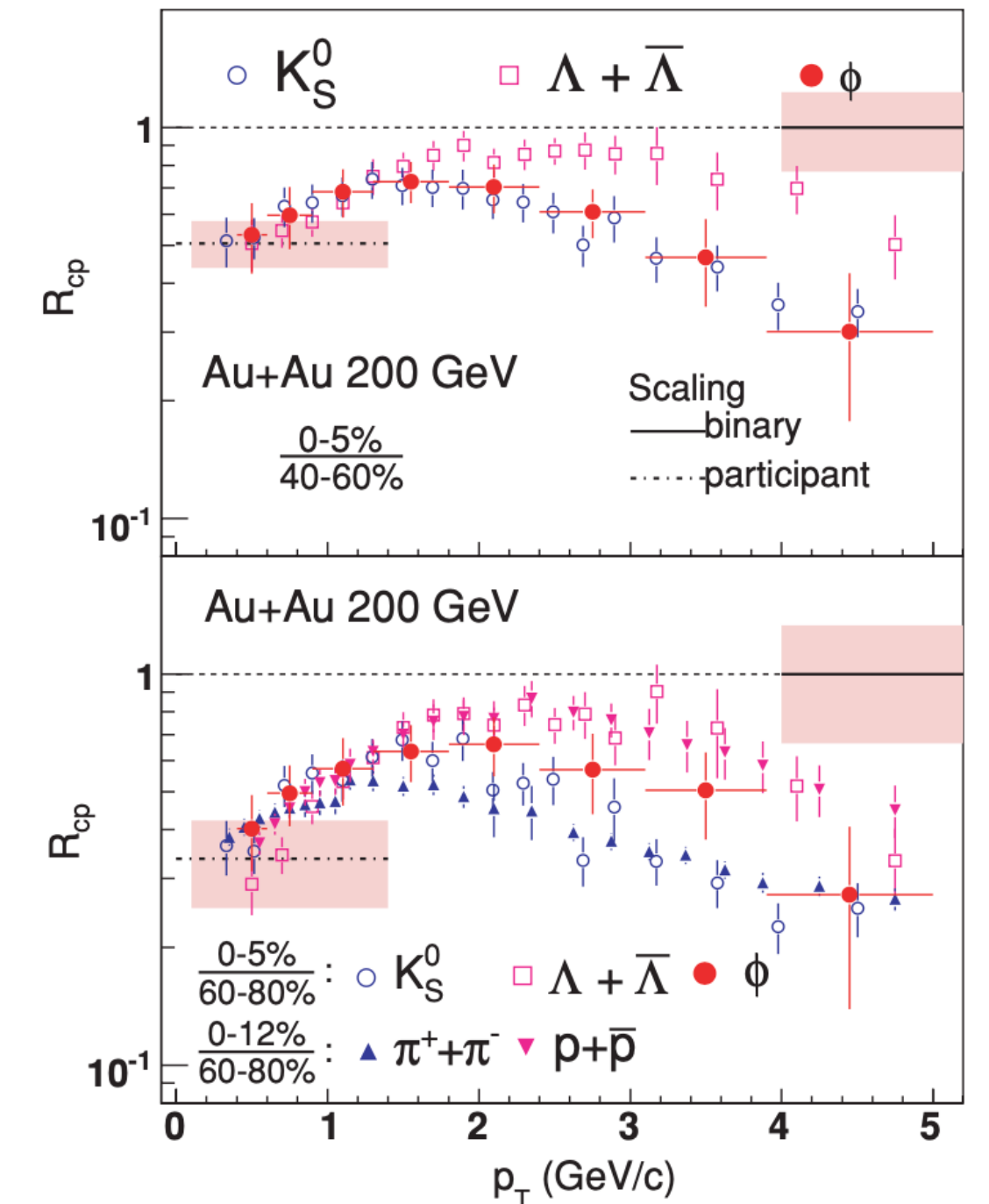
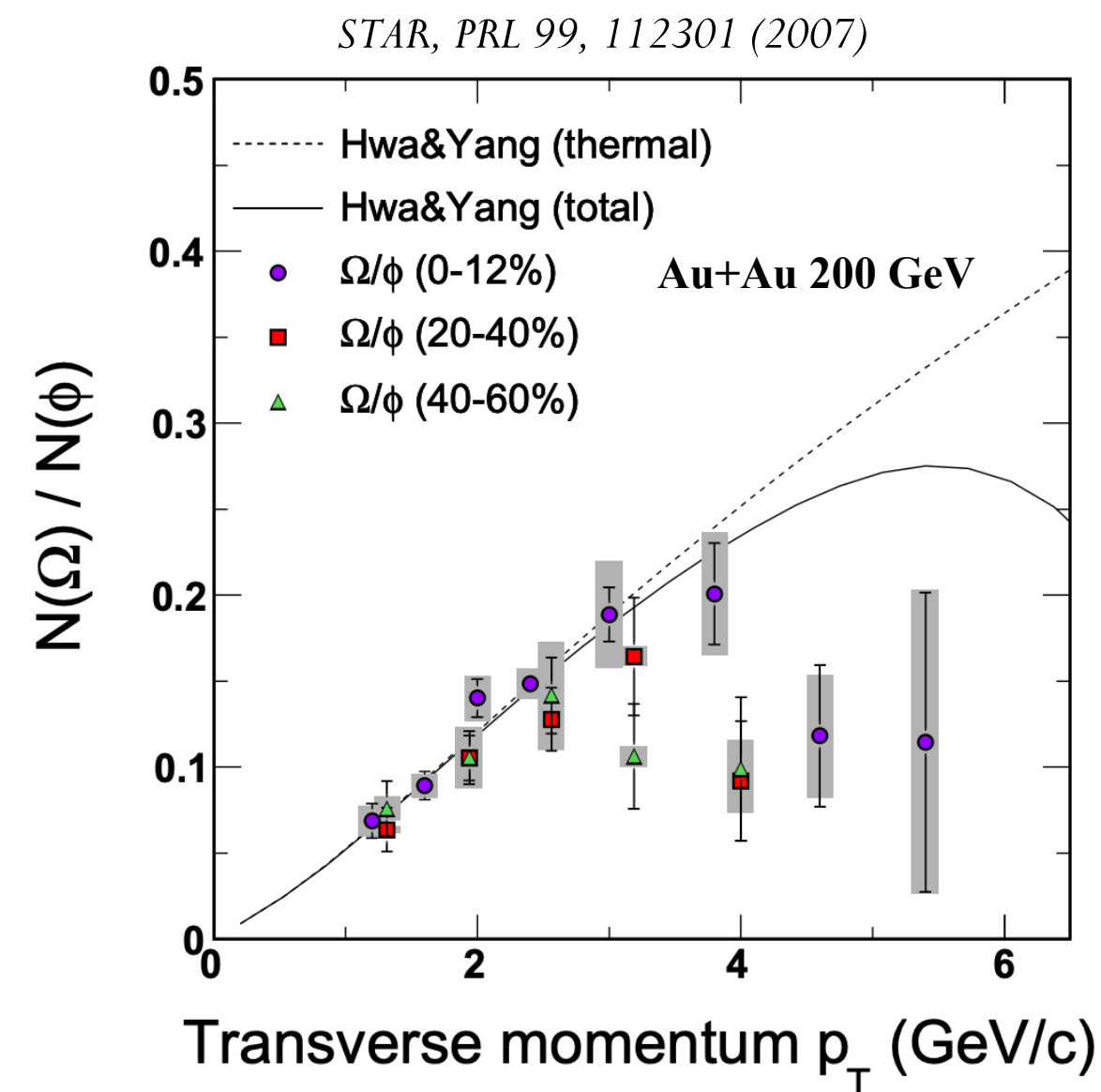
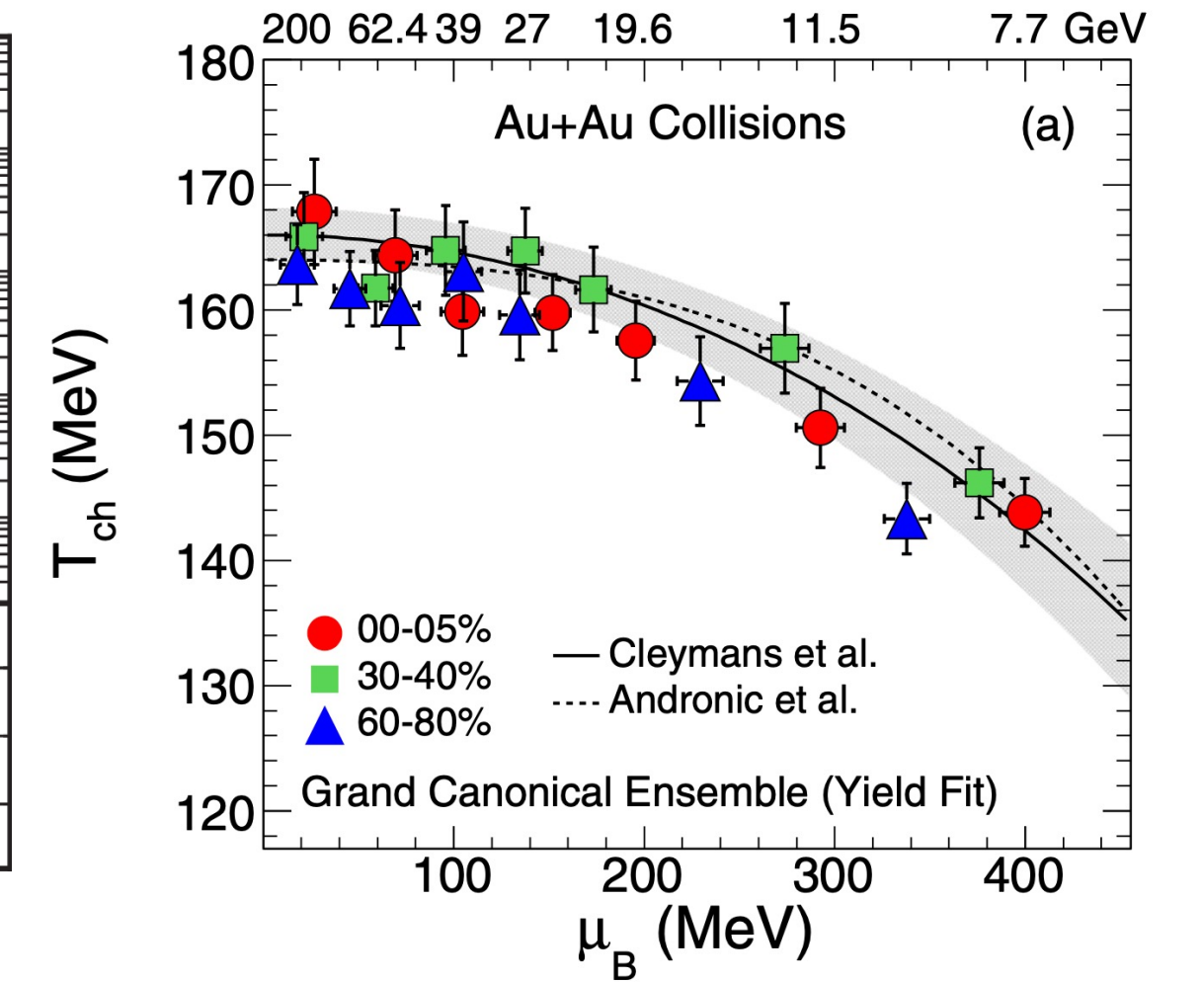
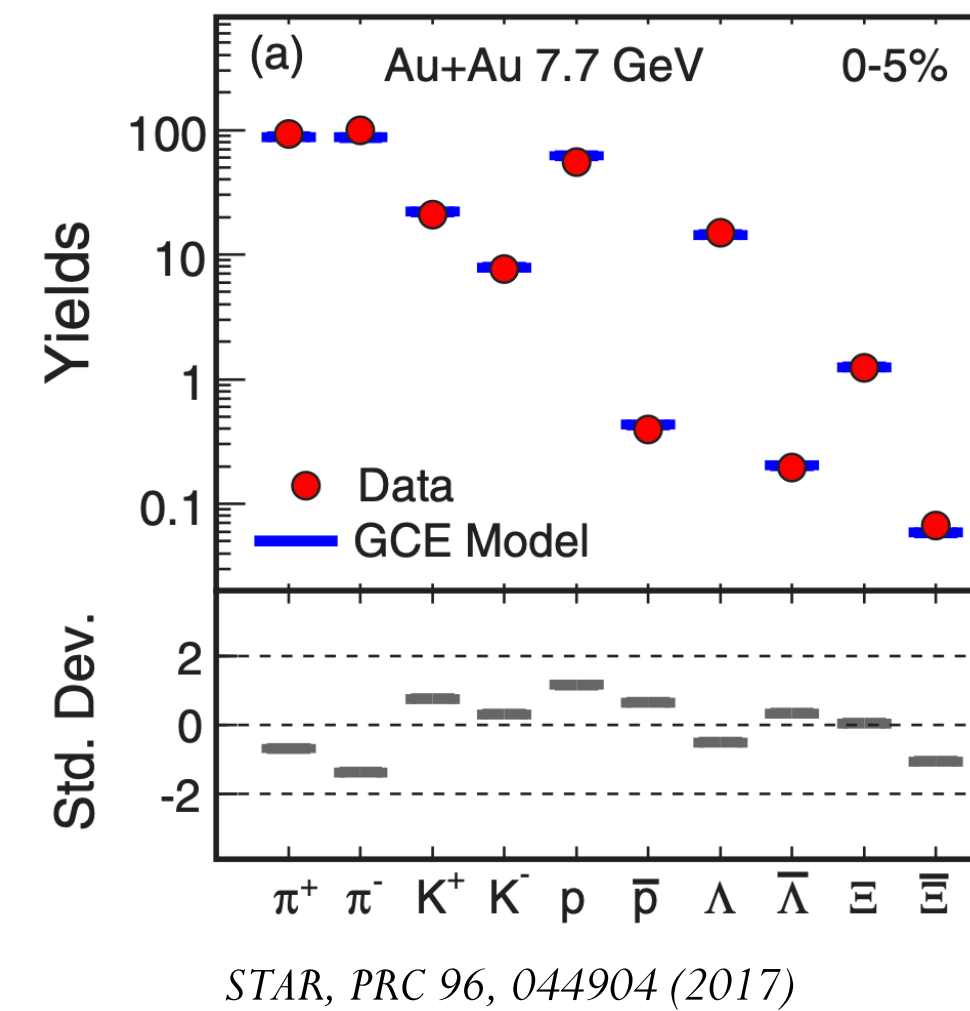
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**ENERGY**

Office of  
Science

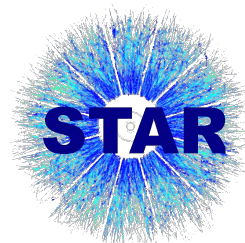


# Strange hadrons as sensitive & versatile probes of HIC dynamics

- Small hadronic cross-sections, sensitive to the early stage dynamics of the medium
- Strange hadron yields (dominated by **low  $p_T$** )
  - enhancement (w.r.t. p+p) originally proposed as a signature of QGP, now described by statistical/thermal models (GCE or CE)
  - can be used to extract chemical freeze-out parameters
- Hyperon-to-meson enhancement at **intermediate  $p_T$** 
  - hadronization with parton coalescence/recombination
- Nuclear modification factors (at **high  $p_T$** )
  - partonic energy loss in medium

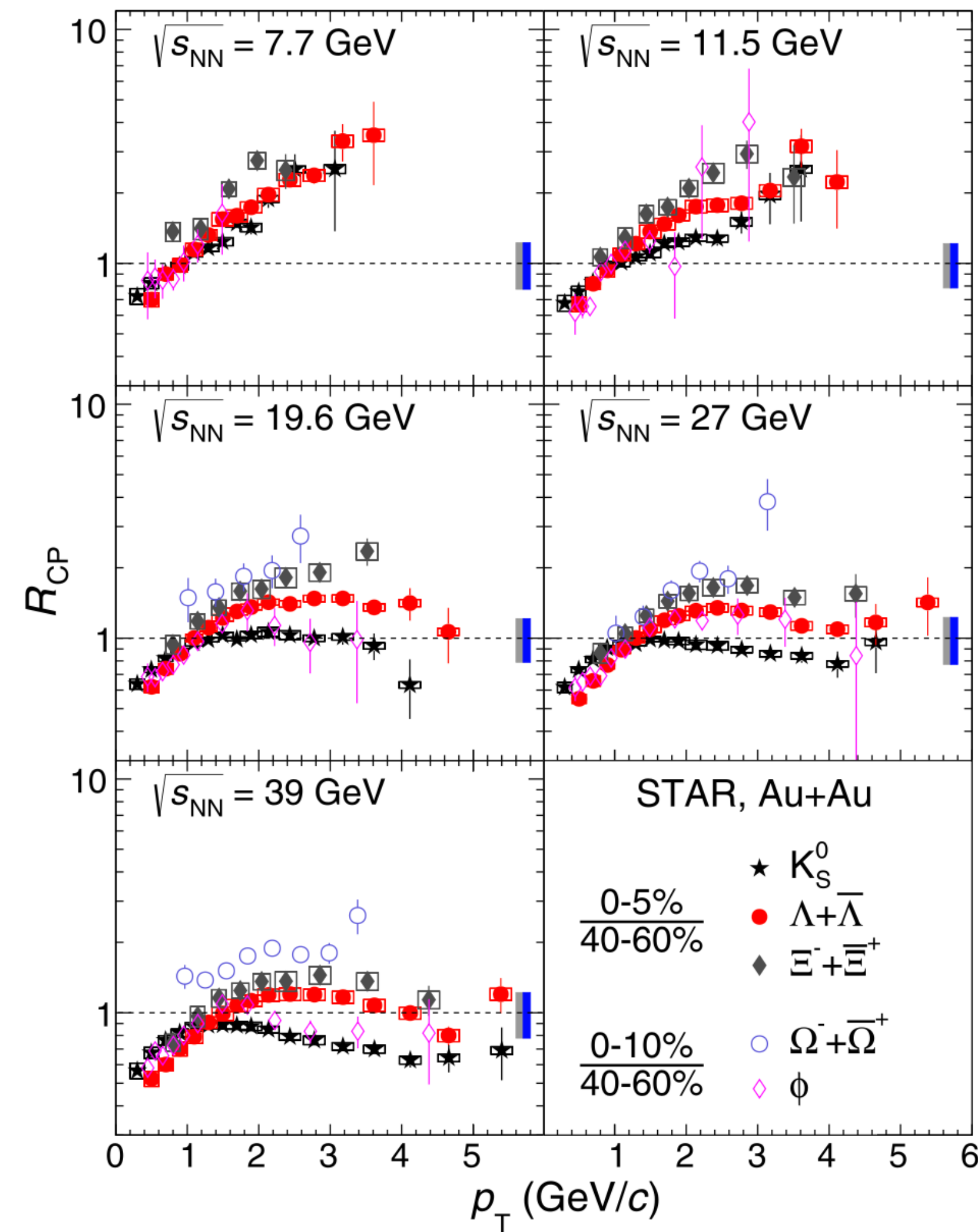


$$R_{CP} = \frac{[(dN/dp_T)/\langle N_{coll} \rangle]_{\text{central}}}{[(dN/dp_T)/\langle N_{coll} \rangle]_{\text{peripheral}}}$$

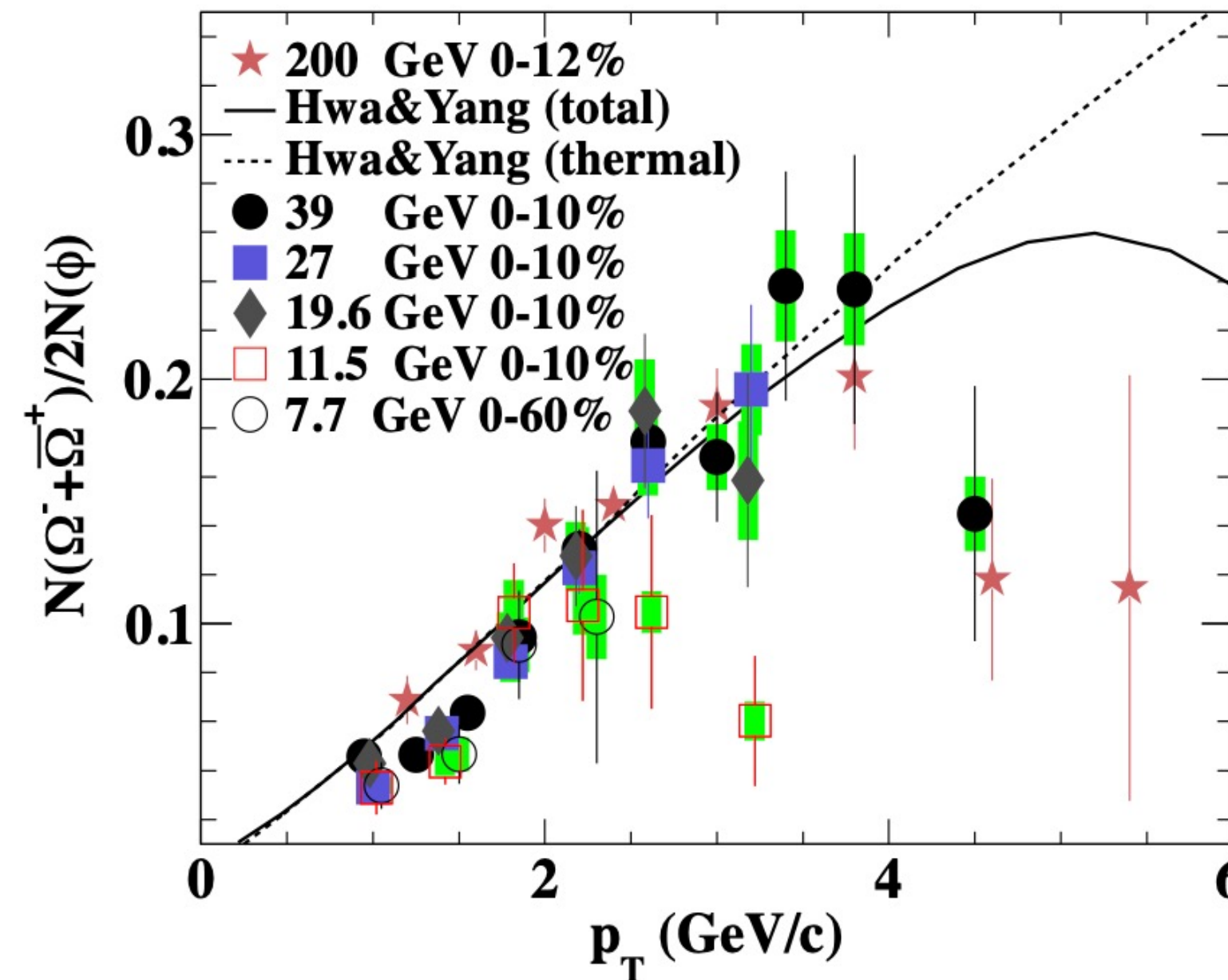


# Energy dependence of strange hadron production

STAR, PRC 102, 034909 (2020)



STAR, PRC 93, 021903 (2016)

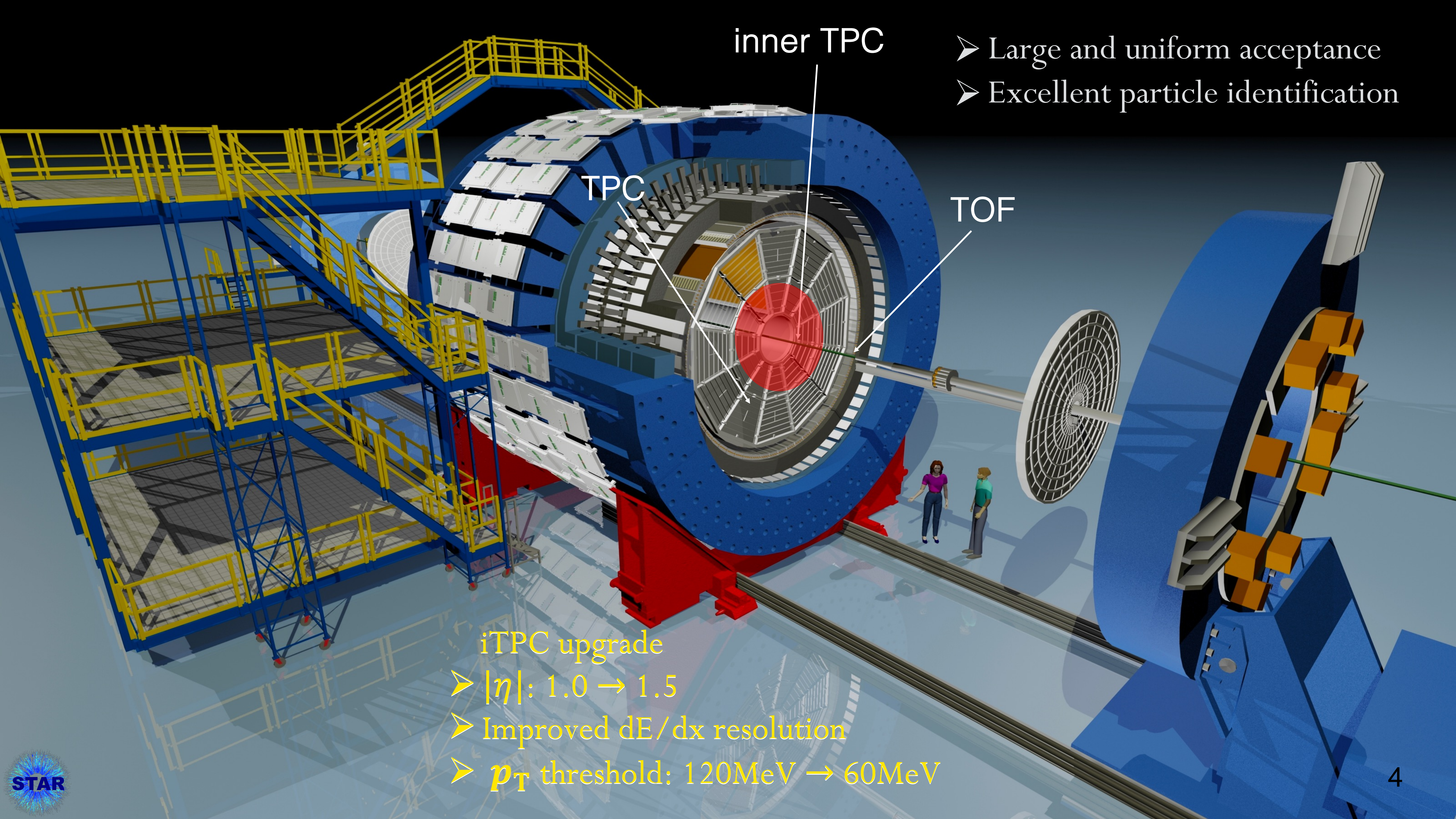


➤ Nuclear modification factor ( $R_{CP}$ ) of  $K_S^0$ ,  $\Lambda$ ,  $\Xi$ ,  $\phi$  and  $\Omega$  (BES-I).

➤  $\Omega/\phi$  ratio with BES-I.

● Large uncertainties below 11.5 GeV

➤ Further explore the chemical freeze-out parameters and the turn-off of QGP signatures with **more precise measurements with BES-II**



inner TPC

- Large and uniform acceptance
- Excellent particle identification

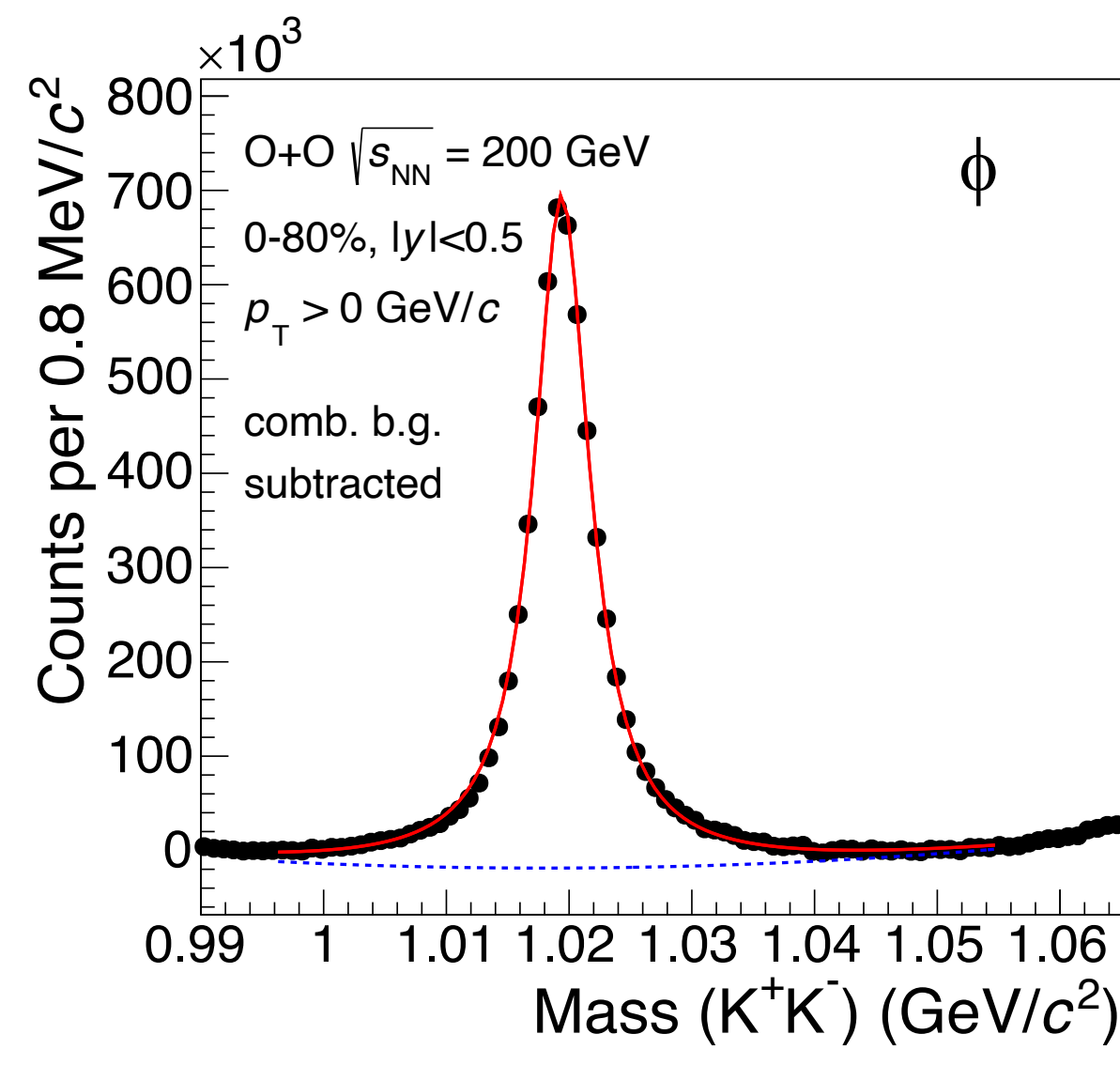
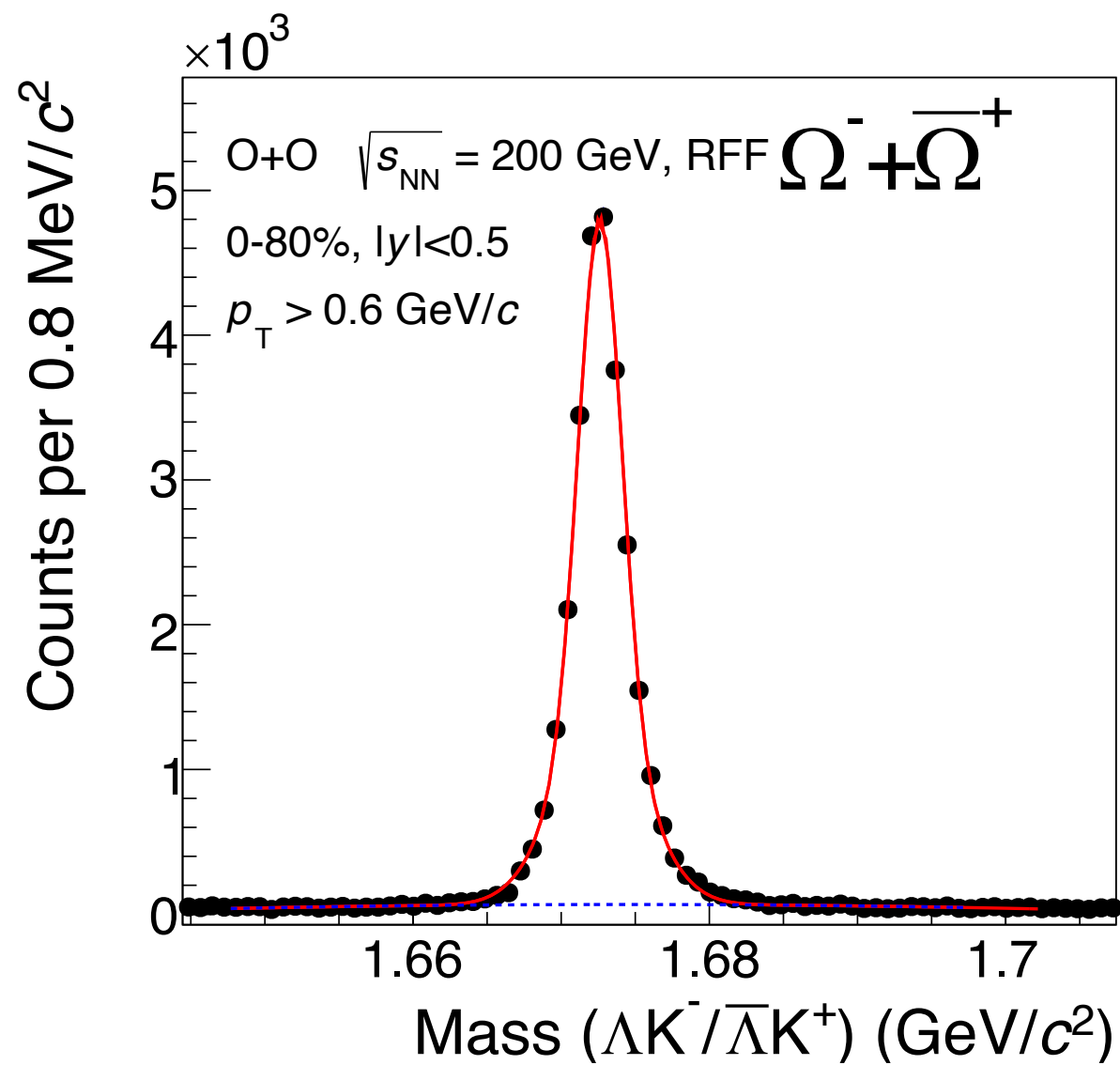
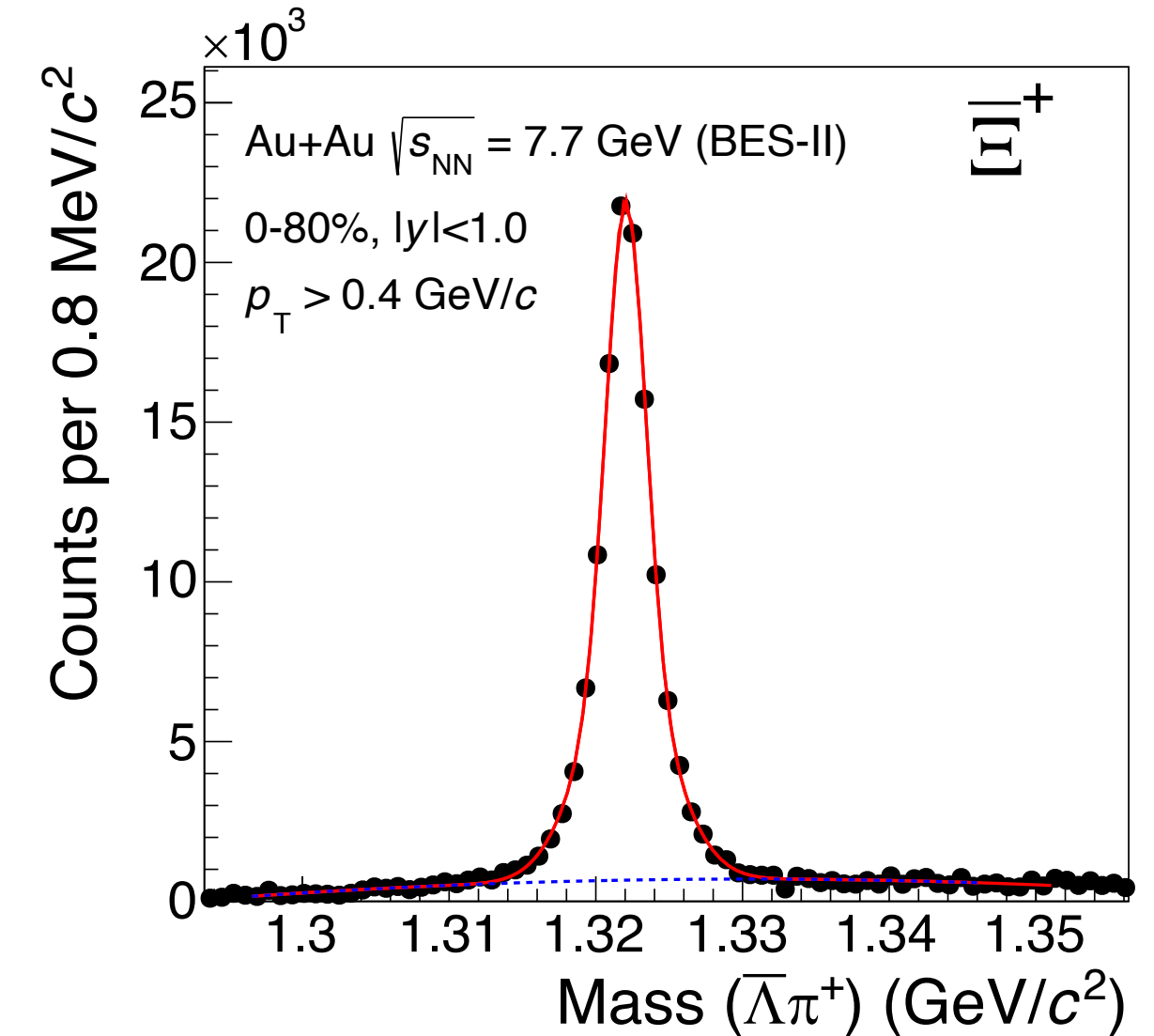
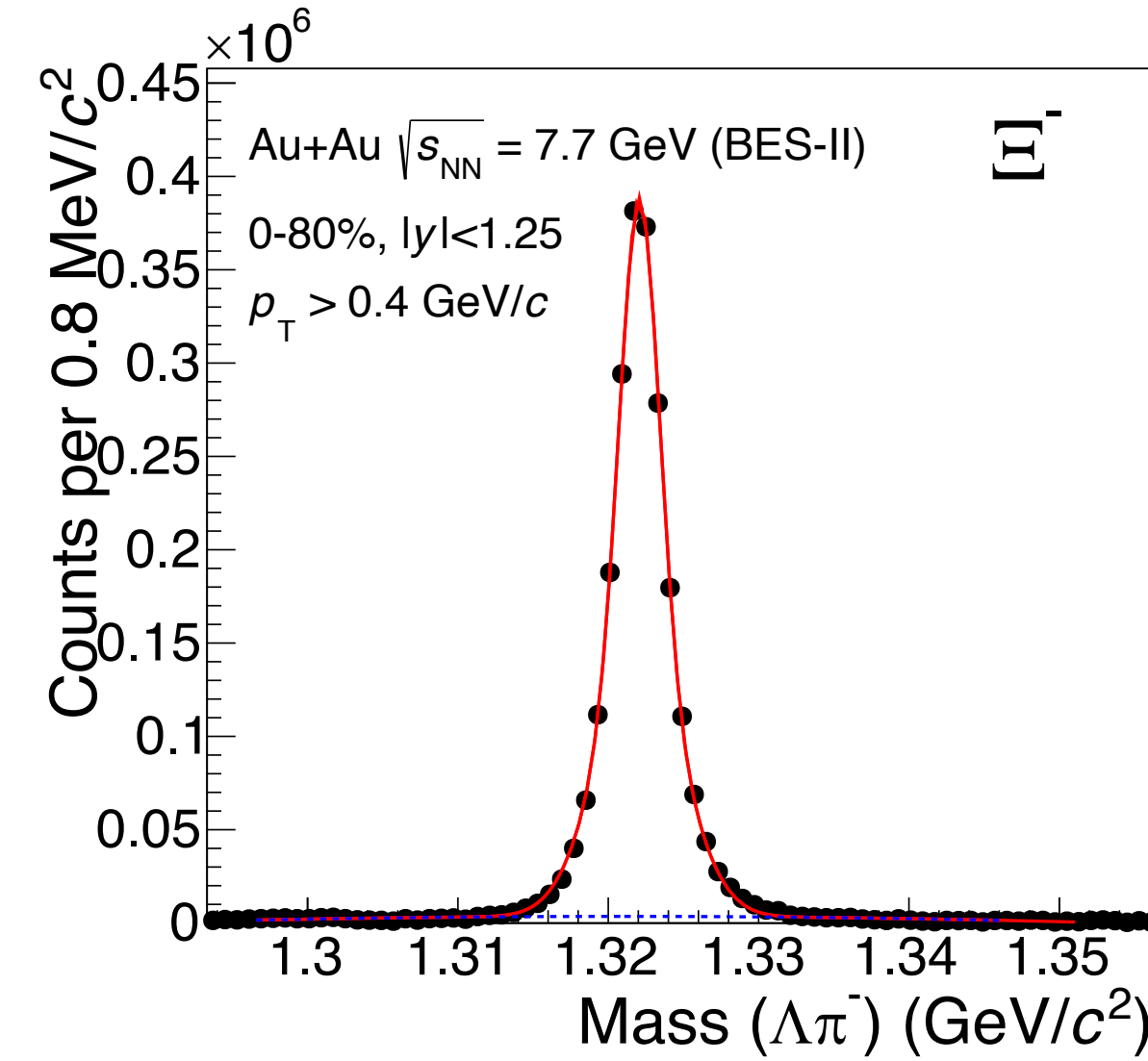
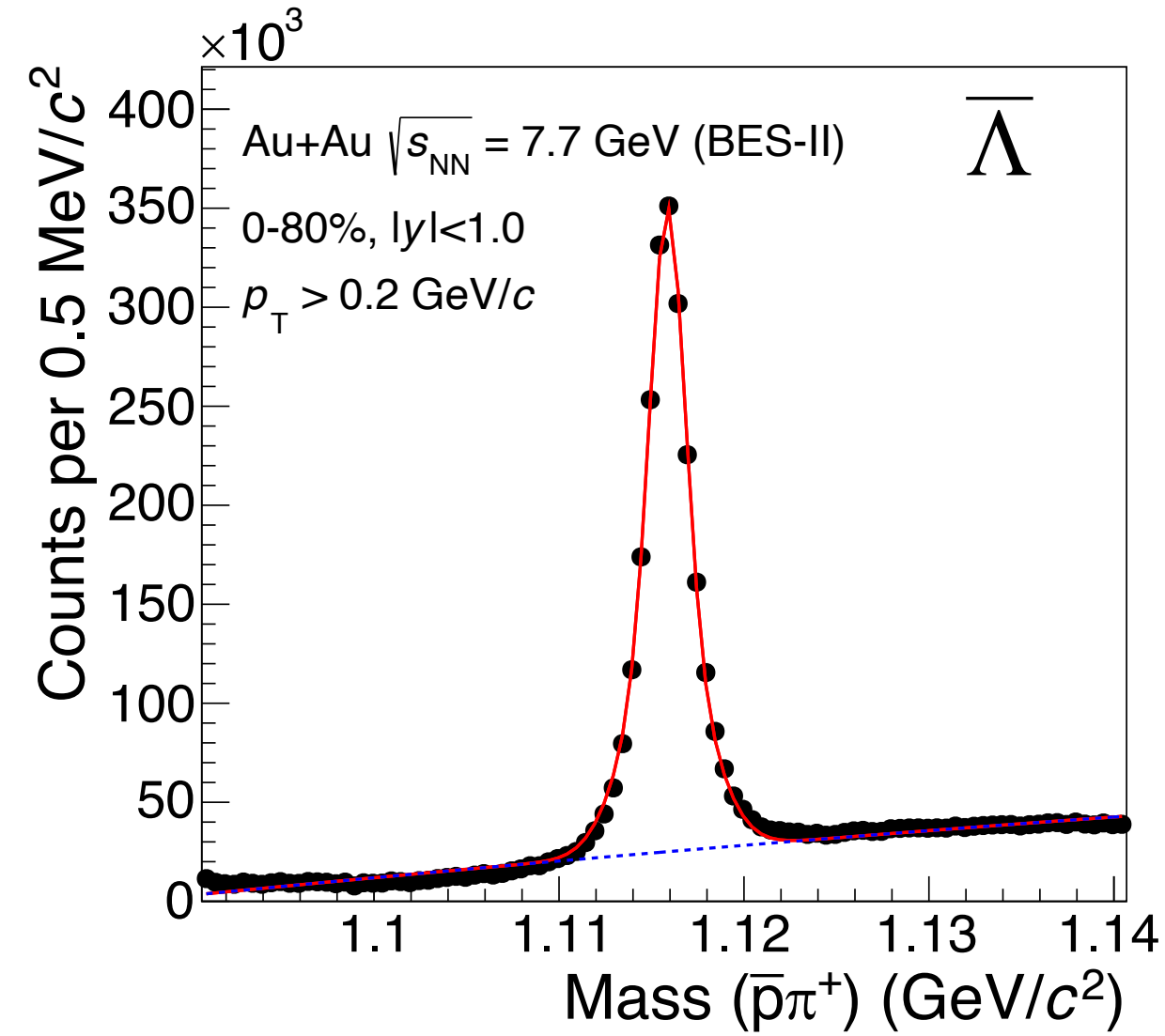
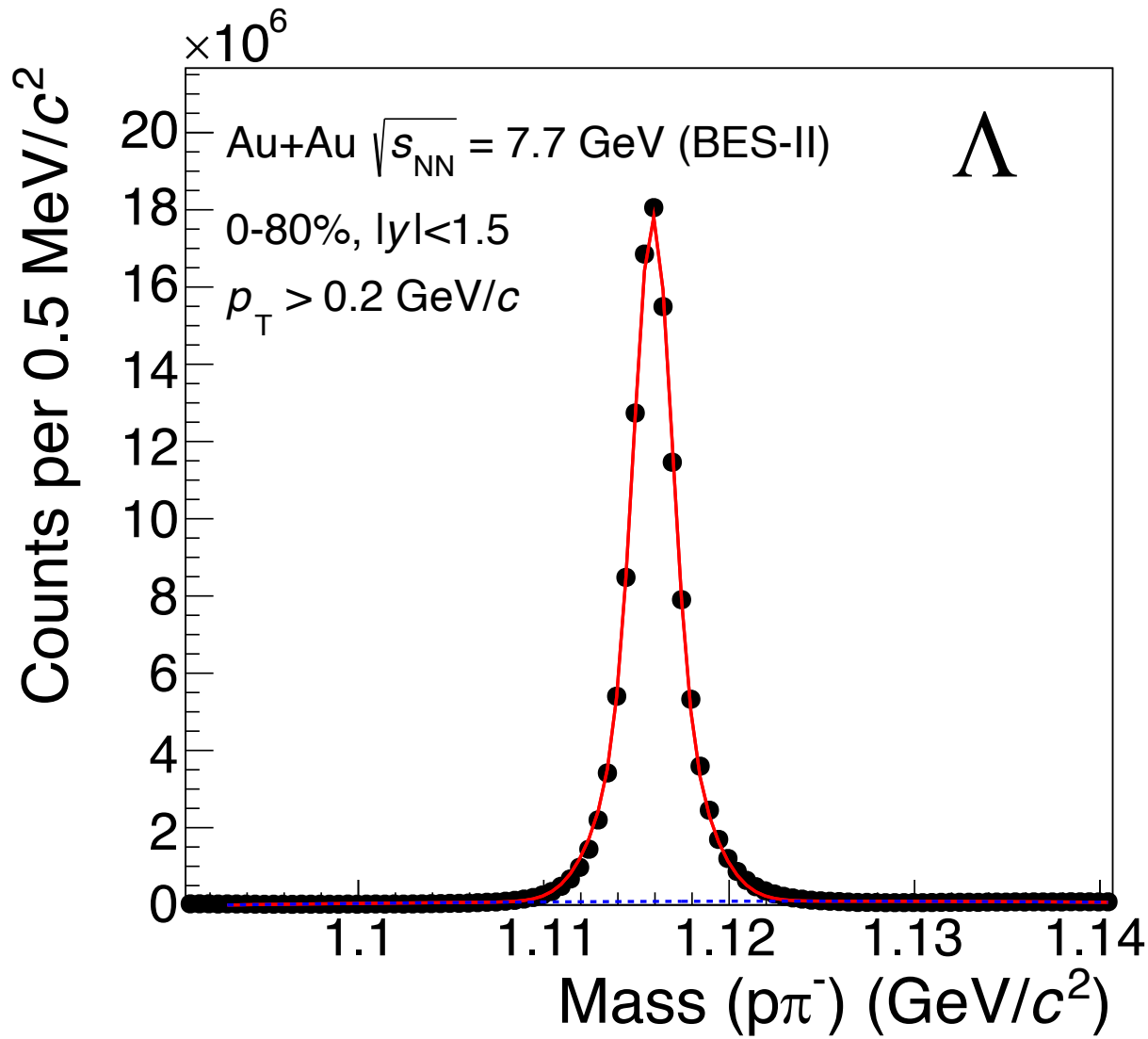
TPC

TOF

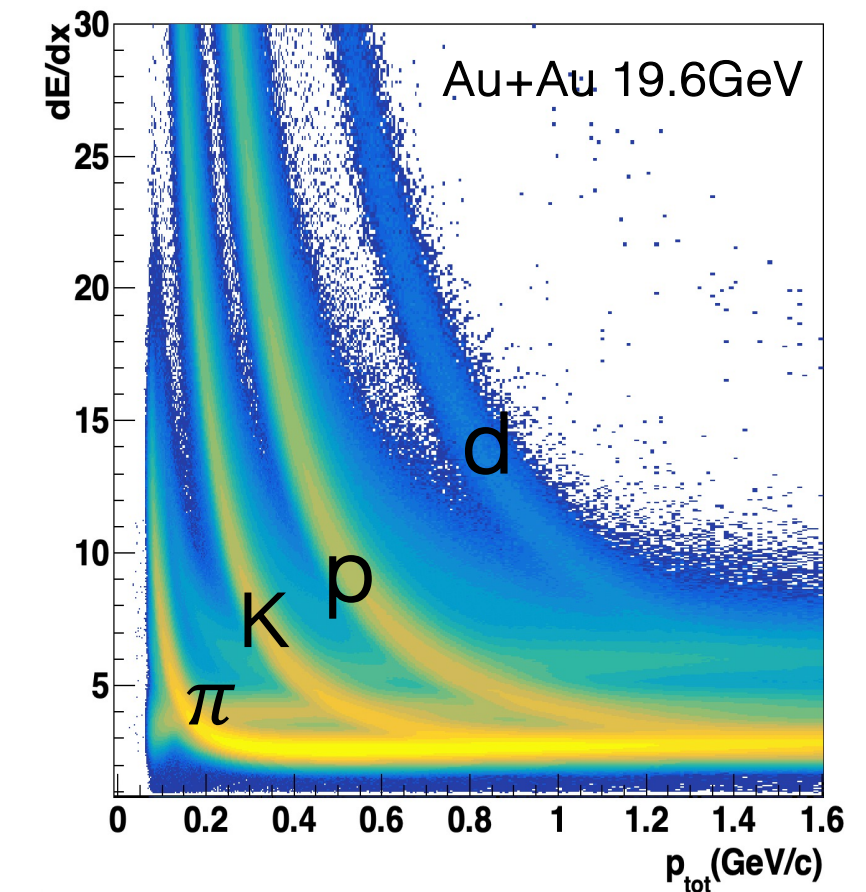
iTPC upgrade

- $|\eta|: 1.0 \rightarrow 1.5$
- Improved  $dE/dx$  resolution
- $p_T$  threshold:  $120\text{MeV} \rightarrow 60\text{MeV}$

# Particle identification and reconstruction



- Particle identification with dE/dx and TOF.
- $\pi, K, p \rightarrow$  reconstruct secondary vertex of strange particles.
- Large signal counts allow multi-differential measurements.



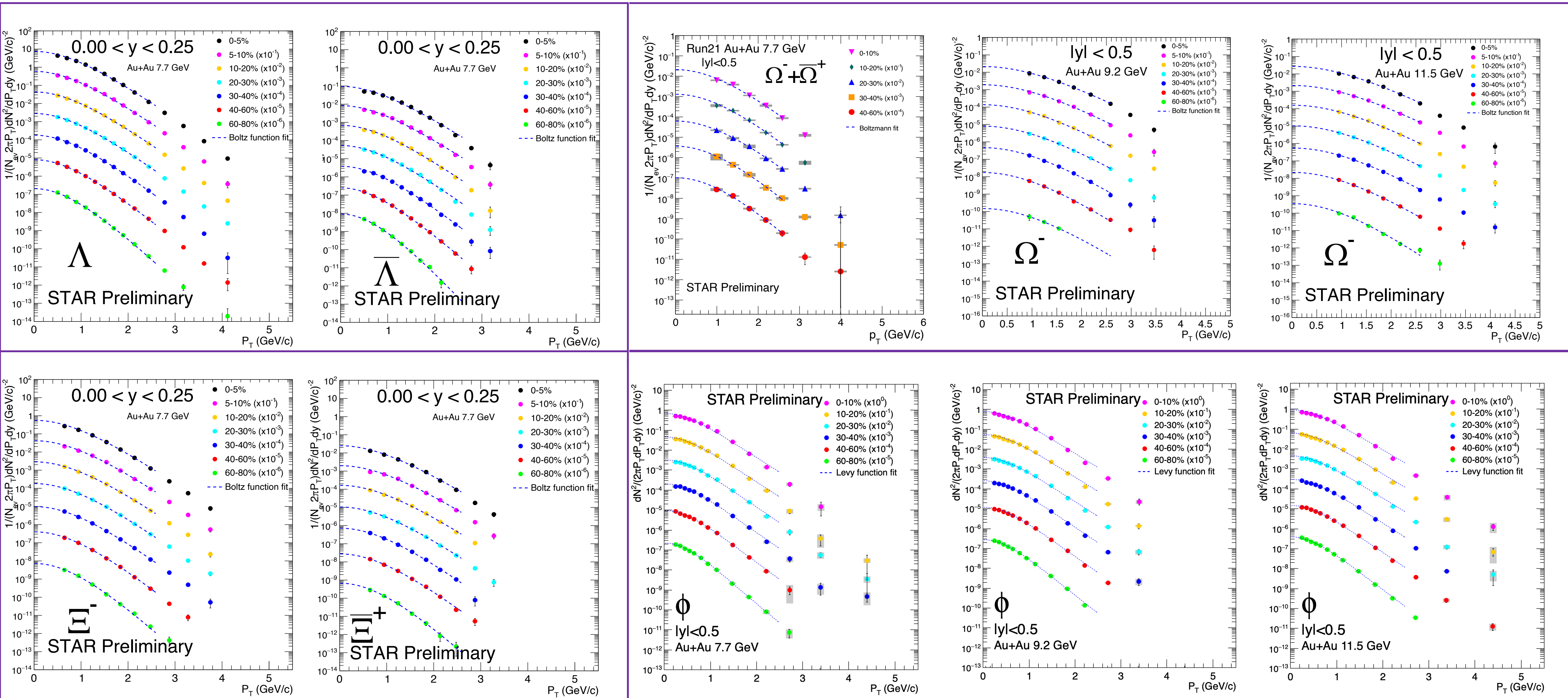
$$\Lambda(\bar{\Lambda}) \rightarrow p(\bar{p}) + \pi^- (\pi^+) (\mathcal{B} = 63.9\%)$$

$$\Xi^- (\bar{\Xi}^+) \rightarrow \Lambda(\bar{\Lambda}) + \pi^- (\pi^+) (\mathcal{B} = 99.9\%)$$

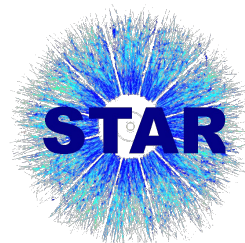
$$\Omega^- (\bar{\Omega}^+) \rightarrow \Lambda(\bar{\Lambda}) + K^- (K^+) (\mathcal{B} = 67.8\%)$$

$$\phi \rightarrow K^+ + K^- (\mathcal{B} = 49.1\%)$$

# $p_T$ Spectra for $\Lambda$ , $\Xi$ , $\phi$ and $\Omega$ (BESII)

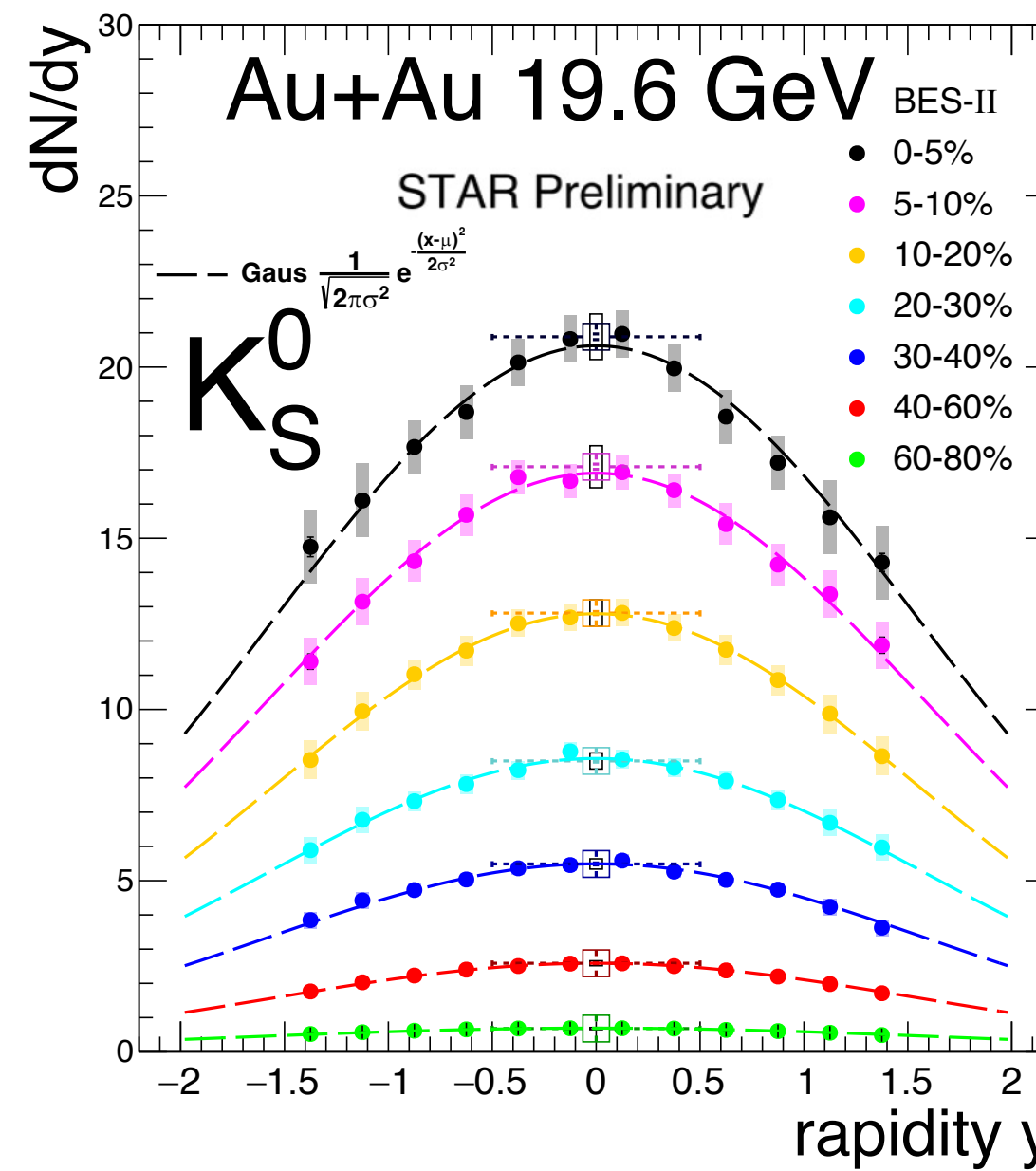
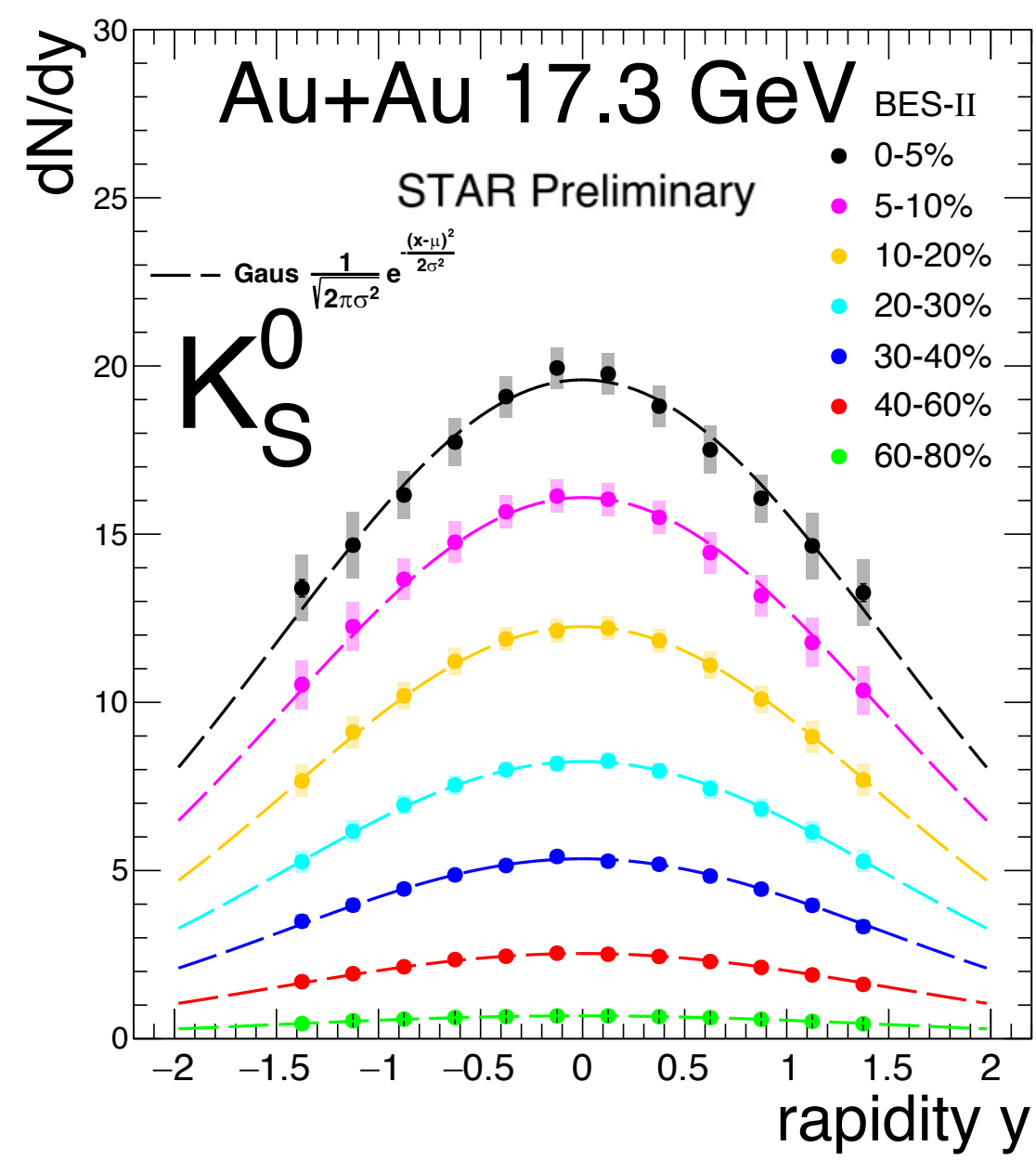
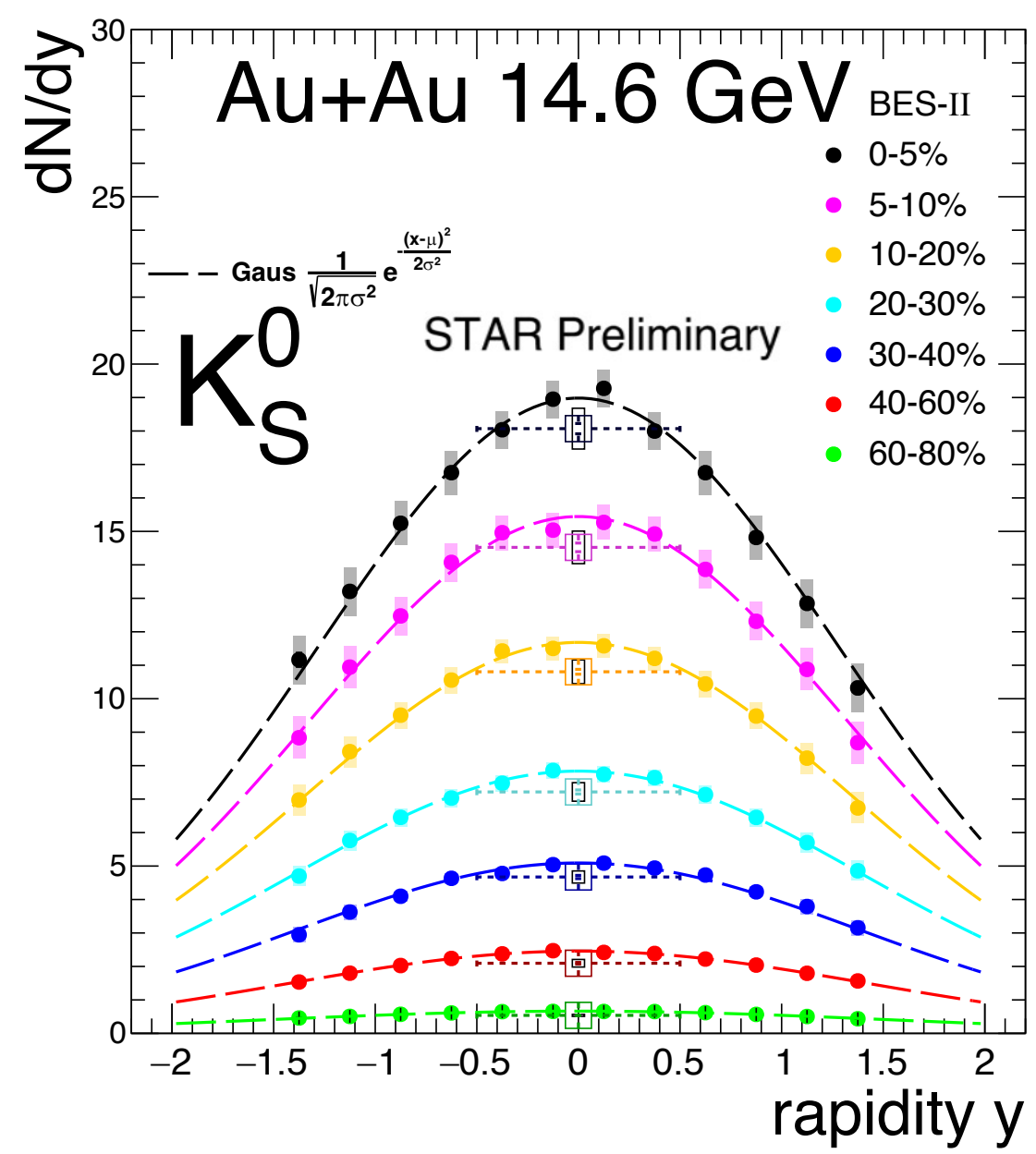
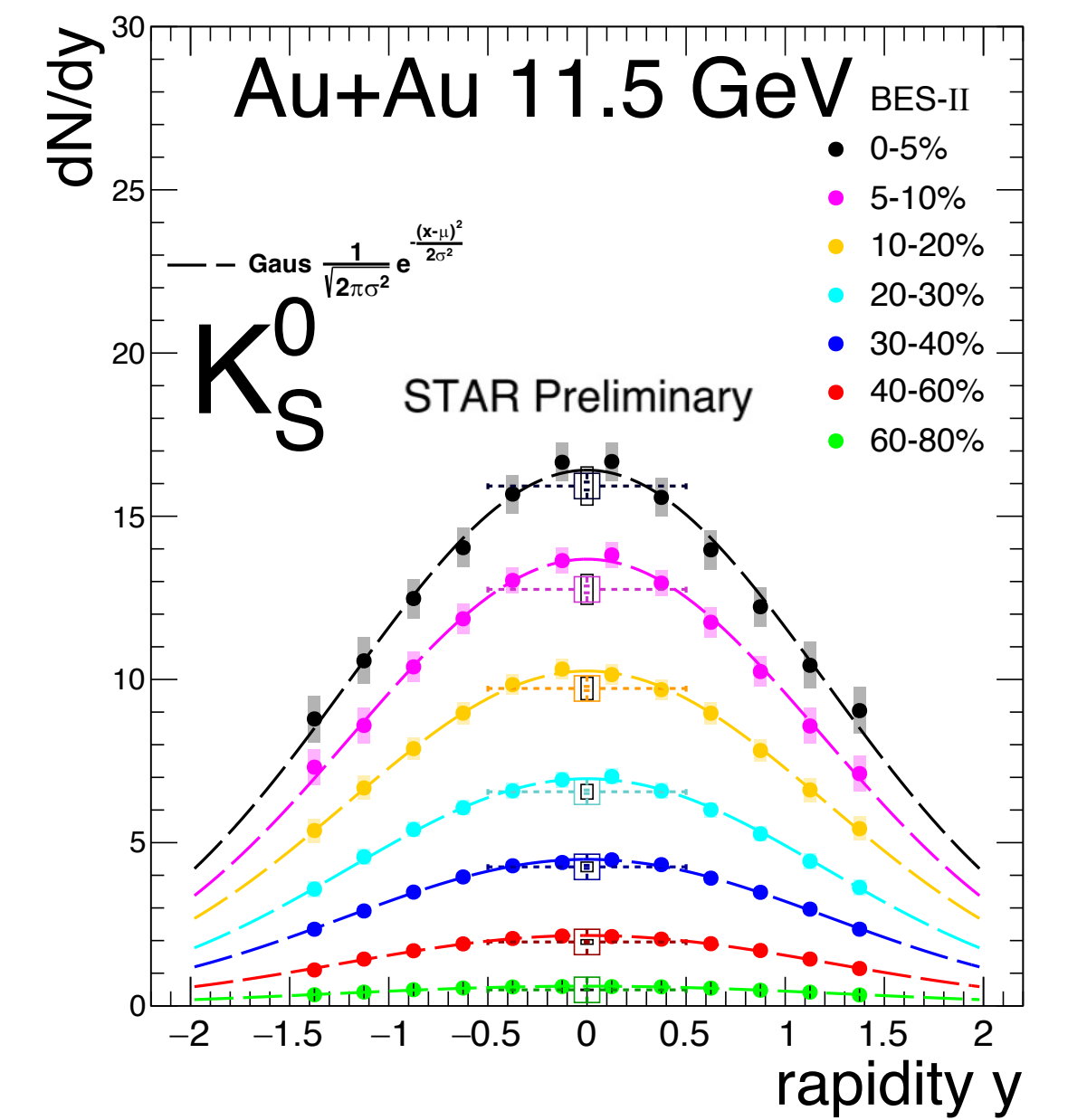
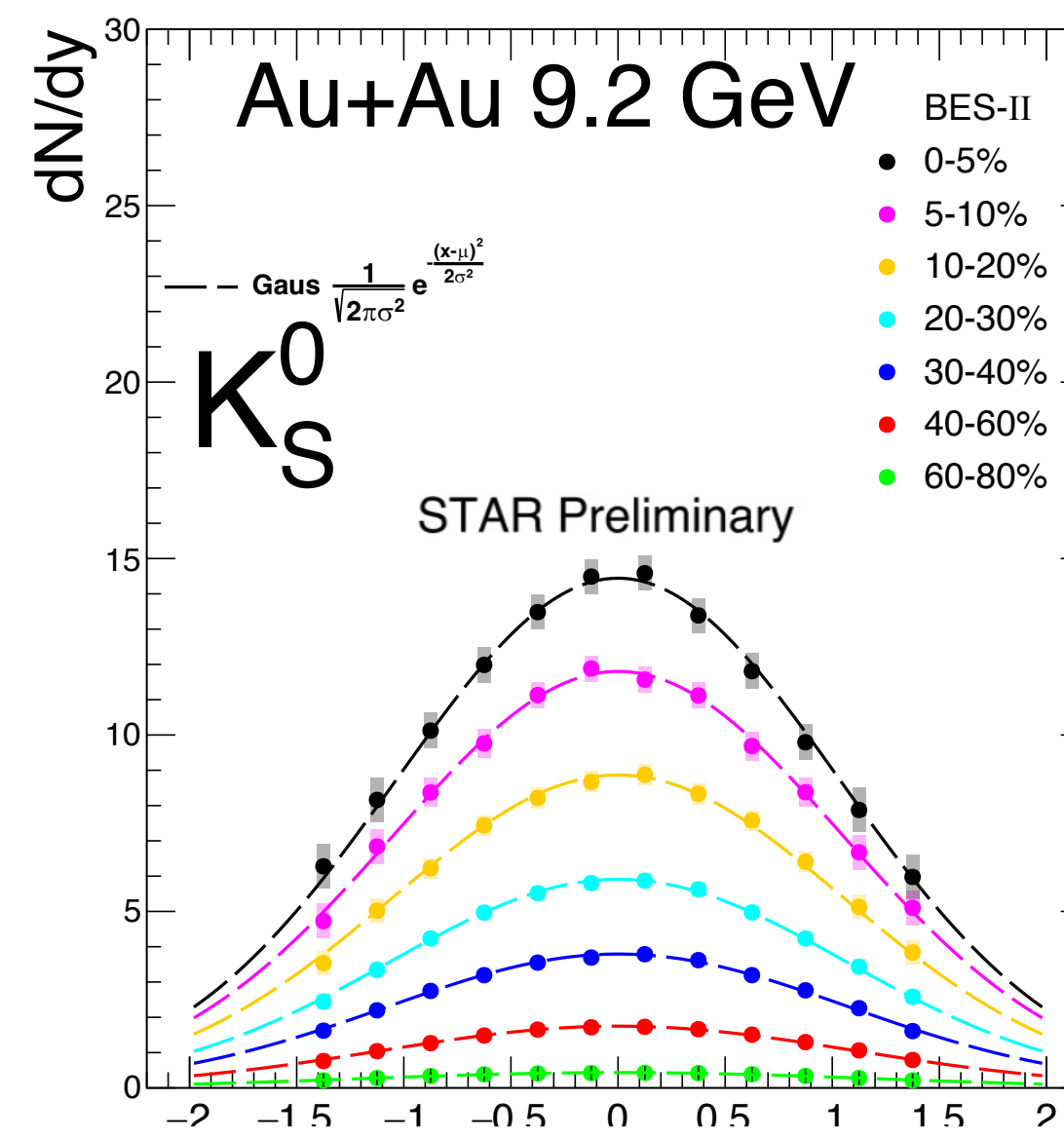
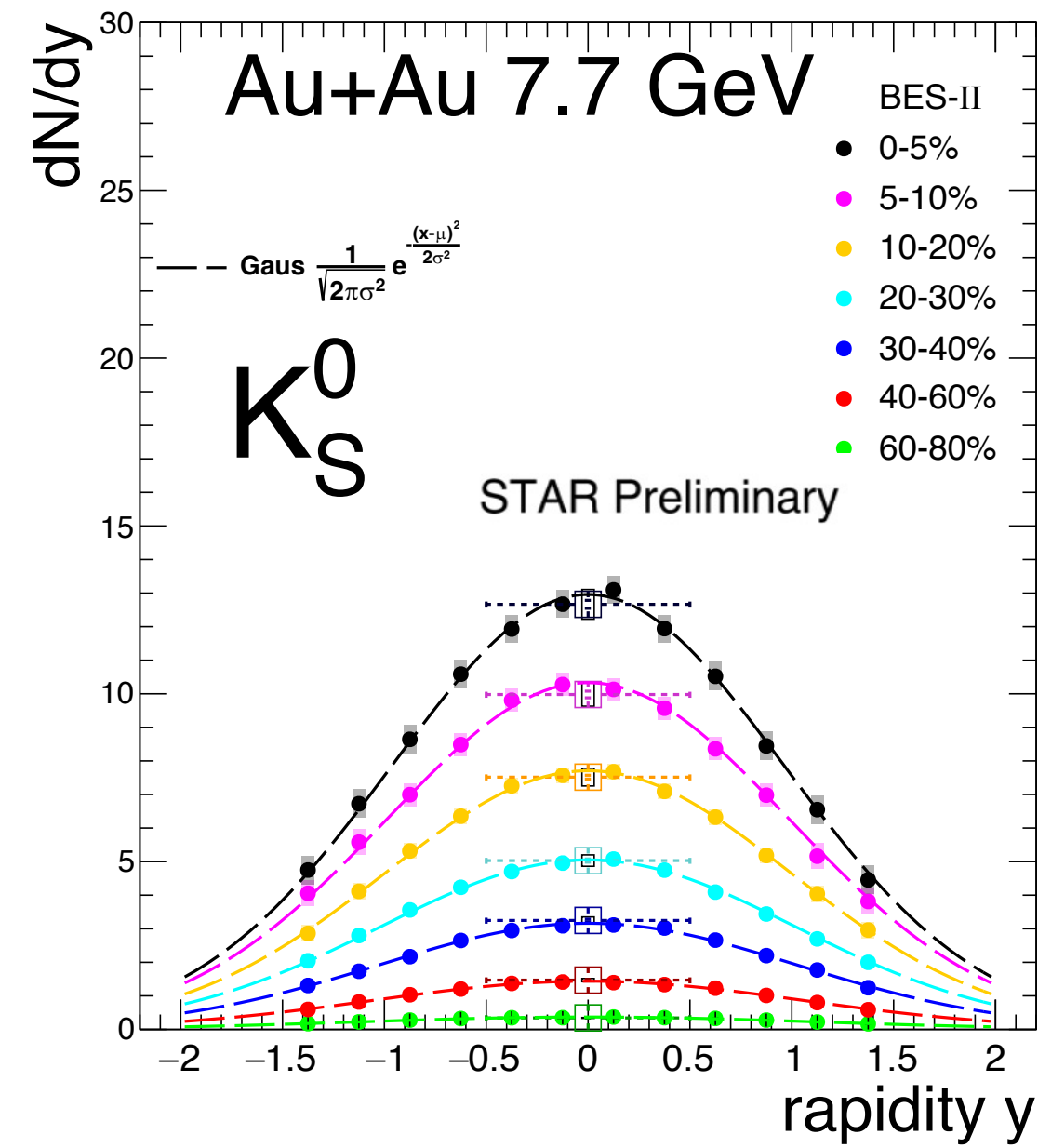
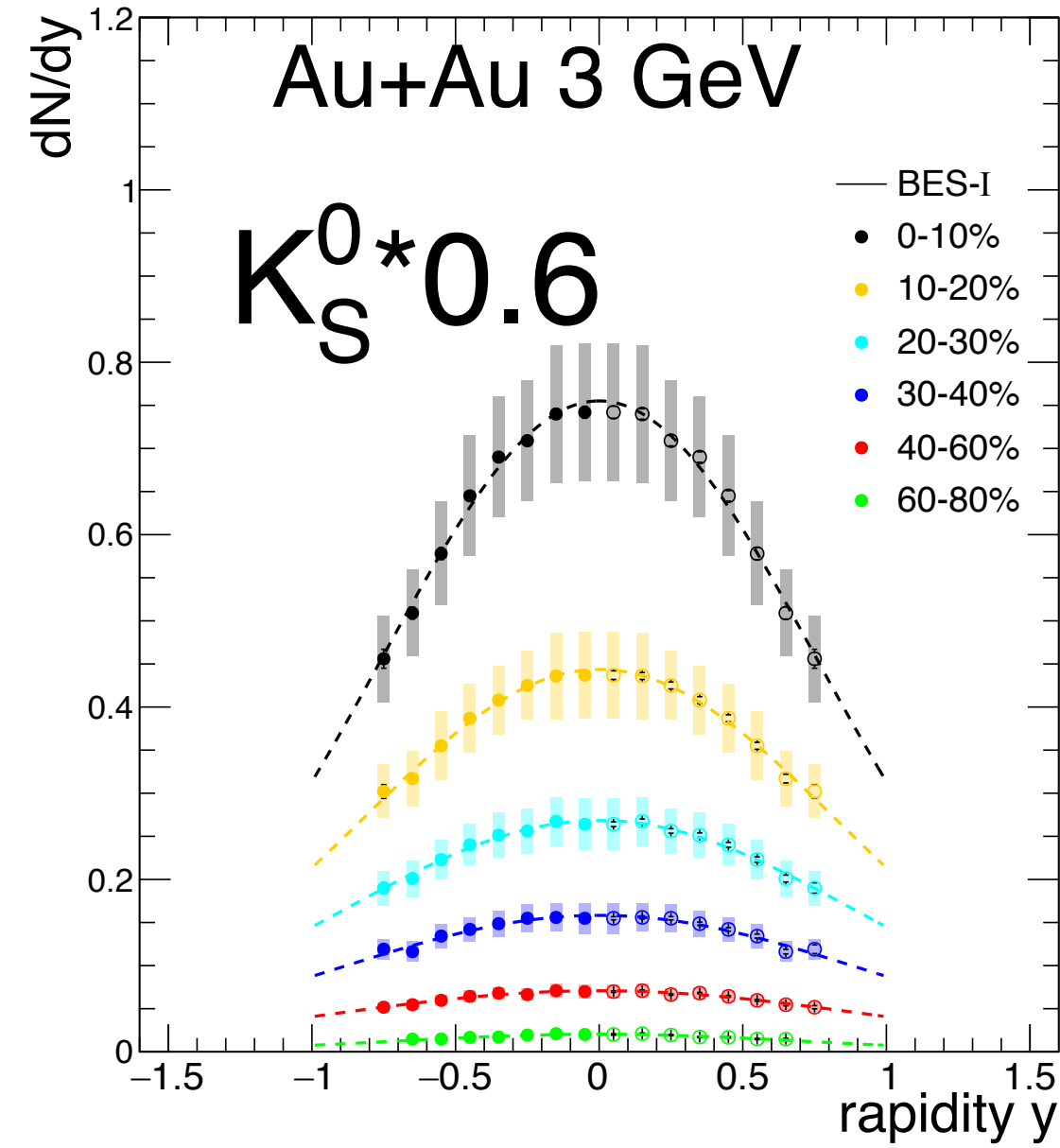


- $\Xi$ ,  $\Omega$  and  $\Lambda$  low  $p_T$  extrapolation: Boltzmann function.
- $\phi$  low  $p_T$  extrapolation: Levy function.



# Rapidity spectra of $K_S^0$ at $\sqrt{s_{NN}} = 3-19.6$ GeV

10.1007/JHEP10(2024)139

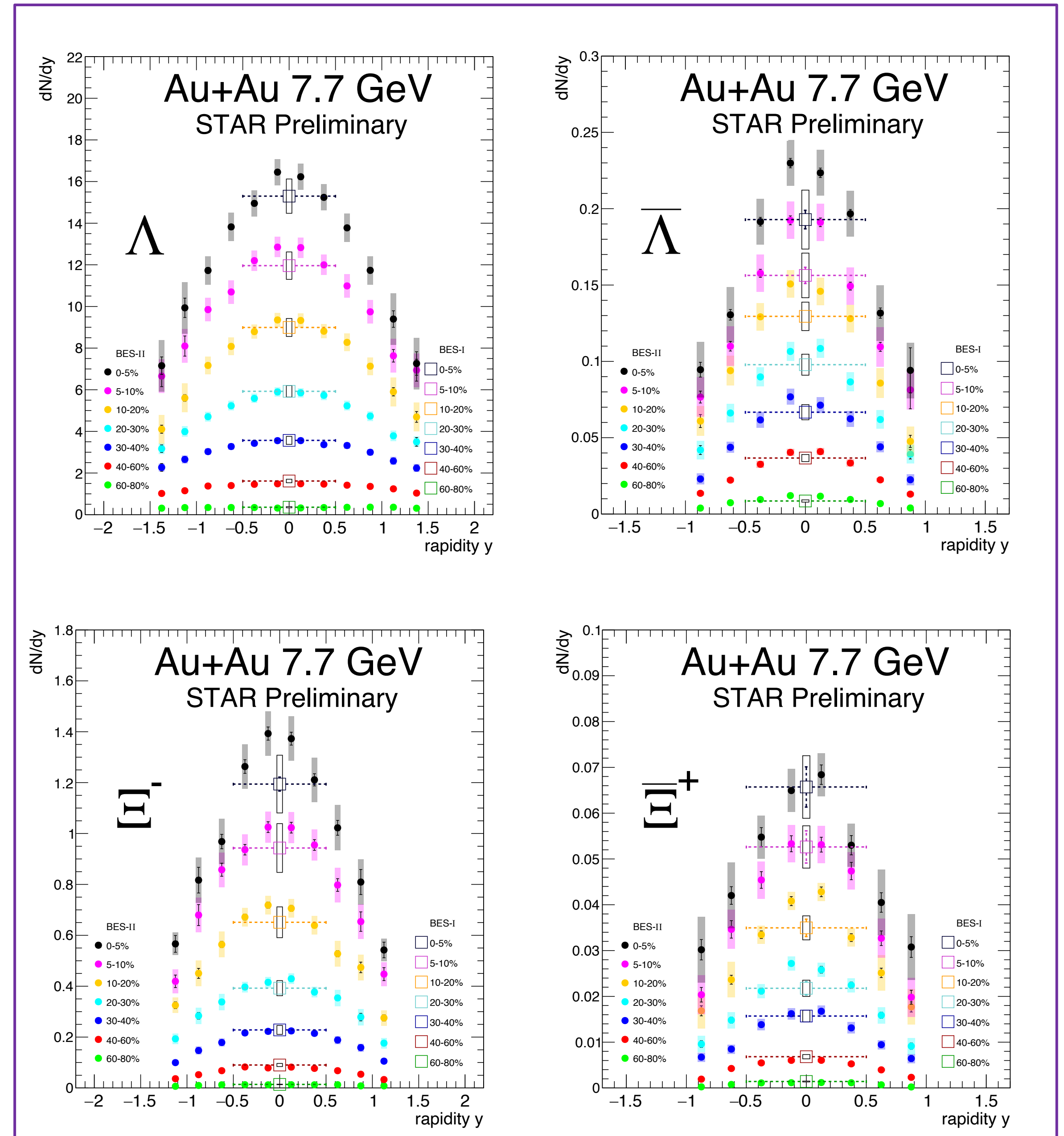


- Rapidity spectra of mesons ( $K_S^0$ ) are Gaussian-like distribution.
- The width of the Gaussian fit increases with beam energy.

# Rapidity spectra of $\Lambda(\bar{\Lambda})$ and $\Xi^-(\bar{\Xi}^+)$ at 7.7 GeV

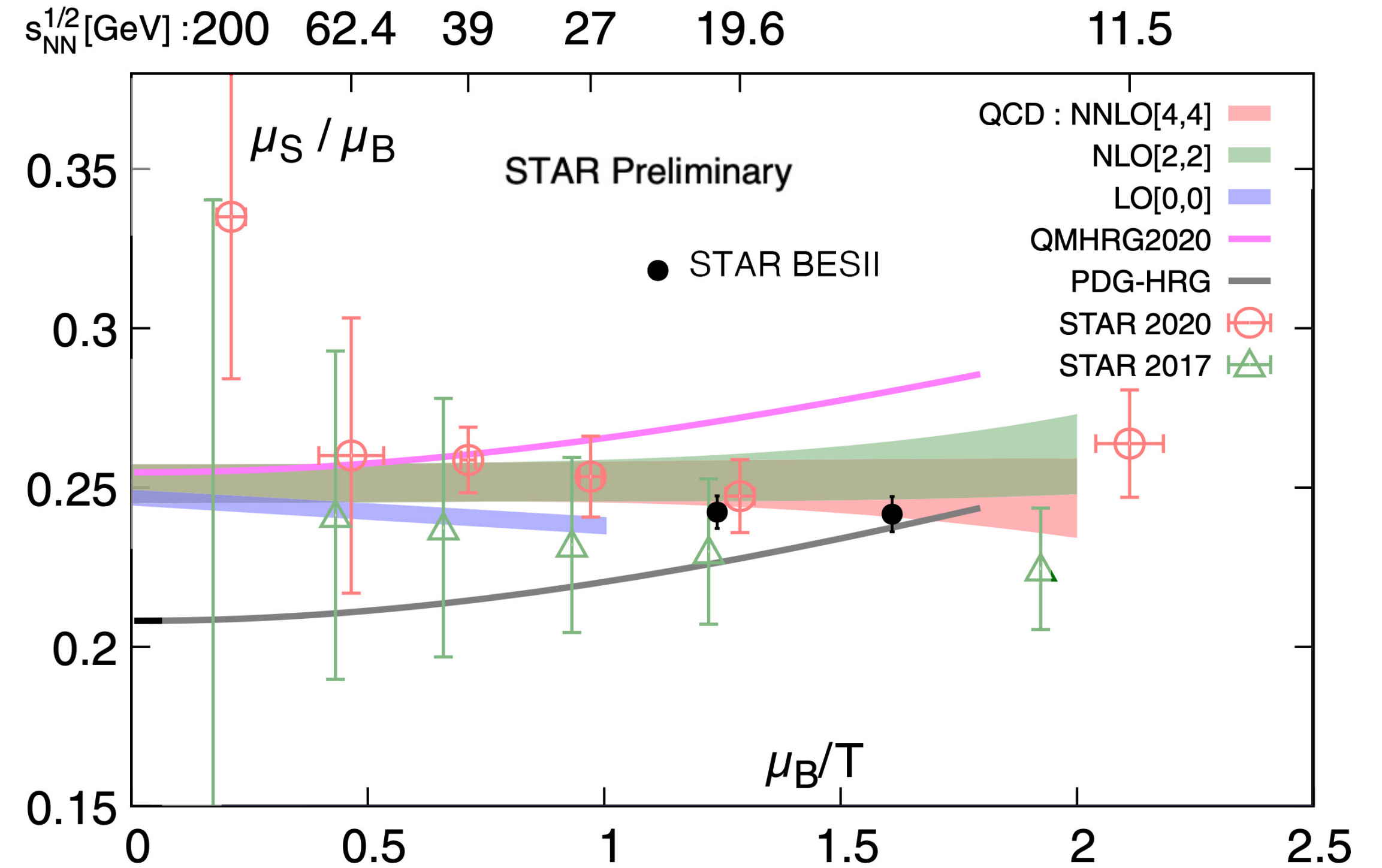
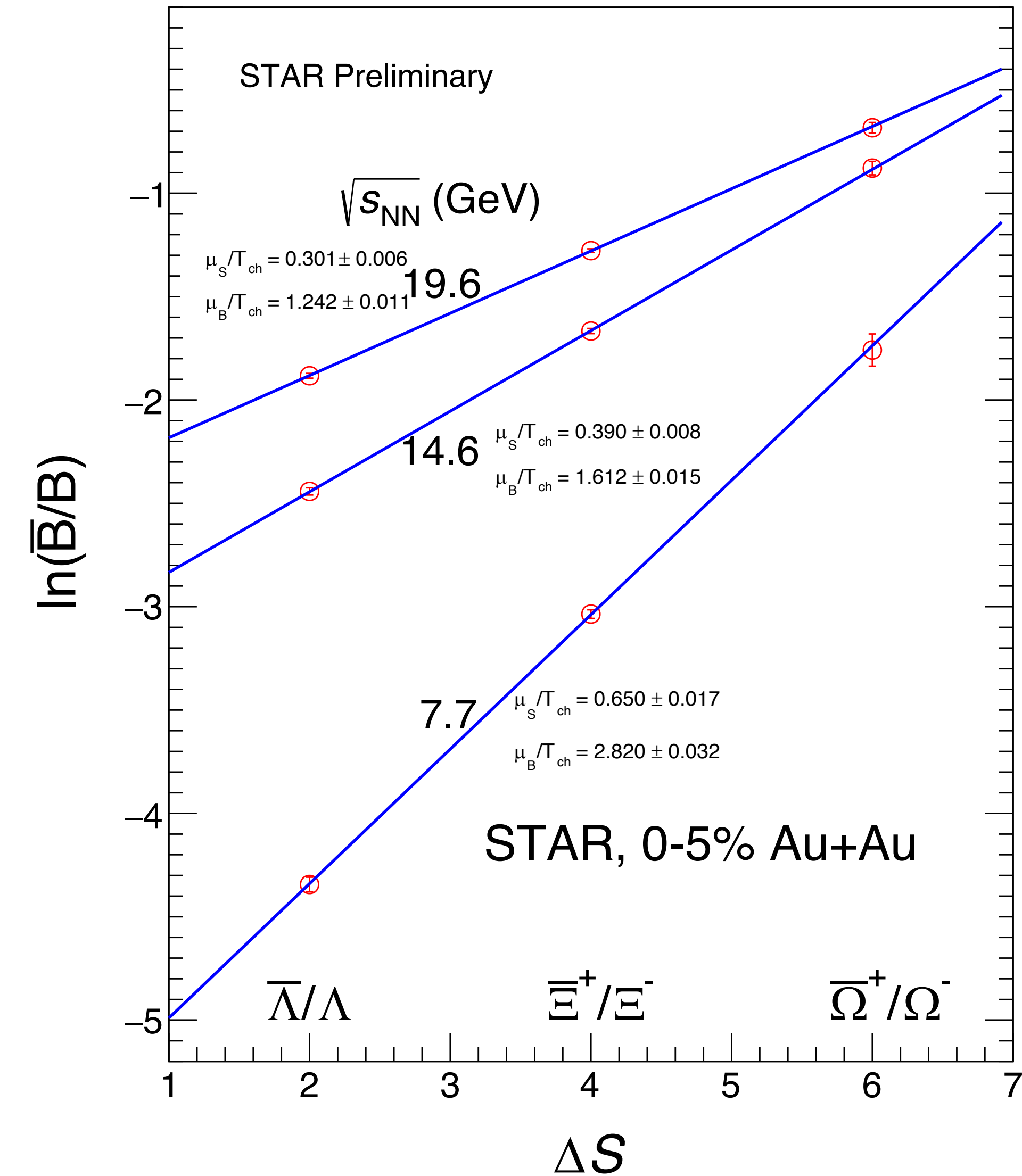
- Rapidity distributions of  $\Lambda$  baryon are wider than those of  $\bar{\Lambda}$  baryon.
  - ✓ Extra contributions from stopped baryons.
- The rapidity distributions of  $\Xi^-$  baryon are slightly wider than that of  $\bar{\Xi}^+$  anti-baryons.
  - ✓ Compared with  $\Lambda(uds)$ , less effect of baryon stopping for  $\Xi^-(dss)$ , due to their quark content.
- Similar trends observed by NA49.

*NA49, PRC 78, 034918 (2008)*



# Anti-baryon to baryon ratios

Thermal model prediction:  $\ln(\bar{B}/B) = -2\mu_B/T_{ch} + \mu_S/T_{ch}\Delta S$ ,



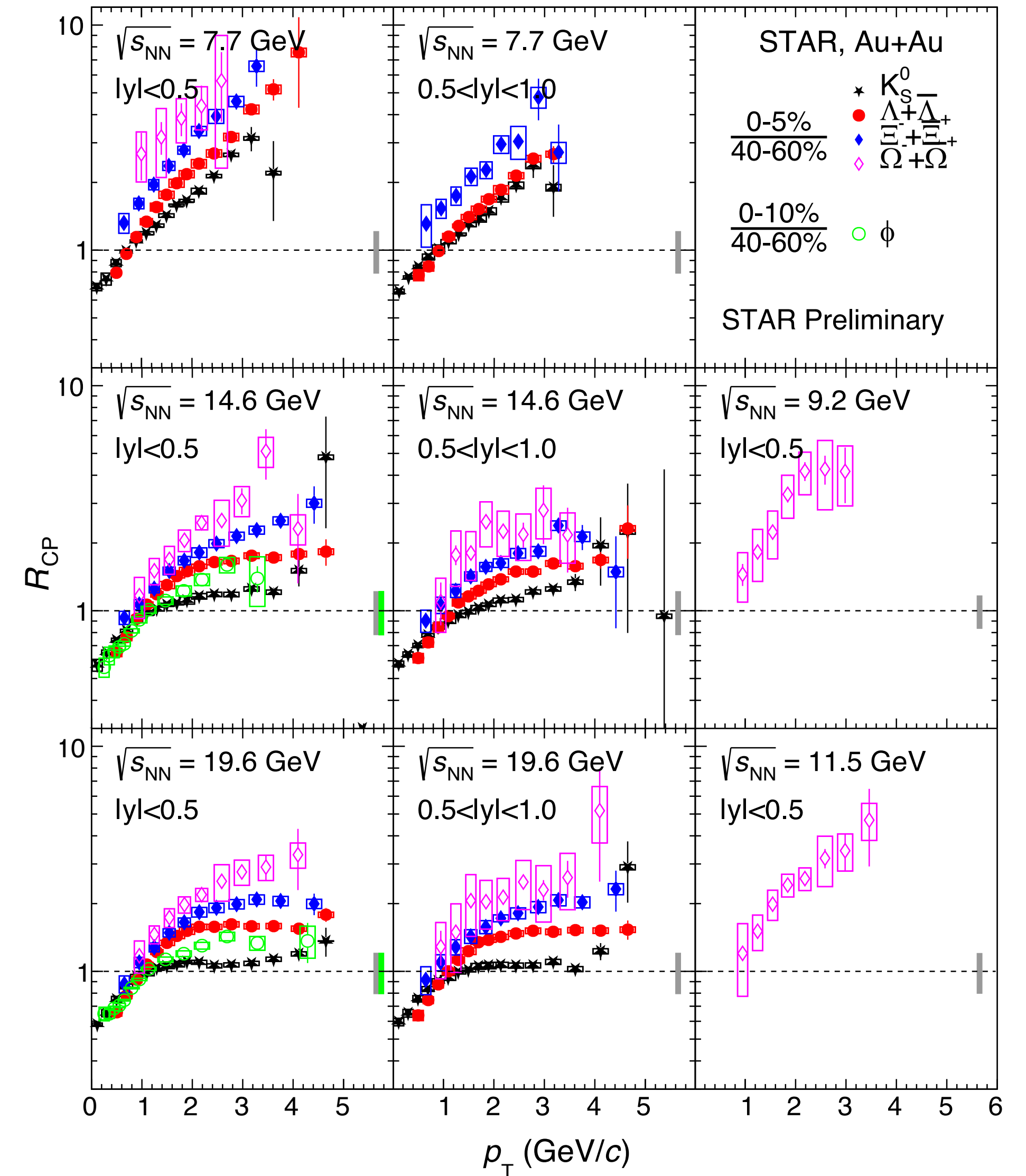
D. Bollweg, H.-T. Ding, J. Goswami, F. Karsch, Swagato Mukherjee, P. Petreczky, and C. Schmidt. PhysRevD.110.054519

- Results from thermal model fits are in good agreement with lattice QCD calculation results.
- Precise extraction of  $\mu_B/T_{ch}$  and  $\mu_S/T_{ch}$  from BES-II data.



# Nuclear modification factor ( $R_{CP}$ ) for strange hadrons

- $R_{CP} = 1$  if nucleus-nucleus collisions are just simple superpositions of nucleon-nucleon collisions.
- $R_{CP}$  tends to be flat and larger than unity at  $p_T > 2$  GeV/c for energies  $\sqrt{s_{NN}} \geq 14.6$  GeV.
- $R_{CP}$  continues to increase beyond  $p_T = 2$  GeV/c at  $\sqrt{s_{NN}} \leq 11.5$  GeV.
  - ✓ Radial flow
  - ✓ Quark coalescence
  - ✓ Cronin effect
- The enhancement is stronger for  $\Omega$  and  $\Xi^-$  compare to  $\Lambda$  and  $K_S^0$ .

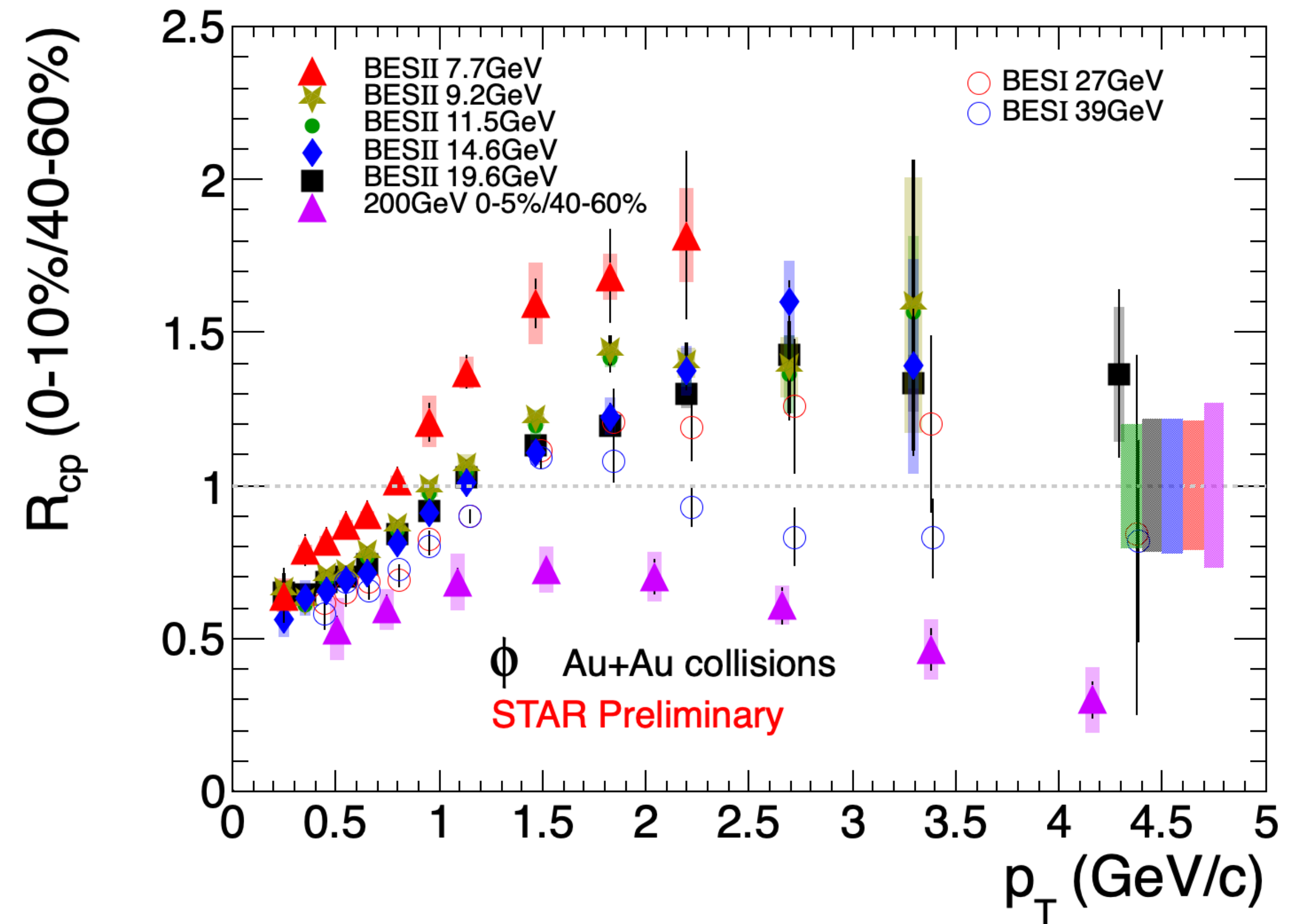


$$R_{CP} = \frac{[(dN/dp_T)/\langle N_{coll} \rangle]_{\text{central}}}{[(dN/dp_T)/\langle N_{coll} \rangle]_{\text{peripheral}}}$$

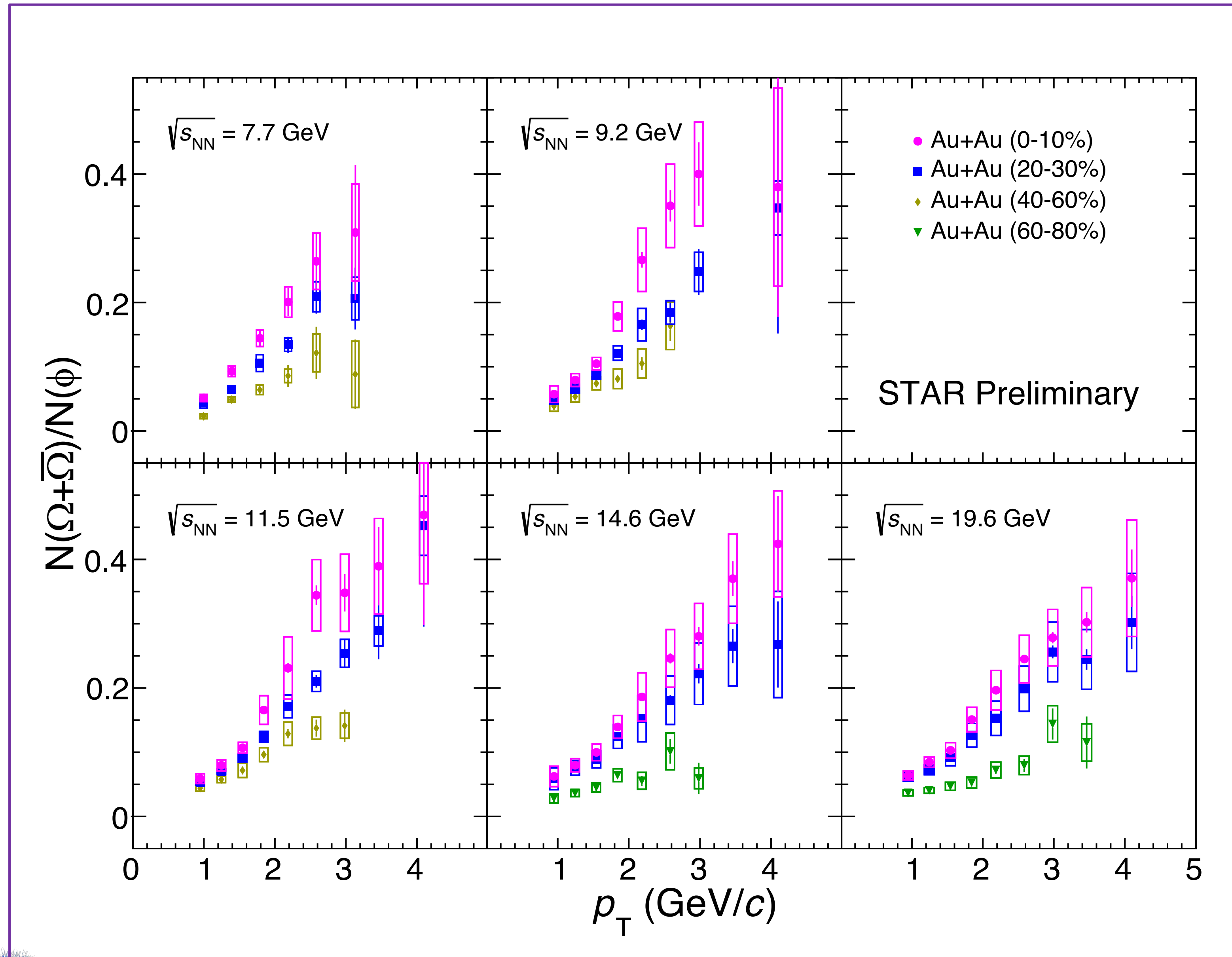


# Energy dependence of nuclear modification factor ( $R_{CP}$ ) for $\phi$

- $R_{CP} > 1$  for higher  $p_T$  at  $\sqrt{s_{NN}} = 19.6$  GeV and lower energies
- $R_{CP} < 1$  for all  $p_T$  at  $\sqrt{s_{NN}} = 200$  GeV
  - ✓ Strong energy loss in QGP at top RHIC energy
- $R_{CP}$  at  $\sqrt{s_{NN}} = 7.7$  GeV is significantly larger than that at  $\sqrt{s_{NN}} = 9.2$  GeV and above.



# Centrality dependence of $\Omega/\phi$ ratio at different energies



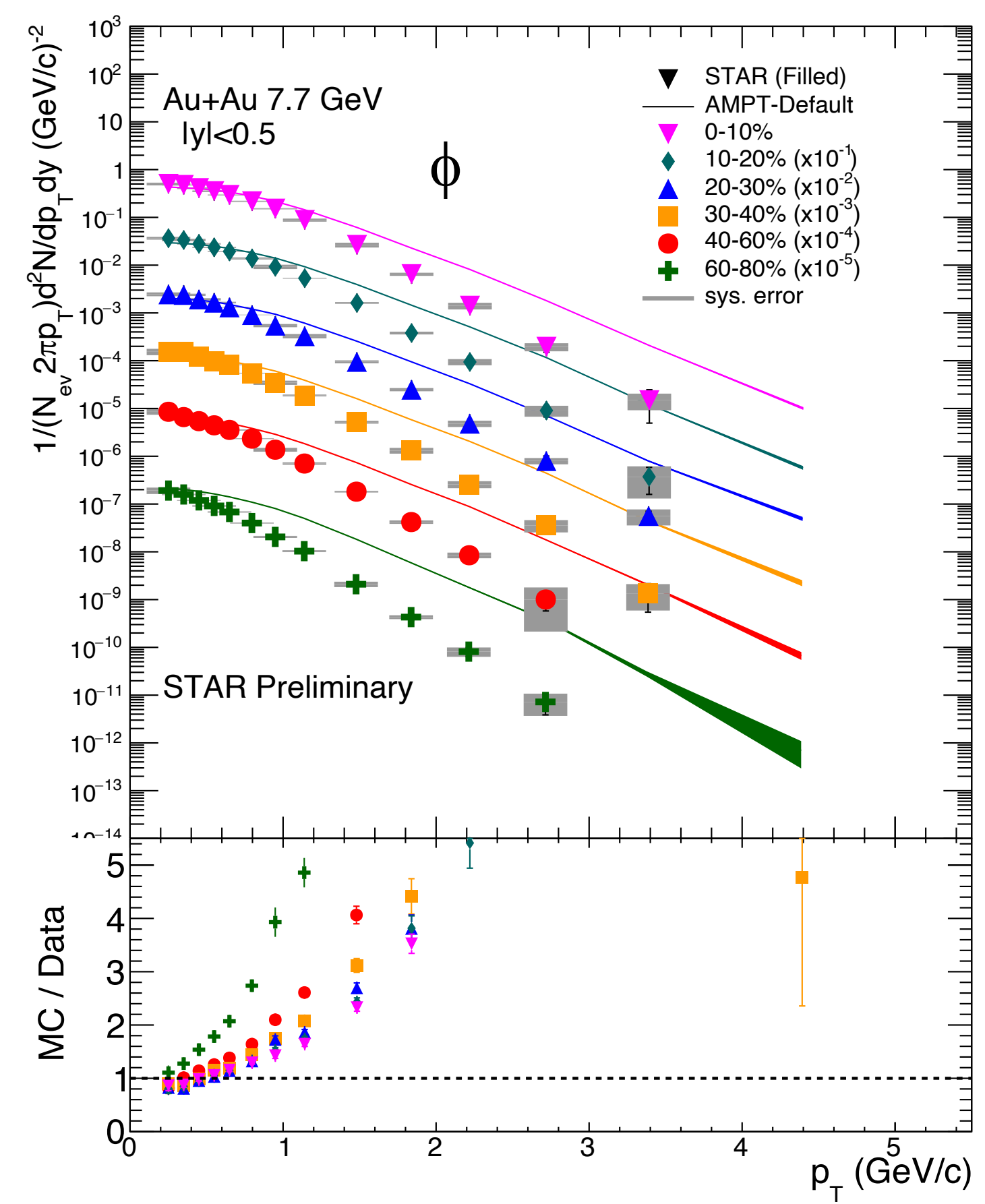
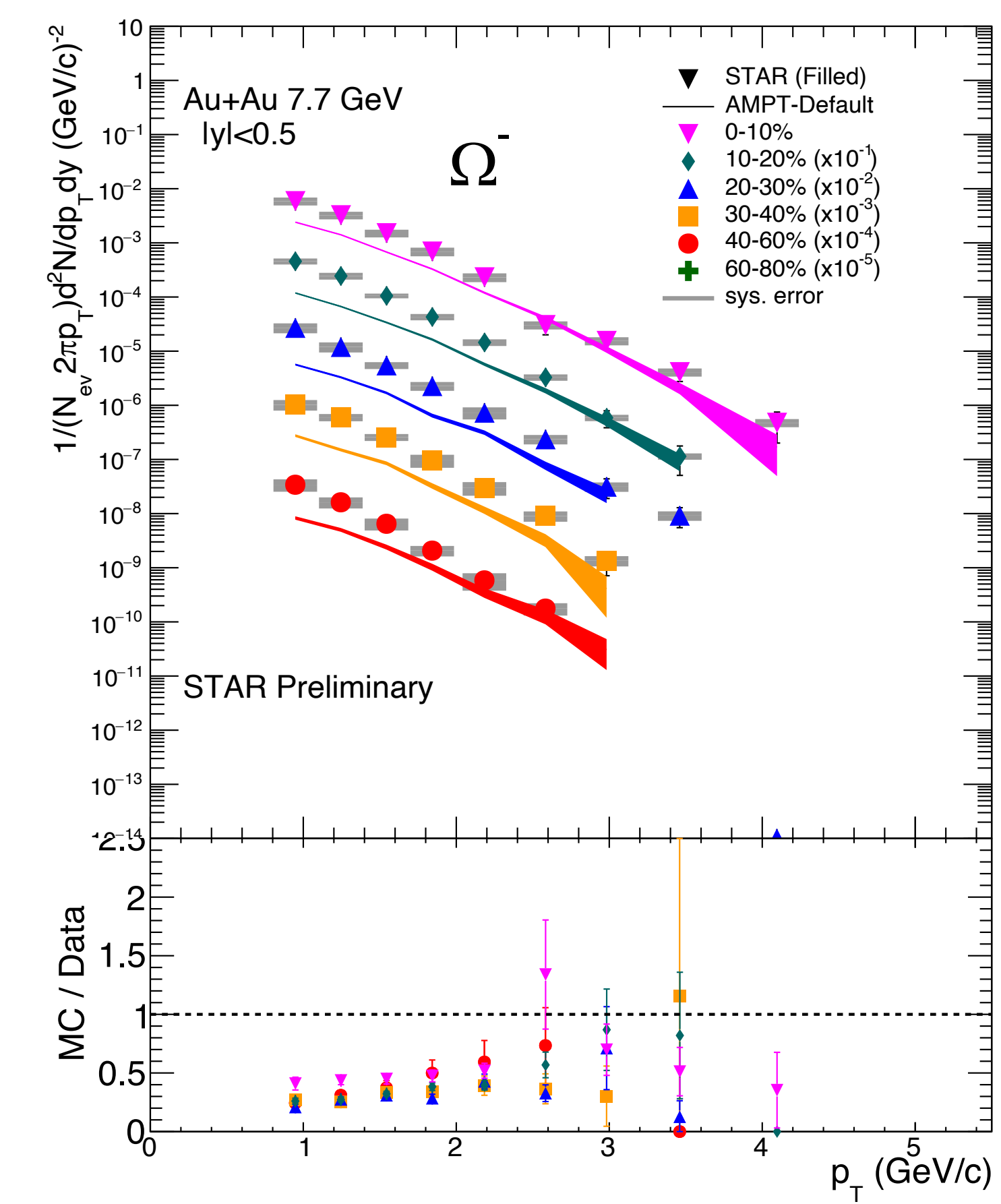
➤ Strong enhancement of  $\Omega/\phi$  ratio at intermediate  $p_T$  is observed in central Au+Au collisions from  $\sqrt{s_{NN}} = 7.7$  to 19.6 GeV.

- ✓ Quark coalescence
- ✓ Cronin effect
- ✓ Radial flow

Q: Which one is dominant?

# Model Calculation: AMPT default

T. Shao, J. Chen, C. Ko, Z. Lin. Phys.Rev.C 102 (2020) 1, 014906

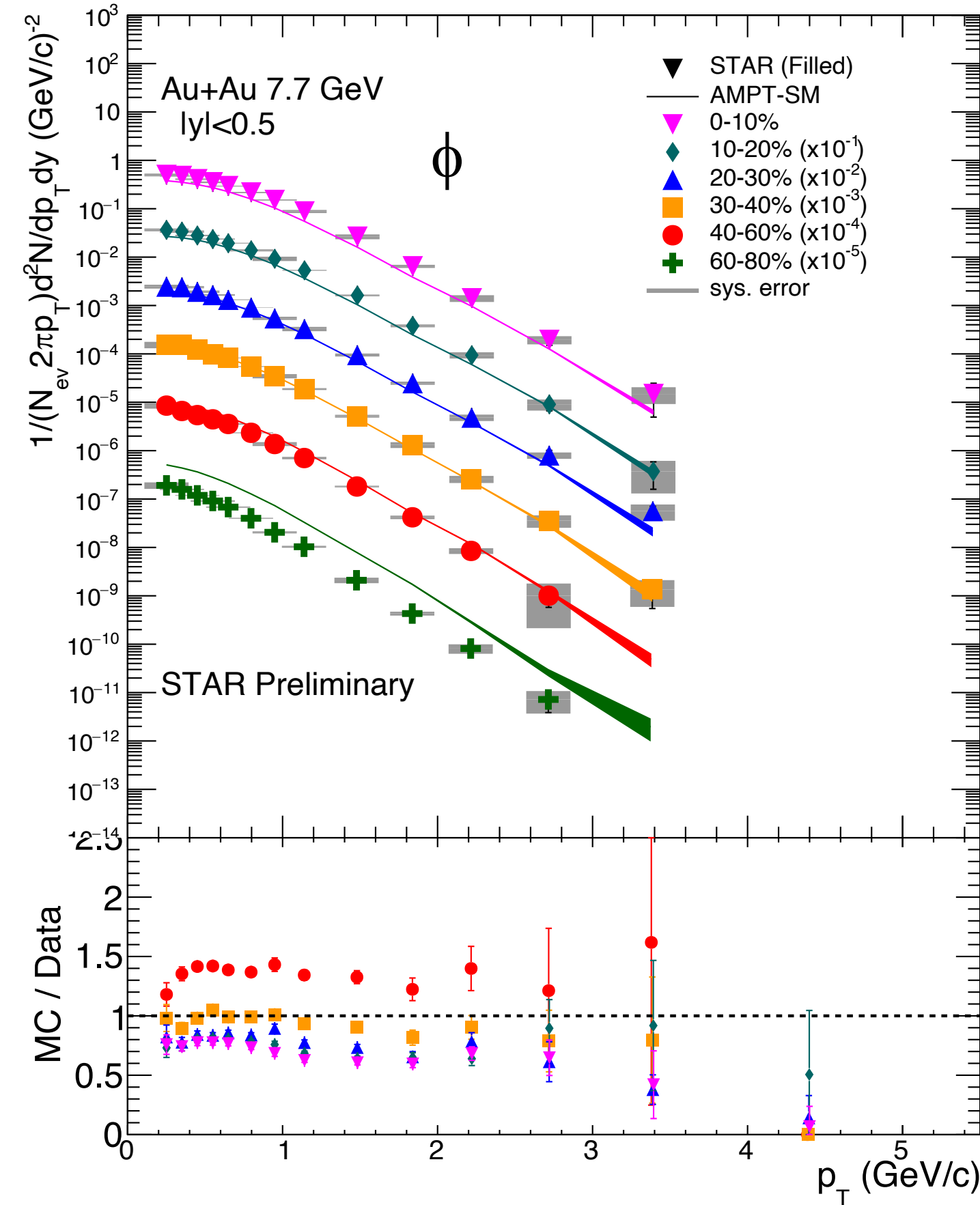
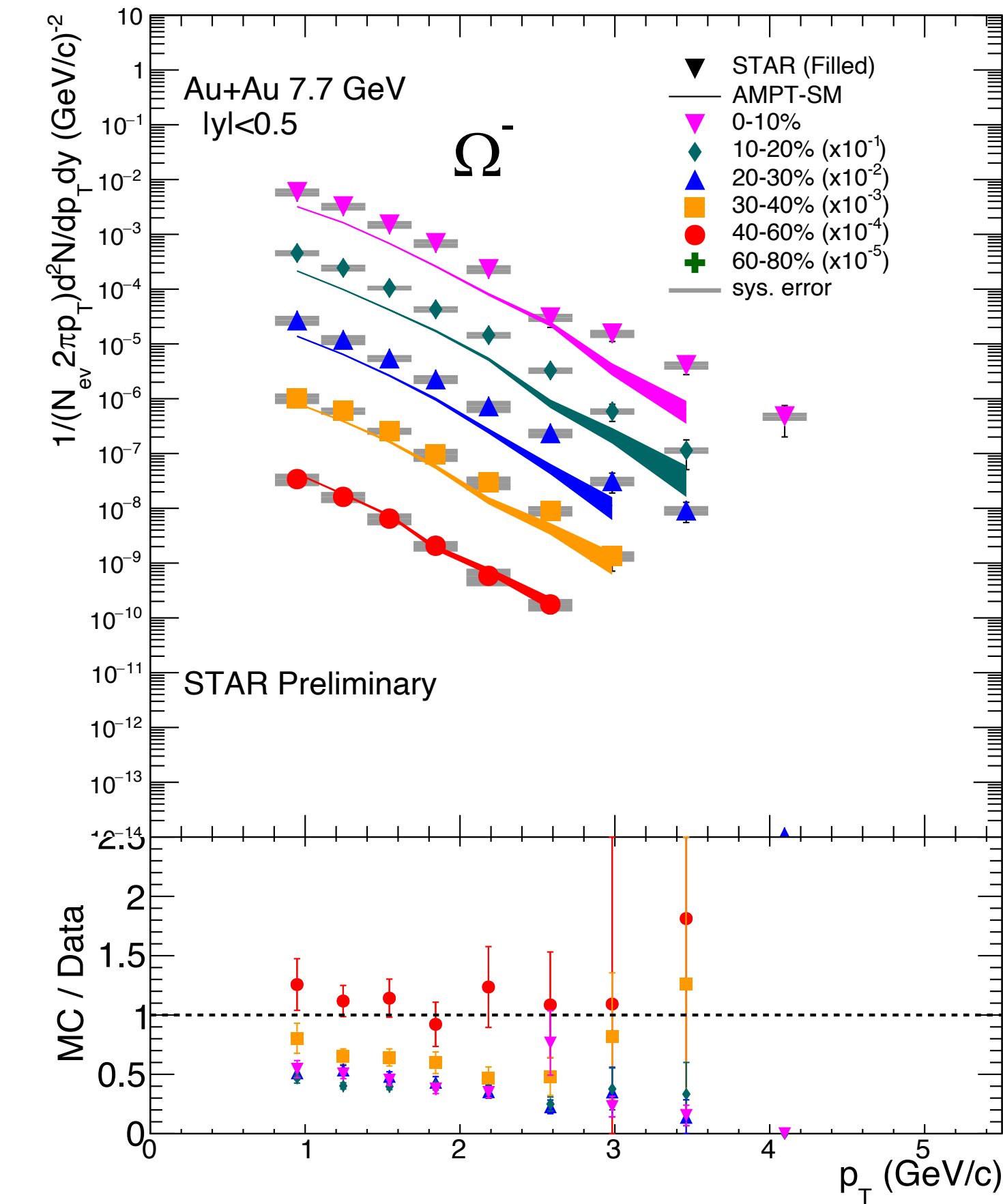


- AMPT default model (no quark coalescence process) calculation at 7.7 GeV
- Fail to describe data in  $p_T$  region above 1 GeV/c
- Model over-estimates  $\phi$  production and under-estimates  $\Omega$  production



# Result & Model Calculation: AMPT String-Melting **modified**

T. Shao, J. Chen, C. Ko, Z. Lin. *Phys.Rev.C* 102 (2020) 1, 014906

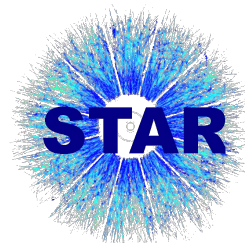


- AMPT String-Melting model (quark coalescence process)
- ✓ Magnitude of s quark production in the string melting process increased to increases the production of s quark

- ✓ B (String fragmentation model parameter) decreased, which led to a increase in the mean transverse momentum

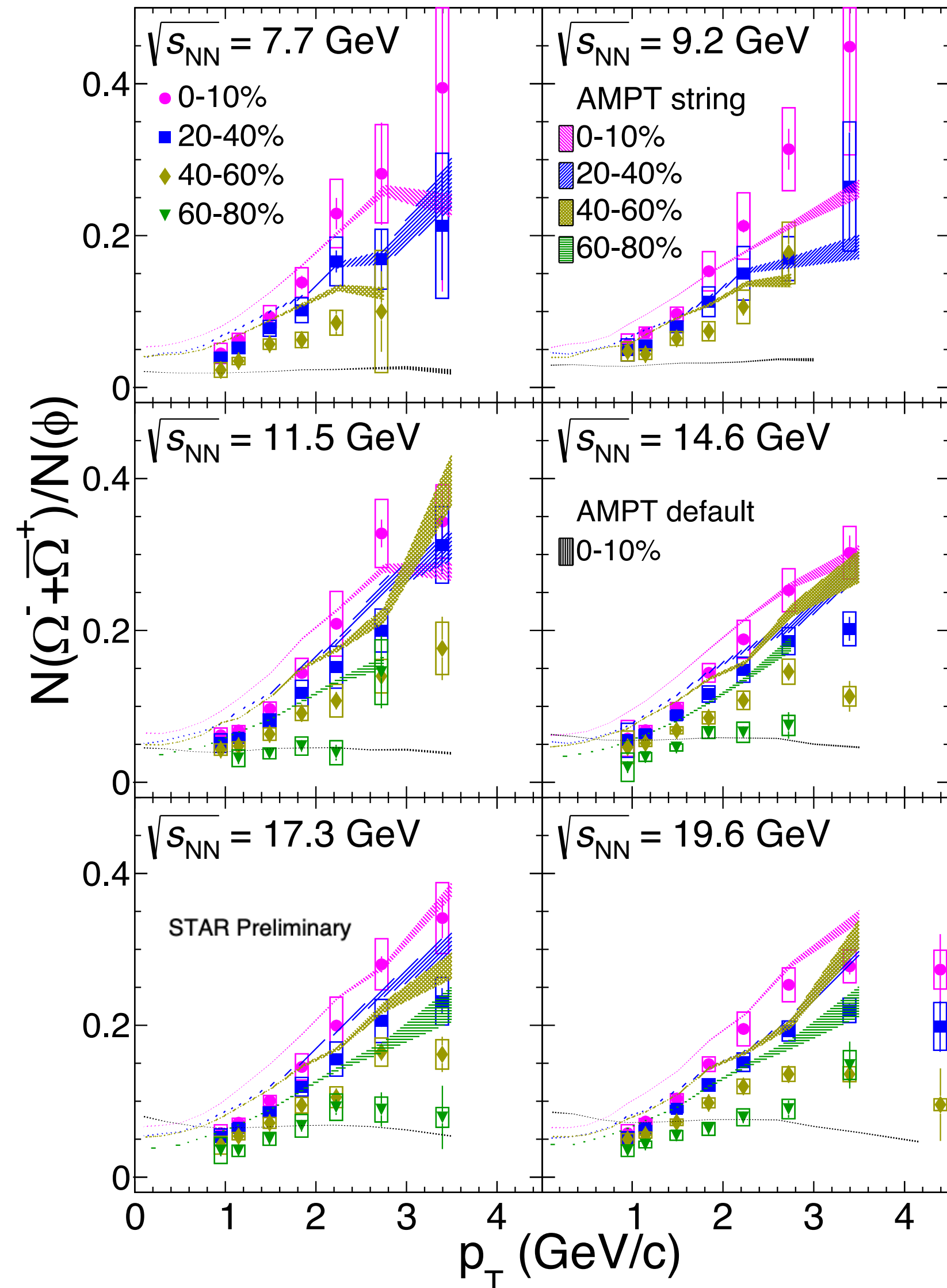
$$\langle p_{\perp}^2 \rangle = \frac{1}{b} \frac{\int_0^1 z(1-z)^a dz}{\int_0^1 (1-z)^a dz} = \frac{1}{b(2+a)} \quad (\text{Massless particles})$$

- Better consistency achieved across BES-II energies



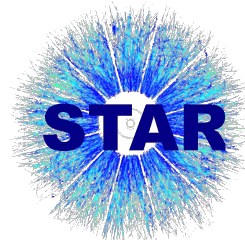


# Result & Model Calculation: $\Omega/\phi$ ratio & AMPT String-Melting (modified)



- Strong enhancement of  $\Omega/\phi$  ratio at intermediate  $p_T$  is observed in central Au+Au collisions from  $\sqrt{s_{NN}} = 7.7$  to 19.6 GeV.
  - Quark coalescence
  - Radial flow
- AMPT default version
  - No QGP assumed, flat  $\Omega/\phi$  ratios
  - Inconsistent with data
- AMPT String-Melting
  - QGP & coalescence assumed
  - Enhancement at intermediate  $p_T$
- Ratios in data are consistent with AMPT String-Melting model at intermediate  $p_T$
- The enhancement of  $\Omega/\phi$  ratio suggests the **QGP formation** in central Au+Au collisions above 7.7 GeV.

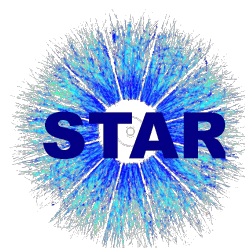
Original AMPT version : *T. Shao, J. Chen, C. Ko, Z. Lin. Phys.Rev.C 102 (2020) 1, 014906*

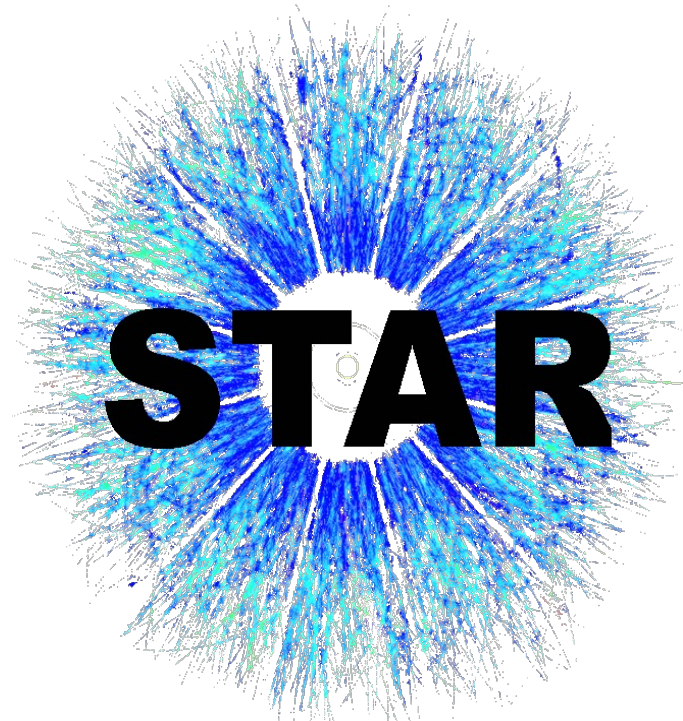


# Summary

- Precise measurement of strangeness production in STAR BES-II.
- $R_{CP}$  is significantly larger at 7.7 GeV compared with other energies for  $\phi$ .
- The  $\Omega/\phi$  enhancement at intermediate  $p_T$  is observed in central Au+Au collisions at  $\sqrt{s_{NN}} \geq 7.7$  GeV across BES-II collider energies, consistent with the AMPT-SM model calculations
  - Indicate that  $\Omega$  and  $\phi$  are created by the coalescence of strange quarks from the hot and dense medium
  - Comparison with AMPT model suggests **the QGP formation** in heavy-ion collisions above 7.7 GeV

Thanks for your attention!!

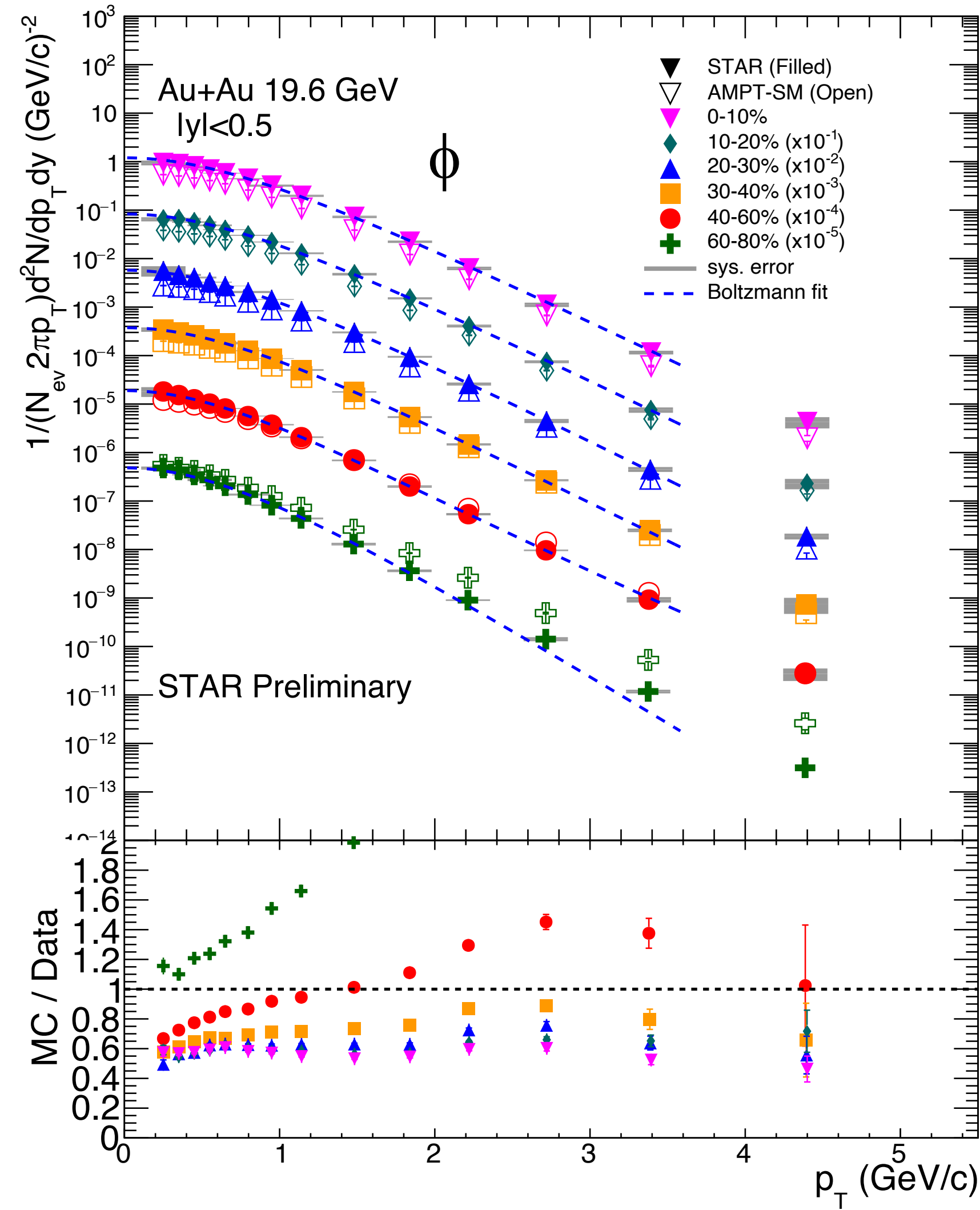
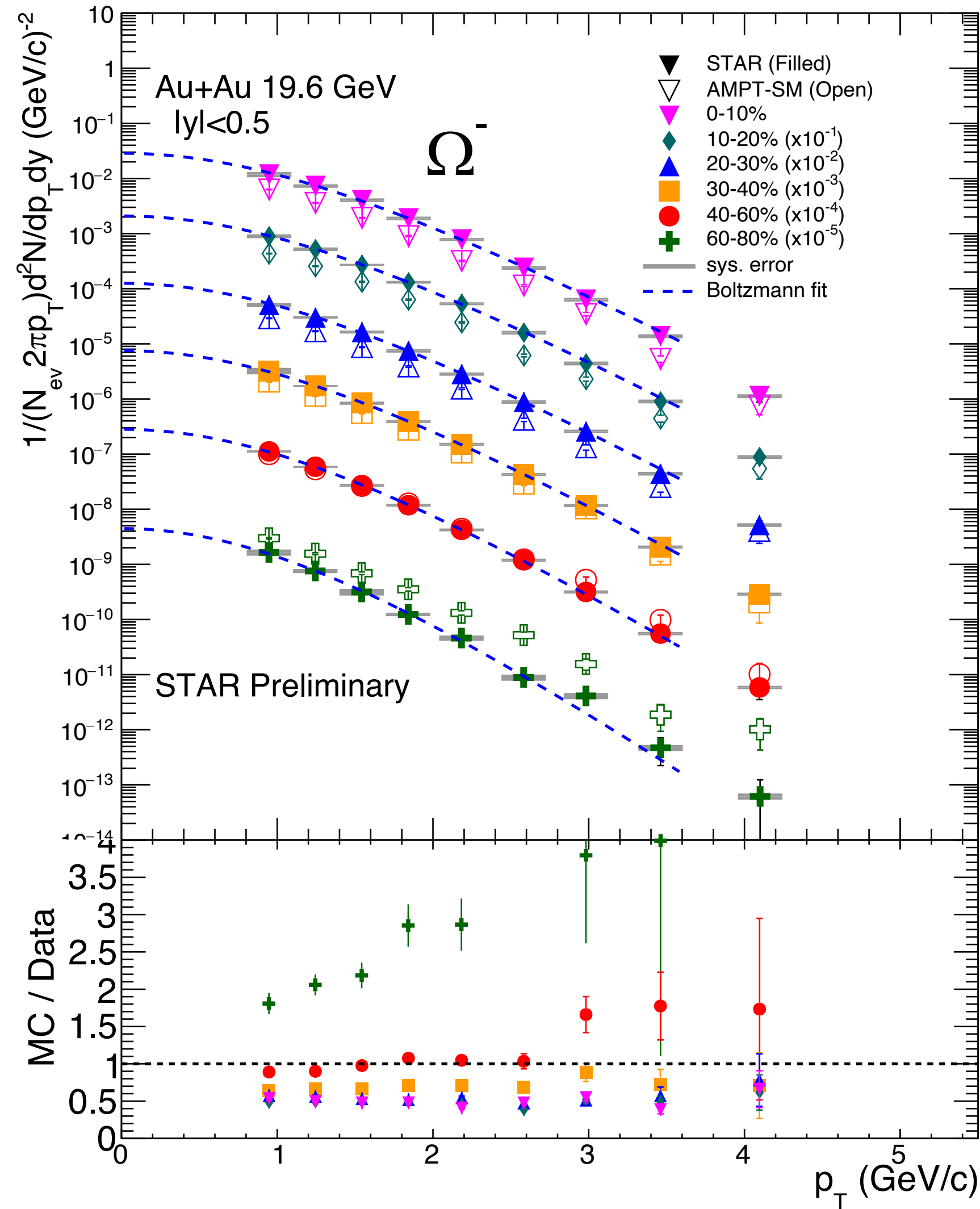




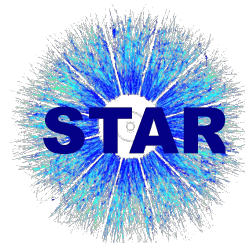
清华大学  
Tsinghua University

# Backup

# Model Calculation: AMPT String Melting

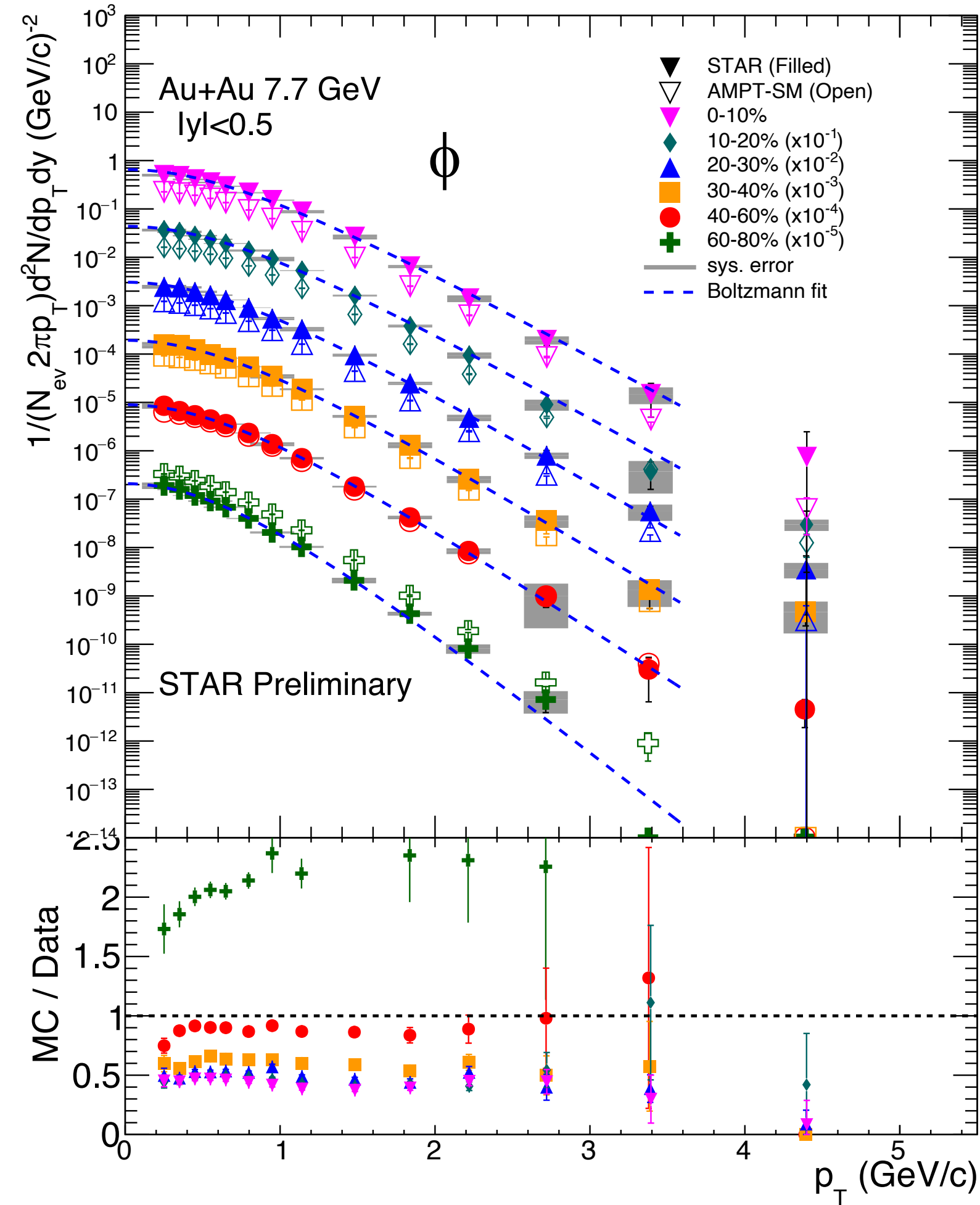
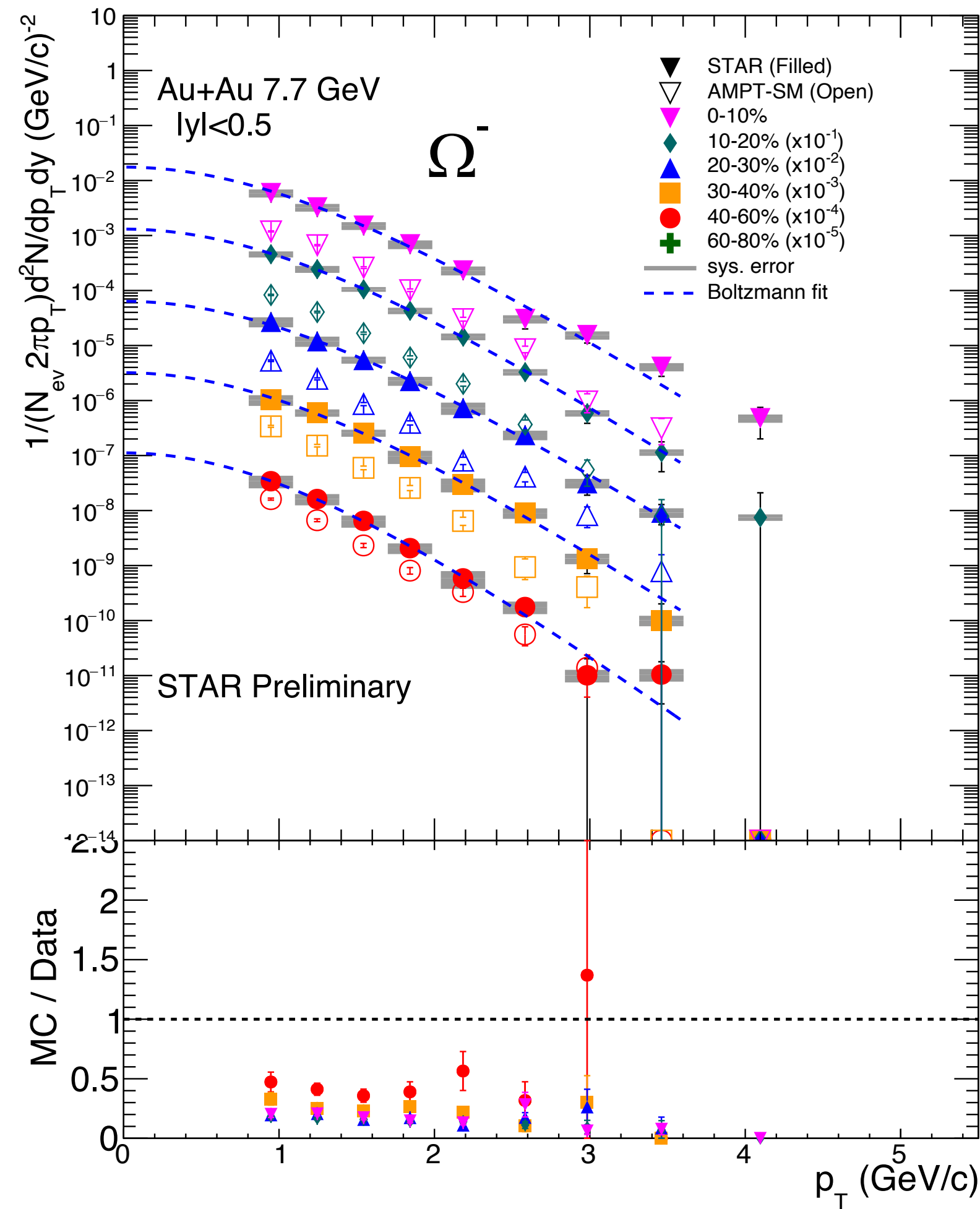


- AMPT SM model calculation
- 19.6 GeV
  - Generally consistent in central collisions
- Fail in peripheral
  - Model over-estimates production
  - Better consistency compared with UrQMD and default version
- Fail at 7.7 GeV
  - Model under-estimates production in all centralities

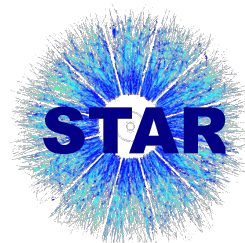


# Model Calculation: AMPT String Melting

Phys.Rev.C 102 (2020) 1, 014906

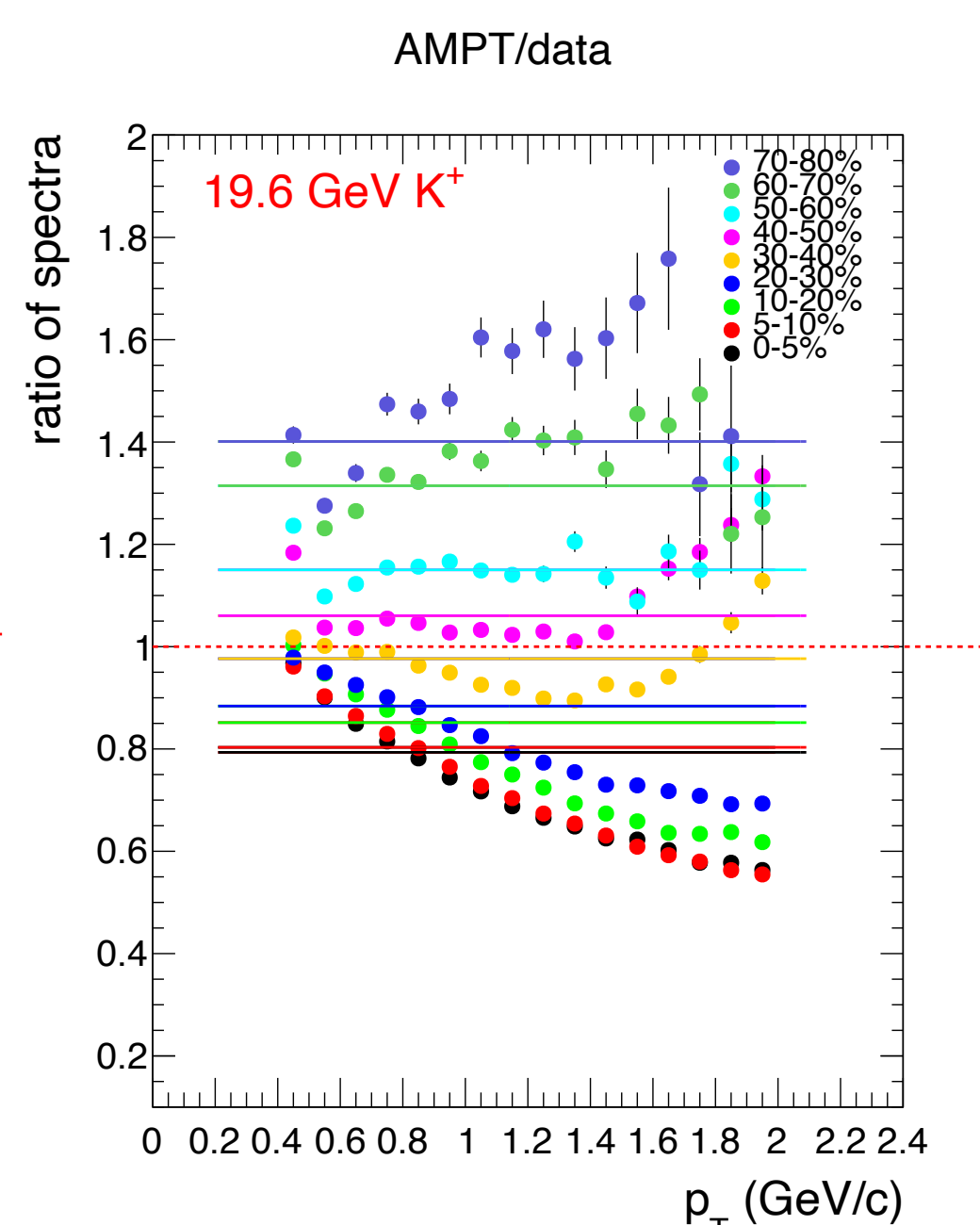
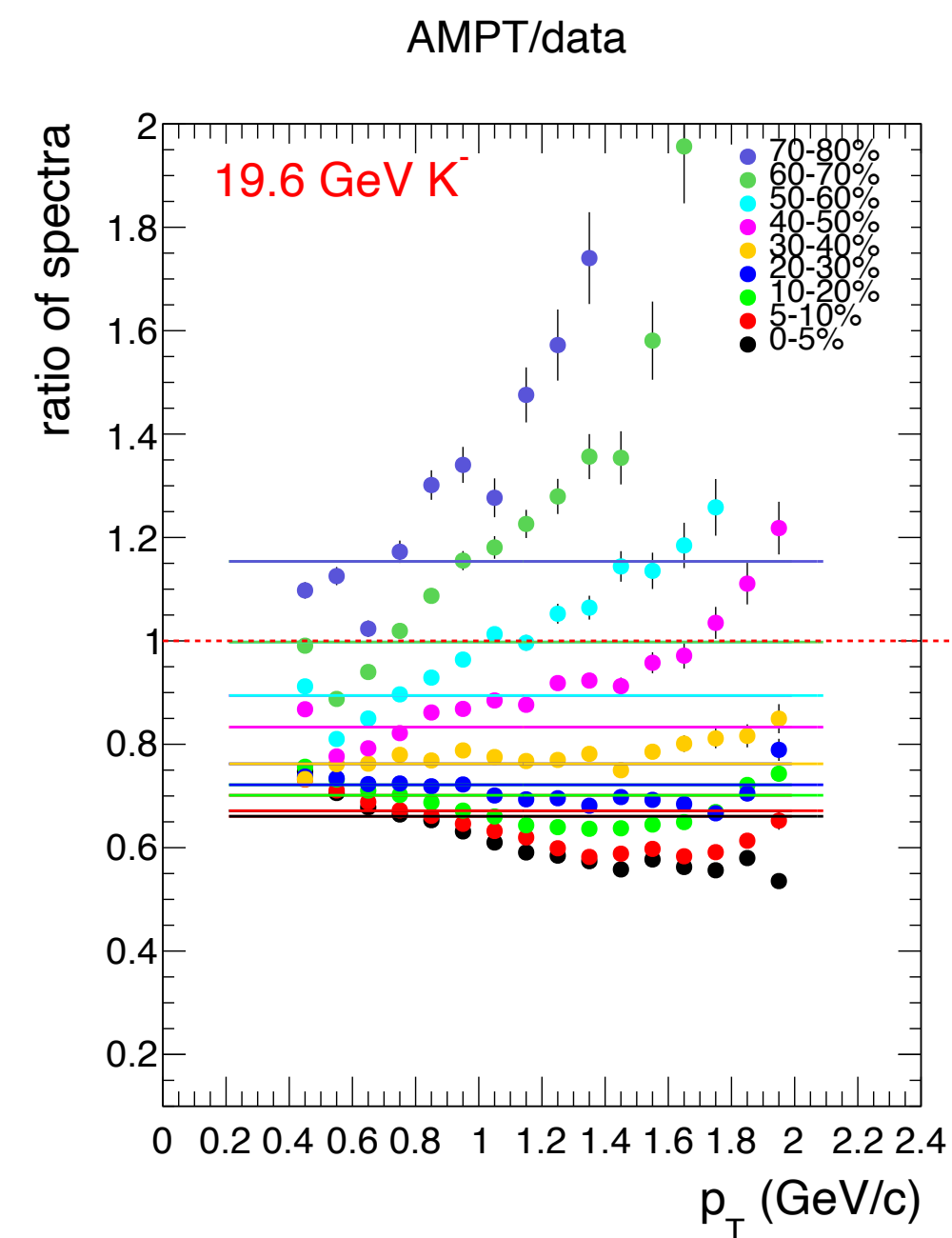
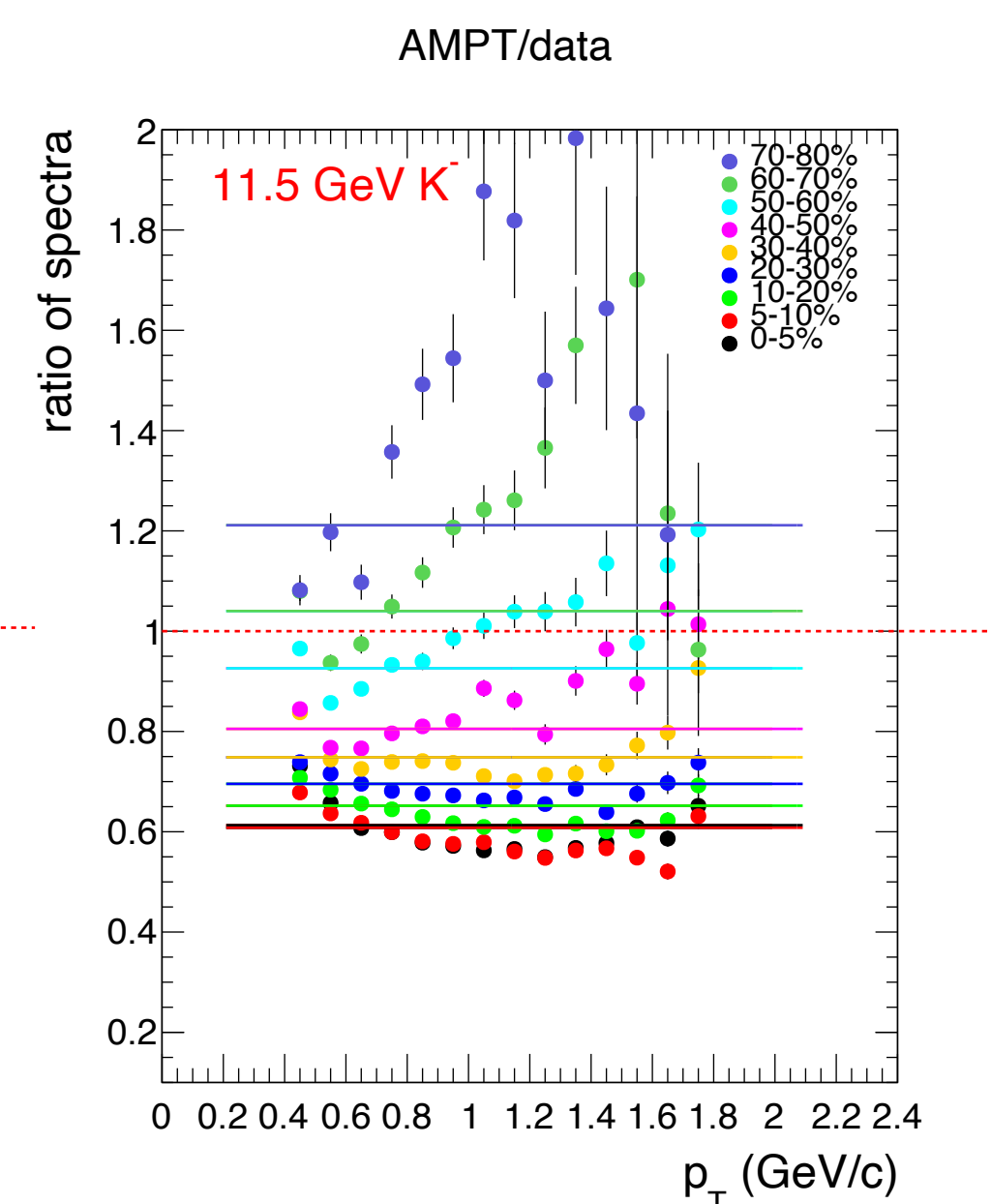
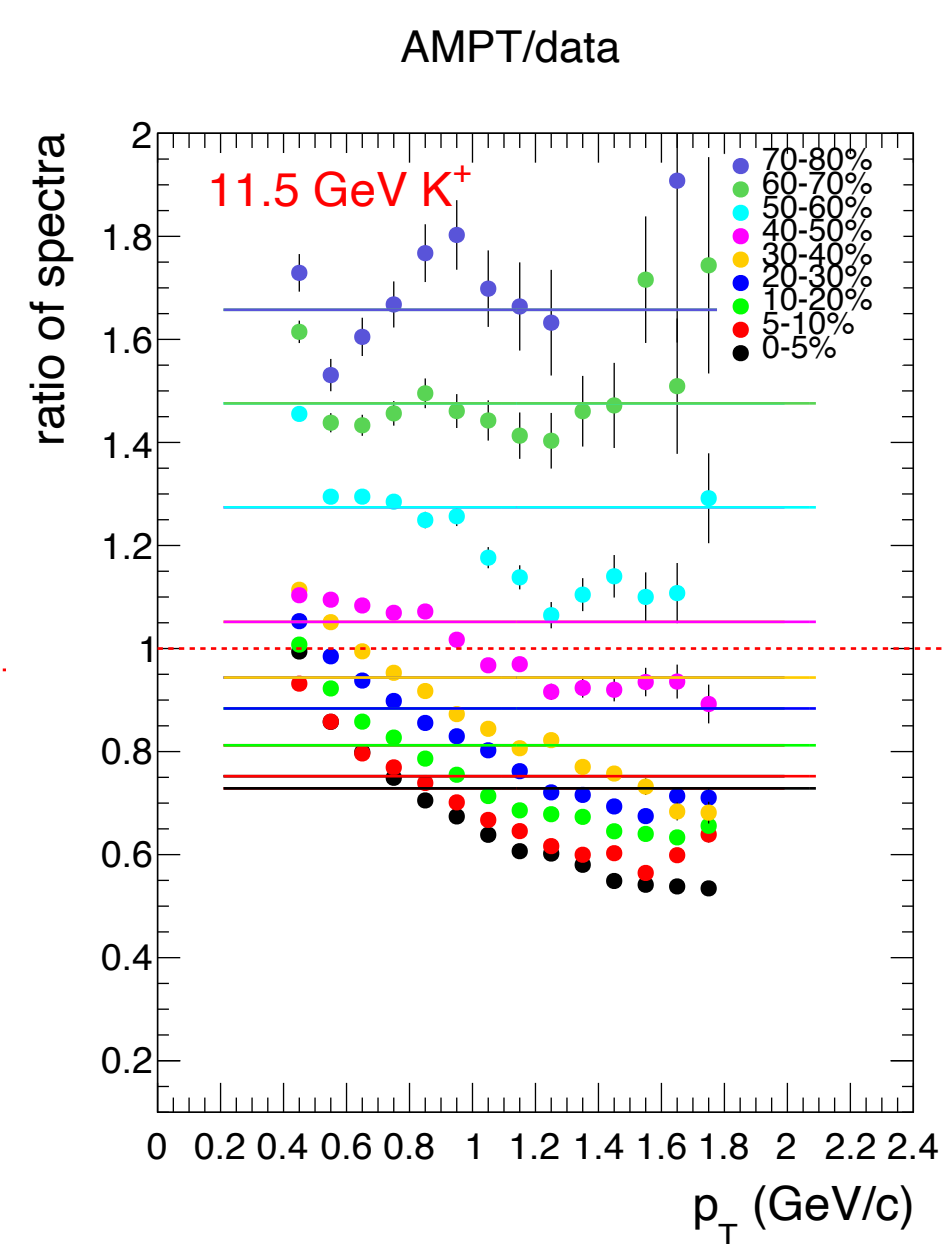
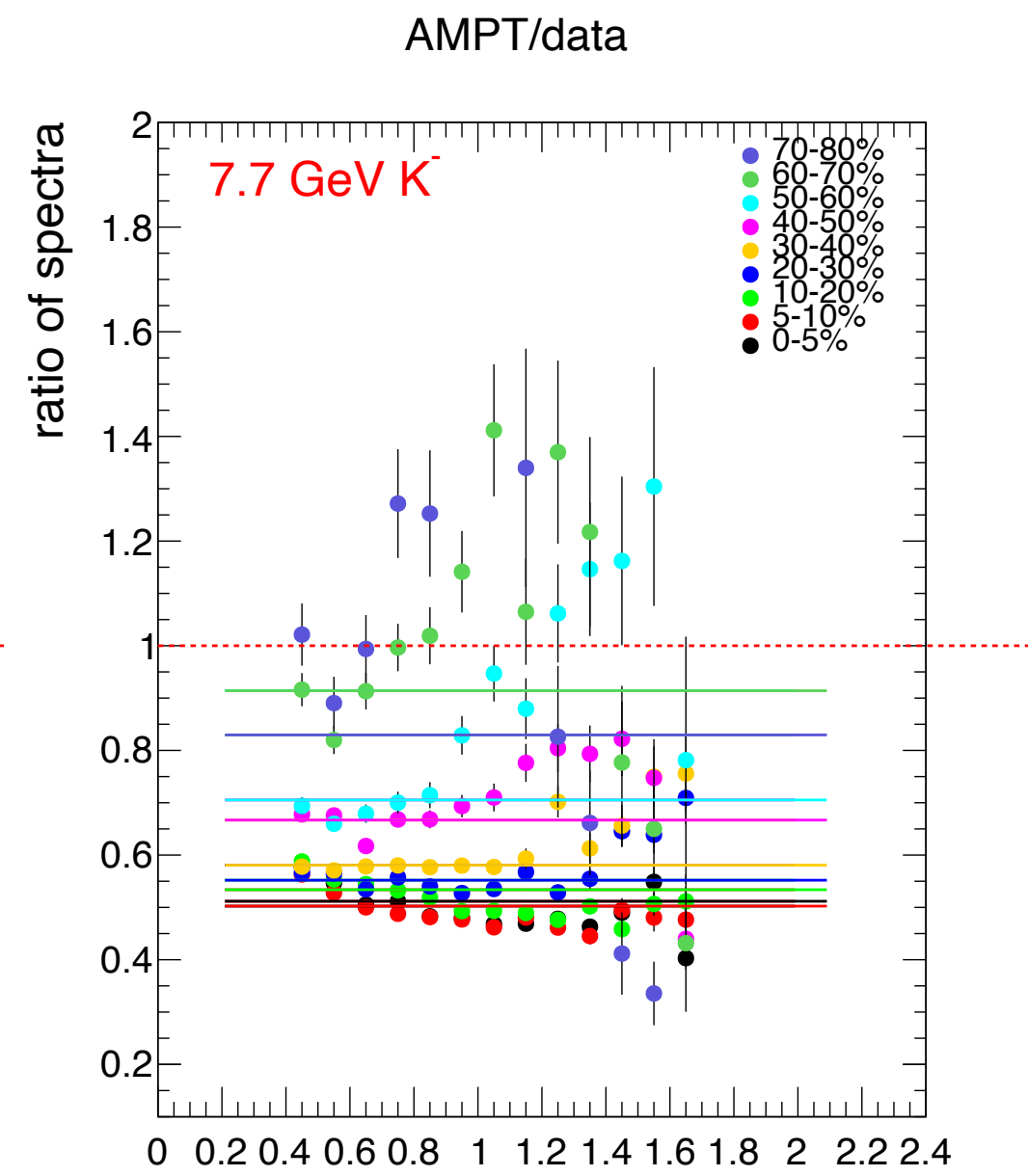
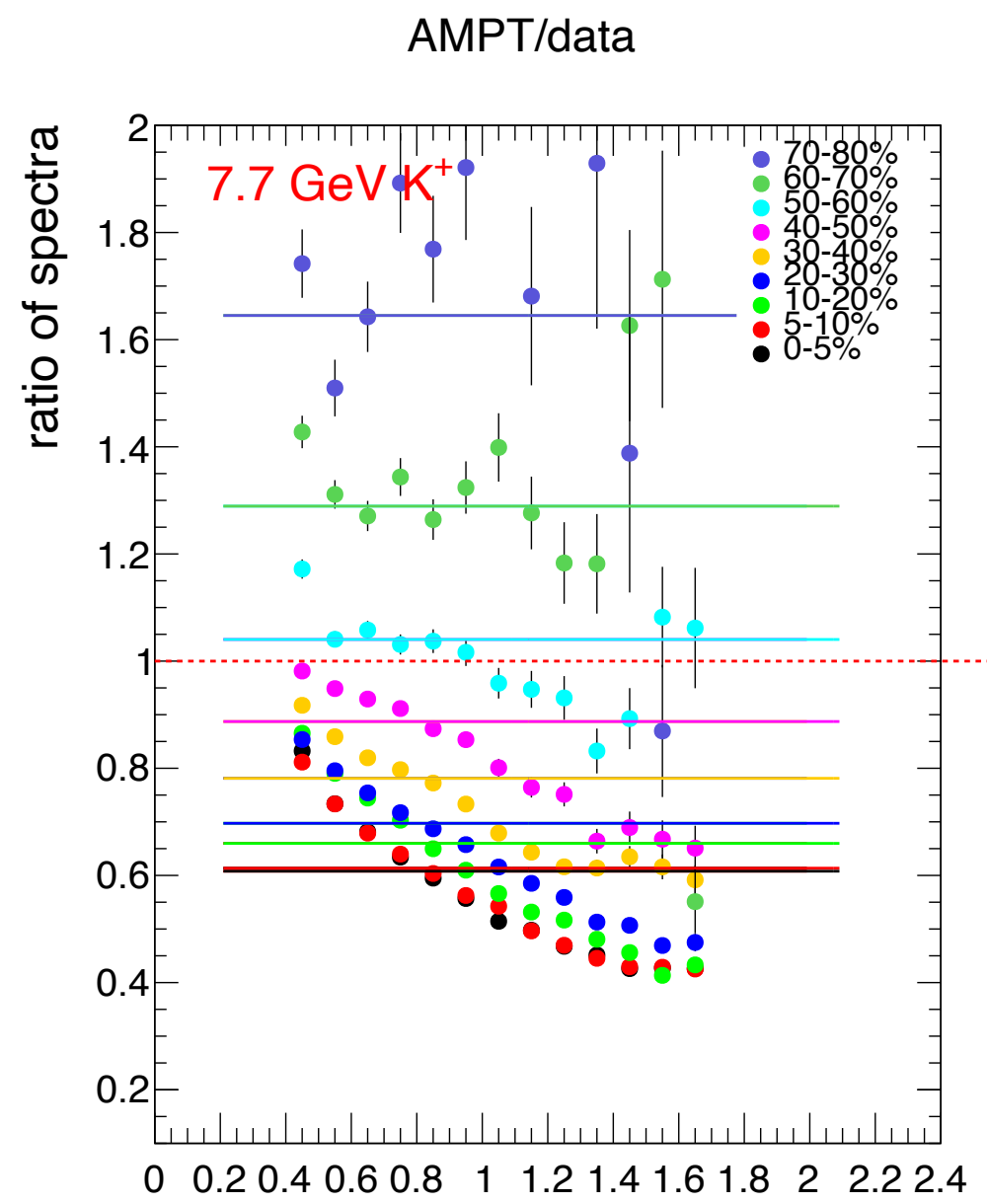


- AMPT SM model calculation
- 19.6 GeV
  - Generally consistent in central collisions
- Fail in peripheral
  - Model over-estimates production
  - Better consistency compared with UrQMD
- Fail at 7.7 GeV
  - Model under-estimates production in all centralities



# Model Calculation: Modify AMPT String Melting

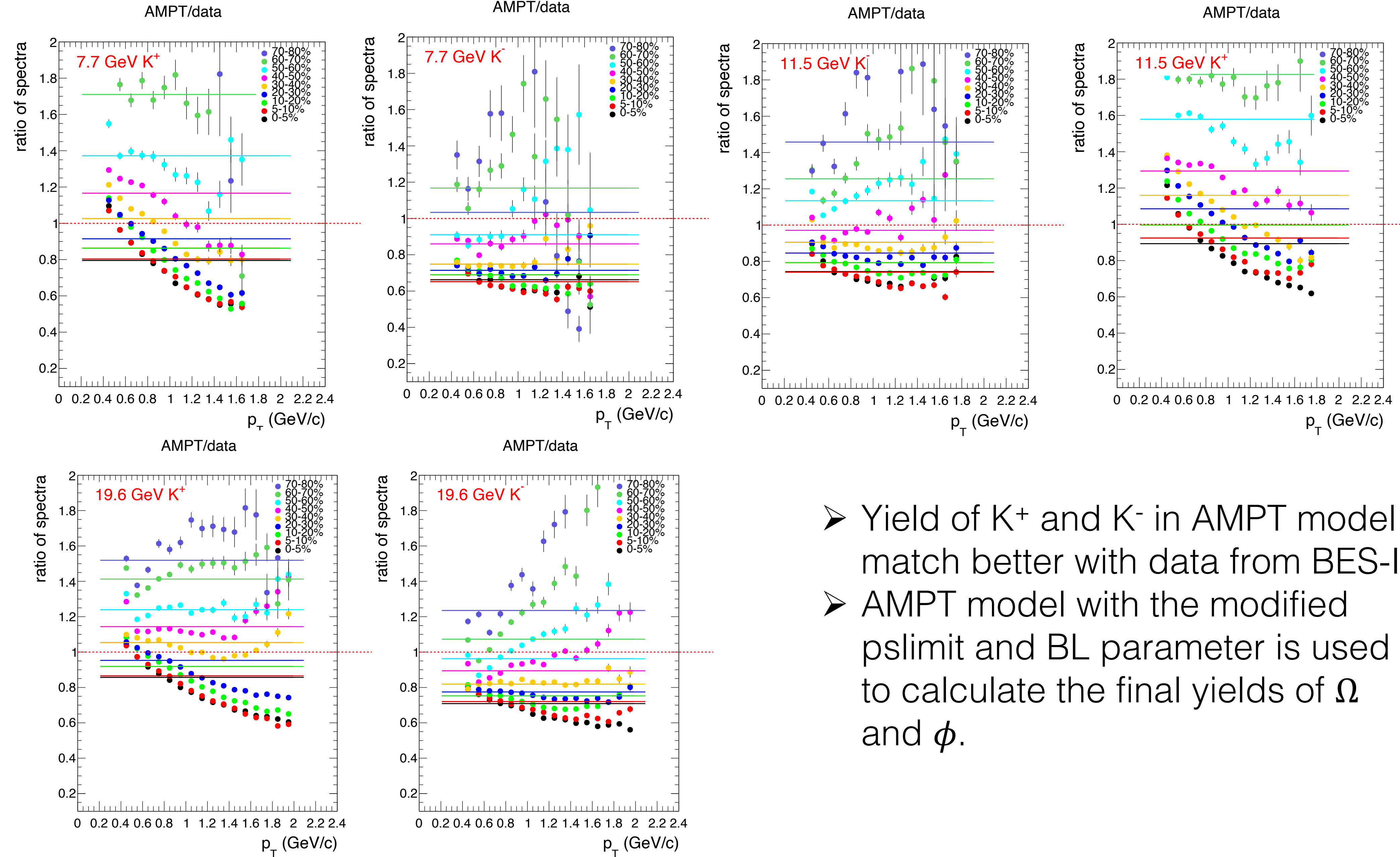
Original AMPT version : *Phys.Rev.C* 102 (2020) 1, 014904  
 Kaon: *Phys.Rev.C* 96 (2017) 4, 044904



- The parameter  $pslimit=0.4$  (default value),  $BL=0.15$  (default value).
- The yield of  $K^+$  and  $K^-$  in AMPT model are lower than data in central collisions
- The discrepancy between the model predictions and the experimental data grows with decreasing collision energy

# Model Calculation: Modify AMPT String Melting

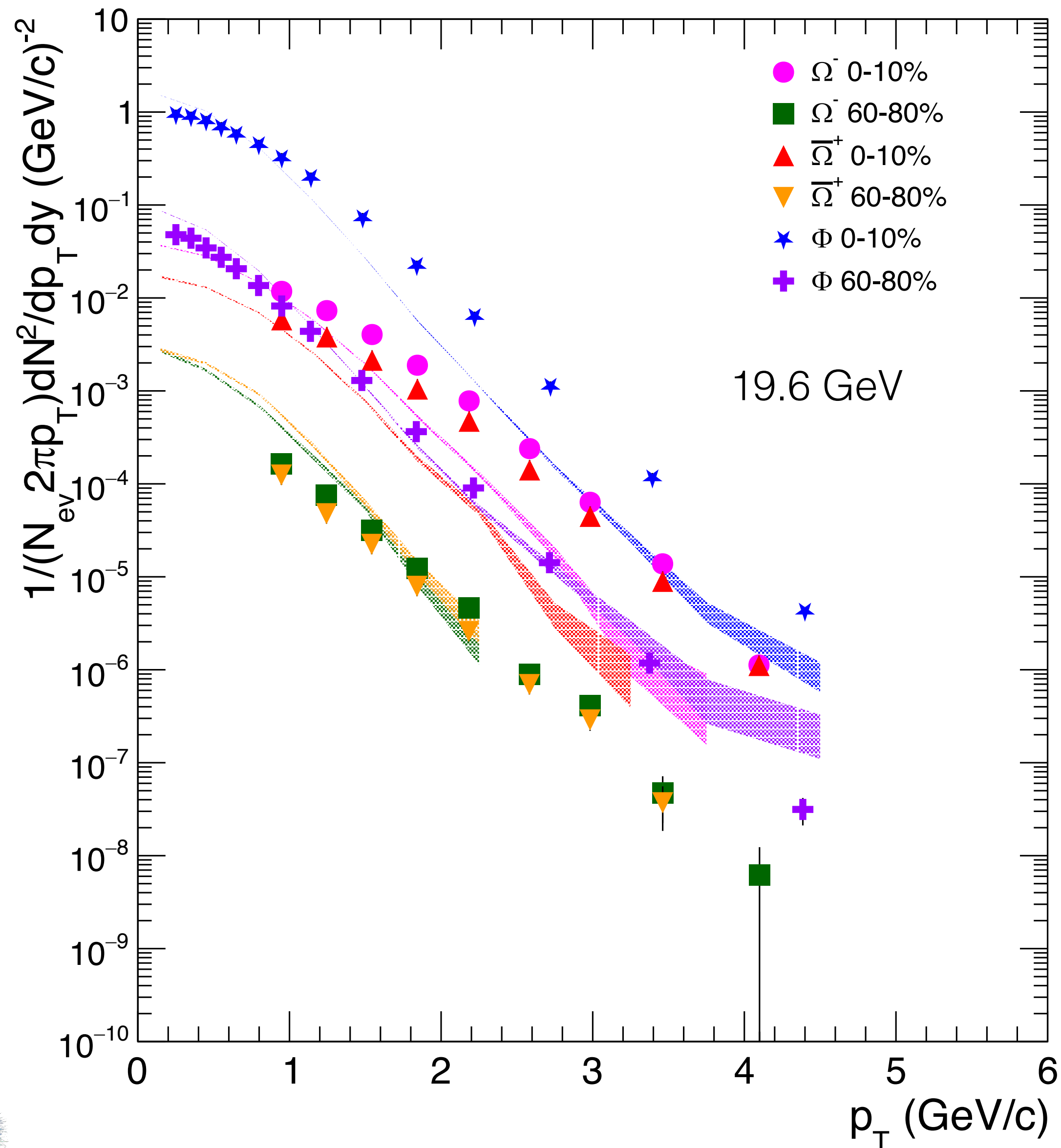
Original AMPT version : *Phys.Rev.C* 102 (2020) 1, 014906  
 AMPT with modified pslimit and BL parameter: *Phys.Rev.C* 96 (2017) 4, 044904



- Yield of  $K^+$  and  $K^-$  in AMPT model match better with data from BES-I
- AMPT model with the modified pslimit and BL parameter is used to calculate the final yields of  $\Omega$  and  $\phi$ .

# Model Calculation: UrQMD

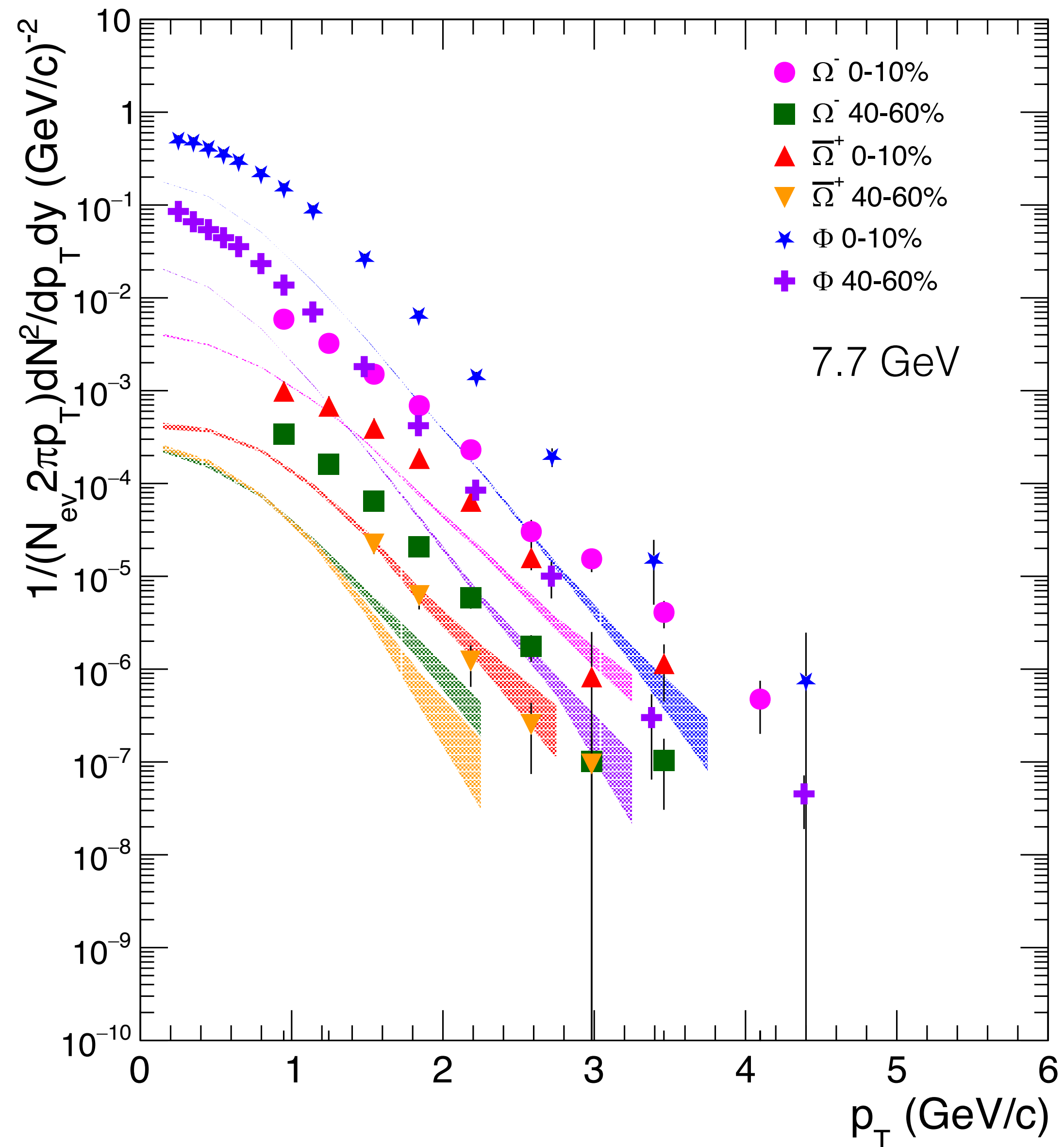
UrQMD: J.Phys.G 25 (1999) 1859-1896



- UrQMD model calculation (Band) at 19.6 GeV
- Generally consistent with experimental data at low  $p_T$  in central collisions
- Fail in peripheral
  - Over-estimate at low  $p_T$
  - Under-estimate at high  $p_T$
  - $\bar{\Omega}$  production higher than  $\Omega$

# Model Calculation: UrQMD

UrQMD: J.Phys.G 25 (1999) 1859-1896



- UrQMD model calculation (Band) at 7.7 GeV
- Model significantly under-estimate production

