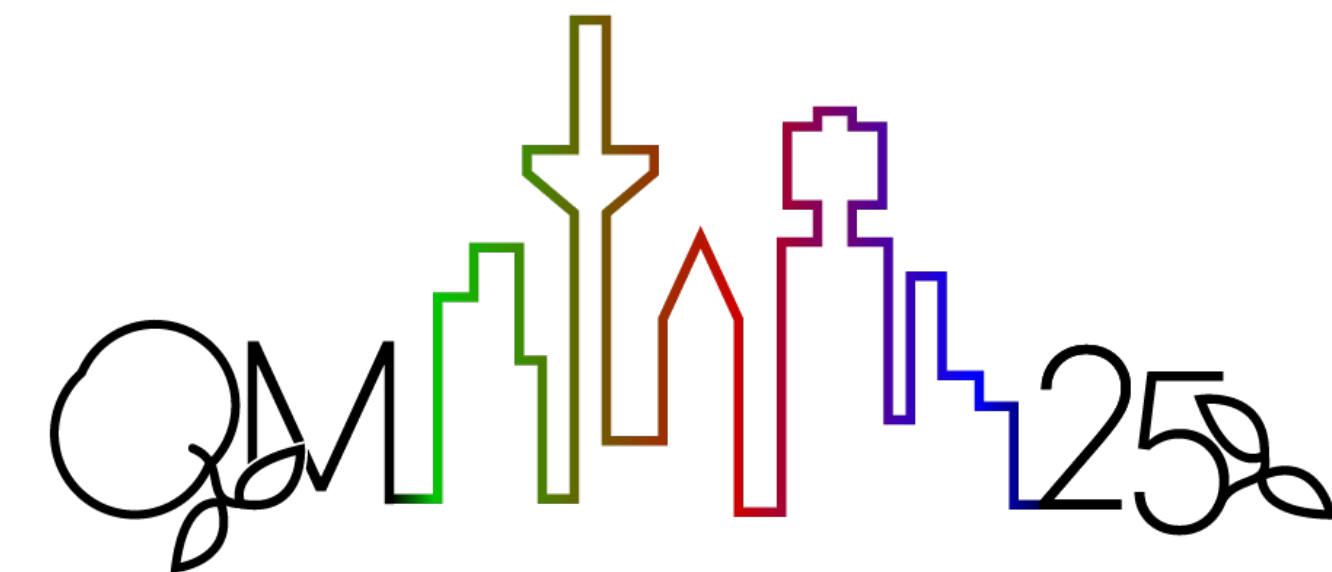




清华大学
Tsinghua University



Strangeness production in different collision systems and at different collision energies with the STAR experiment

*Weiguang Yuan (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 $\bar{B}/B$, ϕ/K , Ω/ϕ ratios
 - ✓ System size dependence of R_{CP} and Ω/π , Ω/ϕ ratios
- Summary

Supported in part by



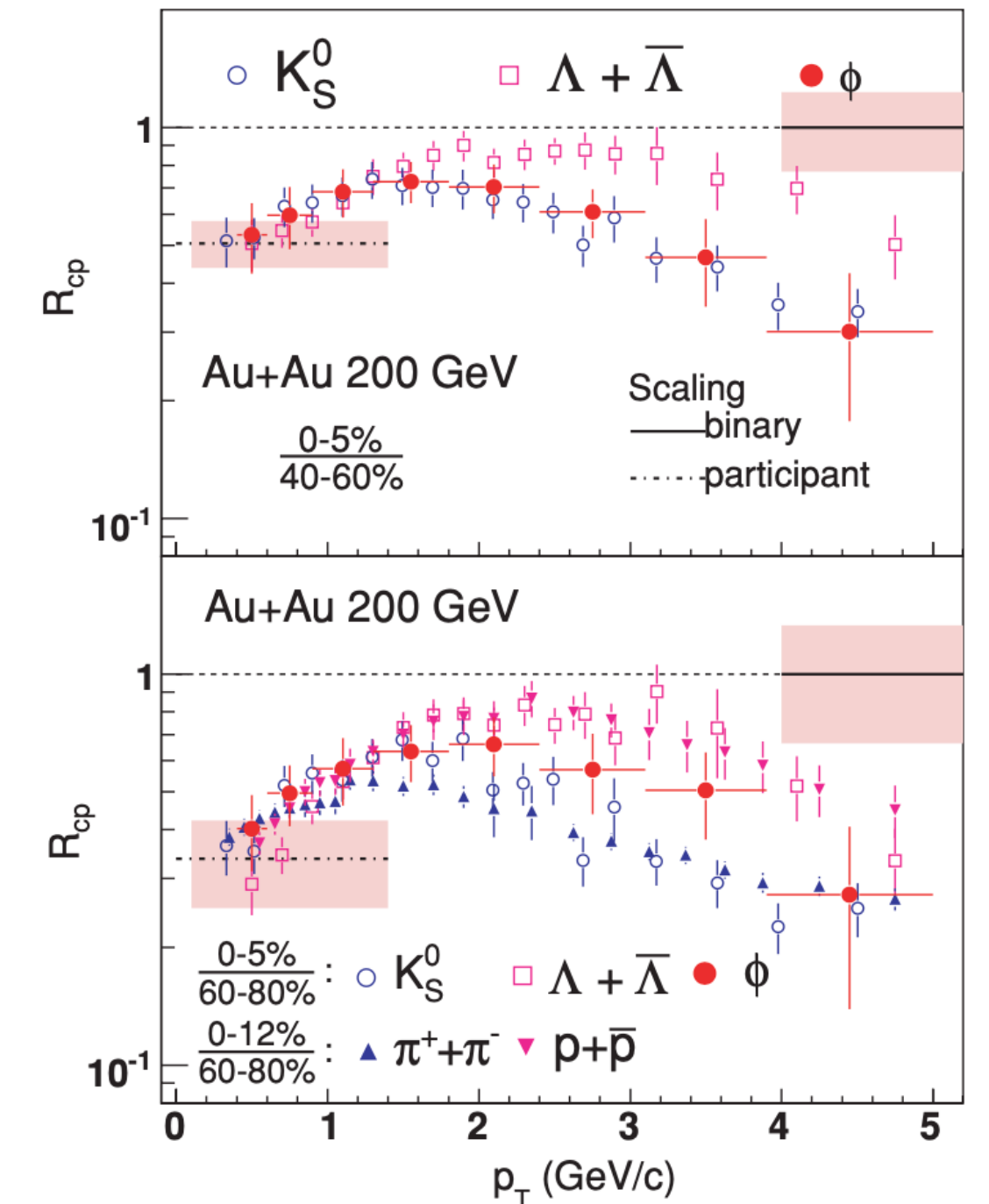
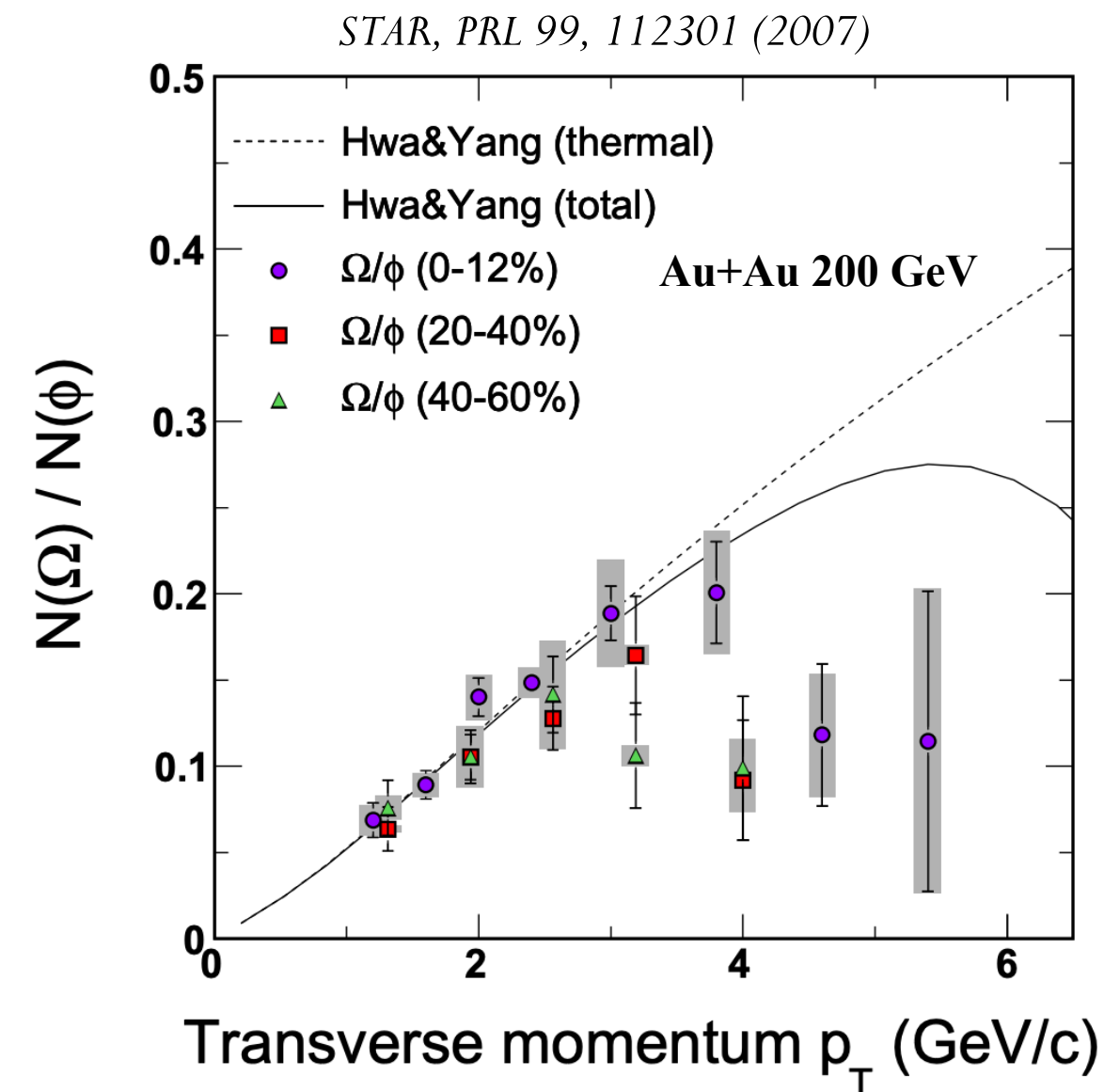
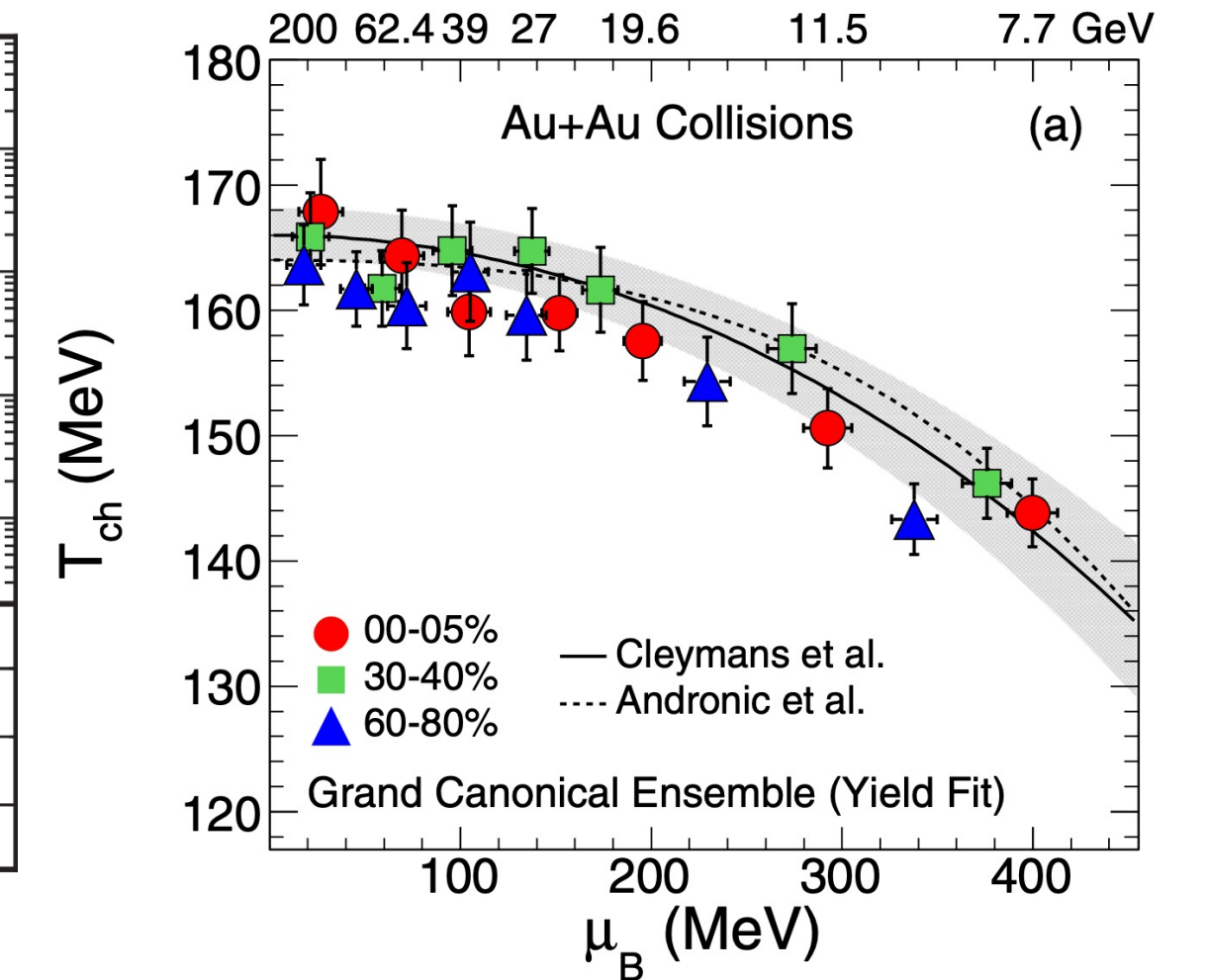
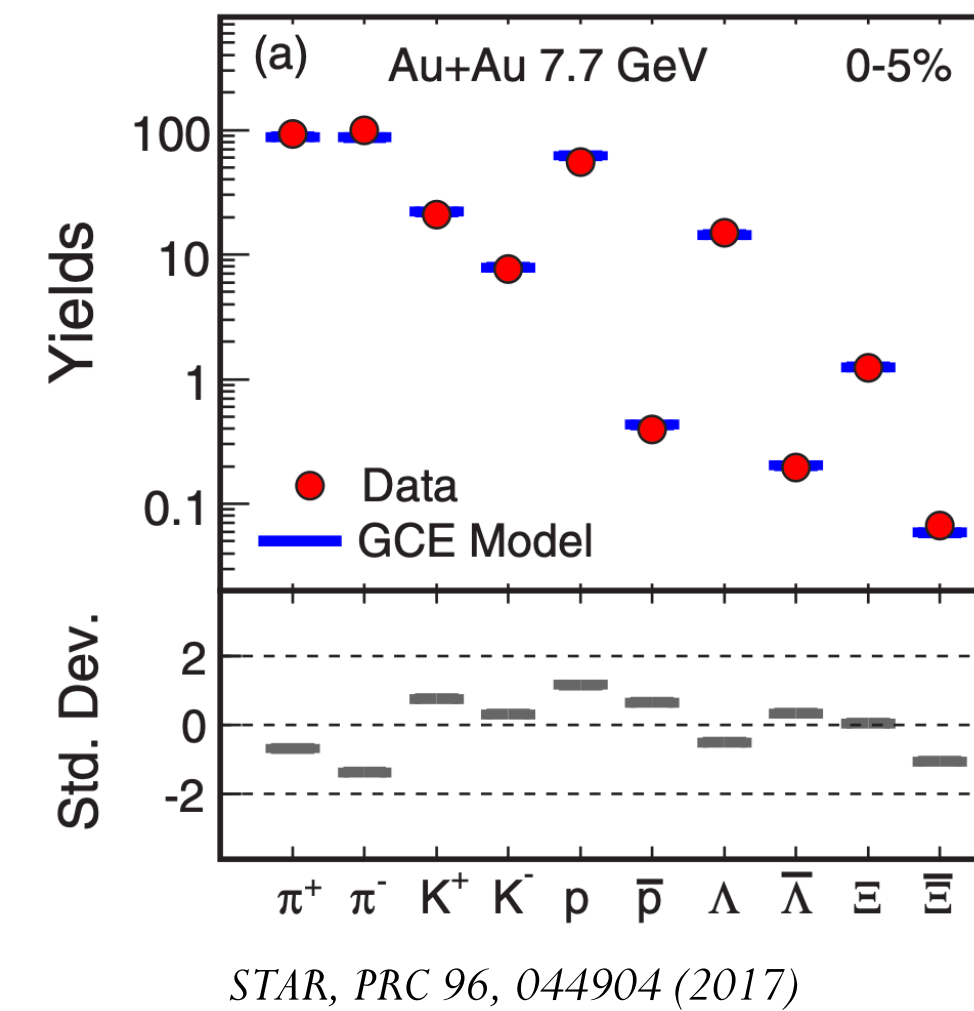
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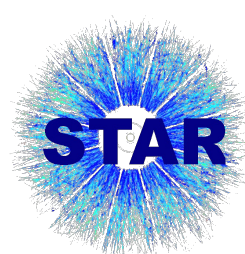


Strange hadrons as sensitive & versatile probes of HIC dynamics

- 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

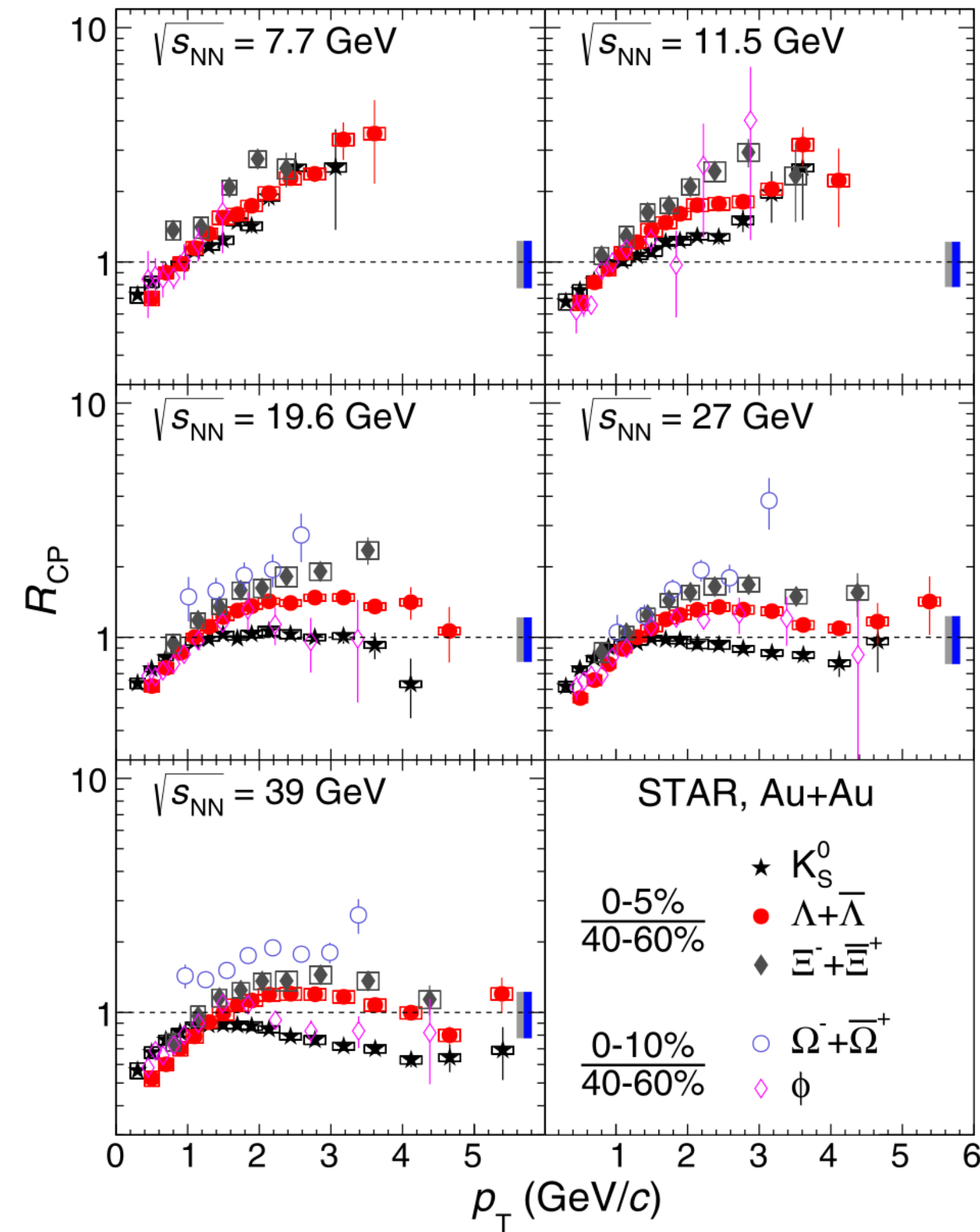


$$R_{CP} = \frac{[(dN/dp_T)/\langle N_{coll} \rangle]_{central}}{[(dN/dp_T)/\langle N_{coll} \rangle]_{peripheral}}$$

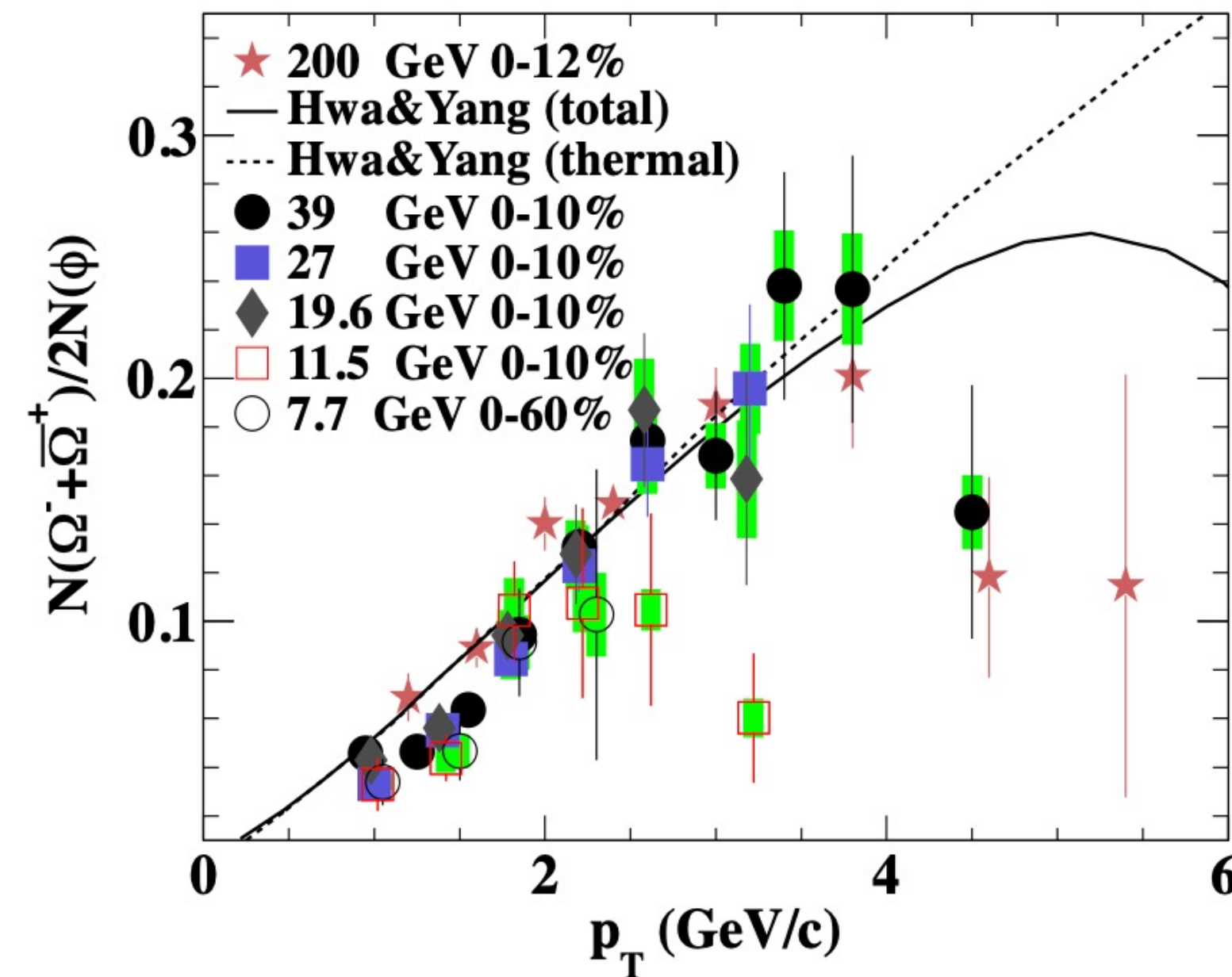


Energy dependence of strange hadron productions

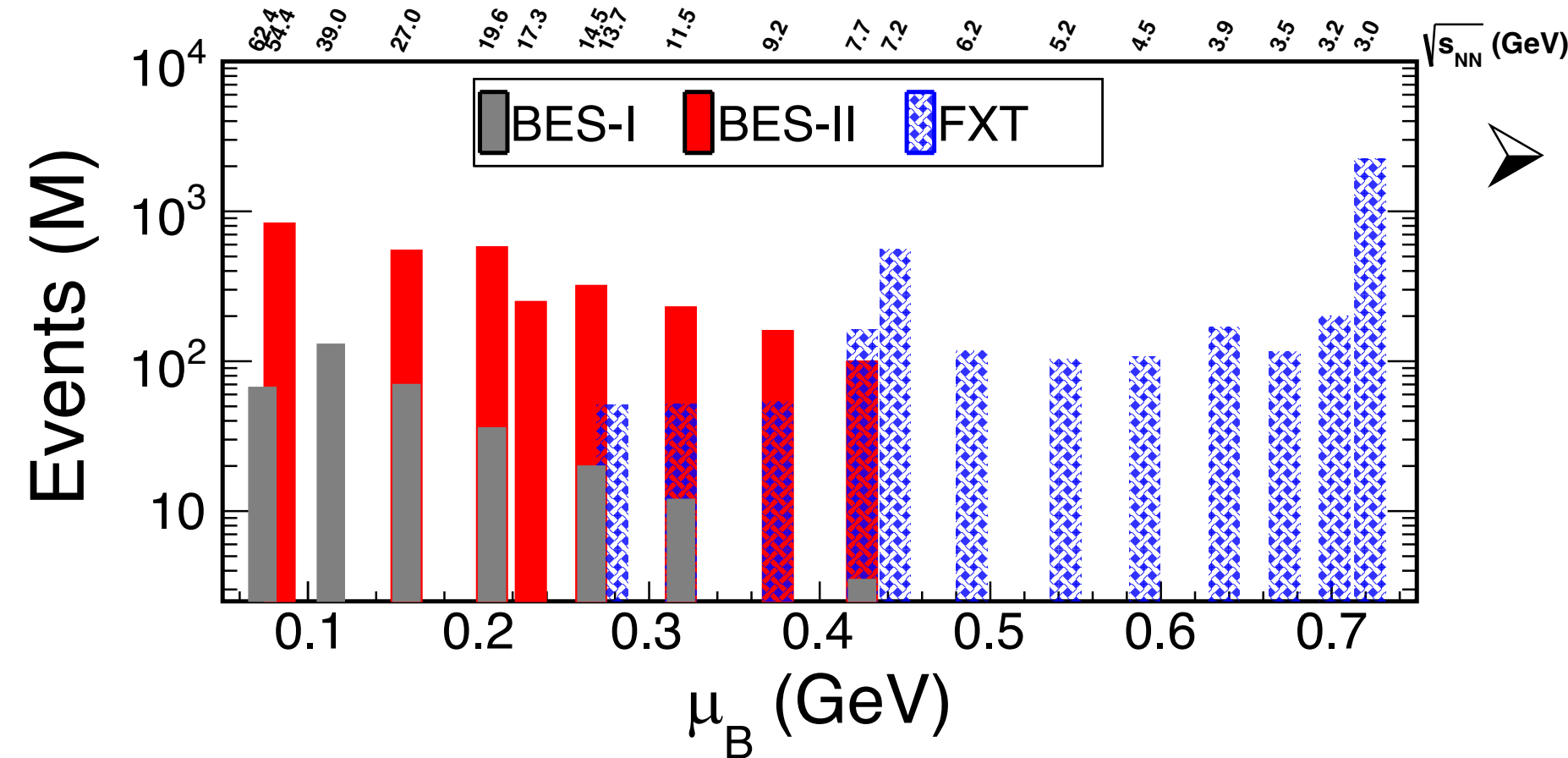
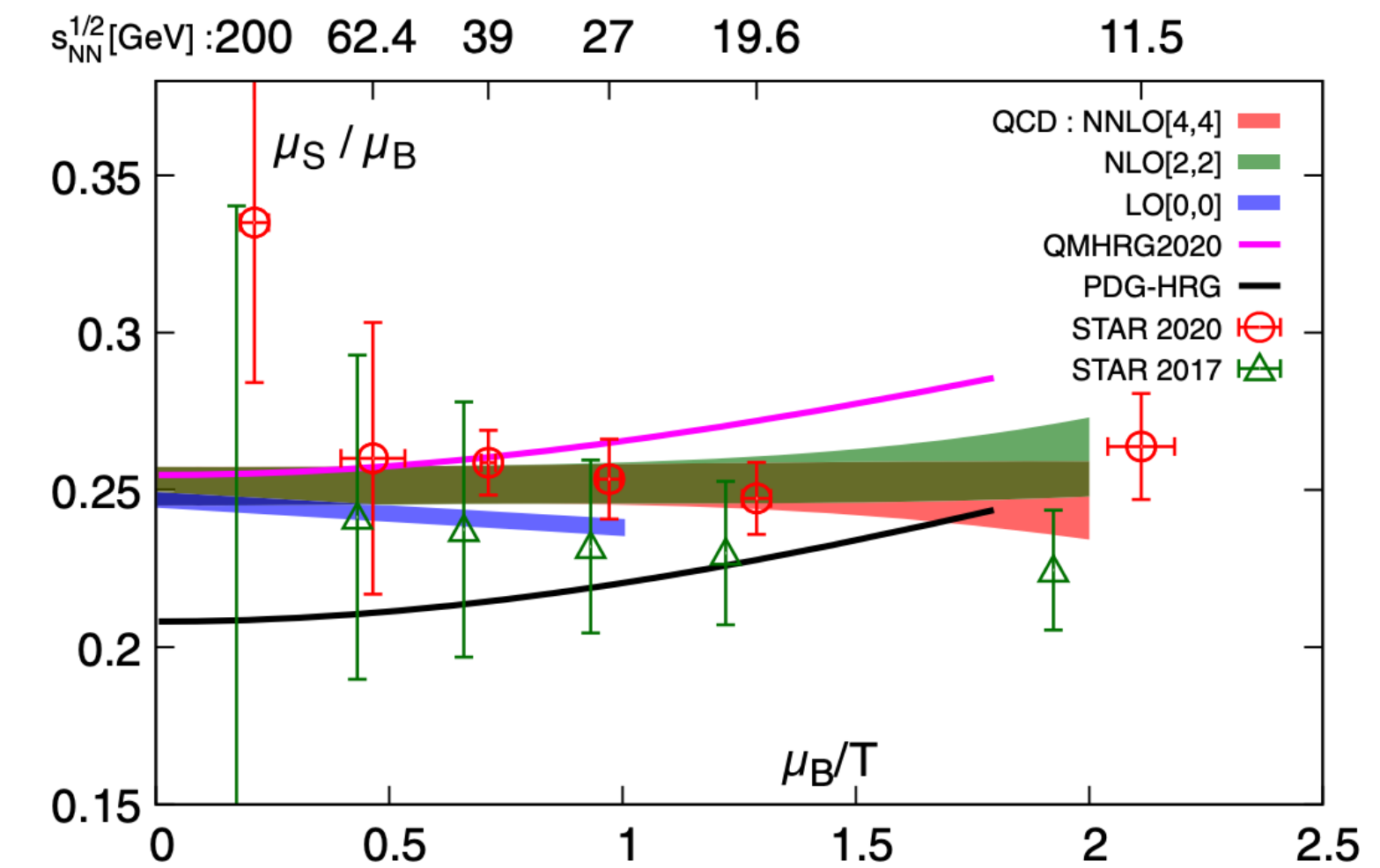
STAR, PRC 102, 034909 (2020)



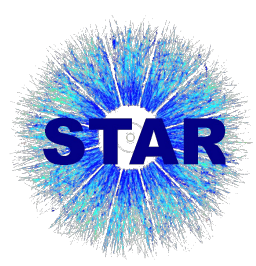
STAR, PRC 93, 021903 (2016)



Bollweg et al., PRD 110, 054519 (2024)



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



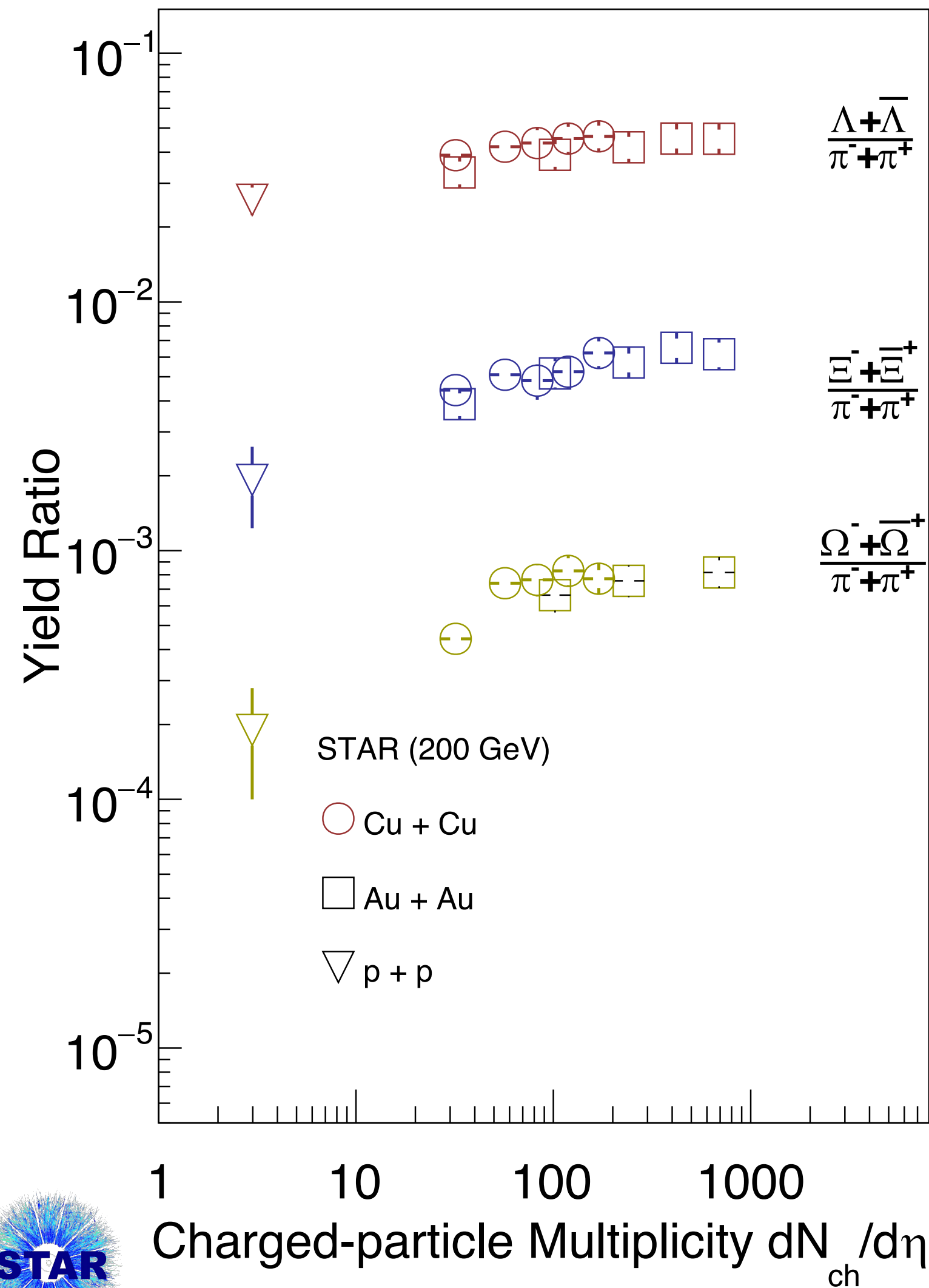
System size dependence of strange hadron productions

STAR : Phys. Rev. C 75, 064901 (2007)

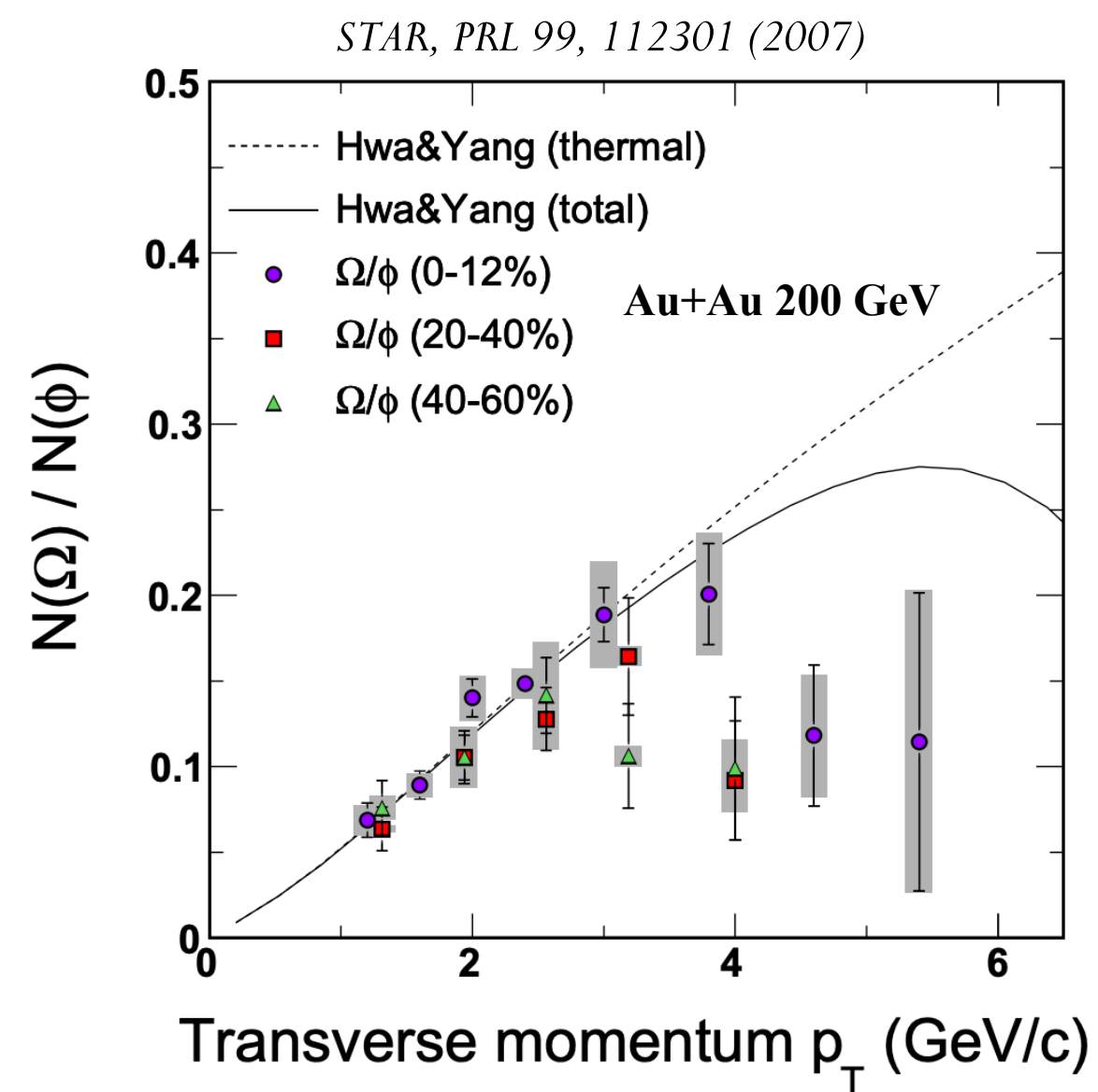
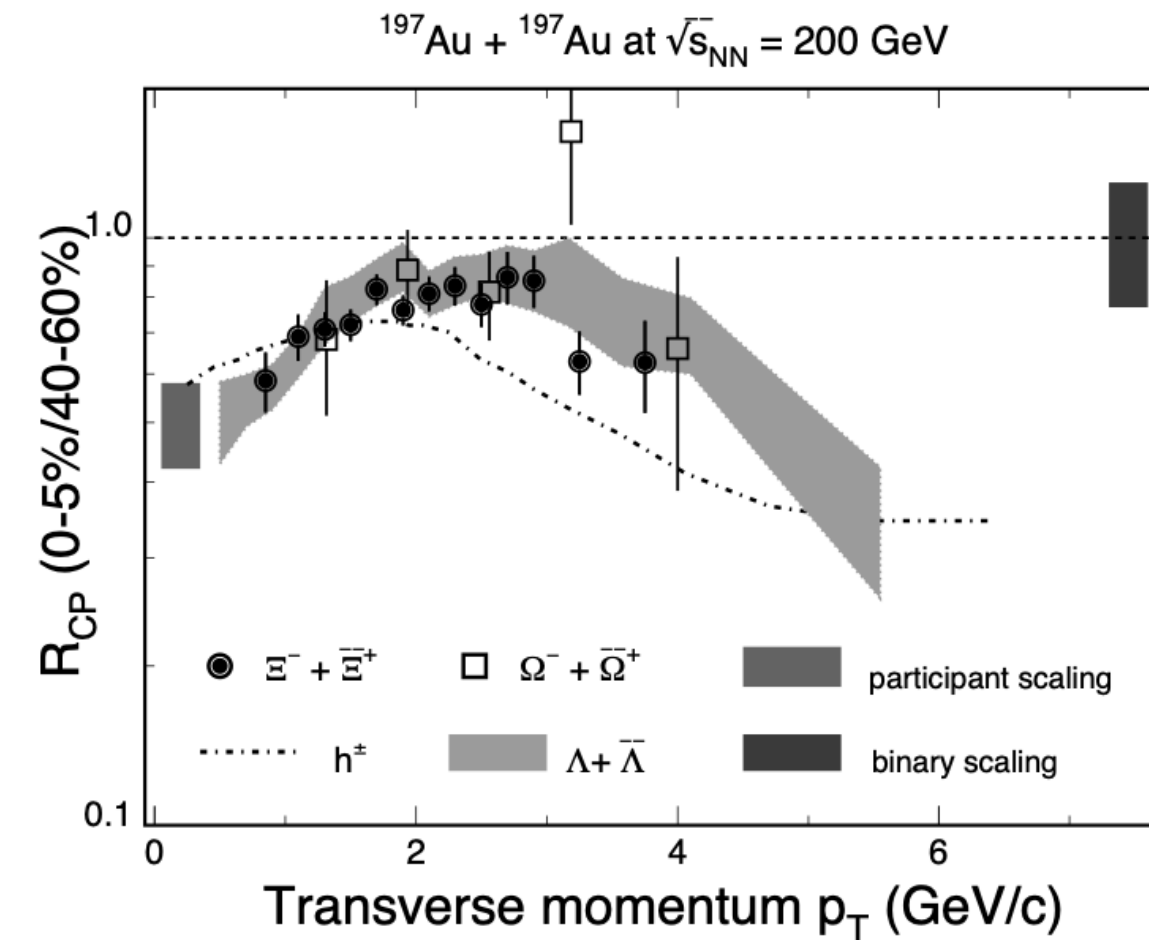
STAR : Phys. Rev. Lett. 108, 072301 (2012)

STAR : Phys. Rev. C 79, 034909 (2009)

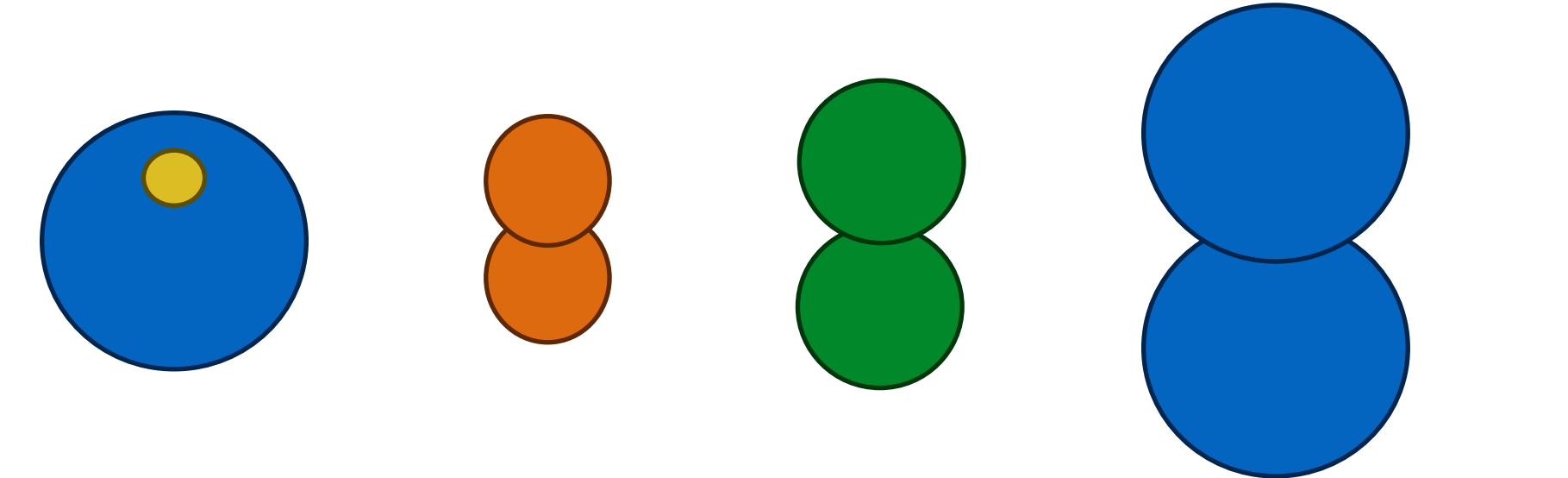
STAR : Phys. Rev. C 83, 034910 (2011)



STAR, Phys. Rev. Lett. 98, 062301 (2007)

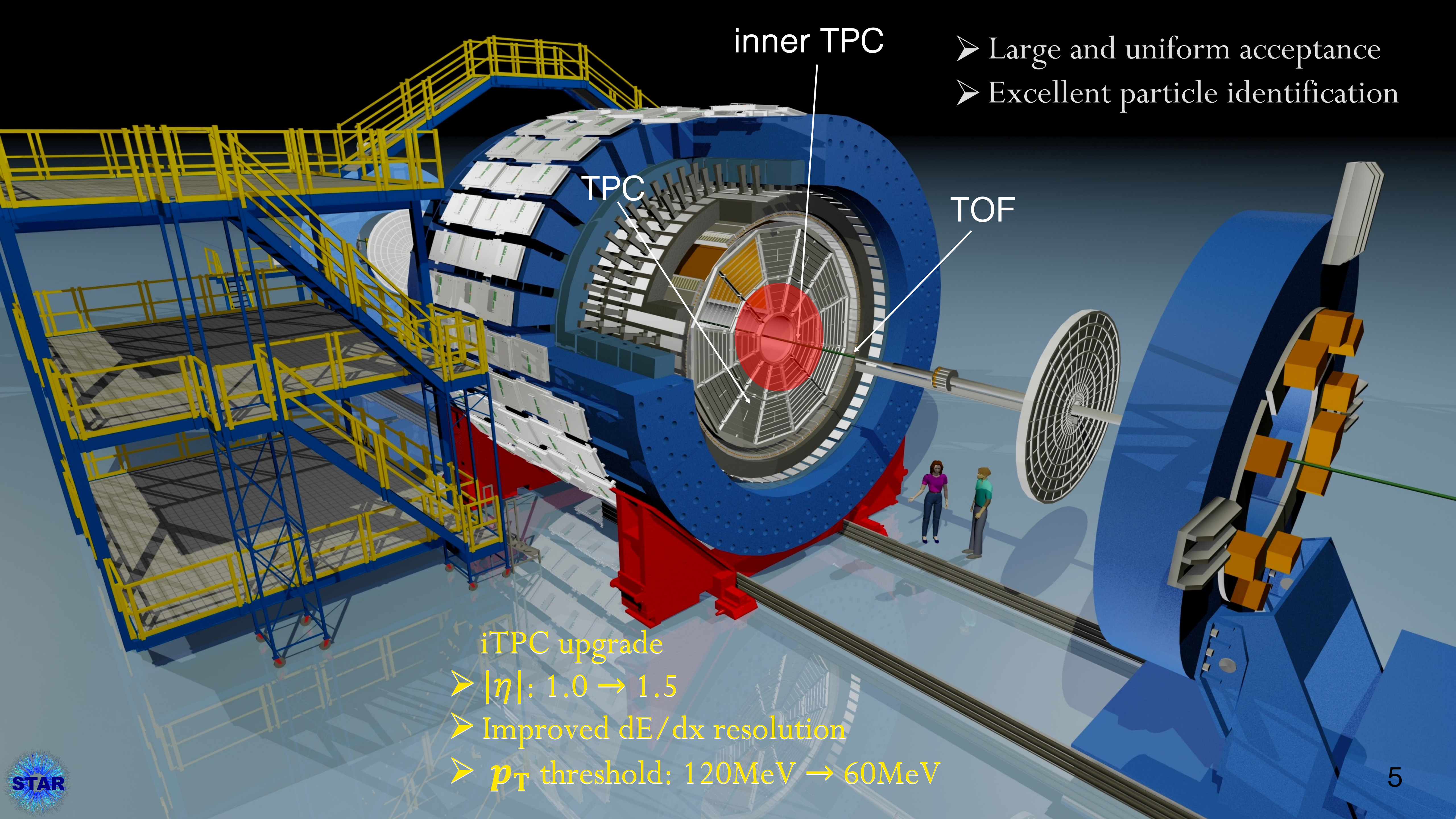


d + Au O+O isobar Au + Au



Increasing system size

- Further explore the evolution of dynamics with system size with precise strange hadron measurements in **isobar** and **O+O** collisions at 200 GeV



inner TPC

- Large and uniform acceptance
- Excellent particle identification

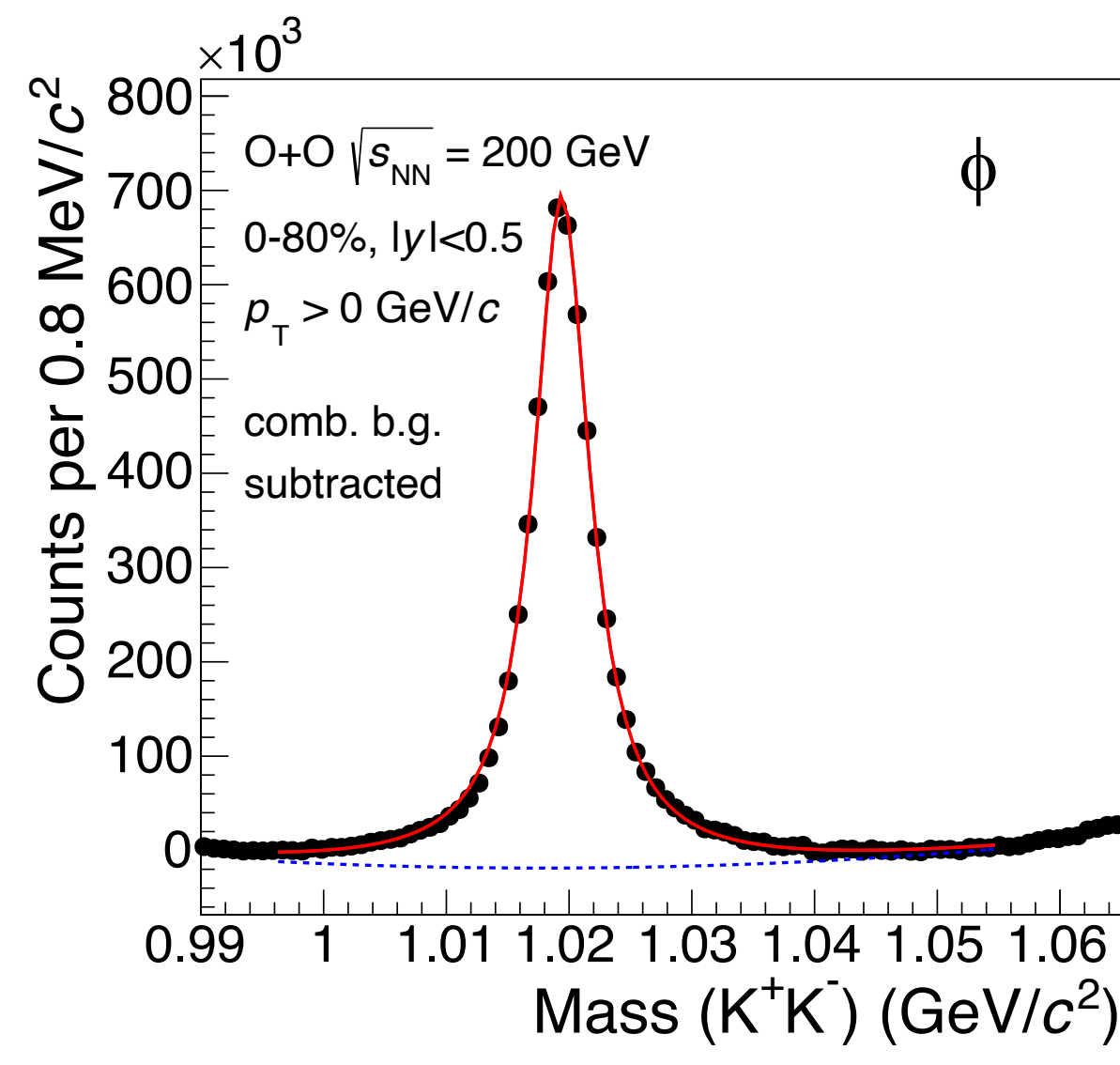
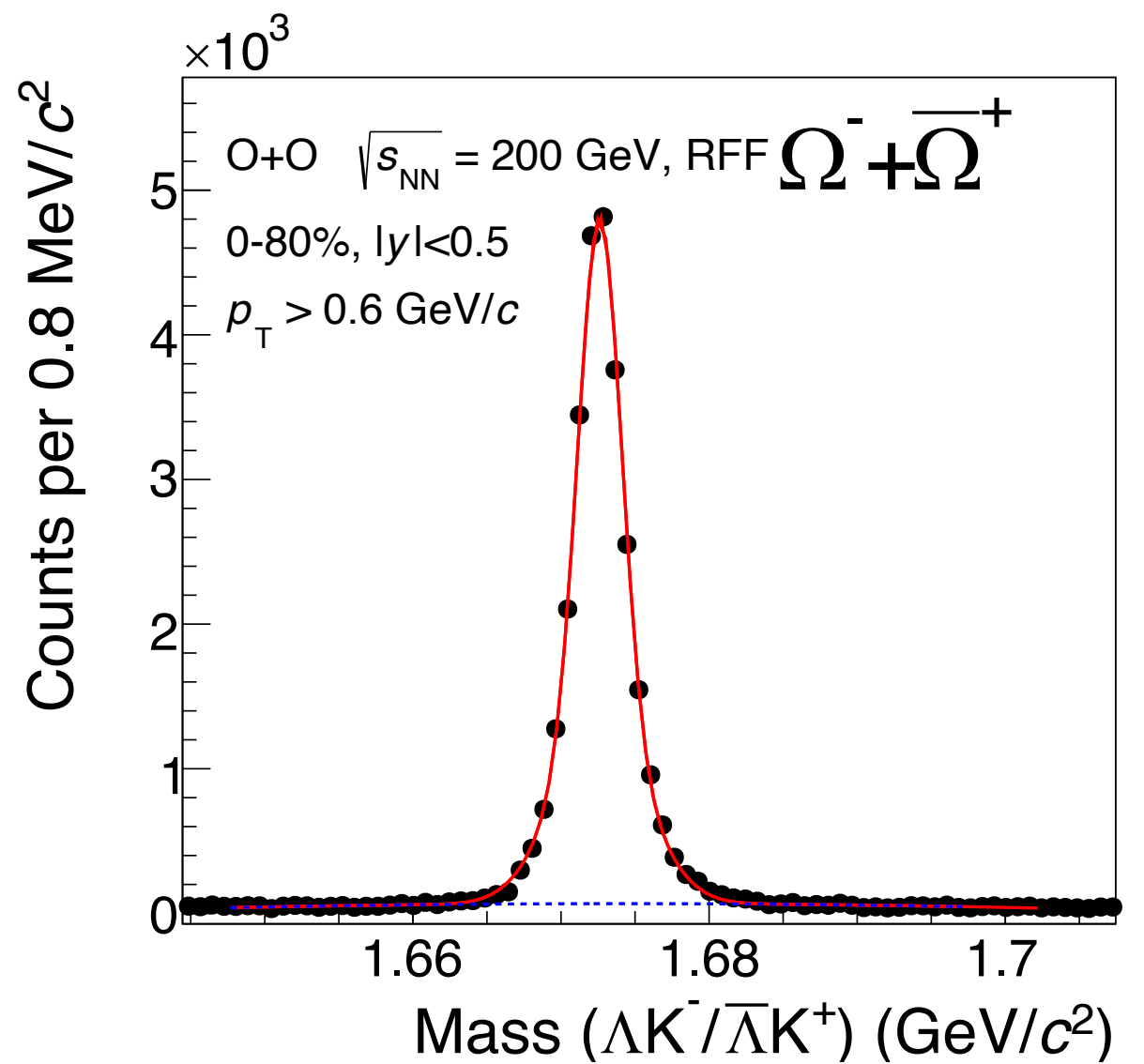
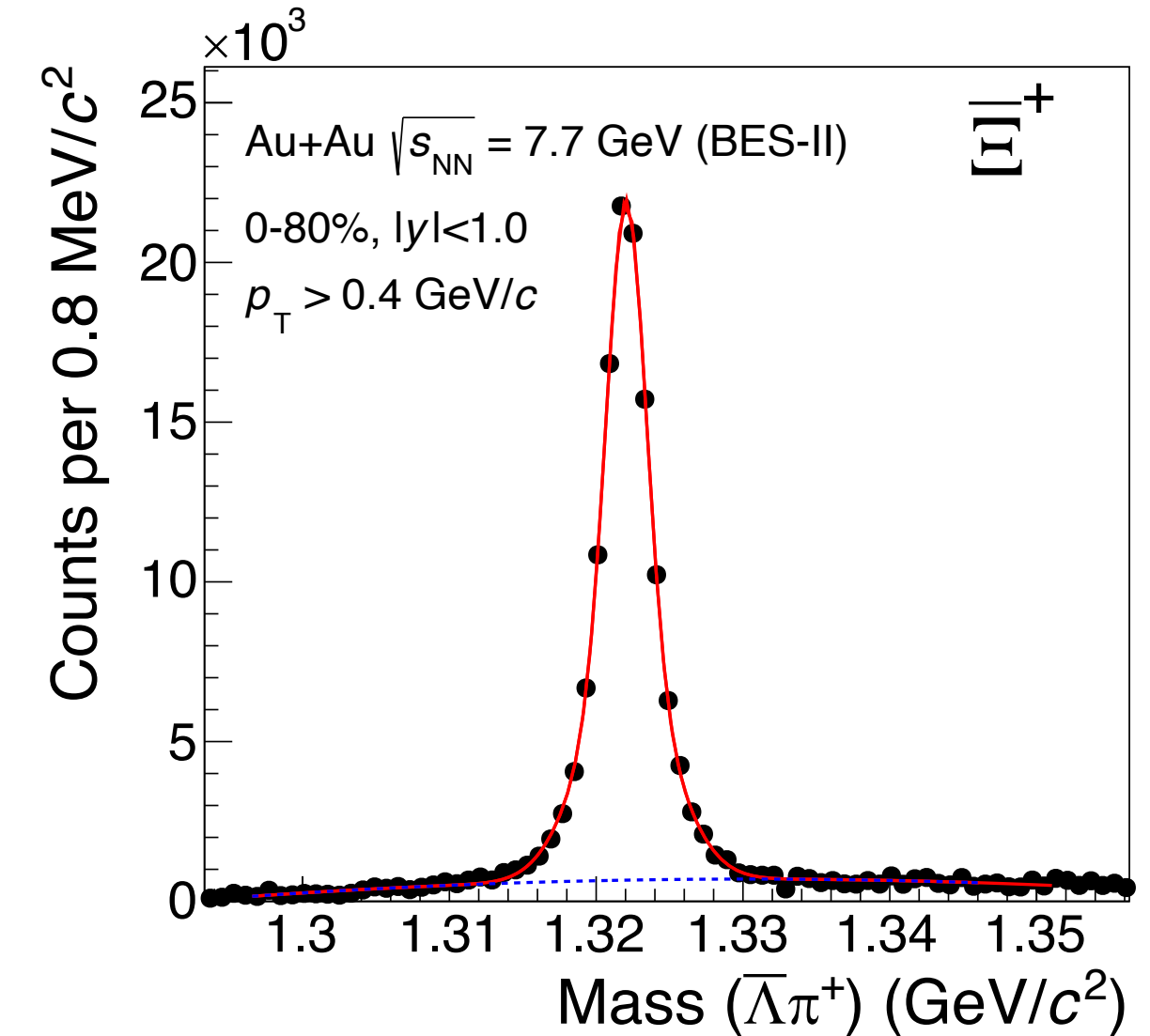
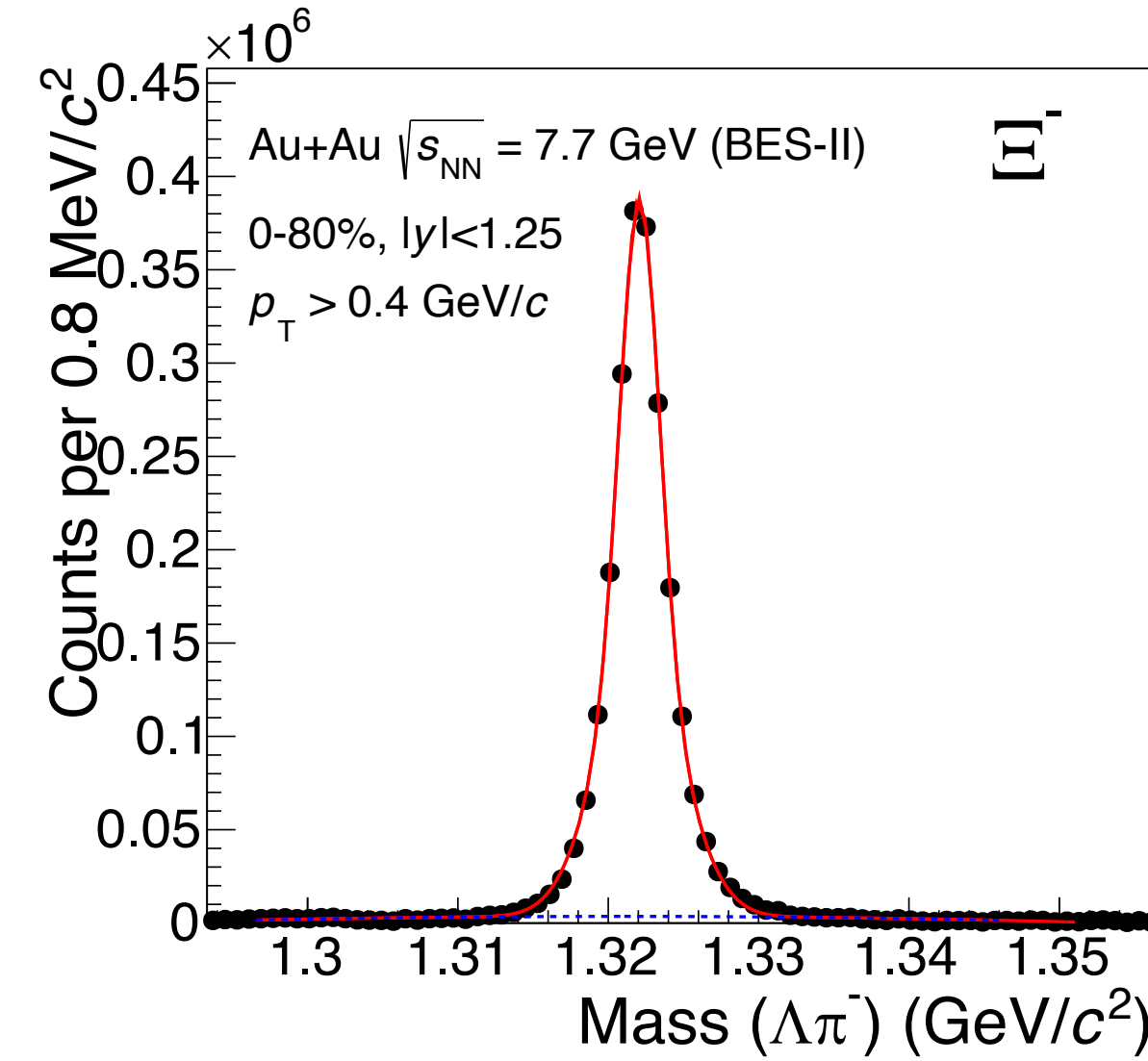
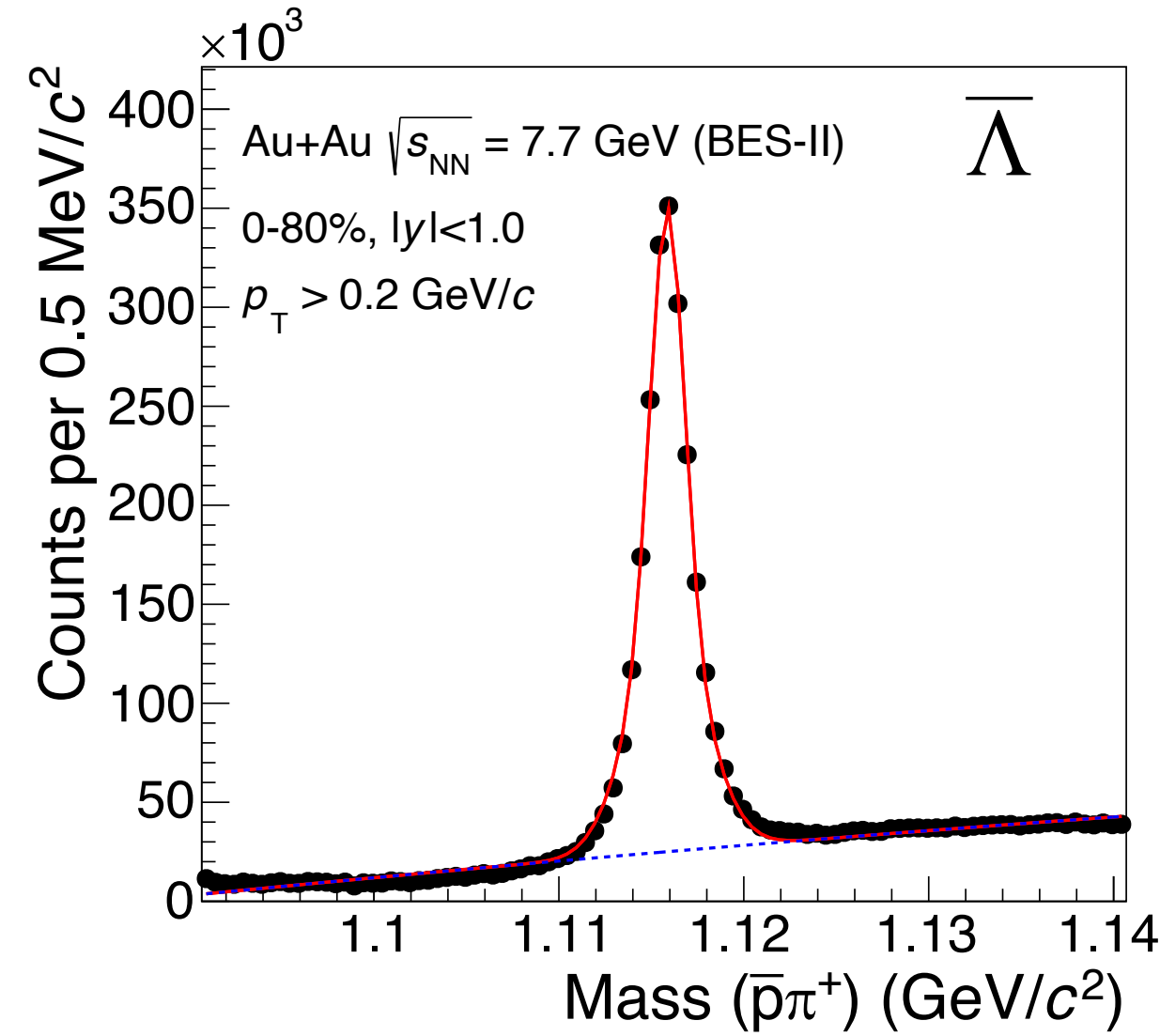
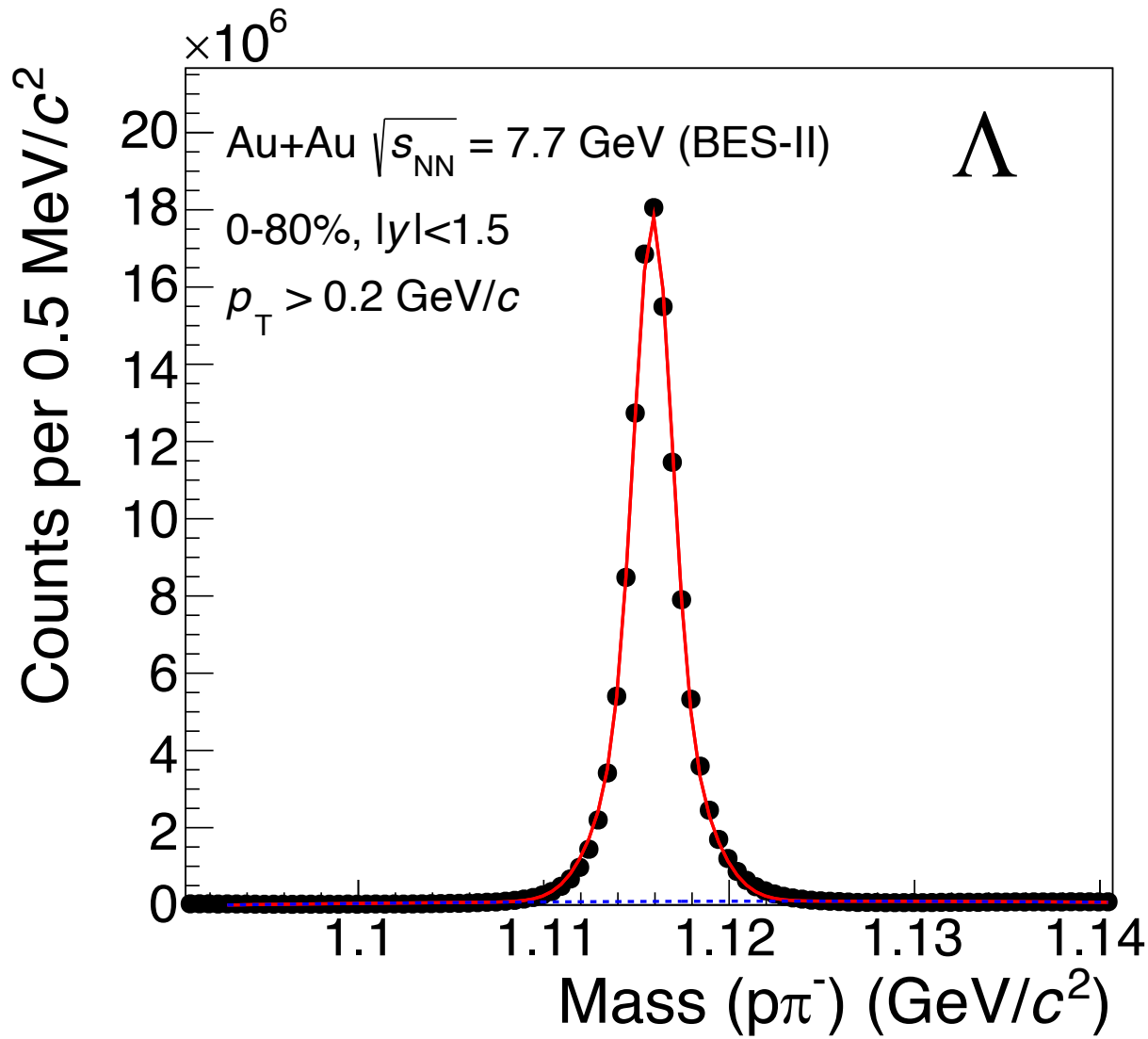
TPC

TOF

iTPC upgrade

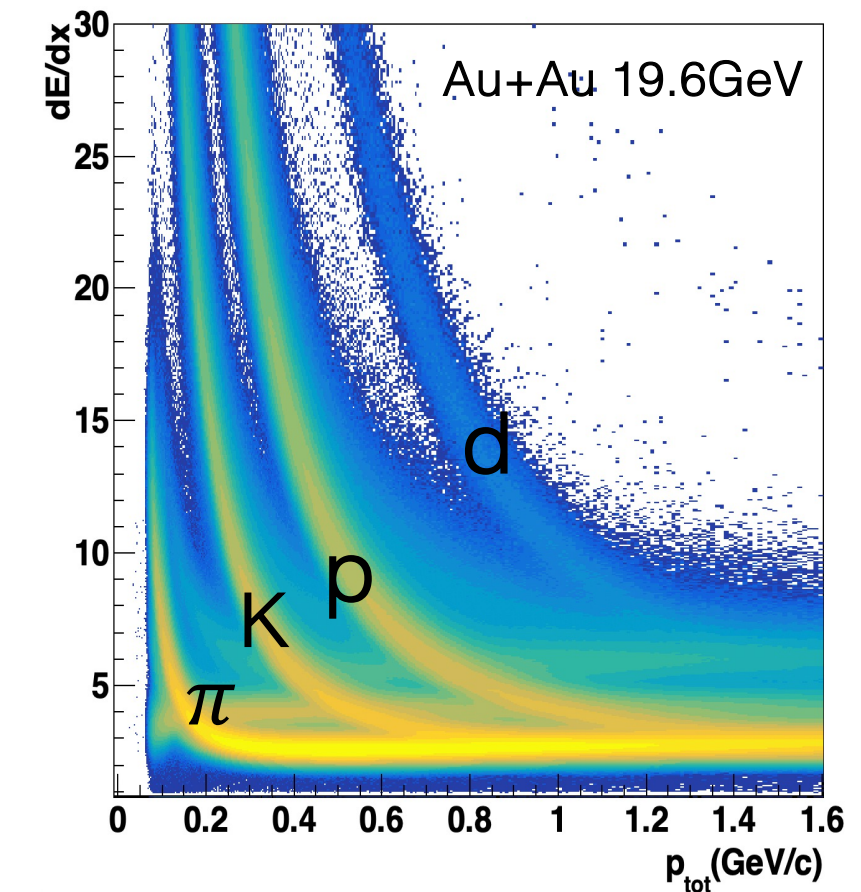
- $|\eta|: 1.0 \rightarrow 1.5$
- Improved dE/dx resolution
- p_T threshold: $120\text{MeV} \rightarrow 60\text{MeV}$

Particle identification and reconstruction

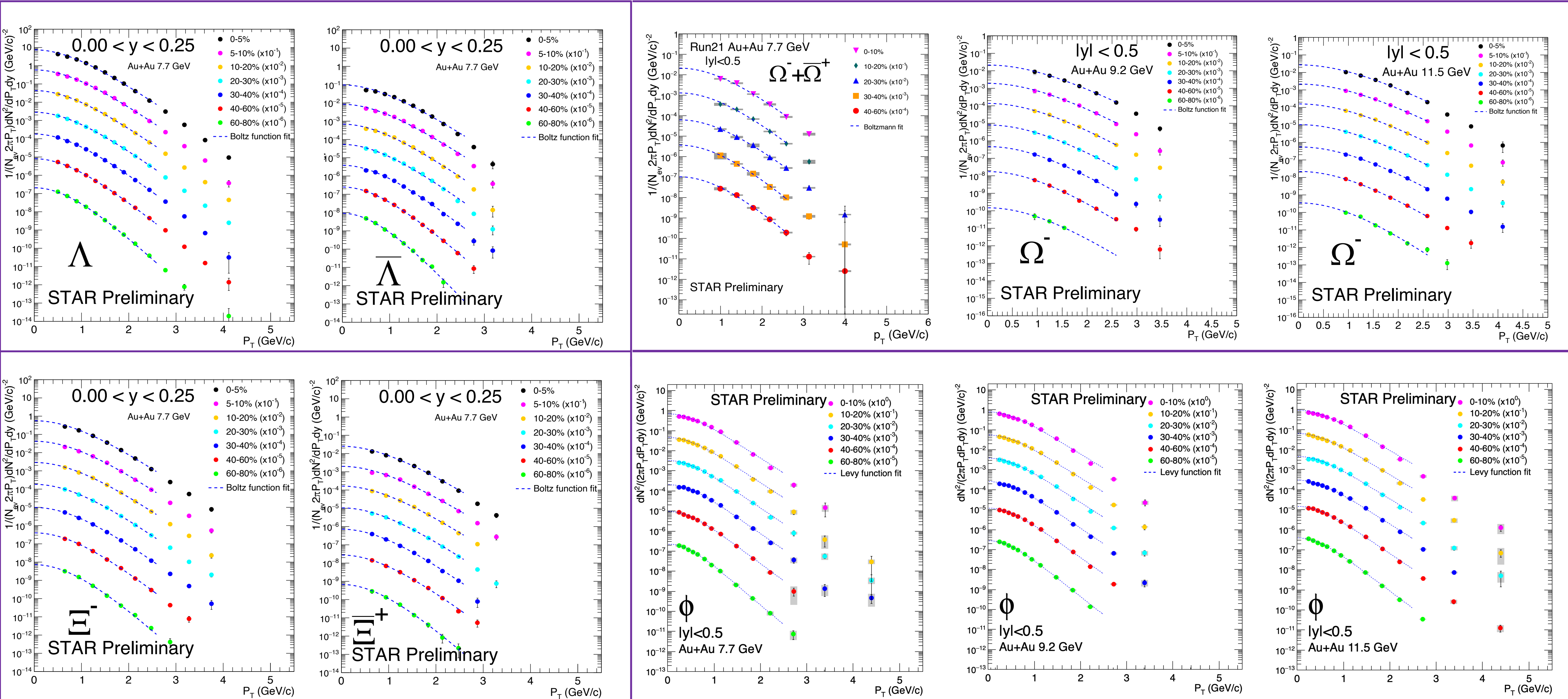


- Particle identification with dE/dx and TOF.
- $\pi, K, p \rightarrow$ reconstruct secondary vertex of strange particles.
- Large signal counts allow multi-differential measurements.

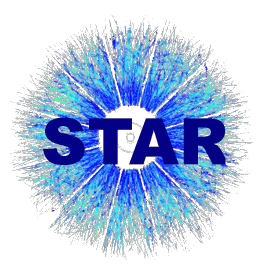
$$\begin{aligned} \Lambda(\bar{\Lambda}) &\rightarrow p(\bar{p}) + \pi^- (\pi^+) (\mathcal{B} = 63.9\%) \\ \Xi^- (\bar{\Xi}^+) &\rightarrow \Lambda(\bar{\Lambda}) + \pi^- (\pi^+) (\mathcal{B} = 99.9\%) \\ \Omega^- (\bar{\Omega}^+) &\rightarrow \Lambda(\bar{\Lambda}) + K^- (K^+) (\mathcal{B} = 67.8\%) \\ \phi &\rightarrow K^+ + K^- (\mathcal{B} = 49.1\%) \end{aligned}$$



p_T Spectra for Λ , Ξ , ϕ and Ω (BESII)



- Ξ , Ω and Λ low p_T extrapolation: Boltzmann function.
- ϕ low p_T extrapolation: Levy function.



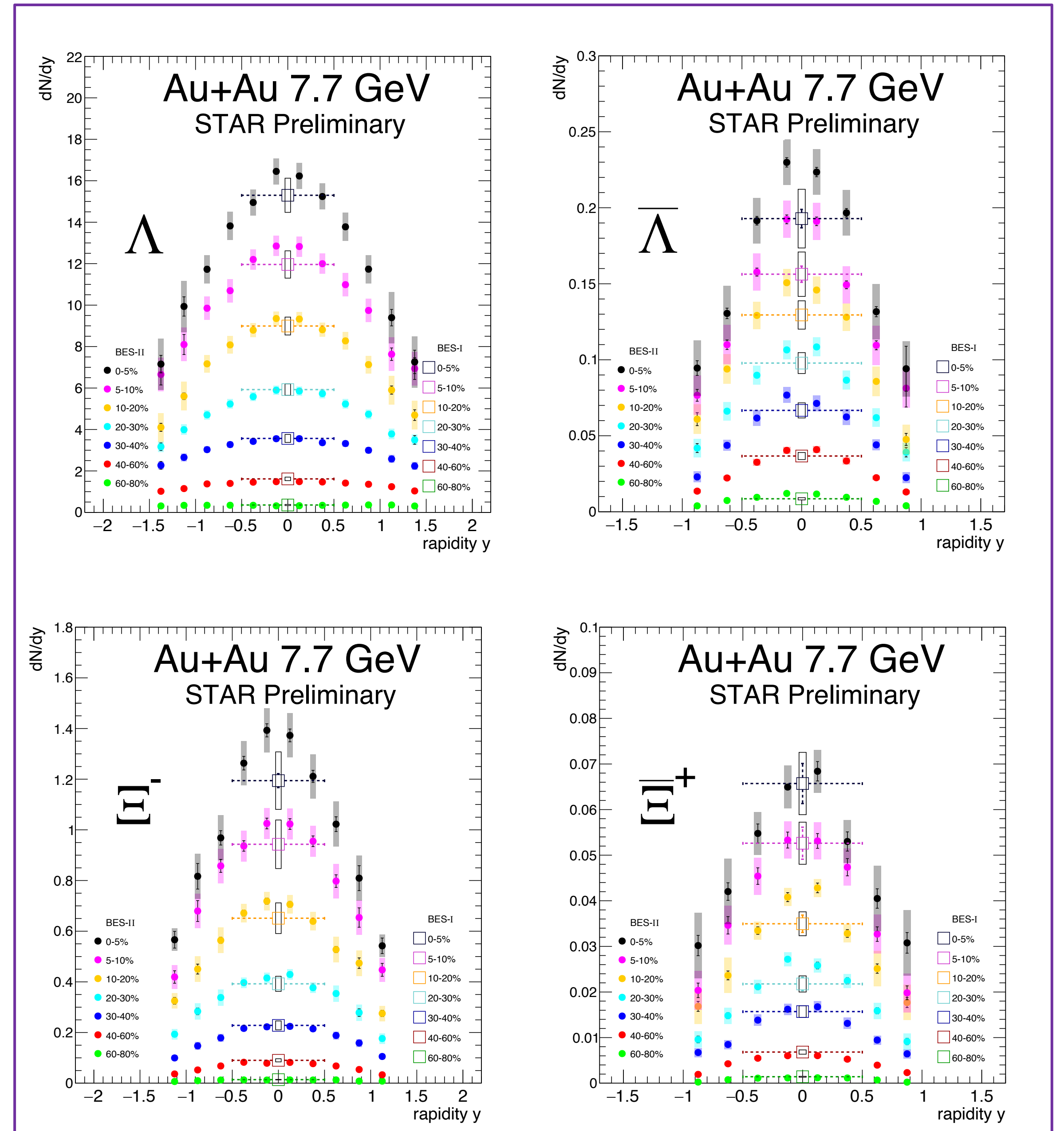
Rapidity spectra of $\Lambda(\bar{\Lambda})$ and $\Xi^-(\bar{\Xi}^+)$ at 7.7 GeV

➤ Rapidity distributions of Λ baryon are wider than those of $\bar{\Lambda}$ baryon.

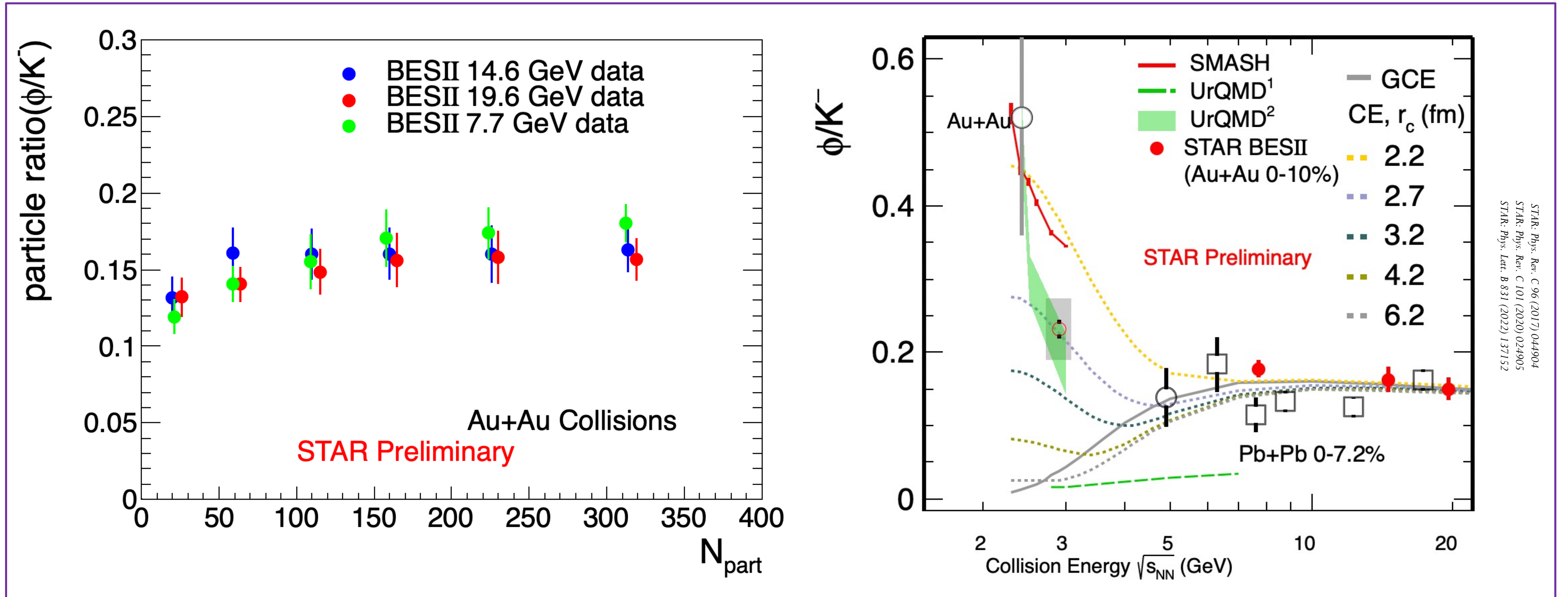
➤ The rapidity distributions of Ξ^- baryon are slightly wider than that of $\bar{\Xi}^+$ anti-baryons.

➤ Similar trends observed by NA49.

NA49, PRC 78, 034918 (2008)

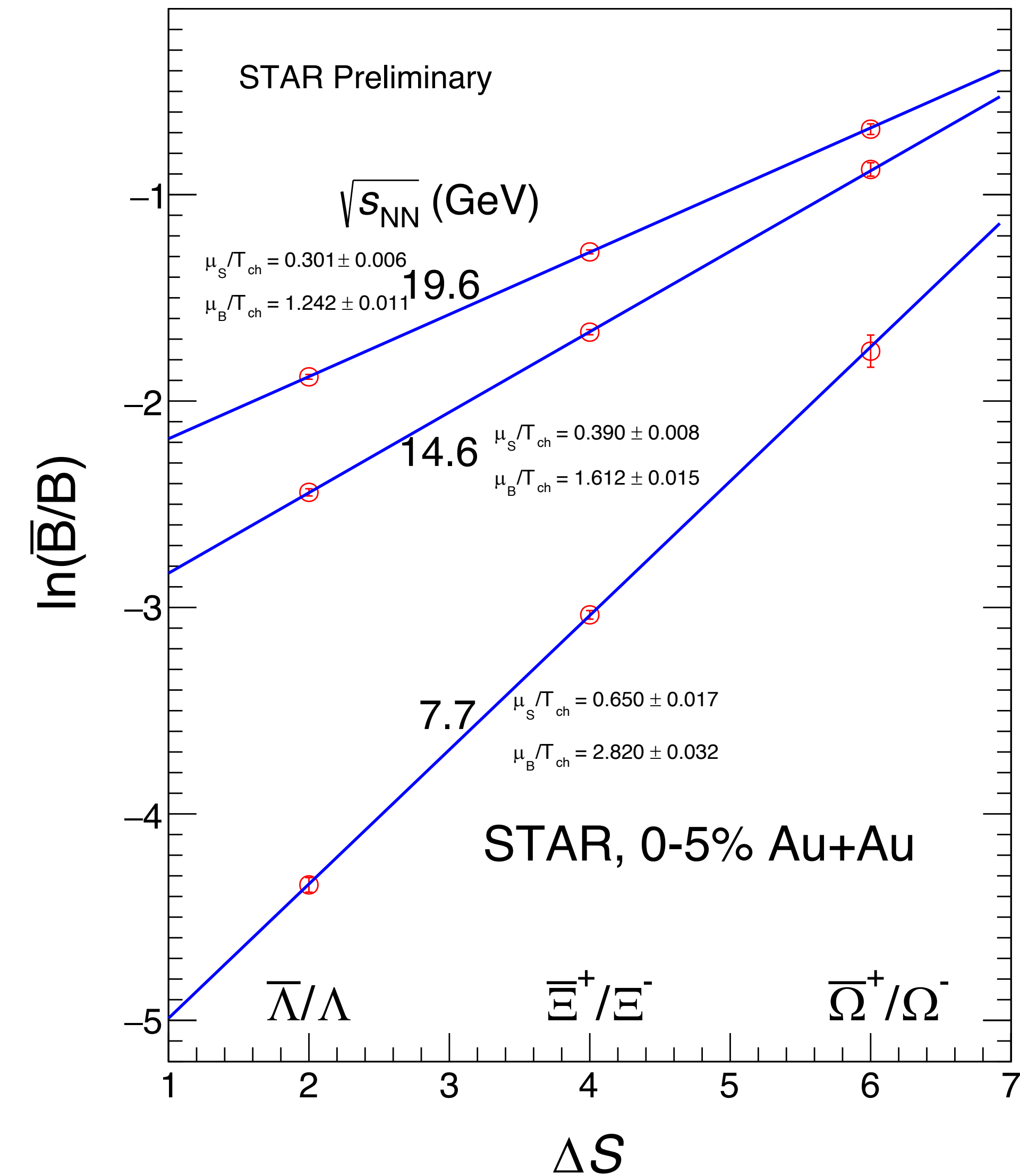


Centrality and Energy dependence of ϕ/K^- ratio

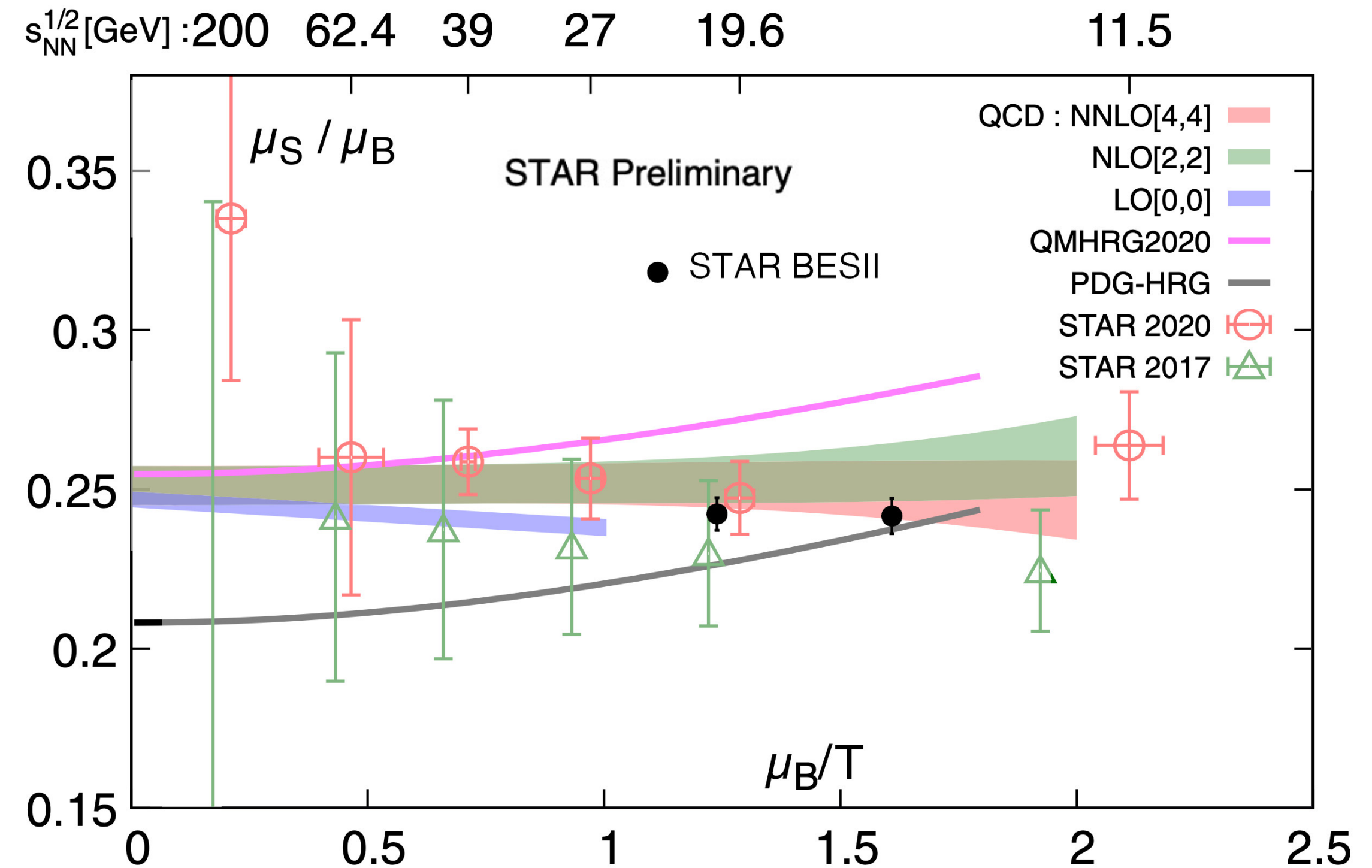


- The ϕ/K^- ratio exhibits no clear dependence on centrality or energy across the range of $\sqrt{s_{NN}} = 7.7$ to 19.6 GeV.
- The ϕ/K^- ratio reaches the GCE limit at $\sqrt{s_{NN}} = 7.7$, 14.6 and 19.6 GeV.

Anti-baryon to baryon ratios

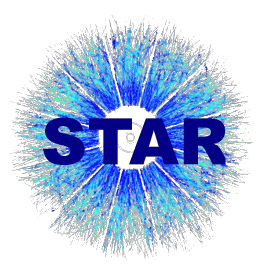


Thermal model prediction: $\ln(\bar{B}/B) = -2\mu_B/T_{ch} + \mu_S/T_{ch}\Delta S$,



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

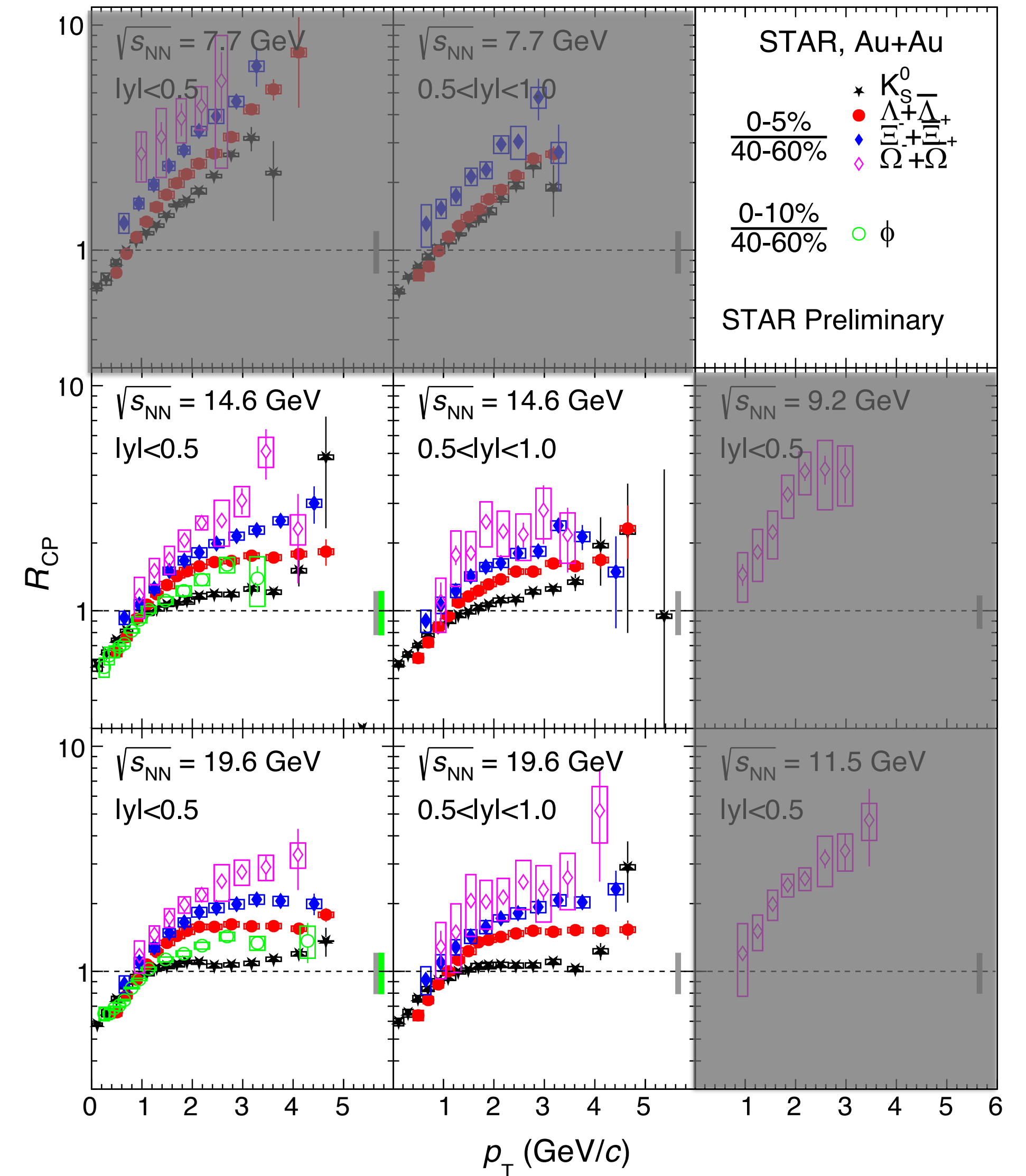
- Results from thermal model fits are in good agreement with lattice QCD calculation results.
- Precise extraction of μ_B/T_{ch} and μ_S/T_{ch} from BES-II data.



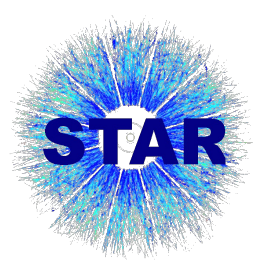
Nuclear modification factor (R_{CP}) for strange hadrons

- $R_{\text{CP}} = 1$ if nucleus-nucleus collisions are just simple superpositions of nucleon-nucleon collisions.
- R_{CP} tends to be flat and larger than unity at $p_{\text{T}} > 2 \text{ GeV}/c$ for energies $\sqrt{s_{\text{NN}}} \geq 14.6 \text{ GeV}$.

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



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

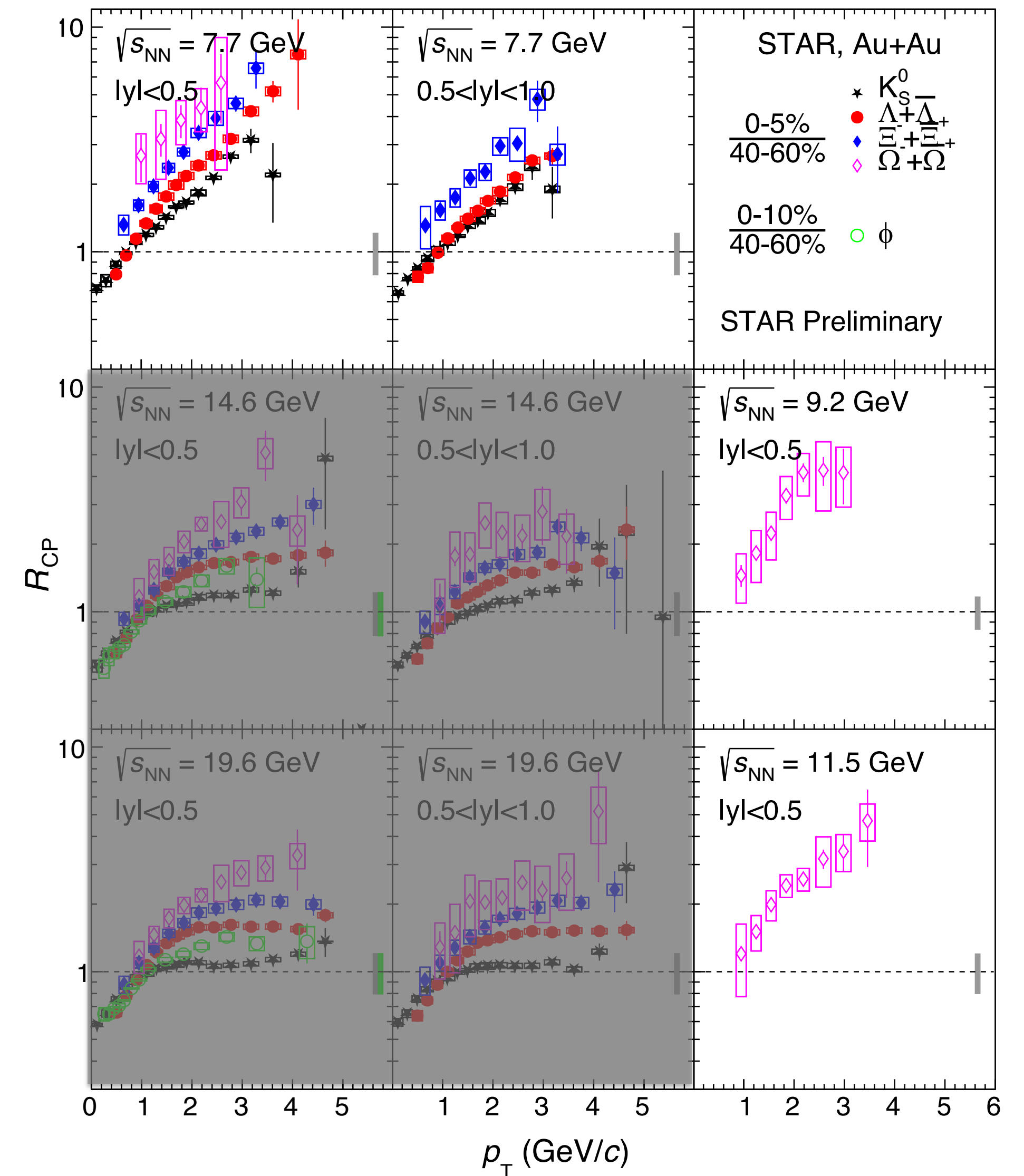


Nuclear modification factor (R_{CP}) for strange hadrons

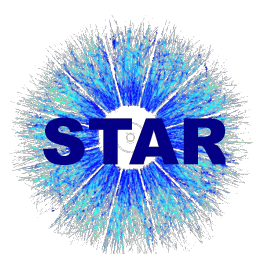
➤ $R_{\text{CP}} = 1$ if nucleus-nucleus collisions are just simple superpositions of nucleon-nucleon collisions.

➤ R_{CP} continues to increase beyond $p_{\text{T}} = 2$ GeV/c at $\sqrt{s_{\text{NN}}} \leq 11.5$ GeV.

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

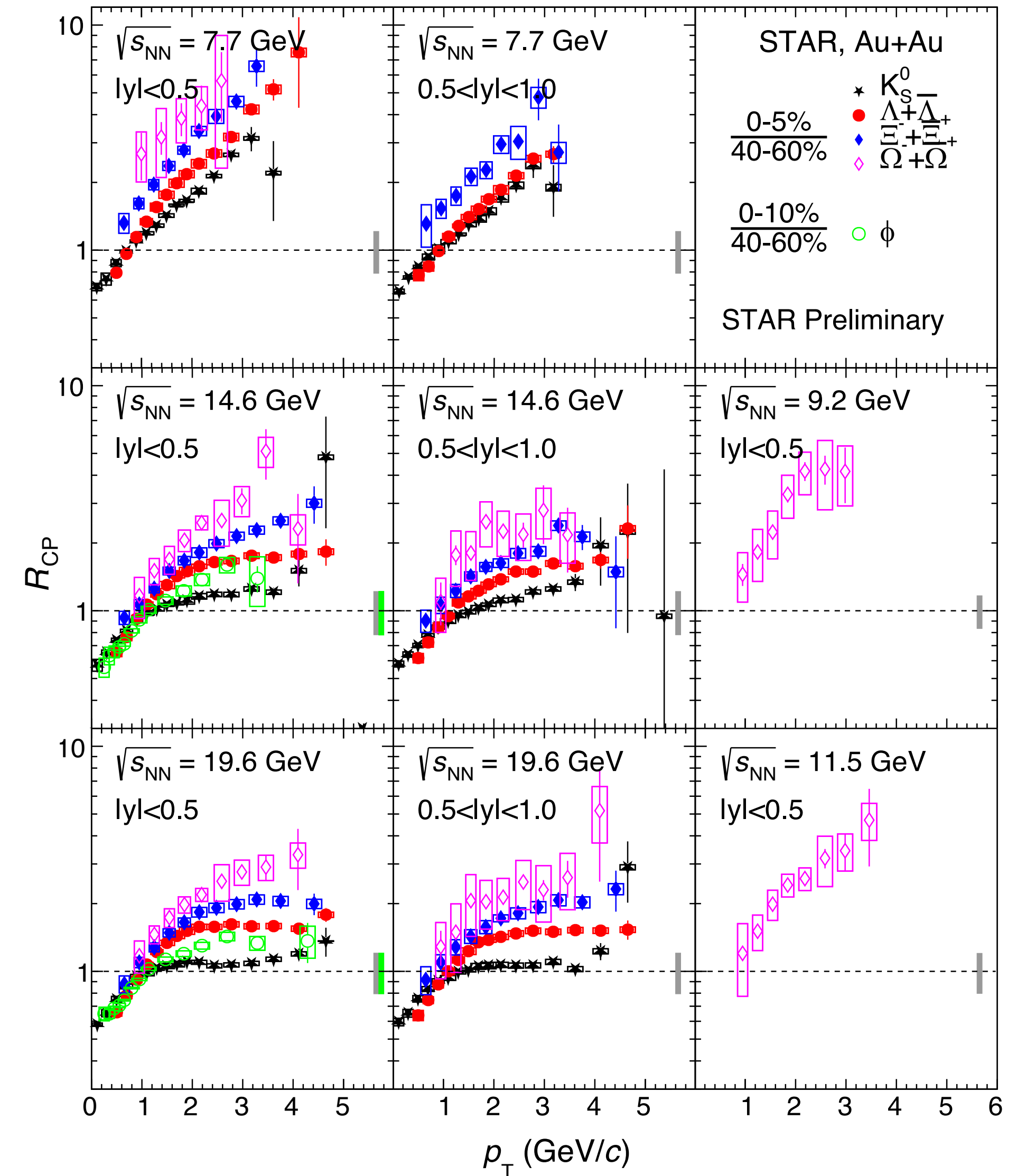


$$R_{\text{CP}} = \frac{[(dN/dp_{\text{T}})/\langle N_{\text{coll}} \rangle]_{\text{central}}}{[(dN/dp_{\text{T}})/\langle N_{\text{coll}} \rangle]_{\text{peripheral}}}$$

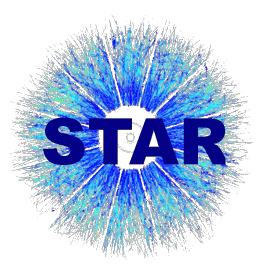


Nuclear modification factor (R_{CP}) for strange hadrons

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- R_{CP} continues to increase beyond $p_{\text{T}} = 2$ GeV/c at $\sqrt{s_{\text{NN}}} \leq 11.5$ GeV.
 - ✓ Radial flow
 - ✓ Quark coalescence
 - ✓ Cronin effect
- The enhancement is stronger for Ω and Ξ^- compare to Λ and K_s^0 .

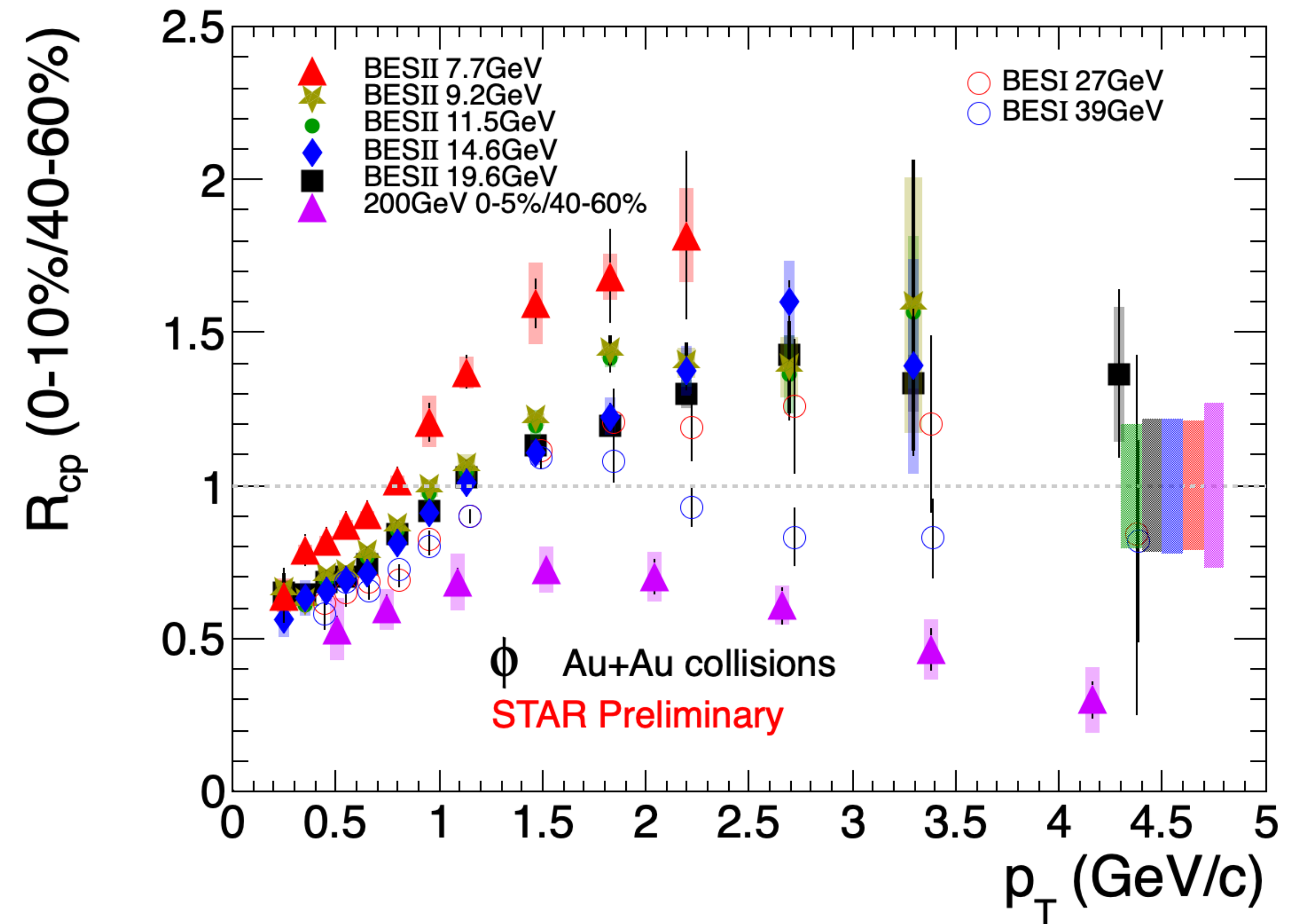


$$R_{\text{CP}} = \frac{[(dN/dp_{\text{T}})/\langle N_{\text{coll}} \rangle]_{\text{central}}}{[(dN/dp_{\text{T}})/\langle N_{\text{coll}} \rangle]_{\text{peripheral}}}$$

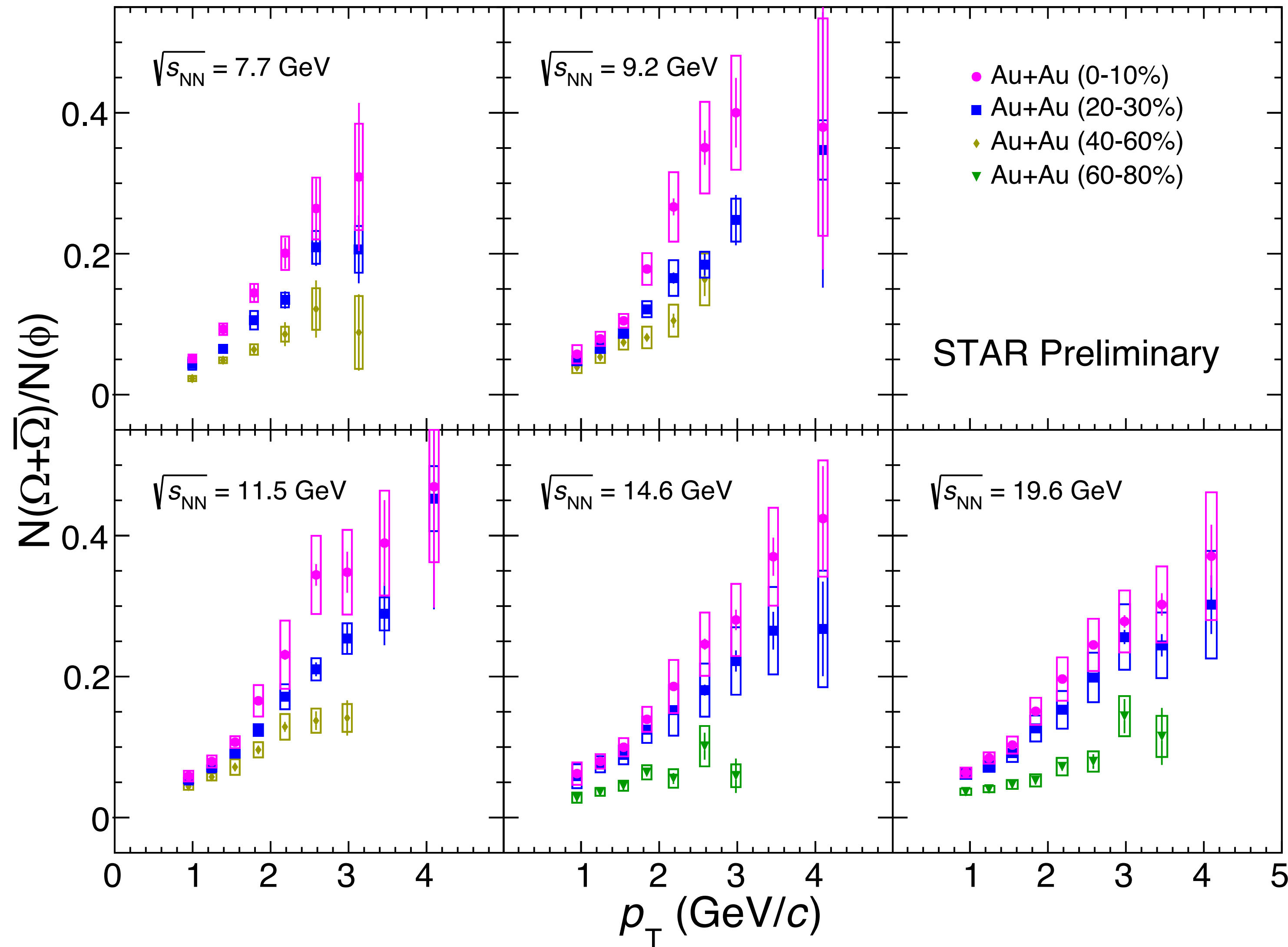


Energy dependence of nuclear modification factor (R_{CP}) for ϕ

- $R_{CP} > 1$ 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.



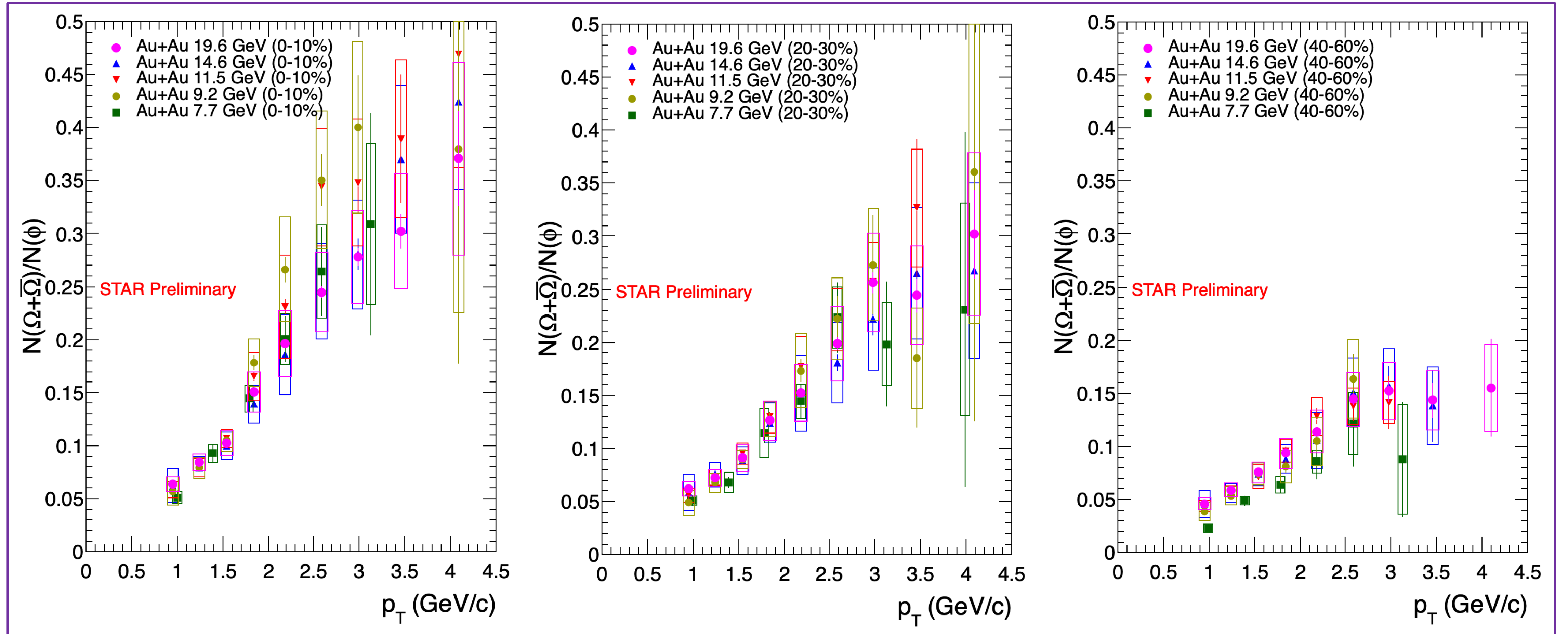
Centrality dependence of Ω/ϕ ratio at different energies



➤ Strong enhancement of Ω/ϕ 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

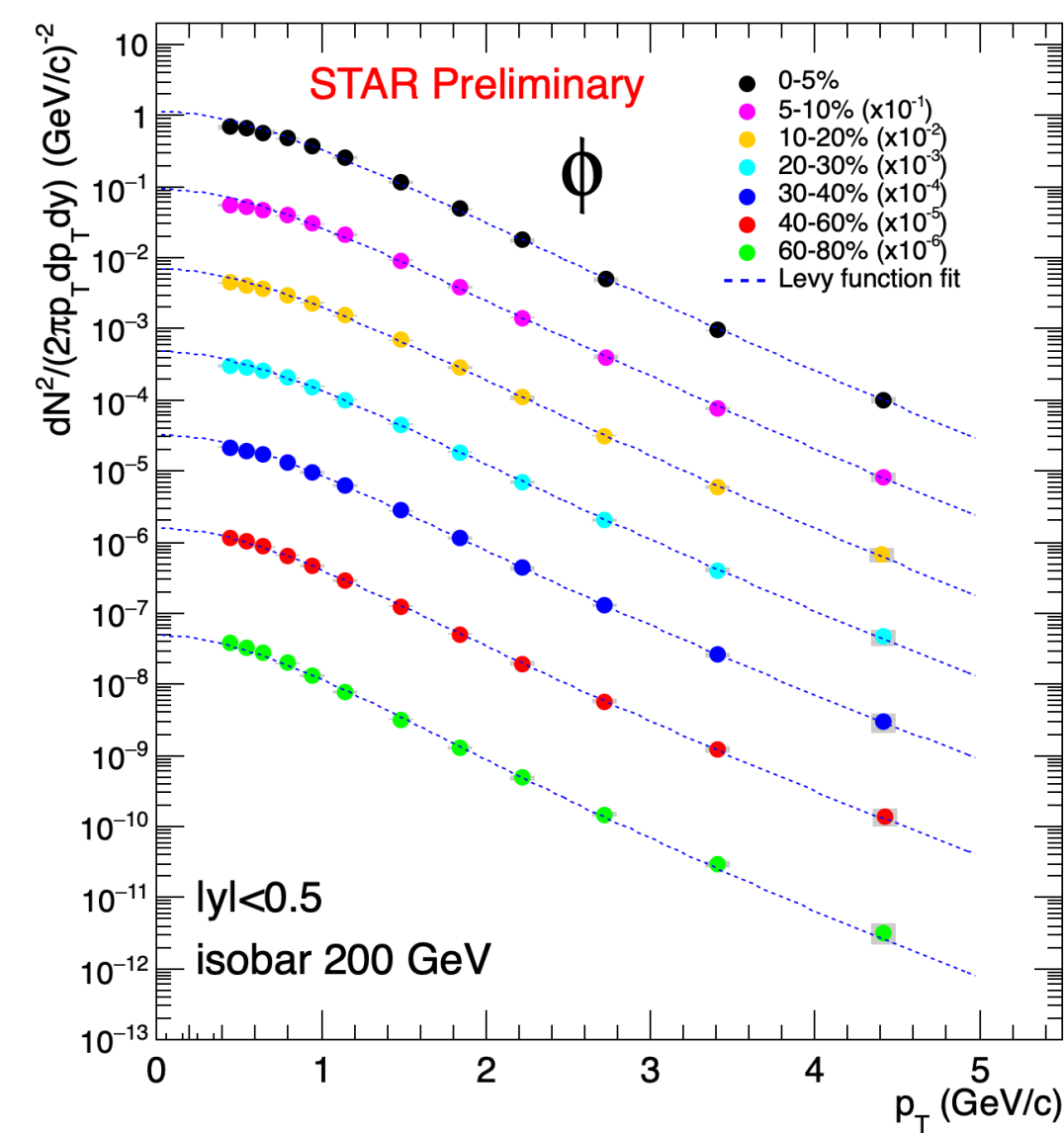
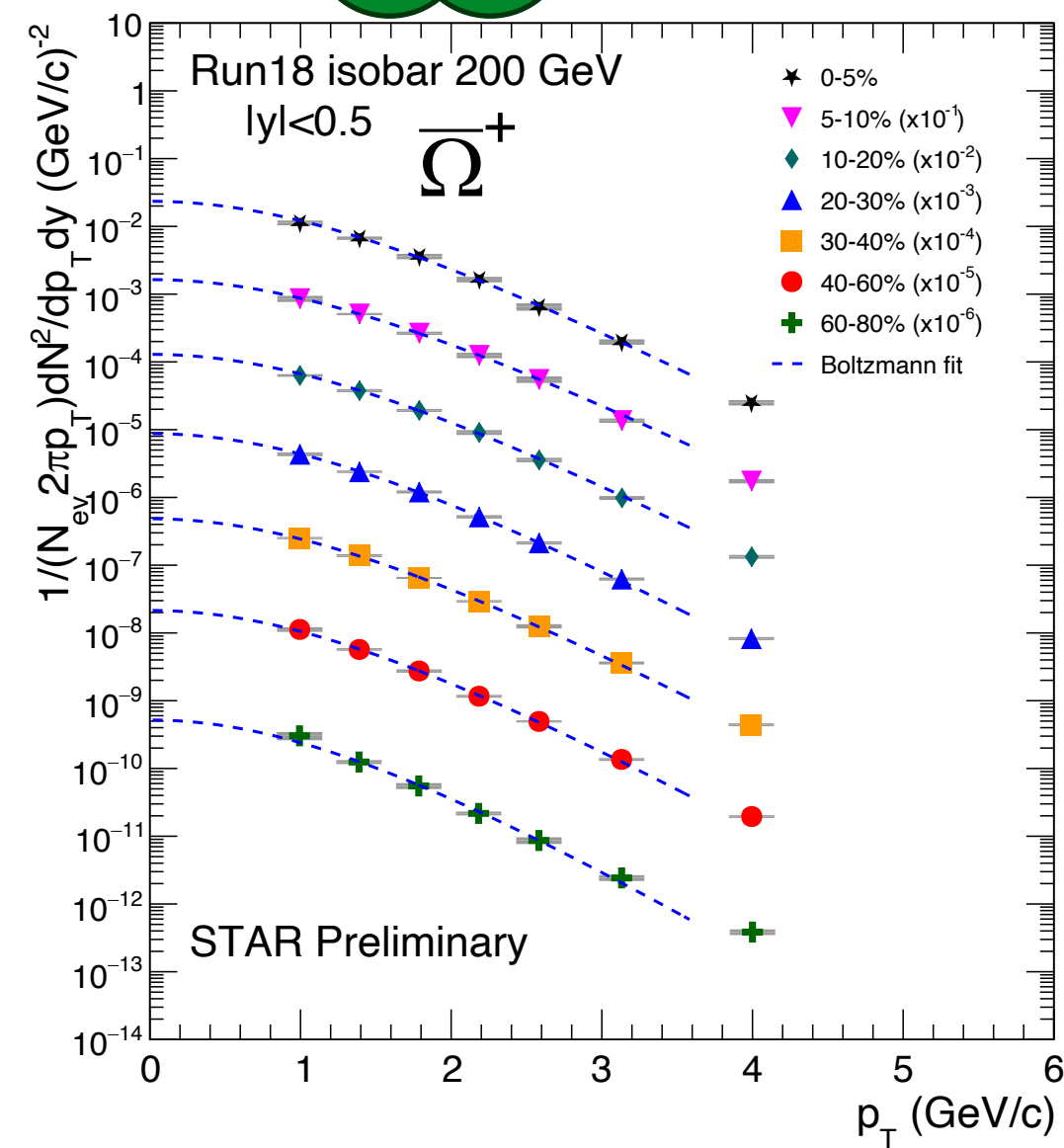
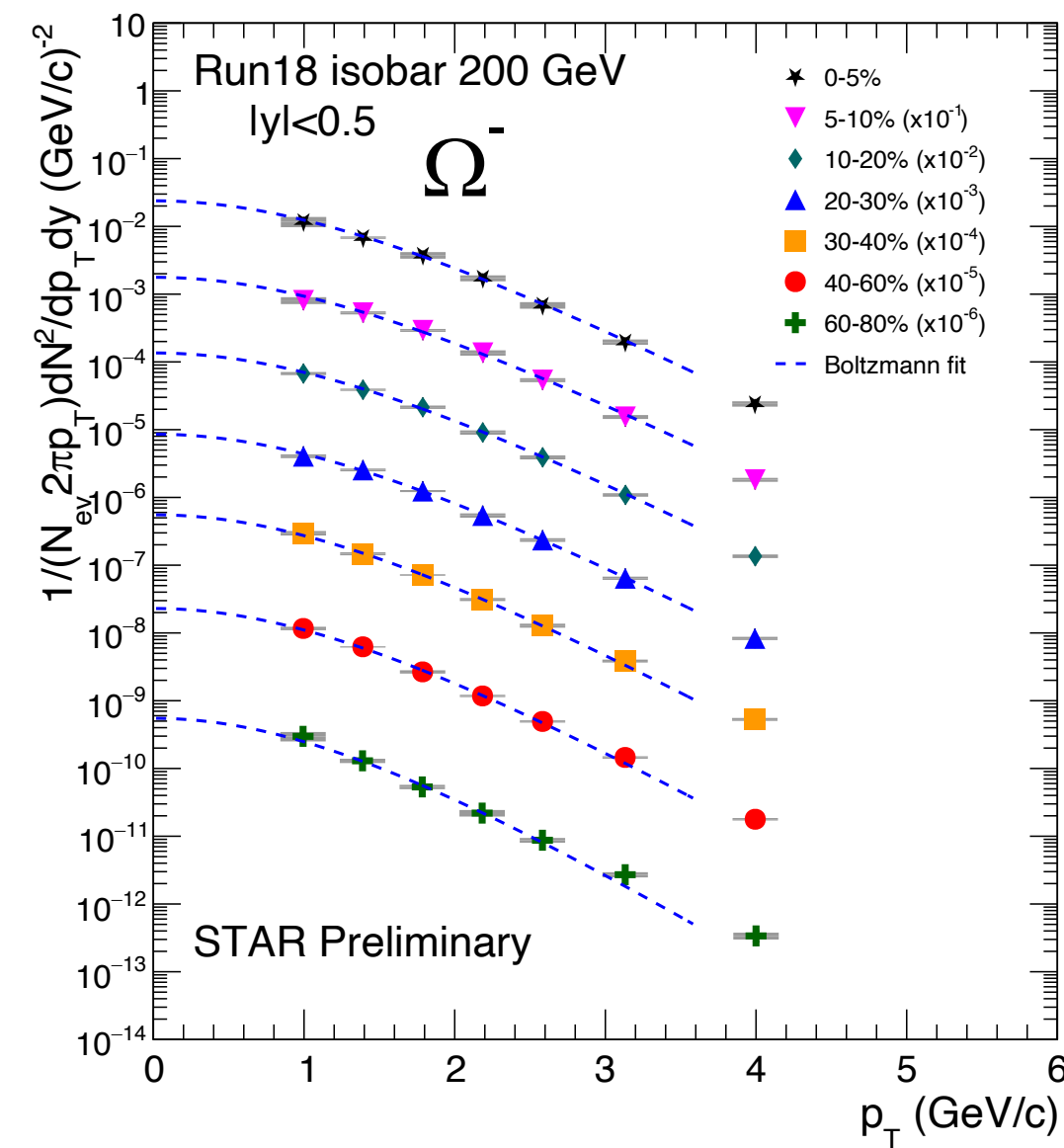
Energy dependence of Ω/ϕ ratio at different centralities



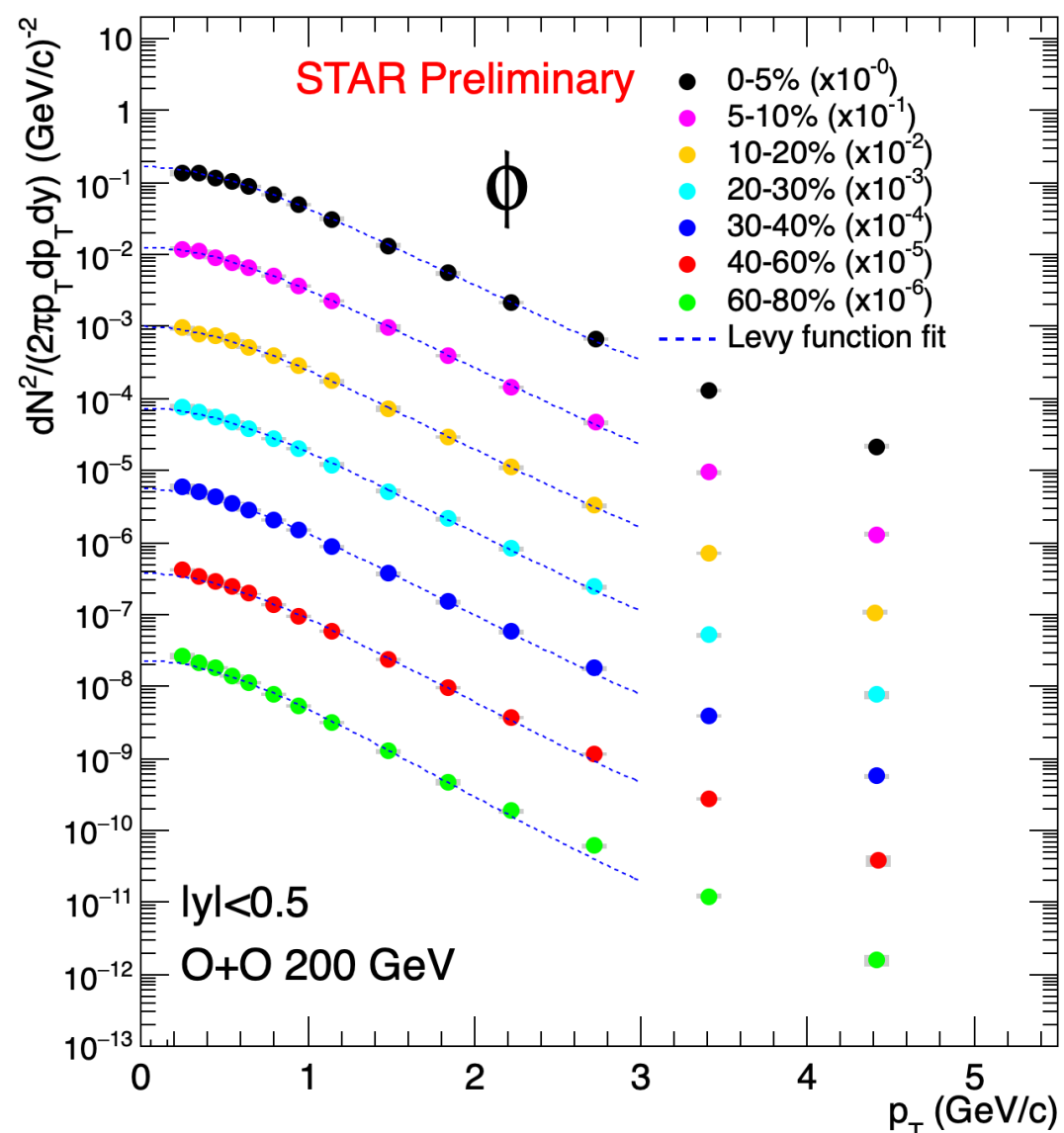
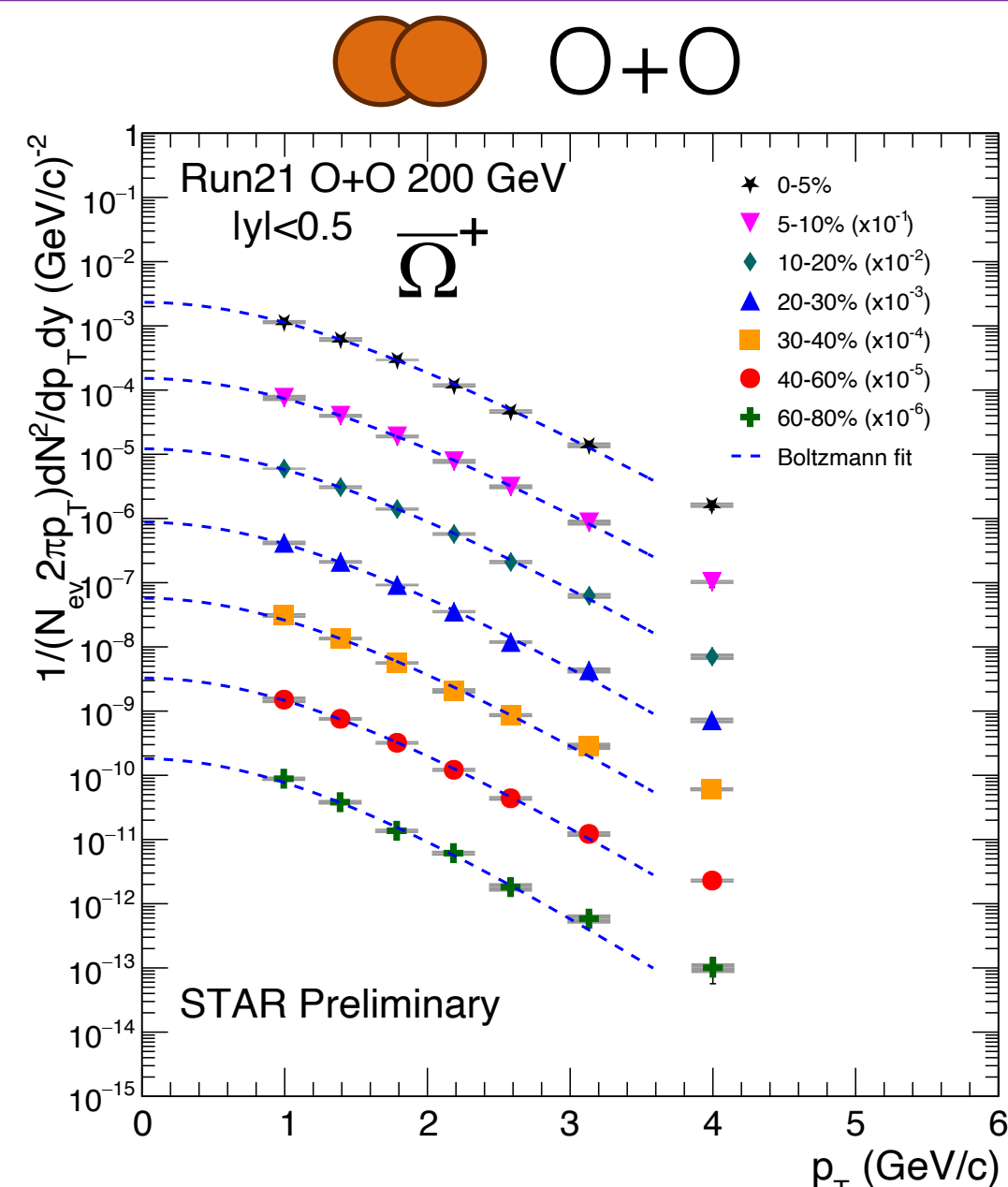
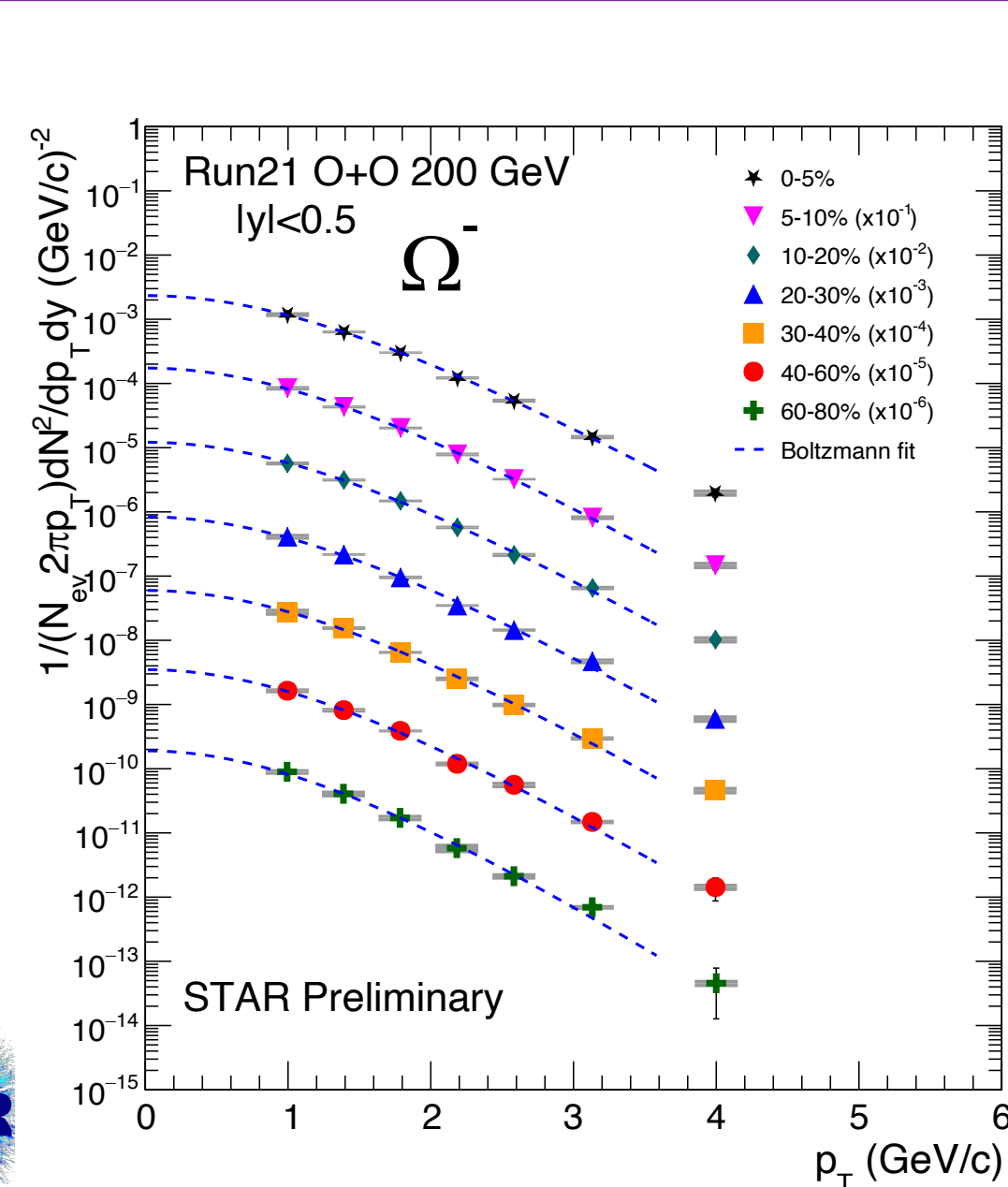
- In each 0-10%, 20-30% and 40-60% centrality bin, the Ω/ϕ ratios are consistent with each other within uncertainty from $\sqrt{s_{NN}} = 7.7$ to 19.6 GeV.

p_T Spectra in isobar and O+O collisions

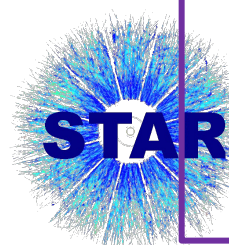
Xiongxiong Xu
poster #812



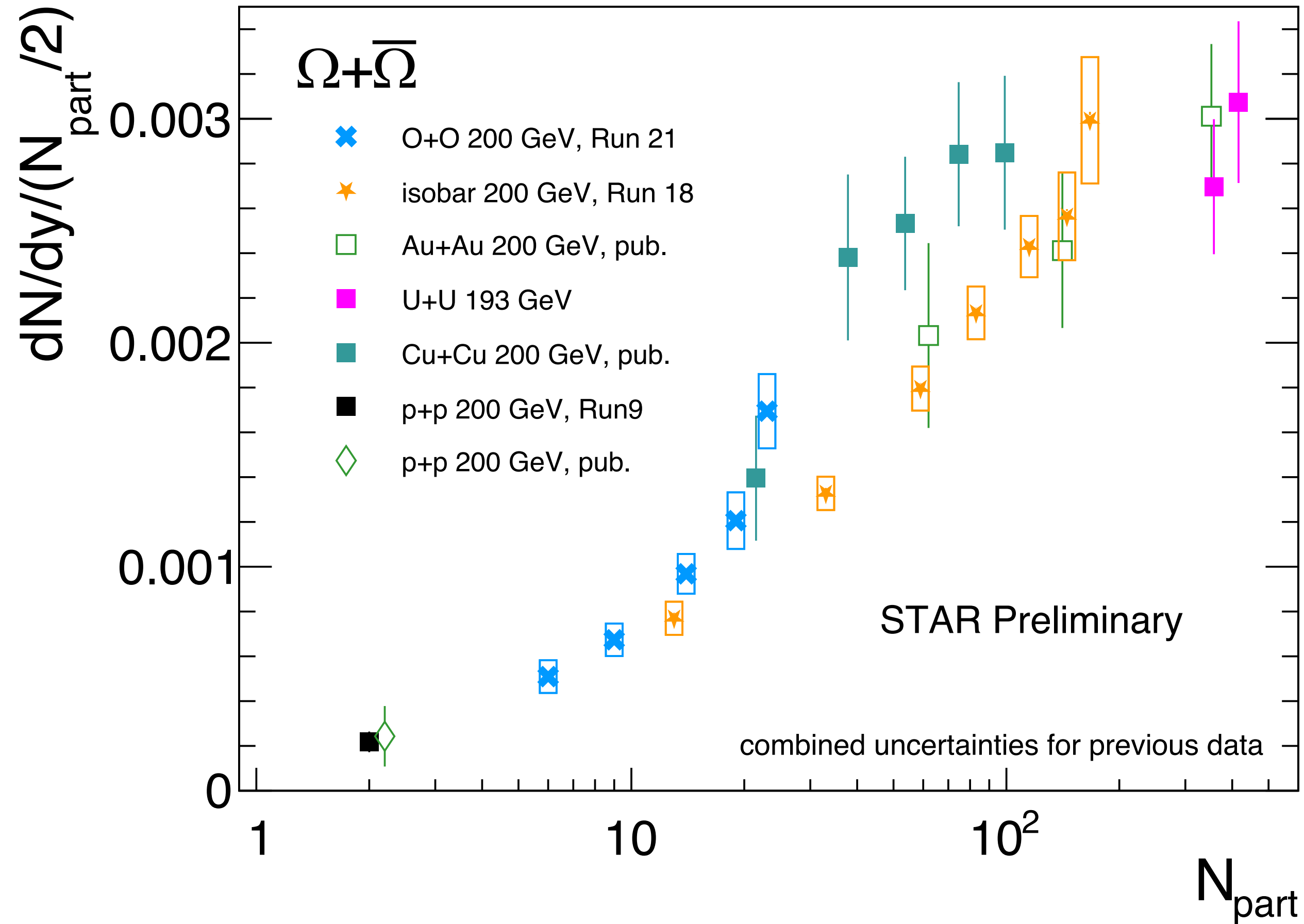
➤ Ω low p_T extrapolation: Boltzmann function.



➤ ϕ low p_T extrapolation: Levy function.



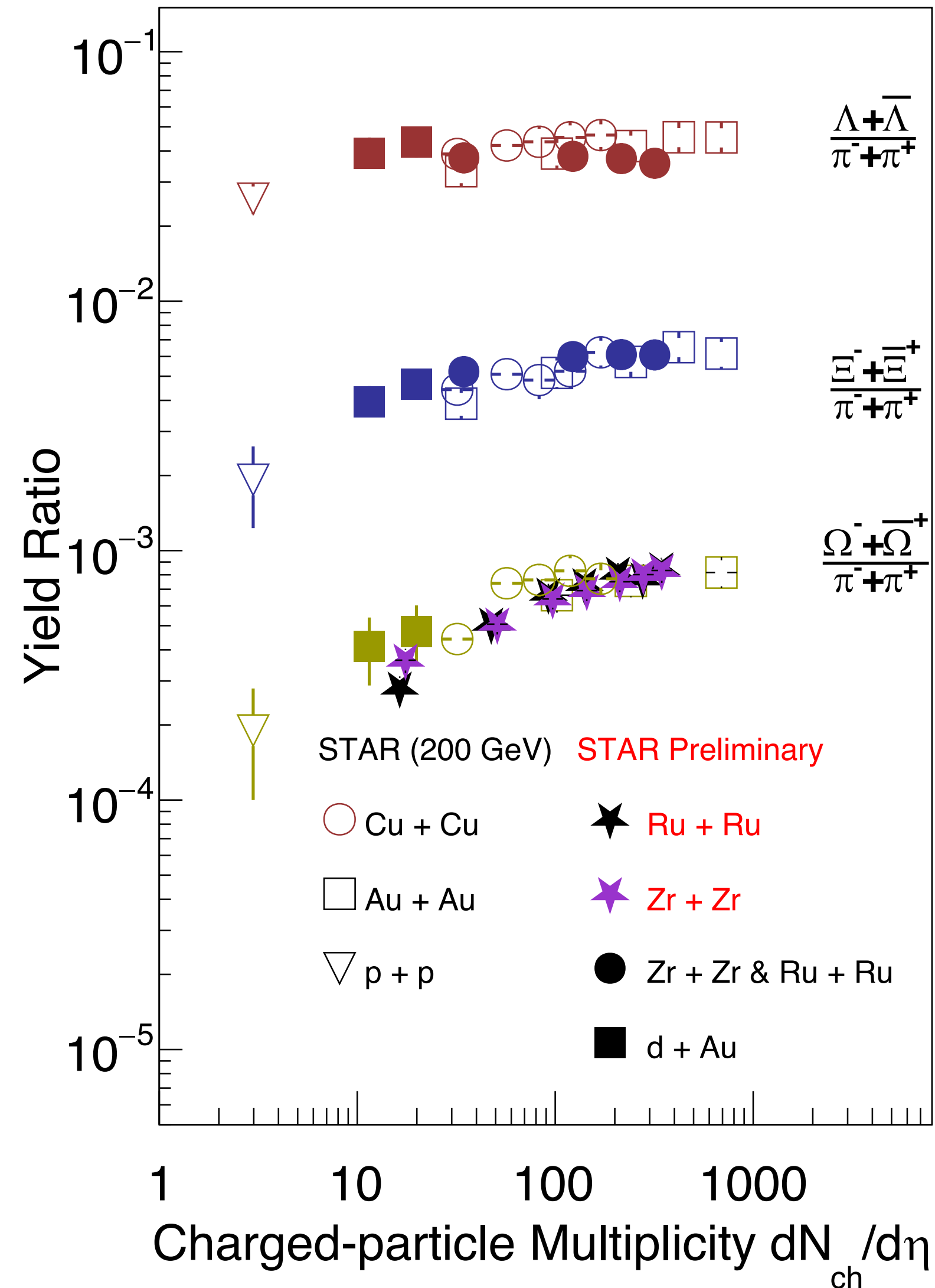
System size dependence of Ω yields



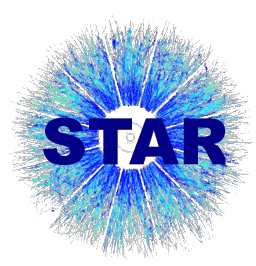
➤ Hint of different N_{part} dependence between isobar and smaller Cu+Cu and O+O systems.

System size dependence of yield ratios

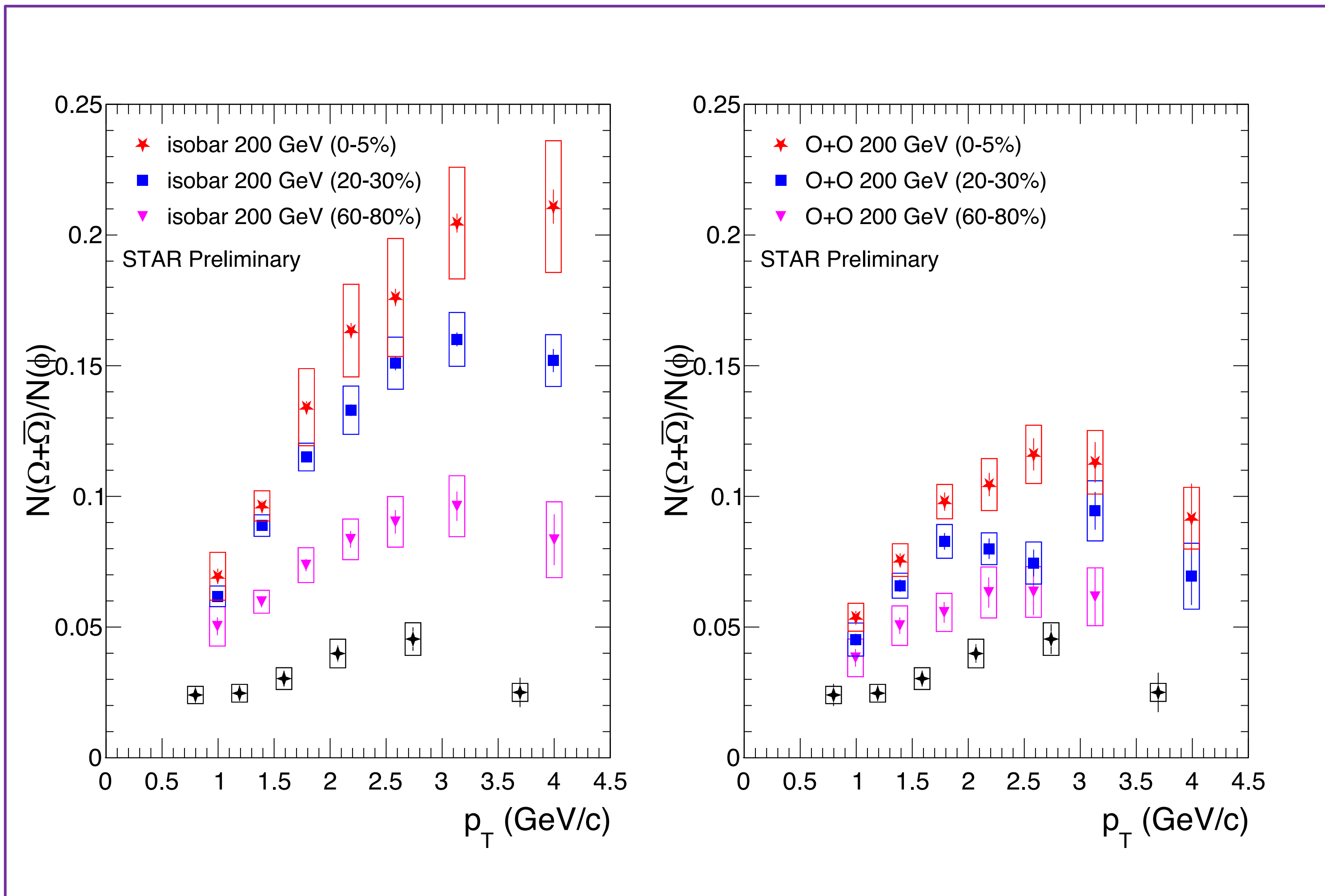
D. Li sQM 24
I. Aggarwal sQM 24
STAR : Phys. Rev. C 75, 064901 (2007)
STAR : Phys. Rev. Lett. 108, 072301 (2012)
STAR : Phys. Rev. C 79, 034909 (2009)
STAR : Phys. Rev. C 83, 034910 (2011)



- Smooth transition of ratios of the strange particles from p+p to A+A collisions.
- Yield ratios of strange particles to pions with more strangeness content decrease faster from high to low multiplicity.

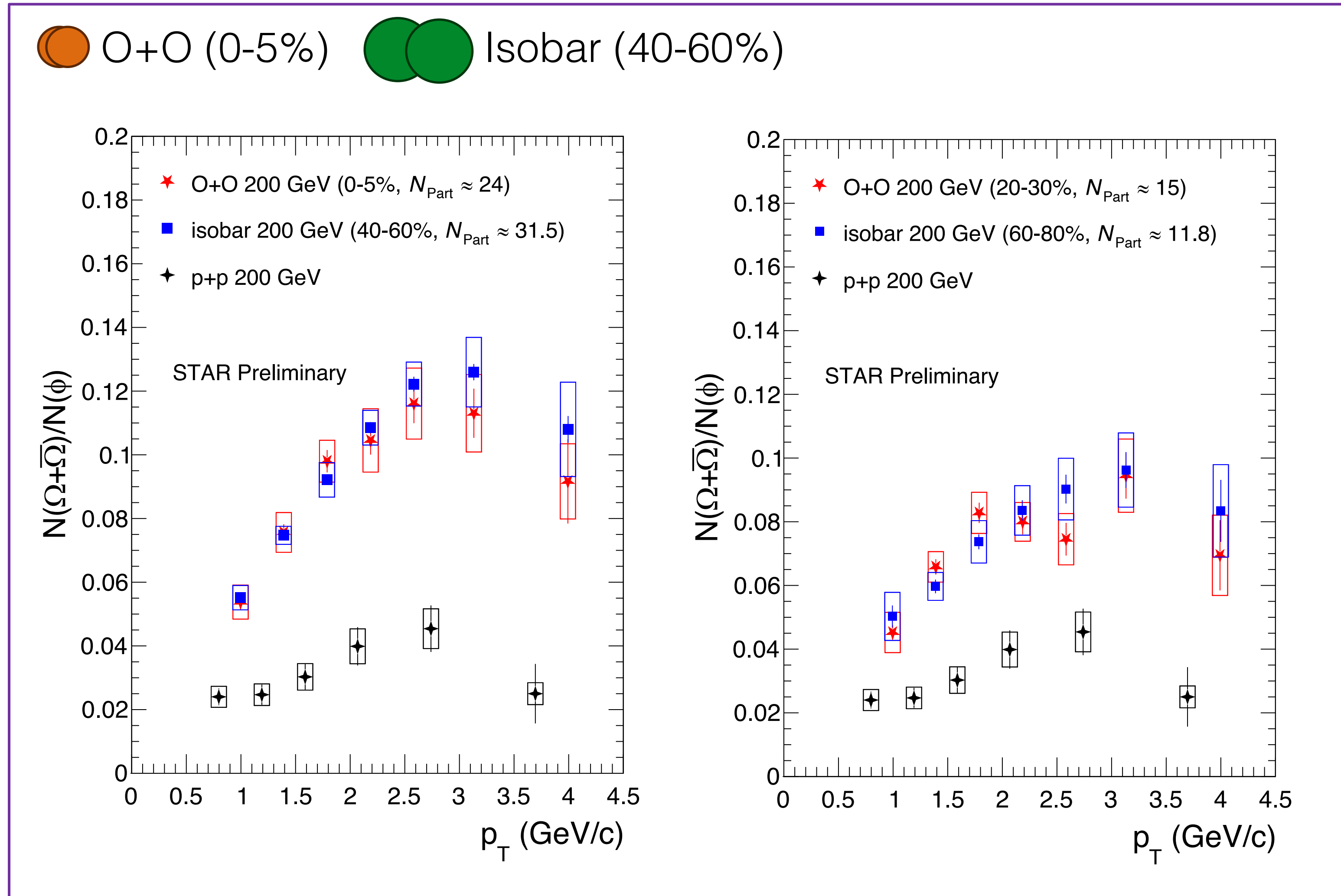


Centrality dependence of Ω/ϕ ratio (different systems)



- In isobar and O+O collisions, Ω/ϕ ratio enhancement is observed with respect to p+p collisions. Enhancement increases from peripheral to central collisions.
- The enhancement of Ω/ϕ ratio is larger in central Isobar collisions than that in central O+O collisions

System size dependence of Ω/ϕ ratio



- Compare Ω/ϕ ratios in different collision systems with similar N_{part} .
- ✓ The enhancement of Ω/ϕ ratio in central O+O collisions is consistent with 40-60% isobar collisions.
- ✓ No clear collision system size dependence.

Summary and outlook

■ Summary

- Precise measurement of strangeness production in STAR BES-II Energies and different systems.
- R_{CP} is significantly larger at 7.7 GeV compared with other energies for ϕ .
- Ω/ϕ enhancement observed in central Au+Au collisions at $\sqrt{s_{NN}} \geq 7.7$ GeV.
- Ω/ϕ enhancement increases from peripheral to central collisions in O+O and isobar collisions, similar enhancement at similar N_{part} .

Thanks for your attention!!

■ Outlook

- Study strangeness enhancement in even smaller systems: e.g. d+Au.
- Further investigate strangeness production in high-multiplicity O+O events.

