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

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- Motivation
- STAR detector and strange hadron reconstruction
- Results
  - ✓ p_{T} and rapidity spectra
  - ✓ Energy dependence of R_{CP} and $\overline{\mathrm{B}}/\mathrm{B}$, 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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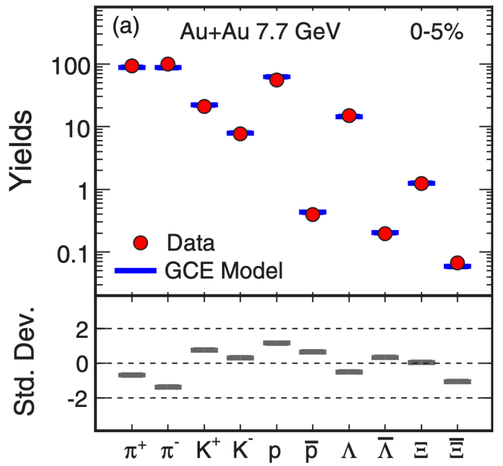
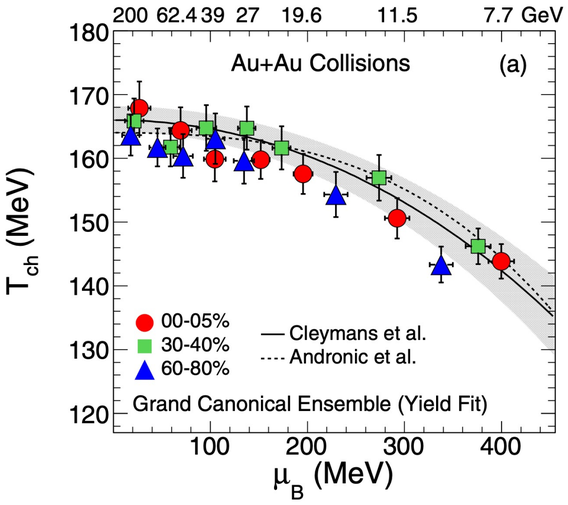
STAR Collaboration

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

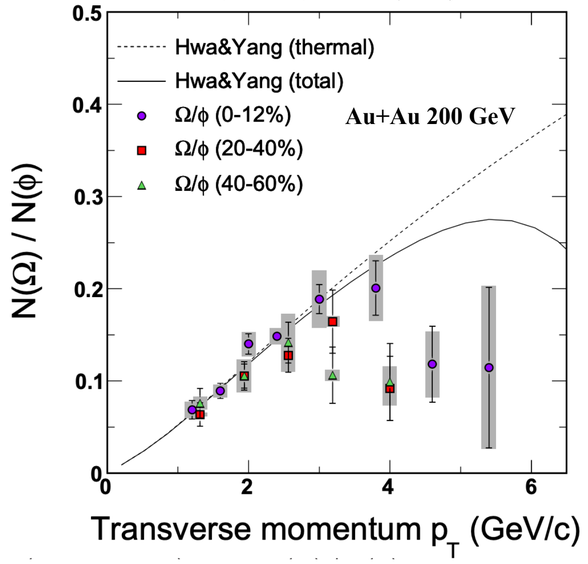
$$R_{\mathrm{CP}} = \frac{[(dN/dp_T)/\langle N_{\mathrm{coll}}\rangle]_{\mathrm{central}}}{[(dN/dp_T)/\langle N_{\mathrm{coll}}\rangle]_{\mathrm{peripheral}}}$$



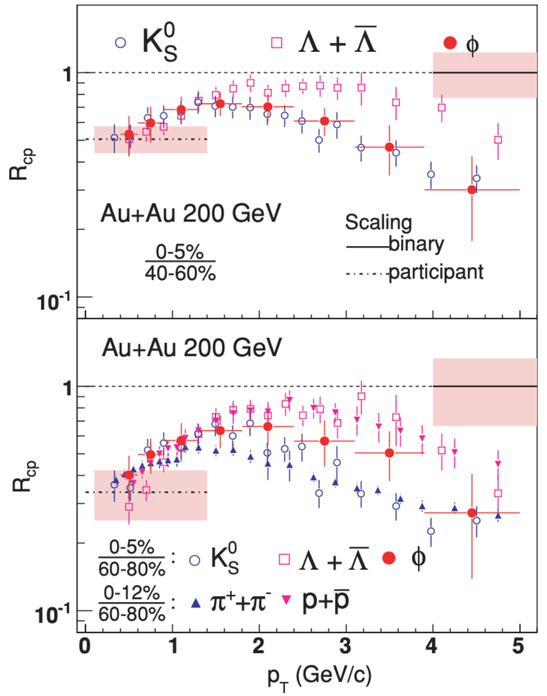


STAR, PRC 96, 044904 (2017)

STAR, PRL 99, 112301 (2007)

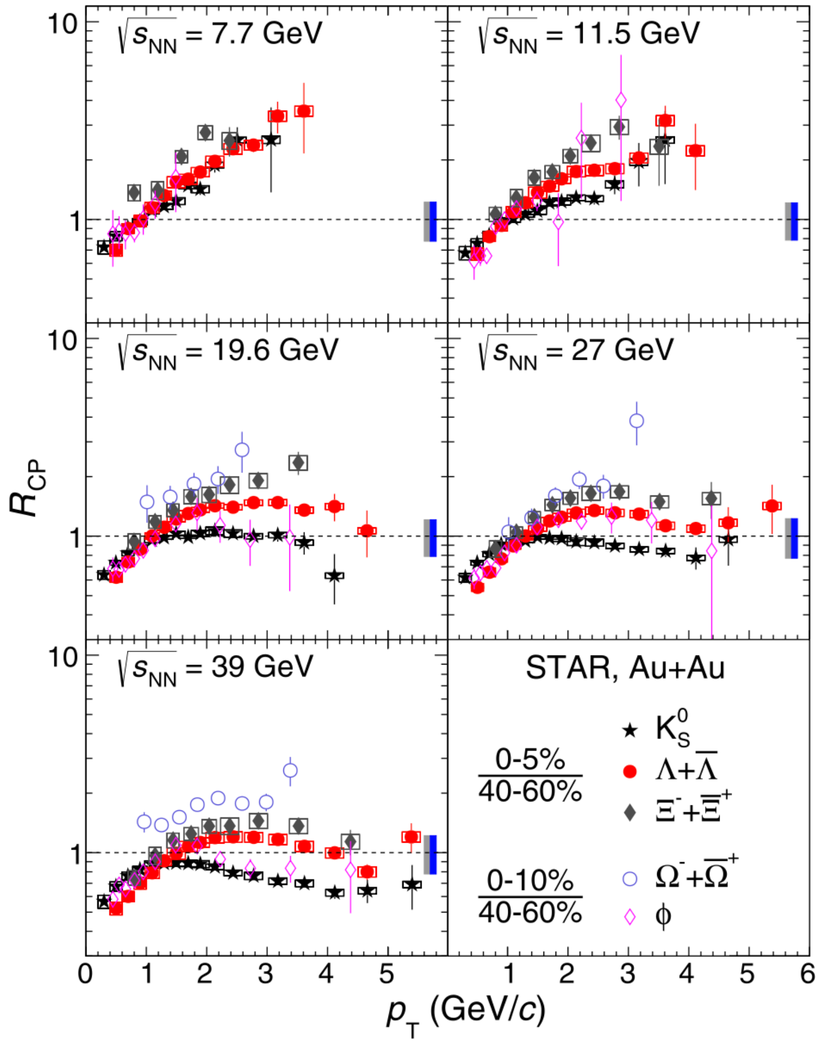


STAR, Phys.Rev.C79, 064903,2009

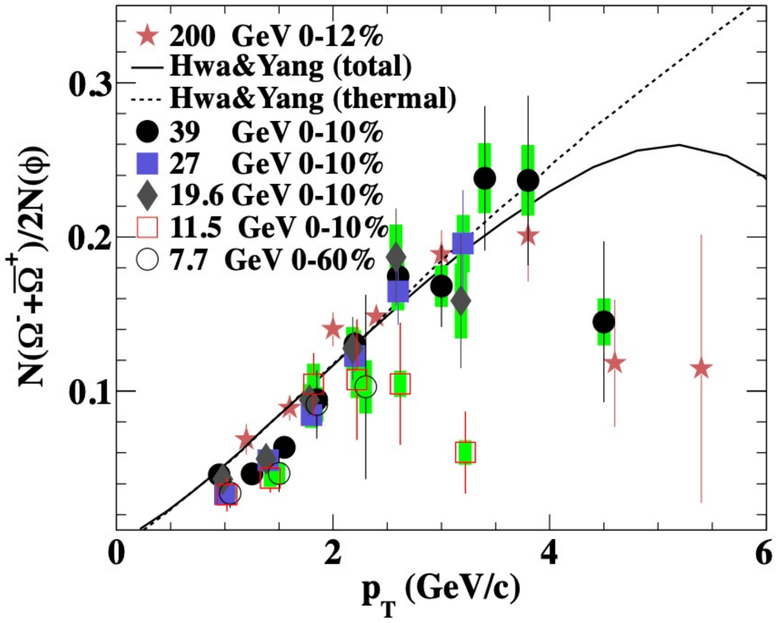


Energy dependence of strange hadron productions

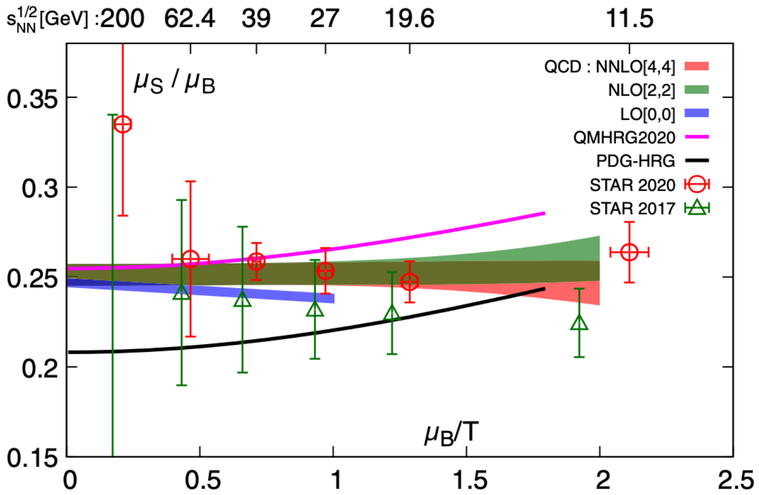
STAR, PRC 102, 034909 (2020)

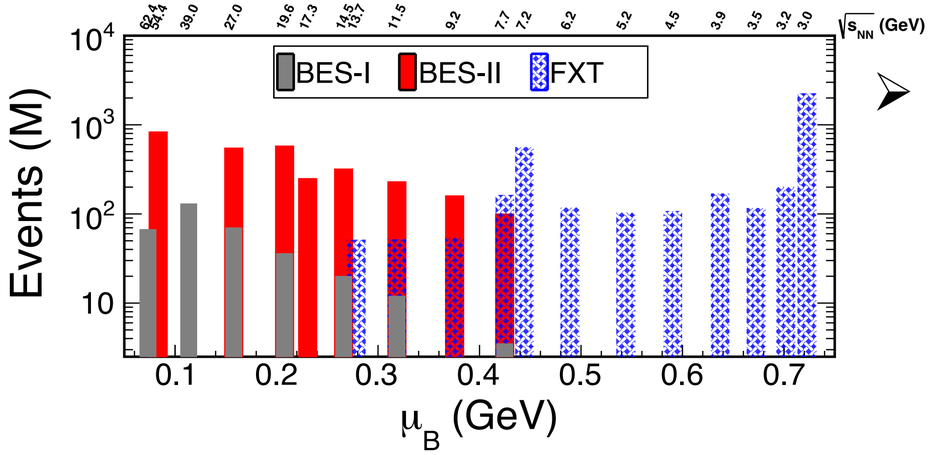


STAR, PRC 93, 021903 (2016)



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

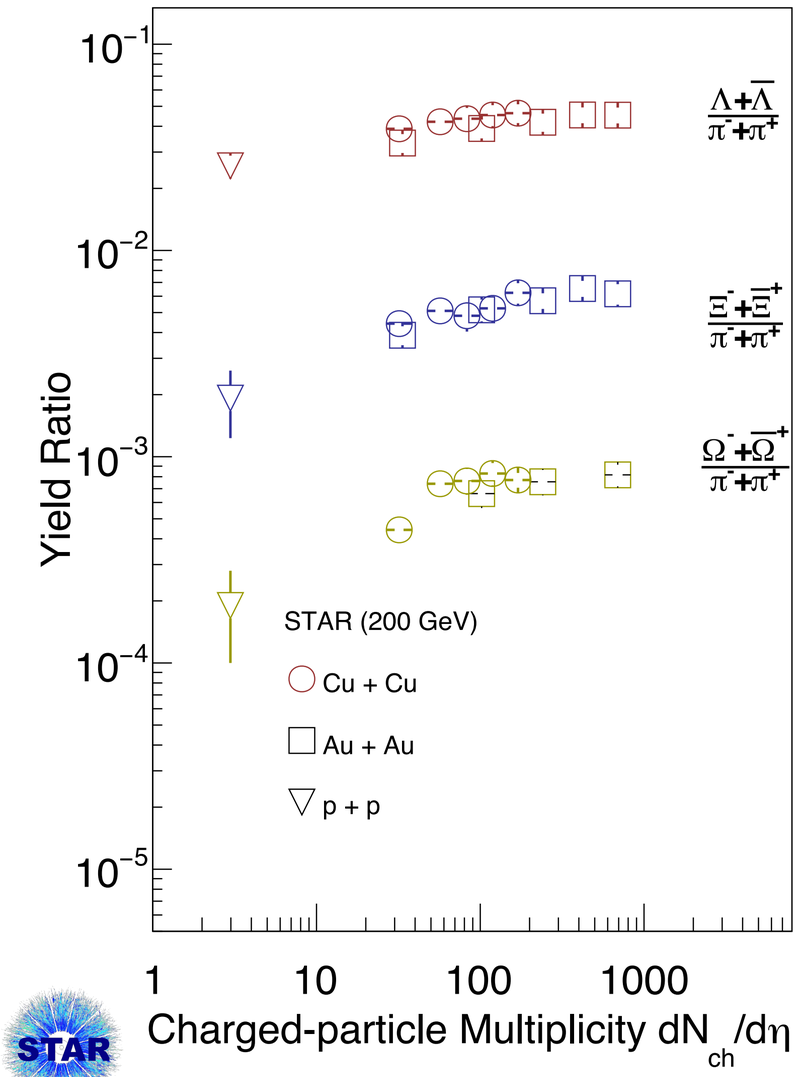




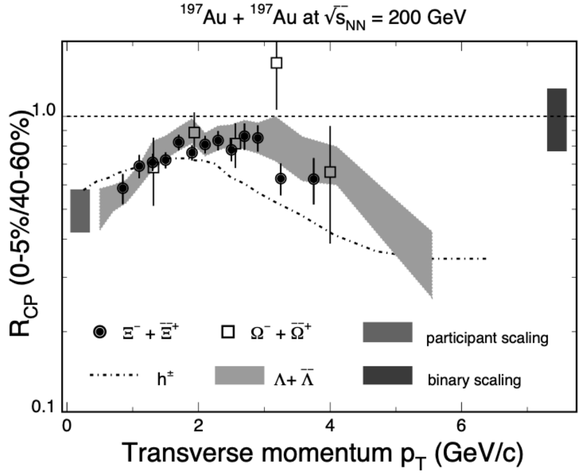
- Further explore the chemical freeze-out parameters and the turn-off of QGP signatures with more precise measurements with BES-II

System size dependence of strange hadron productions

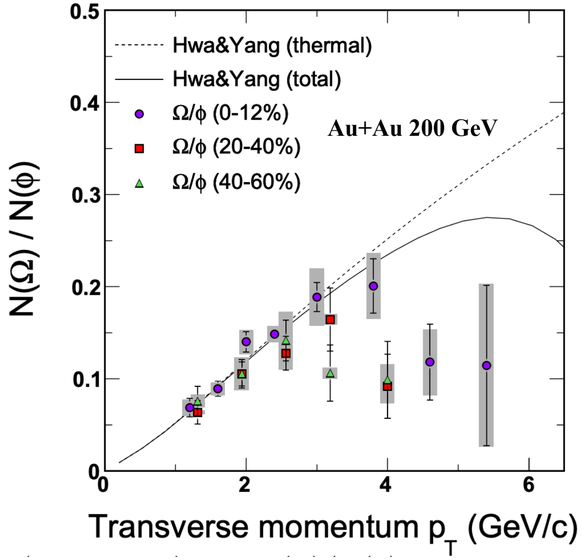
STAR : Phys. Rev. C 75, 064901 (2007)
STAR : Phys. Rev. Lett. 108, 072301 (2012)
STAR : Phys. Rev. C 79, 034909 (2009)
STAR : Phys. Rev. C 83, 034910 (2011)

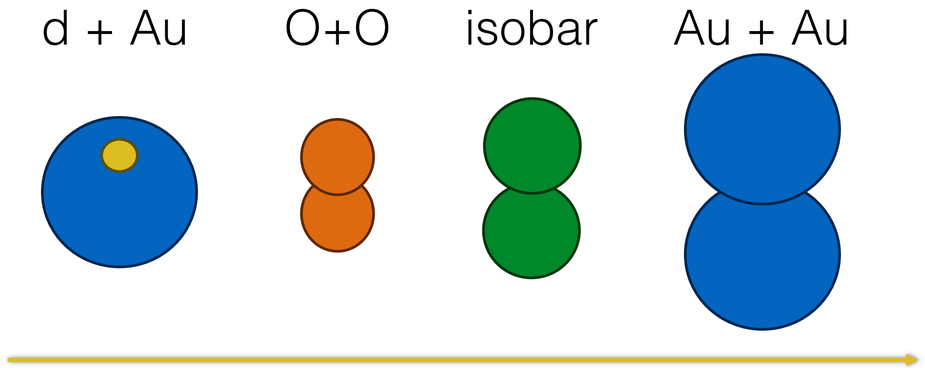


STAR, Phys.Rev.Lett.98, 062301 (2007)

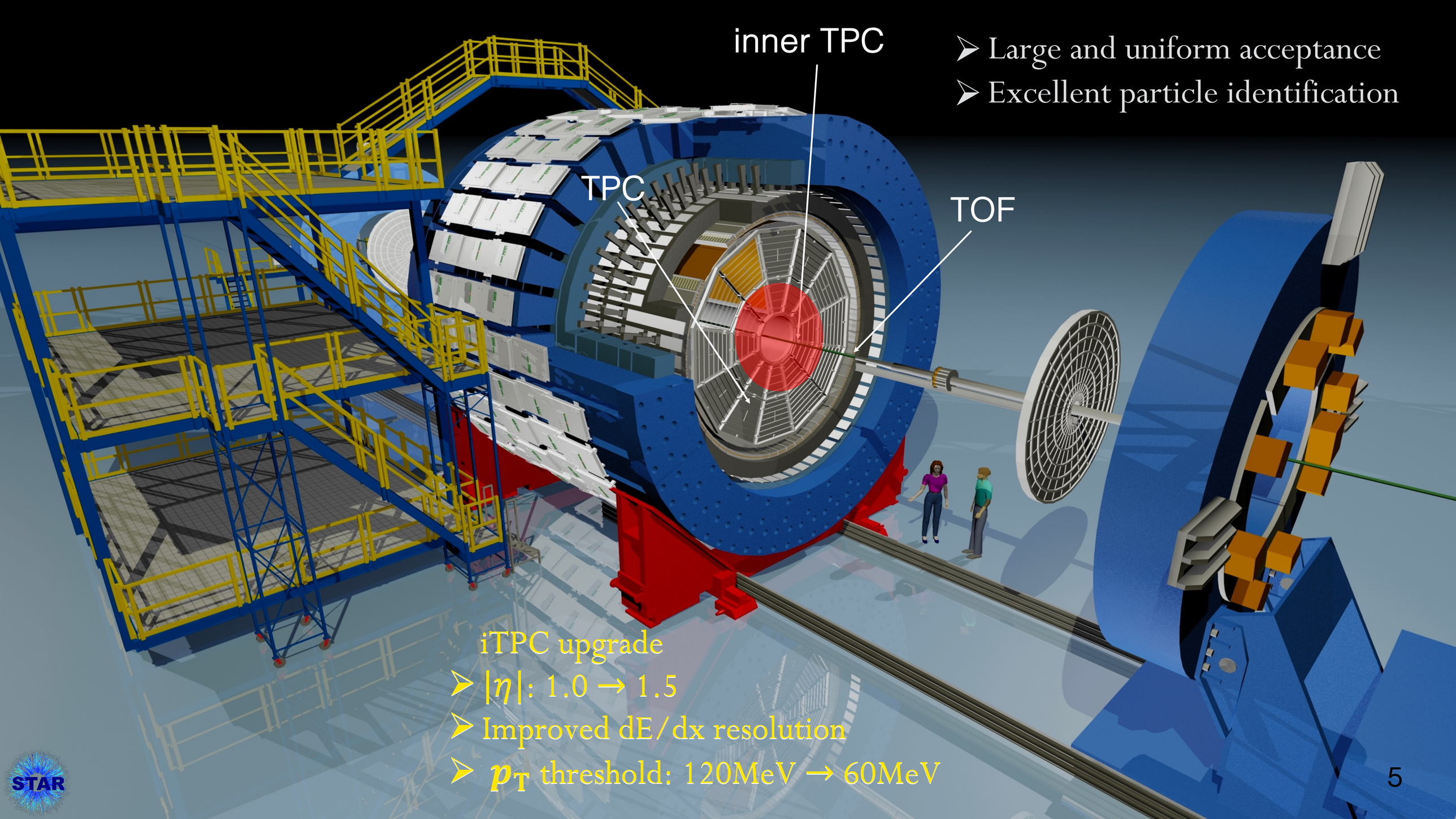


STAR, PRL 99, 112301 (2007)





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

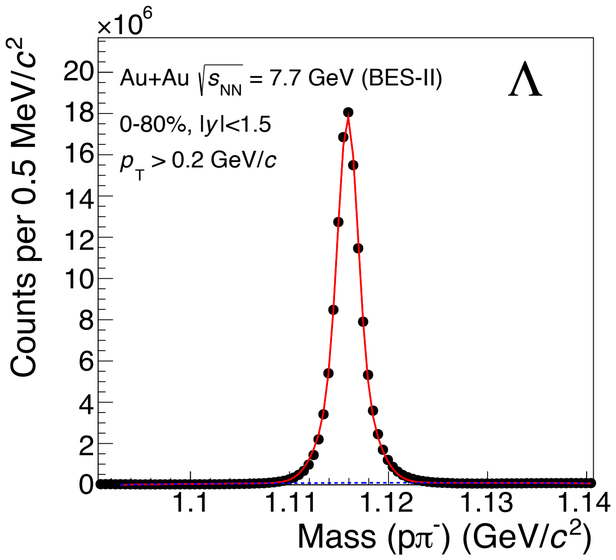


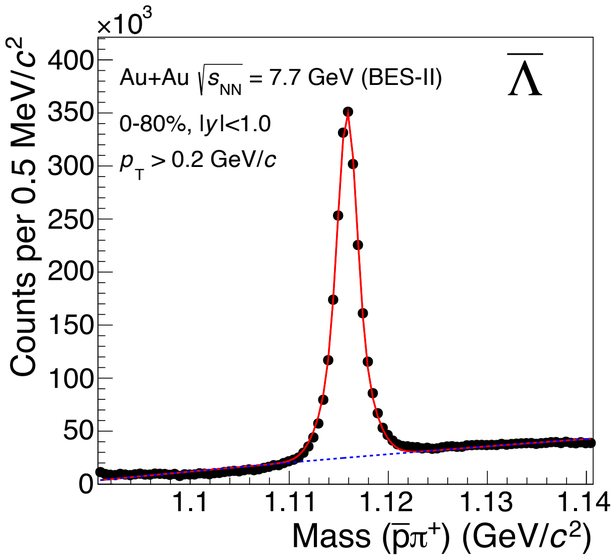
- Large and uniform acceptance
- Excellent particle identification

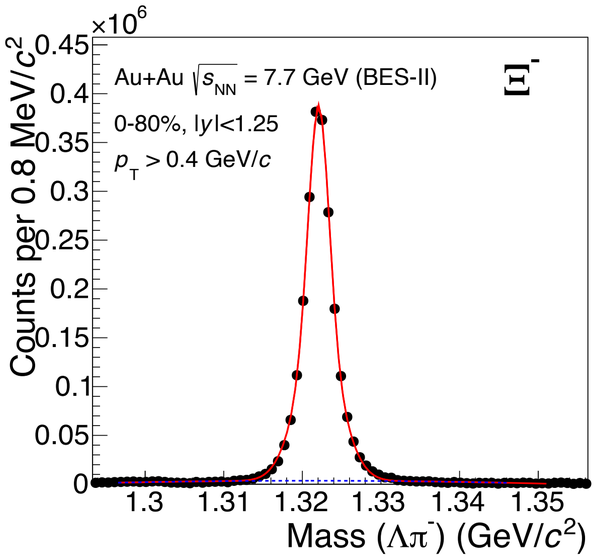
iTPC upgrade

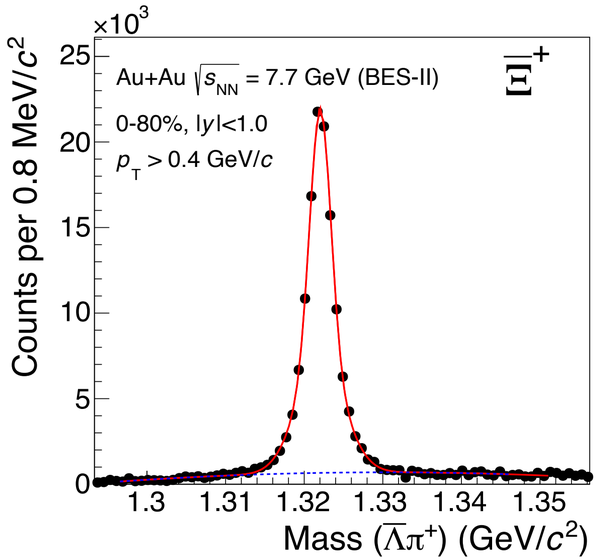
- $|\eta|$: 1.0 → 1.5
- Improved dE/dx resolution
- p_T threshold: 120MeV → 60MeV

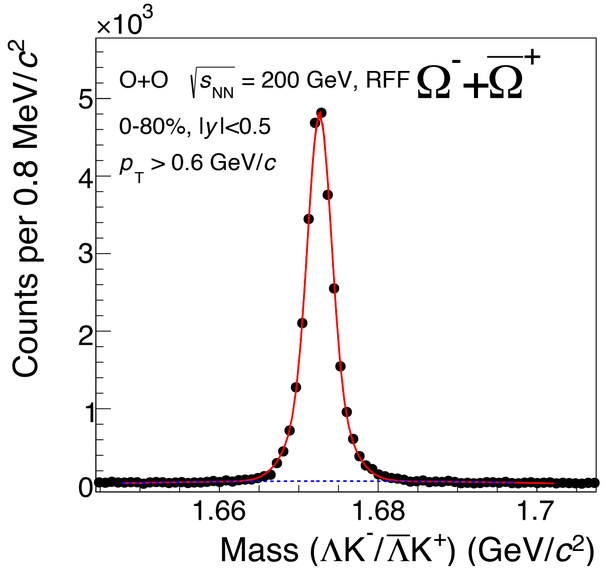
Particle identification and reconstruction

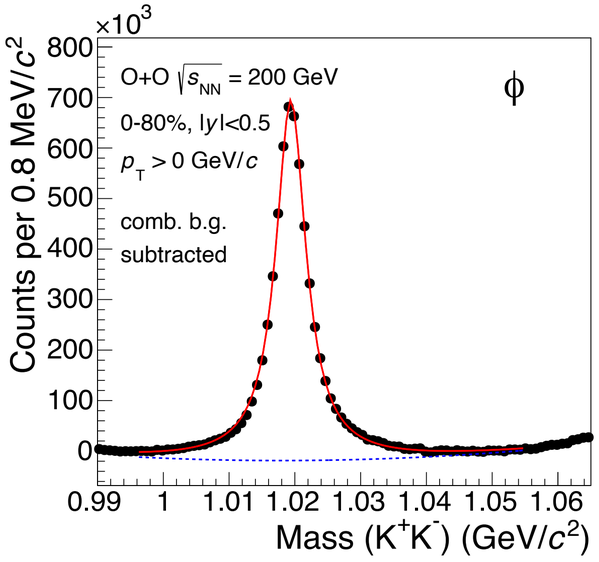




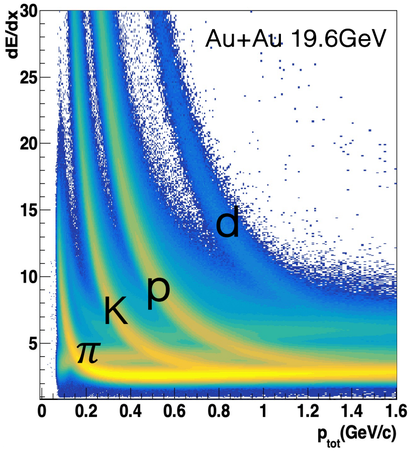






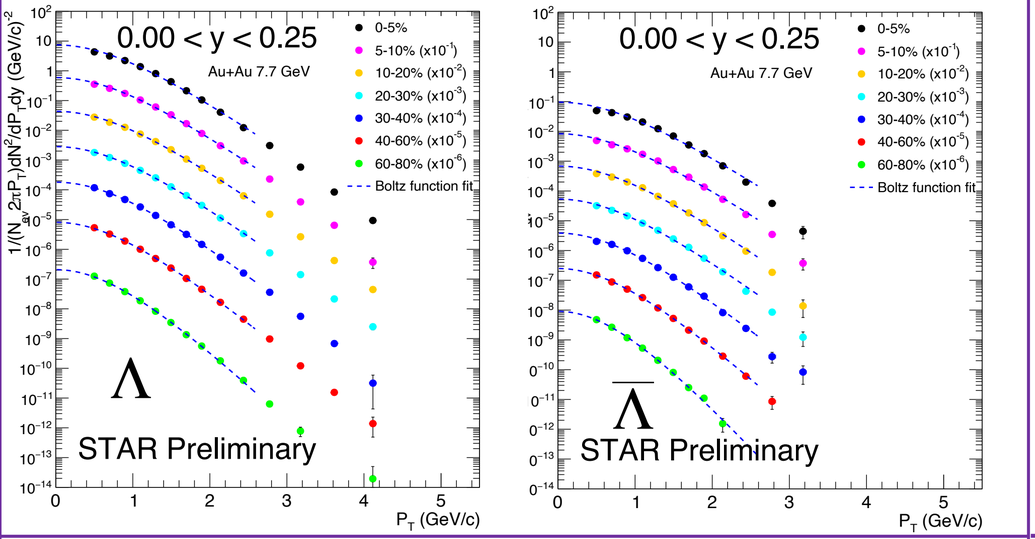


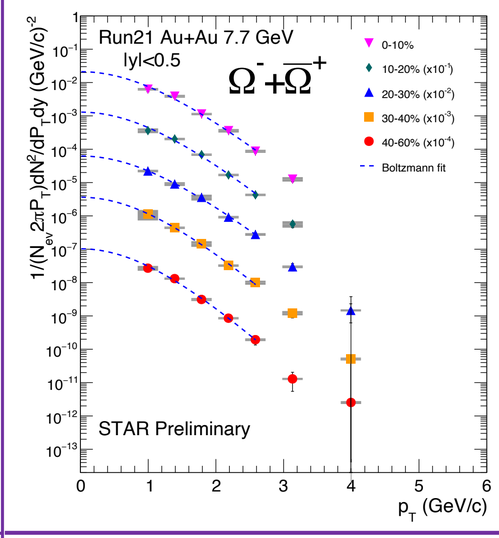
- Particle identification with dE/dx and TOF.
- $\pi, K, p \rightarrow$ reconstruct secondary vertex of strange particles.
- Large signal counts allow multi-differential measurements.

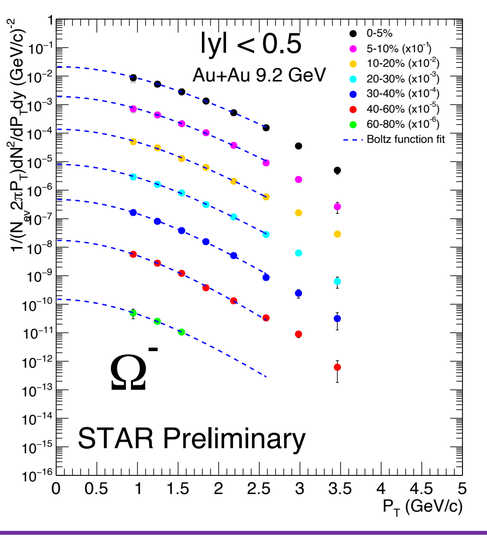


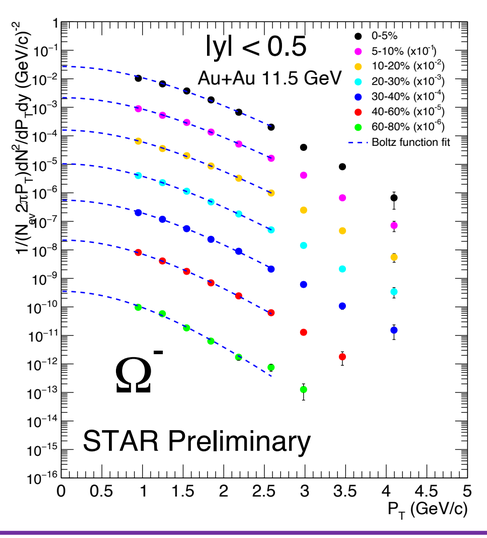
$$\Lambda(\bar{\Lambda}) \rightarrow p(\bar{p}) + \pi^-(\pi^+)(\mathcal{B} = 63.9\%)$$
$$\Xi^-(\bar{\Xi}^+) \rightarrow \Lambda(\bar{\Lambda}) + \pi^-(\pi^+)(\mathcal{B} = 99.9\%)$$
$$\Omega^-(\bar{\Omega}^+) \rightarrow \Lambda(\bar{\Lambda}) + K^-(K^+)(\mathcal{B} = 67.8\%)$$
$$\phi \rightarrow \mathrm{K}^+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

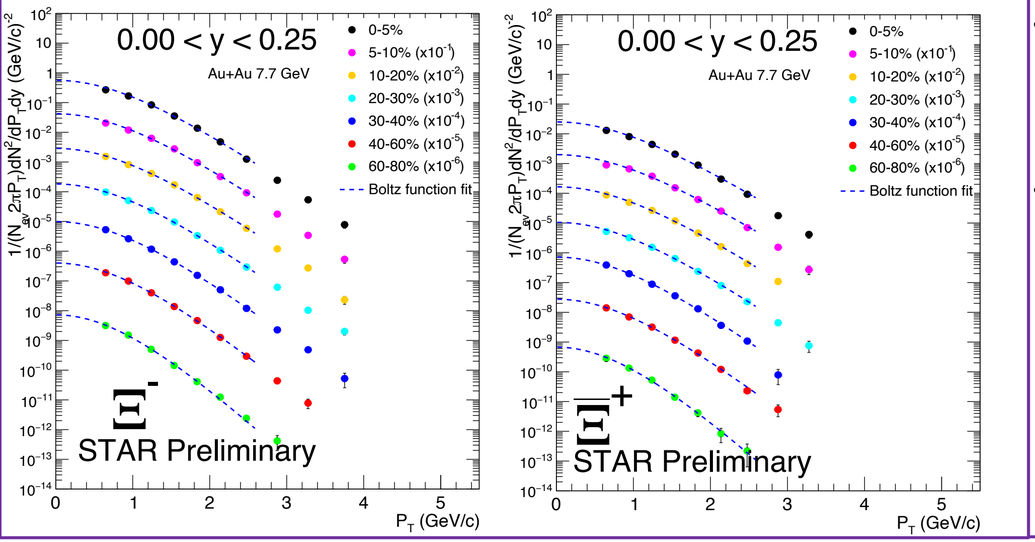
p_T Spectra for Λ, Ξ, ϕ and Ω (BESII)

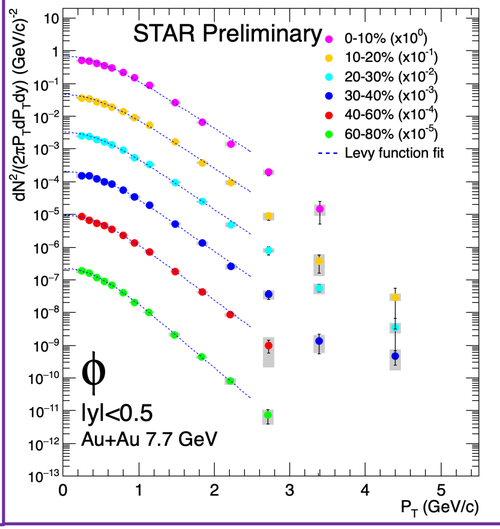


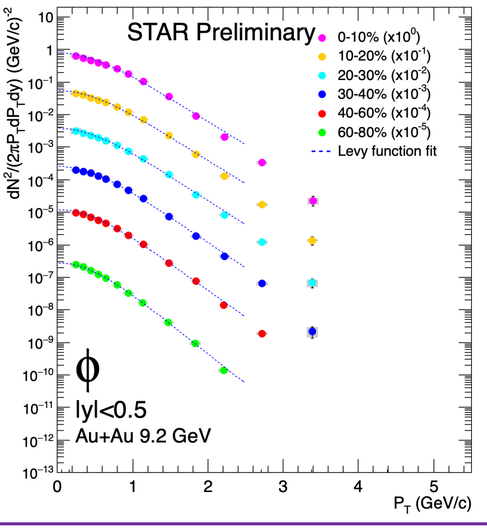


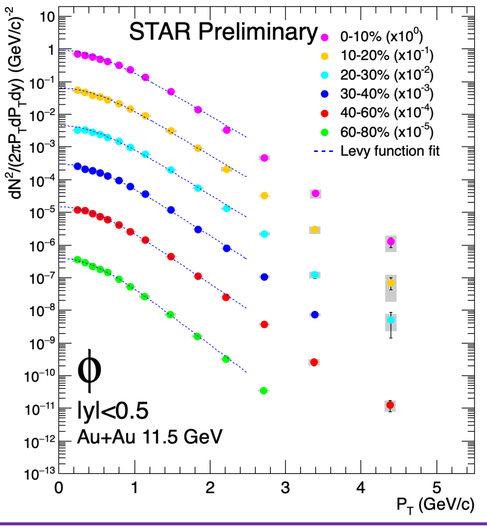










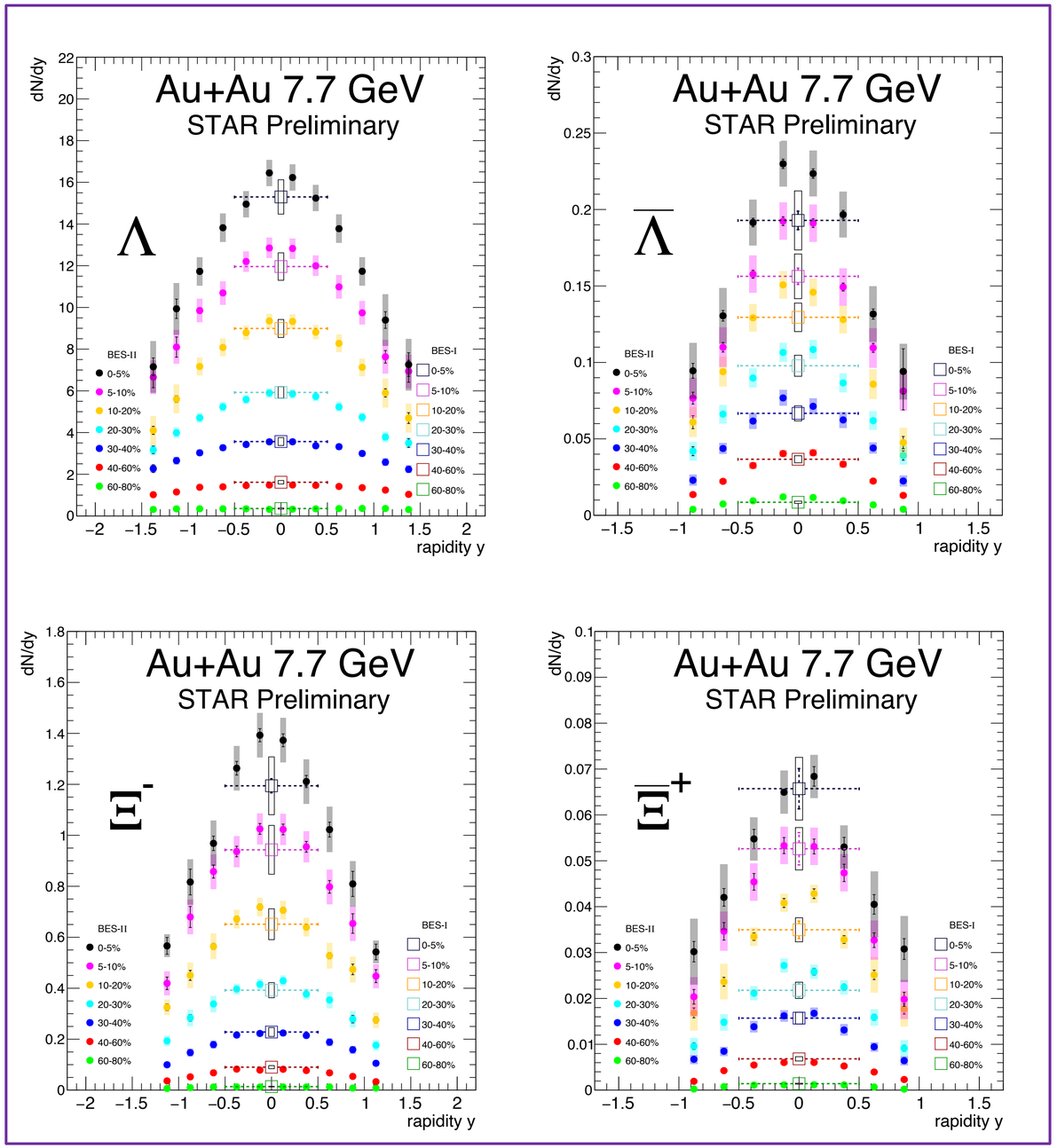


- Ξ, Ω and Λ low p_T extrapolation: Boltzmann function.
- ϕ low p_T extrapolation: Levy function.

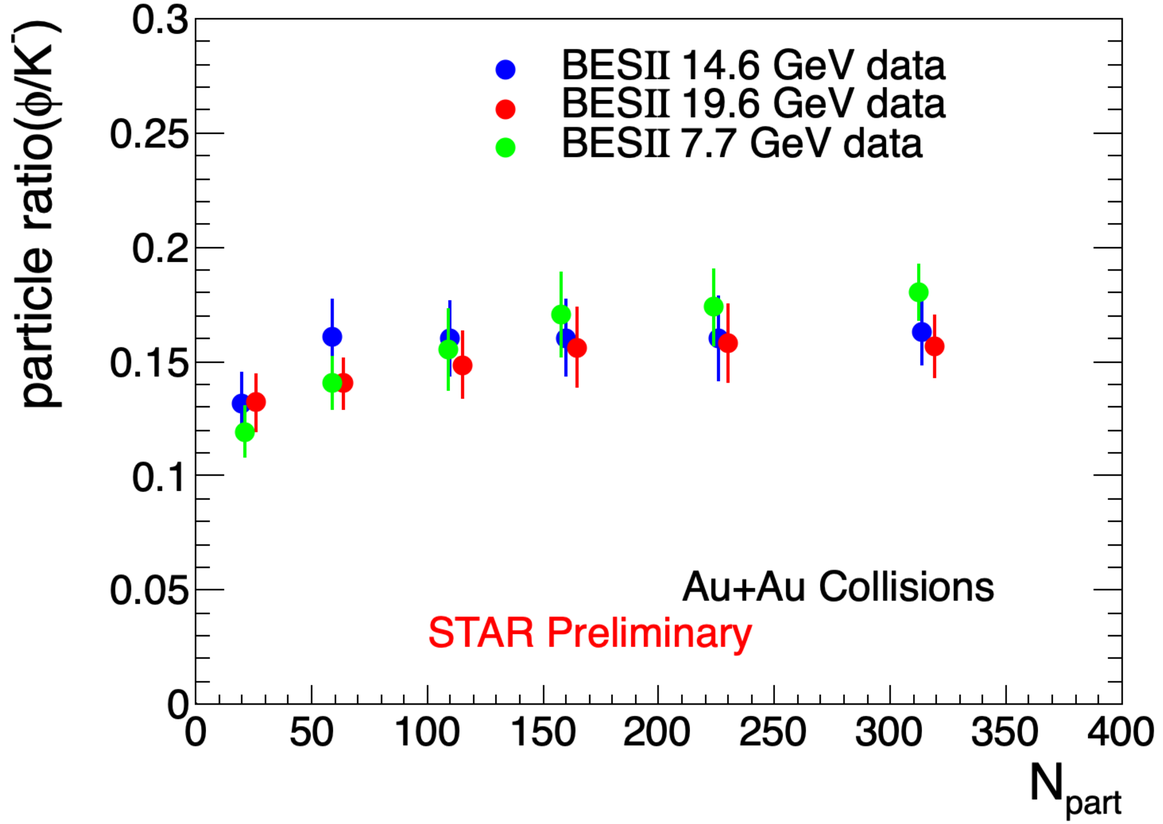
Rapidity spectra of $\Lambda(\bar{\Lambda})$ and $\Xi^-(\bar{\Xi}^+)$ at 7.7 GeV

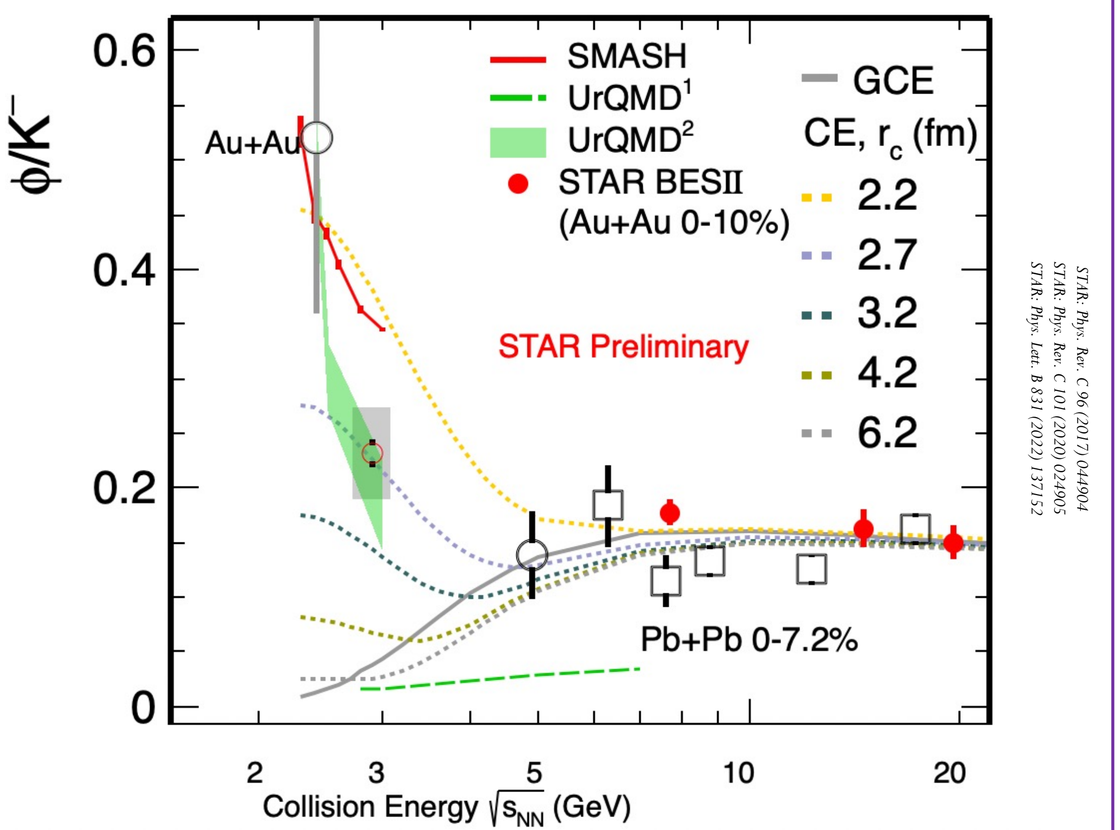
- Rapidity distributions of Λ baryon are wider than those of $\bar{\Lambda}$ baryon.
- The rapidity distributions of Ξ^- baryon are slightly wider than that of $\bar{\Xi}^+$ anti-baryons.
- Similar trends observed by NA49.

NA49, PRC 78, 034918 (2008)



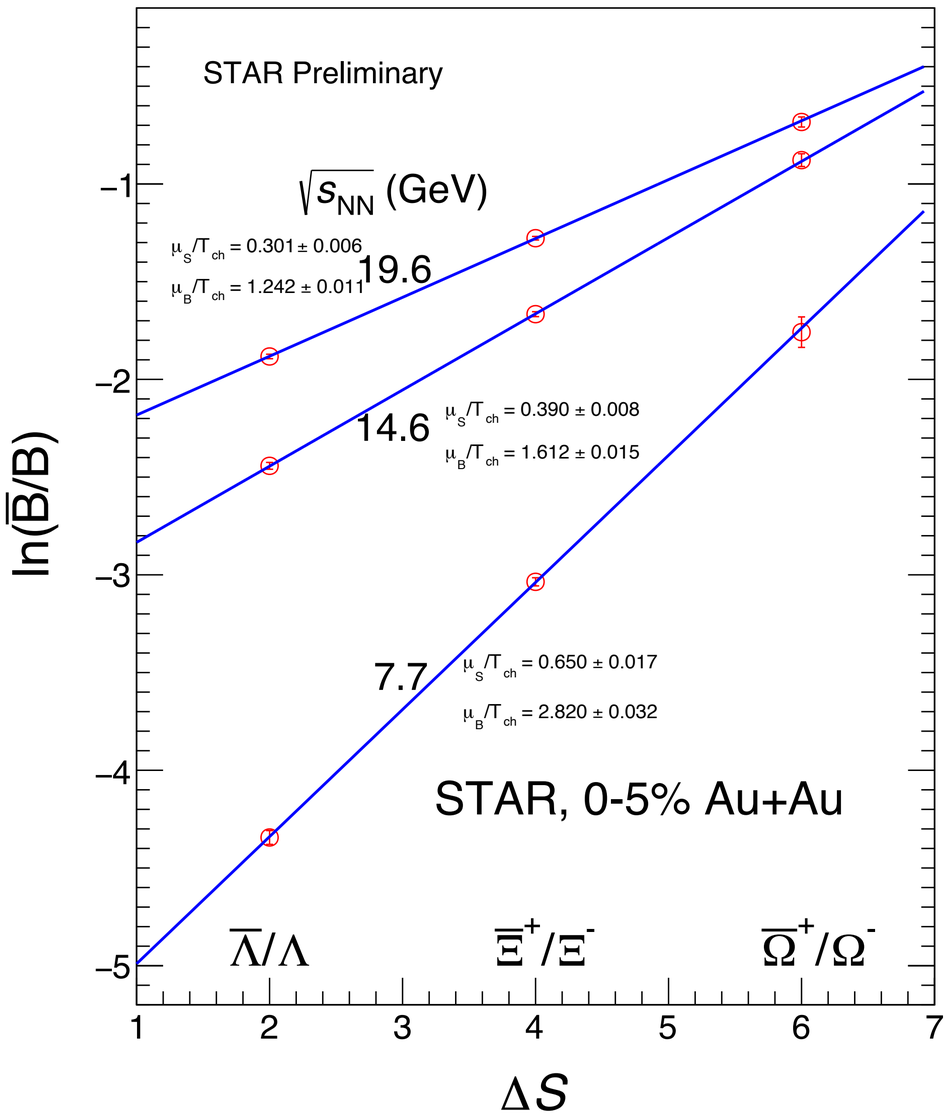
Centrality and Energy dependence of ϕ/K^- ratio



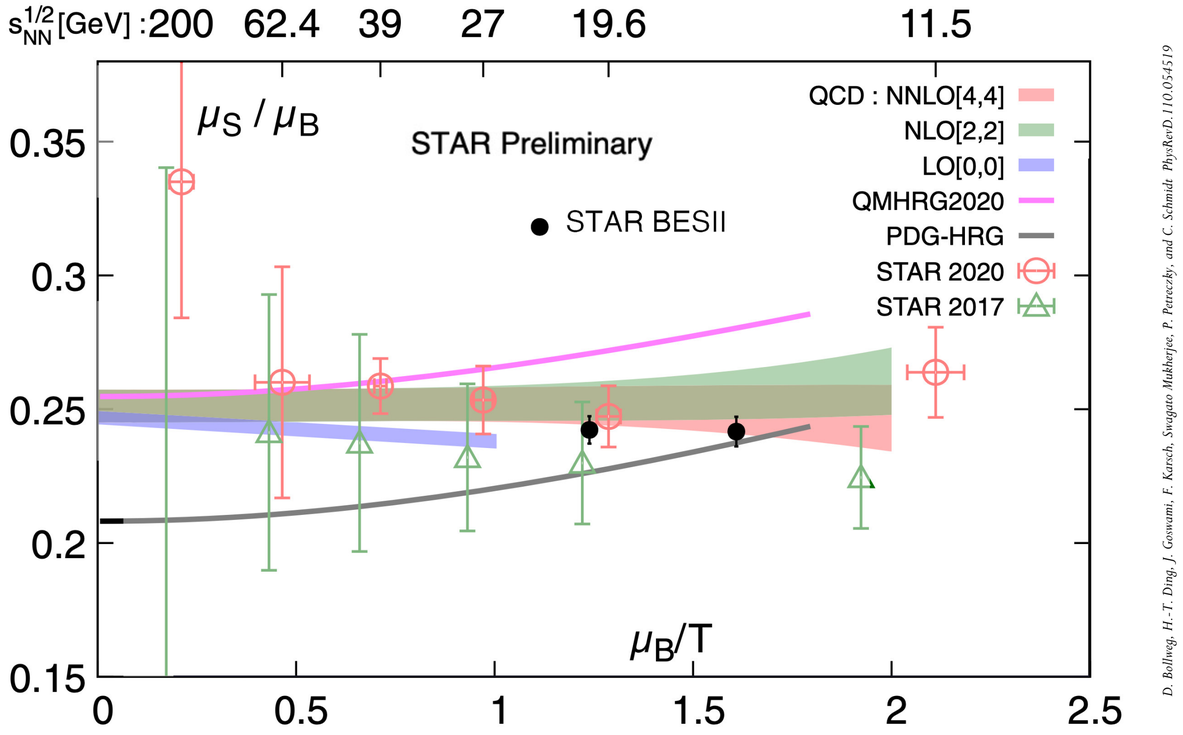


- The ϕ/K^- ratio exhibits no clear dependence on centrality or energy across the range of $\sqrt{s_{NN}}$ = 7.7 to 19.6 GeV.
- The ϕ/K^- ratio reaches the GCE limit at $\sqrt{s_{NN}}$ = 7.7, 14.6 and 19.6 GeV.

Anti-baryon to baryon ratios



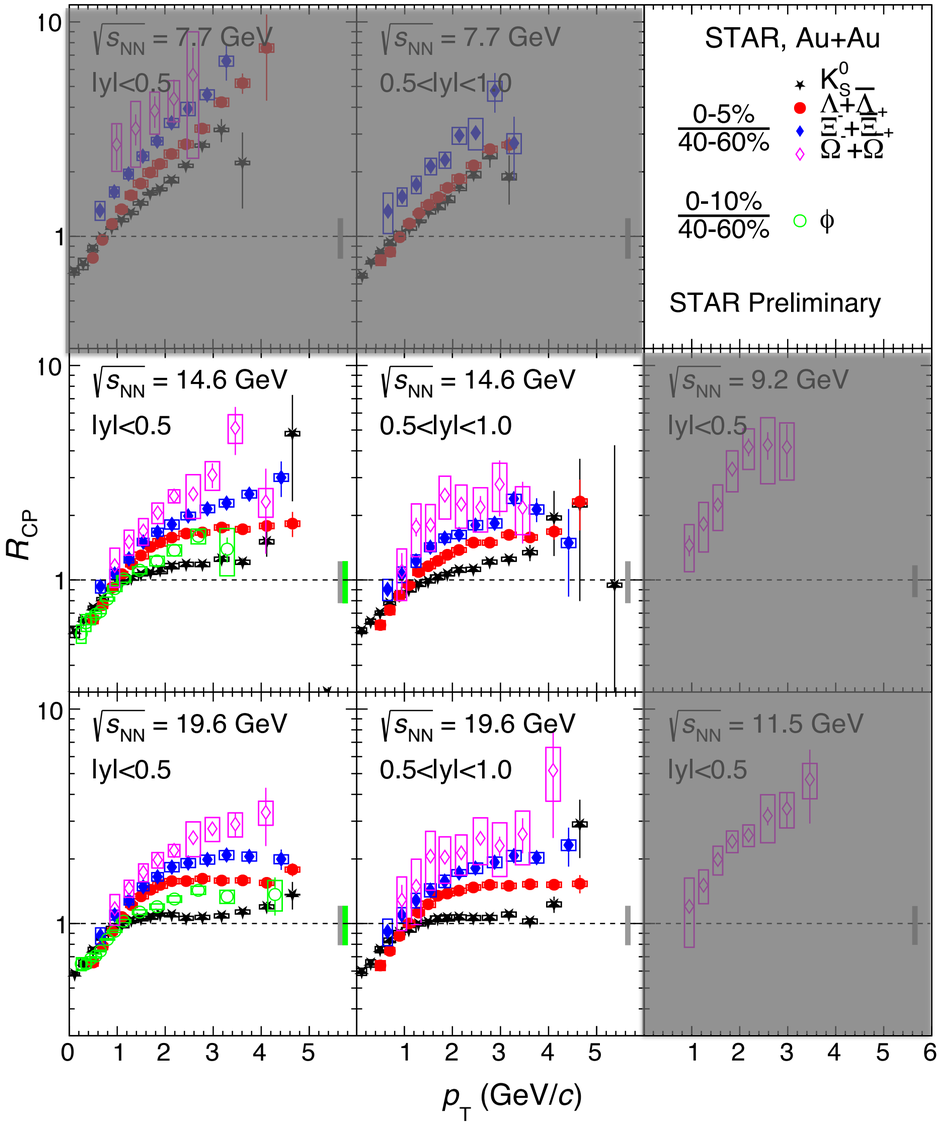
Thermal model prediction: $\ln(\overline{B}/B) = -2\mu_B/T_{ch} + \mu_S/T_{ch}\Delta S,$



- 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

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



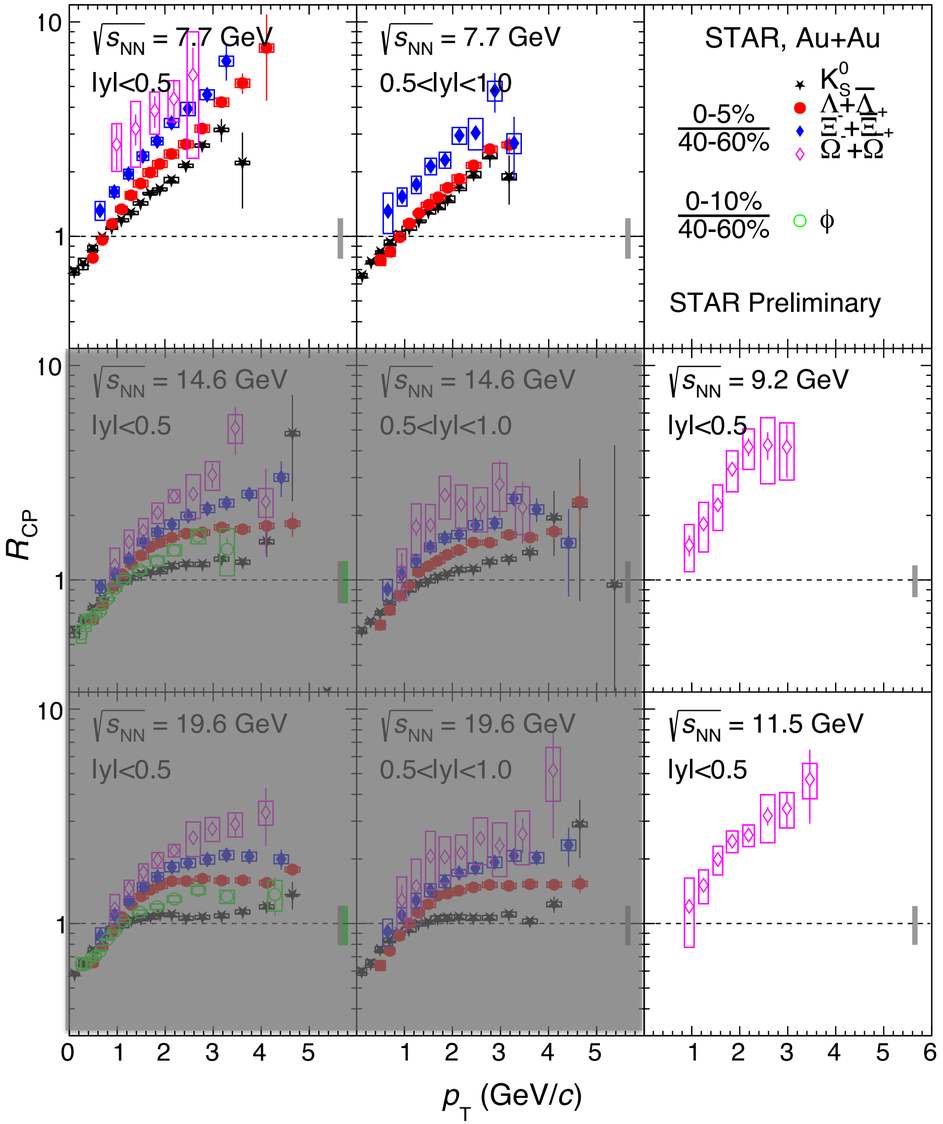
$$R_{\mathrm{CP}} = \frac{[(dN/dp_T)/\langle N_{\mathrm{coll}}\rangle]_{\mathrm{central}}}{[(dN/dp_T)/\langle N_{\mathrm{coll}}\rangle]_{\mathrm{peripheral}}}$$

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

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

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

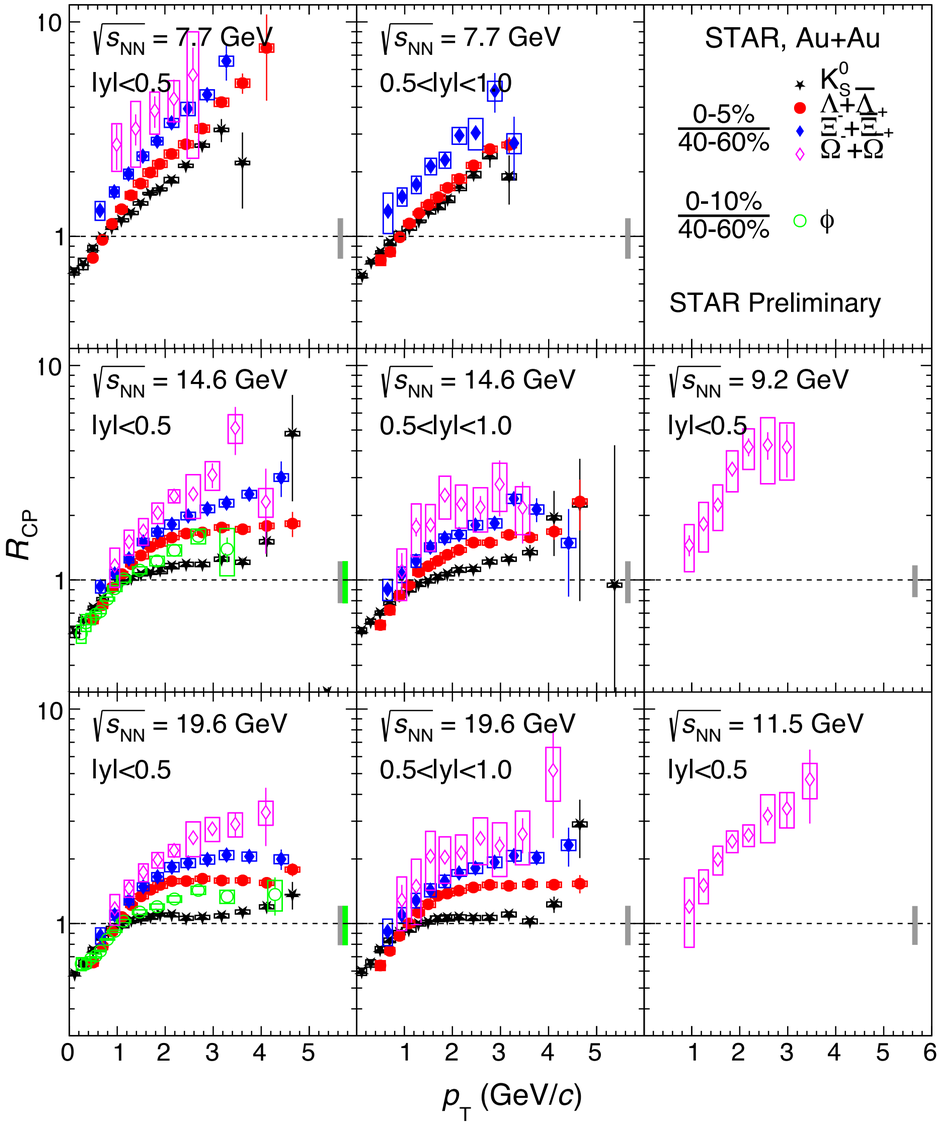
- R_{CP} continues to increase beyond $p_{\mathrm{T}} = 2$ GeV/c at $\sqrt{s_{\mathrm{NN}}} \leq 11.5$ GeV.
  - ✓Radial flow
  - ✓Quark coalescence
  - ✓Cronin effect



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

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

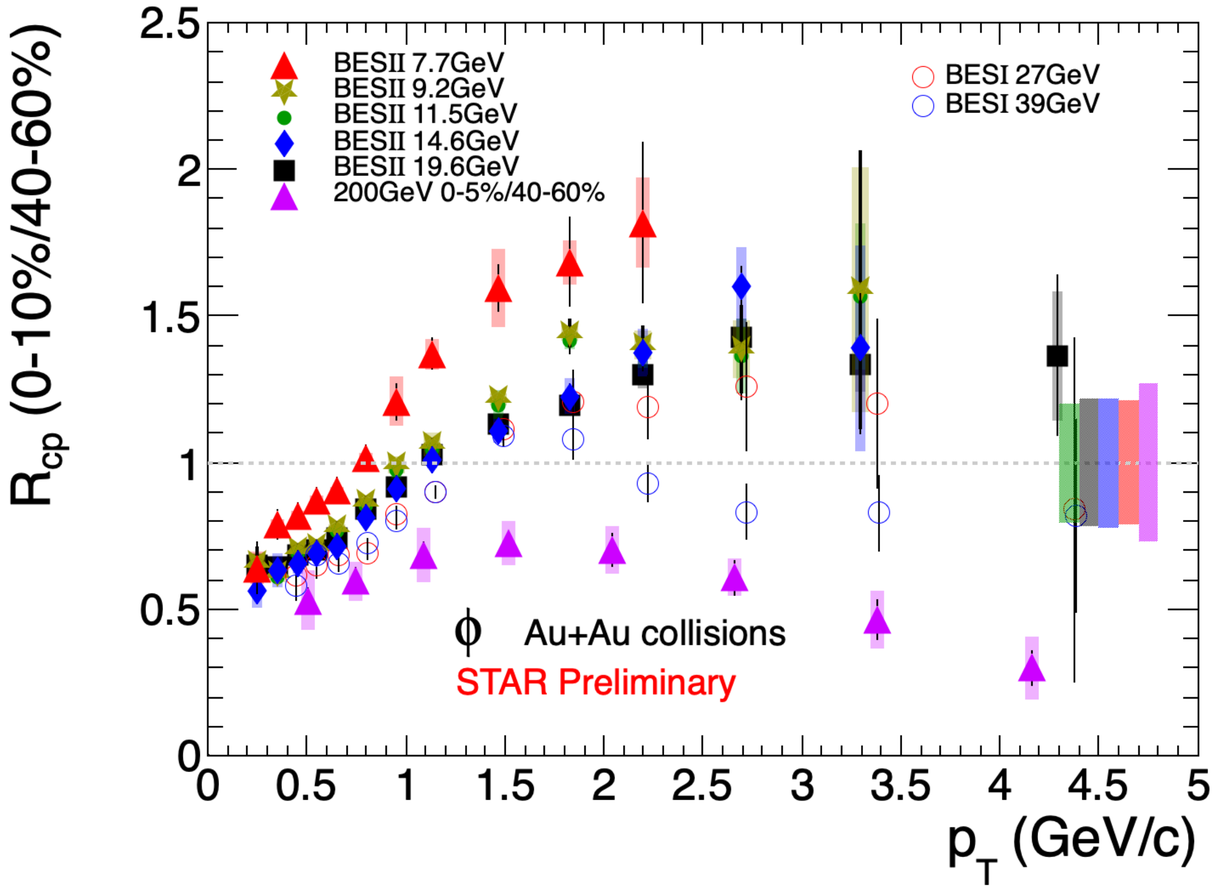
- $R_{\mathrm{CP}} = 1$ if nucleus-nucleus collisions are just simple superpositions of nucleon-nucleon collisions.
- R_{CP} tends to be flat and larger than unity at $p_{\mathrm{T}} > 2$ GeV/c for energies $\sqrt{s_{\mathrm{NN}}} \geq 14.6$ GeV.
- R_{CP} continues to increase beyond $p_{\mathrm{T}}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



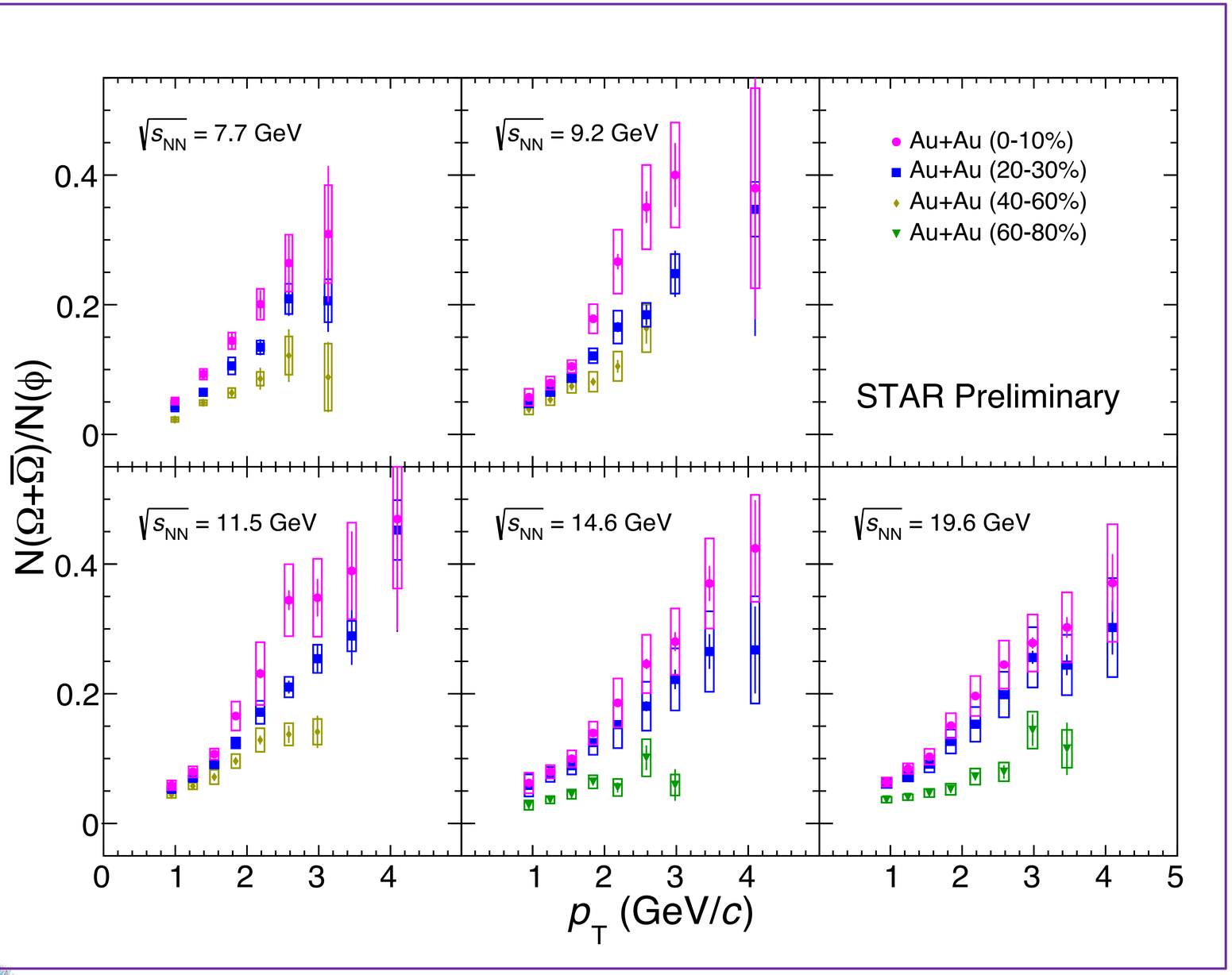
$$R_{\mathrm{CP}} = \frac{[(dN/dp_T)/\langle N_{\mathrm{coll}} \rangle]_{\mathrm{central}}}{[(dN/dp_T)/\langle N_{\mathrm{coll}} \rangle]_{\mathrm{peripheral}}}$$

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

- $R_{\mathrm{CP}} > 1$ for higher p_{T} at $\sqrt{s_{NN}}$ = 19.6 GeV and lower energies
- $R_{\mathrm{CP}} < 1$ 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.

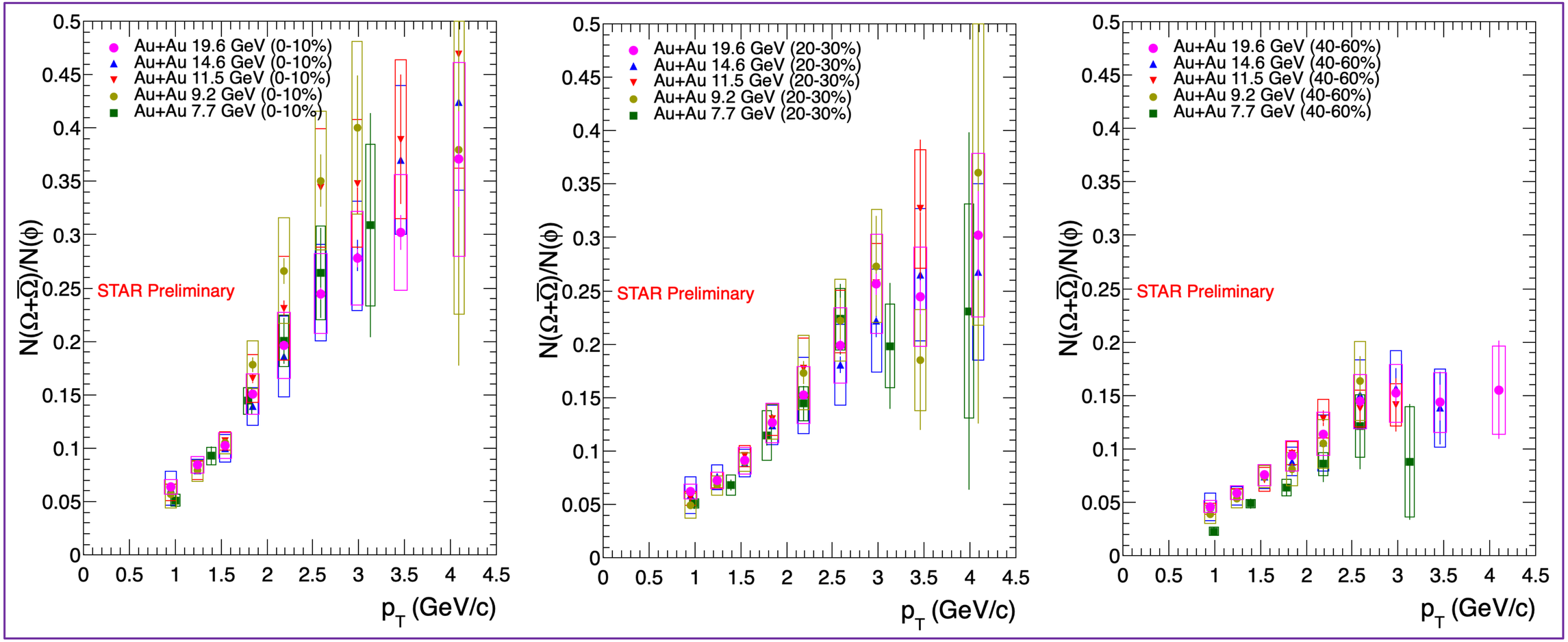


Centrality dependence of Ω/ϕ ratio at different energies



- 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
  - ✓Radial flow

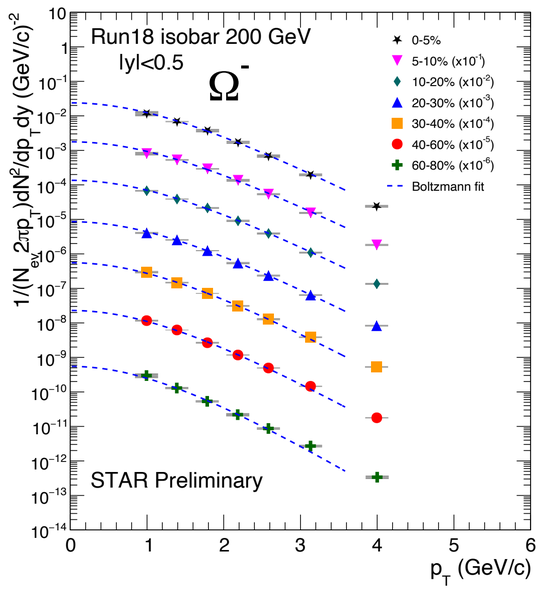
Energy dependence of Ω/ϕ ratio at different centralities

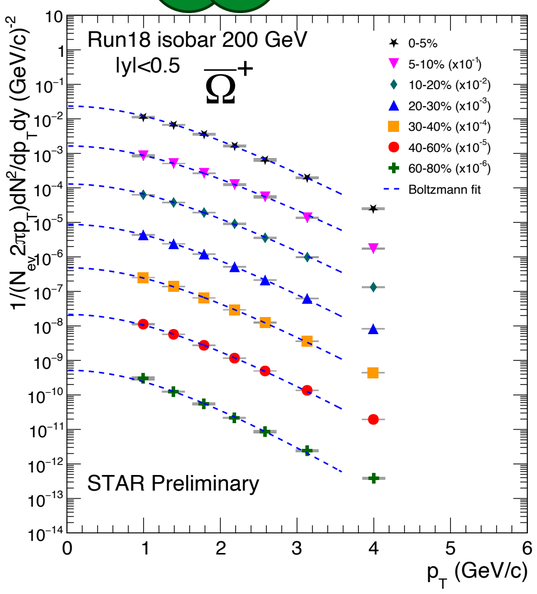


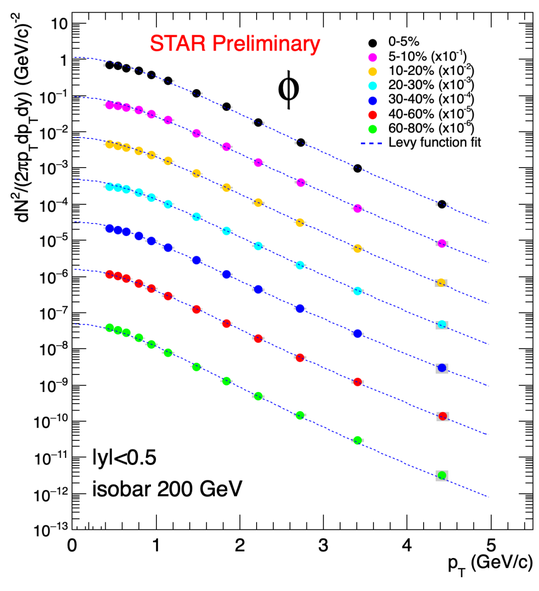
- In each 0-10%, 20-30% and 40-60% centrality bin, the Ω/ϕ ratios are consistent with each other within uncertainty from $\sqrt{s_{NN}}$ = 7.7 to 19.6GeV.

p_T Spectra in isobar and O+O collisions

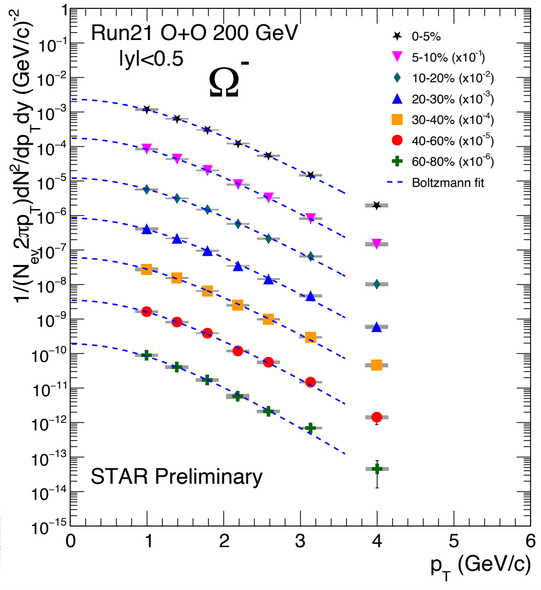
isobar

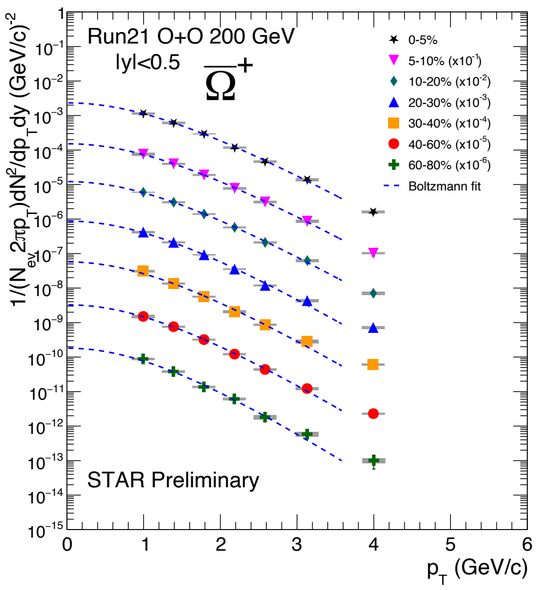


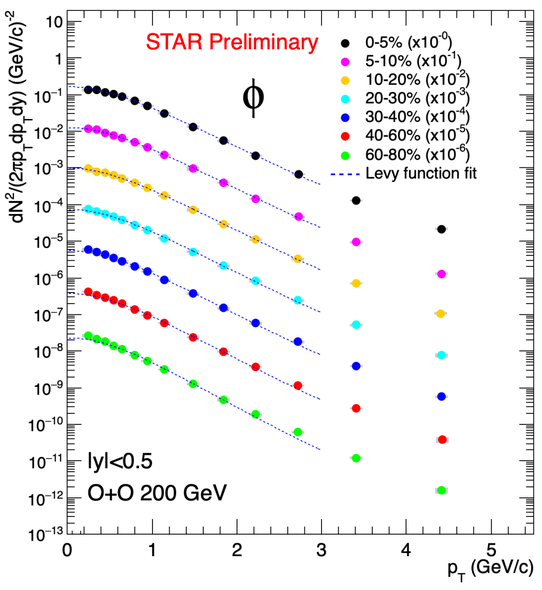




O+O



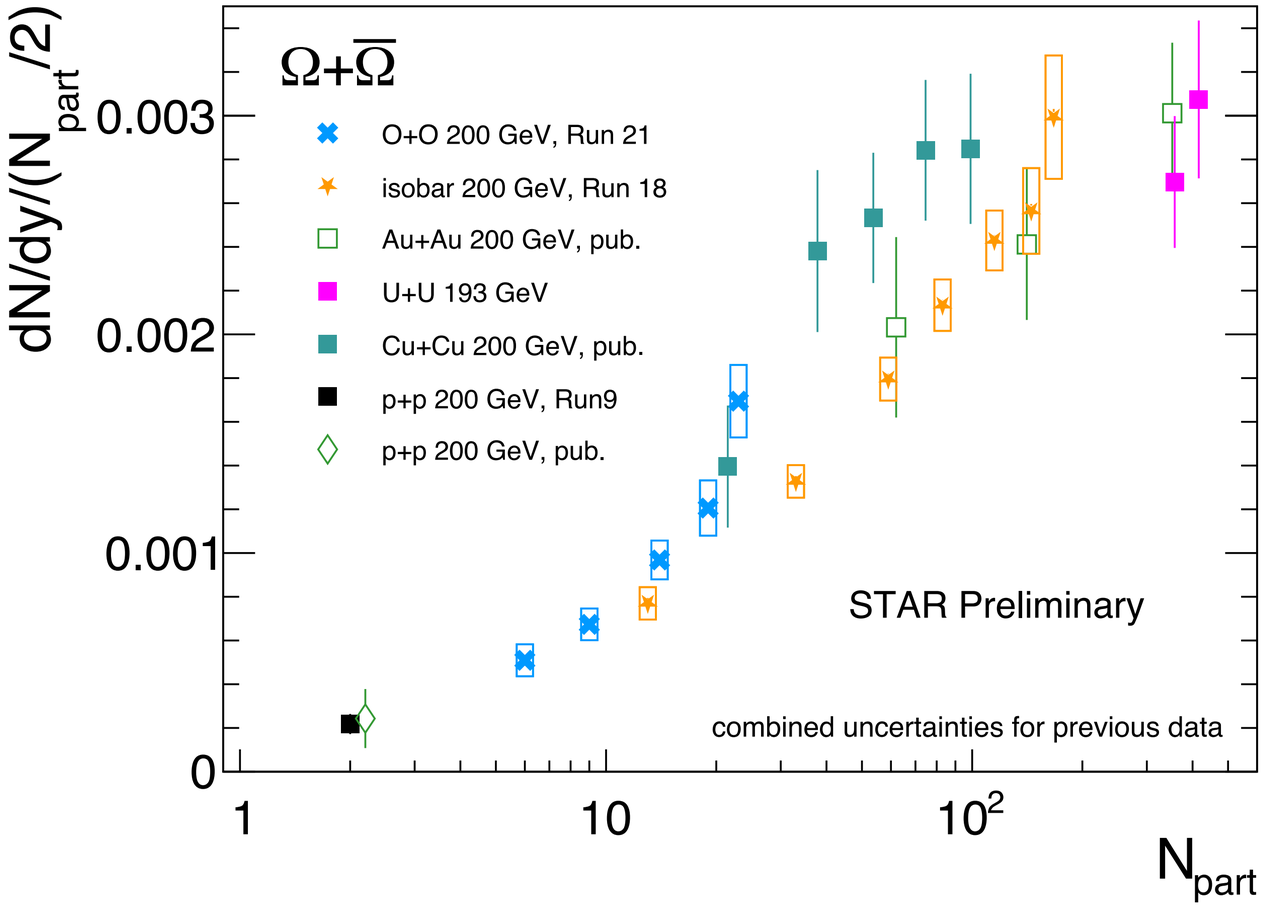




- Ω low p_T extrapolation: Boltzmann function.
- ϕ low p_T extrapolation: Levy function.

Run11 data points Npart shifted for clarity.
Errors from Npart not included.
p+p: STAR, Phys. Rev. C 75 (2007) 064901
pub. Au+Au: STAR, Phys. Rev. Lett. 98 (2007) 062301
Cu+Cu: STAR, Phys. Rev. Lett. 108 (2012) 072301
Au+Au run19: X. Xu QM2023

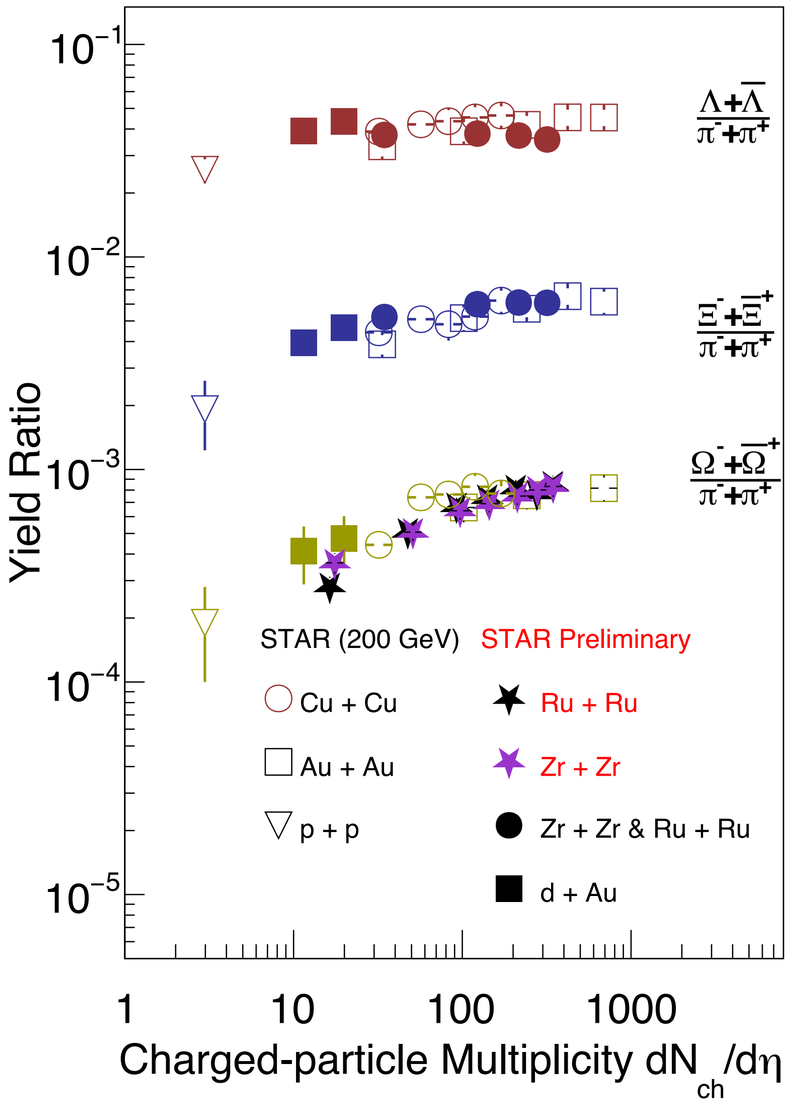
System size dependence of Ω yields



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

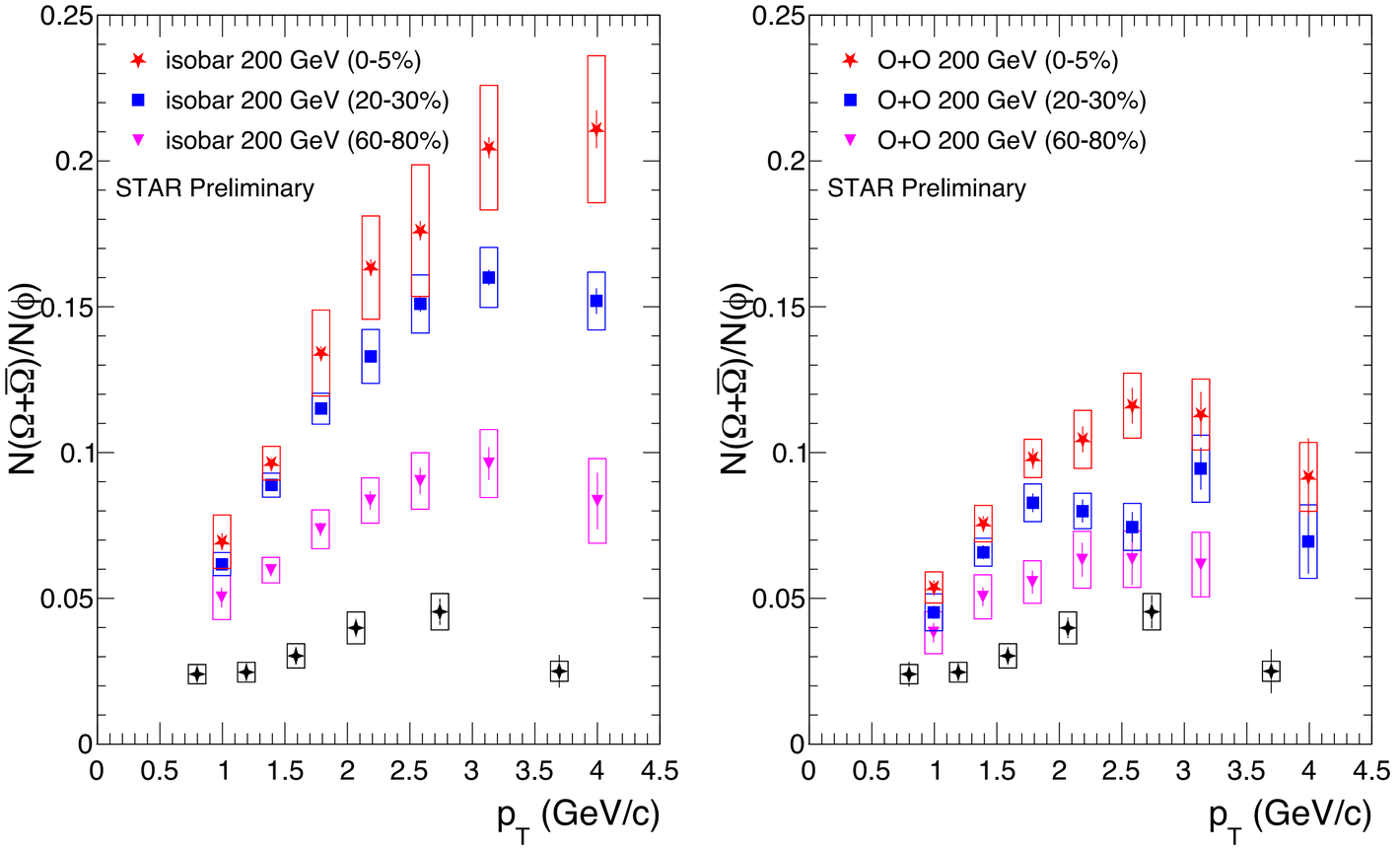
System size dependence of yield ratios

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.

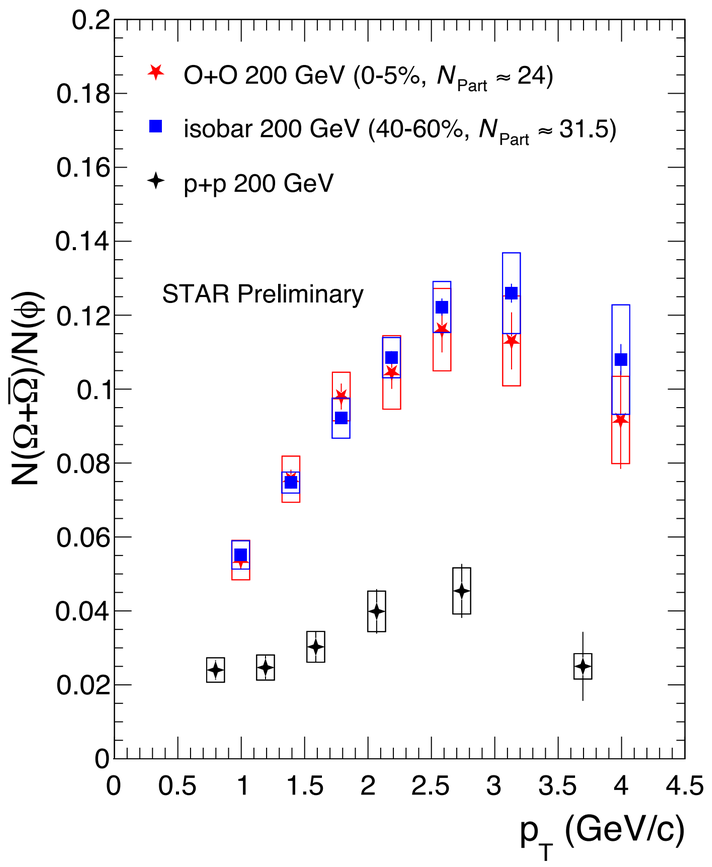
Centrality dependence of Ω/ϕ ratio (different systems)

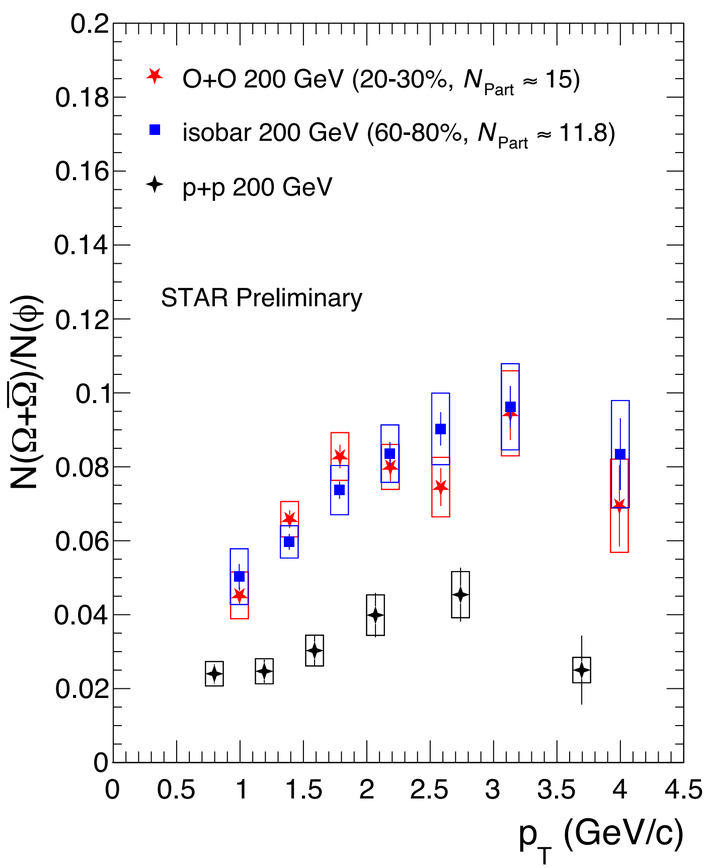


- In isobar and O+O collisions, Ω/ϕ ratio enhancement is observed with respect to p+p collisions. Enhancement increases from peripheral to central collisions.
- The enhancement of Ω/ϕ ratio is larger in central Isobar collisions than that in central O+O collisions

System size dependence of Ω/ϕ ratio

O+O (0-5%) Isobar (40-60%)





- 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.
- $\mathbf{R_{CP}}$ is significantly larger at 7.7GeV 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 $N_{\mathbf{part}}$.

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.