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ϕ production in Au+Au collisions at $\sqrt{s_{NN}}$=19.6, 14.6, and 7.7 GeV with the STAR experiment

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- Motivation
- Experimental analysis
- Results
  - ✓ p_{T} spectra
  - ✓ Rapidity spectra
  - ✓ Nuclear modification factors
  - ✓ ϕ/K^{-}, **Ω/ϕ ratio**
- Summary

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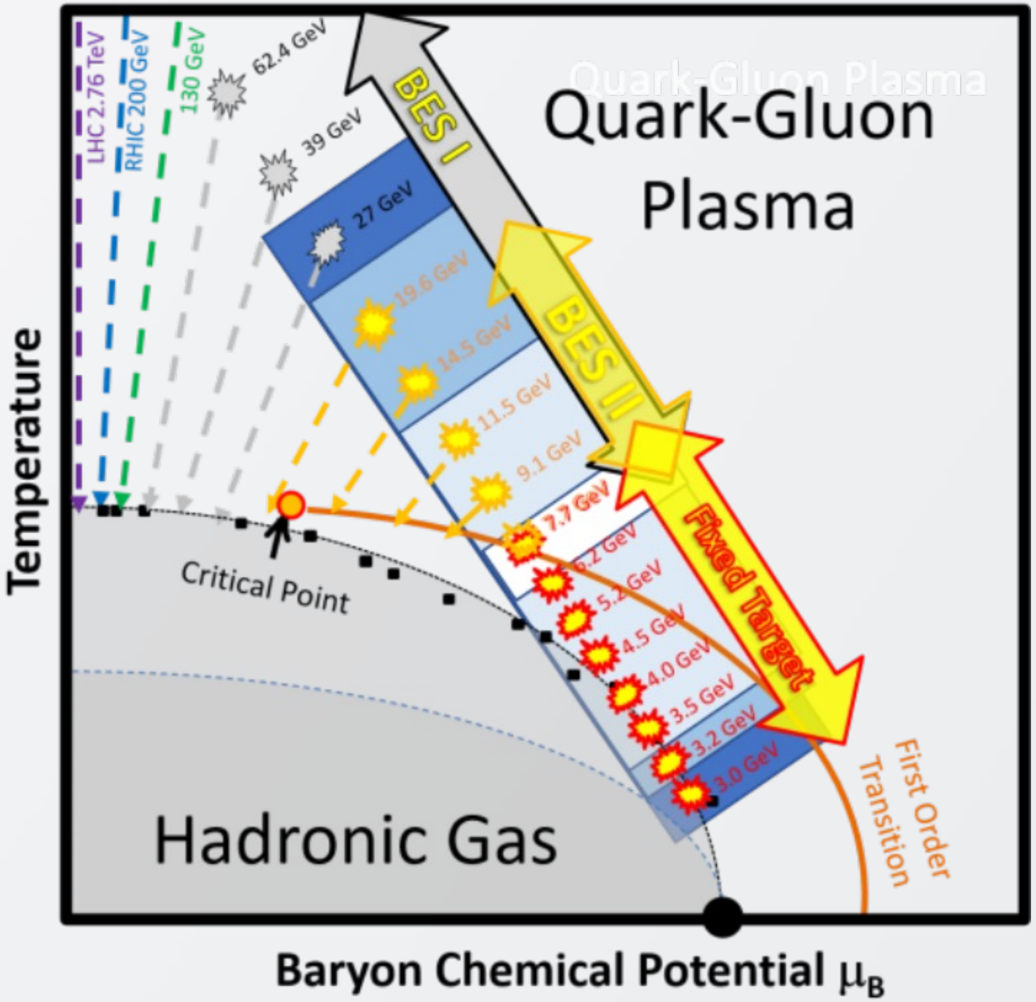
Motivation

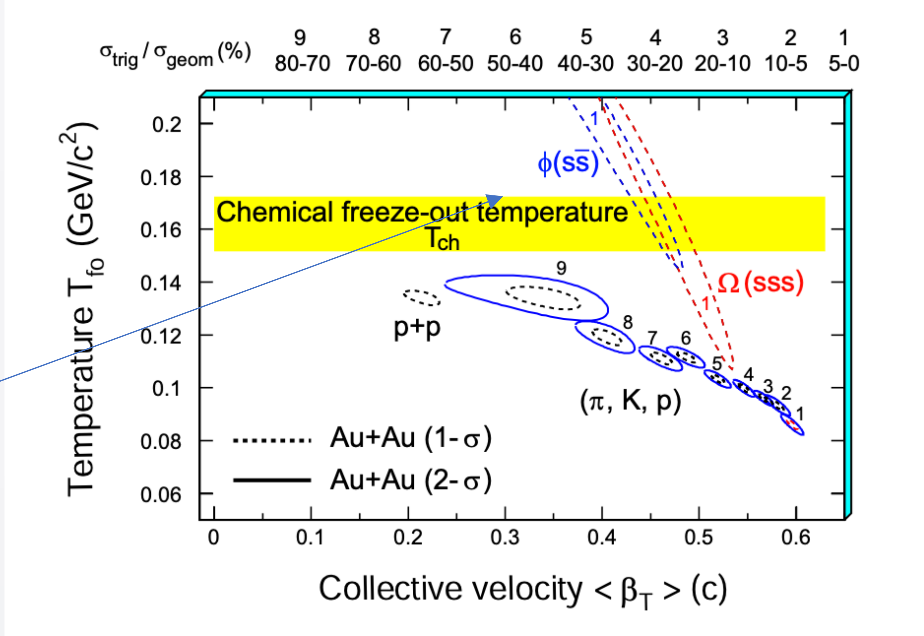
- Beam Energy Scan (BES) program:
  - Search for the critical point
  - Search for the first-order phase transition
  - Search for the threshold of QGP formation
- Energy dependency of QGP signature
  - Strange baryon-to-meson ratio can be utilized to understand hadronization mechanism
  - R_{CP} may give insight into the parton energy loss

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

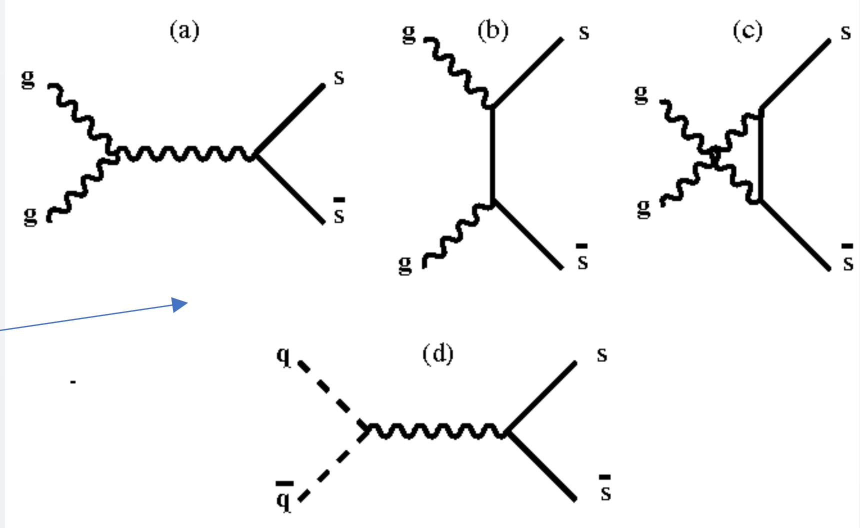


Motivation: Why study ϕ?

- Long lifetime and small reaction cross-section
  - Lifetime: 41 fm/c → the decay products are not disturbed by the late hadronic rescatterings
  - Small cross-section → ϕ is more likely to remain unaffected by the later stage of hadronic interactions

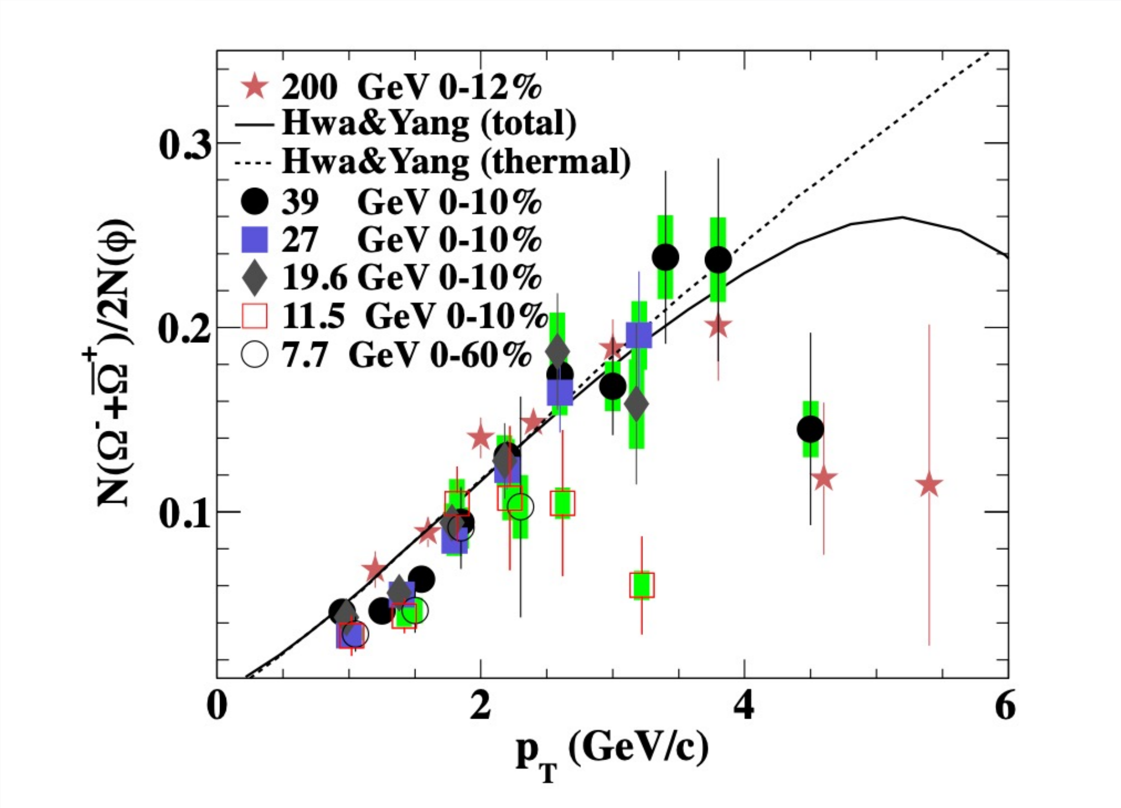


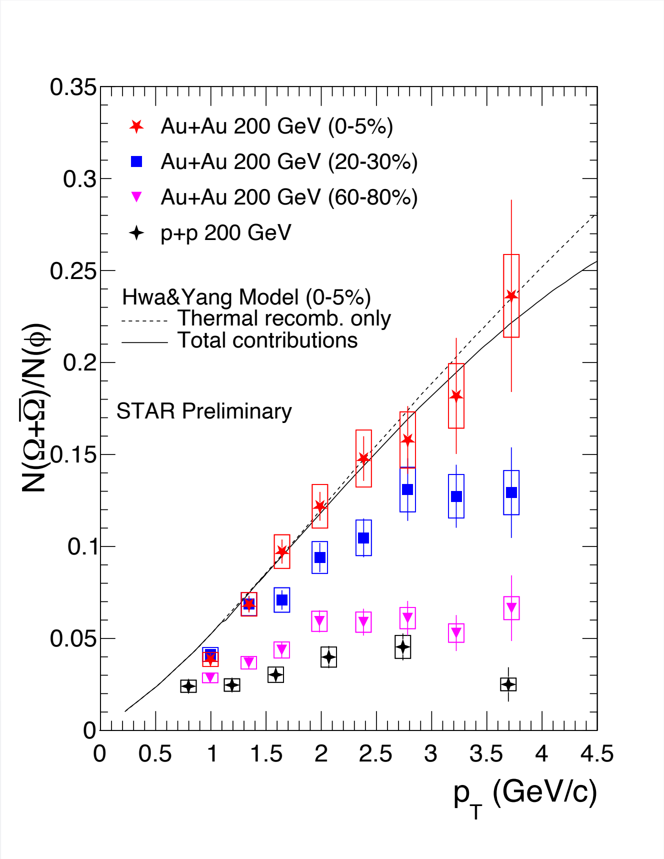
- Enhanced yield in QGP
  - Restored chiral symmetry in QGP → the mass of s and $\bar{s}$ is smaller and $s\bar{s}$ pairs can be produced in large quantities by gluon fusion and light $q\bar{q}$ pairs annihilation



Motivation: Why Ω/ϕ ratio?

STAR: Phys. Rev. C 93 (2016) 2, 021903



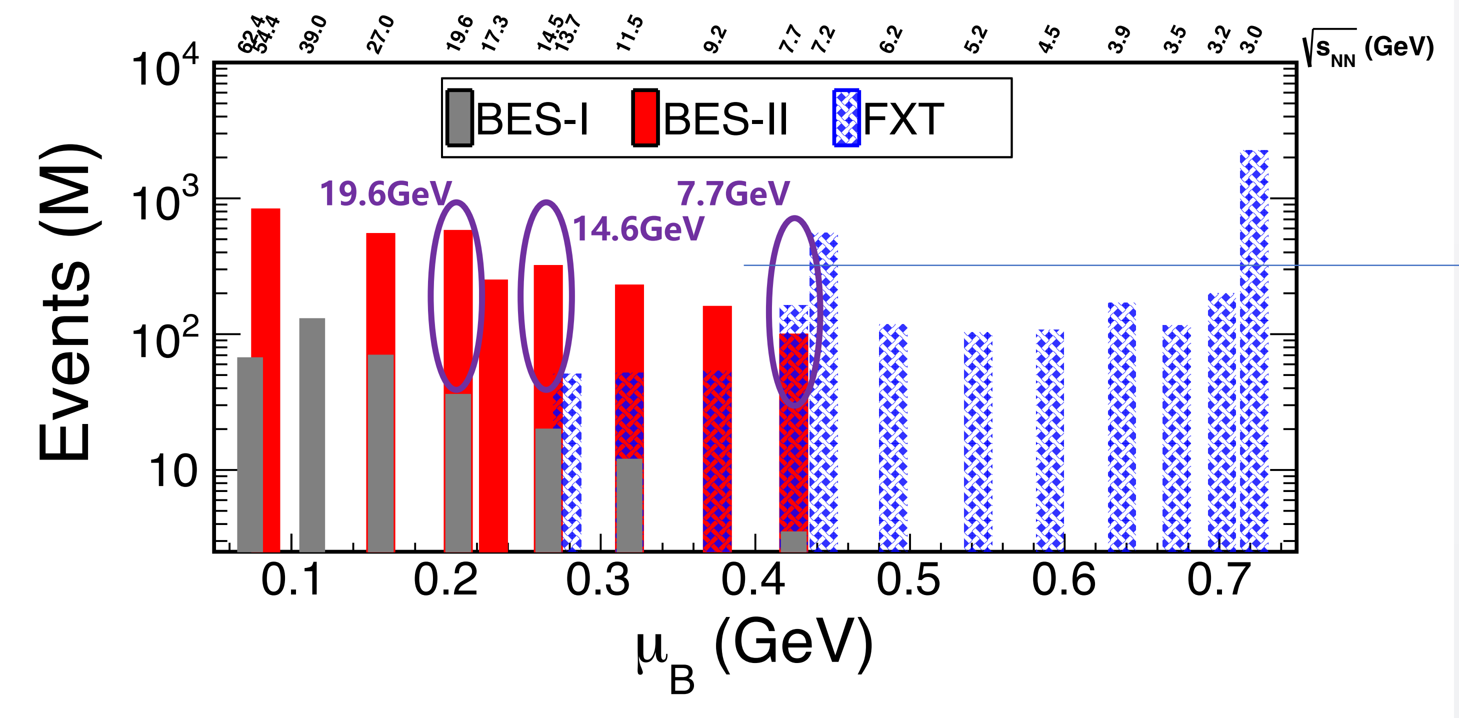


- Ω/ϕ ratio for BES-I energies
- Ω/ϕ ratio for 200 GeV energies

➢ At $\sqrt{s_{NN}}$ = 200 GeV, the enhanced Ω/ϕ ratios from p+p collision to central Au+Au collision may indicate the existence of QGP

➢ For BES-I energy, the uncertainties are too large to draw a firm conclusion below 11.5GeV.

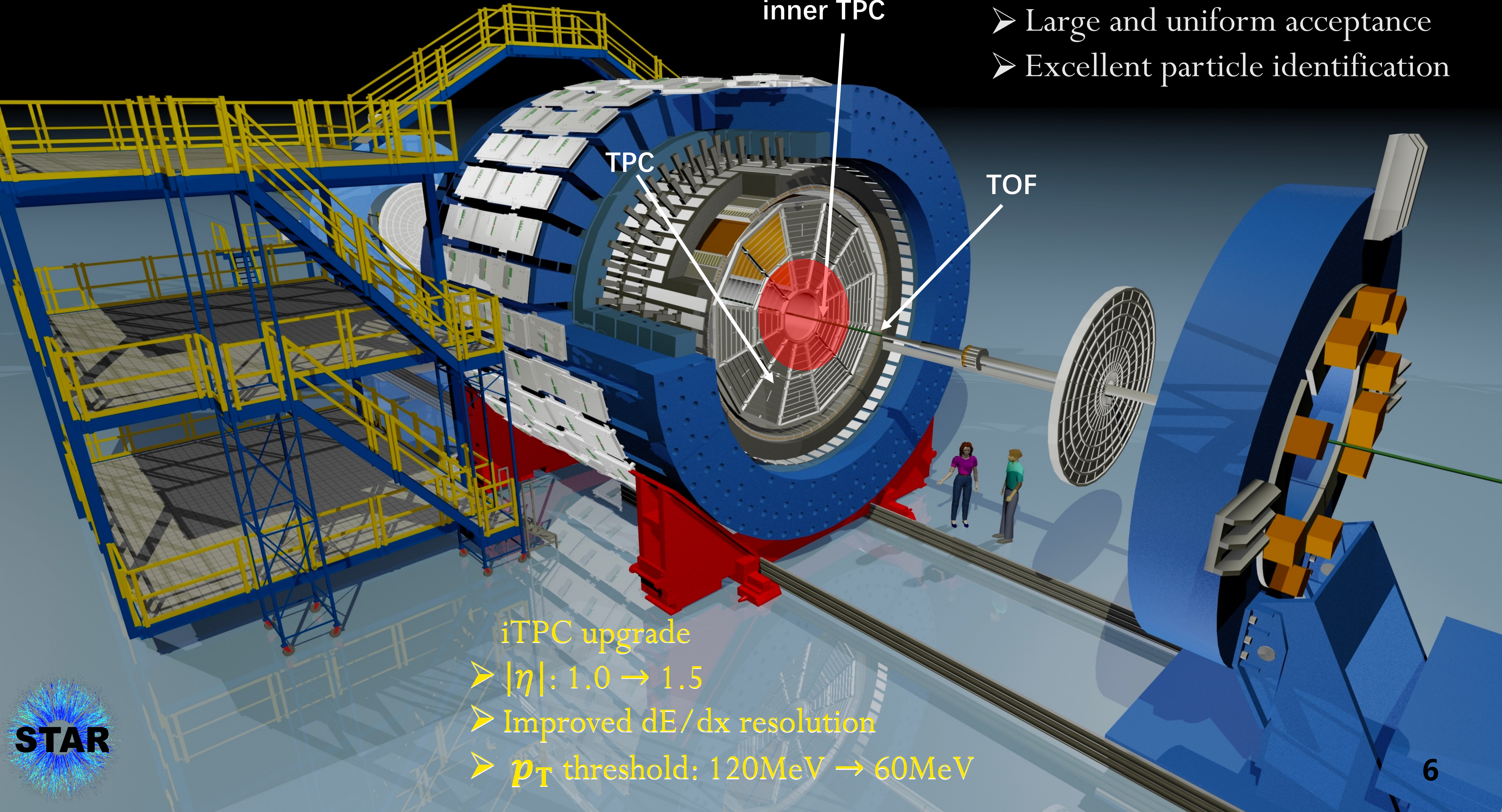
Motivation: More precise measurement



BES-II vs BES-I

$\sqrt{s_{NN}}$ (GeV)	Events BES-I (10^6)	Events BES-II (10^6)
7.7	3	**45**
9.2	-	**78**
11.5	7	**110**
14.5	20	**178**
17.3	-	**116**
19.6	15	**270**
27	30	**220**

- BES-II compared to BES-I: ~10-18 times larger statistics
  → higher precision and wider μ_B coverage



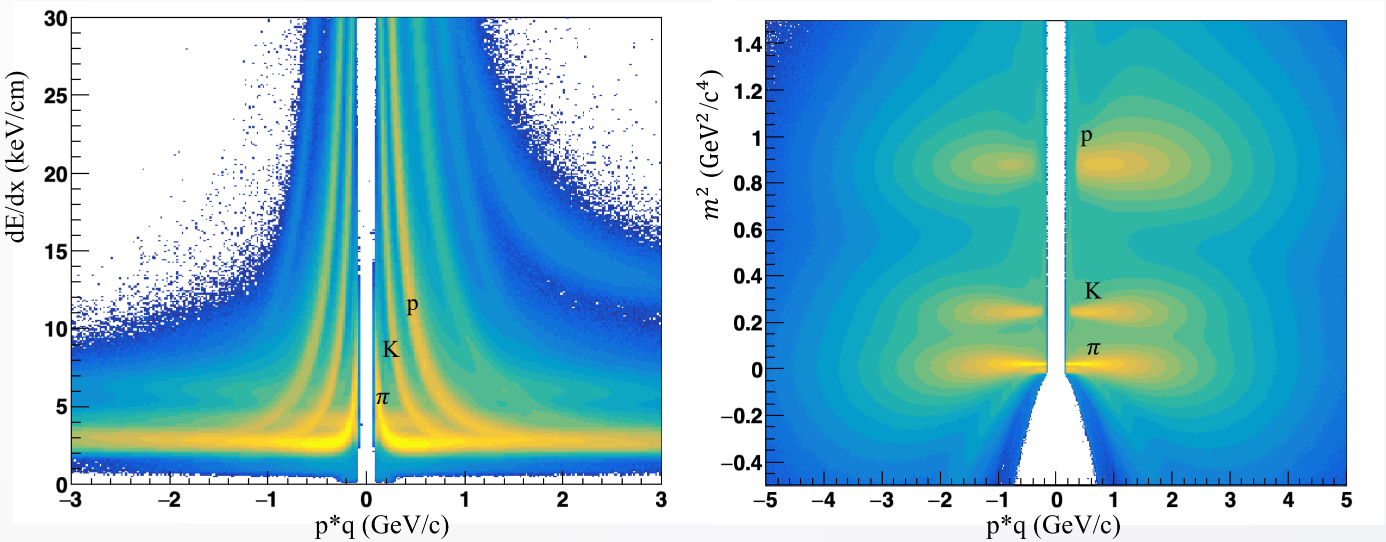
- Large and uniform acceptance
- Excellent particle identification

iTPC upgrade

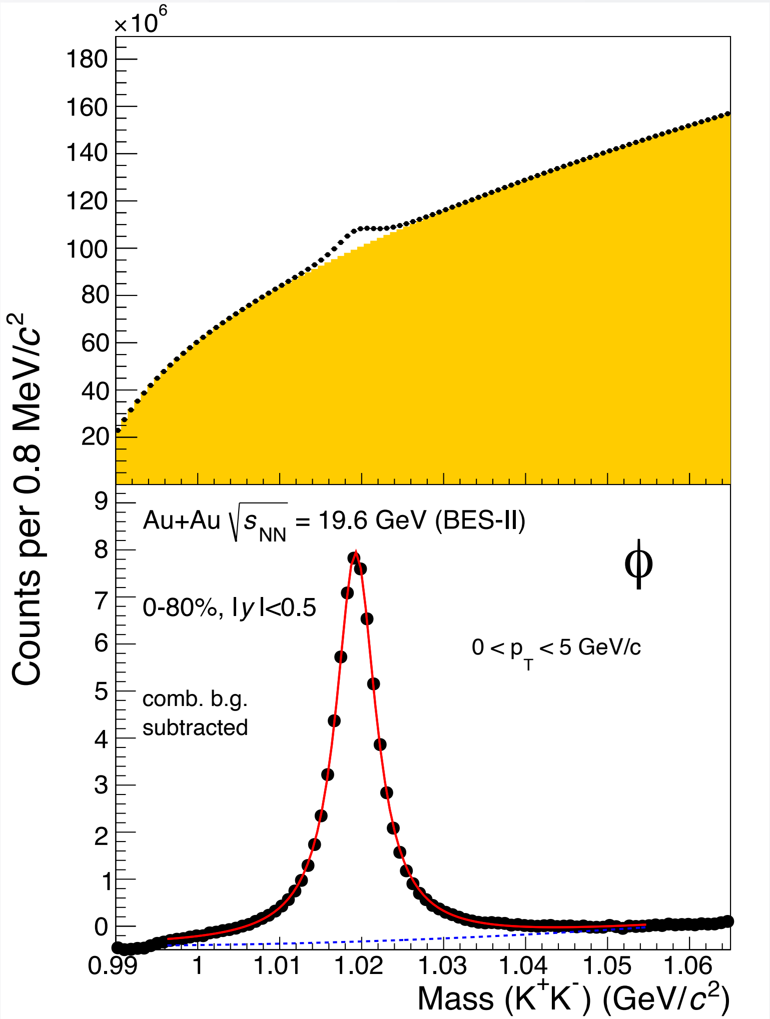
- $|\eta|$: 1.0 → 1.5
- Improved dE/dx resolution
- p_T threshold: 120MeV → 60MeV

Particle identification and reconstruction

Au+Au $\sqrt{s_{NN}} = 19.6$ GeV



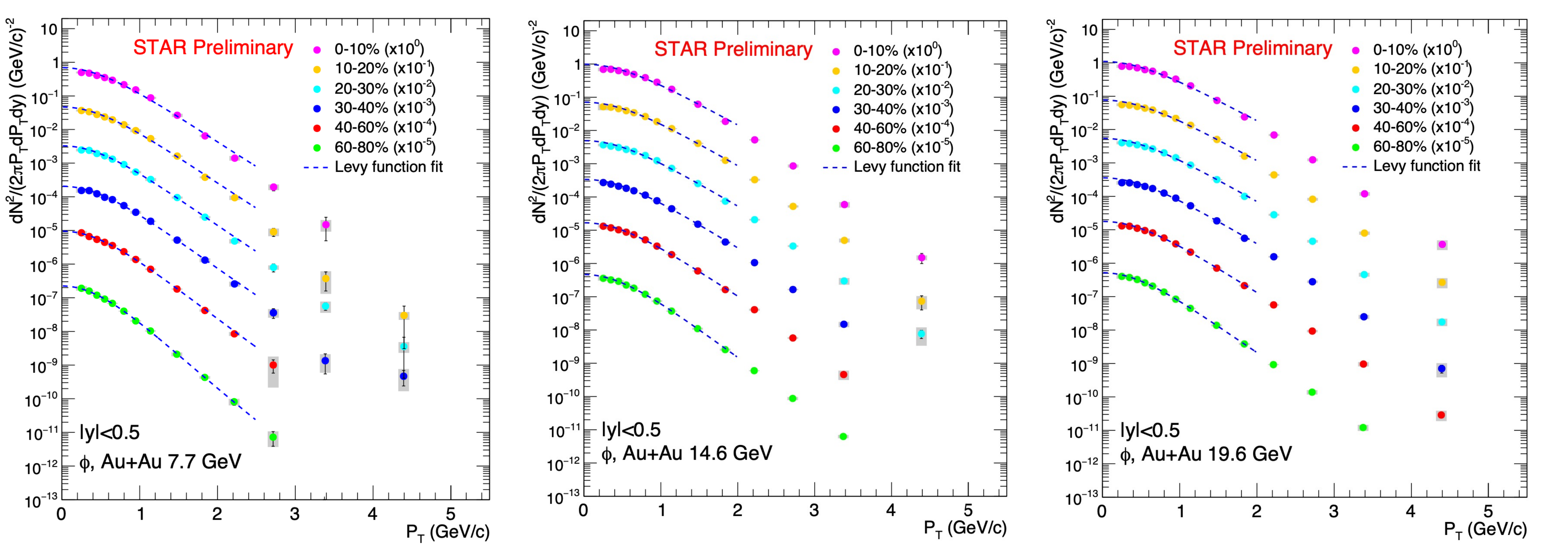
- ➢ Particle identification with upgraded TPC and bTOF



$\phi \rightarrow K^+ + K^-$ (49.1%)

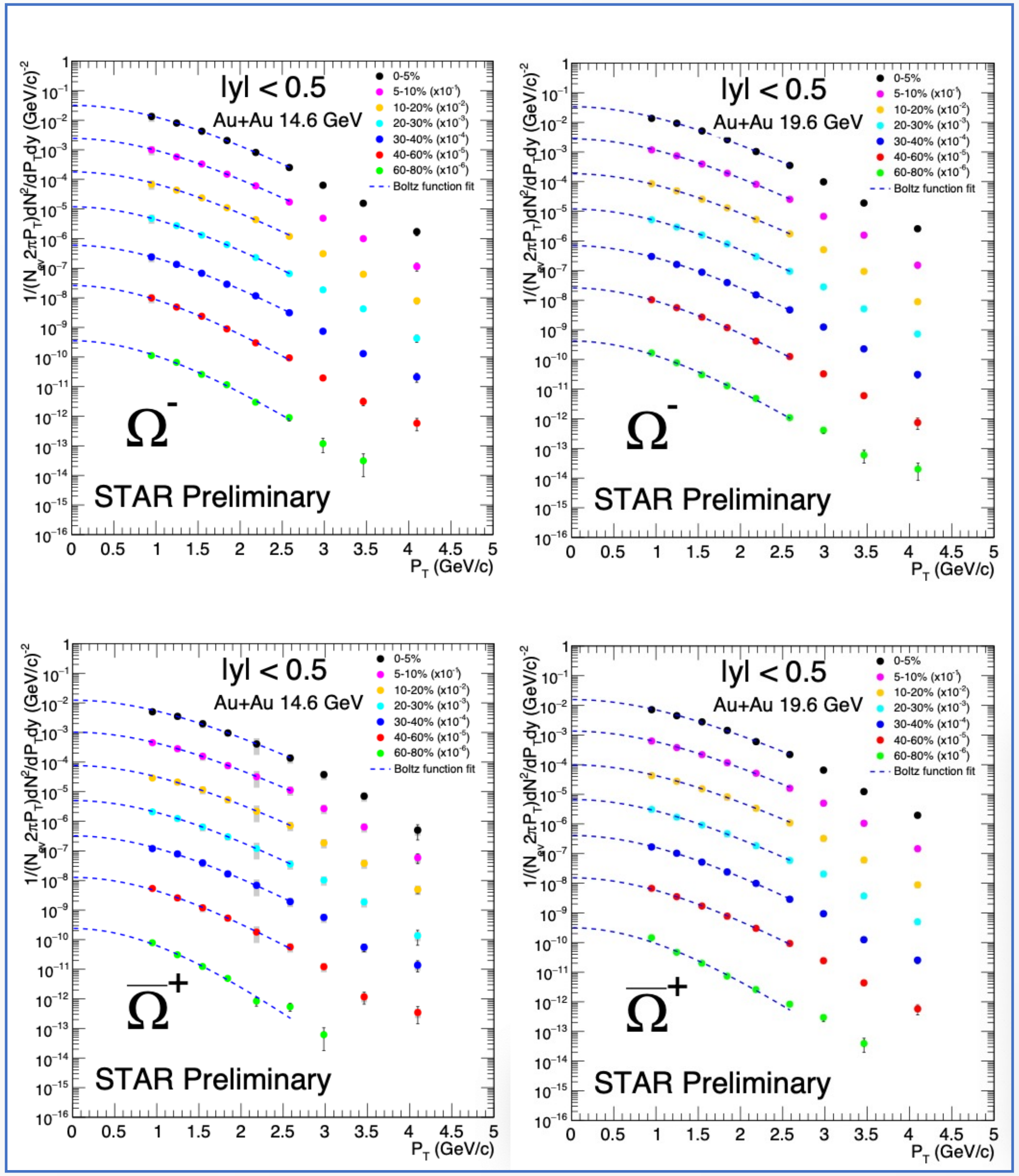
- Combinational background have been removed by Mix-Event Method.

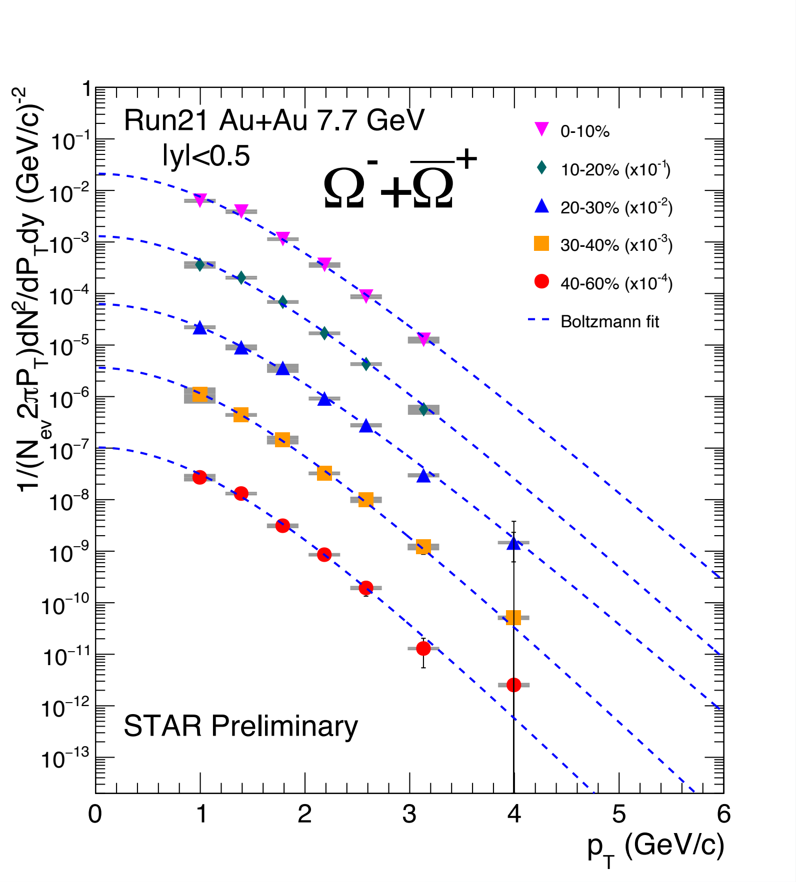
p_T spectra of ϕ at $\sqrt{s_{NN}}$ = 19.6, 14.6 and 7.7 GeV



- For ϕ: Levy function fit to extrapolate down to zero p_T

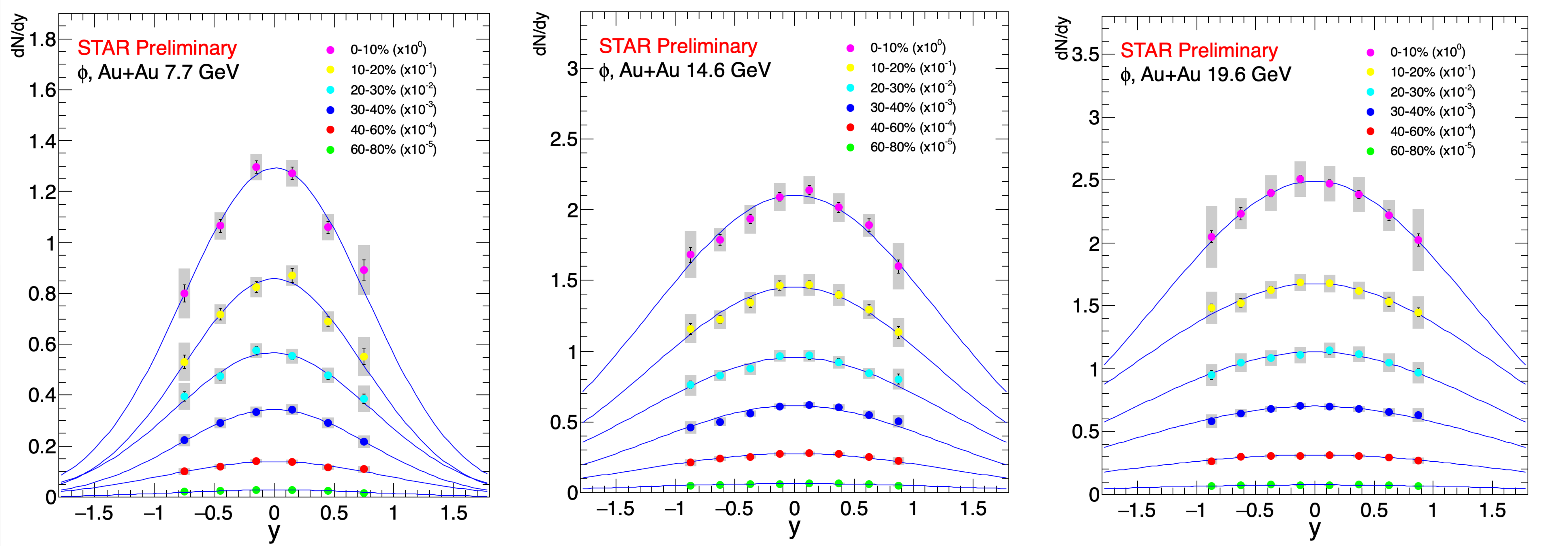
p_T spectra of Ω at $\sqrt{s_{NN}}$ = 19.6, 14.6 and 7.7 GeV





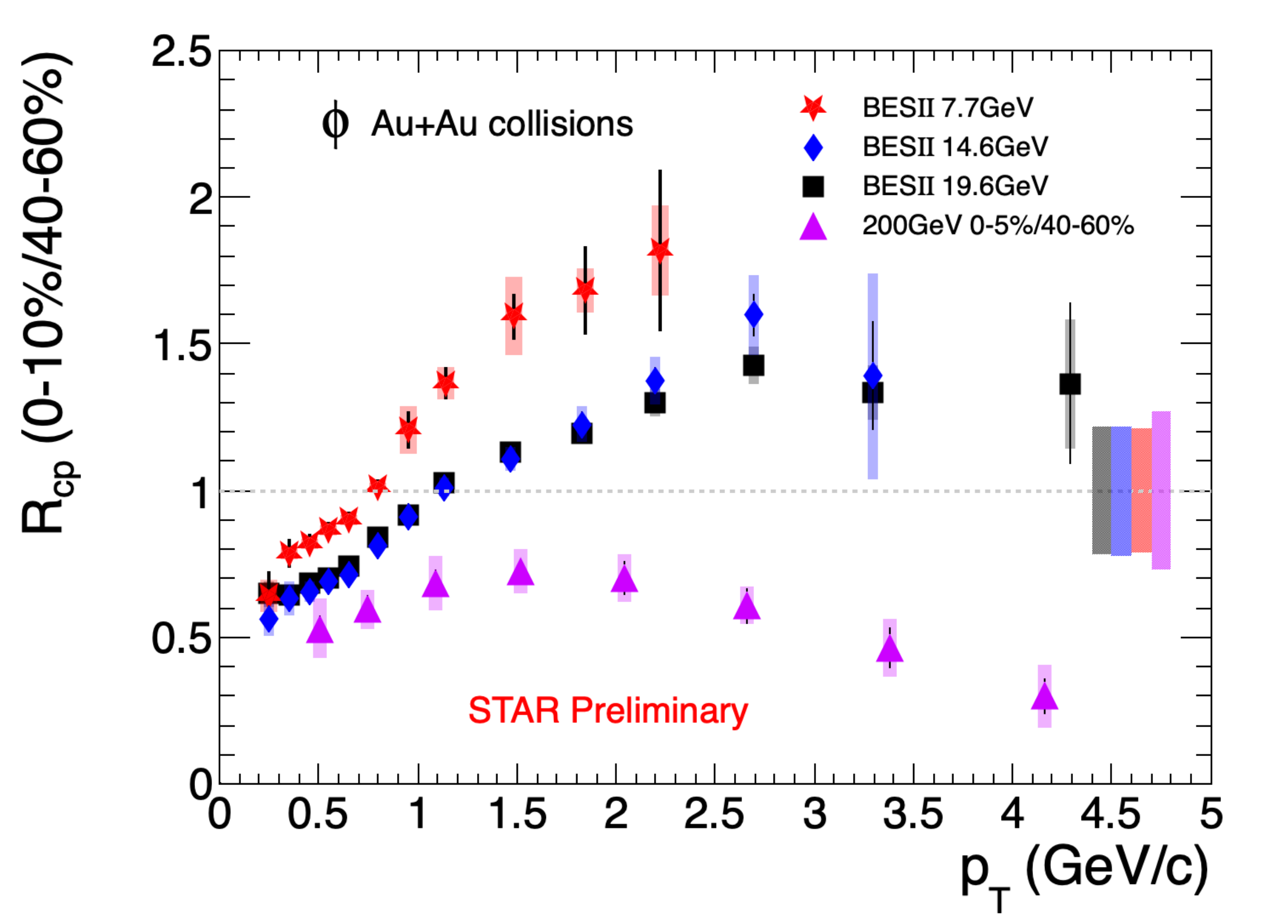
- For Ω: Boltzmann function fit to extrapolate down to zero p_T

Rapidity spectra of ϕ



- Rapidity spectra of ϕ are Gaussian-like distributions
- Rapidity distribution become wider with increasing energy

Nuclear modification factor

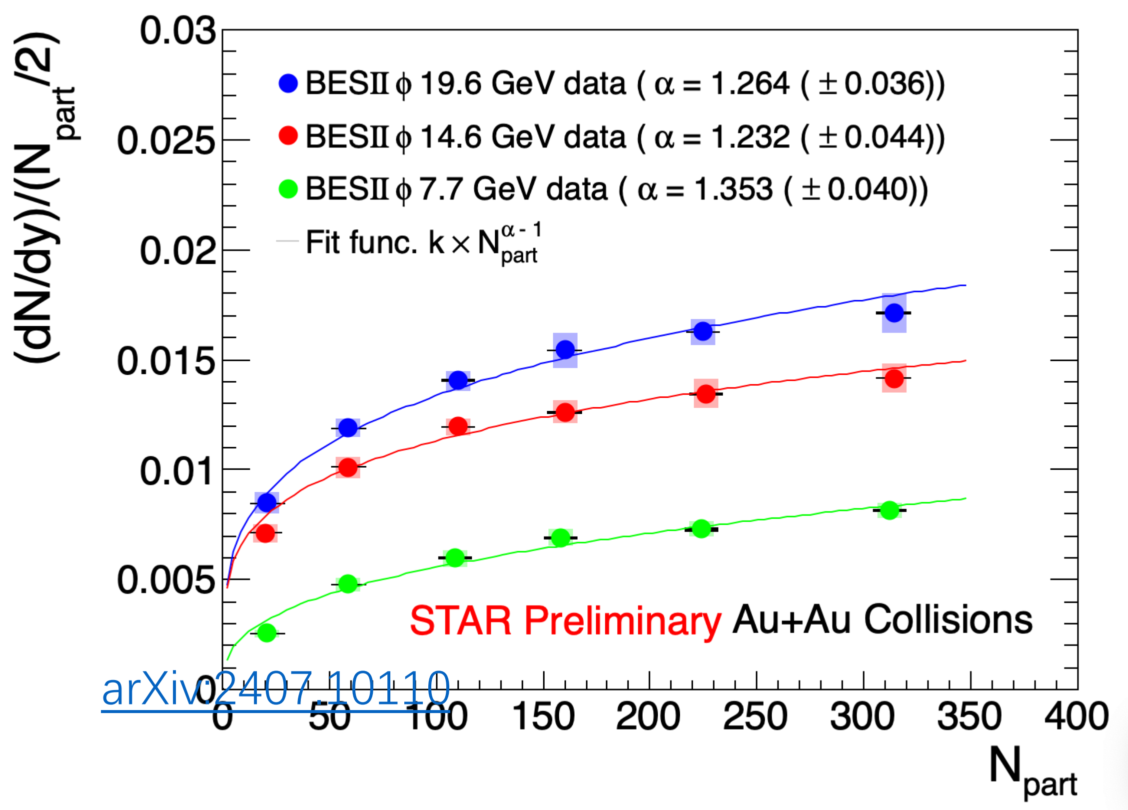


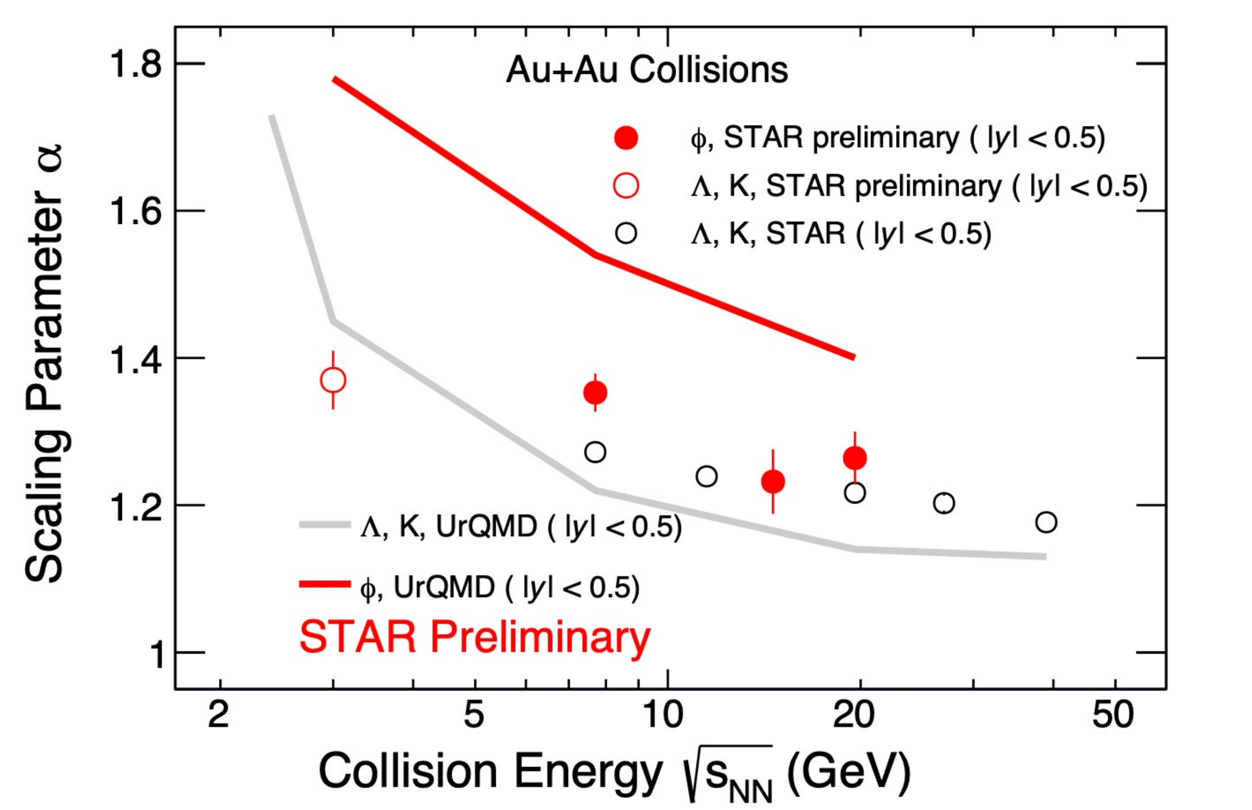
$$R_{CP} = \frac{[(dN/dp_T)/\langle N_{coll}\rangle]_{central}}{[(dN/dp_T)/\langle N_{coll}\rangle]_{peripheral}}$$

- $R_{CP} < 1$ for higher p_T at $\sqrt{s_{NN}} = 200$ GeV → Partonic energy loss in the QGP medium
- $R_{CP} > 1$ for higher p_T at $\sqrt{s_{NN}} = 19.6$ GeV and lower energies → Cronin-type interactions, radial flow and/or coalescence hadronization
- R_{CP} of ϕ at $\sqrt{s_{NN}} = 7.7$ GeV is significantly different from that at $\sqrt{s_{NN}} = 14.6$ and 19.6 GeV

Centrality dependence of ϕ yields (dN/dy)

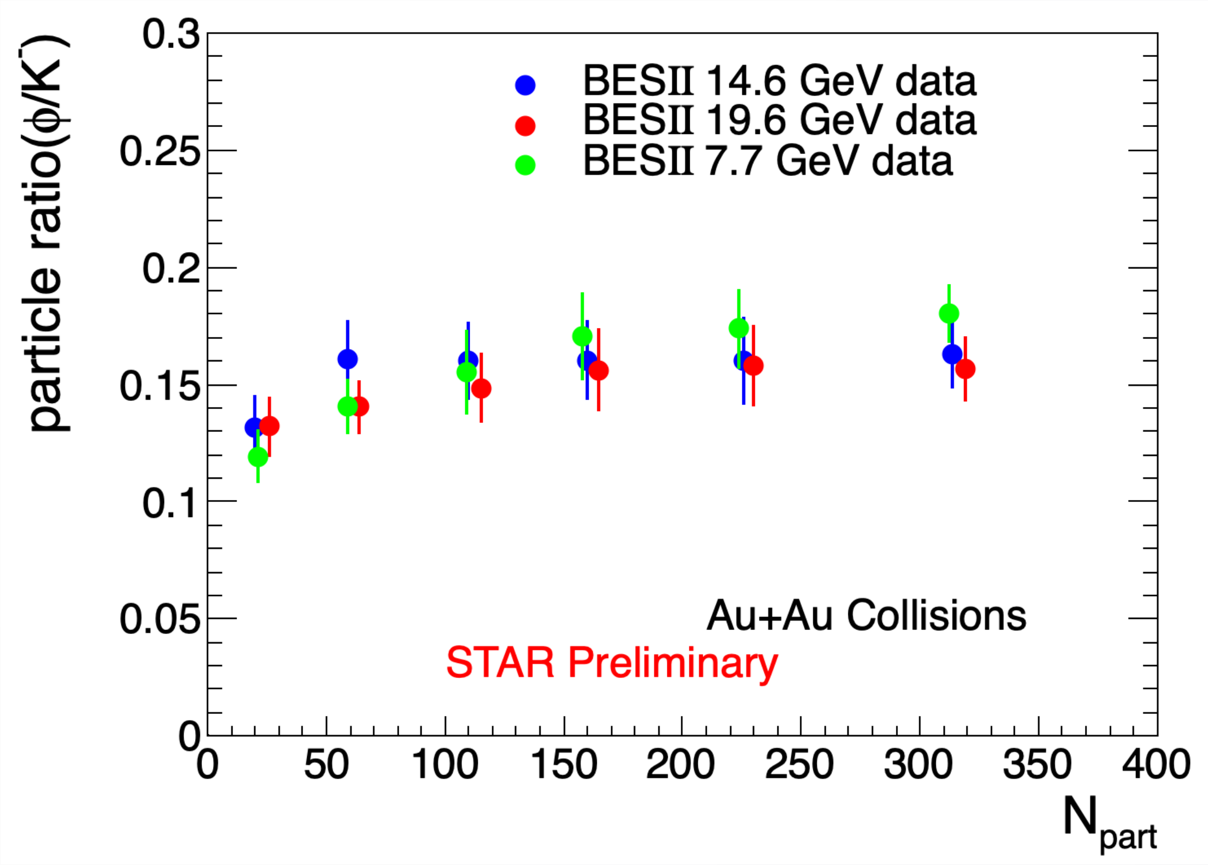
STAR: arXiv2407.10110

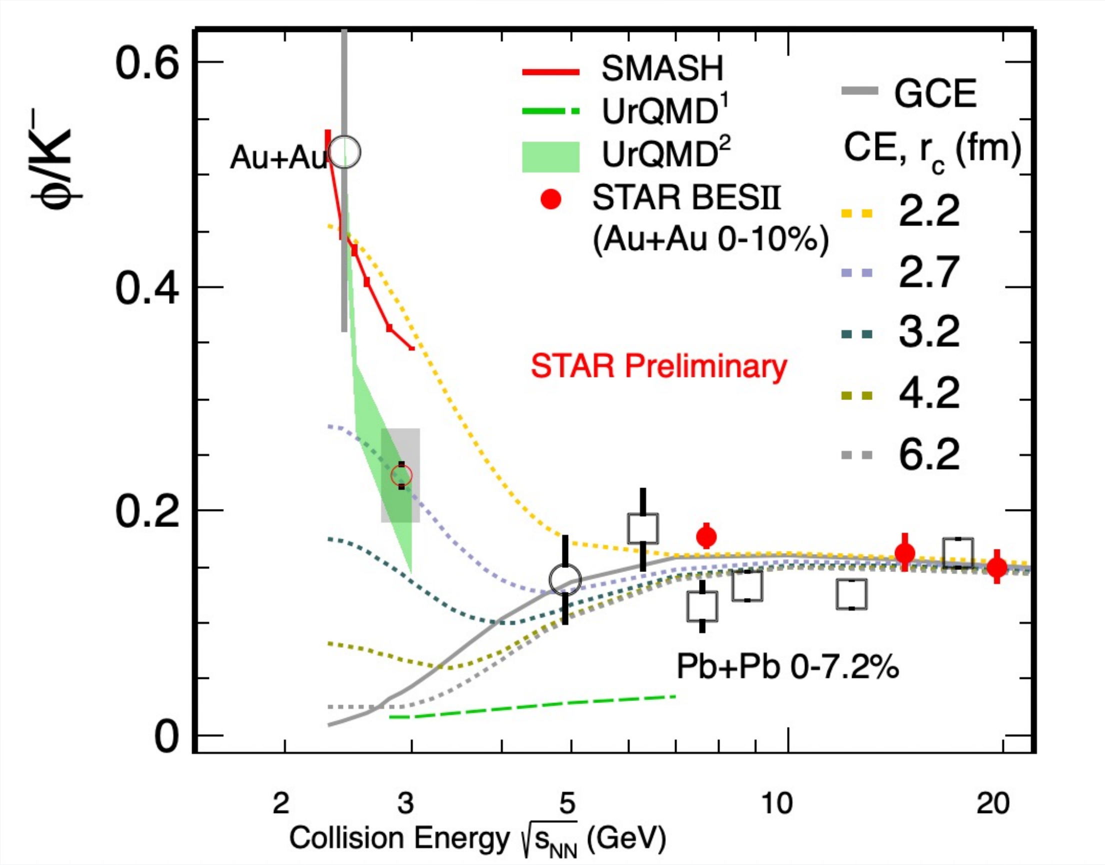




- Fit function: $(dN/dy)/(N_{part}/2) = k \times N_{part}^{\alpha-1}$
- α parameter for ϕ is slightly larger than that for Λ, K and less than UrQMD predictions

Centrality and Energy dependence of ϕ/K^- ratio

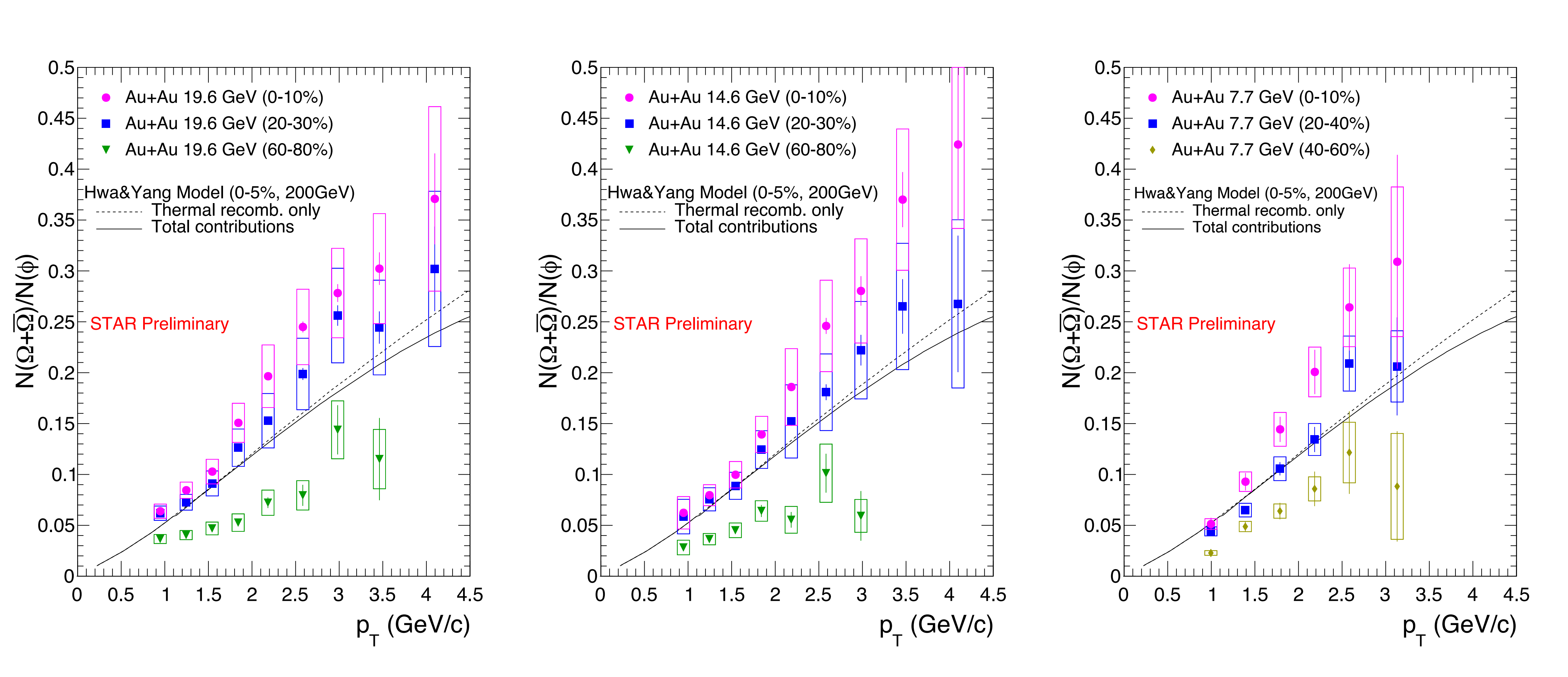




STAR: Phys. Rev. C 96 (2017) 044904
STAR: Phys. Rev. C 101 (2020) 024905
STAR: Phys. Lett. B 831 (2022) 137152

- The ϕ/K^- ratio exhibits no clear dependency 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

$\Omega(sss)/\phi(s\bar{s})$ ratio



- Similar to the observation at $\sqrt{s_{NN}}$ = 200 GeV, the Ω/ϕ ratio increases from peripheral to central collisions at intermediated p_T, which is compatible with the existence of QGP at $\sqrt{s_{NN}} \geq 7.7$ GeV

Summary

Summary:

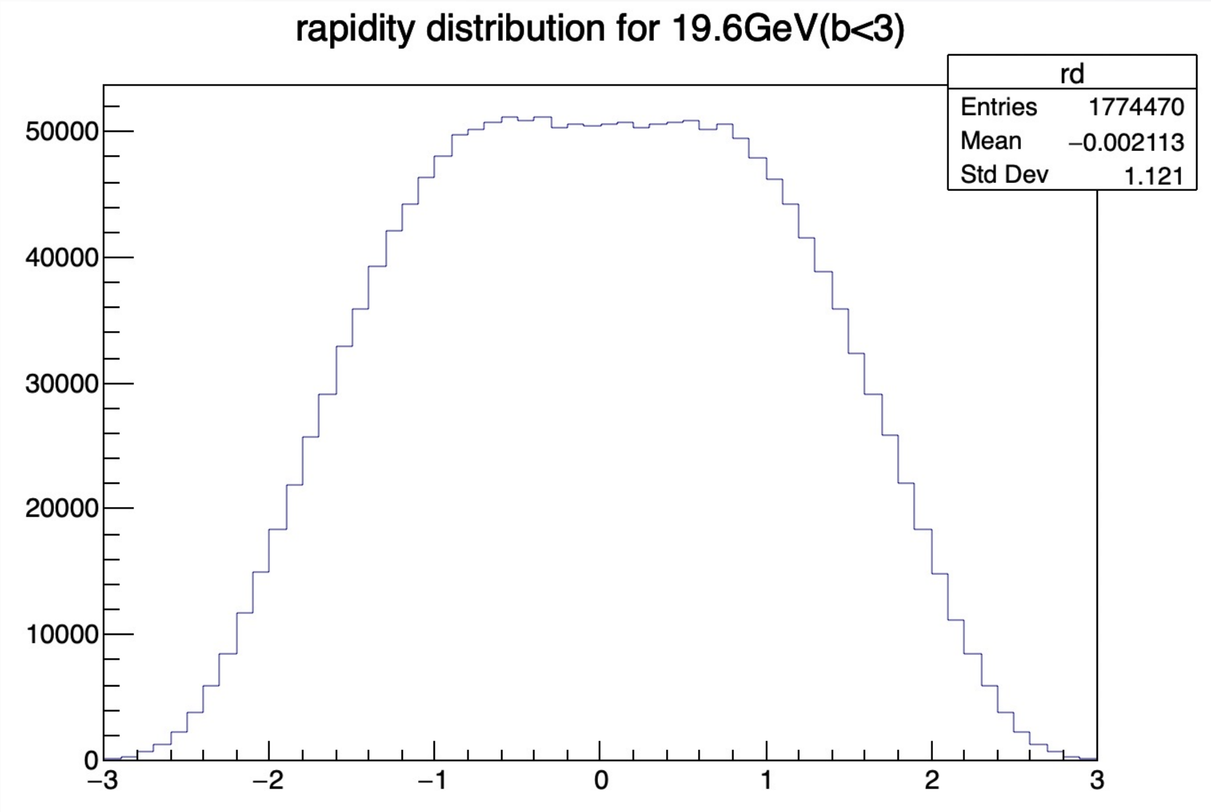
- The p_T, centrality and rapidity dependences of ϕ production at $\sqrt{s_{NN}}$ = 7.7, 14.6 and 19.6 GeV have been presented
- Hadronic transport model UrQMD cannot describe centrality dependence well from $\sqrt{s_{NN}}$ = 7.7 to 19.6 GeV
- For ϕ/K^- ratio, both GCE and CE calculations are consistent with the data across the range of $\sqrt{s_{NN}}$ = 7.7 to 19.6 GeV
- The ϕ R_{CP} at low energies shows the radial flow and quark coalescence effects
- The $\Omega(sss)/\phi(s\bar{s})$ ratio is compatible with the existence of QGP signals at $\sqrt{s_{NN}} \geq 7.7$ GeV

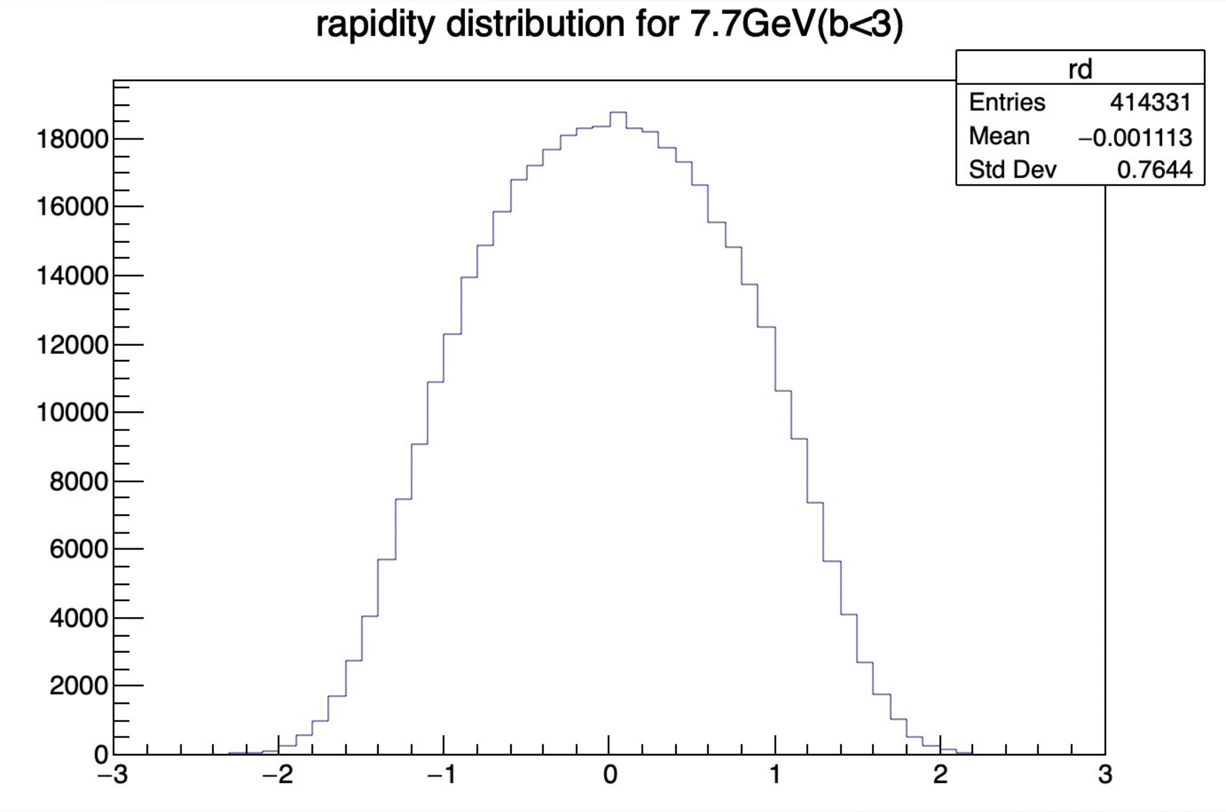
Outlook:

- The measurements in other BES-II datasets at different energies will be conducted
- Other BES-II energies: $\sqrt{s_{NN}}$ = 9.2, 11.5 and 17.3 GeV

Thanks!!

Back up: Rapidity spectra of ϕ in UrQMD at 19.6 GeV





Back up:

Coalescence model

- According to recombination model, if exist QGP, mesons and baryons can be formed by combining quarks.

- The yield distribution of a produced meson with momentum p:

$$p^0\frac{dN_B}{dp}=\int\frac{dp_1}{p_1}\frac{dp_2}{p_2}\frac{dp_3}{p_3}F_{qq'q''}(p_1,p_2,p_3)\,R_B(p_1,p_2,p_3,p).$$

- The yield distribution of a produced baryon with momentum p:

$$p^0\frac{dN_M}{dp}=\int\frac{dp_1}{p_1}\frac{dp_2}{p_2}F_{q\bar{q}'}(p_1,p_2)R_M(p_1,p_2,p),$$

P0为E

$$F_{s\bar{s}} = \mathcal{T}_s\mathcal{T}_s+\mathcal{T}_s\mathcal{S}_s+\{\mathcal{S}_s\mathcal{S}_s\},$$

$$F_{sss} = \mathcal{T}_s\mathcal{T}_s\mathcal{T}_s+\mathcal{T}_s\mathcal{T}_s\mathcal{S}_s+\mathcal{T}_s\{\mathcal{S}_s\mathcal{S}_s\}+\{\mathcal{S}_s\mathcal{S}_s\mathcal{S}_s\}\ .$$

$$\frac{dN_\phi}{pdp} = \frac{g_\phi}{pp_0}F_{s\bar{s}}(p/2,p/2),$$

$$\frac{dN_\Omega}{pdp} = \frac{g_\Omega}{pp_0}F_{sss}(p/3,p/3,p/3),$$

The yield distribution of Ω and ϕ.

$$\mathcal{T}(p_1)=p_1\frac{dN_q^{\mathrm{th}}}{dp_1}=C\,p_1\exp(-p_1/T)\ ,$$

$$\mathcal{S}(p_2)=\xi\sum_i\int_{k_0}^{\infty}dk\,k\,f_i(k)\,S_i(p_2/k)\ .$$

T_s is the thermal parton distribution comes from QGP.
S_s is the shower parton distribution comes from hard scattering.

Back up: Coalescence model

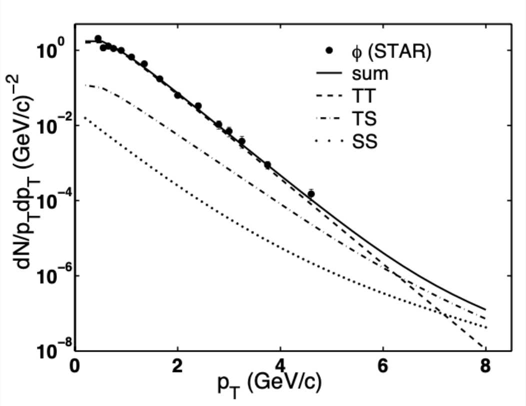
- Just consider the contribution of thermal partons:

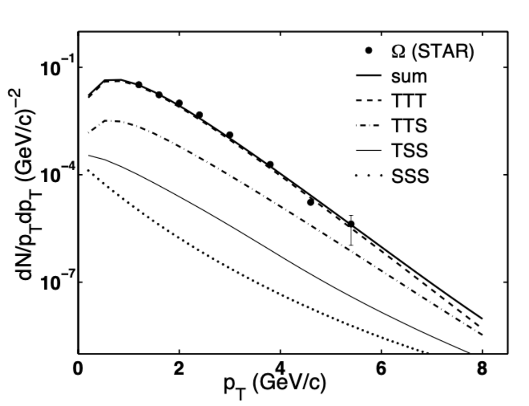
$$\frac{dN_\phi}{pdp} = g_\phi C_s^2 \frac{p}{4p_0} e^{-p/T_s} \ ,$$
$$\frac{dN_\Omega}{pdp} = g_\Omega C_s^3 \frac{p^2}{27p_0} e^{-p/T_s} \ ,$$

$$R^{\rm th}_{\Omega/\phi}(p) = \frac{4 g_\Omega C_s}{27 g_\phi} p,$$

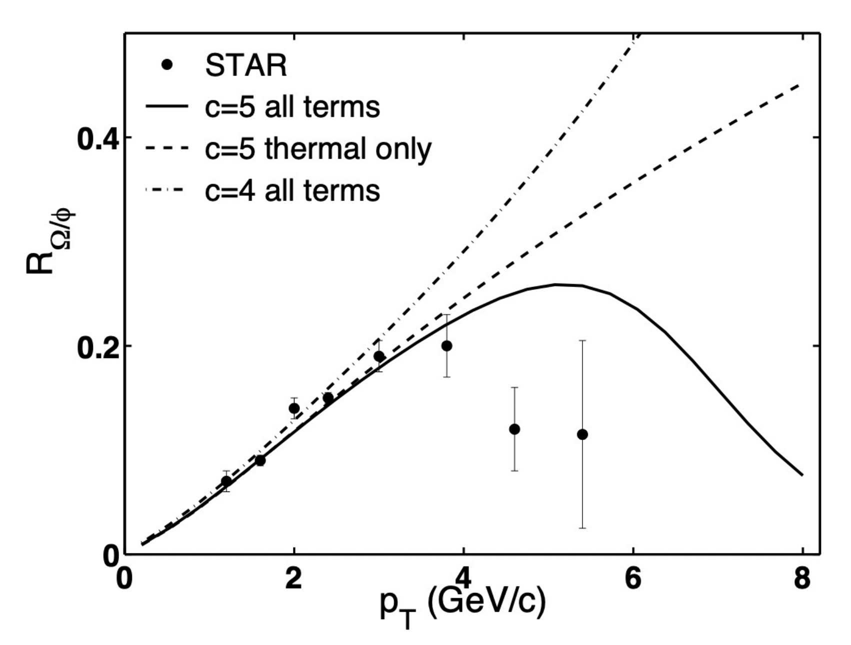
Ratio of Ω/ϕ is proportional to p.

- The Ω/ϕ ratio distribution with p_T



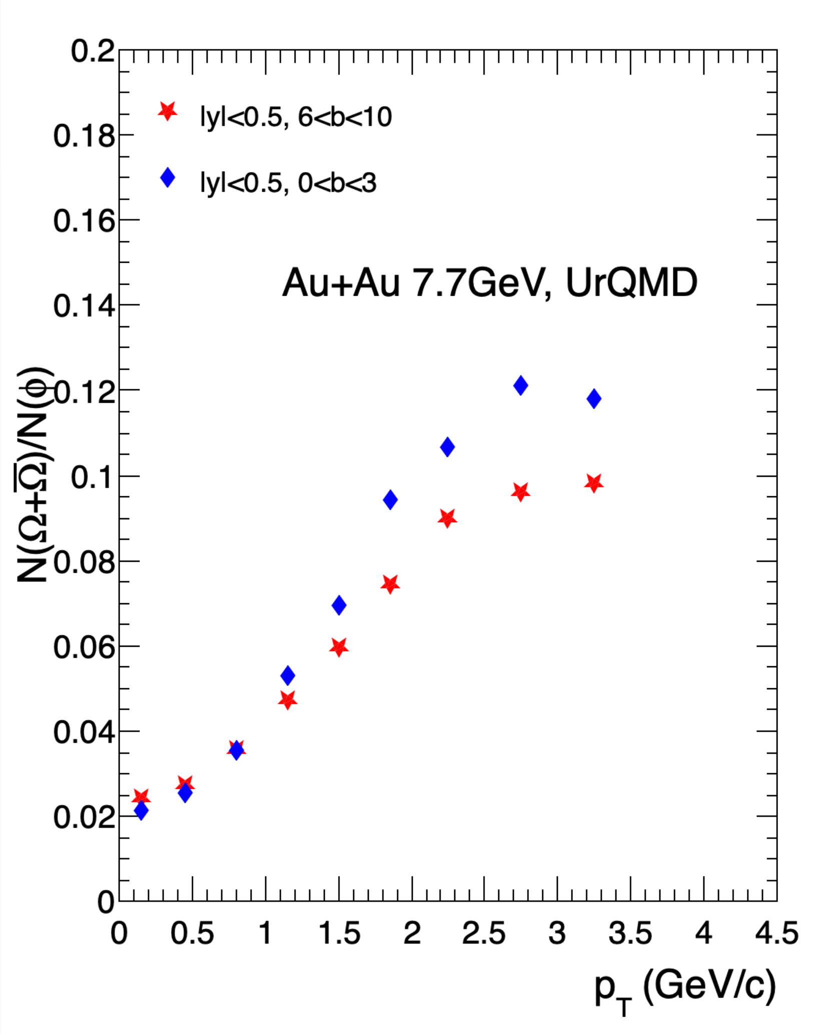


The model prediction result of Ω/ϕ ratio in QGP!



Back up:

UrQMD



No obvious Centrality dependence for 7.7 GeV.