Multiplicity and Rapidity Dependent Study of (Multi)-strange Hadrons in Small Collision System using the STAR Detector

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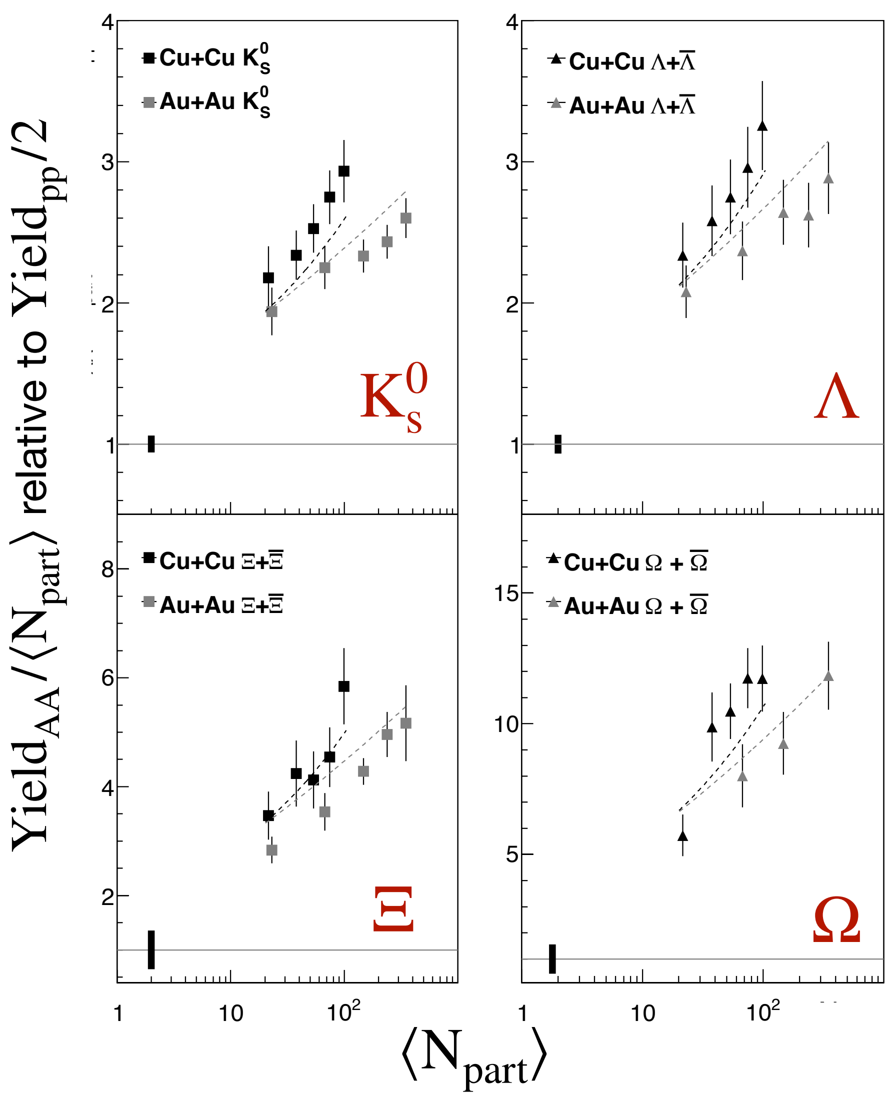
Supported in part by :
U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

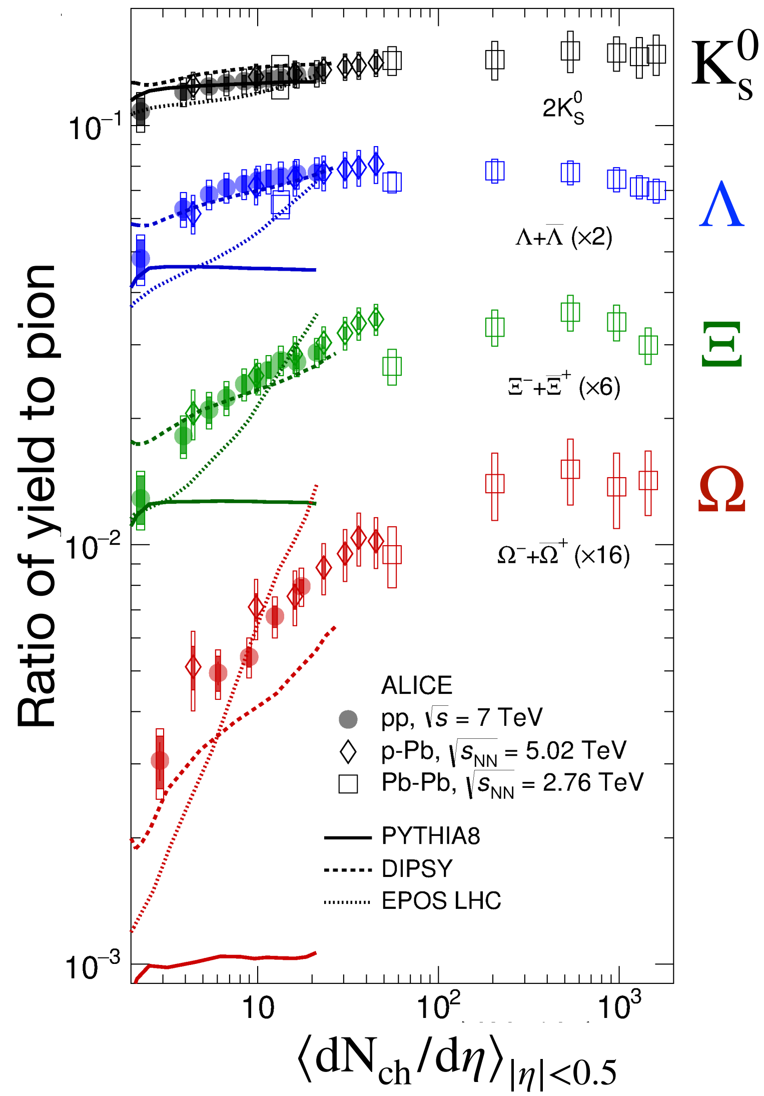
- Motivation
- Overview of STAR Detector
- Dataset and Analysis Technique
- Results
- Summary

Motivation I : Strangeness as a Probe for Deconfinement

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



ALICE : Nature Physics (2017) : 13

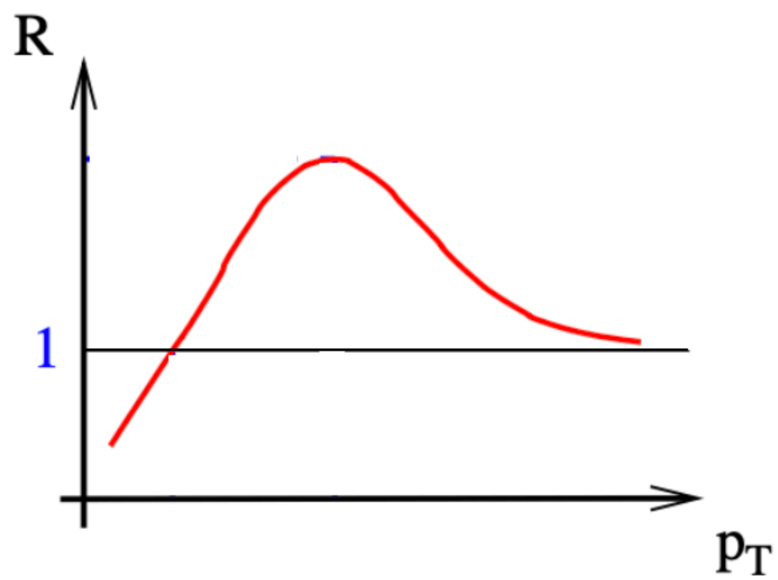


- Strangeness enhancement in A+A collisions w.r.t. p+p → a traditional signature of QGP formation
- Enhancement is more pronounced for (multi-)strange baryons

- Creation of QGP in smaller systems is still under intense debate
- Strangeness measurements in d+Au can bridge the multiplicity gap between peripheral A+A and p+p

We want to look for strangeness enhancement for K^0_S, Λ, Ξ, Ω in d+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV

- Cronin effect studied using nuclear modification factor R

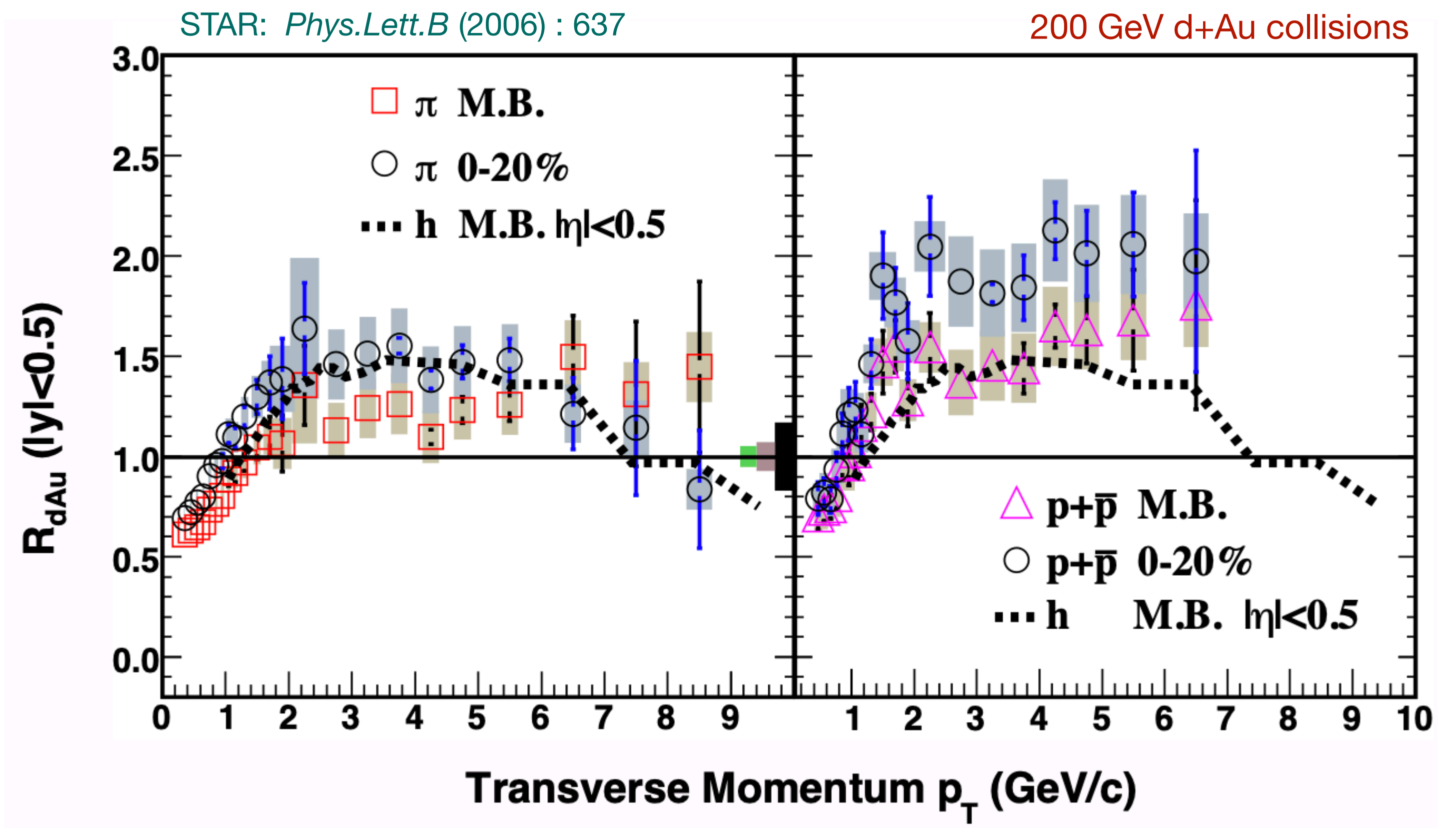


Measurements of particle type and centrality dependence of R_{dAu} (p_T) may help us understand the mechanism behind Cronin effect

Nuclear modification factor R_{dAu}

$$R_{dAu}(p_T) = \frac{d^2N/(2\pi p_T dp_T dy)}{T_{dAu} d^2\sigma^{pp}/(2\pi p_T dp_T dy)}$$

$$T_{dAu} = \langle N_{bin} \rangle / \sigma^{pp}_{inel.}$$



- Hint of Cronin like enhancement has been observed at intermediate p_T for pions as well as for protons
- For $2 < p_T < 5$ GeV/c, R_{dAu} of proton is higher than for pion

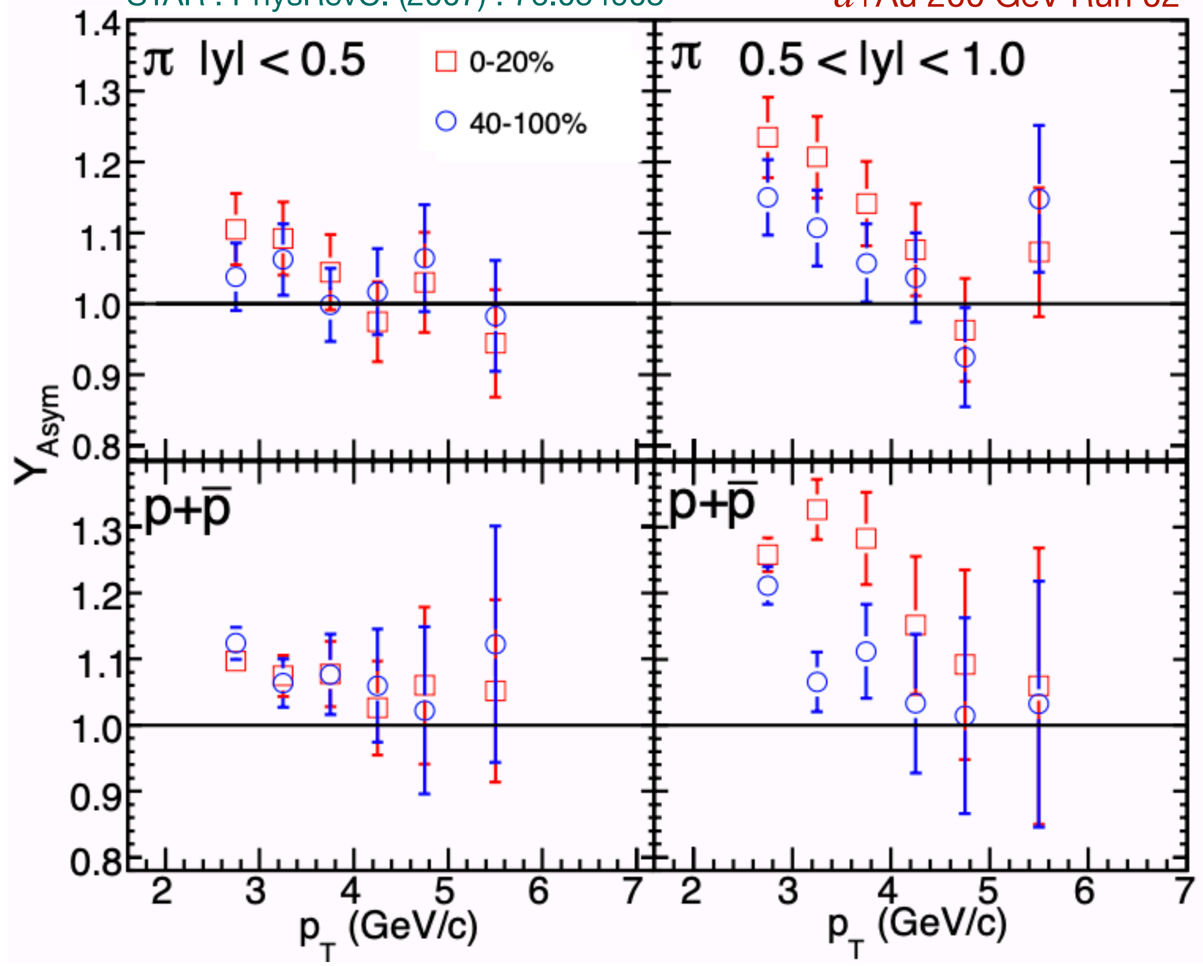
Rapidity Asymmetry :

$$Y_{Asym}(p_T) = \frac{d^2N/(dp_T dy)_{-b<y<-a}}{d^2N/(dp_T dy)_{a<y<b}}$$

Au going side - backward rapidity

d going side - forward rapidity

STAR : PhysRevC. (2007) : 76.054903 — *d*+Au 200 GeV Run 02

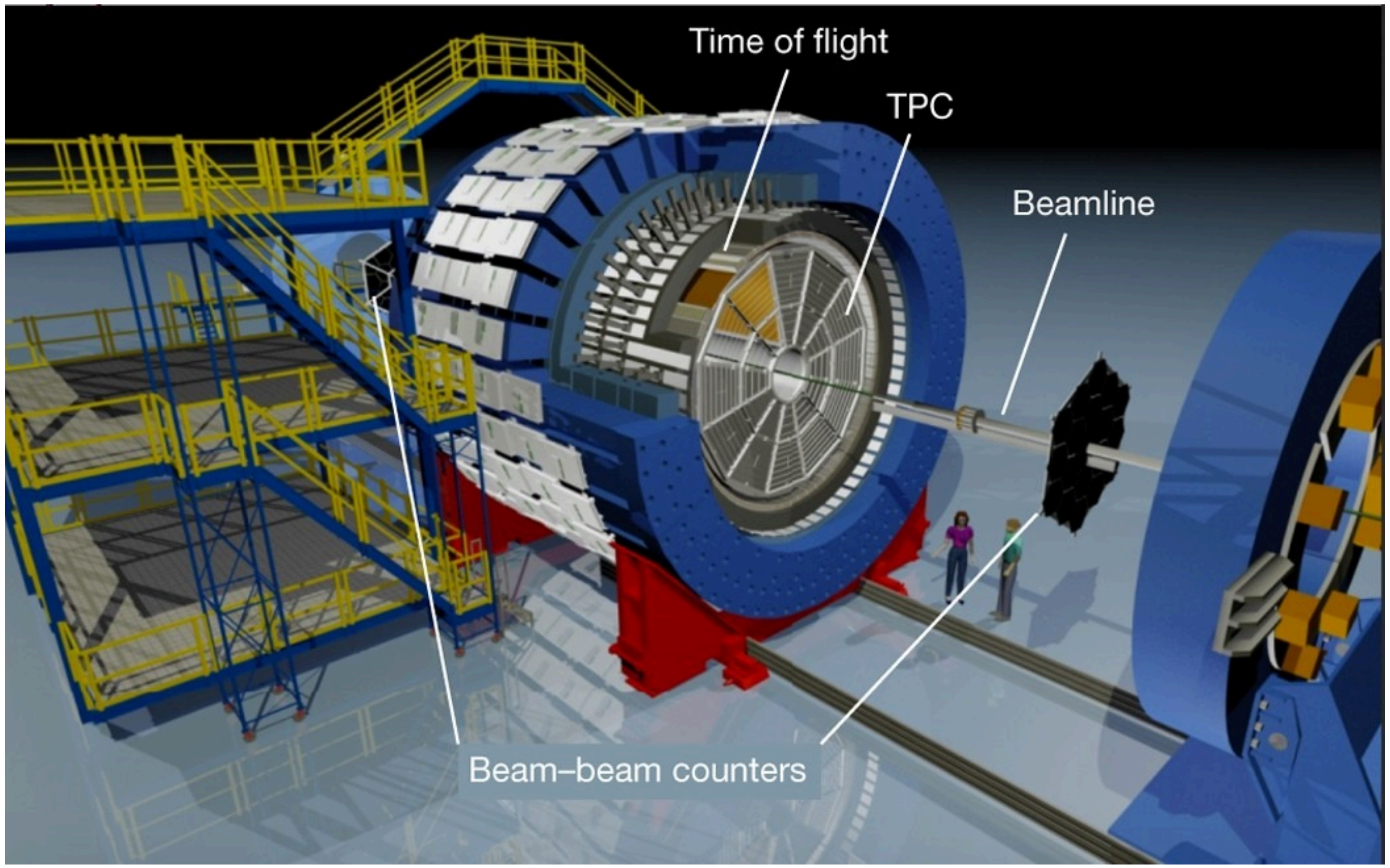


- Rapidity Asymmetry provides unique tool to study contributions from nuclear effects (nuclear shadowing, multiple scattering etc.) to the particle production

- At low p_T :
  $Y_{Asym} > 1 \rightarrow$ presence of nuclear effects
- At high p_T :
  Y_{Asym} is consistent with unity
- Deviations are higher for larger rapidity

A solid understanding in cold nuclear matter effects is essential to distill the potential QGP signal

Overview of STAR Detector



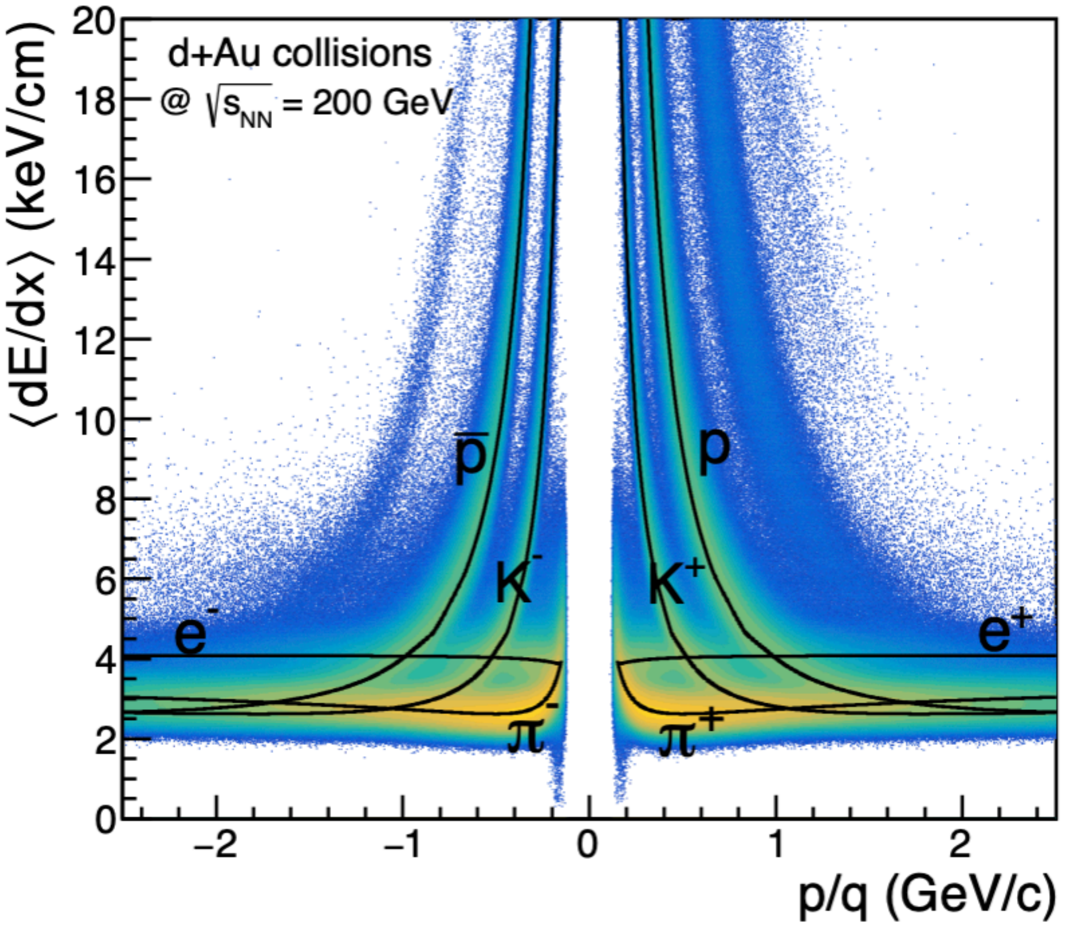
https://www.osti.gov/servlets/purl/1477969

- The **S**olenoidal **T**racker **A**t **R**HIC, known as **STAR**, tracks the thousands of particles produced by heavy-ion collisions at RHIC
- STAR detector is used to study the signatures of the Quark Gluon Plasma (QGP) formation
- Time Projection Chamber (TPC) is the main detector used for the analysis

Centrality is estimated by calculating number of charged tracks ($|\eta| < 0.9$) in d+Au 200 GeV and comparing it to the Glauber model simulations

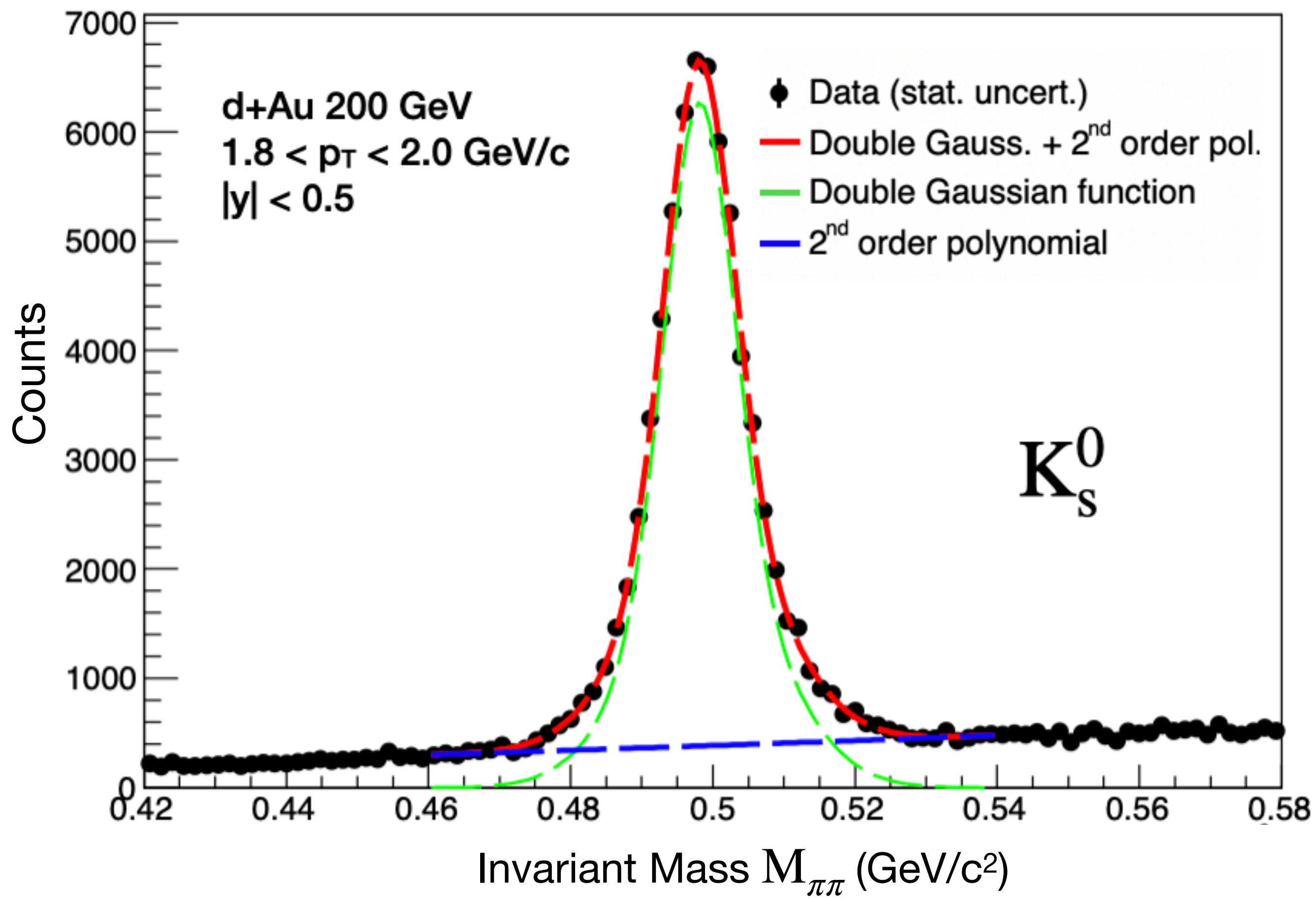
Dataset and Particle Identification

- d+Au collisions @ $\sqrt{s_{NN}}$ = 200 GeV
- Year : 2016
- Events analyzed ~100M
- Particles studied : K^0_S, Λ, Ξ & Ω



Particle identification is done via $\langle dE/dx \rangle$ measured in TPC

Invariant Mass Distribution of K^0_S

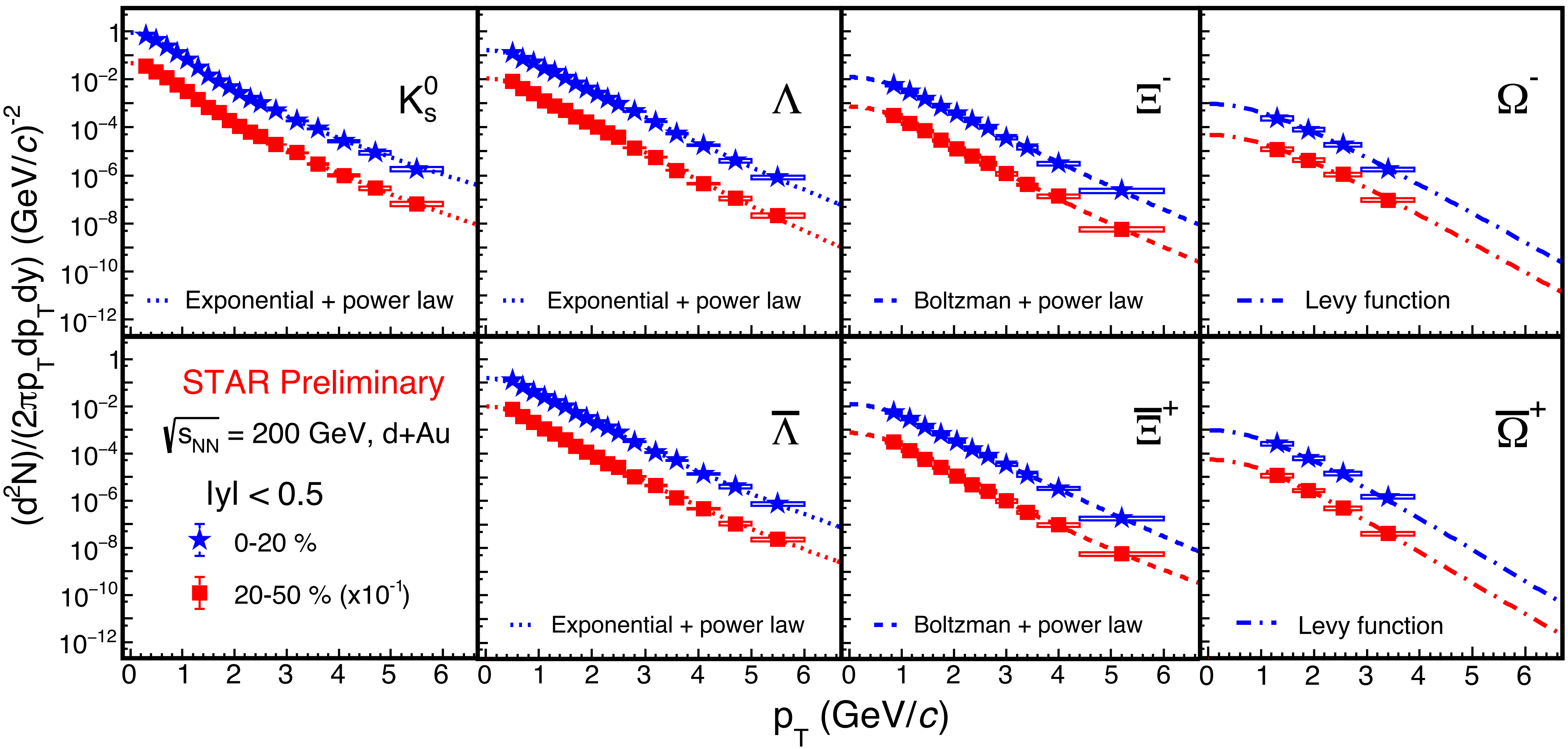


K^0_S, Λ, Ξ, Ω are reconstructed via their hadronic decay channels :

- $K^0_S \rightarrow \pi^+ + \pi^-$, B.R. 69.2%
- $\Lambda(\bar{\Lambda}) \rightarrow p(\bar{p}) + \pi^-(\pi^+)$, B.R. 63.9%
- $\Xi^-(\bar{\Xi}^+) \rightarrow \Lambda(\bar{\Lambda}) + \pi^-(\pi^+)$, B.R. 99.8%
- $\Omega^-(\bar{\Omega}^+) \rightarrow \Lambda(\bar{\Lambda}) + K^-(K^+)$, B.R. 67.8%

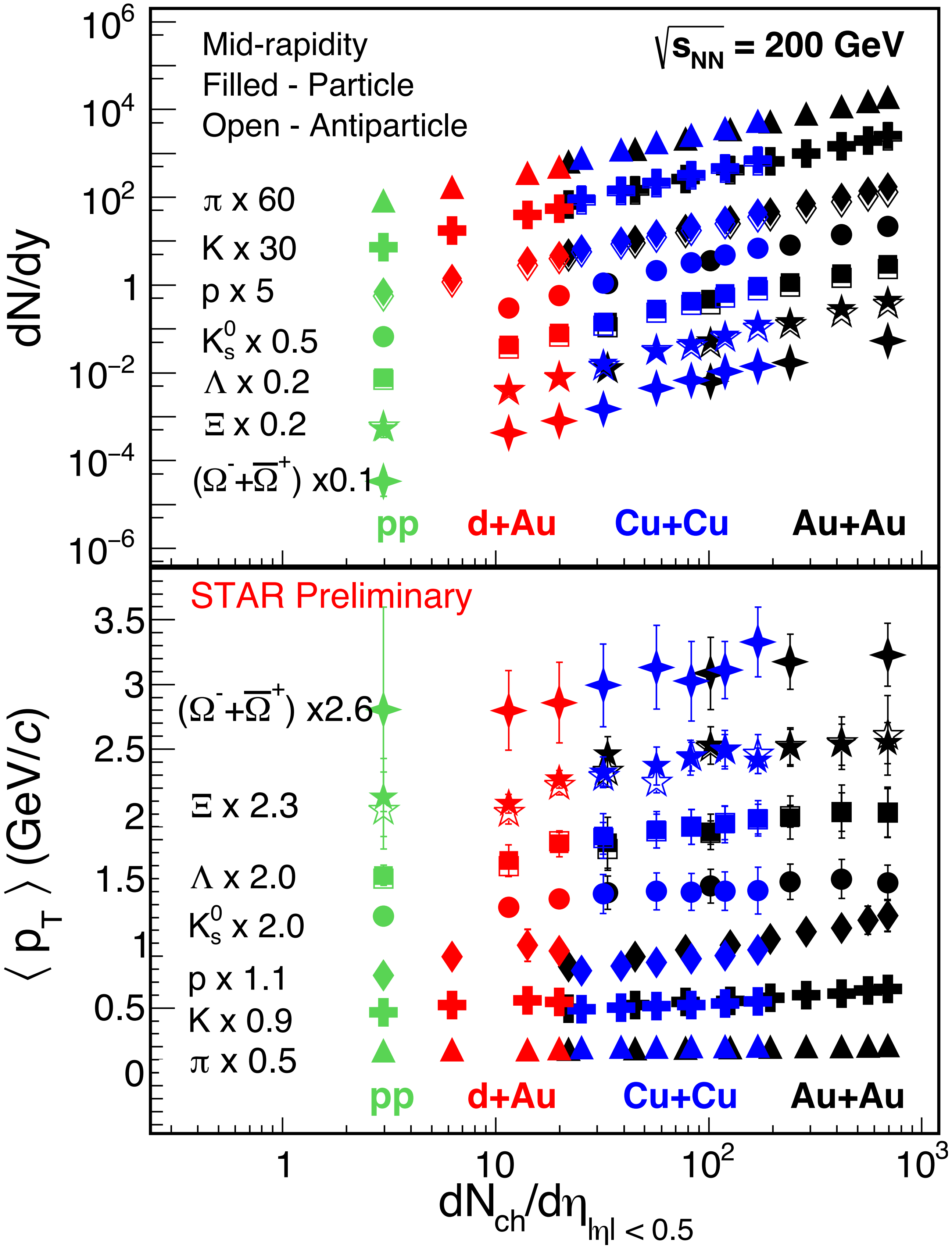
Chin. Phys. C **40**, 100001 (2016)

Transverse Momentum Spectra at Mid-rapidity (|y| < 0.5)



- p_T spectra of K^0_s, $\Lambda(\bar{\Lambda})$, $\Xi^-(\bar{\Xi}^+)$ & $\Omega^-(\bar{\Omega}^+)$ are corrected for acceptance & efficiency and respective branching ratios
- Λ spectra are corrected for weak decay feed down from Ξ

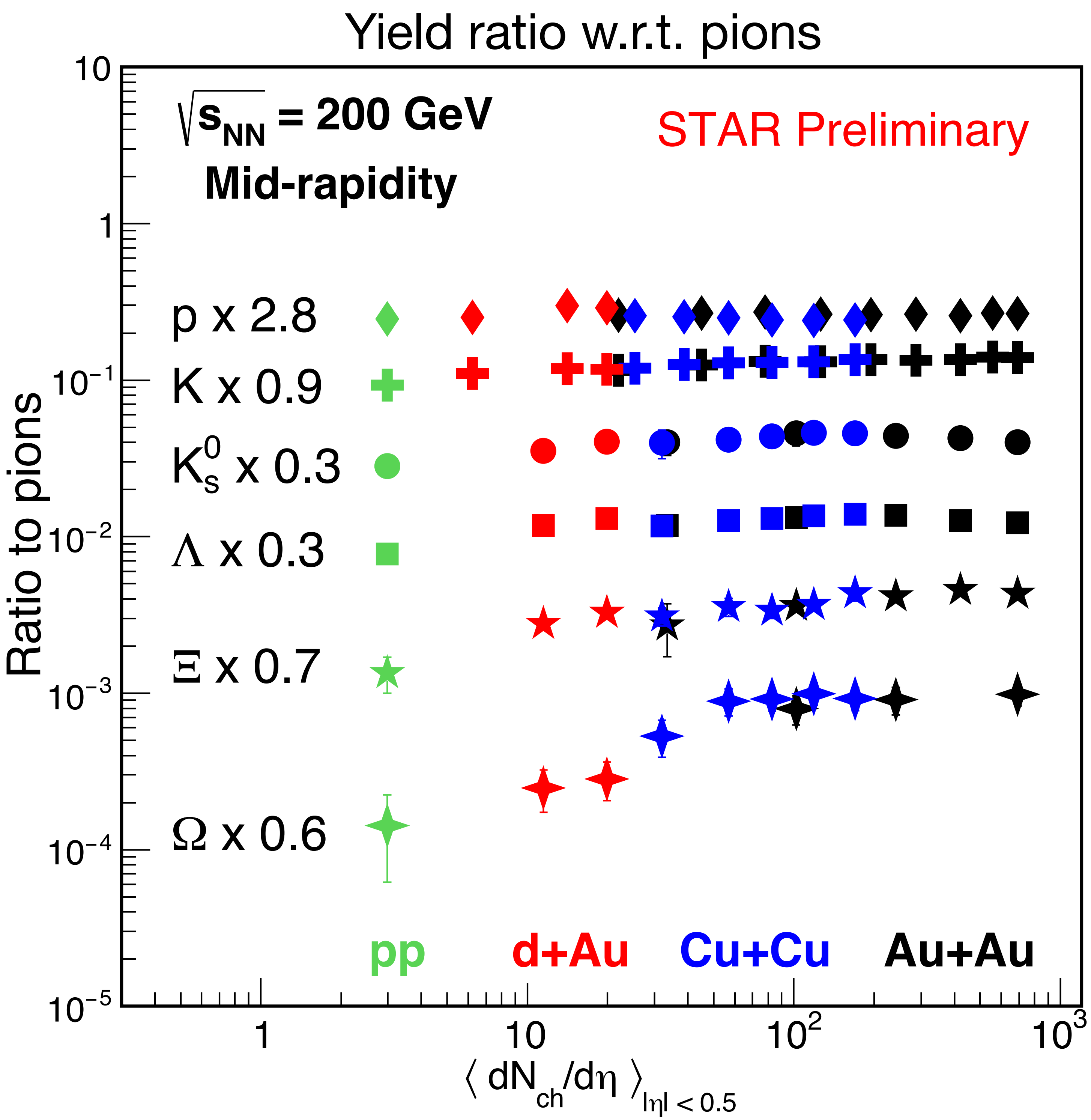
Integrated yields and $\langle p_T \rangle$ as function of Multiplicity



- dN/dy increases as function of $dN_{ch}/d\eta$
- $\langle p_T \rangle$ is larger for heavier particles & hint of increase is observed as function of $dN_{ch}/d\eta$:
  - Supports the picture of collective evolution (radial flow)
- Particle production is driven by $dN_{ch}/d\eta$ not by collision species.

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)

Integrated Particle-to-Pion ratios as function of Multiplicity



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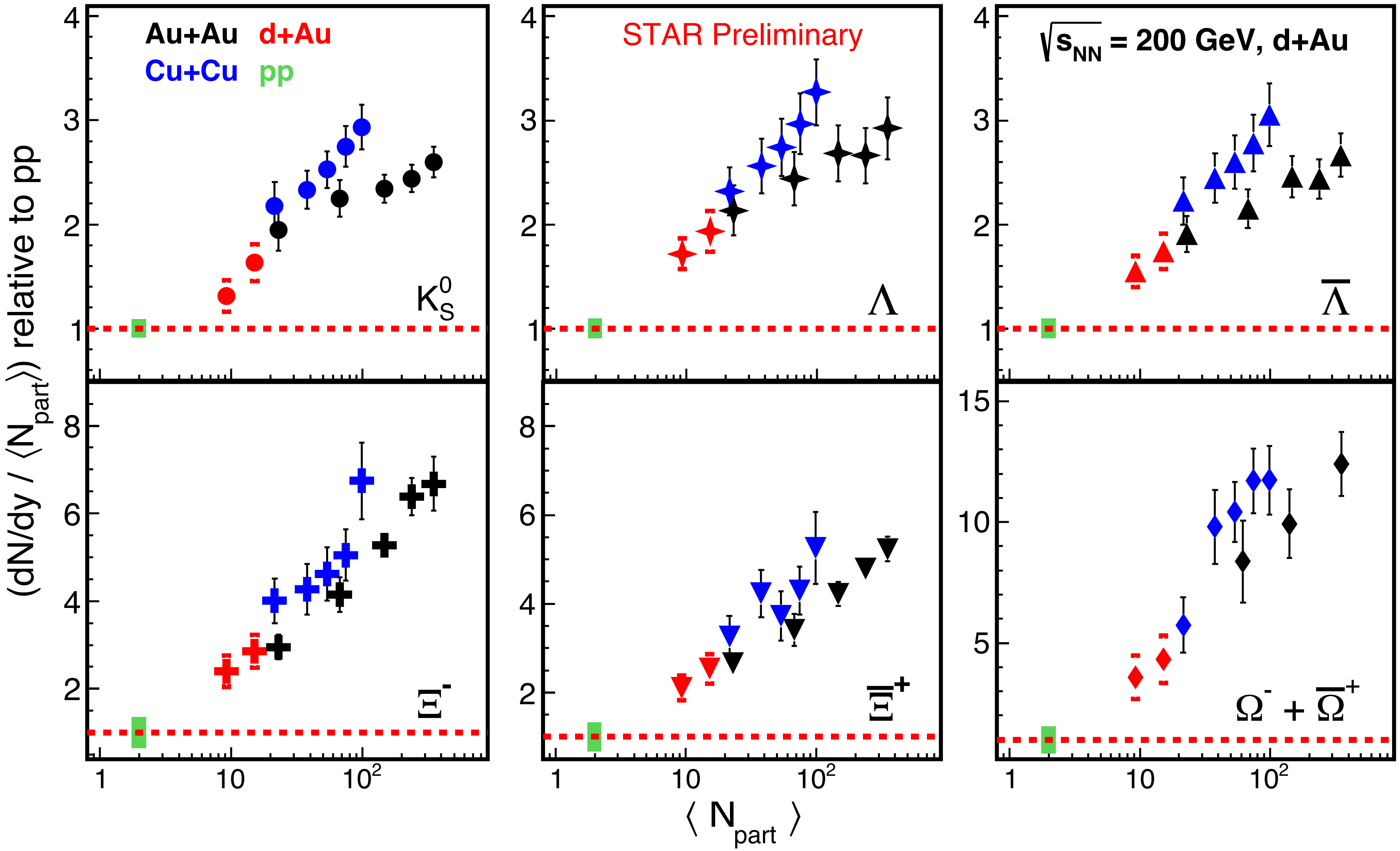
- Smooth transition of ratios of the particles from p+p to A+A collisions
- d+Au system fills the gap between p+p and peripheral Cu+Cu & Au+Au collisions
- Data from different collision systems follow similar trend
- Yield ratio of particles to pions with more strangeness content decrease faster from high to low multiplicity

Strangeness Enhancement



- Strange particle yields in d+Au 200 GeV are enhanced as compared to p+p collisions
- Strange particle yields increase as a function of $\langle N_{part} \rangle$

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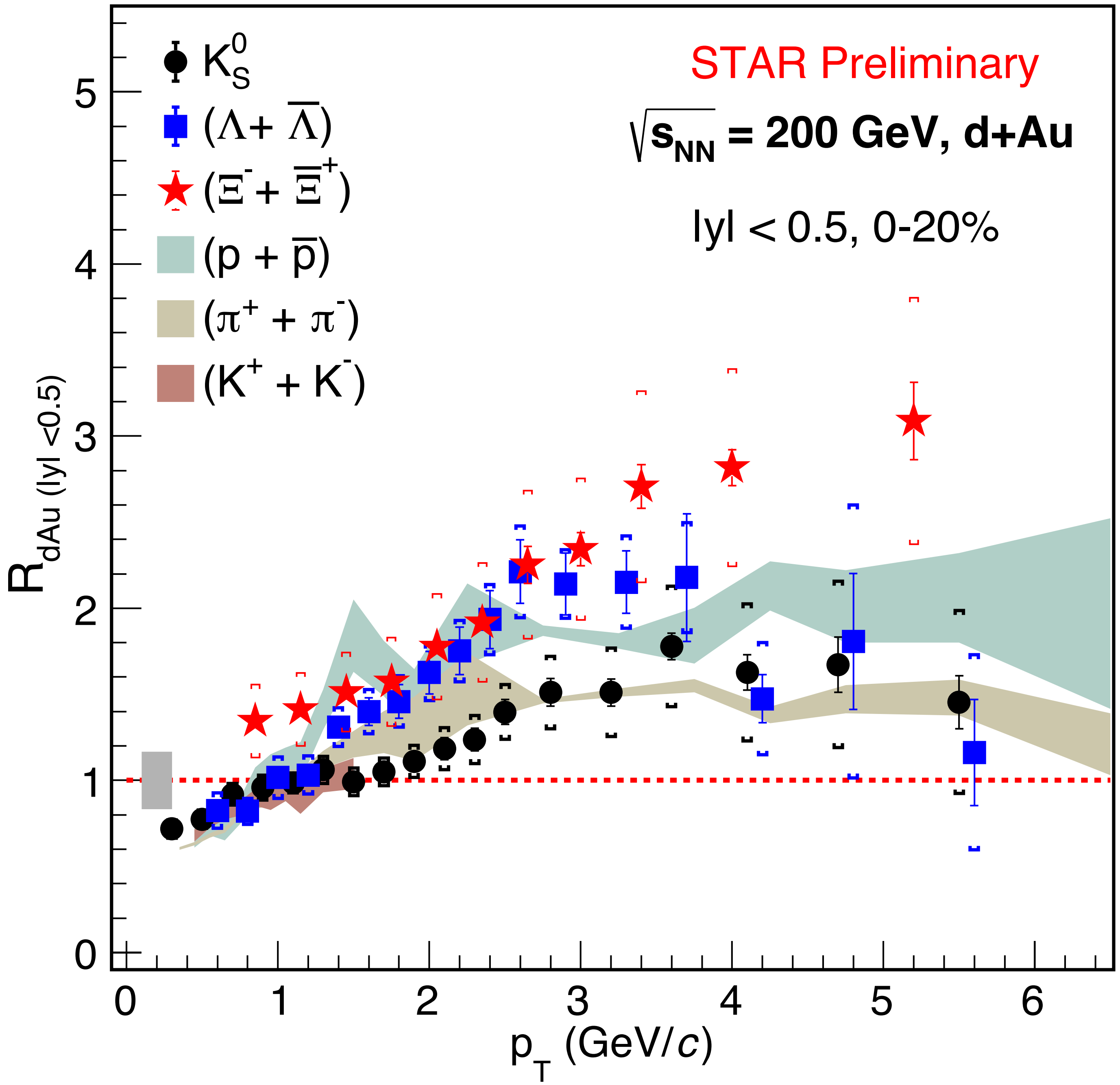
Nuclear Modification Factor



Λ data points are p_T shifted by 0.1 GeV/c for clarity.

π,K,p data are from
STAR : Phys.Lett.B (2006) : 637
STAR : *Phys.Lett.B* (2005) : 616

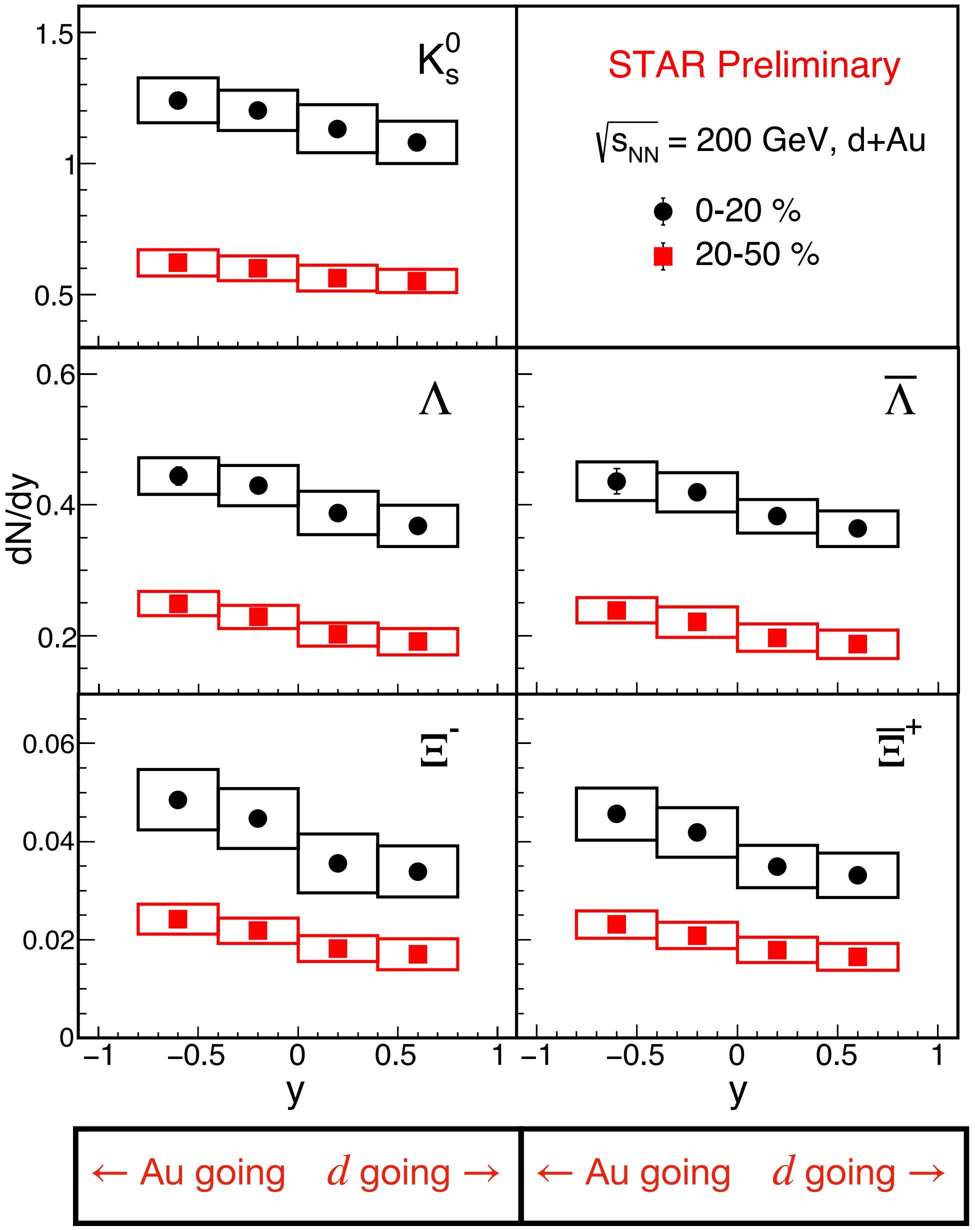
$$R_{dAu}(p_T) = \frac{d^2N/(2\pi p_T dp_T dy)}{T_{dAu} d^2\sigma^{pp}/(2\pi p_T dp_T dy)}$$

$$T_{dAu} = \langle N_{bin} \rangle / \sigma^{pp}_{inel.}$$

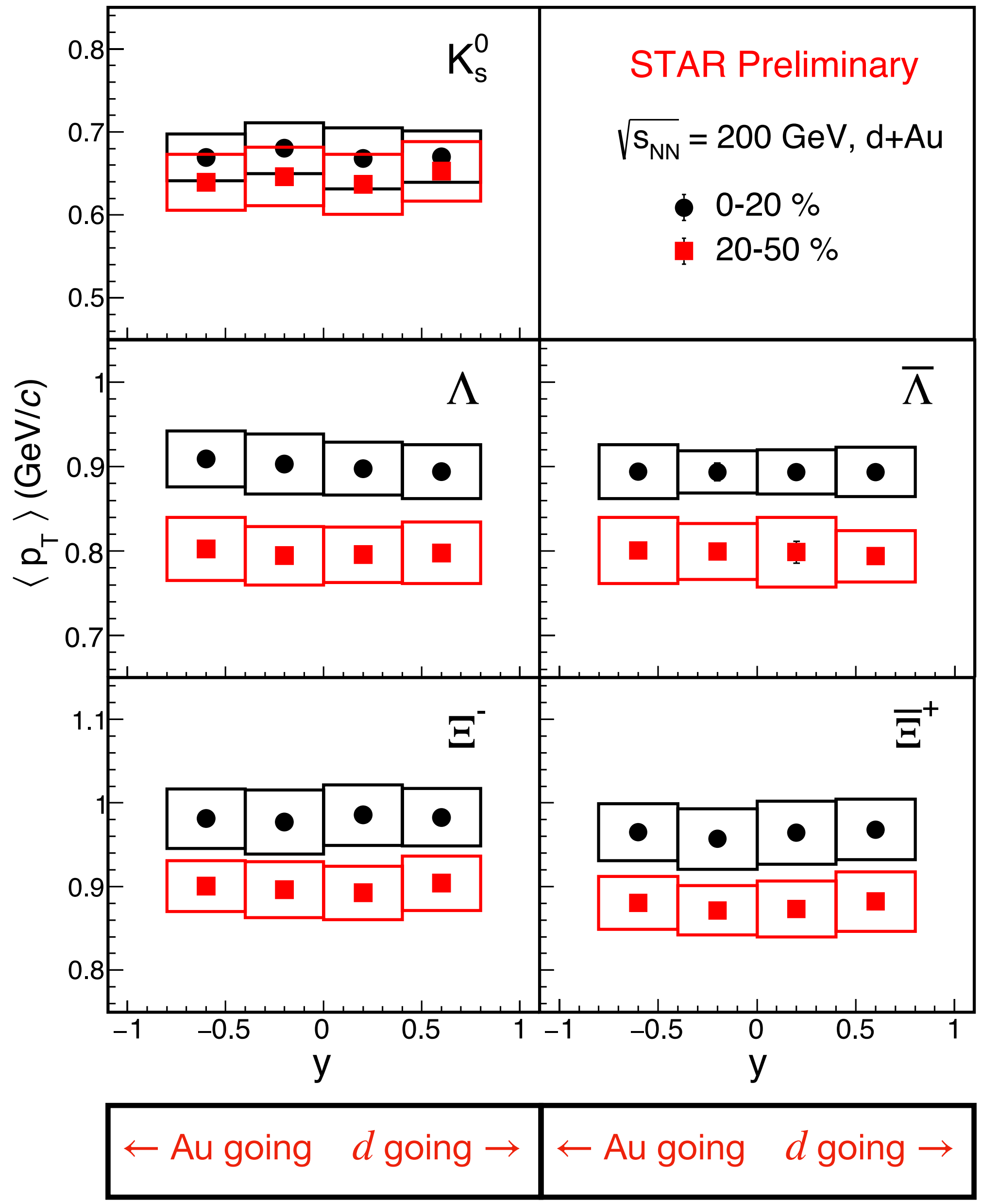
- Cronin like enhancement is observed for K^0_S, Λ & Ξ at intermediate p_T
- Enhancement in d+Au compared to p+p for p_T in 2-4 GeV/c is stronger for baryons (Ξ, Λ & p) compared to mesons (K^0_S, π)

Integrated yields and $\langle p_T \rangle$ as function of Rapidity

dN/dy w.r.t. to y

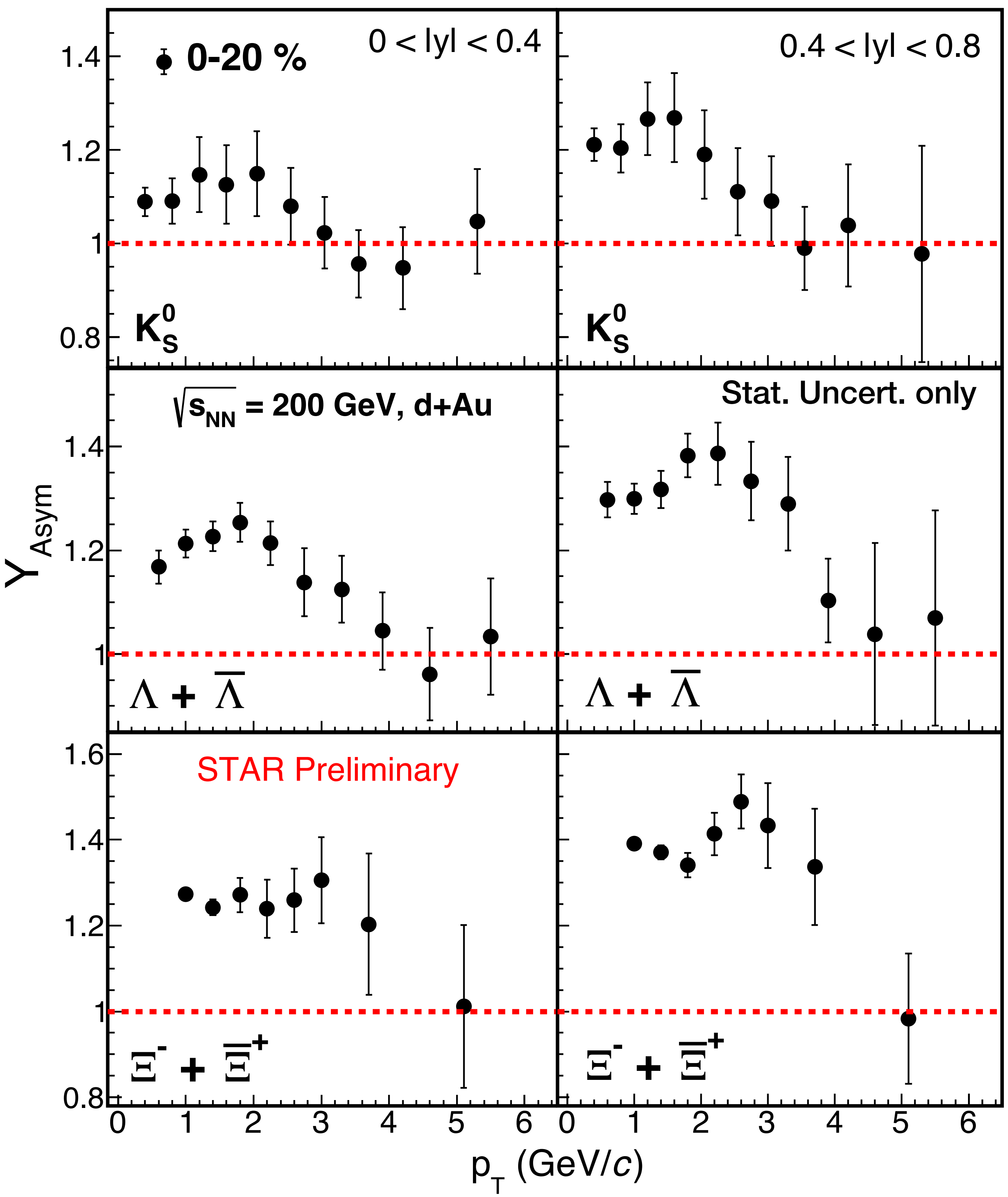


$\langle p_T \rangle$ w.r.t. to y



- dN/dy slightly decreases from negative to positive rapidities for K^0_s, $\Lambda(\bar{\Lambda})$ & $\Xi^-(\bar{\Xi}^+)$
- $\langle p_T \rangle$ is flat vs y for K^0_s, $\Lambda(\bar{\Lambda})$ & $\Xi^-(\bar{\Xi}^+)$: similar radial flow
- Theoretical calculations are welcome

Rapidity Asymmetry



$$Y_{\text{asym}}(p_T) = \frac{d^2N(p_T)/dy_{CM}dp_T|_{y_{CM}\in[-b,-a]}}{d^2N(p_T)/dy_{CM}dp_T|_{y_{CM}\in[a,b]}}.$$

- $Y_{Asym} > 1$ is observed at low p_T
  - Signifies the presence of nuclear effects
- Consistent with unity at high p_T.
- Asymmetry is more prominent for
  - Higher rapidity intervals (0.4 < |y| < 0.8)
  - Heavier mass particle

STAR : PhysRevC.76.054903 (2007)

Summary

- We have presented **Multiplicity and Rapidity dependent studies of K^0_s, Λ, Ξ and Ω in d+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV**
- **Particle production is independent of collision system** and mainly driven by multiplicity
- Yields of K^0_s, $\Lambda(\bar{\Lambda})$, $\Xi^-(\bar{\Xi}^+)$ & $\Omega^-(\bar{\Omega}^+)$ in d+Au are observed to be higher than in p+p collisions at 200 GeV : **Strangeness enhancement**
- **Nuclear modification factors (R_{dAu})** for K^0_s, Λ and Ξ show Cronin like enhancement
- **Integrated yield as function of rapidity** decreases from negative to positive rapidity region while $\langle p_T \rangle$ remains flat.
- **Rapidity asymmetry** for K^0_s, Λ and Ξ is observed
  - At low p_T : indicating presence of nuclear effects
  - Asymmetry is more pronounced for higher rapidity region and for heavier mass particle

Thank You!

BACK UP

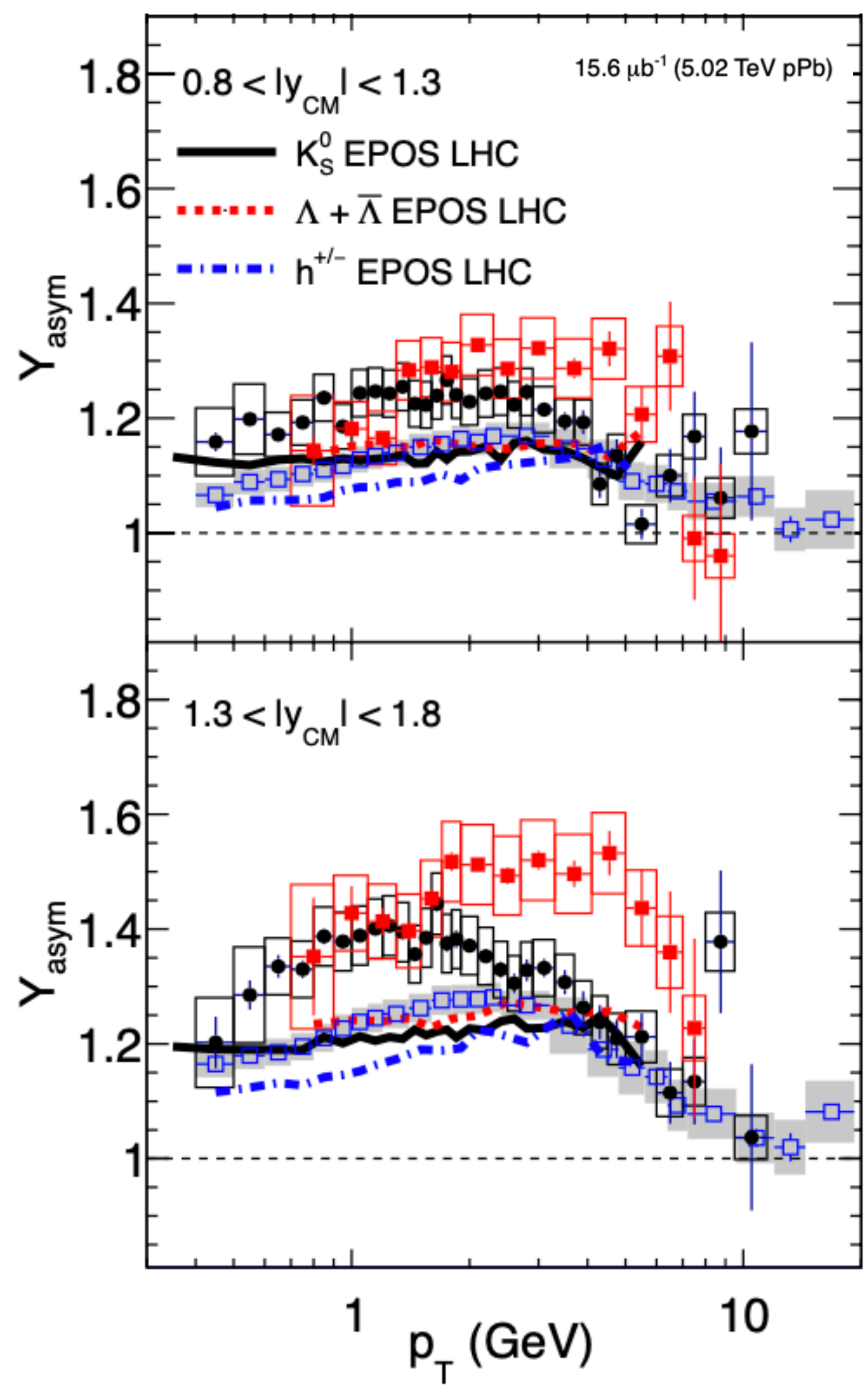
Probing Cold Nuclear Matter Effects in CMS

Rapidity Asymmetry Studied in CMS :

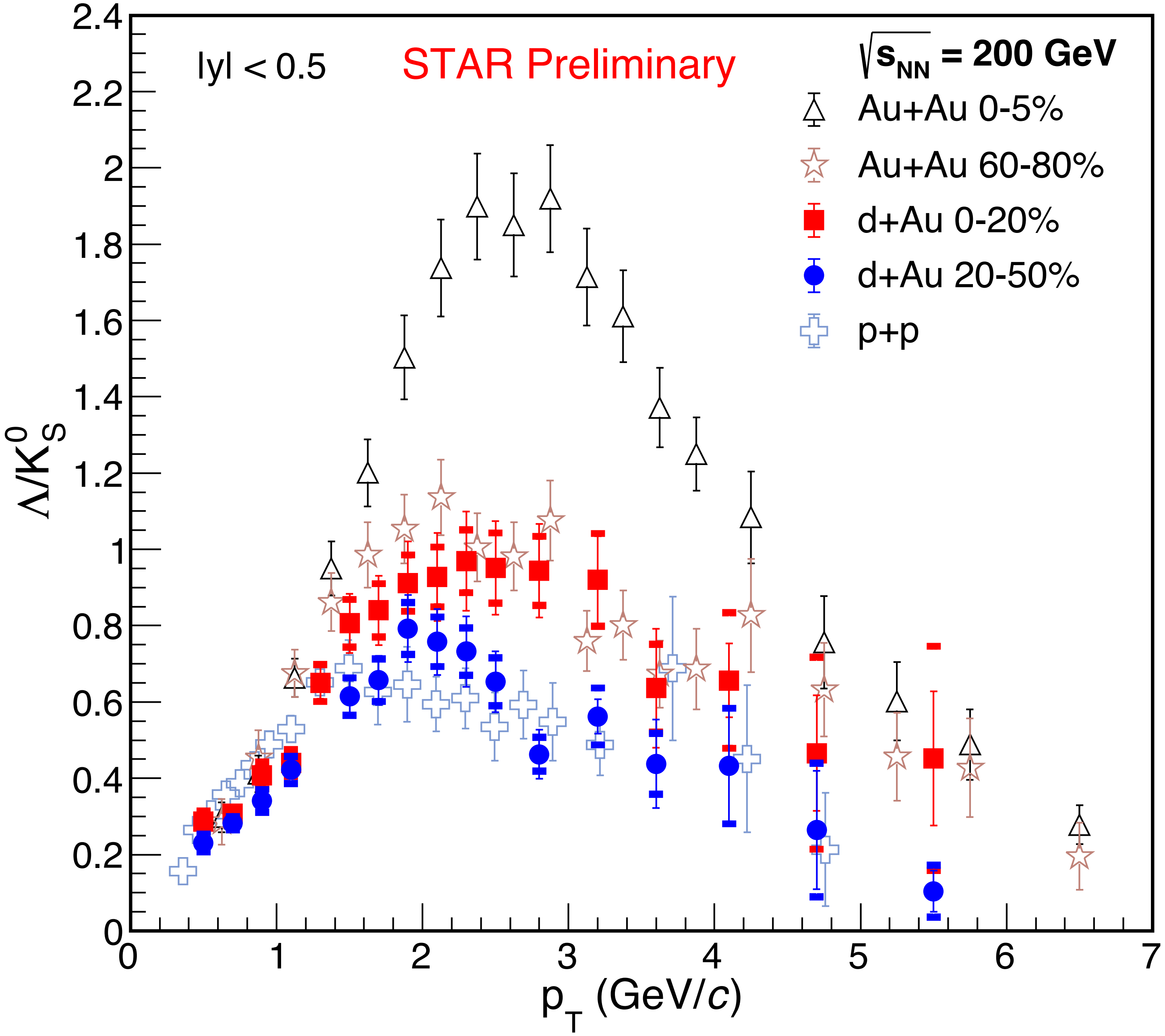
$$Y_{\mathrm{asym}}(p_{\mathrm{T}}) = \frac{\mathrm{d}^2N(p_{\mathrm{T}})/\mathrm{d}y_{\mathrm{CM}}\mathrm{d}p_{\mathrm{T}}|_{y_{\mathrm{CM}}\in[-b,-a]}}{\mathrm{d}^2N(p_{\mathrm{T}})/\mathrm{d}y_{\mathrm{CM}}\mathrm{d}p_{\mathrm{T}}|_{y_{\mathrm{CM}}\in[a,b]}}.$$

- $Y_{asym} > 1$ is observed at low p_T
  - Signifies the presence of nuclear effects
- Consistent with unity at high p_T
- More prominent for higher rapidity interval ($1.3 < |y| < 1.8$)
- Asymmetry is stronger for Λ as compared to that for K_s^0

CMS: PHYSICAL REVIEW C **101**, 064906 (2020)



Baryon to Meson Ratio



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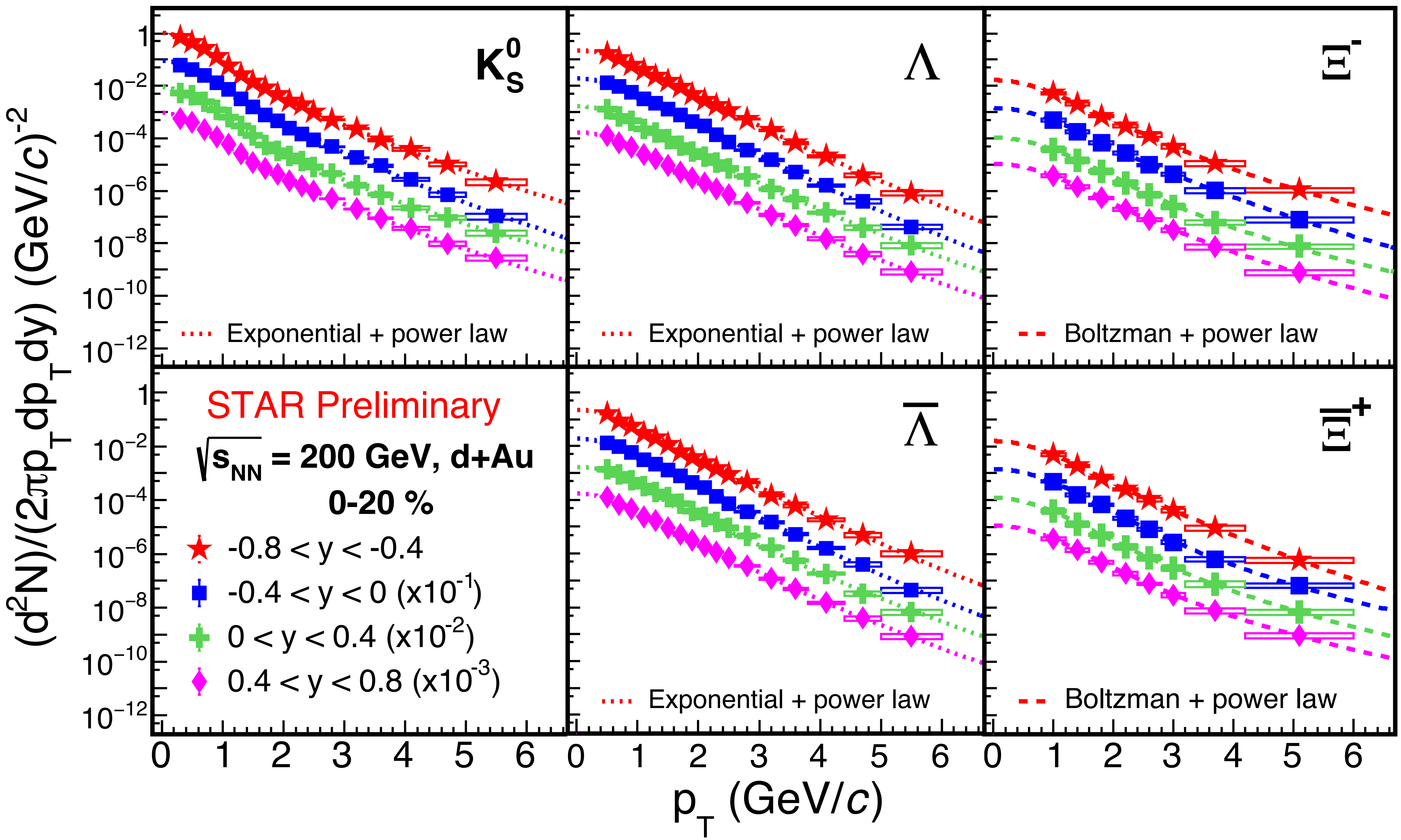
STAR : Phys. Rev. Lett. 108, 072301 (2012)
STAR : Phys. Rev. C 79, 034909 (2009)

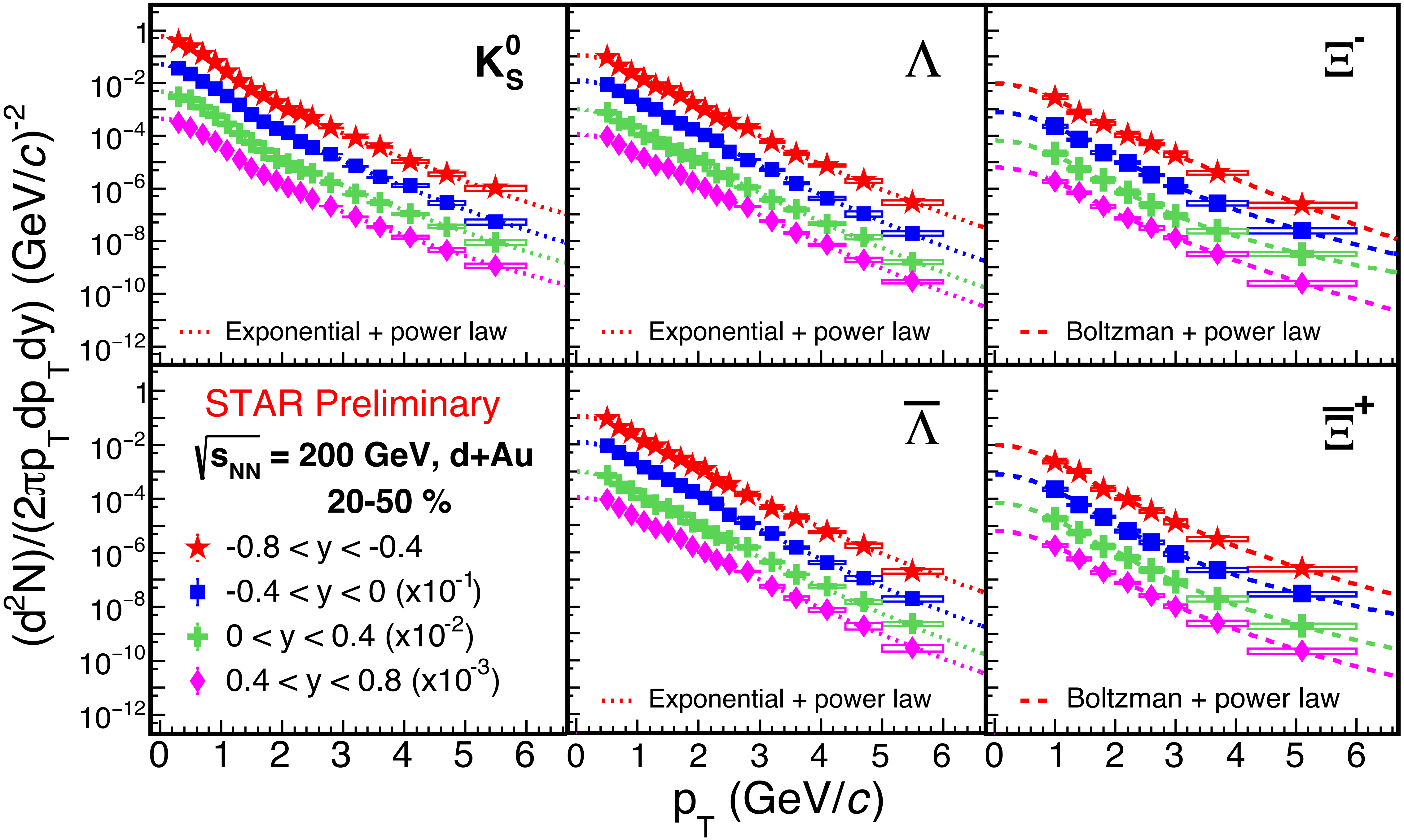
- Λ/K^0_S are significantly enhanced in central Au+Au collisions at 200 GeV compared to p+p
  - recombination of thermalized strange quarks in QGP / radial flow…
- Λ/K^0_S in 0-20% d+Au at intermediate p_T is larger compared to 20-50% d+Au and p+p collisions
- Baryon enhancement is observed in central d+Au 200 GeV
- Similar radial flow for strange particles in 20-50% d+Au and p+p collisions

Transverse Momentum Spectra at Different Rapidities



- p_T spectra of K^0_S, $\Lambda(\bar{\Lambda})$, $\Xi^-(\bar{\Xi}^+)$ for different rapidities are corrected by acceptance & efficiency and respective branching ratios

Transverse Momentum Spectra at Different Rapidities



- p_T spectra of K^0_S, $\Lambda(\bar{\Lambda})$, $\Xi^-(\bar{\Xi}^+)$ for different rapidities are corrected by acceptance & efficiency and respective branching ratios