



Multiplicity and Rapidity Dependent Study of (Multi-)strange Hadrons in d+Au collisions using the STAR detector



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Supported in part by :

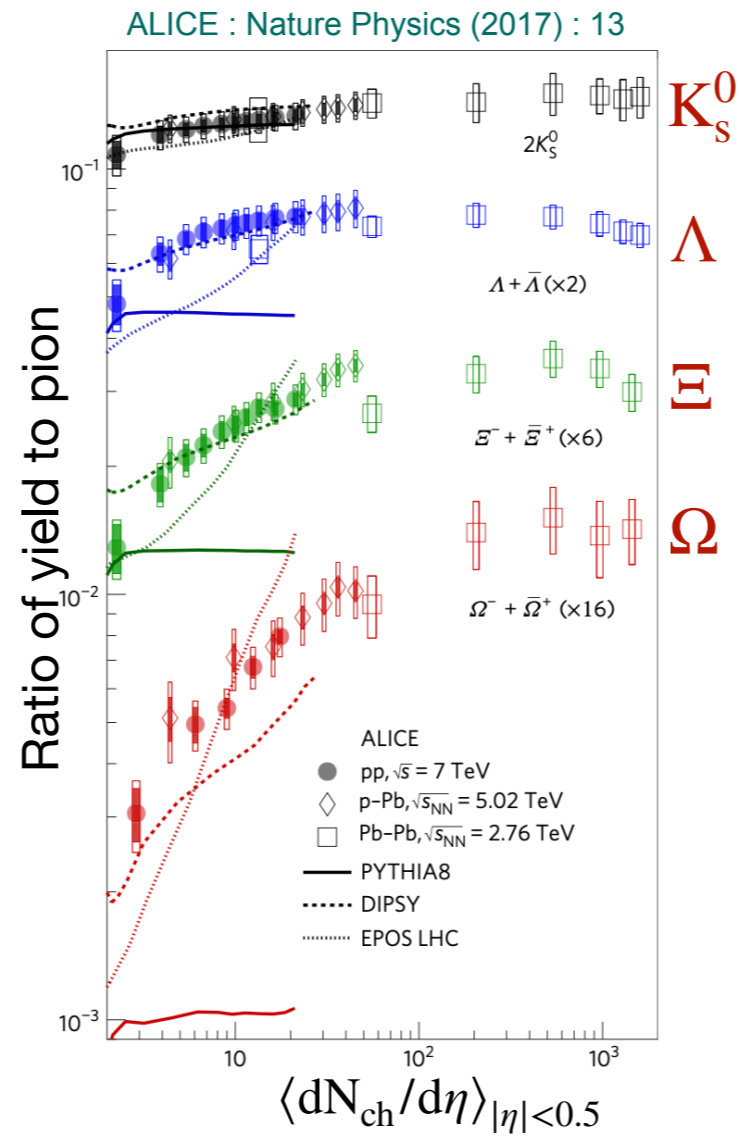
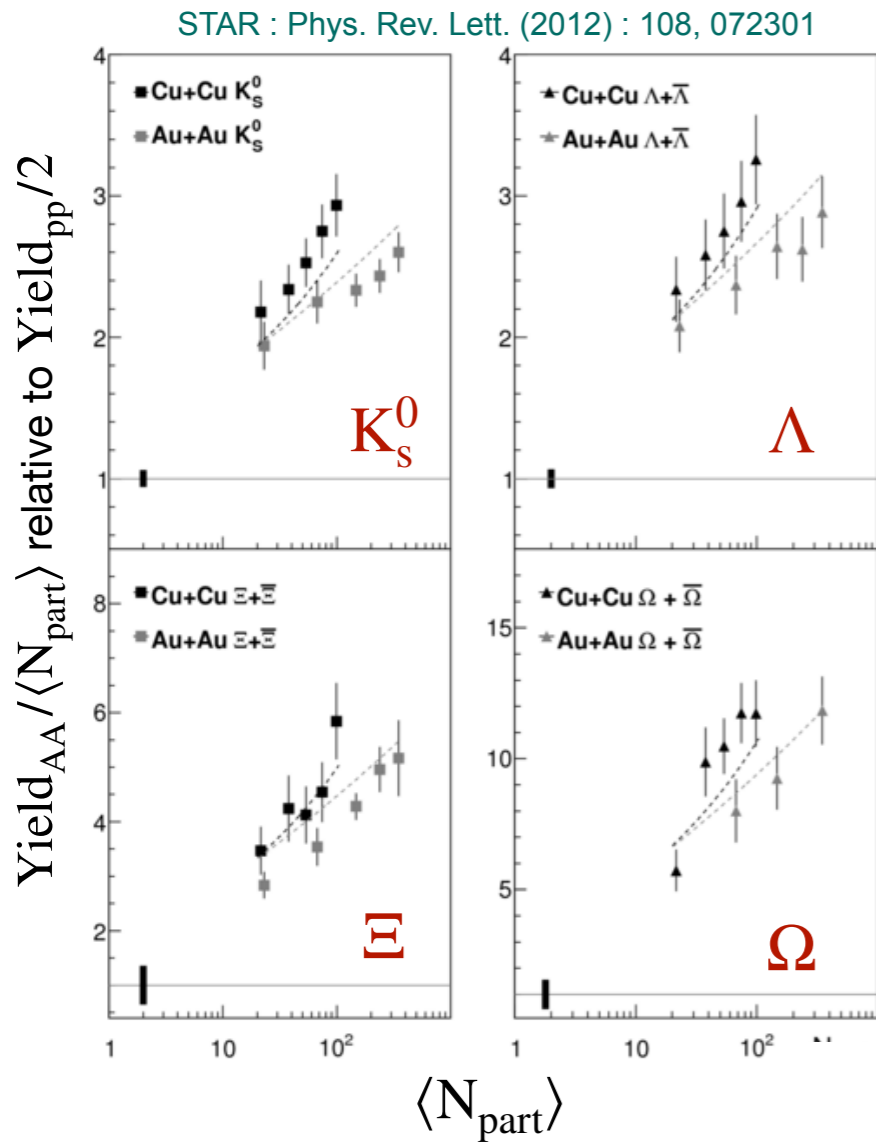


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- Motivation
- Overview of STAR Detector
- Dataset and Particle Identification
- Analysis Technique
- Results
- Summary

Motivation I : Strangeness as a Probe for Deconfinement



- 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

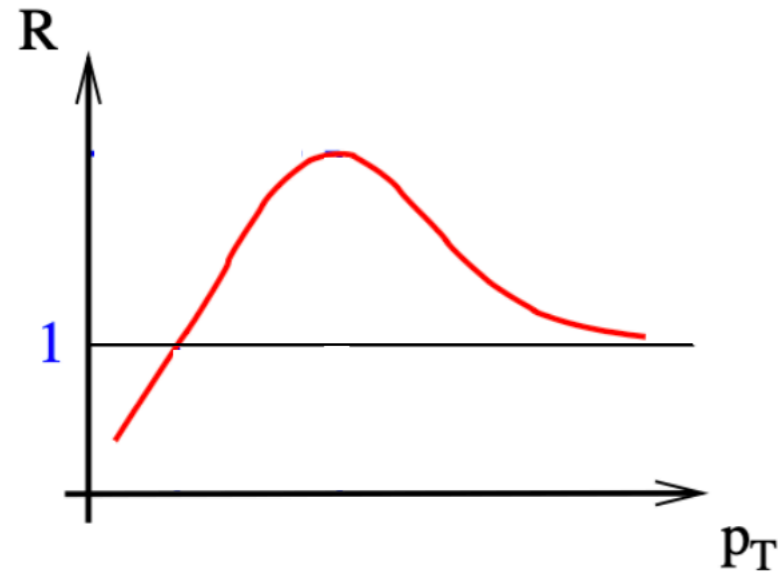
- Creation of QGP in smaller systems is still under intense debate
- Strangeness measurements in d+Au can bridge the multiplicity gap between peripheral A+A and p+p

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

Motivation II : Probing Cold Nuclear Matter Effects



- Cronin effect studied using nuclear modification factor R

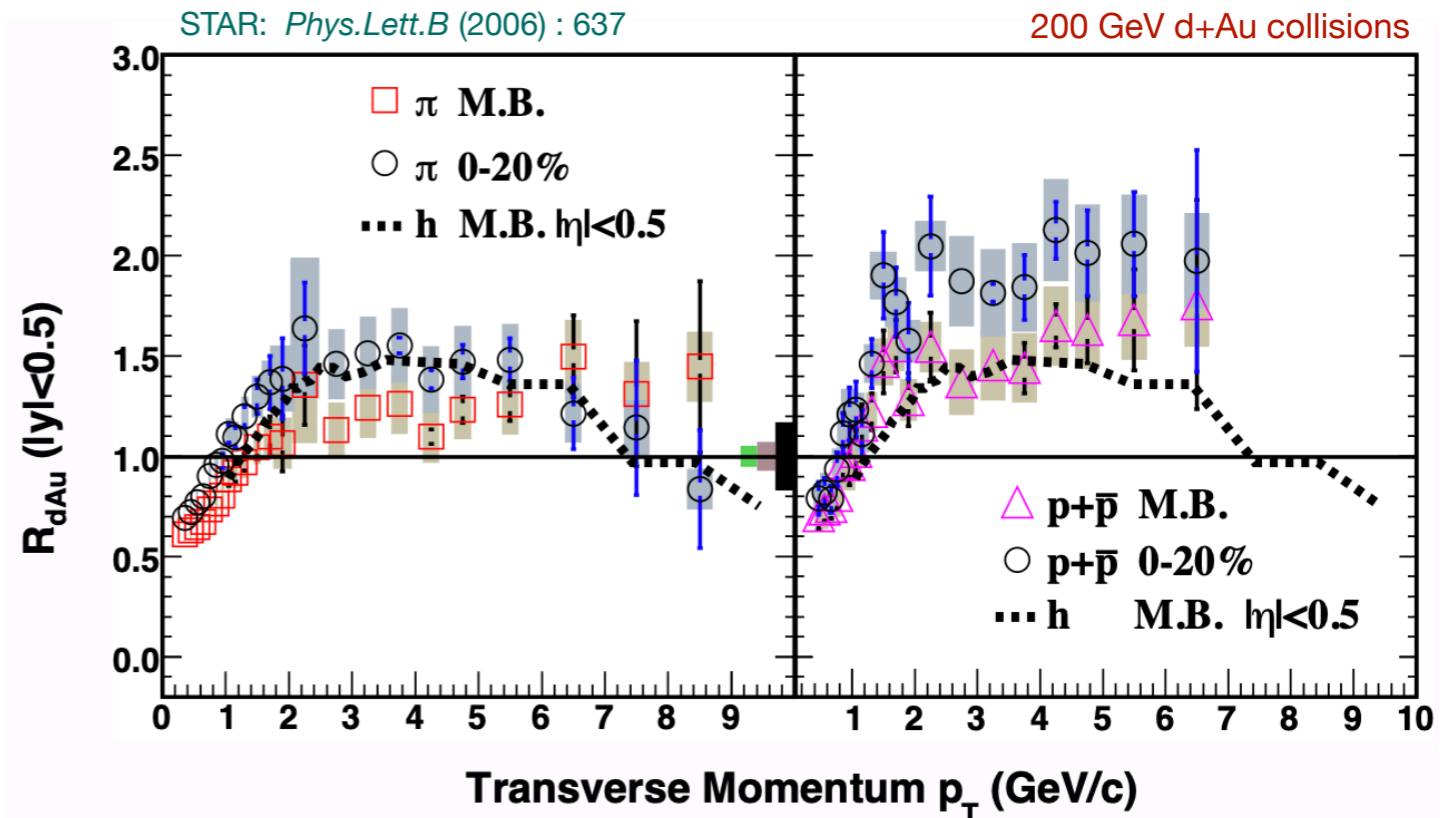


Measurements of particle type and centrality dependence of $R_{dAu}(p_T)$ may help us understand the mechanism behind Cronin effect

Nuclear modification factor R_{dAu}

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

$$T_{dAu} = \langle N_{bin} \rangle / \sigma_{inel}^{pp}$$



- 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

Motivation II : Probing Cold Nuclear Matter Effects

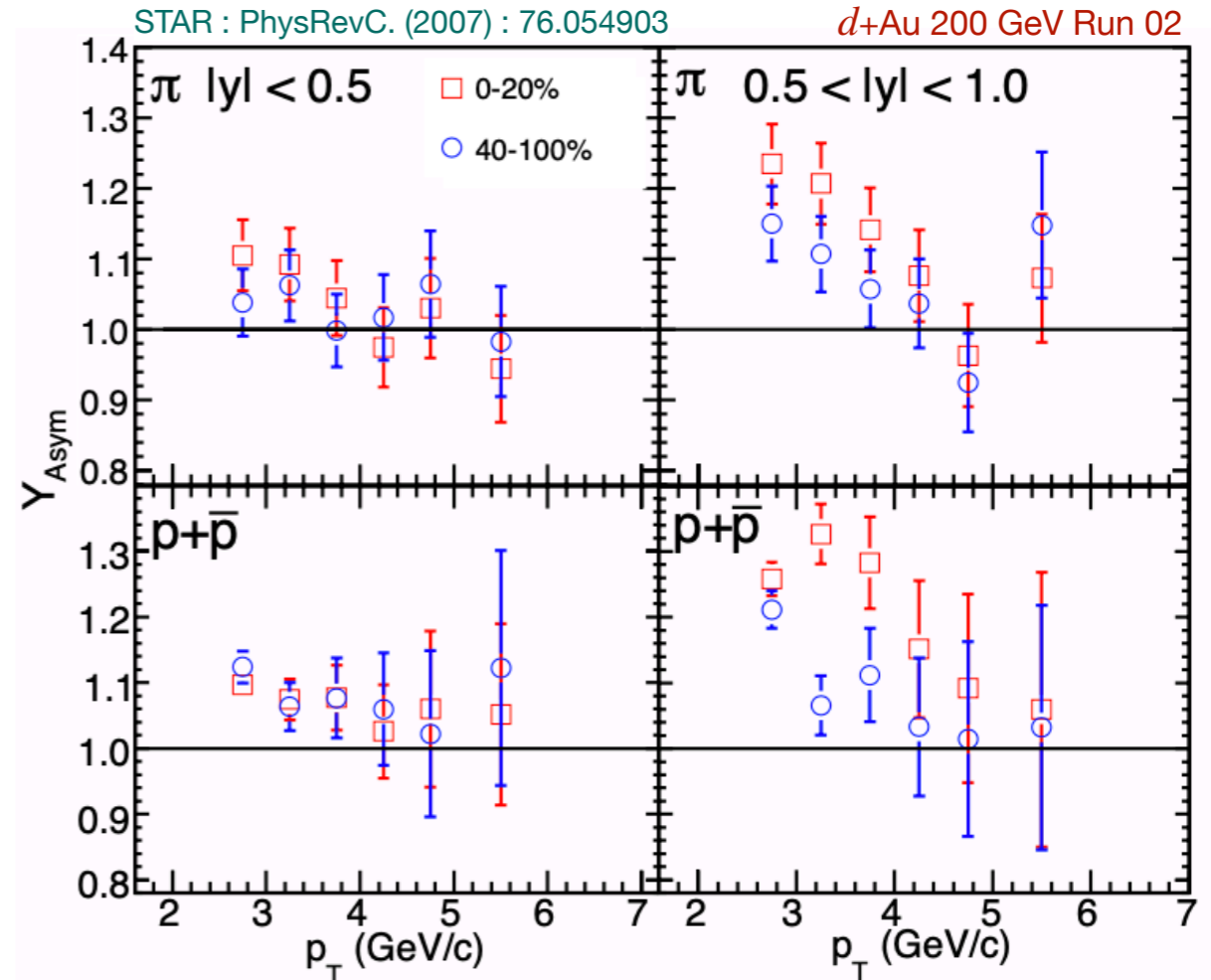


Rapidity Asymmetry :

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

Au going side - backward rapidity
d going side - forward rapidity

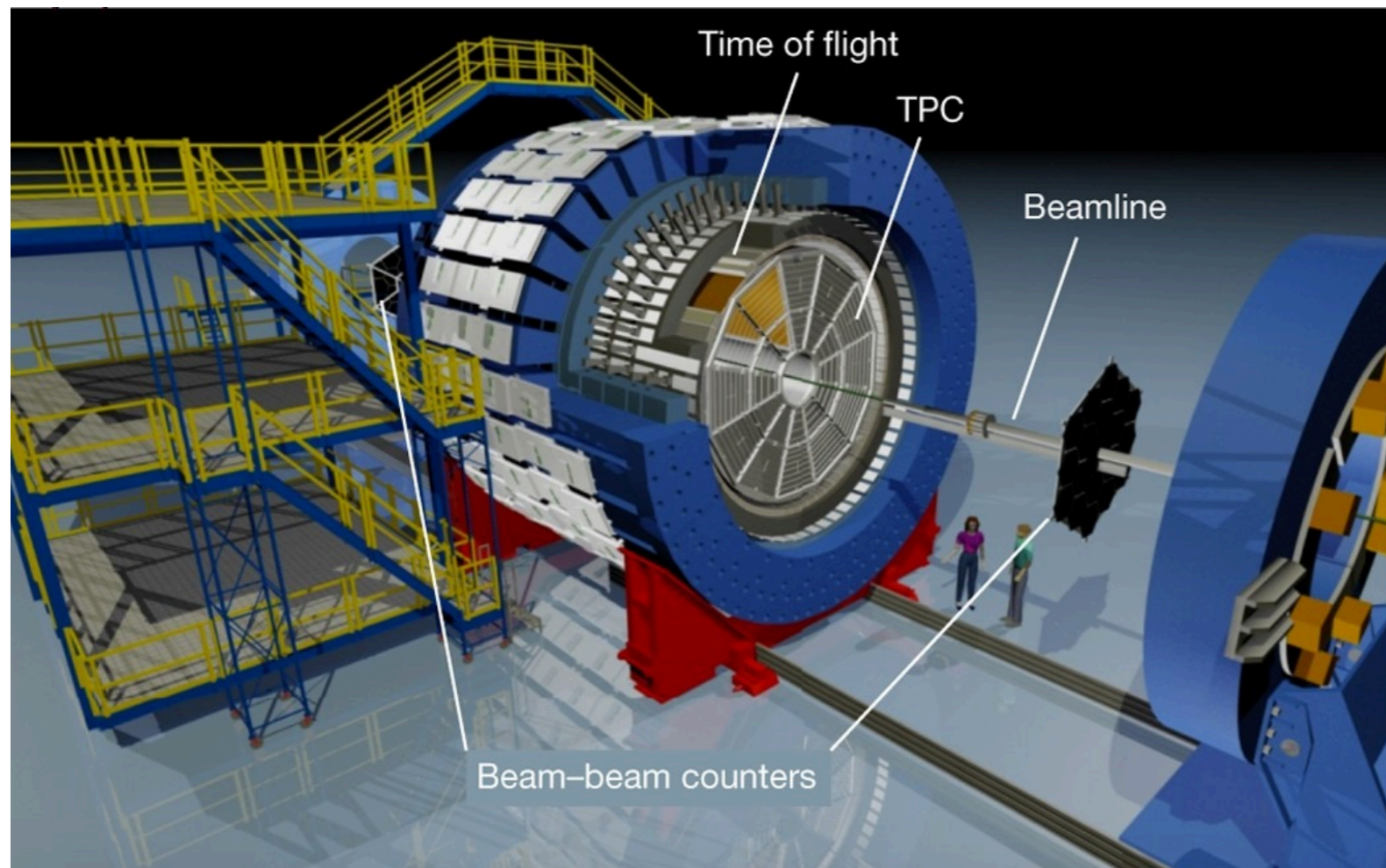
- Rapidity Asymmetry provides unique tool to study contributions from nuclear effects (nuclear shadowing, multiple scattering etc.) to the particle production



- At low p_T :
 $Y_{\text{Asym}} > 1 \rightarrow$ 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>

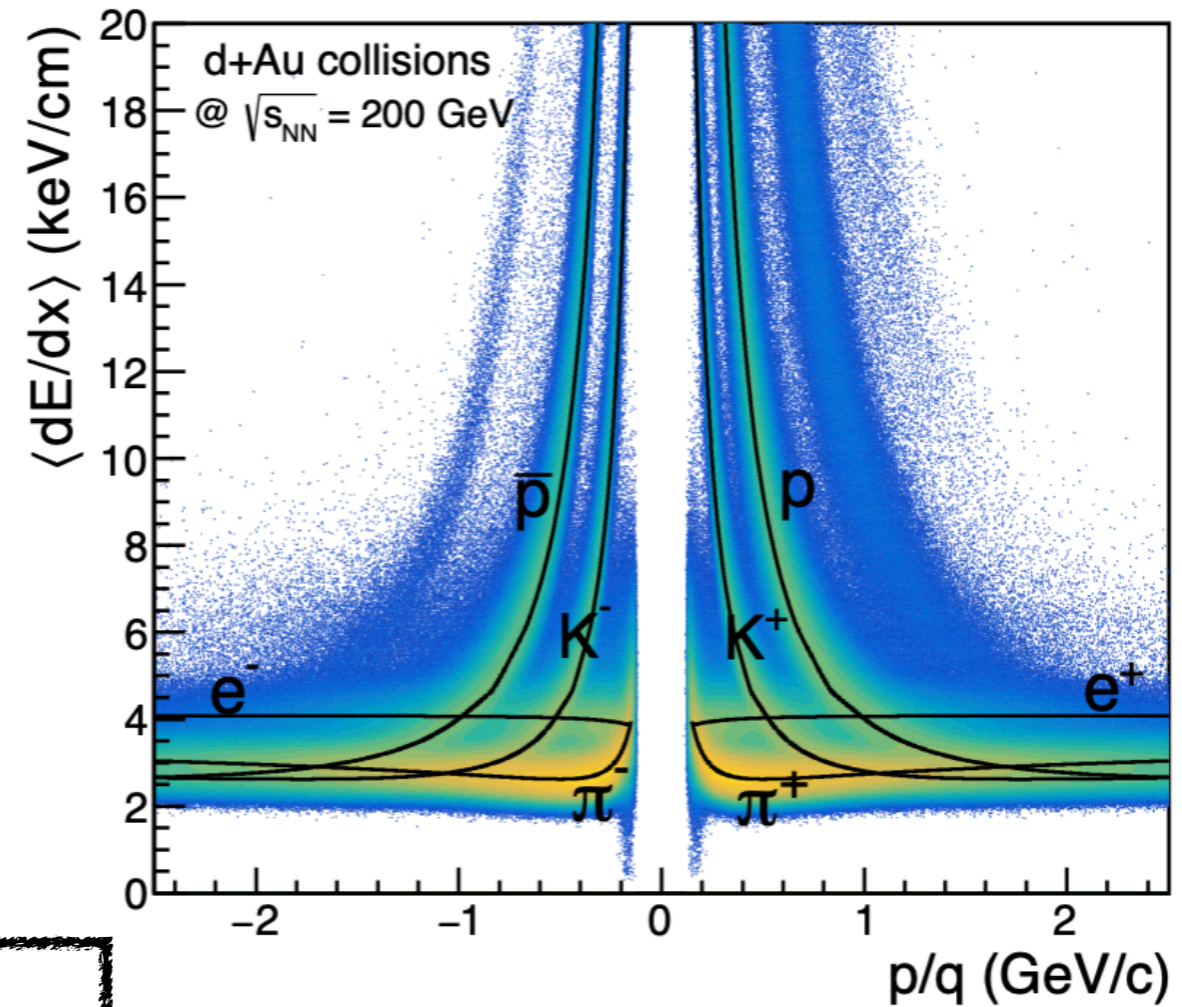
- The **Solenoidal Tracker At RHIC**, known as **STAR**, tracks the thousands of particles produced by heavy-ion collisions at RHIC
- STAR detector is used to study the signatures of the Quark Gluon Plasma (QGP) formation
- Time Projection Chamber (TPC) is the main detector used for the analysis

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

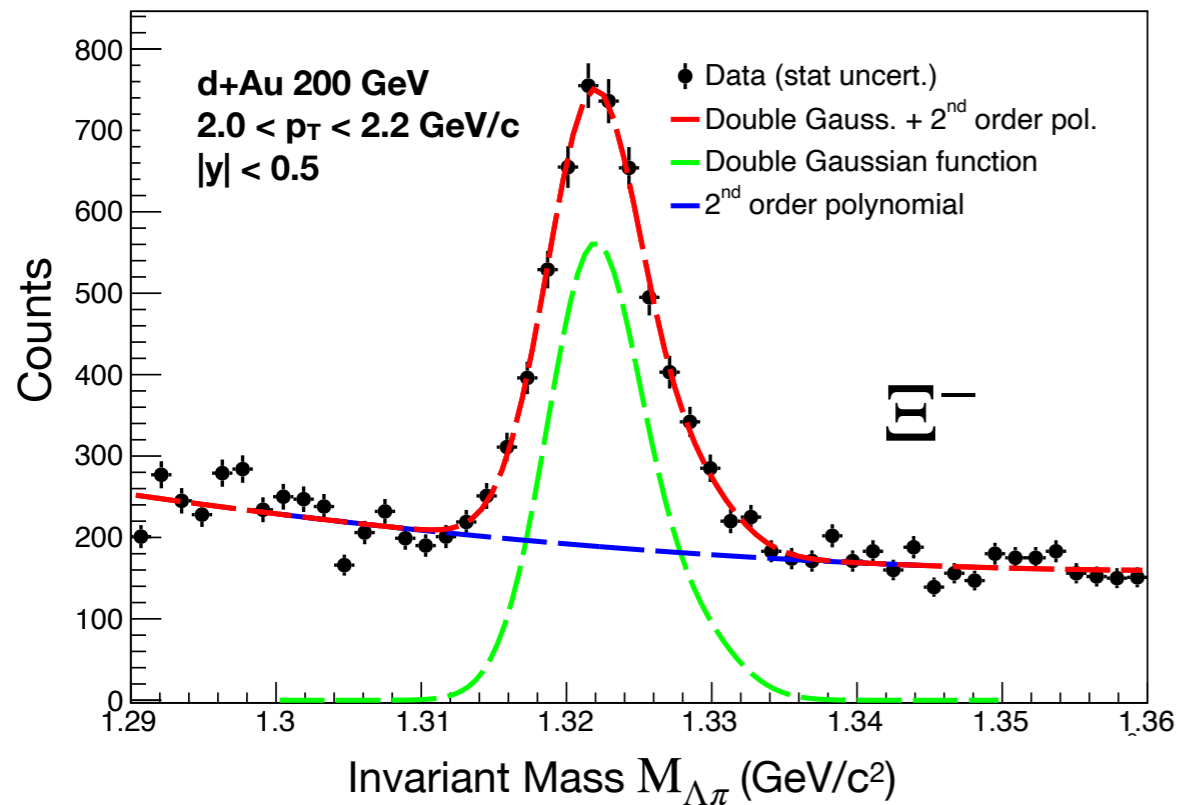
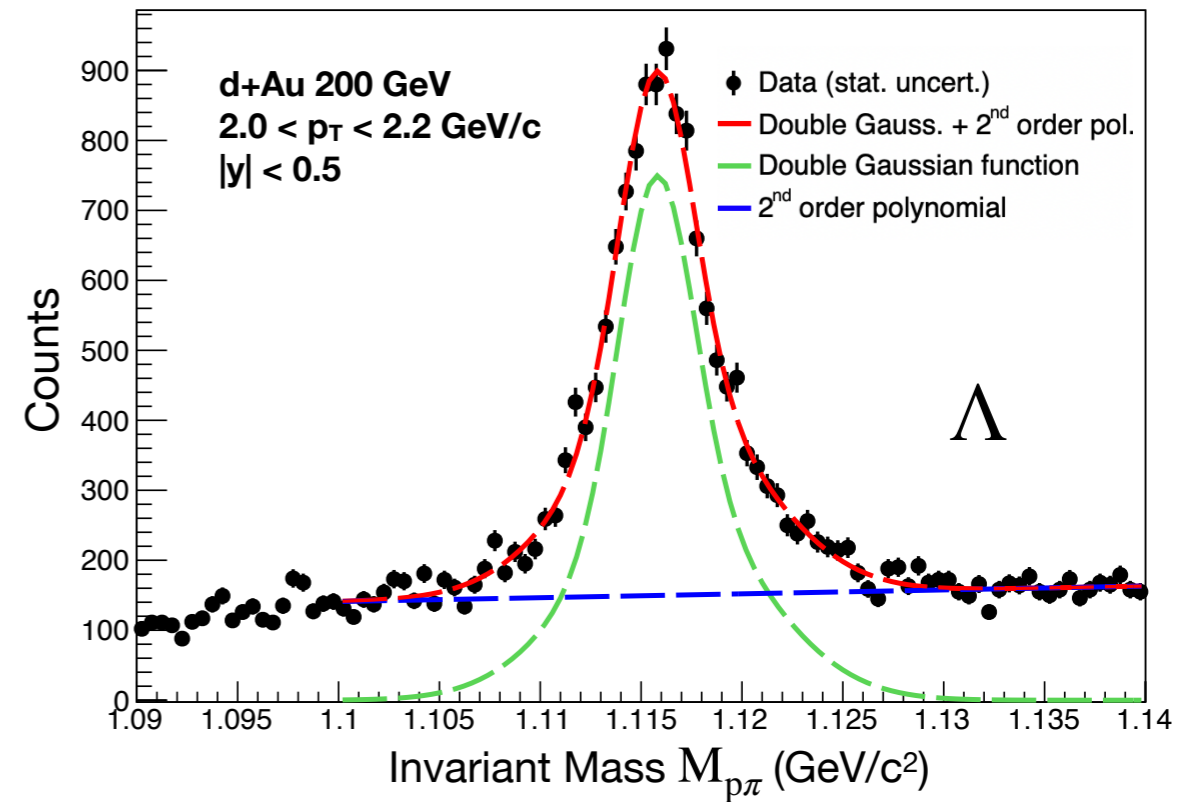
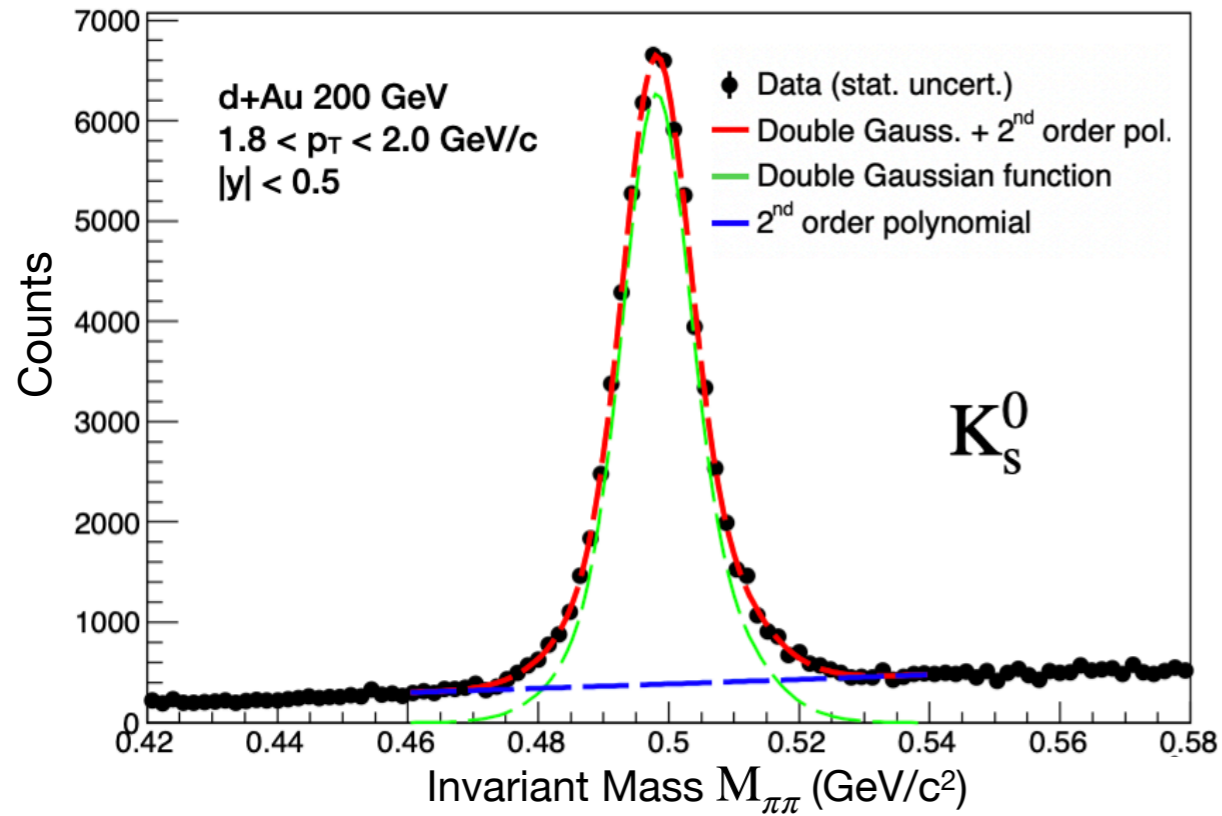


- d+Au collisions @ $\sqrt{s_{NN}} = 200$ GeV
- Year : 2016
- Events analyzed ~ 100 M
- Particles studied : K_s^0 , Λ , Ξ & Ω



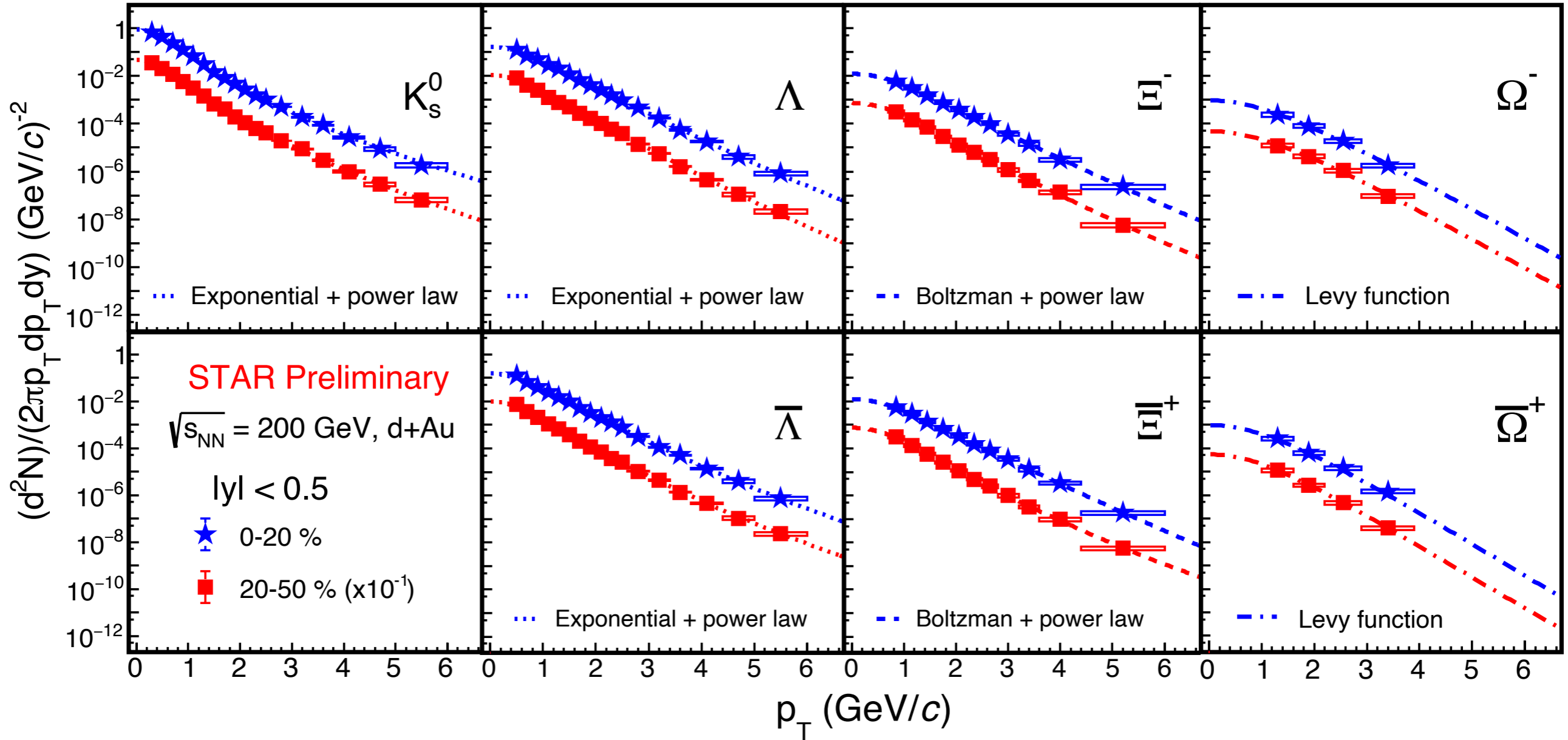
- K_s^0 , Λ , Ξ , Ω are reconstructed via their hadronic decay channels :
- $K_s^0 \rightarrow \pi^+ + \pi^-$, B.R. $(69.2 \pm 0.05)\%$
- $\Lambda(\bar{\Lambda}) \rightarrow p(\bar{p}) + \pi^-(\pi^+)$, B.R. $(63.9 \pm 0.5)\%$
- $\Xi^-(\bar{\Xi}^+) \rightarrow \Lambda(\bar{\Lambda}) + \pi^-(\pi^+)$, B.R. $(99.8 \pm 0.035)\%$
- $\Omega^-(\bar{\Omega}^+) \rightarrow \Lambda(\bar{\Lambda}) + K^-(K^+)$, B.R. $(67.8 \pm 0.7)\%$

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



- **Red line** : Double gaussian + 2nd order polynomial (signal+background)
- **Blue line** : 2nd order polynomial (background)
- **Green line** : Double gaussian (signal)

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

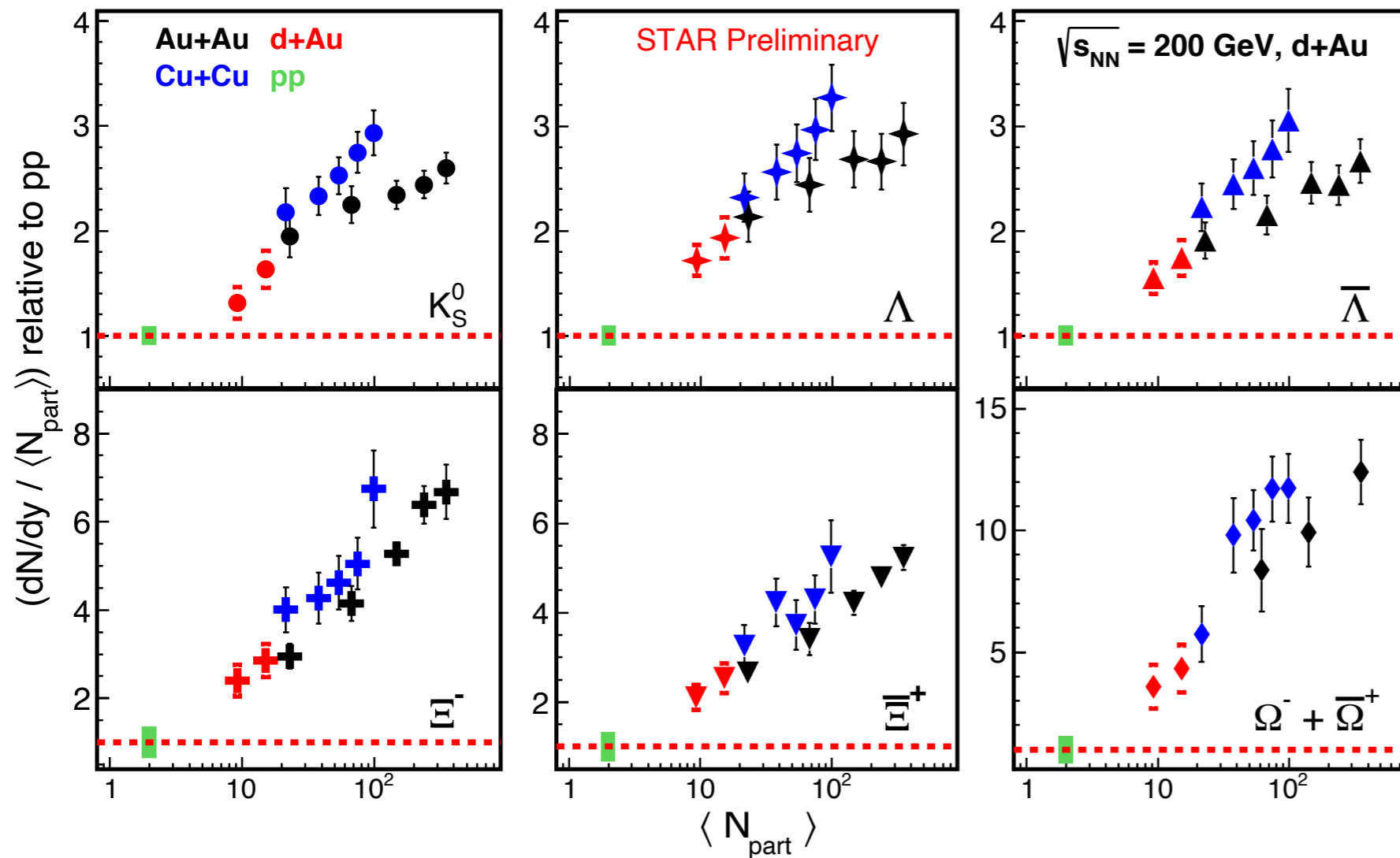


- p_T spectra of K_s^0 , $\Lambda(\bar{\Lambda})$, $\Xi^-(\bar{\Xi}^+)$ & $\Omega^-(\bar{\Omega}^+)$ are corrected for acceptance & efficiency and respective branching ratios
- Λ spectra are corrected for weak decay feed down from Ξ

Strangeness Enhancement

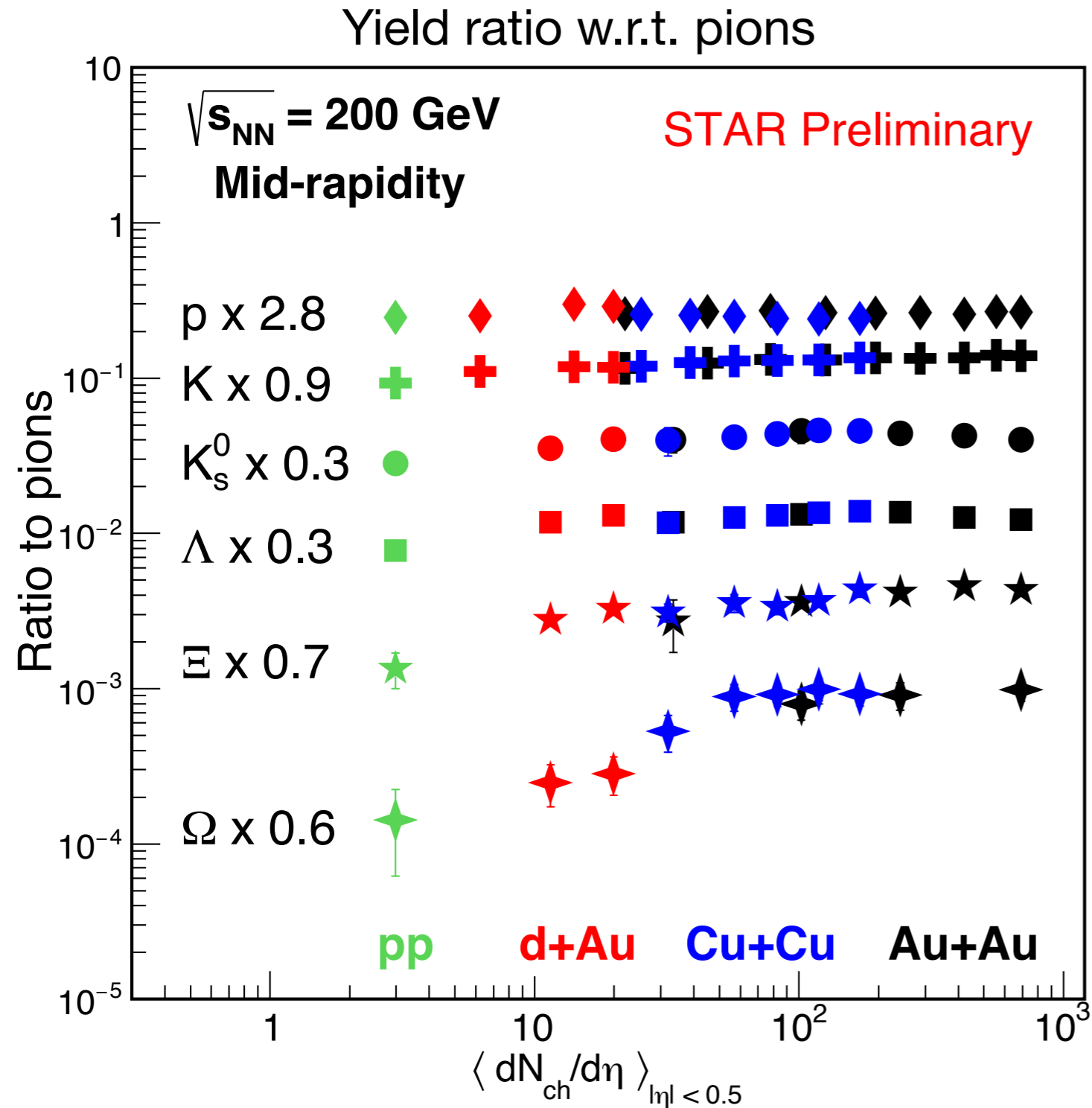


$$\text{Enhancement factor} = \frac{(dN/dy)/\langle N_{part} \rangle}{(dN/dy)_{pp}/\langle N_{part} \rangle_{pp}}$$



- Strange particle yields in d+Au 200 GeV are enhanced as compared to p+p collisions
- d+Au fill the gap between p+p and peripheral Cu+Cu & Au+Au collisions
- Strange particle yields increase as a function of $\langle N_{part} \rangle$

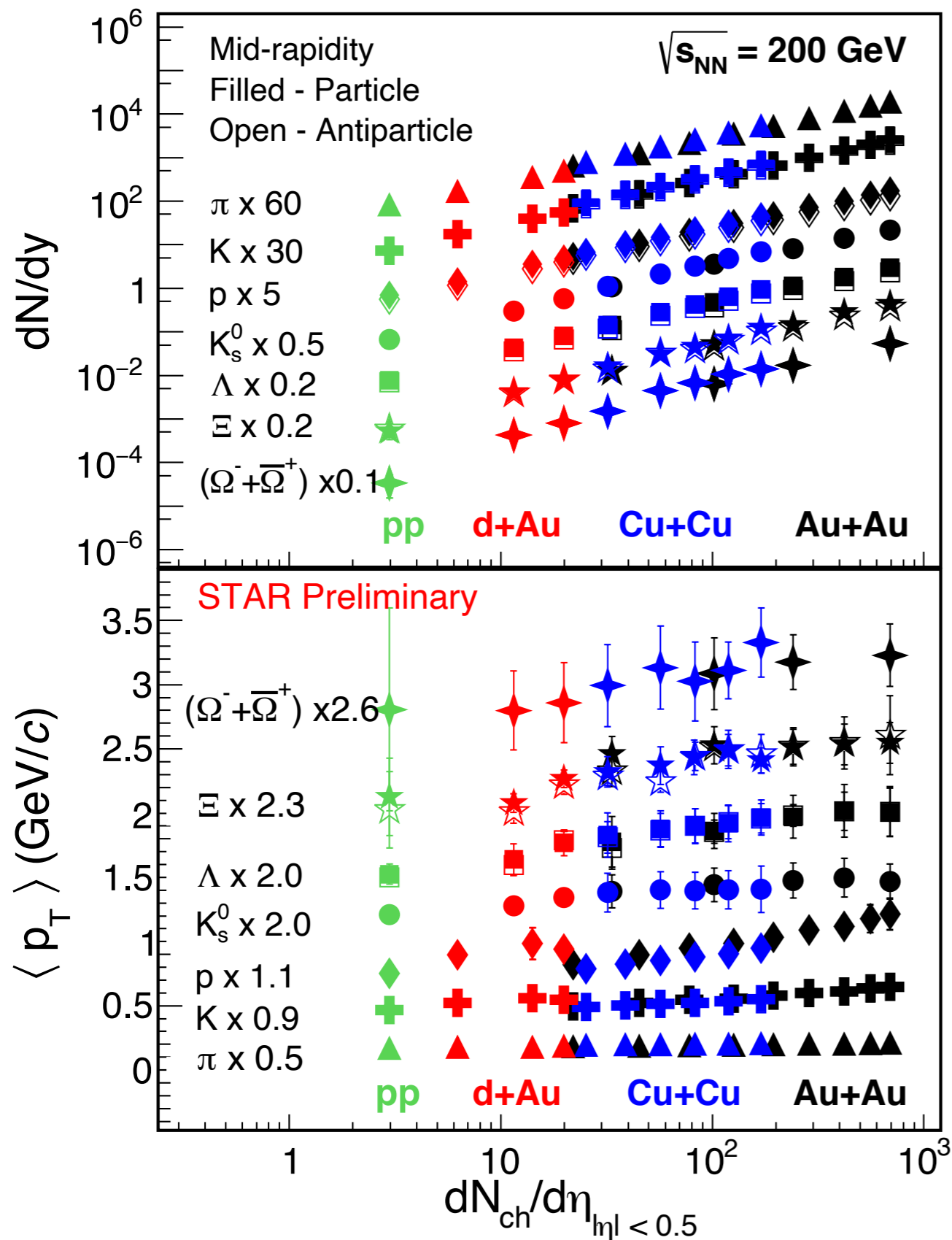
STAR : Phys. Rev. C (2007) : 75, 064901
 STAR : Phys. Rev. Lett. (2012) : 108, 072301
 STAR : Phys. Rev. C (2009) : 79, 034909



- Smooth transition of ratios of the particles from p+p to A+A 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

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)

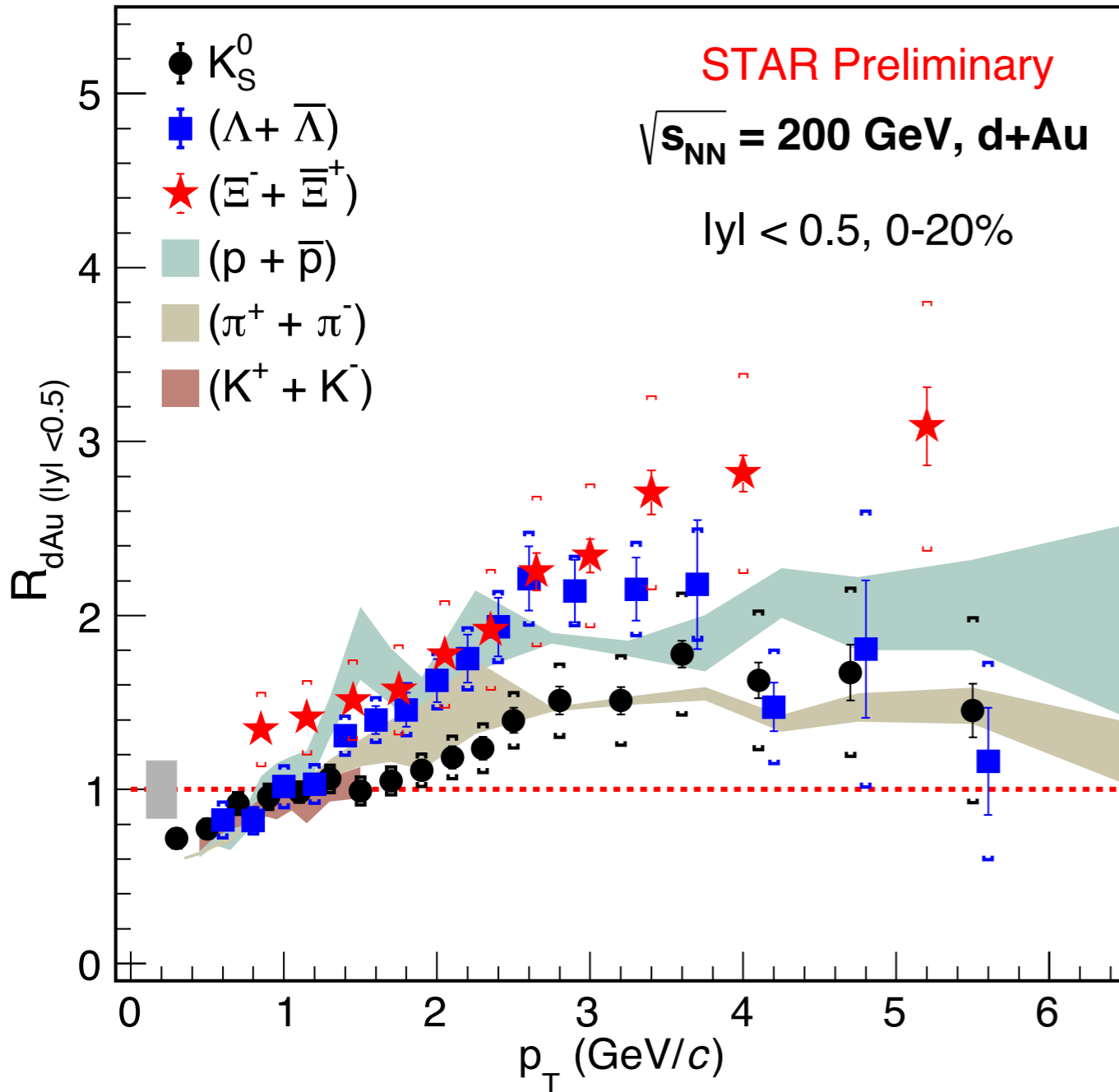
Integrated yields and $\langle p_T \rangle$ as function of Multiplicity



- 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)
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Nuclear Modification Factor



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

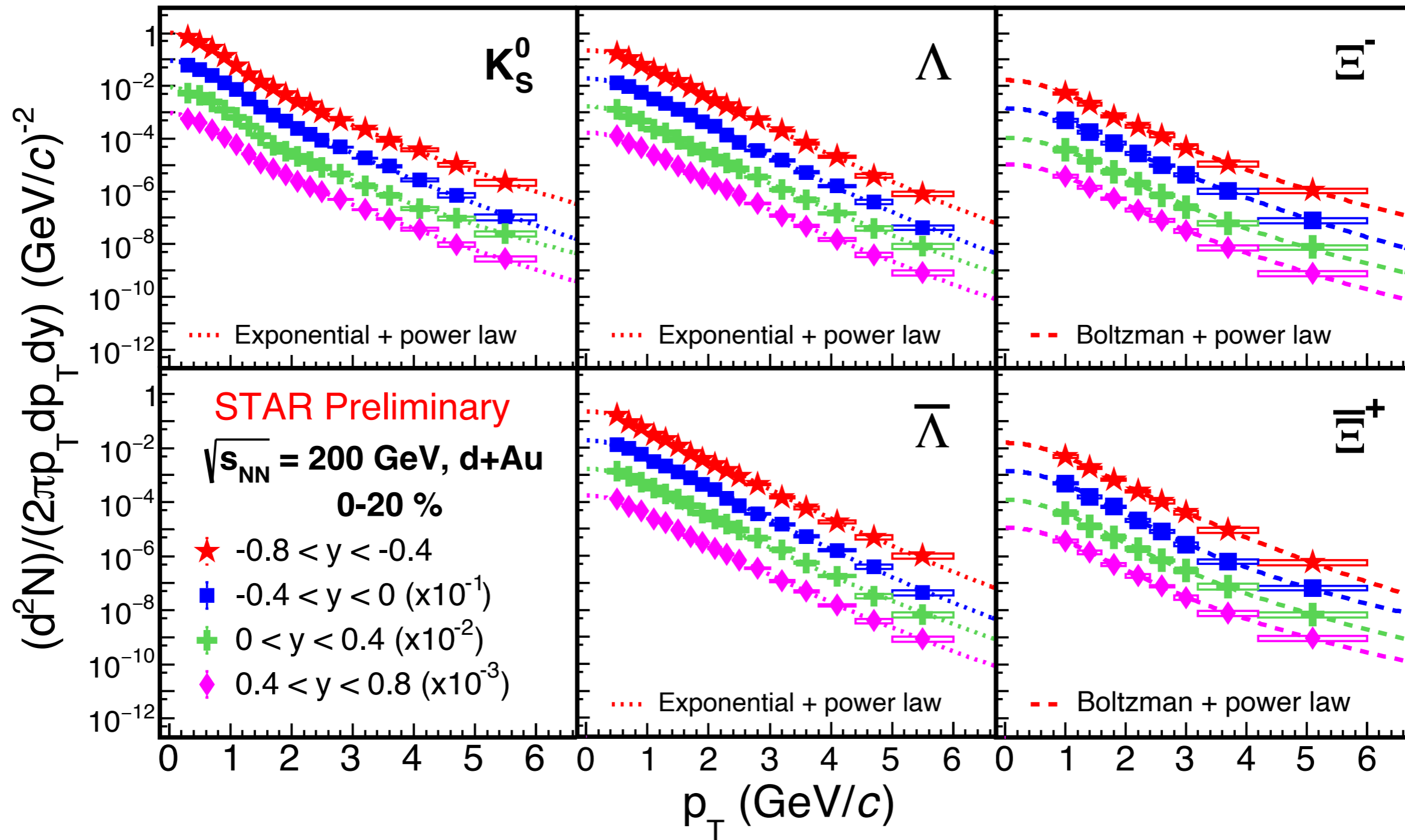
*π, K, p data are from
 STAR : Phys.Lett.B (2006) : 637
 STAR : Phys.Lett.B (2005) : 616*

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

$$T_{dAu} = \langle N_{bin} \rangle / \sigma_{inel}^{pp}$$

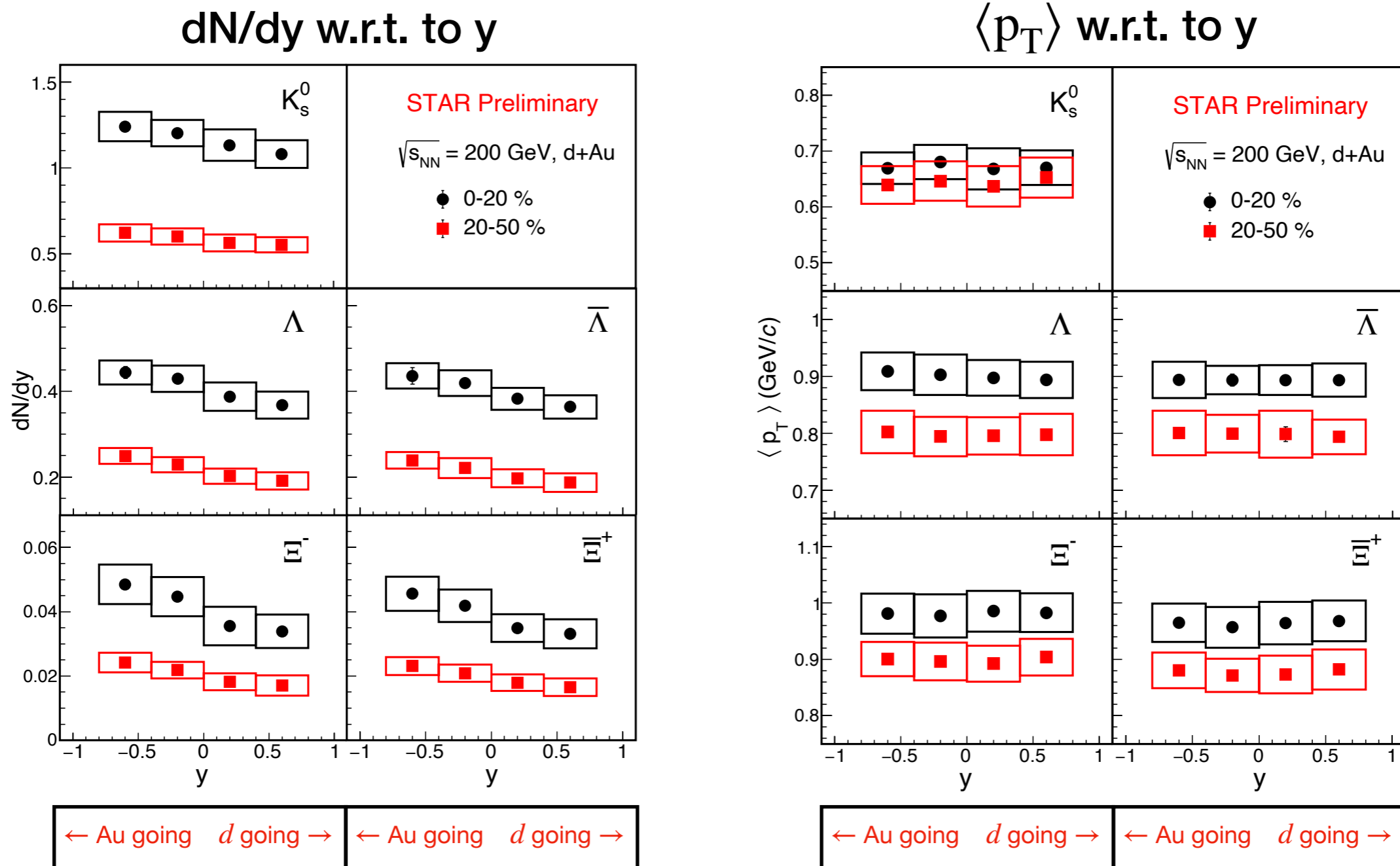
- Cronin like enhancement is observed for K_S^0 , Λ & Ξ at intermediate p_T
- Enhancement in d+Au compared to p+p for p_T in 2-4 GeV/c is stronger for baryons (Ξ , Λ & p) compared to mesons (K_S^0 , π)

Transverse Momentum Spectra at Different Rapidities



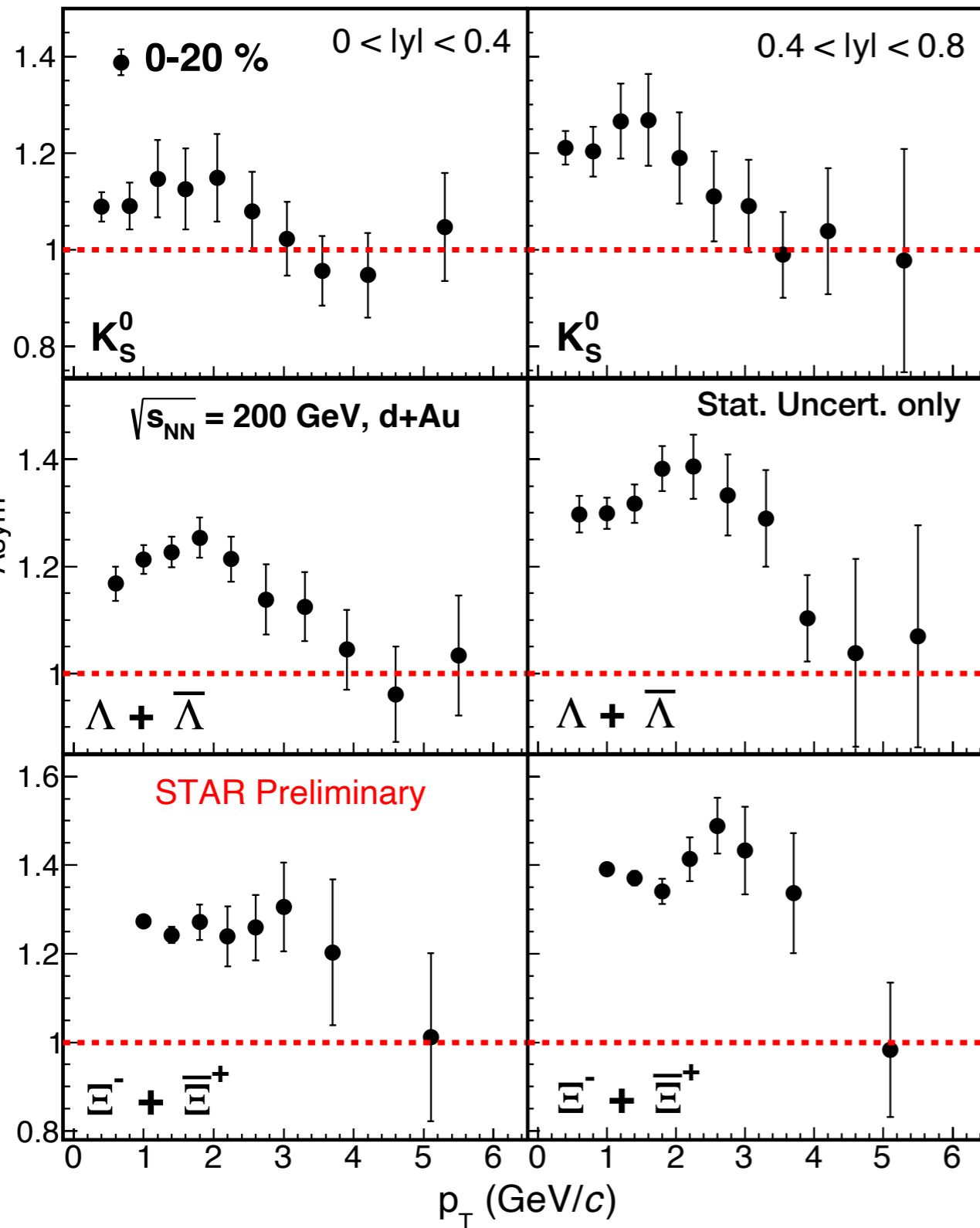
- p_T spectra of K_S^0 , $\Lambda(\bar{\Lambda})$, $\Xi^-(\bar{\Xi}^+)$ for different rapidities are corrected by acceptance & efficiency and respective branching ratios

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



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

Rapidity Asymmetry



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

- $Y_{Asym} > 1$ 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)

- We have presented **Multiplicity and Rapidity dependent studies of K_s^0 , Λ , Ξ and Ω in d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV**
- Yields of K_s^0 , $\Lambda(\bar{\Lambda})$, $\Xi^-(\bar{\Xi}^+)$ & $\Omega^-(\bar{\Omega}^+)$ in d+Au are observed to be higher than in p+p collisions at 200 GeV : **Strangeness enhancement**
- **Particle production is independent of collision system** and mainly driven by multiplicity
- **Nuclear modification factors (R_{dAu})** for K_s^0 , Λ and Ξ show Cronin like enhancement
- **Rapidity asymmetry** for K_s^0 , 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!



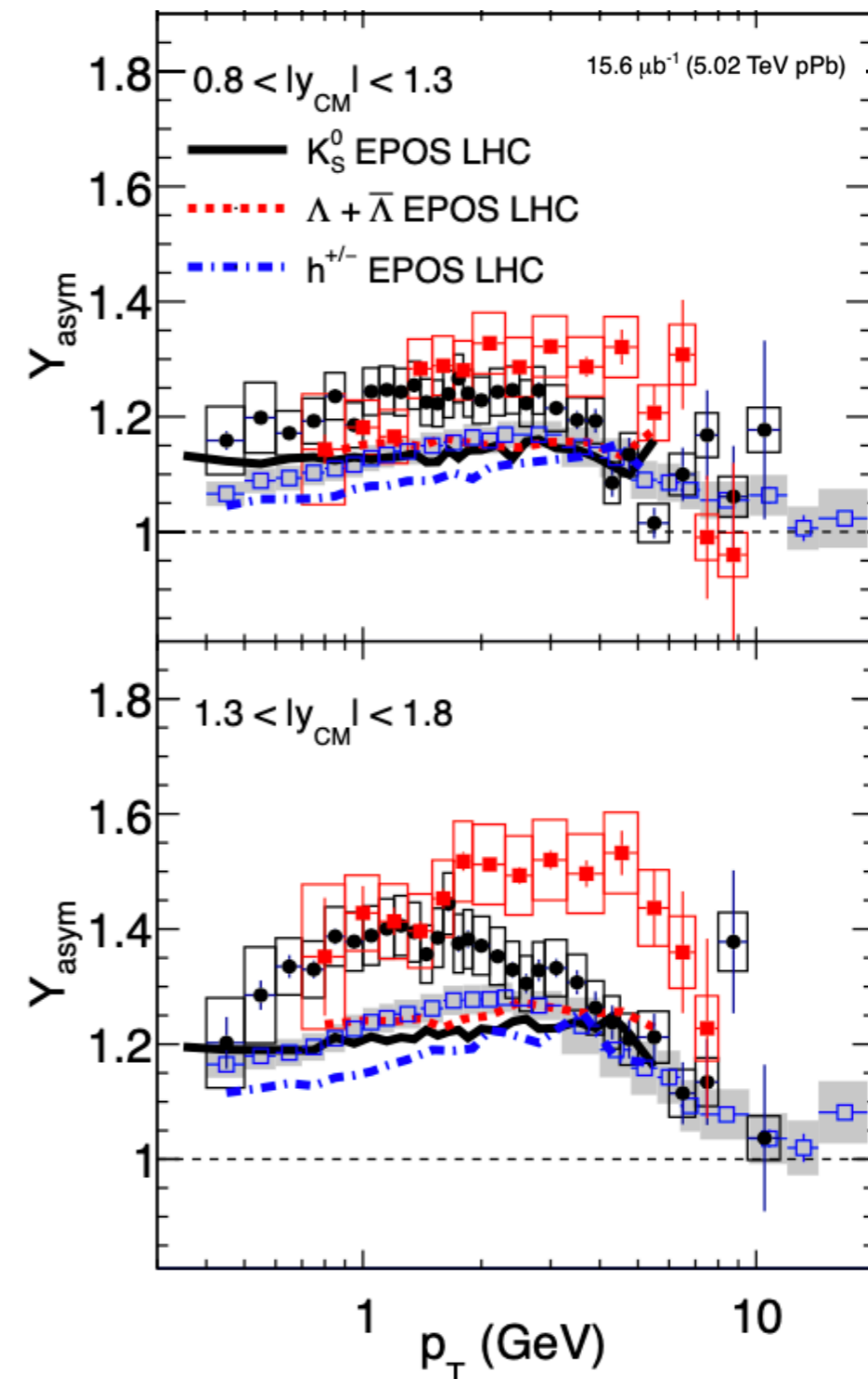
BACK UP

Rapidity Asymmetry Studied in CMS :

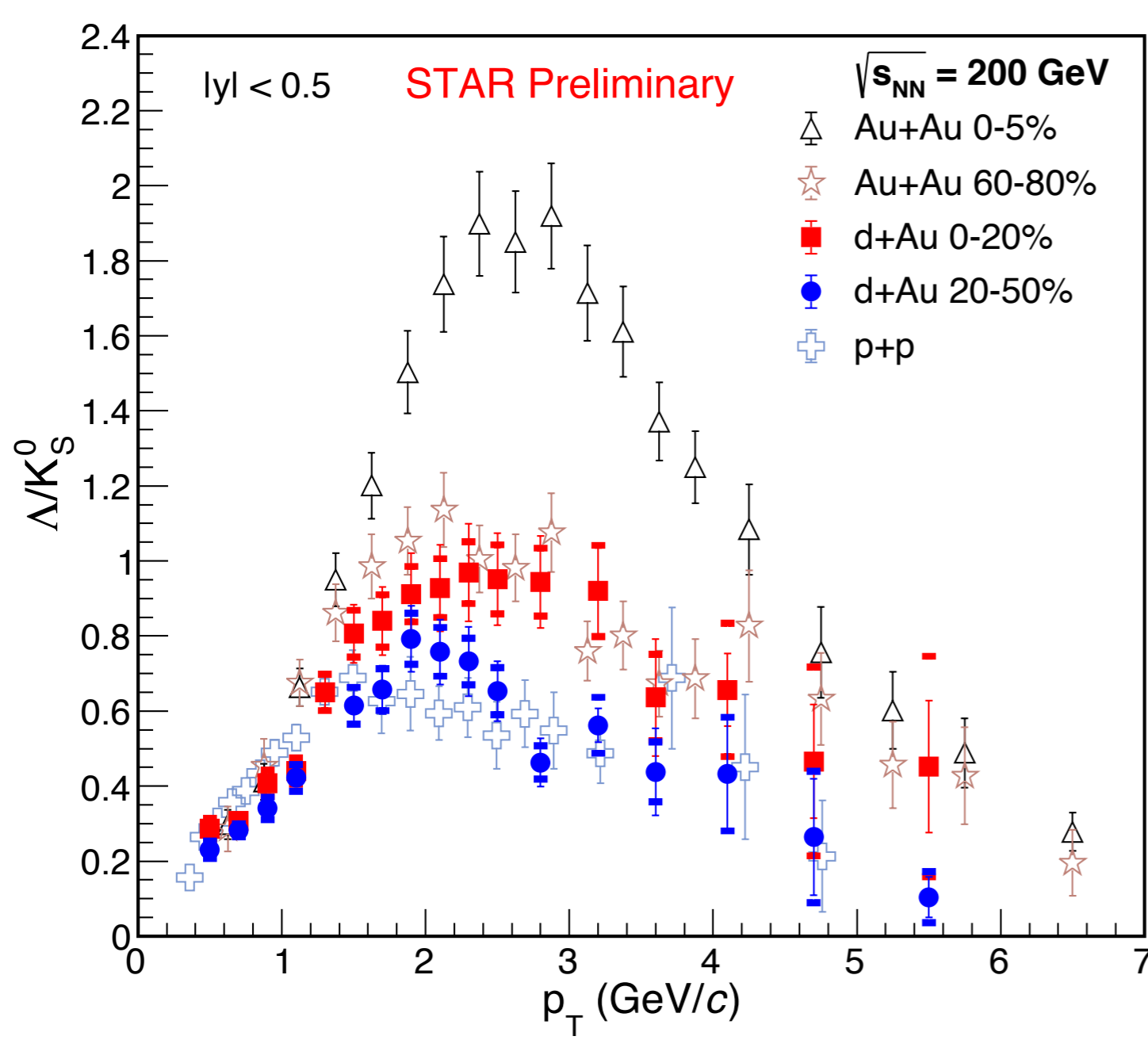
$$Y_{\text{asym}}(p_T) = \frac{d^2N(p_T)/dy_{\text{CM}}dp_T|_{y_{\text{CM}} \in [-b, -a]}}{d^2N(p_T)/dy_{\text{CM}}dp_T|_{y_{\text{CM}} \in [a, b]}}$$

- $Y_{\text{asym}} > 1$ 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)



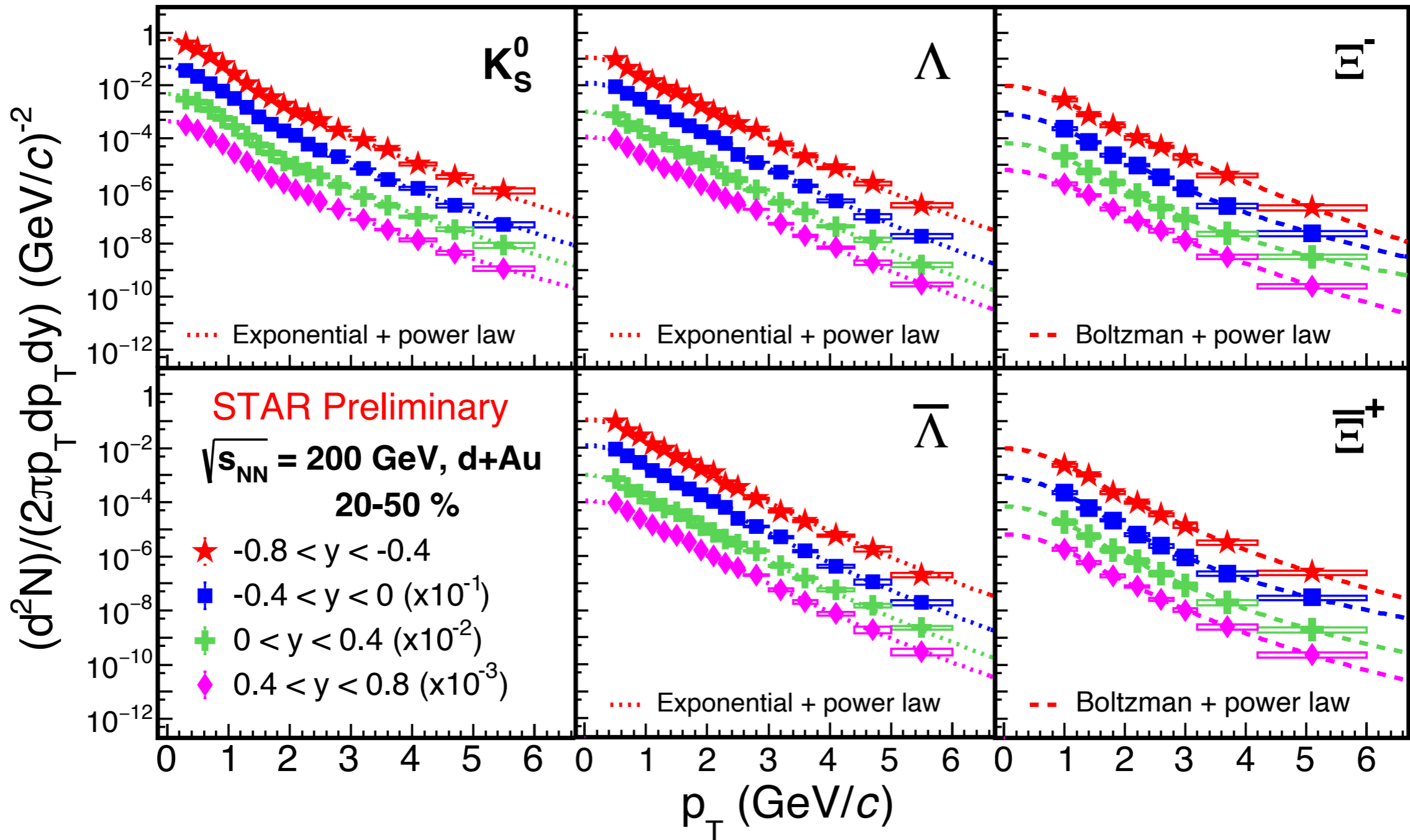
Baryon to Meson Ratio



- Λ/K_S^0 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_S^0 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

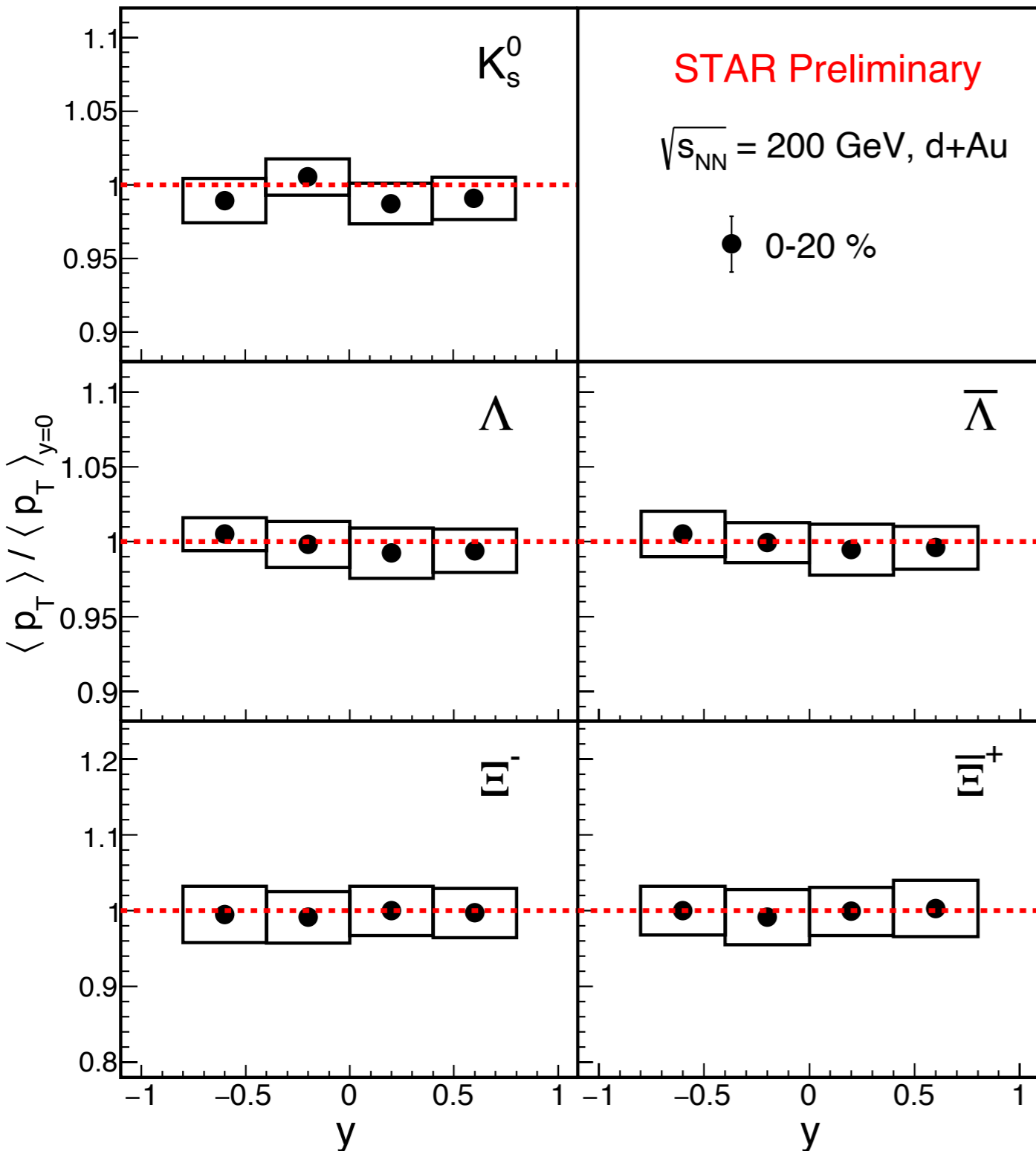
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Transverse Momentum Spectra at Different Rapidities



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

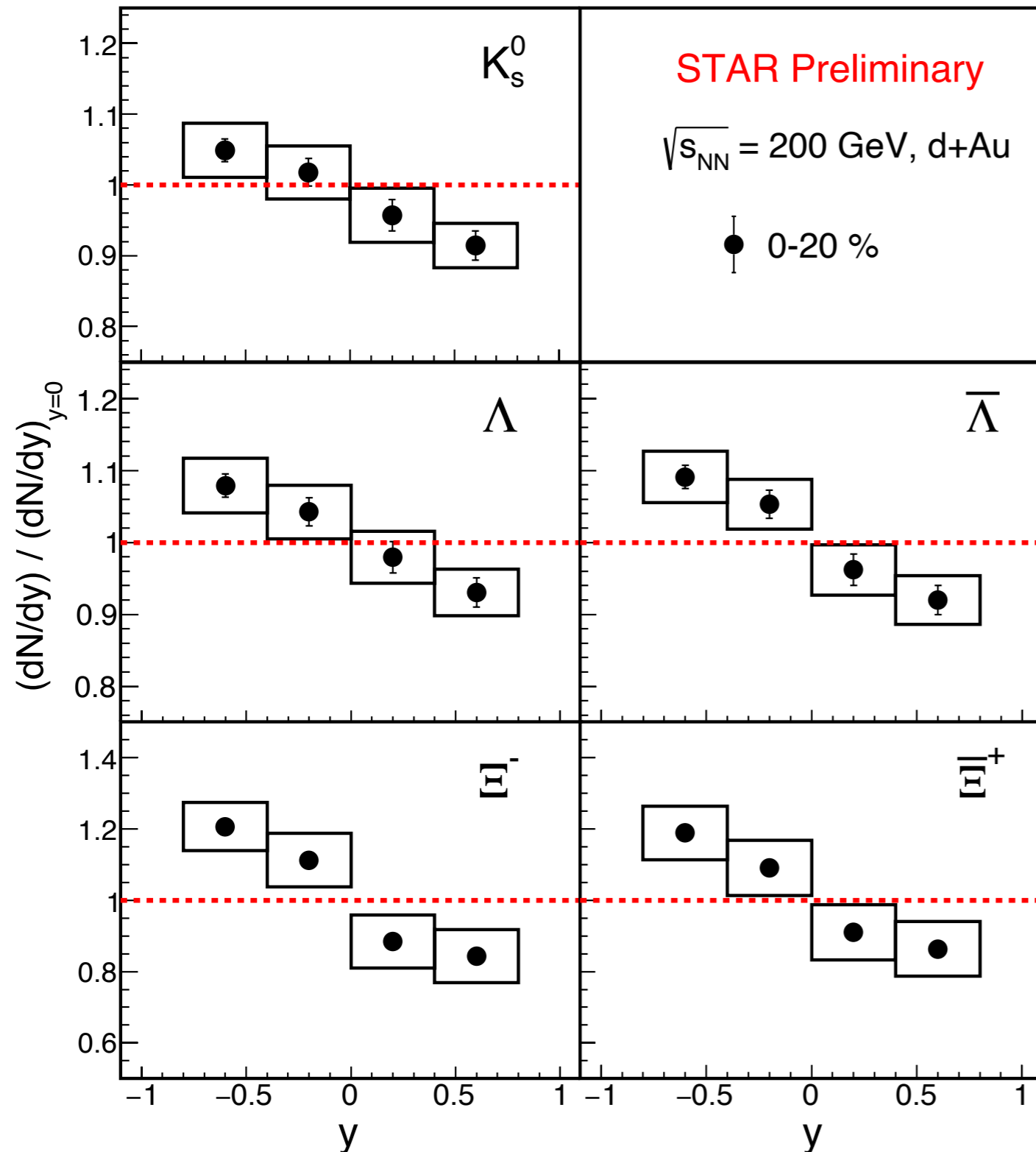
Ratio of $\langle p_T \rangle$ w.r.t. $\langle p_T \rangle$ at $y=0$



Au going side - backward rapidity
d going side - forward rapidity

- $\langle p_T \rangle / \langle p_T \rangle_{y=0}$ for all multiplicity class 0-20% shows a flat behaviour as a function of rapidity in d+Au 200 GeV

Ratio of Yields w.r.t. Yields at $y=0$



Au going side - backward rapidity
d going side - forward rapidity

- $(dN/dy)/(dN/dy)_{y=0}$ of K_S^0 , $\Lambda(\bar{\Lambda})$ & $\Xi^- (\bar{\Xi}^+)$ for 0-20% shows a decreasing trend as a function of rapidity in d+Au 200 GeV