Strange Hadron Production in Small Systems using the STAR detector

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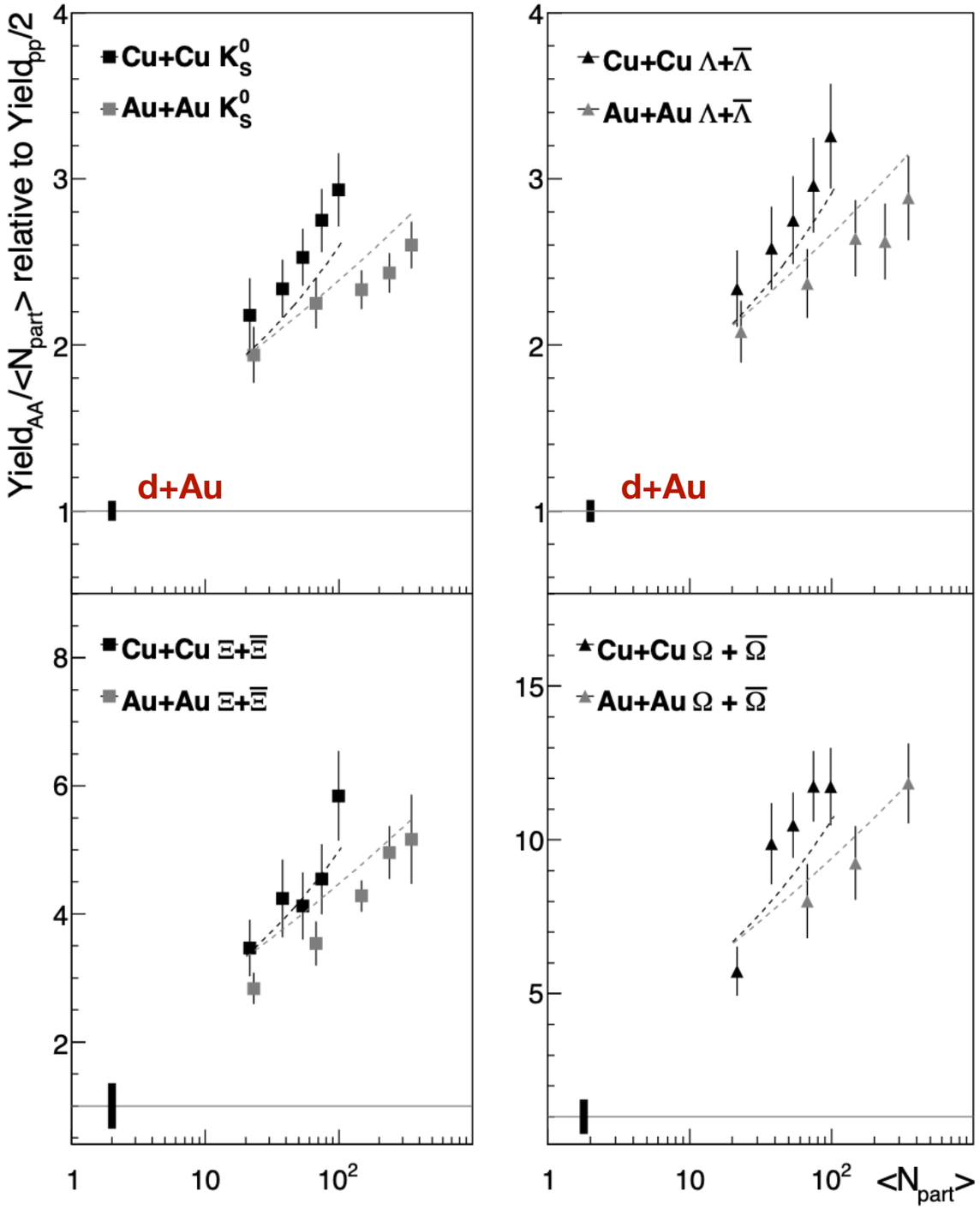
Outline

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

Motivation I : Strangeness as a Probe for Deconfinement



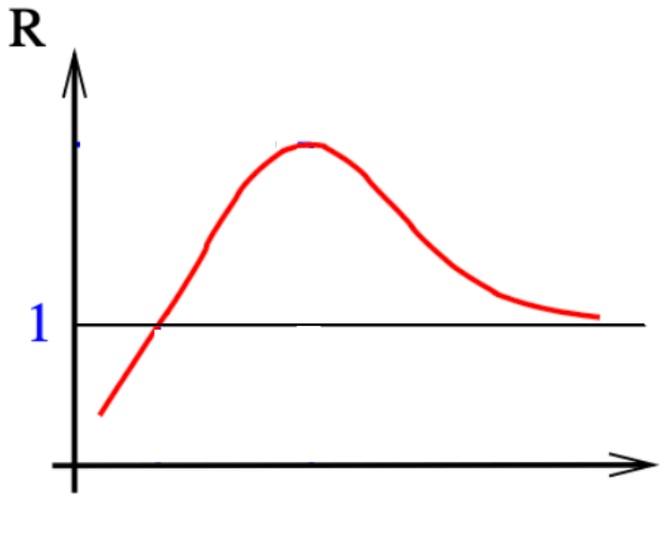
STAR : Phys. Rev. Lett. 108, 072301 (2012)

- Strangeness enhancement in A+A collisions w.r.t. p+p → a traditional signature of QGP formation
- Enhancement increases with increase in strangeness content of the particle species
- 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 in d+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV

Motivation II : Probing Cold Nuclear Matter Effects

- Cronin effect is seen with nuclear modification factor R



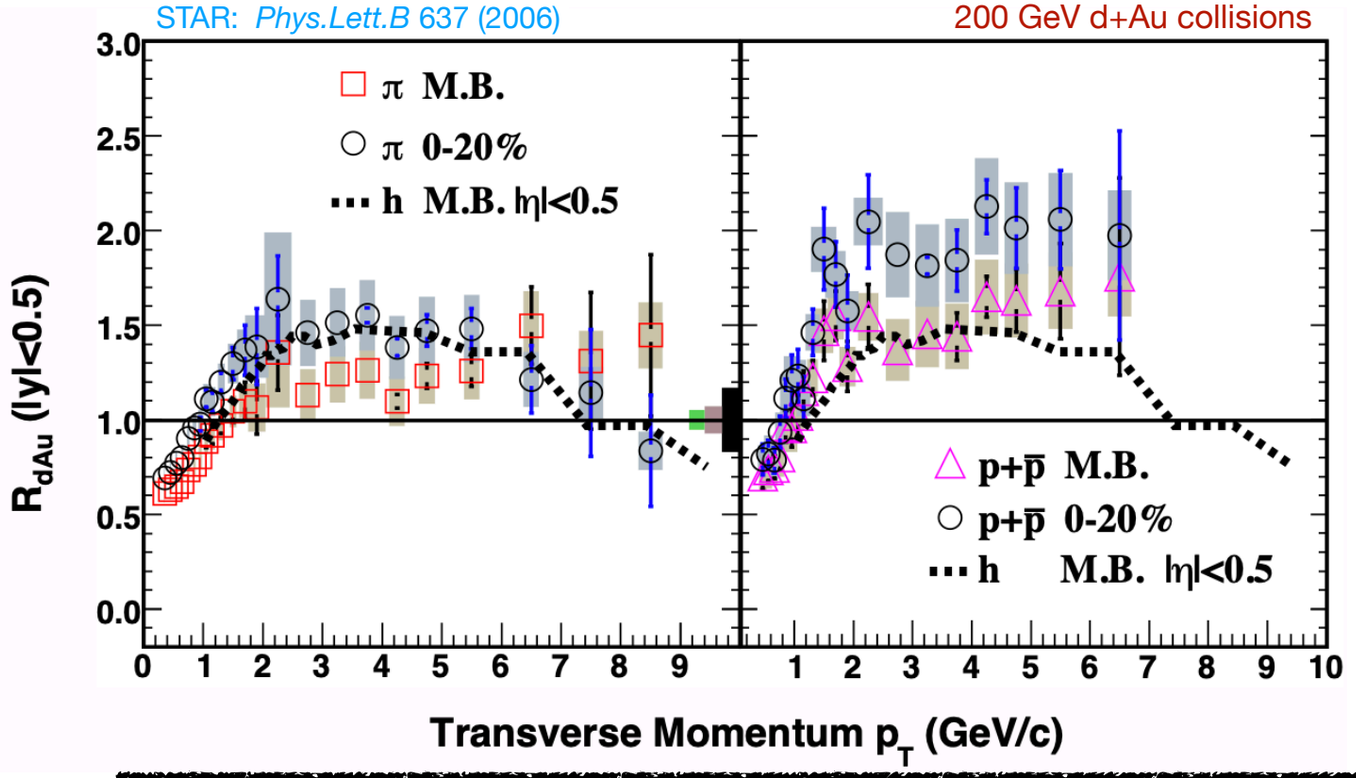
Measurements of particle type and centrality dependence of R_{dAu} (p_T) may help us understand the mechanism behind Cronin Effect

Nuclear modification factor R_{dAu}

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

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

STAR: *Phys.Lett.B* 637 (2006) 200 GeV d+Au collisions



- 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

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

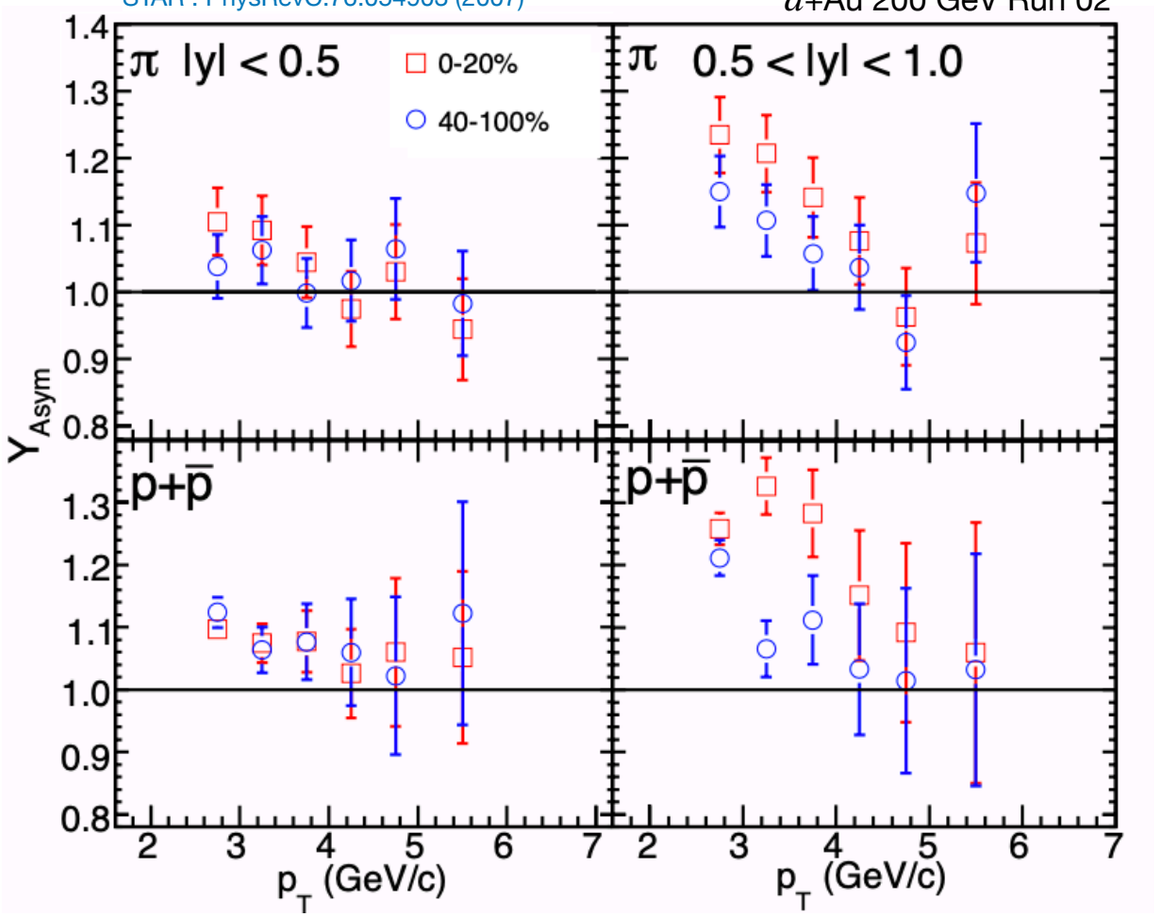
Au going side - backward rapidity

d going side - forward rapidity

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

STAR : PhysRevC.76.054903 (2007)

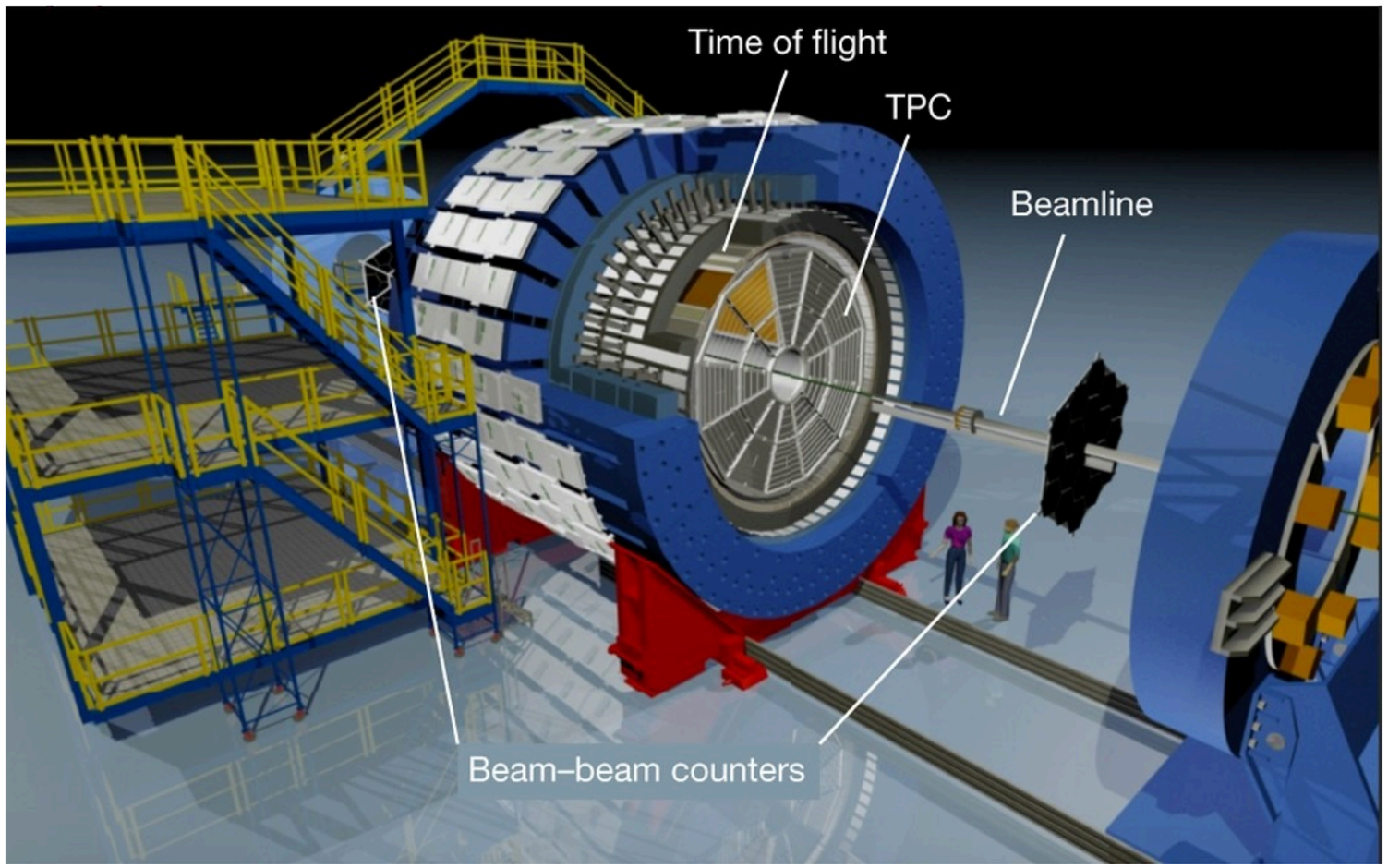
d+Au 200 GeV Run 02



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

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

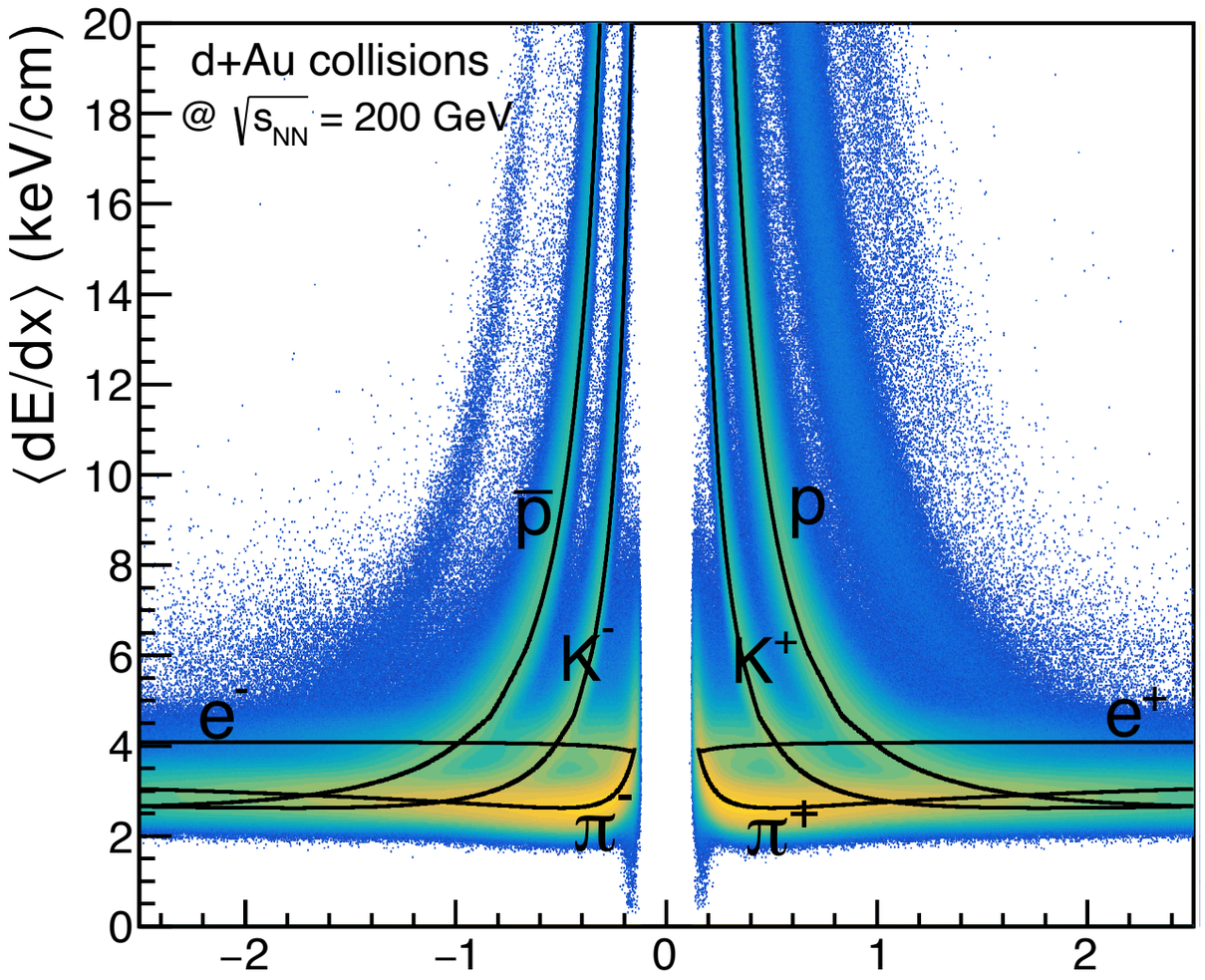
Overview of STAR Detector



- 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 is used to search for signatures of the formation of matter that RHIC was designed to create: the Quark-Gluon Plasma
- Time Projection Chamber (TPC) is the main detector used for the analysis

Dataset and Particle Identification

- d+Au collisions @ $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV
- Year : 2016
- Events analyzed ~100M
- Particles studied : K_s^0, $\Lambda(\bar{\Lambda})$



- **K_s^0, Λ are reconstructed via their hadronic decay channels :**

  $K_s^0 \rightarrow \pi^+ + \pi^-$ (B.R. 69.2%)

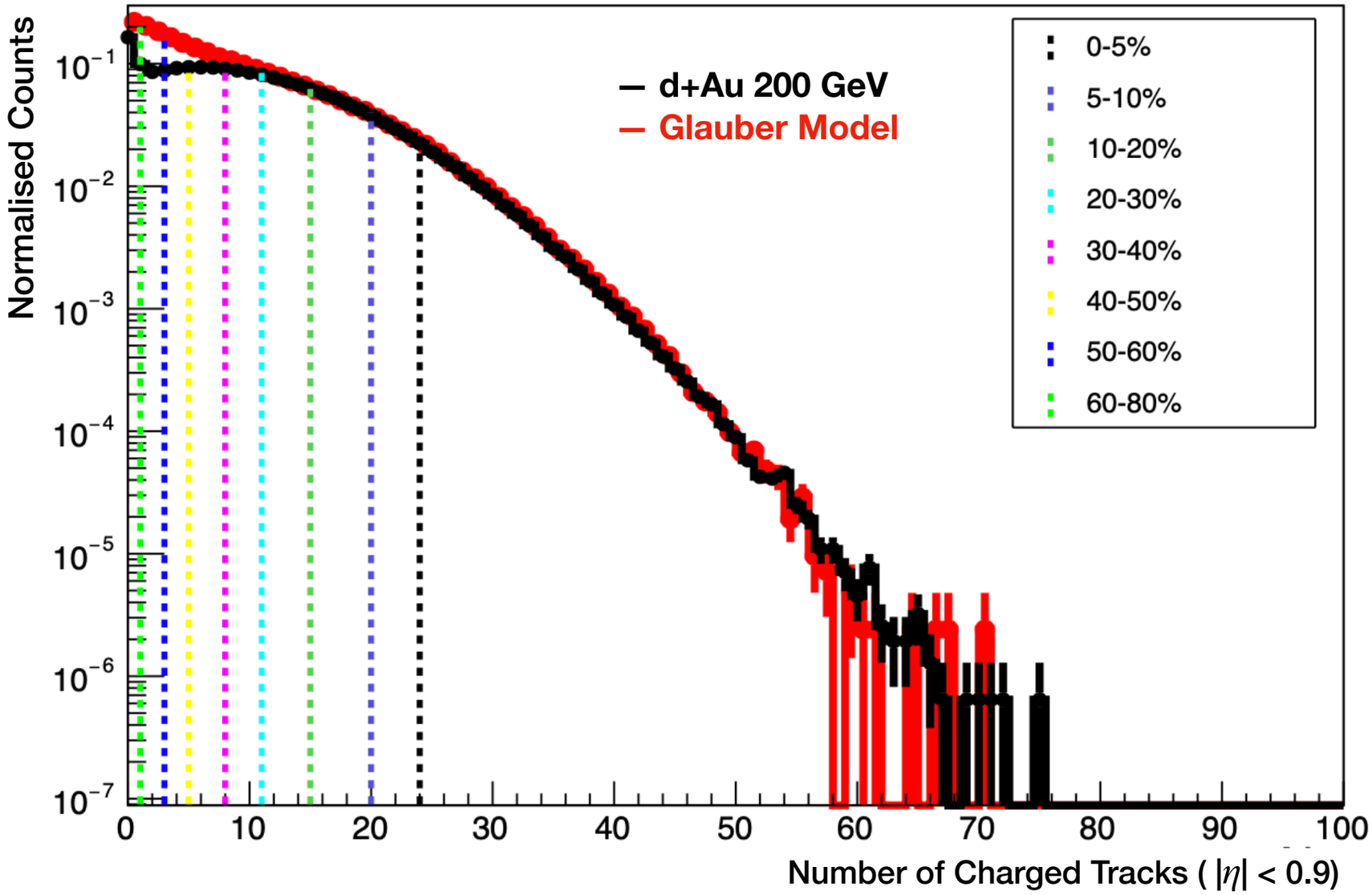
  $\Lambda(\bar{\Lambda}) \rightarrow \mathrm{p}(\bar{\mathrm{p}}) + \pi^-(\pi^+)$ (B.R. 63.9%)

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

$$Z = log\frac{\langle dE/dx\rangle_{measure}}{\langle dE/dx\rangle_{Bichsel}}, R = \frac{z}{\sigma_p},$$

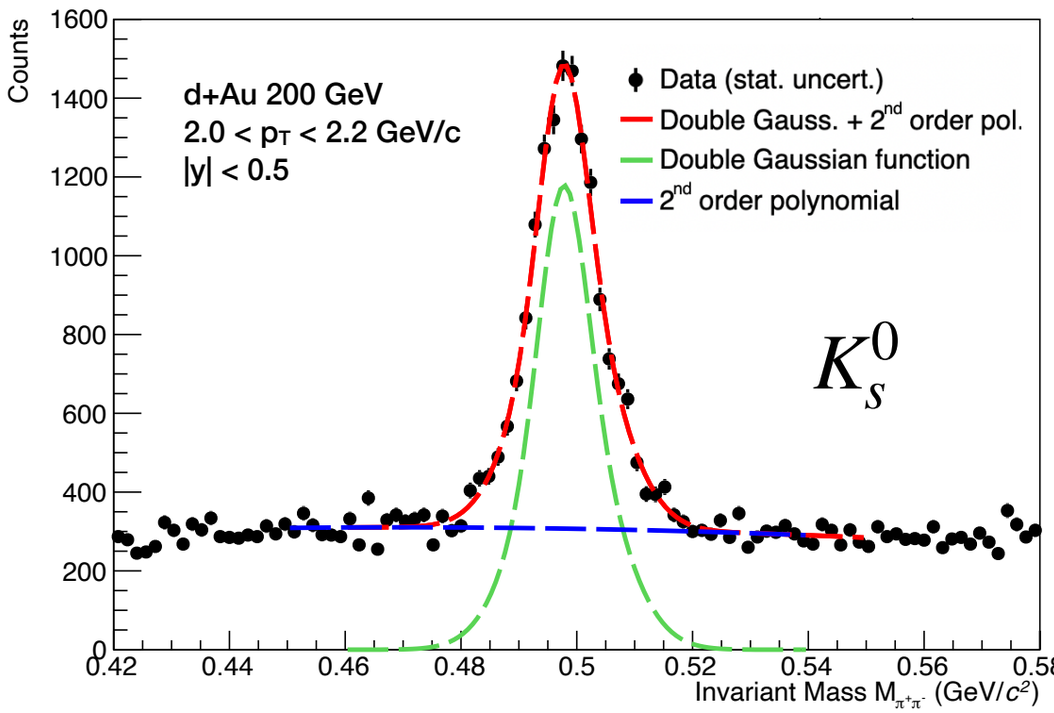
where σ_p is $\langle dE/dx \rangle$ resolution

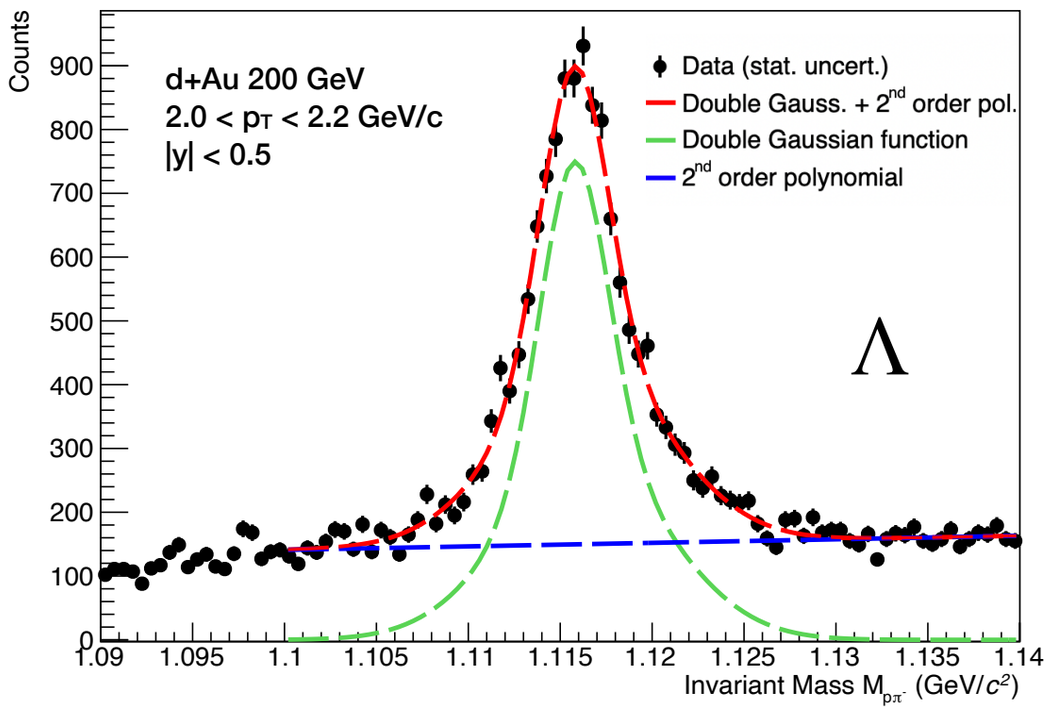
Centrality Study in d+Au Collisions

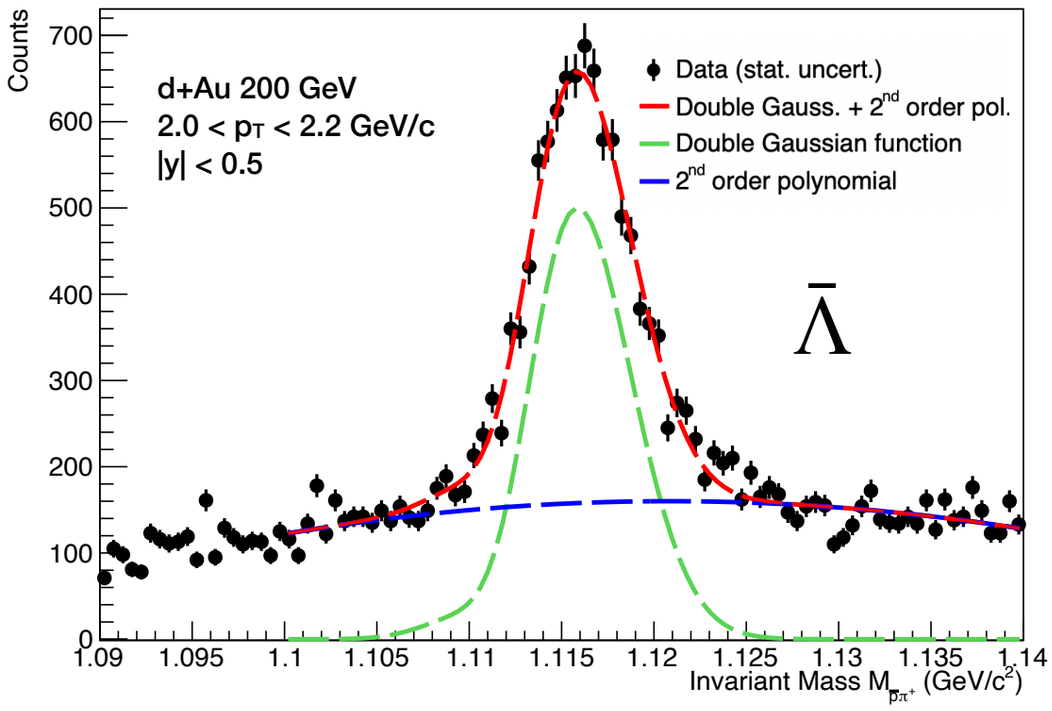


Centrality estimation in d+Au 200 GeV is done using Glauber model

Analysis Technique

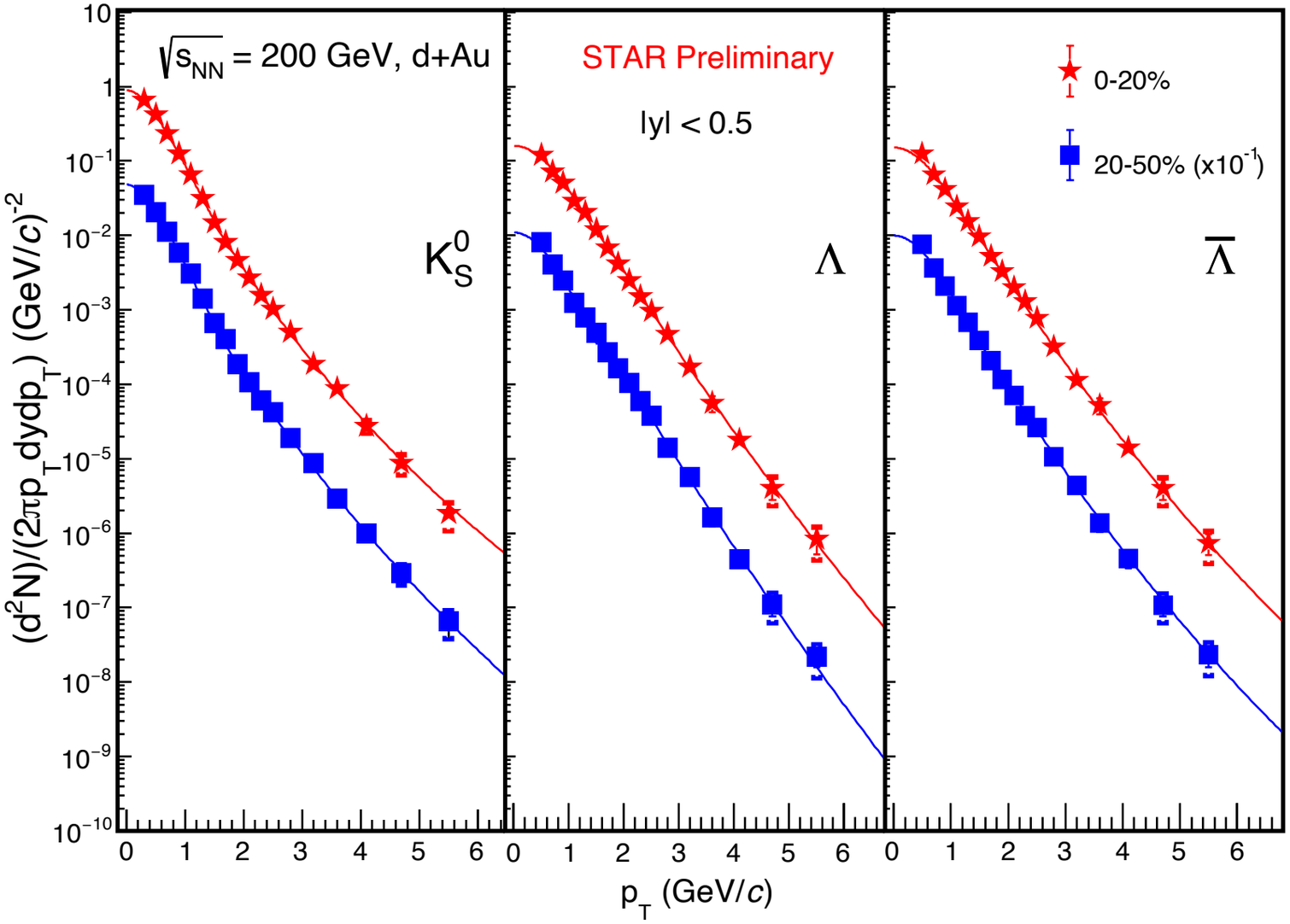






- **Red line :** Double gaussian + 2nd order polynomial (signal+background)
- **Blue line :** 2nd order polynomial (background)
- **Green line :** Double gaussian (signal)

Transverse Momentum Spectra at Midrapidity |y| < 0.5



- Spectra is fitted with

  low p_T – exponential :

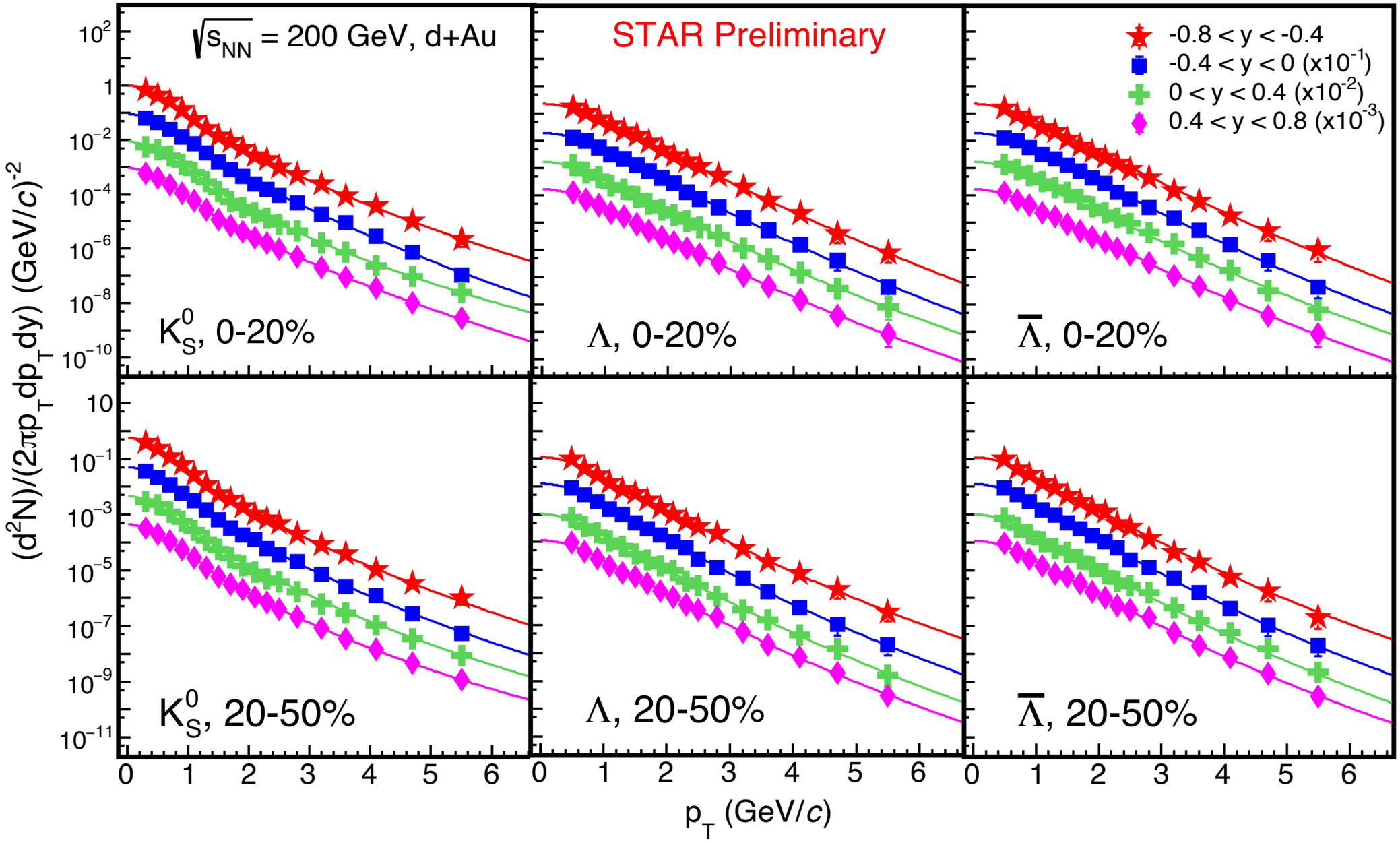
$$\frac{d^2N}{2\pi p_T dp_T dy} \propto e^{-m_T/T}$$

  high p_T – power law :

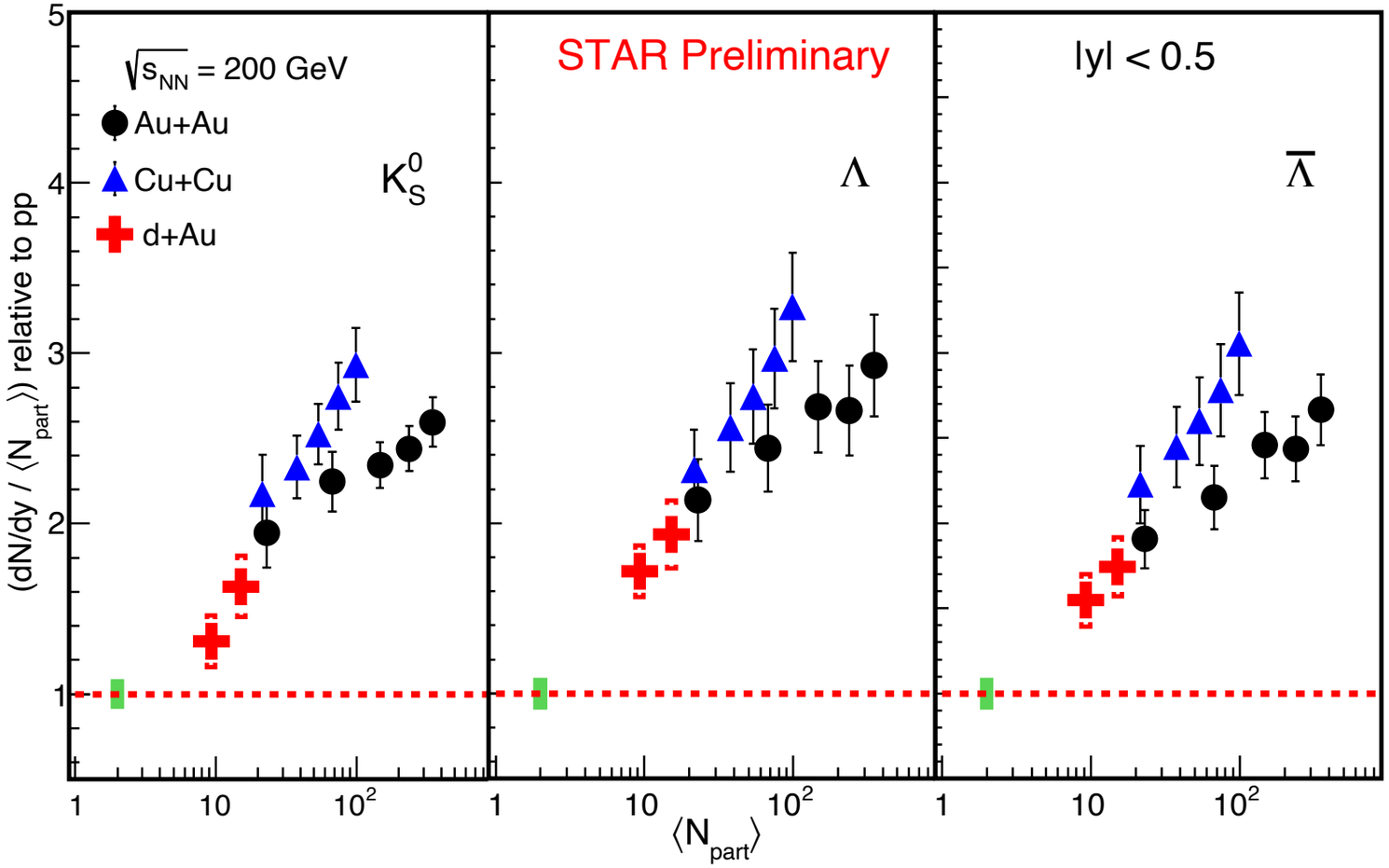
$$\frac{d^2N}{2\pi p_T dp_T dy} \propto (1 + \frac{m_T - m_0}{nT})^{-n}$$

- Λ spectra are corrected for weak decay feed down from Ξ
- K^0_s, $\Lambda(\bar{\Lambda})$ transverse momentum spectra are corrected for acceptance and efficiency

Transverse Momentum Spectra at Different Rapidities



Strangeness Enhancement

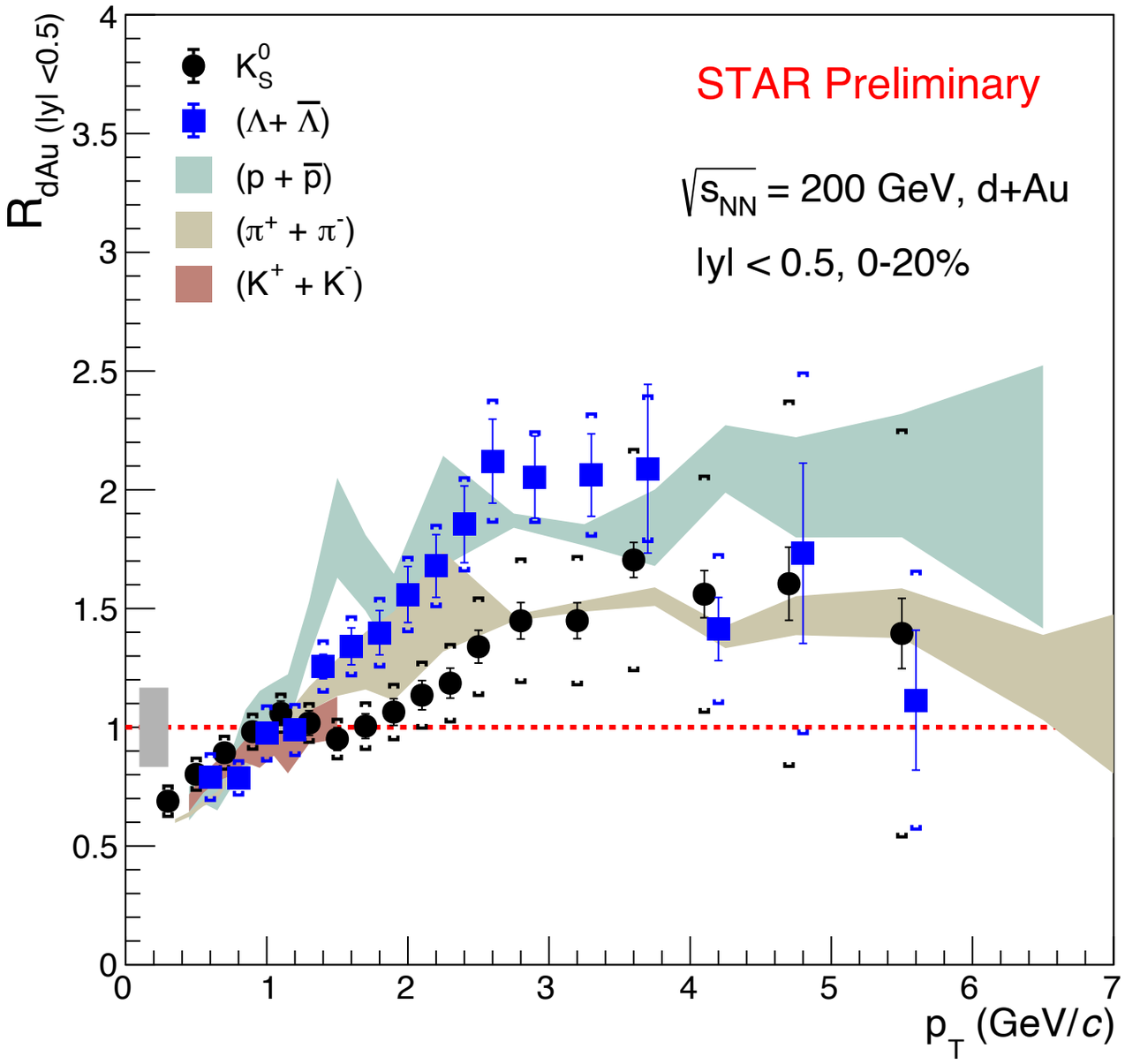


STAR : Phys. Rev. C **75**, 064901 (2007)
STAR : Phys. Rev. Lett. 108, 072301 (2012)
STAR : Phys. Rev. C 79, 034909 (2009)

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

- $\Lambda(\bar{\Lambda})$ and K^0_s yields in d+Au 200 GeV are enhanced as compared to p+p collisions
  - May (partially) be due to canonical suppression in p+p collisions
- $\Lambda(\bar{\Lambda})$ and K^0_s yields connect p+p with peripheral Cu+Cu and Au+Au collisions
- Strange particle yields in 200 GeV mostly driven by $\langle N_{part}\rangle$

Nuclear Modification Factor



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

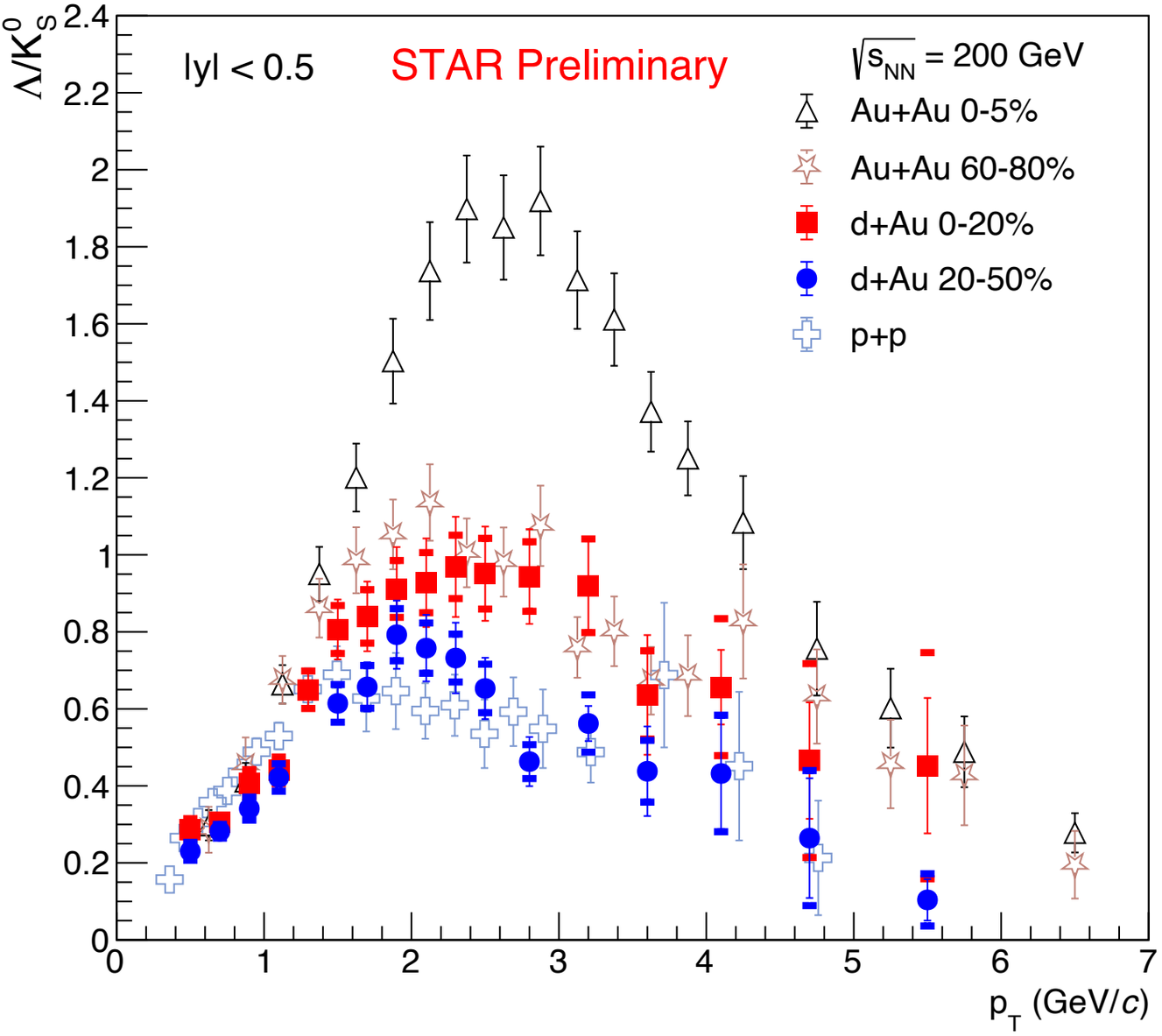
$$R_{dAu}(p_T) = \frac{d^2N/(2\pi p_T dp_T dy)}{T_{dAu} d^2\sigma^{pp}_{inel}/(2\pi p_T dp_T dy)}$$

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

- Cronin like enhancement is observed for K^0_s & Λ at intermediate p_T
- R_{dAu} of K^0_s is consistent with charged kaons
- Enhancement in d+Au compared to p+p for p_T in 2-4 GeV/c is stronger for baryons (Λ, p) compared to mesons (K^0_s, π)

π,K,p data are from
STAR : Phys.Lett.B 637 (2006)
STAR : *Phys.Lett.B* 616 (2008)

Baryon to Meson Ratio

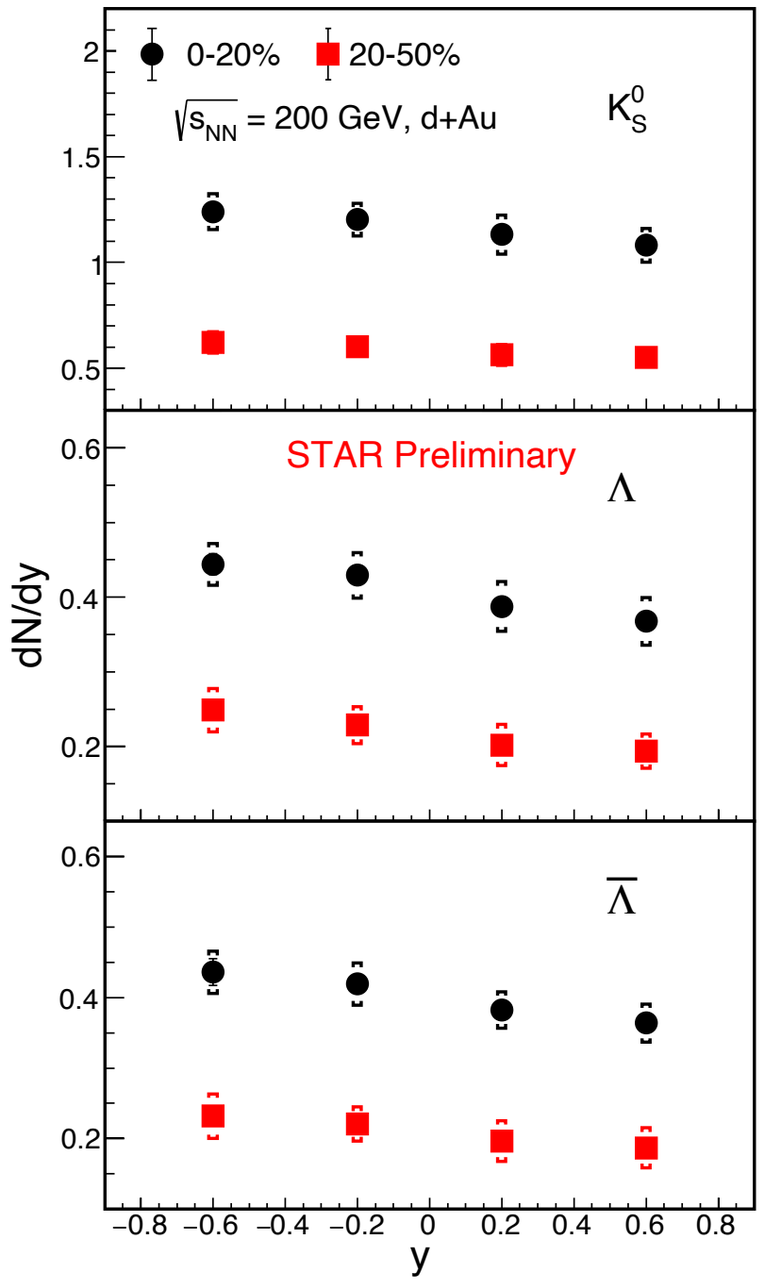


STAR : Phys. Rev. C **75**, 064901 (2007)
STAR : Phys. Rev. Lett. 108, 072301 (2012)
STAR : Phys. Rev. C 79, 034909 (2009)

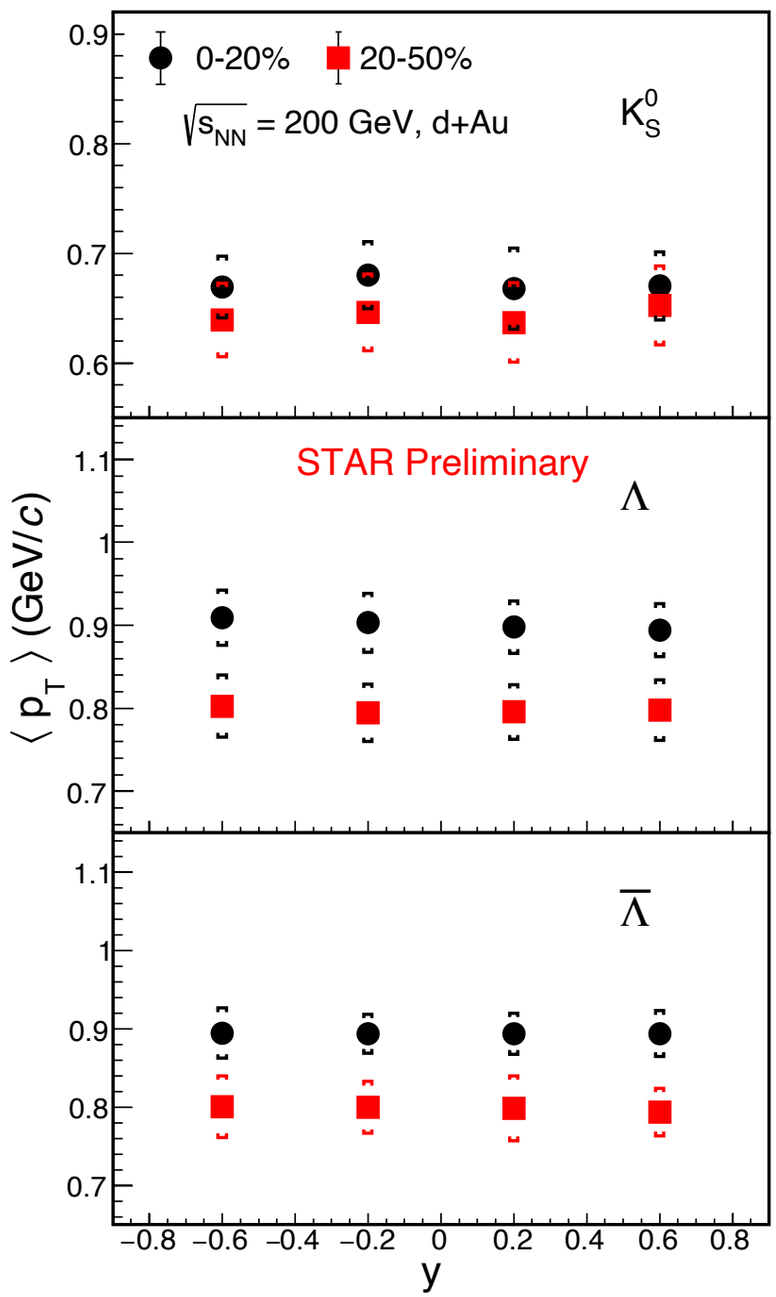
- Λ/K^0_s are significantly enhanced in central Au+Au collisions at 200 GeV compared to p+p
  - recombination of thermalized strange quarks in QGP
- Λ/K^0_s in 0-20% d+Au at intermediate p_T is larger compared to 20-50% d+Au and p+p collisions
- Baryon enhancement is observed in central d+Au 200 GeV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

Related topic Au+Au collisions see Yi's talk Sep 5, 2023, 11:00 AM Ballroom C
"Strangeness production in Au+Au collisions at 7.7, 14.6, 19.6, and 200 GeV with the STAR experiment"

Integrated Yields & Mean Transverse Momentum



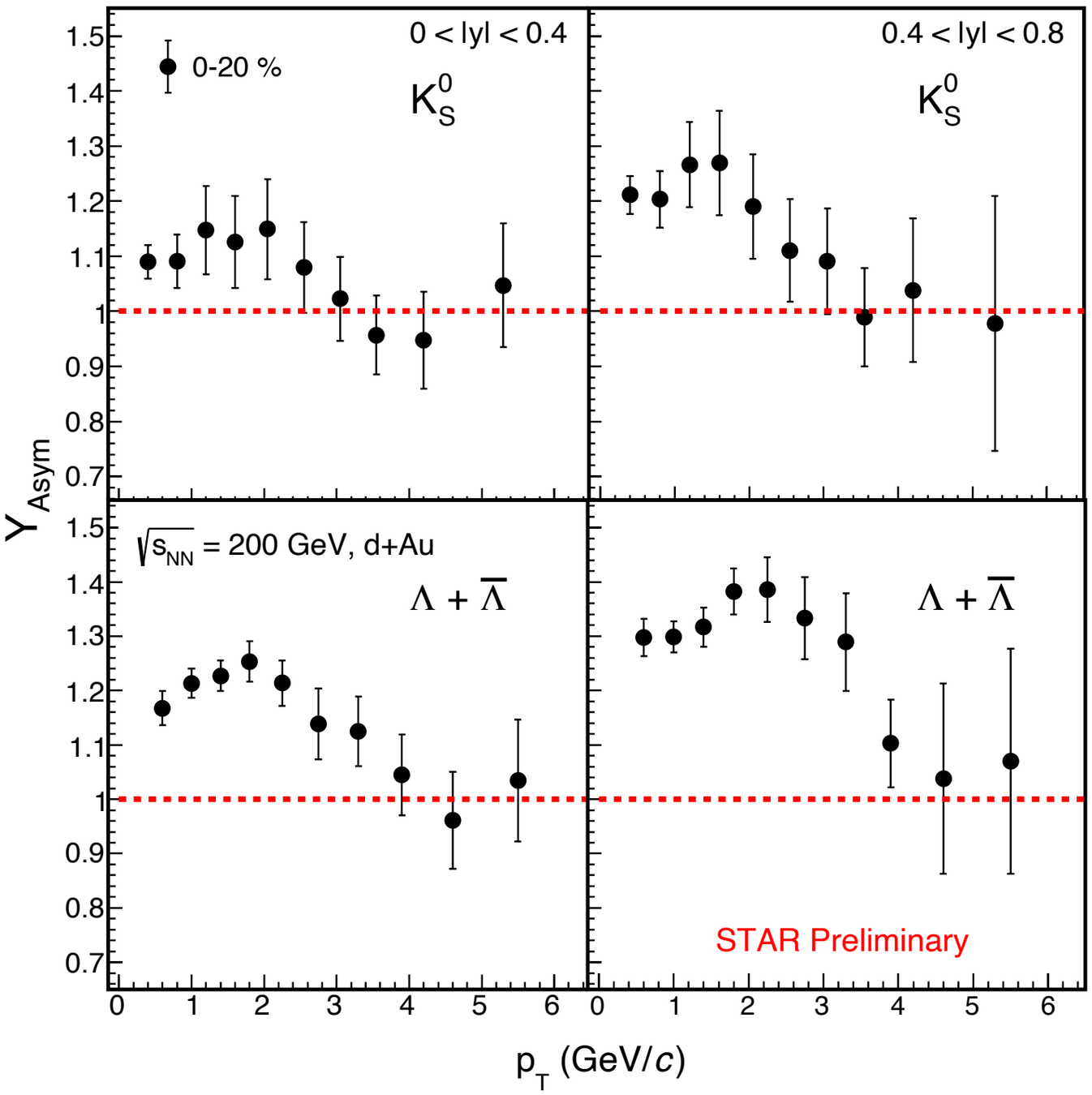
<— Au going *d* going —>



<— Au going *d* going —>

- dN/dy slightly decreases from negative to positive rapidities
  - nPDF ?
  - Initial state multiple scatterings ?
- $\langle p_T \rangle$ is flat vs y : similar radial flow
- Model calculations are welcome

Rapidity Asymmetry



Only Statistical uncertainties

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

- $Y_{asym} > 1$ is observed at low p_T
  - Signifies the presence of nuclear effects
- Consistent with unity at high p_T.
- Hint of more prominent effect towards higher rapidity ($0.4 < |y| < 0.8$)

STAR : PhysRevC.76.054903 (2007)

Summary

- Yields of K_s^0 & $\Lambda(\bar{\Lambda})$ in d+Au are observed to be higher than in p+p collisions at 200 GeV : **Strangeness enhancement**
- **Nuclear modification factor (R_{dAu})** for K_s^0 & $\Lambda(\bar{\Lambda})$ show Cronin like enhancement
- **Baryon enhancement** in central d+Au collisions is observed
- **Rapidity asymmetry** for K_s^0 & $\Lambda(\bar{\Lambda})$ is observed
  - At low p_T : indicating presence of nuclear effects and is more pronounced at more forward rapidity regions.
- Asymmetry is more pronounced for Λ compared to K_s^0 for a given rapidity window

Thank You!

BACK UP

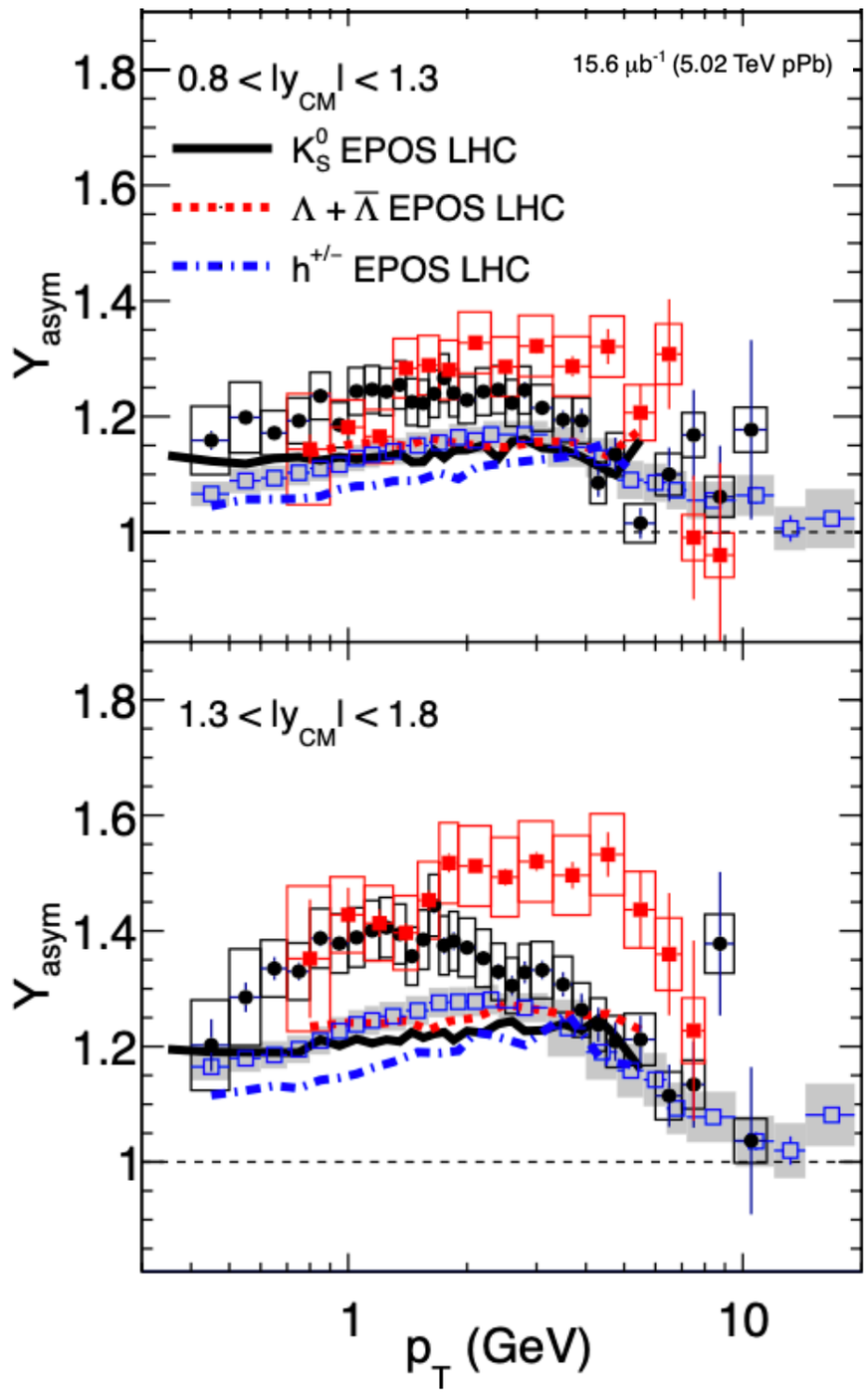
Probing Cold Nuclear Matter Effects In CMS

Rapidity Asymmetry Studied in CMS :

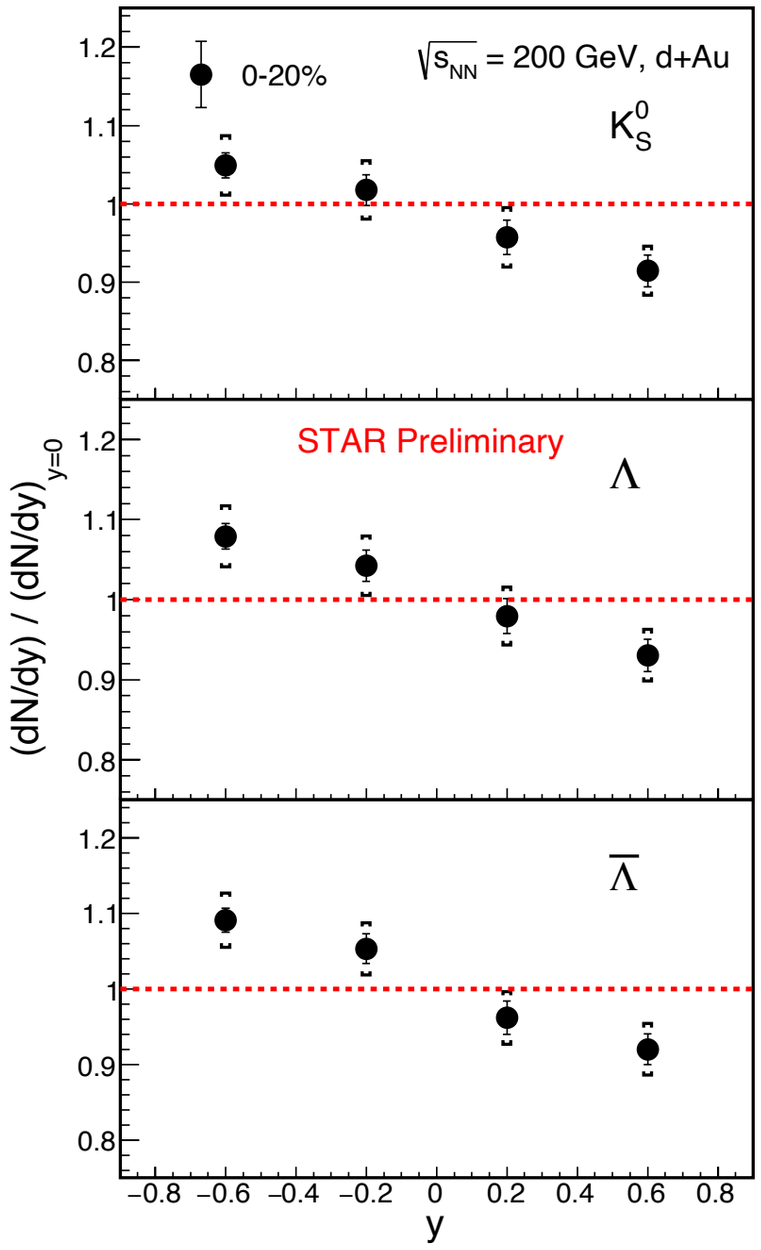
$$\Upsilon_{\text{asym}}(p_{\text{T}}) = \frac{\mathrm{d}^2N(p_{\text{T}})/\mathrm{d}y_{\text{CM}}\mathrm{d}p_{\text{T}}|_{y_{\text{CM}}\in[-b,-a]}}{\mathrm{d}^2N(p_{\text{T}})/\mathrm{d}y_{\text{CM}}\mathrm{d}p_{\text{T}}|_{y_{\text{CM}}\in[a,b]}}.$$

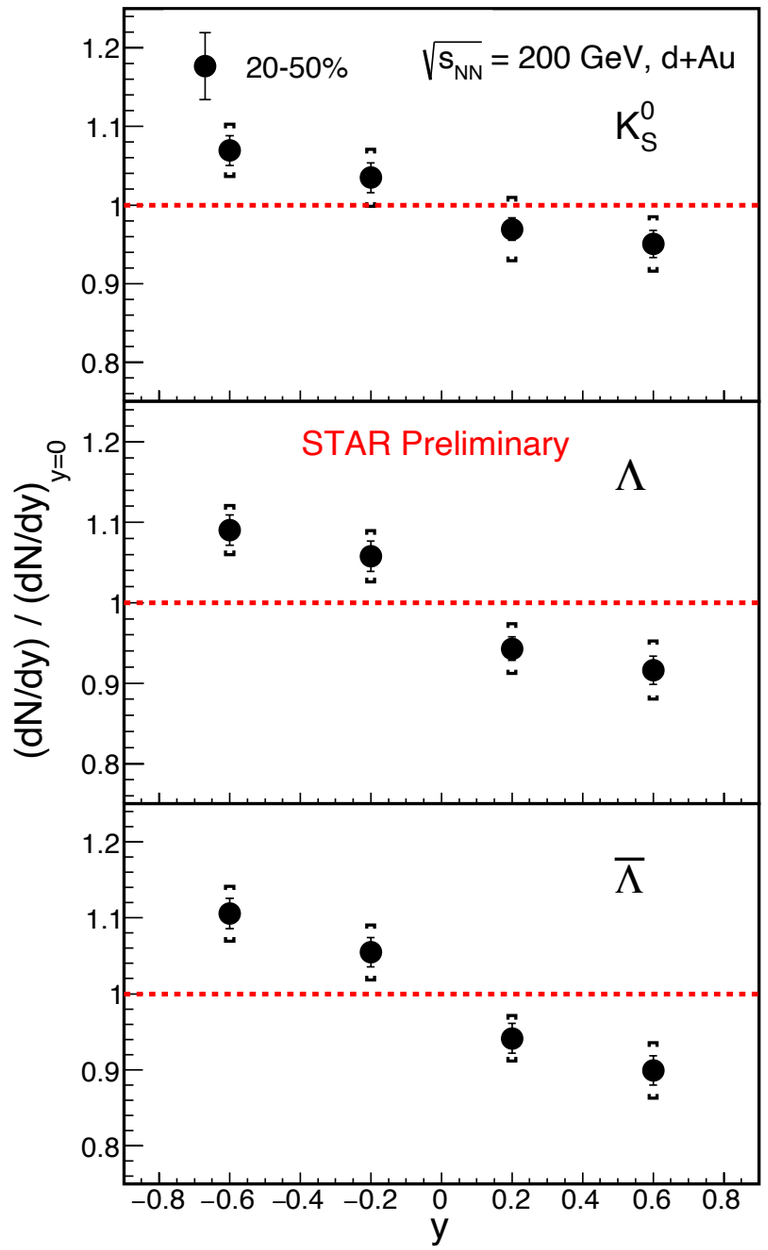
- $Y_{asym} > 1$ is observed at low p_T
  - Signifies the presence of nuclear effects
- Consistent with unity at high p_T
- More prominent for higher rapidity interval ($1.3 < |y| < 1.8$)
- Asymmetry is stronger for Λ as compared to that for K_s^0

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



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

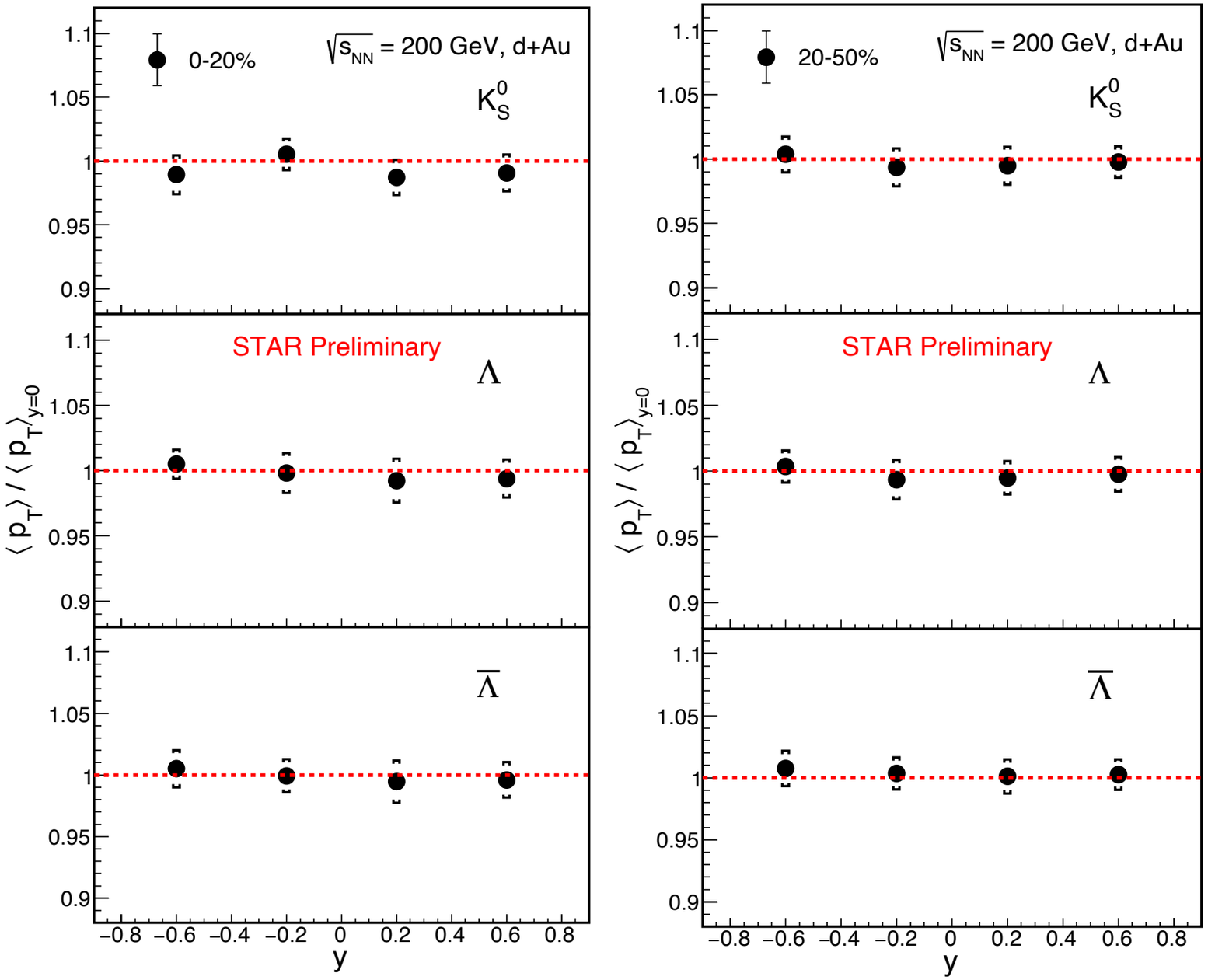




<— Au going d going —>

- $(dN/dy)/(dN/dy)_{y=0}$ for all multiplicity classes shows a decreasing trend as a function of rapidity in d+Au 200 GeV

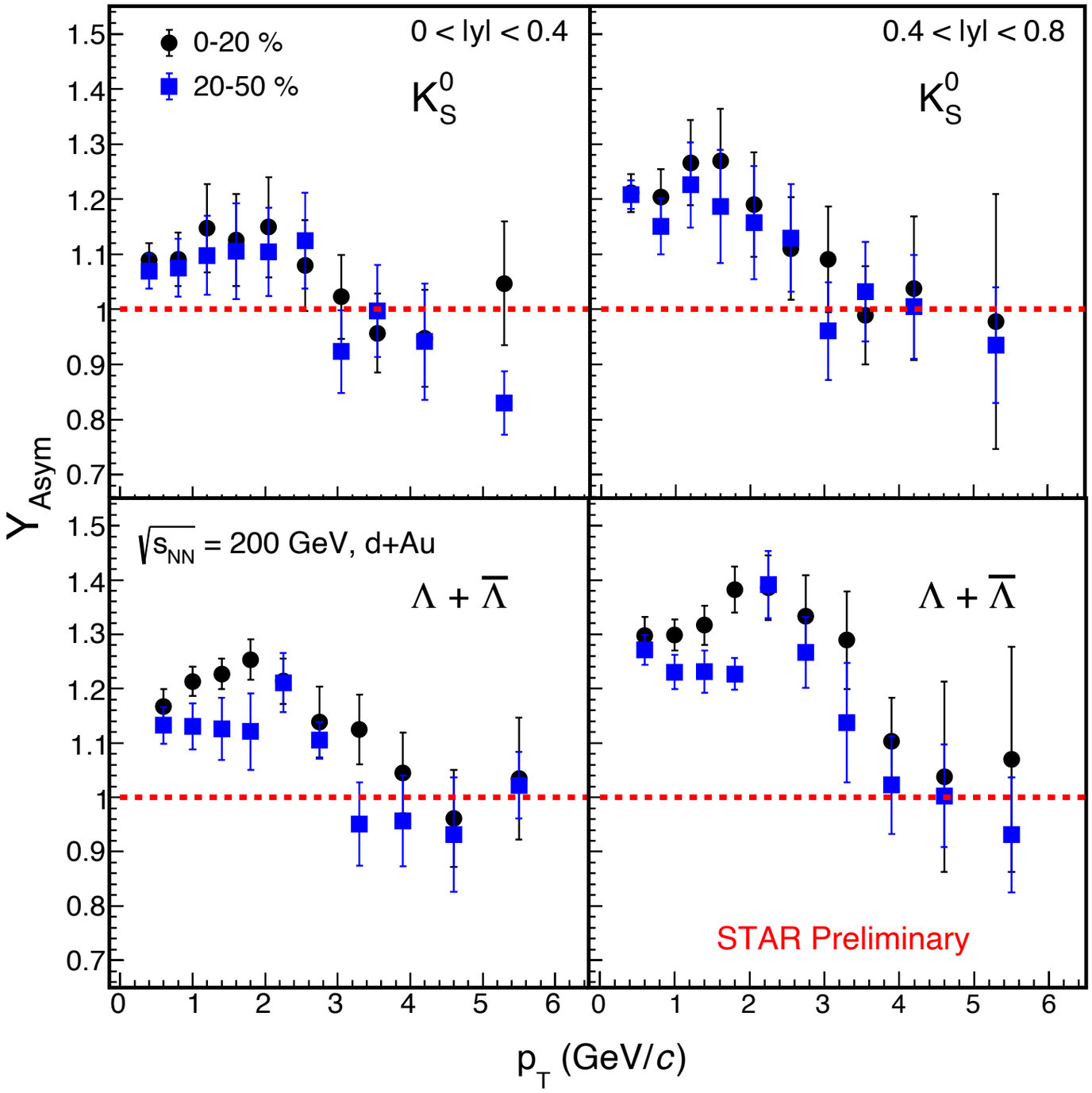
Ratio of Mean Transverse Momentum w.r.t. Mean Transverse Momentum at y=0



<— Au going *d* going —>

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

Rapidity Asymmetry



Only Statistical uncertainties