

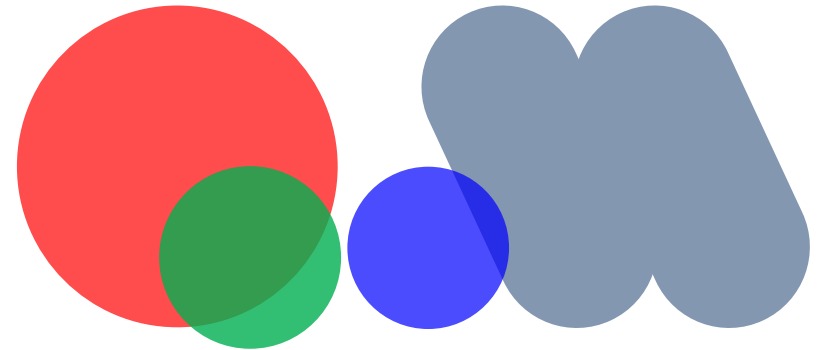
# Identified Light and Strange Hadron Spectra at $\sqrt{s_{NN}} = 14.5$ GeV and Systematic Study of Baryon/Meson Effect at Intermediate Transverse Momentum with STAR at RHIC BES I

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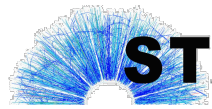
DANIEL BRANDENBURG  
RICE UNIVERSITY  
FOR THE STAR COLLABORATION



RICE



2015 KOBE JAPAN



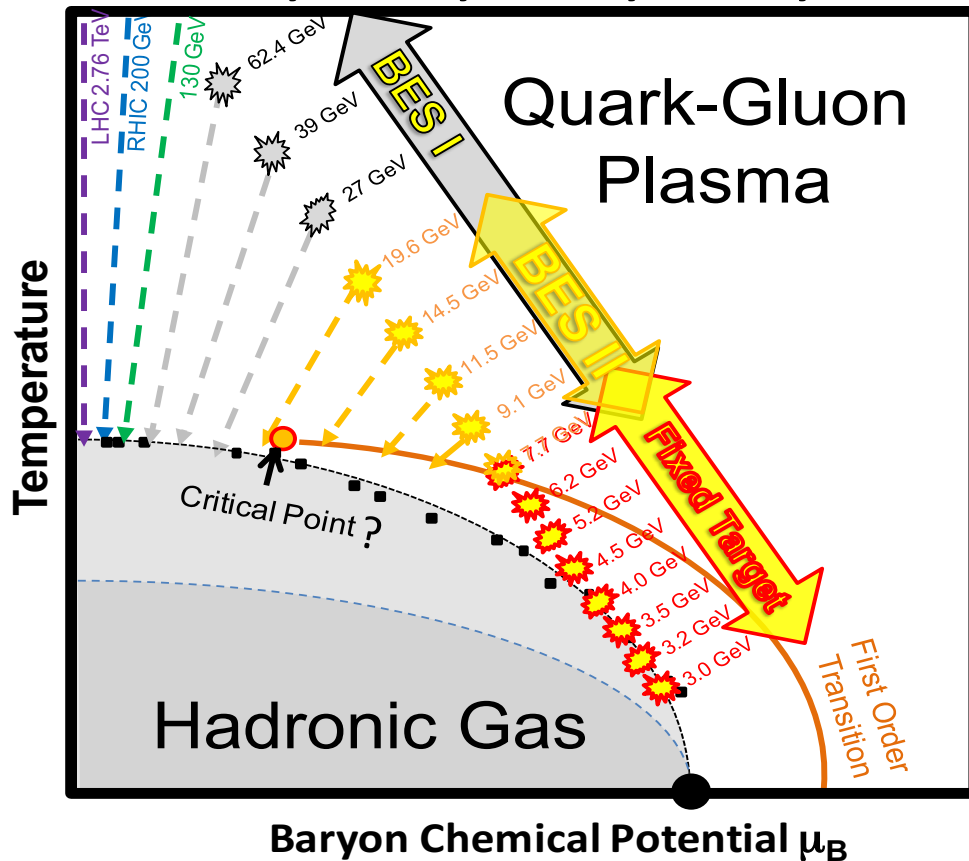
# STAR ☆ RHIC Beam Energy Scan (BES) Phase I

## BES Phase I - Au+Au collisions at 7.7, 11.5, 14.5, 19.6, 27.0, and 39.0 GeV

- Search for Conjectured QCD critical point
- Search for 1<sup>st</sup> order phase transition

Search for the onset of key QGP signatures

- $\sqrt{s_{NN}} = 14.5 \text{ GeV}$
- Important measurement in the relatively large  $\mu_B$  gap between 11.5 and 19.6 GeV



$\sqrt{s_{NN}}$  [GeV] =

7.7    11.5    **14.5**    19.6    27.0    39.0

$\sim \mu_B$  (in central collisions) [MeV]

420    315    **260**    205    155    115

J. Cleymans, H. Oeschler, K. Redlich, and S. Wheaton, Phys. Rev. C73 (2006) 034905



## Nuclear Modification Factor $R_{CP}$

- High  $p_T$  suppression  $\equiv R_{CP} < 1.0$ 
  - Strong suppression observed in inclusive charged hadrons at top RHIC energies.
  - Attributed to energy loss in QGP
- Enhancement  $\equiv R_{CP} > 1.0$ 
  - Cold nuclear matter effects and radial flow.

## Baryon/Meson Ratio eg. ( $\Lambda/K_S^0$ ) and ( $p/\pi$ )

- Baryon enhancement observed in Au+Au collisions at top RHIC energies
- Sensitive to parton recombination, coalescence as well as radial flow and cold nuclear matter effects

## In this talk

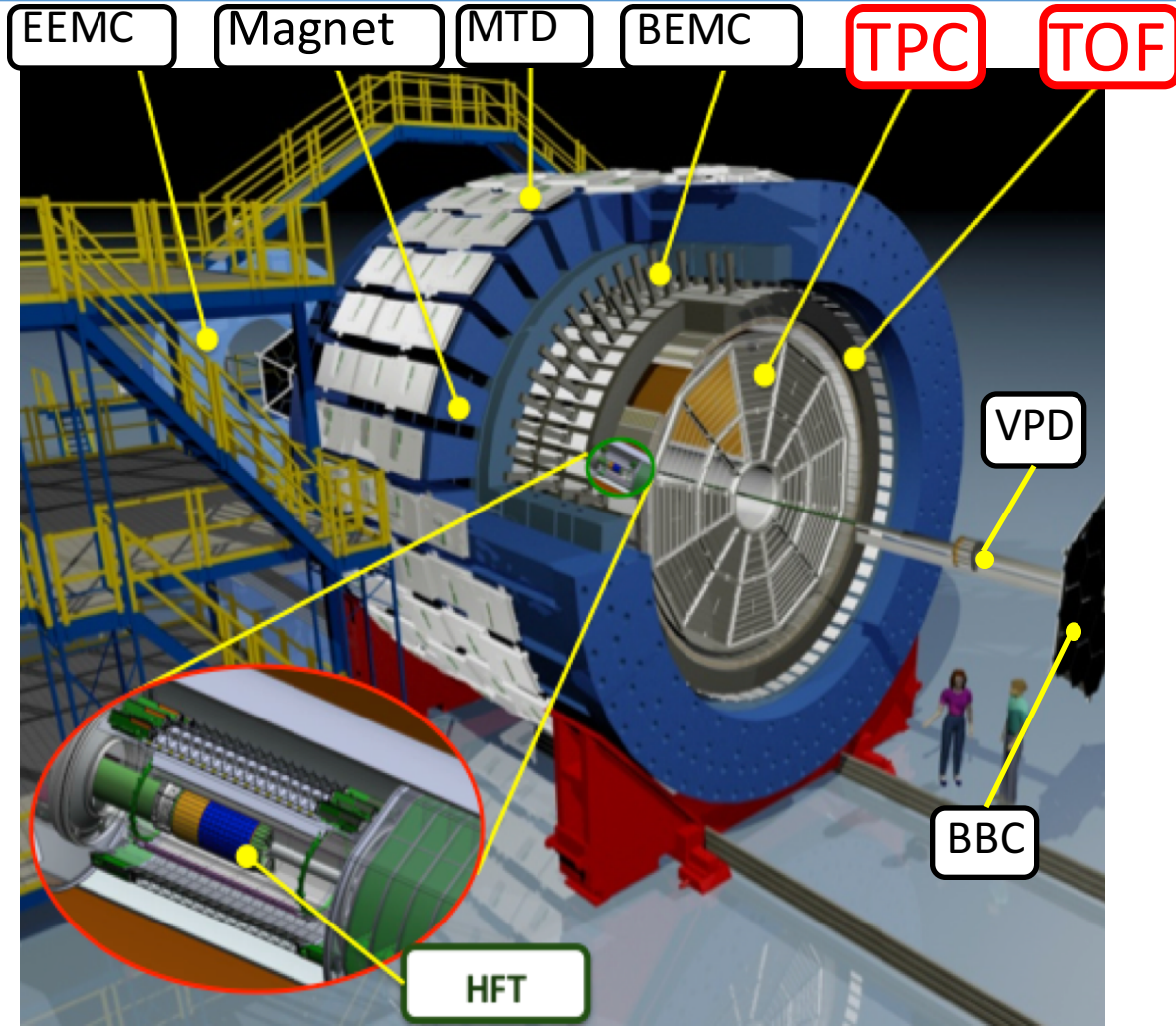
- **New** STAR measurements from Au+Au  $\sqrt{s_{NN}} = 14.5$  GeV

## Time Projection Chamber (TPC)

- Charged Particle Tracking
- Momentum reconstruction
- Particle identification from ionization energy loss ( $dE/dx$ )
- Pseudorapidity coverage  $|\eta| < 1.0$

## Time Of Flight (TOF) Detector

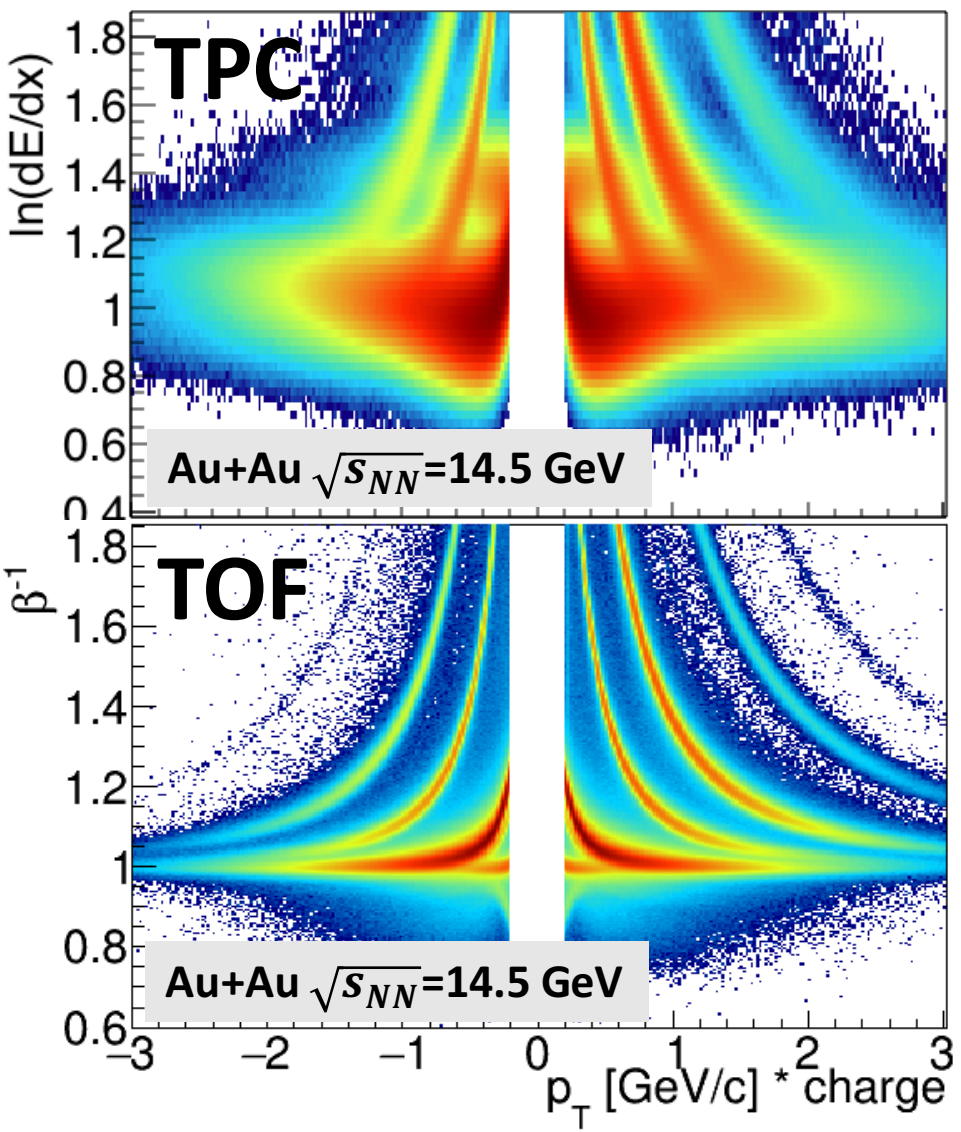
- Particle identification  $1/\beta$
- Pseudorapidity coverage  $|\eta| < 0.9$



VPD and BBC detectors are used to trigger minimum bias collisions

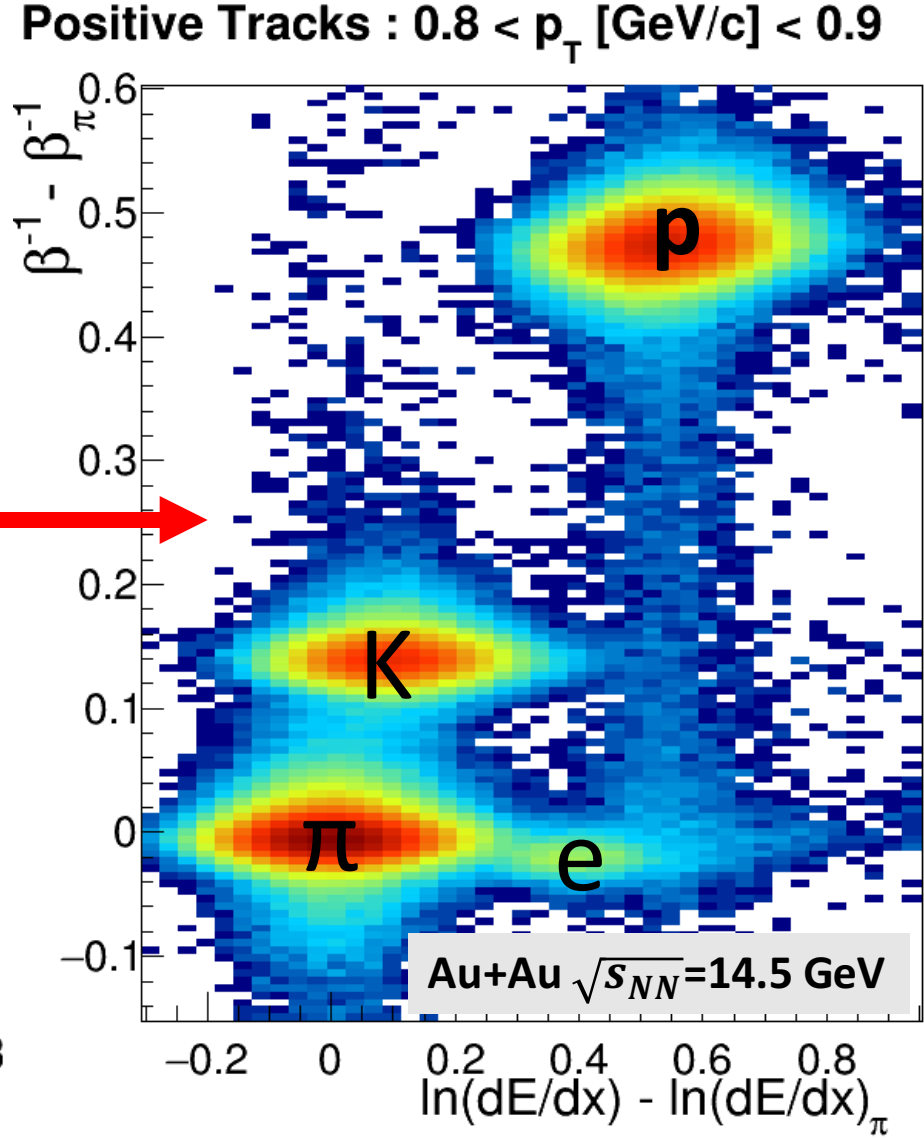
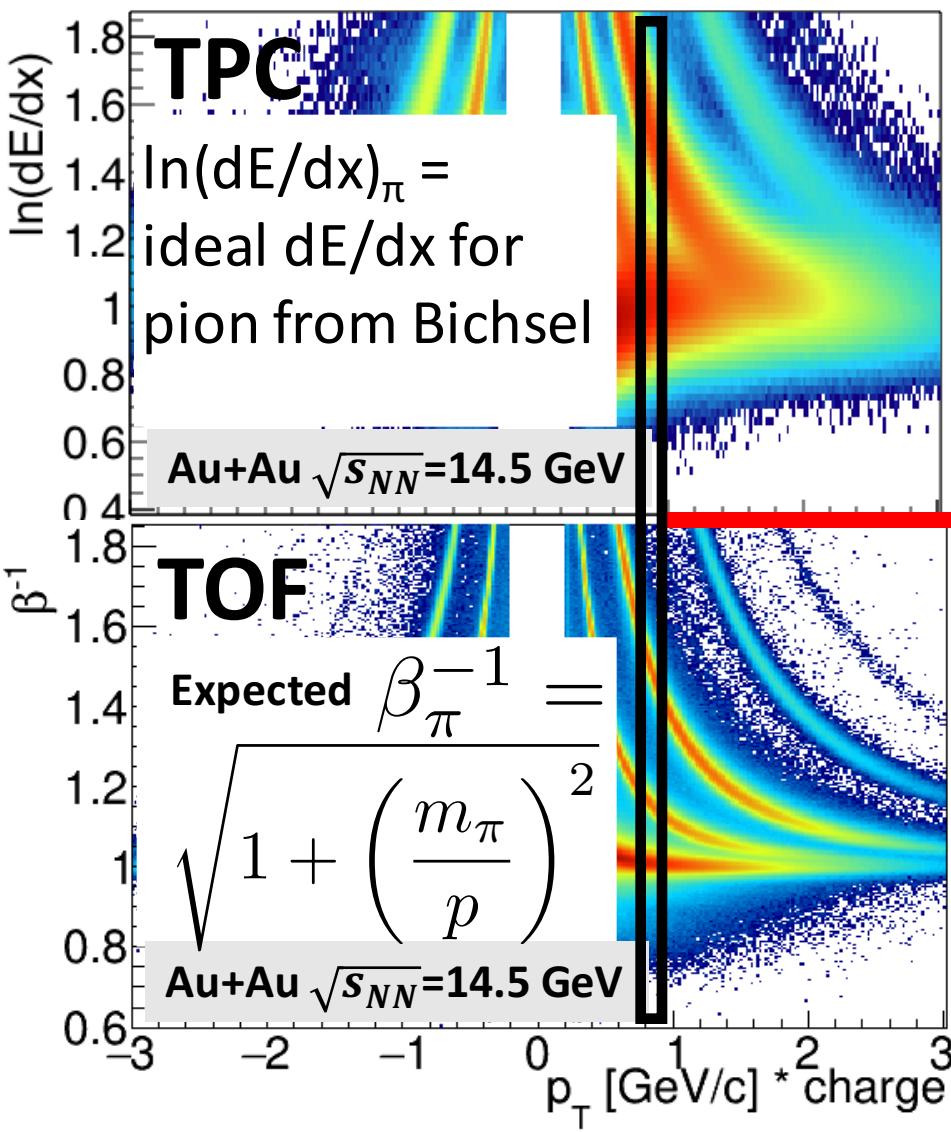


# STAR ☆ Particle Identification @ STAR



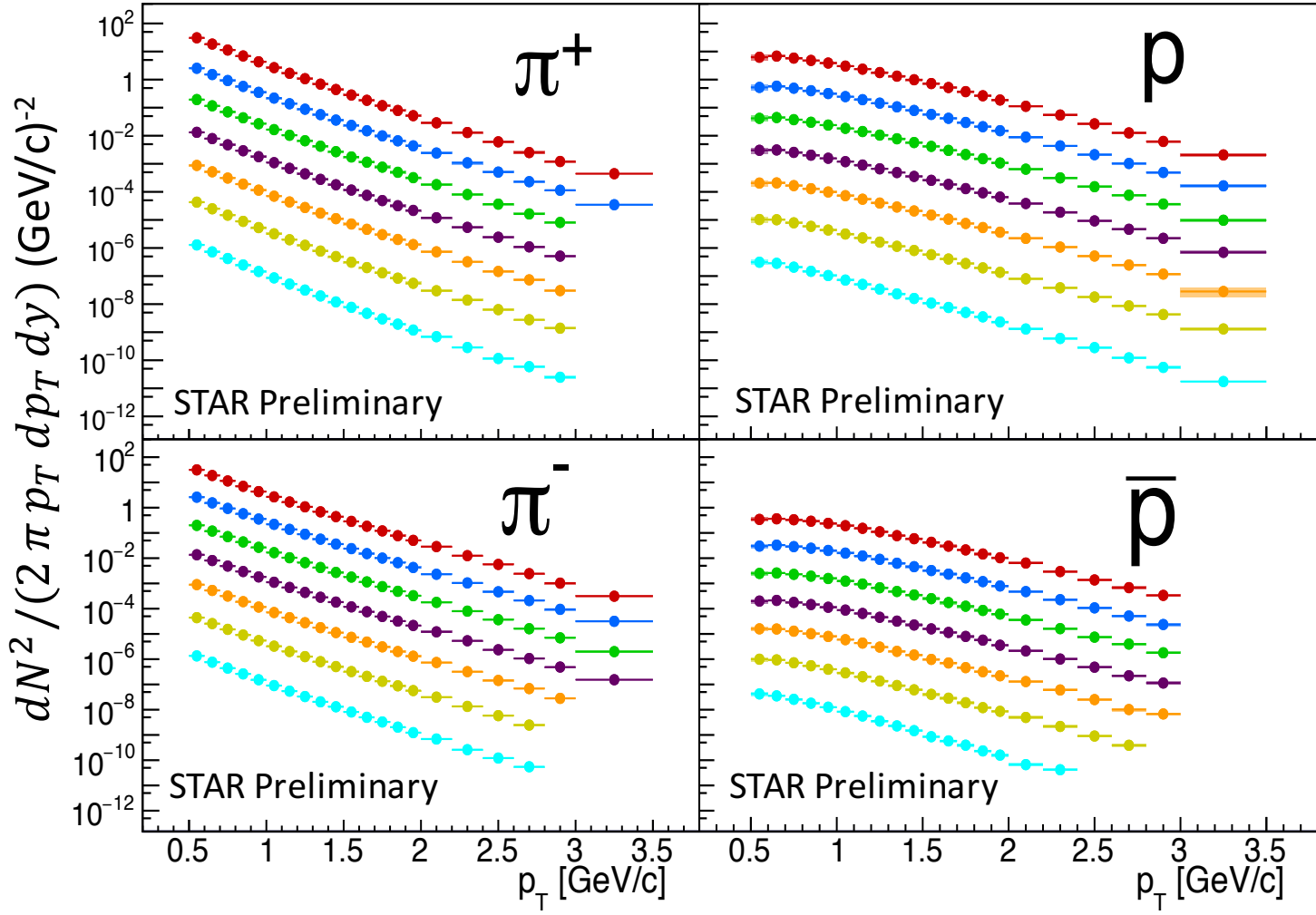


# STAR ☆ Particle Identification @ STAR

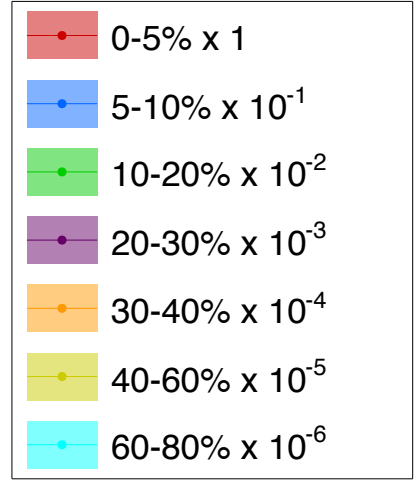




# STAR ☆ Light Hadron Spectra @ Au+Au $\sqrt{s_{NN}}=14.5$ GeV



## Centrality :

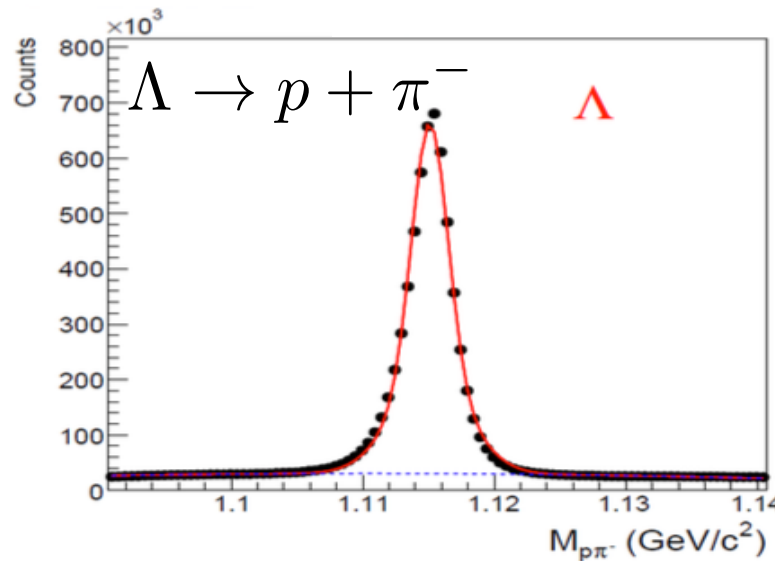
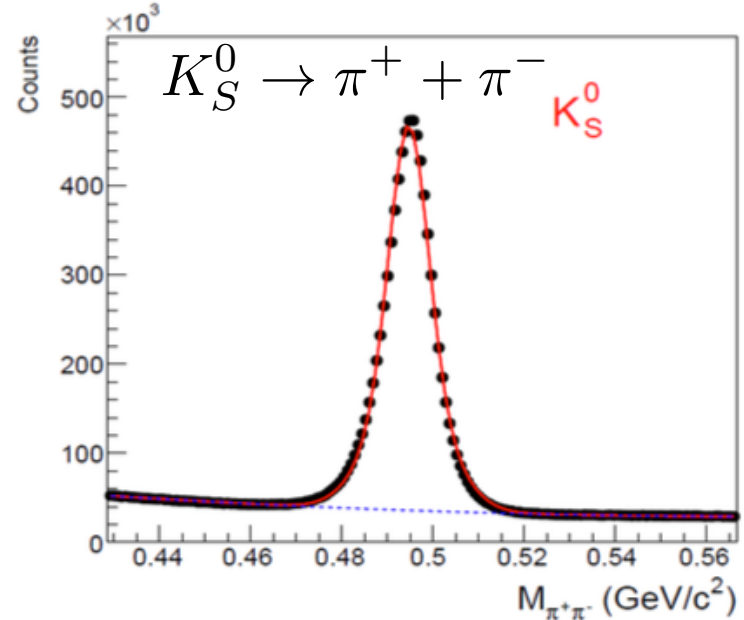
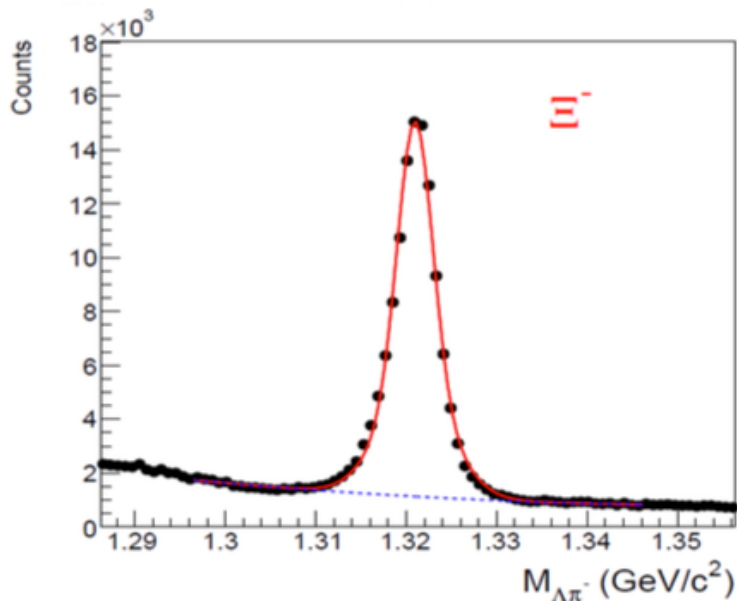
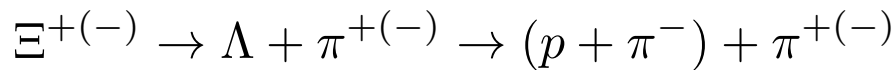


■  $|y| < 0.25$   
 ■  $\pi^{+/-}$  and  $p/\bar{p}$  are weak decay feed-down corrected



# STAR ☆ Topological Particle Identification

- Reconstruct secondary vertex from charged decay products
- Use topological cuts
- Extract yield by fitting to invariant mass peak



Au+Au  
 $\sqrt{s_{NN}}=14.5$  GeV  
 0 – 80% centrality  
 Full  $p_T$  range

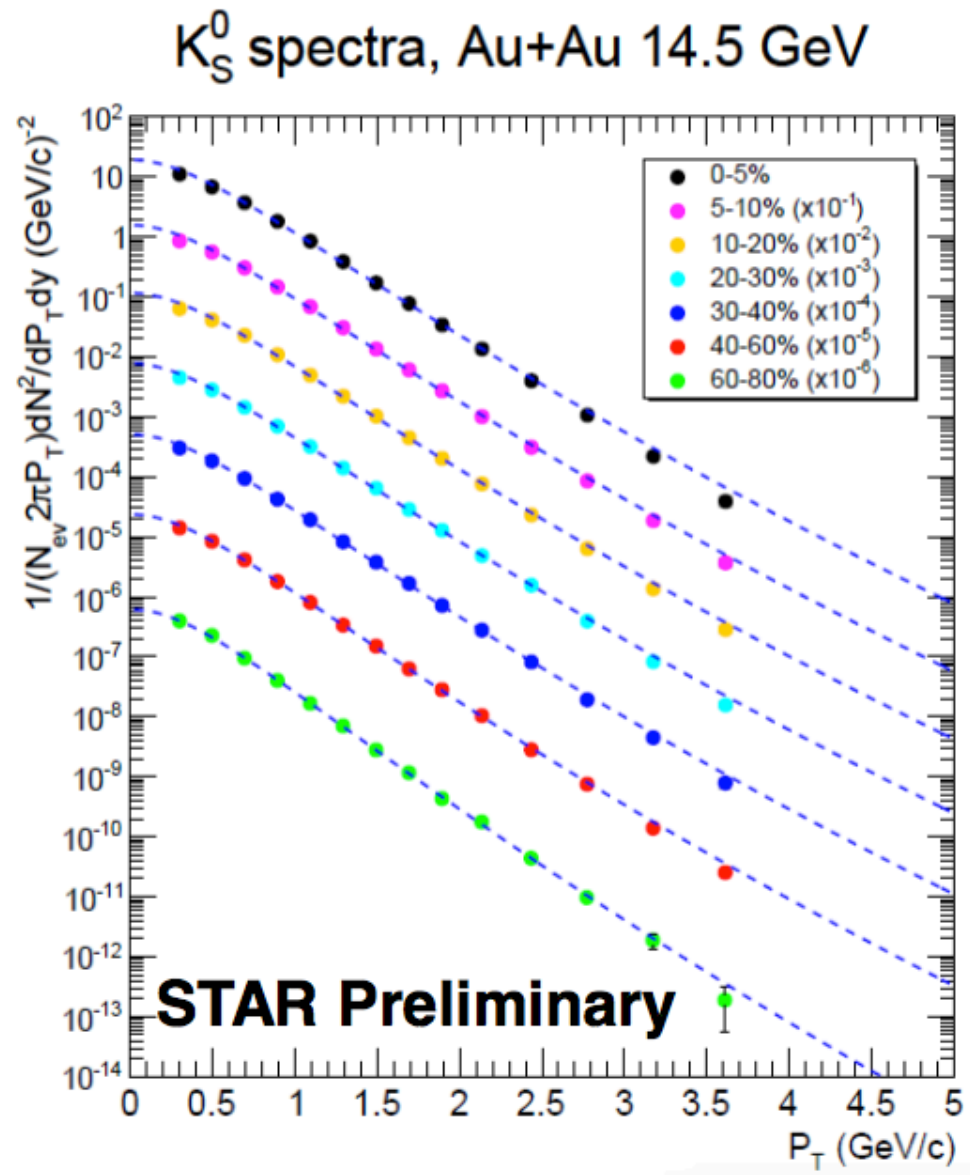




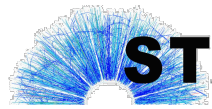
**STAR**



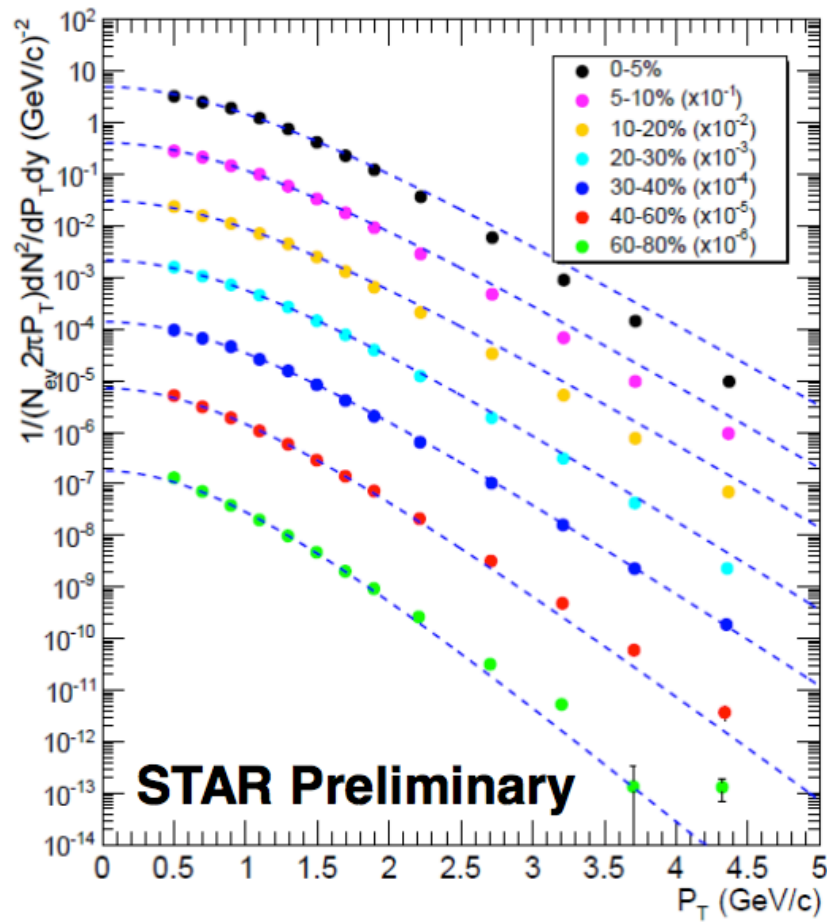
Strange Hadron Spectra @Au+Au  $\sqrt{s_{NN}}=14.5$  GeV



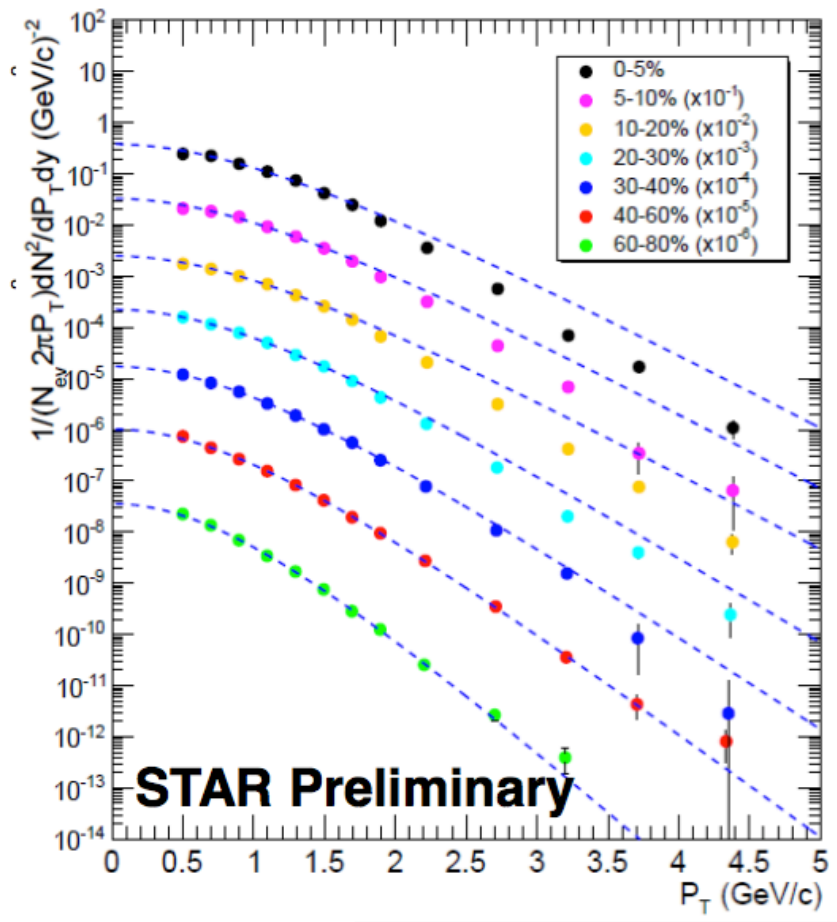
- Statistical Uncertainties only
- $|y| < 0.5$
- Fit with Levy function



$\Lambda$  spectra, Au+Au 14.5 GeV



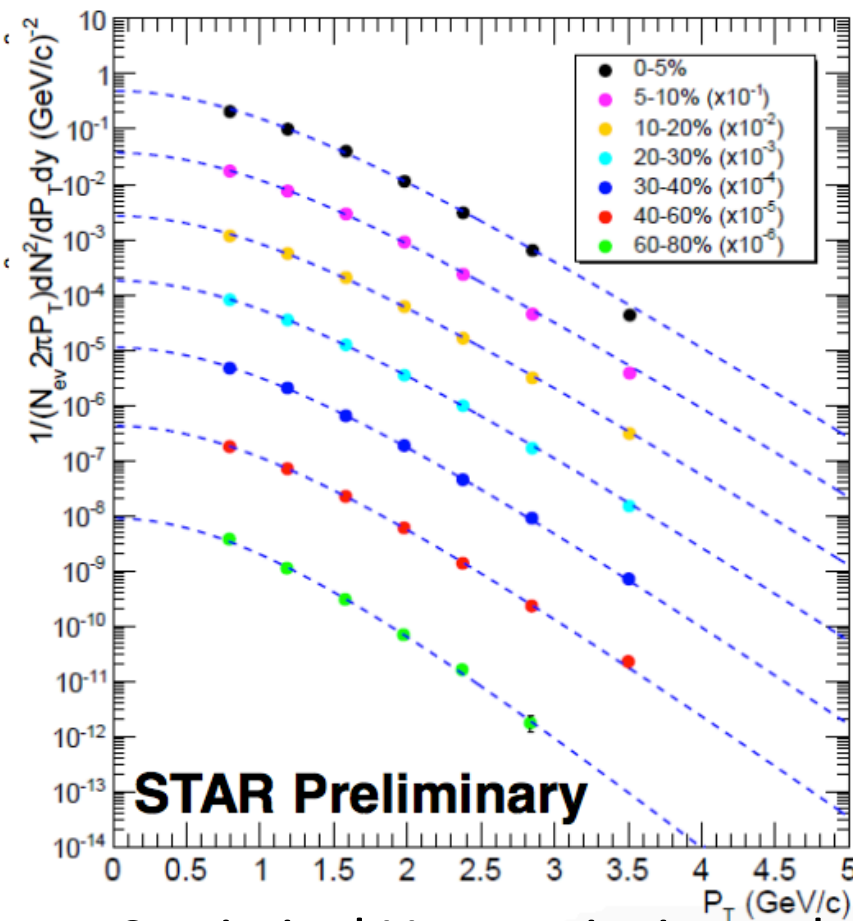
$\bar{\Lambda}$  spectra, Au+Au 14.5 GeV



- Statistical Uncertainties only
- $|y| < 0.5$
- $\Lambda$  spectra are weak decay feed-down corrected
- Fit with Boltzmann function



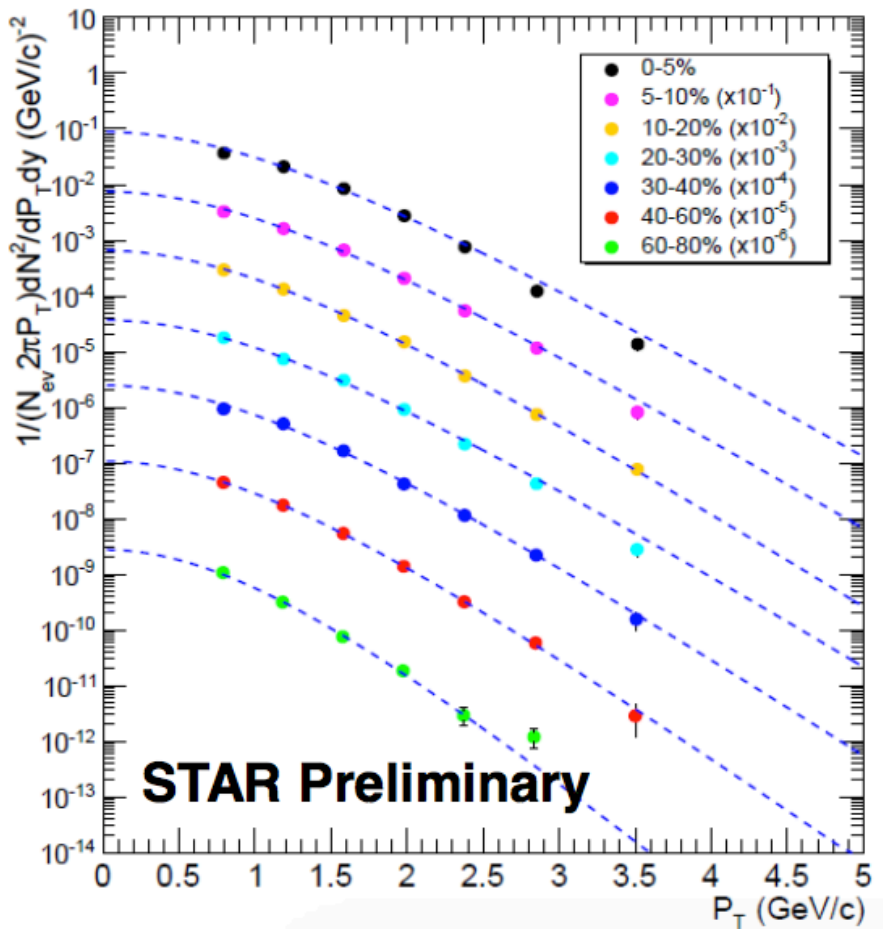
### $\Xi^-$ spectra, Au+Au 14.5 GeV



**STAR Preliminary**

- Statistical Uncertainties only
- $|y| < 0.5$

### $\Xi^+$ spectra, Au+Au 14.5 GeV



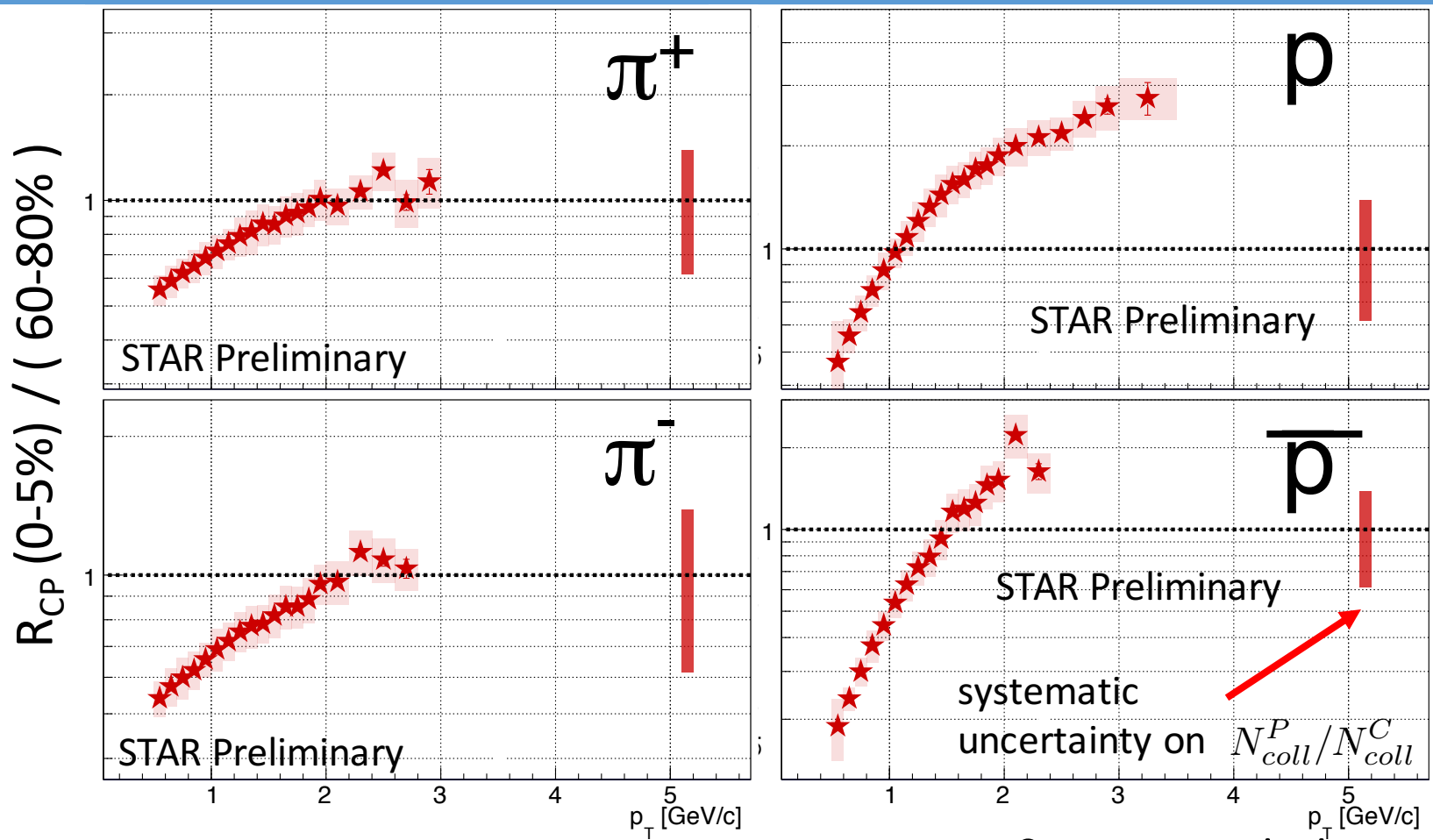
**STAR Preliminary**

- Fit with Boltzmann function



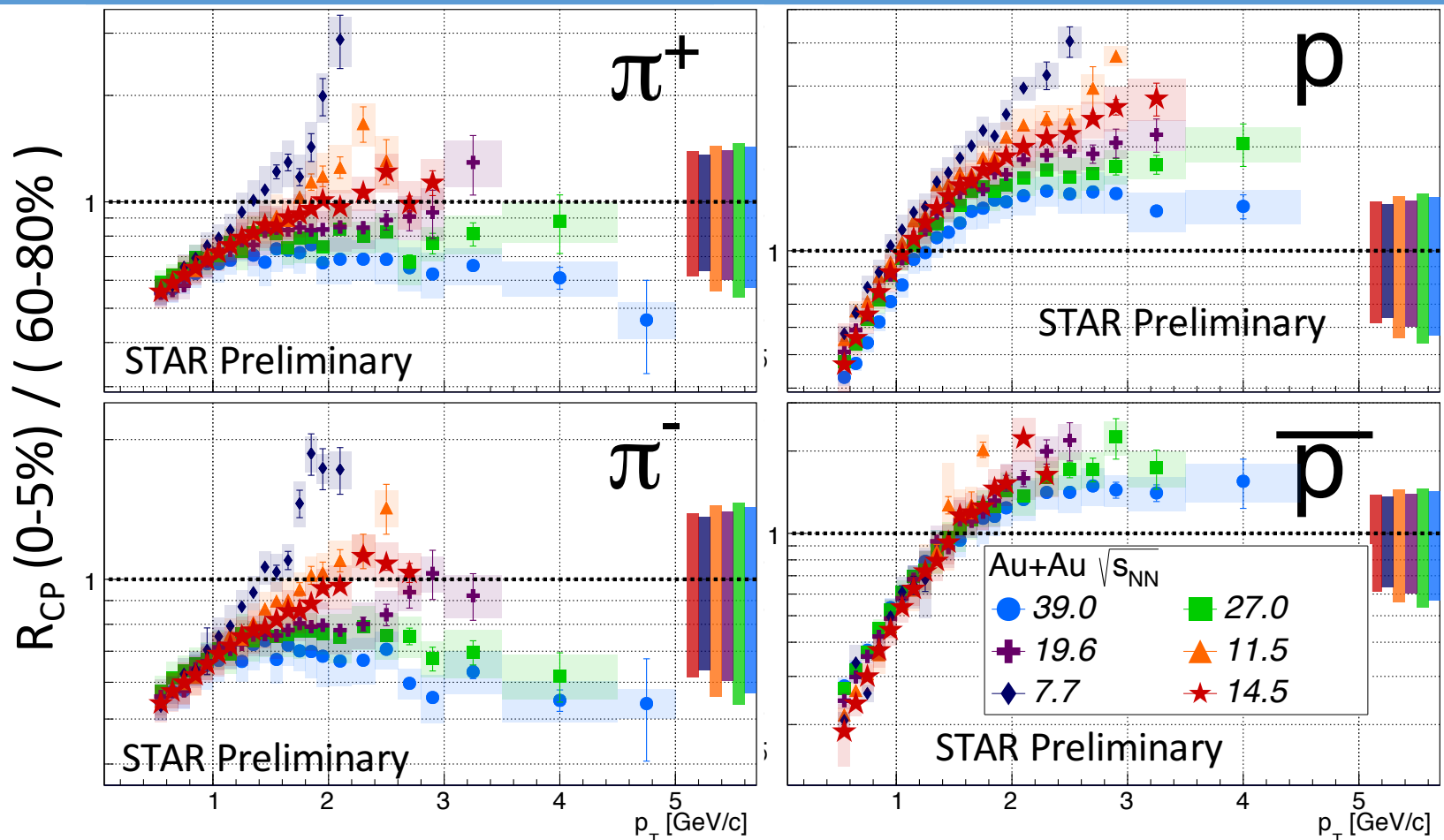
STAR ☆

Nuclear Modification Factor  $R_{CP}$  (0-5%)/(60-80%) @ Au+Au  $\sqrt{s_{NN}} = 14.5$



- Enhancement observed for protons
- Pions around unity for  $p_T > 2.0$  GeV/c

- Stat. uncertainties – vertical bars
- Syst. uncertainties - vertical boxes
- Bin width – horizontal box size

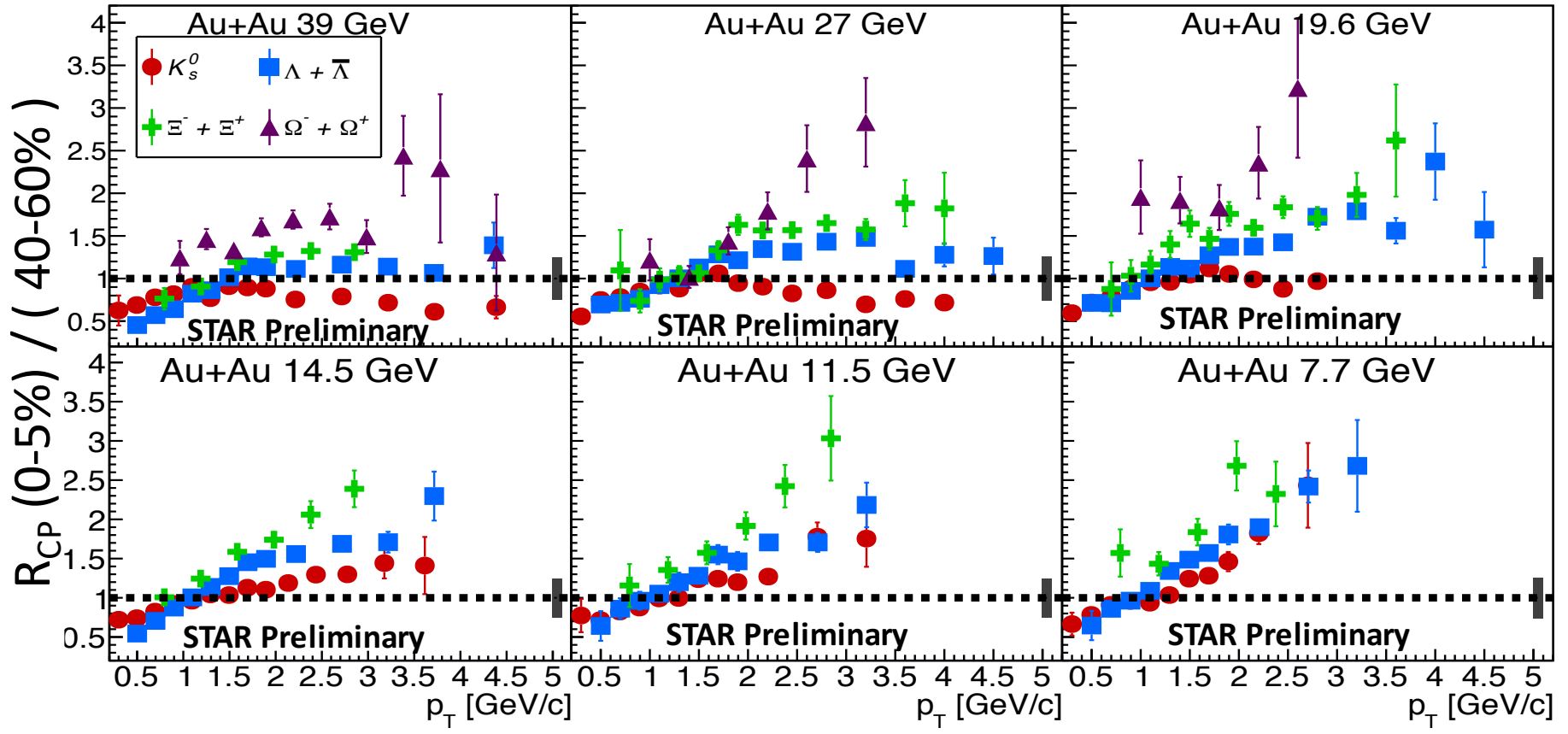


- Enhancement observed for all species @  $p_T > \sim 2.0$  in  $\sqrt{s_{NN}} = 14.5$  GeV and below – **key signature of QGP no longer visible at these energies**
- $R_{CP}$  of different energies splits between  $p_T \sim 1.5 - 3.0$  GeV/c (except in  $\bar{p}$ )
- $R_{CP}$  of  $\sqrt{s_{NN}} = 7.7, 11.5, 19.6, 27, 39$  GeV shown previously at CPOD 2013



# STAR ☆ Strange Hadron $R_{CP}$ (0-5%)/(40-60%)@ BES I Energies

Statistical Uncertainty Only



For  $\sqrt{s_{NN}} = 14.5$  GeV and below:

- $R_{CP}$  is greater than or equal to 1 for  $p_T > \sim 1.5$  GeV/c
- $R_{CP}$  particle type dependence becomes less significant
- Specifically baryon vs. meson difference at intermediate  $p_T$  becomes less pronounced

$\Omega$   $R_{CP}$  in 19.6 and 27 GeV :  
(0-10%) / (40-60%)



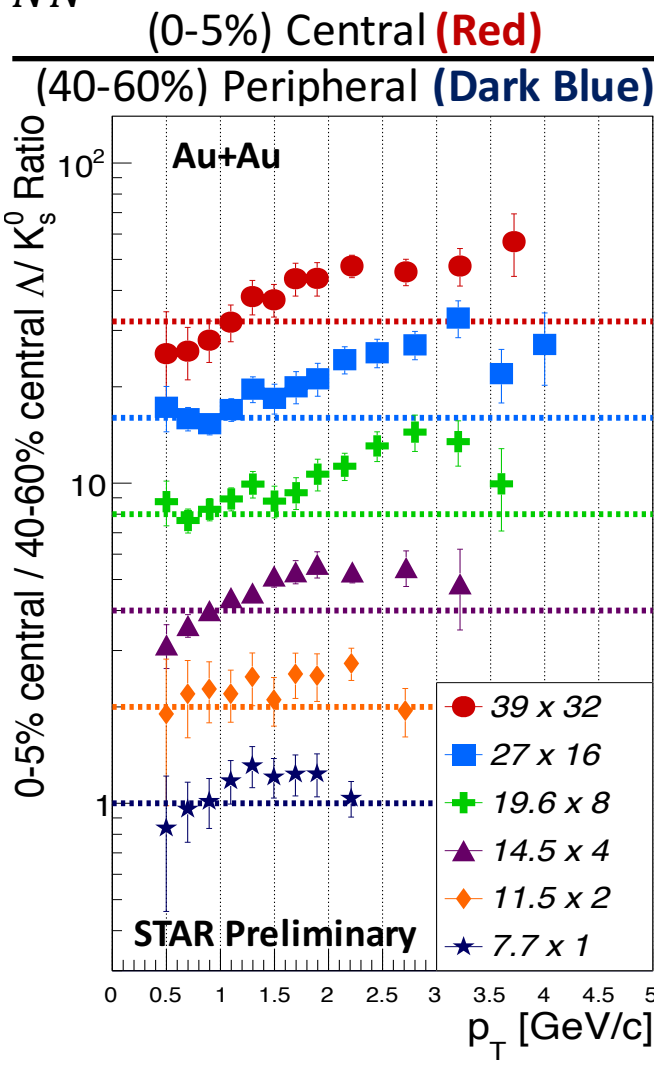
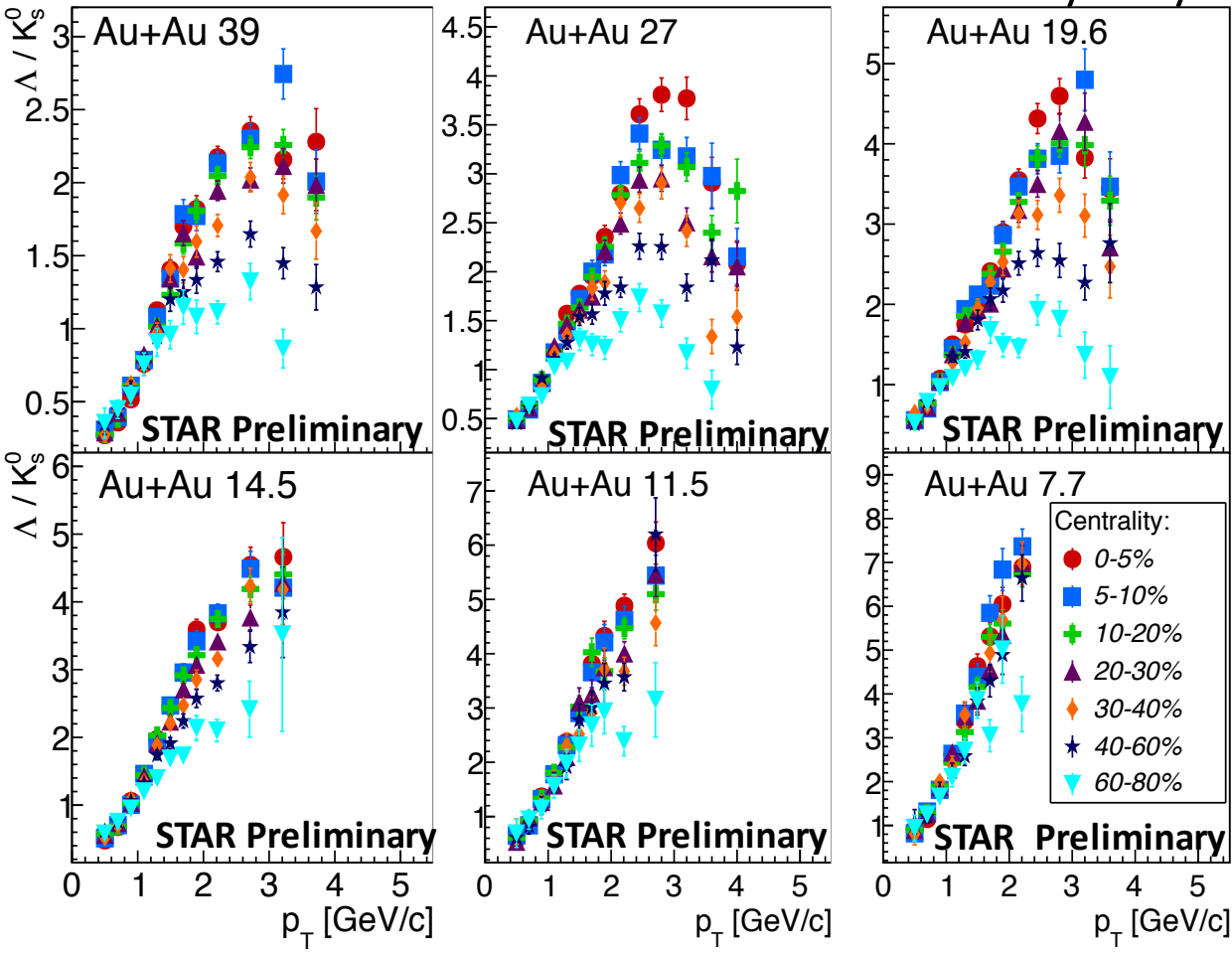


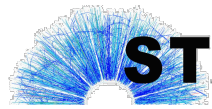




# STAR ☆ Baryon/Meson Ratio : $\Lambda/K_S^0$ @ BES I

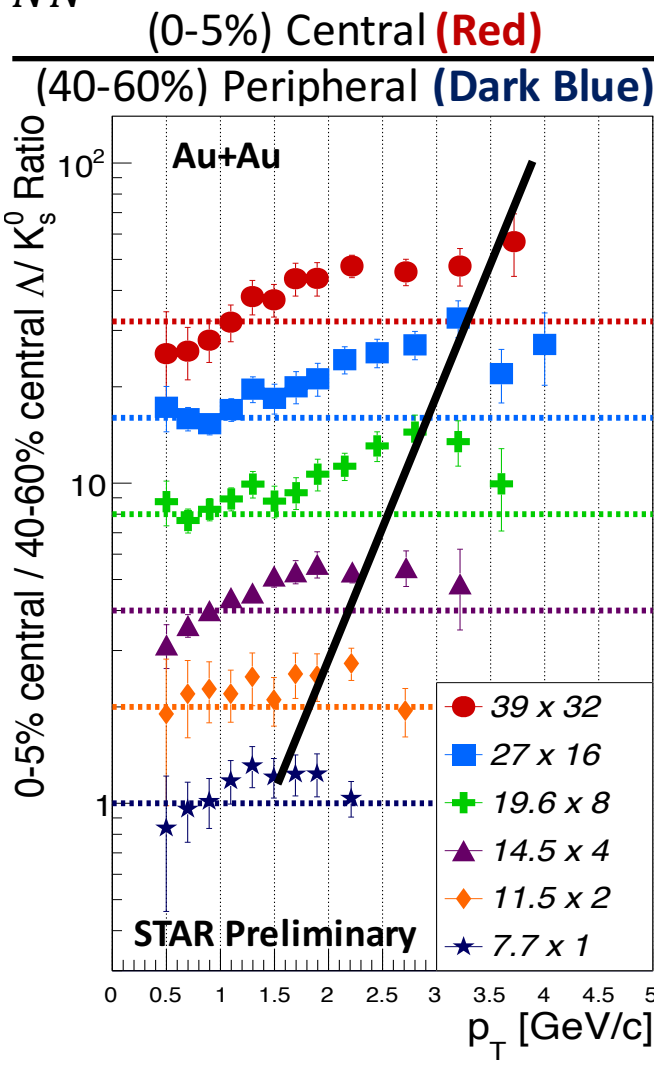
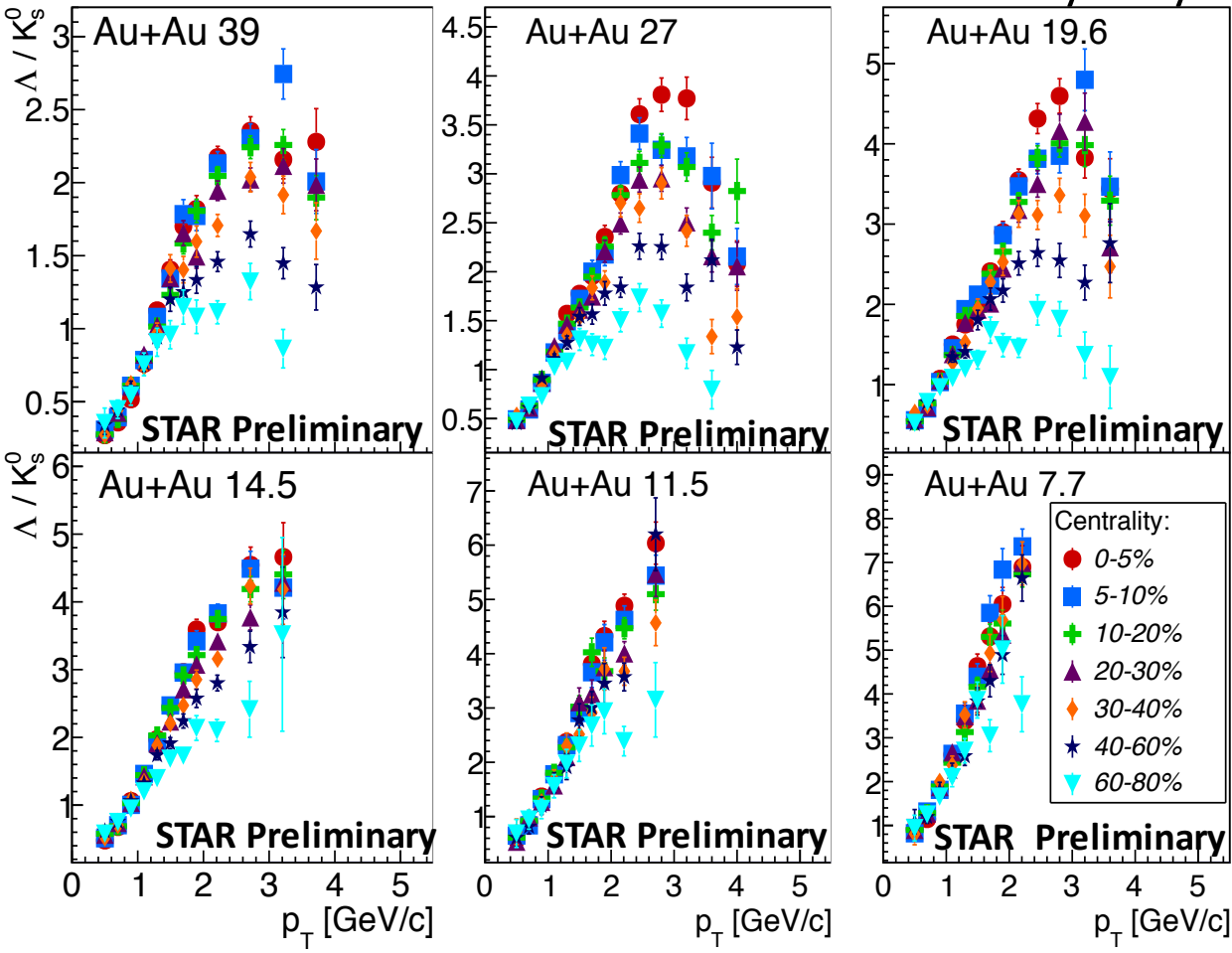
- Separation between centralities decreases with decreasing  $\sqrt{s_{NN}}$
  - “Double ratio” peak  $p_T$  value changes with  $\sqrt{s_{NN}}$
  - “Double ratio” for  $\sqrt{s_{NN}} = 7.7$  consistent with unity
- Statistical Uncertainty Only





# STAR ☆ Baryon/Meson Ratio : $\Lambda/K_S^0$ @ BES I

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  - “Double ratio” peak  $p_T$  value changes with  $\sqrt{s_{NN}}$
  - “Double ratio” for  $\sqrt{s_{NN}} = 7.7$  consistent with unity
- Statistical Uncertainty Only



## **Au+Au Collisions at $\sqrt{s_{NN}} = 14.5$ GeV**

- **New** STAR results in the large  $\mu_B$  gap between 11.5 and 19.6 GeV
- Completes the RHIC Beam Energy Scan Phase I

## **Onset of QGP signatures**

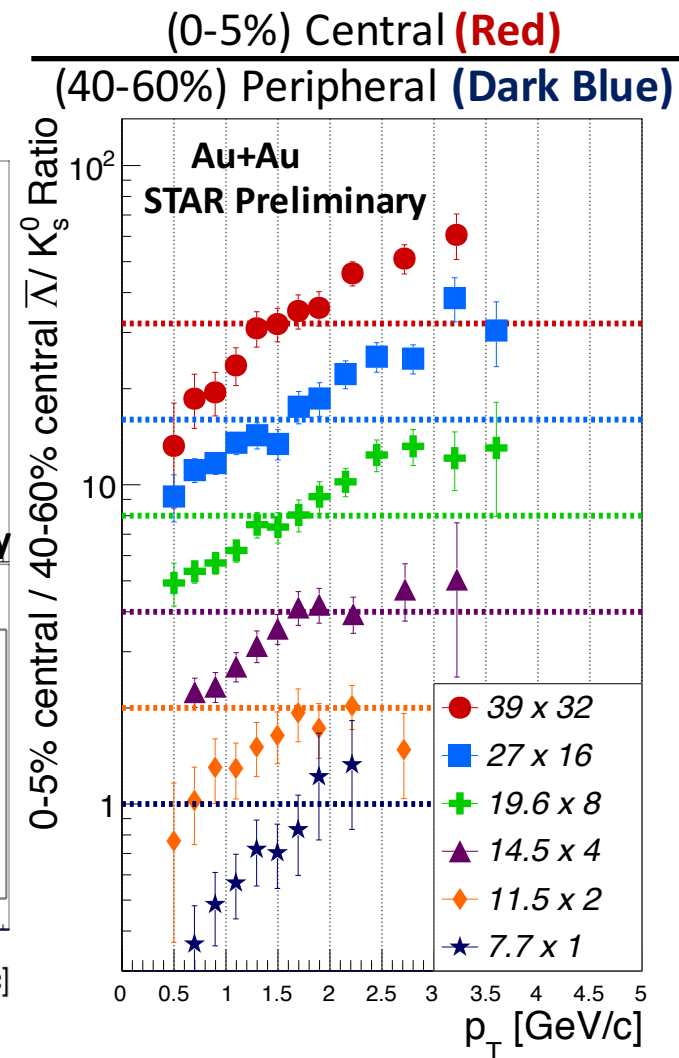
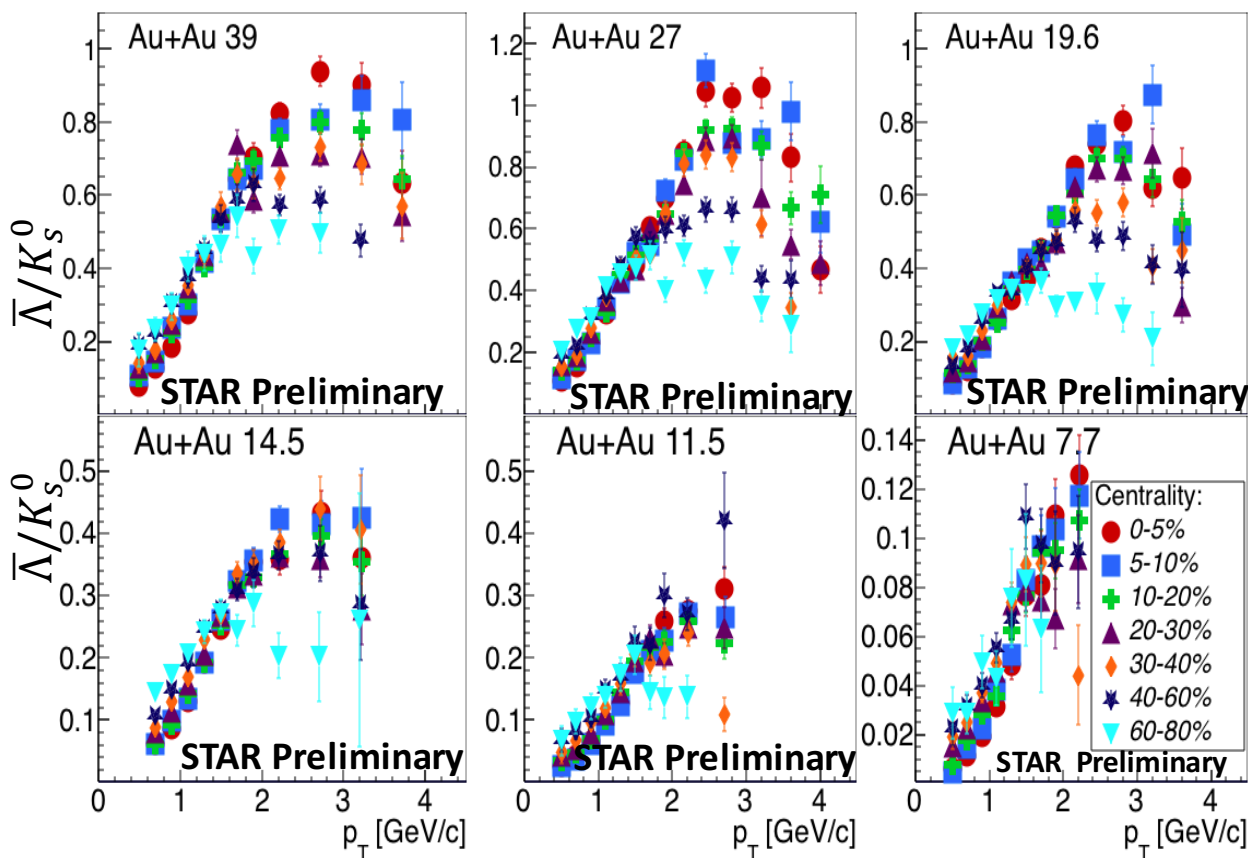
- $R_{CP}$  from  $\sqrt{s_{NN}} = 14.5$  GeV in both light and strange hadrons agrees with the trends from other BES energies
- No evidence of suppression at intermediate  $p_T$  in the  $R_{CP}$  of all species for energies at and below  $\sqrt{s_{NN}} = 14.5$  GeV
- Baryon/Meson ratios show evidence for change in collision dynamics for  $\sqrt{s_{NN}}$  below 19.6 GeV

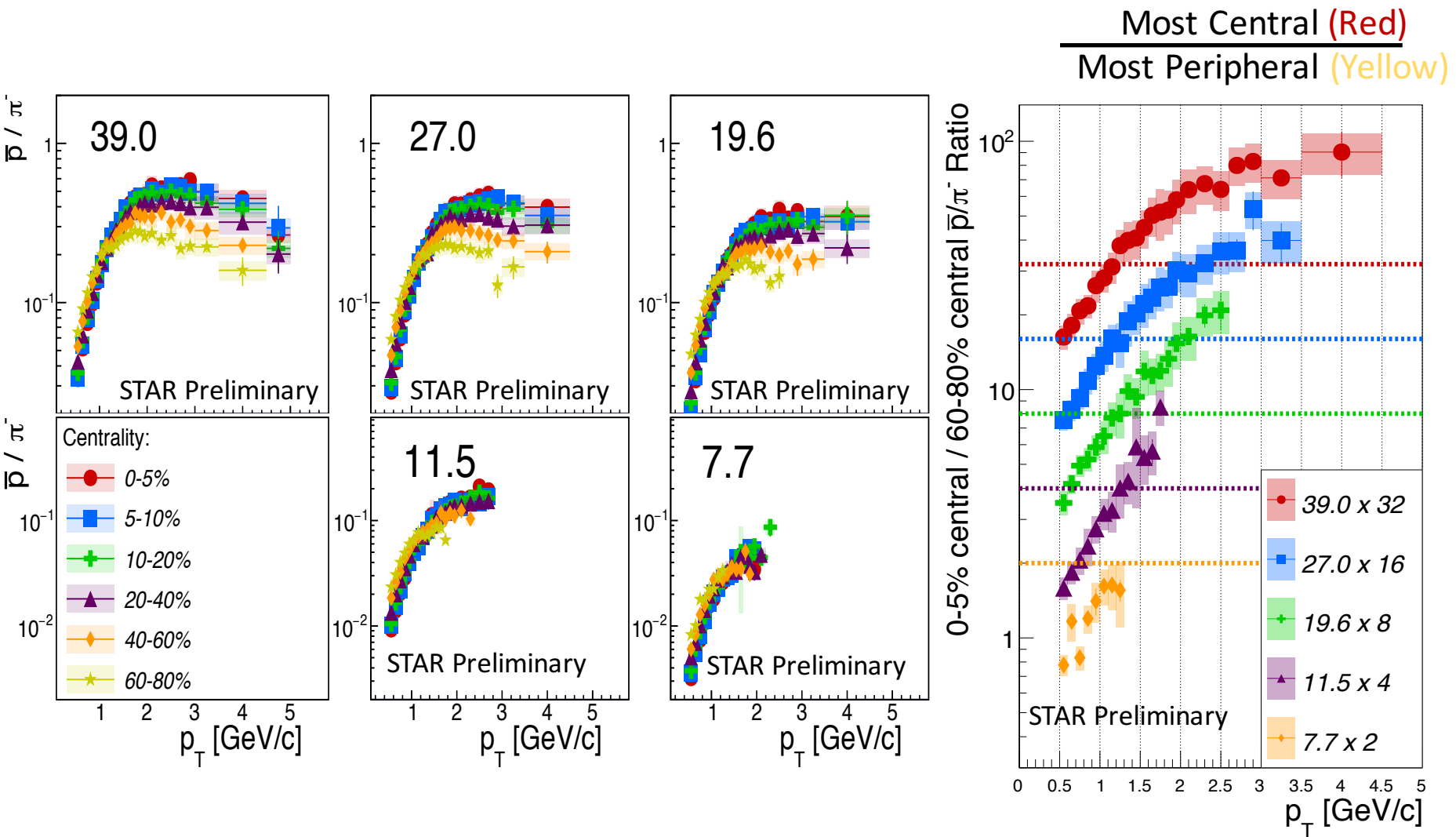
## **Beam Energy Scan Phase II is needed for conclusive results**

- More statistics – push kinematic reach to higher  $p_T$
- More energies below  $\sqrt{s_{NN}} = 20$  GeV

**THANK YOU**

## Statistical Uncertainty Only

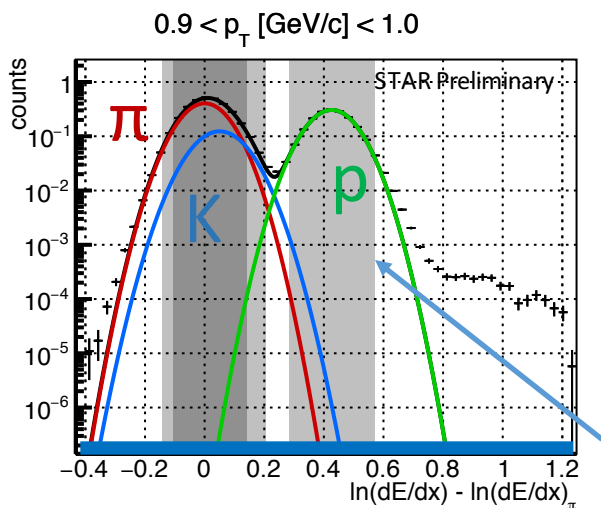
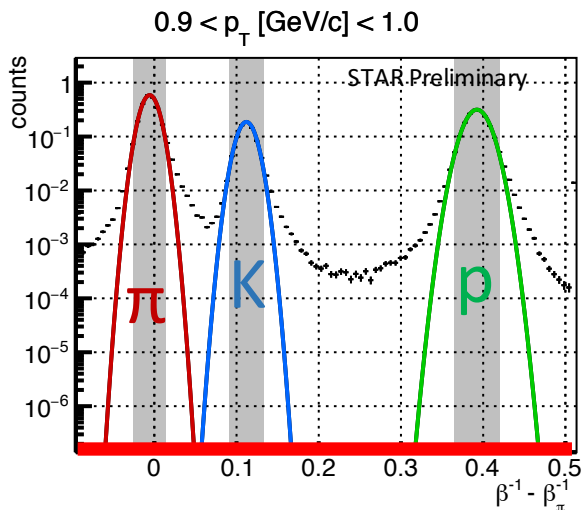






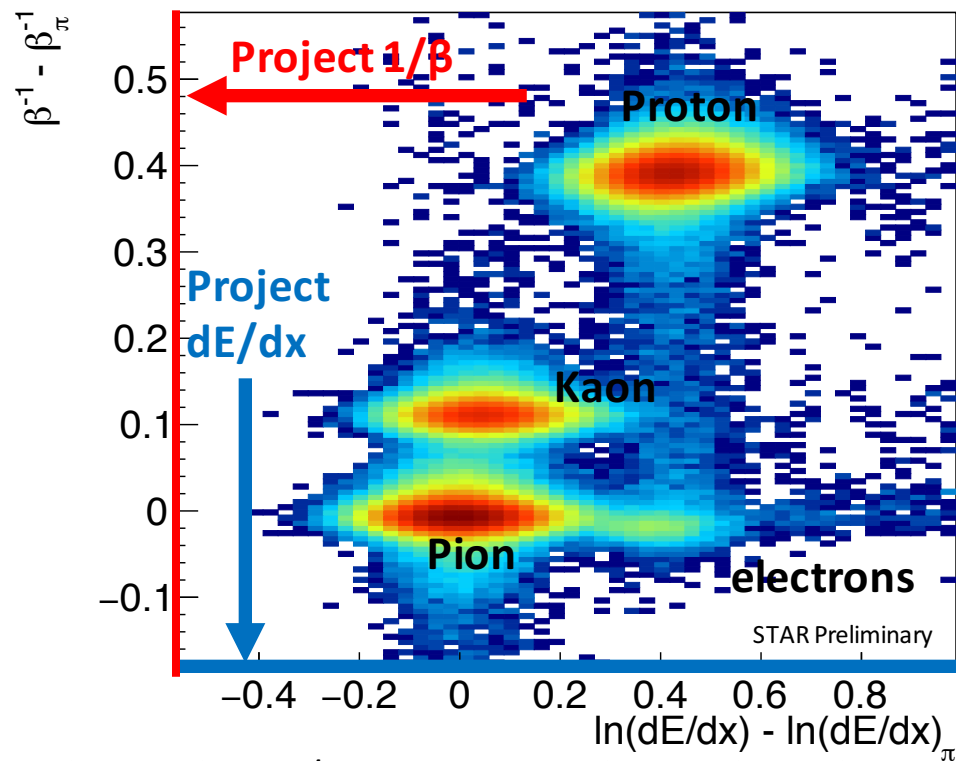
# STAR ☆ $\pi^{+(-)}, K^{+(-)},$ and (anti-)proton particle identification

Extract yields by simultaneously fitting the  $dE/dx$  and  $1/\beta$  distributions.



Combined TPC + TOF for a single  $p_T$  bin

Positive Tracks : 0.9 <  $p_T$  [GeV/c] < 1.0



- Grey bands show  $\pm 2\sigma$  around each particle peak
- The pion and kaon peaks are merged in  $dE/dx$  but are still well separated in  $1/\beta$
- The black band is the total fit result