Tsinghua University

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Measurements of Baryon Correlation Functions in $\sqrt{s_{NN}}$ = 3 GeV Au+Au Collisions at RHIC

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Important dynamical information, such as the spatio-temporal extents and their correlations can be extracted from particle correlation measurements.

In this poster, we illustrate the method to get the baryon correlation functions and report the result for proton-Ξ^- pairs from $\sqrt{s_{NN}} = 3$ GeV Au+Au collisions at RHIC. The data was taken with the fixed-target mode by the STAR experiment. The hadronic transport model UrQMD and an afterburner are used to reproduce the correlations and extract the baryon source extent in such collisions.

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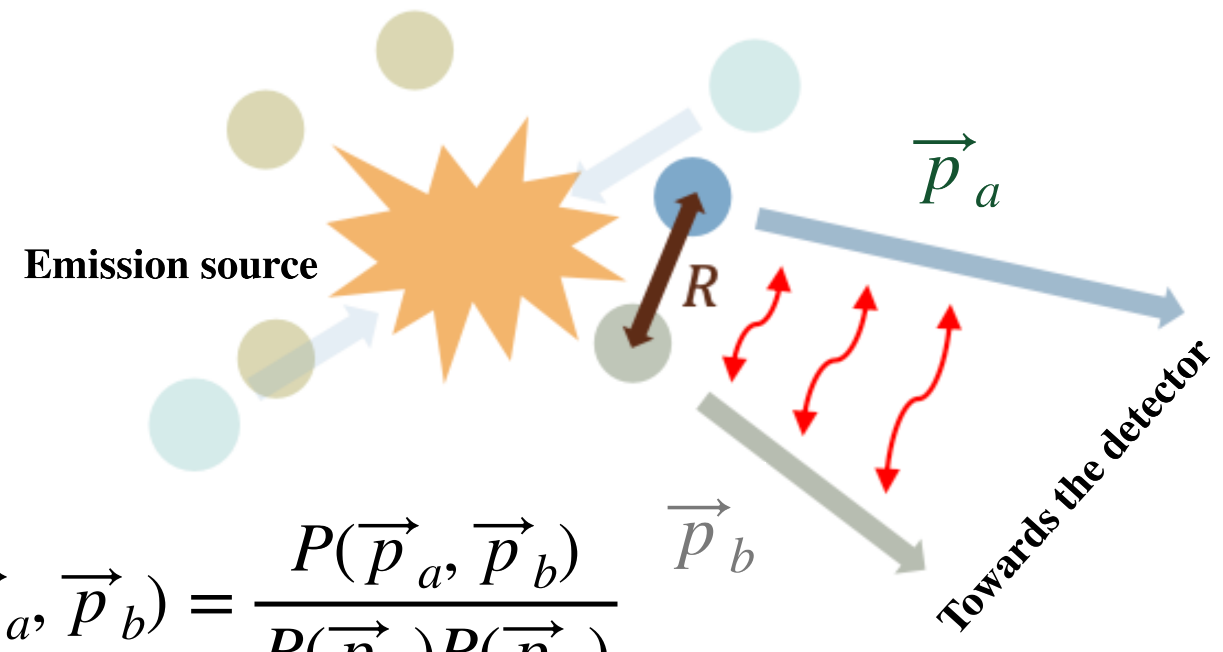
STAR

Introduction

Motivation

- **Strong interaction between hyperons and nucleons has an impact on the description of the equation of state of dense objects and it is not well understood**
- **In heavy-ion collisions, a large number of baryons are produced in each nucleus-nucleus collision, which allows us to study the hyperon-nucleon (YN) interactions**
- **Important dynamical information, such as the spatio-temporal extent of the hyperons and nucleons and correlations between them can be extracted from the particle correlation measurements**
  - An attractive p-Ξ^- interaction has been observed in Au+Au 200 GeV at STAR, p-Pb and pp collisions at ALICE
- **The high baryon density medium is created in the 3 GeV Au+Au collisions. Precision measurements of correlation of hyperon and proton can be made from these data sets**

Femtoscopy



The correlation function:

$$C(\vec{p}_a, \vec{p}_b) = \frac{P(\vec{p}_a, \vec{p}_b)}{P(\vec{p}_a)P(\vec{p}_b)}$$

$\vec{p}_{a,b}$ - momentum of a single particle

Experimentally obtained as:

$$C(k^*) = N\frac{N_{Same}(k^*)}{N_{Mixed}(k^*)}$$

Same: relative momentum distribution of particles in the same event
Mixed: particles from different events (not correlated)
k*: Reduced momentum in the pair rest frame (PRF, denoted by the *) $k^* = \frac{|\vec{p}_a^* - \vec{p}_b^*|}{2}$ and $\vec{p}_a^* + \vec{p}_b^* = 0$
Normalized to unity: $C(k^* > 200\ \mathrm{MeV/c}) = 1$

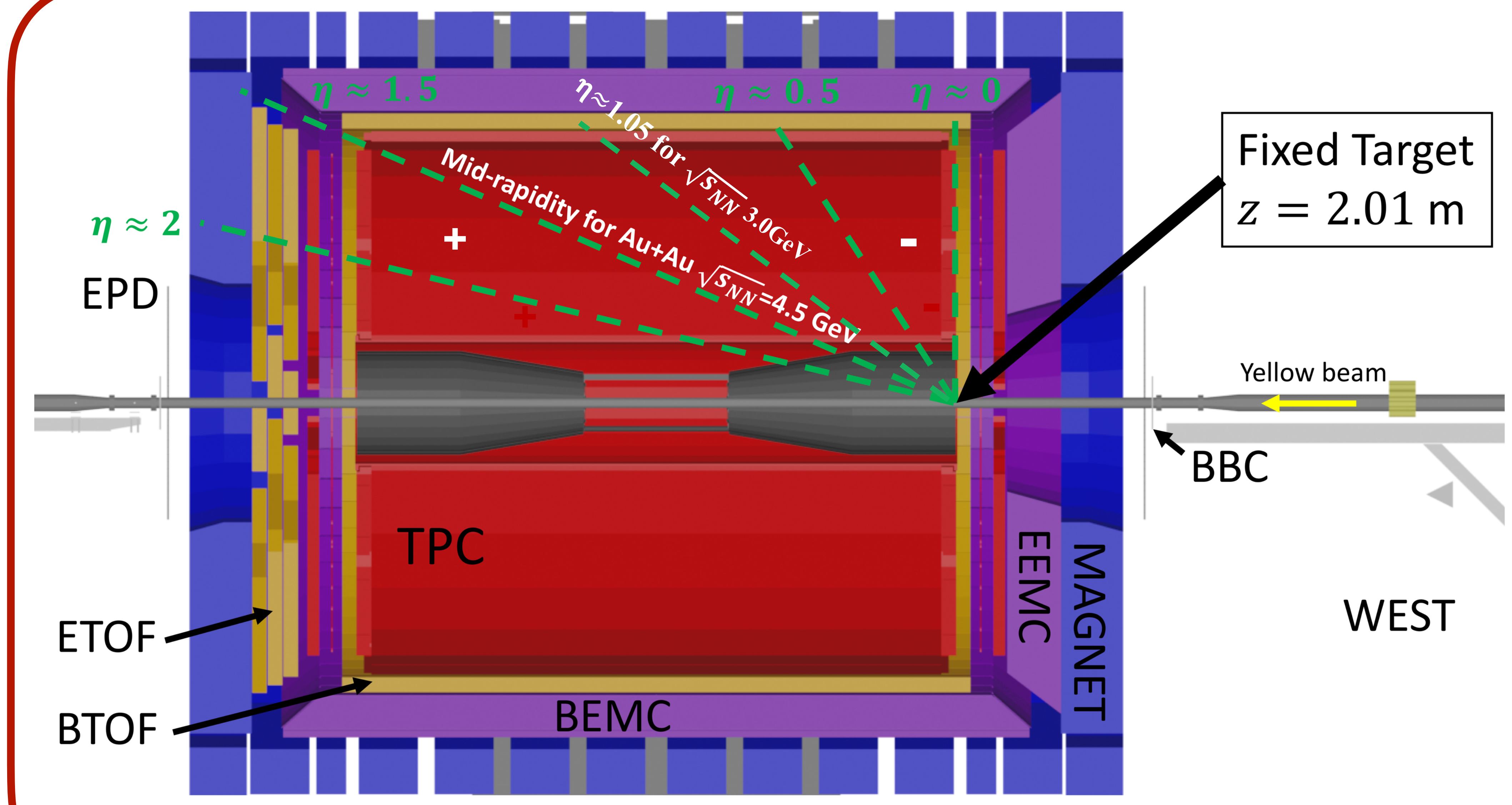
Given by:

Source — Relative wave function — Relative distance

$$C(k^*) = \int S(\vec{r})\,|\Psi(\vec{r}, k^*)|^2 d^3r \quad \text{and } C(k^* \rightarrow \infty) = 1$$

- **If the particles are close both in position and momentum space their interaction will change their final relative coordinates significantly**

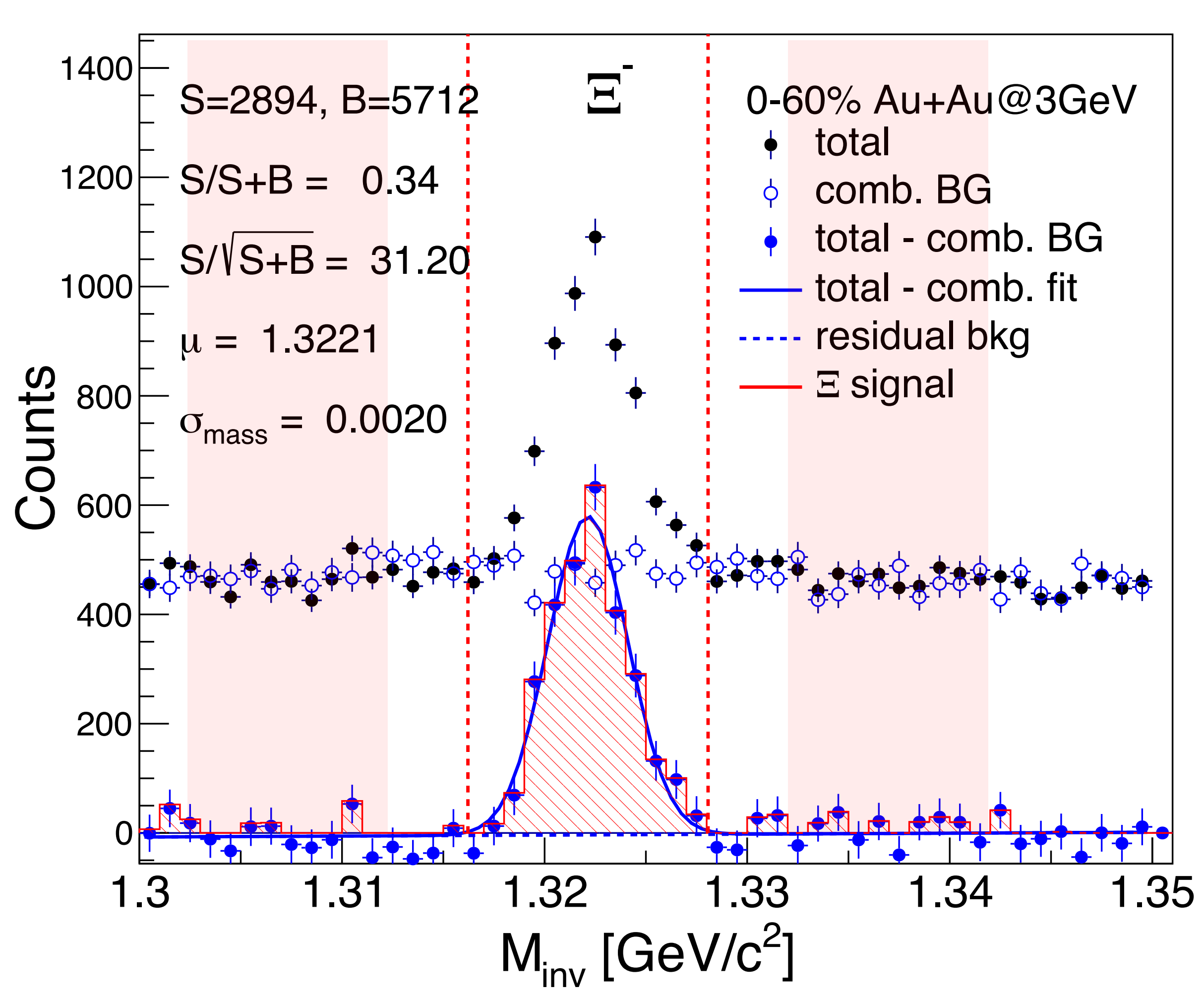
Particle Selection

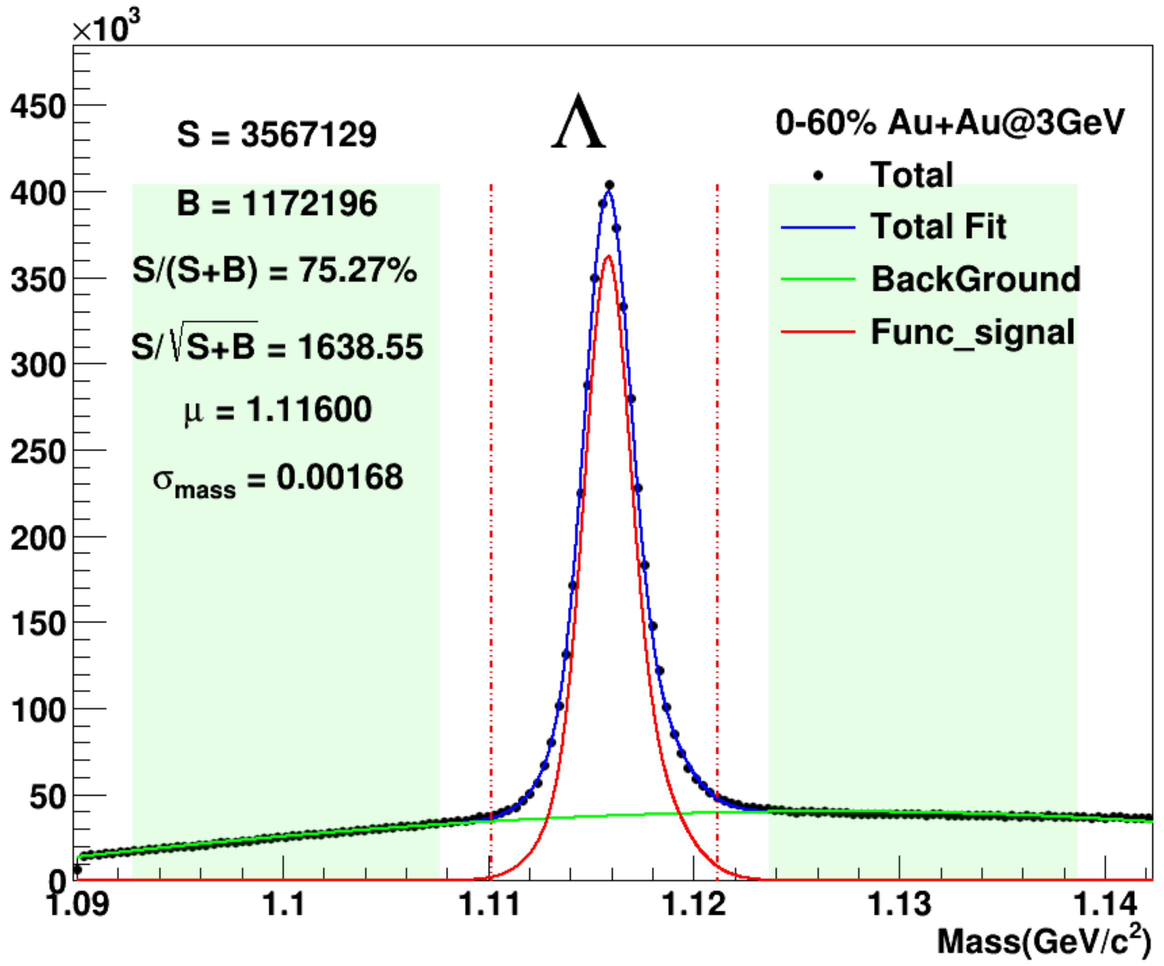


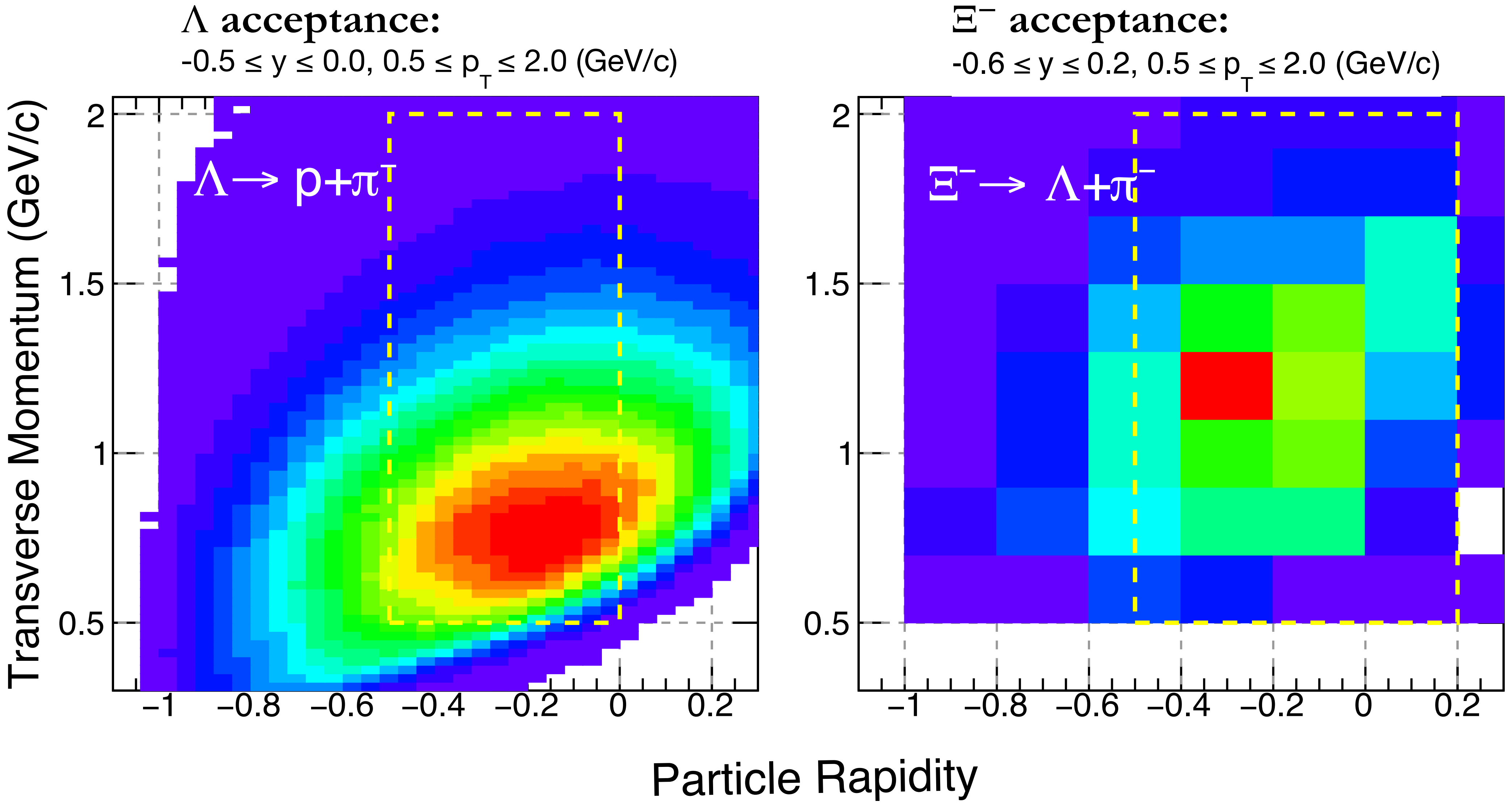
Conventions: beam-going direction is the positive direction

- Target was installed at the edge of the TPC
- Au-Target =0.25 mm thickness, 1% interaction probability
- 260M events for Au+Au FXT at $\sqrt{s_{NN}}$ = 3 GeV
- Good mid-rapidity coverage

- TPC (dE/dx) and TOF (β) for pion, kaon, and proton particle identification
- Hadronic channel: $\Lambda \rightarrow p + \pi^-$, $\Xi^- \rightarrow \Lambda(p\pi^-) + \pi^-$
- KF Particle package is used to improve the significance
- The combinatorial background is reconstructed by the rotation method







Particle Identification, Purity and Background

$$C(k^*) = 1 + \lambda_{genuine} \cdot (C_{genuine}(k^*) - 1) + \sum \lambda_{ij} \cdot (C_{ij}(k^*) - 1)$$

$\lambda_{i,j} = p(X_i)f(X_i)p(Y_j)f(Y_j)$, , **i denotes the particle's i-th contribution**

$$p(X_i) = \begin{cases} 1 - \text{purity} & \textbf{for mis-identification,} \\ \text{purity} & \textbf{for else} \end{cases}$$

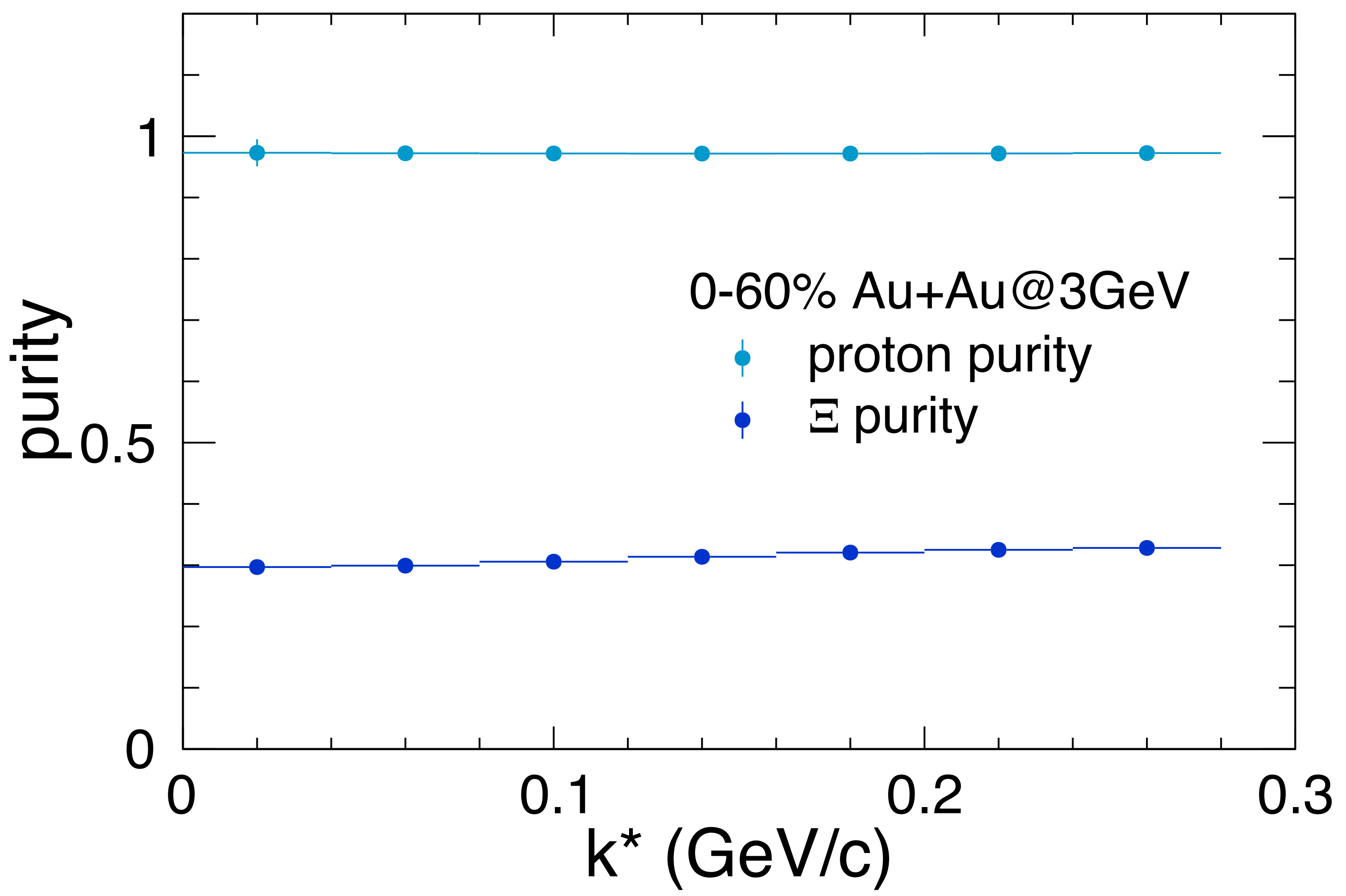
$$f(X_i) = \begin{cases} 1 & \textbf{for mis-identification,} \\ \text{feed down fraction} & \textbf{for else} \end{cases}$$

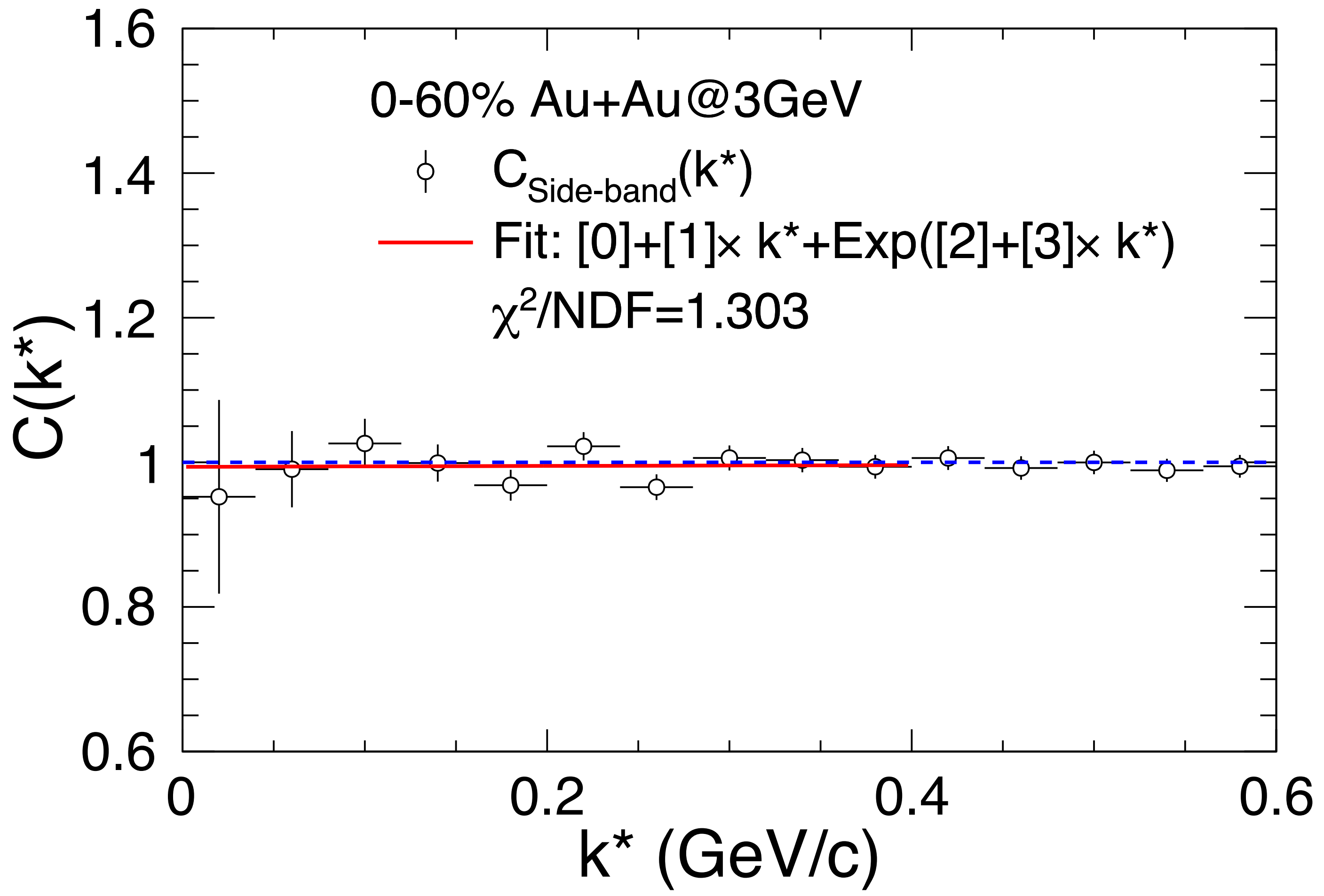
e.g.: $\lambda_{sideband}$ **= proton purity * proton primordial fraction * (1 - Ξ^- purity) * 1**

Proton purity: ~1
Ξ^- purity: ~0.26
Proton primordial fraction: ~98%
Ξ^- primordial fraction: ~84.2% ($\Xi^0(1530)$, $\Xi^-(1530)$: ~15.8%)

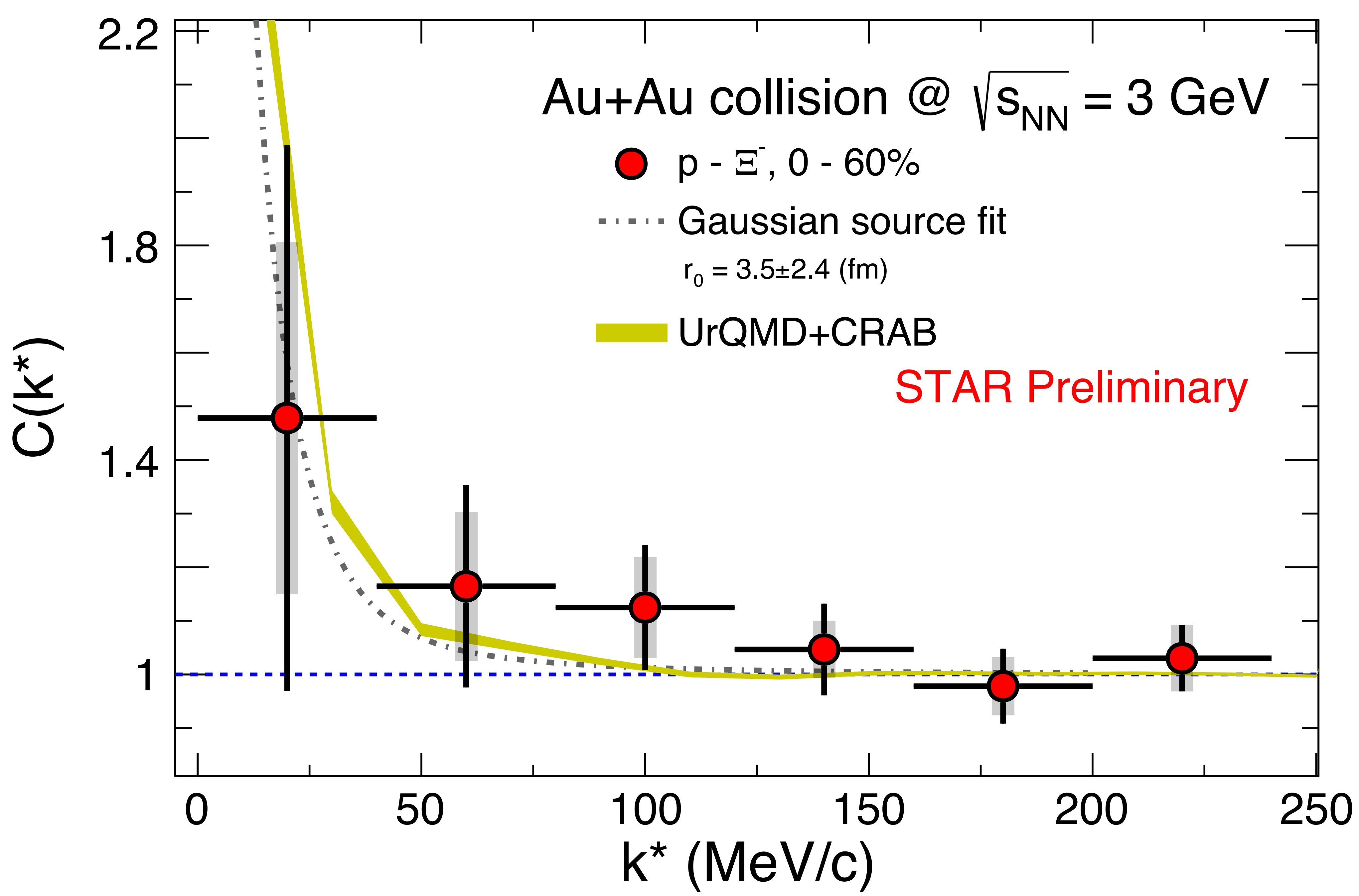
- **Purity from data: fit to the Λ, Ξ^-'s invariant mass distribution, proton's $n\sigma_p$ and m^2 distributon**
  - The impurity of the proton is negligible
  - Correlation function from the impurity of Ξ^- $C_{sideband}(k^*)$: using sideband technique, intentionally pair background particle candidates in the side-band region
- **Using THERMAL FIST model to estimate proton, Λ and Ξ^-'s primordial fraction**
  - Residual correlation from proton paired with $\Xi^-(1530)$, $\Xi^0(1530)$ decayed Ξ^- ($p\Xi^-_{feeddown}$) is assumed to be flat: $\lambda_{p\Xi_{feeddown}}$ is small
  - Residual correlation from feed down proton paired with Ξ^- is assumed to be flat: weak decay fraction from Λ, Σ^+ is negligible

$$C(k^*) = 1 + \lambda_{genuine} \cdot (C_{genuine}(k^*) - 1) + \lambda_{sideband} \cdot (C_{sideband}(k^*) - 1)$$





Result



$$C(k^*) = \int S(\vec{r})|\Psi(k^*,\vec{r})|^2 d^3r, \quad S_{4\pi}(r) = 4\pi r^2 S(r) = \frac{4\pi r^2}{(4\pi r_0^2)^{3/2}}\exp(-\frac{r^2}{4r_0^2})$$

- **Assume spherically symmetric static emitting source with a Gaussian density profile parametrized by a radius parameter r_0 (the size of the source)**
- **CATS + QCD strong potential from HAL QCD lattice collaboration in (2+1) flavor**

- **Use a hadronic transport dynamic model UrQMD to generate particle freezeout distributions: with Gaussian equivalent radius r_0 ~ 3.9 fm**
- **An afterburner code, CRAB (v3.0b), is used to include femtoscopy effects: QCD strong potential from HAL QCD lattice collaboration in (2+1) flavor**

Summary and outlook

- **The first measurements of p-Ξ^- in Au+Au collisions at 3 GeV**
  - UrQMD+CRAB delivers a good description of the correlation signal
- **The analysis of p-Λ correlation is ongoing**
- **STAR has collected more than 2B events of Au+Au collisions at 3 GeV. Precision results of baryon correlation functions will be reported in the future**

Reference

HAL QCD: Nucl. Phys. A967 (2017) 856-859; K. Sasaki, et al., PoS LATTICE2016, 116 (2017)
CATS Framework: Eur. Phys. J. C78 (2018) 394
Correlation Afterburner (CRAB): https://web.pa.msu.edu/people/pratts/freecodes/crab/home.html
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Decomposition of C(k*): Phys. Rev. C 99 (2019), 024001
UrQMD: Phys. Rev. C78, 044901 (2008). [arXiv:0806.1695 [nucl-th]]