Muon Identification for $\Upsilon \rightarrow \mu^+\mu^-$ in Au+Au collisions at STAR

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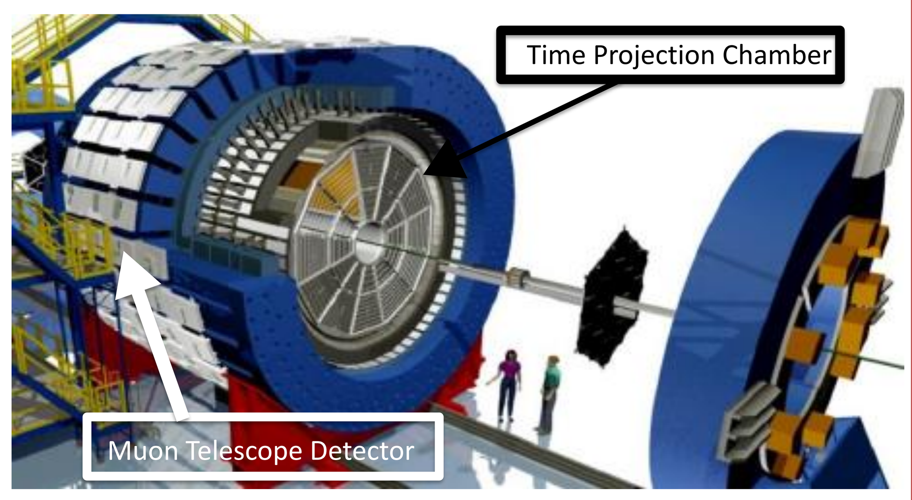
Abstract

The Solenoid Tracker At RHIC (STAR) is an important high-energy nuclear physics experiment at the Relativistic Heavy Ion Collider (RHIC) which is located at Brookhaven National Laboratory (BNL). The main goal of STAR is to study the formation and characteristics of the Quark Gluon Plasma (QGP) state. The results from RHIC and LHC indicate that there is a strong suppression on the quarkonium production in QGP. In this poster, we will present a muon identification method using Likelihood Ratio [1], for the Υ meson decaying into the $\mu^+\mu^-$ final state in Au+Au collisions at $\sqrt{S_{NN}}$ = 200 GeV recorded by the STAR detector.

1. Motivation

The suppression of the quarkonia production in heavy-ion collisions strongly suggests that QGP is created in these collisions. Studying the Υ production in heavy-ion collisions will provide us valuable information about the properties of QGP. To maximally utilize the $\Upsilon \rightarrow \mu^+\mu^-$ decay channel, an efficient muon identification method needs to be developed in order to suppress the large hadronic background in Au+Au collisions.

2. The STAR Detector



Time Projection Chamber (TPC) [2]

TPC is capable of measuring the trajectories of charged particles and provide particle identification through measurements of the ionization energy loss (dE/dx).

Muon Telescope Detector (MTD) [3]

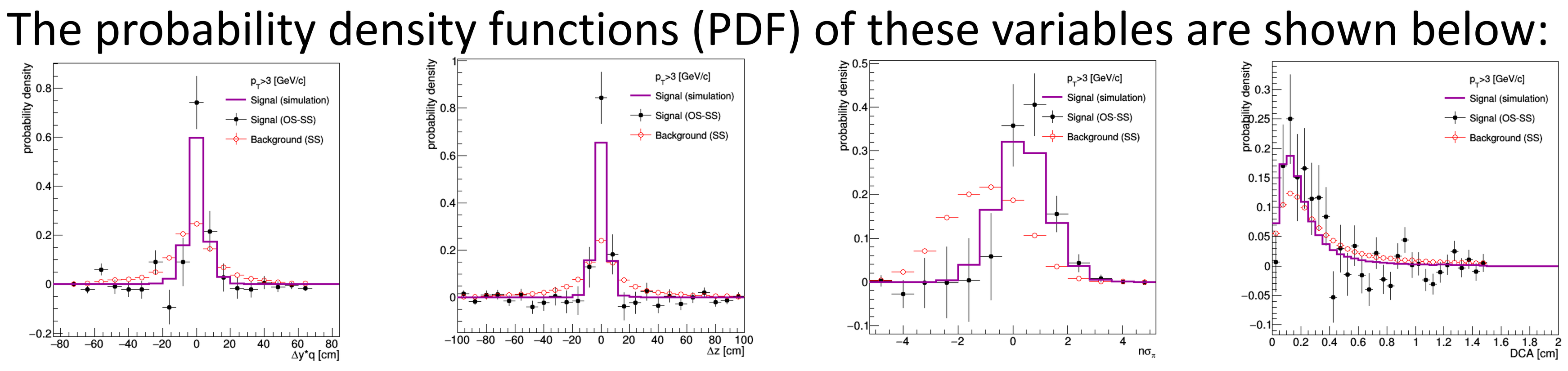
MTD is a muon detector installed outside the flux-return steel bars of the solenoidal magnet acting as a hadron absorber. The MTD modules are based on the Multi-gap Resistive Plate Chamber technology.

3. Muon Identification

The basic selections for each muon pair (TPC track + MTD hit) are p_T > 3 GeV/c and $|\eta|$ < 0.5. To obtain pure muon candidates, there are four useful variables to remove background hadrons:

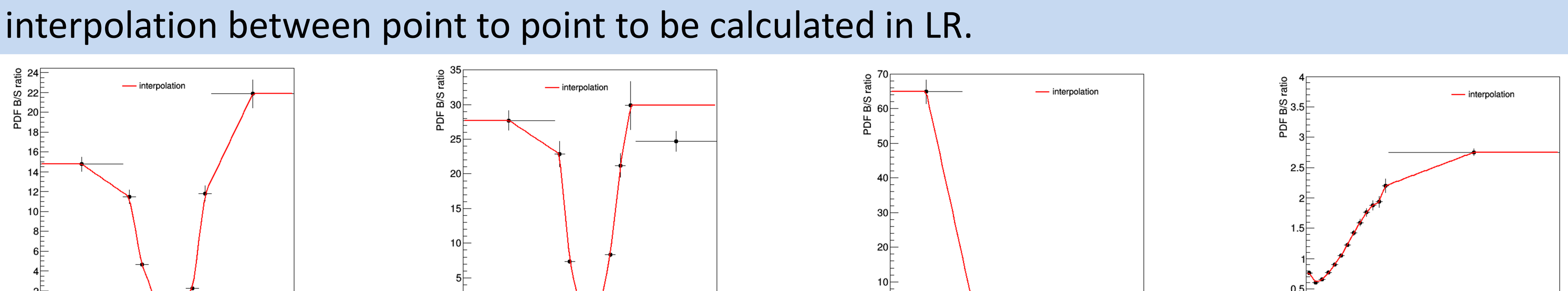
- Δy and Δz: The difference between the hit position in the MTD and extrapolated position from the TPC track in the transverse and longitude directions. Δy is multiplied by charge ($\Delta y \times q$) to eliminate the charge dependence.
- $n\sigma_\pi$: The normalized ionization energy loss (dE/dx) which is defined as: $$n\sigma_\pi = \frac{\log\left(\frac{dE}{dx}\right)_{measured} - \log\left(\frac{dE}{dx}\right)_{\pi\ theory}}{\sigma\left(\log\left(\frac{dE}{dx}\right)_{measured}\right)}$$ Where "measured" and "π, theory" represent the measured dE/dx with pion mass hypothesis and theoretical value for pions, respectively. $\sigma(\log(dE/dx)_{measured})$ is the experimental resolution of log(dE/dx) measurements.
- DCA: The distance of the closest approach to the collision vertex.

The probability density functions (PDF) of these variables are shown below:

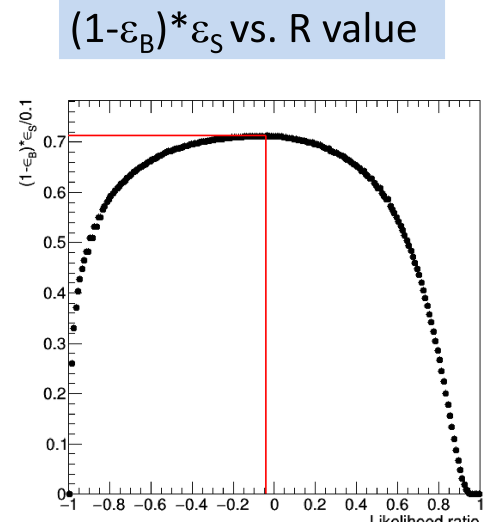


- **Straight Cut method**
  The most straightforward way is to apply cuts directly on each variable, $|\Delta y|$ < 3σ (p_T > 3 GeV/c), $|\Delta y|$ < 2.5σ (p_T < 3 GeV/c), $|\Delta z|$ < 3σ (p_T > 3 GeV/c) , $|\Delta z|$ < 2.5σ (p_T < 3 GeV/c), Δtof < 0.5 ns (2014 run), Δtof < 0.2 ns (2016 run), and -1 < $n\sigma_\pi$ < 3.
- **Likelihood Ratio Method (LR)**
  Discriminating variable "R" is defined as (1-Y)/(1+Y), where $Y = \Pi_i y_i$ and $y_i = PDF_i^{bkg}/PDF_i^{sig}$ is the ratio of the PDFs for background (same-sign) and signal (embedding). The R value will be close to 1 (-1) for muon-like (hadron-like) candidates.

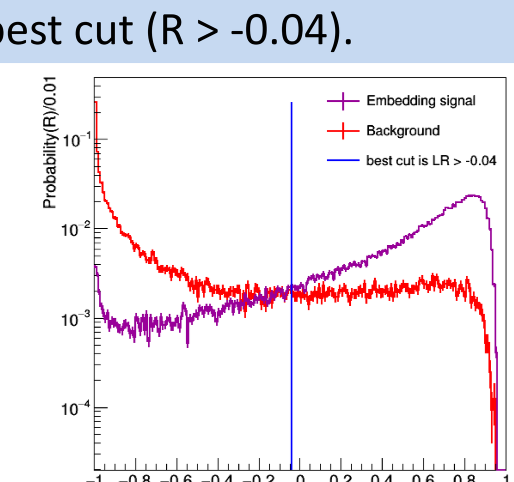
PDF ratios for background (same-sign) and signal (simulation): Where the red line is the interpolation between point to point to be calculated in LR.



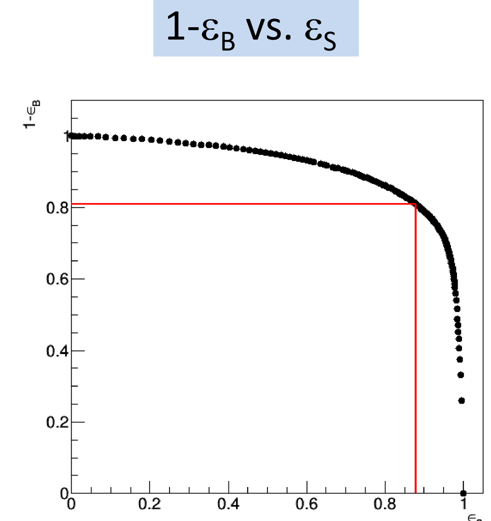
$(1-\varepsilon_B)*\varepsilon_S$ vs. R value



R value: Blue line indicates the best cut (R > -0.04).



$1-\varepsilon_B$ vs. ε_S



4. Muon Identification Efficiency

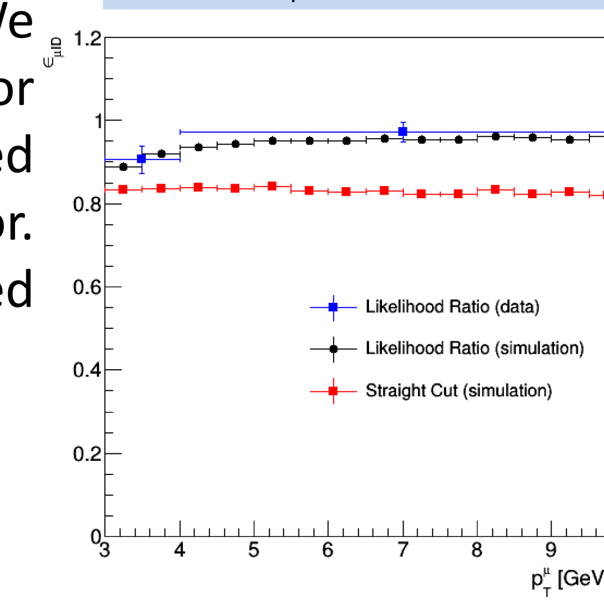
- **Definition**

The muon identification efficiency for LR method and Straight Cut method are evaluated by using the $J/\psi \rightarrow \mu^+\mu^-$ candidates with the tag-and-probe method (data-driven). For the tagged muons, we applied basic selections and required LR > -0.04 to ensure that it is a muon candidate. For probed muons, we applied basic cuts and required LR > -0.04 for the numerator.

We also used the simulation to check the muon identification efficiencies of LR method and Straight Cut method. We applied basic selections for the denominator and the numerator. Additionally, we required muon identification cut on the numerator. The muon identification efficiency defined as :

$$\varepsilon^{\mu ID} = \frac{N_\mu^{\mu\ ID\ cut\ \&\ basic\ cut}}{N_\mu^{basic\ cut}}$$

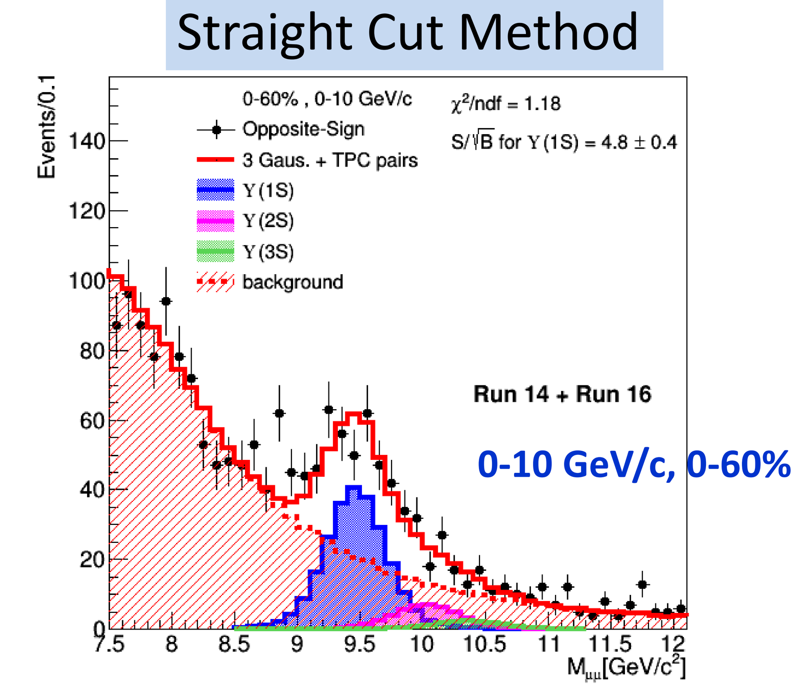
The efficiency as a function of muon p_T



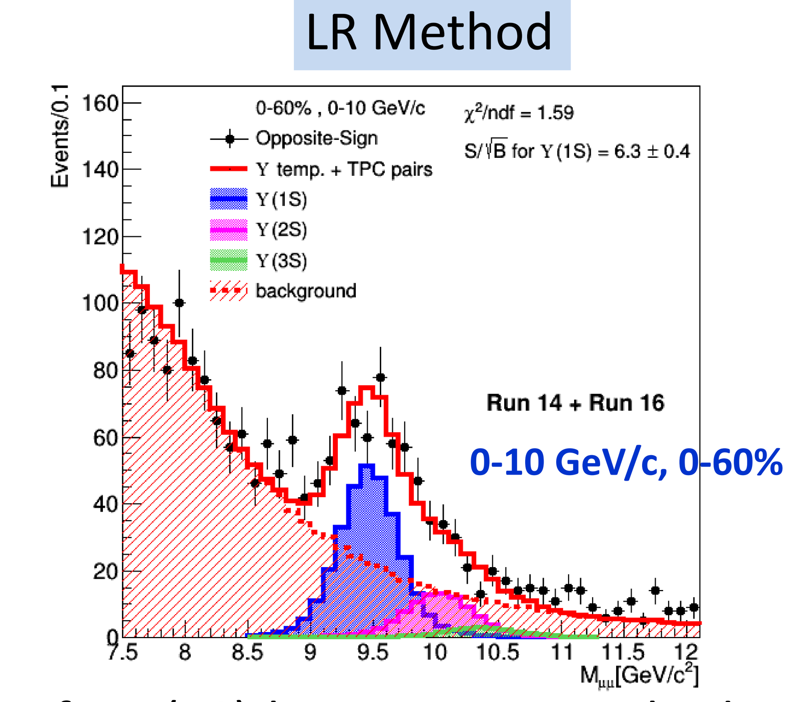
5. The $\Upsilon \rightarrow \mu^+\mu^-$ Yields

We required the p_T for leading (subleading) muons must be larger than 4 GeV/c (3 GeV/c). The Υ templates from simulation are used to describe the shape of the Υ(1S, 2S, 3S) signals and they are parameterized by a double Gaussian function. The TPC pairs are used as the background template. The signal significance and numbers of Υ(1S, 2S, and 3S) are improved by using LR method.

Straight Cut Method



LR Method



The comparisons of S/B and significance for Υ(1S) between LR method and Straight Cut method are shown below:

		0-60%, p_T (0-2) GeV	0-10%	10-30%	30-60%	p_T (0-2) GeV	p_T (2-4) GeV	p_T (4-10) GeV
S/B	LR	1.0 ± 0.1	1.0 ± 0.1	0.8 ± 0.1	0.9 ± 0.2	1.5 ± 0.2	1.1 ± 0.1	0.7 ± 0.2
	Straight Cut	0.8 ± 0.1	0.6 ± 0.1	0.7 ± 0.1	0.9 ± 0.2	1.2 ± 0.2	0.9 ± 0.1	0.8 ± 0.2
Significance ($S/\sqrt{B}$)	LR	6.3 ± 0.4	3.8 ± 0.4	3.4 ± 0.4	2.5 ± 0.4	4.6 ± 0.5	4.3 ± 0.5	2.4 ± 0.4
	Straight Cut	4.8 ± 0.4	2.2 ± 0.4	2.6 ± 0.4	2.2 ± 0.4	3.6 ± 0.4	3.2 ± 0.4	2.2 ± 0.4

6. Future Work

- Measurements of the production cross section σ: $$\sigma = \frac{N}{\varepsilon \times L \times A}$$ N is the number of reconstructed events, ε denotes the efficiencies, L represents the luminosity and A is the kinematic acceptance.
- The Nuclear Modification Factor (R_{AA}) for the Υ mesons: $$R_{AA} = \frac{1}{T_{AA}} \frac{d^2N_{AA}/dp_T dy}{d^2\sigma_{pp}/dp_T dy}$$

7. Conclusions

- We performed the studies on muon identification using Likelihood Ratio method in the STAR detector.
- The Likelihood Ratio method has very high efficiency for p_T^μ > 3 GeV/c.
- The novel method of LR clearly provides better signal significance (~31% higher) and signal to background ratio (~25% higher).

8. Reference

[1]T. C. Huang et al. Nucl. Instrum. Method A 833 (2016) 88-93.
[2]M. Anderson et al. Nucl. Instrum. Method A 499 (2003) 679.
[3]L. Ruan et al. J. Phys. G 36, 095001.