# TOWARD A MEASUREMENT OF THE MULTIPLICITY DEPENDENCE OF THE $J/\psi$ YIELD IN $p+p$ COLLISIONS AT $\sqrt{s} = 510$ GEV IN THE STAR EXPERIMENT

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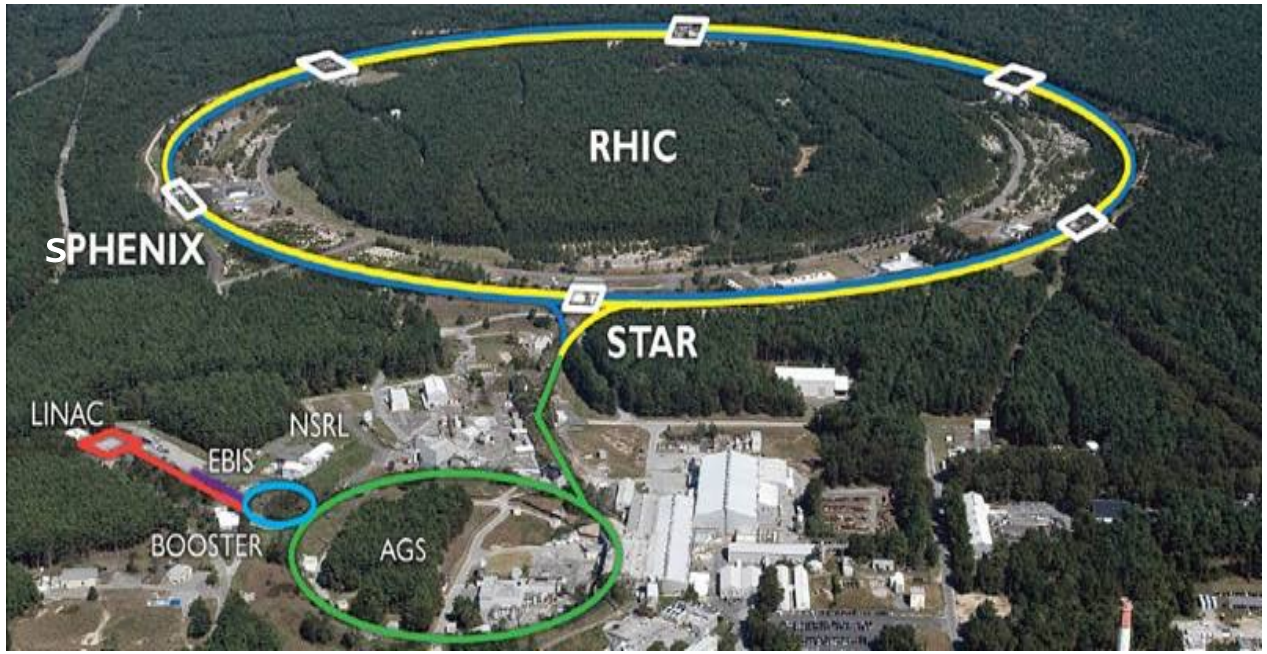
# OUTLINE

- RHIC and the STAR experiment
- J/$\psi$ measurement
- Muon particle ID
- Invariant mass
- Summary and future work

# RELATIVISTIC HEAVY ION COLLIDER

- Collides beams of heavy ions and protons
  - Heavy ion collisions up to center-of-mass energy of 200 GeV
  - $p + p$ collisions up to center-of-mass energy of 510 GeV
- Beams travel in opposite directions around ring
- Only polarized proton beam in the world

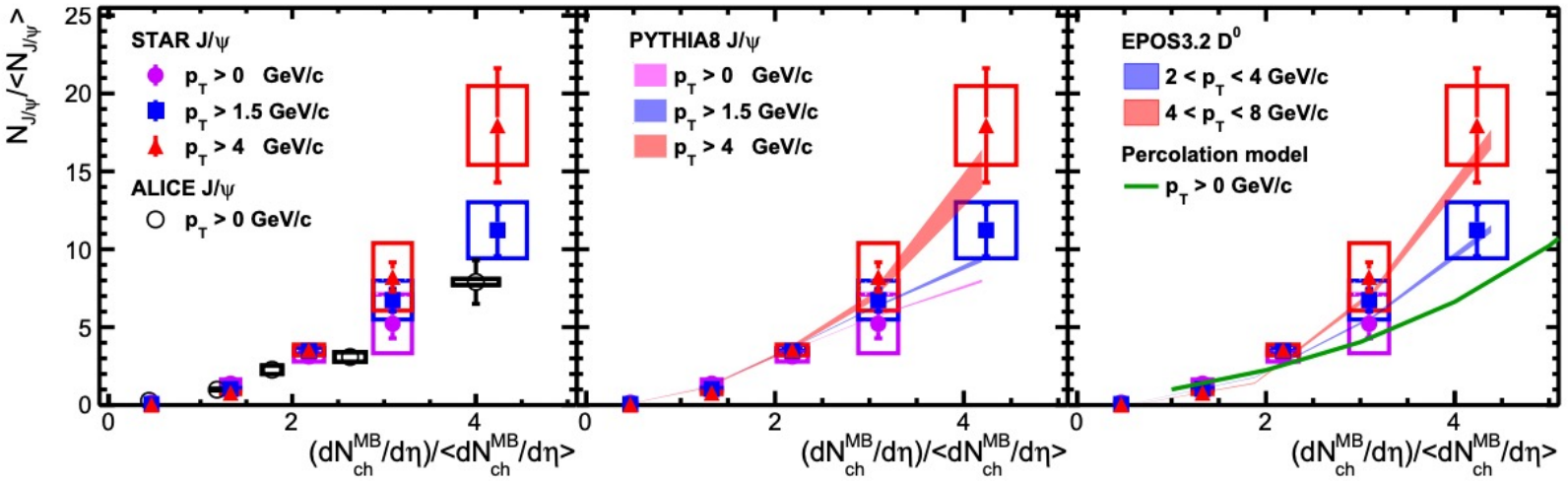


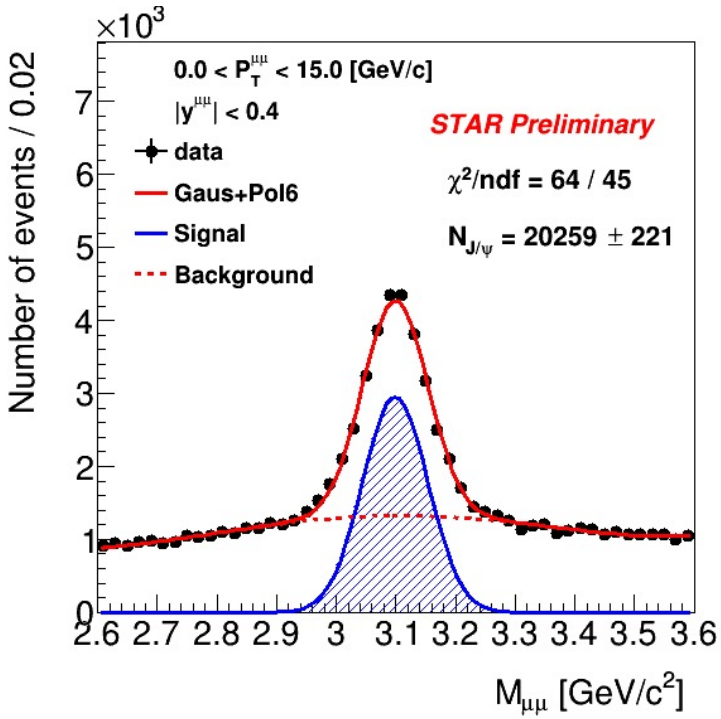
# MEASURING J/$\psi$ YIELD

- Quarkonia: heavy quark-antiquark pairs
- Recent measurements at RHIC and LHC showed faster than linear rise in J/psi production with event multiplicity
  - Model calculations with Multiple-Parton-Interactions (MPI) can reasonably describe data
  - May point to link between hard scattering and underlying soft processes
  - Can test and fine tune existing models
- J/$\psi$ ($c\bar{c}$) can decay through dimuon and dielectron channels
  - Measurement of J/$\psi$ yield using invariant mass via dimuon decay
- Using data from $p+p$ collisions at $\sqrt{s} = 510$ GeV from 2017 data taking
  - Has been done at $\sqrt{s} = 200$ GeV, higher energy will provide higher multiplicity
  - $0 < p_{T,J/\psi} < 30$ GeV/c
  - $|y_{J/\psi}| < 0.5$

# PREVIOUS RESULTS ON $J/\psi$ PRODUCTION AT STAR

- STAR measurements of $J/\psi$ yields ($\sqrt{s} = 200$ GeV) as a function of multiplicity, compared to ALICE results ($\sqrt{s} = 7$ TeV, forward rapidity) and PYTHIA, EPOS, and percolation models
  - PYTHIA and EPOS reproduce data
  - Reasonable agreement with ALICE
- Previous invariant mass measurement using $p + p$ $\sqrt{s} = 510$ GeV data

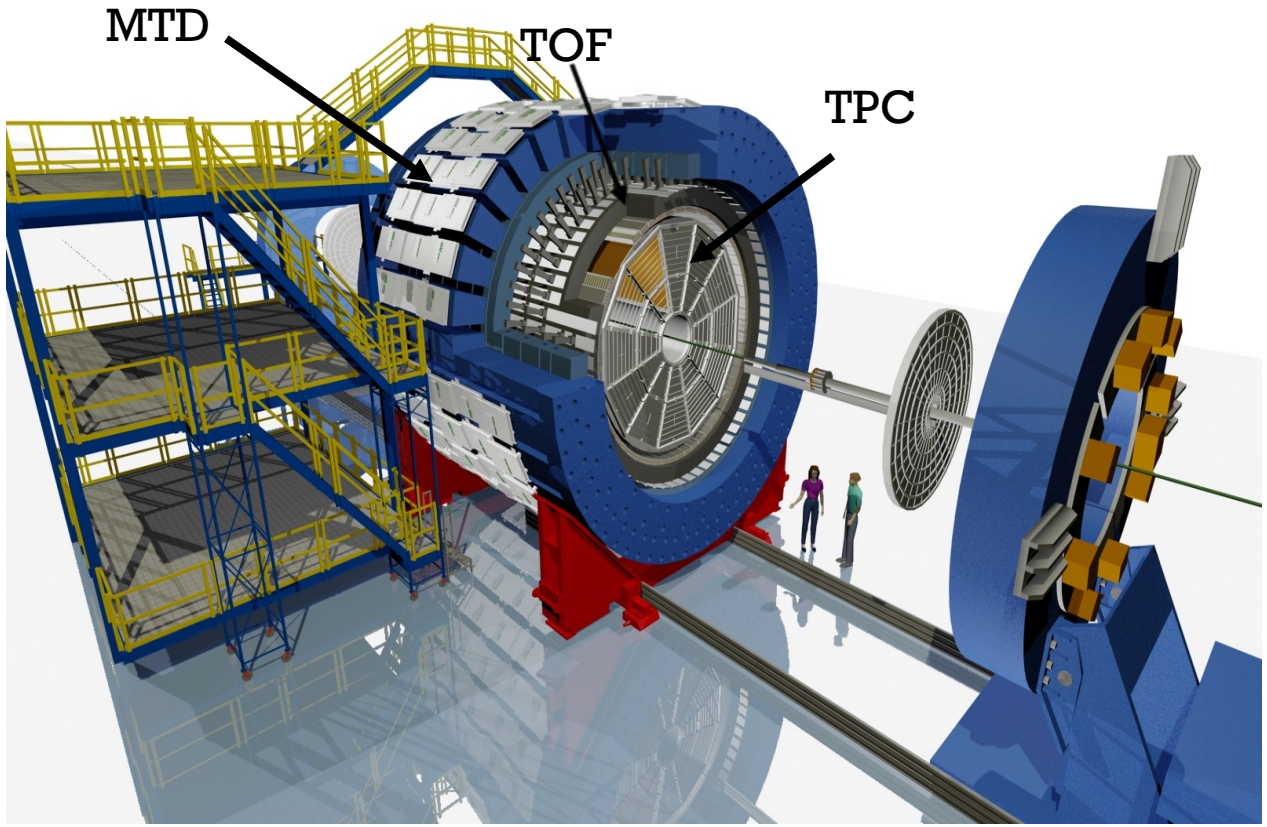



STAR collaboration, Physics Letters B, 786 (2018), p. 87-93.

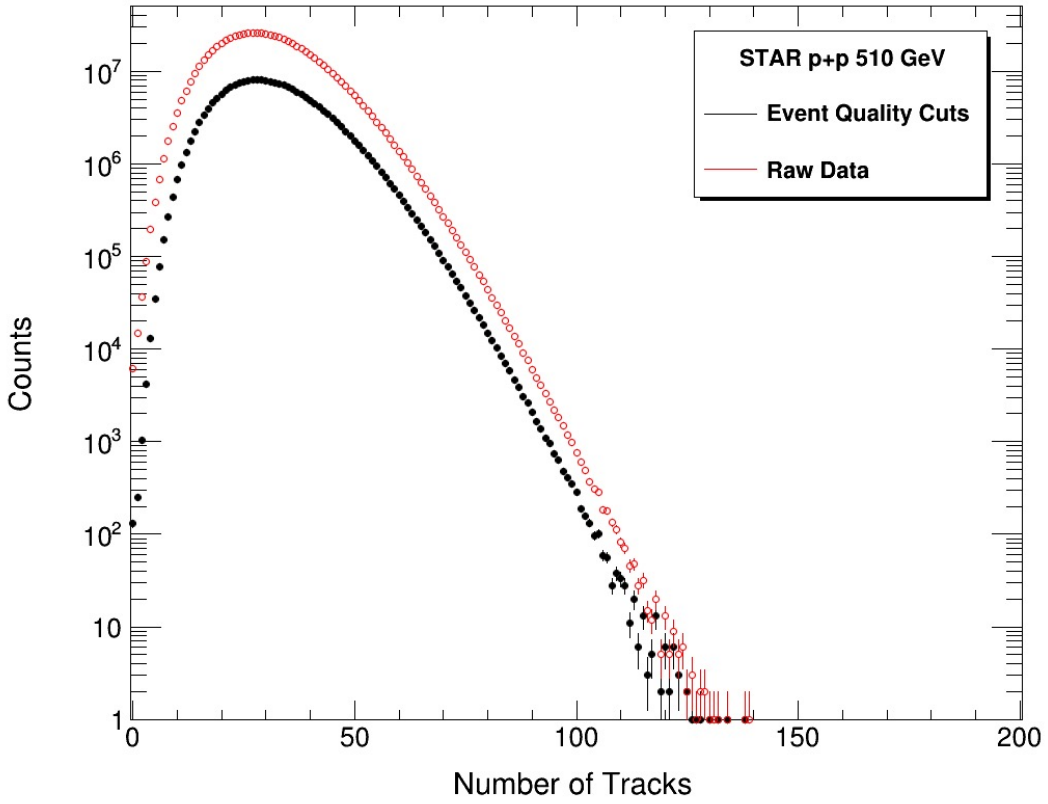
# THE STAR EXPERIMENT

- Time Projection Chamber (TPC)
  - Tracks charged particles
  - Measures momentum and energy loss
  - $|\eta| < 1$, full azimuth
- Muon Telescope Detector (MTD)
  - Identifies and triggers on muons
  - $|\eta| < 0.5$, 45% of azimuth
- Time of Flight (TOF)
  - Identifies particles
  - $|\eta| < 1$, full azimuth
- Vertex Position Detector (VPD)
  - Measures position of primary vertex along beamline
  - $4.24 \leq |\eta| \leq 5.1$



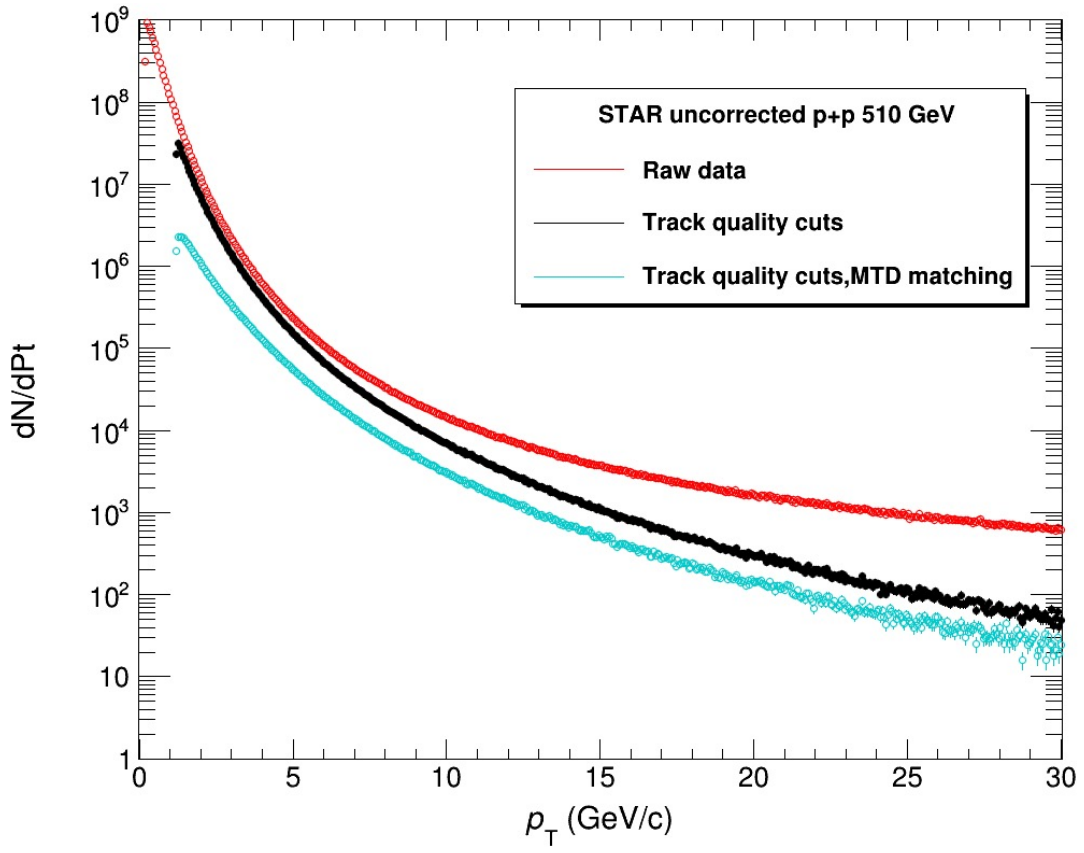
# MULTIPLICITY MEASURED WITH TPC

- Number of charged particles produced at primary vertex
- $v_x$, $v_y$, $v_z$ : Vertex position in the x, y, z direction as measured by the TPC
  - $v_r = \sqrt{v_x^2 + v_y^2}$
- Using dimuon trigger data
- Subject to event quality cuts which select primary vertices most likely to correspond to $J/\psi$ events
  - $|v_z| < 75$ cm
  - $|v_{z,dif}| < 6$ cm: difference between $v_z$ as measured by TPC and VPD, ensures event is not from pile-up



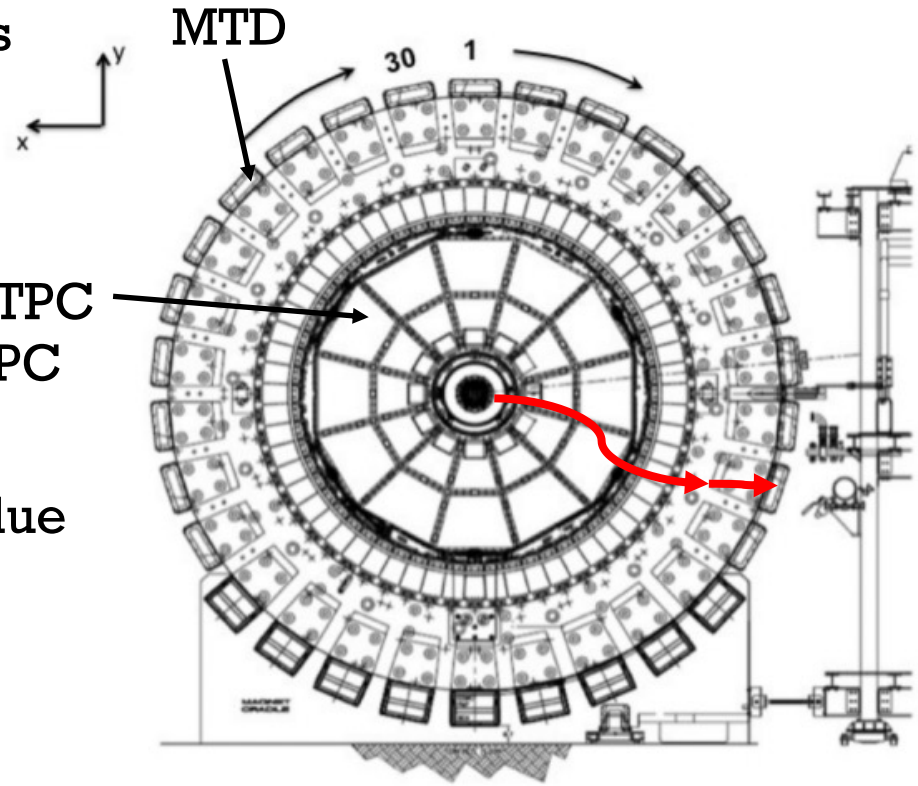
# CHARGED PARTICLE RECONSTRUCTION USING TPC

- Track quality cuts
  - Pseudorapidity ($|\eta| < 0.8$): angle of particle with respect to beam axis
  - Distance of closest approach (DCA < 3 cm): smallest distance to the primary vertex along the track trajectory
  - Number of TPC hits used in track reconstruction $\geq 20$
  - Number of TPC hits used in energy loss measurement $\geq 15$
  - Ratio of used TPC hits to possible TPC hits $\geq 0.52$
  - $p_T > 1.2$ GeV/c



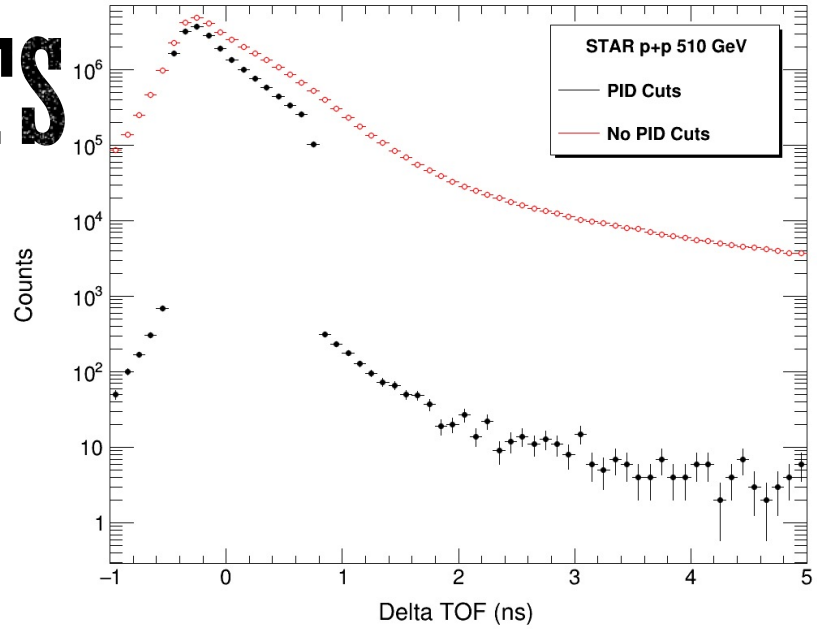
# MUON IDENTIFICATION USING MTD

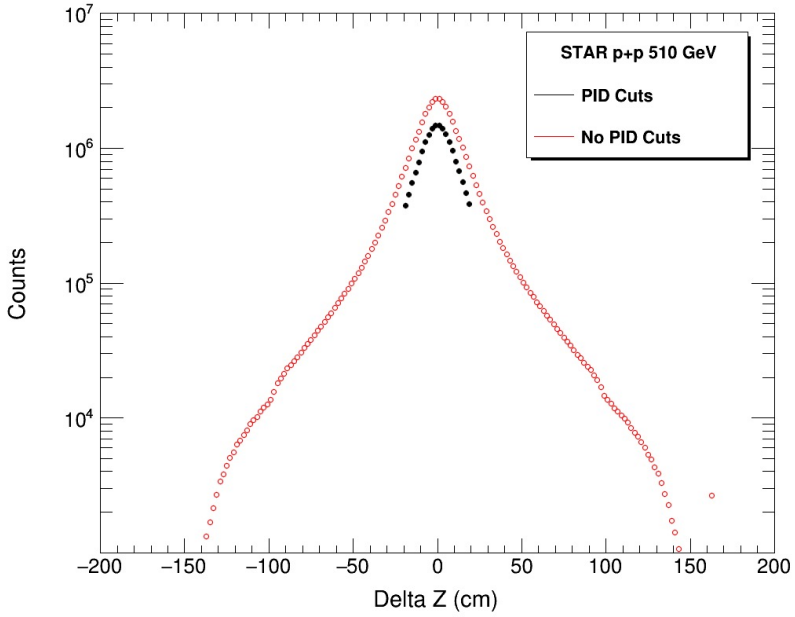
- Array of Multi-gap Resistive Plate Chambers that surrounds the TPC and triggers on muons
  - Muons provide cleaner signal and improved mass resolution due to less bremsstrahlung radiation
  - Magnet coils shield from other hadrons
  - MTD matching ensures a given track is the same in the TPC and MTD
- $\Delta TOF$: difference between expected TOF (time of flight) value and TOF value as measured by MTD
- $\Delta z$: difference between MTD hit position and extrapolated track position, along beam direction
- $\Delta y$: difference between MTD hit position and extrapolated track position, along azimuthal direction

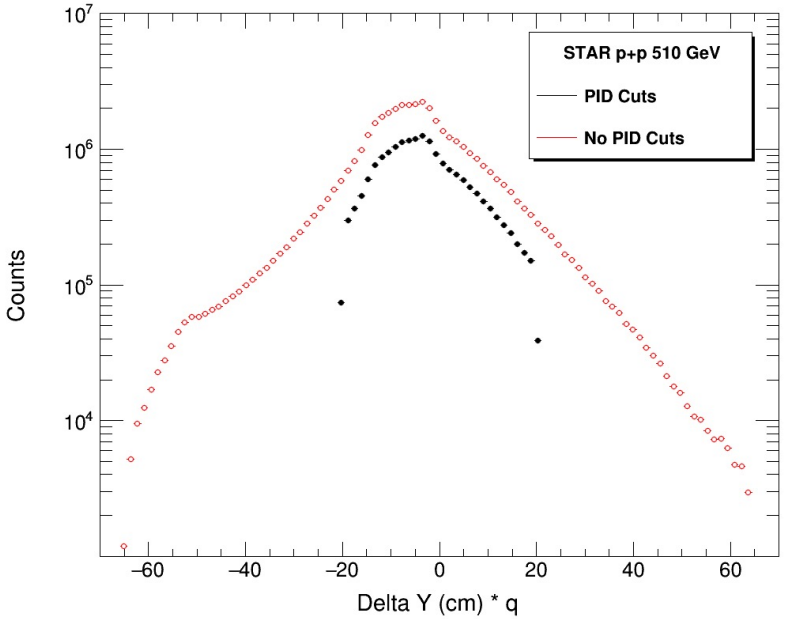


# PID DISTRIBUTIONS AND CUTS

- Particle identification (PID) cuts select muon candidates
  - -0.5 ns < $\Delta TOF$ < 0.75 ns
  - $|\Delta z| < 20$ cm
  - $|\ \Delta y * q| < 20$ cm

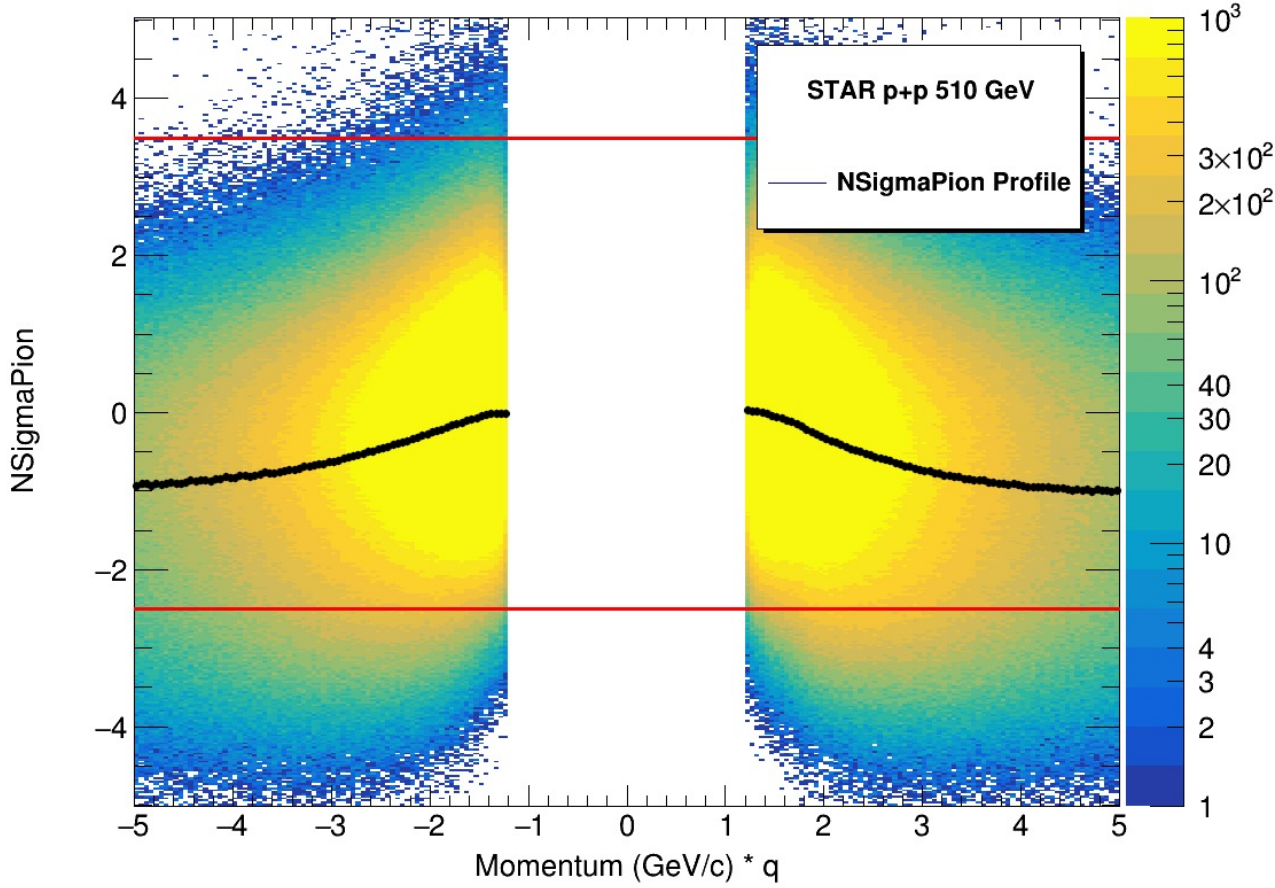


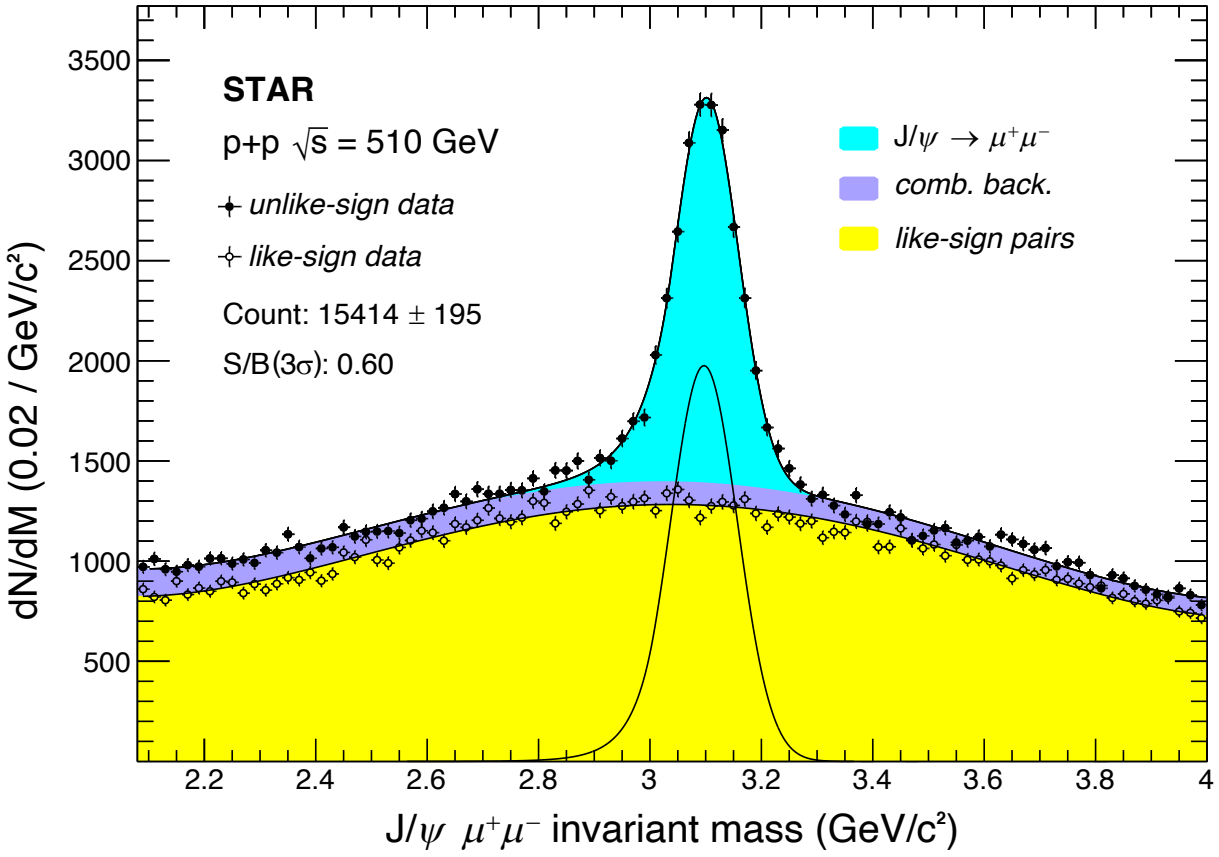
# PID WITH TPC

- $n\sigma_\pi$ : difference between measured and theoretical energy loss assuming pion mass, normalized to energy loss resolution of TPC
  - Pion and muon have similar mass, so this can be used for muon identification
  - Use TPC to determine p,q
  - Use ionization energy loss to select muon candidates
- Event quality cuts, track quality cuts, MTD matching criteria applied
  - Red lines indicate cuts applied to $n\sigma_\pi$
- Ideally centered at zero
  - Can select on $p_T$ to compensate for this



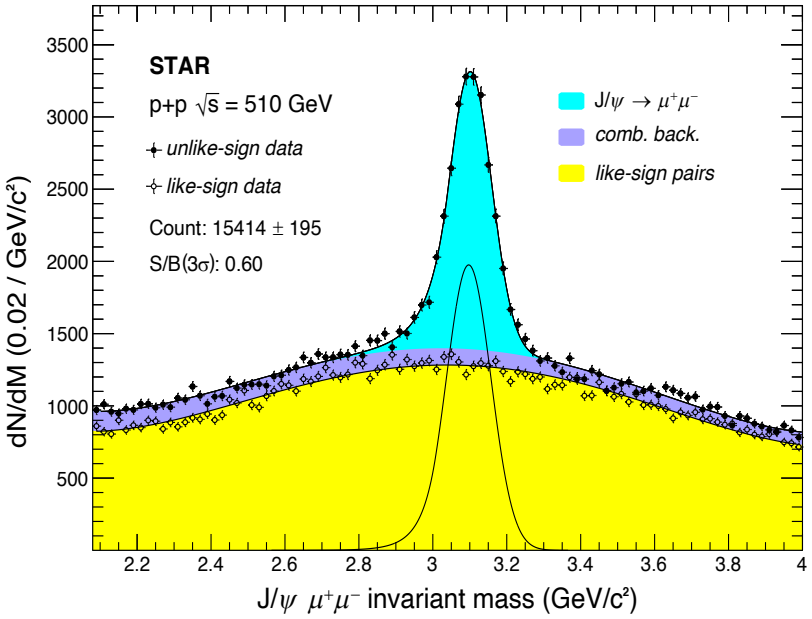
# INVARIANT MASS

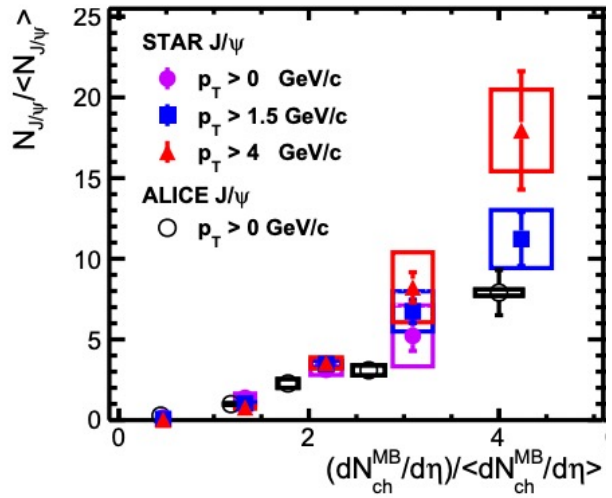
- Reproduced previous analysis
- J/$\psi$ yield determined through fitting, after background subtraction
  - Signal obtained by subtracting like-sign pairs (background) from unlike-sign pairs
  - Signal is fit with Crystal Ball function for J/$\psi$, plus a 4$^{th}$ order polynomial for residual background
  - Yield is the area of signal distribution with all the background subtracted
- Residual background contains other processes such as Drell-Yan



# SUMMARY

- A study of $p + p$ collisions at higher energy can help measure J/psi production at higher multiplicity
- The Muon Telescope Detector (MTD) at STAR allows us to study the dimuon channel of J/$\psi$ decay in $p + p$ collisions.
- Quantities measured using the TPC and MTD enable identification of muon candidates.
- The next step is to obtain the invariant J/$\psi$ yield as a function of multiplicity and as a function of transverse momentum.

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# BACKUP

# $\frac{1}{\beta}$ CURVES WITH TOF

- Time of Flight ($|\eta| < 1$, full azimuth)
  - Measures stop/start time of flight from collision vertex to detector
- $\beta = \frac{v}{c}$ where v is velocity and c is the speed of light
  - Determined by TOF using path length and time of flight
- Event quality cuts, track quality cuts, MTD matching criteria, and PID cuts including a cut on $n\sigma_\pi$ applied
  - TOF selection cuts in progress
- $\frac{1}{\beta}$ curves indicate expected values for different particle species