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Study of J/ψ production with jet activity in *p+p* collisions at √*s* = 200 GeV with the STAR experiment

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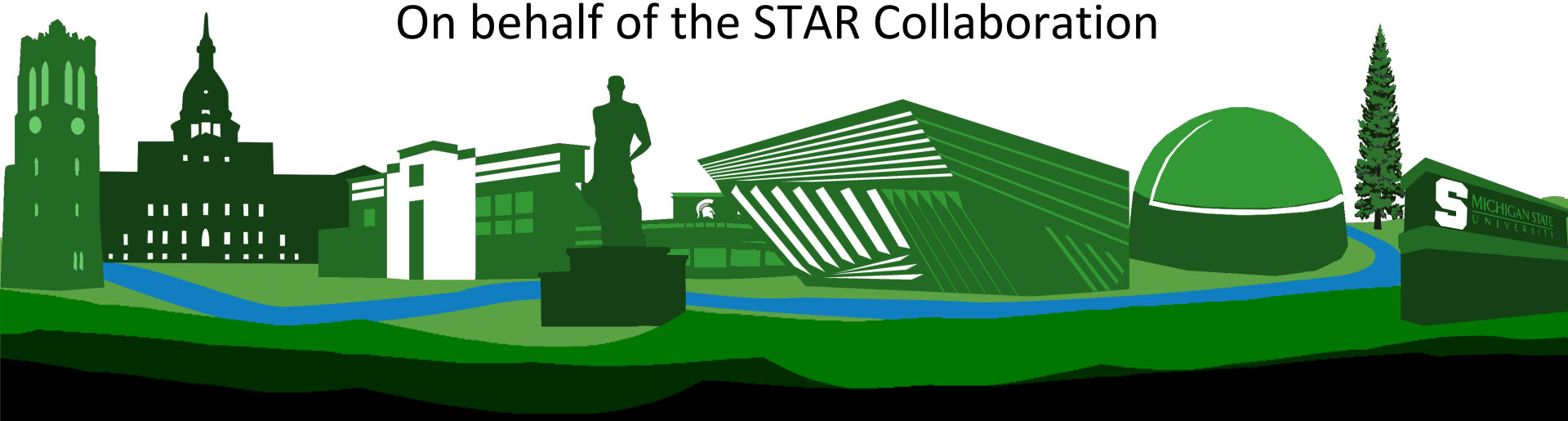
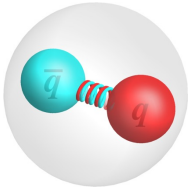
On behalf of the STAR Collaboration



Introduction



- Production of heavy quarkonium (**J/ψ** or **ϒ**) involves two processes:
  - **Hard process (short distance):** the production of $q\bar{q}$ pair and it can be calculated by pQCD
  - **Soft process (long distance):** the formation of quarkonium from $q\bar{q}$ and it can be parameterized by phenomenological models

➔ Studies of quarkonium properties (production, polarization, …) provide valuable insights to QCD

- Models on the market:
  - **Color Singlet Model (CSM)**
  - **Non-Relativistic QCD (CSM + Color Octet Mechanism)**
  - **Color Glass Condensate effective theory (CGC) + NRQCD**
  - **Color Evaporation Model (CEM)/Improved CEM**

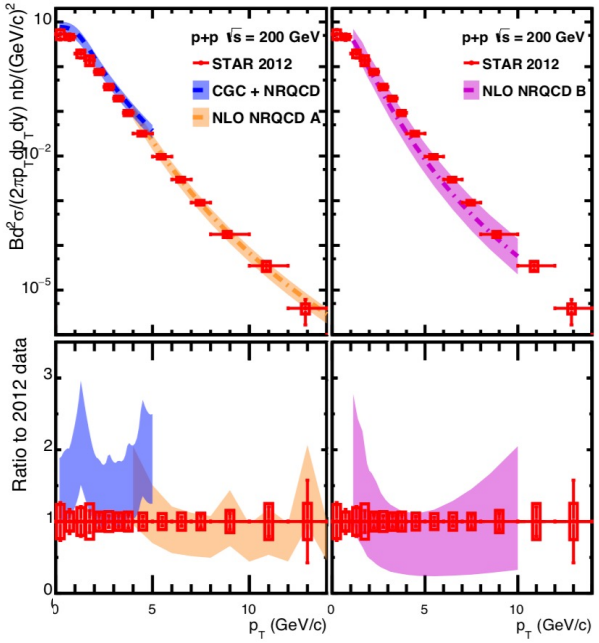
The quantum numbers (spin, color) of the final and initial states are the same

The quantum numbers of the initial and final quark pairs can be different

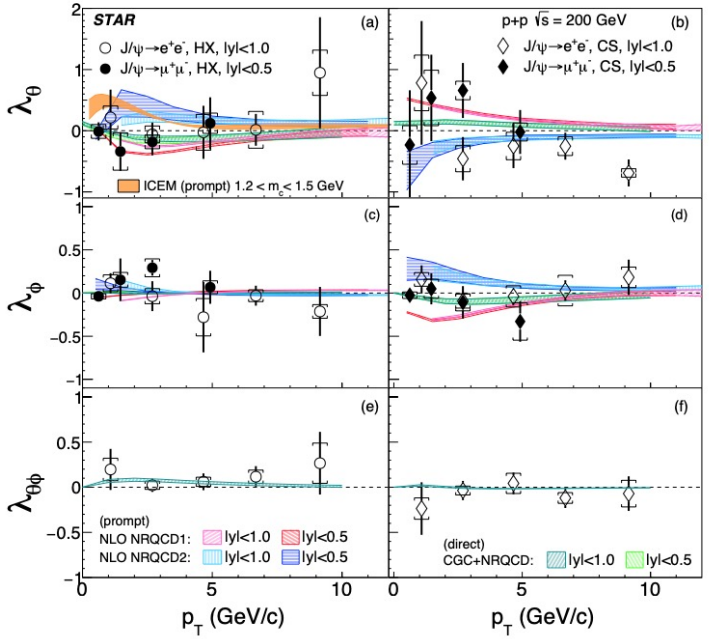
Motivation

- To fully understand the quarkonium production mechanism requires understanding of all variables (not only cross section and polarization)
- It is suggested that quarkonium production from the CSM should result in a larger jet activity (number of jets per event) than that from the COM (Physics Reports, 889, 1 (2020))

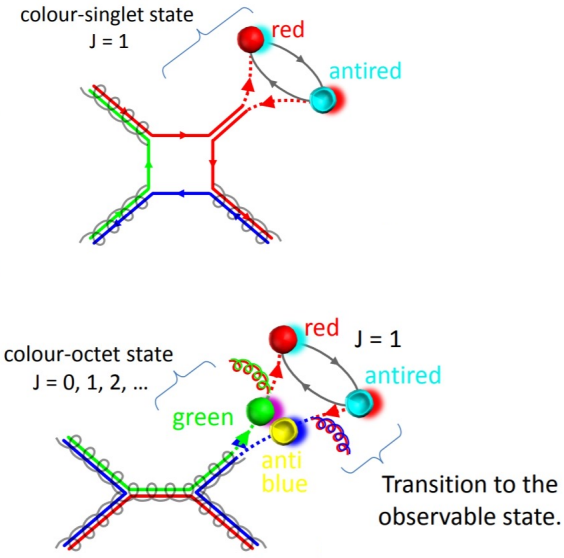
➔ An alternative variable to distinguish different models



STAR 2012: PLB 786 (2018) 87-93
NLO+NRQCD A: PRD 84 (2011) 114001
NLO+NRQCD B: PRL 108 (2012) 172002



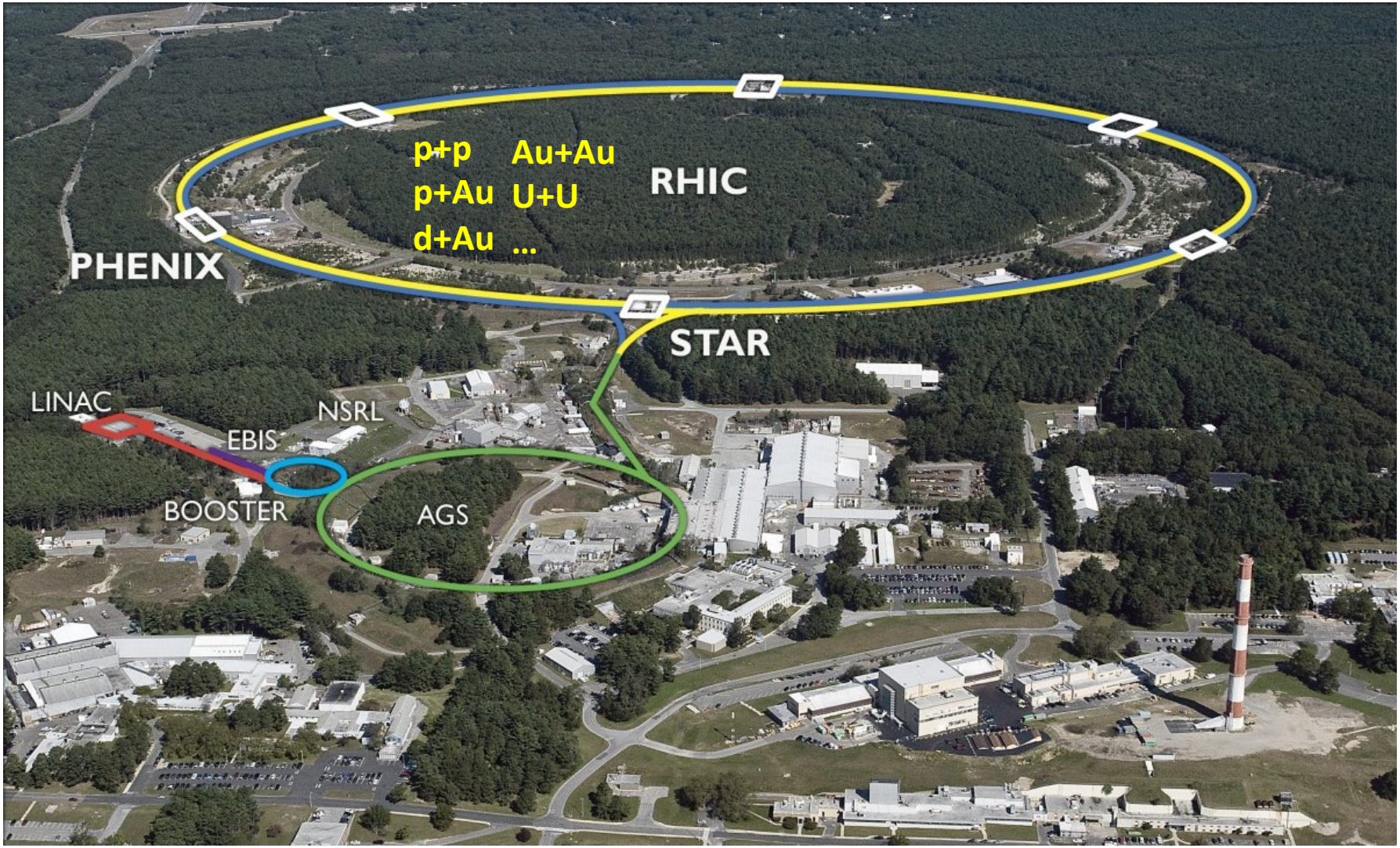
STAR: Phys. Rev. D 102, 092009 (2020)
NLO NRQCD 1:Phys. Rev. Lett. 114 (2015) 092006
NLO NRQCD 2: Phys. Rev. Lett. 110 (2013) 042002



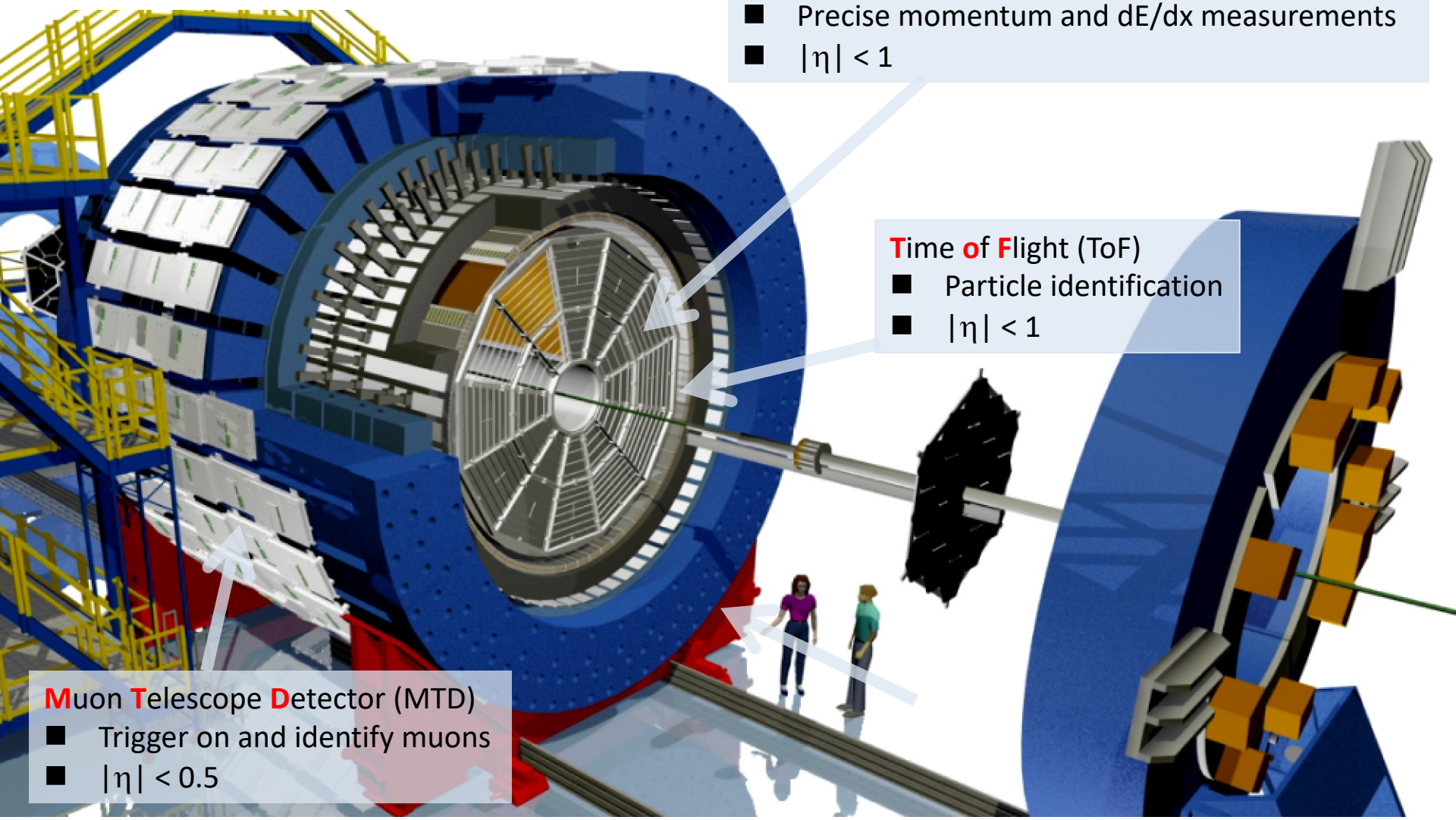
From Cristina Biino's Talk (FPCP2013)

Relativistic Heavy-Ion Collider (RHIC)

- **The most versatile collider in the world!**



The STAR detector



Analysis procedure

- Observable: J/ψ production cross section vs. jet activity
- Data set: *p*+*p* collisions at √s = 200 GeV recorded in 2015

1 **Extract raw $N_{J/\psi}$ vs. raw jet activity**

→

2 **Correct $N_{J/\psi}$**
Use candidate-by-candidate weighting method to correct for efficiencies & acceptances
➔ Corrected $N_{J/\psi}$ vs. raw jet activity

↓

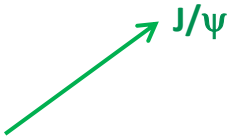
3 **Correct N_{jet}**
Use PYTHIA to construct response matrices and RooUnfold package to obtain true N_{jet}
➔ **Corrected $N_{J/\psi}$ vs. true jet activity**

←

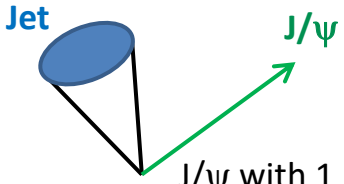
4 **Estimate uncertainties**
Signal extraction, unfolding, etc.
➔ **Final results**

Find J/ψ signal and jets

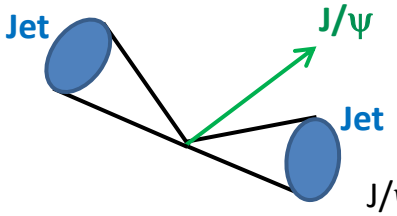
- J/ψ mesons are reconstructed via dimuon decay channel
- Charged jets are reconstructed using anti-k_T algorithm
  - J/ψ and their daughter muons are not included in jet finding
  - Only accept jets with $p_T > 3$ GeV/c
- Two jet radii are considered: R = 0.4 and R = 0.6



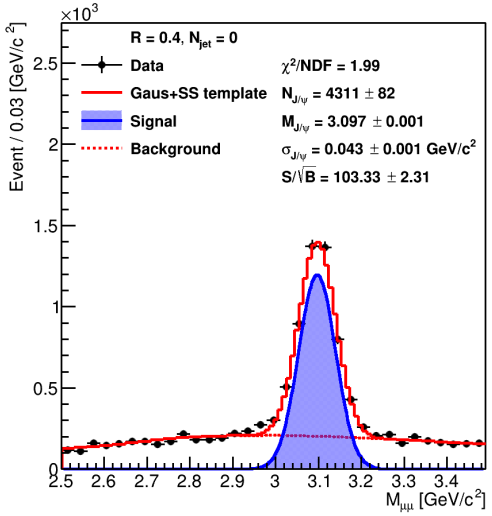
J/ψ with 0 jet

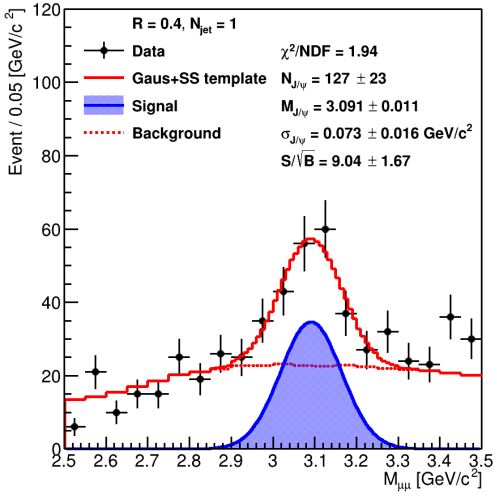


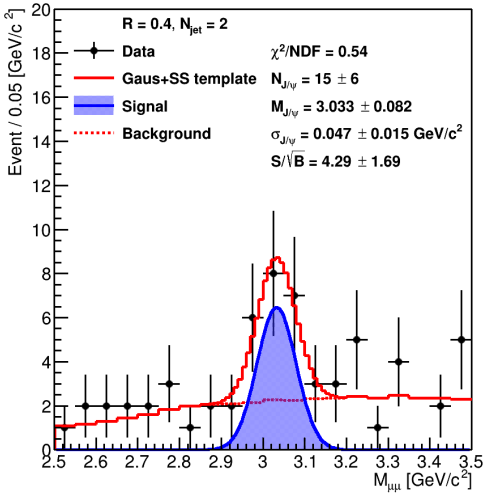
J/ψ with 1 jet



J/ψ with 2 jets

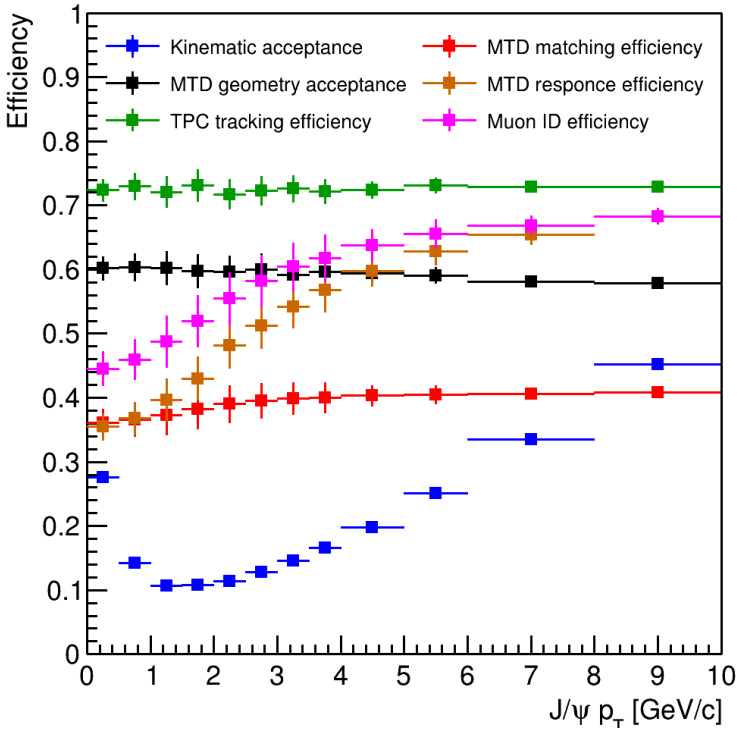


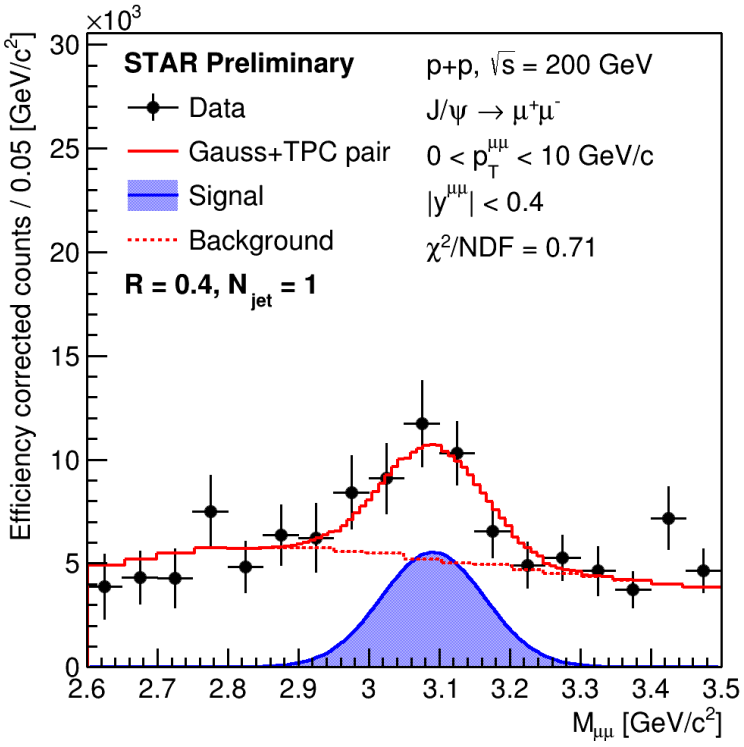




Correction for the number of J/ψ

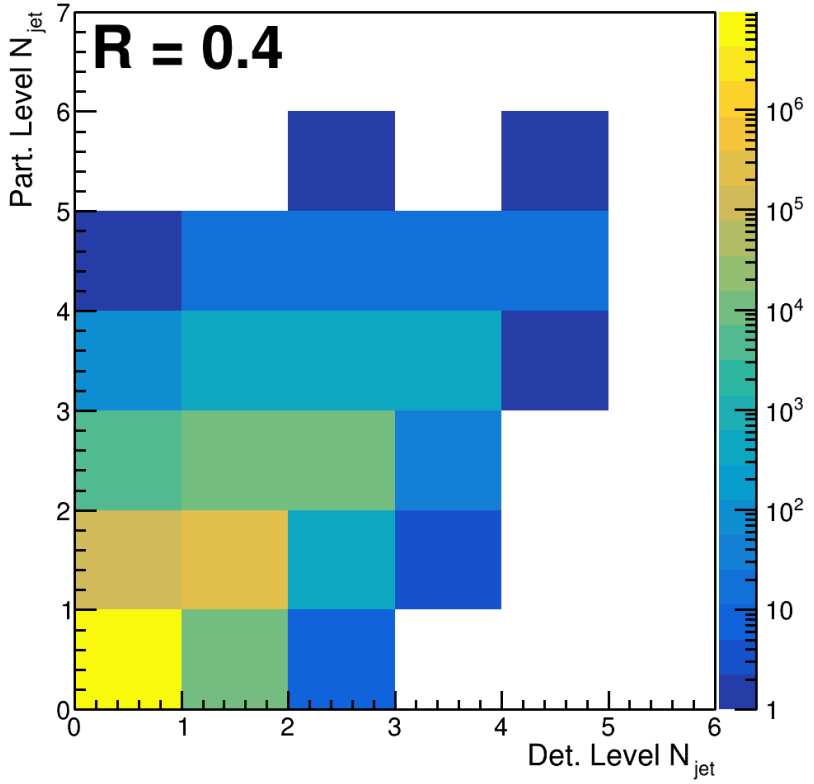
- Candidate-by-candidate weighting method:
  - $N_{J/\psi}^{corrected} = \sum_{1}^{N_{J/\psi}} w_i$, where $w_i = (\varepsilon_{reco} \times A)^{-1}$
  - ε_{reco}: total reconstruction efficiency
  - A: total acceptance (kinematic and MTD geometry)

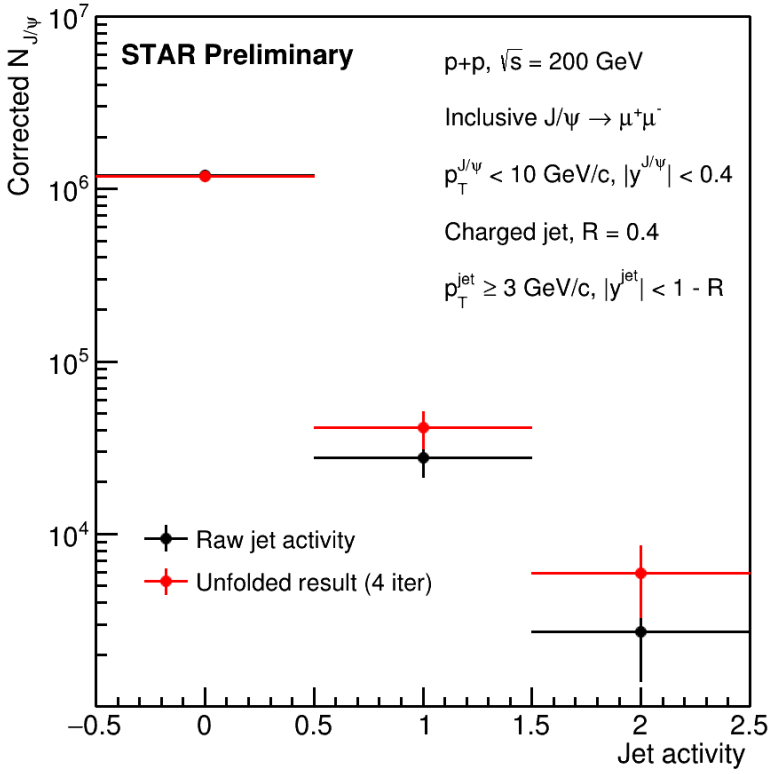




Correction for the jet activity

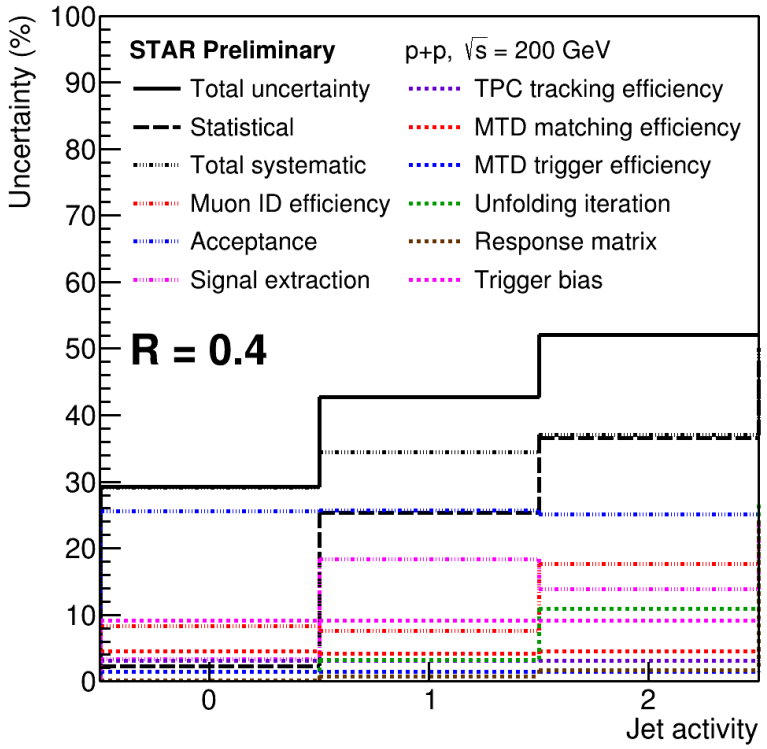
- Unfolding with RooUnfoldBayes algorithm in RooUnfold package
- Response matrices are built using PYTHIA8 events with detector effects





J/ψ cross section and uncertainties

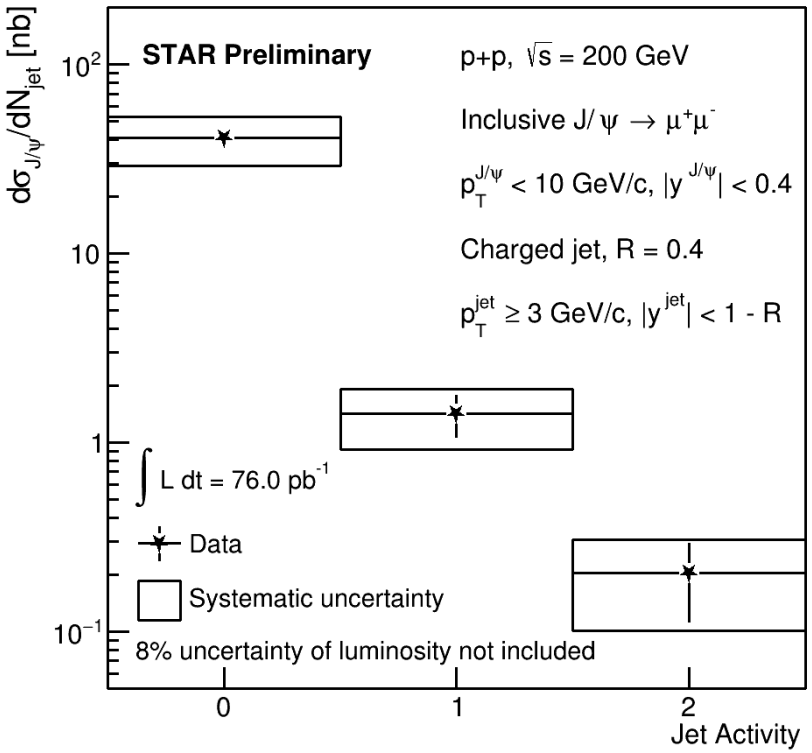
- The J/ψ production cross section as a function of jet activity:
  - $Br(J/\psi \to \mu^+\mu^-) \times \frac{d\sigma}{dN_{jet}} = \frac{1}{\Delta N_{jet}} \times \frac{N^{corrected}_{J/\psi \to \mu^+\mu^-}}{\int L\, dt}$
  - ΔN_{jet} denotes the bin width of each N_{jet} bin, which equals to 1
- Various uncertainties are included
  - **Statistical uncertainty**
  - **Systematic uncertainties**
    - Signal extraction
    - Efficiencies
    - Acceptance
    - Unfolding procedure
    - Response matrix



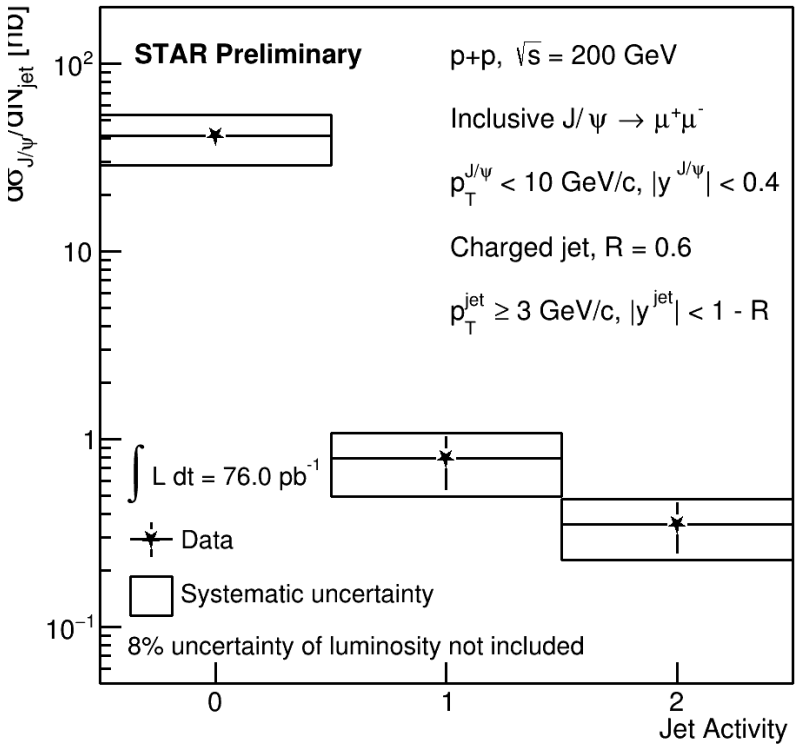
Results

- First results of J/ψ production cross section as a function of jet activity in p+p collisions at $\sqrt{s}$ = 200 GeV
- J/ψ p_T < 10 GeV/c and charged jet $p_T \geq 3$ GeV/c

R = 0.4



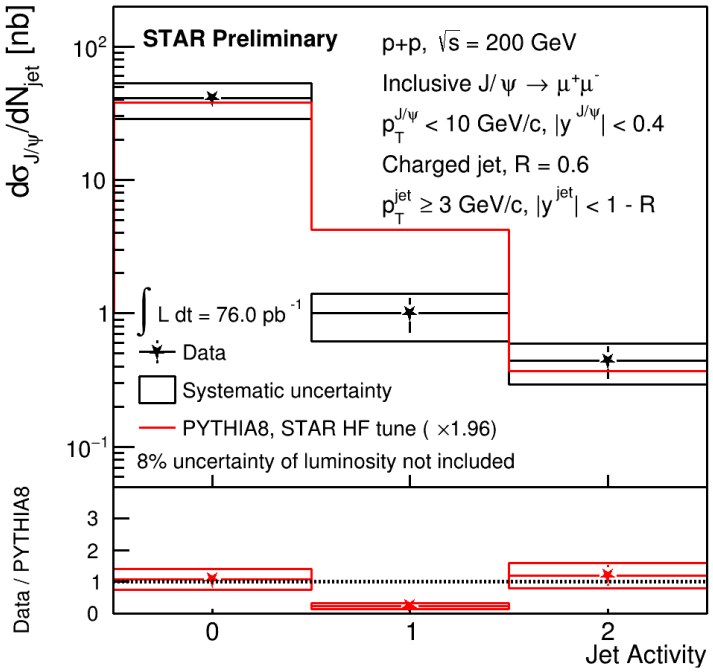
R = 0.6



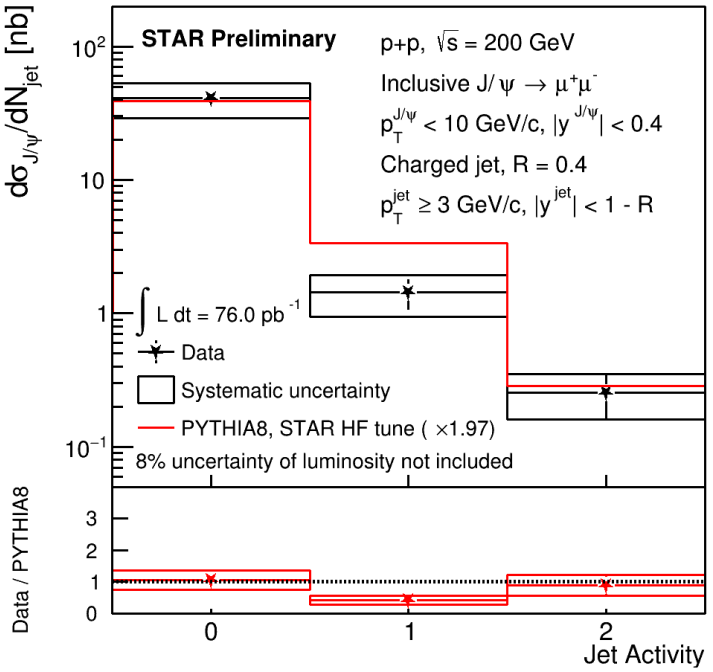
Comparison to PYTHIA

- PYTHIA8 predictions are scaled for shape comparison:
  - PYTHIA8 underestimates the cross section by about a factor of 2
  - The result for R = 0.4 jet has a small discrepancy in shape (p-value = 0.18)
  - The result for R = 0.6 jet shows an inconsistency in shape (p-value = 0.01)
  - Larger fraction of J/ψ are produced associated with jets than in data

R = 0.4



R = 0.6

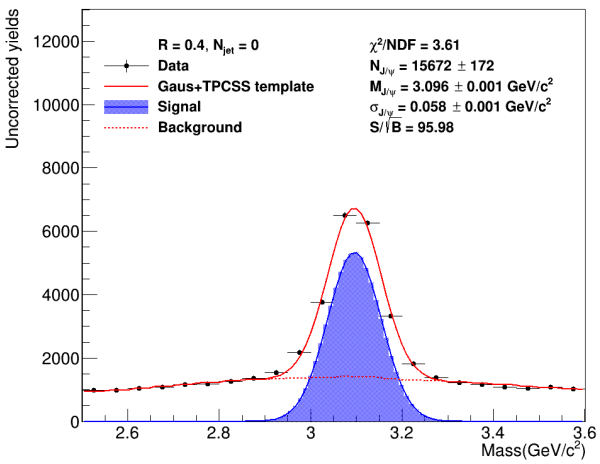


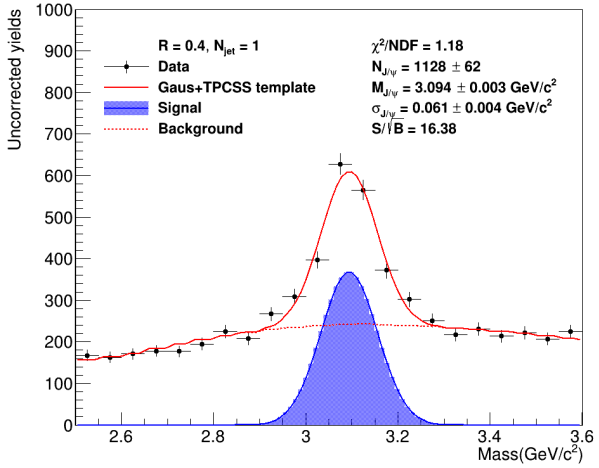
Summary

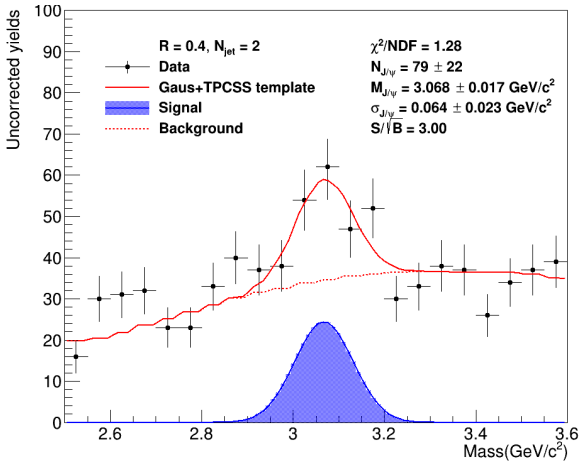
- First results of J/ψ production cross section as a function of jet activity in p+p collisions at $\sqrt{s}$ = 200 GeV
  - Detector effects are corrected, and systematic uncertainties are estimated
- Differences between data and the PYTHIA8 predictions:
  - Inconsistency in shape (p-value = 0.01) with jet R = 0.6
  - Larger fraction of J/ψ are produced associated with jets in PYTHIA8 than data
- A new observable to constrain different models and provide additional insights to the quarkonium production mechanism
- Theorical calculations are welcome

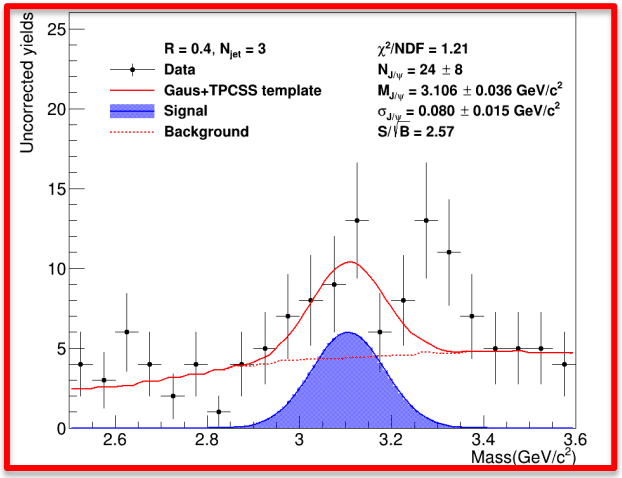
Outlook

- A more precise measurement with an extra jet activity bin can be performed with more than **4 times larger** statistics in *p*+*p* collisions at √s = 500 GeV collected by STAR in 2017

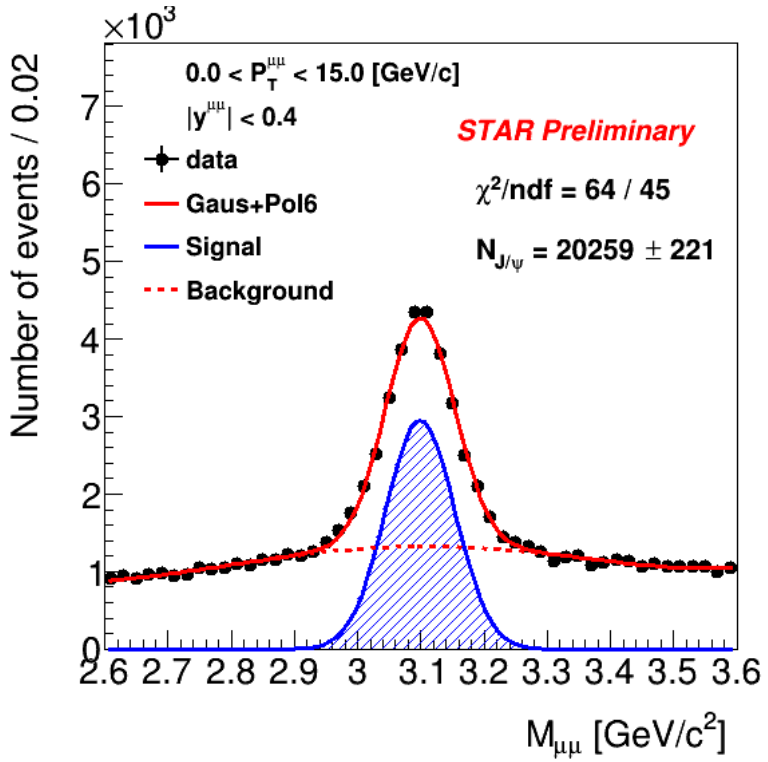








Backup


×10^3
0.0 < P_T^μμ < 15.0 [GeV/c]
|y^μμ| < 0.4
STAR Preliminary
data
Gaus+Pol6
Signal
Background
χ²/ndf = 64 / 45
N_J/ψ = 20259 ± 221
Number of events / 0.02
M_μμ [GeV/c²]