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J/ψ production in jets in p+p collisions at √s = 500 GeV by STAR

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- Motivation of studying J/ψ production
- STAR experiment
- J/ψ fragmentation function in jet at RHIC energy
- Summary

J/ψ production

- J/ψ is a multiscale system that can probe both perturbative and non-perturbative regimes of quantum chromodynamics (QCD)

Production of the $c\bar{c}$ (large momentum transfer) → Evolution of the $c\bar{c}$ pair into J/ψ (small dynamical scale)

pQCD process **non-pQCD process**

- Due to large mass of charm quark, J/ψ is a non-relativistic QCD system ($v^2 << 1$)— one of the simplest systems in QCD

- Easy to measure in experiment: large decay branch ratio to dilepton and larger production cross section compared to bottomonium

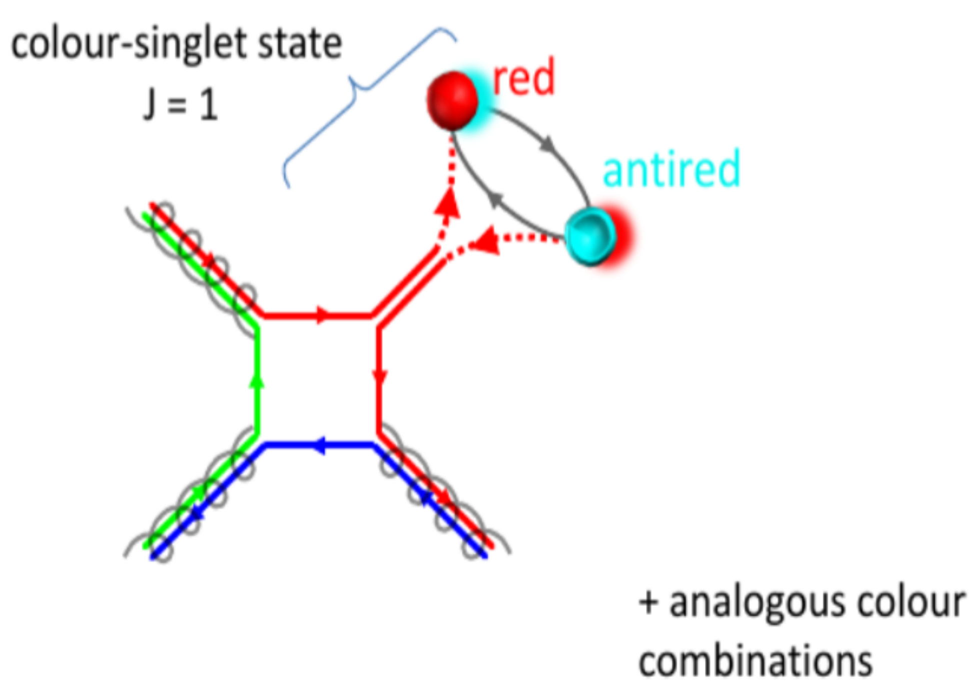
J/ψ: An ideal test ground of QCD!!

J/ψ production models

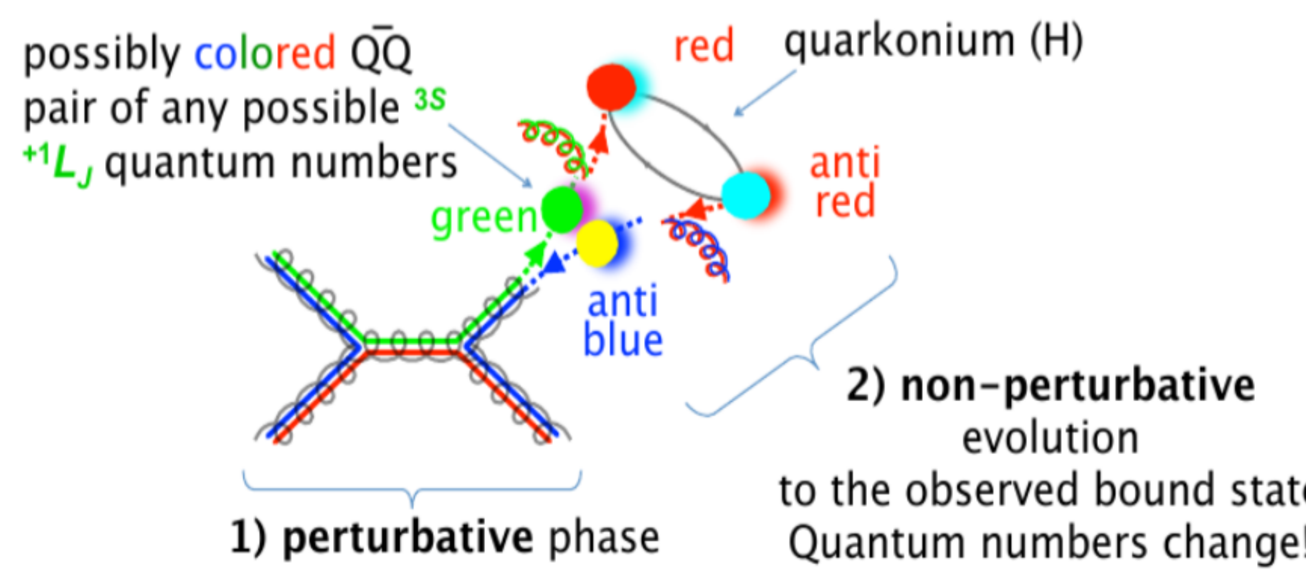
Models differ in $c\bar{c}$ production and the treatment of hadronization:

- Color Singlet Model: color singlet $c\bar{c}$ + its evolution to J/ψ
- NRQCD approach: color singlet/octet $c\bar{c}$ + its evolution to J/ψ (Long distance matrix elements)
- Improved Color Evaporation Model et. al

Color-singlet



Color-octet

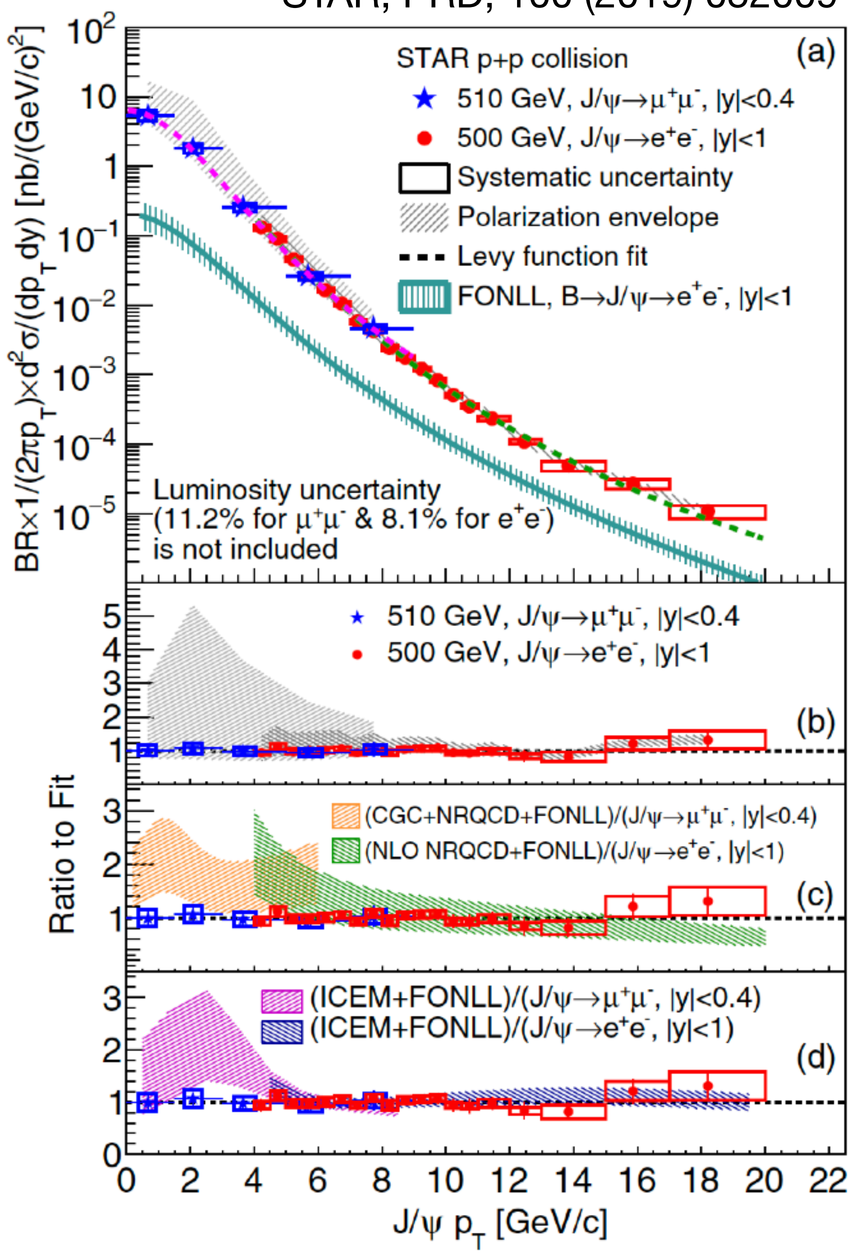


[P. Faccioli, Polarization in LHC physics, Course on Physics at the LHC 2014]

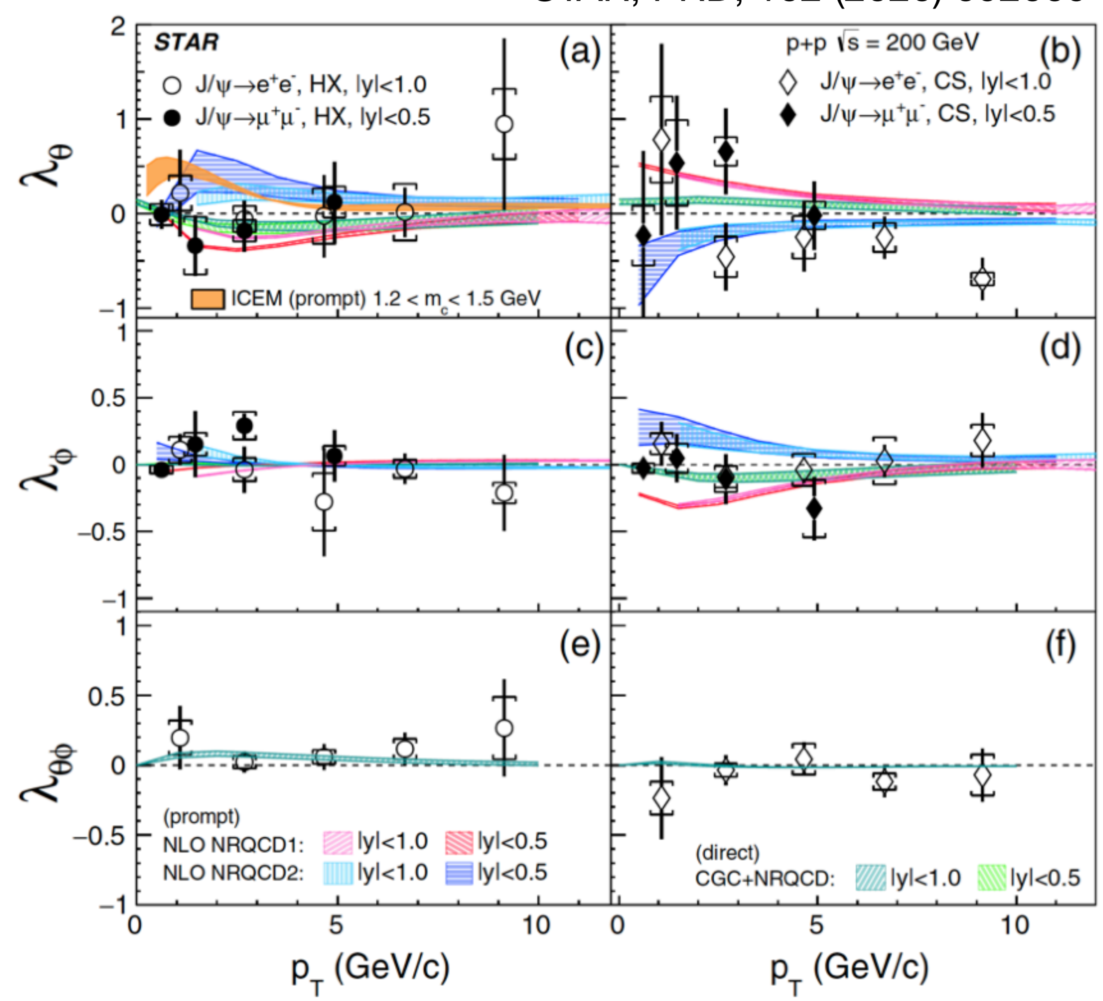
J/ψ production at RHIC

J/ψ cross-section and polarization are two important observables to understand the J/ψ production mechanism

STAR, PRD, 100 (2019) 052009

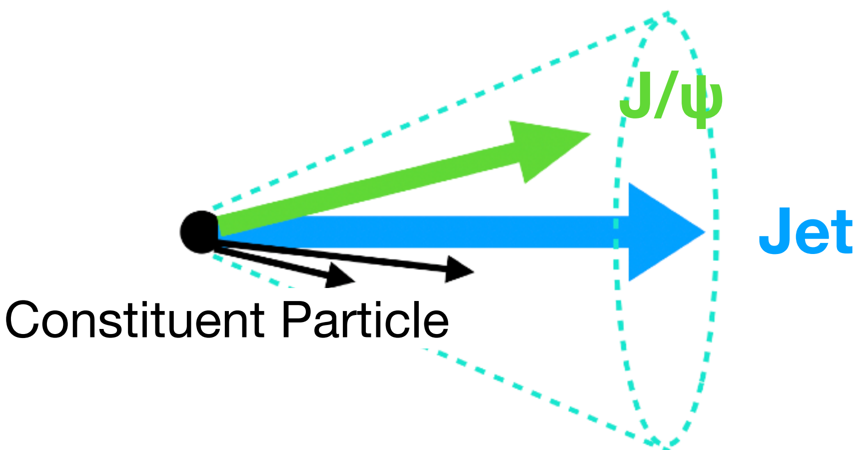


STAR, PRD, 102 (2020) 092009



- More statistics or other variables to discriminate between different models are needed

Fragmentation function

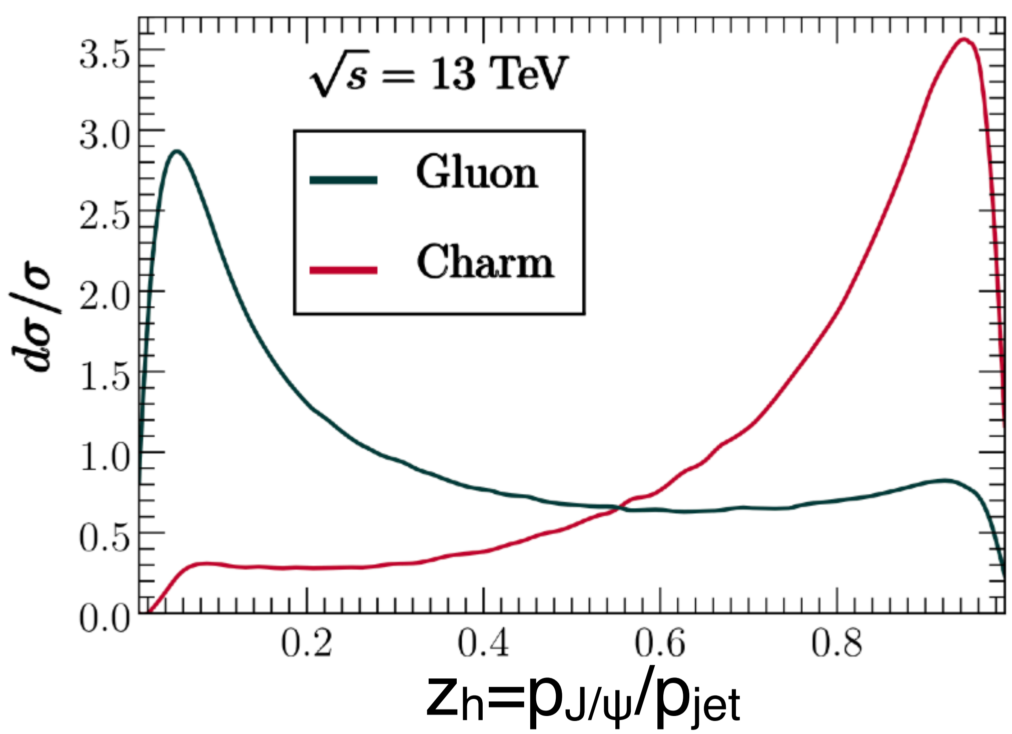


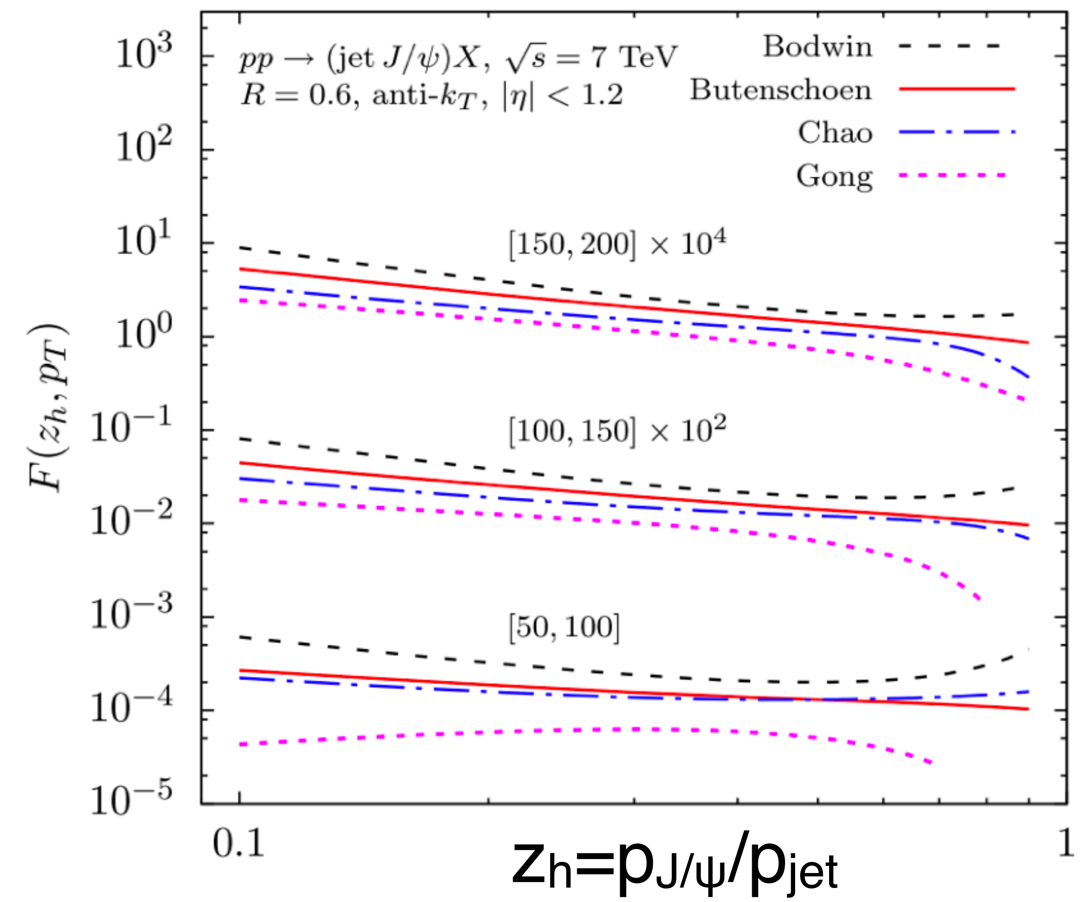
J/ψ NRQCD LDMEs from four different groups

	$\langle\mathcal{O}(^3S_1^{[1]})\rangle$ GeV^3	$\langle\mathcal{O}(^1S_0^{[8]})\rangle$ 10^{-2} GeV^3	$\langle\mathcal{O}(^3S_1^{[8]})\rangle$ 10^{-2} GeV^3	$\langle\mathcal{O}(^3P_0^{[8]})\rangle$ 10^{-2} GeV^5
Bodwin	0[a]	9.9	1.1	1.1
Butenschoen	1.32	3.04	0.16	−0.91
Chao	1.16	8.9	0.30	1.26
Gong	1.16	9.7	−0.46	−2.14

Zhong-Bo Kang et .al, PRL, 119 (2017) 032001

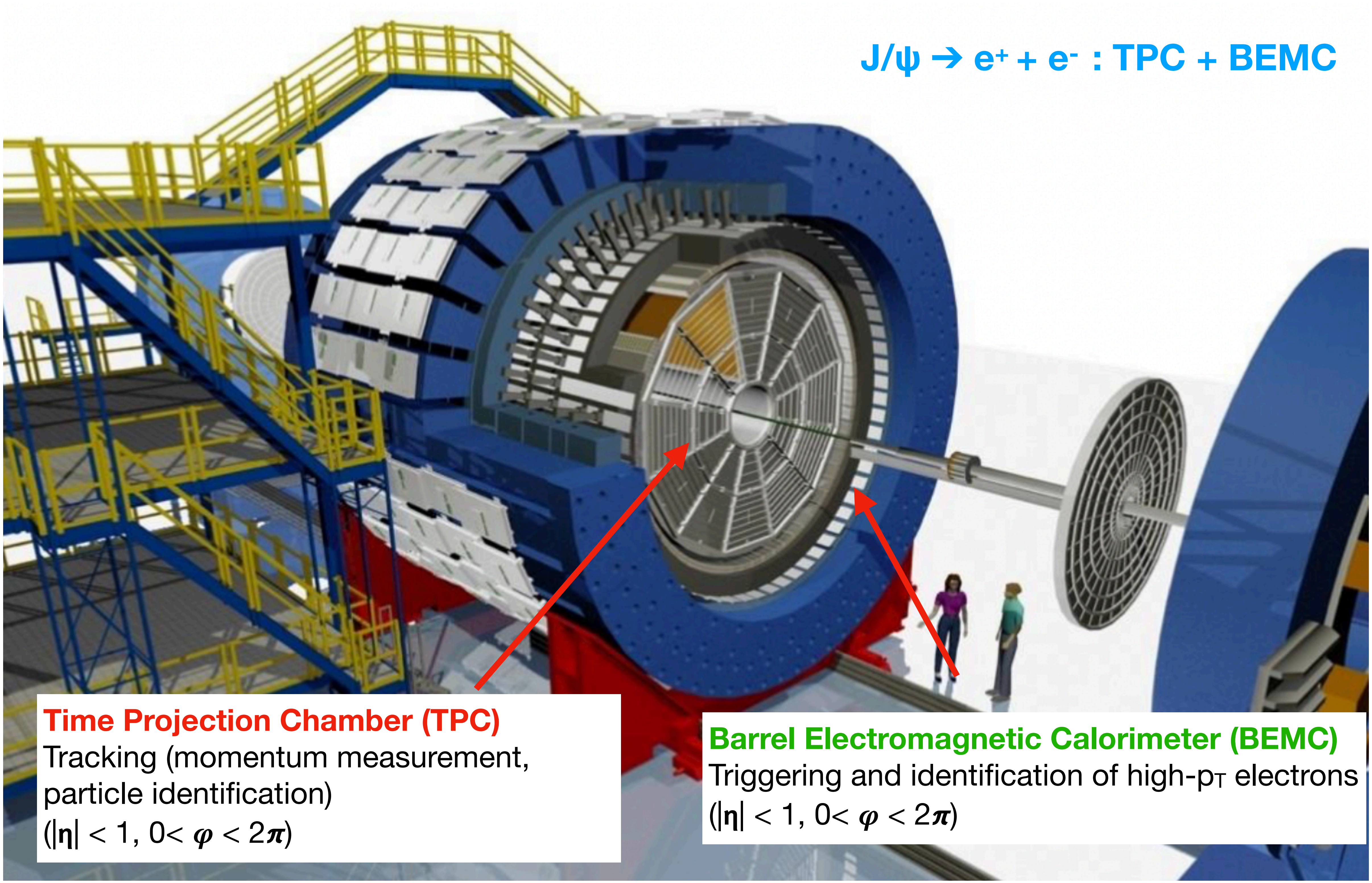
Reggie Bain et .al, PRL, 119 (2017) 032002





- Different fragmentation pattern for different production mechanism

The Solenoidal Tracker at RHIC

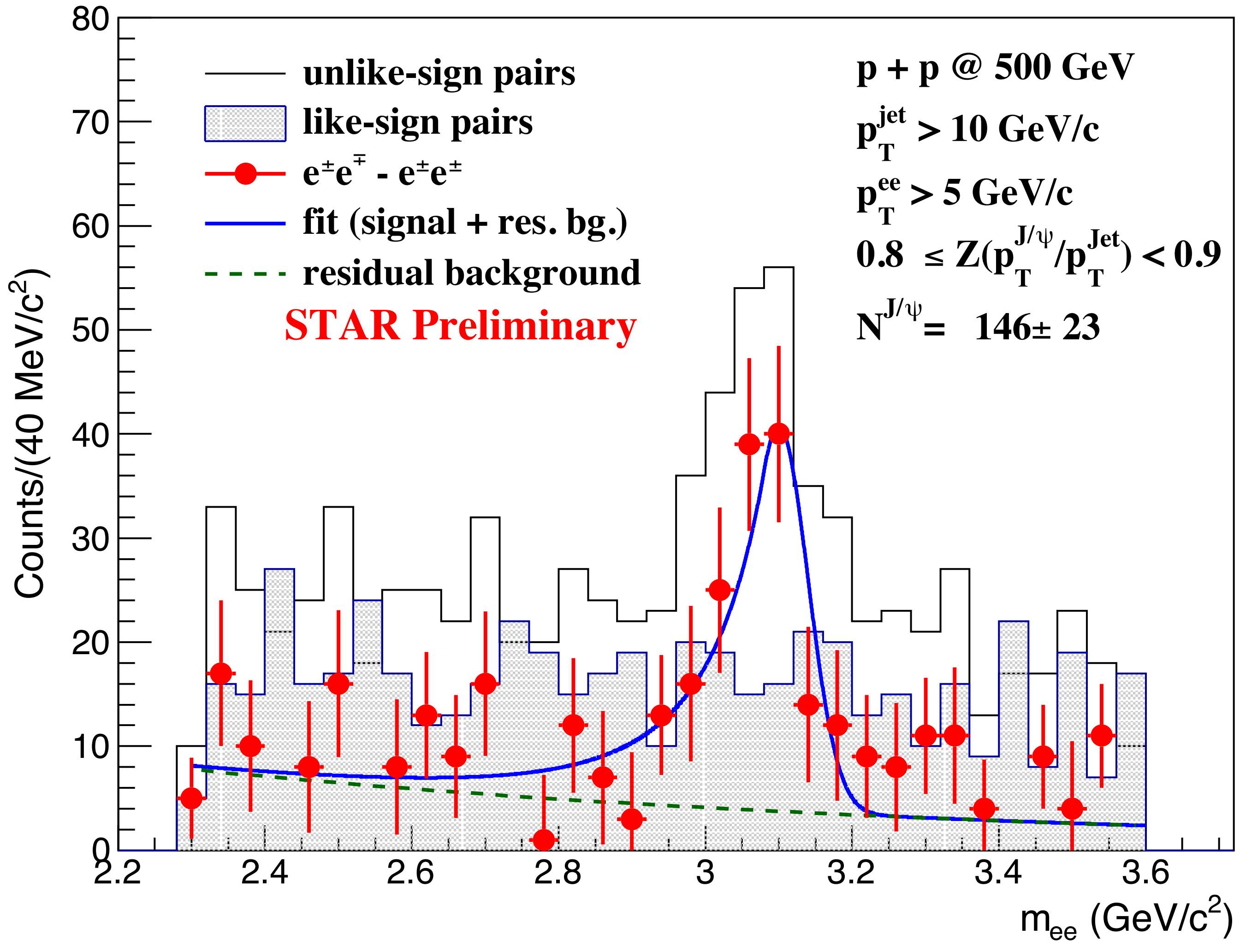


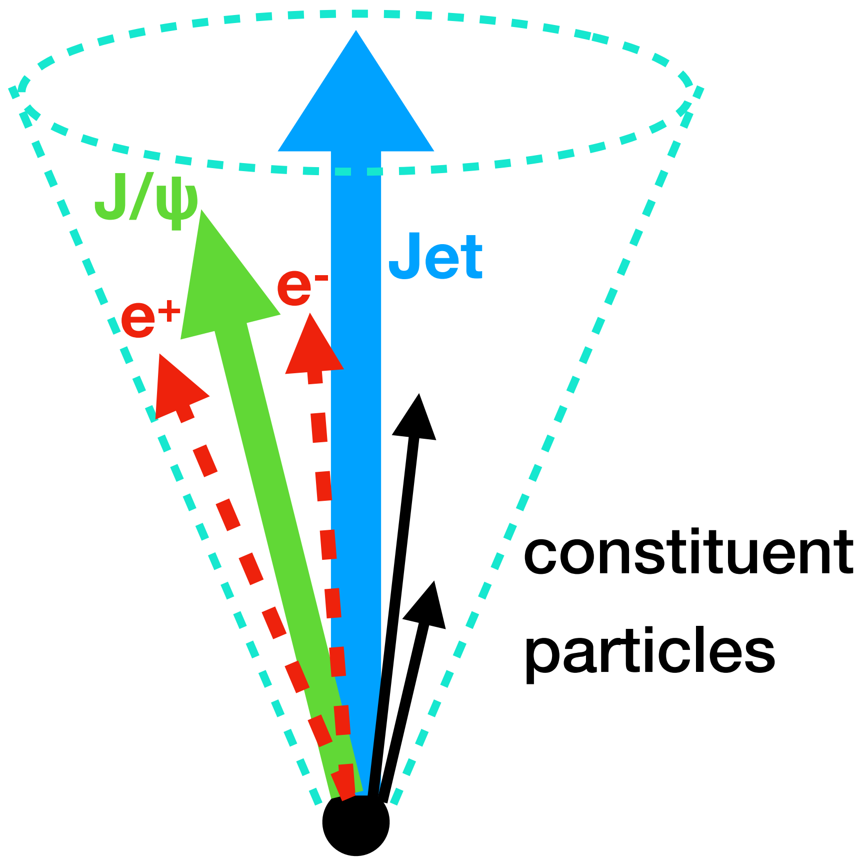
$J/\psi \rightarrow e^{+} + e^{-}$: TPC + BEMC

Time Projection Chamber (TPC)
Tracking (momentum measurement, particle identification)
($|\eta| < 1$, $0 < \varphi < 2\pi$)

Barrel Electromagnetic Calorimeter (BEMC)
Triggering and identification of high-p_T electrons
($|\eta| < 1$, $0 < \varphi < 2\pi$)

J/ψ and jet reconstruction

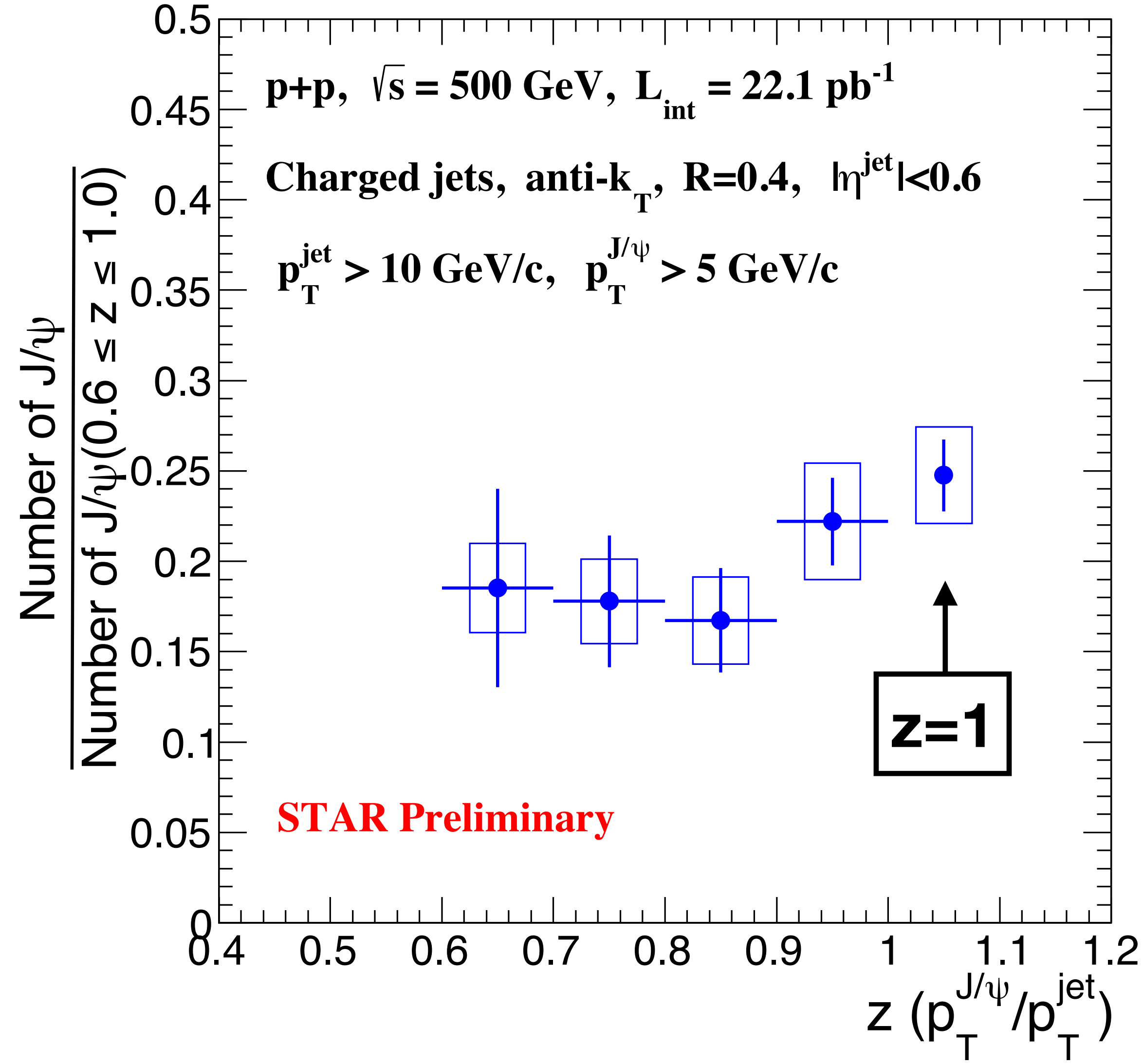




- Anti-k_T, R =0.4
- Jet: Charged particles + J/ψ candidates

- Combinatorial background: Like-sign electron pairs
- Residual background(Drell-Yan, $c\bar{c}$ and $b\bar{b}$): Exponential function
- Signal: Crystal-Ball function

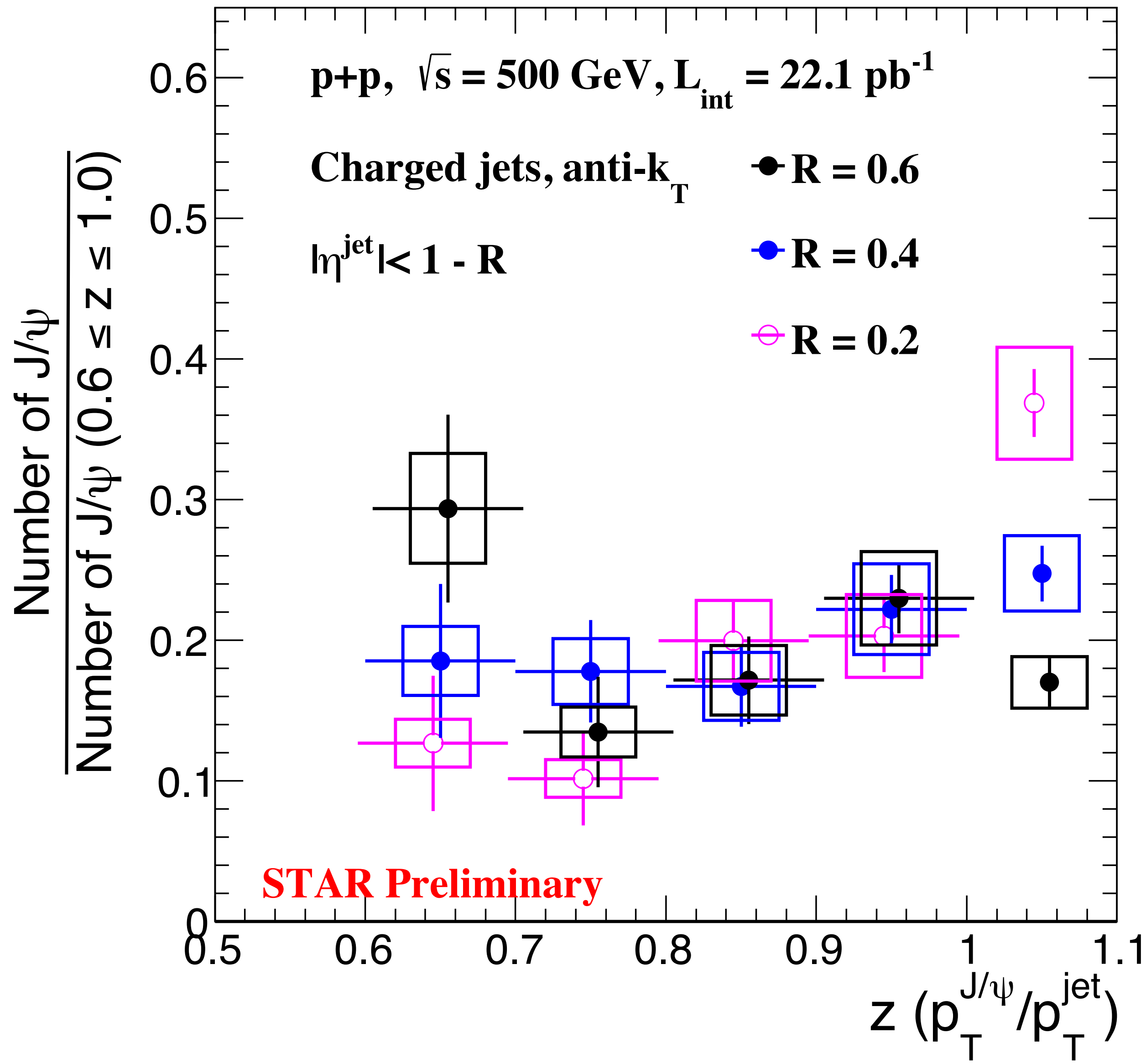
J/ψ in jets



- z is the fraction of the jet transverse momentum carried by the J/ψ meson
- z=1 data point (bin-width=0) is moved to 1.05 for visualization

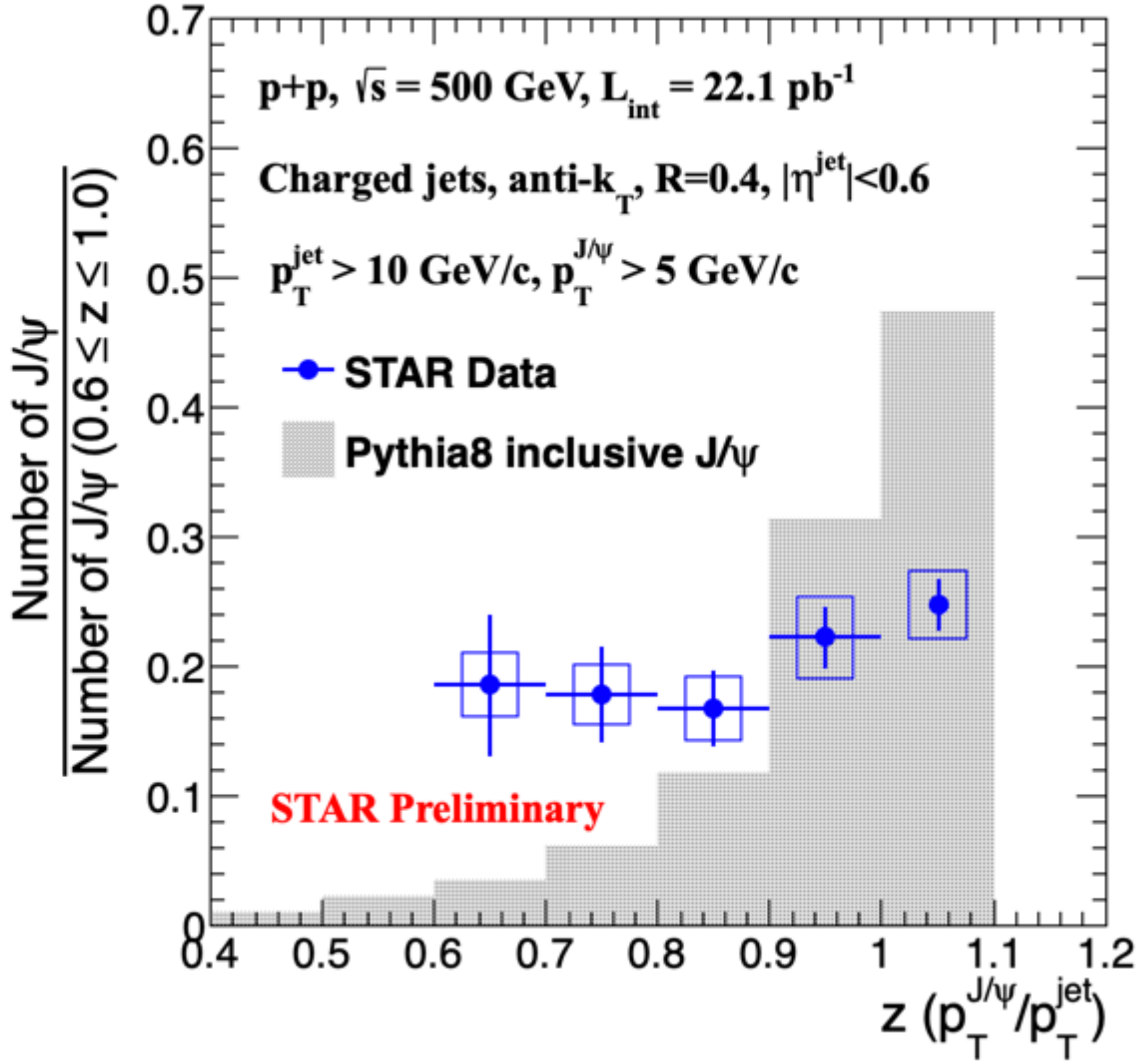
- First measurement of J/ψ production in jets at RHIC
- Detector effects are accounted for via unfolding
- Charged jet to J/ψ fragmentation function :
  - No significant z dependence observed within uncertainties

Cone size dependence



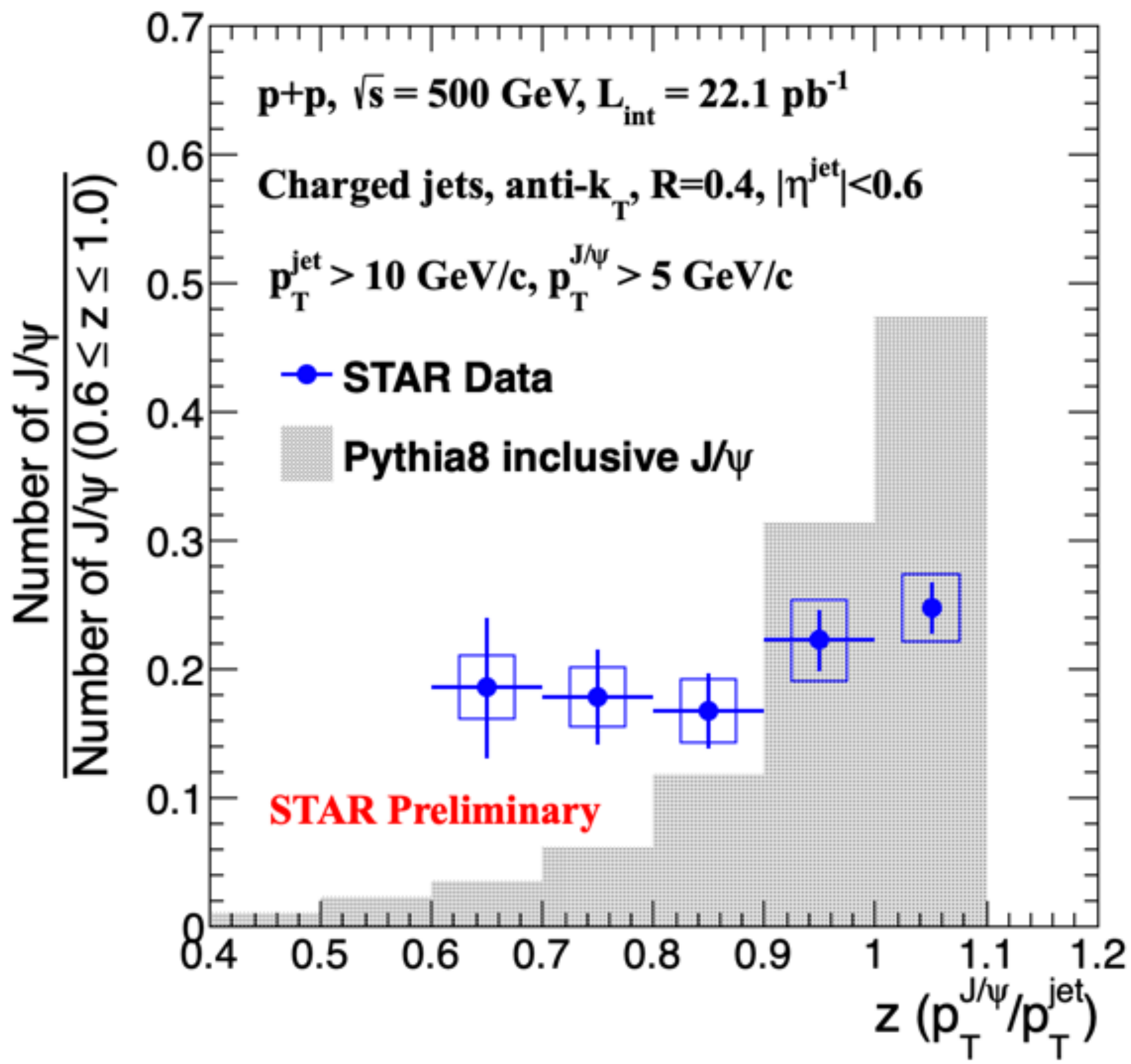
- More data is needed to study the R dependence
- Analysis of high statistics data sample from 2017 (L_{int} = 336.4 pb^{-1}) is ongoing
    ➜More precise measurement

Fragmentation: data vs Pythia8

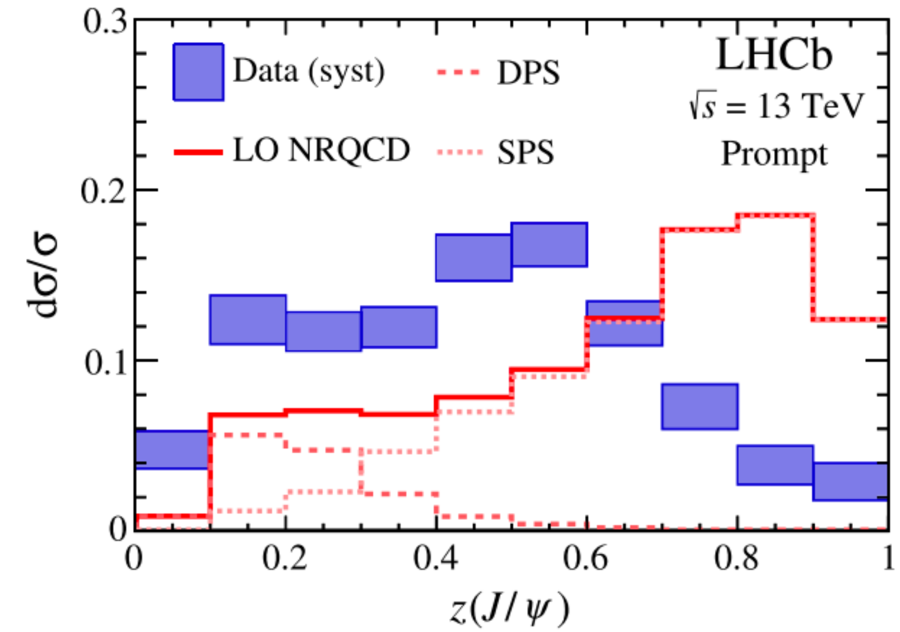


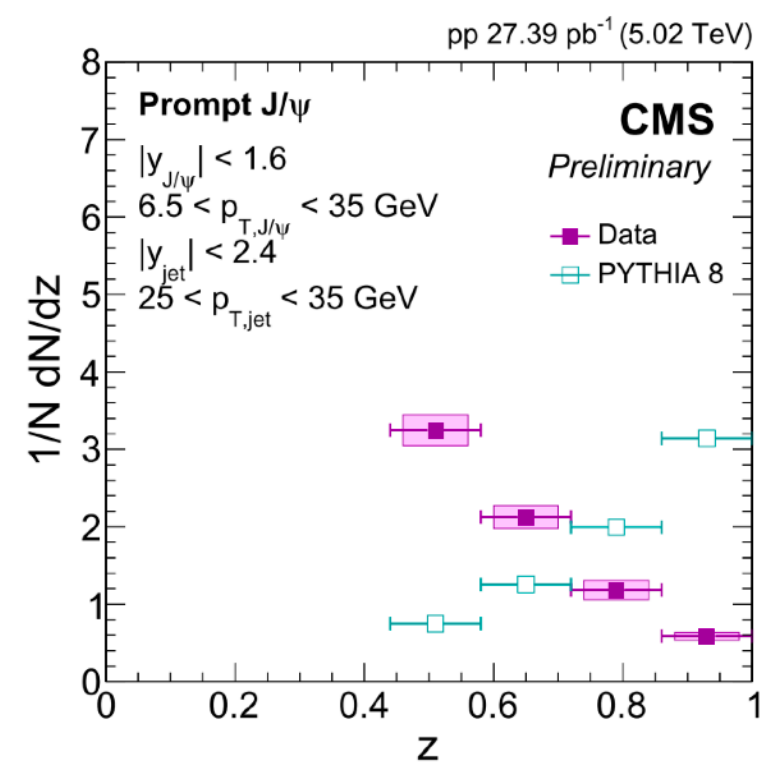
- Different trends, and J/ψ production is less isolated in data than in Pythia8
- May help to understand J/ψ polarization: Lin Dai et .al, PRD, 96 (2017) 036020
  - Production: parton showers vs parton-parton scattering ?

Fragmentation: RHIC vs LHC



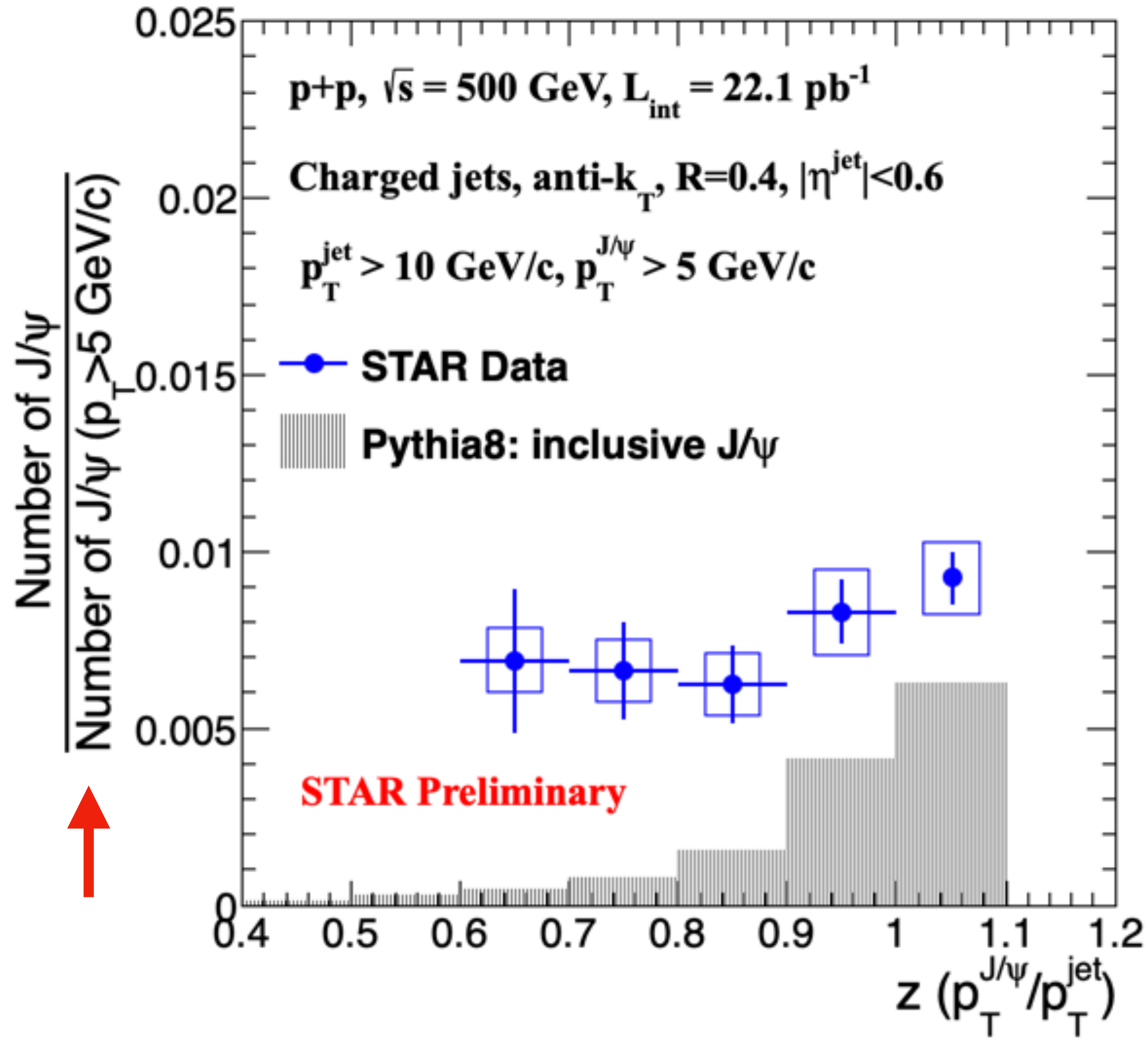
LHCb, PRL 118 (2017) 192001





- Both show less isolated production
- Difference in jet measurements
  - Charged jet at RHIC vs. full jet at LHC
  - Different kinematic range

Fraction of J/ψ produced in jets



STAR, Phys.ReV.D 100(2019) 052009 for $p_T > 5$ GeV/c J/ψ cross section

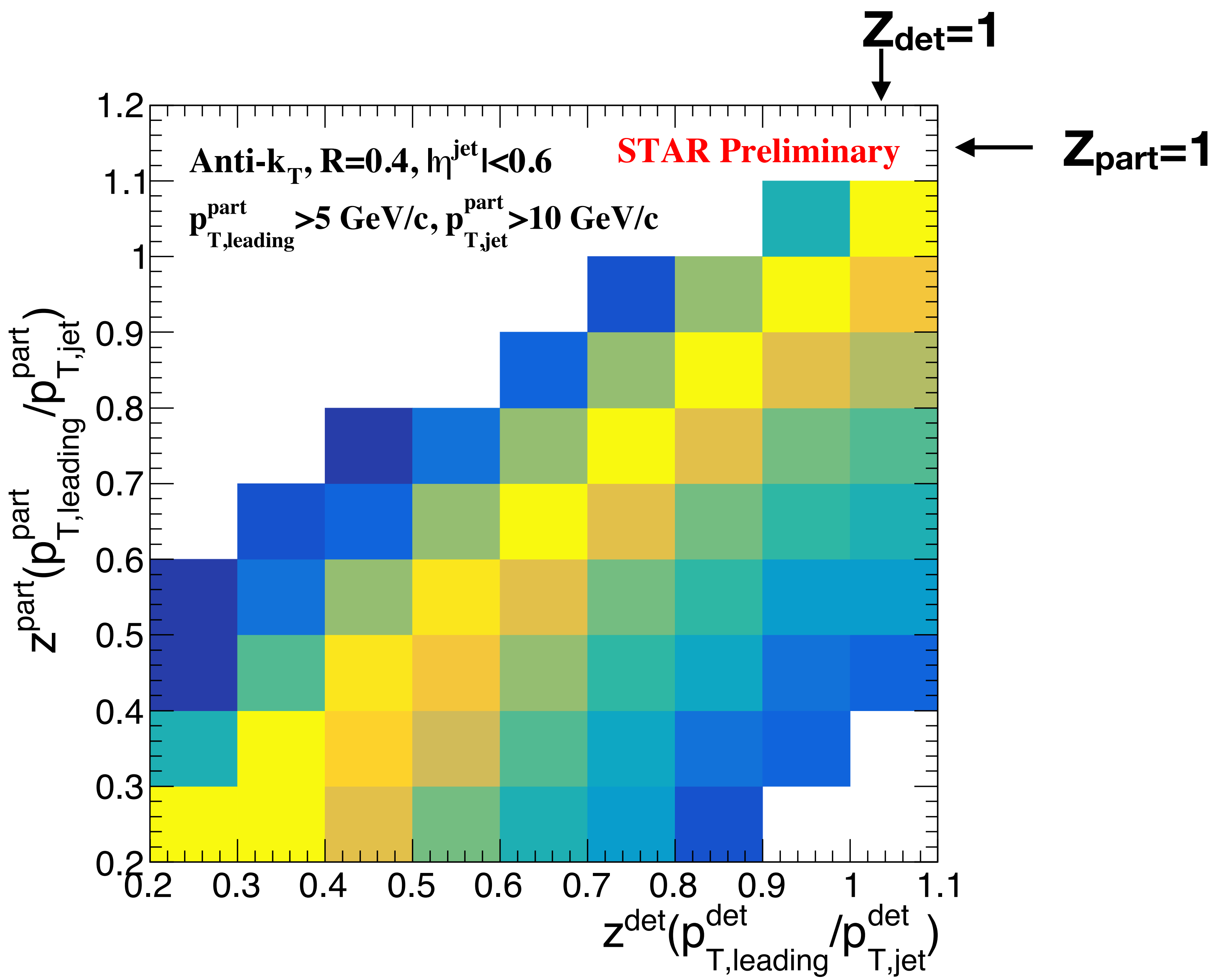
- The fraction of a $p_T > 5$ GeV/c J/ψ produced in a $p_T > 10$ GeV/c jet is 3.7% ± 0.3% (stat.) ± 0.2%(sys.)
- The probability of producing a J/ψ in charged jet is significantly higher in data than in Pythia8 for the measured kinematics

Summary

- First measurement of J/ψ production in jets at RHIC
- No significant z dependence (z<1) of jet to J/ψ fragmentation function is observed for a $p_T > 5$ GeV/c J/ψ produced in a $p_T > 10$ GeV/c jet
- Compared to Pythia8
  - Less isolated production in data
  - More J/ψ produced in jets in data
- Similar observations of less isolated J/ψ production in jets compared to Pythia8 at both RHIC and LHC, despite of different jet measurement methods (charged jet vs. full jet) and different kinematic ranges
- More data are needed for the jet cone size dependence study
- Theory inputs are very welcome

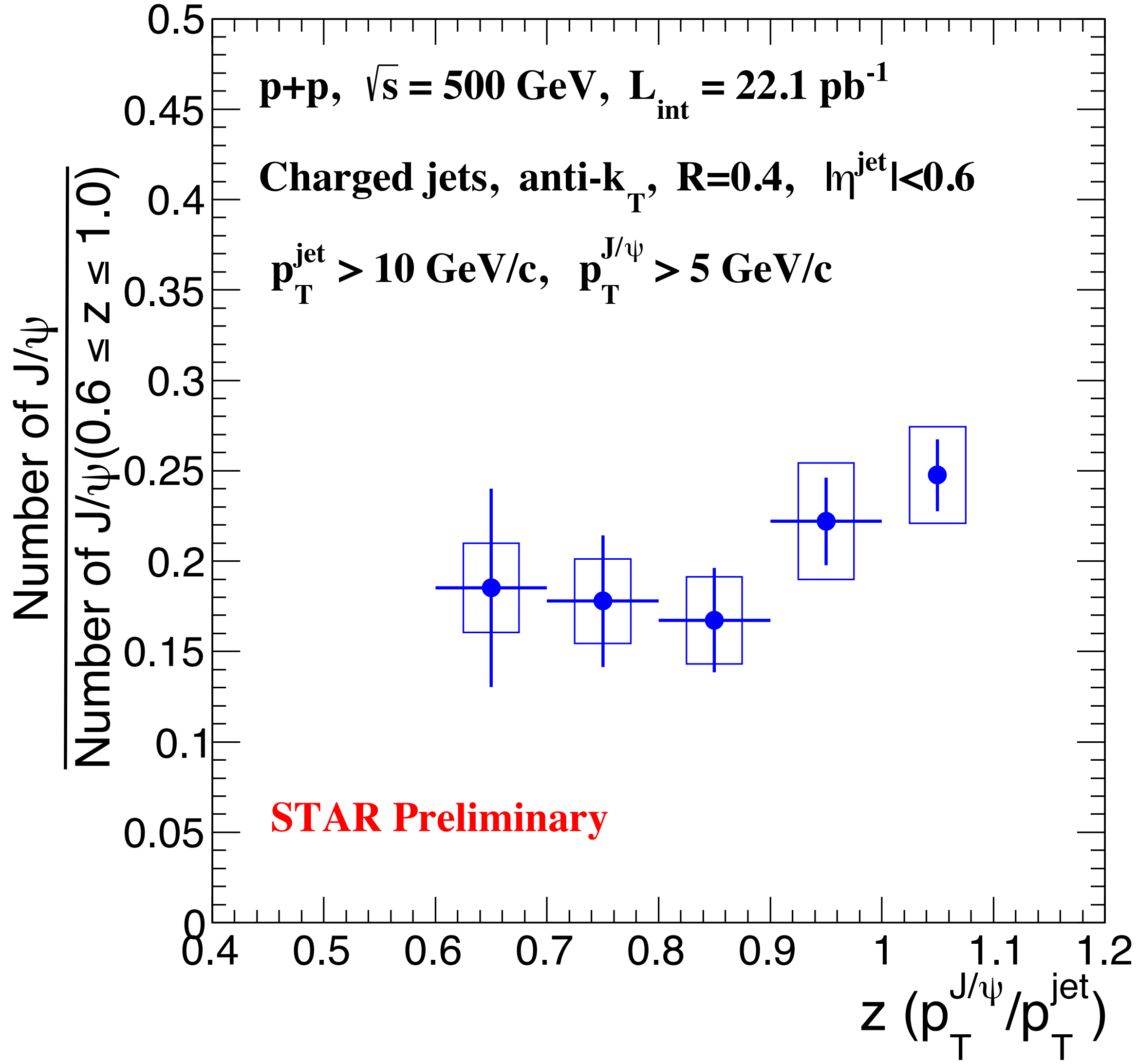
Thanks!

Response matrix



- Response matrix for leading particle
- Leading particle within jet in MB event to mimic J/ψ in jet
- z value is more likely to shift to larger values due to $p_{T,jet}$ (det) < $p_{T,jet}$(part)

Systematic Uncertainty



- Major systematic uncertainty sources:
  - Pile-up tracks (~8%)
  - Min-bias vs. J/ψ PYTHIA events used for response matrix (~5%)
  - Tracking efficiency (~12%)