J/ψ and ψ(2s) production in p+p collisions at $\sqrt{s}$ = 500 GeV from STAR experiment

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Outline

Introduction

- Motivation
- STAR Detector

J/ψ measurement and analysis technique

- Dataset and Trigger
- J/ψ analysis method

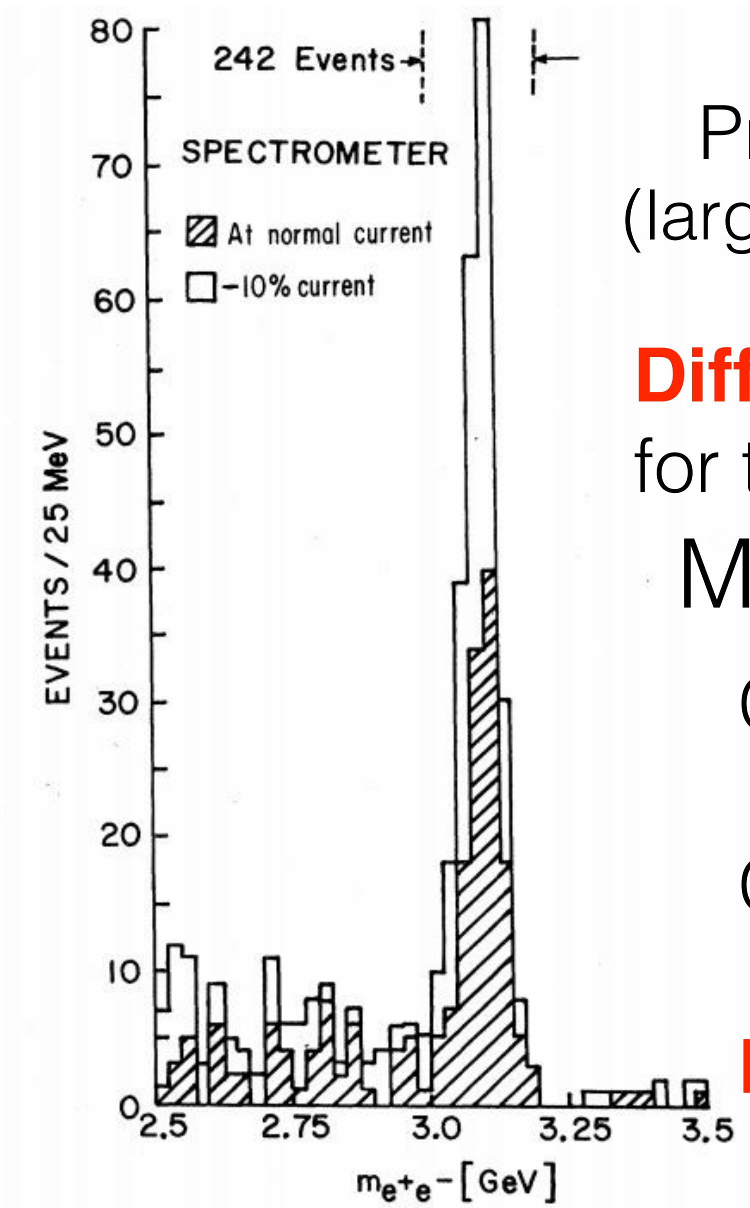
Results

- J/ψ p_T spectrum
- ψ(2s) to J/ψ ratio

Summary

Motivation

J/ψ is one of the simplest QCD bound states, but its production mechanism in p+p is not well understood.



PRL 33,1404(1974)

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

Difficulty:Perturbative theoretical calculation is not applicable for the evolution of c and anti-c pair into J/ψ(soft process).

Models:

Color singlet model
($c\bar{c}$ pair has the same quantum numbers as J/ψ)

Color evaporation model
(constant probability for $c\bar{c}$ evolve into J/ψ)

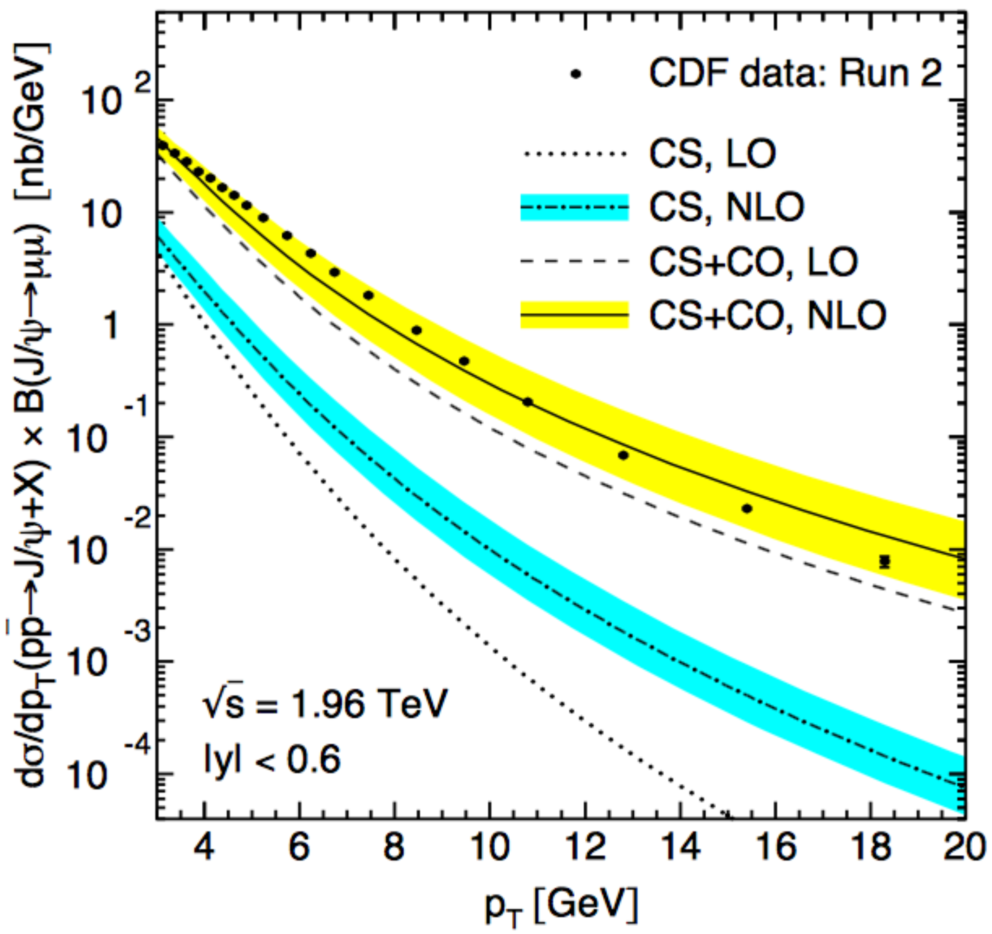
NRQCD model (most successful so far)
($c\bar{c}$ pair in a color-singlet state or a color-octet state)

Fragmentation function approach
(high p_T, light-cone fragmentation)

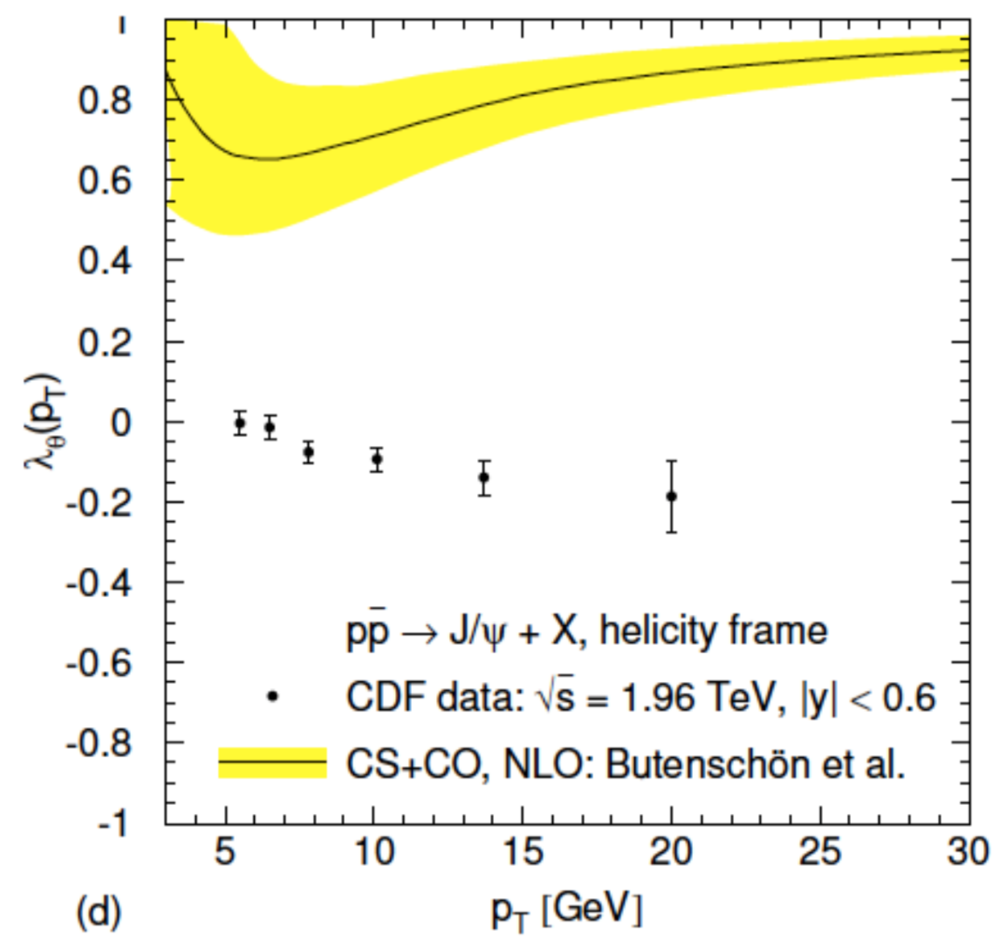
Non-relativistic QCD(NRQCD) factorization approach

- All pairs with various probabilities - NRQCD matrix elements.

World data fitting constrains the universal NRQCD matrix elements at NLO - predictive power in different collision systems, ee, ep and pp.



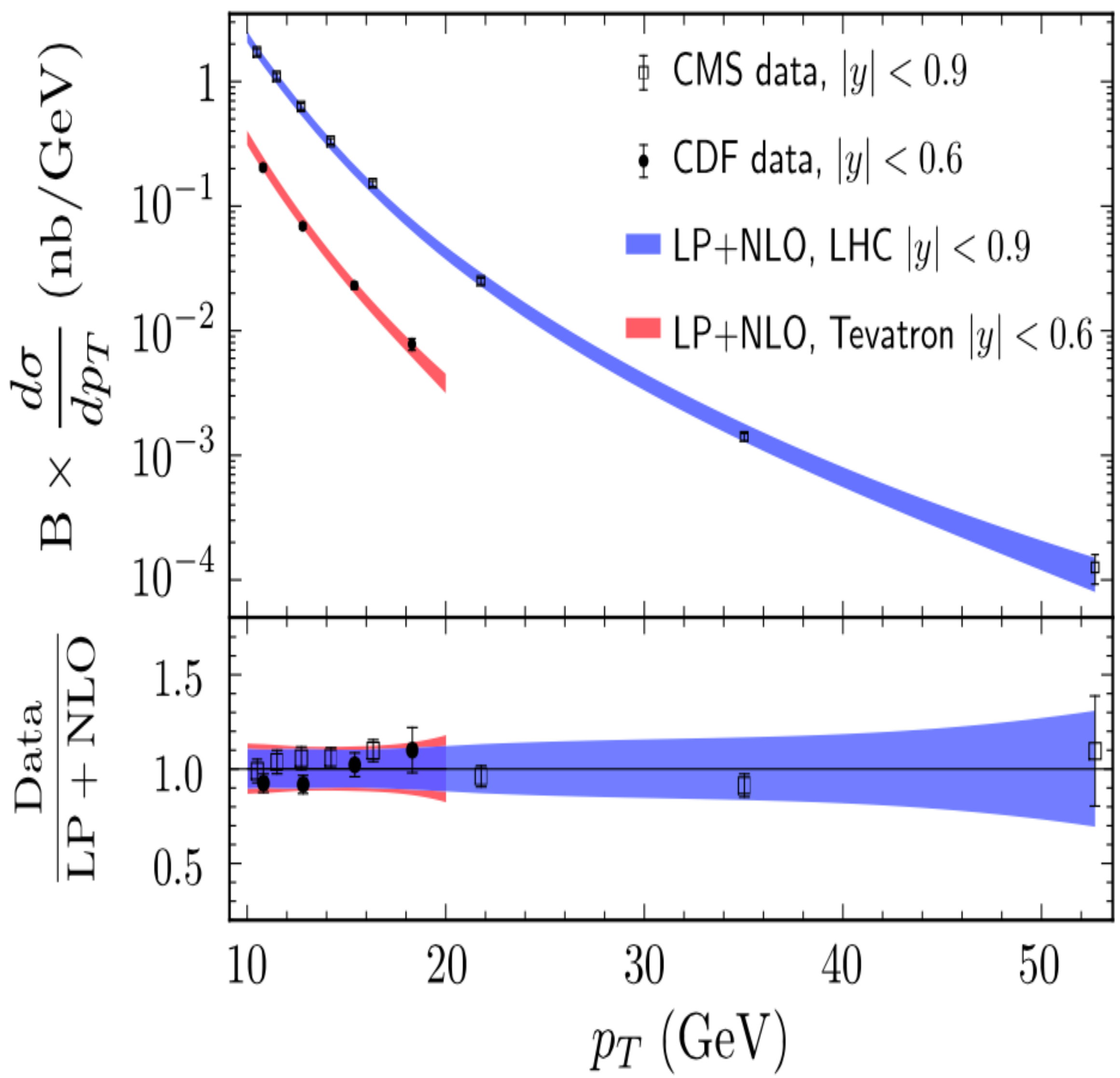
arXiv:1105.0820

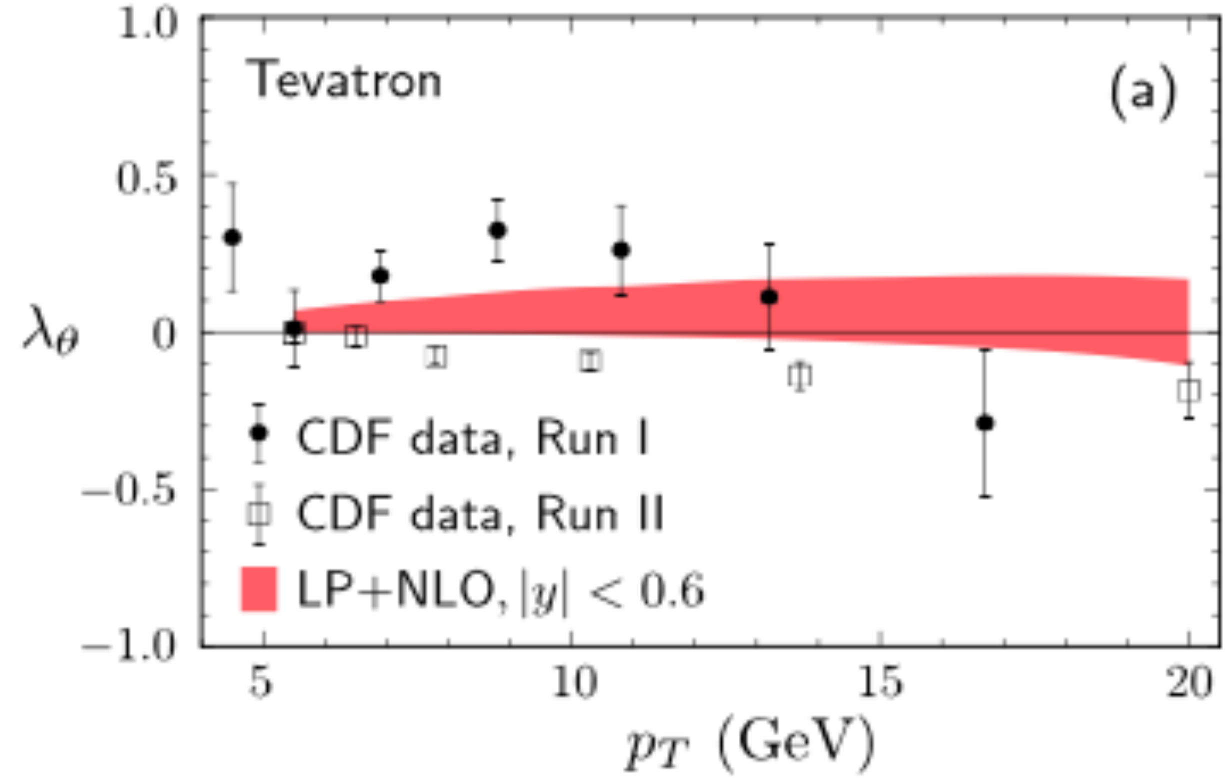


PRL 107,232001(2011)

- Polarization is an ultimate test of NRQCD.
- For some channels, NLO corrections are orders of **magnitude larger** than LO.

Fragmentation function approach





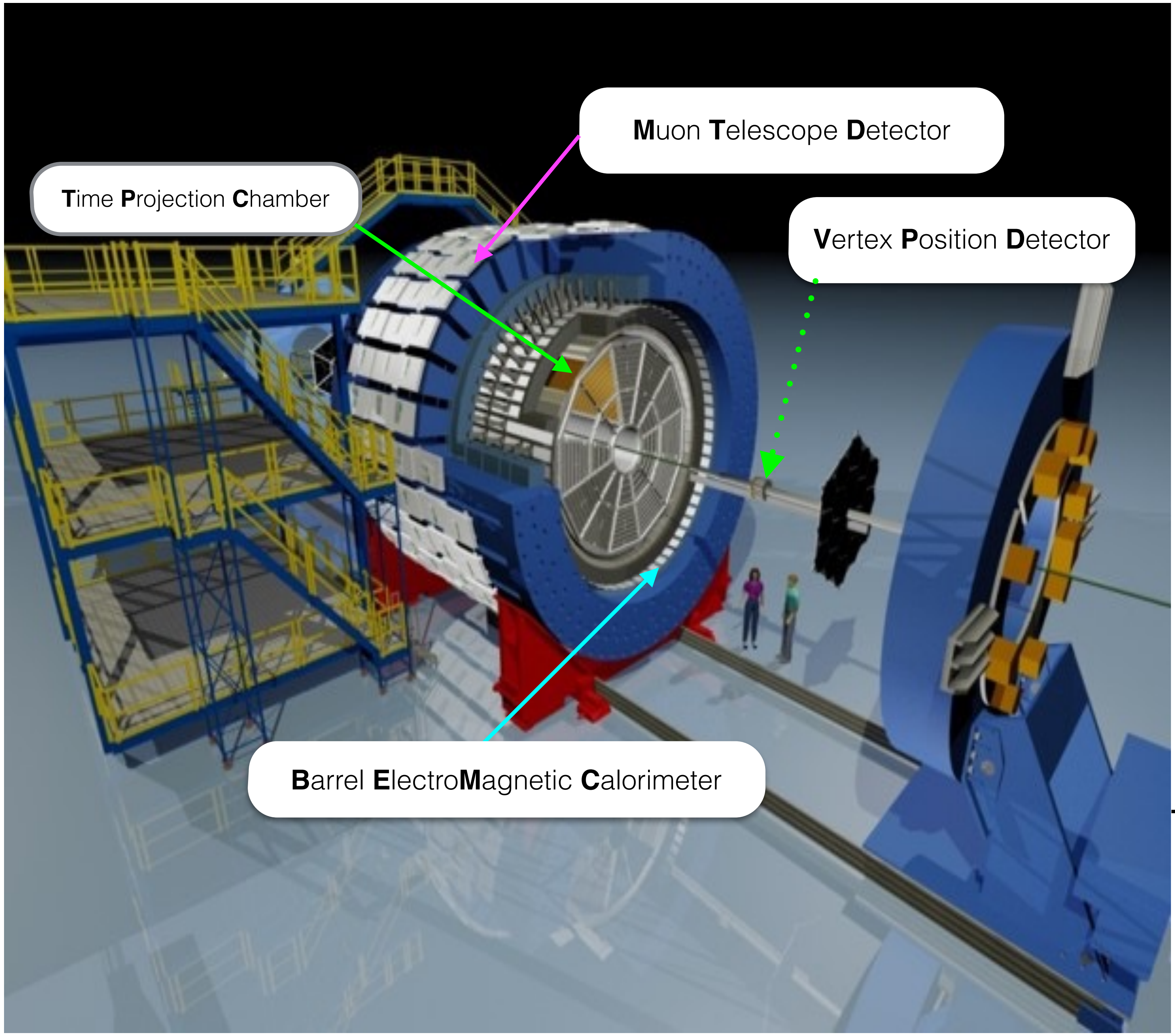
PRL 113,022001(2014)

- Theoretical predictions: **direct** J/ψ .
- Data: **prompt** J/ψ(direct + feed down(χ_{cJ} and ψ(2s)))

- Fragmentation function approach are valid only in **high p_T range**!!!

The Solenoid Tracker At RHIC (STAR)

Large acceptance: $|\eta|<1$, full azimuthal coverage.



Main detectors used in this analysis:

Time Projection Chamber

momentum measurement, particle identification.

Barrel ElectroMagnetic Calorimeter(BEMC):

electron identification, fast triggering

Two new detectors since 2014:

Muon Telescope Detector(**MTD**)

Heavy Flavor Tracker(**HFT**)

Dataset and Trigger

Competition effect:

- High instantaneous luminosity
- Limited event recording rate of slow tracking detector (TPC)

Fast detectors select (or trigger on) interesting events.
Barrel ElectroMagnetic Calorimeter(BEMC) is a good choice.

Channel of interest: $J/\psi \rightarrow e^- e^+$

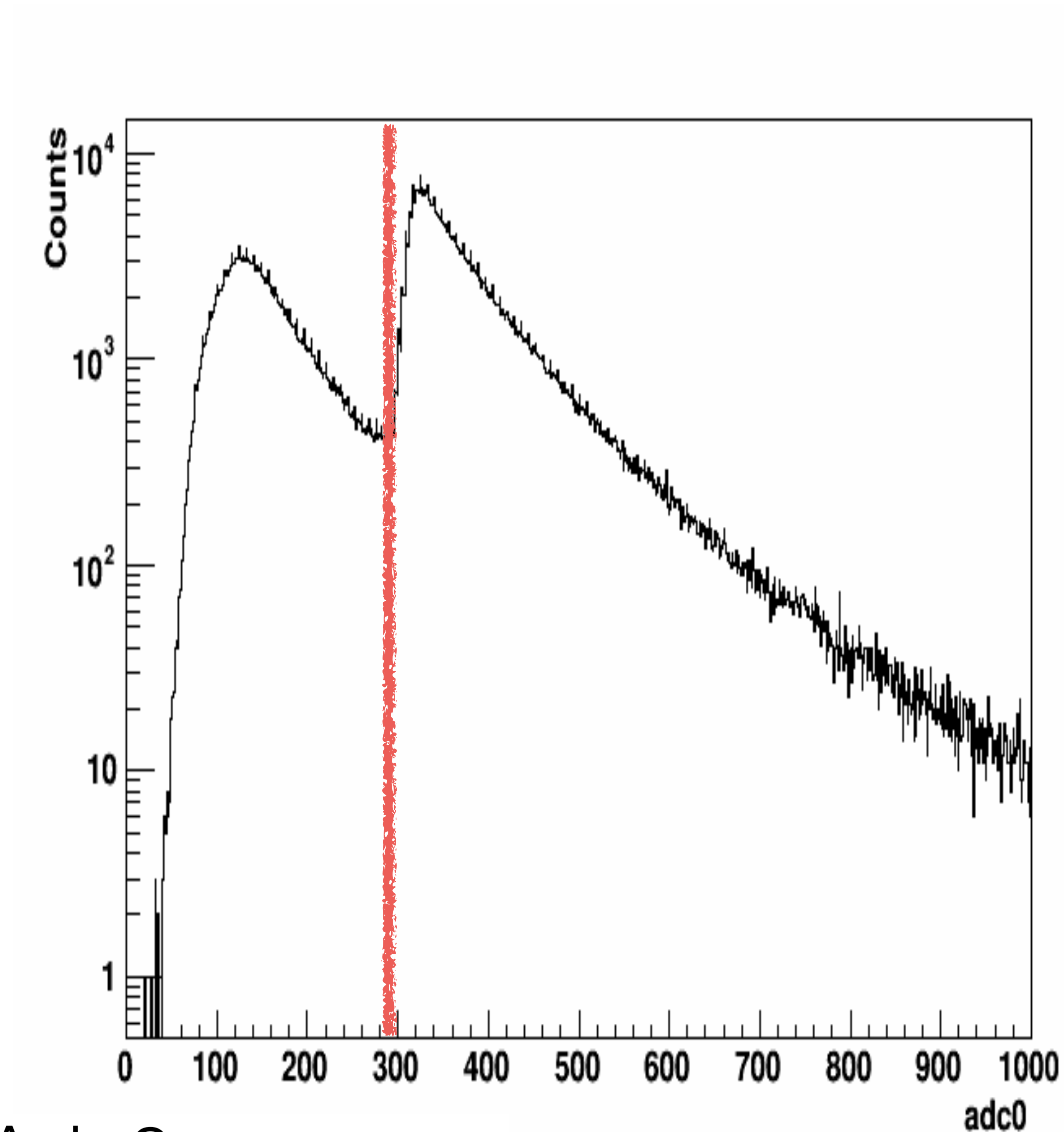
An event with an energy deposition in a single tower of the BEMC above a certain threshold was recorded.

Large BEMC triggered data samples in p+p collisions at $\sqrt{s}$ = 500 GeV from 2011.

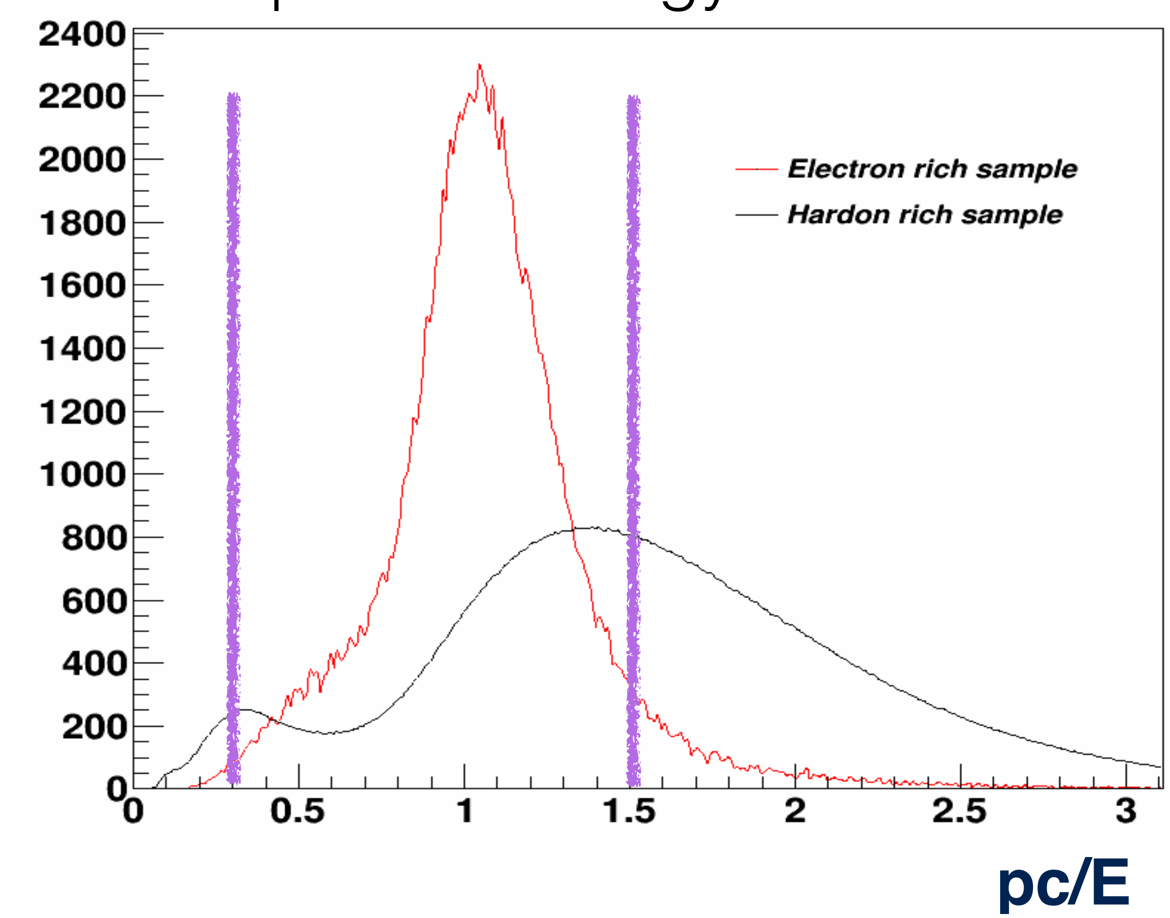
Trigger Name	Trigger Threshold	Number of Events	Sampled Luminosity
BHT1	$E_T > 3.5$GeV	170M	22 pb^{-1}
VPDMB		106M	0.011pb^{-1}

Electron Identification:Triggered electron

Triggered electron: BEMC(adc0 and pc/E) and TPC(dE/dx)



pc/E: ratio of particle momentum to its deposited energy in BEMC.



Adc0:

most energetic tower in a BEMC cluster.

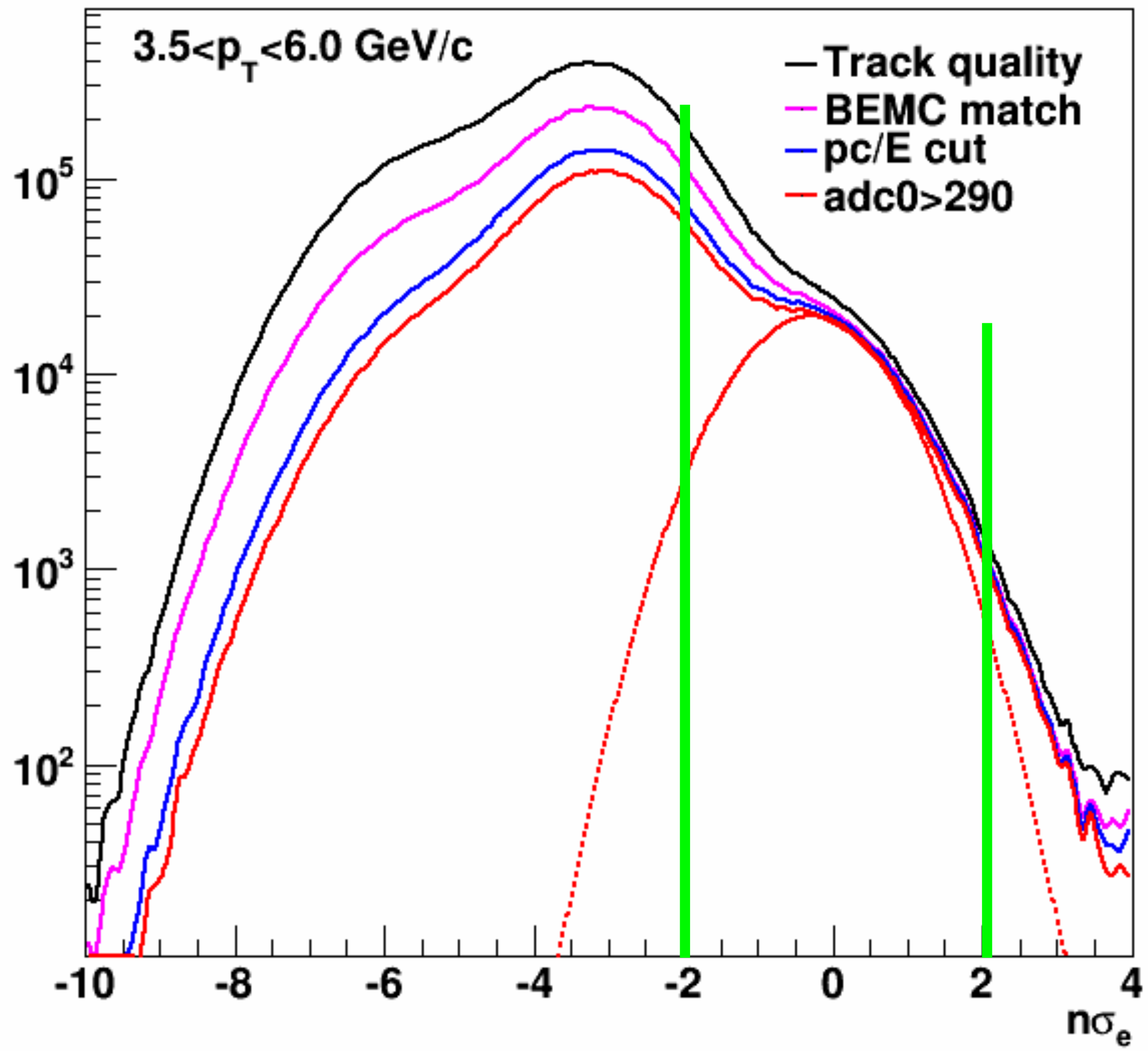
- peak around 300 - electron firing the trigger

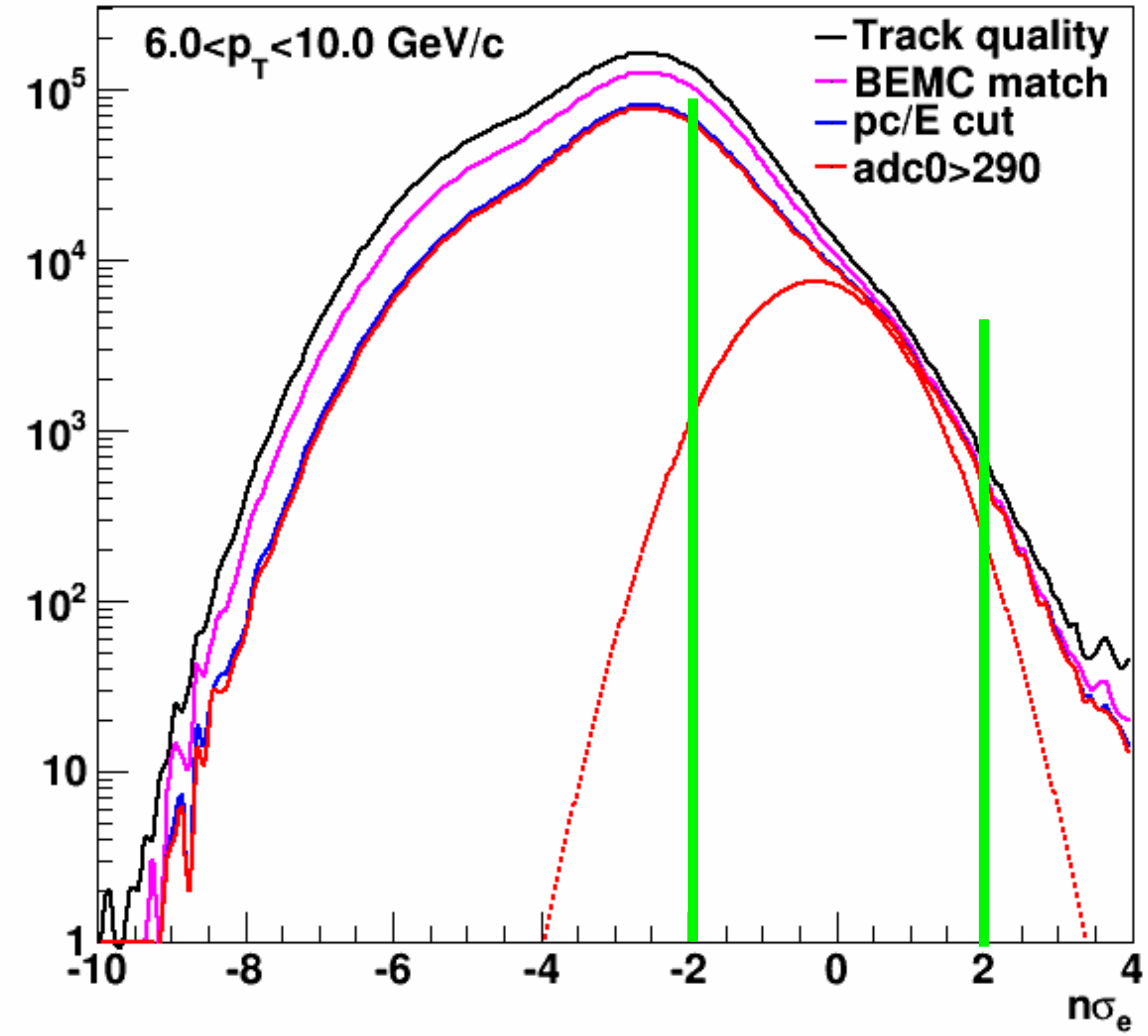
Hadrons: deposit part of its energy in BEMC.

Electron: deposit almost all energy in BEMC

Electron Identification: Triggered electron

$$n\sigma_e = \frac{1}{R} log \frac{dE/dx_{measured}}{< dE/dx >}$$





Triggered electron

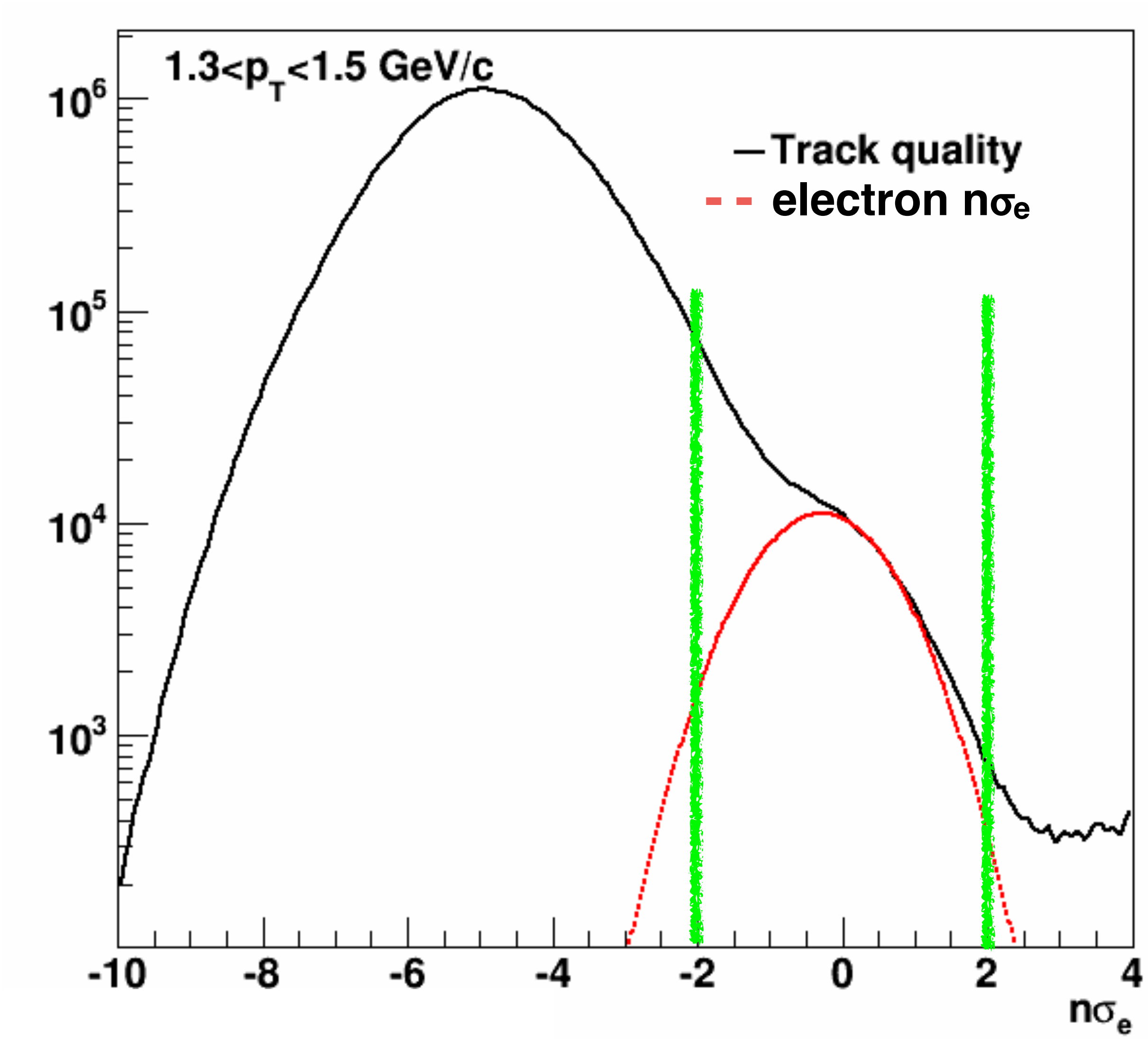
a) adc0>290

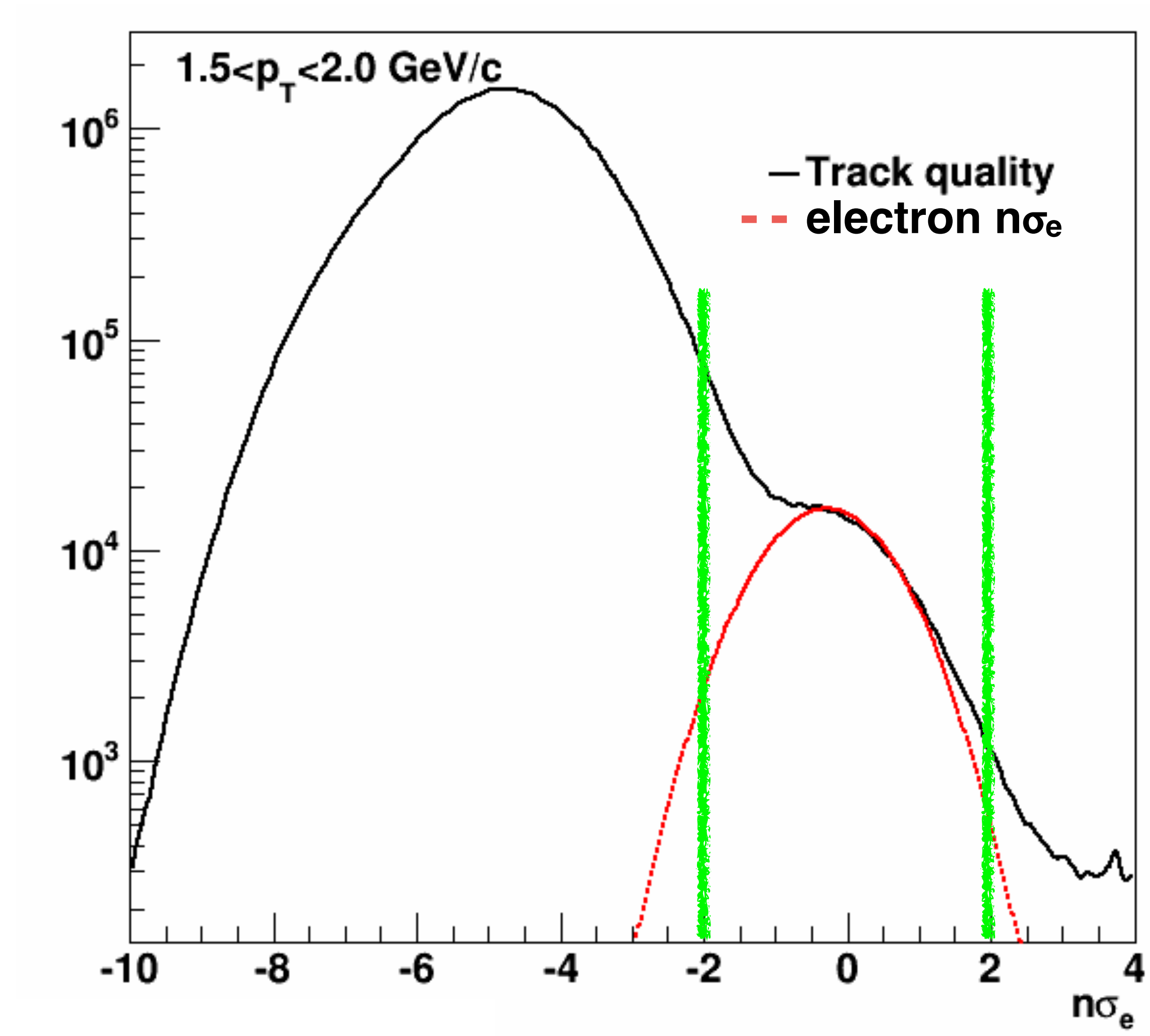
c) 0.3<pc/E<1.5

d) dE/dx cut($-2<n\sigma_e<2$)

Electron Identification: Non-triggered electron

- dE/dx cut ($-2<n\sigma_e<2$)

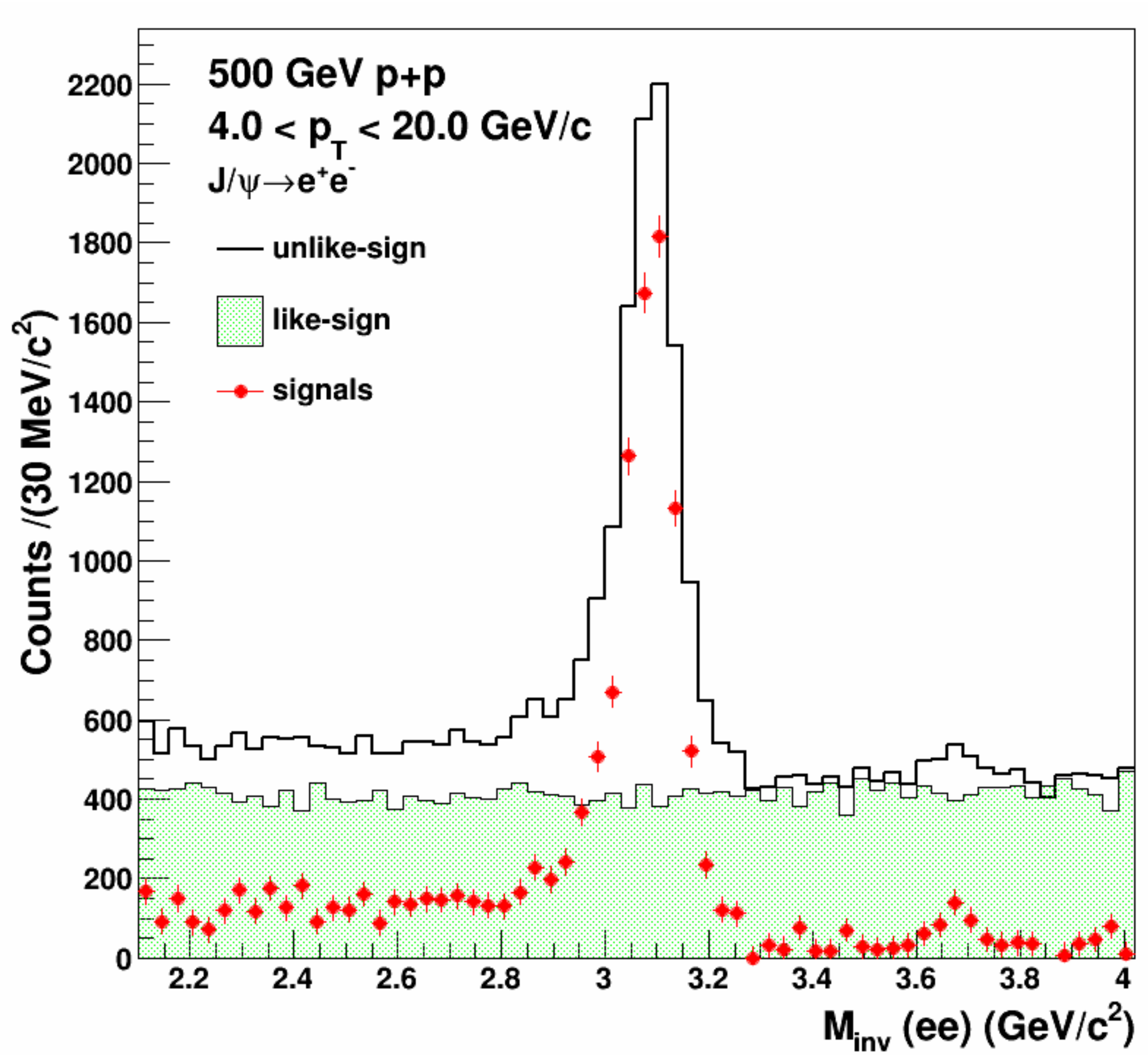




- dE/dx is sufficient for low p_T electron identification.

J/ψ and ψ(2s) Reconstruction

Invariant mass distribution of e^-e^+ pairs



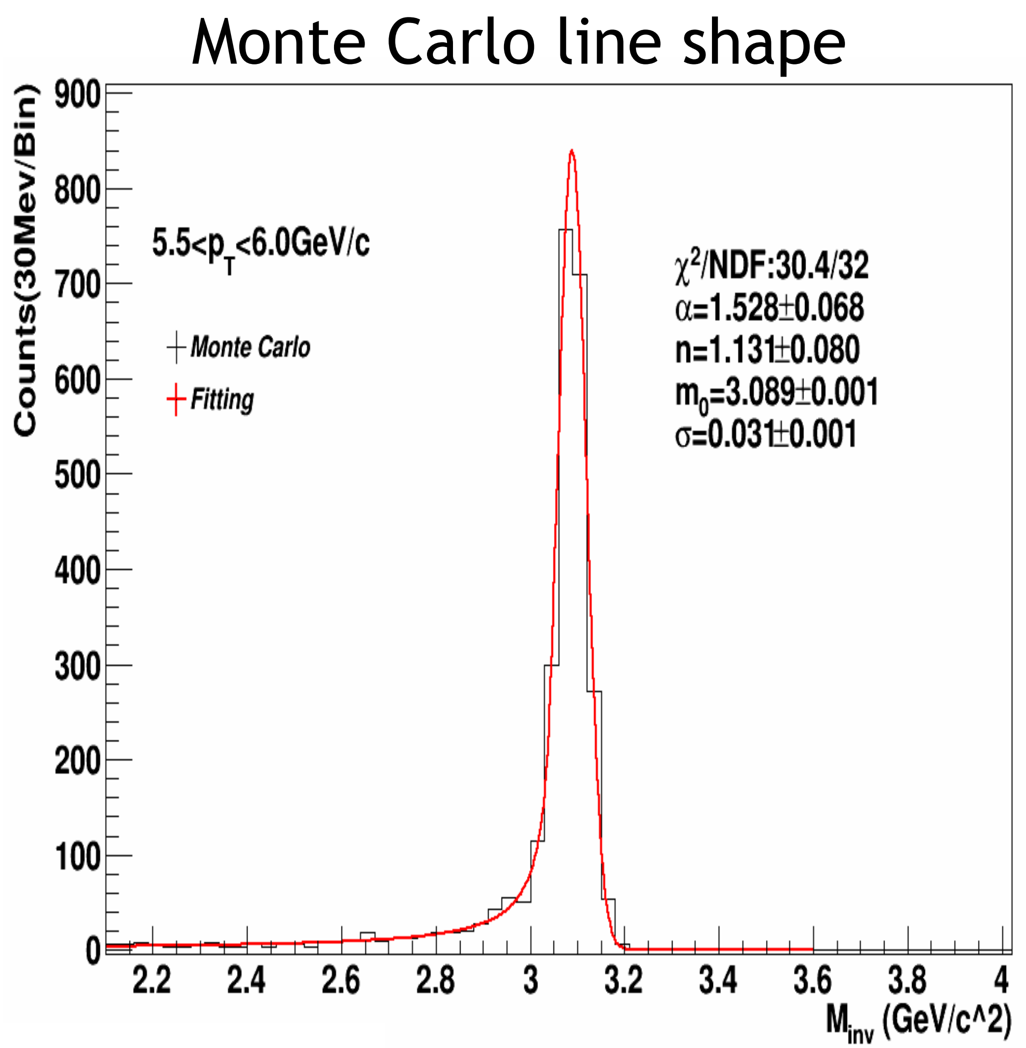
- Reconstruction method:
  - "triggered electron" : identified using TPC and BEMC
  - "non-trigger electron": identified using TPC only
  - "triggered electron" + "non-triggered electron" (and "triggered" + "triggered electron")
- Background reconstruction:
  - Like-sign technique(e^+e^+ + e^-e^-)

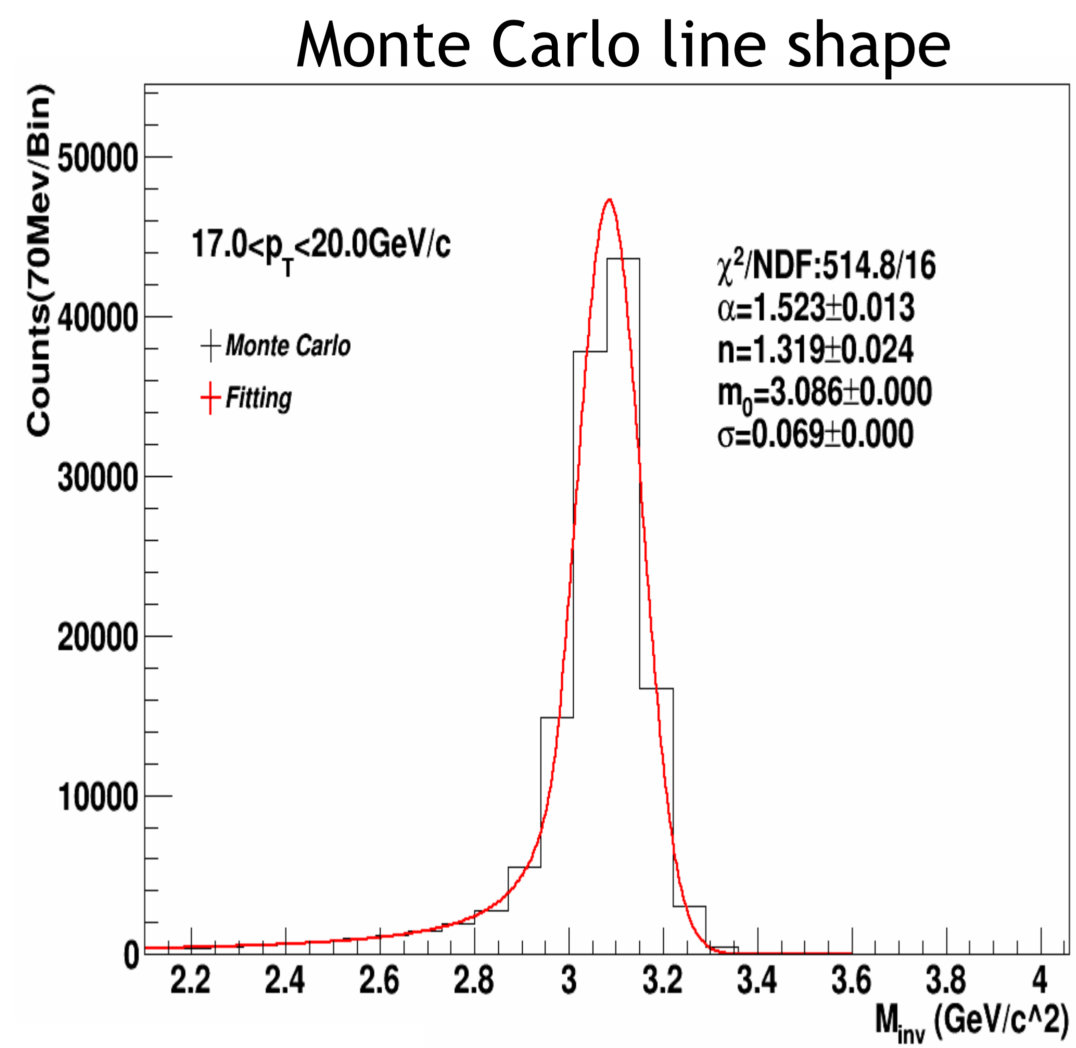
Extract J/ψ line shape from Monte Carlo

bremsstrahlung—tail at low mass range

To account for electron energy loss in detector, Crystal Ball function was used to describe the line shape of J/ψ signal.

$$f_{CB}(m) = \begin{cases} \frac{N}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(m-m_0)^2}{2\sigma^2}\right), & \text{for } \frac{m-m_0}{\sigma} > -\alpha; \\ \frac{N}{\sqrt{2\pi}\sigma} \left(\frac{n}{|\alpha|}\right)^n \exp\left(-\frac{|\alpha|^2}{2}\right) \left(\frac{n}{|\alpha|} - |\alpha| - \frac{m-m_0}{\sigma}\right)^{-n}, & \text{for } \frac{m-m_0}{\sigma} \leq -\alpha. \end{cases}$$

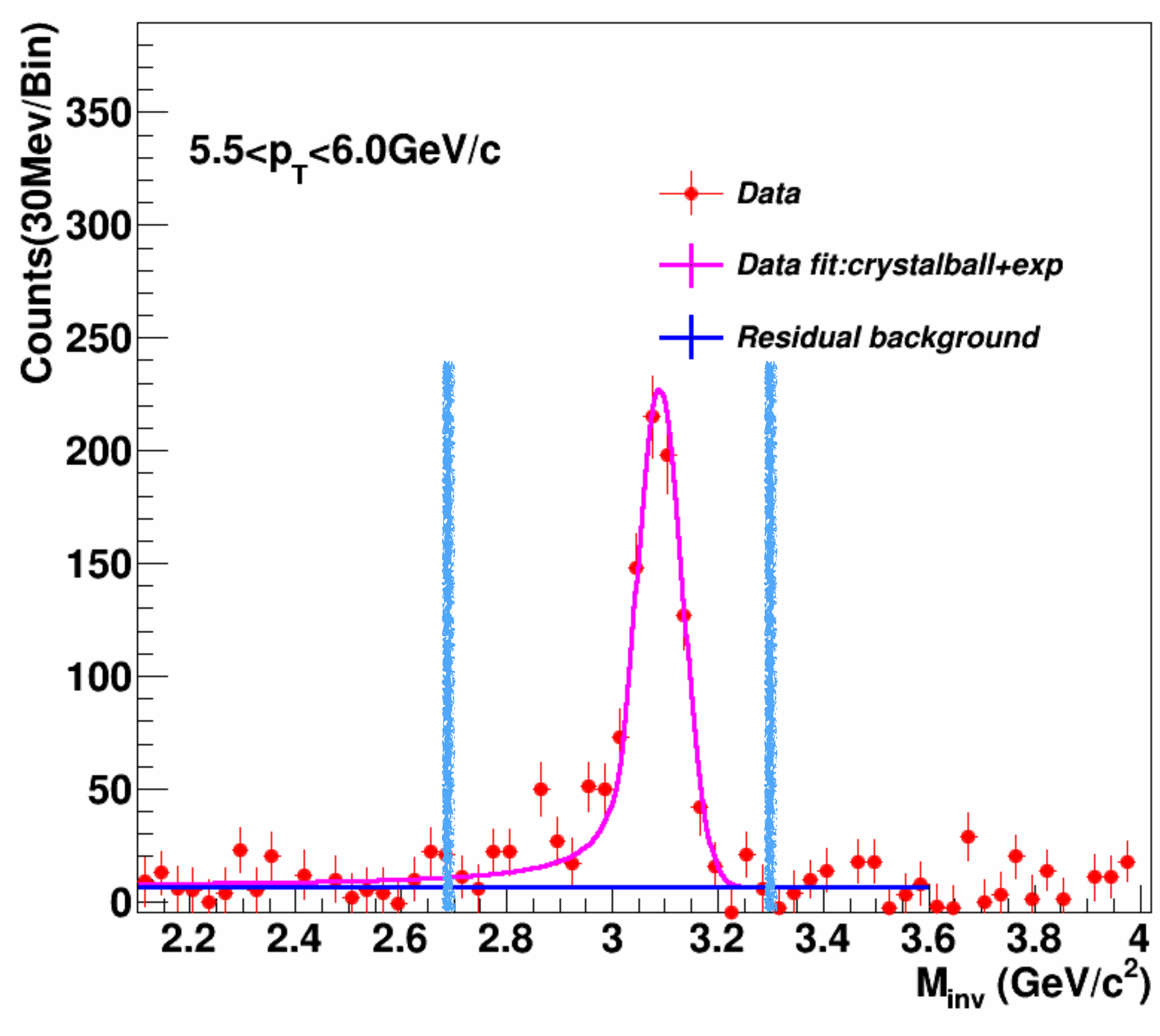


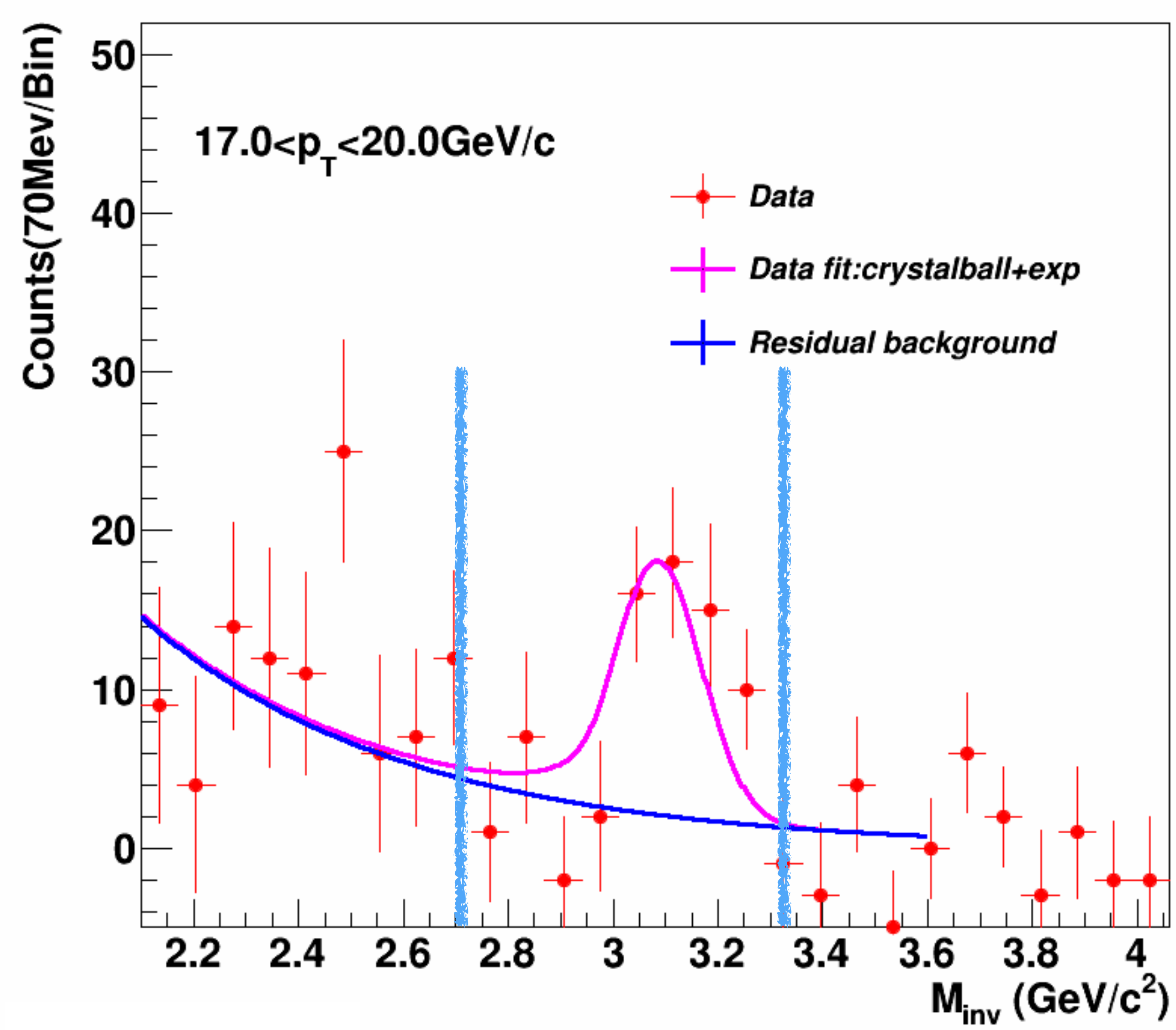


Extract J/ψ yield

J/ψ line shape is extracted from Monte Carlo(fixed m_0, α and n).

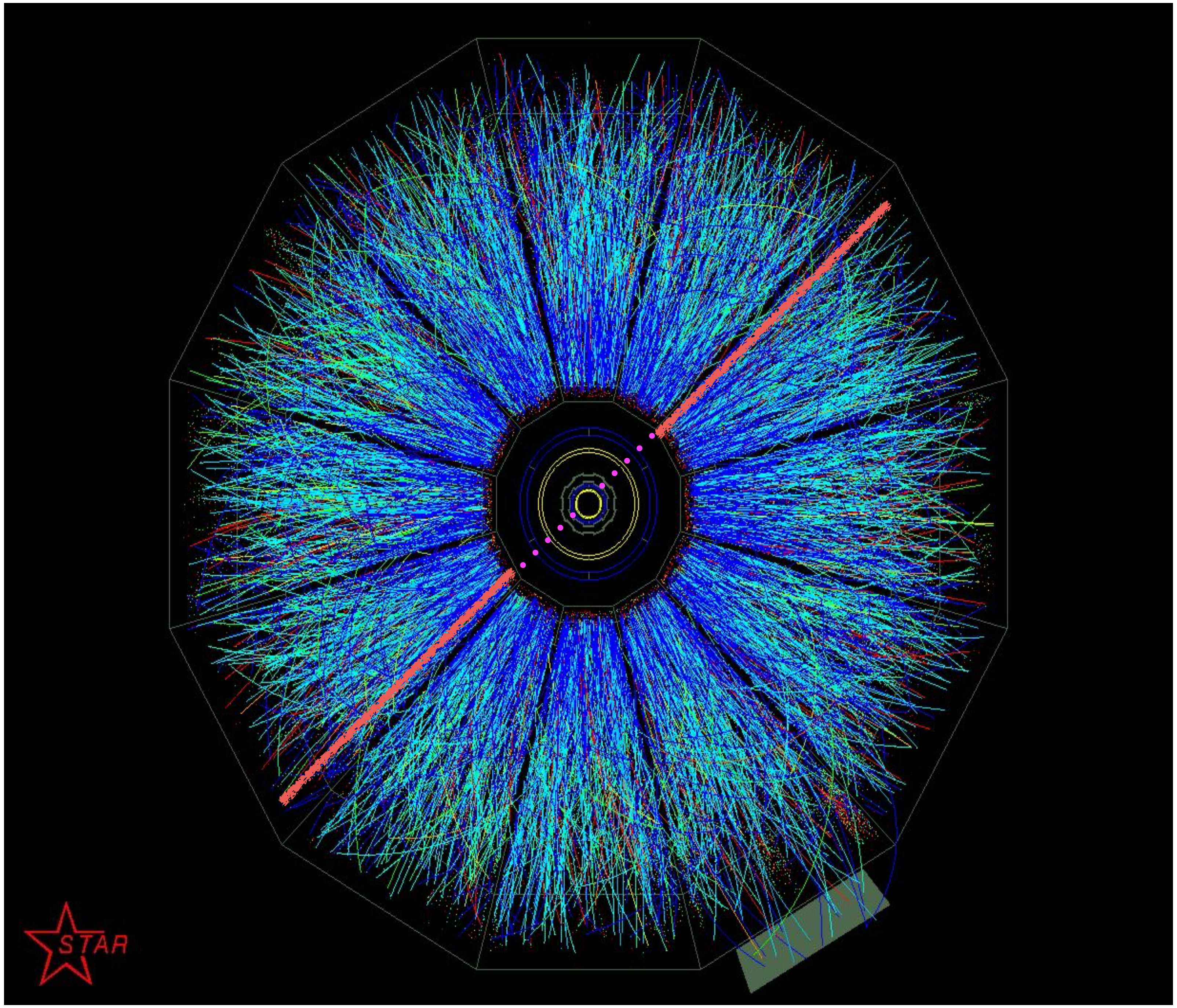
- Crystal ball function and exponential function are used to describe J/ψ signal and residual background.





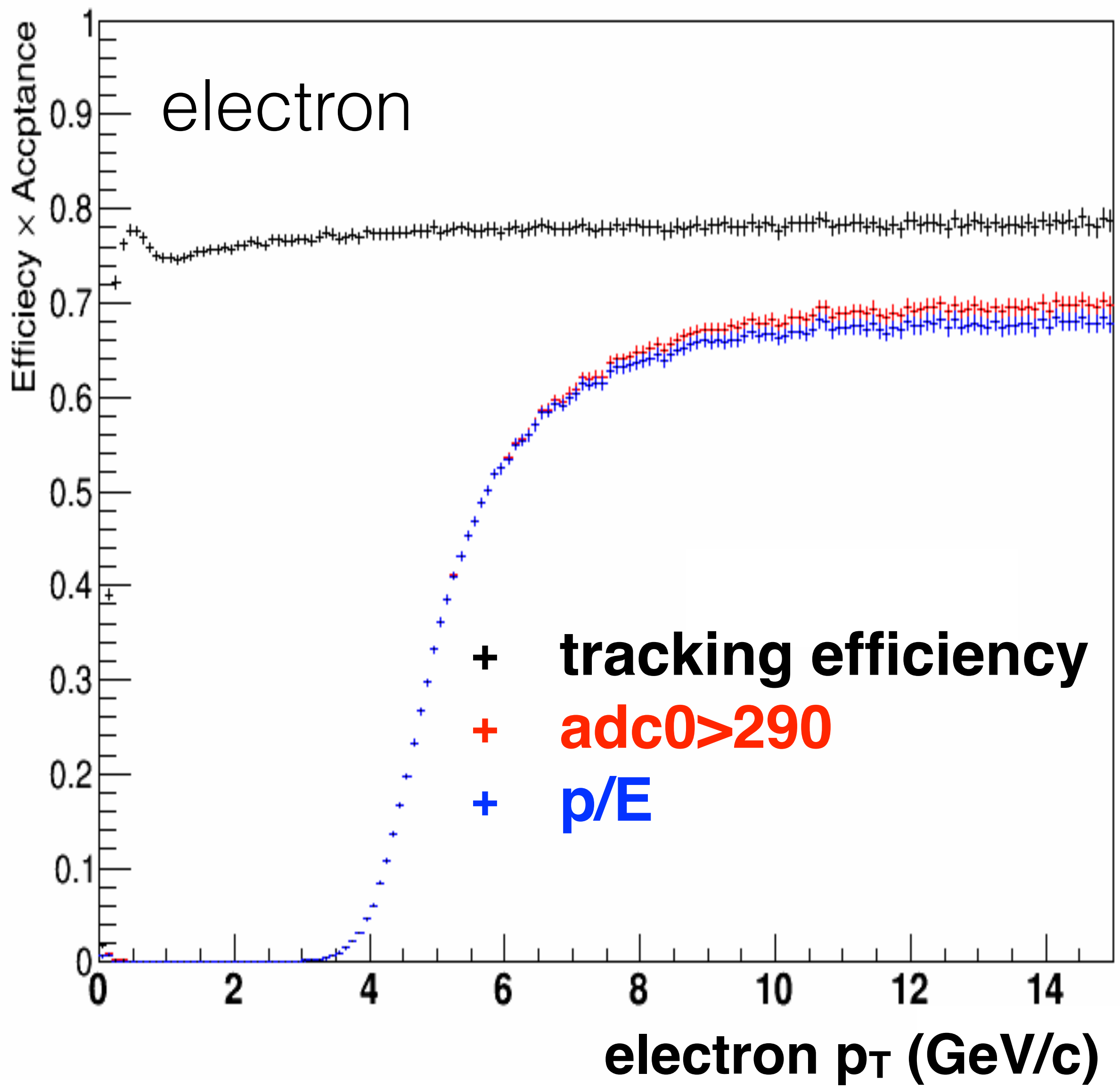
Residual background: $D\bar{D}$ and $B\bar{B}$ decays as well as Drell-Yan process.

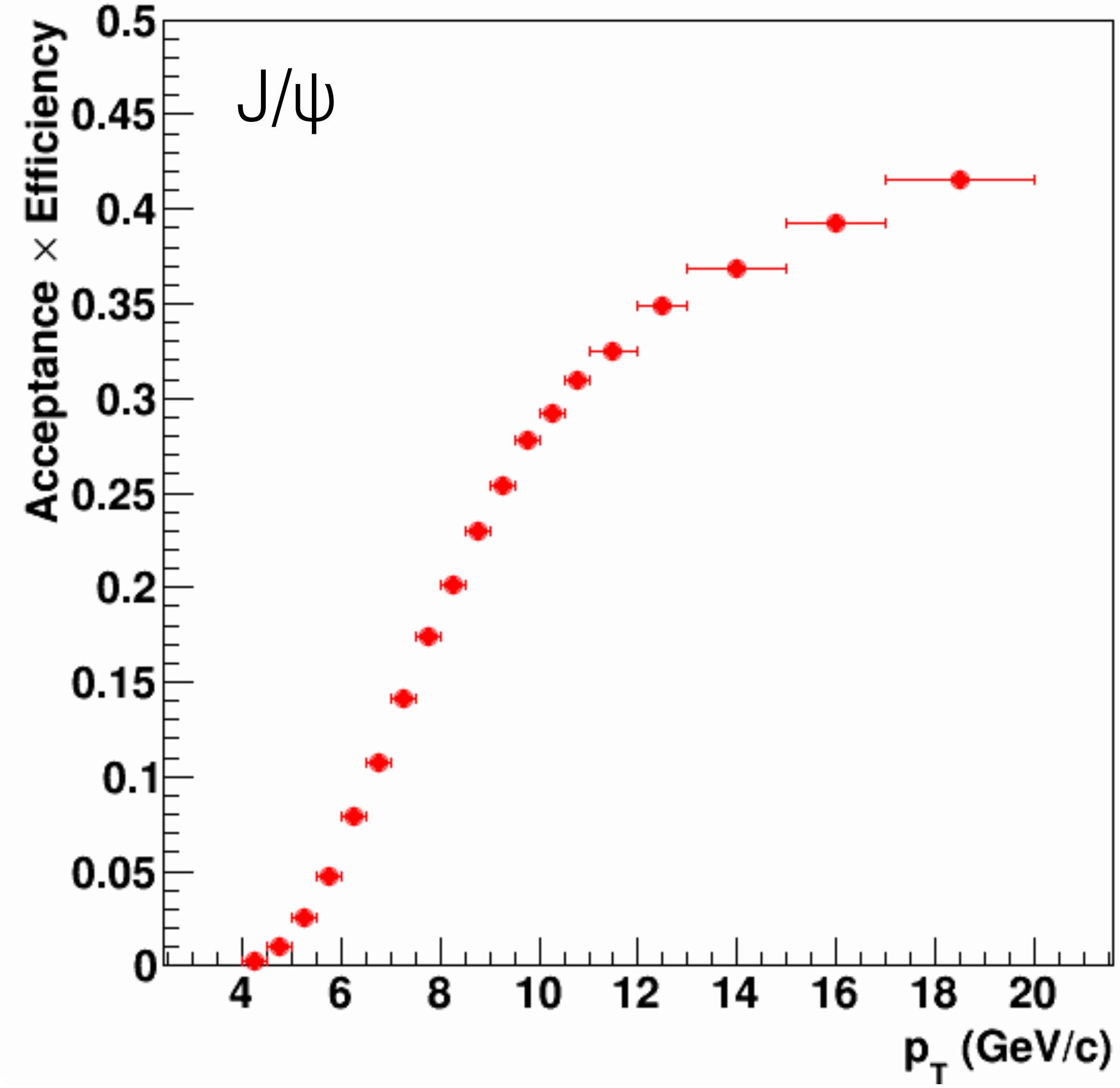
J/ψ efficiency—embedding technique



1. Simulated tracks are embedded into real events at the raw data level.
2. Mixed events are processed through the full reconstruction chain.
3. An association map is created between the input MC tracks and the reconstructed tracks.

J/ψ efficiency and acceptance

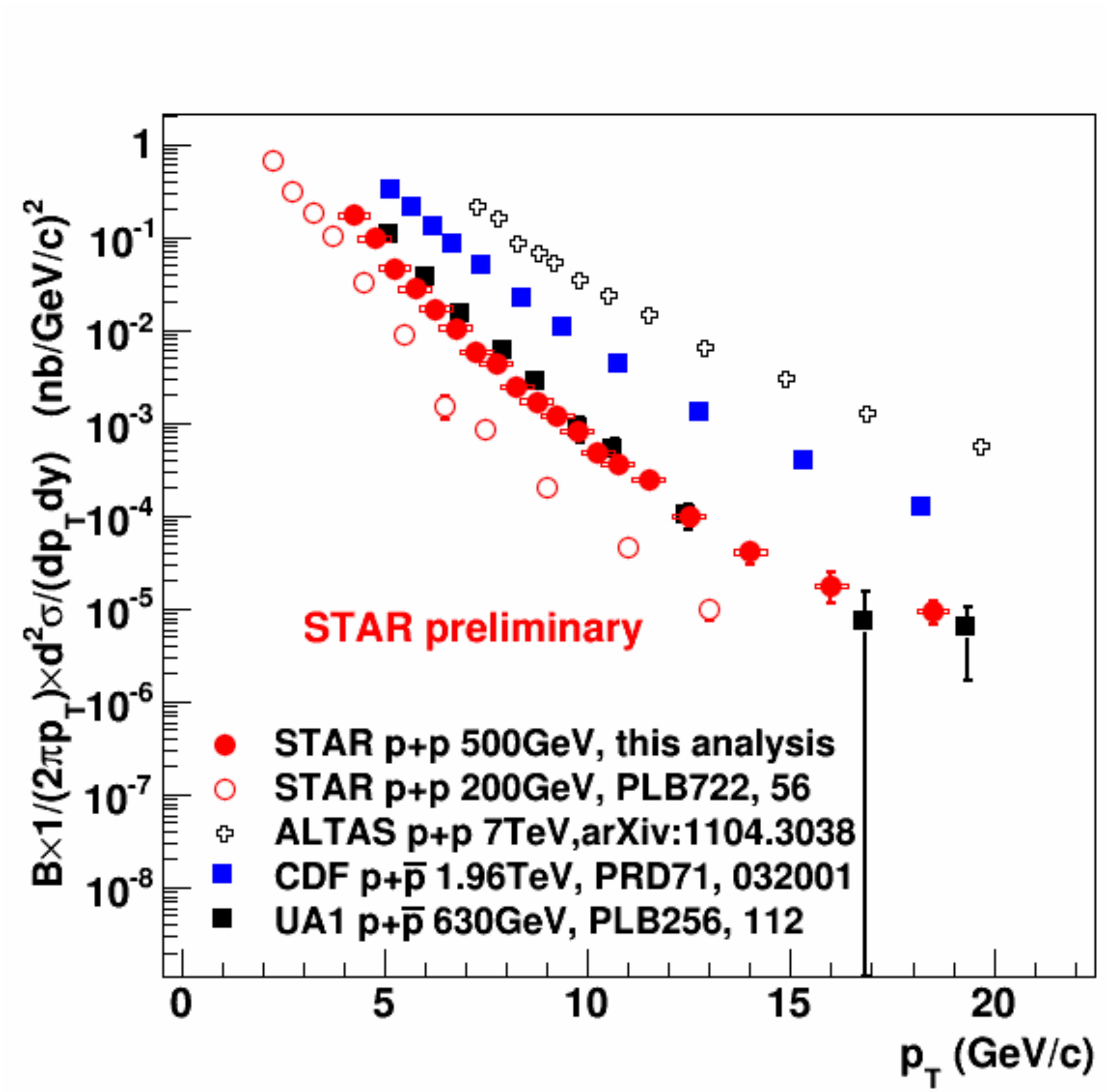




- ~75% tracking efficiency.
- Trigger efficiency turns on 3.5 GeV/c.
- High p/E cut efficiency.

- High efficiency at high p_T
- Gentle efficiency slope

J/ψ invariant cross section



	Systematic uncertainty
yield extraction	1.3%
p_T cut	4.5%
dca	3.0%
p/E	3.0%
adc0	1.0%
$n\sigma_e$	1.0%
total	6.0%

Precise measurements of J/ψ in $4<p_T<20$ GeV/c at p+p 500GeV

Theoretical calculation is very welcome!!

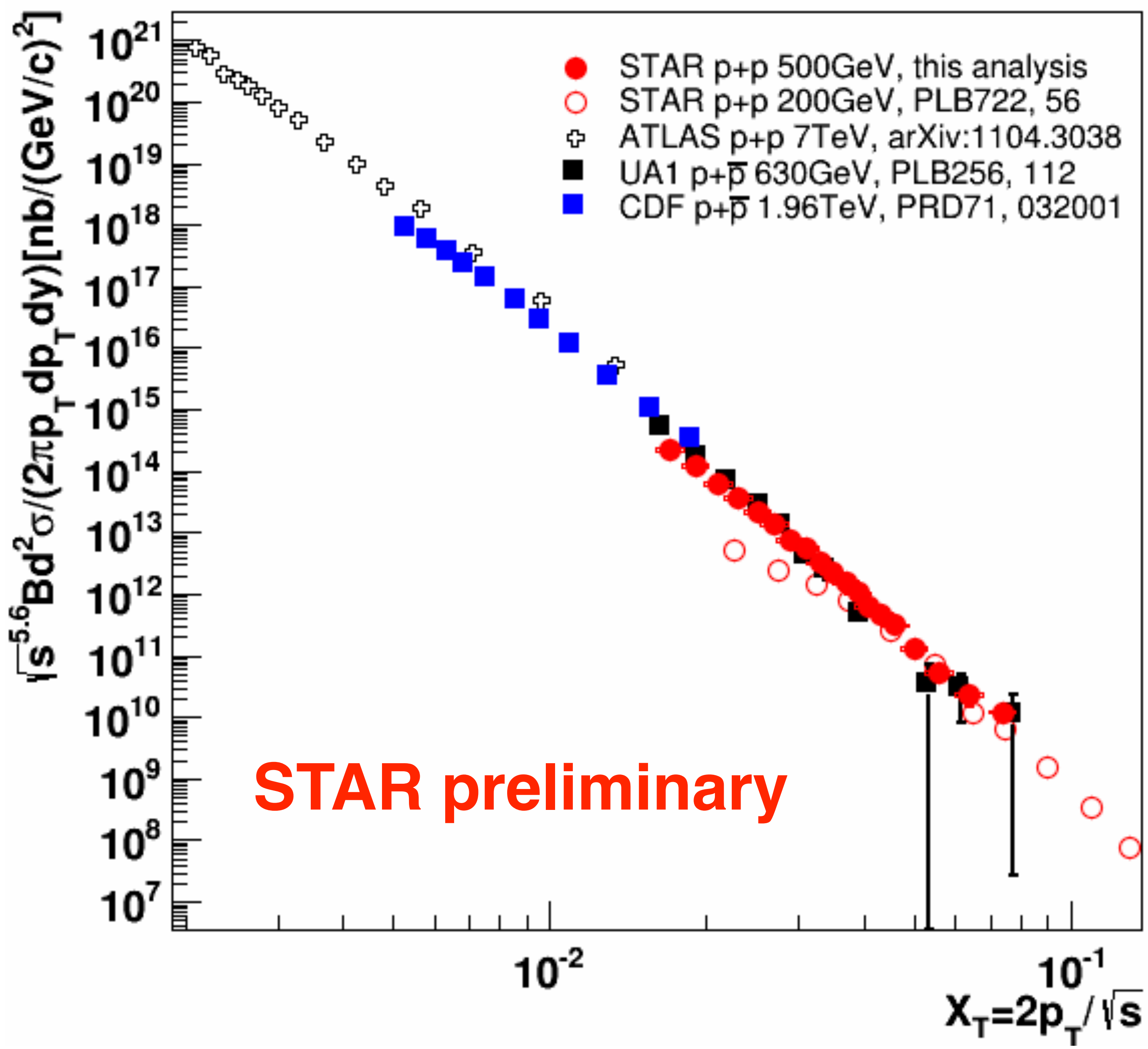
x_T scaling

Proton and pion inclusive production cross sections in high energy p+p collisions have been found to follow x_T scaling:

$$E\frac{d^3\sigma}{dp^3} = g(x_T)\frac{1}{s^{\frac{n}{2}}}$$

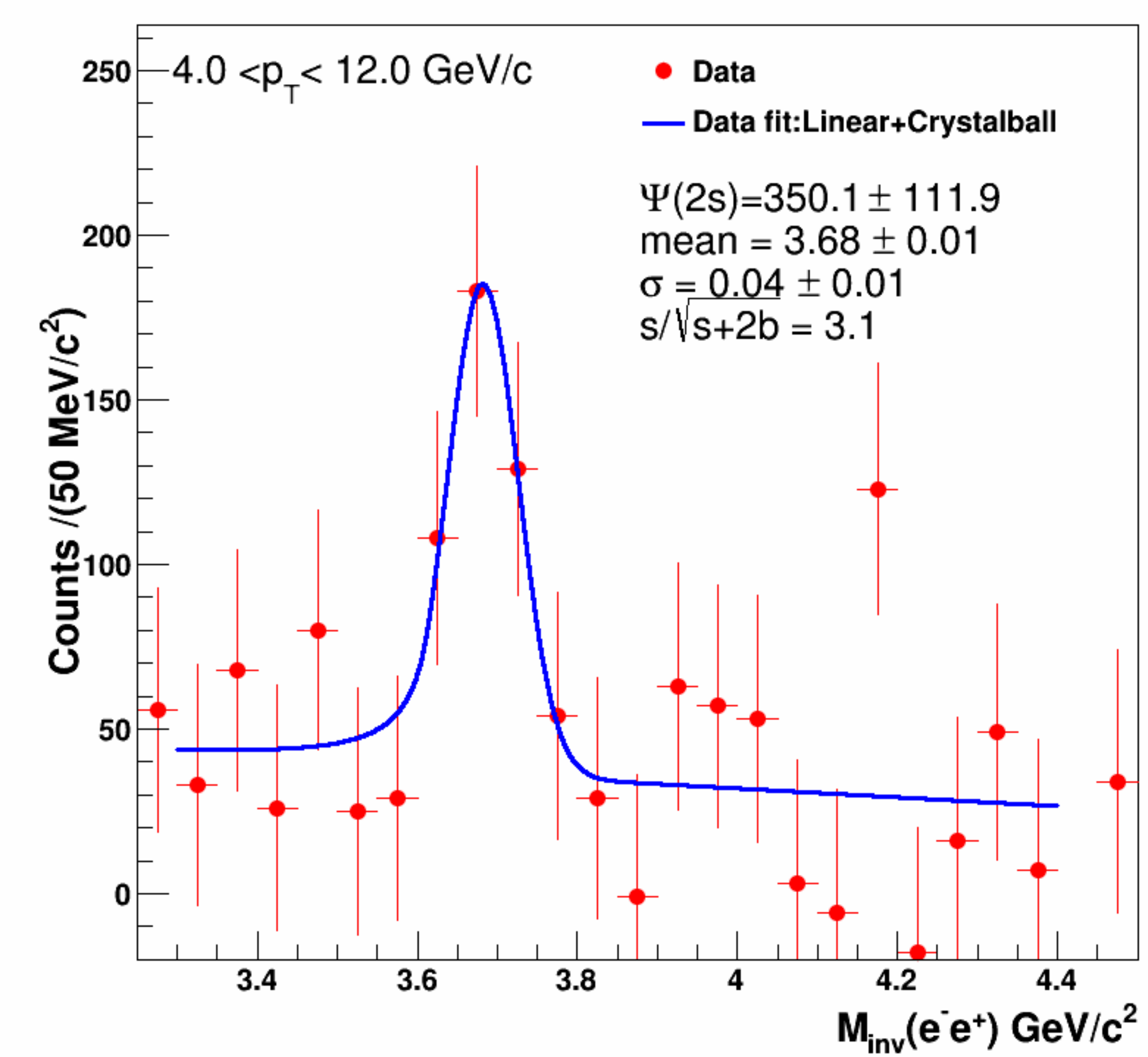
In the parton model, n reflects the number of constituents taking an active role in hadron production.

J/ψ is also found to follow x_T scaling(n=5.6±0.2).
NRQCD prediction n≃6



- J/ψ follows x_T scaling at p_T>4 GeV/c.

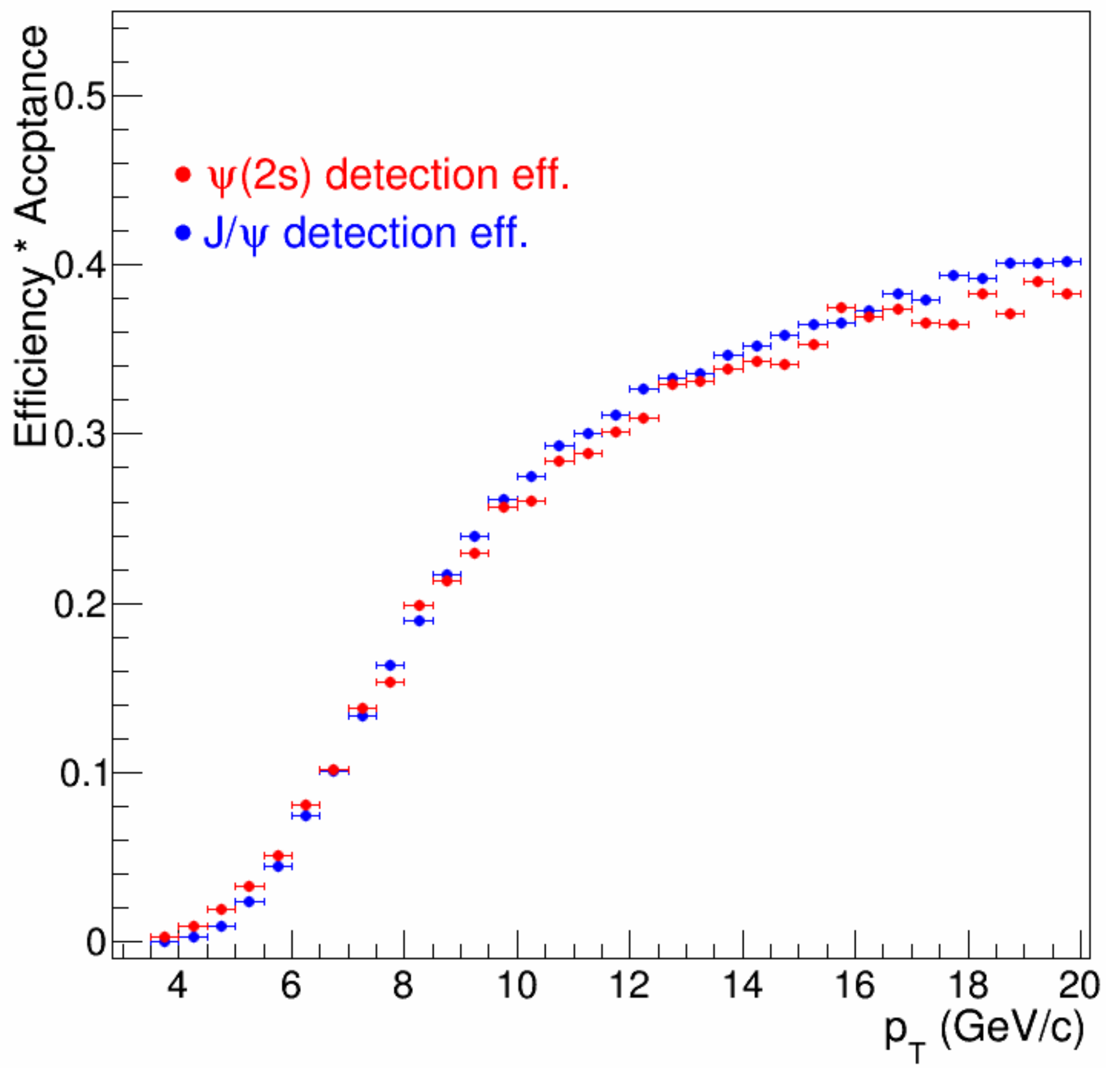
Extract ψ(2s) yield



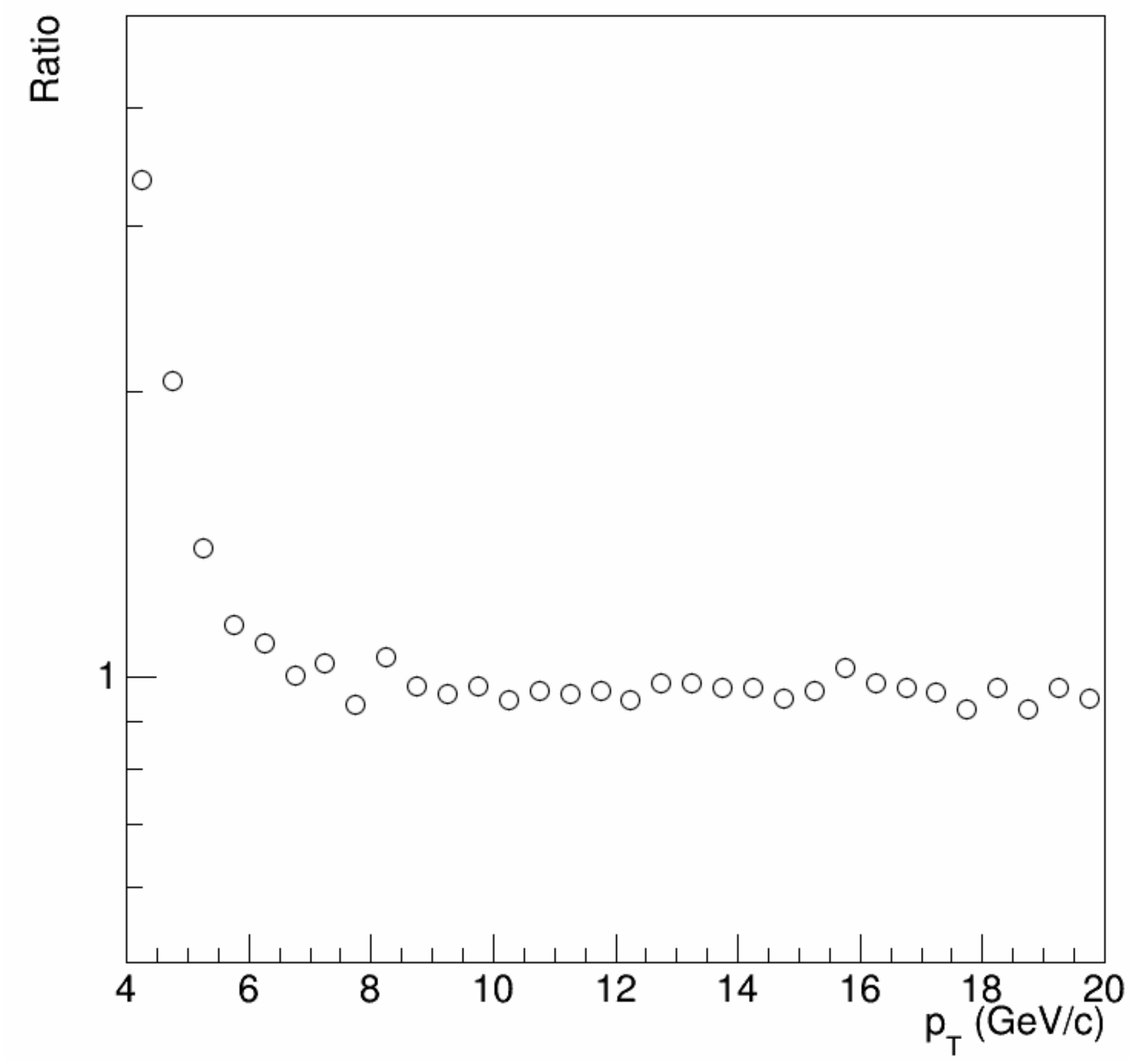
- Crystal ball function and linear function are used to describe ψ(2s) signal and residual background.

ψ(2s) and J/ψ efficiency difference

J/ψ and ψ(2s) detection efficiency as a function of p_T

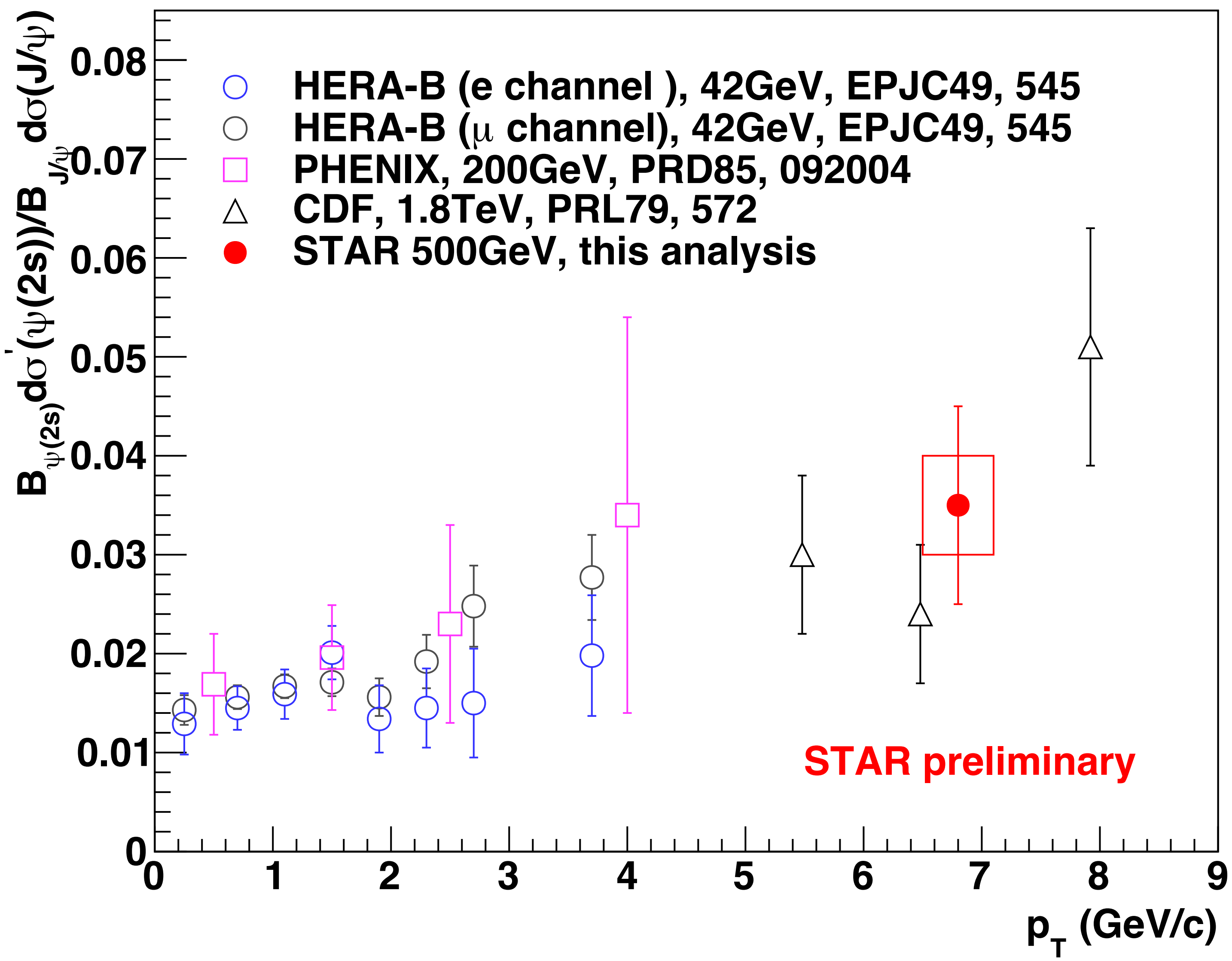


The ratio of ψ(2s) to J/ψ detection efficiency



- At low p_T, **larger mass** of ψ(2s) boosts the p_T of the decay electrons, thus enhancing the trigger efficiency.
- At high p_T, the **larger opening angle** between electron and positron from ψ(2s) results in a smaller acceptance.

ψ(2s) to J/ψ ratio



	Systematic uncertainty
yield extraction	15.1%
p_T cut	6.0%
dca	5.0%
p/E	6.0%
adc0	3.0%
total	18.1%

- STAR results consistent with world data trend with p_T.
- No collision energy dependence is seen with current precision.

Summary

- J/ψ production in the pT range of 4-20 GeV/c in p+p collisions at $\sqrt{s}$ = 500 GeV is measured.
- J/ψ inclusive production cross section follows x_T scaling for pT larger than 4 GeV/c.
- The measured ratio of ψ(2s) to J/ψ is consistent with previous measurements, and no energy dependence is seen.

Outlook

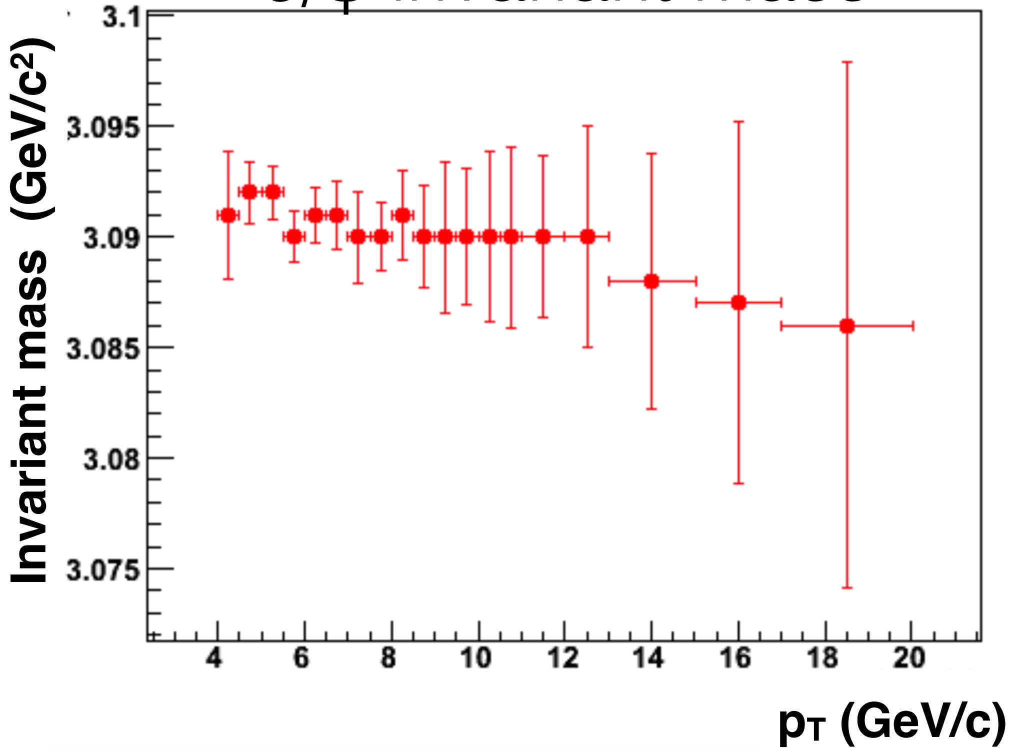
- Data analysis to extract J/ψ polarization is on-going, and the effect on the measured cross-section due to J/ψ polarization is under study.
- Comparison to theoretical calculations is under way. Input is very welcome.
- Low p_T J/ψ using MTD for p+p 500 GeV is ongoing, which is complementary to this analysis. Different kinematic sensitivity, different decay channel, different systematics.

Thank you!

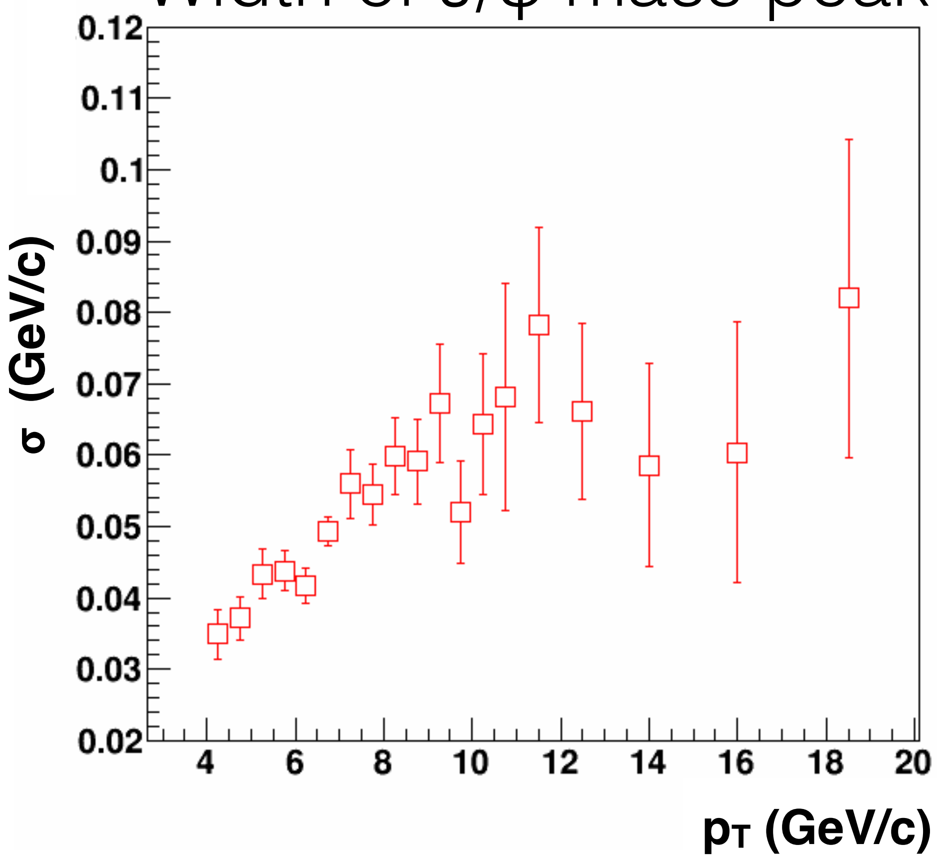
Backup

J/ψ invariant mass, signal width and its raw spectrum

J/ψ invariant mass



Width of J/ψ mass peak



J/ψ raw spectrum