25th Indian-Summer School of Physics

UNDERSTANDING HOT & DENSE QCD MATTER

J/ψ polarization in p+p collisions in STAR

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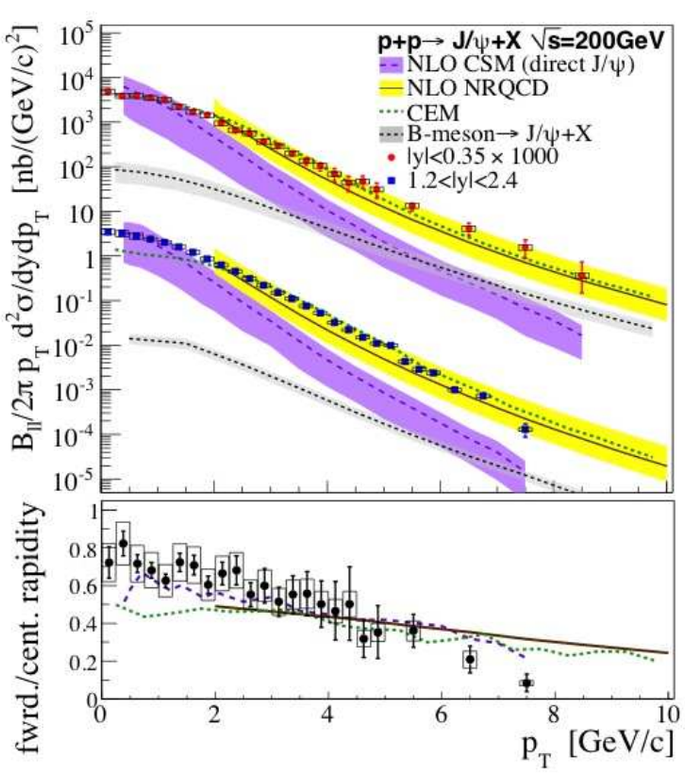
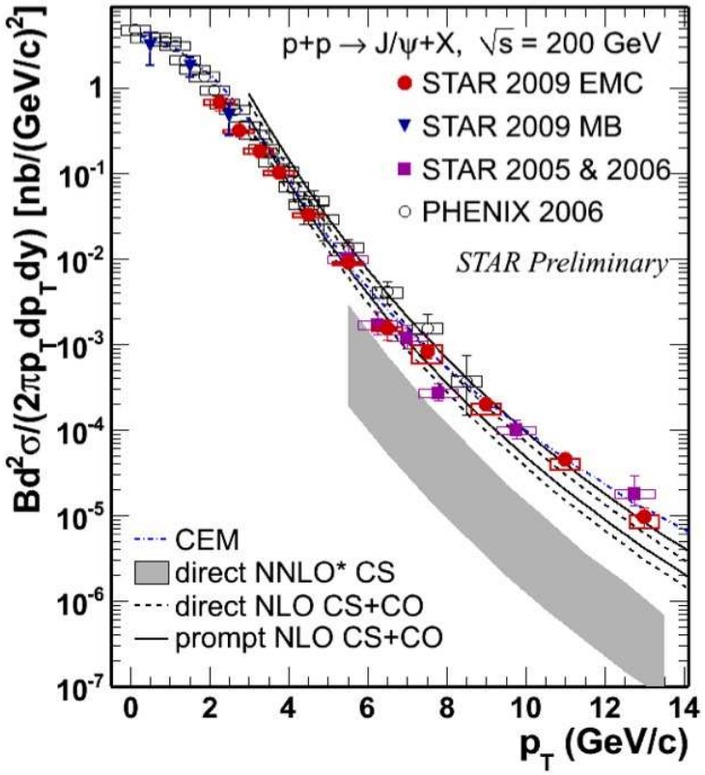
Outline

- *Motivation and model predictions*
- *Decay angular distribution*
- *Electron identification*
- *J/ψ signal*
- *cosθ distributions*
- *J/ψ polarization parameter*
- *Summary*

Motivation

- J/ψ analysis in p+p collisions serves not only as a baseline for the J/ψ production in heavy ion collisions, it is very important tool for understanding the J/ψ production mechanism



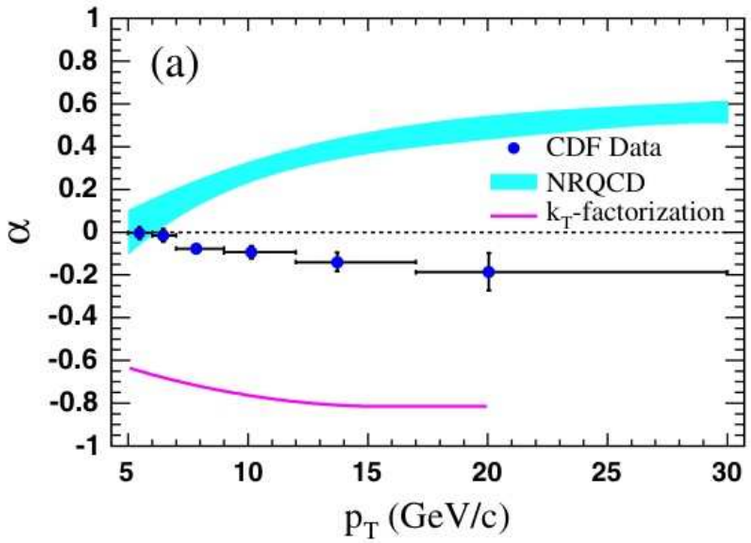


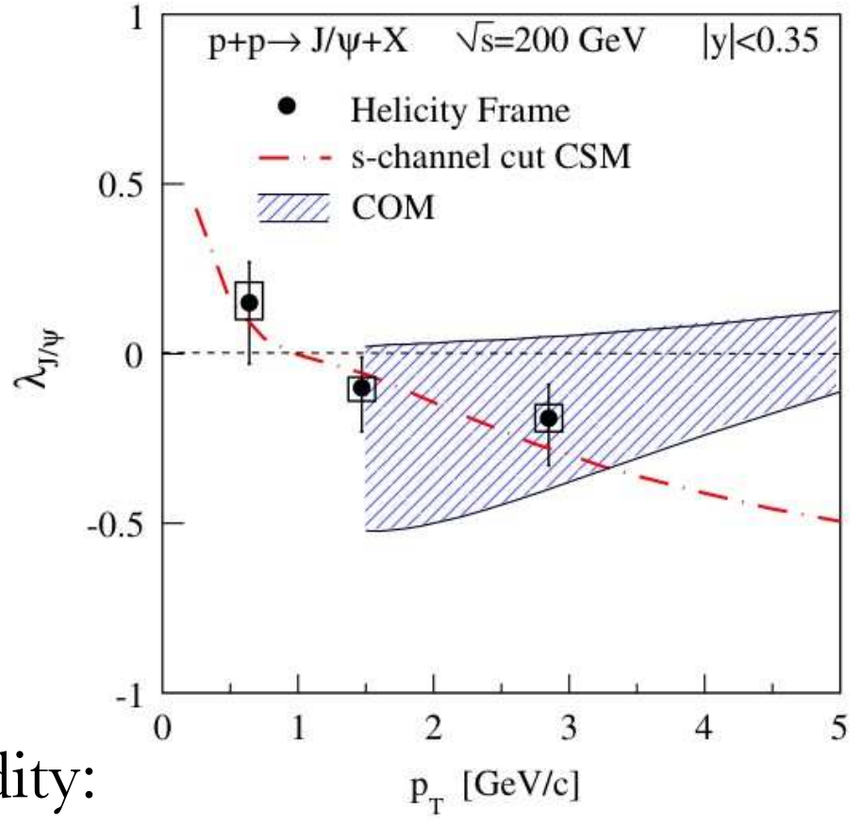
PHENIX: Phys. Rev. D 82, 012001 (2010)
STAR: Phys. Rev. C80, 041902(R) (2009)
STAR high-pr : Phys. Lett. B 722 (2013) 55
direct NNLO: P.Artoisenet et al., Phys. Rev. Lett. 101, 152001 (2008) and J.P.Lansberg private communication
NLO CS+CO: Y.-Q.Ma, K.Wang, and K.T.Chao, Phys. Rev. D84, 51 114001 (2011)
CEM: M. Bedjidian et al., hep-ph/0311048, and R.Vogt private communication

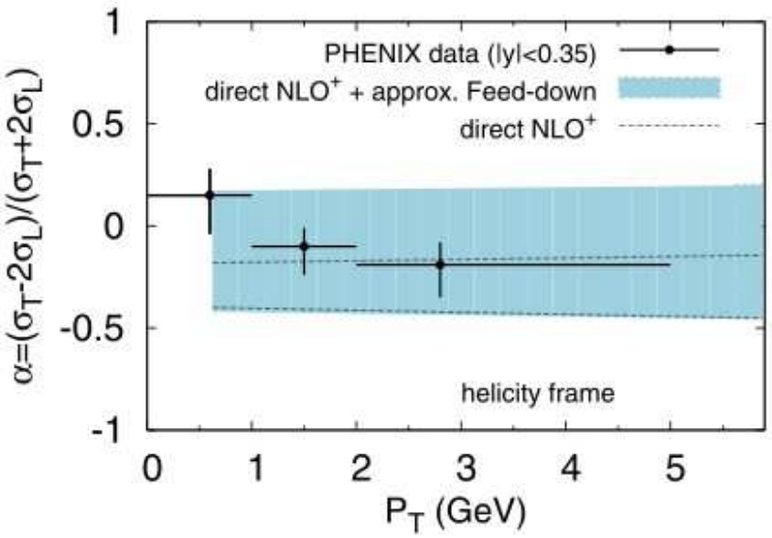
- Currently, various models with different assumptions regarding the J/ψ production mechanism describe the measured J/ψ production cross section rather well; other observables are needed
- *J/ψ polarization measurement at higher p_T is expected to have discrimination power between different models of the J/ψ production mechanism*
  - *Color-singlet process*: J/ψ is produced via intermediate color-neutral ccbar state with the same quantum number as the final state. perturbative
  - *Color-octet process*: J/ψ is produced via intermediate colored ccbar state of any possible quantum numbers. perturbative ⊗ non-perturbative

Model predictions

Various models have different, p_T dependent predictions regarding the J/ψ polarization







[1] Phys. Rev. D 62, 094005 (2000)
[2] Phys. Rev. D 81, 014020 (2010)
[3] Phys. Lett. B, 695, 149 (2011)
[4] Phys. Rev. D 82, 012001 (2010)

Predictions at mid-rapidity:

- *NRQCD calculations with color octet contributions (Color Octet Model)* - transverse polarization at higher p_T, above 5 GeV/c, slightly longitudinal for lower p_T $1.5 < p_T < 5$ GeV/c [1,2]
- *NLO Color Singlet Model* - longitudinal polarization at low and mid p_T [3]
- *Color Evaporation Model* - has no prediction power regarding polarization [4]

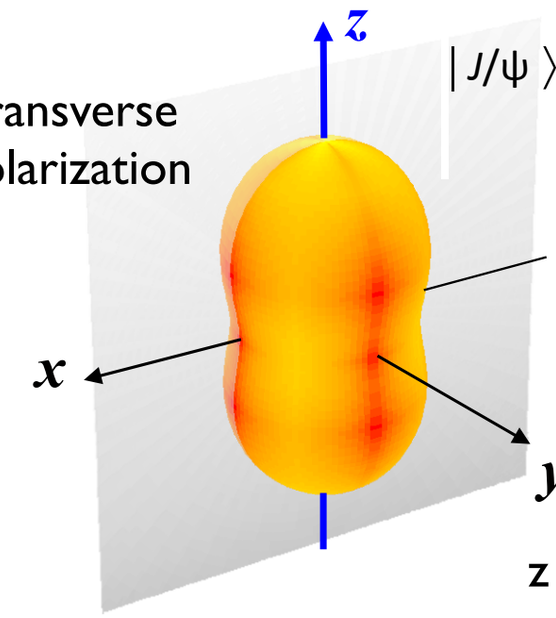
Decay angular distribution

- J/ψ polarization can analyzed via the angular distribution of the decay lepton pair

J=1

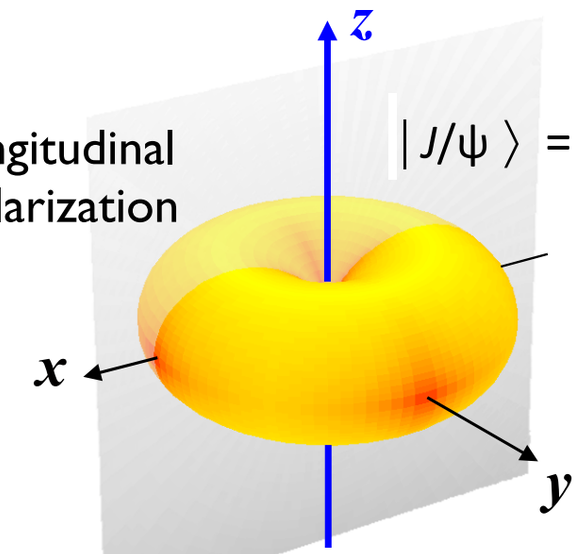
transverse polarization

$|J/\psi\rangle = |1, +1\rangle$ or $|1, -1\rangle$



longitudinal polarization

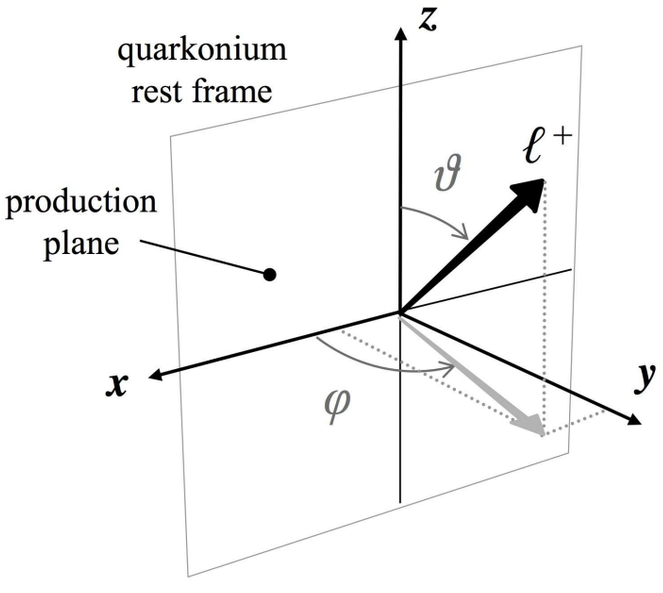
$|J/\psi\rangle = |1, 0\rangle$



z is the polarization axis

The probability of the lepton emission in one direction is represented by the distance of the corresponding surface point from the origin

$$\frac{d\sigma}{d(cos\theta)d\phi} \propto 1 + \lambda_\theta cos^2\theta + \lambda_{\theta\phi} sin(2\theta) cos\phi + \lambda_\phi sin^2\theta cos(2\phi)$$



- For the J/ψ polarization study in an experiment the coordinate system has to be chosen

Polarization parameter λ_θ

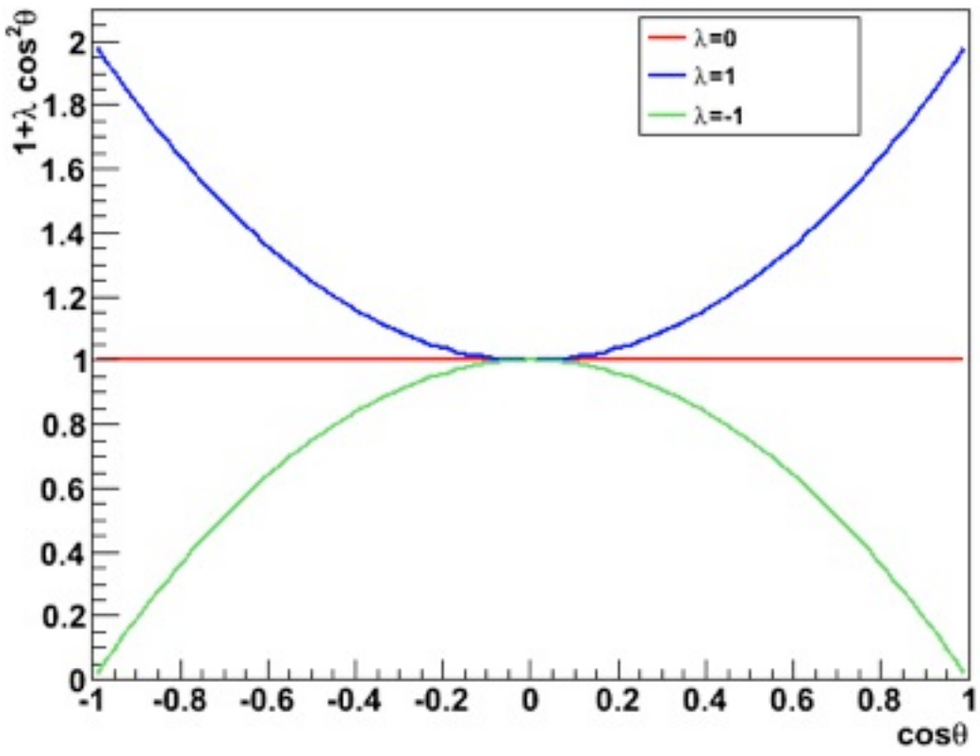
- The angular distribution, integrated over the azimuthal angle, can be parametrized:

$$W(cos\theta) \propto 1 + \lambda_\theta cos^2\theta$$

- The polarization parameter λ_θ contains both the longitudinal and the transverse component of the J/ψ cross section:

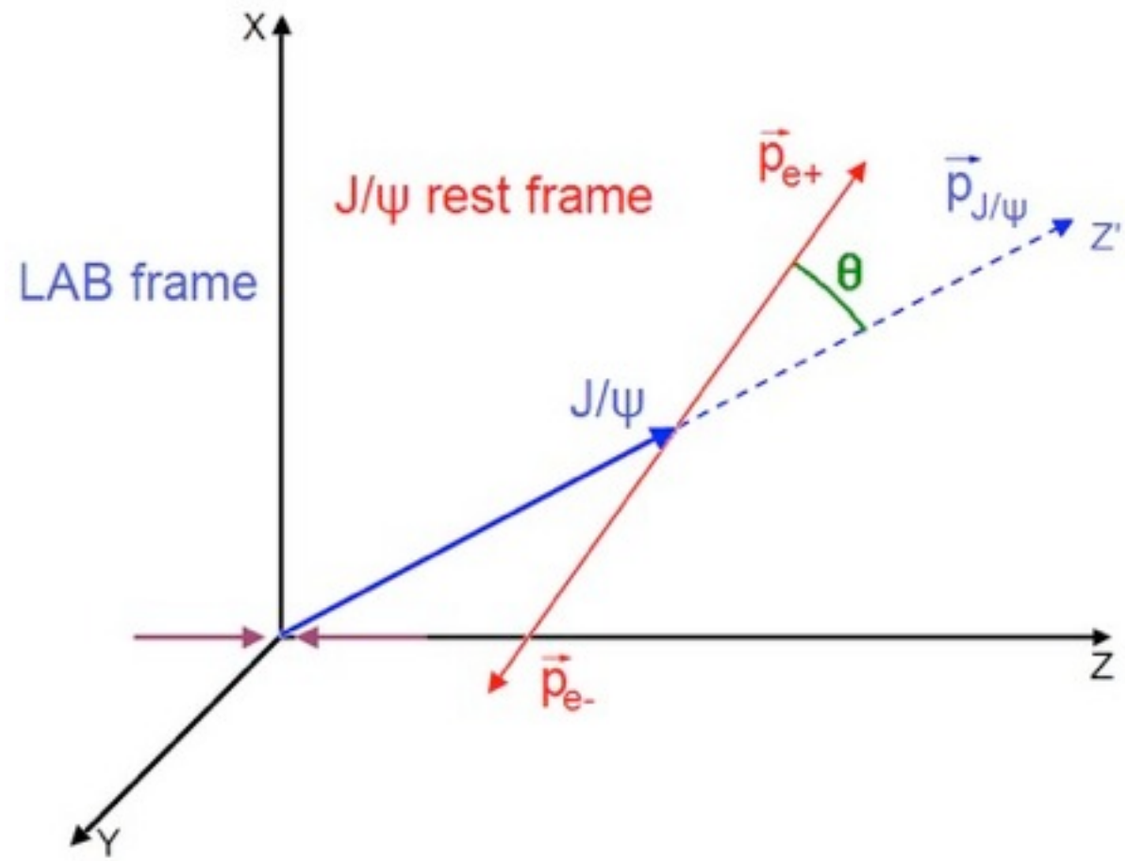
$$\lambda = \frac{\sigma_T - 2\sigma_L}{\sigma_T + 2\sigma_L}$$

- ✓ $\lambda_\theta = -1$ - full longitudinal polarization
- ✓ $\lambda_\theta = 0$ - no polarization
- ✓ $\lambda_\theta = 1$ - full transverse polarization



λ_θ extraction in the analysis

- J/ψ polarization is measured in the **helicity frame** - polarization axis *z* is along the J/ψ direction in the center of mass frame



- The polar angle θ is an angle between the positron momentum vector in the J/ψ rest frame and J/ψ momentum vector in the lab frame

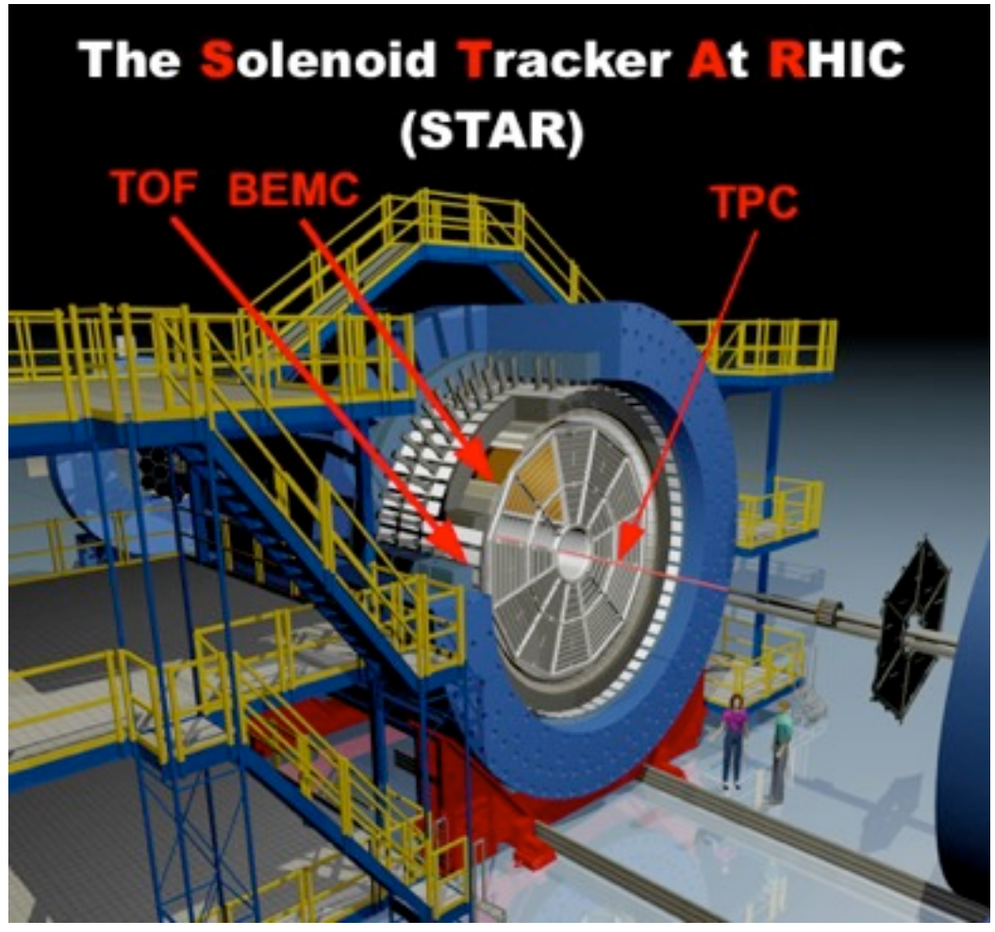
- ***norm(1+λ_θ cos$^2\theta$)*** function is fitted to corrected cosθ distributions

J/ψ reconstruction

$J/\psi \rightarrow e^+ e^-$ (BR 5.9%)

$p_T \geq 1.4$ GeV/c

$|\eta| < 1$



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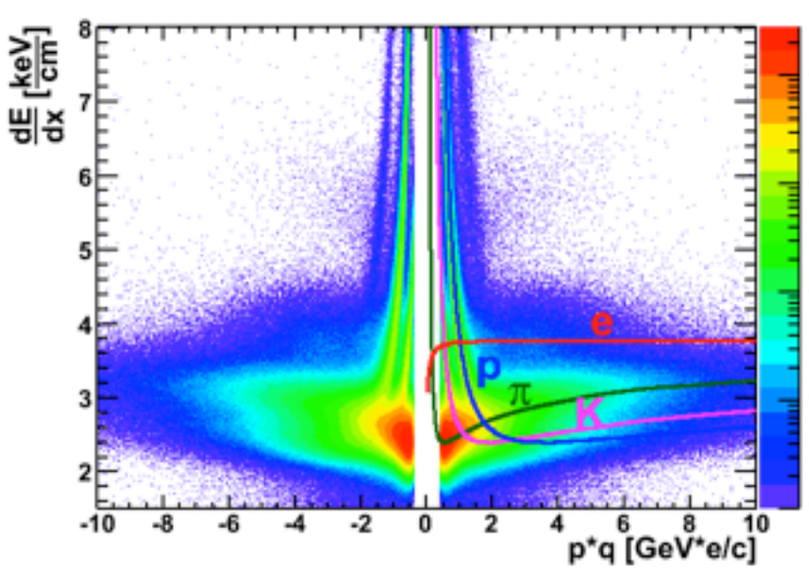
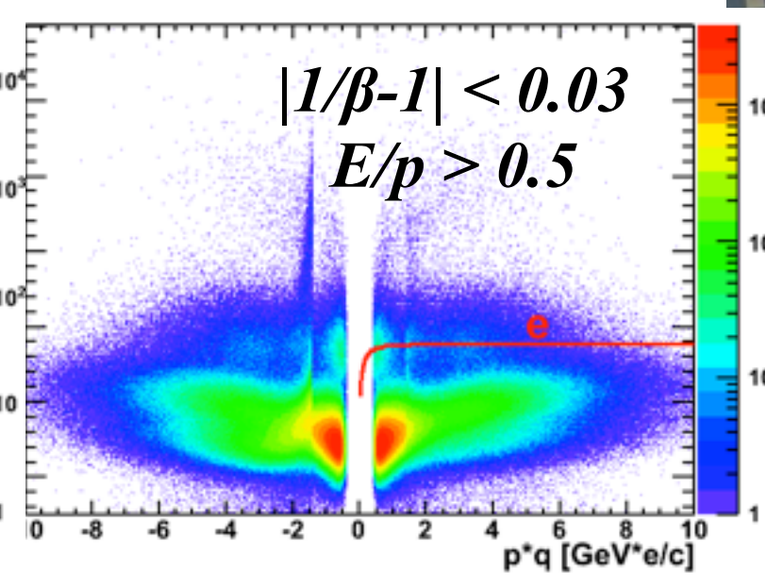
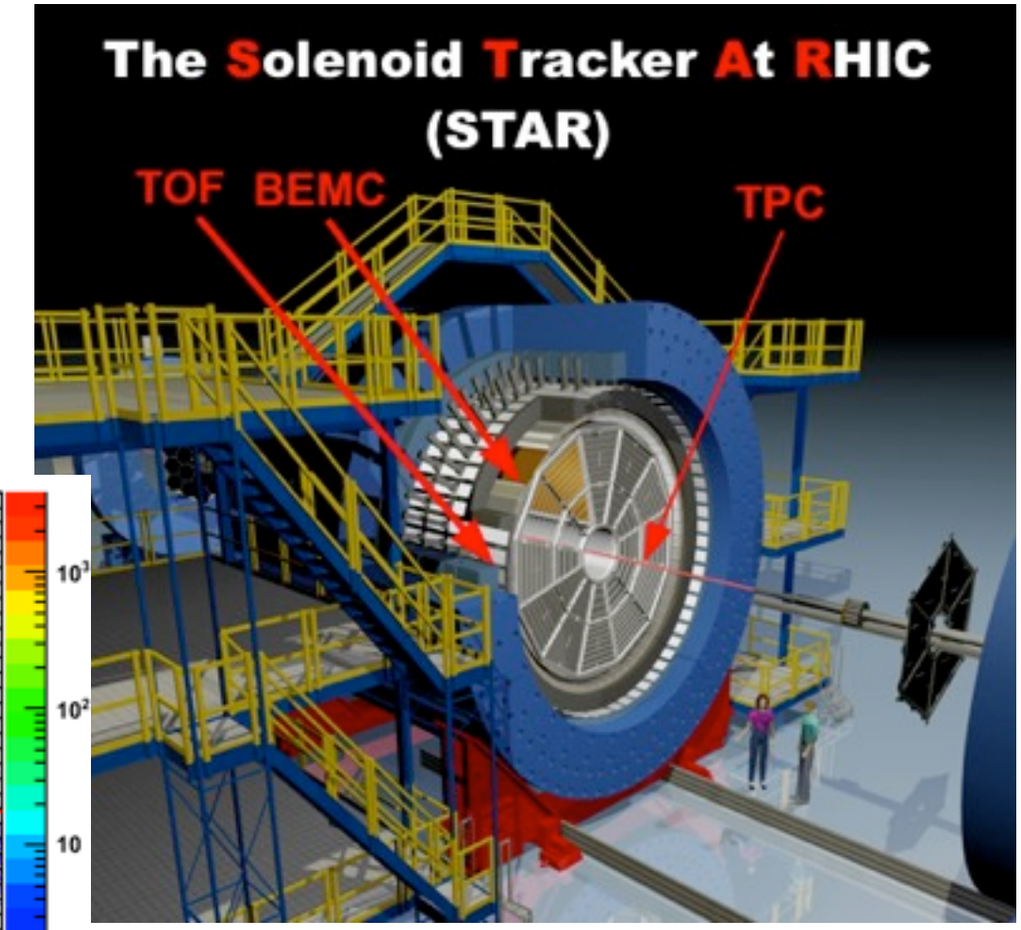
eID

- ***TPC*** - *dE/dx* - used for whole p range

$-1 < n\sigma_e < 2$







$J/\psi \rightarrow e^+e^-$ (BR 5.9%) — J/ψ reconstruction

$p_T \geq 1.4$ GeV/c

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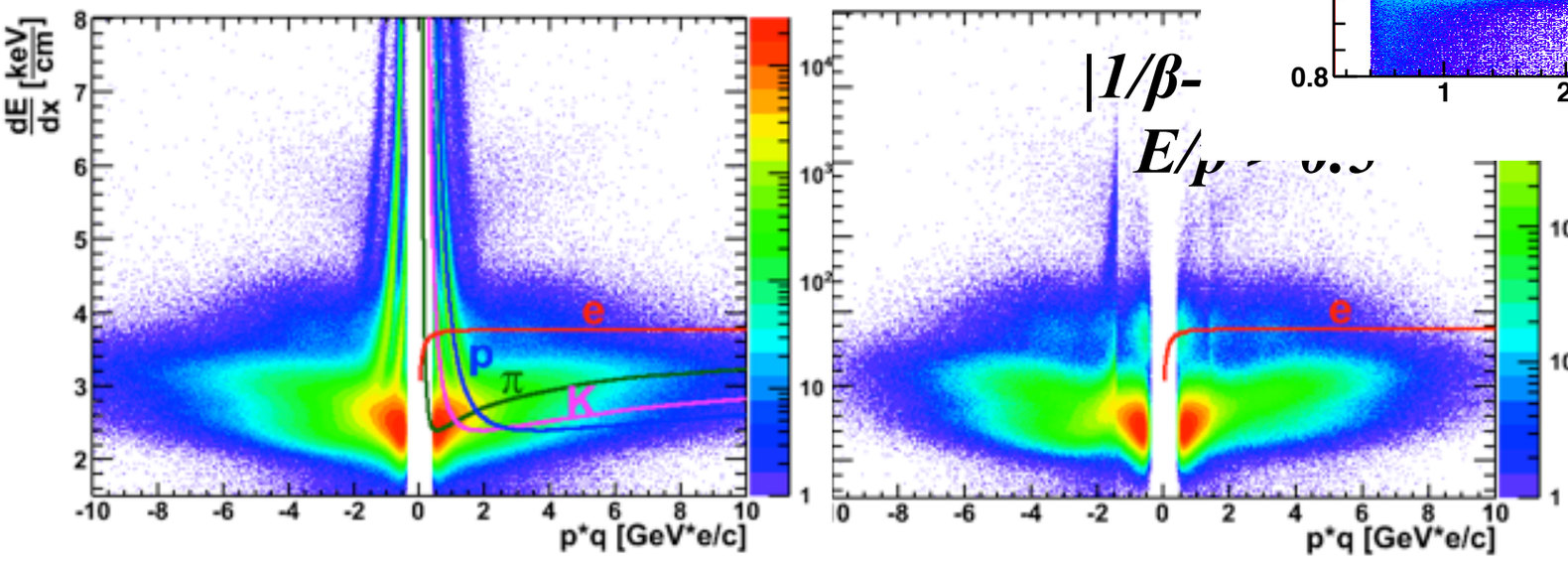
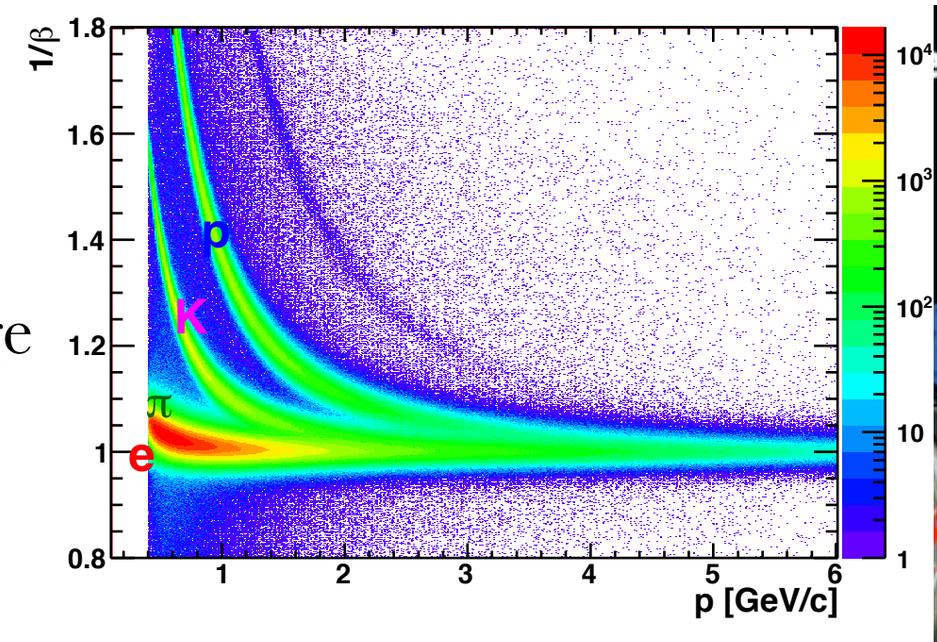


|1/β-

E/p



- ***TOF*** (72% of full TOF in 2009) - *β*

  $|1/\beta - 1| < 0.03$, for $p < 1.4$ GeV/c

  (β = pathLength/TimeOfFlight/c)

$J/\psi \rightarrow e^+e^-$ (BR 5.9%) — J/ψ reconstruction

$p_T \geq 1.4$ GeV/c

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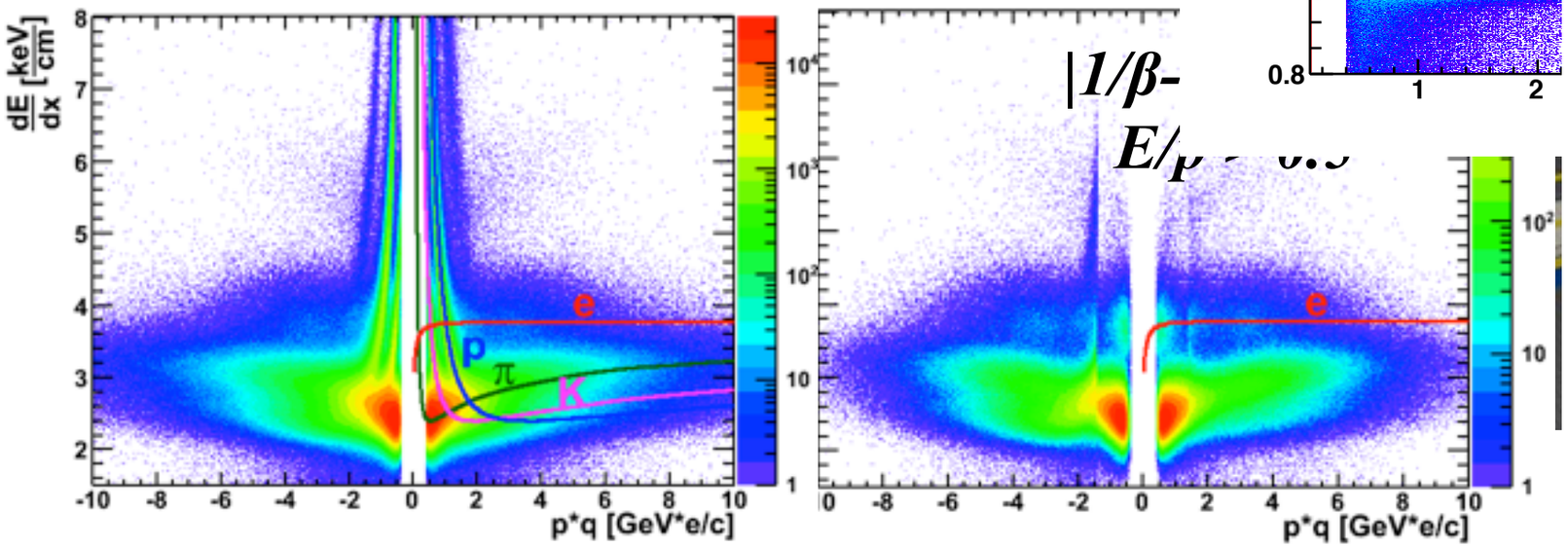

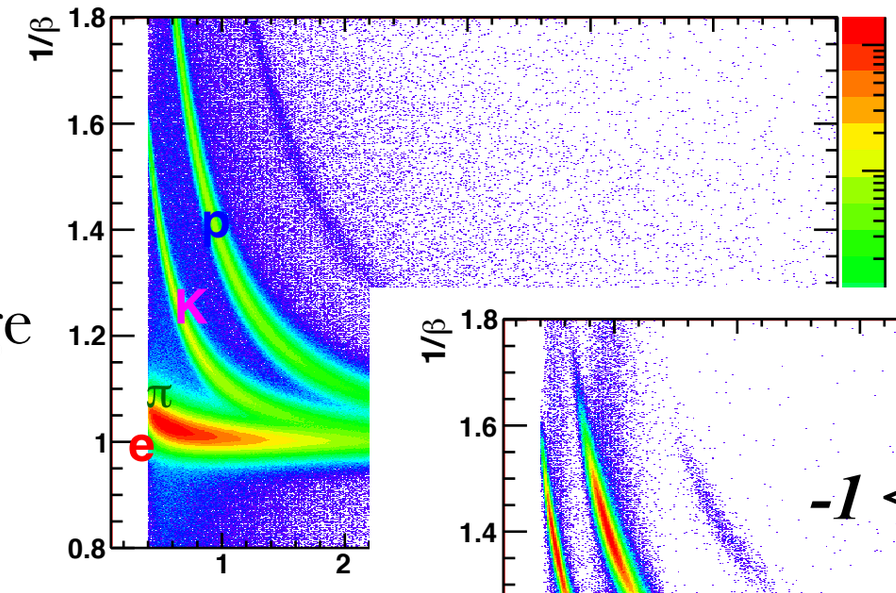

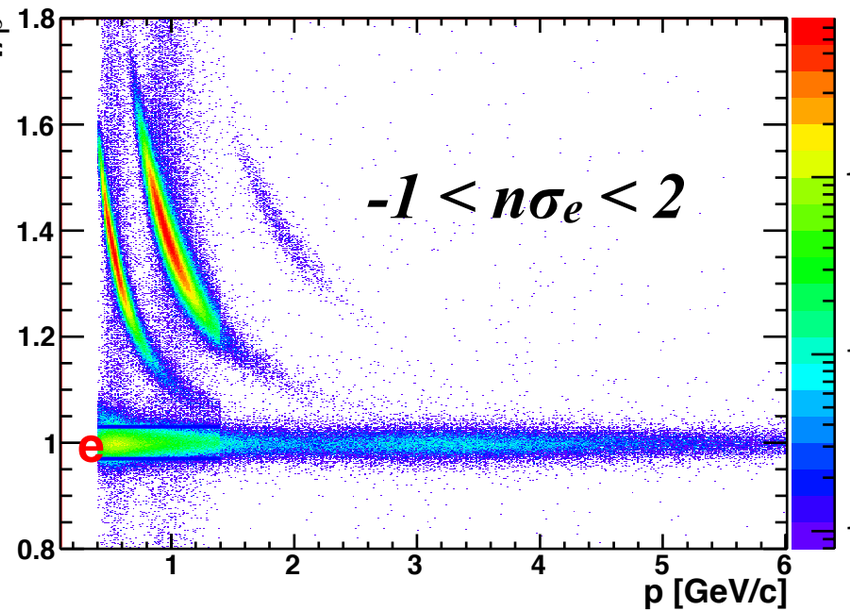

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$p_T \geq 1.4$ GeV/c

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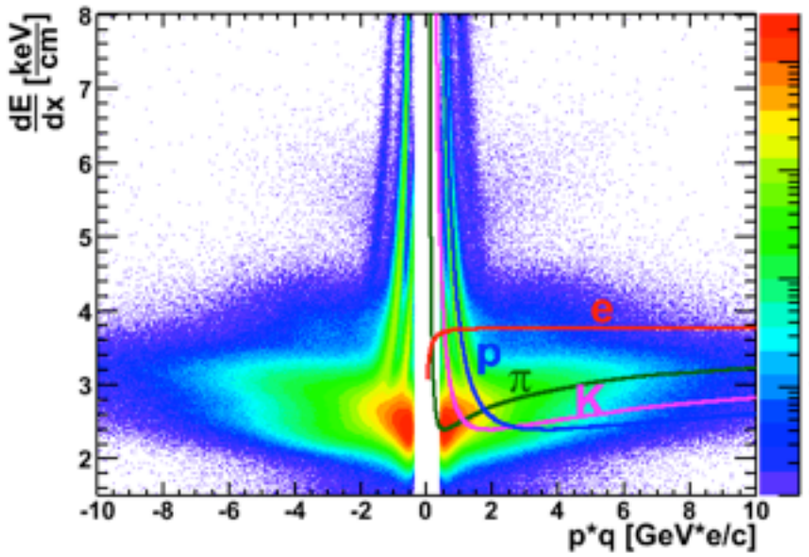

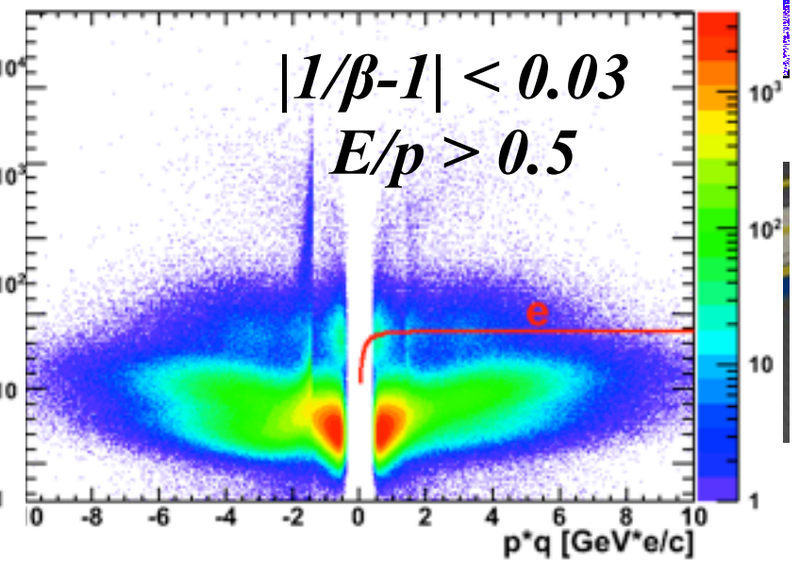

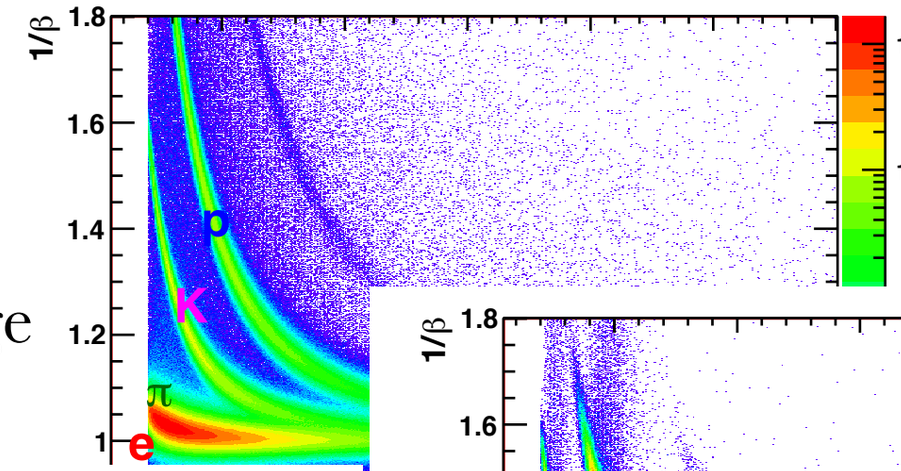

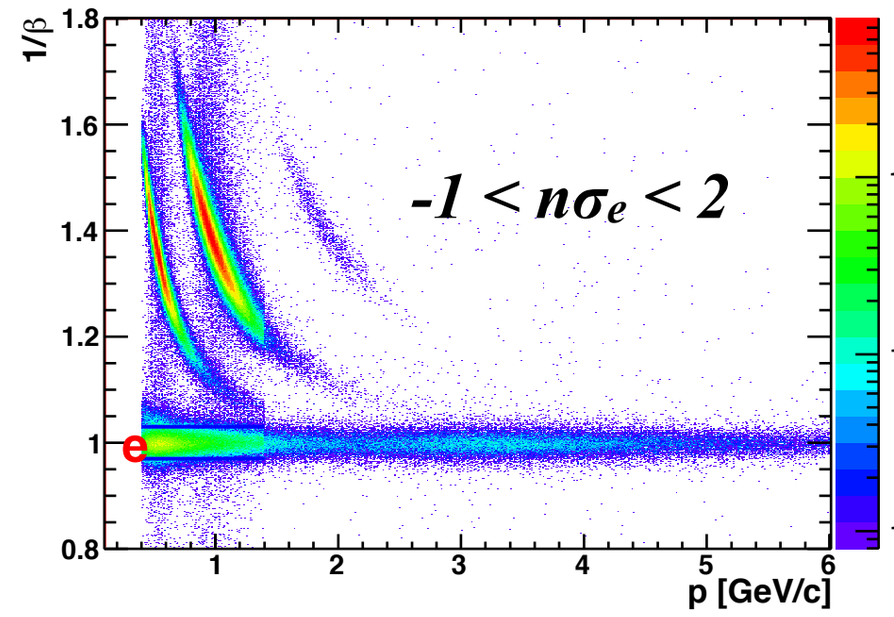

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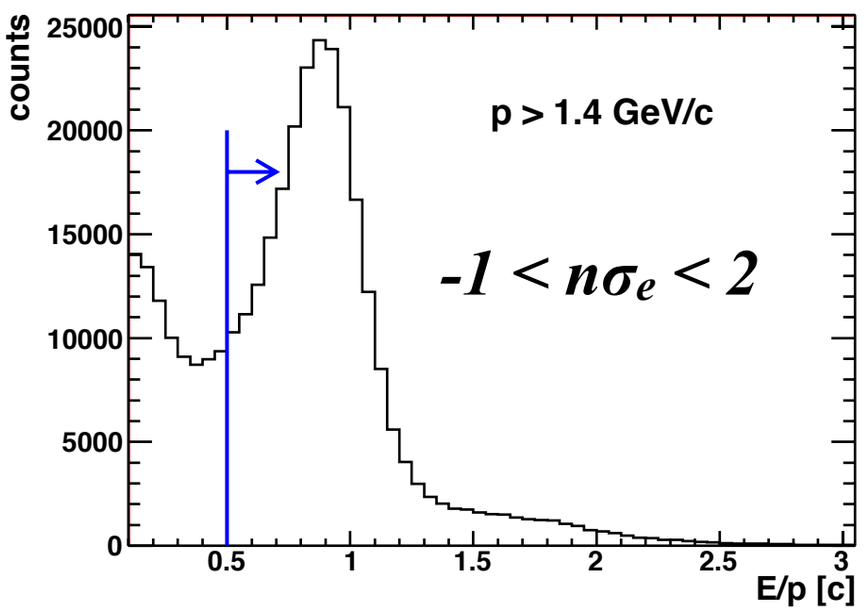
  $|1/\beta - 1| < 0.03$, for $p < 1.4$ GeV/c

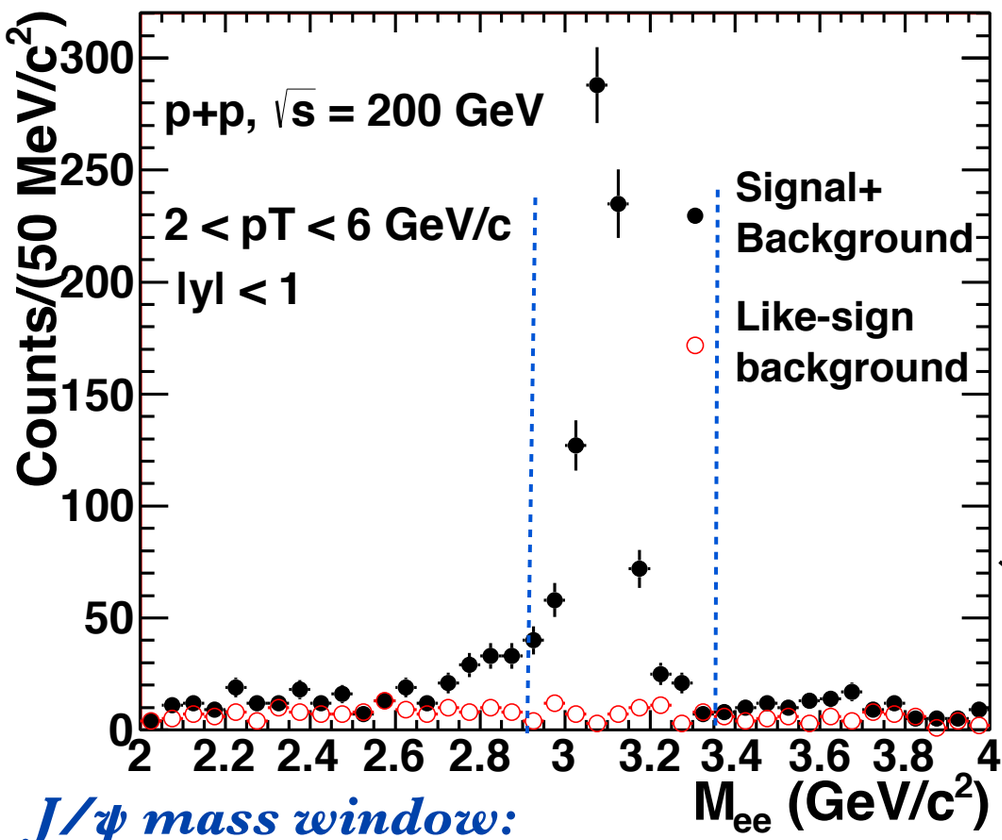
  (β = pathLength/TimeOfFlight/c)

- ***BEMC*** - *E*, energy deposited in a tower - for e E/p ~ 1

  $E/p > 0.5$, for $p \geq 1.4$ GeV/c



J/ψ signal



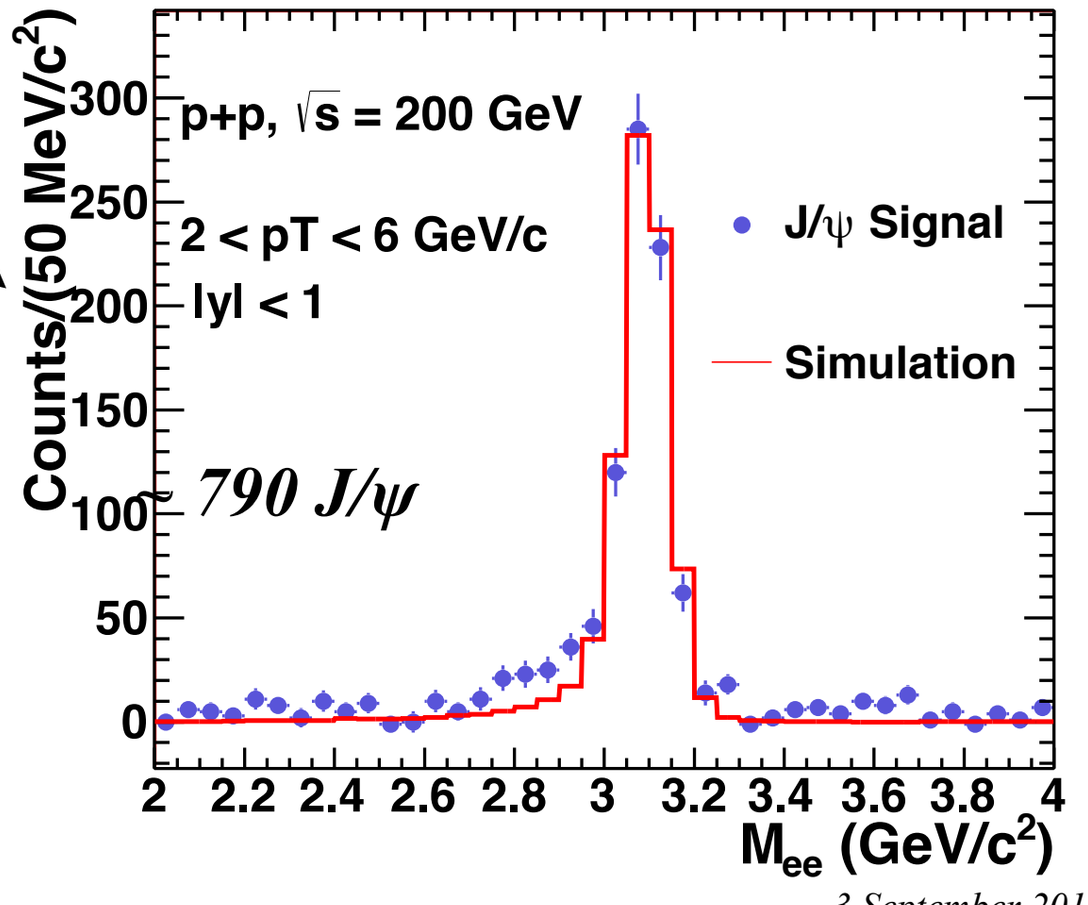
J/ψ mass window: 2.9 - 3.3 GeV/c^2

dataset:

- p+p collisions at $\sqrt{s}$ = 200 GeV from year 2009
- ~ 33 M events with HT trigger:
  2.6 GeV < E_T ≤ 4.3 GeV
- Integrated luminosity ~ 1.6 pb^{-1}
- At least one electron from the J/ψ decay has to fire the HT trigger

significance: $S/dS = S/\sqrt{(S+2B)}$

after background subtraction



background obtained using like-sign technique:

$$N_{e^-e^-} + N_{e^+e^+}$$

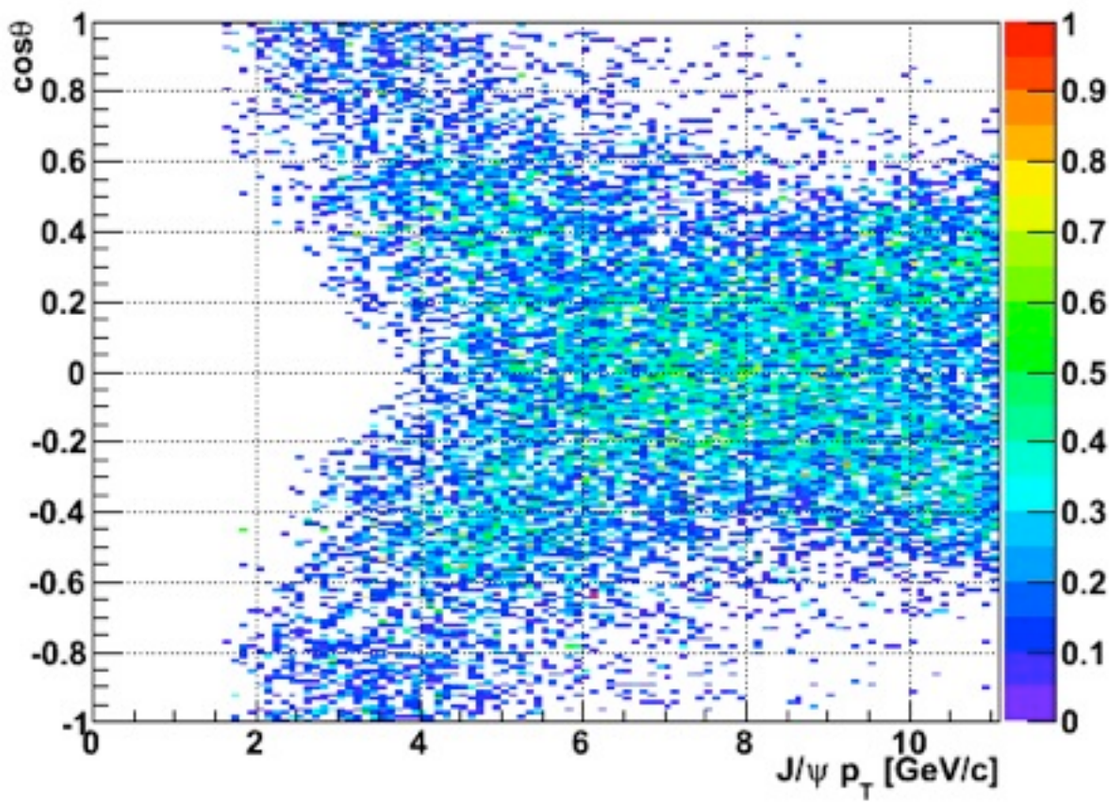
- Clear J/ψ signal with high significance of ***26σ*** in J/ψ p_T range: 2 - 6 GeV/c and rapidity: $|y|<1$
- Obtained number of J/ψs ~ 790 allow to split the signal into 3 p_T bins for polarization analysis

Corrections

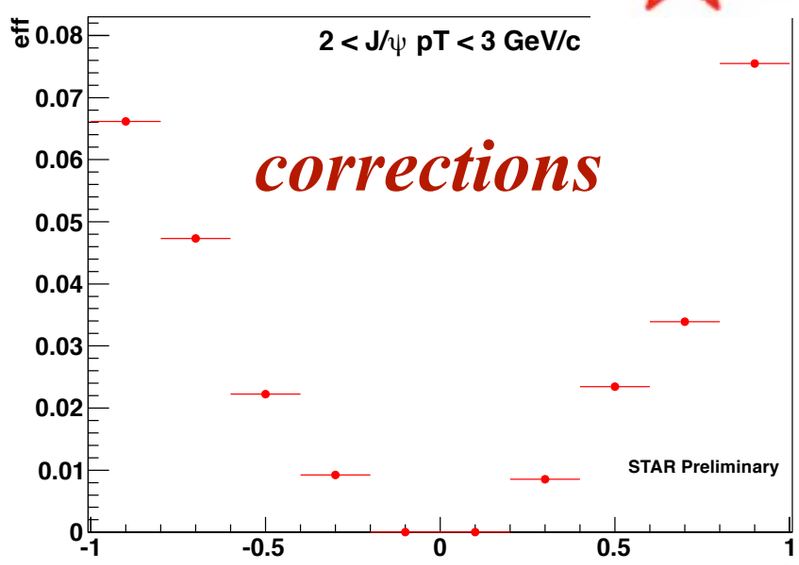
- cosθ corrections are obtained from the simulation:
  - MC J/ψs with uniform p_T and y distributions were embedded into real events and the detector response was simulated
  - simulated J/ψ are also unpolarized - input cosθ distribution is flat
- In the simulation analysis the same cuts (or corresponding weights) as in the data analysis, are used
- Distributions are also re-weighted according to p_T and y distributions from experiments

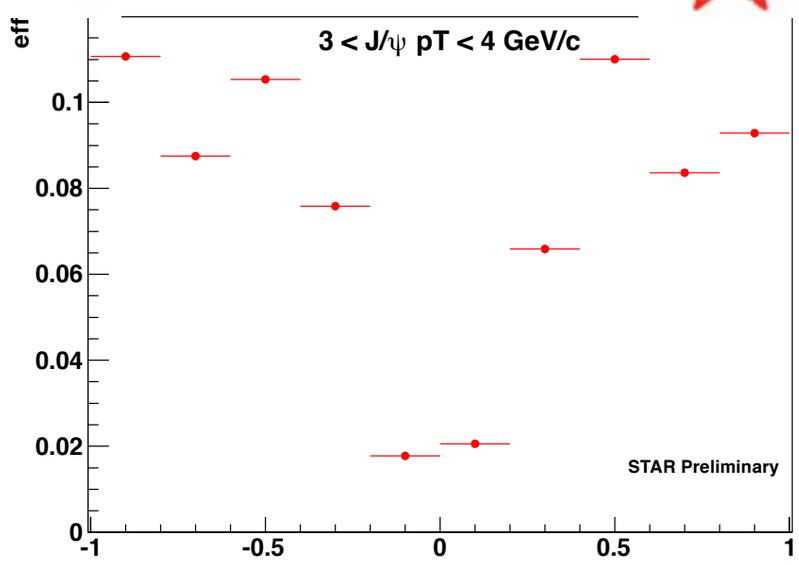
corrections include:

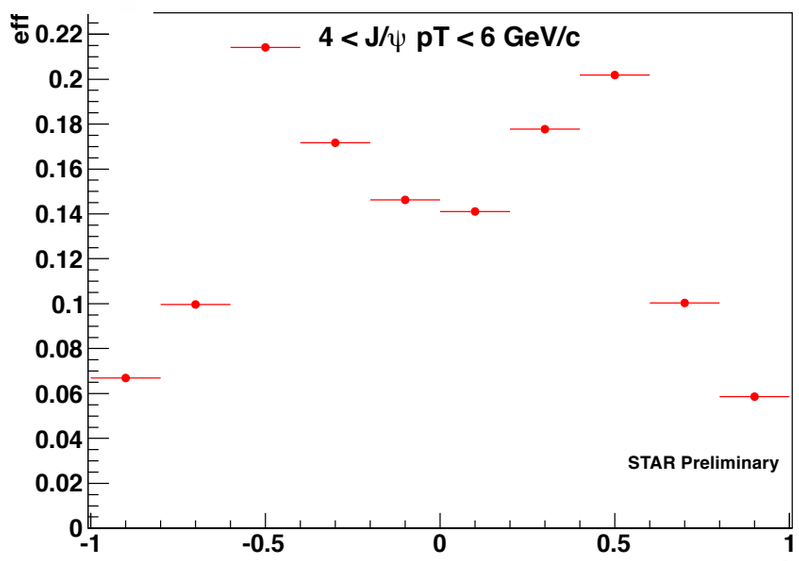
- *acceptance correction*
- *tracking efficiency*
- *electron identification efficiency*
- *HT trigger efficiency*



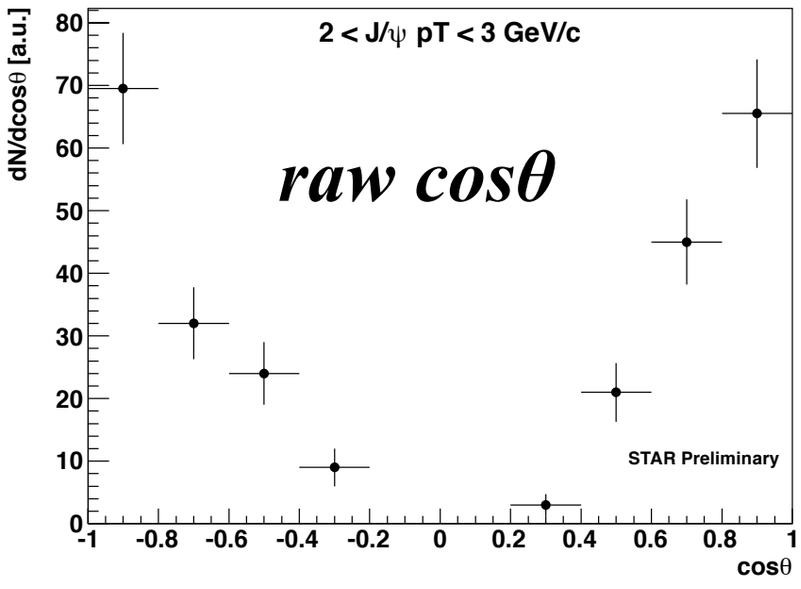
Uncorrected cosθ



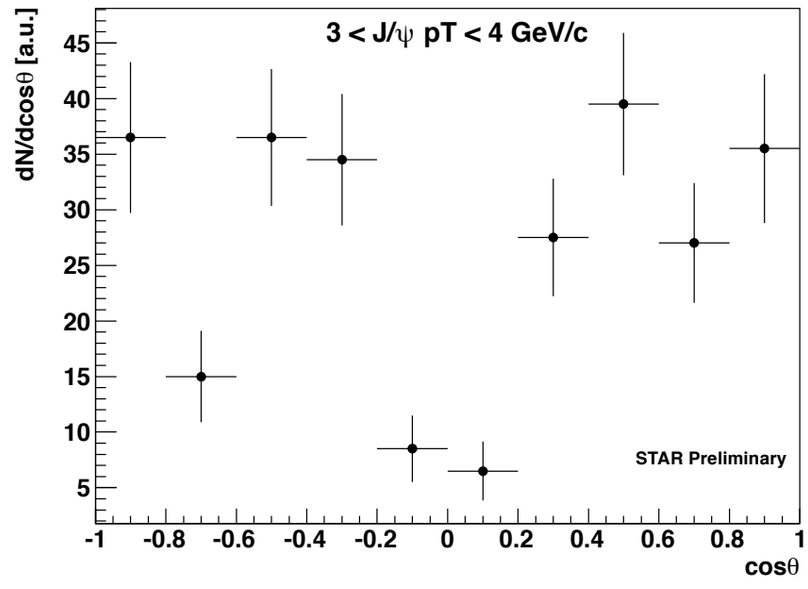




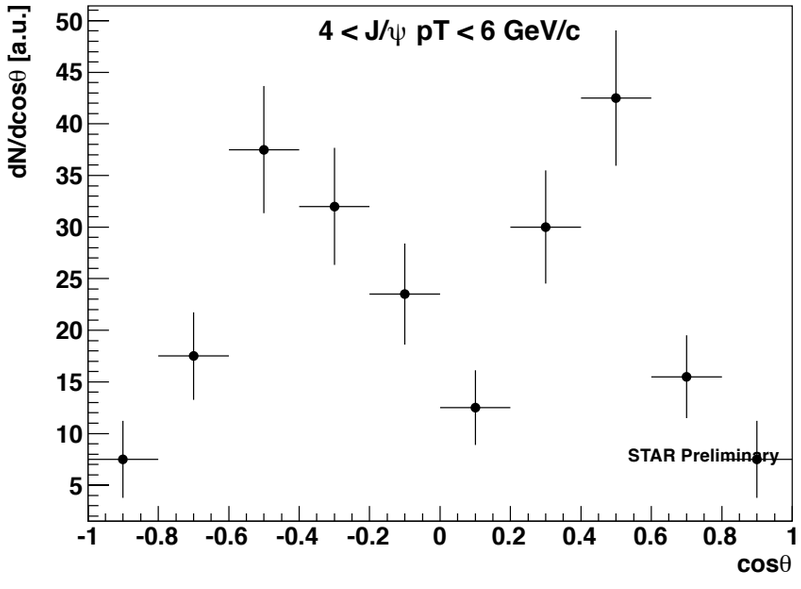
2 < J/ψ p_T < 3 GeV/c



3 < J/ψ p_T < 4 GeV/c



4 < J/ψ p_T < 6 GeV/c



- Uncorrected cosθ distributions are divided by the total efficiency in order to obtain corrected cosθ distributions

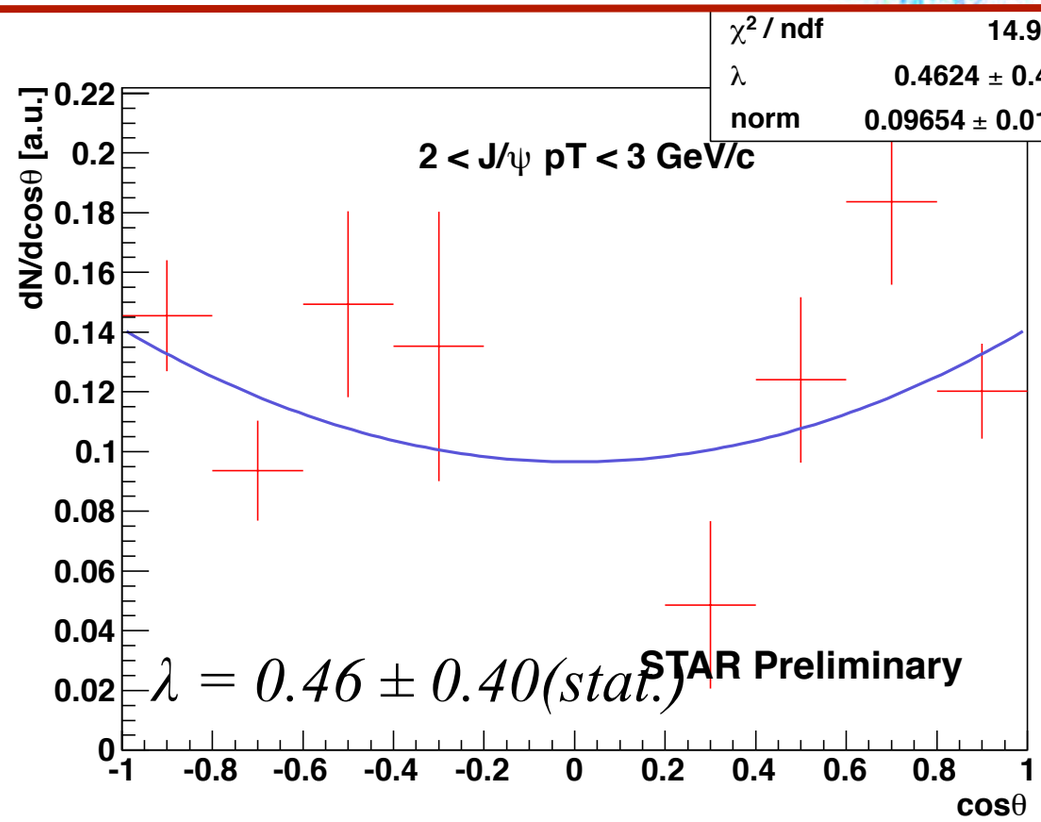
Corrected cosθ distributions

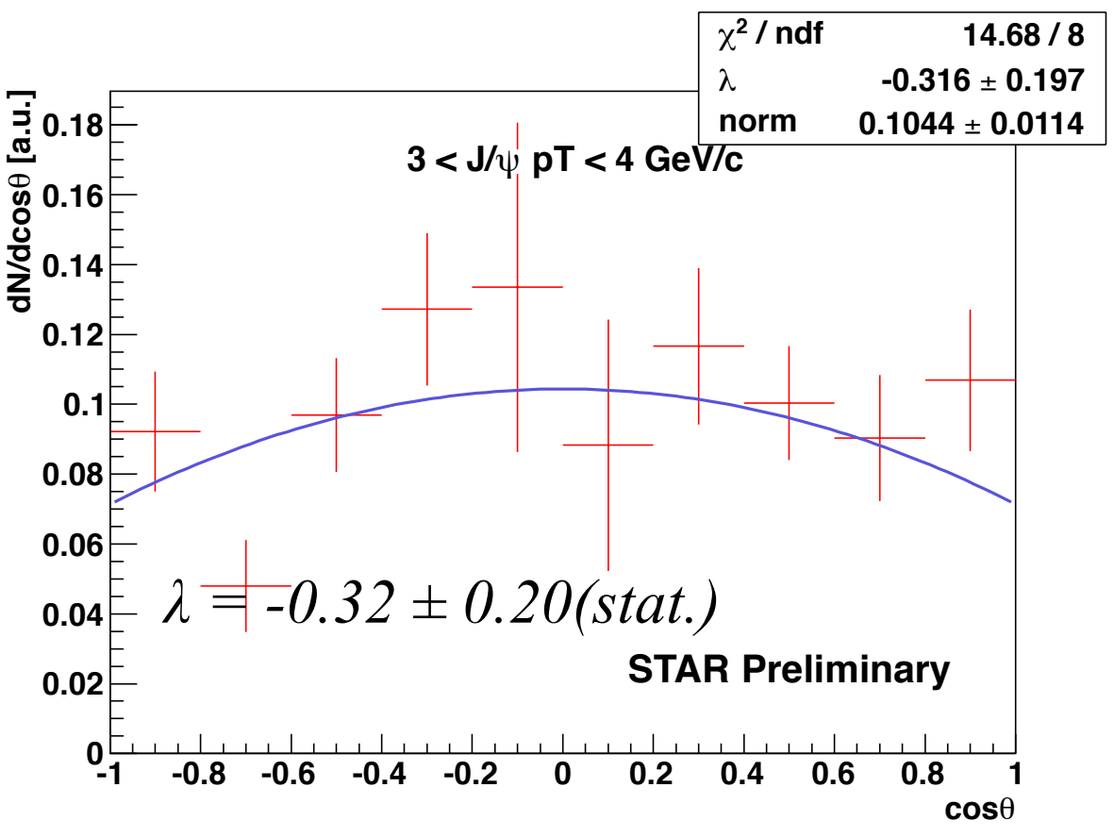
- Polarization parameter λ is extracted in 3 J/ψ p_T bins: 2-3 GeV/c, 3-4 GeV/c and 4-6 GeV/c
- J/ψ polarization parameter is obtained by fitting

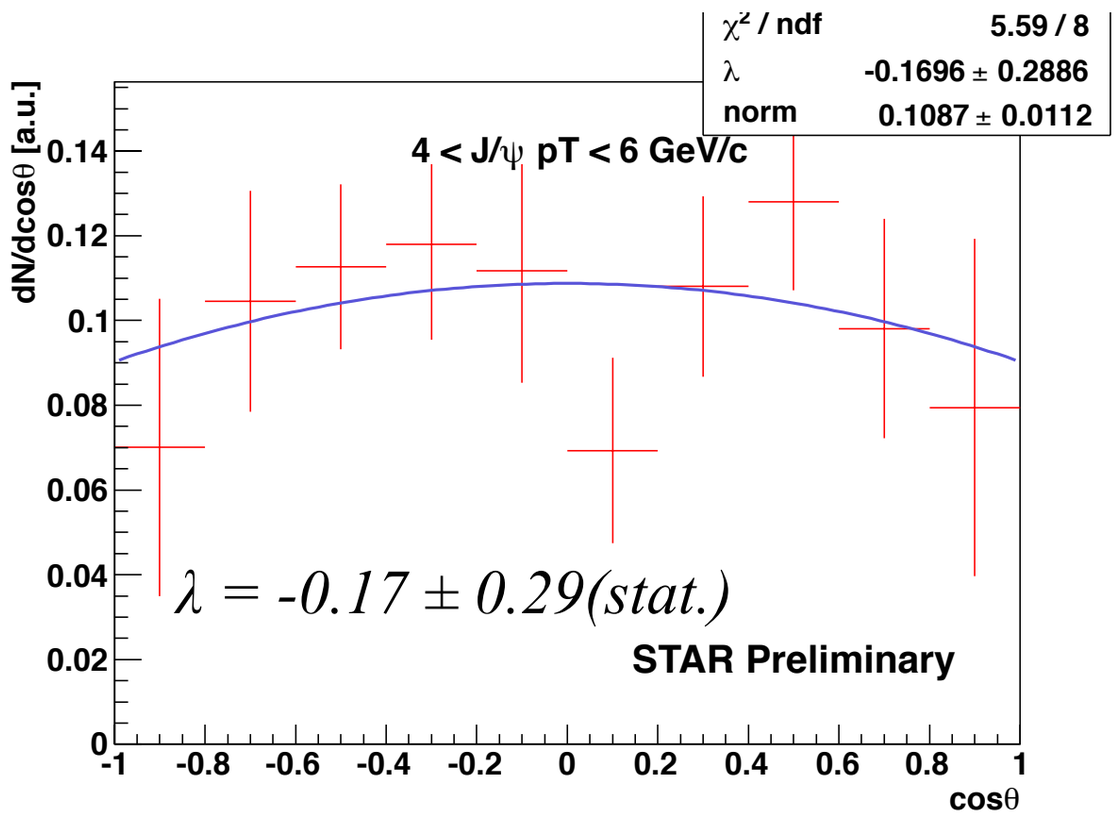
$$norm(1+\lambda_\theta \cos^2\theta)$$

function to corrected cosθ without constraints on the fit parameters

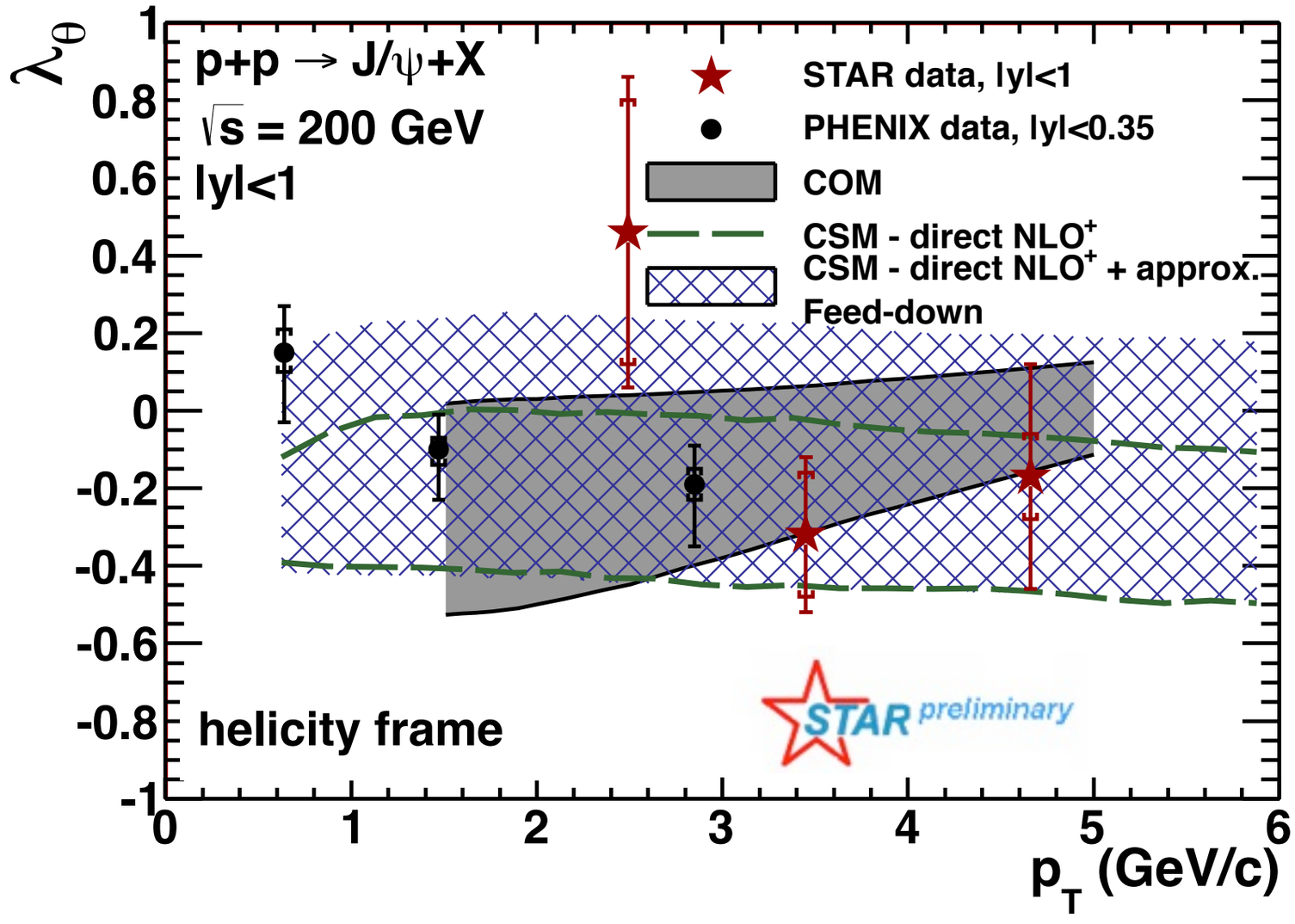
- Lines represent the most likely fit
- Combinatorial background subtracted







J/ψ polarization result



PHENIX: Phys. Rev. D 82, 012001 (2010)
COM: Phys. Rev. D 81, 014020 (2010)
CSM NLO+: Phys. Lett. B, 695, 149 (2011) and private communication

Dominant sources of systematic uncertainties are: cosθ binning and acceptance, J/ψ mass range, electron identification cut, trigger efficiency.

- STAR preliminary result is consistent with the NLO+ CSM and COM predictions
- RHIC J/ψ polarization measurement extended to ~5GeV/c

Summary

- First STAR J/ψ polarization measurement in p+p collisions, at mid-rapidity and for $2 < p_T < 6$ GeV/c
- Polarization parameter λ_θ is extracted in the helicity frame, in 3 J/ψ p_T bins
- Obtained preliminary p_T dependent polarization parameter λ_θ is consistent with NLO+ CSM and COM models predictions and with no polarization within uncertainties
- RHIC J/ψ polarization measurement extended to ~5GeV/c
- Stay tuned - final STAR polarization result coming soon

Thank you !