

Quarkonium detection and physics with ECCE

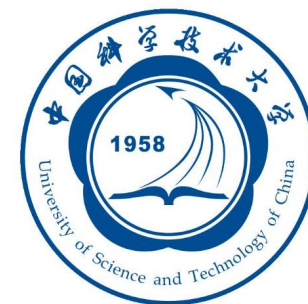
Xinbai Li for ECCE Collaboration
27/10/21



Physics Opportunities with Heavy Quarkonia at the EIC



Xinbai Li



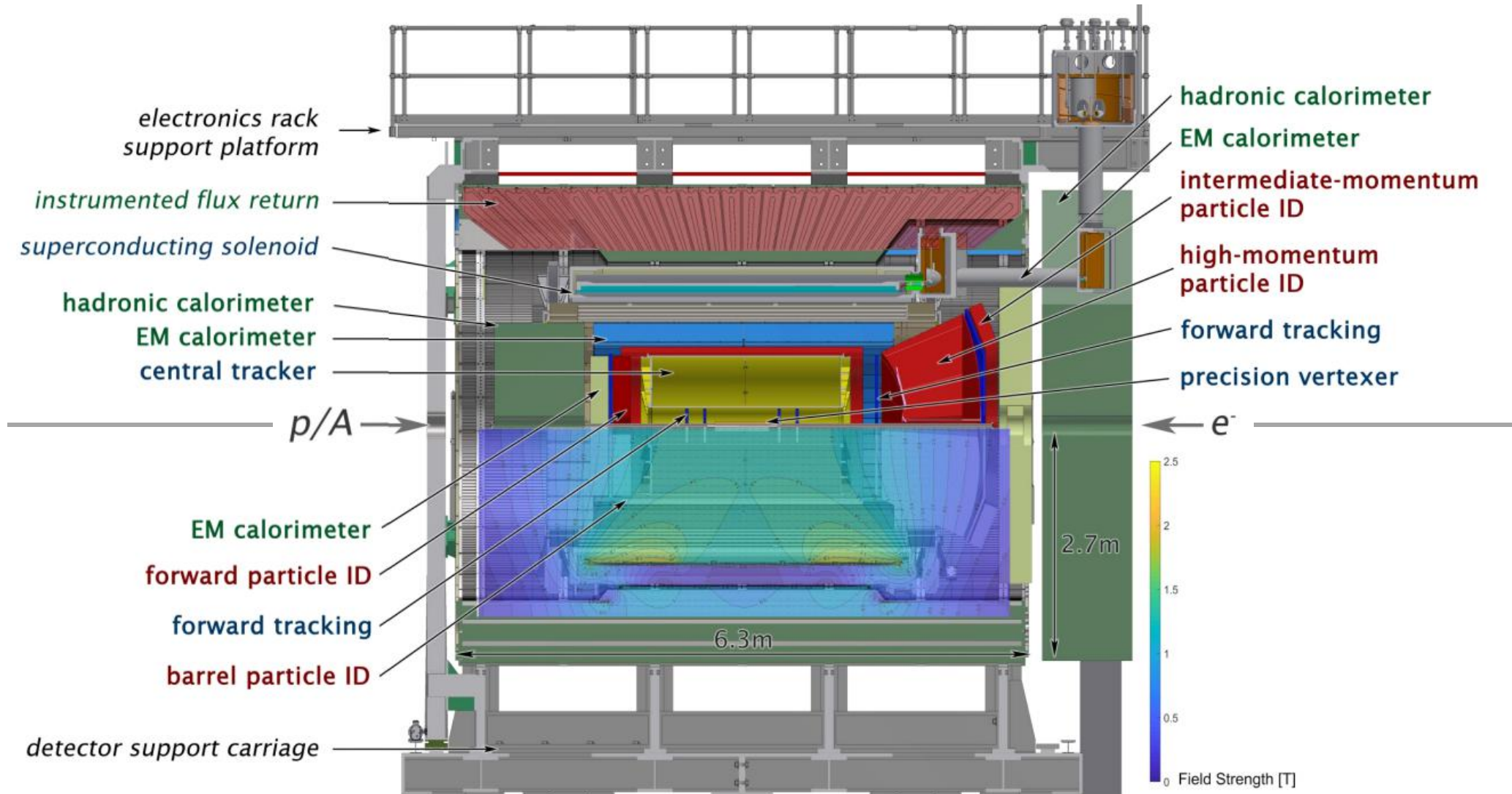
Outline

- Physics Opportunities for Heavy Quarkonia at the EIC
- Detector Configuration of ECCE
- Tracking and electron identification capability
- The simulation of Quarkonia reconstruction at ECCE
- The projection results for J/ψ photoproduction
- Summary and future plan

Physics Opportunities

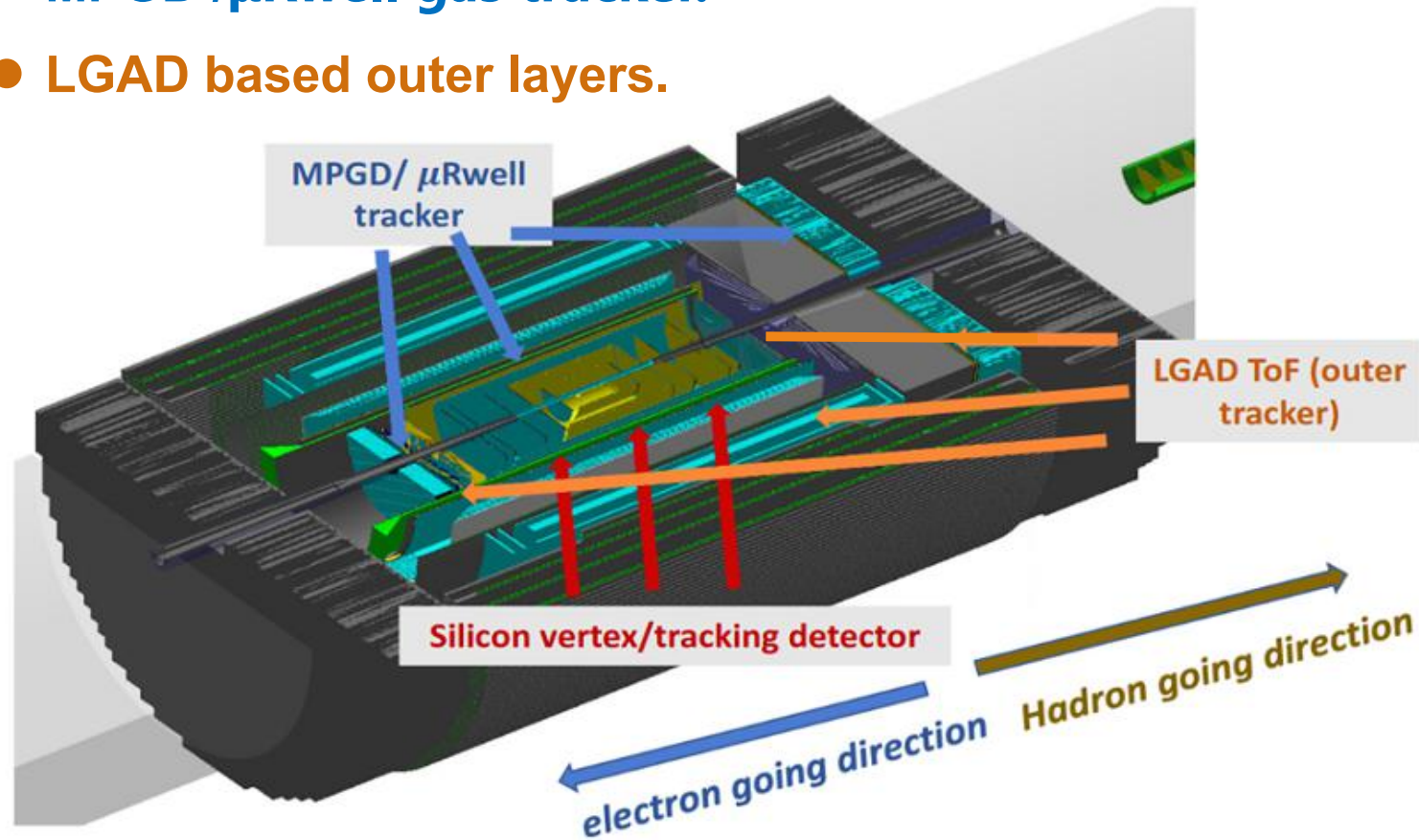
- Production mechanism for quarkonia
 - ✓ Constrain the NRQCD matrix elements
 - ✓ Study the hadronization in nucleus
- 3D tomography of gluon distribution
 - ✓ gluon nPDF (z direction)
 - ✓ Transverse distribution of gluon (x-y direction)
- Near threshold photoproduction
 - ✓ 2g, 3g exchange
 - ✓ The proton mass decomposition

Detector Configuration

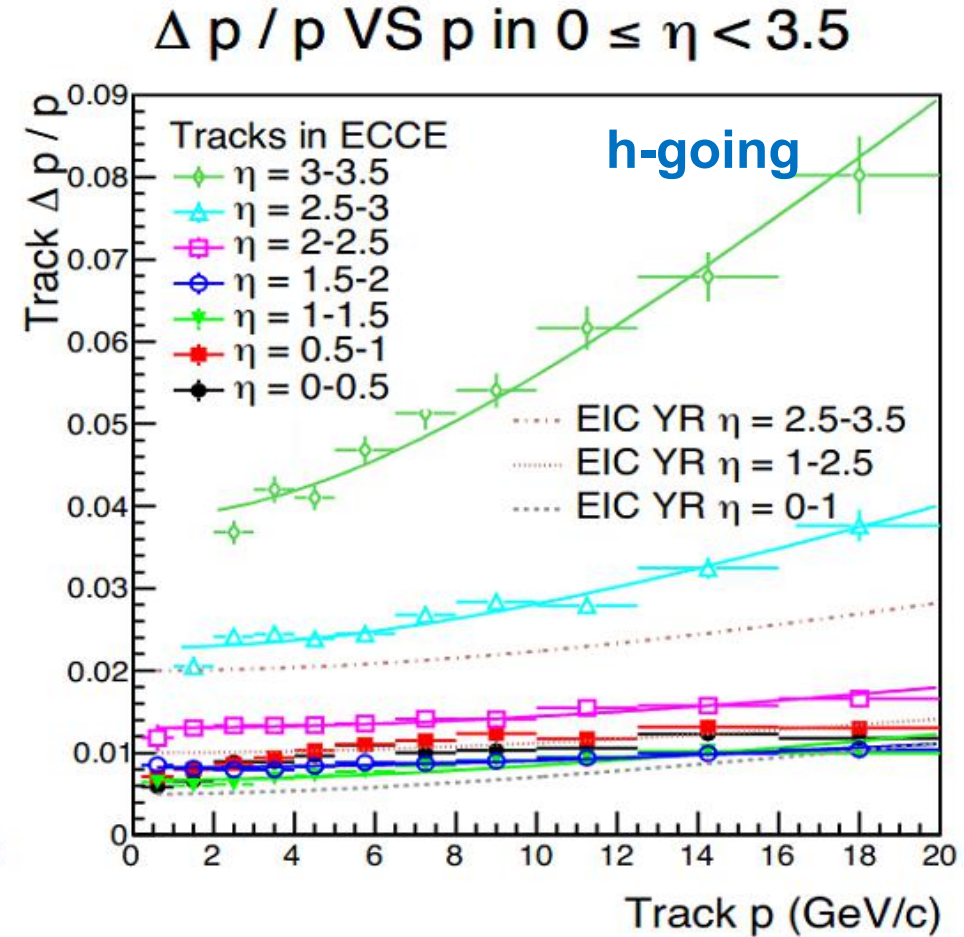
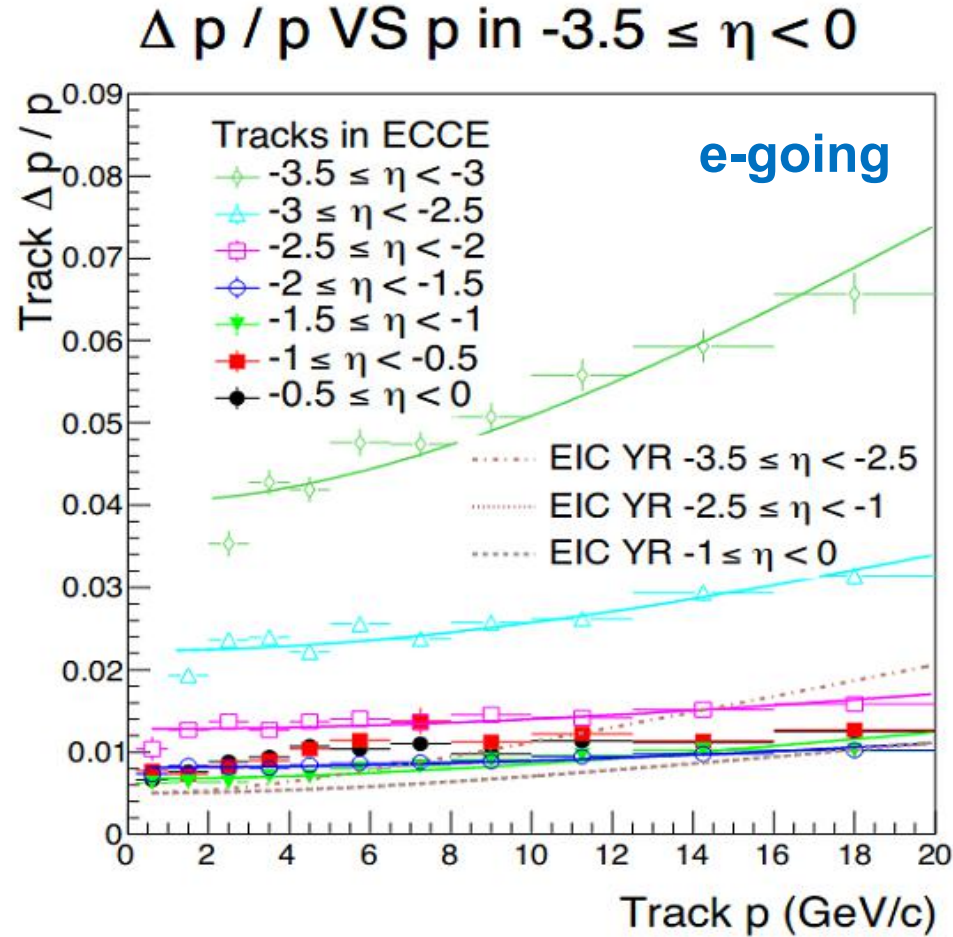


Detector Configuration—Tracking

- MAPS based silicon vertex/ tracking layers/ planes.
- MPGD / μ Rwell gas tracker.
- LGAD based outer layers.



Tracking performance at ECCE

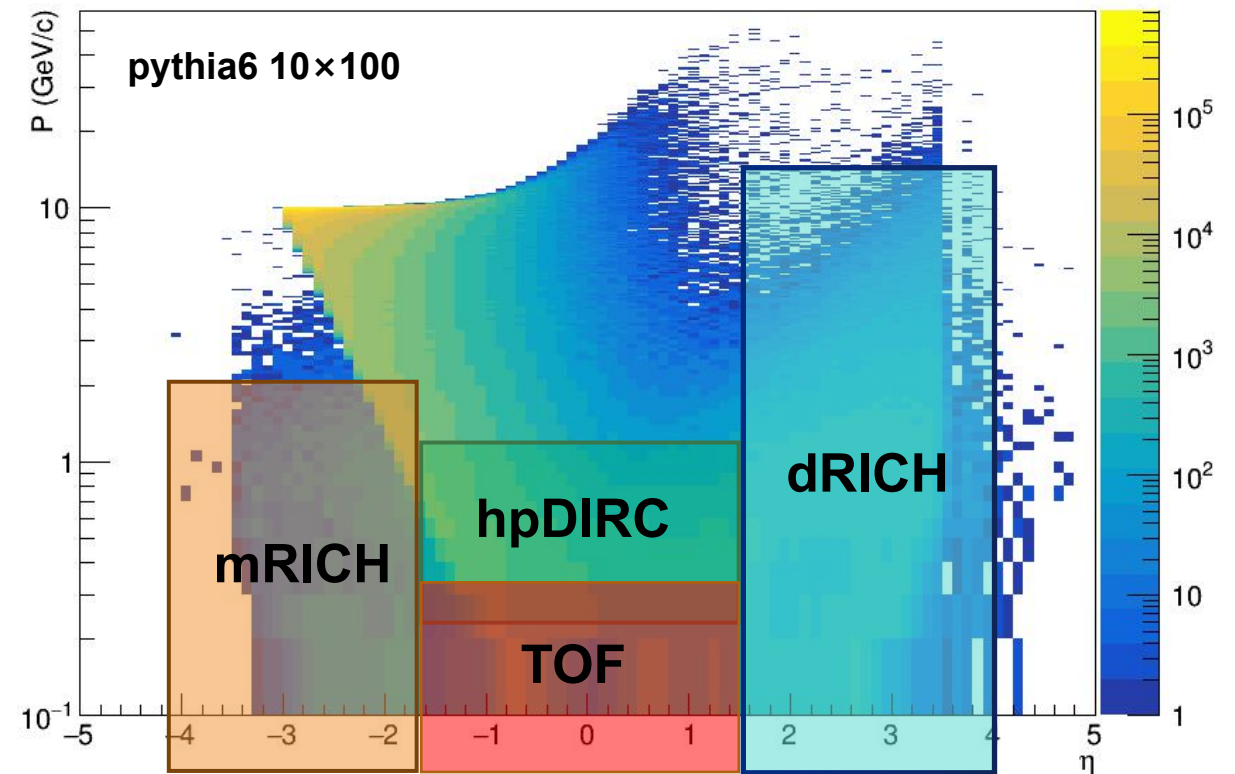
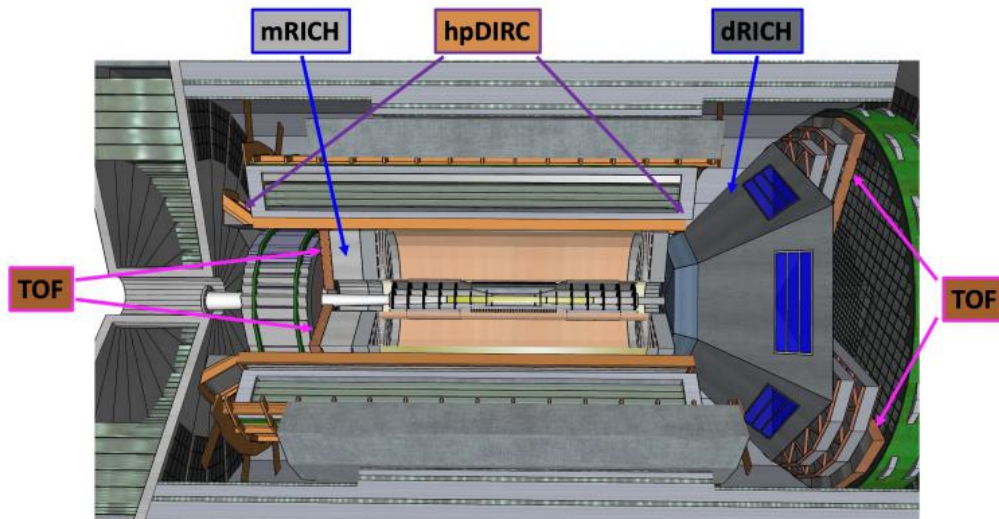


Electron identification capability at ECCE

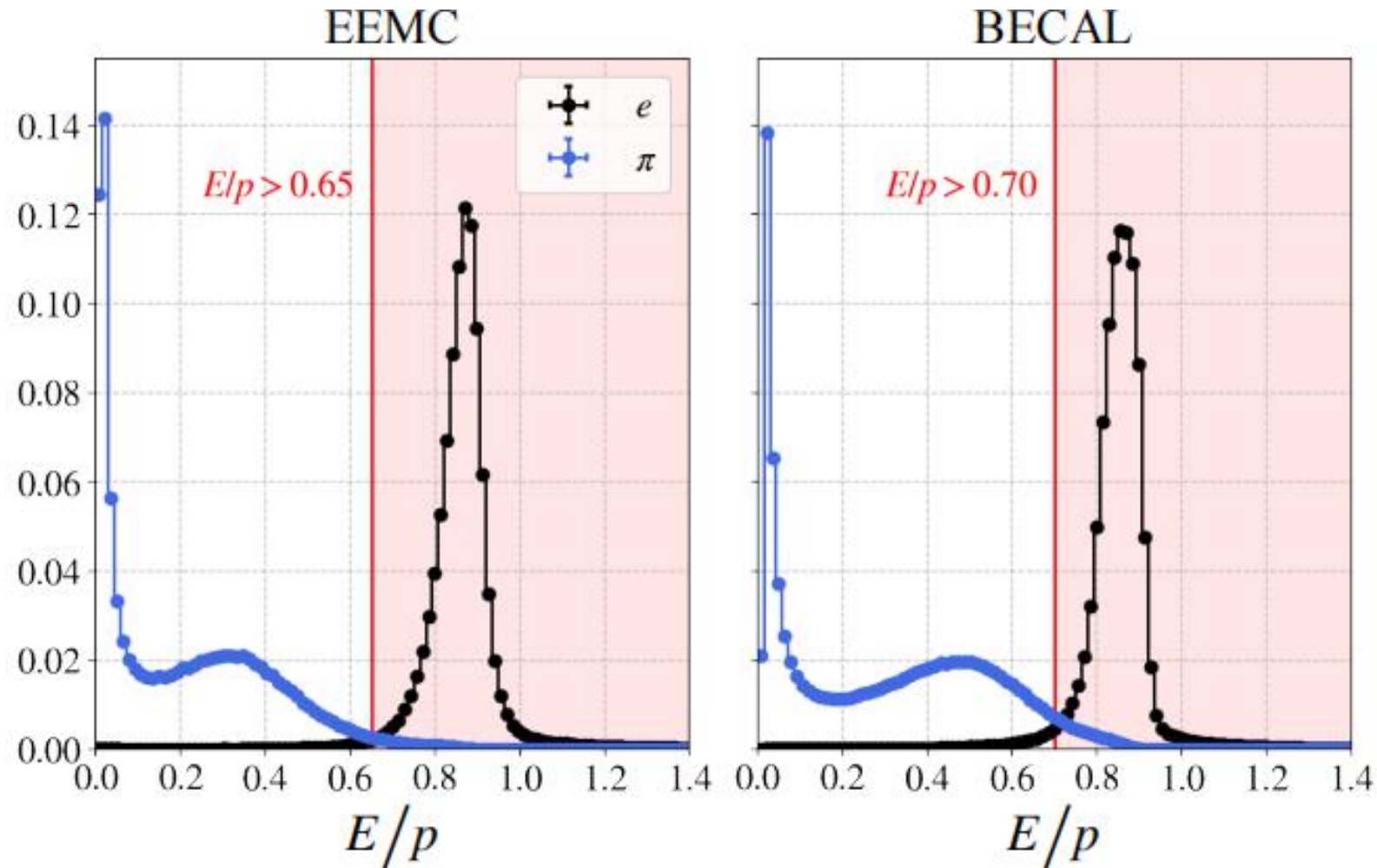
EMCal + Tracking

- ✓ The energy deposition => E/p cut
- ✓ The transverse profile of the showers
- ✓ The position resolution

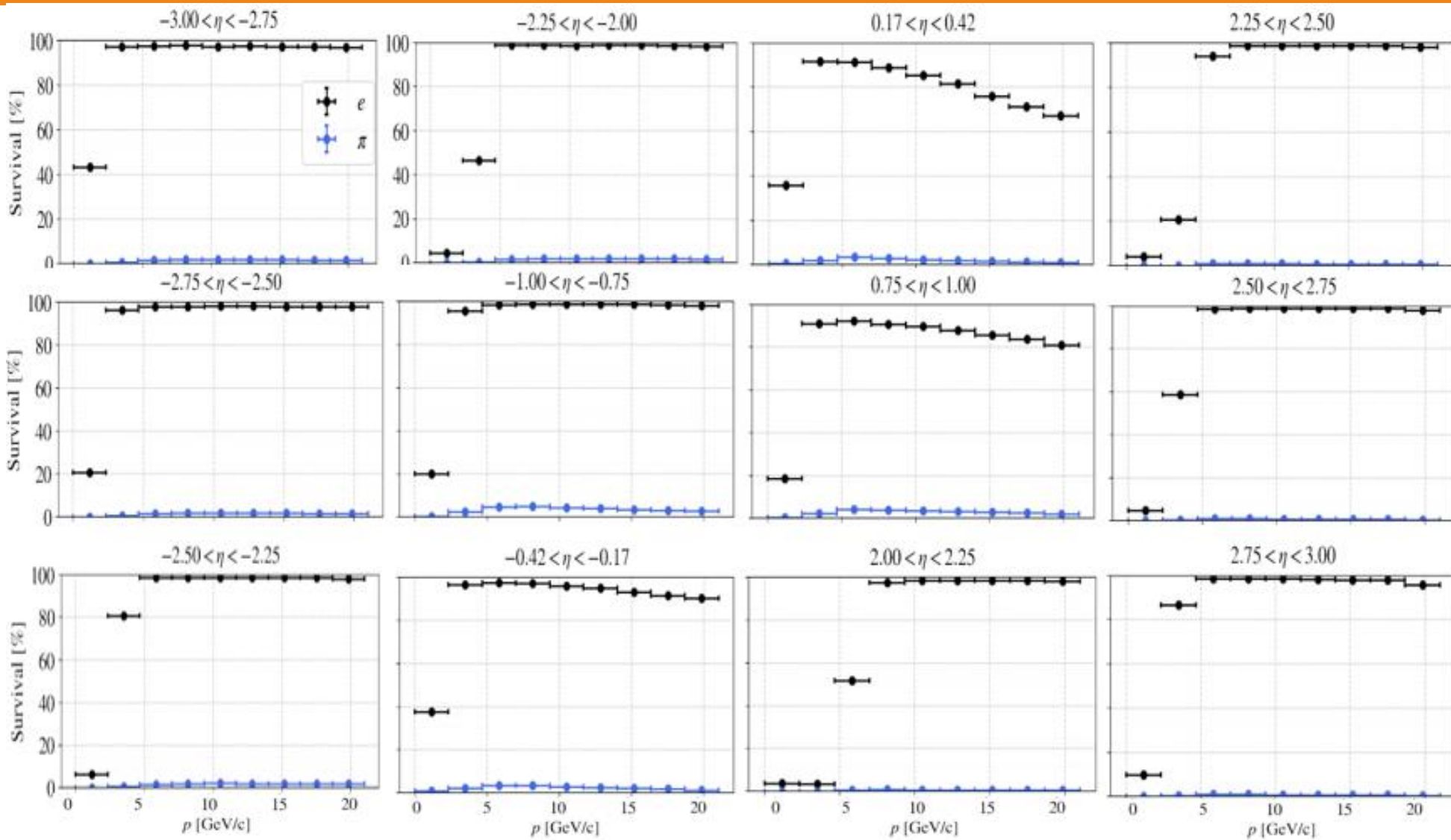
Cherenkov + TOF



Electron identification capability at ECCE—EMCal+Tracking



Electron identification capability at ECCE—EMCal+Tracking



Electron identification capability at ECCE—Cherenkov+TOF

- **h-endcap: dRICH with two radiators (gas + aerogel)**

π/K separation up to ~ 50 GeV/c

e/π separation up to ~ 15 GeV/c

- **e-endcap: compact aerogel mRICH**

π/K separation up to ~ 10 GeV/c

e/π separation up to ~ 2 GeV/c

- **barrel: compact high-performance DIRC**

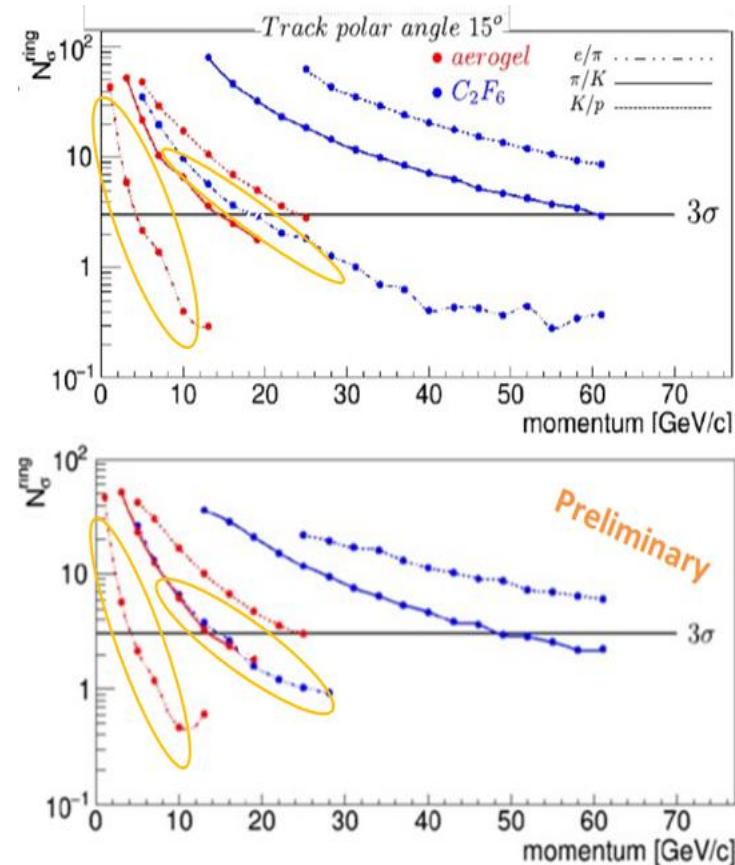
π/K separation up to $\sim 6-7$ GeV/c

e/π separation up to ~ 1.2 GeV/c

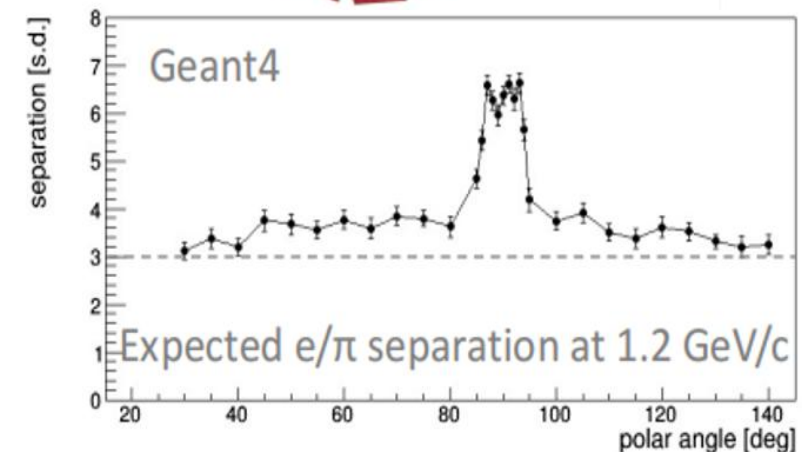
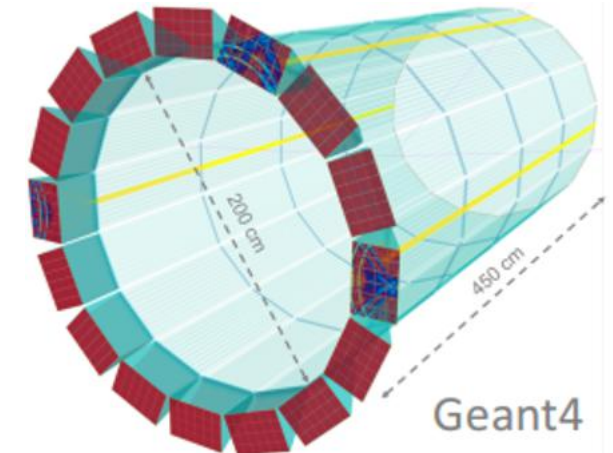
- **LGAD based TOF:**

cover lower momenta down to ~ 0.2 GeV/c

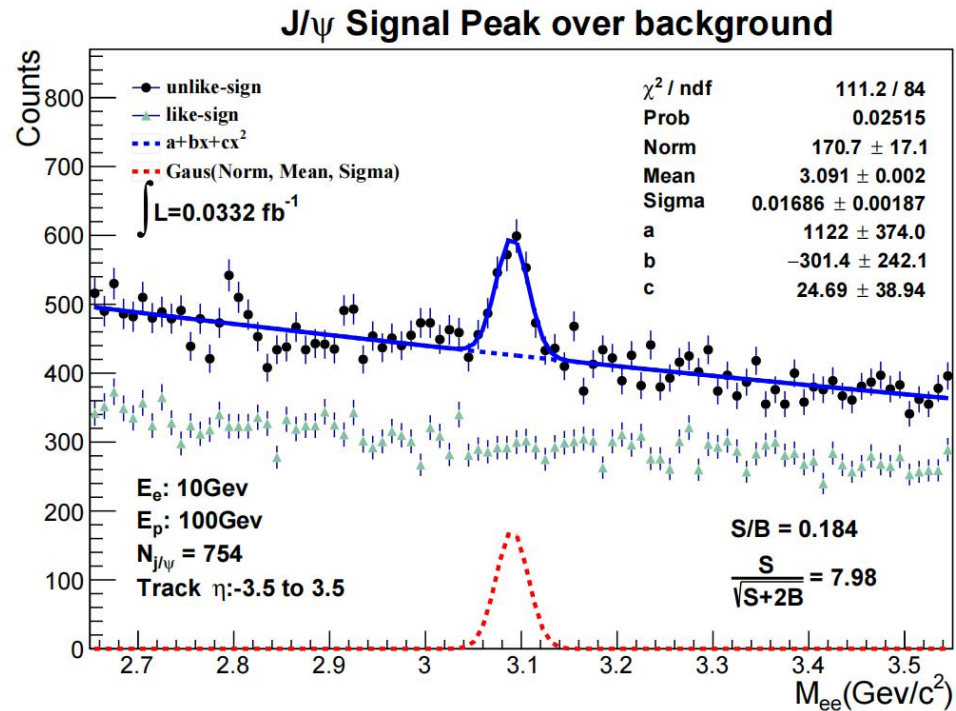
dRICH Simulated Performance



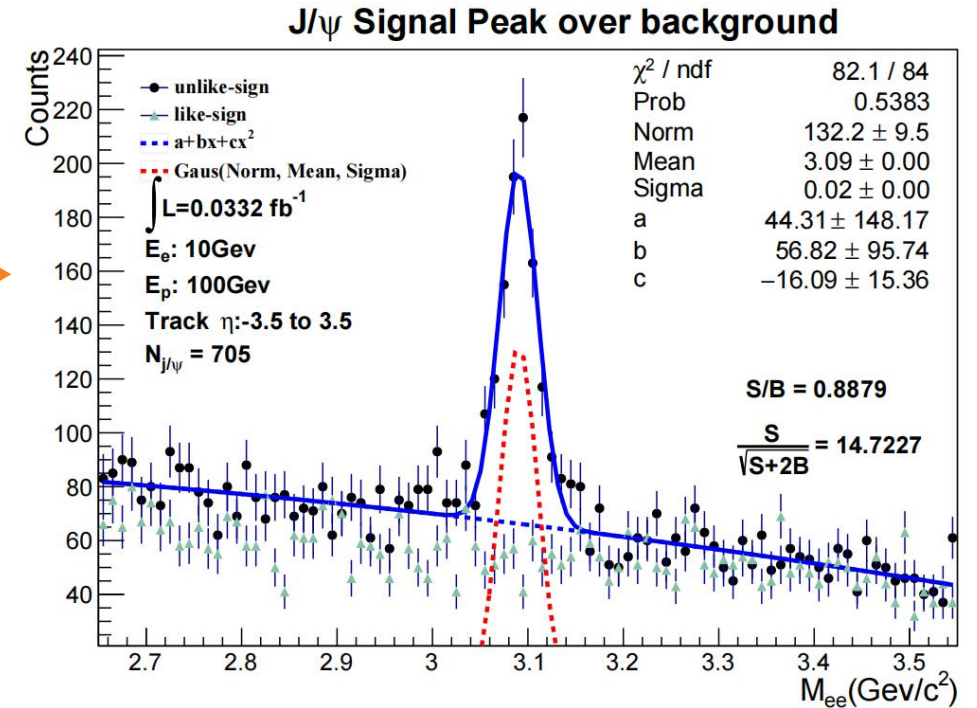
HPDIRC



J/ψ Reconstruction

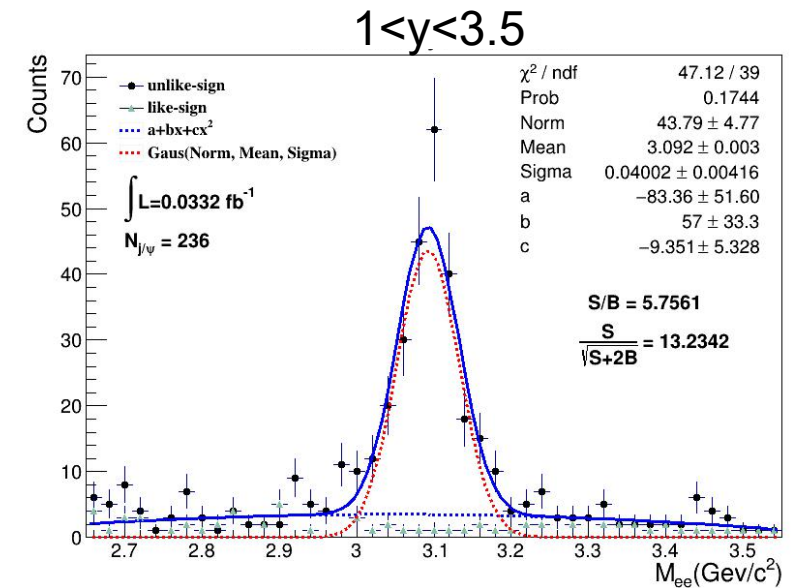
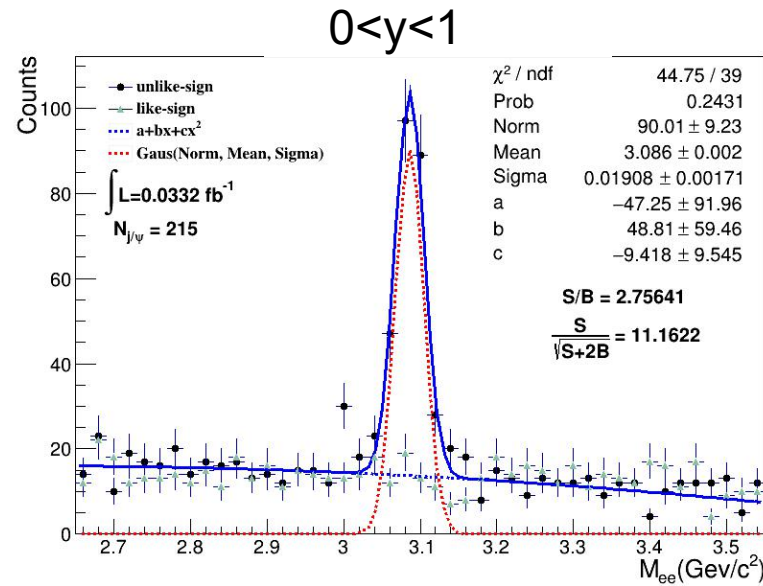
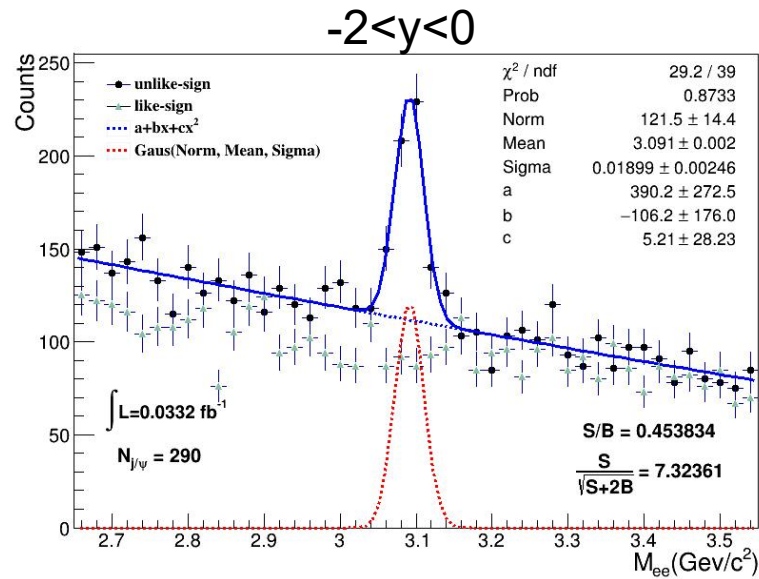


a forward
lightcone cut
 $x_+ < 0.5$



generator: pythia6 (eRHIC tuned) Full Geant simulation (fun4All)
events: ~20million

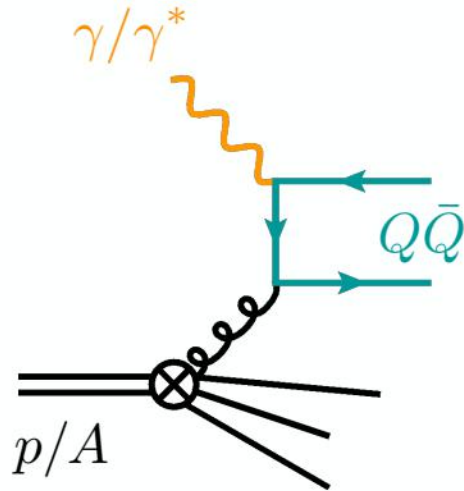
J/ψ Reconstruction



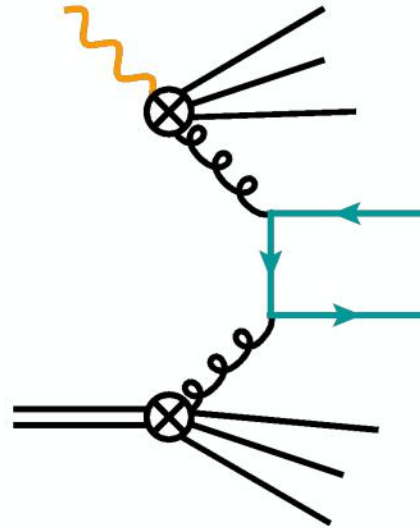
Central region with better mass width.

From e-going to h-going, signal background ratio turns better.

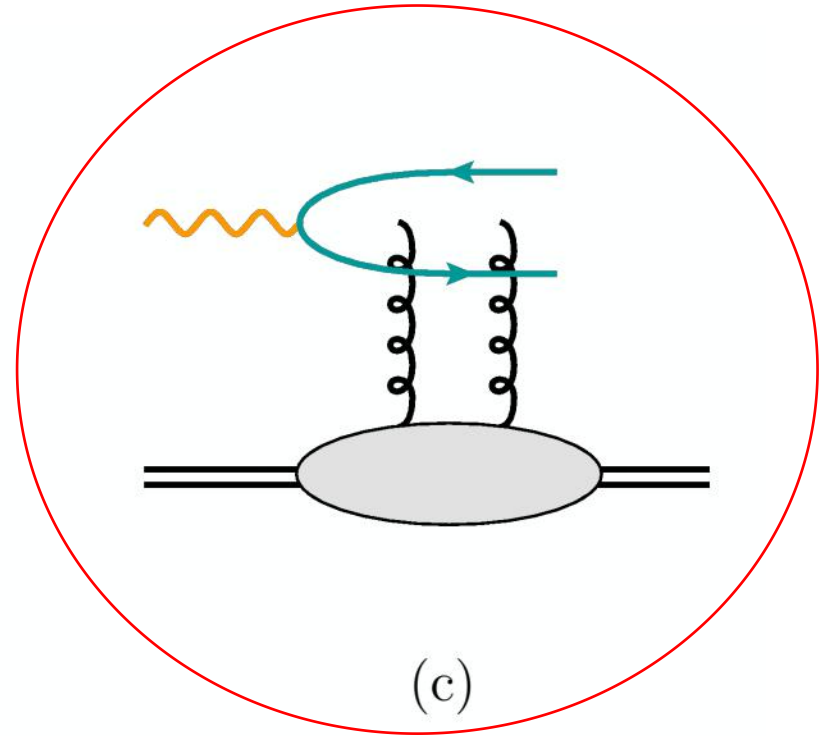
Production mechanism of quarkonia



(a)



(b)



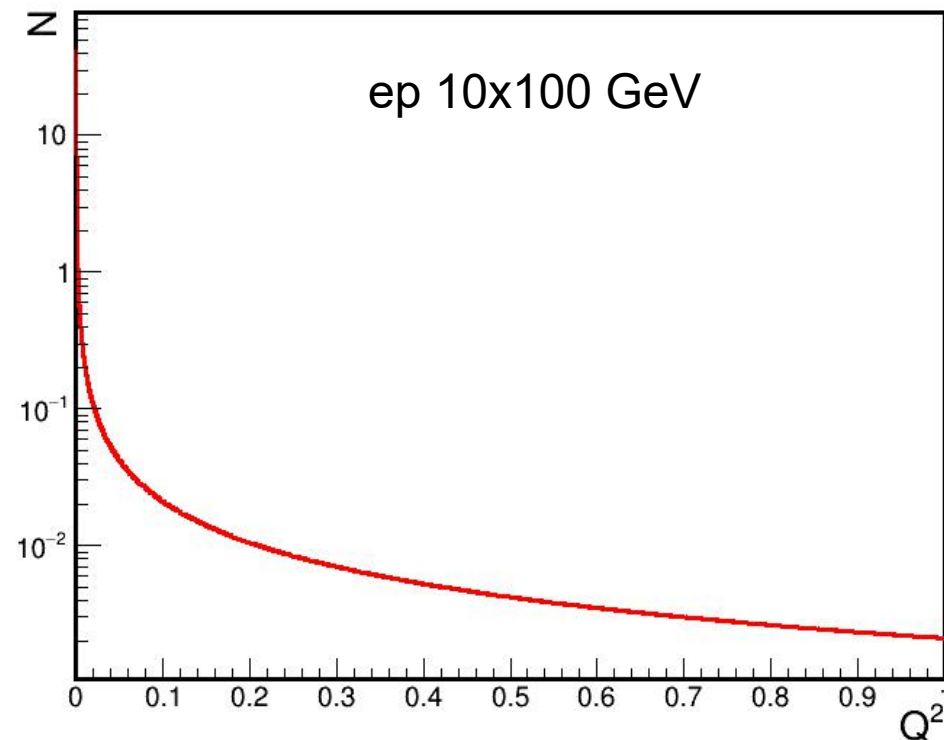
(c)

Direct, Resolve and **Exclusive** process

Yellow Report Fig. 7.95

Event feature of exclusive J/ψ production

- ✓ The scattered proton or nucleus escape undetected down the beampipe at small scattering angles
- ✓ The majority of scattered electron escape undetected (Veto on $Q^2 > 1 \text{ GeV}^2/c^4$)
- ✓ No other event activity except the electron-positron pair from J/ψ decay



The theoretical setup for projection (eSTARLight)

$$\sigma(eA \rightarrow eAV) = \int \frac{dW}{W} \int dk \int dQ^2 \frac{d^2 N_\gamma}{dk dQ^2} \sigma_{\gamma^* A \rightarrow VA}(W, Q^2)$$

$$\frac{d^2 N_\gamma}{dk dQ^2} = \frac{\alpha}{\pi k Q^2} \left[1 - \frac{k}{E_e} + \frac{k^2}{2E_e^2} - \left(1 - \frac{k}{E_e} \right) \left| \frac{Q_{\min}^2}{Q^2} \right| \right]$$

$$\sigma_{\gamma^* A \rightarrow VA}(W, Q^2) = f(M_V) \sigma(W, Q^2 = 0) \left(\frac{M_V^2}{M_V^2 + Q^2} \right)^n \quad n = c_1 + c_2(Q^2 + M_V^2),$$

$$\sigma(W, Q^2 = 0) = \int_{t_{\min}}^{\infty} dt \left. \frac{d\sigma(\gamma A \rightarrow VA)}{dt} \right|_{t=0} |F(t)|^2$$

Can be related to the cross section for $\sigma(\gamma p \rightarrow V+p)$

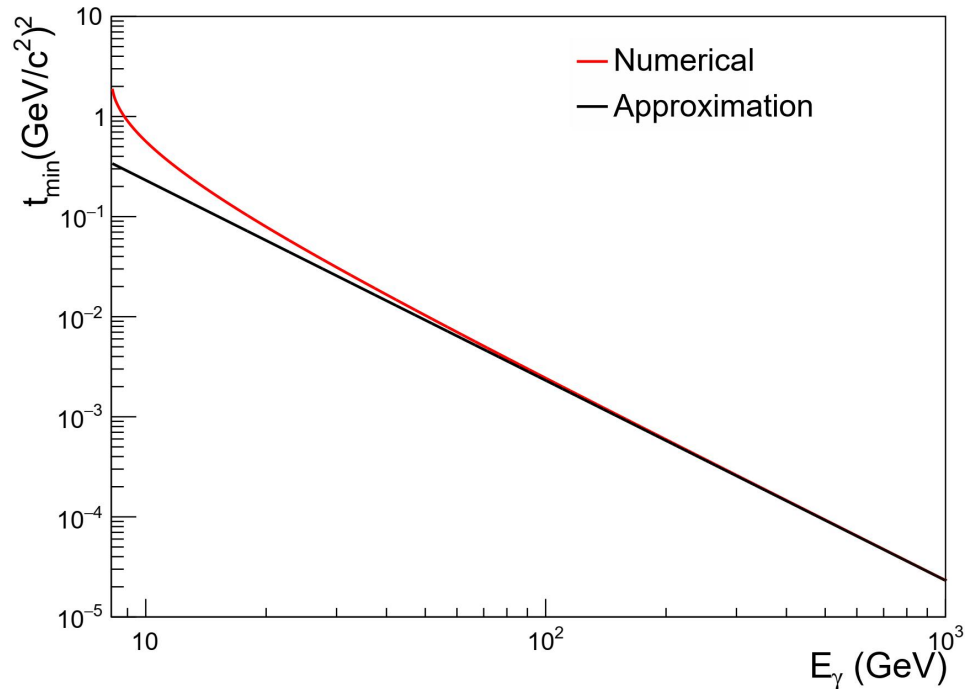
eSTARLight: Michael Lomnitz and Spencer Klein, Phys. Rev. C **99** (2019) 015203

Wangmei Zha et al, Phys. Rev. C **97** (2018) 044910

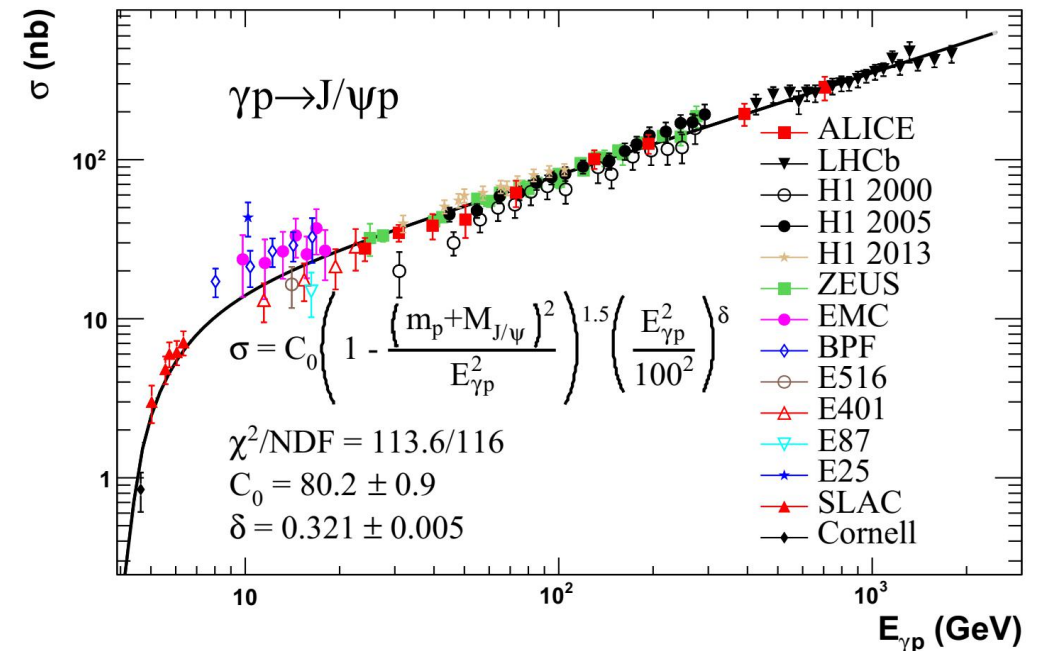
Two improvements for eSTARLight

Minimum momentum transfer

$$t_{\min} = (M_V^2/2k)^2 \text{ Approximation}$$

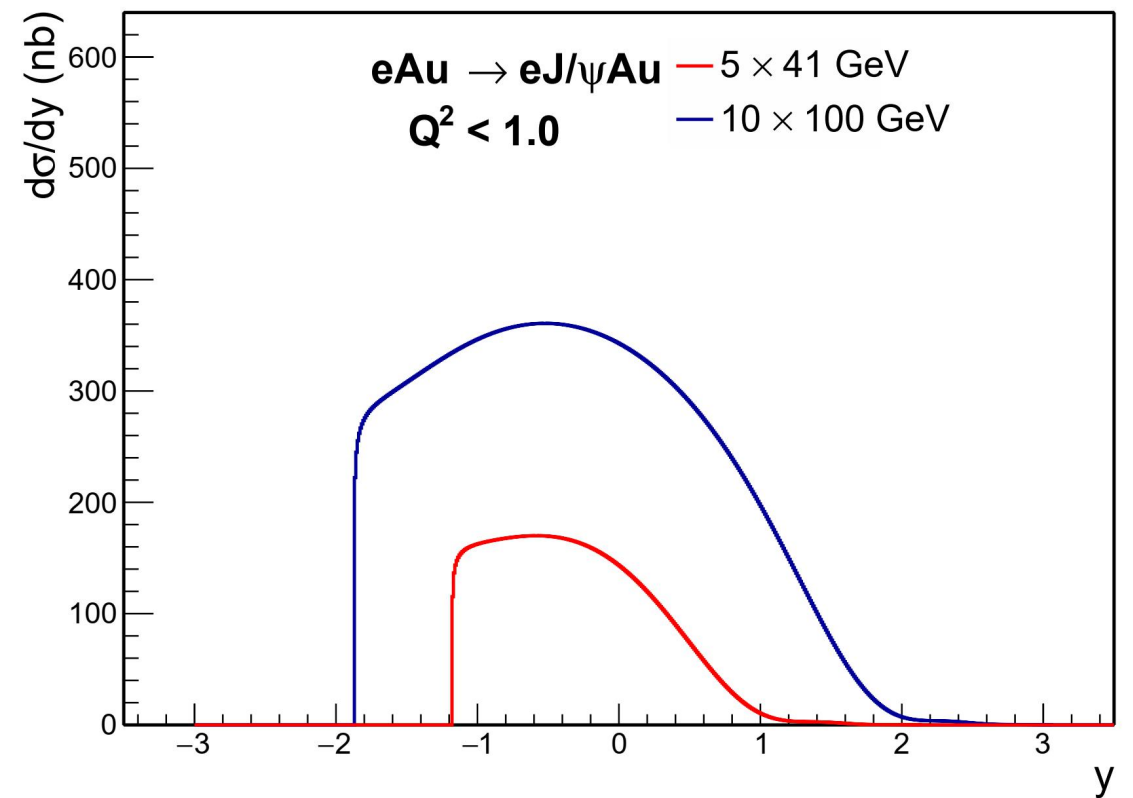
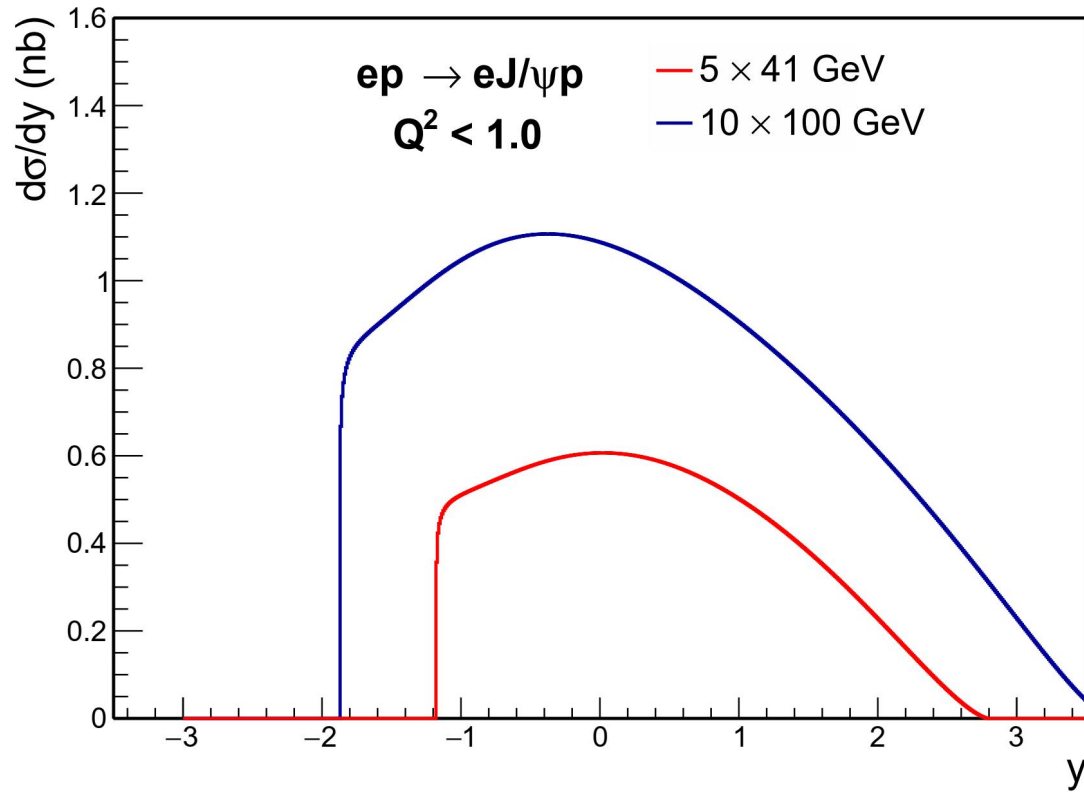


Parametrization for cross section input



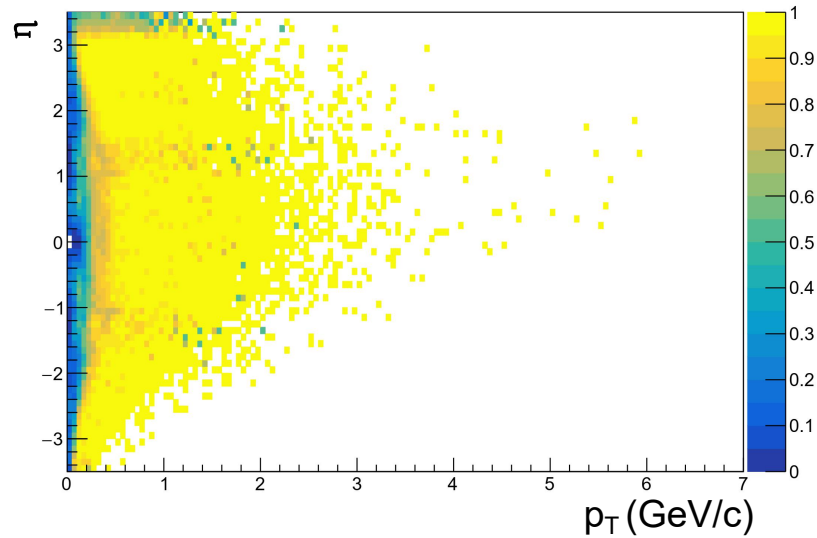
Z. Cao et al., Chin. Phys. C43 (2019) 064103

The theoretical input for ep and eAu

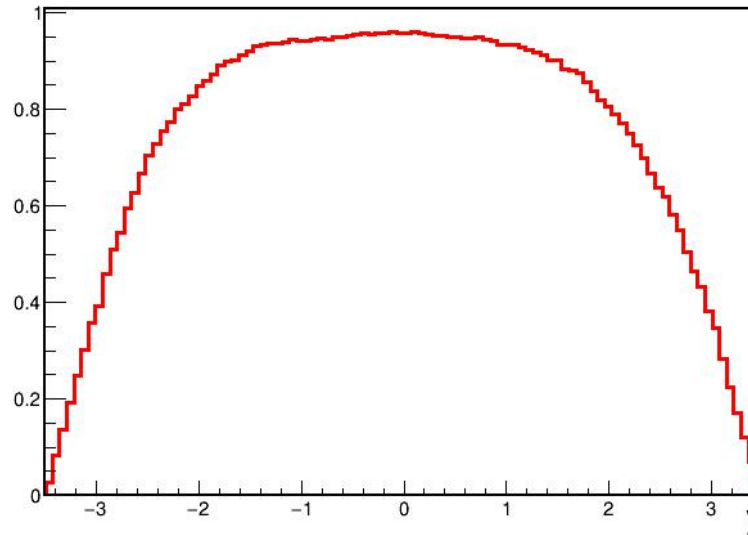


Efficiency and S/B correction

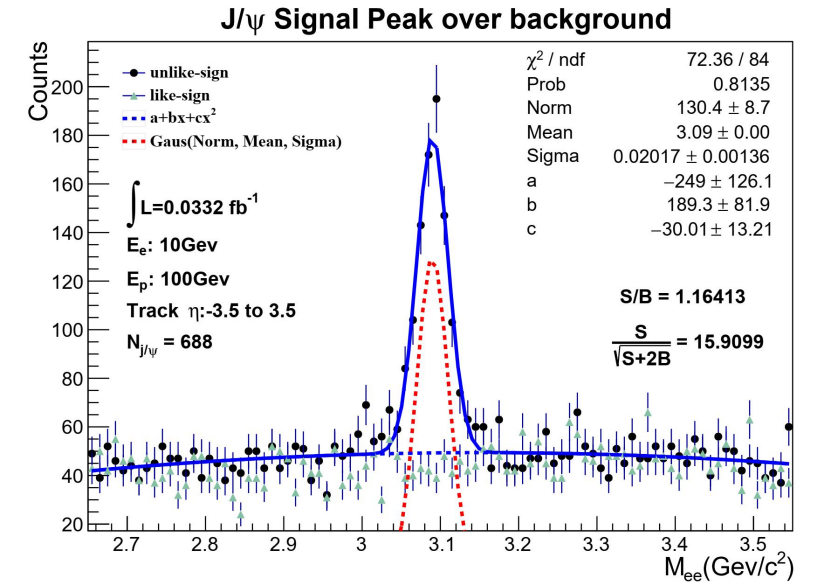
Single electron efficiency



J/ψ efficiency



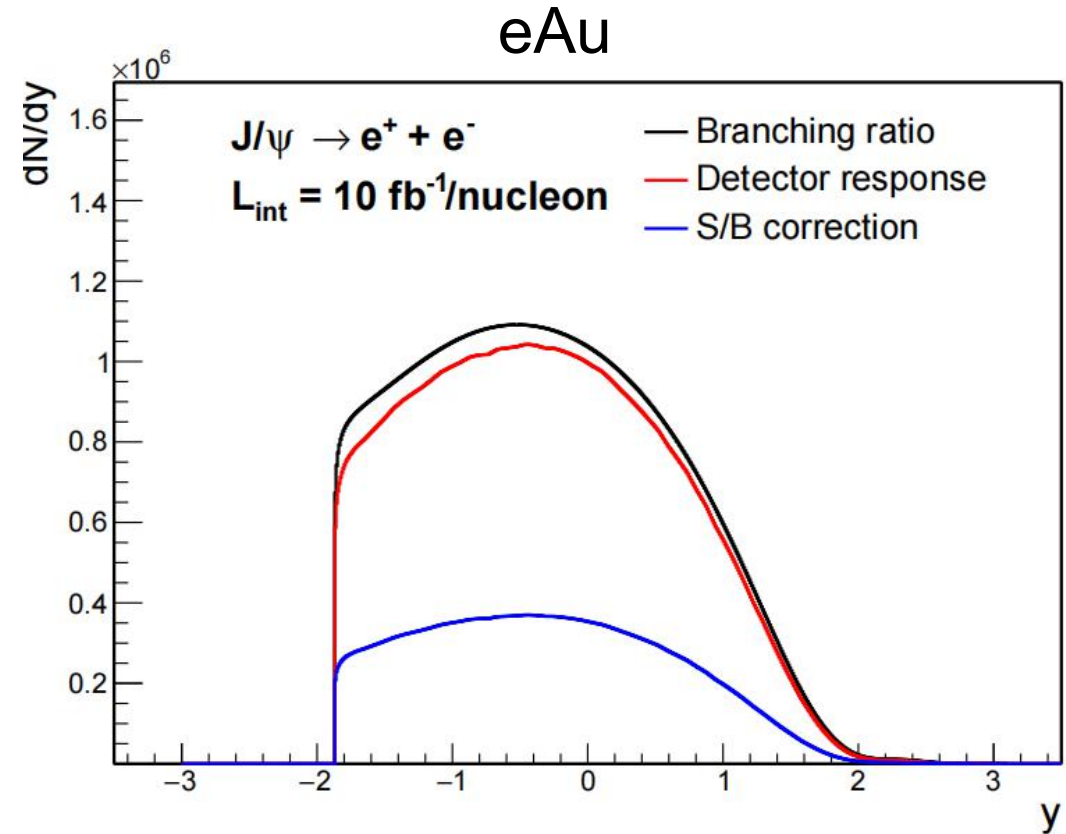
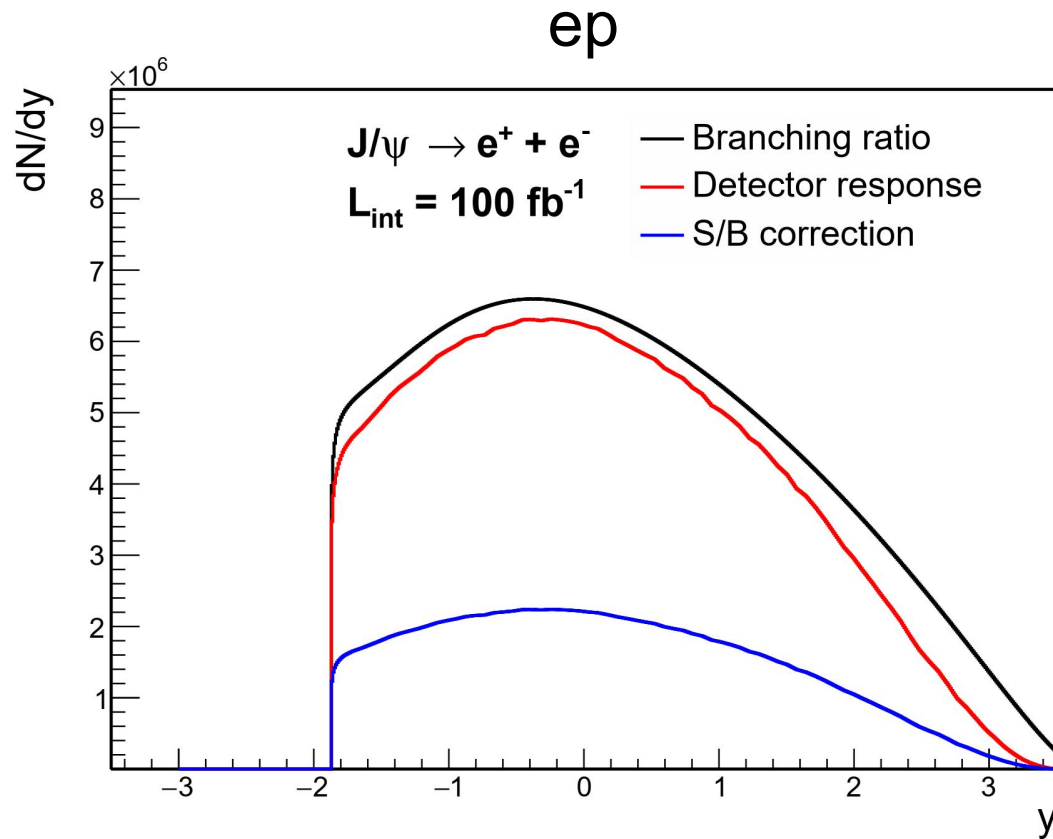
S/B correction



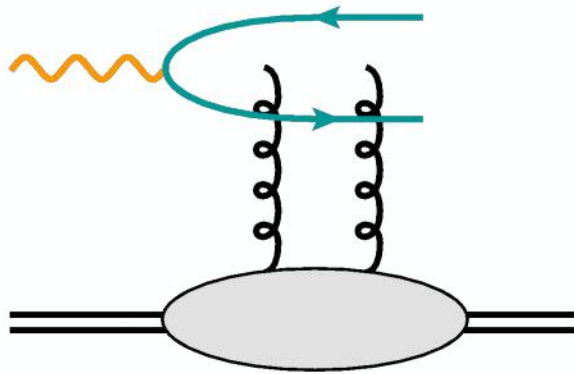
High J/ψ efficiency in central region

Forward region with a low efficiency

The projected statistics

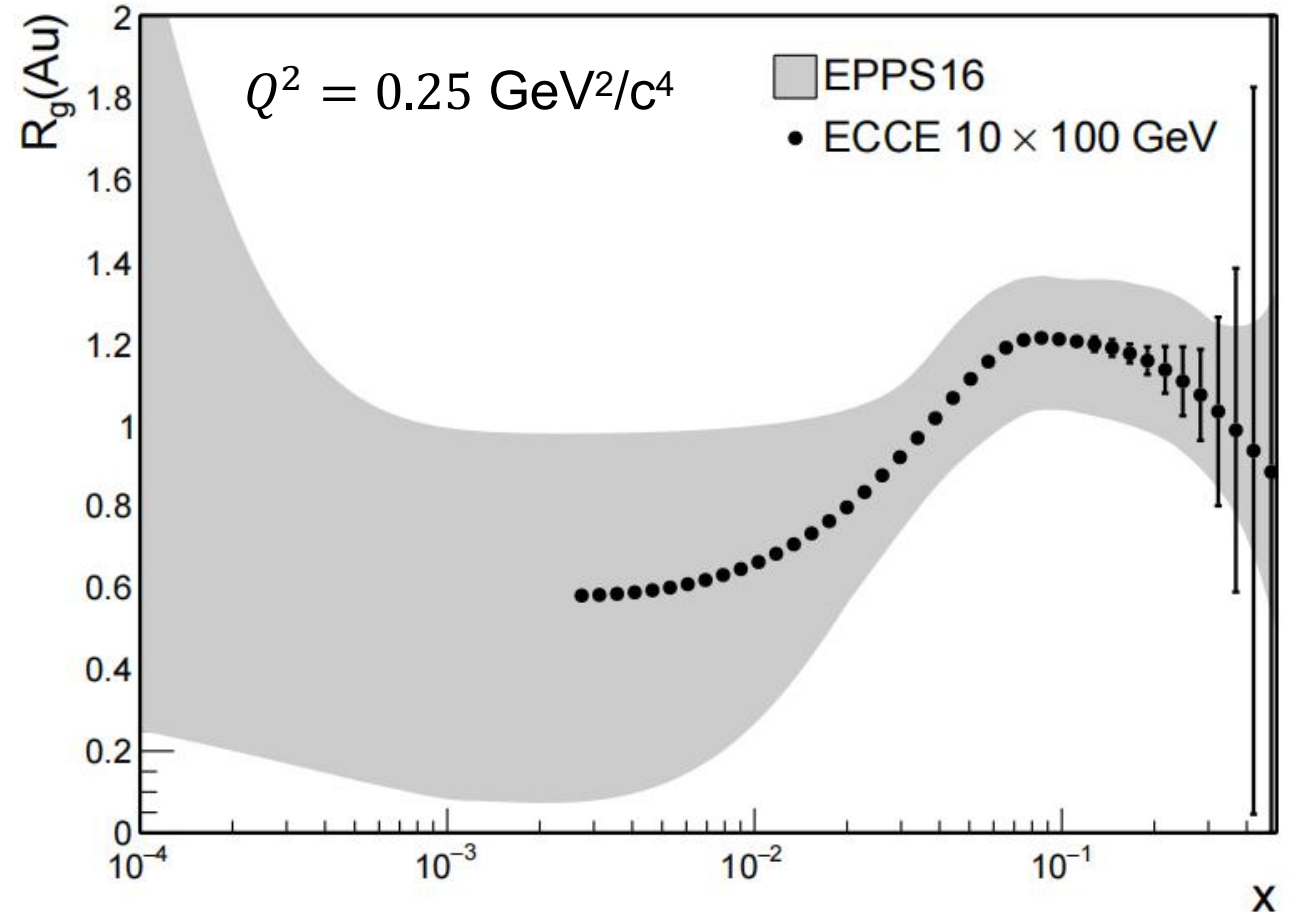


The gluon nPDF projection



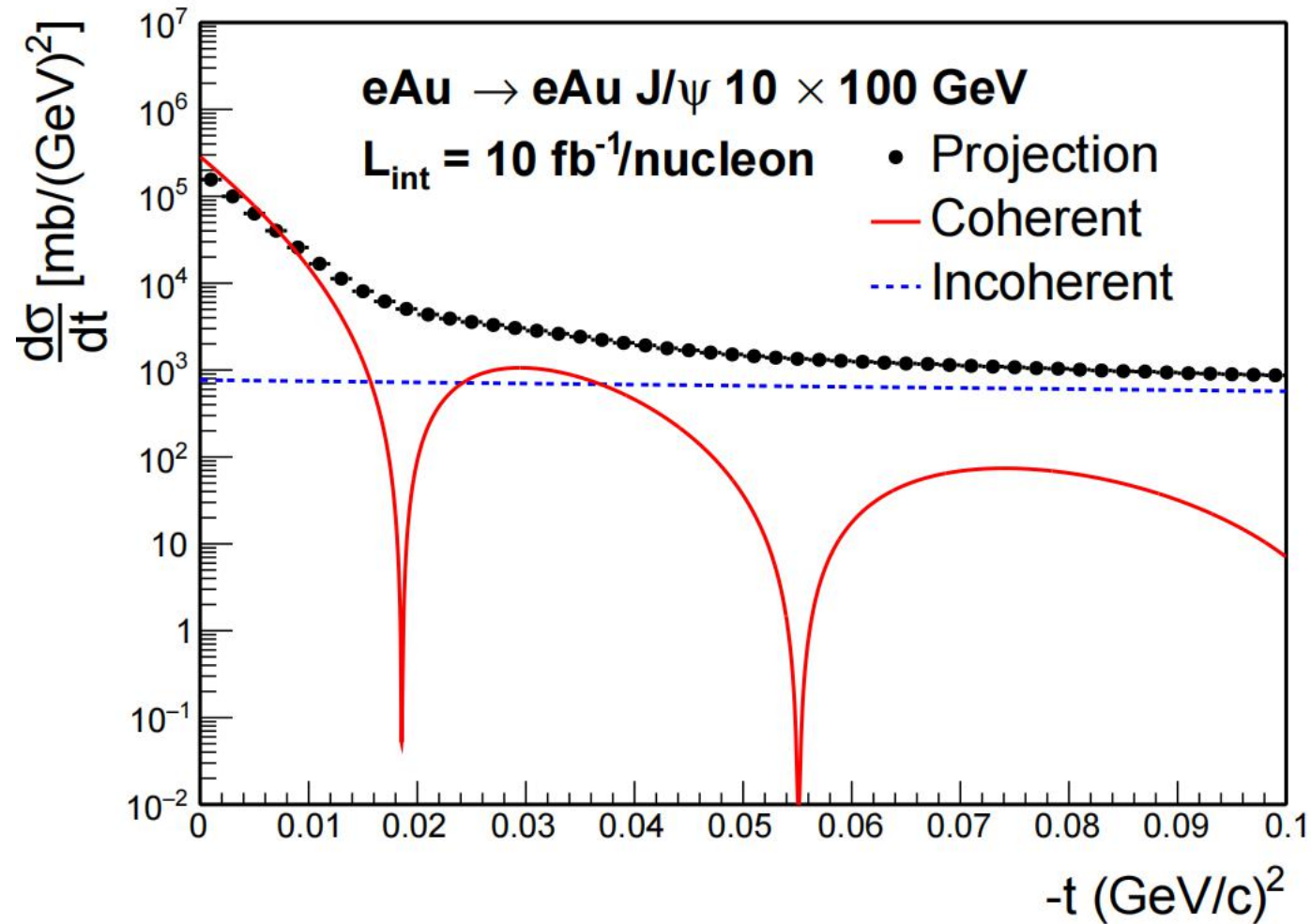
$$\left. \frac{d\sigma(\gamma A \rightarrow V A)}{dt} \right|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 [xG_A(x, Q^2)]^2$$

$$x = \frac{M_V e^{\pm y}}{\sqrt{s}} \quad Q^2 = M_V^2/4$$



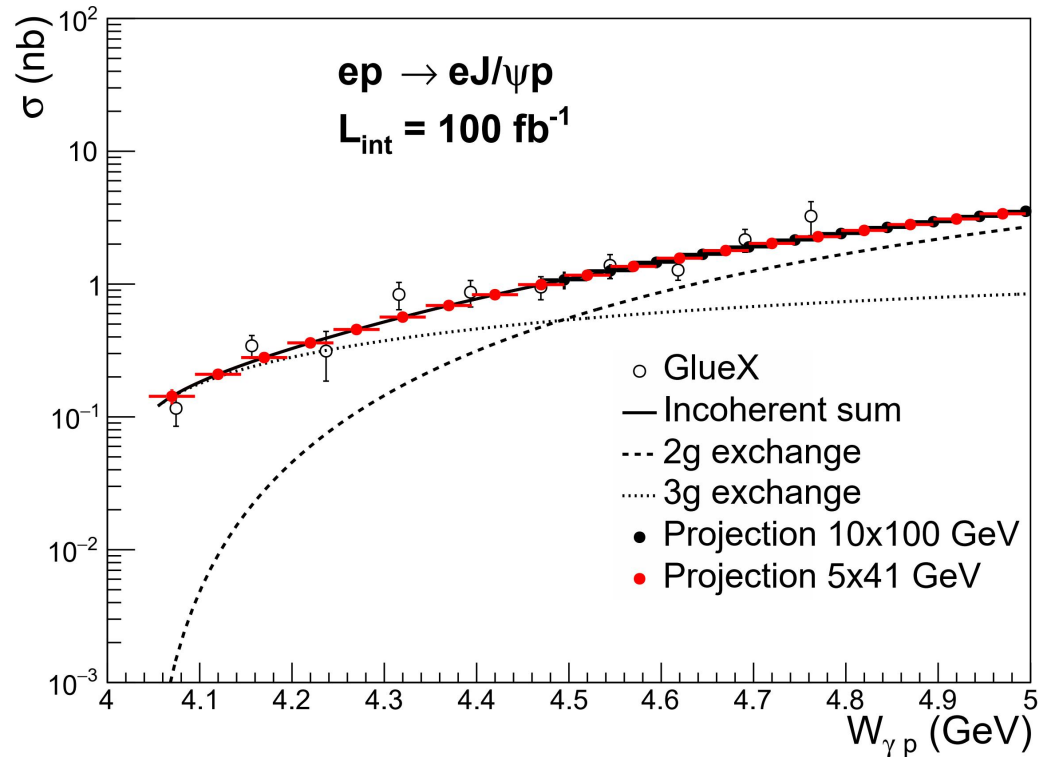
Eskola, K.J., Paakkinen, et al.
EPPS16: EPJC 77 (2017) 163

The t distribution projection



The momentum resolution would wipe out the diffraction dips.

The near threshold production mechanism



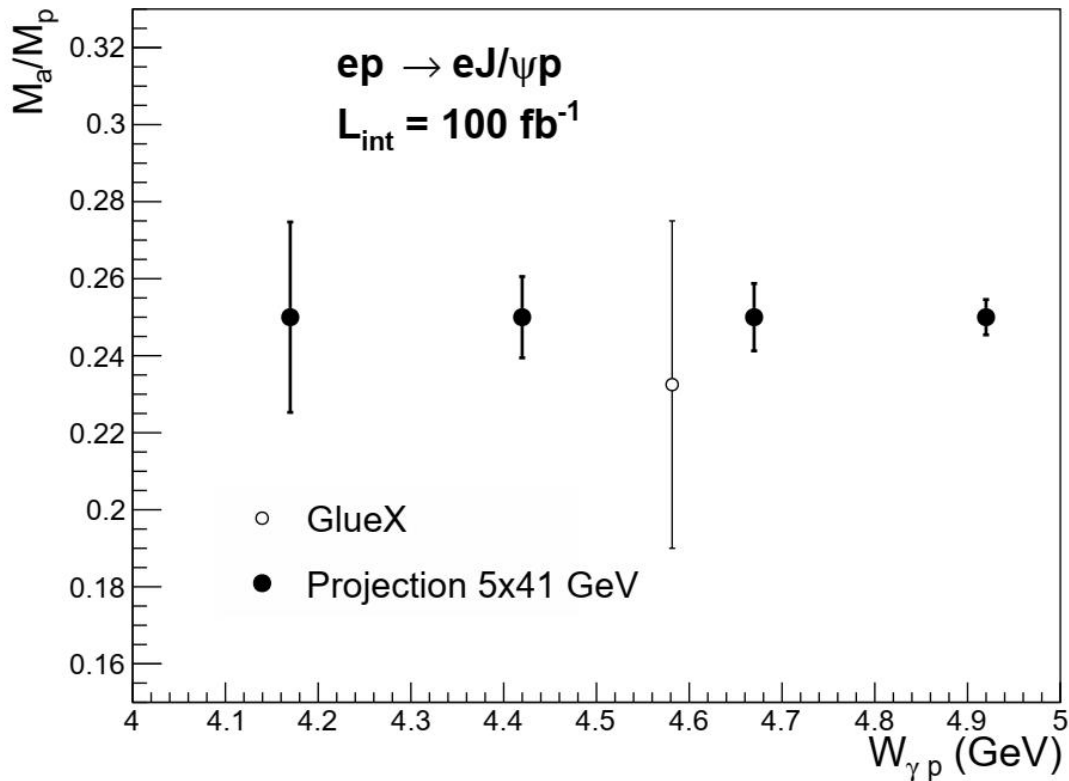
$$\frac{d\sigma}{dt} = \mathcal{N}_{2g} v \frac{(1-x)^2}{R^2 \mathcal{M}^2} F_{2g}^2(t) (s - m_p^2)^2$$

$$\frac{d\sigma}{dt} = \mathcal{N}_{3g} v \frac{(1-x)^0}{R^4 \mathcal{M}^4} F_{3g}^2(t) (s - m_p^2)^2$$

SJ Brodsky, Phys. Lett. B 498 (2001) 23–28

A. Ali et al. (GlueX Collaboration), Phys. Rev. Lett. 123, 072001(2019)

The trace anomaly parameter projection



Guzey, Zhalov, JHEP 10 (2013) 207; JHEP 02 (2014) 046

$$M_q = \frac{3}{4} \left(a - \frac{b}{1 + \gamma_m} \right) M_N,$$

$$M_g = \frac{3}{4} (1 - a) M_N,$$

$$M_m = \frac{4 + \gamma_m}{4(1 + \gamma_m)} b M_N,$$

$$M_a = \frac{1}{4} (1 - b) M_N,$$

Rong Wang, Xurong Chen and Jarah Evslin,
Eur. Phys. J. C (2020) 80:507

Extract the QCD trace anomaly parameter b

Summary and future plan

Summary

- Excellent electron identification capability at ECCE
- Reasonable reconstruction efficiency and coverage of J/ψ
- Plenty physics opportunities for J/ψ photoproduction

Future plan

- The projection results from full Geant simulation
- The projection results for Quarkonia production mechanism

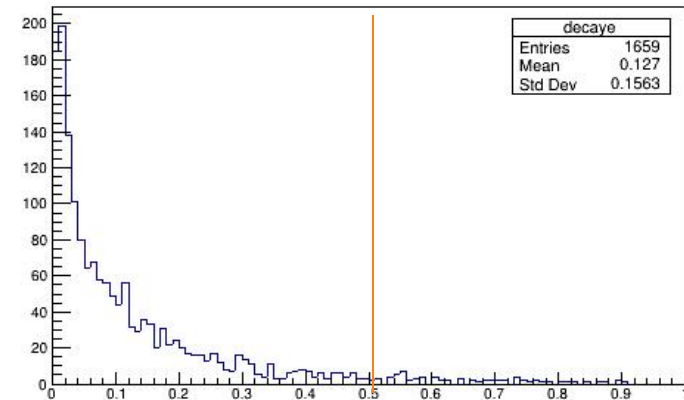
Backup

J/ψ detection (For Page15 S/B)

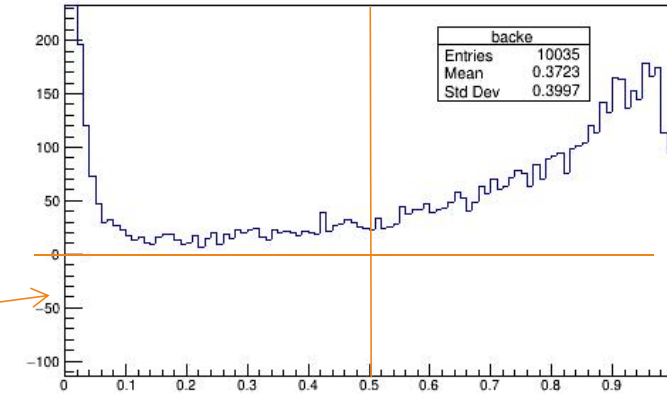
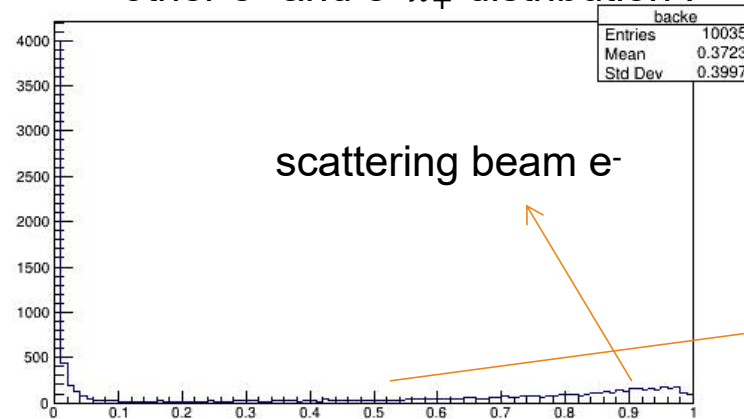
a forward light cone variables can be used to see scattering beam e⁻ influence

$$x_+ = \frac{b_0 + (-b_z)}{a_0 + (-a_z)} \text{ (cause beam e}^- \text{ moves along negative z axis), b is beam e}^-.$$

e⁺ and e⁻ of J/ψ decay x_+ distribution



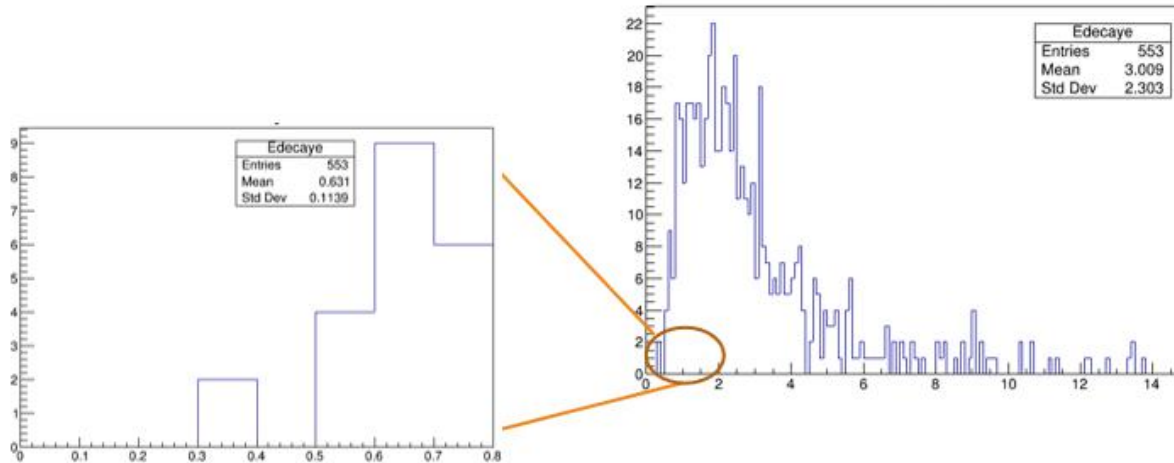
other e⁺ and e⁻ x_+ distribution :



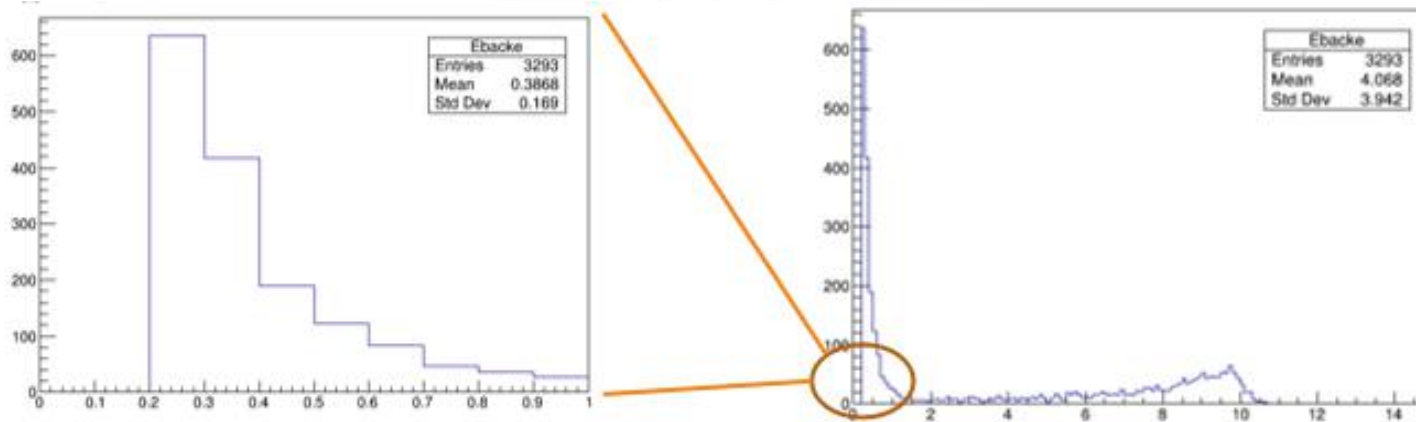
cut: $x_+ < 0.5$

J/ ψ detection (For Page15 S/B)

influence of e^- from light hadron decay

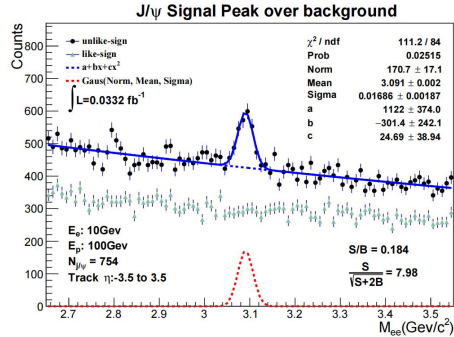


e^+ and e^- of J/ ψ decay E distribution



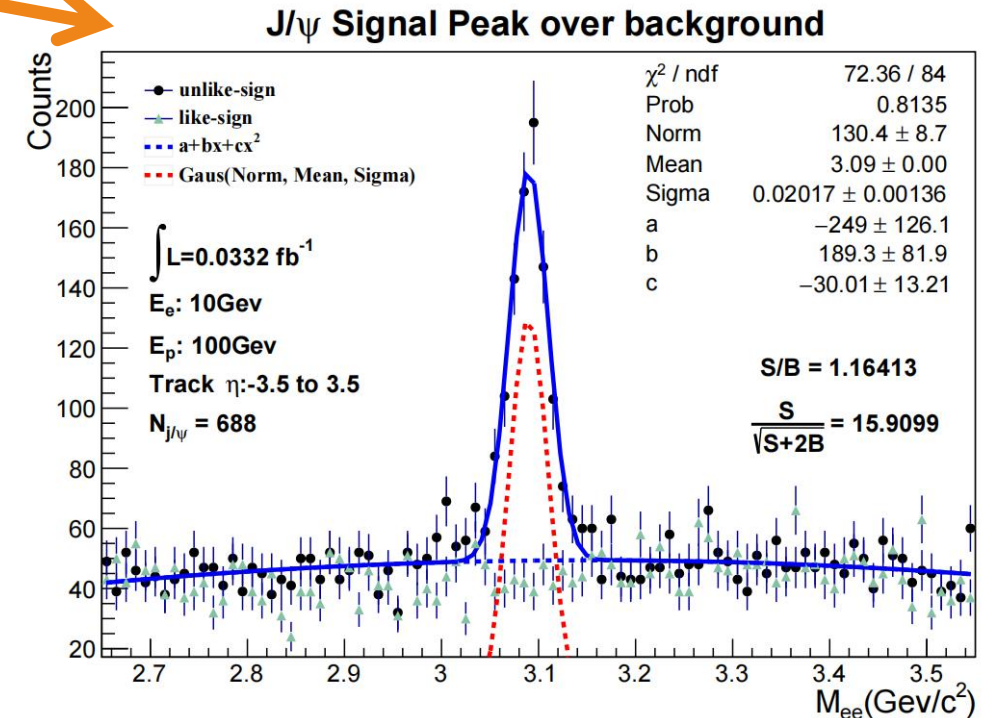
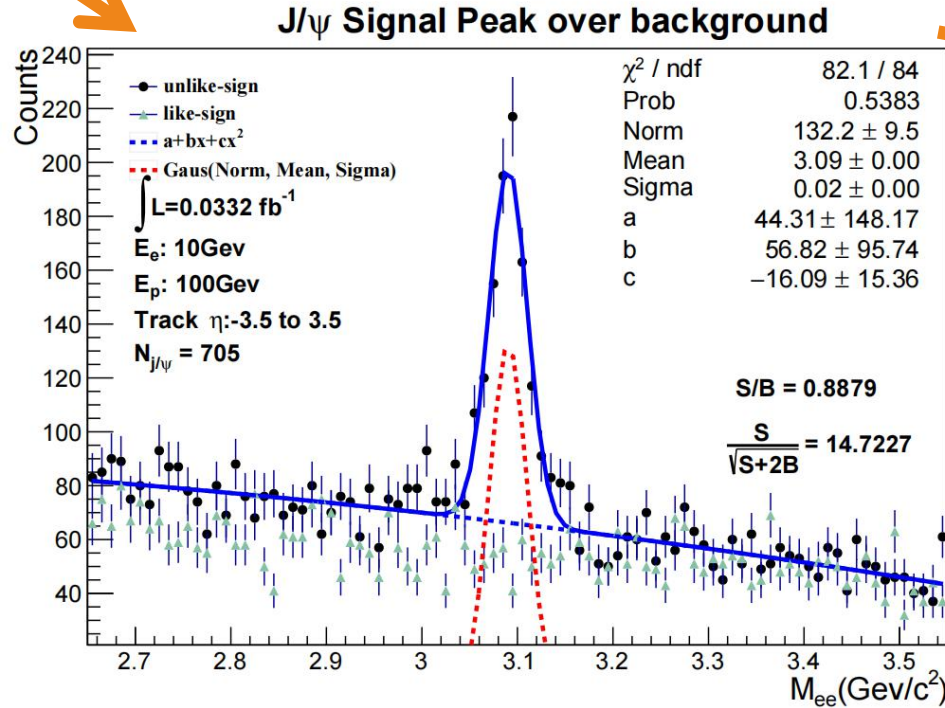
other e^+ and e^- E distribution :

J/ψ detection (For Page15 S/B)



cut: $x_+ < 0.5$
 $S/B: 0.184 \rightarrow 0.888$

cut: $E > 0.6$
 $S/B: 0.888 \rightarrow 1.164$



J/ψ detection (Another way to cut scattered electron)

exclude the scattered e⁻ (with largest p_T)

