Quarkonium detection and physics with ECCE

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27/10/21

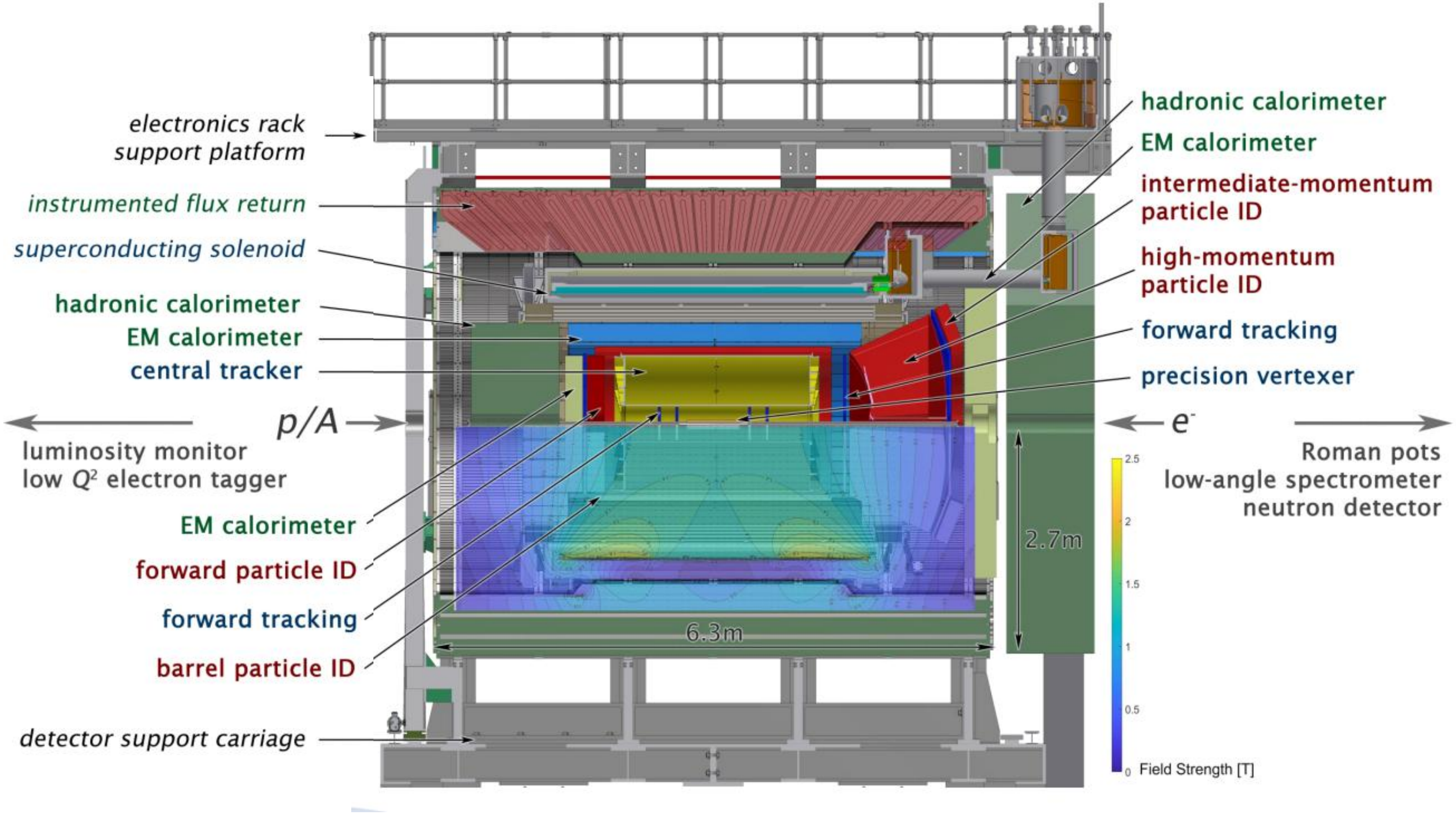
Outline

- Physics Opportunities for Heavy Quarknia 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

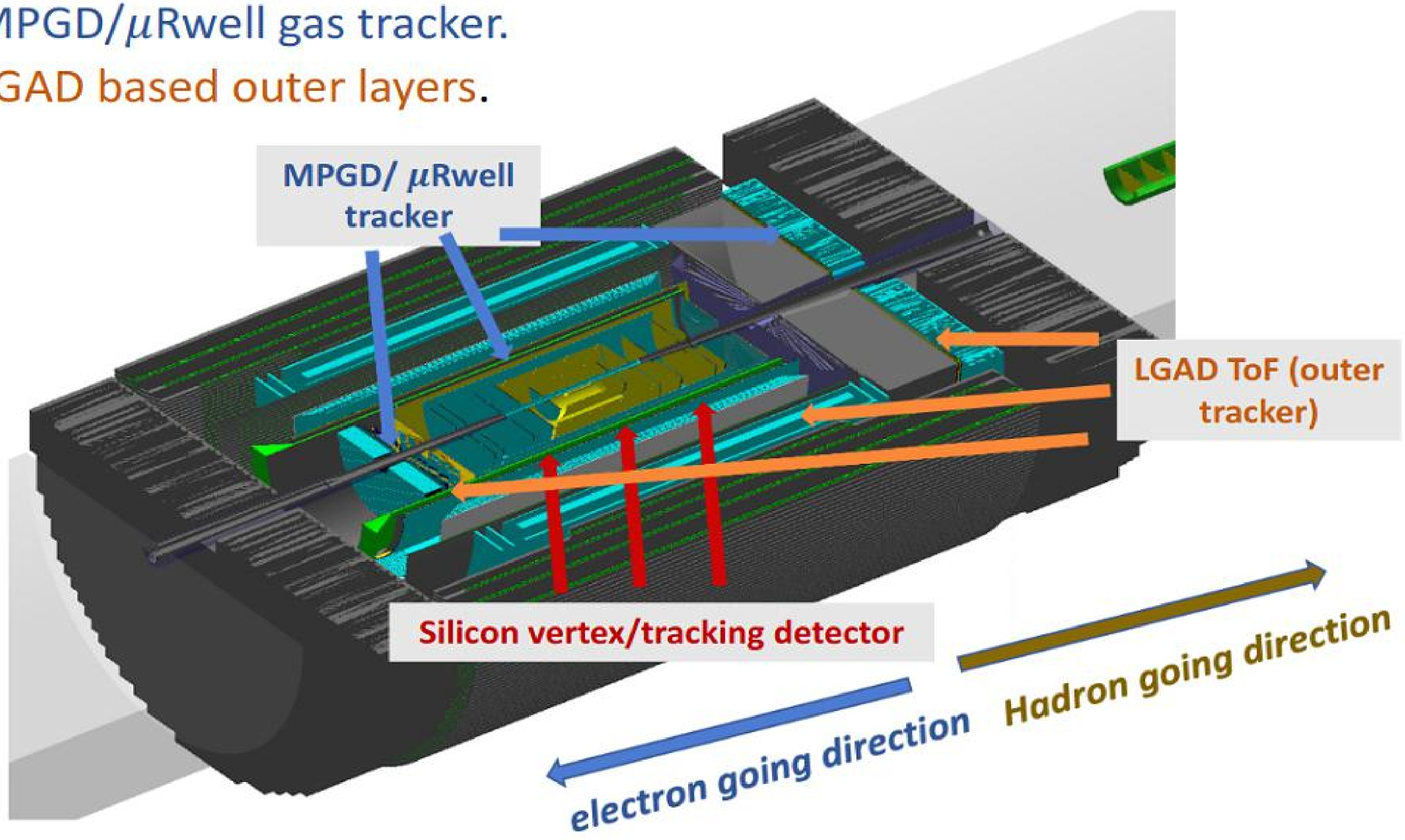
- ➢ Production mechanism for quarkonia
  - ✓ Constrain the NRQCD matrix elements
  - ✓ Study the hadronization in nucleus
- ➢ 3D tomography of gluon distribution
  - ✓ gluon nPDF (z direction)
  - ✓ Transverse distribution of gluon (x-y direction)
- ➢ Near threshold photoproduction
  - ✓ 2g, 3g exchange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

Detector Configuration

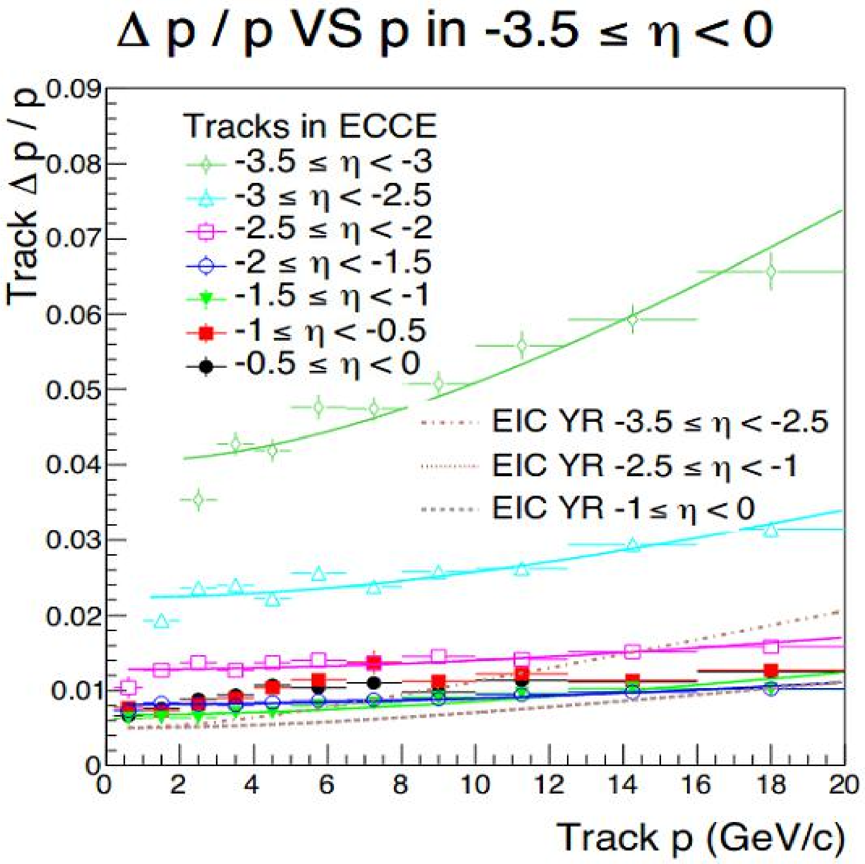


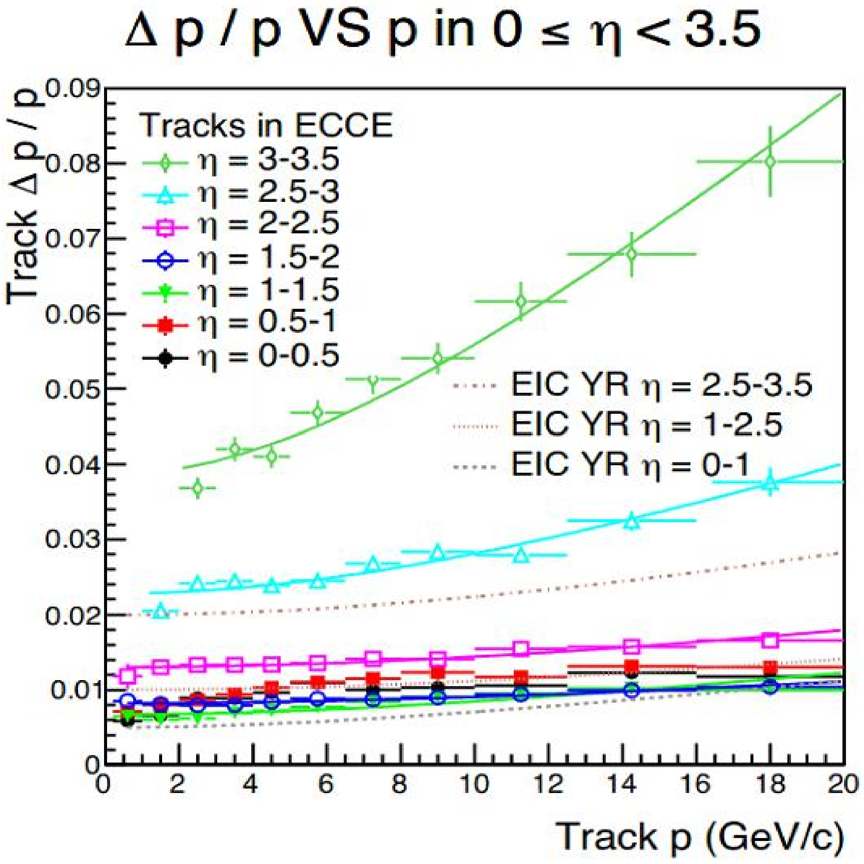
Detector Configuration (June Concept)——Tracking

- 1st simulation camping ECCE tracking detector consists of
  - MAPS based silicon vertex/tracking layers/planes.
  - MPGD/μRwell gas tracker.
  - LGAD based outer layers.



Tracking performance at ECCE



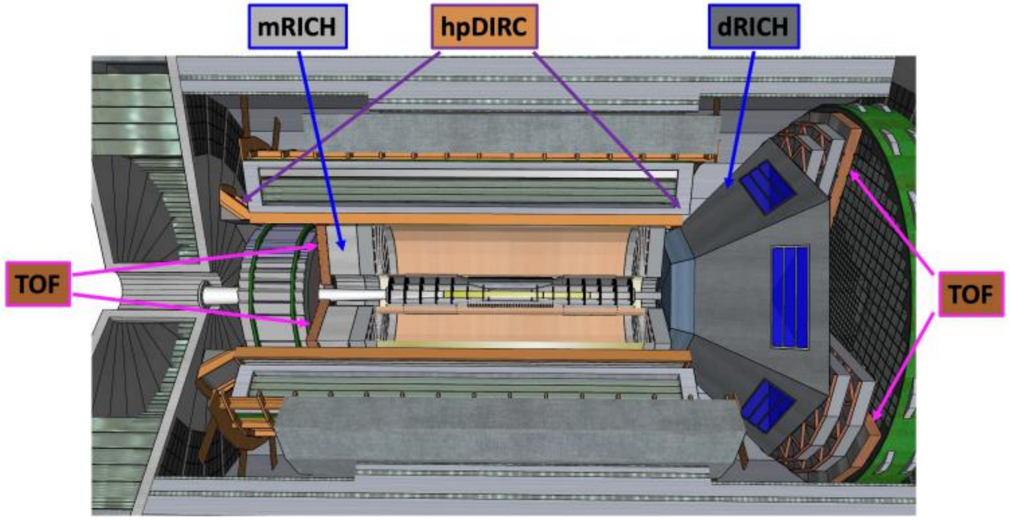


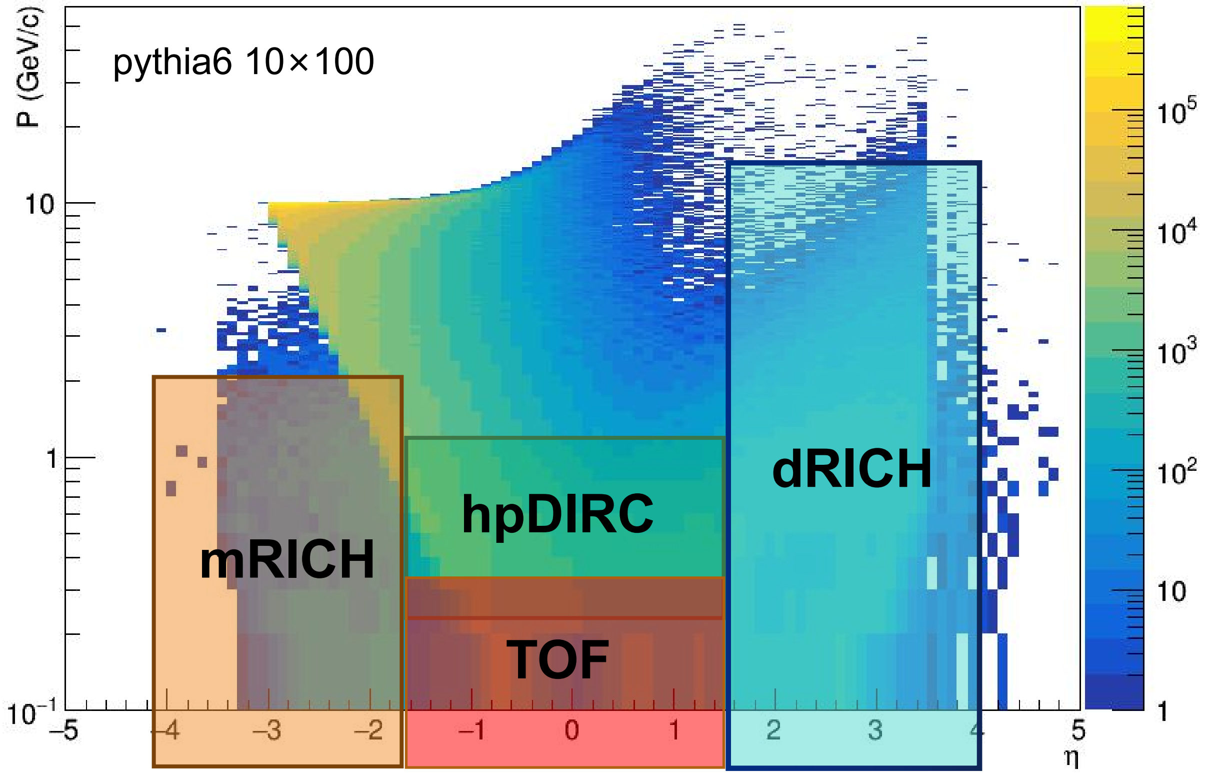
Electron identification capability at ECCE

EMCal +Tracking

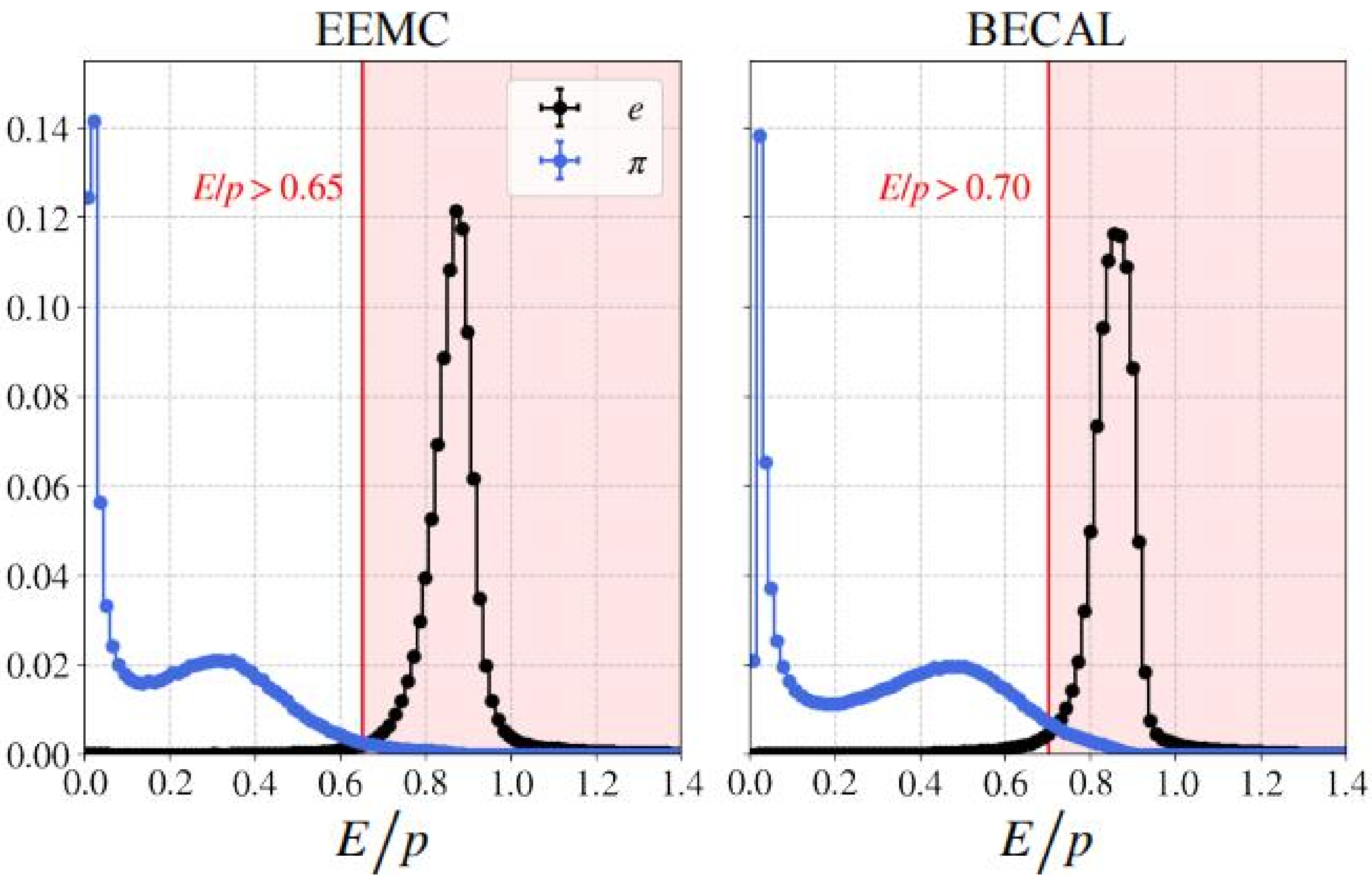
- ✓ The energy deposition => E/p cut
- ✓ The transverse profile of the showers
- ✓ The position resolution

Cherenkov + TOF

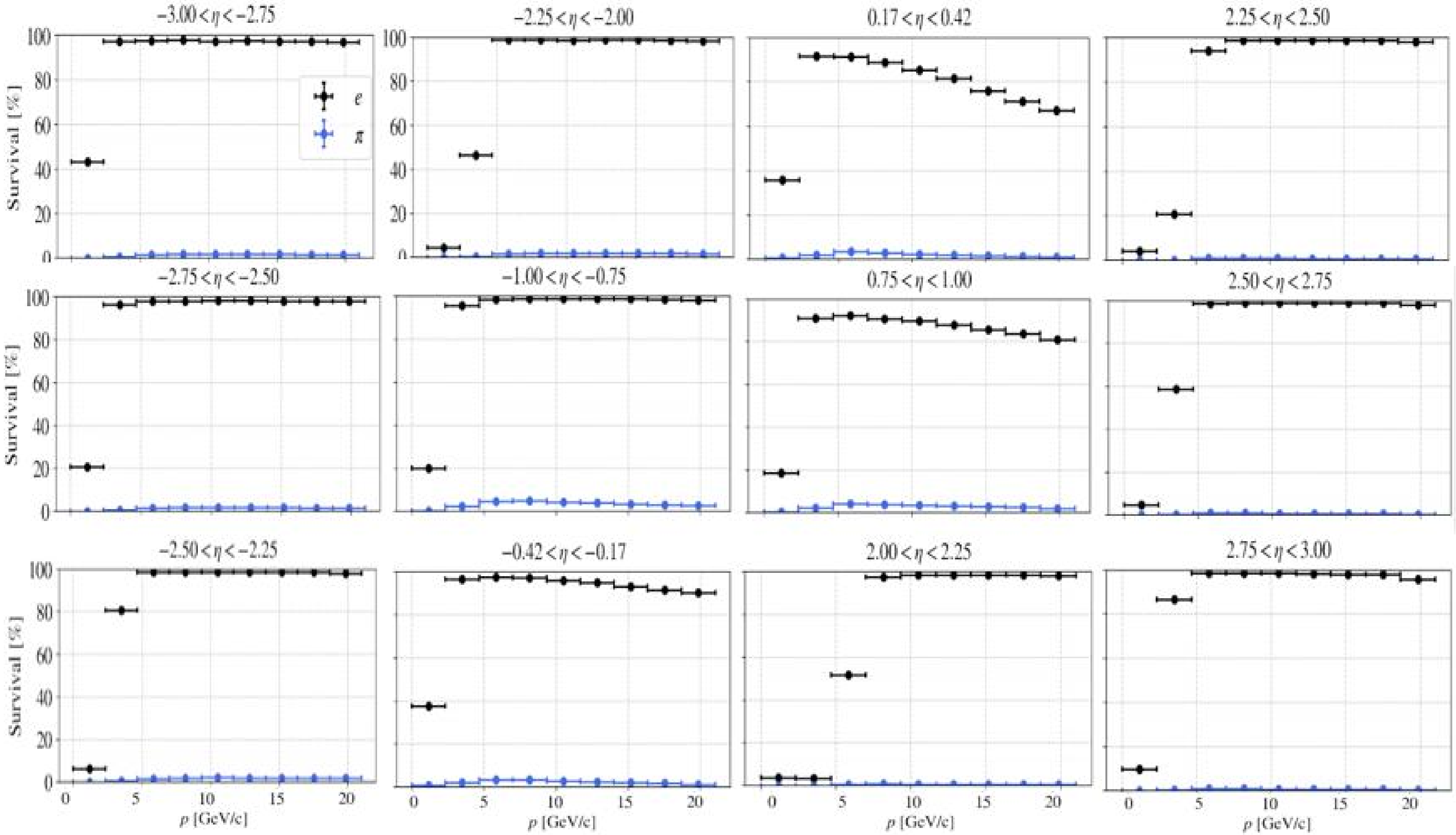




Electron identification capability at ECCE



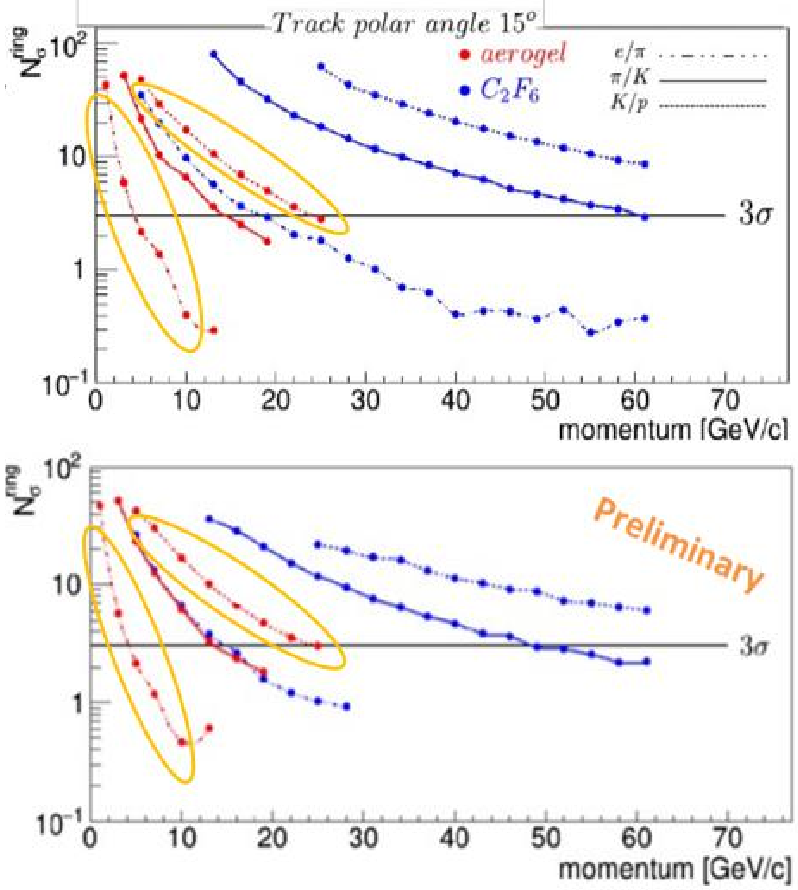
Electron identification capability at ECCE



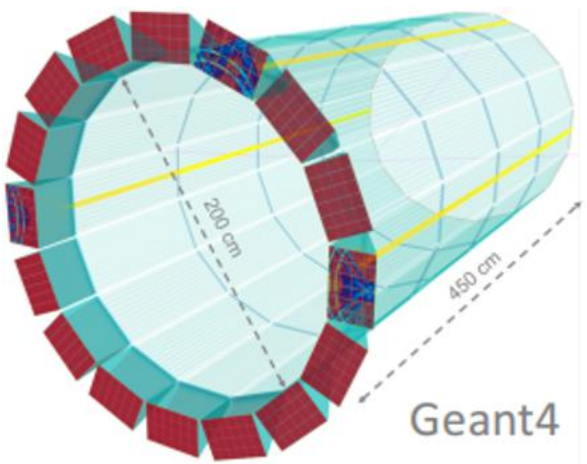
Electron identification capability at ECCE

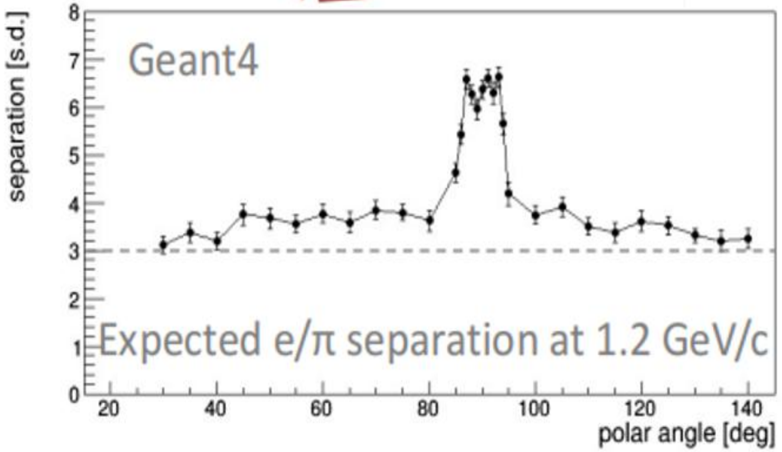
- **h-endcap: dRICH with two radiators** (gas + aerogel)
  - *π/K separation up to ~50 GeV/c*
  - e/π separation up to ~15 GeV/c
- **e-endcap: compact aerogel mRICH**
  - *π/K separation up to ~10 GeV/c*
  - e/π separation up to ~2 GeV/c
- **barrel: compact high-performance DIRC**
  - *π/K separation up to ~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

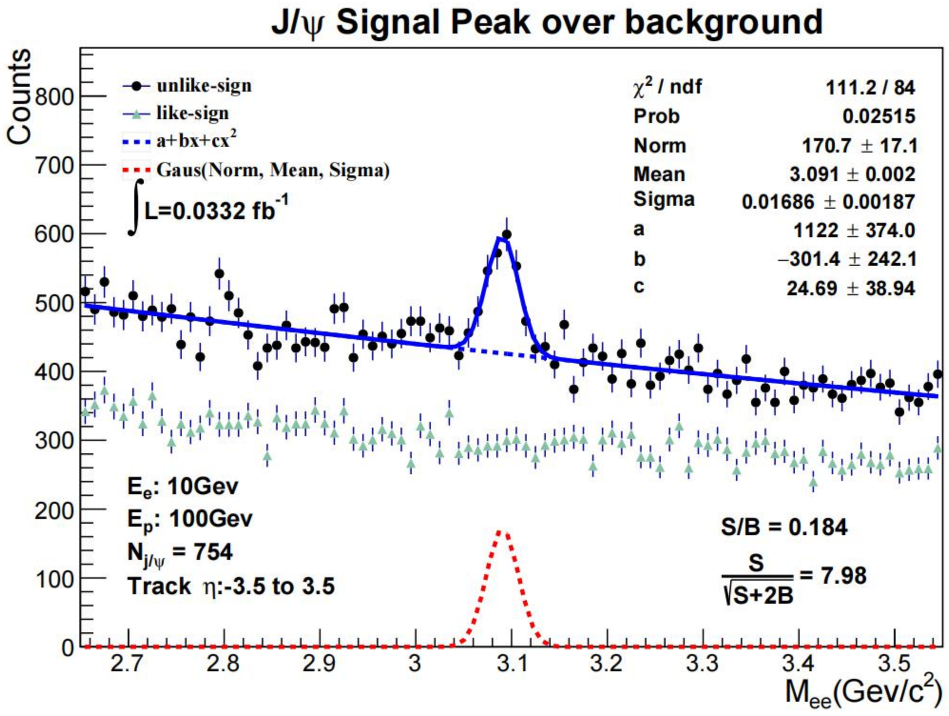


HPDIRC



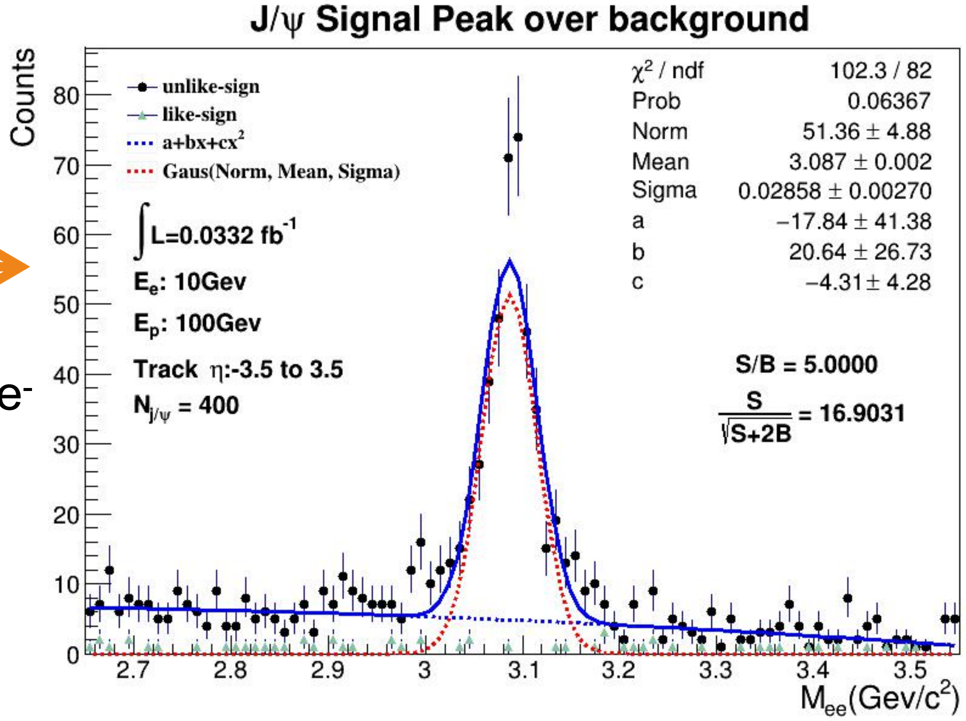


J/ψ Reconstruction



"veto"

exclude the beam scattering e-

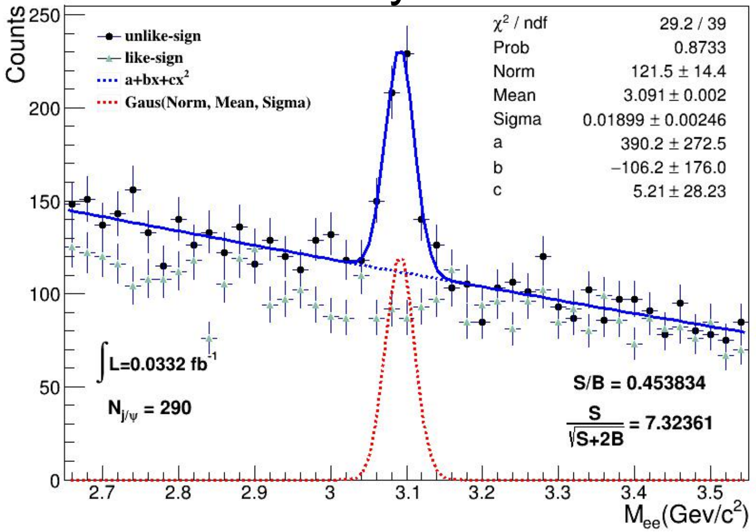


generator: pythia6 (eRHIC tuned) Full Geant simulation (fun4All)

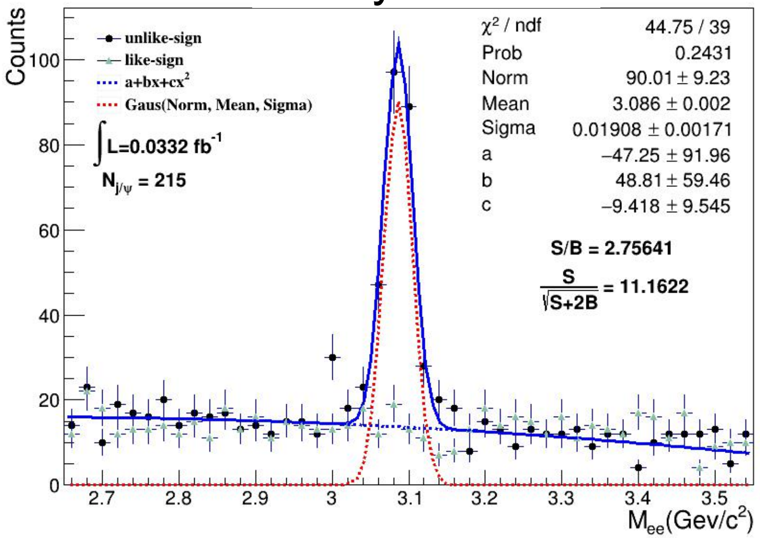
events: ~20million

J/ψ Reconstruction

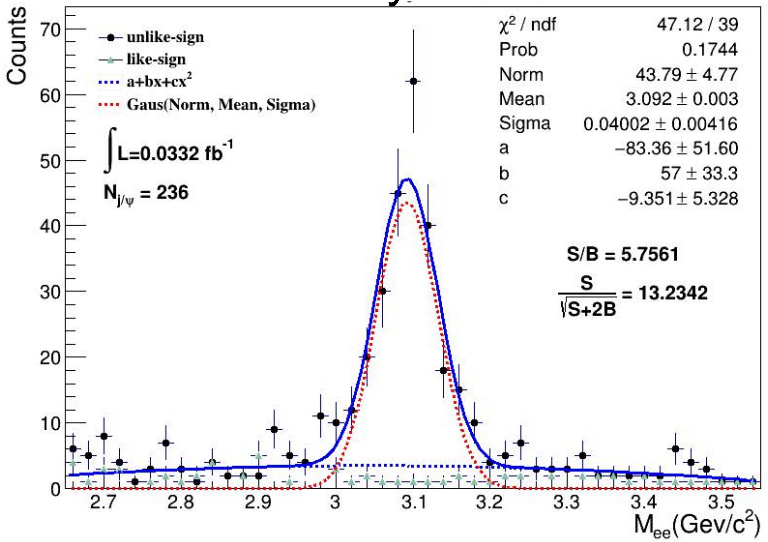
-2<y<0



0<y<1

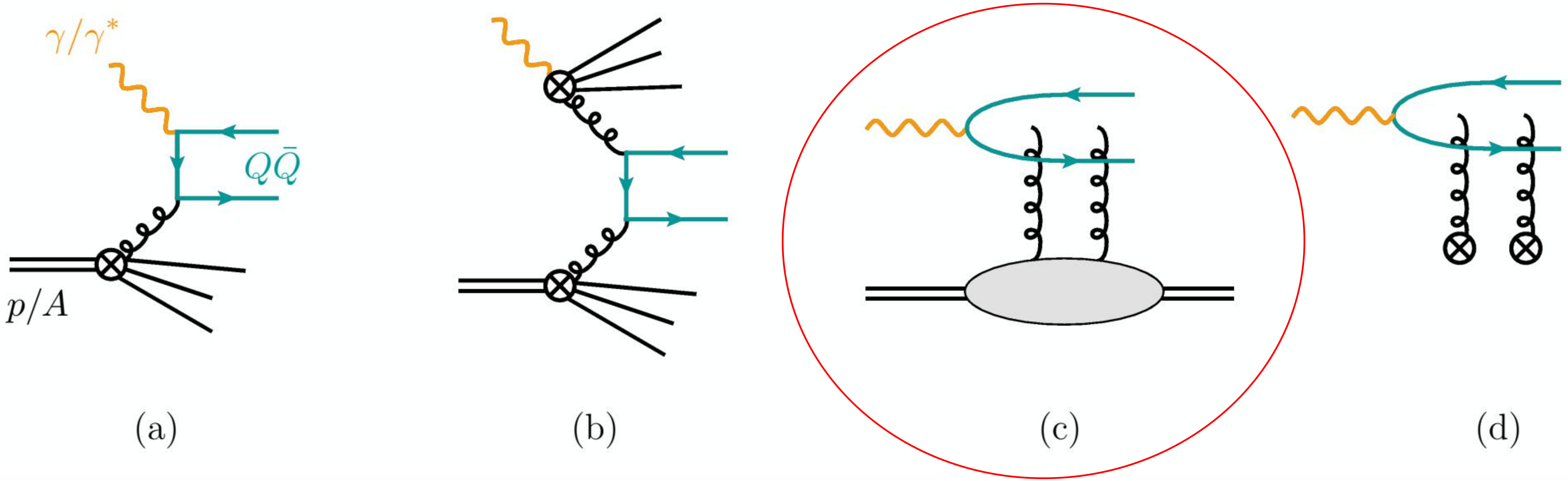


1<y<3.5



Resolution and significance in different rapidity regions

Production mechanism of quarkonia

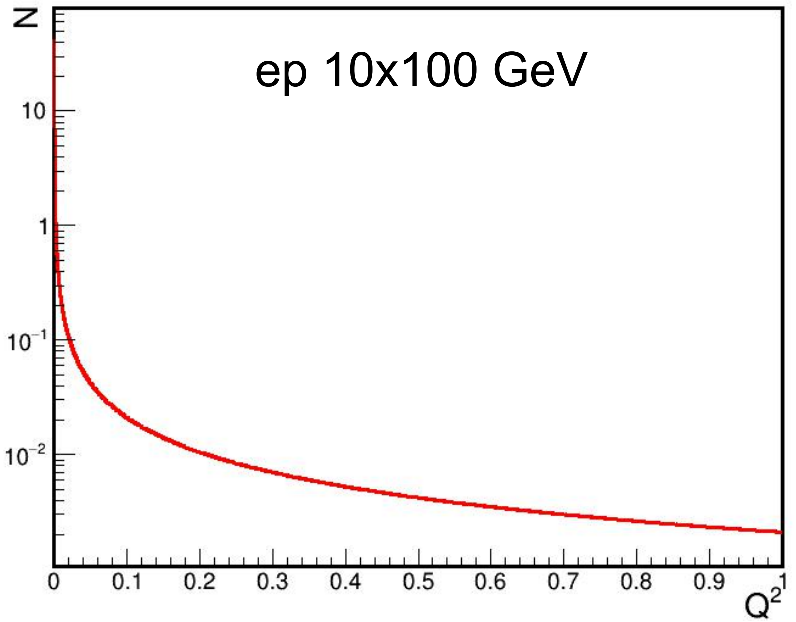


Yellow Report Fig. 7.95

Direct, Resolve and Exclusive process

Event feature of near threshold J/ψ photoproduction

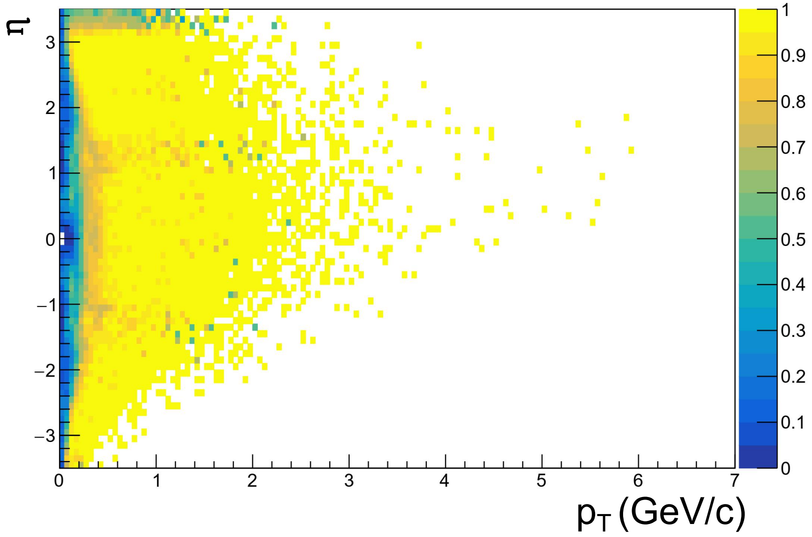
- ✓ The scattered proton or nucleus escape undetected down the beampipe at small scattering angles
- ✓ The majority of scattered electron escape undetected (Veto on $Q^2 > 1(GeV/c^2)^2$
- ✓ No other event activity expect the electron-position pair from J/ψ decay



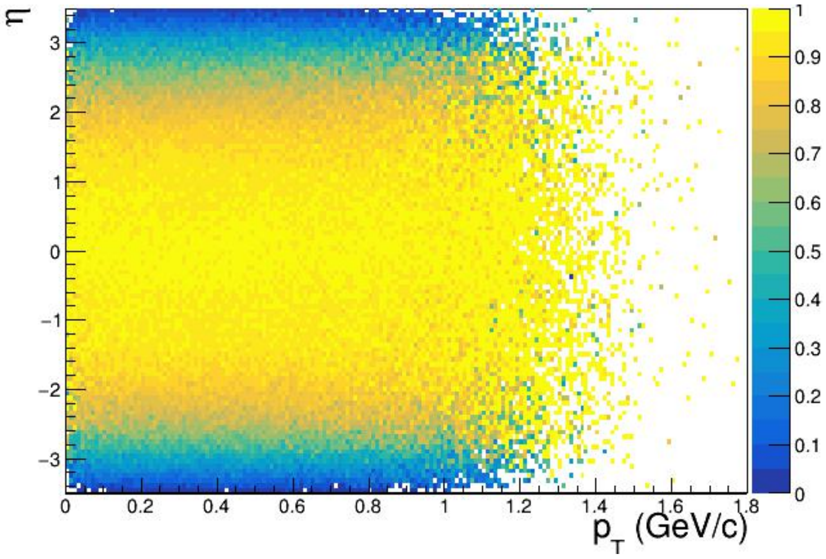
The trigger efficiency is sufficient high, assumed to be 1

Efficiency and S/B correction

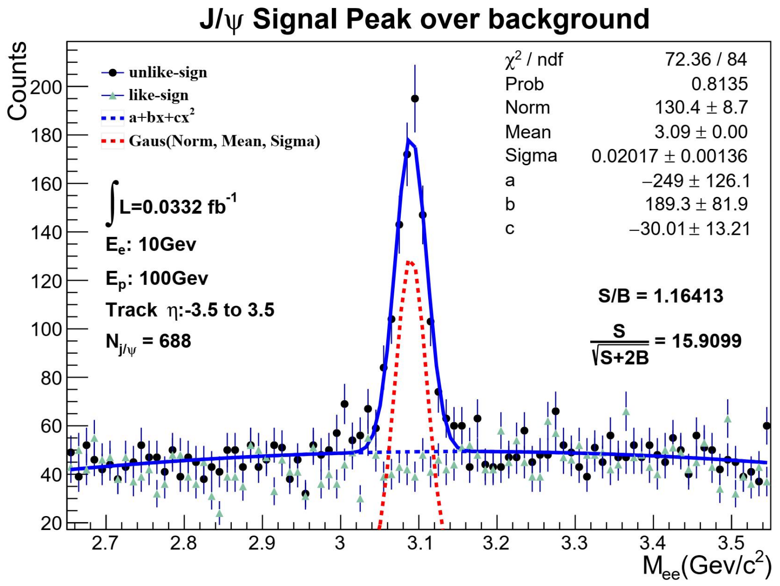
Single electron efficiency



J/ψ efficiency



S/B correction



The theoretical setup for projection (eSTARLight)

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

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

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

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

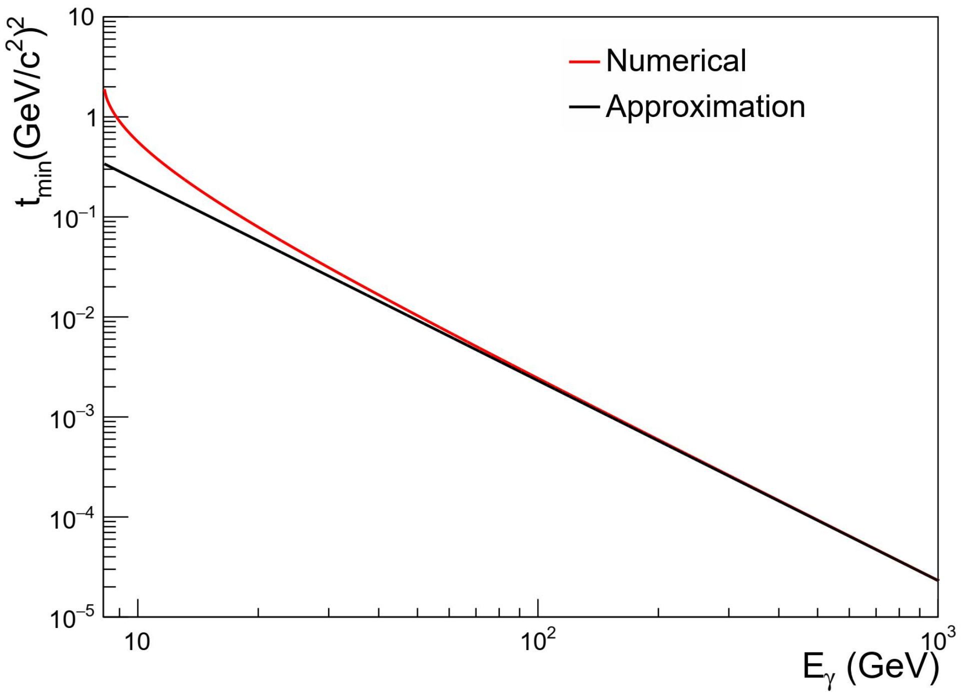
Can be related to the cross section for $\sigma(\gamma + p \to V + p)$

eSTARLight: Michael Lomnitz and Spencer Klein, Phys. Rev. C **99** (2019) 015203
Wangmei Zha etal, Phys. Rev. C **97** (2018) 044910

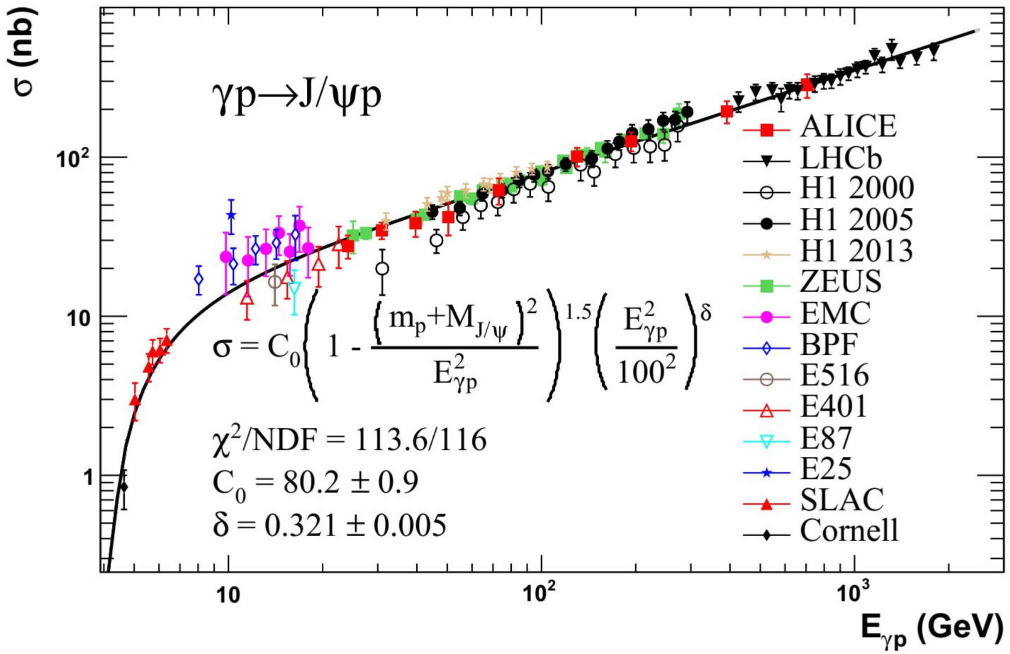
Two improvements for eSTARLight

Minimum momentum transfer

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

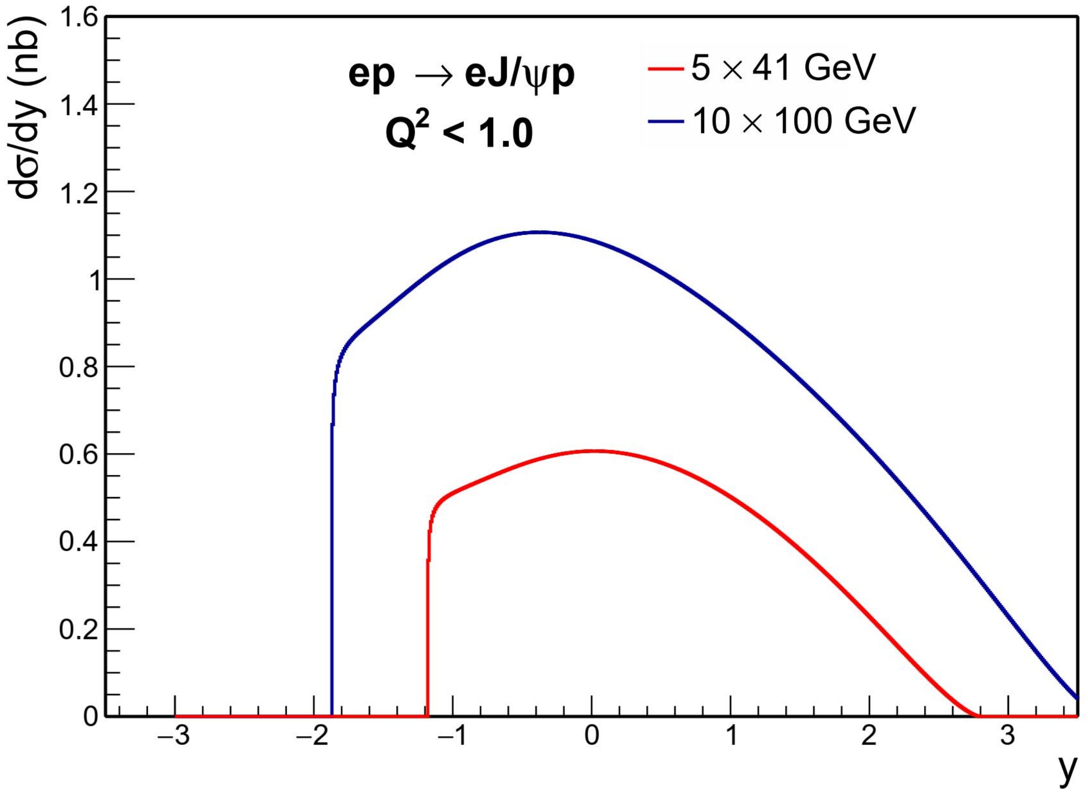


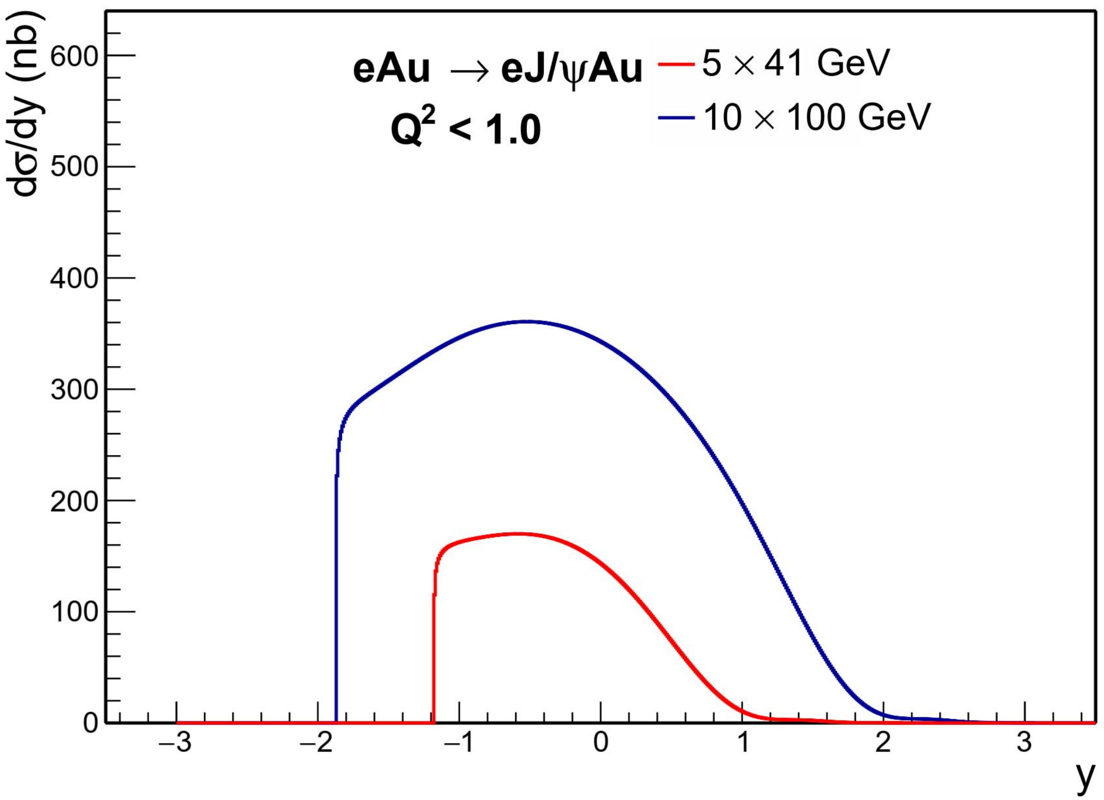
Parametrization for cross section input



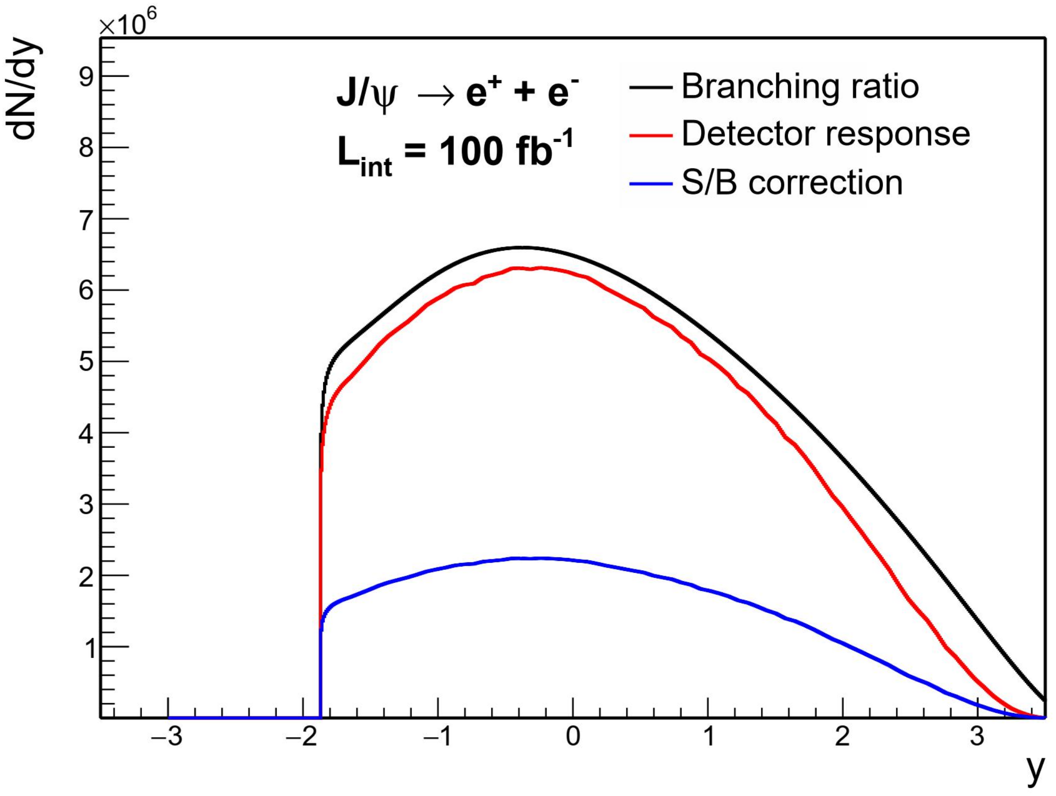
Z. Cao etal., Chin. Phys. C43 (2019) 064103

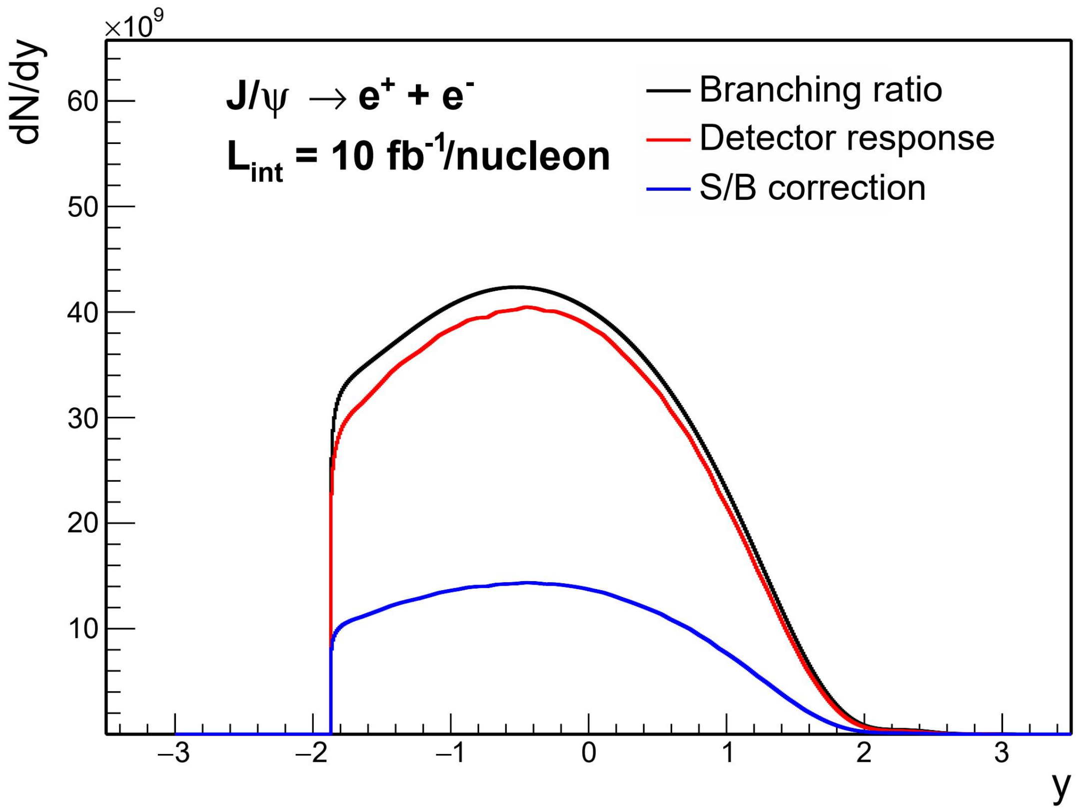
The theoretical input for ep and eAu



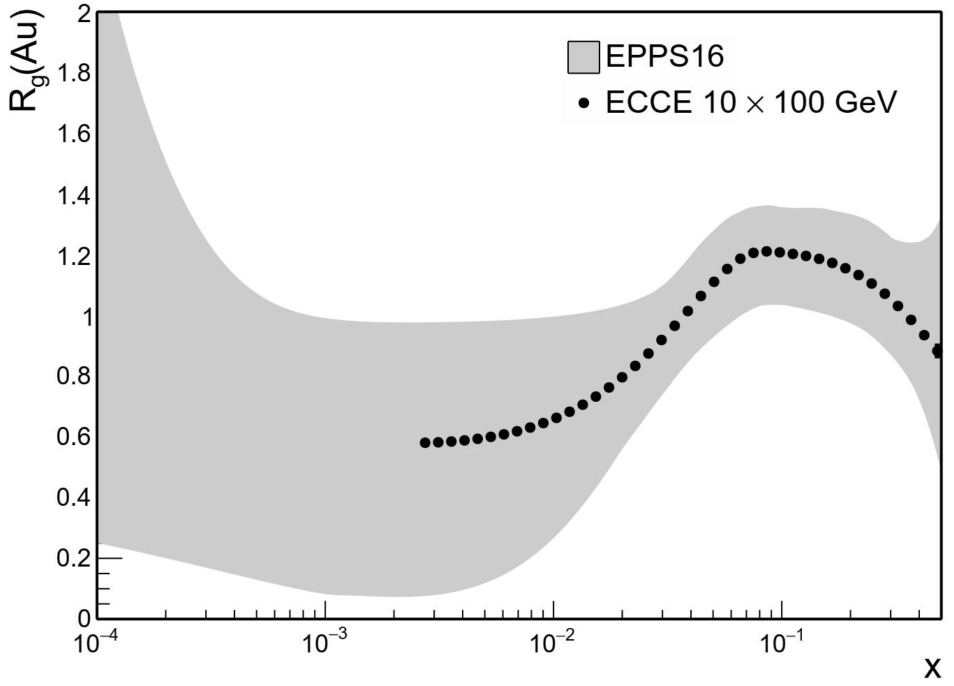


The projected statistics





The gluon nPDF projection



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

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

If there is no shadowing

$$d\sigma_{\gamma A}/dt|_{t=0} = d\sigma_{\gamma p}/dt|_{t=0} \times A^2$$

Some remarks

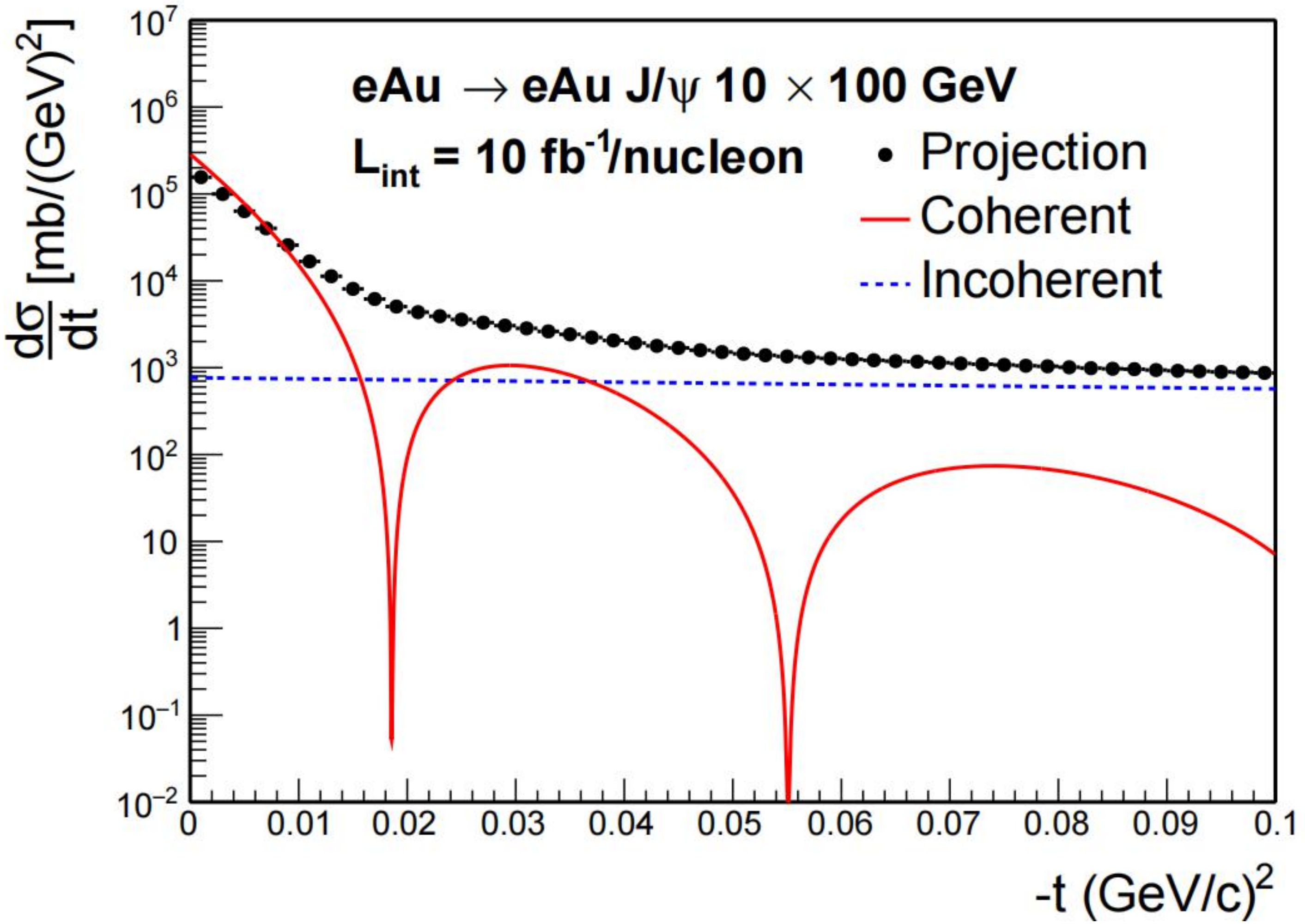
$$\rho(x) = \tan\left(\frac{\pi \Delta_{\mathbb{P}}}{2}\right)$$

$$R_{\text{skewed}} = \frac{2^{2\Delta_{\mathbb{P}}+3}}{\sqrt{\pi}} \cdot \frac{\Gamma(\Delta_{\mathbb{P}} + 5/2)}{\Gamma(\Delta_{\mathbb{P}} + 4)}$$

$$K = (1 + \rho^2(x)) \cdot R_{\text{skewed}}^2$$

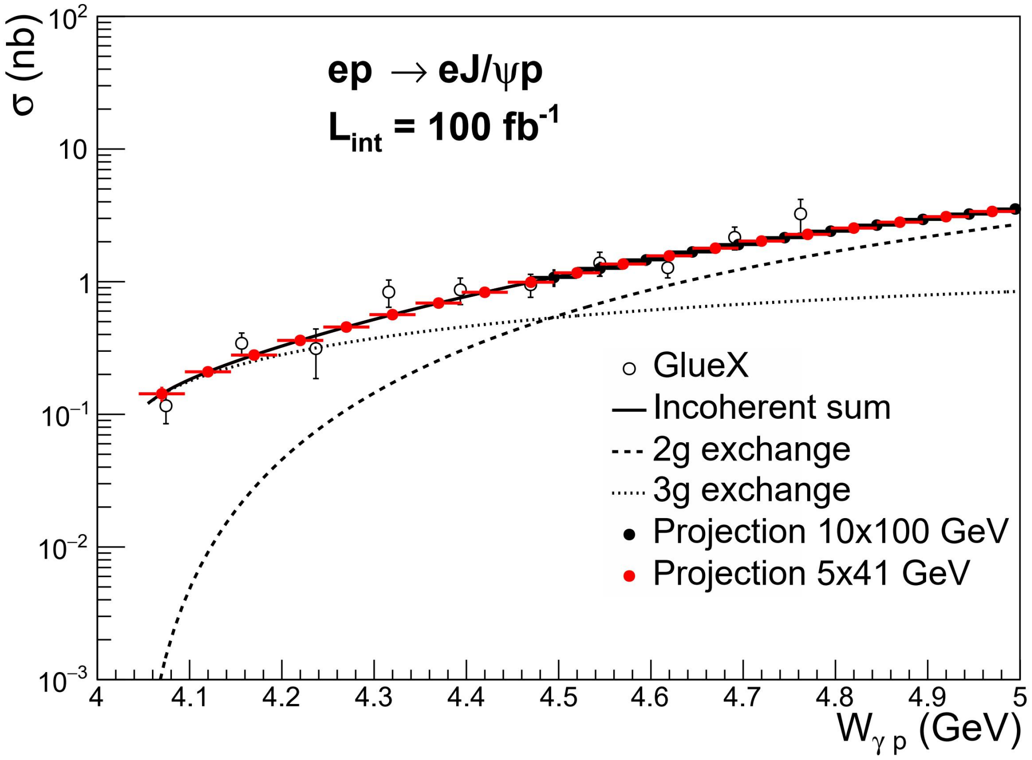
Assume the correction is the same for p and Au

The t distribution projection



The momentum resolution would wipe out the diffraction dips.

The near threshold production mechnasim



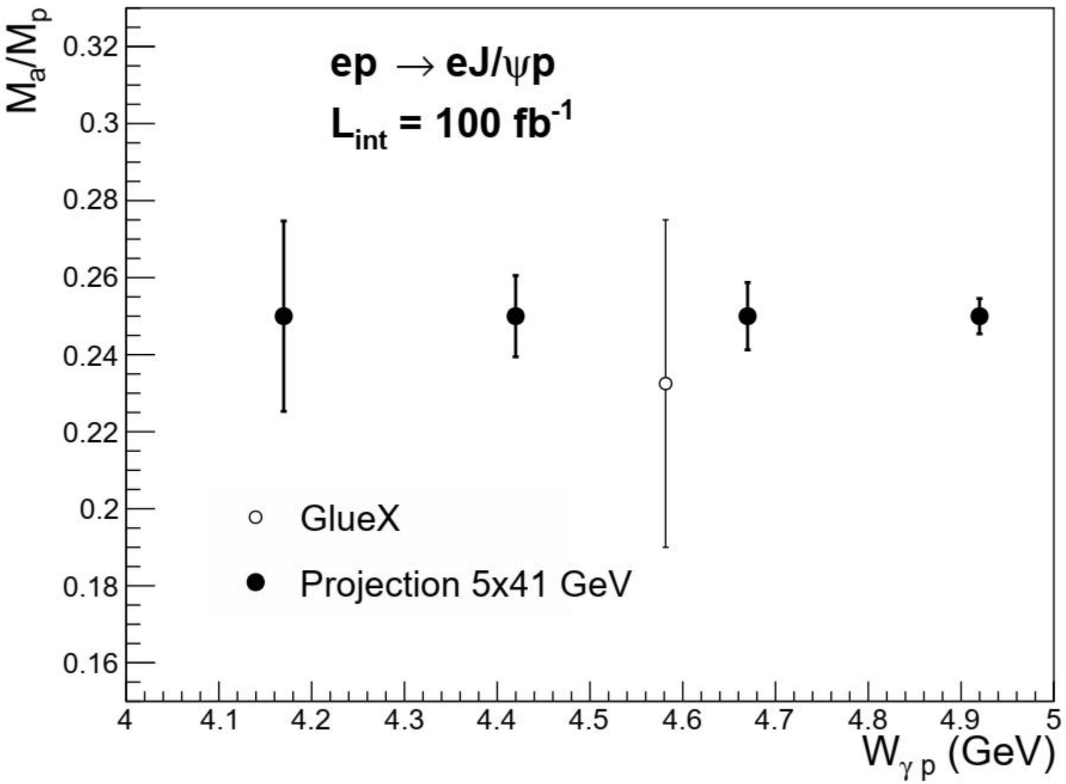
Phys. Rev. Lett. 123, 072001(2019)

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

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

Physics Letters B 498 (2001) 23–28

The trace anomaly parameter projection



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

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

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

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

Eur. Phys. J. C (2020) 80:507

Extract the QCD trace anomaly parameter b

Summary and future plan

Summary

- Excelent electron identification probability at ECCE
- Reasonable mass resolution for J/ψ reconstruction
- High statitics to study the photoproduction of J/ψ

Future plan

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

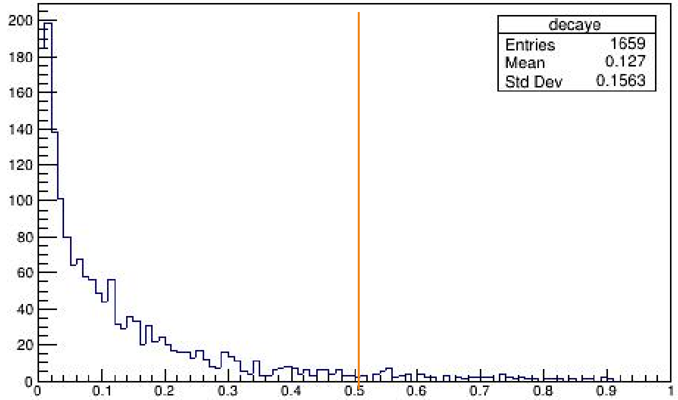
Backup

J/ψ detection (For Page15 S/B)

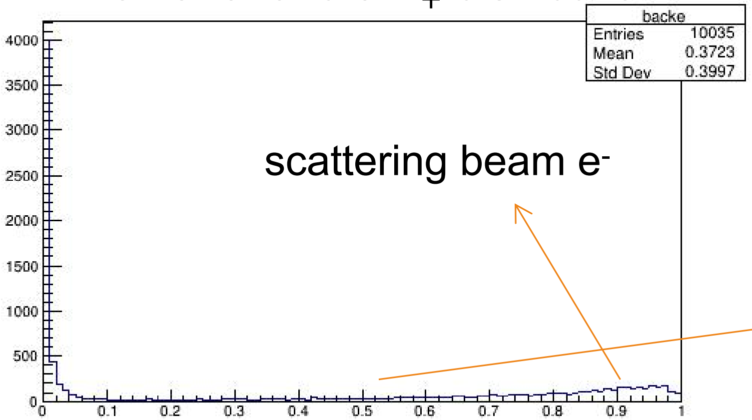
a forward light cone variables can be used to see scattering beam e- influence

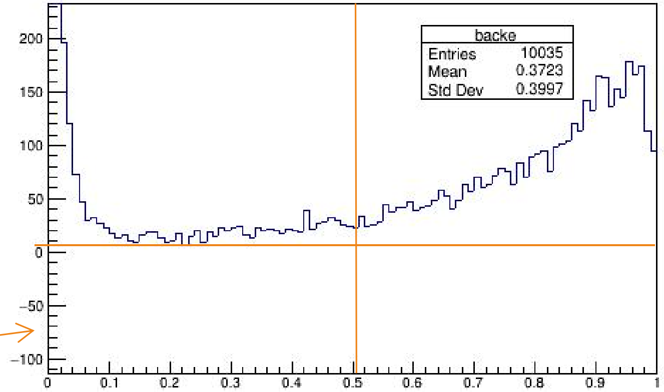
$x_+ = \frac{b_0+(-b_z)}{a_0+(-a_z)}$ (cause beam e- moves along negative z axis), b is beam e-.

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



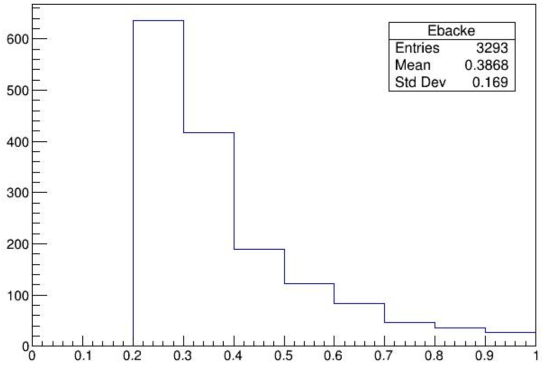
other e+ and e- x_+ distribution :



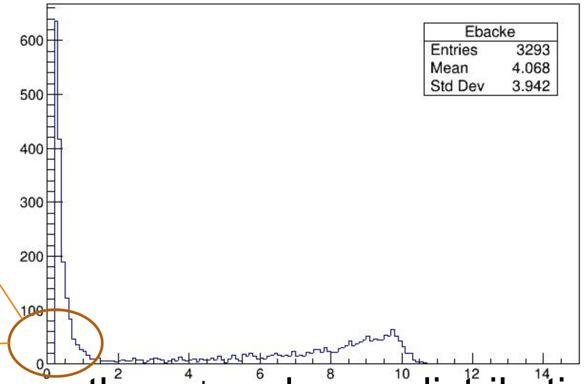


cut: $x_+ < 0.5$

influence of e- from light hadron decay

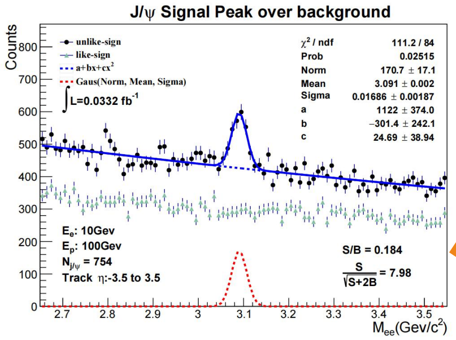


e+ and e- of J/ψ decay x_+ distribution



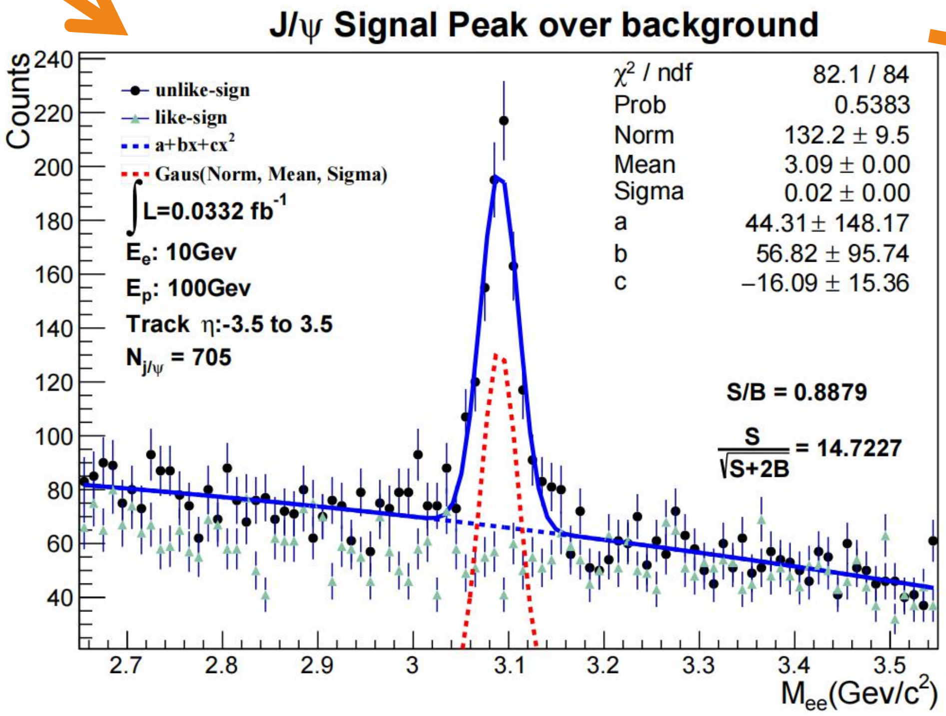
other e+ and e- x_+ distribution :

J/ψ detection (For Page15 S/B)



cut: $x_+ < 0.5$

S/B: 0.184 —> 0.888



cut: E>0.6

S/B: 0.888 —> 1.164