Quarkonium detection and physics with ECCE

Xinbai Li for ECCE Collaboration

27/10/21

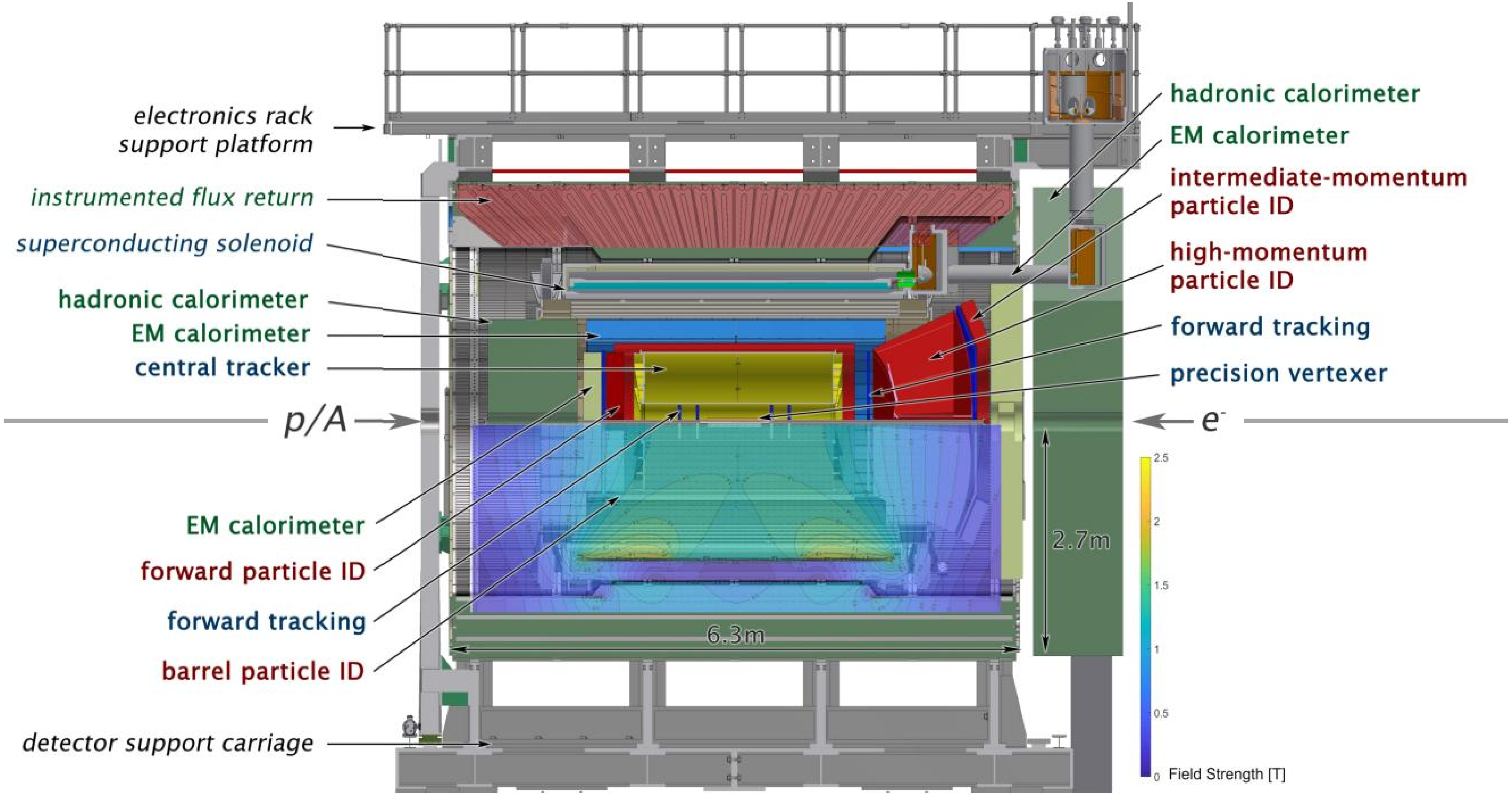
Outline

- 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

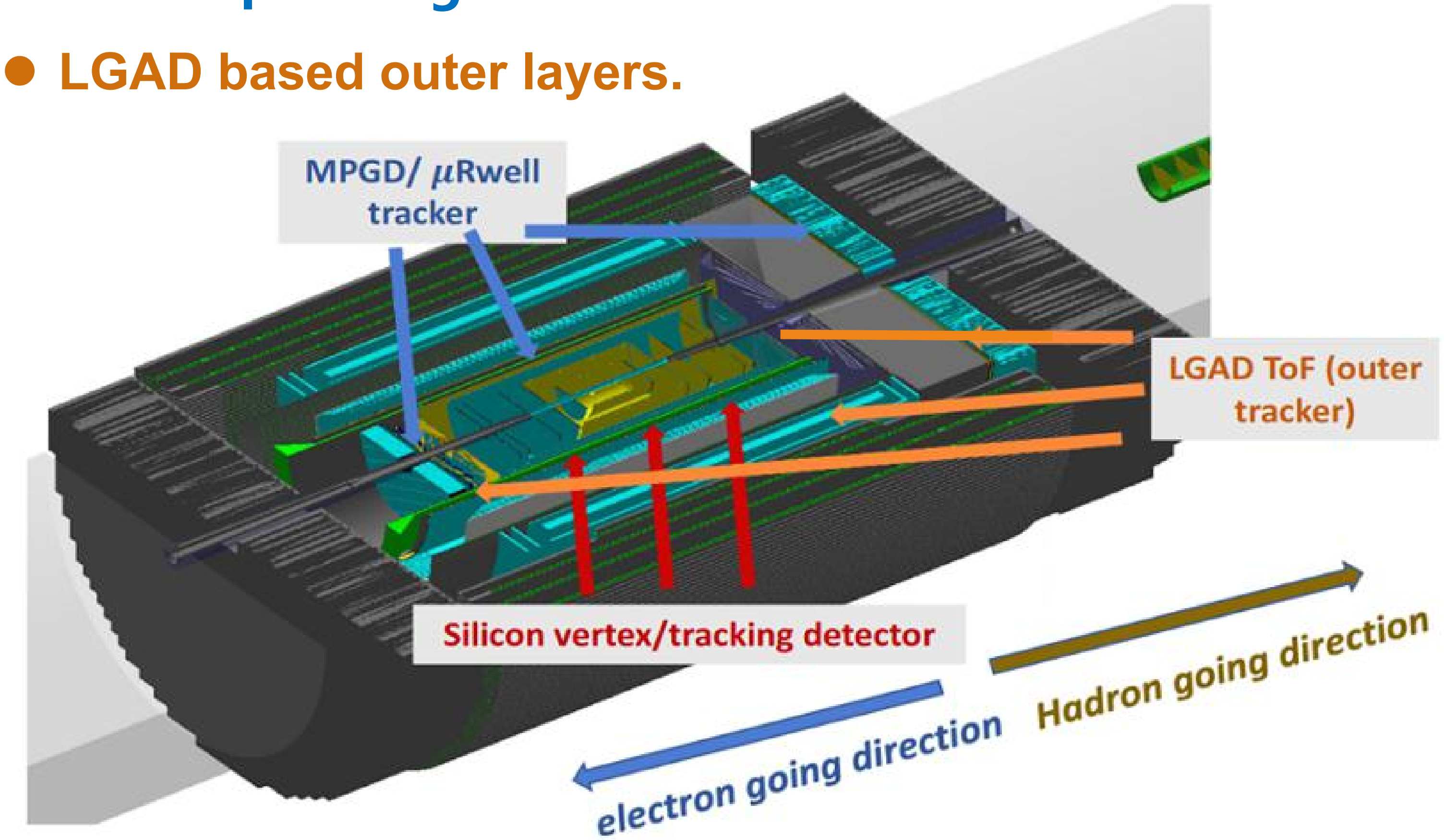
- Production mechanism for quarkonia
  - ✓ Constrain the NRQCD matrix elements
  - ✓ Study the hadronization in nucleus
- 3D tomography of gluon distribution
  - ✓ gluon nPDF (z direction)
  - ✓ Transverse distribution of gluon (x-y direction)
- Near threshold photoproduction
  - ✓ 2g, 3g exchange
 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

Detector Configuration

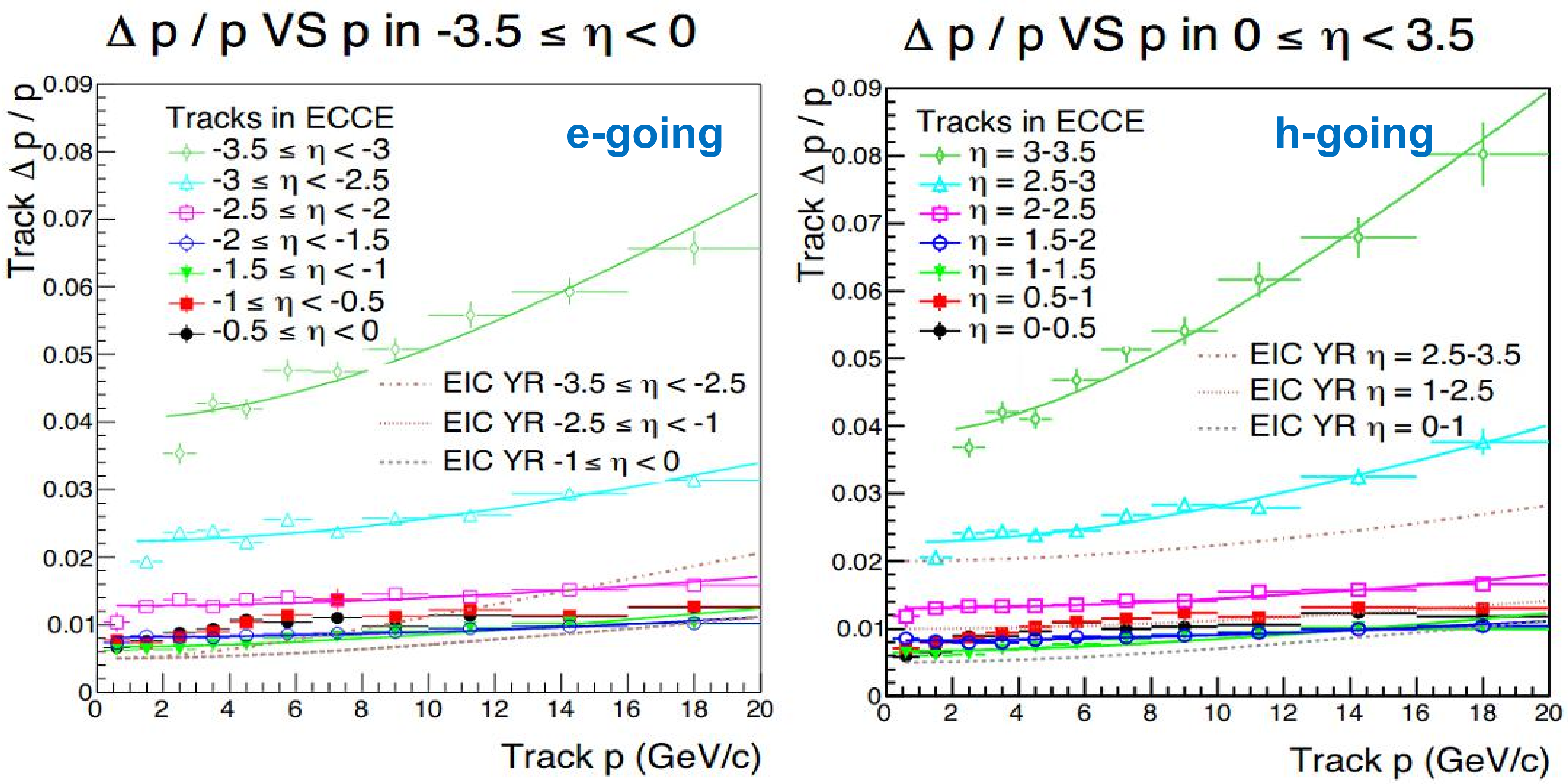


Detector Configuration——Tracking

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



Tracking performance at ECCE

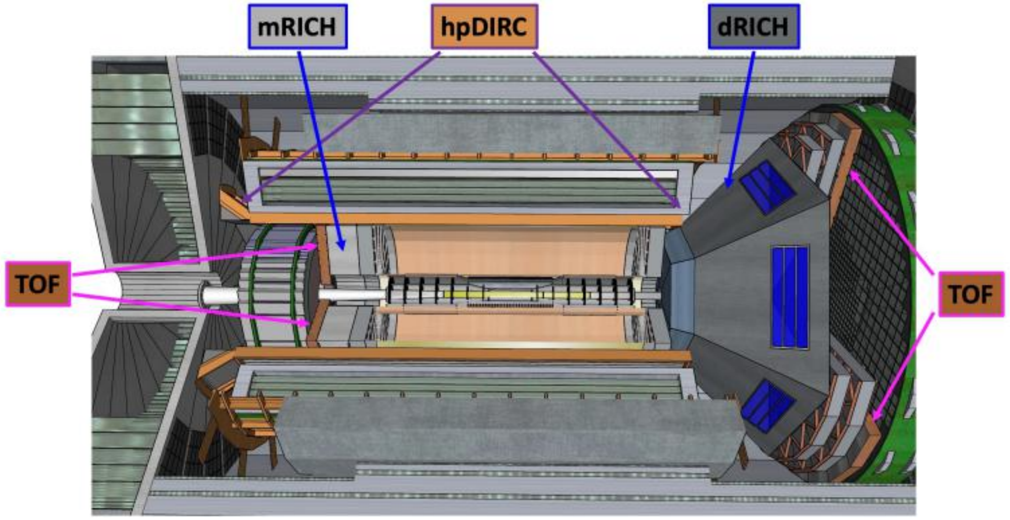


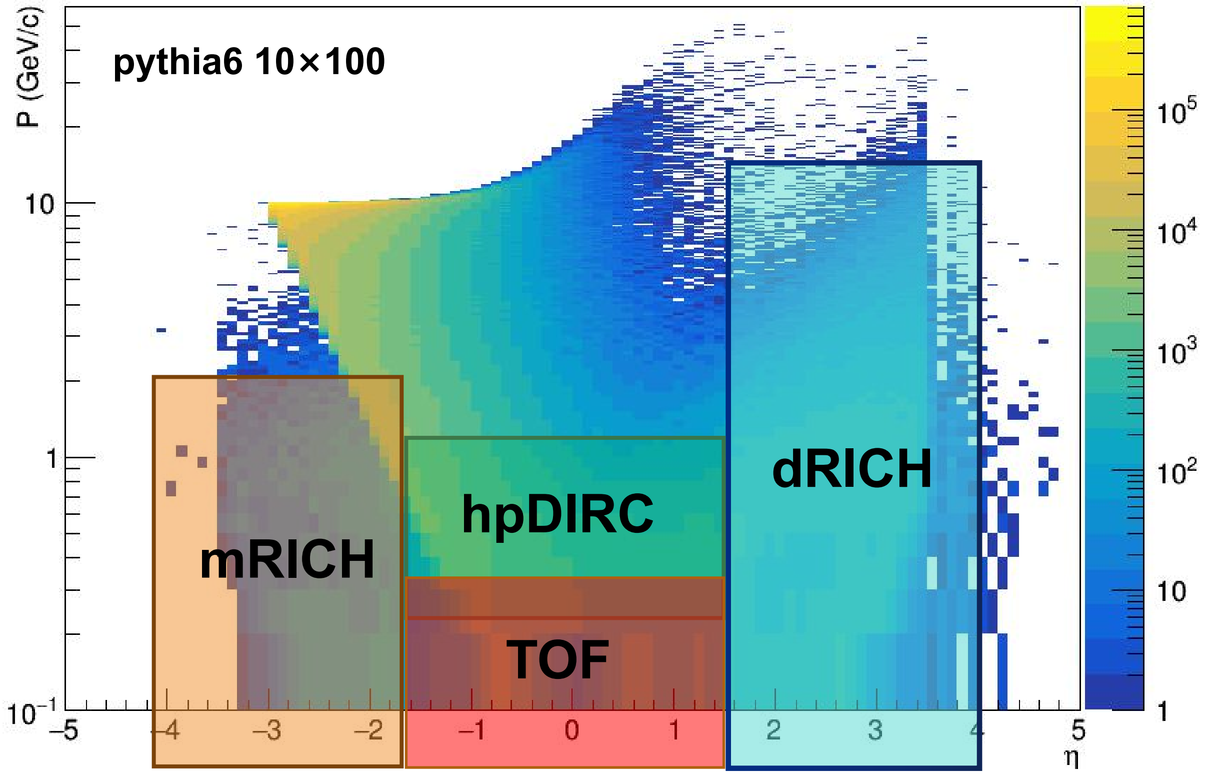
Electron identification capability at ECCE

EMCal +Tracking

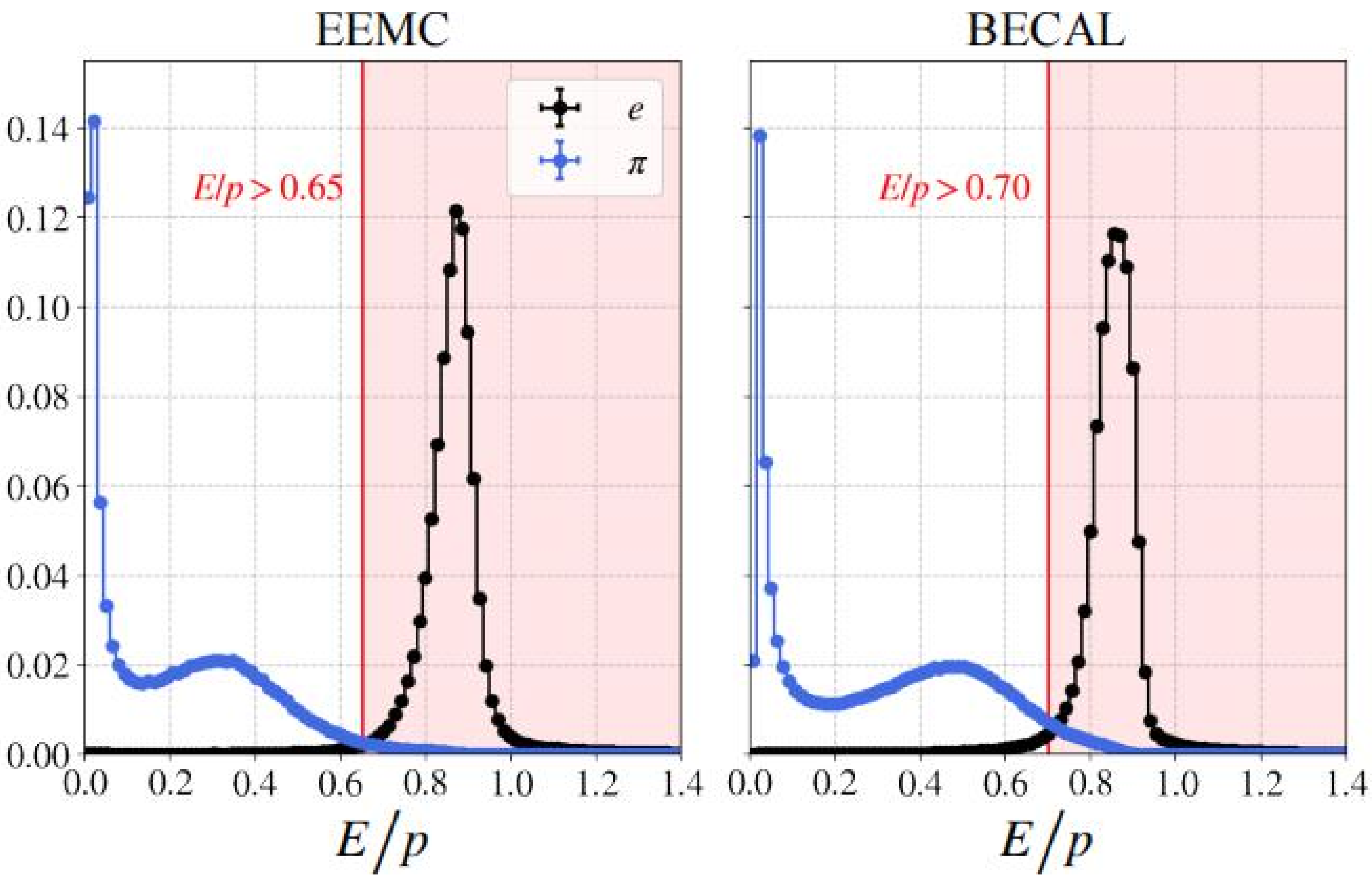
- ✓ The energy deposition => E/p cut
- ✓ The transverse profile of the showers
- ✓ The position resolution

Cherenkov + TOF

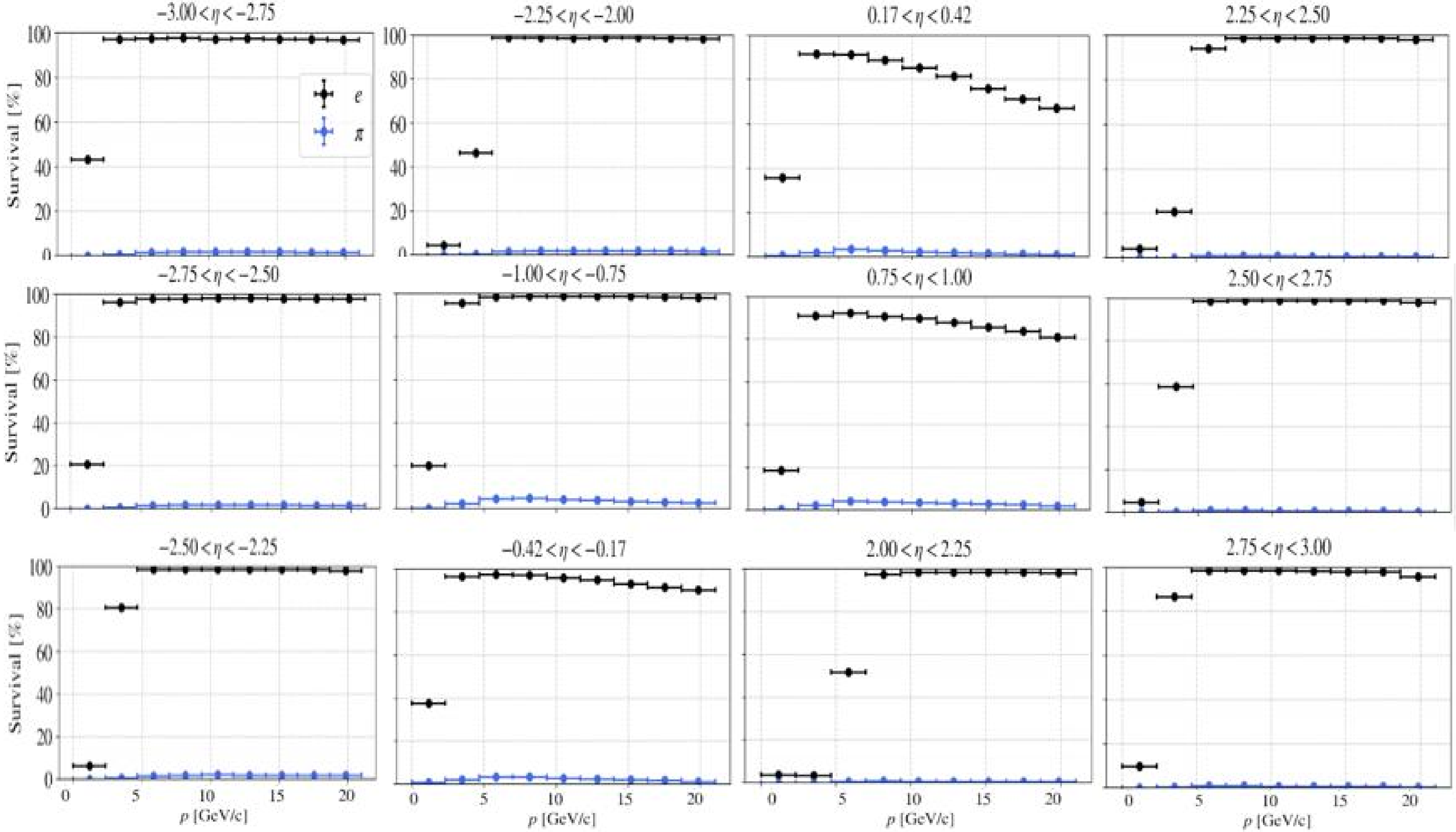




Electron identification capability at ECCE—EMCal+Tracking



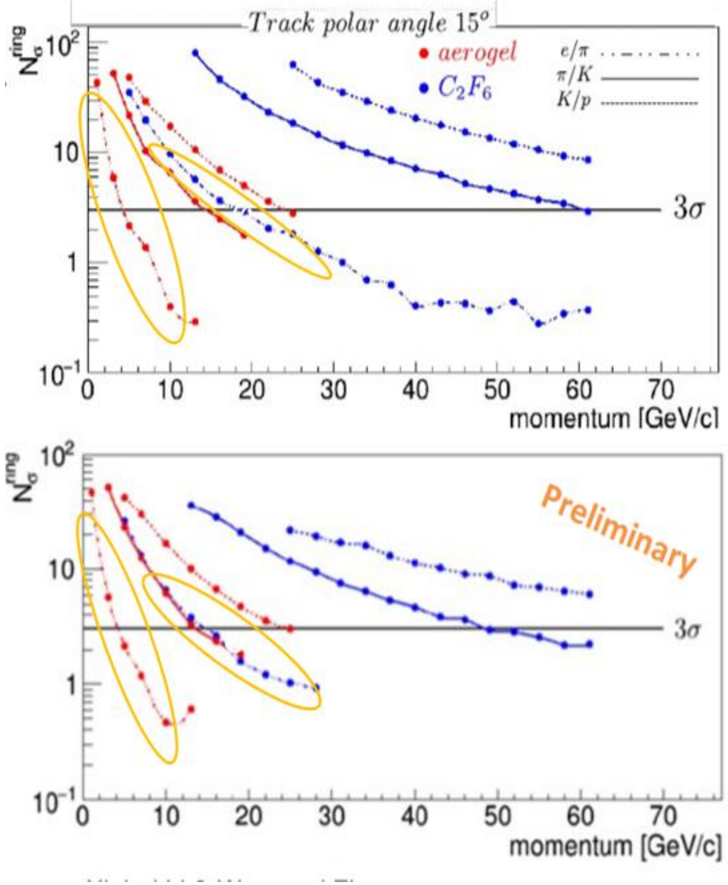
Electron identification capability at ECCE—EMCal+Tracking



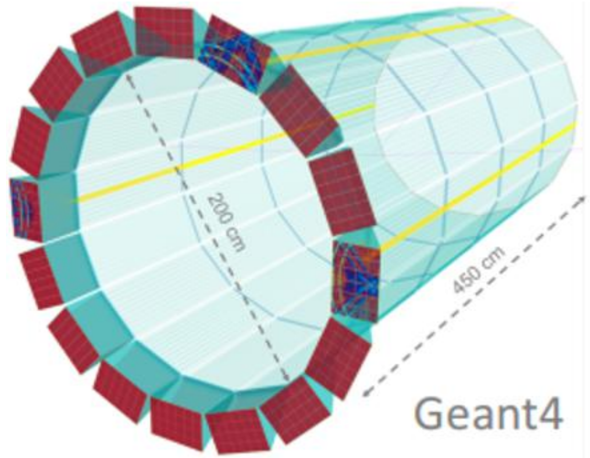
Electron identification capability at ECCE—Cherenkov+TOF

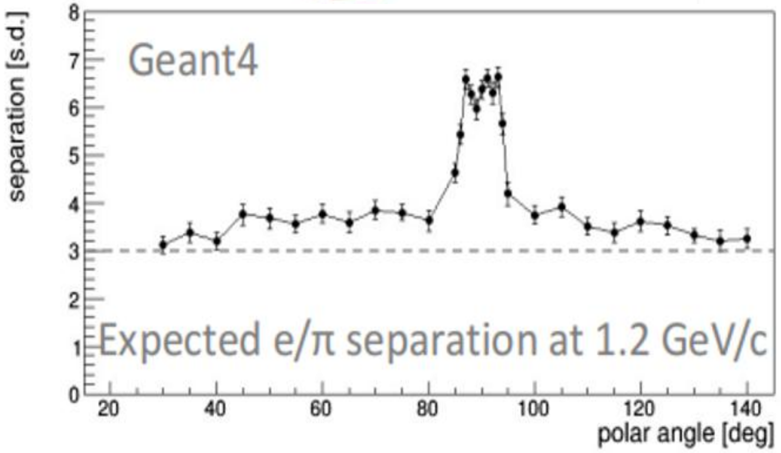
- **h-endcap: dRICH with two radiators** (gas + aerogel)
  π/K separation up to ~50 GeV/c
  e/π separation up to ~15 GeV/c
- **e-endcap: compact aerogel mRICH**
  π/K separation up to ~10 GeV/c
  e/π separation up to ~2 GeV/c
- **barrel: compact high-performance DIRC**
  π/K separation up to ~6-7 GeV/c
  e/π separation up to ~1.2 GeV/c
- **LGAD based TOF:**
  cover lower momenta down to ~0.2 GeV/c

dRICH Simulated Performance

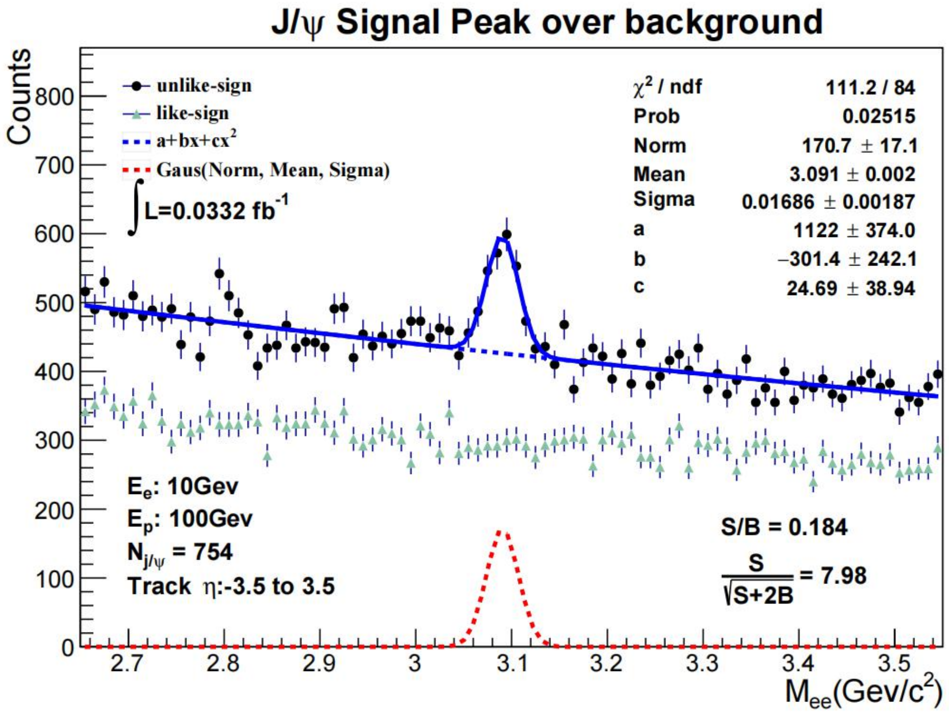


HPDIRC

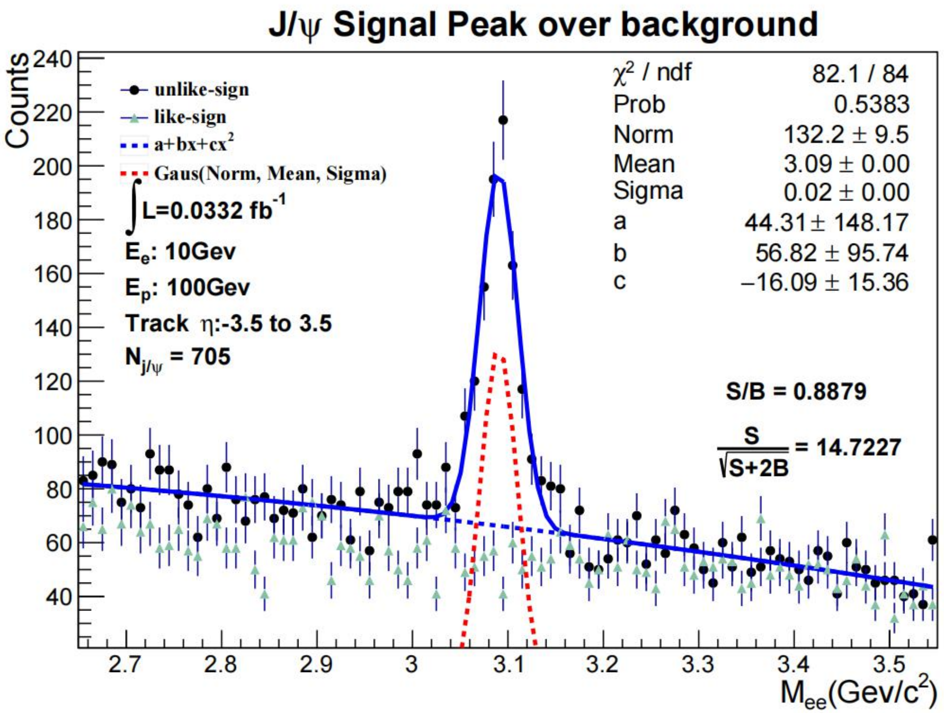




J/ψ Reconstruction



a forward lightcone cut $x_+ < 0.5$

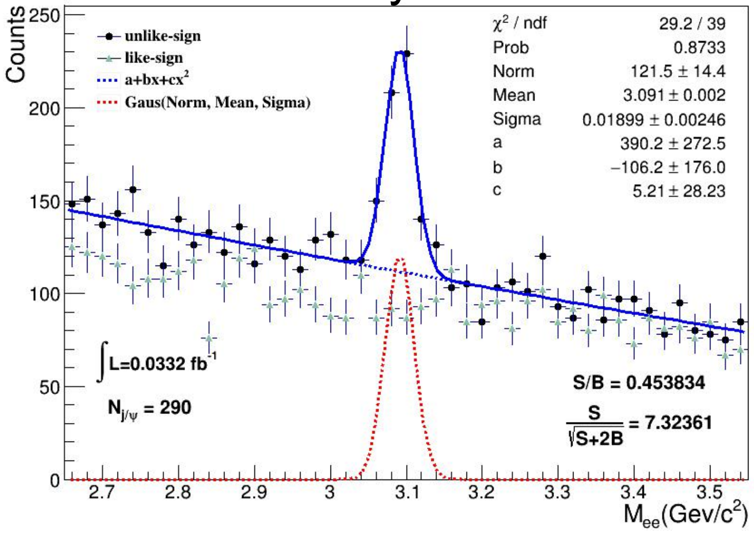


generator: pythia6 (eRHIC tuned)   Full Geant simulation (fun4All)

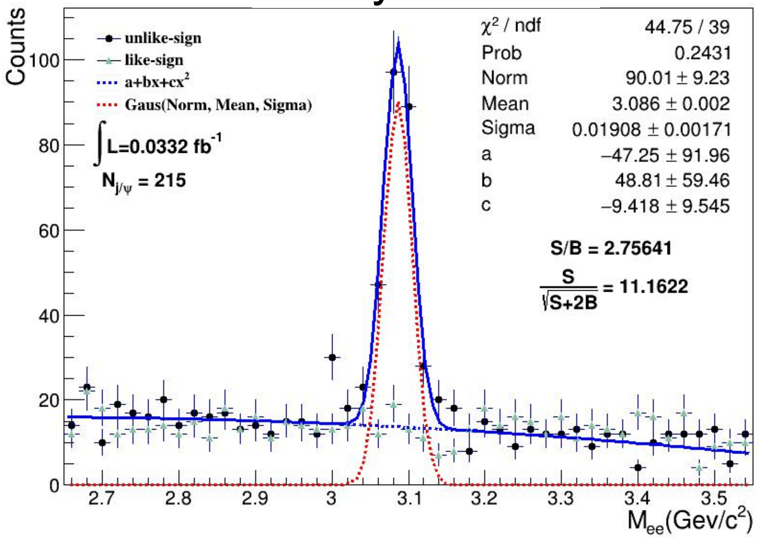
events: ~20million

J/ψ Reconstruction

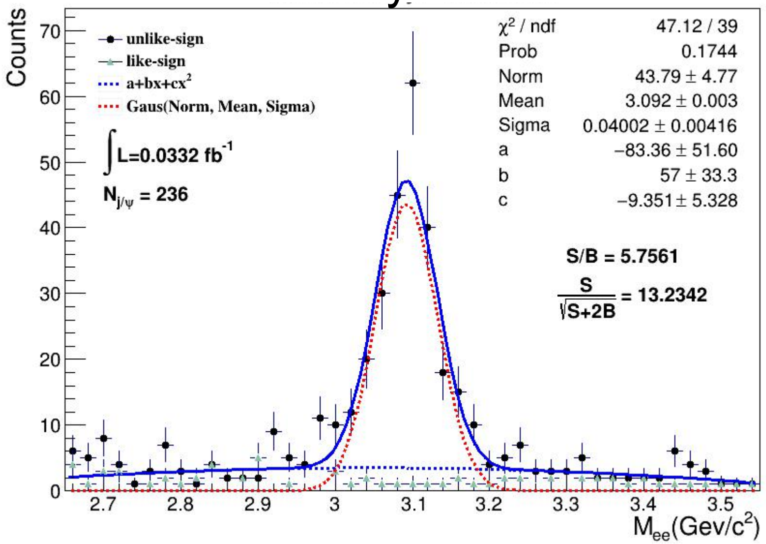
-2<y<0



0<y<1



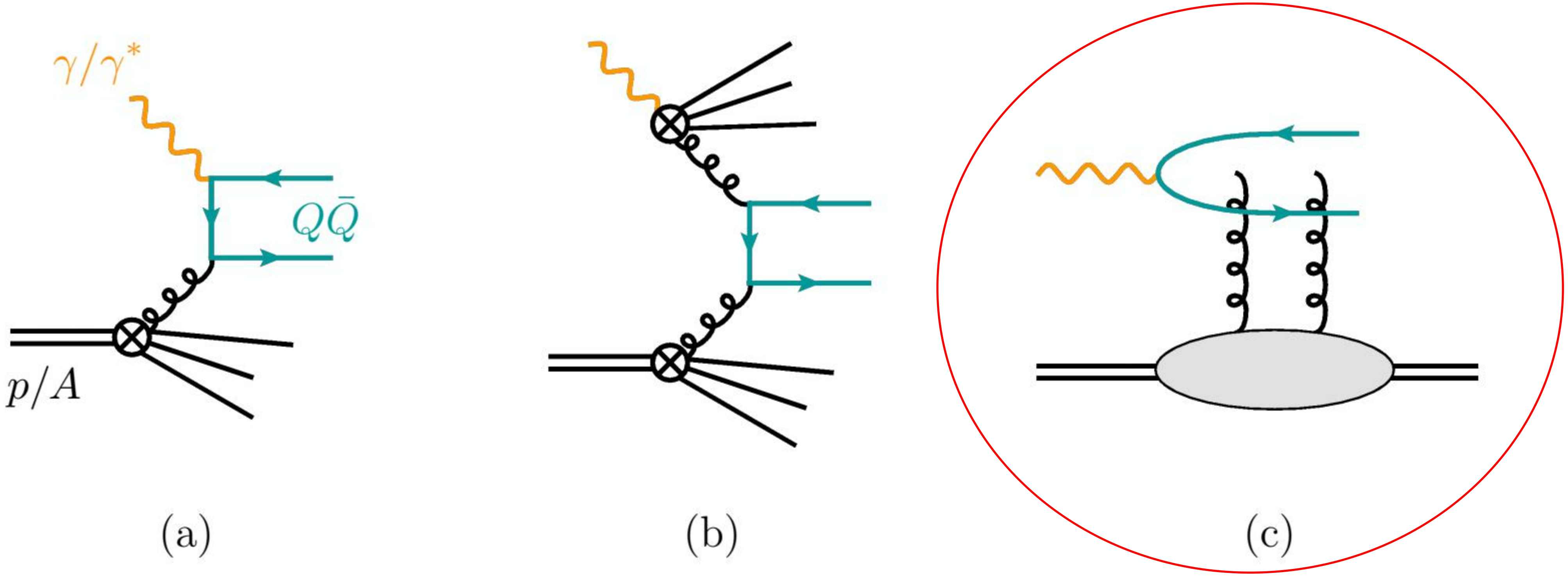
1<y<3.5



Central region with better mass width.

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

Production mechanism of quarkonia

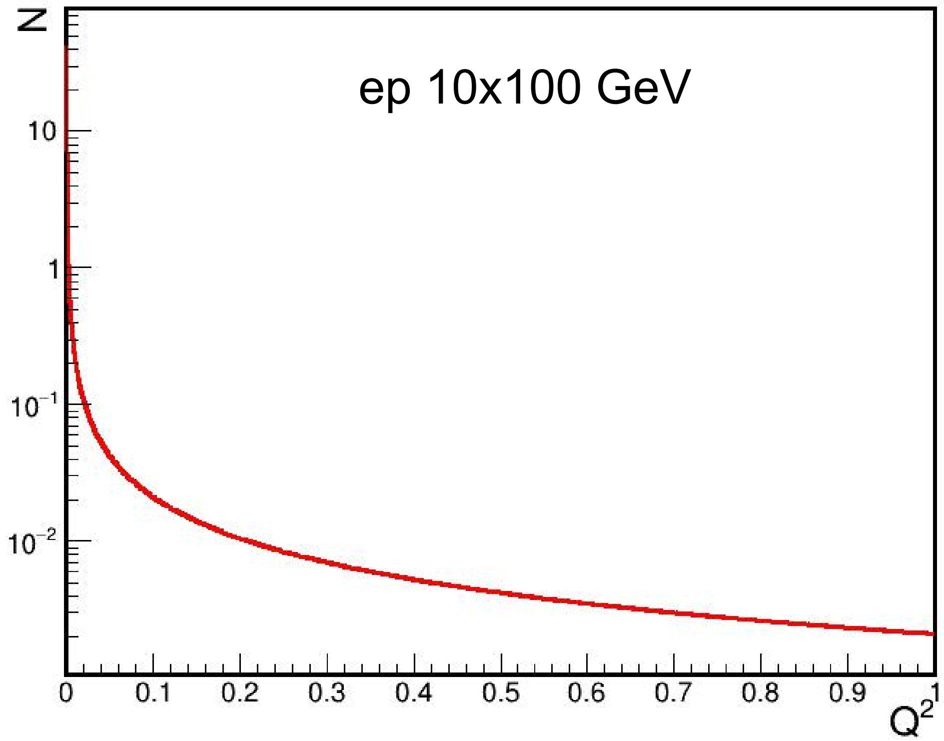


Yellow Report Fig. 7.95

Direct, Resolve and Exclusive process

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 GeV^2/c^4)
- ✓ No other event activity except the electron-positron pair from J/ψ decay



The theoretical setup for projection (eSTARLight)

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

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

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

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

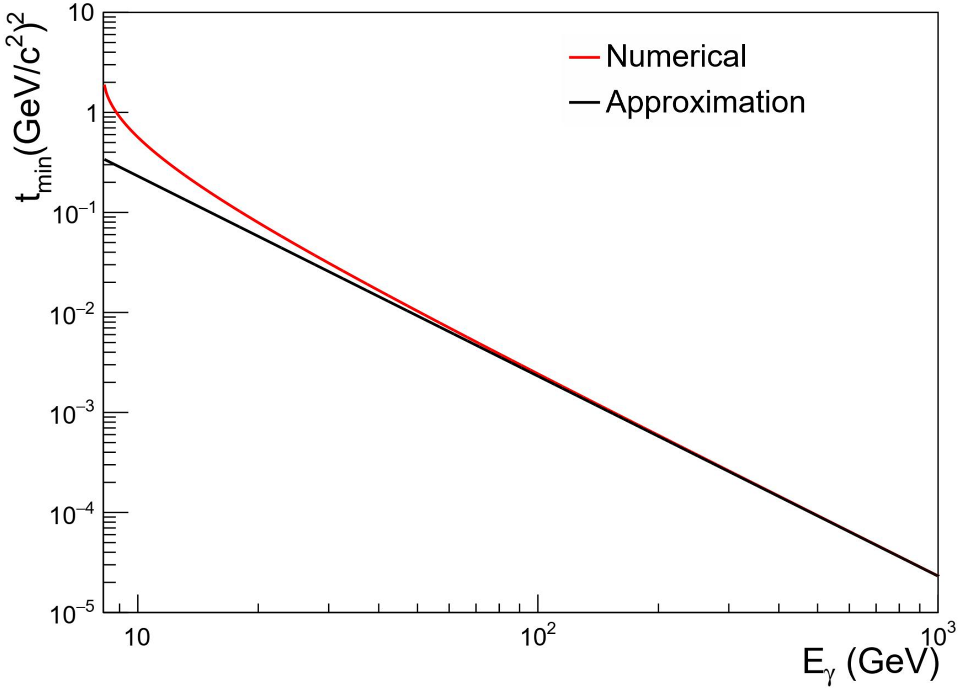
Can be related to the cross section for σ(γ+p → V+p)

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

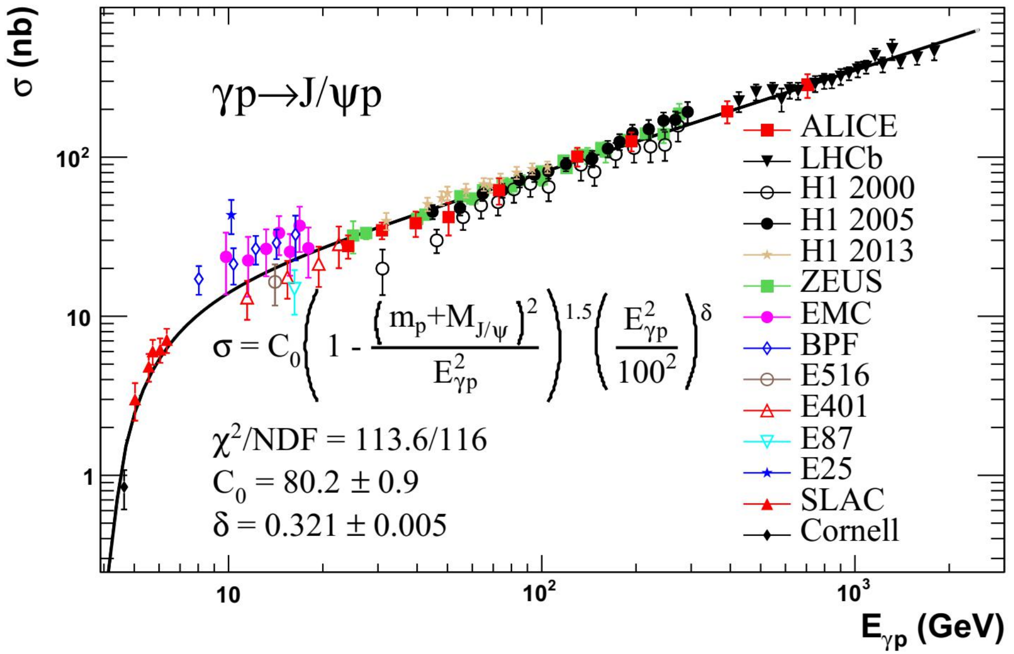
Two improvements for eSTARLight

Minimum momentum transfer

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

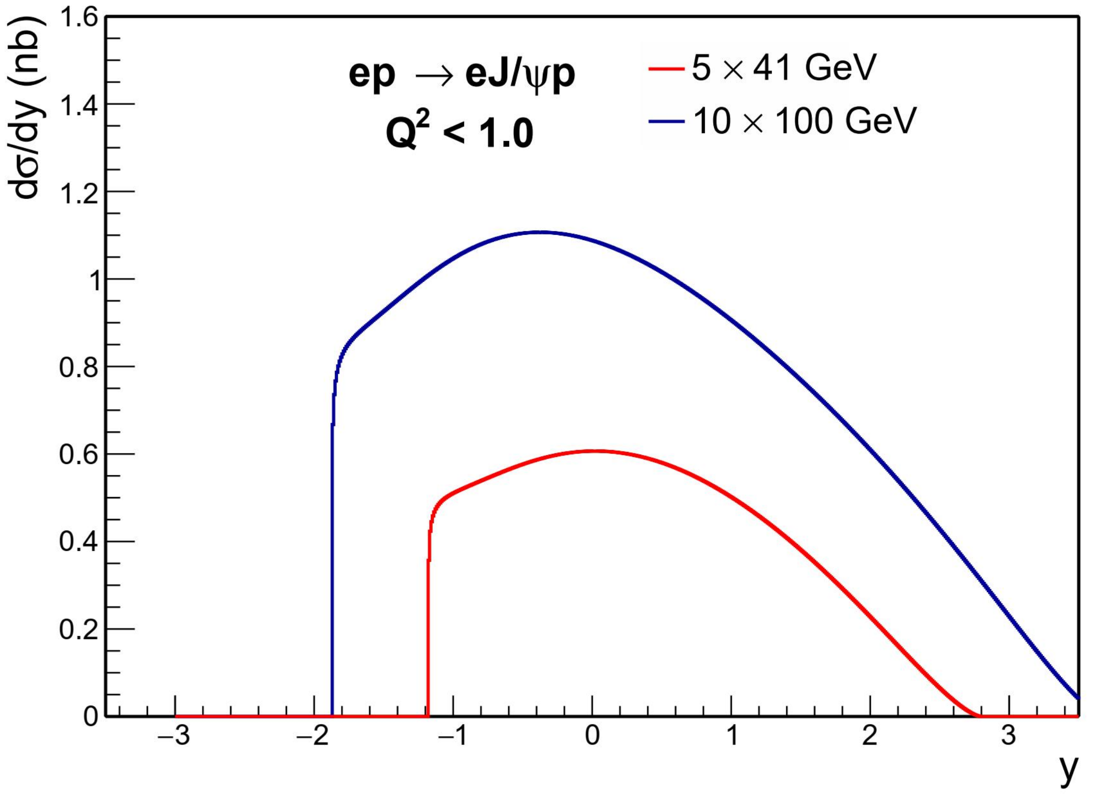


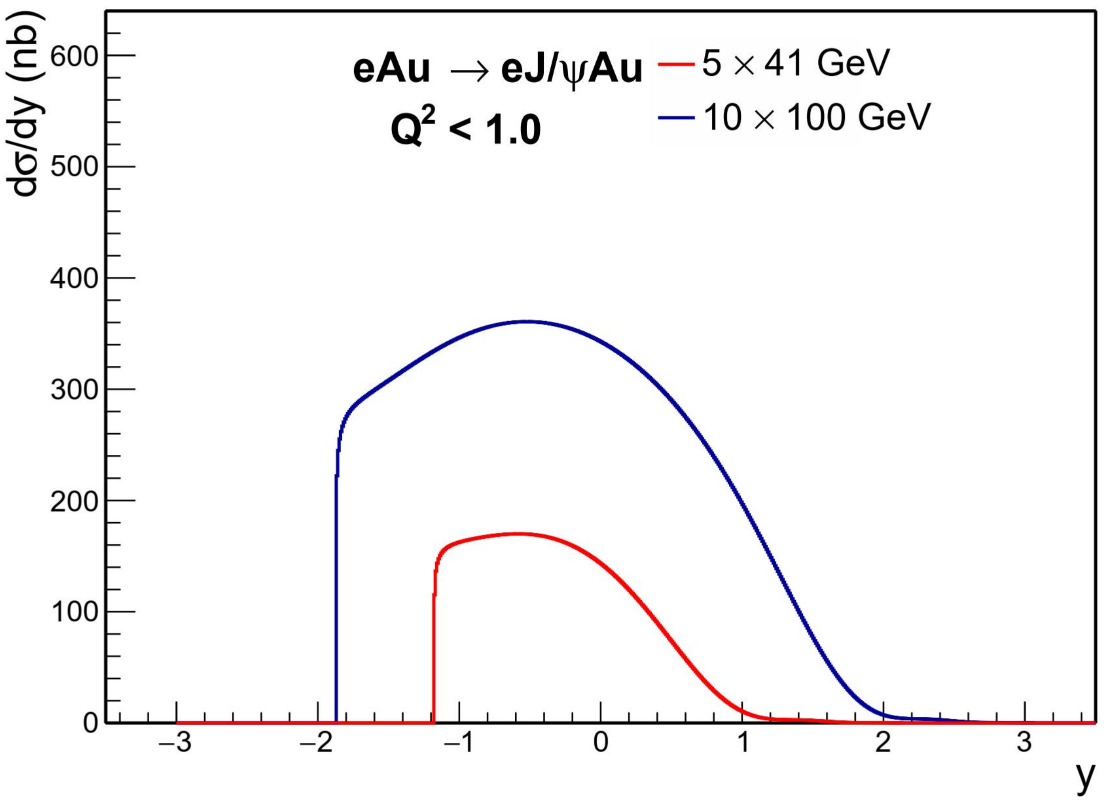
Parametrization for cross section input



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

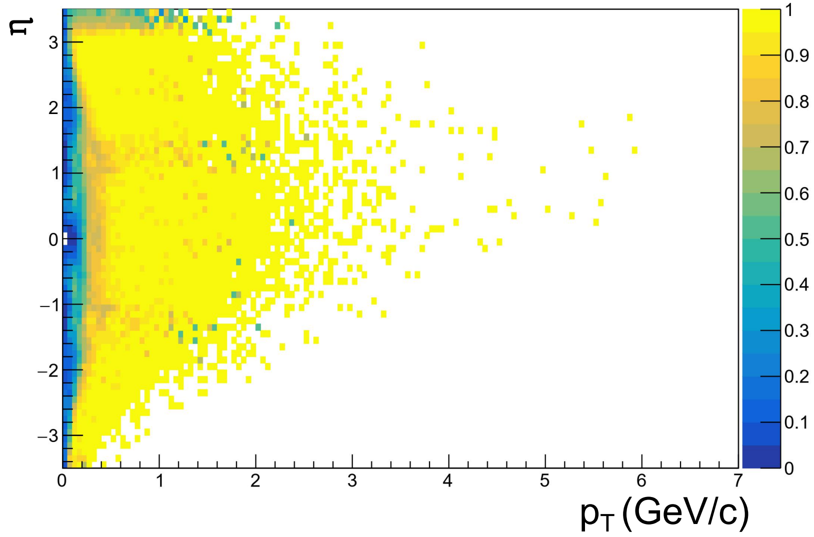
The theoretical input for ep and eAu



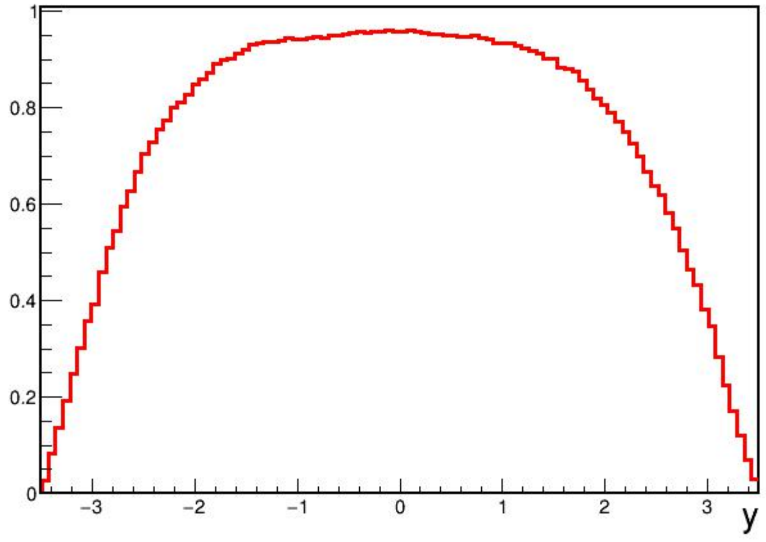


Efficiency and S/B correction

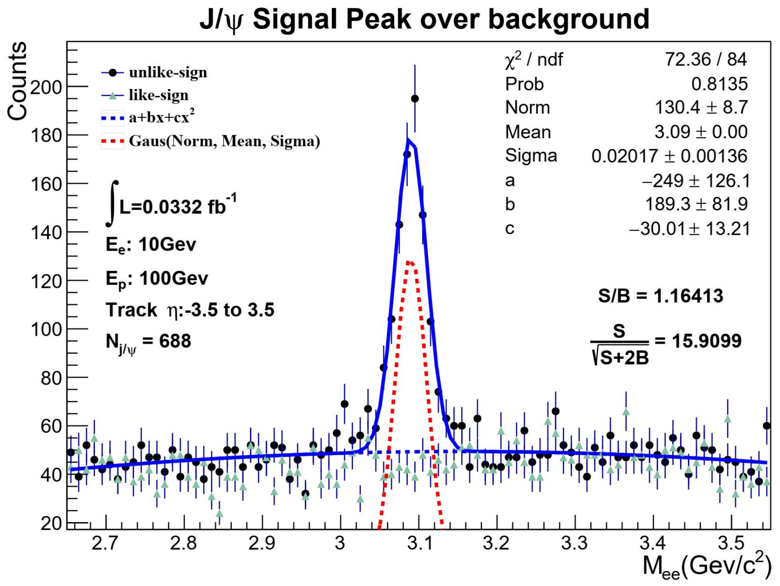
Single electron efficiency



J/ψ efficiency



S/B correction

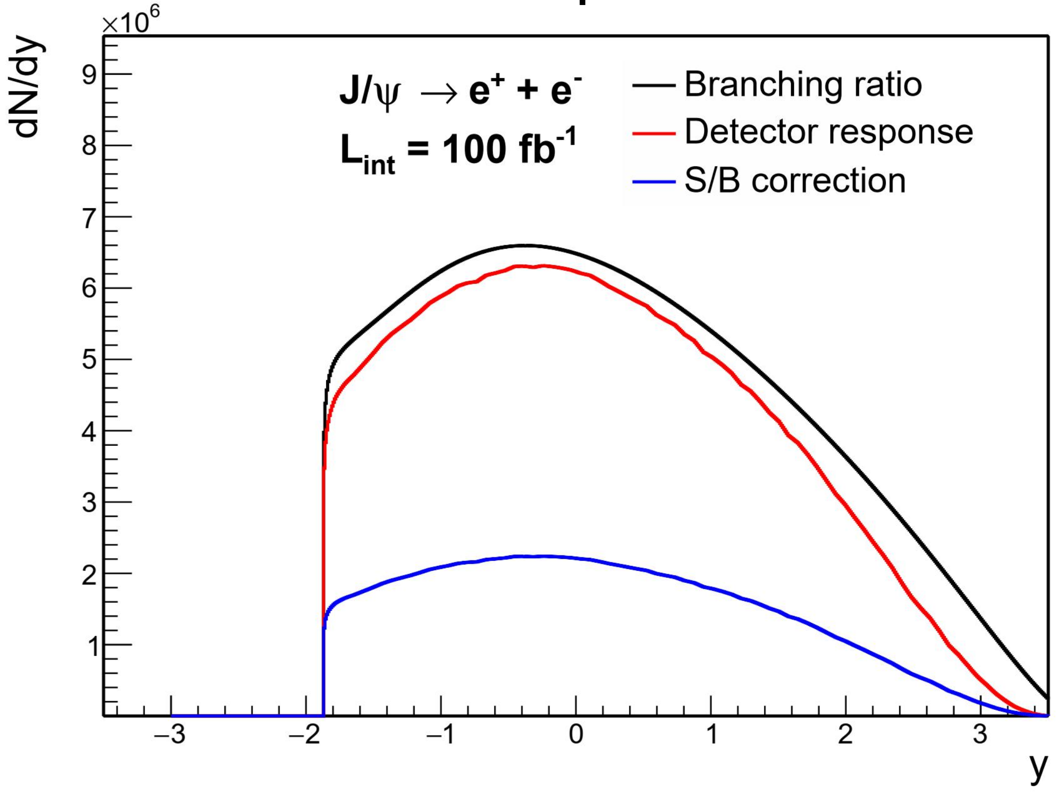


High J/ψ efficiency in central region

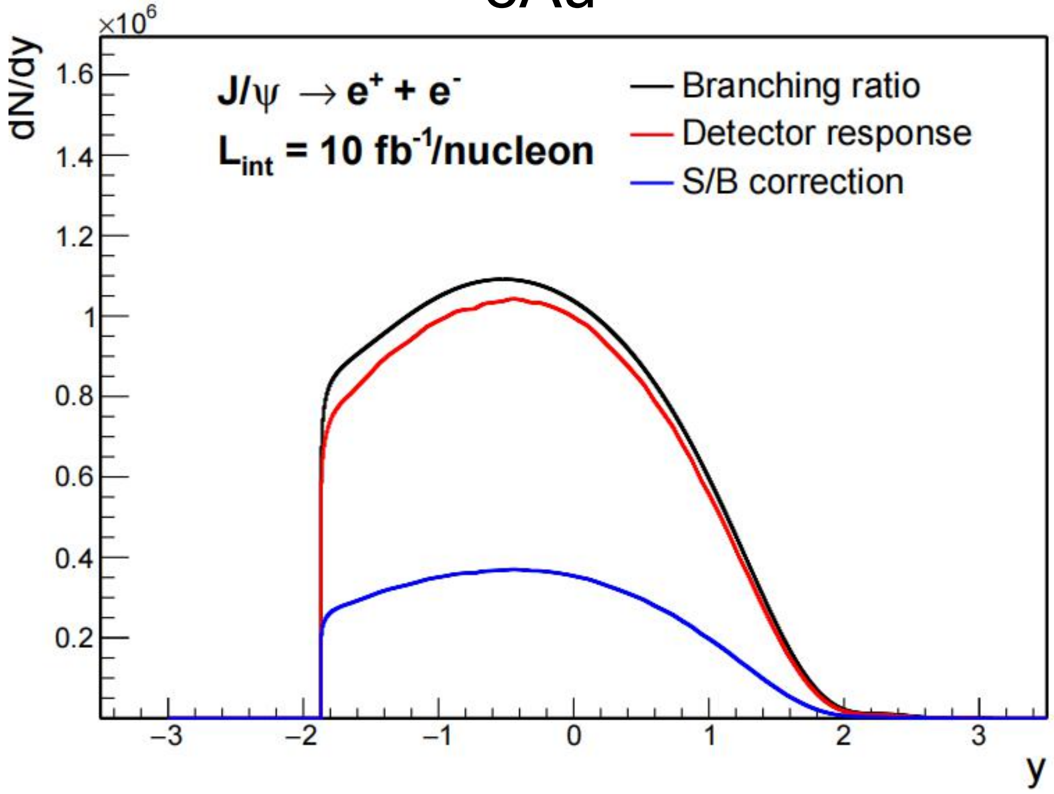
Forward region with a low efficiency

The projected statistics

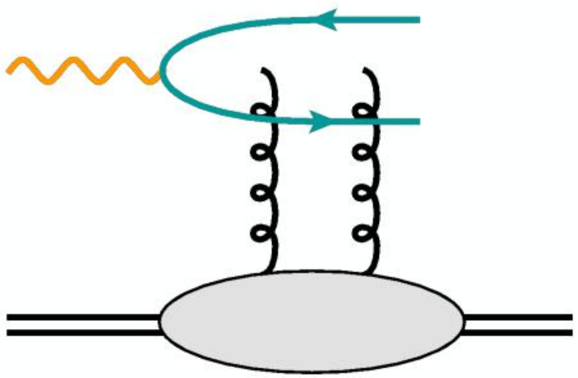
ep



eAu

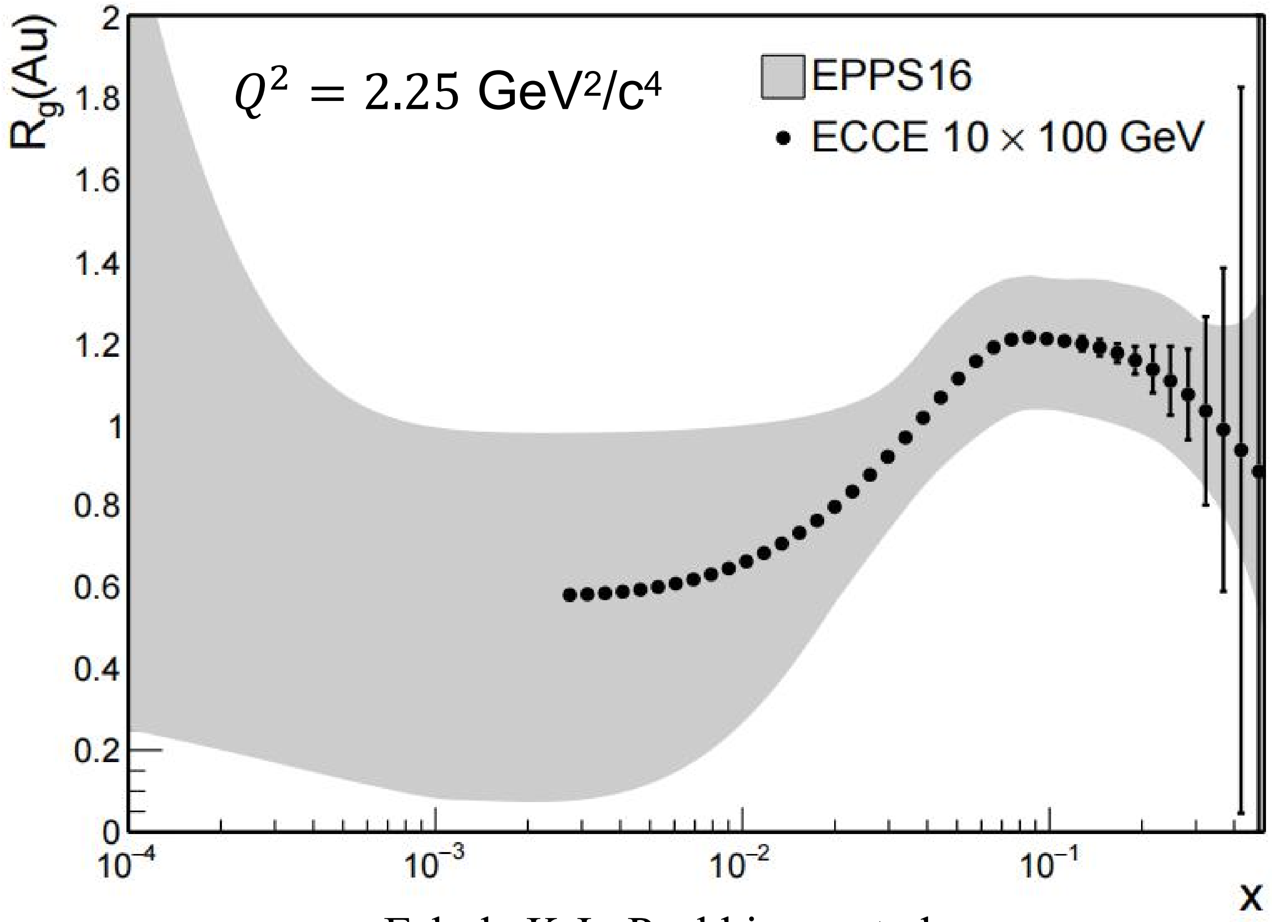


The gluon nPDF projection



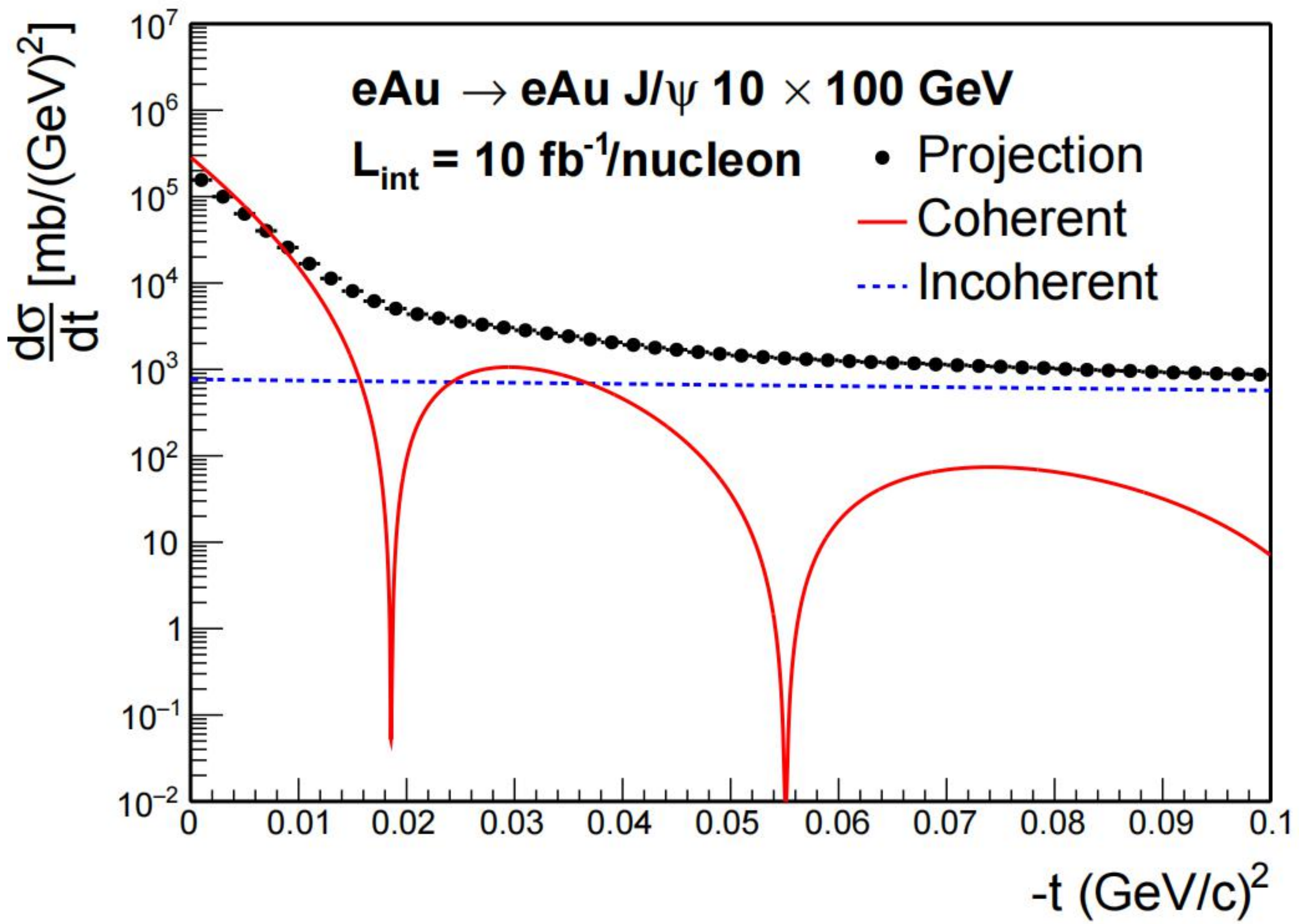
$$\left.\frac{d\sigma(\gamma A \to V A)}{dt}\right|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 \left[x G_A(x, Q^2) \right]^2$$

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



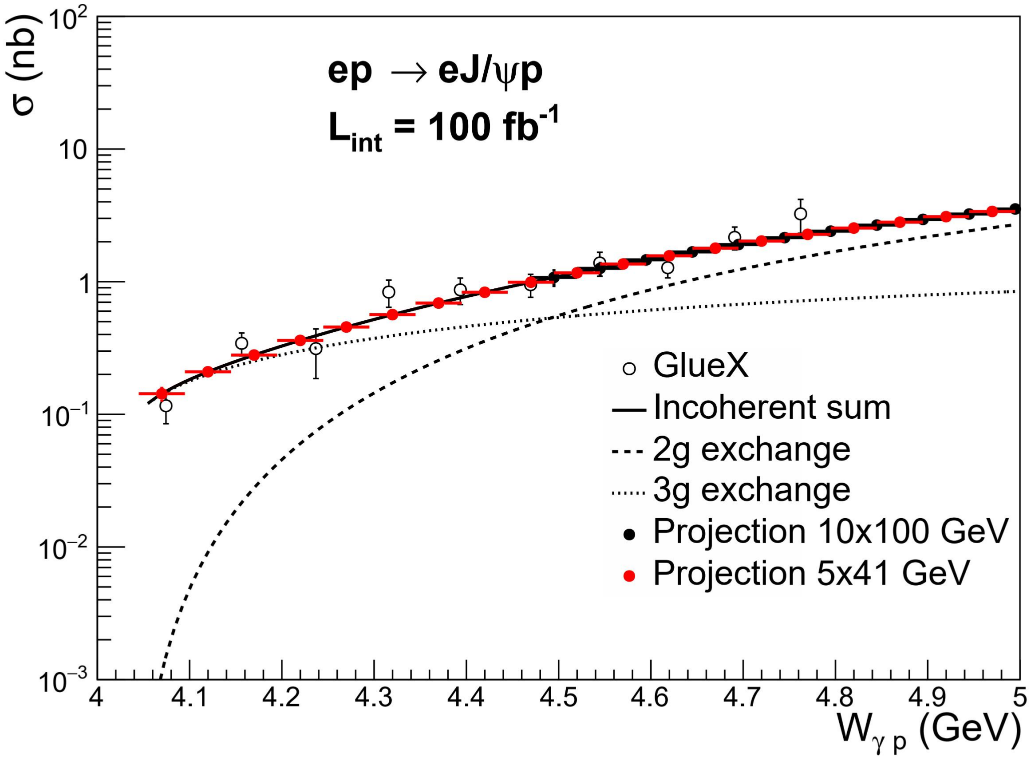
Eskola,K.J., Paakkinen, et al.
EPPS16: EPJC 77 (2017) 163

The t distribution projection



The momentum resolution would wipe out the diffraction dips.

The near threshold production mechanism



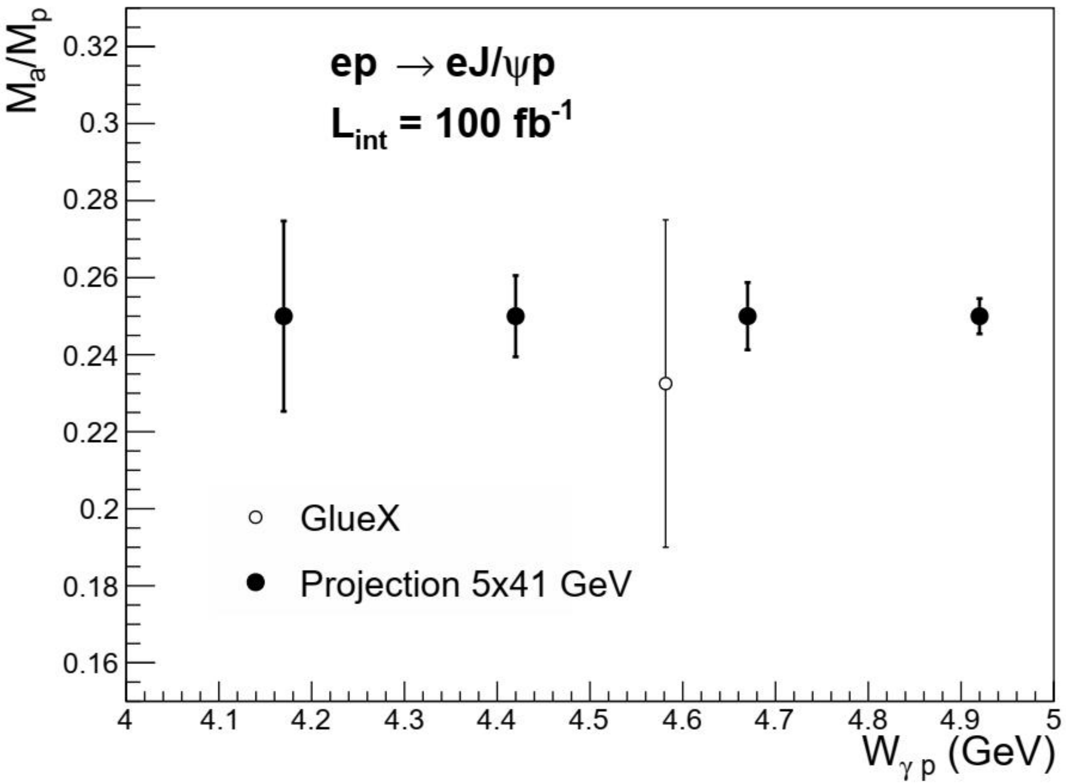
A. Ali et al. (GlueX Collaboration), Phys. Rev. Lett. 123, 072001(2019)

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

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

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

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

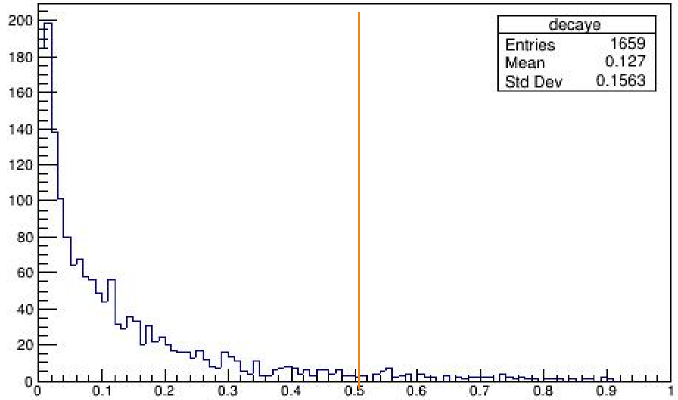
Backup

J/ψ detection (For Page15 S/B)

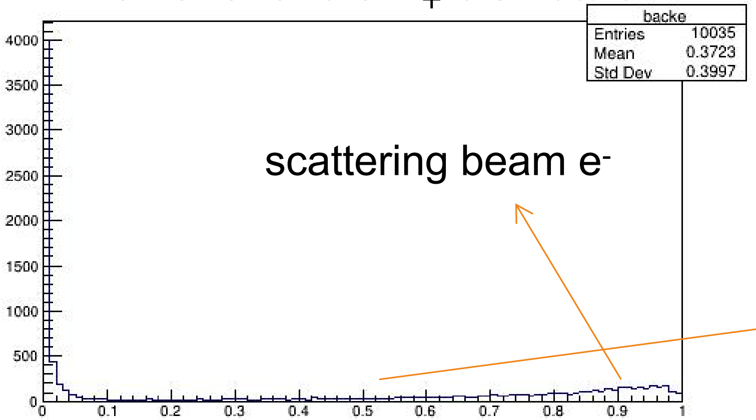
a forward light cone variables can be used to see scattering beam e$^-$ influence

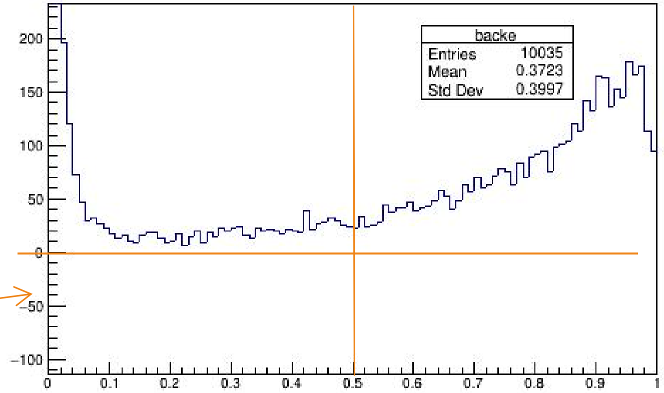
$x_+ = \frac{b_0 + (-b_z)}{a_0 + (-a_z)}$ (cause beam e$^-$ moves along negative z axis), b is beam e$^-$.

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



other e$^+$ and e$^-$ x_+ distribution :

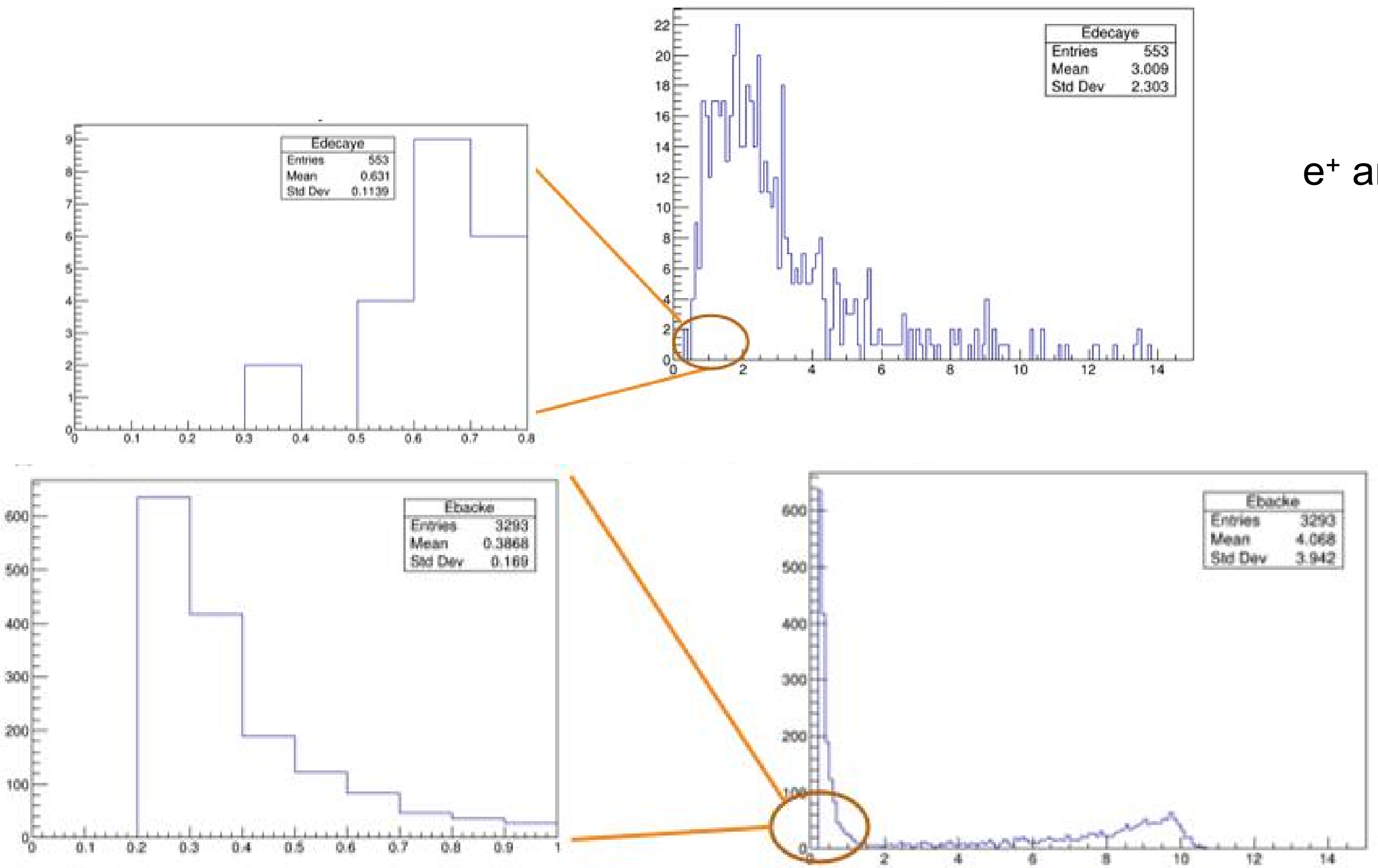




cut: $x_+ < 0.5$

J/ψ detection (For Page15 S/B)

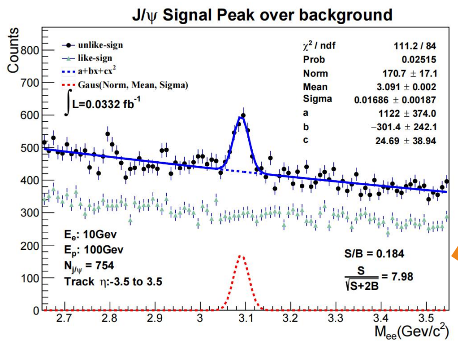
influence of e^- from light hadron decay



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

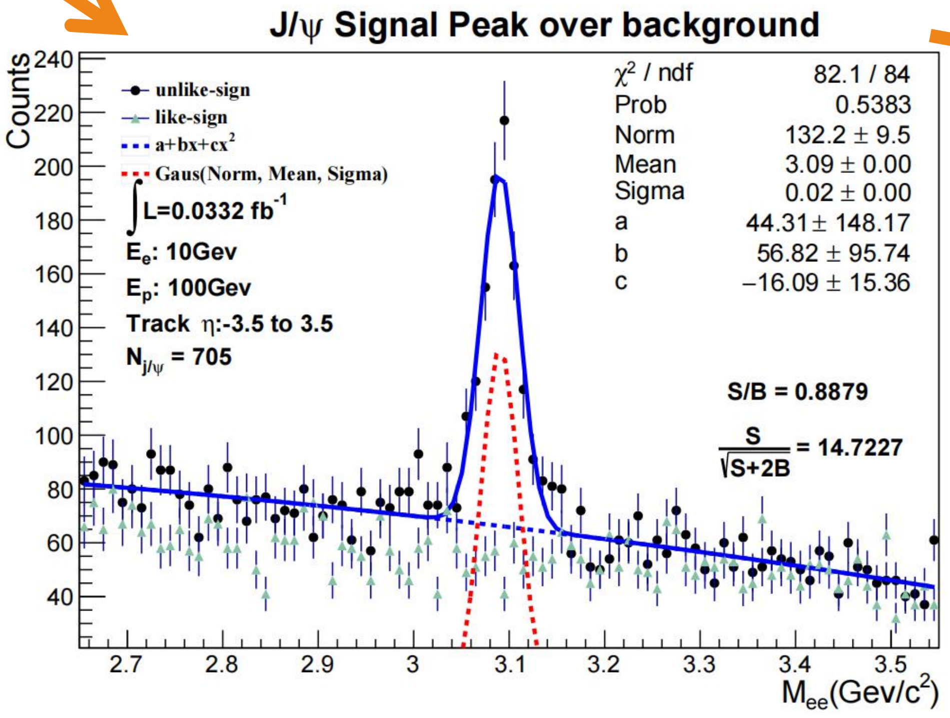
other e^+ and e^- E distribution :

J/ψ detection (For Page15 S/B)



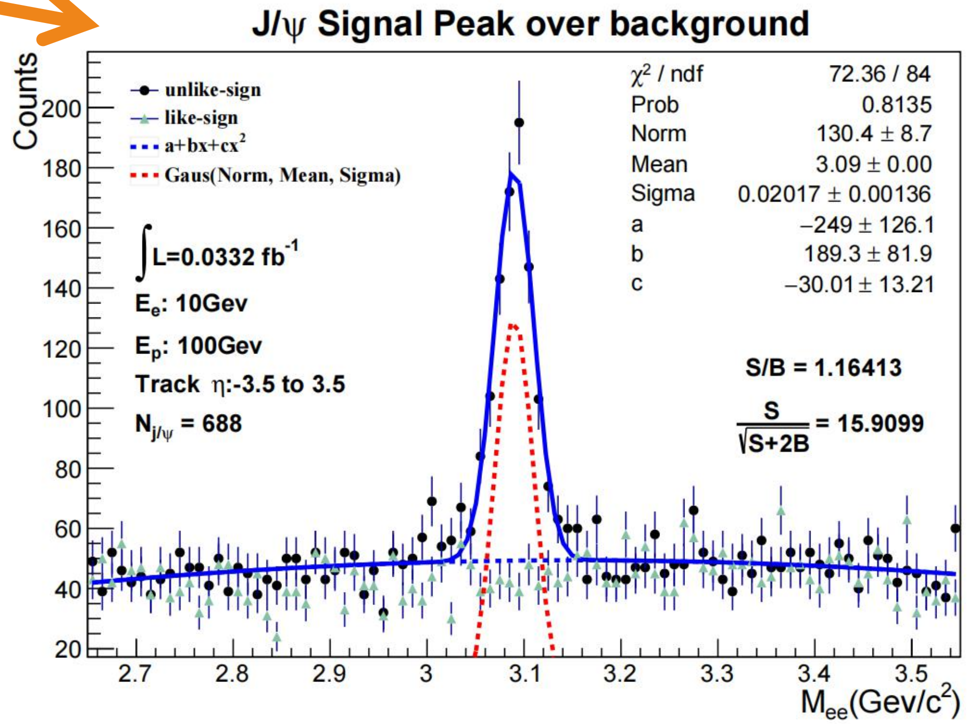
cut: $x_+ < 0.5$

S/B: 0.184 —> 0.888



cut: E>0.6

S/B: 0.888 —> 1.164



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

exclude the scattered e^- (with largest p_T)