Quarkonium detection and physics opportunities at the EIC

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University of Science and Technology of China

Quarknia As Tools 2022, Centre Paul Langevin,
9–15 Jan 2022

Physics Opportunities at the EIC

- Global properties and parton structure of hadrons
  - ✓ Scaling violations of the inclusive structure function $g_1(x, Q^2)$
  - ✓ The gluon polarization $\Delta g(x, Q^2)$
- Multi-dimensional imaging of nucleons and nuclei
  - ✓ Probe quark TMDs and TMD evolution
  - ✓ Probe gluon Sivers TMD
- The nucleus: a laboratory for QCD
  - ✓ Probe the linearly polarized gluon distributions
  - ✓ Nuclear PDFs
  - ✓ Strong interactions in nuclei

Production mechanism for quarkonia

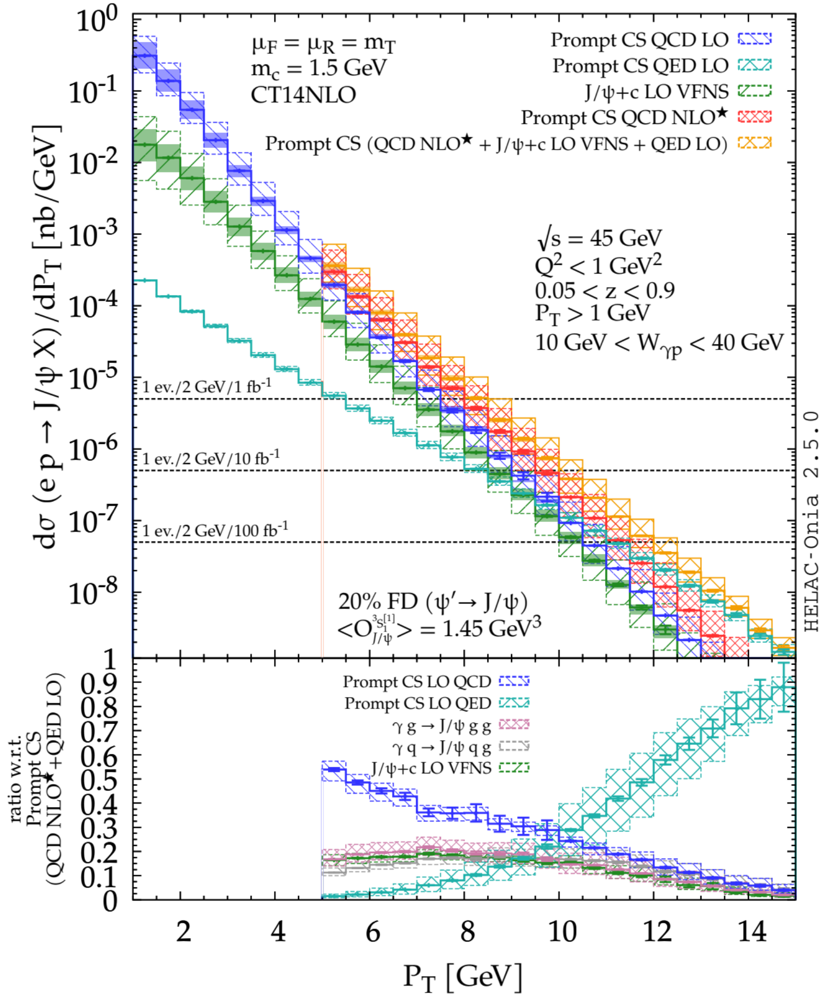
C. Flore, J.P. Lansberg etal., Phys. Lett. B (2020) 135926

Part of global Quarkonia puzzle

- ✓ Colour Singlet Model
- ✓ NRQCD and Colour Octet Mechanism
- ✓ Colour Evaporation Model

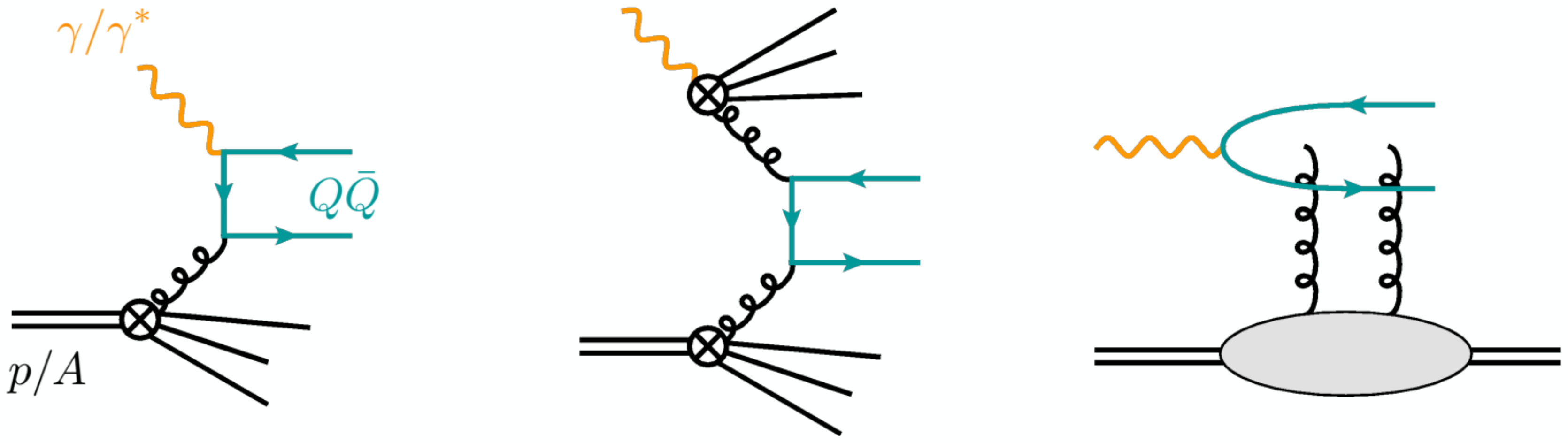
Explore the cold medium effect

- ✓ A + A collisions
- ✓ p + A collisions
- ✓ e + A collisions
- ✓ e + e collisions



(a) $\sqrt{s_{ep}}$ = 45 GeV

Gluon tomography and mass decomposition

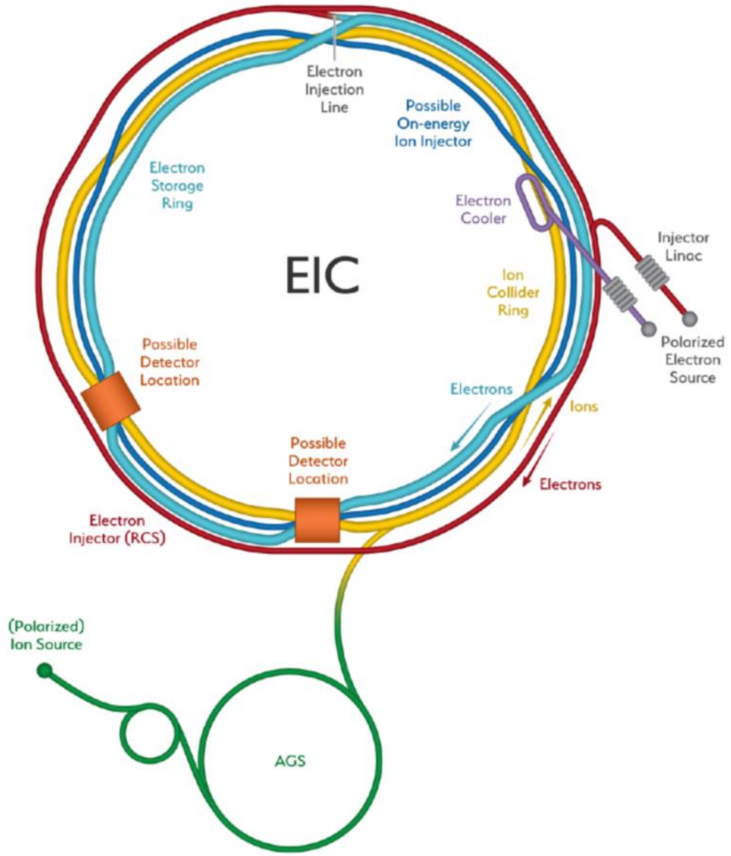


(a) (b) (c)

Sensitive to the gluon distribution

- ✓ Image the gluon distribution in nucleon
- ✓ The mass decomposition of proton (near threshold photoproduction)

The facility: EIC at BNL

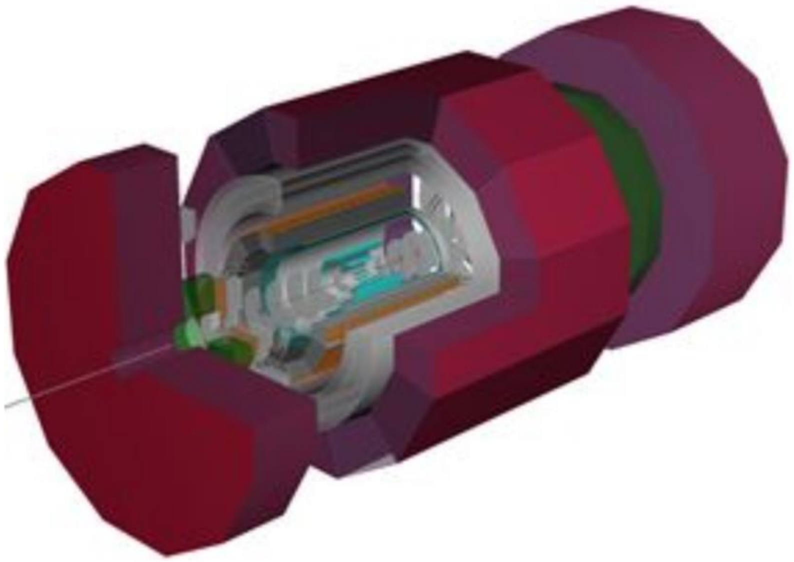


- ✓ Luminosity: $10^{33\text{-}34}$ $cm^{-2}sec^{-1}$ (100-1000 times HERA)
- ✓ Hadrons up to 275 GeV
- ✓ Electrons : 5-10 (20) GeV
- ✓ CM energy: 20-100 (140) GeV
- ✓ Polarized beams

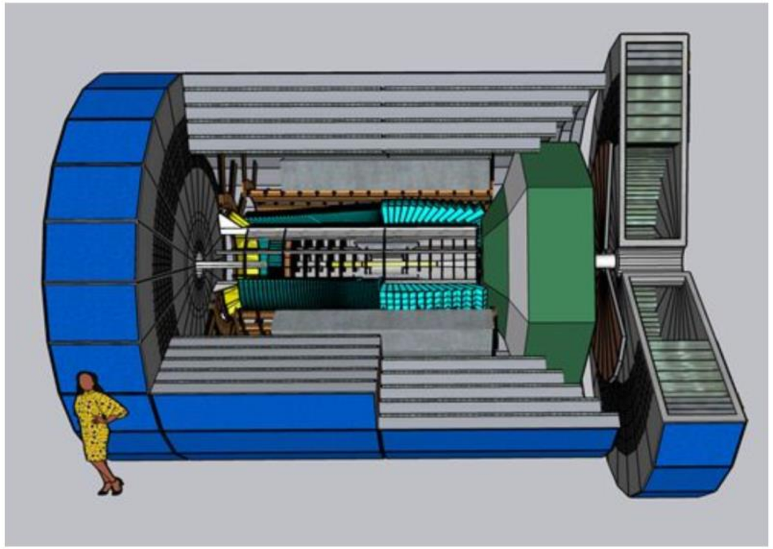
- ✓ >1200 scientists, 250 institutions [Webpage]
- ✓ CD0 and site selection at Brookhaven National Lab in 2019
- ✓ Framework for international participation being set up CD1 achieved in 2021 [Webpage]
- ✓ Project hosted/managed jointly by BNL and JLab
- ✓ EIC Yellow Report Physics-Detector studies completed 2021 [2103.05419]
- ✓ Call for Collaboration Proposals for EIC detectors (1 Dec, 2021) [Webpage]
- ✓ CD4 and operations expected in 2030+

The candidates of detector system at EIC

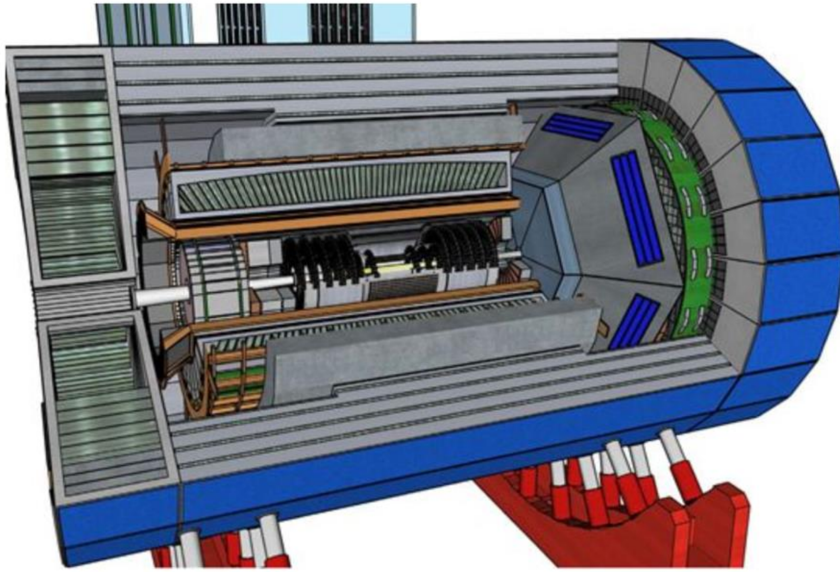
ATHENA: athena-eic.org



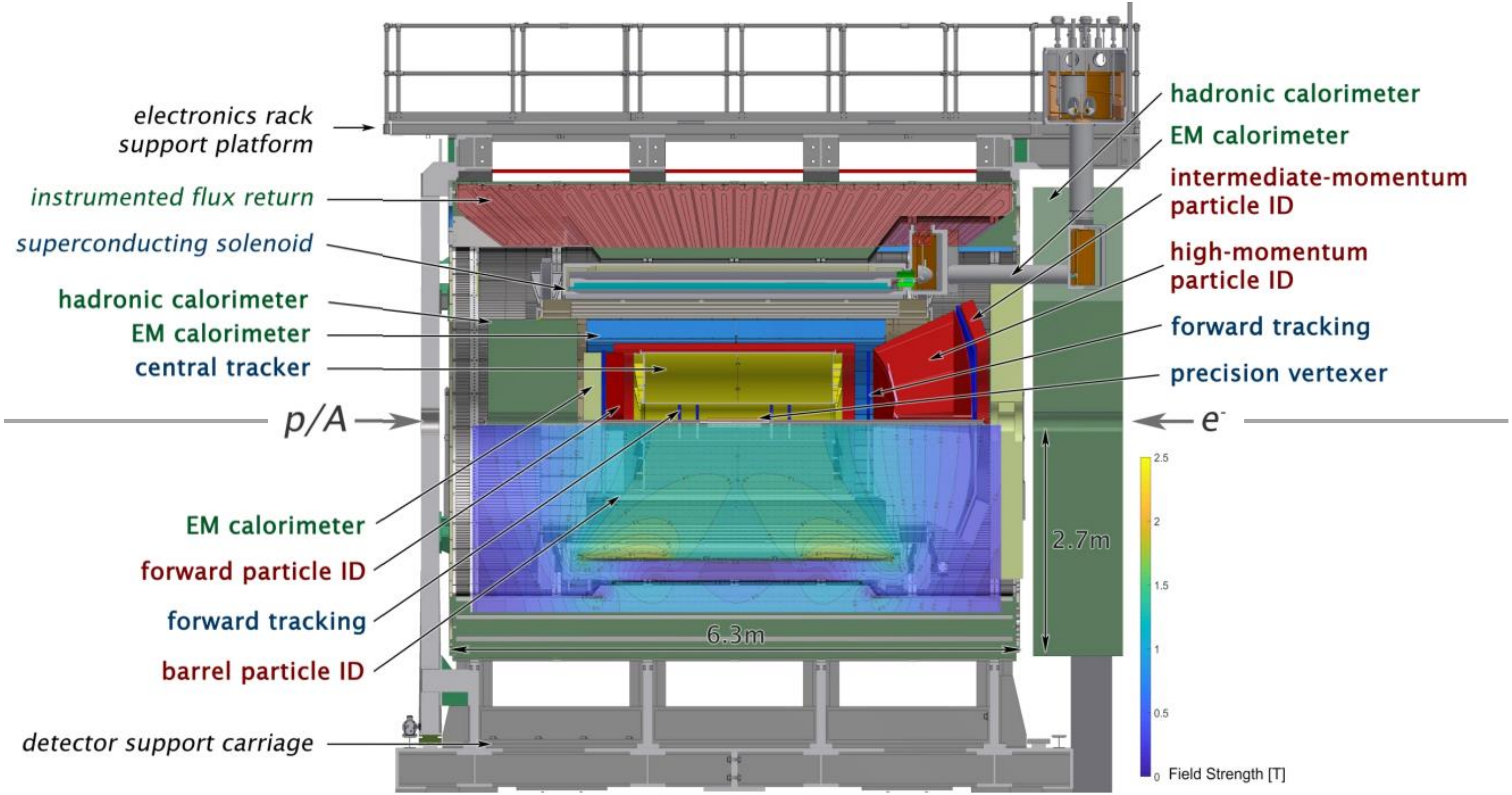
CORE: eic.jlab.org/core



ECCE: ecce-eic.org

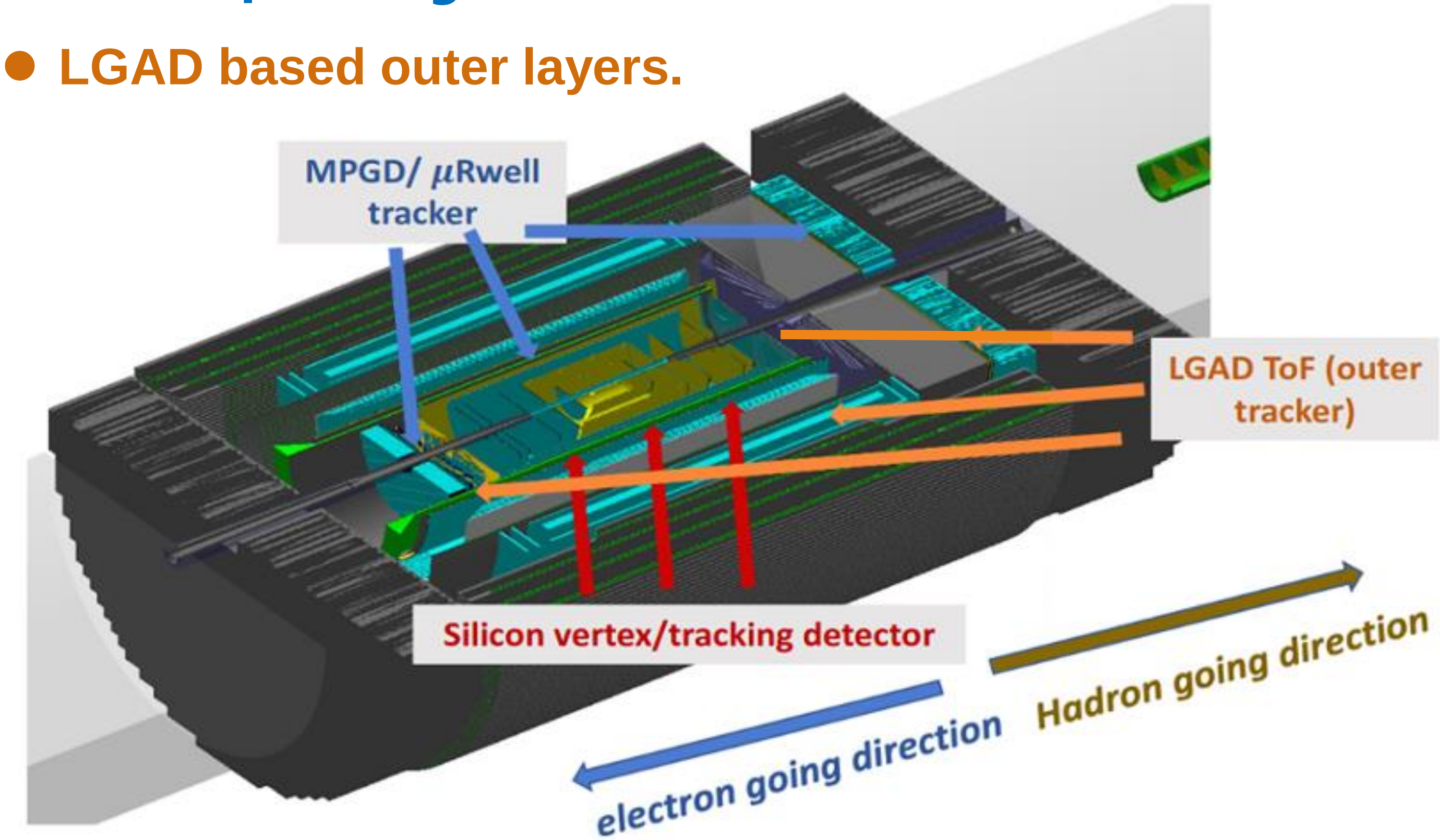


Detector Configuration of ECCE

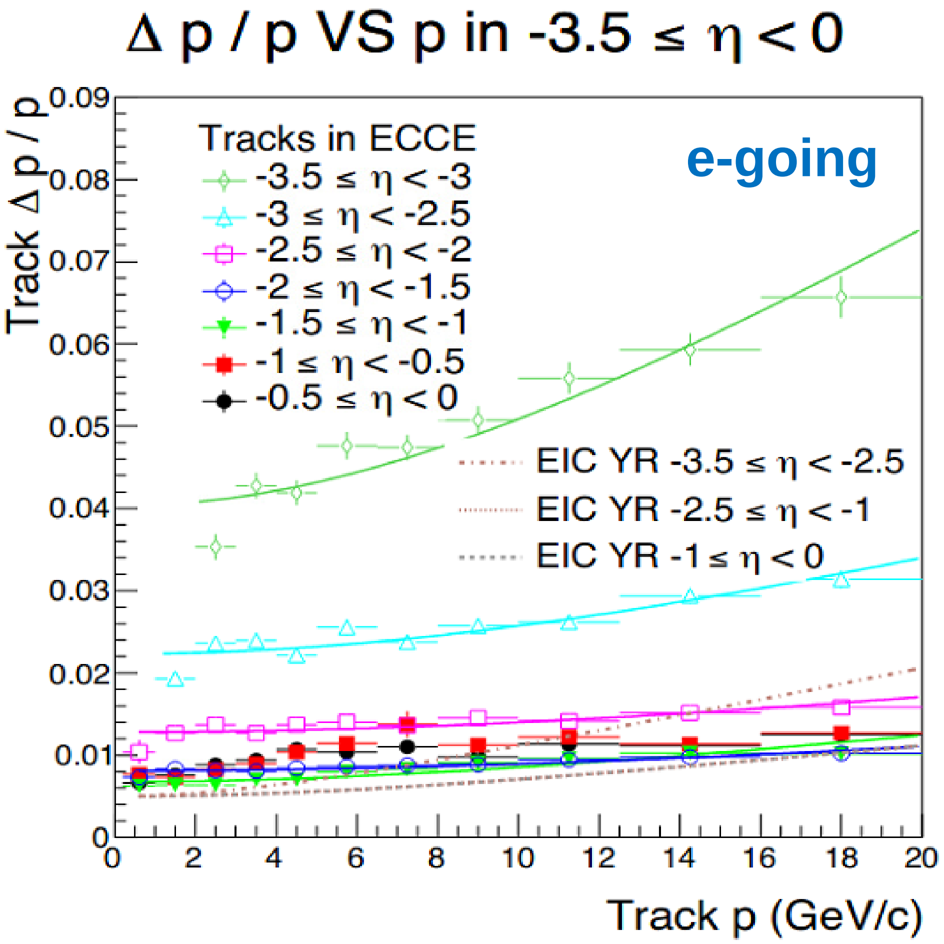


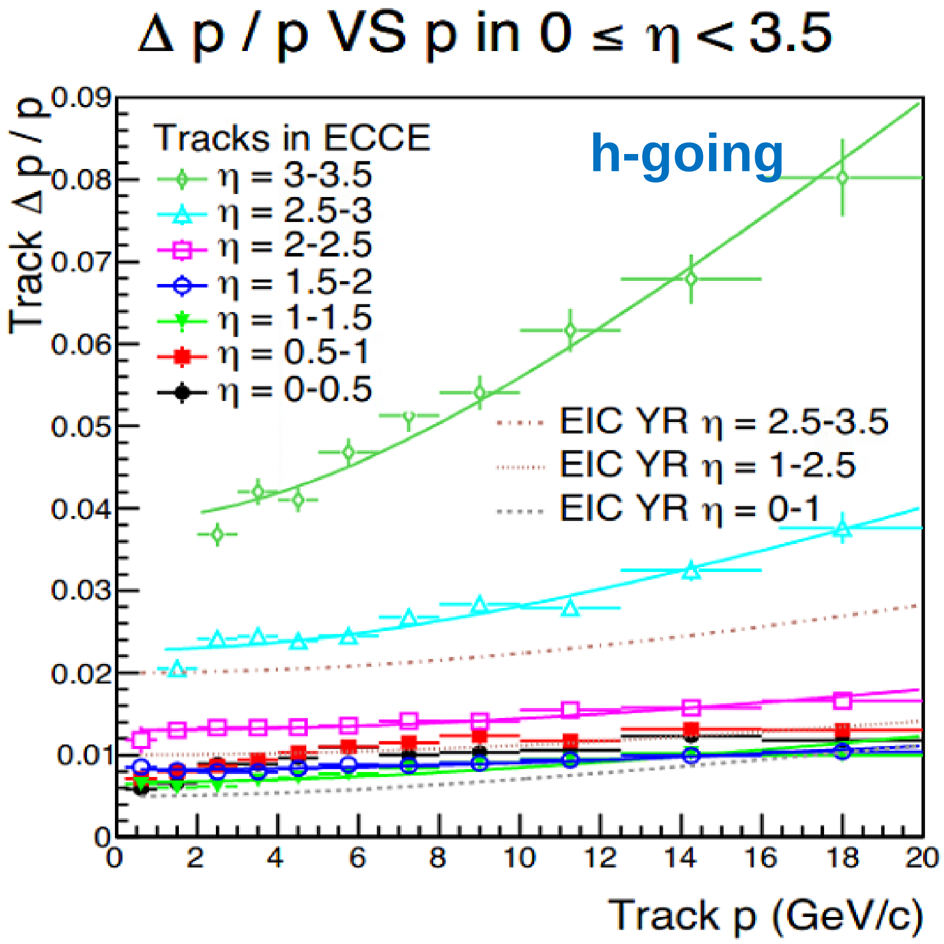
Detector Configuration——Tracking

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



Tracking performance at ECCE



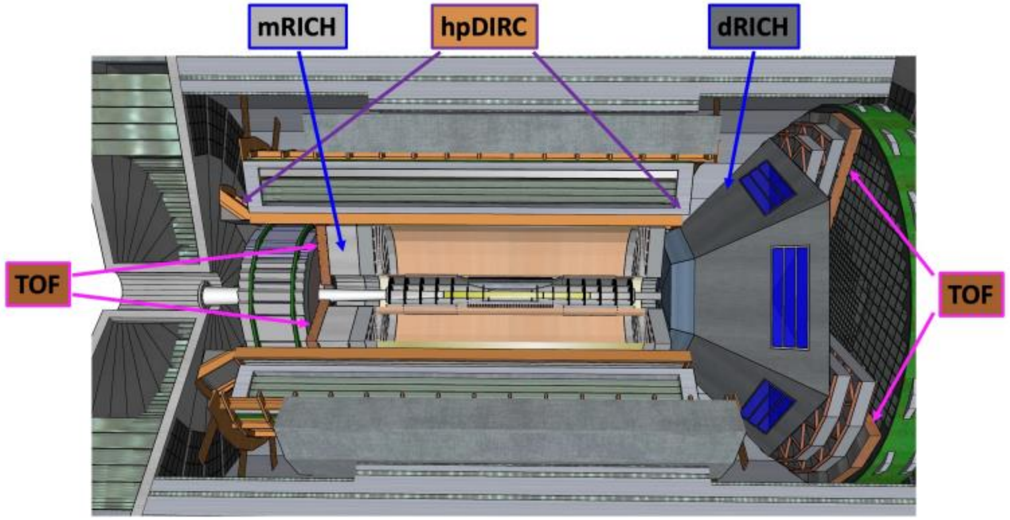


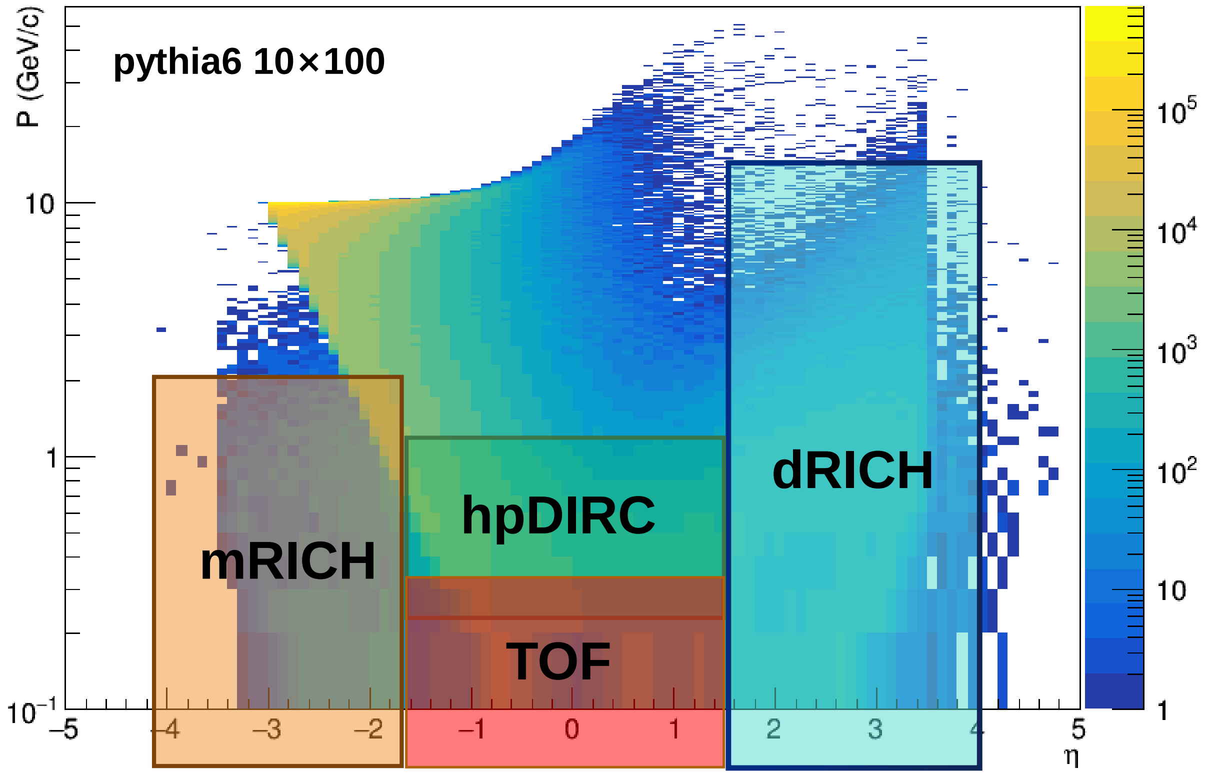
Electron identification capability at ECCE

EMCal +Tracking

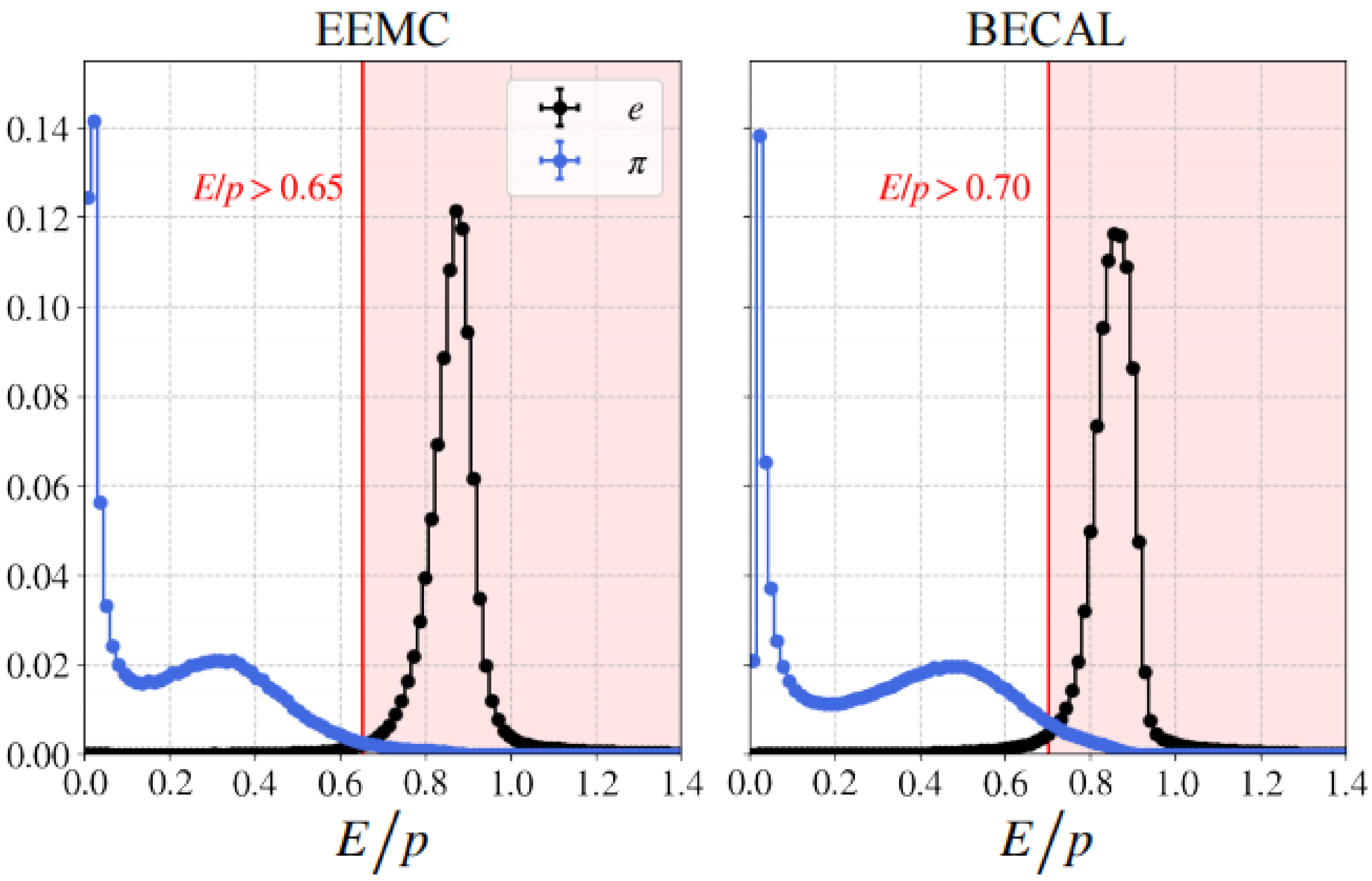
- ✓ The energy deposition => E/p cut
- ✓ The transverse profile of the showers
- ✓ The position resolution

Cherenkov + TOF

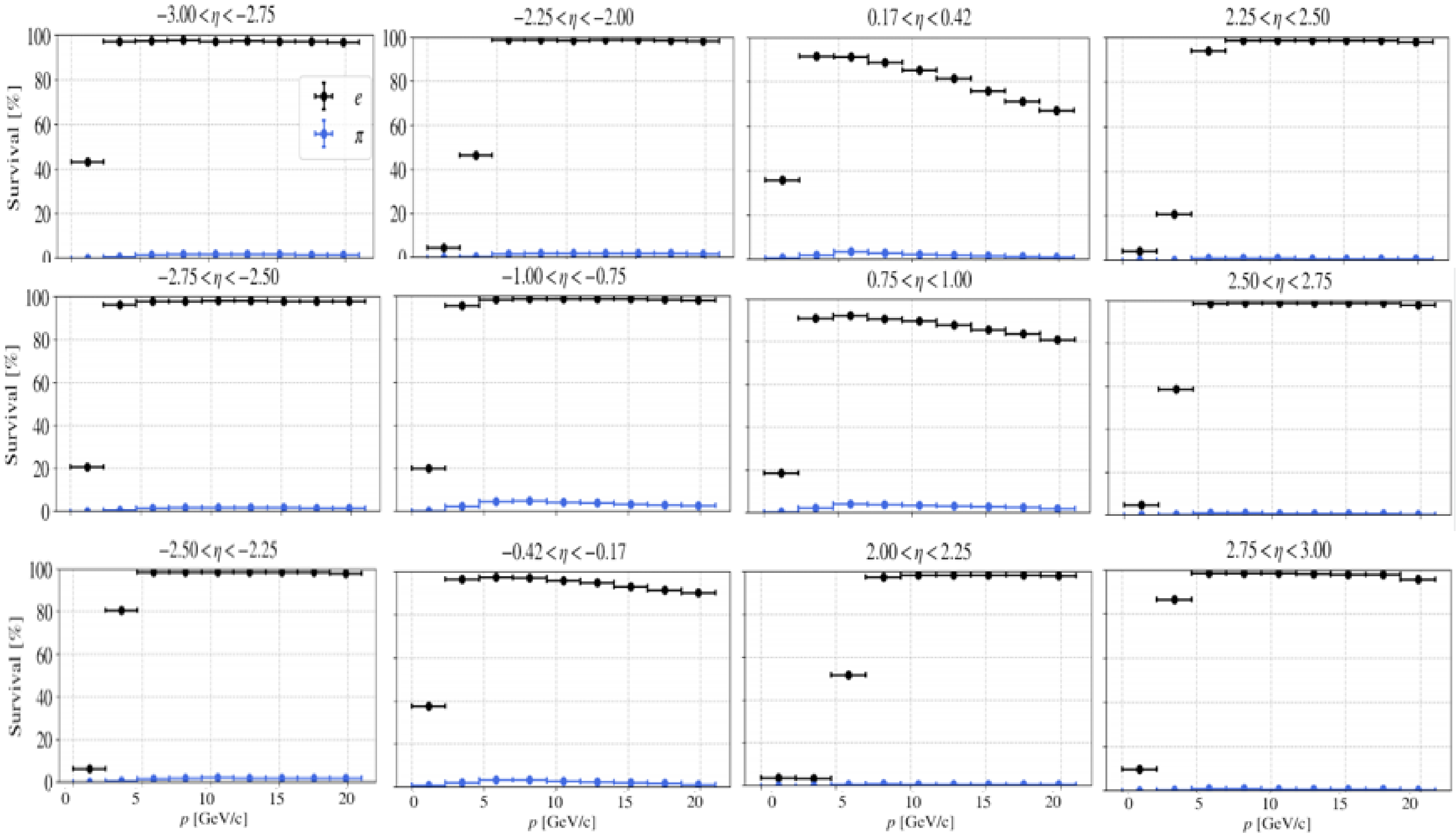




Electron identification capability at ECCE—EMCal+Tracking



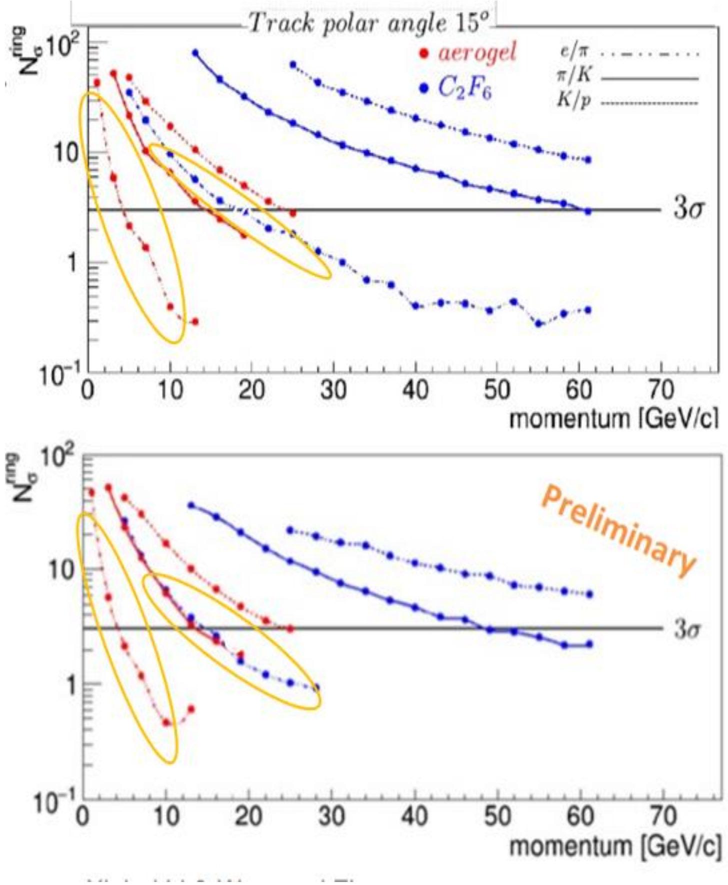
Electron identification capability at ECCE—EMCal+Tracking



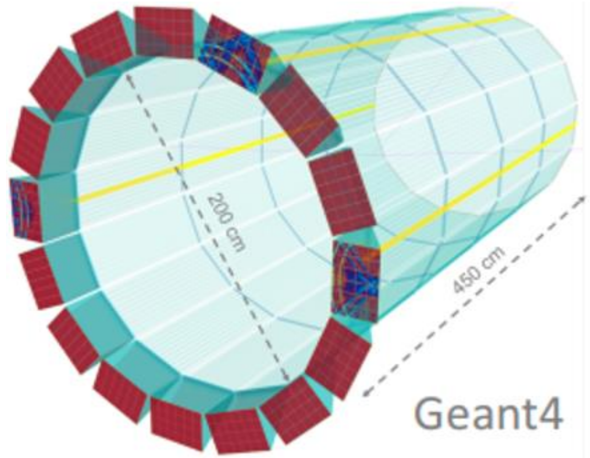
Electron identification capability at ECCE—Cherenkov+TOF

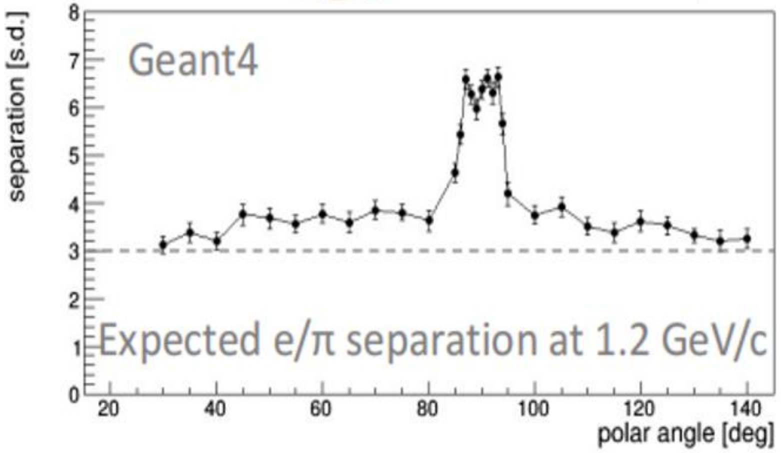
- **h-endcap: dRICH with two radiators** (gas + aerogel)
  π/K separation up to ~50 GeV/c
  e/π separation up to ~15 GeV/c
- **e-endcap: compact aerogel mRICH**
  π/K separation up to ~10 GeV/c
  e/π separation up to ~2 GeV/c
- **barrel: compact high-performance DIRC**
  π/K separation up to ~6-7 GeV/c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

dRICH Simulated Performance

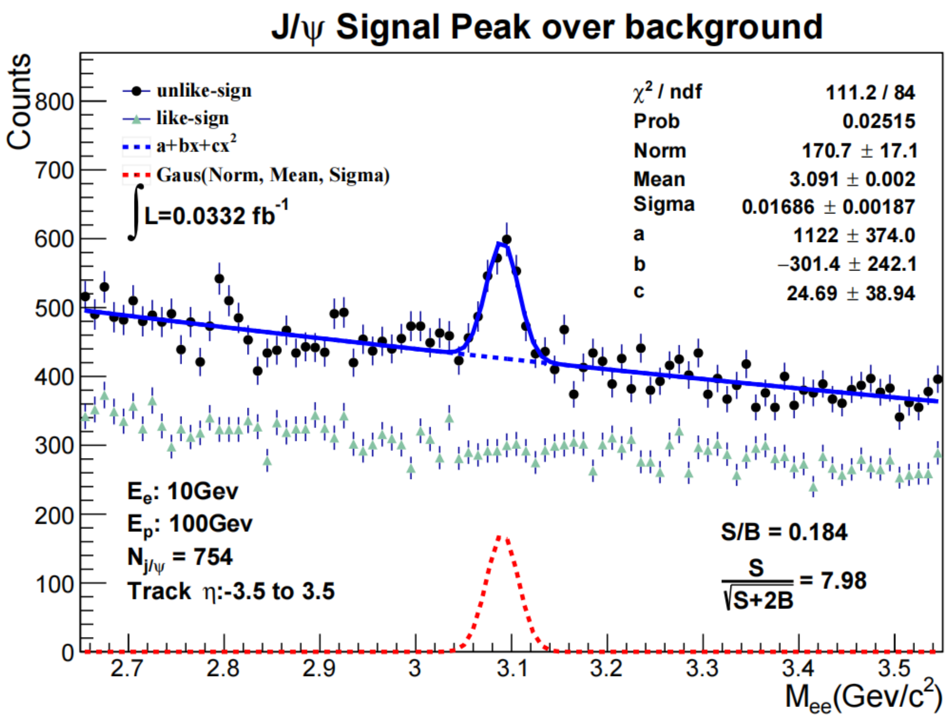


HPDIRC



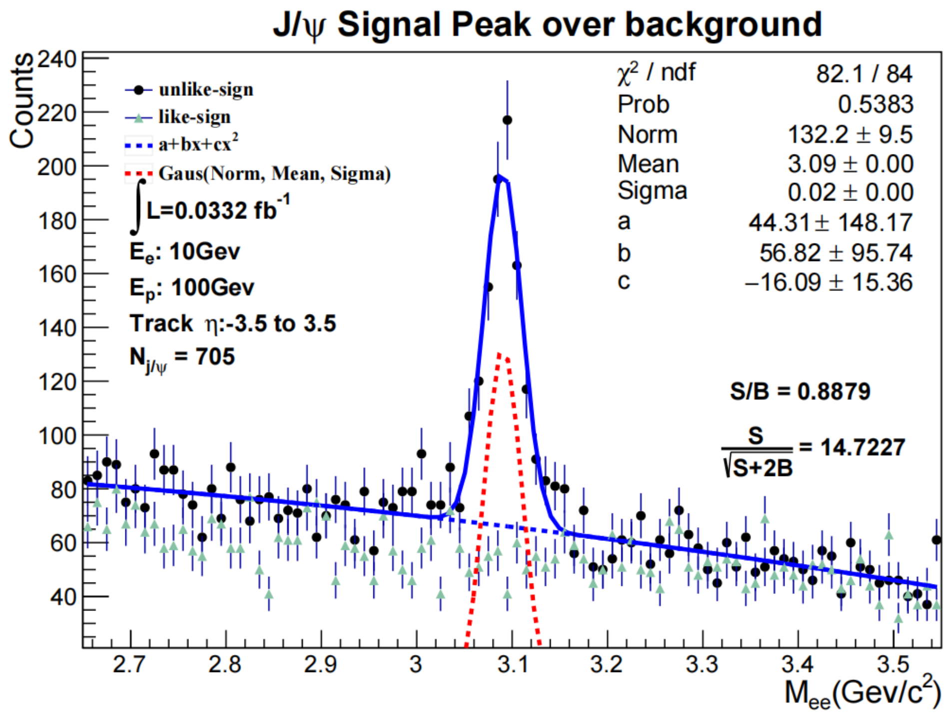


J/ψ Reconstruction



a forward lightcone cut

$x_+ < 0.5$

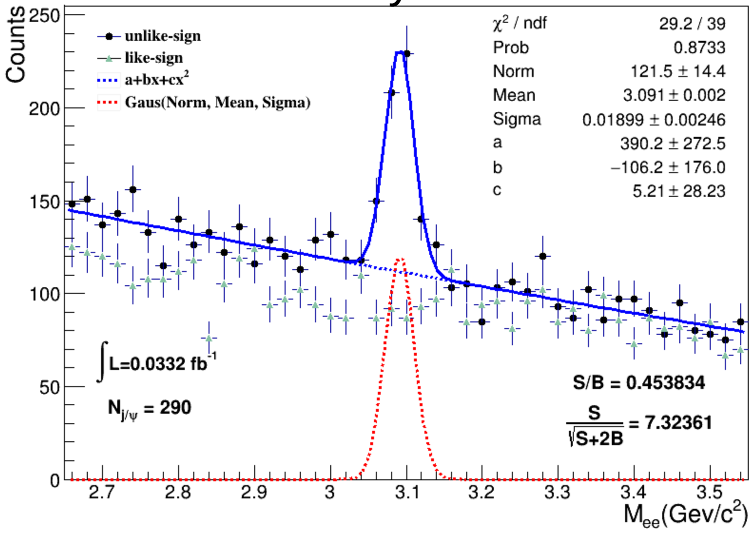


generator: pythia6 (eRHIC tuned) Full Geant simulation (fun4All)

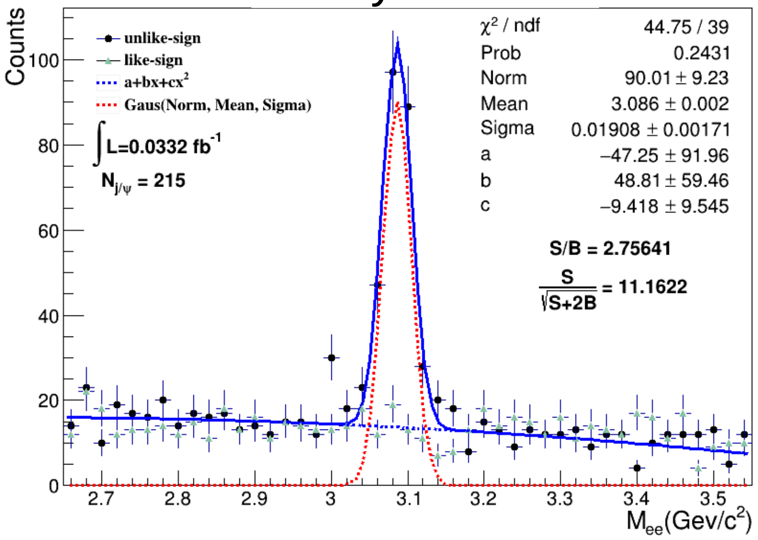
events: ~20million

J/ψ Reconstruction

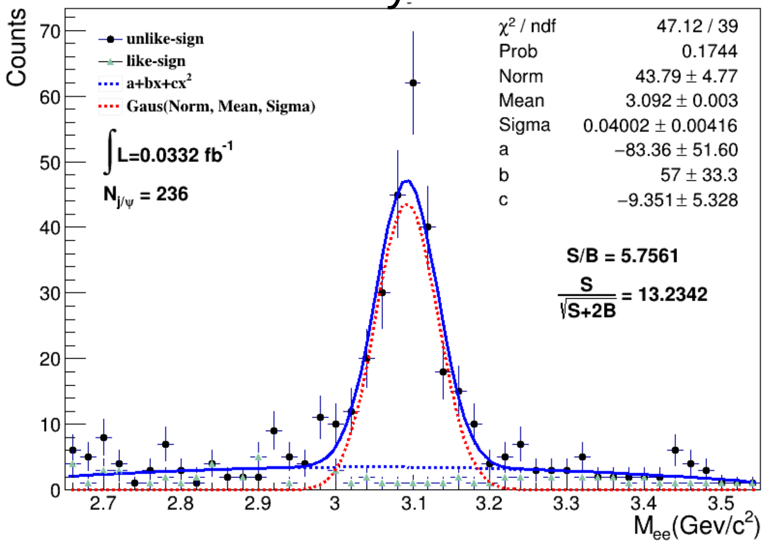
-2<y<0



0<y<1



1<y<3.5



Central region with better mass width.

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

The theoretical setup of exclusive process (for projection)

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

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

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

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

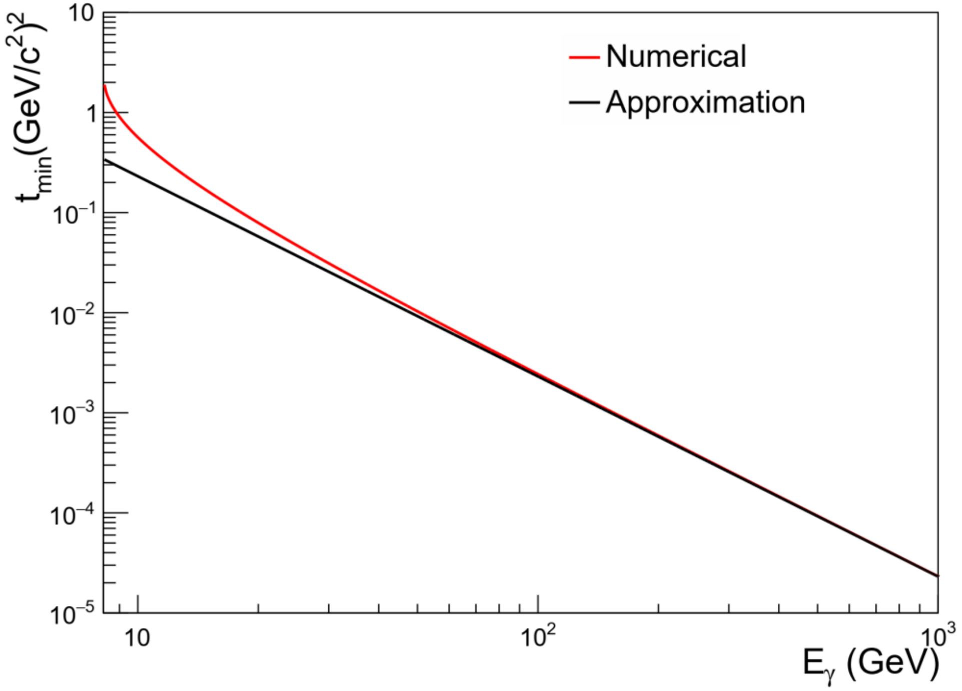
Can be related to the cross section for σ(γ+p → V+p)

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

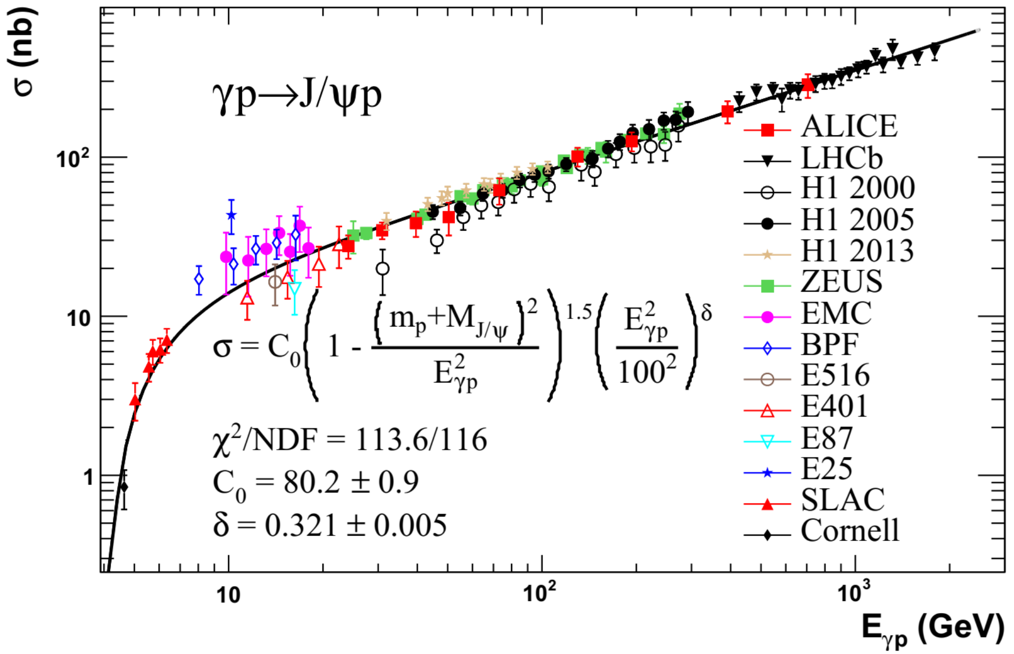
Two improvements for eSTARLight

Minimum momentum transfer

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

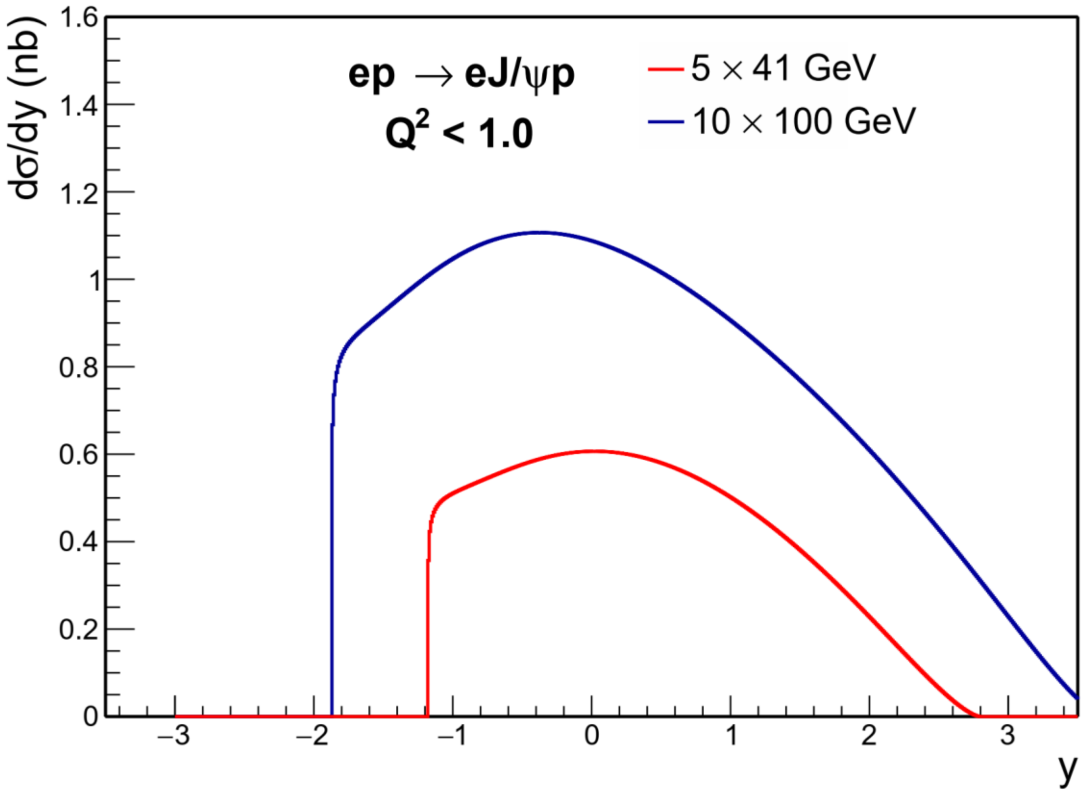


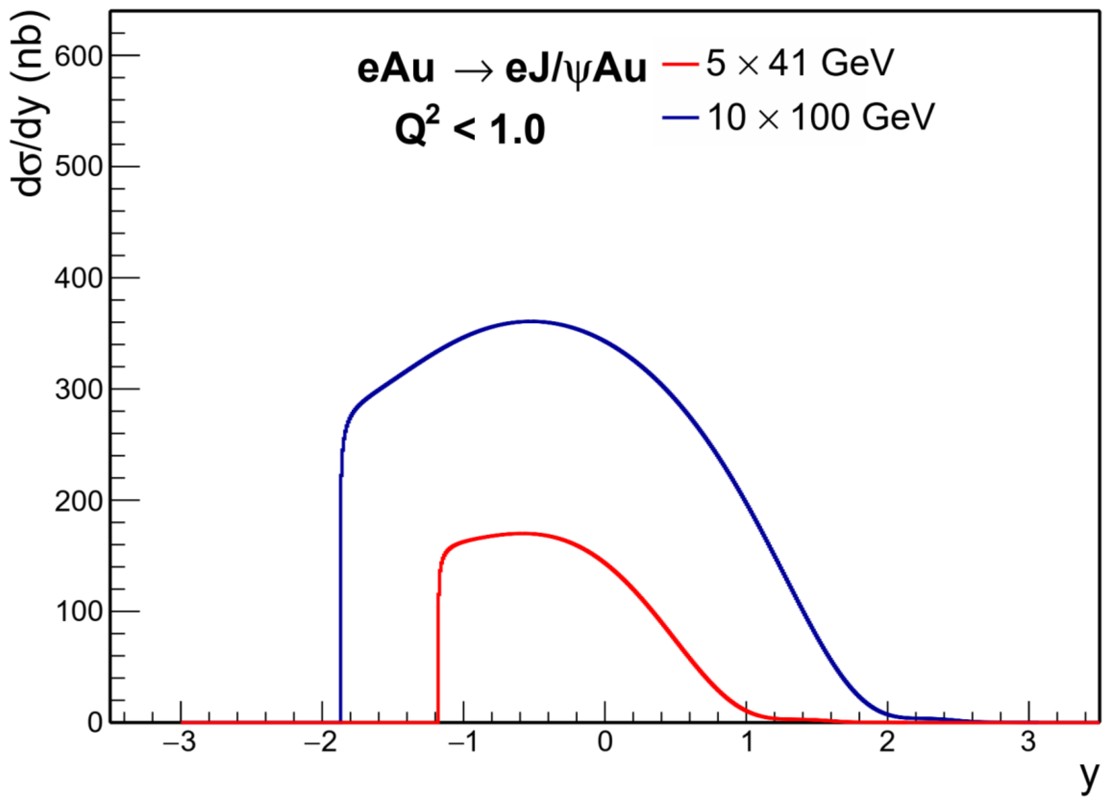
Parametrization for cross section input



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

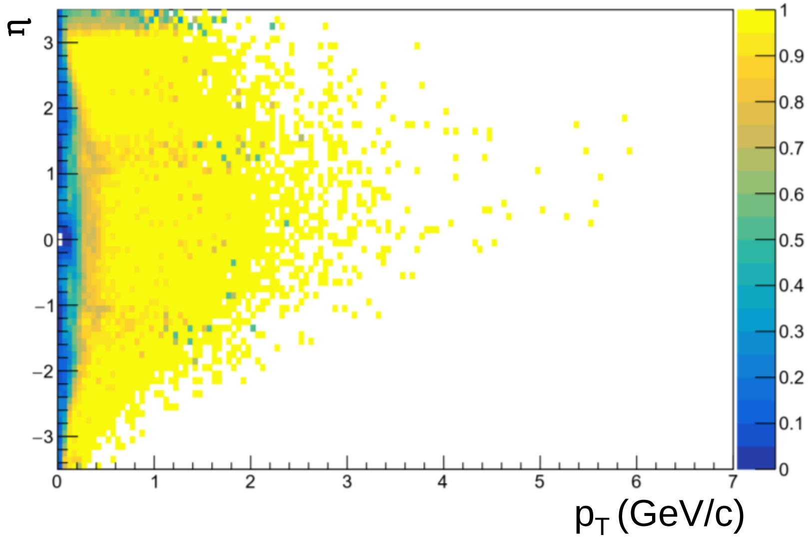
The theoretical input for ep and eAu



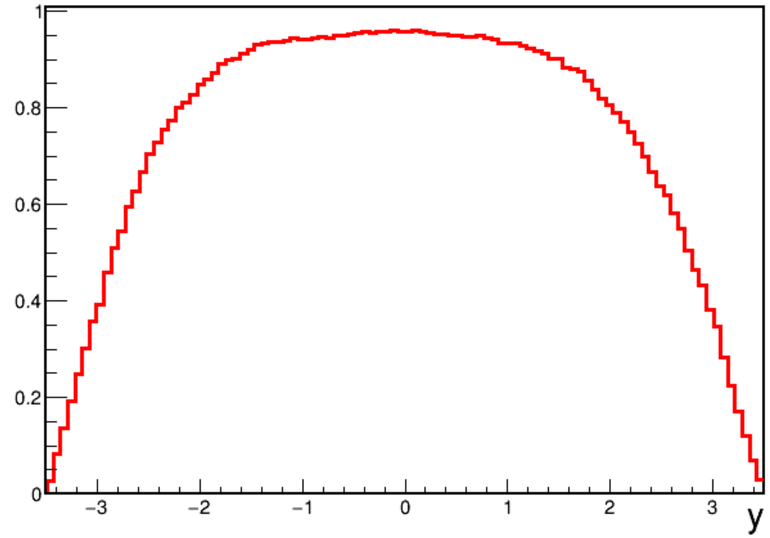


Efficiency and S/B correction

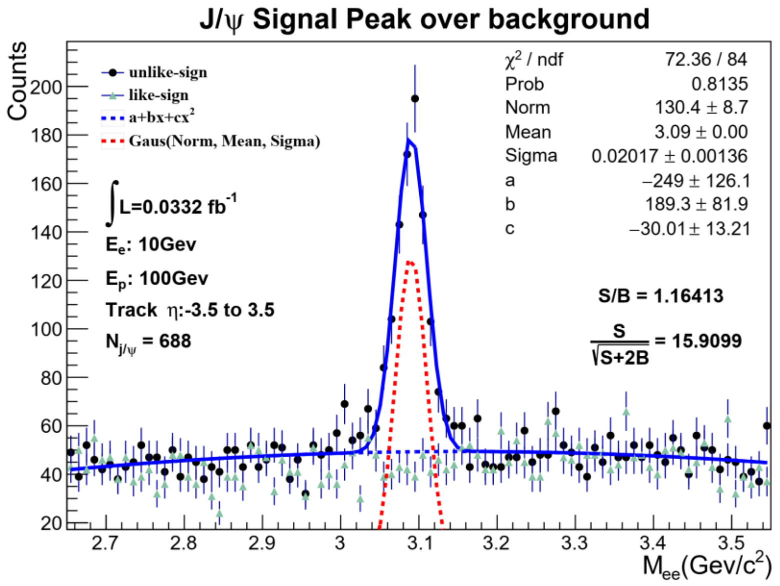
Single electron efficiency



J/ψ efficiency



S/B correction

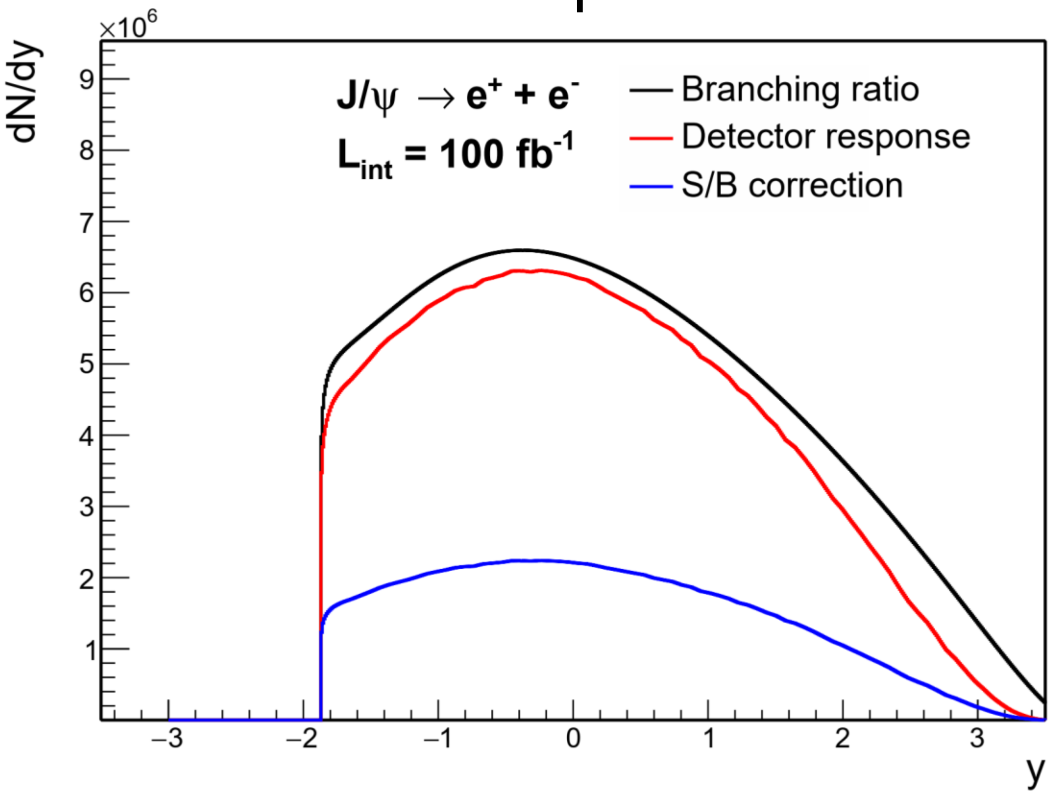


High J/ψ efficiency in central region

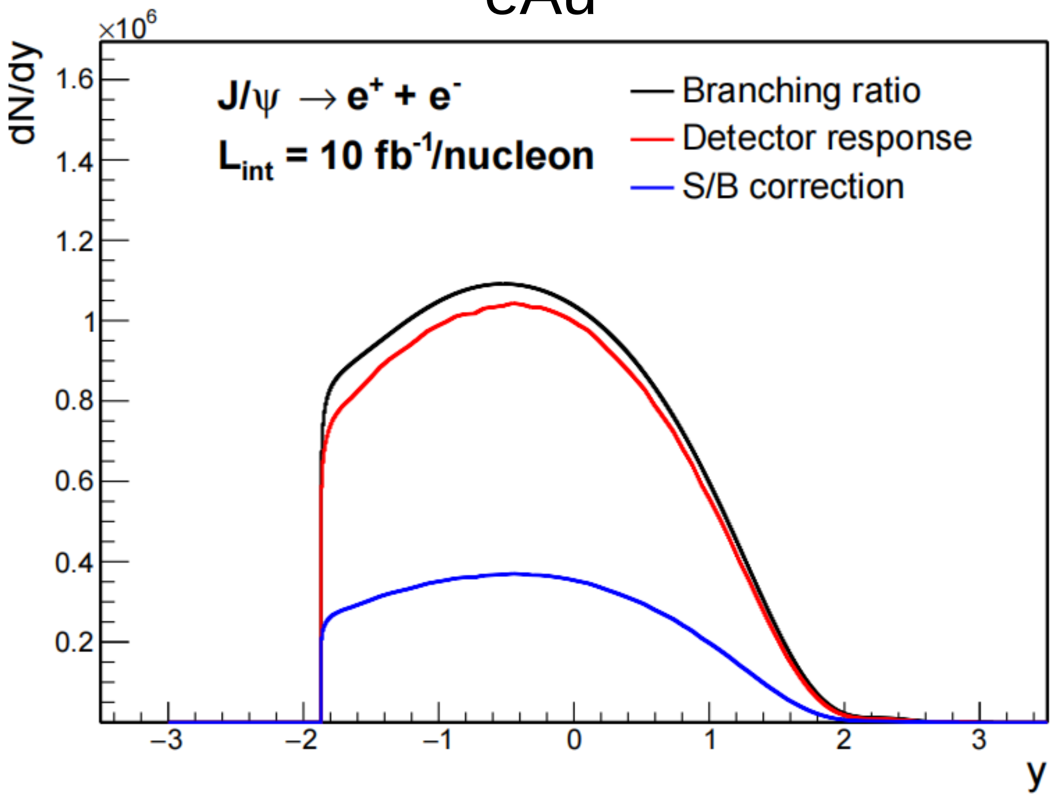
Forward region with a low efficiency

The projected statistics

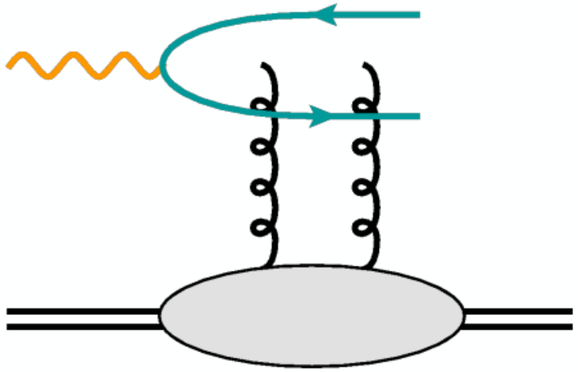
ep



eAu



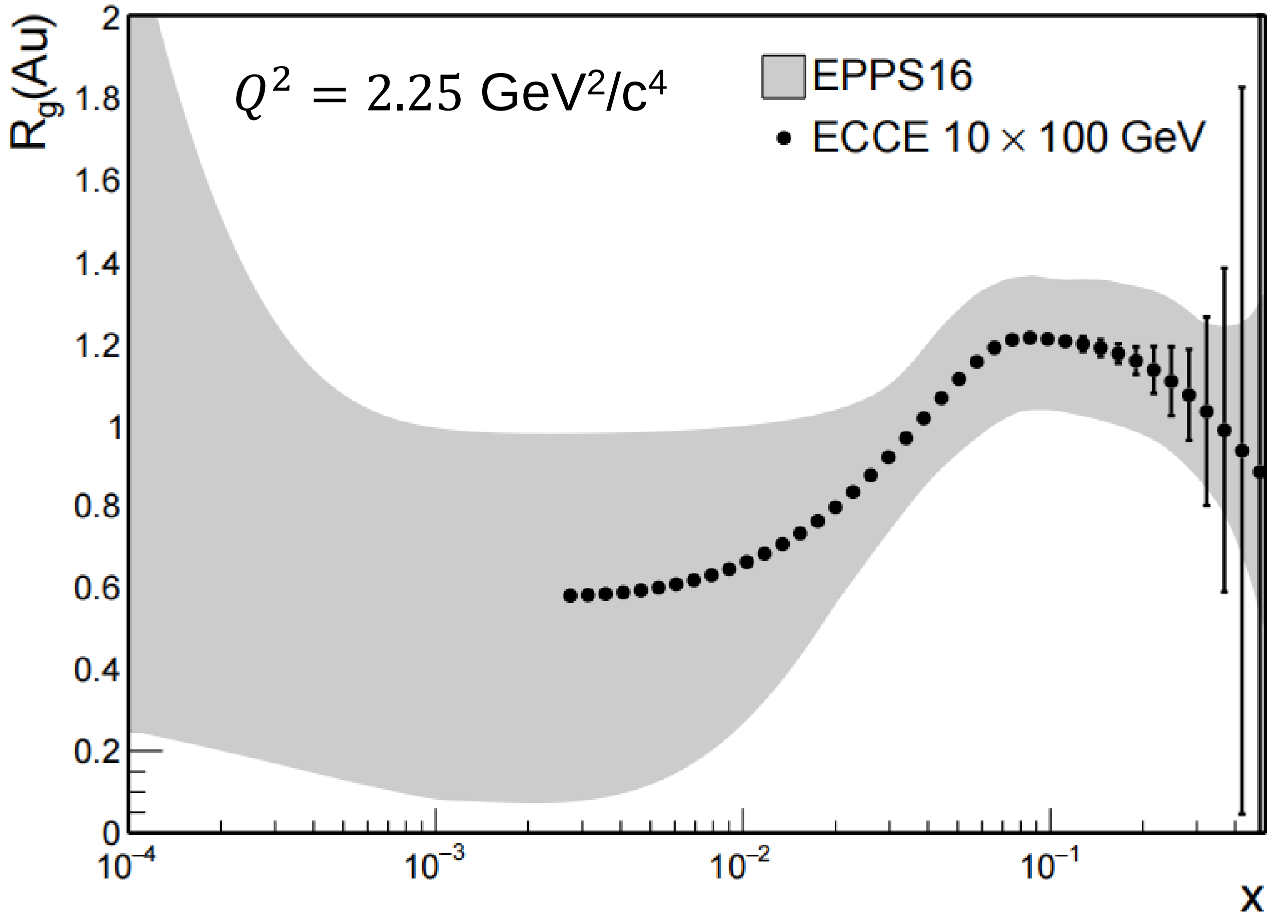
The gluon nPDF projection



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

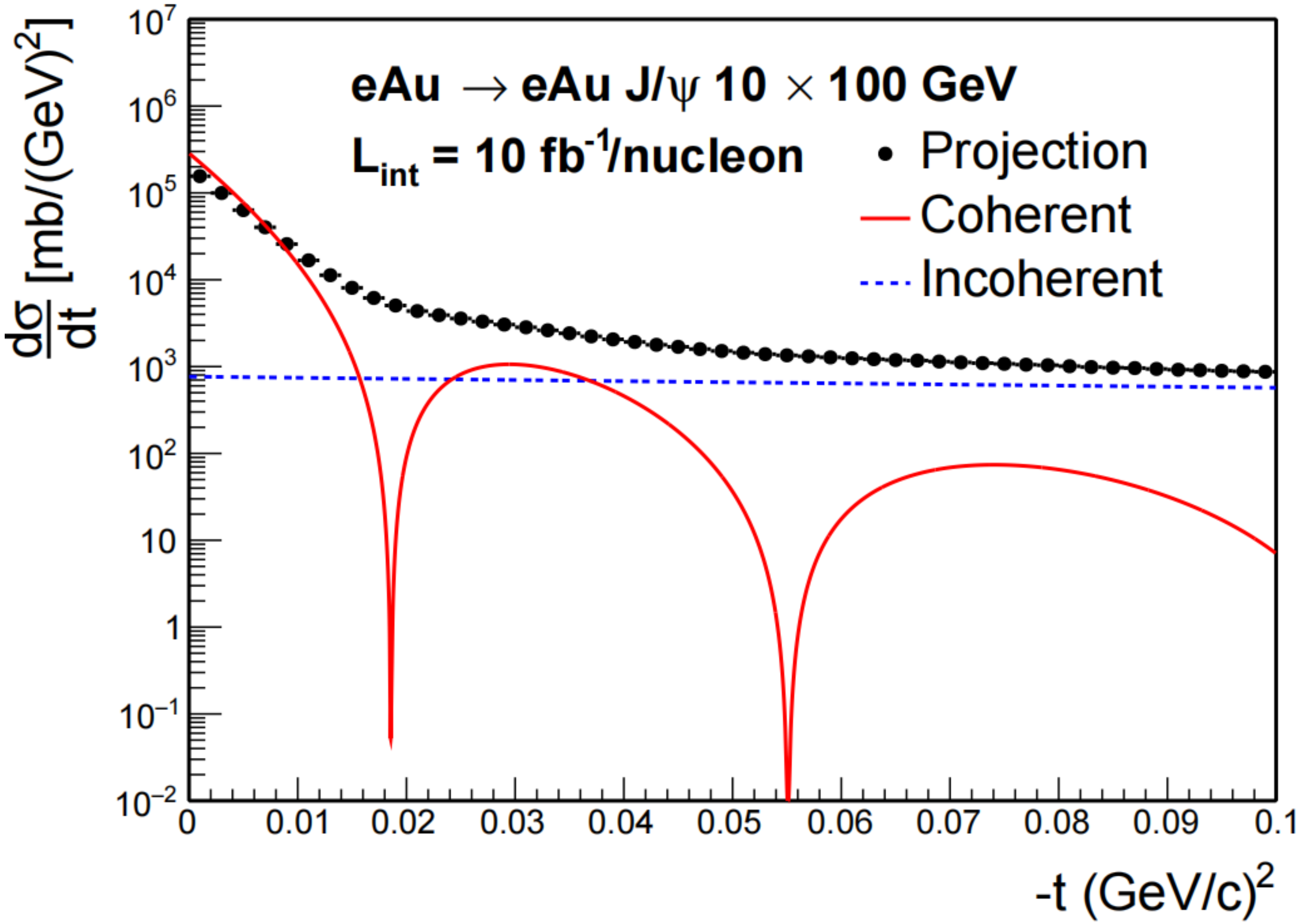
$$x = \frac{M_V e^{\pm y}}{\sqrt{s}} \quad Q^2 = M_V^2/4$$

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



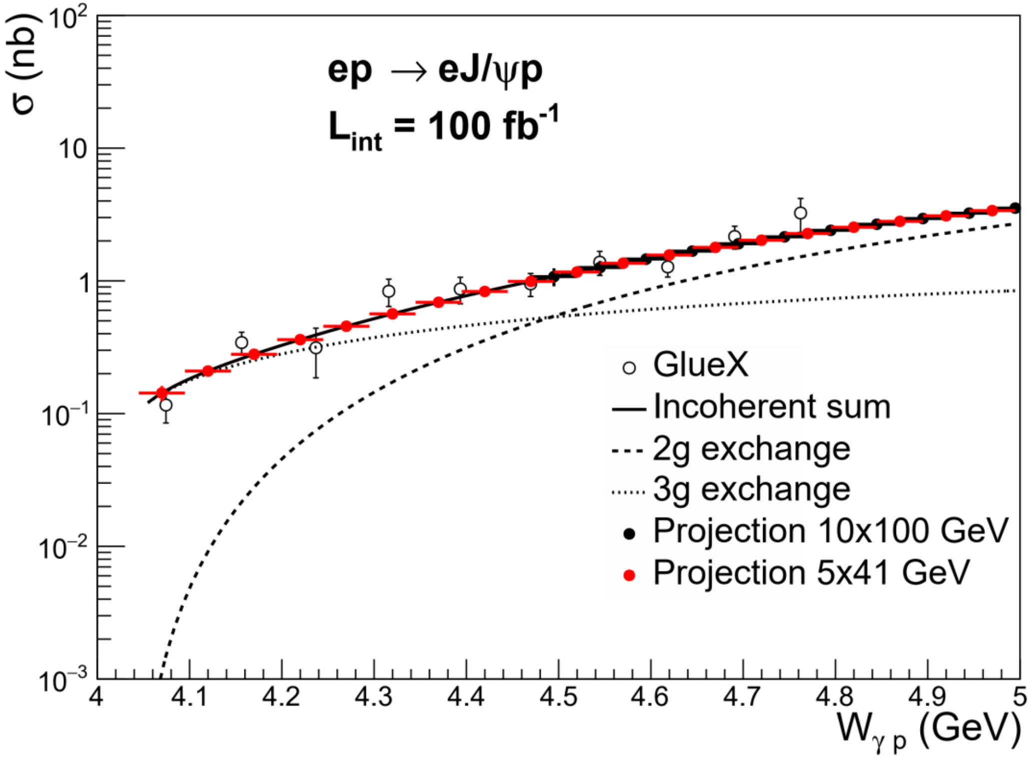
Eskola,K.J., Paakkinen, et al.
EPPS16: EPJC 77 (2017) 163

The t distribution projection



The momentum resolution is important!

The near threshold production mechanism



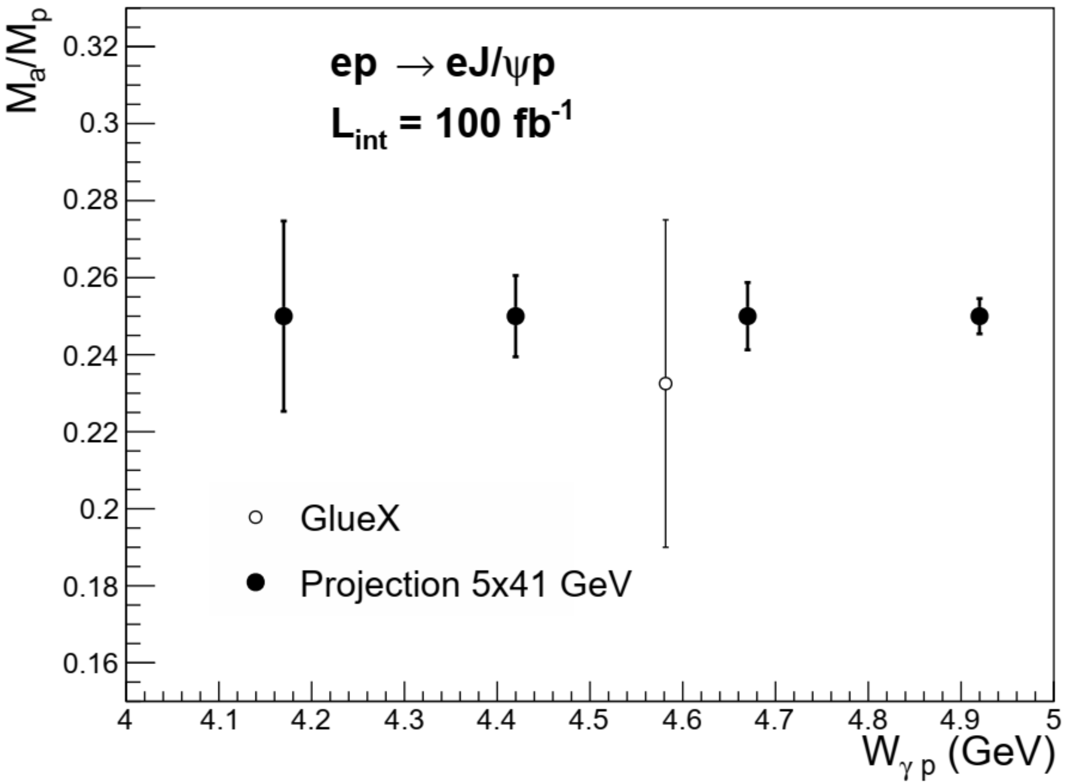
A. Ali et al. (GlueX Collaboration), Phys. Rev. Lett. 123, 072001(2019)

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

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

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

The trace anomaly parameter projection



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

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

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

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

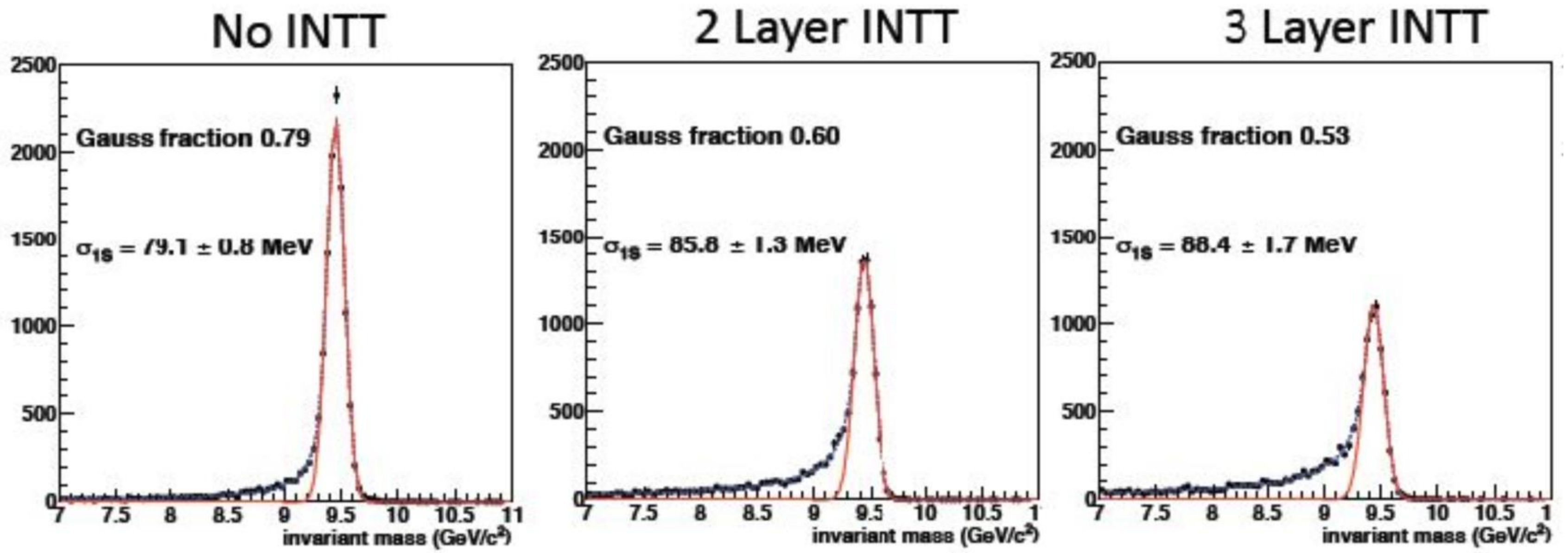
Rong Wang, Xurong Chen and Jarah Evslin,
Eur. Phys. J. C (2020) 80:507

Extract the QCD trace anomaly parameter b

Muon ID at EIC?

- ✓ Less bremsstrahlung
- ✓ Internal photon radiation
- ✓ Combinatorial background

- ✓ Detector technology?
- ✓ R&D and cost evaluation?
- ✓ Space limitations?



Impact from material to Upsilon (ee) measurement [early sPHENIX optimization]

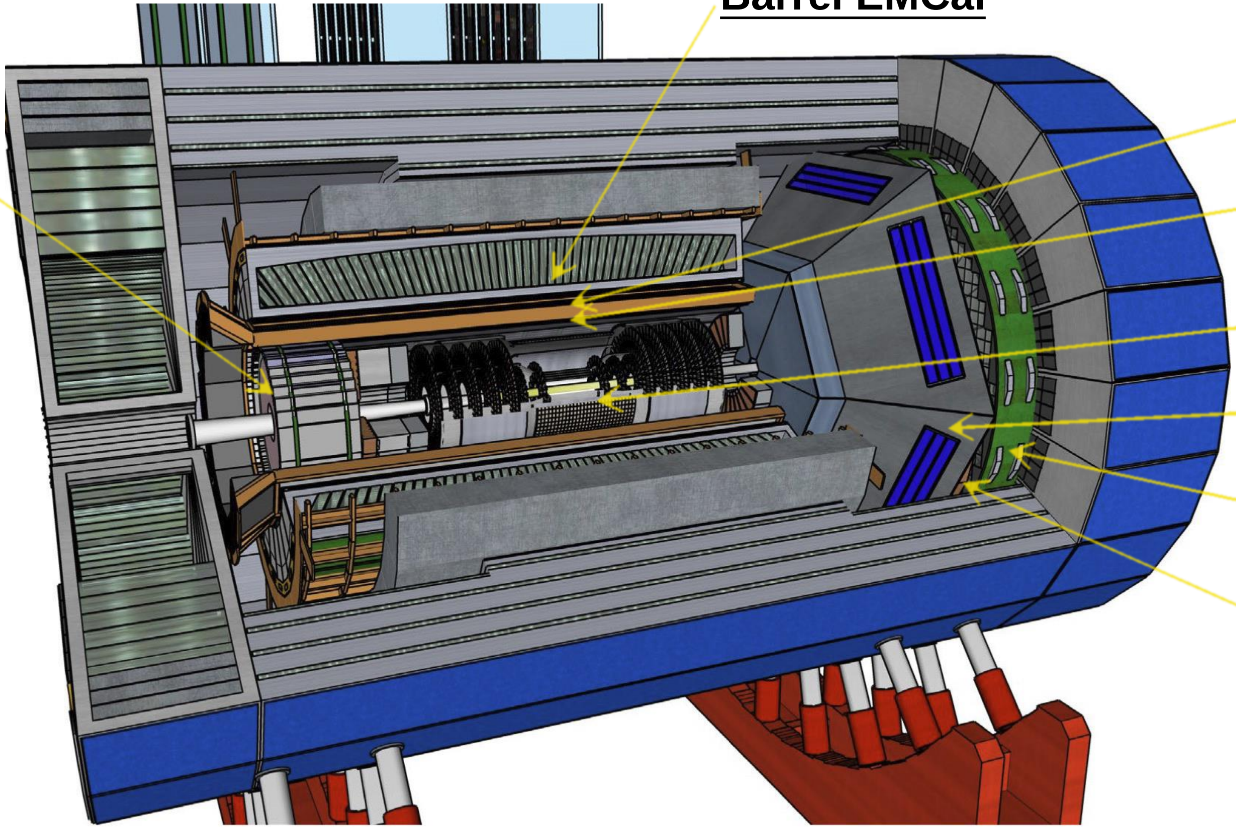
Summary

- Rich physics opportunities with heavy Quarkonia at EIC
- Excellent capability of J/ψ reconstruction at ECCE
- Some selected projection results at ECCE
- More input, ideas and requirements from theorists

Thank you!

Backup

Detector Configuration (July Concept)



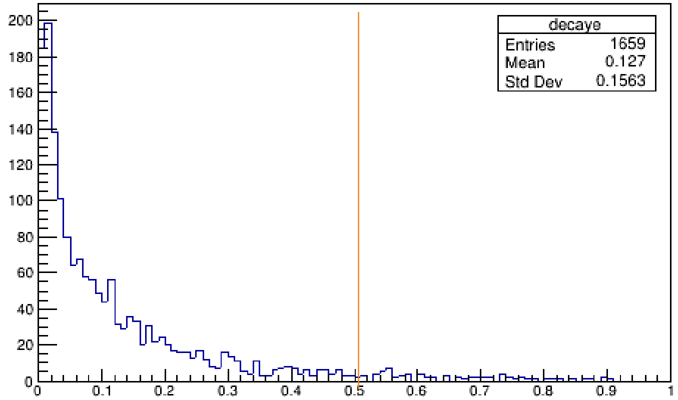
Nearly final ECCE detector image for the proposal

J/ψ detection

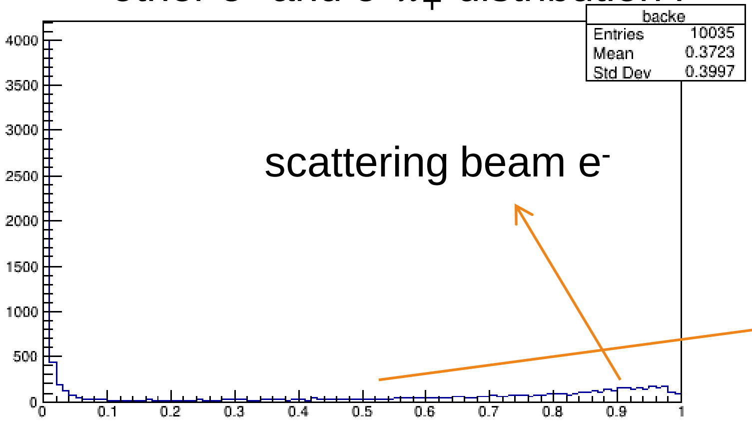
a forward light cone variables can be used to see scattering beam e$^-$ influence

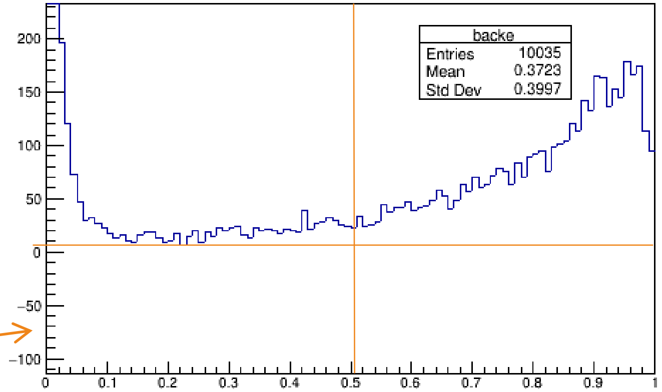
$x_+ = \frac{b_0 + (-b_z)}{a_0 + (-a_z)}$ (cause beam e$^-$ moves along negative z axis), b is beam e$^-$.

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



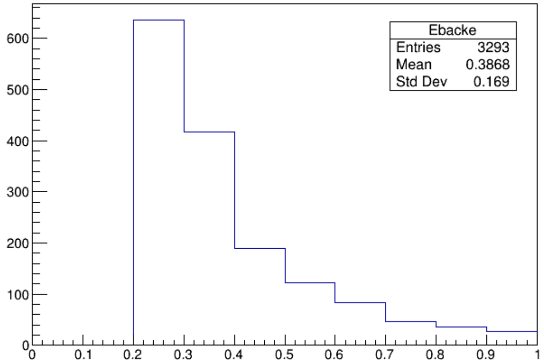
other e$^+$ and e$^-$ x_+ distribution :



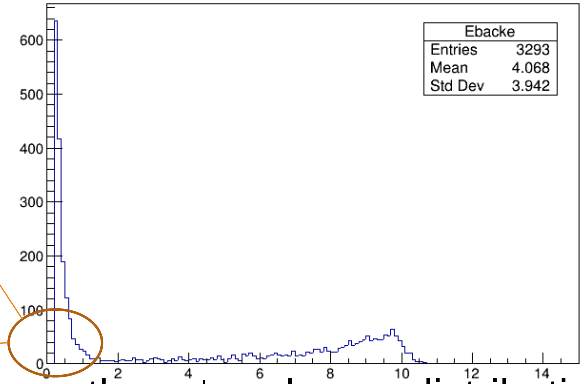


cut: $x_+ < 0.5$

influence of e$^-$ from light hadron decay

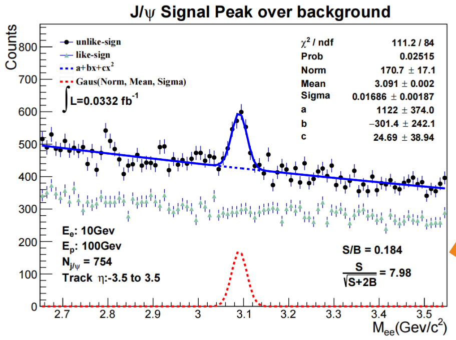


e$^+$ and e$^-$ of J/ψ decay x_+ distribution



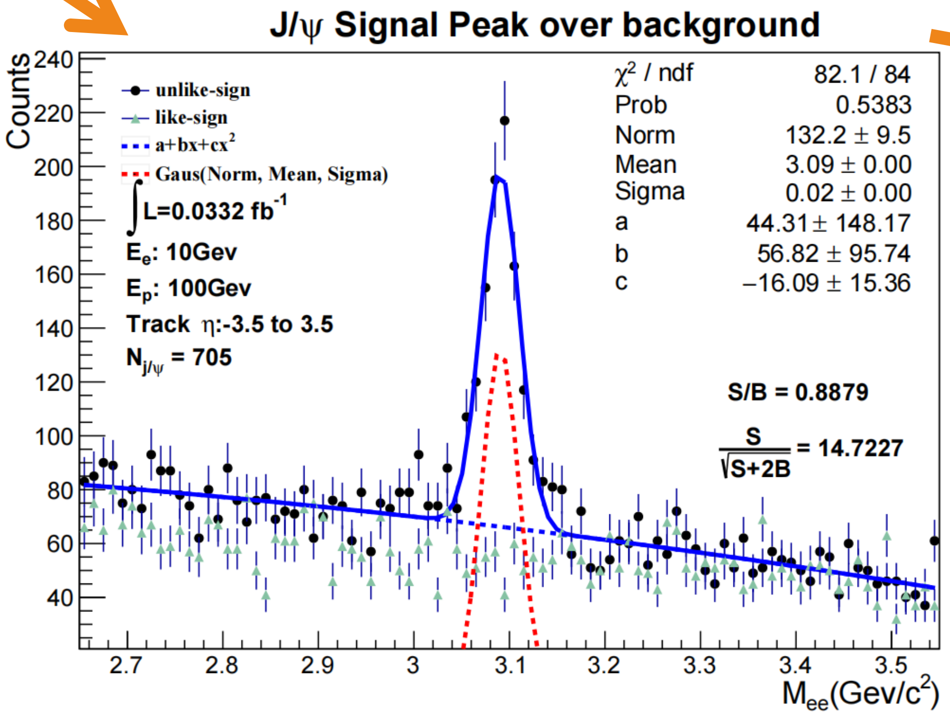
other e$^+$ and e$^-$ x_+ distribution :

J/ψ detection



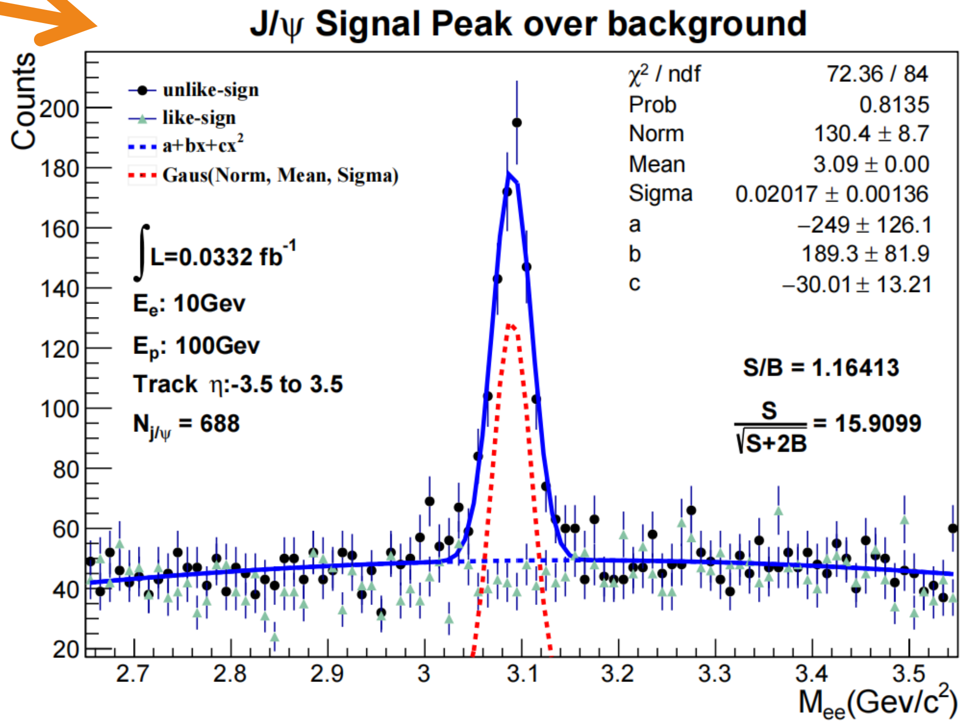
cut: $x_+ < 0.5$

S/B: 0.184 —> 0.888



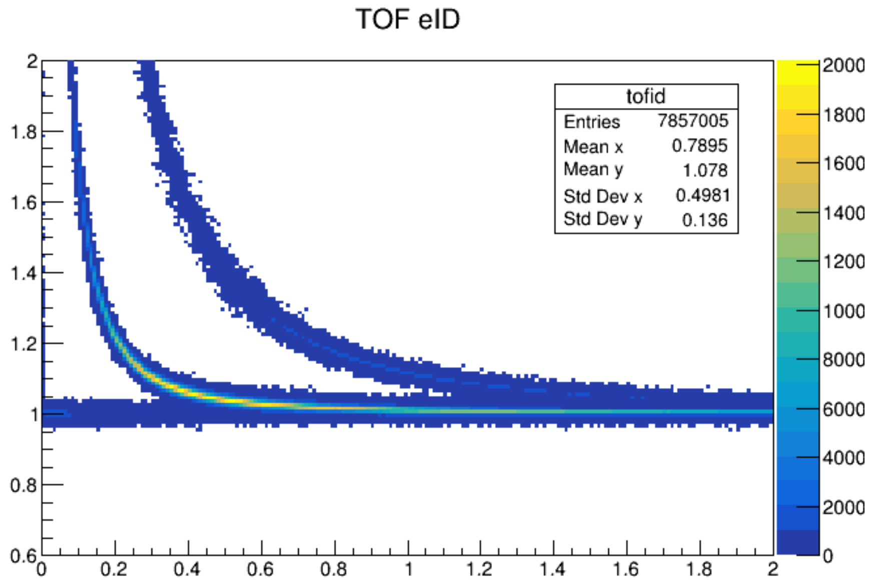
cut: E>0.6

S/B: 0.888 —> 1.164



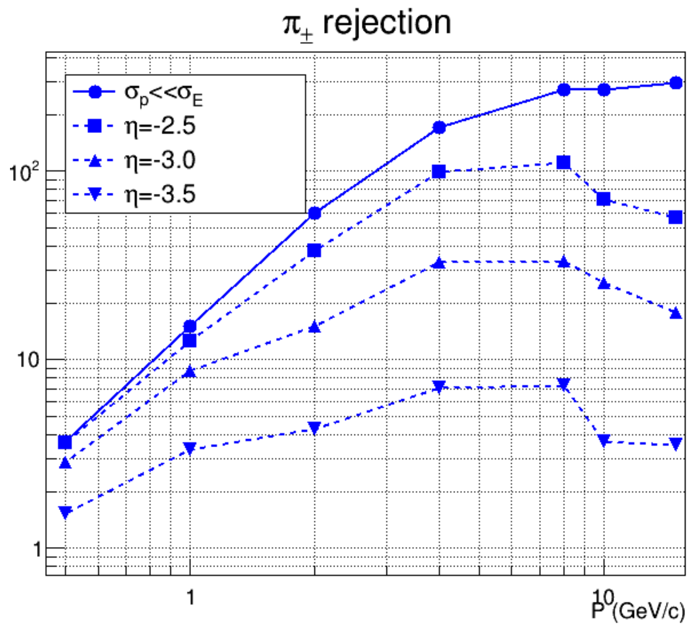
eID——TOF(fastsimulation)

	η range	path length	time resolution
forward	-1.5>η>-3.5	|250(cm) / cos(Θ)|	20 (ps)
barrel	1.5>η>-1.5	50 / sin(Θ)	20
end	3.5>η>1.5	|150 / cos(Θ)|	20



$p < 0.4$(GeV/c) $|1/\beta-1|<0.04$
survival possibility:
e: 99.5% π: 0.1%

Electron identification capability at ECCE



E/p > 1 - 1.6$\cdot\sqrt{\sigma_{EMC}^2 + \sigma_p^2}$ to keep $\boldsymbol{\varepsilon}_e$=95%

	Depth, X_0	$\frac{\sigma_E}{E}$	Depth, λ_I
W/SciFi (sPHENIX, GEANT)	~20	$\frac{13\%}{\sqrt{E}}\oplus 3\%$	~0.83

Electron identification capability at ECCE