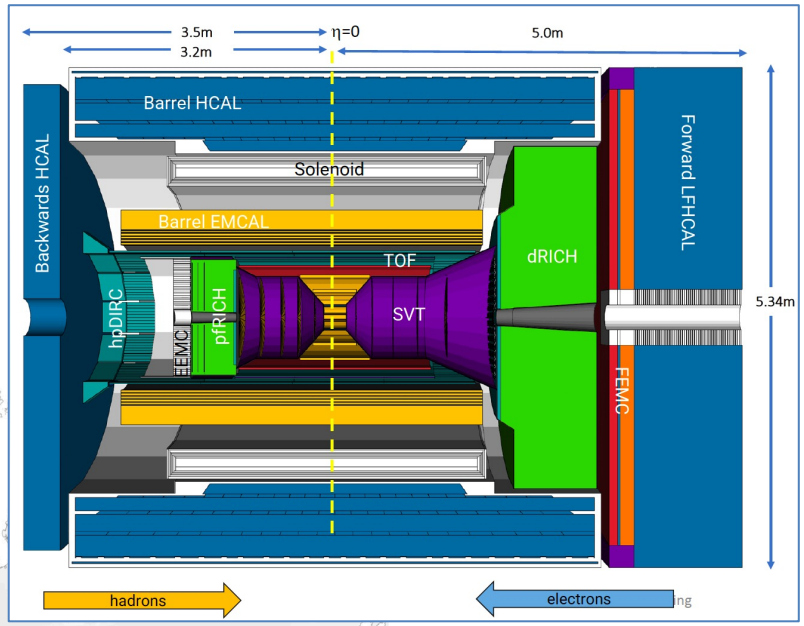
Status of EIC experiment

Yongsun Kim (SJU, BNL)

April 25 2025

Korean EIC-th meeting

ePIC - First EIC detector collaboration

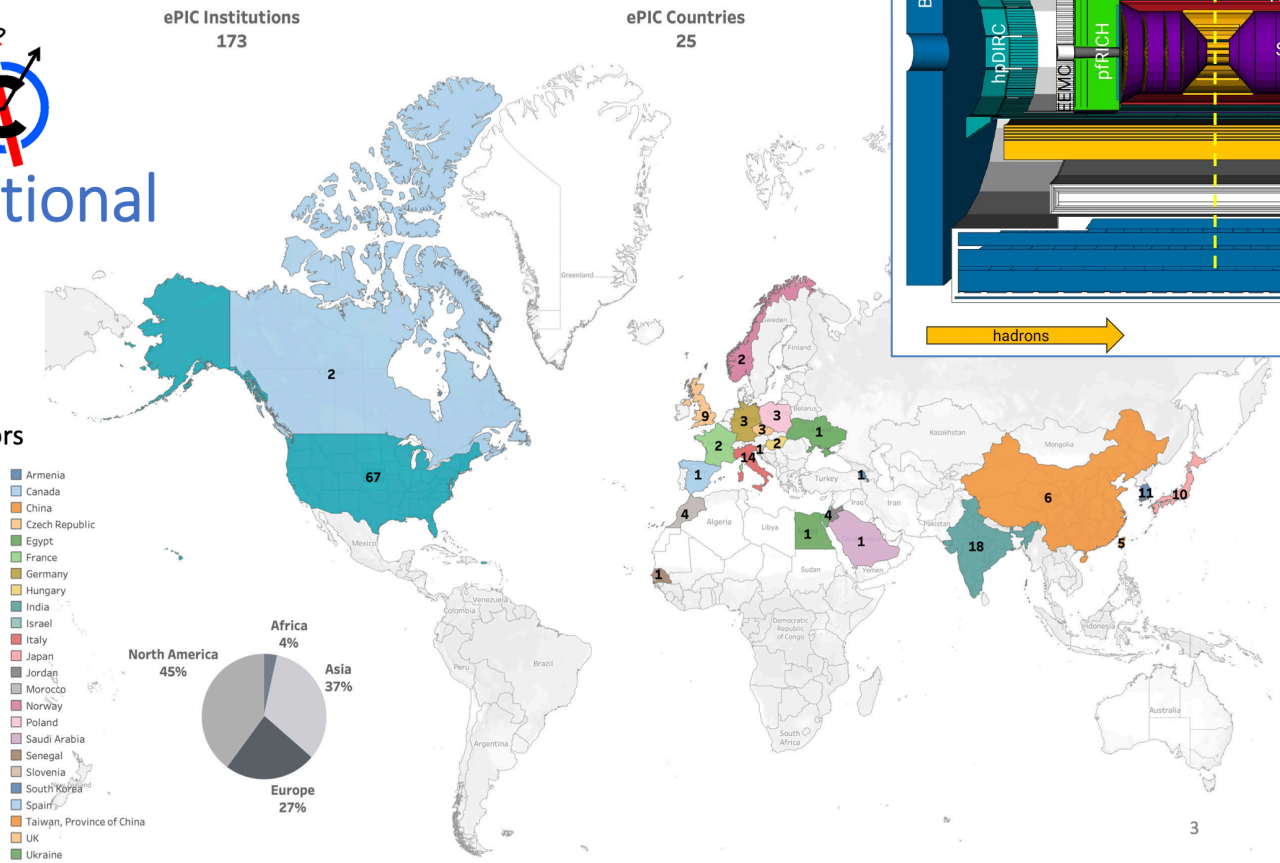


International

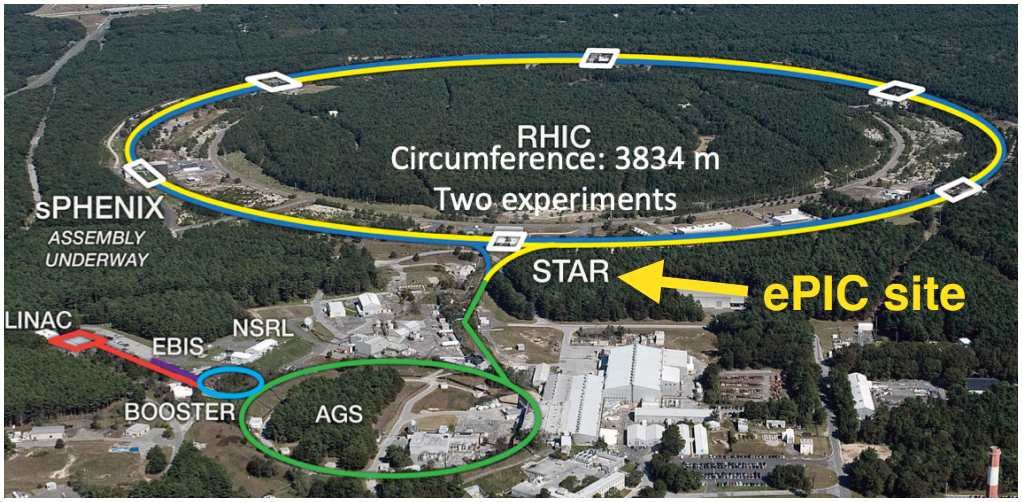
ePIC Initiated in July 2022

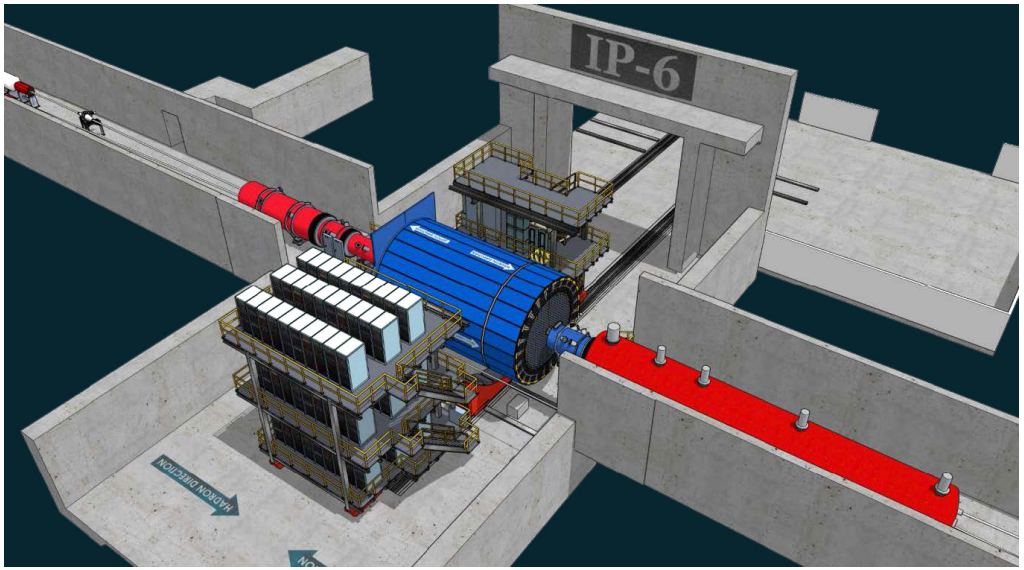
Currently:
>850 collaborators (from 2024 Institutional Survey)

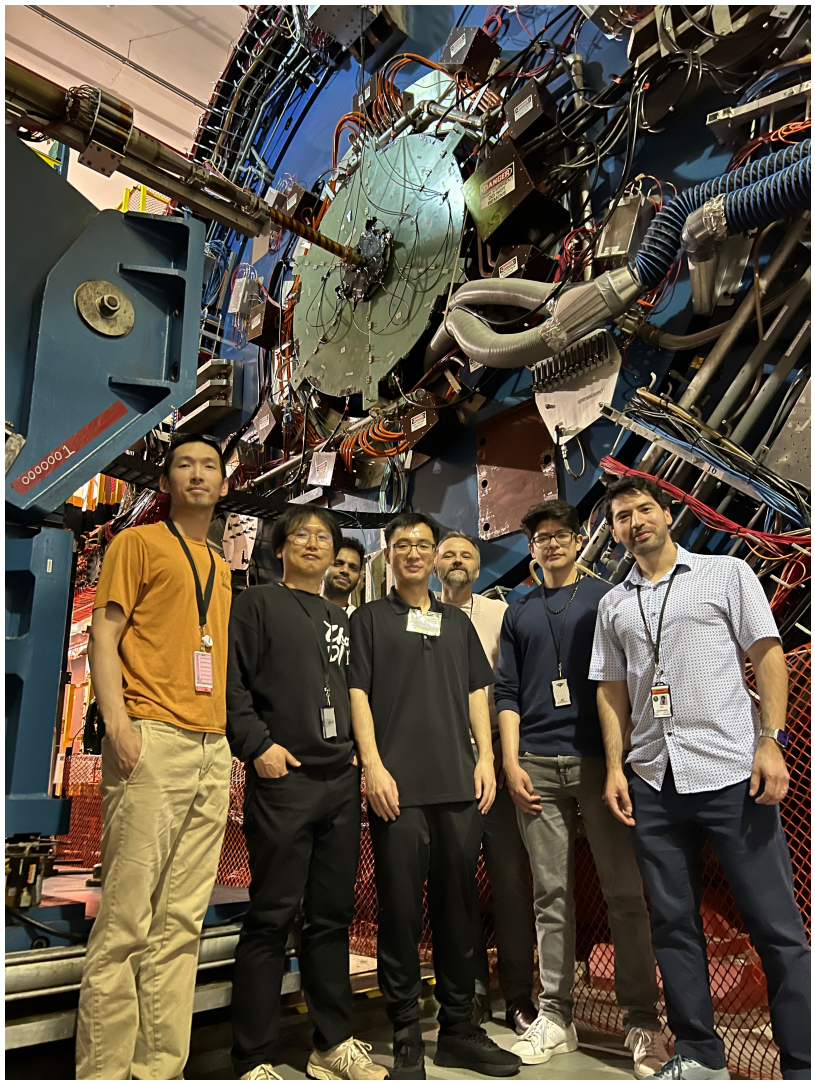
>650 members active in ePIC activities



ePIC detector

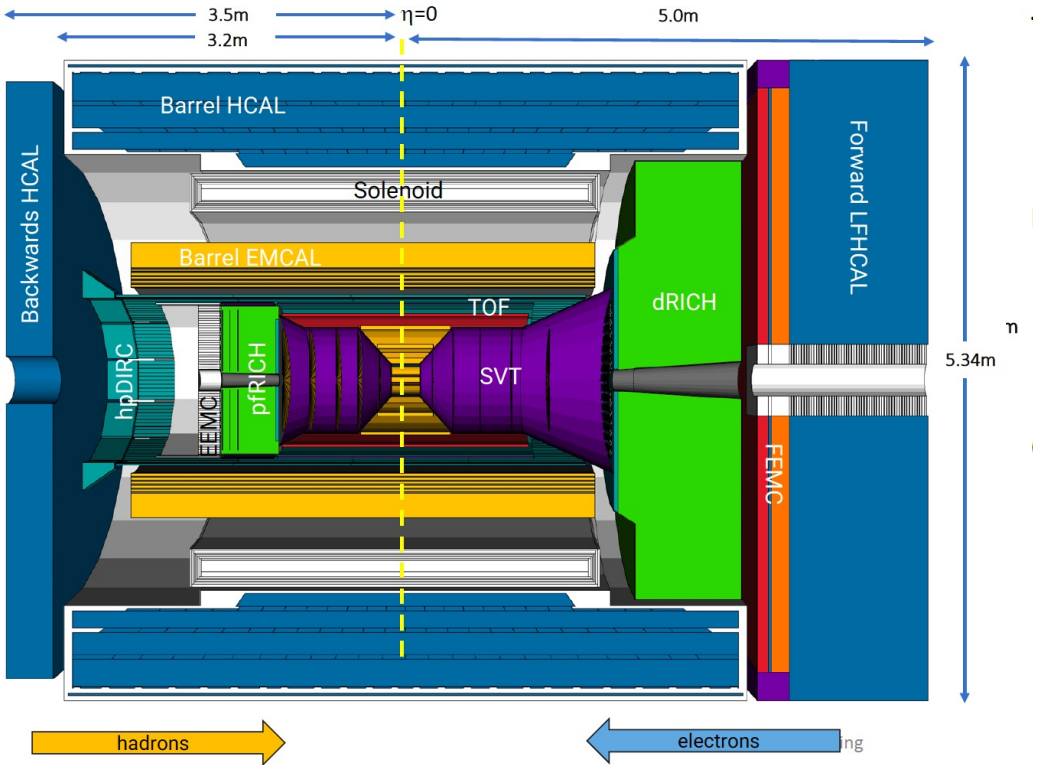






ePIC detector

ePIC Detectors: Central Barrel



Tracking:

- New 1.7T solenoid
- Si MAPS Tracker
- MPGDs (μRWELL/μMegas)

PID:

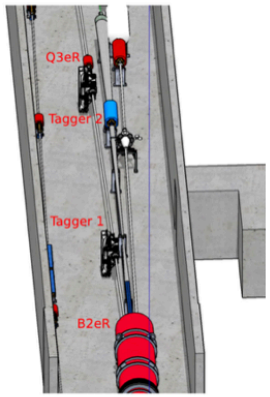
- hpDIRC
- pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

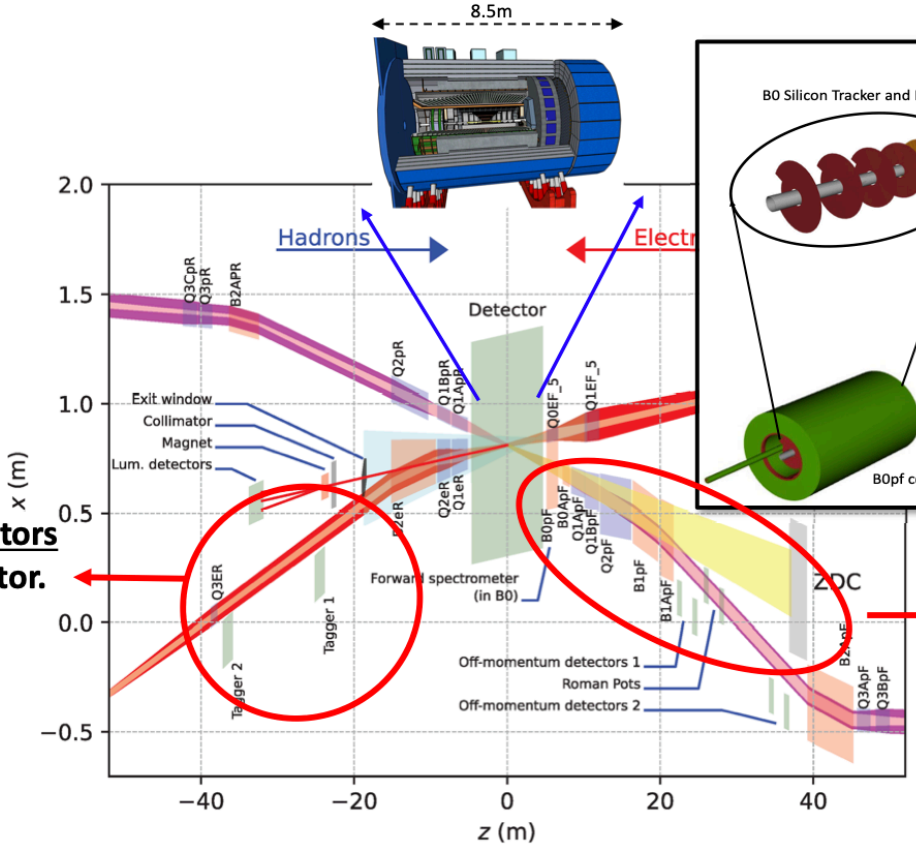
Calorimetry:

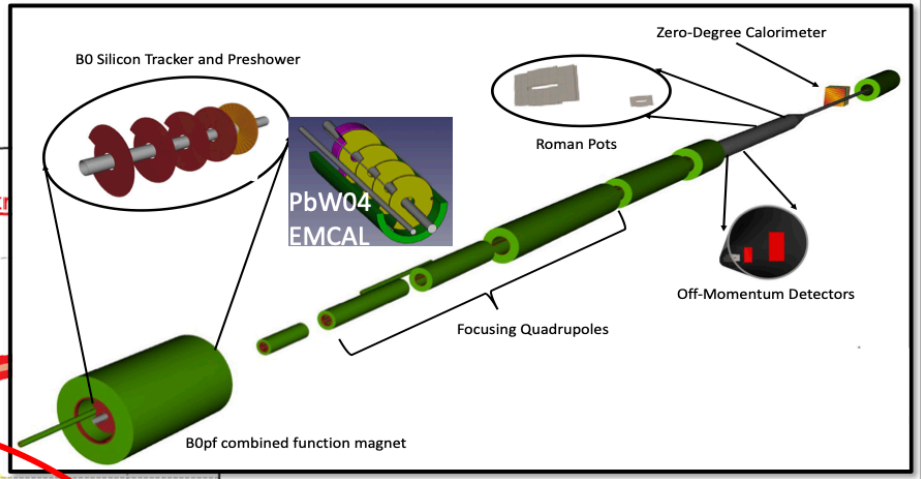
- Imaging Barrel EMCal
- PbWO4 EMCal in backward direction
- Finely segmented EMCal +HCal in forward direction
- Outer HCal (sPHENIX re-use)
- Backwards HCal (tail-catcher)

from T. Gunji

Far-forward system







Far-Backward Detectors

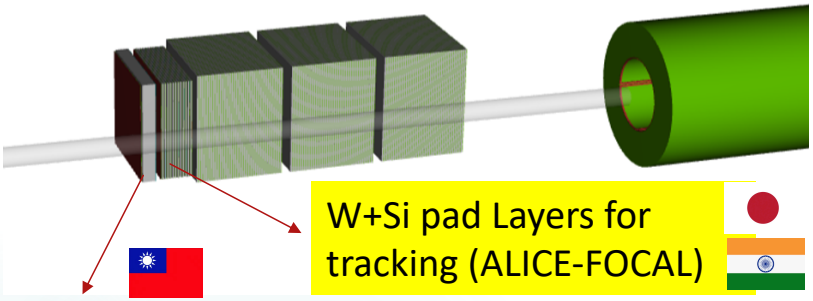
- **Luminosity monitor.**
- **Low-Q^2 Tagging Detectors**

Far-Forward Detectors

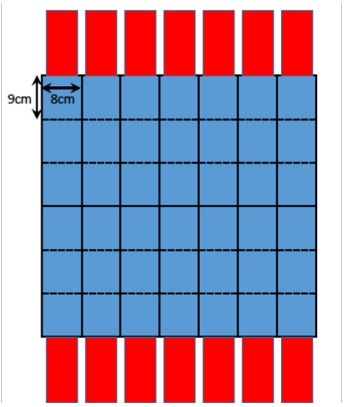
- **B0 Tracking and Photon Detection**
- **Roman Pots and Off-Momentum Detectors.**
- **Zero-Degree Calorimeter.**

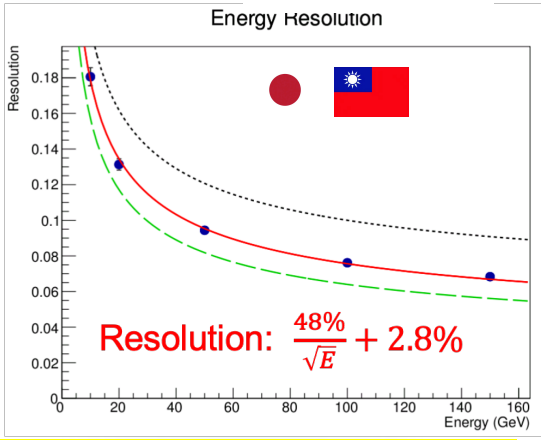
ZDC for neutral particle diffraction measurement

ZeroDegree Calorimeter



W+Si pad Layers for tracking (ALICE-FOCAL)

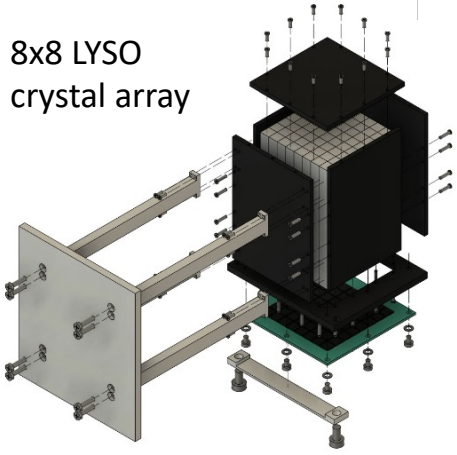




LYSO Crystals

50 LYSO crystals were produced

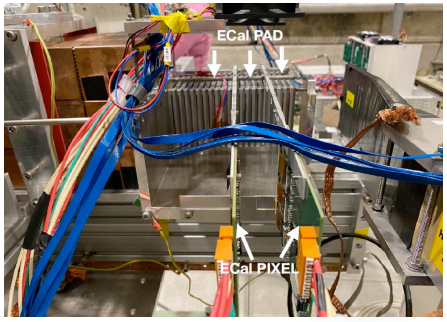
8x8 LYSO crystal array



beam test at ELPH in February 2024

W+Si pad Layers for tracking (ALICE-FOCAL)

ALICE-FoCAL beam test@CERN



Neutron irradiation at RIKEN RANS

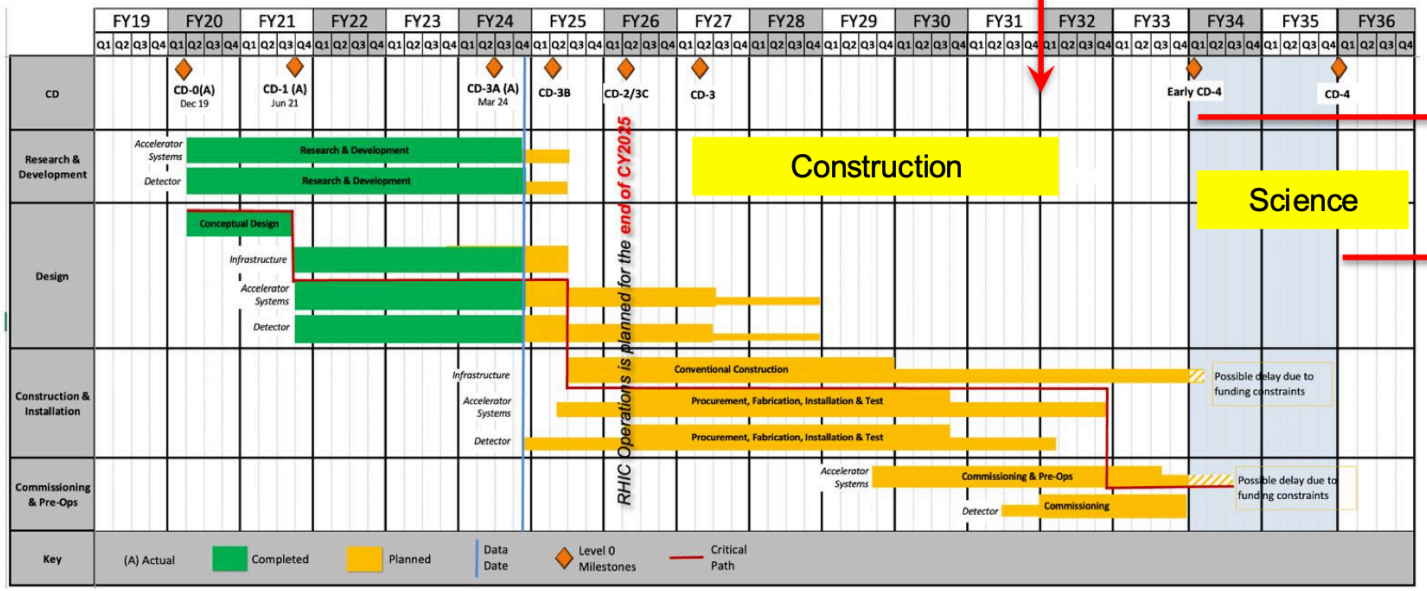
from T. Gunji

Updates from EIC RRB

Reference Schedule

Deadline for “our” detectors in: ~second half of 2031

CD-2 plans will be revised to address actual funding and the Director’s Review.



Construction

Science

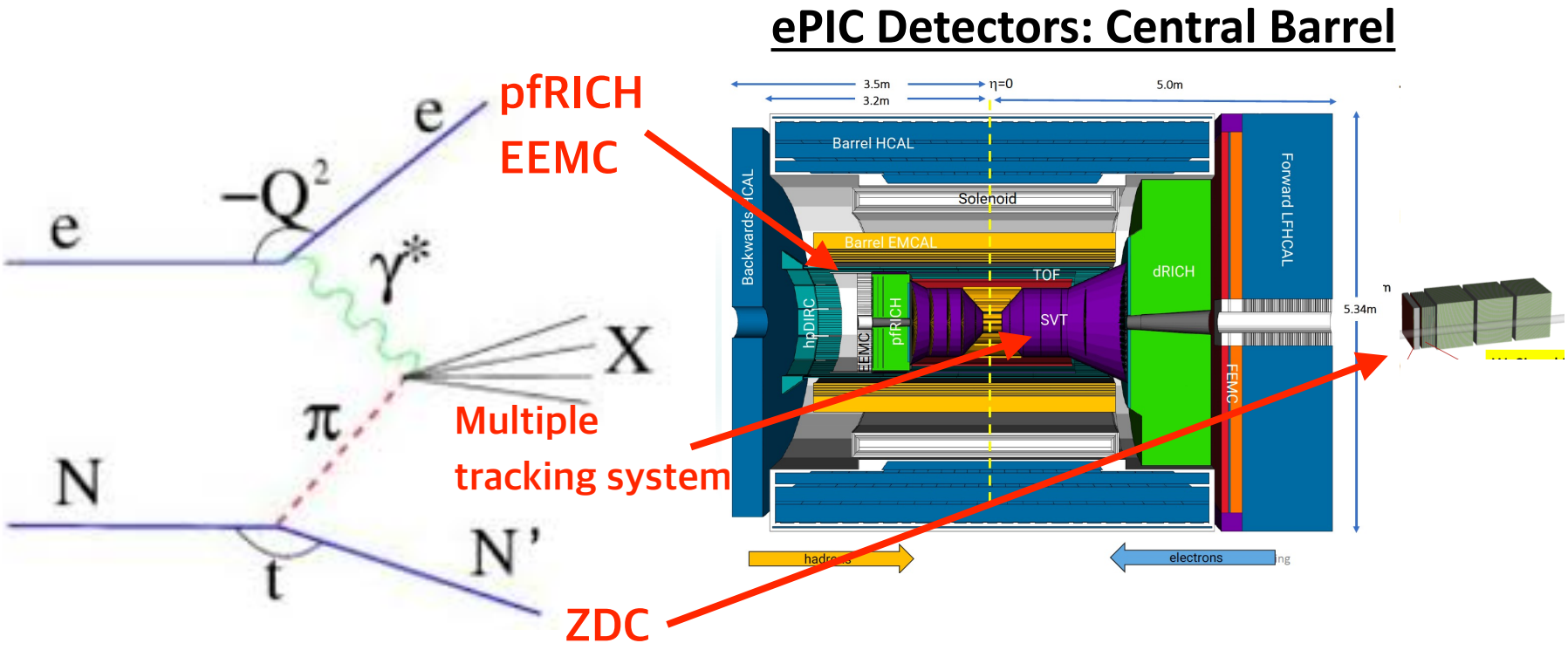
First beams & physics: ~2034

Full EIC science: ~2036

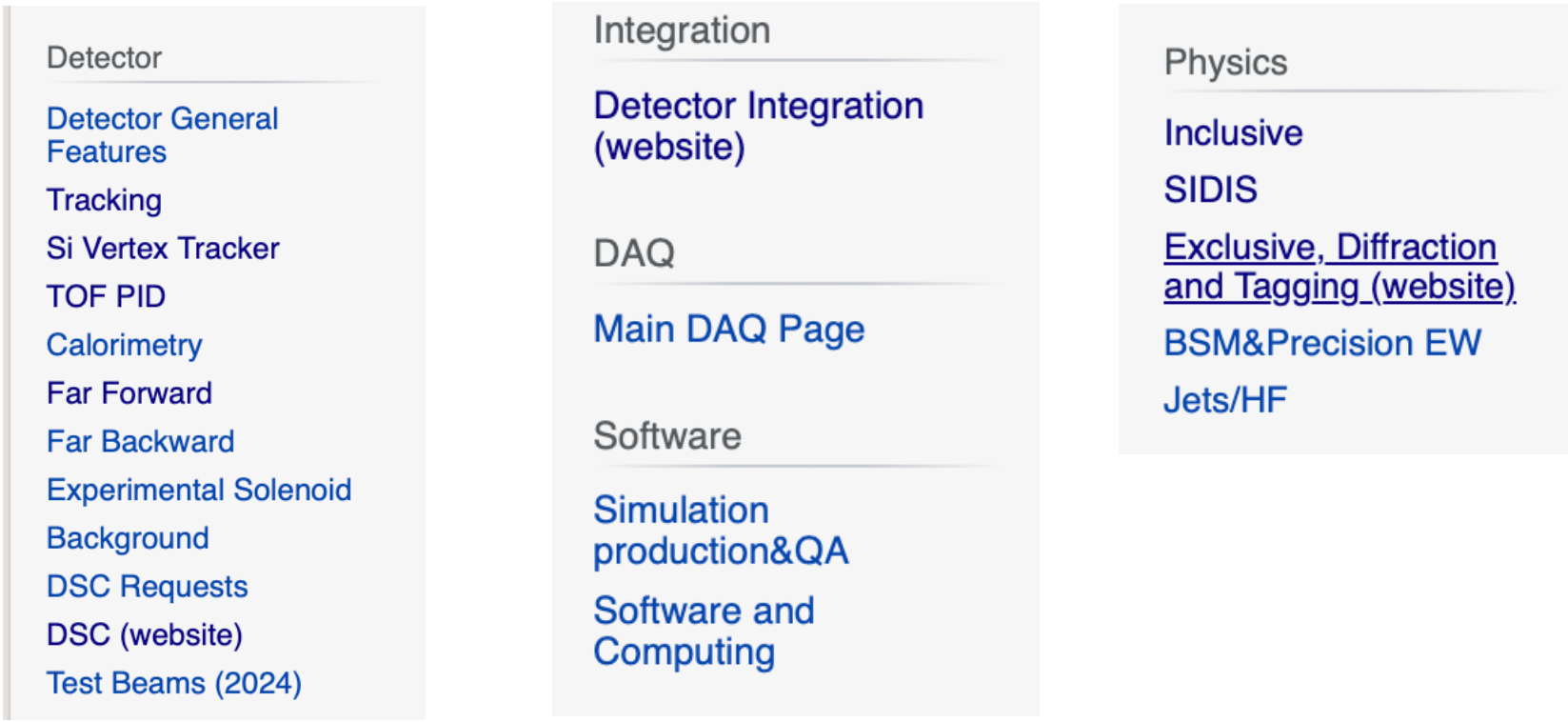
Critical Path is Accelerator Systems

Physics topic and hardware development

- In the detector building phase, physics topic and hardware developments are not correlated



Organization of ePIC collaboration



- In the early phase, most of funding and efforts go toward engineering aspects
- A well-balanced investment in hardware development, physical simulation, and theoretical research is crucial. -> 정책과제 초기 제안

Korean institutes interested in ePIC (2023)

Calorimeter (barrel)

Yonsei U, SKK U, KNU, PNU

(Dual readout + Si teams)

Calorimeter (ZDC)

Sejong U, Korea U

*ALICE Focal + LAMPS**

μRWELL

SNU, U of Seoul

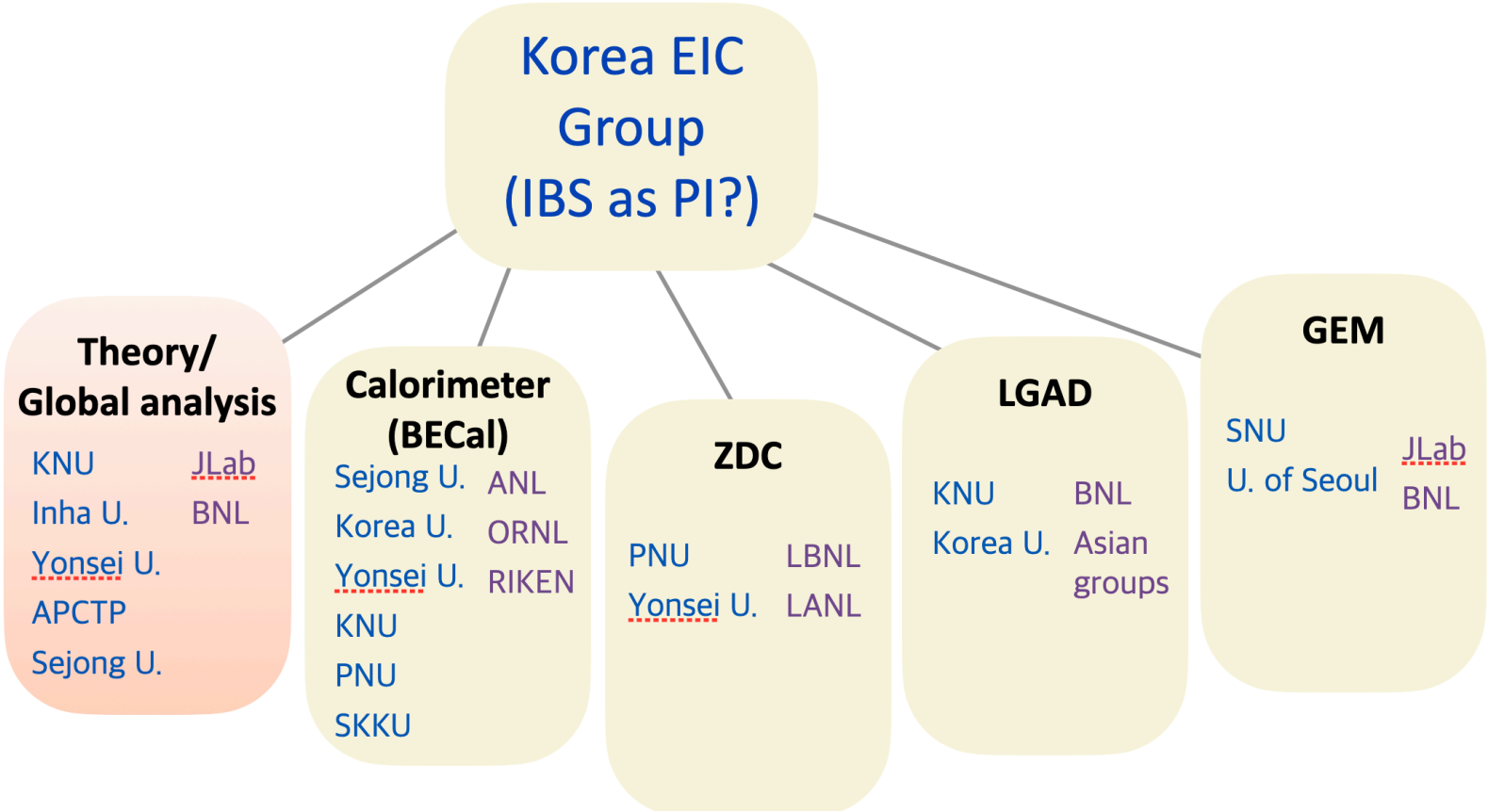
Korean CMS group

LGAD

KNU, Korea U

Korean CMS group

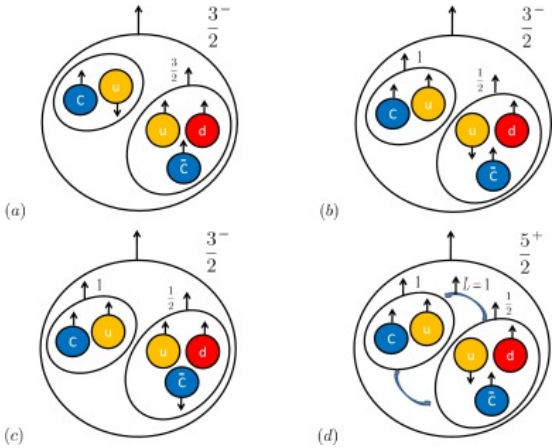
정책과제 (2024)



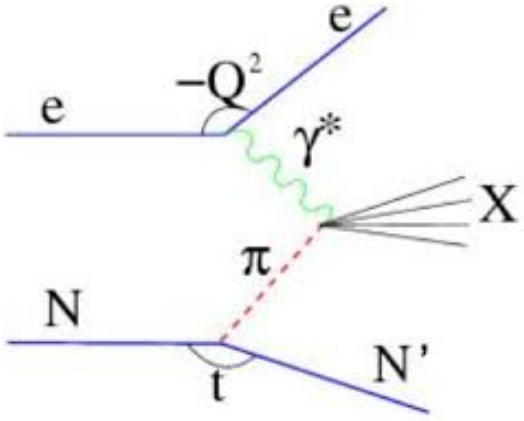
- 2024년 정책과제 시절에 남승일, 최호명 교수님을 PI로 하는 이론 그룹을 만들것을 제안하였고, advisory committee가 모두 동의하였으나, 현재 과기부가 진행하는 EIC-Korea 프로젝트에서 이론 연구가 빠지고, hardware에만 집중이 된 상태.
- 이론그룹은 새로운 펀딩 모색이 필요함. (브레인 링크 사업? BRL?)

(Personally) Interesting topics for both theory and experiment

1. Penta-quark production



2. Meson PDF



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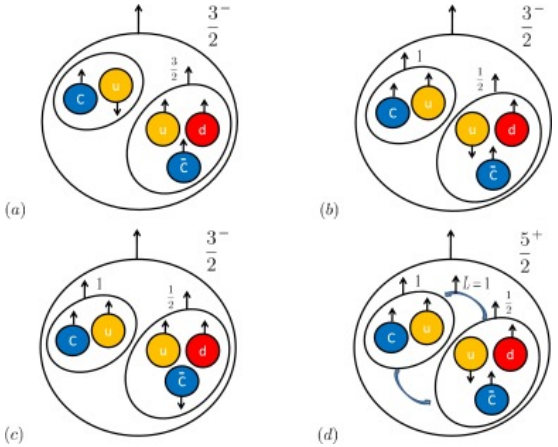

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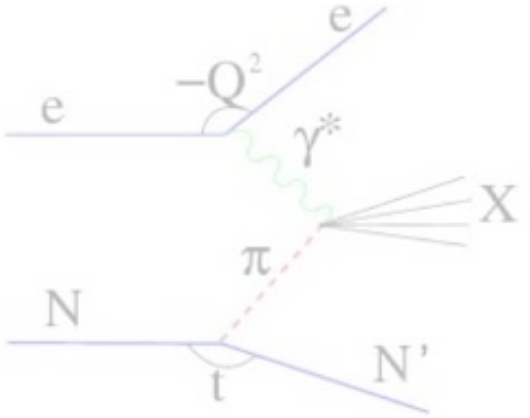


Papers on P_c and P_s

High Energy Physics - Phenomenology

[Submitted on 23 Feb 2022]

Production of $P_c(4312)$ state in electron-proton collisions

In Woo Park, Su Houng Lee, Sungtae Cho, Yongsun Kim

We study the
pentaquark s
$\sqrt{s}$ is set to
asses the po
comparing th
electron bea
$P_c \to p + J/$
considered a

High Energy Physics - Phenomenology

[Submitted on 12 Feb 2024]

Study on the ϕ-meson photoproduction off the proton target with the pentaquark-like $K^*\Sigma$ bound state P_s

Sang in Shim, Yongsun Kim, Seung-il Nam

We utilize the e
photoproductic
the Pomeron, f
resonance state
indicate that, a
a limited impac
crucial, particul

High Energy Physics - Phenomenology

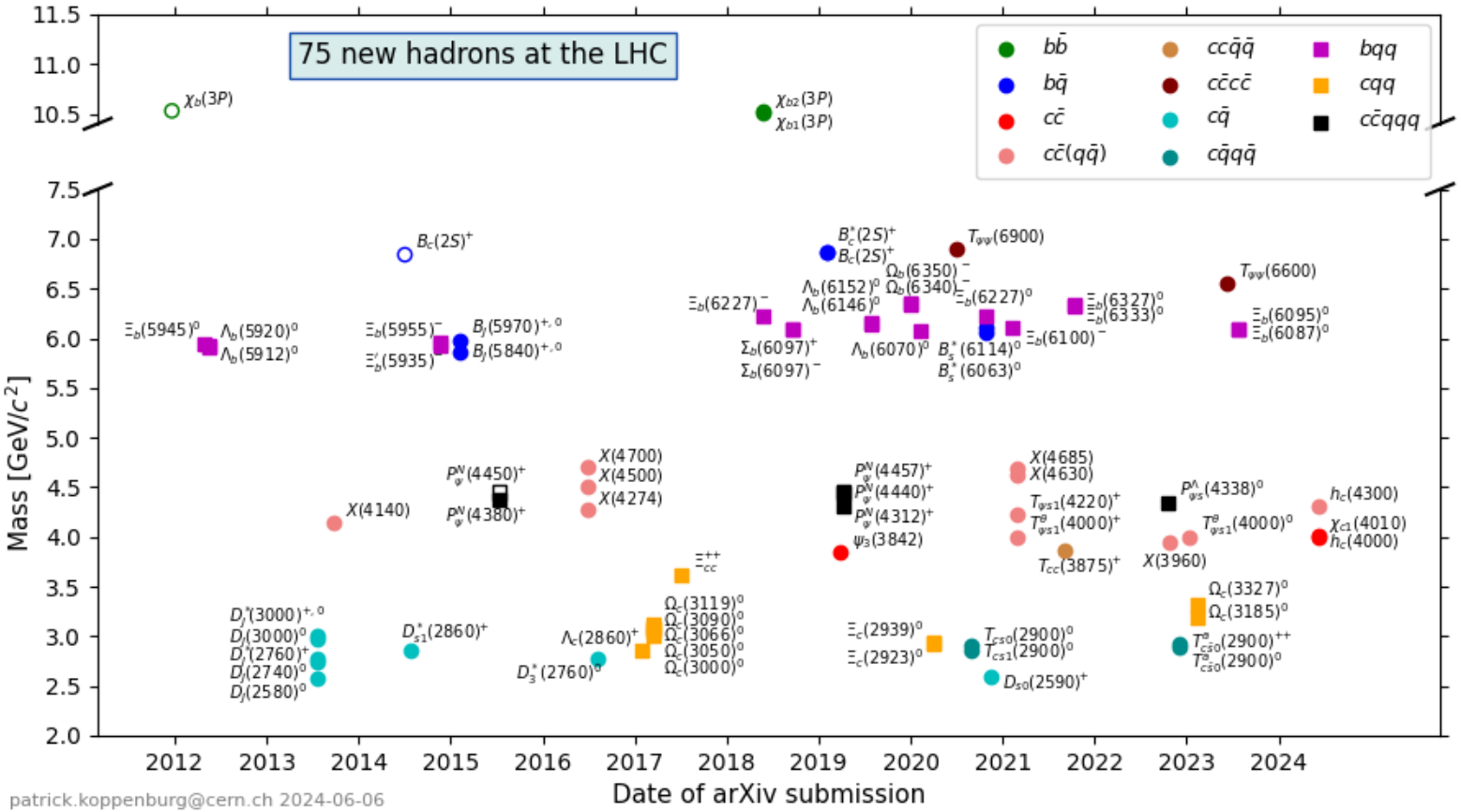
[Submitted on 4 Mar 2025]

The Electron-Ion Collider as A Prospective Facility for Pentaquark Measurements

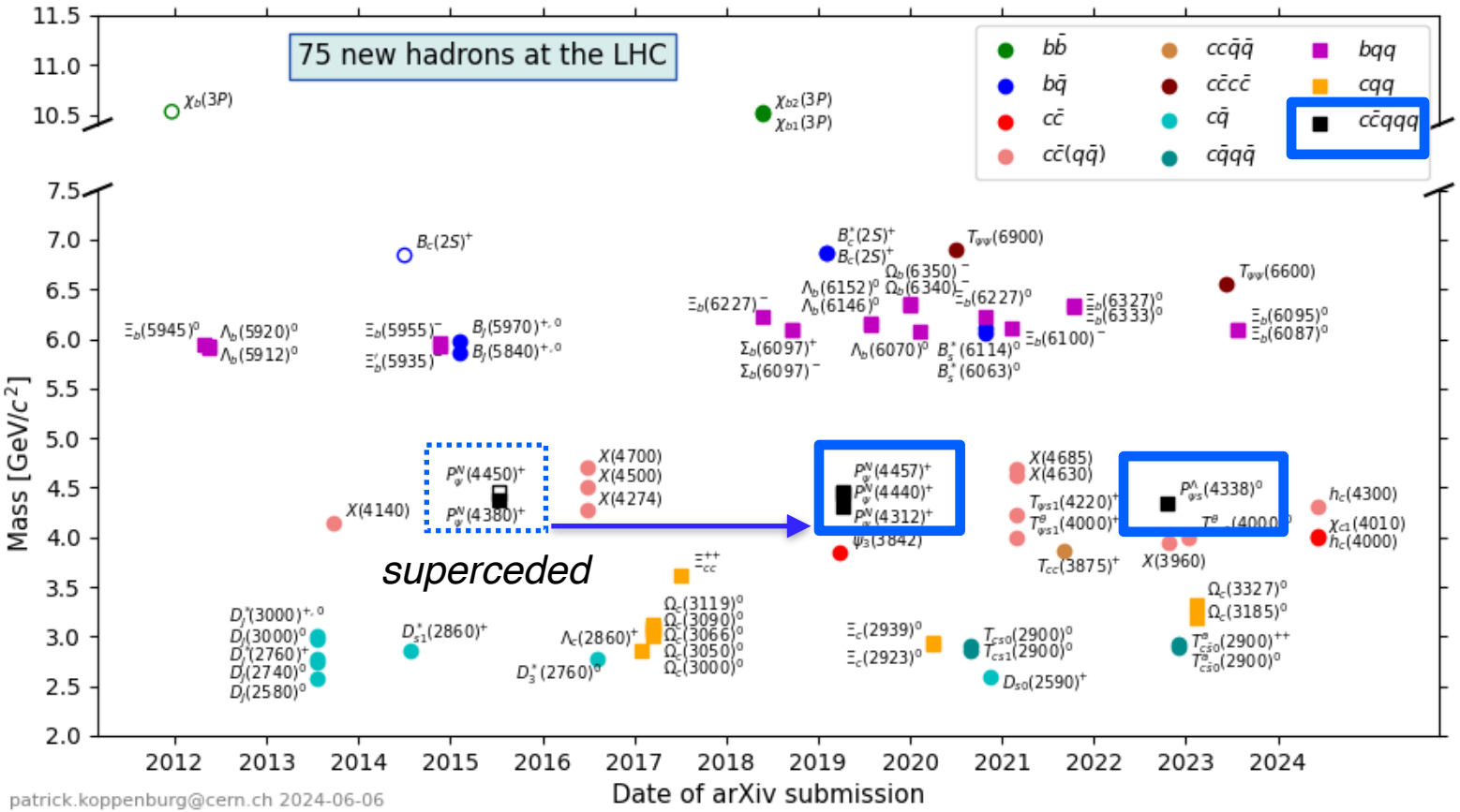
In Woo Park, Sungtae Cho, Yongsun Kim, Su Houng Lee

The Electron-Ion Collider provides a groundbreaking opportunity to study heavy pentaquarks with unprecedented precision, leveraging its high collision energy and beam spin polarization capabilities. As a representative case, we analyze electroproduction cross sections of Pc (4312) under different spin-parity hypotheses using the vector meson dominance model. To ensure a parameter-free approach and minimize ambiguity, we incorporate results from the LHCb and GlueX experiments. To characterize the spin and the parity of Pc (4312), we propose measuring the beam spin asymmetry and decay kinematic polarization, quantities that can be accurately determined by the ePIC detector. Our approach can be extended to investigate other heavy pentaquarks produced in electron-proton and electron-deuteron collisions, as well as to study their interactions with nuclear matter in electron-heavy ion collisions. We strongly encourage the EIC community to explore this potential and integrate pentaquark studies as a critical element of the scientific mission.

New exotic particles at LHCb

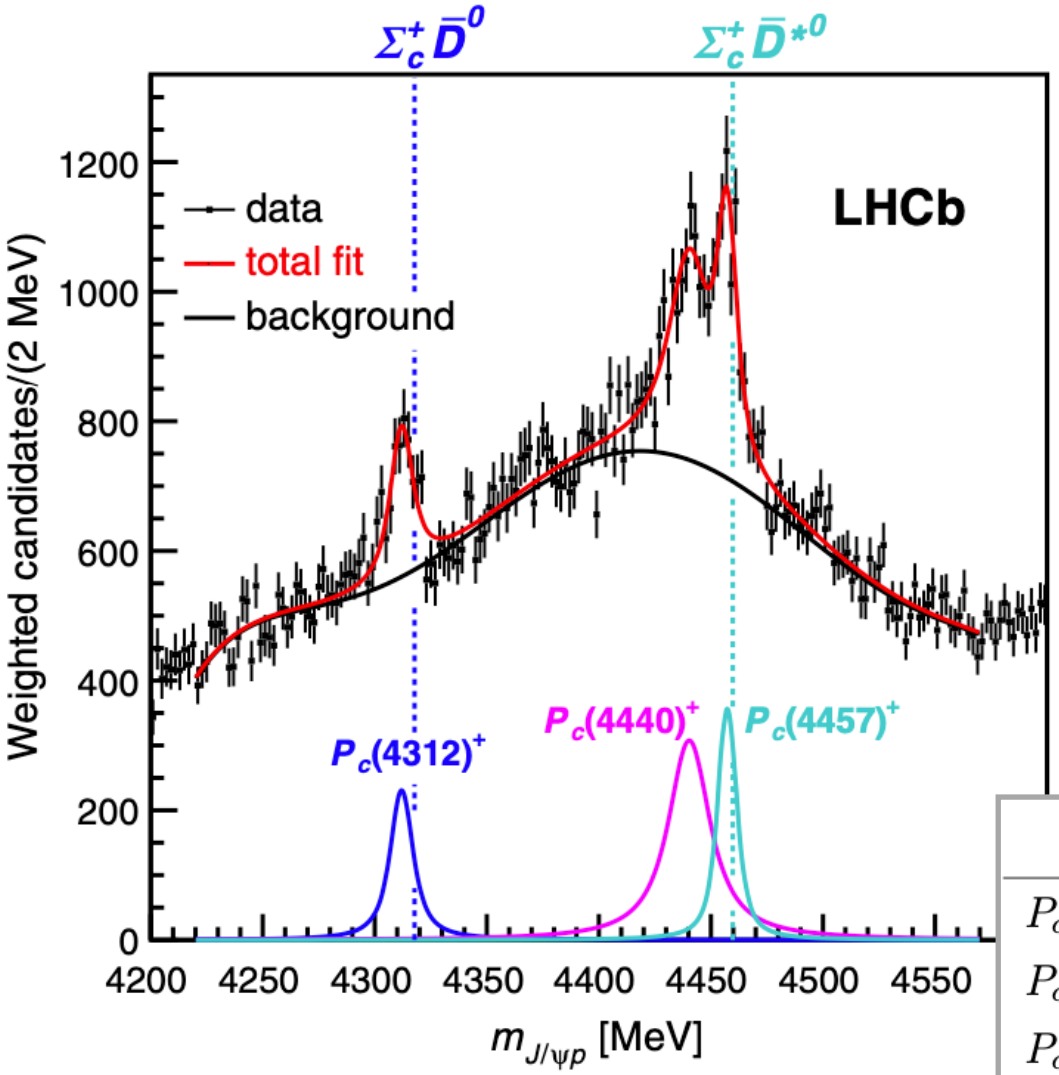


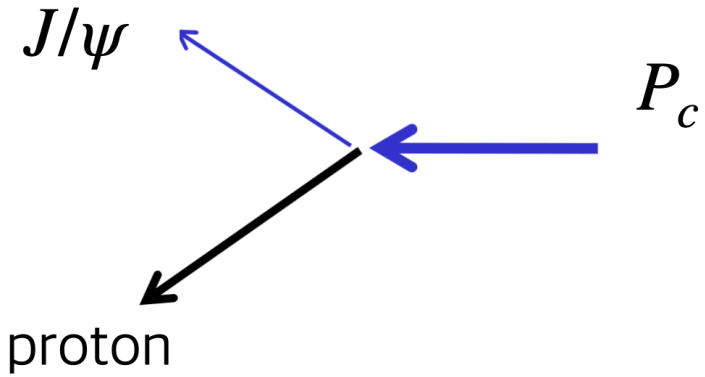
New exotic particles at LHCb



- $P_c\ (uudc\bar{c}) \rightarrow J/\psi + p$
- $P_{cs}\ (uusc\bar{c}) \rightarrow J/\psi + \Lambda$

P_c brothers discovered by LHCb

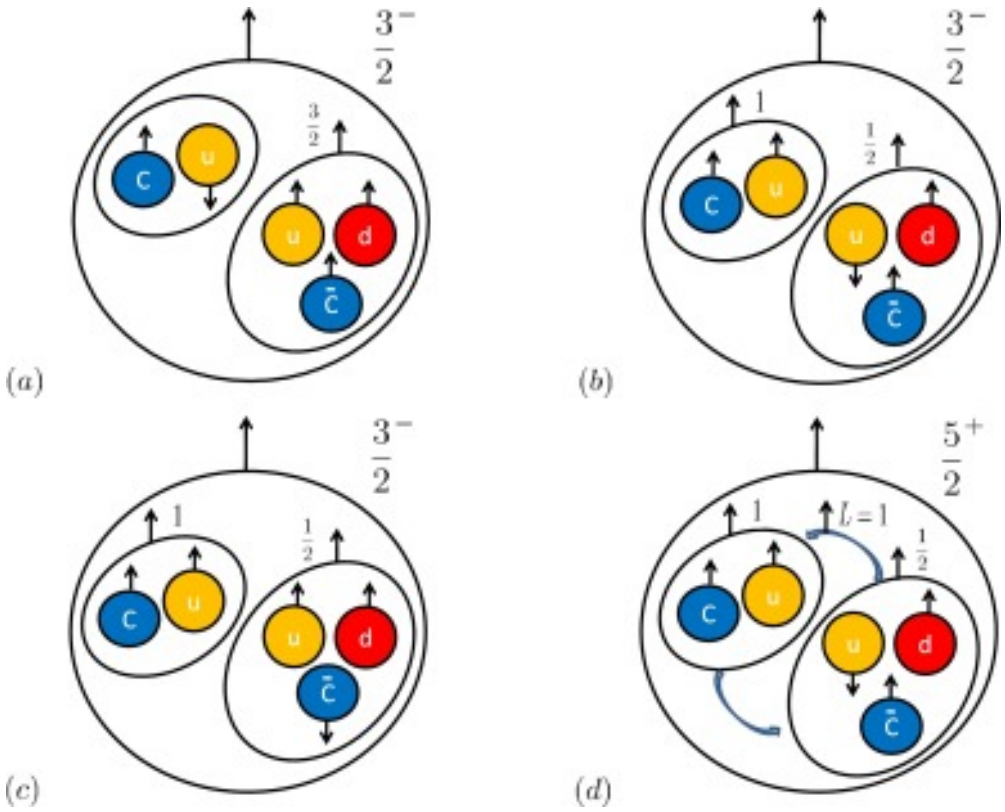




- Decay width of P_c's

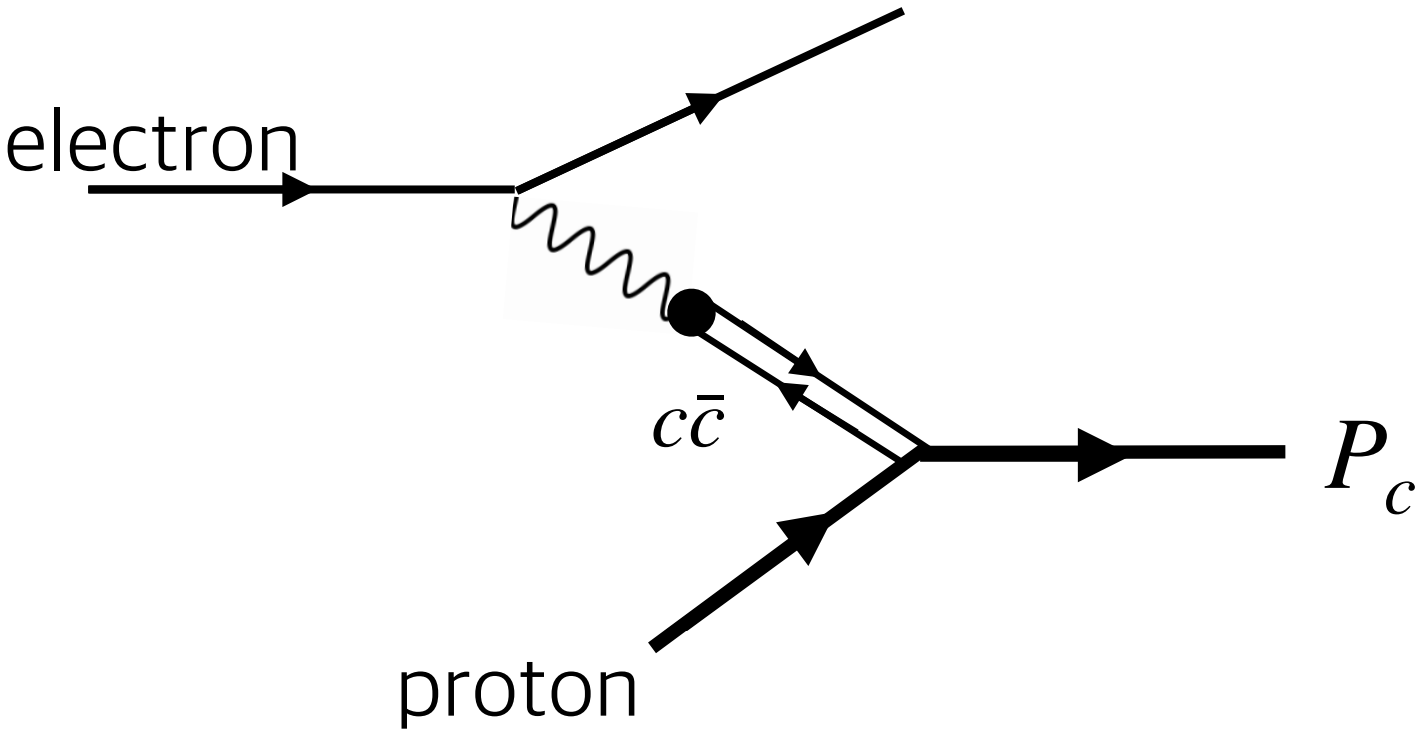
State	M [MeV]	Γ [MeV]
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+\ 3.7}_{-\ 4.5}$
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+\ 8.7}_{-10.1}$
$P_c(4457)^+$	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+\ 5.7}_{-\ 1.9}$

Characterization of P_c



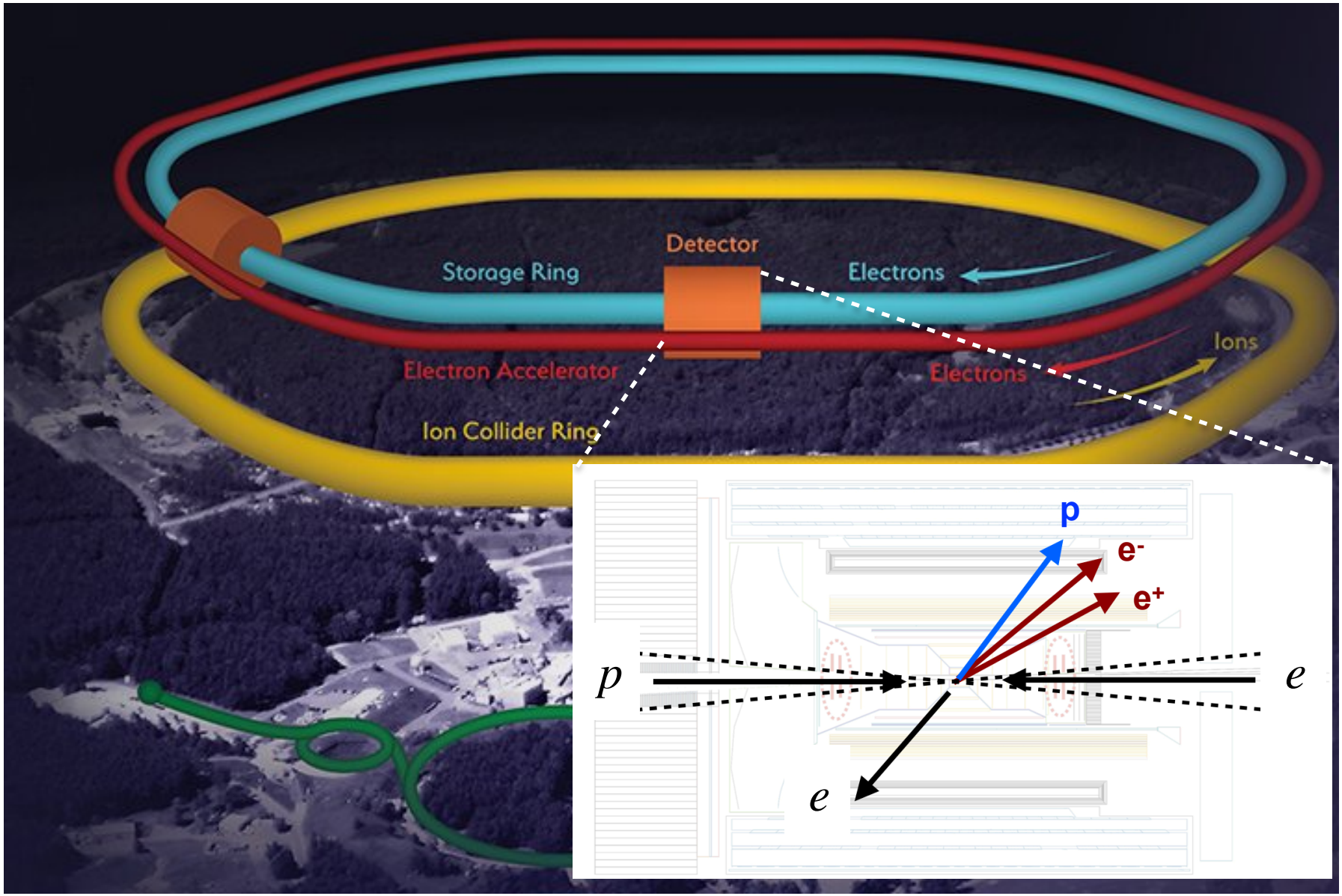
- Discovered, yet the internal structure and quantum numbers remains in question
  - Spin 1/2? 3/2? 5/2?
- What **the best machine** to shed light on it?

Photo-production of P_c



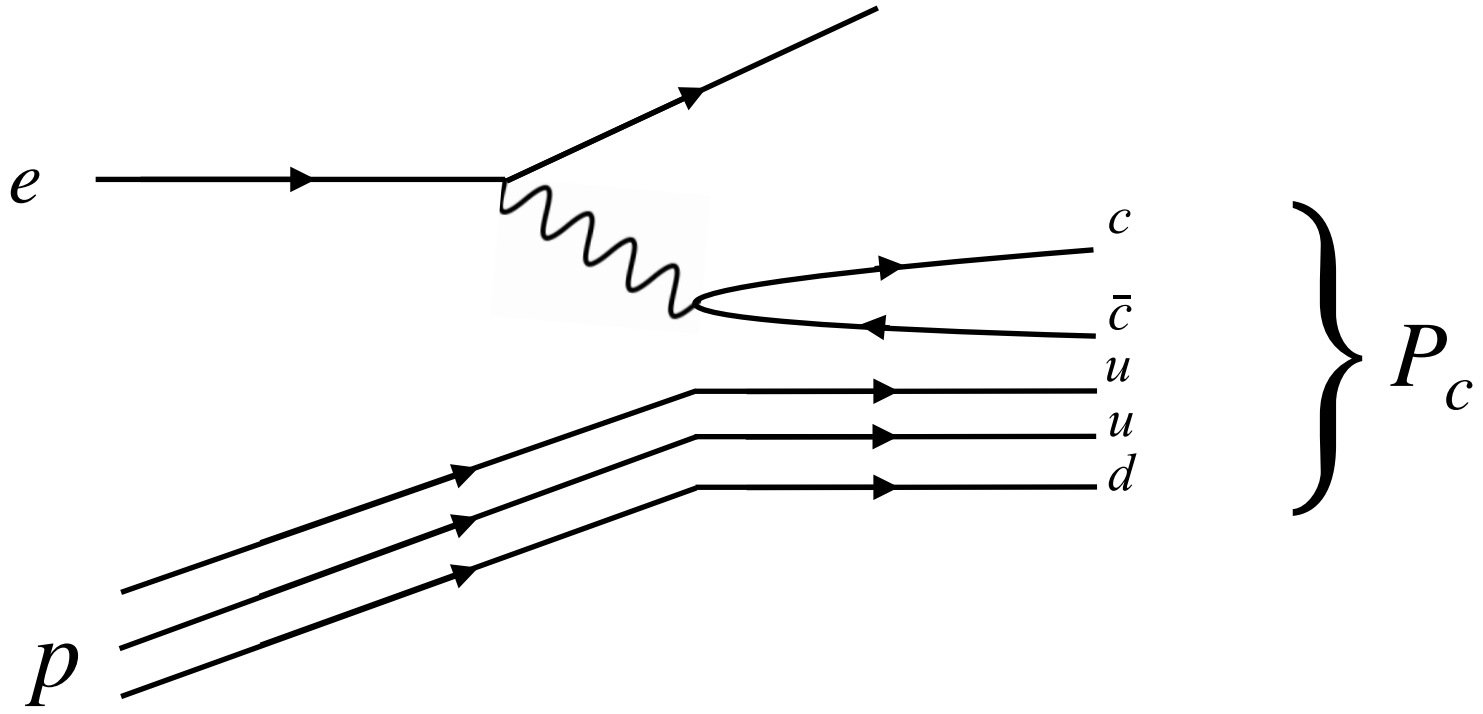
Perhaps we can create P_c by $e + p \rightarrow e + p_c$
in the e+p collision ***in near future!***

Electron Ion Collider



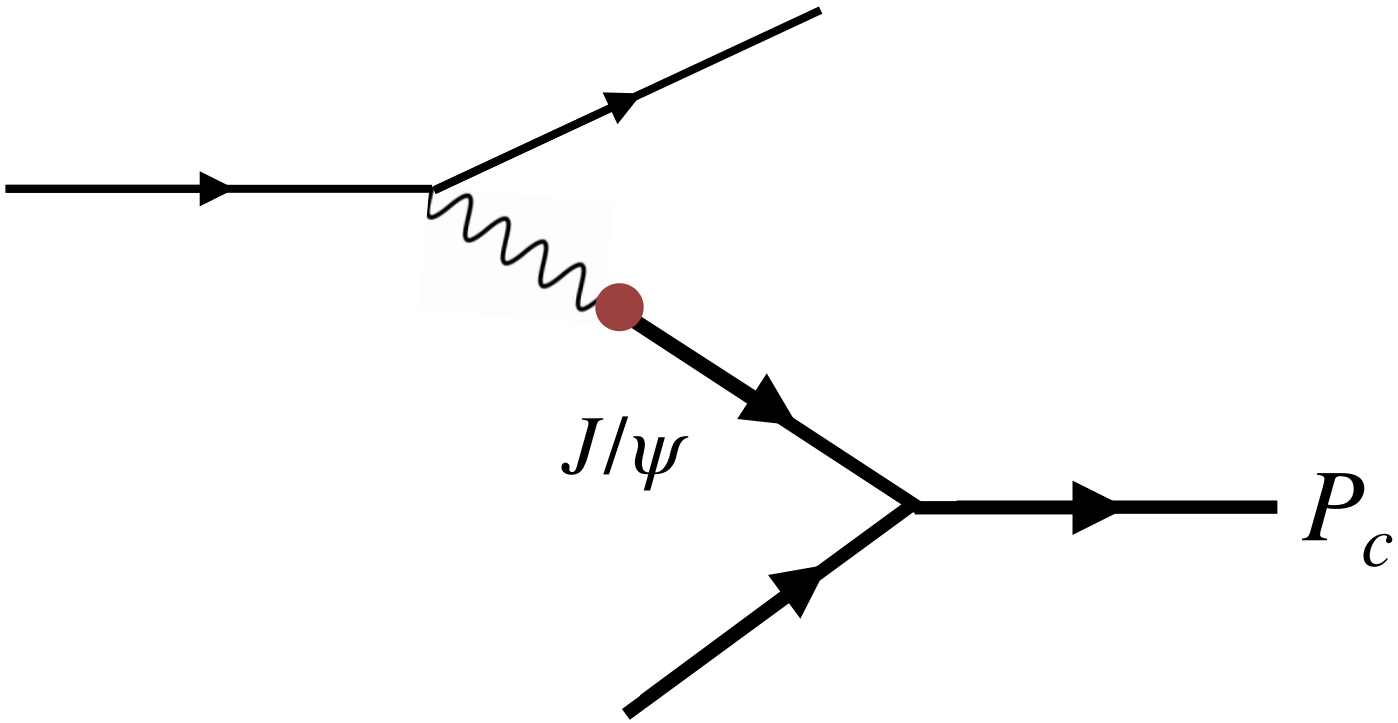
[1] *https://www.bnl.gov/eic/science.php*

P_c production in e+p system



Cross section?

P_c production in e+p system

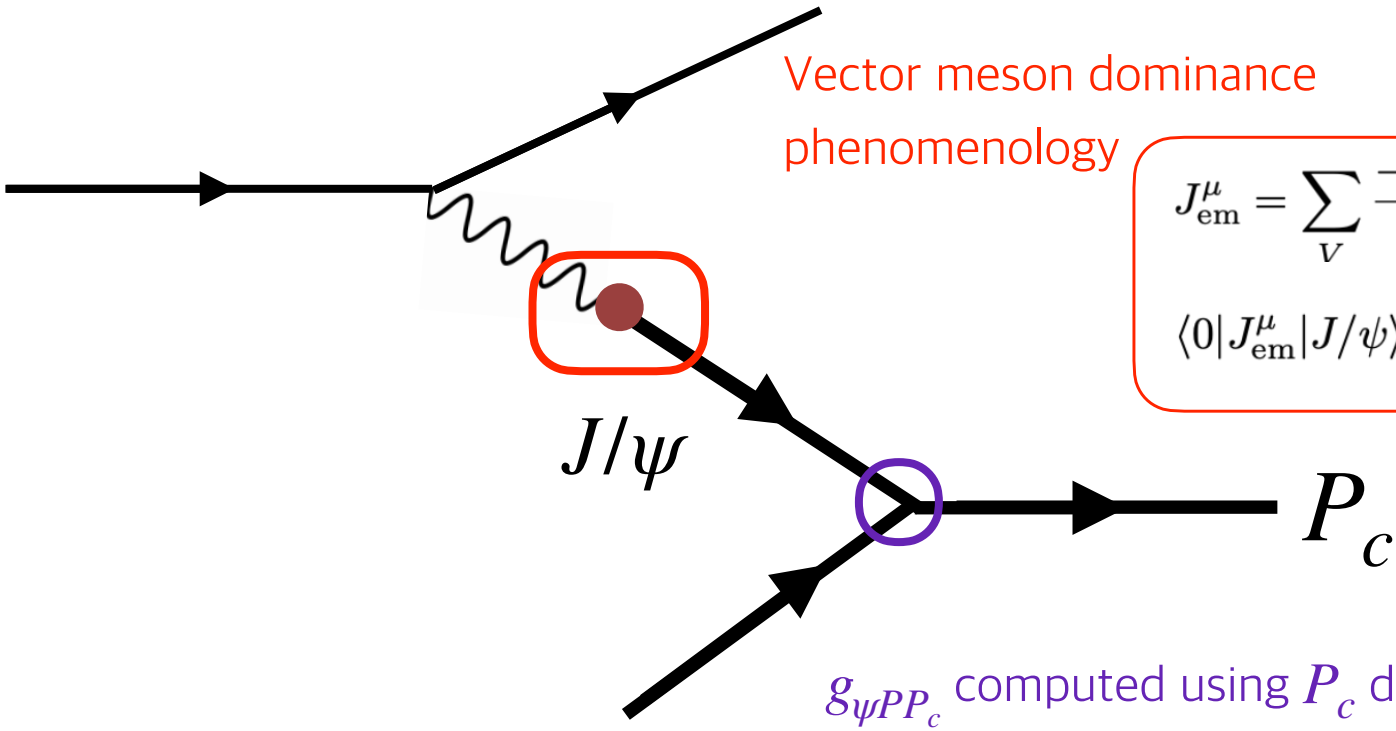


Cross section?

[1] Gounaris, Sakurai PRL 21, 244-247 (1968)

[2] *Klingl et al, Z.Phys. A356 (1996) 193-206*

Computation of P_c cross section at EIC



Vector meson dominance phenomenology

$$J^{\mu}_{\rm em} = \sum_V \frac{-m_V^2}{g_V} V^{\mu}$$

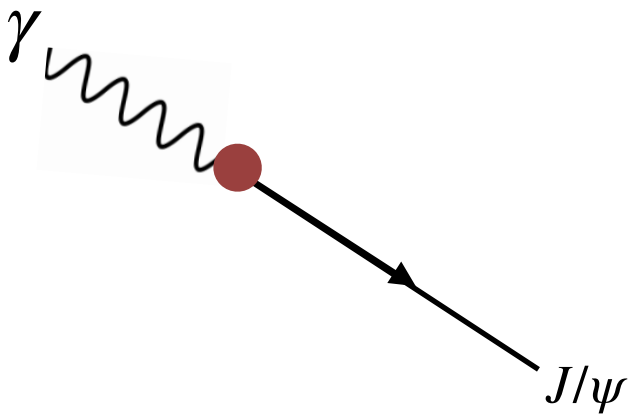
$$\langle 0|J^{\mu}_{\rm em}|J/\psi\rangle = -\frac{m^2_{J\psi}}{g_J}\varepsilon^{\mu}_J.$$

$g_{\psi PP_c}$ computed using P_c decay width measured at LHCb

[1] Gounaris, Sakurai PRL 21, 244-247 (1968)

[2] *Klingl et al, Z.Phys. A356 (1996) 193-206*

Formalism for VMD



- Vector meson dominance model

$$\mathcal{L}_{J/\psi\gamma} = -\frac{e}{2g_J} F^{\mu\nu} F^J_{\mu\nu},$$

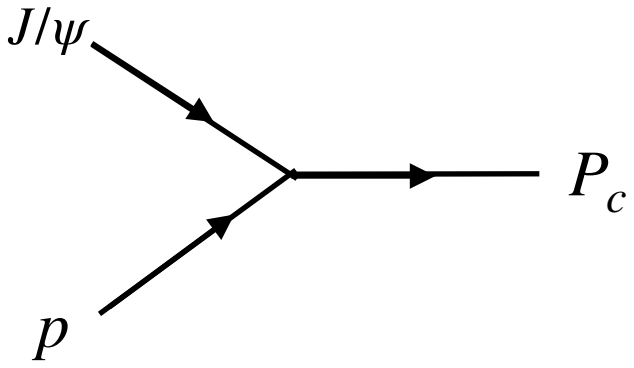
$$\mathcal{L}_{\gamma e^- e^+} = -e\bar{\psi}\gamma^\mu A_\mu \psi,$$

- Coupling constant g_J is computed from $J/\psi \rightarrow e^+e^-$ decay width

$$\Gamma = \frac{4\pi}{3}\frac{\alpha^2}{g_J^2}\sqrt{m_{J/\psi}^2 - 4m_l^2}\left(1 + \frac{2m_l^2}{m_{J/\psi}^2}\right)$$

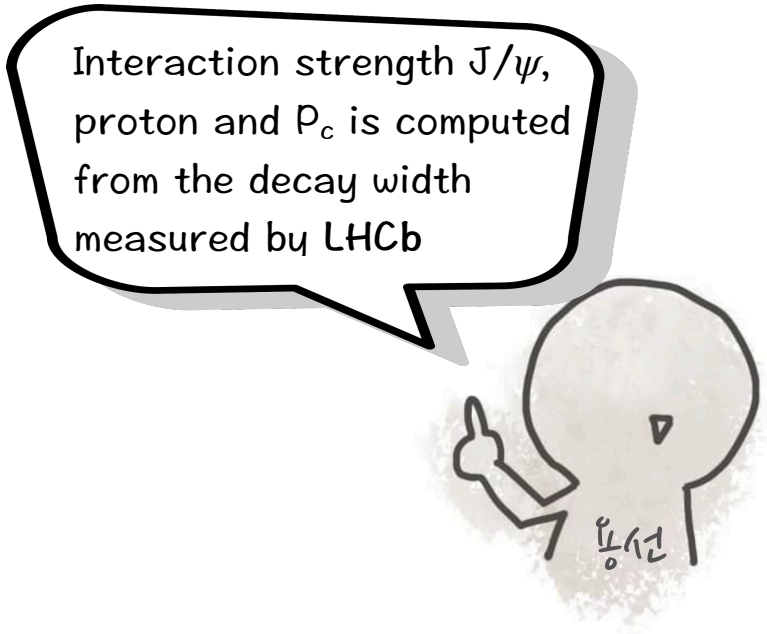
$$= 92.9 \text{ keV} \times 0.05971,$$

Formalism for P_c production



- Lagrangian (tensor potential & R-S eq.)

$$\mathcal{L}_{\rm int} = \begin{cases} \frac{g_{JpP_c}}{m_{J/\psi}} \bar{\psi}_p \sigma^{\mu\nu} F^J_{\mu\nu} \psi_{P_c} & J^P = \frac{1}{2}^+, \\ \frac{g_{JpP_c}}{m_{J/\psi}} \bar{\psi}_p \gamma_5 \sigma^{\mu\nu} F^J_{\mu\nu} \psi_{P_c} & J^P = \frac{1}{2}^-, \\ \frac{g_{JpP_c}}{m_{J/\psi}} \bar{\psi}_p \gamma_5 \gamma^{\mu} F^J_{\mu\nu} \psi^{\nu}_{P_c} & J^P = \frac{3}{2}^+, \\ \frac{g_{JpP_c}}{m_{J/\psi}} \bar{\psi}_p \gamma^{\mu} F^J_{\mu\nu} \psi^{\nu}_{P_c} & J^P = \frac{3}{2}^-. \end{cases}$$



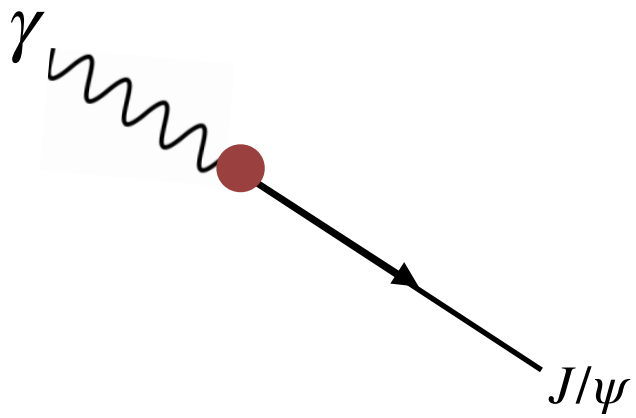
- Fix interaction strength using Γ

$$\Gamma_{P_c \to p + J/\psi} = \frac{1}{8\pi} \frac{|\vec{p}_f|}{m^2_{P_c}} |\mathcal{M}|^2$$

- Results in 2 spin x 2 parity cases

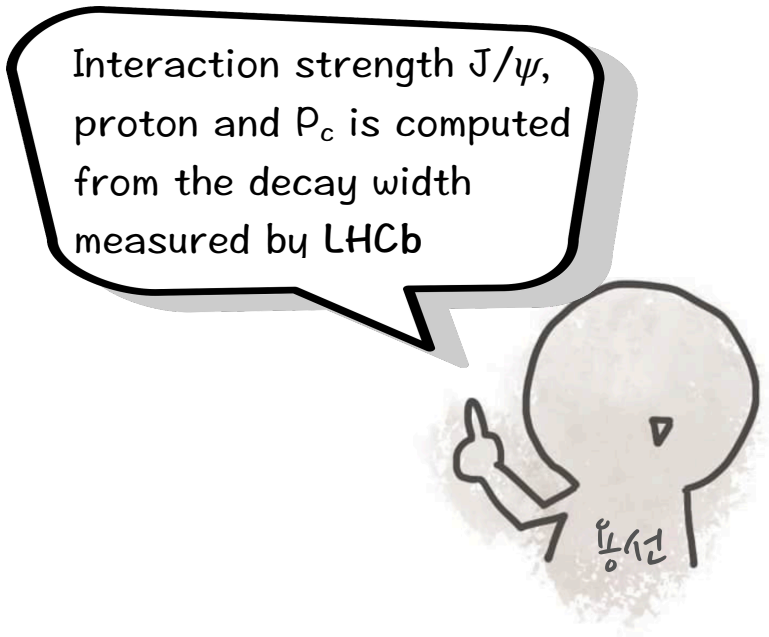
J^P	$\frac{1}{2}^+$	$\frac{1}{2}^-$	$\frac{3}{2}^+$	$\frac{3}{2}^-$
g_{JpP_c}	0.379	0.169	1.47	0.599

Formalism for P_c production



- Photo-production strength

$$g_{\gamma p P_c} = -\frac{e g_{J p P_c} q^2}{g_J} \frac{1}{q^2 - m_{J/\psi}^2}$$



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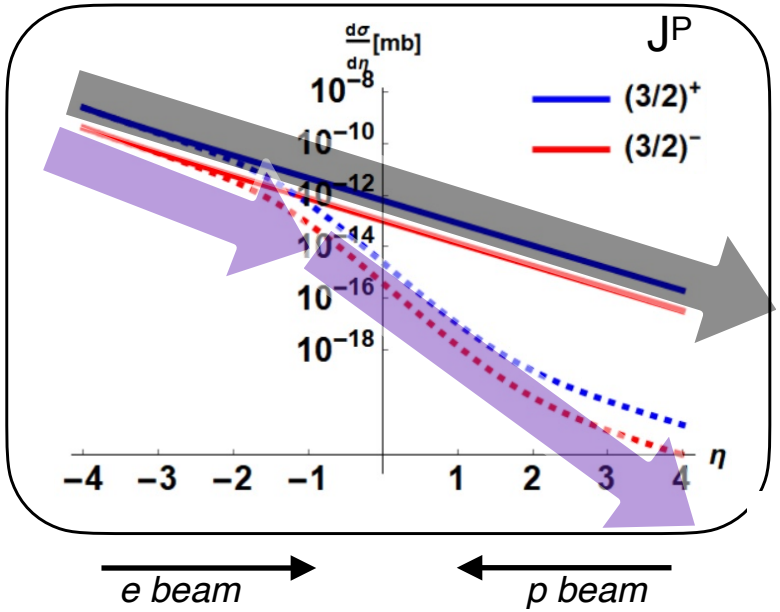
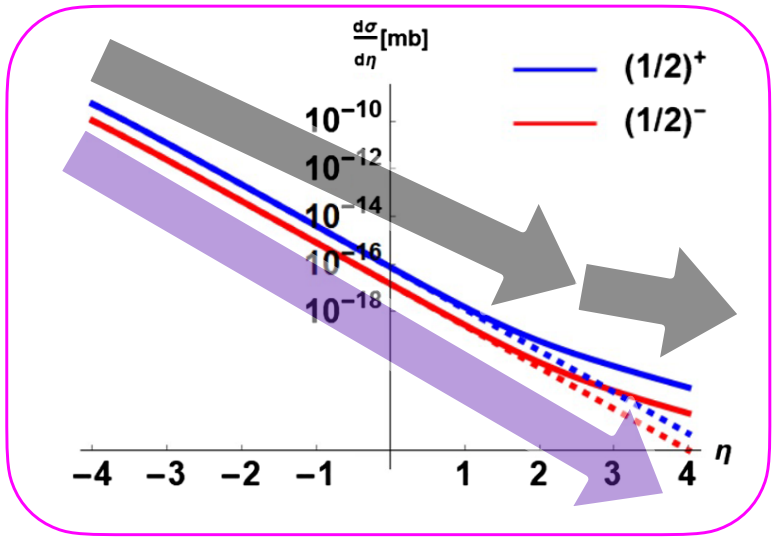
$P_c(4312)$ yields in polarized e+p



Spin 3/2 case

Parallel polarization

Anti-parallel polarization



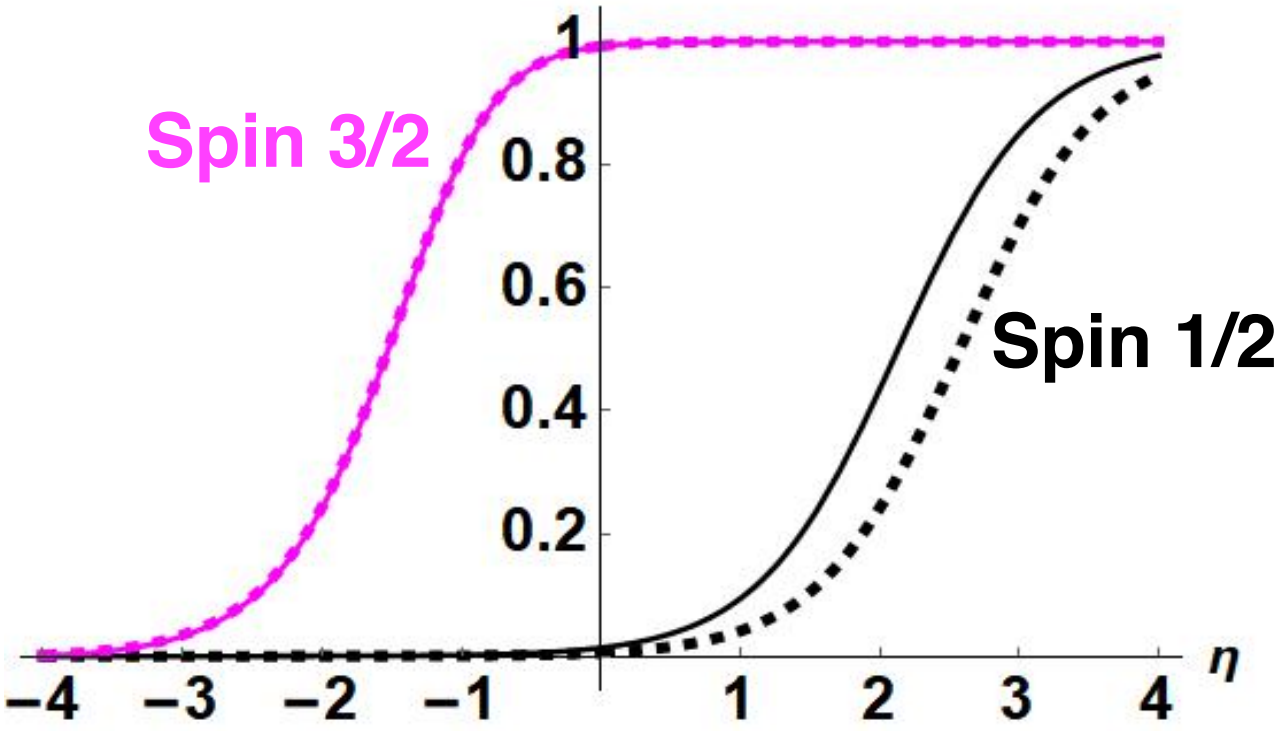
Spin 1/2 case

Parallel polarization

Anti-parallel polarization

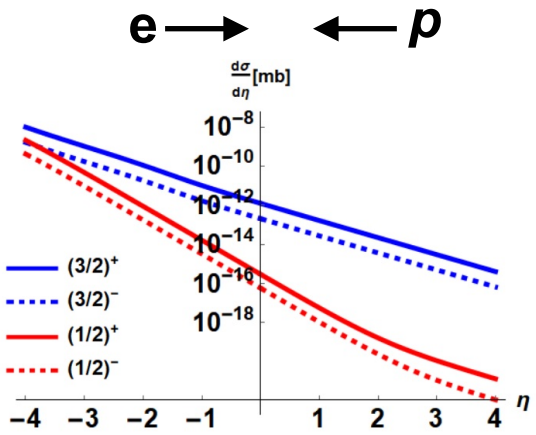
$P_c(4312)$ yields in polarized e+p

$$BSA\ (\eta) = \frac{d\sigma/d\eta\ [RL] - d\sigma/d\eta\ (RR)}{d\sigma/d\eta\ [RL] + d\sigma/d\eta\ [RR]}$$

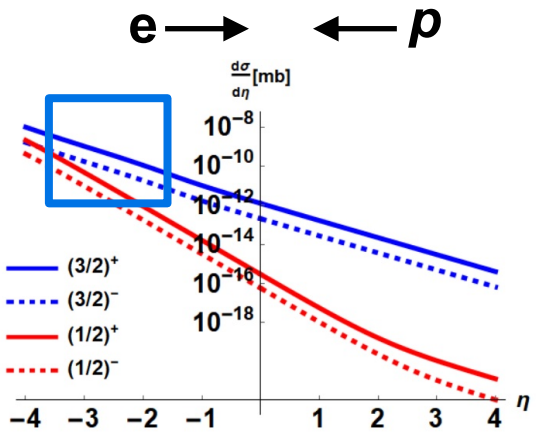


Spin of P_c can be resolved by measuring forward-to-backward ratio!

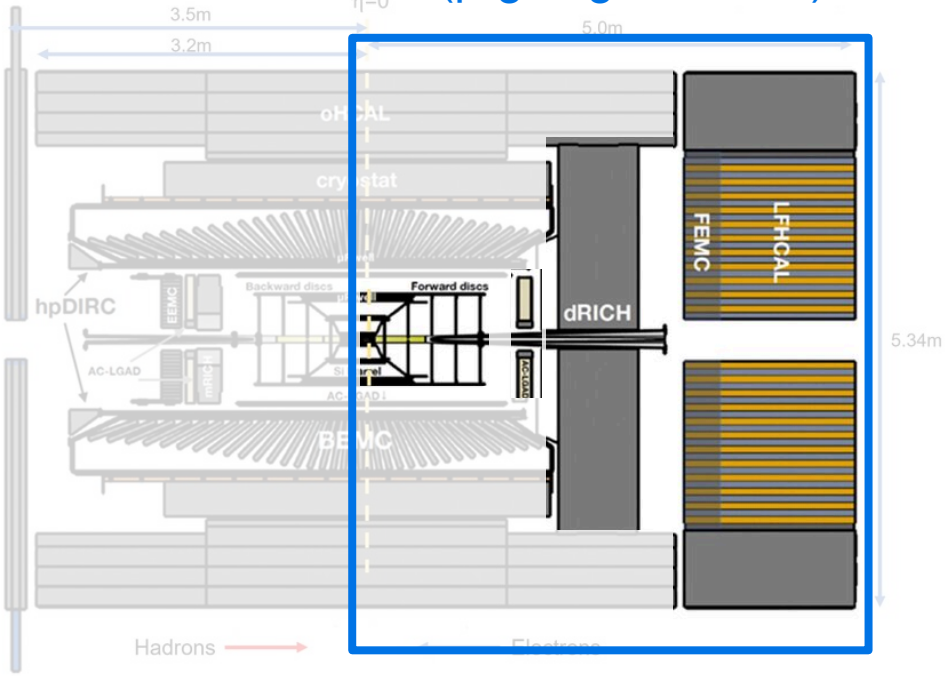
$P_c(4312)$ in ePIC simulation



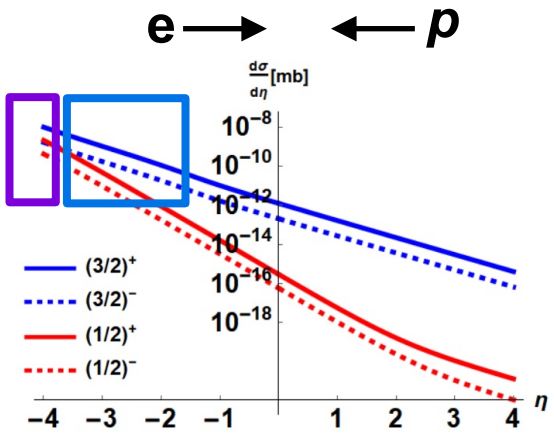
$P_c(4312)$ in ePIC simulation



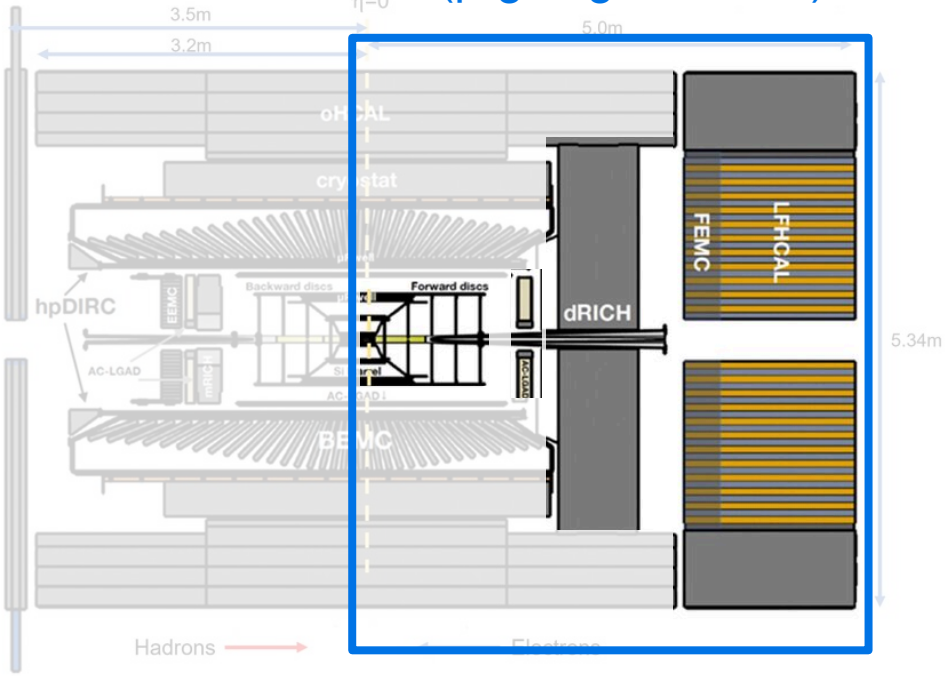
Forward detectors (p-going direction)



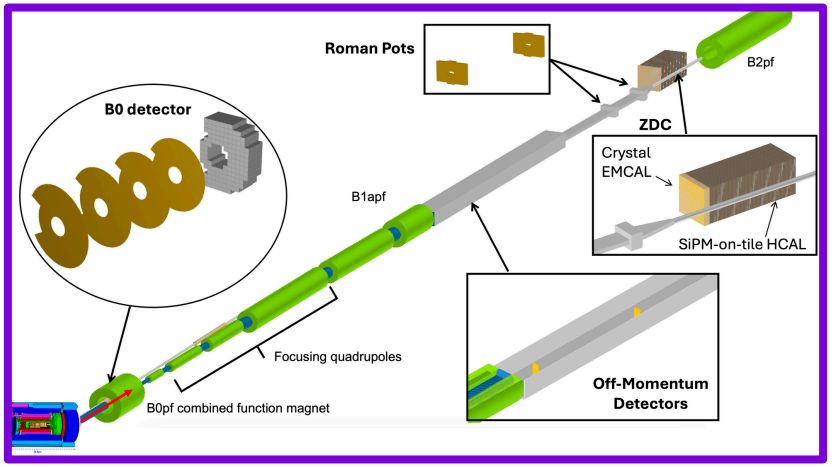
$P_c(4312)$ in ePIC simulation



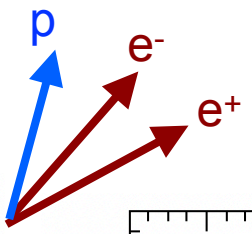
Forward detectors (p-going direction)

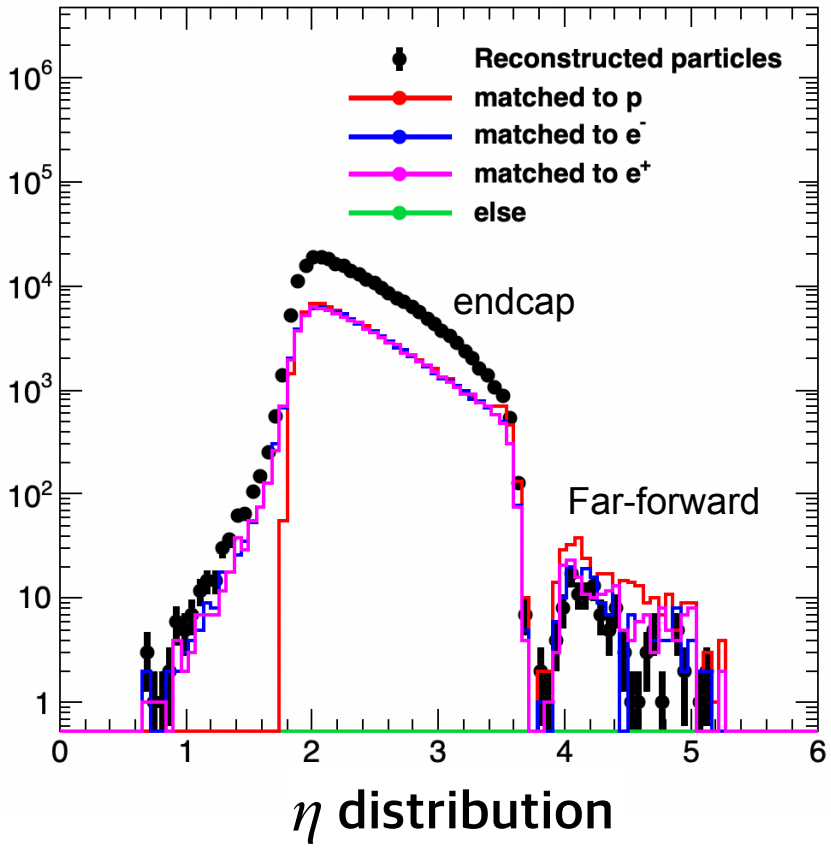


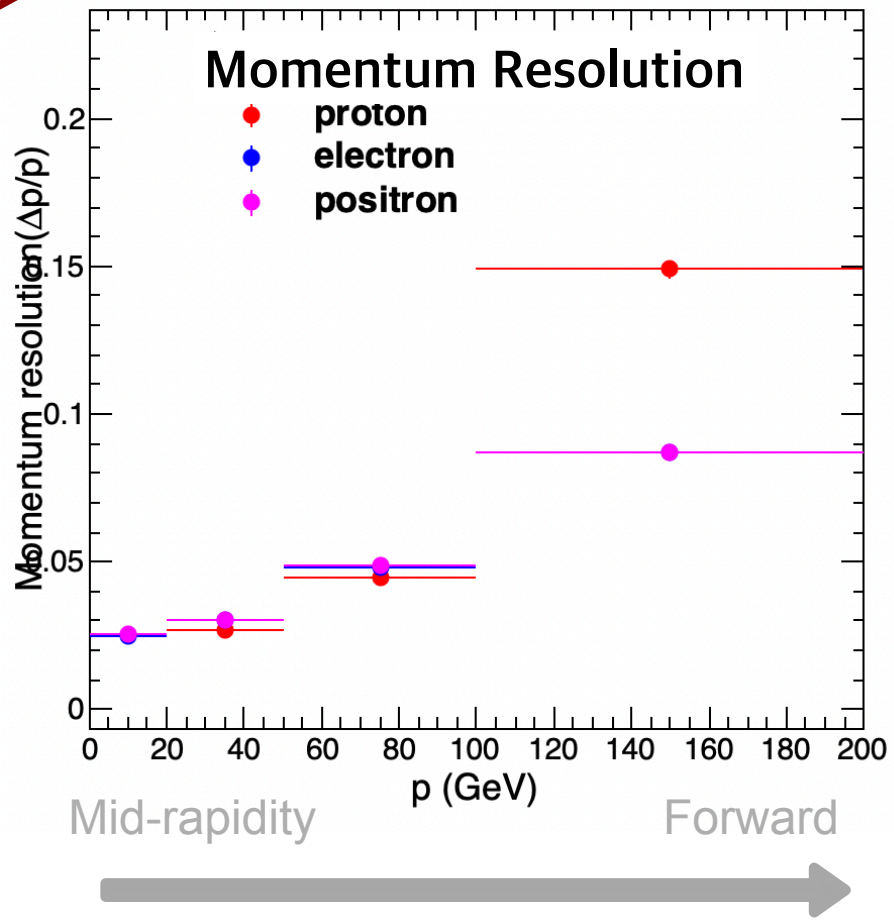
Far-Forward detectors



Particle reconstruction performance



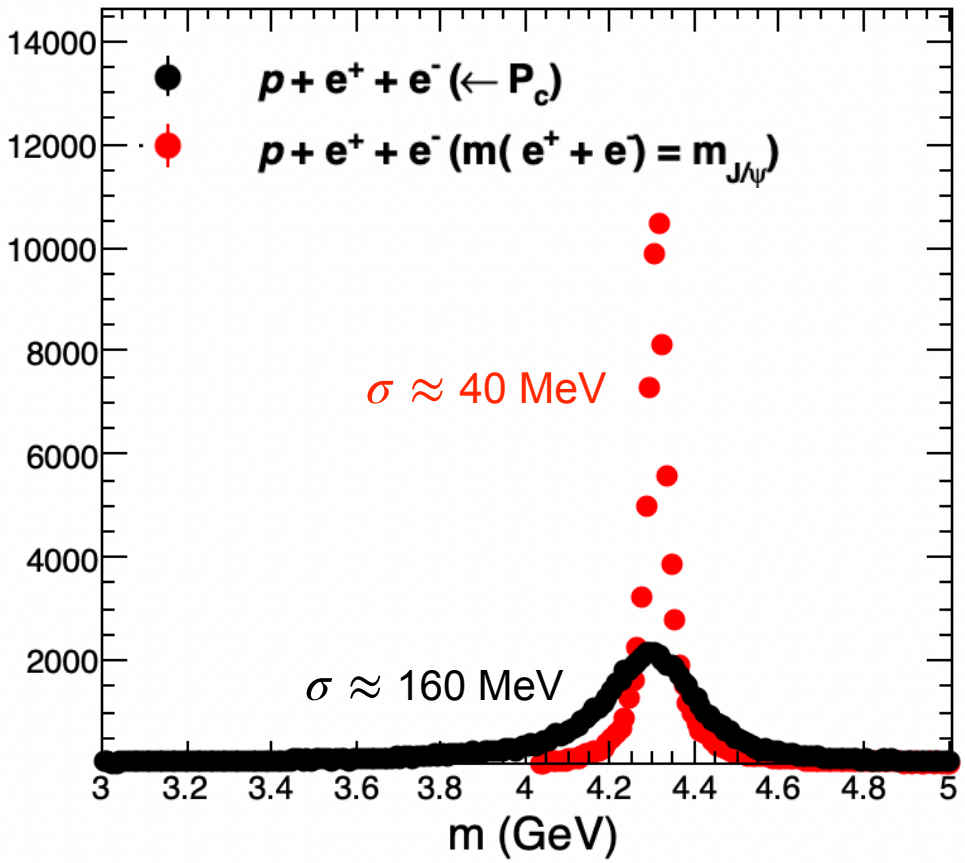


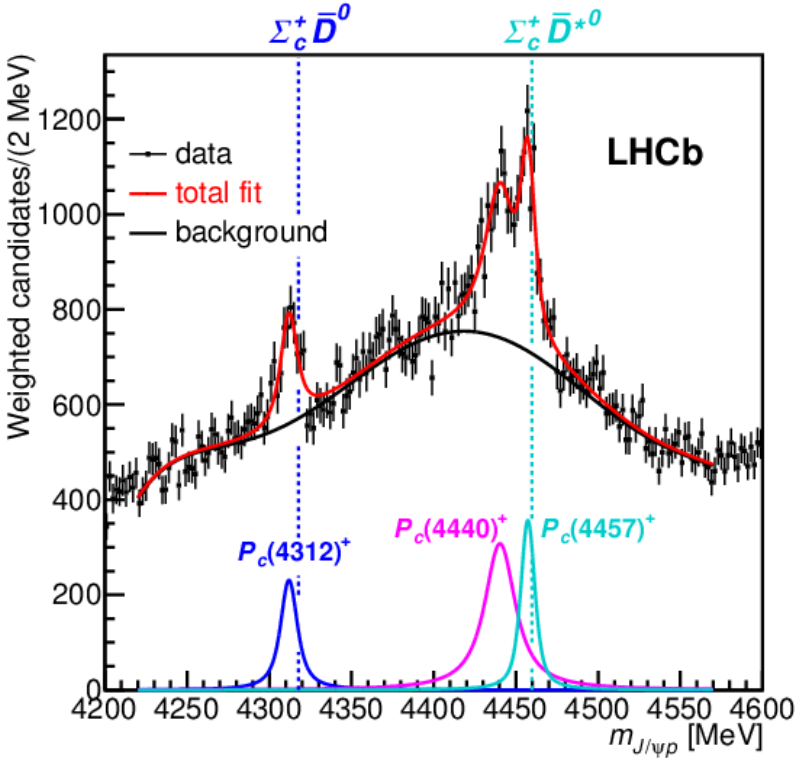


(η is one-to-one function of p due to 2-body process)

Particle reconstruction performance

$\eta(P_c) > 2$

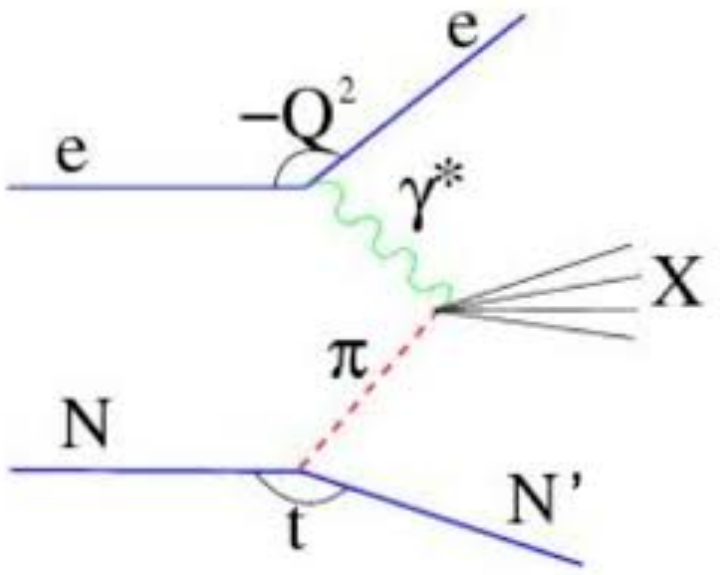




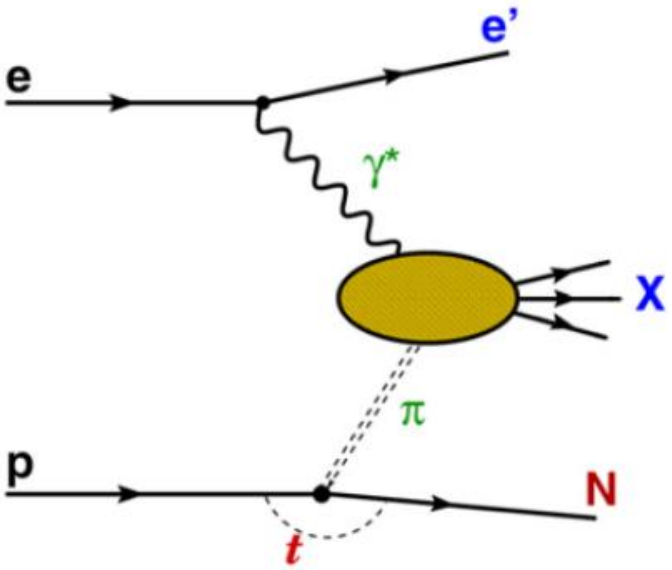
σ measured in LHCb: 9.8 (±2.7 +3.7/-4.5) MeV

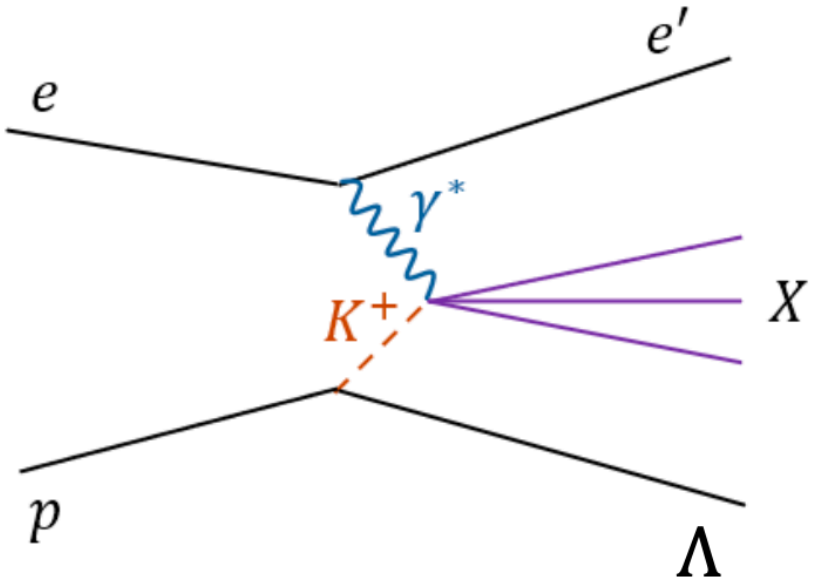
Fixing $m_{e^+e^-} = m_{J/\psi}$, we can resolve *$P_c(4312)$* and *$P_c(4440)$* with ePIC

2. Meson PDF



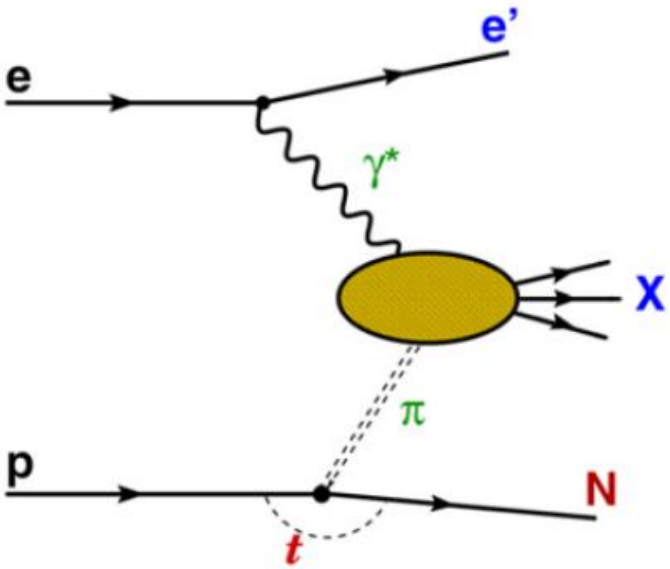
Sullivan process

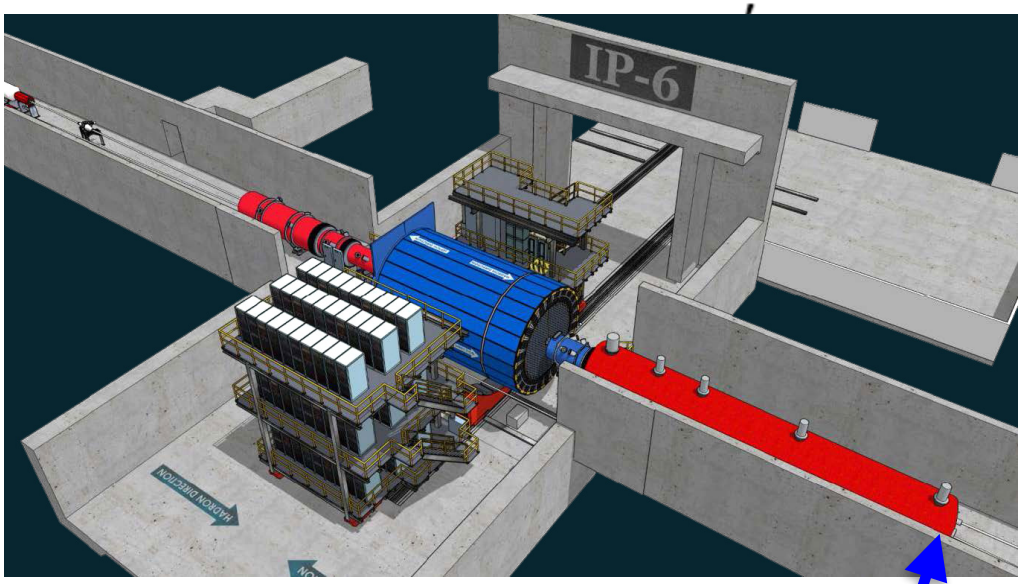


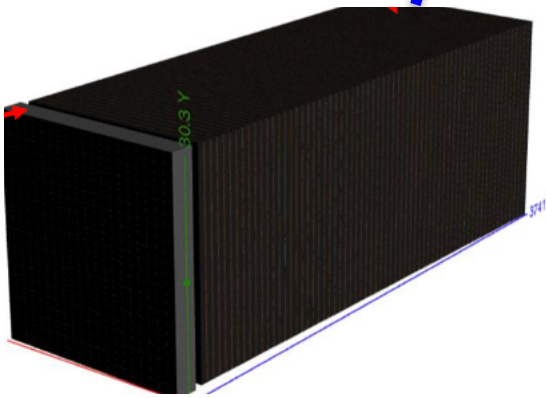


- DIS for pion and Kaon
- EIC can shed light on meson structure function more clearly
  - Tagging X -> exclusive measurement
  - Measurement of forward π^0, n and Λ are all possible
  - Polarized beams are huge benefit

Sullivan process



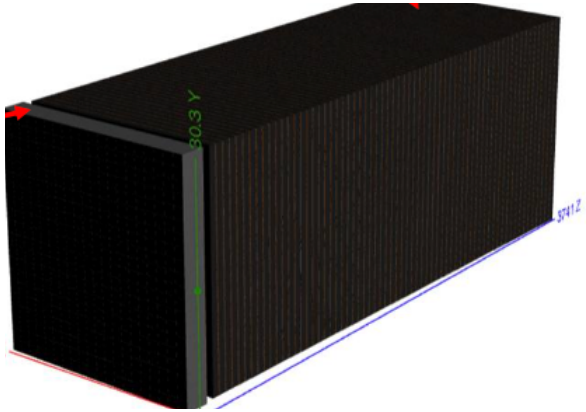




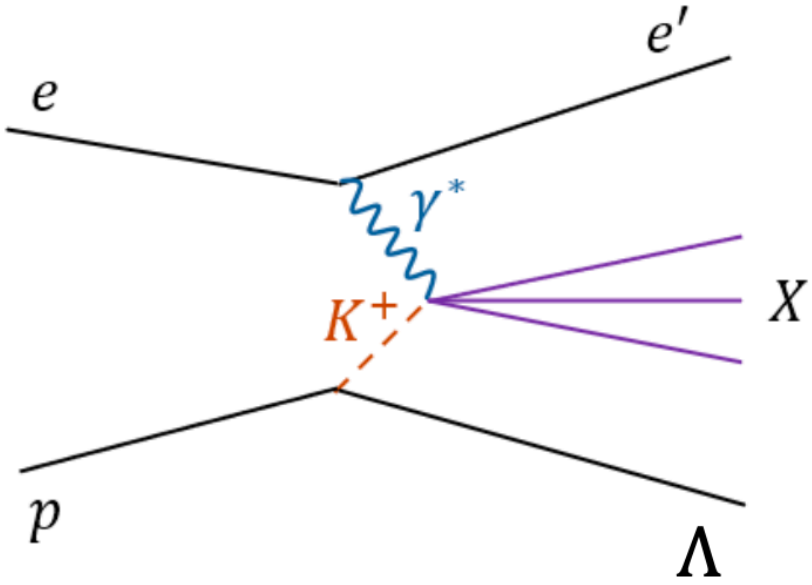
- Tagging this event will rely solely on the ZDC!
- To be made by Korea-Japan collaboration
- EMCal + Hcal (Silicon trackers)

ZDC (Zero Degree Calorimeter)

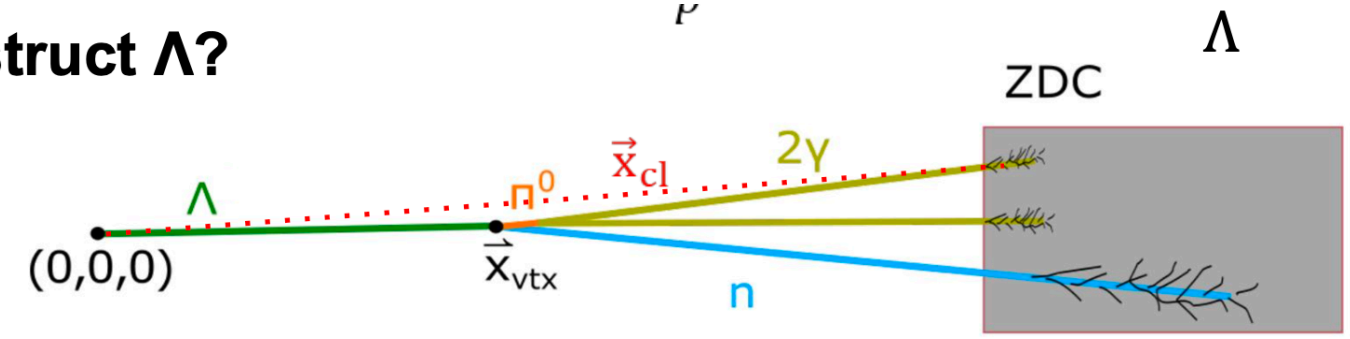
ZDC detector



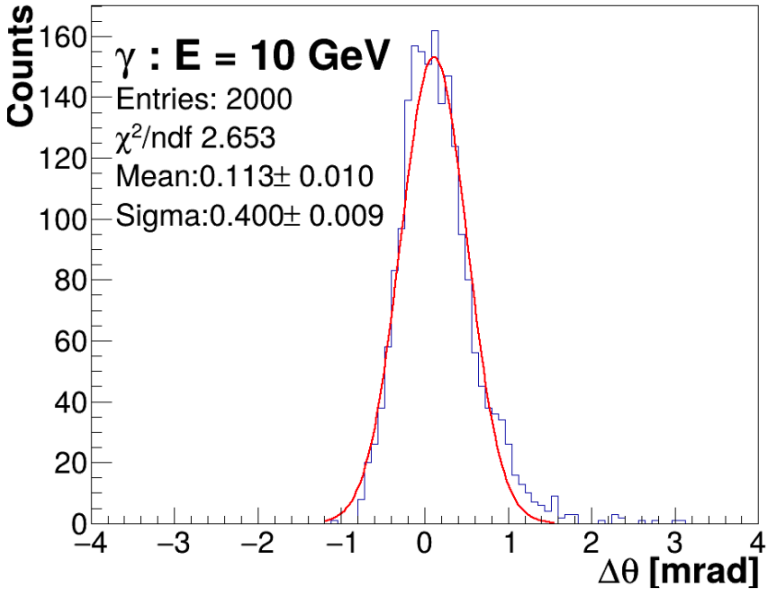
ZDC (Zero Degree Calorimeter)

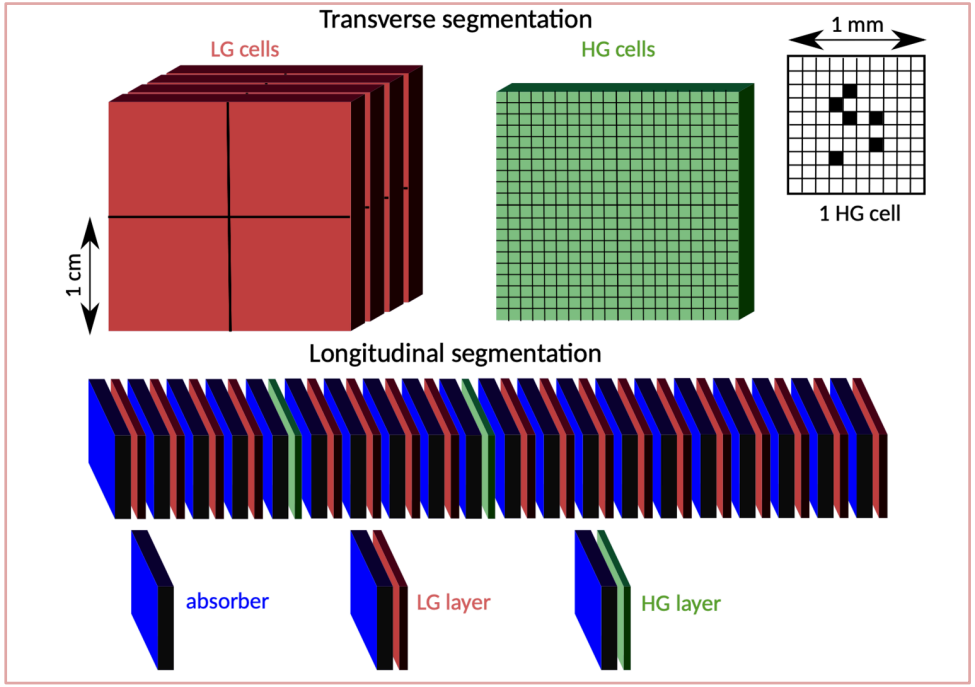


- **How to reconstruct Λ?**
  - ✓ (67%) Λ → p + π^+
  - ✓ **(33%) Λ → n + π^0**
    - **π^0 → γ + γ**



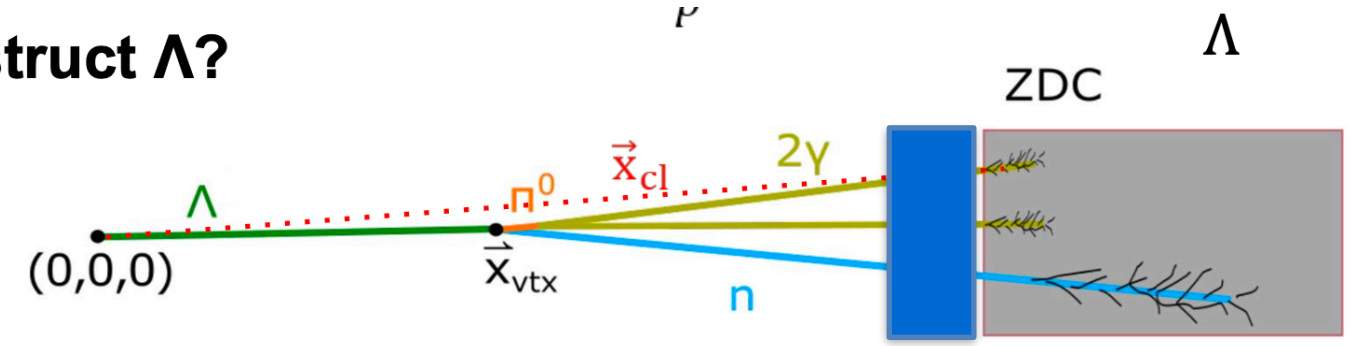
ZDC detector





- Japan and Korea collaboration suggested to upgrade ZDC with Silicon detector (ALICE FoCal-like)

- **How to reconstruct Λ?**
  - ✓ (67%) $\Lambda \rightarrow p + \pi^+$
  - ✓ **(33%) $\Lambda \rightarrow n + \pi^0$**
    - **$\pi^0 \rightarrow \gamma + \gamma$**



Summary

- The experimental community is putting most effort into detector R&D and manufacturing, which are not correlated with physical topics
- Yet, there are ongoing efforts to explore novel opportunities on the experimental side.
- From a theoretical perspective, some topics appear to be particularly interesting:
  - Pentaquarks — studies of cross sections, internal structure, quantum numbers, and more
  - Meson form factors — investigations of pion and kaon form factors through analytical methods or lattice QCD
- Of course, we should also not overlook the potential application of quantum computing algorithms in EIC physics, either for data analysis or for simulating scattering processes