ePIC-ZDC

EIC-Asia Workshop

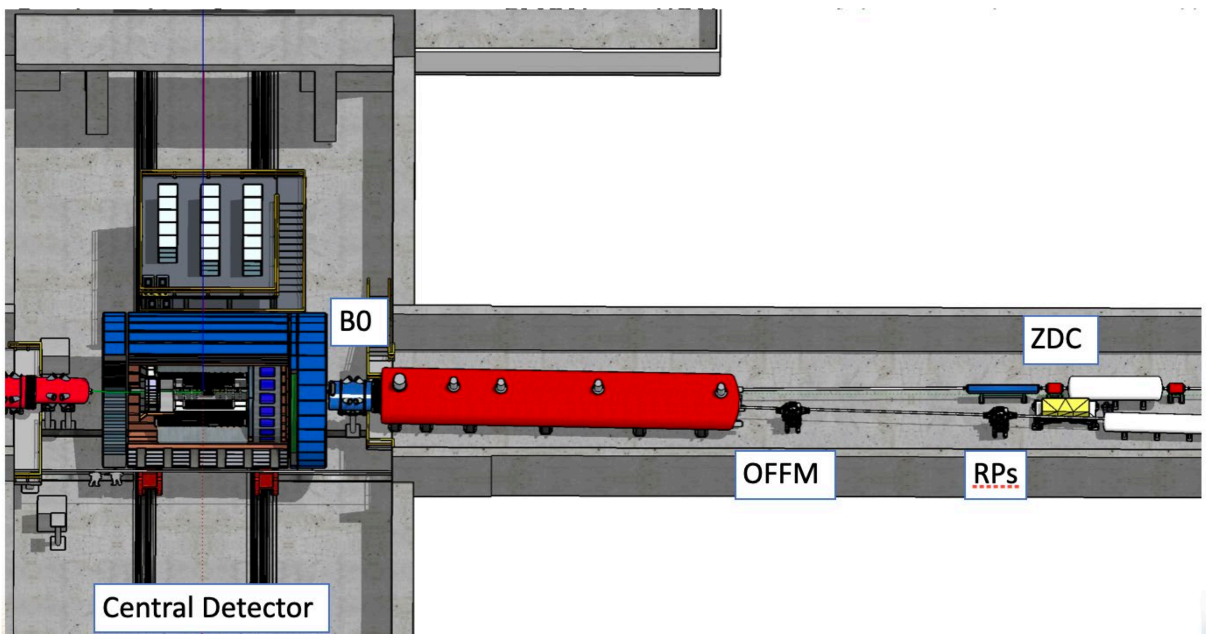
National Cheng Kung University, Tainan, Taiwan

January 30th, 2024

Yuji Goto (RIKEN)

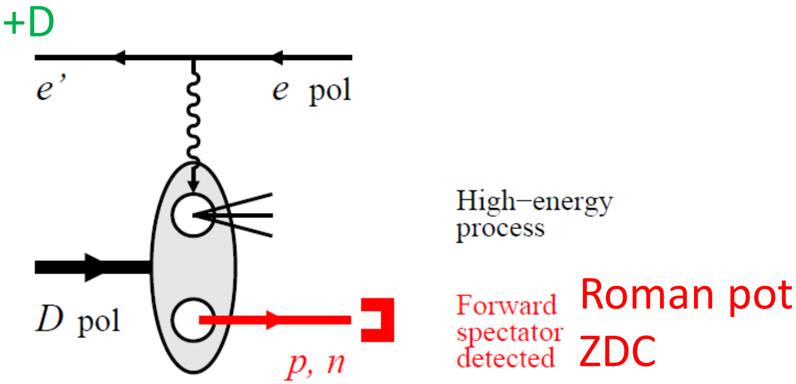
ePIC ZDC group

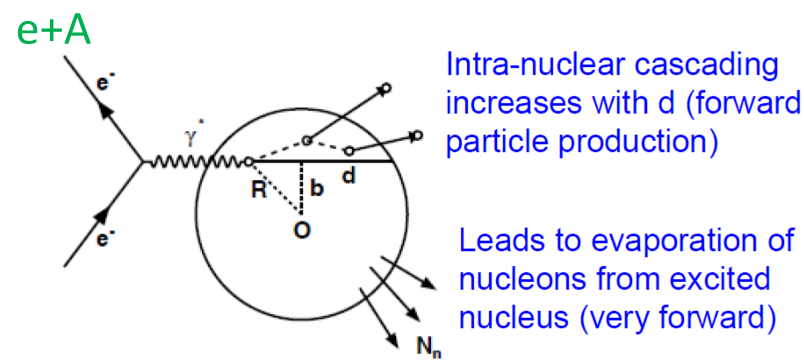
- Japan
  - RIKEN
  - Kobe Univ.
  - Shinshu Univ.
  - Univ. of Tsukuba
  - Tsukuba Tech. Univ.
- Taiwan
  - NCU
  - Academia Sinica
- Korea
  - Sejong Univ.
- USA
  - Kansas Univ.
  - PNNL
  - UC Riverside

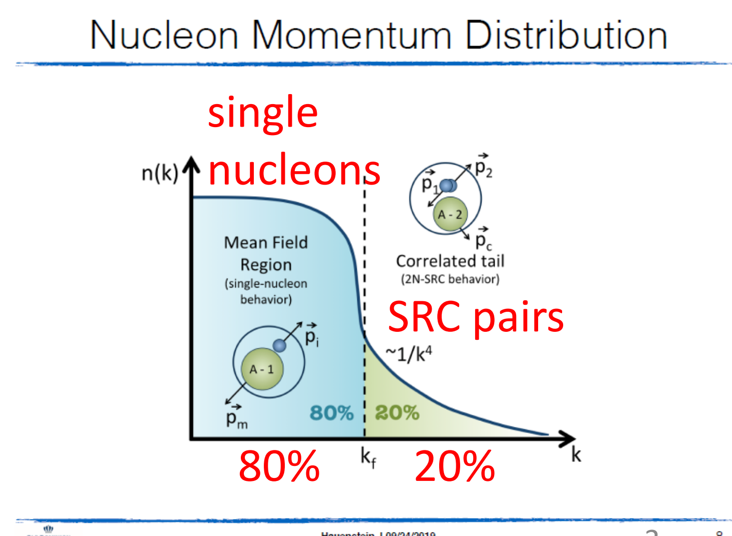


Far-forward physics at EIC

- Spectator tagging in e+d/^{3}He collisions
  - Neutron structure
    - Neutron spin structure, S & D waves
- e+A collisions at zero degree
  - Breakup determination of the excited nucleus
    - Veto with evaporated neutrons and photons from de-excitation
  - Geometry tagging in e+A collisions
    - Event-by-event characterization of collision geometry
    - Study of nuclear medium effects
  - Short-range correlation (SRC) and EMC effect
    - Nuclear PDF significantly modified by SRC pairs







Far-forward physics at EIC

- Mass of the proton, pion, kaon

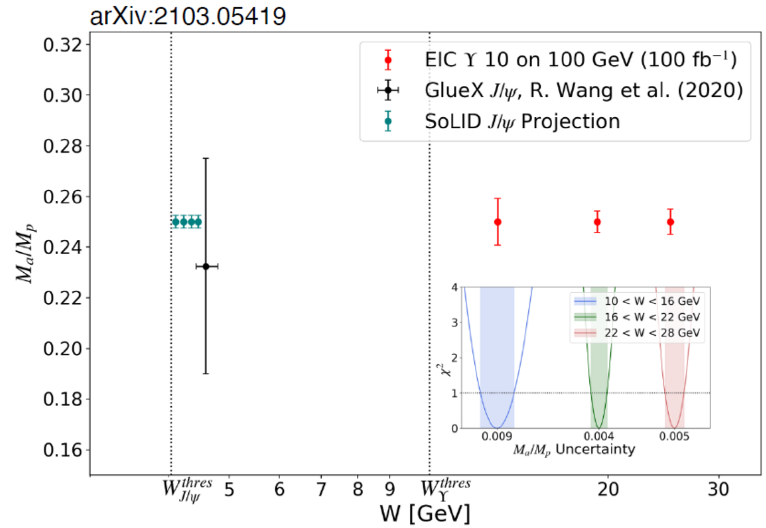
Relativistic Motion | Chiral Symmetry Breaking | Quantum Fluctuations

$$M = E_q + E_g + \chi_{m_q} + T_g$$

X. Ji, PRL 74 1071 (1995)

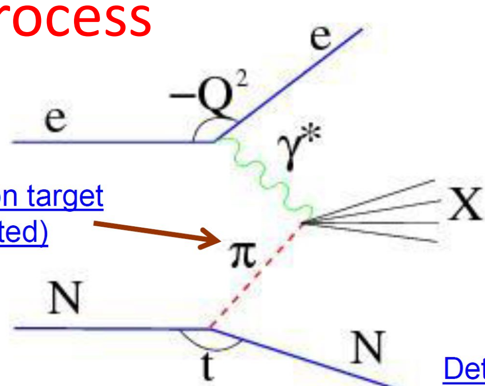
Quark Energy | Gluon Energy | Quark Mass | Trace Anomaly

- Proton
  - Determination of an important term contributing to the proton mass, the so-called "QCD trace anomaly"
  - Through dedicated measurements of exclusive production of J/ψ and Υ close to the production threshold
- Pion and kaon
  - Determination of the quark and gluon contribution to mass with the Sullivan process



Sullivan process

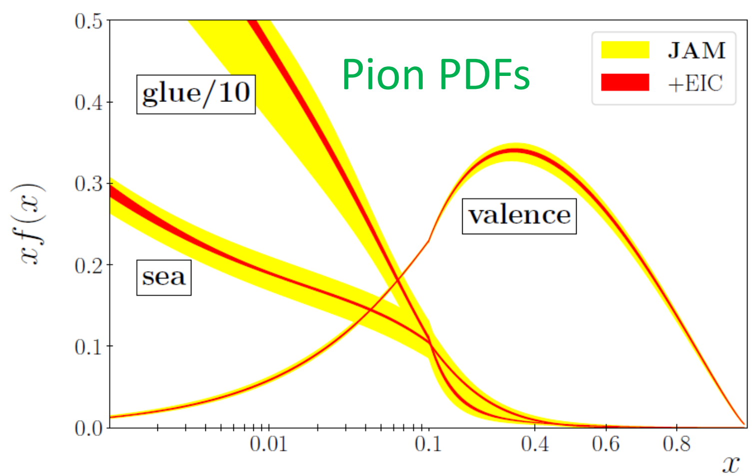
Detect scattered electron



Pion/Kaon target (undetected)

DIS event – reconstruct x, Q^2, W^2, also M_X (W_π) of undetected recoiling hadronic system

Detect "tagged" neutron/lambda



Requirements to ePIC ZDC

- Large acceptance
  - Large aperture → large ZDC
- Soft photon detection of O(100) MeV
  - Detection efficiency more than 90%
- Neutron measurement
  - Energy up to 275 GeV (beam energy)
  - Energy resolution 50%/√E(GeV) + 5%
  - Position resolution 3 mrad/√E(GeV)
- Photon measurement
  - Soft photon with 20-30% energy resolution
  - 20-40 GeV photon with 35%/√E(GeV) energy resolution and 0.5-1 mm position resolution
- Radiation tolerance
  - $O(10^{12}\text{-}10^{13})\ n_{eq}/cm^2$ (1MeV neutron eq.) in several years

Requirements to ePIC ZDC

- EM energy resolution
  - Not demanding, but degradation may occur for crystals and/or photon sensors due to radiation
- EM position 0.5mm
  - Fine pitch layer needed

	Energy range	Energy resolution	Position resolution	Others
Neutron	up to the beam energy	$\frac{50\%}{\sqrt{E}} + 5\%$, ideally $\frac{35\%}{\sqrt{E}} + 2\%$	$\frac{3mrad}{\sqrt{E}}$	Acceptance: 60 cm × 60 cm
		Note: The acceptance is required from meson structure measurement. Pion structure measurement may require a position resoultion of 1 mm.		
Photon	0.1 – 1 GeV	20 – 30%		Efficiency: 90 – 99%
		Note: Used as a veto in e+Pb exclusive J/ψ production		
	20 – 40 GeV	$\frac{35\%}{\sqrt{E}}$	0.5–1 mm	
		Note: u-channel exclusive electromagnetic π^0 production has a milder requirement of $\frac{45\%}{\sqrt{E}} + 7\%$ and 2 cm, respectively. Events will have two photons, but a single-photon tagging is also useful. Kaon structure measurement requires to tag a neutron and 2 or 3 photons, as decay products of Λ or Σ.		

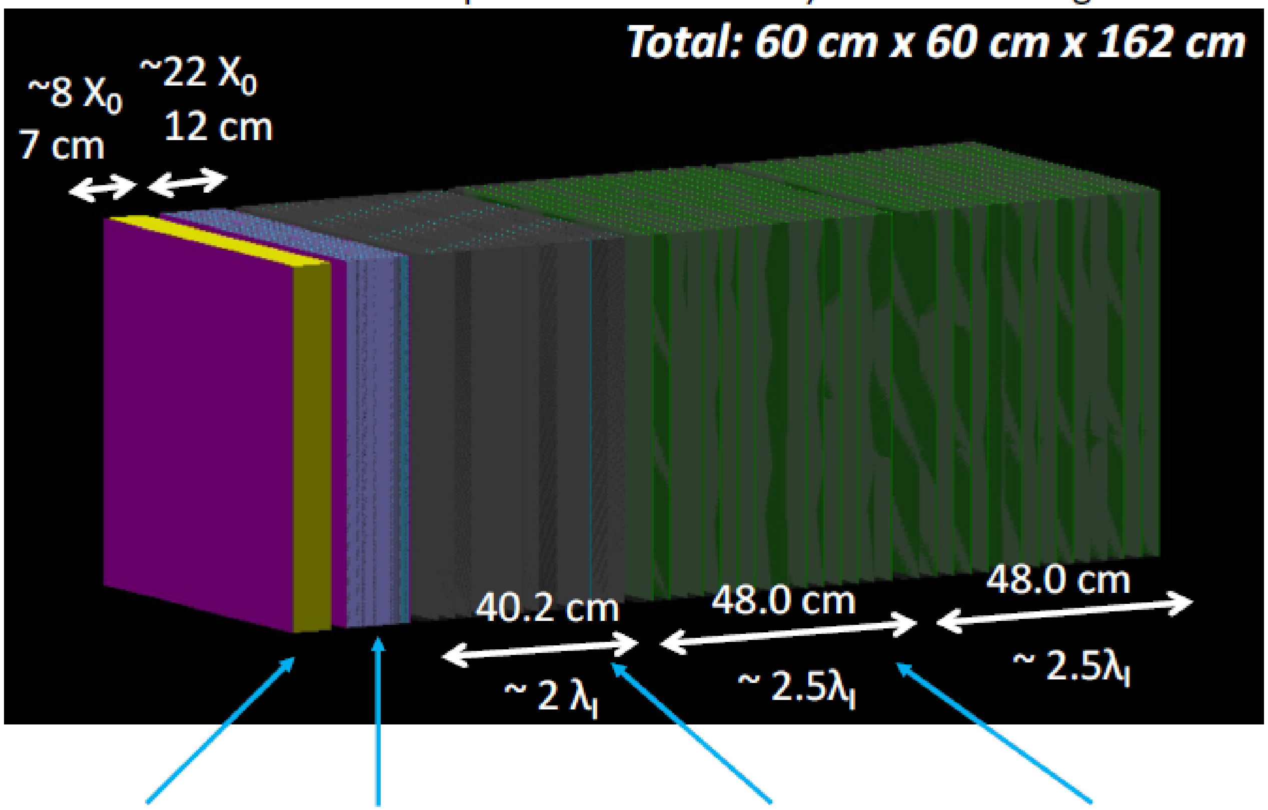
Table 2: Physics requirement for ZDC

- Neutron position
  - 3mrad/√E or 6mm @ 275 GeV
  - Better resolution is not necessary since energy resolution also contributes to p_T
  - Crucial to determine the zero degree: still good position resolution is useful
- Calibration: kinematic end point (275 GeV)
- Need dynamic range up to multi TeV for HI

ePIC-ZDC 1st design

Previous ~~Current~~ ZDC design

*note: space for readout may extend the longitudinal length.



Crystal ($PbWO_4$)
+ Silicon Pixel layer

W/Si calo.
3 Pixel layers are inserted.

Pb/Si calo.

Pb/Sci. calo.

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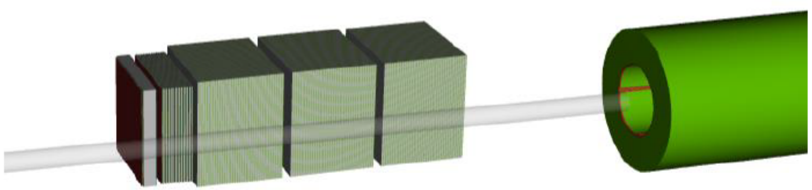
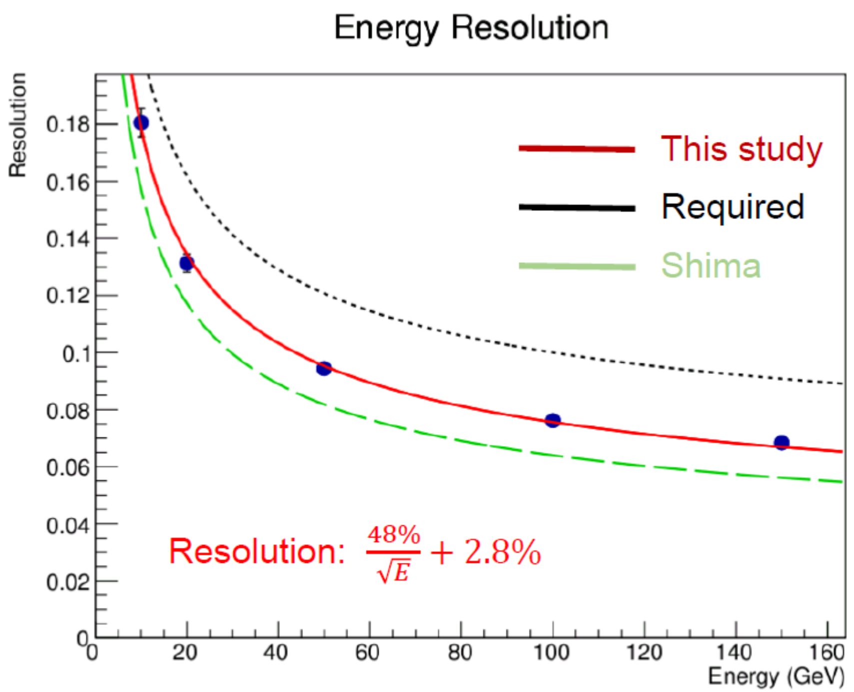
ZDC updated design

- Cost reduction design
  - Smaller EMCAL
  - Pb-Si imaging HCAL removed
  - By Po-Ju Lin (NCU) and Michael Pitt (Kansas)



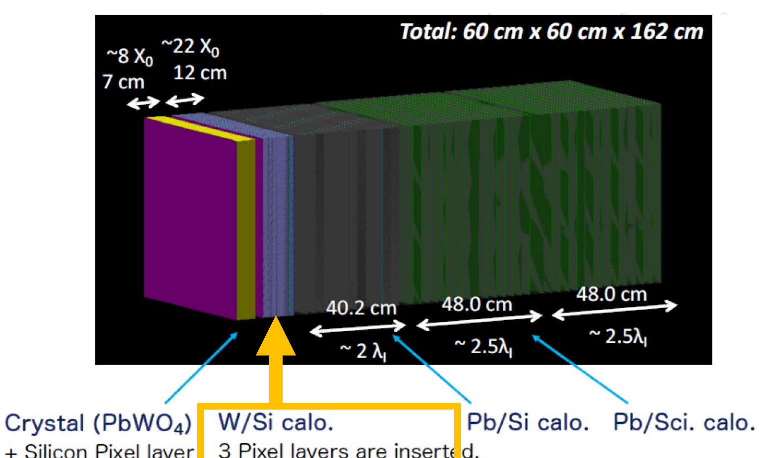
- Use only three Pb/Sci blocks to fit the dimension limitation
  - Overall length approximately 182.7 cm
  - Gaps between crystal-W/Si and W/Si-PbSci: 2 cm
  - Gaps between Pb/Sci blocks: 5 cm
  - In Pb/Sci: Lead thickness = 10.0 mm, scintillator thickness = 2.5mm

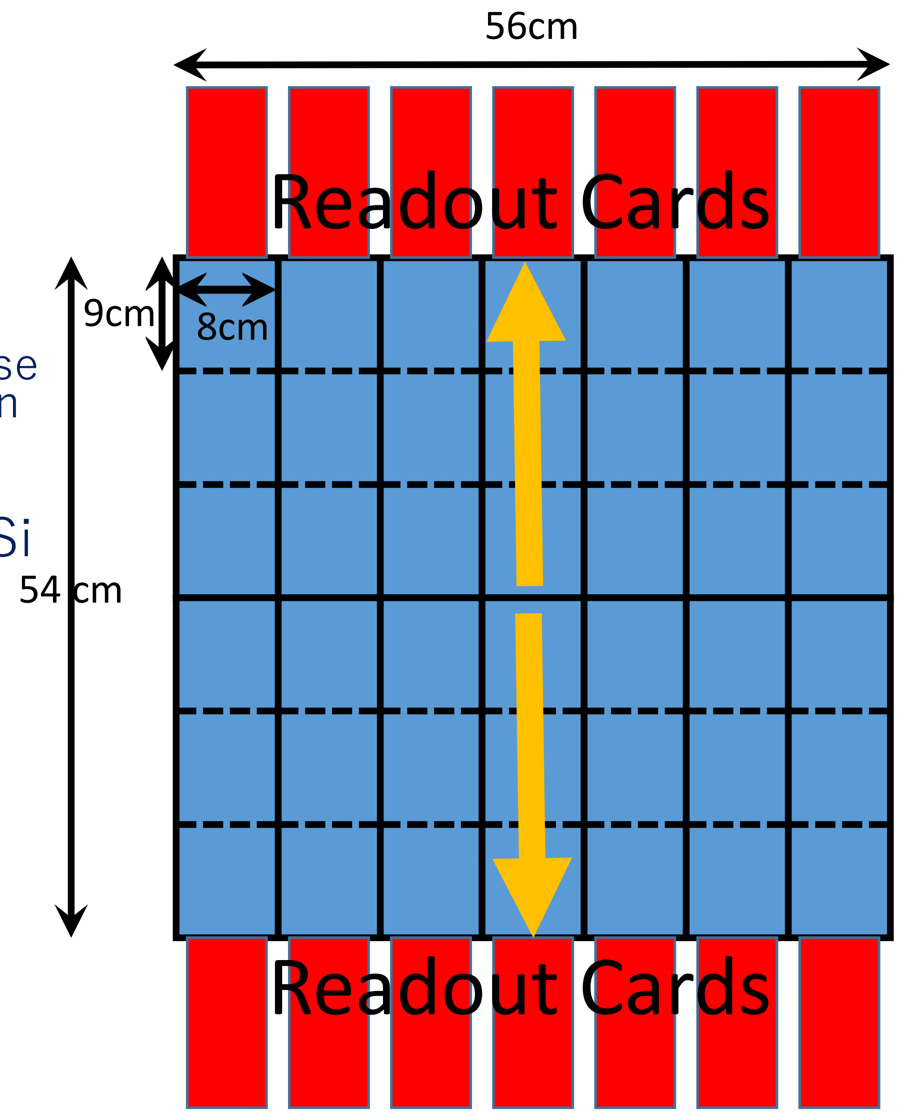


Slide by Po-Ju Lin (NCU)

EM calorimeter

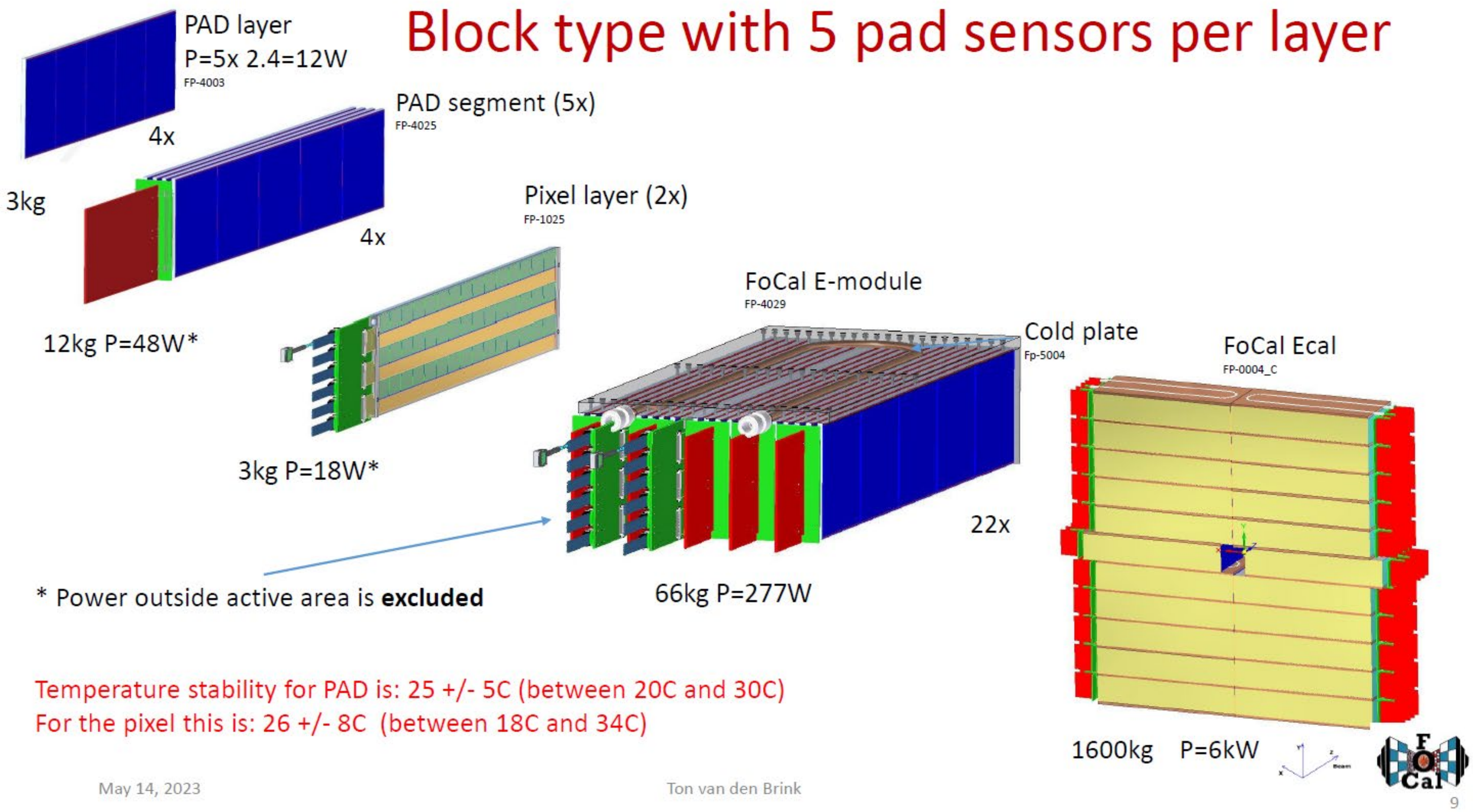
- W-Si imaging calorimeter
  - ALICE FoCal-E Pad technology
- 2nd design
  - Lateral dimension based on FoCal-E Pad sensor size 9cm x 8cm → 6 sensors x 7 sensors = 54cm x 56cm
    - Smaller than the 1st design because EM shower leakage is smaller than hadron shower leakage
  - Number of Si readout layers; e.g. $2X_0$ (7.0mm) x 11 W layers + 11 Si readout layers
    - Cost reduction option





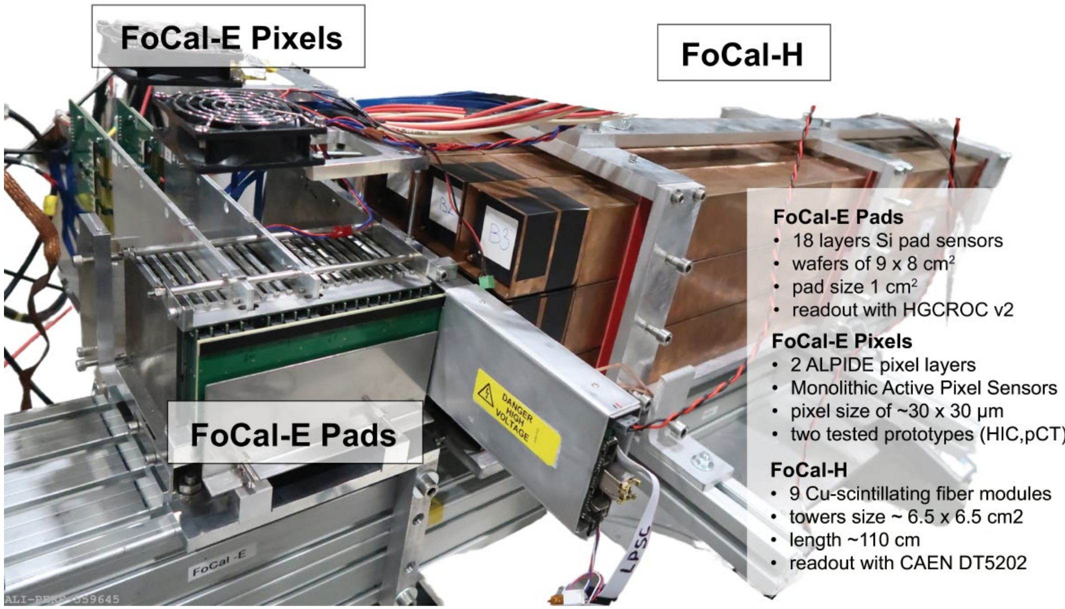
FoCal-E design

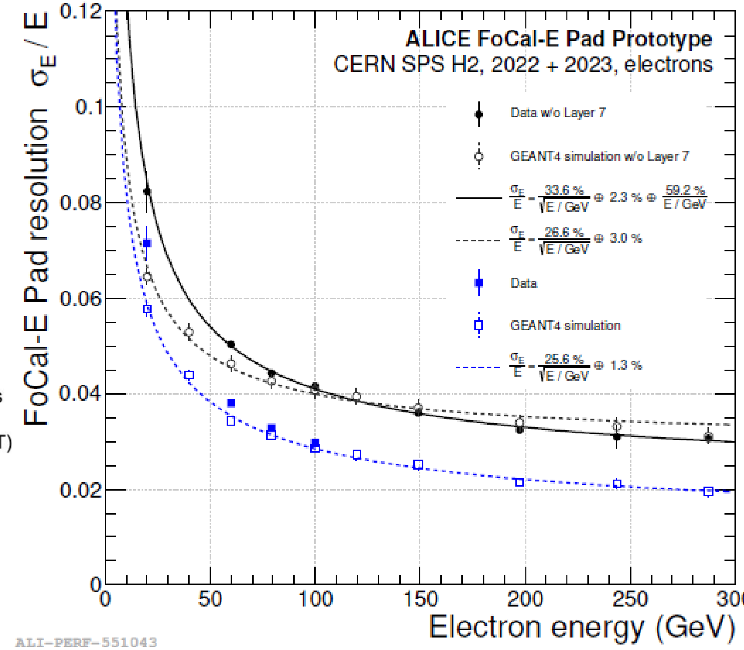
- Including cooling & support



FoCal test beam

- arXiv/2311.07413
  - Various test beams in 2021-23 at CERN PS and SPS

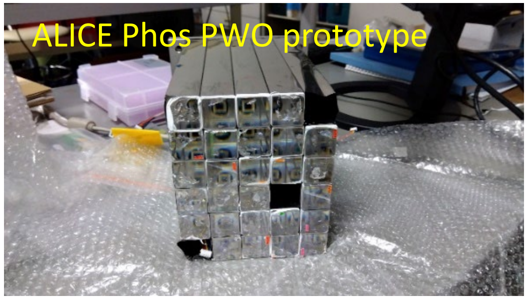


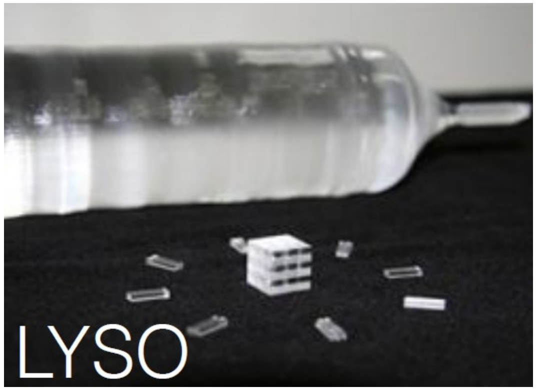


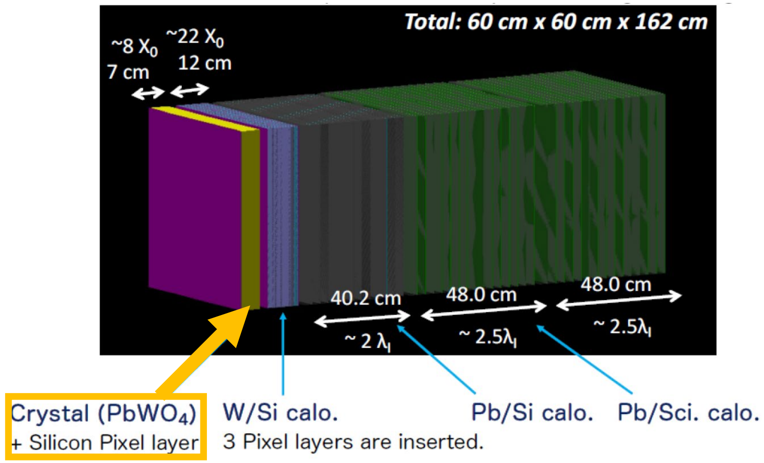
- Test beams in Japan
  - FoCal-E Pad test beams at Tohoku Univ. ELPH
    - Next: February 2024
  - Neutron irradiation test in 2022-23 at RIKEN RANS
    - Sensor, photodetectors, chips, cables

EM calorimeter

- Crystal calorimeter
- 2nd design
  - Lateral dimension 54cm x 56cm matching to W-Si imaging calorimeter
  - Crystal scintillator choice
    - $PbWO_4$ vs LYSO
    - LYSO crystal by Taiwan group (from CMS)
    - Cooperation with B0 EMCAL
- Crystal calorimeter should be removable if possible
  - Necessary only in eA collisions
  - To reduce radiation







	X_0	LY (ph/MeV)	T dep. of LY (%/K)	Decay time (ns)	λ_{em} nm
$PbWO_4$ (CMS)	0.89 cm	200	-1.98	5 (73%) 14 (23%) 110 (4%)	420
LYSO	1.14 cm	30,000 (market standard)	-0.28	36	420
SciGlass	2.4-2.8 cm	>100		22-400	440-460

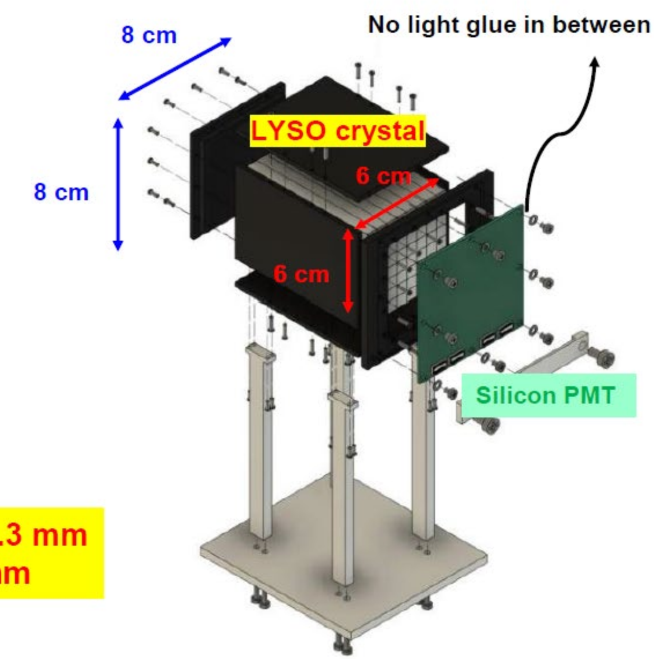
EM calorimeter

- Crystal calorimeter
  - LYSO test module design for test beam by Taiwan group
  - Lab test with radiation source Co-60 performed in Taiwan

LYSO Calorimeter

LYSO crystal

one pixel = 7.12 mm x 7.12 mm x 88.3 mm
8 * 8 pixels = 56.96mm * 56.96mm



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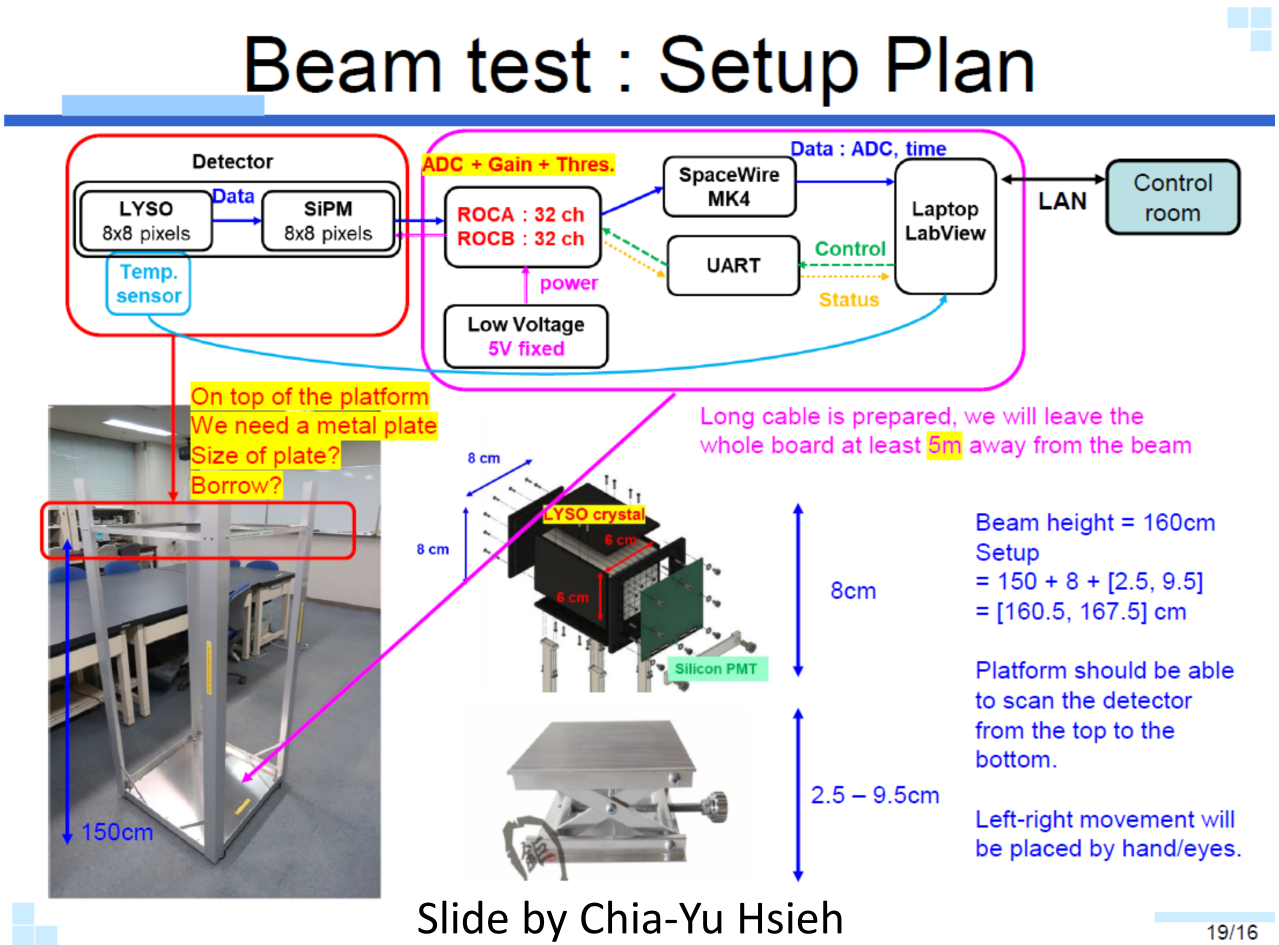
Slide by Chia-Yu Hsieh
(Academia Sinica)

EM calorimeter

- Test beam at ELPH, Tohoku Univ., Feb. 19-21, 2024
  - NCU, Academia Sinica, Sejong Univ., RIKEN, Tsukuba Univ., Tsukuba Tech Univ.
  - To be continued after the FoCal-E pad test beam (Feb. 13-14) conducted by Tsukuba group



Slide by Chia-Yu Hsieh (Academia Sinica)

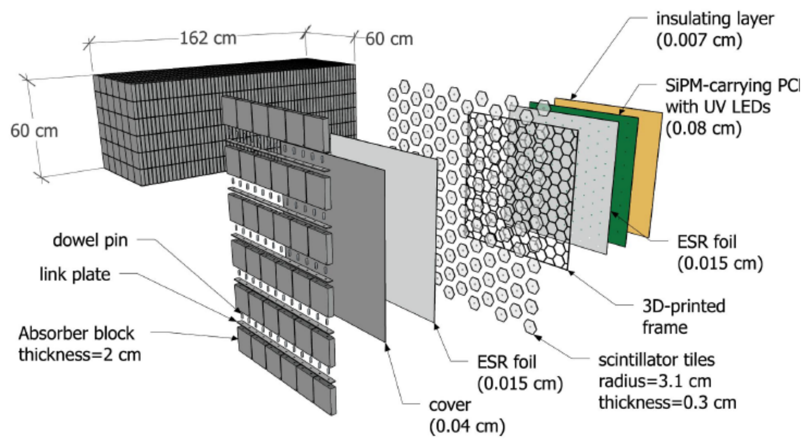
Hadron calorimeter

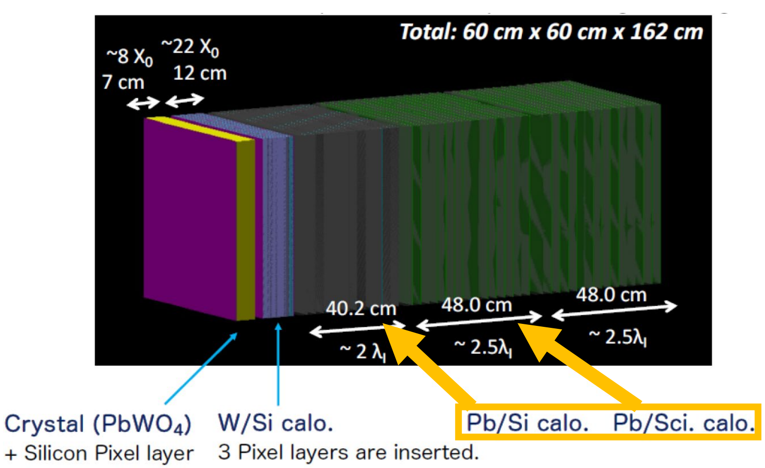
- 2^{nd} design
  - No Pb-Si imaging calorimeter
  - SiPM-on-tile technology

A possible SiPM-on-tile ZDC design

Slide by Sebouh J. Paul (UCR)

- SiPMs and bias & readout (HGROC) and scintillator cells (injection molding) relatively inexpensive.
- Could work with either Fe or Pb, but if we use Fe it could be very inexpensive:
  - Could reuse 2×10×10 cm^3 absorber blocks from STAR





- Major effort to reduce cost of hadronic calorimeter
- Moving to Fe/Scintillator with SiPMs on each tile gives major reduction in cost
- Significant synergies with Forward Hadron Calorimeter

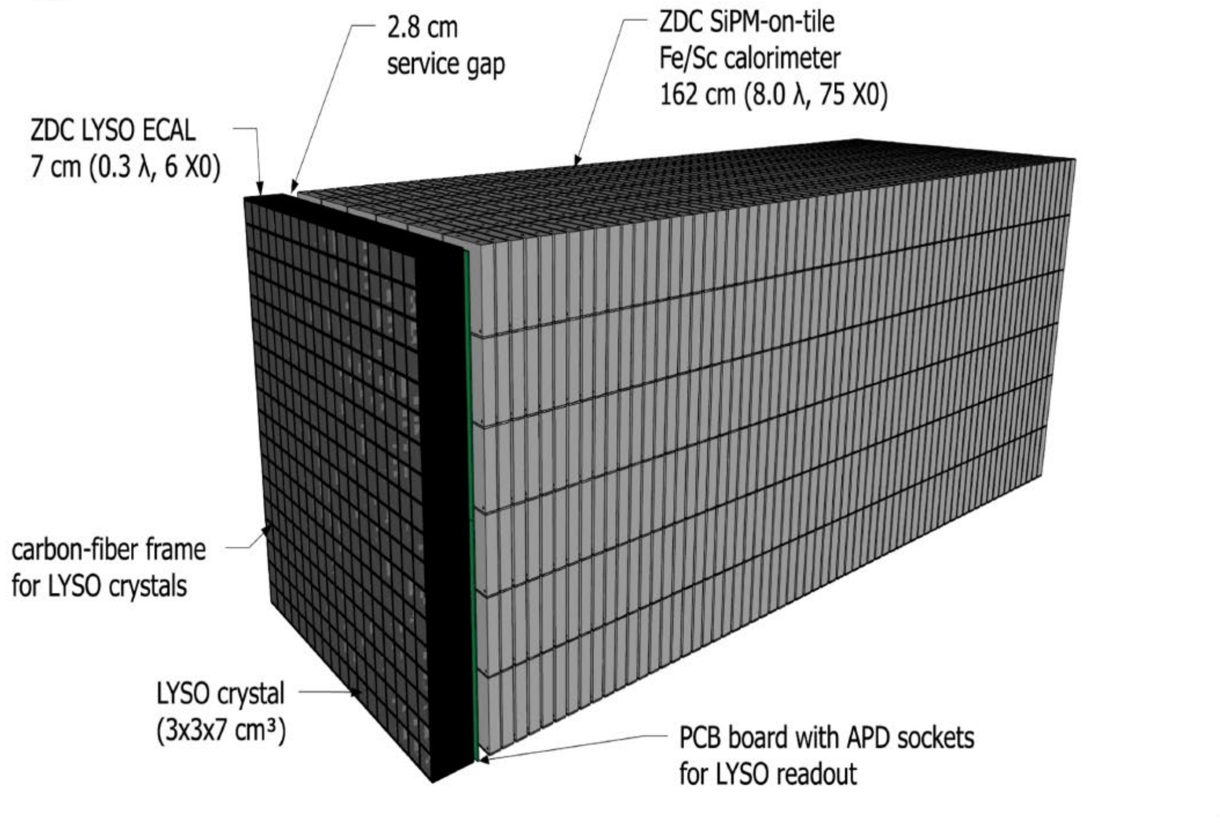
EIC status

- EIC Resource Review Board Meeting
  - 2nd meeting: 2023.12.7-8 in Washington DC
  - EIC IKC (in-king contribution) CD-2 expectations
    - At DOE CD-2/3 Review, planned for early 2025, scope without identified IKC partners will be assumed as DOE scope, and pursued as opportunities
    - IKC are expected to be identified and agreed upon at all stages of the EIC project and the timing of approval cycles in different countries
    - e.g., detector upgrades, accelerator installation and commissioning, in the detector area such as Canada, Japan, Korea, Taiwan, etc.
- EIC Far-Forward and Backward Preliminary Design Review
  - 2024.2.11

Preliminary design

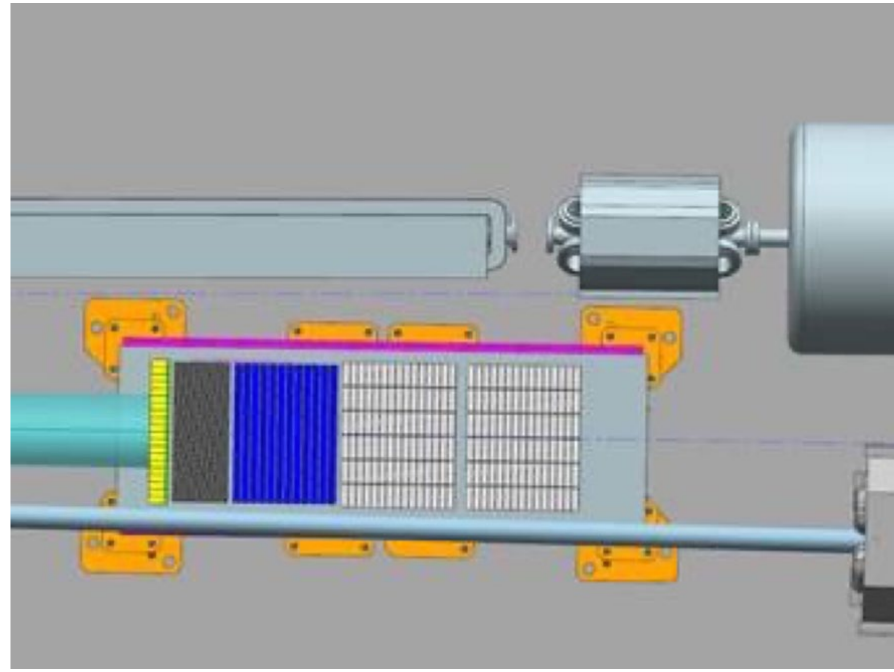
- LYSO crystal calorimeter
- SiPM-on-tile Fe/Sci calorimter

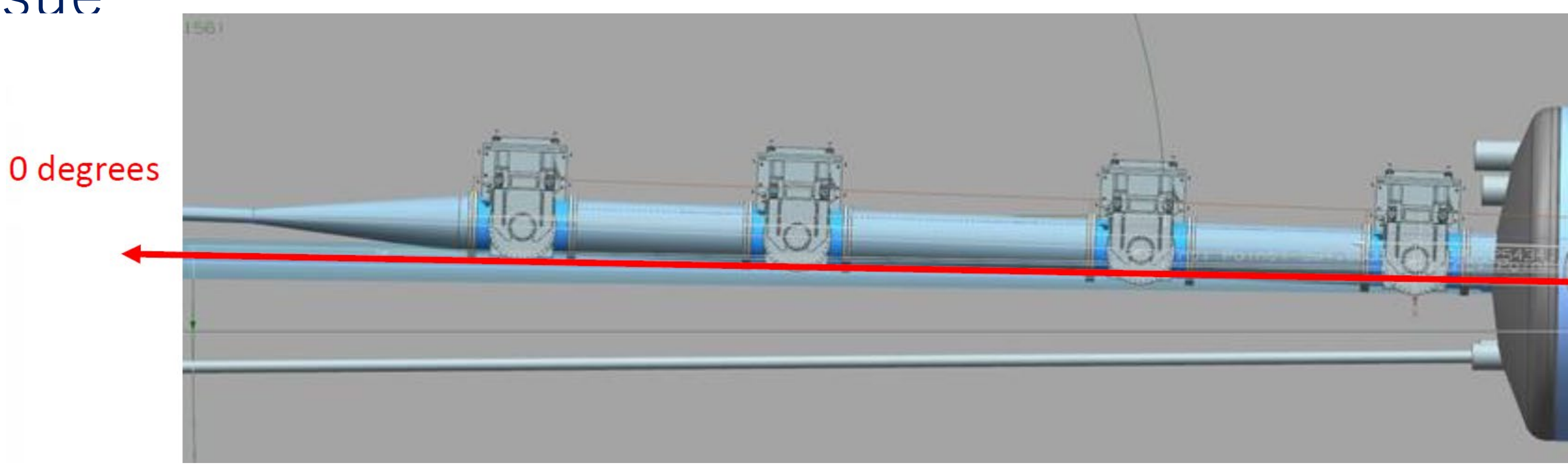
Current Design



ZDC integration issues

- ZDC sits outside of the beam pipe
  - Keeping ZDC clear of magnet cryostats, crab cavity on electron side, and hadron beam pipe
- Current hadron beam pipe cuts acceptance for photons
  - Machine is aware of this issue





Summary

- ePIC ZDC updated design
  - EM calorimeter
    - Dimension
    - Crystal scintillator evaluation
  - Hadron calorimeter
    - No imaging layer
    - SiPM-on-tile design
  - Position (& timing) layer
- Preliminary design
  - LYSO crystal calorimeter
  - SiPM-on-tile Fe/Sci calorimeter
- Integration issues