Status of ZDC

EIC-Asia Group Meeting

May 25, 2023

Yuji Goto (RIKEN/RBRC)

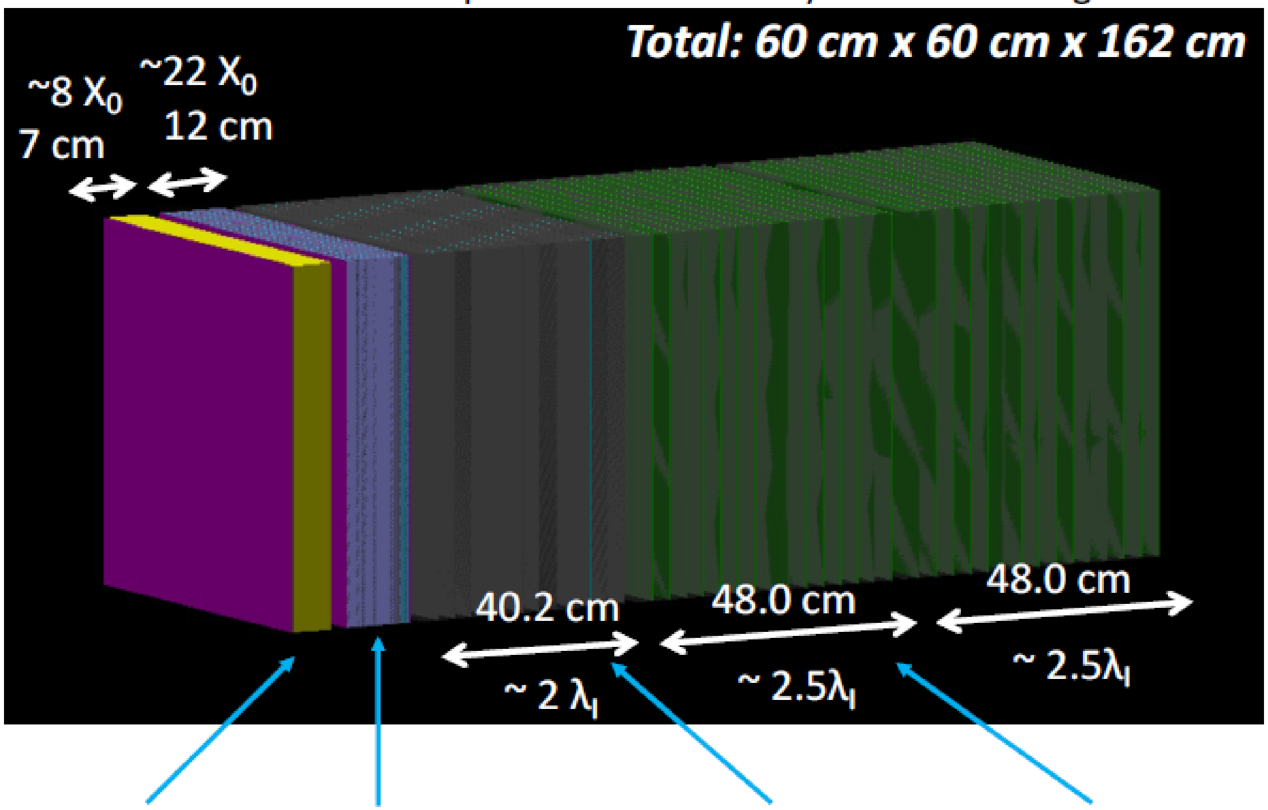
ePIC-ZDC discussion

- Task assignment
  - Review the detector design
    - Optimization including cost review
  - Integration & Mechanical design
  - Readout devices, electronics, DAQ
  - Prototype production, test & evaluation
  - Software development & simulation studies
- Timeline and goals
  - Pre-TDR $\rightarrow$ CD3a (2024.1)
    - No need because of no Long Lead-time Procurements
  - TDR $\rightarrow$ CD2/3 (2025.4)
    - Final design (80% ready): 2024.4?
    - Specs/docs/first article, etc.
  - Construction: 2025-2030?
    - Start: 2025.5?
  - Integration: 2030-2031?

ePIC-ZDC 1st design

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.

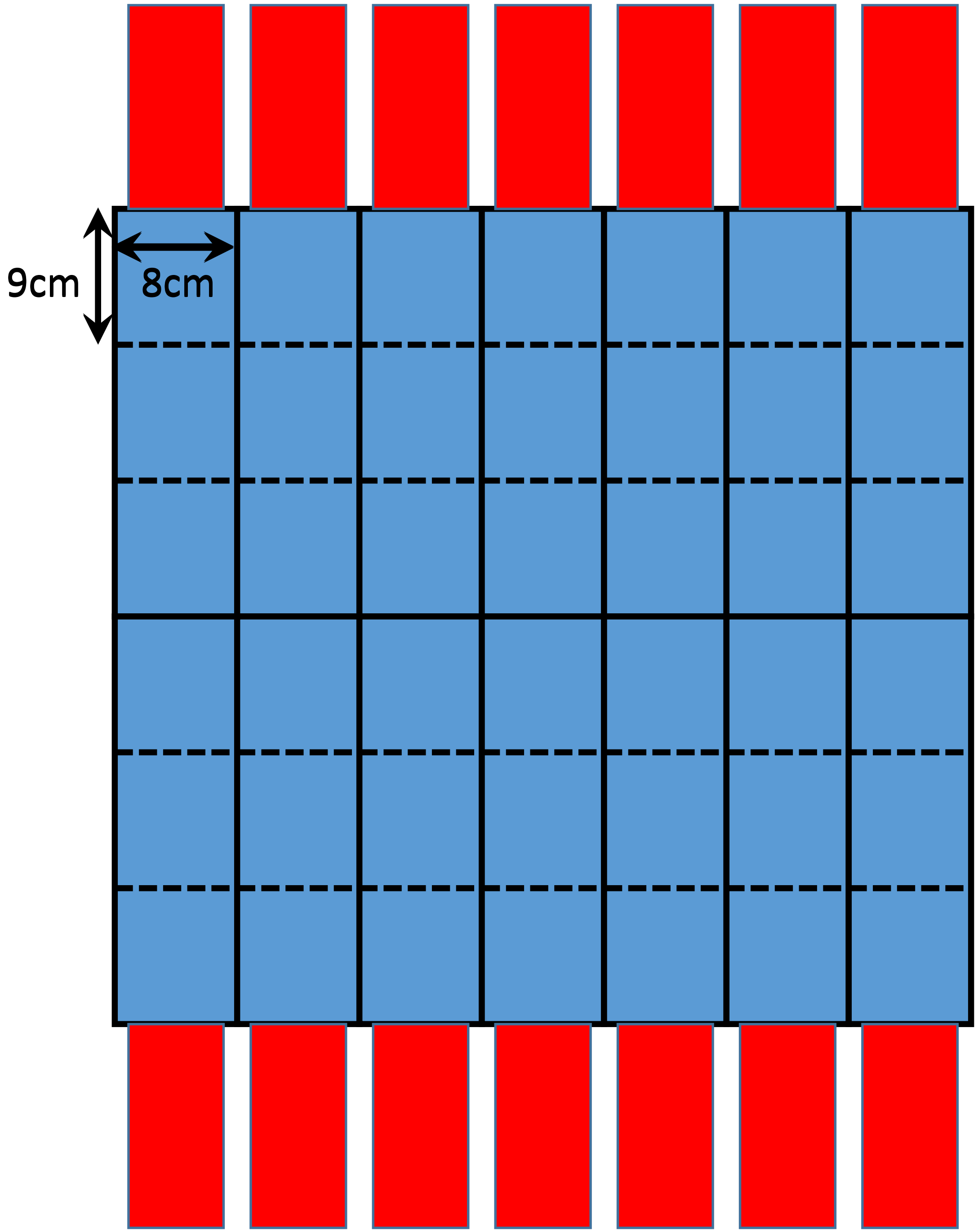
5

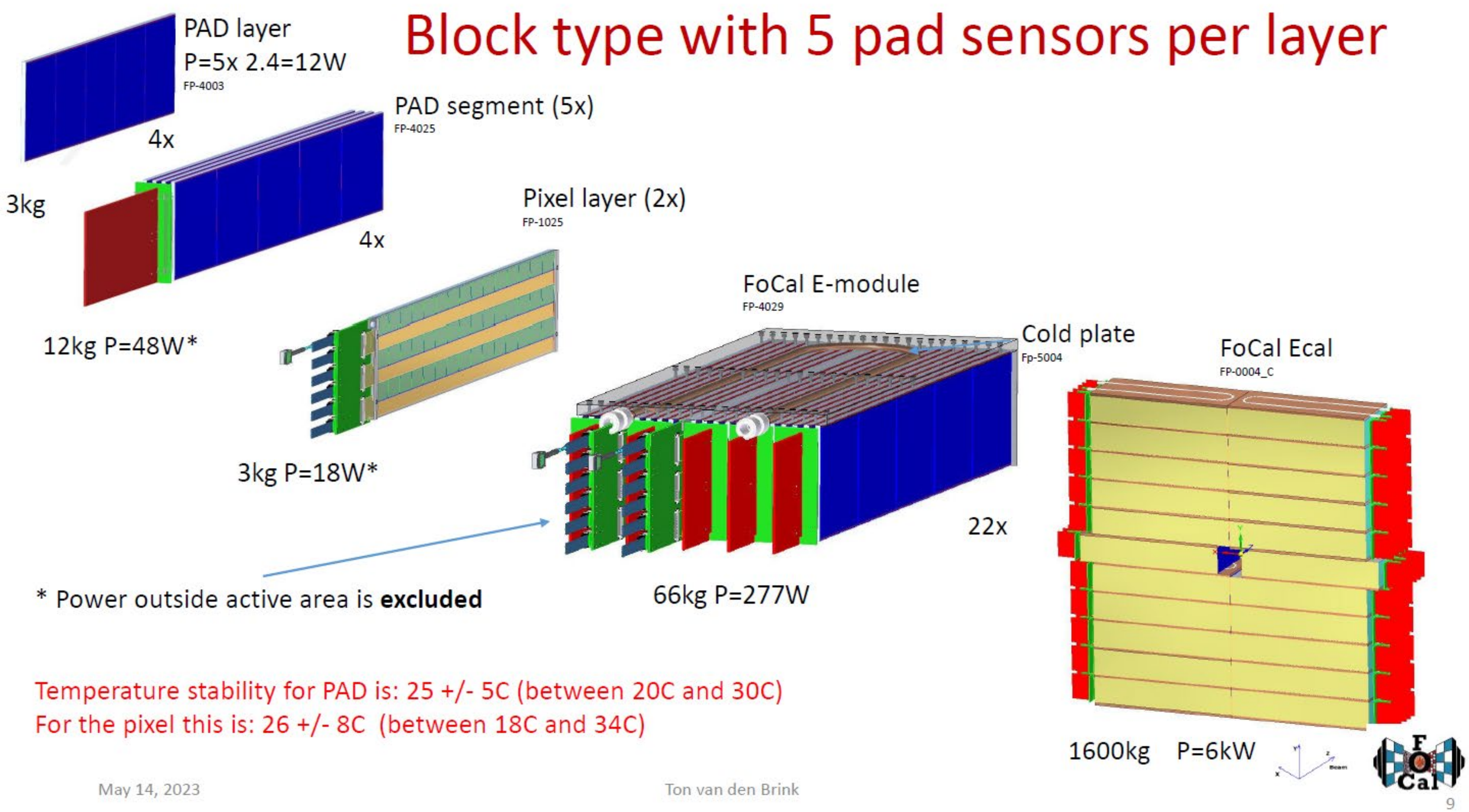
2023 task plan

- Plan for “timeline & goals”
  - Plan and discussion for each task assignment
- Software development
  - Cooperation between US (PNNL) & Asia groups
- Simulation studies
  - Revisit radiation dose
  - Comparison with FLUKA result
- Review the detector design
- Prototype production
  - Crystal + Imaging calorimeter (W-Si)
- Test beam at ELPH, Tohoku Univ.
  - 2023 Autumn beam time
  - Participation of Asia (Taiwan) group
- Radiation tolerance test (neutron irradiation) @ RIKEN RANS
  - Comparison of new & old ALICE-FoCal-E Pad sensors

ePIC-ZDC detector design

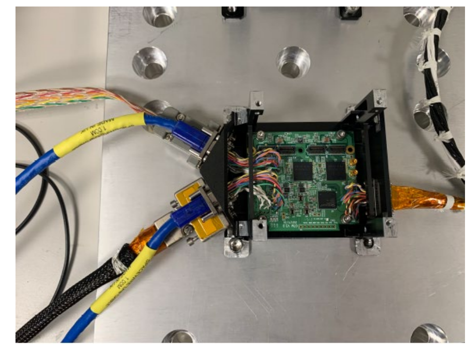
- Crystal calorimeter
  - 1st design: 60cm x 60cm PWO crystal 8X_0
  - Design update option:
    - Smaller lateral dimension? 60cm x 60cm necessary to cover lateral hadron shower leakage (EM shower leakage smaller)
- W-Si imaging calorimeter
  - 1st design: 60cm x 60cm W-Si 22X_0 (22 layers)
  - Design update option:
    - Smaller lateral dimension? e.g. ALICE-FoCal-E Pad size 9cm x 8cm $\rightarrow$ 6 x 7 = 54cm x 56cm?
    - Smaller number of layers? e.g. 1X_0 x 22 layers $\rightarrow$ 2X_0 x 11 layers?
- Hadron calorimeter
  - 1st design:
    - Pb-Si 0.16λ_I x 12 layers (40cm)
    - Pb-Scintillator 10cm x 10cm x 48cm (2.5λ_I) tower, 10 x 10 x 2
  - Design update option:
    - No imaging (Pb-Si) layers?
    - Pb-(Scintillator + Fused silica) 10cm x 10cm x 48cm tower 4 x 4?


9cm
8cm


Block type with 5 pad sensors per layer
PAD layer
P=5x 2.4=12W
FP-4003
4x
PAD segment (5x)
FP-4025
3kg
4x
Pixel layer (2x)
FP-1025
12kg P=48W*
FoCal E-module
FP-4029
Cold plate
Fp-5004
FoCal Ecal
FP-0004_C
3kg P=18W*
22x
* Power outside active area is excluded
66kg P=277W
Temperature stability for PAD is: 25 +/- 5C (between 20C and 30C)
For the pixel this is: 26 +/- 8C (between 18C and 34C)
1600kg P=6kW
May 14, 2023
Ton van den Brink
9

Crystal calorimeter prototype

- Plans by Taiwan group
  - Discussed today in the ePIC-ZDC discussion meeting
- Place the order for LYSO crystals
  - Need to determine the cross section area
  - Worry: large LY of LYSO so that saturation→ smaller cross section can be better (6mm x 6mm ?)
  - G4 study is underway to estimate the energy deposit with the beams at Tohoku university
- Purchase SiPM
- Design an adapted board
  - Readout board designed by Chih-Hsun Lin of Academia Sinica

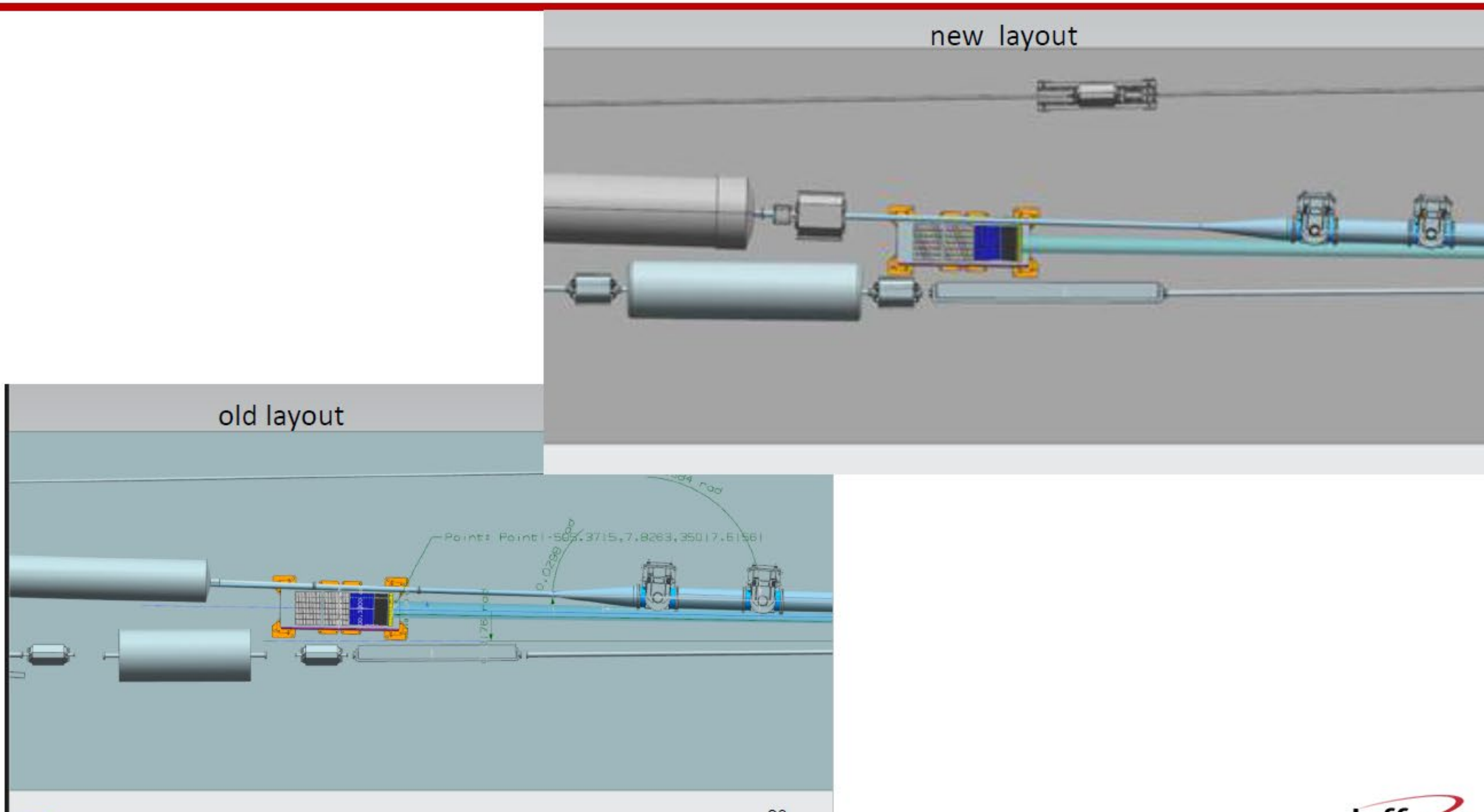


Crystal calorimeter prototype

- ALICE-Phos PWO prototype
  - Hiroshima Univ.
  - 2cm x 2cm x 18cm
  - APD readout
  - Shipped to RIKEN
  - Some towers to be sent to Taiwan for prototype module
- Evaluation using a test beam with FoCal-E W/Si-Pad

ePIC-ZDC geometry update

ZERO-DEGREE CALORIMETER



Backup Slides

Task assignment

- Review the detector design
  - Hadron calorimeter not necessary an imaging calorimeter (Pb-Si) but a dual-readout calorimeter of fused-silica + plastic scintillator?
    - Only plastic scintillators except near the beam axis and at the downstream?
    - Better simplification of design
  - Reduce number of EM imaging calorimeter layers?
- Plan for “timeline and goals”
  - Crystal calorimeter
    - Taiwan group
  - Imaging calorimeter (EM+hadron)
    - Japan group
  - Plastic-scintillator or dual-readout hadron calorimeter
    - Korea group
  - Software
    - US group (PNNL) and Po-Ju

Radiation dose

- "Backgrounds in the Electron Ion Collider Experimental Hall and ZDC Life Time in FLUKA model," M. Murray, V. Baturin, C. Hyde, et al.
  - The hadron calorimeter part (ZDC Si 4 in Table 1) also has a neutron fluence of 10^{13} neutron/cm^2 after several years of operation
  - Radiation tolerance should be considered in the technology selection

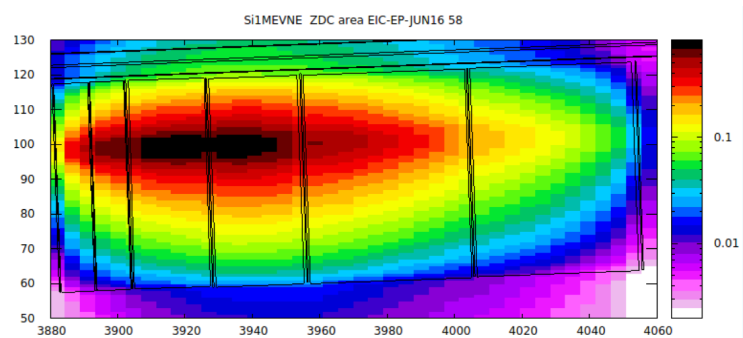
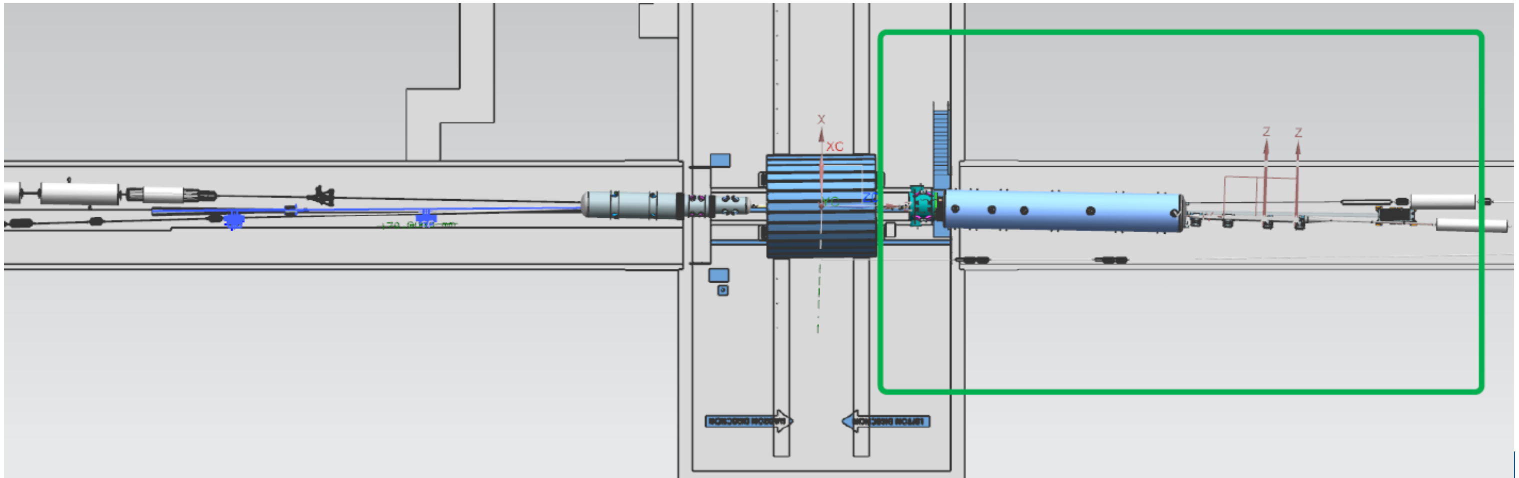


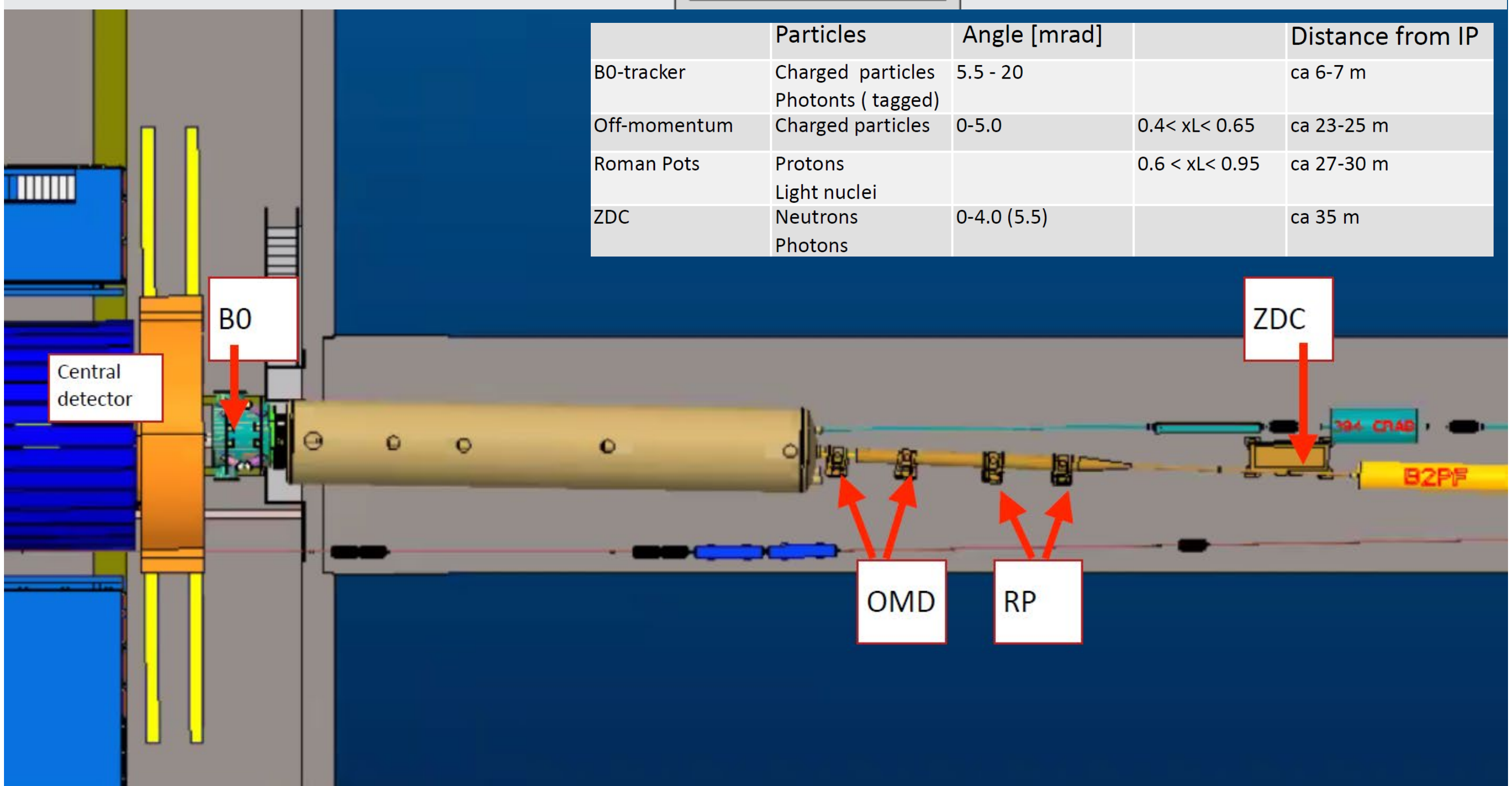
FIG. 5. Neutron MEQ fluence in the area of ZDC from $e(10\ GeV) + p(275\ GeV)$–collisions. Vertical scale: X coordinate perpendicular to the e-beam line (cm); Horizontal scale: coordinate Z along the electron beam line (cm). Electrons travel in $-Z$ direction. Fluence is given in units of neutrons/cm^2 per primary ep-collision. The maximum fluence in the center of ZDC is of 8.E-1 neutrons/cm^2 per primary ep interaction. At maximal luminosity (10^{34}/cm^2/sec the ep interaction rate is $\sim 5 \cdot 10^5$/sec. fff182

One MeV neutron equivalent fluxes F through the silicon material and life time						
Detector.	R_{min}/cm	R_{max}/cm	Z_{mea}/cm	$F_{p+rg}/(cm^2 s)$	$F_{e+p}/(cm^2 s)$	$F_{tot}/(cm^2 OY)$
ZDC Si 1	58	120	3880	1.2E+3	5.5E+4	5.6E+11
ZDC Si 2	59	118	3890	5.4E+3	3.8E+5	3.8E+12
ZDC Si 3	60	119	3910	6.6E+3	7.1E+5	7.1E+12
ZDC Si 4	61	121	3930	4.6E+3	3.6E+5	3.6E+12
ZDC Si 5	62	122	3960	3.6E+3	1.4E+5	1.4E+12
Si in B0	13	22	650	1.2E+3	15.E+4	1.6E+11

TABLE I. Critical neutron MEQ fluxes in potential locations for readout Si based detectors at the proton beam (275 GeV/c) current 1 A, residual gas pressure 1.E-9 mbar, and $e(10)+p(275)$–interaction rate $0.5\times10^{+6} Hz$ (at the luminosity of 10^{+34}cm^{-2}s^{-1}). Columns: (1) – detector area, (2,3) – radial coordinates in cm, (4)–mean coordinate along the electron beam in cm, (5,6,7)–fluxes from $p + rg$, ep–collisions in units of MEQ neutrons/cm^2/s and from both sources in f MEQ neutrons/cm^2/OY, where OY stands for "Operational Year" ($10^{+7}s$). The last has to be compared with 10^{+14} for regular silicon readout detectors and 10^{+11} for silicon photo multipliers. ttt1991

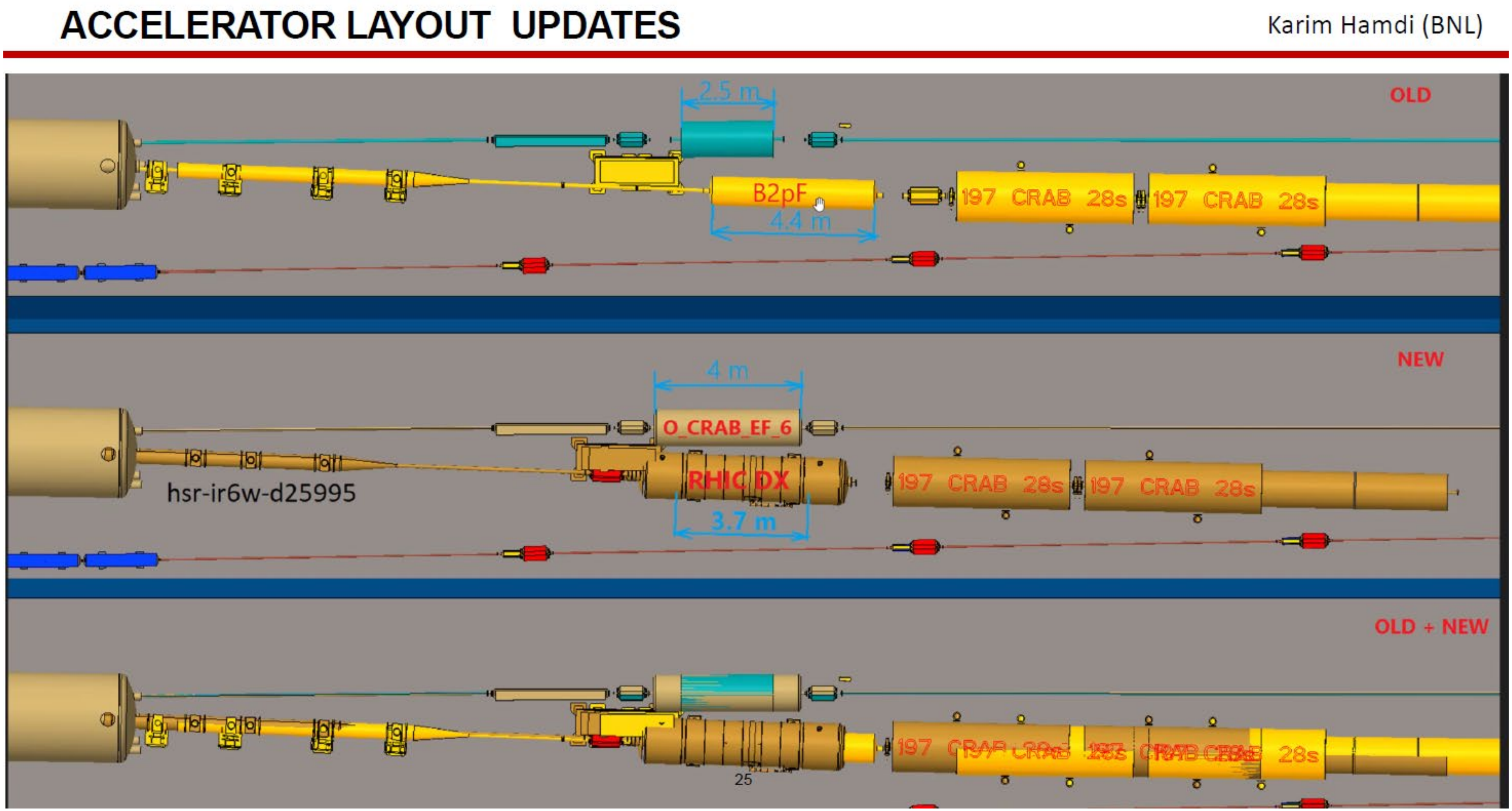
ePIC far-forward detectors





	Particles	Angle [mrad]		Distance from IP
B0-tracker	Charged particles Photonts (tagged)	5.5 - 20		ca 6-7 m
Off-momentum	Charged particles	0-5.0	0.4< xL< 0.65	ca 23-25 m
Roman Pots	Protons Light nuclei		0.6 < xL< 0.95	ca 27-30 m
ZDC	Neutrons Photons	0-4.0 (5.5)		ca 35 m

ePIC-ZDC geometry update

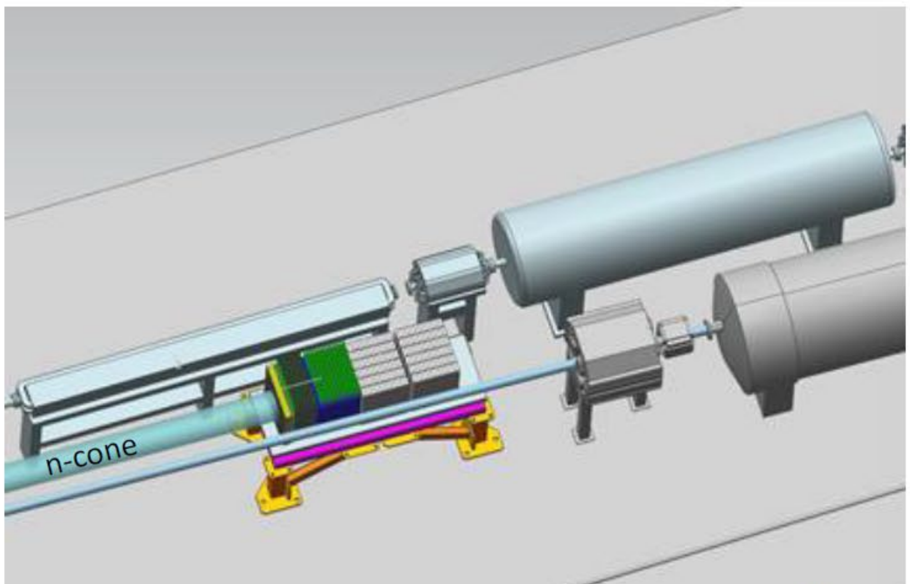


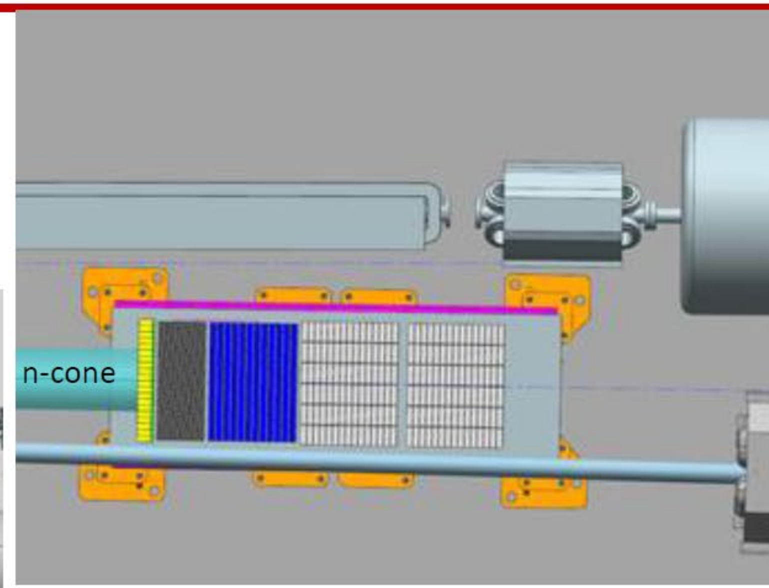
ePIC-ZDC geometry update

ZDC

"Stay-clear" zone around the beam-pipe
Placement of readout boards

Z-placement , transverse size



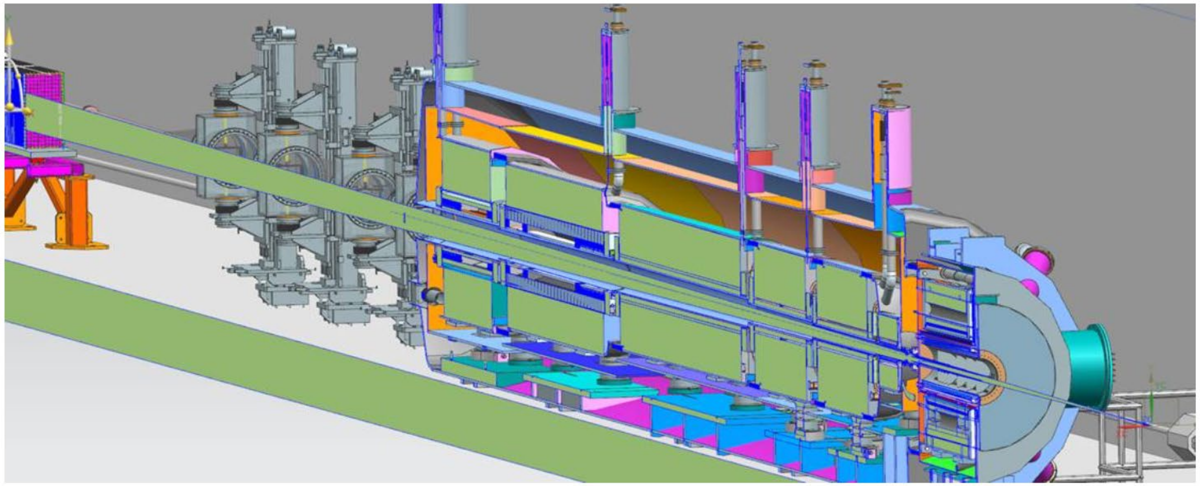


24

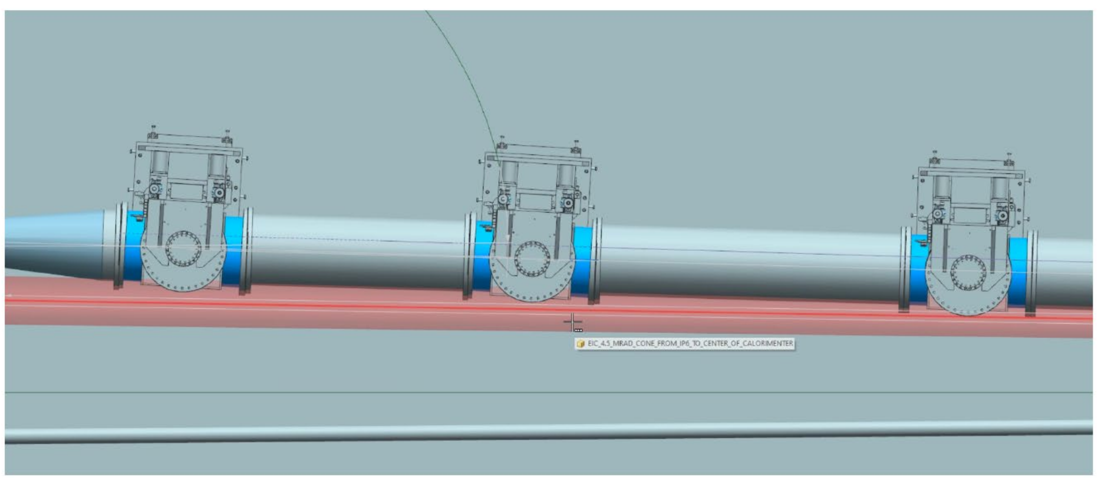
Jefferson Lab

Neutron cone

4.5 mrad cone towards ZDC (in green)



NEUTRON-CONE (NEED TO CHECK!)



W-Si module design

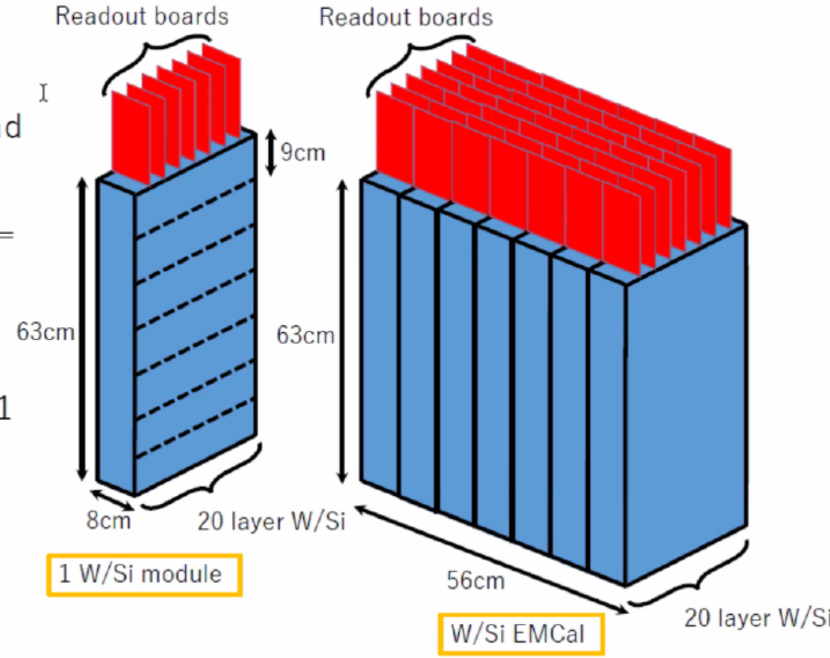
FAR-FORWARD - ZDC

Overleaf document
(internal notes, preTDR)
- requirements
- current design and motivations

Meetings with Yuji & Yuji

W/Si EMCal

- This is an design example using 8cm x 9cm ALICE-FoCal-E Pad Sensor
  - 1 pad = 1cm x 1cm
  - 1 sensor = 9 cm x 8cm = 72 pads
  - 1 tower = 20 layers
  - 1 module = 7 towers
  - ZDC W/Si = 7 modules
- 1 sensor is readout by 1 HGCROC (72 ch)
- 3 layers readout by 1 readout board in this design
- Similar design possible for the Pb/Si HCal



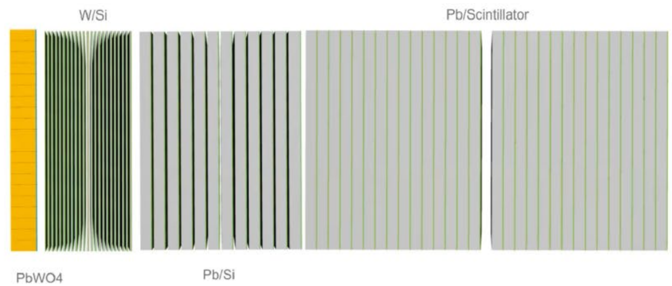
29

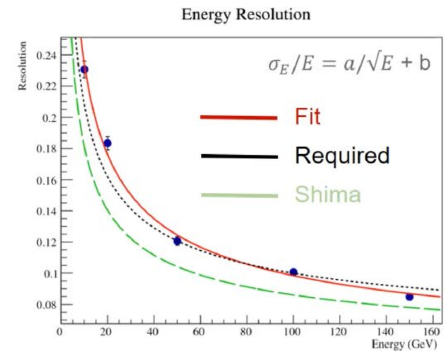
Simulation study

- Energy resolution by Po-Ju

ZDC RESOLUTION (NEUTRONS)

Po-Ju Lin (CEA- Université Paris-Saclay)





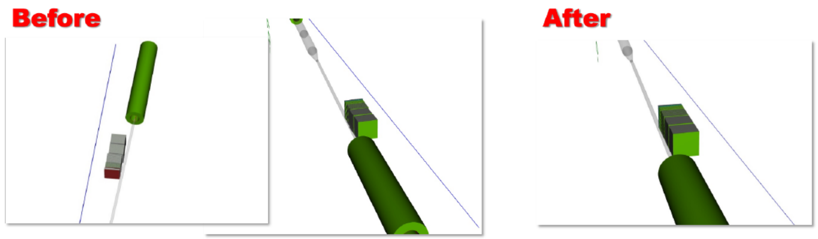
- Fit: $\frac{63\%}{\sqrt{E}} + 3.6\%$
- Required: $\frac{50\%}{\sqrt{E}} + 5\%$
- Shima: $\frac{44\%}{\sqrt{E}} + 4.2\%$

23

Jefferson Lab

ZDC Monte Carlo implementation (1/2)

Po-Ju Lin



- Po-Ju Lin of Academia Sinica started to pick up simulation work from Shimizu-san
- A bug of alignment issued reported by other collaborators (issue #309) was fixed
- The ZDC complex rotation has been modified to have a consistency in codes between Athena and ECCE version. Merged to the EPIC GitHub already.

EIC Asia Workshop 9 2023/3/17

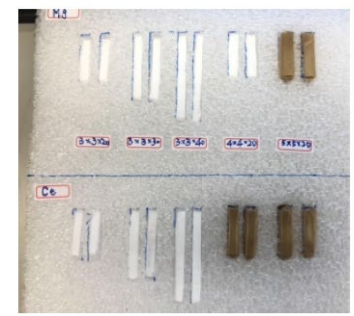
LYSO Crystal by Taiwan group

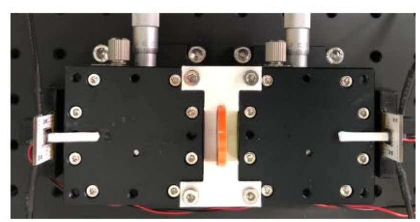
$PbWO_4$ vs LYSO vs SciGlass

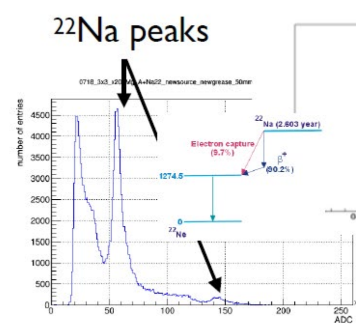
	X_0	LY (ph/MeV)	T dep. of LY (%/K)	Decay time (ns)	λ_{em} nm
$PbWO_4$ (CMS)	0.89 cm	200	-1.98	5 (73%) 14 (23%) 110 (4%)	420
LYSO	1.14 cm	30,000 (market standard)	-0.28	36	420
SciGlass	2.4-2.8 cm	>100		22-400	440-460

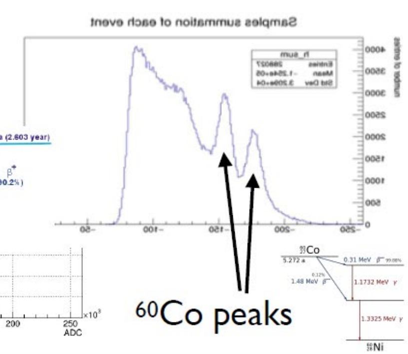
LYSO crystal characterization

- NTU is setting up measurements for
  - absolute light yield of LYSO crystal using PMTs
  - time resolution of LYSO using SiPM
  - reach coincident time resolution of ~130ps





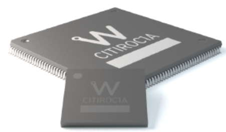




Crystal readout by Taiwan group

Readout (1/2)

- available readout board with Citiroc1A from wee roc for multichannel SiPM (Chih-Hsun Li, Academia Sinica) → can be used for first prototype study



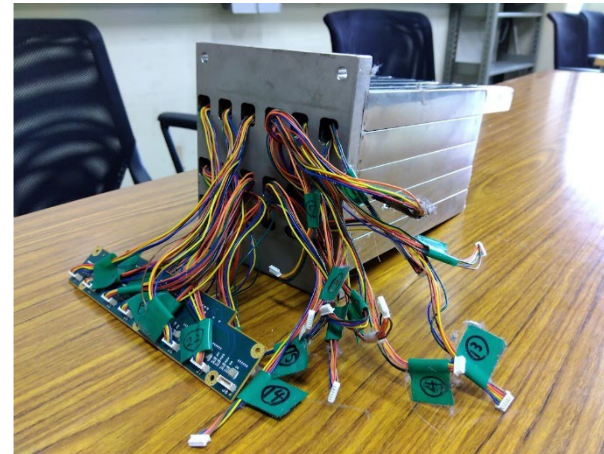
- need a suitable readout for critical fluence value ($10^{14}/cm^2$)
  - CMS ECAL
    - barrel: APD, up to $4 \times 10^{13}/cm^2$
    - endcap: VPT (vacuum phototriodes), up to $7 \times 10^{15}/cm^2$
  - CMS MTD BTL (LYSO tiles with SiPM readout)
    - radiation (4/ab): $2 \times 10^{14}/cm^2$

Readout (2/2)

- extensive studies of radiation damage, including temperature effects and annealing on SiPM were performed by CMS MTD
- HPK MPPC-HDR2-3015 used by CMS in R&D in 2019
- However, there are challenges
  - need to operate at -45°C to suppress the noise from increased dark count rate and avoid SiPM SPAD saturation
  - still high power consumption → specific packaging and mechanical support for heat extraction for stable operation

Crystal Calorimeter

- ALICE-Phos PWO prototype
  - Hiroshima Univ.
  - 2cm x 2cm x 18cm
  - APD readout
  - Shipped to RIKEN



- LYSO crystal by Taiwan group
  - Offer from Taiwan Group for test module production, simulation calculation, etc.

- Considering evaluation using a test beam