

Zero-Degree Calorimeter

FF/FB Cross-Cutting WG Meeting

May 23, 2023

Yuji Goto (RIKEN)

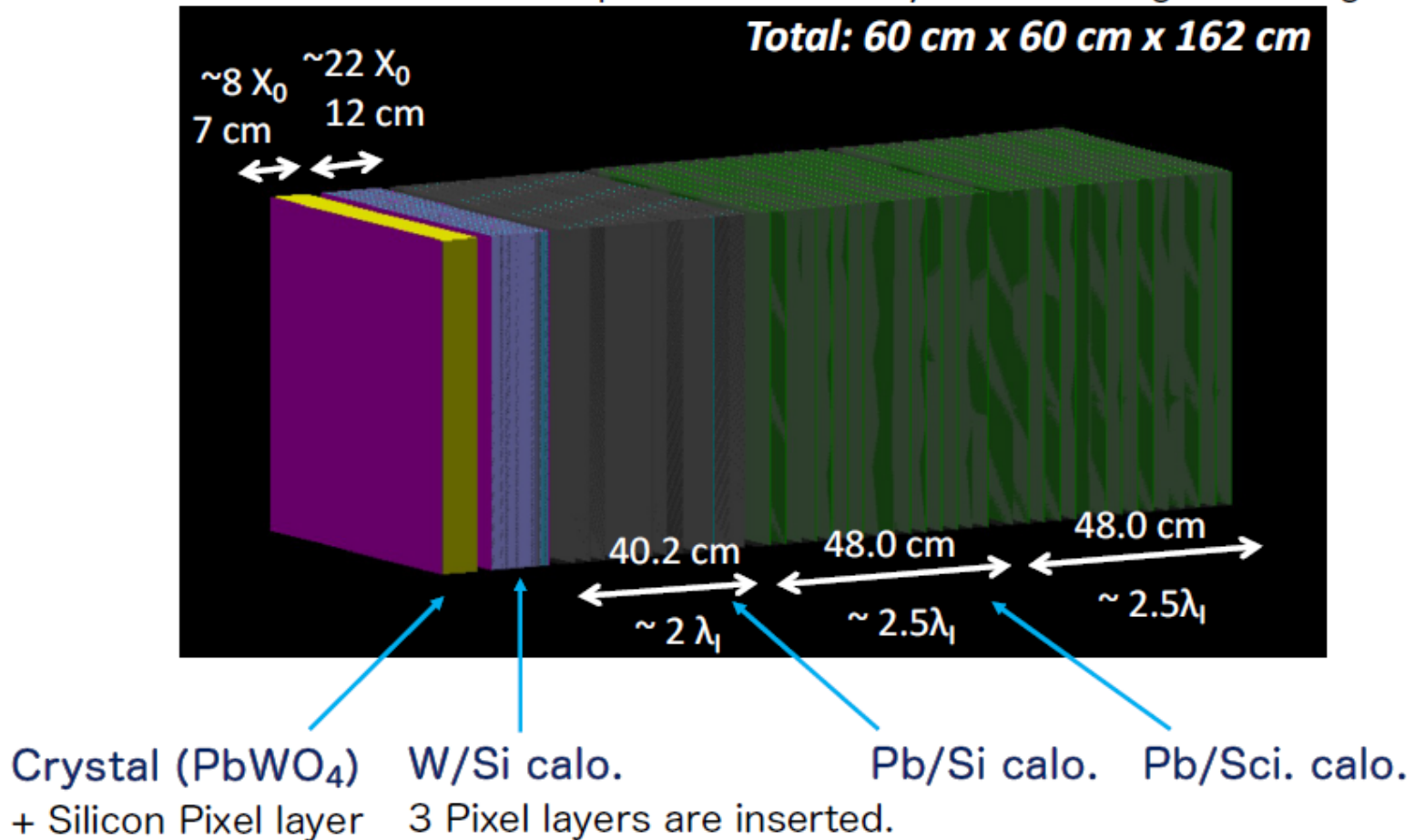
ePIC-ZDC discussion

- 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 → CD3a (2024.1)
 - No need because of no Long Lead-time Procurements
 - TDR → 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.



Task assignment

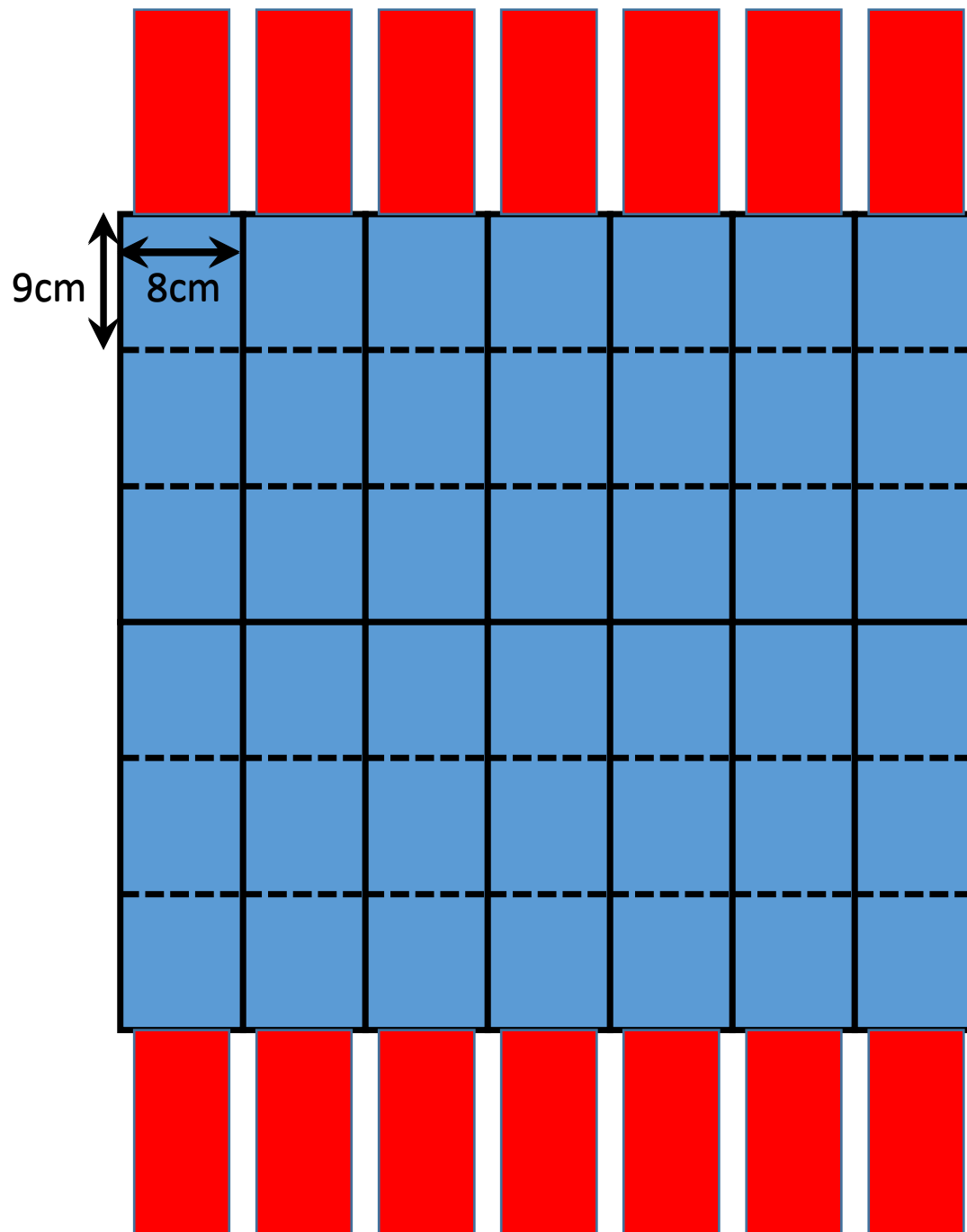
- Review the detector design
 - Hadron calorimeter not necessary an imaging calorimeter (Pb-Si) but a dual-readout calorimeter of fused-silica + plastic scintillator?
 - Only plastic scintillators except near the beam axis and at the downstream?
 - Better simplification of design
 - Reduce number of 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

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 $\rightarrow 6 \times 7 = 54\text{cm} \times 56\text{cm}$?
 - Smaller number of layers? e.g. $1X_0 \times 22 \text{ layers} \rightarrow 2X_0 \times 11 \text{ layers}$?
- Hadron calorimeter
 - 1st design:
 - Pb-Si $0.16\lambda_I$ x 12 layers (40cm)
 - Pb-Scintillator 10cm x 10cm x 48cm ($2.5\lambda_I$) 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?



Backup Slides

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/cm² after several years of operation
 - Radiation tolerance should be considered in the technology selection

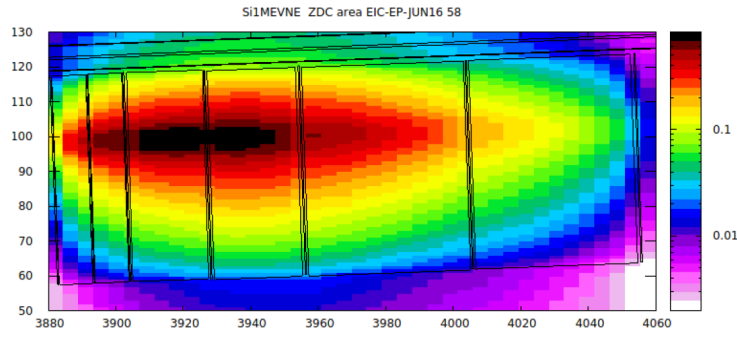
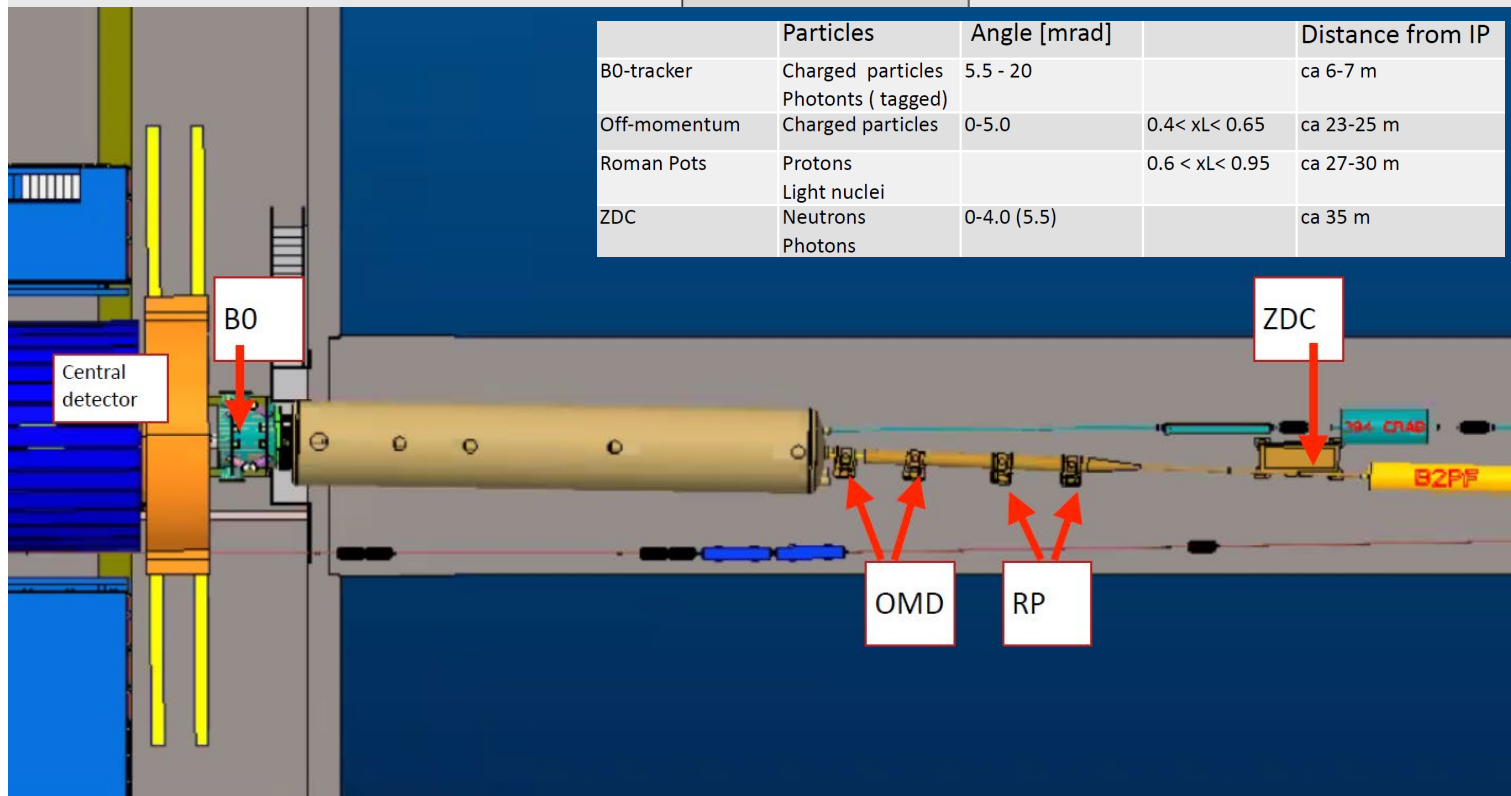
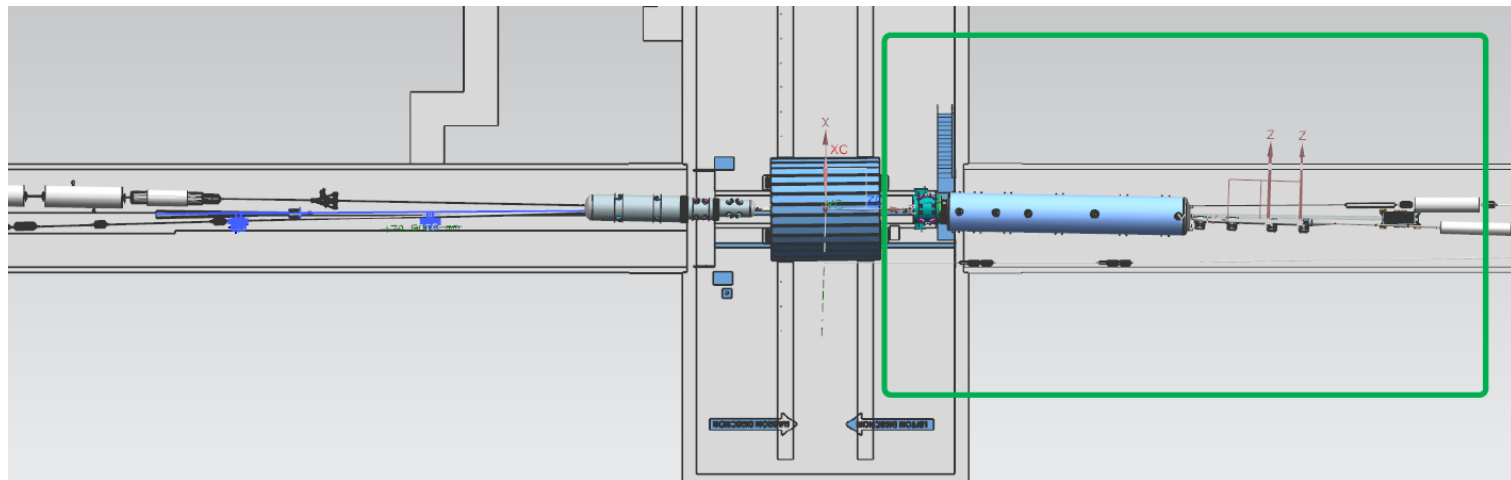


FIG. 5. Neutron MEQ fluence in the area of ZDC from $e(10 \text{ GeV}) + p(275 \text{ GeV})$ -collisions. Vertical scale: X coordinate perpendicular to the e-beam line (cm); Horizontal scale: coordinate Z along the electron beam line (cm). Electrons travel in $-Z$ direction. Fluence is given in units of neutrons/cm² per primary ep -collision. The maximum fluence in the center of ZDC is of $8.E-1$ neutrons/cm² per primary ep interaction. At maximal luminosity (10^{34} /cm²/sec the ep interaction rate is $\sim 5 \cdot 10^5$ /sec. ffl182

One MeV neutron equivalent fluxes F through the silicon material and life time						
Detector.	R_{min}/cm	R_{max}/cm	Z_{mea}/cm	$F_{p+rg}/(cm^2s)$	$F_{e+p}/(cm^2s)$	$F_{tot}/(cm^2OY)$
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 $0.5 \times 10^{16} Hz$ (at the luminosity of $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$). 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/cm²/s and from both sources in f MEQ neutrons/cm²/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

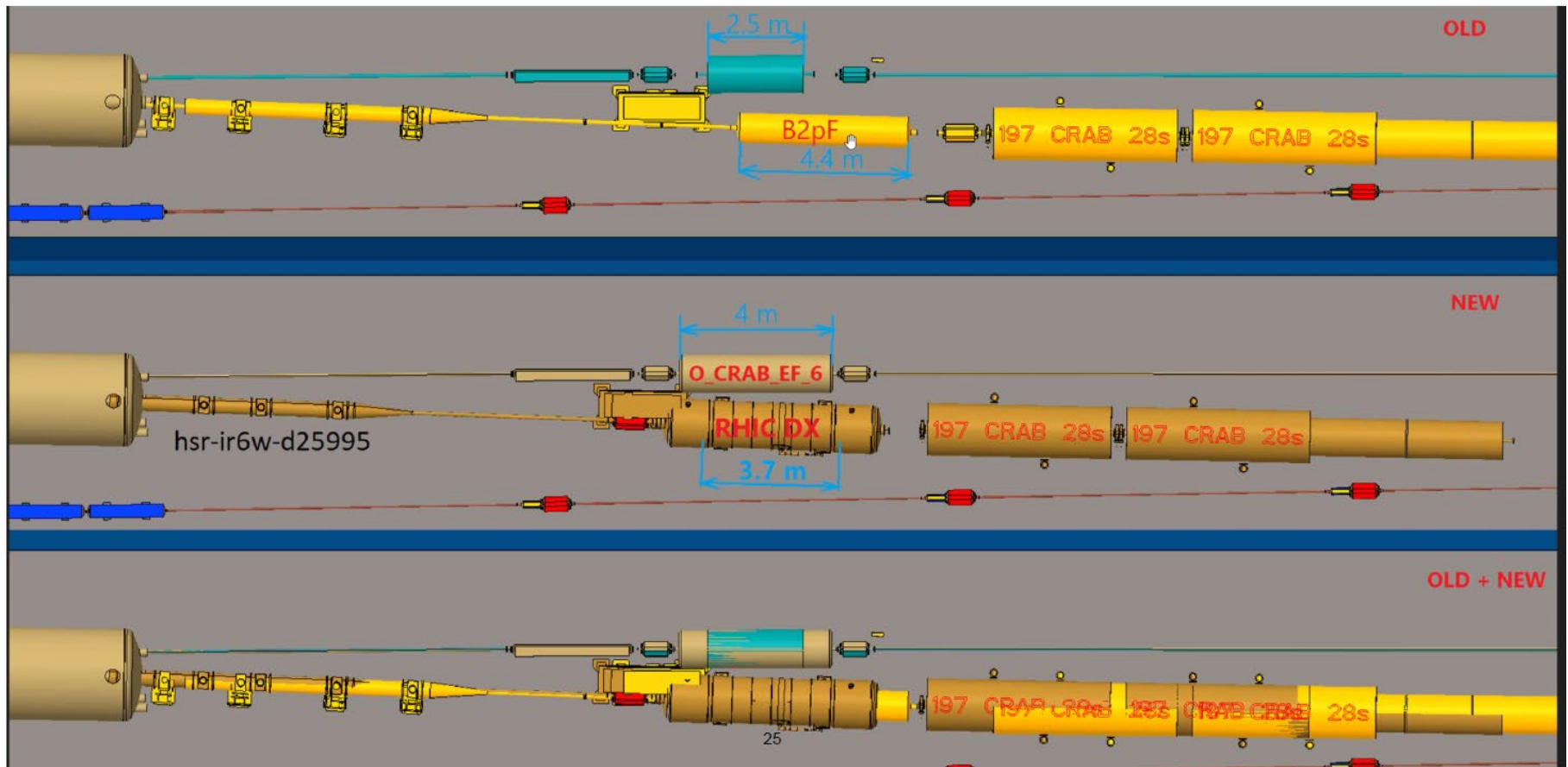
ePIC far-forward detectors



ePIC-ZDC geometry update

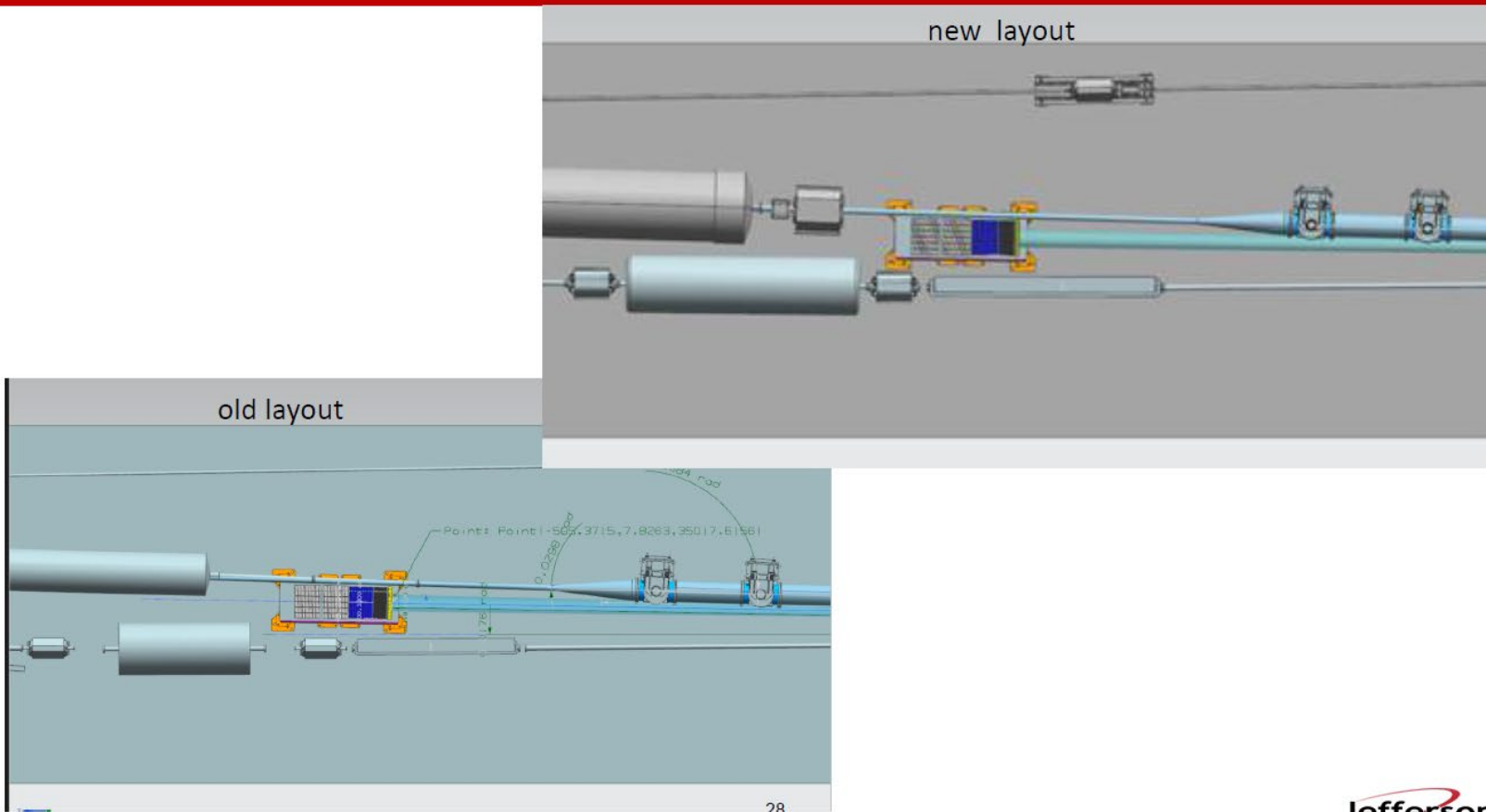
ACCELERATOR LAYOUT UPDATES

Karim Hamdi (BNL)



ePIC-ZDC geometry update

ZERO-DEGREE CALORIMETER

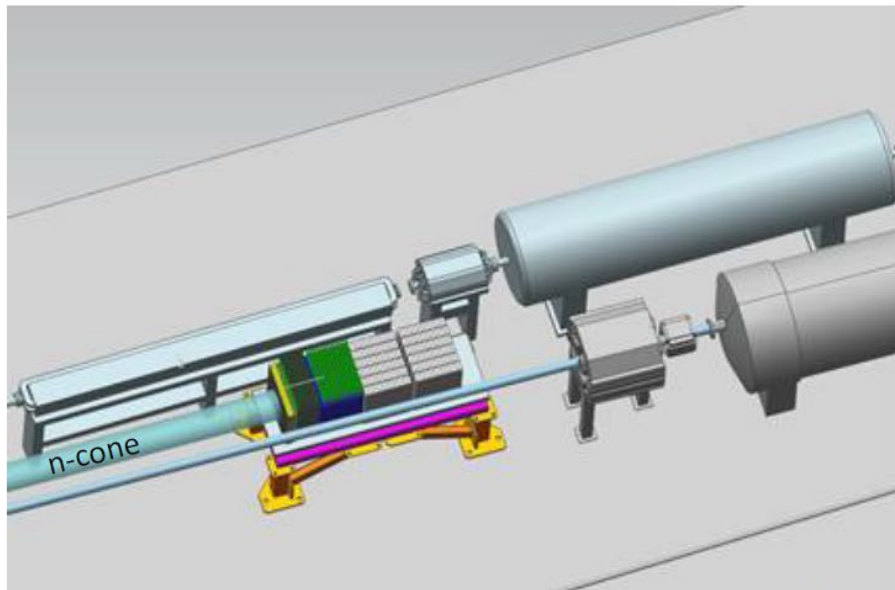


ePIC-ZDC geometry update

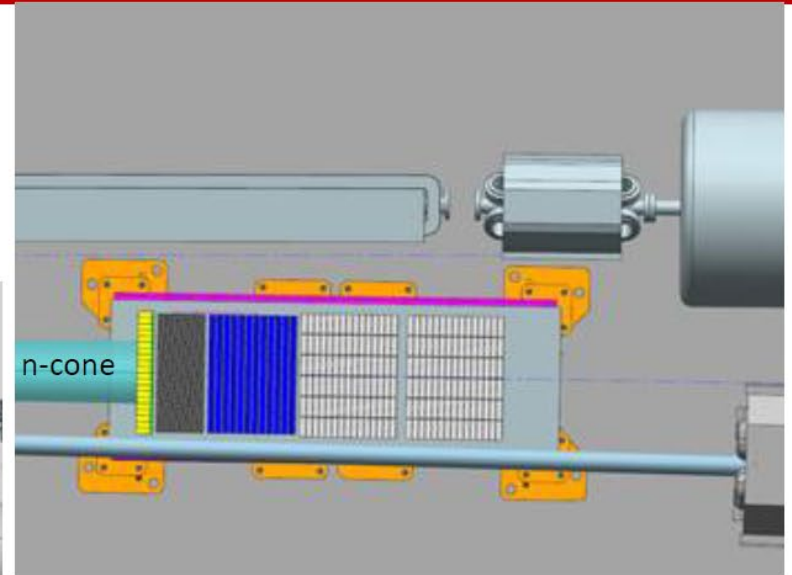
ZDC

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

Z-placement , transverse size



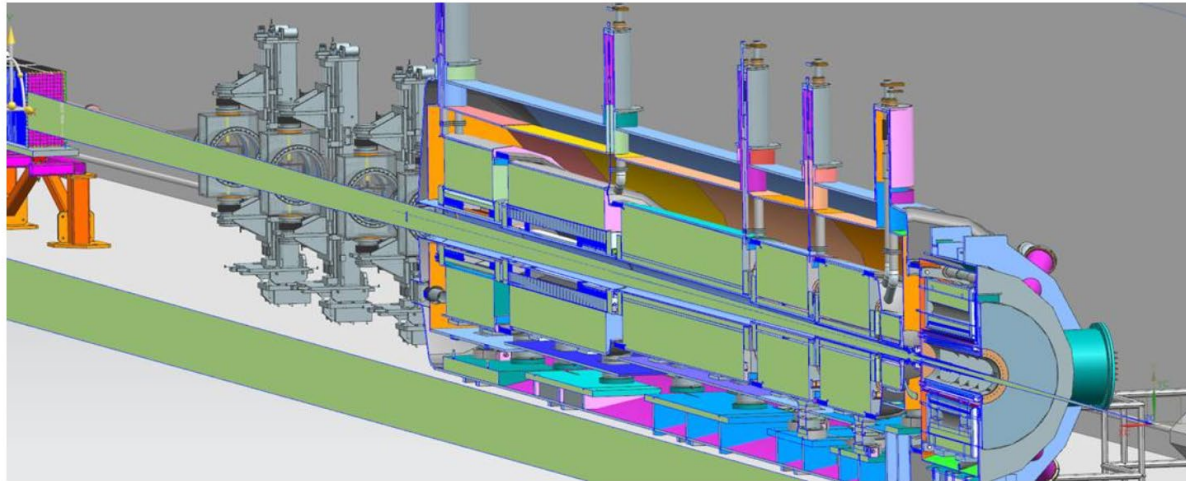
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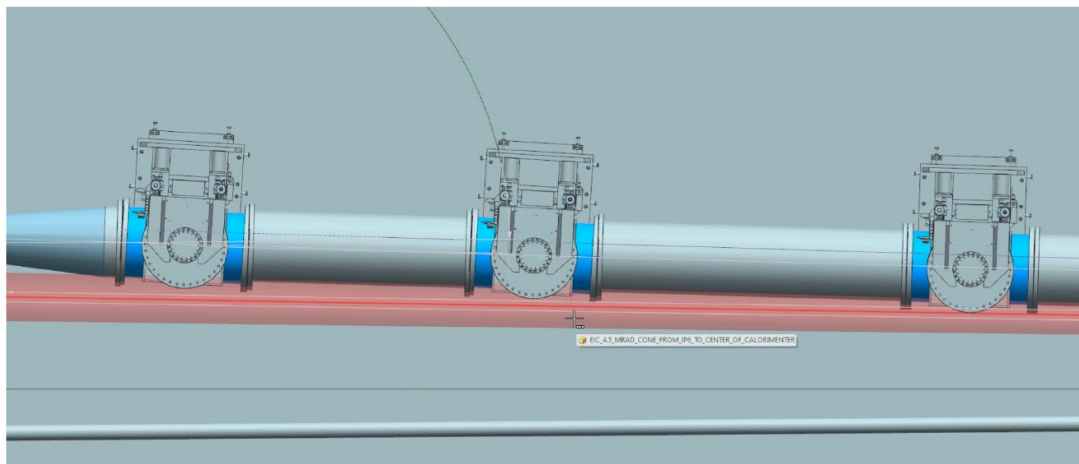
Jefferson Lab

Neutron cone

4.5 mrad cone towards ZDC (in green)



NEUTRON-CONE (NEED TO CHECK!)



W-Si module design

FAR-FORWARD - ZDC

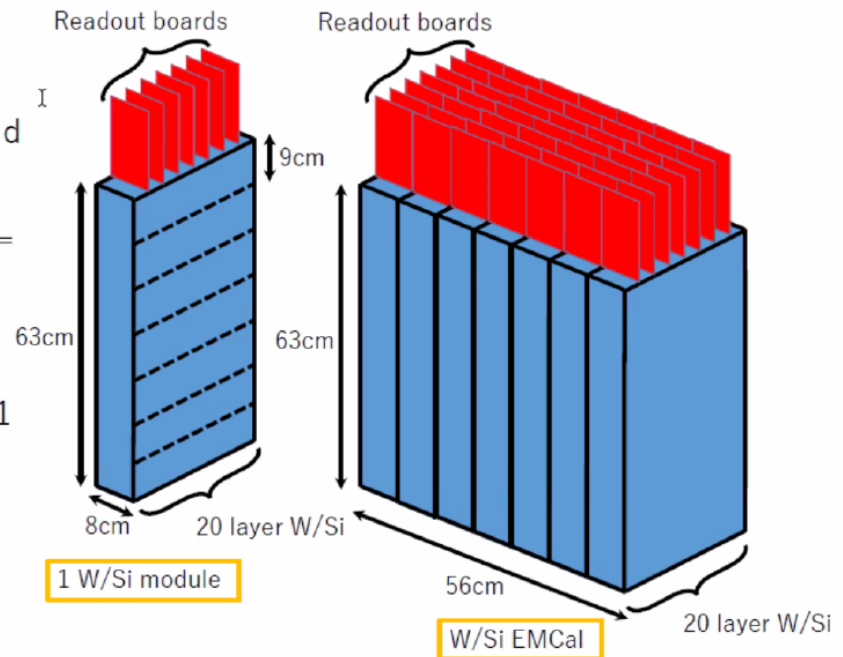
Overleaf document
(internal notes, preTDR)

- 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

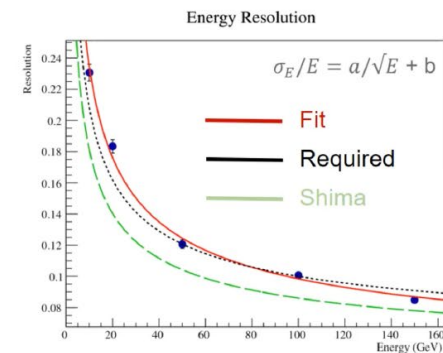
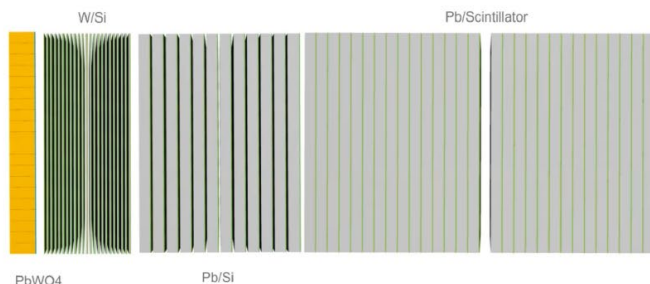


Simulation study

• Energy resolution by Po-Ju

ZDC RESOLUTION (NEUTRONS)

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

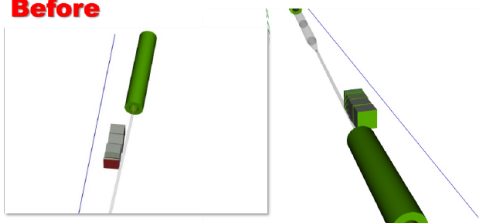


- Fit: $\frac{63\%}{\sqrt{E}} + 3.6\%$
- Required: $\frac{50\%}{\sqrt{E}} + 5\%$
- Shima: $\frac{44\%}{\sqrt{E}} + 4.2\%$

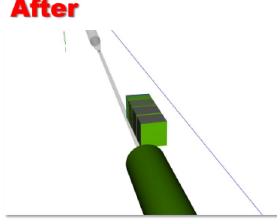
ZDC Monte Carlo implementation (1/2)

Po-Ju Lin

Before



After



23

Jefferson Lab

- 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.

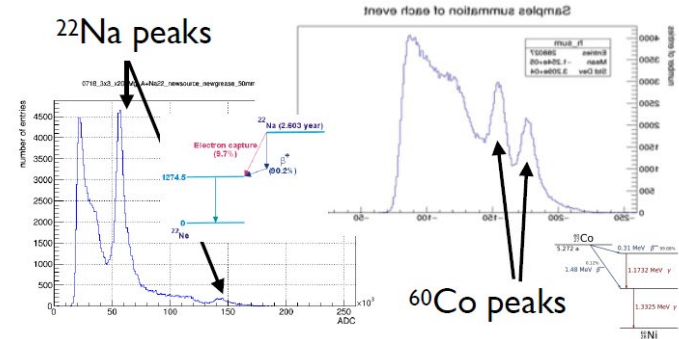
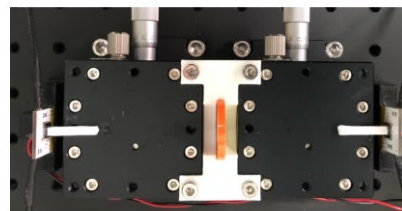
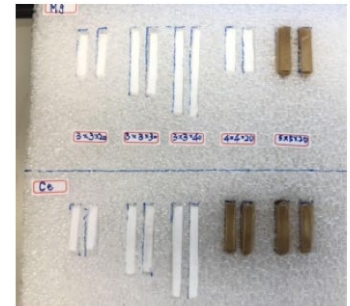
LYSO Crystal by Taiwan group

PbWO₄ 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

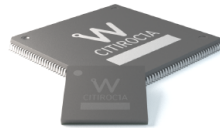
- NTU is setting up measurements for
 - absolute light yield of LYSO crystal using PMTs
 - time resolution of LYSO using SiPM
 - reach coincident time resolution of ~130ps



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



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