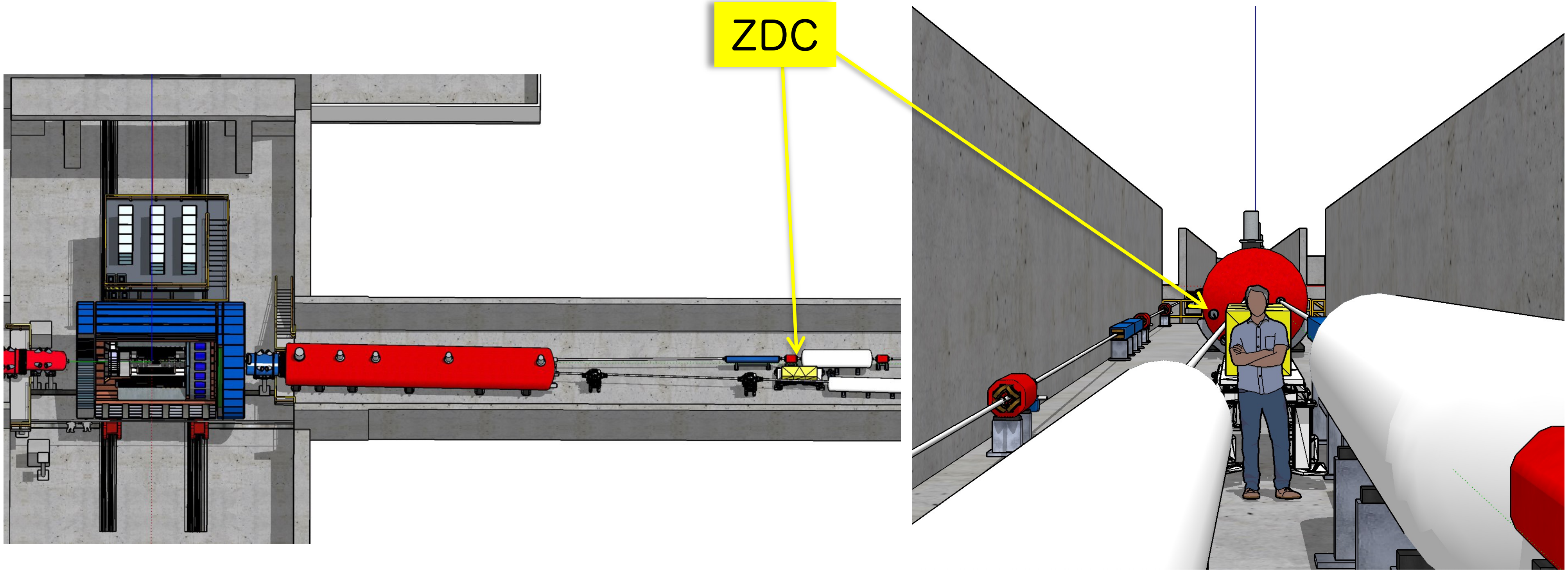
Zero Degree Calorimeter（ZDC)

Calorimeter to measure photons and neutrons.
ZDC sits at ~38m from interaction point.



Shima Shimizu (RIKEN/JSPS)
for the eRD27 collaboration

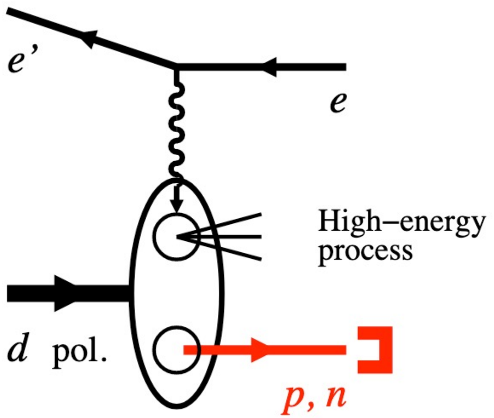
EIC IR Integration and Auxiliary Far-Forward/Far-Backward
Detectors Technical Design Review (27/Apr/2022)

Physics case for the ZDC

- Neutron-tagging e+d DIS

  From comparison to e+p DIS, access to nucleon structure in the deuteron

  → Reduction of uncertainties in use of e+d data in proton PDF determination.

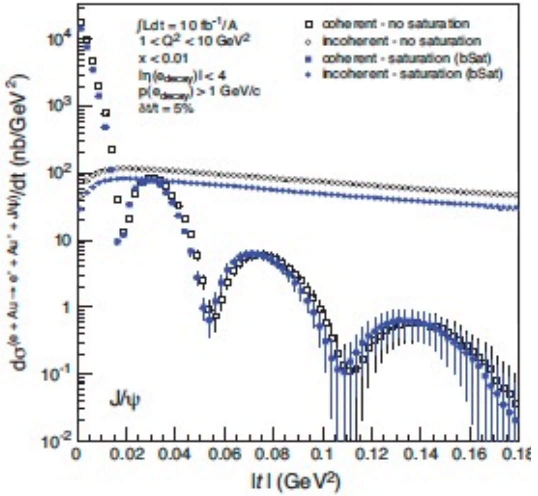


Forward detection

- Vector Meson production in e+A

  Veto incoherent events by tagging photons and/or neutrons.

  → Sensitivity to gluon saturation



← Incoherent

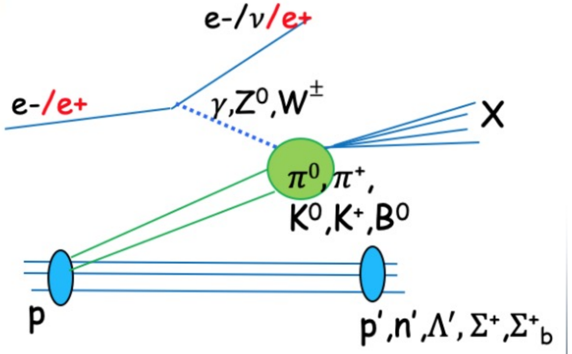
← Coherent

- Meson structure (Sullivan Process)

  Measure neutron or Λ （→n+2γ）in far-forward

  → Structure of π, K, etc.

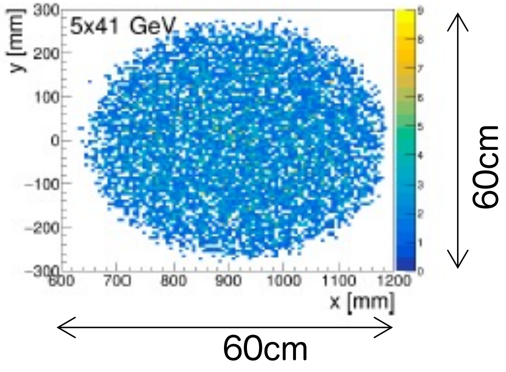
and diffraction, leading neutrons measurements…



Performance requirements

YR Fig. 8.104

Neutrons from e+p→ e'+X+n

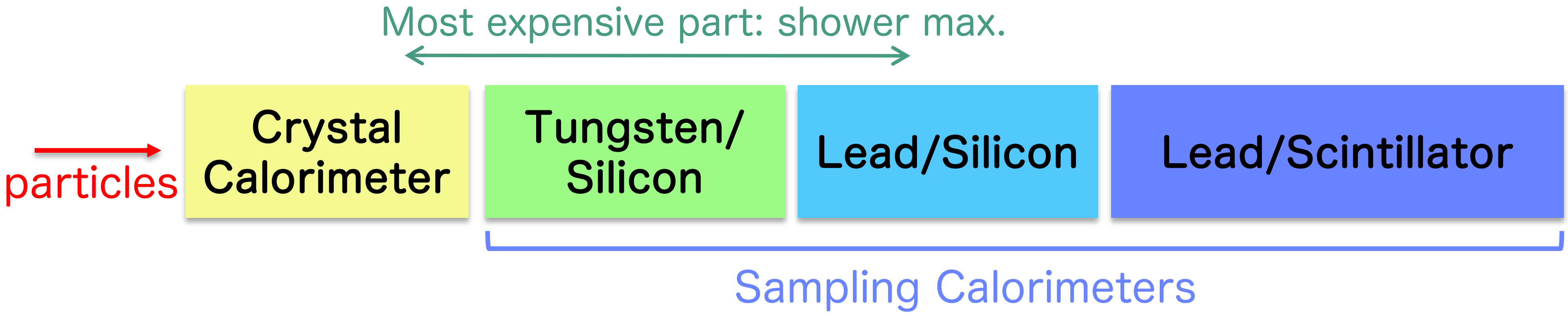


- Large acceptance: 60 cm x 60 cm
- Measurement of GeV photons and neutrons
- Detection of soft photons, with detection efficiency > 90%

	Energy range	Energy resolution	Position resolution
Neutron	$\sim 275\ \mathrm{GeV}$ (up to beam energy)	$\frac{50\%}{\sqrt{E}} + 5\%$	$\frac{3\ \mathrm{mrad}}{\sqrt{E}}$
Photon	$\mathrm{O}(100)\ \mathrm{MeV}$	$20\sim30\%$	
	$20\sim40\ \mathrm{GeV}$	$\frac{35\%}{\sqrt{E}}$	$0.5\sim1\ \mathrm{mm}$

→ Huge energy range requires very detailed reconstruction of photon and neutron showers.

Design concept: Full shower reconstruction



Most expensive part: shower max.

particles

Crystal Calorimeter

Tungsten/ Silicon

Lead/Silicon

Lead/Scintillator

Sampling Calorimeters

Meas. of O(100) MeV photons

Meas. of GeV-photons, shower, and position
ALICE FoCal-E type calorimeter
←Expected energy resolution: 25%/√E+2%

Meas. of hadron shower (Si for rad-hard.)

Meas. of hadron energy

Transverse granularity

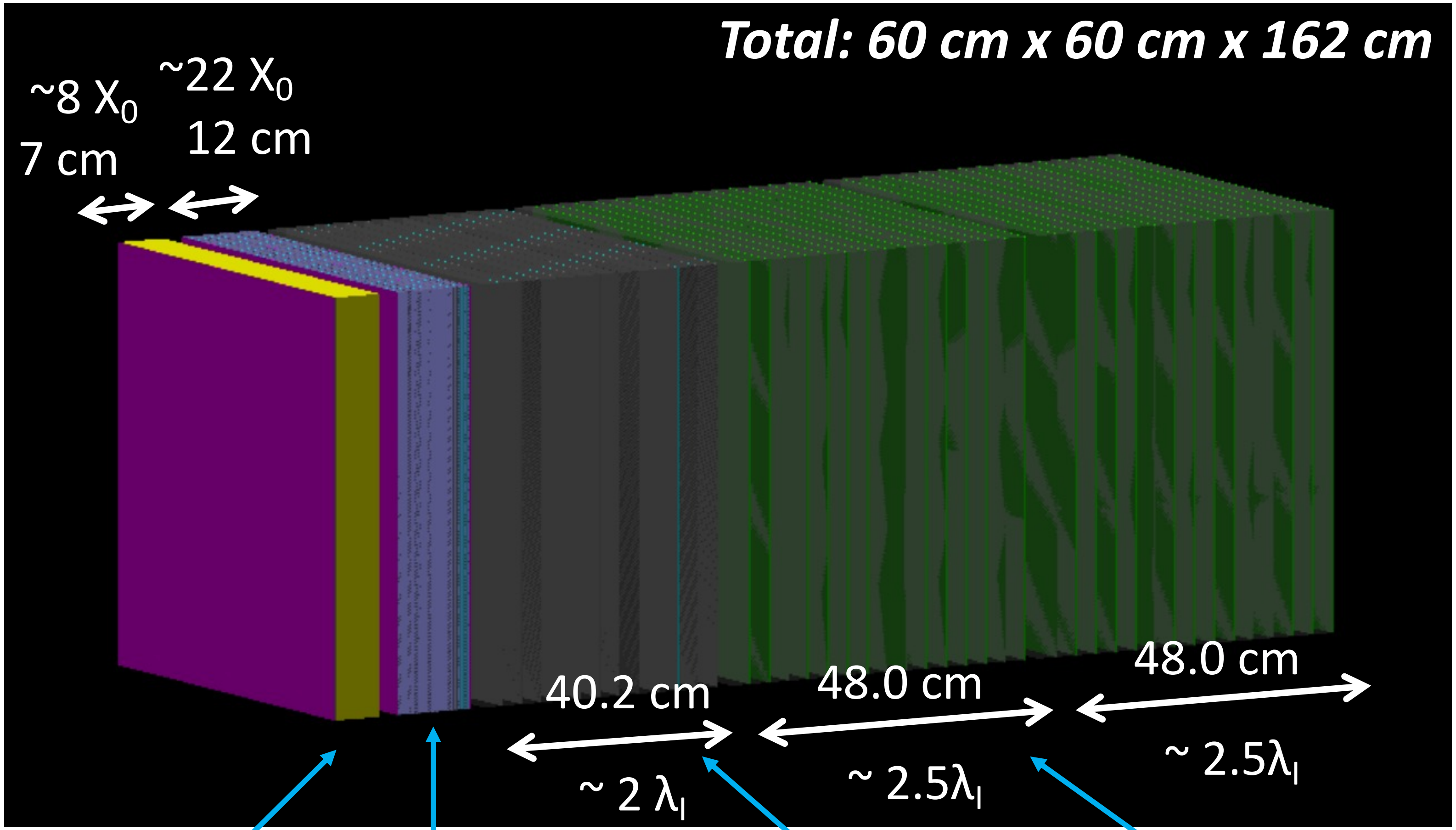
Crystal
3cm x 3cm

Silicon
Pad layer 1cm x 1cm
Pixel layer 3mm x 3mm

Scintillator
10cm x 10cm

Current ZDC design

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



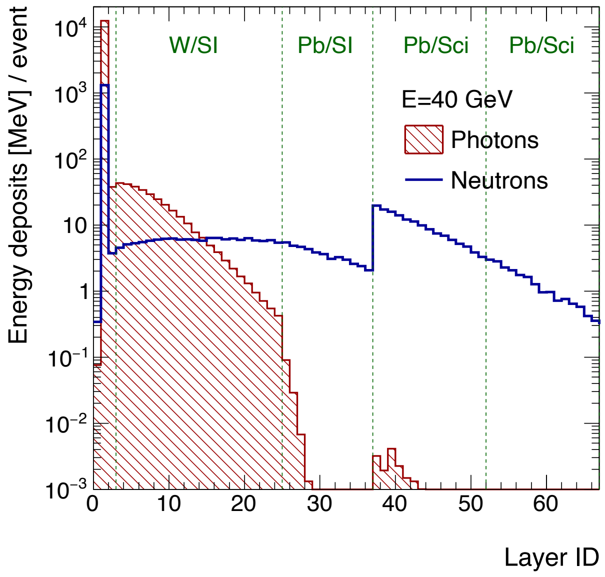
Crystal ($PbWO_4$)
+ Silicon Pixel layer

W/Si calo.
3 Pixel layers are inserted.

Pb/Si calo.

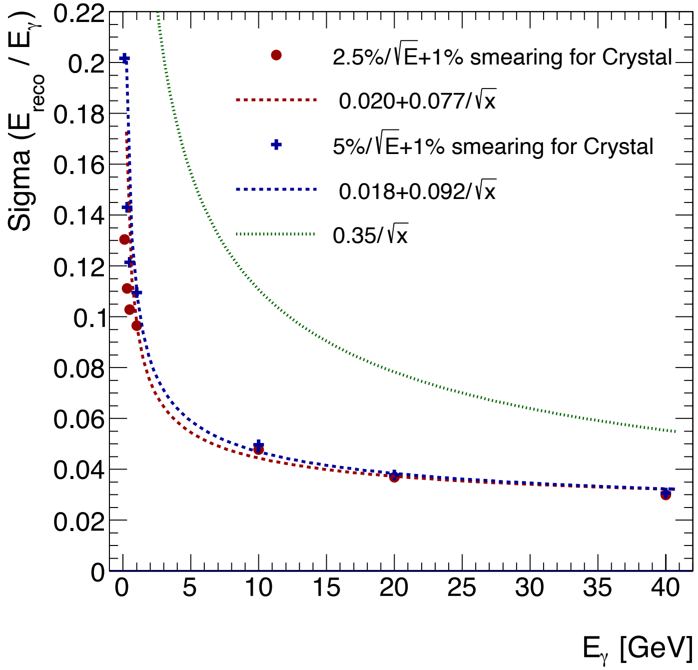
Pb/Sci. calo.

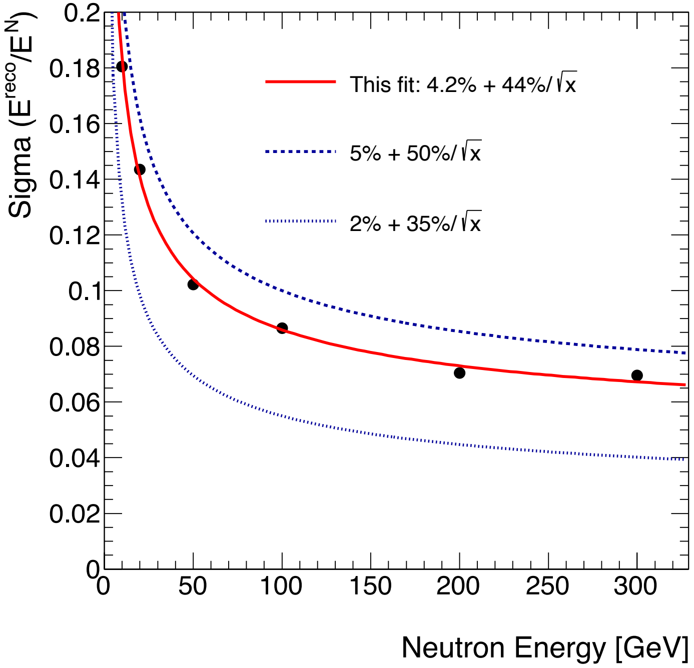
Simulated performance meets requirements



Geant4 simulation uses energy deposits, not the scintillated photons.

Some of service/readout materials are not in the simulation.





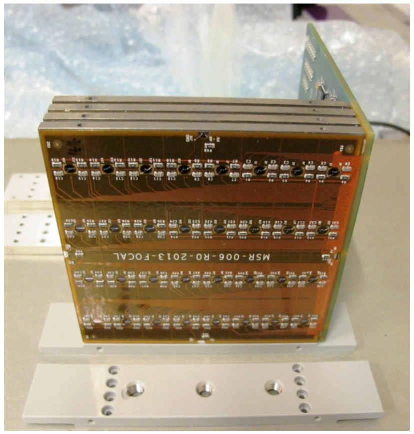
Readout based on ALICE FoCal

	N. of ch. per unit	total N. of ch.	Readout technology in consideration
Crystal	400	400	APD, if it has sufficient radiation hardness.
Silicon pad	3600 / layer	115200	HGCROC, as in the ALICE FoCal-E pad layers.
Silicon pixel	40000 / layer	160000	Need discussion. → slide 9
Scintillator	36 / box	72	APD (15 layers are read together. by Shashlik?)

ALICE FoCal EM section

ALICE-PUB-2020-005 https://cds.cern.ch/record/2696471

A readout board is inserted right after each silicon layer.



Prototype of an ALICE FoCal-E pad segment

NIM A 988 (2021) 164796

Major open points

- **Which crystal?**

	light yield	cost	note
$PbWO_4$	low	less expensive	
LYSO	high (>100 x $PbWO_4$)	high	good timing resolution
SciGlass	better than $PbWO_4$	not high	still in development

- **Readout of silicon pixel?**
  - Finer version of silicon pad?
  - ALICE FoCal high-granularity readout?

- **AC-LGAD?**
  - Timing information for particle ID/energy measurement.
  - Photon detectors for crystals?

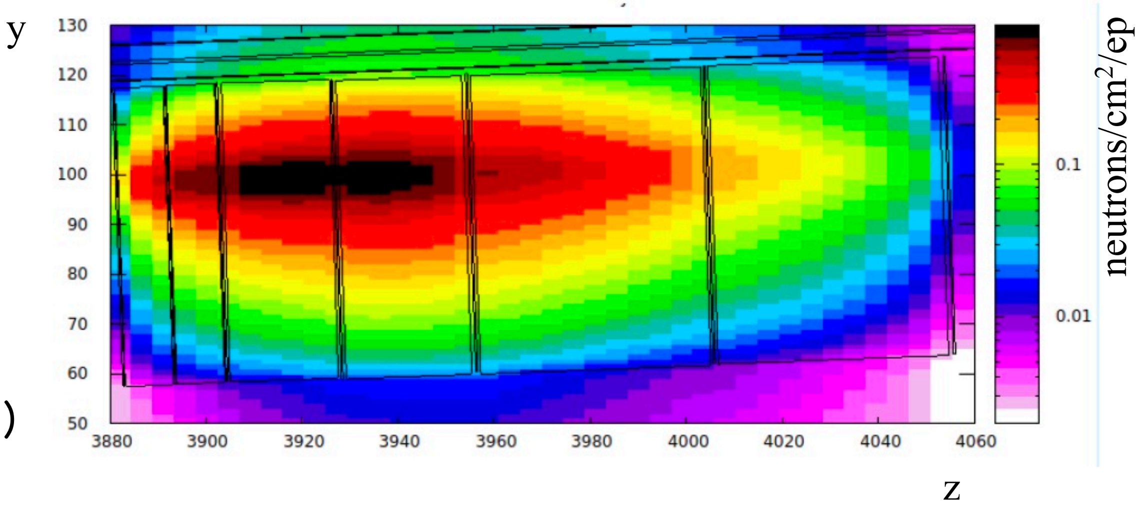
Radiation load

- First radiation estimate:

  Operation for 1/3 of a year
  → 8 x 10^{12} n_{eq}/cm^2

  (work by V. Baturin)

Neutron MEQ fluence from ep (10GeV x 275GeV)



- Irradiation tests at RIKEN.
  - In March 2022, in collaboration with FoCal
    - Max. 10^{14} neutrons/cm^2 in 2 days.
    - Silicon chips and APDs are irradiated.
  - More tests in future

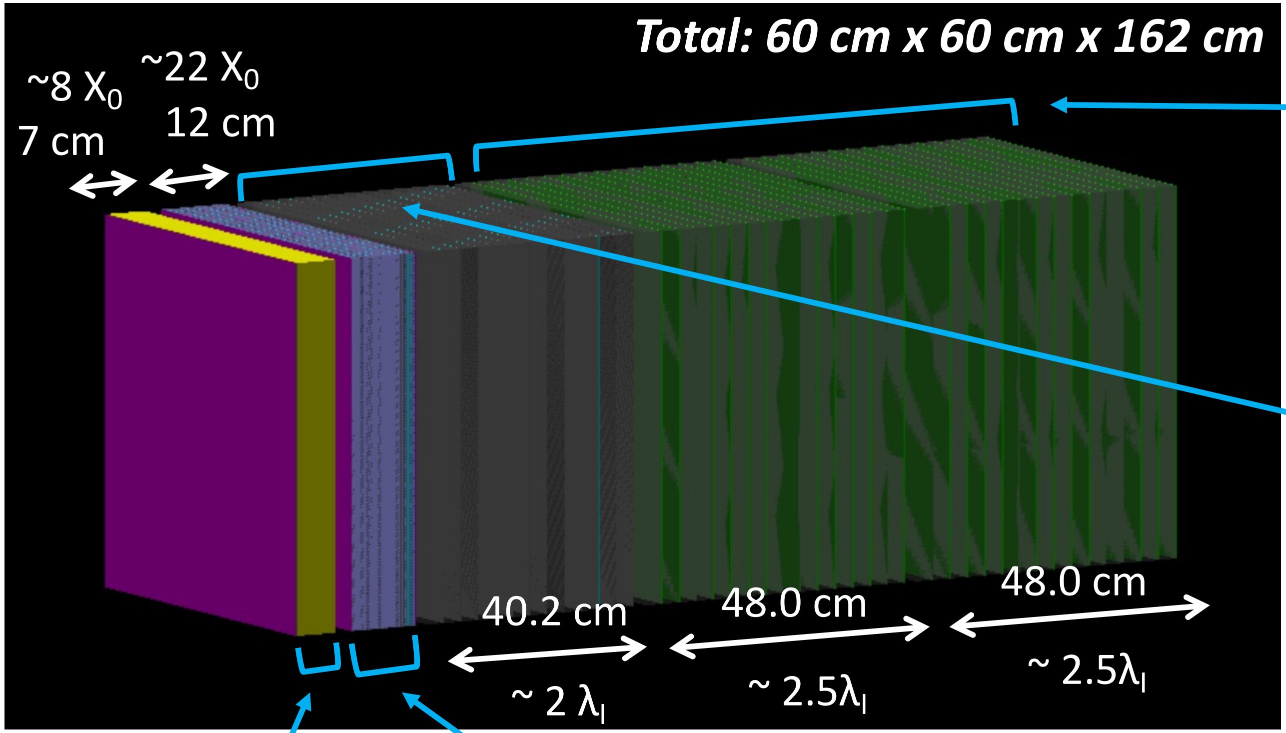
Summary

- ZDC is designed to measure O(100) MeV photons, GeV photons, and neutrons up to the beam energy.
- Currently designed as a complex of a crystal calorimeter and 3 types of sampling calorimeters.
- Details of the design will be further optimized/updated.

Backup

Current ZDC design

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



15 layers x 2

Pb 3cm thickness

Scintillator
10 cm x 10 cm x 2 mm

12 layers

Pb 3cm thickness

Silicon pad layer
1 cm x 1 cm x 320 µm

1 layer

Silicon pixel layer
3 mm x 3mm x 300 µm

Crystal (PbWO4)
3cm x 3cm x 7 cm

Si: 3 layers
Si: 20 layers = Si + 2 x
W: 22 layers

10 layers

Tungsten 3.5 mm thickness

Silicon pad layer
1 cm x 1 cm x 320 µm

+

1 layer

Tungsten 3.5 mm thickness

Silicon pixel layer
3 mm x 3mm x 300 µm

Cost estimation

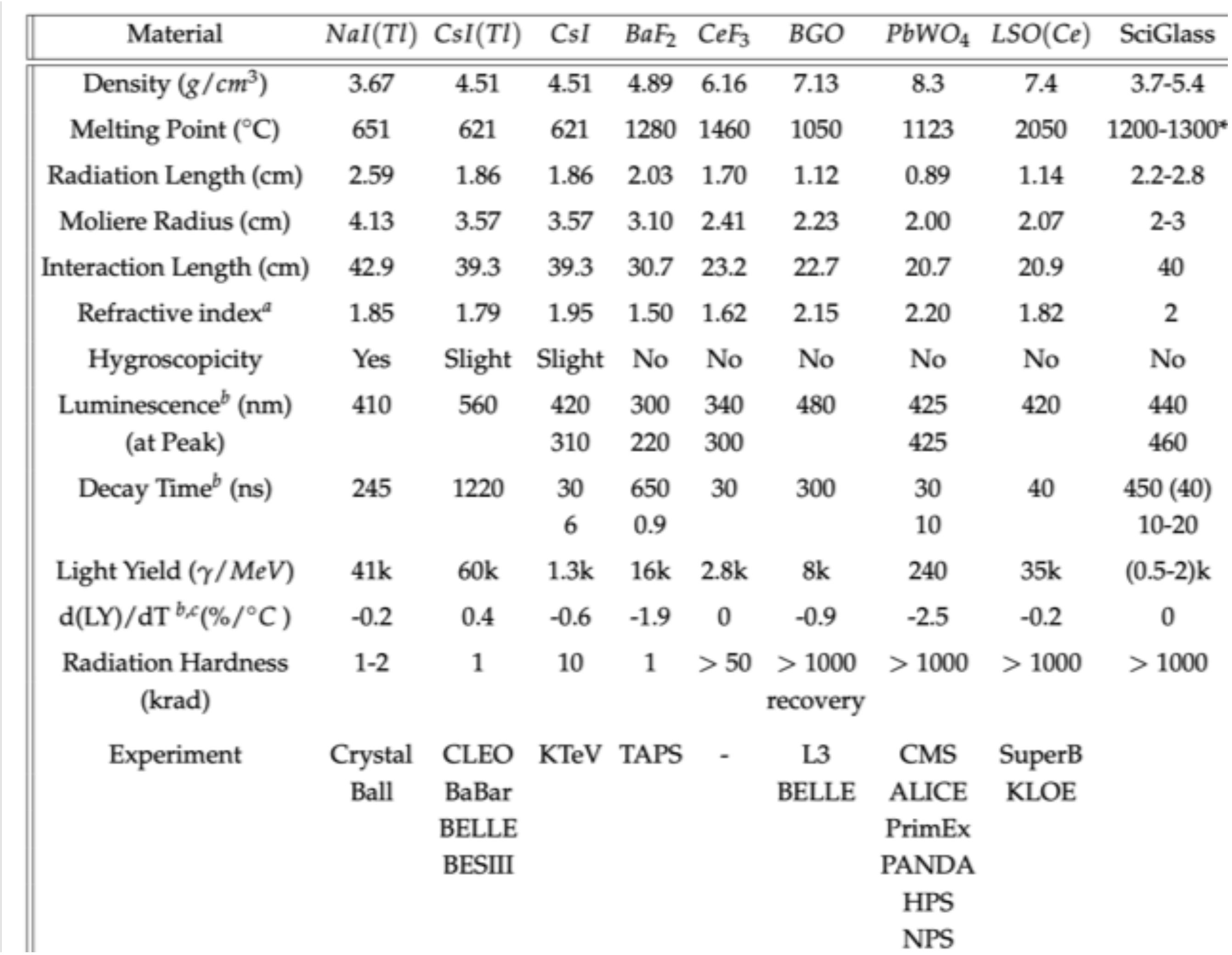
- In ECCE proposal:
  $ 7M (All in-kind cost)

- Estimation for detector itself (materials + readout) in EIC-Japan:
  $ 5.4M

Crystal cal.	$ 0.9M
W/Si cal.	$ 2.7M
Pb/Si cal.	$ 1.1M
Pb/Sci cal.	$ 0.6M

$PbWO_4$ $385K, Crystal readout $251K
Si-pad $56K/layer, Si-pad readout $22K/layer
Si-pixel $56K/layer, Si-pixel readout $247K/layer
W plates $12.5K/layer, Pb plates $12.5K/layer
Pb+Scintillator $110K x 2, Pb+Scintillator readout $200K x 2

Comparison of materials



Material	$NaI(Tl)$	$CsI(Tl)$	CsI	BaF_2	CeF_3	BGO	$PbWO_4$	$LSO(Ce)$	SciGlass
Density (g/cm^3)	3.67	4.51	4.51	4.89	6.16	7.13	8.3	7.4	3.7-5.4
Melting Point (°C)	651	621	621	1280	1460	1050	1123	2050	1200-1300*
Radiation Length (cm)	2.59	1.86	1.86	2.03	1.70	1.12	0.89	1.14	2.2-2.8
Moliere Radius (cm)	4.13	3.57	3.57	3.10	2.41	2.23	2.00	2.07	2-3
Interaction Length (cm)	42.9	39.3	39.3	30.7	23.2	22.7	20.7	20.9	40
Refractive index[a]	1.85	1.79	1.95	1.50	1.62	2.15	2.20	1.82	2
Hygroscopicity	Yes	Slight	Slight	No	No	No	No	No	No
Luminescence[b] (nm) (at Peak)	410	560	420 310	300 220	340 300	480	425 425	420	440 460
Decay Time[b] (ns)	245	1220	30 6	650 0.9	30	300	30 10	40	450 (40) 10-20
Light Yield (γ/MeV)	41k	60k	1.3k	16k	2.8k	8k	240	35k	(0.5-2)k
d(LY)/dT [b,c](%/°C)	-0.2	0.4	-0.6	-1.9	0	-0.9	-2.5	-0.2	0
Radiation Hardness (krad)	1-2	1	10	1	> 50	> 1000 recovery	> 1000	> 1000	> 1000
Experiment	Crystal Ball	CLEO BaBar BELLE BESIII	KTeV	TAPS	-	L3 BELLE	CMS ALICE PrimEx PANDA HPS NPS	SuperB KLOE	

Photon energy reconstruction