EIC Zero Degree Calorimeter

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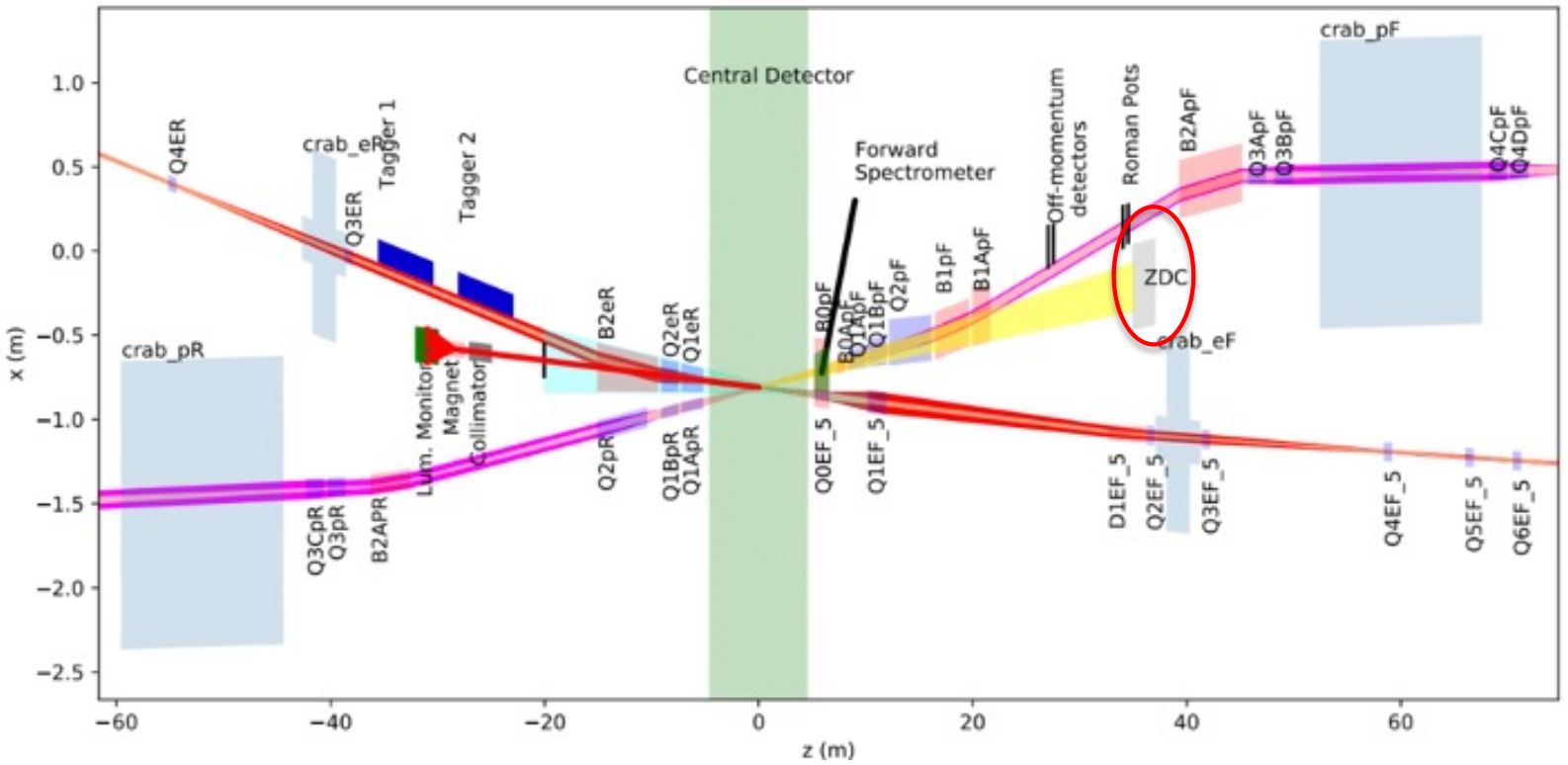
EIC Zero Degree Calorimeter

- A calorimeter to tag photons and neutrons in the proton beam forward direction.
  - 37.5 m (33.5 m) away from the interaction point of IP6 (IP8).



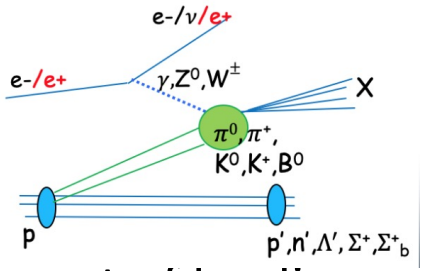
Yellow Report Fig. 11.85 (arXiv:2103.05419)

IP6, but x direction is flipped upside down

Relevant Physics

The list is not completed…
Please see YR (arXiv:2103.05419) for details (sec. 8.4, 8.5)

- Exclusive vector meson production in e+A
  - → Sensitive to saturation
  - Separation of coherent vs incoherent processes
    - ^{208}Pb de-excitation
- u-channel exclusive electroproduction of π^0 (e + p → e’ + p’ + π^0)
  - → Nucleon-to-meson Transition Distribution Amplitudes
- Spectator neutron tagging in e+d DIS (e + d → e’ + X + n)
  - → Nuclear modifications of p and n structure, such as EMC effect.
  - Diffractive J/Ψ in e+d scattering (arXiv: 2005.14706)
    - → Short range correlation (SRC)
- Meson structure (Sullivan process)
  - e+p->(π) -> e’+X+n
  - Λ decay



- Cross section and asymmetry measurement of leading neutrons

Physics requirements

- Neutrons
  - Need to measure neutrons with $E \sim E_p^{beam}$
  - Energy resolution: acceptable **50%/√E + 5%**, ideally **35%/√E + 2%**
  - Angular resolution: **3mrad/√E** (but < 300 µrad is not useful)

    300 µrad <-> 1 cm on ZDC <-> $p_T \sim$ 30 MeV for 100 GeV neutron
  - Large acceptance of 60cm x 60 cm.

- Photons
  - Detect soft photons: O(100) MeV
  - Also, Interested energy region: ~ 20-40 GeV
  - Energy resolution: **45%/√E + 7.5%**
  - Position resolution: 0.5-1mm (tentative)
    - for the meson structure measurement

The first ZDC design

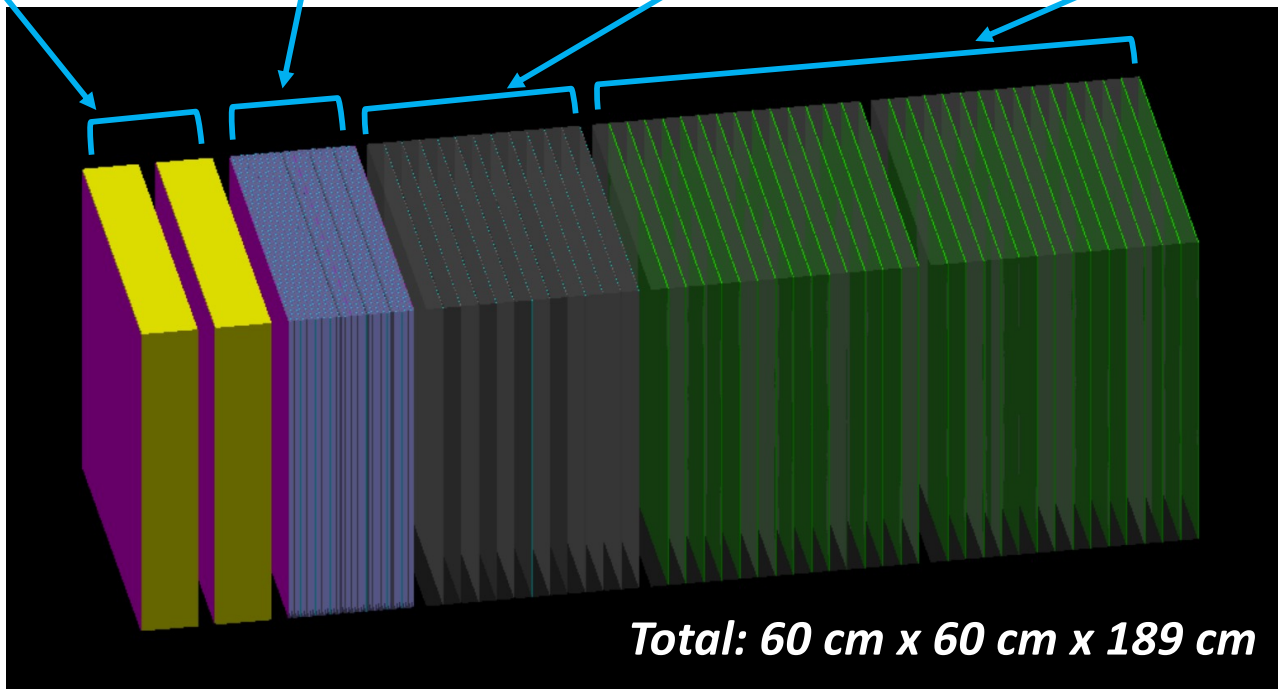
- Concept: **Crystal** + **FoCal style EM calorimeter** + **Hadron Calorimeter**

Silicon
(3 mm x 3mm)
Crystal (PbWO4)
- Tag low energy photon

Tungsten
Silicon (1 cm x 1 cm)
with a few **Si** (3mm x 3mm) layers
- Measure EM shower
- Identify photon/neutron

Pb
Silicon (1 cm x 1 cm)
- Measure starting of hadron shower (position)
- Radiation hardness

Pb
Scintillator
- Measure hadron energy



The first design

Si + 2 x { 20 layers + 1 layer }

- **Tungsten** 3.5 mm Thickness
- **Silicon** 1 cm x 1 cm x 320 µm
- **Tungsten** 3.5 mm Thickness
- **Silicon** 3 mm x 3mm x 300 µm

Si: 3 layers
Si: 40 layers
W: 42 layers

2 layers

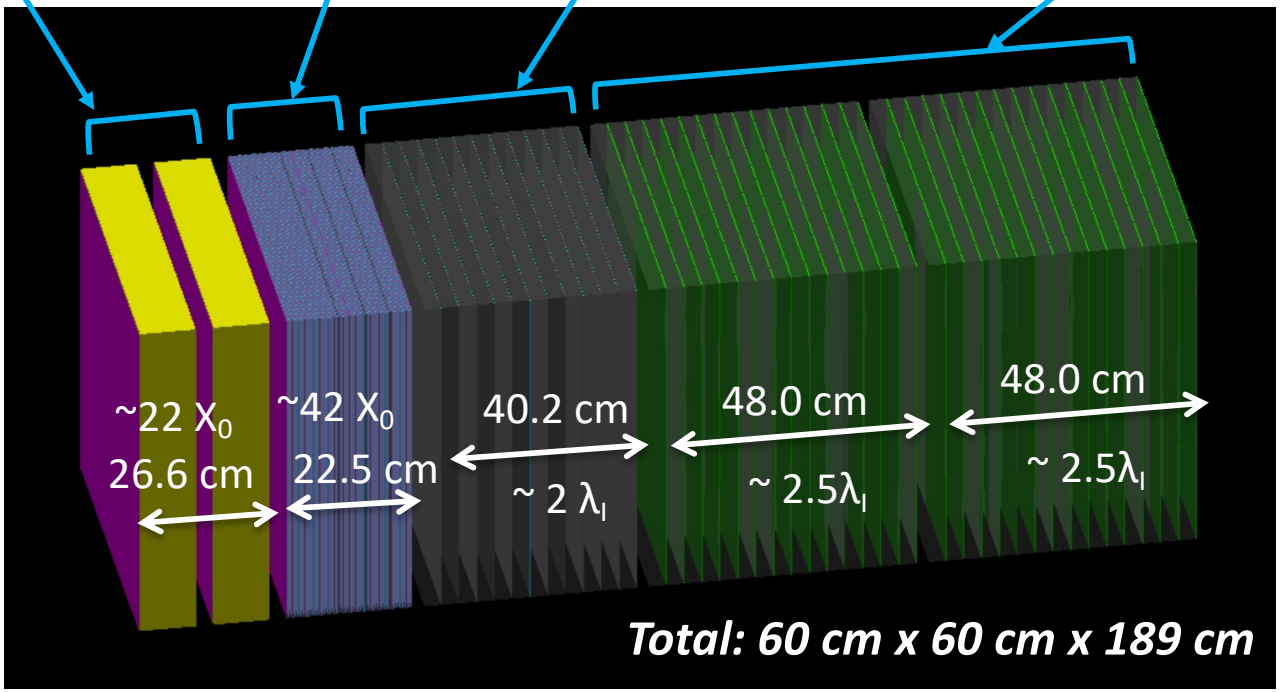
Silicon
3 mm x 3mm x 300 µm
Crystal ($PbWO_4$)
3cm x 3cm x 10 cm

12 layers

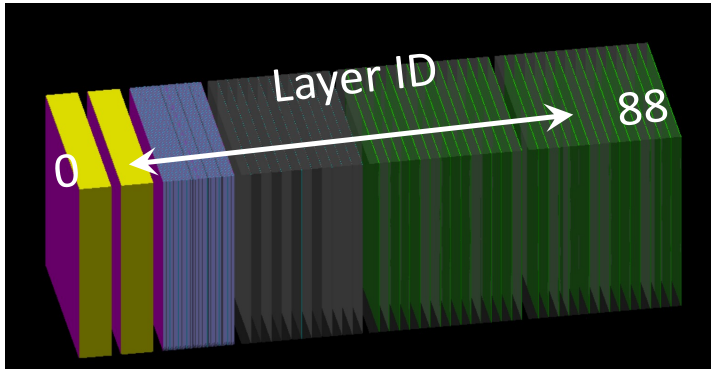
Pb 3cm Thickness
Silicon
1 cm x 1 cm x 320 µm

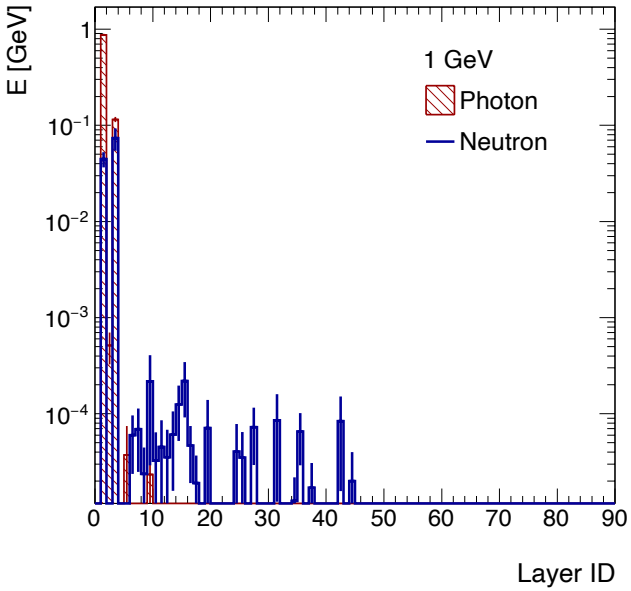
30 layers (15 layers x 2)

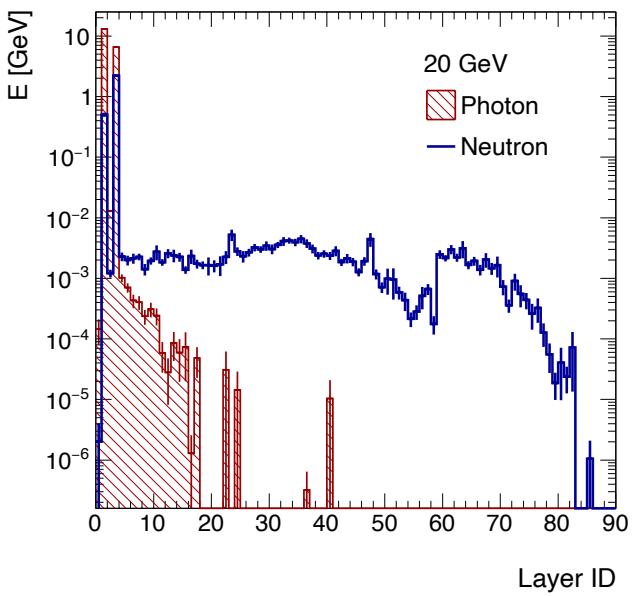
Pb 3cm Thickness
Scintillator
10 cm x 10 cm x 2 mm

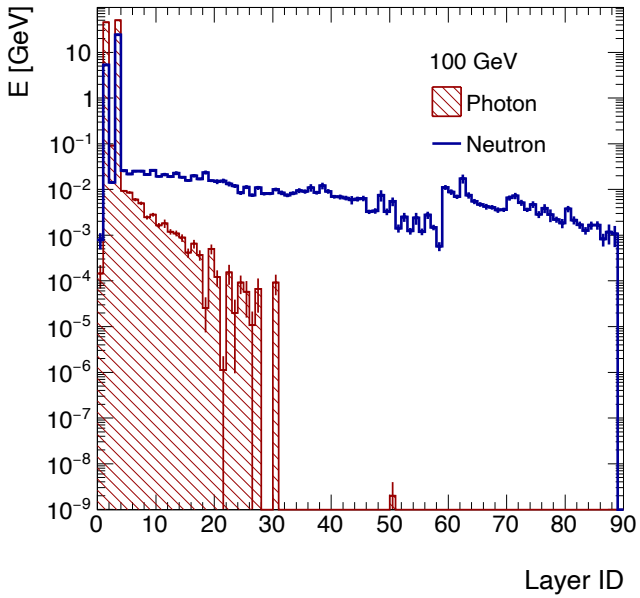


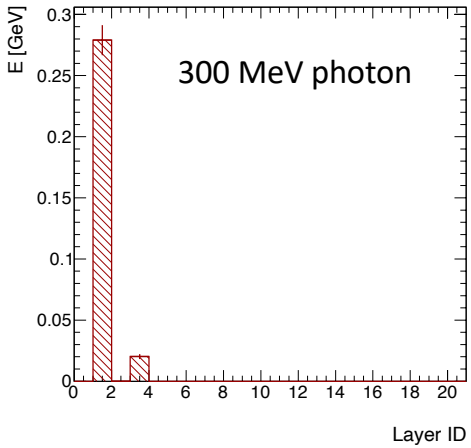
The first design:
Energy deposition per layer











Layer ID	Type	Thickness
1, 3	Crystal 3cm x 3cm	10 cm
0, 2, 4, 25, 46	Silicon 3mm x 3mm	300 µm
5-24, 25-45	Silicon 1cm x 1cm (w/ Tungsten)	320 µm
47-58	Silicon 1cm x 1cm (w/ Pb)	320 µm
59-88	Scintillator 10cm x 10cm	2 mm

Energy map w/ 100 GeV photon or neutron

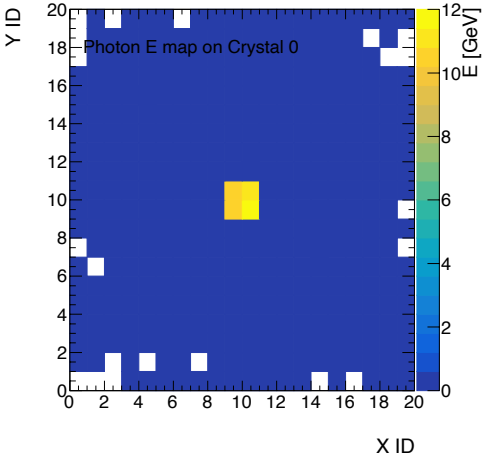
Layer 1
(Crystal 0)

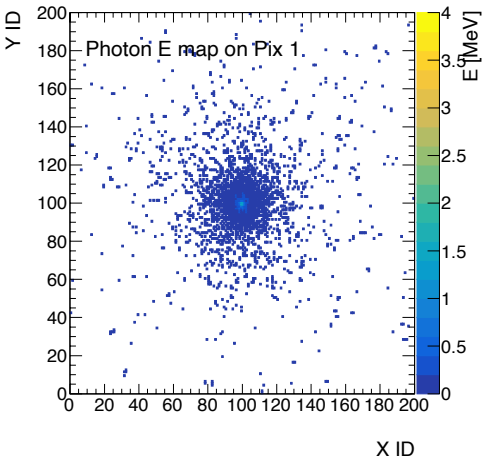
Layer 2
(3mm x 3mm Silicon)

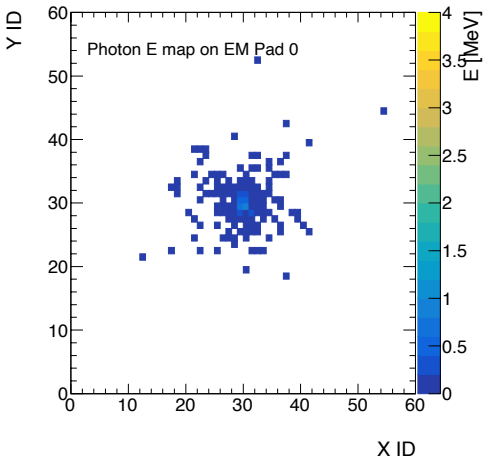
Layer 5
(1cm x 1cm Silicon
absorber = Tungsten)

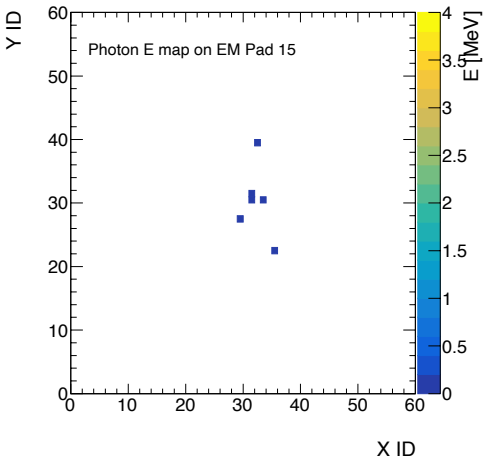
Layer 20
(1cm x 1cm Silicon,
absorber = Tungsten)

Photon

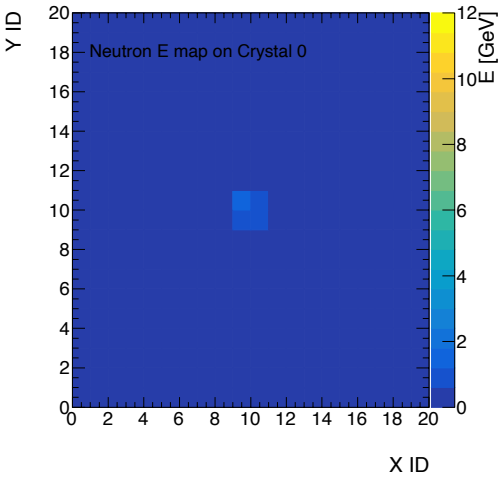


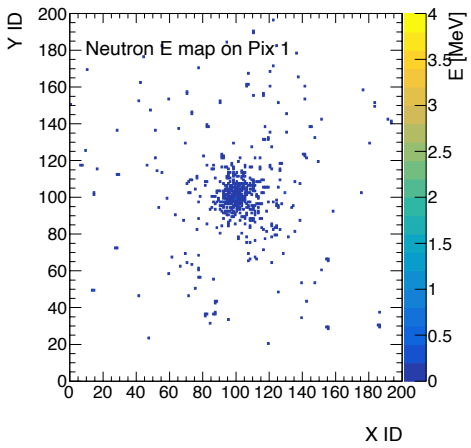


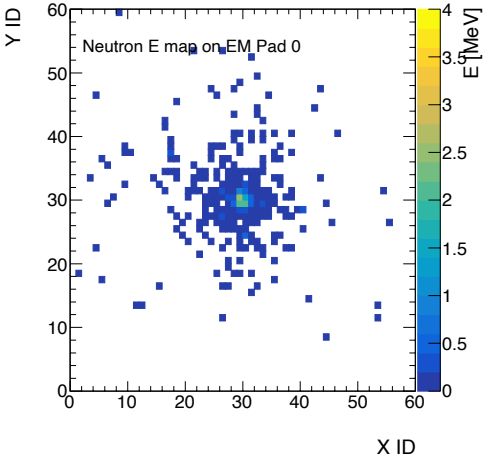


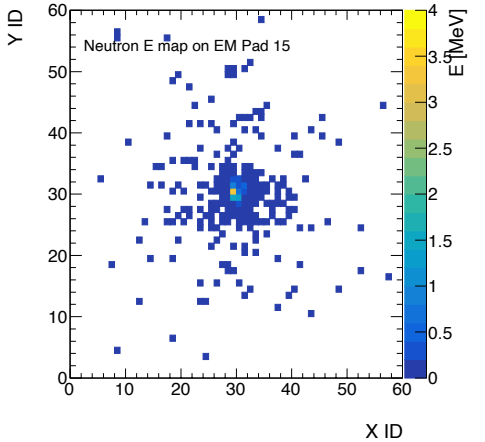


Neutron









Towards the update of the design

- Need understanding of the current design.
  - Check of the performance of EM Calorimeter.
    - Current EM Calorimeter is probably too long and too expensive.

      → Consider the reduction of size.
  - Reconstruction of neutrons.
    - See if the energy measurement is good enough.

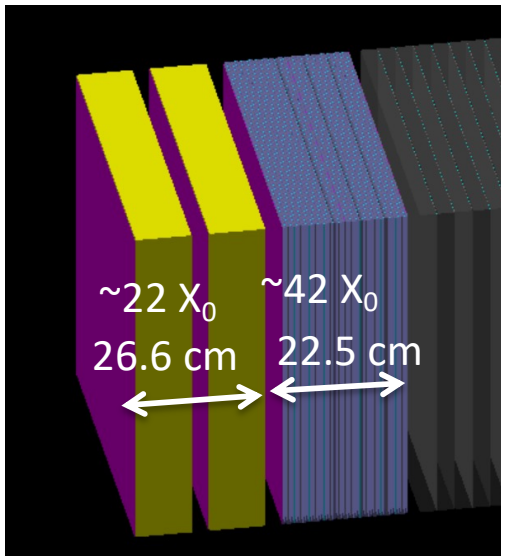
      ZDC can get longer in Z direction. (i.e. > 2m long).

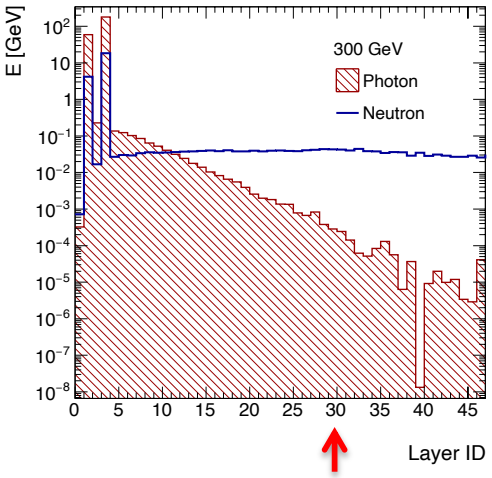
Other factors to be considered:

- Reduction of costs.
- Radiation hardness.
- Consideration of the readout system.

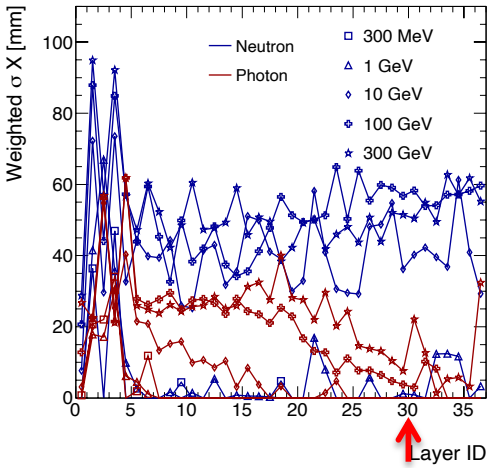
Reduction of EM calorimeter size

- Current EM calorimeter: 64 X_0 in total.
  → Consider reduction of the size.
- With reduced size of crystals (16 X_0: tentative), performance of W/Si layers are checked.





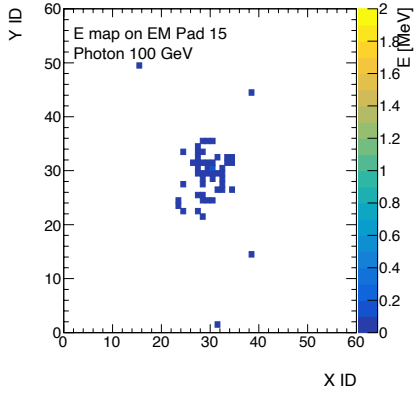
Tiny energy deposits for Layer ID > 30, for photons.

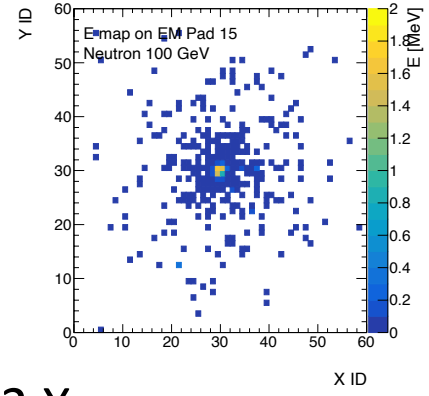


Energy weighted sigma shows the spread of hits.

- Difference of shower shape.
- EM shower is fading from layer ID~20.

Shower shapes at layer ID =20 (photon vs neutron)





Deletion to 26 W/Si layers (Layer ID= 30↑) is quite safe ➔ Total 42 X_0

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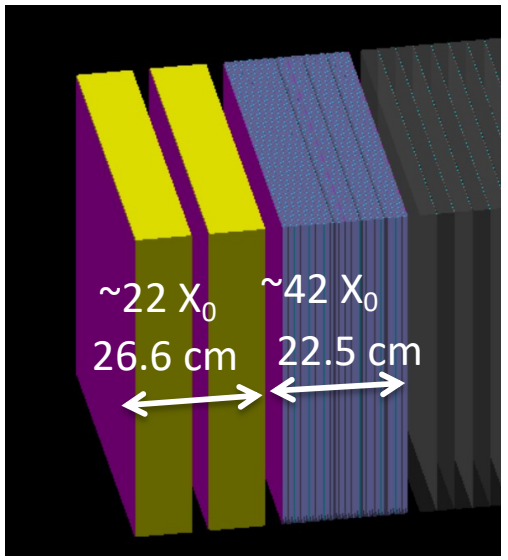

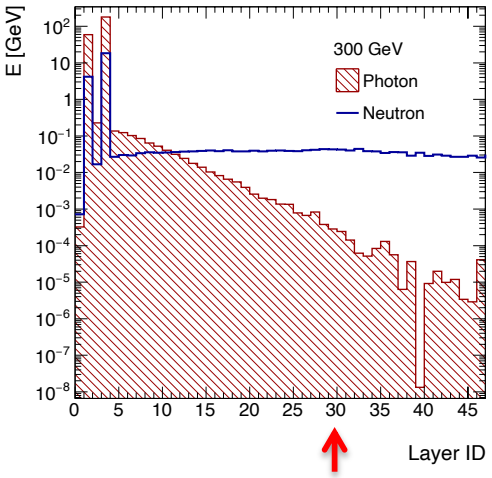

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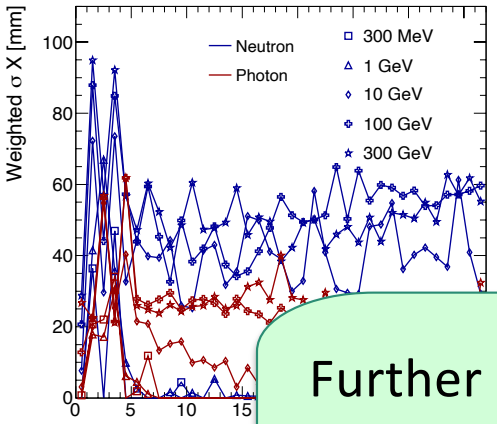

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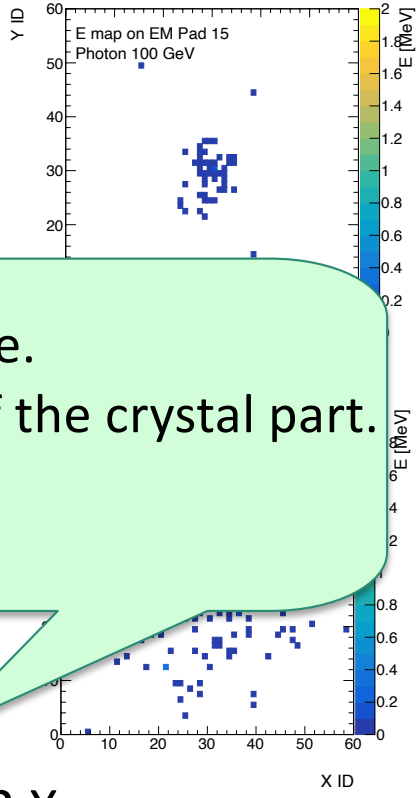


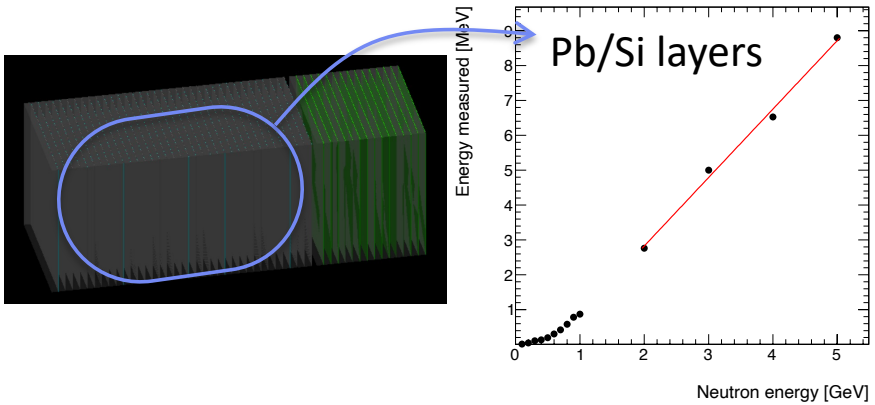
Further reduction is possible.
Next: Performance check of the crystal part.

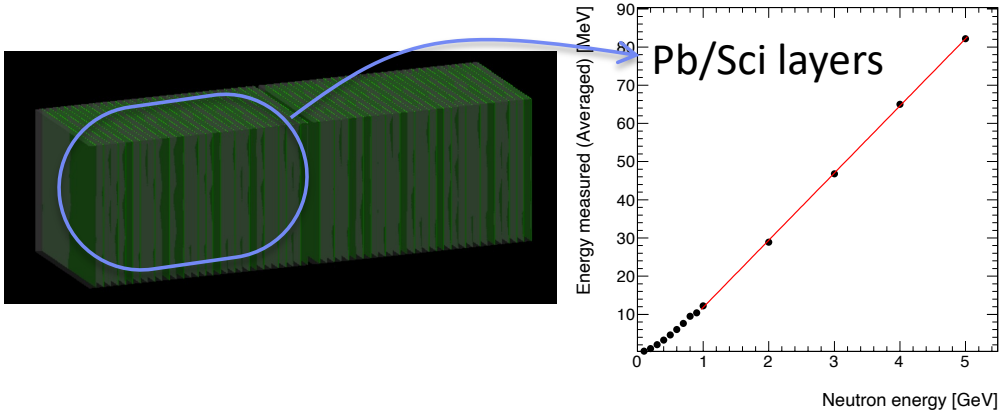
- Can it be thinner?
- Can it be only 1 layer?

Deletion to 26 W/Si layers (Layer ID= 30↑) is quite safe ➔ Total 42 X_0

Reconstruction of neutrons in had. calorimeters

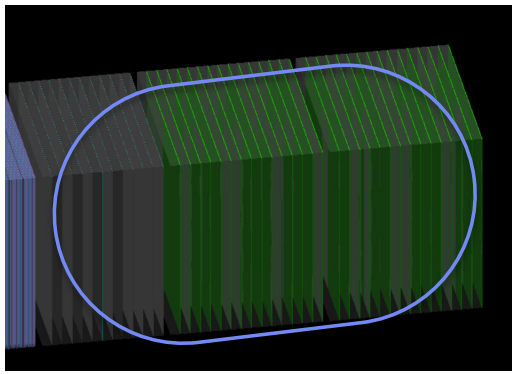
- First trial is ongoing:
  1. With enlarged calorimeters, low energy neutrons (<= 5 GeV) are shot to get [Measured energy] <-> [Induced energy] functions.

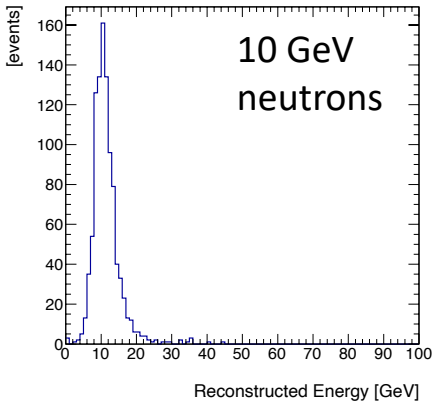


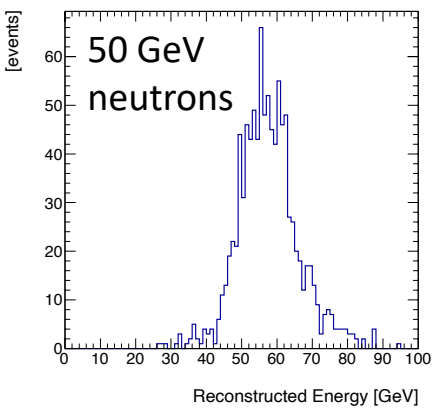


  2. With the functions, reconstruct neutrons in the hadron calorimeters.

→ Succeeded to reconstruct 10 GeV neutrons, but not 50 GeV neutrons.







More study is needed.
(A closer look indicates energy reconstruction in Pb/Si gets worse.)

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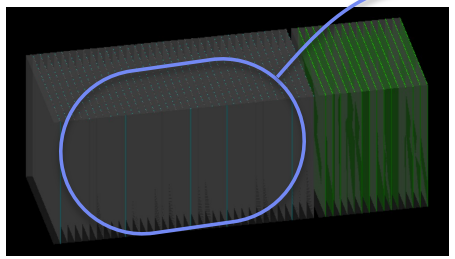
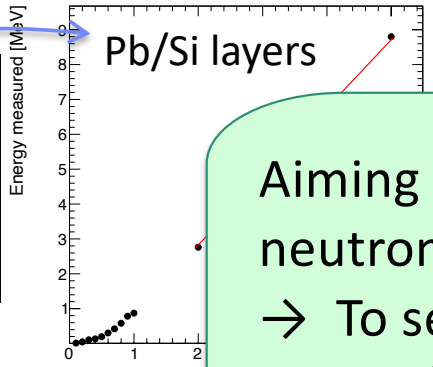
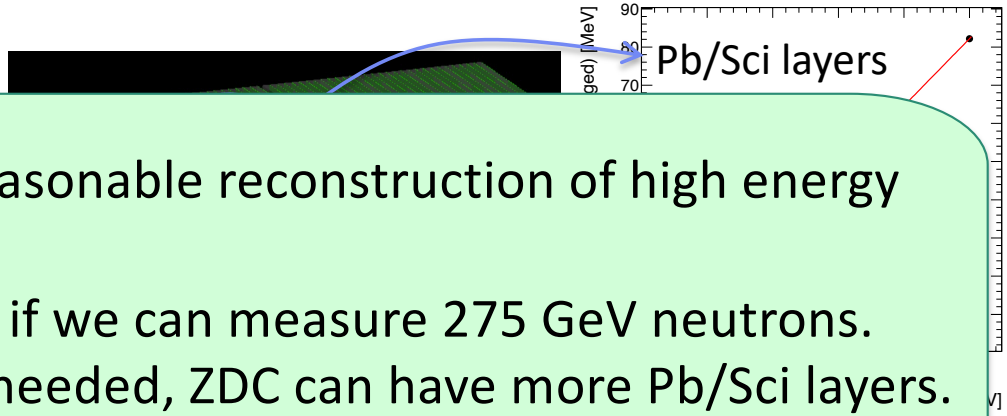


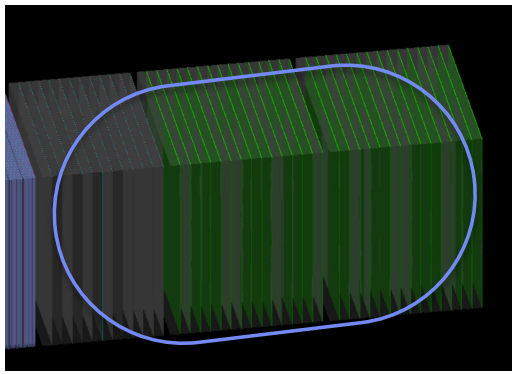


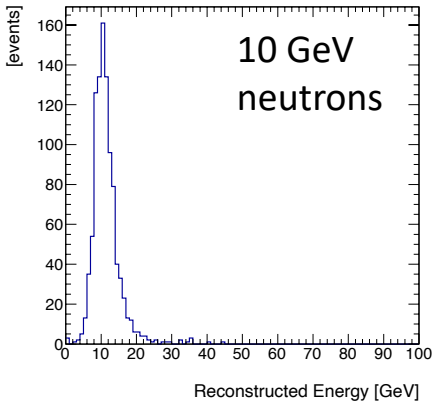


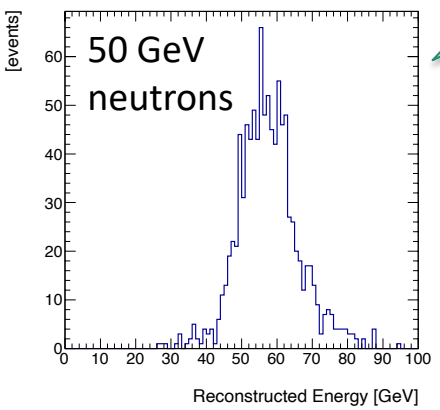
Aiming reasonable reconstruction of high energy neutrons.
→ To see if we can measure 275 GeV neutrons.
e.g. If needed, ZDC can have more Pb/Sci layers.
(Space should be OK.)

  2. With the functions, r

→ Succeeded to reconstruct 10 GeV neutrons, but not 50 GeV neutrons.







More study is needed.
(A closer look indicates energy reconstruction in Pb/Si gets worse.)

Summary: Current status and To-do

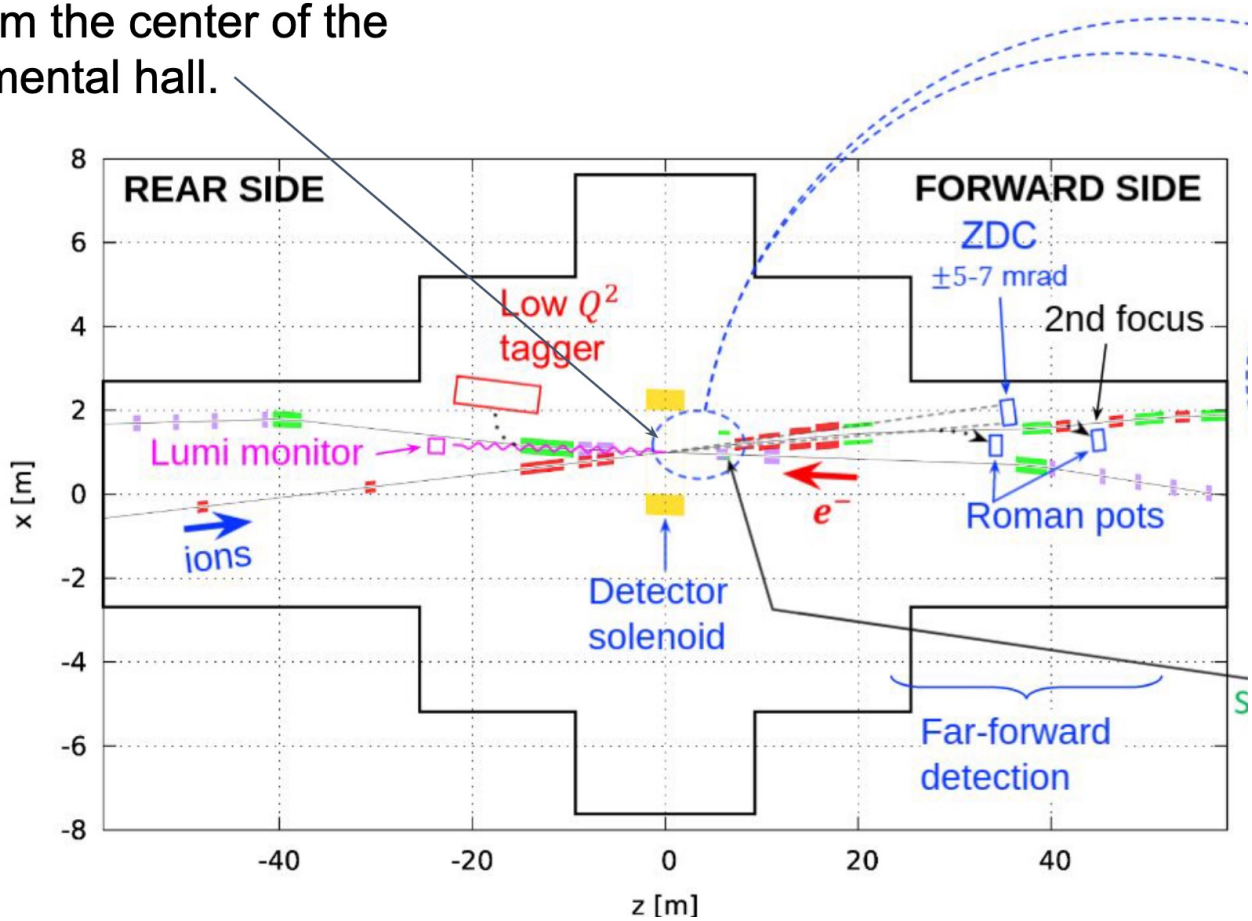
- **ZDC is a calorimeter to measure photons and neutrons at the Far-Forward region.**
- **Our first ZDC design is available in the simulation.**
  - It is already in ECCE software and can be used as an option.
    - **To do**: preparation of reconstruction codes.
  - Understanding of the first design is ongoing.
    - **To do**: Understanding of performance against low energy photons.
    - **To do**: Reconstruction of neutron.

      Also to see energy resolution and position reconstruction.
- **Simulation of radiation dose is ongoing by US colleagues.**
  - Using FLUKA to have estimation of realistic dose.
- **To do**: **Consideration of readout system**.

➔ Will be reflected on the next design of the ZDC deign.

IP8 configuration

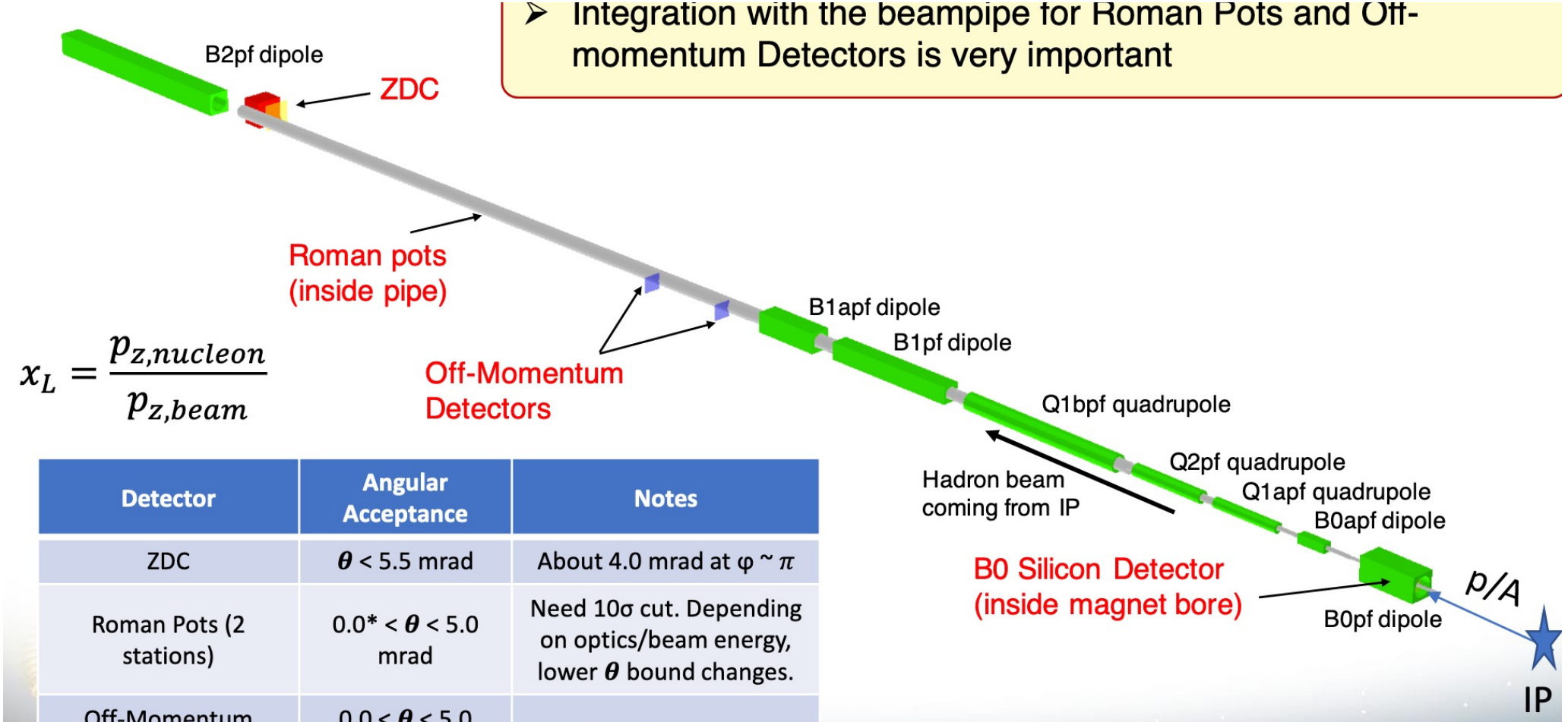
IP is 1m towards the center of the ring from the center of the experimental hall.



slide from Randika Gamage
https://indico.bnl.gov/event/12068/contributions/50456/attachments/34996/56934/2nd_IR_layout.pdf

Forward detectors

- Integration with the beampipe for Roman Pots and Off-momentum Detectors is very important



$$x_L = \frac{p_{z,nucleon}}{p_{z,beam}}$$

Detector	Angular Acceptance	Notes
ZDC	θ < 5.5 mrad	About 4.0 mrad at $\varphi \sim \pi$
Roman Pots (2 stations)	0.0* < θ < 5.0 mrad	Need 10σ cut. Depending on optics/beam energy, lower θ bound changes.
Off-Momentum Detectors	0.0 < θ < 5.0 mrad	Roughly 0.4 < x_L < 0.6
B0 Sensors (4 layers, evenly spaced)	5.5 < θ < 20.0 mrad	Could change a bit depending on pipe and electron quad