the Monte Carlo Simulation of the Zero Degree Calorimeter

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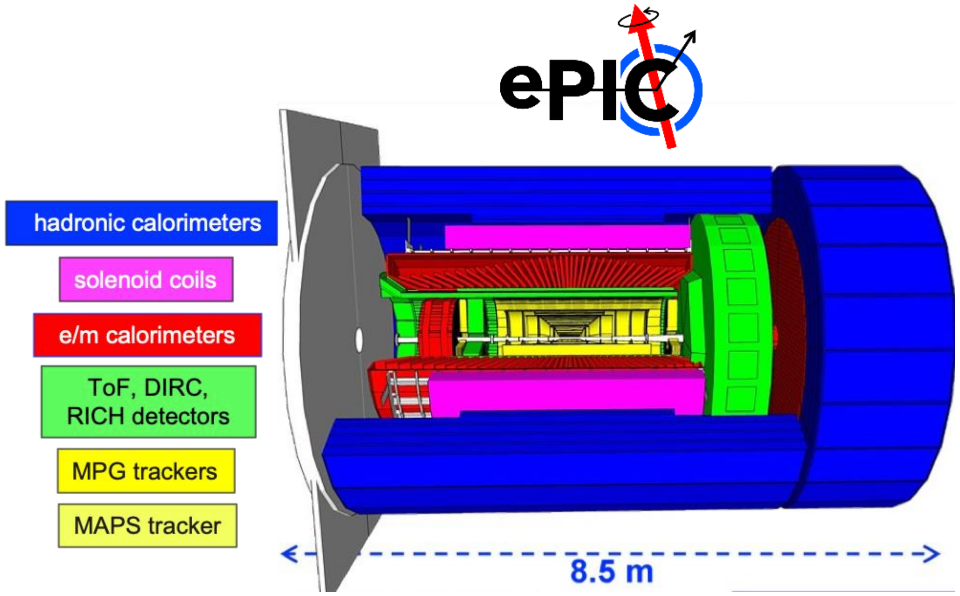
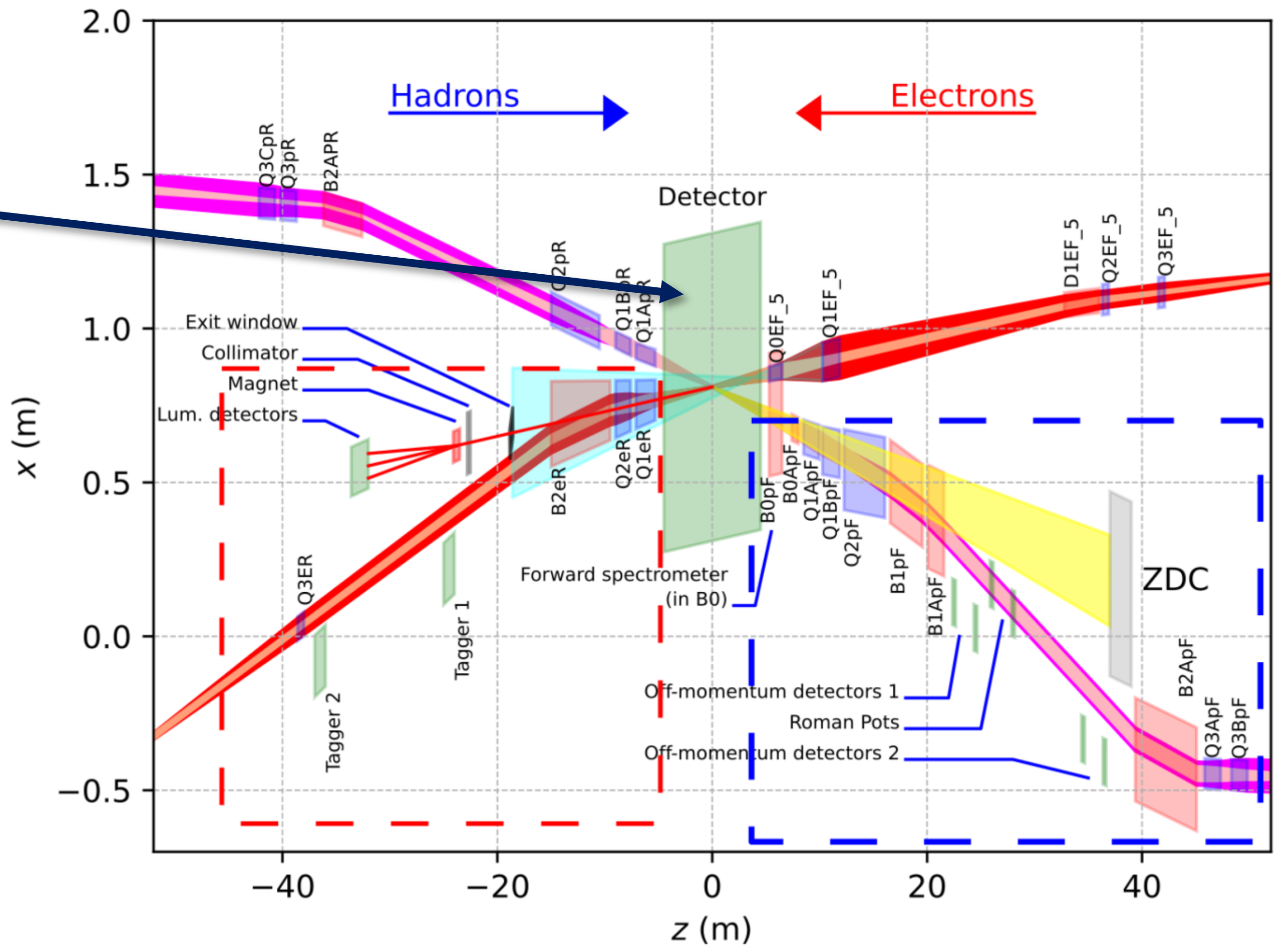
Brief Intro. & Acknowledgement

The ZDC MC implementation is mainly contributed by Dr. Shimizu, and I visited RIKEN to take over the MC wrok in at the end of last November. The materials given here are mostly provided by Dr. Shimizu and Dr. Goto.

The Electron Ion Collider

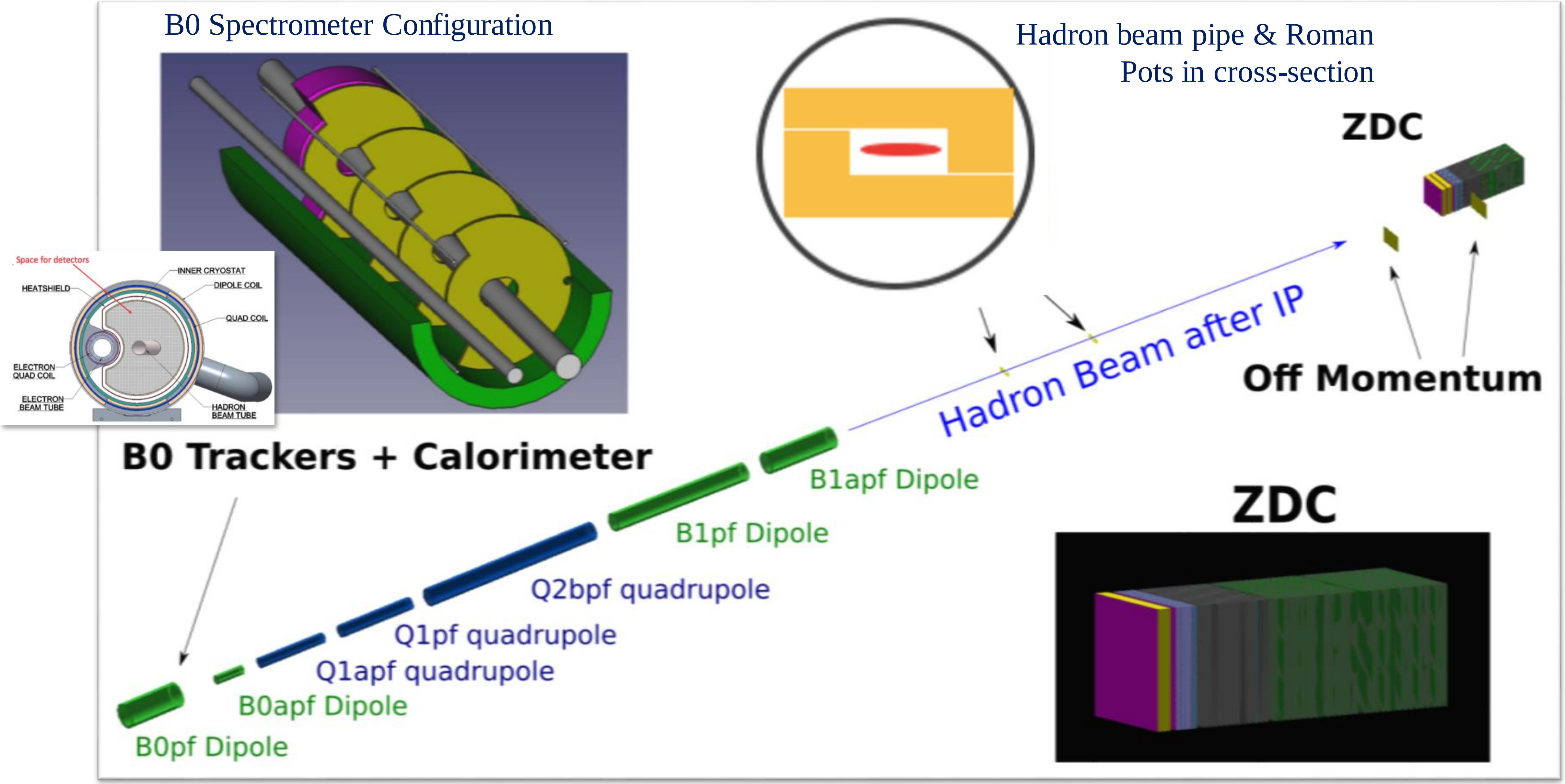


- ➢ Auxiliary detectors needed to tag particles with very small scattering angles both in the outgoing lepton and hadron beam direction.



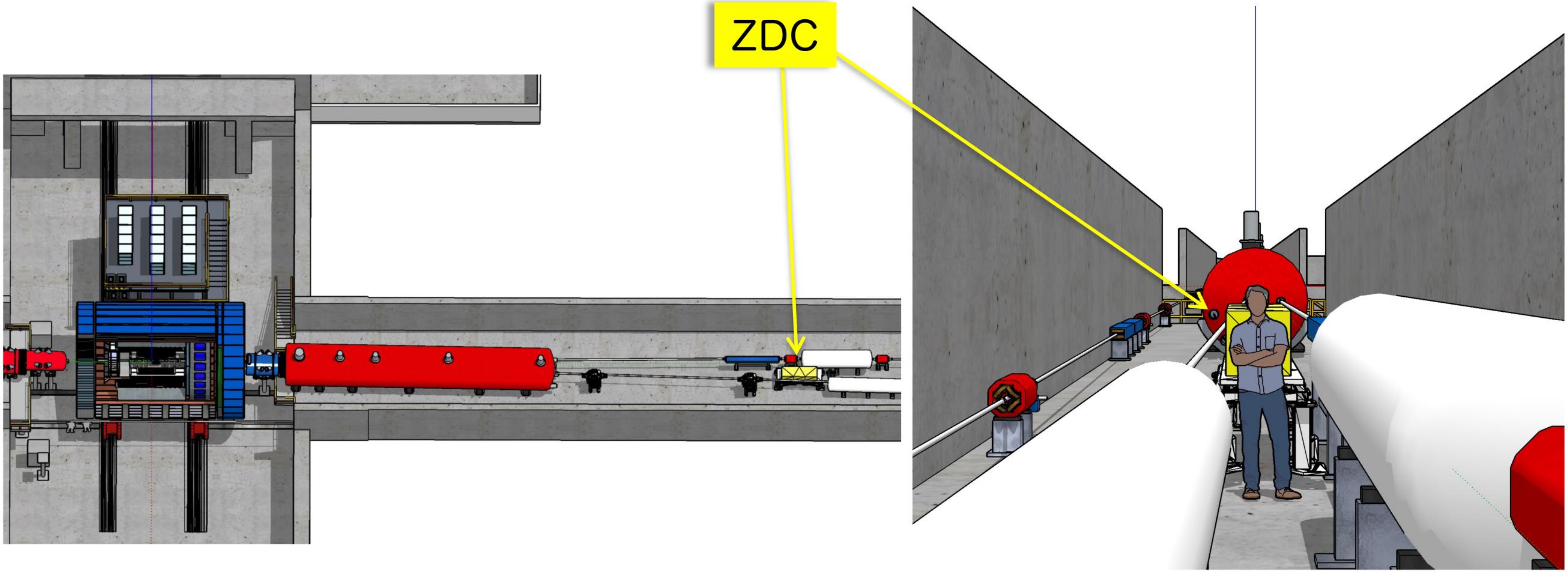
- ➢ Far forward and backward detectors provide vital information for the reaction kinematics of the colliding systems.

Far-Forward Detectors



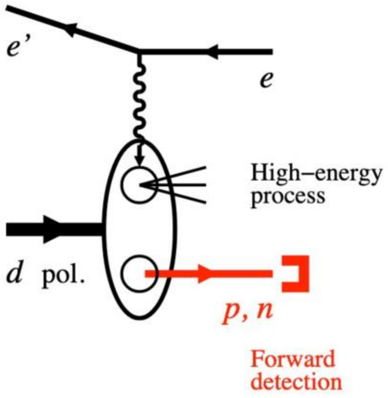
Zero Degree Calorimeter (ZDC)

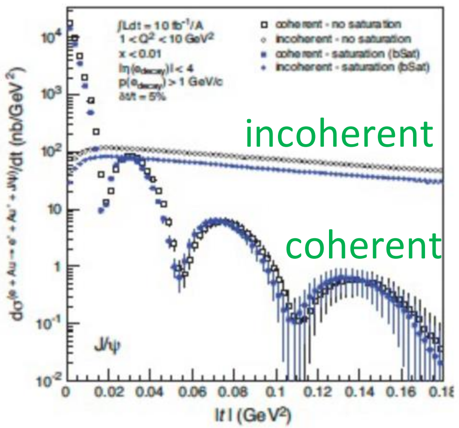
A calorimeter for measuring photons and neutrons.
ZDC sits at about 30m from the interaction point.

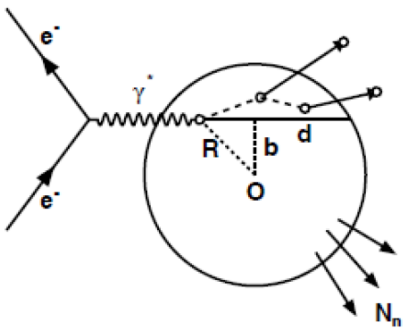


Physics Related to ZDC

- Spectator tagging in $e + d/^{3}He$ collisions
  - Neutron structure, spin structure
  - Proton by B0/Roman pots and neutron by ZDC





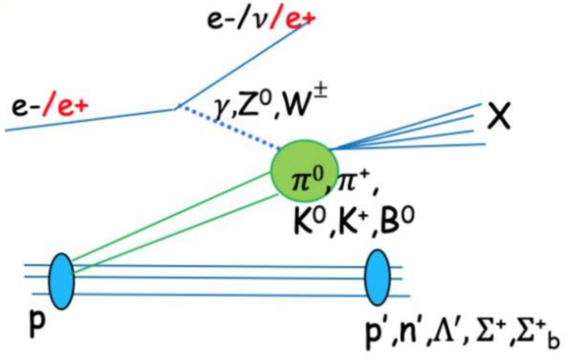


Intra-nuclear cascading increases with d (forward particle production)

Leads to evaporation of nucleons from excited nucleus (very forward)

- $e + A$ collision at small angle
  - Determination of excited nucleus breakup
    - Veto with evaporated neutrons and photons from de-excitation
  - Collision geometry characterization in $e + A$ collisions
    - Correlated to neutron multiplicity
    - Study of nuclear matter effect

- Meson structure via Sullivan Process
  - Measure neutron or $\Lambda(\rightarrow n + 2\gamma)$ in far-forward region
    - Structure of π, K, etc.



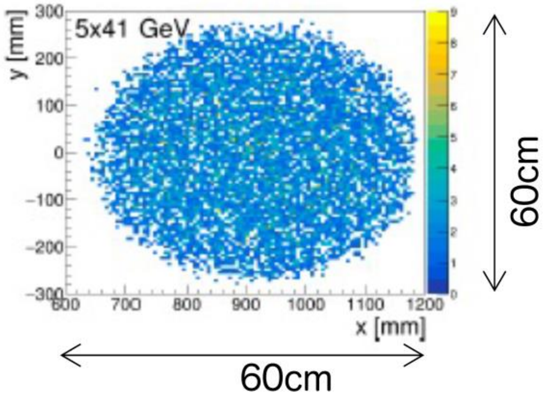
- And more…

Performance Requirements

- Large acceptance: $60cm \times 60cm$ front surface → From meson structure measurement
- Measurement of GeV photons and neutrons
- Detection of soft photons, with efficiency $> 90\%$

YR Fig. 8.104

Neutrons from e+p→ e'+X+n



	Energy range	Energy resolution	Position resolution
Neutron	~275 GeV (up to beam energy)	$\frac{50\%}{\sqrt{E}} + 5\%$	$\frac{3\ \mathrm{mrad}}{\sqrt{E}}$
Photon	O(100) MeV	20~30%	
	20~40 GeV	$\frac{35\%}{\sqrt{E}}$	0.5~1 mm

→ Pion structure may require 1mm pos. resol.

→ Veto in $e + Pb$ exclusive J/ψ production

→ u-channel exclusive π^0

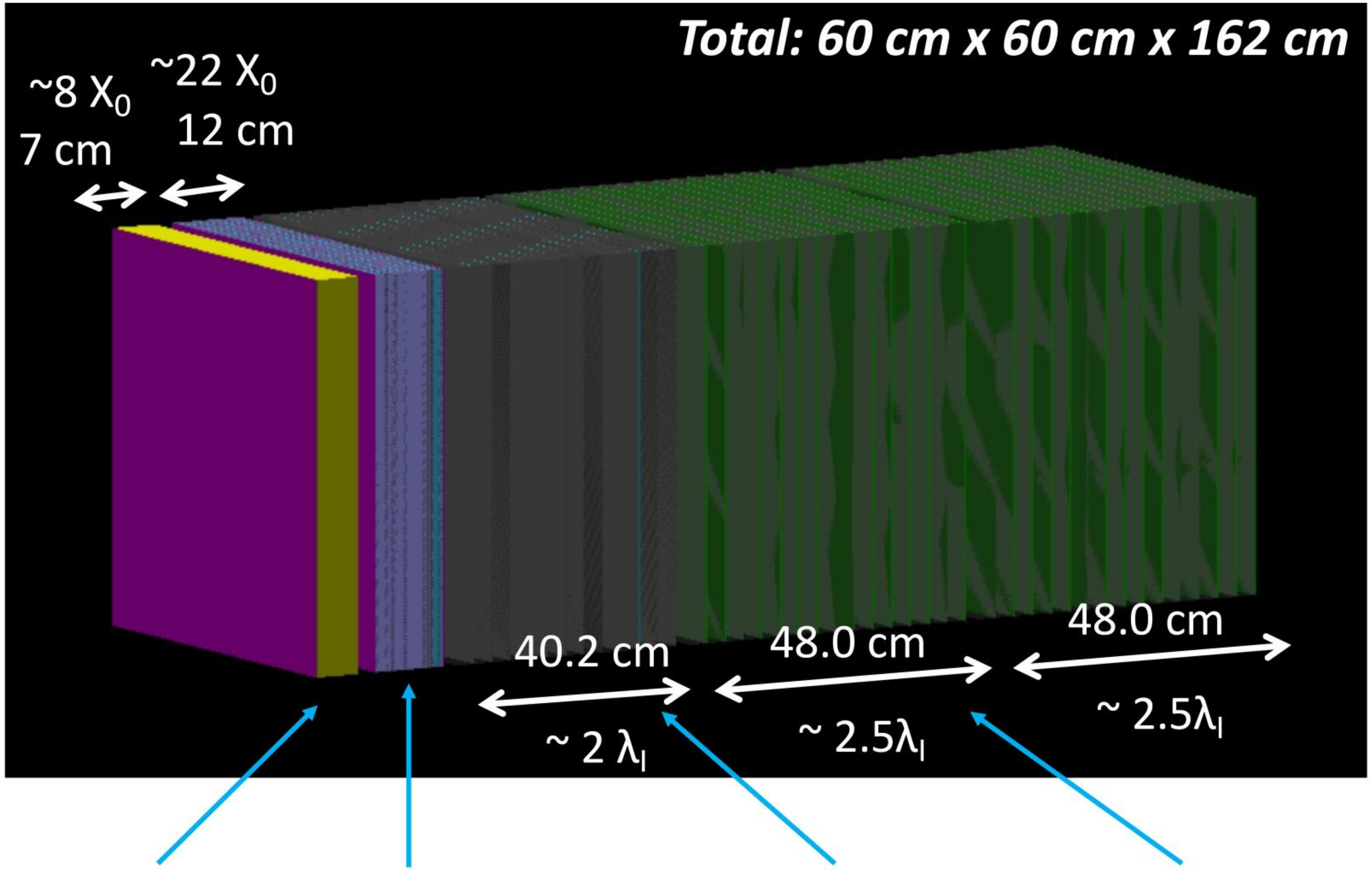
→ Kaon structure requires tagging n and 2 or 3 γ (Λ or Σ)

- Challenge: large energy coverage, detailed reconstruction of photon and neutron showers

Current ZDC Design

- A composition of four different calorimeter configurations

*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.

Design Concept: Full Shower Reconstruction

particles → | Crystal Calorimeter | Tungsten/ Silicon | Lead/Silicon | Lead/Scintillator |

Sampling Calorimeters (Tungsten/Silicon, Lead/Silicon, Lead/Scintillator)

Meas. of O(100) MeV photons

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

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

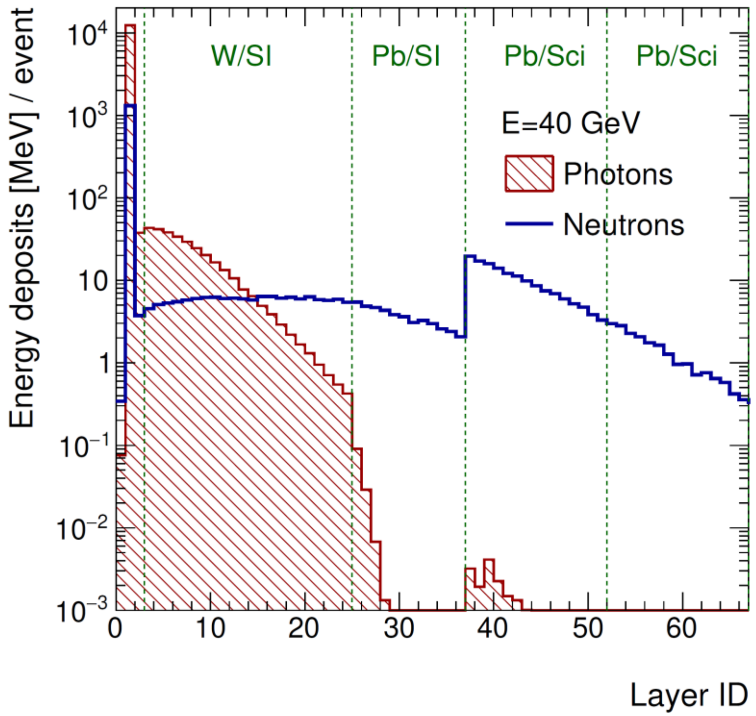
Meas. of hadron energy

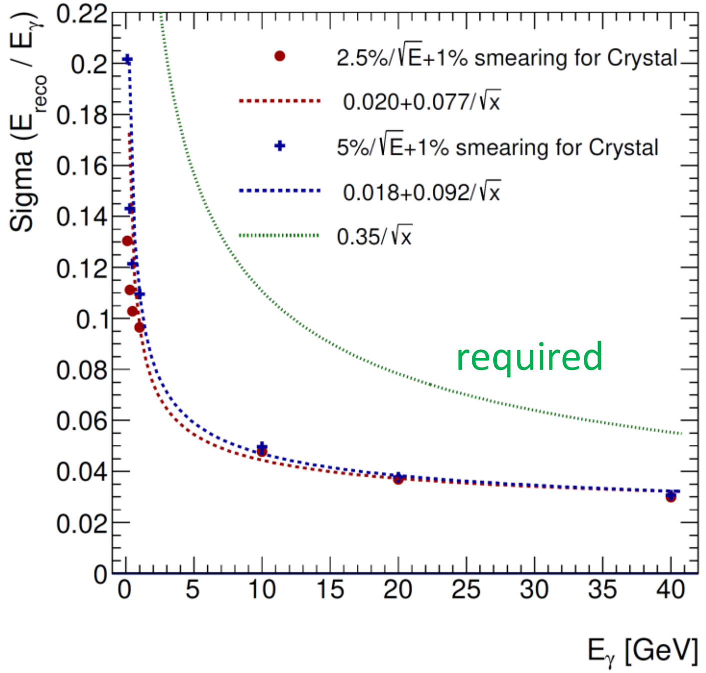
<u>Transverse granularity</u>

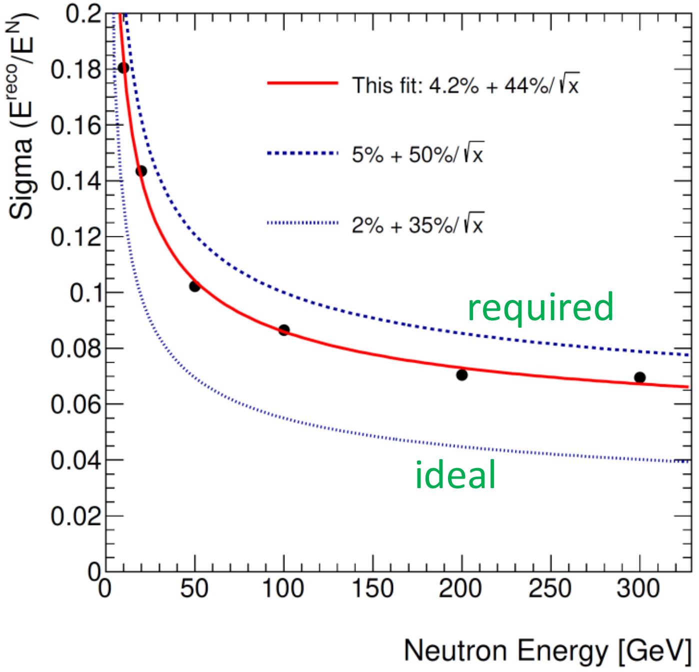
Crystal	Silicon	Scintillator
3cm x 3cm	Pad layer 1cm x 1cm Pixel layer 3mm x 3mm	10cm x 10cm

Simulation Performance

- Geant4 simulation uses energy deposits, not the scintillated photons.
- Clear difference of ZDC response against photons and neutrons → reflecting the difference of their shower development.







- Some of the service/readout materials are not in the simulation → optimistic estimation.
- Energy resolution meets requirements.

Open Questions

➢ Which type of 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?

➢ Silicon pixel and readout?

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

➢ AC-LGAD?

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

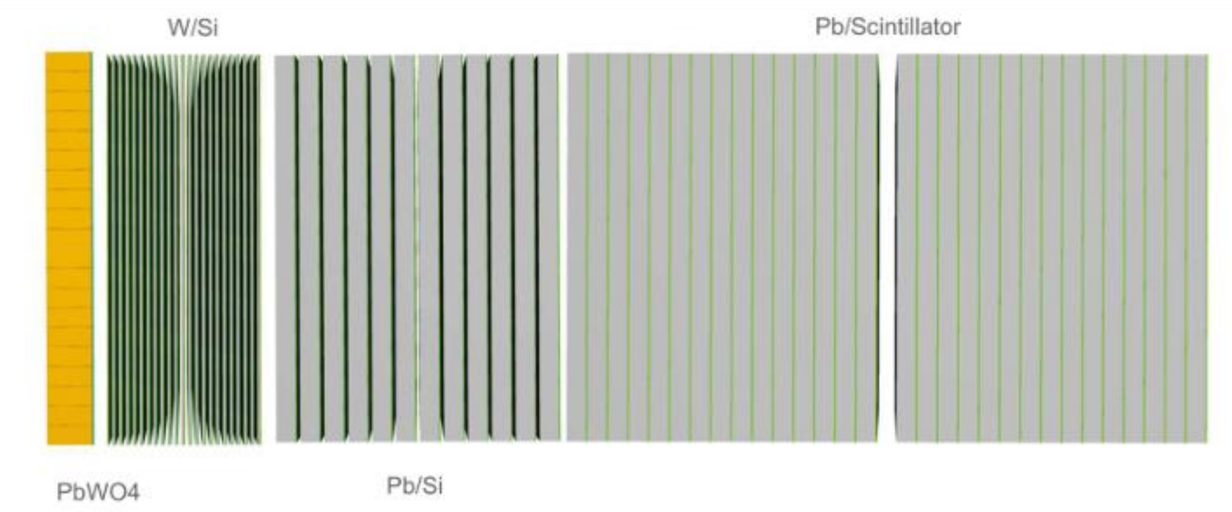
Monte Carlo Implementation

➢History…

- Athena: DD4hep, ECCE: Fun4All
- EPIC has chosen DD4hep for MC development

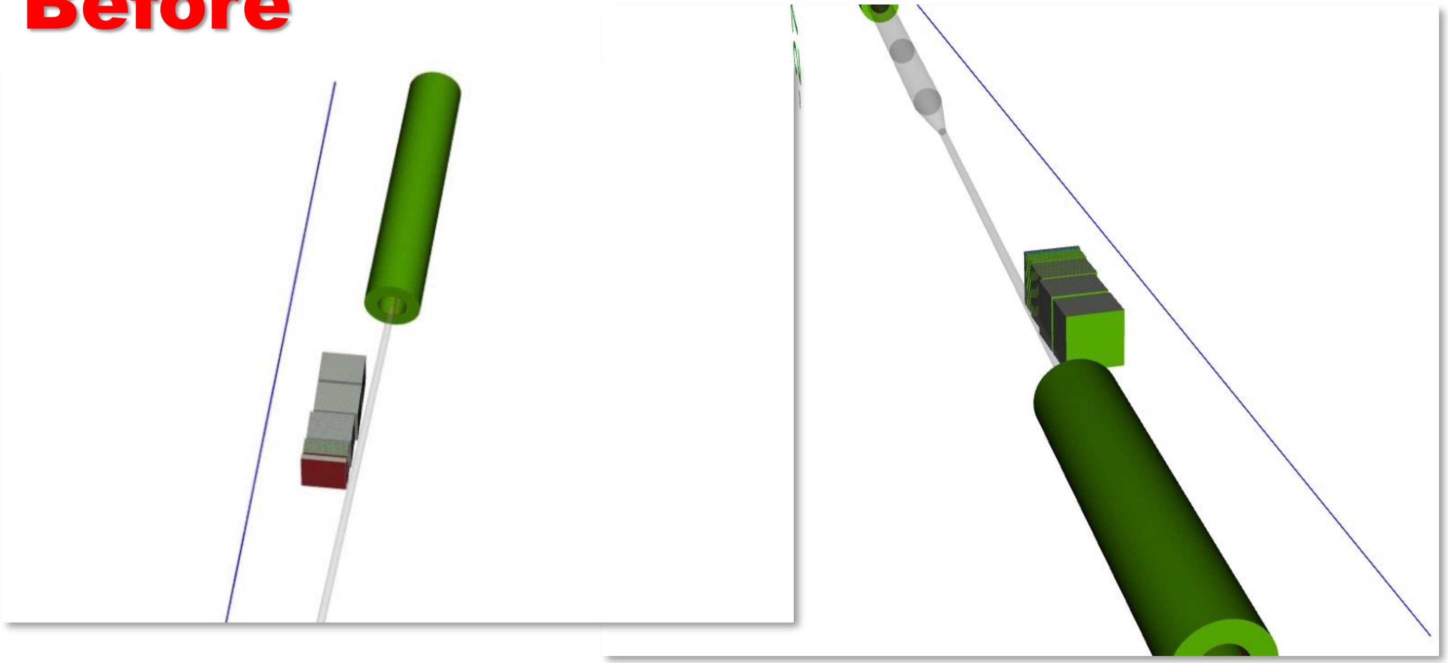
➢First MC campaign for detector study has begun

- The Athena version of ZDC is currently used.
- Need to update it to the ECCE/EPIC-style one.
- May need to carry out modification based on specific needs

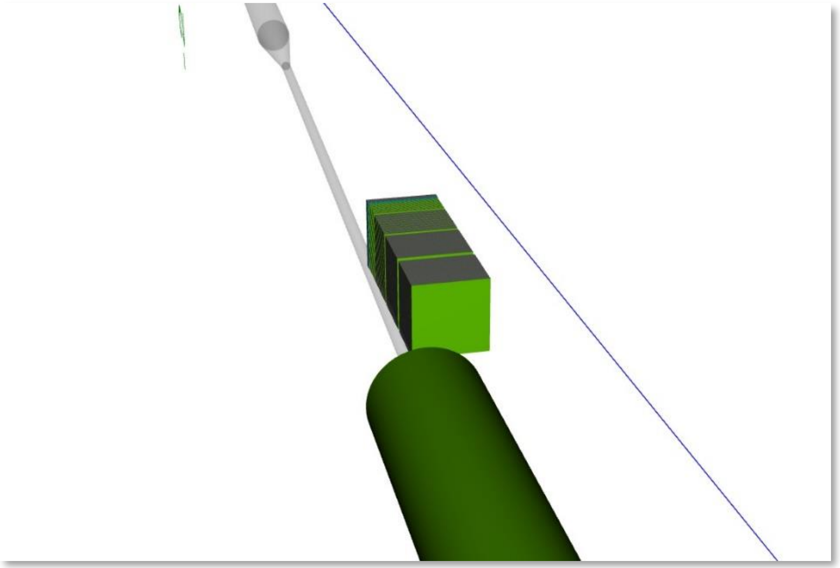


Monte Carlo Implementation

Before

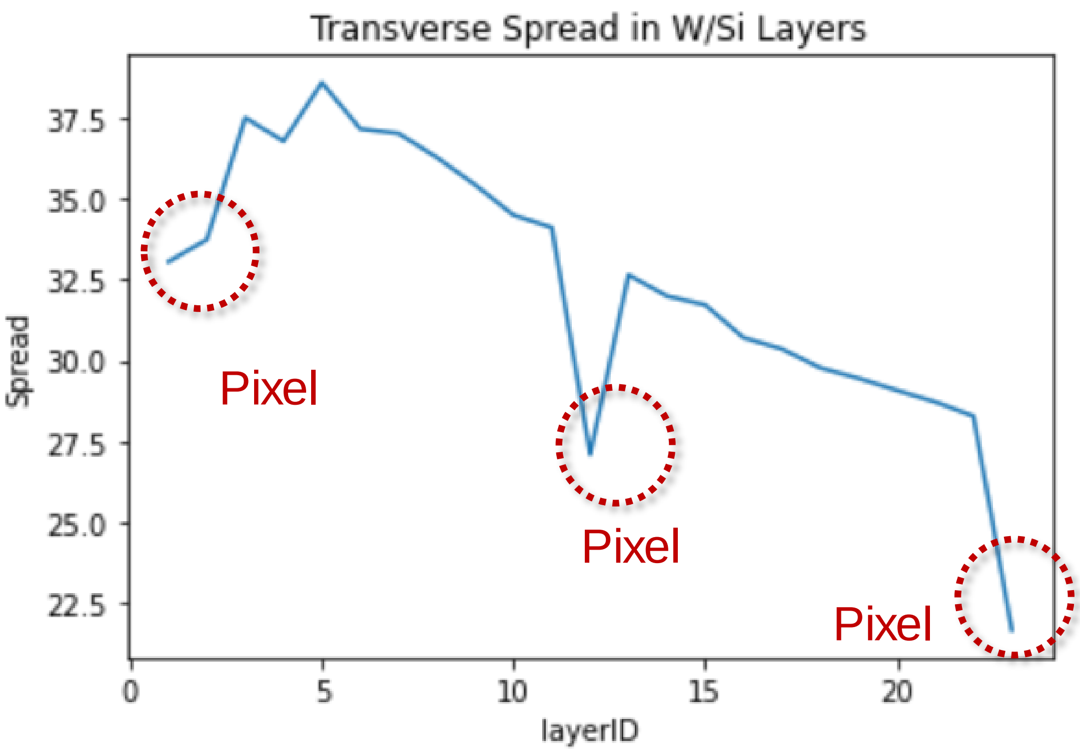


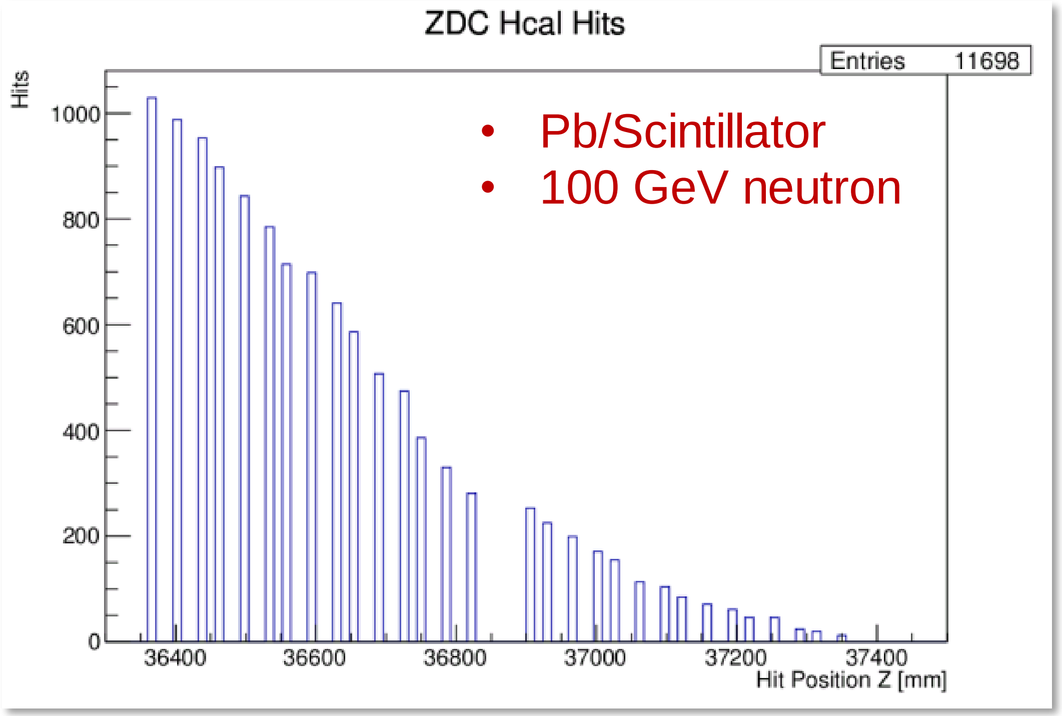
After



- The implementation has been mostly carried out by Dr. Shimizu.
- We fixed a bug of alignment issue reported by other collaborators (issue #309).
- The ZDC complex rotation has been modified to have a consistency in codes between Athena & ECCE version. Merged to the EPIC github already.

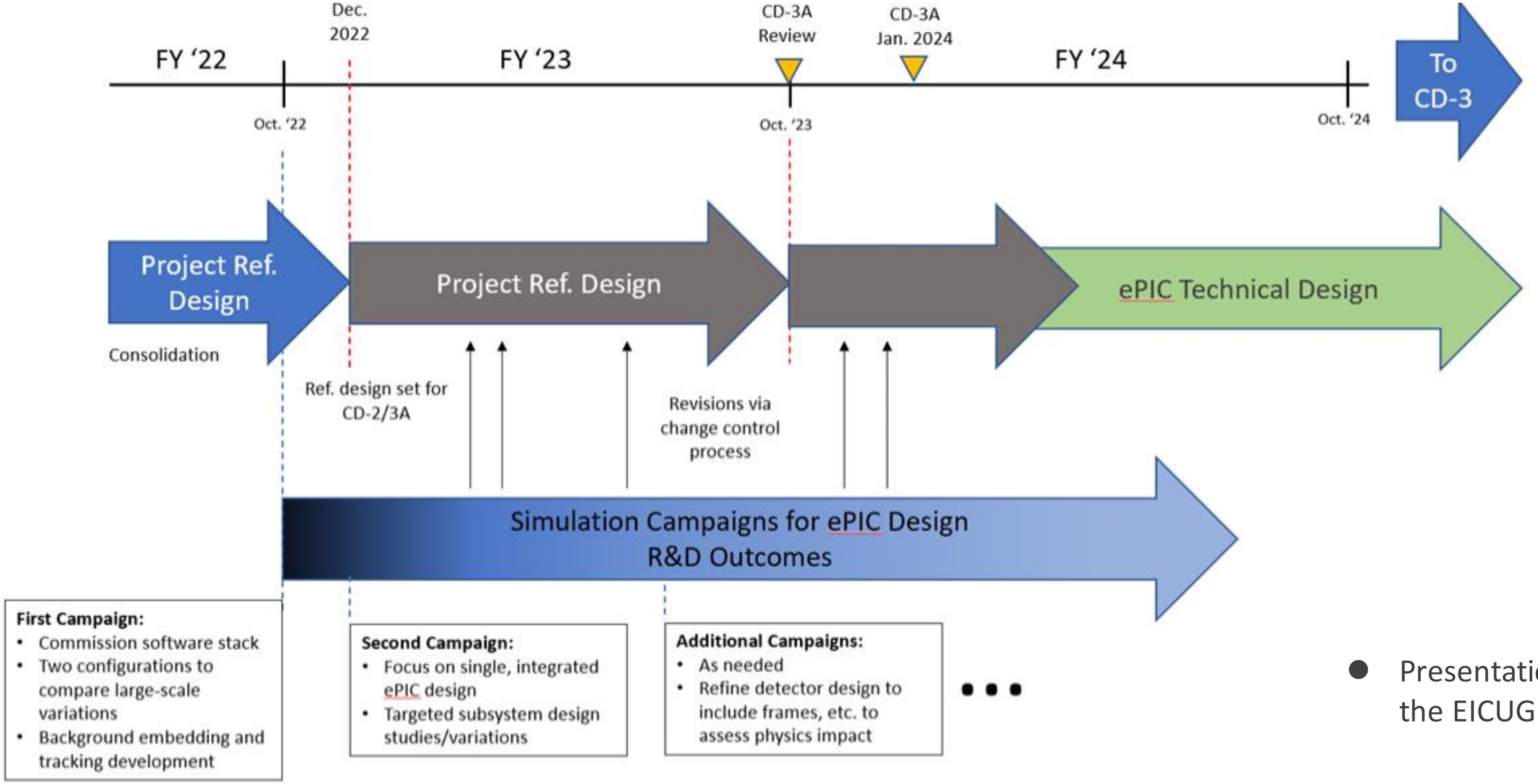
Monte Carlo Implementation





- ➢ Discrepancy in energy deposit/spread between silicon pad & pixel layers understood (issue #1020)
- ➢ Further debugging on-going.

Next Steps



- Presentation, Silvia Delatorre in the EICUG meeting Jan. 2023

- Current ZDC design has been constructed and merged to EPIC GitHub
- Digging into details of ZDC codes → bug fixing & design changes in the future.
- Infrastructure for hit reconstruction → be prepared for the next simulation campaign.
- Join the effort of ZDC shower with machine learning (?)