# Proposed detector designs and technologies for the Far-Forward region

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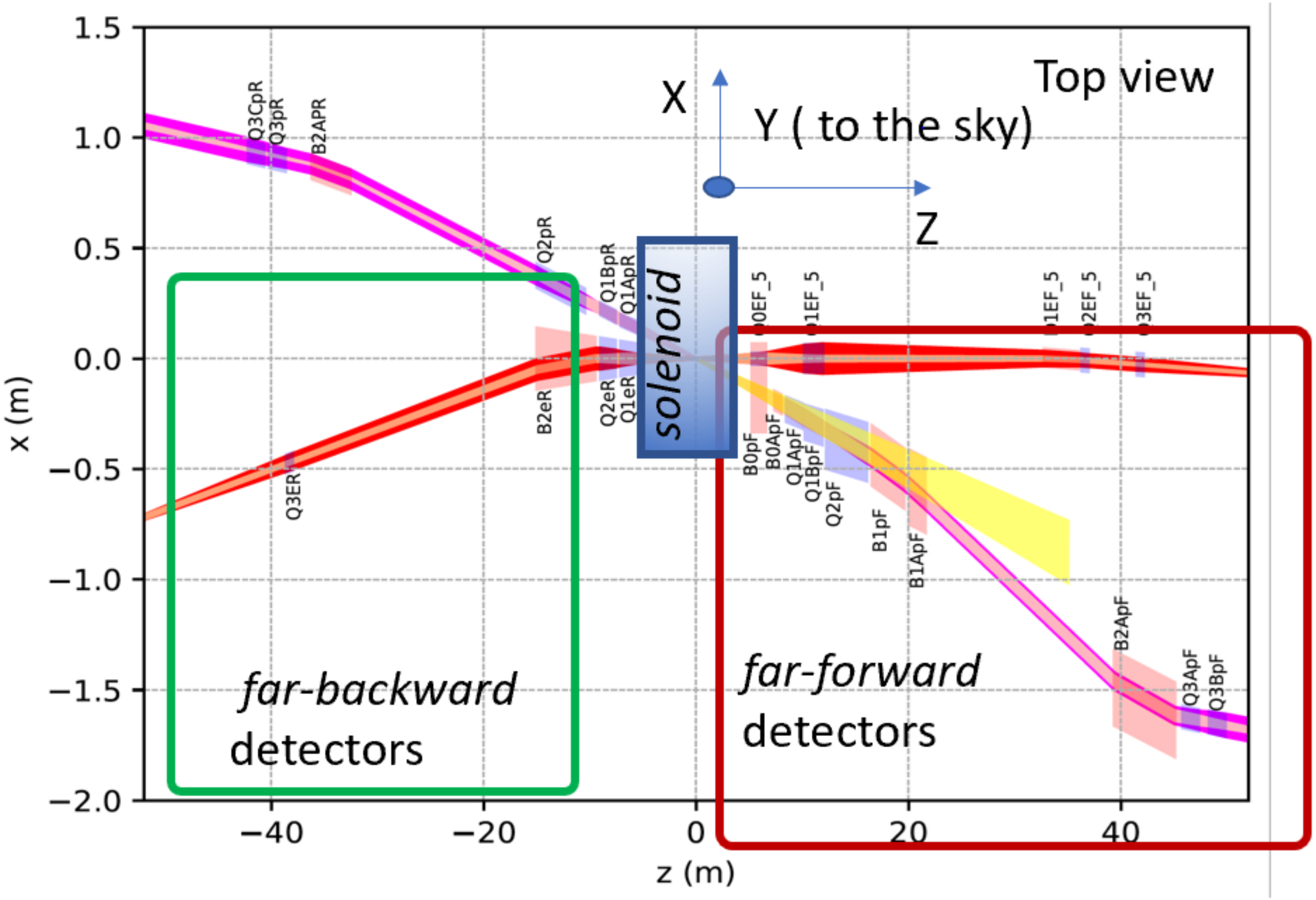
(together with ATHENA, CORE and ECCE experts)

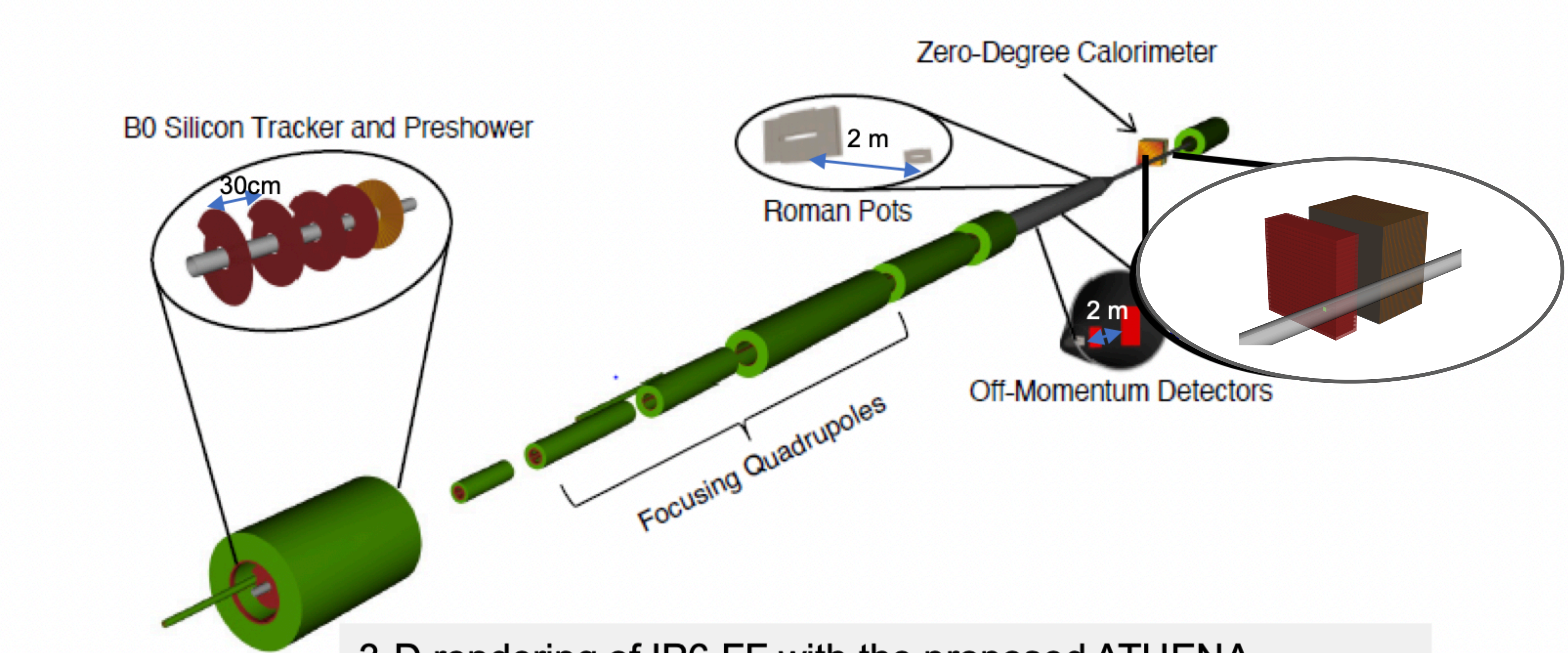
U.S. DEPARTMENT OF ENERGY   JSA   Jefferson Lab   EIC$^2$ EIC Center at Jefferson Lab

# IP-6 layout




- ✓ Coordinate flip to match the detector lab-frame
- ✓ 50cm shift

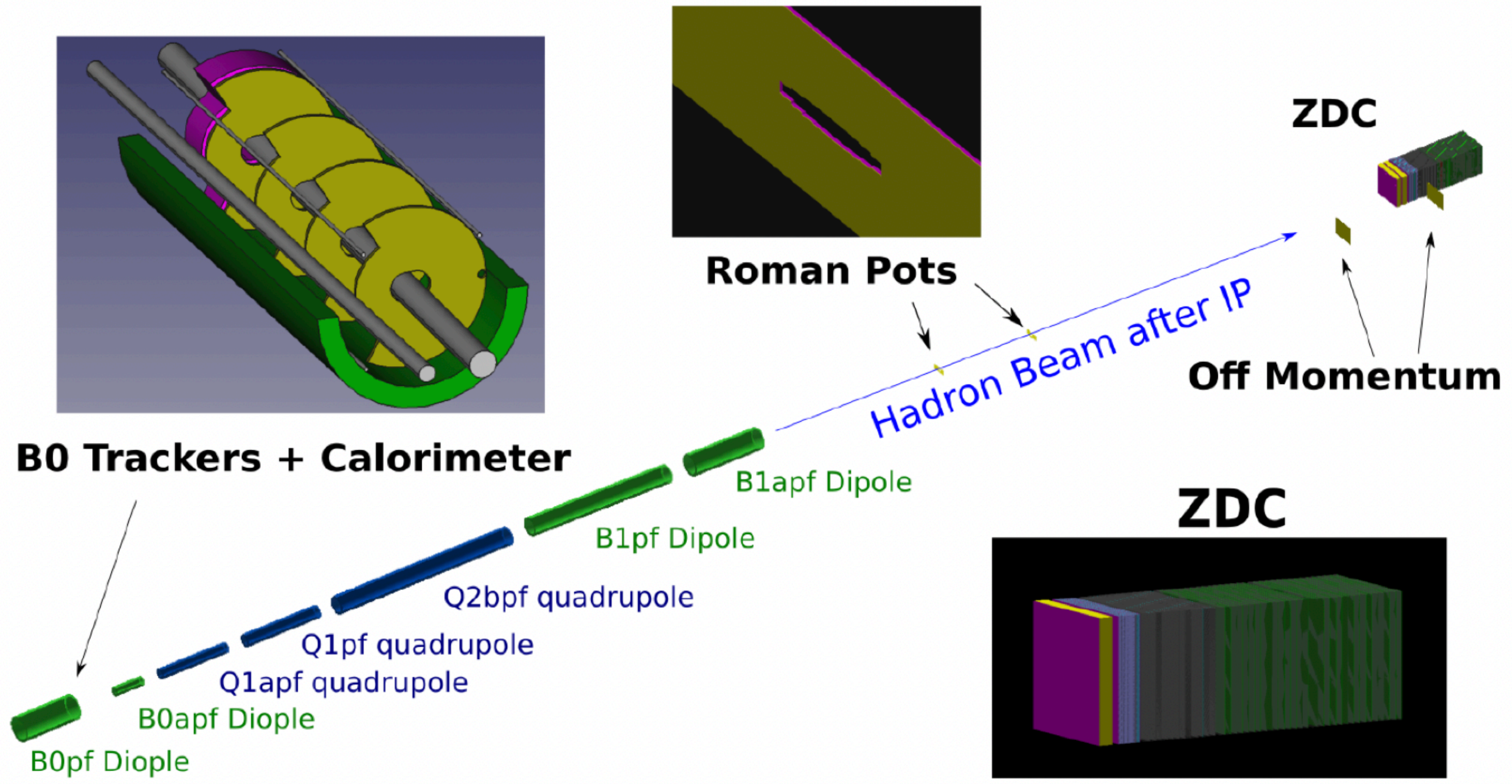
# ATHENA




3-D rendering of IP6 FF with the proposed ATHENA instrumentation from the DD4HEP geometry implementation.

# ECCE

Different placement of RPs and OFFM?



# ATHENA

| Detector | $\theta$ accep. [mrad] | Rigidity accep. | Particles | Technology |
|---|---|---|---|---|
| B0 tracker | 5.5–20.0 | N/A | Charged particles<br>Tagged photons | MAPS<br>AC-LGAD |
| Off-Momentum | 0.0–5.0 | 45%–65% | Charged particles | AC-LGAD |
| Roman Pots | 0.0–5.0 | 60%–95%* | Protons<br>Light nuclei | AC-LGAD |
| Zero-Degree Calorimeter | 0.0–4.0 | N/A | Neutrons<br>Photons | W/SciFi (ECal)<br>Pb/Sci (HCal) |

# ECCE

| Detector | (x,z) Position [m] | Dimensions | $\theta$ [mrad] | Notes |
|---|---|---|---|---|
| ZDC | (-0.96, 37.5) | (60cm, 60cm, 1.62m) | $\theta < 5.5$ | $\sim$4.0 mrad at $\phi = \pi$ |
| Roman Pots (2 stations) | (-0.83, 26.0) (-0.92, 28.0) | (30cm, 10cm) | $0.0 < \theta < 5.5$ | 10 $\sigma$ cut. |
| Off-Momentum Detector | (-1.62, 34.5), (-1.71, 36.5) | (50cm, 35cm) | $0.0 < \theta < 5.0$ | $0.4 < x_L < 0.6$ |
| B0 Trackers and Calorimeter | (x = -0.15, 5.8 < z < 7.0) | (32cm, 38m) | $6.0 < \theta < 22.5$ | $\sim$20 mrad at $\phi$=0 |

# ATHENA-B0

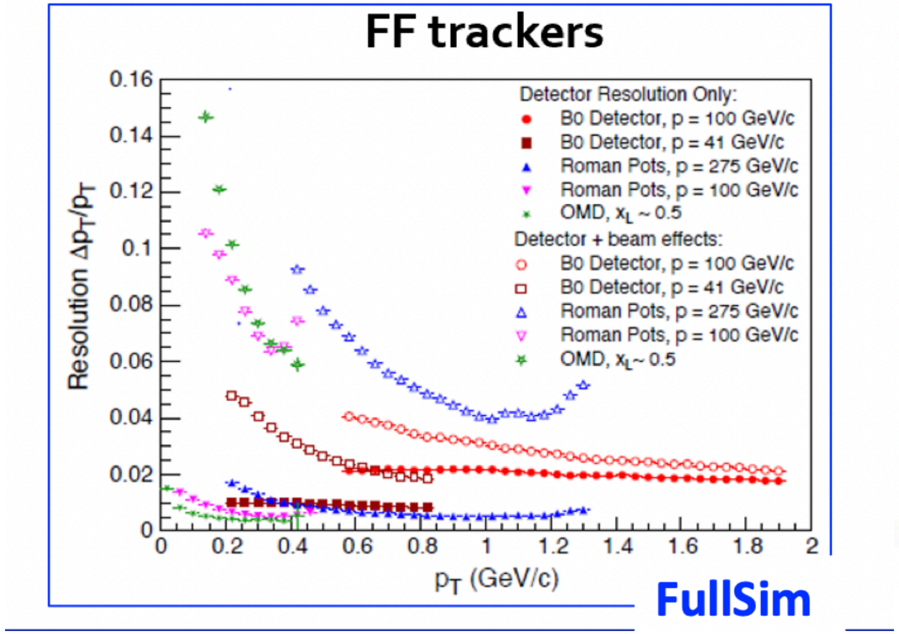
**Tracking:**

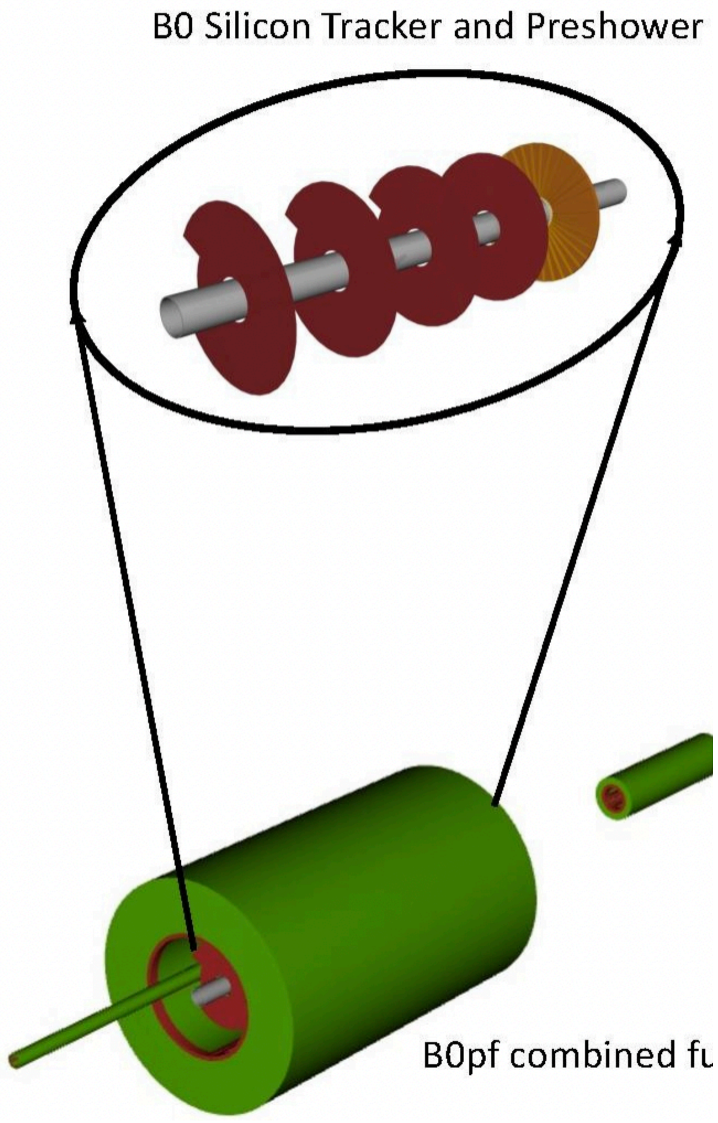
2-3 layers being comprised of **MAPS** (< 20um spatial resolution), and 1-2 layers being comprised of **AC-LGADs** spaced evenly by 30cm inside

ALPIDE chip: 28$\mu m$ x 28$\mu m$ pitch ( ca 5 $\mu m$ spatial resolution)

**Preshower:**

A simple photon tagger in the form of a **preshower** detector is included. This layer consists of 2 radiations lengths of **Pb converter,** followed by a layer of **AC-LGADs**.

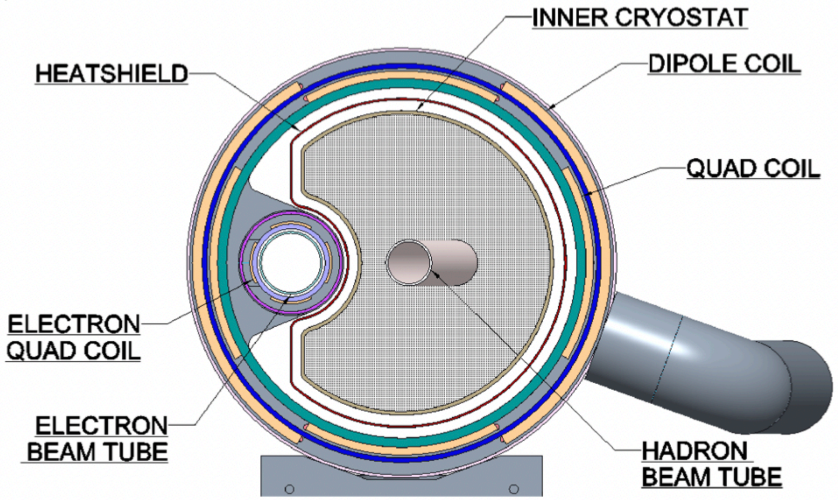


# ECCE -B0

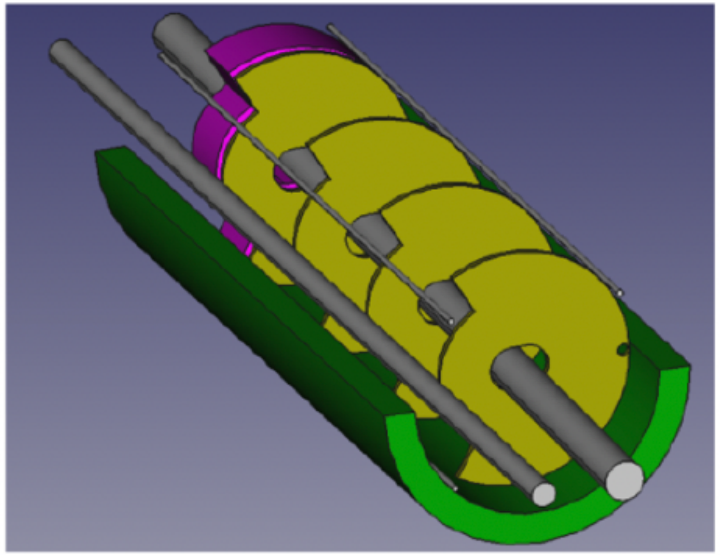
**B0-spectrometer**

- Warm space for detector package insert located inside a vacuum vessel to isolate from insulating vacuum.
- **ECCE: 4 AC-LGAD trackers with 30 cm spacing** between each layer providing **charged particle detection for 6 < $\theta$< 22.5 mrad**.
- Add a **$PbWO_4$ (11.2 R.L.) calorimeter behind the 4th tracking layer to obtain 100% acceptance** for $\gamma+\gamma$ from $\pi^0$ to cleanly isolate u-channel DVCS

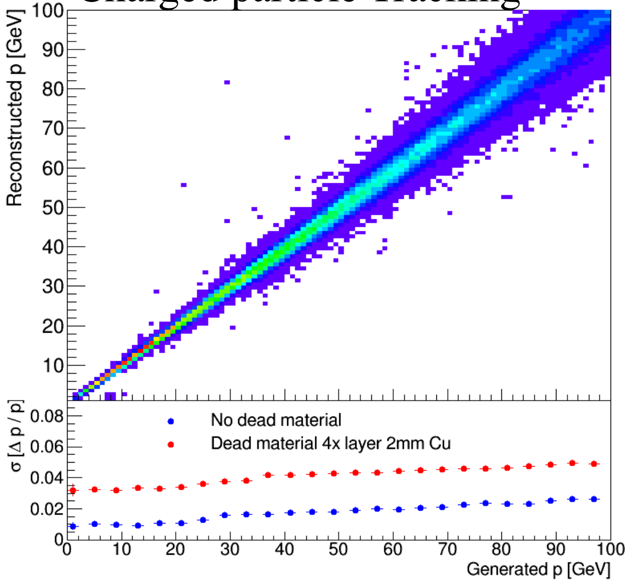




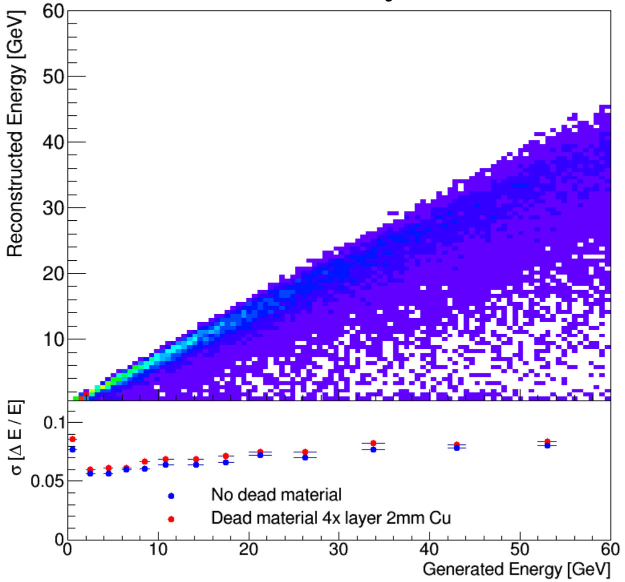

PbWO4: 250 crystals, each 10 cm long with a surface area of 2x2 $cm^2$



Charged particle Tracking




Photon calorimetry



# ATHENA

**RPs:**

two stations ( 2m apart)

each with two layers of **AC-LGAD** sensors

pixels assumed ( 500$\mu m$) => ~ 143 $\mu m$ spatial resolution

Timing resolution ca 35ps

(~12cm tall and ~26cm wide)

**OFFM :**

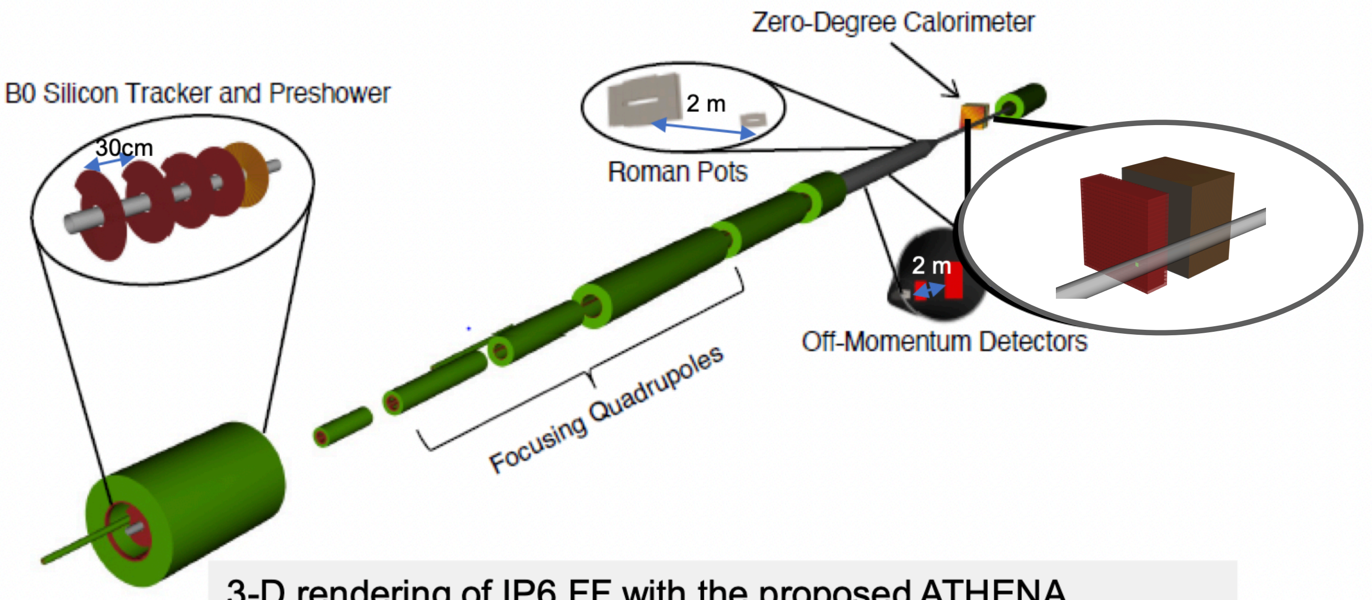
2 stations (separated by 2m) .

each with two layers of **AC-LGAD .**

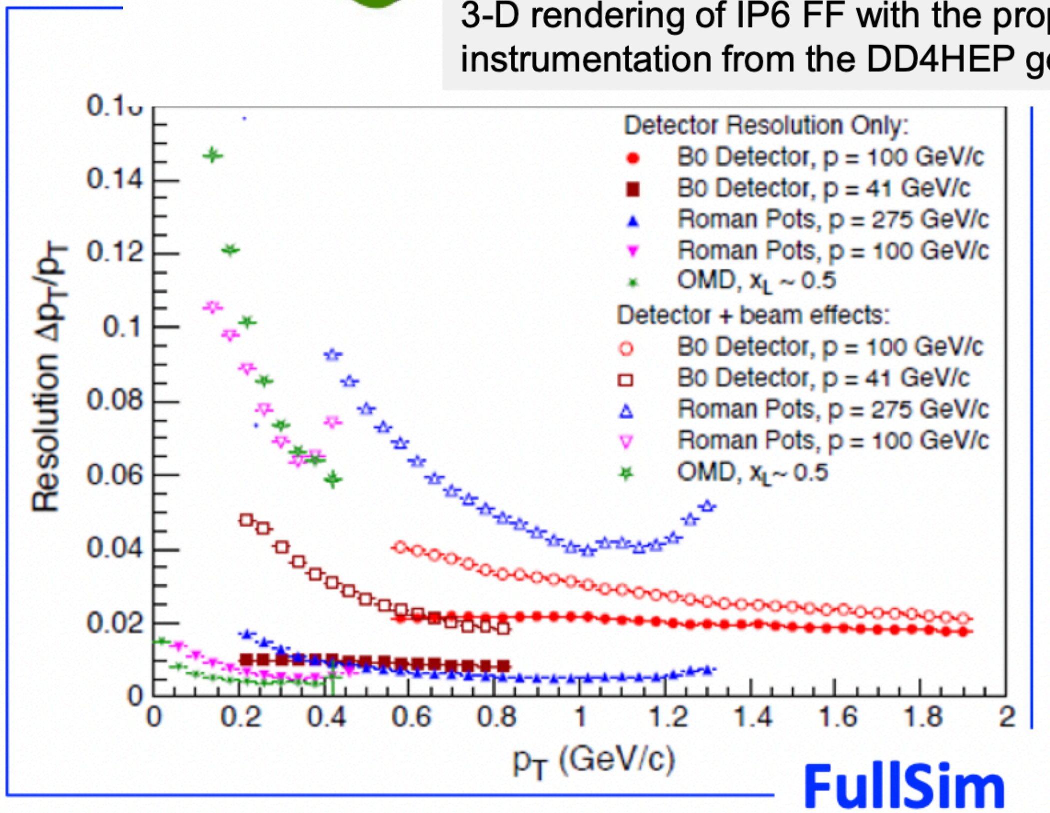
**pixels** assumed ( 500$\mu m$) => ~ 143 $\mu m$ spatial resolution

Timing resolution ca 35ps

(10cm x 20cm)




3-D rendering of IP6 FF with the proposed ATHENA instrumentation from the DD4HEP geometry implementation.



# ECCE

**RPs:**

Two stations ( 2m apart)

Each double-layer **AC-LGAD** sensors

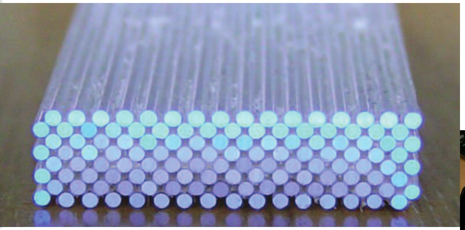
(~12cm tall and ~25cm wide)

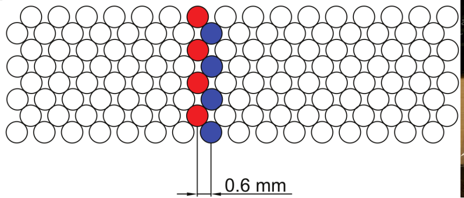
**OFFM :**

2 stations.

each with two layers of **AC-LGAD .**

Also exploring cheaper fiber-based design

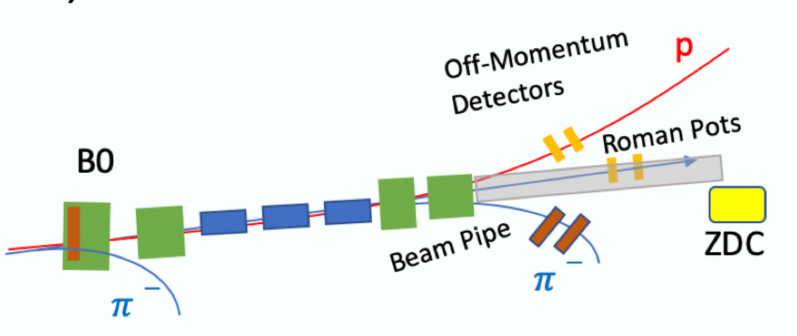





Kuraray Scin. Fiber arrived last week for Radiation test at Hall A

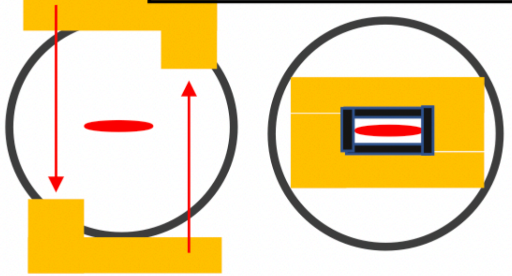
## Roman-Pots and Off-momentum detectors

0.0* (10σ $cut$) < $\boldsymbol{\theta}$ < 5.0 mrad




- **Roman Pots**: detect protons with high energy and small pT (< 1.3 GeV) particles with with small separation from the hadron beam. They will consist of two double-layer 25x12 cm$^2$ AC-LGAD stations, located **inside the beam line** and 10$\sigma$ from the main beam.

$$\sigma(z) = \sqrt{\varepsilon \cdot \beta(z))}$$

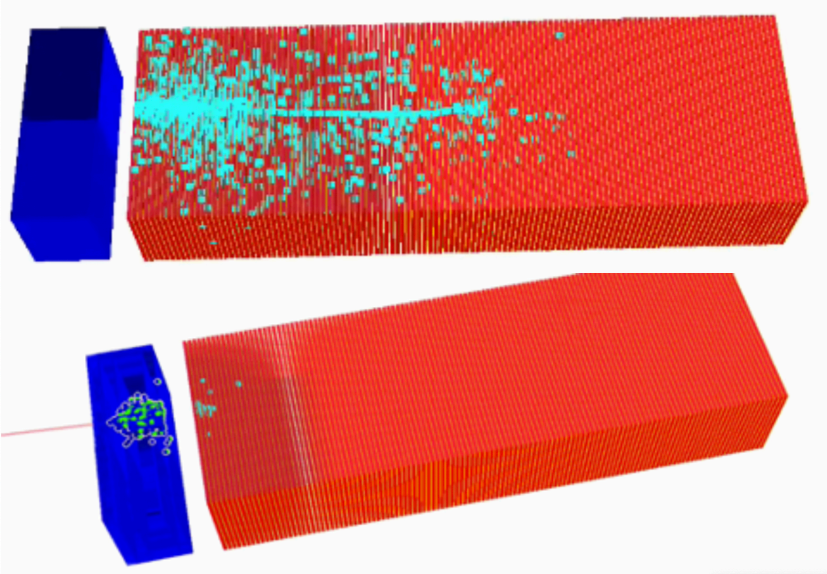


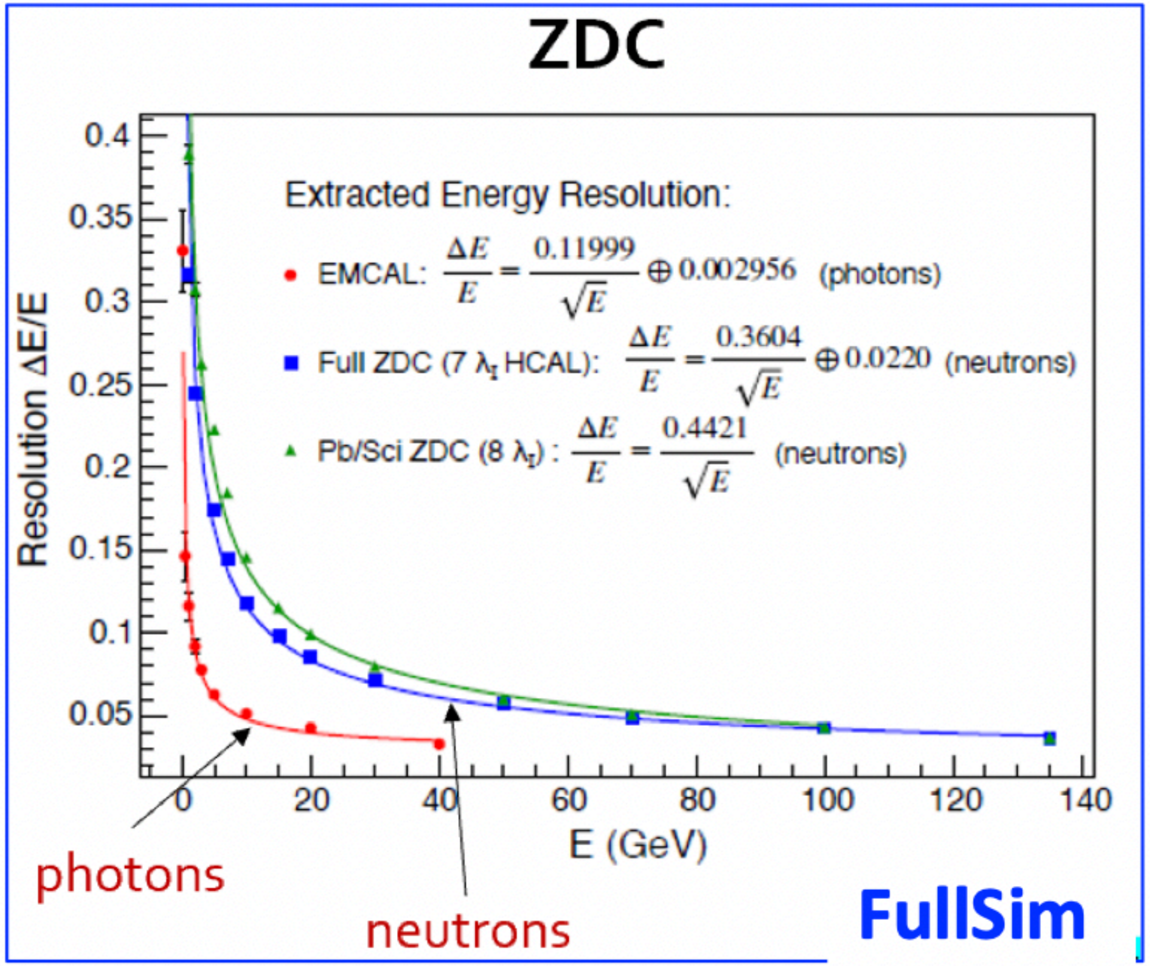
- **Off-momentum detectors** measure charged particles that have a smaller magnetic rigidity than the main hadron beam. Such particles will be **bent outside the beam pipe**. The detectors consist of tracking planes based on AC-LGAD sensors.
- Fast Timing to take into account crab crossing

# ATHENA ZDC

**ECAL** : **W/ScFi** towers 2.5cm x 2.5cm x 17cm ( the Energy resolution $\frac{\Delta E}{E} = \frac{10-12\,\%}{\sqrt{E}} + 0.3\,\%$ )

**HCAL** : **Pb/Sci** sampling calorimeter with 10cm x 10cm towers will be a 7 interaction length ( combined with ECAL $\frac{\Delta E}{E} = \frac{35-45\,\%}{\sqrt{E}} + 2\,\%$ )





# ECCE - ZDC

**ECAL :** **PbWO4** ( $8X_0$)

the photon resolution (conservative) $\frac{\Delta E}{E} = \frac{9\,\%}{\sqrt{E}} + 2\,\%$

( a silicon pixel layer is attached in front )
( tower size 3cmx3cm; 400 towers )

**Imaging layer**: **W/Si** (22X0) -tracking ( tail catcher )

**HCAL** : **Pb/Si ( 2$\lambda$) + Pb/Scintillator ( 5$\lambda$)**

**Pb/Si:**

3 cm-thick lead plane, Si pad-layer design is as in the W/Si

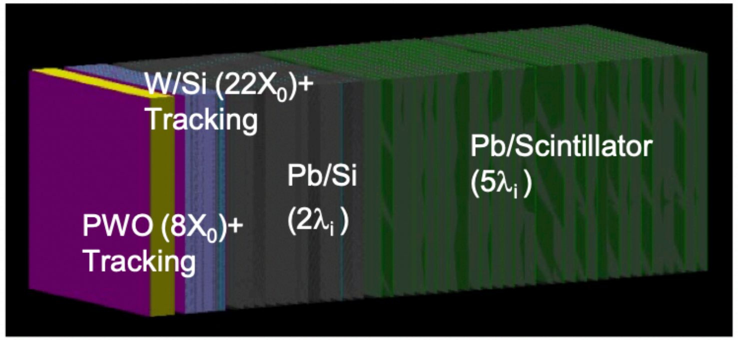
**Pb/Scintillator:**

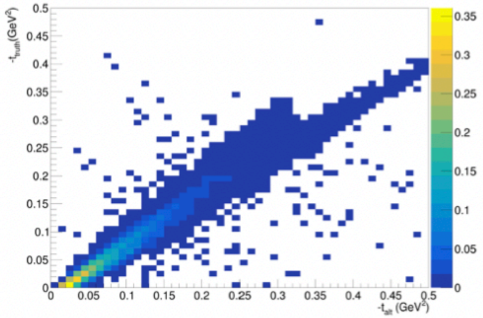
3 cm thick lead plane absorbers with 2 mm-thick scintillator planes

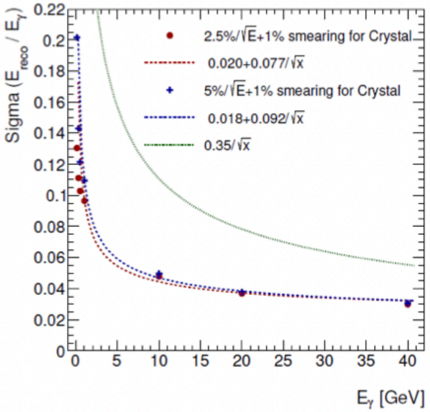
( neutron energy resolution : $\frac{\Delta E}{E} = \frac{44\,\%}{\sqrt{E}} + 4.2\,\%$ )

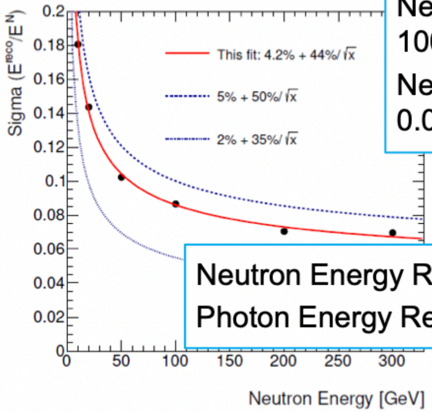
## Zero Degree Calorimeter

- ECCE ZDC has dimensions of 60cm x 60cm x 162cm for the needed acceptance (YR) and consists of $PbWO_4$ crystal, W/Si layer, Pb/Si, and Pb/Scintillator layers
- ECCE ZDC **provides detection for photons and neutrons (0<θ<5.5 mrad) with the required performance**





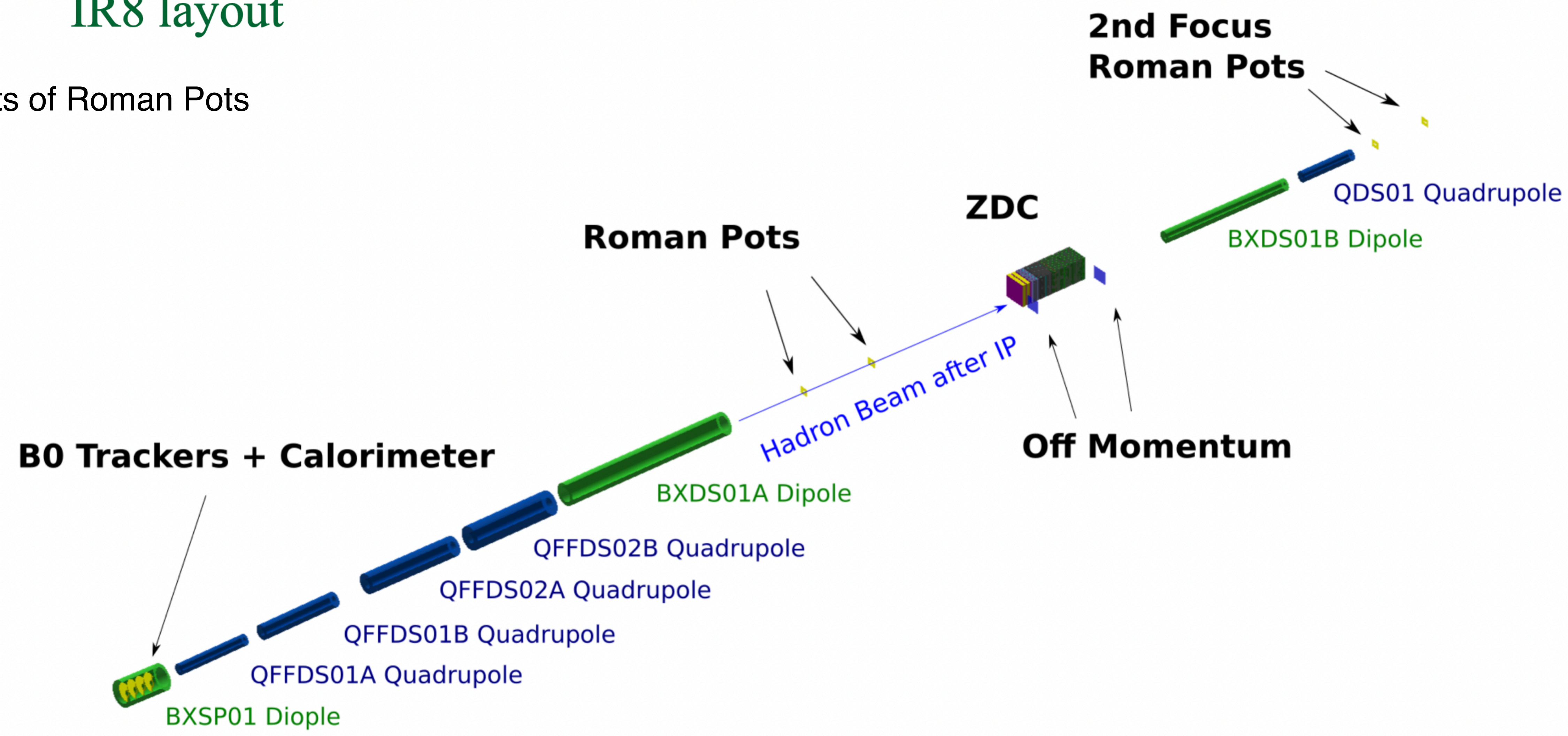

Neutron detection fraction: 100% (59% at 5 on 41 GeV)
Neutron t-resolution: 0.005-0.007 $GeV^2$ (0.019 $GeV^2$)

Neutron Energy Resolution: 44%/√E +4.2%
Photon Energy Resolution: 2.5%/√E+1%

# CORE

## IR8 layout

2 sets of Roman Pots



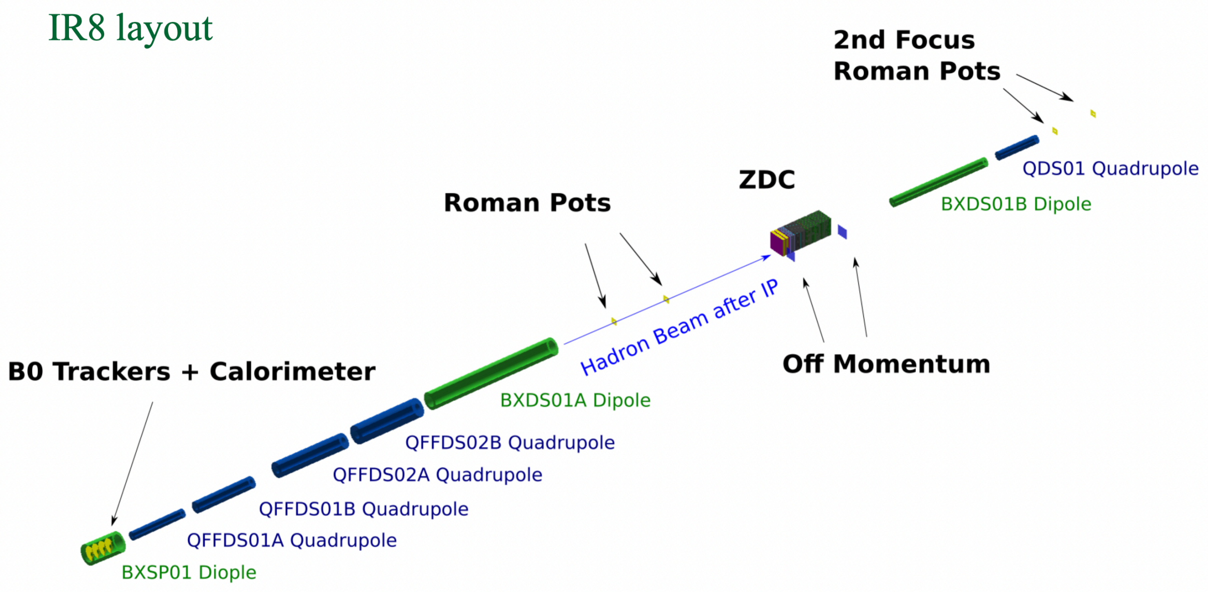
# CORE

A small EMcal is also located inside the B0.

The RPs and OMBs are grouped in pairs, except in the 4 m section at the 2nd focus where there would be one RPs at the focus and one on each side.

AC-LGAD tracker, which would provide both position and time information (although a pixel readout would be required to handle the near-beam rates that limit how close to the beam one can operate the detector).

For the RP detectors at the secondary focus of IR8, we include a thin quartz Cherenkov counter for nuclear-charge tagging via the Z^2 dependence of the Cherenkov amplitude.




ZDC :

EmCAL: LYSO would be a better choice than $PbWO_4$ due to its higher photoelectron yield (not included into the proposal). but assumed that the EMcal is of the simpler W/SciFi type.

prefer LYSO in order to perform spectroscopy on short-lived rare isotopes that might not be accessible at FRIB. We also prefer LYSO (or at least PWO) for vetoing photo decays to suppress background in e.g. exclusive deep virtual J/PSi production on medium to heavy nuclei.

HCAL: can follow the ECCE or ATHENA designs

# Conclusion

- We have a  lot of similarities in the designs of sub-detectors.
- Common technologies   such as AC-LGAD, or HCAL part of the ZDC
- Synergies with sub-components of the Central detector