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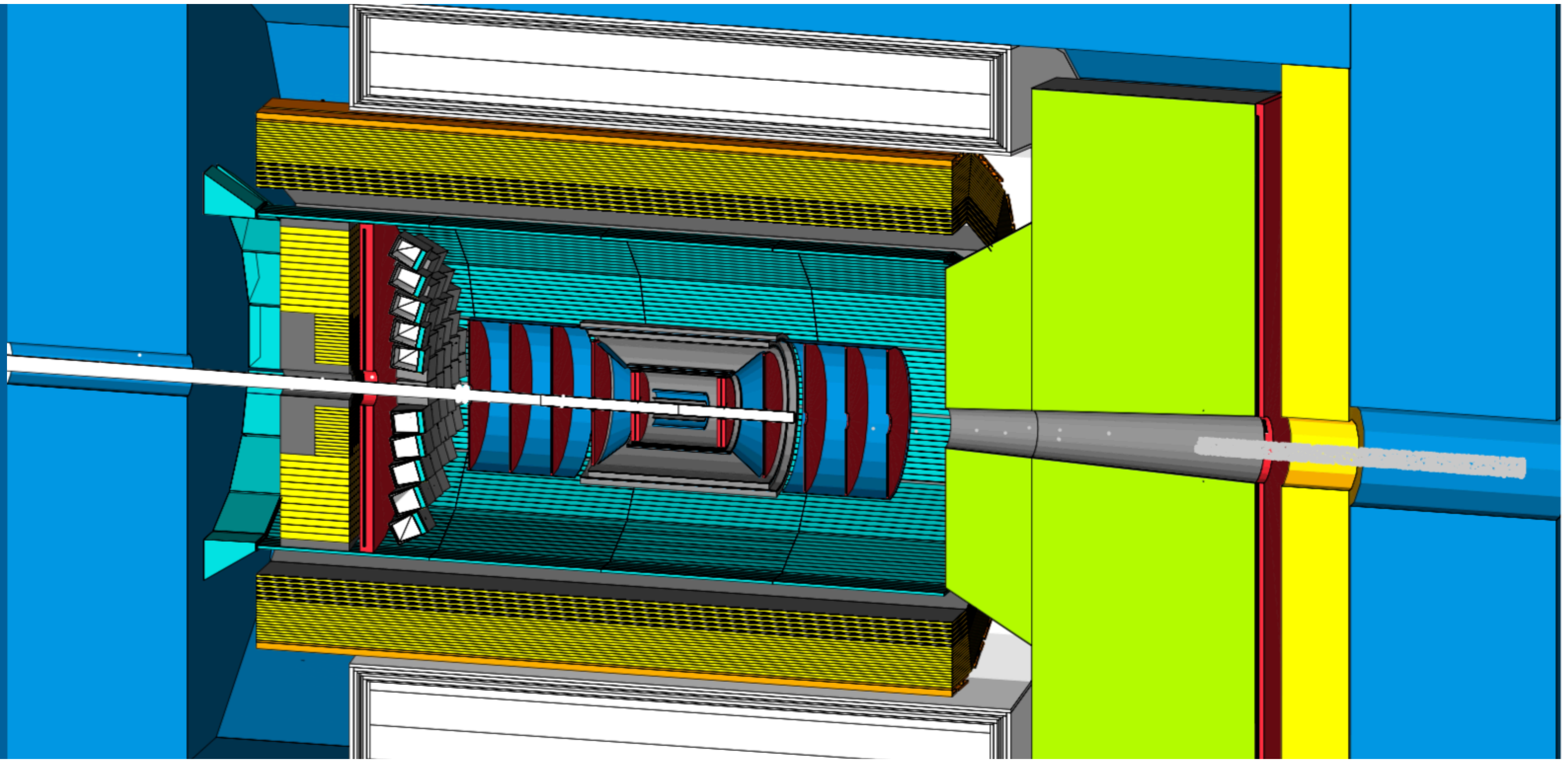
SOFTWARE TUTORIAL IIA

THE ROLE OF SOFTWARE IN DETECTOR DESIGN AND OPTIMIZATION



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CFNS EIC Summer School
Thursday, August 19, 2021

A NEW DETECTOR FROM SCRATCH?

From the EIC Yellow Report to an optimized EIC detector

η	Nomenclature	Tracking						Electrons and Photons			$\pi/K/p$		HCAL		Muons
		Resolution	Relative Momentun	Allowed X/X_0	Minimum-p_T (MeV/c)	Transverse Pointing Res.	Longitudinal Pointing Res.	Resolution σ_E/E	PID	Min E Photon	p-Range	Separation	Resolution σ_E/E	Energy	
< -4.6	Low-Q2 tagger														
-4.6 to -4.0		Not Accessible													
-4.0 to -3.5			Reduced Performance												
-3.5 to -3.0	Backward Detector		$\sigma_p/p \sim 0.1\% \times p \oplus 2\%$	~5% or less	150-300			$1\%/E \oplus 2.5\%/\sqrt{E} \oplus 1\%$	π suppression up to 1:10^4	20 MeV	≤ 10 GeV/c	≥ 3σ	$50\%/\sqrt{E} \oplus 10\%$	~500MeV	Muons useful for background suppression and improved resolution
-3.0 to -2.5															
-2.5 to -2.0			$\sigma_p/p \sim 0.02\% \times p \oplus 1\%$												
-2.0 to -1.5						dca(xy) ~ $40/p_T$ μm ⊕ 10 μm	dca(z) ~ $100/p_T$ μm ⊕ 20 μm	$2\%/E \oplus (4\text{-}8)\%/\sqrt{E} \oplus 2\%$	π suppression up to 1:(10^{-3}-10^{-2})	50 MeV					
-1.5 to -1.0															
-1.0 to -0.5	Barrel		$\sigma_p/p \sim 0.02\% \times p \oplus 5\%$		400	dca(xy) ~ $30/p_T$ μm ⊕ 5 μm	dca(z) ~ $30/p_T$ μm ⊕ 5 μm	$2\%/E \oplus (12\text{-}14)\%/\sqrt{E} \oplus (2\text{-}3)\%$	π suppression up to 1:10^{-2}	100 MeV	≤ 6 GeV/c		$100\%/\sqrt{E} \oplus 10\%$		
-0.5 to 0.0															
0.0 to 0.5															
0.5 to 1.0															
1.0 to 1.5	Forward Detectors		$\sigma_p/p \sim 0.02\% \times p \oplus 1\%$		150-300	dca(xy) ~ $40/p_T$ μm ⊕ 10 μm	dca(z) ~ $100/p_T$ μm ⊕ 20 μm	$2\%/E \oplus (4^{*}\text{-}12)\%/\sqrt{E} \oplus 2\%$	3σ e/π up to 15 GeV/c	50 MeV	≤ 50 GeV/c		$50\%/\sqrt{E} \oplus 10\%$		
1.5 to 2.0															
2.0 to 2.5															
2.5 to 3.0			$\sigma_p/p \sim 0.1\% \times p \oplus 2\%$												
3.0 to 3.5															
3.5 to 4.0	Instrumentation to separate charged particles from photons		Reduced Performance												
4.0 to 4.5		Not Accessible													
> 4.6	Proton Spectrometer / Zero Degree Neutral Detection														

+ new developments

Detector & reconstruction requirements

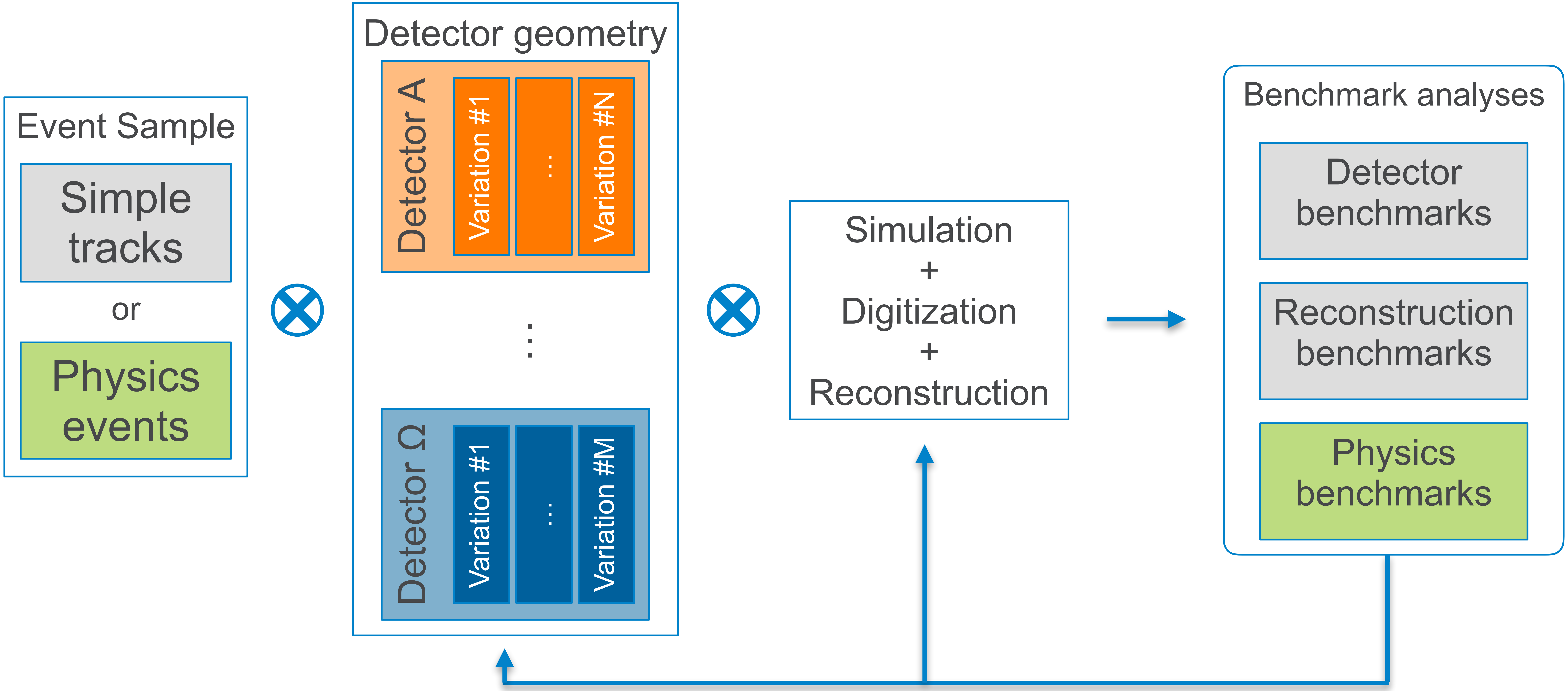
Extensive list of key performance parameters inform detector choices. This table of requirements could be interpreted as a series of automized tests that a detector implementation needs to pass.

Physics requirements

Detector design has to enable many key physics measurements, while being flexible enough to accommodate new developments through the next 2 decades

…from physics to simulated data and back…

THE SIMULATION-RECONSTRUCTION-ANALYSIS LOOP



DIFFERENT EVENTS OF INTEREST

What types of events do we need, and why?

Event Sample

Simple tracks

or

Physics events

- Validate detector and benchmark reconstruction chain against YR requirements (using particle guns)

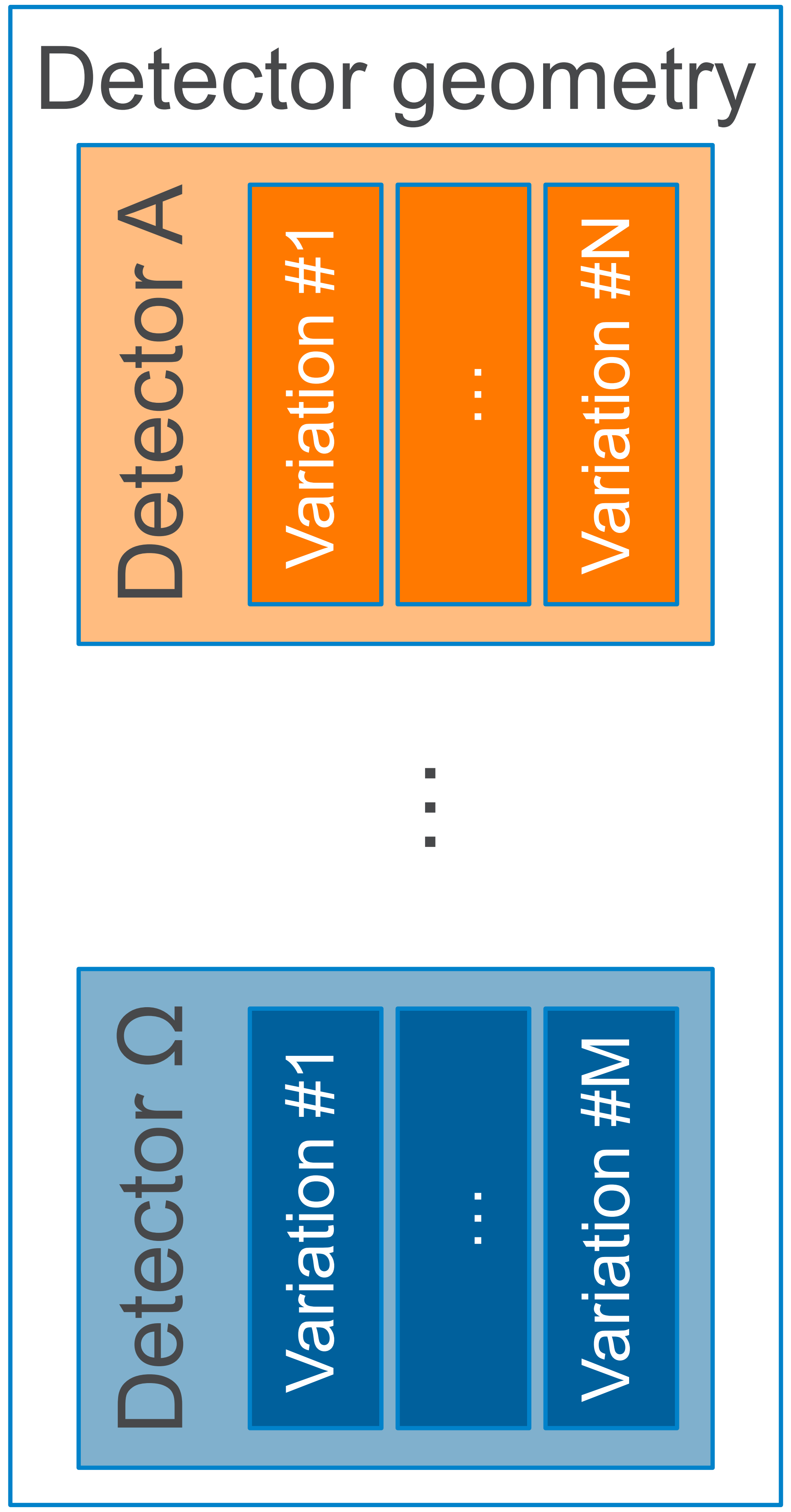
- Characterize and benchmark detector setup for desired physics observables (using physics event generators)

- Towards a fully integrated setup for on-demand event generation to cover all physics requirements for EIC

https://github.com/AIDASoft/DD4hep
https://eicweb.phy.anl.gov/EIC/NPDet
https://eicweb.phy.anl.gov/EIC/detectors/athena

DETECTOR GEOMETRY

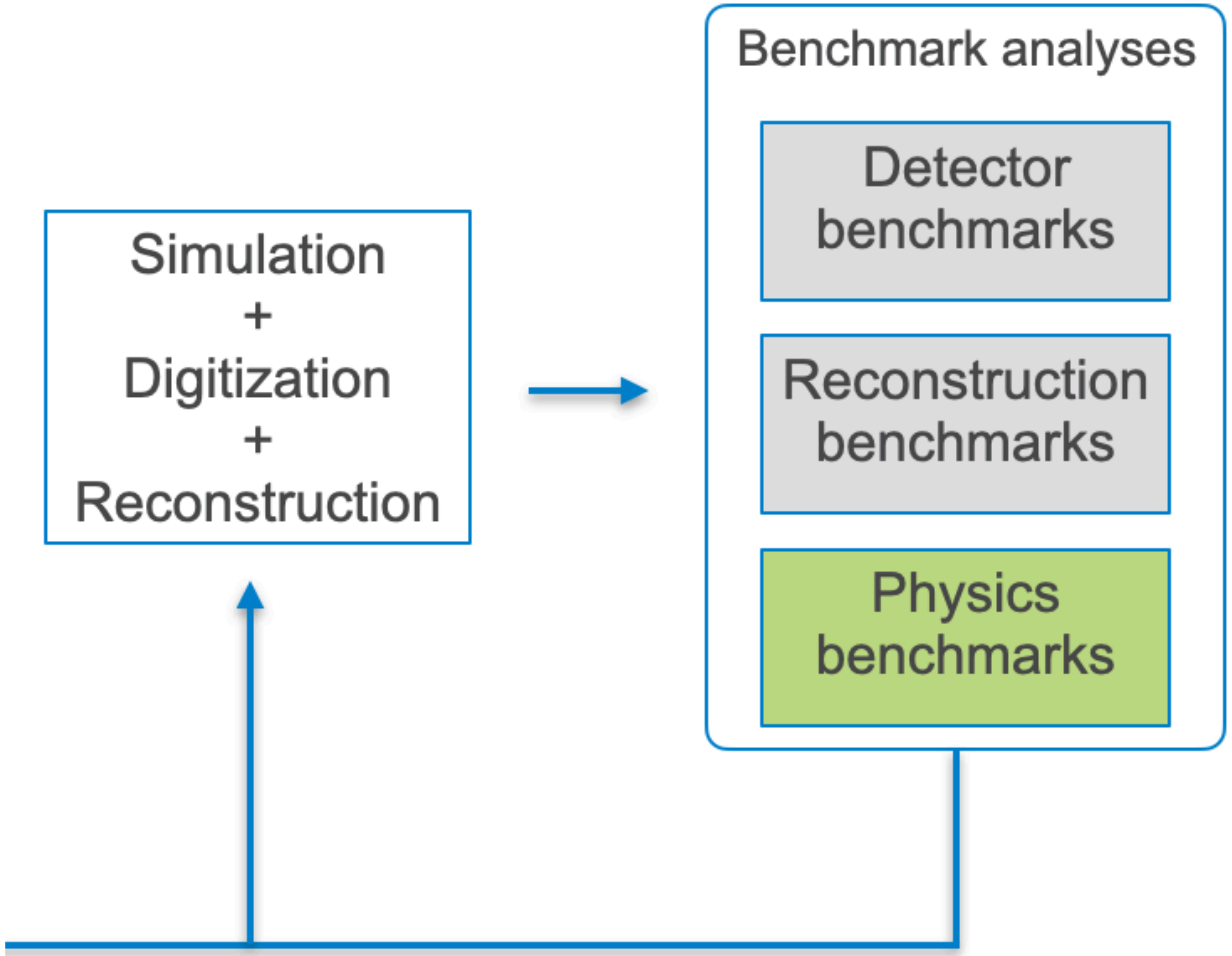
This is what we want to optimize!



- Need to benchmark and optimize many variations of our detector.
- Major variations: pick the overall concept that works the best
- Minor variations: now fine-tune the concept
- Modern software tools, such as DD4hep (used for ATHENA), allow us to build a library of configurable detector options to feed into the benchmark & optimization process.

WHAT COMES AFTER GEOMETRY?

…GEANT4 simulation, event reconstruction and physics analysis

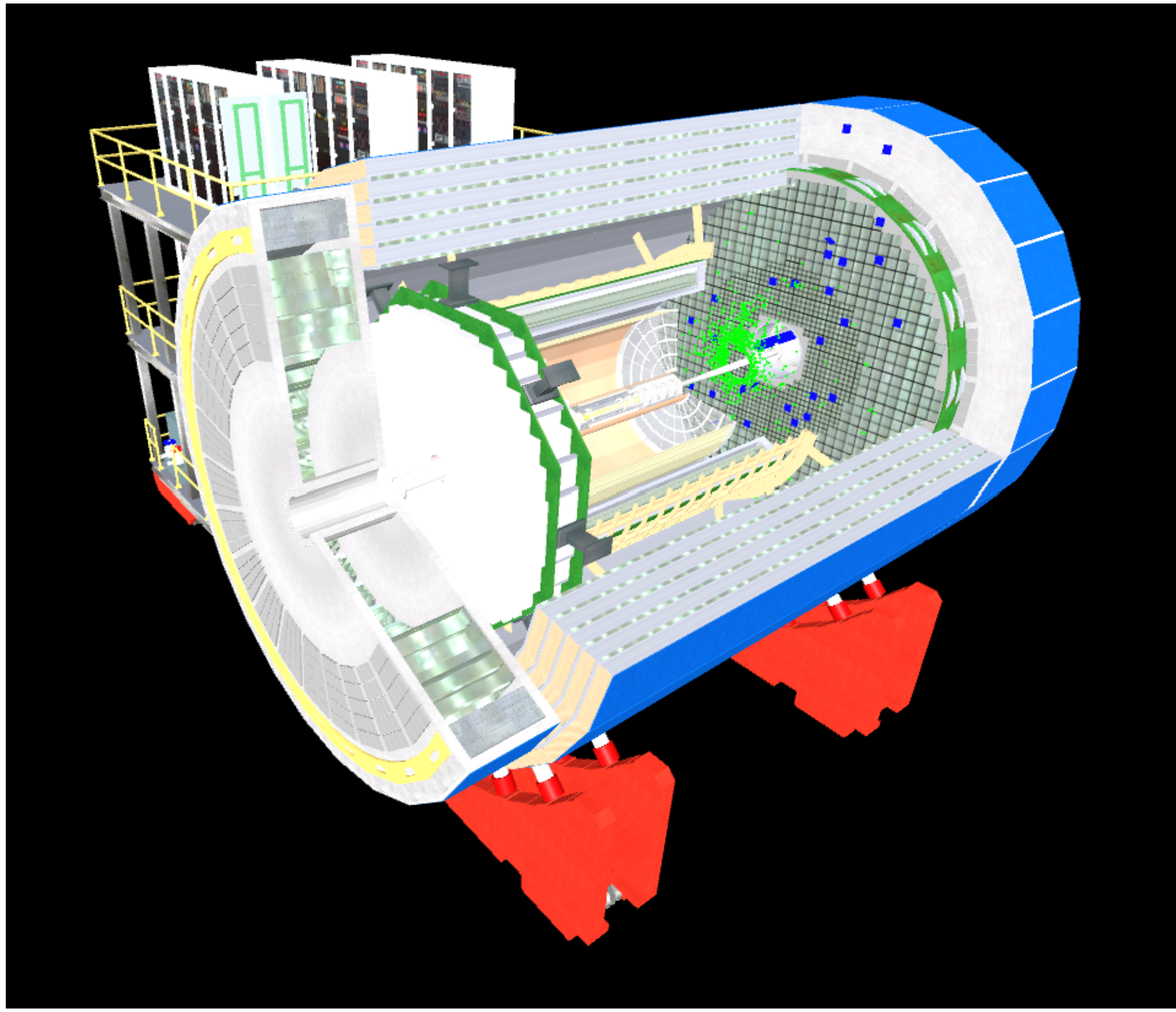


- **Simulation**: walk the events through the detector geometry accounting for all relevant physics.
- **Digitization**: take the output hits from the simulation and make them look like real experimental data
- **Reconstruction:** take our mock experimental data and reconstruct the events
- **Analysis:** extract key physics quantities and judge detector performance

THE ATHENA DETECTOR PROPOSAL

A collaboration around the Yellow Report Reference Detector

- Detector proposal based around a new large 3T magnet setup to maximize the scientific reach for the EIC.
- State-of-the-art detector setup.
- Collaboration of 96 institutes worldwide.
- Larger detector footprint maximizes the space for future upgrades



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A TOUR THROUGH THE ATHENA DETECTOR

Rendering of the current ATHENA “baseline” geometry

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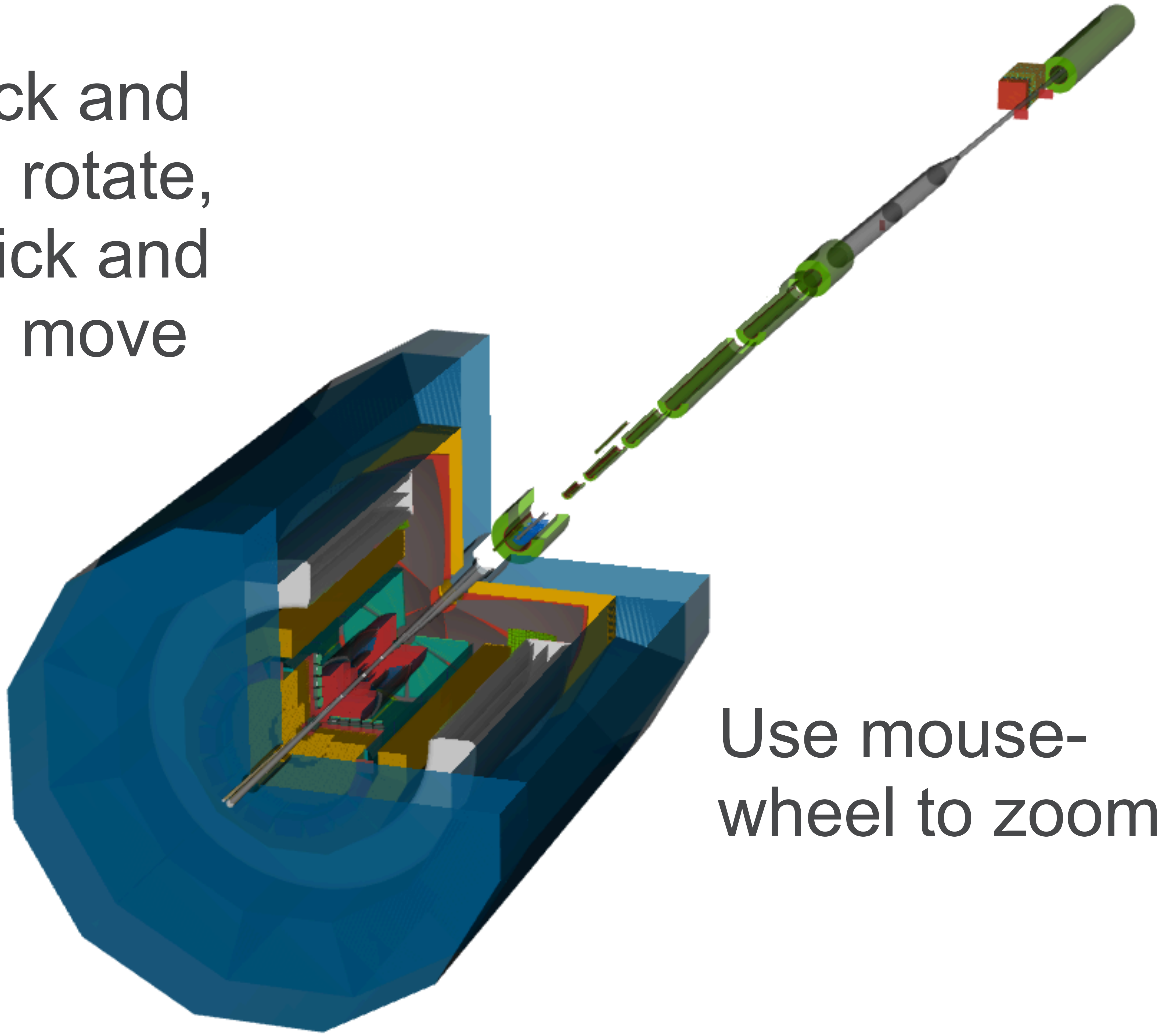
Software Tutorial IIa

You can see some real-life examples of one of the ATHENA geometry configurations here:

- Full detector view
- Inner detector view
- PID subsystem view
- Tracking subsystem view
- Silicon tracker view

Go to “full detector view” for an overview of the detector and interaction point.

Left-click and drag to rotate, right-click and drag to move



Use mouse-wheel to zoom

https://eic.phy.anl.gov/geoviewer/examples/cfns21_school/

ATHENA

THE TRACKING SYSTEM

At the heart of the detector

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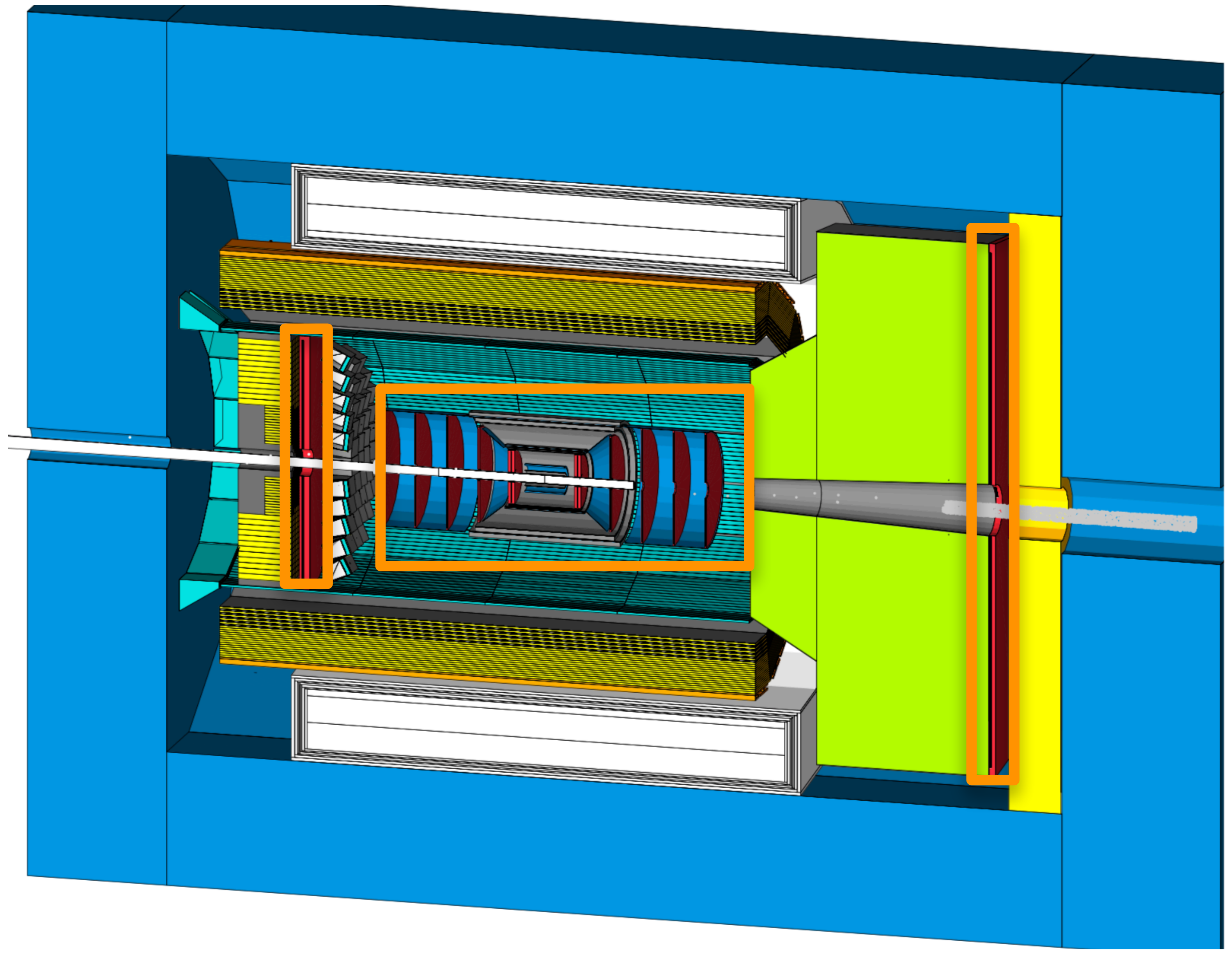
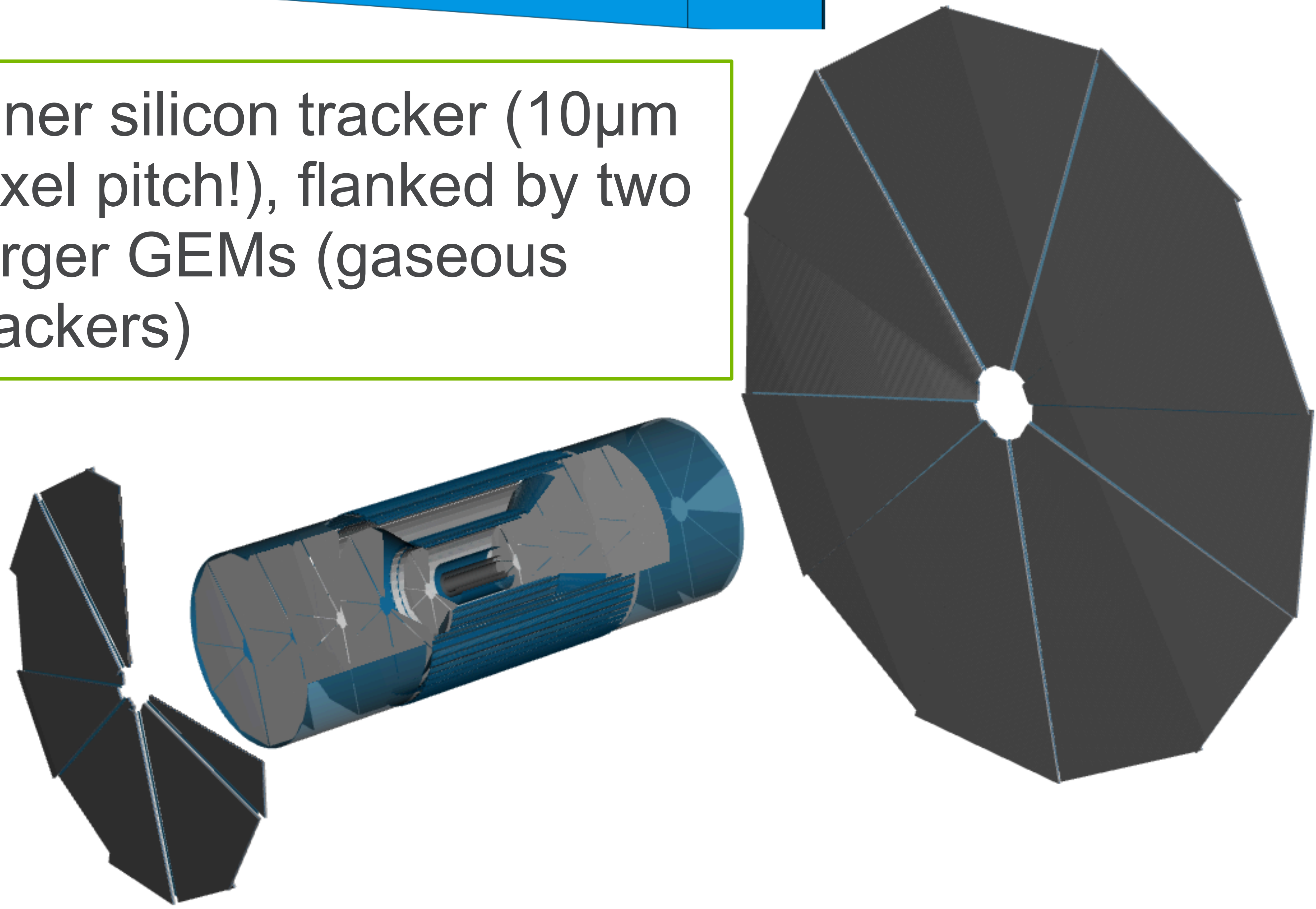
Go to “Tracking subsystem view”



The tracking system registered hits from charged particles as they spiral through the solenoidal magnetic field.

The tracking reconstruction algorithm uses this information to reconstruction particle 3-momentum and charge.

Inner silicon tracker (10μm pixel pitch!), flanked by two larger GEMs (gaseous trackers)



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ATHENA

THE PID SYSTEM

Particle IDentification is crucial at EIC

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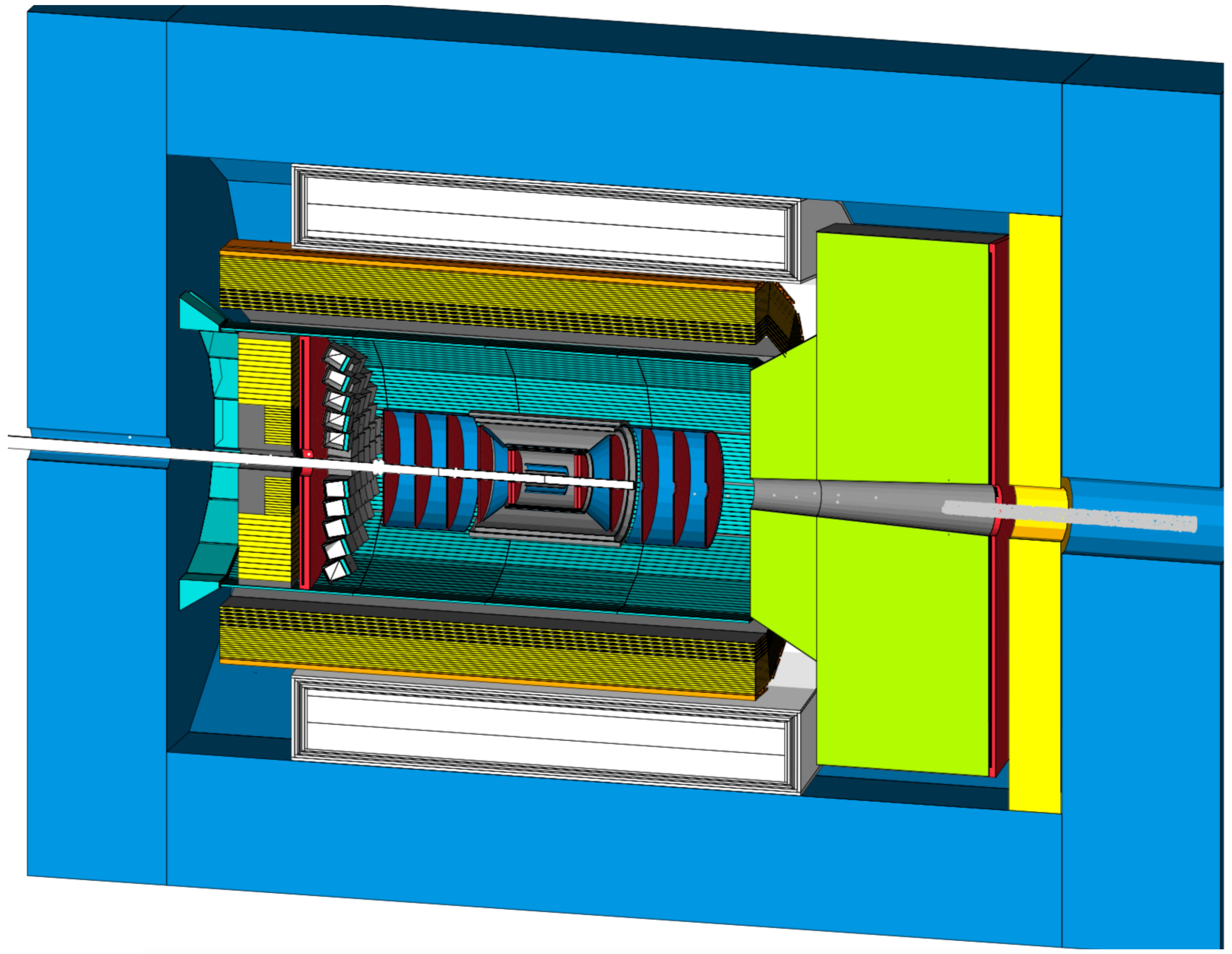
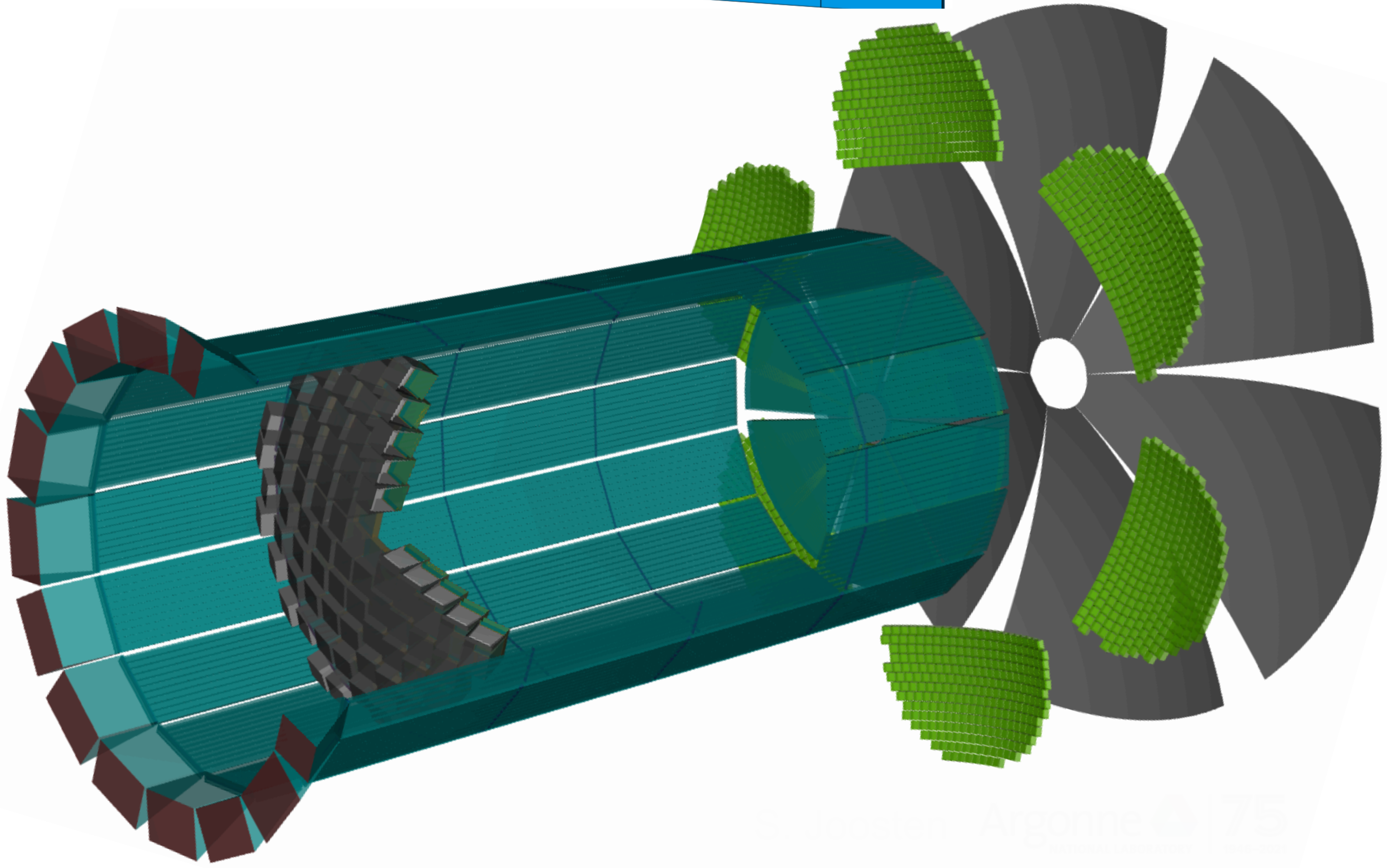
Go to "PID subsystem view"

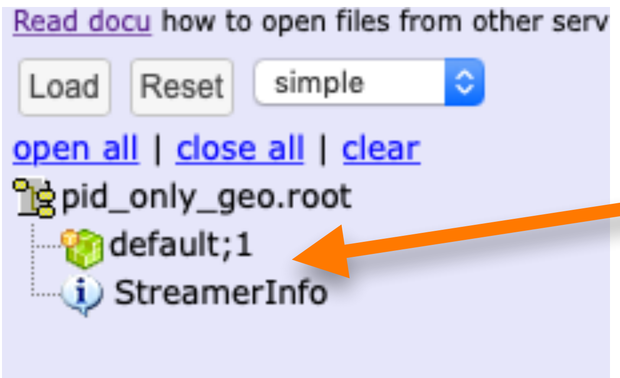
The PID system consist of a dual radiator RICH, modular RICH and DIRC detector. All are Cherenkov detectors that measure the Cherenkov cone of a particle, which relates to its velocity.
Together with momentum (from tracking!) we can then identify the particle mass and species.



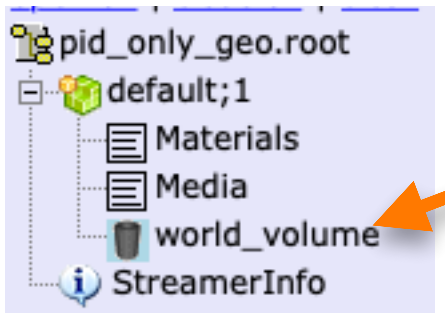


DETAIL: THE MRICH

Let's look a *inside* an MRICH box

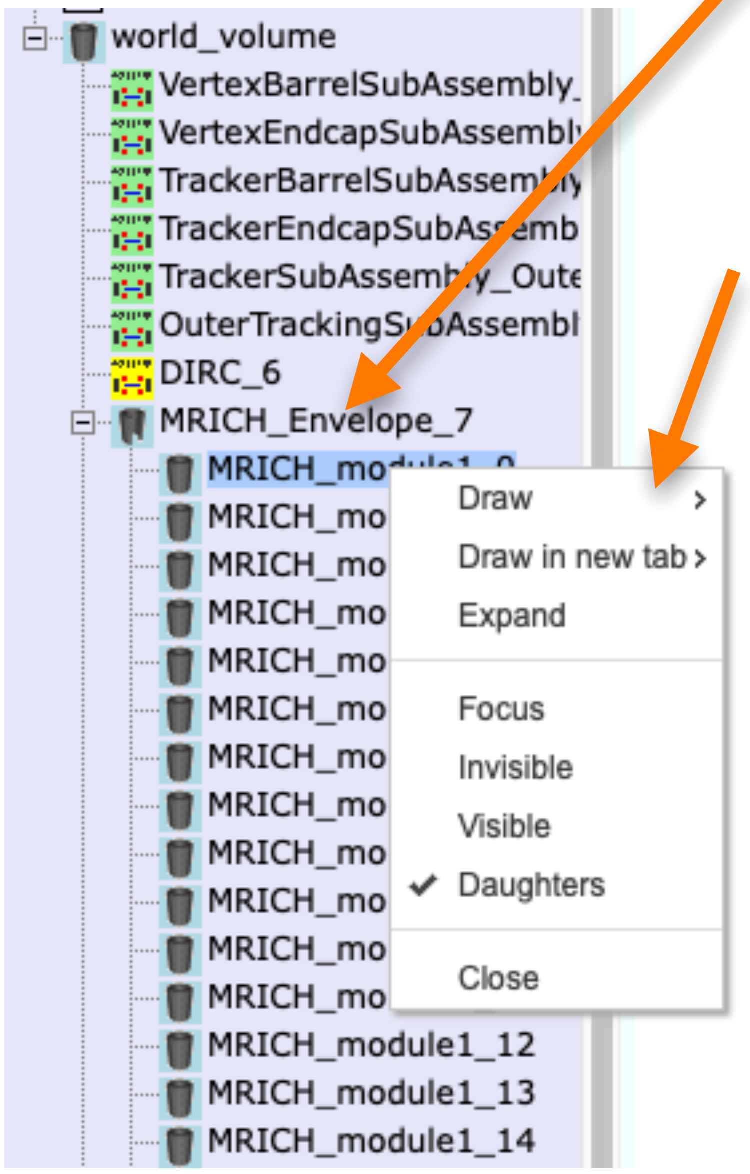


1. Click on "default"

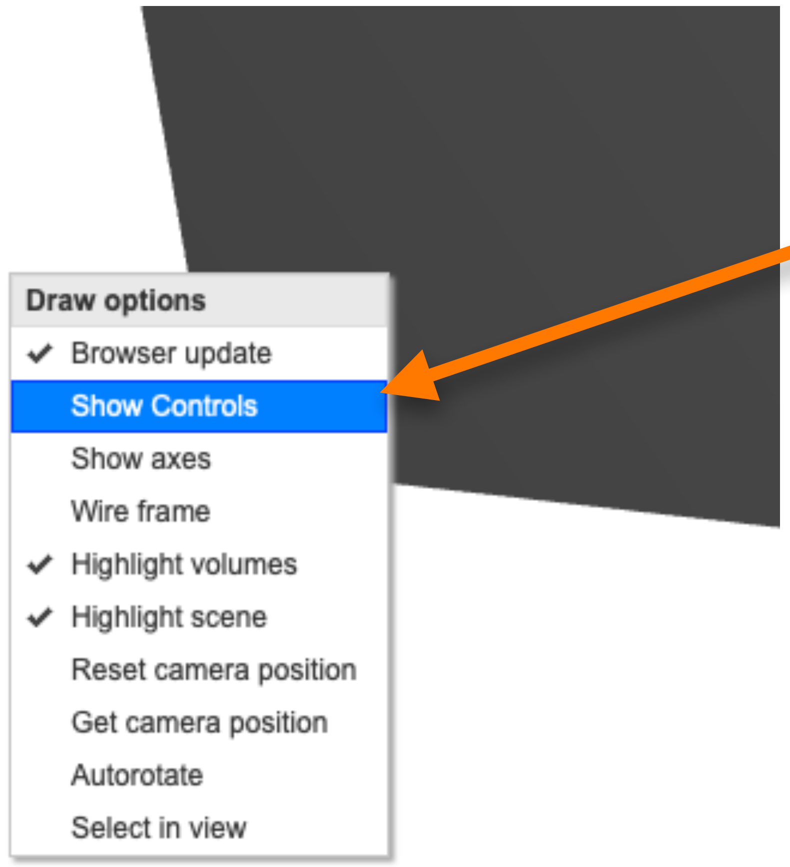


2. Click on "world_volume"

3. Click on "MRICH_Envelope"

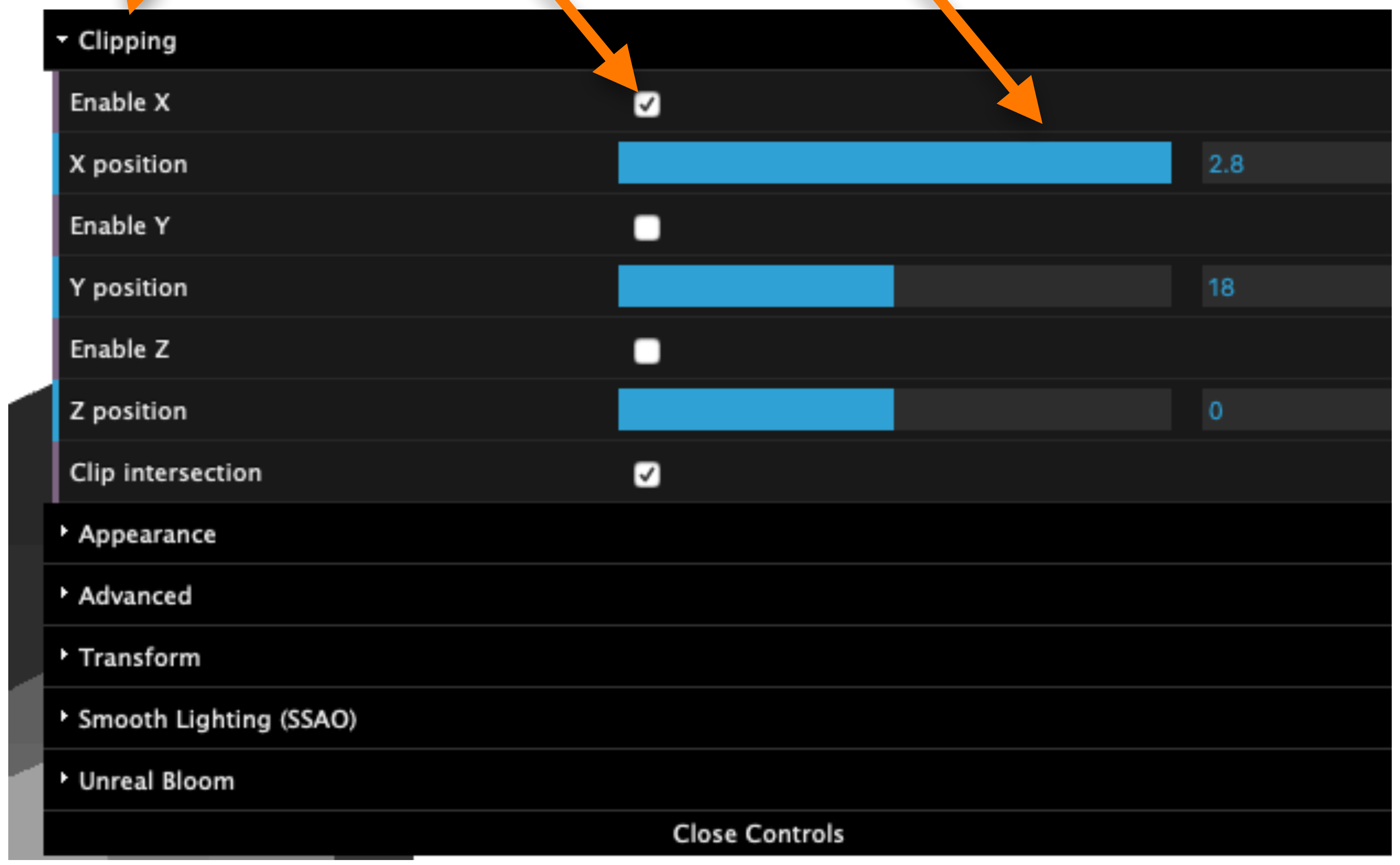


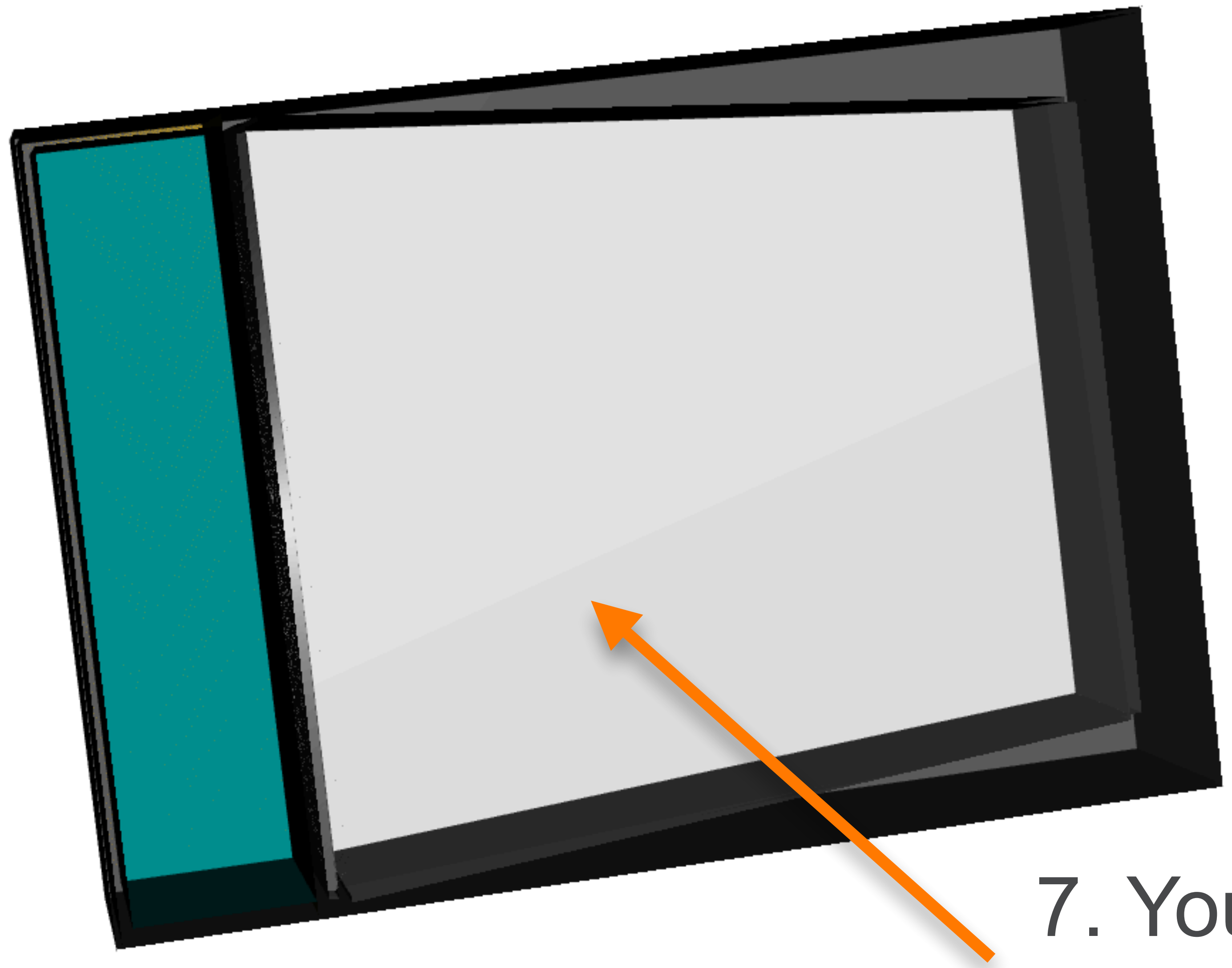
4. Right-click on MRICH_module1_0 and click on "Draw"



5. Right-click on the canvas (white space around the black box) and select "show controls"

6. Unfold "Clipping", select the box for "Enable X", and drag the bar to set the x-position to its maximum value





7. You can now look inside an MRICH box! *Can you find the Fresnel lens?*

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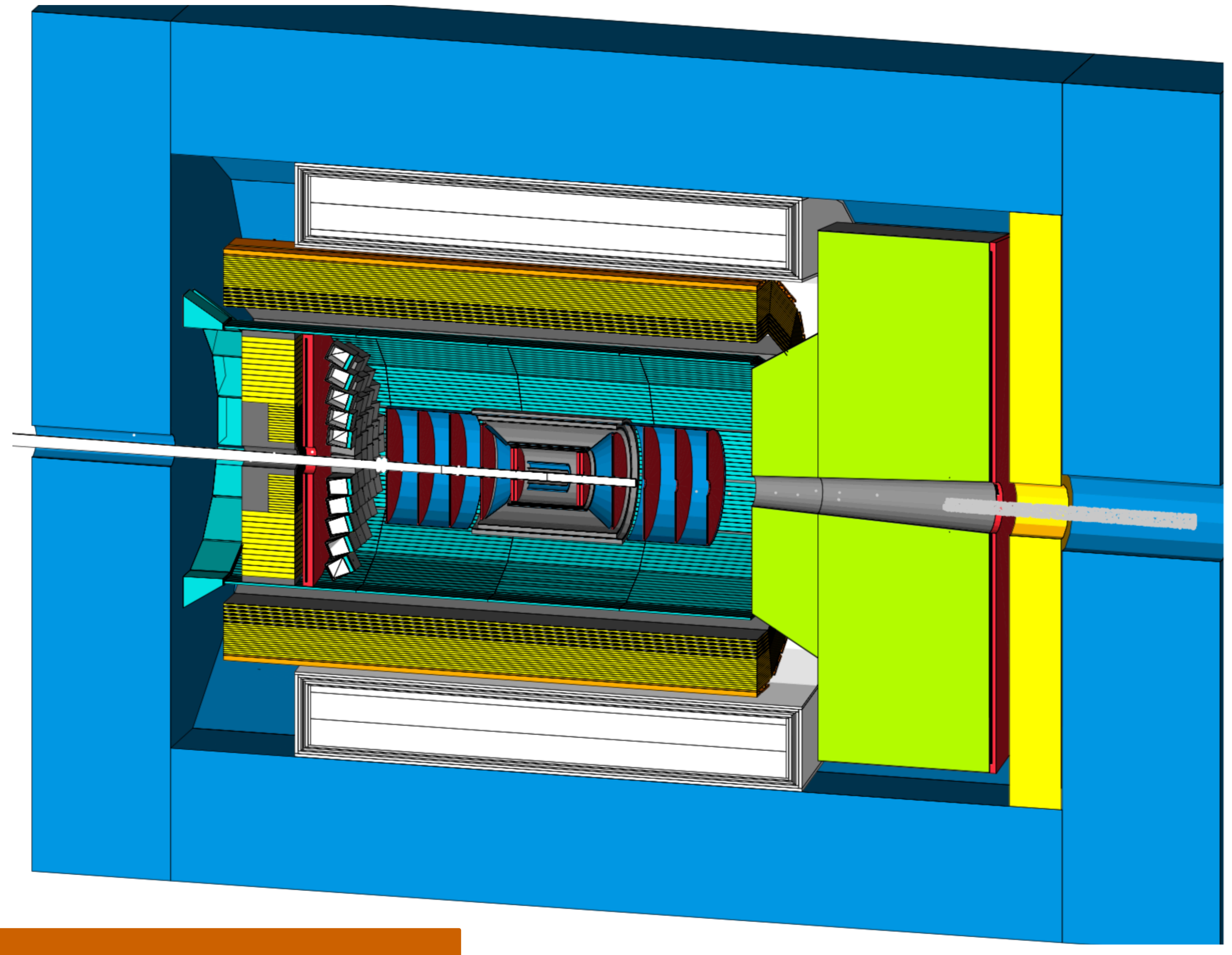
THE ECAL SYSTEM

Electromagnetic calorimetry



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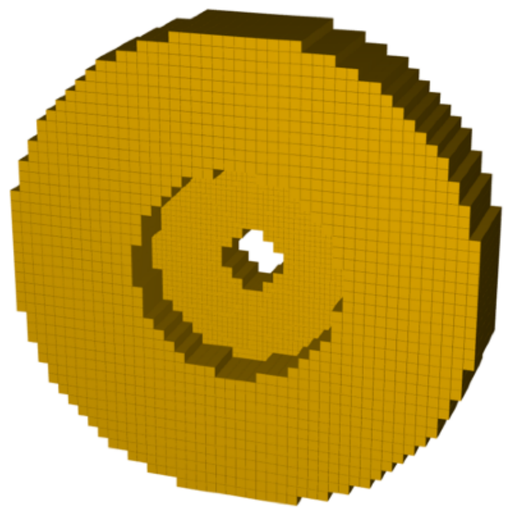
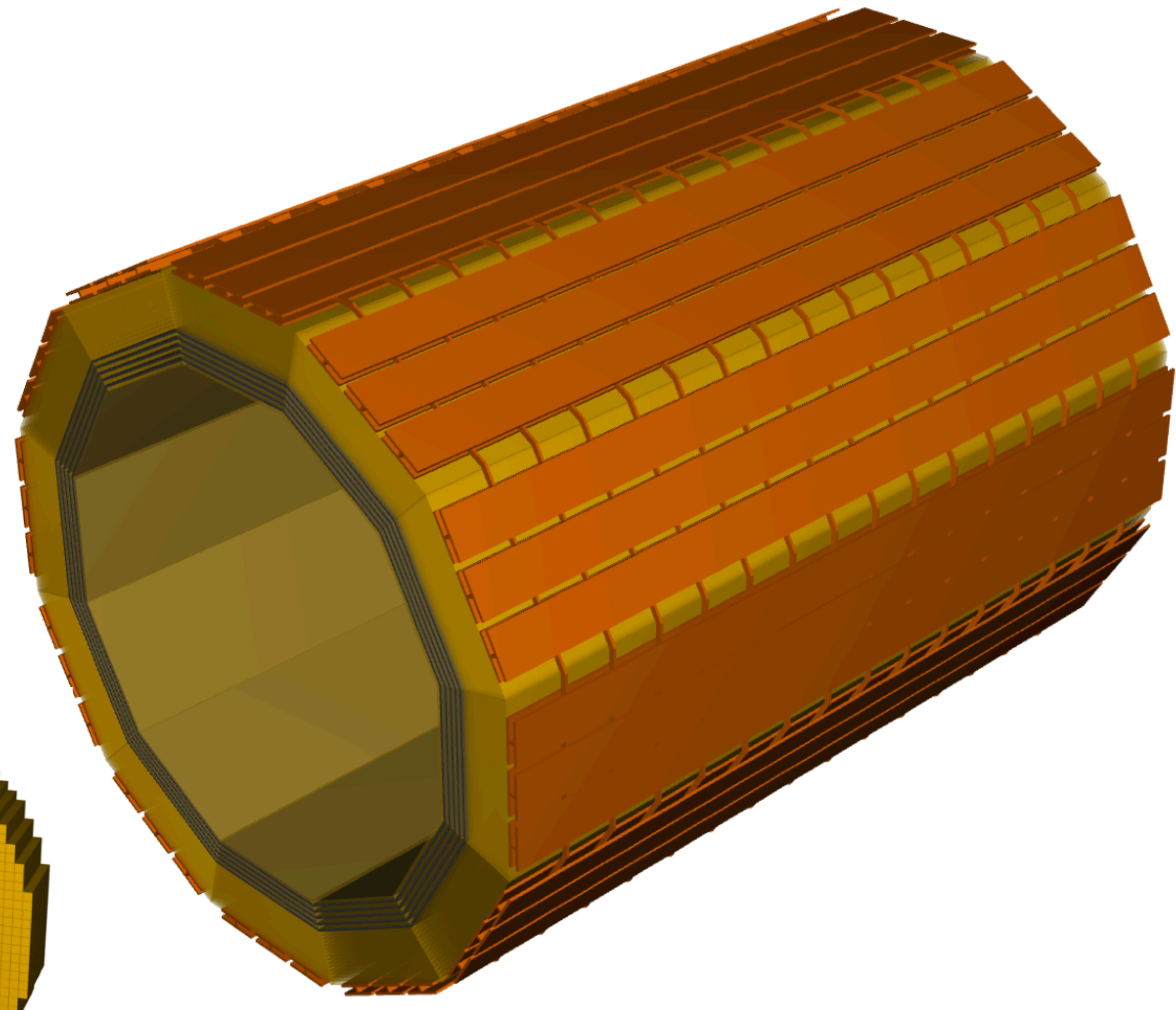
Go to "Full detector view"

You can expand different detectors through the side-bar to see more detail

The electromagnetic calorimetry system is important for electron-pion separation, for the energy measurement of neutral particles, and for precision measurement of the electron energy for electrons that scatter at a very small angle

The ATHENA detector uses an imaging calorimeter for the barrel region, which leverages silicon sensors to measure the path of all showering particles. This can give particularly good electron-pion separation.





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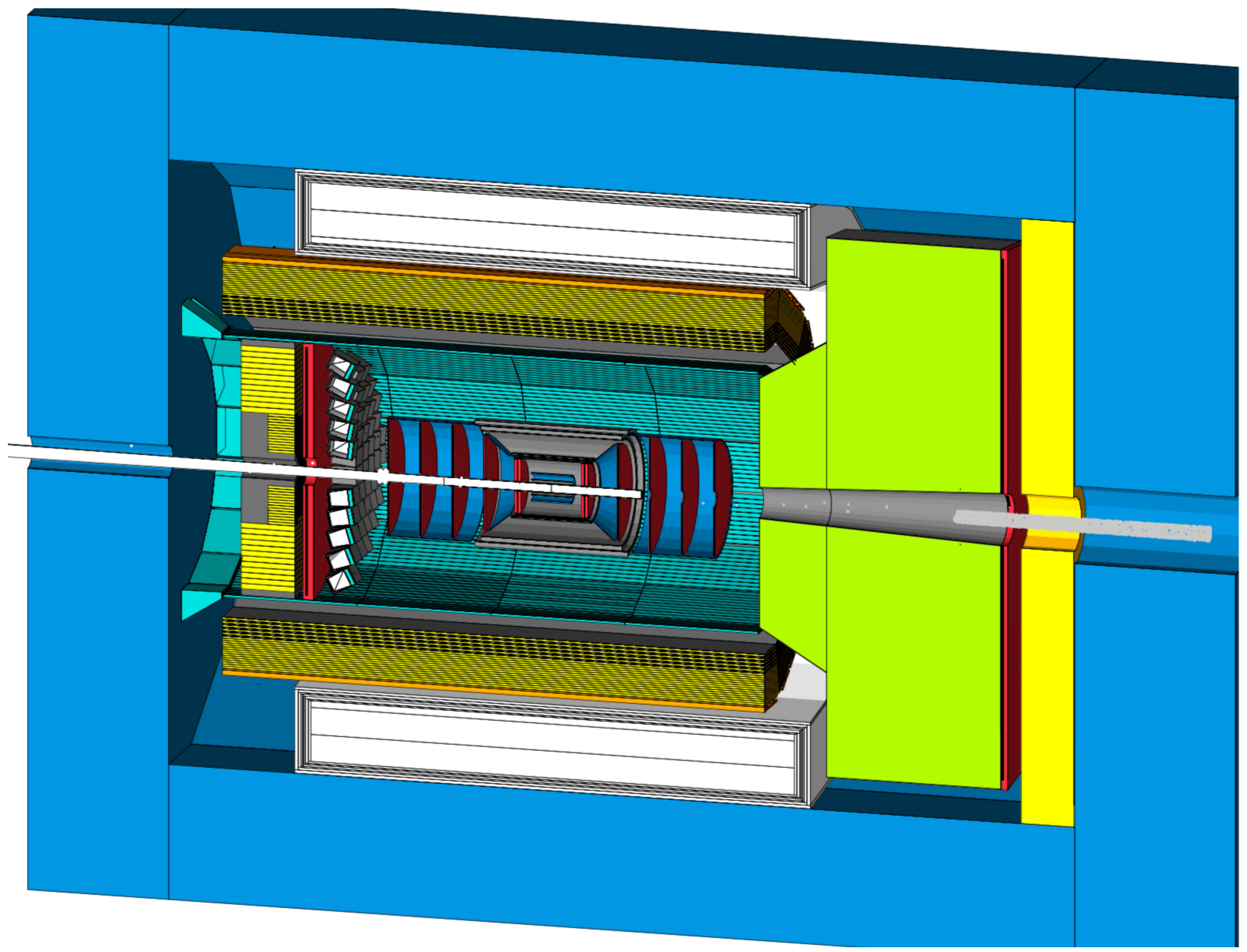
THE HCAL SYSTEM

Catching *all* the particles



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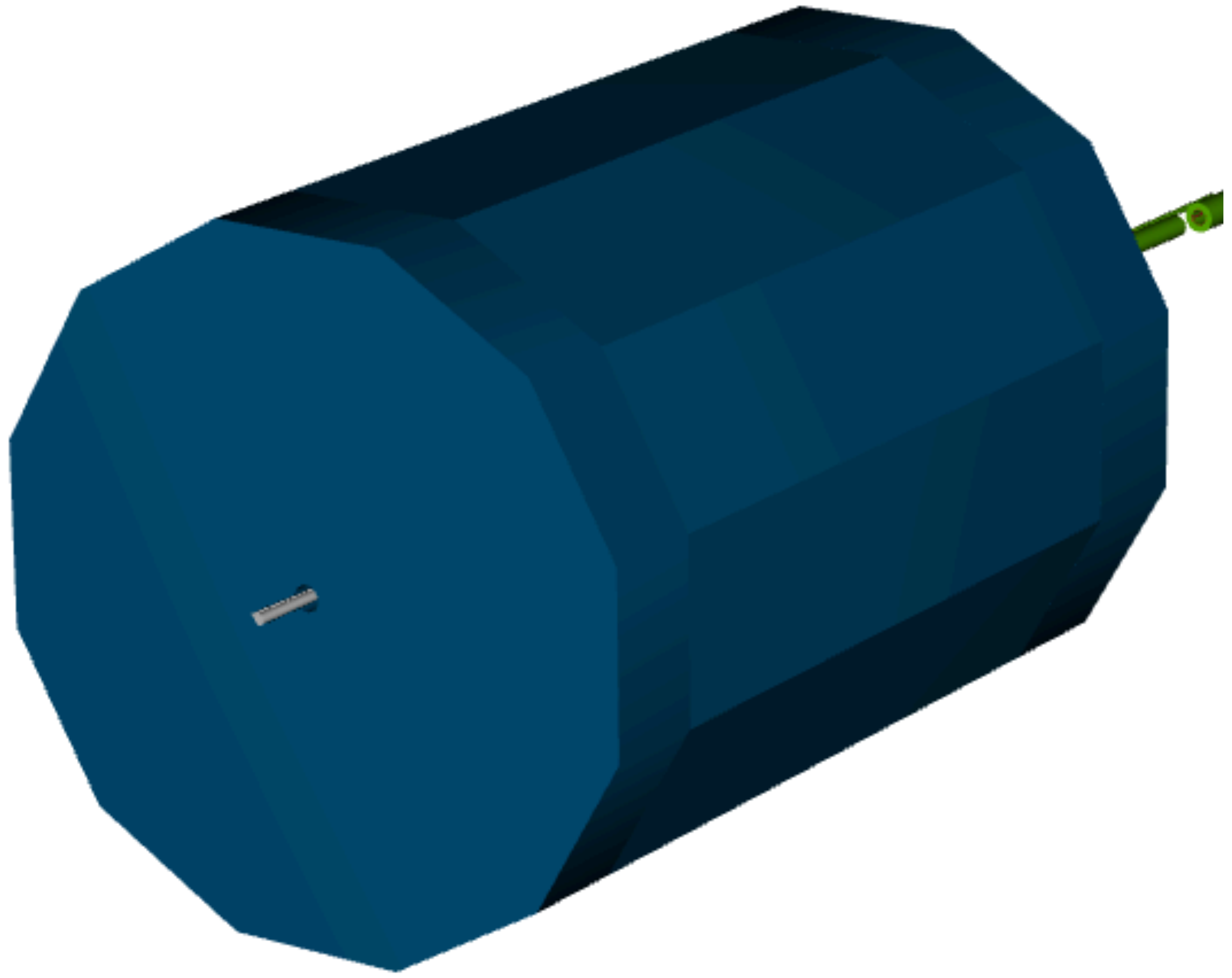
Go to “Full detector view”

The HCAL system encloses the entire spectrometer, ensuring that the detector is hermetic, meaning that we catch *all* the particles of interest.
The baseline HCAL is constructed from layers of iron and scintillator pads



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ATHENA

THE FAR FORWARD SYSTEM

Measuring particles at small angles

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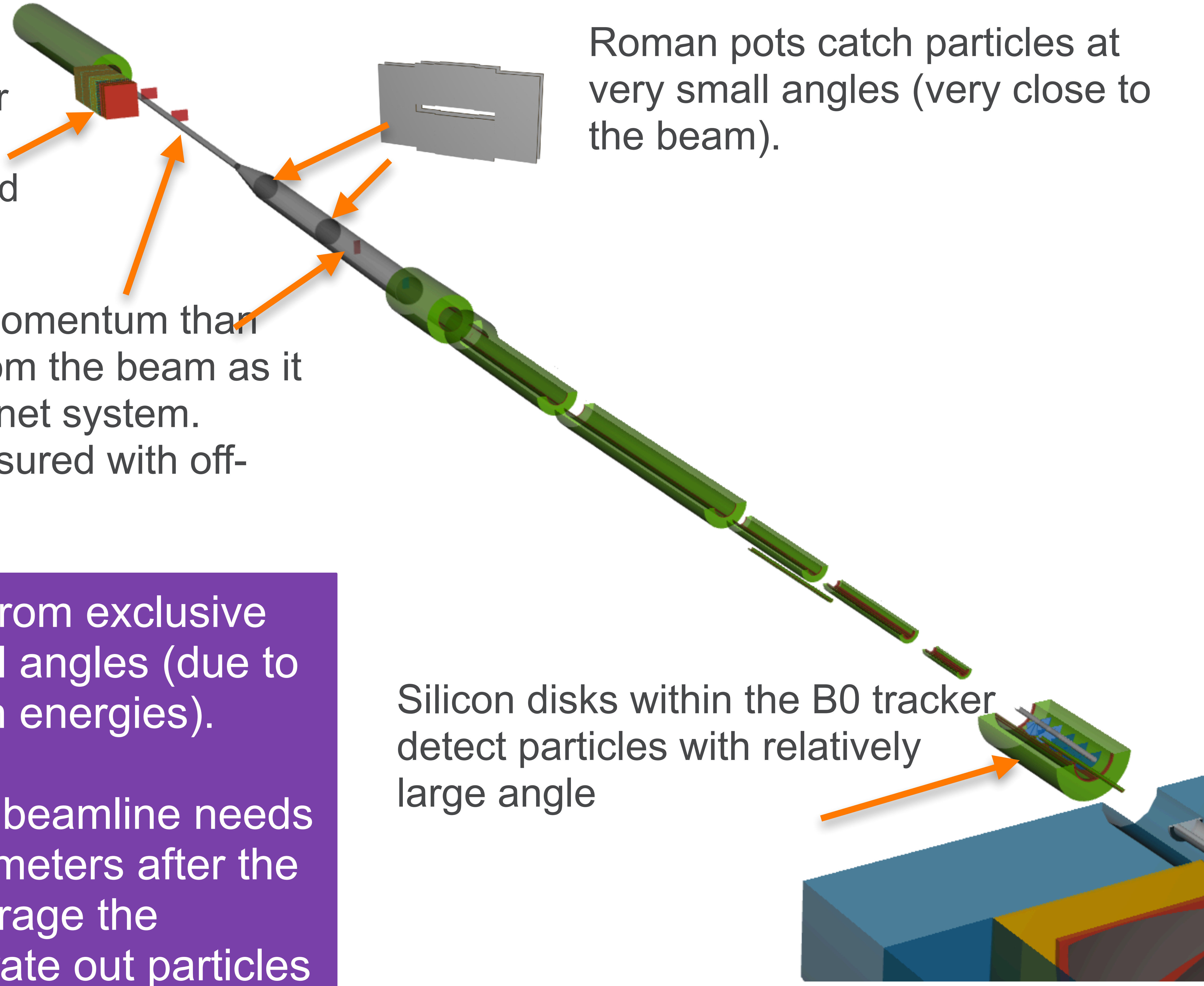
- Silicon tracker view

Go to “Full detector view”



Zero-degree Calorimeter measures neutral particles that do not bend with the magnet system

Roman pots catch particles at very small angles (very close to the beam).

Particles with different momentum than the beam move away from the beam as it passes through the magnet system. These particles are measured with off-momentum detectors.

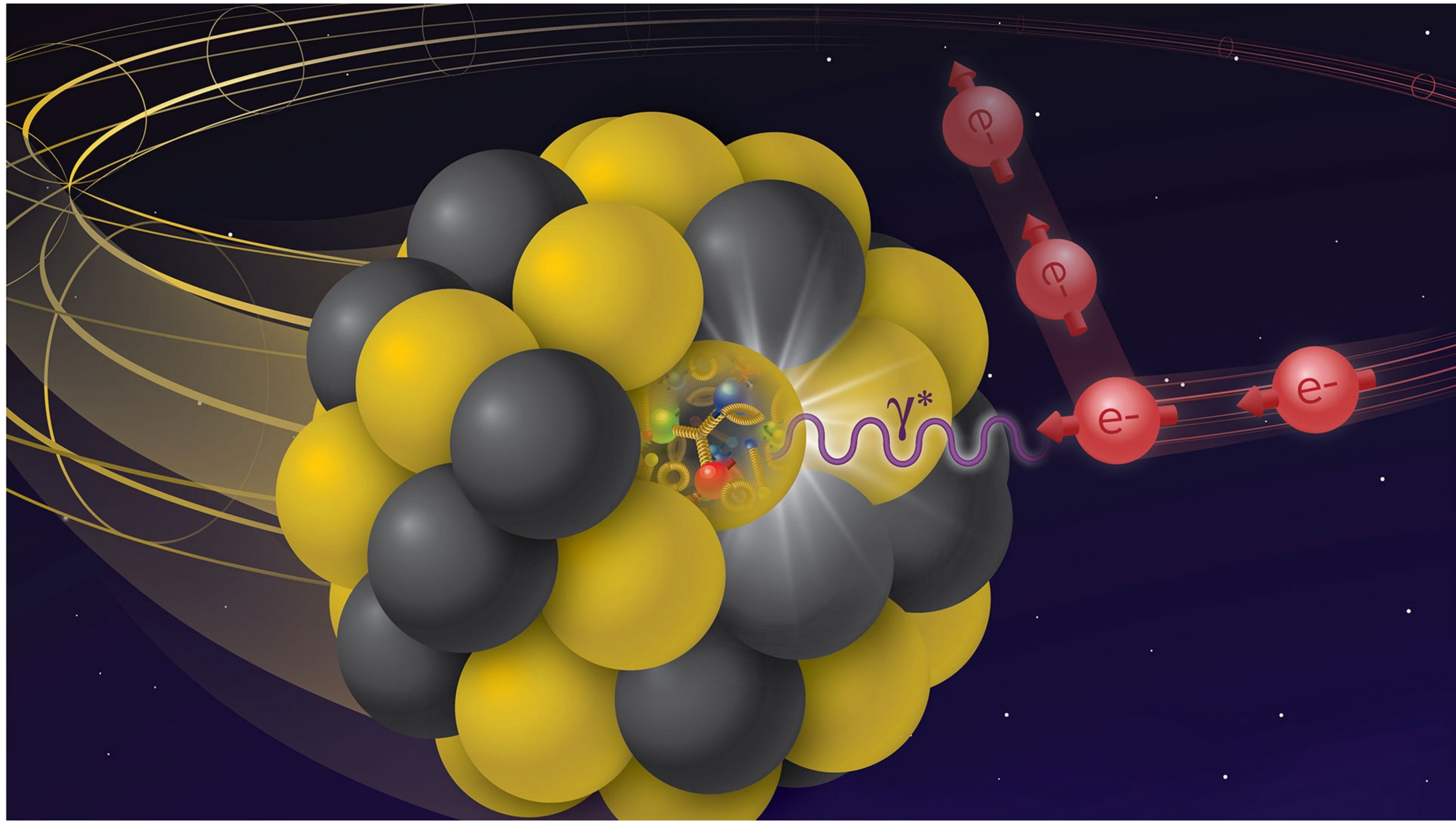
Silicon disks within the B0 tracker detect particles with relatively large angle

Many protons/neutrons/ions from exclusive processes leave at very small angles (due to the asymmetry in the collision energies).

To detect these particles, the beamline needs to be instrumented for many meters after the central detector. We can leverage the accelerator magnets to separate out particles of interest.

SUMMARY

- We need the best possible detectors in order to ensure a successful physics program for decades to come at the EIC.
- **Software plays a central role in the simulation/optimization effort for these detectors**
- EIC should run for multiple decades: ensure we both cover the key deliverables for EIC (mass, spin, imaging, saturation) as well as have a flexible and upgradable detector for many years to come!



THE END