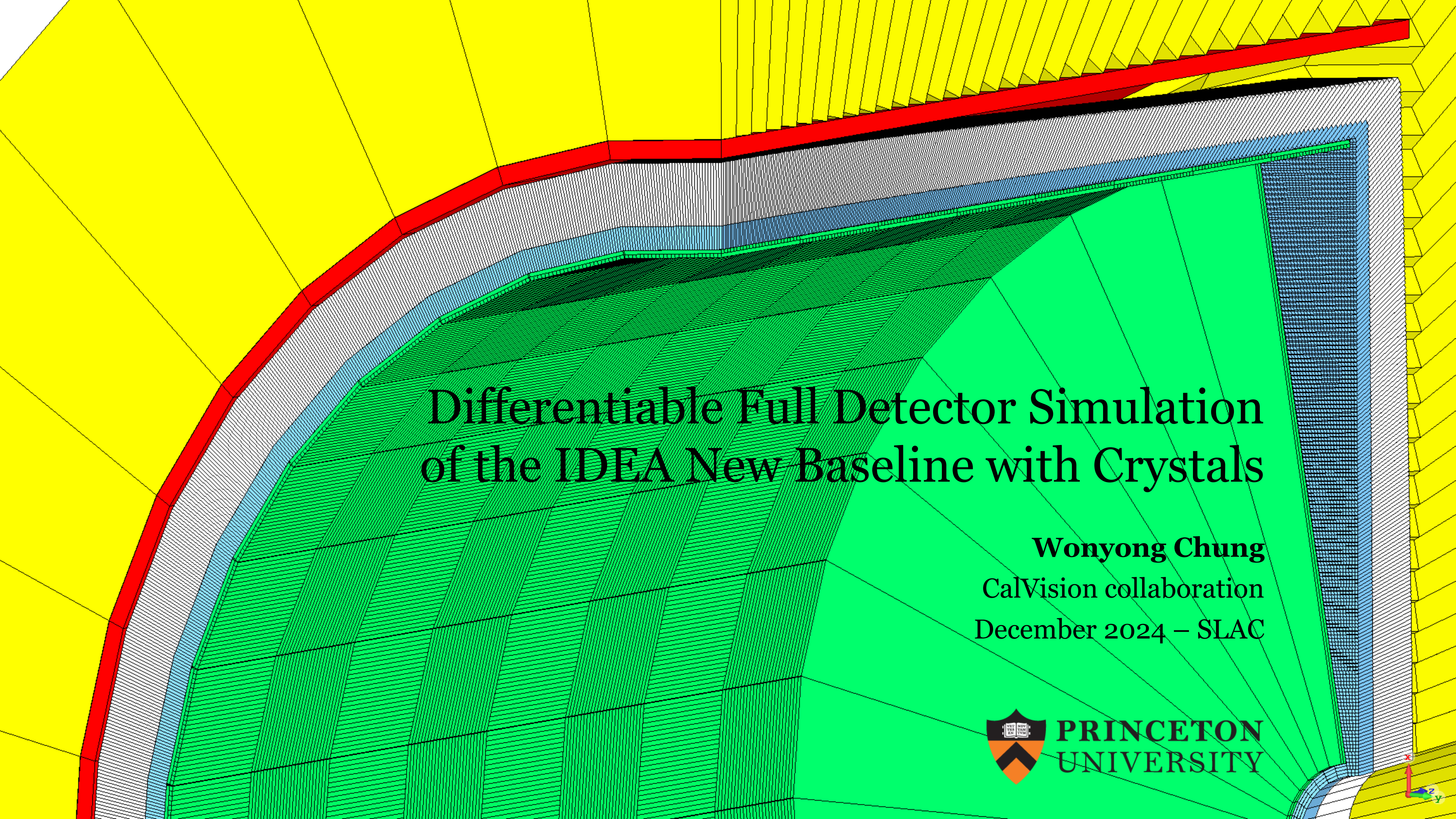


Differentiable Full Detector Simulation of the IDEA New Baseline with Crystals

Wonyong Chung

CalVision collaboration

December 2024 – SLAC

PRINCETON UNIVERSITY

New IDEA baseline

Beampipe

LumiCal

Vertex Detector

Drift Chamber

Silicon Wrapper

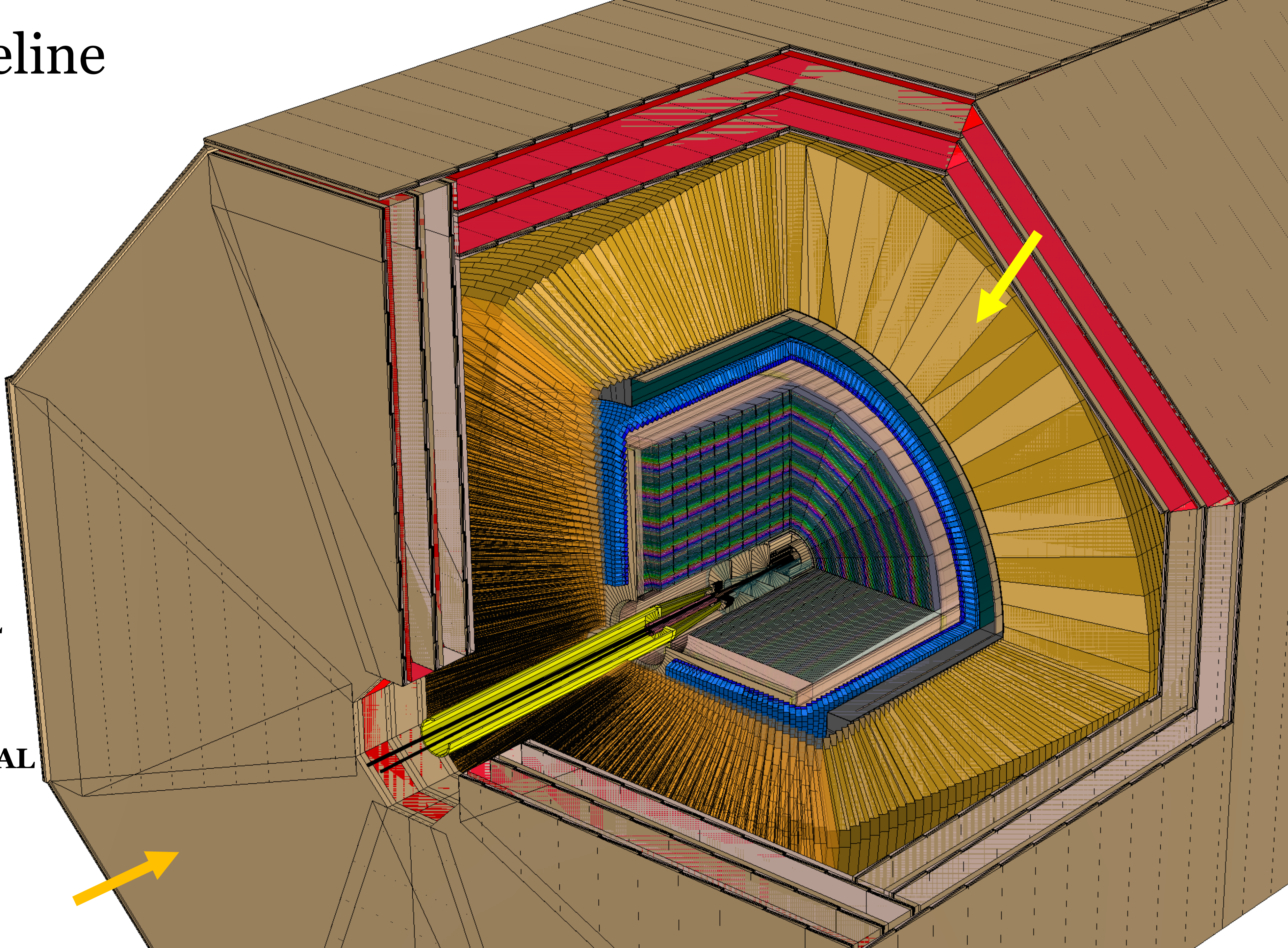
Endplate Absorber

Dual-readout Crystal ECAL

Solenoid

Dual-readout Fiber HCAL

Muon System



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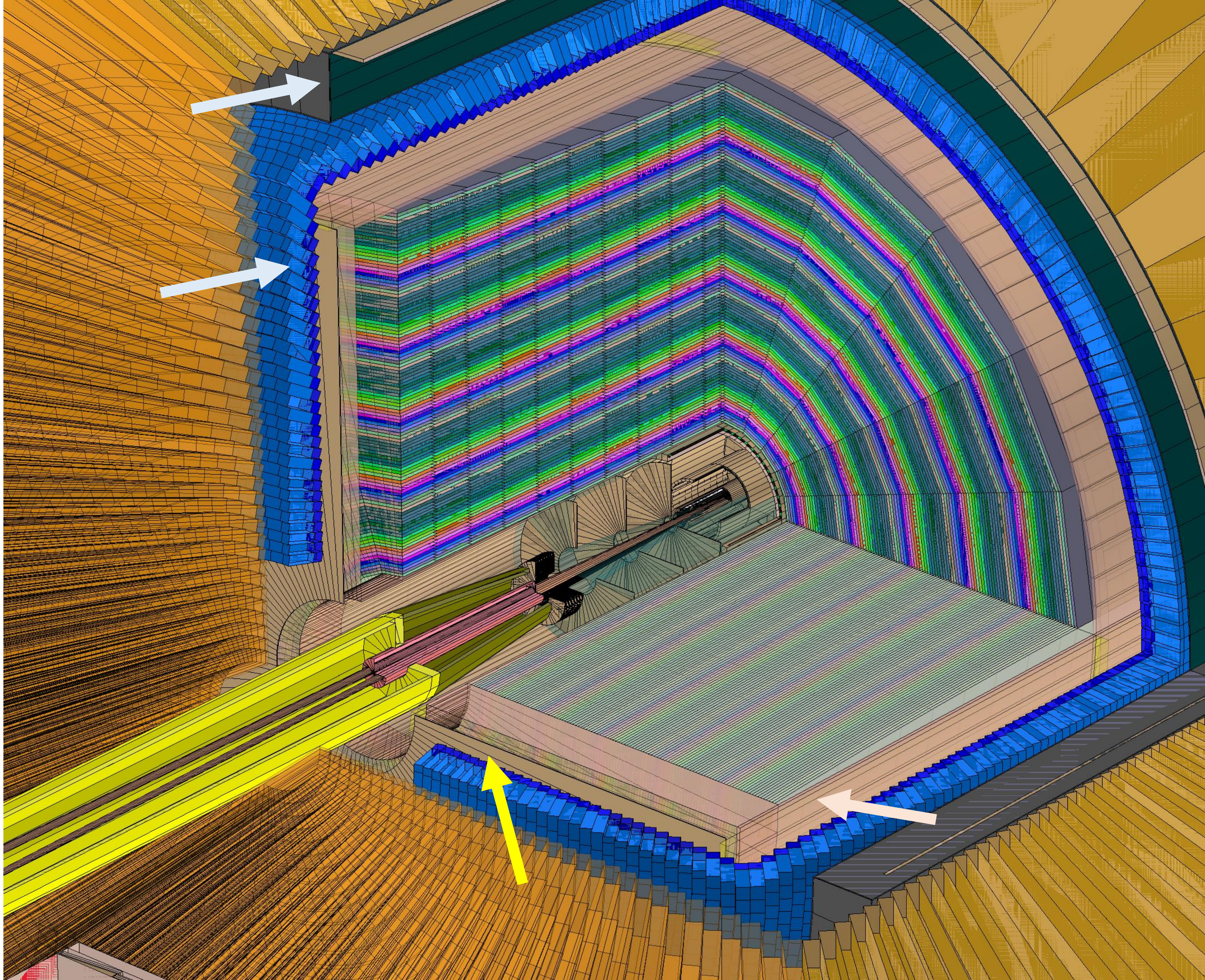

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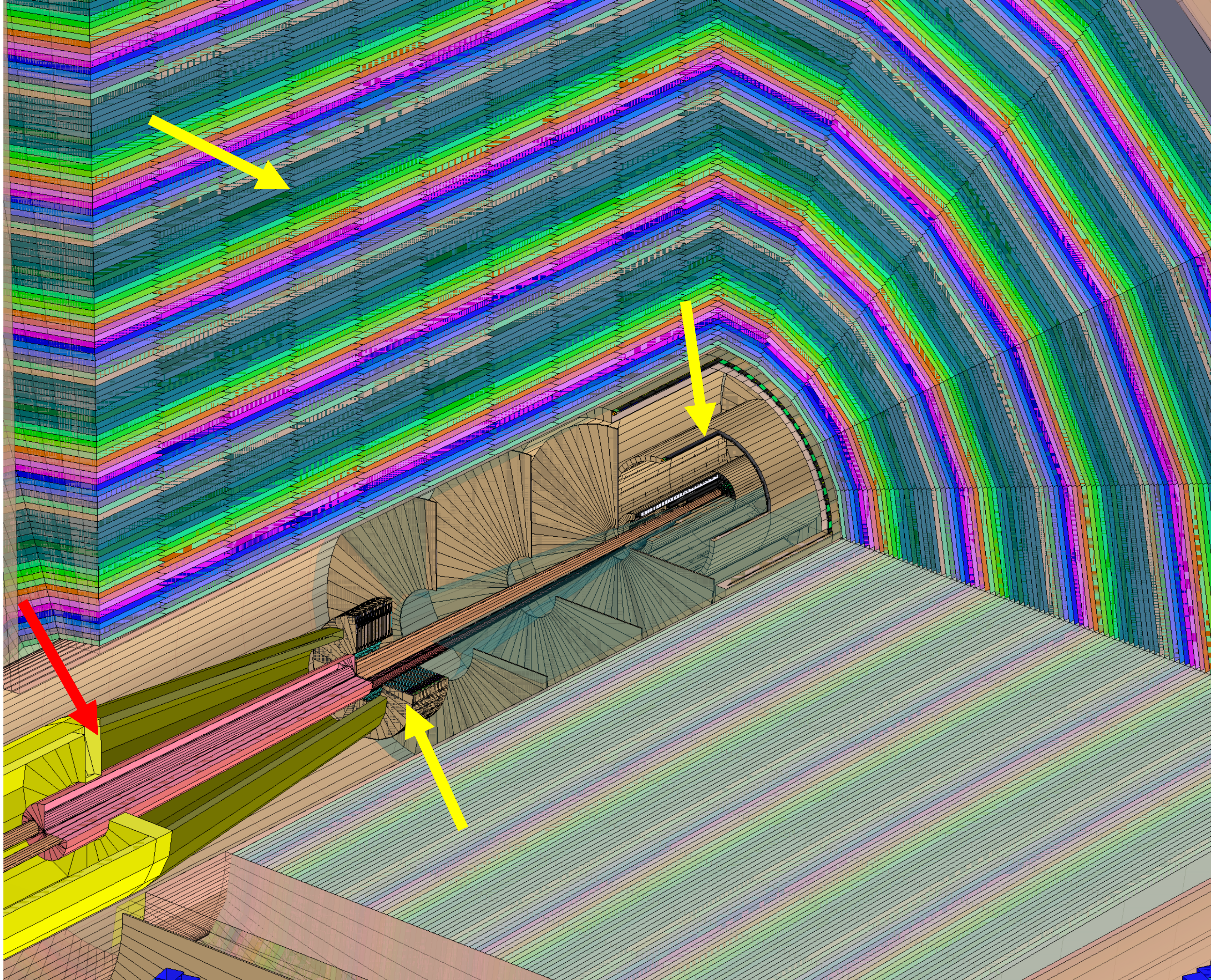


Differentiable simulation in dd4hep

- Fully parameterized idealized projective geometry
- Subdetectors defined in compact XML
- Physics config in steering file
- Customizable detector response function

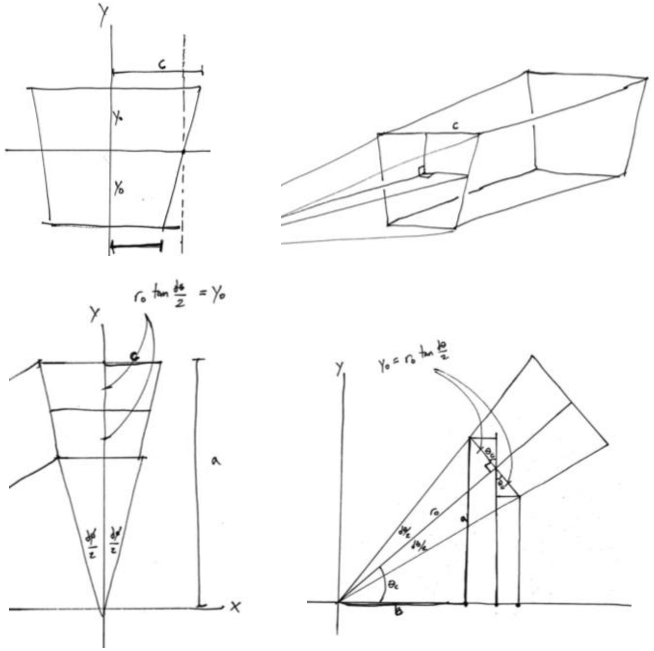
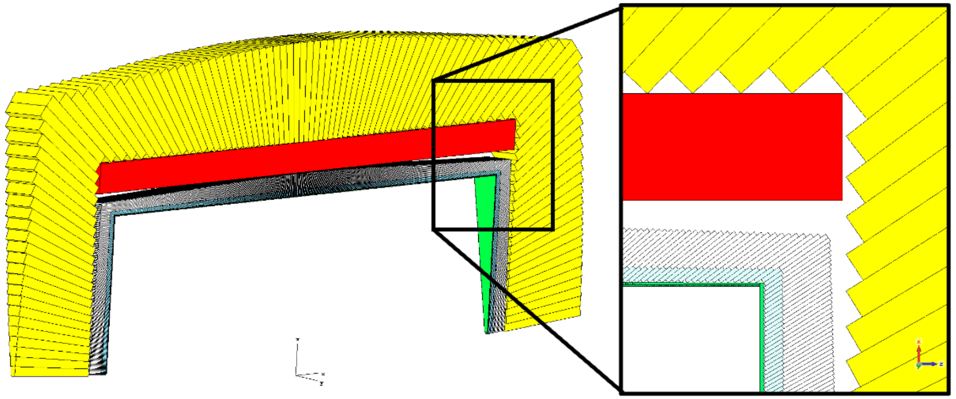


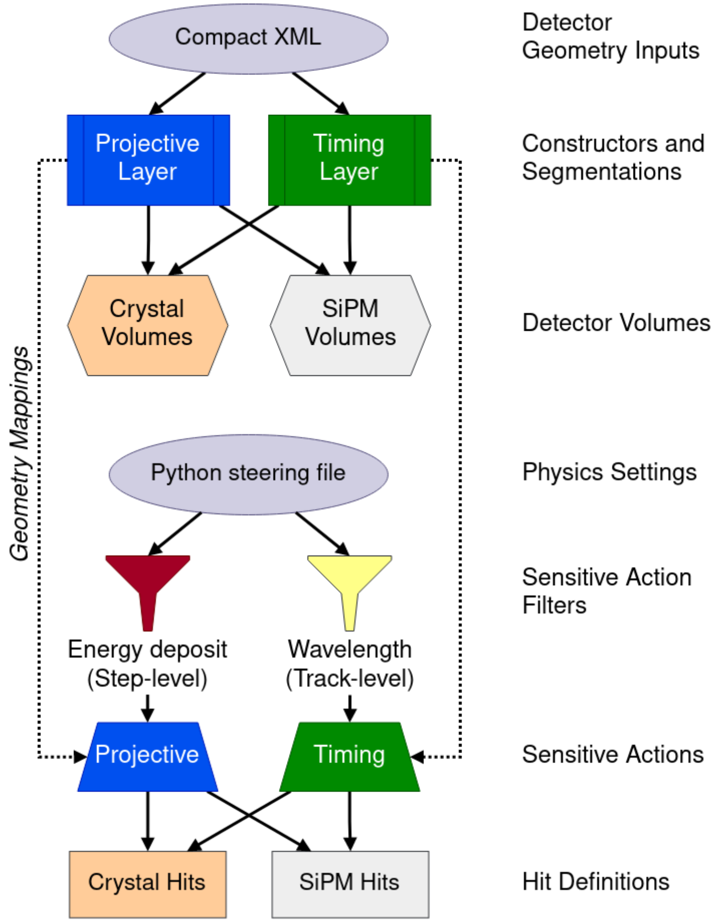
Table 1. Input parameters for parameterized geometry construction.

Description	Variable Name	Value
Half Z-extent of the barrel	Z_B	2.40 m
Inner radius of the barrel	R_{inner}	2.25 m
Global number of phi segments	N_Φ	128
Nominal square face width of the front crystals	C_{fw}	1 cm
Nominal square thickness of timing crystals	T_{th}	3 mm
Front crystal length	F_{dz}	5 cm
Rear crystal length	R_{dz}	15 cm
SiPM wafer thickness	S_{th}	0.5 mm

Table 2. Secondary parameters calculated from input parameters.

Description	Variable Name	Formula
Angular size of a single phi segment	$d\Phi$	$2\pi/ N_\Phi$
Angular size of barrel region	Θ_B	$\text{atan}(Z_B/R_{\text{inner}})$
Angular size of endcap region	Θ_E	$\text{atan}(R_{\text{inner}}/Z_B)$
Number of barrel segments in θ	$N\theta_B$	$\text{floor}(2Z_B/C_{\text{fw}})$
Number of endcap segments in θ	$N\theta_E$	$\text{floor}(R_{\text{inner}}/C_{\text{fw}})$
Angular size of a single barrel segment in θ	$d\theta_B$	$(\pi - 2\Theta_E)/N\theta_B$
Angular size of a single endcap segment in θ	$d\theta_E$	$\Theta_E/N\theta_E$
Number of barrel segments in ϕ in a single phi segment	$N\phi_B$	$\text{floor}(2\pi R_{\text{inner}}/(N_\Phi C_{\text{fw}}))$
Number of endcap segments in ϕ in a single phi segment*	$N\phi_E^*$	$\text{floor}(2\pi R_{\text{inner}}^*/(N_\Phi C_{\text{fw}}))$
Angular size of barrel segments in ϕ	$d\phi_B$	$d\Phi/N\phi_B$
Angular size of endcap segments in ϕ	$d\phi_E^*$	$d\Phi/N\phi_E^*$

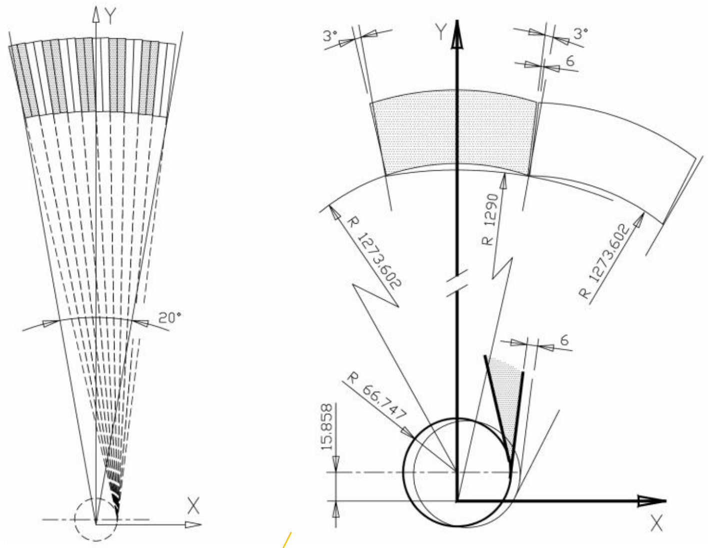


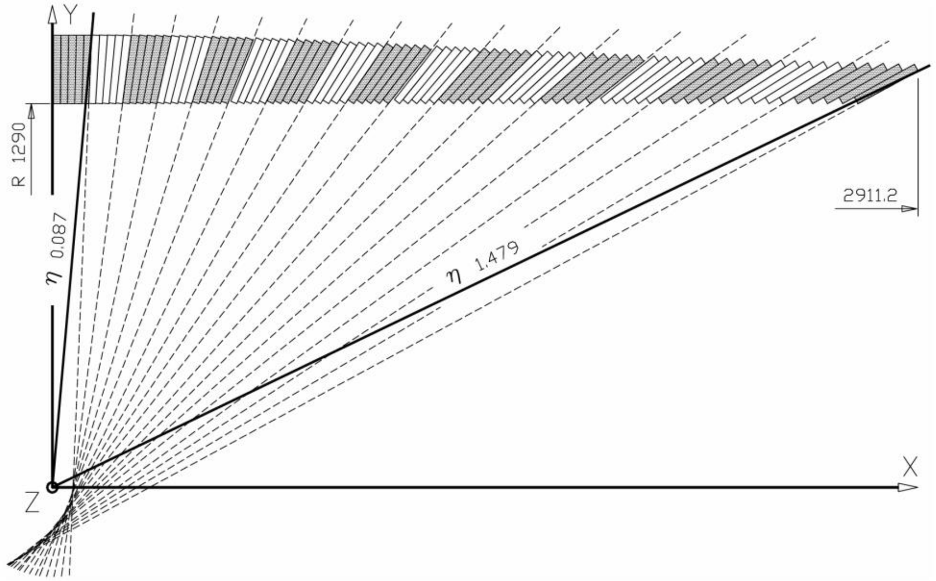


Projective gaps

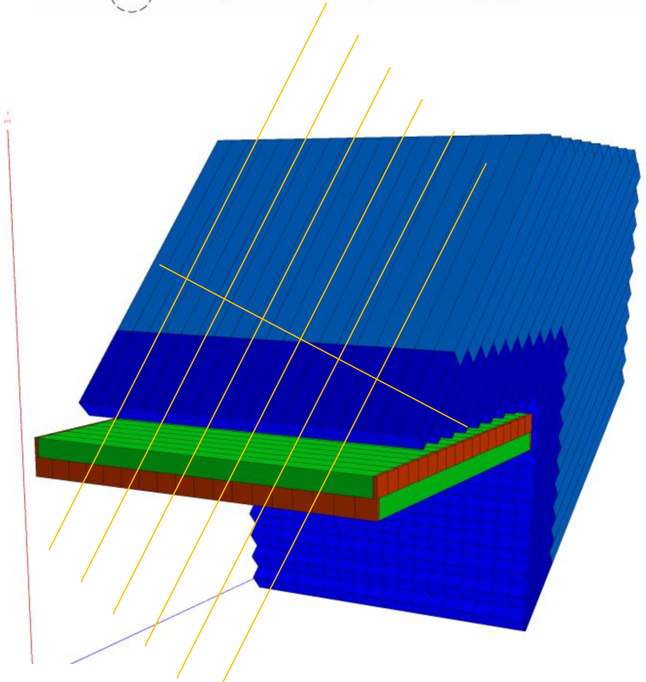
- Different ways to handle phi and theta projective cracks

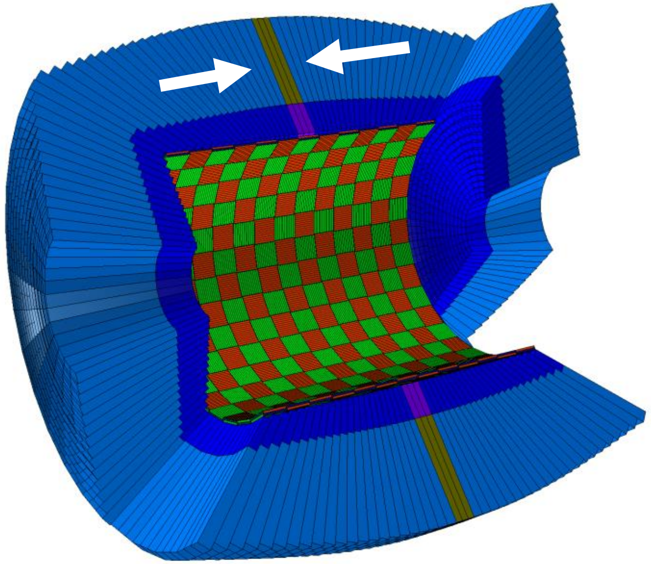
- **CMS**: uniform angular tilt offset in both





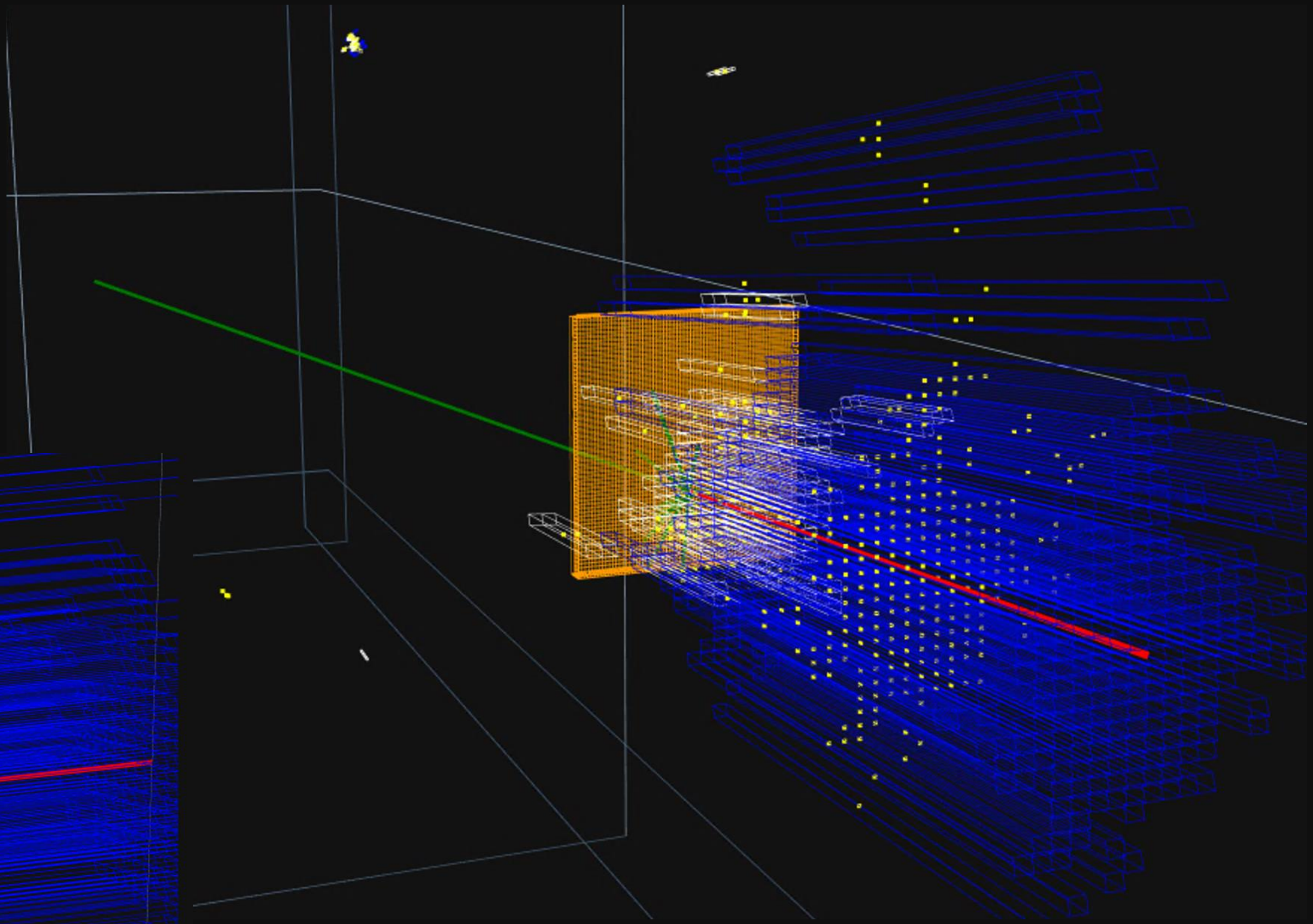
- **SCEPCal**: linear planar offsets
  - ➢ Flat phi segmentations
  - ➢ Global z-offset in theta

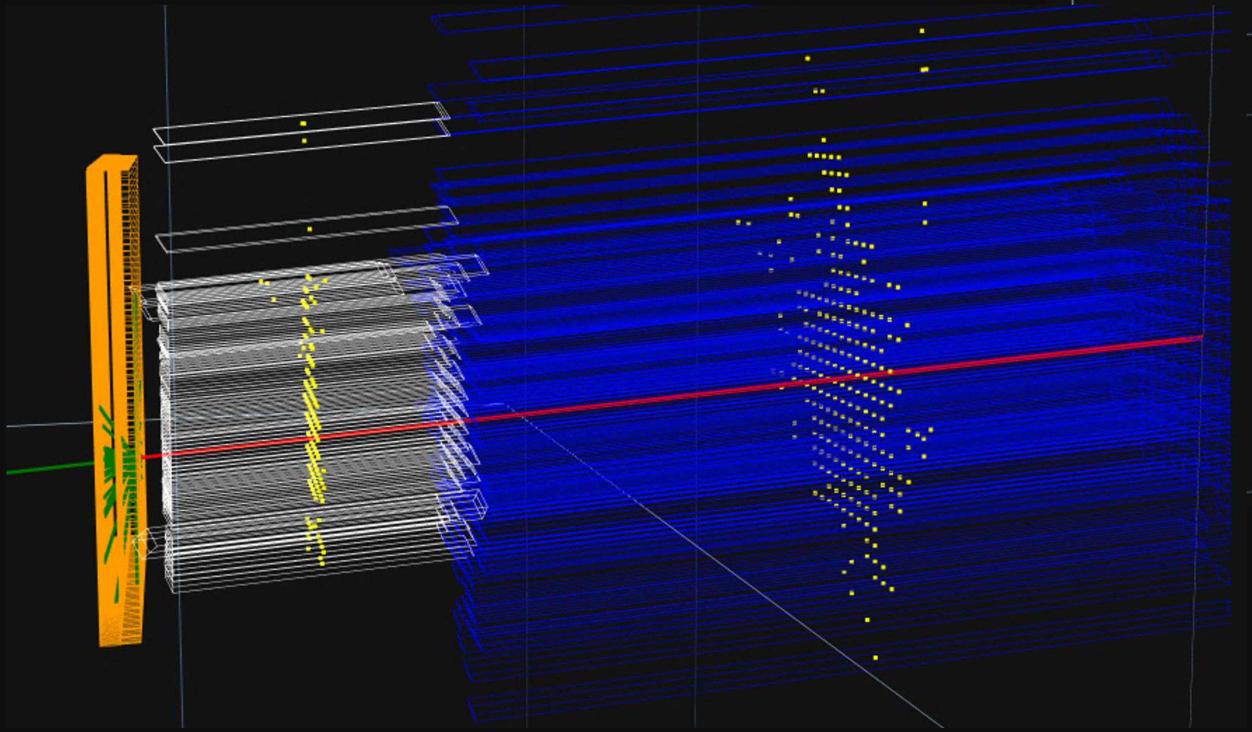




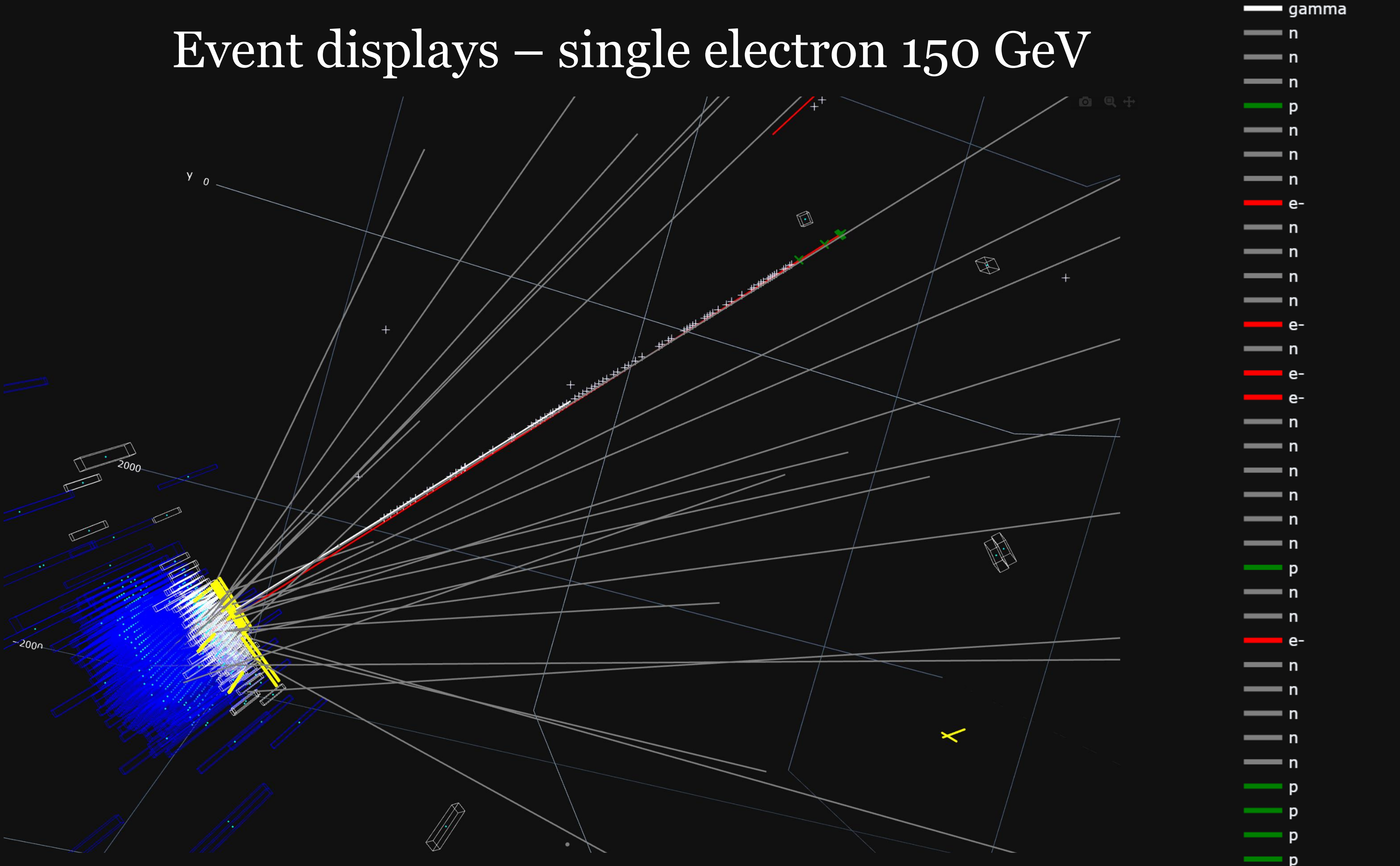
Event displays – single photons (10-50 GeV)

- Have hit positions, have geometry calculations
- Plot hits and redraw geometry
- Lightweight, portable, runs in python notebooks

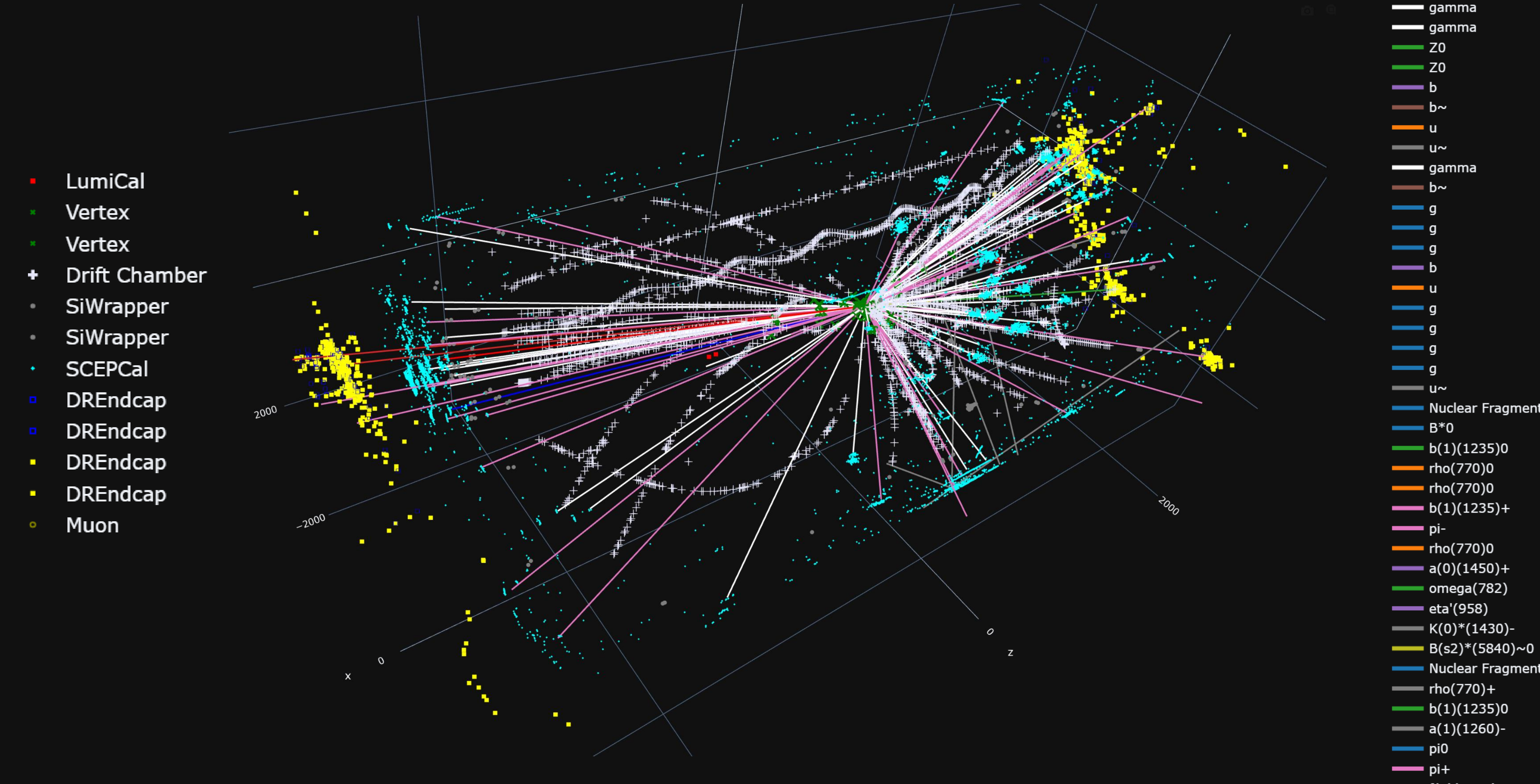




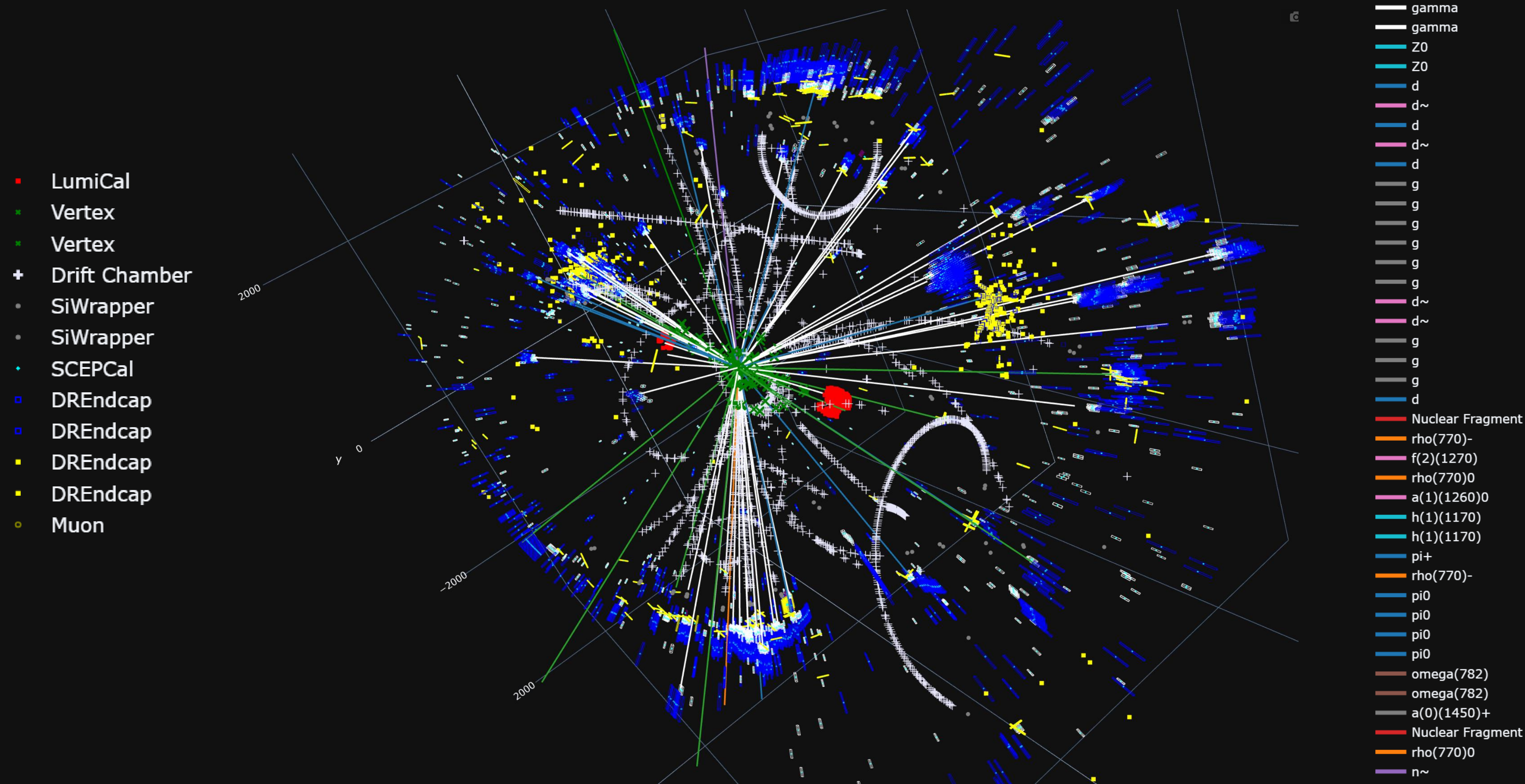
Event displays – single electron 150 GeV



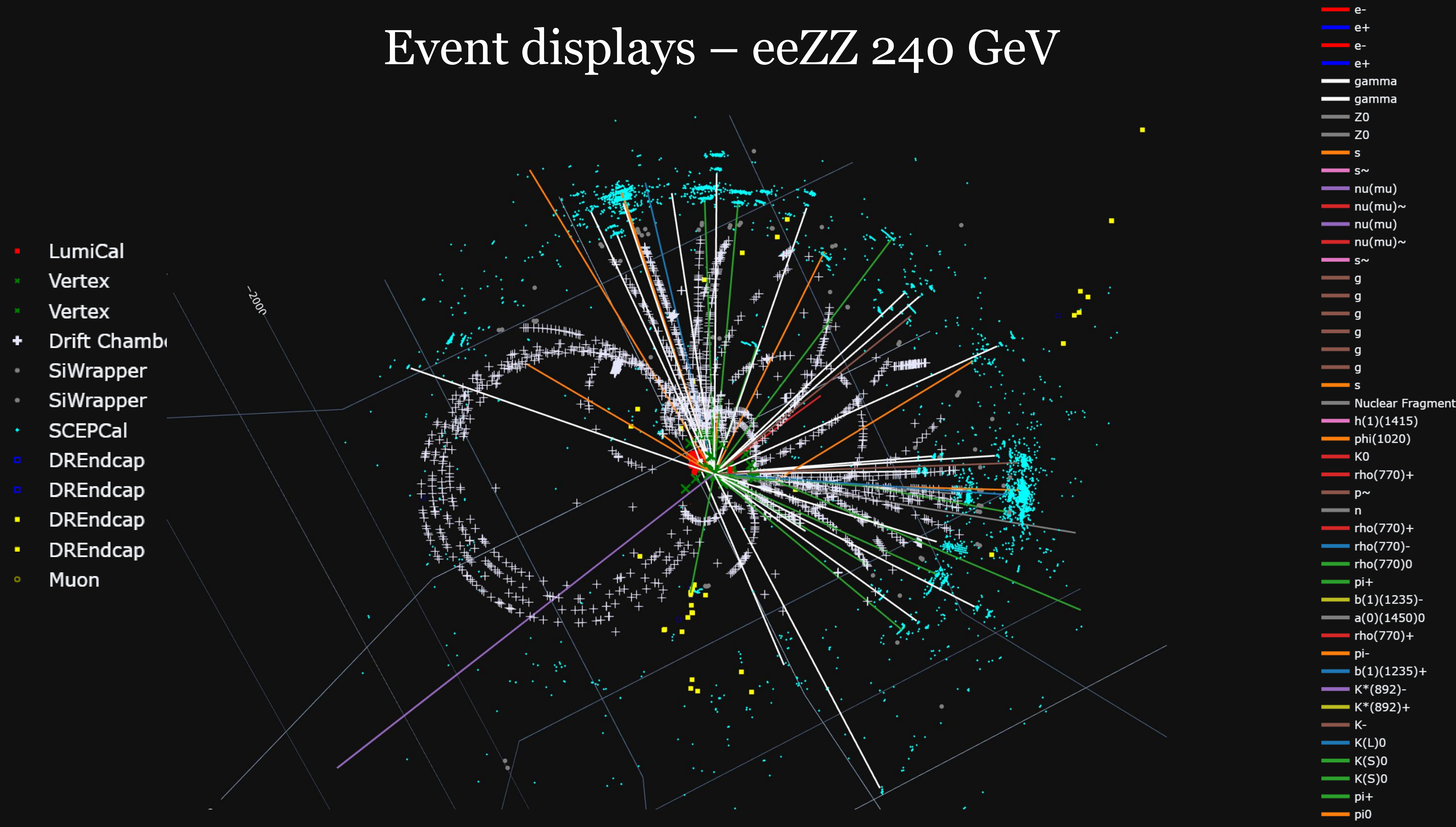
Event displays – eeZZ 240 GeV



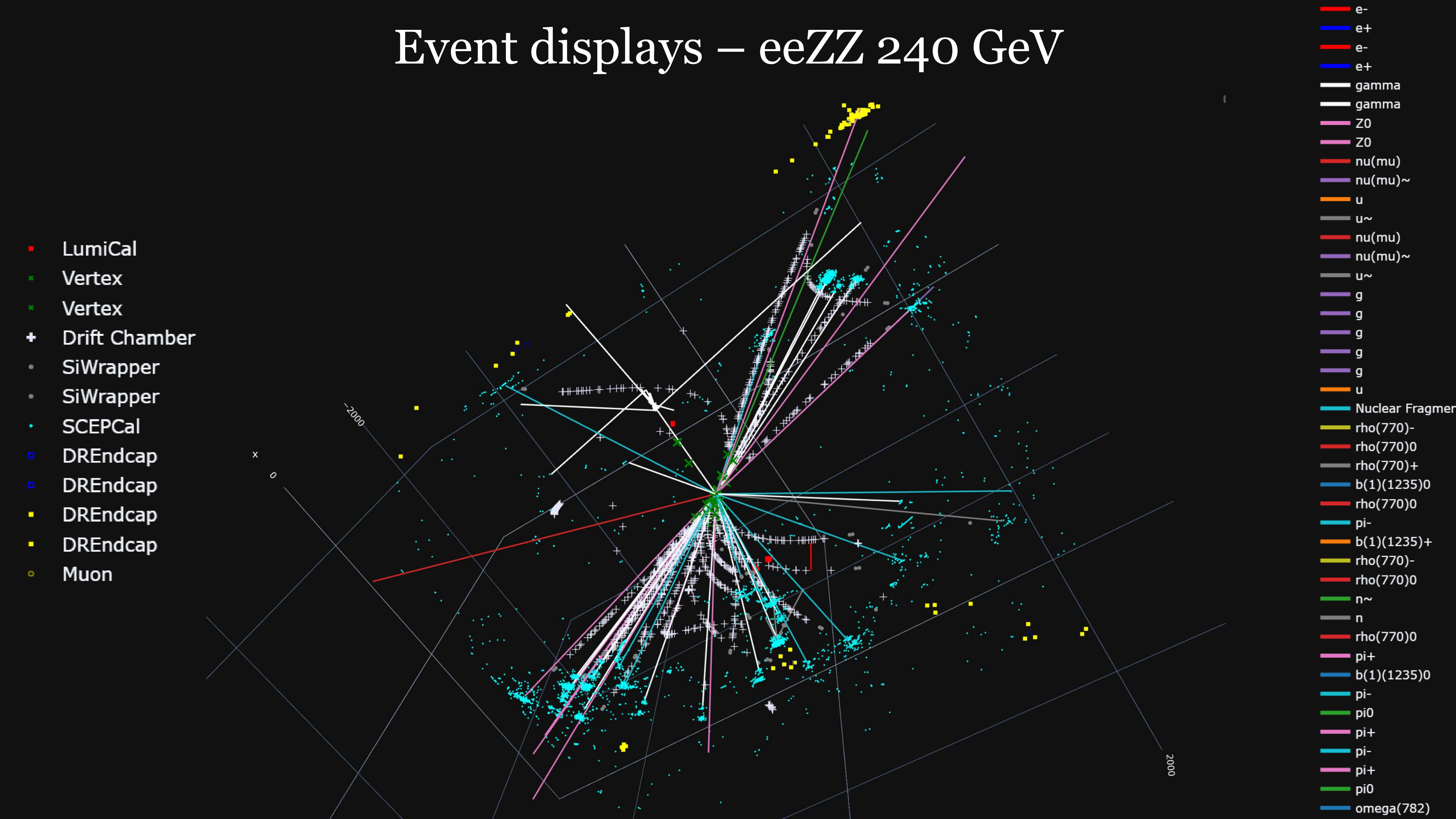
Event displays – eeZZ 240 GeV



Event displays – eeZZ 240 GeV



Event displays – eeZZ 240 GeV

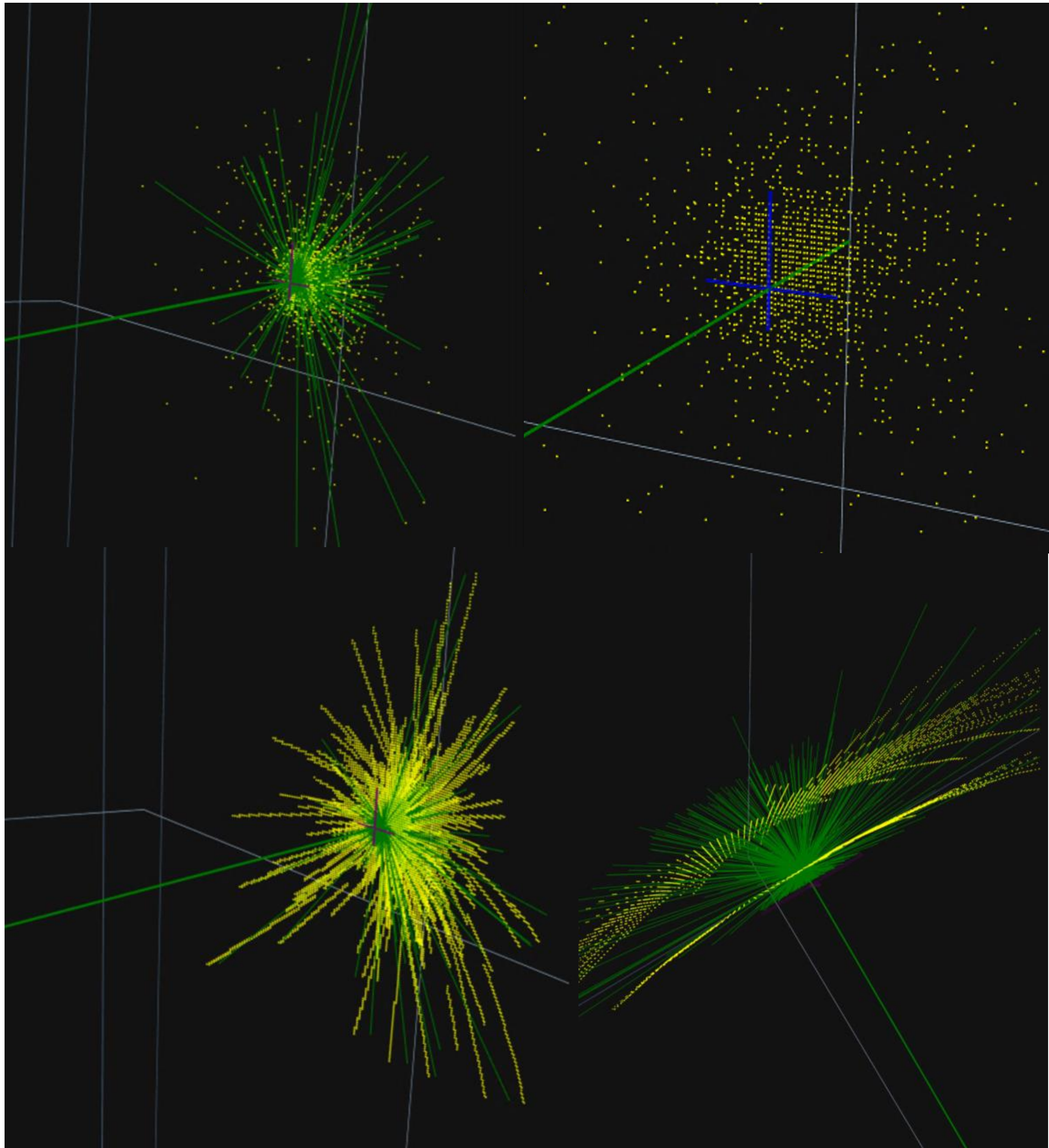


Detector response and synthetic data

- “Sensitive action” processes particle step interactions into hits
- “Sensitive action filters” apply cuts on steps to be processed
- Effectively acts as a detector response function
  - Default is energy deposit per step (1 keV)
- For optical photons, change to wavelength cut at track-level, not step
- New representations of same processes
  - “Synthetic data”
- Comparison for 10 MeV gamma shown
- Potentially useful as a new handle for PFA, studies ongoing
- Material properties also have big effect
- Many, many parameters to dial

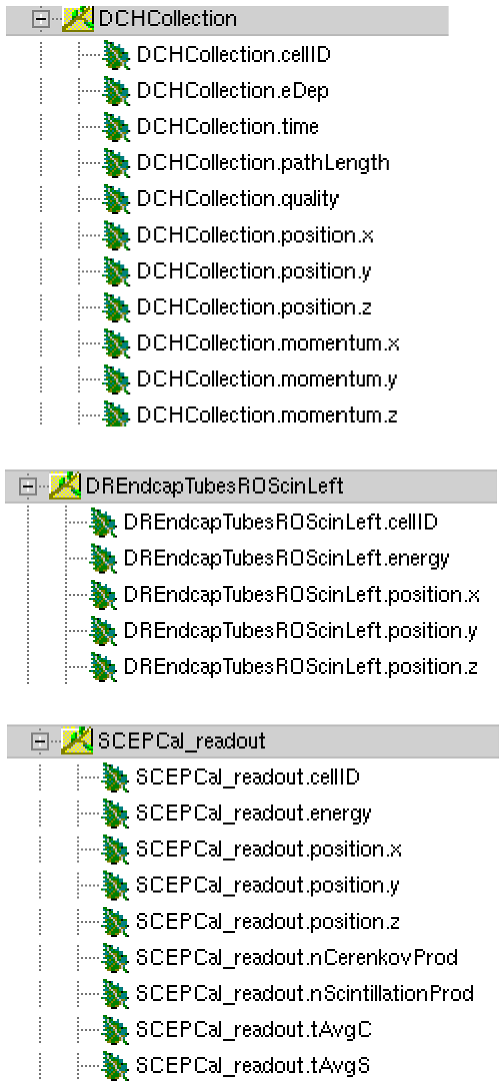
edep0

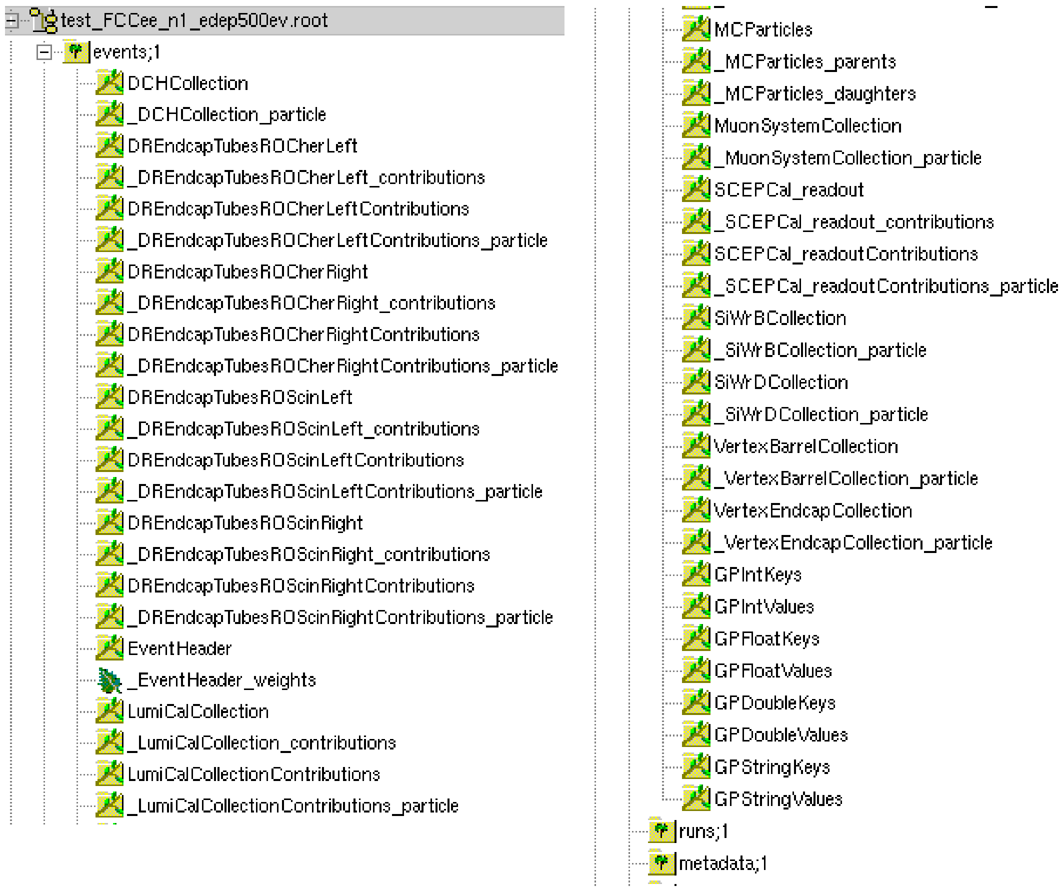
wavelength (200nm)



Readout structure

- Each subdetector has separate readout collection
- Standardized hit classes
  - SimTrackerHit
  - SimCalorimeterHit
  - SimDRCalorimeter Hit
- Easy to spin up ad-hoc python classes or use something more official
- To dos:
  - Digitization -> RECO
  - Performance optimizations
  - High-quality sample production
  - FCC calorimeter workshop in spring





More studies

- **Bi-level optimization**
  - Reconstruction vs. geometry parameters
- **Detector response and synthetic data**
  - More speculative studies
- **Picking the right neural network for the detector**
  - Long context – transformers
  - Noise – diffusion
  - Adversarial combination, etc.
- **Let the physics case drive hardware development**
  - e.g. HHH from single loop corrections to HZ cross section
  - Light-jet background apparently dominates
  - Work backwards to define detector requirements for desired precision
- **Commit to full sim side-by-side comparisons for competing technologies for a given physics goal requirement**
- **Assess innovations in material/sensor properties**
  - Lattice-oriented crystals
  - Chromatic calorimetry
  - 1000nm+ SiPMs
  - etc.