Full Simulation of a Segmented Crystal ECAL in IDEA

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CalVision collaboration

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# Segmented Crystal EM Precision Calorimeter (SCEPCal)

New perspectives on segmented crystal calorimeters for future colliders
https://arxiv.org/abs/2008.00338 (JINST)
Particle Flow with a Hybrid Segmented Crystal and Fiber Dual-Readout Calorimeter
https://arxiv.org/abs/2202.01474 (JINST)

Basic idea covered in several talks
References above remain sound
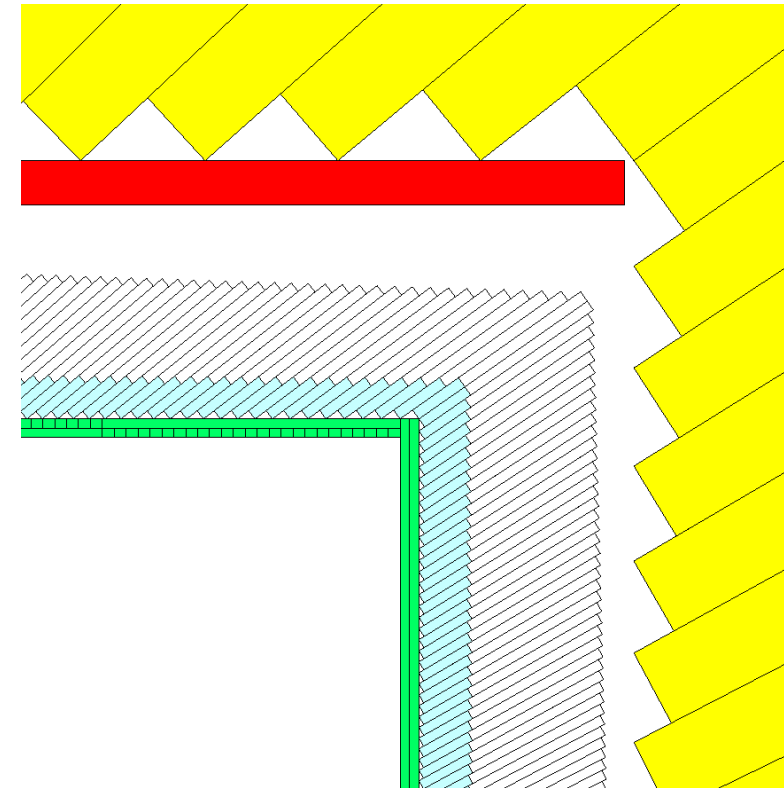"proto-PFA" studies done in pure Geant4
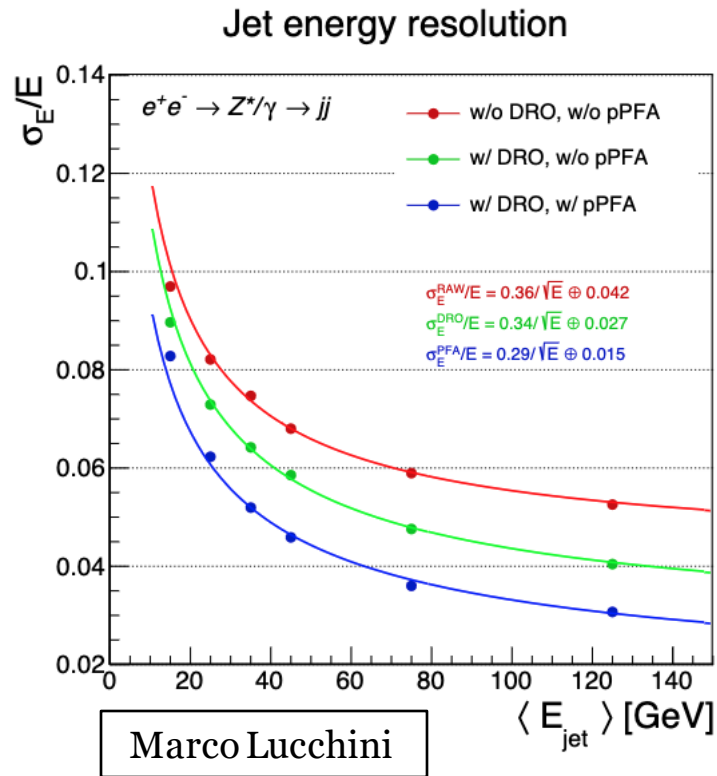
This talk:

Implementation in dd4hep from scratch

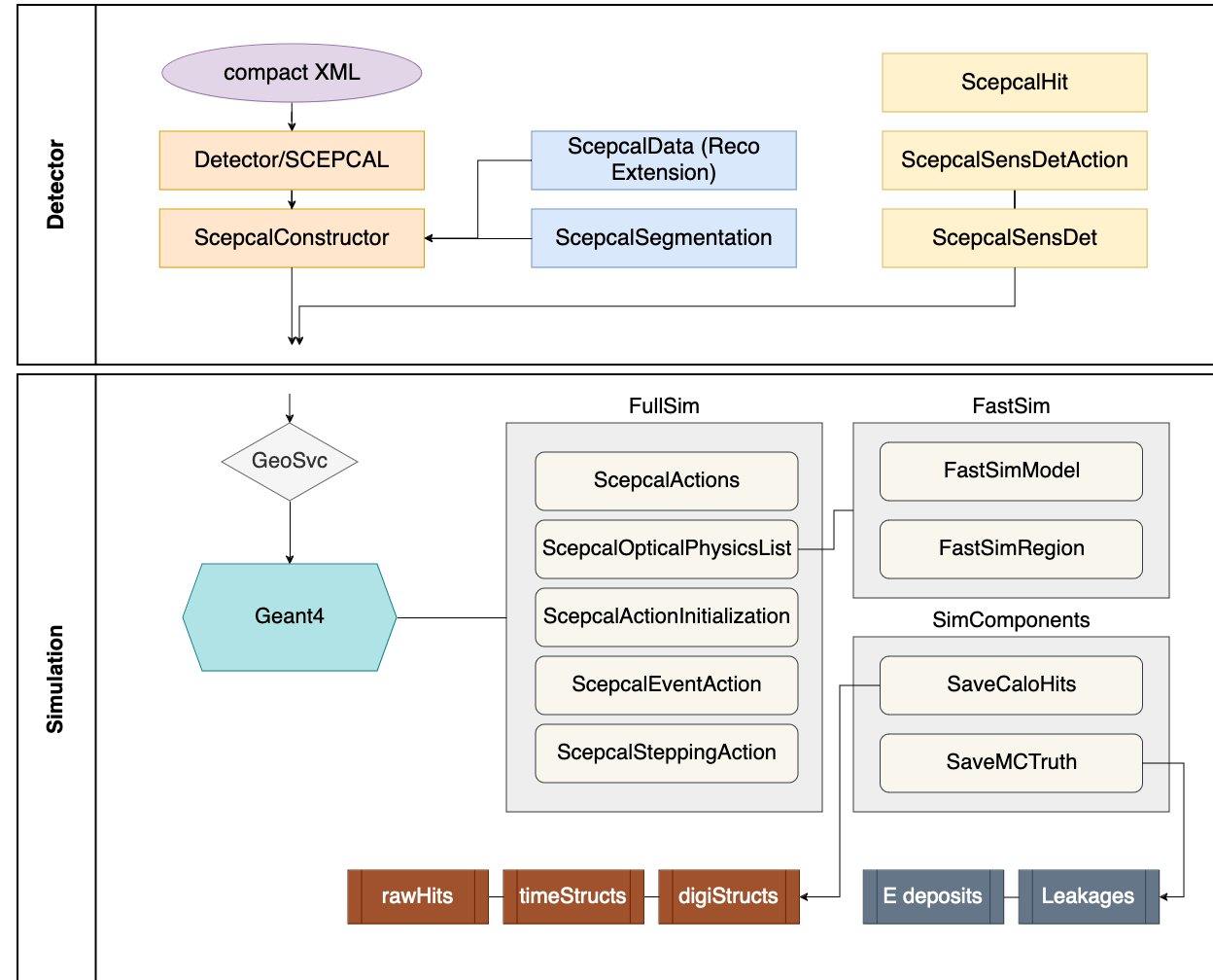Development environment

Detector description

Vertically integrated detector development

Towards a first full sim ML/PF

Jet energy resolution

$e^+e^- \rightarrow Z^*/\gamma \rightarrow jj$

- w/o DRO, w/o pPFA
- w/ DRO, w/o pPFA
- w/ DRO, w/ pPFA

$\sigma_E^{RAW}/E = 0.36/\sqrt{E} \oplus 0.042$
$\sigma_E^{DRO}/E = 0.34/\sqrt{E} \oplus 0.027$
$\sigma_E^{PFA}/E = 0.29/\sqrt{E} \oplus 0.015$

Marco Lucchini

Implementing a new detector from scratch in dd4hep

- **What you need:**

- Detector:
  - Compact XML description
  - Geometry constructor
  - Material definitions
  - Segmentation class, factory, handle

- ddsim:
  - Sensitive Detector class, wrapper
  - Sensitive Detector Hit class
  - Sensitive Detector Action
  - Reco extension structs – attached to geometry

- Gaudi + k4 (FWCore, Geant4Sim, Gen):
  - G4 Actions (Event/Stepping), Initializations
  - Event collections (MC, hits)
  - GeoSvc

- Steering (config) files

- Remaining: Digitization

Development environment

New detector development necessitates local visualization
- XForwarding over ssh? **Pffft**
- Mount /cvmfs across the Atlantic? **Yeah right**
- Web-based viewers (JSROOT?) **Good luck**
- Export/import geo files? **Still requires local deps**

Recommendation: AlmaLinux9 + key4hep-spack
- Previously used: Debian, Fedora, nixOS
- Still need a couple of mods in key4hep-spack, but not bad
- Some deep dependencies (e.g. Cython) do not compile on arm64 – so no macs
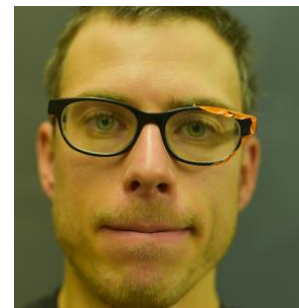
Takeaway:
- Sometimes it's just hard to know in advance

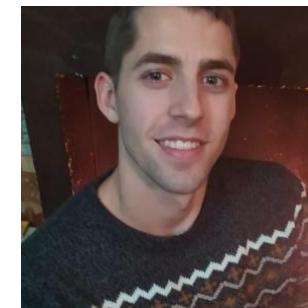key4hep and spack have matured in 2023
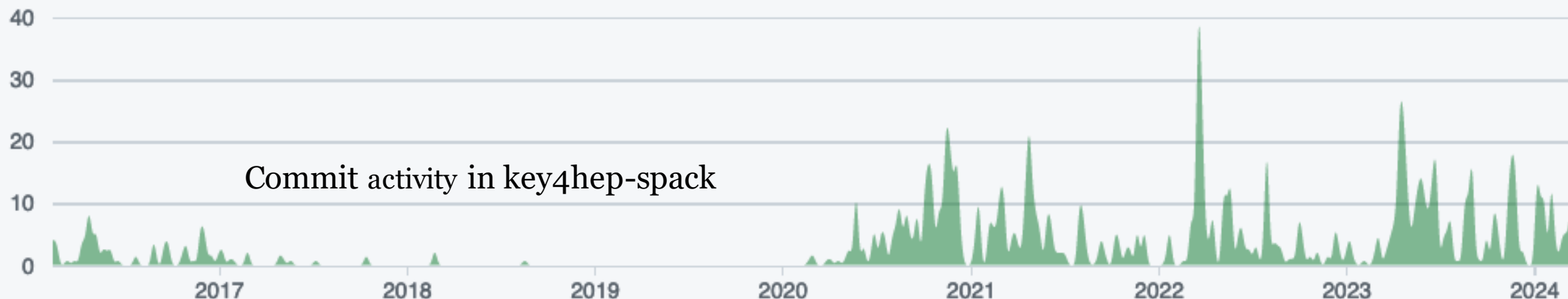- But someone still had to add the hashes manually

Valentin Volkl   Thomas Madlener   Juan Miguel Carceller

Commit activity in key4hep-spack
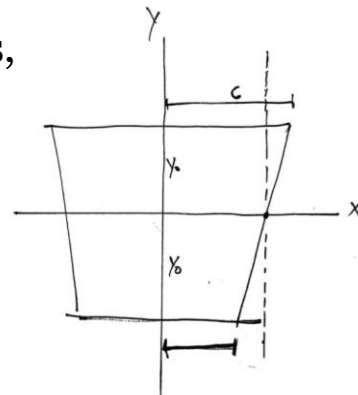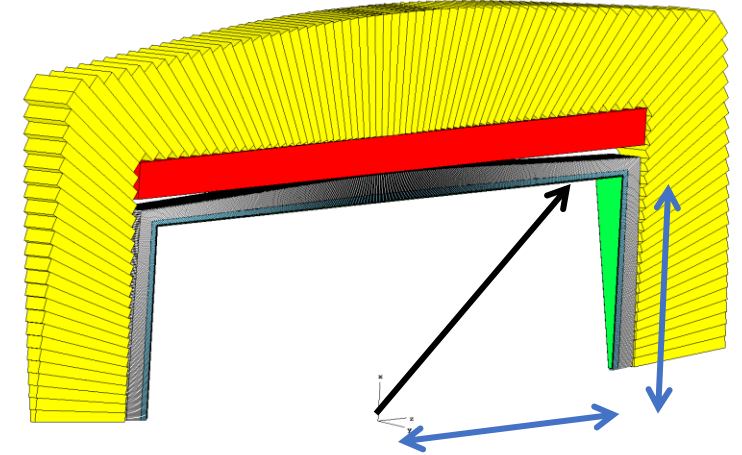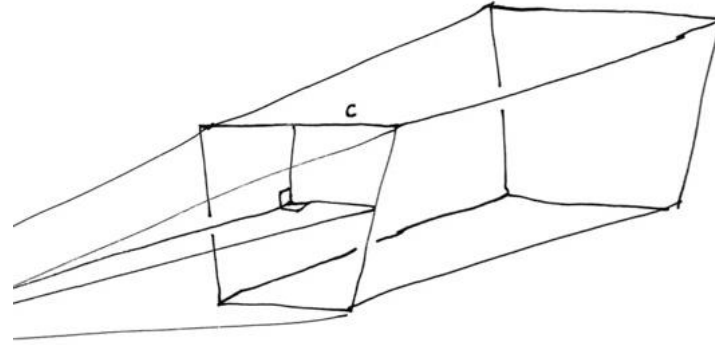
Detector description

- **Fully parametrized construction**

- Only 7 params needed:
  - Inner radius
  - Z extent
  - Crystal face width (nominal)
  - Front crystal length
  - Rear crystal length
  - Timing crystal thickness (nominal)
  - Number of phi segments
    - Ensures hermeticity
    - Enables timing layer
    - Takes care of projective gaps

- Geometry optimizations
  - Intermediate envelope volumes, <1000 volumes per
  - Orange slices (barrel)
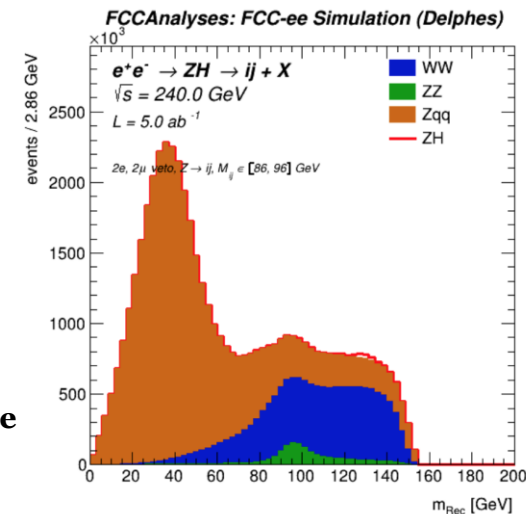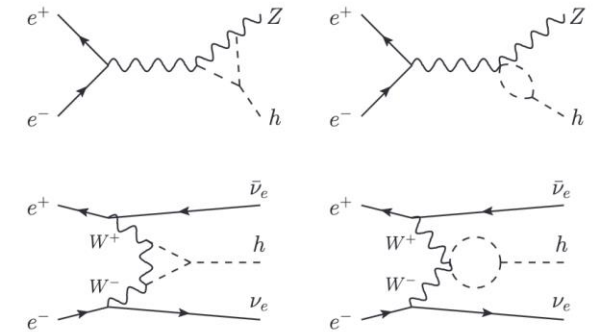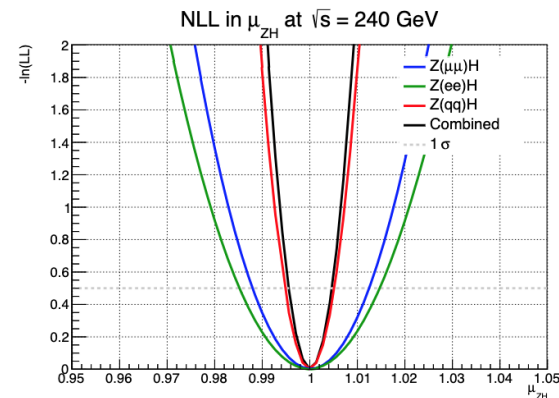 - Rings (endcap)

  - Quite fast!
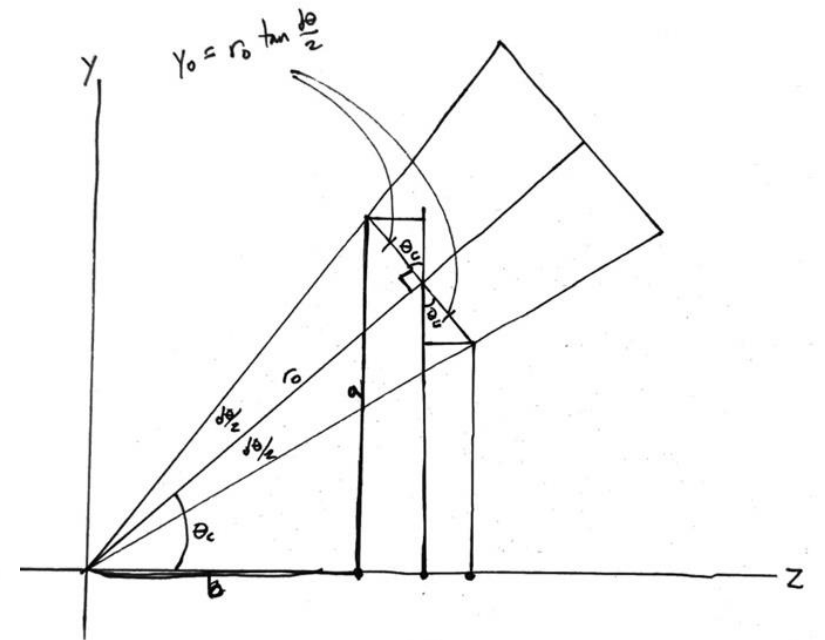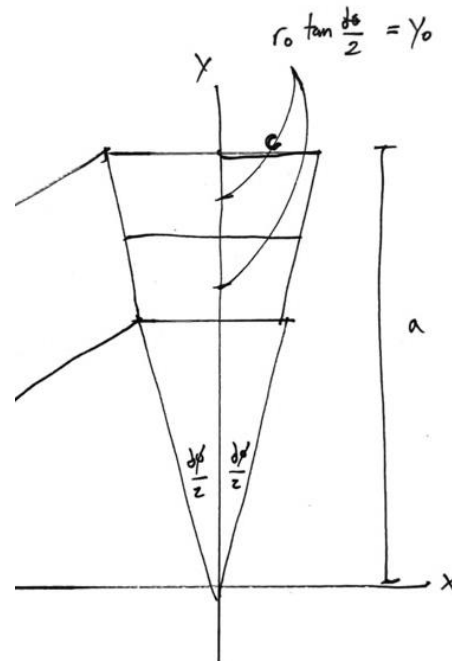
Detector design in AI/ML era

- Top-down view of detector geometry and data readout
  - Handles for ML/PF
  - Still room for classical ML?
- Hot-swappable sub-detectors
- Parametrized descriptions ideal for optimization studies
- Opportunity for unprecedented vertical integration
- Real-time inference on ASICs
- New dimension of timing
- However, this should be the baseline
  - We need order of magnitude improvements
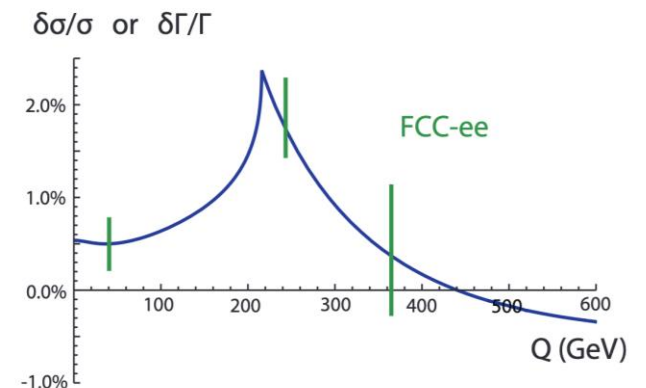 - Quantum sensing for HEP whitepapers

Physics case

- HHH from loop correction to the HZ cross section
- Z(qq)H apparently dominates
- Hinges on ability of detector to reduce ZZ background
  - Jet IDs ultimately are fed from PFA
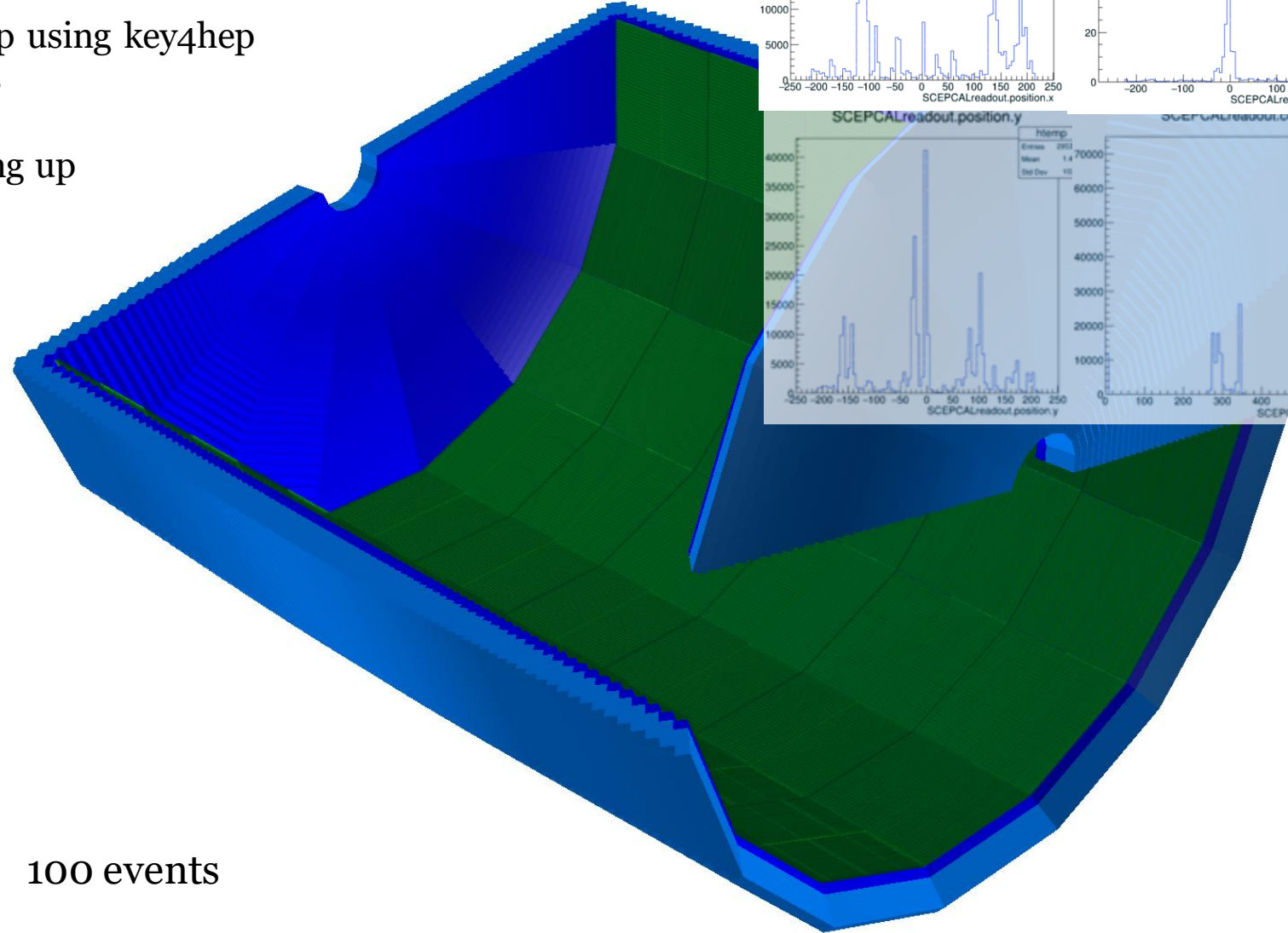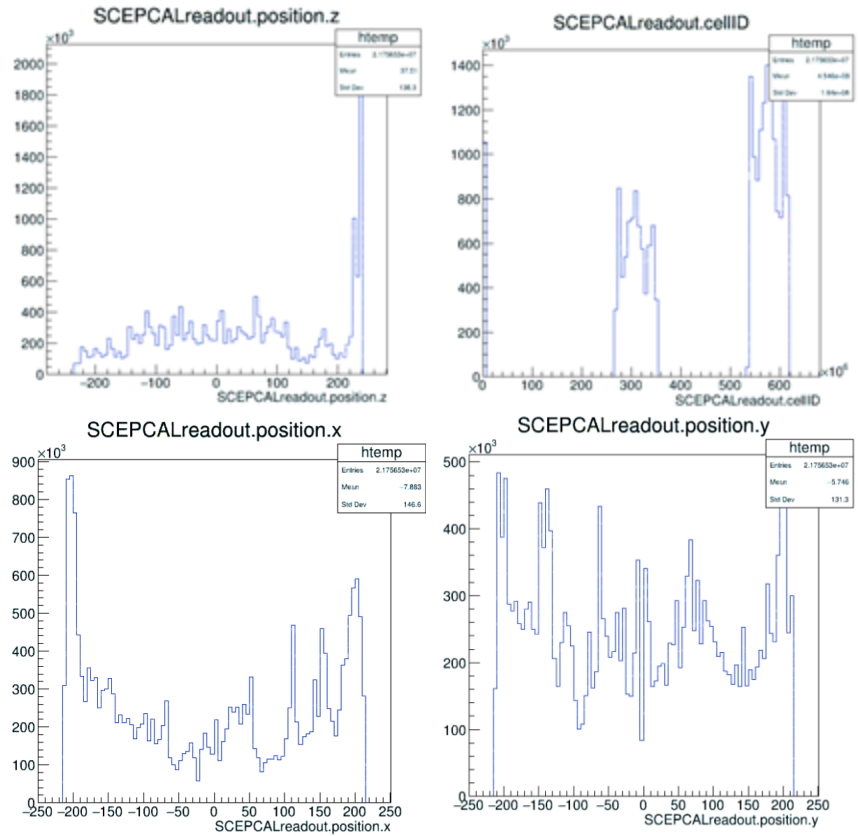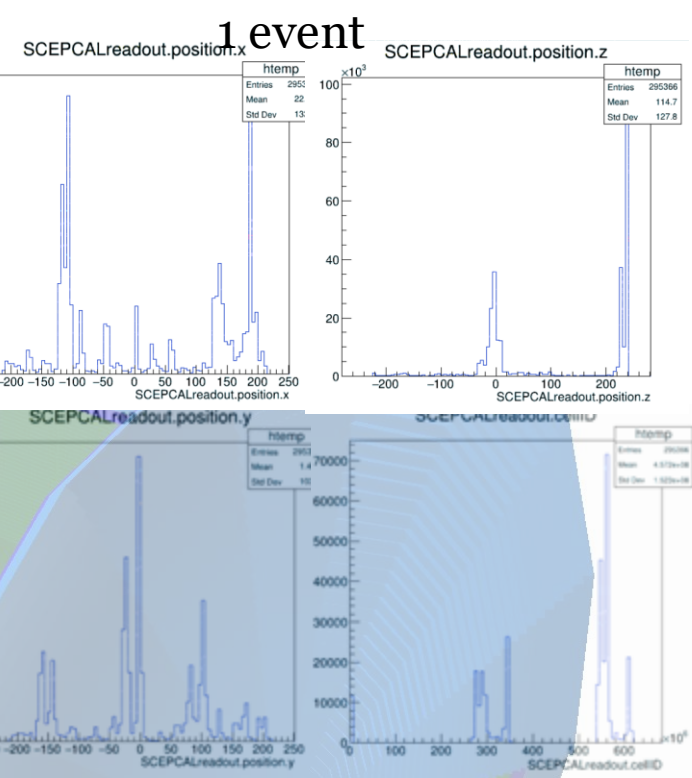
Probing the Higgs sector at the FCC-ee
https://cds.cern.ch/record/2835483

NLL in μ_{ZH} at $\sqrt{s}$ = 240 GeV

FCCAnalyses: FCC-ee Simulation (Delphes)

$e^+e^- \rightarrow ZH \rightarrow ij + X$
$\sqrt{s}$ = 240.0 GeV
L = 5.0 ab^{-1}

2e, 2μ veto, $Z \rightarrow ij$, $M_{ij} \in$ [86, 96] GeV

- WW
- ZZ
- Zqq
- ZH

A special Higgs challenge
https://arxiv.org/pdf/2106.15438

$\delta\sigma/\sigma$ or $\delta\Gamma/\Gamma$

FCC-ee

Let's get it

- New detector fully implemented in dd4hep using key4hep
- Runs FCC-ee events and outputs Calo hits
- Plots - *wzp6_ee_ZZ_test_ecm240*
- First full simulation ML/PF studies coming up
- https://github.com/SCEPCAL/SCEPCAL

1 event

100 events