Dual-Readout Crystals in DD4hep

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- Physics-case oriented detector design with PFA

- General Thoughts/Questions

Links
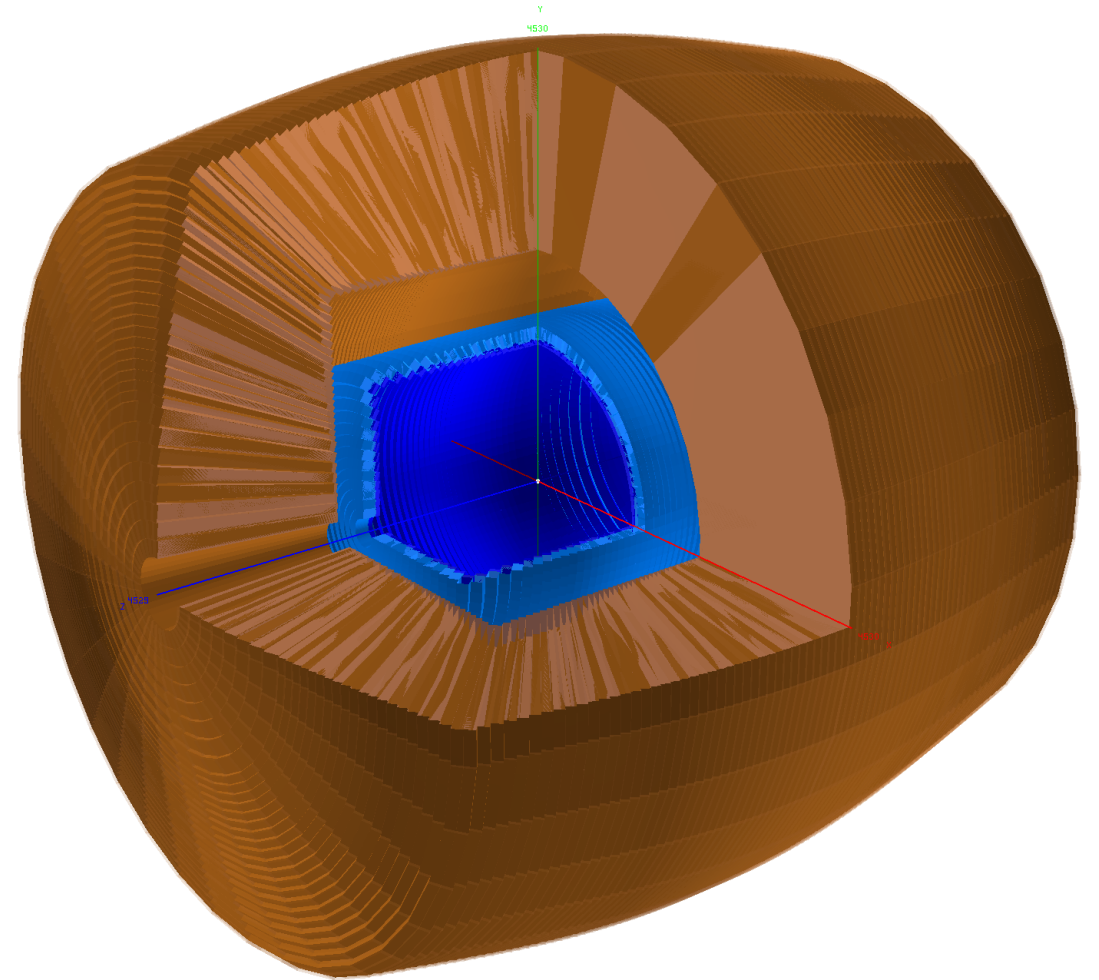- https://github.com/wonyongc/dual-readout
- https://github.com/SanghyunKo/dual-readout

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

Projective Geometry Approach

- Each tower projects a constant $d\theta$, $d\phi$ from IP

- Towers can be either...
  - Integer division of overall detector dimensions/nominal face dimension
  - Fixed dimension x number of towers

- Physics-dependent, crystal faces are nominally 1x1 cm, Front:Rear lengths are ~6:16 X_0

- Construct in θ, rotate in ϕ

- Add additional θ slices in center to account for projective gaps (~10cm is enough)

Timing Layer
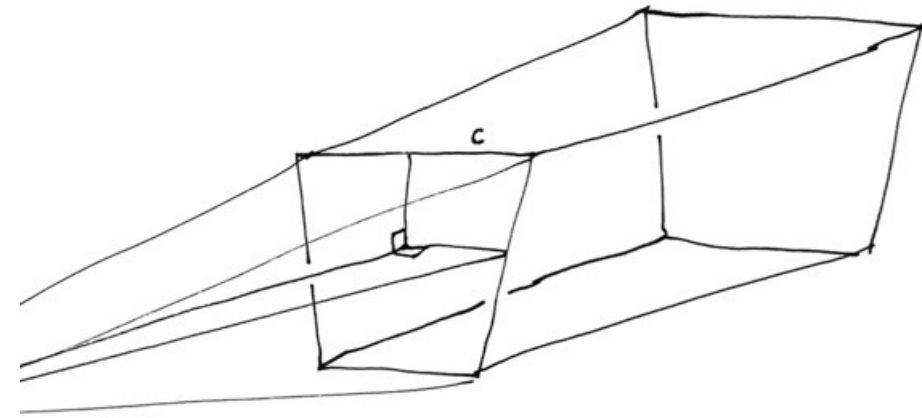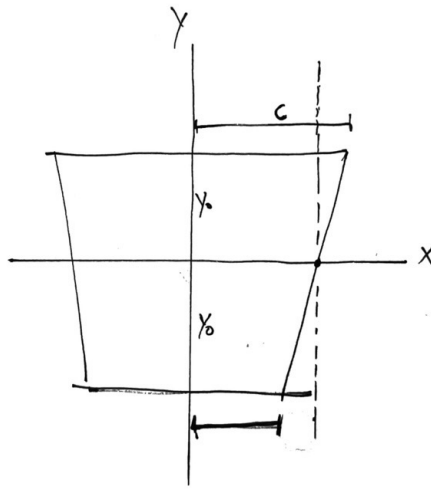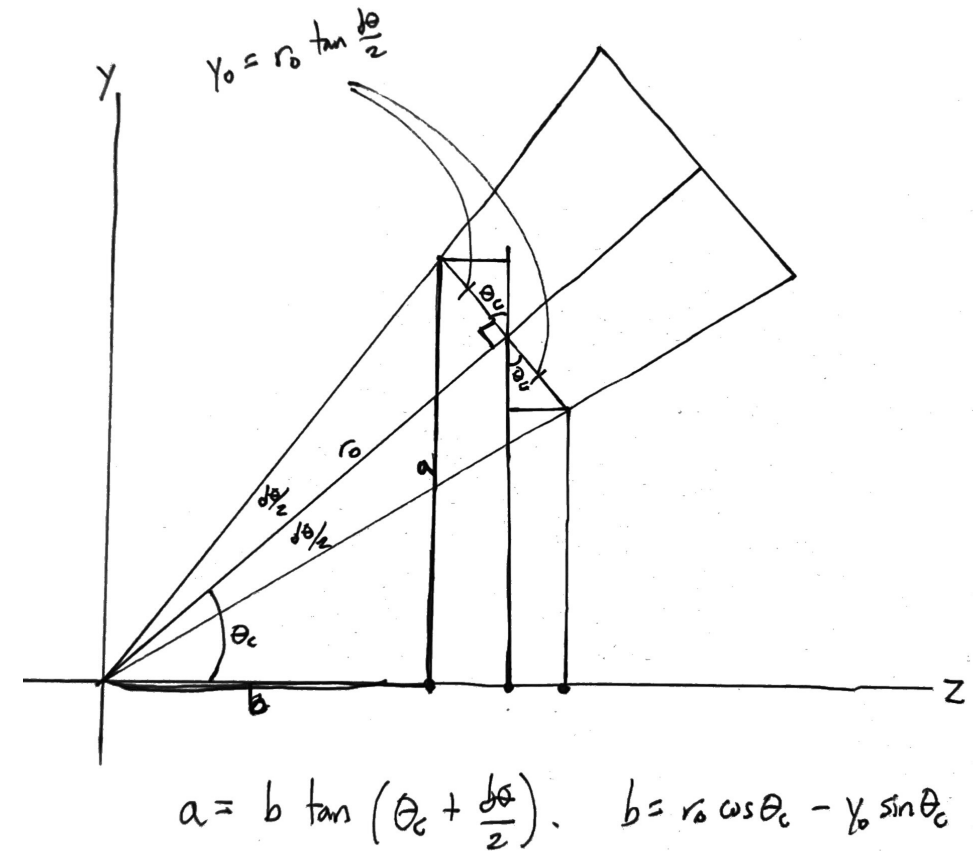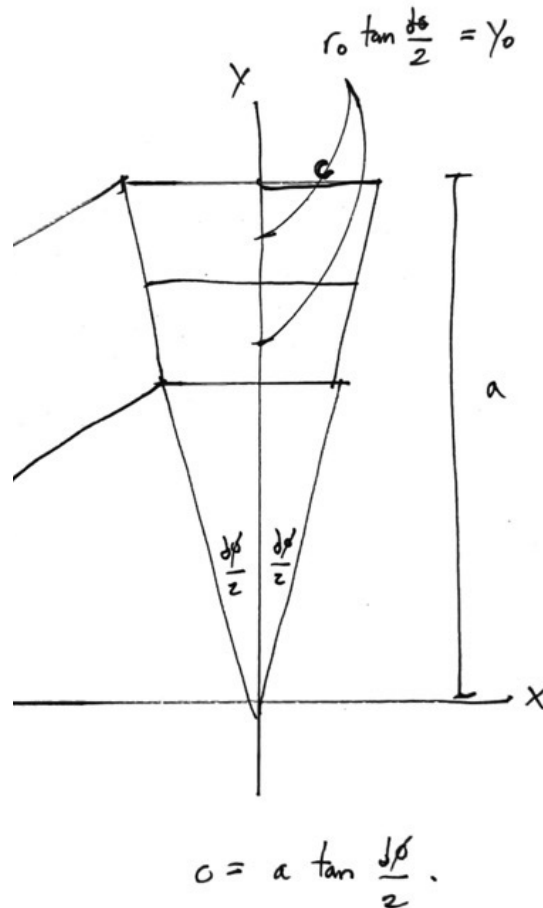- ~1x1x10cm in alternating cross pattern in front of crystals
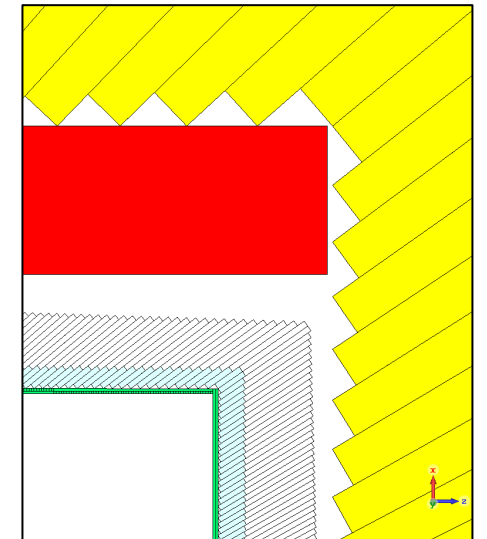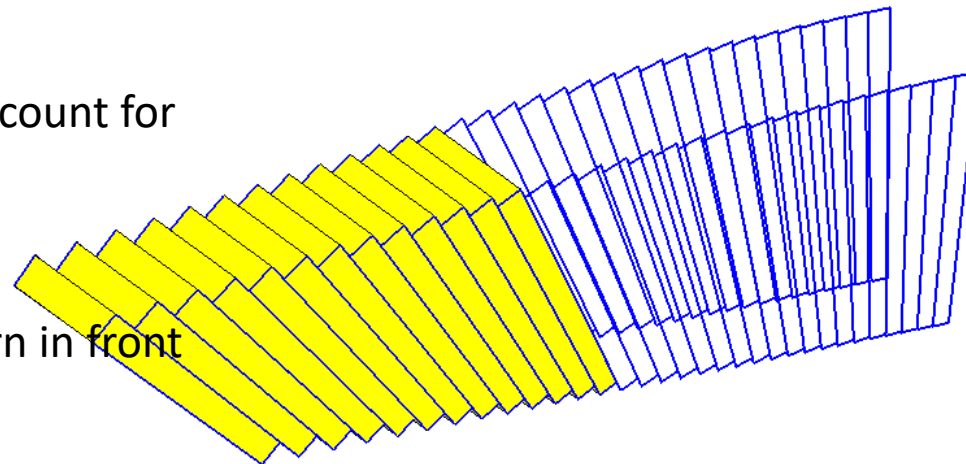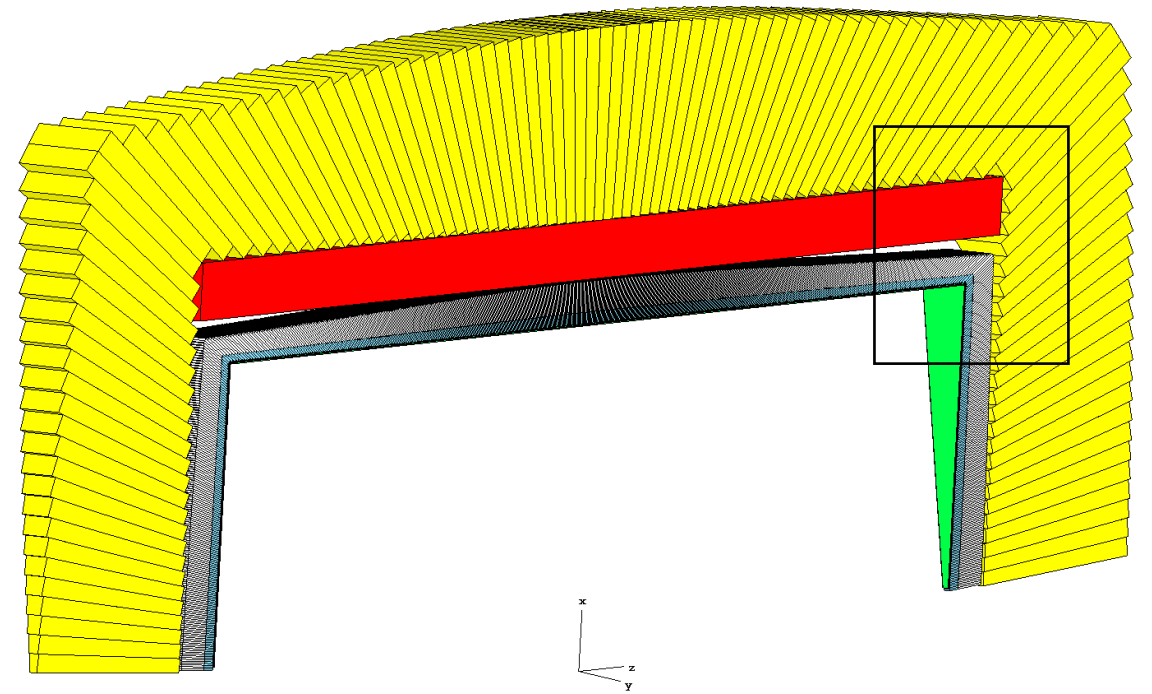
Projective Geometry Calculations

- Need to account for tilt for hermetic projection
- Faces are normal to IP always

Implementation

- Use EightPointSolid volume to fully specifiy vertices
- Use dd4hep::RotationZYX to rotate in θ, then
- Use ROOT::Math::RotationZ to rotate in ϕ (thanks Sanghyun!)
- Place with dd4hep::Position of tower face center

- Use detector/eta/phi/depth as copyID/physVolID for readout

$$r_0 \tan \frac{d\theta}{2} = Y_0$$

$$Y_0 = r_0 \tan \frac{d\theta}{2}$$

$$c = a \tan \frac{d\phi}{2}$$

$$a = b \tan\left(\theta_c + \frac{d\theta}{2}\right). \qquad b = r_0 \cos\theta_c - Y_0 \sin\theta_c$$

Physics-case oriented detector design with PFA

- SW framework is built for PFA – allows for top-down detector and data model design

- The goal – HHH from loop correction to the HZ cross section
- Z(qq)H apparently dominates
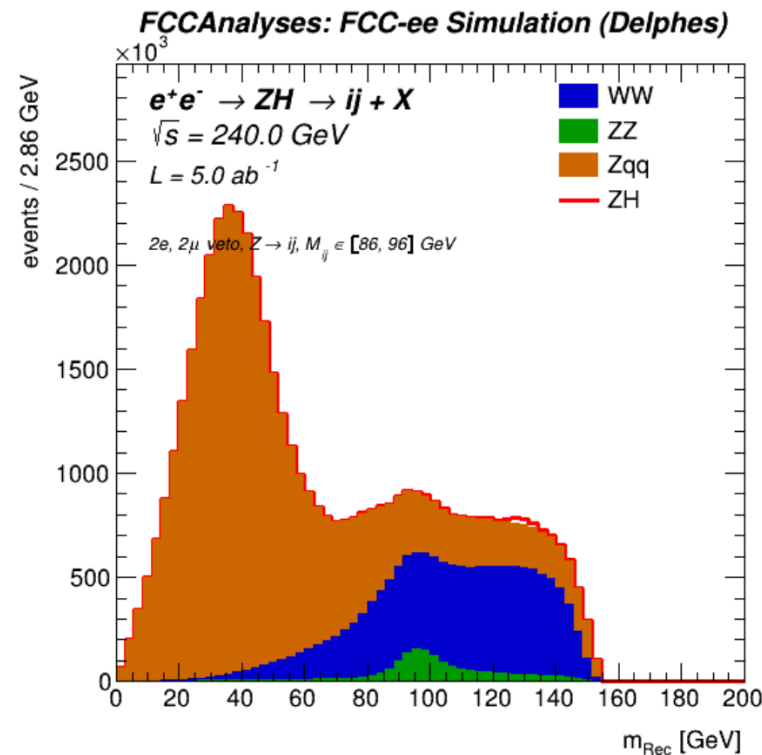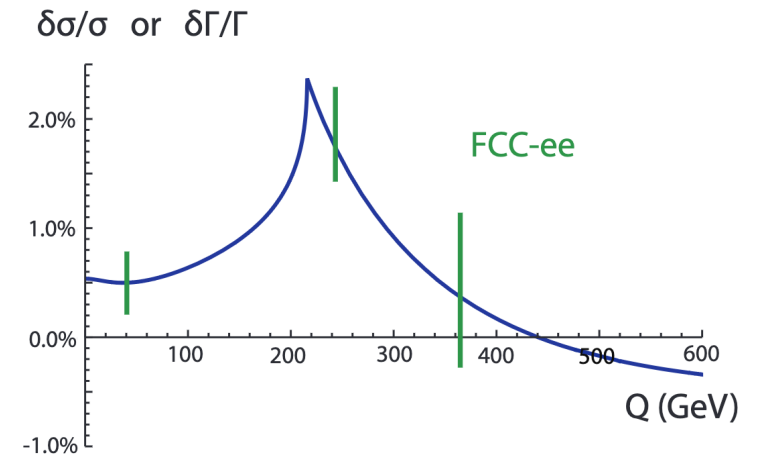- Hinges on ability of detector to reduce ZZ background
  - Jet IDs ultimately are fed from PFA

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

NLL in μ_{ZH} at $\sqrt{s}$ = 240 GeV

- Z($\mu\mu$)H
- Z(ee)H
- Z(qq)H
- Combined
- 1 σ
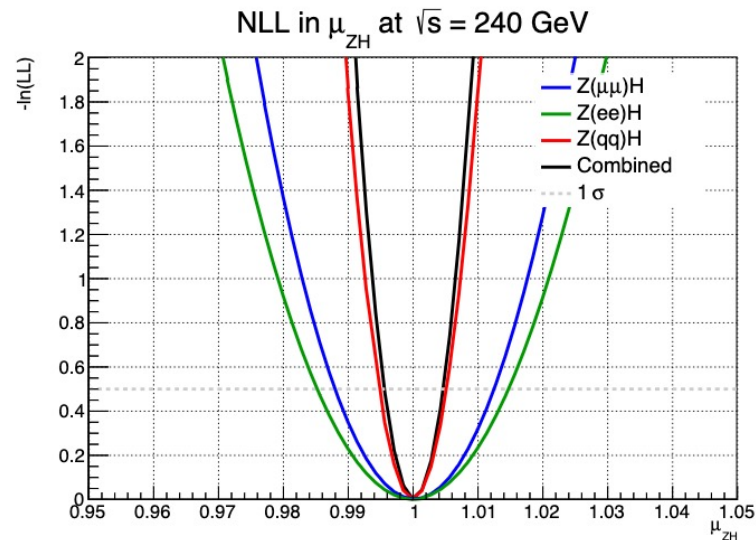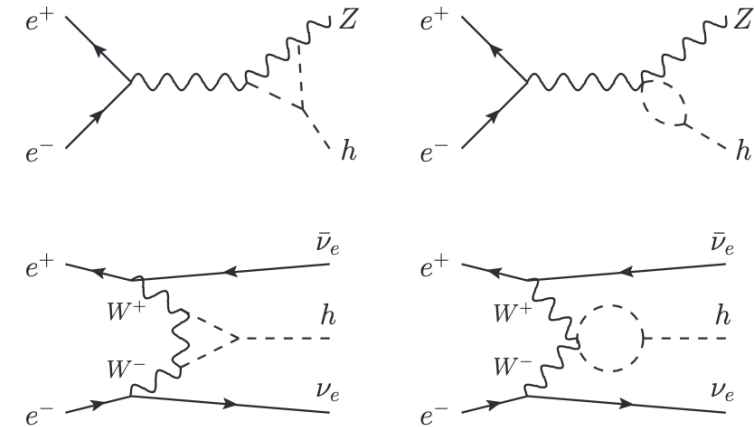
Probing the Higgs sector at the FCC-ee
https://cds.cern.ch/record/2835483

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

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

FCC-ee

General Thoughts/Questions

- What is your development environment?
  - geoDisplay is critical for new detector design, basically impossible over ssh
  - Distro-hopped for a while (debian, SL7, centOS 7/8, fedora), settled on nixOS

- For migration into k4geo -
  - Combined HCAL+ECAL or separate?
  - Segmentation classes?

- Currently forked from Nov 2021 of SanghyunKo/dual-readout
  - Notice of any pitfalls to watch out for when updating to latest versions would be greatly appreciated

- Current states
  - SIM working – adjusted readout bit words for ECAL/HCAL consistency in Reco
  - DIGI not implemented – using RawCaloHits for PFA
  - RECO – in progress

- Integration with analysis repos?
  - e.g. https://github.com/HEP-FCC/FCCAnalyses

- Looking into ray-tracing extensions for optical photons
  - e.g. https://github.com/hanswenzel/CaTS

- Event Display?
  - e.g https://github.com/HSF/phoenix

- Group chat?