Status of the SciGlass barrel electromagnetic calorimeter in DD4hep

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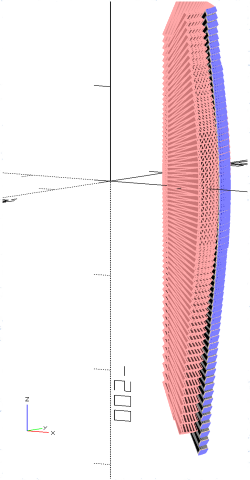
Approaches to an implementation

- Tesselated solids generated from the CAD geometry
  - Centralized source of the geometry
  - Every change has to go through CAD design tooling
  - Tesselated solids are slower to process than native
- List of pre-generated parametrized solids
  - Done for ECCE BECAL in Fun4All (generator code is private)
- Parametrized geometry with solids generated on startup
  - Suggested by DD4hep's design (detector = XML + C++)
  - Re-implements functionality of the generic CAD solver (e.g., constraints on spacing and alignment), but specifically to a single detector
  - AI/ML-friendly
  - Native TGeo/Geant4 shapes are easier to analyze programmatically (e.g., for reconstruction)
  - Overhead of maintaining two designs: one for CAD and one for analysis

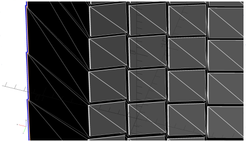
Current geometry in Fun4All

Comparison of Fun4All (in **black** and blue) to a CAD model from Joshua Crafts (in pink, only a 90° section shown):

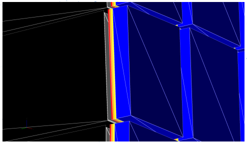


- **Carbon fiber** wrap (0.9 mm thickness)
- SciGlass
  - 38×38 or 46.2×46.2 mm front face
  - 448 or 449.2 mm long
  - azimuthal and polar flaring ("trap" shape, but x1=x2 and x3=x4)
- Polysterene (1 mm)
- Kapton (1 mm)
- Quartz (1 mm)
- Carbon (10 mm)

Tower front view:



Tower rear view:



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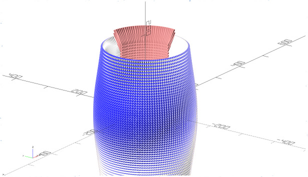
Current geometry in DD4hep (PANDA-like)

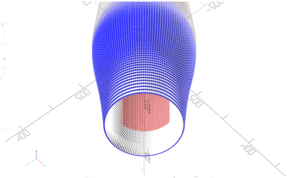
A PANDA-like geometry implemented in current EPIC geometry:
`https://github.com/eic/epic/blob/main/src/SciGlassCalorimeter_geo.cpp`
`https://github.com/eic/epic/blob/main/compact/ecal_barrel_sciglass.xml`

Comparison of PANDA-like (in white and blue) to a CAD model from Joshua Crafts (in pink, only a 90° section shown):

Detector top view:



Detector view:



PANDA-like detector effectively shifted by $\approx$ 20 cm in the $-z$ direction.

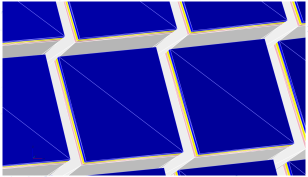
Along polar dimension:

- PANDA-like:
  68 identical towers
- CAD model:
  66 towers of 6 different shapes

Tower materials:

- SciGlass
  - 39×39 mm front face
  - 455 mm long
  - azimuthal and polar flaring ("trd" shape)
- Silicon (2 mm)
- Quartz (2 mm)
- Carbon (2 mm)

Tower rear view:



New geometry (``tiltless'')

The new geometry has no φ-rotation of towers.

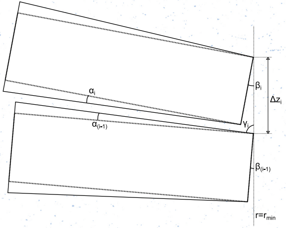
Updated design from Joshua Crafts came in a form of an STL file (tesselated mesh).

Implemetation strategy was:

1. Analyze mesh like a dataset using numpy-stl to enhance understanding
2. Develop with an intermediate prototype in OpenSCAD
    1. Load mesh into OpenSCAD as a transparent overlay
    2. Implement G4Trap as a function in OpenSCAD programming language, implement design using that
    3. Rapidly iterate until the program in OpenSCAD reproduces the design
    4. Port program to C++ for DD4hep

Tower stacking along z-axis

Using the Law of Sines one can figure out how to stack towers:



Vertical shift can be expressed in terms of tower polar flaring angle α_i and polar tilt β_i and front face height h:

$$\Delta z_i = \left(\frac{\text{(tower gap)}}{\cos(\alpha_i)} + h \right) \times \frac{\sin(180^\circ - \gamma_i - \beta_i)}{\sin(\gamma_i)}$$

where

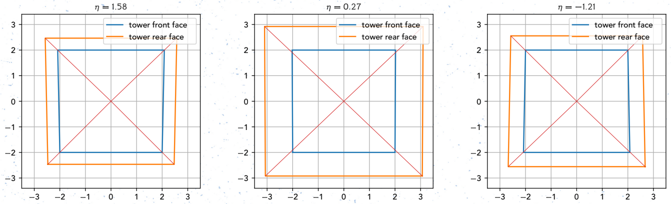
$$\gamma_i = 90^\circ - \alpha_{(i-1)} - \beta_{(i-1)}$$

$$\beta_i = \beta_{(i-1)} + \alpha_{(i-1)} + \alpha_i$$

Meanwhile the AutoCAD subscription is $1,865/year...

Geometry analysis: an example

Faces are not rectangular anymore, but trapezoidal (have “flaring-at-face”).
Plotting tower faces from the CAD model in their respective local coordinates:



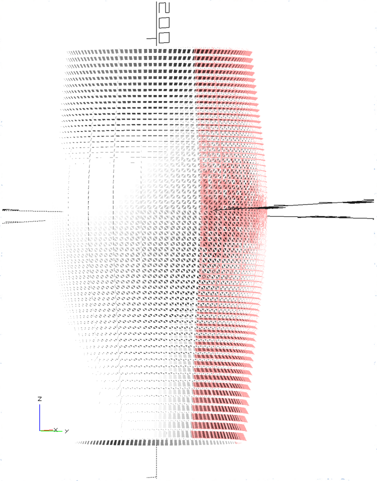
For towers with around $\eta = 0.27$ diagonals of the rear face don’t go through the vertices of the front face

⇒ Faces are not geometrically similar

⇒ Tower shape is not exactly one of a truncated pyramid

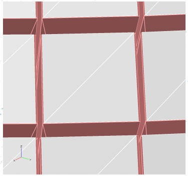
DD4hep implementation for the "tiltless" geometry

Work in progress at `https://github.com/eic/epic/pull/45`
Comparison of new DD4hep (in white) to a CAD model from Joshua Crafts (in pink, only a 90° section shown):



- Only SciGlass towers are implemented, no support material yet
- Towers are implemented truncated pyramids
  ⇒ azimuthal and longitudinal flarings are coupled, only polar flaring is parametrized
- Flaring-at-face implemented

Tower rear view (showing the worst agreement):



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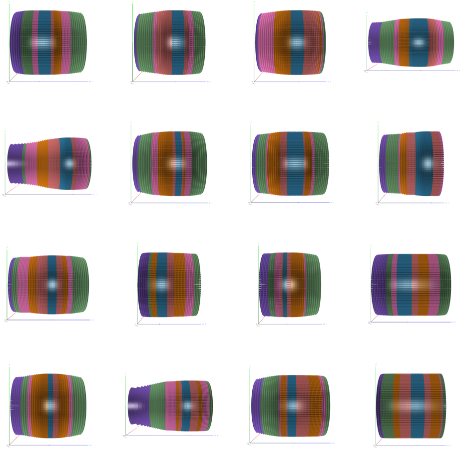
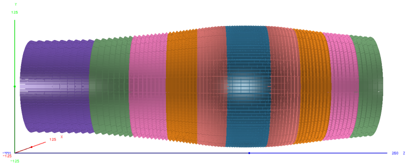
AI/ML friendliness

Random sample from the design space:



A toy optimization (for max volume):



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Issue: Outer Barrel MPGD

- DD4hep allows for global parametrizations of the detector through constant definitions
- In EPIC, we currently have:

  $\texttt{EcalBarrel\_rmin} = \texttt{CentralTrackingRegion\_rmax} + \texttt{BarrelPIDRegion\_thickness} + \texttt{BarrelExtraSpace\_thickness}$, where:

  $\texttt{CentralTrackingRegion\_rmax} =$ 71.5 cm

  $\texttt{BarrelPIDRegion\_thickness} =$ 7 cm

  $\texttt{BarrelExtraSpace\_thickness} =$ 5 cm ← should be effectively 2 cm
- This results in $\texttt{EcalBarrel\_rmin} =$ 83.5 cm, which is different from the intended value of 80.5 cm
- Menagerie suggests, Barrel EMCal envelope starts at 79.5 cm
- but, instead, we have $\texttt{OuterMPGDBarrelLayer\_rmax} =$ 82 cm

  $\texttt{OuterMPGDBarrelLayer\_rmin} =$ 80 cm

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Things to do

» Remaining TODO for October 3rd

- (High priority) Have outer barrel MPGD fixed to ensure correct tower gaps
- (High priority) Fix global azimuthal rotation to match the CAD design
- (Medium priority) Implement support material
- (Low priority) Decouple azimuthal flaring from polar flaring

» Non-campaign infrastructure TODO

- Improving the official benchmarks `https://eicweb.phy.anl.gov/EIC/benchmarks/detector_benchmarks/-/tree/master/benchmarks/barrel_ecal`
- Further pinpointing discrepancies in resolution vs Fun4All
- Implementing Cherenkov radiation for SciGlass and a slow simulation with optical photons