Detector design of cylindrical crystal ECAL

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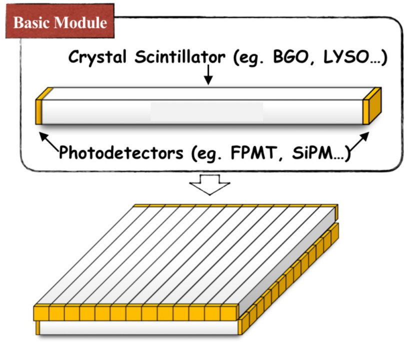
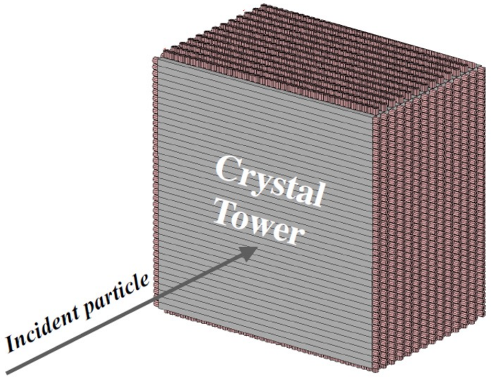
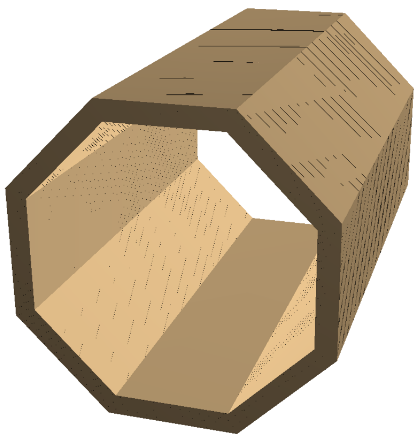
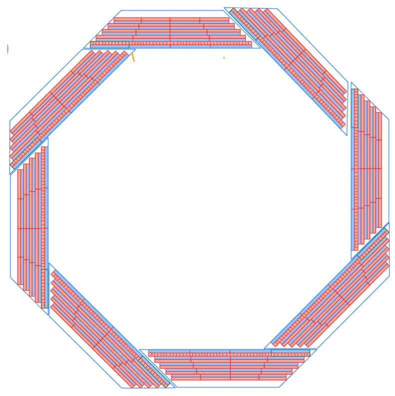
Motivation of cylindrical crystal ECAL

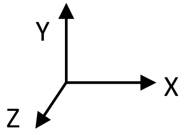
- Basic detector unit of crystal ECAL:
  - long crystal bar: charge/time measurements at double-side readouts.
  - crossed arrangement in adjacent layers.
  - optimal energy resolution: $\sim 3\%/\sqrt{E} \oplus \sim 1\%$.
  - significant reduction of number of readout channels.
- Detector design of barrel crystal ECAL:
  - 8 trapezoidal modules → cylindrical crystal ECAL.
  - decrease outer radius of ECAL and reduce cost of outer detector (HCAL, MUC).

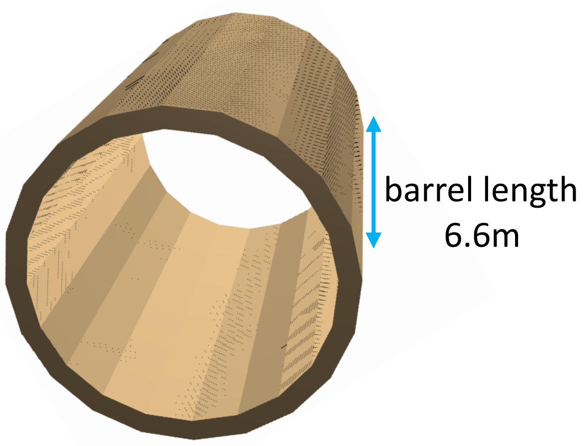


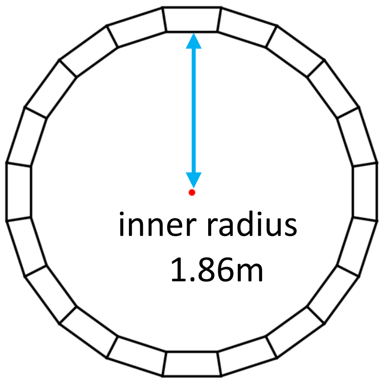






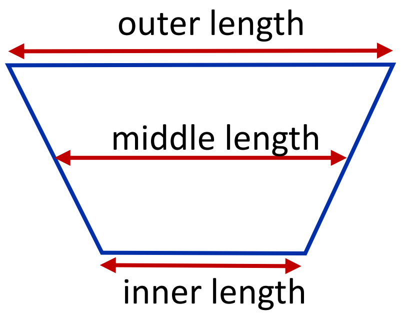




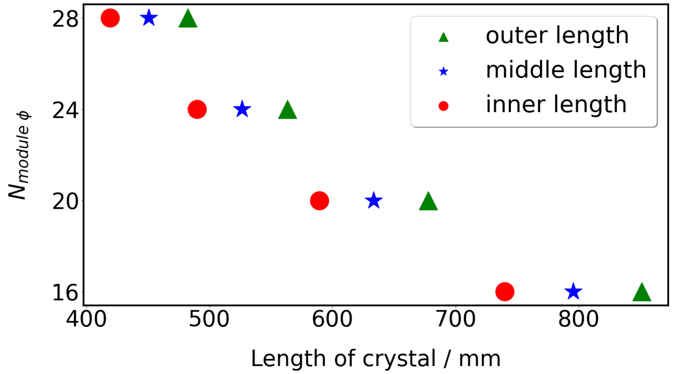


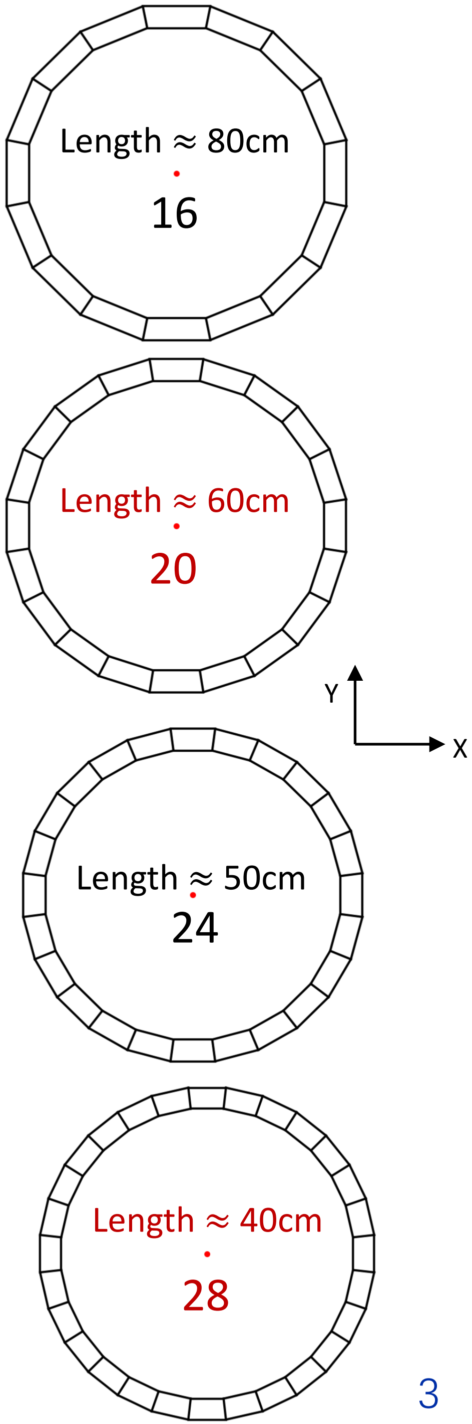
Dimension of long crystal bar

- Length of long crystal bar
  - 40 cm: 28 modules in XY
  - 60 cm: 20 modules in XY
- Size of long crystal bar
  - 1cm × 1cm
  - 1.5cm × 1.5cm

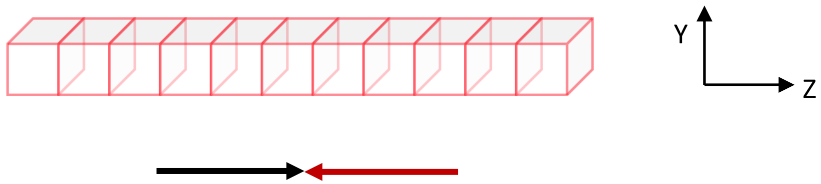


*crystal module in XY





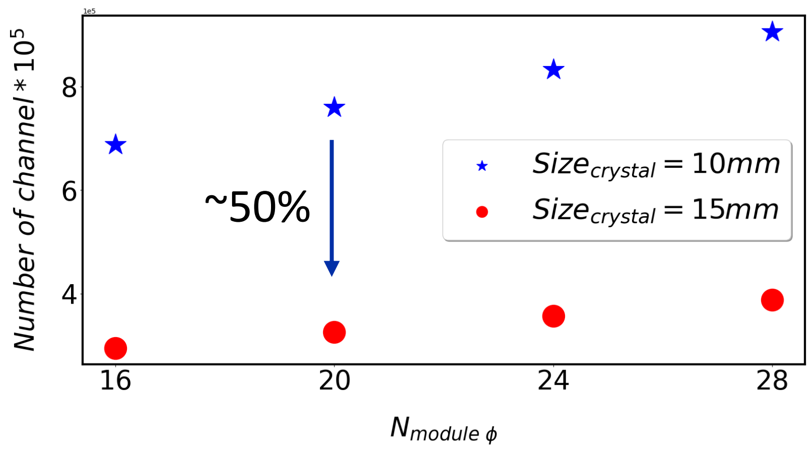
Barrel length 6600 mm	$N_{module\ Z}$	9	10	11	12	13	14	15
	Z crystal length/mm	733.33	660	600	550	507.69	471.43	440
	$N_{module\phi}$	16	20	20	24	24	28	28
	XY crystal length/mm	795.65	633.54	633.54	526.61	526.61	450.69	450.69

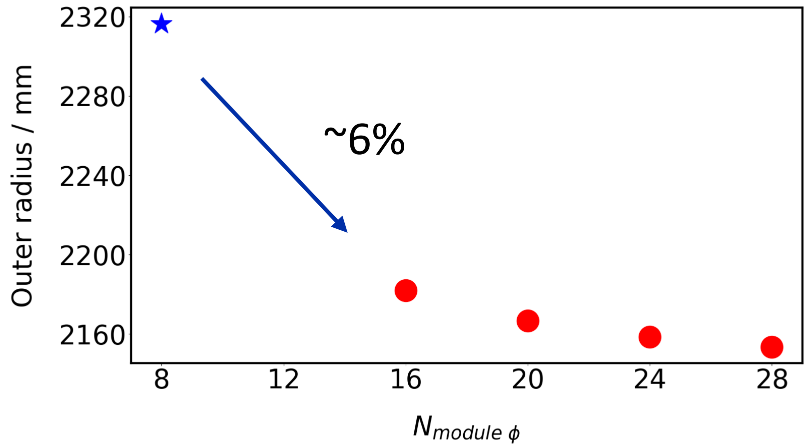


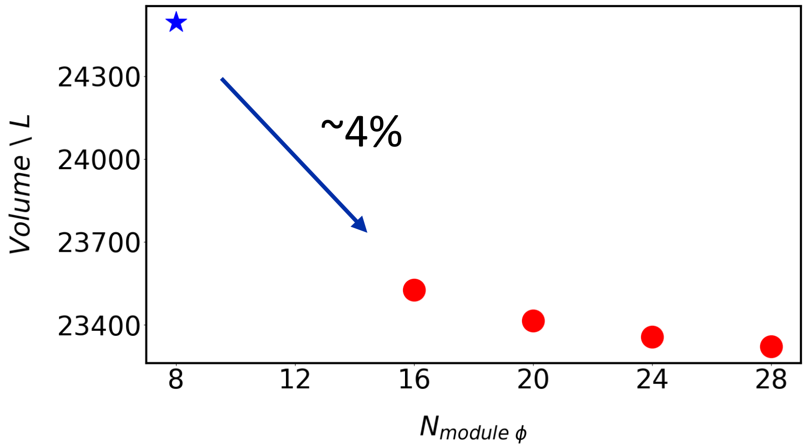
- length of crystals in two direction need to be close as much as possible.

Dimension of long crystal bar

- Comparison: number of readout channels reduce ~50%, 1cm × 1cm → 1.5cm × 1.5cm
- ~6% reduction of outer radius of ECAL, ~4% reduction of volume of crystal: 8 trapezoidal modules → cylindrical crystal ECAL.



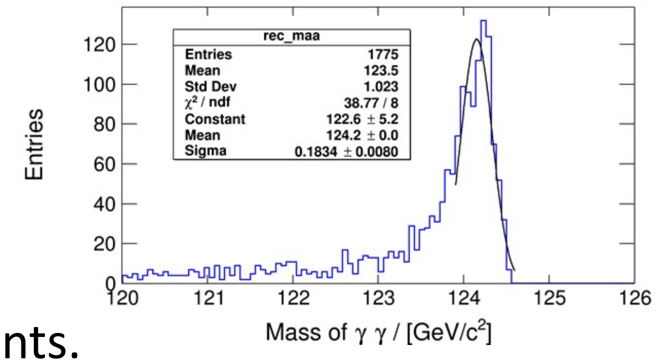


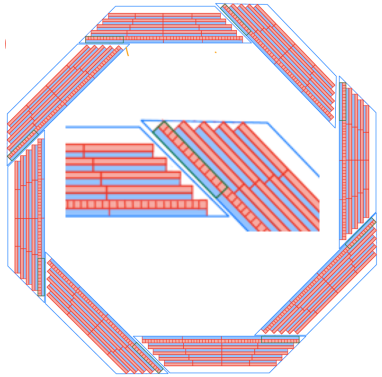


*ideal situation (isosceles trapezoid) for estimation ignoring gap

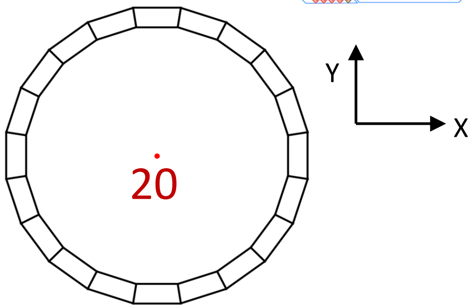
Cracks on the boundary between two modules

- Energy distribution of $H \rightarrow \gamma\gamma$ is skewed to low-energy side, which is a result of energy leakage caused by cracks between two modules.



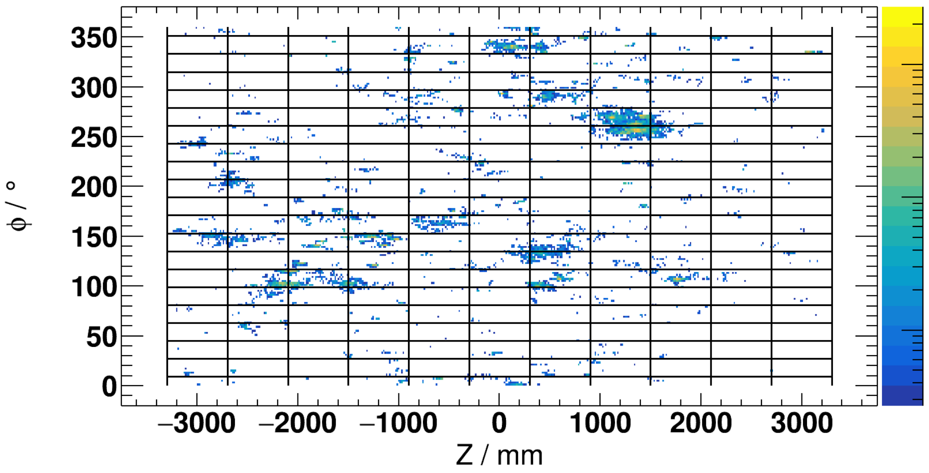


- Sample: 240GeV, $e^+ + e^- \rightarrow ZH \rightarrow qqgg$, 4-jet events.
- Simulation in CEPCSW: A cylindrical crystal ECAL consisted of 20 isosceles trapezoid modules is applied.

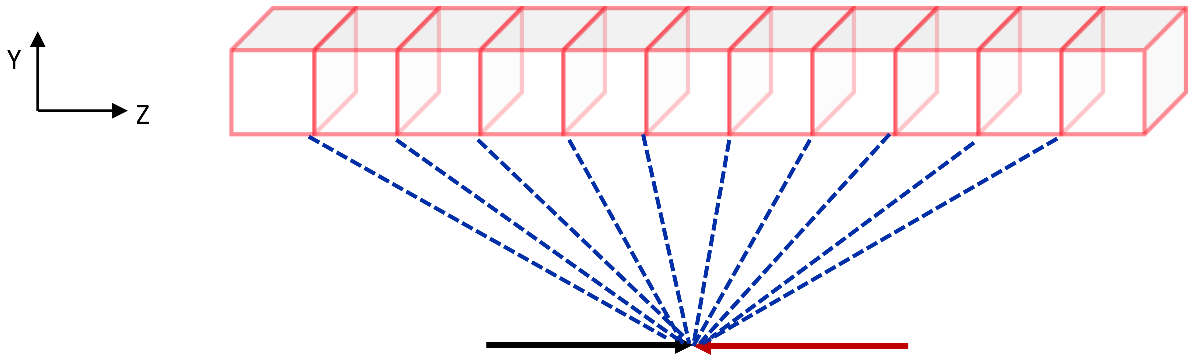


- It is unavoidable that some particles of jet go through cracks between modules and energy leakage will deteriorate energy resolution of jet events.

- Avoid cracks pointing to interaction point in both XY and Z: tilt or displacement.



Cracks on the boundary between two modules in Z



- Avoid cracks pointing to interaction point in Z: modules in Z need to be odd!

Barrel length 6600 mm	$N_{module\ Z}$	9	10	11	12	13	14	15
	Z crystal length/mm	733.33	660	600	550	507.69	471.43	440
	$N_{module\phi}$	16	20	20	24	24	28	28
	XY crystal length/mm	795.65	633.54	633.54	526.61	526.61	450.69	450.69

↓

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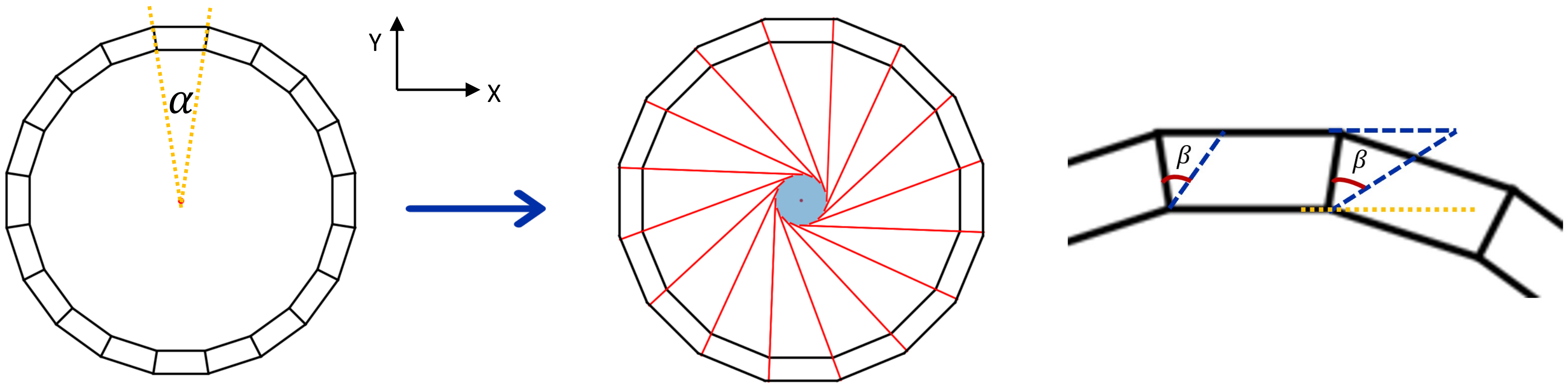
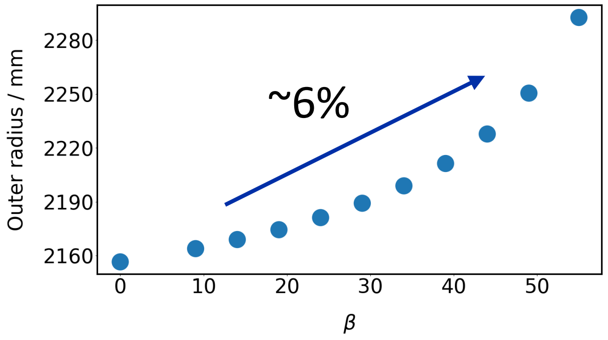
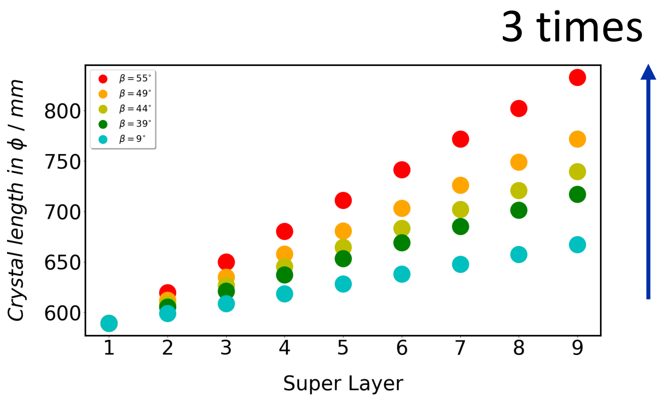
Cracks on the boundary between two modules in XY



- Avoid cracks pointing to interaction point in XY:
  tilt of cracks between modules.

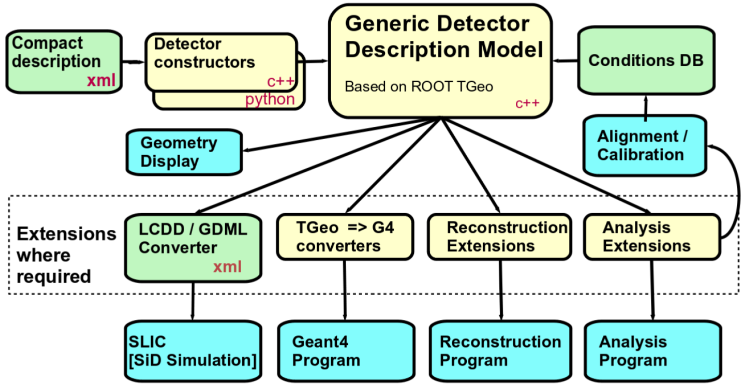
- tilt of cracks β increase:
  - → less projective cracks, less lateral non-hermeticity and easy to calibration.
  - → larger outer radius of ECAL and more cost.
  - → larger deviation between inner crystal length and outer crystal length.

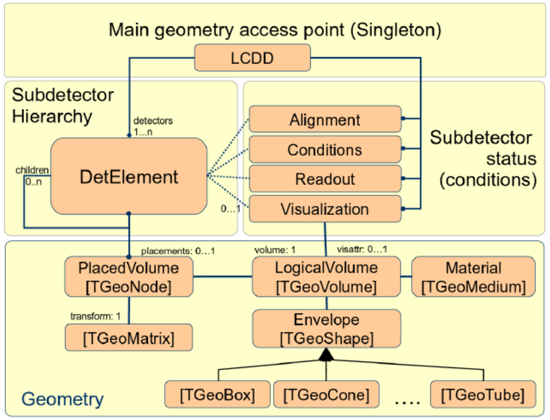


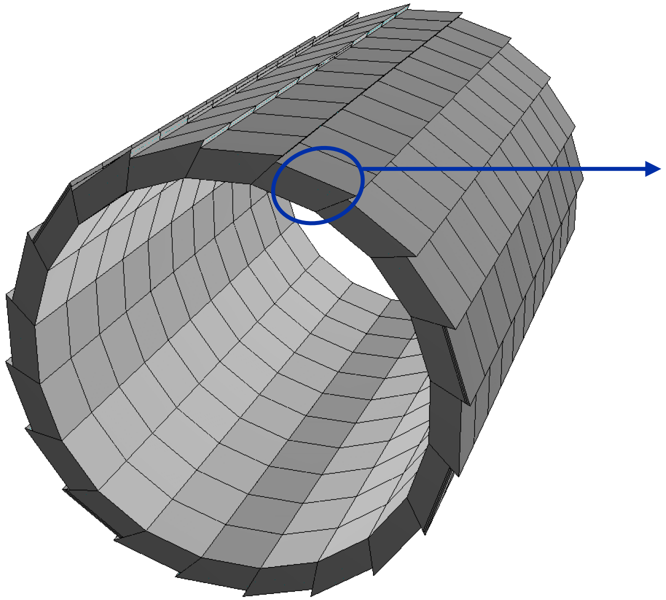


Implementation of cylindrical crystal ECAL with less projective cracks

- Detector description including geometry and material (BGO) is complemented using DD4hep in CEPCSW.
- Number of modules: $N_{\phi} \times N_z$

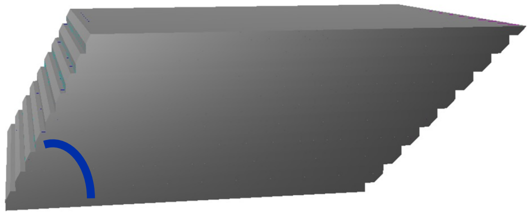






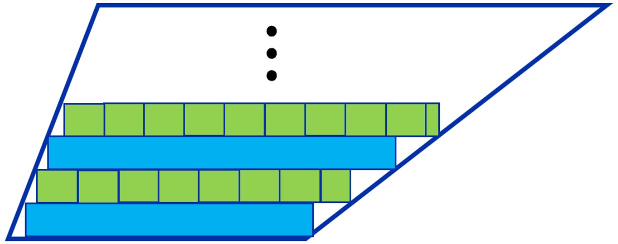
cylindrical crystal ECAL

module



$\frac{\pi}{2} - \frac{\alpha}{2} - \beta$

arrangement of crystals

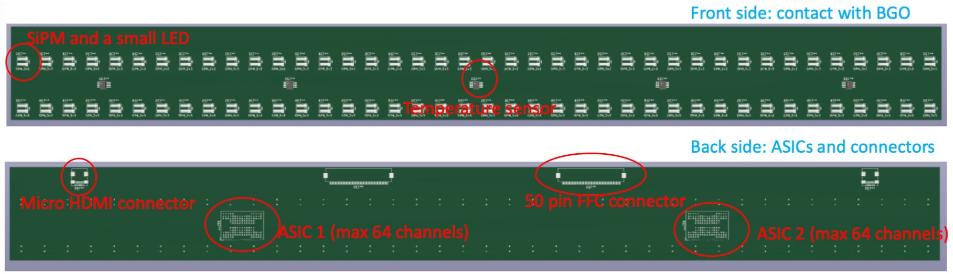


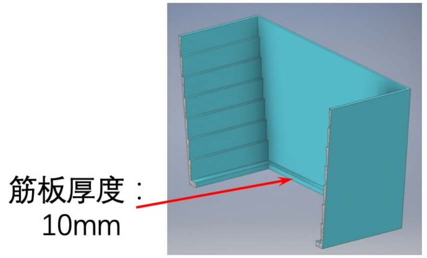
- there are two types of crystals:
  1. ϕ crystals (blue)
  2. Z crystals (green)

Simulation results with cylindrical crystal ECAL with less projective cracks

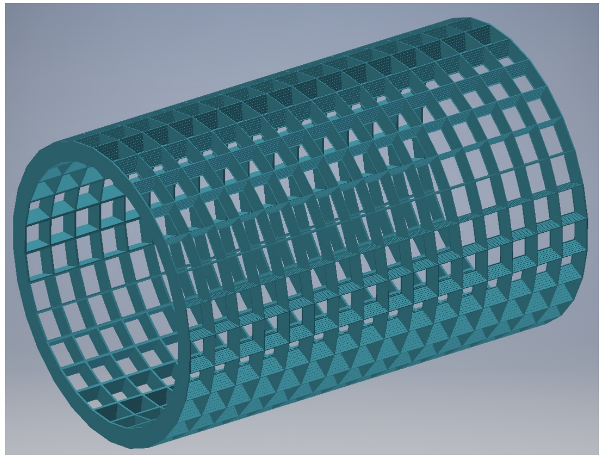
dead material: electronics(deep blue) + mechanical supporting(gray)

1. SiPM: 1mm
2. PCB: 1.5mm
3. ASIC: 1mm
4. carbon fiber: 5mm

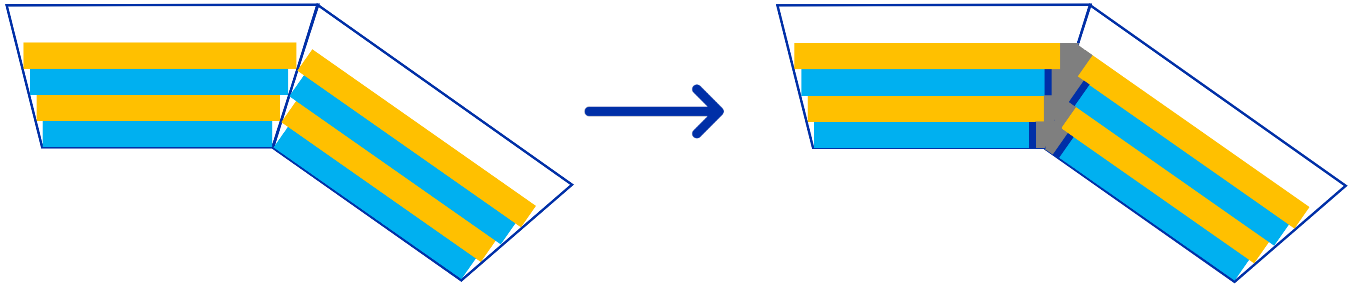




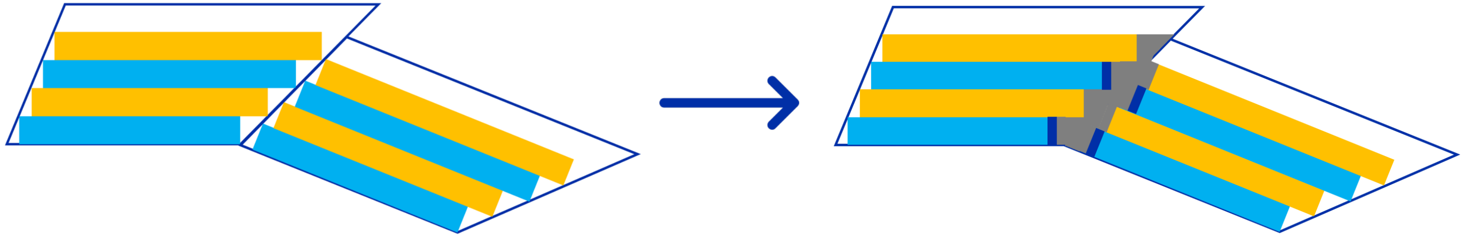
from quan, baohua



without tilt



$\beta = 18^{\circ}$

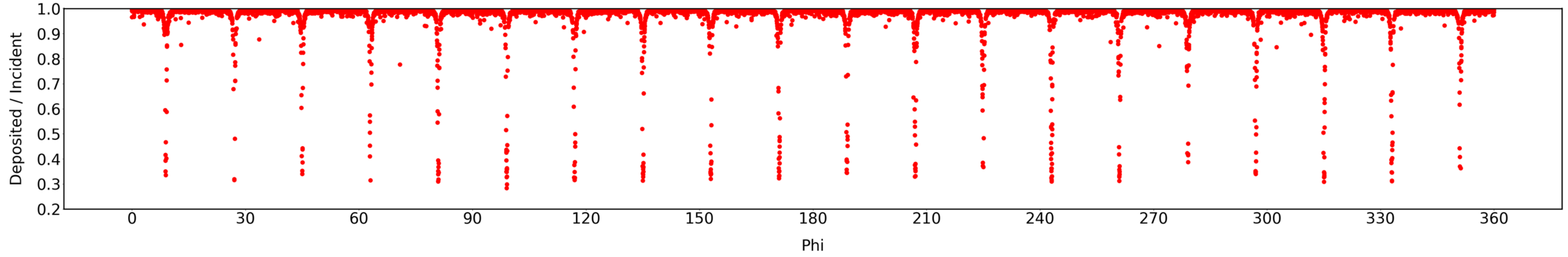


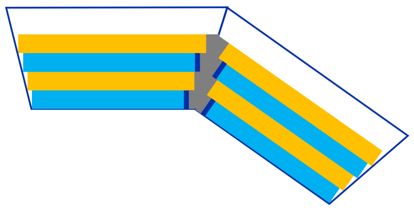
Simulation results with cylindrical crystal ECAL with less projective cracks

10 GeV $\phi = 0^{\circ} - 360^{\circ}$ single photons events

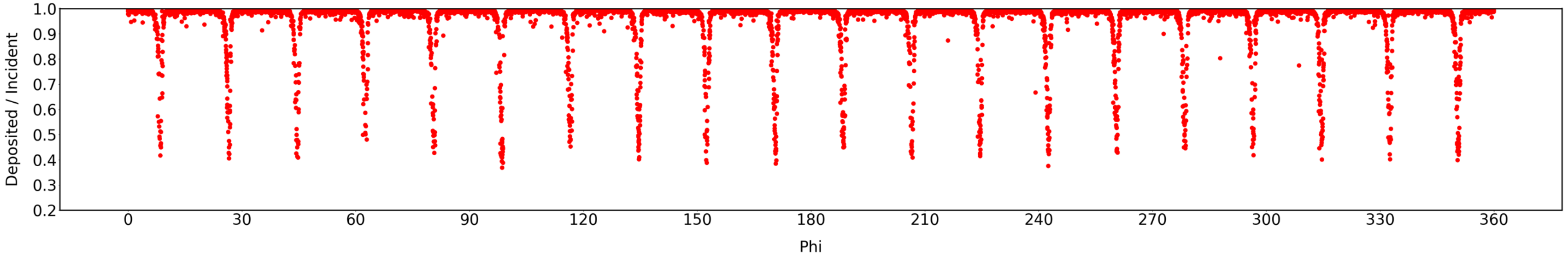
preliminary

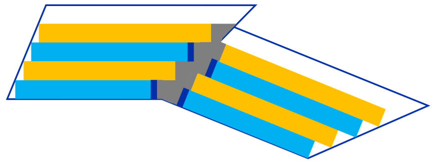
without tilt

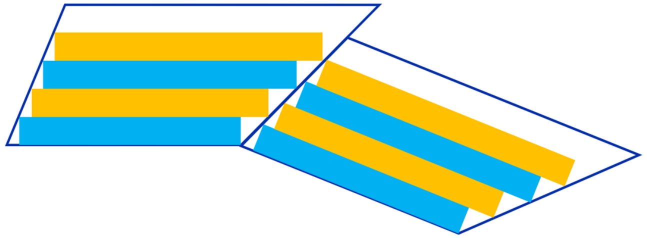




$\beta = 18^{\circ}$



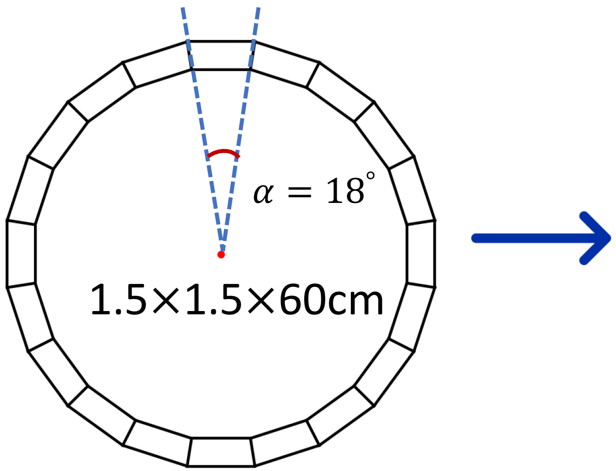


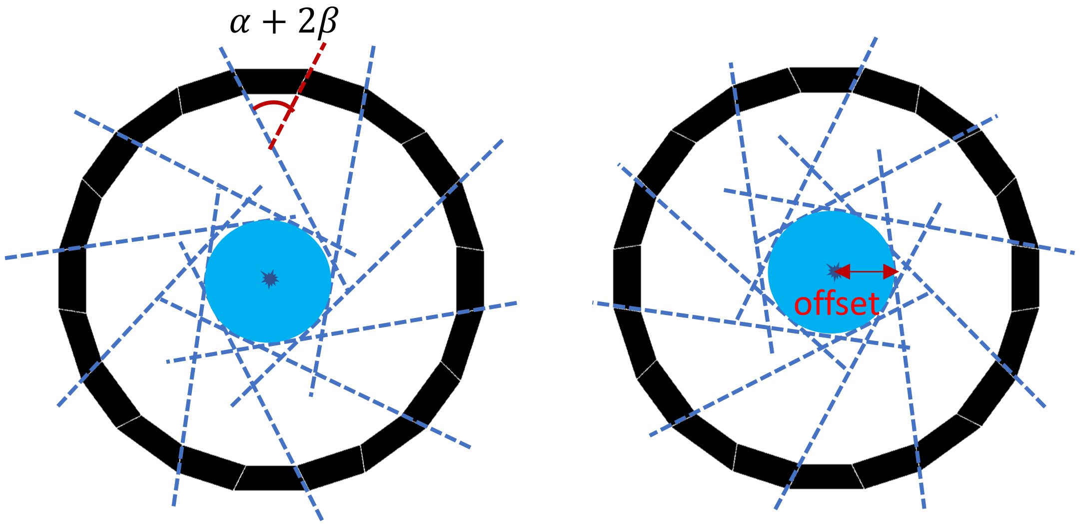


Slight improvement with tilt:

need optimization of cracks!

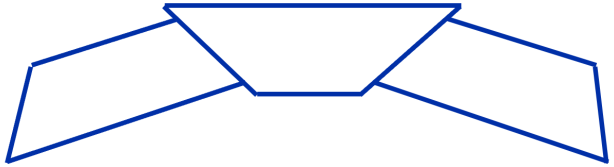
Trapezoids and upside-down trapezoids arranged in sequence

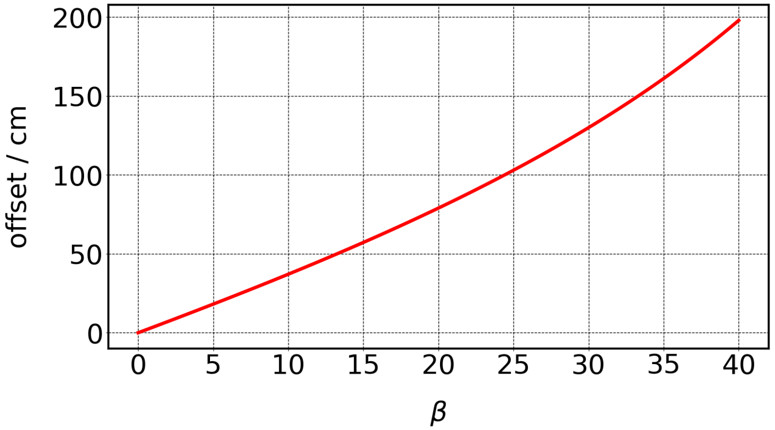


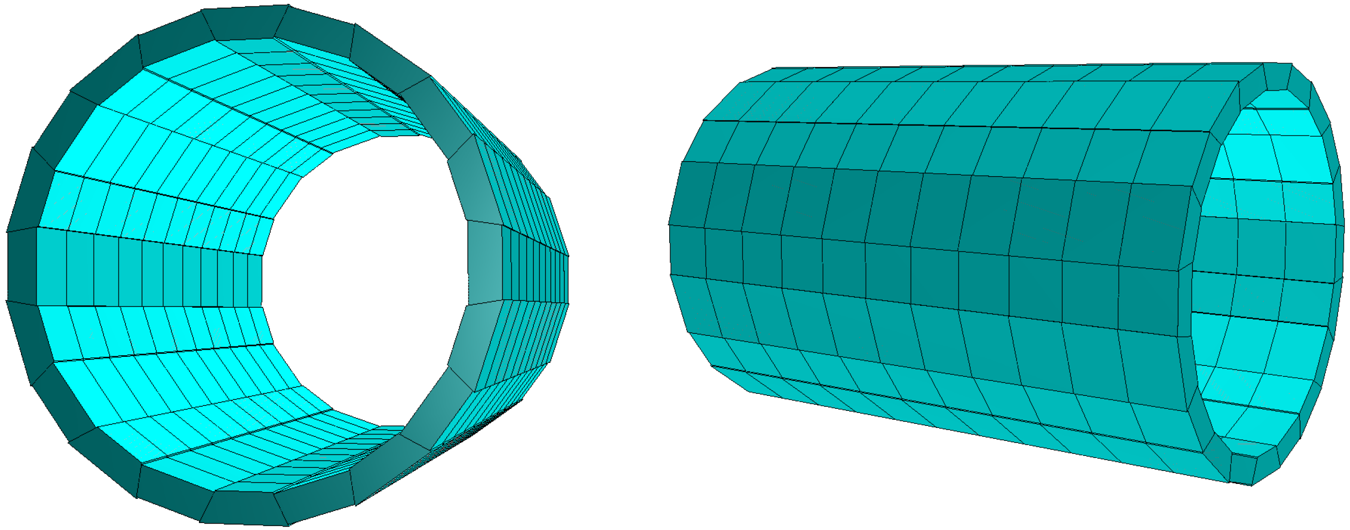


avoid cracks pointing into region of interaction point

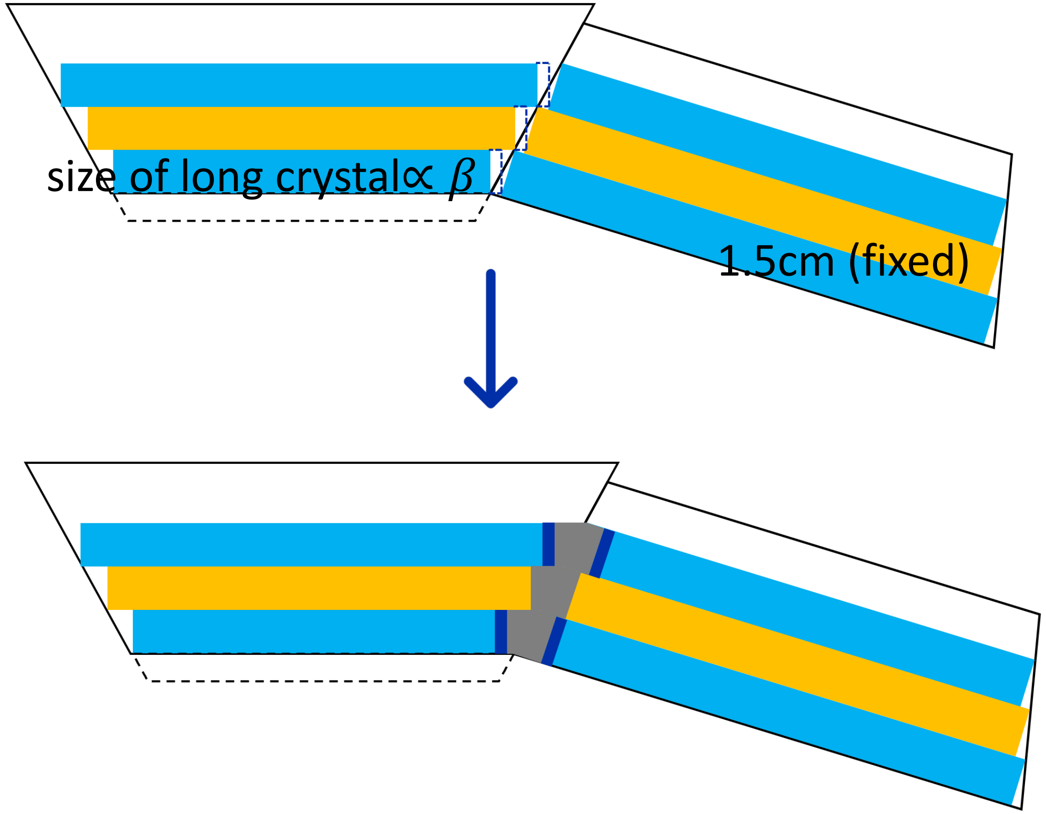
β: angle of tilt





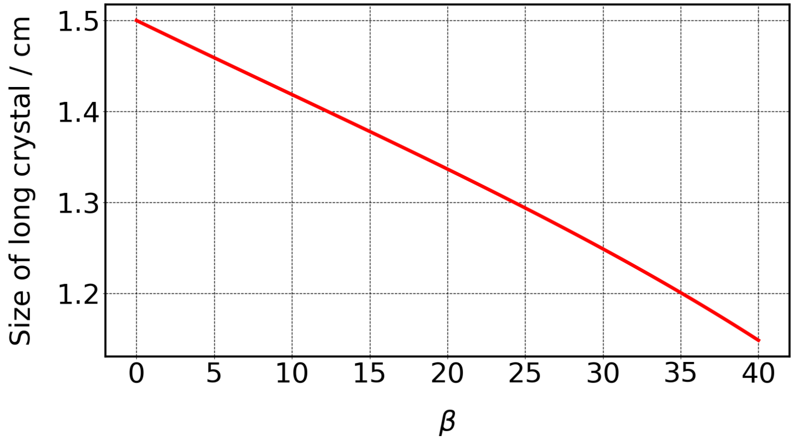


Configuration of trapezoids and upside-down trapezoids



matching of long crystal bars in the same layers between two adjacent modules:

1. different size of long crystal bars
2. need more layers in upside-down trapezoid



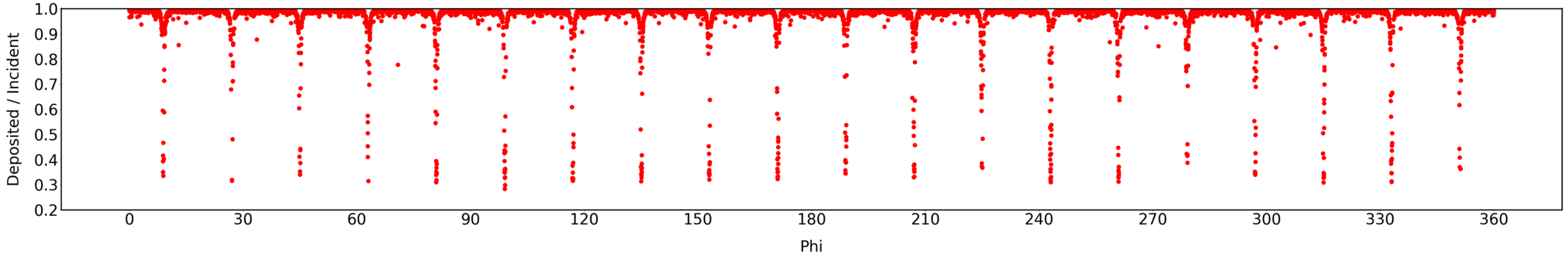
dead material: 3.5mm electronics(deep blue) + 5mm mechanical(gray)

Simulation results with trapezoids and upside-down trapezoids

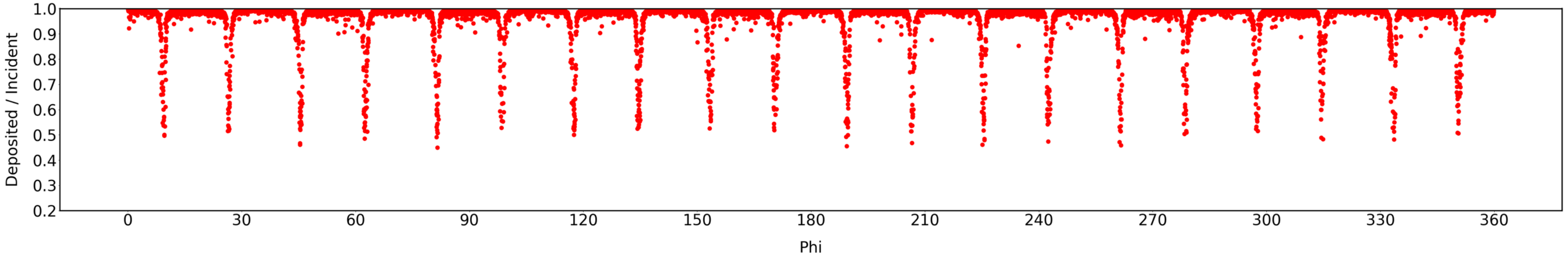
10 GeV $\phi = 0^{\circ} - 360^{\circ}$ single photons events

preliminary

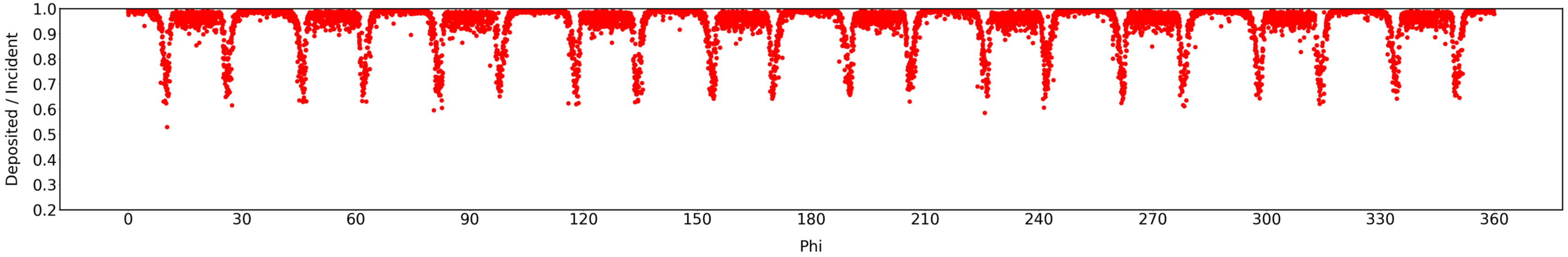
without tilt



$\beta = 18^{\circ}$



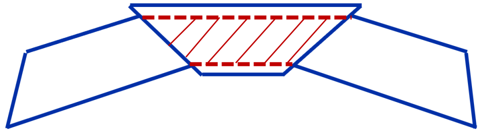
$\beta = 36^{\circ}$



increasement of tilt:

1.maximum of energy leakage decreases

2. longitudinal energy leakage in upside-down trapezoids

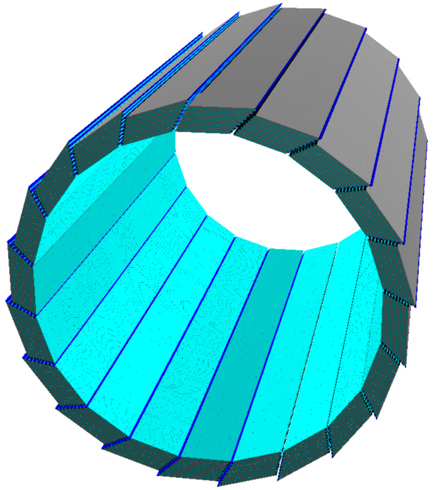


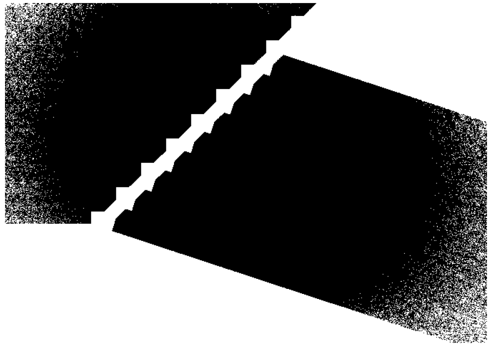
Correction to energy leakage in the cracks

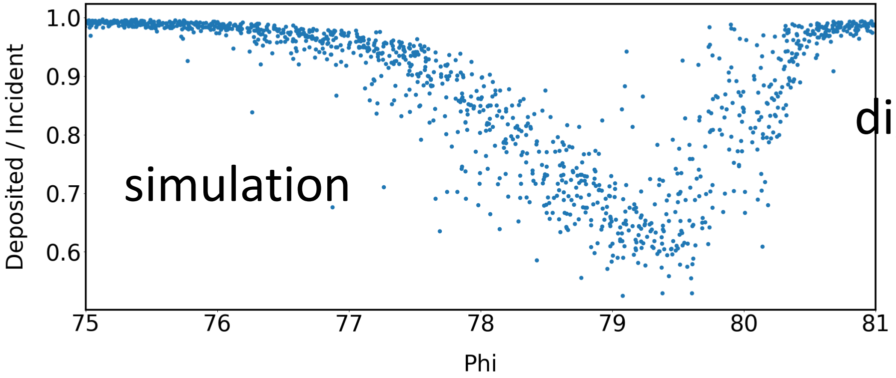
- Take size of long crystal is 1.5cm, length of long crystal is about 60cm, angle of tile is 37° and dead material (SiPM, PCB, carbon fiber and etc) between two modules is 2 cm as an example.

- Sample: 10 GeV $\phi = 75^{\circ} - 81^{\circ}$ single photon events.

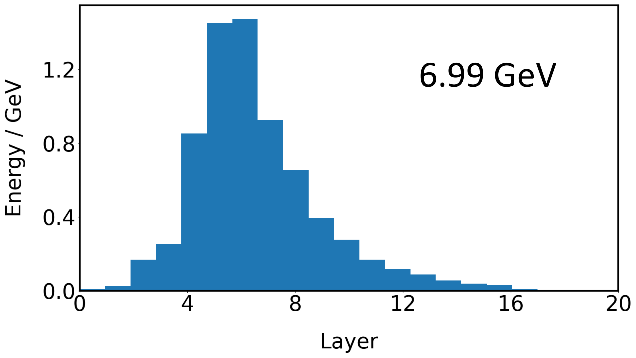
- Two potential methods of correction: ongoing…
  1.position reconstruction of cluster.
  2.longitudinal energy distribution of electromagnetic shower.

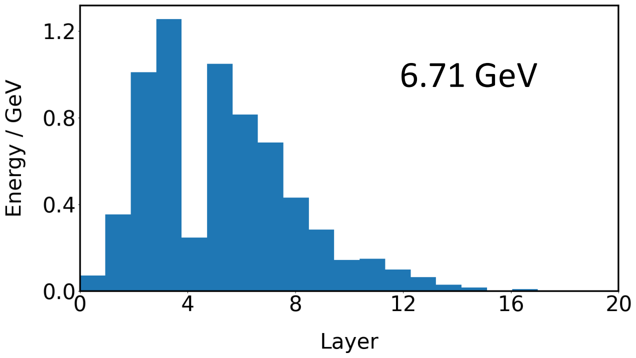






digitization





Summary and prospects

- Dimension of long crystal bar in cylindrical crystal ECAL:
  - ✓ 1cm×1cm×~40cm: 28 modules in XY and 15 modules in Z.
  - ✓ 1.5cm×1.5cm×~60cm: 20 modules in XY and 11 modules in Z.
- Cylindrical crystal ECAL with less projective cracks is complemented based on DD4hep:
  - ✓ parameterized and automated.
- Energy leakage of jet in cracks between modules will deteriorate energy resolution:
  - ✓ tilt make cracks less projective.
  - ➢ energy leakage in the cracks is unacceptable based on preliminary simulation results. Need optimization of detector design.

➢ Focus on trapezoids and upside-down trapezoids arranged in sequence.

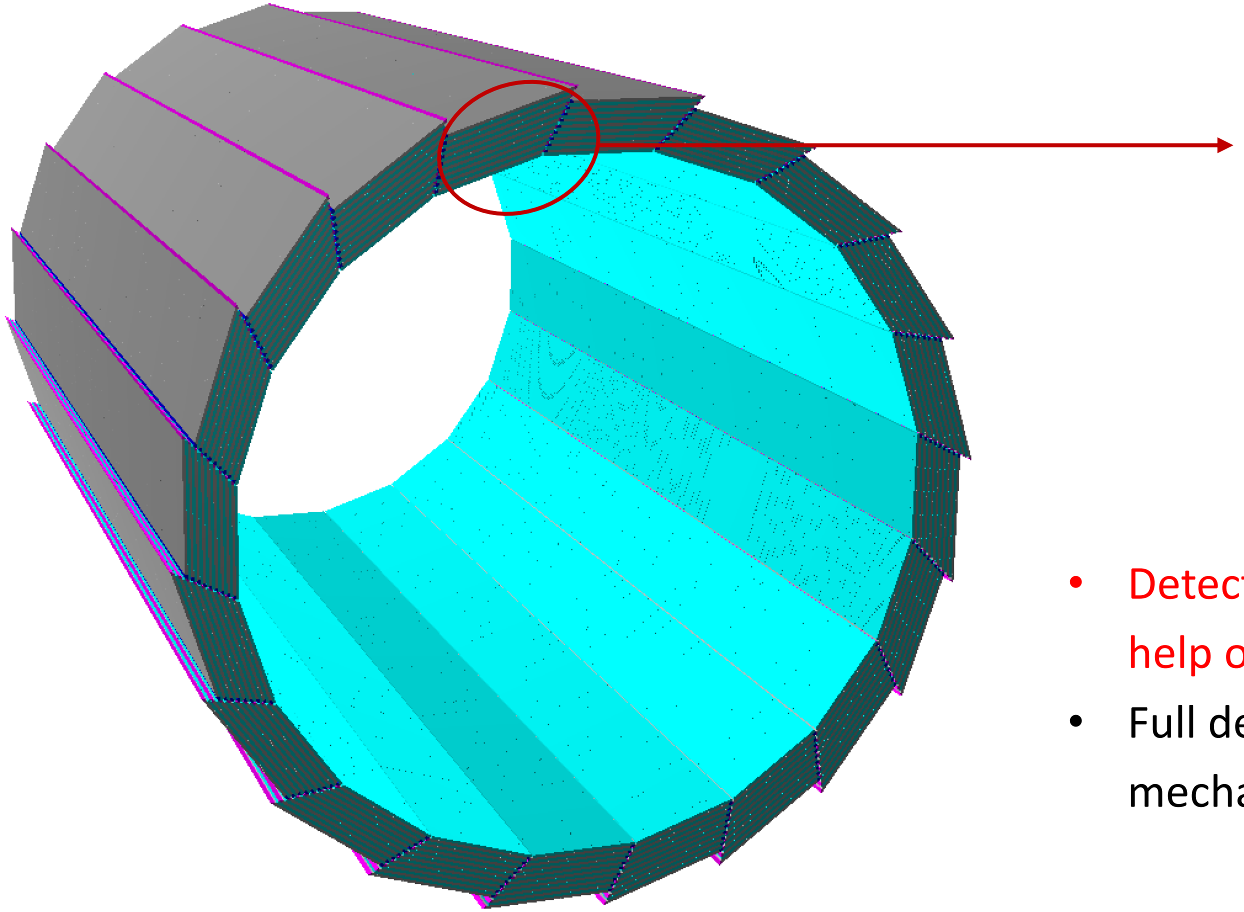
➢ Correction to energy leakage.

Thanks!

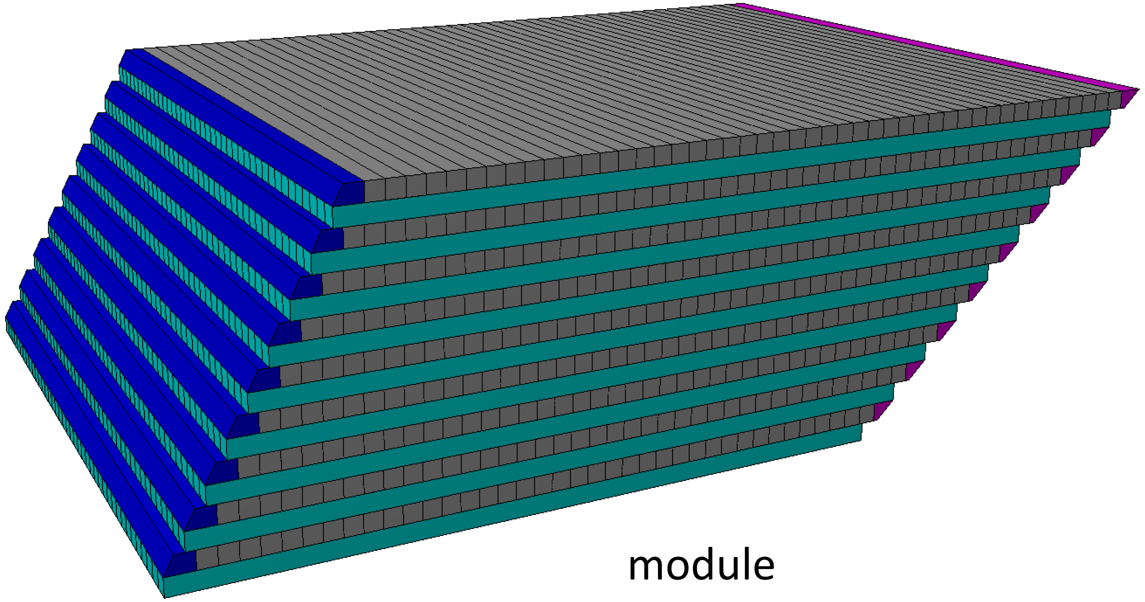
back up

Implementation of cylindrical crystal ECAL with less projective cracks

- Take size of long crystal is 1.5cm, length of long crystal bar is about 60cm and angle of tilt is 37° as an example.



cylindrical crystal ECAL



module

- Detector description is parameterized and automated with help of DD4hep.
- Full detector description is lack of electronics, supporting mechanics and cooling, etc.

*angle of tile is taked as 37° just for schematic diagram