CEPC Crystal Calorimetry

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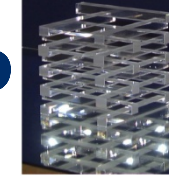
Advances in HEP Calorimetry

- The mission of HEP calorimetry is the measurements of the energy, location and time of electromagnetic and hadronic showers, as well as missing energy.
- An imaging calorimetry has been developed under the leadership of CALICE, and adapted by the CMS FCAL as well as the ILC/CLIC community. Particle flow Algorithm (PFA) has been adopted for object reconstruction in a complex system of inter-connected detectors.
- High precision timing detectors are used to distinguish events from one bunch crossing at the HL-LHC, leading to a 4D calorimetry.
- **There are concerns on imaging calorimetry, such as the cost and complication. Timing is less important at CEPC.**

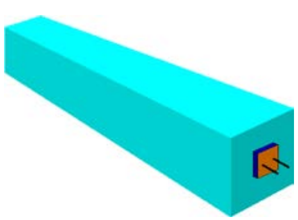
Why Crystal Calorimetry?

- **Precision γ/e measurements enhance physics discovery potential in HEP experiments.**
- **Performance of crystal calorimeter in γ/e measurements is well understood:**
  - **The best possible energy and position resolutions;**
  - **Good e/γ identification and reconstruction efficiency.**
- **Challenges on crystal calorimetry:**
  - **Ultrafast and radiation hard crystals and γ-ray direction measurement at the energy frontier (HL-LHC);**
  - **Ultrafast crystals at the intensity frontier (Mu2e-II);**
  - **Cost-effective crystals for the Homogeneous HCAL;**
  - **Calibration for highly segmented crystal calorimetry, such as HERD LYSO calorimeter at IHEP.**

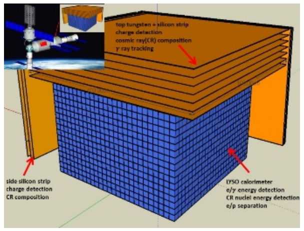
Existing Crystal Calorimeters in HEP



Date	75-85	80-00	80-00	80-00	90-10	94-10	94-10	95-30
Experiment	C. Ball	L3	CLEO II	C. Barrel	KTeV	*BaBar*	BELLE	CMS
Accelerator	SPEAR	LEP	CESR	LEAR	FNAL	SLAC	KEK	CERN
Crystal Type	NaI(Tl)	BGO	CsI(Tl)	CsI(Tl)	CsI	CsI(Tl)	CsI(Tl)	$PbWO_4$
B-Field (T)	-	0.5	1.5	1.5	-	1.5	1.0	4.0
r_{inner} (m)	0.254	0.55	1.0	0.27	-	1.0	1.25	1.29
Number of Crystals	672	11,400	7,800	1,400	3,300	6,580	8,800	76,000
Crystal Depth (X_0)	16	22	16	16	27	16 to 17.5	16.2	25
Crystal Volume (m^3)	1	1.5	7	1	2	5.9	9.5	11
Light Output (p.e./MeV)	350	1,400	5,000	2,000	40	5,000	5,000	2
Photosensor	PMT	Si PD	Si PD	WS[a]+Si PD	PMT	Si PD	Si PD	APD[a]
Gain of Photosensor	Large	1	1	1	4,000	1	1	50
σ_N/Channel (MeV)	0.05	0.8	0.5	0.2	small	0.15	0.2	40
Dynamic Range	10^4	10^5	10^4	10^4	10^4	10^4	10^4	10^5



LSO/LYSO for COMET, HERD, and HL-LHC (Sampling)
CsI and BaF_2:Y for Mu2e, Super τ/c, PWO for PANDA
BGO, BSO or scintillating glasses for HHCAL
CEPC crystal calorimetry?

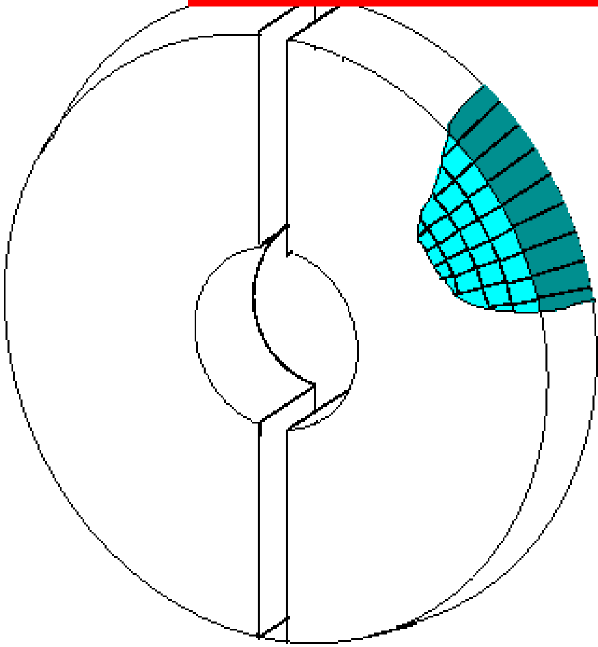


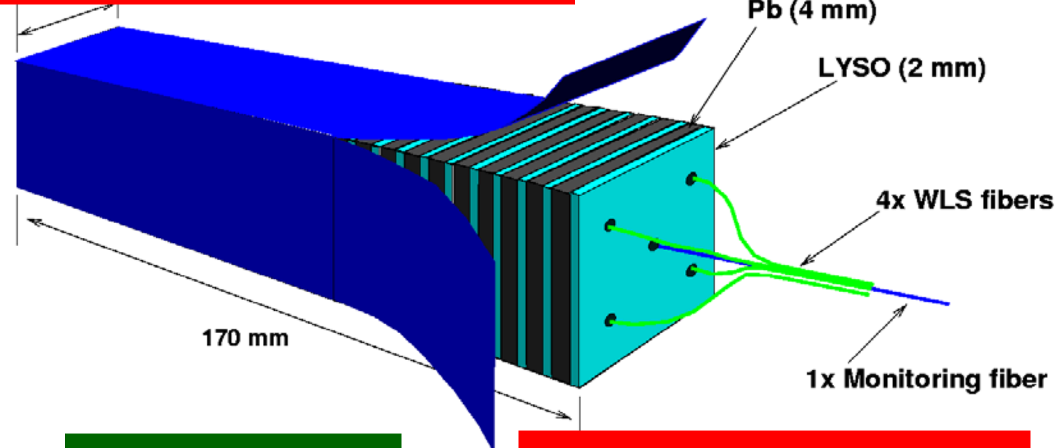
Thoughts: CEPC Calorimetry

- Try the best possible measurements of fundamental particles, such as photons and electrons, as well as missing E_T and jets;
- Following the above priority to optimize the calorimeter design and control the calorimeter cost;
- Use a few benchmark physics processes as criterion for detector optimization.
- A prototype test beam to prove performance.
- A FLUKA simulation to understand radiation level, including integrated dose and dose rate.
- **Iterations may be needed to reach an optimized calorimeter design for CEPC**.

CMS Forward Calorimeter Upgrade

Talk in CMS FCAL Taskforce Meeting at CERN, 6/30/2011

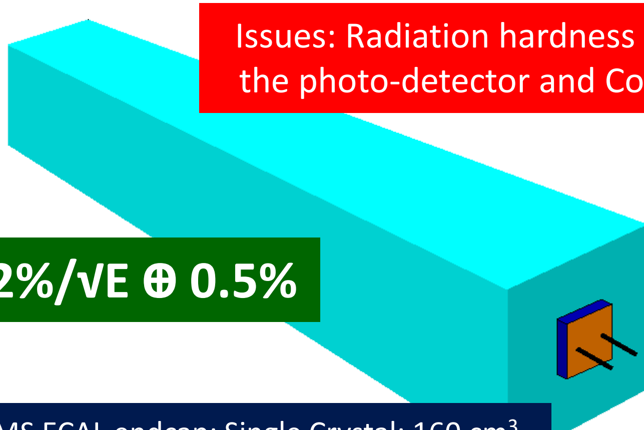




10%/√E ⊕ 1%

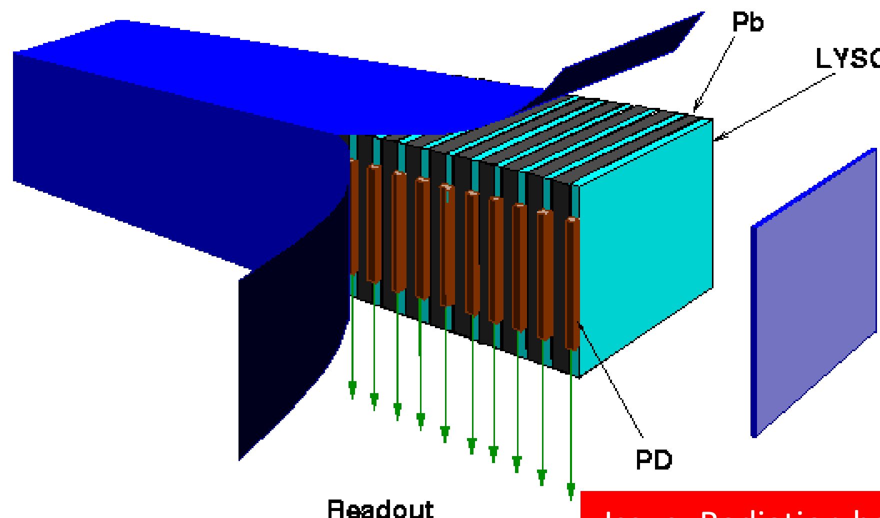
Issues: Radiation hardness of photo-detector and WLS fiber

Issues: Radiation hardness of the photo-detector and Cost



2%/√E ⊕ 0.5%

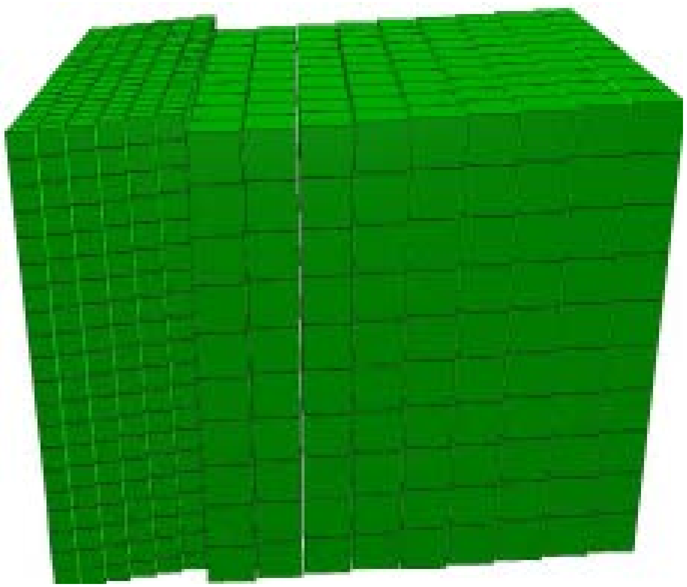
CMS ECAL endcap: Single Crystal: 160 cm^3
Total number: 16,000 Total Volume: 3 m^3
Expected Crystal Cost: ~$90M@$30/cc

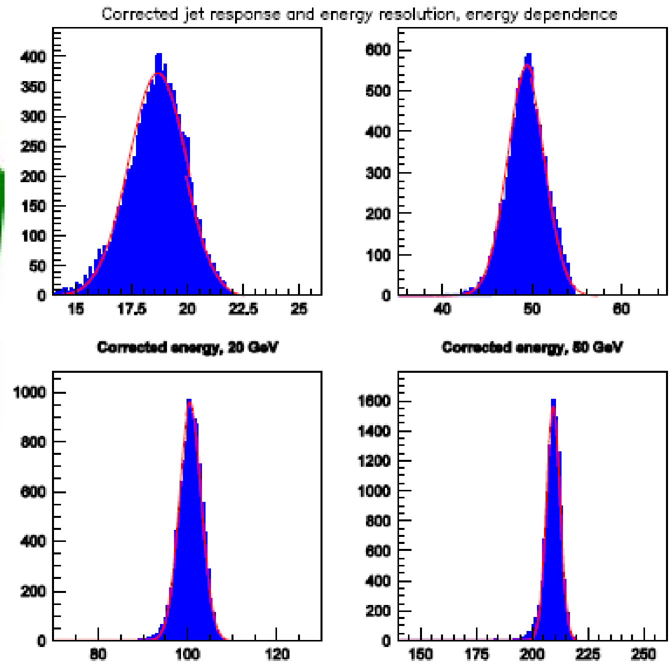


With longitudinal segmentation

Issue: Radiation hardness of the photo-detector

The HHCAL Detector Concept

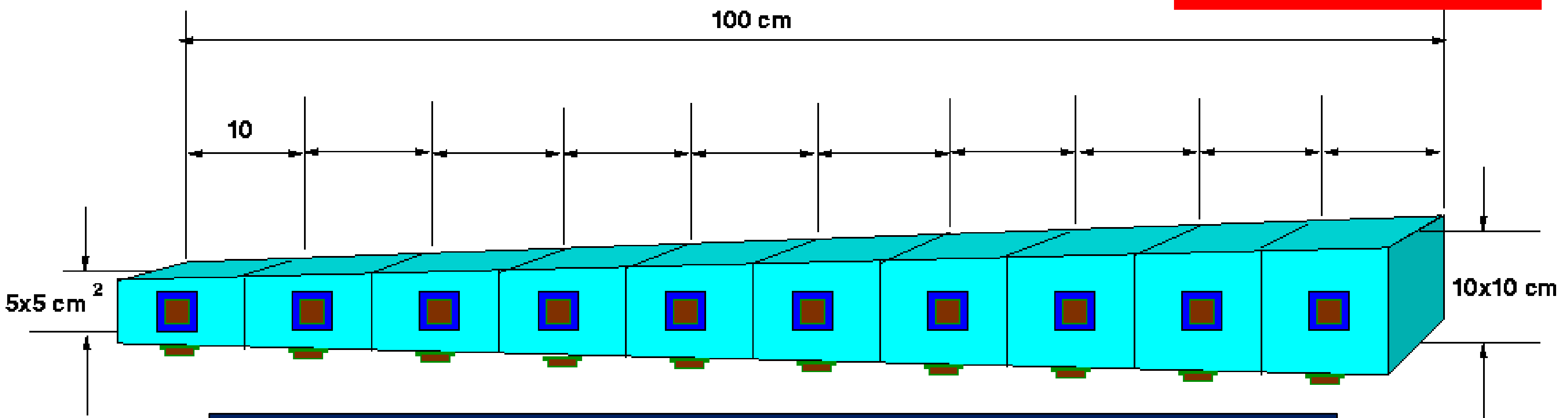




A. Para, H. Wenzel, and S. McGill, Callor2012: GEANT simulations show a jet energy resolution at a level of 20%/√E.

Also dual gate.

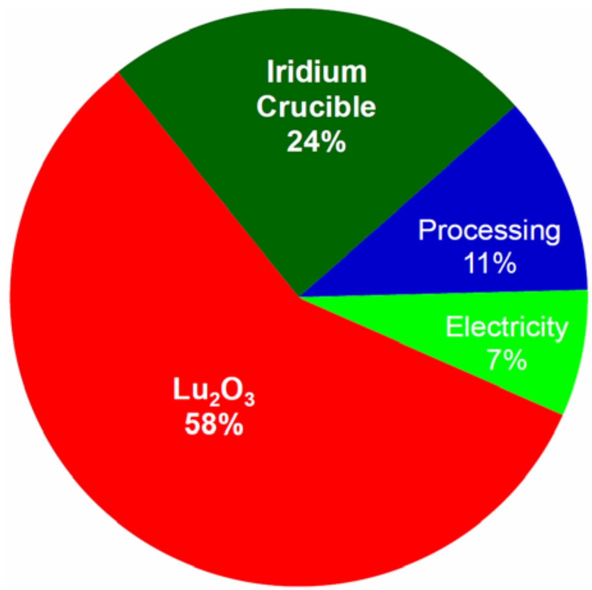
Can we afford?



R.-Y. Zhu, ILCWS-8, Chicago: a HHCAL cell with pointing geometry

LSO/LYSO/LFS Crystal Cost

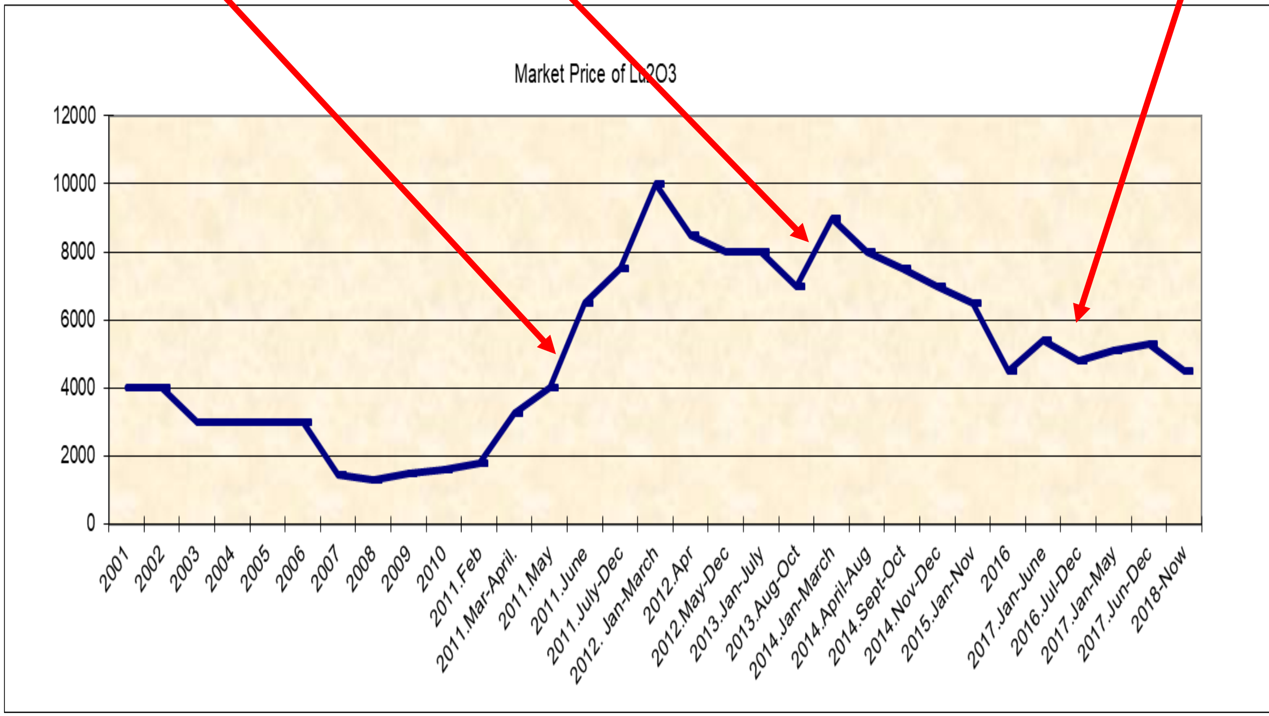
Crystal Cost Breakdown



Rare earth export control in China

Rare earth strategic reserve in China

Rare earth market going to normal



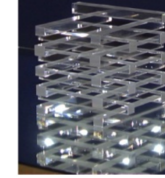
Assuming Lu_2O_3 at \$400/kg and 33% yield the cost is about \$18/cc. Quotations received at \$22-25/cc.

Current Lu_2O_3 price indicates that LYSO price is at a level of \$30/cc

Cost of Mass Produced Crystals

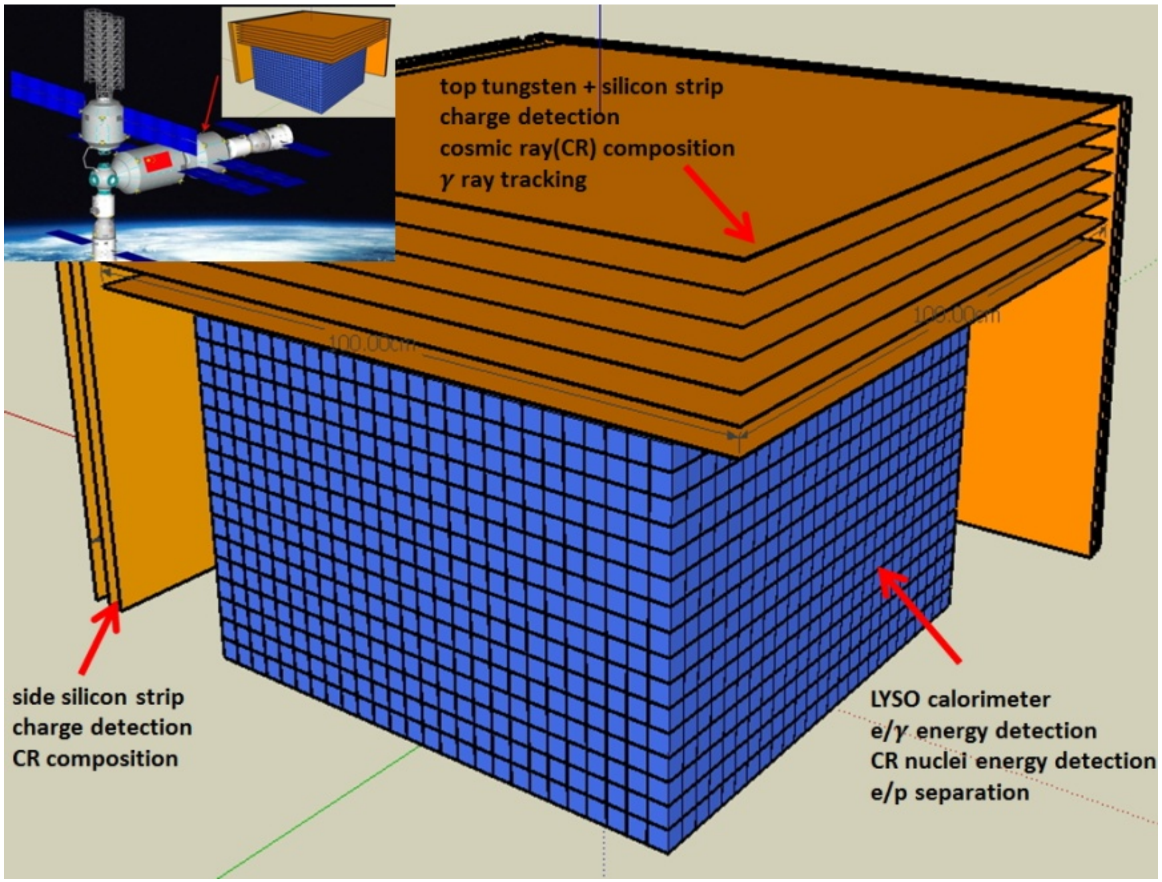
Order of crystal cost: PWO, BGO, CsI, BSO, BaF_2:Y, LYSO

Item	Size	1 m^3	10 m^3	100 m^3
BGO	22.3×22.3×280 mm	$8/cc	$7/cc	$6/cc
BaF_2:Y	31.0×31.0×507.5 cm	$12/cc	$11/cc	$10/cc
LYSO	20.7x20.7x285 mm	$36/cc	$34/cc	$32/cc
PWO	20x20x223 mm	$9/cc	$8/cc	$7.5/cc
BSO	22x22x274 mm	$8/cc	$7.5/cc	$7.0/cc
CsI	35.7x35.7x465 mm	$4.6/cc	$4.3/cc	$4.0/cc



The HERD LYSO Calorimeter

9261 LYSO crystals of 3 cm cube with WLF readout: 55 X_0 and 3 λ



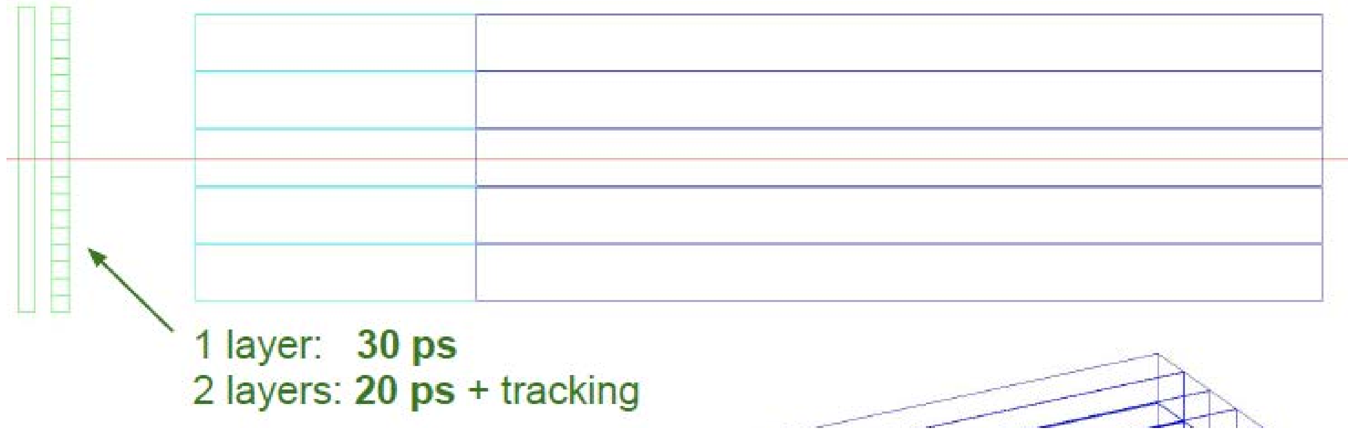
See presentations by Chris Tully, Yong Liu, Zhigang Wang and Yuexin Wang, on novel designs of Crystal EM Calorimeters for CEPC.

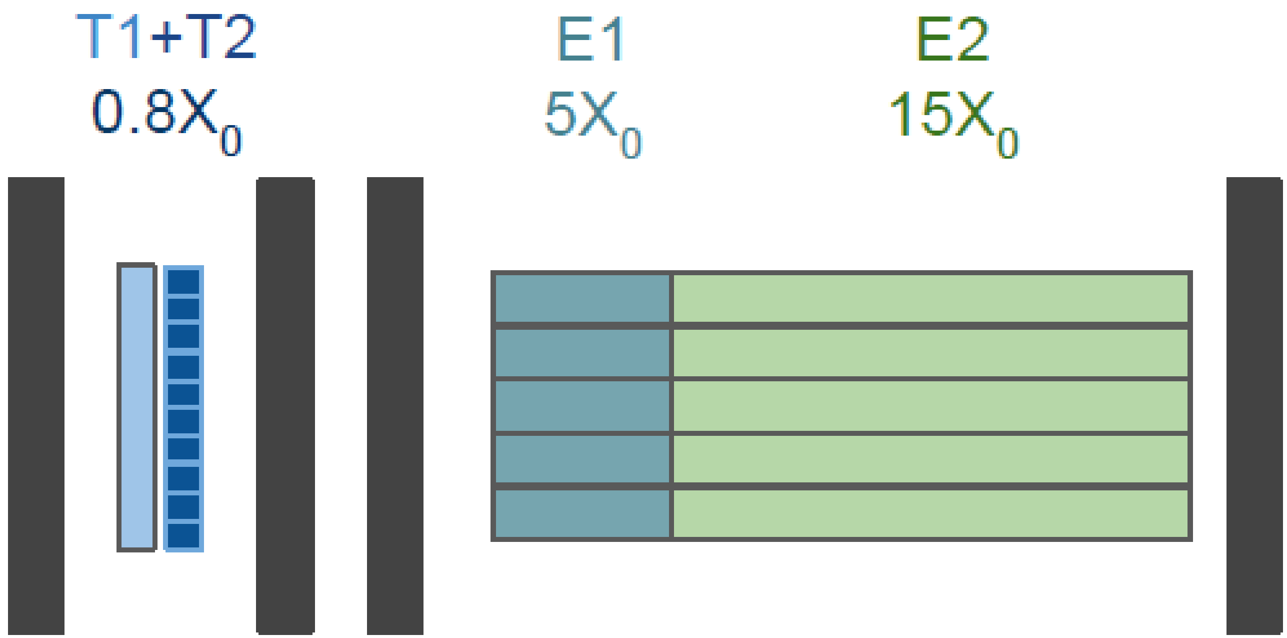
Good resolutions for γ/e energy, position and direction

C. Tally, M. Lucchini & S. Eno

5%/√E ⊕ 1%, can be better with large coverage

A two fold segmented PWO calorimeter (96 M€) follows two LYSO/SiPM timing lasers (28 M€)





Young Liu

- Si-W ECAL: as a starting point

10-15%/√E ⊕ 1% can be achieved

- Idea 1: replace the W-plates with scintillating crystals (homogeneous ECAL)
  - Maximize the sampling fraction, while still keeping high-granularity with silicon pads
  - Optimal intrinsic energy resolution: MC simulation in Geant4
  - Estimate of major constraints
- Idea 2: introduce Si-Sc-W super-layers (hybrid-1)
  - Still higher sampling fraction than Si-W
  - Possibility of compactness: tune the ratio of Sc-W thickness
  - Uniform sampling fraction of each super-layer
- Idea 3: inhomogeneous sampling fraction (hybrid-2)
  - Put crystals in first layers to cover most shower maxima
  - Use Si-W layers in rear layers to constrain the "shower tails"

New ideas: to improve intrinsic energy resolution of PFA calorimetry

- Total absorption ECAL with silicon and crystal: optimal resolution
- Hybrid variants: balance between resolution and compactness
  - Si-Sc-W: homogenous sampling fraction
  - Si-Sc+Si-W: measure shower maxima precisely with crystal, leave most shower tails to Si-W; inhomogeneous sampling fraction; penalties for PFA?

Junguang Lvy & Zhigang Wang

ECAL optimization:

1 Higher energy resolution

2 Basic structure

(1) Finely segmented in transverse and longitudinal direction：
cell size =1cmx1cm, at least 10 layers;

(2) 24 radiation length
thickness <=30cm, the new ECAL will be compatible with existing design.

3 Cost ≤ 1.5 billion ￥

New ideas on the ECAL design

Option 1: Sampling ECAL

Option 2: Segmented crystal ECAL

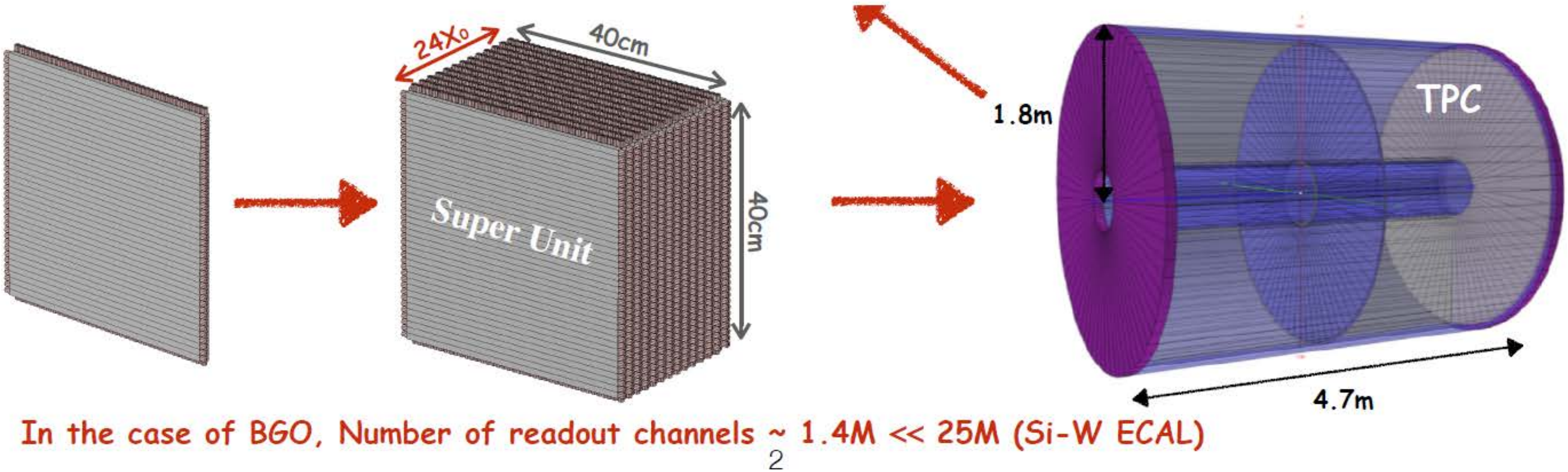
KLOE Pb/Sc fiber: 6%/√E ⊕ 1%

PWO blocks: <4%/√E ⊕ 1%

Just conceptual design,
Detailed MC and test study will carried out in the near future.

Yuexin Wang & Manqi Ruan

Excellent design for space science. Works needed for Colliders



Homogenous crossing strip crystal ECAL

✓Reduce the number of readout channels to a certain extent

✓Homogenous structure can offer a more precise energy measurement

→Separation problem of multi-particle shower is not so severe

Summary

- In addition to imaging calorimeter with PFA approach, it is healthy for the CEPC community to pursue alternative approach for the best measurements of photons, electrons, missing ET and jets.
- Historically, crystal calorimetry provides strong track record in physics discovery and detector simplicity. It is expected to continue doing so at CEPC.
- CEPS environment is not as stringent as LHC, so allow a wide range of calorimeter design.
- **This workshop opens widely the game of CEPC calorimetry. Given the time constraints of the CEPC project, young physicists will play crucial role in this endeavor. Enjoy the fun of physics.**