CMS Forward ECAL Upgrade LYSO Shashlik Design and Matrix

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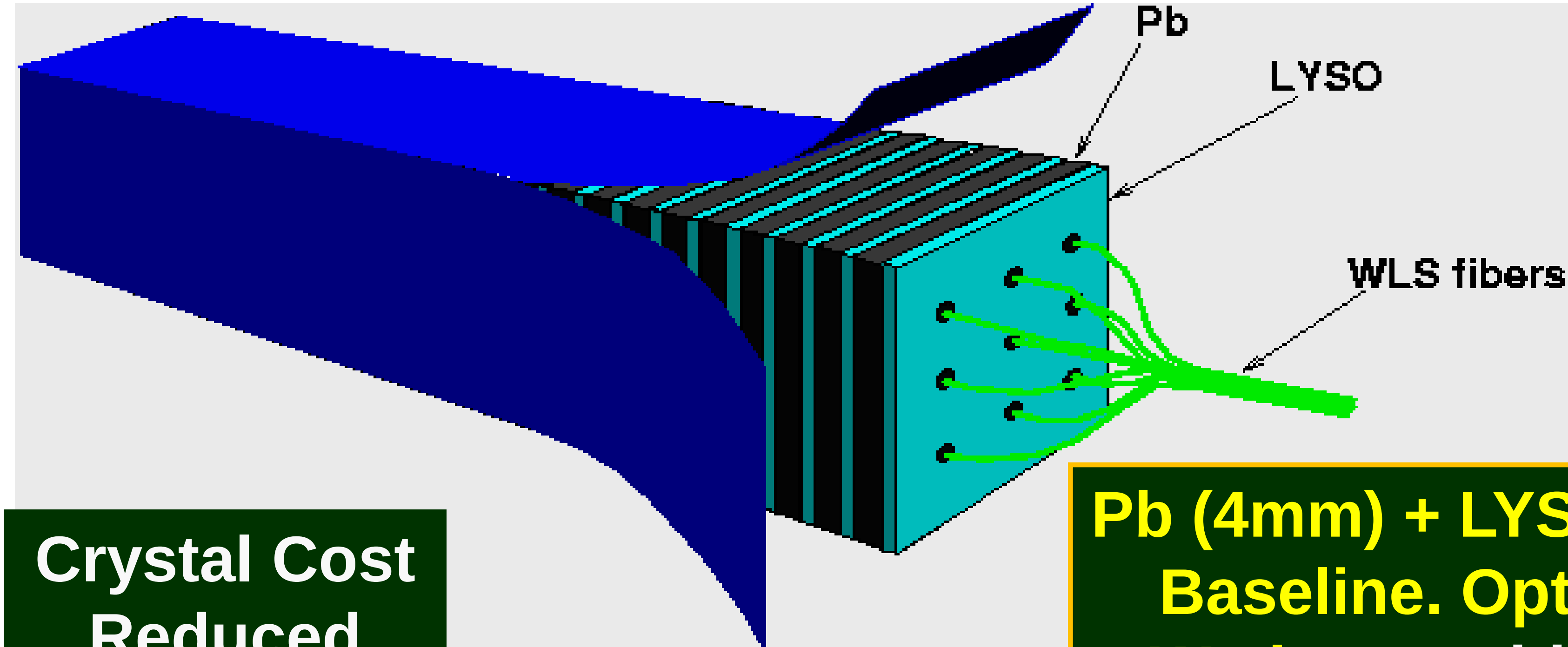
Shashlik ECAL Design

Target e/γ resolution ~10%/sqrt(E) + 1%



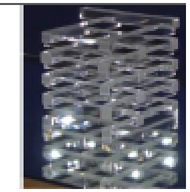
Crystal Cost Reduced

Pb (4mm) + LYSO (2mm) Baseline. Option for W plates at high η to maximize jet separation

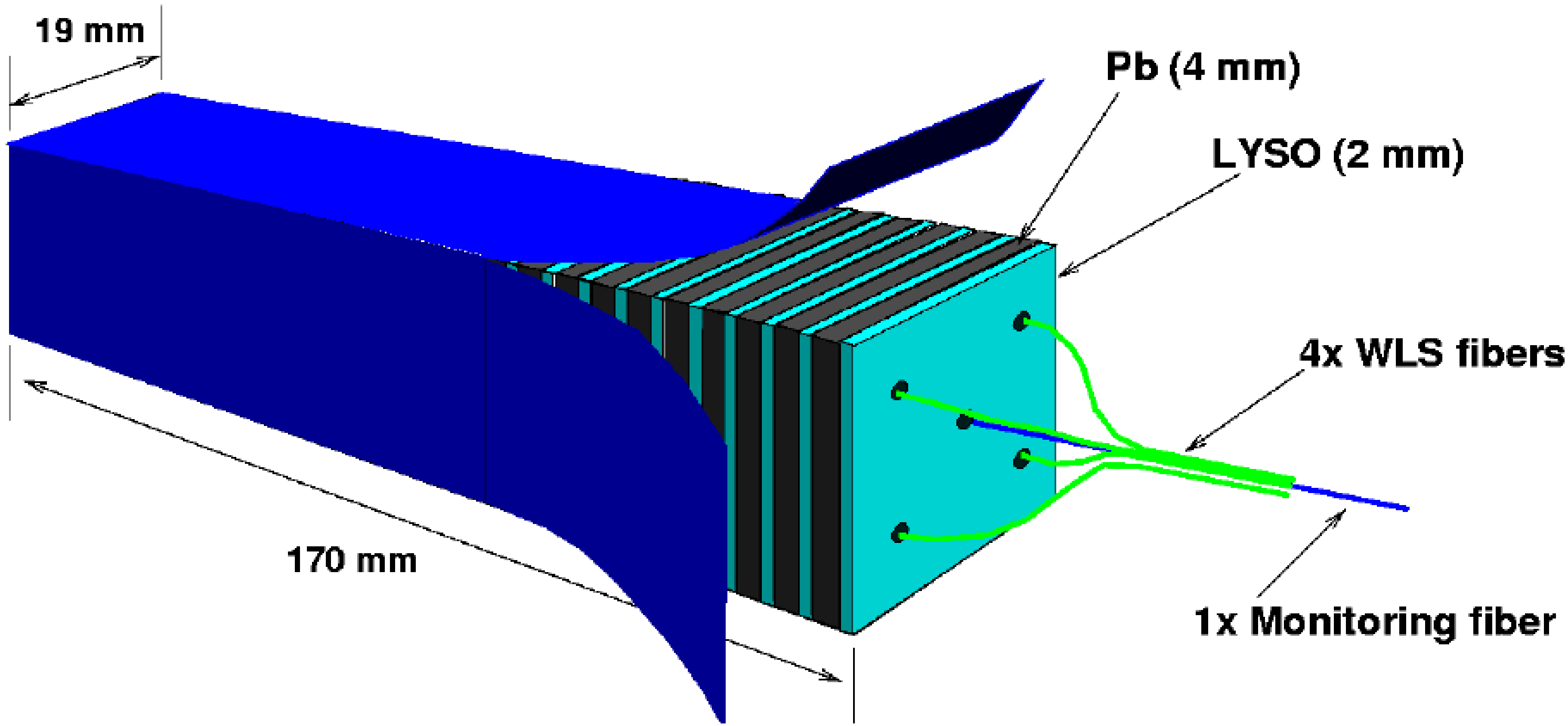
Design Couples: Cell Size (R_M), Depth (X_0), Sampling Fraction and Cost

Issues: Radiation hardness of (1) photodetector (2) WLS fiber

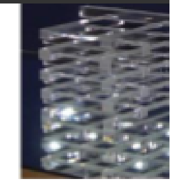
LYSO-Pb Shashlik Cell



Presented in the 8/30/12 forward calorimetry taskforce meeting



LYSO Shashlik Cell Design



Presented by R.Y. Zhu 12/12/13

		LHCb	Plan-1	Plan-2
		Lead (Pb)	Lead (Pb)	Tungsten (W)
Absorber	Density (g/cm3)	11.4	11.4	19.3
	Radiation Length (cm)	0.56	0.56	0.35
	Moliere Radius (cm)	1.60	1.60	0.93
	dE/dX (MeV/cm)	12.74	12.74	22.1
	Thickness (mm)	2	4	2.5
	Plates number	66	28	28
Scintillator		BASF-165 Polystyrene (Sc)	LYSO	LYSO
	Density (g/cm3)	1.06	7.4	7.4
	Light Yield (photons/MeV)	5200	20000	20000
	Radiation length (cm)	41.31	1.14	1.14
	Moliere Radius (cm)	9.59	2.07	2.07
	dE/dX (MeV/cm)	2.05	9.55	9.55
	Plate Thickness(mm)	4	2	2
	Plates number	67	29	29
WLS Fiber		Kurarray Y-11(250)	Kurarray Y-11(250)	Kurarray Y-11(250)
	Diameter (mm)	1.2	1.2	1.2
	Number /Cell	16	4	4
Cell Properties	Total Depth (X0)	24.22	25.09	25.09
	Sampling Fraction (MIPs)	0.25	0.28	0.26
	Total Physical Length (cm)	40	17	12.8
	Total Sc Length (cm)	26.8	5.8	5.8
	Absorber Weight Ratio	0.84	0.75	0.76
	Scintillator Weight Ratio	0.16	0.25	0.24
	Average Density (g/cm3)	4.47	10.04	13.91
	Average Radiation Length (cm)	1.65	0.68	0.51
	Average Moliere Radius (cm)	3.6	1.7	1.2
	Transverse Dimension (cm)	4.1	1.9	1.4
	Sc-depth/Total-depth in X0	0.0268	0.2028	0.2028
	WLS Fiber Density (N/cm2)	0.97	1.06	2.07
MIPs Energy Deposition	Sc plates (MeV)	54.94	55.39	55.39
Light Yield using MIPs	Photon Electrons/GeV	3077	11932	11932
Signal of MIPs	Photon Electrons / MIP	169	661	661
Energy Resolution	Stochastic term "a" (%)*	8.2	5.4	5.6

* Assuming the same relation between stochastic term "a" and (Sc thickness/Sampling Fraction)$^{1/2}$ for LYSO crystal and plastic scintillator based Shashlik calorimeters.

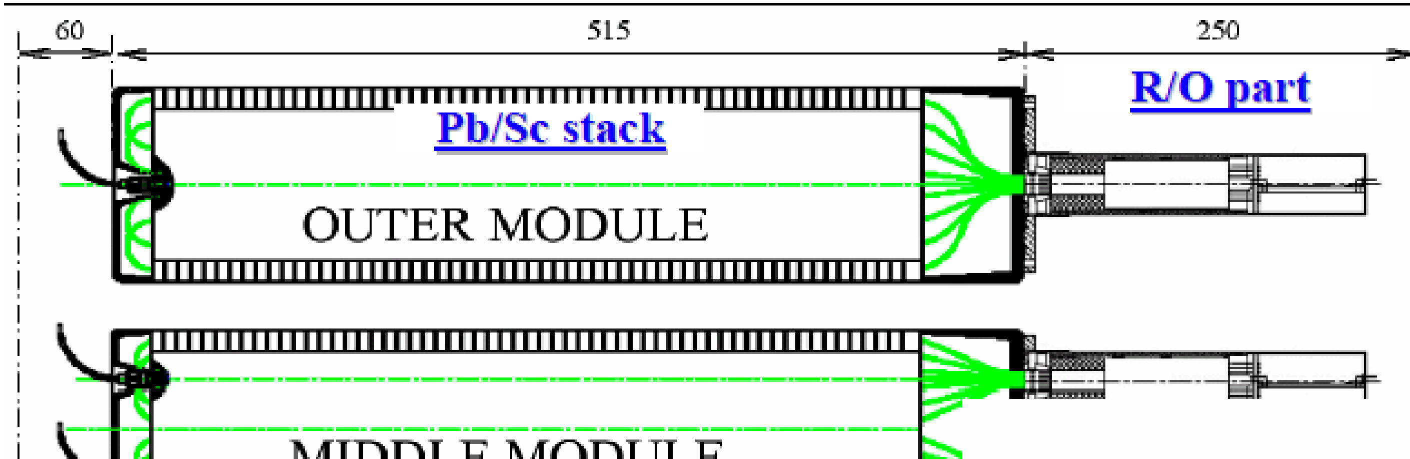
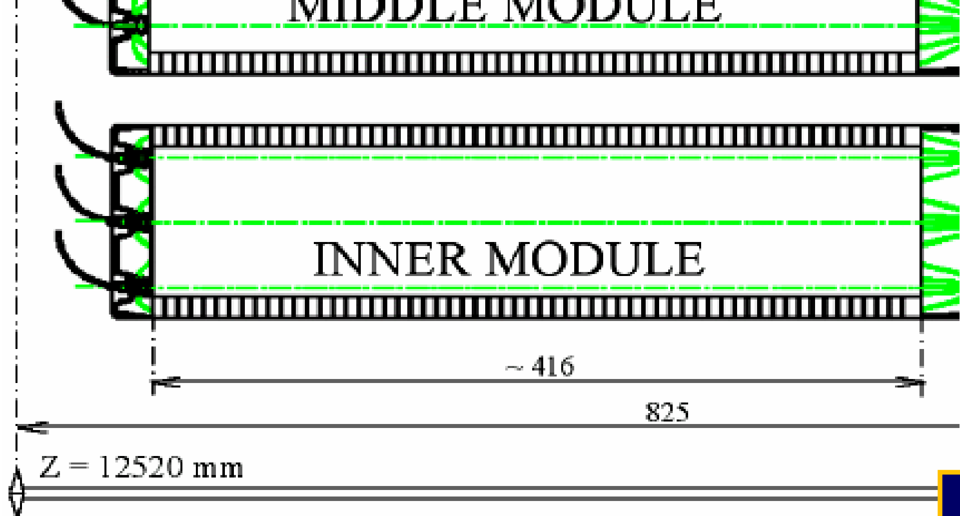
Shashlik ECAL Design Key Parameters

4 Readout Fibers and 1 Monitoring Fiber Per Cell	Pb (4mm) + LYSO (2mm)	W (2.5mm) + LYSO (2mm)
Plates	28 Pb + 29 LYSO	28 W + 29 LYSO
Total No. of X0	25.1	25.1
Length	170 mm	128 mm
Transverse Size	19 mm (1.1 R_M)	14 mm (1.1 R_M)
Cells (2 Endcaps)	~36k	~65k
Crystal Volume (m^3)	~0.38	~0.38
Avg. R_M	17 mm	12 mm
Avg. X0	6.8 mm	5.1 mm
WLS Fiber Density/cm^2	1.06	2.07
P.E./GeV	11.9k	11.9k
P.E./MIP	660	660
Stocastic Term	5.4%	5.6%

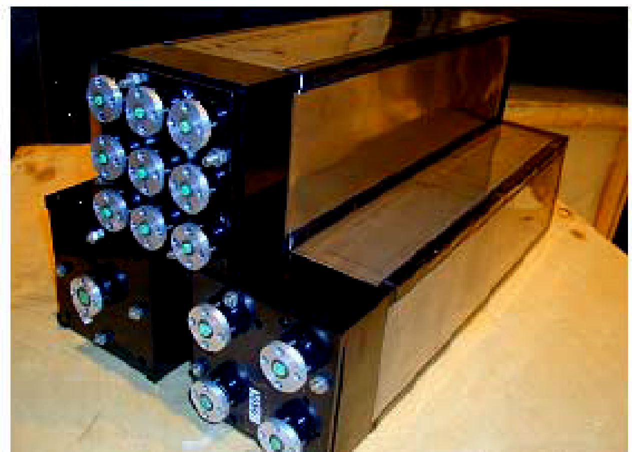
Use Super-towers

LHCb ECAL: 3.3k Modules

12 X 12,
6 X 6 and
4 X 4 cm^2
Modules
6.6k Channels

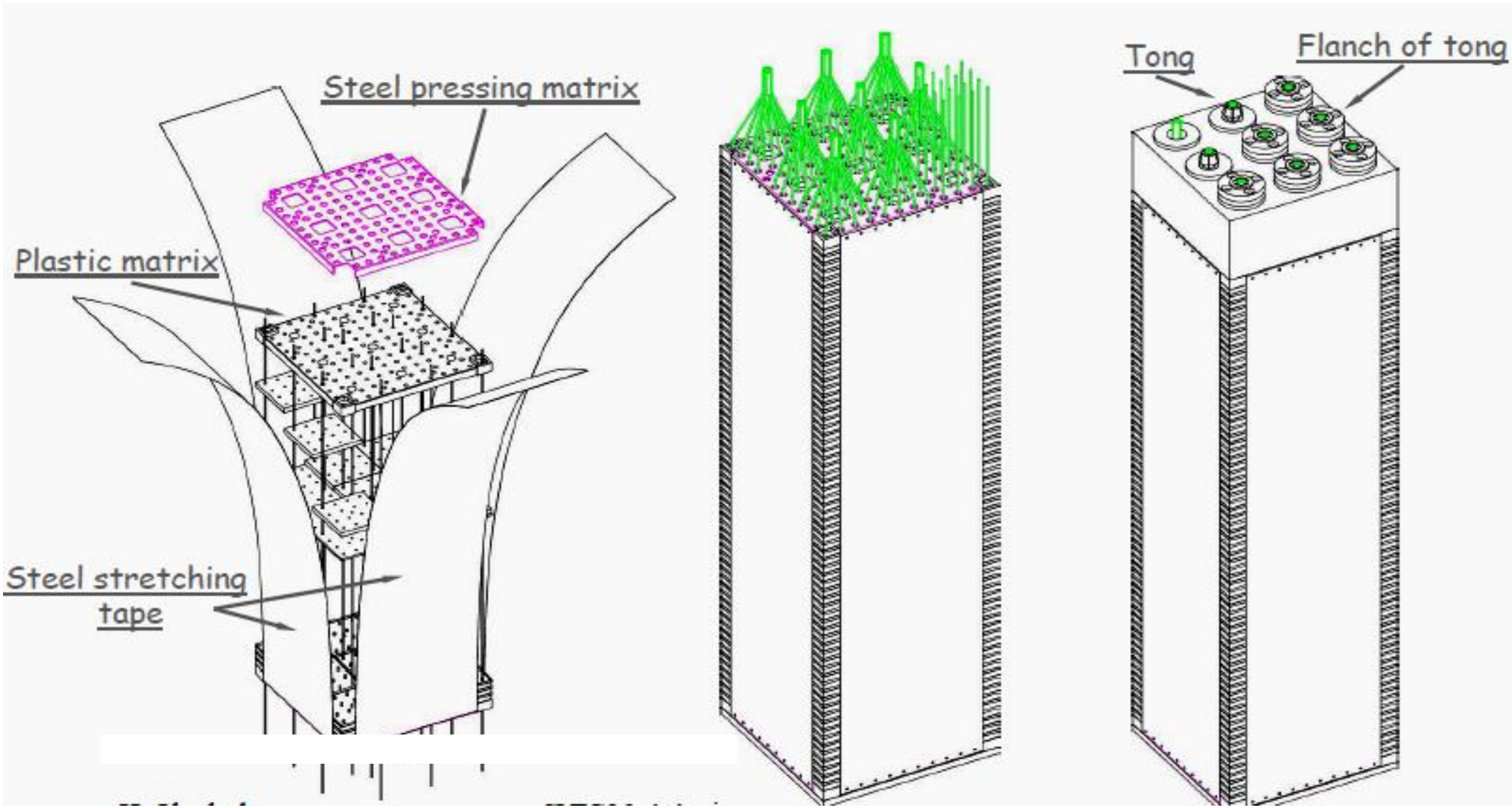



All ECAL modules produced



CMS Concept: More Compact
***Thin* Scintillator + Pb or W Plates**
Solid State GaAs readout

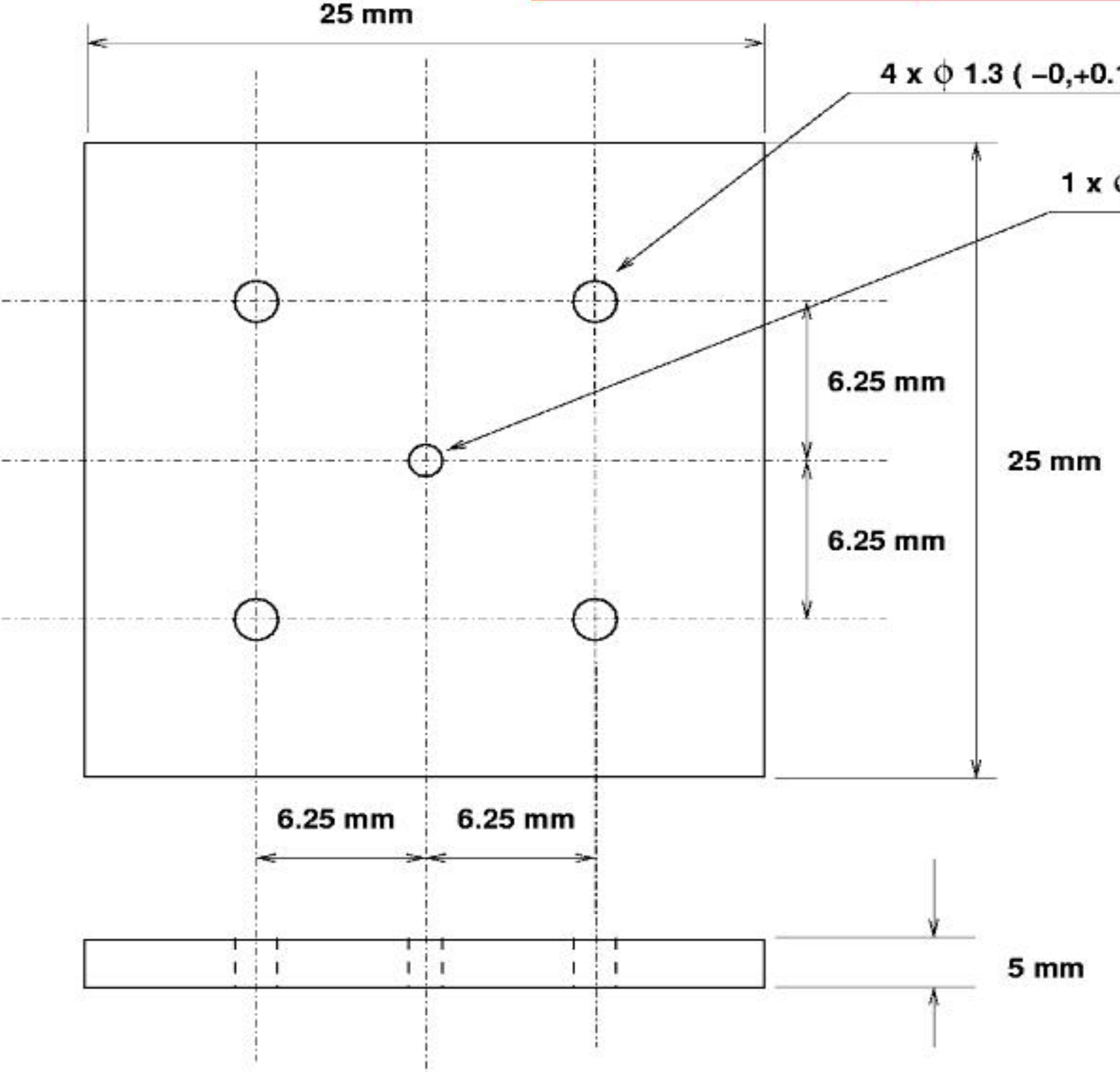
LHCb Pb/Sc Shashlik ECAL Construction



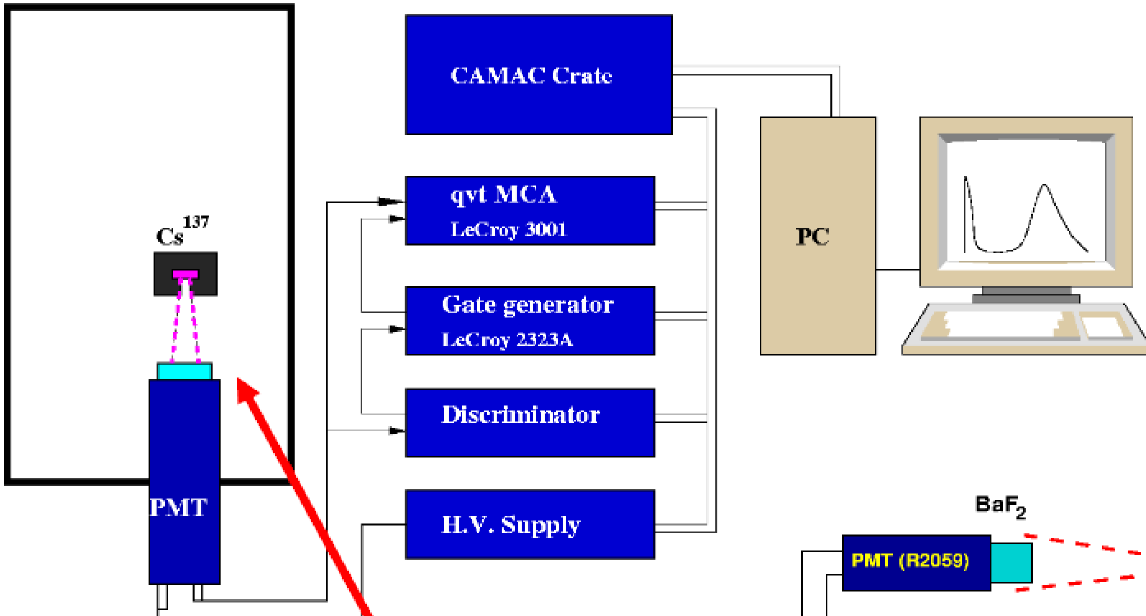
Three LYSO Plates with Holes

Presented by
R.Y. Zhu
12/12/13

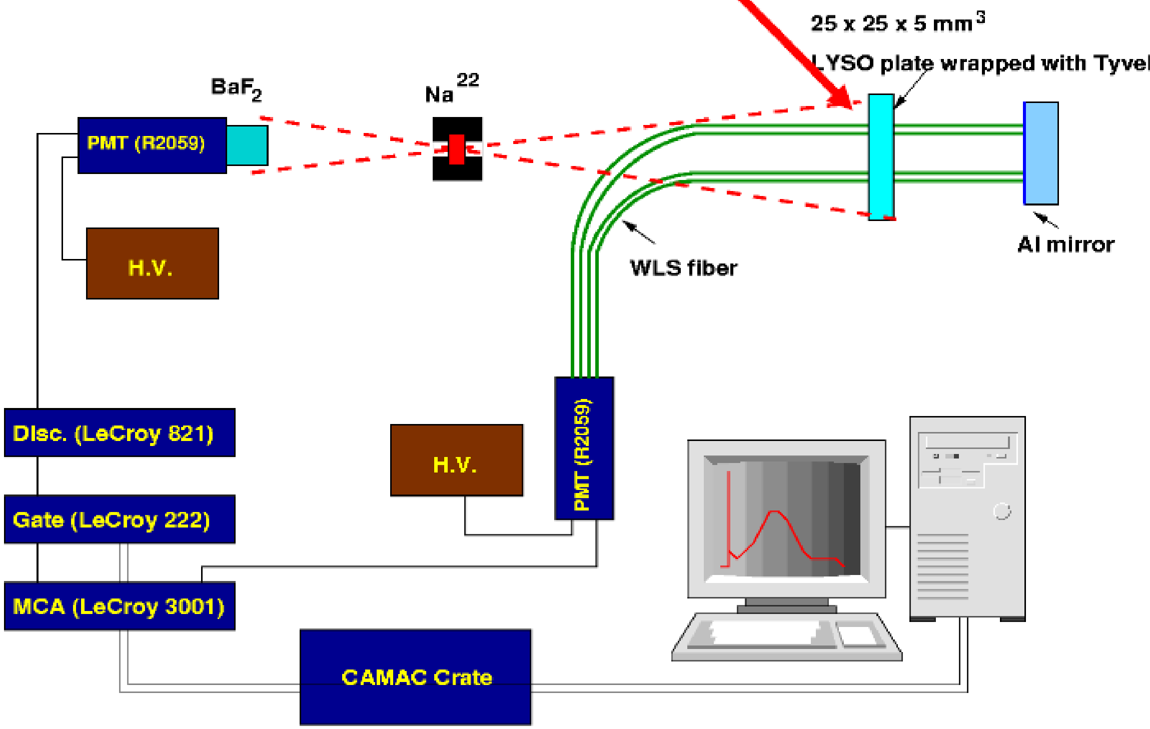
25 × 25 × 5, 3 and 1.5 mm^3



Two Measurement Setups



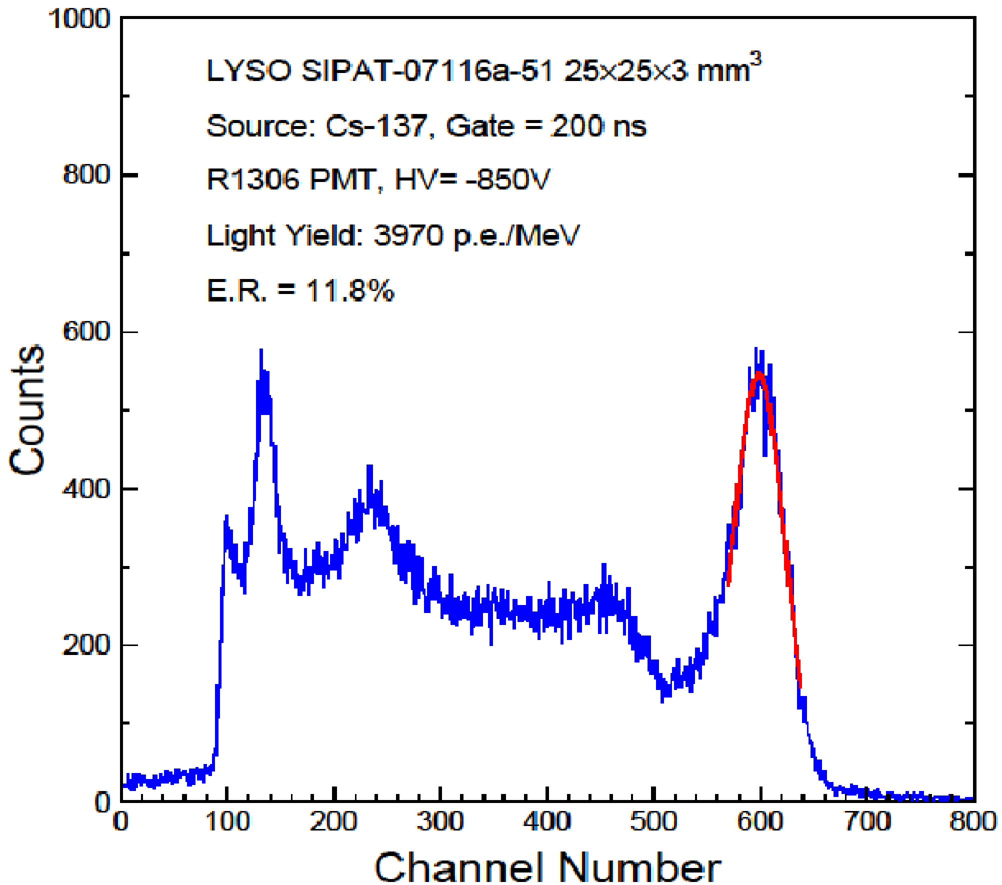
2) LYSO plates with Tyvek wrapping are readout with four Y11 WLS fibers of 40 cm long and a R2059 PMT using a Na-22 γ-ray source and coincidence.



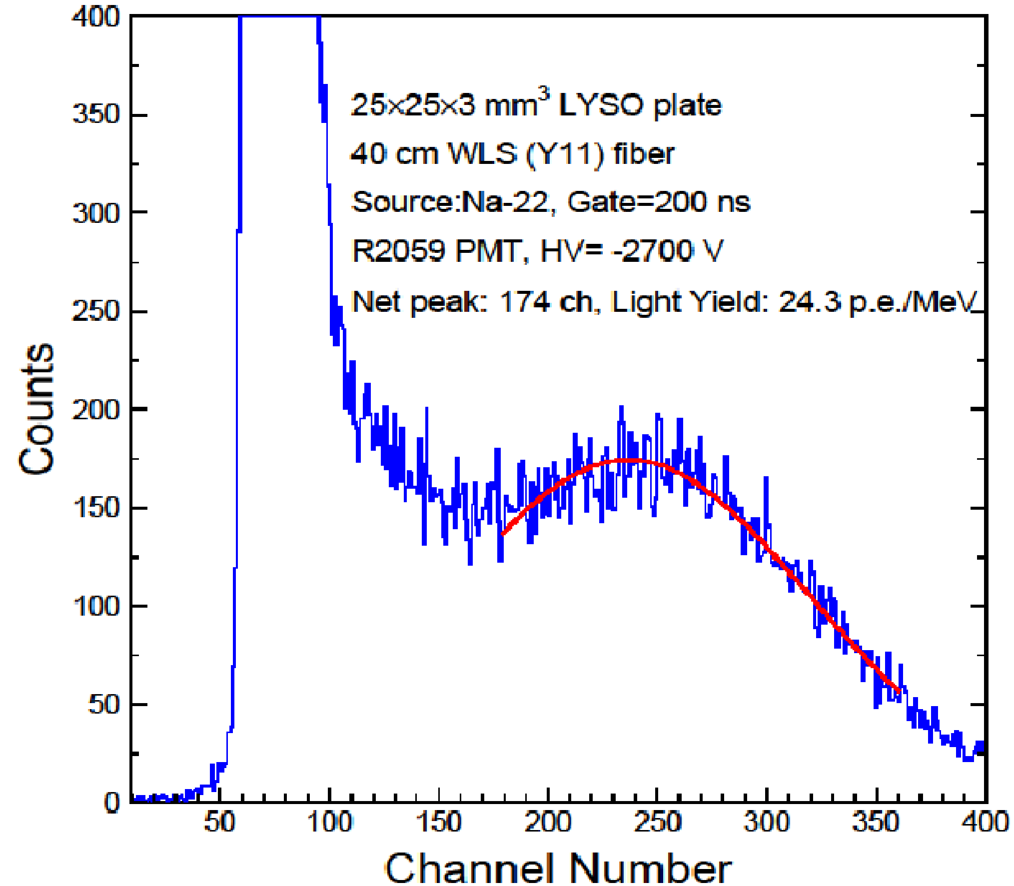
1) LYSO plates with Tyvek wrapping are readout directly by a R1306 PMT using a Cs-137 γ-ray source.

PHS of 3 mm LYSO Plate

LYSO 25 × 25 × 3 mm^3



3 mm plate & 4 x 40 cm Y11 fiber



γ-ray peaks are clearly visible

Light Collection Efficiencies

Samples	5 mm LYSO	3 mm LYSO	1.5 mm LYSO	LHCb cell*
LO_1 (p.e. /MeV)	3760	3970	4370	
LY_1 (Photons /MeV)	29150	30780	33880	5200
LO_2 (p.e./MeV)	20.7	24.3	17.9	3.1
LY_2 (Photons /MeV)	154	179	132	
MIP (p.e./55 MeV)	1140	1340	990	169
LO_2/LO_1 (%)	0.55	0.61	0.41	
LO_2/LY_1 (%)	0.07	0.08	0.05	0.06

* 2009 J. Phys.: Conf. Ser. 160 012047.

Measured light collection efficiencies consist with LHCb data

Shashlik ECAL: References

1) Irina Machikhiliyan for the LHCb calorimeter group, "The LHCb electromagnetic calorimeter", XIII International Conference on Calorimetry in High Energy Physics (Calor2008).

2) A. Bamberger et al., "The ZEUS forward plug calorimeter with lead-scintillator plates and WLS fiber readout", NIM A450 (2000), p 235-252.

3) C.S. Atoyan et al., "Lead-scintillator electromagnetic calorimeter with wavelength shifting fiber readout", NIM A320 (1992), p144-154.

4) L. labarga and E. Ros, "Mont Carlo study of the light yield, uniformity and energy resolution of electromagnetic calorimeter with a fiber readout system", NIM A249 (1986), p228-234.

Forward ECAL Shashlik Matrix
Step by Step (1)

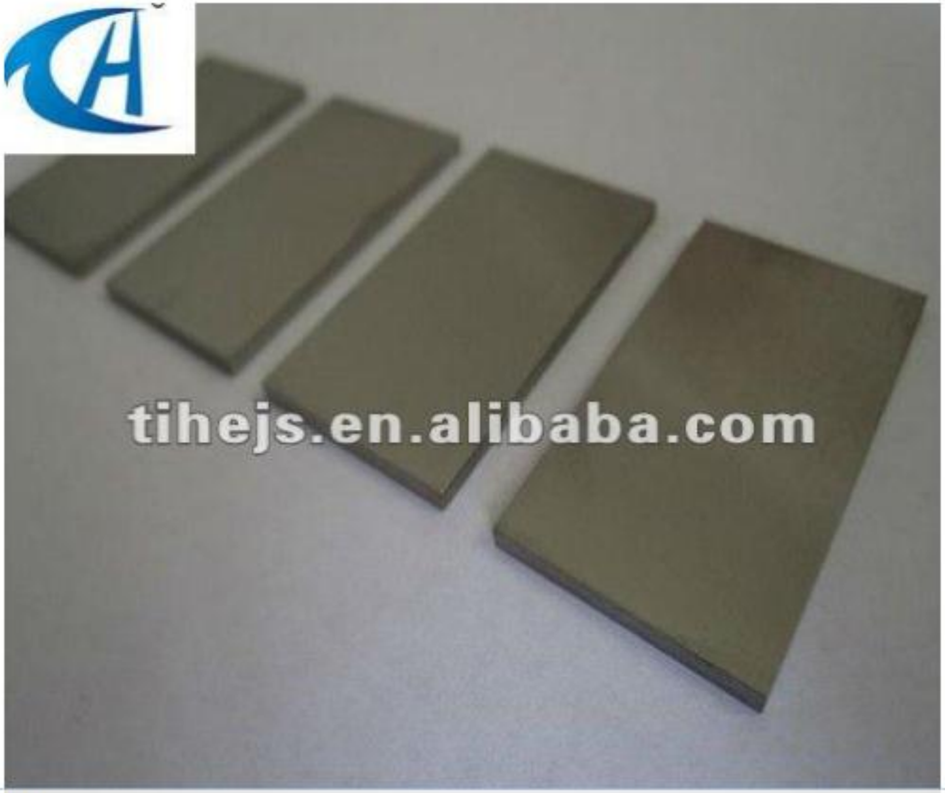
1. Define the scope of the testbeam matrix [Or Matrices; more later]
   - ❒ 5 X 5 Cells: Rectangular geometry - all tiles are the same size.
   - ❒ Normal Y11 fiber (capillaries later)
   - ❒ Photodevices: SiPMs (GaAs or GaInP later)
   - ❒ Keep in mind a Series of TB matrices; with increasing realism
2. Choose plate layout baseline: for example Pb(4mm) + LYSO (2mm)
   - ❒ W (2.5mm) + LYSO (2mm) may be done in a second TB round
   - ❒ Or – Swap the two designs with the W design going first
3. Define Cell design and assembly sequence
   - ❒ Mechanical design – Supertowers ?; Compression straps; fixtures. Provision for mounting photodevices and readout
   - ❒ Define tolerances [e.g. plate tolerances done & sent for quotes]
   - ❒ Define Assembly procedure
   - ❒ Define Tolerance Test after assembly
4. Cell Element Acceptance and Test Procedures
   - ❒ LYSO tiles: quality control; lab test
   - ❒ SiPMs: Acceptance and test

Forward ECAL Shashlik Matrix
Step by Step (2)

4. Define Laboratory Cell-Test Procedures
   - CR Tests: Test Stand
   - Sources
5. Define and commission Matrix Test in lab: stand, CR, sources
6. Element Acquisition, Preparation and Costs
   - Cost of Pb or W Tiles
     - Edges pre-machined or machined in-house
     - Delivered predrilled or drilled in house
   - LYSO Tiles
   - Y11 Fibers
   - SiPMs
7. Purchasing
8. Construction
   - First Single Cell Followed by Complete Test Sequence
   - Define Production cell assembly and test procedure
9. Matrix Assembly and Test

Tungsten Plates in Stock
“$ 20-60 Per Kg”

tungsten plate in stock



Brief Description

1.Materials: Pure Tungsten 99.95% Min 2.Size: 500 X 100X 0.5-100mm 3.Surface:Electropolishing
4.Standard: ASTMB760.

Verified Company

2YR Baoji Taihe Nonferrous Metal Co., Ltd.

[Shaanxi, China (Mainland)]

Main Products: Titanium Plate,Titanium Pipe,Titanium Bar,Nickel Plate,Titanium Wire

Onsite Checked

No substantiated complaints in last 90 days

Supplier's last login time: **Within 24 hours**

Contact Details

View this Supplier's Website

Offline

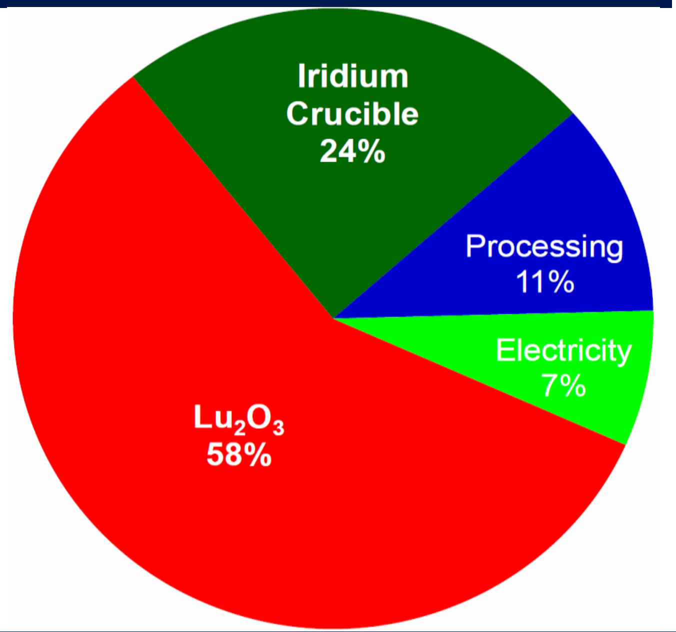
Contact Supplier

Send a Message to this Supplier

Need to understand the cost of many finished small tiles with holes

LSO/LYSO Crystal Cost
Now we need a series of small tiles

Crystal Cost Breakdown



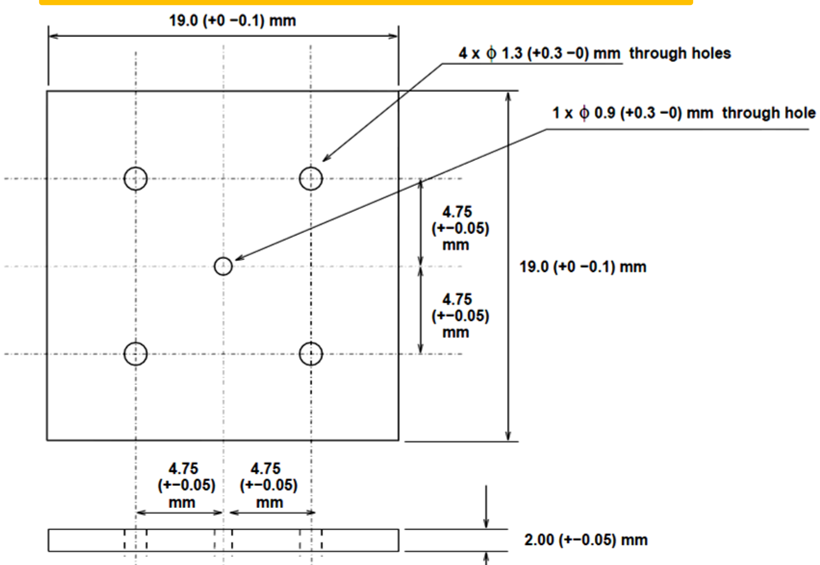
Lu_2O_3 price fluctuates up in 2011 and down in 2012, showing market speculation on the rare earth control policy of the Chinese government.

Assuming Lu_2O_3 at $4000/kg and 33% yield the cost is about $18/cc. Quotations received at $22-25/cc.

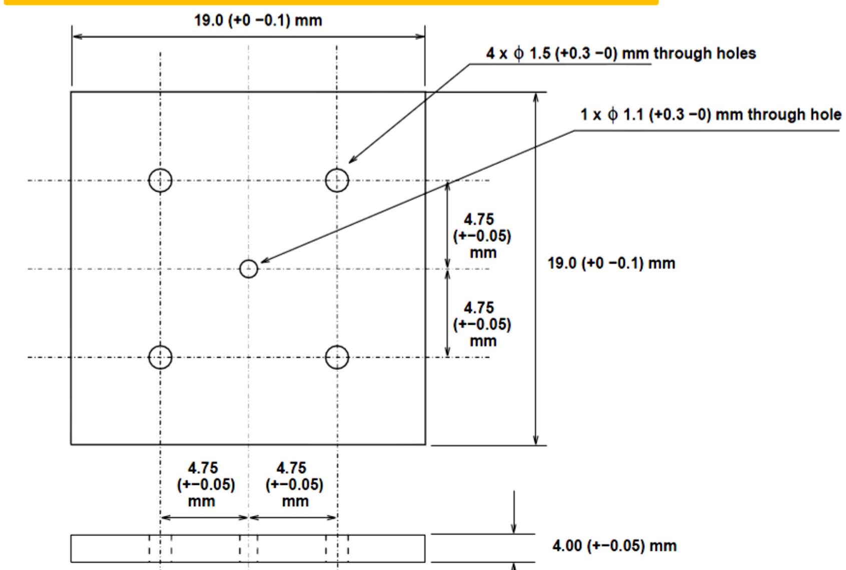
NOTE: We need to know the price for finished small tiles: 29 X 25 = 725 plus spares are required.
Do we need to cut and polish our own tiles ?

LYSO, Pb and W Plates: with defined tolerances; sent out for quotes

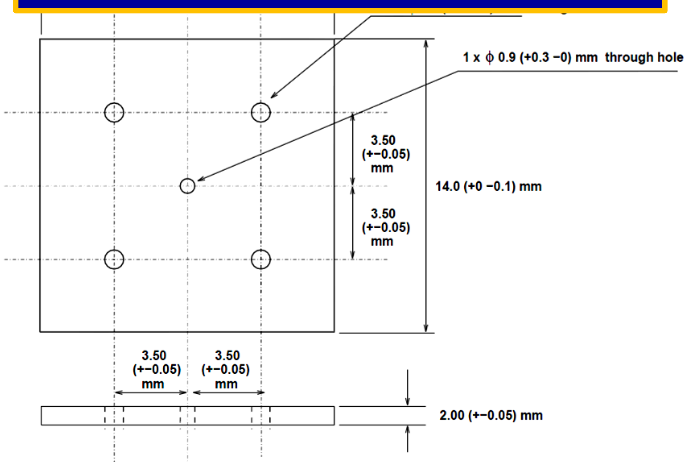
LYSO Plate, Pb Design



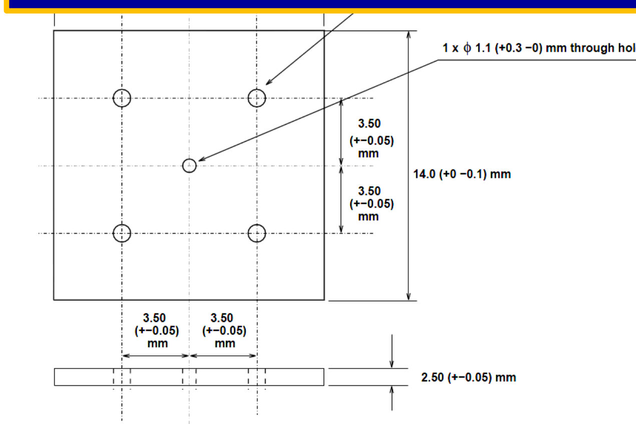
Pb Plate



LYSO Plate, W Design



W Plate



Conclusions

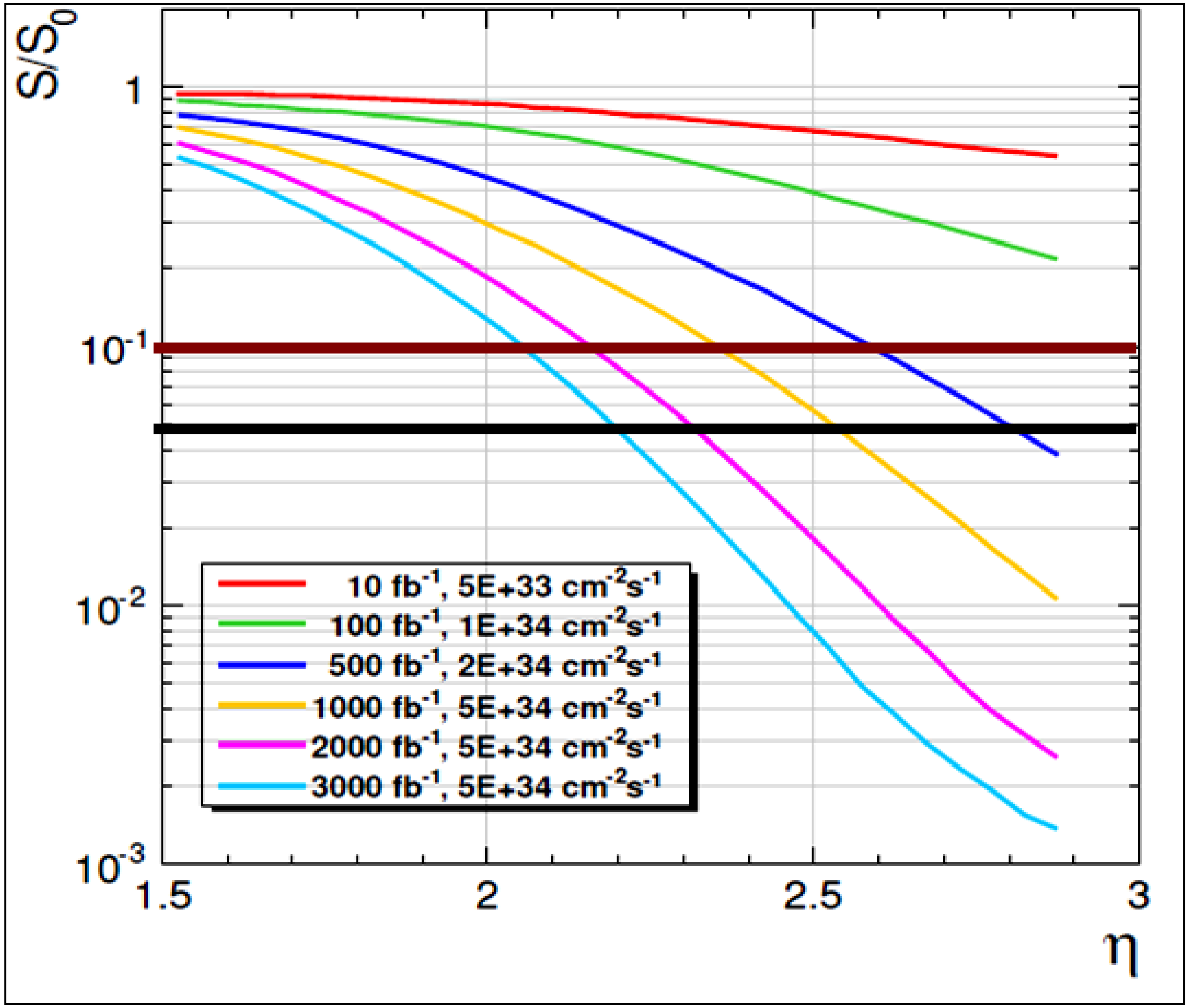
- We need a bottoms-up cost and schedule before scheduling a beam test of a 5 X 5 cell matrix.
- We need to confirm that we have the funds and level of effort required
- Shall we consider bringing a single cell or a 3 X 3 submatrix to the test beam first

Backup Slides Follow

Remarks

- LYSO is a radiation hard material with high speed and light output. It has been chosen as the baseline for these candidate design sketches for this reason.
- Potential Alternatives: So far not shown to be practical
  - Ceramics: not radiation hard so far
  - YSO: Not a cost advantage: Perhaps 50% lower material cost, but larger volume is required, and there are no mass production sources
- In addition to Higgs candidate mass resolution, good EM resolution and granularity are needed for:
  - Identification and background suppression, as well as the measurement of EM (e,γ) objects
  - Jet resolution and MET tail suppression (w/track or PF jets)
- We will progressively need better EE performance; also for X_H decay modes and other new physics searches or study.
- With the present ECAL Endcap, we could have a problem with jet measurements already by LS2 (2018):
  - η = 2.7 – 3.0 could be ~lost by LS2
  - η = 2.45 – 3.0 could be ~lost by LS3

Model Predictions for EE Light Yield for 50 GeV Electrons. Simulation by Ledovskoy



Results [90% LY Loss]:
η=2.6 – 3.0 ~Lost for Jets After LS2
η=2.35 – 3.0 ~Lost for Jets Between LS2 & LS3
η=2.05 – 3.0 ~Lost for Jets By End of HL-LHC

Results [95% LY Loss]:
η=2.8 – 3.0 ~Lost for Jets After LS2
η=2.55 – 3.0 ~Lost for Jets Between LS2 & LS3
η=2.2 – 3.0 ~Lost for Jets By End of HL-LHC

NB: 1.5-2X for neutron damage (above fission threshold) + Noise Term Still to be Added

Basic Question of EE Replacement, and When, Remains

Alternate Planning Considerations

- ❒ Serious consideration should be give to the following alternative plan, <u>If Necessary:</u>
  - ➡ Remove ES and replace it by a compact ECAL insert, like the Shashlik (W+LYSO) design shown for example
  - ➡ Cover at least η = 2.45 – 3.0; possibly 2.0 – 3.0 if time permits
  - ➡ If jet measurements are verified to be severely impacted, as indicated so far, then we may need to do this even if the endcap is moved back a few centimeters; Else fit in the available space.
- ❒ Installing a "plug" in place of ES in LS2 will in any case be essential to understand the needs for LS3, if a full size forward ECAL insert cannot be done in time for LS2
- ❒ We need to proceed to system design considerations, and targeted R&D on specific items, starting now
- ❒ Further studies, to guide and help pin down the future plan and upgrade schedule, are crucial now.

Higgs (Now X_H) Analysis

We need to consider the "Higgs" Analysis Needs

Note: present EE has ~no role in H ➡ $\gamma\gamma$: Resol'n + MET Tail

- ❒ Endcap ECAL performance resolution needs improvement
  - ❒ Need to consider crystals, ES + VPT degradation over time
  - ➡ Need to study this in more detail in the determination of the Higgs properties analysis, as well as SUSY
- ❒ X_H BRs (WW, ZZ*, $\gamma\gamma$, $\tau\tau$), spin, and other properties using larger acceptance (high R9) for higher resolution and ID is now important
- ❒ 2015-2018, as well as 2019-2021 (After LS2) will be crucial:
  - ❒ We need to realistically evaluate the ECAL performance versus time, to frame the physics program for Phase 1 and Phase 2
  - ❒ Apart from the ECAL performance in isolation, we need to have a realistic picture of the trigger, reconstruction and selection, in the presence of pileup at ~13 TeV, 25 nsec bunch spacing: for jets as well as photons and electrons.

Crystal R&D Result

LSO/LYSO is a bright (200 times light of PWO) and fast (40 ns) crystal scintillator. It has been widely used in the medical industry. Its good mechanical characteristics allow it to be used in various forms for different calorimeter designs.

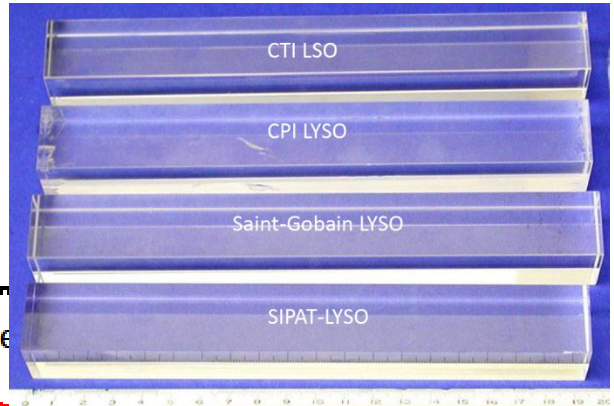
Supported by DOE ADR and US CMS Upgrade Effort the Caltech group has been investigating this material for HEP applications since 2005 [*]. Findings:

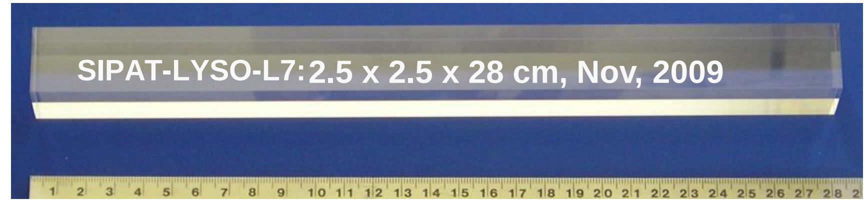
- **Its radiation hardness is excellent against γ–ray, neutrons and high energy protons (ETH data).**
- **There is no recovery, so calibration is relatively easy.**
- **As a result, total absorption LYSO ECAL is now baselined for both the Mu2e and SuperB experiments.**

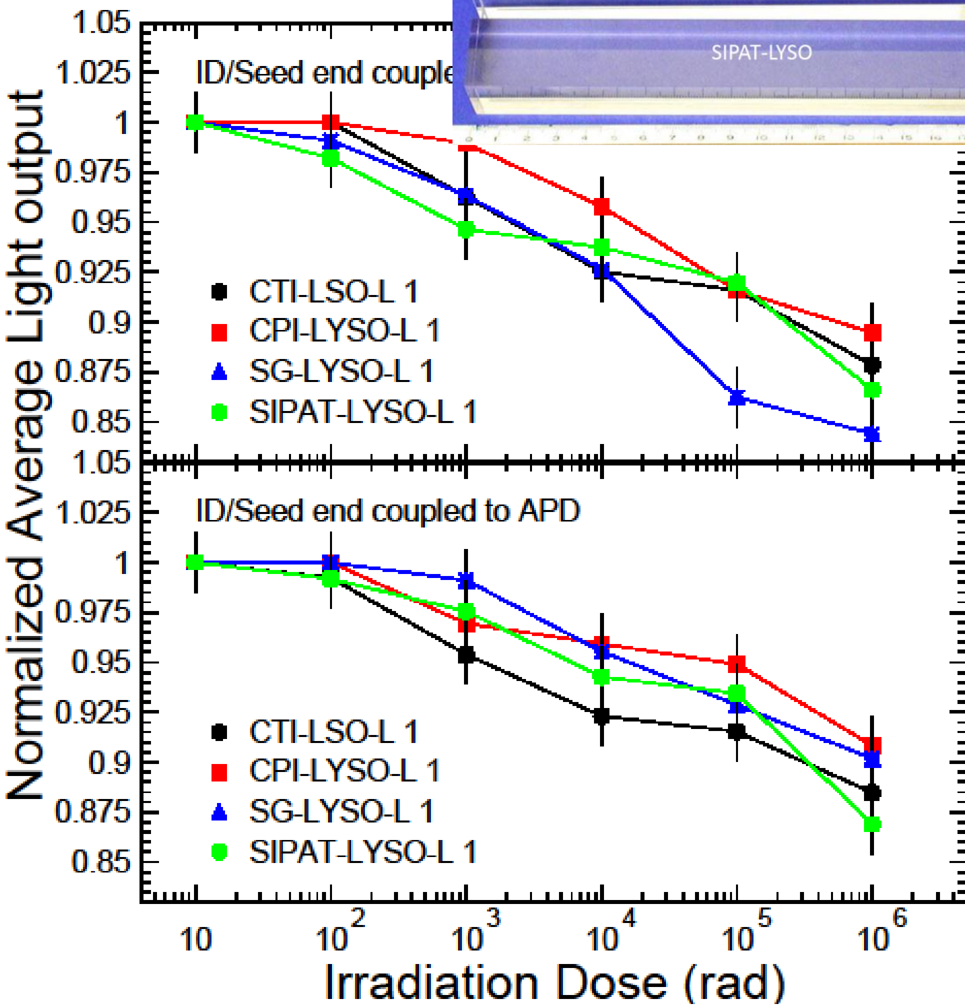
[*] References: ***IEEE Trans. Nucl. Sci.*** **NS-52 (2005) 3133-3140,** ***Nucl. Instrum. Meth.*** **A572 (2007) 218-224,** ***IEEE Trans. Nucl. Sci.*** **NS-54 (2007) 718-724,** ***IEEE Trans. Nucl. Sci.*** **NS-54 (2007) 1319-1326,** ***IEEE Trans. Nucl. Sci.*** **NS-55 (2008) 1759-1766 and** ***IEEE Trans. Nucl. Sci.*** **NS-55 (2008) 2425-2341, paper N69-8 @ NSS08, Dresden, paper N32-3, N32-4 and N32-5 @ NSS09, Orlando, paper N38-2 @ NSS10, Knoxville, and paper N29-6 @ NSS11, Valencia .**

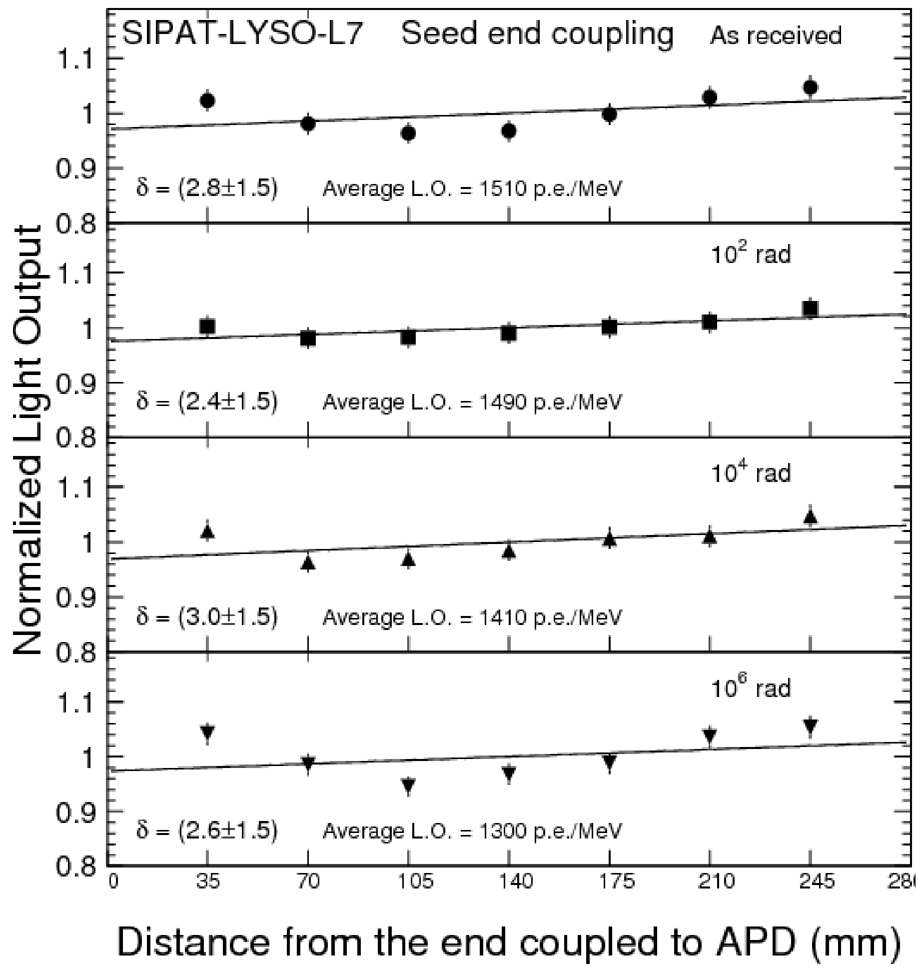
LYSO Crystal Against Gamma-Rays

2.5 x 2.5 x 20 cm Samples

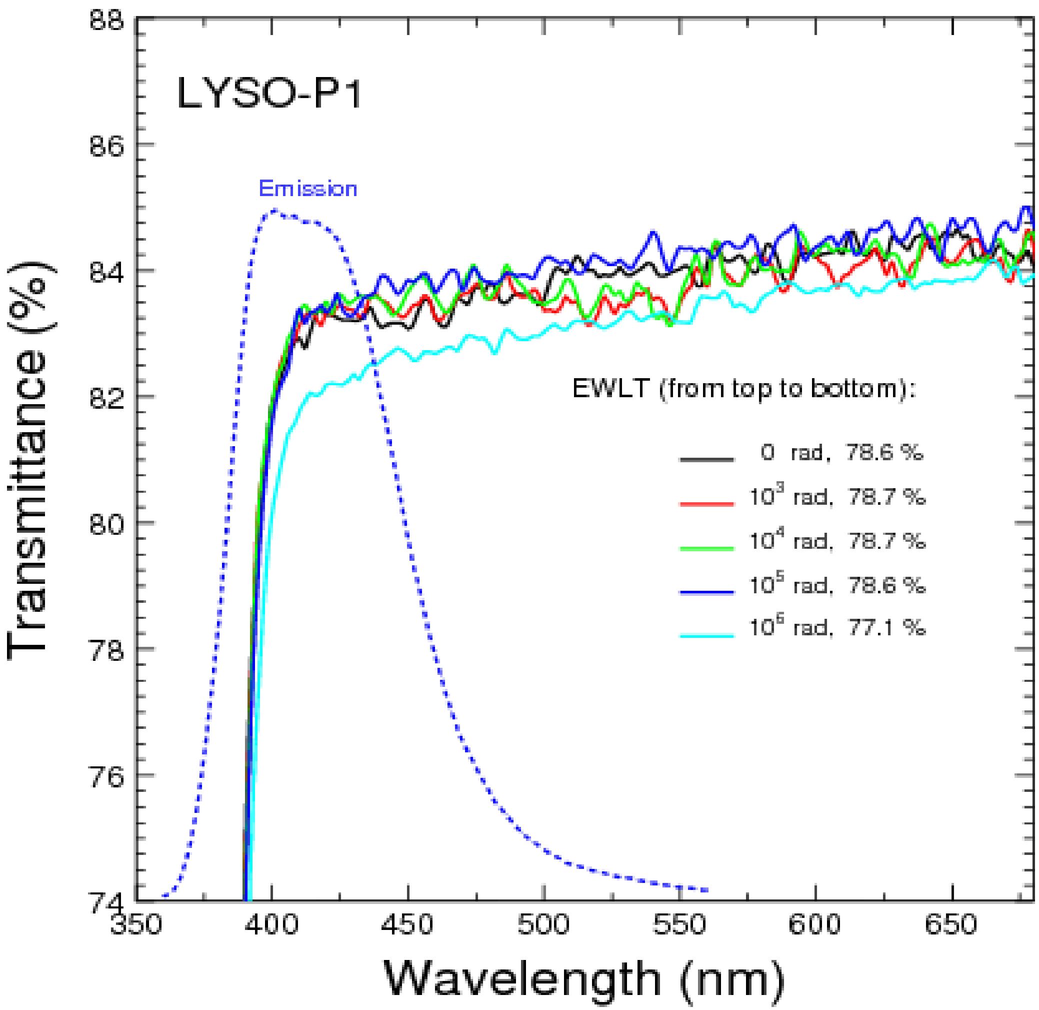


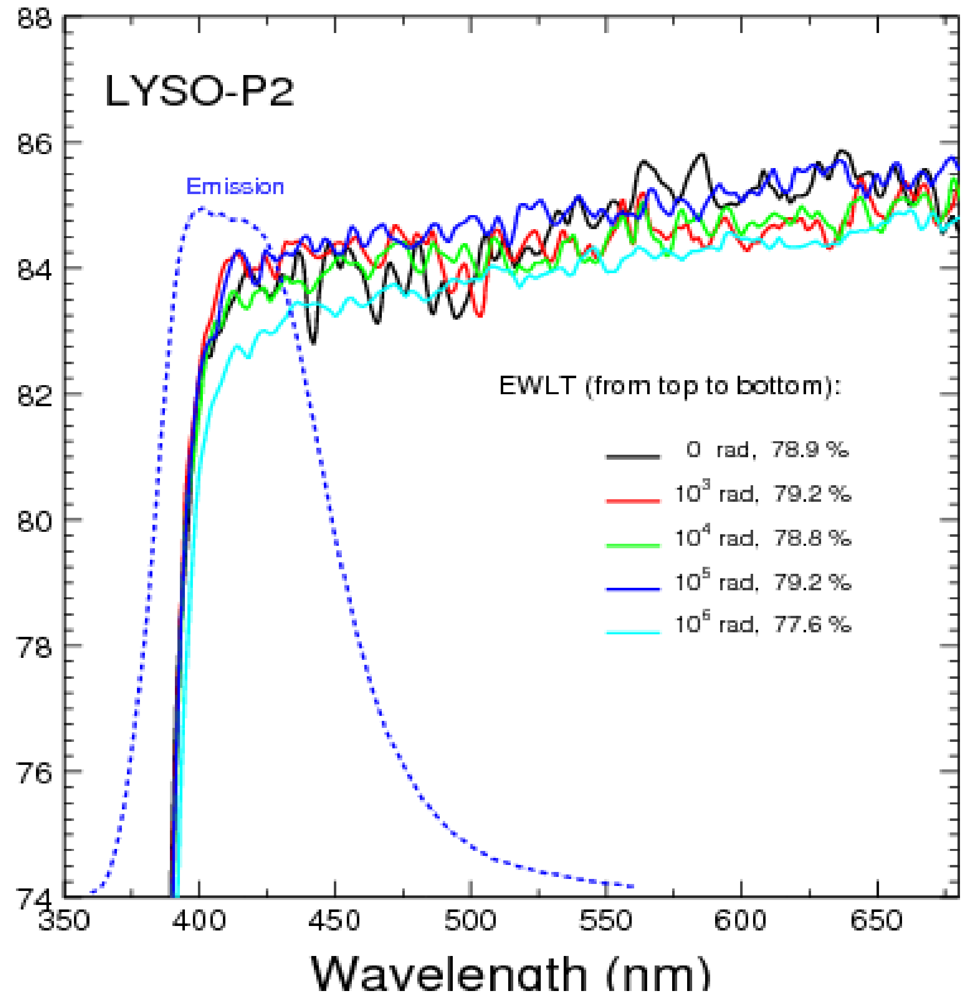






Radiation Hard LYSO Plates





Summary of Fast Scintillation Crystals (Zhu)

	LSO/LYSO	BaF_2	CsI	CeF_3	$CeBr_3$	$LaBr_3$	$LaCl_3$	YSO	GSO
Density (g/cm^3)	7.40	4.89	4.51	6.16	5.10	5.29	3.86	4.54	6.71
Rad. Length (cm)	1.14	2.03	1.86	1.70	1.96	1.88	2.81	3.04	1.38
Molière Rad. (cm)	2.07	3.10	3.57	2.41	2.97	2.85	3.71	2.87	2.23
Interaction Length (cm)	20.9	30.7	39.3	23.2	31.5	30.4	37.6	27.3	22.2
Z value	64.8	51.6	54.0	50.8	45.6	45.6	47.3	33.3	57.9
dE/dX (MeV/cm)	9.55	6.52	5.56	8.42	6.65	6.90	5.27	6.70	8.88
Emission Peak[a] (nm)	420	300 220	420 310	340 300	371	356	335	420	430
Refractive Index[b]	1.82	1.50	1.95	1.62	2.3	1.9	1.9	1.80	1.85
Rel. Light Yield[a,c]	100	42 4.8	4.2 1.3	8.6	144	153	15 49	40	35
Decay Time[a] (ns)	40	650 0.9	30 6	30	17	20	570 24	70	65
d(LY)/dT[d] (%/^{o}C)	-0.2	-1.9 0.1	-1.4	~0	-0.1	0.2	0.1	-0.3	-0.7

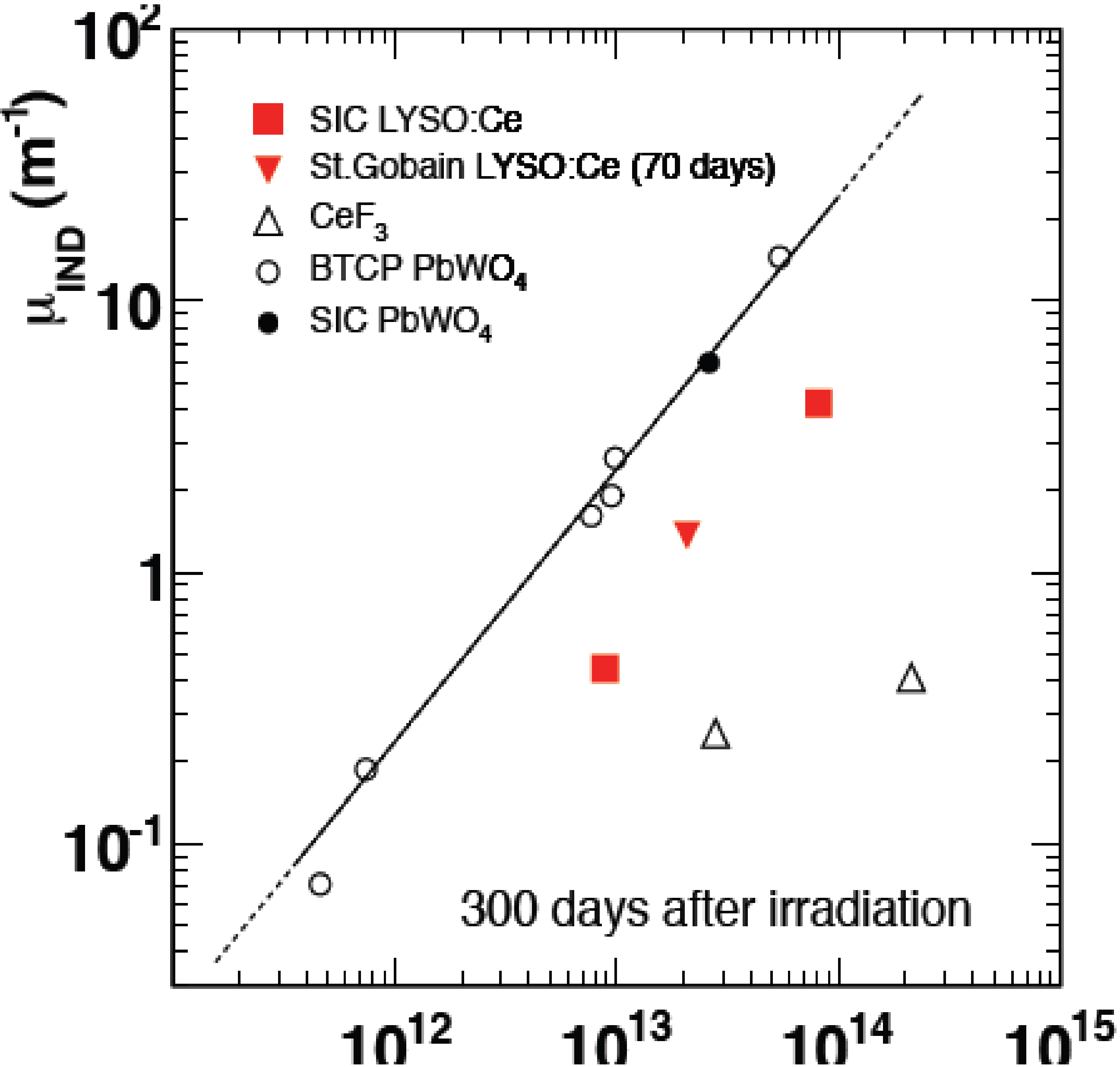
a. Top line: slow component, bottom line: fast component.

b. At the wavelength of emission maximum.

c. Relative light yield normalized to the light yield of LSO

d. At room temperature (20^{o}C)

LYSO Crystal Against Hadrons



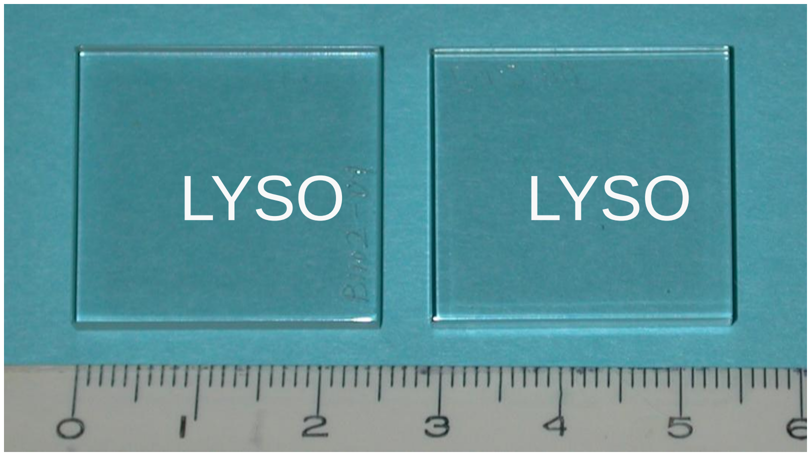
F. Nessi, talk at Forward Calorimeter Workshop, Fermilab:

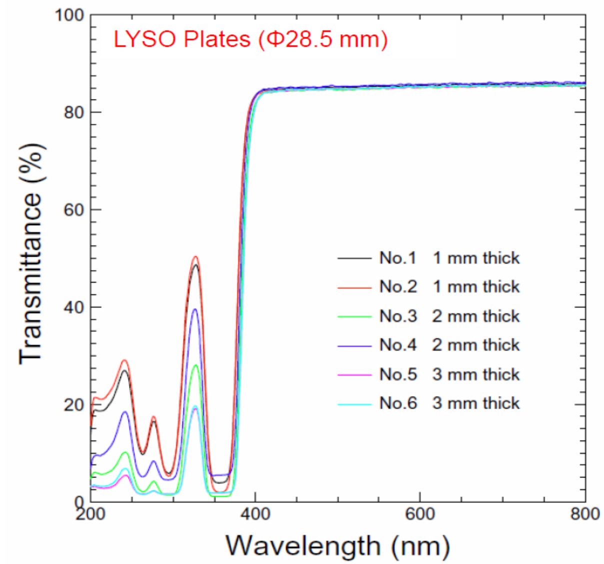
Hadron damage in LYSO Is a factor of five less severe that that in PWO.

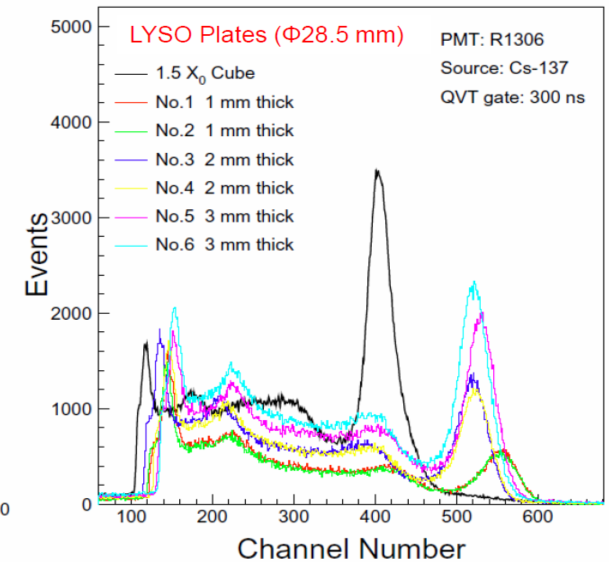
Longer than 30 cm light attenuation length is expected after 10^{14} hadrons/cm^2.

Performance of Scintillator Plates

Crystals

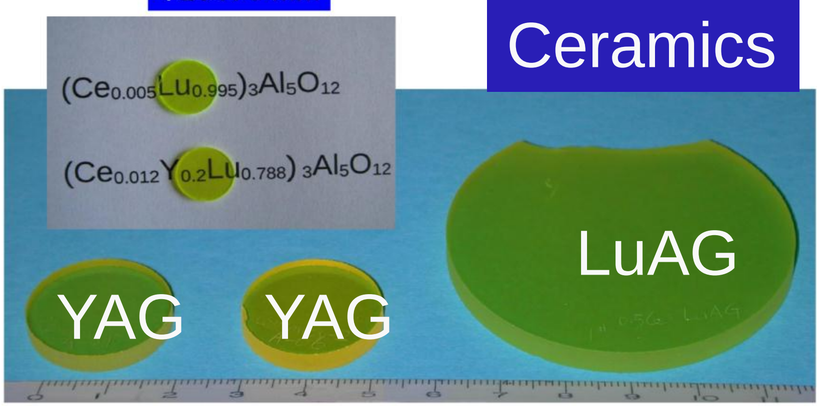






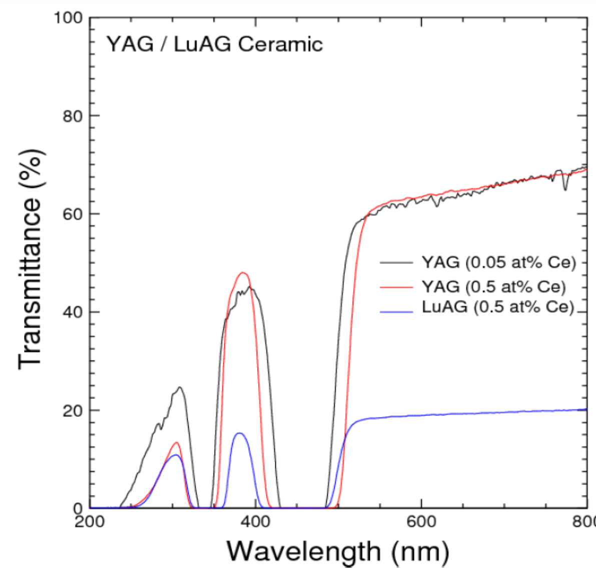
Φ20 X 3 mm

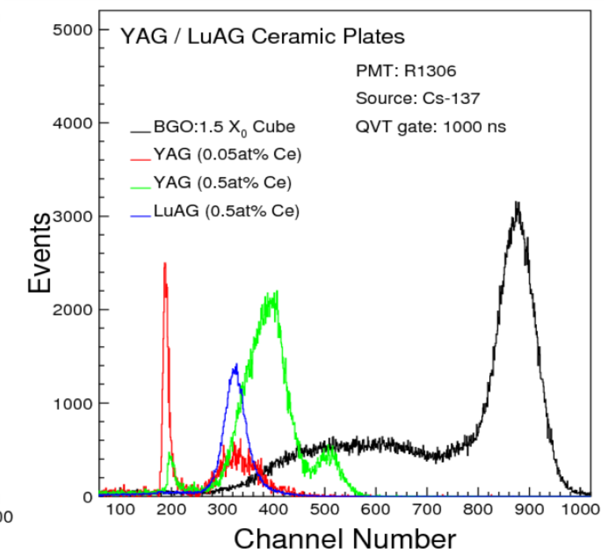
Ceramics



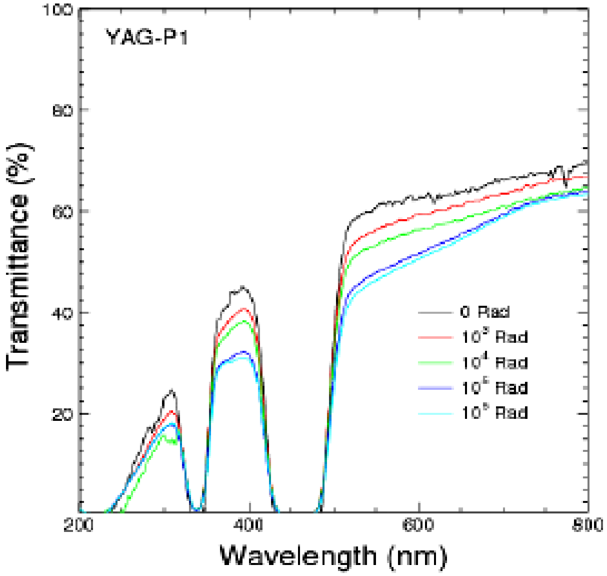
YAG: Φ22 x 4 mm

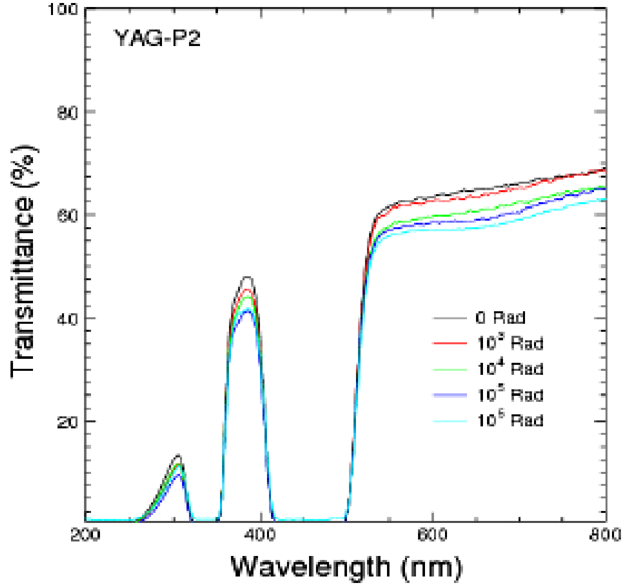
LuAG Φ56 x 5 mm

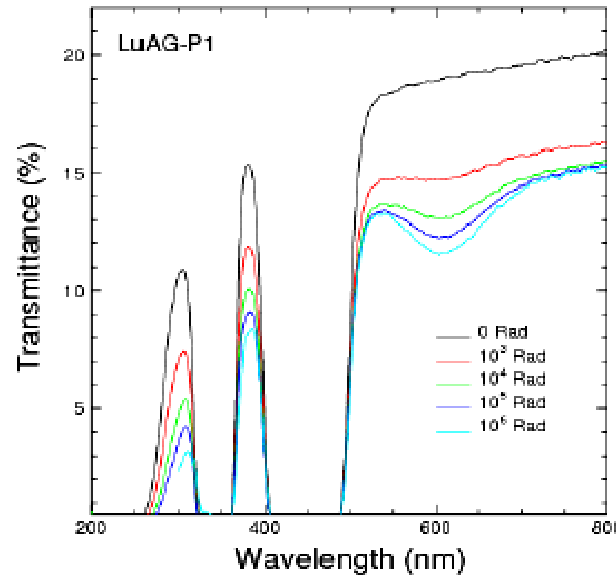


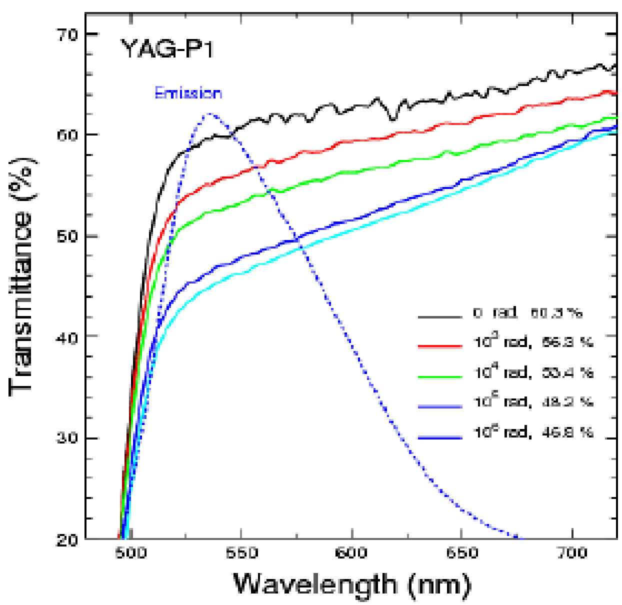


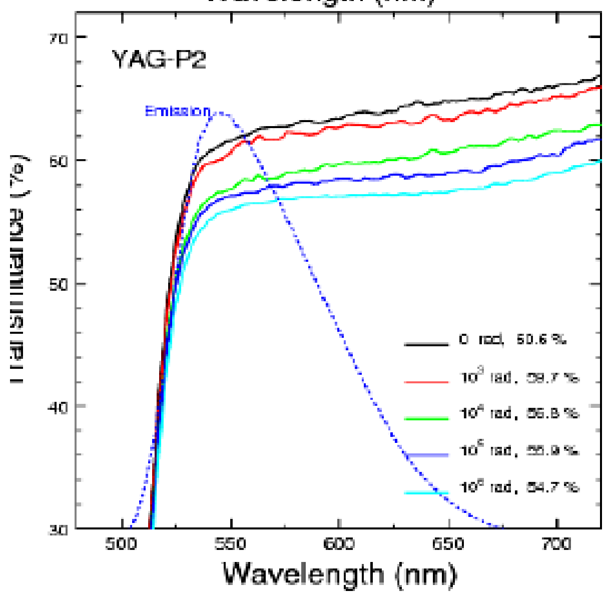
Radiation Hardness of Ceramics

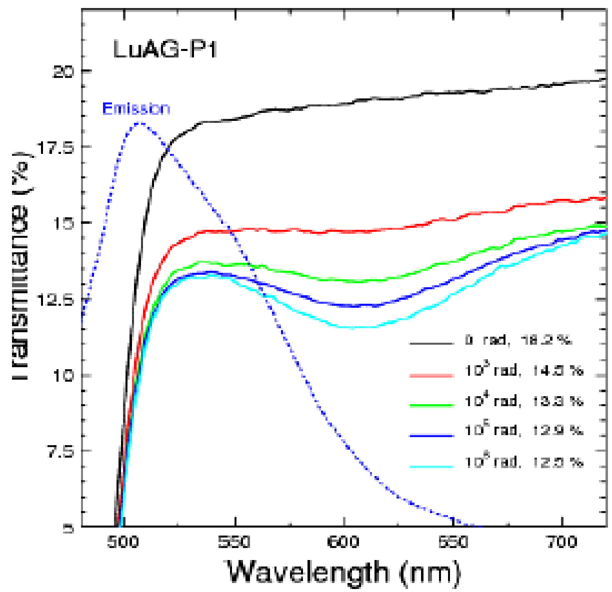










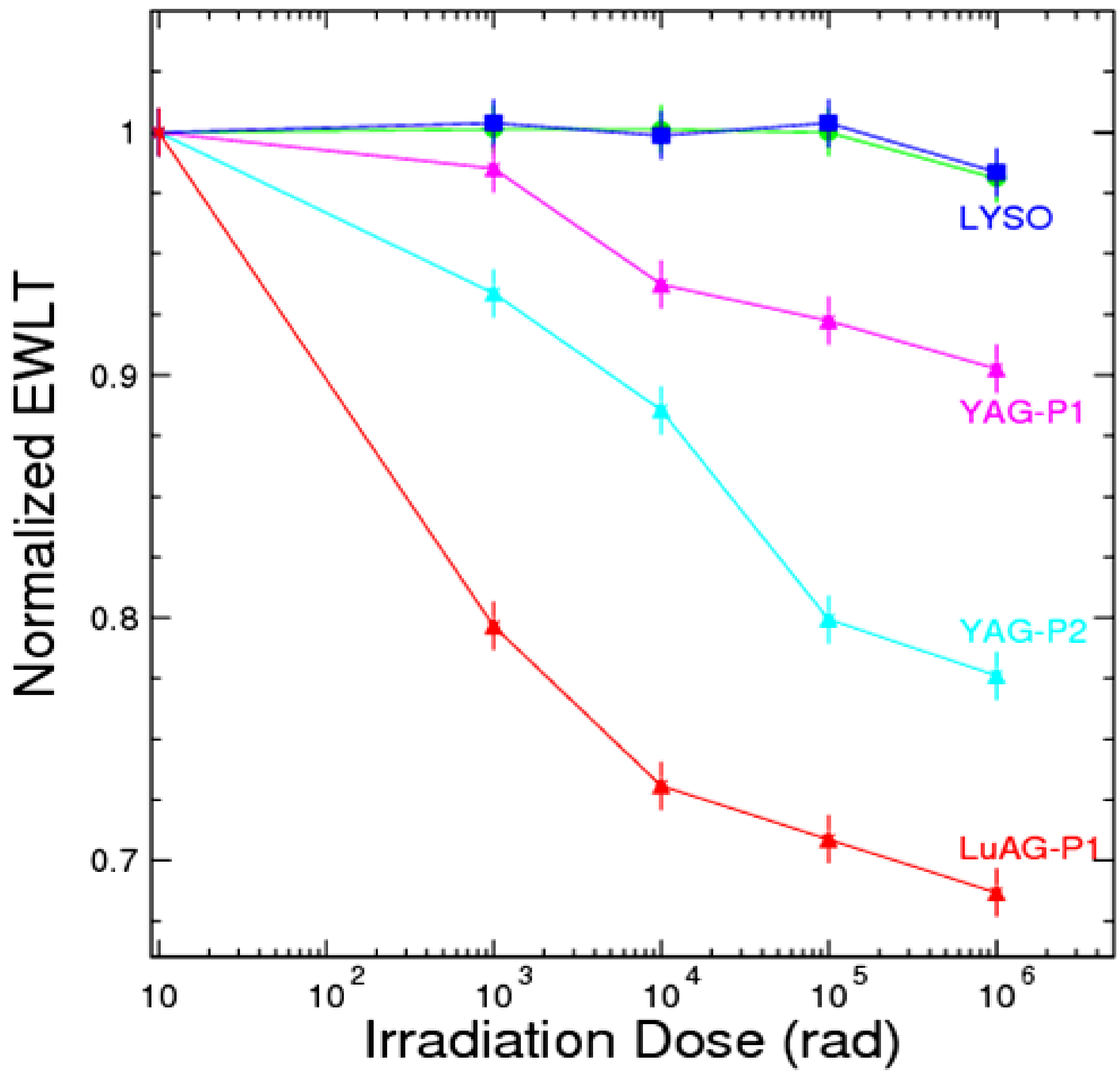


Normalized EWLT: LYSO & Ceramic

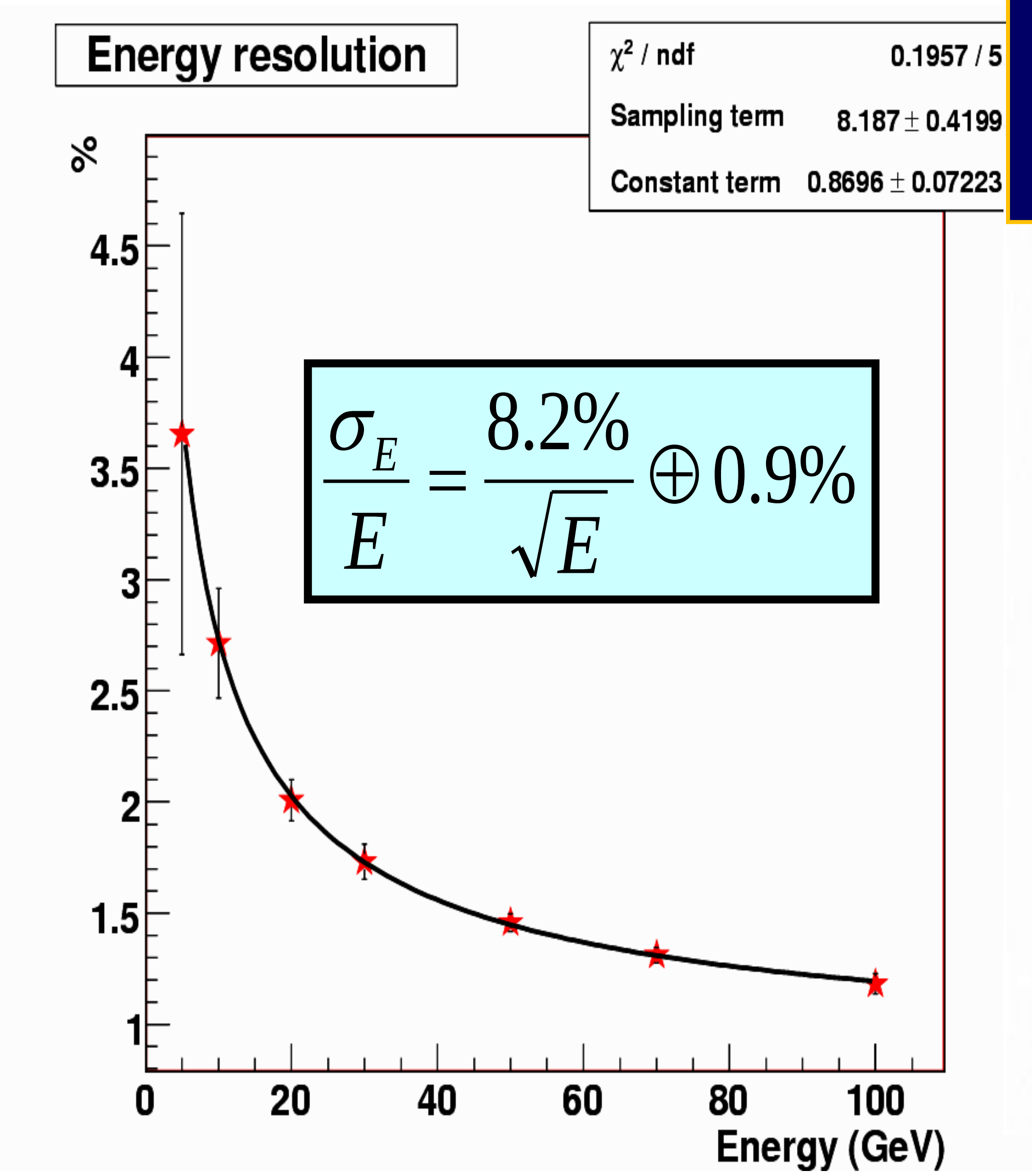
As expected LYSO is radiation hard: a few % @ 1 Mrad

Ceramics, on the other hand, seem not radiation hard

Further Investigation is needed.



Peformance of Pb/Sc Shashlik ECAL



Pizero Peak:
<m> = (135.0±0.6) MeV
σ = (10.9±0.7) MeV