LYSO Shashlik Light Collection and Fast Crystal Choice

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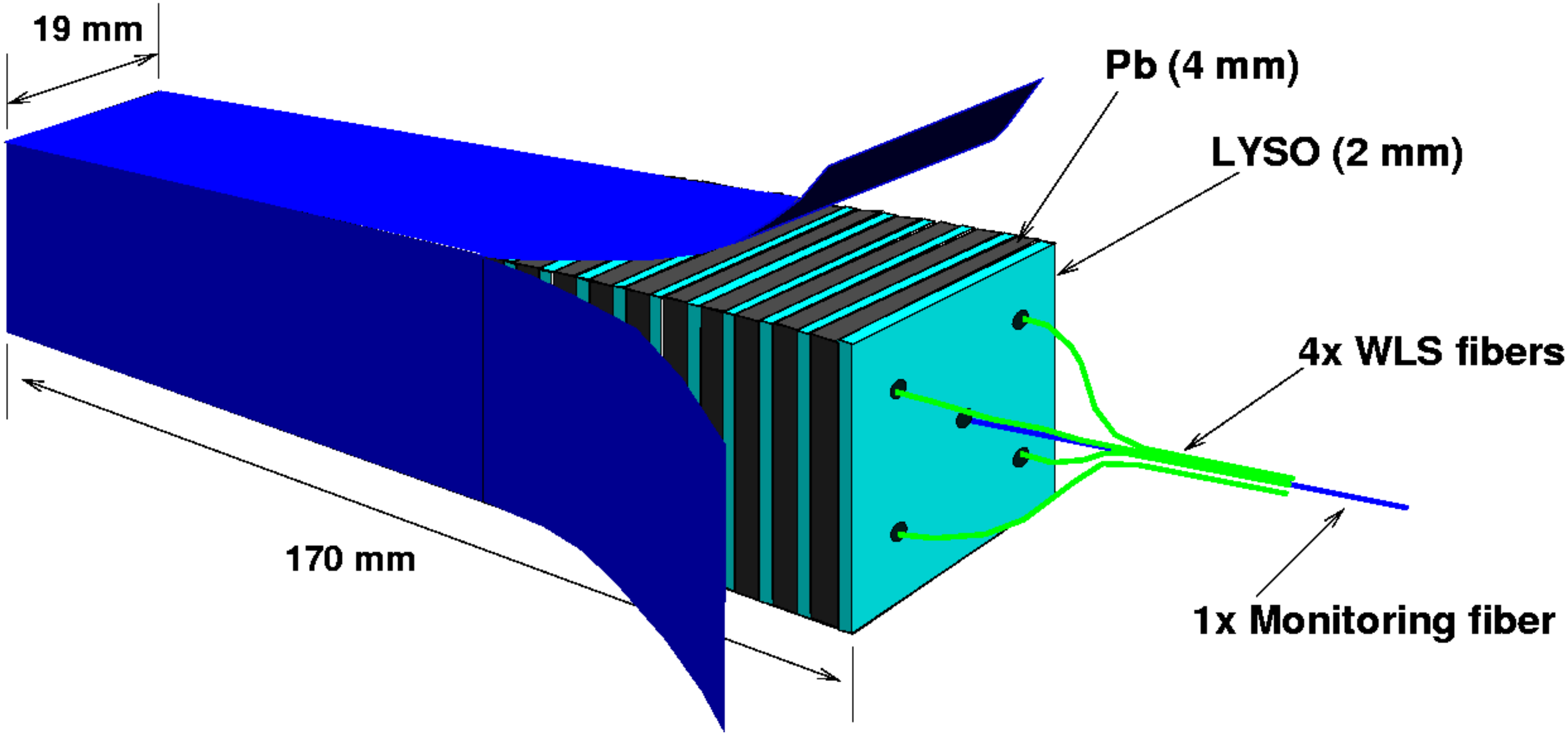
LYSO-Pb Shashlik Cell

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



LYSO Shashlik Cell Design

		LHCb	Plan-1	Plan-2
Absorber		Lead (Pb)	Lead (Pb)	Tungsten (W)
	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	30000	30000
	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	17897	17897
Signal of MIPs	Photon Electrons / MIP	169	991	991
Module Properties	Energy Resolution (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.

Cell Design Constraints

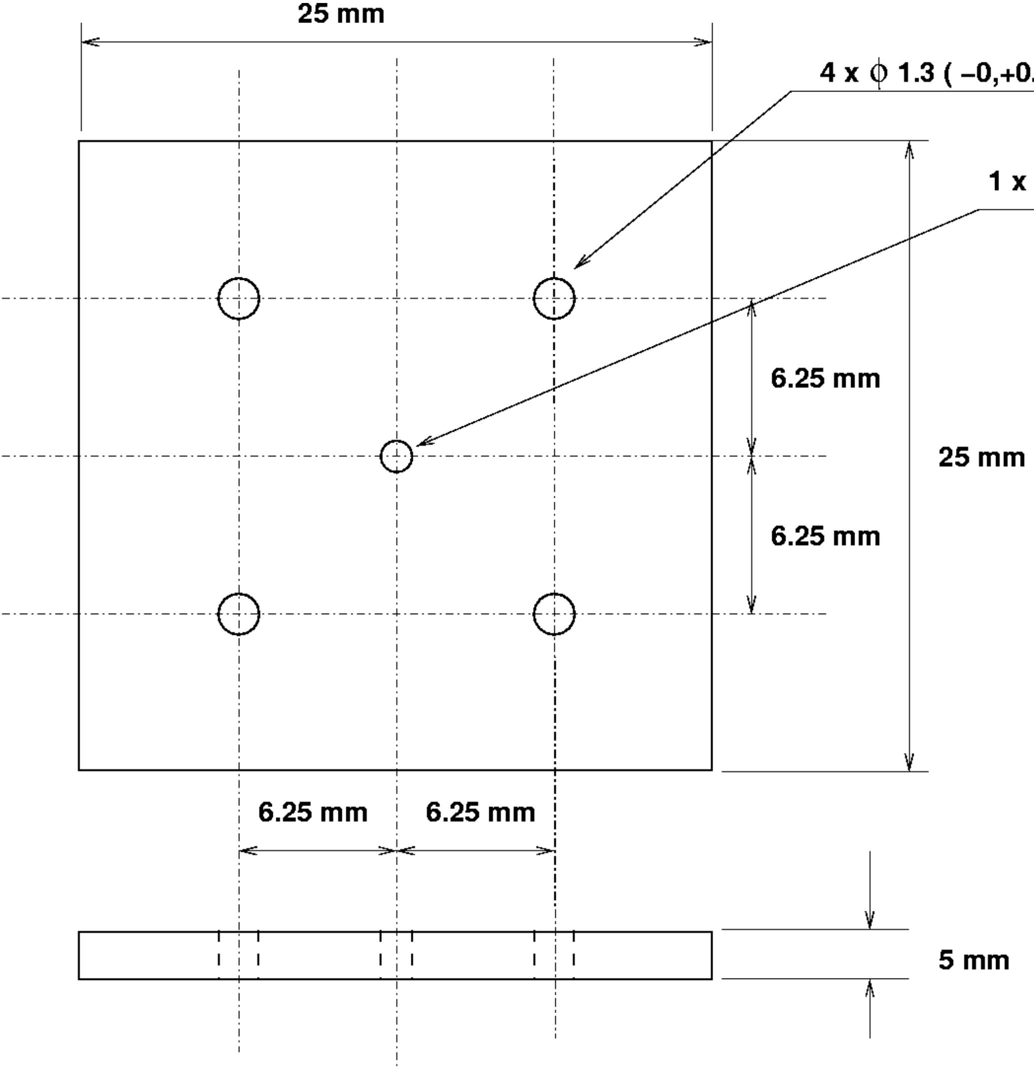
- Crystal Depth / Total Absorption Depth: < 0.2
- Total Cell Depth: ~ 25 X_0
- Sampling Fraction (MIPs): ~ 25%
- Lateral Dimension: ~ 1.1 Rm
- WLS Fiber Density: ~ 1/cm^2
- WLS Fiber distribution: uniform
- Thicknesses of absorber and scintillation plates: reasonable for manufacture

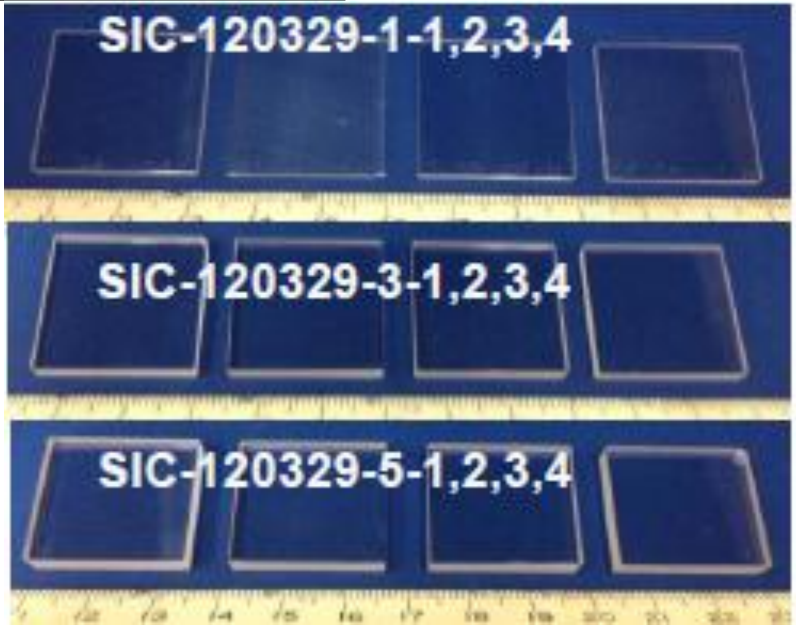
References

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.

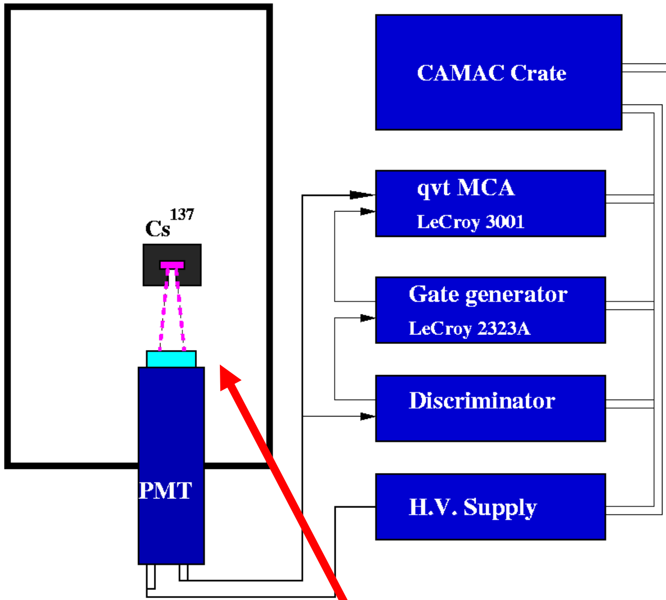
Three LYSO Plates with Holes

25 × 25 × 5, 3 and 1.5 mm^3

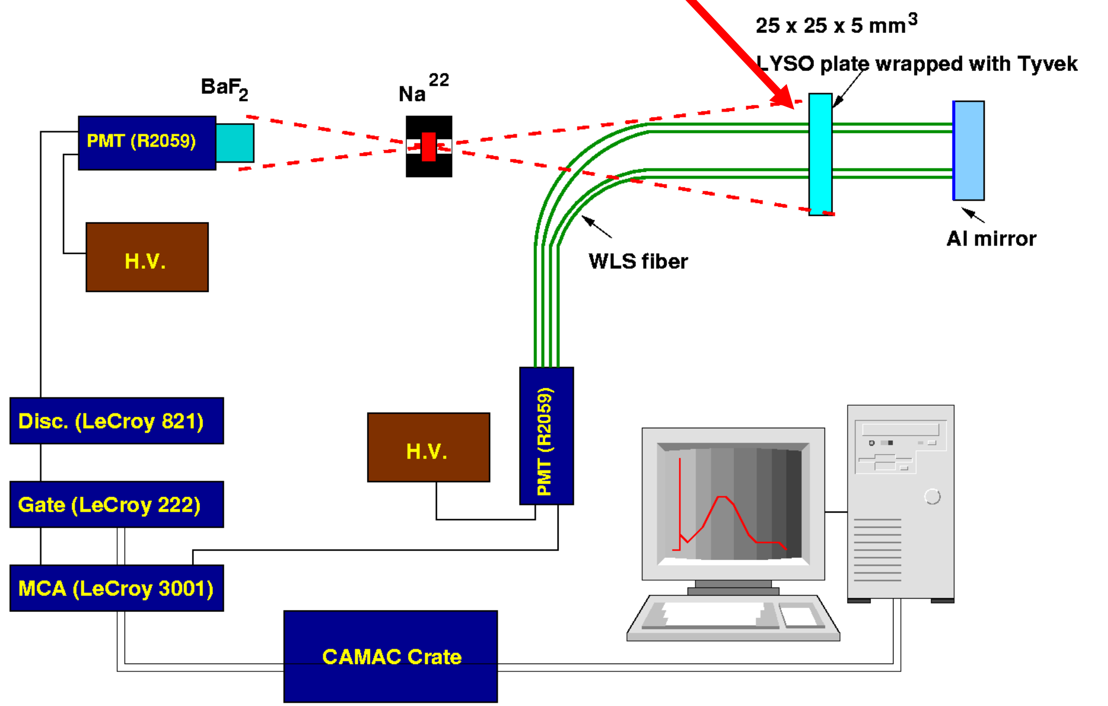




Two Measurement Setups



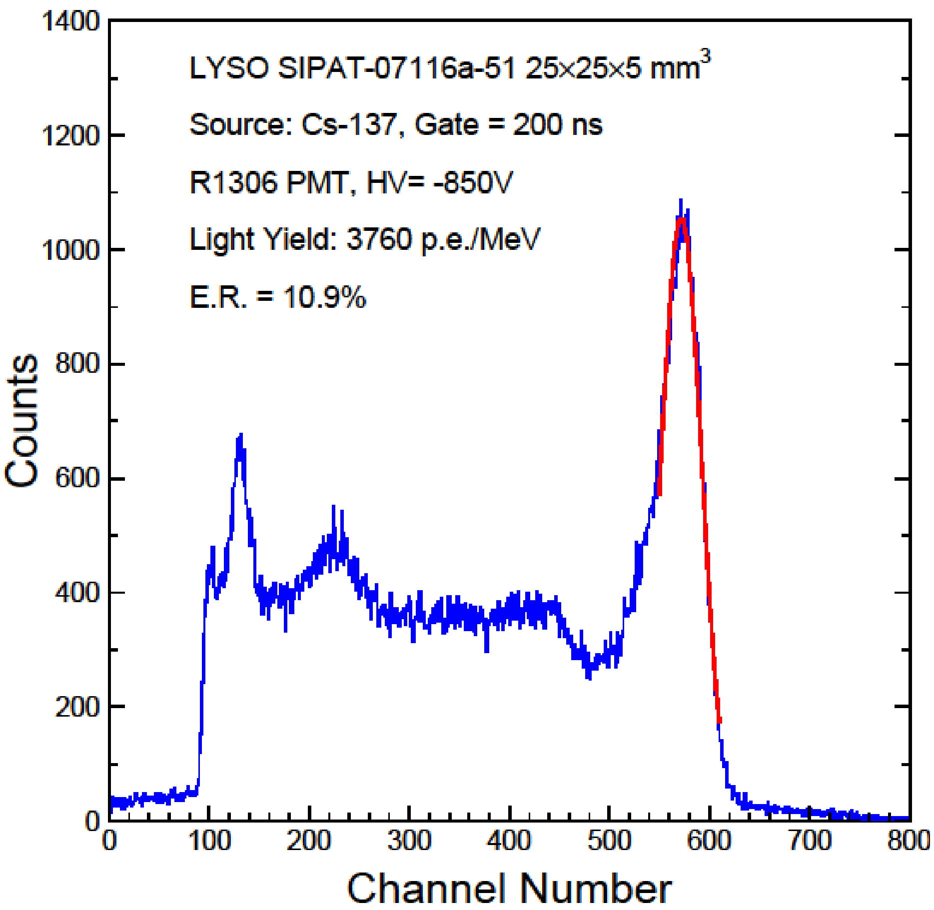
2) LYSO plates with Tyvek wrapping are readout with four Y11 WLS fibers of 40 cm long and a R2059 PMT using a Na-22 γ-ray source and coincidence.



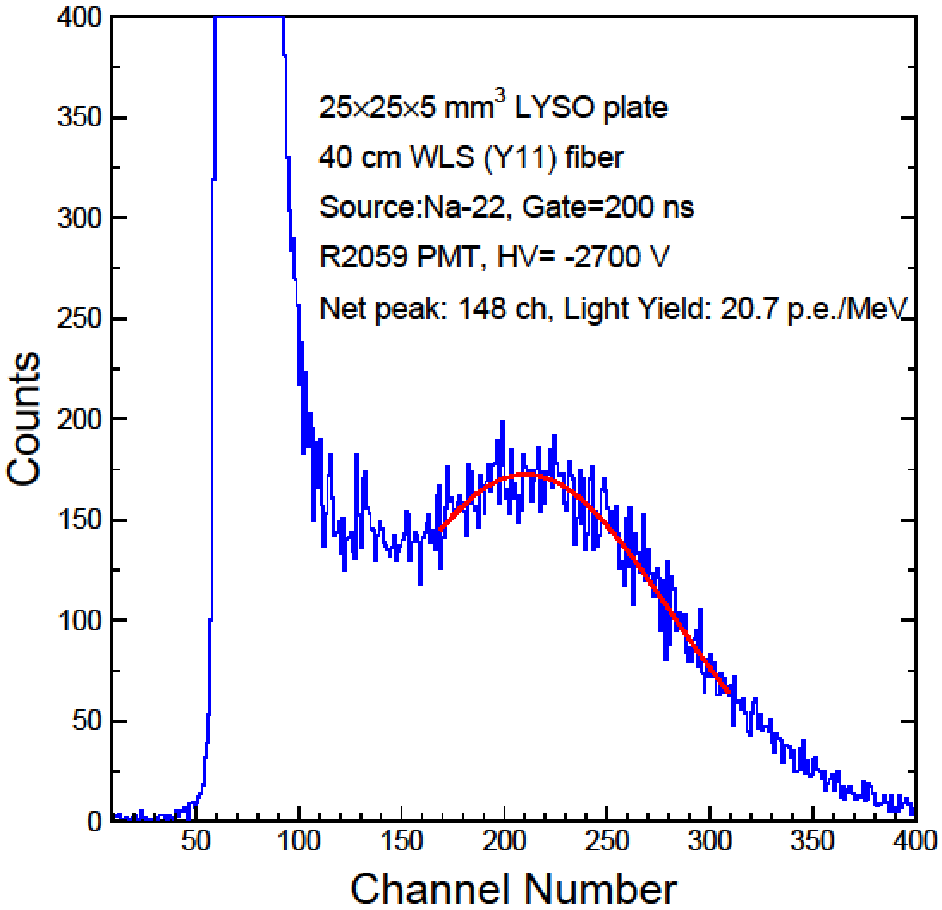
1) LYSO plates with Tyvek wrapping are readout directly by a R1306 PMT using a Cs-137 γ-ray source.

PHS of 5 mm LYSO Plate

LYSO 25 × 25 × 5 mm^3



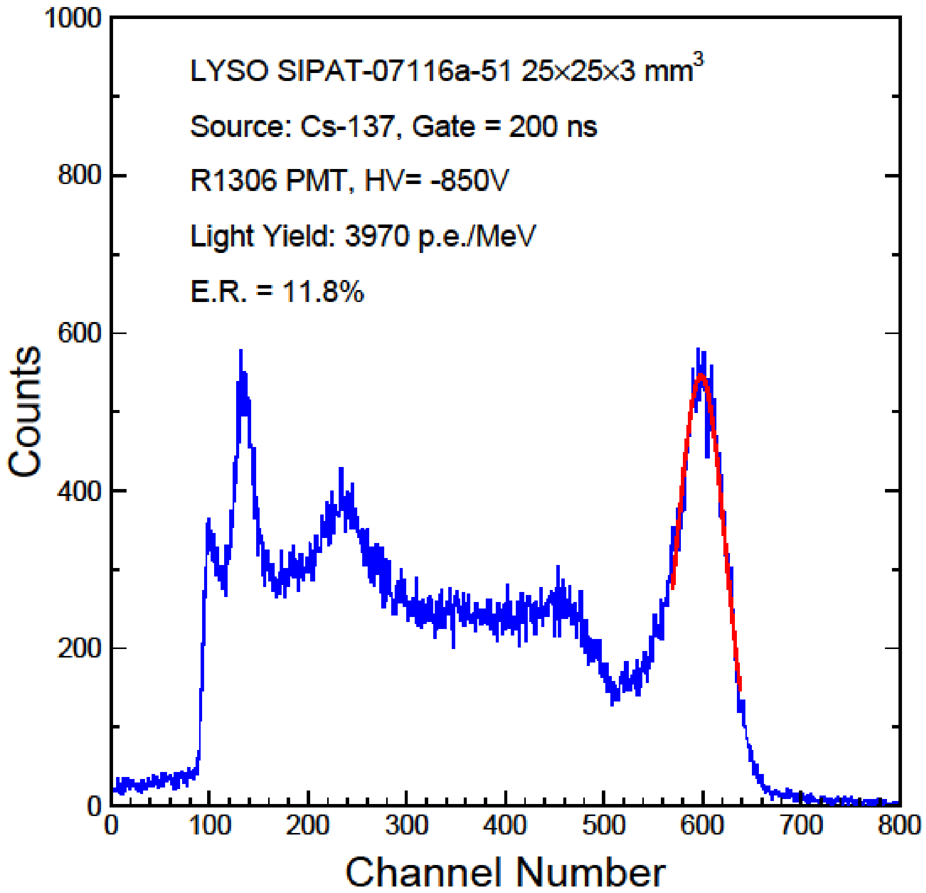
5 mm plate & 4 x 40 cm Y11 fiber



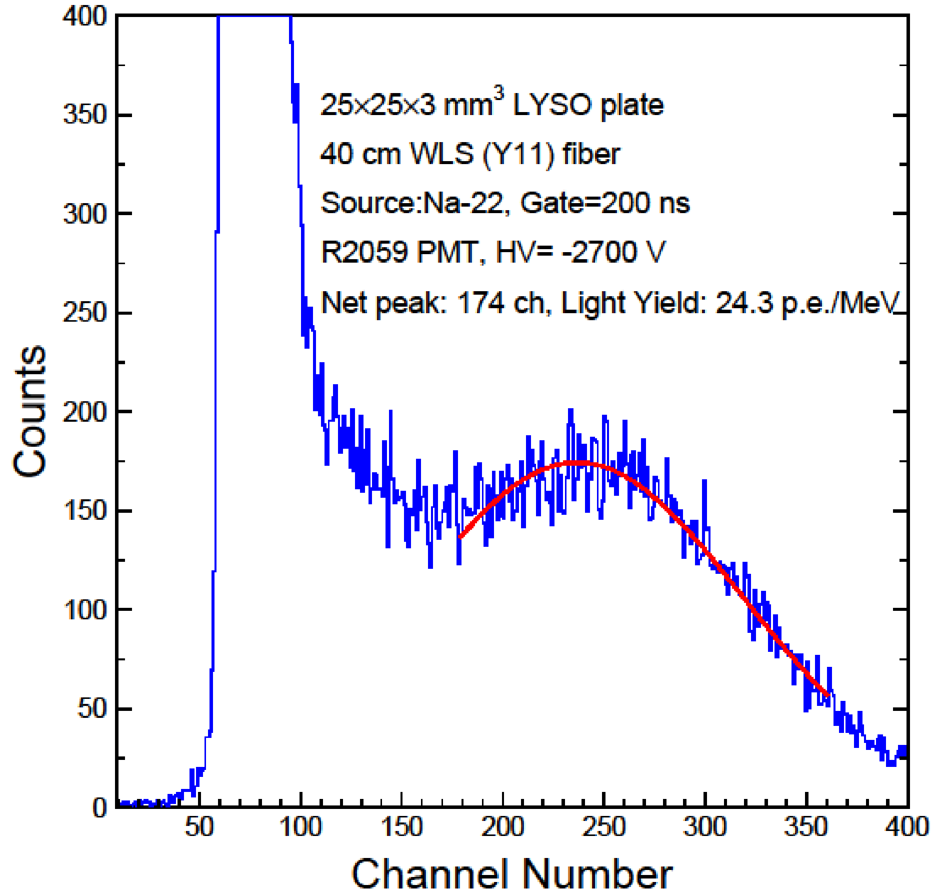
γ-ray peaks are clearly visible

PHS of 3 mm LYSO Plate

LYSO 25 × 25 × 3 mm³



3 mm plate & 4 x 40 cm Y11 fiber

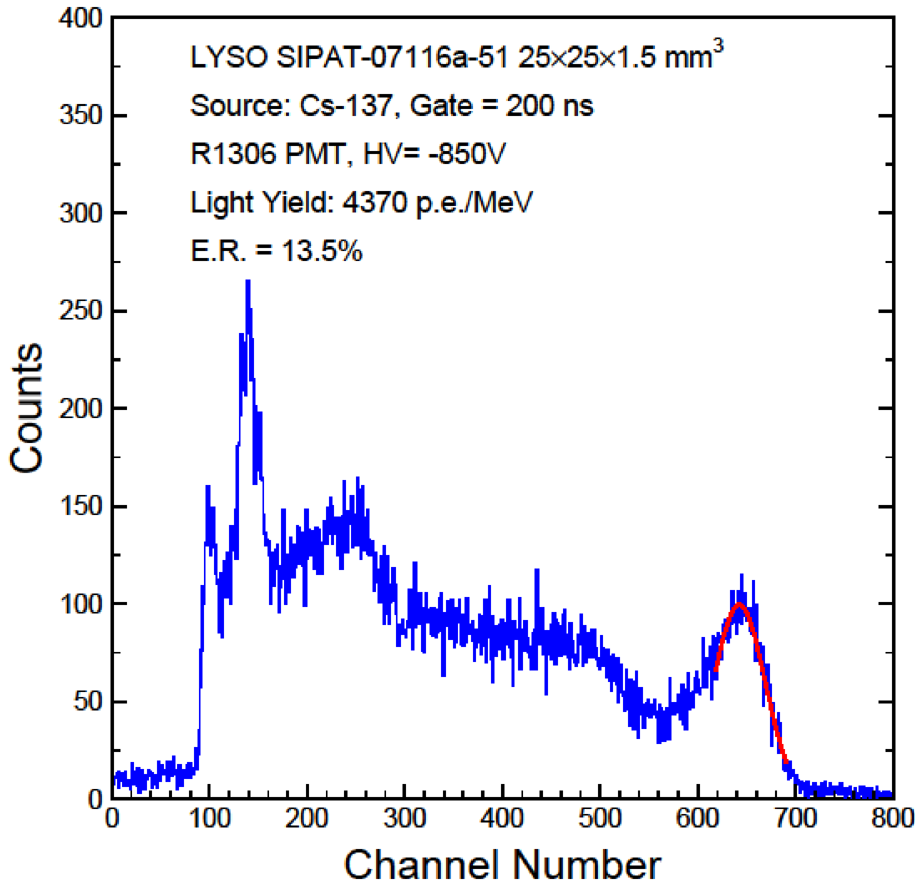


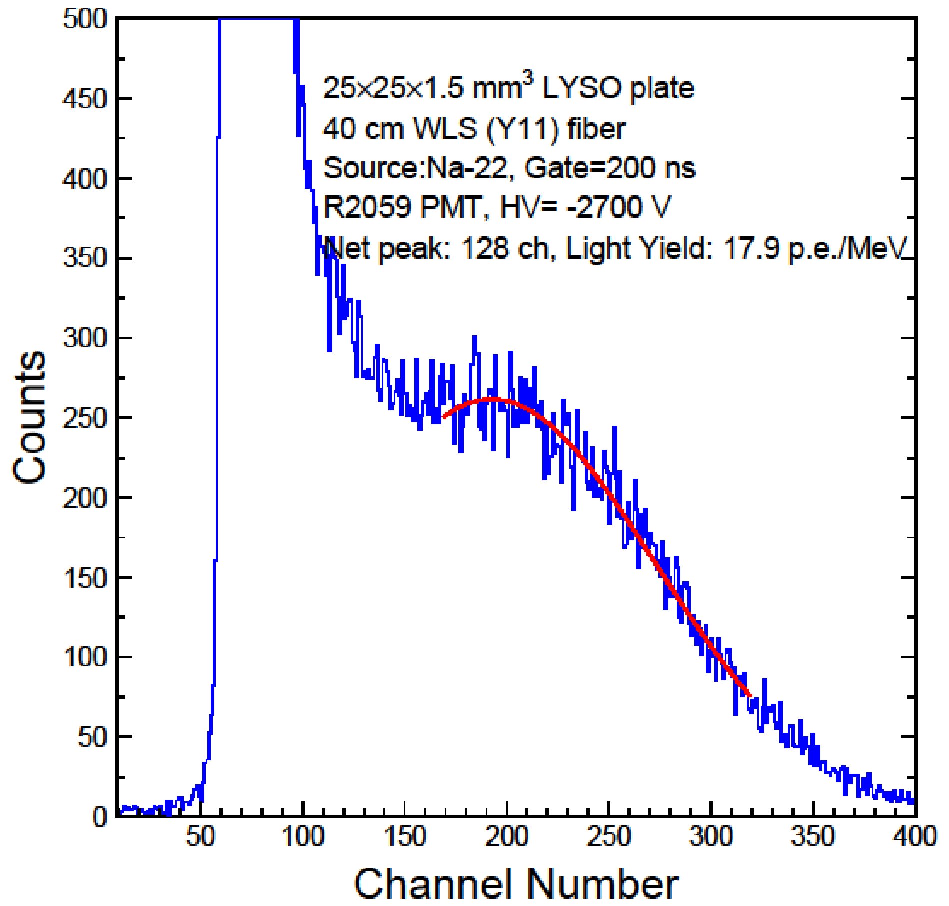
γ-ray peaks are clearly visible

PHS of 1.5 mm LYSO Plate

LYSO 25 × 25 × 1.5 mm^3

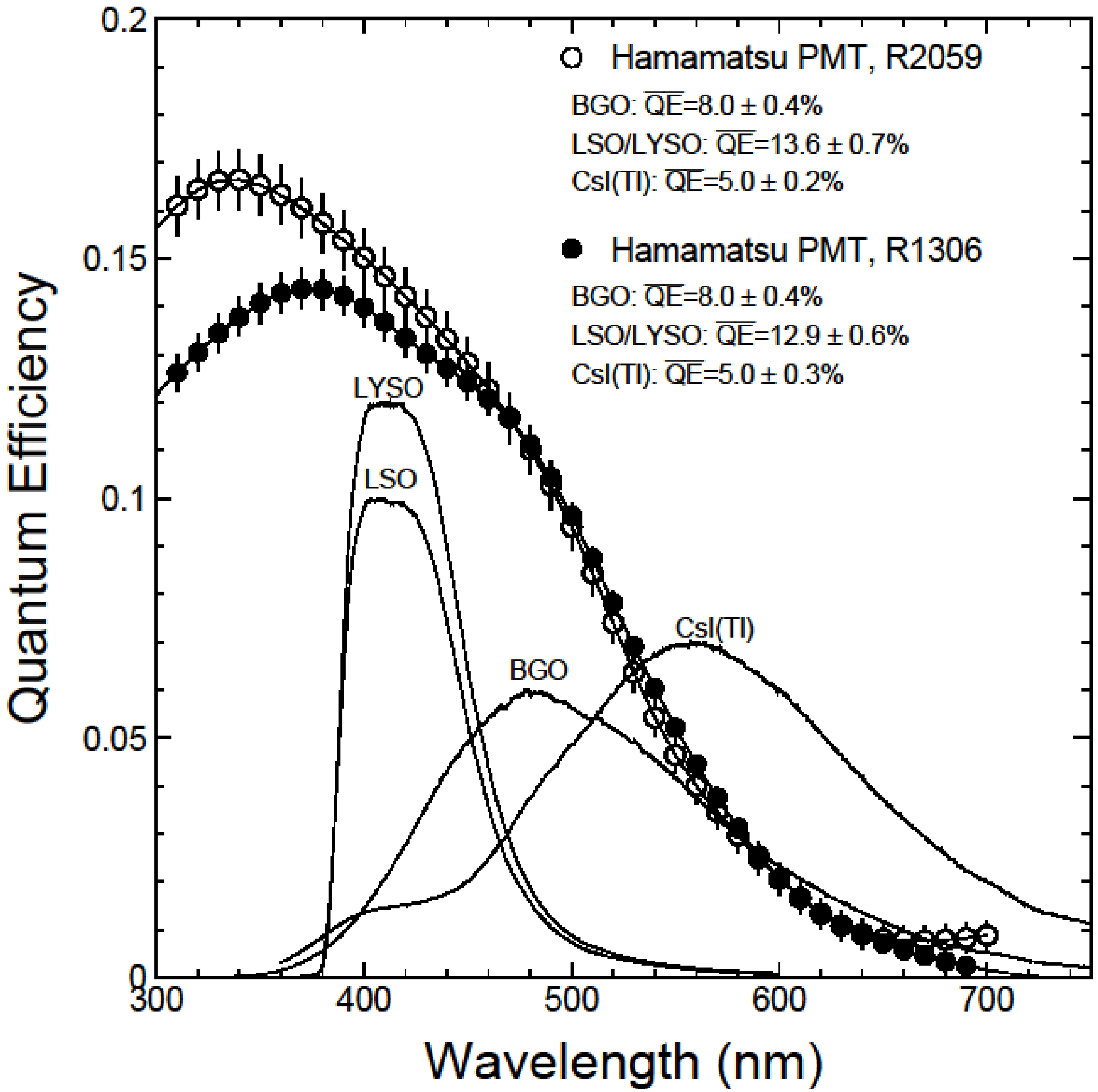
1/5 mm plate & 4 x 40 cm Y11 fiber





Less total absorption events

PMT Quantum Efficiency



Light Output (LO) measured in p.e./MeV are converted to Light Yield (LY) in photons/MeV by taking out the QE of the PMT

LY = LO / QE

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
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

Alternative Fast Crystals

R.-Y. Zhu, Talk in CMS Forward Calorimetry Task Force Meeting, CERN, June 27, 2012

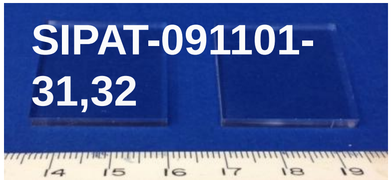
	LSO/LYSO	GSO	YSO [1]	CsI	BaF_2	CeF_3	$CeBr_3$ [2]	$LaCl_3$	$LaBr_3$	Plastic scintillator (BC 404) [3]
Density (g/cm³)	7.40	6.71	4.44	4.51	4.89	6.16	5.23	3.86	5.29	1.03
Melting point (°C)	2050	1950	1980	621	1280	1460	722	858	783	70#
Radiation Length (cm)	1.14	1.38	3.11	1.86	2.03	1.70	1.96	2.81	1.88	42.54
Molière Radius (cm)	2.07	2.23	2.93	3.57	3.10	2.41	2.97	3.71	2.85	9.59
Interaction Length (cm)	20.9	22.2	27.9	39.3	30.7	23.2	31.5	37.6	30.4	78.8
Z value	64.8	57.9	33.3	54.0	51.6	50.8	45.6	47.3	45.6	-
dE/dX (MeV/cm)	9.55	8.88	6.56	5.56	6.52	8.42	6.65	5.27	6.90	2.02
Emission Peak[a] (nm)	420	430	420	420 310	300 220	340 300	371	335	356	408
Refractive Index[b]	1.82	1.85	1.80	1.95	1.50	1.62	1.9	1.9	1.9	1.58
Relative Light Yield[a,c]	100	45	76	4.2 1.3	42 4.8	8.6	141	15 49	153	35
Decay Time[a] (ns)	40	73	60	30 6	650 0.9	30	17	570 24	20	1.8
d(LY)/dT [d] (%/°C)	-0.2	-0.4	-0.3	-1.4	-1.9 0.1	~0	-0.1	0.1	0.2	~0

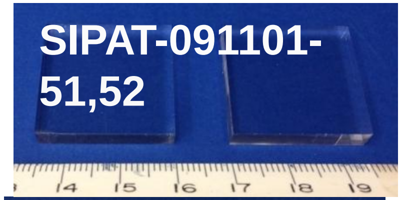
a. Top line: slow component, bottom line: fast component.
b. At the wavelength of the emission maximum.
c. Relative light yield normalized to the light yield of LSO
d. At room temperature (20°C)
#. Softening point

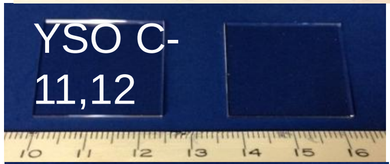
1. N. Tsuchida et al ***Nucl. Instrum. Methods Phys. Res. A,*** 385 (1997) 290-298
http://www.hitachi-chem.co.jp/english/products/cc/017.html
2. W. Drozdowski et al. ***IEEE TRANS. NUCL. SCI***, VOL.55, NO.3 (2008) 1391-1396
Chenliang Li et al, ***Solid State Commun***, Volume 144, Issues 5–6 (2007),220–224
http://scintillator.lbl.gov/
3. http://www.detectors.saint-gobain.com/Plastic-Scintillator.aspx
http://pdg.lbl.gov/2008/AtomicNuclearProperties/HTML_PAGES/216.html

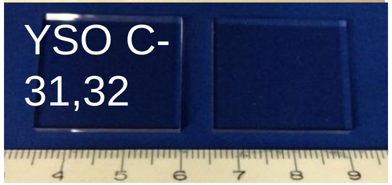
SIC-120329-1-1,2,3,4

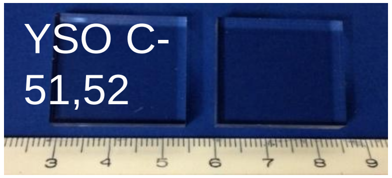
YSO Samples

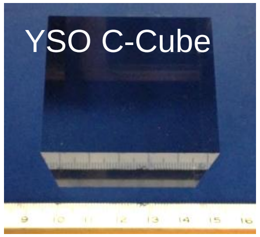












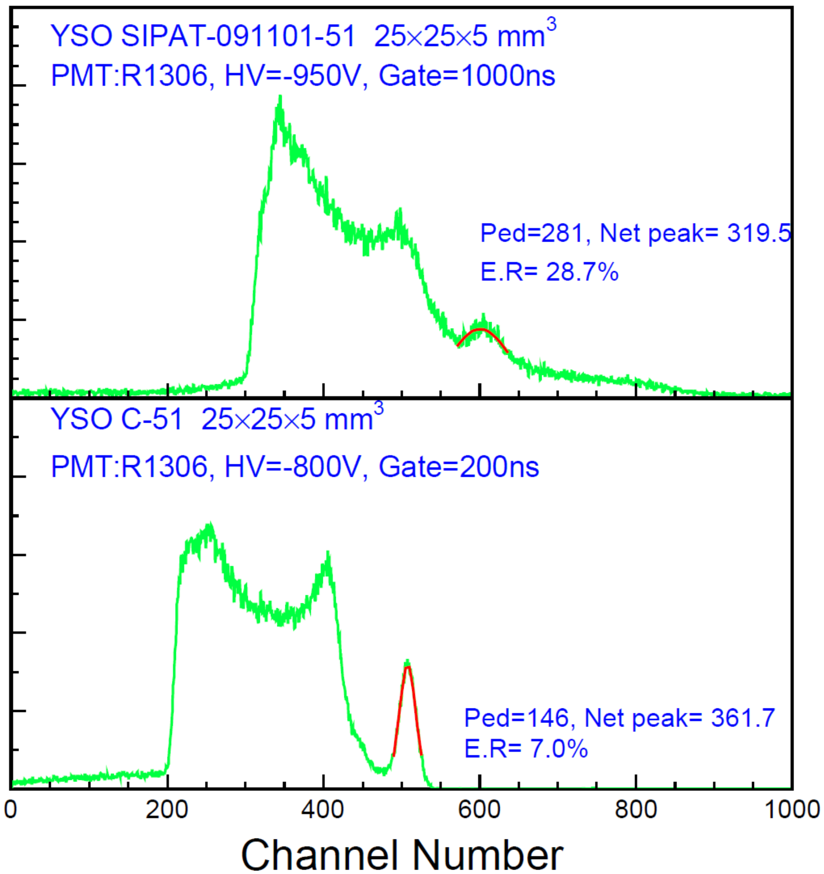
Vendor	Sample ID	Received Date	Dimension (mm^3)	Polish
SIPAT	091101-31,32	4/17/2012	25×25×3	Six faces
	091101-51,52	4/17/2012	25×25×5	Six faces
CPI	C-11,12	10/11/2012	25×25×1.5	Six faces
	C-31,32	10/11/2012	25×25×3	Six faces
	C-51,52	10/11/2012	25×25×5	Six faces
	C-Cube	10/11/2012	40×40×46	Six faces

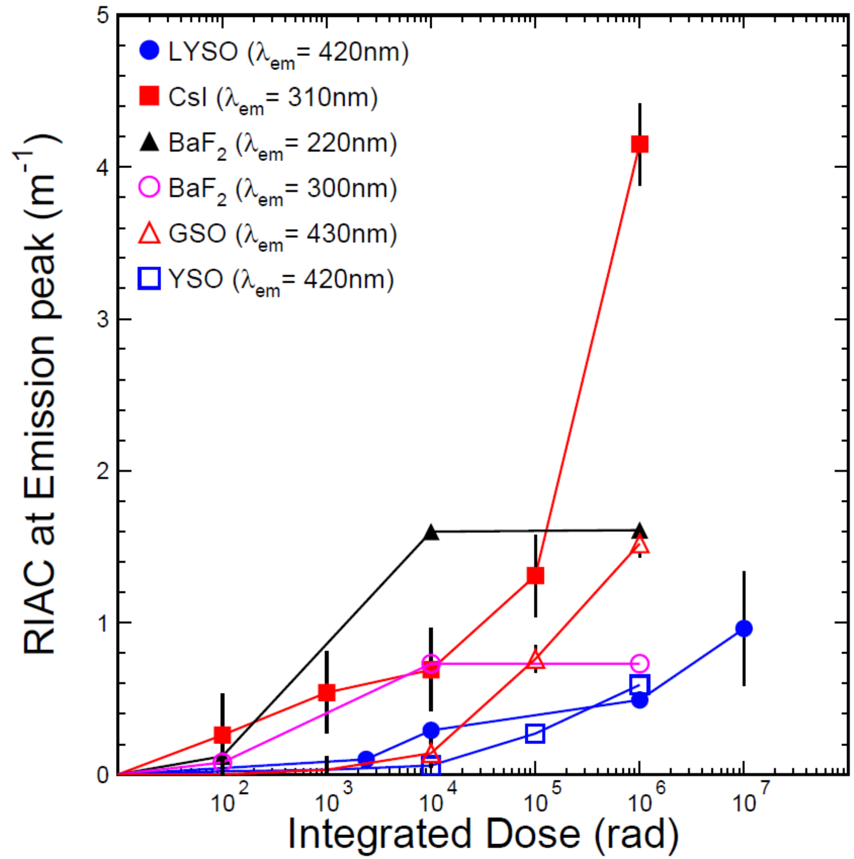
Experiments

- Transmittance, PL
- LO, Decay, PHS and Uniformity by PMT: R1306, grease coupling, Cs-137
- The cube sample went through γ-ray irradiations for 100, 1K , 10K , 100K, 1M and 10M rad

Crystal Radiation Hardness

Sample	EWLT (%)	LO (p.e./MeV)	EWLT loss (%)					LO loss (%)				
			10^2 rad	10^3 rad	10^4 rad	10^5 rad	10^6 rad	10^2 rad	10^3 rad	10^4 rad	10^5 rad	10^6 rad
YSO C-Cube	66.2	2123	0±0.2	0.15±0.2	0.76±0.2	3.3±0.2	6.5±0.2	0.24±1.0	-0.52±1.0	0.05±1.0	2.3±1.0	6.5±1.0





YSO is not yet an Alternative

- YSO is yet to be qualified as LYSO, e.g. hadrons damage etc.
- The cost of YSO is not extremely low because of its high melting point as LYSO. Its mass production cost is expected to be lower than LYSO, say 50%?. To achieve the same sampling fraction, however, the amount of YSO needed would be 60% more than LYSO, so the overall saving is no significant.
- Unlike LYSO there are not many YSO vendors because of its lacking application in γ-ray spectroscopy or PET.

Comments on Fast Crystals

+ : pro. - : con. 0 : OK.

	LSO/LYSO	GSO	YSO	CsI	BaF_2	CeF_3	$CeBr_3$	$LaCl_3$	$LaBr_3$	Plastic scintillator (RP-408)
Light Yield	+	0	+	-	-	-	+	0	+	0
Radiation (γ) Hardness	+	-	+	-	-	0	N/A	N/A	N/A	-
Neutron x-section	N/A	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Emission Matching Y11 WLS Excitation	+	+	+	-	-	-	0	0	0	+
Hygroscopicity	+	+	+	0	0	0	-	-	-	+
Unit cost	0	0	+	+	+	+	-	-	-	+
Cell cost	0	0	0	+	+	+	-	-	-	+
Mass Production	+	0	0	+	+	0	N/A	N/A	N/A	+

LSO/LYSO is the front runner. YSO may serve as an alternative.

Summary

- The light collection efficiency (LCE) of LSO/LYSO plates with 4 x Y11 fiber readout is at a level of 0.5%. This result is consistent with the LHCb data.
- 3 mm thick LYSO plate seems having a better LCE than that of 1.5 mm and 5 mm.
- Among all fast crystal scintillators LSO/LYSO crystals are the best candidate for the sampling crystal calorimeter option for the endcap ECAL at HL-LHC. YSO may also serve as an alternative with further development.

Future Plan

- Measure Shashlik cell longitudinal response uniformity by moving the LYSO plate along the Y11 WLS fibers.
- Measure Shashlik cell transverse response uniformity by injecting collimated γ-ray source into LYSO plates.
- Build the first rectangular cell, and test it with cosmic MIPs.
- Further investigation on alterative fast crystals, such as YSO.
- Harvey's proposal: quartz on quartz fibers with Y11 or similar dye incorporated. Look whether it can be incorporated in the core, or at the core-cladding interface.
- Optimizing Shashlik cell design: plate thickness, sampling fraction etc.