LYSO for the Super*B* Endcap

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Paris SuperB Workshop
March 9, 2007

All L(Y)SO studies by Ren-yuan Zhu

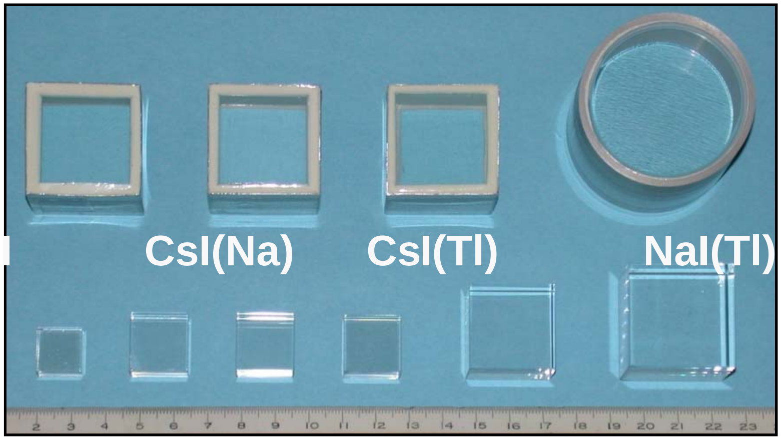
- Ren-yuan Zhu at Caltech has continued his detailed studies of scintillating crystal properties and his work with crystal growers to improve uniformity and reduce the price
- We have been using the shorthand L(Y)SO to represent the two types of crystals, LSO(Ce) and LYSO(Ce)
    - The uniformity of Ce doping, and hence light output, in large crystals is better in LYSO
        - This is apparently due to structure formation during crystal growth (Y and Ce ions have the same valence and similar size)
    - Henceforth, we will concentrate on the development of LYSO and will drop the ()

Mass-produced Crystals (new, for PDG)

Crystal	NaI(Tl)	CsI(Tl)	CsI	BaF_2	BGO	PWO(Y)	LSO(Ce)	GSO(Ce)
Density (g/cm^3)	3.67	4.51	4.51	4.89	7.13	8.3	7.40	6.71
Melting Point (ºC)	651	621	621	1280	1050	1123	2050	1950
Radiation Length (cm)	2.59	1.86	1.86	2.03	1.12	0.89	1.14	1.38
Molière Radius (cm)	4.13	3.57	3.57	3.10	2.23	2.00	2.07	2.23
Interaction Length (cm)	42.9	39.3	39.3	30.7	22.8	20.7	20.9	22.2
Refractive Index [a]	1.85	1.79	1.95	1.50	2.15	2.20	1.82	1.85
Hygroscopicity	Yes	Slight	Slight	No	No	No	No	No
Luminescence [b] (nm) (at peak)	410	550	420 310	300 220	480	425 420	402	440
Decay Time [b] (ns)	230	1250	30 6	630 0.9	300	30 10	40	60
Light Yield [b,c] (%)	100	165	3.6 1.1	36 3.4	21	0.29 .083	83	30
d(LY)/dT [b] (%/ ºC)	-0.2	0.3	-1.3	-1.3	-0.9	-2.7	-0.2	-0.1
Experiment	Crystal Ball	CLEO BaBar BELLE BES III	KTeV	TAPS (L*) (GEM)	L3 BELLE PANDA?	CMS ALICE PrimEx PANDA?	-	-

a. at peak of emission; b. up/low row: slow/fast component; c. PMT QE taken out.

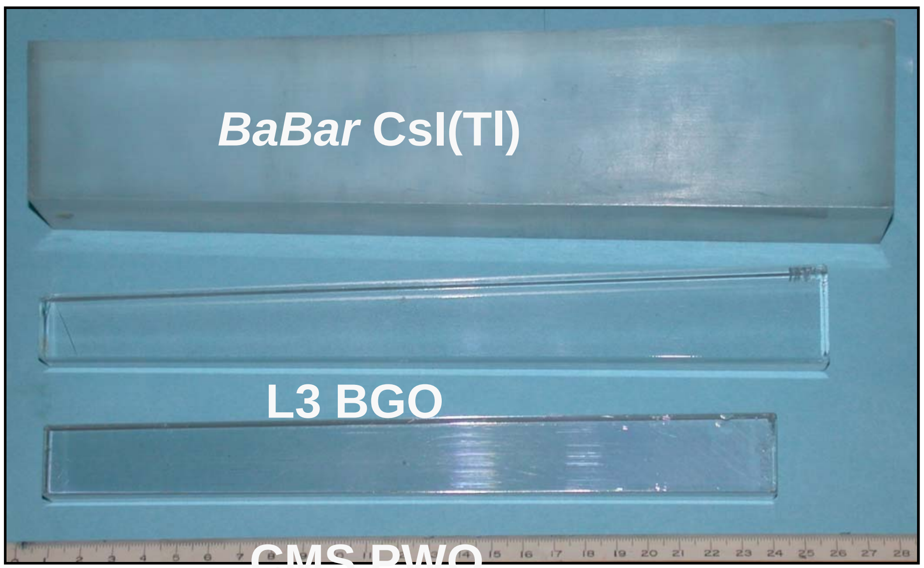
Crystal Density: Radiation Length



1.5 X_0 Cubic Samples:

Hygroscopic Halides

Non-hygroscopic



Full Size Crystals:

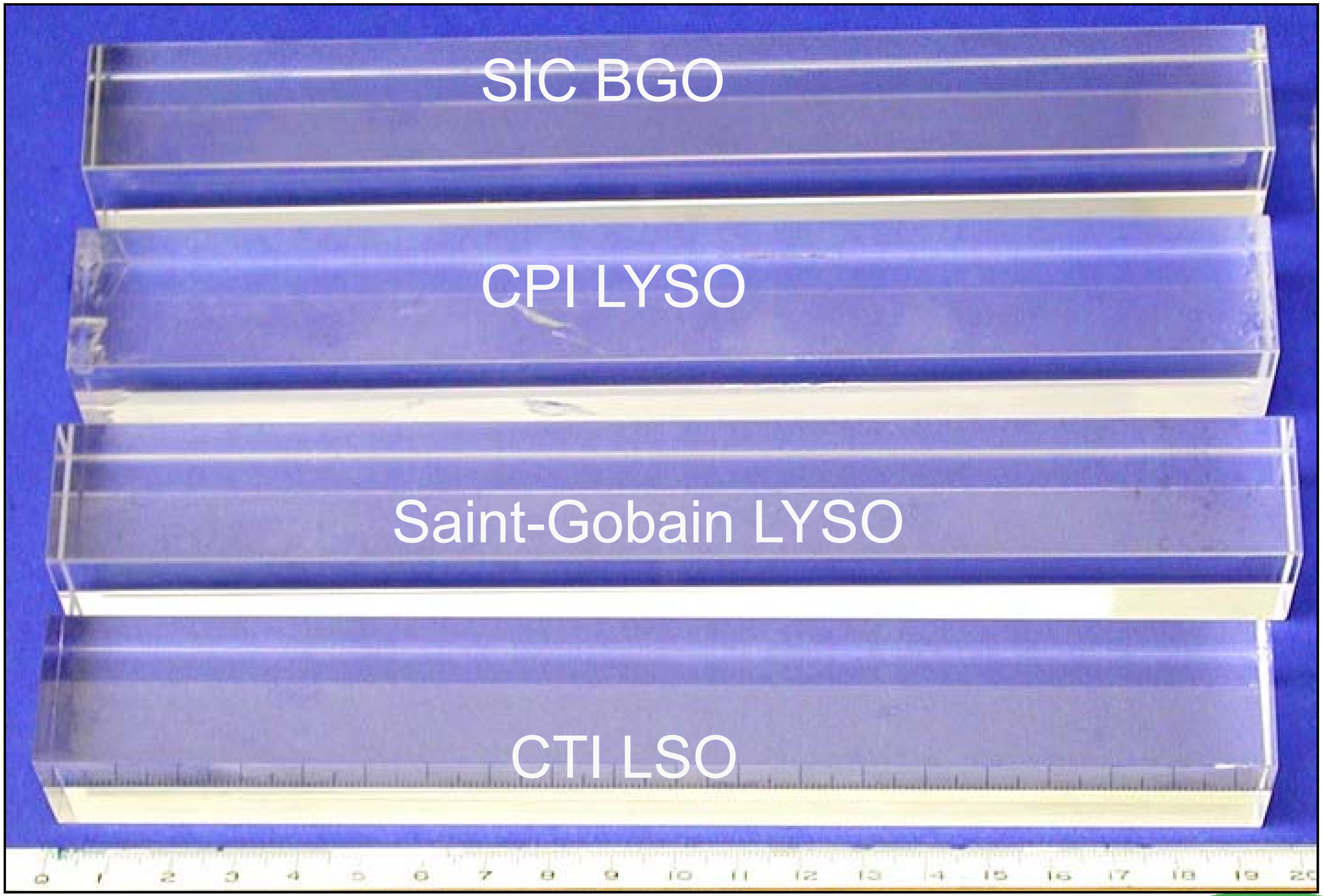
BaBar CsI(Tl): 16 X_0

L3 BGO: 22 X_0

CMS PWO(Y): 25 X_0

BGO, LSO & LYSO Samples

2.5 x 2.5 x 20 cm (18 X_0) Bar

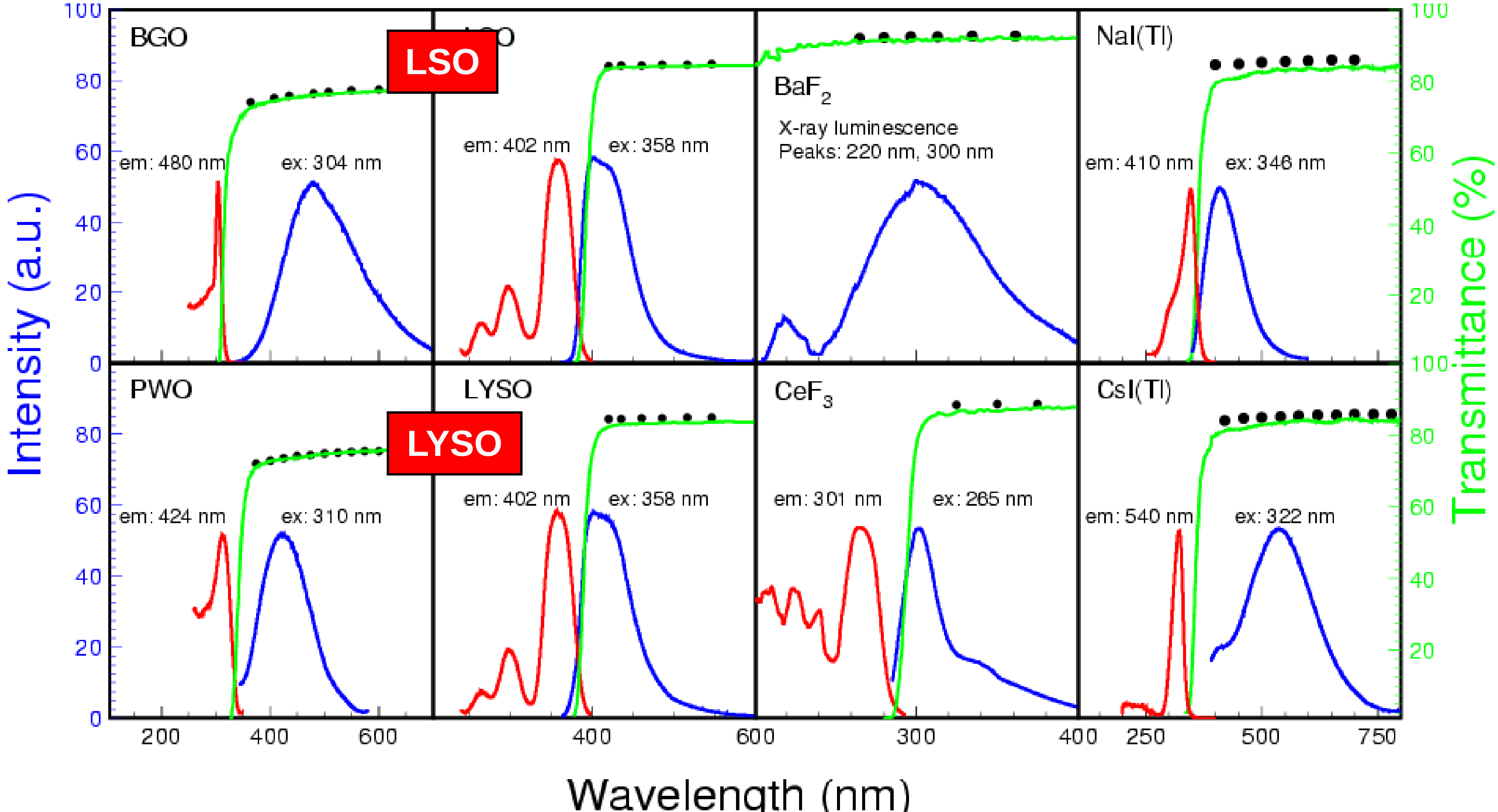


Excitation, Photo-Luminescence, Transmission

$$T_s = (1-R)^2 + R^2(1-R)^2 + \ldots = (1-R)/(1+R), \text{ with}$$

$$R = \frac{(n_{crystal} - n_{air})^2}{(n_{crystal} + n_{air})^2}.$$

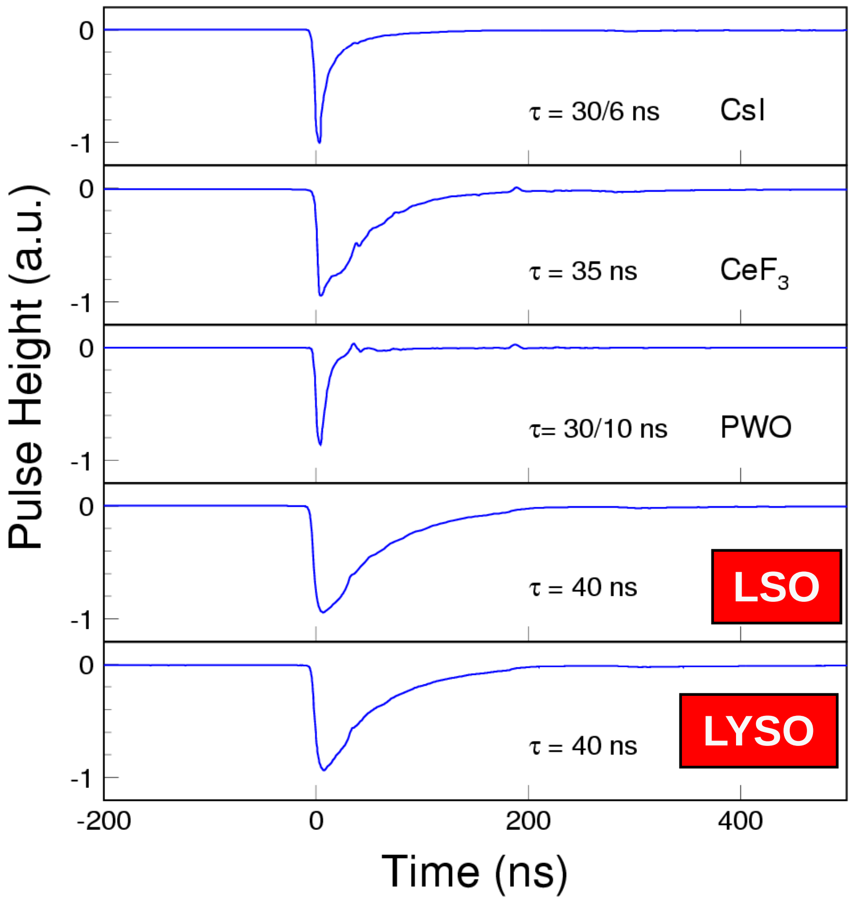
Black Dots: Theoretical limit of transmittance: NIM **A333** (1993) 422



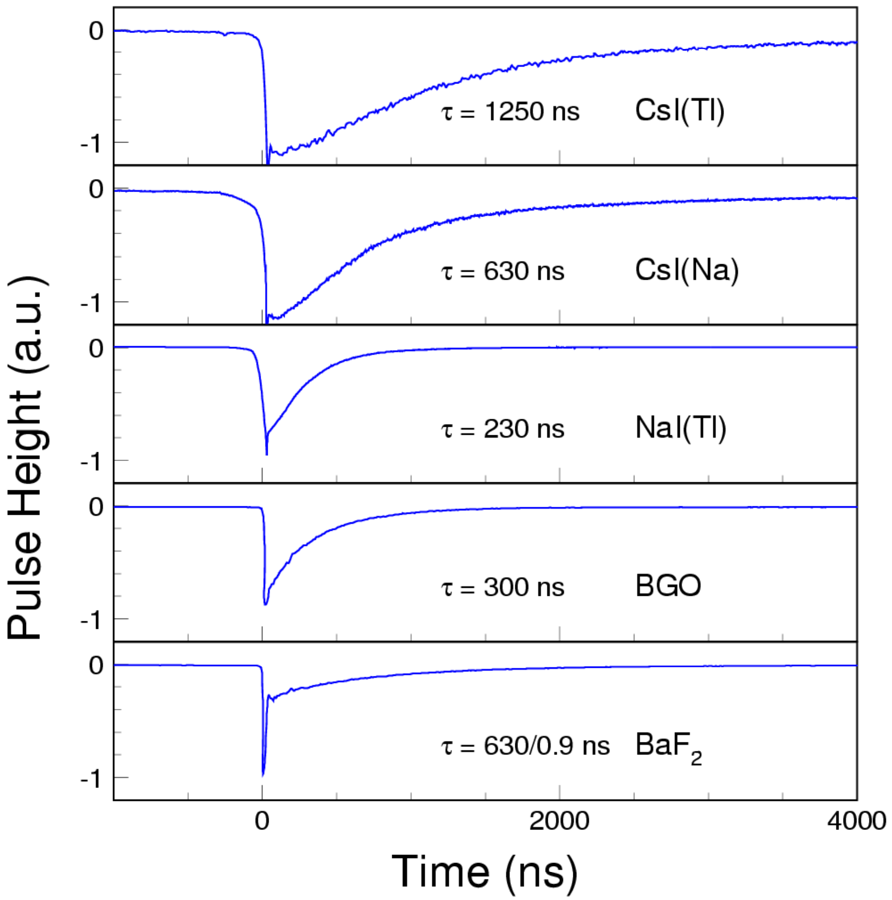
Scintillation Light Decay Time

Recorded with Agilent 6052A digital scope

Fast Scintillators



Slow Scintillators



Temperature Dependent Light Output

LSO/LYSO light output has a small temperature coefficient

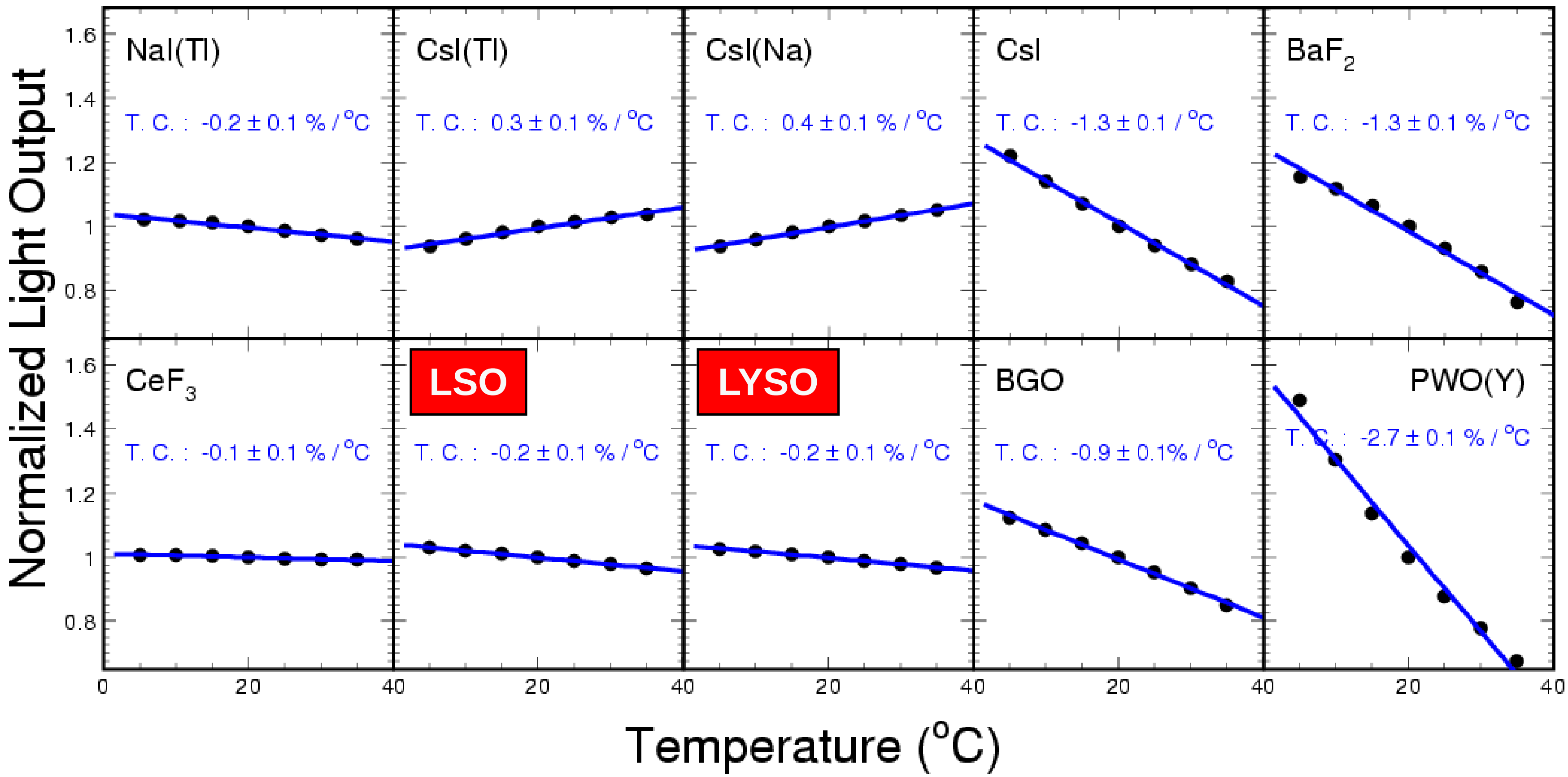
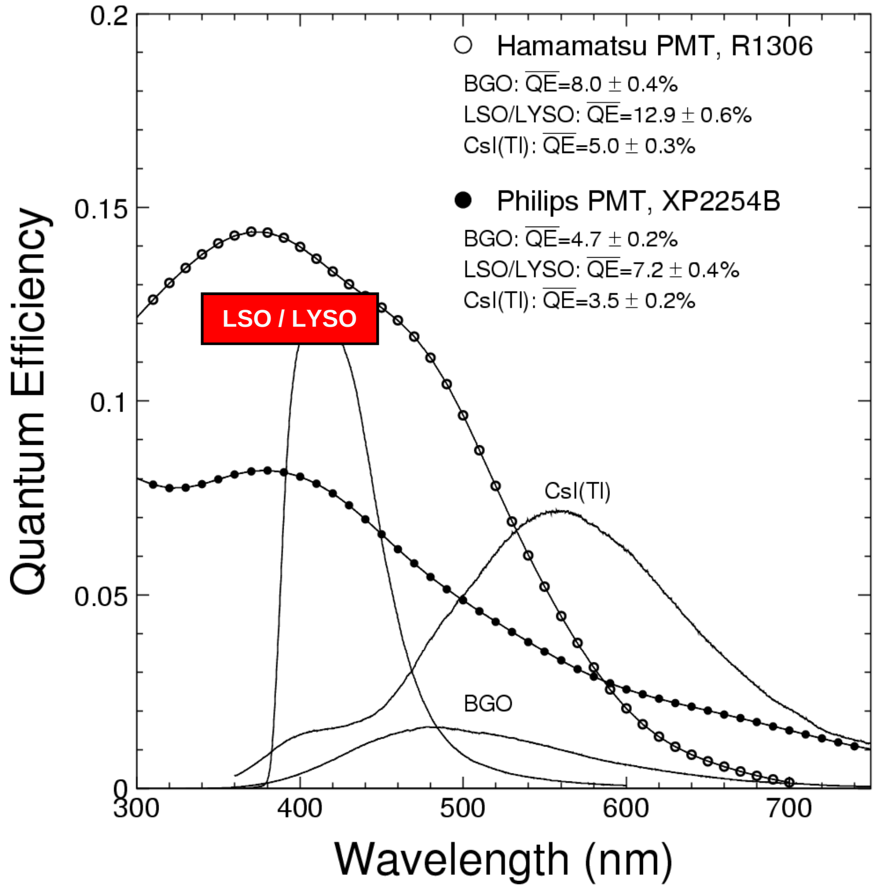
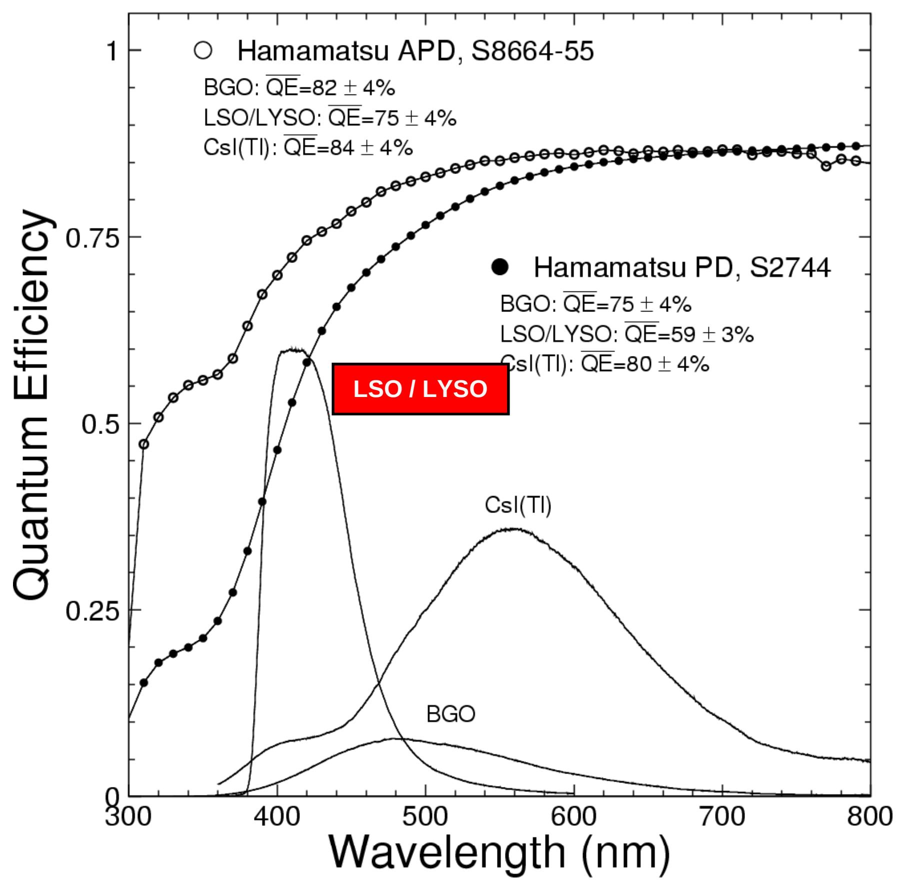


Photo-Luminescence Weighted Q.E.

Taking out QE, L.O. of LSO/LYSO is 4/200 times BGO/PWO
Hamamatsu S8664-55 APD has QE 75% for LSO/LYSO



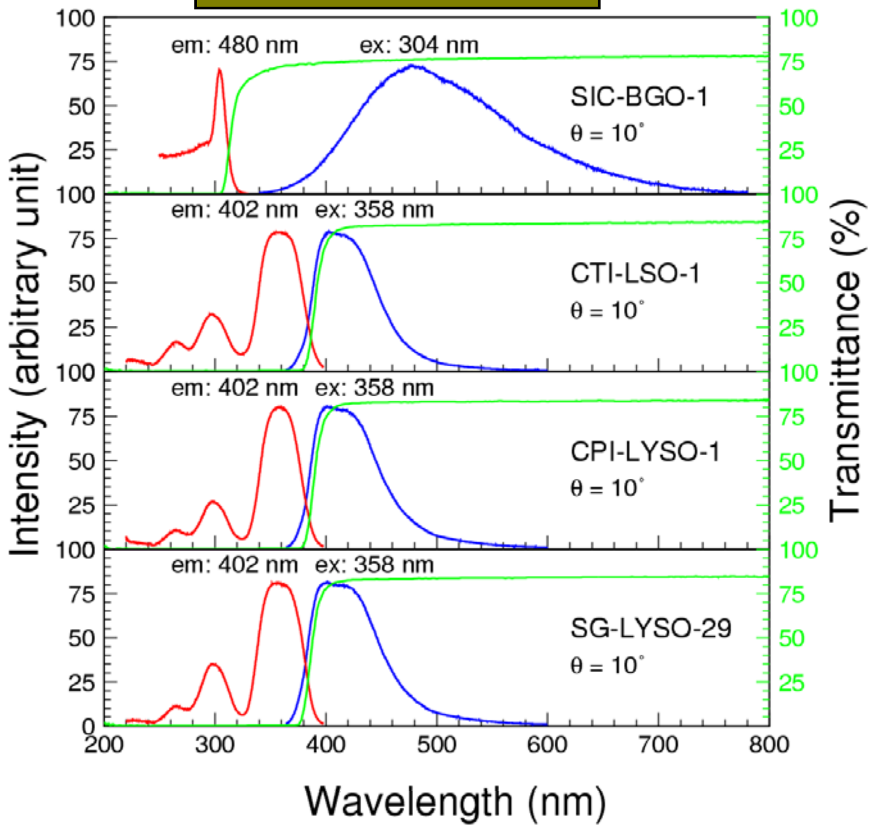


Excitation, Photo-Luminescence, Transmission

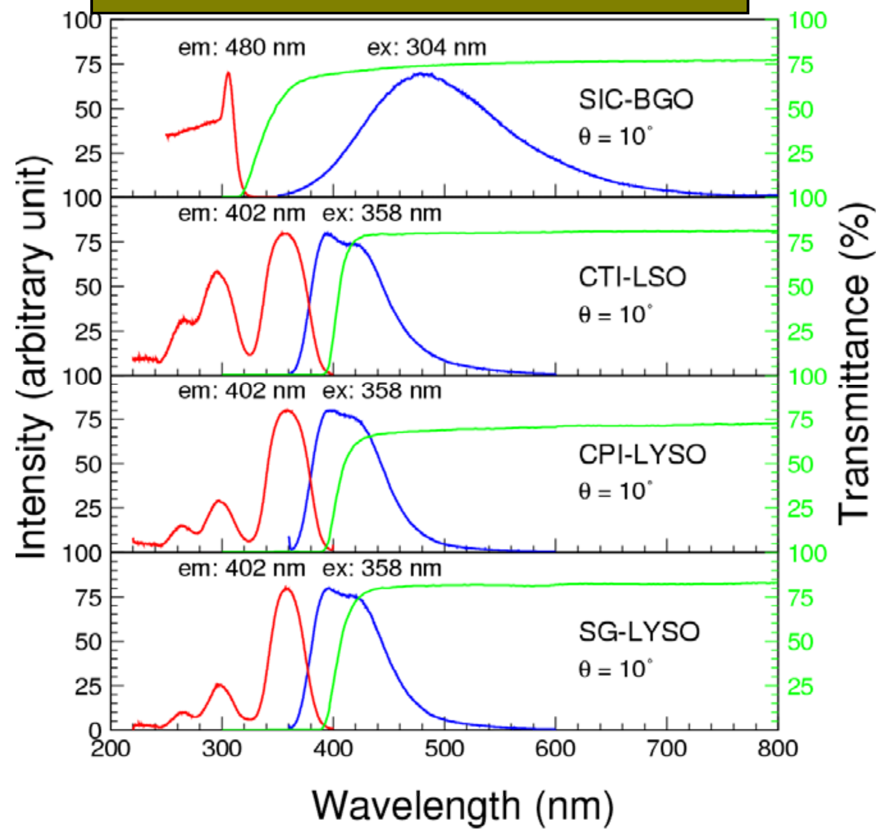
Identical transmittance, emission & excitation spectra

Part of emitted light may be self-absorbed in long samples

1.7 cm Cube

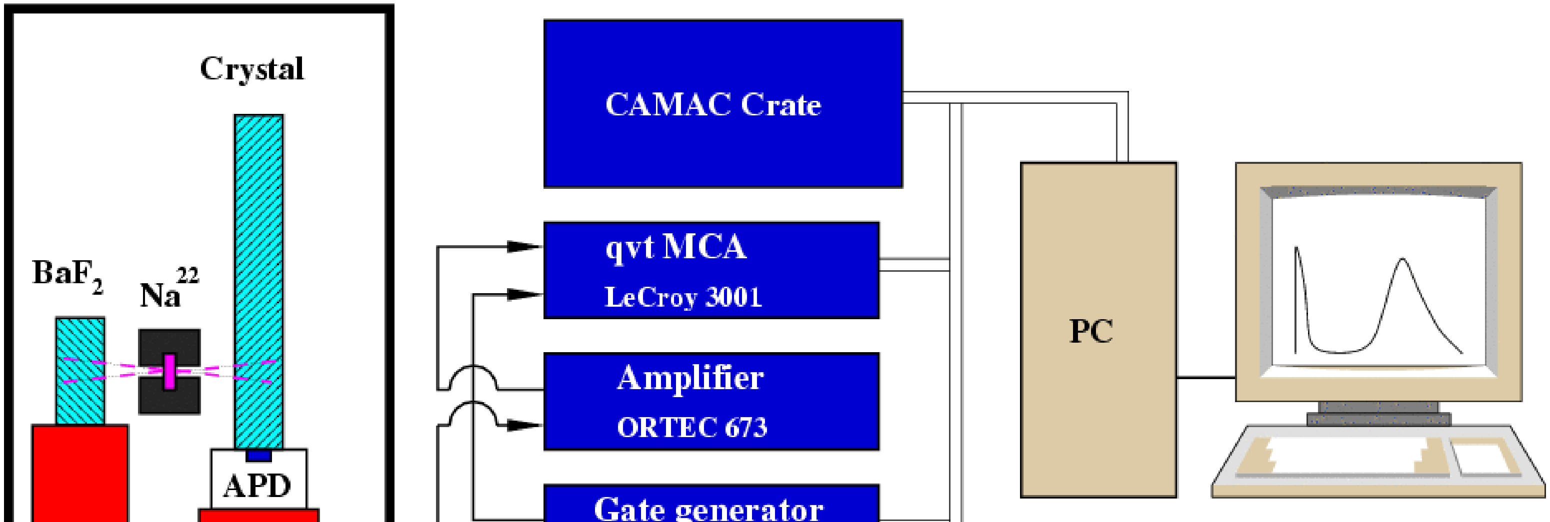


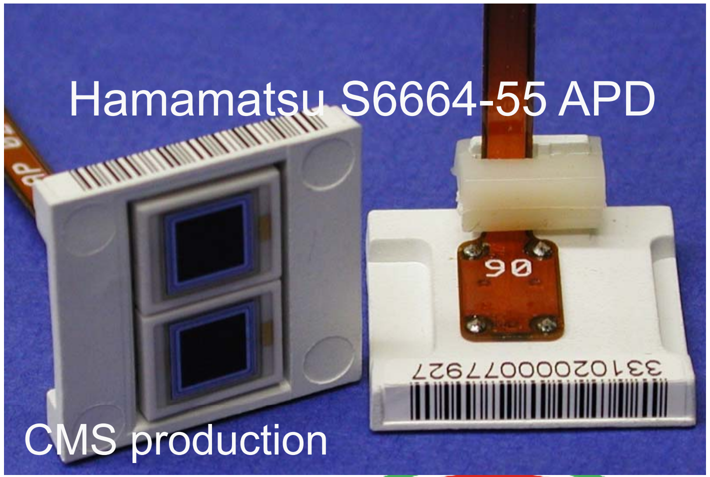
2.5 x 2.5 x 20 cm Bar



APD readout with coincidence (^{22}Na)

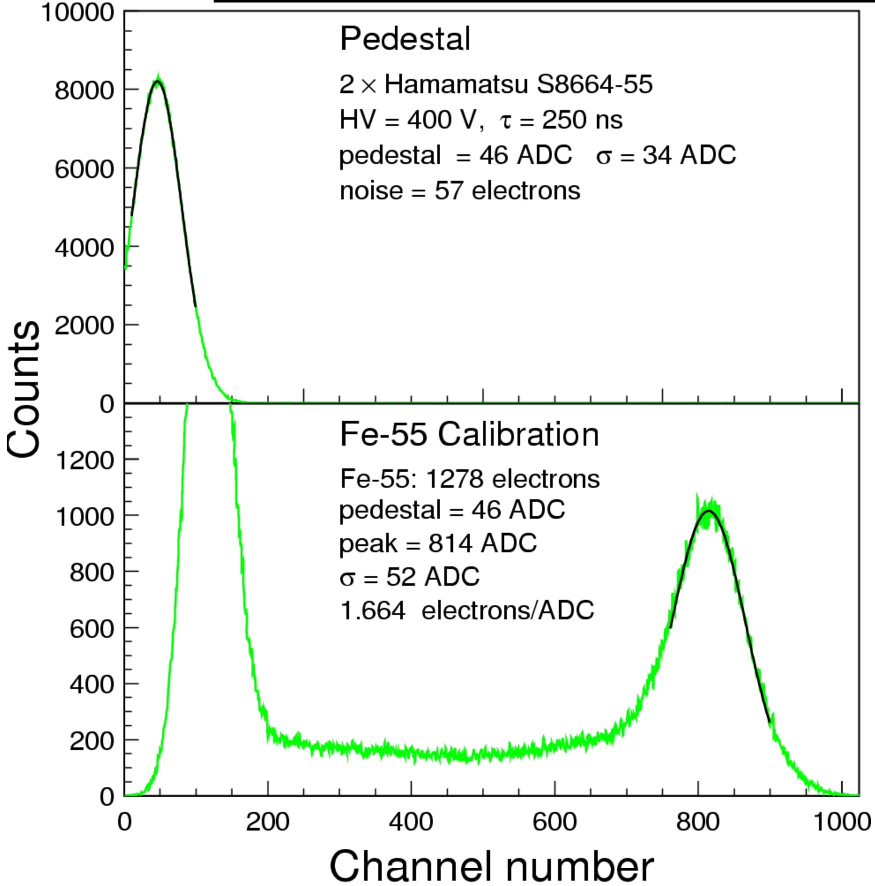
Two Hamamatsu S6664-55 APD, Canberra 2003 BT preamplifier and ORTEC 673 shaping amplifier with shaping time 250 ns

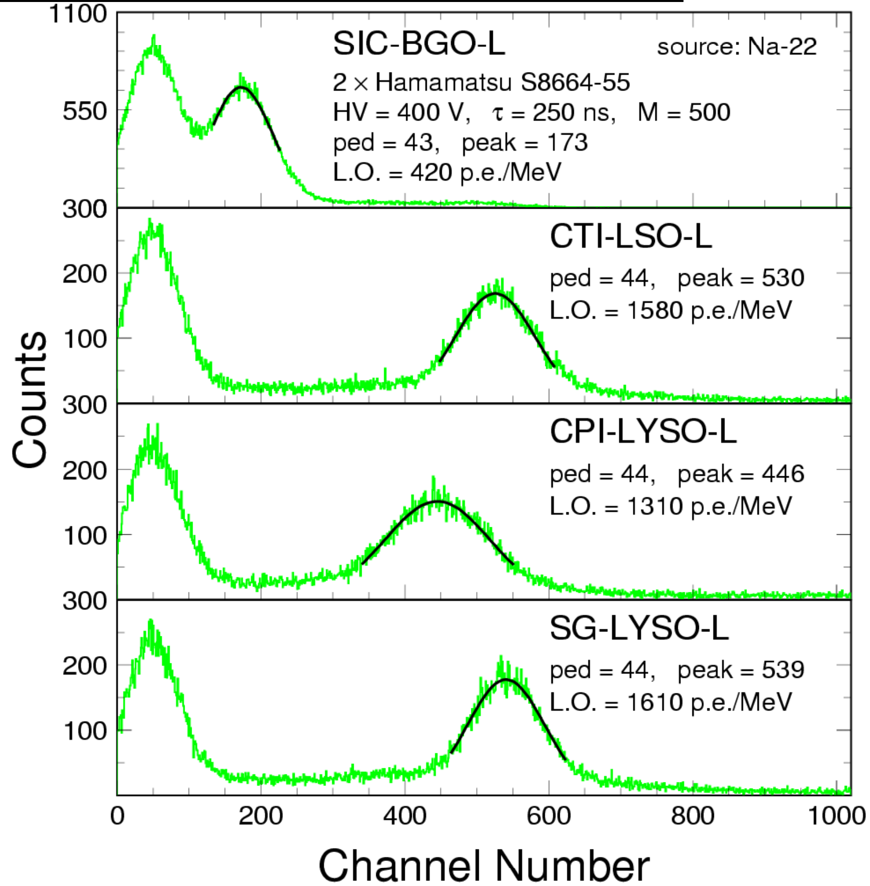




LSO/LYSO with APD readout

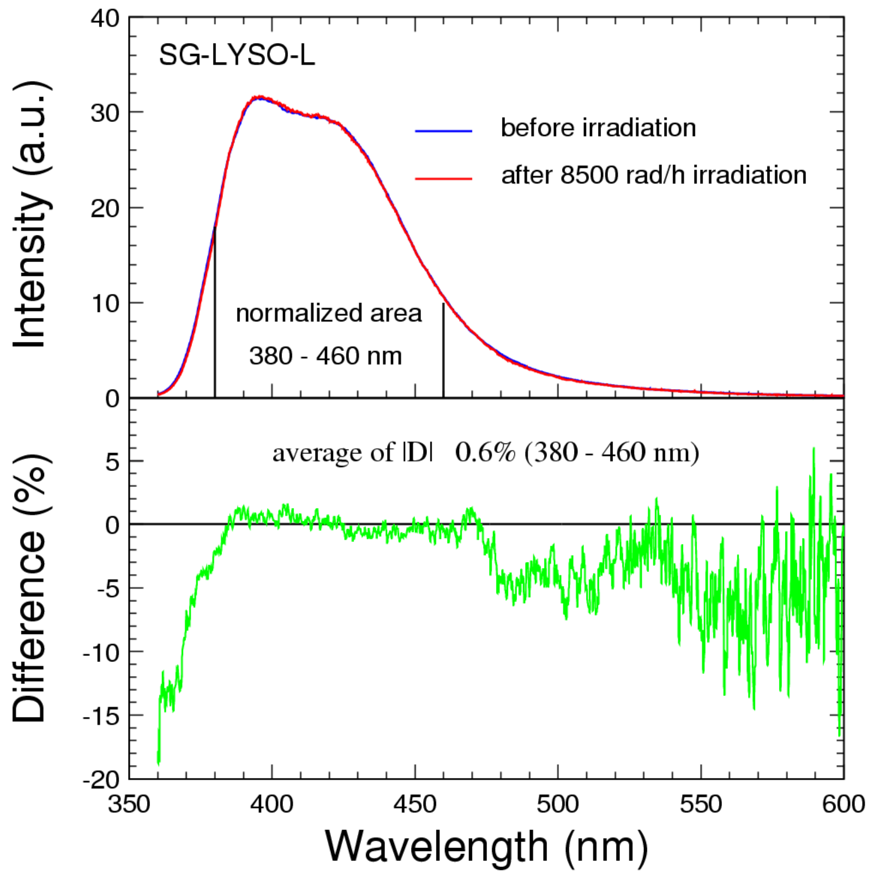
L.O.: 1,500 p.e./MeV, 4/200 times of BGO/PWO
Readout Noise: < 40 keV



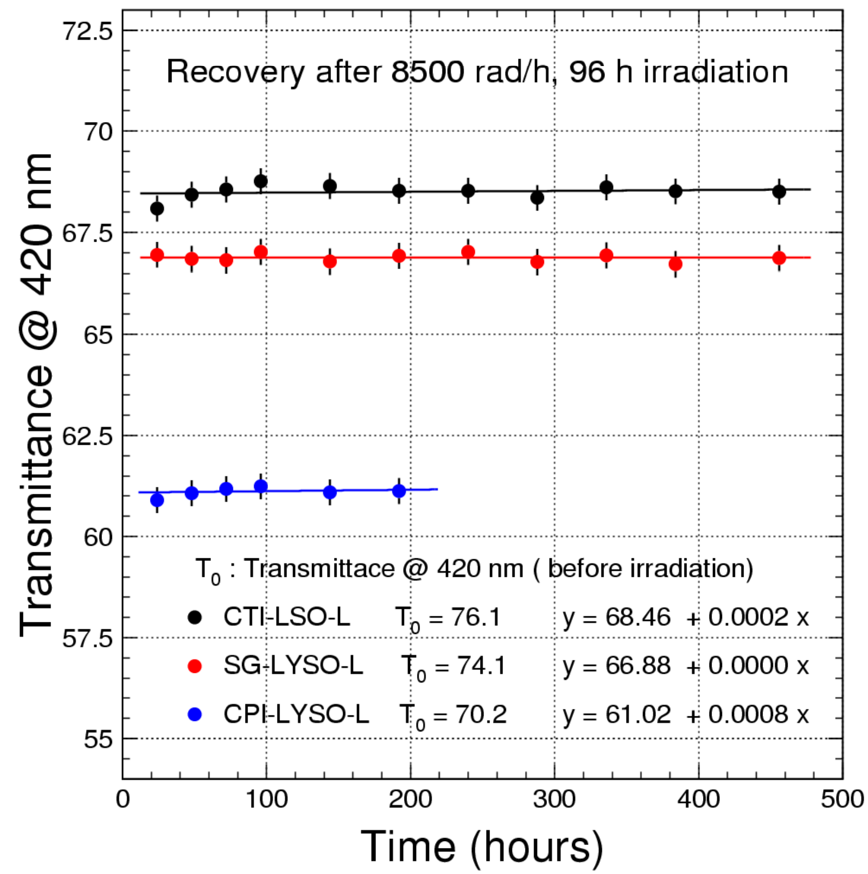


γ ray-induced damage in LSO/LYSO

No damage in Photo-Luminescence

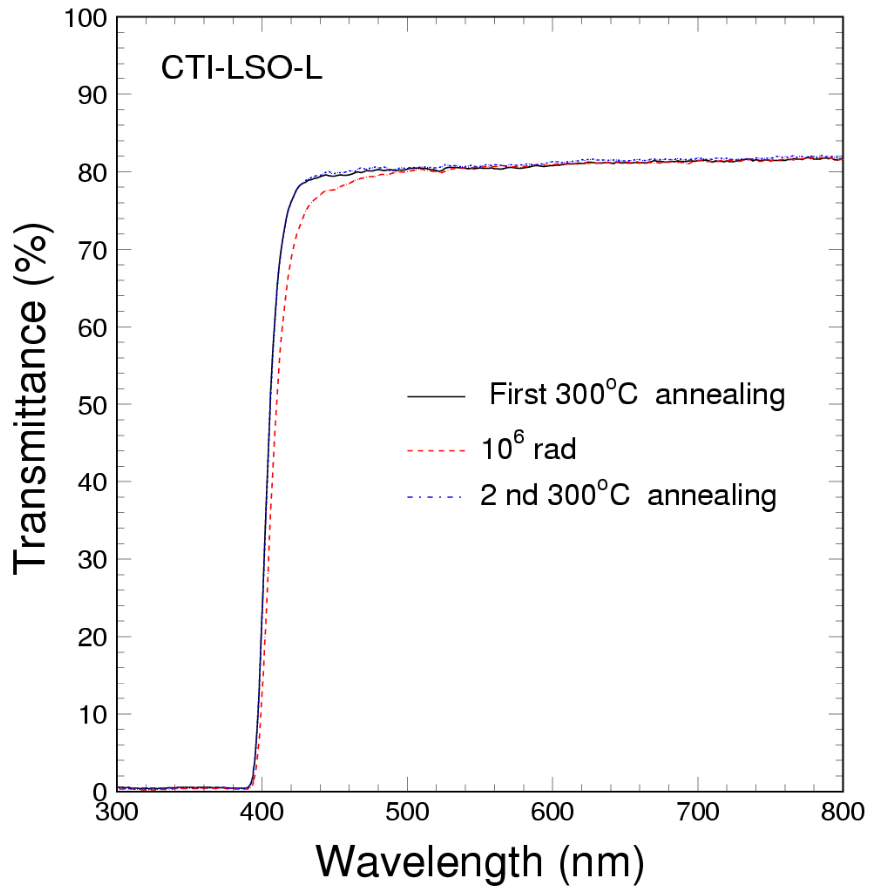


LT Recovery very slow

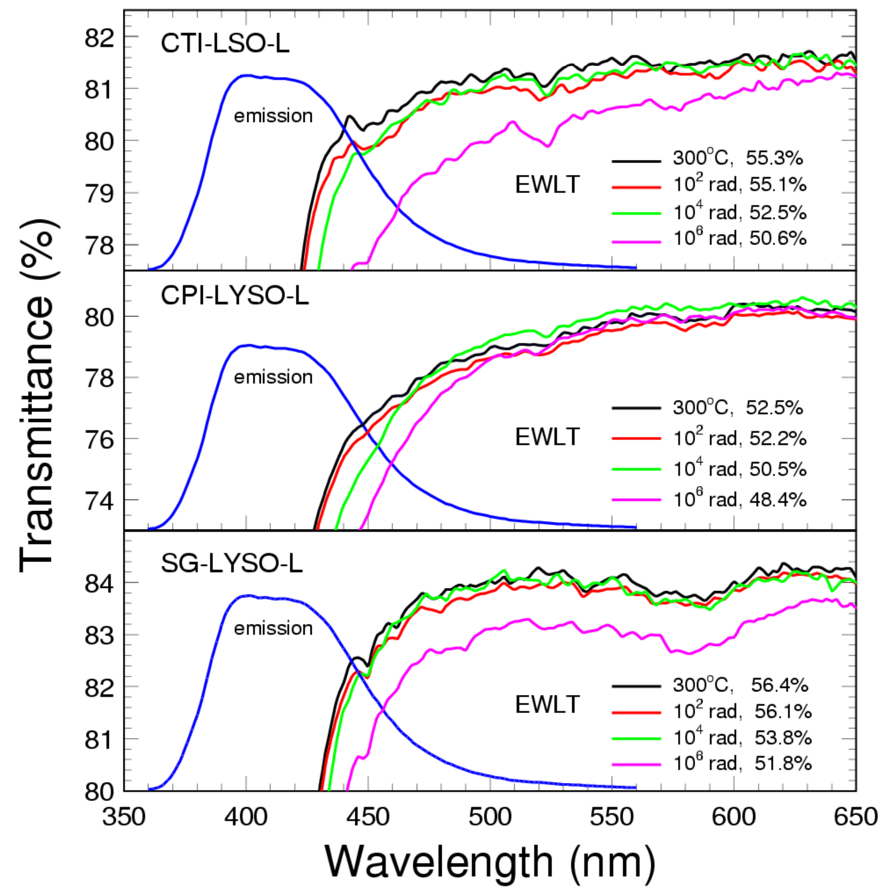


Transmittance damage

300°C thermal annealing effective



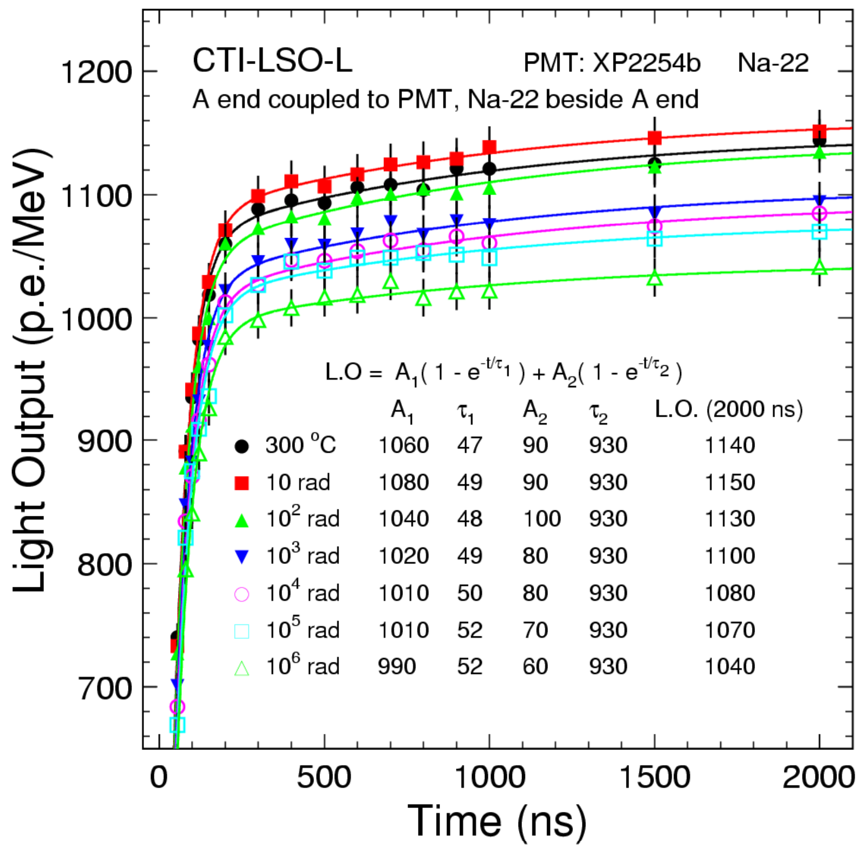
LT damage: 8% @ 1 Mrad



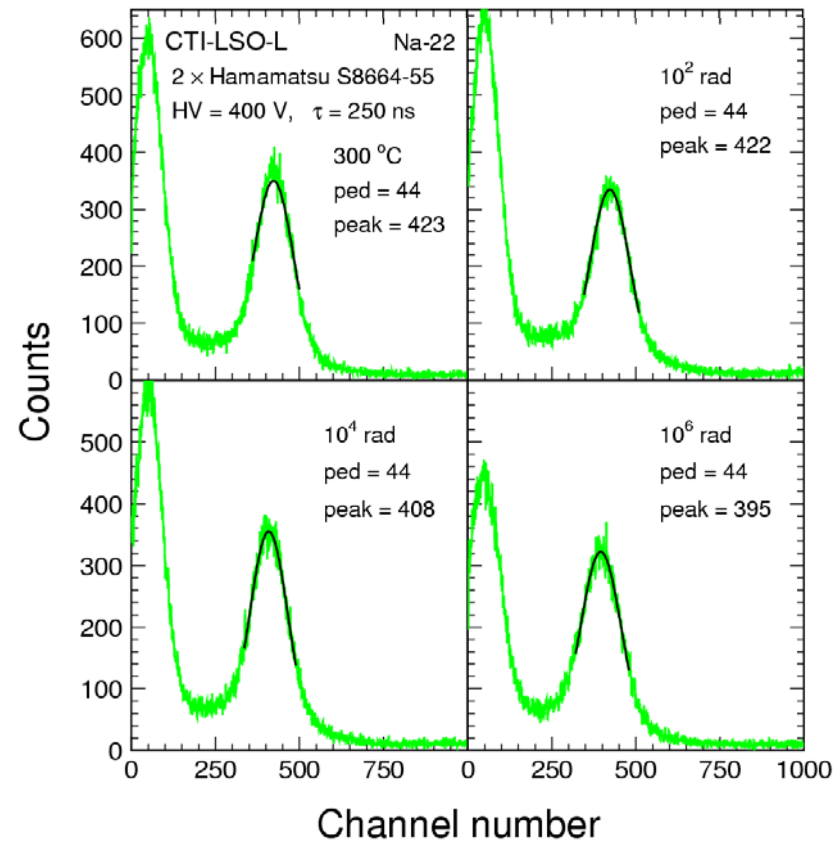
Light output damage

Typical light output loss: about 8% to 12% @ 1 Mrad

PMT Readout

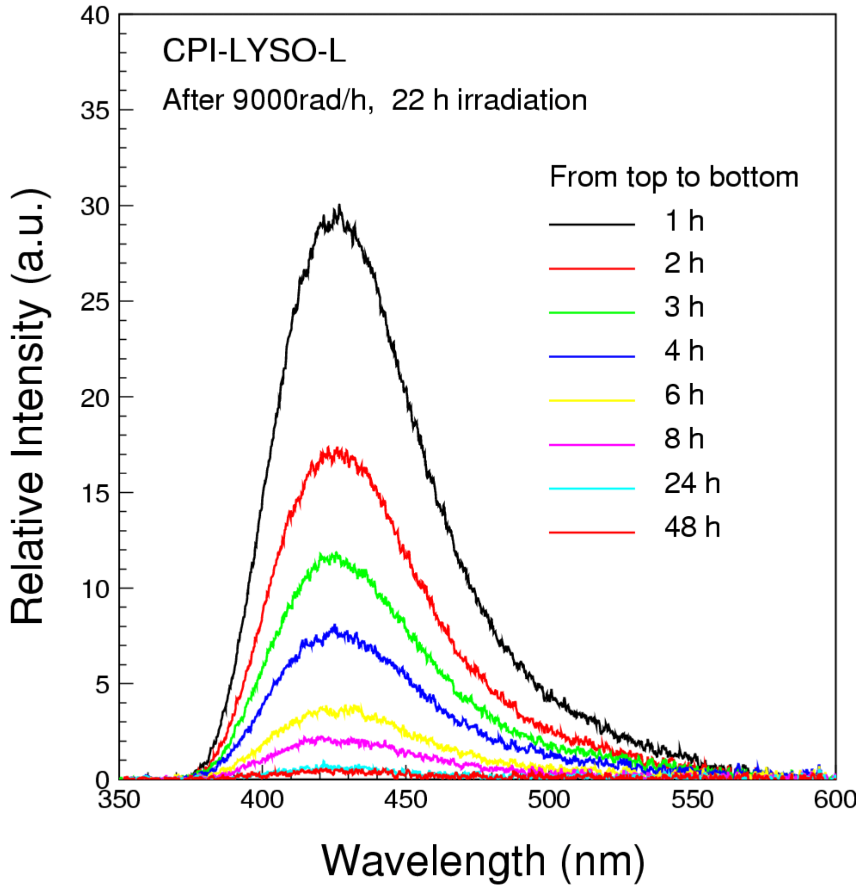


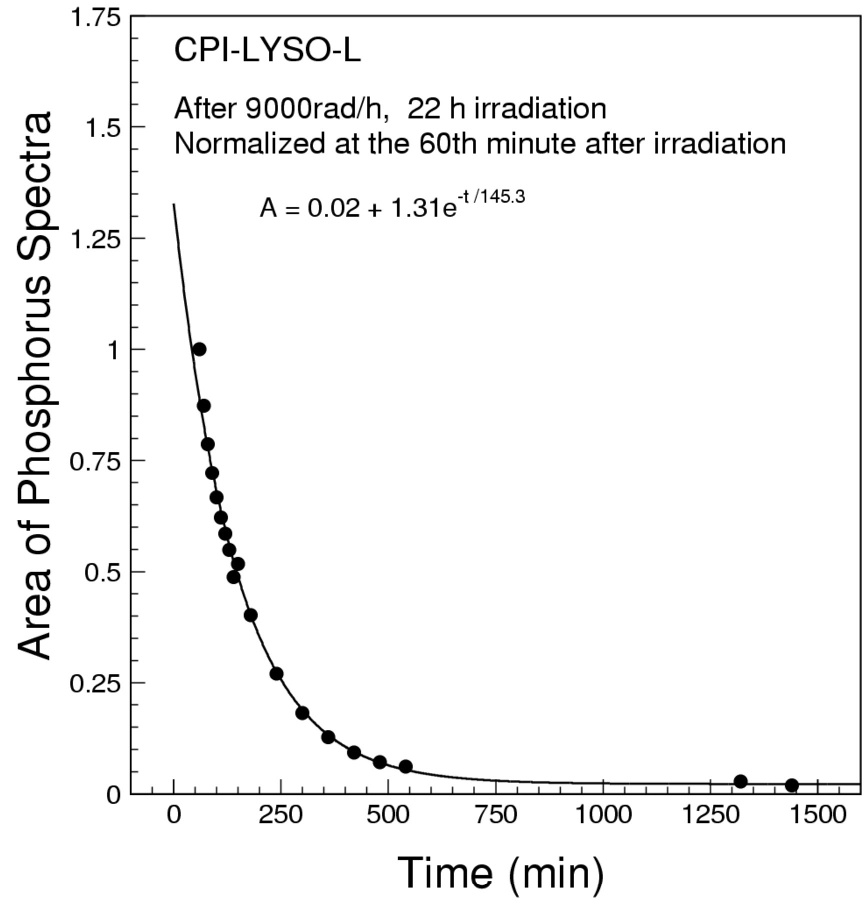
APD Readout



Radiation-induced phosphorescence

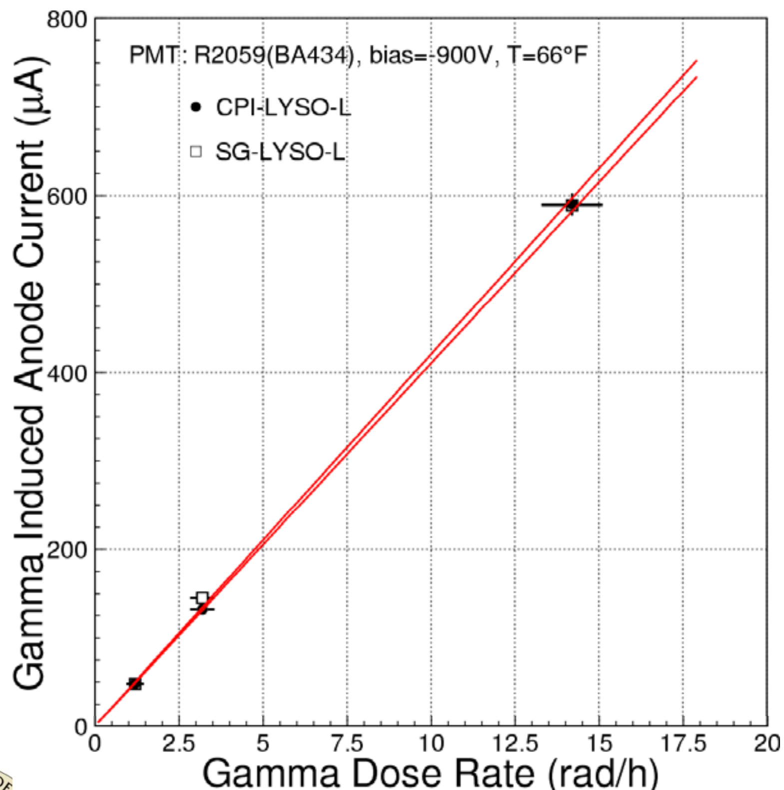
Phosphorescence peaks at 430 nm
with decay time constant of 2.5 h





γ ray-induced readout noise

Sample ID	L.Y. p.e./MeV	F μA/rad/h	$Q_{15\ rad/h}$ p.e.	$Q_{500\ rad/h}$ p.e.	$\sigma_{15\ rad/h}$ MeV	$\sigma_{500\ rad/h}$ MeV
CPI	1,480	41	6.98×10^4	2.33×10^6	0.18	1.03
SG	1,580	42	7.15×10^4	2.38×10^6	0.17	0.97



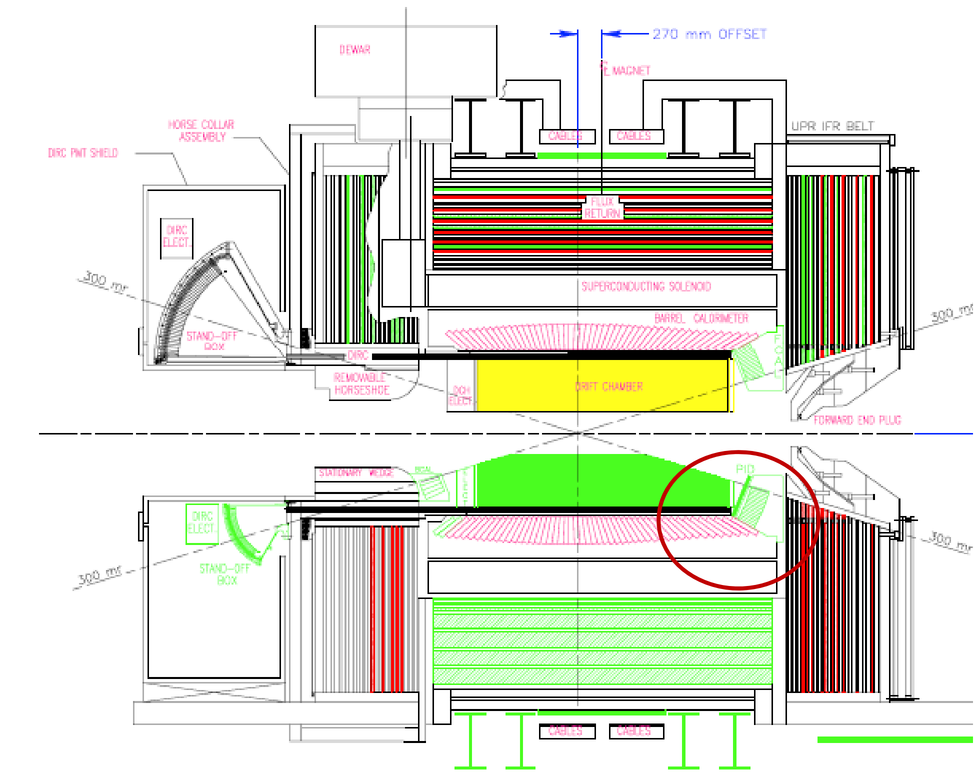
γ–ray induced PMT anode current can be converted to the photoelectrons (Q) integrated in a 100 ns gate. Statistical fluctuations in this charge contributes to readout noise (σ)

LSO/LYSO EMC performance summary

- Very high light output
- Good match to APD or PD
- Small temperature coefficient of emission
- Radiation damage is less of an issue than other crystals
- Energy resolution should be better at low energies than L3 BGO CMS PWO and BABAR/Belle CsI (Tl) because of high light output and low readout noise: (R-y.Z. prediction):

$$2.5\% / \sqrt{E} \oplus 0.55\% \oplus 0.2 / E$$

Forward endcap layout



Ring in ϕ	Radius (mm)	Crystal Face (mm)	Crystal Volume (cc)	# Crystals
1	597-620	24.4× 31.9	171	120
2	620-643	24.4× 33.1	178	120
3	643-666	24.4× 29.4	158	140
4	666-689	24.4× 30.5	164	140
5	689-712	24.4× 27.5	148	160
6	712-735	24.4× 28.4	152	160
7	735-758	24.4× 26.1	140	180
8	758-781	24.4× 26.9	144	180
9	781-804	24.4× 24.9	134	200
10	804-827	24.4× 25.6	137	200
11	827-850	24.4× 23.9	128	220
12	850-873	24.4× 24.6	132	220
13	873-896	24.4× 23.2	125	240
14	896-919	24.4× 23.8	128	240

.36 m^3 2520 crystals

Endcap calorimeter R&D, design

- Next steps
  - A beam test with a ~49 crystal array, using Hamamatsu (CMS) APD readout, or equivalent
    - Form an international R&D collaboration
  - Mechanical design and prototypes of forward endcap, possible vestigial rear endcap for neutral hermeticity
    - LYSO is mechanically strong
      - Do not need to support individual crystals, à la CsI(Tl) in *BABAR*
      - Less material between crystals should further improve energy resolution
  - Electronics: new frontend optimized for 40 ns decay time, APD readout and new DAQ design

Production capability

- There is a lot of LSO, LYSO production capacity, but the $/cc is expensive
- Zhu has been working with Chinese crystal growers to reduce the price and improve quality (remove trace elements that are the source of phosphorescence, improve Ce doping uniformity, optimize boule size)
  - The most advanced relationship is with SIPAT in Sichuan
  - They have given us a written quote for $15/cc
  - They have produced crystals of the required length, of a diameter large enough to yield several crystals, but have had difficulty with lengthwise cutting

LSO/LYSO Mass Production

CTI: LSO

CPI: LYSO

Saint-Gobain LYSO

Sichuan Institute of Piezoelectric and Acousto-optic Technology (SIPAT)

SIPAT LSO

Quoted Price: 15 USD/cc

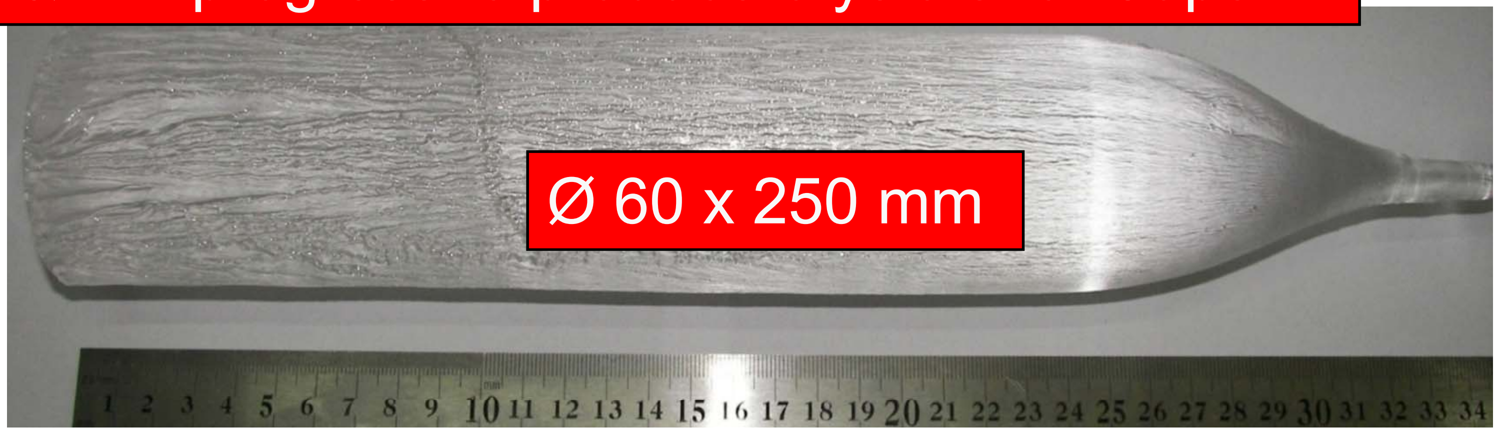
Φ80 x 70

Φ80 x 120

Large size LSO ($Ce:Lu_2SiO_5$) crystals are in production

First SIPAT LYSO boule for HEP

R&D in progress to produce crystals for Super*B*



Ø 60 x 250 mm

Broken after 1st cut for two 2.5 x 2.5 x 20 cm samples