Optical and Scintillation Properties of Heavy Crystal Scintillators

Rihua Mao, Liyuan Zhang and Ren-yuan Zhu

California Institute of Technology

Introduction

- This is a part of the work to improve the inorganic scintillator section in the particle data book (PDB). The crystal table in the PDB provides a comparison of light output measured by PMTs with a bi-alkali cathode for samples with undefined size and wrapping.

- To accommodate readout devices other than PMT with bi-alkali cathode, such as silicon photodiode (PD) and avalanche photodiode (APD), the quantum efficiencies (QE) of the PMT should be taken out. To reduce sample size and wrapping dependence samples should have defined dimension and wrapping.

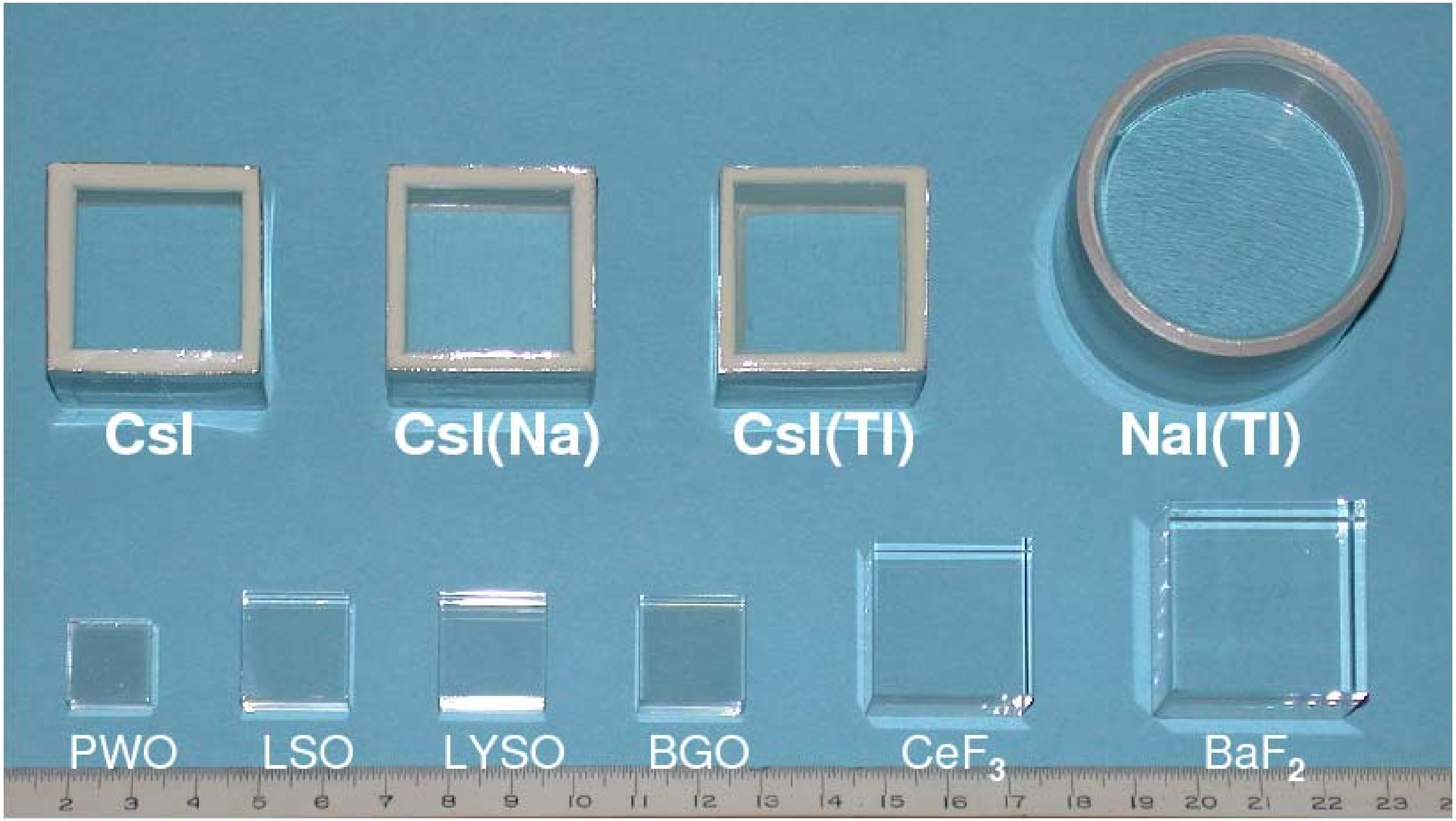
- Properties investigated: UV excitation and emission spectra, optical transmittance, light output, decay kinetics and temperature coefficient.

Inorganic Scintillators in the 2006 PDB

Crystal	NaI(Tl)	CsI(Tl)	CsI	BaF_2	BGO	$PbWO_4$	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	560	420 310	300 220	480	560 420	420	440
Decay Time [b] (ns)	230	1300	35 6	630 0.9	300	50 10	40	60
Light Yield [b,c] (%)	100	45	5.6 2.3	21 2.7	13	0.1 0.6	75	30
d(LY)/dT [b] (%/ ºC)	~0	0.3	-0.6	-2 ~0	-1.6	-1.9	~0	-0.1
Experiment	Crystal Ball	CLEO BaBar BELLE BES III	KTeV	TAPS (L*) (GEM)	L3 BELLE PANDA?	CMS ALICE PANDA? (BTeV)…	-	-

a. at peak of emission; b. up/low row: slow/fast component; c. measured by PMT of bi-alkali cathode.

Samples

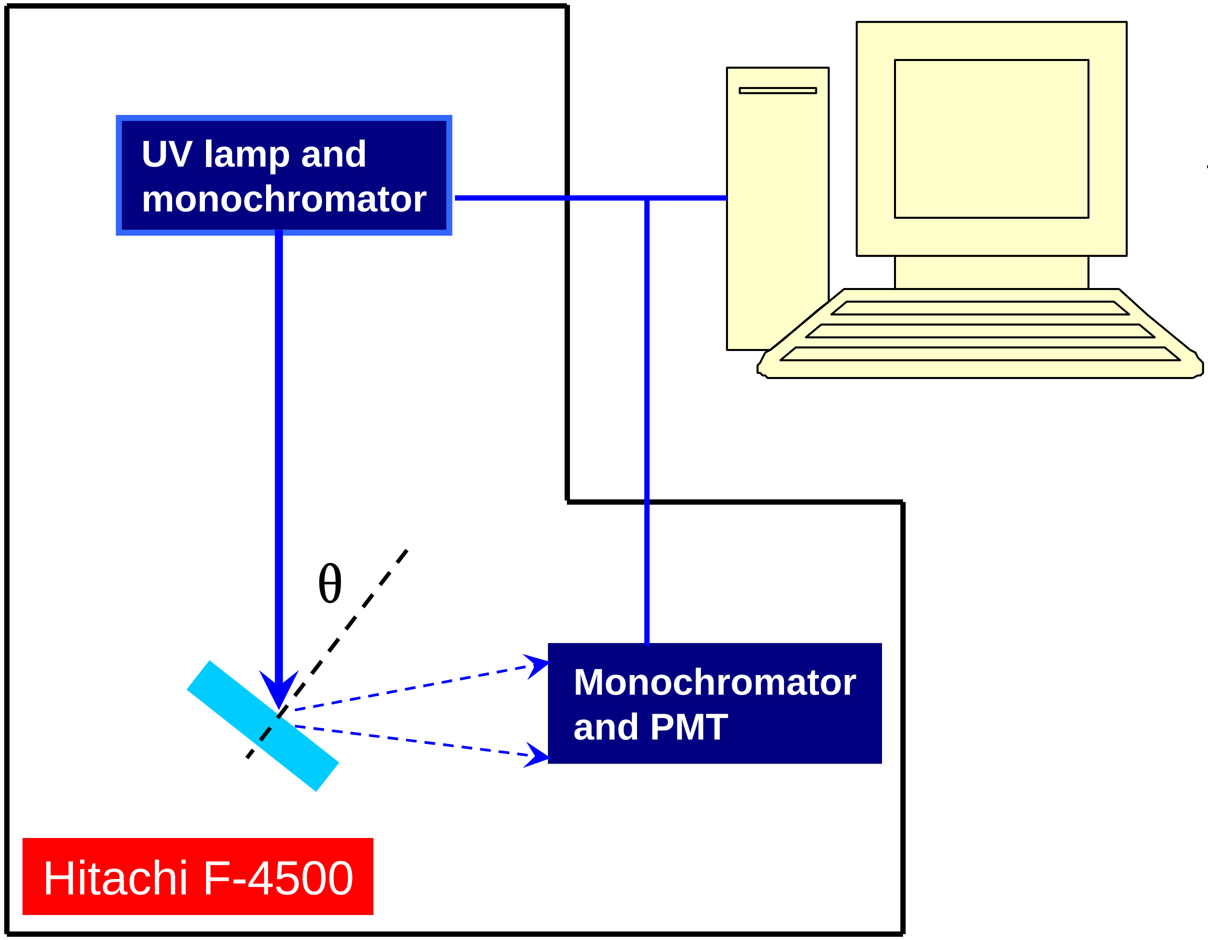


Sample size: All are cube of 1.5 X_0. NaI(Tl) is a cylinder of 1.5 X_0 long and 1.5 $\times$ 1.5 X_0^2 area at two ends to match 2” PMT.

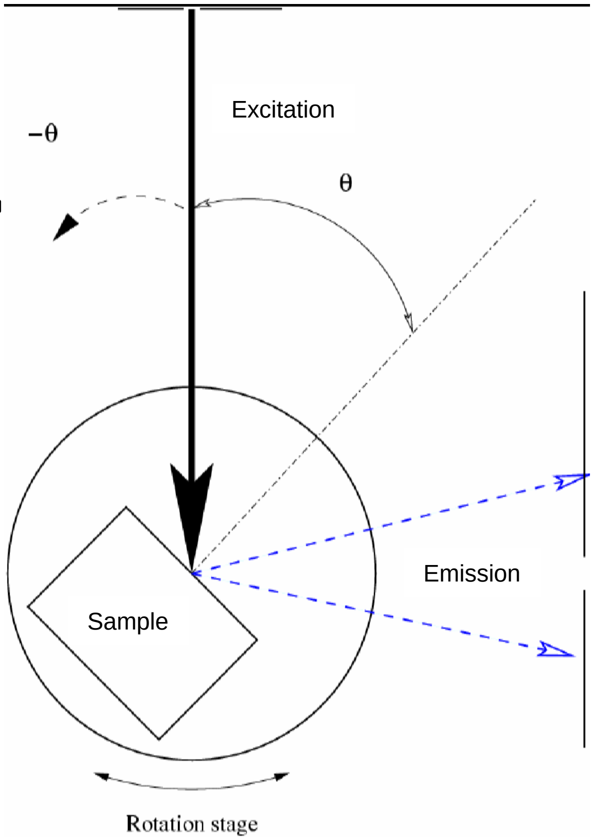
Sample Wrapping: All are wrapped with Tyvek paper. Hygroscopic samples (NaI and CsI) are sealed in 3 mm thick quartz window.

Excitation & Photo Luminescence

Emission measured with θ = 10º: No internal absorption

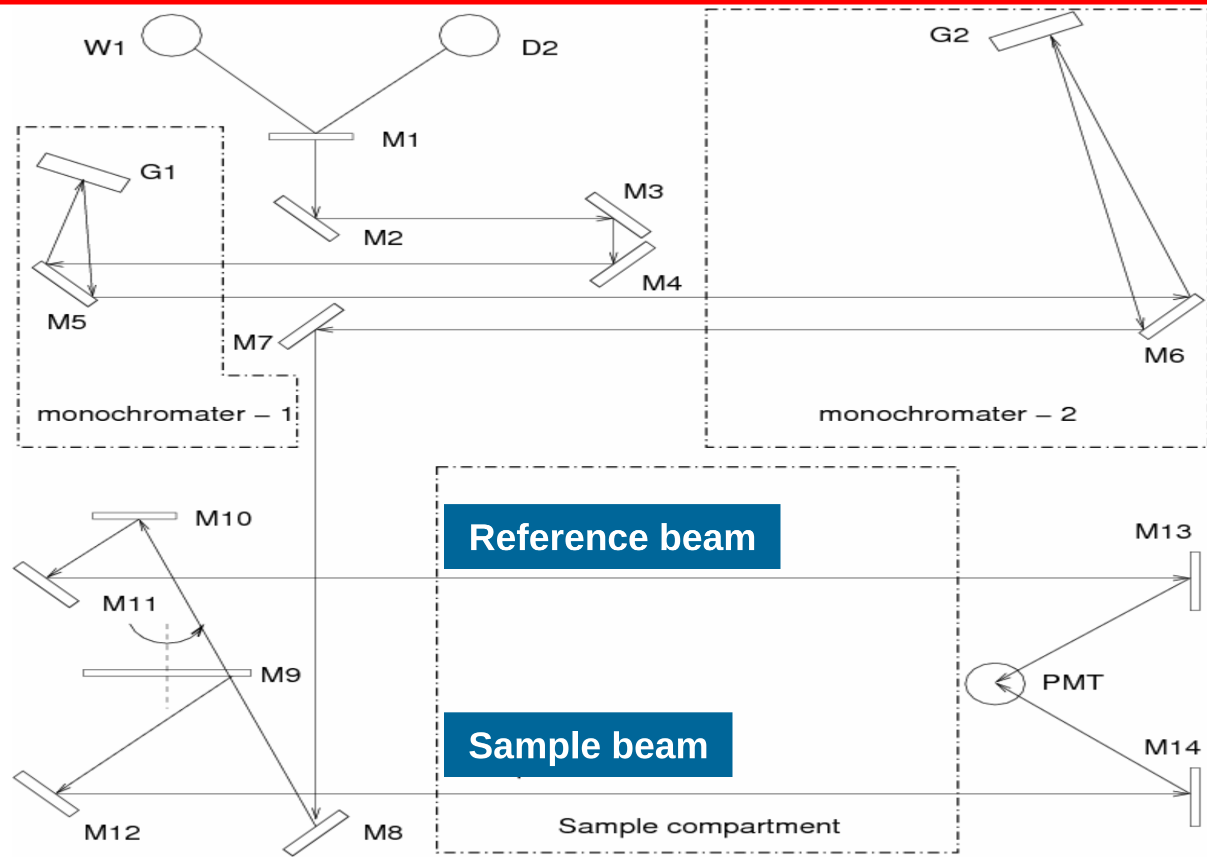


Sample Orientation



Transmittance Measurement

Perkin Elmer Lambda-950 spectrophotometer with double beam, double monochromator and GPOB



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

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

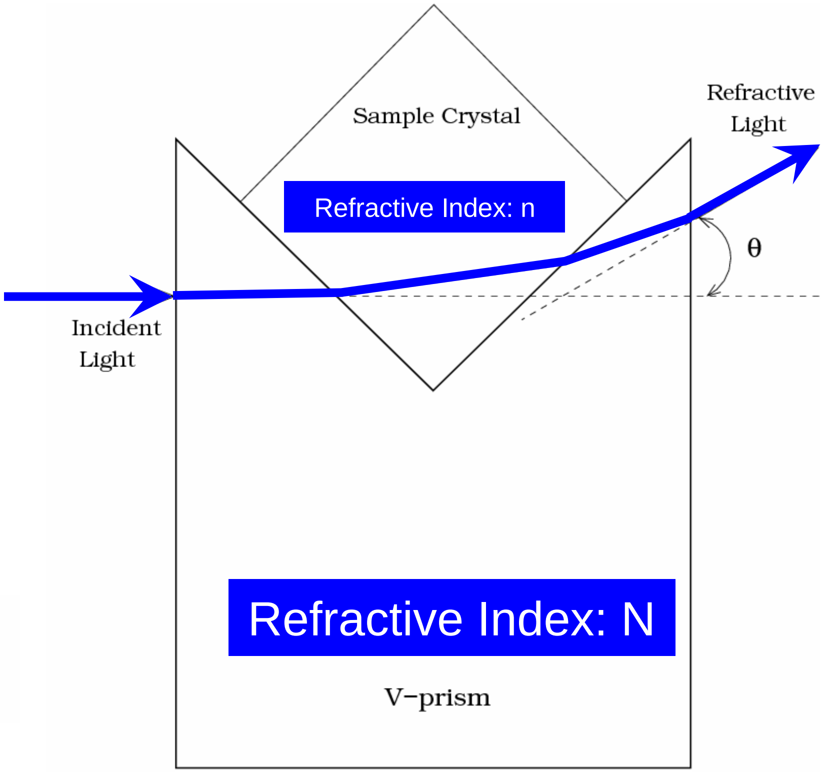
Theoretical limit: R.Y. Zhu, NIM **A333** (1993) 422

LSO/LYSO Refractive Index

Wavelength dependent measurement by a V-prism

- Cubic sample placed inside a V-prism
- Incident light shooting perpendicularly to one side of the prism
- The refractive index is calculated according to the following the equation:

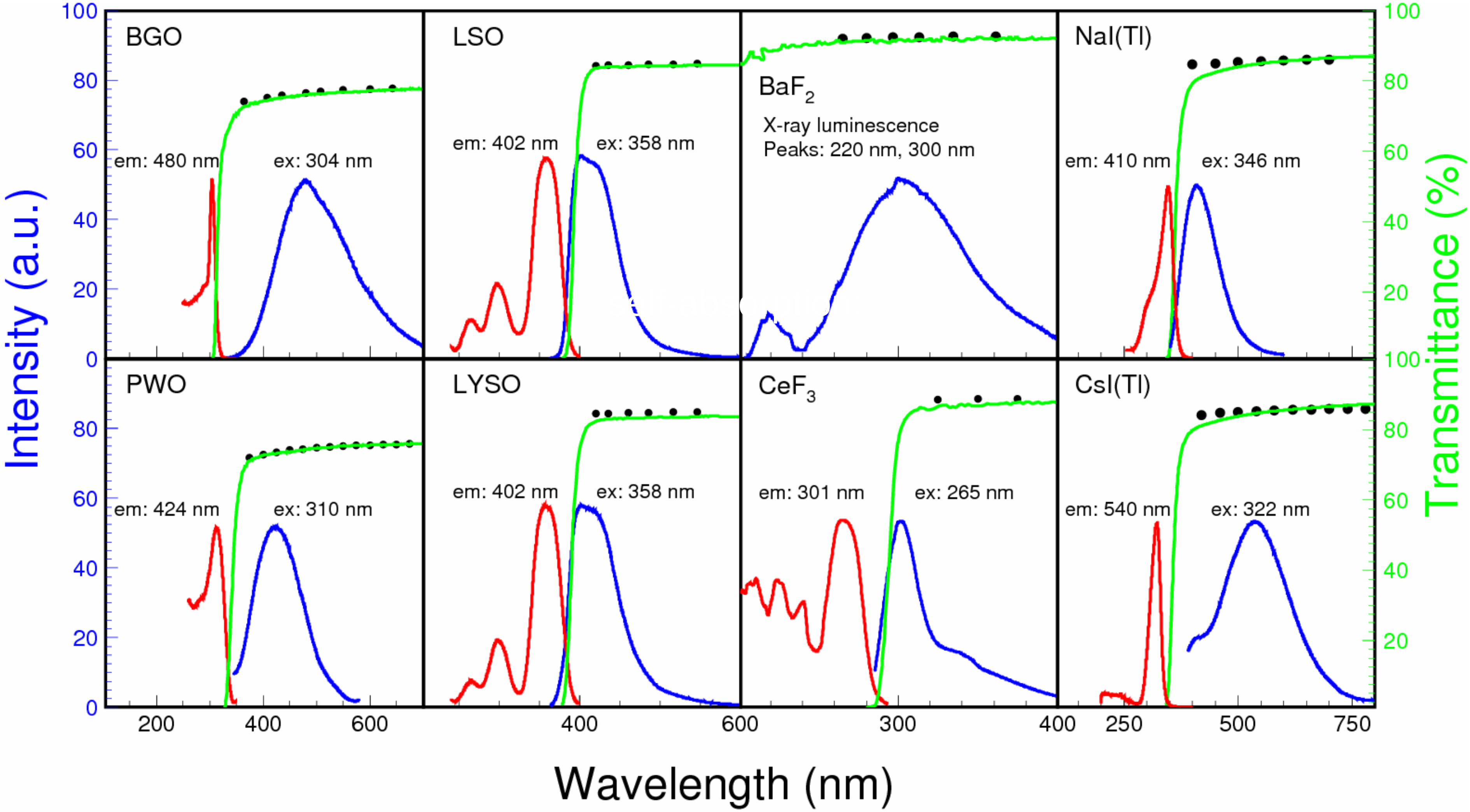
$$n = \left(N^2 + \sin\theta\sqrt{N^2 - \sin^2\theta} \right)^{\frac{1}{2}}$$



λ (nm)	405	420	436	461	486	516	546
R. I.	1.833	1.827	1.822	1.818	1.813	1.810	1.806

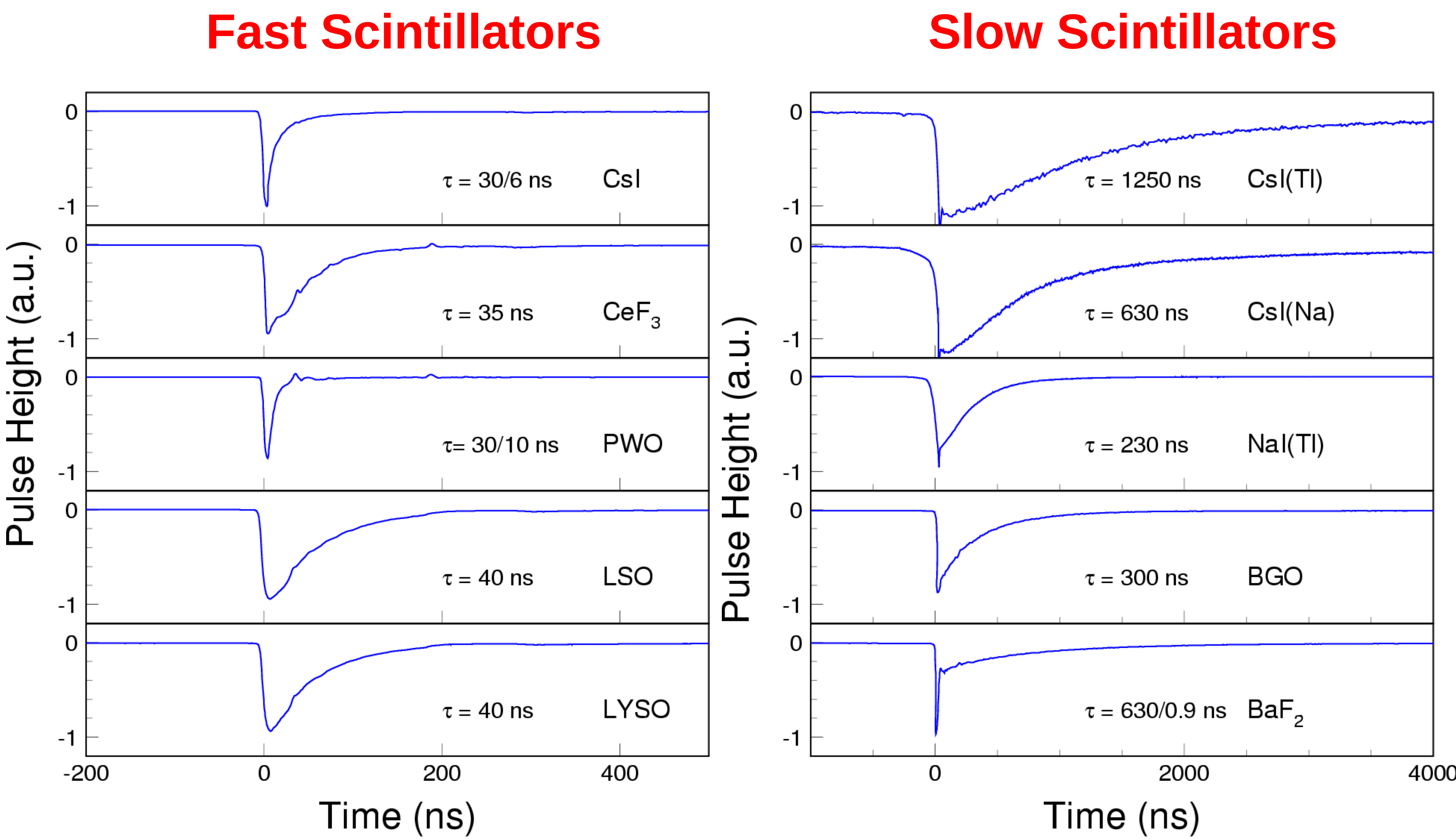
Excitation, Emission, Transmittance

Watch emission versus transmittance edge for self-absorption

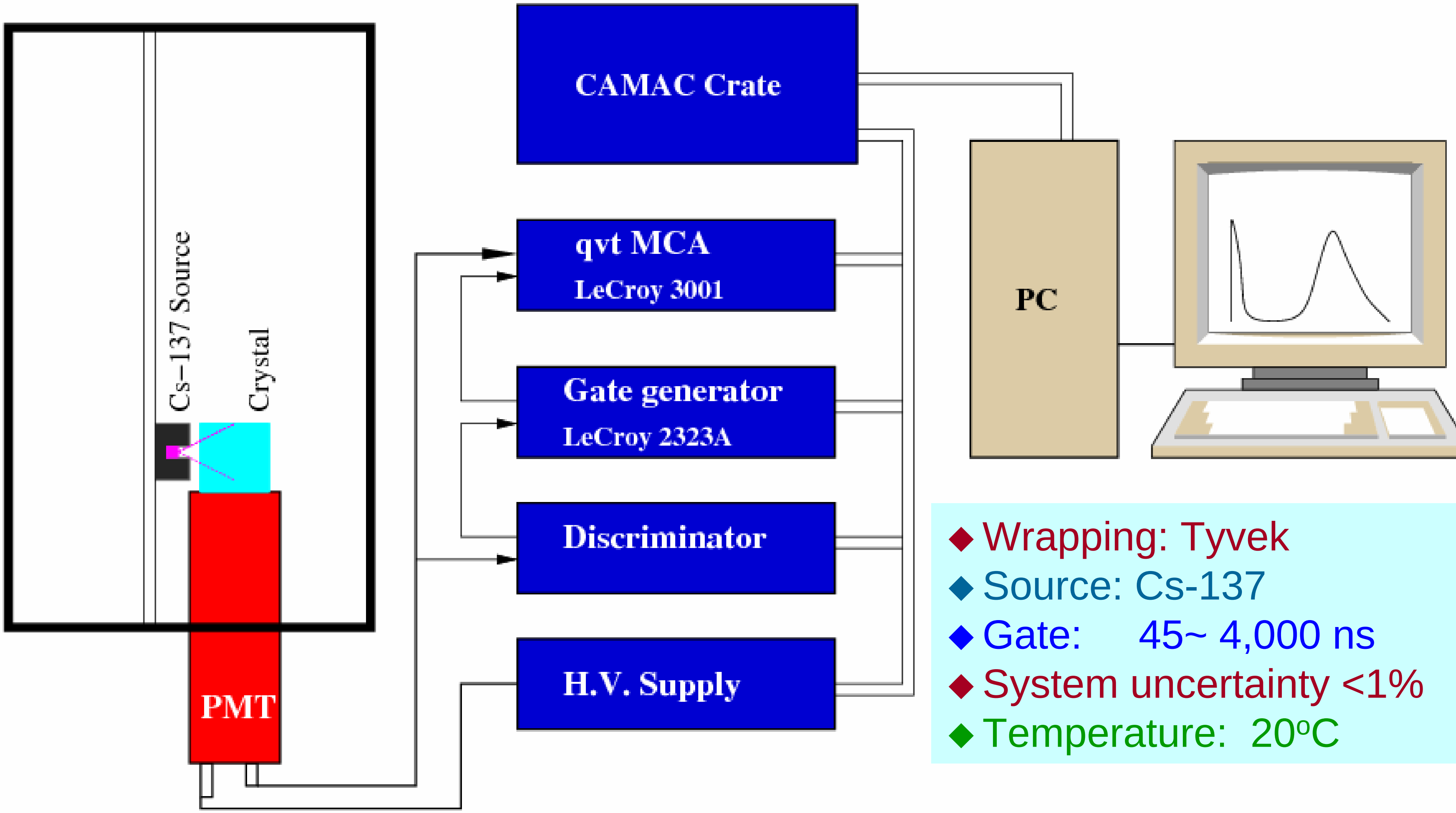


Scintillation Light Decay Time

Recorded with an Agilent 6052A digital scope



Light Output Measurement

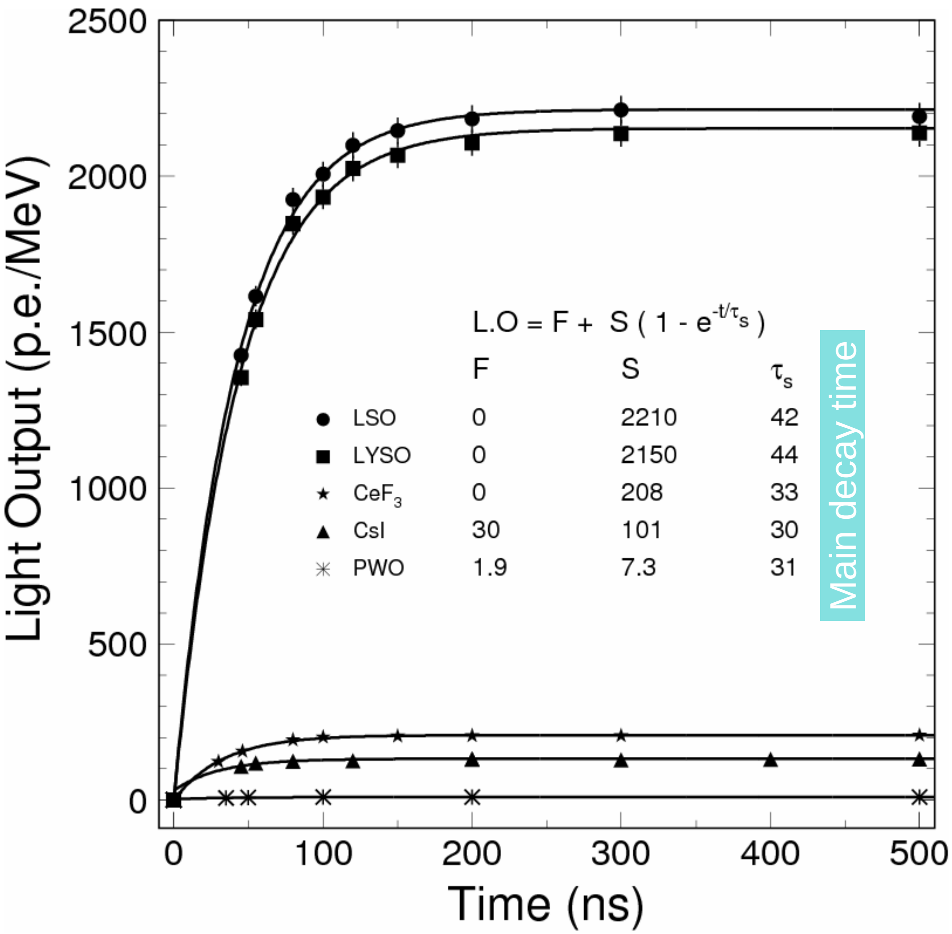


- Wrapping: Tyvek
- Source: Cs-137
- Gate: 45~ 4,000 ns
- System uncertainty <1%
- Temperature: 20°C

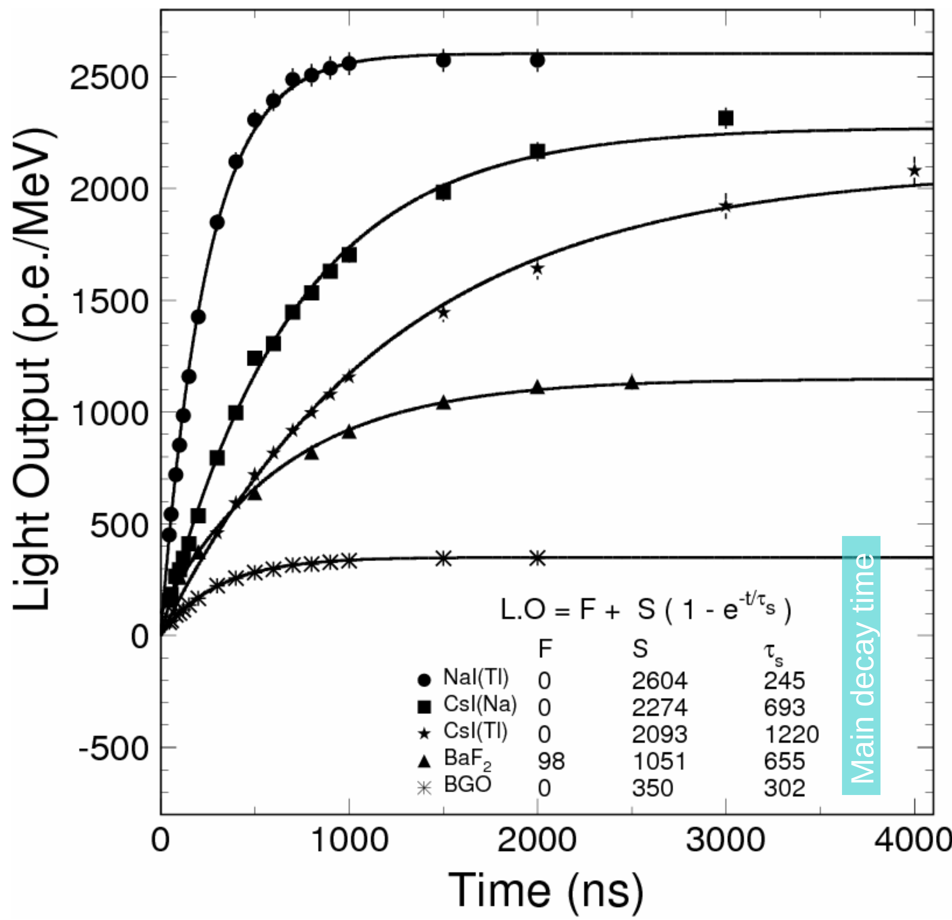
Light Output and Decay Kinetics

Photoelectron/MeV measured with a XP2254B PMT

Fast scintillators

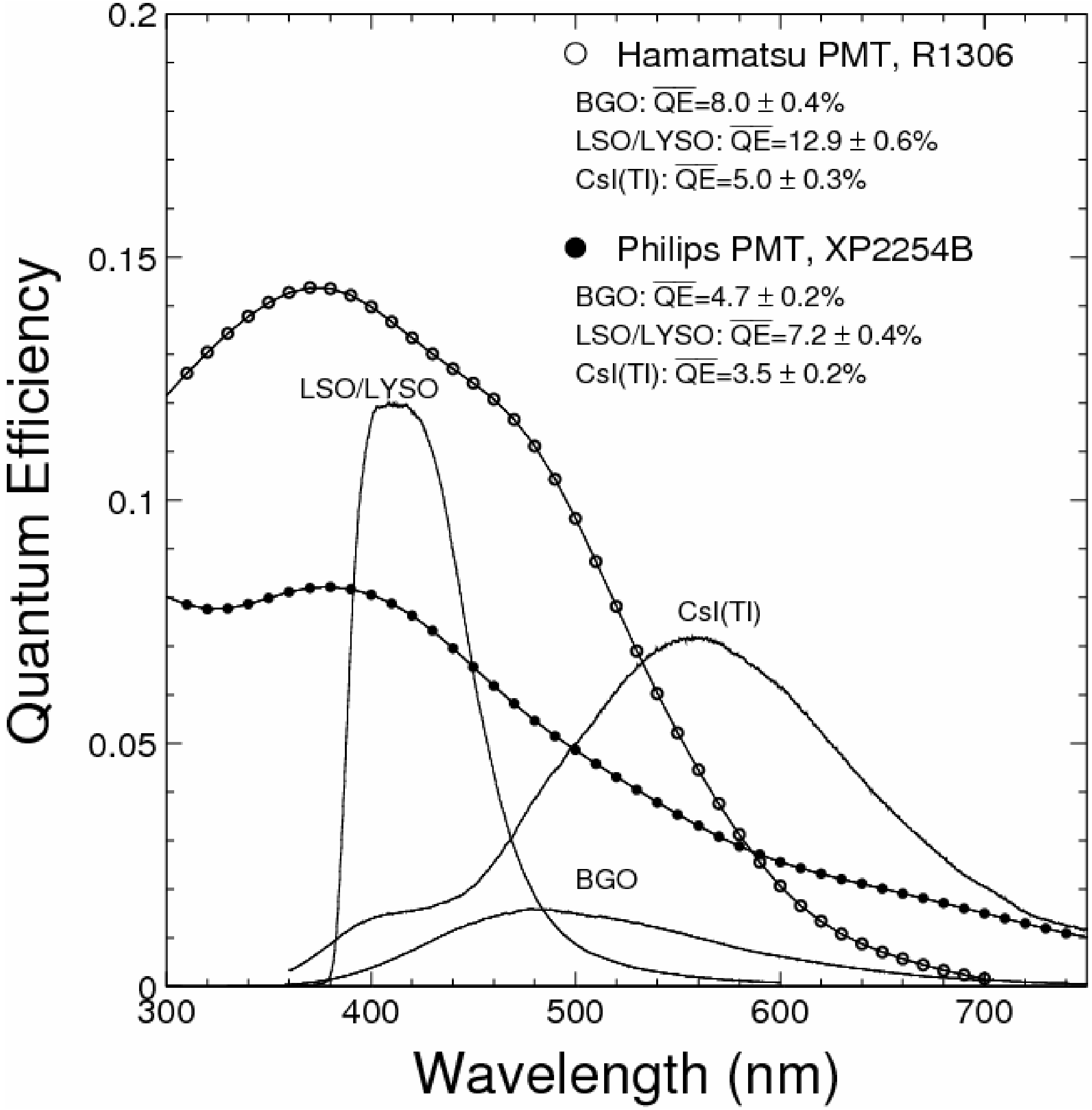


Slow scintillators



PMT Quantum Efficiencies

Emission weighted QE used to calculate Photons/MeV



Emission weighted QE is calculated according to the following equation:

$$\overline{QE} = \frac{\int QE(\lambda)Em(\lambda)d\lambda}{\int Em(\lambda)d\lambda}$$

Where *QE(λ): quantum efficiency of cathode*
Em(λ): scintillation intensity

Light Output and Decay Kinetics

Light output, decay time & relative L.O. with PMT QE taken out

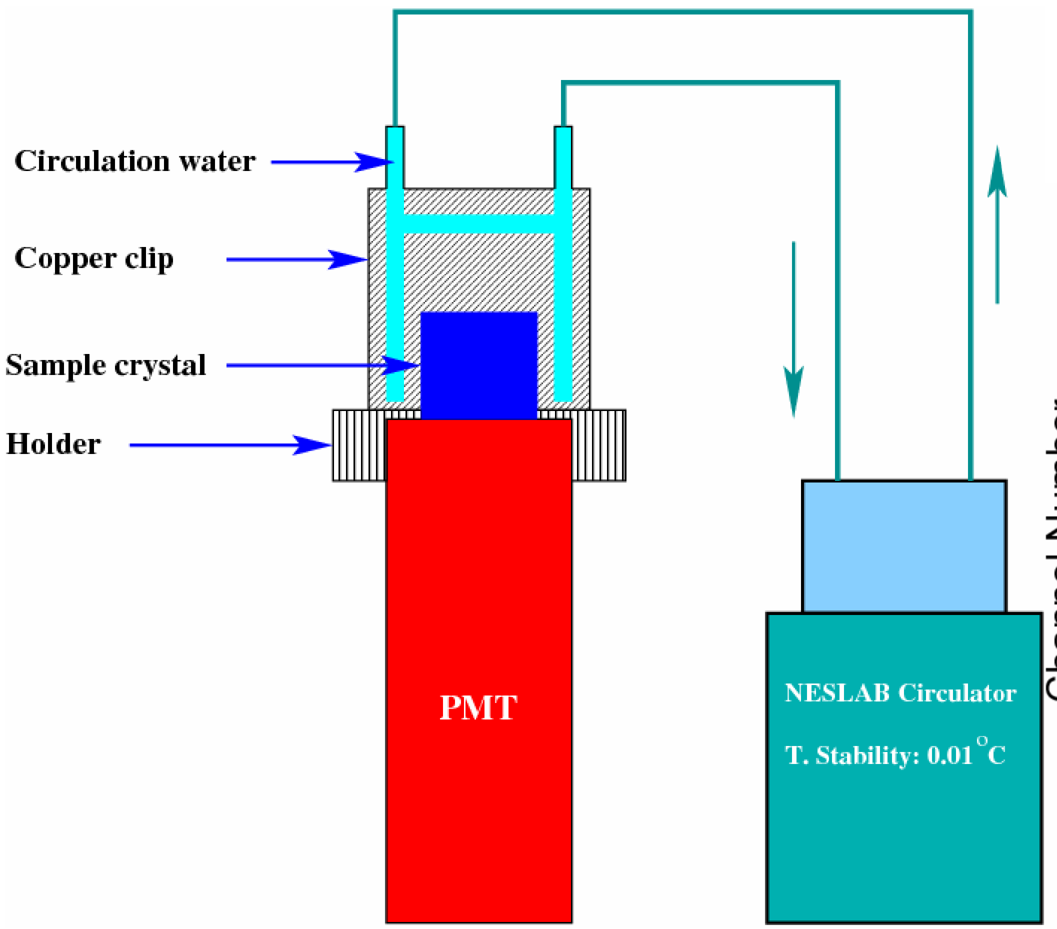
LIGHT OUTPUT [a,b]

Sample	L.Y. (Fast)				L.Y. (Slow)				Decay time
ID	p.e./MeV	Photons/MeV	Relative L.O.	EWQE	p.e./MeV	Photons/MeV	Relative L.O.	EWQE	τ (ns)
NaI(Tl)	0	0		–	2604	36170	100	0.072	245
CsI(Na)	0	0		–	2274	32030	88	0.071	693
CsI(Tl)	0	0		–	2093	59800	165	0.035	1220
BaF_2	98	1500	4.1	0.065	1051	13000	36	0.081	655
BGO	0	0		–	350	7446	21	0.047	302
LSO	0	0		–	2210	30690	85	0.072	42
LYSO	0	0		–	2150	29860	83	0.072	44
CeF_3	0	0		–	208	2630	7.3	0.079	33
CsI	30	390	1.1	0.077	101	1310	3.6	0.077	30
PWO	1.9	28	0.1	0.068	7.3	107	0.3	0.068	31

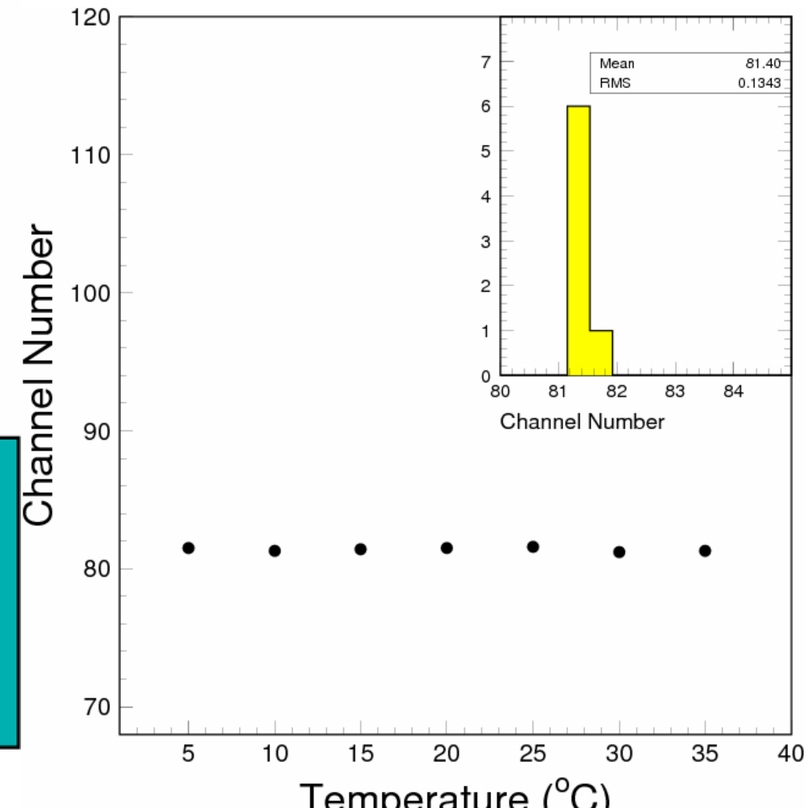
[a] NaI(Tl) sample is cylinder with diameter of 44 mm and 39 mm long, while all other samples are 1.5 radiation length in cubic.
[b] By Photonis XP 2254b PMT.

Temperature Coefficient Measurement

A NESLAB circulator used to keep sample at a fixed temperature with precision 0.01°C

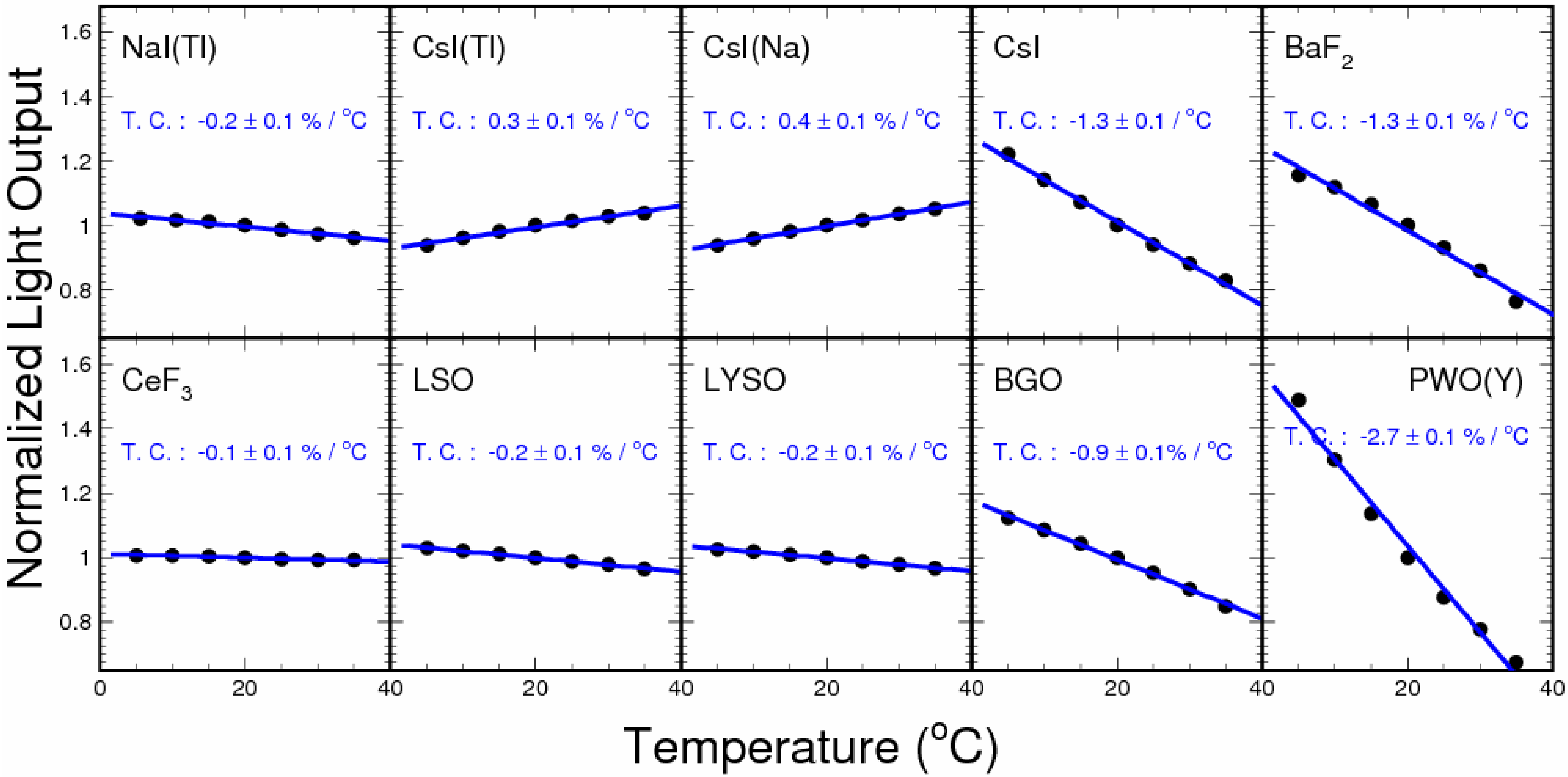


Sensitivity of PMT cathode versus temperature checked by LED



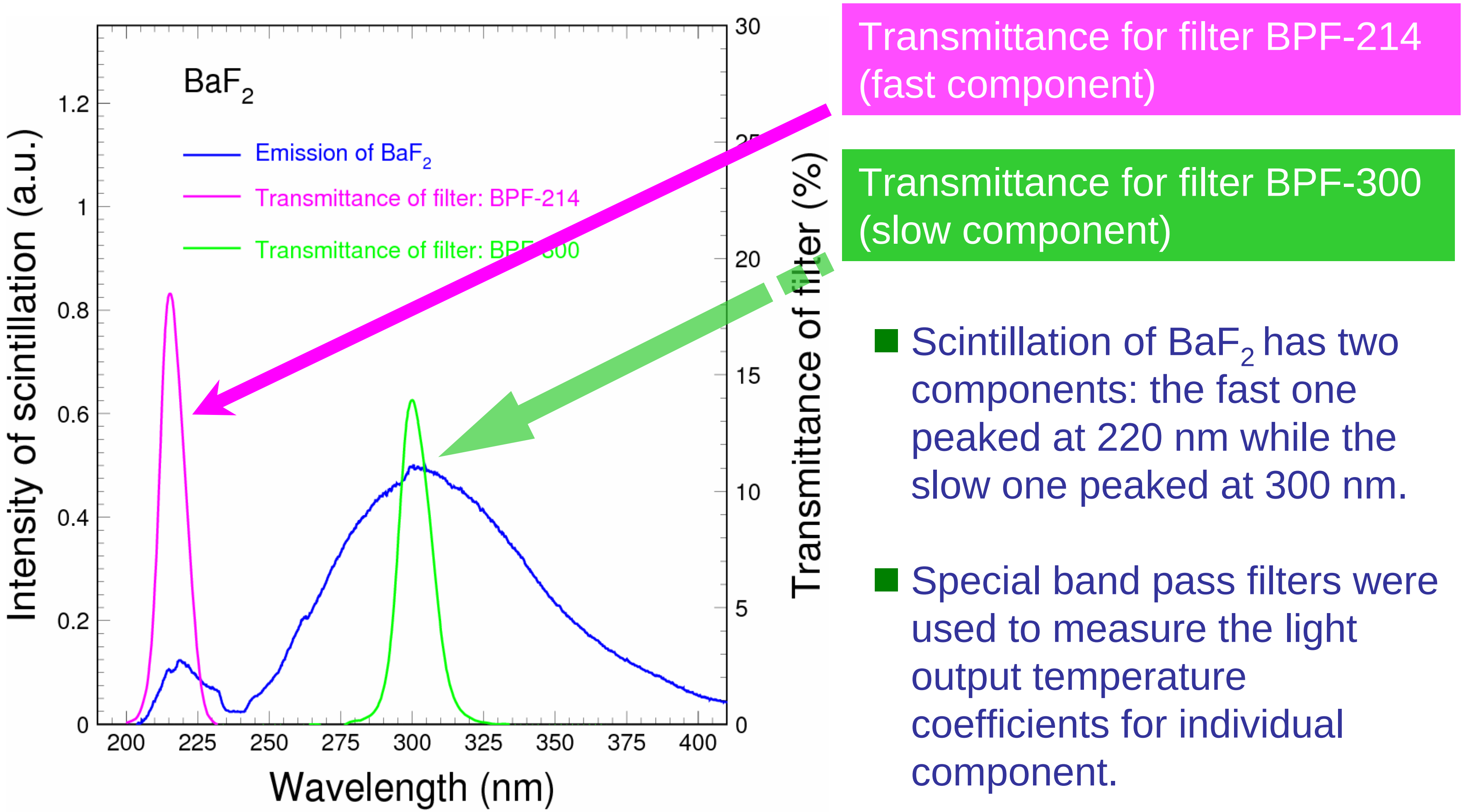
Light Output Temperature Coefficient

Temperature Range: 5 ~ 35 ºC



BaF_2: Fast and Slow Components

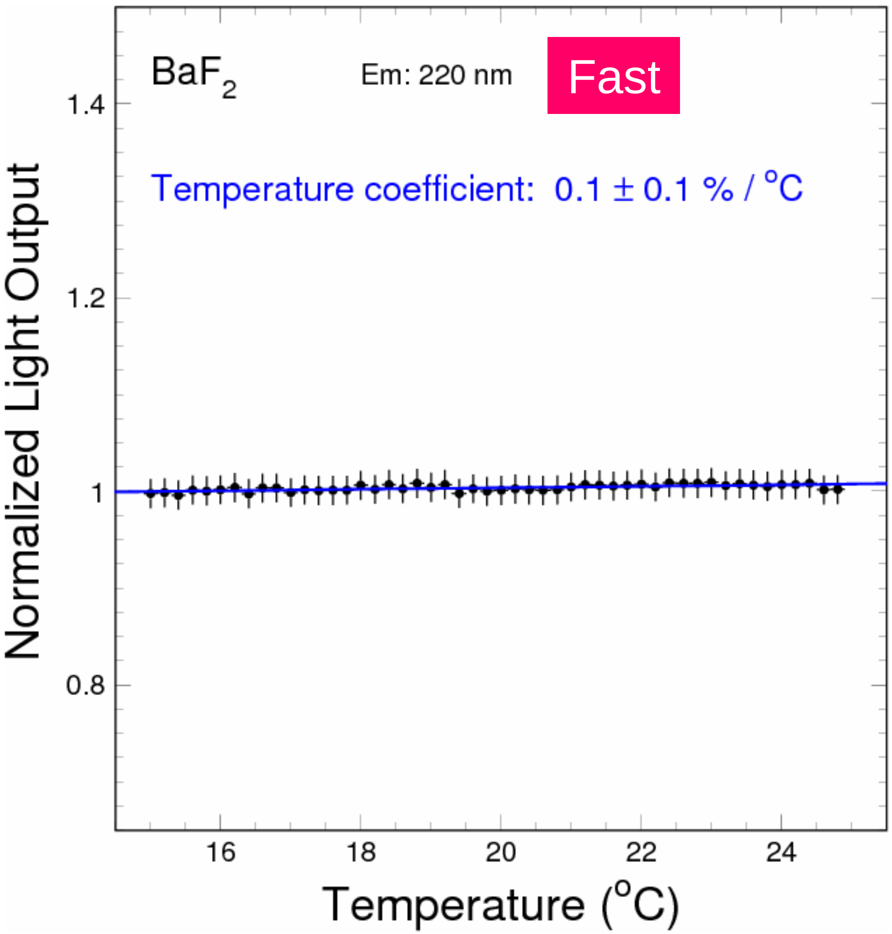
Two filters used to select scintillation component

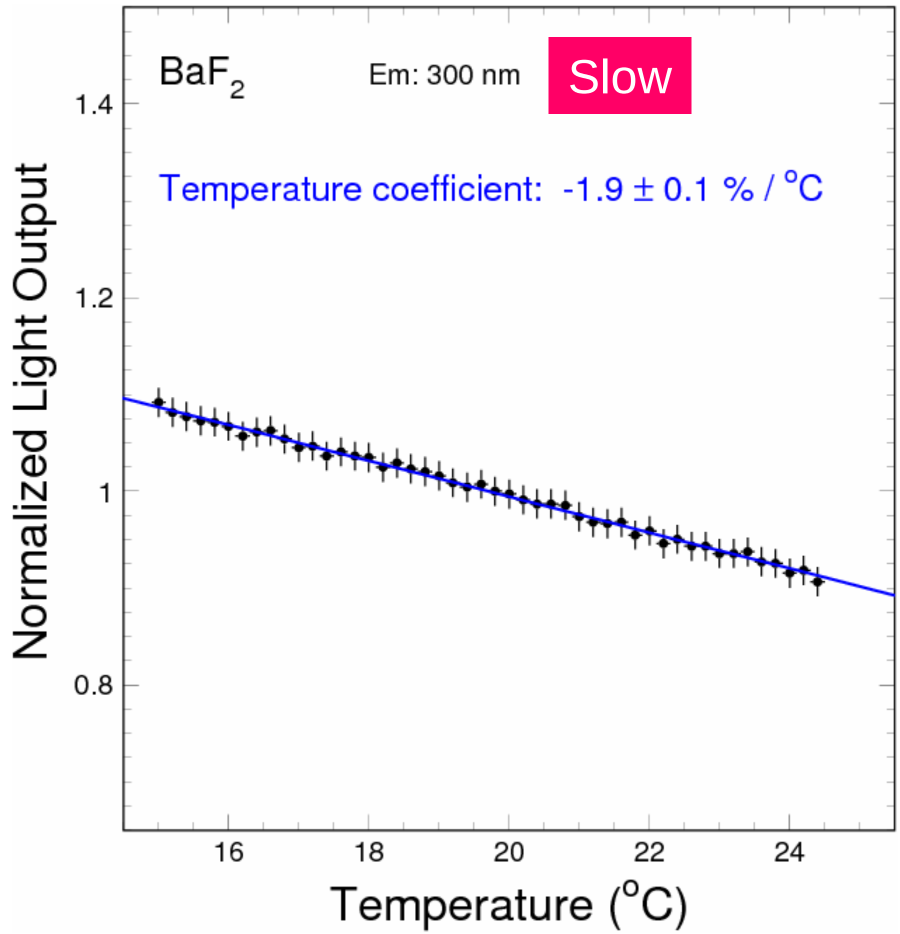


- Scintillation of BaF_2 has two components: the fast one peaked at 220 nm while the slow one peaked at 300 nm.
- Special band pass filters were used to measure the light output temperature coefficients for individual component.

BaF_2 Light Output Temperature Coefficient

Fast and slow components have very different temperature coefficient





Light Output Temperature Coefficient

Temperature Range: 15 ~ 25 ºC

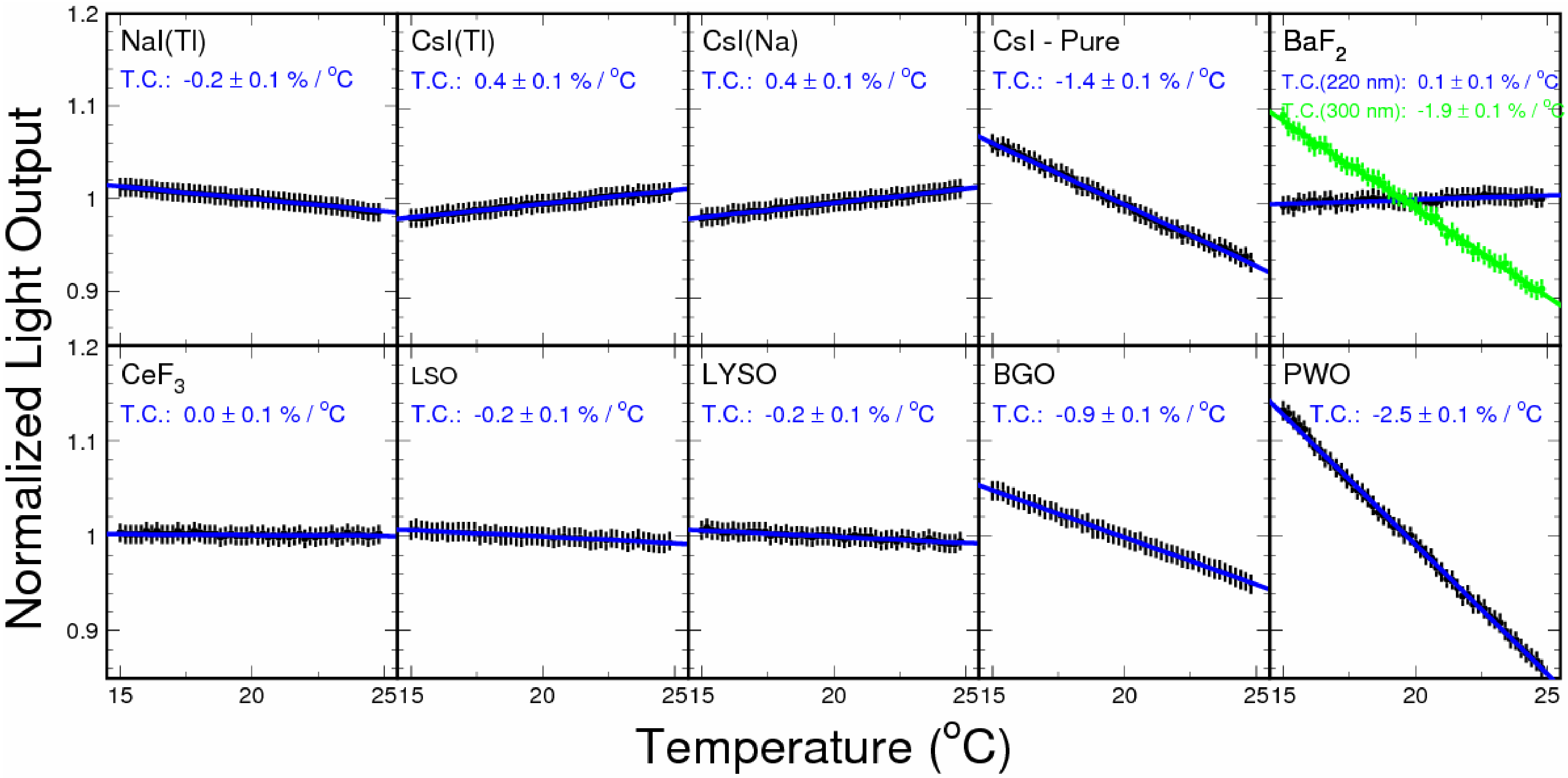


Table of Inorganic Scintillators

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Hygroscopicity	Yes	Slight	Slight	Slight	No	No	No	No	No
Luminescence [b] (nm) (at peak)	410	550	420	420 310	340 300	300 220	480	425 420	402
Decay Time [b] (ns)	245	1220	690	30 6	30	650 0.9	300	30 10	40
Light Yield [b,c] (%)	100	165	88	3.6 1.1	7.3	36 4.1	21	0.3 0.1	85
d(LY)/dT [b] (%/ ºC)	-0.2	0.4	0.4	-1.4	0	-1.9 0.1	-0.9	-2.5	-0.2

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

Summary

- A comparative study on inorganic crystal scintillators commonly used in high energy physics experiments was carried out.
- Refractive indices for LSO/LYSO were measured by using a V-prism.
- Relative light output was measured for samples of 1.5 X_0 with Tyvek wrapping and with quantum efficiencies of the readout devices taken out.
- Light output temperature coefficients at room temperature were measured.
- Result presented here will be used in the inorganic scintillator section of the 2008 PDB.