28th International Scientific Conference of Young Scientists and Specialists

Study of the influence of absorbed dose on scintillation properties of inorganic scintillators BaF_2 and LYSO:Ce

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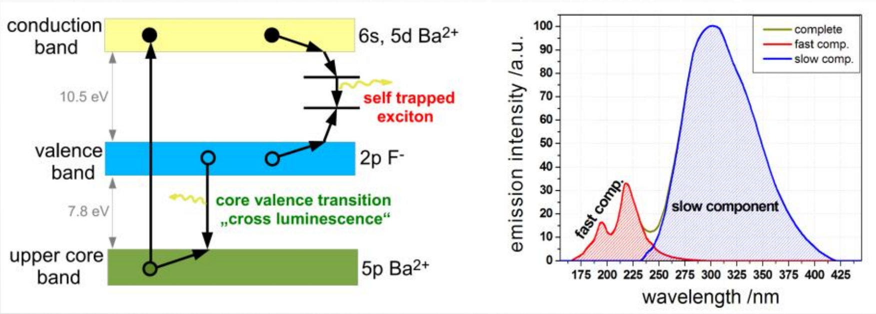
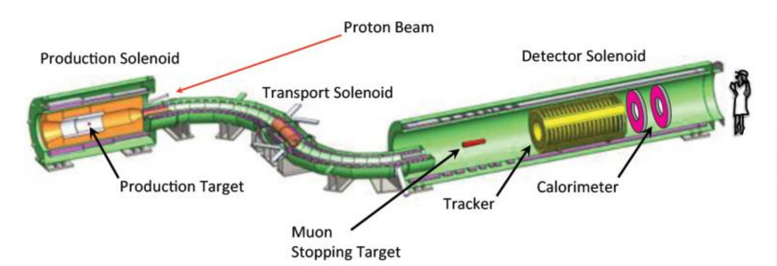
MOTIVATION

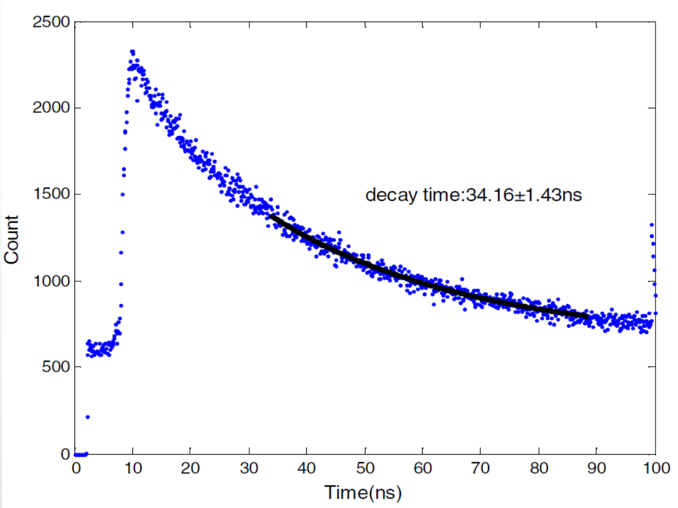
- Inorganic scintillators BaF_2 and LYSO:Ce are considered as candidates for use in the electromagnetic calorimeter of the Mu2e-II experiment at FNAL, USA.



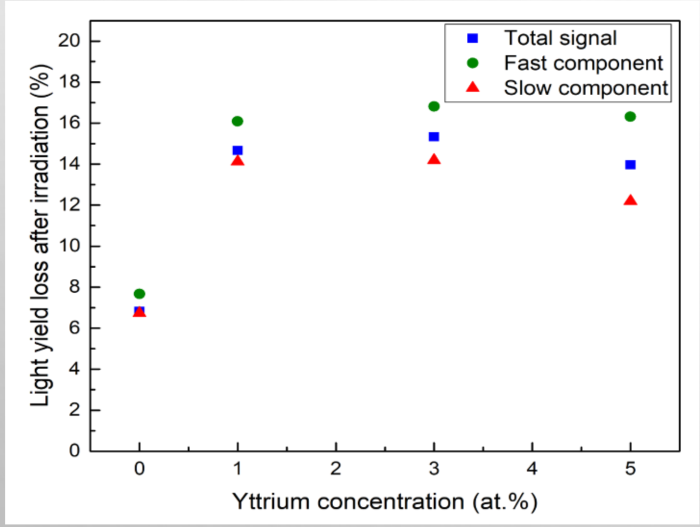
Scintillation mechanism (left) and emission spectrum (right) of BaF2. Reproduced from Diehl, Novotny, Wohlfahrt, Beck, 2015 with open access.



Mu2e experiment scheme. (Mu2e TDR, 2014)



LYSO:Ce scintillation kinetics. (Du, Wang, Zhang etc., 2009)



Light yield loss after $2{,}3\times10^{14}$ neutron/cm^2 irradiation (*Baranov, Davydov, Vasilyev, 2022*).

This work is a continuation of our research and is aimed at studying the effect of γ-irradiation on the scintillation properties of the BaF_2 and LYSO:Ce.

GOAL AND OBJECTIVES

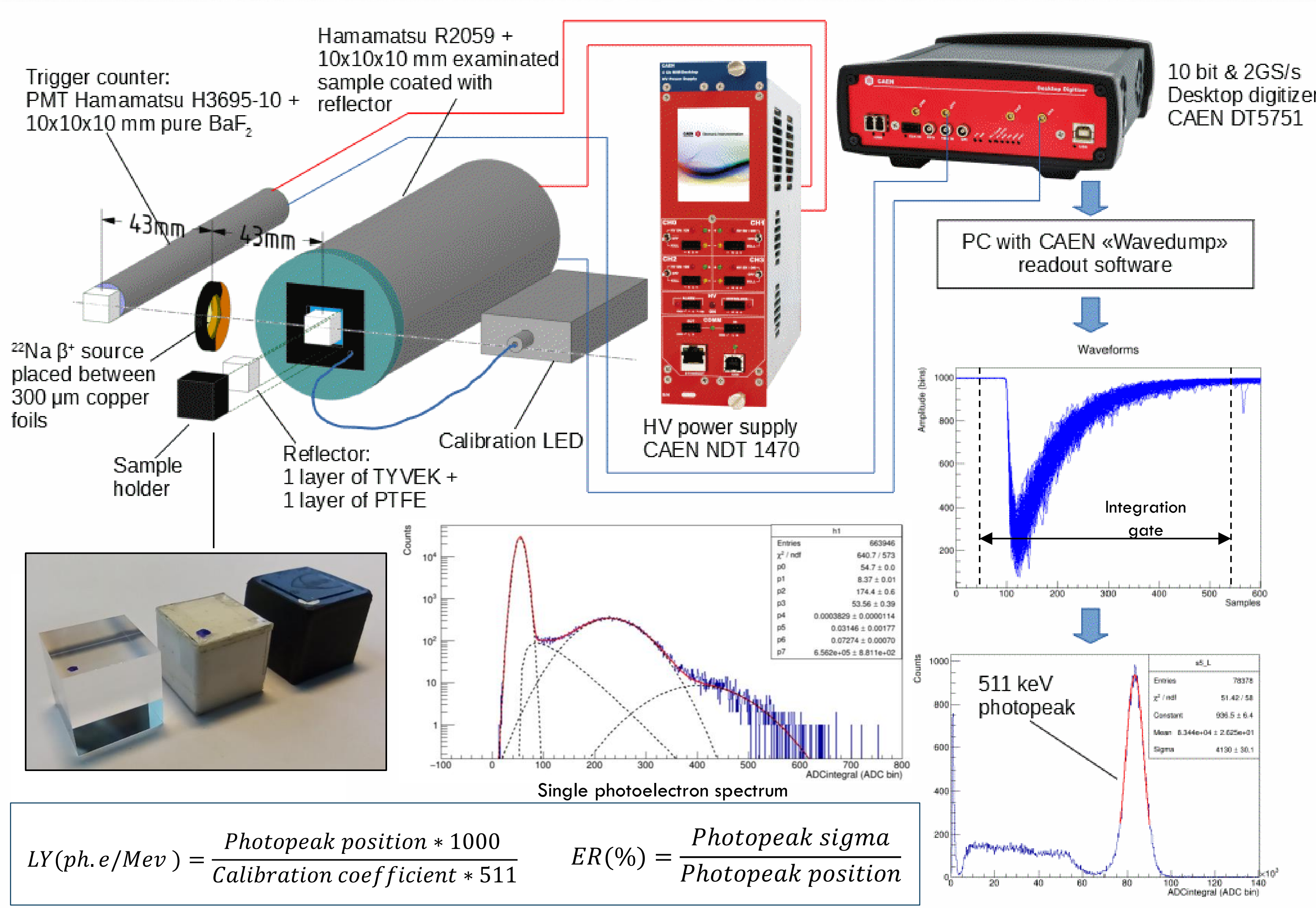
Goal:

- Study the influence of γ-irradiation on the light yield (LY), energy resolution (ER) and scintillation kinetics (SK) of the pure and yttrium-doped (1, 3 & 5 at. % Y) BaF_2 and LYSO:Ce samples.

Objectives:

- Create the experimental setup for measuring the LY, ER and SK of the samples.
- Tune the parameters of the experimental setup (geometry, HV, thresholds, cable delays etc.).
- Measure the LY, ER of the samples before irradiation.
- Irradiate samples with ^{60}Co γ-source to obtain absorbed dose approximately 1 Gy, 10 Gy, 100 Gy, 1 kGy, 10 kGy, 100 kGy.
- Measure the LY, ER and try to investigate a SK of the samples after irradiation.

EXPERIMENTAL SETUP FOR LY AND ER MEASUREMENTS



$$LY(ph.e/Mev) = \frac{Photopeak\ position * 1000}{Calibration\ coefficient * 511} \qquad ER(\%) = \frac{Photopeak\ sigma}{Photopeak\ position}$$

IRRADIATION OF THE SAMPLES

Irradiation of the samples was carried out at irradiation facility of Institute of Radiation Problems, Ministry of Science and Education of the Republic of Azerbaijan.

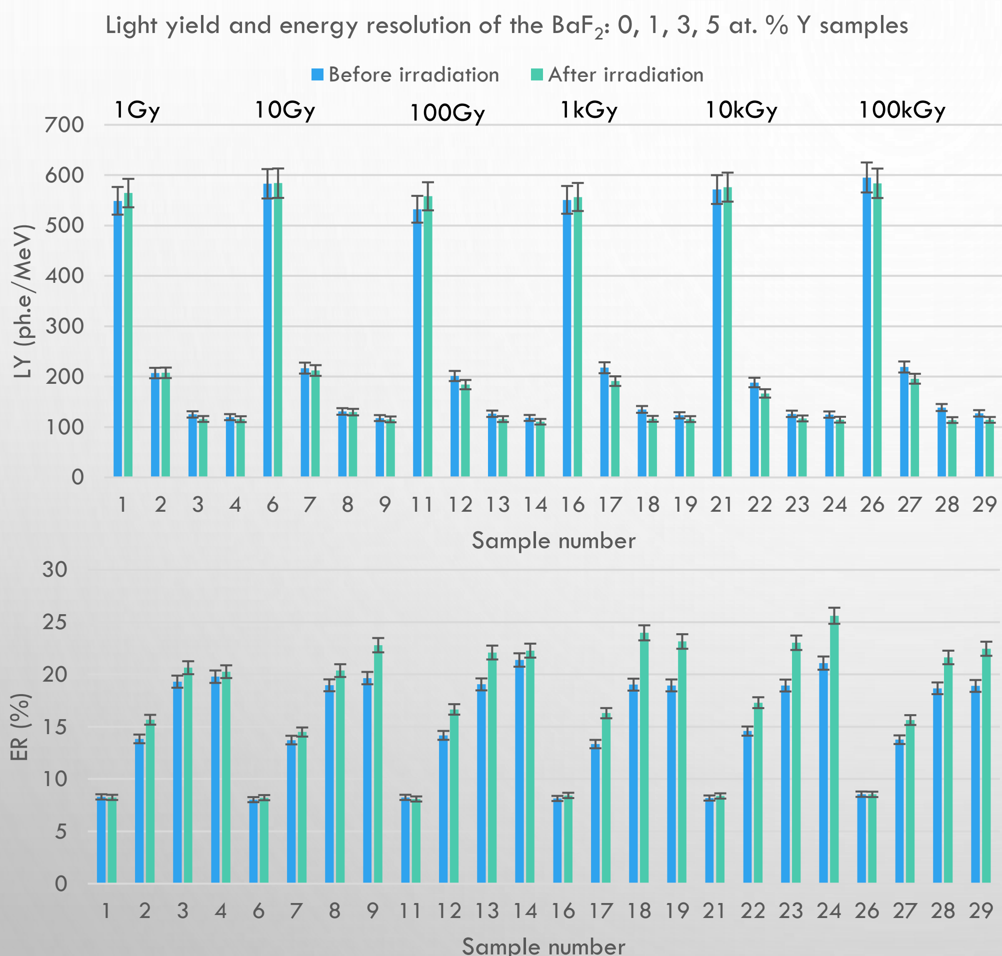
Target dose (Gy)	BaF_2 pure	BaF_2:1 at.% Y	BaF_2:3 at.% Y	BaF_2:5 at.% Y	LYSO:Ce
1	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
10	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
100	Sample 11	Sample 12	Sample 13	Sample 14	Sample 15
1000	Sample 16	Sample 17	Sample 18	Sample 19	Sample 20
10000	Sample 21	Sample 22	Sample 23	Sample 24	Sample 25
100000	Sample 26	Sample 27	Sample 28	Sample 29	Sample 30

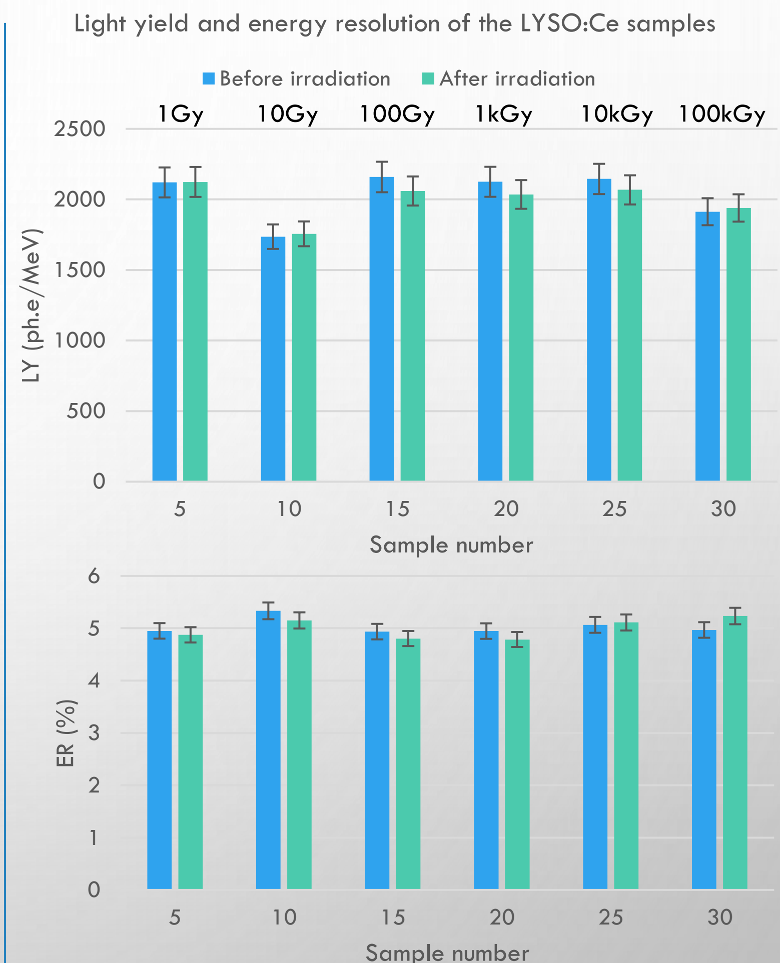
Irradiation setup	Dose rate for alanine (Gy/s)	Target dose (Gy)	Dose measured with radiochromic films (Gy)	Alanine equivalent dose (Gy)	Dose measured with radiochromic films (Gy)	Alanine equivalent dose (Gy)
			BaF_2:0,1,3,5 at.% Y		LYSO:Ce	
GFRCCA-20000	0,00212	1	-	0,29	-	0,195
		10	-	2,9	-	1,95
		100	-	29	-	19,5
MRCFG-25	1,28	1000	1222±49	290	-	195
		10000	10758±49	2900	11502±73	1950
		100000	142250±196	29000	114223±146	19500

Irradiation team at IRP irradiation facility.

Color centers formation in the BaF_2 after 100 kGy absorbed dose.

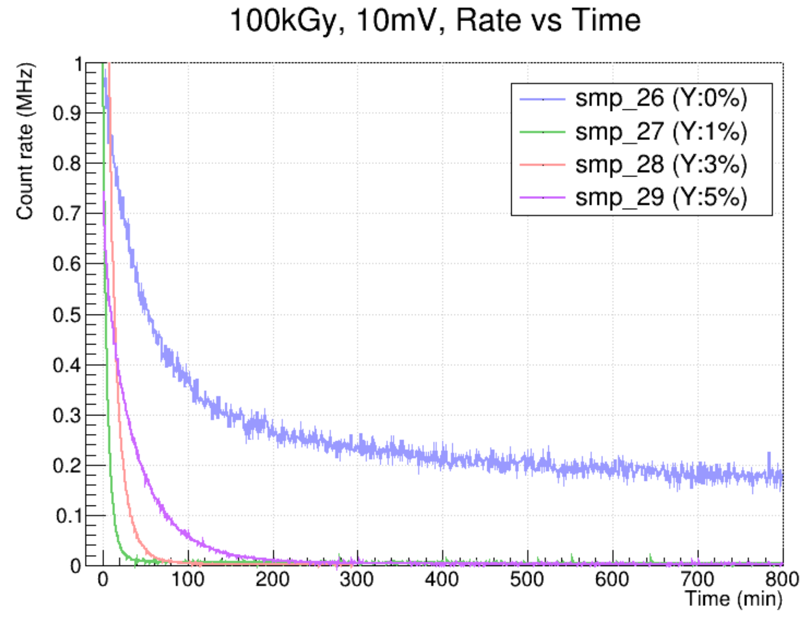
PRELIMINAR LY AND ER MEASUREMENTS RESULTS



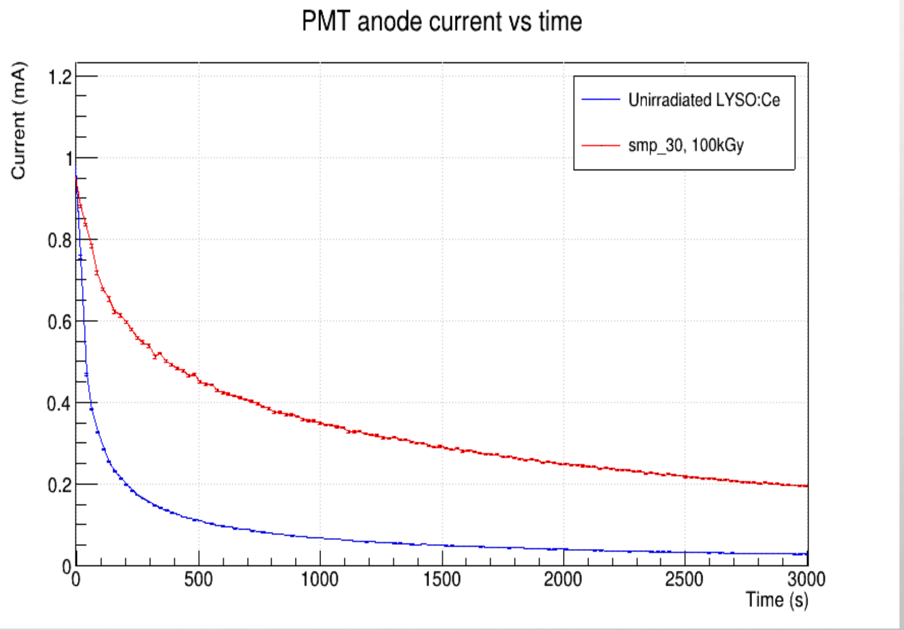


RADIATION INDUCED PHOSPHORESCENCE

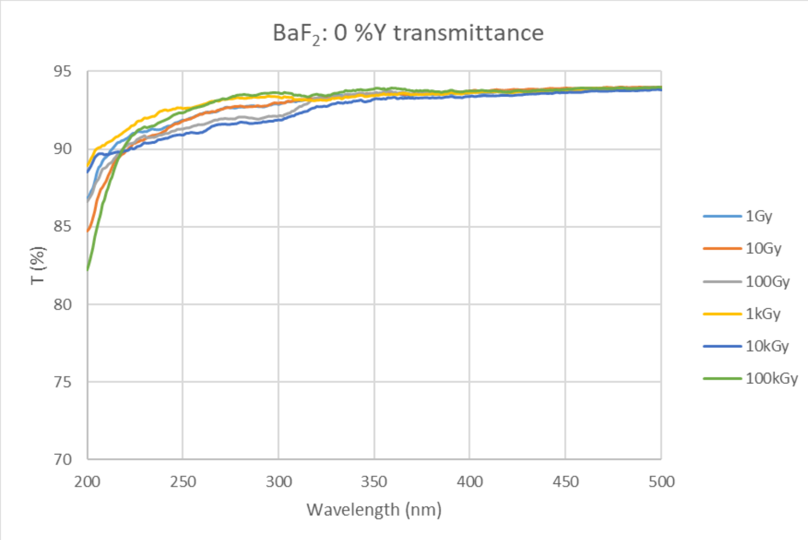
BaF2 phosphorescence after 100 kGy

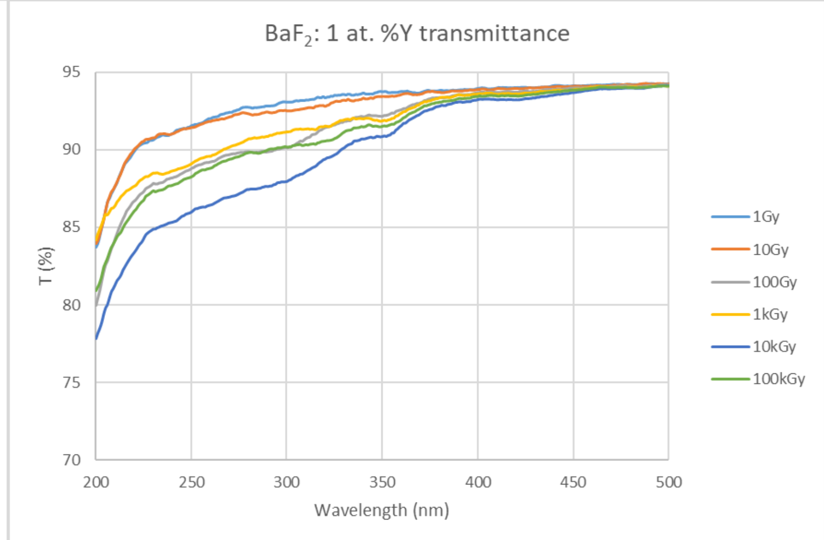


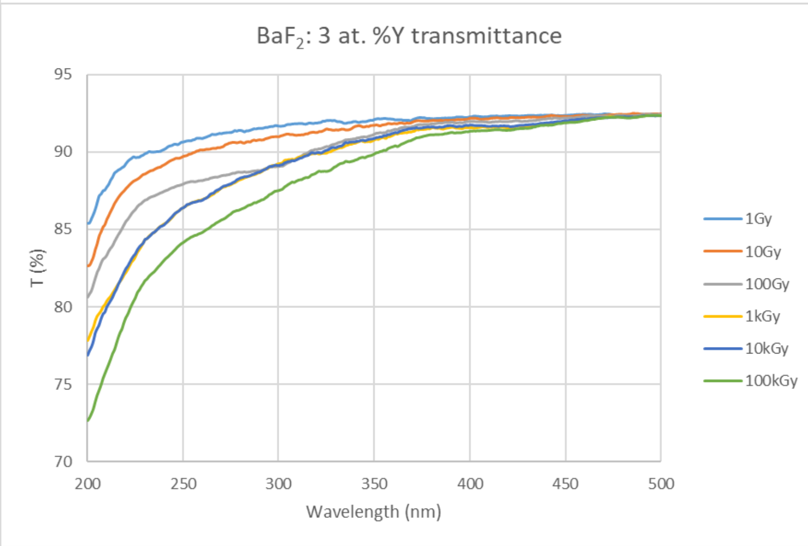
LYSO:Ce phosphorescence after 100 kGy

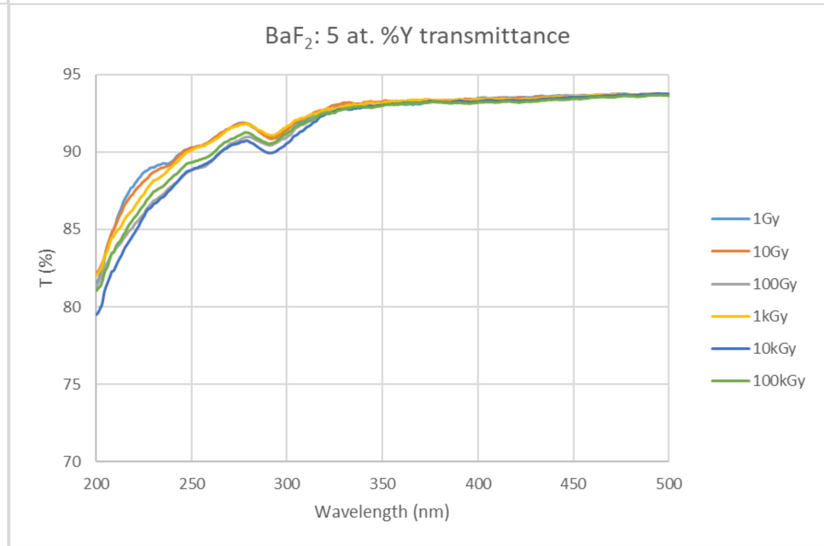


BaF_2 TRANSMITTANCE



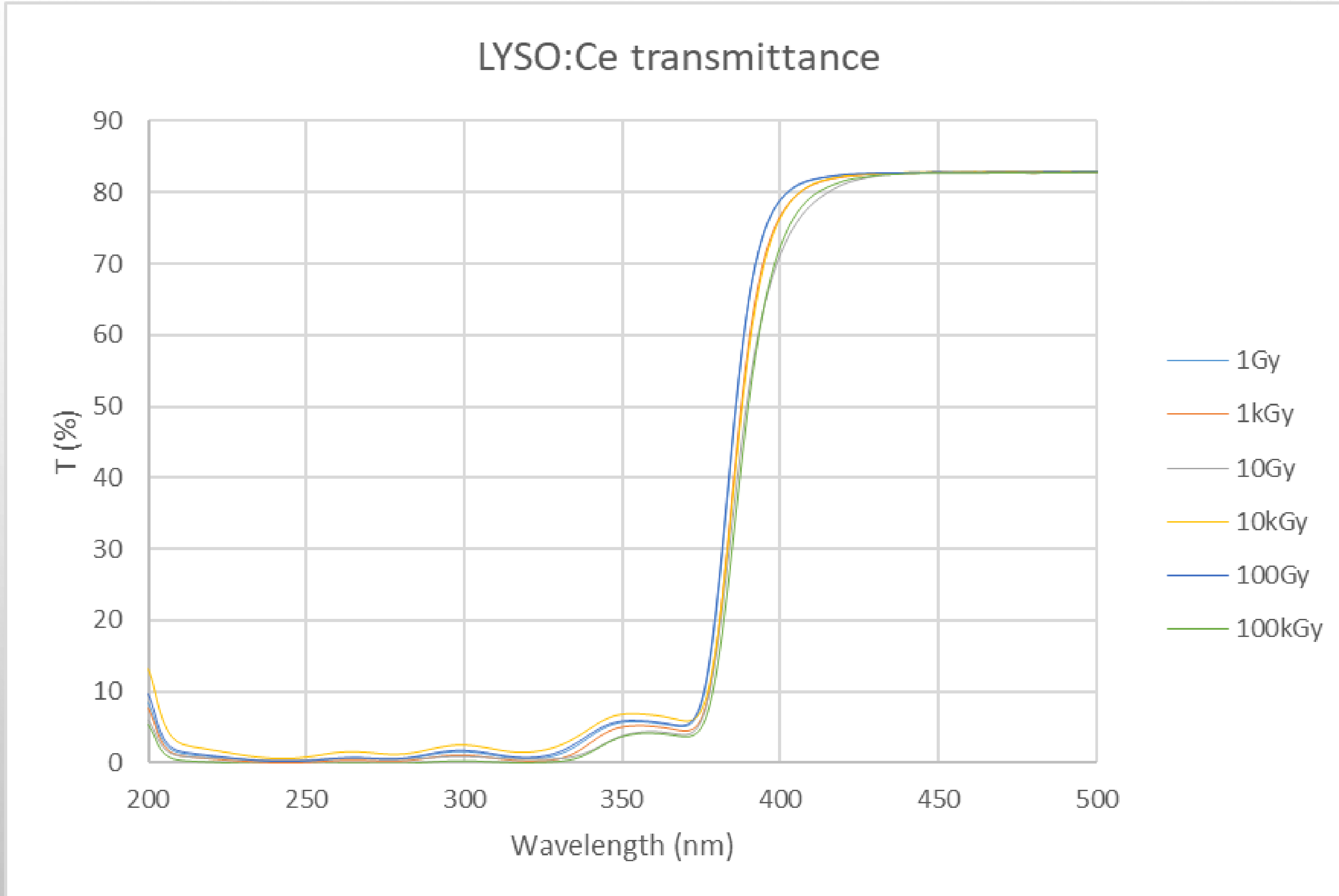




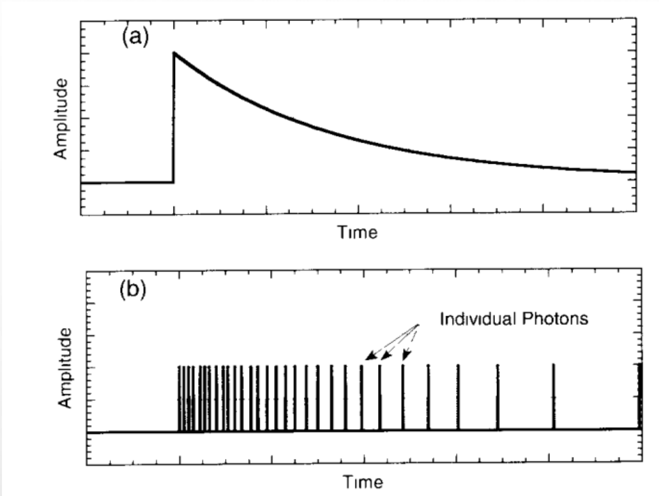


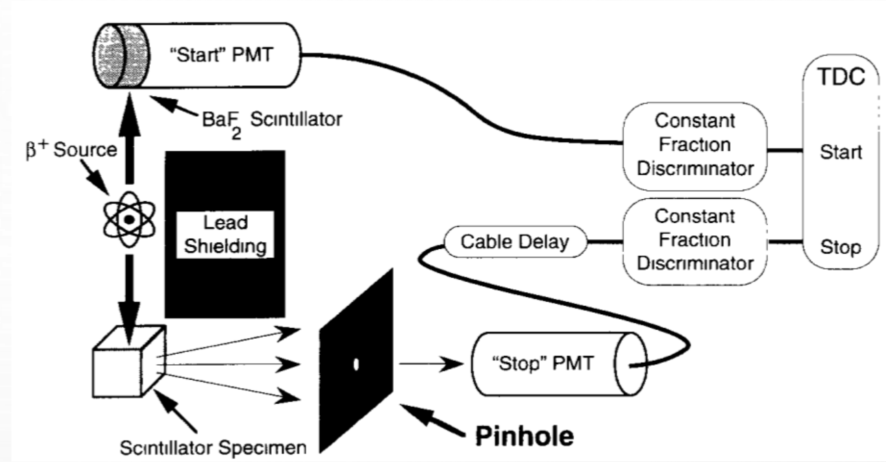
*Transmittance was measured with SHIMADZU 3700-DUV spectrophotometer.

LYSO:CE TRANSMITTANCE

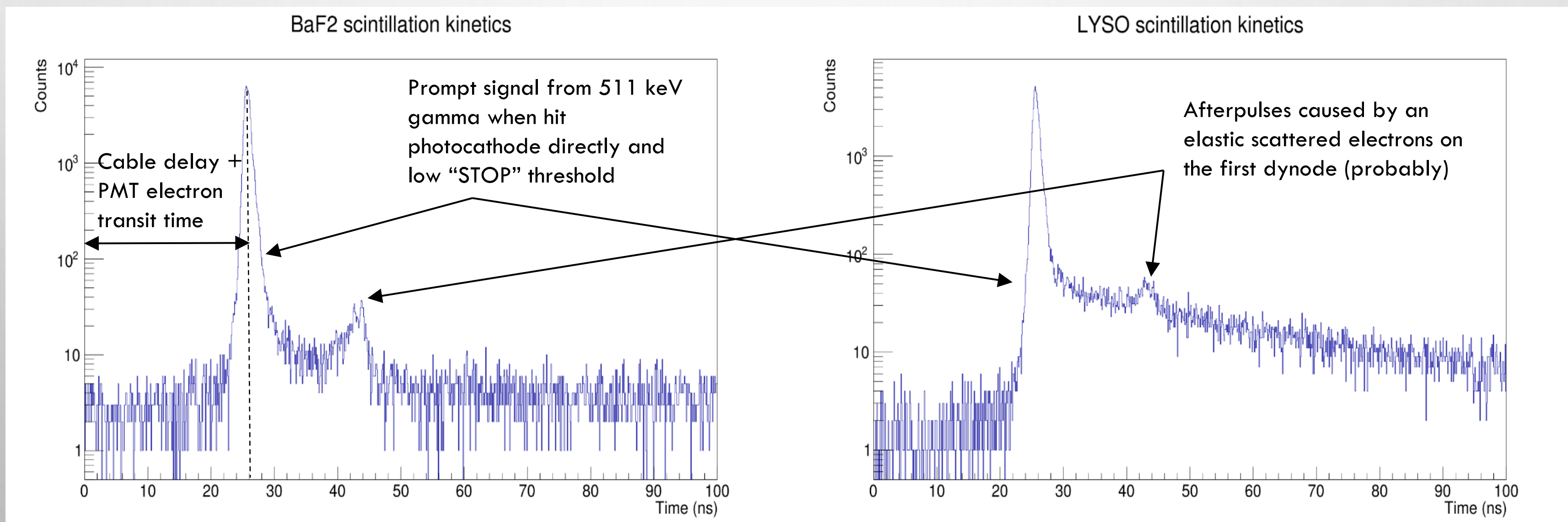


SCINTILLATION KINETICS STUDY





Principle of the delayed-coincidence method (left) and typical experimental configuration (right) (Moses, 1993).



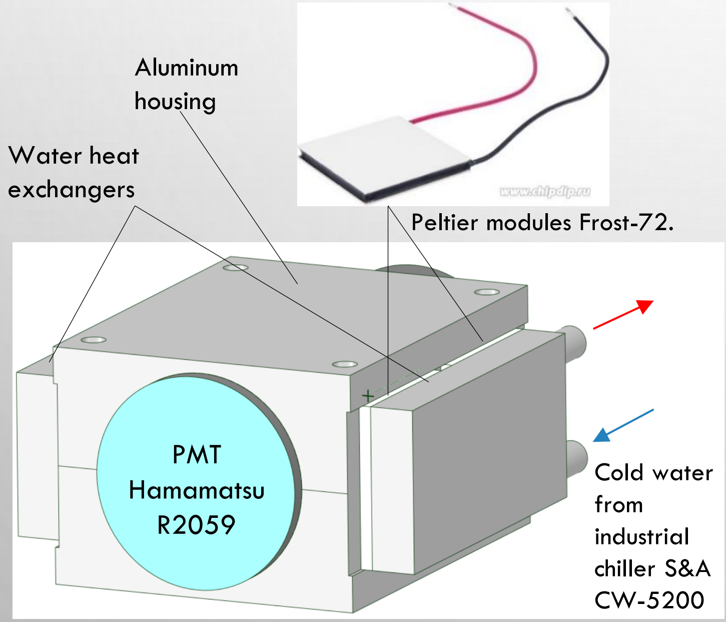
WORK ON MISTAKES

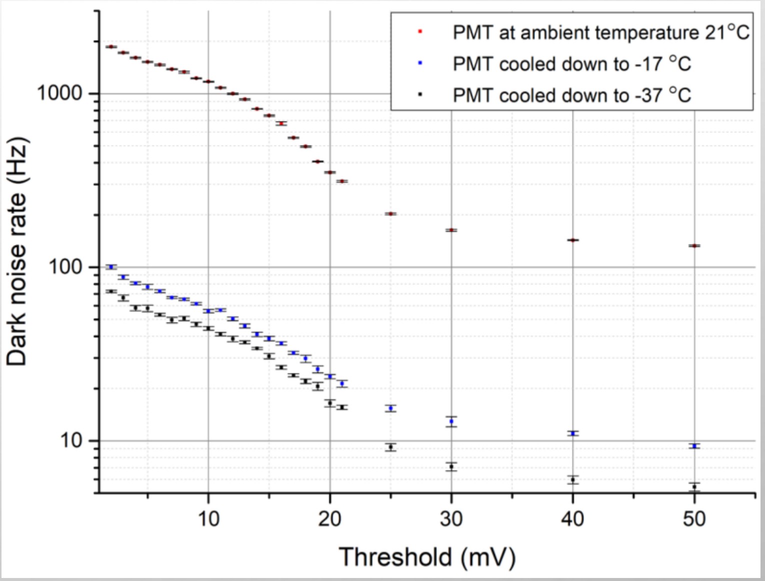
Main backgrounds:

- Scattered 511 keV photons interacting directly in the "stop" photomultiplier tube, which causes a prompt signal that can be misinterpreted as a fast scintillation component.
- Cross talk in the photomultiplier tube high voltage power supplies or the constant fraction discriminators can also lead to a spurious prompt signal.
- Events in which a second 511 keV photon interacts in the scintillator sample during the TDC sampling period.
- Random coincidences between the "start" and "stop" signals and dark photoelectron emission in the "stop" photomultiplier tube.

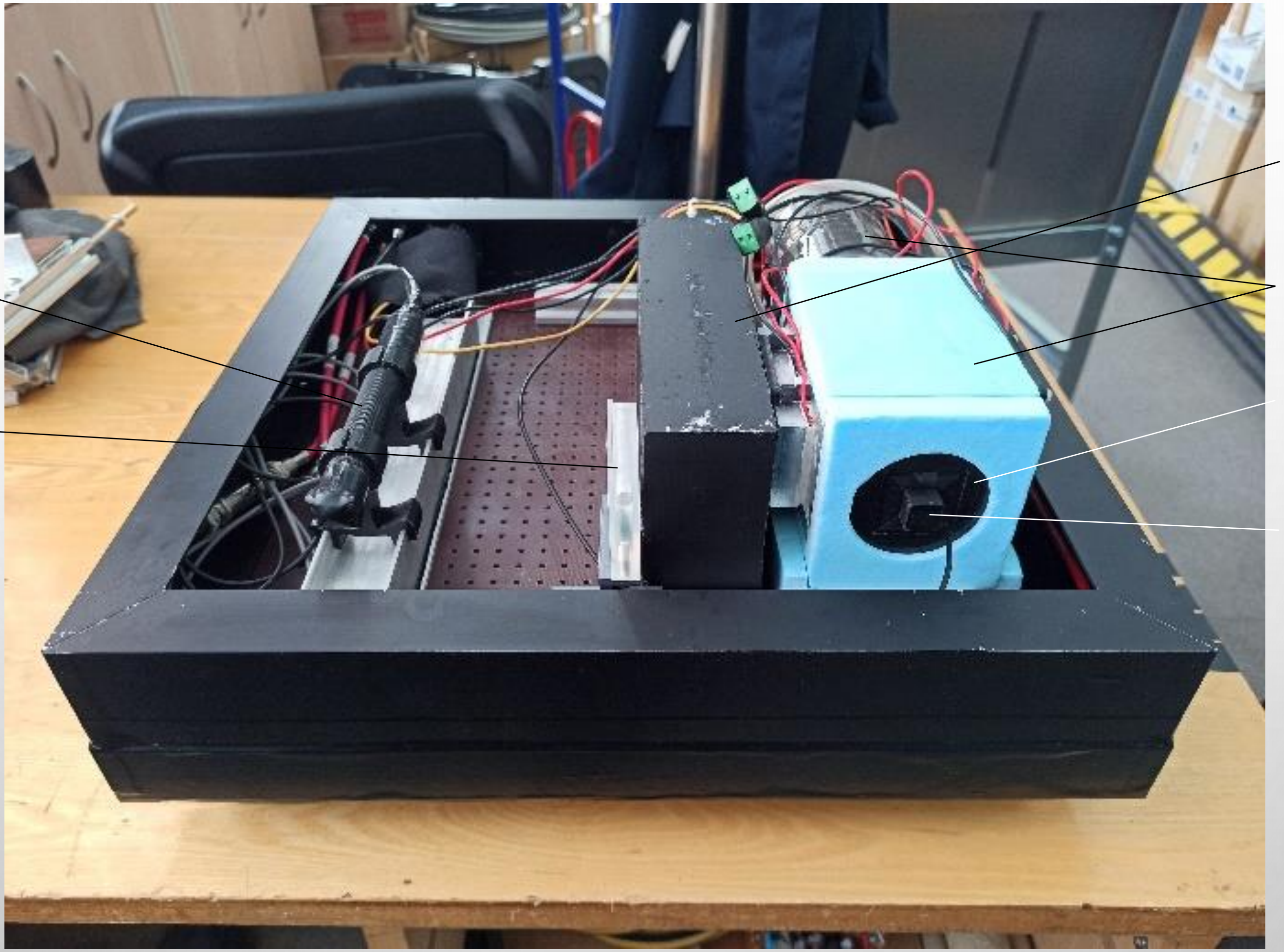
Solution:

- Lead shielding at least 5 cm thick.
- Background spectrum can be measured with an opaque material instead a pinhole.
- Time between “start” pulses have to be much longer than TDC sampling period.
- Well alignment of the source, trigger scintillator and examinated sample. Cool down the PMT to decrease dark current.





UPGRADED SETUP FOR SK STUDY



Scintillation kinetics study had to be interrupted at this stage because of LY & ER measurements priority.

CONCLUSIONS

- The scintillation and optical properties of pure and yttrium doped BaF_2 (1, 3, 5 at. % Y) and LYSO:Ce samples have been studied before and after γ-irradiation.
- Preliminar analysis of the experimental data did not show significant changes of the LY of LYSO:Ce samples for the absorbed doses up to 100 kGy while the LY & ER of the doped BaF_2 samples tends to deteriorate with increasing dose.
- Radiation induced phosphorescence have been observed in BaF_2 and LYSO:Ce samples.
- Deterioration of the transmittance of BaF_2 samples in the UV-region starting from 100 Gy have been observed while there is no significant changes of transmittance of LYSO:Ce samples.
- First attempts to study SK were made. It was found that the experimental setup should be upgraded concerning all background sources.
- "STOP" PMT cooling system has been created that allowed to decrease dark noise rate by about 15 times compared to the dark noise rate at room temperature.

FUTURE PLANS

- Thorough analysis of experimental data to obtain final results.
- Study the scintillation kinetics of the samples with upgraded experimental setup.
- Study the radiation induced phosphorescence phenomena.

THANK YOU FOR YOUR ATTENTION!

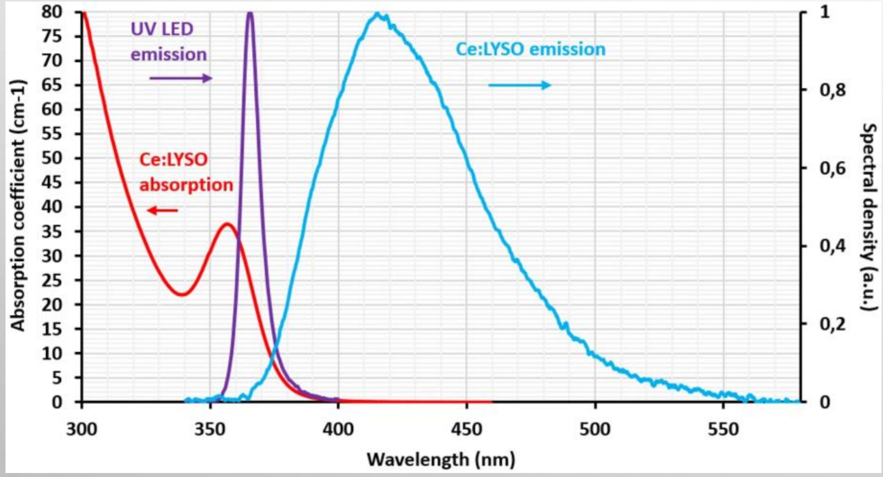
BACKUP SLIDES

Some information about BaF_2 and LYSO:Ce

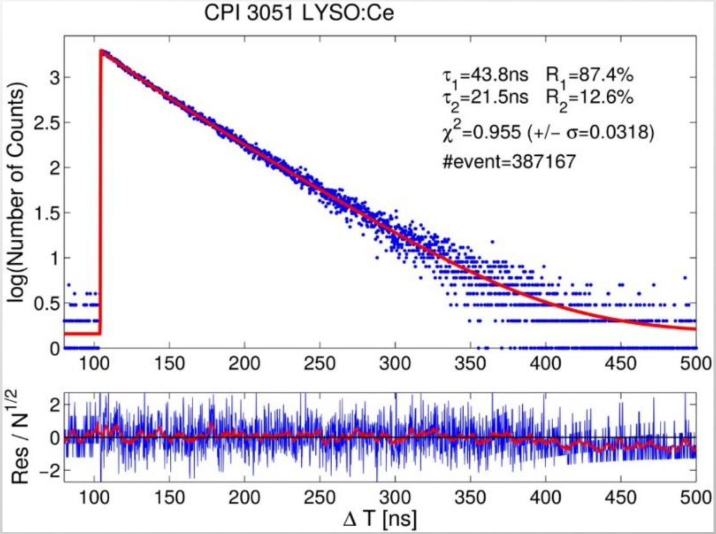
- BaF_2 – an inorganic scintillator, which has an ultrafast scintillation component with about 600 ps decay time peaked at 220 nm, and a 630 ns slow component peaked at 310 nm with much higher intensity, which would cause pileup in a high rate environment. Doping BaF_2 with yttrium allows to suppress its slow luminescence component (*Hu, Xu, Zhang et.al, 2019*), but negatively impacts on the scintillation properties after neutron irradiation (*Baranov, Davydov, Vasilyev, 2022*).
- LYSO:Ce – is bright, fast and radiation hard inorganic scintillator. But its scintillation properties are largely depend on Lu/Y ratio, Ce distribution in the volume of the boule which are directly depend on the crystal growing process used by a particular manufacturer. We have at our disposal samples of LYSO:Ce from "SICCAS".

Crystal	**BaF_2**	**LYSO**
Density (g/cm^3)	4.89	7.28
Radiation length (cm) X_0	2.03	1.14
Molière radius (cm) Rm	3.10	2.07
Interaction length (cm)	30.7	20.9
dE/dx (MeV/cm)	6.5	10.0
Refractive Index at λ_{max}	1.50	1.82
Peak luminescence (nm)	220, 300	402
Decay time τ (ns)	0.9, 650	40
Light yield (compared to NaI(Tl)) (%)	4.1, 36	85
Light yield variation with temperature (% / °C)	0.1, -1.9	-0.2
Hygroscopicity	None	None

(Represented from Mu2e TDR, 2014)



(Represented from Lopez, Pichon, Loiseau et al., 2023)



(Represented from Gundaker, Turtos, Auffray, Lecoq, 2018)

“STOP” PMT CALIBRATION