Characterization of different scintillation materials

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Overview

- **Organic material polyethylene naphthalate (poly(ethylene 2,6-naphthalate) or PEN)**
- **Study of temperature kinetics dependence of different materials**
- **Ba-Si-Gd:Ce Glass Scintillation Material**

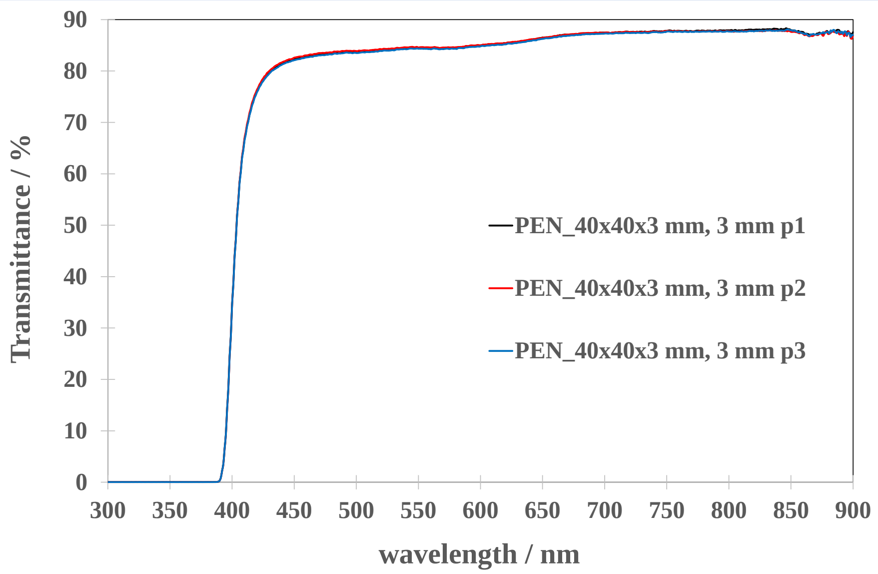
PEN material

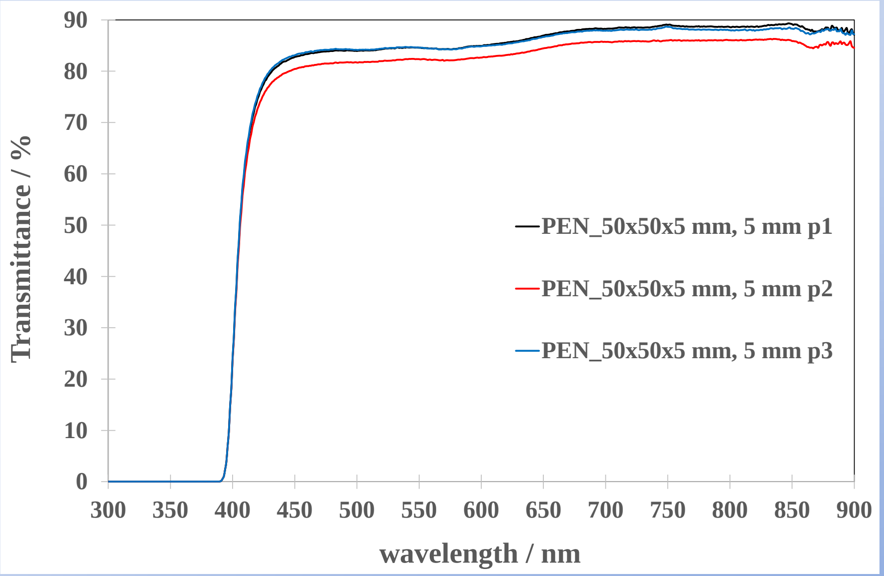
We tested a set of PEN samples produced by injection molding in the framework of R&D towards the LEGEND project for the search of neutrinoless double beta decay, samples provided by TUM group:

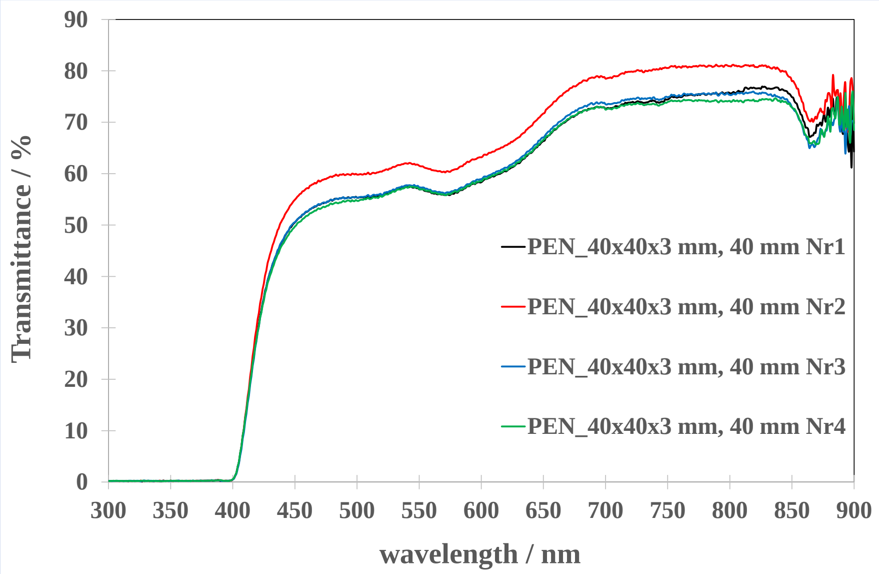
4 samples with dimensions 40x40x3 mm^3
1 sample with dimensions 50x50x5 mm^3

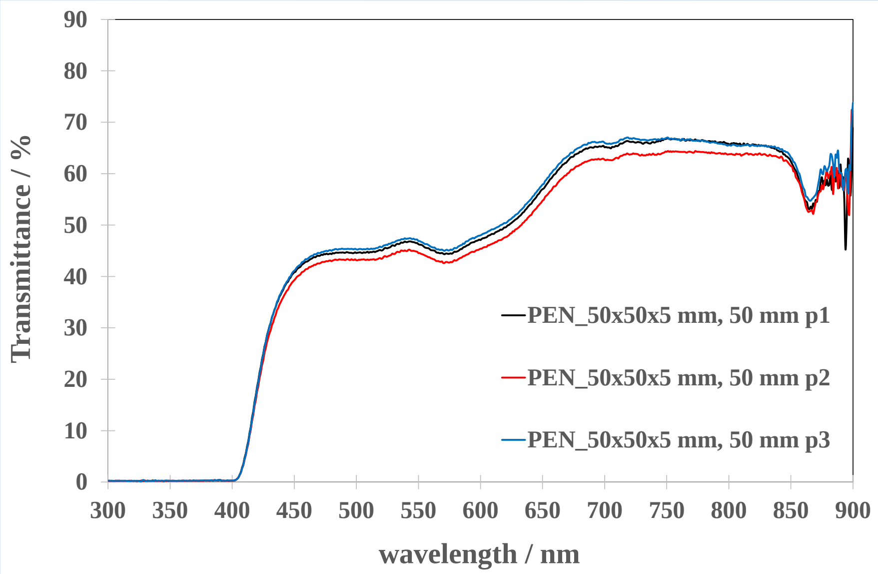
Transmittance measurements were done for 3, 5, 40 and 50 mm light paths
Light yield and kinetics were measured for 40x40x3 mm^3 sample

Transmittance

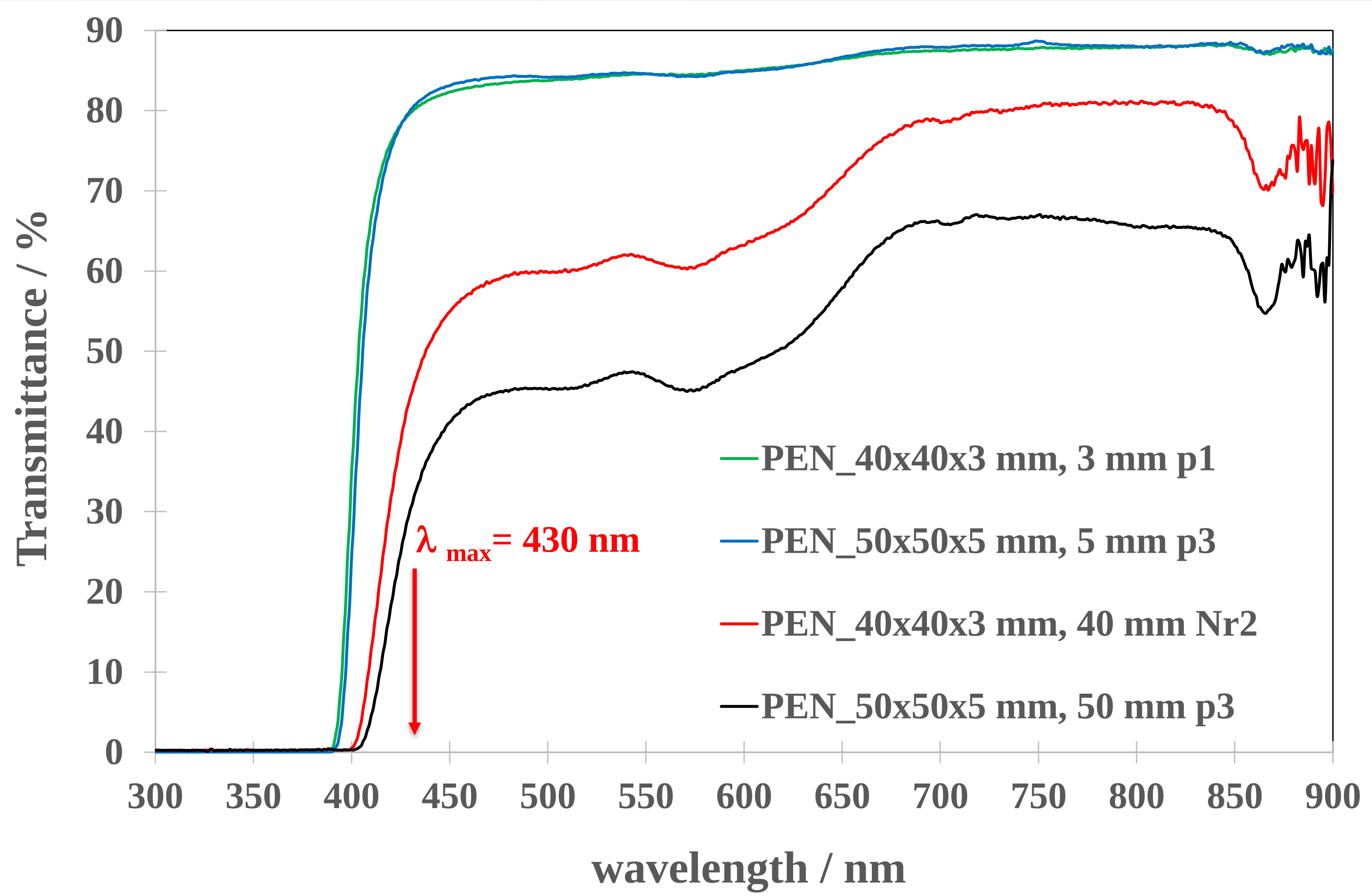






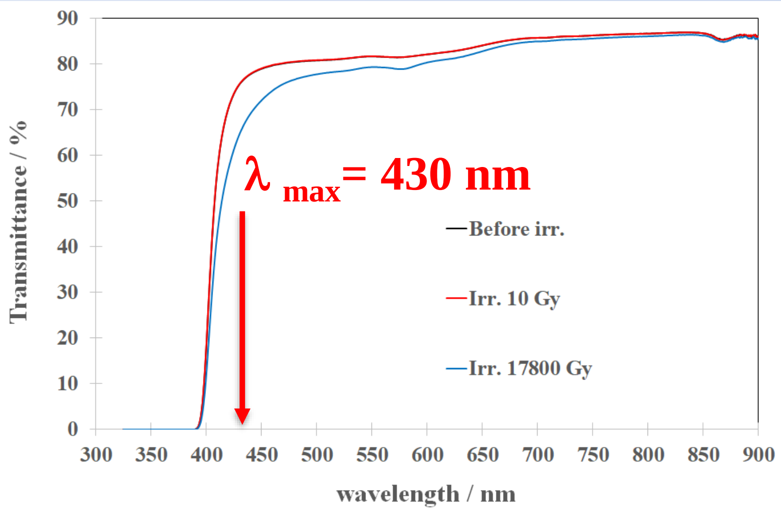


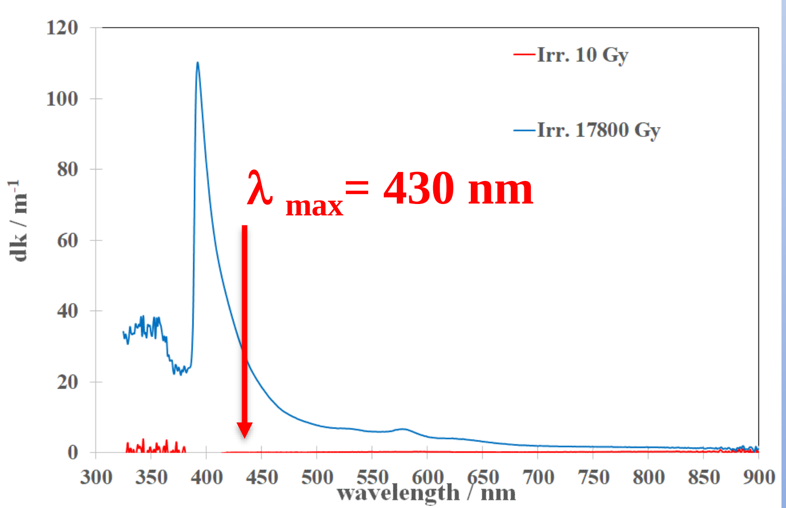
Transmittance

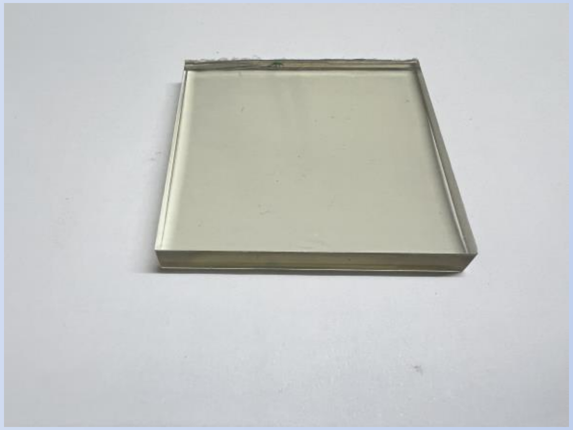


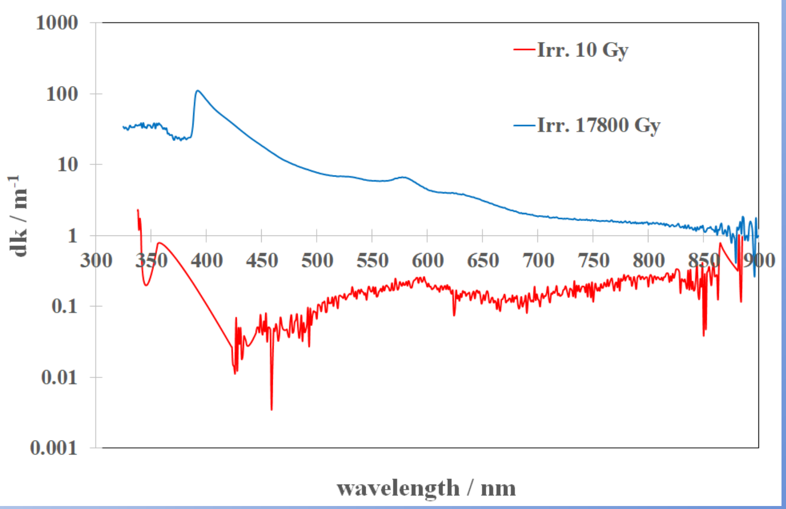
Radiation hardness

Sample 5x5x0.5 cm
^{60}Co source dose rate = 0.52 Gy/min.

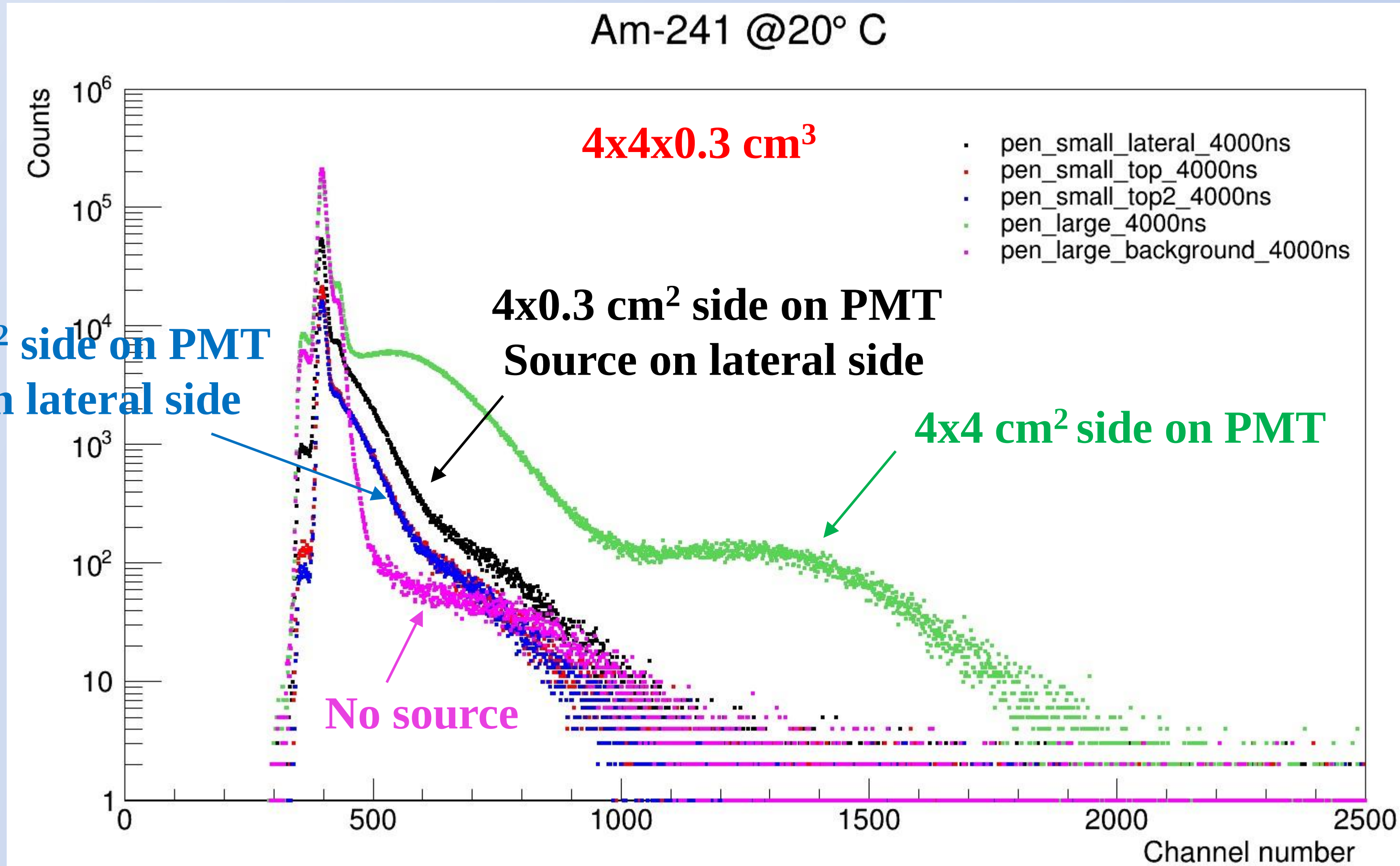






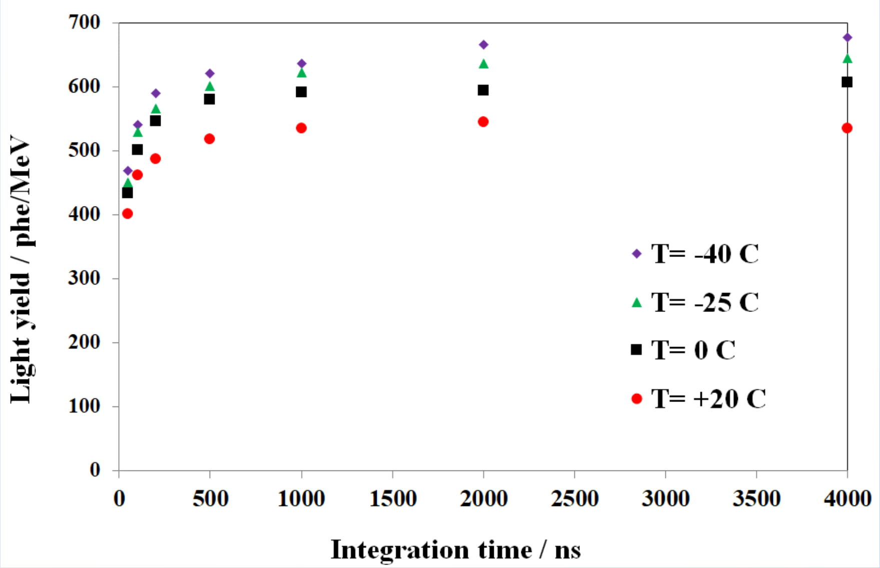


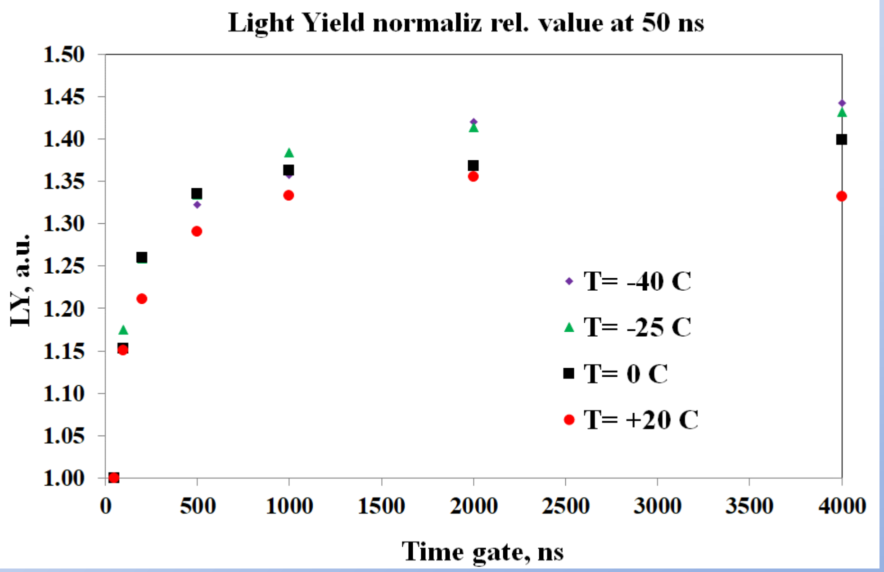
Light Yield measurements

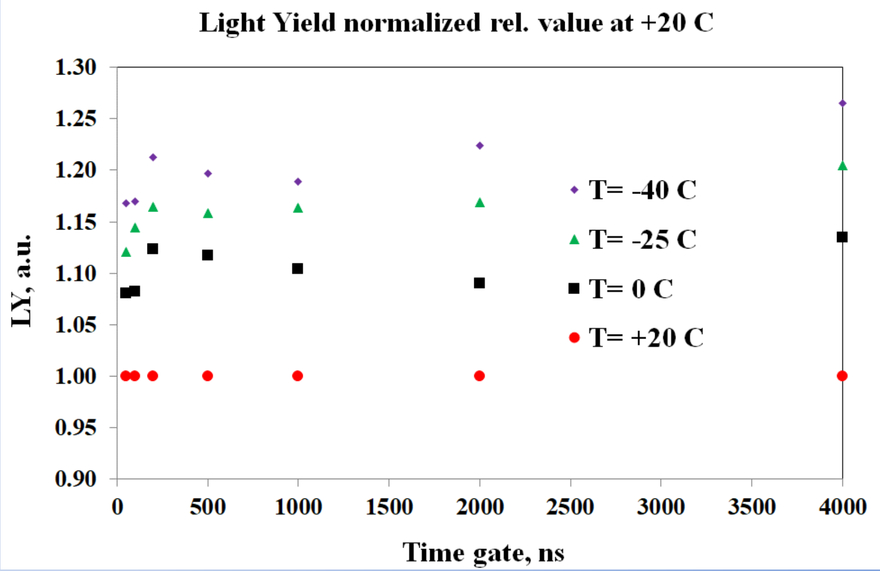


4x0.3 cm² side on PMT
Source on lateral side

Light Yield vs integration time

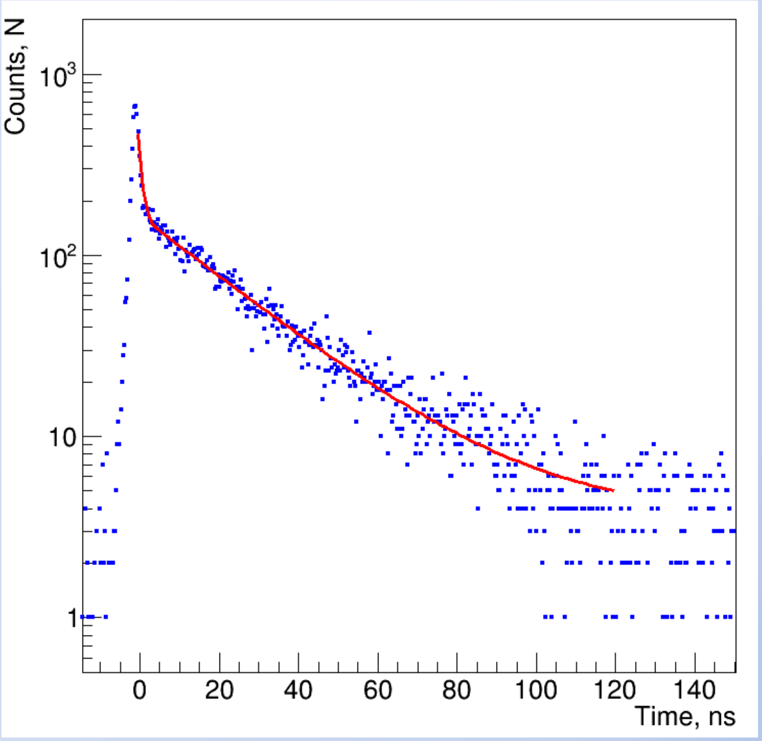


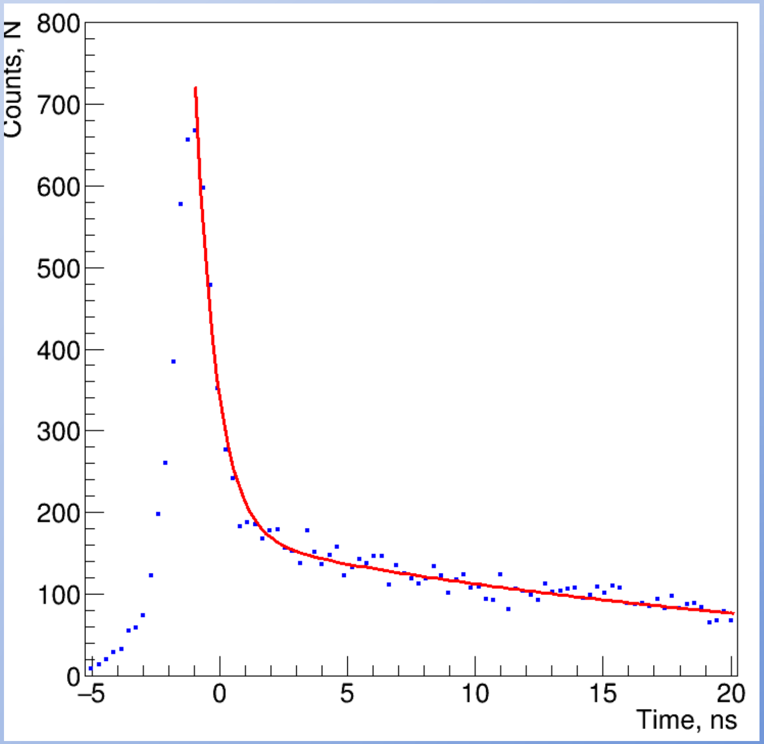




Kinetics of scintillation (1)

Kinetics of scintillation was measured by two methods:
1) "Start-stop" method: coincidence between 2 gamma-quanta of ^{22}Na (511 keV) source. Start detector: BaF2 + UV filter attached to PMT. Stop channel: sample placed on the distance from second PMT. Tektronix MSO66B40 oscilloscope was used to arrange the data acquisition system (DAQ)



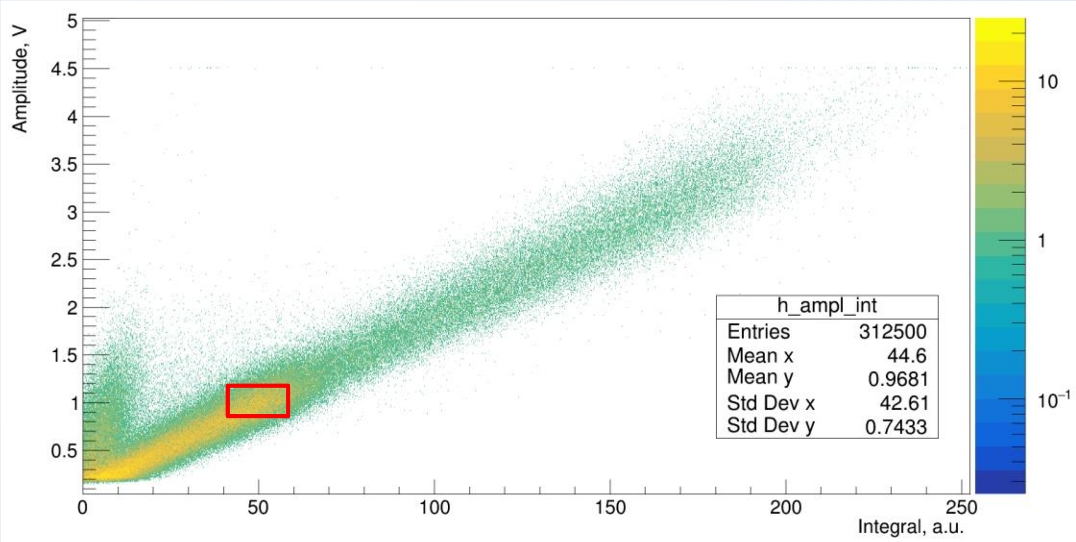


$$Fit = 149.6 \cdot e^{\left(\frac{-(x-1.97)}{25.2}\right)} + 16.37 \cdot e^{\left(\frac{-(x-1.97)}{0.83}\right)} + 3.59$$

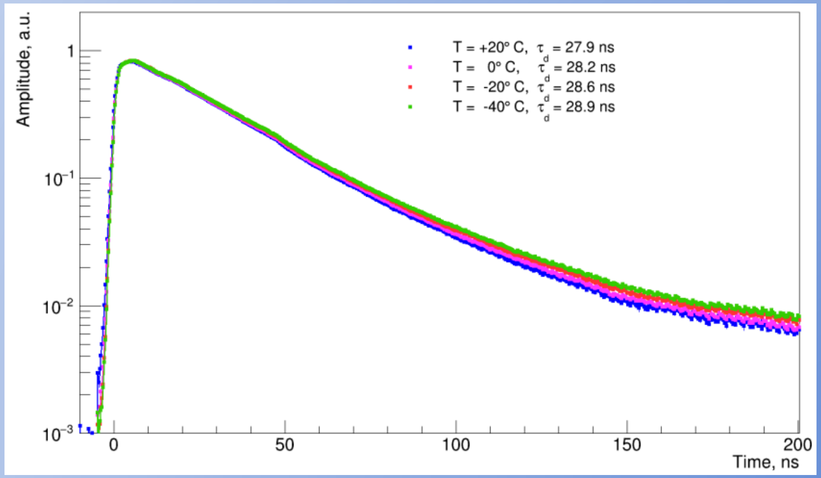
τ_{d1} = 0.83 ns, τ_{d2} = 25.2 ns

Kinetics of scintillation (2)

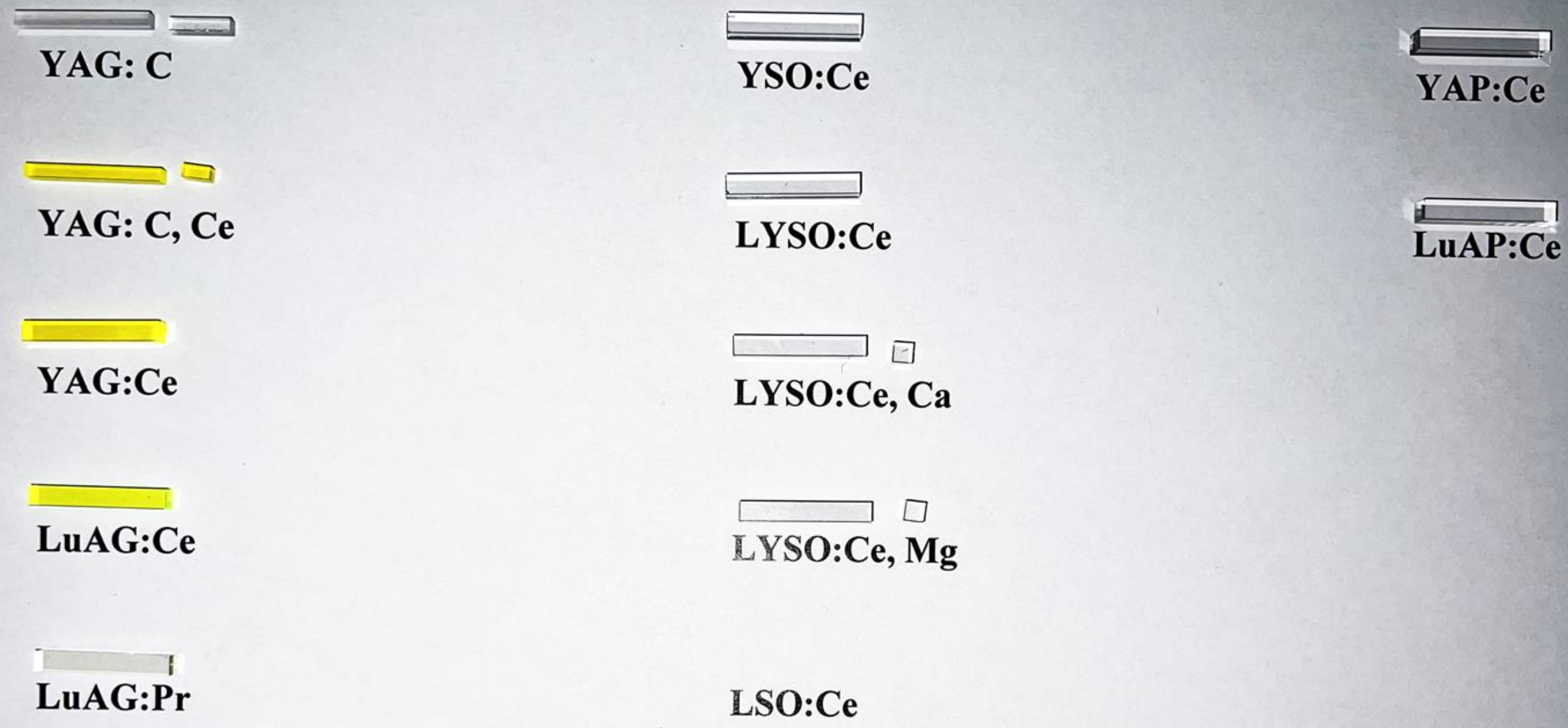
2) Fit of average pulse from photopeak of the energy spectrum.
Tektronix MSO66B40 oscilloscope was used to arrange the data acquisition system (DAQ)



Na-22 source
About 40000 traces from amplitude range [0.8; 1.1] and [40; 60] integral belong to 511 keV photopeak area



Study of different materials



Study of different materials

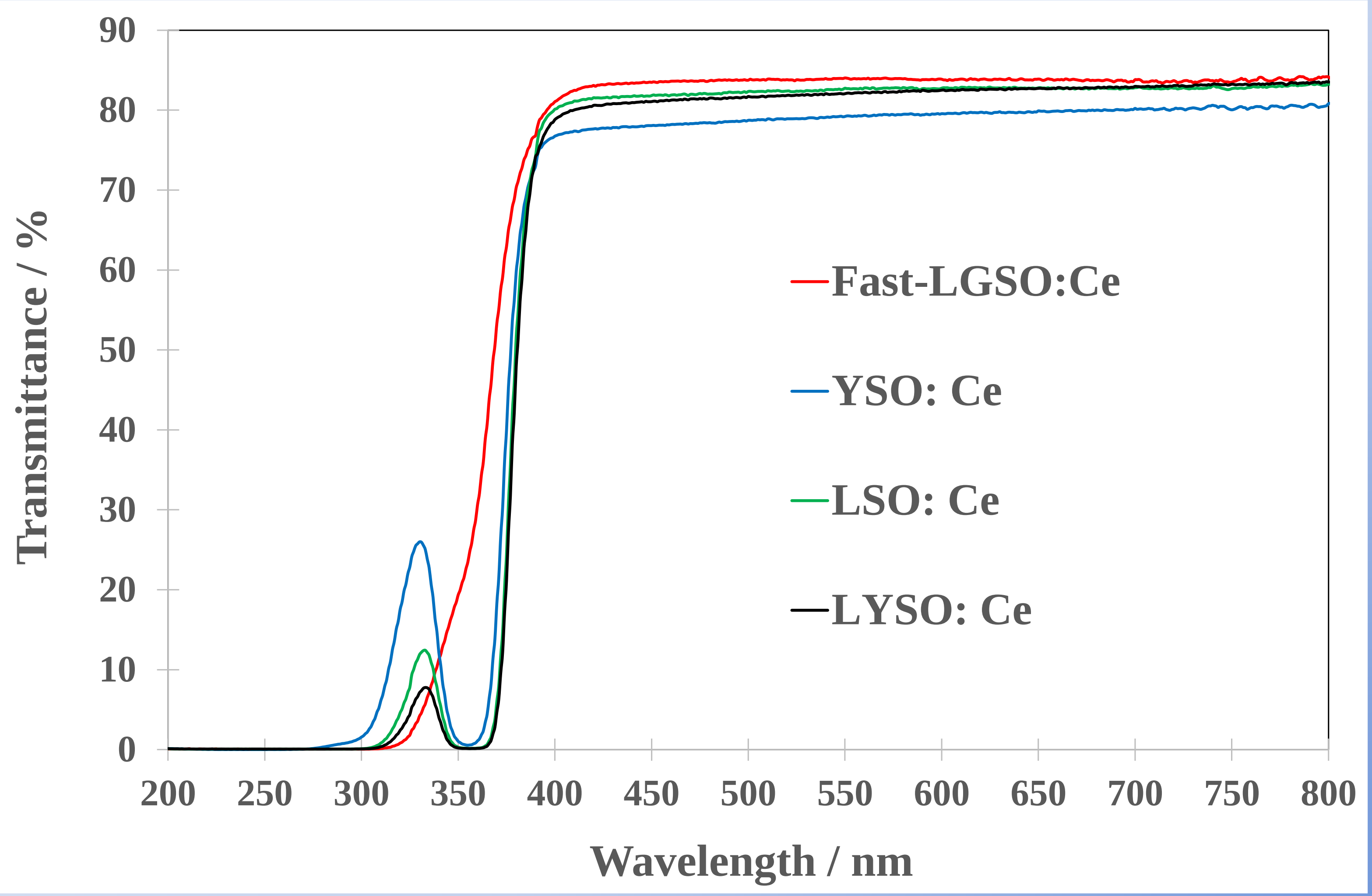
Lutetium-Yttrium-Gadolinium Oxyorthosilicates
Y_2SiO_5: Ce (YSO :Ce) produced by OST (China)
$Lu_{2(1-x)}Y_{2x}SiO_5$ (LYSO)
LYSO: Ce produced by OST (China)
LYSO: Ce, Ca produced by Taiwan Applied Crystal
LYSO: Ce, Mg produced by Taiwan Applied Crystal
Lu_2SiO_5: Ce (LSO: Ce) produced by ADVATEC (UK)
$Lu_{2(1-x)}Gd_{2x}SiO_5$: Ce (Fast-LGSO) produced by OXIDE (Japan)

Garnet family:
$Y_3Al_5O_{12}$: Ce (YAG: Ce)
$Lu_3Al_5O_{12}$: Ce (LuAG: Ce)
$Lu_3Al_5O_{12}$: Pr (LuAG: Pr)
produced by CRYTUR (Czech Republic)

$Gd_3Al_2Ga_3O_{12}$: Ce (GAGG: Ce) UltraFast version produced by ADVATECH (UK)
Transparent scintillation ceramics $(Gd,Lu,Y)_3Al_2Ga_3O_{12}$:Ce (GYL)

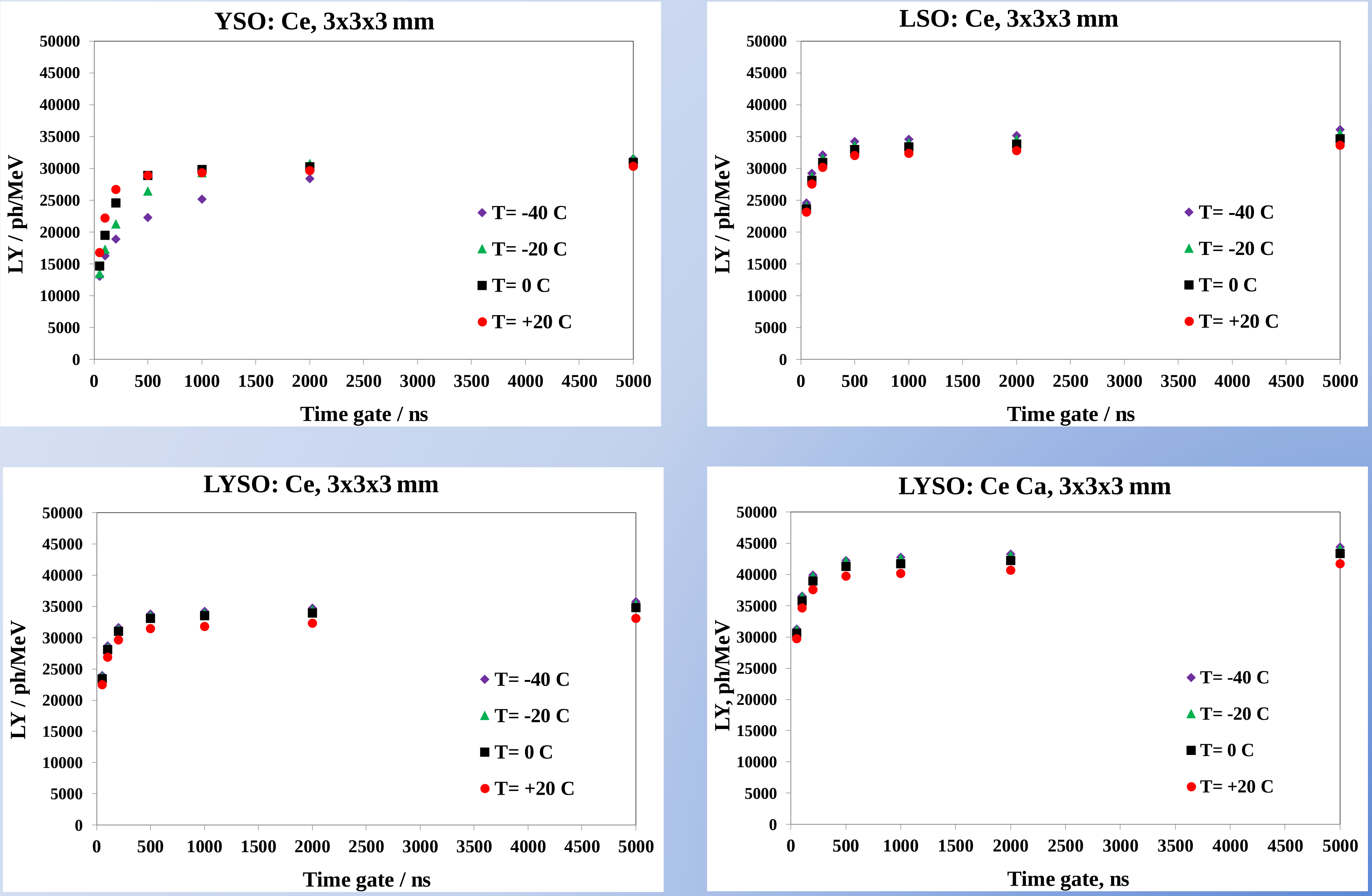
Transmittance

Sample thickness = 3 mm



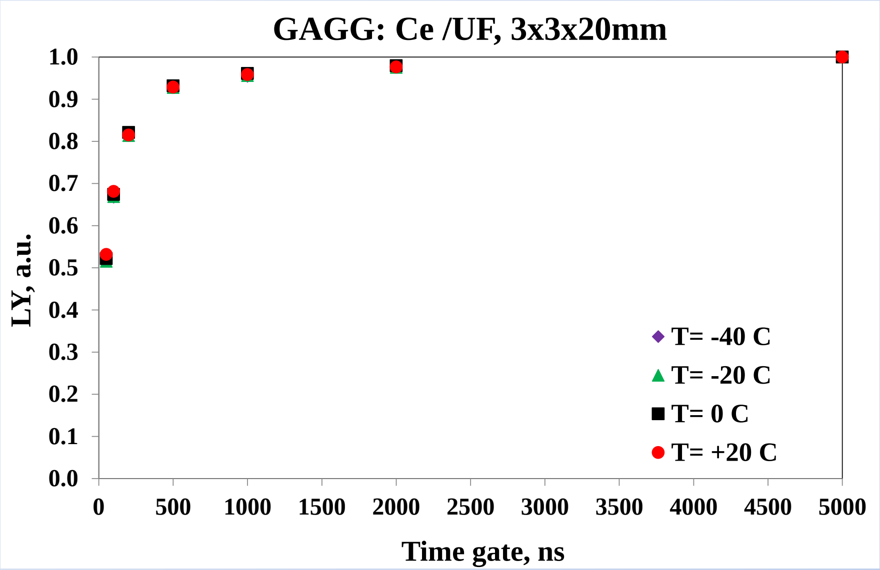
Light Yield measurements of oxyorthosilicates

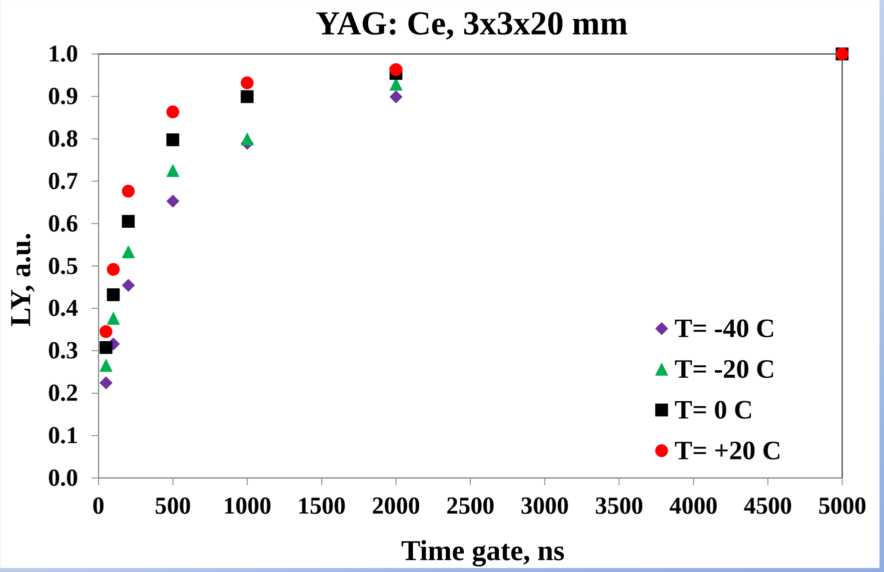
Light yield in photons/MeV, calculated relatively a quantum efficiency value at the luminescence maximum (420 nm)

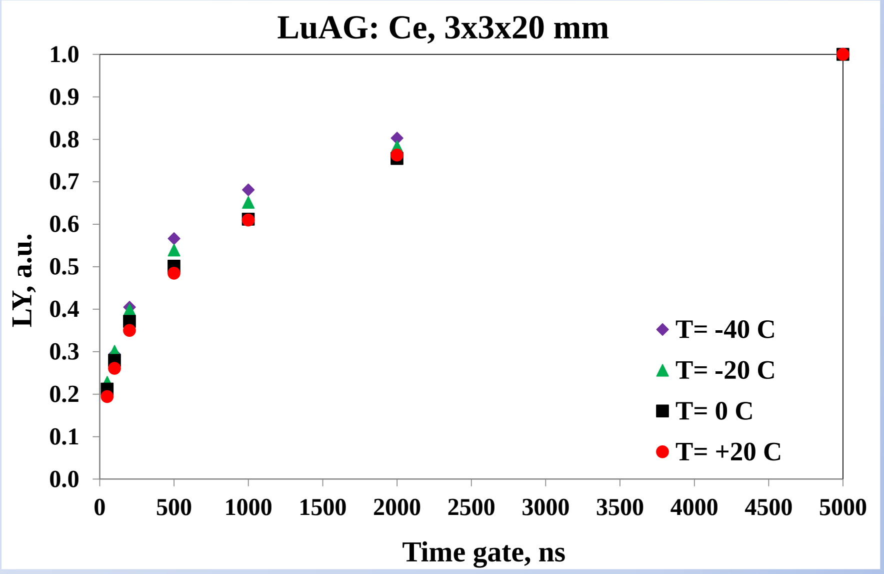


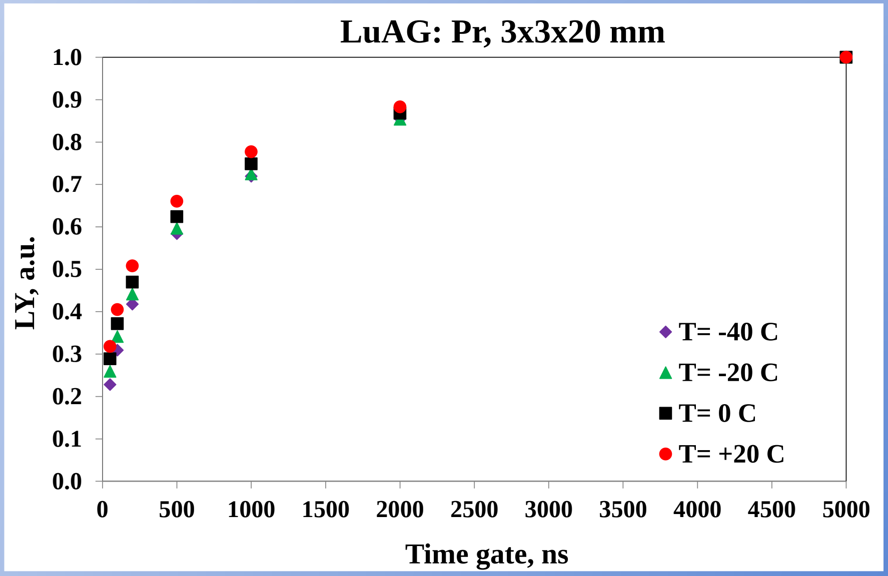
Light Yield measurements of garnets

Calibrated light yield relatively values at 5000 ns time gate for each temperature





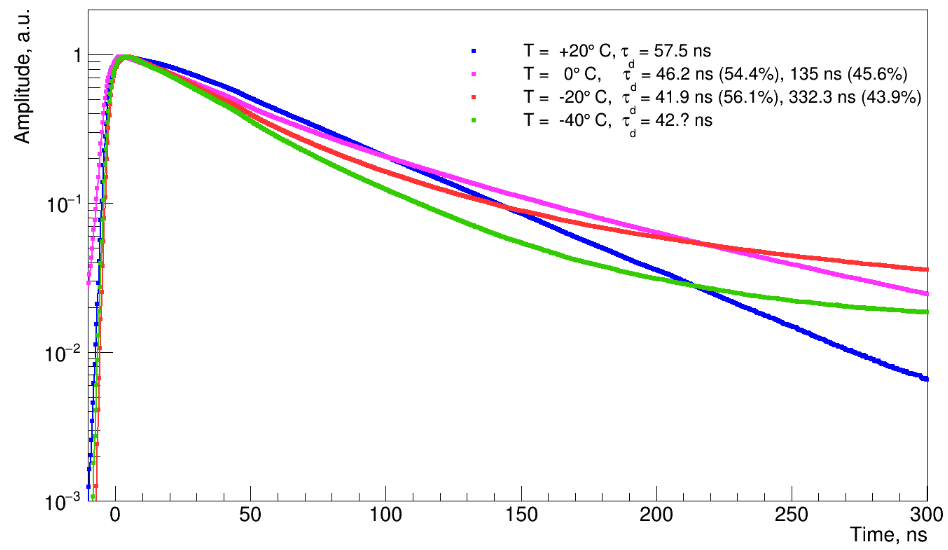




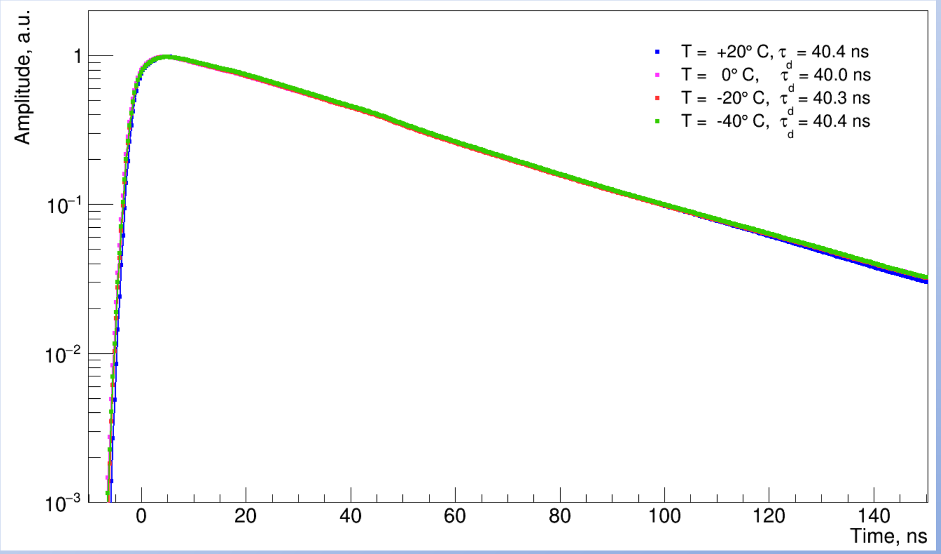
Kinetics vs Temperature

Kinetics fit was done for averaged pulse shapes measured with ^{137}Cs gamma-source

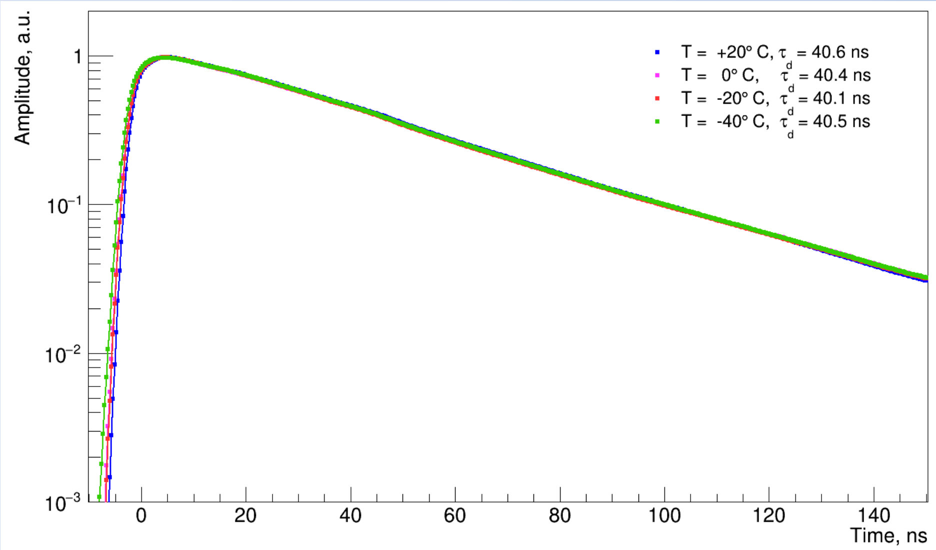
YSO:Ce



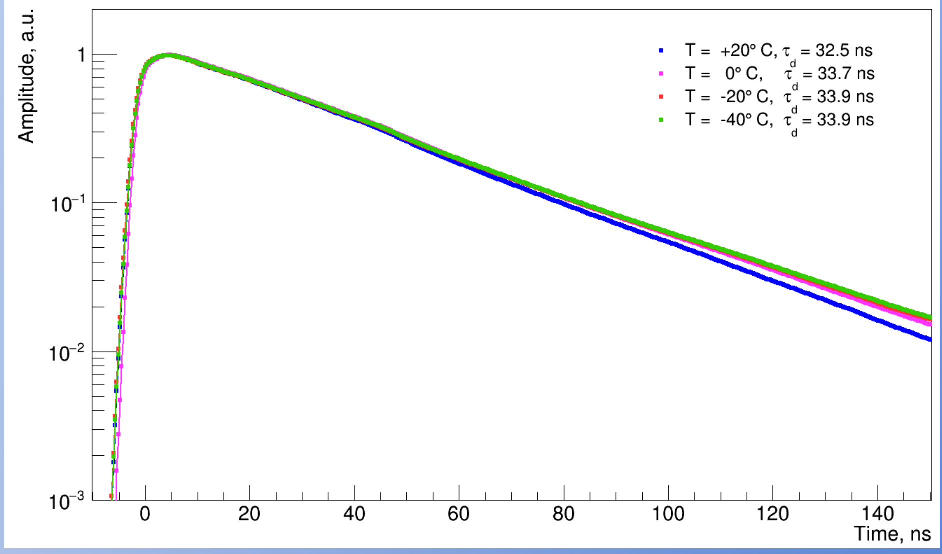
LSO:Ce



LYSO:Ce



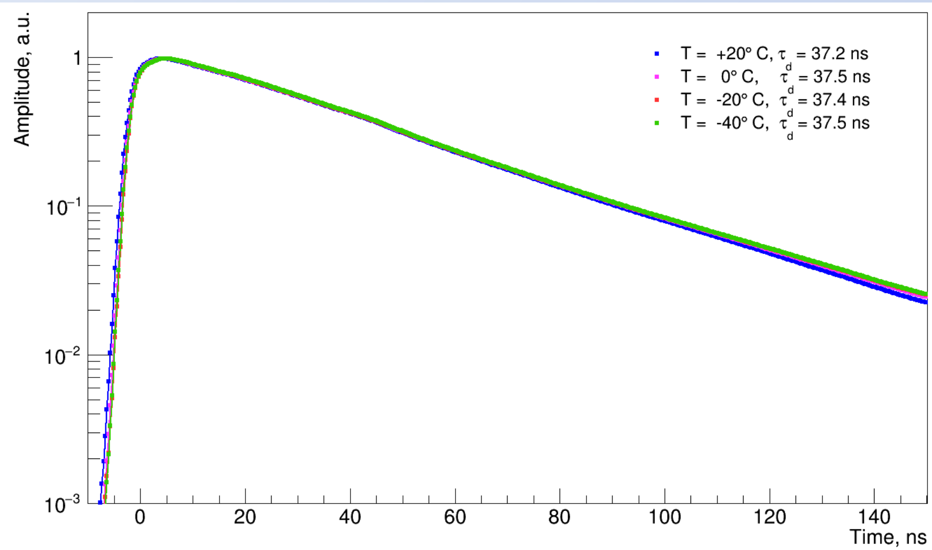
LGSO:Ce



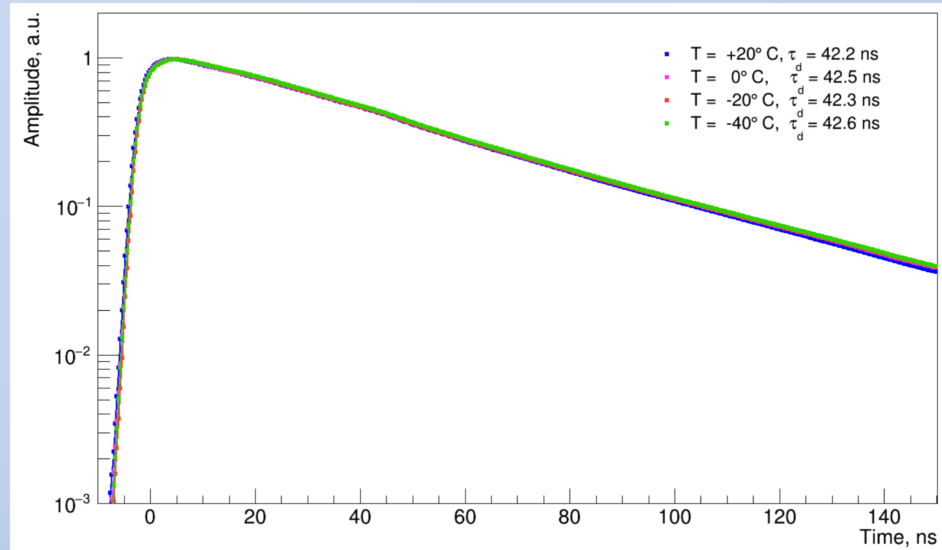
Kinetics vs Temperature

Kinetics fit was done for averaged pulse shapes measured with ^{137}Cs gamma-source

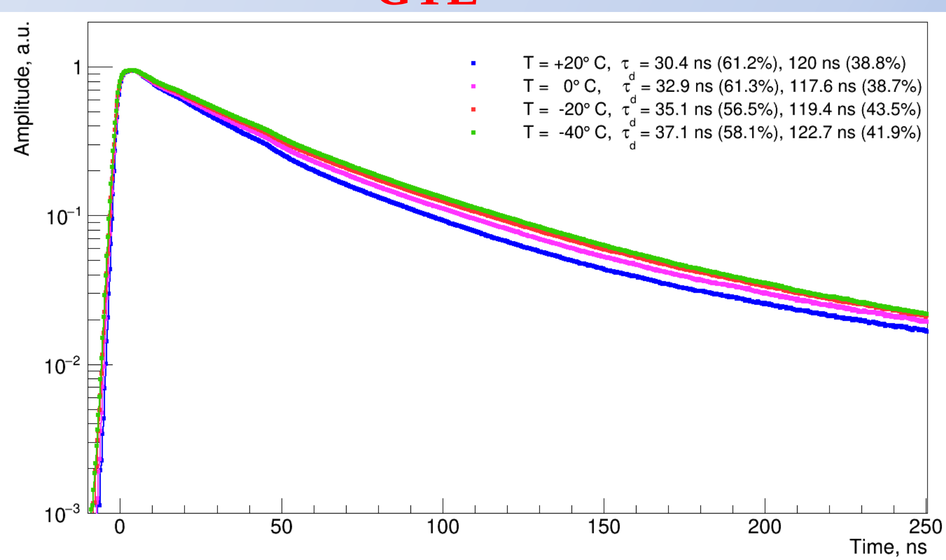
LYSO:Ce,Ca



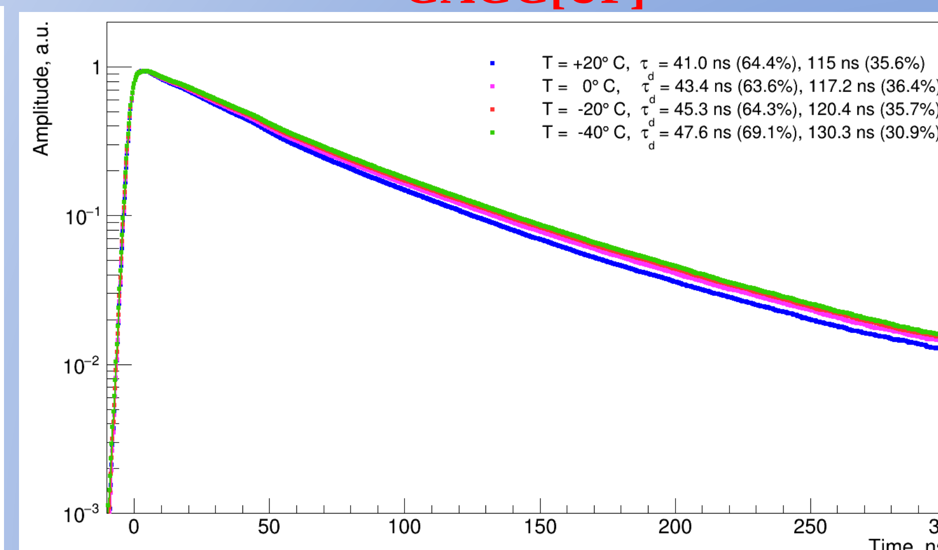
LYSO:Ce,Mg



GYL



GAGG[UF]



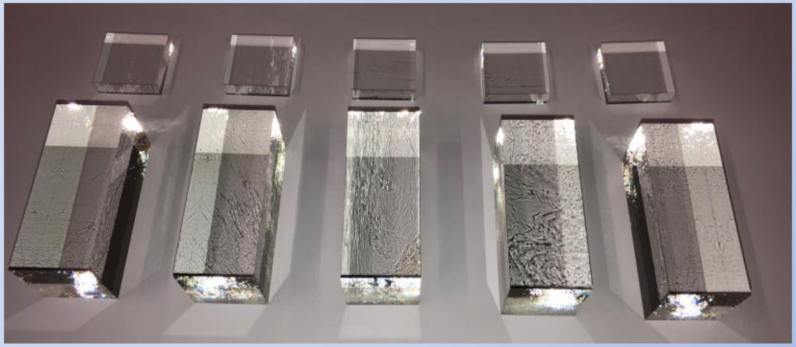
Physical properties of different heavy silica glasses

Material	ρ g/cm3	Z_{eff}	X_0 cm	λ_{max} nm	Cut-off undoped material / nm
$BaO*2SiO_2$	3.7	51	3.6	-	310
DSB: Ce	3.8	51	3.5	440-460	310
$BaO*2SiO_2$:Ce glass heavy loaded with Gd	4.7-5.4(?)	58	2.2	440-460	318

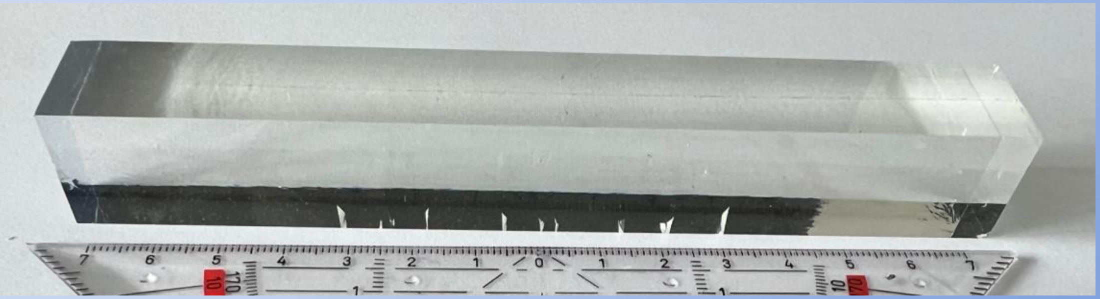
Technology: Typical glass production technology combined with successive thermal annealing (800 – 900^{o}C). Technological process is manageable at any glass production facility worldwide.

Glass samples produced by Schott Company (Mainz)

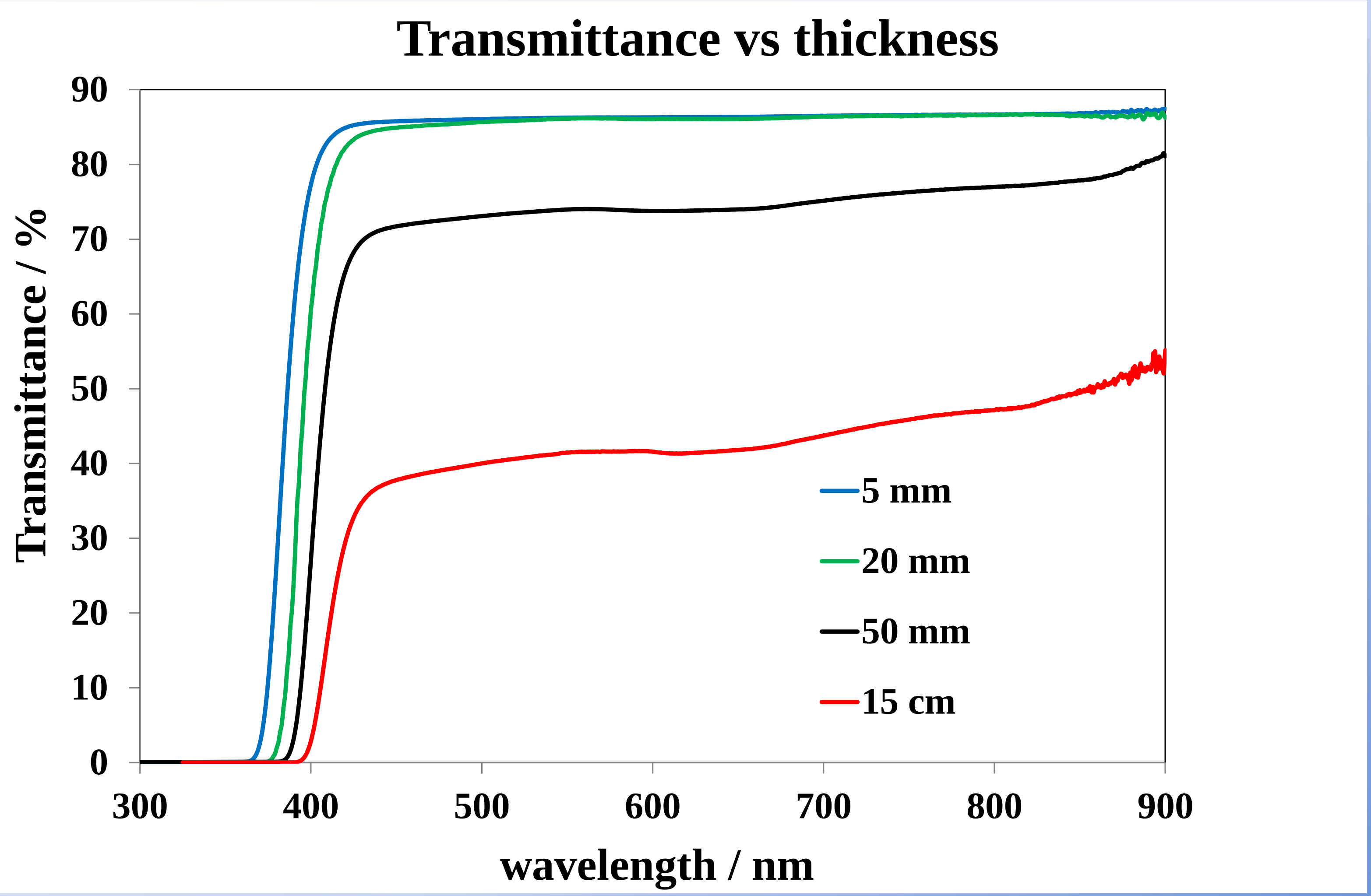
Two types of the glass materials have been delivered in 2021:
5 samples with 20x20x5 mm^3 dimensions;
5 samples with 20x20x50 mm^3 dimensions;



Long DSB glass sample 2x2x15 cm^3 was delivered in 2022

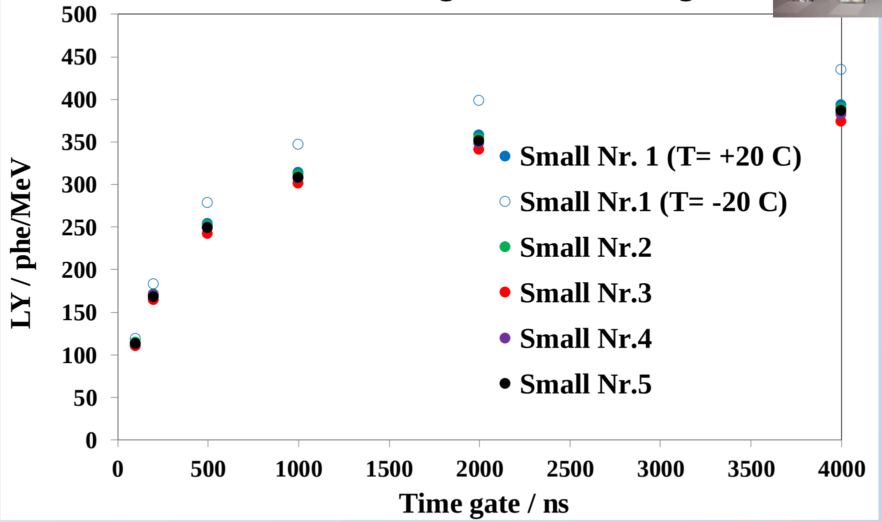


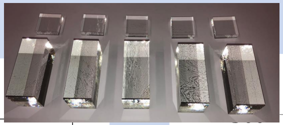
Transmittance vs sample thickness

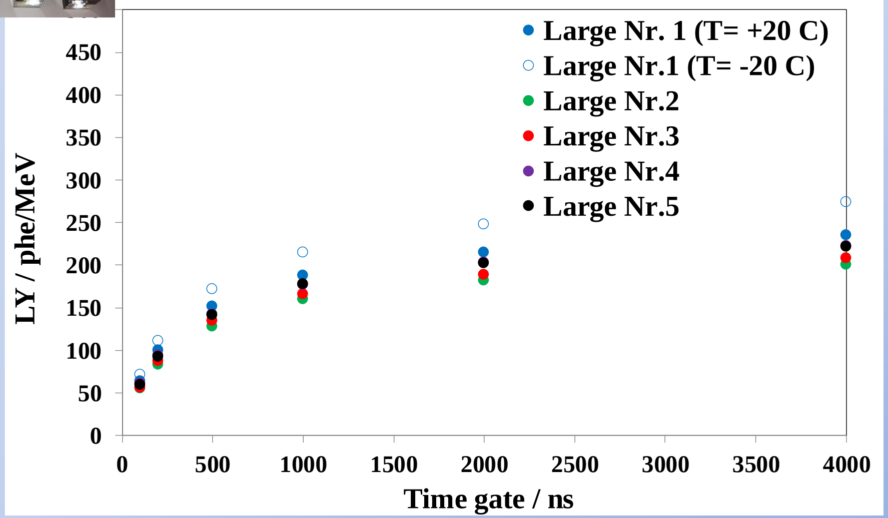


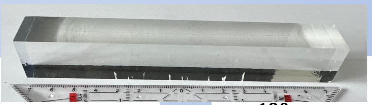
DSB glass samples: Light Yield

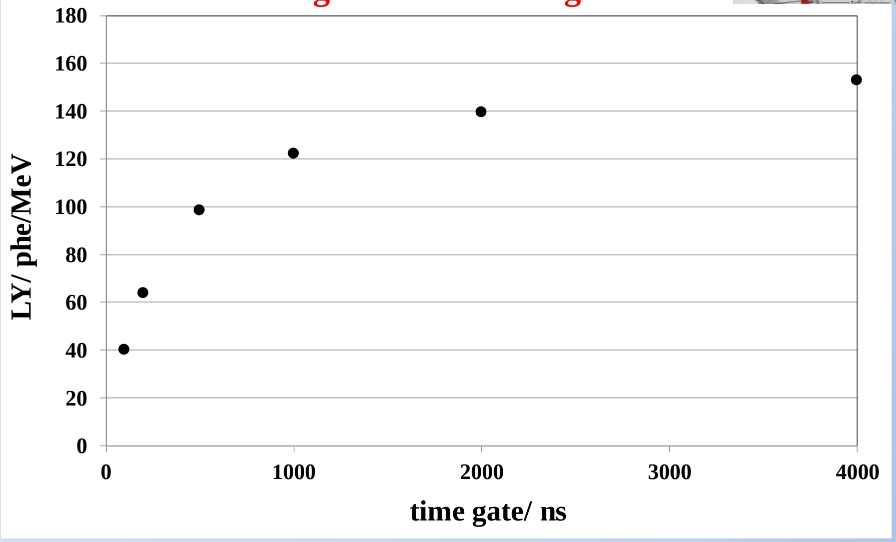
Measurements were done with ^{241}Am γ-source (E_γ = 60 keV), PMT Hamamatsu R2059

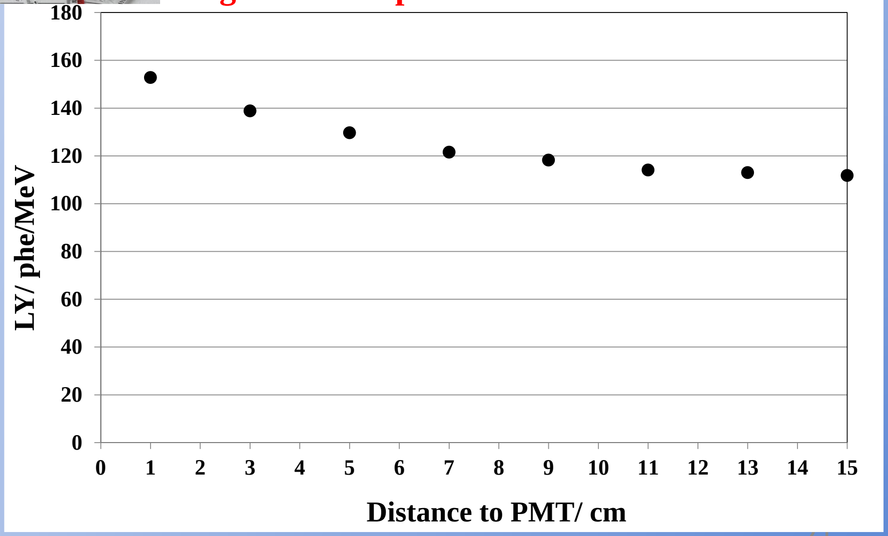




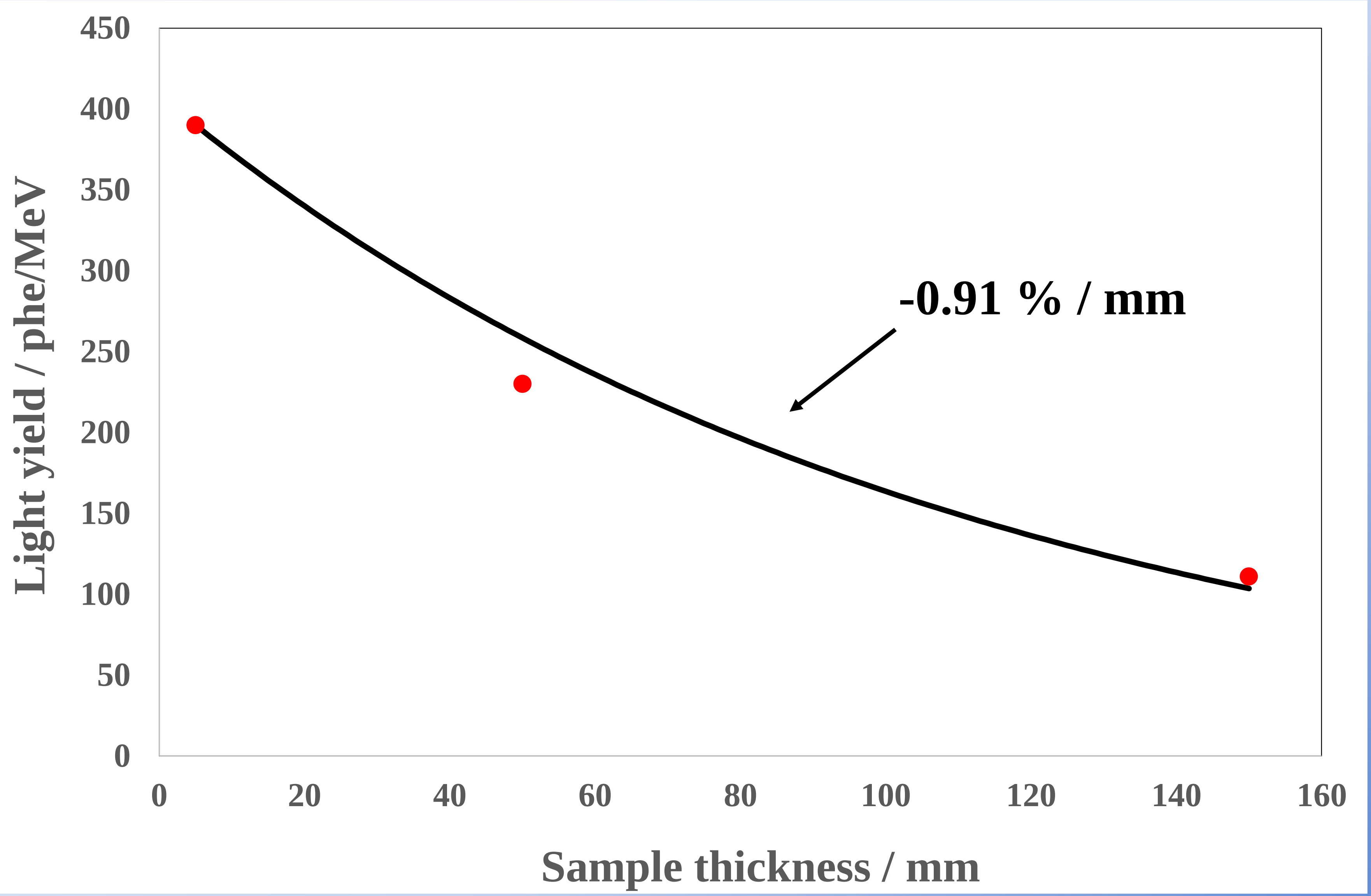






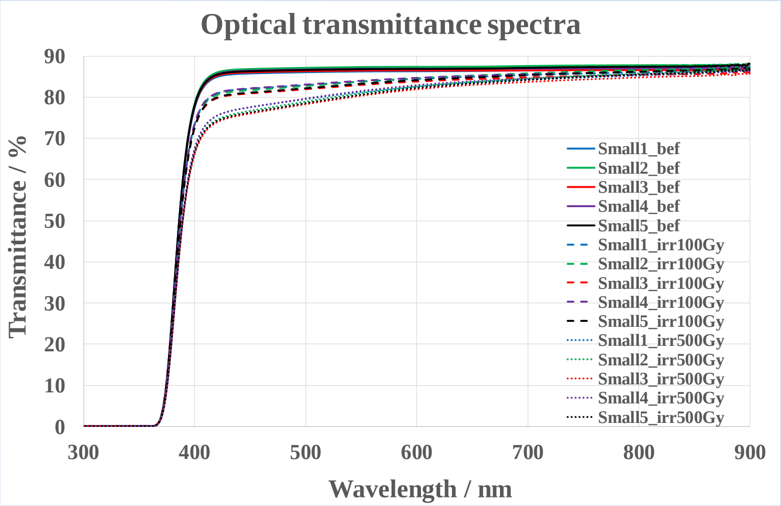


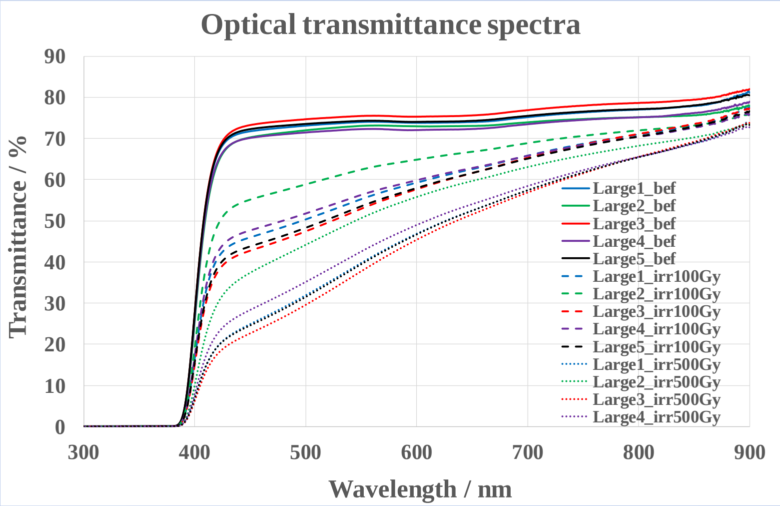
Light yield vs sample thickness

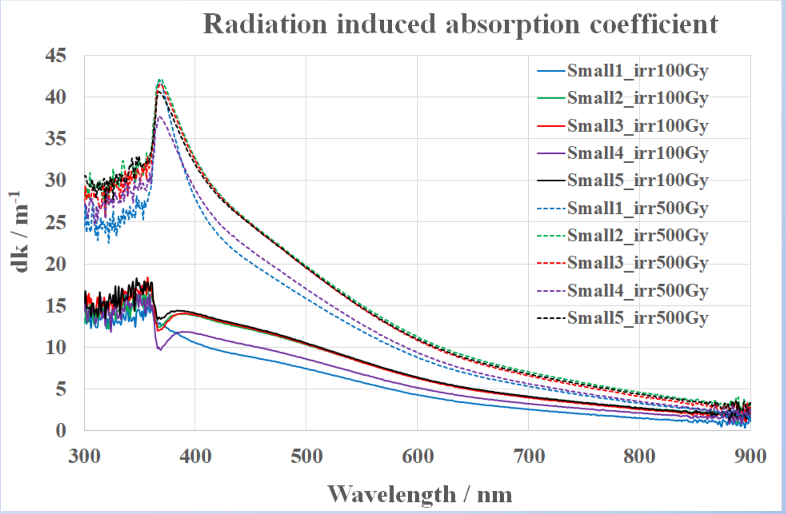


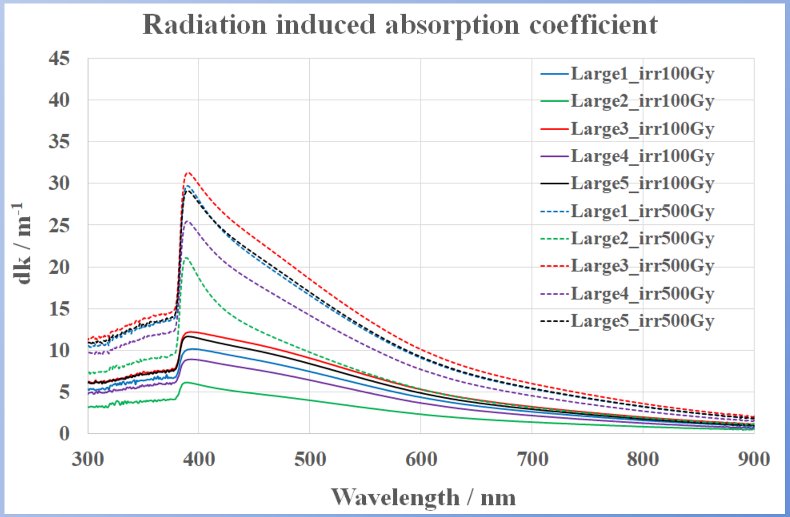
DSB glass samples: radiation damage

^{60}Co source dose rate = 0.7 Gy/min.

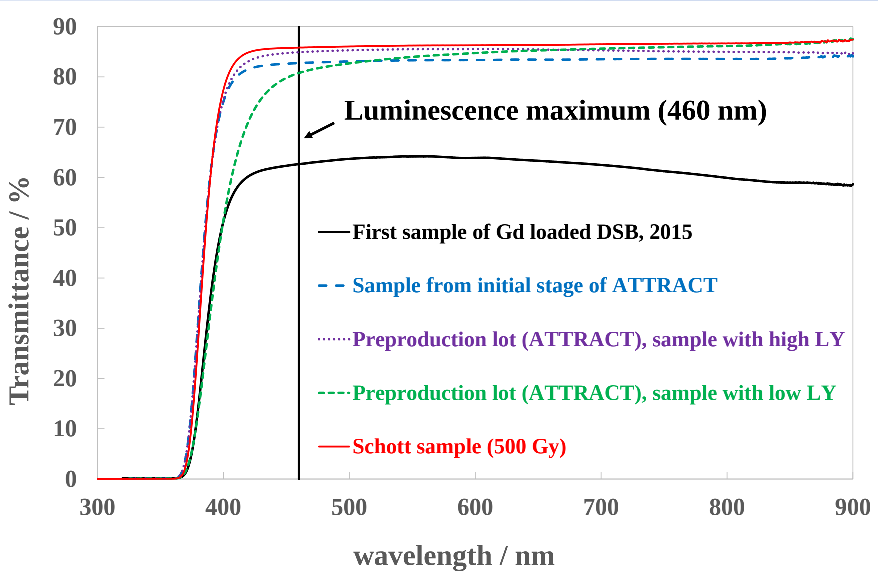


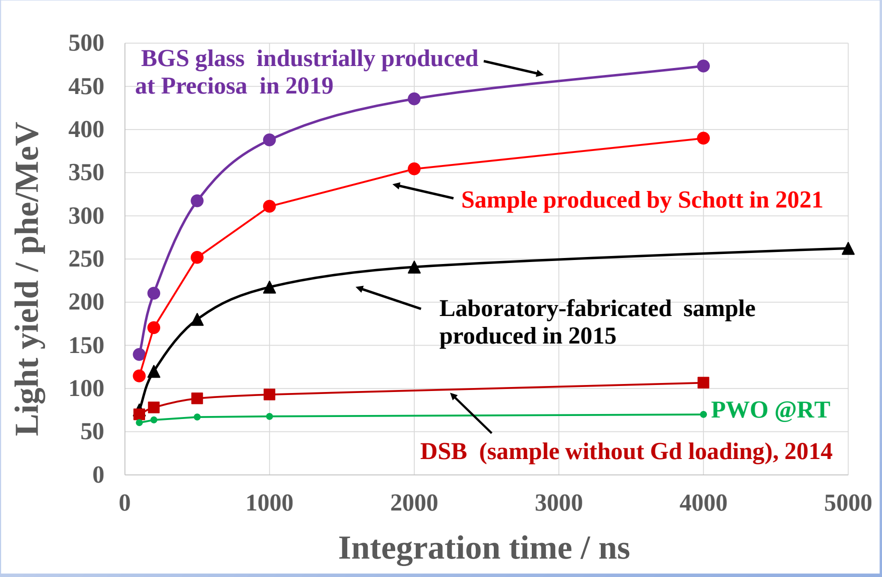


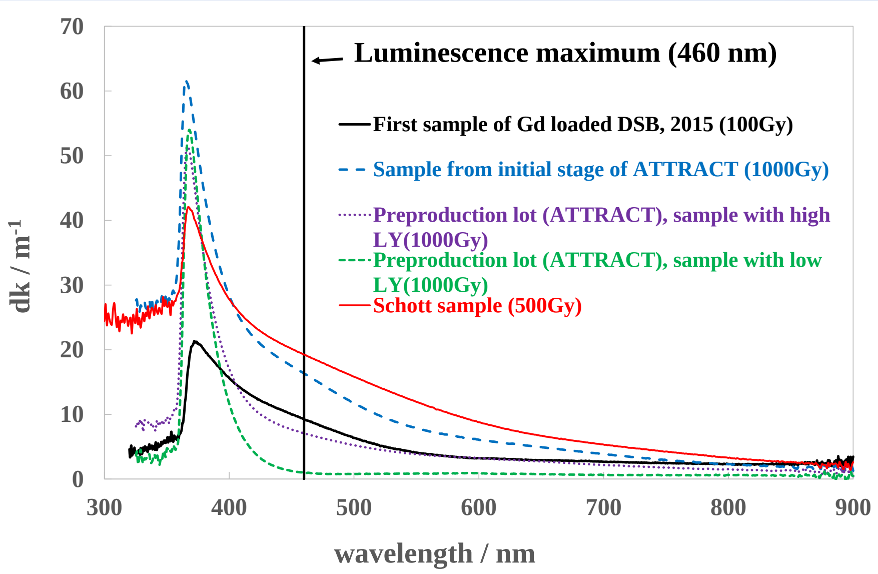


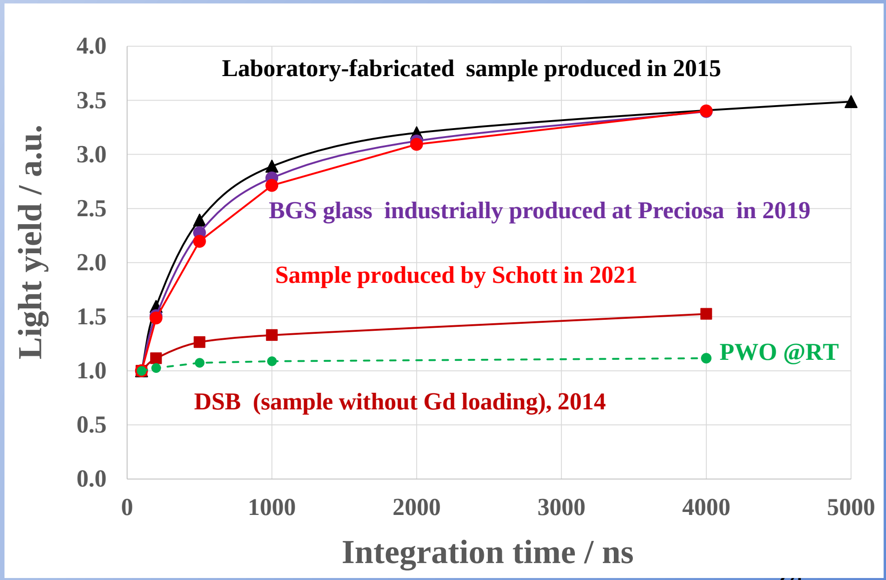


Properties evolution

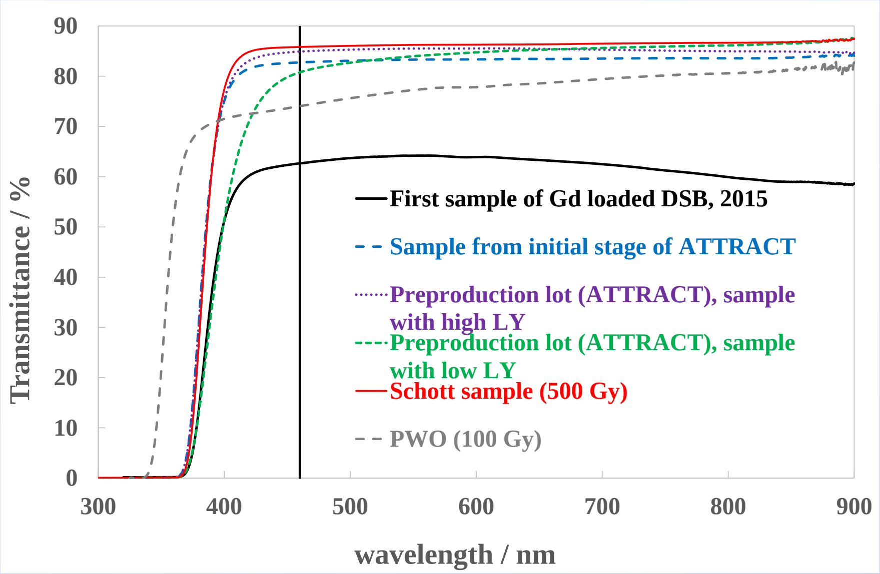


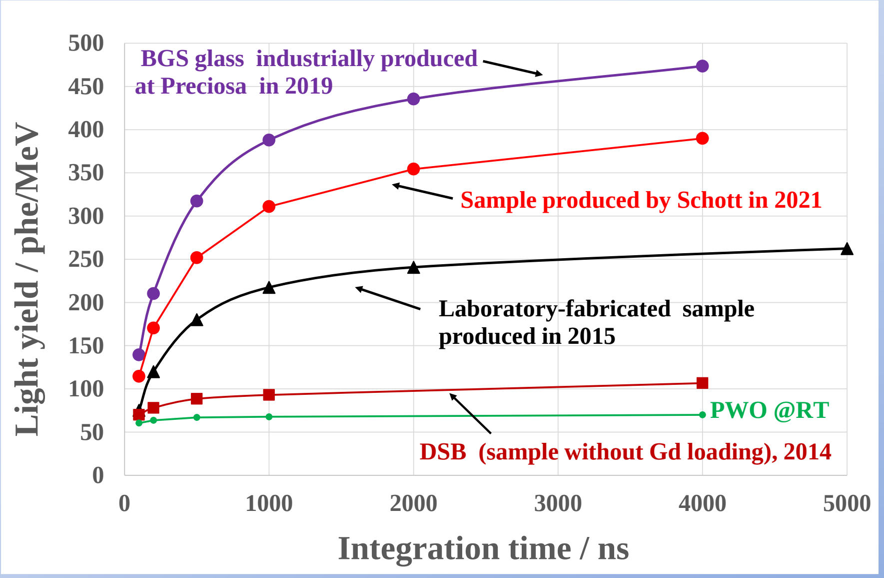


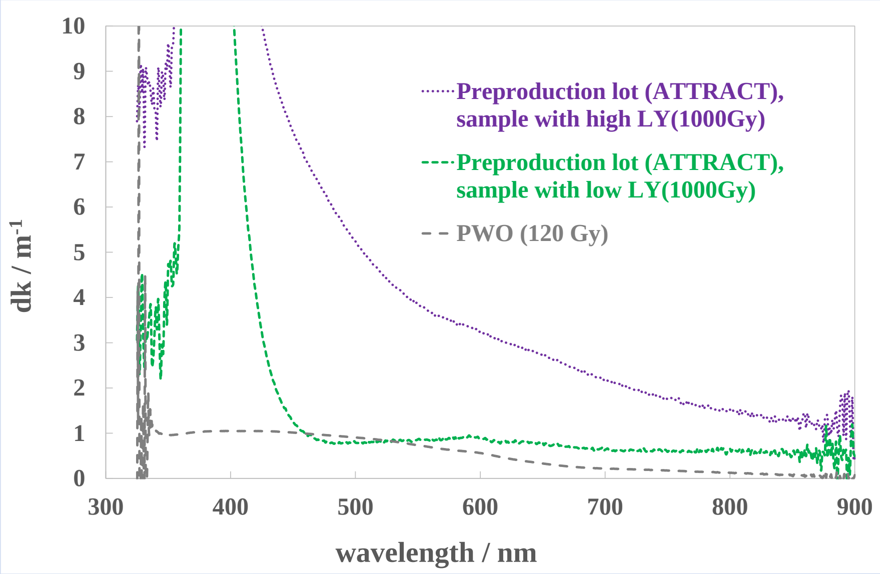


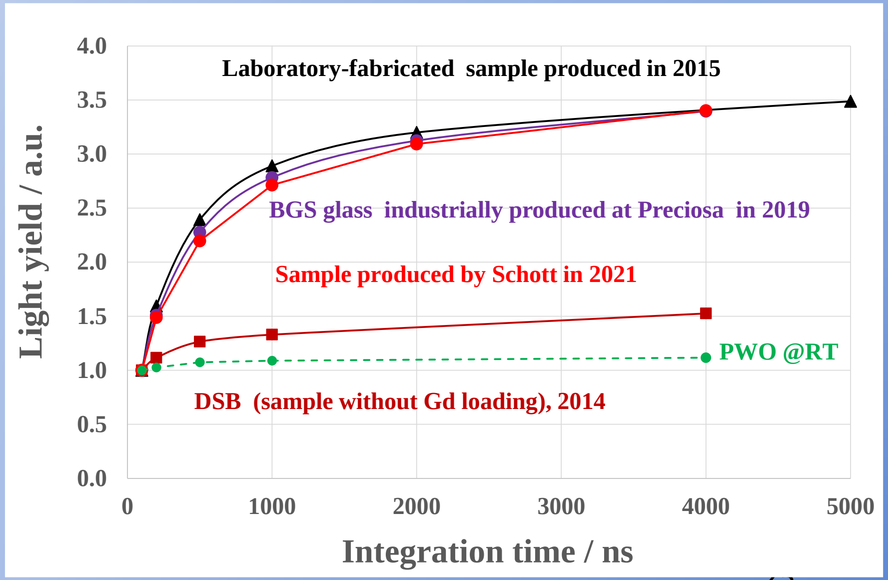


Properties evolution







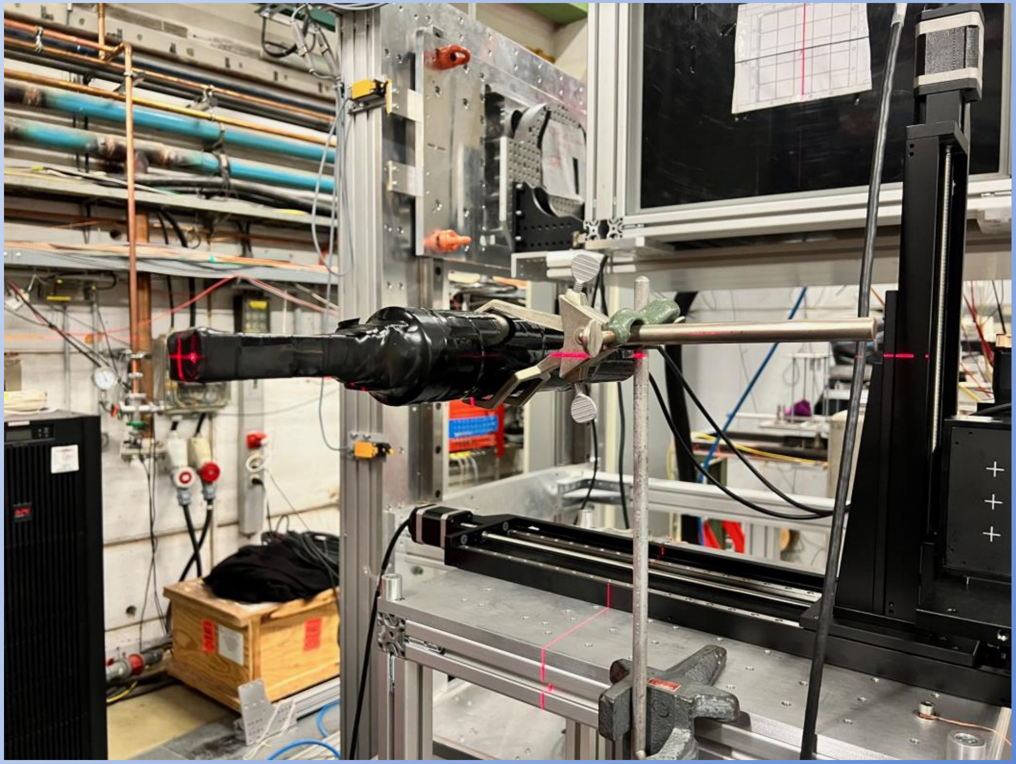


Large DSB glass sample: 2x2x15 cm^3

Beam test results with marked high-energy photons @ MAMI June 2023

Sample was wrapped in 8 layers of teflon film
Attached to Hamamatsu 2059 PMT
Optical grease: Basylon 300.000
Measurements were done for three High Voltages of PMT: 1500, 1550, 1700 V
Photon (Tagger) energies: 19.4 28.3 39.8 58.1 69.2 100.6 MeV
16 channel digitizer CAEN 1730 V was used for data acquisition

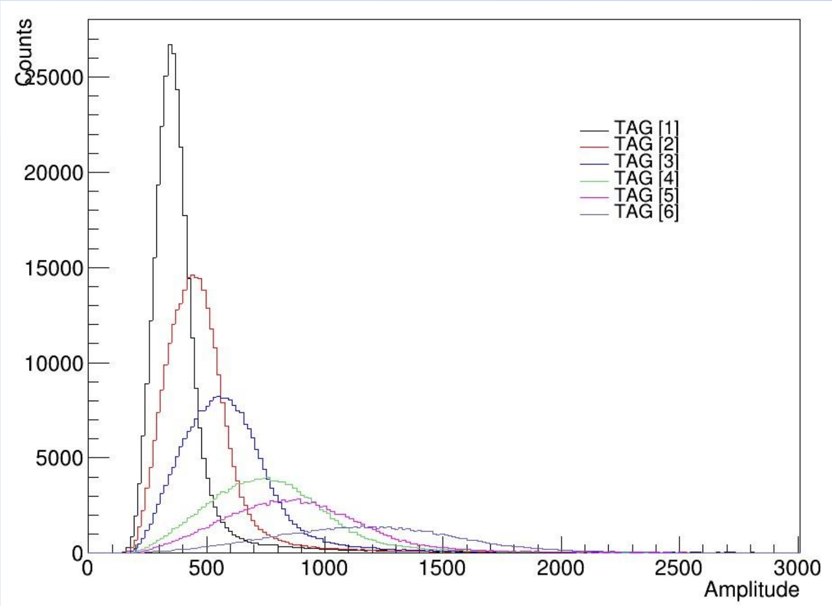
For every channel information of time marker and trace with 1 microsecond length was recorded if amplitude was above threshold.
Energy was defined as a sum pulse of the trace.
Coincidence scheme was realized as logic AND of time markers between DSB channel and logic OR of six Tagger channel.



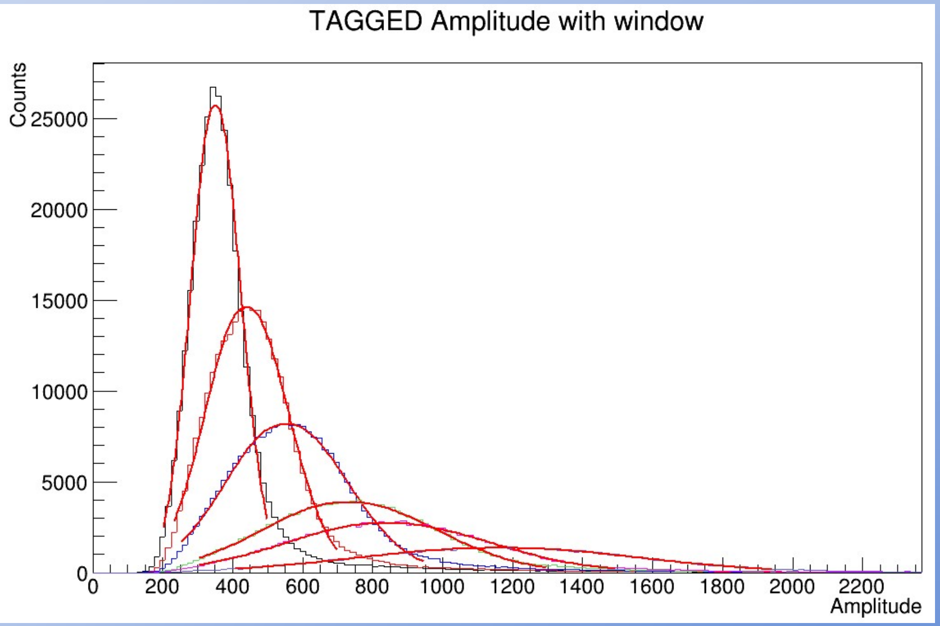
Large DSB glass sample: 2x2x15 cm^3

Photon (Tagger) energies: 19.4 28.3 39.8 58.1 69.2 100.6 MeV

Energy distributions of six tagger energies

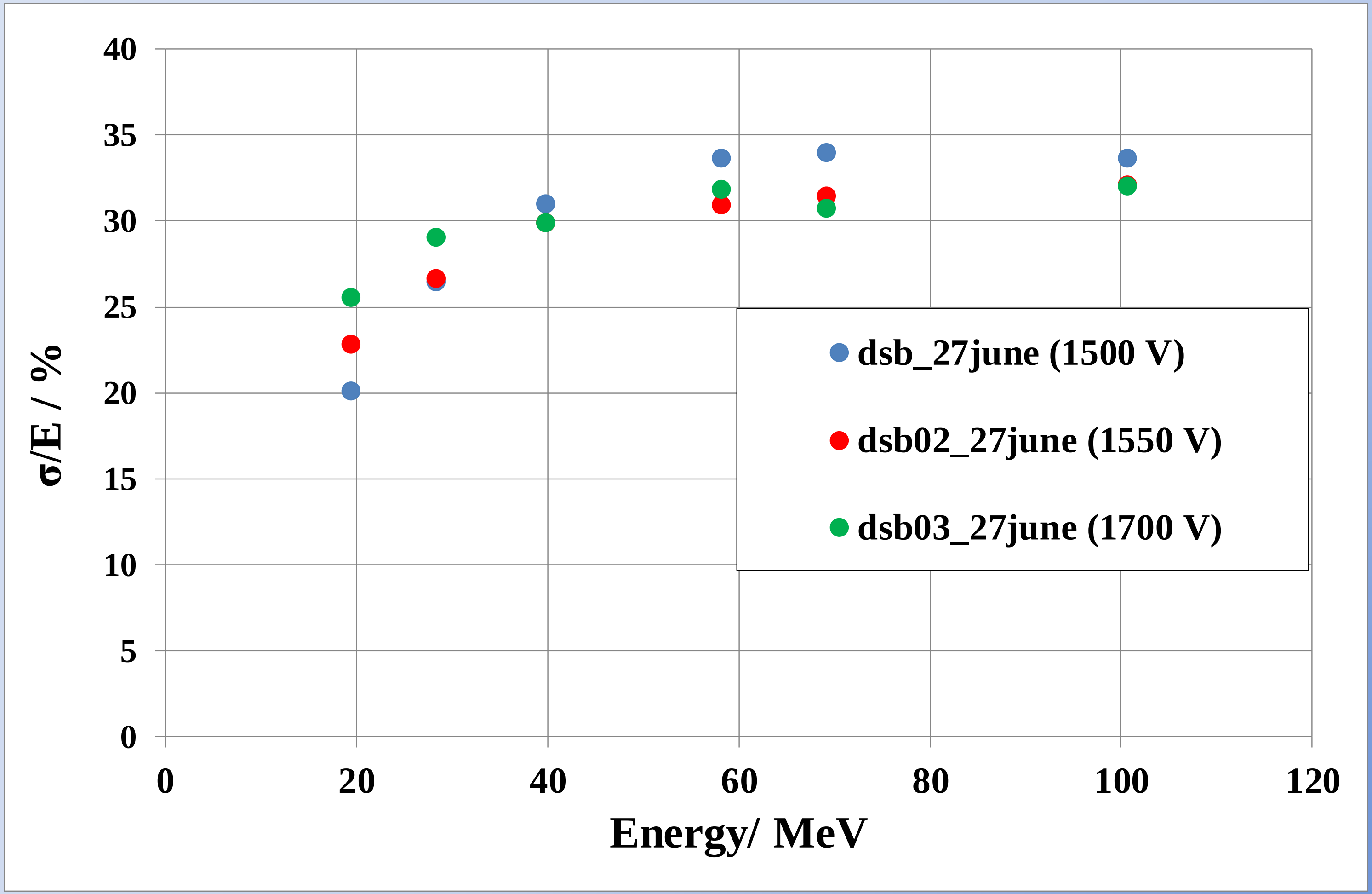


Fits with Novosibirsk fitting function



Large DSB glass sample: 2x2x15 cm^3

Energy resolution



Three samples (5 mm, 5 cm and 15 cm length) were provided to Caltech for tests
Samples will be tested in the CalVision beam test at DESY this Summer

All samples measured at Caltech HEP Crystal Lab

	BGO	BSO	PWO	PbF_2	PbFCl	Sapphire:Ti	AFO Glass	DSB:Ce Glass	ABS:Ce Glass
Density (g/cm^3)	7.13	6.8	8.3	7.77	7.11	3.98	4.6	4.3	6.0
Melting point (°C)	1050	1030	1123	824	608	2040	980[7]	1550	?
X_0 (cm)	1.12	1.15	0.89	0.94	1.05	7.02	2.96	2.58	1.55
R_M (cm)	2.23	2.33	2.00	2.18	2.33	2.88	2.90	3.24	2.50
λ_I (cm)	22.7	23.4	20.7	22.4	24.3	24.2	26.4	30.9	24.7
Z_{eff} value	71.5	73.8	73.6	76.7	74.7	11.1	41.4	49.5	56.9
dE/dX (MeV/cm)	8.99	8.59	10.1	9.42	8.68	6.75	6.84	6.1	8.0
Emission Peak[a] (nm)	480	470	425 420	\	420	300 750	365	420	400
Refractive Index[b]	2.15	2.68	2.20	1.82	2.15	1.76	?	?	?
LY (ph/MeV)[c]	7,500	1,500	130	\	150	7,900	450	>1,360	>1,140
Decay Time[a] (ns)	300	100	30 10	\	3	300 3200	40	500	1,200
d(LY)/dT (%/°C)[c]	-0.9	?	-2.5	\	?	?	?	0.3	?
Cost ($/cc)	6.0	7.0	7.5	6.0	?	0.6	2.0	2.0	<1

[a] Top line: slow component, bottom line: fast component. [b] At the wavelength of the emission maximum. [c] At room temperature (20°C) with PMT QE taken out.

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Conclusion

- **PEN material is a potential cost-effective organic scintillator**
- **Further properties optimization and investigation should be done**
- **Oxyorthosilicates and garnets demonstrates dependence of scintillation kinetics timing properties on co-dopings with temperature changes. Fitting of the average pulse shape is fast method of the kinetics properties evaluation**
- **DSB glass material can be considered as potential material for large volume homogenous calorimeters, but technology should be optimized improving properties uniformity and density increasing. Project application in frames of ECFA DRD-on-Calorimetry Collaboration?**