Status report of the activity with different scintillation materials

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List of tested Scintillators

Property	YAG:Ce	YAG: C	YAG: C, Ce	GAGG: Ce, Mg	LuAG: Ce	LuAG:Pr	YSO:Ce	LYSO:Ce	LYSO: Ce, Ca	LYSO: Ce, Mg	LSO:Ce	YAP:Ce	LuAP:Ce
Density, g/cm^3	4.57	4.57	4.57	6.67	6.73	6.73	4.5	7.1	7.1	7.1	7.4	5.37	8.34
Zeff	35	35	35	54.4	62.9	62.9	39	65	65	65	75	36	64.9
Hardness by Mohs	8.5	8.5	8.5	8	8.5	8.5	5.8	5.8	5.8	5.8	5.8	8.6	8.5
Index of refraction at max. emission	1.82	1.82	1.82	1.9	1.84	1.84	1.79	1.81	1.81	1.81	1.82	1.95	
Melting point, °C	1970	1970	1970	1850	2020	2043	2273	2100	2100	2100	2050	1875	1960
Wavelength of max. emission, nm	550	UV(?), 550	550	530	535	310	425	420	420	420	420	370	365
Decay time, ns	70	75(10 %)/ 375(90%)	62(71%)/ 160(29%)	30(25%)/ 80(60%)/ 200(15%)	70	20	50-70	41	39	40(?)	40	25	18
Radiation length , cm	3.5	3.5	3.5	1.61	1.41	1.41		1.35	1.35	1.35	1.14	2.2	-
Photon yield, 10^3 ph/MeV	30		30	30/upto 46 x	15-25	15-22	10-30	24	24/43.5	25	30	25	11
Producer	CRYTUR	ISMA	ISMA	FOMOS	CRYTUR	CRYTUR	OST	OST	TAC	TAC	ADVATECH	CRYTUR	OST

Outline

- **Ceramics scintillation material $(Gd_2Y_{0.5}Lu_{0.5})Al_2Ga_3O_{12}$: Ce, Mg**
- **$BaO*2SiO_2$: Ce (DSB) glass scintillation material**
- **Conclusion**

Properties of heavy and bright scintillators in comparison to members of the GAGG family

Material	Density, g/cm^3	Light Yield, ph/MeV	τ_{sc}, ns	λ_{max}, nm
$Bi_3Ge_4O_{12}$ (BGO)	7.1	9 000	300	505
Lu_2SiO_5:Ce (LSO)	7.4	26 000	40	420
$(Lu_{0.8}\text{-}Y_{0.2})_2SiO_5$:Ce (LYSO)	7.0	30 000	36	420
$Gd_3Al_2Ga_3O_{12}$:Ce , Mg (GAGG)	6.6	46 000	80	530
$(Gd,Y)_3Al_2Ga_3O_{12}$:Ce , Mg (GYAGG)[1]	5.8	52 000	50	520
$(Gd,Lu)_3Al_2Ga_3O_{12}$:Ce (GLAGG)[2]	6.8	50 000	75, 190, 1300	545

[1] M. Korzhik *et al*., “Engineering of a new single-crystal multi-ionic fast and high-light-yield scintillation material (Gd0.5–Y0.5)3Al2Ga3O12:Ce,Mg.“ *CrystEngComm*, 2020, V. 22, pp. 2502–2506, https://doi.org/10.1039/D0CE00105H.

[2] https://www.rmdinc.com/product-category/glugag-gamma-neutron-ceramic-scintillation-detector/

GYAGG is too light
GLAGG has an additional very slow component that can be critical for CTR

$(Gd_2Y_{0.5}Lu_{0.5})Al_2Ga_3O_{12}$:Ce, Mg as scintillation ceramics

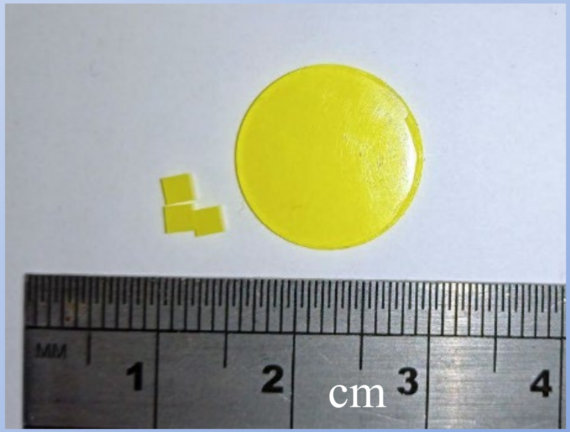
Goals:

Increase of density

Best combination of cations to optimize Z_{eff}, LY, CTR

Reduction of slow component based on implementation of Lu in the matrix

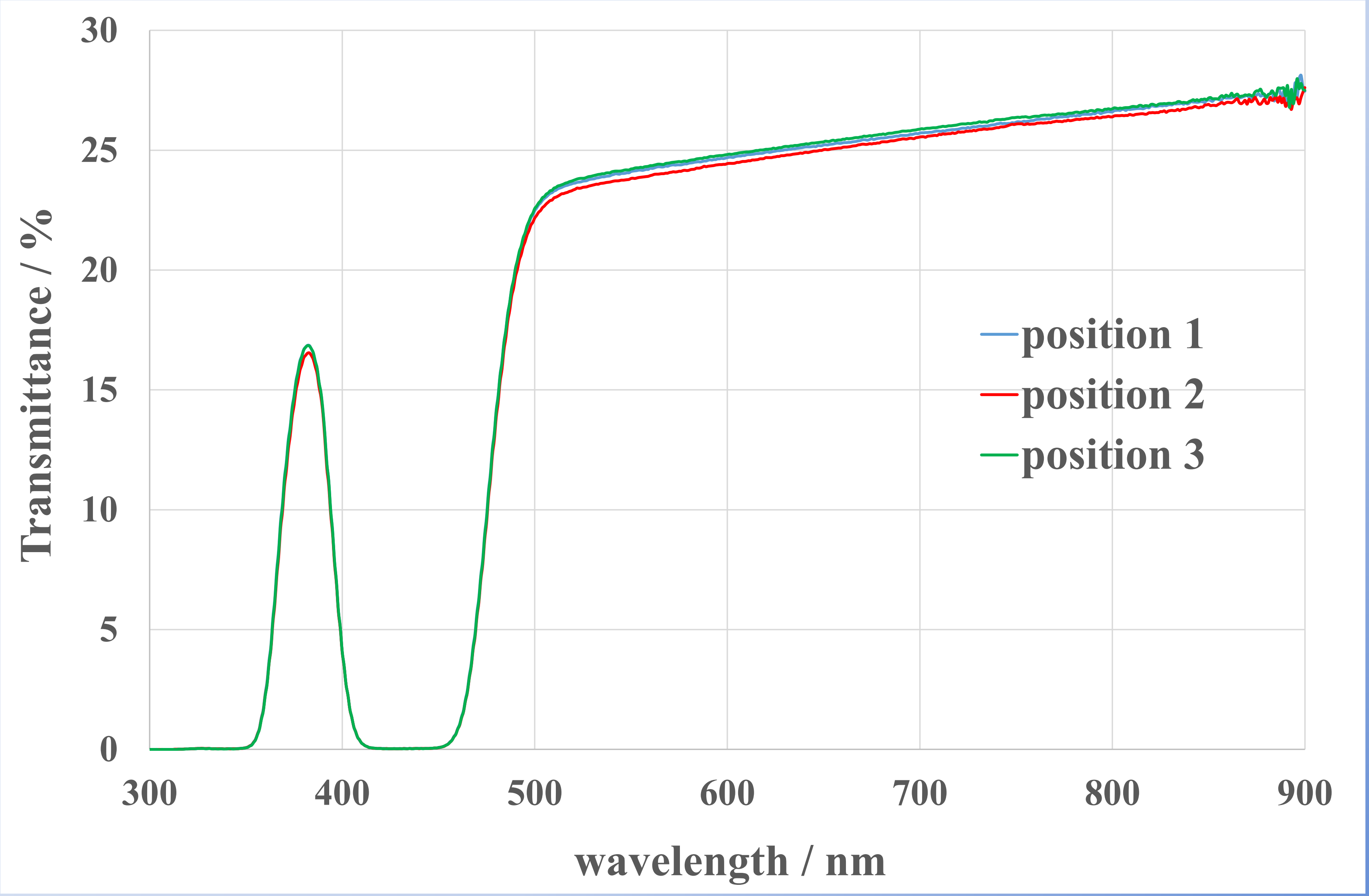
Dimensions: **1 sample Ø14×1 mm²**
3 samples 2×2×1 mm³



Property	$(Gd_2Y_{0.5}Lu_{0.5})Al_2Ga_3O_{12}$:Ce (2000 ppm), Mg (50ppm)
Density, g/cm³	6.45
λ_{max}, nm	520
Primary decay time, ns	30
LY, 10³ ph/MeV	32000

Transmittance spectra

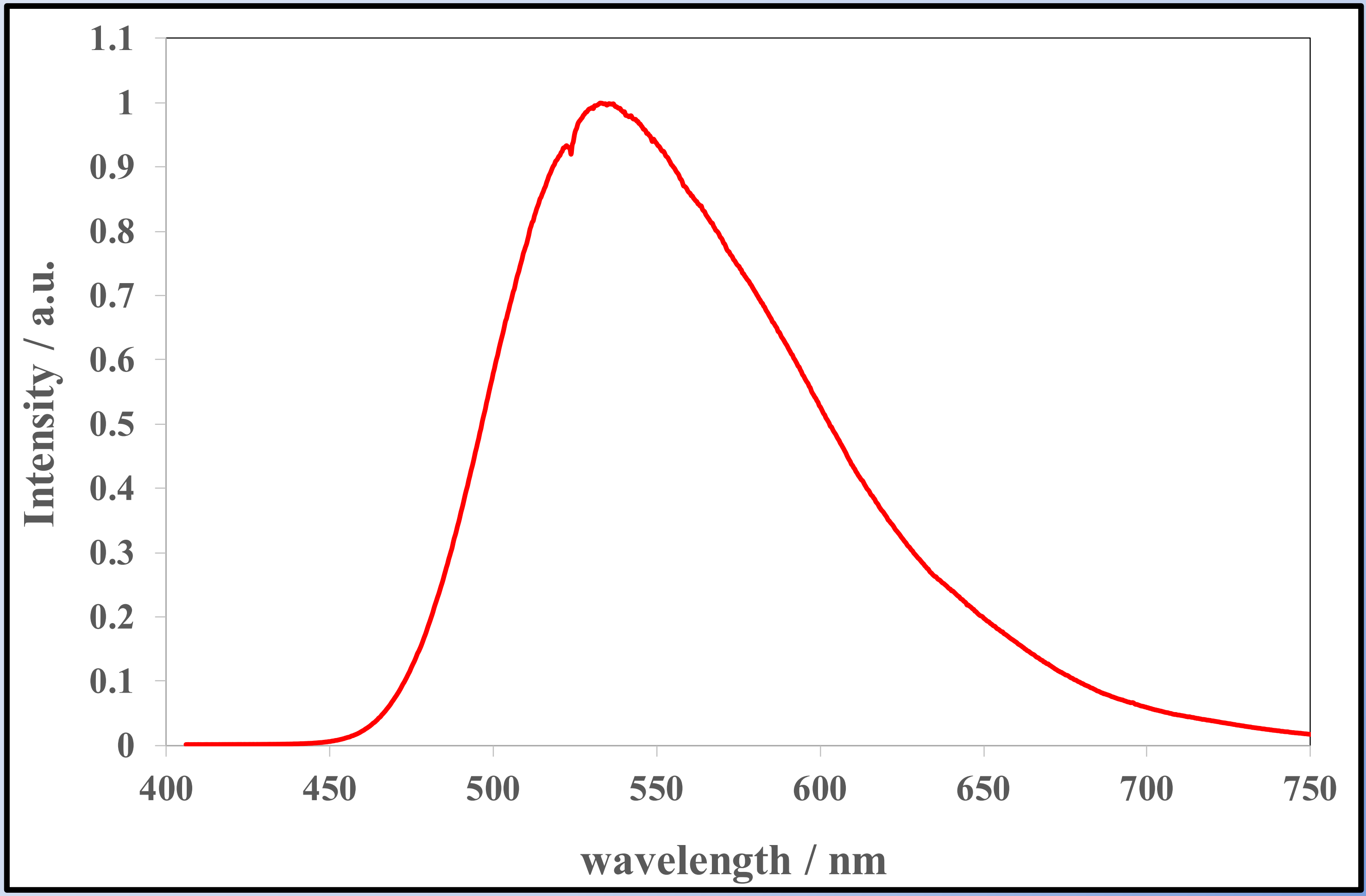
Sample: Ø14×1 mm²



Luminescence spectrum

Excitation with laser diode λ_{max} = 325 nm, power = 25 mW

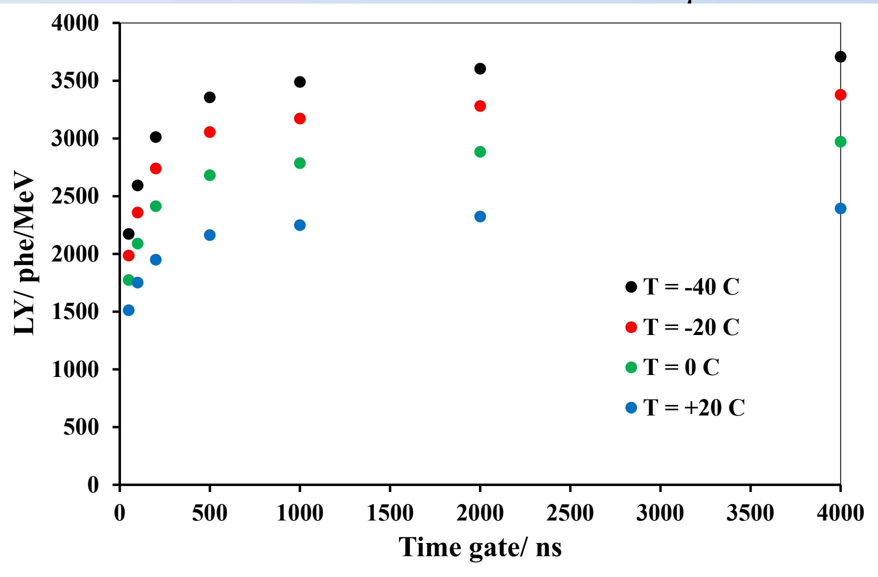
Sample size: Ø14×1 mm²

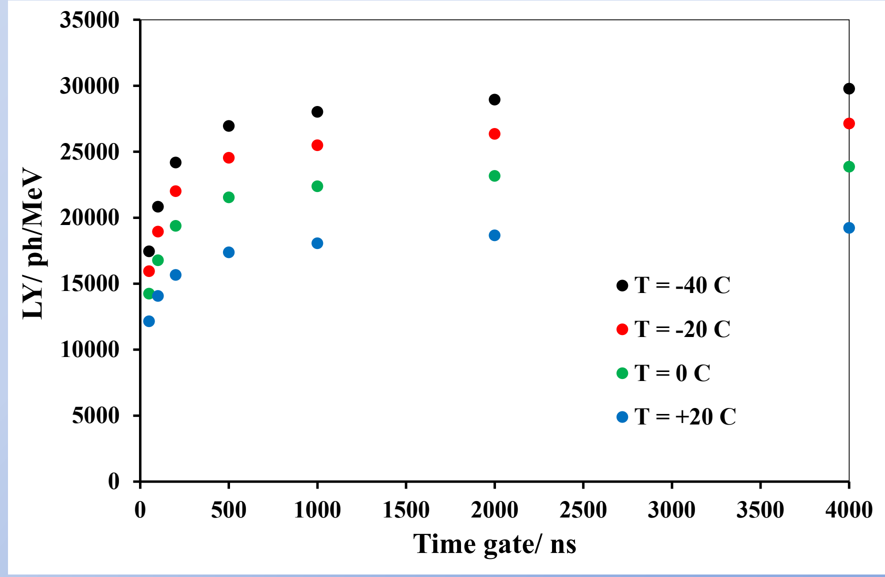


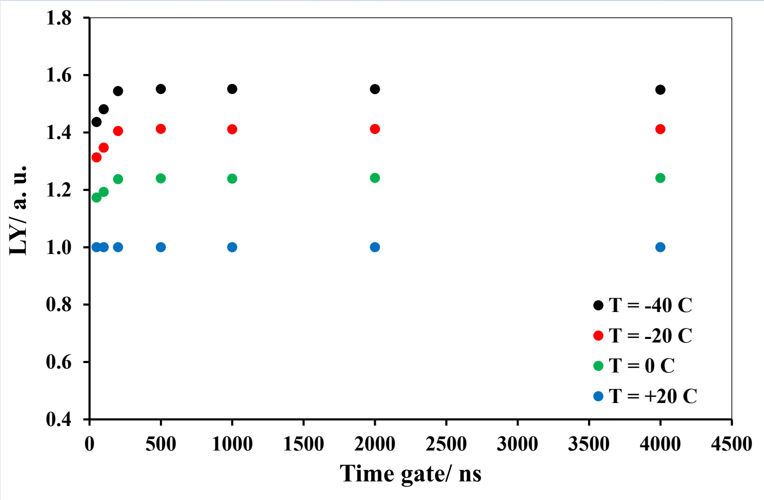
Light Yield

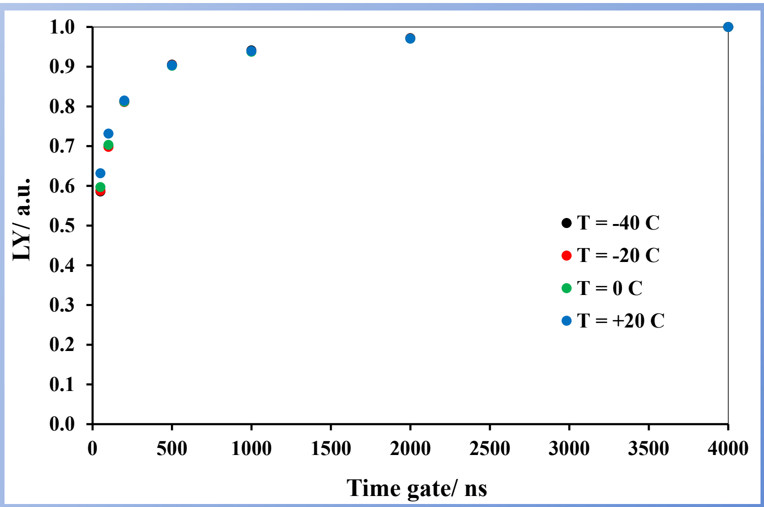
Absolute and relative light yield as a function of integration gate measured at different temperatures.

[^{137}Cs γ-source (E_{γ} = 662 keV), QE(PMT)=12.5%@520nm]









Kinetics of scintillation (1)

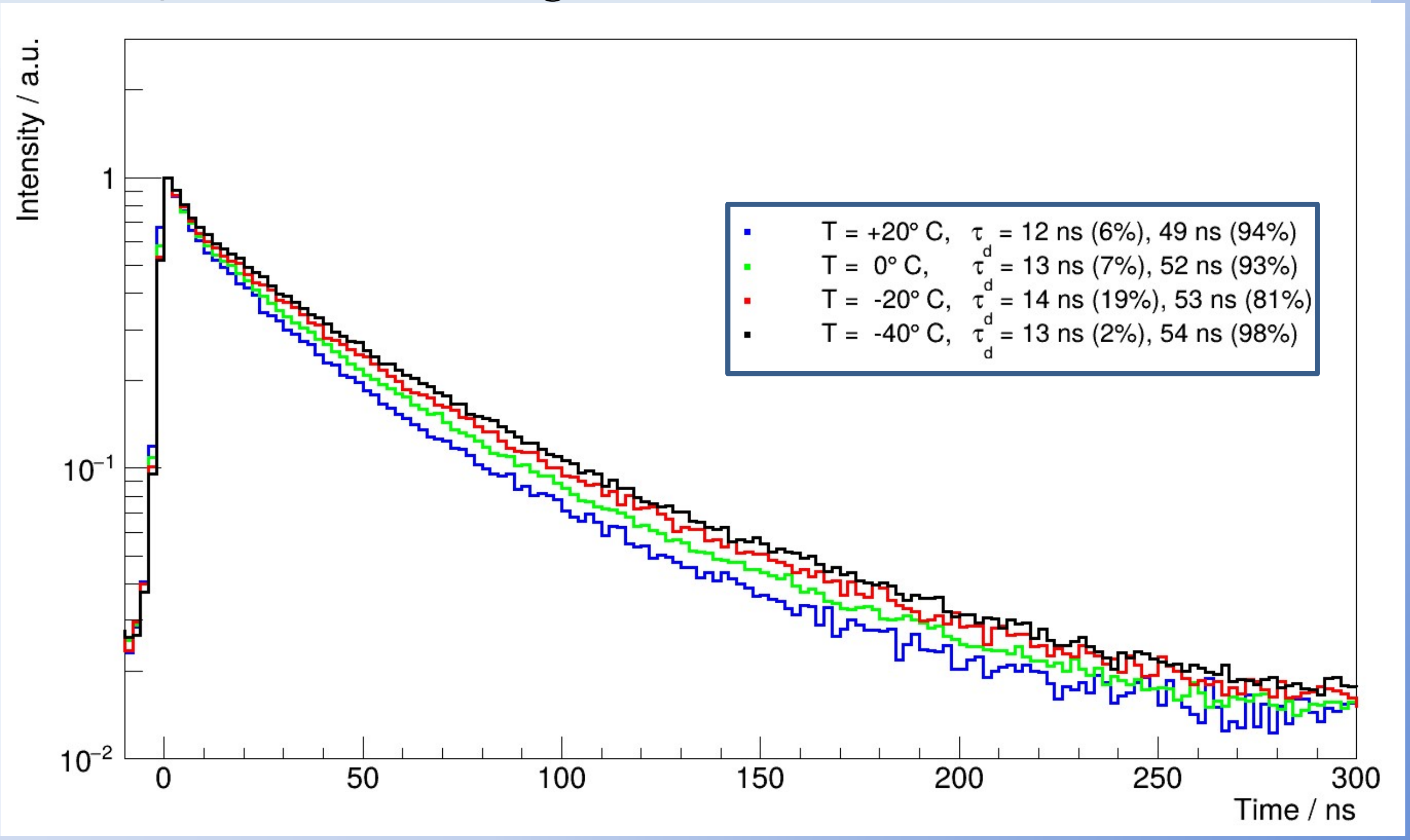
Experimental technique: Start-Stop method

Coincidence between 2 annihilation γ-quanta of a ^{22}Na-source.

Start detector: BaF2 + UV filter attached to PMT.

Stop channel: sample placed on the distance from second PMT.

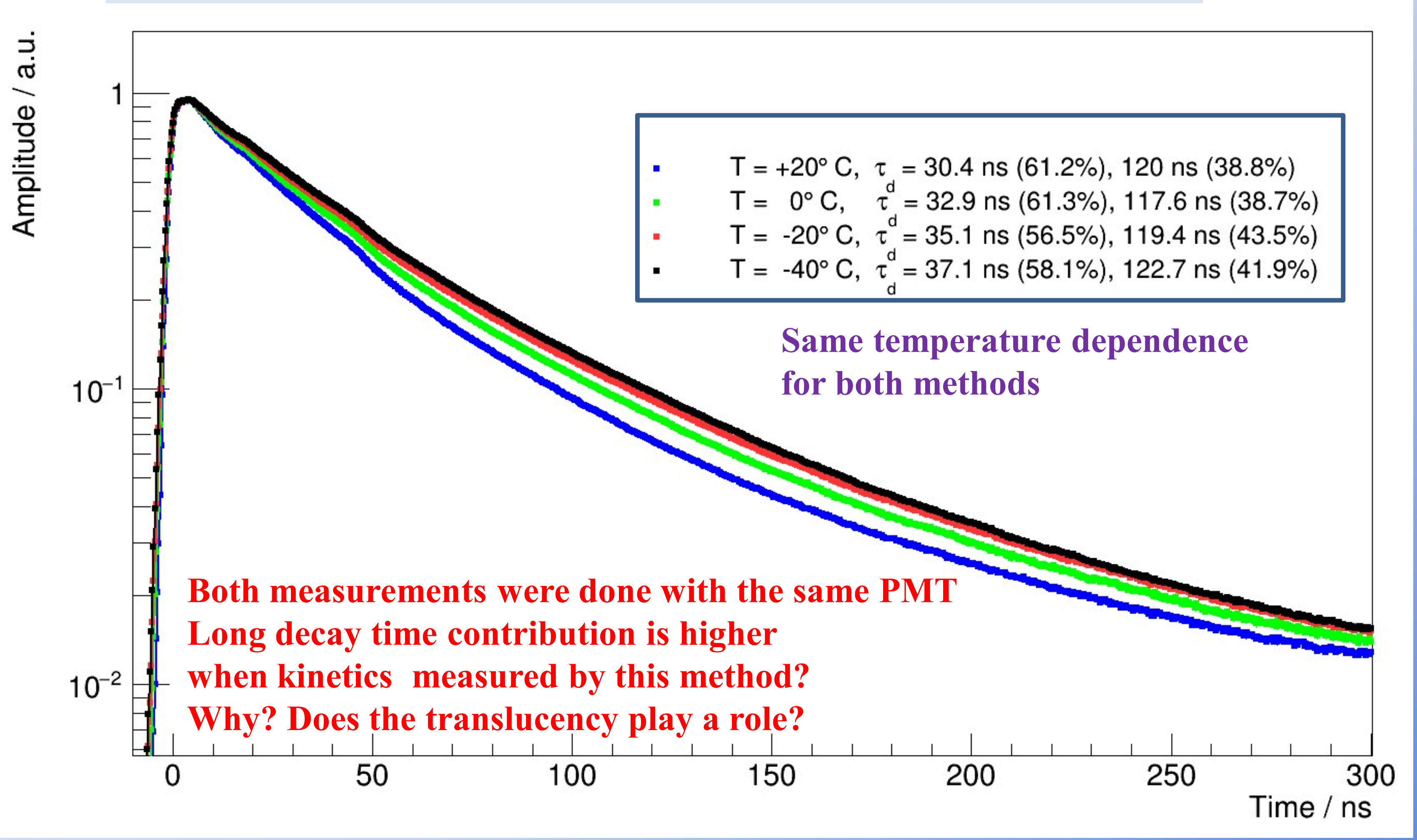
DAQ: CAEN V1730 S digitizer



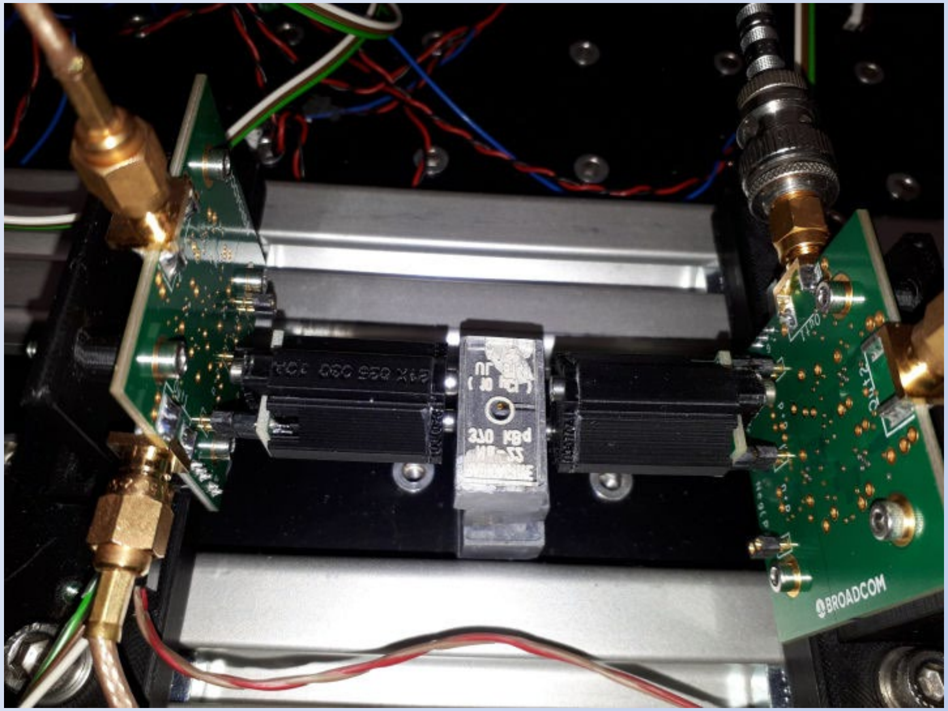
Kinetics of scintillation (2)

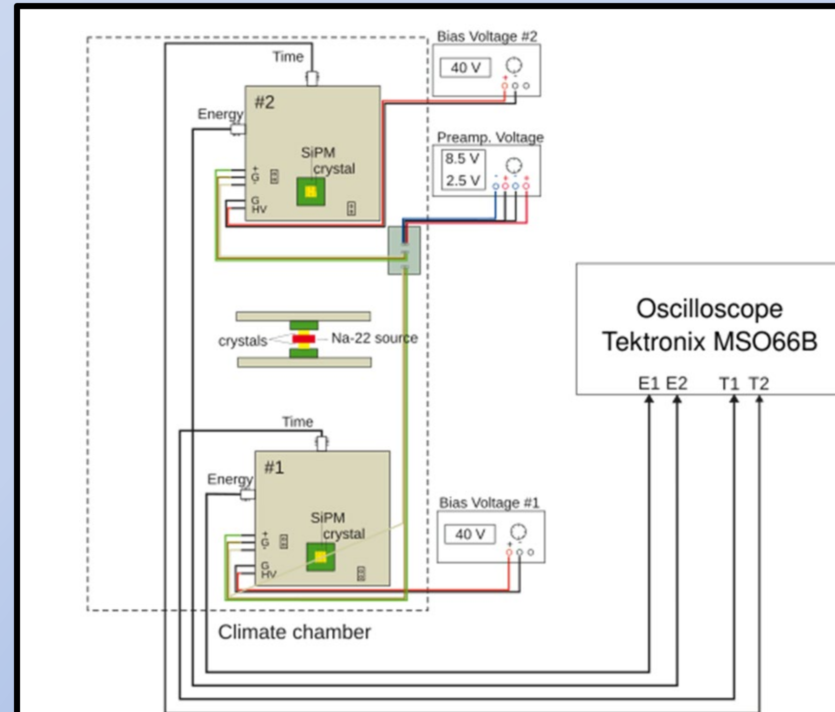
Experimental technique: pulse-shape

Fitting of averaged pulse-shape using Tektronix MSO66B40



Coincidence Time Resolution (CTR)





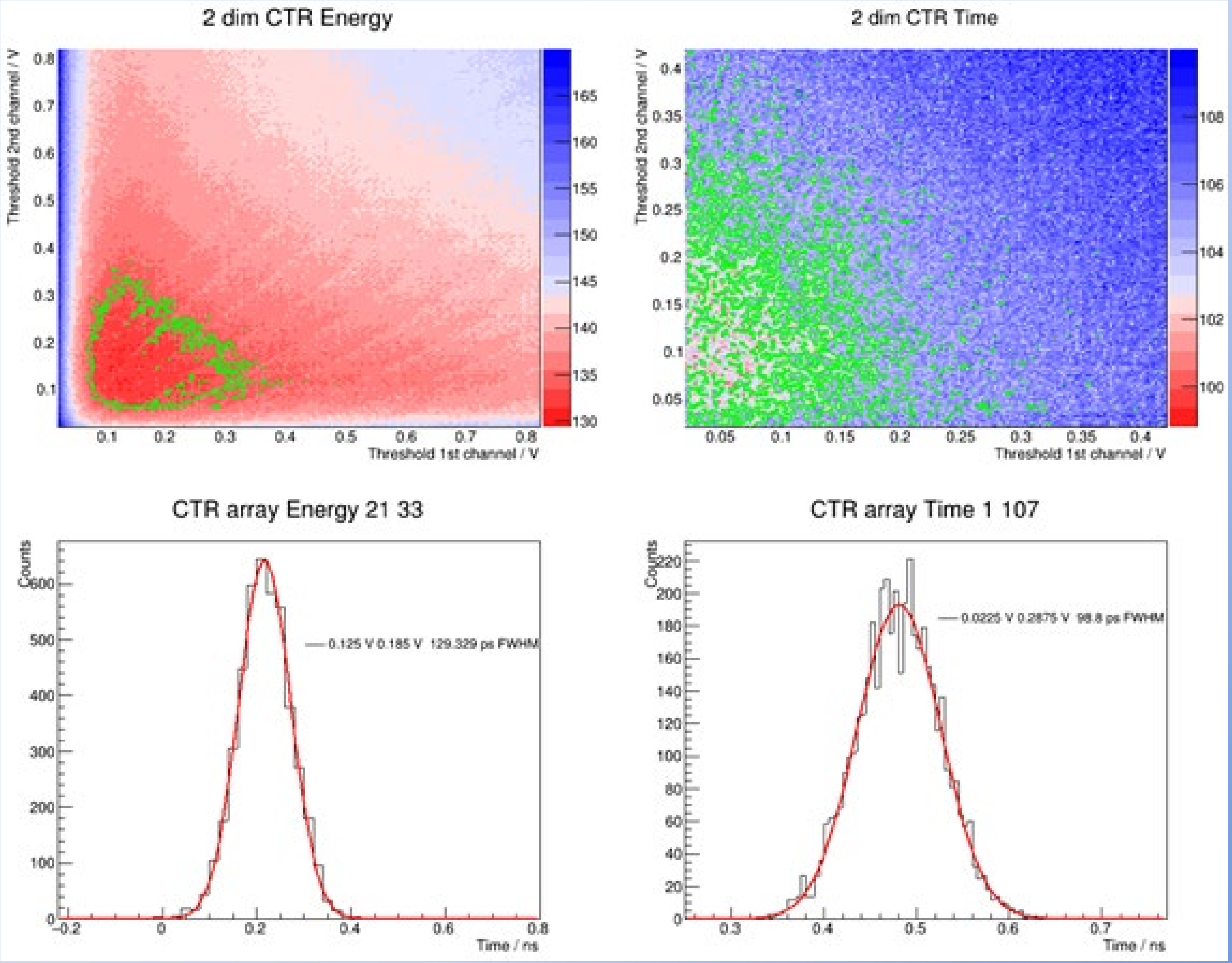
Experimental set-up:

Two similar crystals attached to SiPMs (Broadcom AFBR-S4N44C013)
Readout via Broadcom evaluation board (AFBR-S4E00)
DAQ: Tektronix MSO66B oscilloscope

All measurements were performed in a climate chamber WEISS Technik WK3-340/40 for temperature stabilization

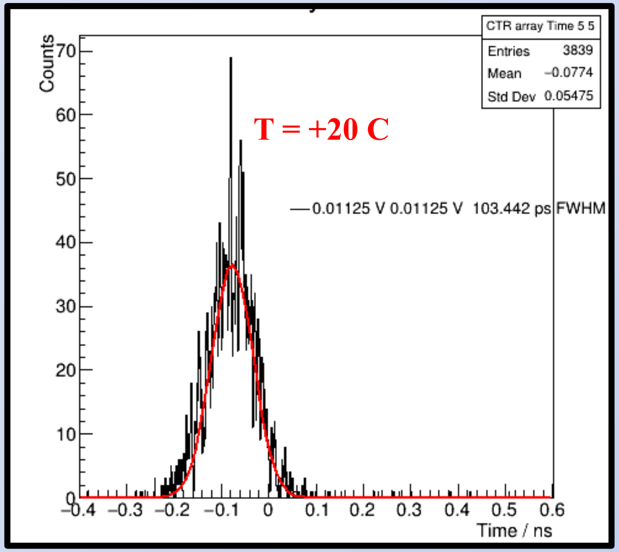
Coincidence Time Resolution (CTR)

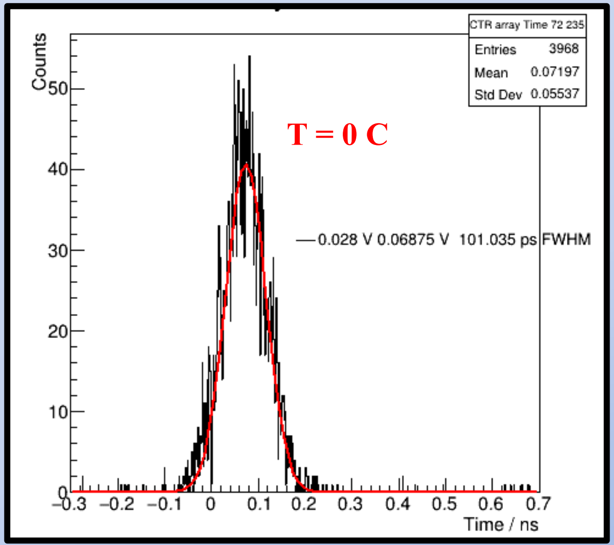
2-dimensional energy and time correlations

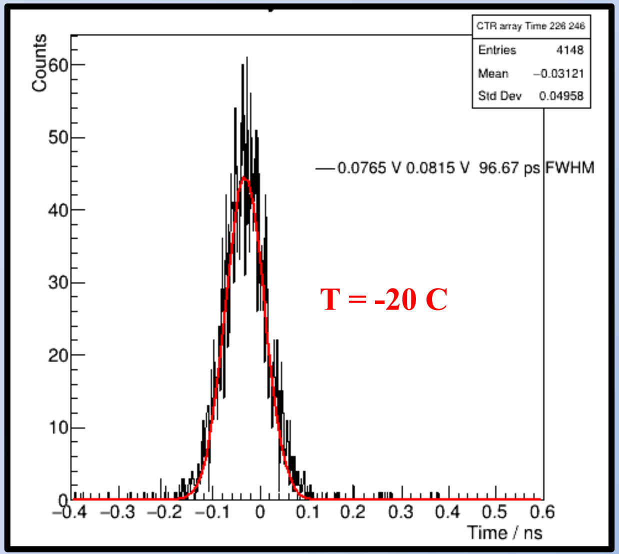


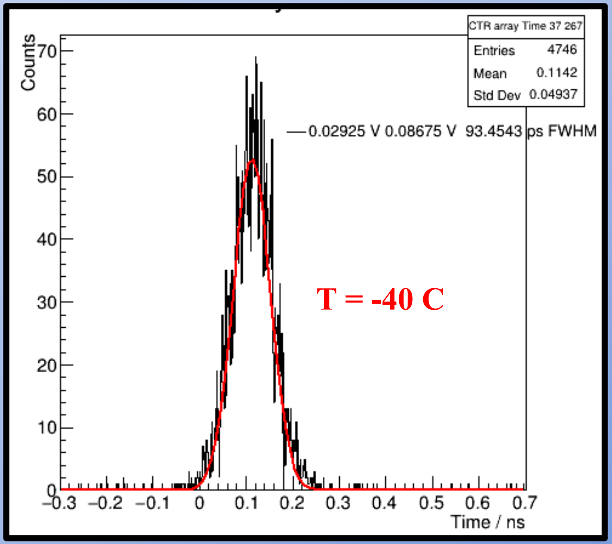
CTR results

Obtained at different temperatures









CTR FWHM, ps			
@+20°C	@0°C	@-20°C	@-40°C
103.4	101.0	96.7	93.5

Conclusion

- **The new samples show a relatively high light yield without significant contribution of slow decay components.**
- **For the first time, CTR (FWHM) values below 100 ps have been achieved for samples of the GAGG family.**
- **The CTR values based on SiPM-readout improve even further for lower operating temperatures.**
- **The tested technology allows to produce transparent and 3-4mm wide ceramic plates, allowing to produce cheaper detector components if aiming tracking detector or thermal neutron detector**

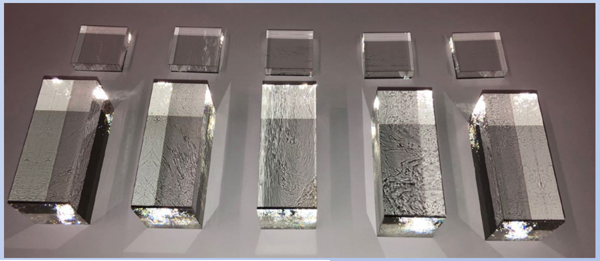
Physical properties of different heavy silica glasses

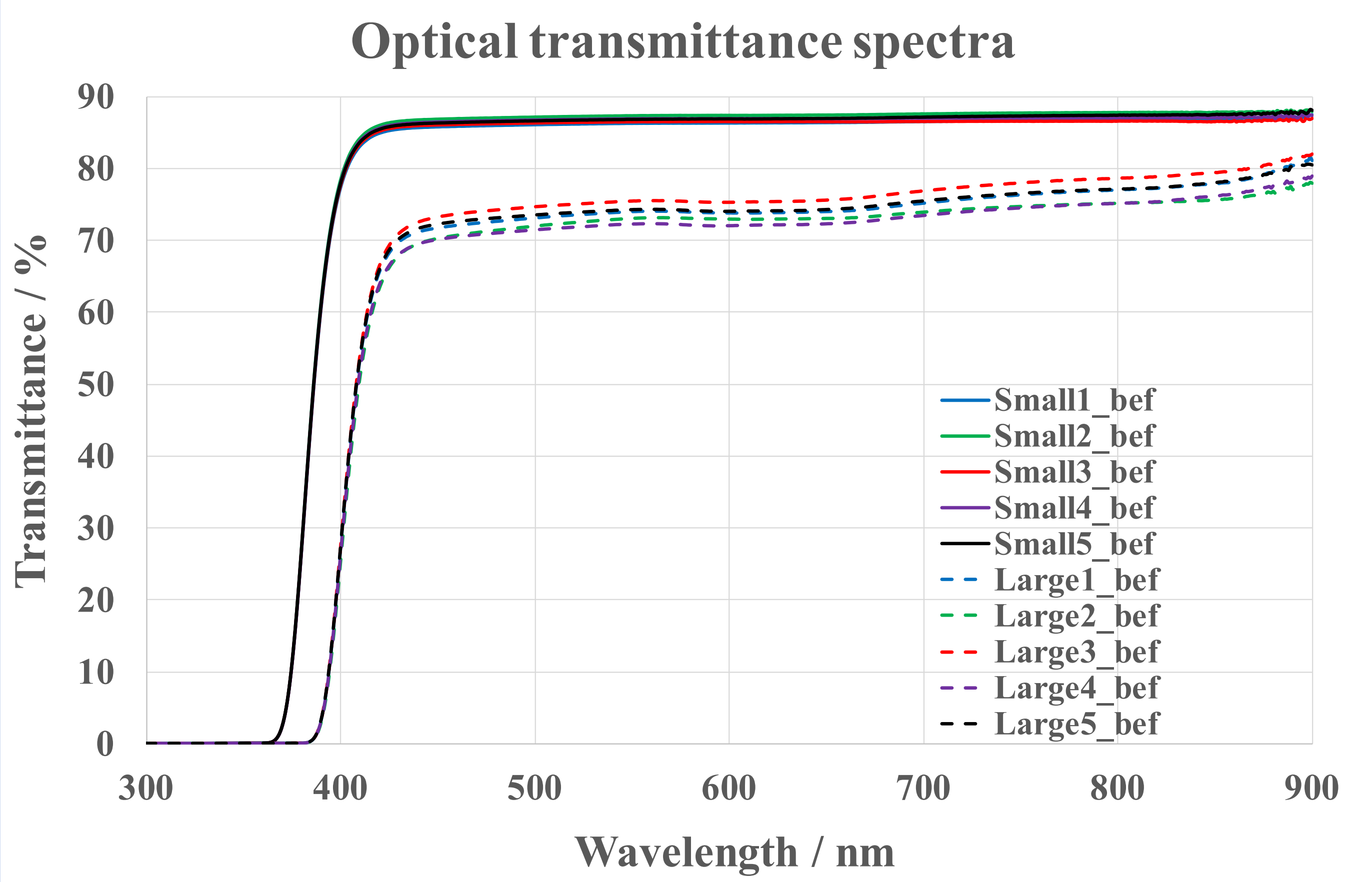
Material	**ρ g/cm3**	**Z_{eff}**	**X_0 cm**	**λ_{max} nm**
$BaO*2SiO_2$	3.7	51	3.6	-
DSB: Ce	3.8	51	3.5	440-460
$BaO*2SiO_2$:Ce glass heavy loaded with Gd	4.3-5(?)	56.9	2.6	440-460

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

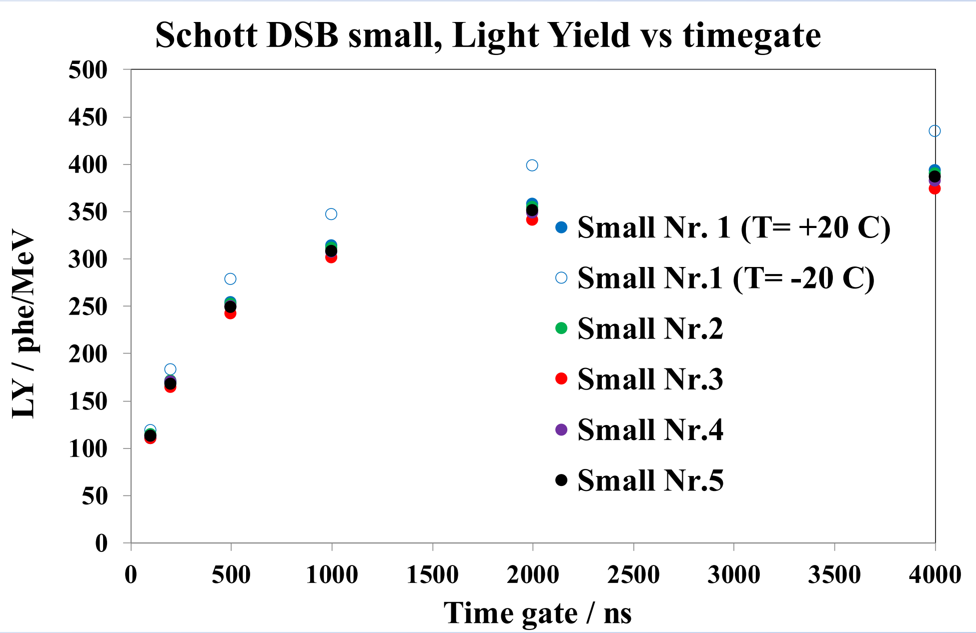
Glass samples produced by Schott Company in 2021

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





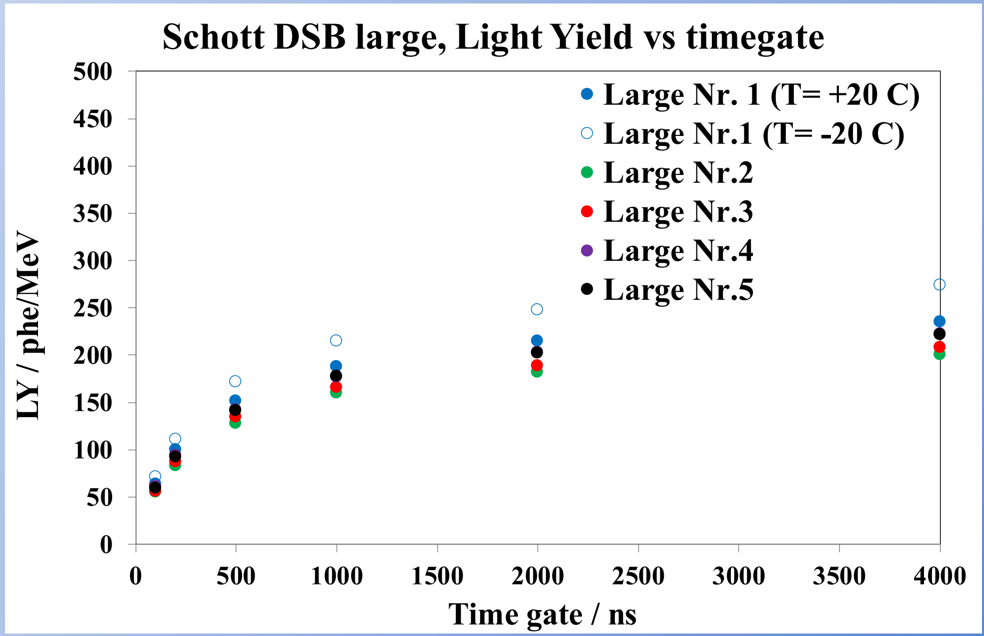
DSB glass samples: Light Yield



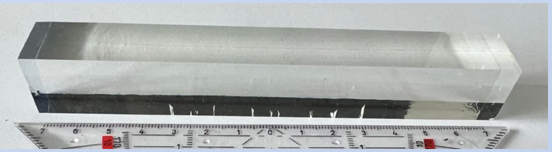
LY (phe/MeV) = (PP-ped)/(SE_Peak-ped)/E$_\gamma$

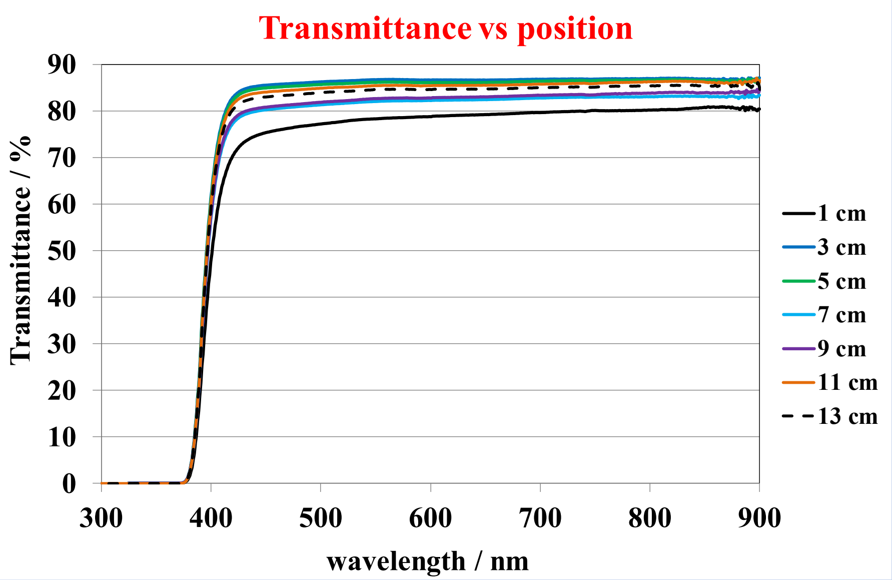
where *PP* - photopeak position of obtained spectrum, *ped* - pedestal peak positon (nonzero shift of channels due to electronics noise), *SE_peak* – a single electron peak position of the PMT, E_γ - energy of g-quanta. For temperature stabilization, the whole set-up is located vertically in a climate chamber (Weiss Technik WK3-340/40).

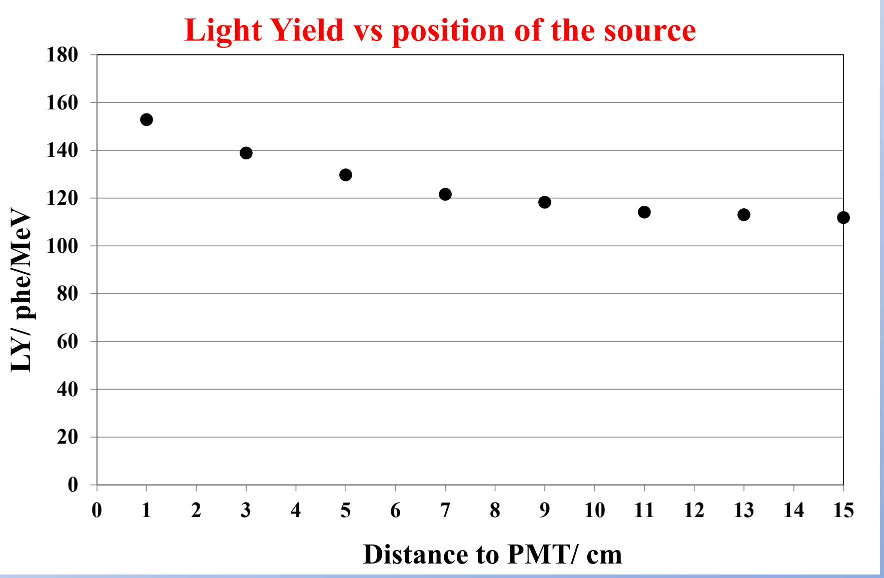
Measurements were done with ^{241}Am γ-source (Eγ = 60 keV), PMT Hamamatsu R2059

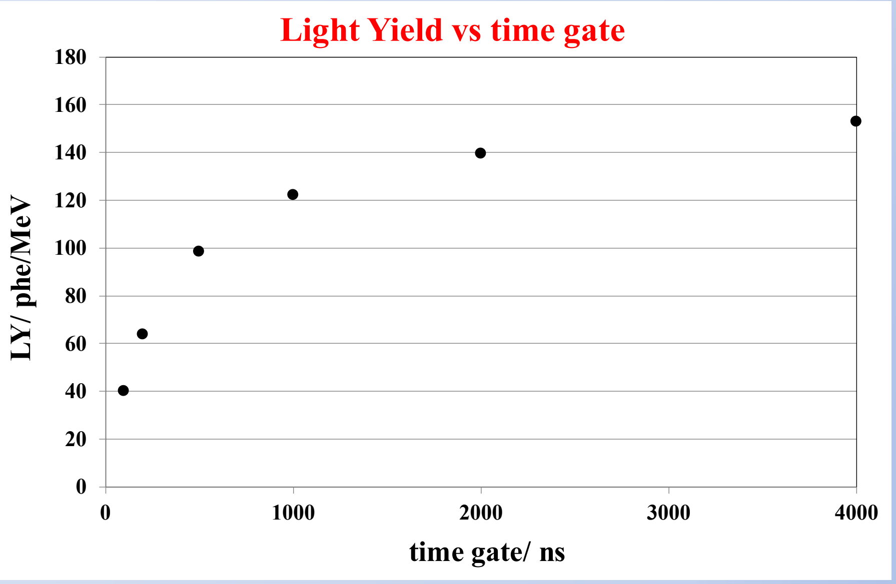


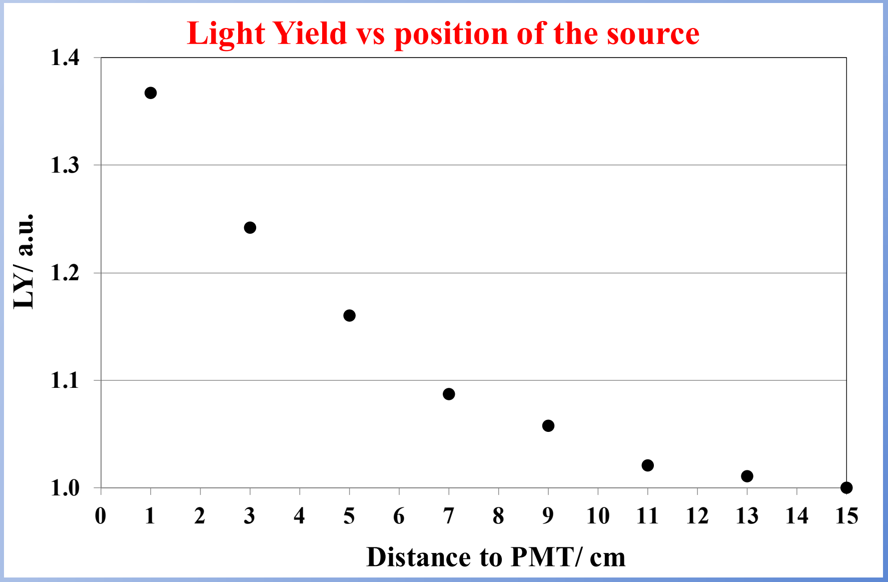
Large DSB glass sample: 2x2x15 cm^3



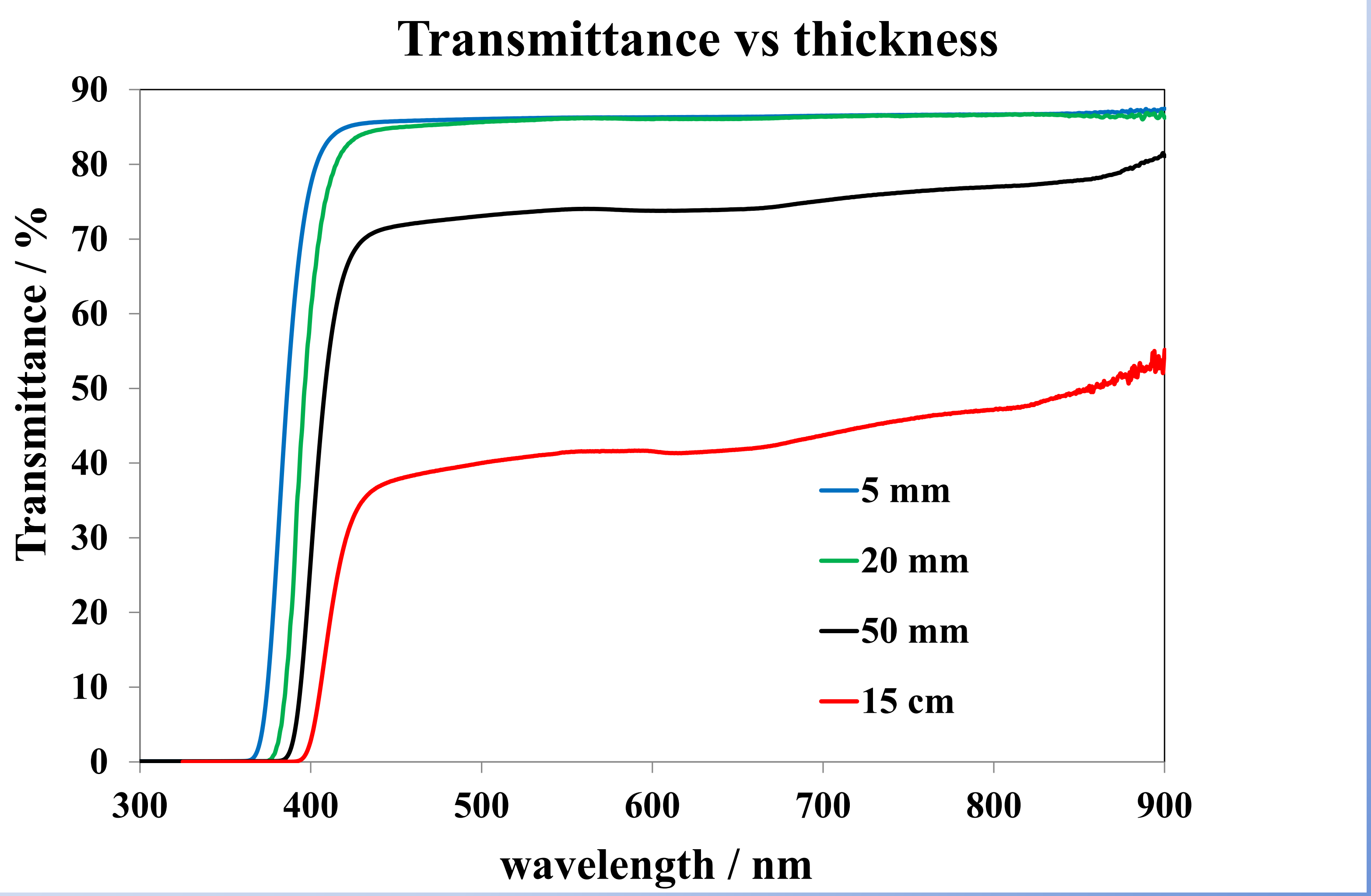




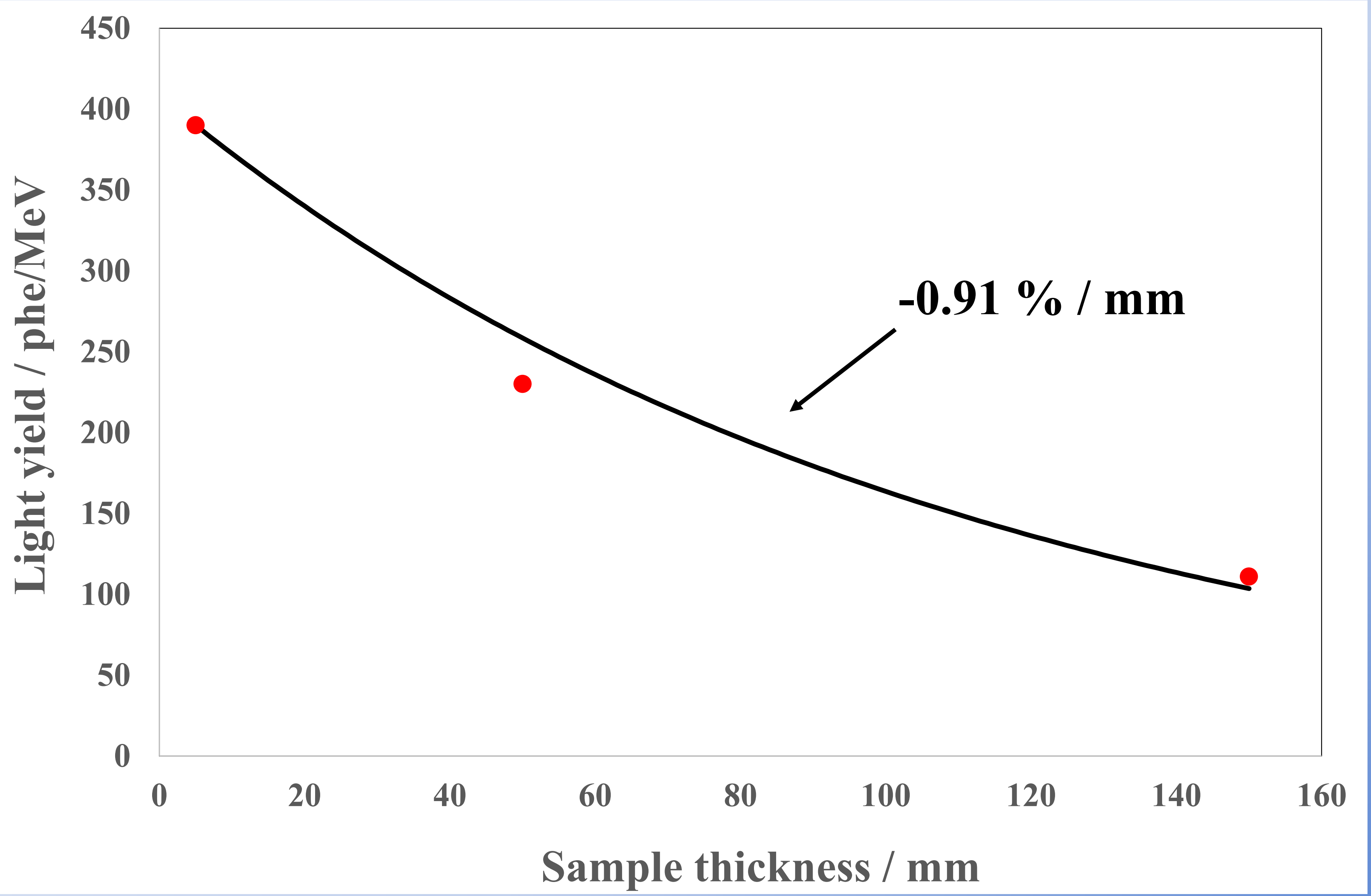




Transmittance vs sample thickness



Light yield vs sample thickness

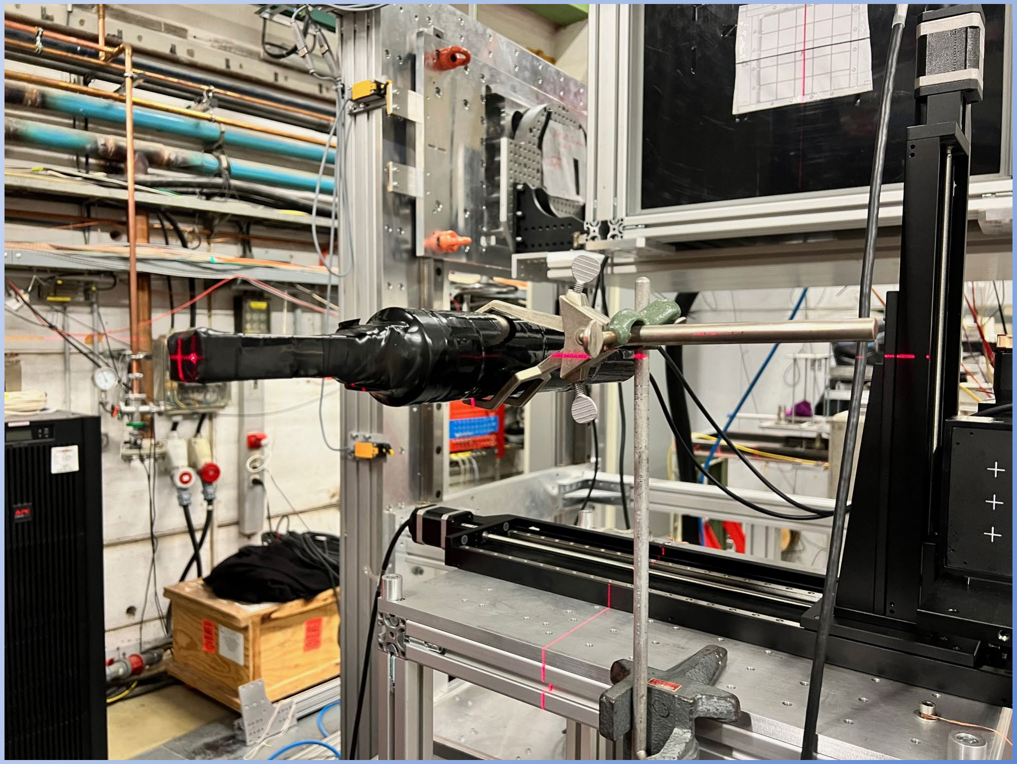


Large DSB glass sample: 2x2x15 cm^3

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

Sample was wrapped in 8 layers of teflon film
Attached to Hamamatsu R2059 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.

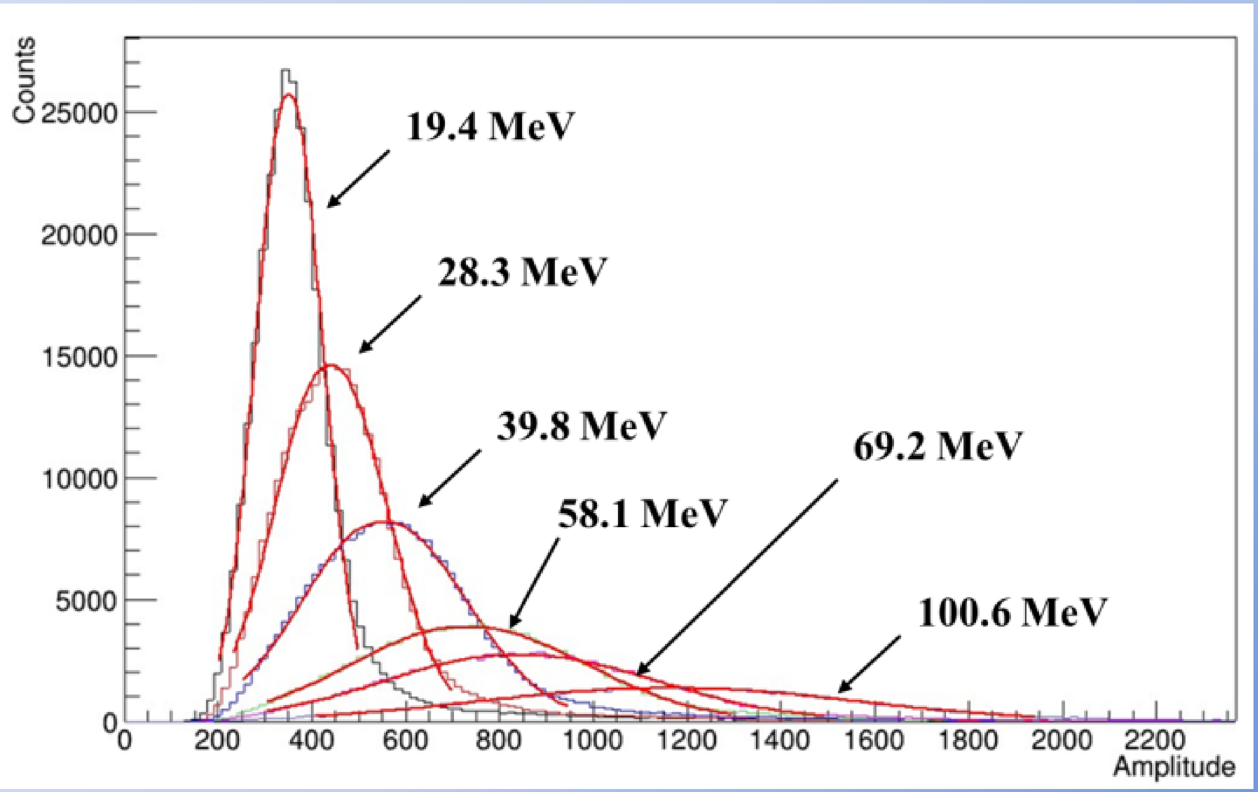


Large DSB glass sample: 2x2x15 cm^3

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

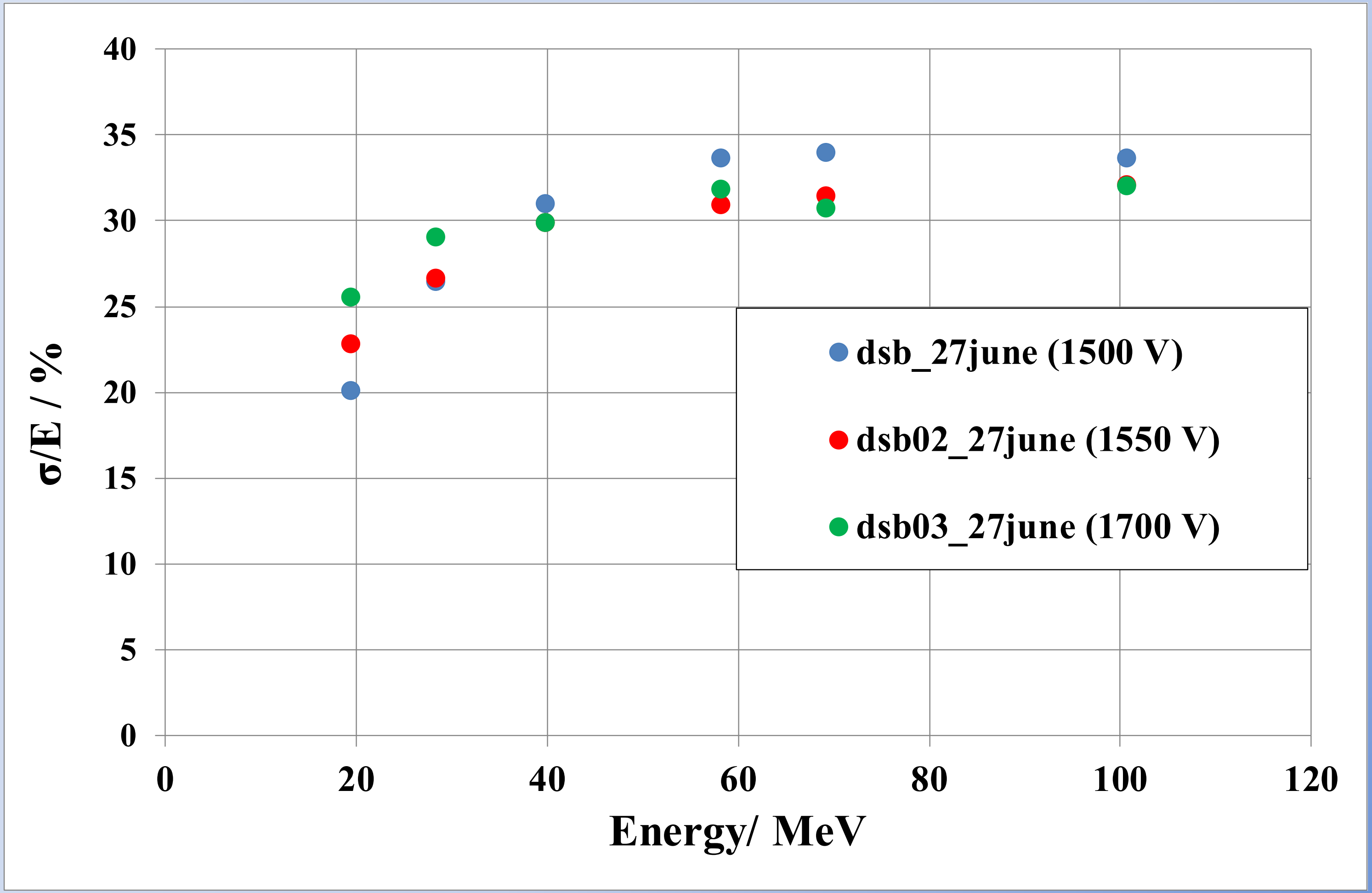
Energy distributions of six tagger energies

Fits with Novosibirsk fitting function

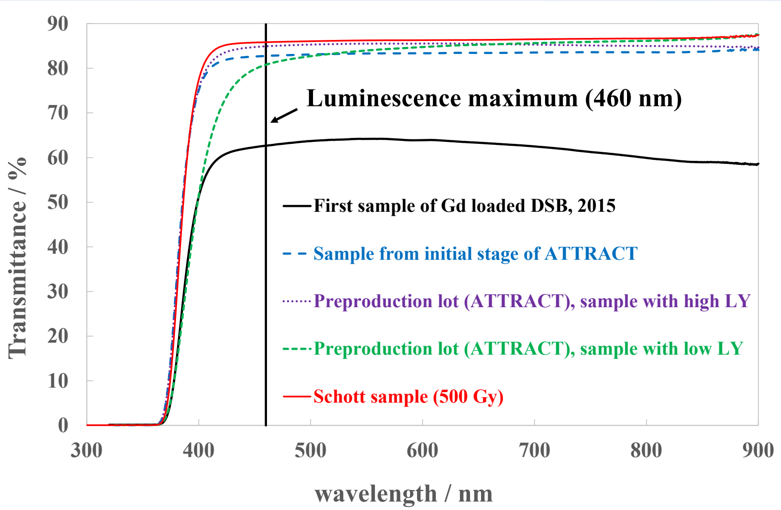


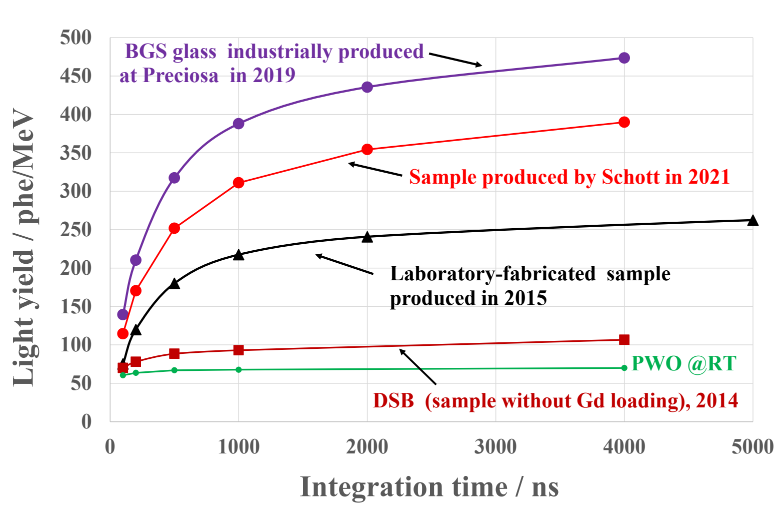
Large DSB glass sample: 2x2x15 cm^3

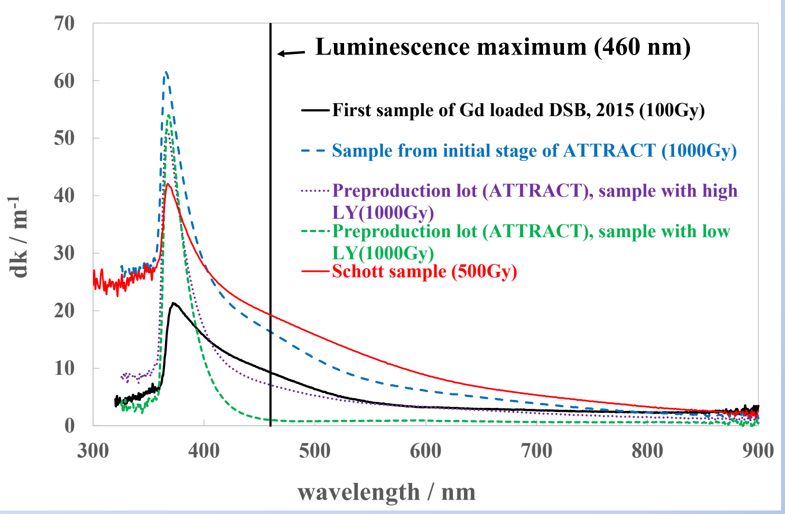
Energy resolution

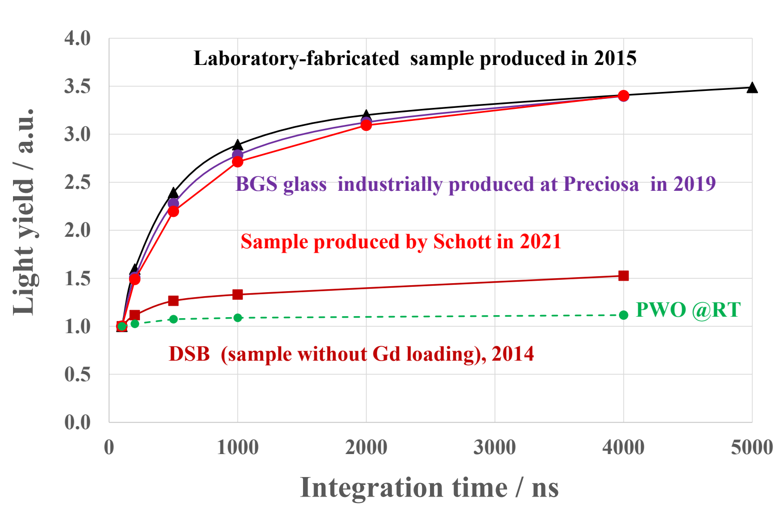


Properties evolution

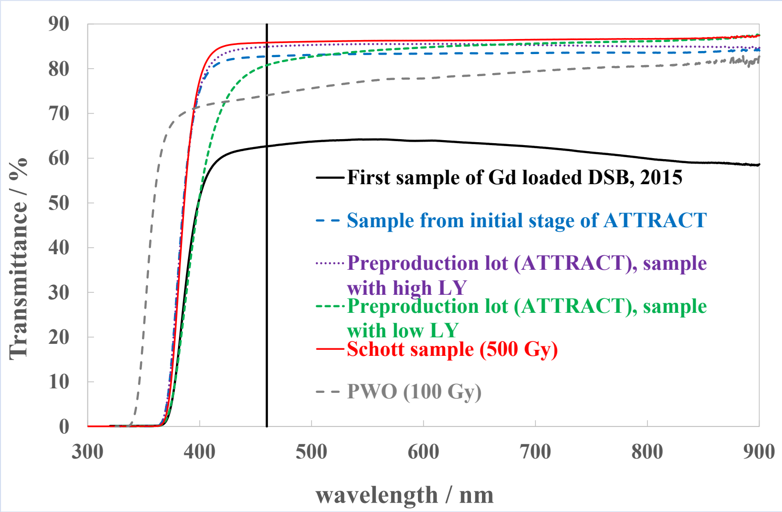


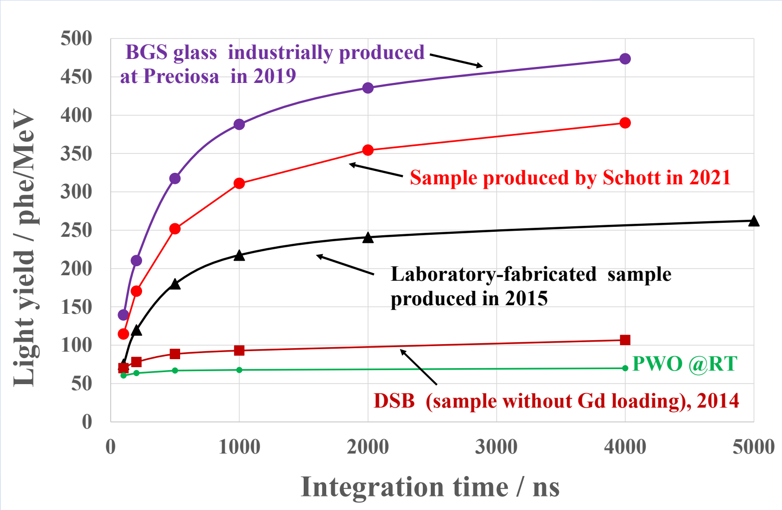


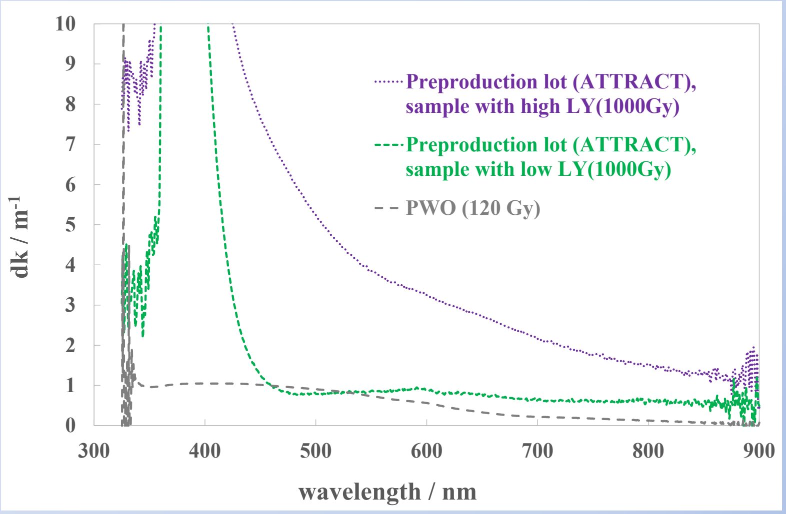


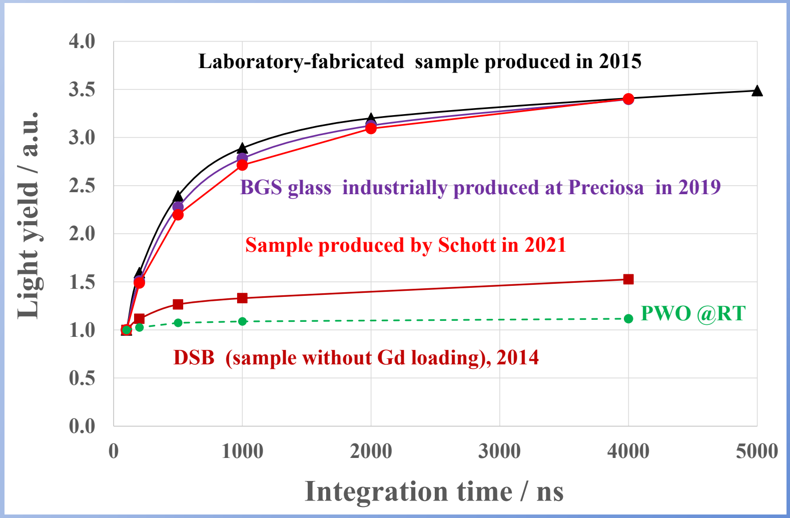


Properties evolution





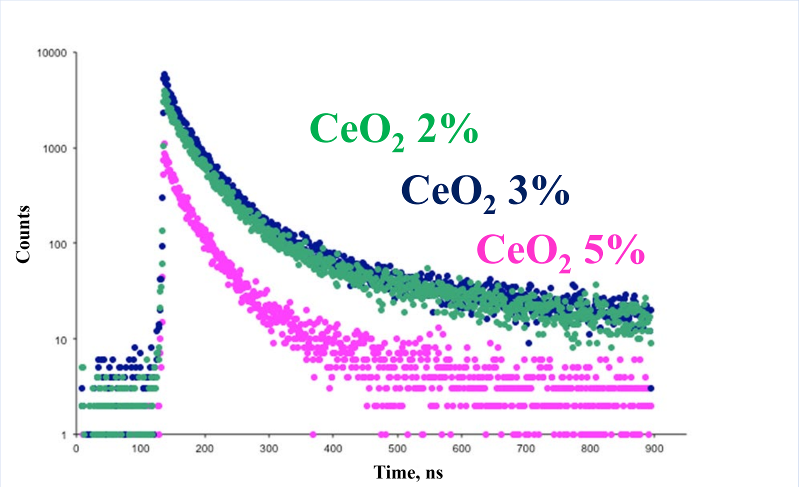




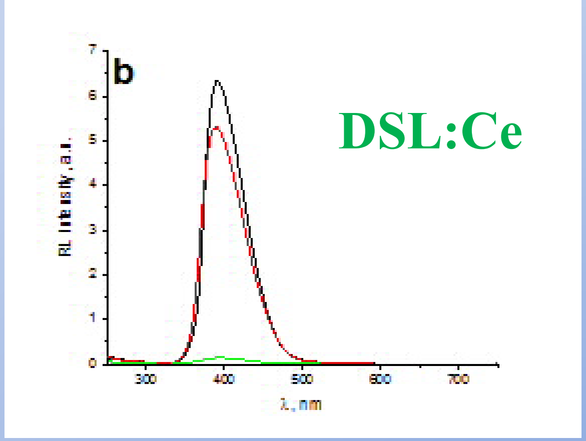
Lithium glass scintillator

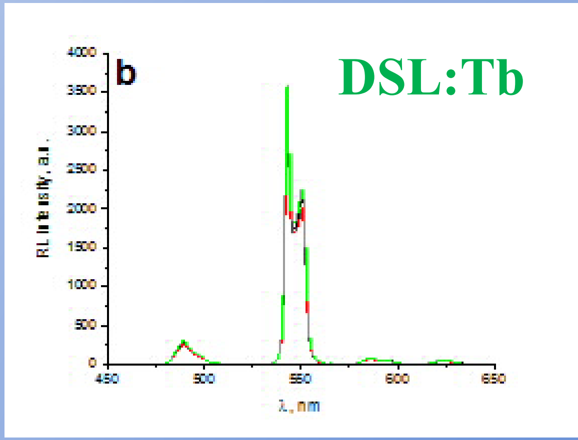
Li_2O-$2SiO_2$ (DSL) doped by Ce or Tb

Kinetics spectra of DSL:Ce

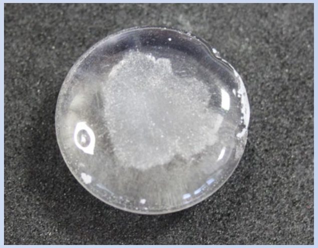


Luminescence spectra





DSL: Ce sample provided to Giessen for tests
diameter 34 mm, height 16mm



Conclusion

- **The DSB glass is a low-cost material and even at the present stage shows already attractive properties, which further can be customized to specific applications. The present density is significantly higher in comparison to plastic scintillators and allows as well variable shapes due to casting.**
- **DSB being loaded with Gd has been a first attempt to increase the density, which leads automatically to a larger light yield. Even if there is presently no possibility to reduce the absorption length, the detection of high energetic showers due to photons or hadrons can be considered by significantly enlarging the length of the glass rods on the level of 30-50cm.**
- **However, macro-defects are still the limiting factor. According to the experience of the manufacturer, the well-known and already developed technology for the mass production of large glass volumes, should overcome the present problems with lab-size prototypes. Further technology optimization should be targeted to improve timing characteristics of the material and the radiation hardness**