Characterization of different scintillators for future calorimetry

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on behalf of Giessen group

Test results of
- **Garnet materials**
- **Lutetium-Yttrium Oxyorthosilicates**

Search for the optimal scintillator

- **High light yield**

=> energy resolution, dynamic range => energy resolution

⇒ signal/noise ratio => better time and energy resolutions

⇒ Fast rise time, short decay => time resolution, count rate, pileup

First photons of scintillation pulse and geometry of single detector unit are very critical.

- **Density => geometry limitations, angle resolution**

Best solution: inorganic scintillators

- **Resistance to the radiation damage (electromagnetic and hadron components)=> longevity of the detector, limits the energy resolution**

Electromagnetic and hadron parts of the radiation field should be investigated separately

- **Price limits the detector dimensions**

Detector volume

Number of channels

Scintillation garnet materials for the next generation of HEP experiments

Garnets scintillation materials like $Y_3Al_5O_{12}$ (YAG), $Y_3Al_2Ga_3O_{12}$ (YAGG), $Gd_3Al_2Ga_3O_{12}$ (GAGG) co-doped with the divalent ions of the second group are candidates to improve the scintillation response.

Crystal co-doping with Mg^{2+} or Ca^{2+} decreases the amount of Ce^{3+} in the crystal and deteriorates its light yield as well.

An alternative concept to control afterglow and timing parameters of garnets by the variation of the Al/Ga ratio in the crystal. It does not affect the valence state of the Ce^{3+} as activating ion but acts via the control of the thermo-induced ionization rate of the excited state of Ce^{3+}.

High Light yield, Medium/High density, perfect radiation hardness, kinetics parameters are variable, Price

Possible candidates of garnets materials

- **Three cation garnets YAGG $Y_3(Al_x\text{-}Ga_{1-x})_5O_{12}$: Ce with varied containment of Ga**
- **Two cation garnets YAG ($Y_3Al_5O_{12}$): Ce , C**
- **Three cation garnets GAGG ($Gd_3Al_2Ga_3O_{12}$): Ce, Mg or Ca and Ti**

The same mechanism works in LYSO too

Properties of 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

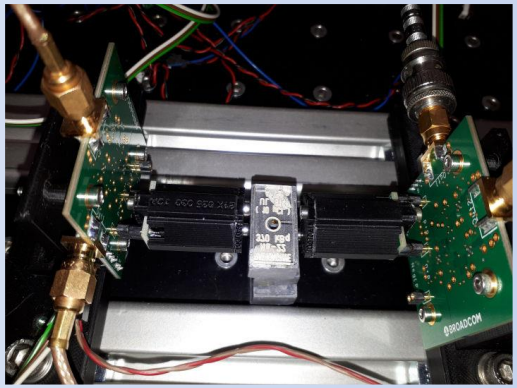
Properties characterization

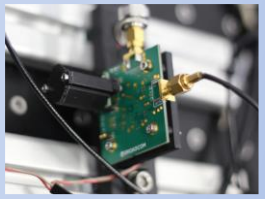
Transmittance: **HITACHI U-3200 photospectrometer, measurements were done for 3mm and 20 mm light path**

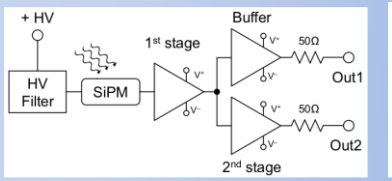
Light yield: **PMT Hamamatsu R-2059, Basylone 300.000 of 3M®, multilayers of Teflon film or Tyvek paper as reflector material, 60 keV gammas of ^{241}Am source, time gates: 50-5000 ns, T= +20° C, 0° C, -20° C, -40° C,**

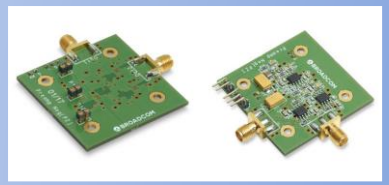
Future tests:

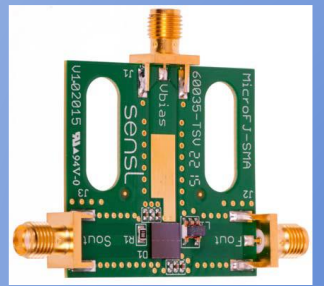
CTR: **Broadcom Evaluation Kit AFBR-S4E001 with AFBR-S4N44C013 SiPM, Different types of SiPms with self-developed preamp, ONSEMI SiPM with fast output 3D printed holders, multilayers of Teflon film as reflector material**











Garnets samples

$Y_3Al_5O_{12}$: Ce (YAG: Ce) 3x3x20 mm^3

$Lu_3Al_5O_{12}$: Ce (LuAG: Ce) 3x3x20 mm^3

$Lu_3Al_5O_{12}$: Pr (LuAG: Pr) 3x3x20 mm^3

produced by CRYTUR (Czech Republic)

$Gd_3Al_2Ga_3O_{12}$: Ce (GAGG: Ce) **UltraFast version**

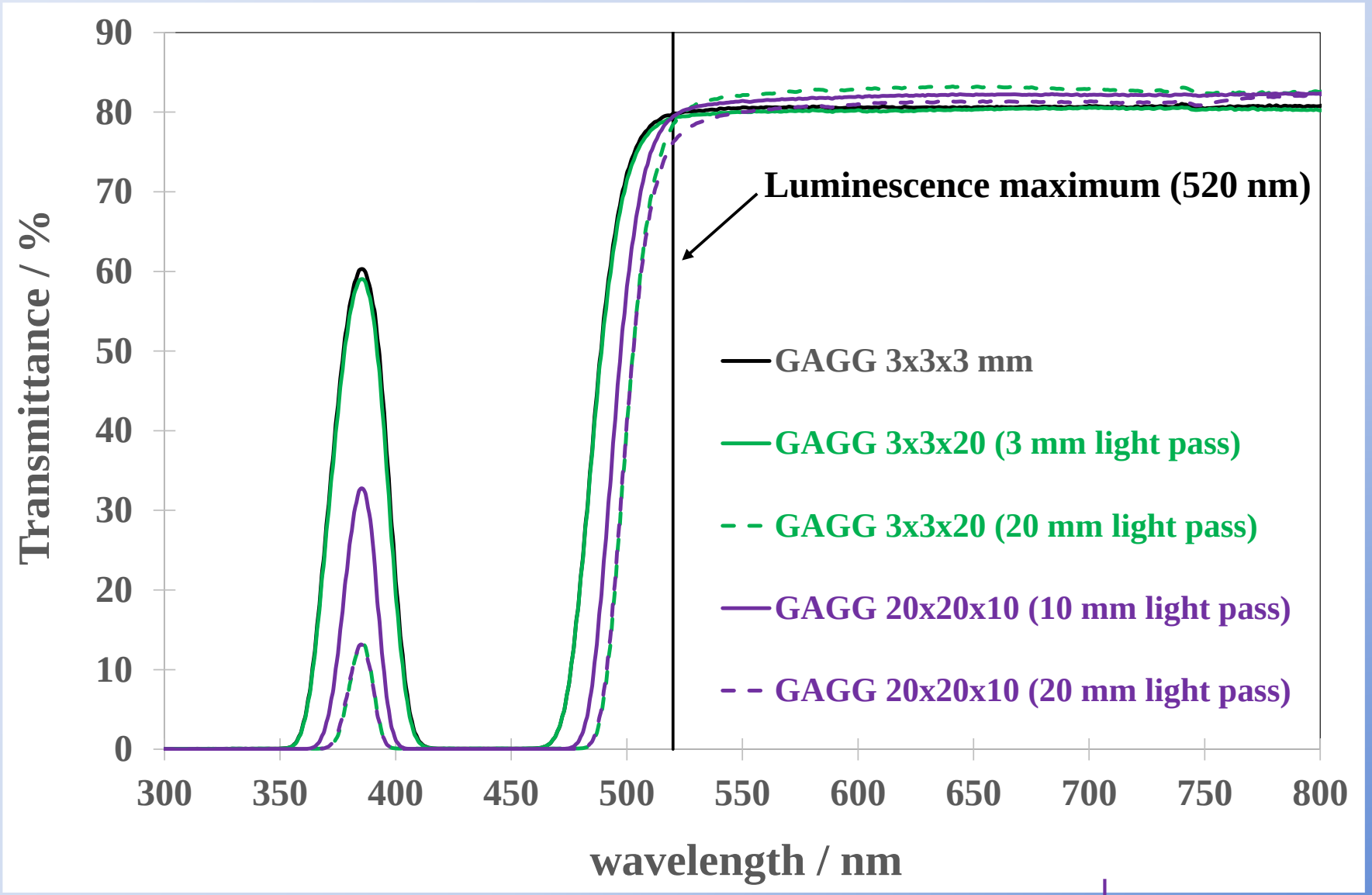
pixels: 3x3x3 mm^3, 3x3x20 mm^3

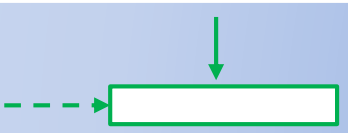
bulk: 20x20x10 mm^3

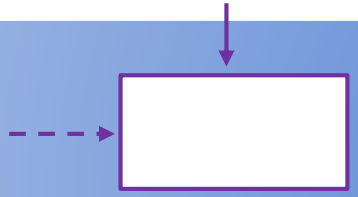
produced by ADVATECH (UK)

Producer declared only Ce doping of GAGG, type of co-doping(s) unknown.

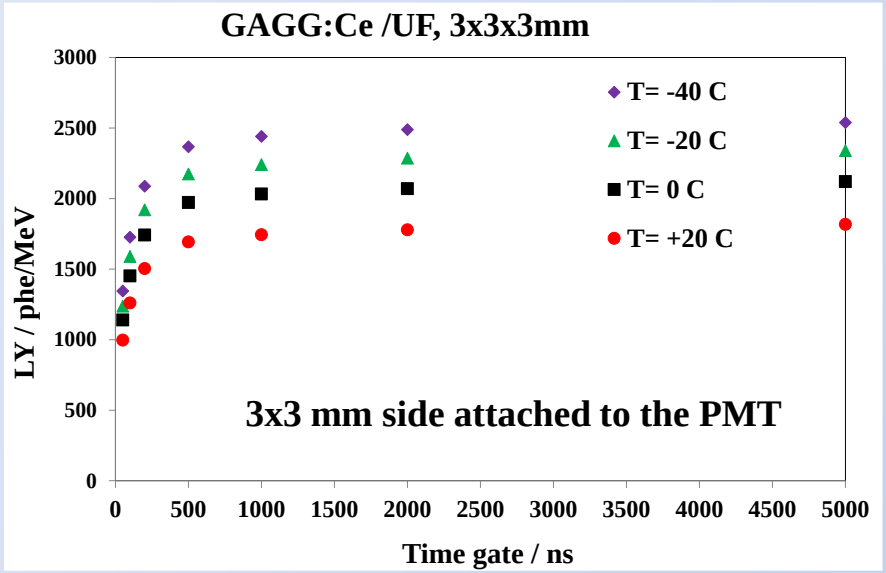
Transmittance measurements GAGG: Ce /UF

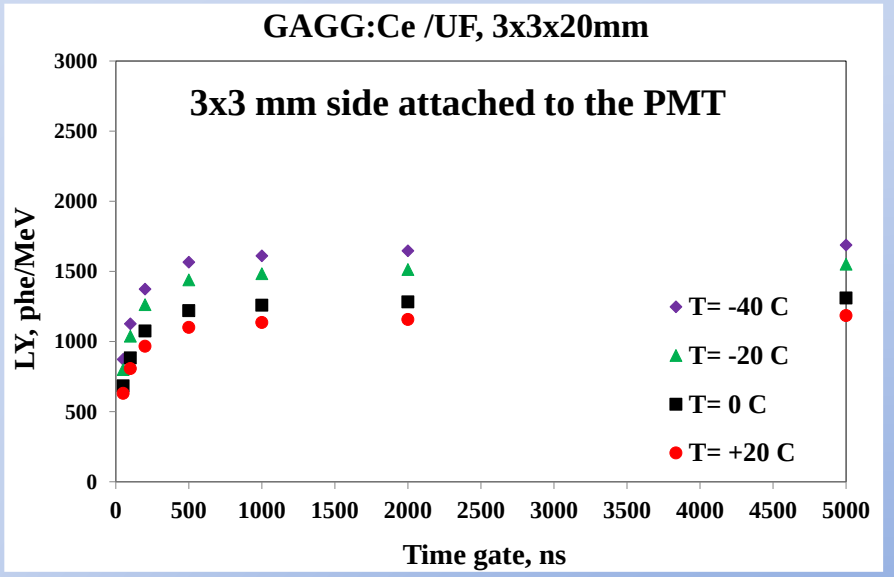


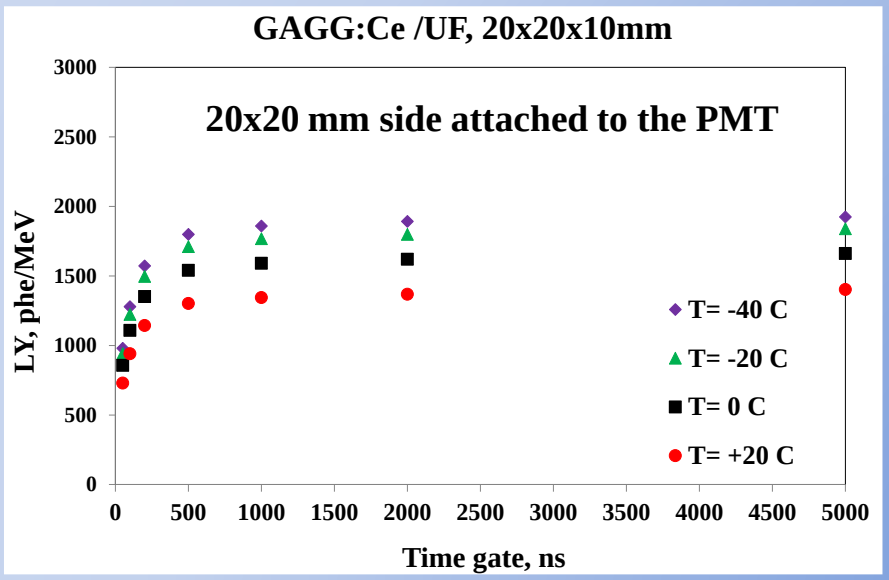




Light Yield measurements GAGG: Ce /UF

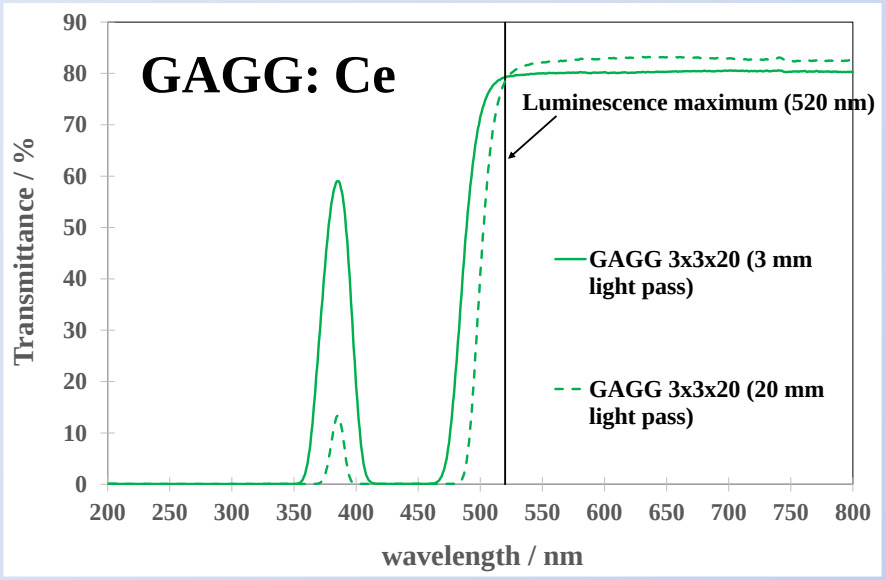


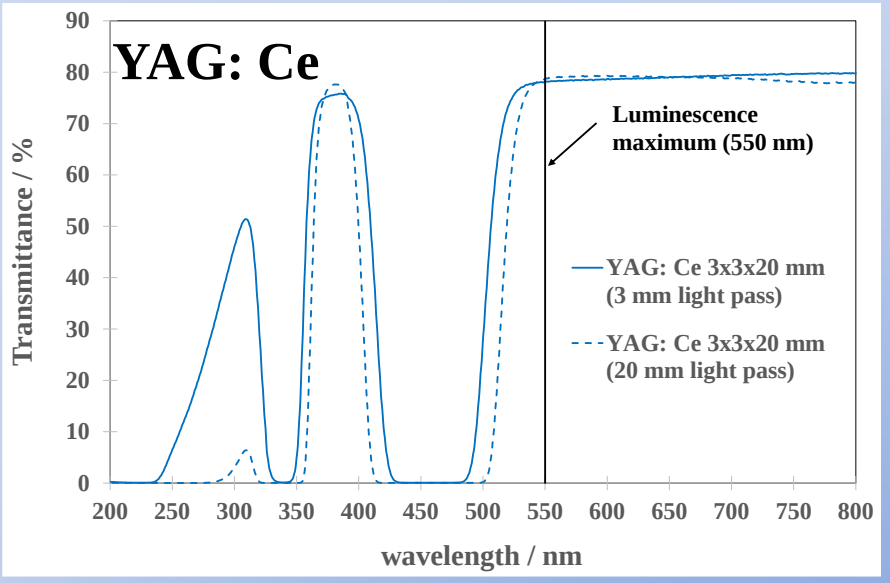


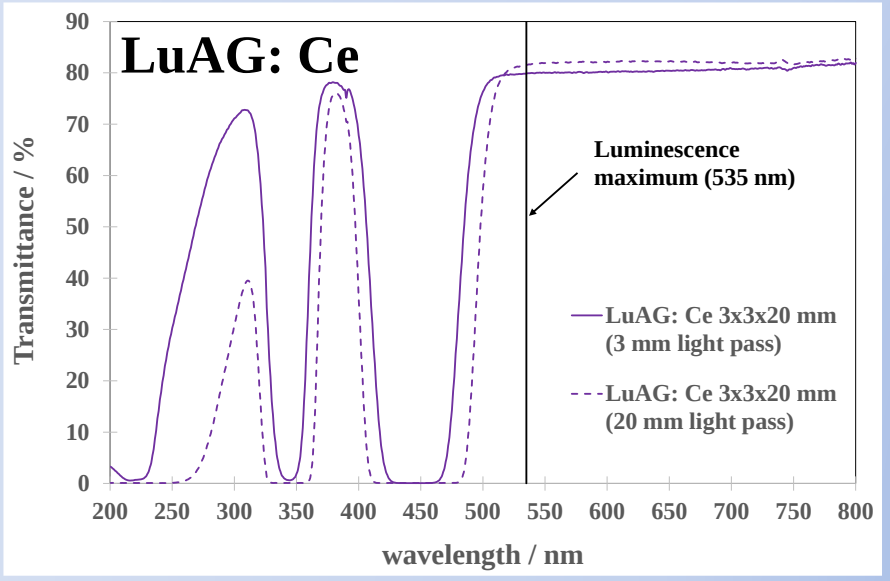


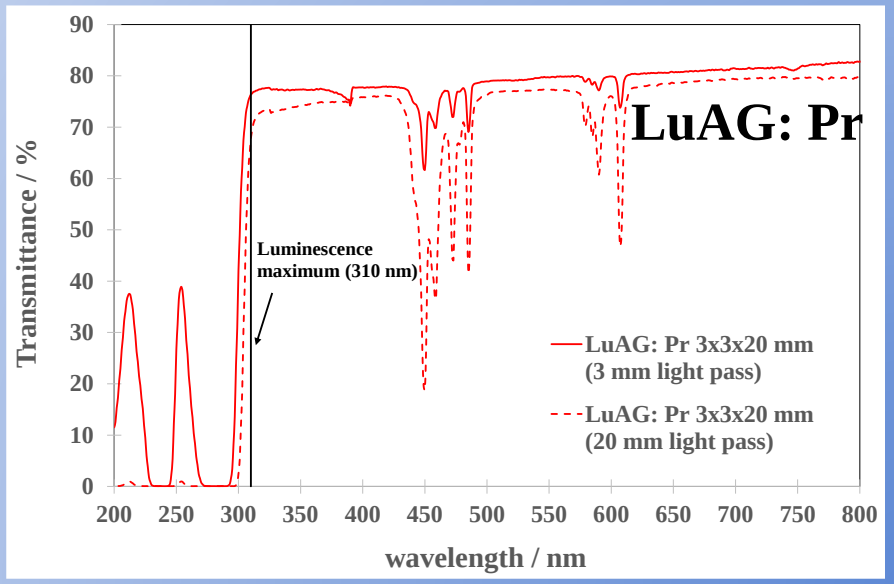
Light yield measurements were done with 241 Am γ-source (E_γ=60 keV) using calibrated Hamamatsu R2059 PMT

Transmittance measurements all garnets 3x3x20 mm



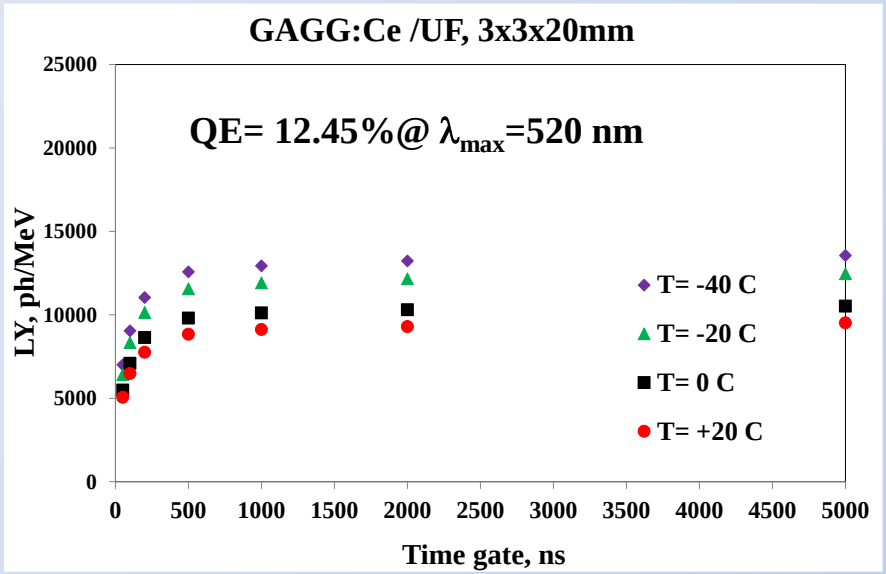


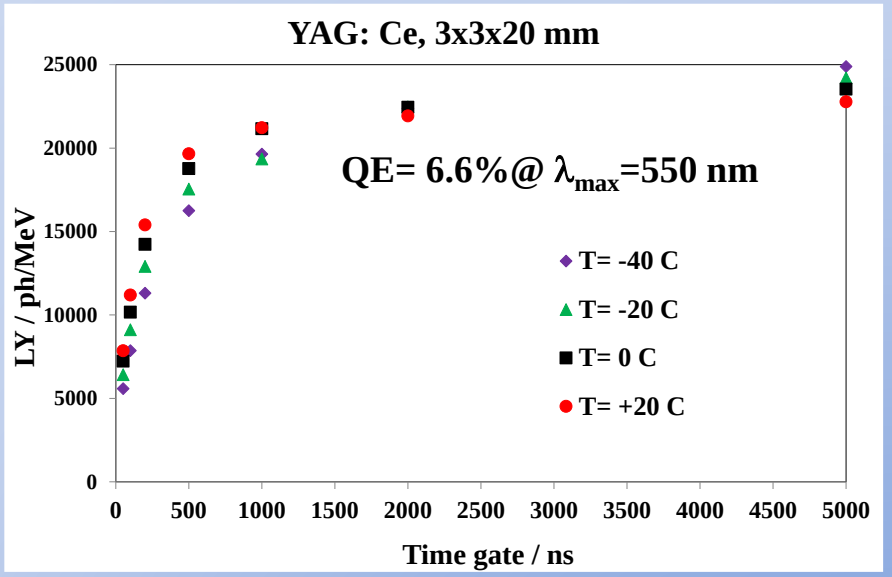


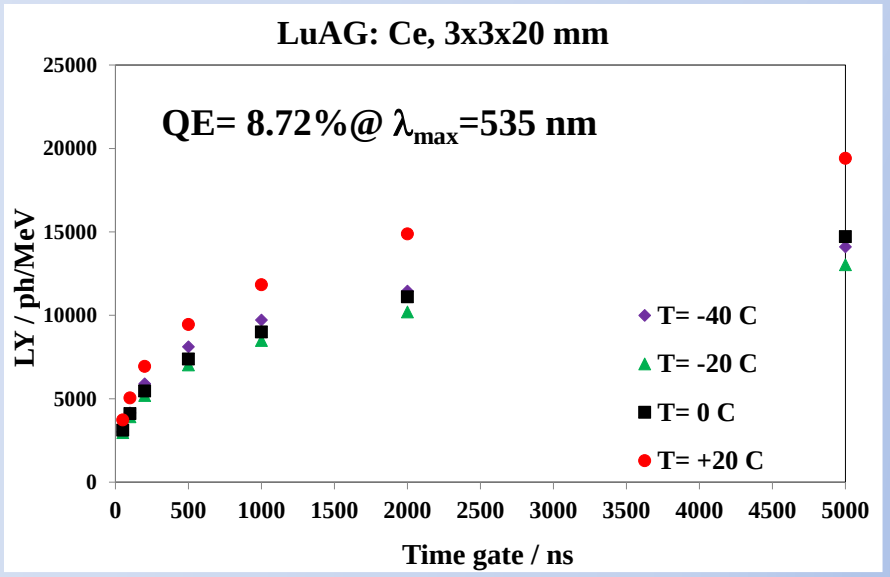


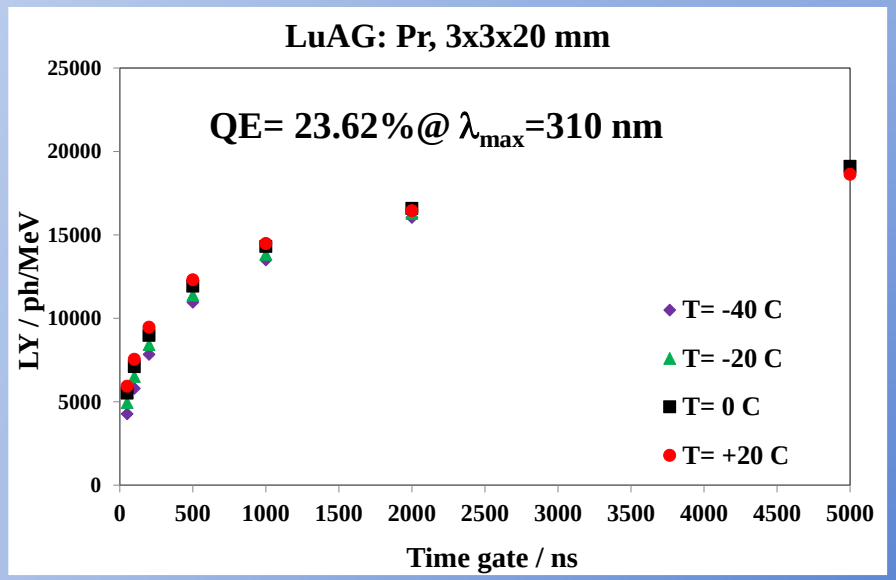
Light Yield measurements all garnets 3x3x20 mm

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



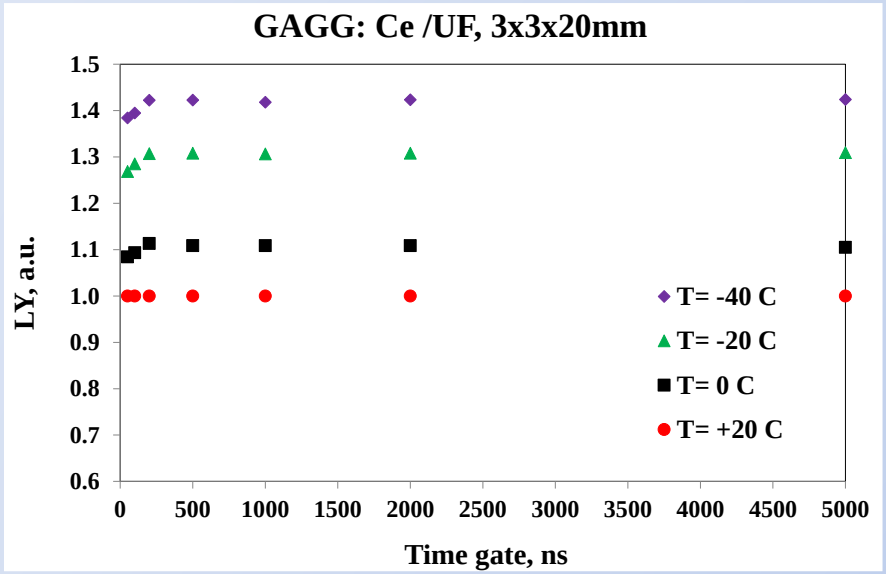


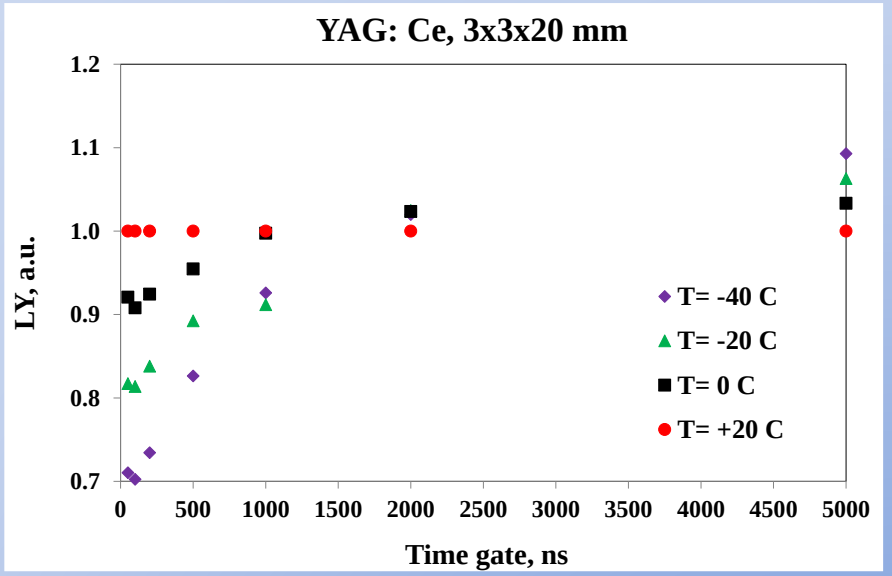


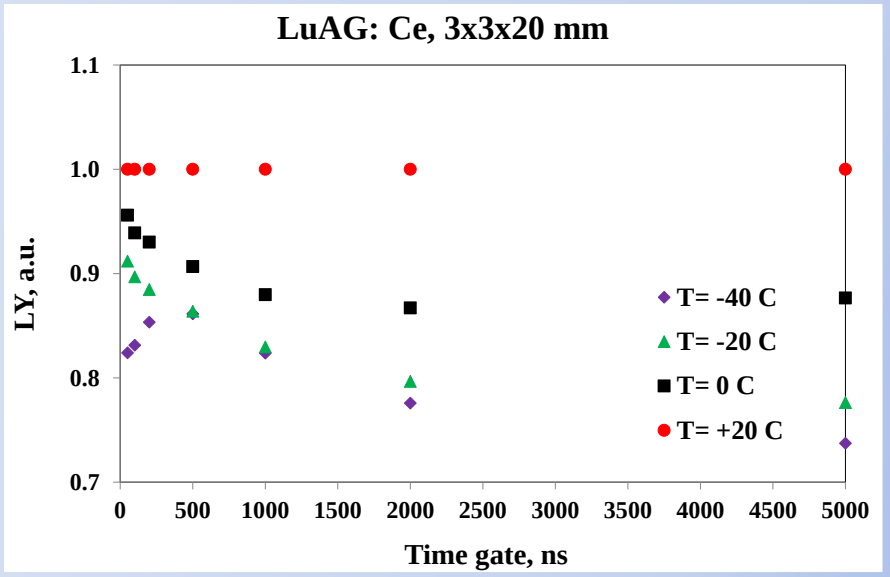


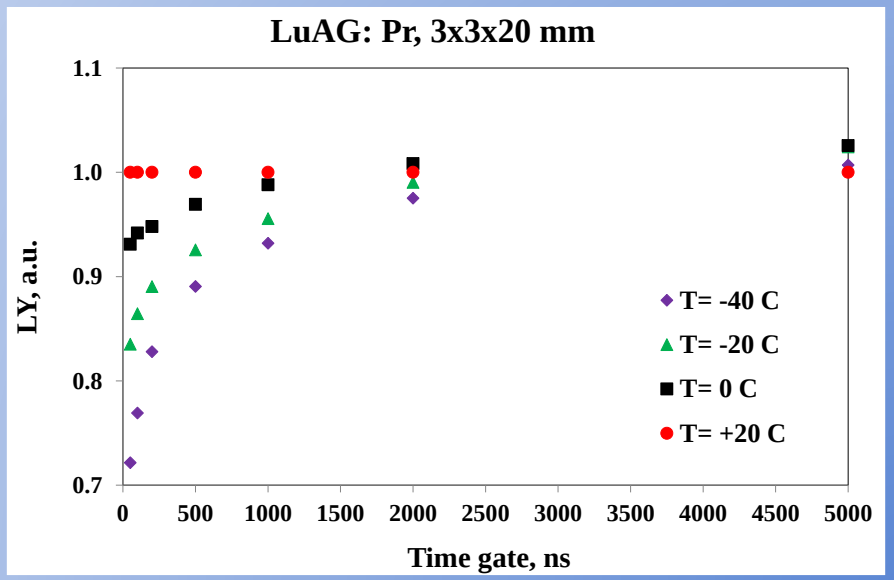
Light Yield measurements all garnets 3x3x20 mm

Calibrated light yield relatively values at T= +20 C for each time gate



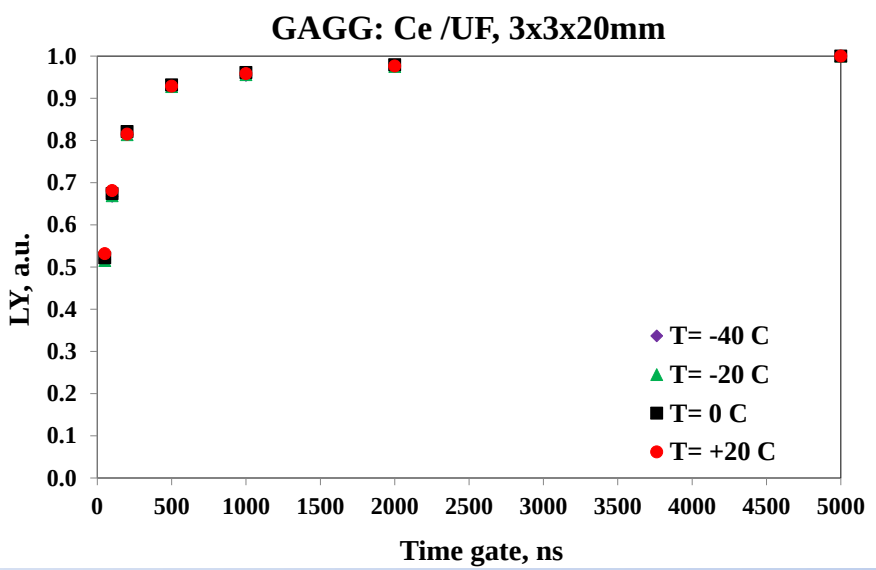


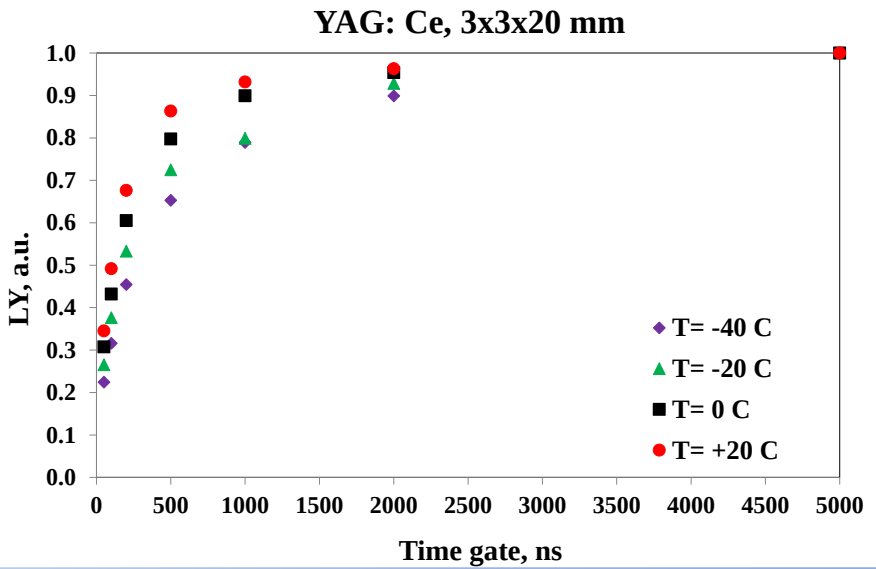


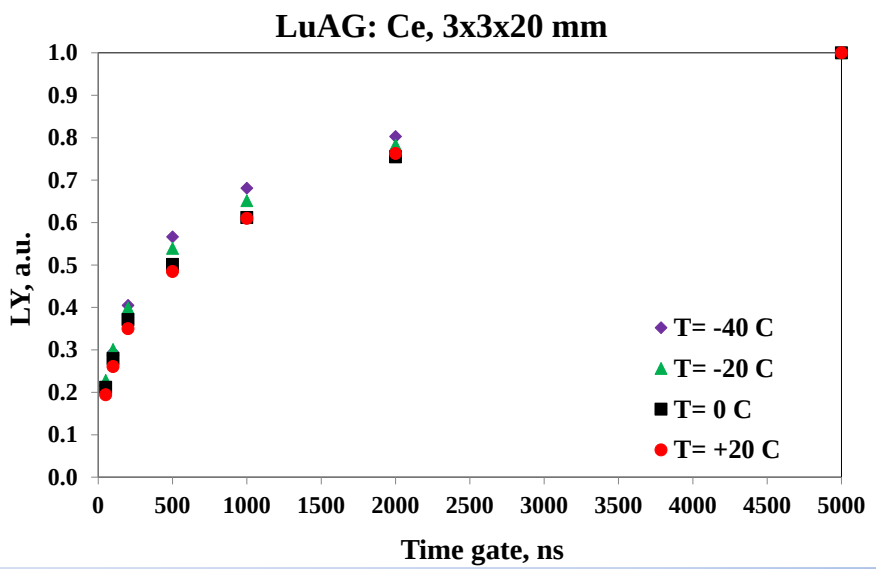


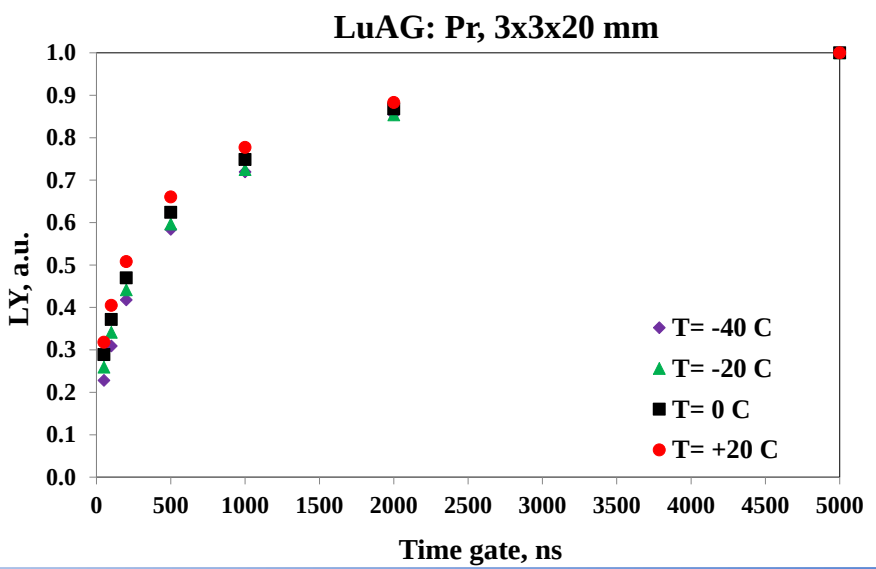
Light Yield measurements all garnets 3x3x20 mm

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

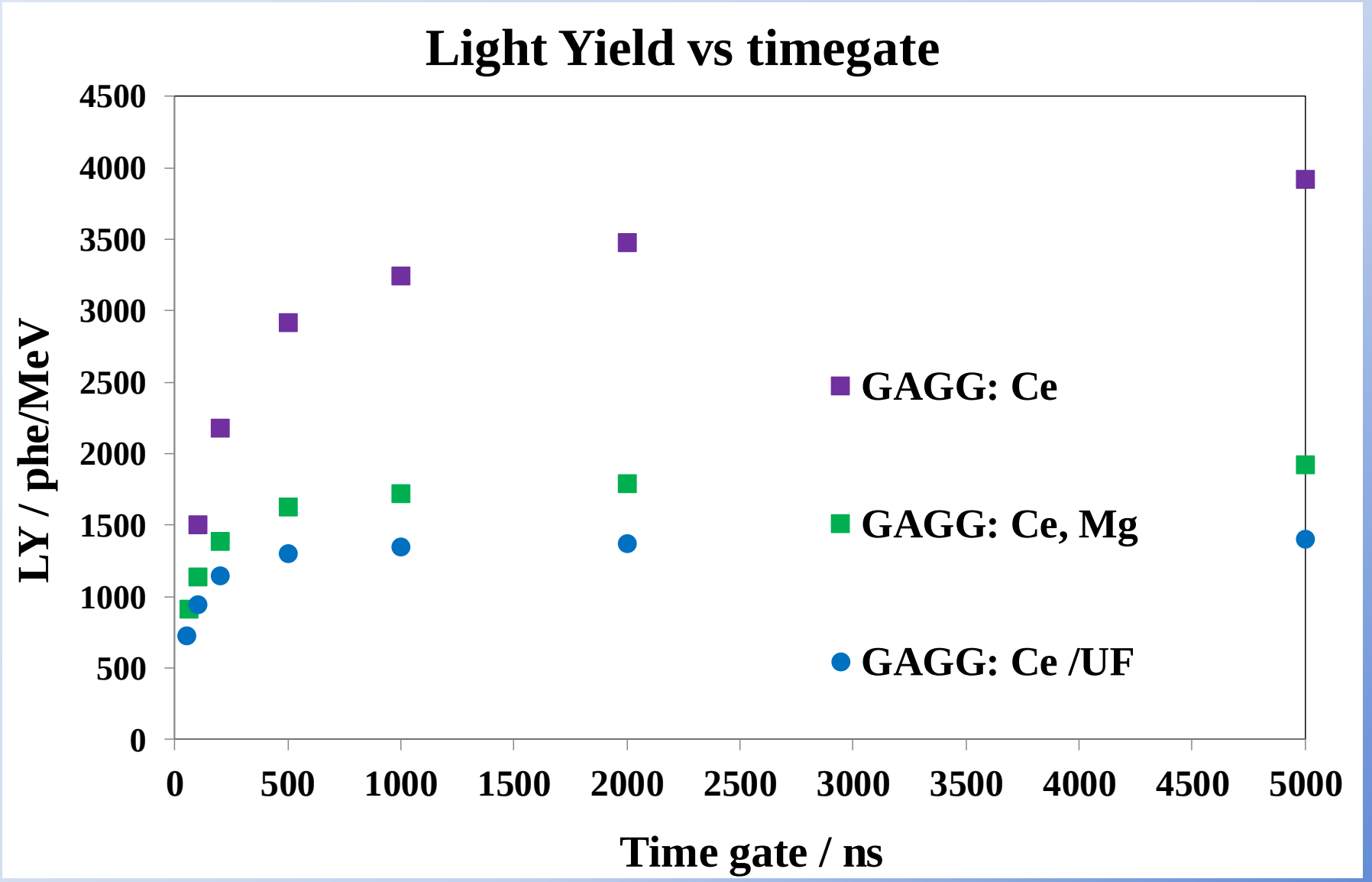




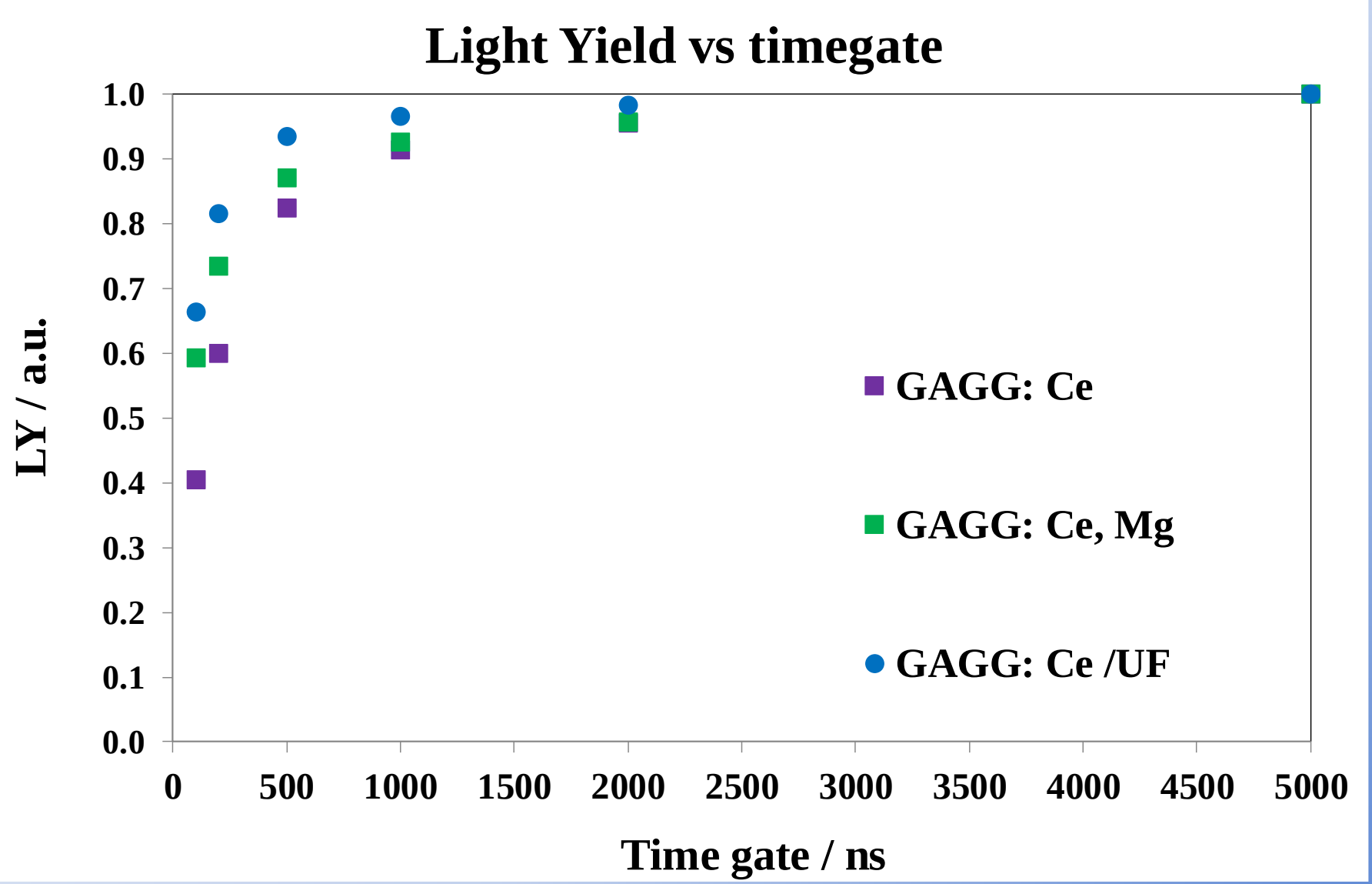




Light Yield comparison of GAGG samples



Light Yield comparison of GAGG samples



Lutetium-Yttrium Oxyorthosilicates

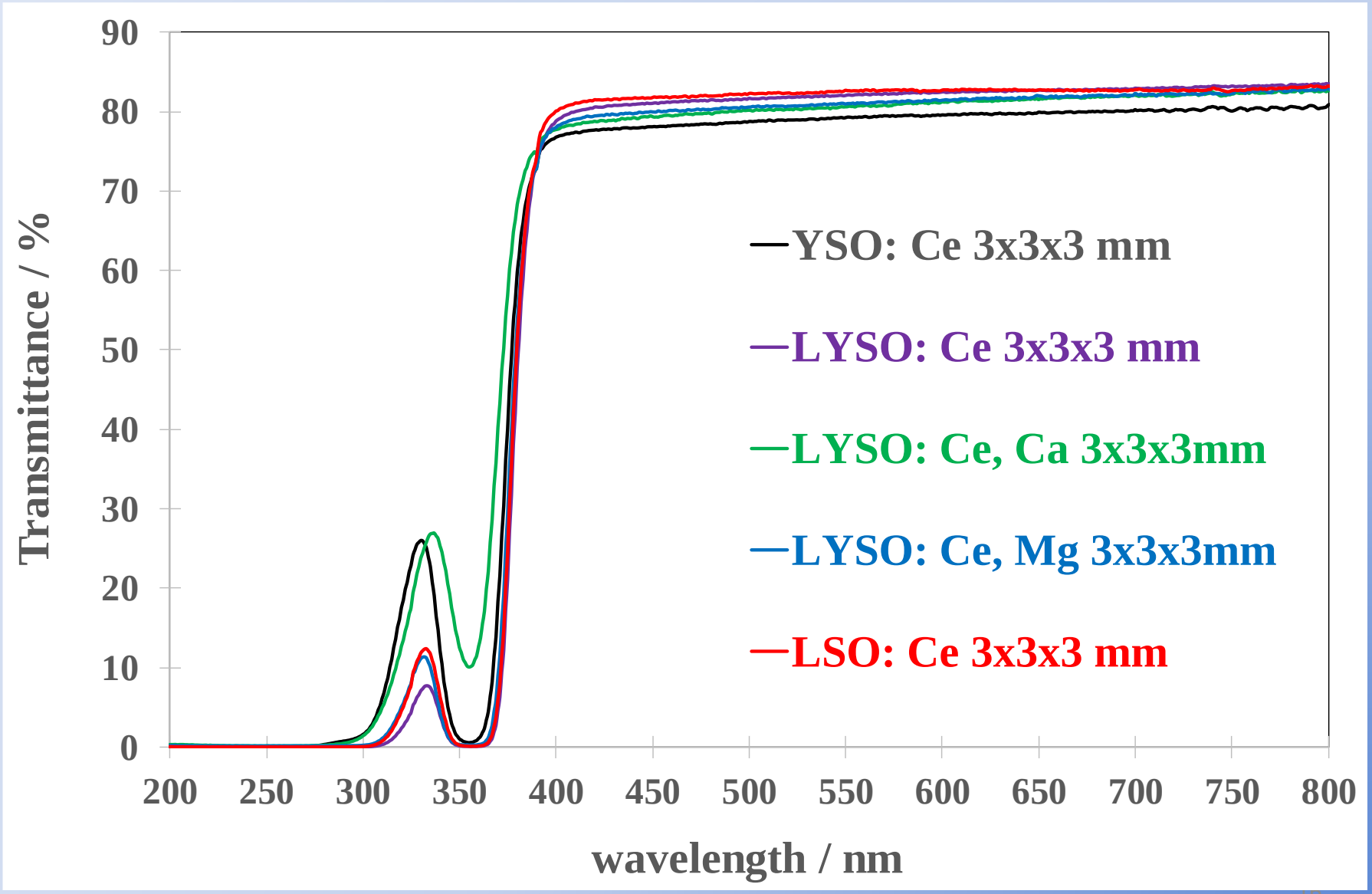
Y_2SiO_5: Ce (YSO :Ce) **3x3x3 mm^3, 3x3x20 mm^3** **produced by OST (China)**

$Lu_{2(1-x)}Y_{2x}SiO_5$ (LYSO)

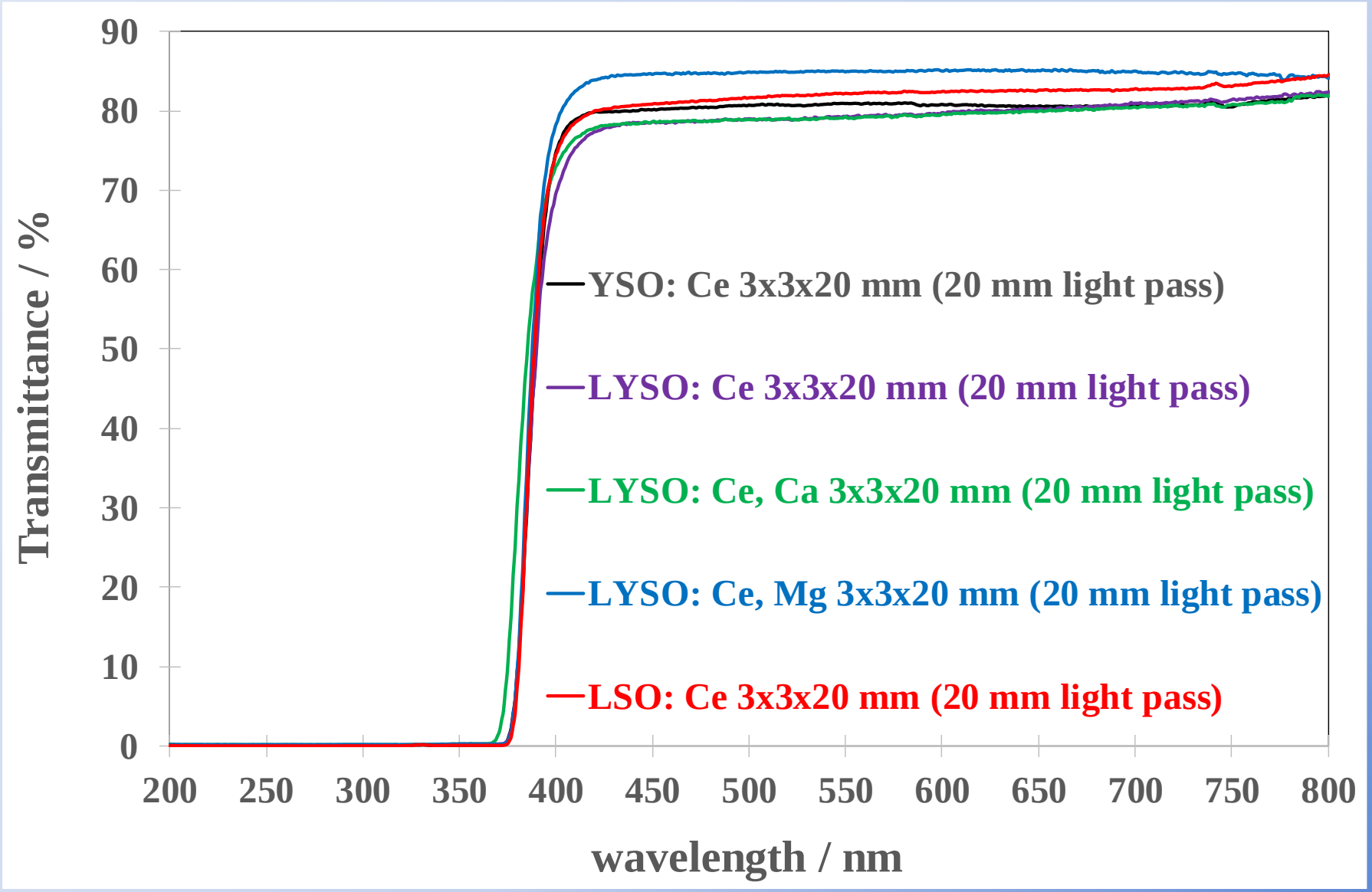
LYSO: Ce	**3x3x3 mm^3, 3x3x20 mm^3**	**produced by OST (China)**
LYSO: Ce, Ca	**3x3x3 mm^3, 3x3x20 mm^3**	**produced by Taiwan Applied Crystal**
LYSO: Ce, Mg	**3x3x3 mm^3, 3x3x20 mm^3**	**produced by Taiwan Applied Crystal**

Lu_2SiO_5: Ce (LSO: Ce) **3x3x3 mm^3, 3x3x20 mm^3** **produced by ADVATEC (UK)**

Transmittance measurements YSO-LYSO-LSO, 3 mm

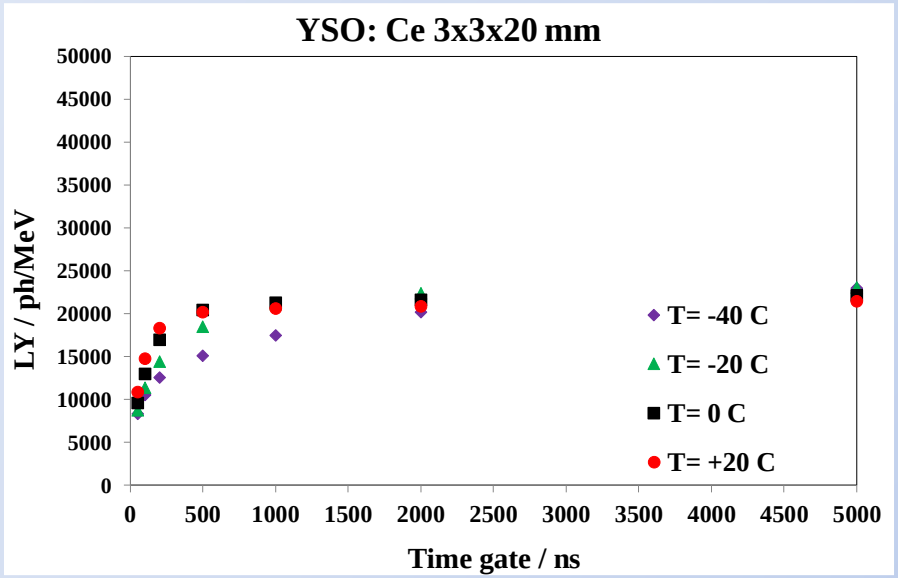


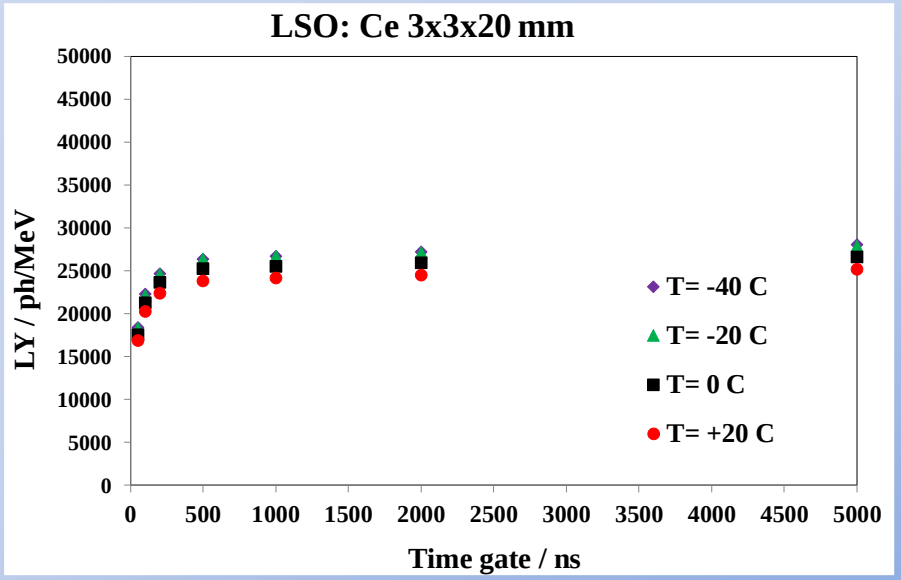
Transmittance measurements YSO-LYSO-LSO, 20 mm

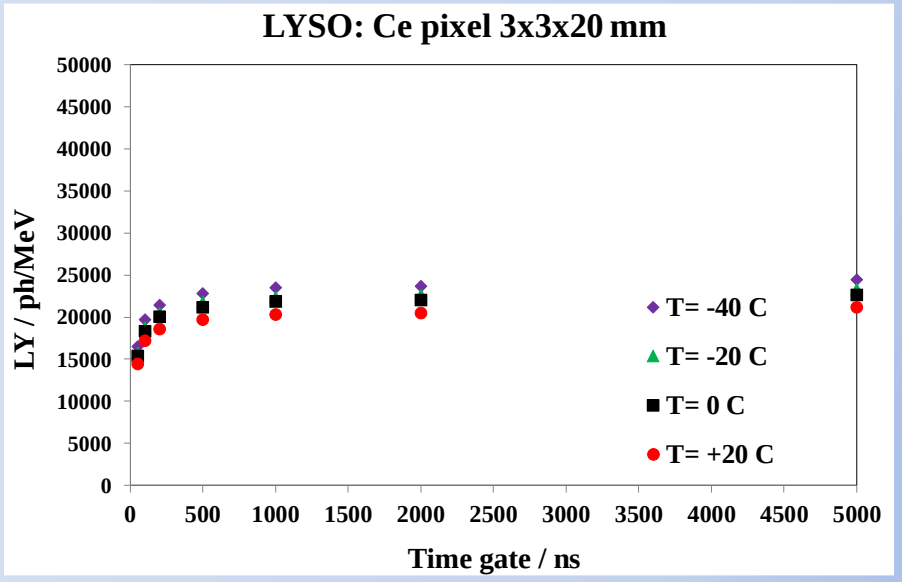


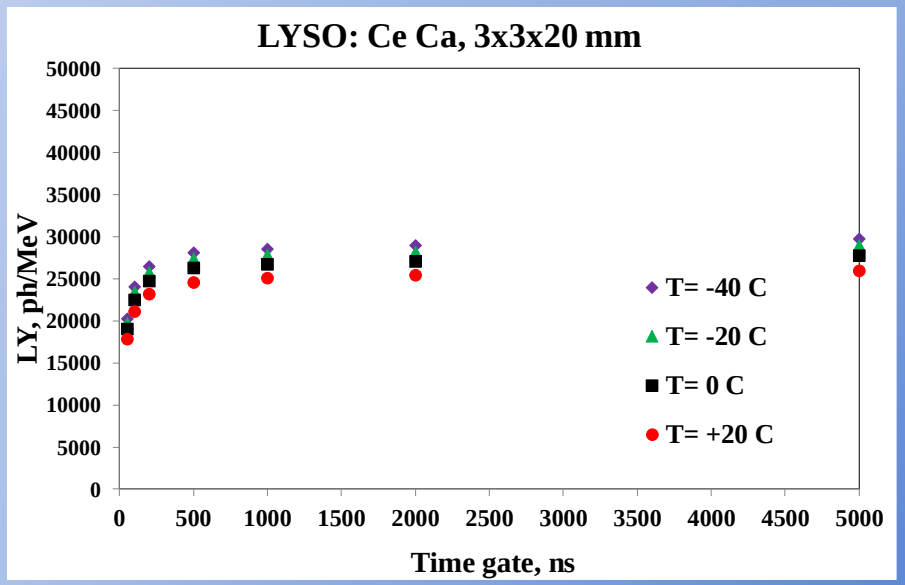
Light Yield measurements YSO-LYSO-LSO, 3x3x20 mm

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



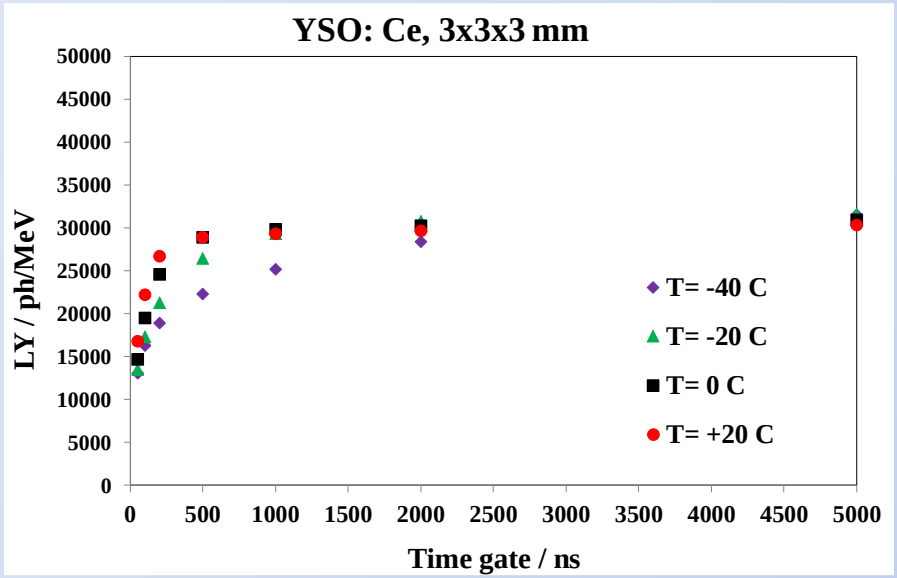


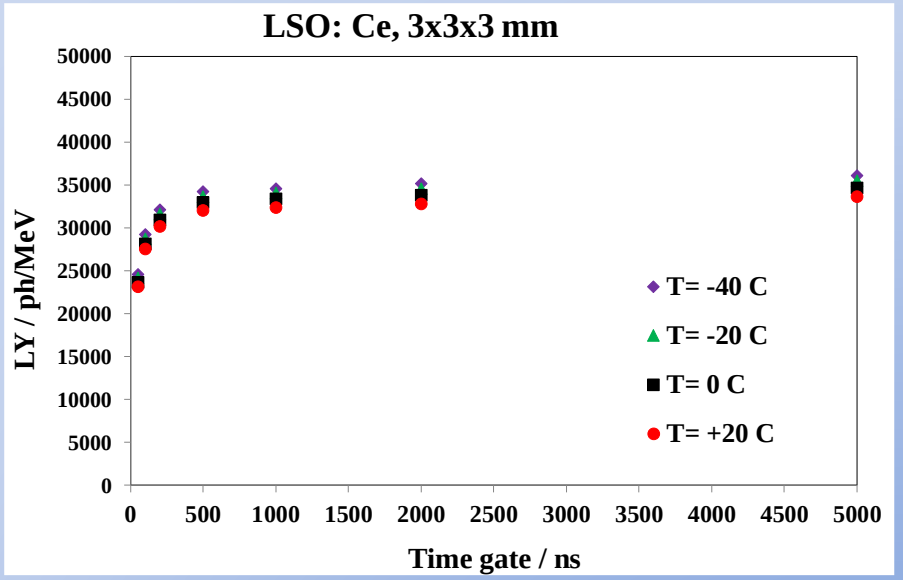


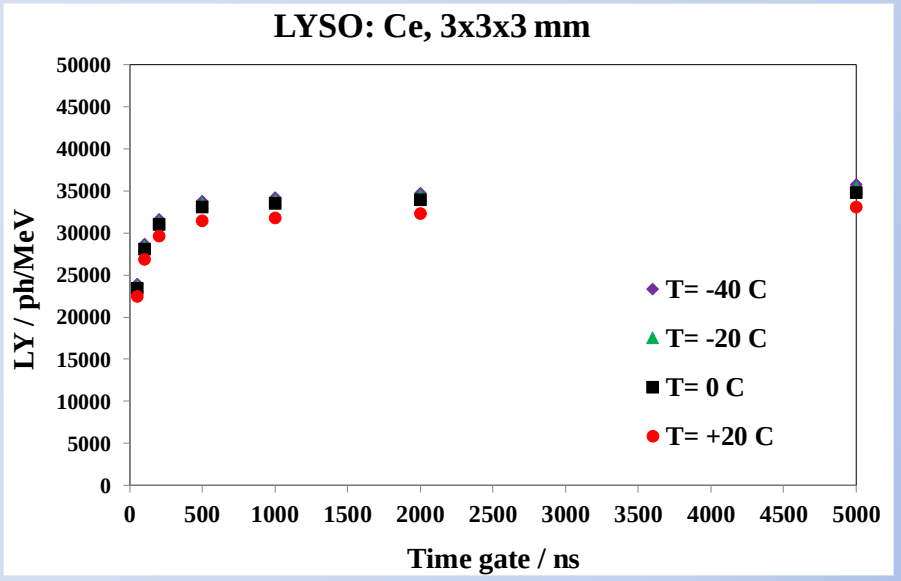


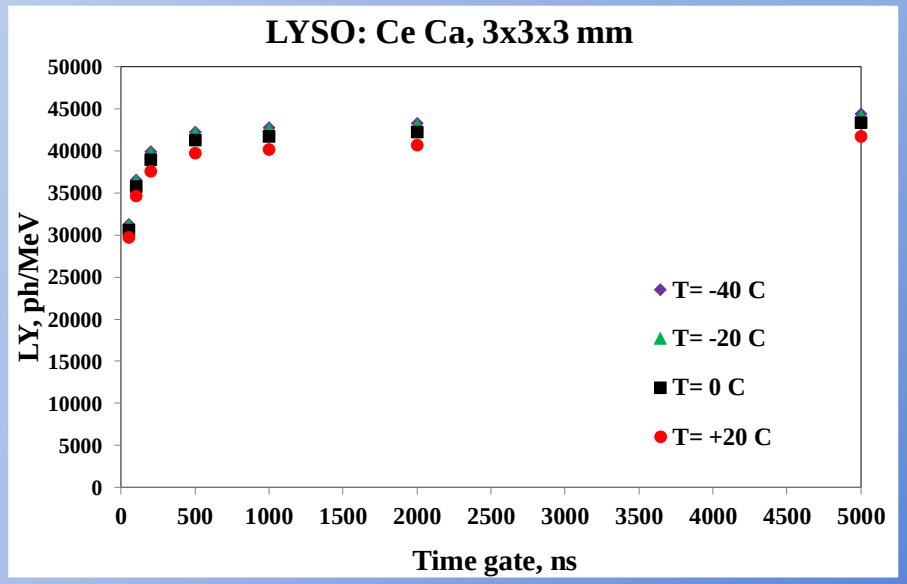
Light Yield measurements YSO-LYSO-LSO, 3x3x3 mm

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



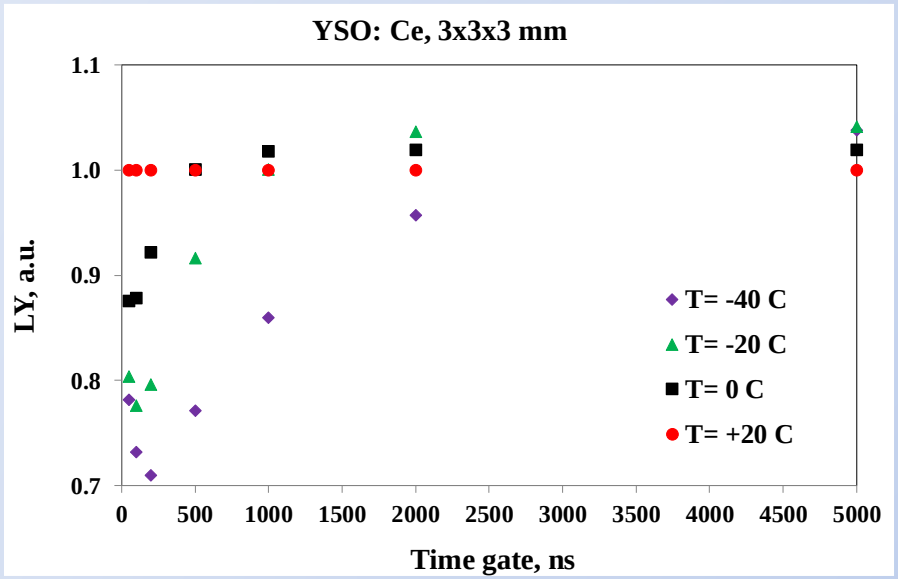


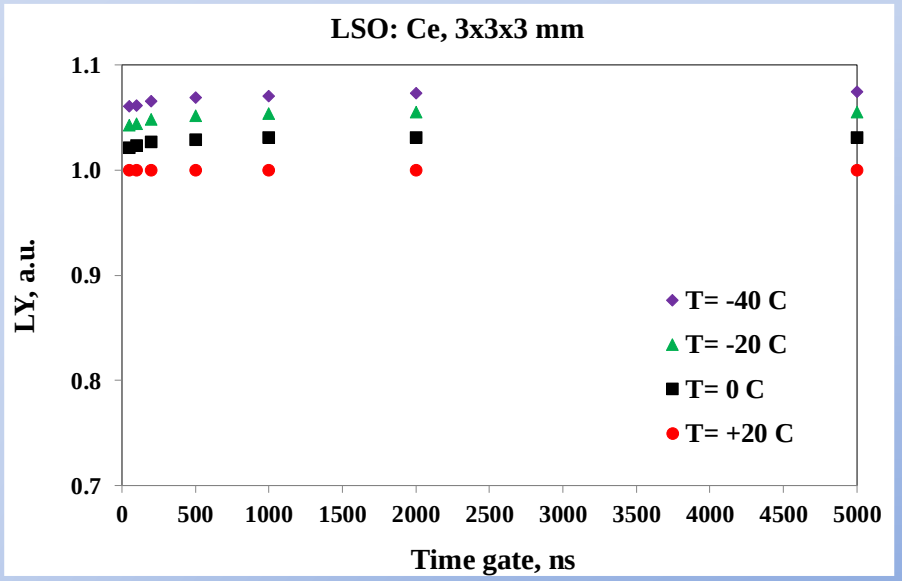


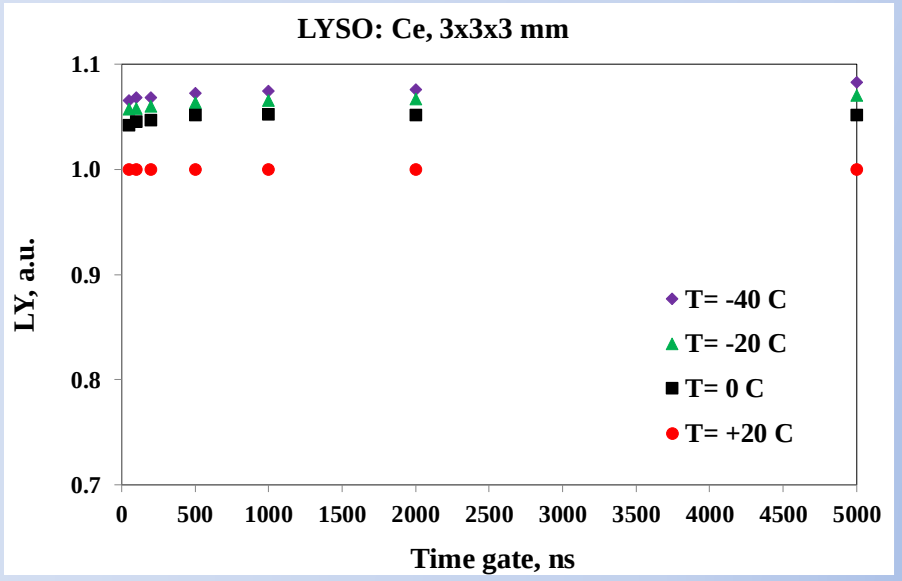


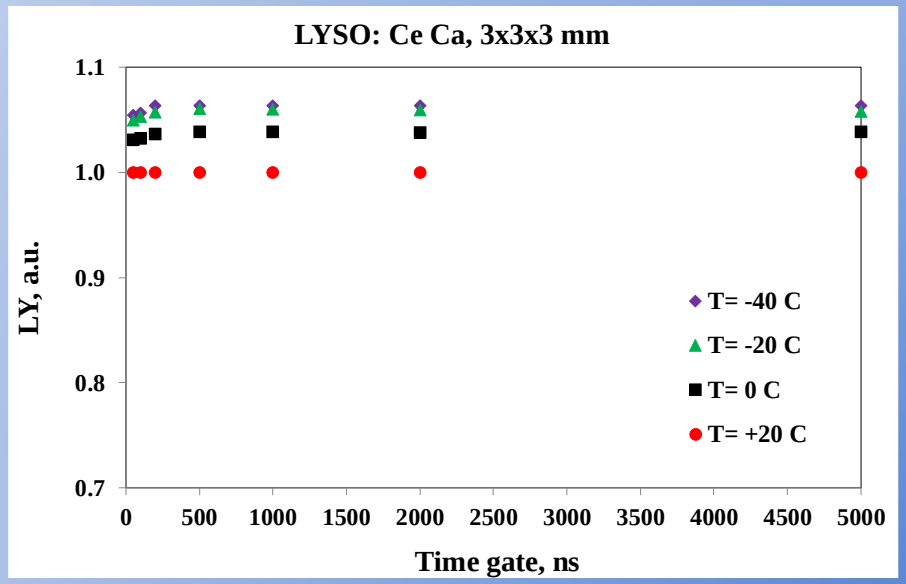
Light Yield measurements YSO-LYSO-LSO, 3x3x3 mm

Calibrated light yield relatively values at T= +20 C for each time gate



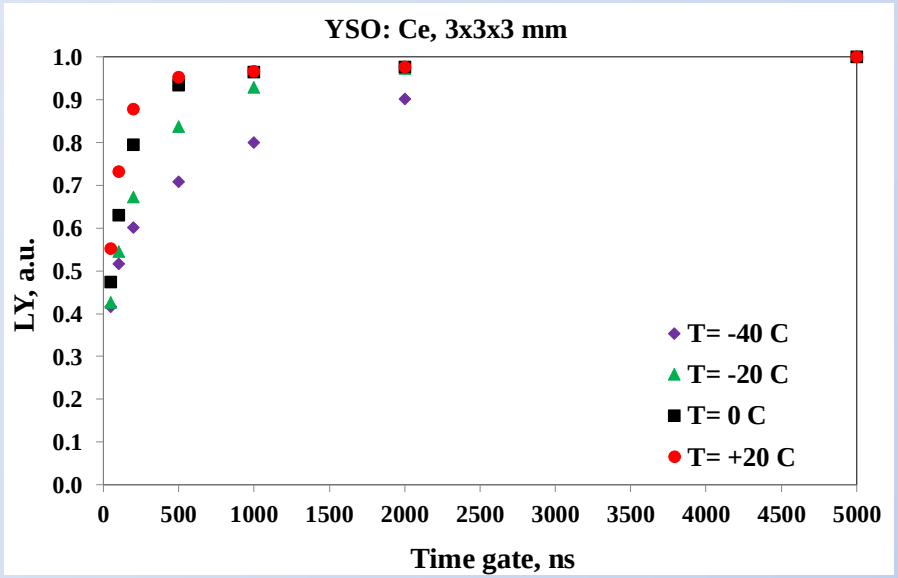


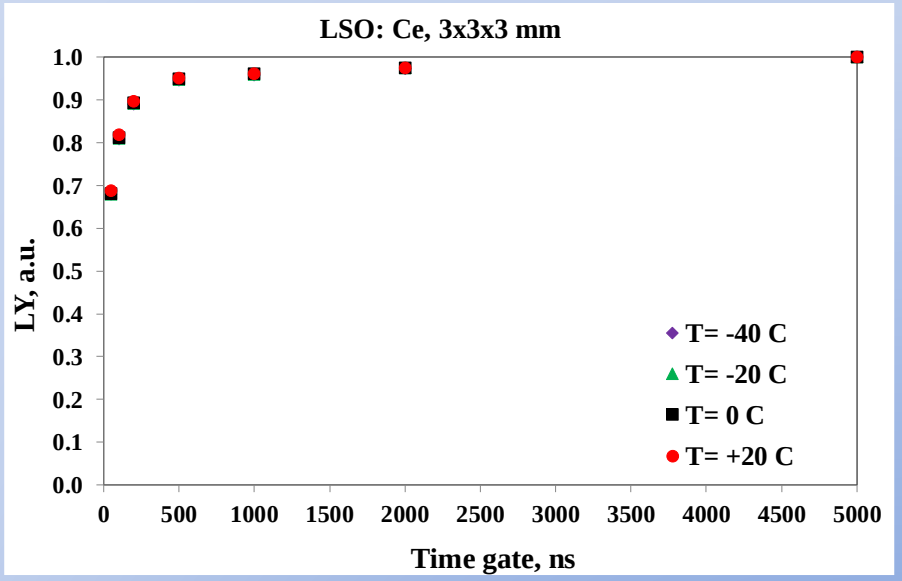


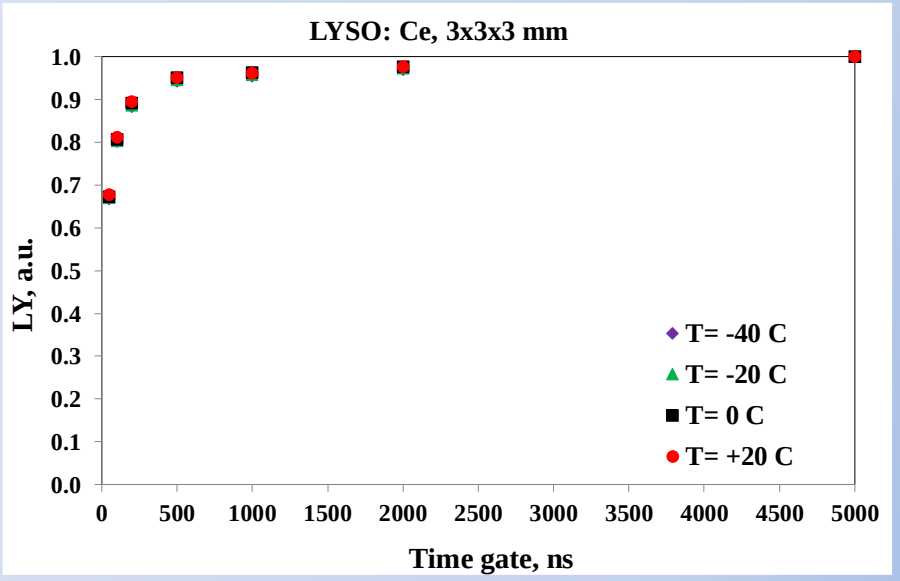


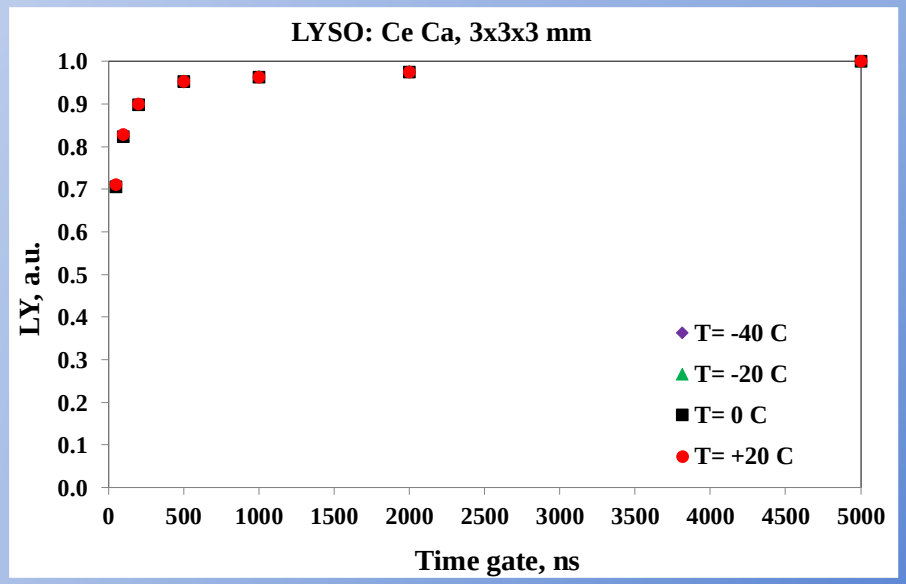
Light Yield measurements YSO-LYSO-LSO, 3x3x3 mm

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









Conclusion

- **Co-doping of garnets and Lutetium-Yttrium Oxyorthosilicates with Mg and Ca leads to improving light yield characteristics**
- **GAGG and LYSO have a good potential to be applied for nonhomogeneous detecting cells of electromagnetic calorimeters to operate in a harsh irradiation environment**
- **Co-doped versions of the GAGG materials demonstrate significant suppression of the long decay components in scintillating kinetics**
- **LYSO: Ce, Ca and LYSO: Ce, Mg have higher light yield at in comparison with LYSO: Ce without degradation of the timing characteristics**
- **More detailed properties characterization should be done**