TRENDS, NEEDS AND SYNERGIES IN SCINTILLATING MATERIALS

DRD6 collaboration WP3 meeting

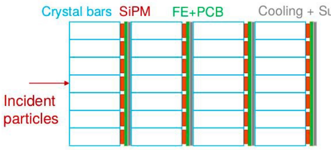
E. Auffray, *CERN, EP-CMX*

WP3: a variety of optical calorimeter concepts

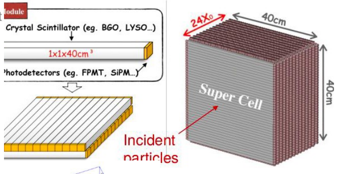
Homogeneous EM

HGCCAL

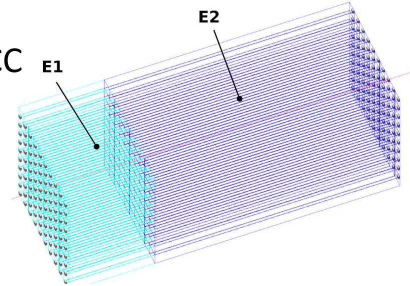
Design 1



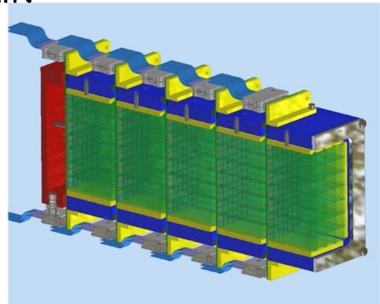
Design 2



MAXICC

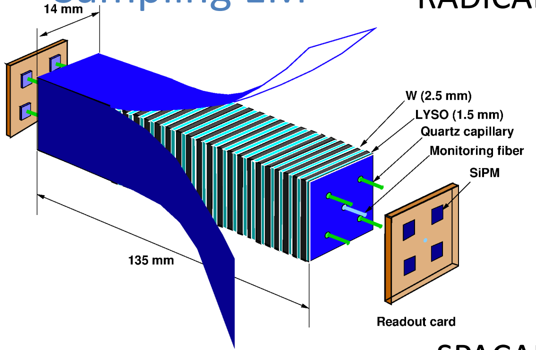


CRILIN

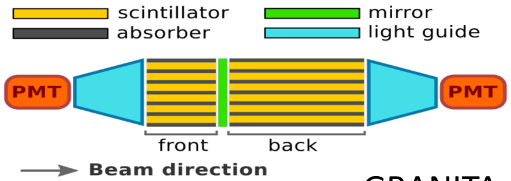


Sampling EM

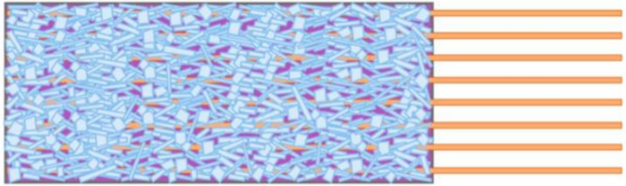
RADICAL



SPACAL

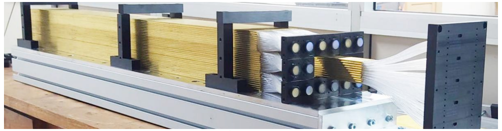


GRANITA

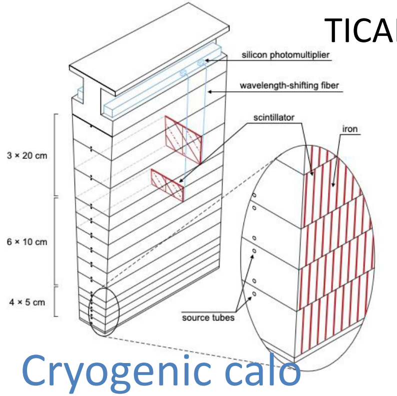


Sampling EM/HM

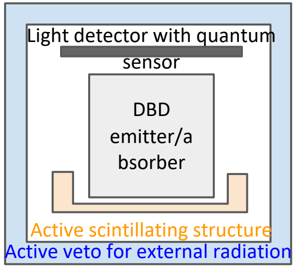
DRCAL



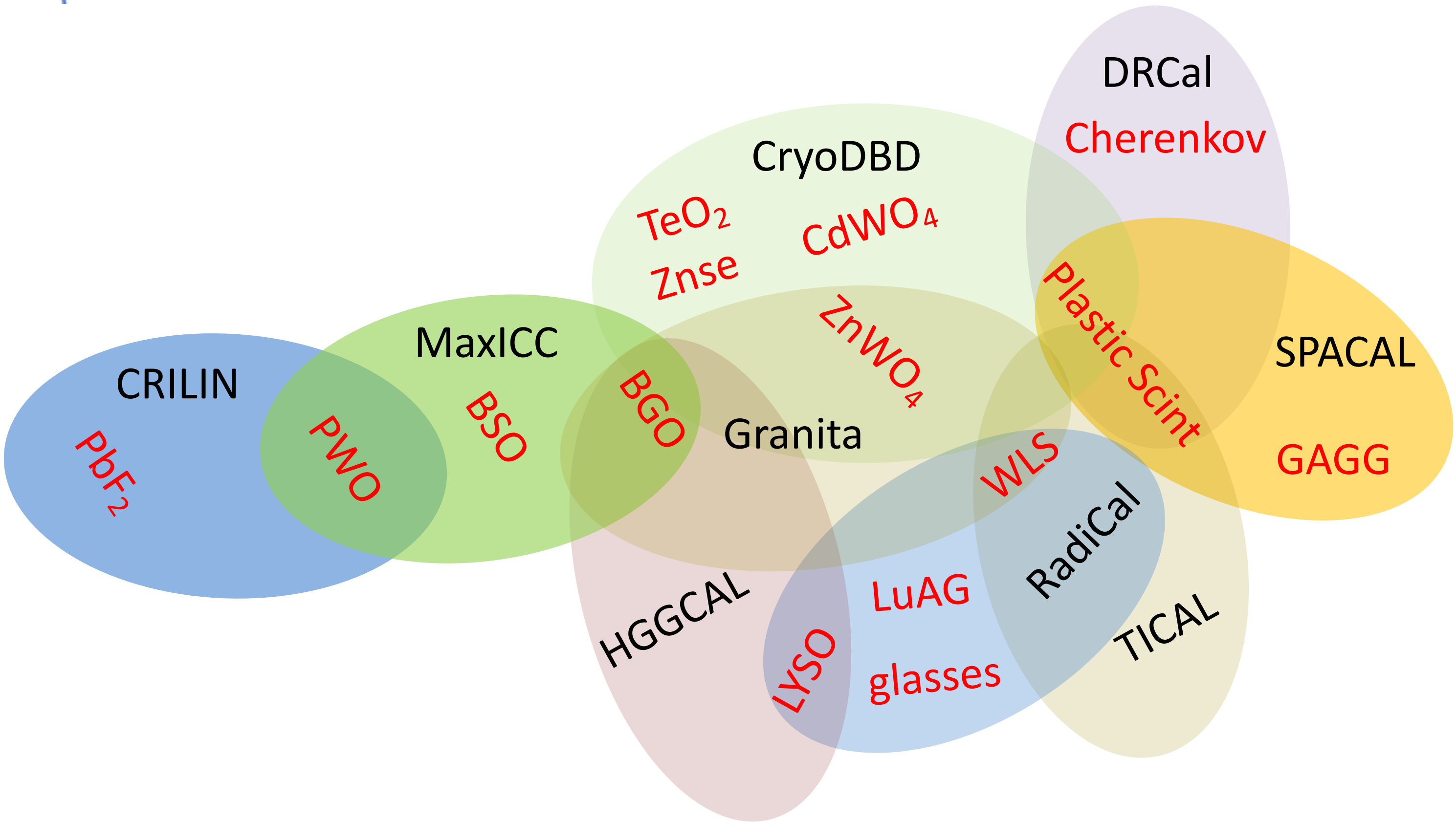
TICAL



Cryogenic calo



Common scintillating materials between projects



Overview of WP3 proposed calorimeter concepts

Project	Scintillator/WLS	Photodetector	DRDTs	Target
Task 3.1: Homogeneous and quasi-homogeneous EM calorimeters				
HGCCAL	BGO, LYSO	SiPMs	6.1, 6.2	e^+e^-
MAXICC	PWO, BGO, BSO	SiPMs	6.1, 6.2	e^+e^-
Crilin	PbF_2, PWO-UF	SiPMs	6.2, 6.3	$\mu^+\mu^-$
Task 3.2: Innovative Sampling EM calorimeters				
GRAiNITA	$ZnWO_4$, BGO	SiPMs	6.1, 6.2	e^+e^-
SpaCal	GAGG, organic	MCP-PMTs,SiPMs	6.1, 6.3	e^+e^-/hh
RADiCAL	LYSO, LuAG	SiPMs	6.1, 6.2, 6.3	e^+e^-/hh
Task 3.3: (EM+)Hadronic sampling calorimeters				
DRCal	PMMA, plastic	SiPMs, MCP	6.2	e^+e^-
TileCal	PEN, PET	SiPMs	6.2, 6.3	e^+e^-/hh
Task 3.4: Materials				
ScintCal	-	-	6.1, 6.2, 6.3	$e^+e^-/\mu^+\mu^-/hh$
CryoDBD Cal	TeO, ZnSe, LiMoO NaMoO, ZnMoO	n.a.	-	DBD experiments

$BGO, ZnW0_4, CdWO_4$
Plastic scint.

All based on inorganic or organic scintillators

Main Requirements

- **Fast and radiation-hard organic and inorganic scintillators:**
  SPACAL, RADICAL, CRILIN, TICAL
  + any calorimeter based on scintillators in high radiation environment
- **Radiation-hard wavelength shifters**
  RADICAL, TICAL,
  + any calorimeter using wavelength shifters in high radiation environment
- **Dense**
  MAXICC, HGCCAL, GRANITA; CryoDBDcal
- **Exploitation Scintillation and Cherenkov**
  MAXICC, DRCal
- **Cost-effective inorganic scintillators:**
  MAXICC, CRILIN; HGCCAL, GRANITA, Radical, SPACAL, CryoDBDcal
- **Ultrafast inorganic scintillators for ultrafast calorimetry**

=> Common R&D between calorimeter projects and ScintCAL subtask

Ongoing Development

- R&D on garnet materials: YAG, LuAG, GAGG, LuGAGG, GYAG, etc..
  ⇒ Accelerate decay time and preserving radiation hardness
- R&D on exploitation Cherenkov in scintillating materials
  - Improve transmission in UV
  - Investigation of the readout of both signal
- R&D on crossluminescence for fast timing calorimeter and time tagger

Need UV photodetectors
=> DRD4 development

- R&D on radiation hard plastic
  Synergy with DRD4-WP5 => need to work together

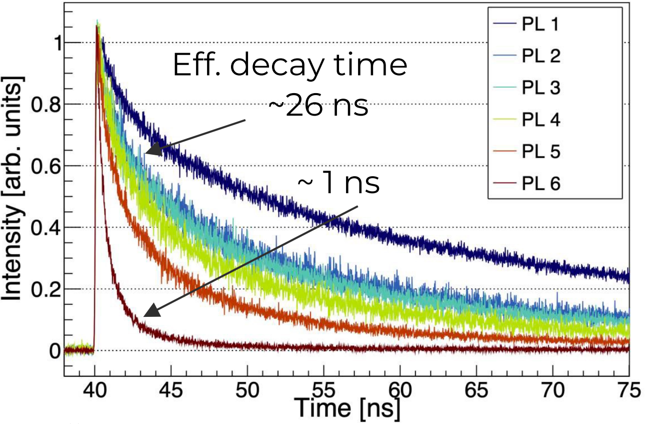
Explore new developments
with nanocomposite
scintillators

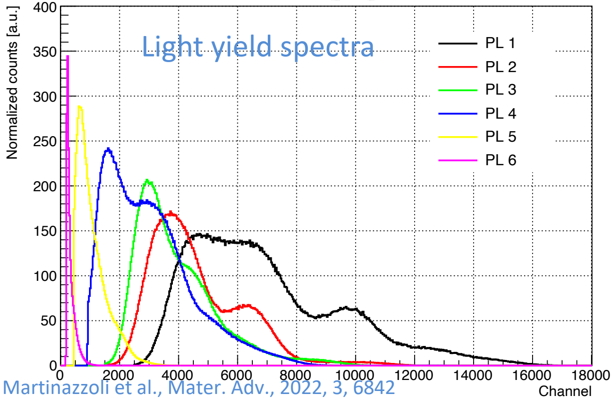
- R&D on radiation hard wavelength shifters
- R&D of scintillating glasses or Ceramics

Acceleration of GAGG emission

Heavy co-doping Ce^{3+}/Mg^{2+}

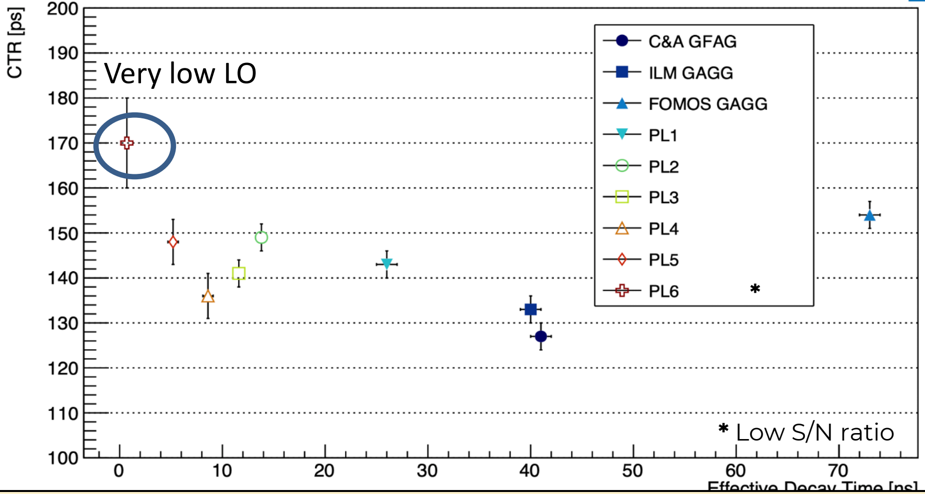
Scintillation decay - Pulsed X-Rays





L. Martinazzoli et al., Mater. Adv., 2022, 3, 6842

Coincidence time resolution vs effective decay time



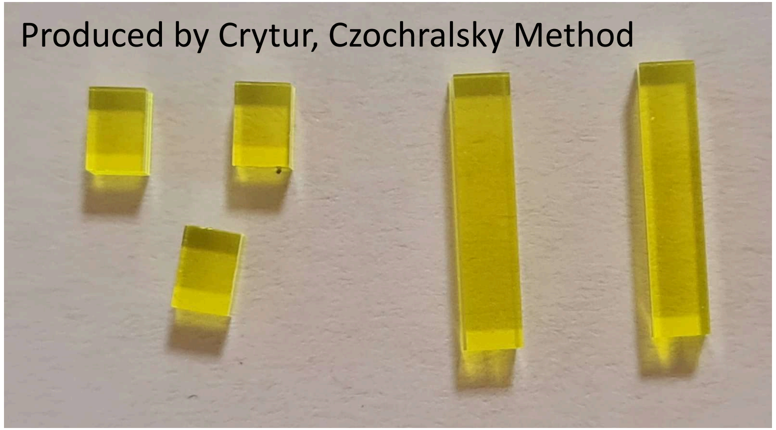
No major loss of time resolution!
Decay time decrease compensated the Light output reduction
=> the same photon time-density

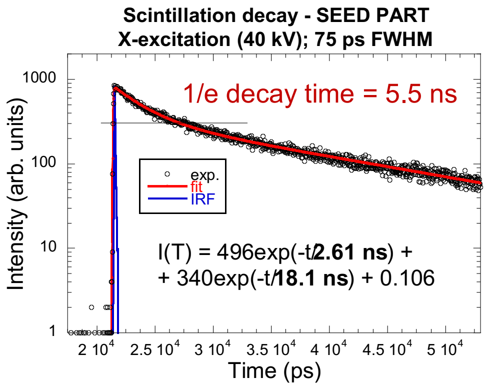
R&D on going in different groups for define optimal composition and production

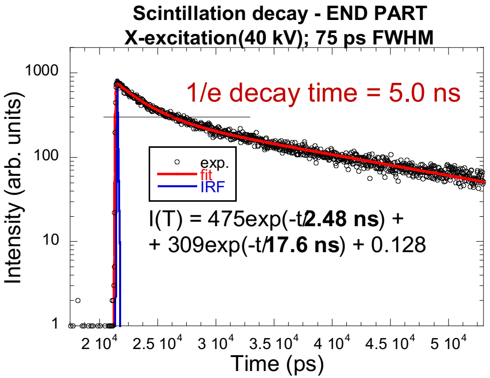
Acceleration of GAGG emission

Heavy co-doping Ce^{3+}/Mg^{2+}

First results obtained by Crytur Company



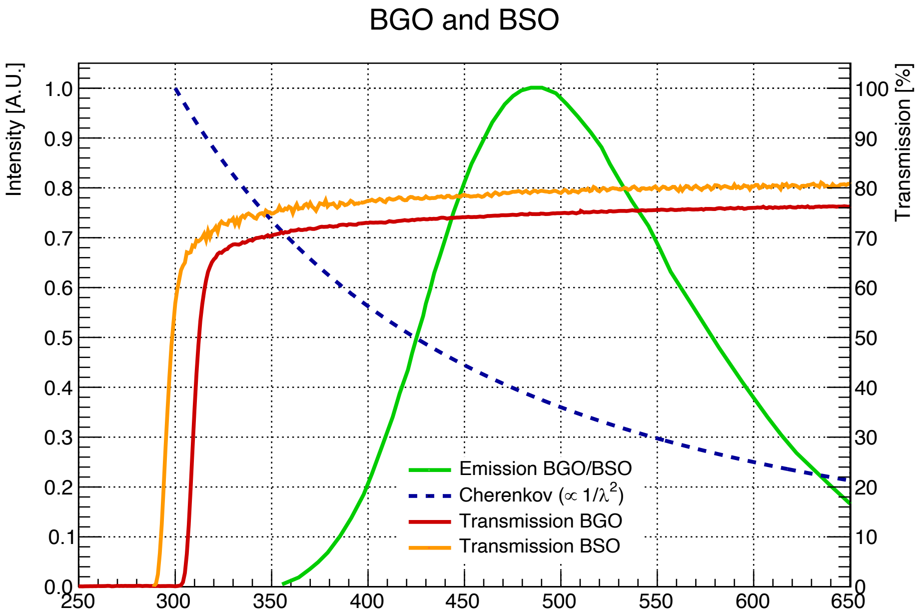




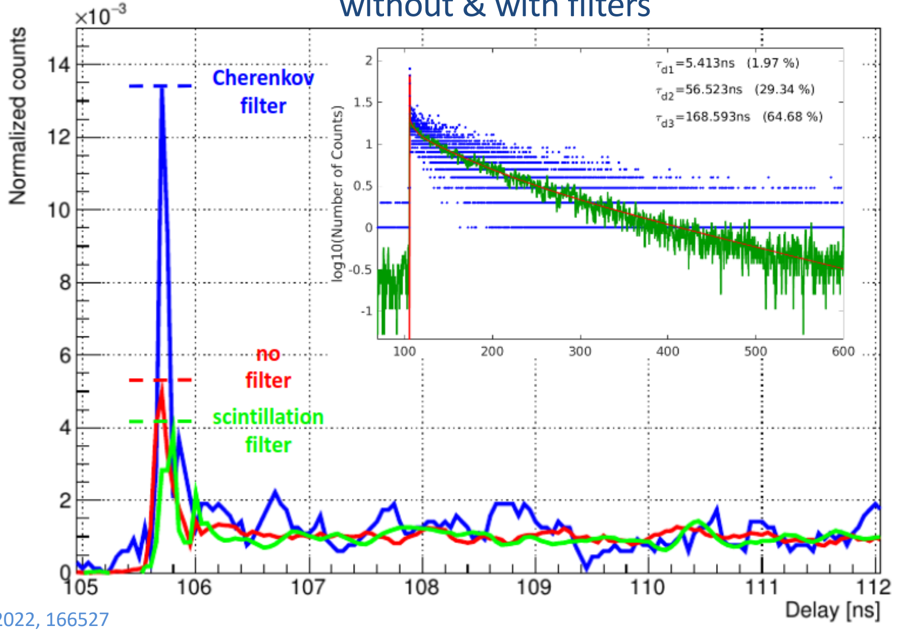
Measured by FZU, M. Nikl

No slow component, decay time below 10ns!

Exploitation of Cherenkov/scintillation in intrinsic scintillating crystals

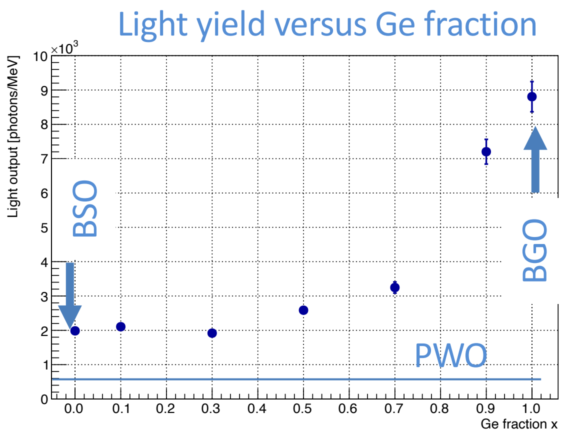


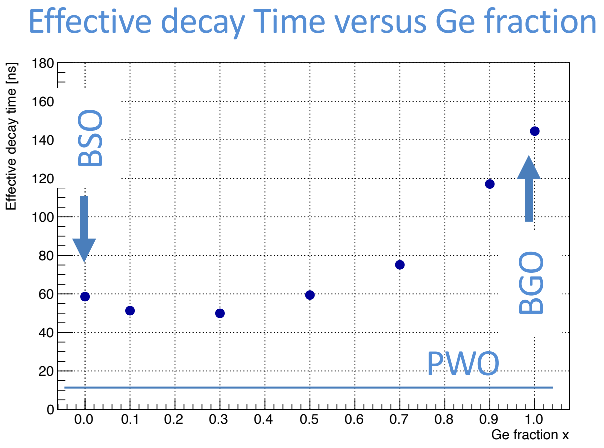
Decay time spectra of BSO under 511 keV excitation without & with filters

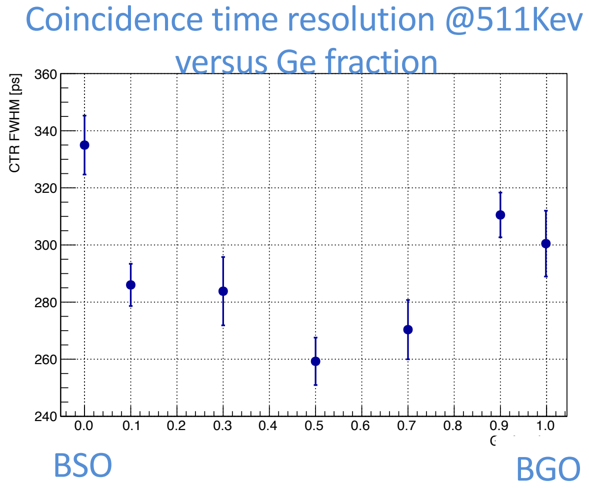


R. Cala et al, NIMA 1032, 2022, 166527

Mixed Material: BGO-BSO ($Bi_4(Ge_xSi_{1-x})_3O_{12}$)



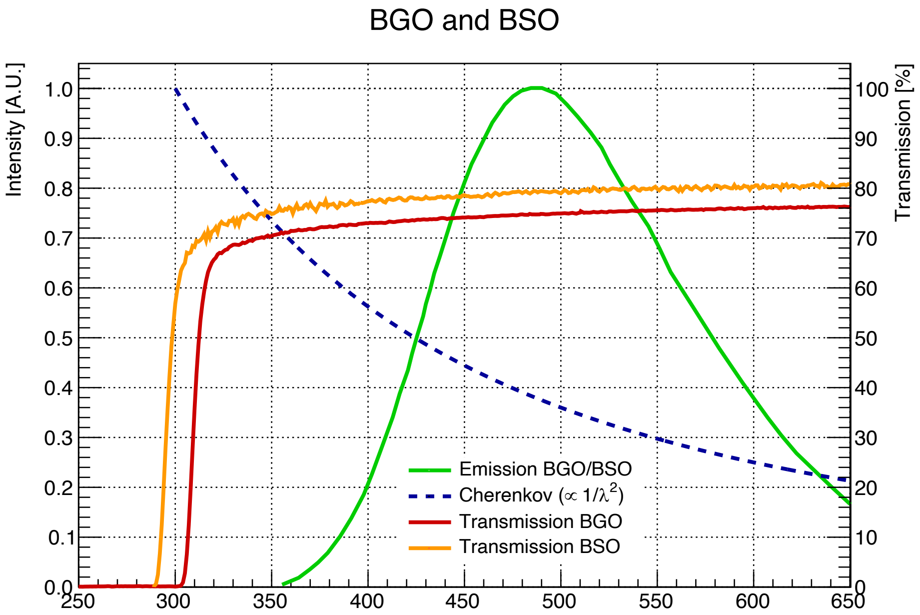




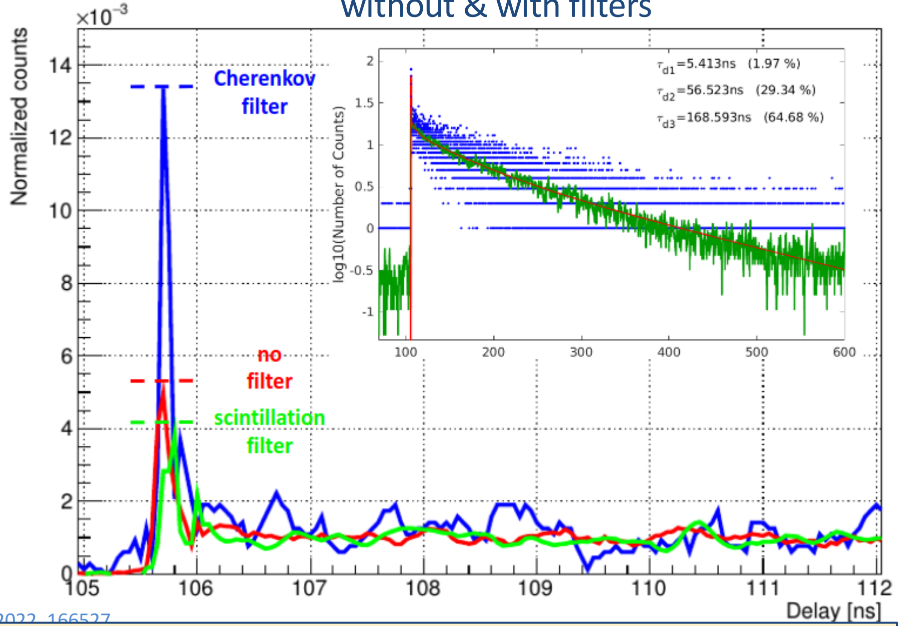
BSO (BGSO) may be a good candidate for Dual Readout:
Better transmission in UV than PWO and BGO (higher Cherenkov among),
better Light Yield than PWO and faster thanBGO
R&D on production on going

R. Cala et al, NIMA, A 1032 (2022) 166527

Exploitation of Cherenkov/scintillation in intrinsic scintillating crystals



Decay time spectra of BSO under 511 keV excitation without & with filters



R. Cala et al. NIMA 1032, 2022, 166527

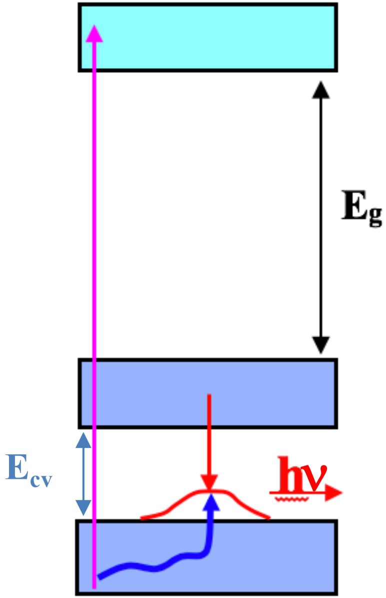
R&D on going to optimise:

readout separation Cherenkov & scintillation with filters and/or pulse discrimination

Can we find/develop other dense scinillators with better transmission in UV for higher Cherenkov light collection ?

Crossluminescence material

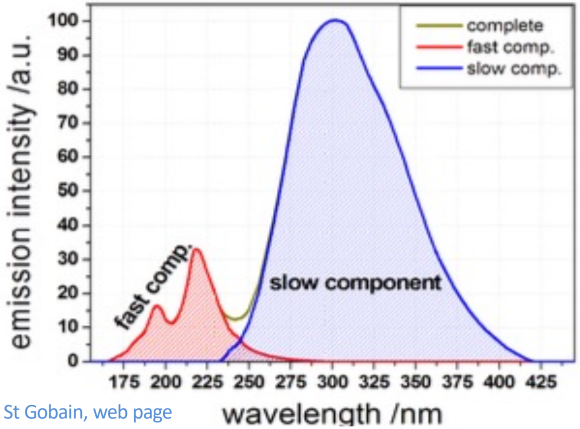
Radiative transition between the core- and valence bands.



$E_{cv} < E_g$

Very fast emission < 2ns
but generaly in UV emission

BaF_2 emisison spectra



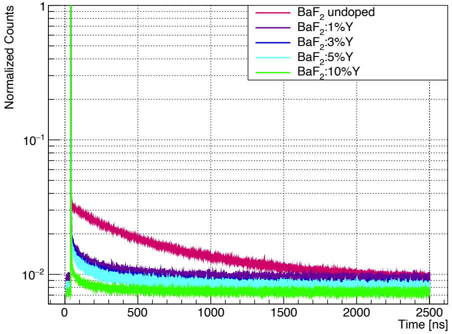
St Gobain, web page

R&D to **suppress the slow component in BaF_2 by doping**

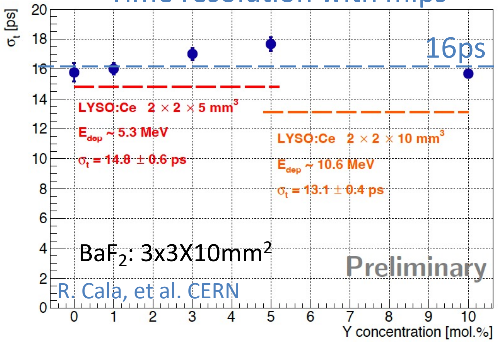
⇒ No change in short decay

⇒ No impact on time resolution

Decay time spectra



Time resolution with mips

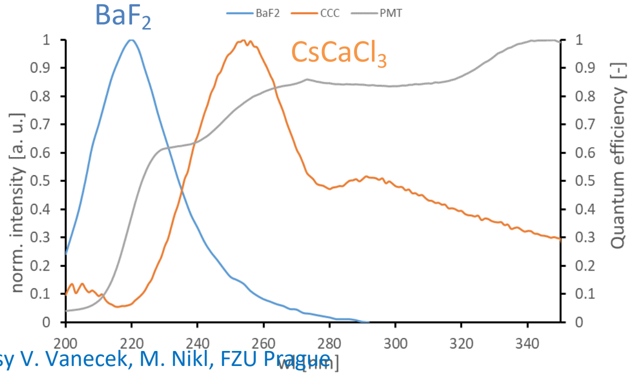


J. Chen, et al., IEEE Trans. Nucl. Sci., vol. 65, no. 8, pp. 2147-2151, 2018.
R. Cala et al, SCINT2022 conference SantaFe Sept2022

Crossluminescence recent Developments

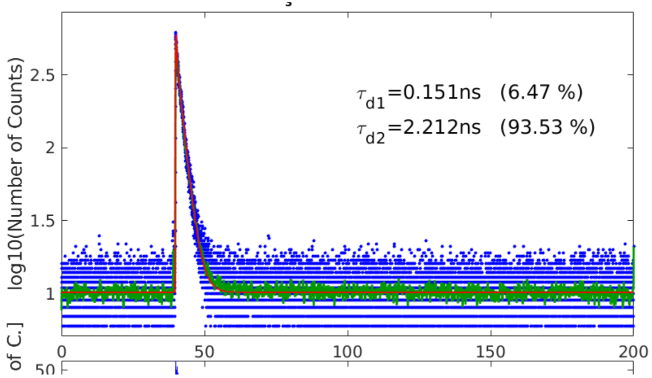
R&D **to shift the emission in UV Visible**

Emission spectra



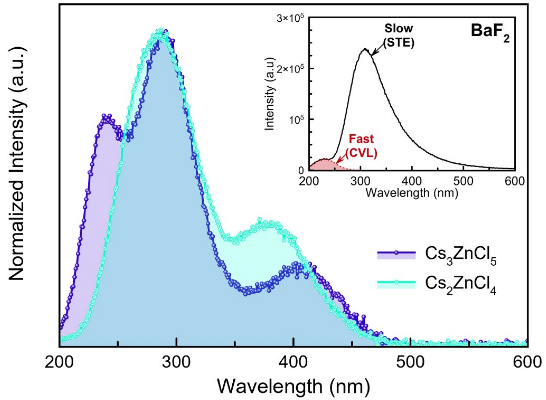
Courtesy V. Vanecek, M. Nikl, FZU Prague

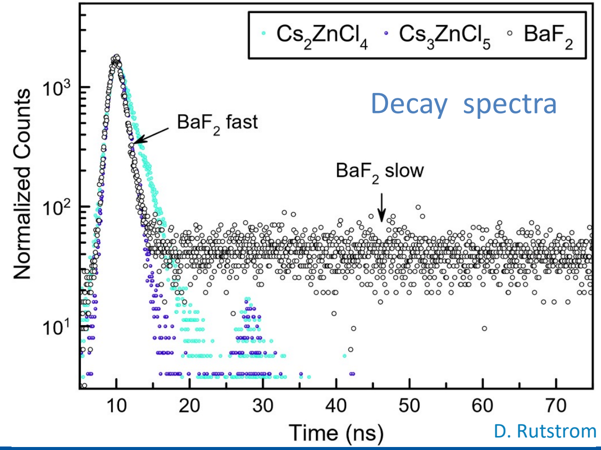
Data for BaF_2 from M. Laval et al. , NIM Phys. Res., 206 (1983) 169–176



V. Vanecek et al., Optical Materials X 12 (2021) 100103

Emission spectra





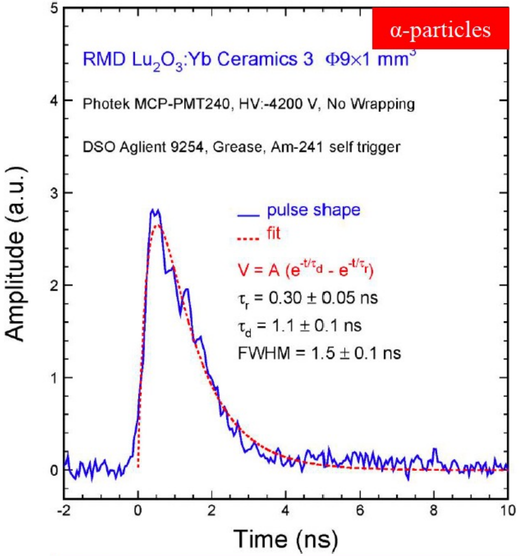
D. Rutstrom et al, Optical Materials 133 (2022) 112912

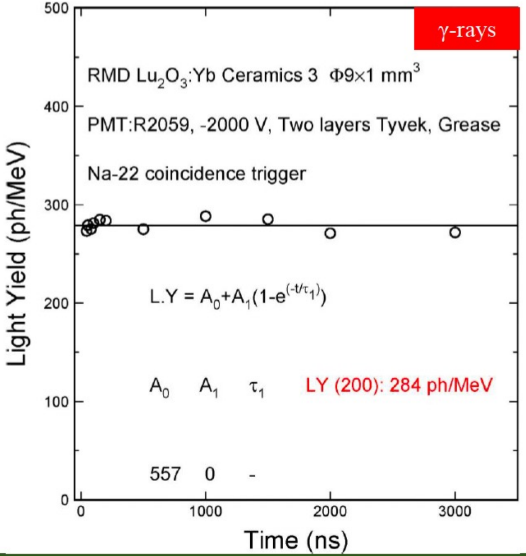
Other materials investigated by other groups

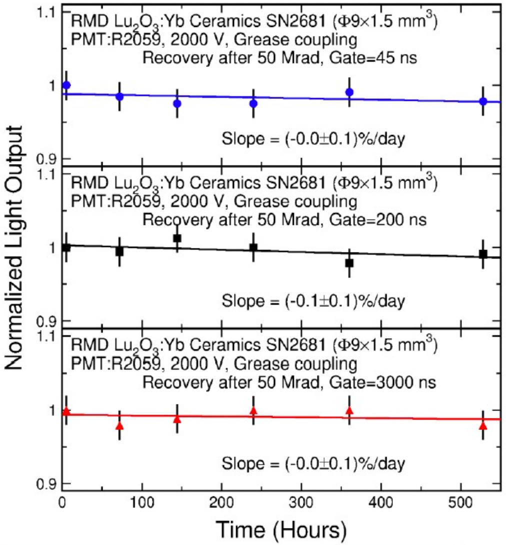
Development of Fast Ceramics

Novel Lu_2O_3:Yb Ceramics

Presented in the NSS2022 conference https://www.its.caltech.edu/~rzhu/talks/NSS22_N21-03.pdf







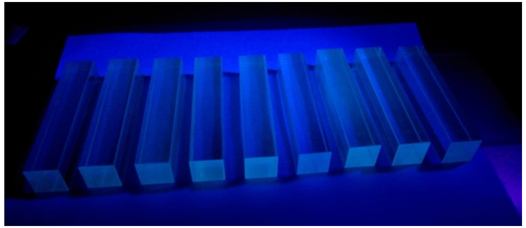
Lu_2O_3:Yb ceramic of 9.4 g/cc shows an ultrafast decay time of **1.1 ns** by Am-241 with negligible slow component observed in integrated light output measurement

Development on Scintillating Glasses

- Since some years new developments on glasses within different projects (eg ATTRACT project, EIC R&D)
  - Oxyde and Fluoro glasses
    - Attempt to increase the density and the radiation hardness
    - Progress in production scale

Exemple DSB Glasses

Intelum

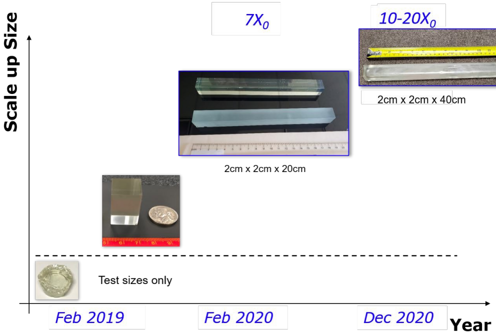


Industrial development via ScintiGlass: Attract project with Preciosa Company

ATTRACT

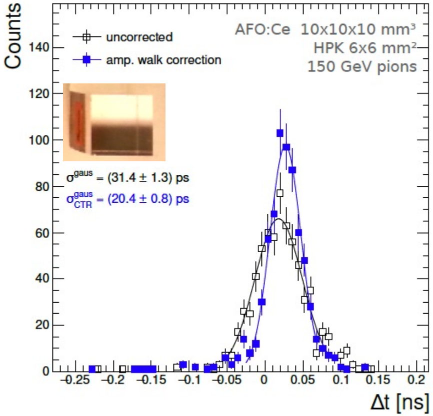
V. Dormenv et al, NIMA, 1015, 2022, 165762

EIC R&D: eRD105 (SciGlass)



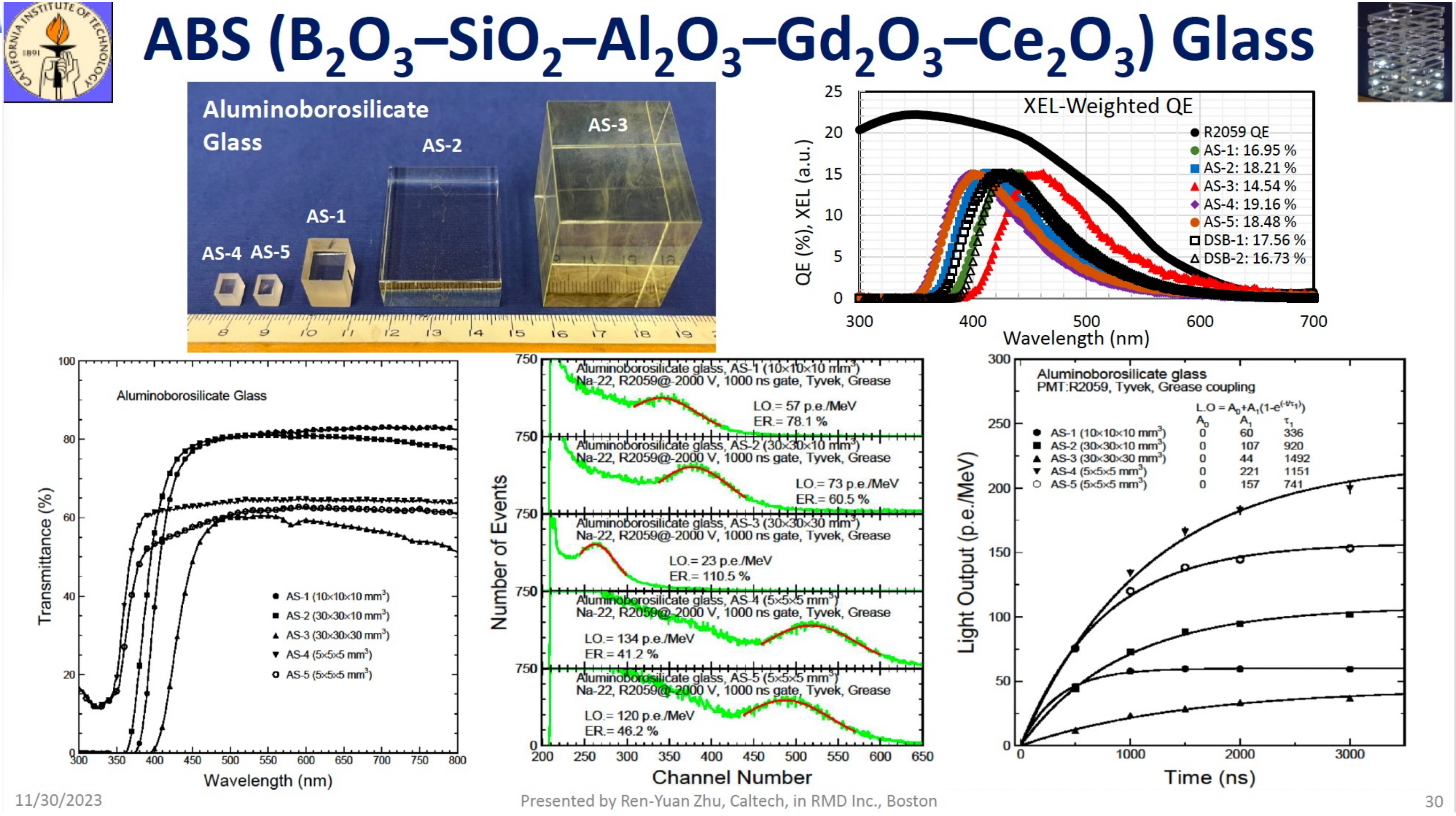
From T. Horn, CERN EP R&D, Nov21

Fluorophosphate AFO glasses
Timing resolution with mip



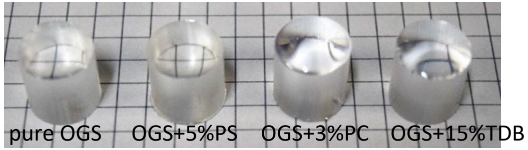
M. Lucchini et al., arXiv:2212.03368, submitted to NIMA

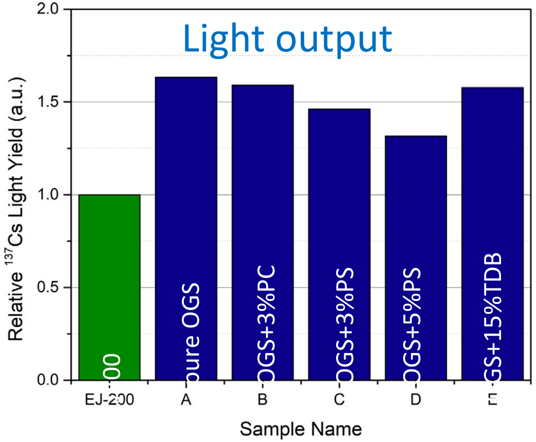
Development on Scintillating Glasses



R&D for Organic Scintillators

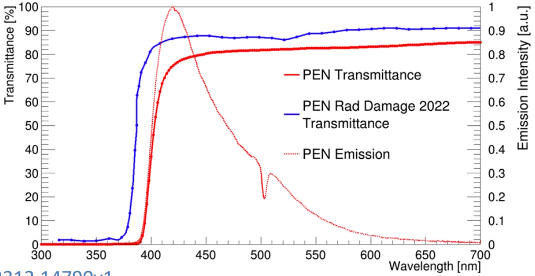
Organic glasses developed in Sendai National lab





From L. Q Nguyen et al., NIMA 1036 (2022) 166835

Polyethylene Naphtalate(PEN)

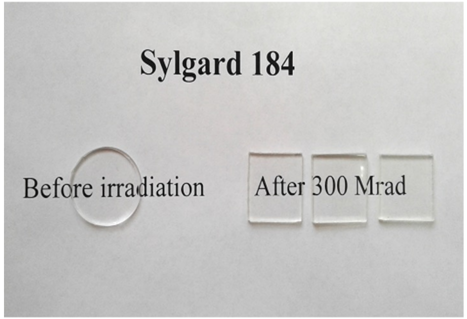


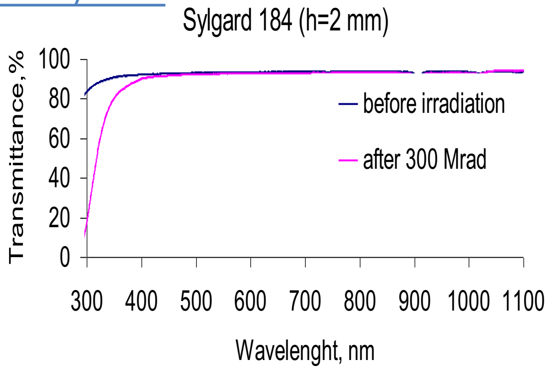
P. Conde Muino et al. , arXiv:2312.14790v1

Polysiloxane materials

Irradiation with electrons (E_0 = 8.3 MeV) up to 300 MRad dose

ISMA (Kharkiv) tests





See also A. Boyarintsev NIMA 930, 2019, 180–184

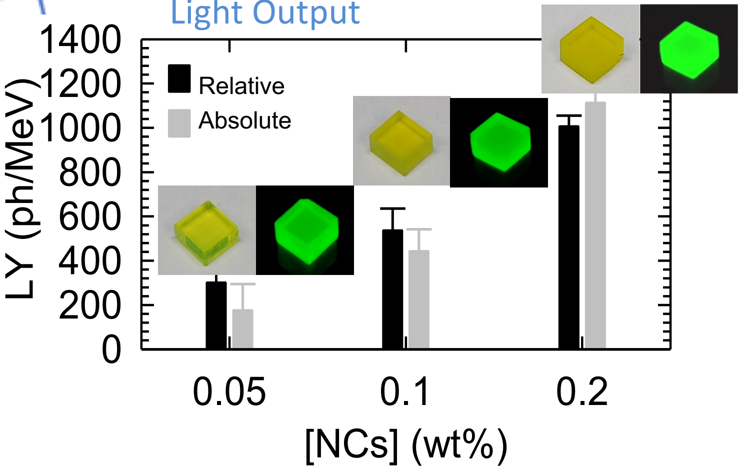
A. Quaranta et al. NIM B, 268, Issue 19, 2010, Pages 3155-3159

Courtesy A Boyarintsev, ISMA, Kharkiv

R&D on scintillating nanocomposite

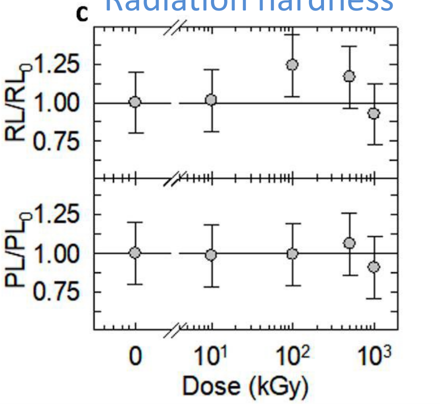
eg: $CsPbBr_3$

Light Output

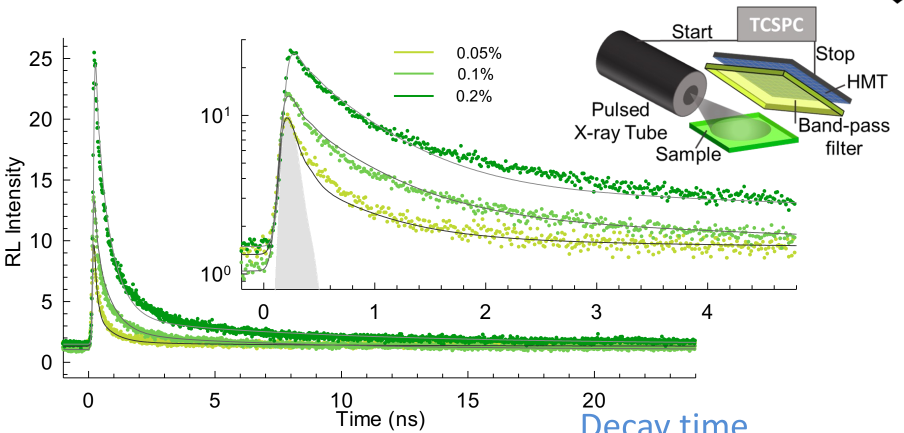


No degradation up to 1 MGy

Radiation hardness



Decay spectra



Decay time

[NC] (wt %)	Prompt	t_1		t_2	
	R_P	R_1	ns	R_2	ns
0.05	0.30	0.37	0.61	0.33	22
0.1	0.32	0.21	0.62	0.47	8.7
0.2	0.34	0.22	0.60	0.44	6.8

Very fast emission

A. Erroi et al, *ACS Energy Lett.* 2023, 8, 3883–3894

R&D on Wavelength Shifters

Some examples of studied wavelength shifters in RADICAL subtask

Example Scintillator Material (wavelength, type)	Candidate Matched Wavelength Shifter (wavelength, type)
LYSO:Ce (420nm) inorganic crystal	DSB1 (495nm) organic filament
LYSO:Ce (420nm) inorganic crystal	LuAG:Ce (510nm) ceramic filament
LuAG: Ce (510 nm) crystal, ceramic	Quantum Dots (580nm) glass or ceramic
LuAG:Pr (310 nm) crystal, ceramic	pTP (350nm) organic filament
CeF_3 (330nm) crystal	pTP (350nm) organic filament
CeF_3 (330nm) crystal	Flavonols (530-560nm) organic filament
Lu_2O_3:Yb (370nm) ceramic	Flavonols (530-560nm) organic filament
BaF_2:Y (220nm, fast component) crystal	TBD

Conclusion

- Many developments on scintillators are ongoing
  => Need input/requirements from all the subtasks to direct the research

- Common family of materials planned to be used by various subtasks
  => Need to mutualise the effort R&D on these materials

- Need multidisciplinary expertise
  - Crystal growth, material, scintillation, instrumentation

- Synergy with other DRDs
  ⇒ DRD4 for radiation hard plastic scintillators
  ⇒ DRD5 for nanomaterials
    ⇒ Need to communicate and work together