Characterization of new crystals for X-rays detection

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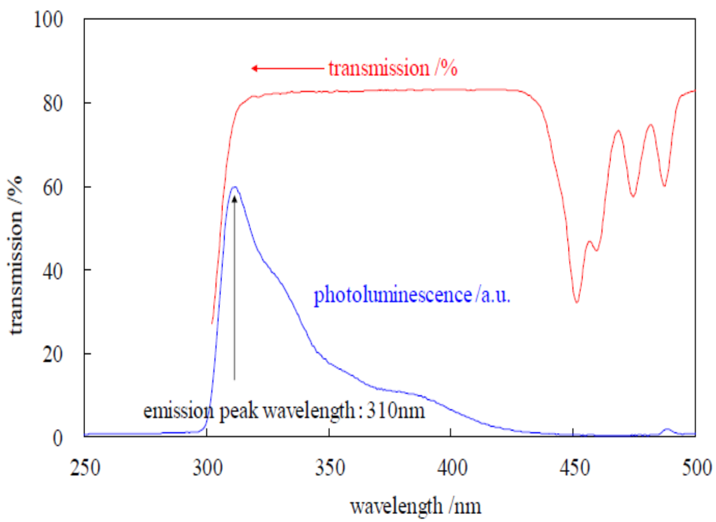
Properties of PrLuAg crystals

Physical and Scintillation Properties

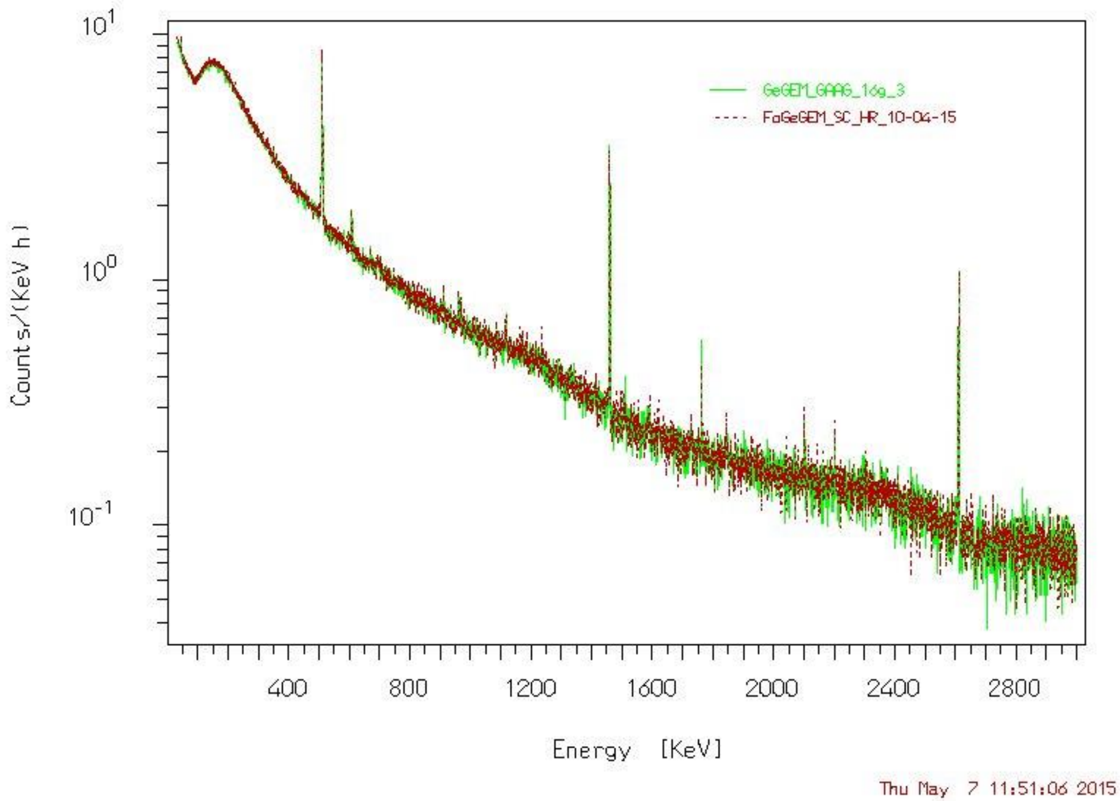
Scintillators	Pr:LuAG	Ce:LYSO	BGO	Ce:$LaBr_3$
Density (g/cm^3)	6.73	7.1	7.13	5.08
Light yield (photon/MeV)	22,000	34,000	8,000	75,000
Decay time (ns)	20	40	300	30
Peak emission (nm)	310	420	480	360
Energy resolution (%@662keV)	4.2	10	12	2.6
Hygroscopicity	No	No	No	Yes
Cleavage	No	No	No	No
Melting point (℃)	2,043	2,150	1,050	783



Emission and absorption spectra of PrLuAG

- ***High density, non-hygroscopic***
- ***Short decay time; good light yield***
- ***BUT: peak emission in UV -> problems with photodetectors***
- ***and slightly radioactive: 36 Bq/g due to Pr***

Intrinsic activity of PrLuAg crystals



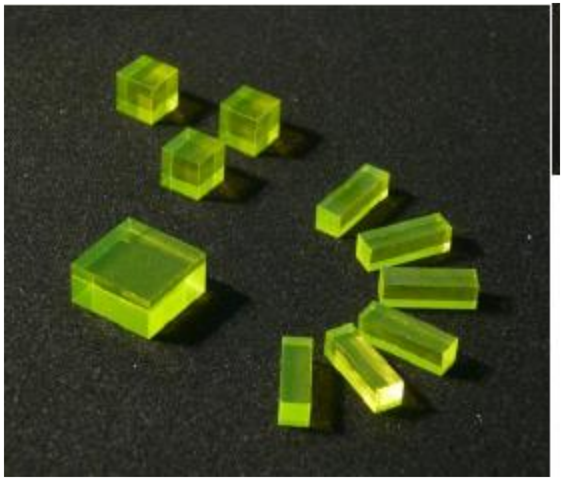
- *Measured with a HpGE detector*
- *Total activity due to Lu^{176} 36 Bq/g*

HpGE detector → **Pre-amp** → **Spectroscopy amplifier Ortec 672** → **MCA**

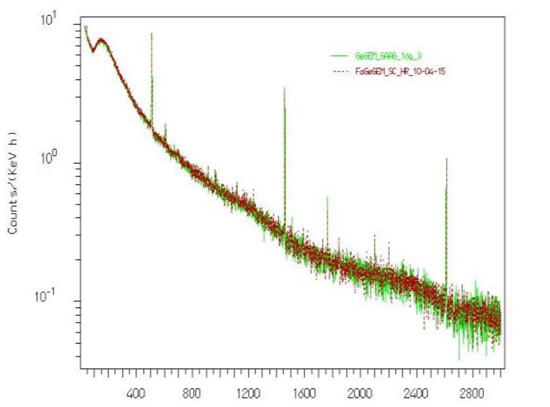
Properties of CeCAAG crystals

Physical and Scintillation Properties

Scintillators	$Ce:Gd_3Al_2Ga_3O_{12}$ (Ce:GAGG)	$Ce:Lu_{1.8}Y_{0.2}SiO_5$ (Ce:LYSO)	$Bi_4Ge_3O_{12}$ (BGO)	$Ce:LaBr_3$
Density (g/cm^3)	**6.63**	7.1	7.13	5.08
Light yield (photon/MeV)	**57,000**	34,000	8,000	75,000
Decay time (ns)	**88 (91%) 258 (9%)**	40	300	30
Peak emission (nm)	**520**	420	480	375
Energy resolution (%@662keV)	**5.2** ($5x5x5mm^3$ with APD)	10	12	2.6
Hygroscopicity	**No**	No	No	Yes
Cleavage	**No**	No	No	No
Melting point (℃)	**1,850**	2,150	1,050	783



LiveTime	355h
	Activity [Bq/kg]
^{232}Th	
^{228}Ac	<0.6
^{208}Tl	<0,5
^{238}U	
^{226}Ra	<5
^{214}Bi	<0,6
^{235}U	<0,4
^{40}K	<6
^{60}Co	<0,2
^{137}Cs	<0,2

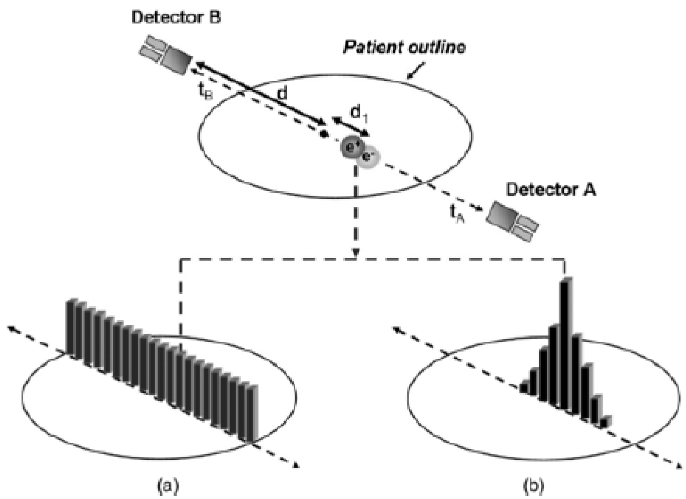


Natural radioactivity of CeCAAG crystals

- ***High density, non hygroscopic***
- ***No intrinsic activity (<15 Bq/kg)***
- ***Short decay time, high yield***
- ***Emission peak ~520 nm well matched to SiPMT and SiPMT arrays***

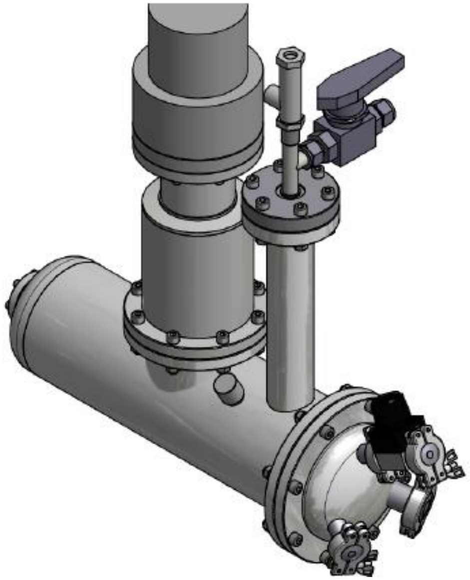
Possible applications

Phys. Med. Biol. 53 (2008) R1

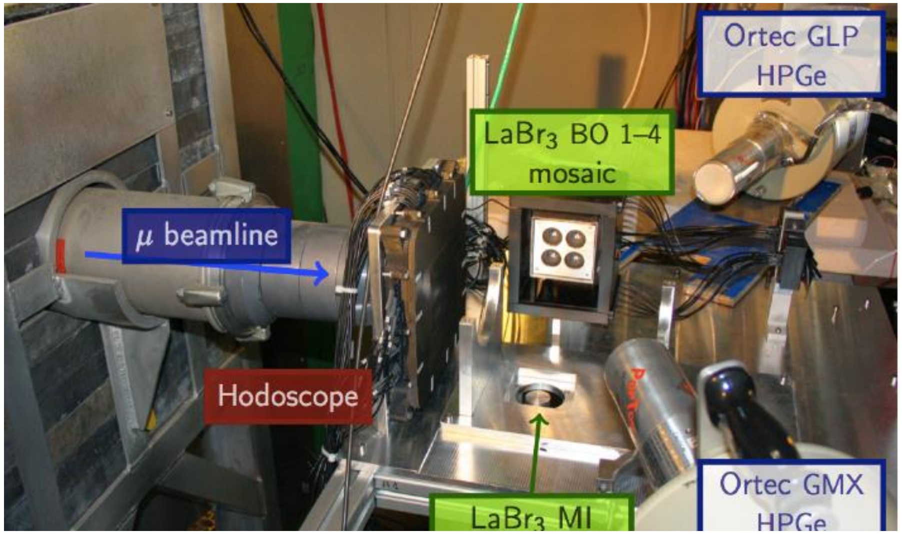


TOF PET imaging (Medical Physics)

- large soft photon yield per MeV
- high density crystals (stopping power)
- soft photon detection in magnetic fields
- compact design
- high granularity
- non-hygroscopic
- affordable



Measurement of transfer functions from $\mu^- p + Z \rightarrow \mu^- Z^* + p$ ($Z=O_2$, Ar, Ne, CH4, C2H6, CO_2) at RiKEN-RAL, preliminary to experiment for R_p measurement (FAMU experiment at RAL). Needs to detect low-energy X-rays (Nuclear Physics)



Detector requirements

- High photon yield + good timing resolution (some tens of ns)
- Good energy resolution at low X-rays energy (~ 100 KeV)
- Low cost
- Simple photon readout

	Ge	NaI	LaBr3	CeCAAG	PrLuAg
150 keV	0.9 cm	0.5 cm	0.5 cm	0.3 cm	0.2 cm
500 keV	2,8 cm	3.5 cm	2.6 cm	1.8 cm	1.6 cm
800 keV	3.5 cm	4.9 cm	3.6 cm	2.6 cm	2.4 cm

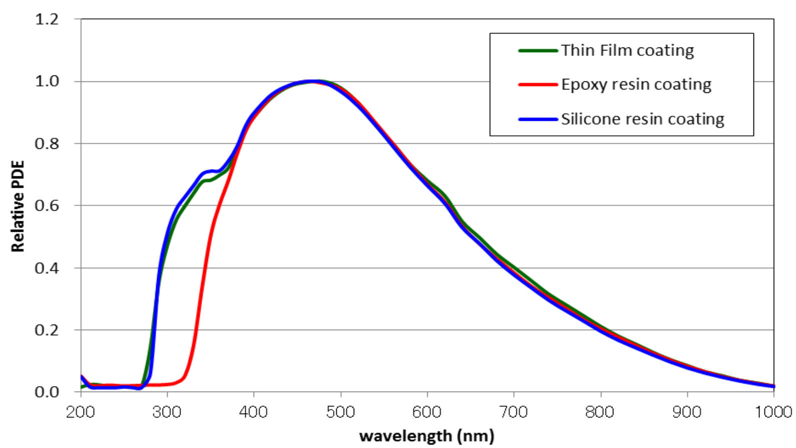
Crystal thickness for 70% X-rays detection efficiency

A simple solution is a crystal read out by a SiPMT array, where cells outputs are summed up. Analogue signal may then be digitized by a fast (> 500 MHz) digitizer . As an alternative crystals may be read by a suitable PMT (R11065 with MgF_2 window for X-rays detection)

Used SiPMT arrays

Tested SiPMT arrays use 3x3 mm² macro-cells arranged in 4x4 arrays.

- *SENSL ArrraySB-4-30035-CER arrays with 3x3 mm² macrocells, V_{op} ~27 V*
- *Hamamatsu S13361 arrays with 3x3 mm² macrocells, V_{op}~53.8V, TSV technology*
- *Advansid ASD-SiPM3S-4x4T (RGB) arrays with 3x3 mm² macrocells, V_{bkw} ~28.5 V*



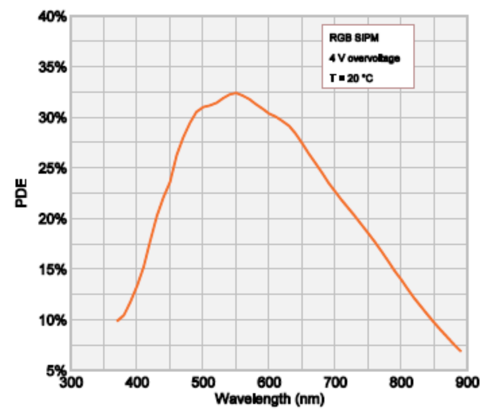
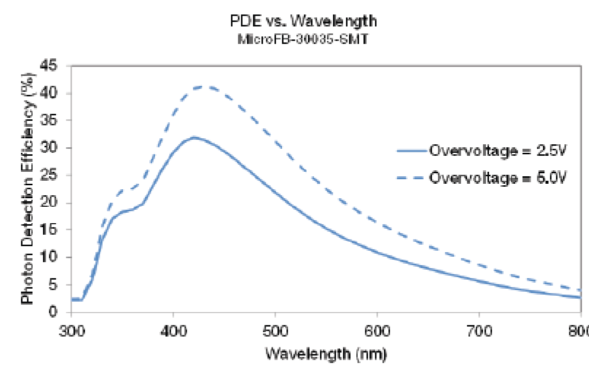


Fig.8 Photo detection efficiency (PDE) in RGB-SiPMs as a function of wavelength (crosstalk and afterpulse not included).

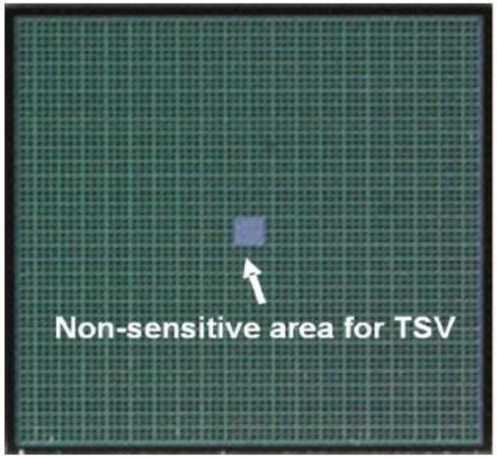


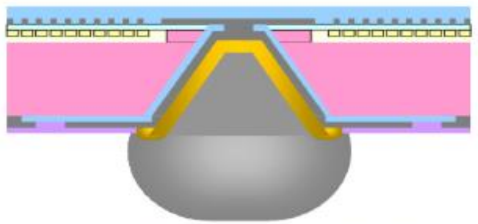
PDE for Hamamatsu TSV SiPMT (suitable for UV detection)

PDE for RGB Advansid SiPMT (well suited for RGB detection)

PDE for B-extended SENSL SiPMT

Some more details on Hamamatsu TSV arrays





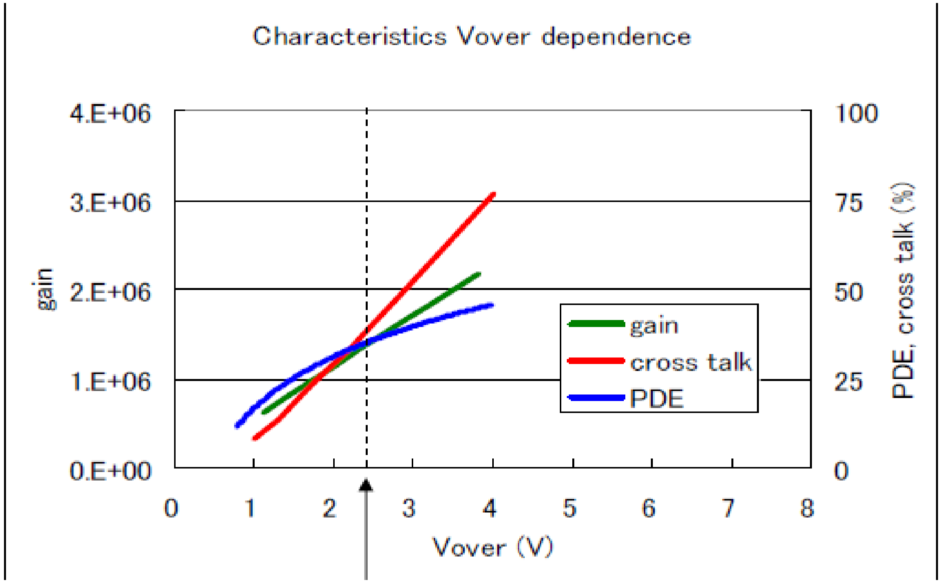
- *TSV (``through Silicon Via") technology used to eliminate the need of a wire bonding pad, that creates dead spaces problems*
- *The anode of each channel is traced to the backside pad by TSV*
- *In principle better for timing application (smaller timing jitter)*

Example: Hamamatsu S13361

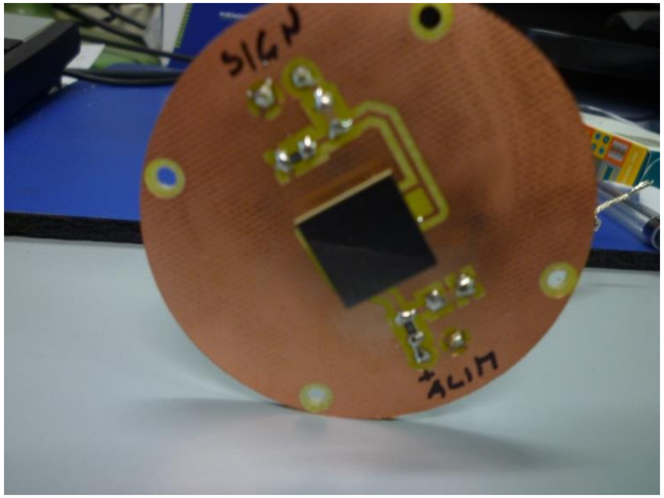
■ **Electrical and optical characteristics**
(Typ. Ta=25 deg C, per 1 ch., Vover=2.4V [*1] Unless otherwise noted)

Parameters		Symbol	S12642-0404PA-50 S12642-0404PB-50	Unit
Spectral response range		λ	320 to 900	nm
Peak sensitivity wavelength		λp	450	nm
Photon detection efficiency at λp [*1]		PDE	35	%
Dark count [*2]	Typ.	-	2	Mcps
	Max		3	
Terminal capacitance		Ct	320	pF
Gain [*3]		M	1.25×10^6	-
Breakdown voltage		V_{BR}	65±10	V
Recommended operating voltage [*4]		Vop	V_{BR} +2.4	V
Vop variation between channels (+/-)	Typ.	-	0.05	V
	Max.		0.15	
Temperature coefficient of reverse voltage		ΔTVop	60	mV/°C

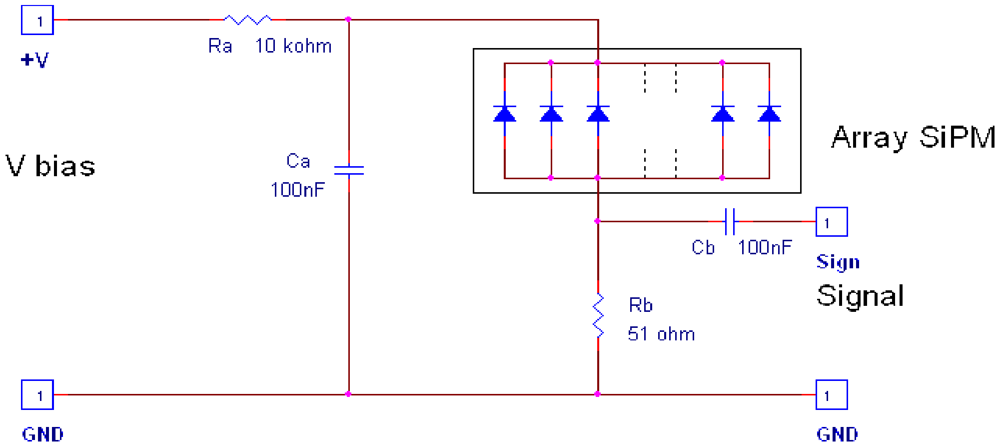
*1: Photon detection efficiency does not include crosstalk and afterpulses.
*2: The data will be measured by current.
*3: Characteristics change with applied over voltage. Please refer to next section in detail.
*4: Refer to the data attached for each product.



Readout chain for SiPMT arrays



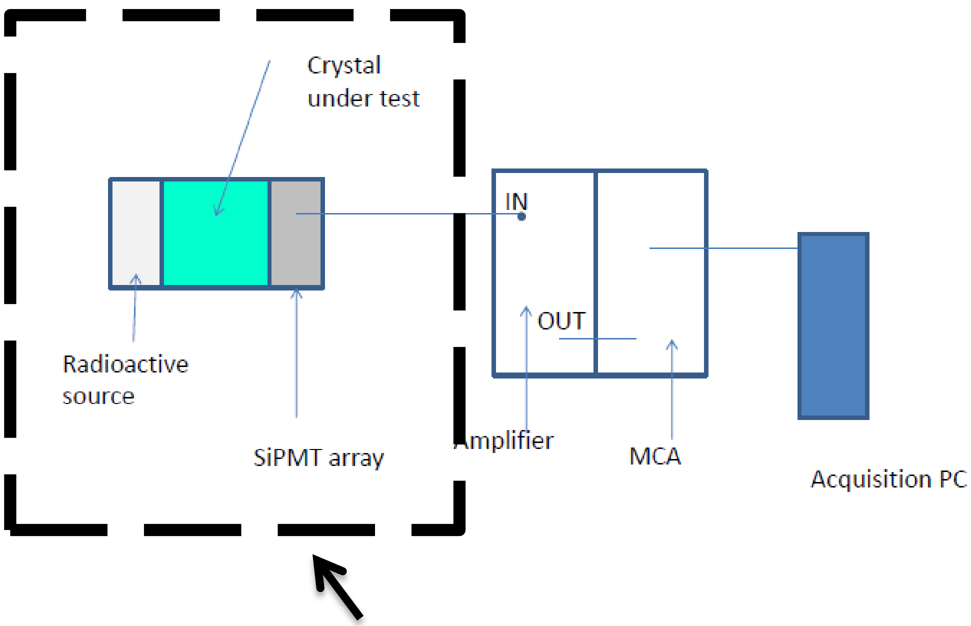
- *SiPMT array custom mount*
- *16 3x3 mm^2 cells signals are summed up in the basette and then amplified (parallel readout) : it may be optimized*



Schematic of one ``basette"

Experimental layout

- Tests with PMT readout (Hamamatsu R11065, suitable for UV light) and different SiPMT arrays from Hamamatsu, SENSL, Advansid
- Different crystal wrapping for crystals (Teflon, Aluminized Mylar, $BaSO_4$)
- Standard spectroscopic readout chain . Ortec 570, 579 or 672 amplifiers + CAEN N951 MCA or ORTEC EasyMCA
- Different calibrated X-rays sources from Spectrum Techniques
- In some tests a Voetsch VT7004 climatic chamber was used



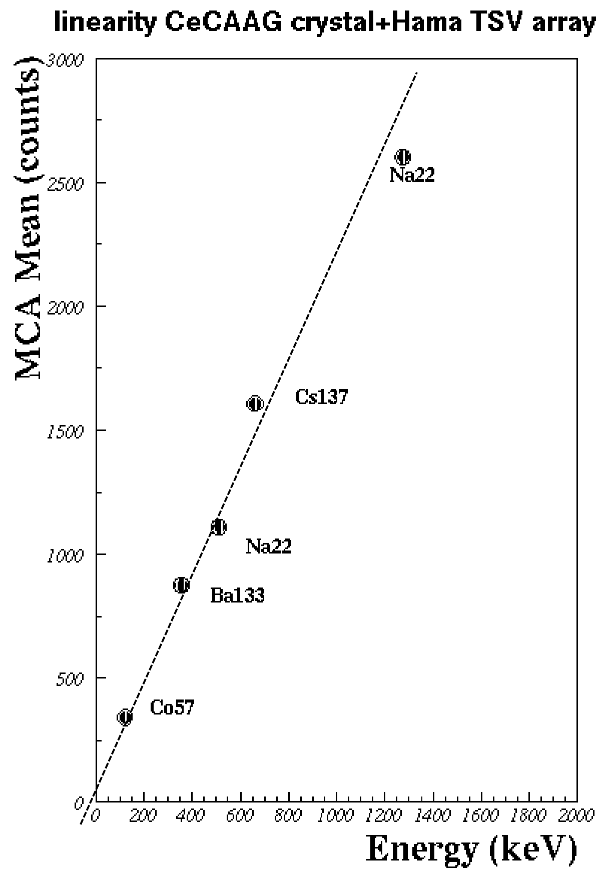
direct SiPMT-array signal , no amplification

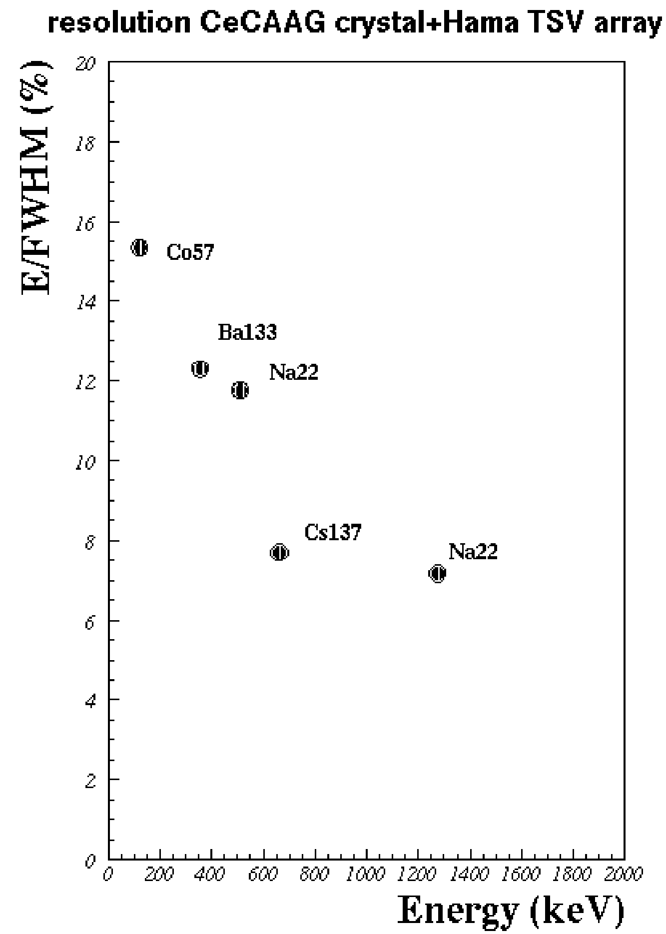
Inside ARMFLEX insulation (at room temperature) or climatic chamber

Results with CeCAAG crystals and SiPMT array readout

	Vop	Amplifier gain	MCA mean at Cs^{137} peak	Resolution at Cs^{137} peak (FWHM/E)
SENSL B-extended	-27 V	150 x (*)	2048	10.4%
Advansid 4x4 RGB	29.5 V	125 x (0)	653.6	9.9 %
Hama S13361 TSV	53.8 V	50 x (0)	1606	7.7 %

- ***Tests done in "realistic experimental conditions" without a climatic chamber, but with ARMFLEX insulation (thermal excursion ~1-2 degs)***
- ***Tests with Ortec 579 fast amplifier [0] (always same settings, aside gain to avoid signal saturation) or Ortec spectroscopy amplifier 672 [*]***
- ***Results compare well with previous ones with MPPC readout (~12% or worse), but still worse with PMT readout***
- ***Better results with Hamamatsu S13361 TSV 4x4 arrays (total area 14x14 mm^2) are probably due to better matched PDE (l) and reduced noise in nearby cells. No clear improvements increasing V_{op} in a sensible range (+ 1-2 V).***

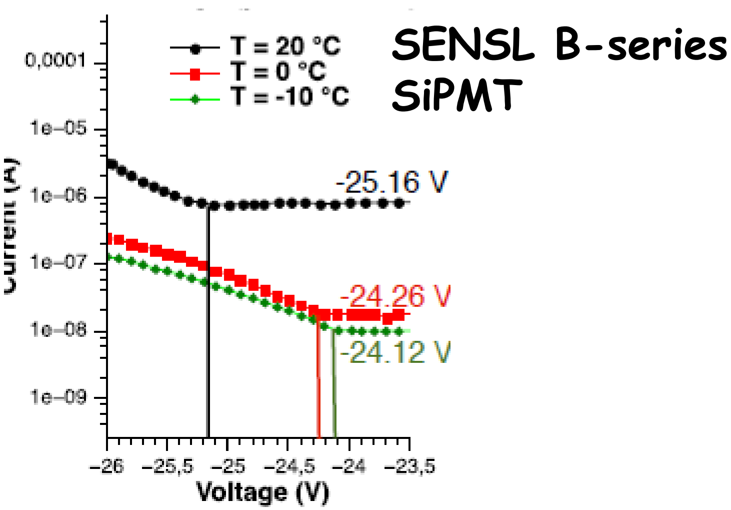


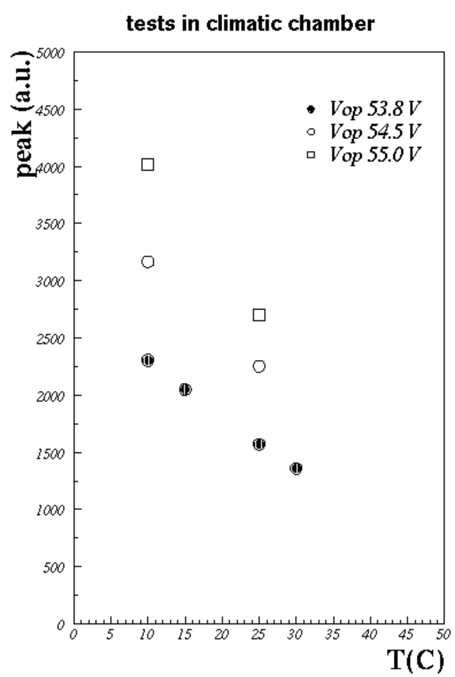


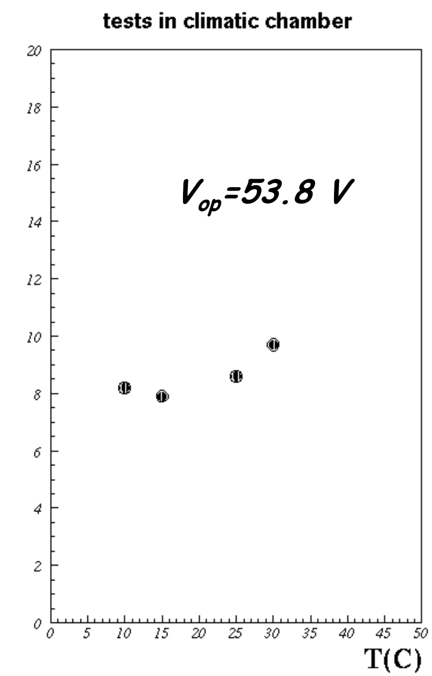
- *Studies at room conditions (~25^{0}C with +- 1 ^{0} excursions)*
- *In the resolution are folded: crystal intrinsic resolution and dimensions, effect of thermal excursions on SiPMT arrays, electronic noise (signals from cell SiPMT array are simply summed up), optical coupling, …*
- *Results are obtained with an Ortec 579 Fast amplifier, but they do not change with dedicated spectroscopy amplifiers as Ortec 672*

Tests in a climatic chamber

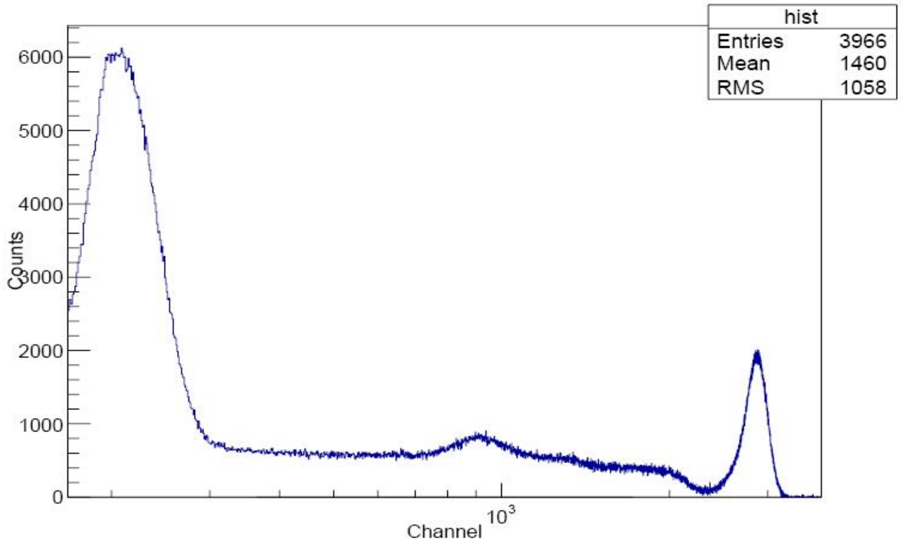
- Climatic chamber Voetsch VT7004: stability ~1K
- Same setup as before
- Effects may be explained with decrease of V_{brk} with temperature lowering

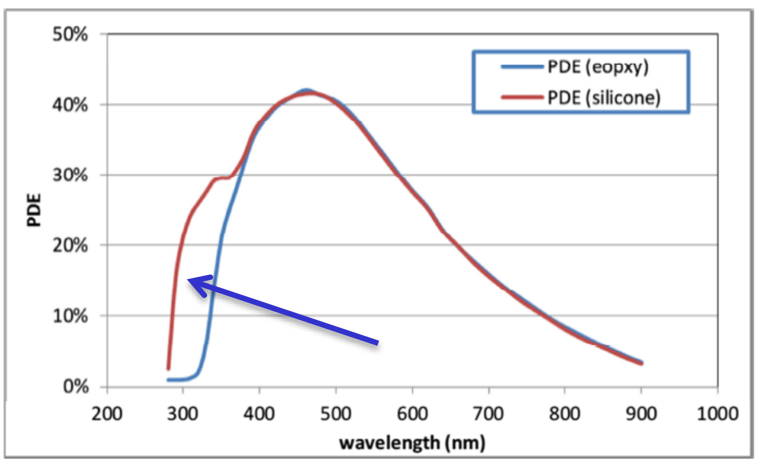






Results with PrLuAG crystals and SiPMT array readout

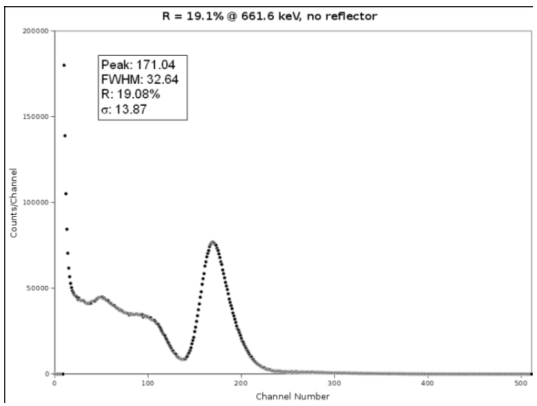


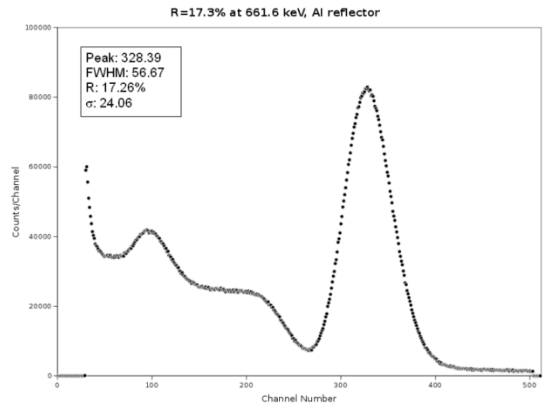


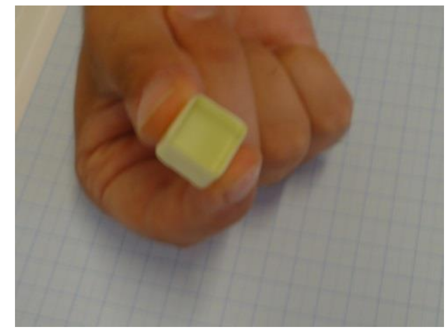
- ❑ *Teflon wrapping and optical grease (BC600) to make contact between crystal and SiPMT Array*
- ❑ *Studies at room temperature ~25 ^{0}C*
- ❑ *Hamamatsu TSV array S13361 with silicon epoxy window (UV extended)*
- ❑ *With Ortec 672 spectroscopy amplifier FWHM/E ~ 10% ; with Ortec 579 Fast Amplifier ~12%*
- ❑ *worse than published results with UV-extended PMTs or single SiPMT (but area much bigger than 3x3 mm^2)*
- ❑ *Needs additional work on coating ($BaSO_4$)*

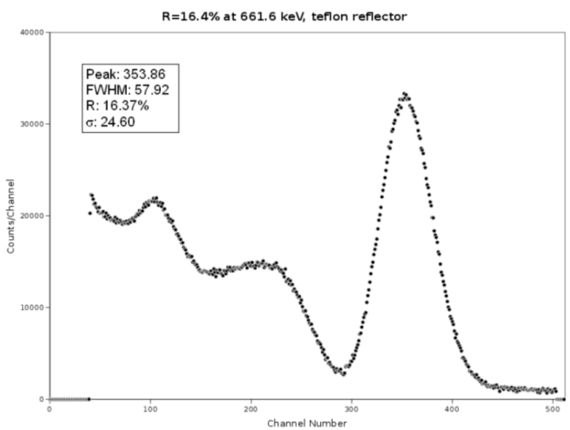
Different reflectors for PrLuAG

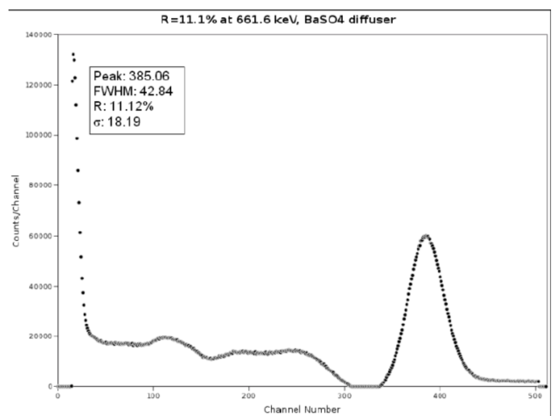
- *PrLuAG emission ~310 nm (UV) . Reflectors may influence results*
- *Tests with 14x14x13 mm^3 crystal, with PMT's readout. Polished-only, Teflon-wrapped, Al mylar wrapped and BaSO4 coated crystals . Improvement seen with BaSO4 coating*
- *Signal amplitude increases of ~15% and resolution of ~ 50% with BaSO4 reflector*
- *For CeCAAG (peak emission ~520 nm) reflector problem less relevant*











Studies are under way to improve BaSO4 coating

Conclusions

- ***PrLuAG and CeCAAG large area crystals (~1/2 ") are promising crystals for X-rays detection : low cost, dense, not hygroscopic, fast***
- ***A solution with SiPMT array readout has been shown and is feasible***
- ***But to have a real working detector a lot of points must be clarified :***
    - ***Crystal wrapping/coating (especially for PrLuAG that emits in near UV)***
    - ***Noise reduction using SiPMT arrays***
    - ***Factors that affect resolution at low X-rays energy (O(100 KeV))***
    - ***…***
- ***Performances (energy resolution) still worse than LaBr3***
- ***In conclusions: STILL A LOT OF WORK NEEDED (THEY ARE NOT OFF_THE_SHELL DETECTORS)***

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