

# ISMA R&D scintillators for medical application and HEP projects

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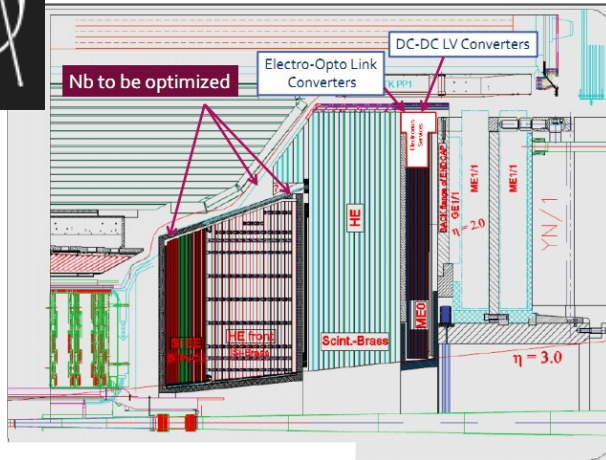
# OUTLINE

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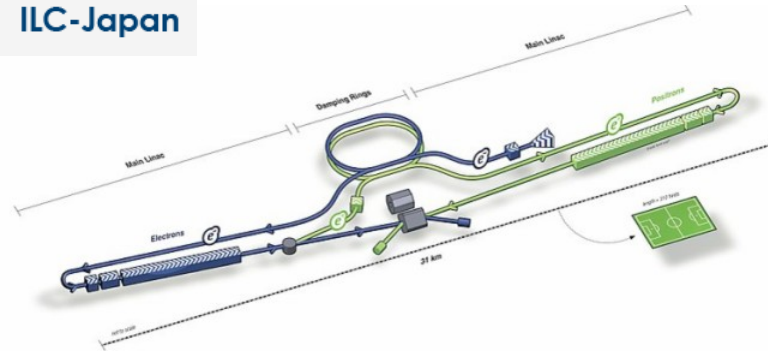
- 1. Scintillators for High Energy Physics**
- 2. Scintillators for medical application**
- 3. Scintillators for rare events searches**

# ISMA scintillators for HEP projects

# ISMA scintillators for HEP projects

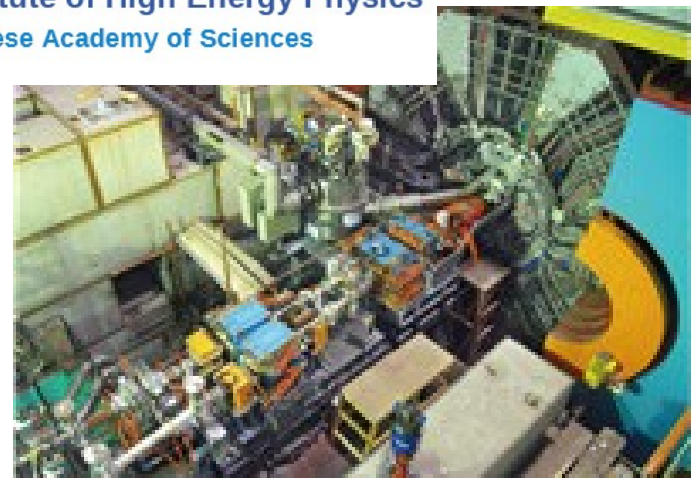


**HL LHC after upgrade**



**Institute of High Energy Physics**  
Chinese Academy of Sciences

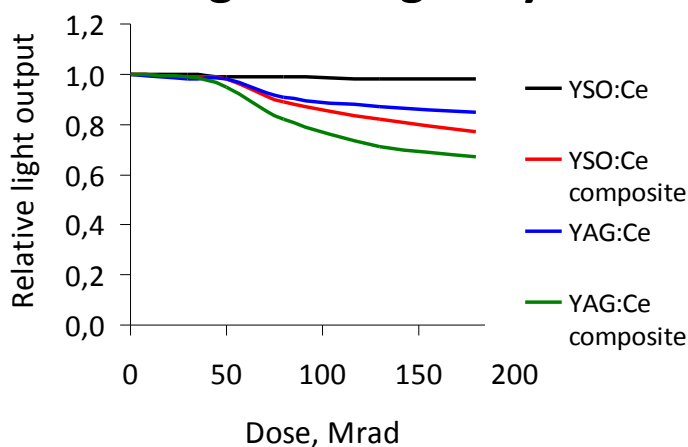
**Scintillators - what can we offer ?**



# ISMA scintillators for HEP projects

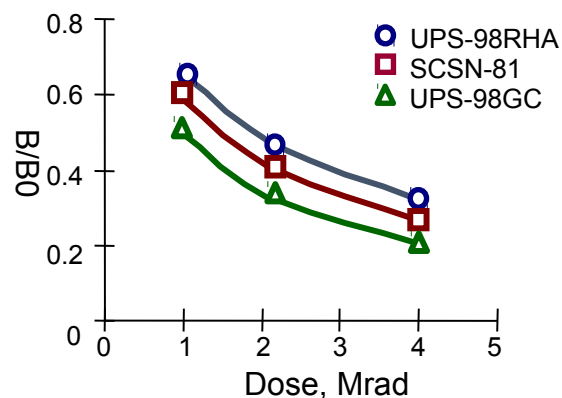
## Radiation hardness of organic vs inorganic scintillators

### Inorganic single crystals



**Radiation hardness  
more 100 MRad**

### Plastic scintillator

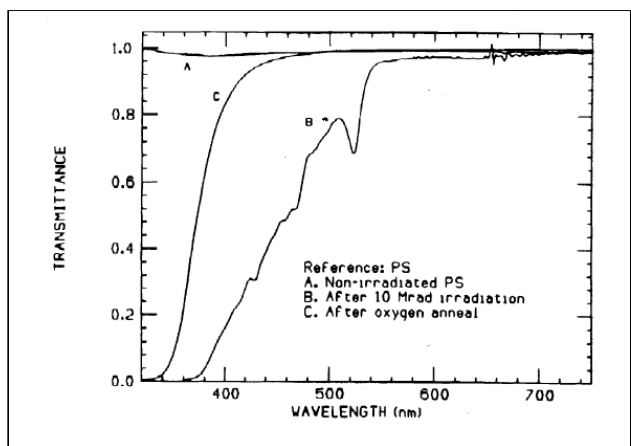


**Radiation hardness  
up to 5 MRad**

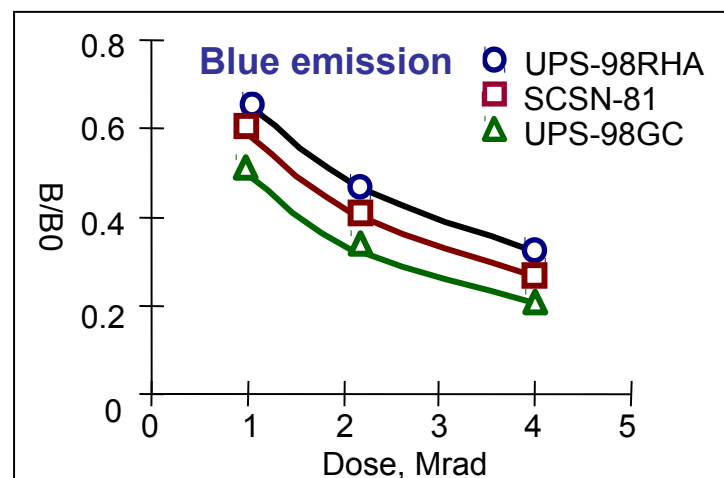
**Radiation hardness of inorganic crystals is 20 times higher vs plastic scintillators!**

# ISMA scintillators for HEP projects

## Plastic scintillators: increasing of radiation hardness



Transmission spectra of undoped polystyrene before and after irradiation with 10 MRad dose (A.D.Bross, A.Pla-Dalmau)



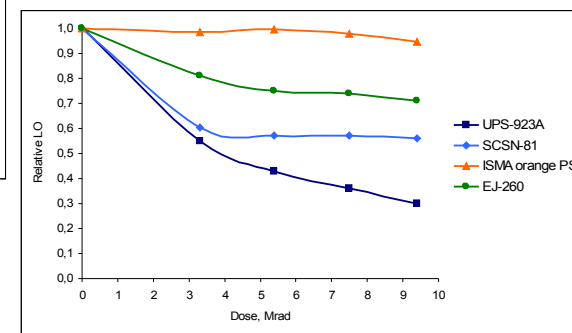
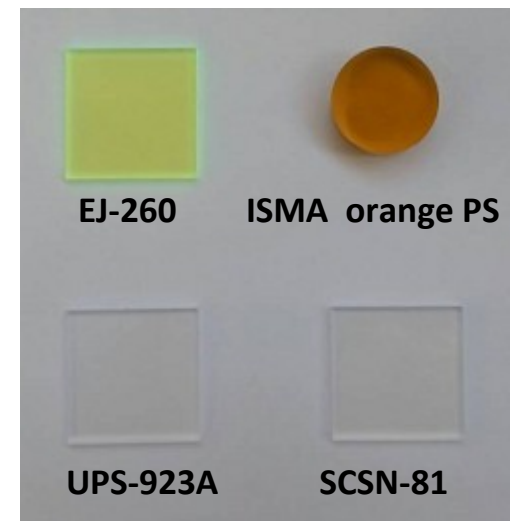
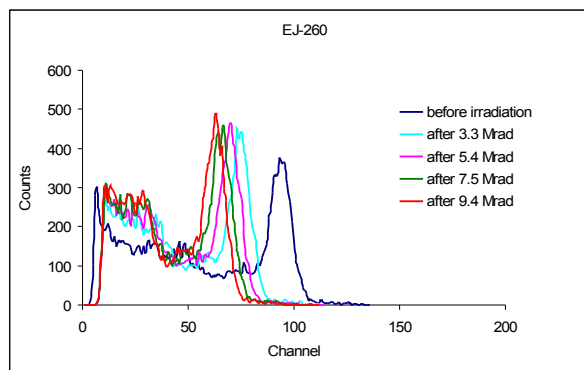
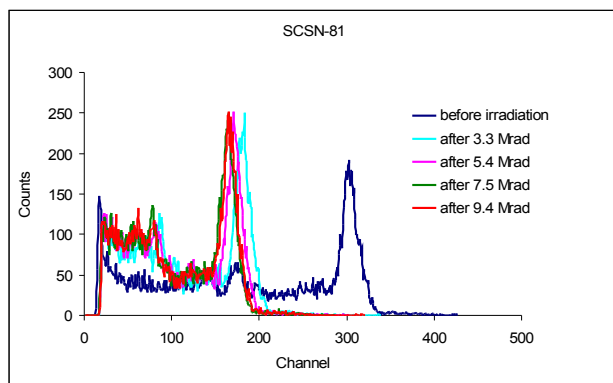
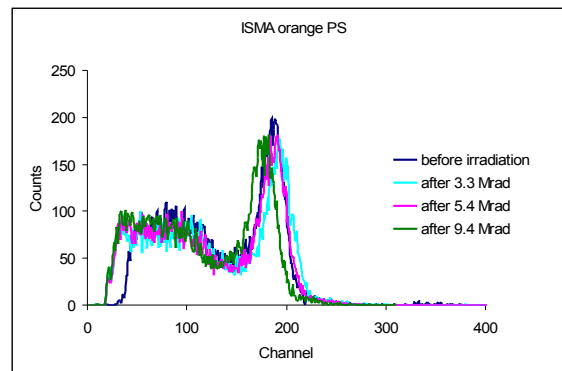
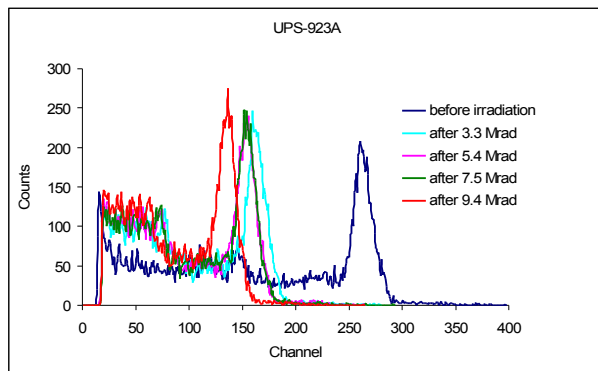
Irradiation induce decrease of light yield in plastic scintillator

### Radiation hardness may be improved by:

- shifting of luminescence maximum of plastic scintillator into long-wave region
- increasing of radicals mobility without changes in mechanical properties of plastic scintillator

# ISMA scintillators for HEP projects

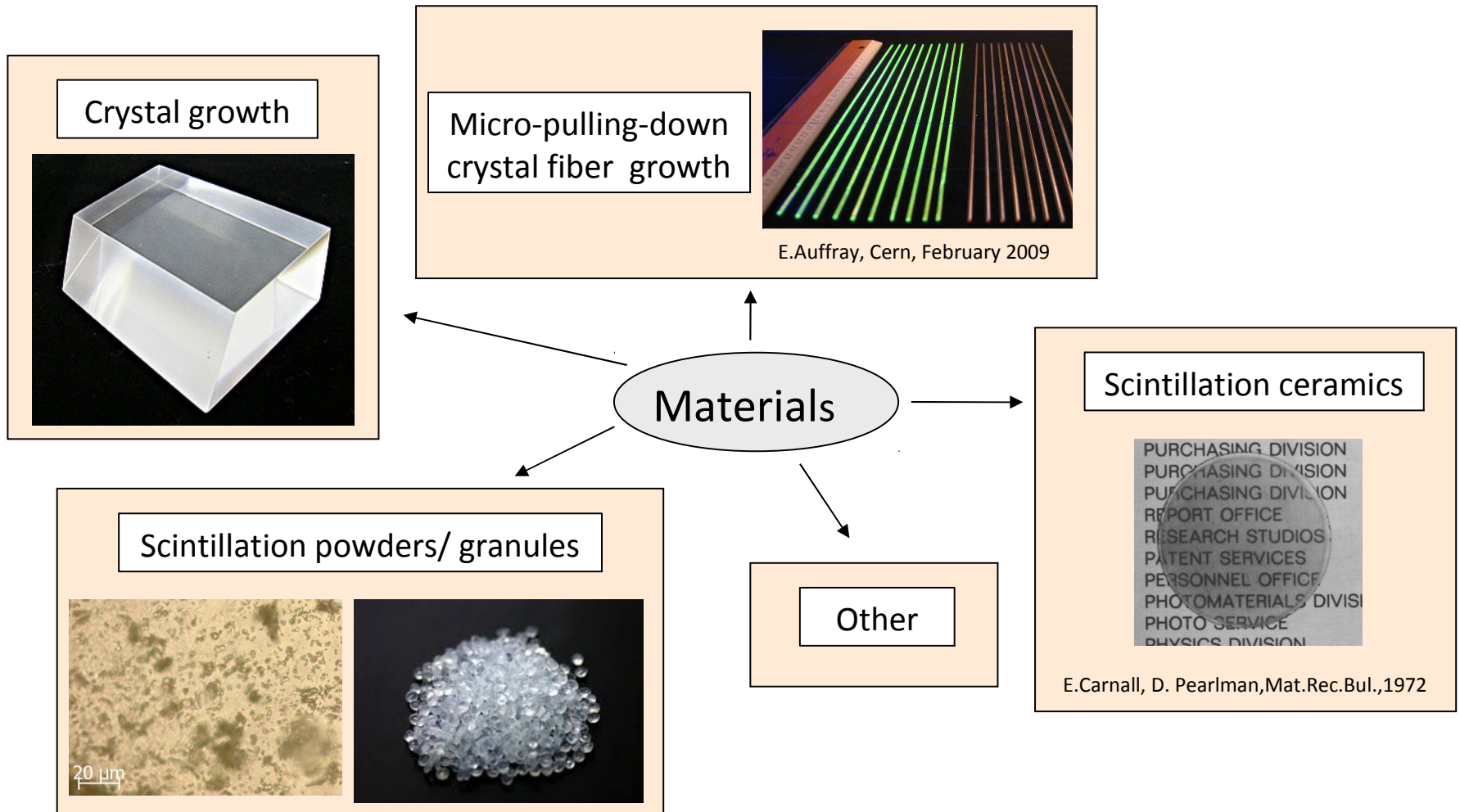
## Radiation hardness of plastic scintillators



**Radiation hardness of ISMA orange PS reaches 10 Mrad**

# ISMA scintillators for HEP projects

## Scintillation detectors

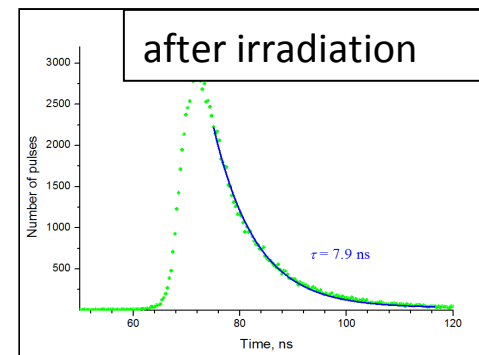
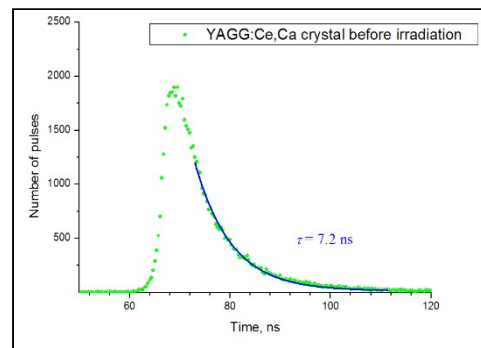
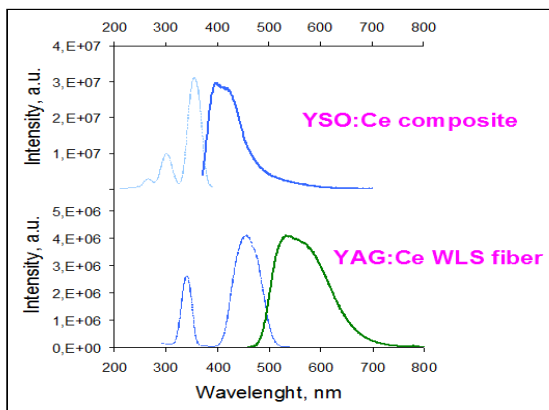
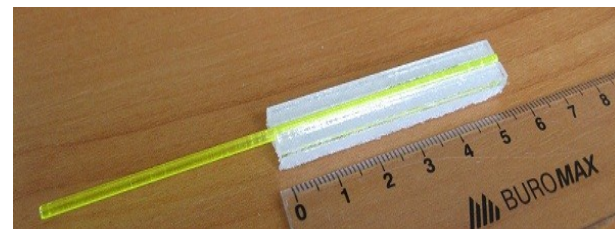
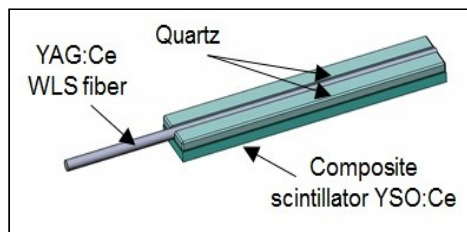




# ISMA scintillators for High Energy Physics

## Scintillation element (oxide crystal based)

**Composite scintillator – YSO:Ce**  
**Light guiding layer – quartz**  
**WLS fiber – YAG:Ce or YAGG:Ce**



**Essential overlapping of YSO:Ce emission spectrum and YAG:Ce or YAGG:Ce absorption spectrum**

**Decay time YAGG:Ce, Ca fiber before and after irradiation with dose of 50 MRad**

**Decay time of composite scintillation element with YAGG:Ce fiber - 22ns**

**Radiation hardness is more than 100 MRad**



# ISMA scintillators for medical application

# ISMA scintillators for medical application

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## “New scintillation composite detectors for medical X-ray diagnostics”

Project in frame of LIA-SFFR of Ukraine collaboration (2017-2018):

### Organisations:

1. Institute for scintillation materials NAS of Ukraine
2. Taras Shevchenko national university of Kyiv

**Goal:** Development of scintillation composite X-ray detectors for dental diagnostics and mammography.

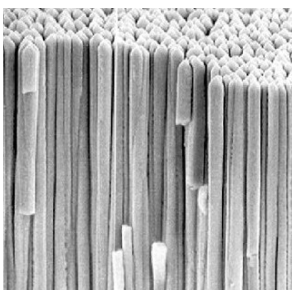
**Project F-79 publication:** S.M.Galkin, O.G.Trubaeva, O.I. Lalayants et al. Functional Materials (25), № 1 2018, p. 21-27.

# ISMA scintillators for medical application

## Composite scintillators for “soft” X-ray detectors

Commonly used scintillators for CMOS-based X-ray imaging detectors:

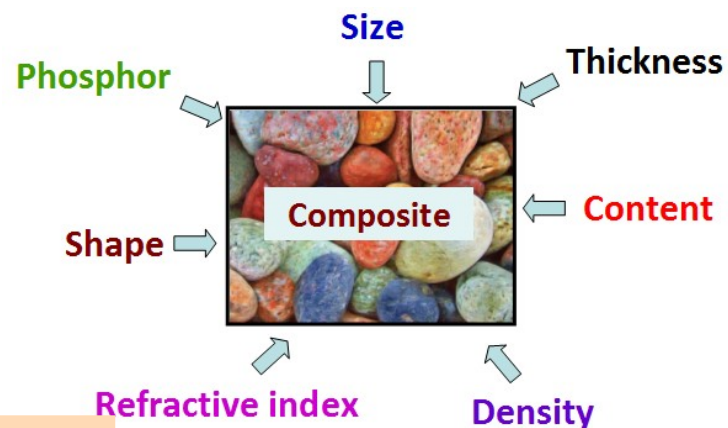
CsI:Tl columnar or needle-like structure



Gd<sub>2</sub>O<sub>2</sub>S:Tb phosphor screen

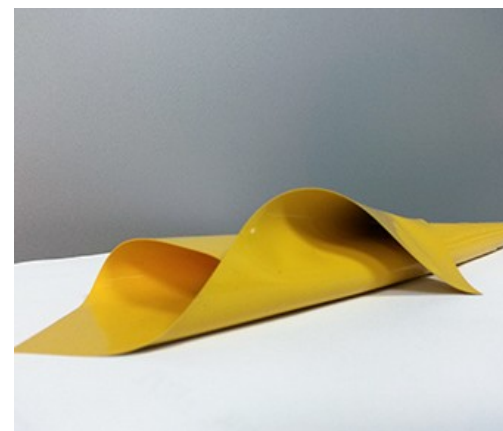


Composite scintillators as alternative material:



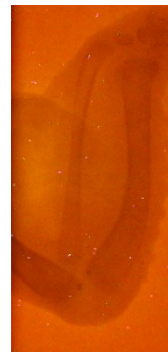
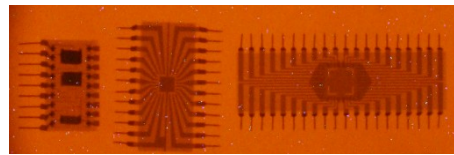
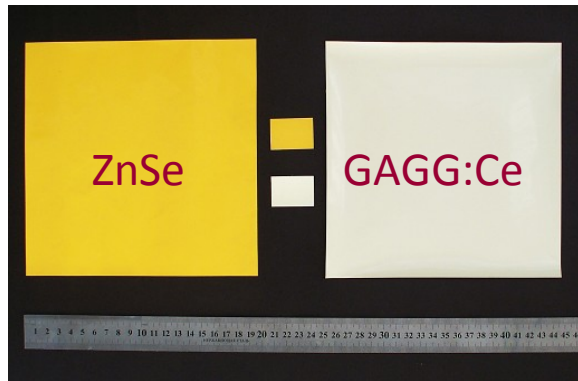
Technical and technology attraction of composites:

- ✓ Use of synthesized scintillation powders
- ✓ Variable thickness (from 30-50 micron) and shape
- ✓ High spatial resolution and uniformity
- ✓ Large area any complex shapes
- ✓ Commercially available components
- ✓ Ready to visualization

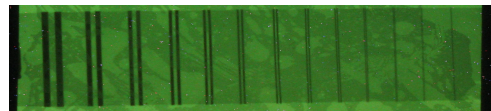


# ISMA scintillators for medical application

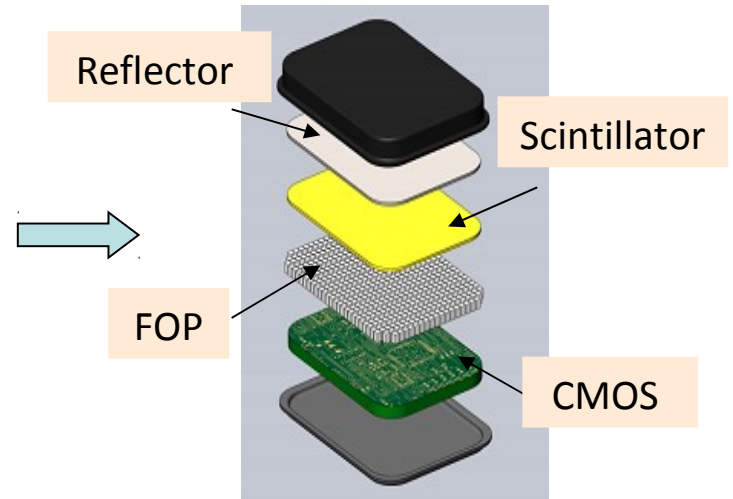
## Development of scintillation films for CMOS-based X-ray detectors



ZnSe film x-ray image



GAGG:Ce film x-ray image



**Dental detector is under development**

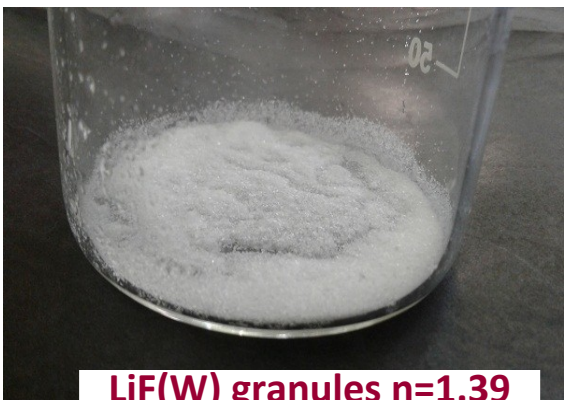
**Bright and uniform scintillation films with thickness from 50  $\mu\text{m}$  to 200  $\mu\text{m}$  have been developed**

**Thickness vs. Transparency**

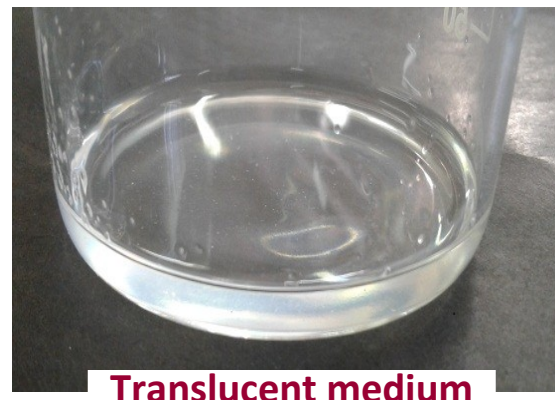
# ISMA scintillators for medical application

## Ways for transparency improvement:

### 1. Refractive index: granules and binder



**binder**  
→  
 **$n=1.39$**



**binder**  
→  
 **$n=1.50$**

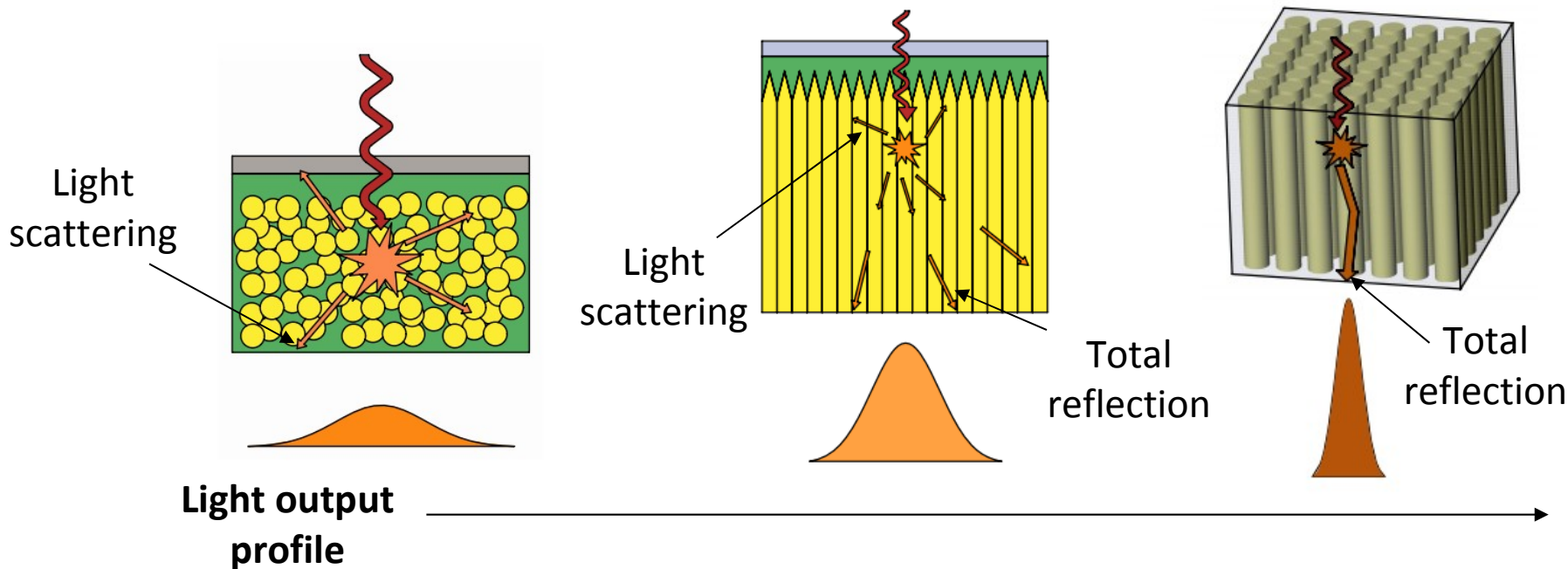


# ISMA scintillators for medical application

## Ways for transparency improvement:

2. Scintillation granules: surface quality

3. High resolution: scintillator fiber array



# ISMA scintillators for medical application

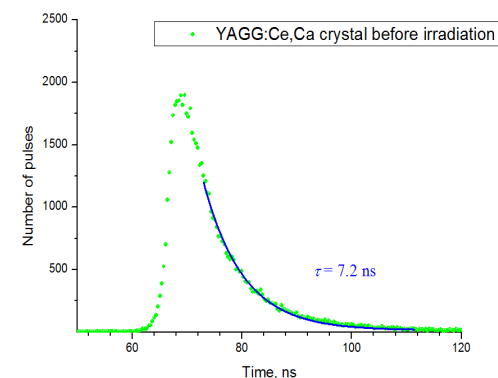
## Medical imaging (PET)

### Requirements to scintillators:

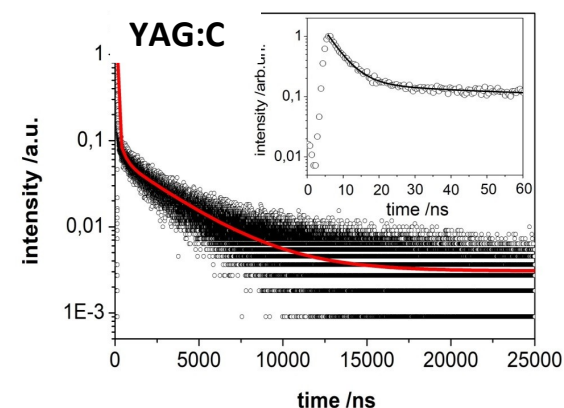
- High density /  $z_{\text{eff}}$
- Decay time up to 20 ns
- High transparency for good spatial resolution
- Good energy resolution
- High timing resolution



### Fast garnets for PET



Scintillator	Density g/cm <sup>3</sup>	Decay ns	Refractive index	LY ph/MeV	Emission nm
YAG:C	5.5	4-6	~1.8	22 000	400
YAGG:Ce,Ca	5.6	7	~1.8	20 000	540





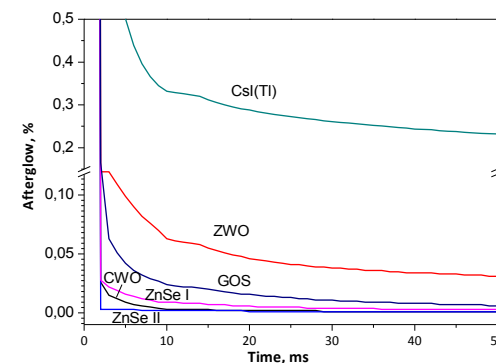
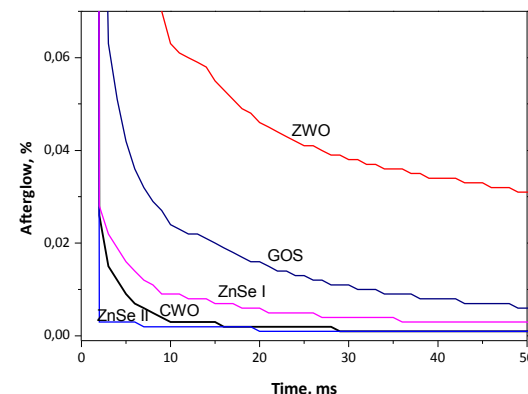
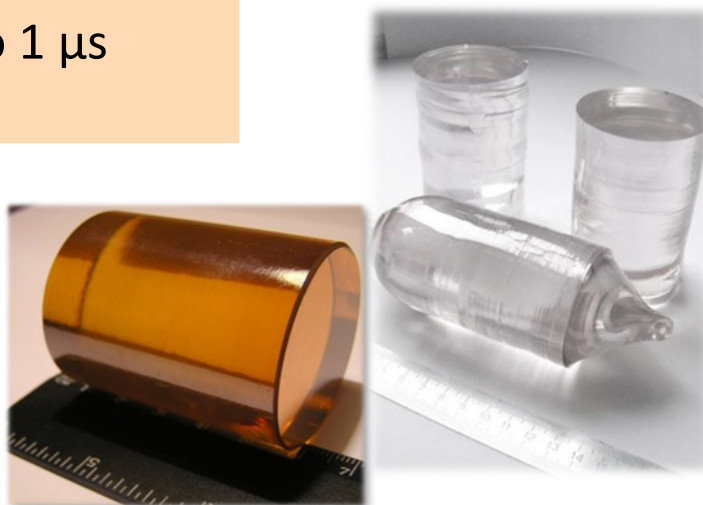
# ISMA scintillators for medical application

## Medical imaging (CT scanners)

### Requirements to scintillators:

- High stopping power /  $z_{\text{eff}}$
- Decay time up to 1  $\mu\text{s}$
- Low after glow

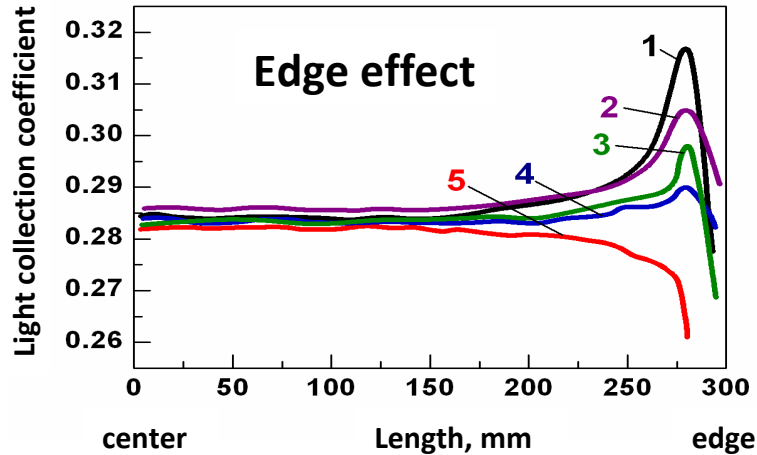
### Low afterglow scintillators for CT



Scintillator	Z eff	Decay $\mu\text{s}$	Refractive index	LY, ph/MeV	Emission nm
ZnWO <sub>4</sub>	61	1	2.14	10 000	480
CsI:Tl	54	1	1.79	65 000	550
ZnSe	33	1	2.64	60 000	610

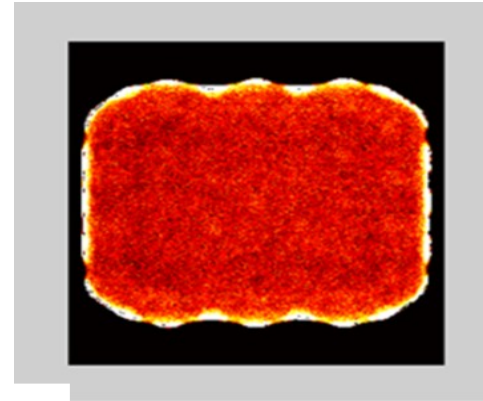
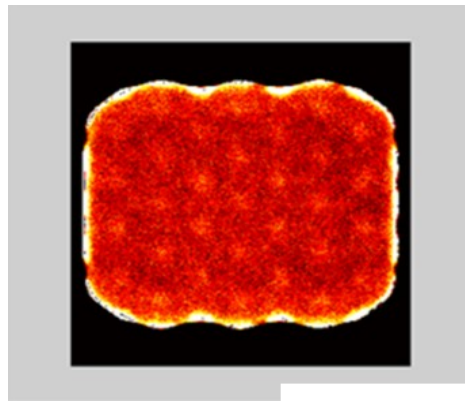
# Detectors for SPECT imaging

## Medical imaging: light collection and edge effect



### Image Uniformity

- LSF variation
- Crystal uniformity
- Edge effect influence



**SPECT imaging**

# ISMA scintillators for rare events searches

# ISMA scintillators for rare events searches

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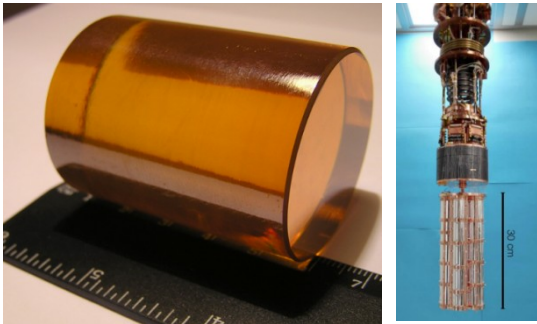
## Requirements to scintillators for rare event searches

- extremely low level of radioactive contamination
- presence of specific nuclei ( $2\beta$  decay)  
(for example  $^{64,70}\text{Zn}$ ,  $^{180,186}\text{W}$ ,  $^{92,98,100}\text{Mo}$ ,  $^{82}\text{Se}$ )
- variety of elements in scintillation targets (Dark matter)
- high light output at milli-Kelvin temperature
- high optical quality
- high crystalline structure perfection

# ISMA scintillators for rare events searches

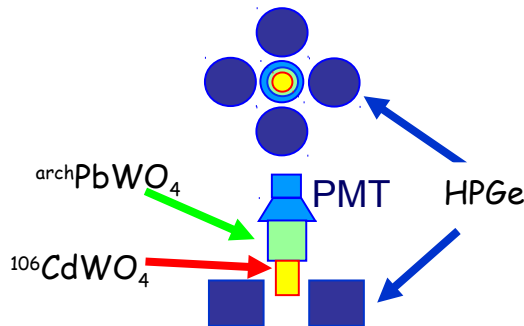
## ISMA / Gran Sasso laboratory, Italy collaborations

### 1. Zn<sup>82</sup>Se for CUPID-0 bolometric 0νββ experiment



- 24 pcs bolometric elements of Zn<sup>82</sup>Se
- The lowest background level  $.6 \cdot 10^{-3} \text{cps}/(\text{keV} \cdot \text{kg} \cdot \text{yr})$
- High light output

### 2. ARCH PbWO<sub>4</sub> for 2β decay of <sup>106</sup>Cd with enriched <sup>106</sup>CdWO<sub>4</sub>



- Detection efficiency  $\sim 5 - 7\%$
- Background expected : several events during a year
- Estimated sensitivity to two neutrino  $\epsilon\beta^+$  and  $2\beta^+$  in <sup>106</sup>Cd:  $T^{1/2} \sim 10^{20} - 10^{21} \text{ yr}$   
 Theory:  $2\nu 2K$   $10^{20} - 5 \cdot 10^{21} \text{ yr}$   
 $2\nu\epsilon\beta^+$   $8 \cdot 10^{20} - 4 \cdot 10^{22} \text{ yr}$

**Requirement: precise crystal growth equipment**

# ISMA scintillators for rare events searches

## Oxide scintillators for rare event searches

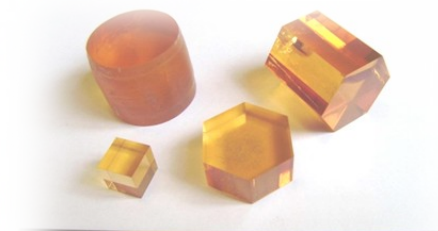
- $\text{ZnWO}_4$   $2\beta$   $^{64,70}\text{Zn}$ ,  $^{180}\text{W}$ ,  $^{186}\text{W}$ ; DM
- $\text{PbMoO}_4$   $2\beta$   $^{100}\text{Mo}$
- $\text{ZnMoO}_4$   $2\beta$   $^{100}\text{Mo}$ ,  $^{64,70}\text{Zn}$
- $\text{Li}_2\text{MoO}_4$   $2\beta$   $^{100}\text{Mo}$ ,  $^{64,70}\text{Zn}$
- $\text{MgWO}_4$  DM
- $\text{ZnMgWO}_4$  DM



$\text{ZnWO}_4$



$\text{MgWO}_4$



$\text{ZnMoO}_4$

### Requirements:

- High purity raw material
- Stoichiometry
- Precise crystal growth equipment

# ISMA scintillators for rare events searches

## Halide scintillators for rare event searches

- NaI:Tl
- CsI:Tl

- Growth of crystals with low radioactive background

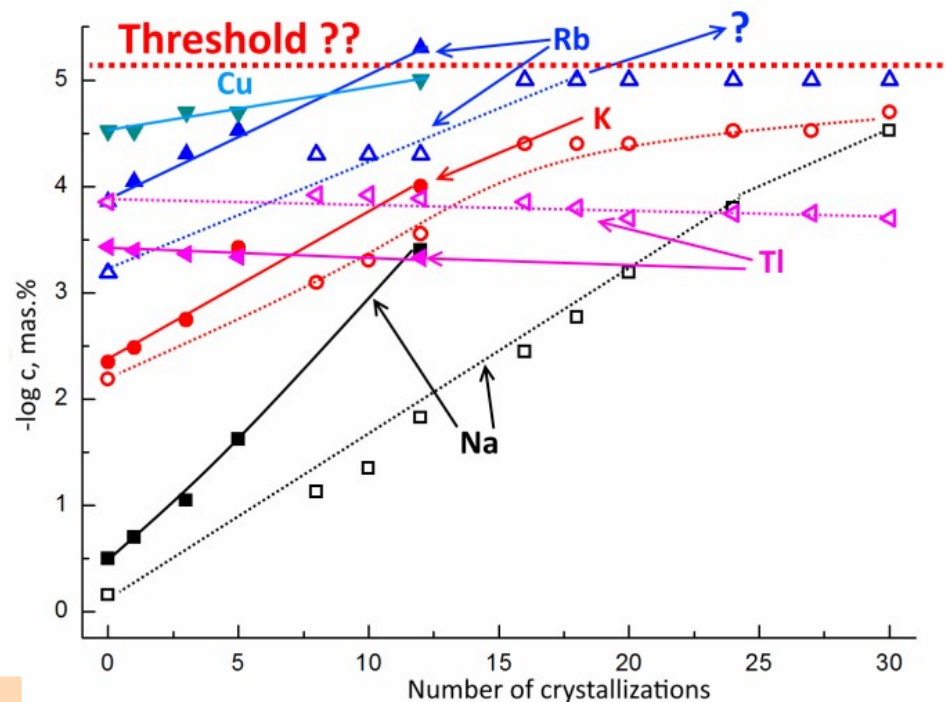
- Total quantity of isomorphous impurities in raw materials :

for NaI:Tl -  $2 \cdot 10^{-6}$  wt. %

for CsI:Tl -  $5 \cdot 10^{-6}$  wt. %

### Requirements:

- High purity raw material
- Stoichiometry
- Precise crystal growth equipment



**Thank you!**