# ISMA R&D scintillation detectors for high energy physics projects and medical application

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# OUTLINE

1. History and development reasons

2. Problems and solutions

3. Light collection as the part of technology

4. Scintillation detectors for HEP of development

5. Scintillation detectors for medical application

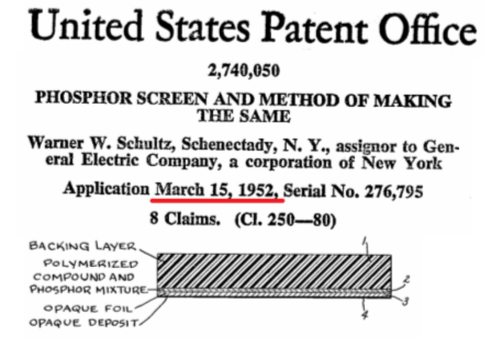
6. Conclusion

# Historical current needs

**Single crystalline scintillator is probably the best but the most complex and expensive decisions**
**Non growth technology as an alternative:**

- **50th - start of both option and …era of growth domination**
- **70th - ceramics as alternative to the growth**
- **2015 – return to composites as an efficient and cheap solution**

## 1950's - composite



United States Patent Office

2,740,050

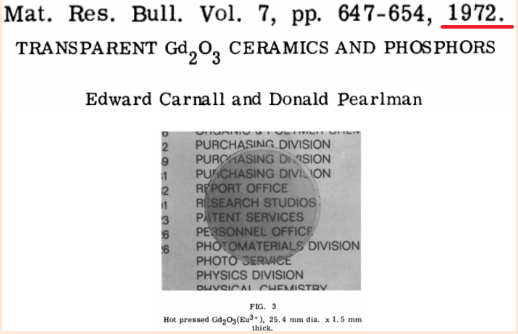
**PHOSPHOR SCREEN AND METHOD OF MAKING THE SAME**

Warner W. Schultz, Schenectady, N. Y., assignor to General Electric Company, a corporation of New York

Application March 15, 1952, Serial No. 276,795

8 Claims. (Cl. 250—80)

## 1970's - ceramics



Mat. Res. Bull. Vol. 7, pp. 647-654, 1972.

TRANSPARENT $Gd_2O_3$ CERAMICS AND PHOSPHORS

Edward Carnall and Donald Pearlman

FIG. 3

Hot pressed $Gd_2O_3(Eu^{3+})$, 25.4 mm dia. x 1.5 mm thick.

## 2010's - again to composite

United States Patent

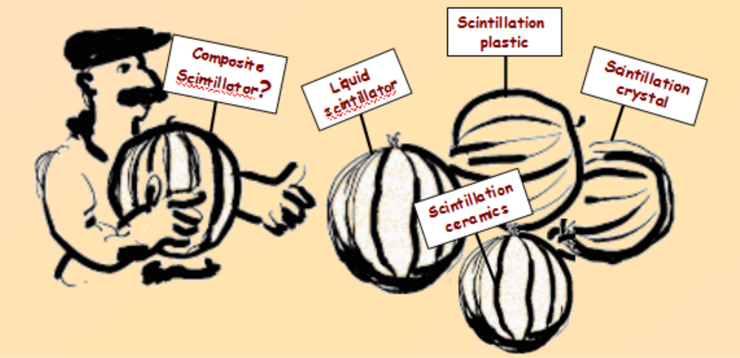
Patent No.: US 8,633,449 B2
Date of Patent: Jan. 21, 2014

SCINTILLATOR INCLUDING A SCINTILLATOR PARTICULATE AND A POLYMER MATRIX

Inventor: **Peter R. Menge**, Novelty, OH (US)

Assignee: **Saint-Gobain Ceramics & Plastics, Inc.**, Worcester, MA (US)

## Renaissance of composite technology – the dream or reality?



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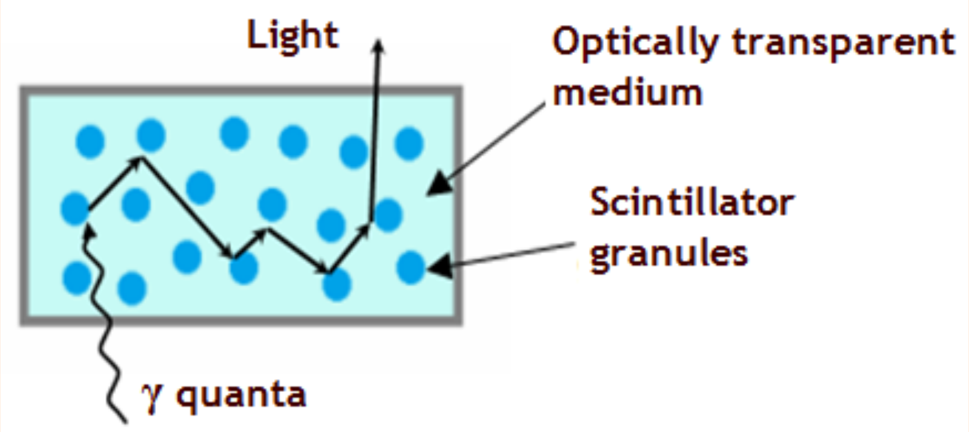
# Composites - what is it?



**Composite scintillator** – small scintillator particles/granules embedded to immersion gel

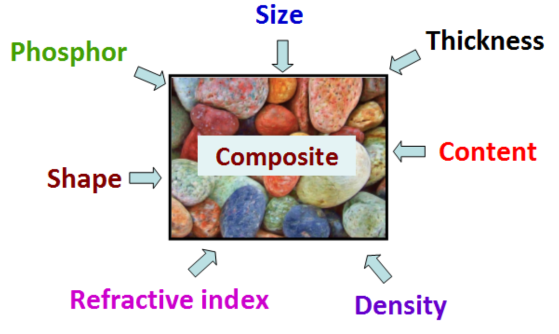
**Driving force** for development is the search of cost efficient solution for many detector designs. There are no any application claiming for lower price!

# Composites - what is attractive?

## Technical and technology advantages:

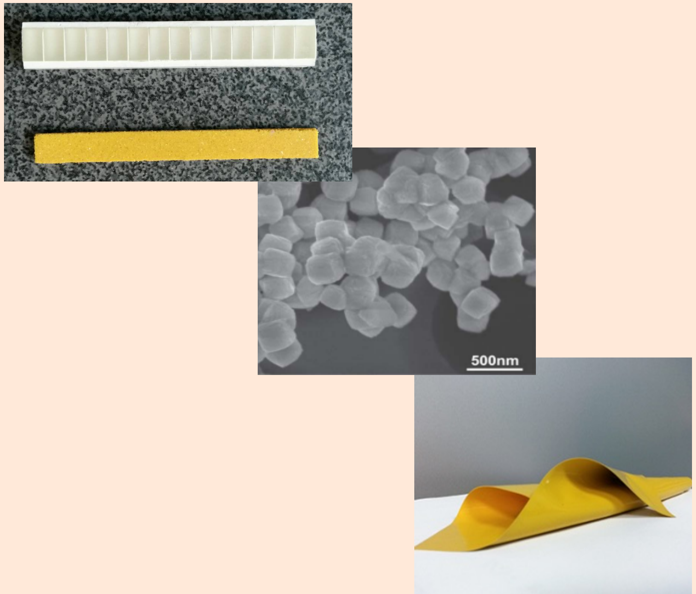
- ✓ Use of synthesized scintillation powders
- ✓ Variable thickness (from 50 micron)
- ✓ High spatial resolution
- ✓ High uniformity
- ✓ Large area any complex shapes
- ✓ Commercially available components
- ✓ Ready to visualization

## Composite technology is multidisciplinary process



## Initial problems:

- ✓ Low transparent media, light scattering
- ✓ Customized design for each customer
- ✓ Simulation and optimization for each design
- ✓ Particles analysis and presize synthesis
- ✓ Light guide output solution for thick detector



# Composites - scintillators for customer requirements

## Scintillation powder fabrication

Synthesis

Chemical

Solid state

- ✓Sol-gel
- ✓Precipitation
- ✓Hydrothermal
- ✓Other

**Advantage**

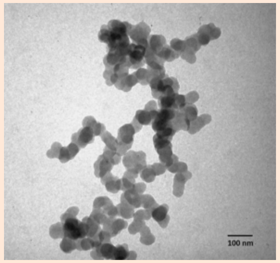
- ✓Easy to obtain
- ✓High purity

**Drawback**

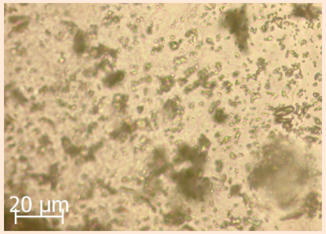
- ✓Irregular shape
- ✓Additional milling is required
- ✓Non uniformity size form 10s of nm

**Advantage**

- ✓Regular shape
- ✓Control of particles size
- ✓Ultrafine and fine powders (1-5000 nm)

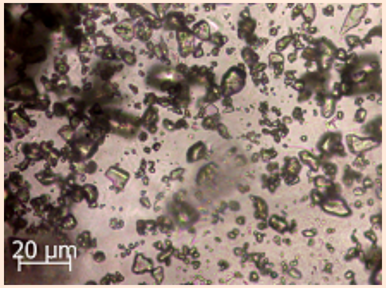


$CeO_2$



GOS:Pr,Ce

GAGG:Ce



**Scintillation powder is the main problem for technology**

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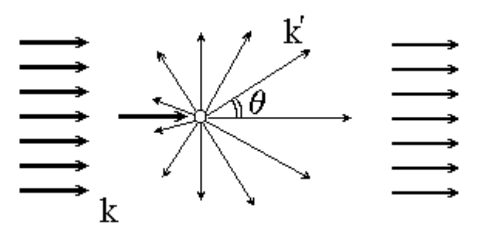
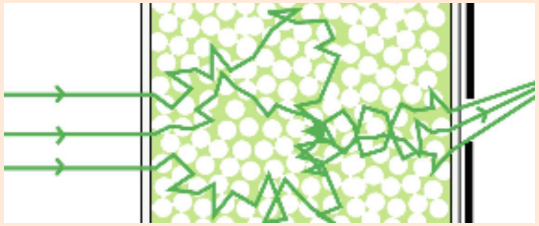
# Light collection in composites

## Granule size selection

Light scattering in heterogeneous system





| Granule size | Light attenuation | |
|---|---|---|
| < 30 nm<br>Nanoparticles | Granule size significantly less than scintillation wavelength | Weak emission |
| ~ 100-200 nm | Granule size less than emission wavelength | Rayleigh scattering |
| 300-800 nm | Granule size is comparable with emission wavelength | Mie scattering |
| > 1000 nm | Large crystal | |

# Light collection in composites

## Base requirements for composites

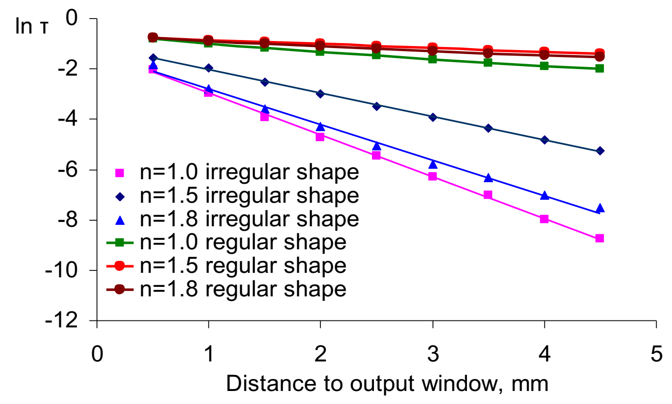
✓ Refractive index

✓ Granule shape

✓ Granule size

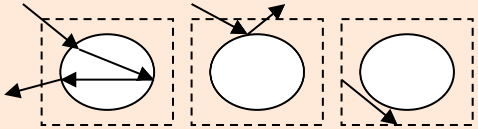
✓ Concentration and distribution uniformity

Light collection simulation



**Monte Carlo simulation should cover at least:**

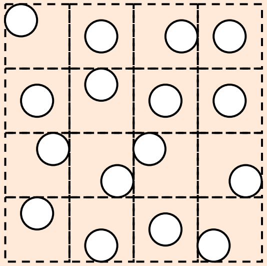
A. Light passage in imaginary cell



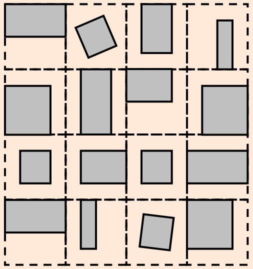
B. Simulation of light transport

$$\tau(L) = \frac{j(L)}{S} = \frac{\frac{\beta_1\beta_2}{\chi} sh\chi L + \beta_2 ch\chi L}{(\chi + \frac{\beta_1\beta_2}{\chi}) sh\chi l + (\beta_1 + \beta_2) ch\chi l}$$

C. Regular shape



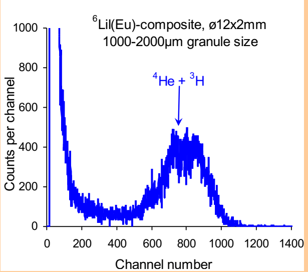
Irregular shape

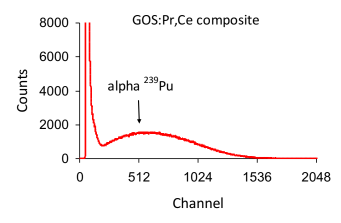


# Composites application

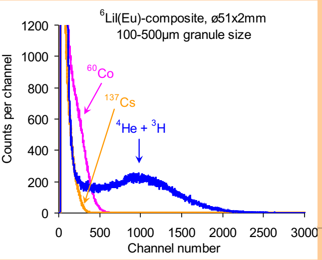
## Spectrometry

- ✓ Composites with large granules size
- ✓ Granule size is commensurate with absorbed energy





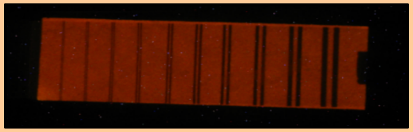
## Neutron detection



$^6$Li base detector

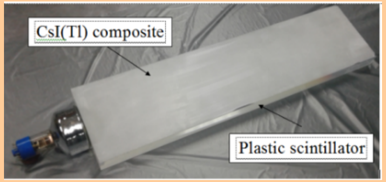
## X-ray screening

- ✓ Good transparency without pixelation
- ✓ Direct application onto CMOS
- ✓ Good spatial resolution and uniformity



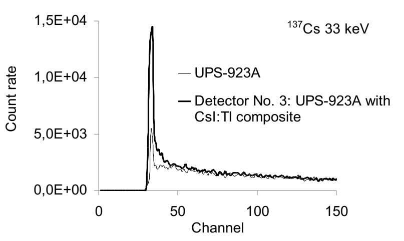
film, x-ray image @80 keV

## Gamma detection



- ✓ High threshold of sensitivity to low gamma

Combine detector



## HEP projects

CERN

ILC
ILC-Japan

Institute of High Energy Physics
Chinese Academy of Sciences

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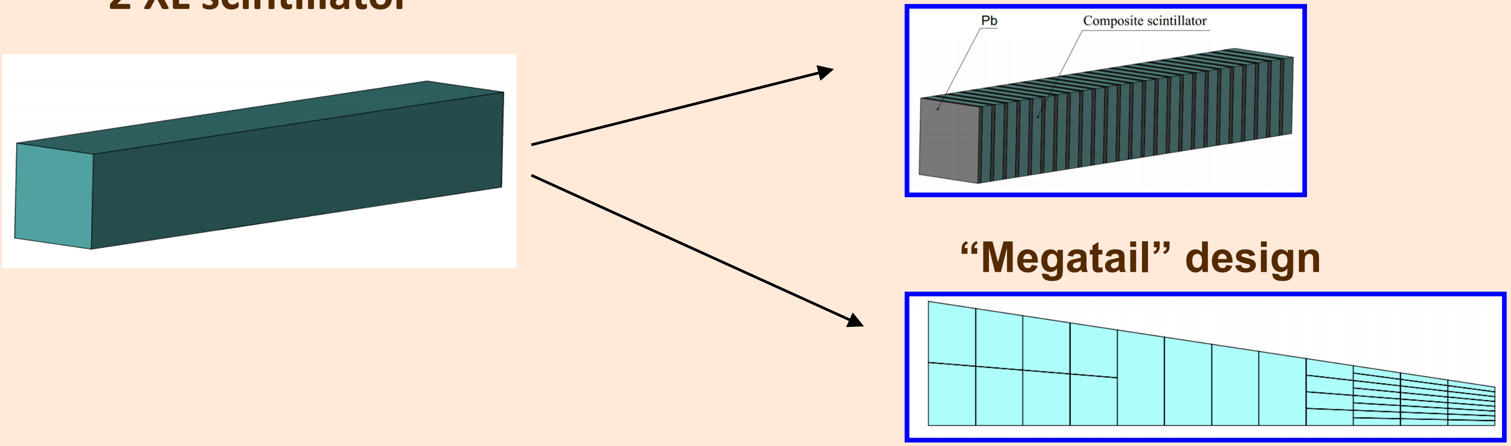
# Composite scintillators application for HEP



**2 XL scintillator**

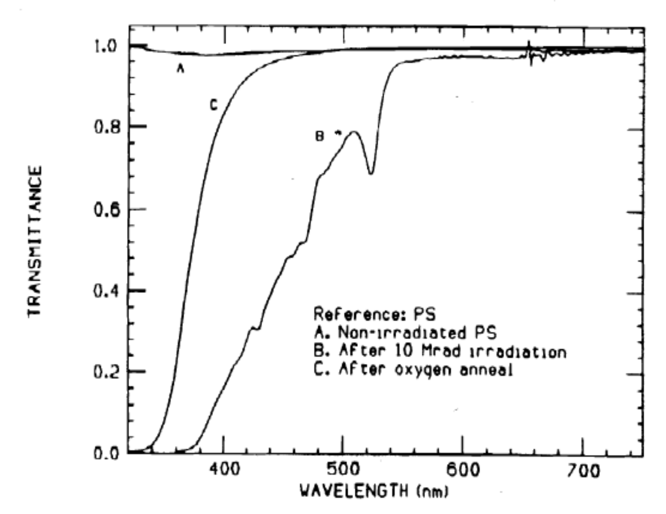
**“Shashlyk ” design**

**“Megatail” design**

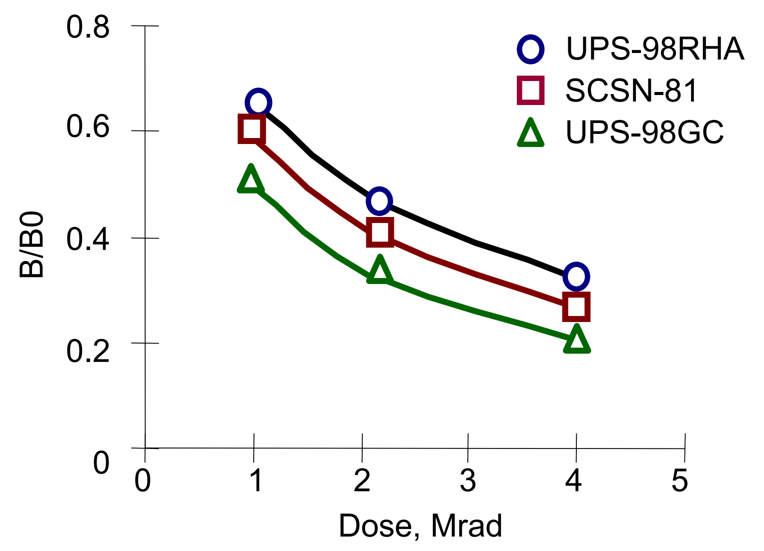
| | Scintillation plastic | Scintillation crystal | Composite scintillators |
|---|---|---|---|
| radiation resistance | up to 5 Mrad | Yes | Yes |
| cover large area | Yes | No | Yes |
| cost-efficiency | Yes | No | Yes |

**Composite scintillator is the alternative to the scintillation plastic but possesses with higher radiation resistance comparable with inorganic crystals**

# Ways of  improvement of radiation hardness plastic scintillators



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



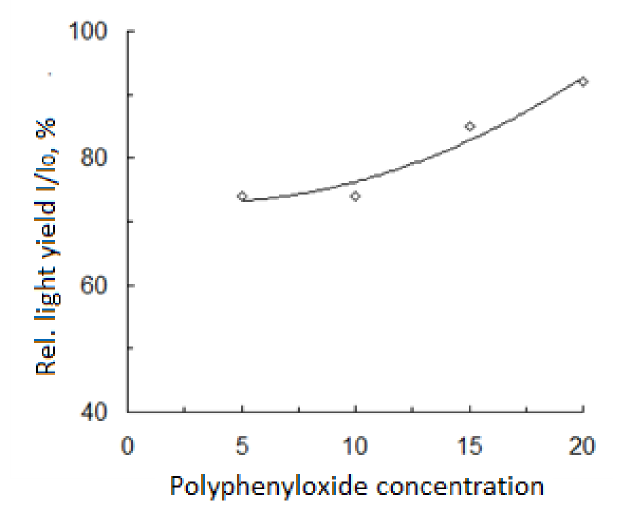
Irradiation induced decrease of light yield in plastic scintillator

**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**

# Improvement of radiation hardness via increasing of radicals mobility

Doping of plastic scintillator polymer base with diffusion amplifier may result in increase of radiation hardness



Light yield dependence of plastic scintillator on polyphenyl oxide concentration (diffusion amplifier in polysterene) under irradiation with 2.8 MRad dose

Introducing of diffusion amplifiers levels dependence of traps formation rate on irradiation dose rate,

**but**

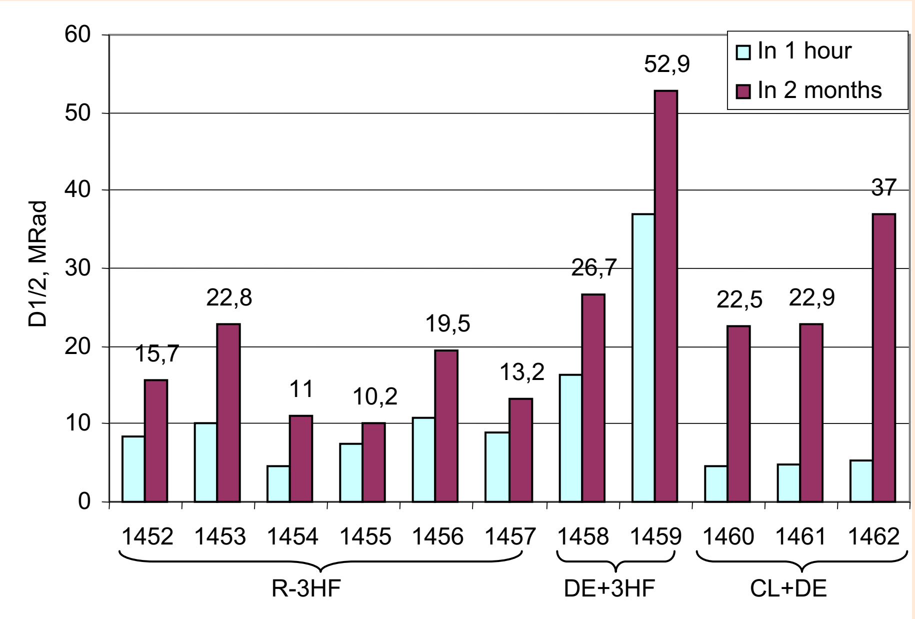
**disimprove the mechanical properties of plastic scintillator**

**“Cross-linking” of polymer base is the way to improve the properties of radiation hardness plastic scintillator**

# Improvement of radiation hardness plastic scintillators

- Shifting of luminescence maximum into the region of transparency
- Introducing of diffusion amplifiers into cross-linked polymer backbone

## Increase of radiation hardness threshold up to 10 MRad



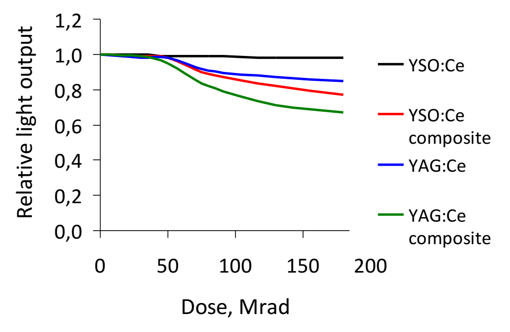
| ID scint. | Light yield, % (rel.) | | D1/2, MRad |
|---|---|---|---|
| | 0 Mrad | 5 Mrad | |
| 1 | 80 | 49 | 7.0 |
| 2 | 55 | 48 | 11.4 |
| 3 | 59.5 | 41 | 9.3 |

P. Zhmurin, ISMA

# Development of thin-layer detectors for HEP

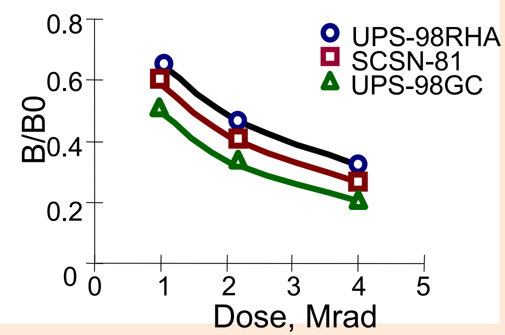
## Radiation hardness of organic vs inorganic scintillators

### Single crystal and composites



Radiation hardness more 100 MRad

### Polysterene



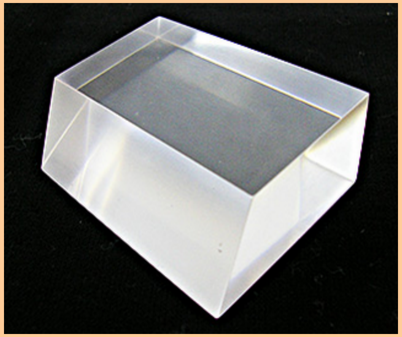
Radiation hardness up to 5 MRad

**Radiation hardness of oxide based composites is in 20 times higher than scintillation plastic!**

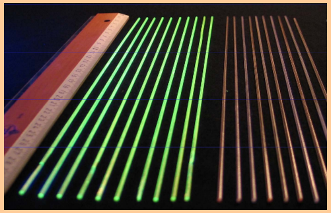
# Scintillation detectors

Materials

Crystal growth

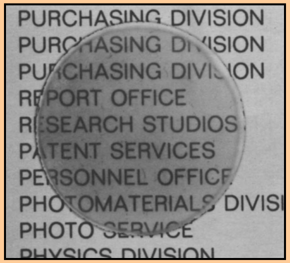


Micro-pulling-down crystal fiber growth



E.Auffray, Cern, February 2009

Scintillation ceramics



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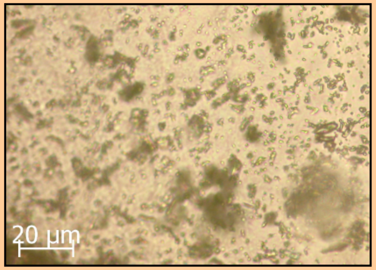
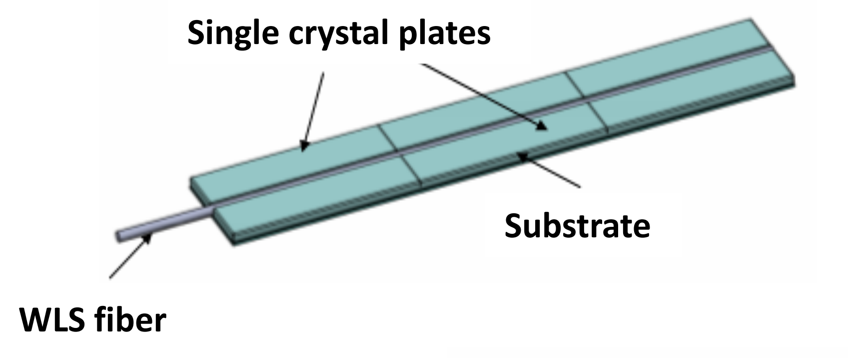
E.Carnall, D. Pearlman,Mat.Rec.Bul.,1972

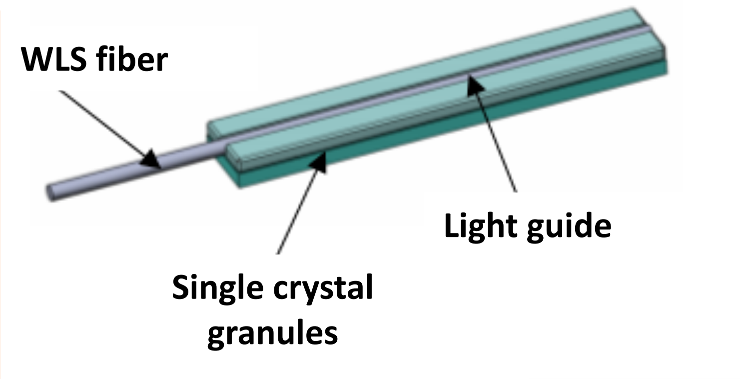
Scintillation powders/ granules

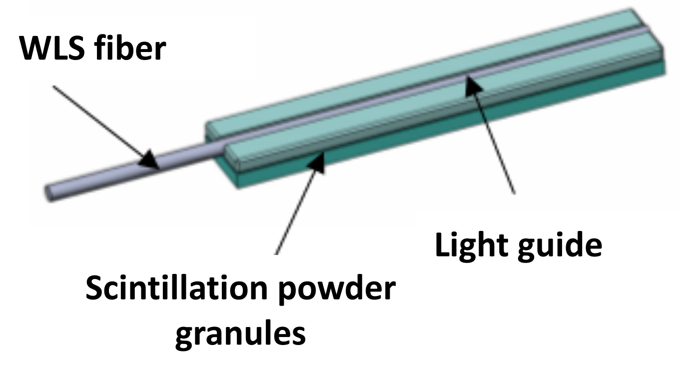


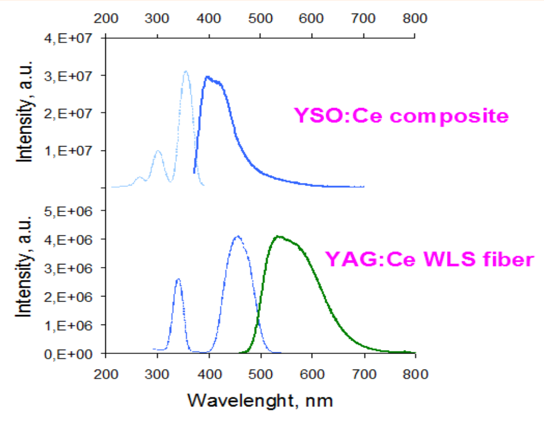
Other

# Composite elements for various loading doses





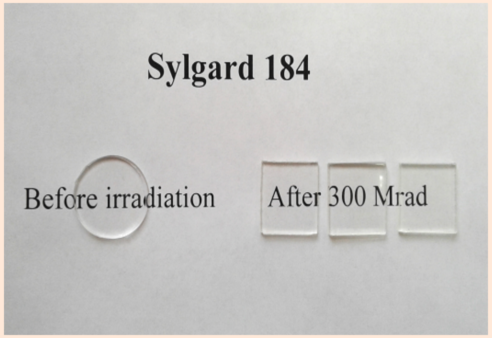


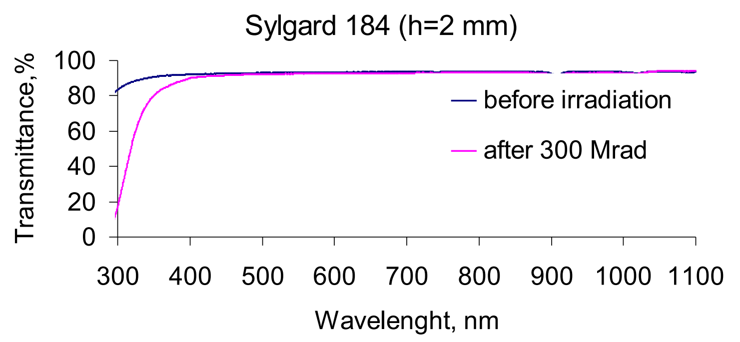


Essential overlapping of YSO:Ce emission spectrum
and YAG:Ce absorption spectrum

# Radiation hardness of polysiloxanes

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





## Irradiation with protons (150 KeV)

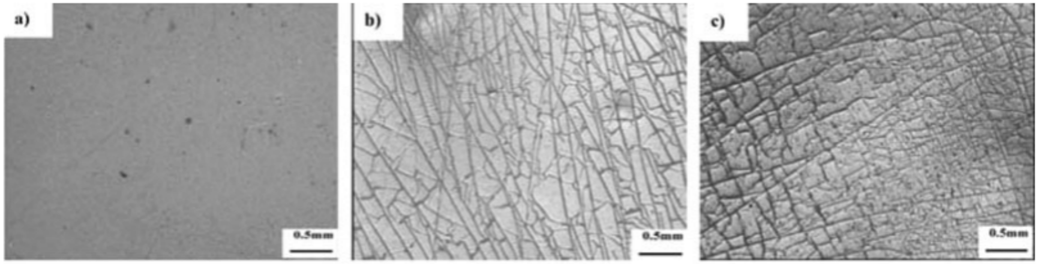


**Figure 2** Change in surface morphology of samples with increasing proton fluence: (a) 0 $cm^{-2}$, (b) 5 × $10^{14}$ $cm^{-2}$, (c) 1 × $10^{15}$ $cm^{-2}$,

Haiying Xiao et al., Journal of Applied Polymer Science, ·2008

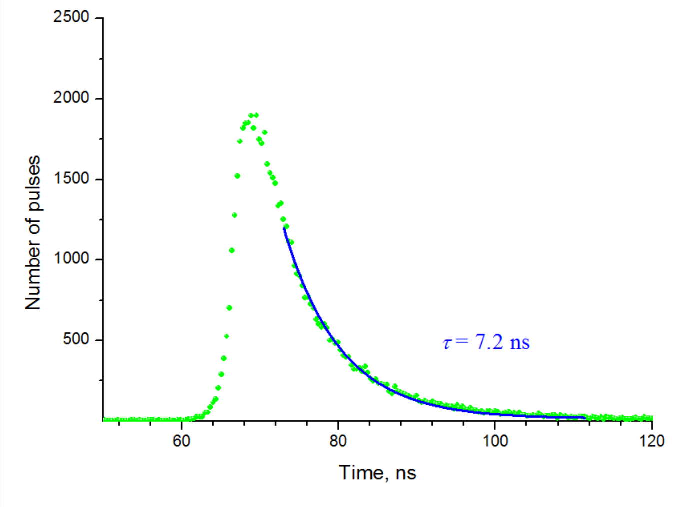
- **Loss of transparency is the result of microcracks appearance**
- **Appearance of microcracks is due to:**

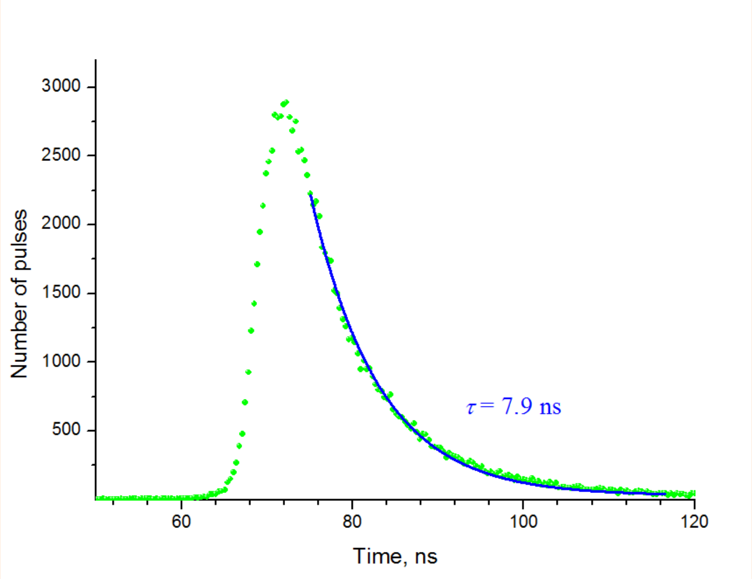
  **- leaving of the methyl groups**

  **- formation of an inorganic, silica-like final product, which consists of $SiO_x$**

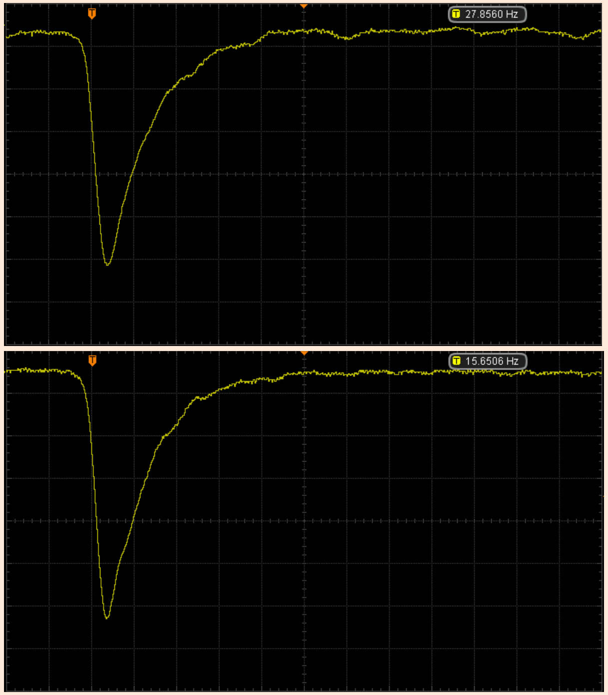
The possible way to increase of radiation resistance
is **hardening of polysiloxane matrix with scintillation granules**

# YAGG:Ce as a material for WLS fiber





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



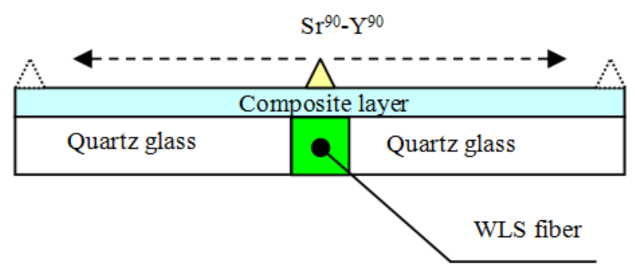
**Decay time, Composite Scintillator element with YAGG:Ce fiber , 22ns**

**Radiation hardness is more than 100 MRad**

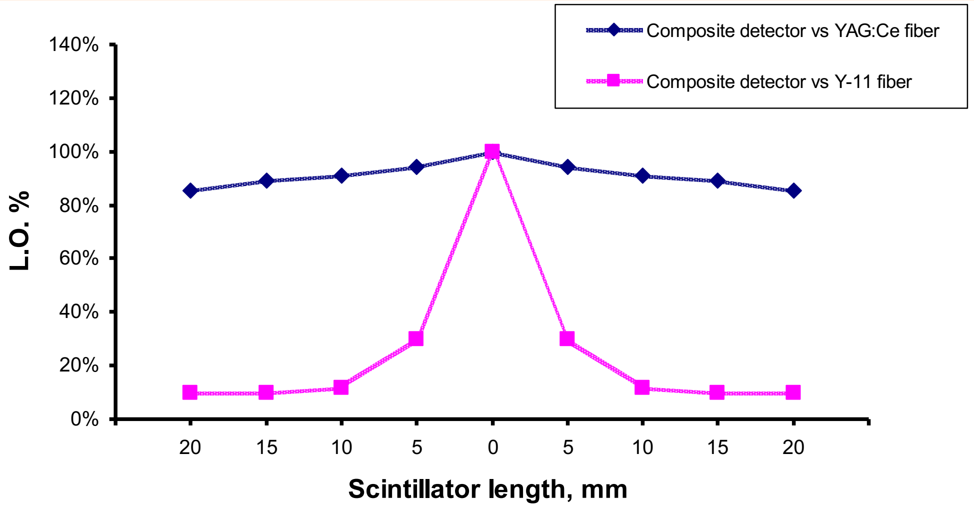
# Light collection in scintillation layer

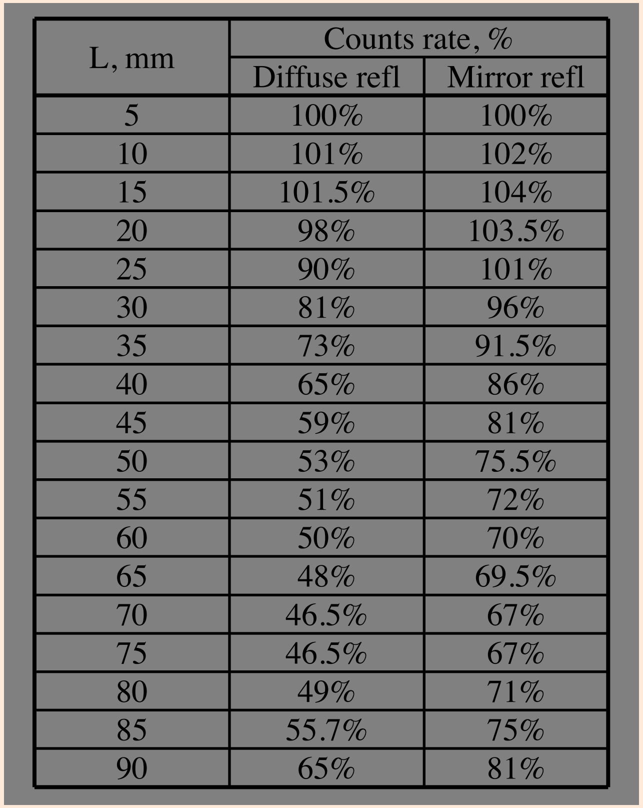
## *WLS fiber – YAG:Ce*

### Testing scheme



### Nonuniformity of composite scintillator

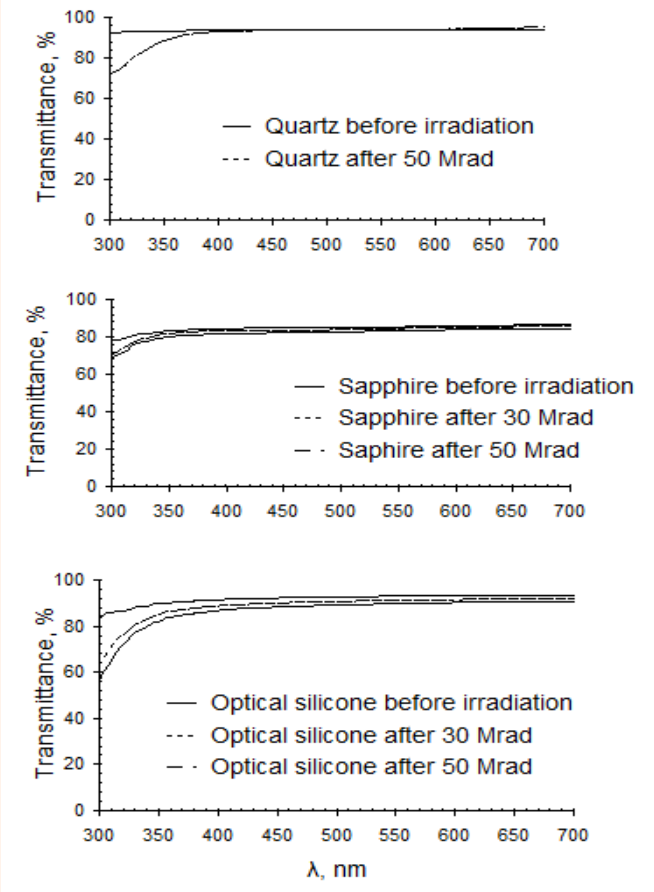




| L, mm | Counts rate, % | |
|---|---|---|
| | Diffuse refl | Mirror refl |
| 5 | 100% | 100% |
| 10 | 101% | 102% |
| 15 | 101.5% | 104% |
| 20 | 98% | 103.5% |
| 25 | 90% | 101% |
| 30 | 81% | 96% |
| 35 | 73% | 91.5% |
| 40 | 65% | 86% |
| 45 | 59% | 81% |
| 50 | 53% | 75.5% |
| 55 | 51% | 72% |
| 60 | 50% | 70% |
| 65 | 48% | 69.5% |
| 70 | 46.5% | 67% |
| 75 | 46.5% | 67% |
| 80 | 49% | 71% |
| 85 | 55.7% | 75% |
| 90 | 65% | 81% |

***Nonuniformity is up to 15% for composite scintillator of 40 mm width***

# Optical light guide selection



**Quartz glass** and silicone are transparent in the range λ>400 nm
**for doses up to 100 Mrad**

**Sapphire** is transparent in the range λ>350 nm
**for doses more than 100Mrad**

**Molding silicone** for optical light guide

| Scintillation type | Optical light guide | Relative light output |
|---|---|---|
| Plastic | - | 100% |
| YSO:Ce composite | Silicone | 250% |
| YSO:Ce composite | Quartz | 120% |
| YSO:Ce composite | Sapphire | 50% |

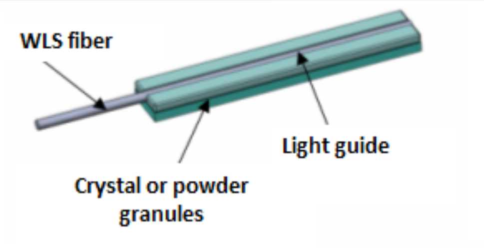
**We have different materials for composite detectors and we propose optical materials with the best radiation hardness**

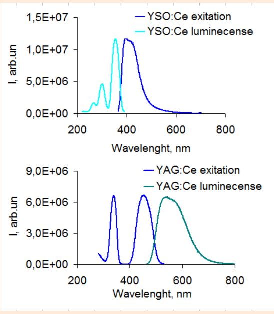
# Development of thin-layer detectors for HEP

## Composite detector

### Requirements

- ✓Super granularity
- ✓Radiation hardness
- ✓Decay time not more 20 ns



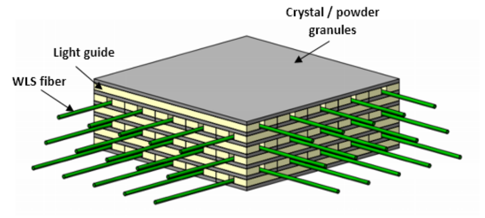


### Available now

- ✓Decay time 10-20 ns
- ✓LO comparable with polysterene
- ✓Radiation hardness >100 MRad
- ✓Radiation hard WLS and opto fiber in complect
- ✓Cherenkov and scintillation signal simultaneous registration

### Possible designes for “warm” calorimeter

- ✓Technology of powder synthesis, ceramics, melting
- ✓Crystal WLS fiber growth



Position sensitivity design – coincidence counting

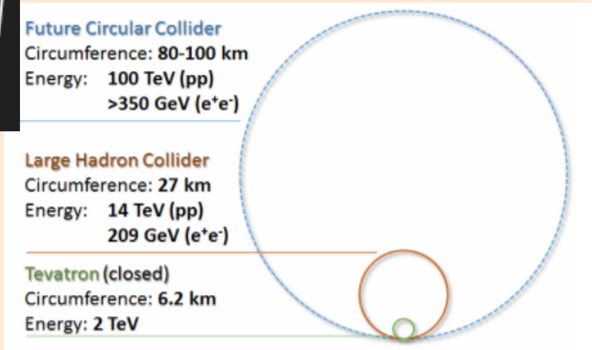
**“Warm” version of calorimeter is possible**

# Development of thin-layer detectors for HEP

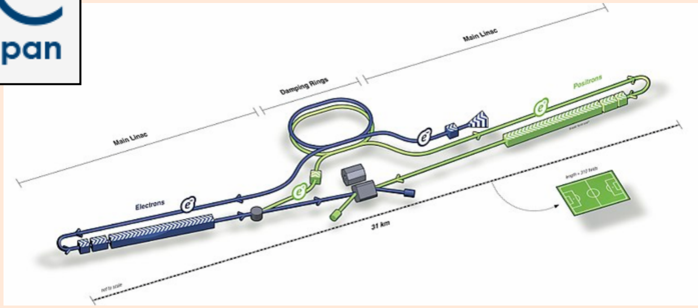
## Future HEP projects

**Semiconductor detector is main applicant to HL LHC and new project upgrade today**

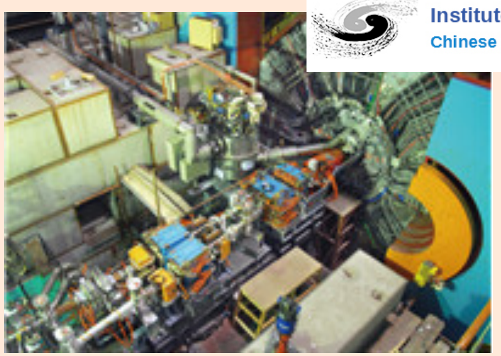
CERN



ILC-Japan



Institute of High Energy Physics
Chinese Academy of Sciences



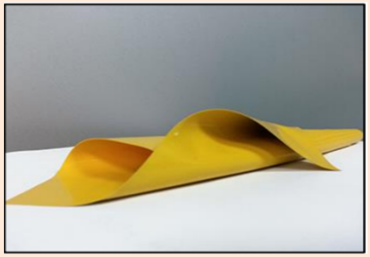
**Future detector – super granularity design**

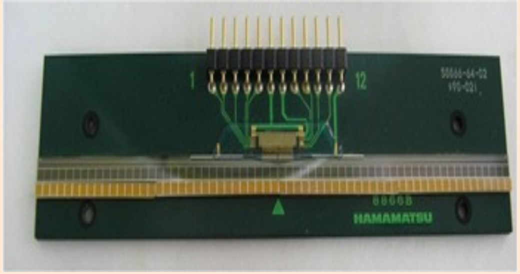
**Composites implementation .**
**What we can offer?**

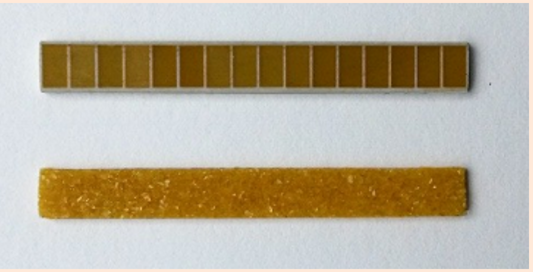
# OUTLINE

1. History and development reasons
2. Problems and solutions
3. Light collection as the part of technology
4. Scintillation detectors for HEP of development
5. **Scintillation detectors for medical application**
6. Conclusion

# Flexible scintillators for photodetector and CMOS application

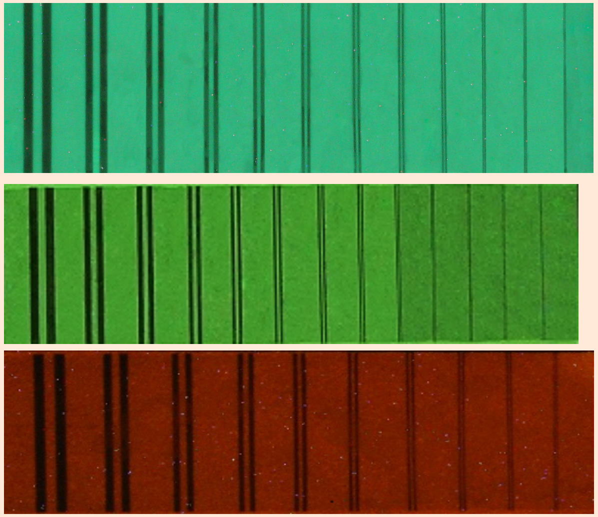




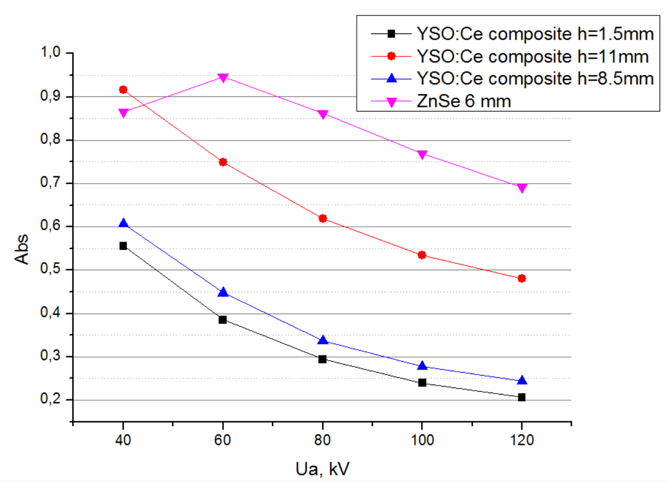


**Pixel detectors VS flat panel**

| Graine size, microns | Thikness, mm | Ligh yield flexible VS crystal |
|---|---|---|
| Up to 40 | 0,1-0,3 | 30 |
| 40-120 | 0,3-0,5 | 55 |
| 120-200 | 0,5-1,5 | 80 |



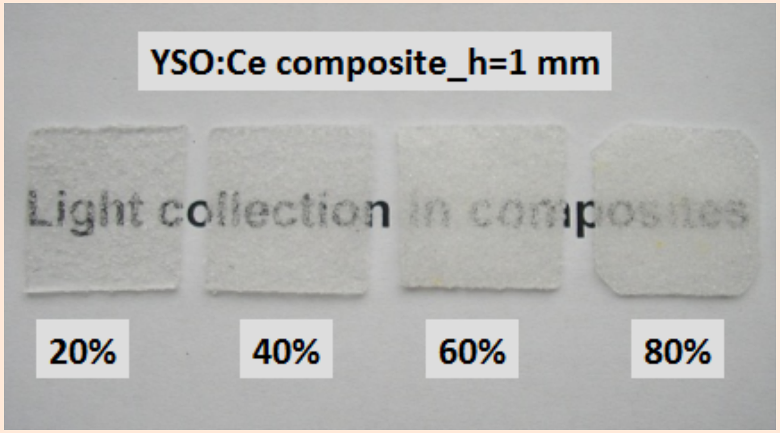
**Position sensitive flexible scintillators without pixelation**



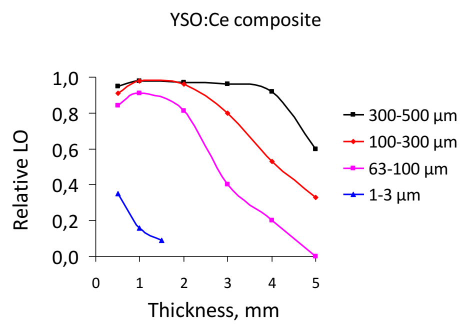
**Light output of composite scintillators**

# Transparent flexible scintillators

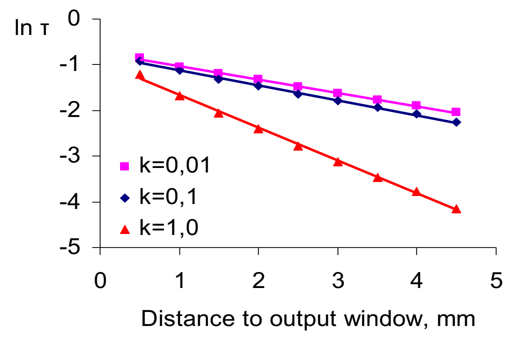
## Experimental data



### Correlation of experiment and theory



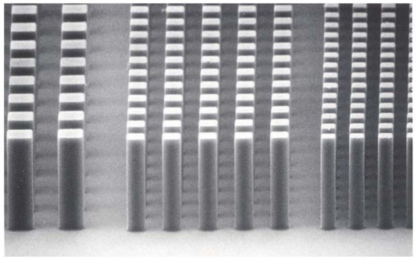
Experiment



Theory

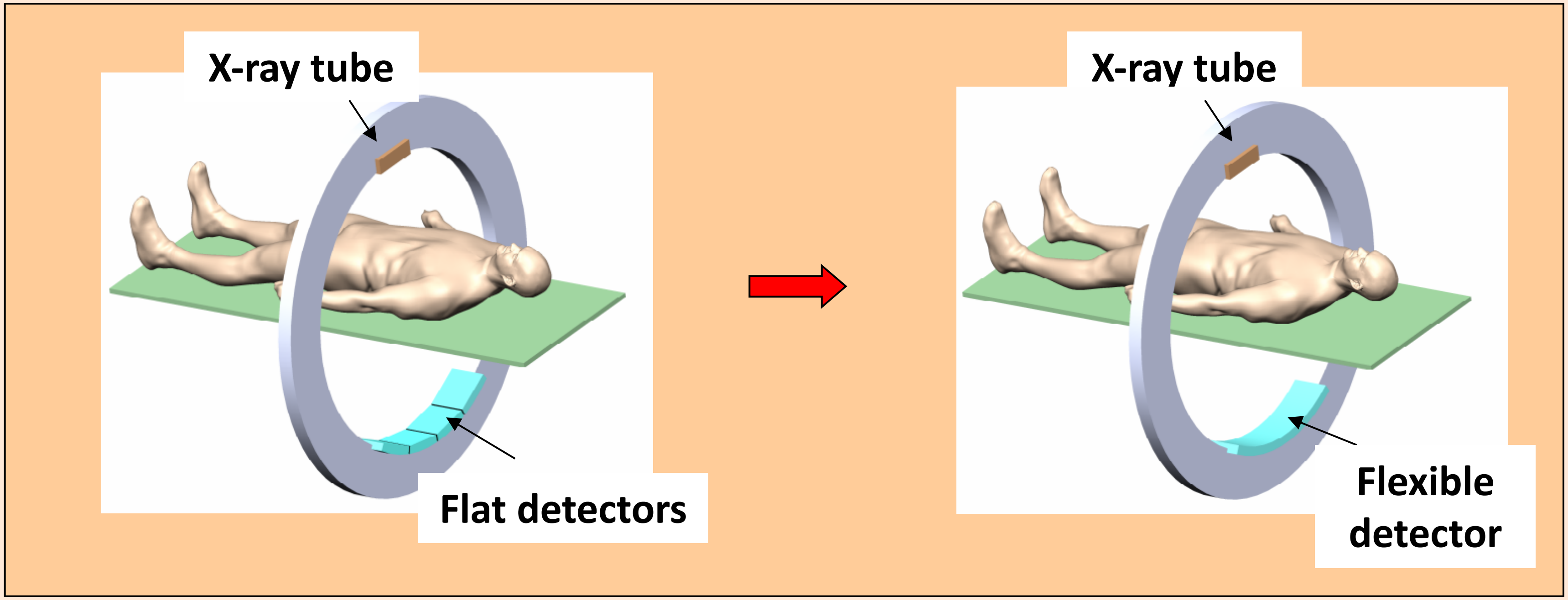
### Ways to increase of transparency

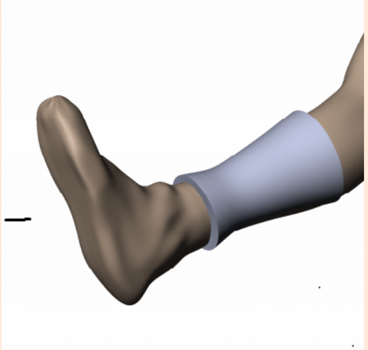
- ✓ Granule size
- ✓ Granule shape
- ✓ Micro light guides and micropixel technology on photoresist base



10 um features, 50 um SU-8 2000 coating

# Medical application





**Advantage of flexible detector**

- ✓ High position sensitivity
- ✓ Takes a form of organ or tissue under study
- ✓ Good spatial resolution
- ✓ High uniformity
- ✓ Good performance
- ✓ Easy production in a variety of shapes

**Transition from flat detectors to flexible ones**

# Conclusion

1. There are many materials on the market meeting the main customer requirements on physical parameters.

2. Searching for materials meeting economical and technological requirements is the problem of current interest.

3. Last decade technologies for obtaining radiation detectors alternative to scintillation crystals have been actively developing.

4. Creation of multicomponent scintillation systems is the way for obtaining of cost efficiency detectors.

Thank you!