CALOR 2018

Performance of DSB - a New Glass and Glass Ceramic as Scintillation Material for Future Calorimetry

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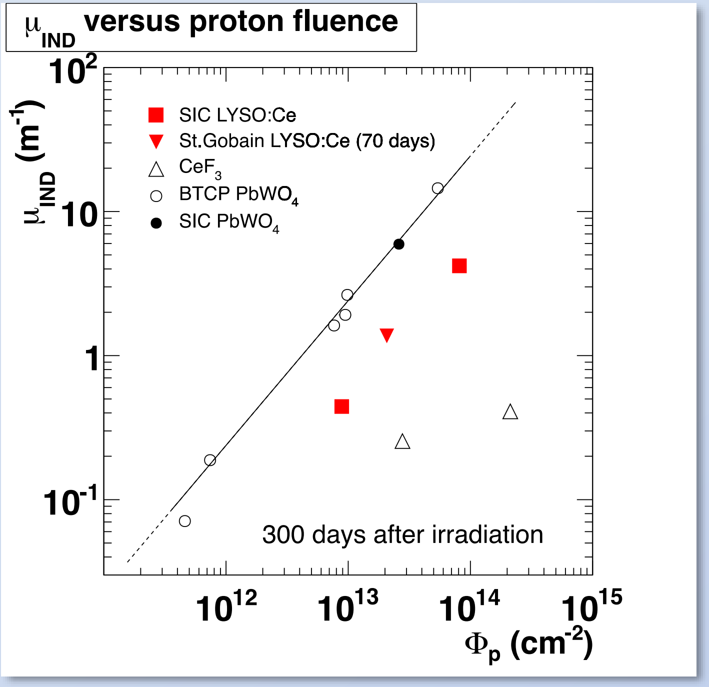
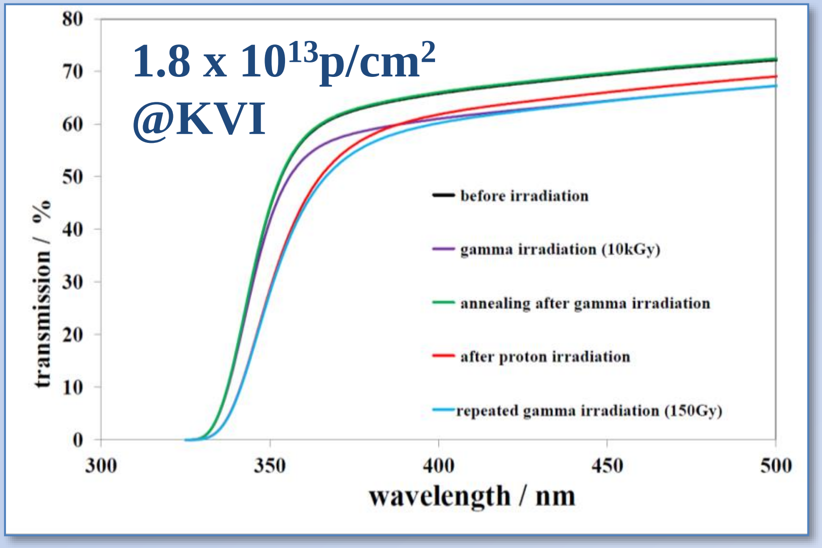
and for the Crystal Clear Collaboration

- **motivation: severe radiation damage due to hadrons**
- **properties of the new material DSB:Ce/Gd**
  - ✓ **structure**
  - ✓ **radiation hardness and recovery**
  - ✓ **scintillation parameters**
- **characterization of bulk and fiber material**
- **response function of a first 3x3 matrix**
- **summary and outlook**

motivation: calorimetry limited by severe hadronic radiation damage

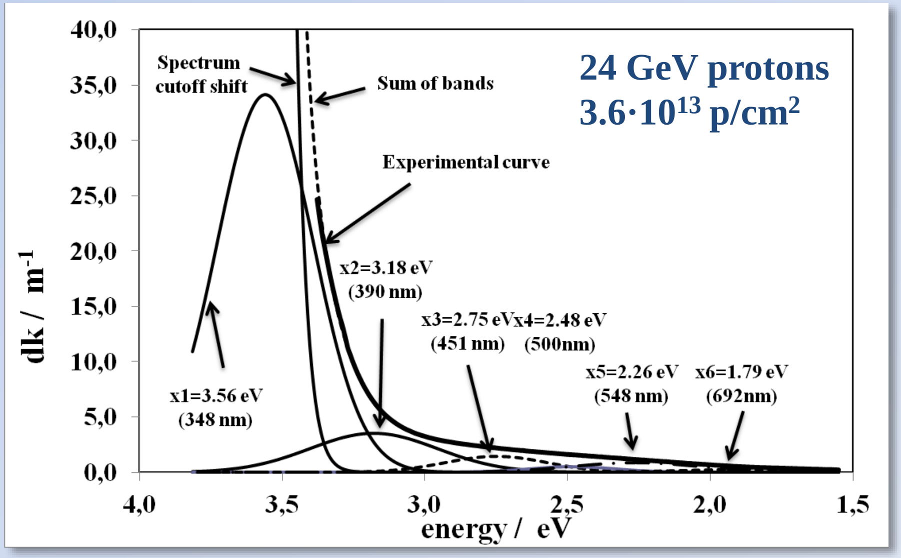


change of optical transmission due to 150MeV protons



Francesca Nessi-Tedaldi
(ETH, Zürich, Switzerland)

- creation of macro defects
- highly ionizing fission products
- ion displacements



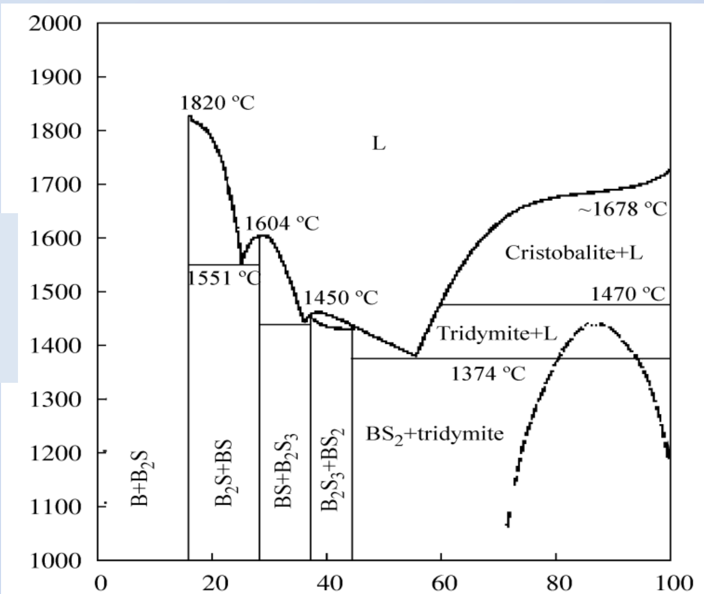
→ lower Z material required
sampling calorimetry
cheap for mass production

properties

material	ρ g/cm^3	Z_{eff}	X_0 cm	λ_{max} nm	cutoff undoped material nm
$(BaO*2SiO_2):Ce$ glass	3.7	51	3.0[1]	440, 460	310
DSB:Ce	3.8	51	3.5	440, 460	310
$(BaO*2SiO_2):Ce$ glass heavy loaded with Gd	4.7 - 5.4*	58	2.2**	440, 460	318

1)GEANT4

T / °C

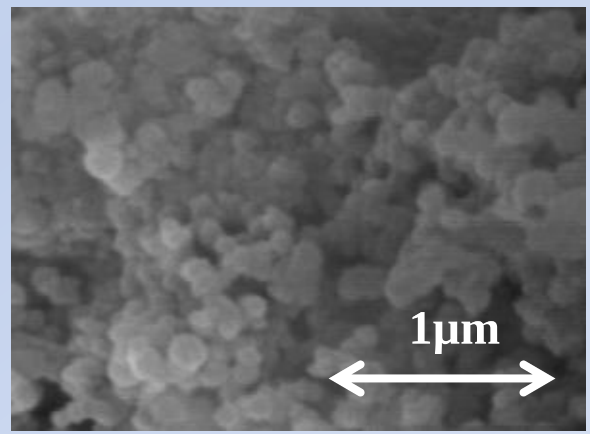


weight % SiO_2

phase diagram of the $BaO*SiO_2$ system

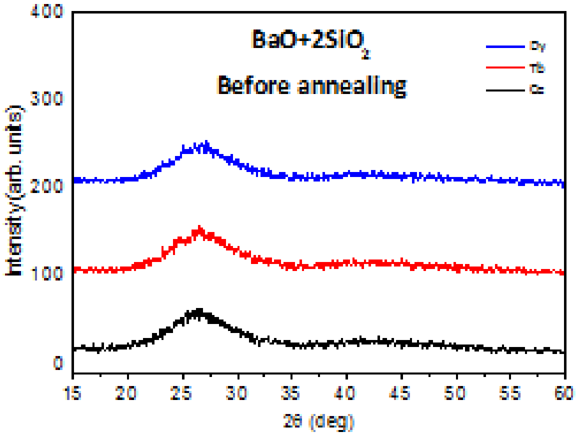
- nano-sized particles of $\mathbf{Ba_2SiO_5}$ improve scintillation!
- Ba-Si system allows to incorporate trivalent ions: **Lu, Gd, Yb**

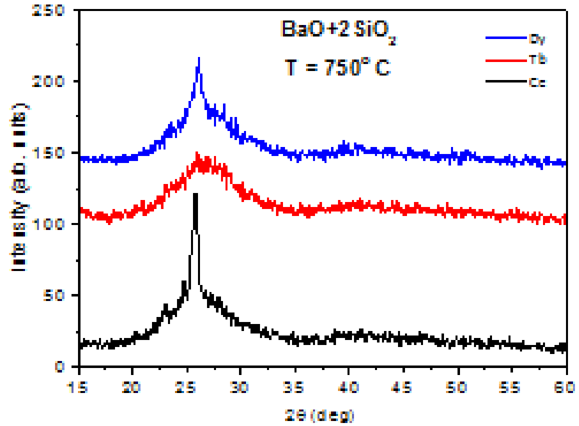
technology: glass production combined with successive thermal annealing (800 – 900°C)

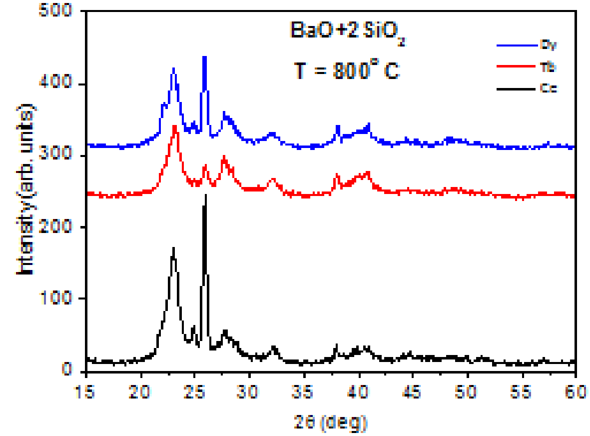


SEM image of recrystallized $BaO*2SiO_2$ at 950°C

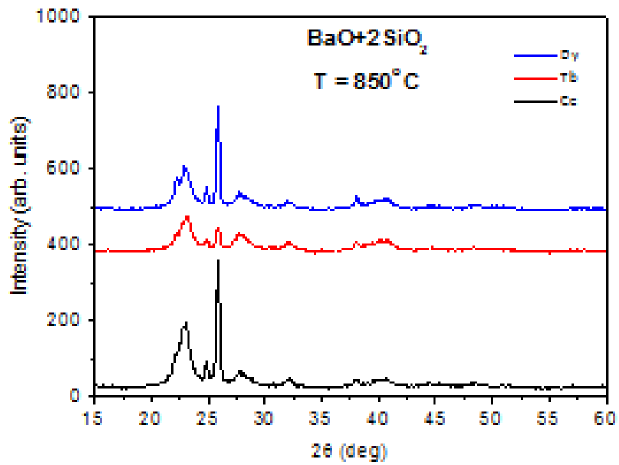
XRD tests of BaO+2(SiO_2): Dy/ Tb/ Ce

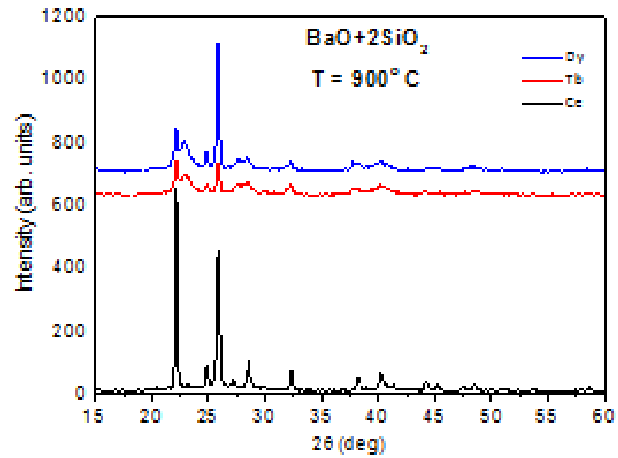






(in collaboration with D. Rinaldi, SIMAU, Ancona, Italy)



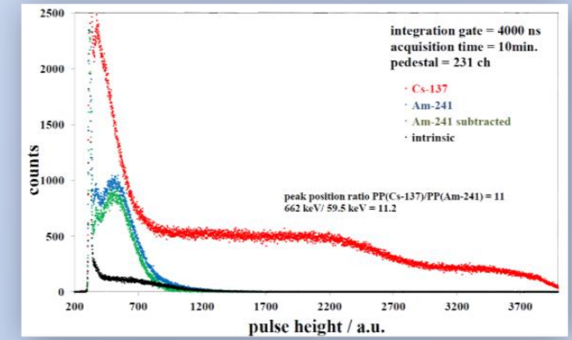


The crystallization of the BaO+2SiO_2 samples increases with the annealing temperature. Beyond T = 900°C the system crystallizes as a mixture of $BaSi_2O_5$ and β-$BaSiO_3$.

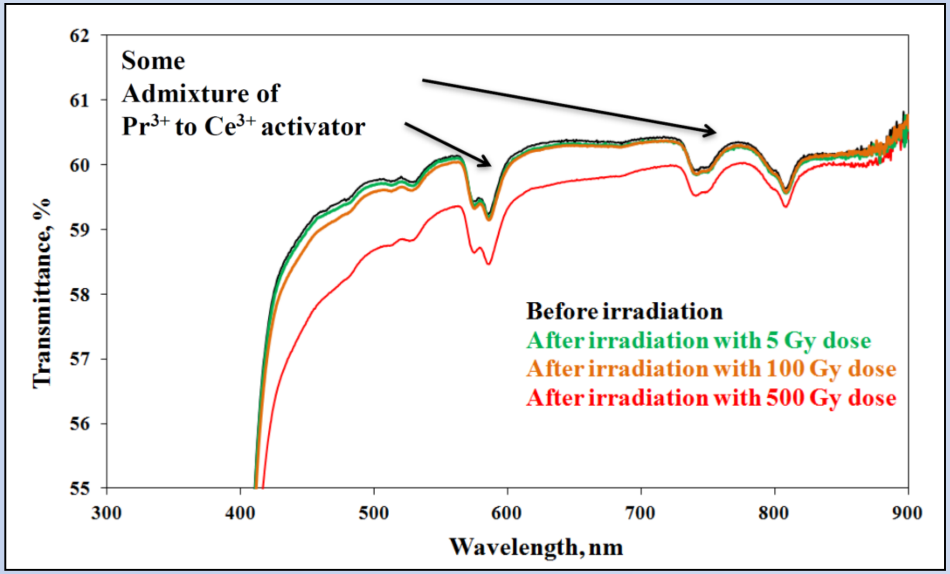
irradiation and recovery studies: 1.2 MeV γ – rays (^{60}Co)

quality of samples:

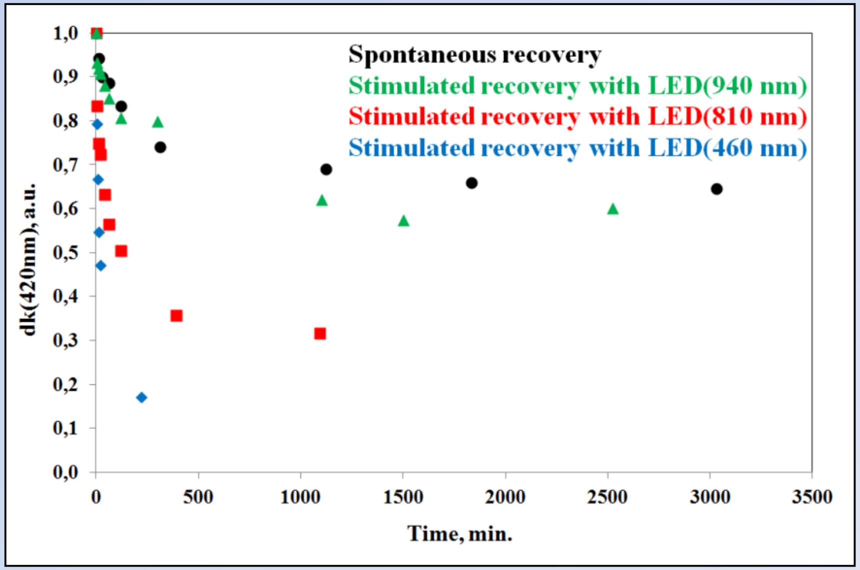
@RT, integration 4μs
dLY:/dT: +0.05%/°C
LY @ RT: 110 phe/MeV (4μs)



irradiation with ^{60}Co, 2Gy/min



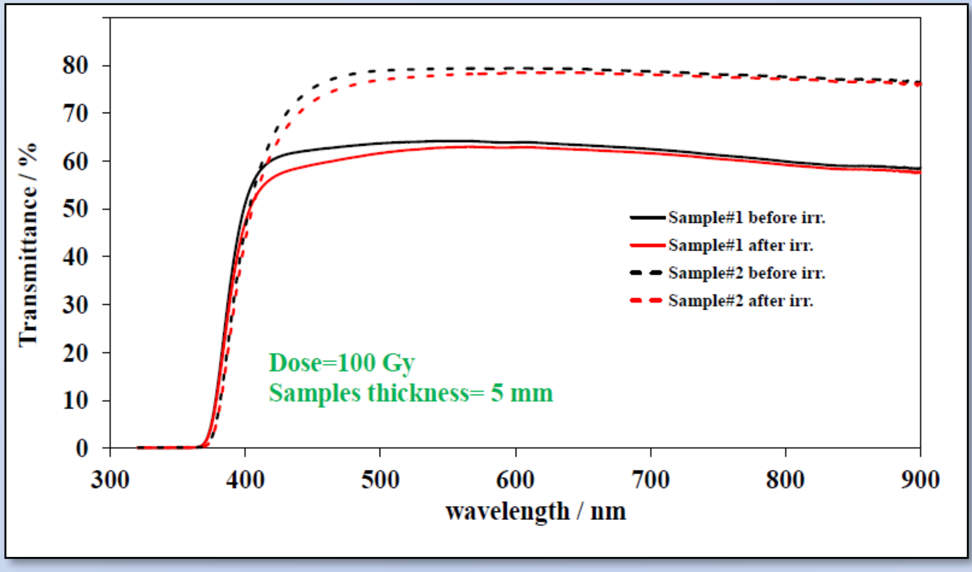
spontaneous and stimulated recovery



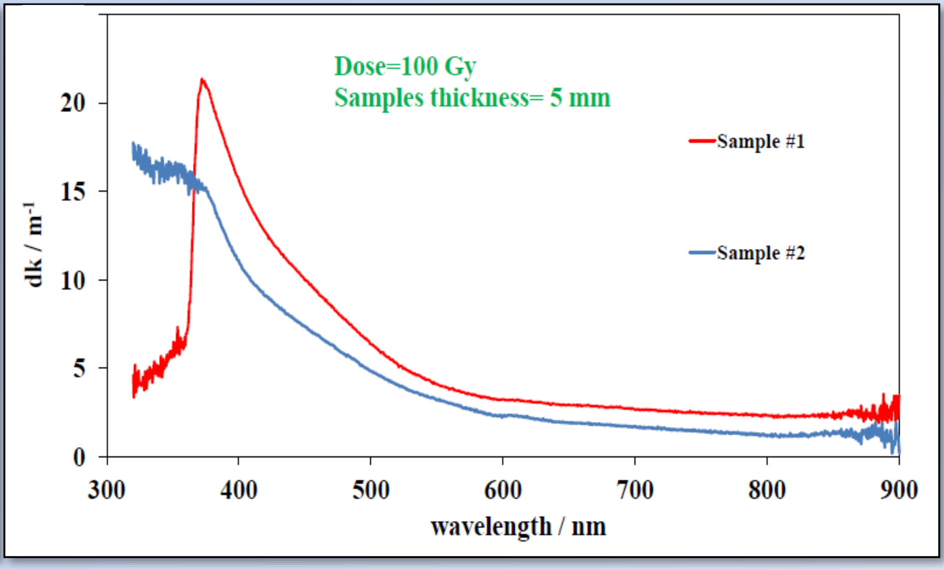
irradiation and recovery studies: 1.2 MeV γ – rays (^{60}Co)

DSB:Ce heavy loaded with Gd

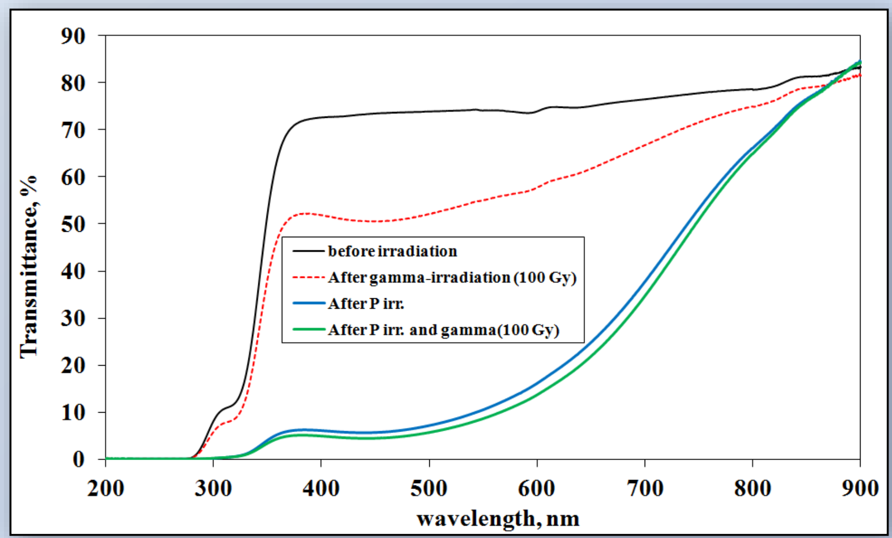
optical transmission



radiation induced absorption



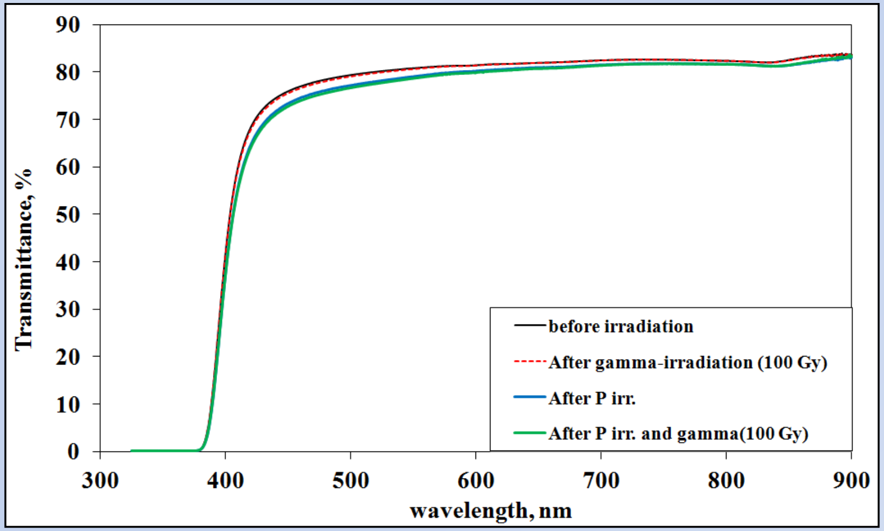
irradiation and recovery studies: with 150 MeV protons



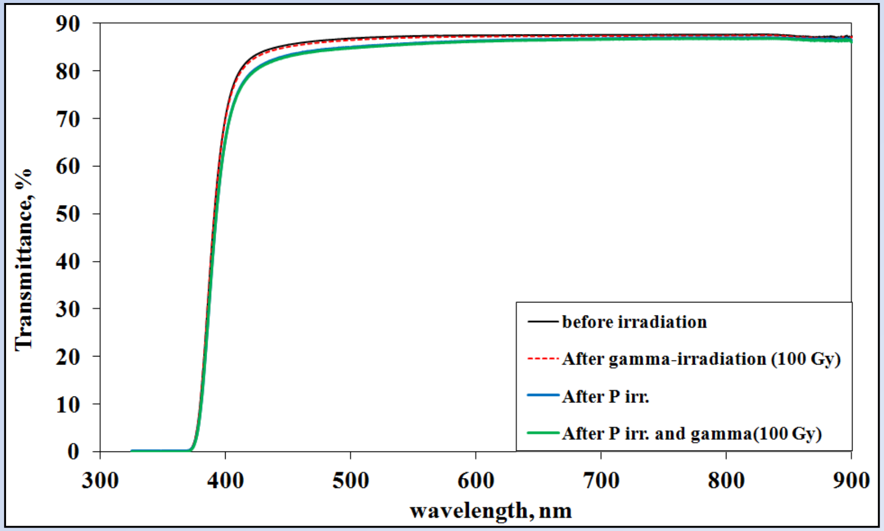
flux $\leq 2 \times 10^{11}$ p/s cm^2
integral fluence = 5×10^{13} p/cm^2

BaO x $2SiO_2$
(undoped mother glass)

BaO x $2SiO_2$: Ce
(without thermal treatment)



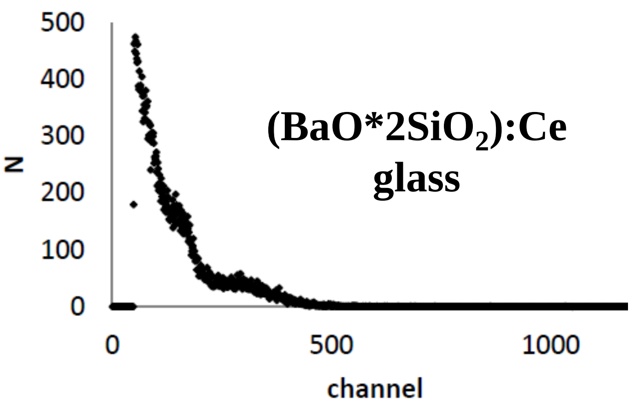
DSB: Ce
(after thermal treatment)

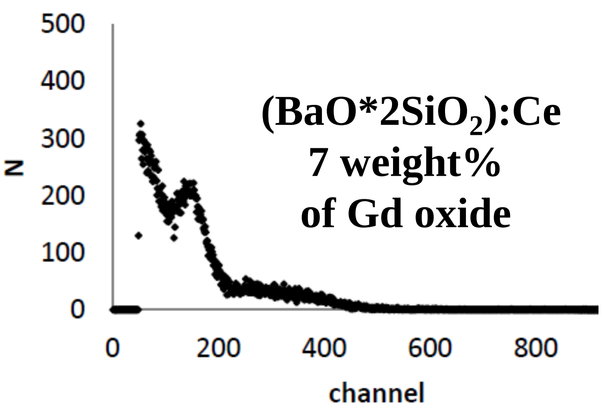


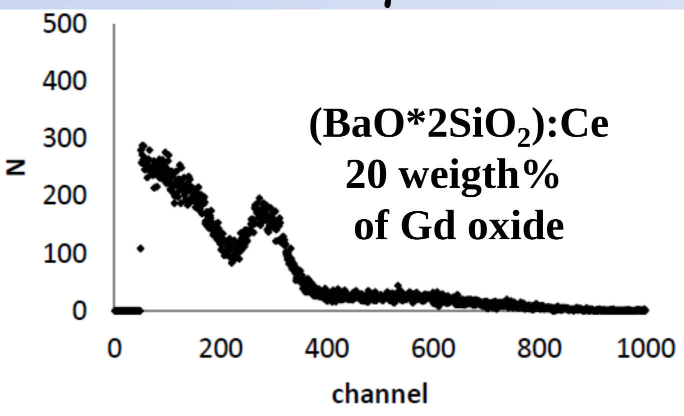
scintillation properties: kinetics

material	decay constants and their fractions in the kinetics		
	fast ns (%)	middfast ns (%)	slow ns (%)
$(BaO*2SiO_2)$:Ce glass	22 (12)	72(50)	450(38)
$(BaO*2SiO_2)$:Ce glass loaded with 7 weight% of Gd oxide		86(40)	330(60)
$(BaO*2SiO_2)$:Ce glass loaded with 20 weigth% of Gd oxide	50(19)	120(39)	400(40)

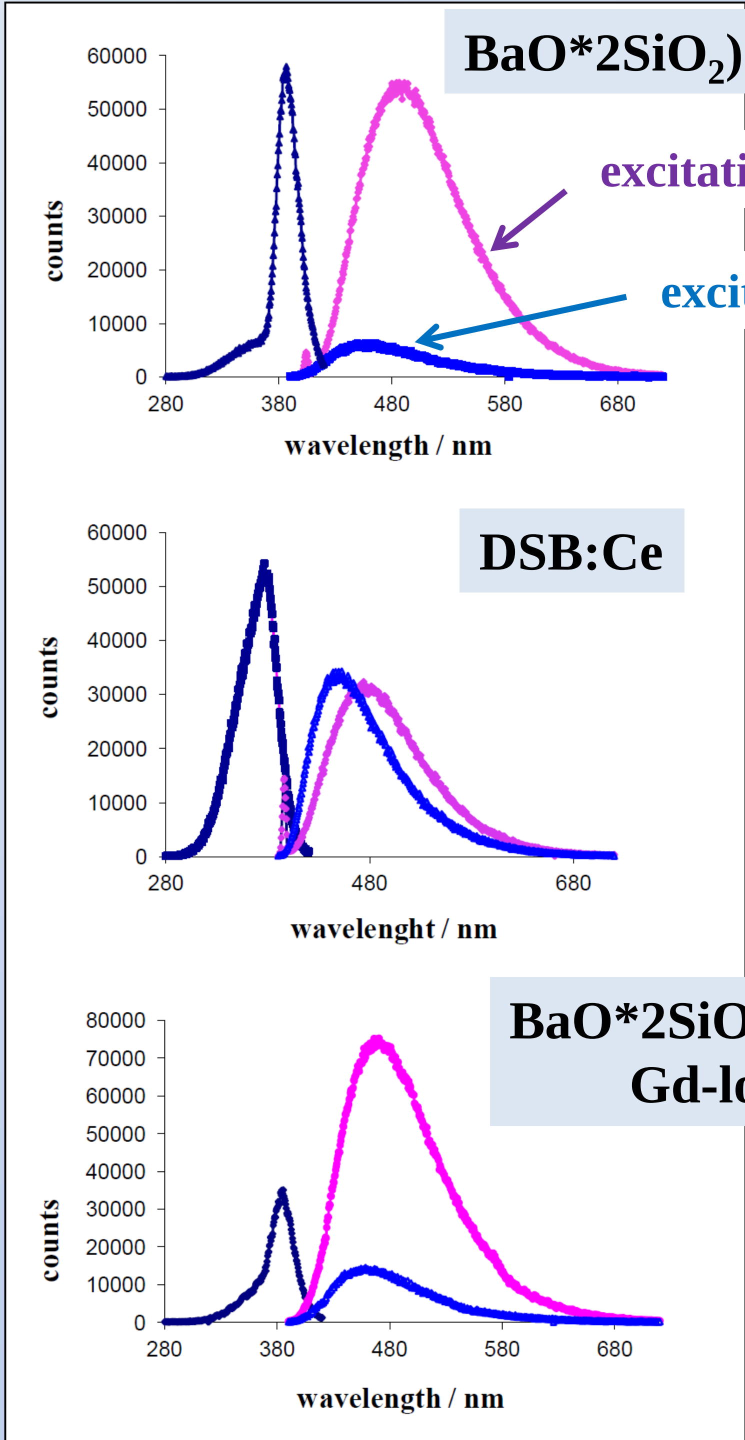
Leads to significant increase of light output measured with a ^{22}Na γ-source







the luminescence properties

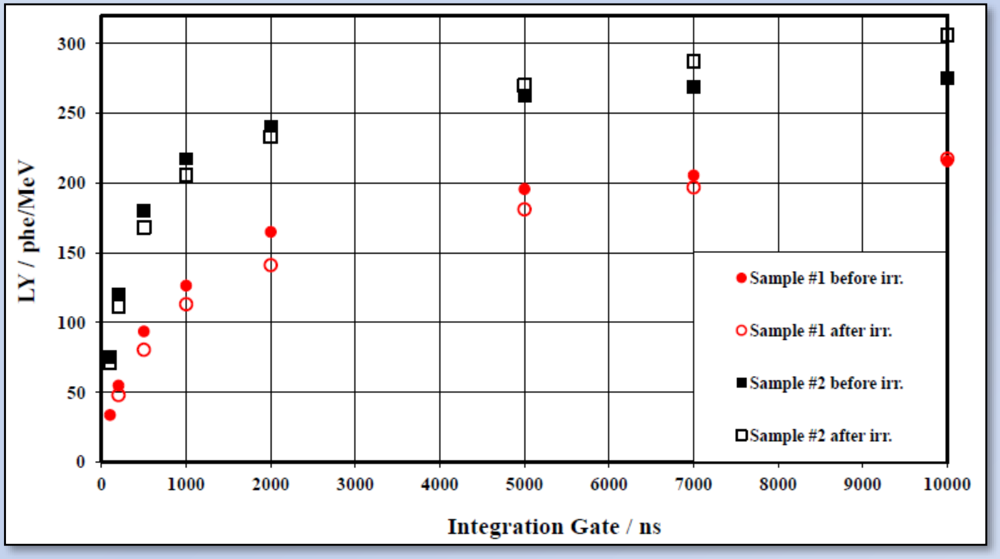


Gd^{3+}-loaded glass appears not to change the scintillation created by the Ce^{3+} centers

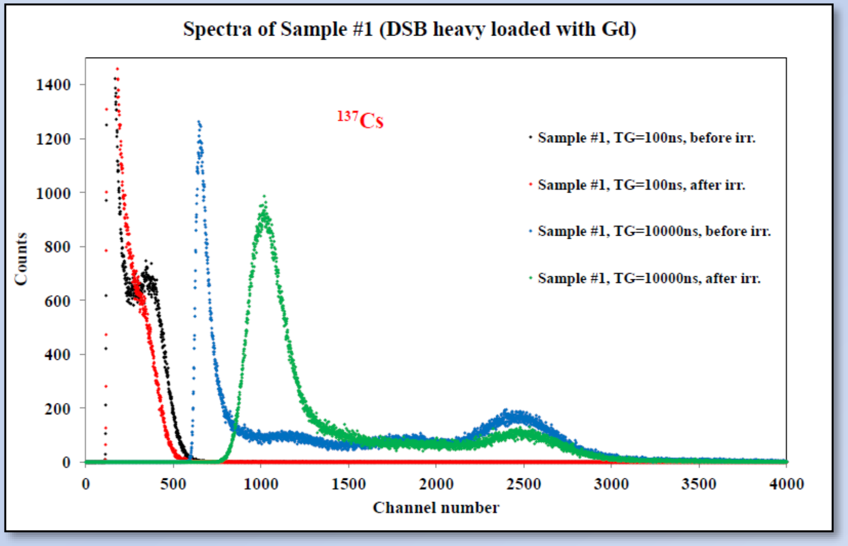
scintillation property of Gd-loaded samples

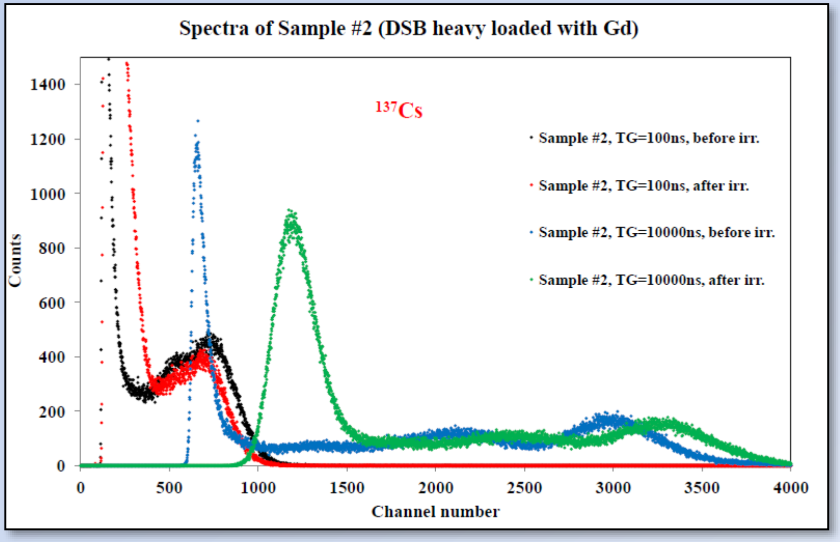
#1: 10 weight% Gd_2O_3
#2: 20 weight% Gd_2O_3
both: 0.5 weight% Ce

light yield as a function of integration length



response to ^{137}Cs-source (662keV)

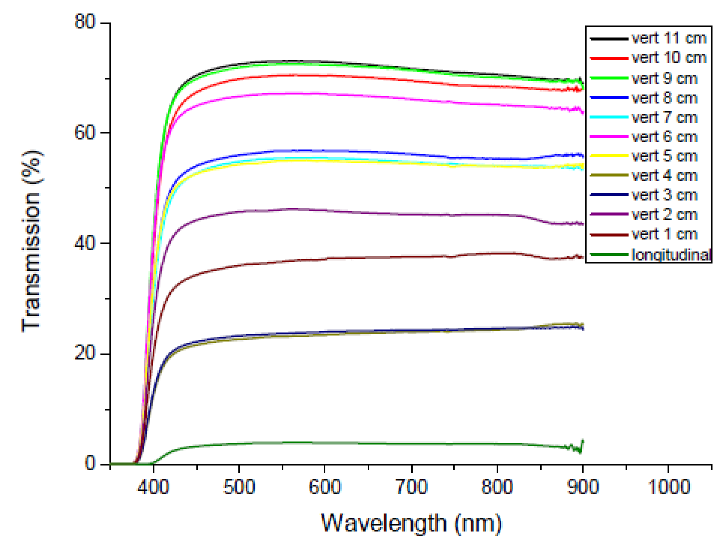




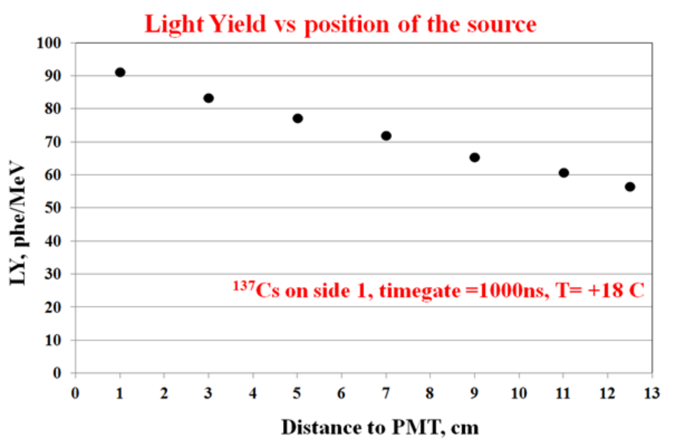
disturbed stoichiometry leads to additional traps and slows down the scintillation

DSB:Ce / Gd loaded large volume 23 x 23 x 125 mm^3

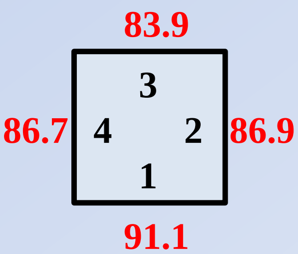
optical transmission



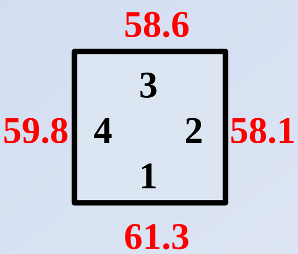
non-uniformity of light yield and light collection



Position 1 cm

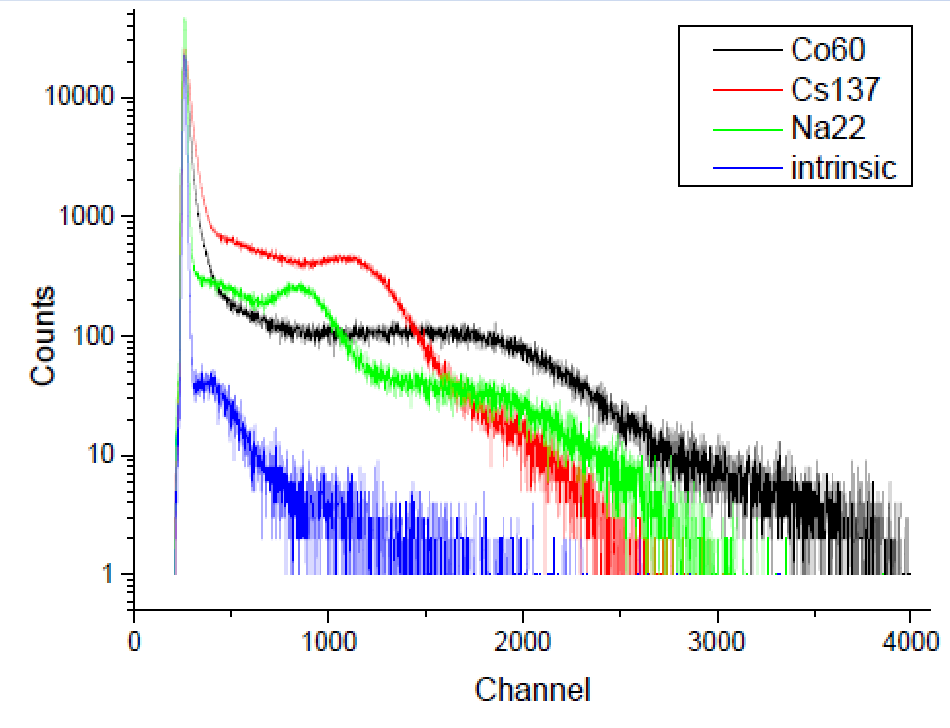


Position 11 cm

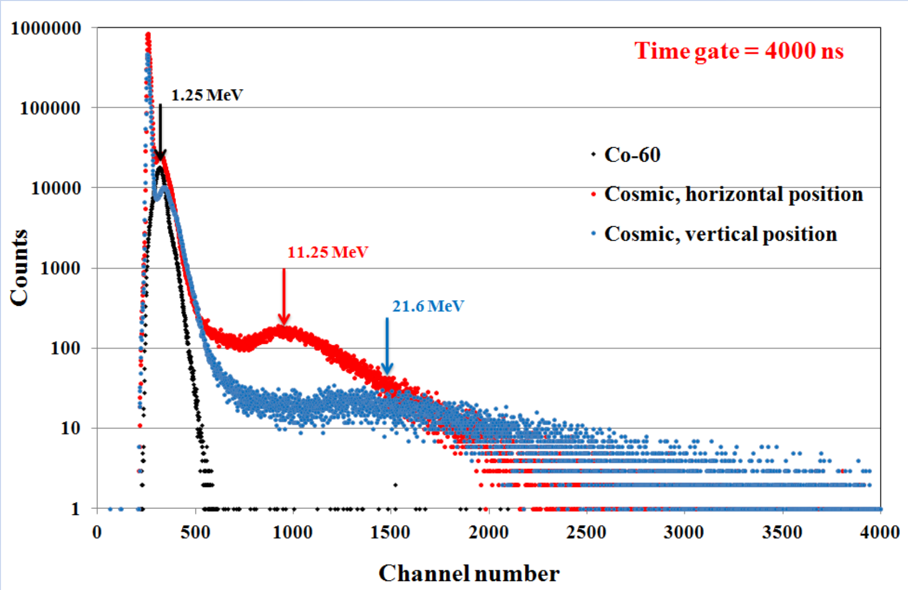


DSB:Ce / Gd loaded   large volume 23 x 23 x 125 mm^3

response to low energy γ-sources



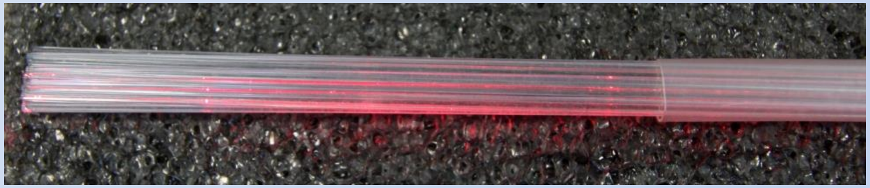
response to cosmic muons



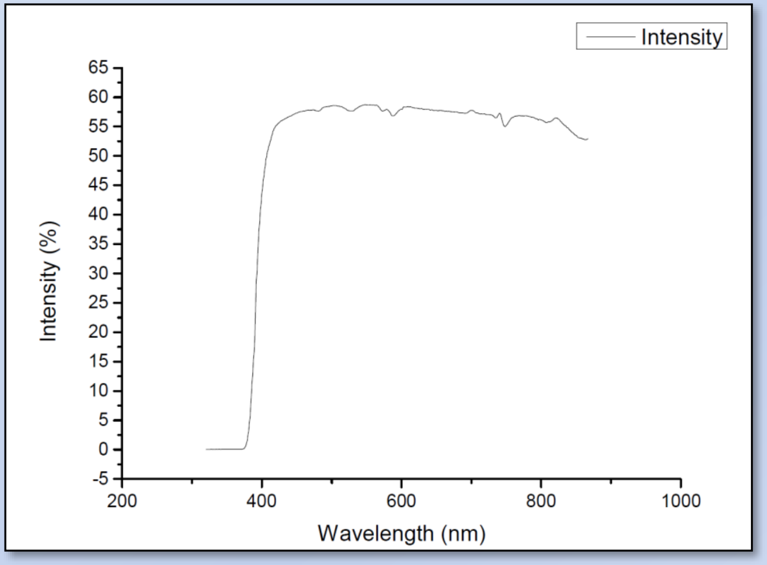
DSB:Ce fibers

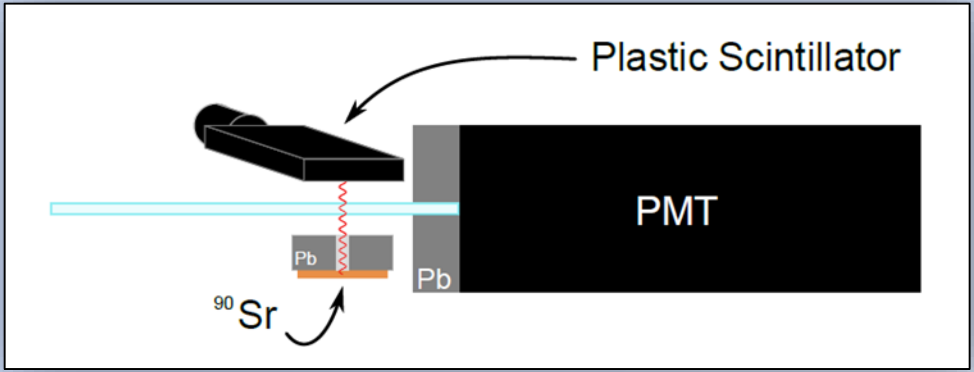
length: 200 mm

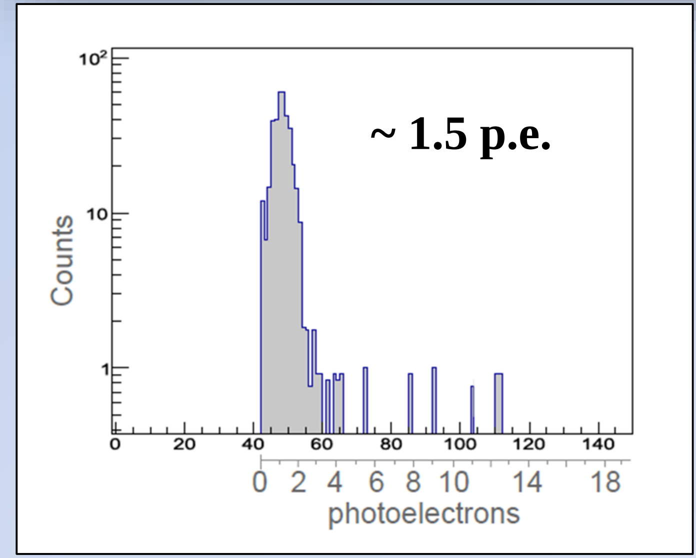
- **several macro defects**
- **short attenuation length**



optical transmission



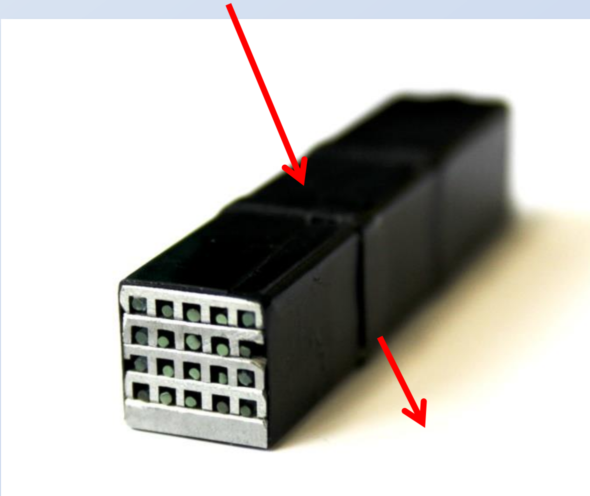


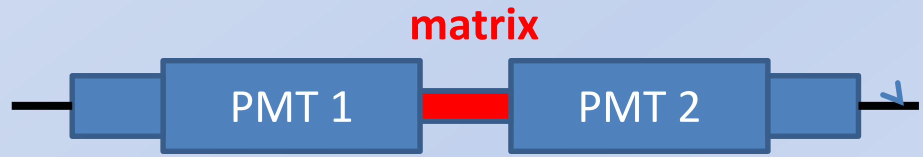


response to electrons (^{90}Sr)

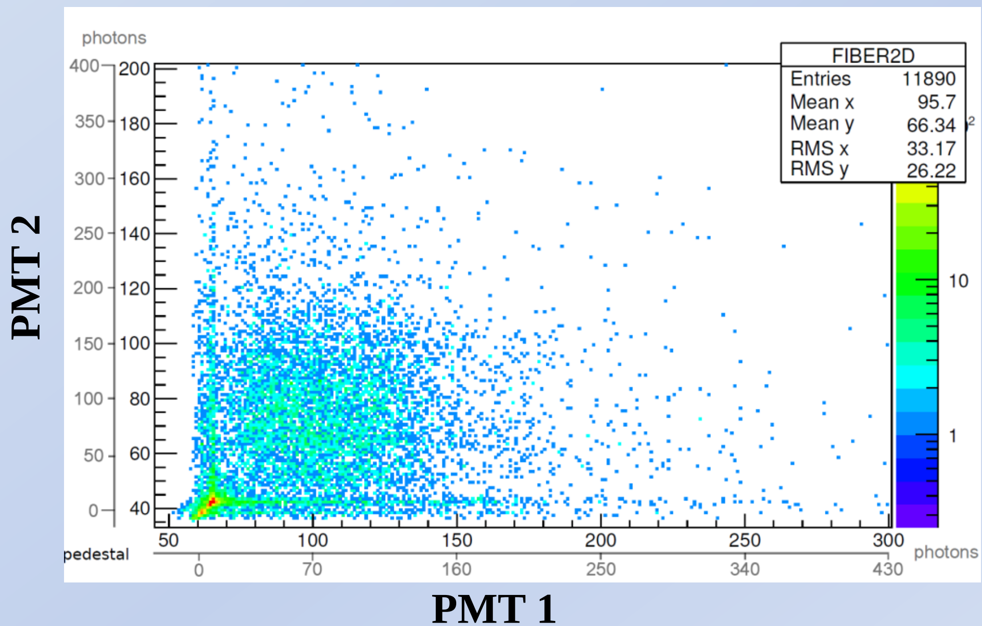
DSB:Ce testmatrix: 4 x 5

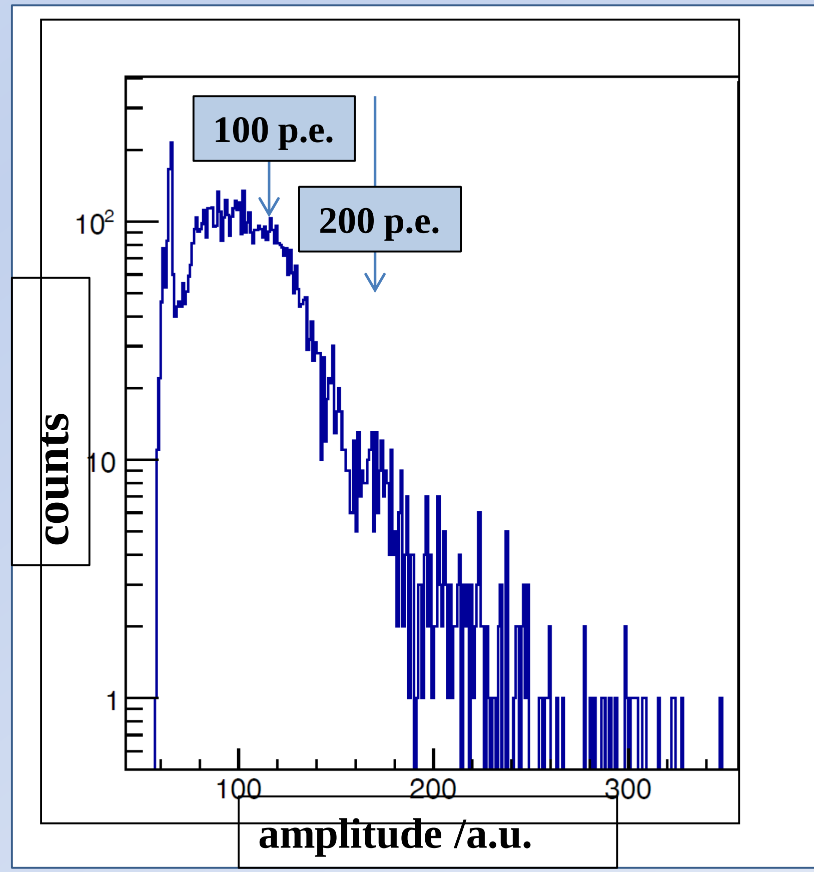
composed of: 20 fiber (1mm$^{\varnothing}$), 50mm
Mo - structure





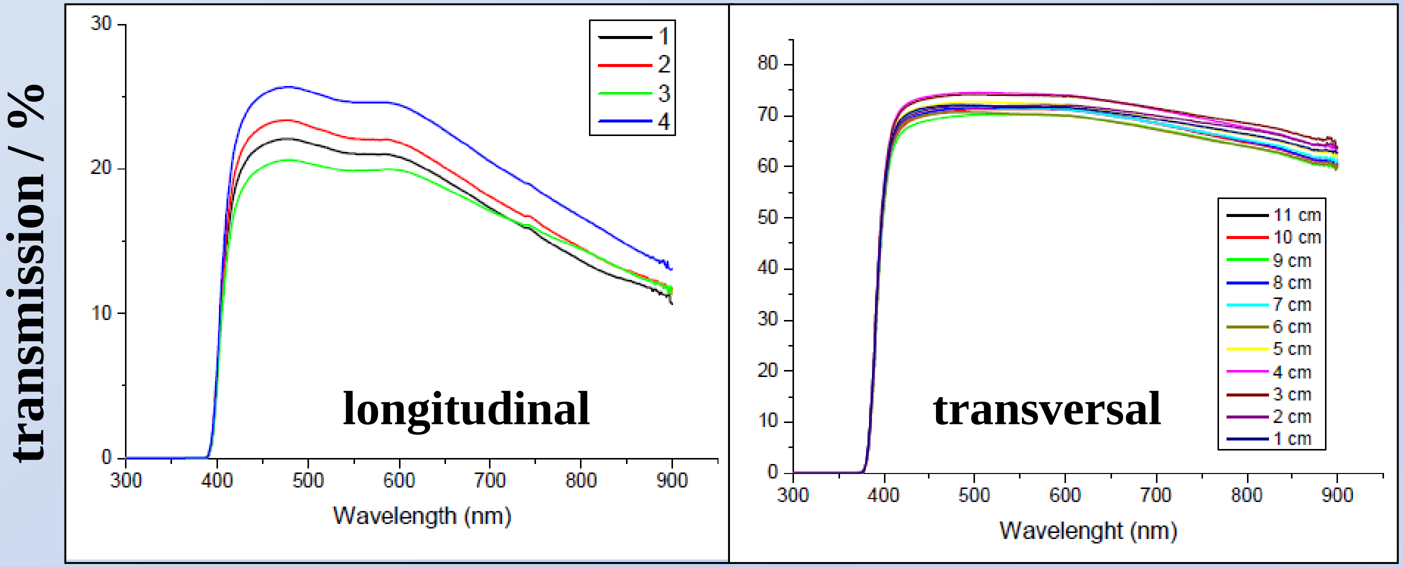
response to cosmics

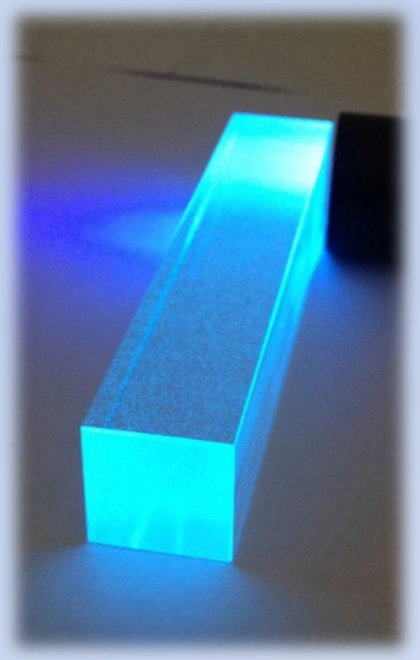




DSB:Ce large volume 23 x 23 x 120 mm^3

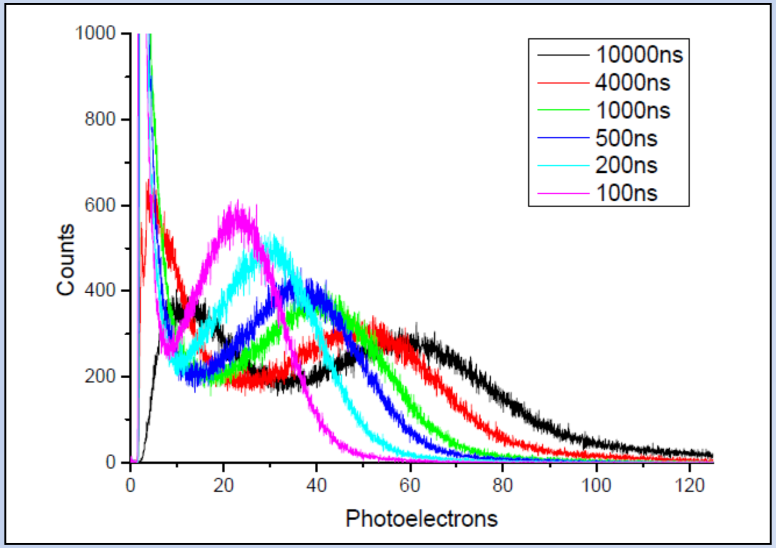
optical transmission

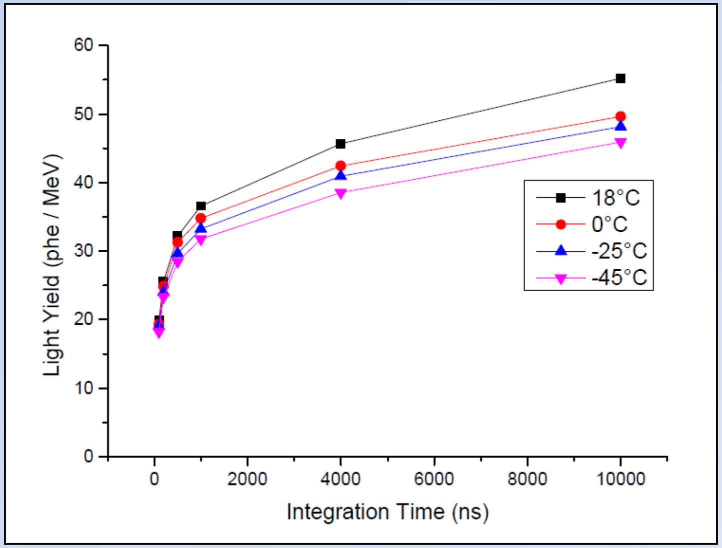




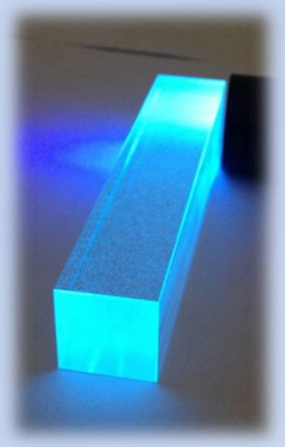
light yield

^{137}Cs

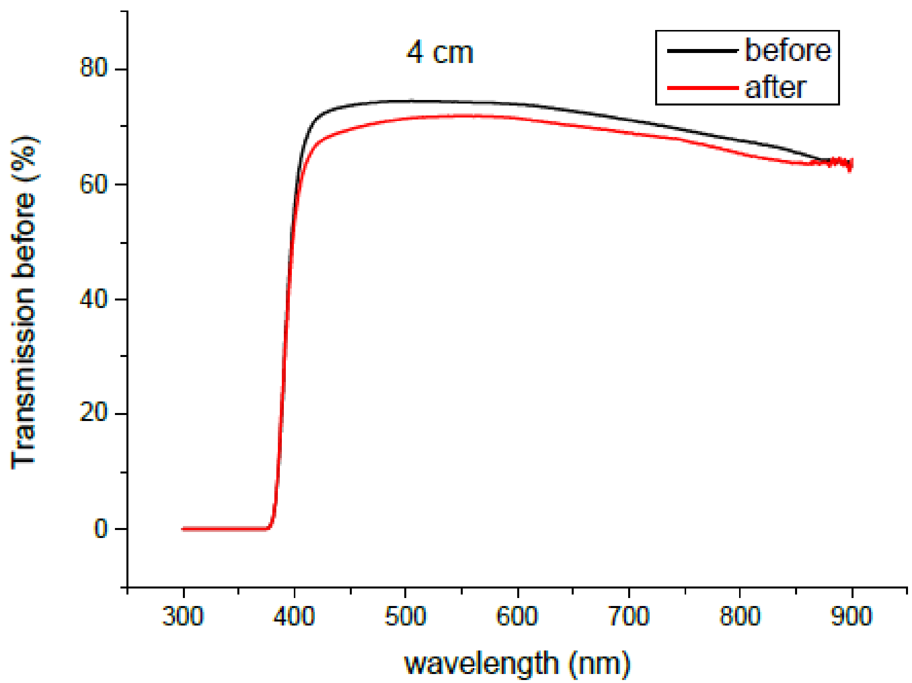


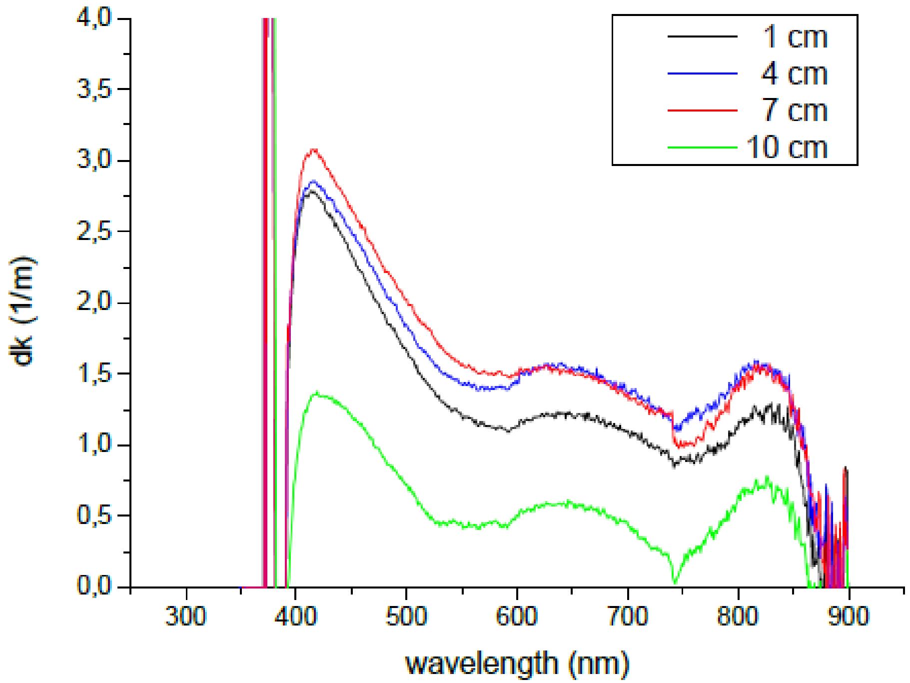


DSB:Ce large volume 23 x 23 x 120 mm^3



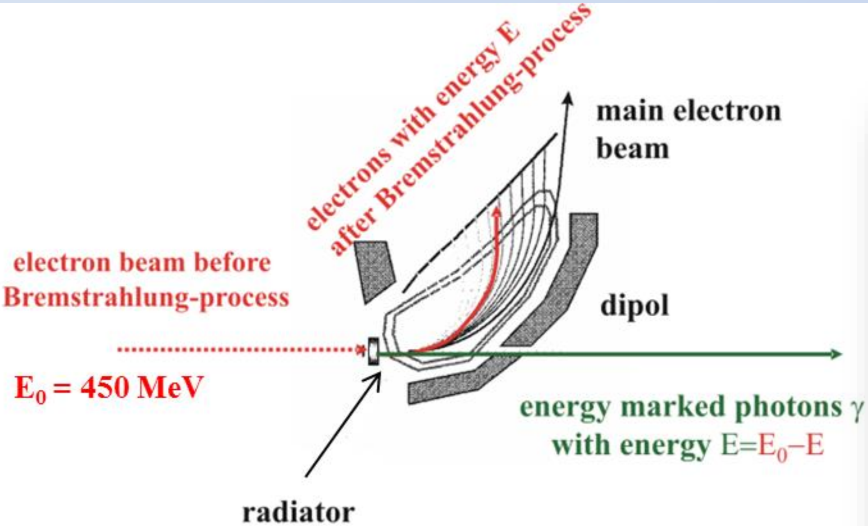
radiation hardness: **integral dose: 100Gy ^{60}Co**



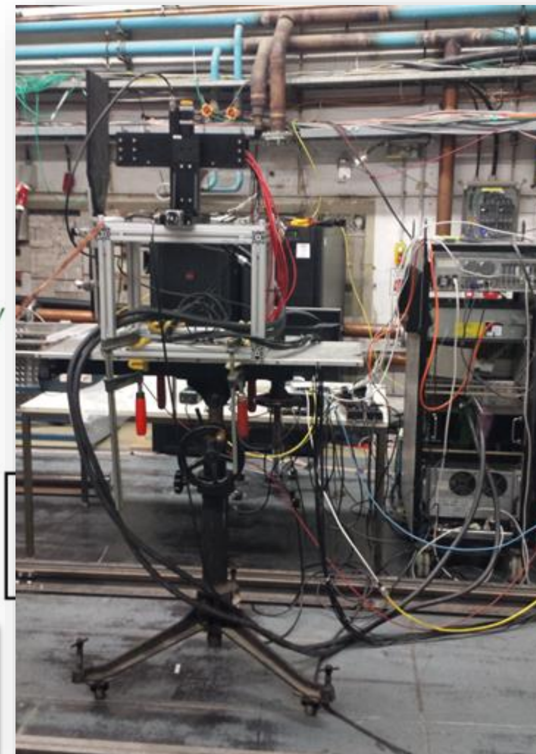


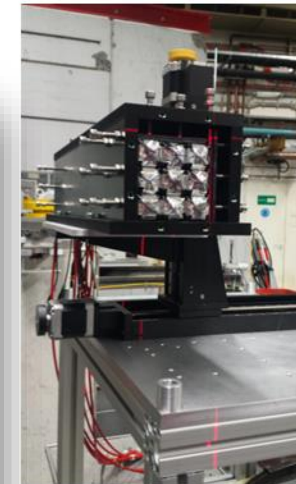
test of a 3x3 matrix made of DSB:Ce

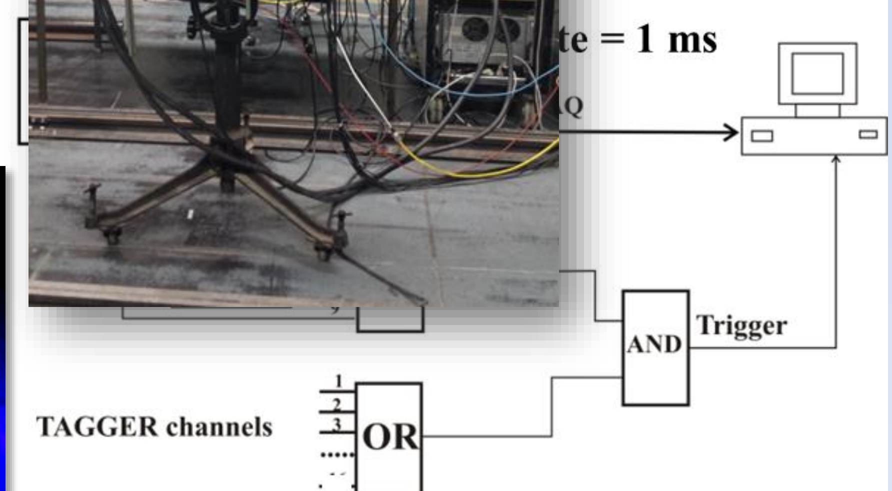
- composed of 9 DSB:Ce blocks 20 x 20 x 100 mm^3 (delivered in 6/2017)
- response function measured with energy-marked photons (21.8 – 180.7 MeV) at MAMI

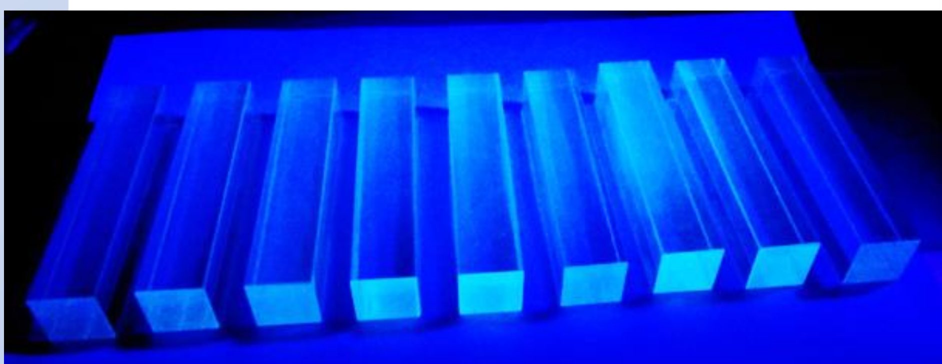


The collimated photon beam (∅ < 10 mm) was hitting the central module of the 3x3 DSB matrix
Scintillators read-out via PMT: Philips XP1911.



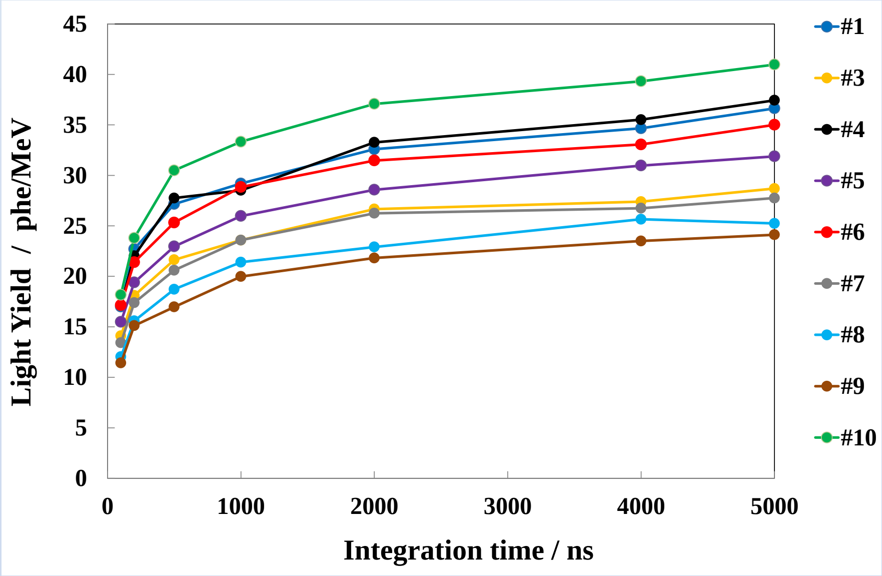


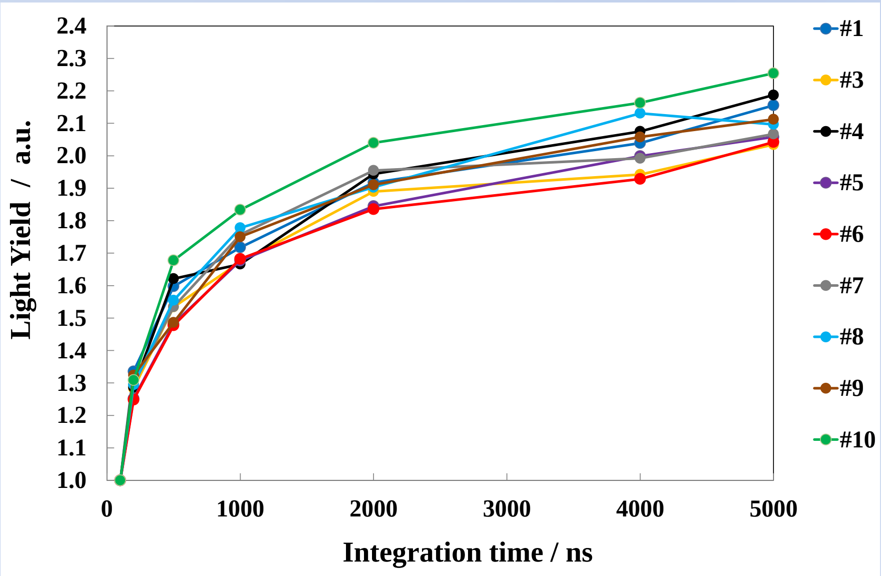




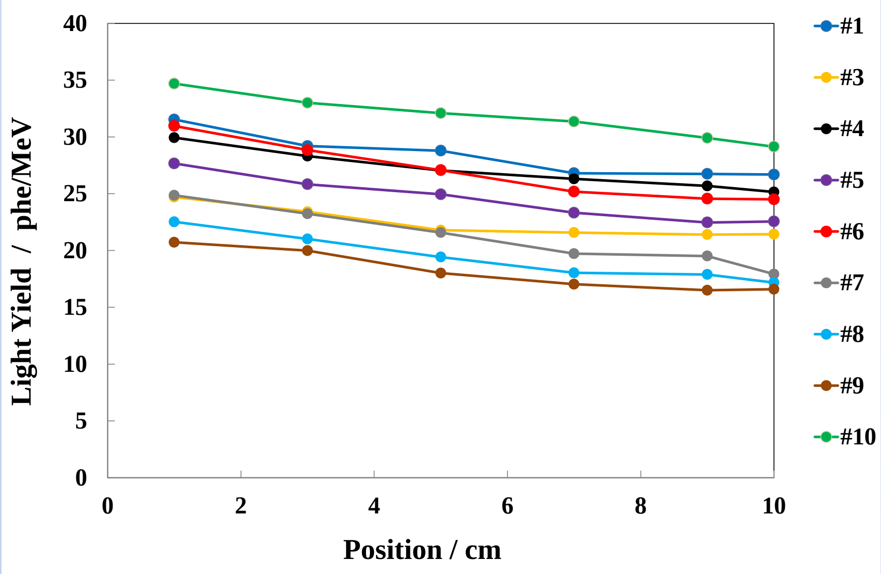
individual properties of the 9 DSB:Ce samples

light yield as a function of integration time @ room temperature

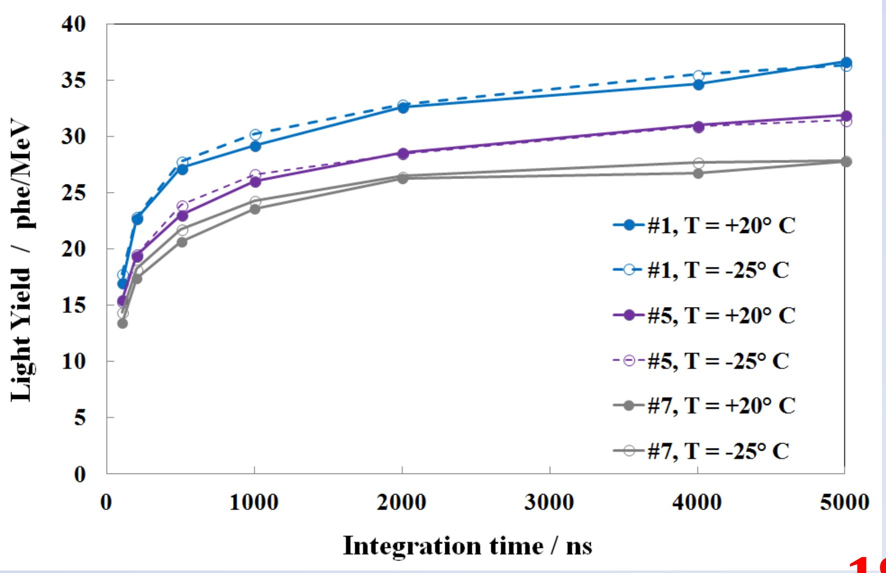




non-uniformity of the light yield

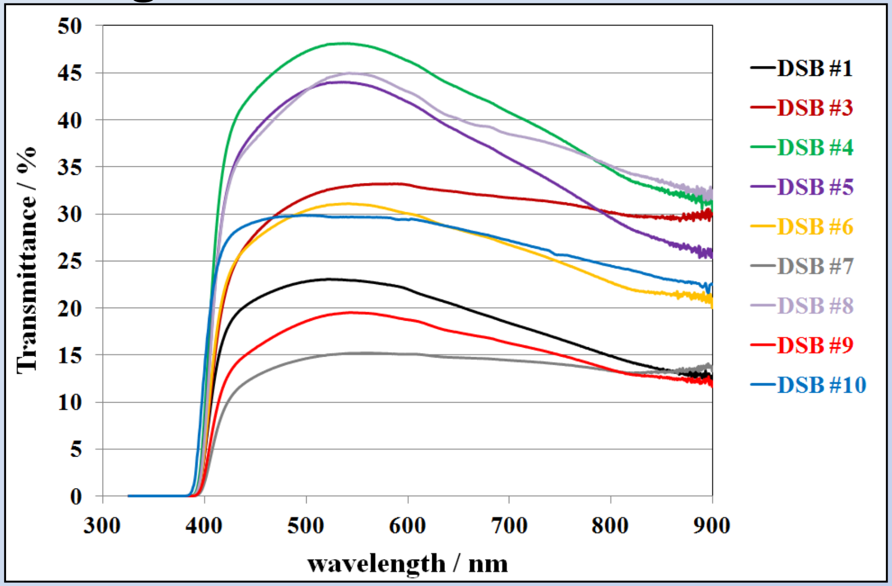


light yield as a function of temperature

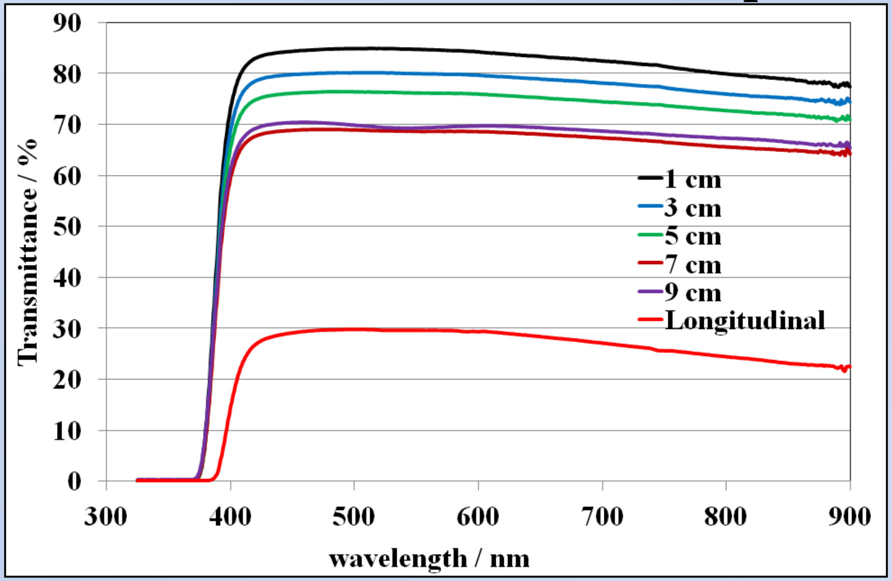


individual properties of the 9 DSB:Ce samples

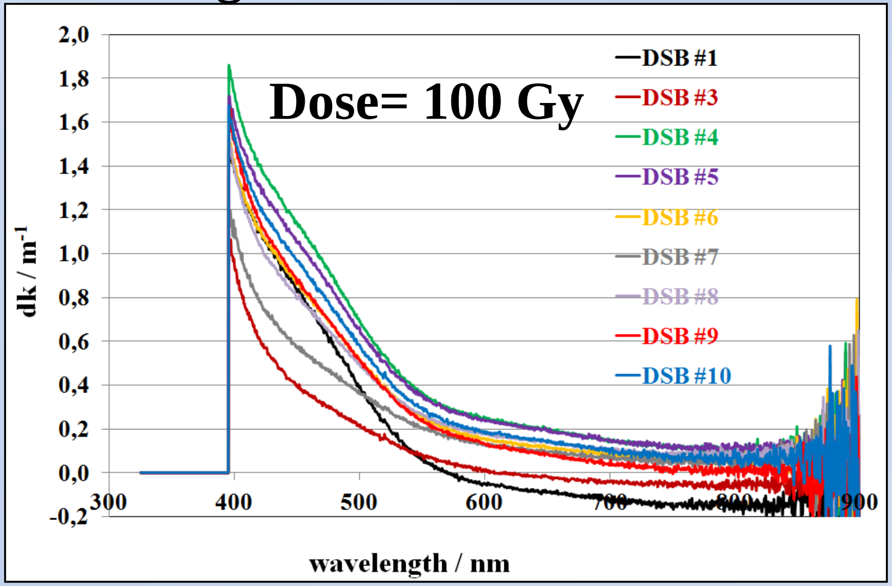
longitudinal transmittance



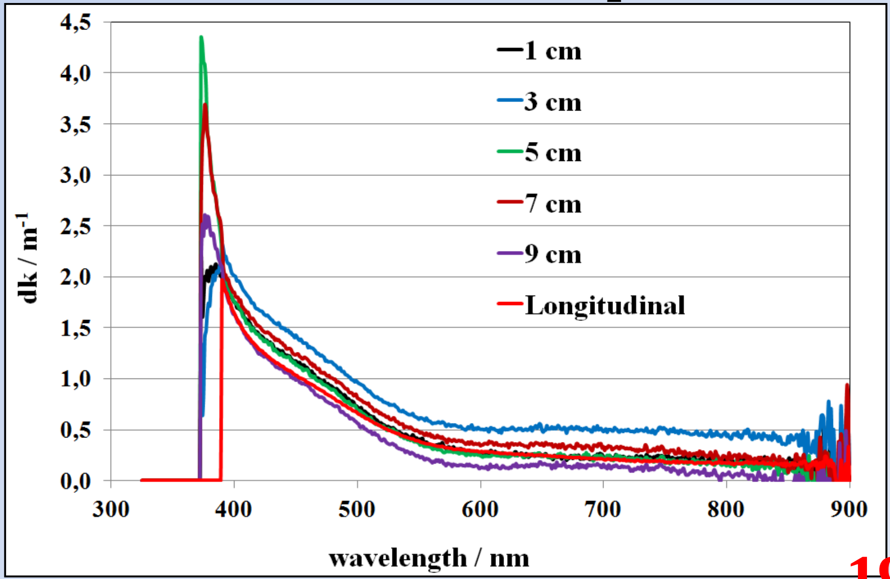
transversal transmittance of sample #10



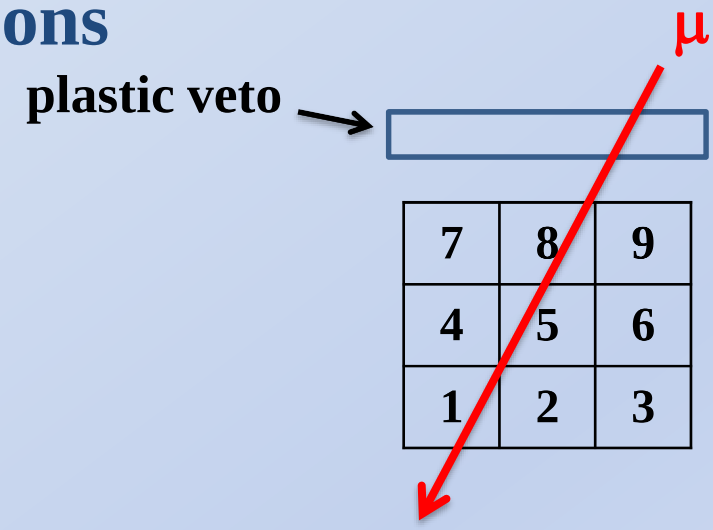
longitudinal dk

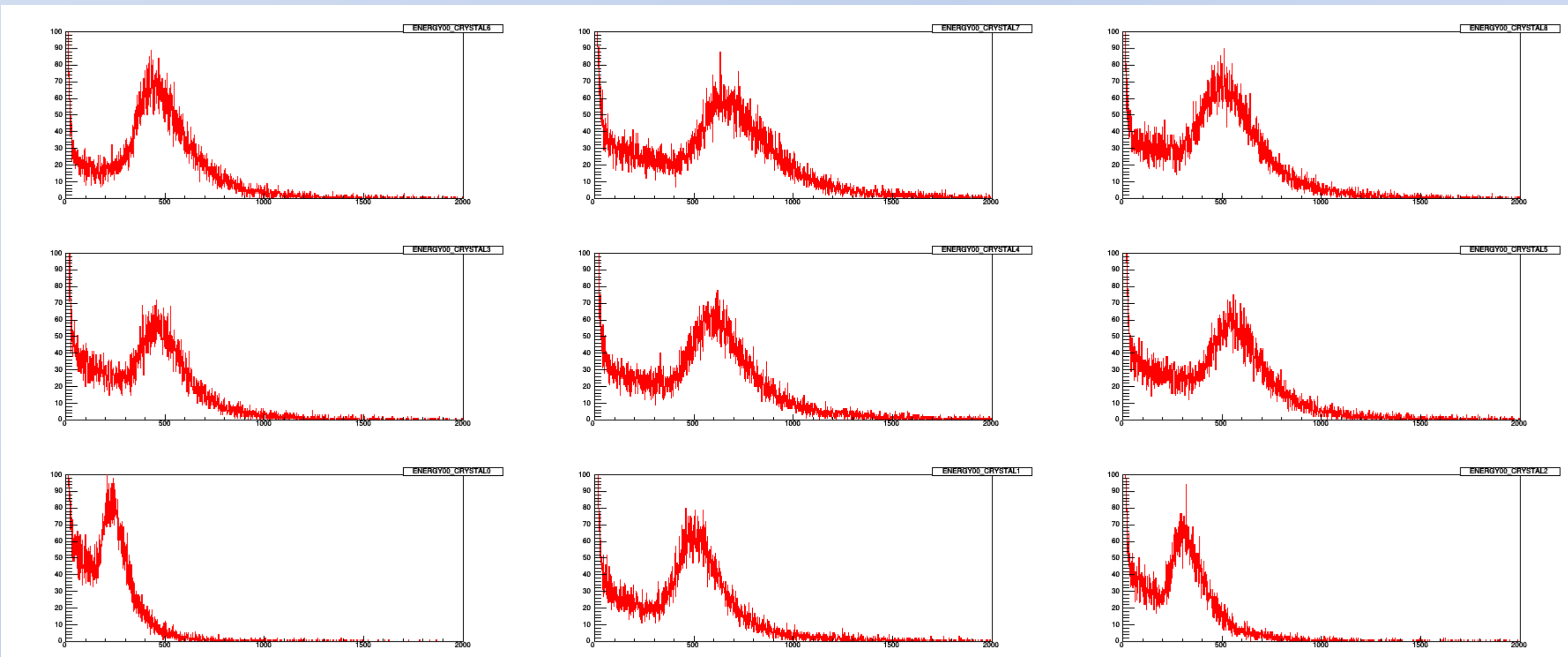


transversal dk of sample #10



response to cosmic muons





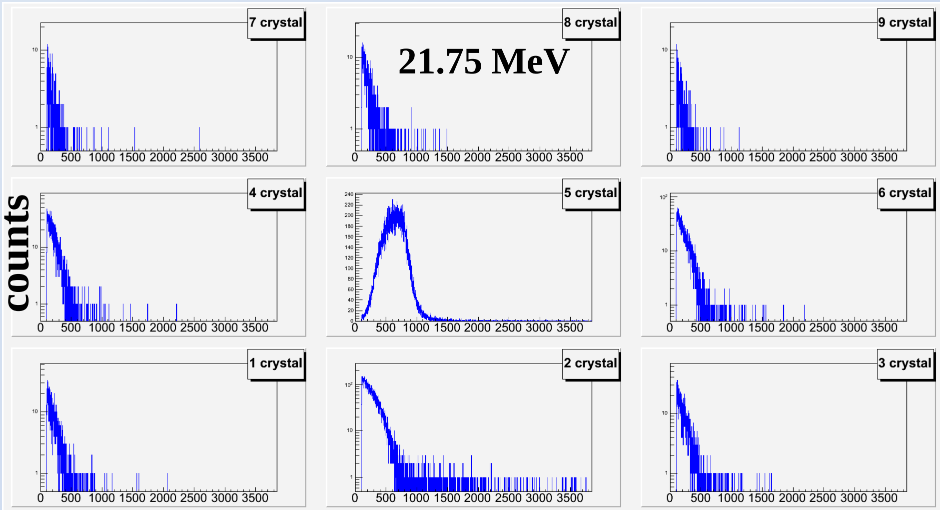
counts

energy deposition / a.u.

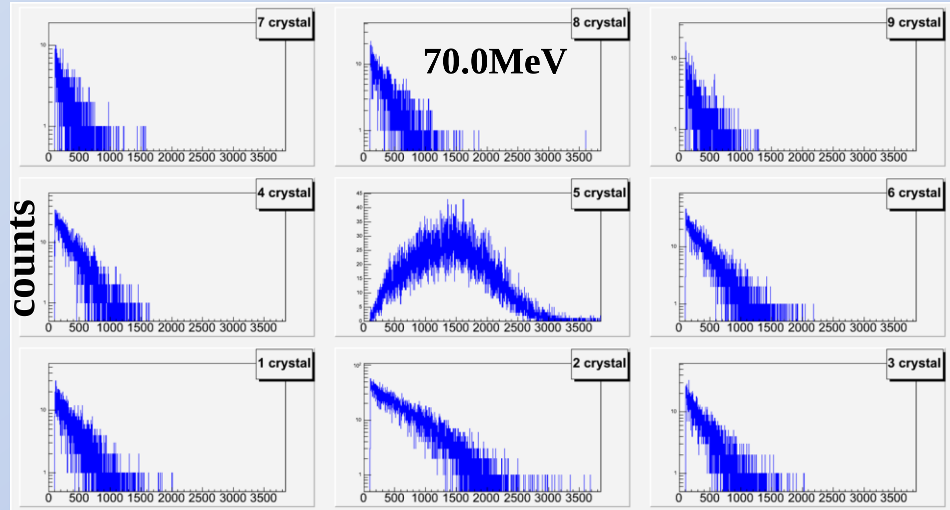
shower response

E_{thr} = 2 MeV

counts

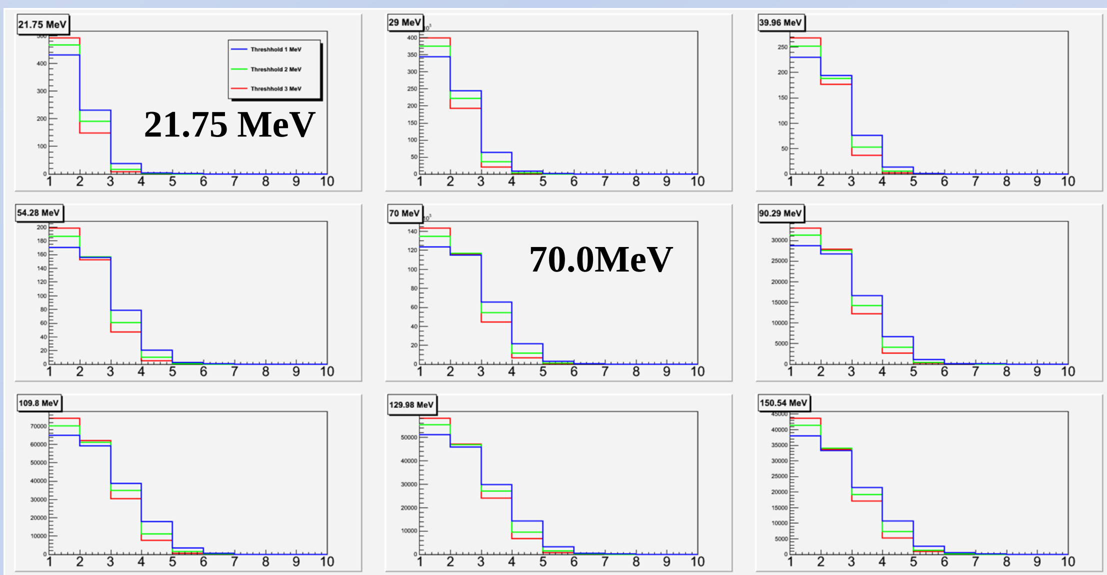


counts



energy deposition / a.u.

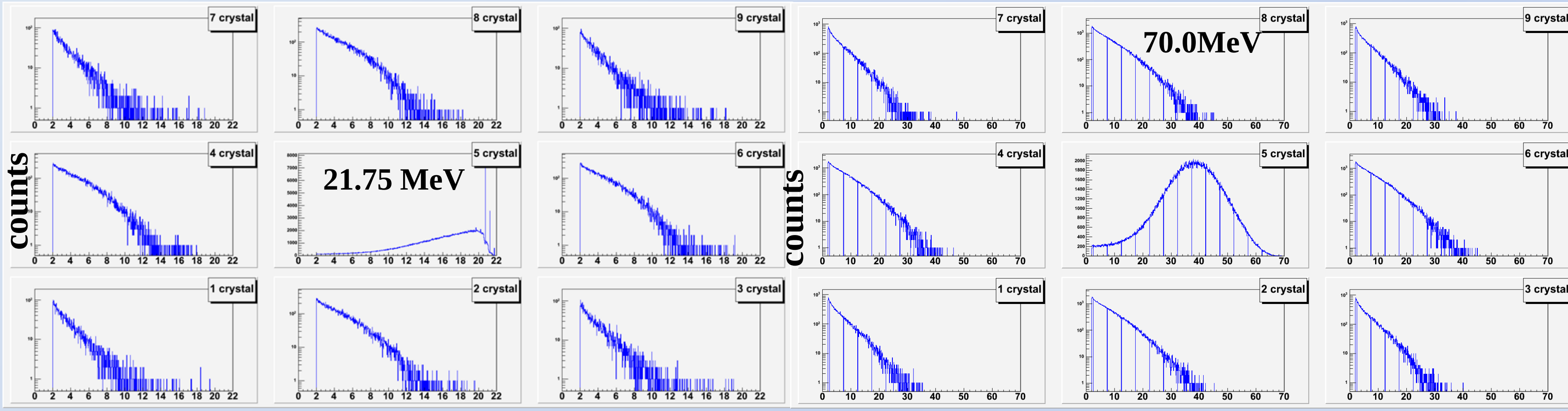
counts



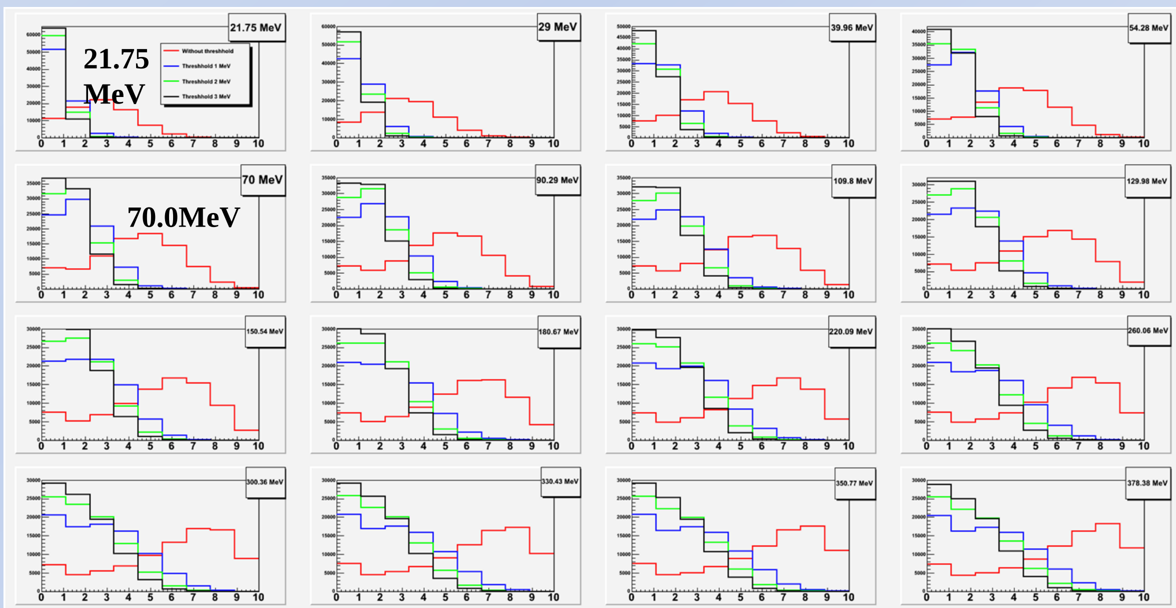
multiplicity

shower response

simulation GEANT4



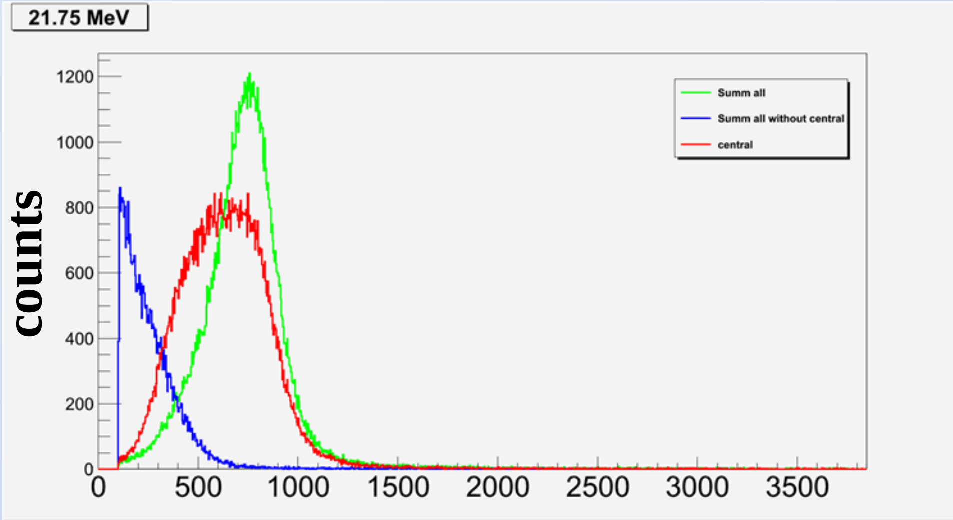
energy deposition / a.u.

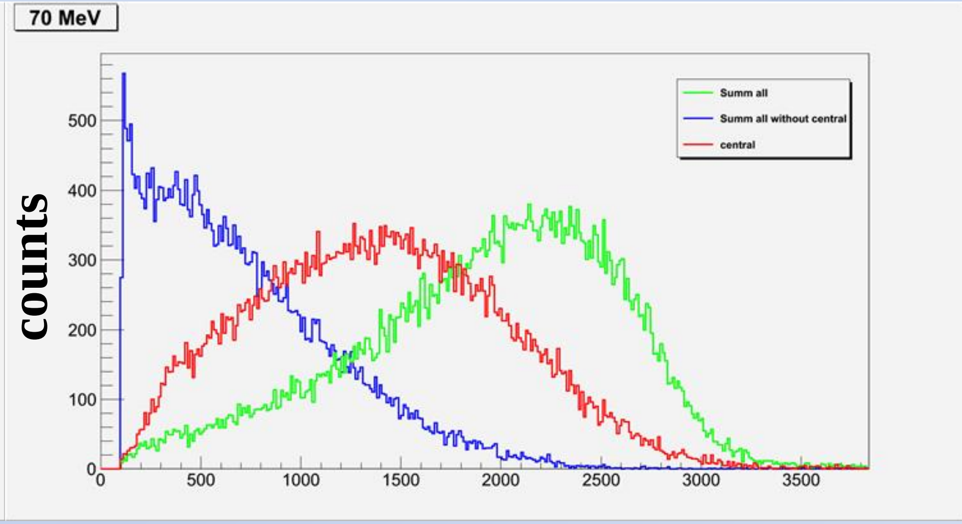


counts

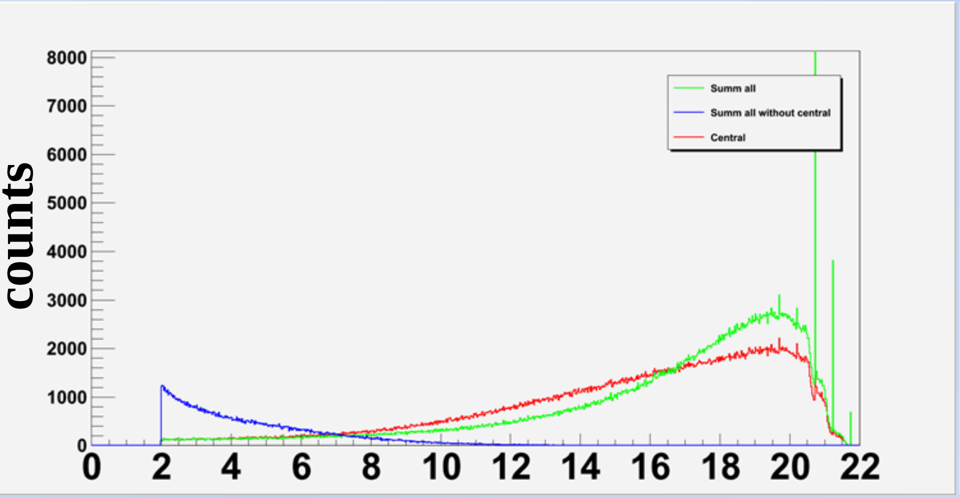
multiplicity

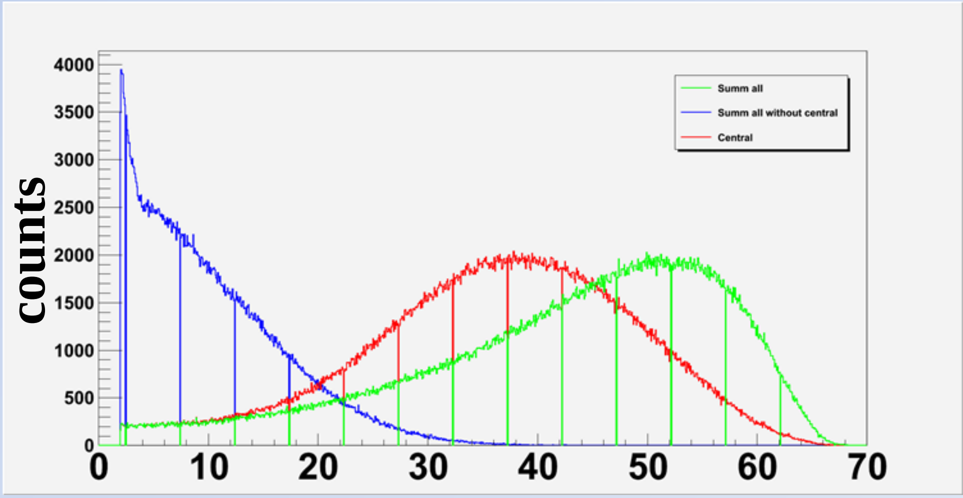
energy response and resolution





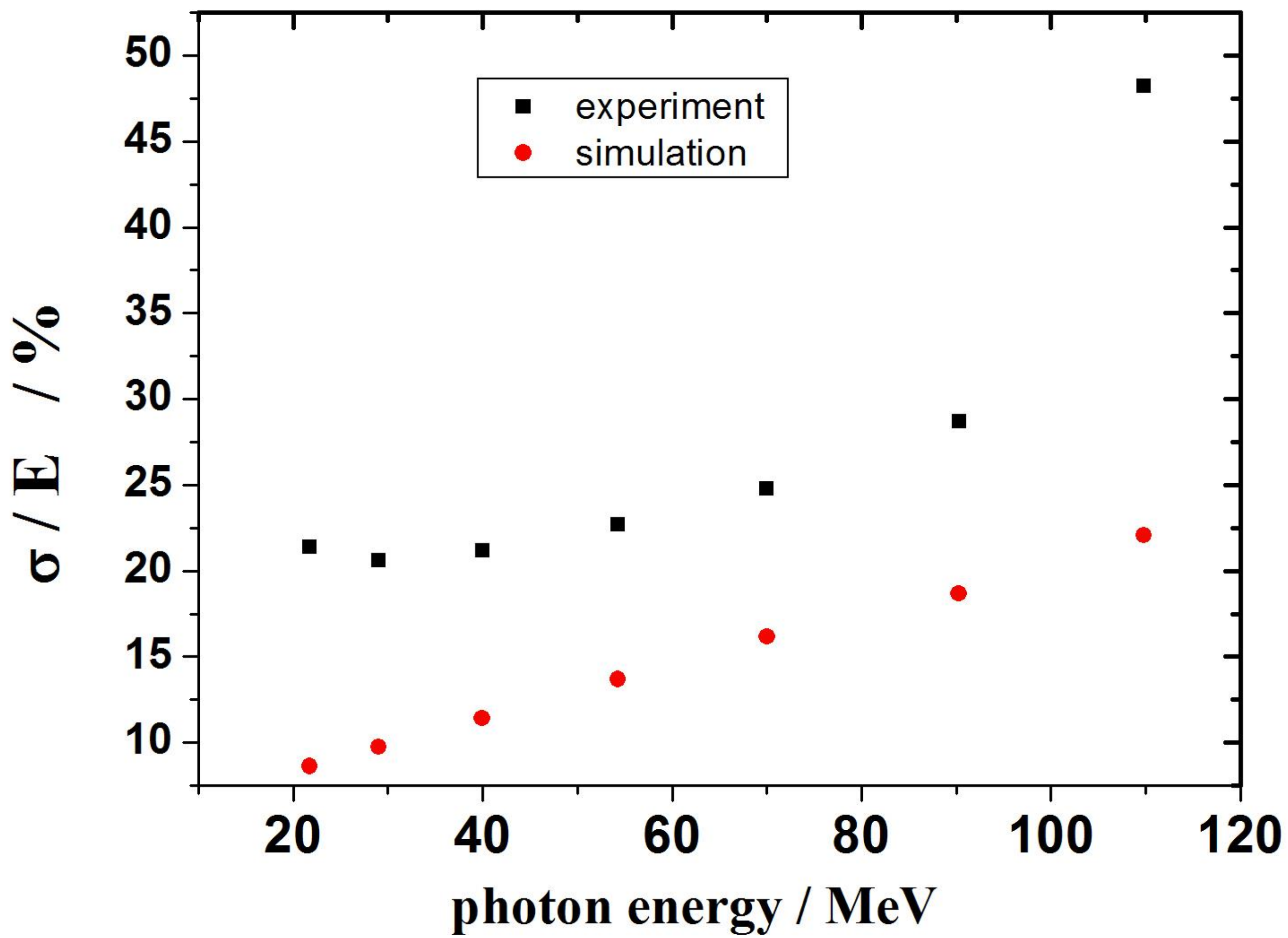
energy deposition / a.u.



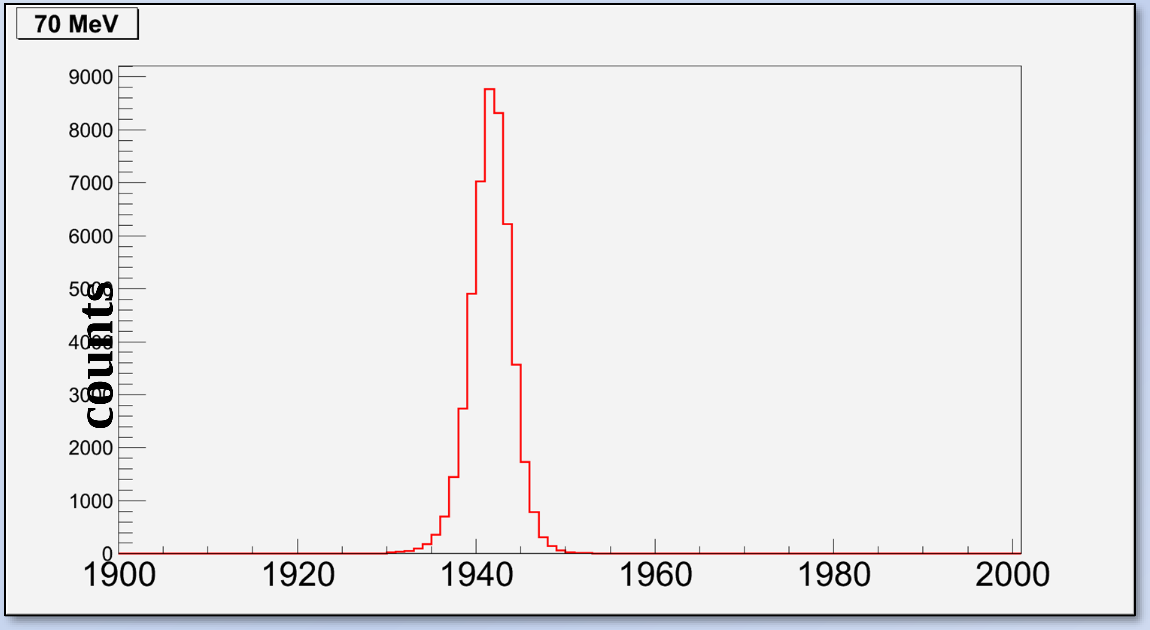


energy deposition / MeV

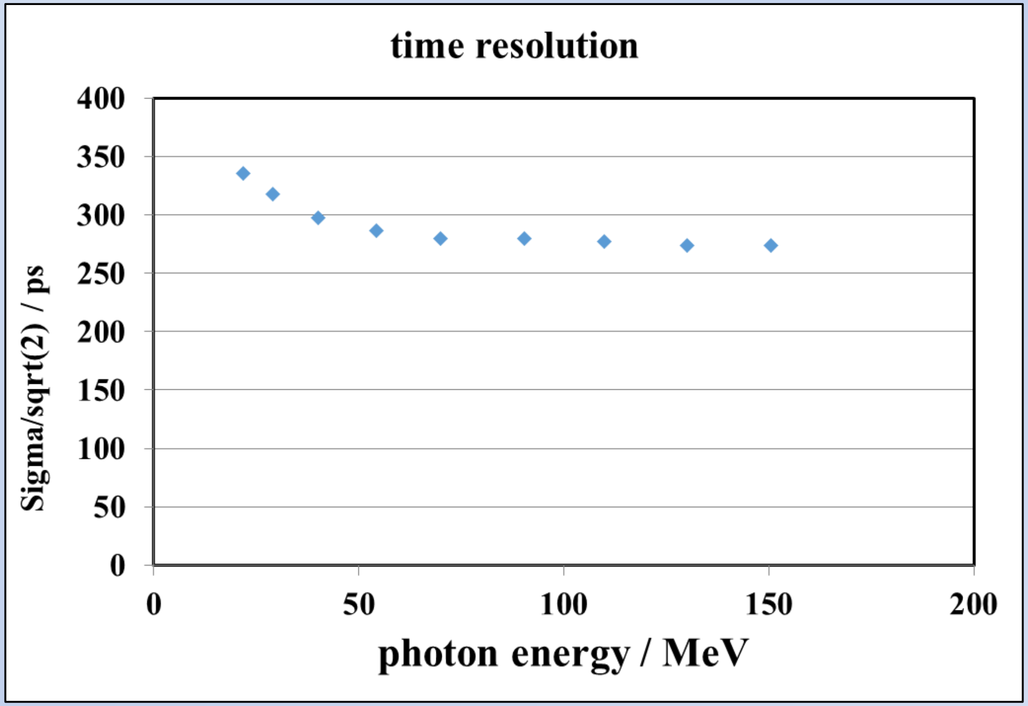
energy response and resolution



time response



time difference / a.u.

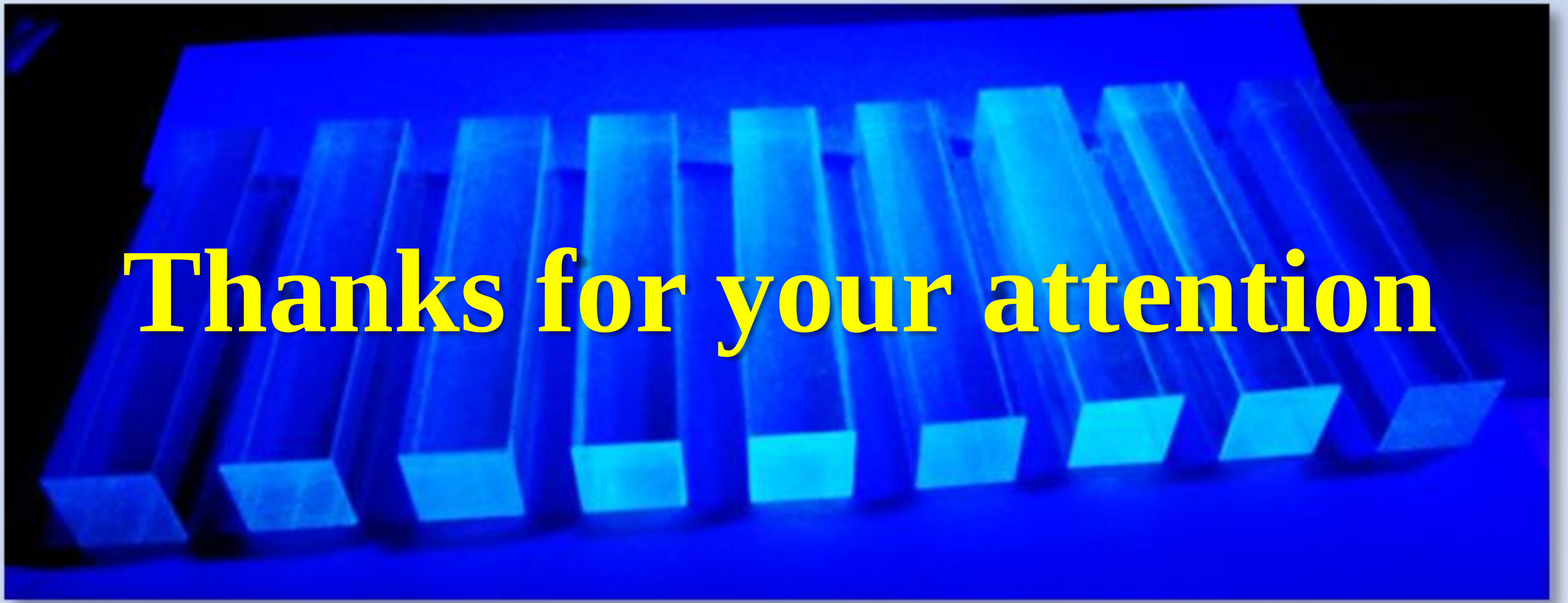


summary and outlook:

- DSB:Ce appears to be a promising material
- loading with Gd^{3+} increases the sensitivity to e.m. probes
- variable scintillator shapes

to do list:

- detailed understanding of scintillation centers and the process of thermal annealing
- homogeneity of large scintillator blocks
- optimization of Ce^{3+} concentration and Gd/Ce ratio
- fiber production free of cracks
- alternative: cutting of rectangular fibers from blocks



Thanks for your attention