Irradiation tests and characterization on pure and thallium doped CsI crystals and optical components at ENEA-Casaccia

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INFN Frascati (Italy)

Belle2 Italia Meeting, December 17, 2014

Outline

- ✓ **Optical and scintillating properties of CsI(Tl) and pure CsI scintillating crystals (different manufacturers) before and after gamma irradiation**

  - *Radiation hardness* (longitudinal transmission spectra)

    - *Light Yield* (monitoring the CR amplitude peak as a function of irradiation dose)

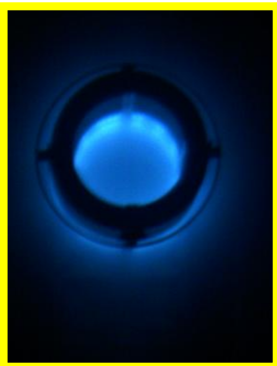
- ✓ **Performances evaluation of optical coupling materials**

  (silicon resins)

- ✓ **APD Quantum Efficiency with calibrated PIN diode** (before and after irradiation)

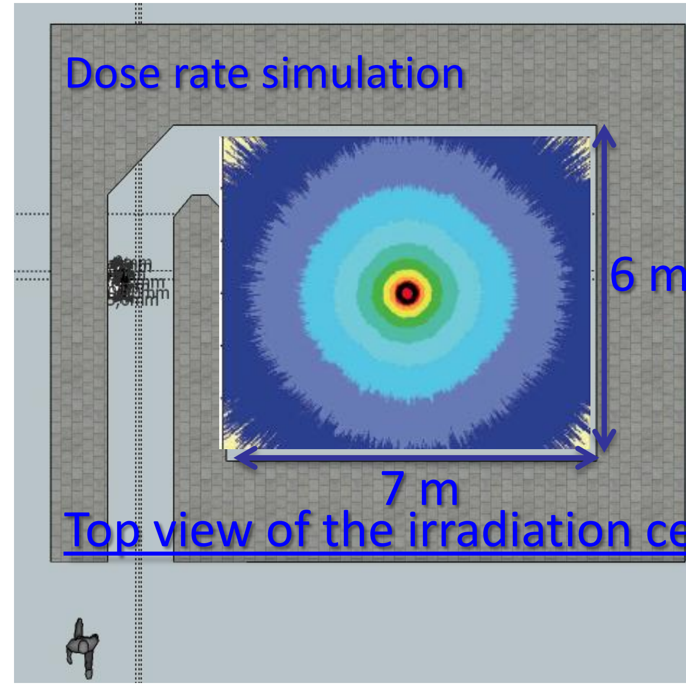
Calliope Gamma Irradiation Facility

Calliope facility: ^{60}Co high intensity gamma irradiation facility (up to 3×10^{15} Bq)



Mean energy:

1.25 MeV



Up to 2.3 kGy/h dose rate

Down to 0.1 Gy/h dose rate

Characterization of CsI (Tl) scintillating crystals

Amcrys (Ukraine)

CsI (Tl) crystals and characterizations

I group: *two spare (not irradiated) crystals produced for BaBar/SuperB*

Amcrys 005 and Amcrys 006

5 x 5 cm^2 cross section, 30 cm. length

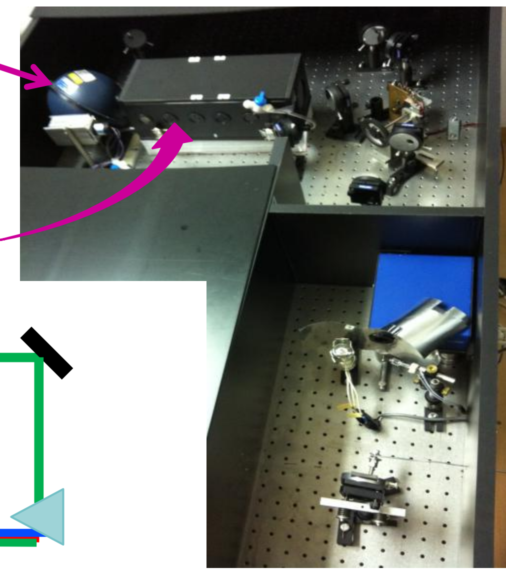
- **Longitudinal Transmittance (%T):**

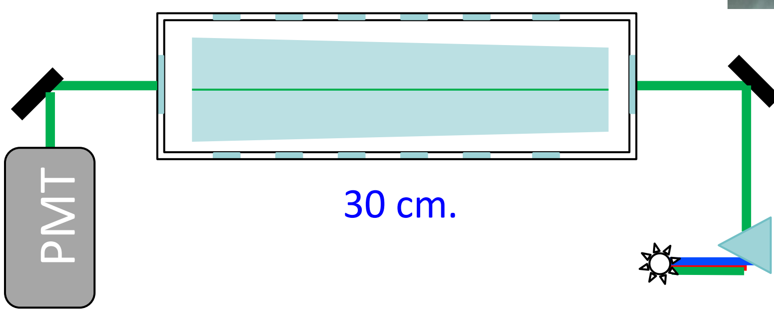
range: 230-600 nm

Lumen spectrophotometer

(optical bench equipped with integrating sphere)

All measurements were carried out
in the dark and dry air atmosphere (box)





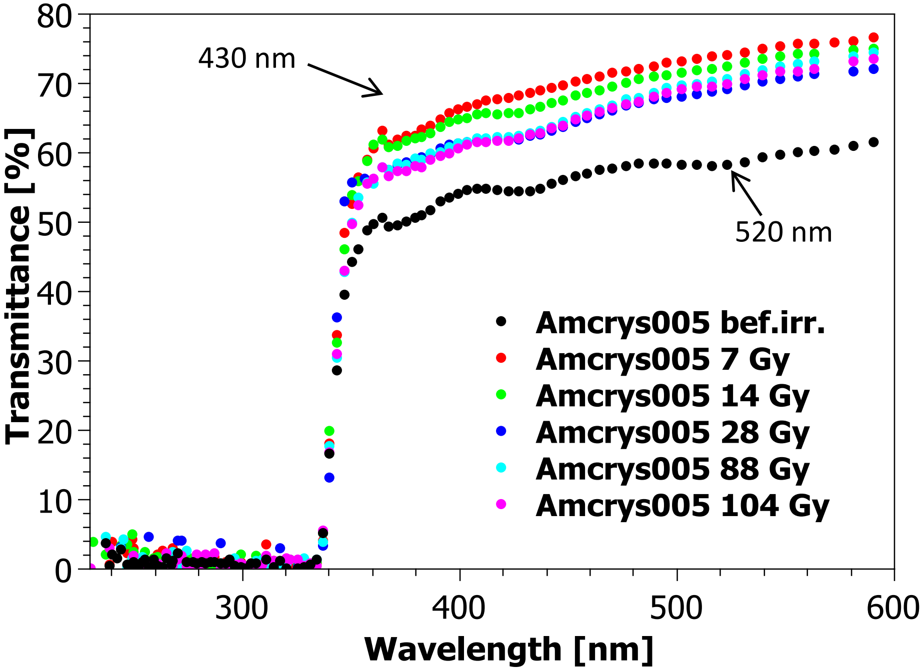
- **Gamma irradiation tests:**

Dose rate: **4.5 Gy_{air}/h**

Total absorbed doses: **up to 104 Gy (Amcrys 005) and up to 16Gy (Amcrys 006)**

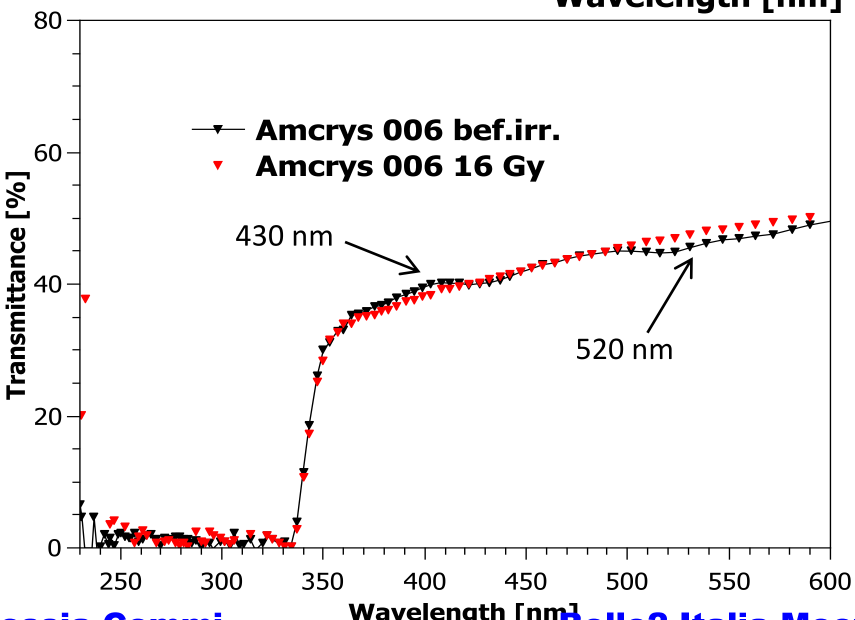
Crystals were always irradiated and stored in the dark, in argon atmosphere, at RT. Transversally irradiated (CsI crystal attenuation length of ^{60}Co gamma rays is 5.2cm-EGS simulation (SLAC-Report-265, 1985)

CsI (Tl) Transmission spectra



%T

✓ *same manufacturer but different optical behavior*



✓ *Amcrys 006:*
slight irradiation effect (@16Gy)

CsI (Tl) crystals and characterizations

<u>II group</u>: *three spare (not irradiated) trapezoidal crystals produced for Belle (equipped with PIN diodes)*

6.5 x 5.5 cm^2 cross section, 30 cm. length

Crystal no. 1: S/N 327017
Crystal no. 2: S/N 311017

gamma irr.

Crystal no. 3: S/N 319065 (reference, **not irradiated**!)

Gamma irradiation tests:

Dose rate: **4.5 Gy_{air}/h**

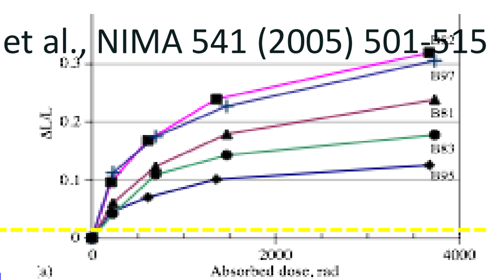
Total absorbed doses: **up to <u>670 Gy</u> (Cristal no.1) and up to <u>125Gy</u> (Cristal no.2)**

Transversally irradiated; same side

Previous studies of CsI(Tl) radiation hardness show a large variation in the LY degradation for different crystals (up to 30-35%) ….. but at absorbed doses lower than 40Gy

(expected dose for Belle2: 10Gy/y x 10y = 100Gy)

D.M.Beylin et al., NIMA 541 (2005) 501-515

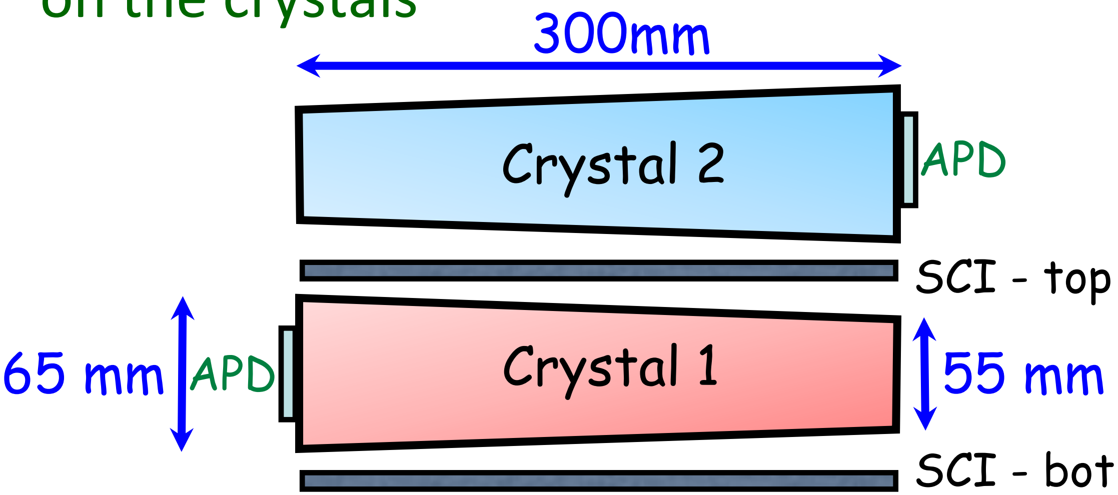


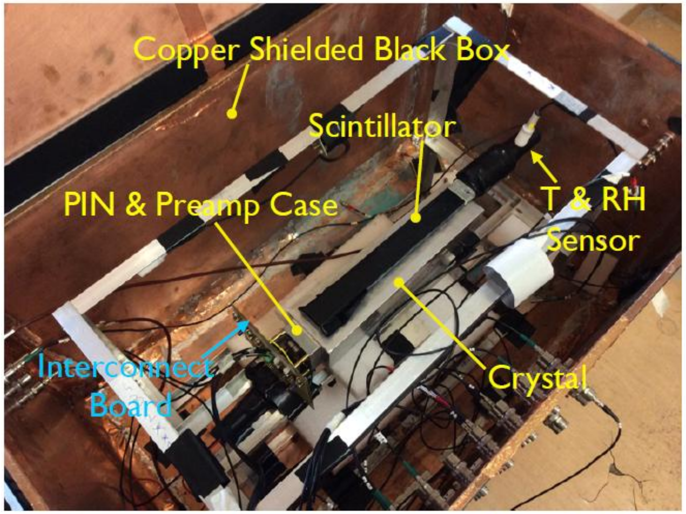
A.Beaulieu, Belle2 Weekly Meeting October 3 2014

CsI (Tl) crystals: CR Data and set up

- CR run before irradiation taken for both crystals
- Irradiation Cycle:
  1. Irradiate with γ from the Co^{60} source
  2. Take CR run ~2-3 kEvents ⇒ get amplitude peak position
  3. Go to Step 1.

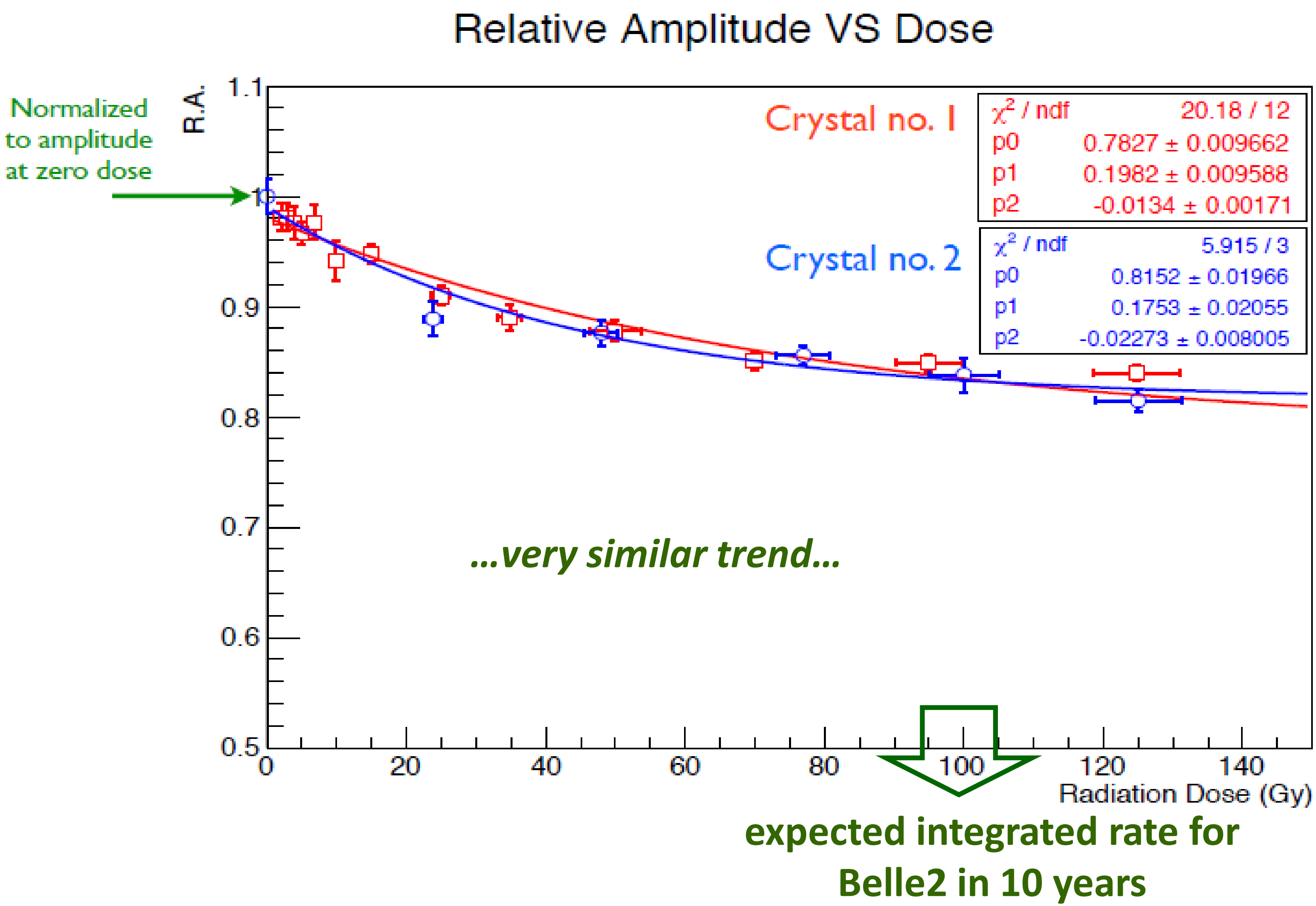
CR data by a pair of 3x30 cm^2, 10 mm thick, trigger scintillators placed longitudinally on the crystals





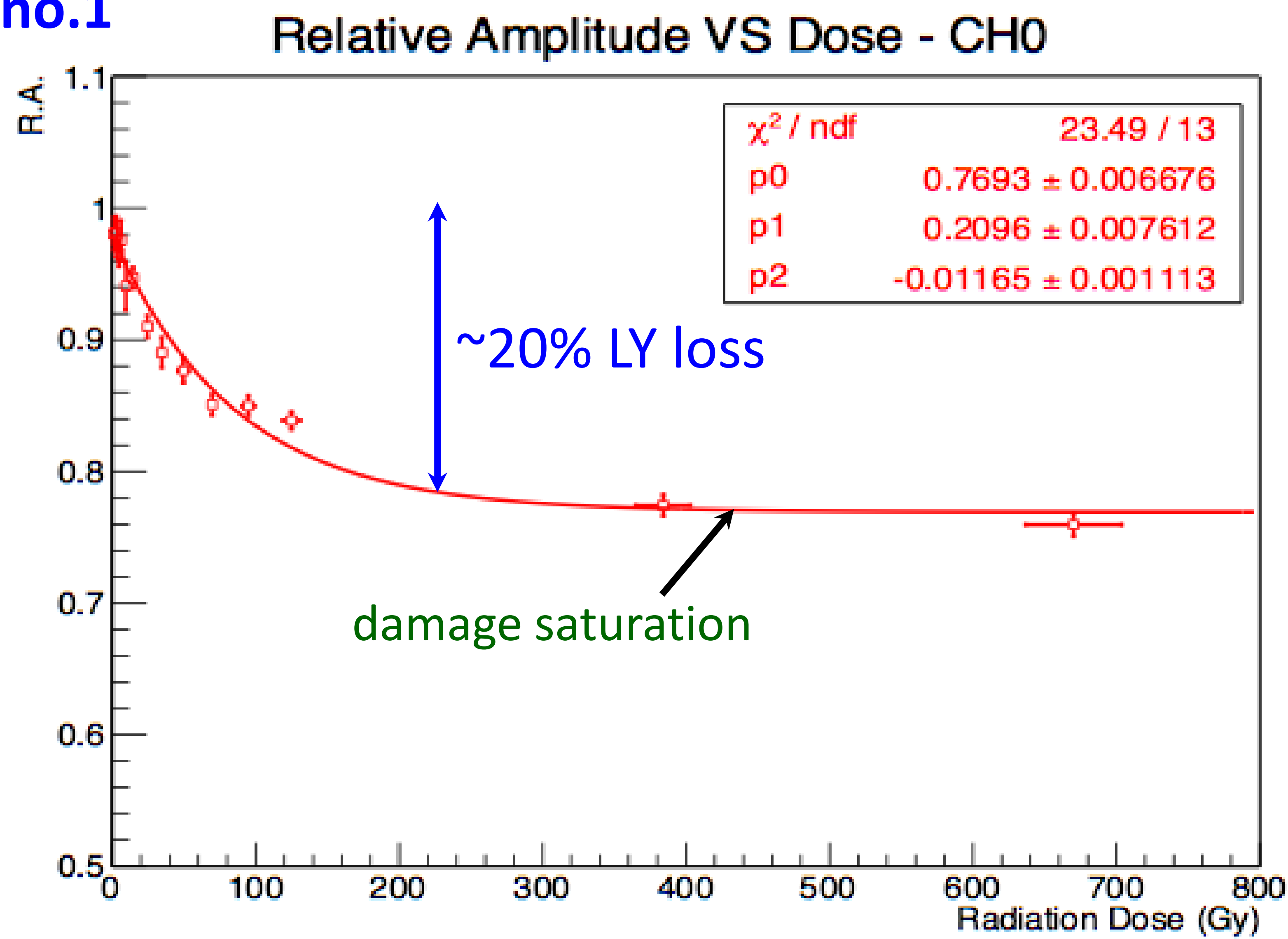
Dry air circulated in the box (RH<~15%)

CsI (Tl) crystals: CR Data

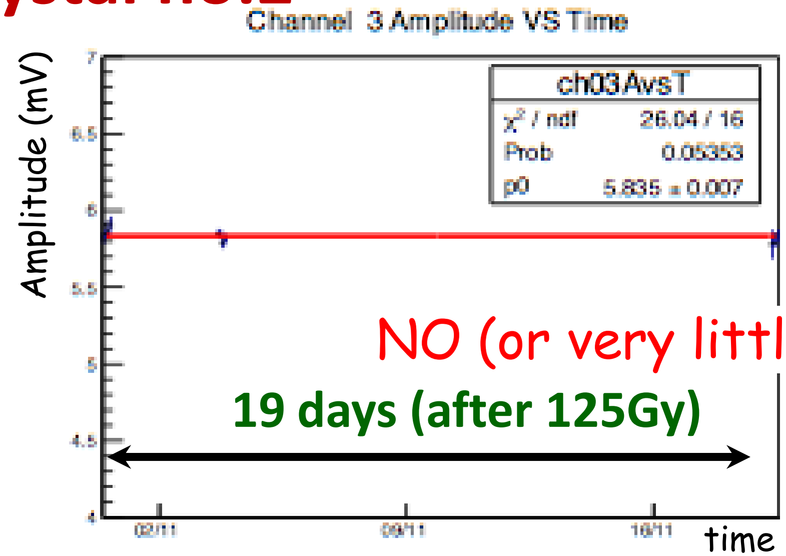


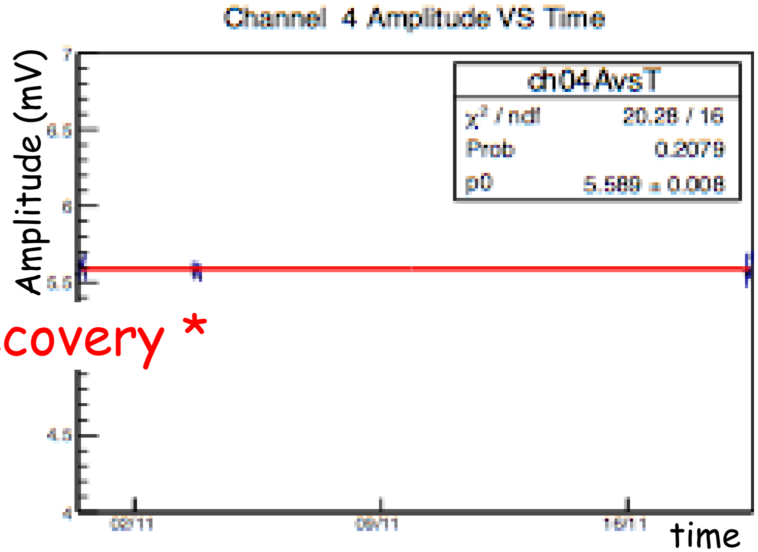
CsI (Tl) crystals: CR Data (Crystal no.1)

Crystal no.1



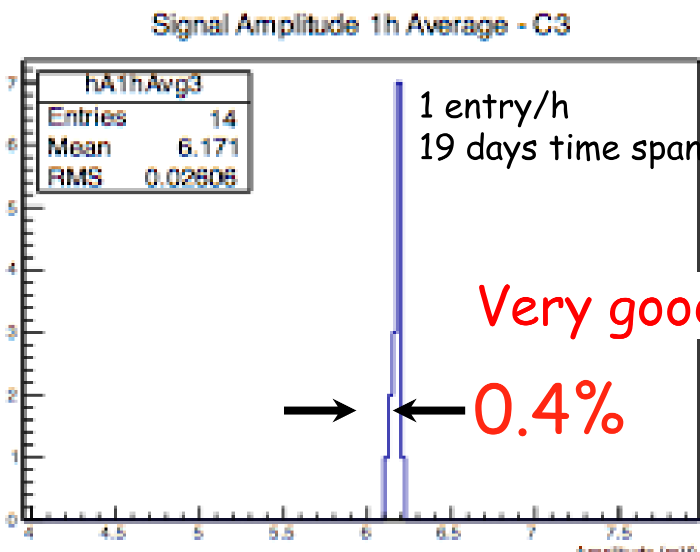
Crystal no.2

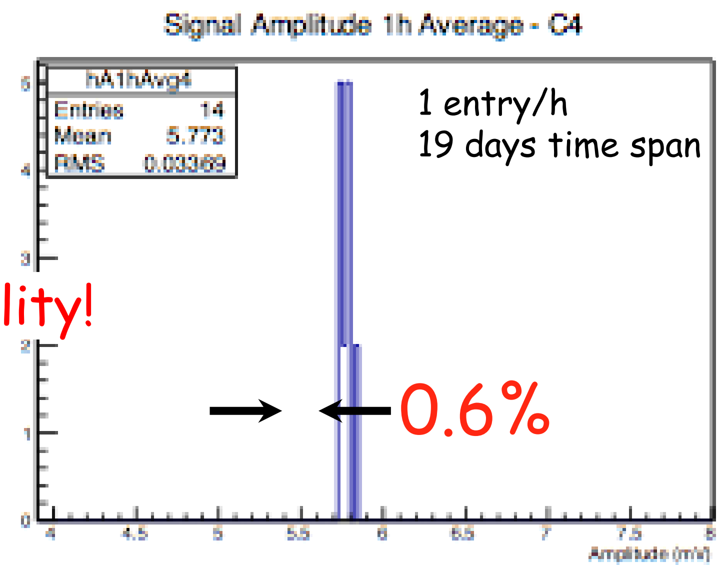




NO (or very little) recovery *

19 days (after 125Gy)

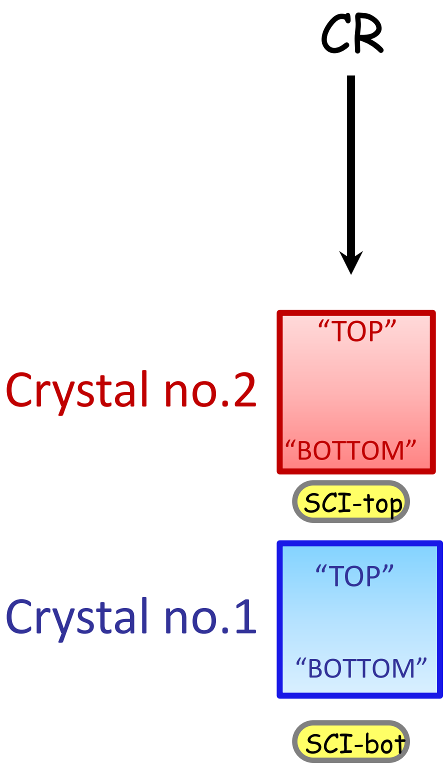




Very good stability!

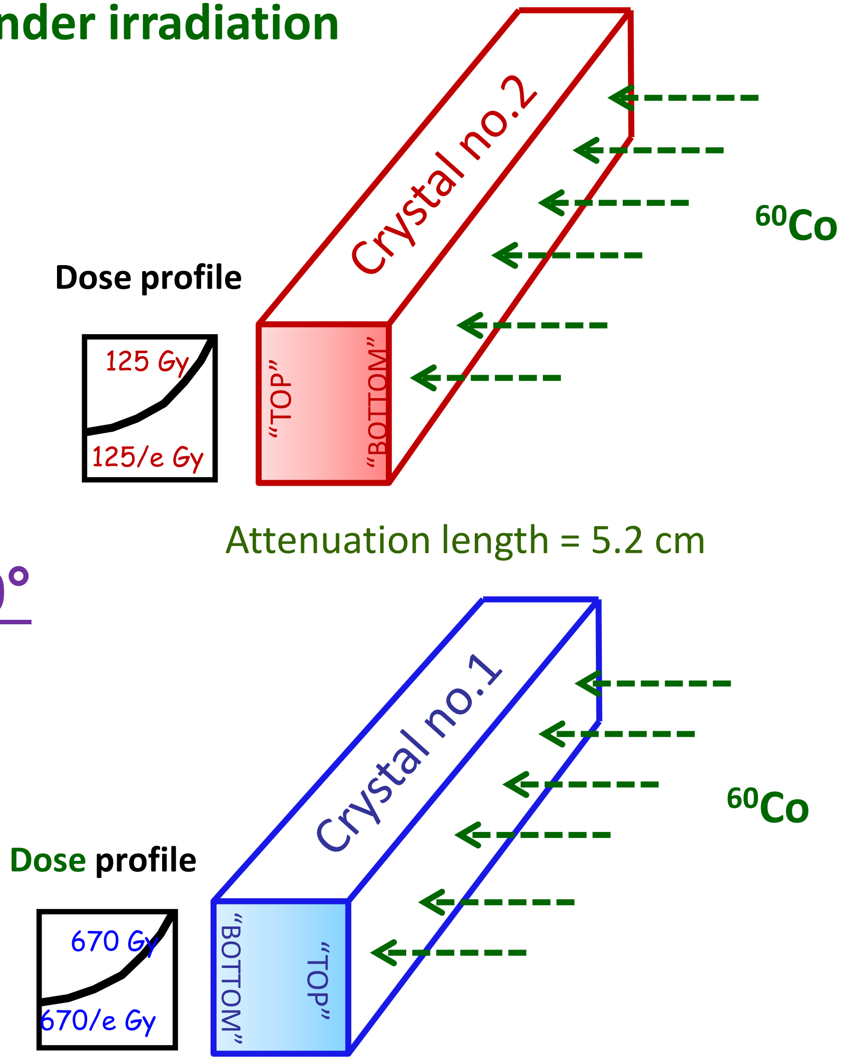
(*) as reported in the literature

CR experimental set up

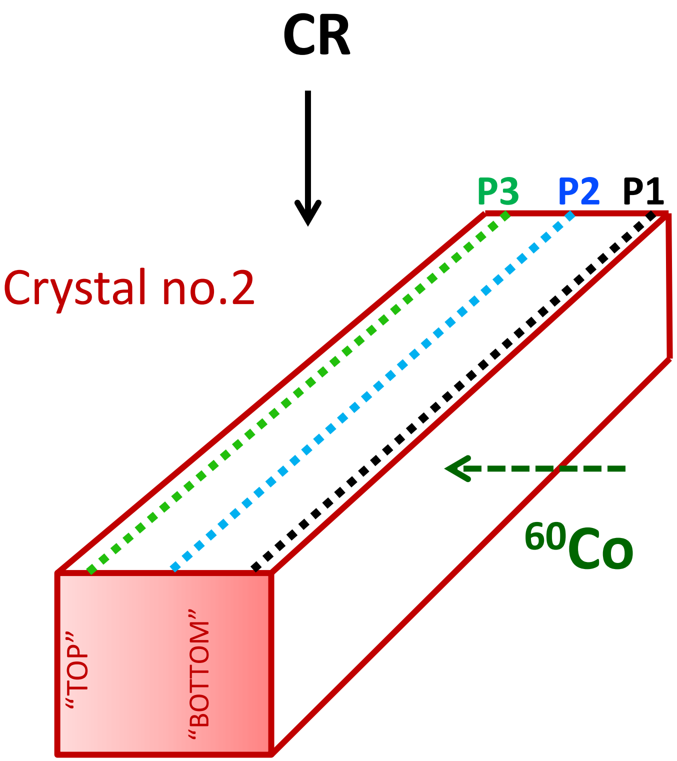


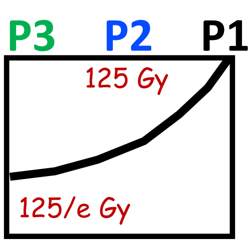
Rotation: 90°

under irradiation

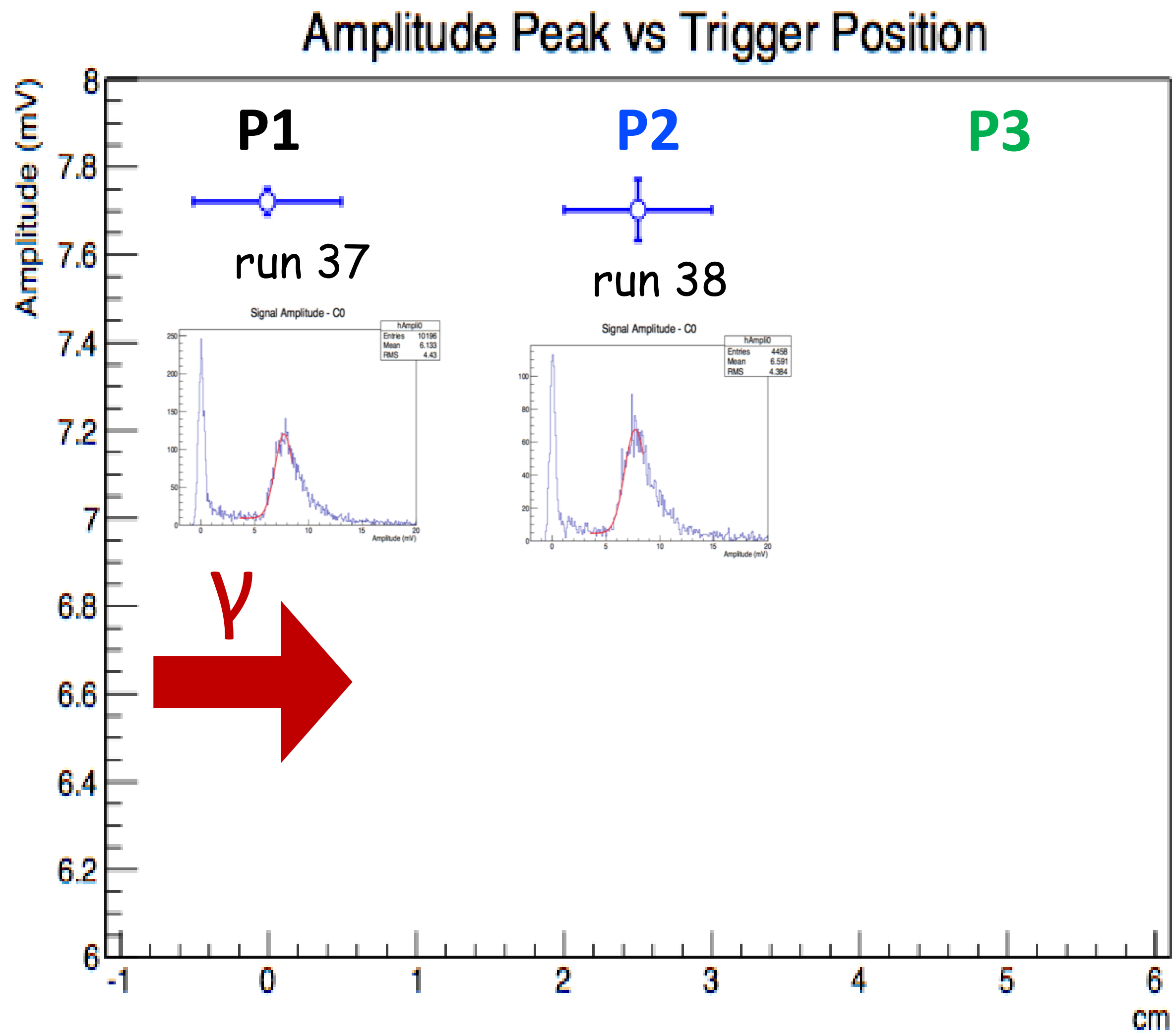


CsI (Tl) crystals: CR Data





Dose profile



Characterization of pure CsI scintillating crystals from different manufacturers

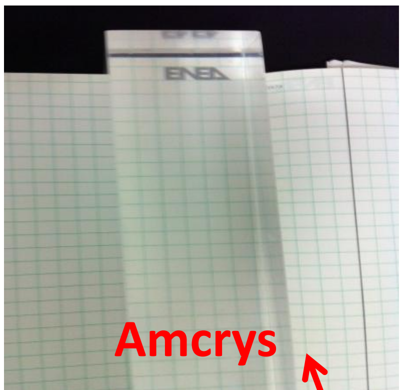
Amcrys (Ukraine)

Optomaterials (Italy)

Pure CsI crystals

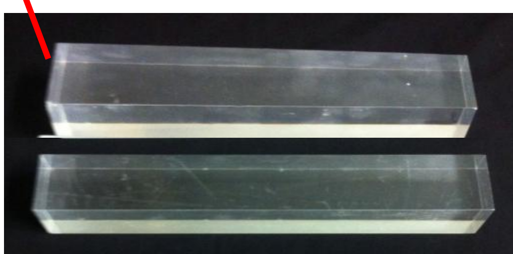
Crystal Amcrys 002 (Amcrys, Ukraine):

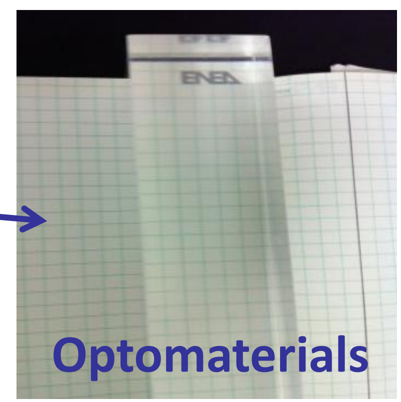
trapezoidal shape ~ 7.5 x 6.5 cm^2 cross section



Optomaterials 402 (Optomaterials, Italy)

5 x 5 cm^2 cross section





30 cm.

(Belle II ECL standard size)

Pure CsI optical characterization

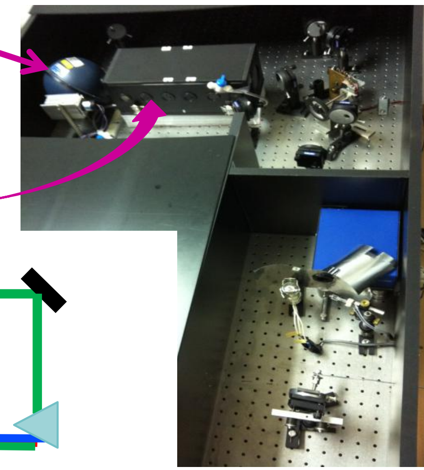
- **Longitudinal Transmittance (%T):**

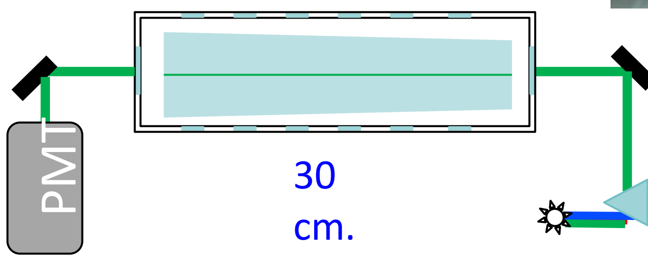
range: 230-600nm

Lumen spectrophotometer

(optical bench equipped with integrating sphere)

All measurements were carried out in the dark and dry air atmosphere (box)

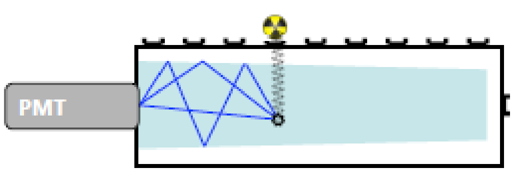




- **Gamma irradiation tests:**

Dose rate: **4.5 Gy_{air}/h**

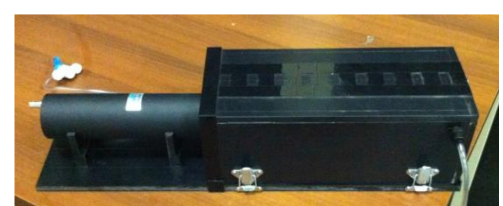
Total absorbed doses: **up to 104 Gy**



- **Light Yield measurements:**

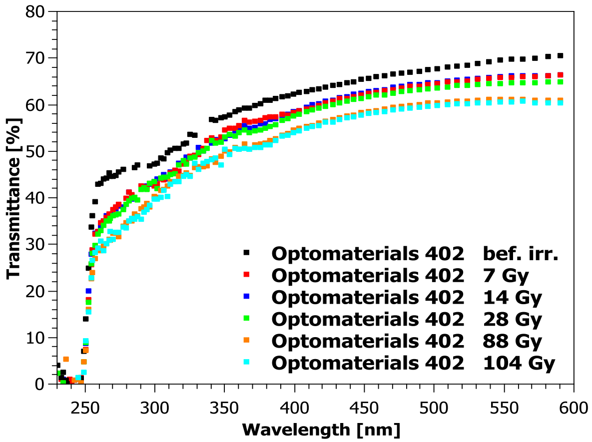
^{137}Cs, ^{22}Na sources + dry box + UV-sensitive PMT + QDC

9+1 positions

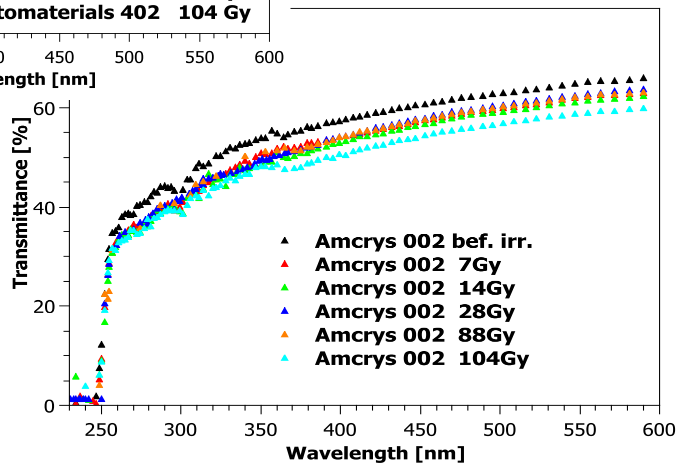


Pure CsI Transmission spectra and LY

%T error = ± 1%



%T

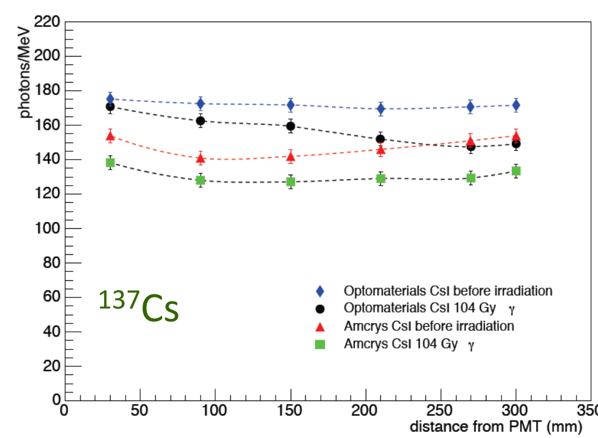


Absorbed dose [Gy]	Transmittance @ 315nm [%]	
	Amcrys 002	Optomat. 402
Before irr.	48.26	50.67
104	43.57	43.64

- ✓ *transmittance dependent on the absorbed doses*
  (max Δ% @315nm= - 7% @ 104Gy)
- ✓ *saturation effect*
- ✓ *similar %T trends for both crystals*
  (different manufacturers)

LY

- ✓ *similar behavior for both crystals*
  (LY loss @ 104Gy = -8%)



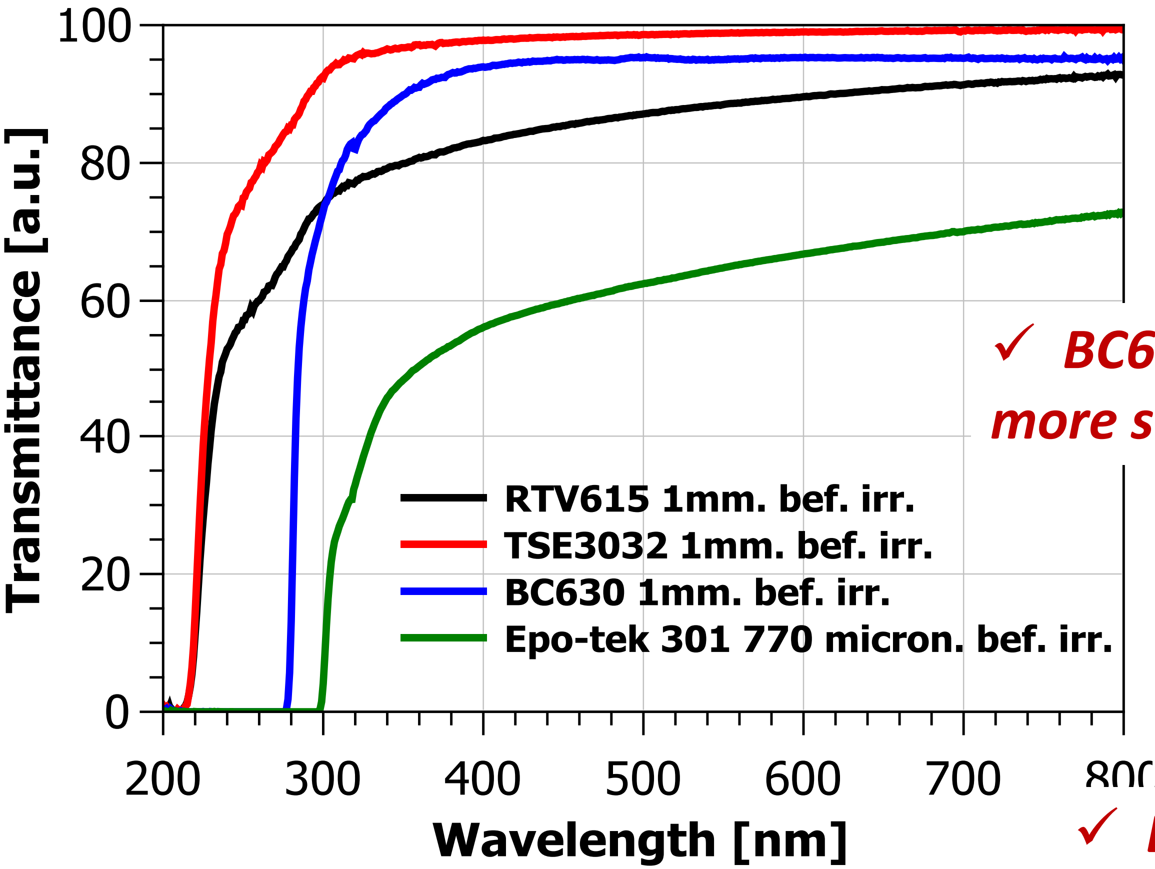
Optical coupling materials

Two-component silicon resins
(Momentive, USA)

Optical coupling materials: final evaluation

Transmittance curves
Range: 200-800 nm

Dose rate: **5 Gy_{air}/h**
Total absorbed doses: **up to 44 Gy in air, at RT**



under irradiation (13.2Gy):

- ✓ ***BC630 and RTV615: more stable*** *(ΔT% @ 315 nm = - 2%)*

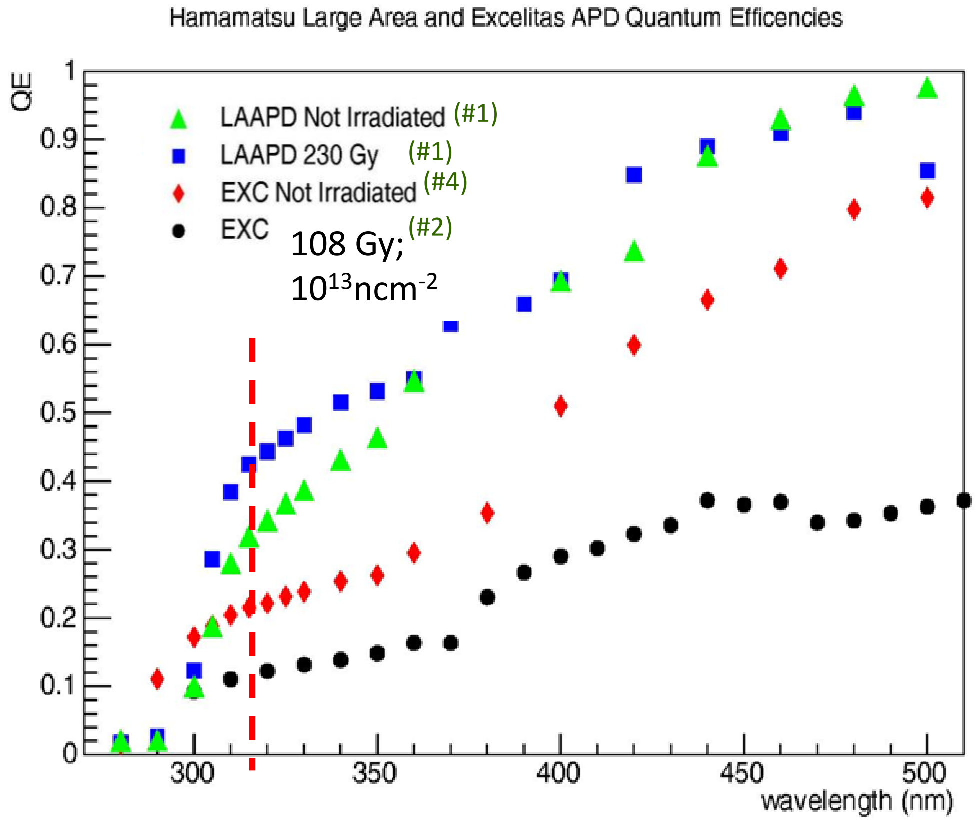
after irradiation
(stability ~ 30 days) :

- ✓ ***BC630: the best performances***
- ✓ ***Resins:*** *ΔT% @ 315 nm = - 5%)*

APD Quantum Efficiency

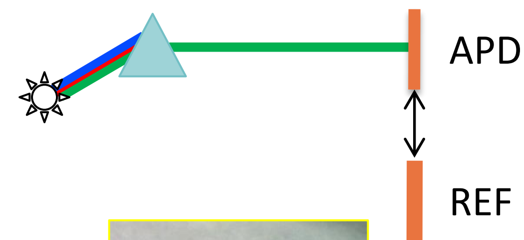
APD QE after irradiation

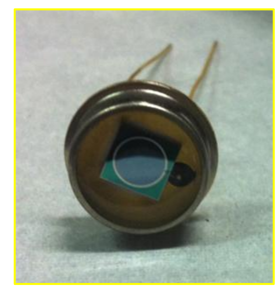
The APDs were irradiated with fast (0.1-10 MeV) neutrons at Tapiro (Excelitas), up to a fluence of $1x10^{13}$ n/cm^2 (10 years x5 of Belle2) and with gamma rays at Calliope facility (Excelitas and LAAP)



QE measurement at Gain = 1

Hamamatsu **calibrated** PIN diode used as reference





Excelitas APDs show a significant loss in Quantum Efficiency after $1x10^{13}$ n/cm^2 :

- Main component is probably due to damage to resin cover
- A scan around 315 nm should be repeated for both LAAPD and Excelitas

Conclusions

- ✓ **CsI(Tl):** from Amcrys. *%T:* Optical properties not comparable for both crystals (before and after irradiation). A sort of saturation and Tl absorption peaks appear with the increase of the absorbed dose.

  LY: The crystals present similar behavior and a CR amplitude peak reduction of about 22% is observed at absorbed doses higher than 300 Gy
- ✓ **CsI:** Optomaterials crystal presents very good results (longitudinal transmittance) under irradiation (similar to Amcrys). Both crystals show a fast recovery, also in the dark. A saturation effect is evident at higher doses. Comparable %T and LY performances loss.
- ✓ **Optical couplings materials**: BC630 grease and two-component silicon resins gave very interesting performances under gamma rays and are stable after the end of the irradiation tests. Suitable for Belle II (scintillation wavelength and radiation environment).
- ✓ **APD Quantum Efficiency**: LAAP and Excelitas APDs were characterized by a calibrated PIN diode. LAAP (230 Gy) maintains the same QE of the unirradiated sample. Neutron and gamma irradiation on Excelitas APD produces a significant loss in QE.

Further activities

…more crystals are needed…

- **CsI(Tl) :**

  %T - optical characterization after irradiation (*stability*).

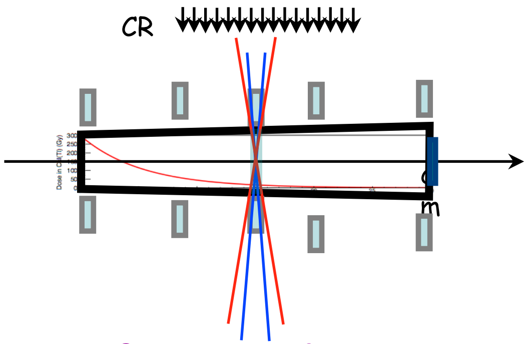
  LY - *<u>Crystal no.1</u>* (670 Gy): recovery evaluation

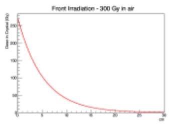
  <u>Crystal no.2</u> (125 Gy): irradiation at 125 Gy (one-shot) after 90° rotation and CR data acquisition

  <u>Crystal no.3</u> (reference): irradiation at 300 Gy to investigate the LY uniformity variation along the longitudinal axes.

  (CR data in 5 transverse position)

gamma rays





- **CsI:** longitudinal/transverse transmittance measurements after irradiation and recovery (*Optomaterials*: *manufacturer qualification);* Light Yield measurements after irradiation

- **APDs Quantum Efficiency:** neutron irradiation of LAAP and gamma irradiation of Excelitas to distinguish the different effects. PIN diodes QE evaluation before and after irradiation (gamma and neutron).

Thank you
for your
attention

alessia.cemmi@enea.ir

Introduzione

- Domande aperte
  - Quanto sono resistenti i cristalli di CsI(Tl) alla radiazione?
    - È necessario sostituire i cristalli di CsI(Tl) con altri con maggiore resistenza alla radiazione?
      - Letteratura + Studio di irraggiamenti di CsI(Tl)
    - Il CsI puro è resistente alla radiazione?
      - Studio di irraggiamenti di CsI puro
  - Quanto sono resistenti alla radiazione le altre componenti del rivelatore?
    - Studio di irraggiamenti di PIN diodes, APD, resine, colle ecc.
  - Qual'è l'effetto della radiazione sull'uniformità del LY nei cristalli?
    - Studio LY in funzione della posizione longitudinale (vari esempi in letteratura)
  - Quanto peggiorano le prestazioni di fisica del rivelatore a causa del pile-up?
    - È veramente necessario sostituire il CsI(Tl) con il CsI puro, che è più veloce?
  - Quanto peggiorano le prestazioni di fisica del rivelatore a causa del danno da radiazione (minore light yield)?

Vedi talk di Benjamin

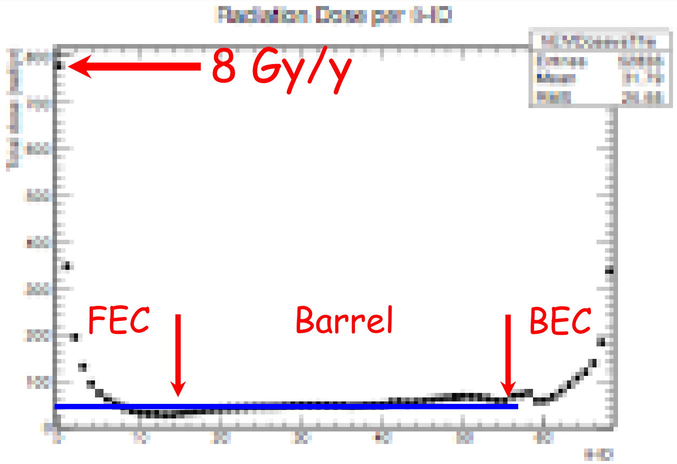
  - Simulazioni e Software ☞

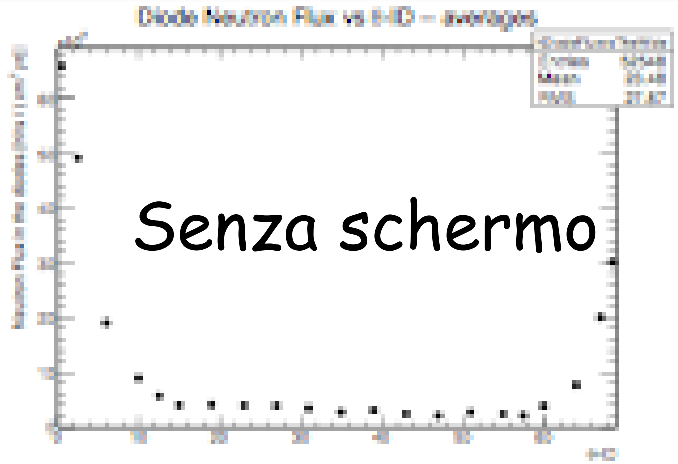
Stato dell'arte

- Esistono studi precedenti condotti all'epoca di BaBar e Belle (ormai ~20 anni fa!) sullo CsI(Tl), e altri (per es. CMS)
  - L'effetto della radiazione gamma sullo CsI(Tl) è di ridurre la luce raccolta al foto-rivelatore
  - C'è una grande variabilità da cristallo a cristallo
  - La luce può diminuire fino a valori significativi ~30÷35%
- Il limite comune di questi lavori è che la massima dose esplorata ~40 Gy è inferiore a quella aspettata per Belle-II
- In Belle-II, la dose aspettata è stimata con simulazioni dedicate del fondo
  - I valori trovati oscillano da produzione a produzione di fattori 2-3
    - Motivi di prudenza consigliano di utilizzare valori più alti delle presenti simulazioni

Alexandre Beaulieu[1]
[1]University of Victoria, Canada

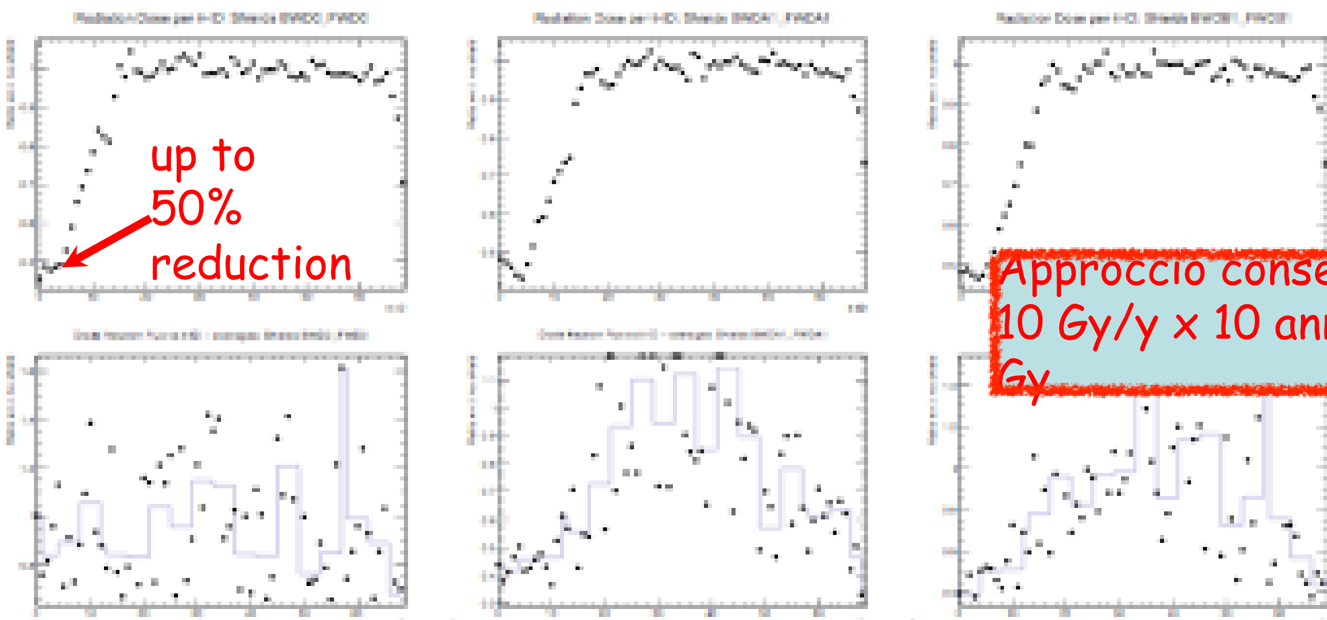
Simulated Expected Dose





Limit dose: 1000 rad/yr
Limit n-flux: 100 x 10^9 / (yr · cm^2)

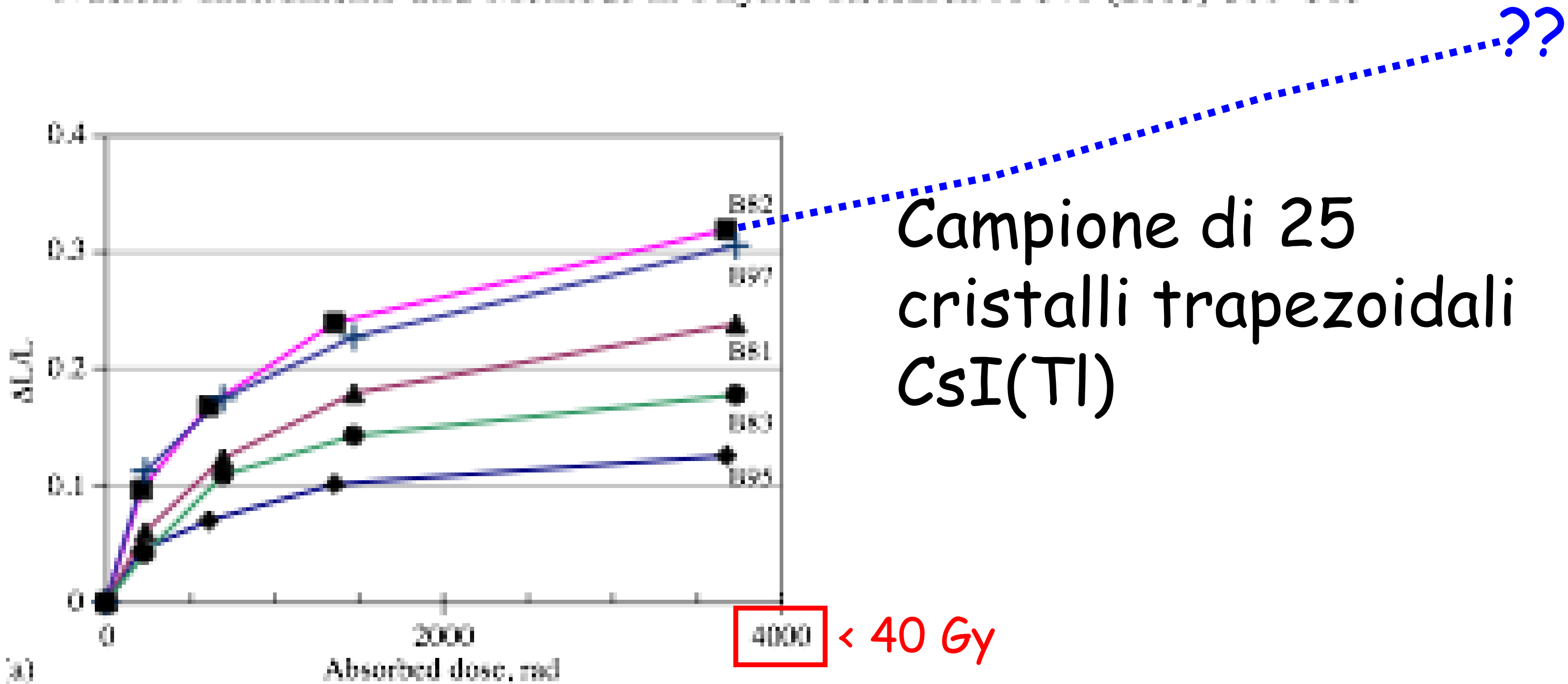
3 diversi modelli di schermo



Approccio conservativo:
10 Gy/y x 10 anni=100 Gy

Previous Measurements

D.M.Beylin, et al.
Nuclear Instruments and Methods in Physics Research A 541 (2005) 501–515



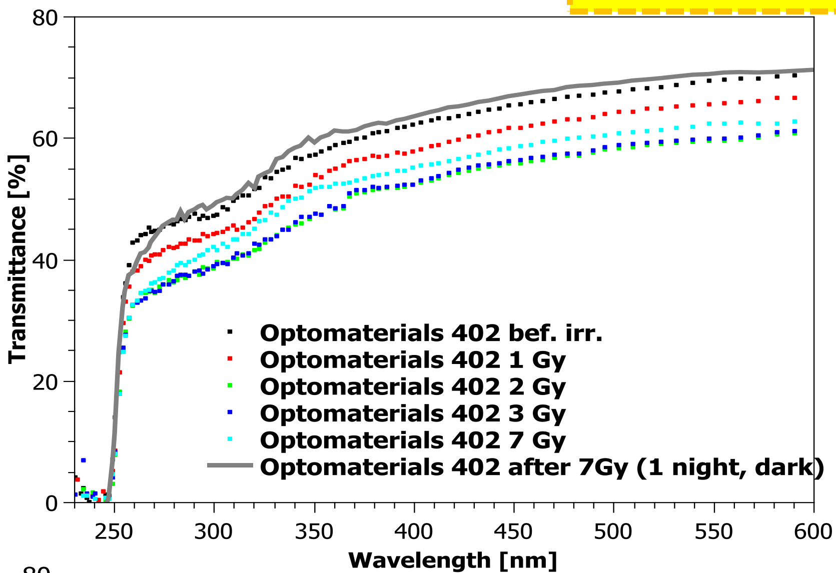
Campione di 25 cristalli trapezoidali CsI(Tl)

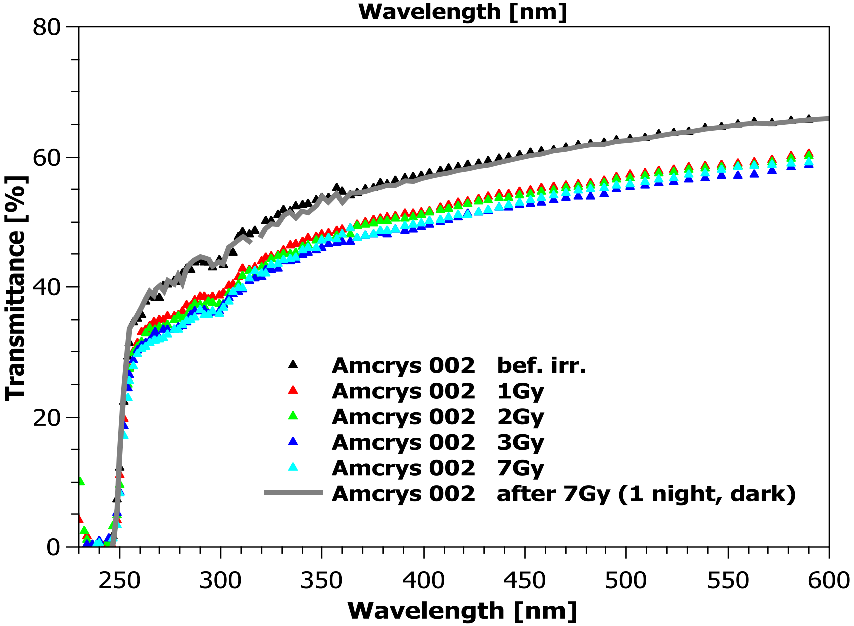
- Dalle vecchie misure, non è chiaro se il danno continua ad aumentare con la dose.
  - ☞ Estendere il range di dose

Pure CsI Transmission spectra

%T error = ± 1%

Low dose range (up to 7Gy)



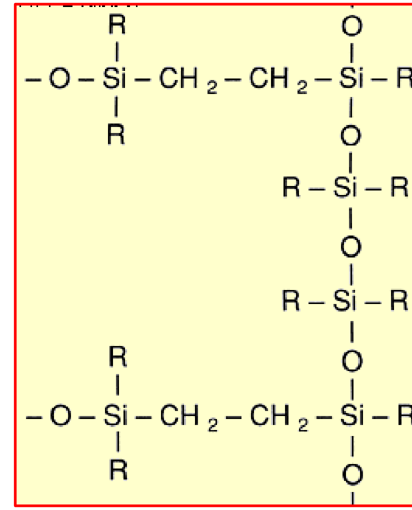


Absorbed dose [Gy]	Transmittance @ 315nm [%]	
	Amcrys 002	Optomat. 402
Before irr.	48.26	50.67
1	42.82	45.36
2	42.63	41.01
3	41.05	40.87
7	41.44	44.85
Recovery after 7Gy (1 night, dark)	47.71	51.51

- ✓ ***transmittance dependent on the absorbed doses***
- ✓ ***complete and fast recovery in the dark***
  (gray line in the plots)

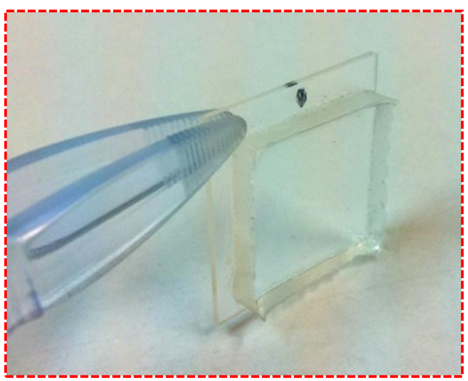
Silicon resins

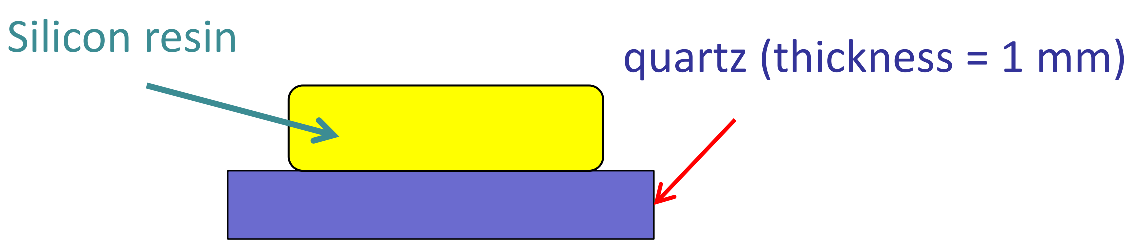
RTV 615 and TSE 3032



Refractive Index : 1.406

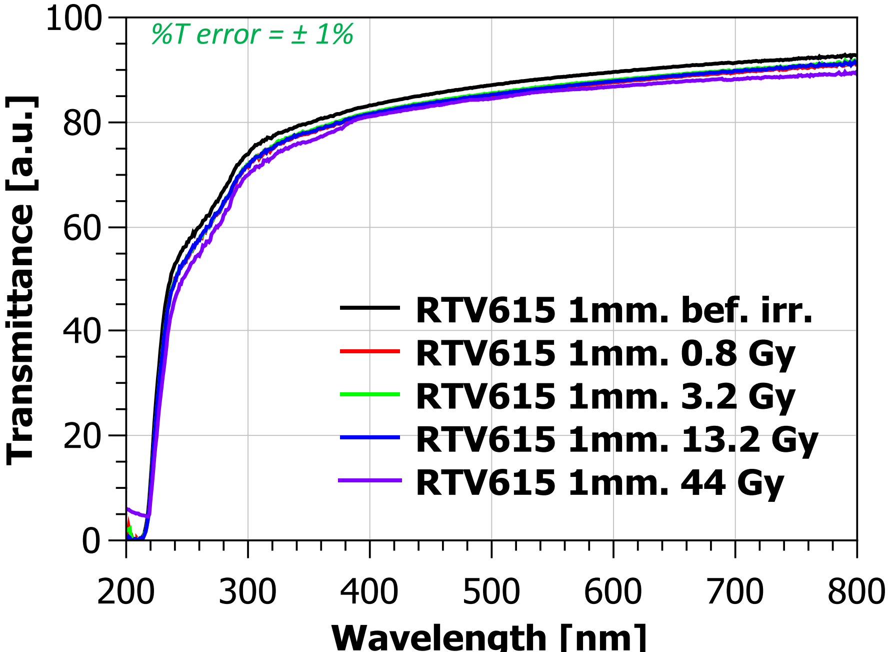
Low viscosity, transparent silicon rubber designed for protection of electronic components and assemblies against shock, vibration, moisture, ozone, dust, chemicals, and other environmental hazards by potting or encapsulation of the components and assemblies.

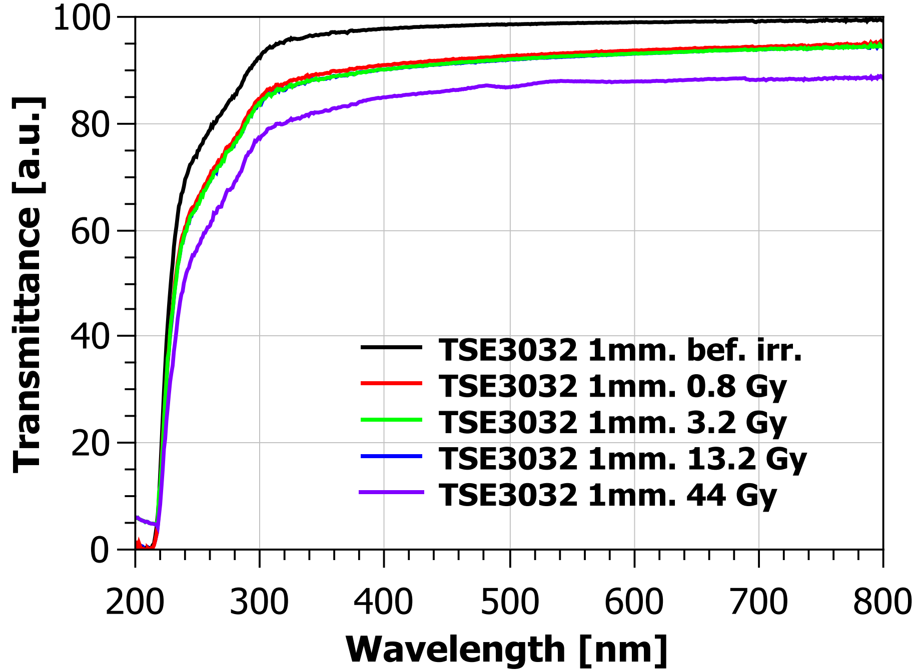




- ✓ different thickness (1mm; 2mm)
- ✓ transparent, not rigid

Silicon resins: gamma irradiation





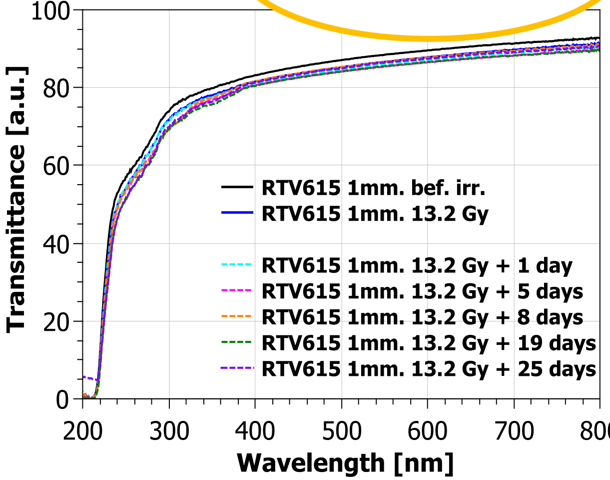
Absorbed dose [Gy]	Transmittance @ 315nm [%]	
	RTV615 (1mm)	TSE3032 (1mm)
0	76.63	94.96
0.8	74.06	86.66
3.2	74.31	86.23
13.2	74.21	86.07
44	72.56	79.90

- ✓ *RTV615: more stable*
- ✓ *TSE3032: max ΔT% @ 315 nm = - 15%*

Silicon resins: stability after gamma irradiation

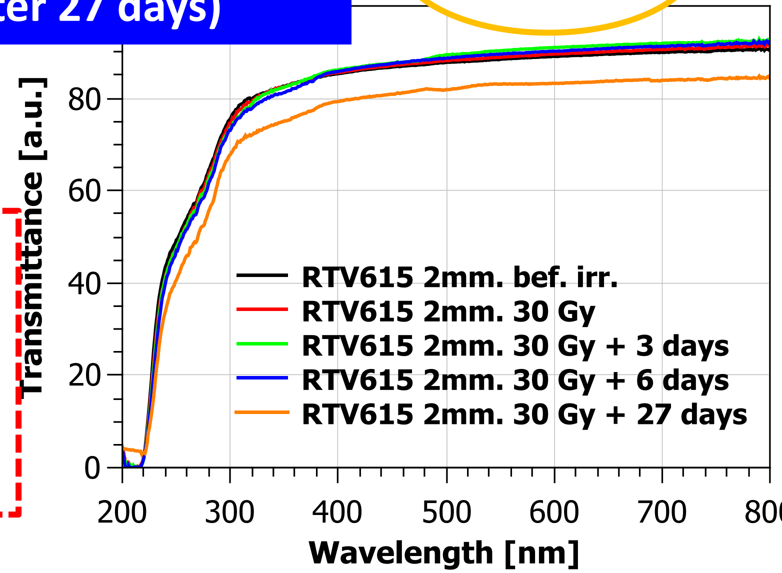
%T error = ± 1%

13.2 Gy

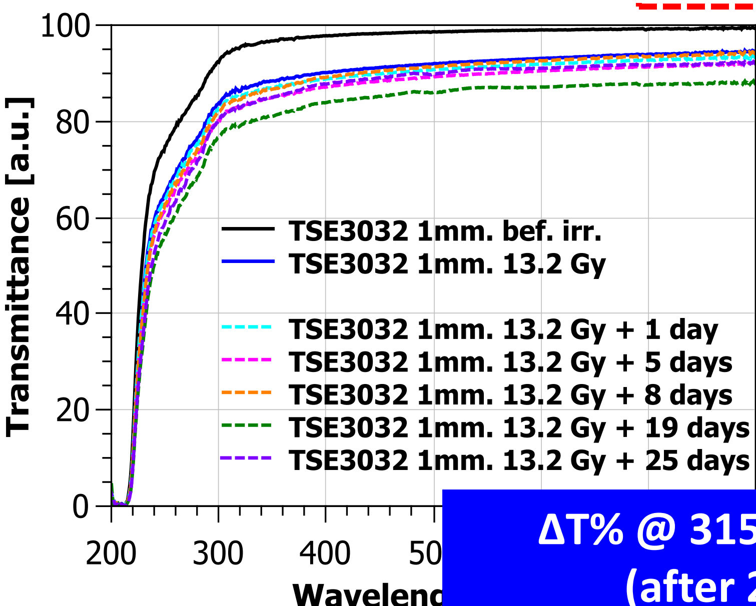


ΔT% @ 315nm = -7.00%
(after 27 days)

30 Gy



The best results are dependent on the absorbed dose and on the material



ΔT% @ 315nm = -12.20
(after 25 days)