Irradiation tests for crystals

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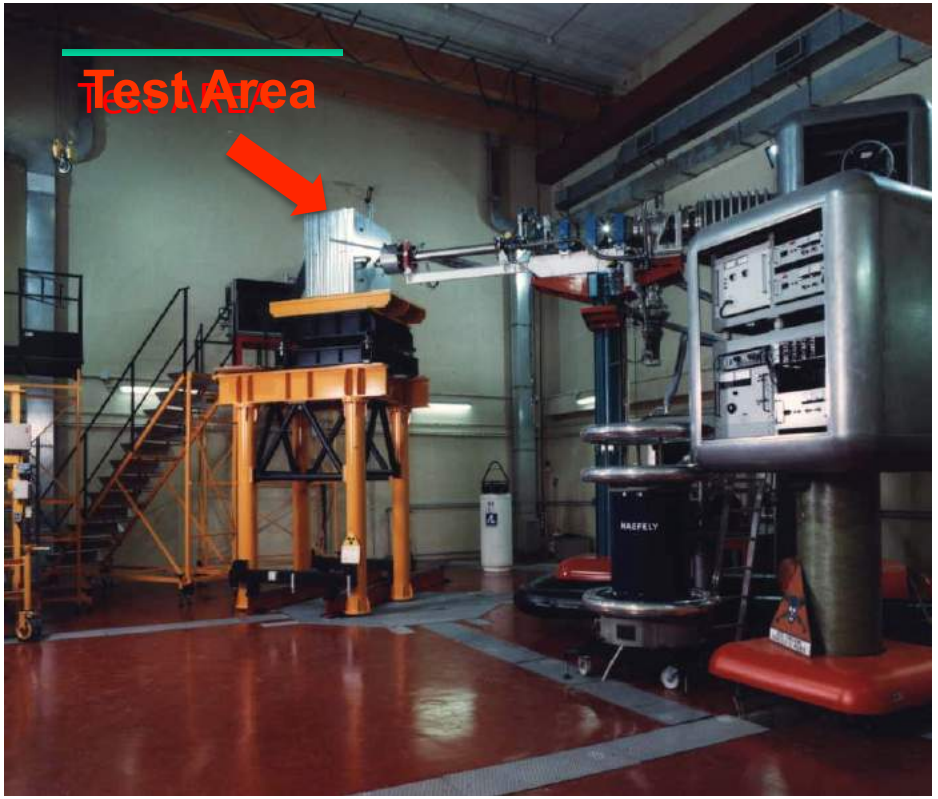
MUSE Meeting: irradiation test @ HZDR
LNF – 18 January 2016

FNG: the ENEA neutron irradiation facility

FNG uses a deuteron beam accelerated up to 300 keV impinging on a tritiated target to produce a nearly isotropic 14 MeV neutron output via the T(d,n)α fusion reaction.



14 MeV neutron on 4π solid angle

- **Max Neutron flux = 0.5 x 10^{11} n/s close to target**
- **Radius dependence → $1/R^2$**
- **Neutron intensity selected moving the crystal position in the test area**

Neutron irradiation test: crystals

4 crystals (3 × 3 × 20) cm^3 tested:

1 CsI from SICCAS (China)
1 CsI from ISMA (Russia)
1 CsI from Opto Materials (Italy)
1 BaF_2 from ICROM (Russia)

Irradiation scheme:

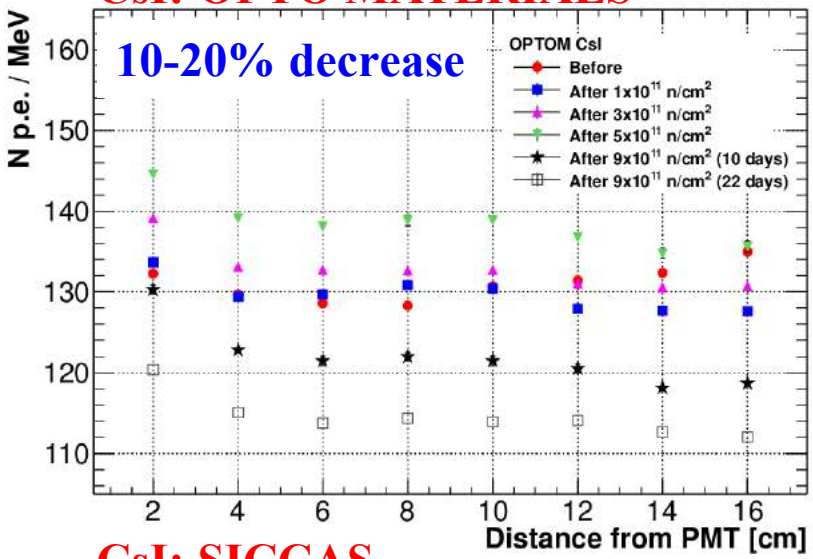
Day 1: 1×10^{11} n/cm^2
Day 2: 3×10^{11} n/cm^2
Day 3: 5×10^{11} n/cm^2
Day 4: 9×10^{11} n/cm^2

No measurements during irradiation. After each day of irradiation:

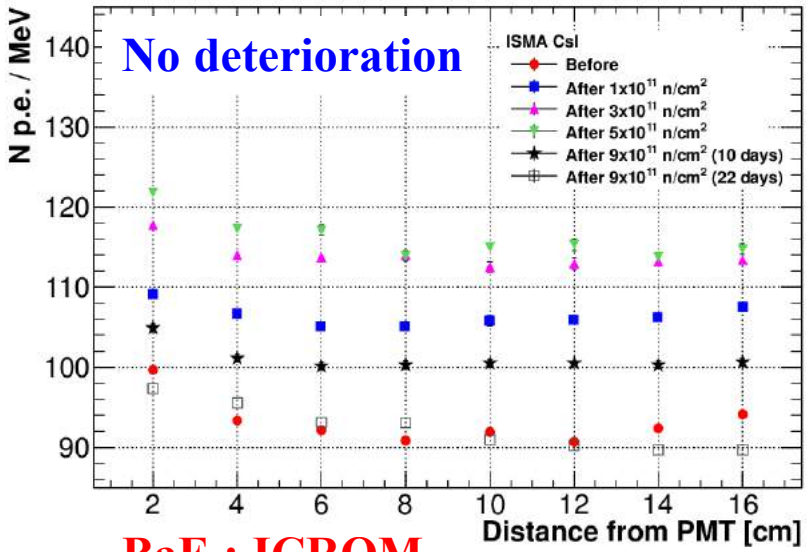
- Light yield
- Fluorescence
- Transmittance with UV light

Neutron irradiation test: light yield

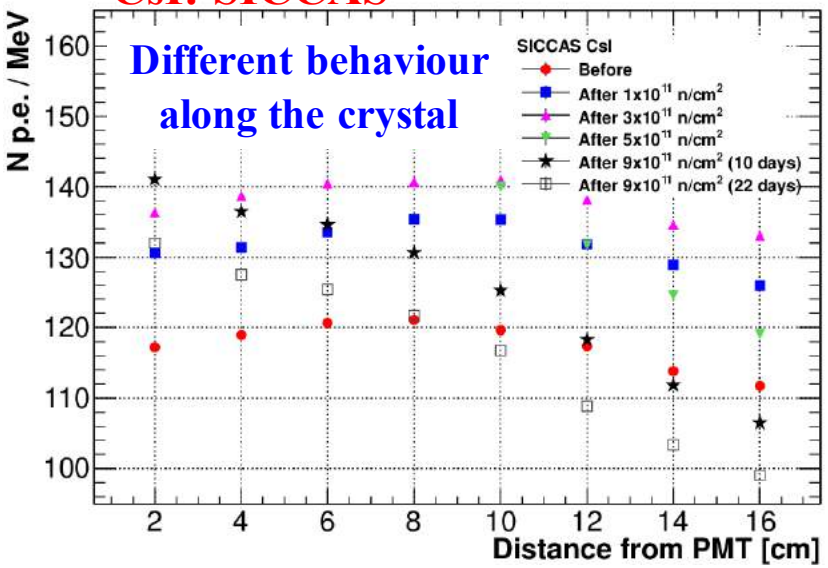
CsI: OPTO MATERIALS



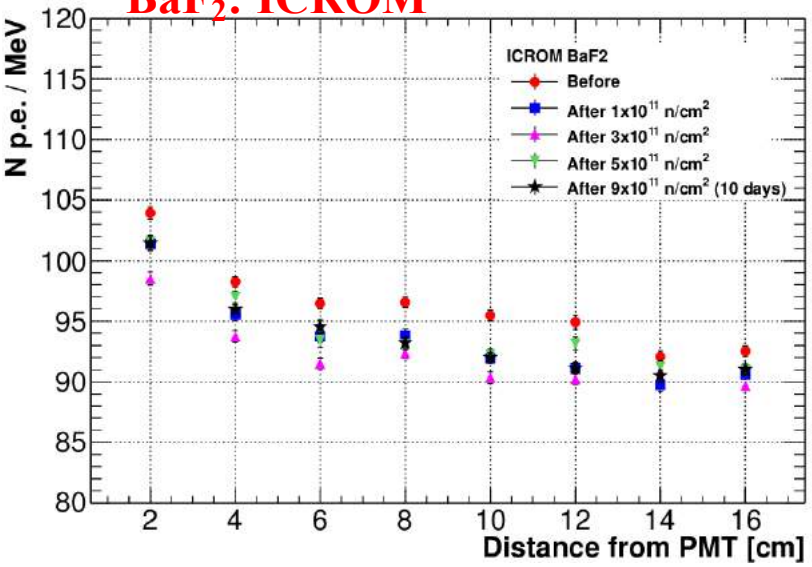
CsI: ISMA



CsI: SICCAS

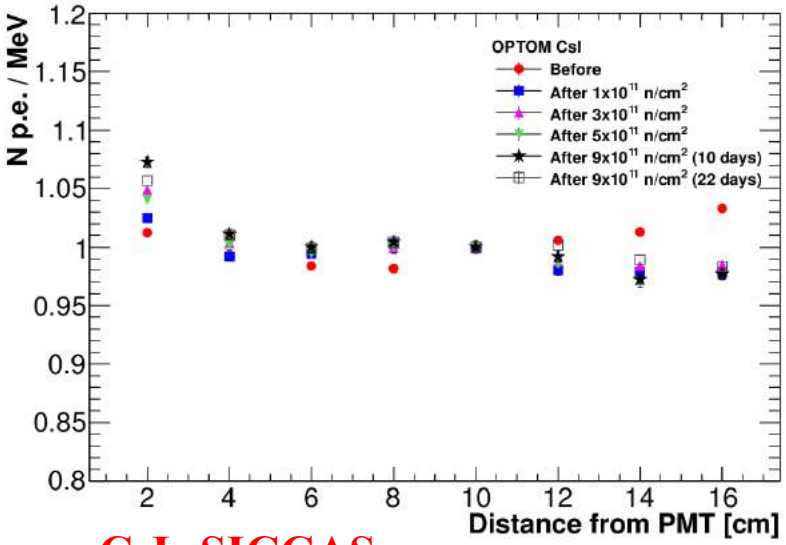


BaF_2: ICROM

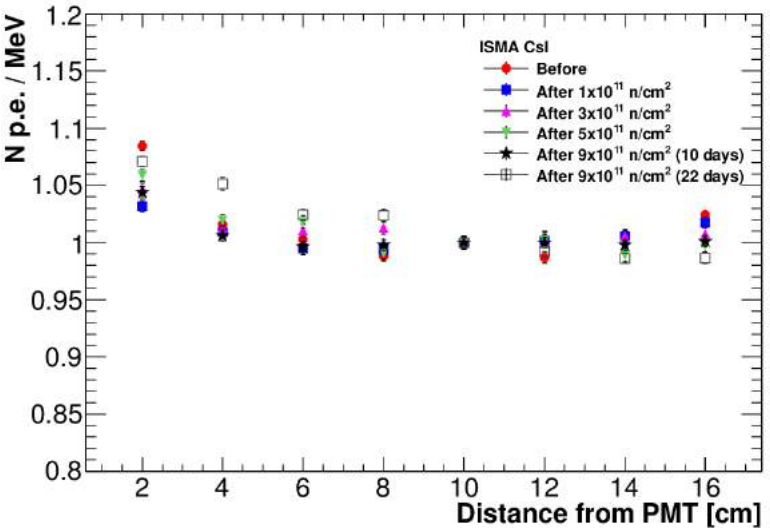


Neutron irradiation test: LRU

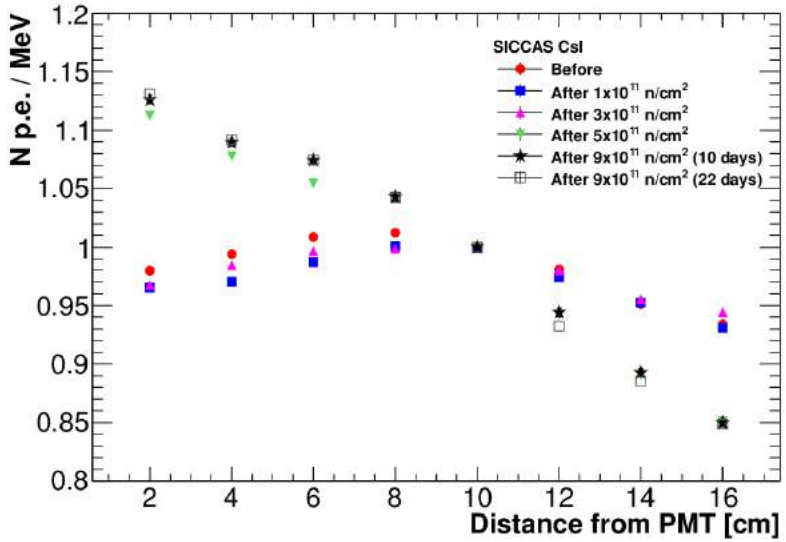
CsI: OPTO MATERIALS



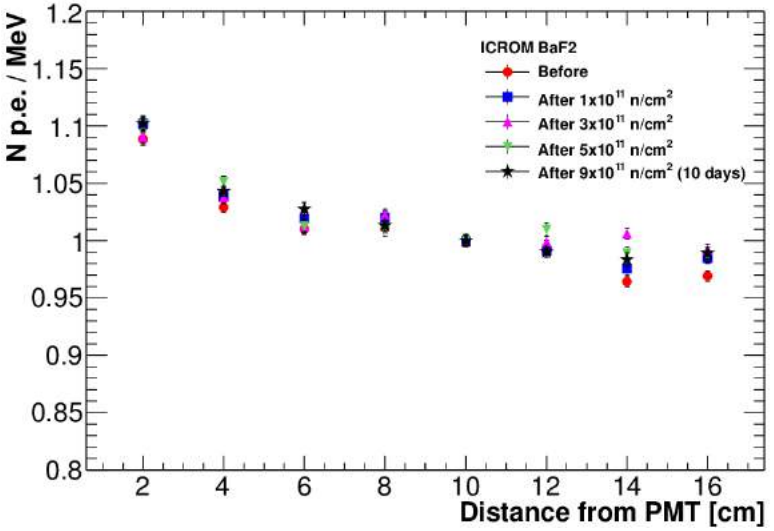
CsI: ISMA



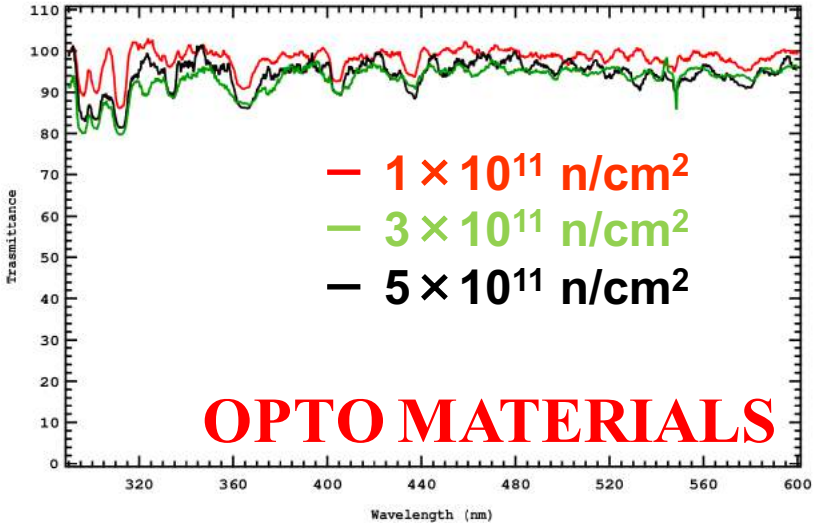
CsI: SICCAS

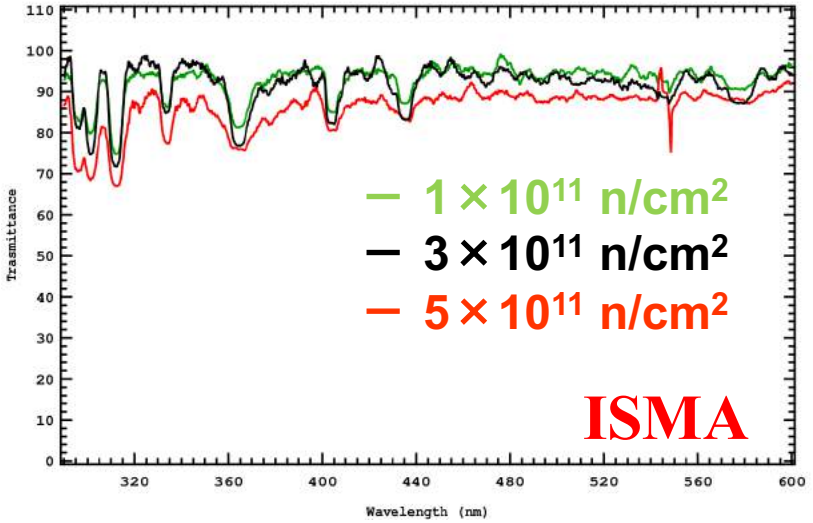


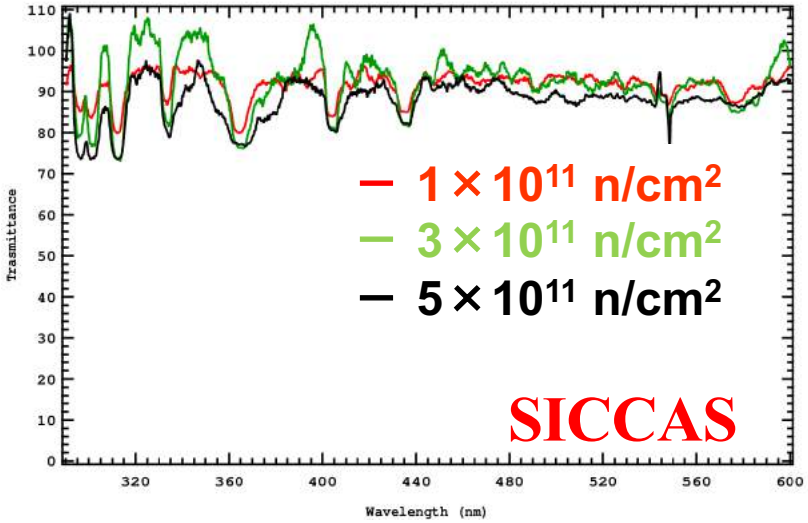
BaF_2: ICROM



Neutron irradiation test: CsI transmittance

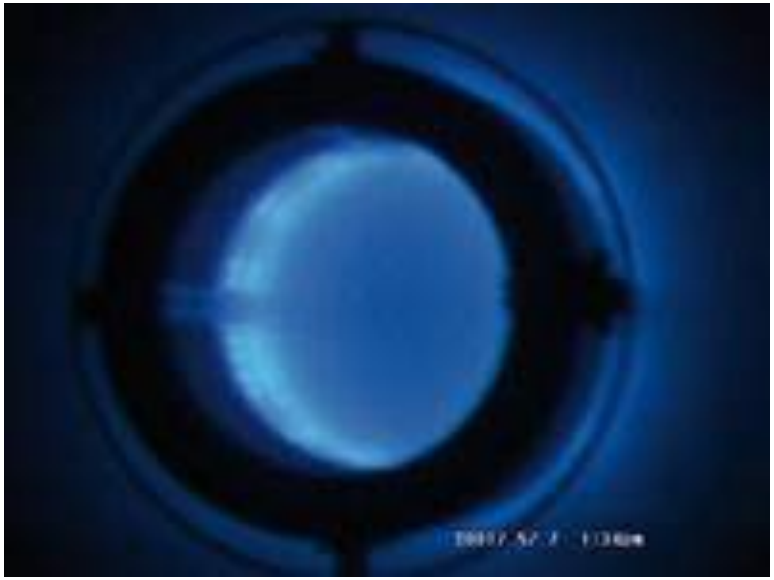






- UV lamp does not have a continuous spectrum
- Values above 100 are due to low radiation regions, with not stable signal
- Minima correspond to peaks of the lamp

CALLIOPE: the ENEA γ irradiation facility



Irradiation dose done in December 2014 @ ENEA-Casaccia:

- ✓ ^{60}Co source (1.25 MeV)
- ✓ 48 bars with cylindrical shape housed along two concentric disks
- ✓ Current activity: 0.35 $\times 10^{15}$ Bq (max. allowed: 3.7 $\times$ 10^{15} Bq)
- ✓ A lot of space for irradiation ($7 \times 6 \times 3.9$) m^3
- ✓ From 10 to 2 Gy/h at ~ 5 m distance
- ✓ Simple access (8□□

Test setup

Today results
On CsI only

- LYSO [(1.5 × 1.5 × 13) cm^3] and **CsI [(3 × 3 × 18) cm^3] from SICCAS** tested. Same dose along longitudinal crystal axis.
- Measurement of light yield with our system based on ^{22}Na source.
  No wrapping on crystals, PM coupling in air
- Irradiation scheme:
  - 2 days @ 2.23 Gy/h
  - 7 days @ 4.86 Gy/h

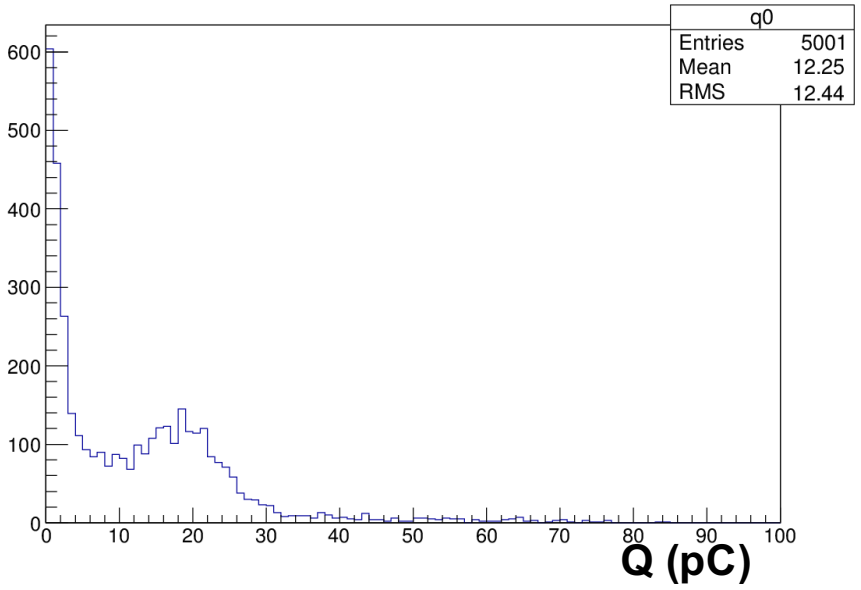
Total dose: 90 krad

i.e. ~ 3 × 3 years of Mu2e running in nine days

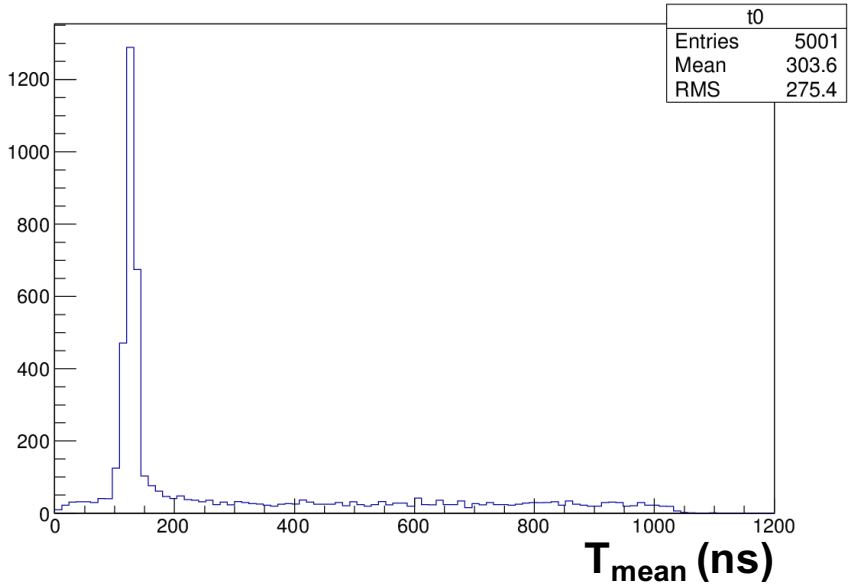
CsI: light yield measurement

- ✓ ^{22}Na source: two back-to-back 511 keV photon
- ✓ Source placed between the crystal and a small monitor system (MS), $(3 \times 3 \times 15)$ mm^3 LYSO crystal readout by a (3×3) mm^2 MPPC
- ✓ Events triggered by MS

Integrated charge



Energy weighted mean time evaluated in ±10 ns window around the peak

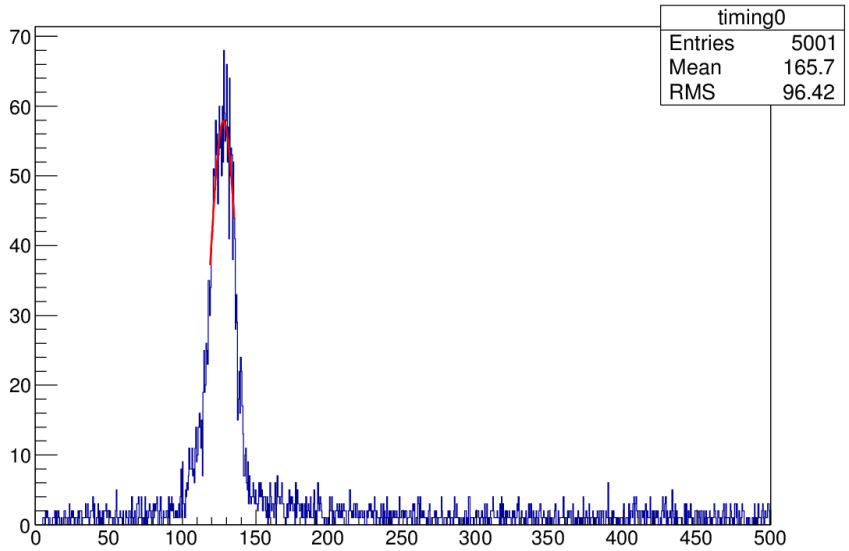


CsI light yield: data cleanup

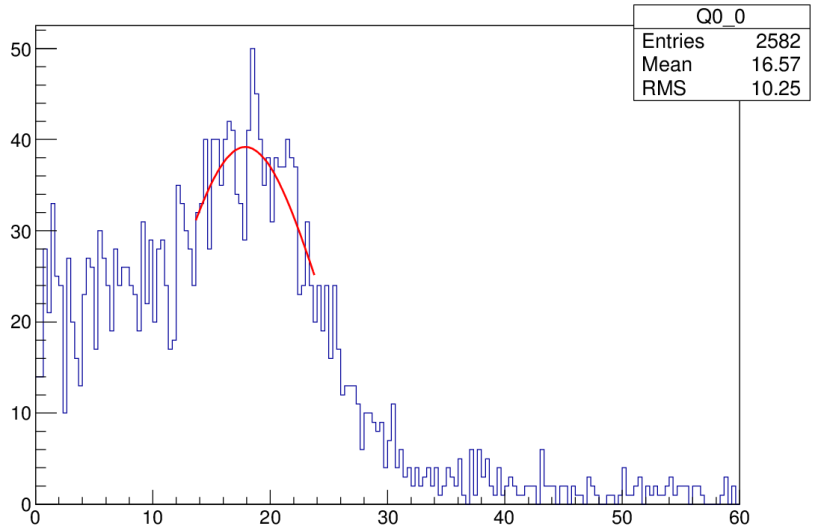
Gaussian fit on CsI time distribution in the peak region

Integrated charge spectrum for events within $\mu_T \pm 3\,\sigma_T$

Gaussian peak on Q to extract light yield

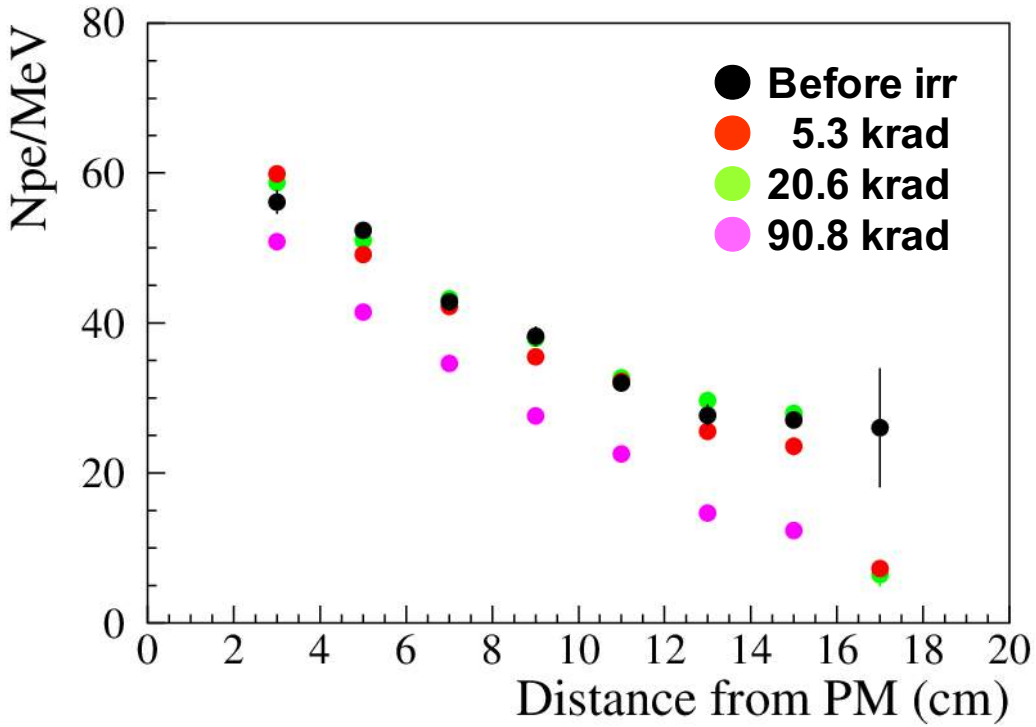


T_{mean} (ns)



Q (pC)

CsI light yield @ different doses



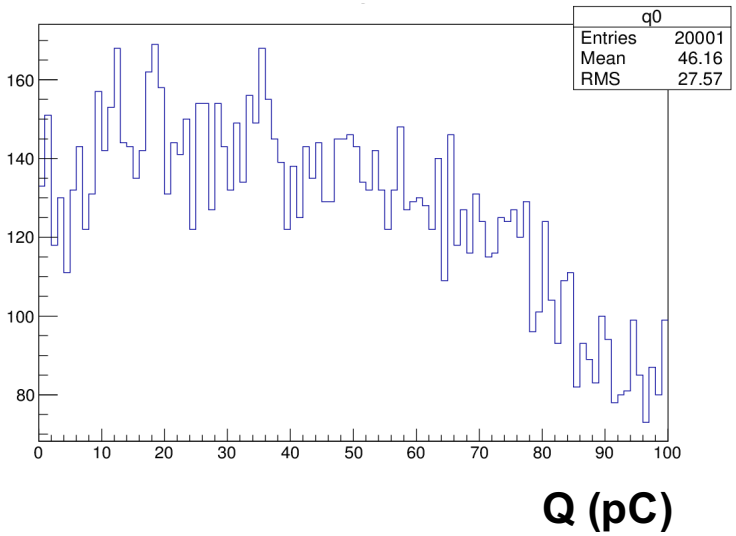
Large variation of LRU response also before irradiation

Minimal light yield reduction up to 20 krad

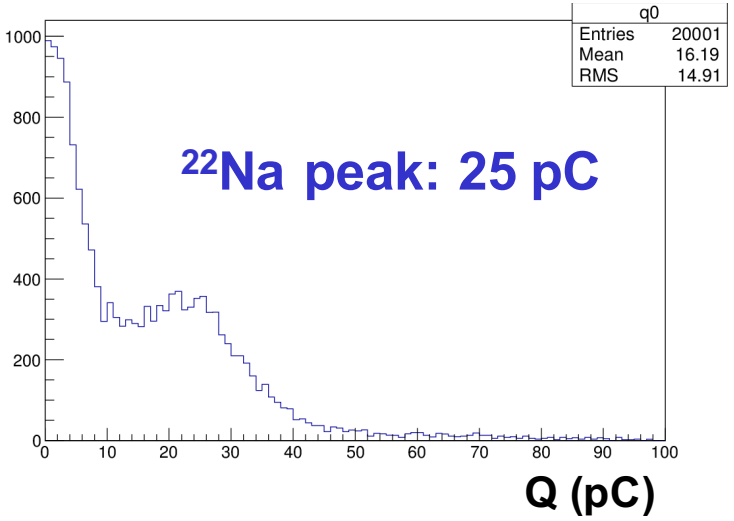
~20% light yield reduction, increasing with distance from PM, after 90 krad

CsI: fluorescence effect

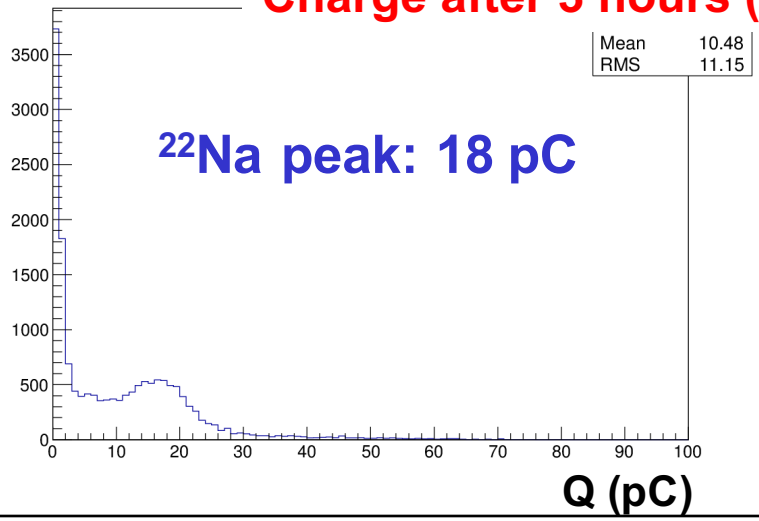
Charge just after irradiation (90 krad)



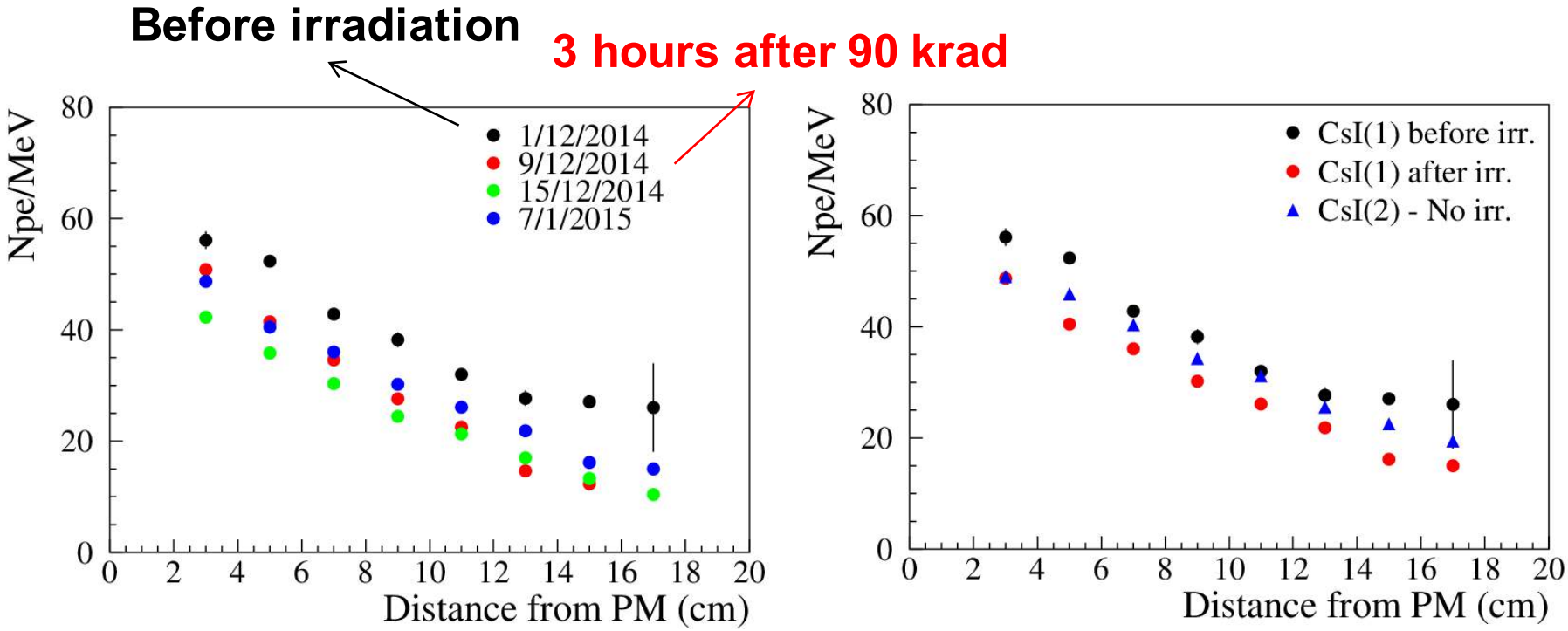
Charge after 20-30 minutes (90 krad)



Charge after 3 hours (90 krad)



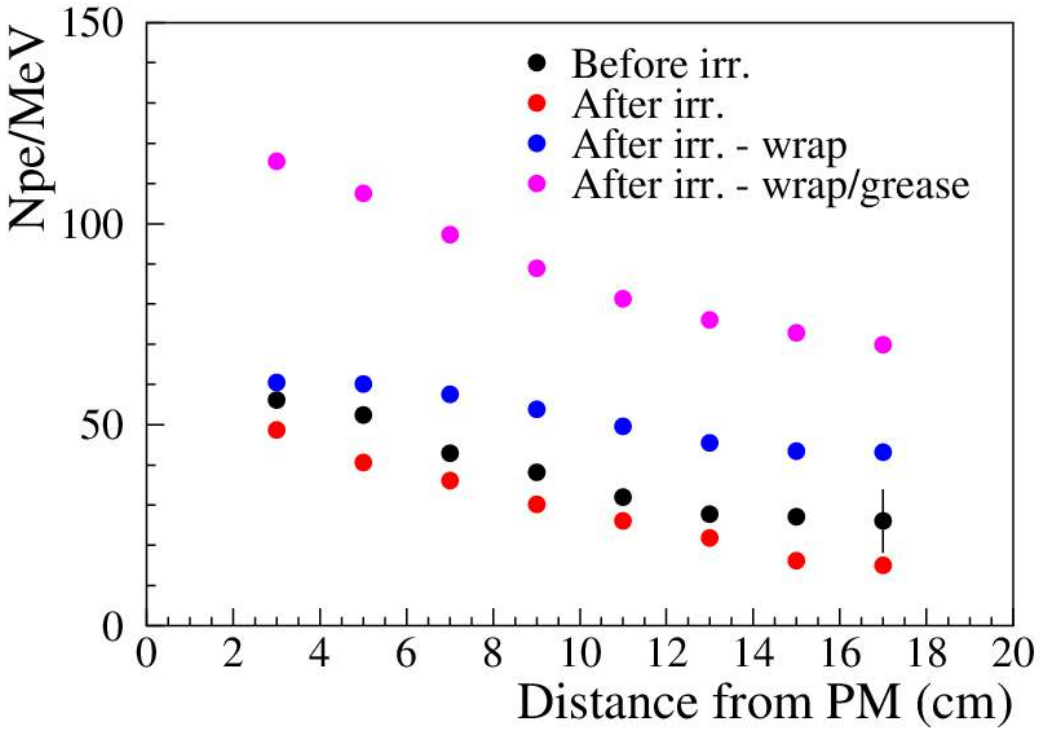
CsI: light yield recovery



No relevant recovery seen one month after irradiation

Comparison between irradiated crystal (CsI(1)) and a companion CsI from SICCAS not exposed to dose (CsI(2)) shows consistent results

CsI light yield: wrapping & PM coupling



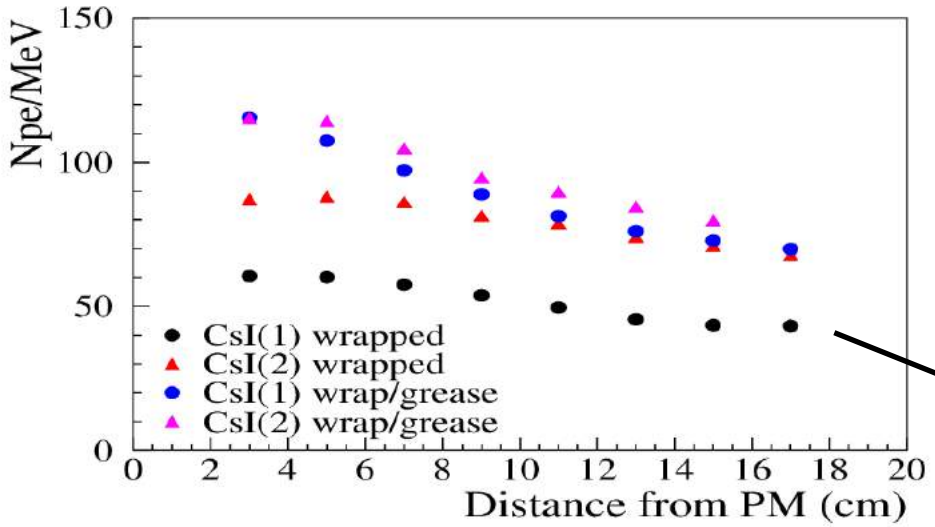
Wrapping (teflon foil): ♦ light yield increases by 1.5 in the readout region

♦ large improvement in LRU (±20%) recovering light loss by internal reflection

Wrapping + grease: ♦ further increase in LY. Npe ~ 80 @ crystal center

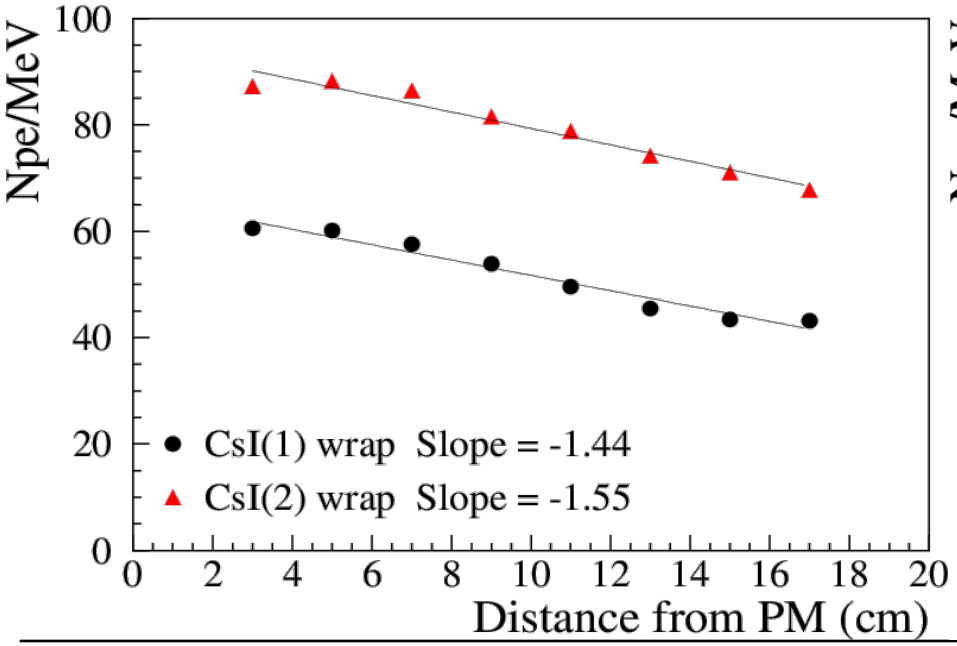
♦ longitudinal response uniformity ±30%

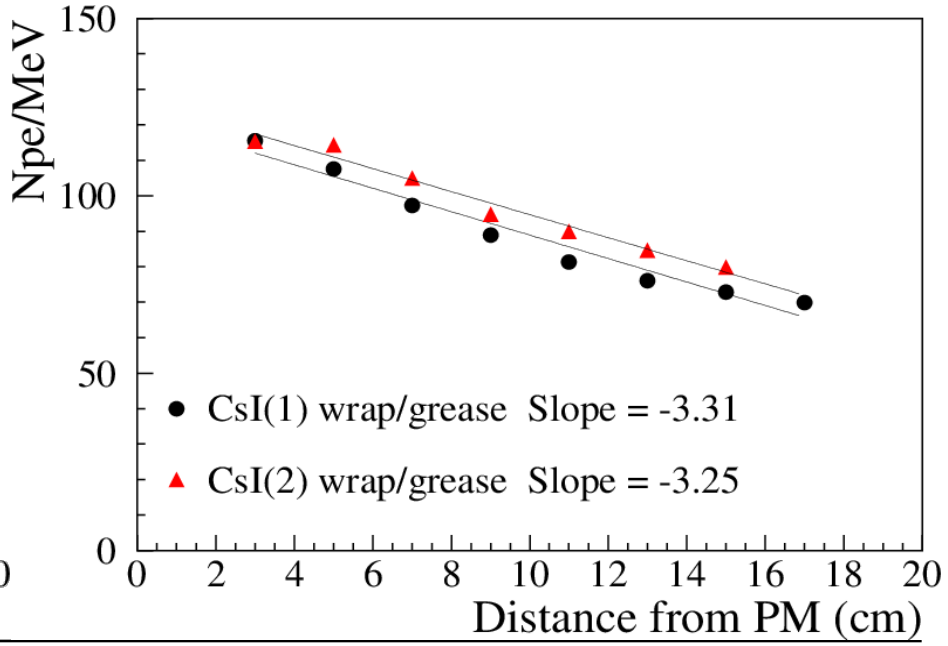
CsI LRU: wrapping & PM coupling (I)



Same LRU for irradiated and not irradiated crystal

Bad PM coupling?

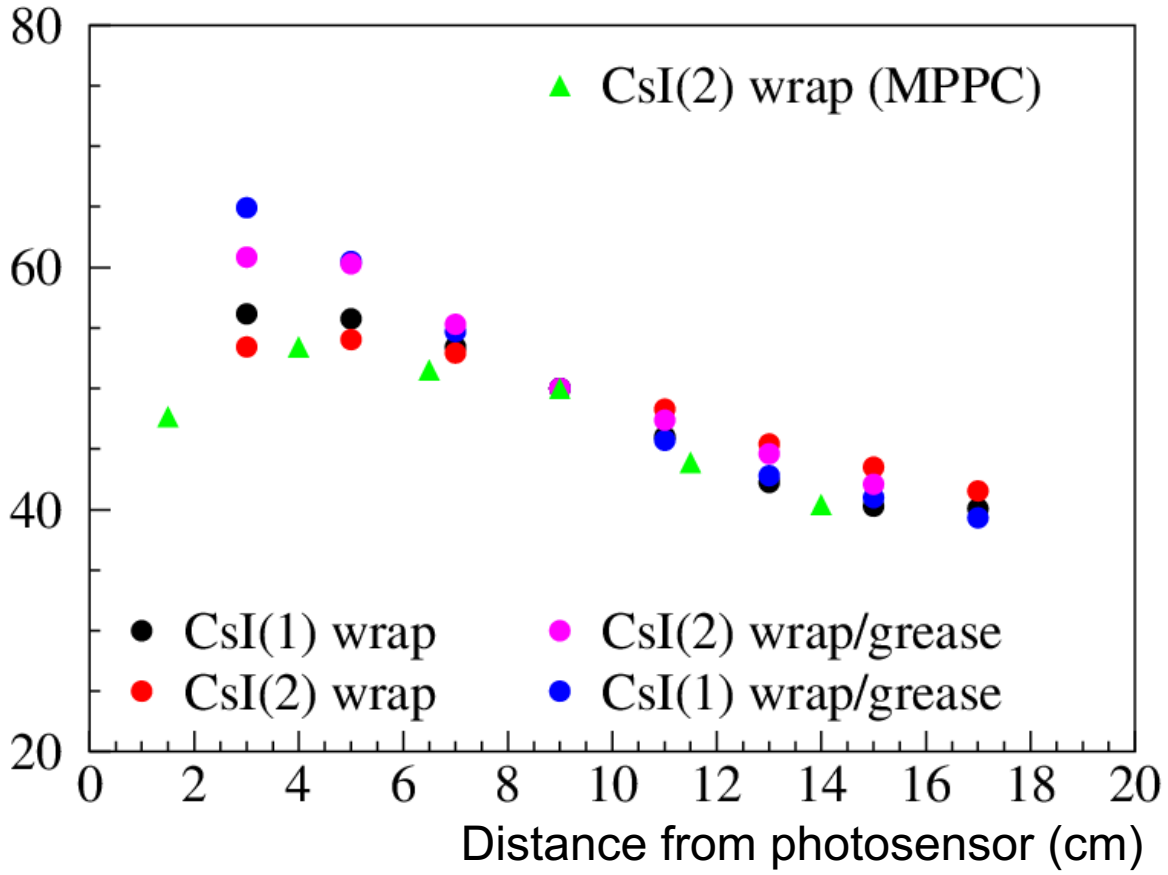




CsI LRU: wrapping & PM coupling (II)

LRU for irradiated and not irradiated CsI crystal and different readout

Normalization: LY=50 @ crystal center



Conclusions

- FNG irradiation test:
  - Negligible or acceptable LY deterioration after 9×10^{11} n/cm^2
  - LRU uneffected, eccept for SICCAS CsI
  - Not negligible fluorescence/activation after big irradiation dose
  - Transmittance marginally affected

- CALLIOPE irradiation test:
  - LY reduction of 20% after 90 krad
  - After irradiation, Npe 80/MeV @ crystal center using teflon wrapping and grease
  - LRU between 20 and 50% (no wrap, no grease)
  - Not negligible fluorescence after big irradiation dose