Characterization of a compact $LaBr_3$ detector with Silicon photomultipliers at high 14 MeV neutron fluxes

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** See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia*

Aim of the work

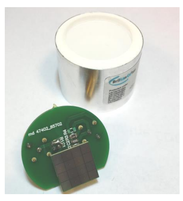
- In this work we present the response of the $LaBr_3$(Ce) crystal to 14 MeV neutron irradiation measured at the Frascati Neutron Generator (FNG) together with a comparison with the MCNP simulations.
- Furthermore, the neutron resistance of the SiPM has been also assessed after a neutron irradiation up to about 10^{10} n/cm^2.

Gamma-ray emission in fusion plasmas

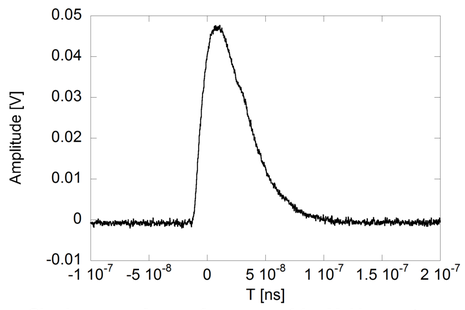
- **Gamma-ray spectroscopy** is a plasma diagnostic technique investigating the behaviour of fast ions in high temperature fusion plasmas
- Gamma-ray emission in thermonuclear plasmas is mainly due to reactions between fast particles and fuel ions or impurities
- The Gamma Camera installed at JET consists of a vertical and a horizontal camera made of 9 and 10 collimated lines of sight, respectively.
- Measurements along this multiple set of channels allow the tomographic reconstruction of the gamma emission source in the plasma.
- The detection of the **4.44 MeV γ-rays** from the $^9Be(\alpha,n\gamma)^{12}C$ reaction gives **information on alpha particles in deuterium-tritium (DT) plasmas**.

The GCU $LaBr_3$ gamma-ray spectrometer

- SiPMs represent a good alternative to PMT: high internal gain, insensitivity to magnetic field and extremely compact size.
- **Read-out electronic circuit was ad hoc built to combine the high counting rate capability with the good energy resolution**
- A proper pole zero cancellation network able to shorten the output signal to 120 ns has been implemented allowing spectroscopy at MHz count rate [1, 2].
- **Energy resolution 5% @ 0.661 MeV**



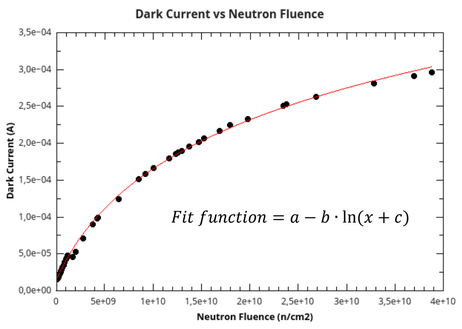
LaBr3 crystal and Silicon Photo-Multiplier with its read-out circuit board.

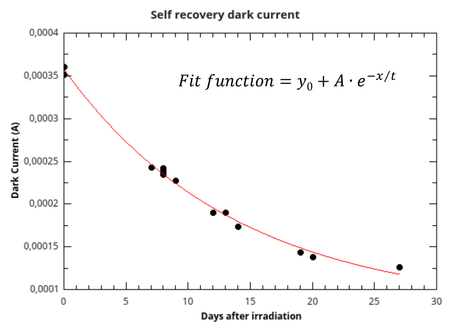


Single waveform from a 14 MeV neutron interacting with a diamond detector

SiPM resistance to neutron flux

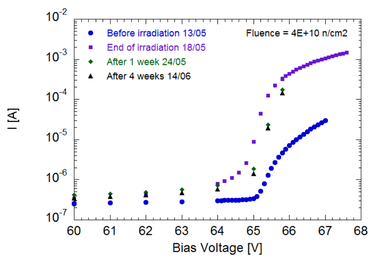
- It is well known that silicon devices can get damage by neutrons
- We need **to investigate the neutron damage** in our **SiPMs** in view of the DT JET campaign, in terms of **effects** on the **PHS** and on the **Dark Current**
- Estimated neutron fluxes for full DT plasmas are:
  - 10^7 n/s/cm2 on the central channel of the vertical camera (VC)
  - 10^8 n/s/cm2 on the central channel of the horizontal camera (HC)





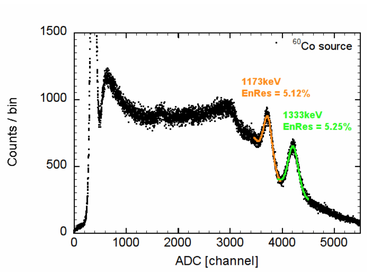
Dark current partially decrease in few days

- We reached **fluencies** up to **$4 \cdot 10^{10}$ n/cm^2** = { **400 s of full power DT for the HC** / **4000s of full power DT for the VC**



Differences in the I-V curve but the breakdown point does not change significantly

The I-V curve partially recovers after few weeks



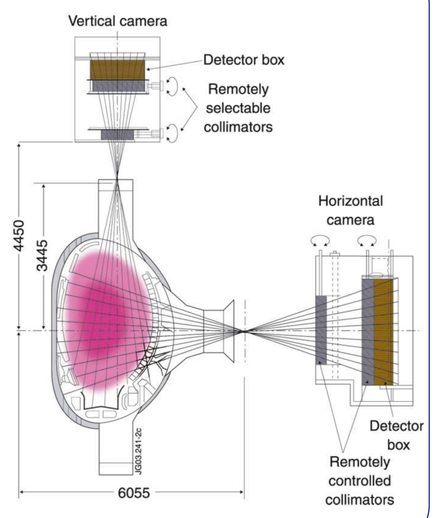
We can still clearly observe the peaks from ^{60}Co source after F=$1.5 \cdot 10^{10}$ n/cm^2!

No significant differences are shown in the pulse height spectrum (PHS)

Still a good energy resolution has been obtained

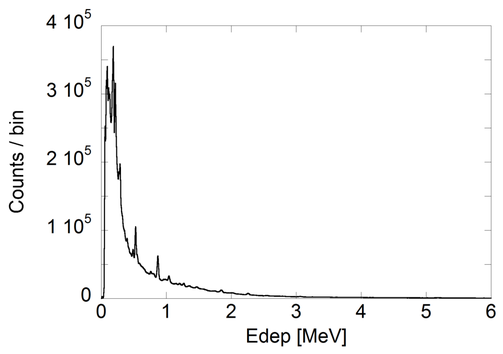
Gamma-ray Camera upgrade

- The Gamma-ray Camera Upgrade (GCU) project aims to improve the spectroscopic capabilities allowing:
  - γ-ray measurements at MHz counting rate
  - Enhanced energy resolution in a harsh neutron-gamma mix environment.
- Important existing **constraints** (available space for detectors and shielding, use existing cables).
- New **compact gamma-ray spectrometers** based on a **Silicon Photo-Multiplier** (SiPM) coupled to a **$LaBr_3$** crystal have been developed.
- The first ten detectors have been installed at JET in the horizontal camera in March 2017.

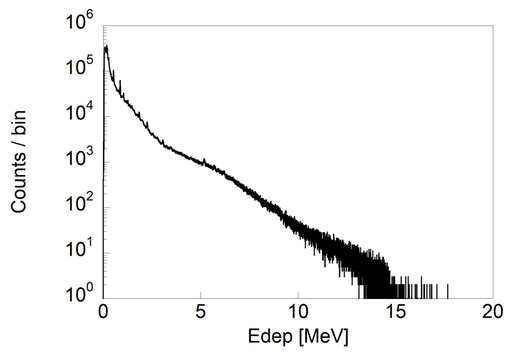


$LaBr_3$ response to 14 MeV neutrons

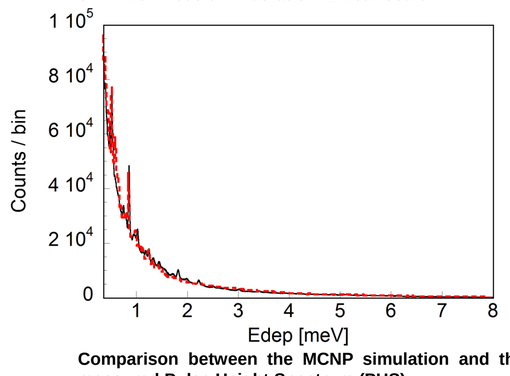
- A $LaBr_3$ scintillator crystal coupled to an Hamamatsu Photo-Multiplier tube has been irradiated at the Frascati Neutron Generator (FNG) with a **14MeV neutron beam**.
- A CAEN digitizer (500MHz, 14-bit) able to perform on-line measurements of the pulse area was used.
- Before irradiation, the detector has been calibrated with ^{137}Cs and ^{60}Co gamma sources.
- **Neutron fluence ≈ 4.2 E+7 n/cm2** **Counting Rate ≈ 57 KHz** (Very limited pile-up fraction)
- ε_{TOT} ≈ 25 (1.2 % of this events at E>3 MeV)



Pulse height spectrum recorded during 1200 seconds of 14 MeV neutron irradiation. Linear scale.



Pulse height spectrum recorded during 1200 seconds of 14 MeV neutron irradiation. Log scale .



Comparison between the MCNP simulation and the measured Pulse Height Spectrum (PHS).

The detector load is reduced significantly (by about 300 times) in the region around the 4.44 MeV peak

Average gamma-ray energy $\langle E_\gamma \rangle \approx$ 0.68 MeV

Conclusions

- The effect of 14 MeV neutrons on both **LaBr3 crystal** and the **SiPM** was measured
- The GCU LaBr3 has about 25 **% detection efficiency** to 14 MeV neutrons.
- **The neutron induced background under the 4.44 MeV peak from $^9Be(\alpha,n\gamma)^{12}C$ reaction is 1/300 of that at low gamma-ray energies.**
- 14 MeV neutrons have some effects on the SiPM (I_{dark} increase), but we can still measure a spectrum from a ^{60}Co source with good energy resolution .
- The SiPM self recovers (I_{dark} decreases) to some extent over a period of a few days

References

[1] D. Rigamonti et al., "Performance of the prototype LaBr3 developed for the JET gamma-ray camera upgrade", Rev. Sci. Instrum. 87, 11E717 (2016)
[2] M. Nocente et al., "Gamma-ray spectroscopy at MHz counting rates with a compact LaBr3 detector and silicon photomultipliers for fusion plasma applications", Rev. Sci. Instrum. 87, 11E714 (2016)

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