NCBJ - IPPLM Activities in Gamma Diagnostics Upgrade at JET

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GCU Gamma Ray Camera Upgrade
GSU Gamma Ray Spectrometer Upgrade
LRM Lost Alpha Gamma Rays Monitor

These 3 projects are implemented under the EUROFusion Consortium for the period 1st January 2014 to 31st December 2017

and they are parts of the JET Enhancements Programme WPJET4

Close collaboration with Italian institutes

GCU **Gamma Ray Camera Upgrade**

GSU **Gamma Ray Spectrometer Upgrade**

Luca Giacomelli, Giuseppe Gorini, Massimo Nocente, Valeria Perseo, *Marco Tardocchi, Davide Rigamonti*, …

$$\mathbf{D + T \rightarrow \alpha + n}$$

$$^{9}\mathrm{Be} + \alpha \rightarrow \; ^{13}\mathrm{C} \xrightarrow{n} \; ^{12}\mathrm{C}^{*} \xrightarrow{\gamma(4.44\ \mathrm{MeV})} \; ^{12}\mathrm{C}_{\ g.s.}$$

$$^{16}\mathrm{O} + n \rightarrow \; ^{16}\mathrm{N} + p, \qquad ^{16}\mathrm{N} \xrightarrow{\beta} \; ^{16}\mathrm{O}^{*} \xrightarrow{\gamma(6.13\ \mathrm{MeV})} \; ^{16}\mathrm{O}_{\ g.s.}$$

In laboratory conditions radioactive sources used to test detector systems

- **standard γ-ray sources**
  - **^{137}Cs, ^{22}Na, ^{60}Co and many other**
- **PuBe with 4.44 MeV γ-ray**
- **PuC with 6.1 MeV γ-ray**

Scintillation detectors use crystals that emit light when gamma rays interact with the atoms in the crystals (photoelectric effect, Compton effect, pair production).

The intensity of the light produced is proportional to the energy deposited in the crystal by the gamma ray.

The detectors are coupled to photodetectors that convert light into electrons and then amplify the electrical signal provided by those electrons.

Scintillation detectors can also be used to detect alpha- and beta-radiation as well as neutrons.

The most important scintillator parameters include a detector resolution and a detector efficiency.

Scintillators

- $CeBr_3$, $LaBr_3$:Ce, NaI, CsI, GAGG, BGO, YAP, …
- dimensions: 10×10×5 mm^3 to 3”×3”
- cuboid and cylindrical shapes

Photodetectors

- pin-diode (PiN)
- photomultiplier (PMT)
- silicon photomultiplier (multi pixel photon counter MPPC)

PROPERTIES

PMT

Advantages

- fast response enabling measurements at high counting rates
- high gain and extremely low excess noise factor resulting in good energy resolution
- large photosensitive area
- large linear dynamic range in which an output signal is proportional to a registered energy

Main drawback

- sensitivity to magnetic field

PiN

Advantages

- small dimensions
- low operating voltage
- immunity to magnetic field

Main drawback

- gain = 1

MPPC

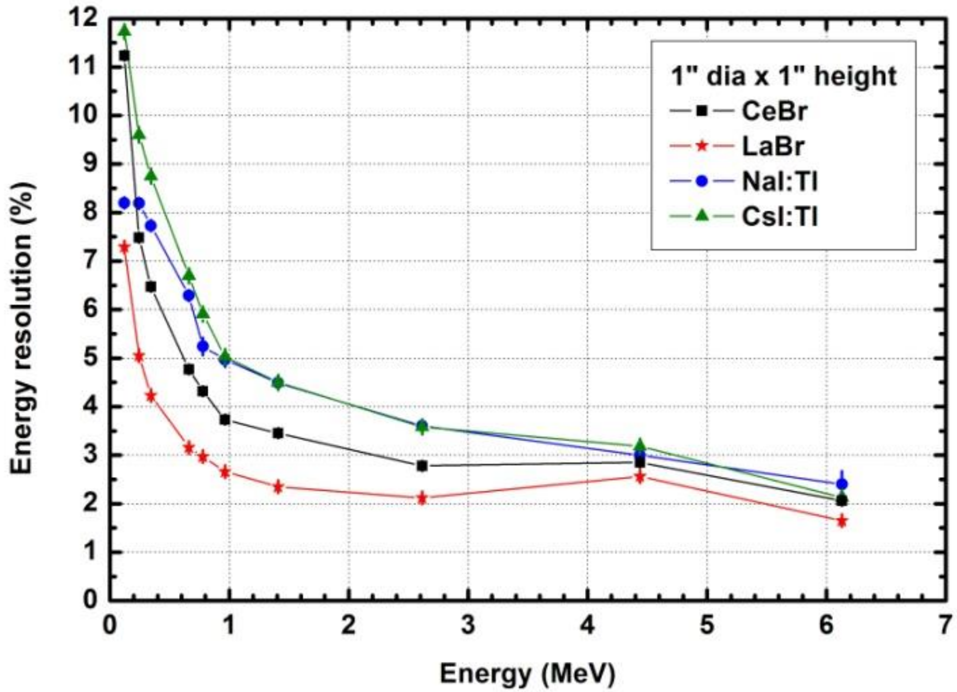
Advantages

- fast response
- high gain resulting in good energy resolution
- immunity to magnetic field

Main drawbacks

- gain sensitivity to temperature and voltage bias
- limited dynamic range

Energy resolution



Energy resolution for 1”×1” scintillators in the γ -ray energy range between 0.1 and 6.13 MeV

Doppler broadening effect linked to the emission of 4.44 MeV γ-rays from the excited state of ^{12}C

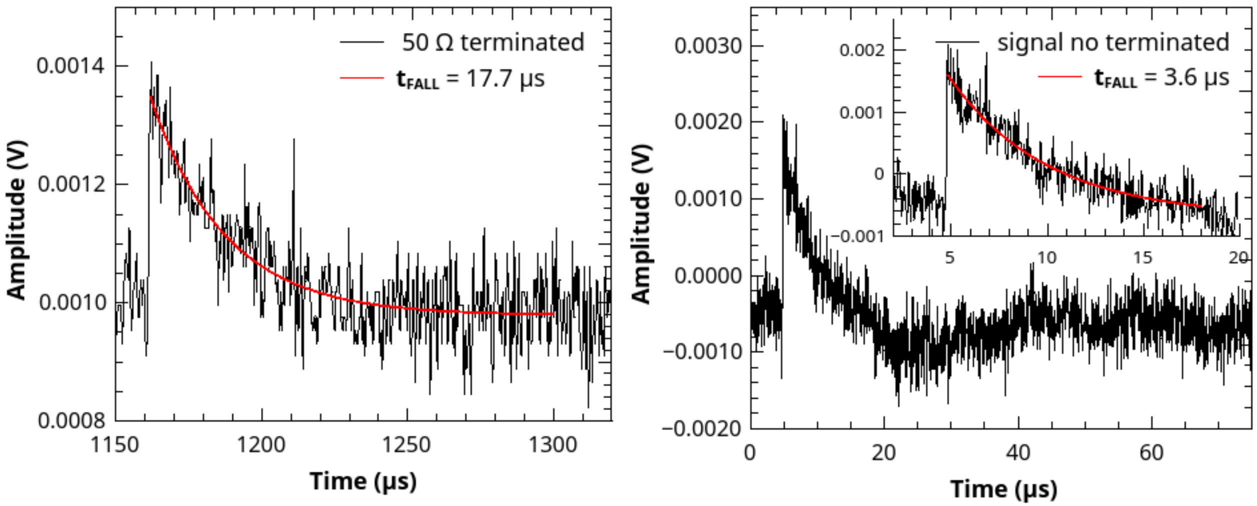
Gamma Camera Upgrade (GCU)

Replacement of the CsI detectors in the Gamma Ray Camera

- The Gamma Ray Camera in JET is equipped with a detector array which comprises 19 CsI:Tl photodiodes with a diameter of 20 mm and a thickness of 15 mm.
- CsI:Tl crystals are characterised by a comparatively long scintillation decay time, around 1000 ns.
- At the expected high counting during D-T campaigns (in MHz range) it is required to replace CsI by detectors with a shorter decay time, e.g., $CeBr_3$ or $LaBr_3$:Ce detectors with a scintillation time around 20 ns.
- New detector material should not contain oxygen to avoid unwanted background due to a reaction on oxygen.

Detector setup based on $CeBr_3$ coupled to PiN diode photodetector

1. the observed signals are very similar with the incoming signals from CsI based detectors, currently installed at JET
2. signals characterized by a very low signal to noise ratio and much longer signal time
3. over 60% worse energy resolution for ^{137}Cs source in comparison with a MPPC based detector



Examples of pulses stored at 2.5 Msps rate with 50 Ω channel termination (left) and without termination (right). Fitted red curves defines a fall time of signals to be equal to 17.7 μs and 3.6 μs, respectively. The time scale is relative.

Silicon-based photodetectors

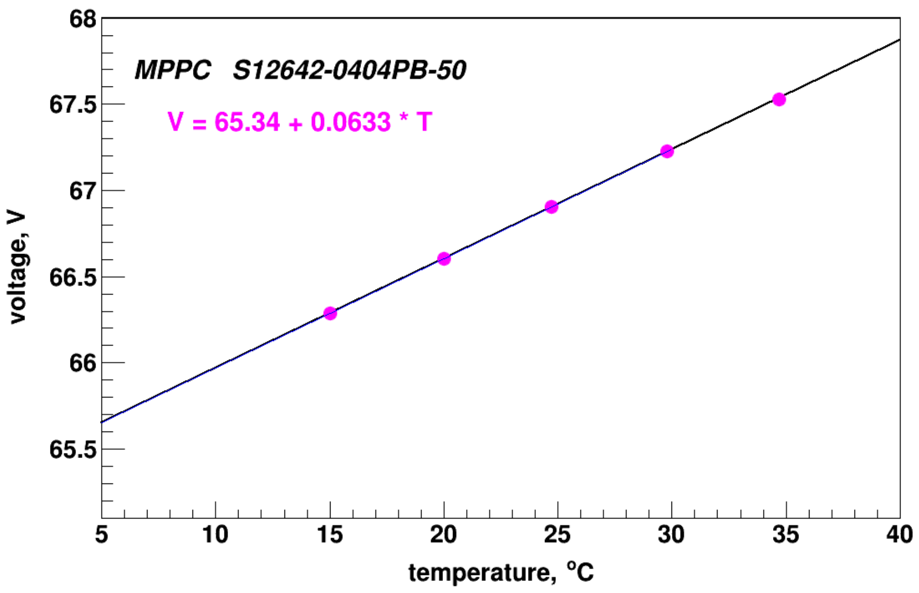
MPPC - Multi-Pixel Photon Counter – is a silicon-based monolithic array of micro-pixel avalanche diodes operating in a Geiger mode.

MPPC is characterized by large internal gain, high photon detection efficiency, high-speed response, excellent time resolution, wide spectral response, immunity to magnetic fields, resistance to mechanical shocks, low power/voltage operation and compactness.

MPPC is therefore an alternative to a photomultiplier tube if operating at high count rate in harsh radiation environment.

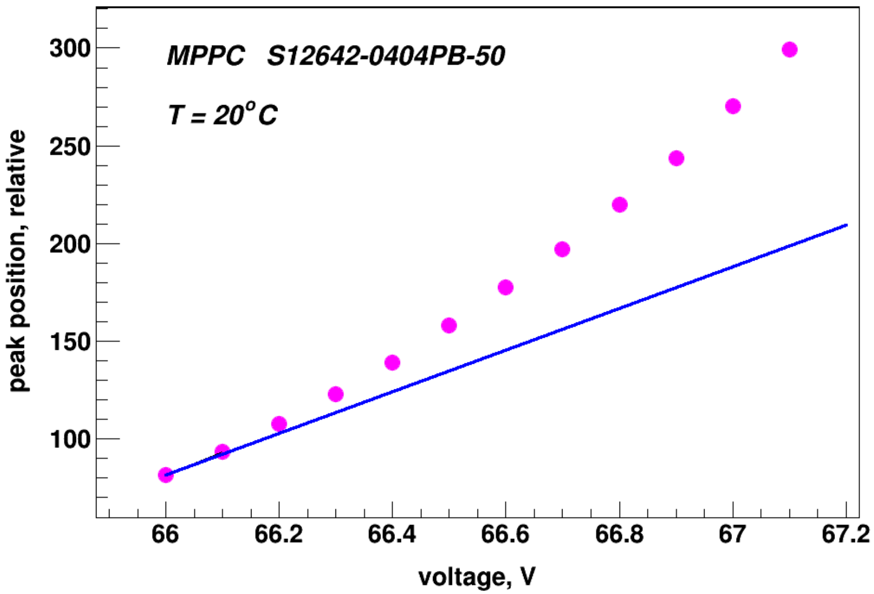
Due to the fact that properties of MPPC can be strongly affected by temperature, it is necessary to stabilize MPPC operation under temperature variations.

Temperature and voltage dependence of the MPPC detectors



Slawek Mianowski & **Valeria Perseo**

Peak position and voltage dependence of the MPPC detectors

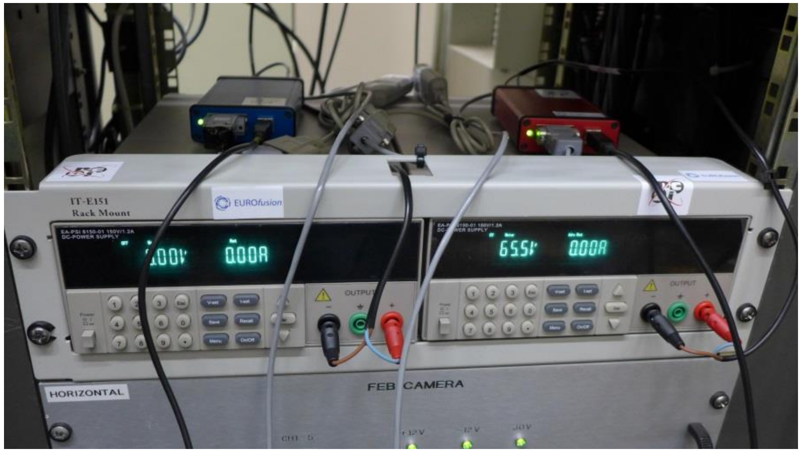


Slawek Mianowski & **Valeria Perseo**

MTCD@ NCBJ

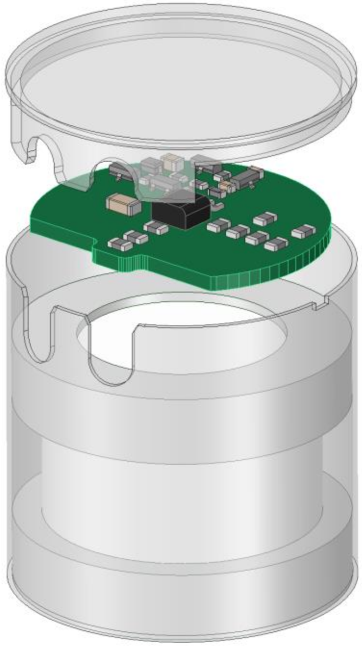
MPPC Temperature Compensation Device

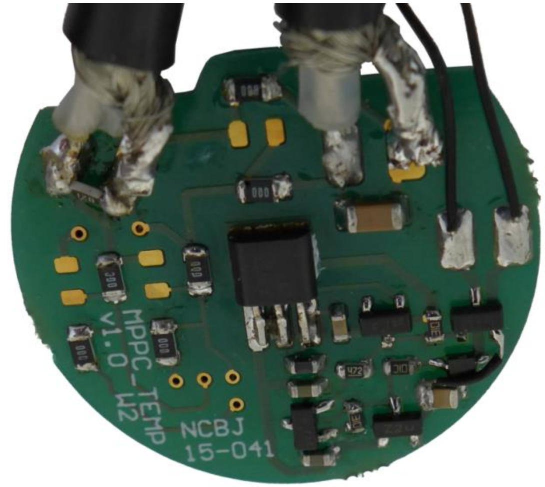
for real-time temperature monitoring and MPPC gain stabilization, necessary due to the fact that properties of MPPC are strongly affected by temperature

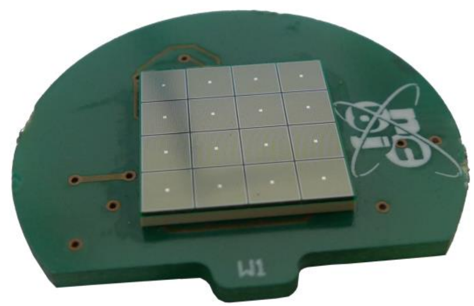


installed at JET in May 2015

providing a current limitation and filtering of the MPPC bias voltage and is using a measured dependence of a bias voltage on temperature to maintain a constant value of the MPPC gain







At JET in four conductors of 80 m long electrical cables, 2 conductors were chosen to be used only for MPPC power supply.

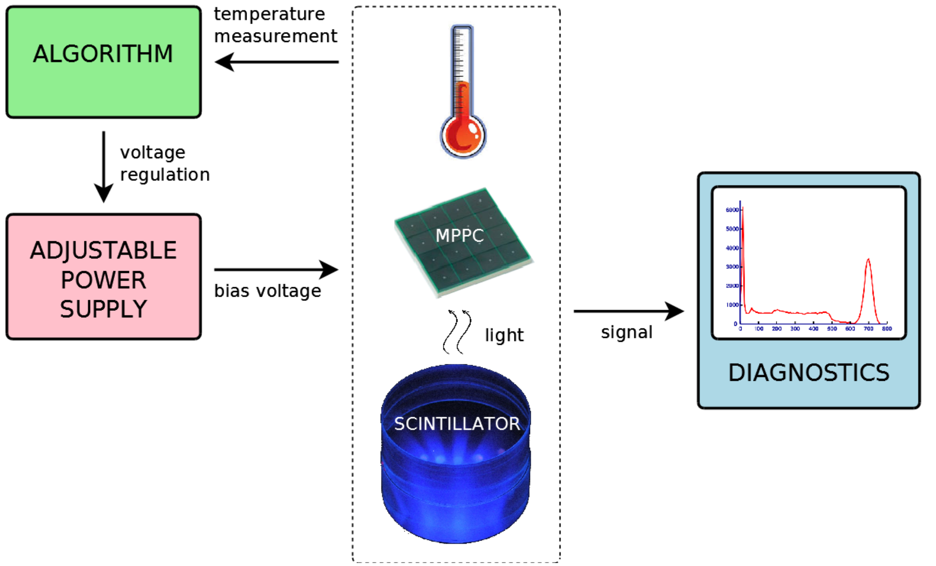
Two other conductors were used to send measured temperature values to a C&M system from MTCD@NCBJ.

Existing cylinder detector capsules

Φ 35 × H 35 mm

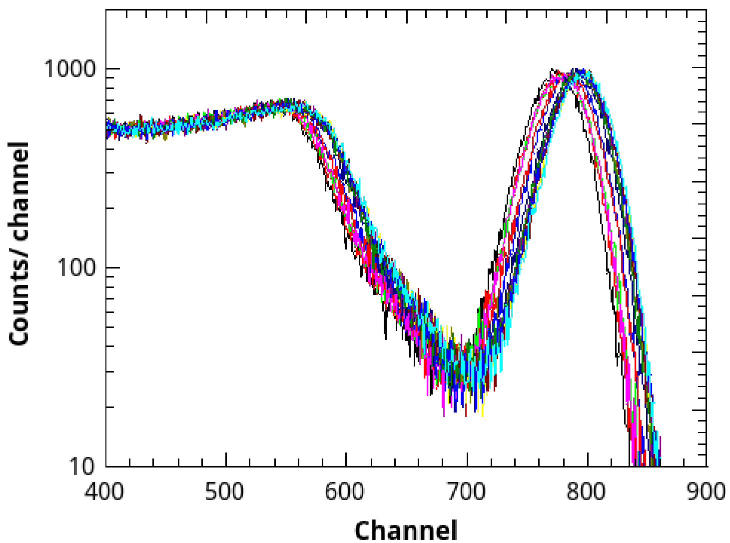
mounted on a slider to be used with new scintillators.

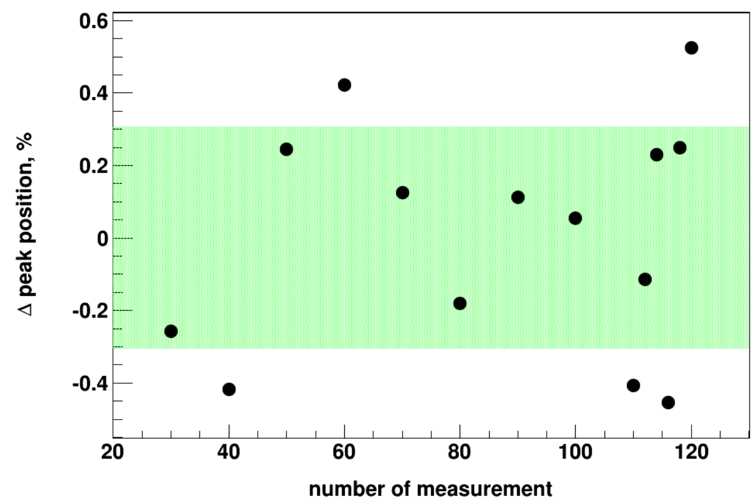
Dedicated MPPC PCB for detectors installed at JET in May 2015



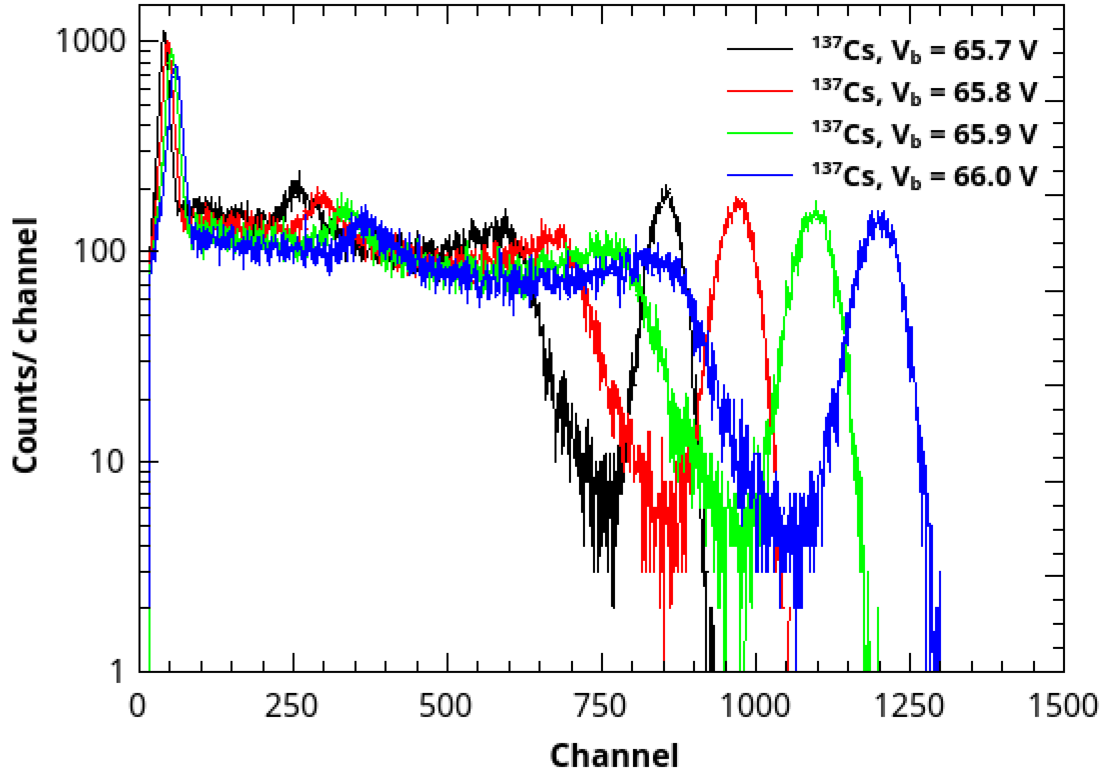
MTCD@NCBJ, a temperature compensation device, is based on an Atmega128 microcontroller, controlling an EA-PSI6150-01 power supply by an opto-isolated serial interface.
Temperature of the scintillator is measured by a TSIC506F digital thermometer integrated with the detector. The thermometer has an accuracy of ±0.1 K in a temperature range from +5 to +45°C.
MTCD@NCBJ is using a measured dependence of a bias voltage on temperature to maintain a constant value of the MPPC gain. The device can supply an output voltage up to 80 V.
All functions are controlled from a personal computer

MTCD@ NCBJ PERFORMANCE





- ***661.7 keV gamma line measured with 20×15 mm $CeBr_3$ scintillator***
- ***120 measurement sessions at NCBJ, each lasted 500 s of live time***
- ***17 hours of measurements during day and night with ΔT=2-3°***
- **change in Full Energy Peak (FEP) position below 1%**



^{137}Cs spectra measured at constant room temperature

at different MPPC bias voltage

ΔU_b=100 mV → ΔFEP ≈ 100 channels

ΔT = 1°C → ΔU_b=70 mV

JET REQUIREMENTS

1. **limited space for a MPPC-based scintillation detector → dedicated detector setup fitted to "old" CsI capsules**
2. **new electronics using existing cabling: 80 m long cables, four wires in a cable**
3. **power supplies and control system put in one box**

MTCD@NCBJ - CONCLUSIONS

1. MTCD@NCBJ optimises a detector operation in varying temperatures.
2. MTCD@NCBJ is easily extended to a setup for 19 detector system.
3. 19 MPPC power supplies will be integrated in C&M box.
4. measured temperature values will be off-line available for further use, including date and time information.

CONCLUSIONS
FROM MEASUREMENTS IN MARCH 2015 AT JET

- **Setups based on a MPPC photodetector are the most suitable candidates for new prototype detectors.**

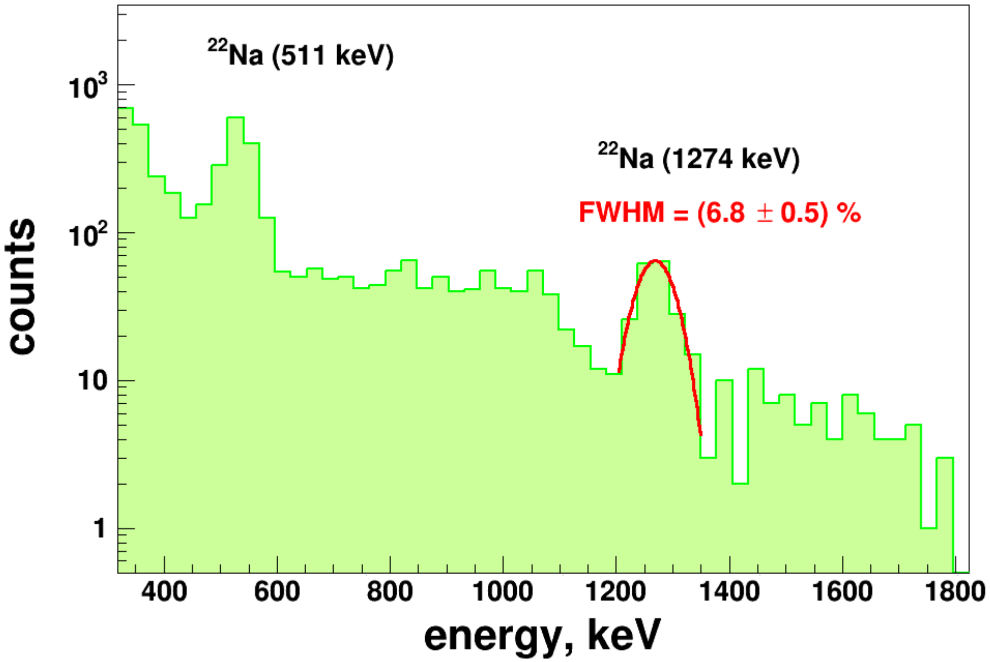
- **Detector signals registered in the setup without a preamplifier are characterized by a good signal to noise ratio and short total length (~1 μs).**

- **These parameters allow to produce proper energy spectra with a good energy resolution.**

^{22}Na spectrum measured by $CeBr_3$ coupled to MPPC in the Gamma Camera channel 9 (4096 bins) in May 2015

data acquired at 200 MSPS

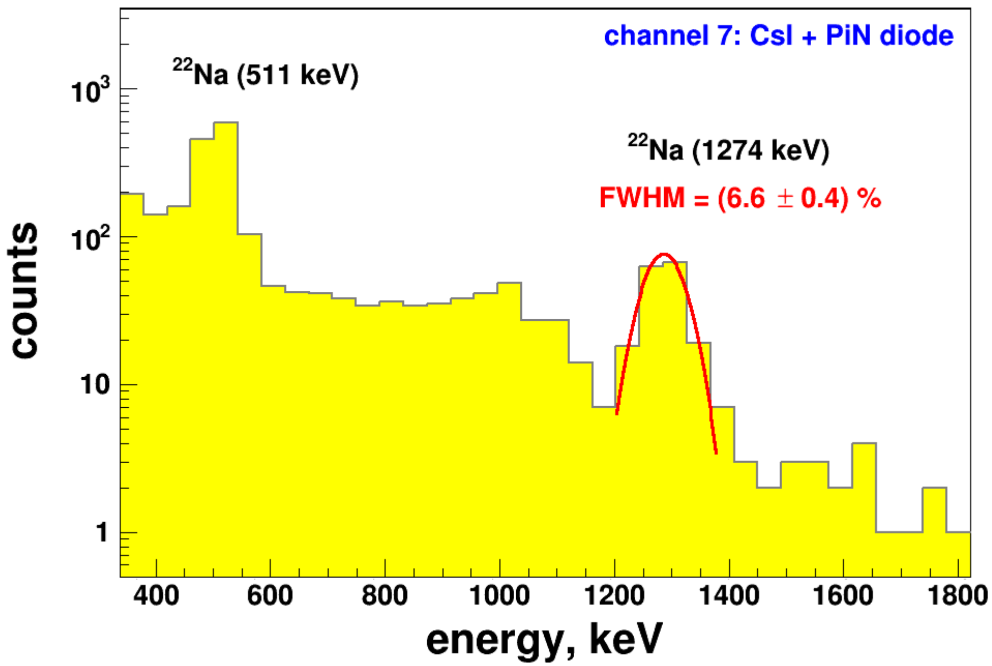
spectra built with a fast, non-optimized algorithm



^{22}Na spectrum measured by CsI:Tl coupled to PiN diode in the Gamma Camera channel 7 in May 2015

data acquired at 2.5 MSPS

spectra built with an optimized algorithm for CsI pulses



To continue tests in 2015 necessary to operate the MPPC-based prototypes in the 2015-2016 campaign

a. **to perform tests with prototypes when the Gamma Camera in place with available AmBe source,**

b. **to replace power supplies for two capsules with MPPCs by a device prepared for 19 channels. If a new power supply device is installed in December 2015, it could be tested in 2016 by the end of the campaign.**

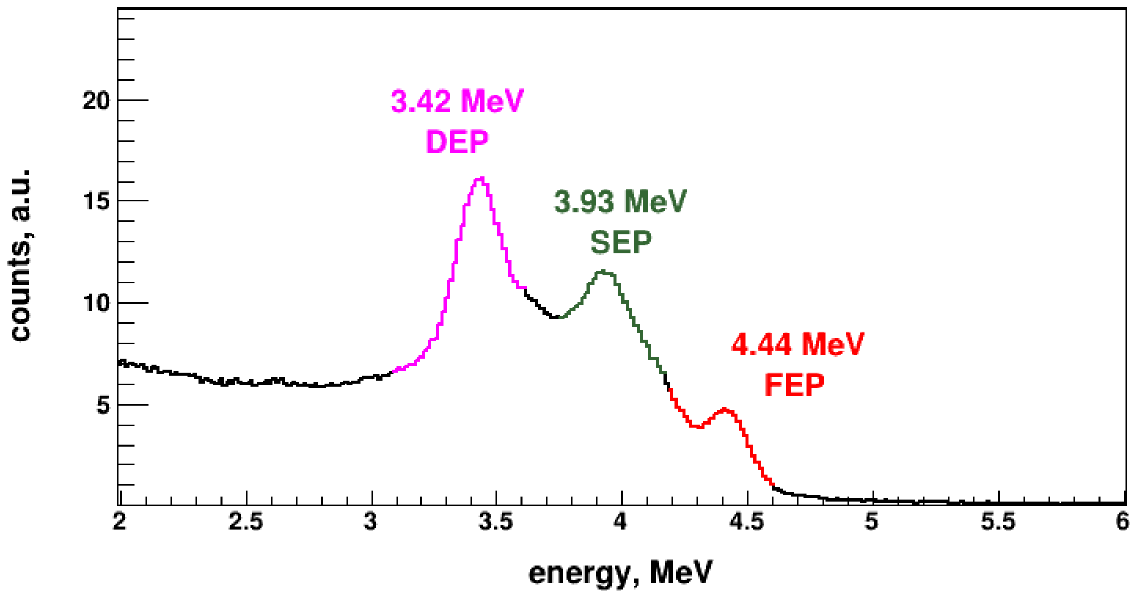
Gamma Spectrometer Upgrade (GSU)

Replacement of the existing BGO detector in the Gamma Spectrometer

- Gamma ray detector must work at high count rates – detector based on the BGO scintillator has a long decay time and old electronics that does not fulfill requirements for high count rate measurements (DT experiments).

- New material should not contain oxygen to avoid unwanted background.

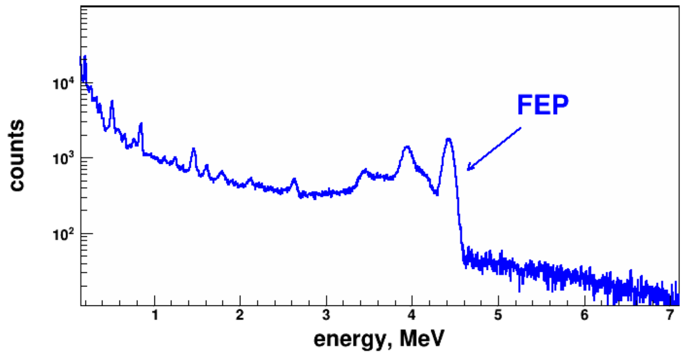
Response of 1”×1” $CeBr_3$ scintillator to PuBe source emitting 4.44 MeV γ-rays



FEP (full energy peak) is detected at 4.44 MeV.
After annihilation of a positron inside the crystal, two 0.511 MeV photons are emitted. It is possible that one or two of those photons can escape a scintillator, which gives rise to the single escape peak (SEP) at 3.42 MeV and double escape peak (DEP) at 3.93 MeV.

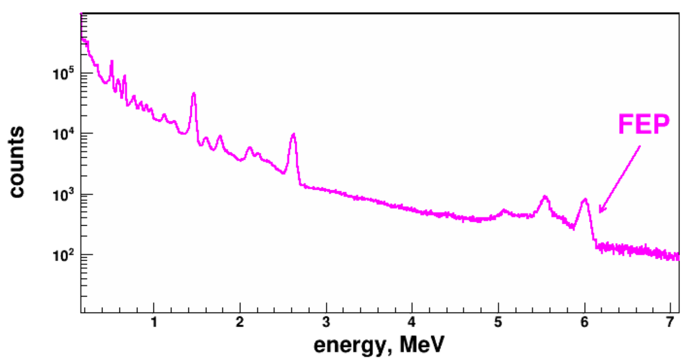
3” x 3” $CeBr_3$ + PMT

results obtained with a similar scintillator setup as ordered for GSU



PuBe

FEP at E_γ = 4.44 MeV

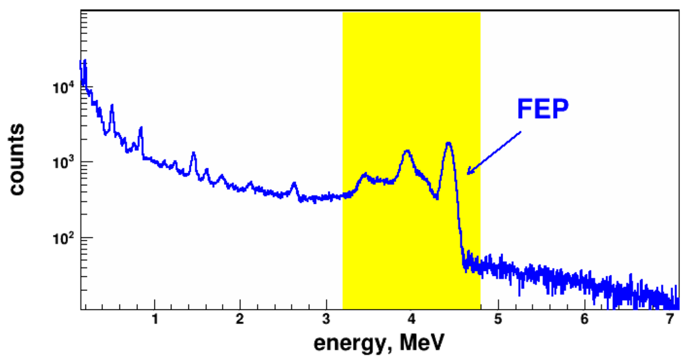


PuC

FEP at E_γ = 6.13 MeV

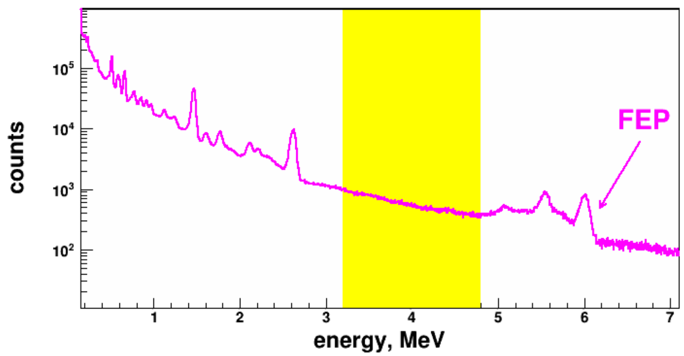
3” x 3” $CeBr_3$ + PMT

results obtained with a similar scintillator setup as ordered for GSU



PuBe

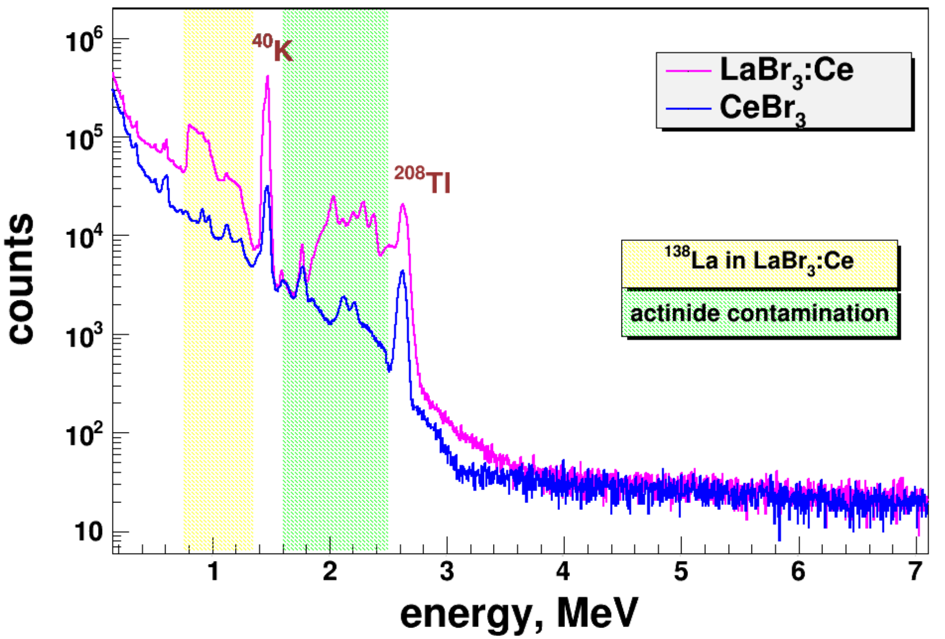
FEP at E_γ = 4.44 MeV



PuC

FEP at E_γ = 6.13 MeV

Response of $CeBr_3$ and $LaBr_3$:Ce to natural background radiation



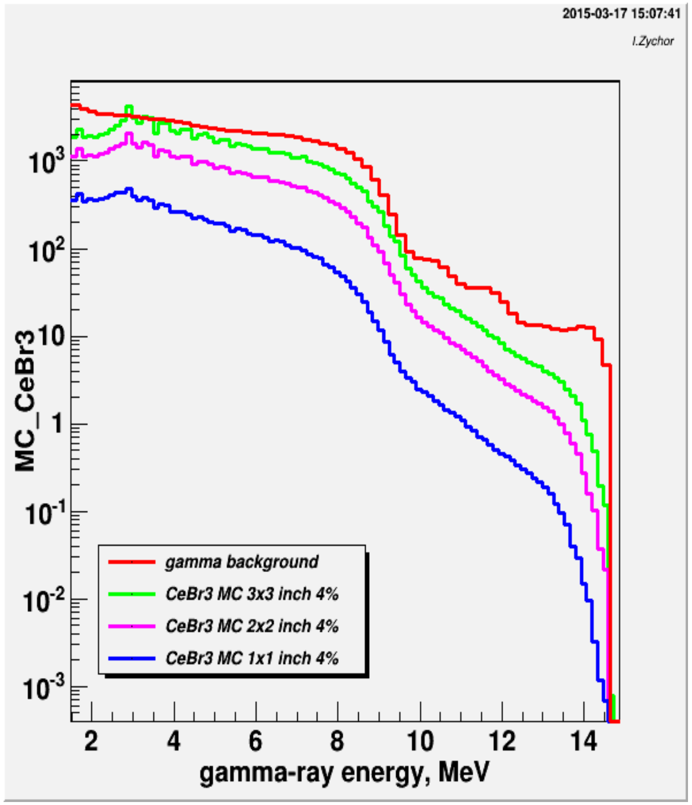
Natural background: ^{40}K (1.461 MeV), ^{208}Tl (2.615 MeV)

$LaBr_3$:Ce is contaminated also with naturally occurring ^{138}La decaying by electron capture or β– decay

Events due to internal contamination by actinides: 1.5-2.5 MeV

Lost Alpha Gamma Rays Monitor (LRM)

- **For lost α-particle studies, a new diagnostics is proposed**
- **No final decisions made: PBM on July 9th, 2015 ?**
- **IPPLM contributions**
  - design, manufacture and installation of two KA4 detectors based on $CeBr_3$, similar to GCU detectors
  - calculation of KA4 detector response function



A comparison of normalised event numbers obtained from Monte Carlo simulations.

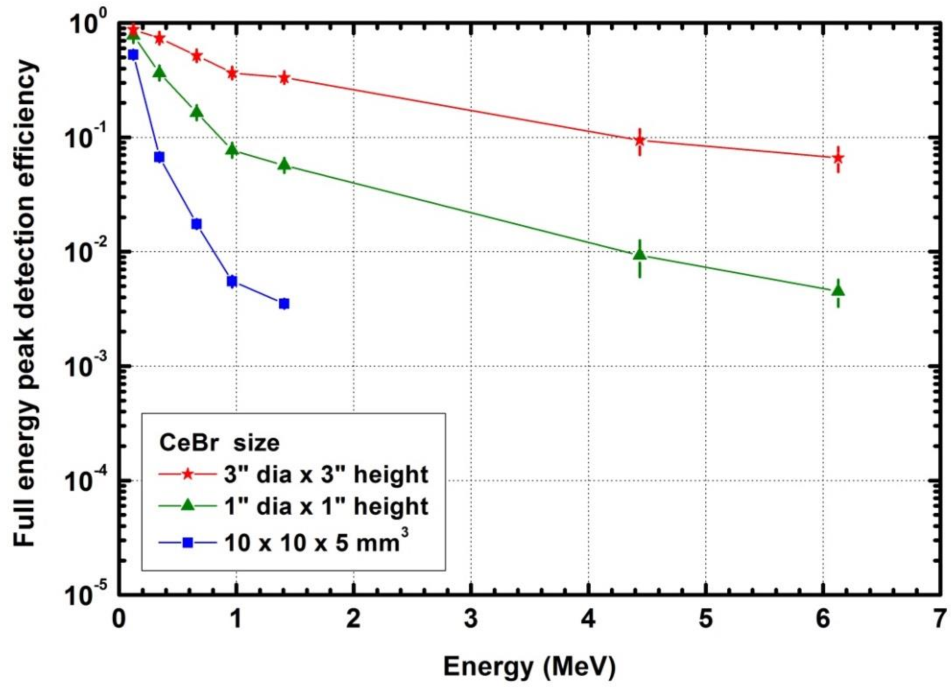
$CeBr_3$ scintillator	average event number	event number at 1.5 MeV	**event number at 4.4 MeV**	event number at 6.1 MeV
1"x1"	1.0	1.0	**1.0**	1.0
2"x2"	4.1	4.3	**4.6**	5.0
3"x3"	8.1	8.8	**9.4**	10.8

As it was expected, bigger scintillators have a higher detection efficiency for gamma ray energies around 4.4 MeV.

Monte Carlo simulations for different $CeBr_3$ scintillators performed to evaluate a detector response to gamma radiation in DT experiments *used in Phase I of the project to find optimal detector dimensions.*

A 0 approx. gamma-ray background normalised to the integral spectrum provided by V.Kiptily. The spectrum covers a range of gamma ray energy from 1.5 to 14.9 MeV.

Detection efficiency *vs.* detector size



FEP detection efficiency measured for $CeBr_3$ scintillators

The results for 4.44 MeV and 6.13 MeV γ-rays are not available for the smallest sample because the mean free path is too long to produce FEP is in this scintillator during acceptable acquisition time.

Performance and cost estimations for the LRM detector options

- **PMT and MPPC photodetectors are the best candidates for light readout for scintillators in the LRM project**

PMT is a better and more reliable solution

- **Detector dimensions: dependent on a final position of the LRM setup**

SUMMARY

- JET4 projects in a close collaboration with Italian colleagues in all stages.
- Similar tasks allow us to exchange experience and know-how.
- Already gained experience makes us sure that our projects will be successful.

Collaboration between NCBJ and IPPLM

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G.Boltruczyk
M.Gosk
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P.Sibczynski
L.Swiderski

and colleagues from
Nuclear Techniques & Equipment Department (NCBJ)