Polish Activities in Gamma-ray Diagnostics Upgrade at JET

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- Italian – Polish Collaboration

  - Istituto di Fisica del Plasma „Piero Caldirola” (CNR)
  - Dipartimento di Fisica “G. Occhialini”, Università degli Studi di Milano-Bicocca, Milano, Italy
  - *Dipartimento di Fisica, Università di Padova and INFN sezione di Padova*

  - Narodowe Centrum Badań Jądrowych (NCBJ), Otwock-Swierk, Poland
  - Instytut Fizyki Plazmy i Laserowej Mikrosyntezy (IFPiLM), Warszawa, Poland

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

parts of the JET Enhancements Programme WPJET4

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

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

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

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**

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.

Gamma Spectrometer Upgrade (GSU)

Replacement of the BGO detector in the Gamma-Ray Spectrometer

- Gamma ray detector must work at high count rates – detector based on the 3”×3” 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.

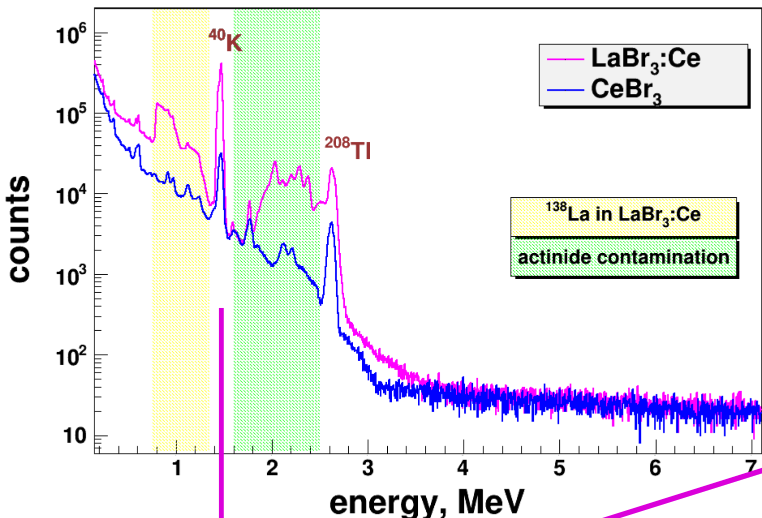
Requirements for DT campaigns

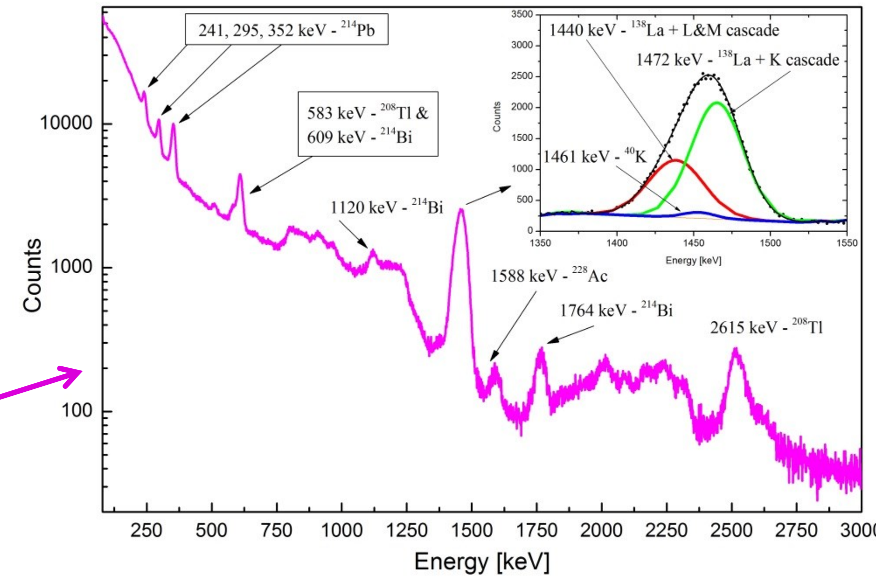
- energy resolution: a few % at 1.1 MeV
- short decay time
- high detection efficiency

		CsI:Tl	BGO	$CeBr_3$	$LaBr_3$:Ce
manufacturer		Amcrys-H	Novosibirsk	Scionix	St-Gobain
density (g/cm^3)		4.51	7.13	5.18	5.06
effective atomic number, Z_{eff}		54.0	71.5	45.9	45.2
decay time (ns)		780 ± 50 (46% fast component)	300	19 ± 2	18 ± 2
energy resolution (FWHM, %) at 1.1 MeV		4.9 ± 0.1	8.8 ± 0.3	3.4 ± 0.1	2.4 ± 0.1
detection efficiency (%)at 1.1 MeV	1”×1”	6 ± 1	19 ± 1	6 ± 1	7 ± 1
	3”×3”	–	40 ± 1	29 ± 2	27 ± 3

$CeBr_3$ *vs.* $LaBr_3$:Ce

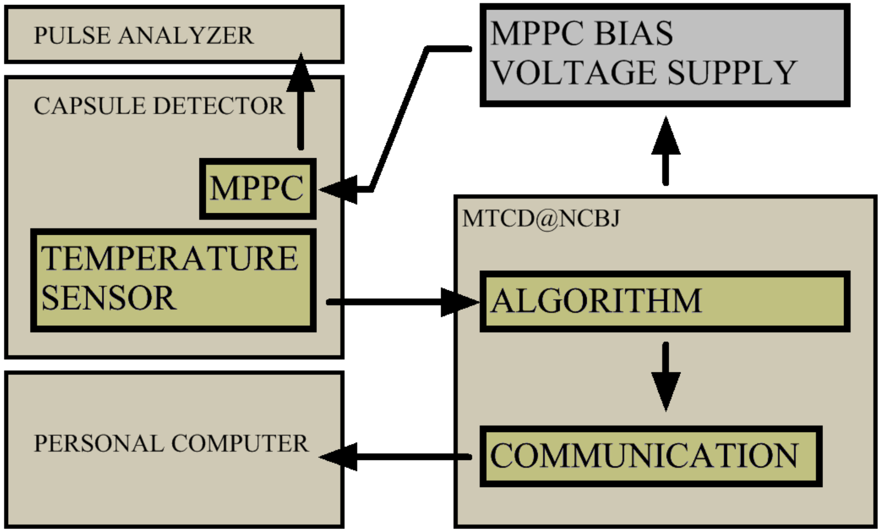
$LaBr_3$:Ce presence of the long-lived naturally occurring ^{138}La isotope

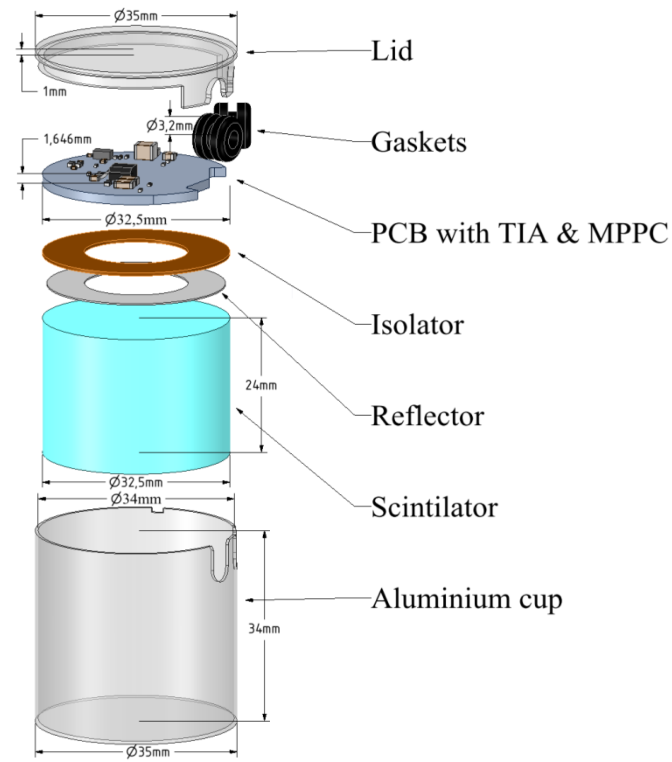




1472 keV peak in $LaBr_3$:Ce

- 1440 keV corresponding to 1436 keV + L and M cascade
- 1472 keV corresponding to 1436 keV + K cascade
- 1461 keV corresponding to ^{40}K



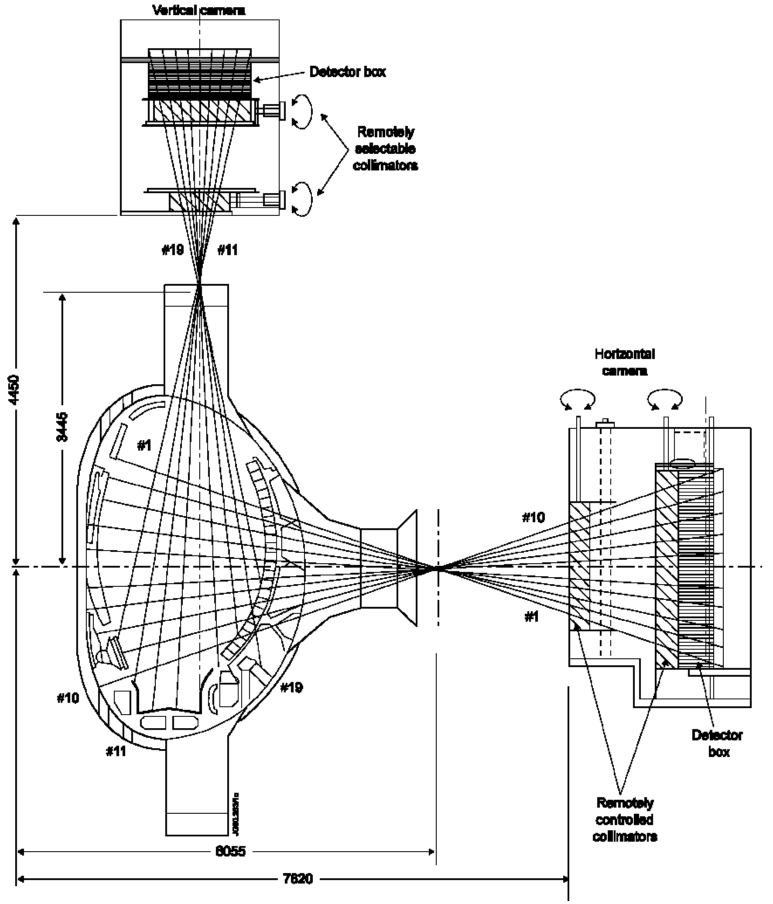


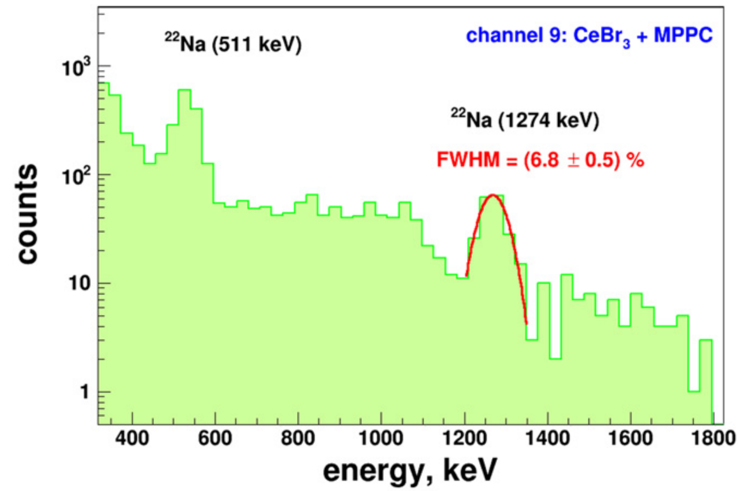
35 × 35 mm

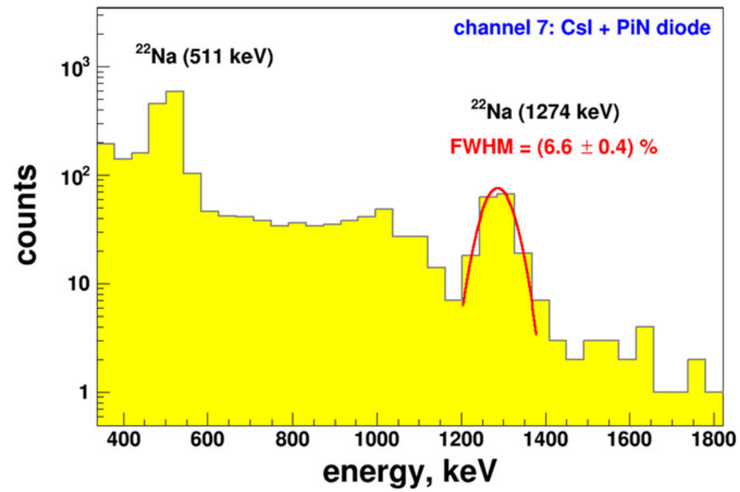
MTCD@NCBJ

MPPC Temperature Compensation Device

- measurement of detector temperature
- setting of MPPC bias Voltage
- constant MPPC gain by changing MPPC bias voltage as a function of detector temperature
- integrated power supply MAX1932
- advanced power supply closed loop control


Vertical camera
Detector box
Remotely selectable collimators
#19
#11
4450
3445
#1
#10
#19
#11
Horizontal camera
#10
#1
Detector box
Remotely controlled collimators
6055
7820


^{22}Na (511 keV)
channel 9: $CeBr_3$ + MPPC
^{22}Na (1274 keV)
FWHM = (6.8 ± 0.5) %
counts
energy, keV


^{22}Na (511 keV)
channel 7: CsI + PiN diode
^{22}Na (1274 keV)
FWHM = (6.6 ± 0.4) %
counts
energy, keV

PASSIVE *vs.* ACTIVE

Passive RC-CR circuit

- no additional heating source (no active elements)
- simple, reliable solution (limited error prone elements)
- large sense resistor (high gain) causes **high time constant** and **slow response** (signal shape)
- low signal-to-noise ratio may be unacceptable

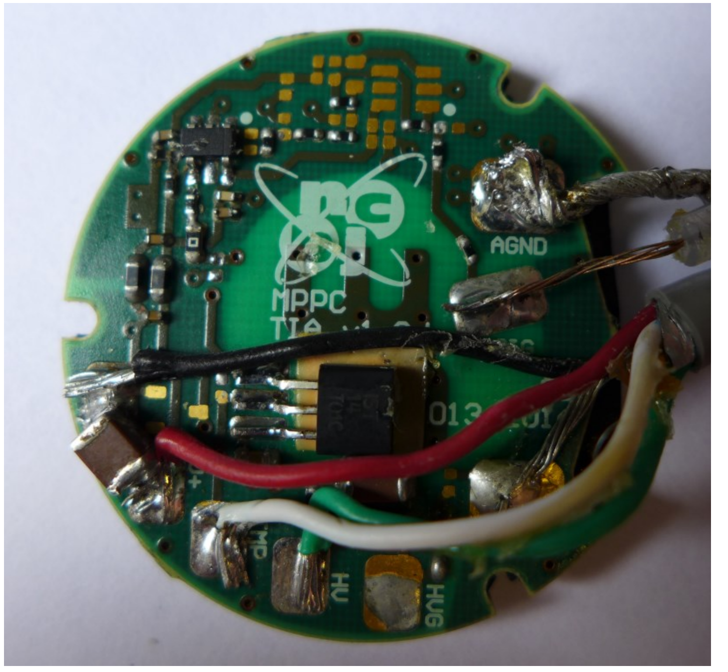
Active TIA

(transimpedance amplifier)

- **faster response** (signal shape) - crucial for high count rate measurements
- **high output amplitude** (high gain)
- **low time constant**
- additional heating source

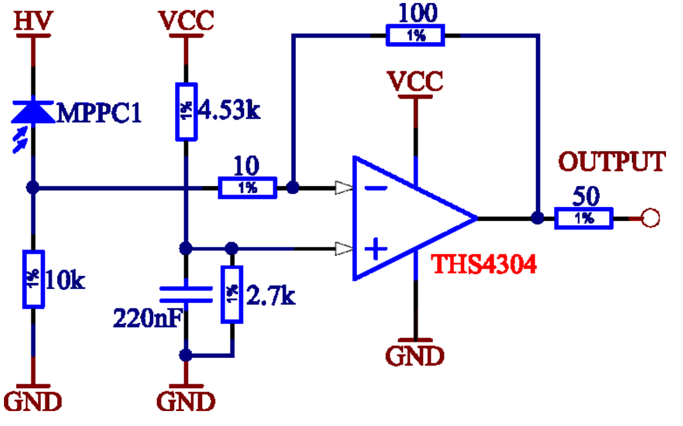
MPPC readout front-end based on Transimpedance Amplifier (TIA)

- Current-to-voltage converter
- High signal amplification
- Improved signal to noise ratio
- Improved signal timing – crucial for high count rate measurements



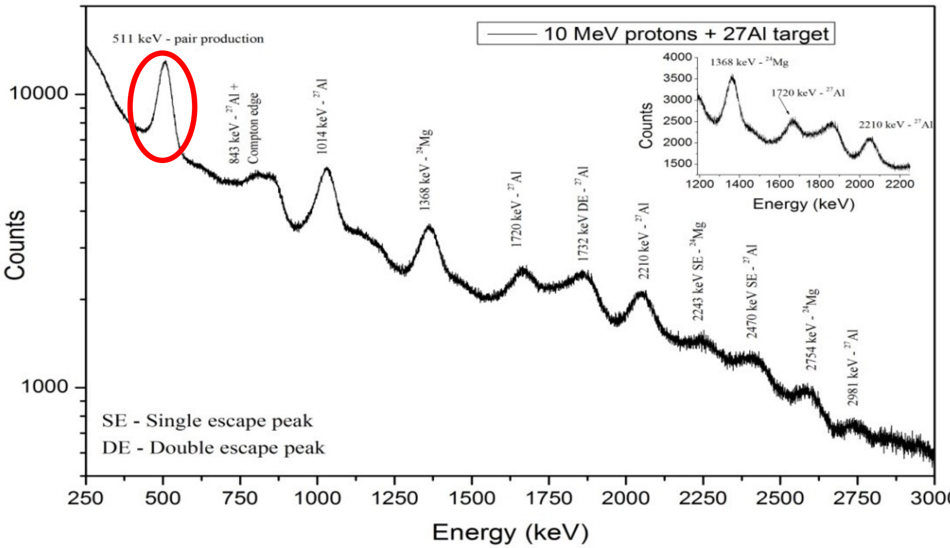
MPPC readout Printed Circuit Board

- Board size compatible with JET capsule
- All components on a single board
- Integrated temperature sensor and voltage filters



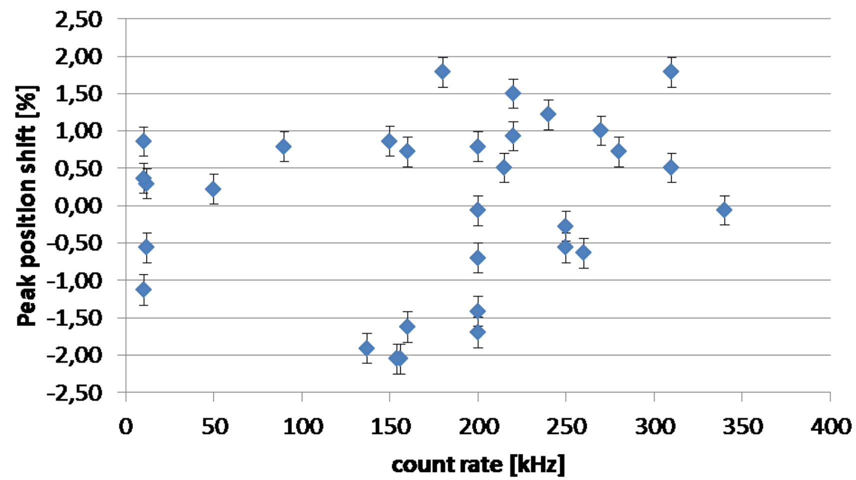
High rate detector tests with MPPC-active base in Legnaro National Laboratories (LNL)

TANDEM-ALPI, 10 MeV protons on ^{27}Al



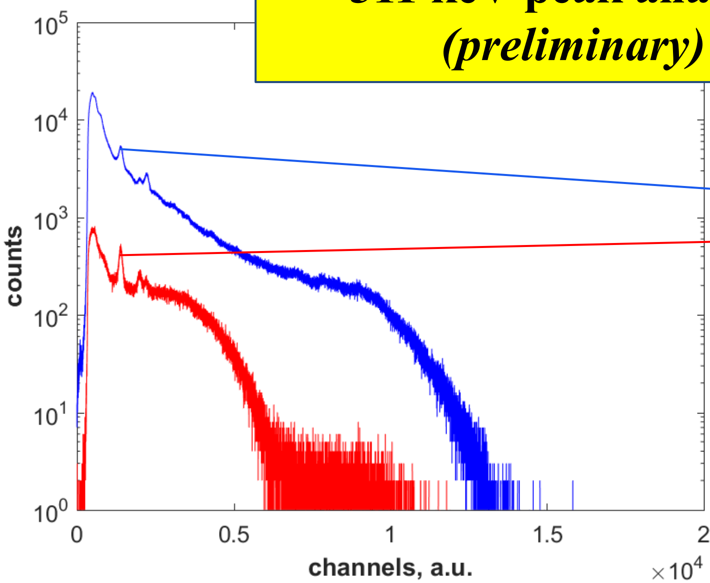
Typical spectrum measured for 30 nA current, with the rate of about 340 kHz and 120 s measuring time in Legnaro, 20x15 mm $CeBr_3$, MPPC, TIA, MTCD

Dependence of 511 keV peak position on count rate *(preliminary)*



Frascati 14 MeV irradiation
MPPC and $CeBr_3$ activation response to neutrons

511 keV peak analysis
(preliminary)



All events (blue)
and last 10^7 events (red)

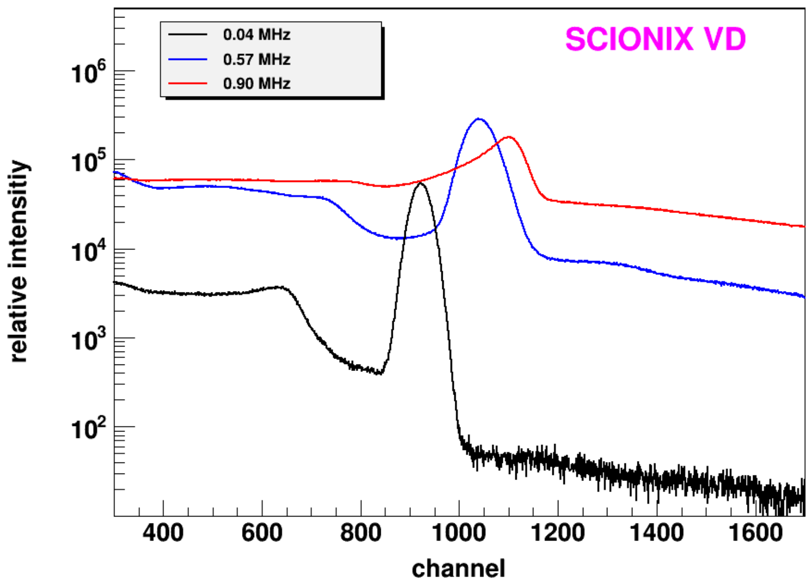
	All events		Last 10^7 events	
n/s ($\cdot 10^{10}$)	Peak position	FWHM, %	Peak position	FWHM, %
0.4	1402	9.1	1396	8.8
1.1	1396	9.8	1403	8.5
2.1	1374	9.9	1381	8.8
1.1	1332	10.9	1345	9.0
1.4	1342	11.2	1345	10.5
1.9	1148	14.9	1163	13.2

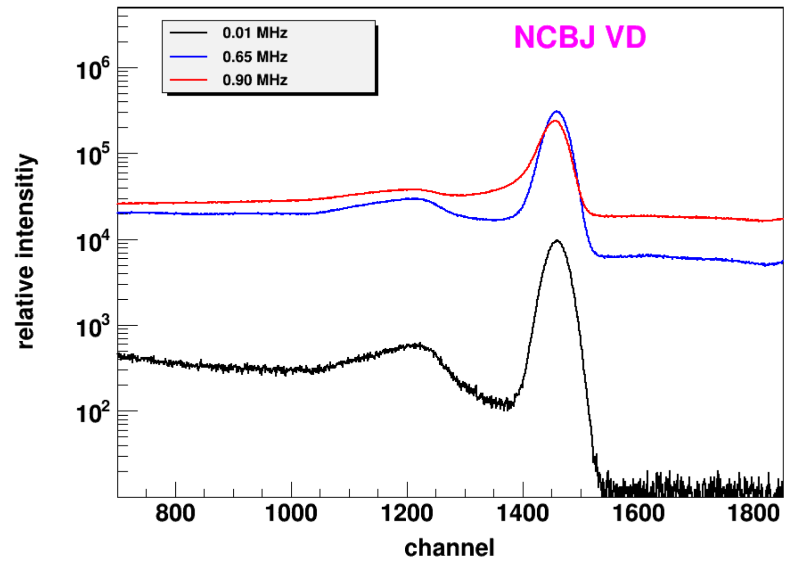
3” × 3” $CeBr_3$ scintillator for Gamma Spectrometer Upgrade

- 76 mm in diameter, 76 mm height
- 1 mm thick aluminium housing
- coupled with R6233-100
- SMA connector
- ready for installation at JET

γ energy (keV)	γ-ray source	FWHM (%)	Full energy peak detection efficiency (%)
511	^{22}Na	4.9±0.1	58±3
667	^{137}Cs	4.3±0.1	49±2
1115	^{65}Zn	3.5±0.1	37±2
1173	^{60}Co	3.3±0.1	34±1
1275	^{22}Na	3.3±0.1	33±2
1332	^{60}Co	3.3±0.1	33±1
4439	PuBe	2.7±0.1	14±2

NCBJ active voltage divider





In December 2015: a request from SCIONIX to prepare the NCBJ offer for voltage divider

Lost Alpha Gamma Rays Monitor (LRM)

For lost α-particle studies, a new diagnostics was proposed.

The EUROfusion WPJET4 Project Board decided on 03.07.2015 to close down the LRM project as no technical solution that could be designed and constructed with the available resources could be found.

Final report

Feasibility study and conceptual design for the Lost Alpha Monitor (LAM). Phase I

with Polish contribution (NCBJ / IPPLM Report)

design of a detector and evaluation of expected KA4 detector response to gamma radiation for DT experiments

Visits

M.Tardocchi, M.Nocente, D.Rigamonti, V.Perseo (NCBJ)
A.Broslawski, M.Gosk, S.Korolczuk, I.Zychor
CNF Milano, LNL Legnaro, ENEA Frascati

Master degree thesis

„Development of gamma ray spectroscopy camera for fusion plasmas" by V.Perseo, 2016

PhD thesis – in preparation: A.Broslawski, S.Korolczuk, D.Rigamonti

Papers

- **Scintillators for high temperature plasma diagnostics**
  Ł.Świderski, A.Gójska, M.Grodzicka, S.Korolczuk, S.Mianowski, M.Moszyński, J.Rzadkiewicz, P. Sibczyński, A.Syntfeld-Każuch, M.Szawłowski, T.Szczęśniak, J.Szewiński, A.Szydłowski, I.Zychor,
  Proceedings of Science Vol. ECPD2015 (2015) 162
- **Digital Acquisition in High Count Rate Gamma-Ray Spectrometry**
  S. Korolczuk, S. Mianowski, J. Rzadkiewicz, P. Sibczynski, L. Swiderski and I. Zychor,
  IEEE Trans. Nucl. Sci. 99 (2016)
- **High performance detectors for upgraded gamma ray diagnostics for JET DT campaigns**
  I. Zychor et al., *Phys. Scr. 91 (2016) 064003*

Conferences

- 4th International Conference Frontiers in Diagnostic Technologies, ICFDT 2016
- 21st Topical Conference on High Temperature Plasma Diagnostics 2016
- *29th Symposium on Fusion Technology, SOFT 2016*
- Advancements in Nuclear Instrumentation Measurement Methods and their Applications, ANIMMA 2015
- The 1st EPS Conference on Plasma Diagnostics, ECPD 2015
- International Conference on Research and Applications of Plasmas, PLASMA 2015

Reports

www.fusion.ncbj.gov.pl

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.

Polish team

G.Boltruczyk
A.Broslawski
M.Gosk
S.Korolczuk
R.Kwiatkowski
M.Linczuk
A.Szydlowski
A.Urban
I.Zychor

and colleagues from
Nuclear Techniques & Equipment Department (DTJ-NCBJ)