EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments
2007-2013

Extreme Light Infrastructure-Nuclear Physics
(ELI-NP) - Phase II

Project co-financed by the European Regional Development Fund through the Competitiveness Operational Programme
"Investing in Sustainable Development"

The segmented clover detector array (ELIADE) for NRF experiments at ELI-NP

Gabriel Suliman, ELI-NP

Outline

- The defining parameters of the ELI-NP Gamma Beam System for NRF experiments
- NRF experiments at ELI-NP
- The ELI-NP array of HPGe CLOVER detectors (ELIADE)
  - Design principles
    - Segmentation
    - Anti-Compton shields
  - Status
- Future plans

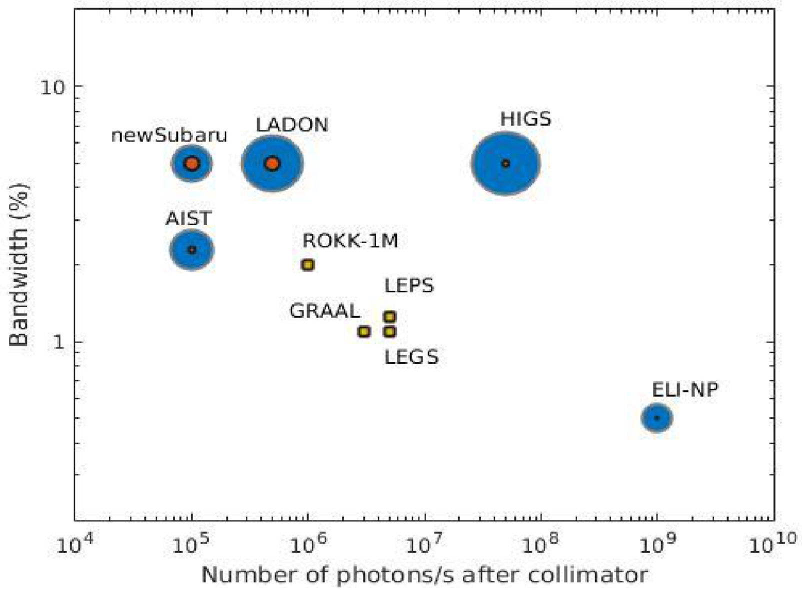
ELI-NP large equipment

- **High Power Laser System** - 2 x 10 PW maximum power
  - *contracted by Thales Optronique SA*
- **Gamma Beam System** - high intensity, tunable energy up to 20MeV

maS

ELI–NP GBS Parameters

Energy (MeV)	0.2 – 19.5
Spectral Density (ph/s·eV)	> $0.5 \cdot 10^4$
Bandwidth rms (%)	≤ 0.5
# photons per pulse within FWHM bdw.	~10^5
# photons/s within FWHM bdw.	10^8 – 10^9
Source rms size (μm)	10 – 30
Source rms divergence (μrad)	25 – 200
Peak brilliance (N_{ph}/sec·mm²·mrad²·0.1%)	10^{20} – 10^{23}
Radiation pulse length rms (ps)	0.7 – 1.5
Linear polarization (%)	> 95
Macro repetition rate (Hz)	100
# pulses per macropulse	32
Pulse–to–pulse separation (nsec)	16



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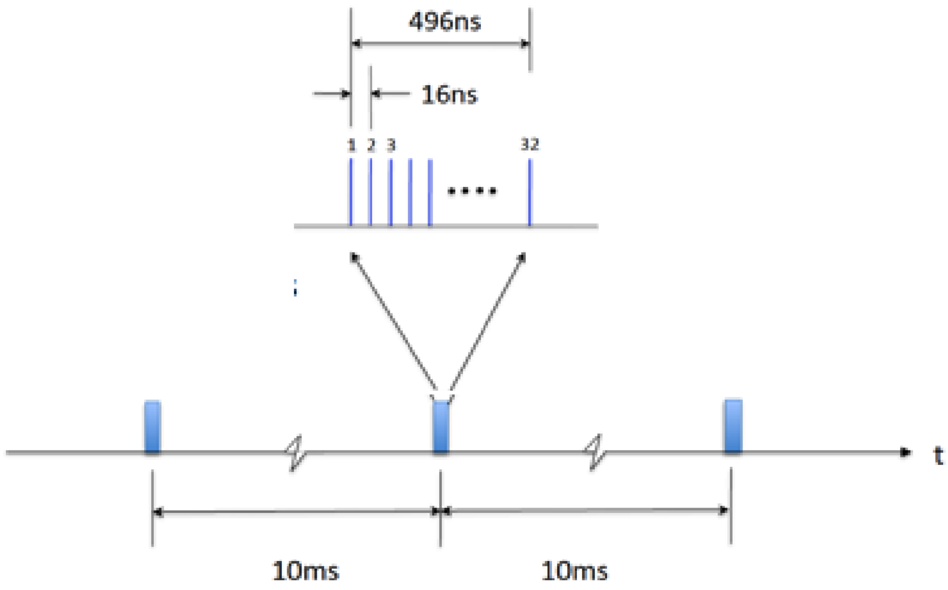
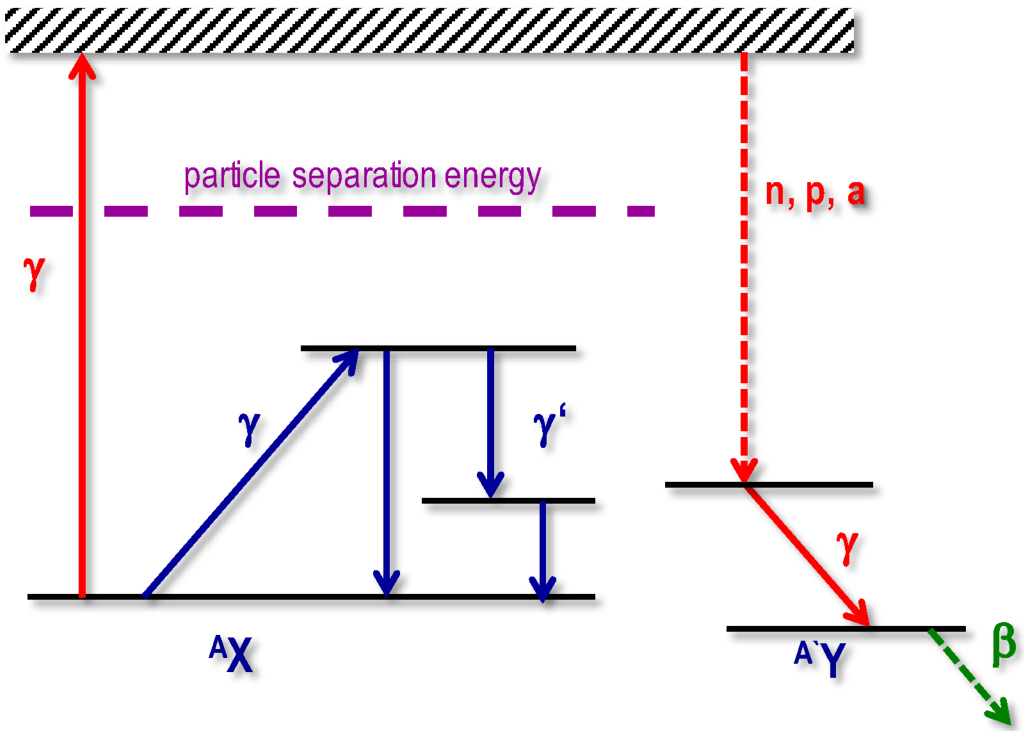


Photonuclear Reactions with Gamma Beams

nuclear physics



Fundamental Research

- Nuclear Resonance Fluorescence (γ, γ')
- Nuclear Astrophysics $(\gamma$,p) (γ,α)
- Photonuclear Reactions $(\gamma$,n)
- Photofission & Studies of Exotic Nuclei

Applications

- Gamma Imaging
- Material Science with Positrons
- Medical Radioisotopes

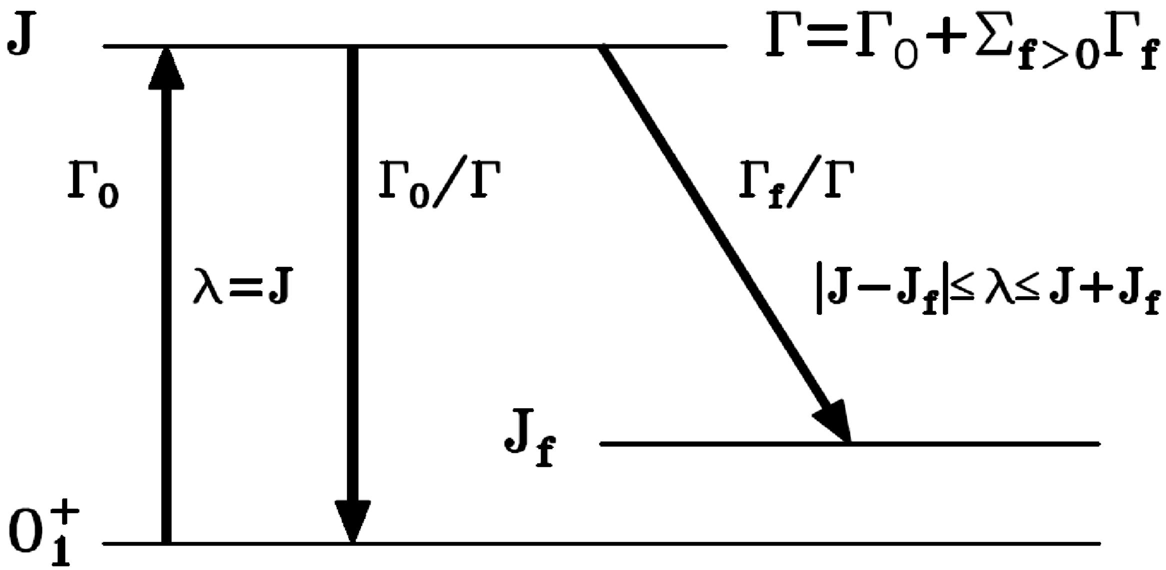
R&D Detectors

- Gamma Beam Delivery and Diagnostics
- Gamma–ray detectors
- Charged particle detectors
- Neutron detectors

Nuclear Resonance Fluorescence (NRF)

Observables

- Excitation Energy E_x
- Spin and parity *J, p*
- Decay Energies E_g
- Partial Widths Γ_i/Γ_0
- Multipole Mixing d
- Decay Strengths B(pl)
- Level Width Γ (eV)
- Lifetime t (ps – as)



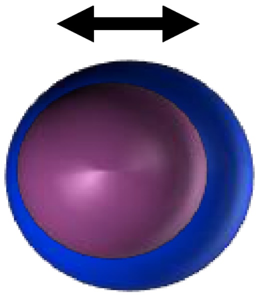
completely model independently !

Physics cases for NRF at ELI-NP: Examples

- Investigation of the Pygmy Dipole Resonance
- Parity violaton in nuclear excitations (^{20}Ne)
- Constraints on neutrinoless double-beta decay matrix elements: A novel decay channel of the scissors mode
- Proton-neutron symmetry breaking: Rotational 2^+ states of the nuclear scissors mode
- The origin of matter: Studies of the photoresponse of weakly abundant p nuclei
- Photons and radioactive isotopes: Electric and magnetic dipole response of unstable nuclei
- Model and calibration independent width determination at ELI–NP: self–absorption measurements

*C.A.Ur , Rom. Rep. Phys **68** (2016), S483*

An access to the equation of state and to neutron rich matter: The Pygmy Dipole Resonance



Neutron skin oscillates against neutron/proton core

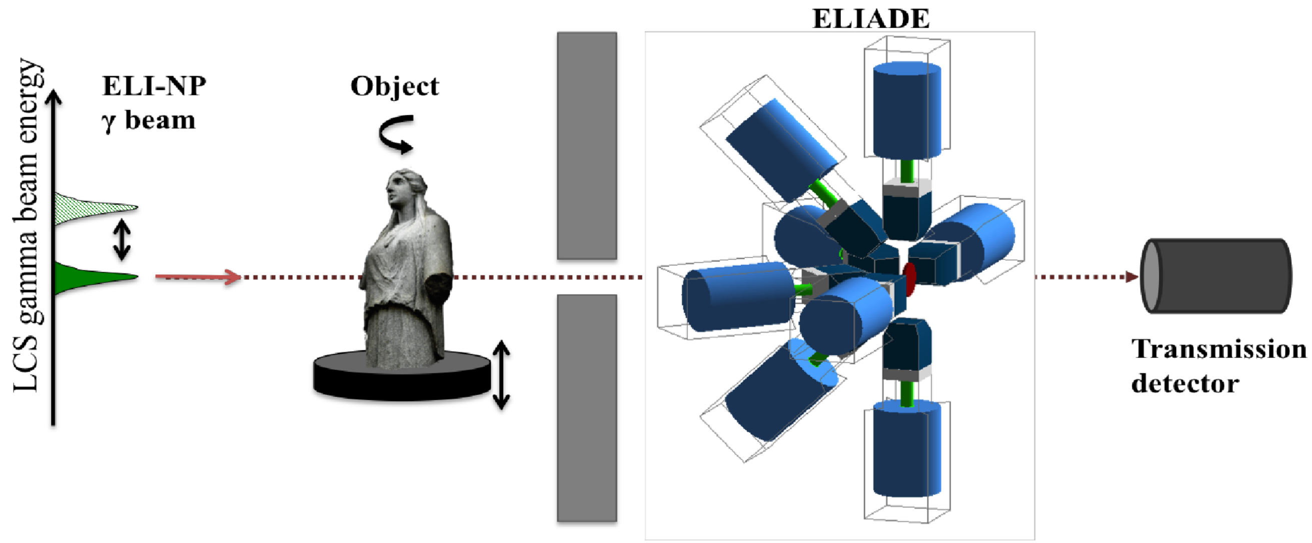
→ Electric dipole mode around 5-10 MeV
→ Impact on EOS, Nucleosynthesis, neutron star radii

NRF@ELI-NP:

- Narrow bandwidth allows single state excitation
  → measure branching ratios to excited states
- High intensity and small beam diameter
  → study E1 distribution in rare isotopes

D. Savran, T. Aumann, and A. Zilges, Prog. Part. Nucl Phys. ***70*** *(2013) 210*

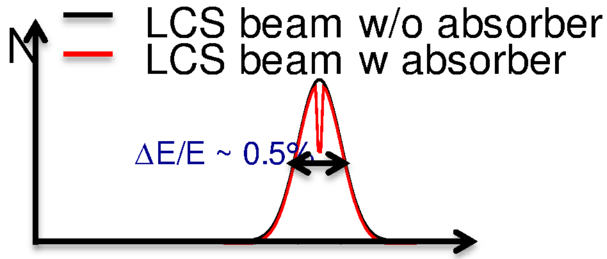
Self-absorption measurements



NRF@ELI-NP:

- Energy tunability
  → measure the photon response
  → interogate object composition

- High intensity and small beam diameter
  → study rare isotopes
  → study thick objects

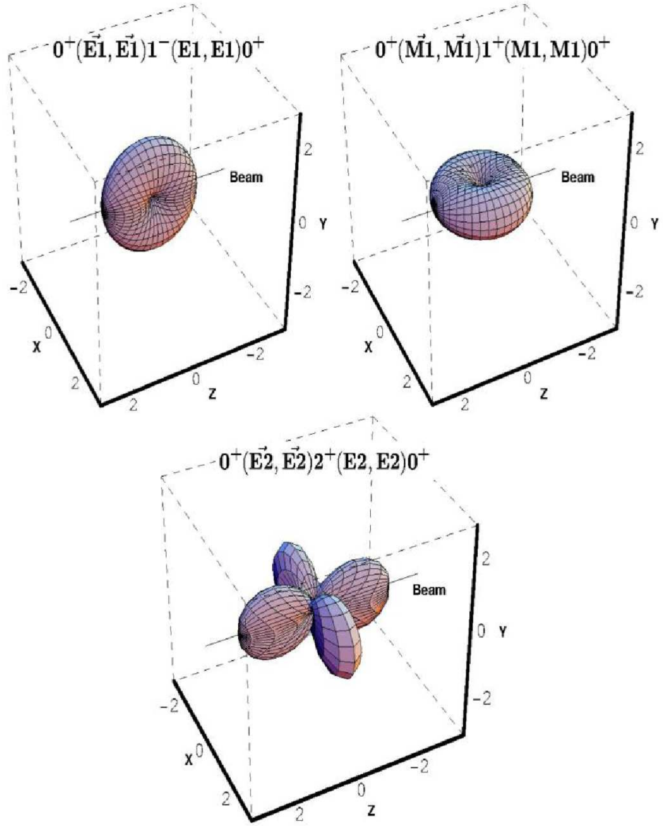


Suliman et al. Rom. Rep. Phys **68** (2016), S799

Bertozzi et al. Nucl. Instr. Meth. Phys. Res. **B**

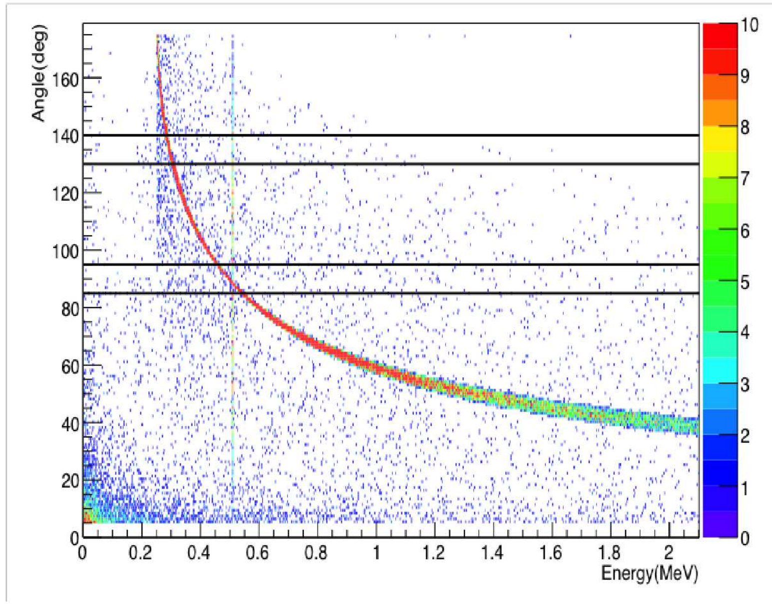
Design principles

Angular distribution of NRF photons



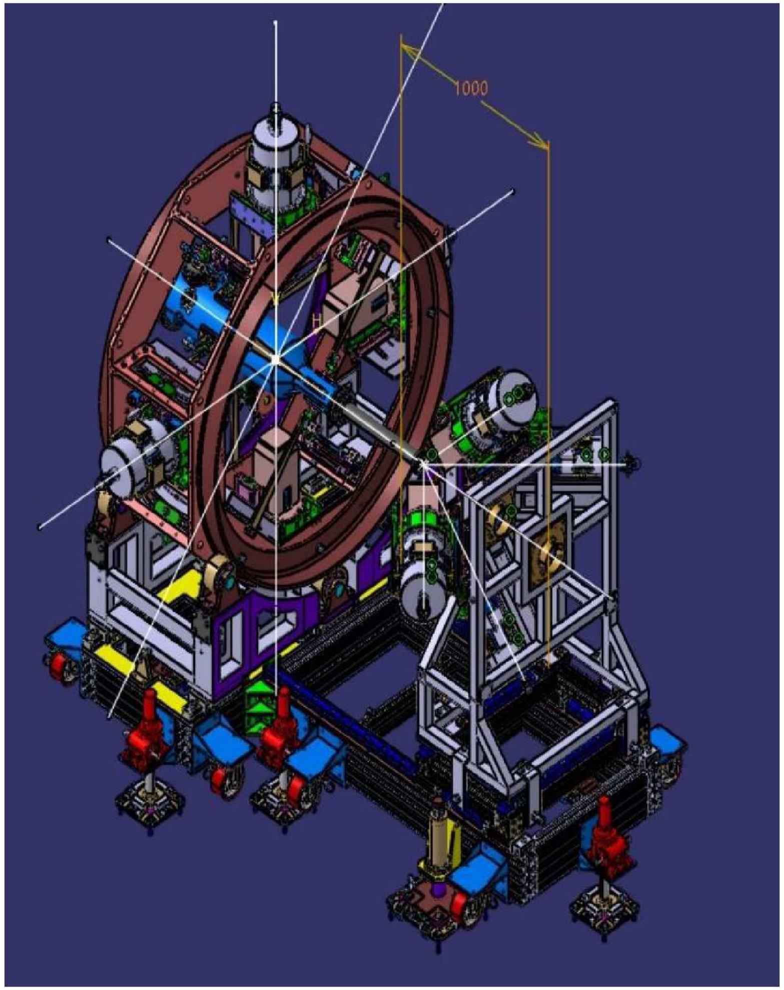
Background radiation in the detectors

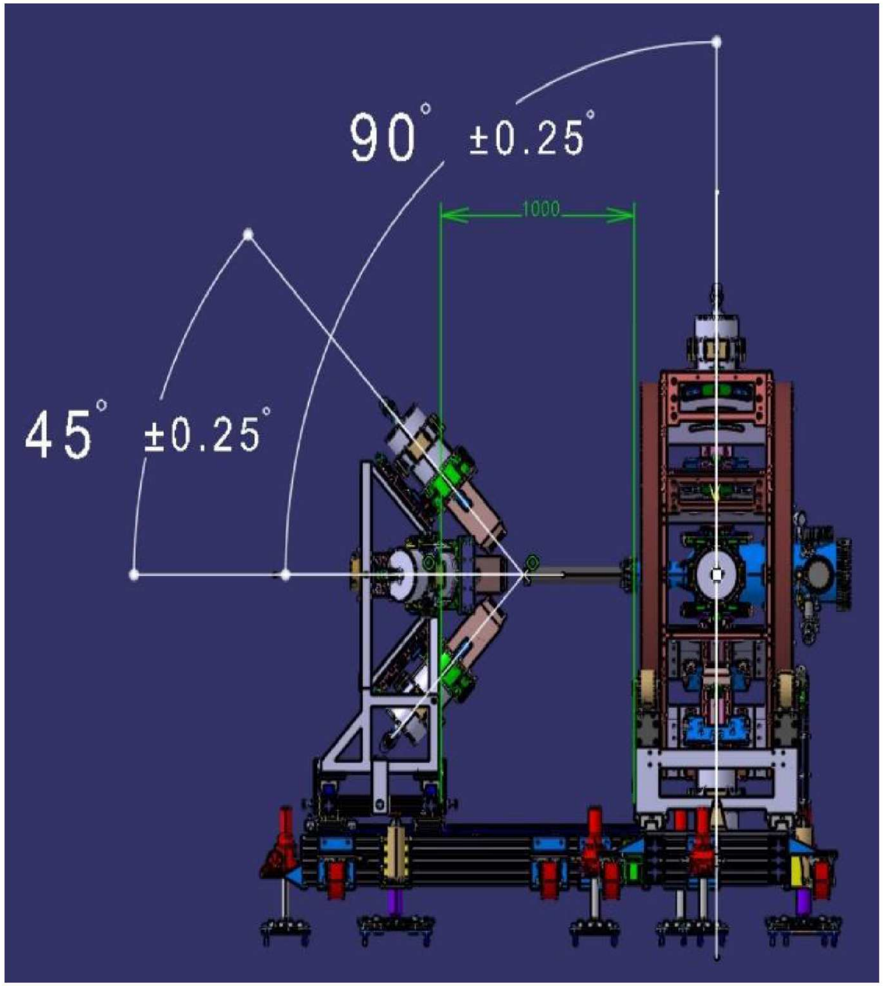
- Compton scattering of the beam



- 511 keV from positrons annihilation

Proposed mechanical structure



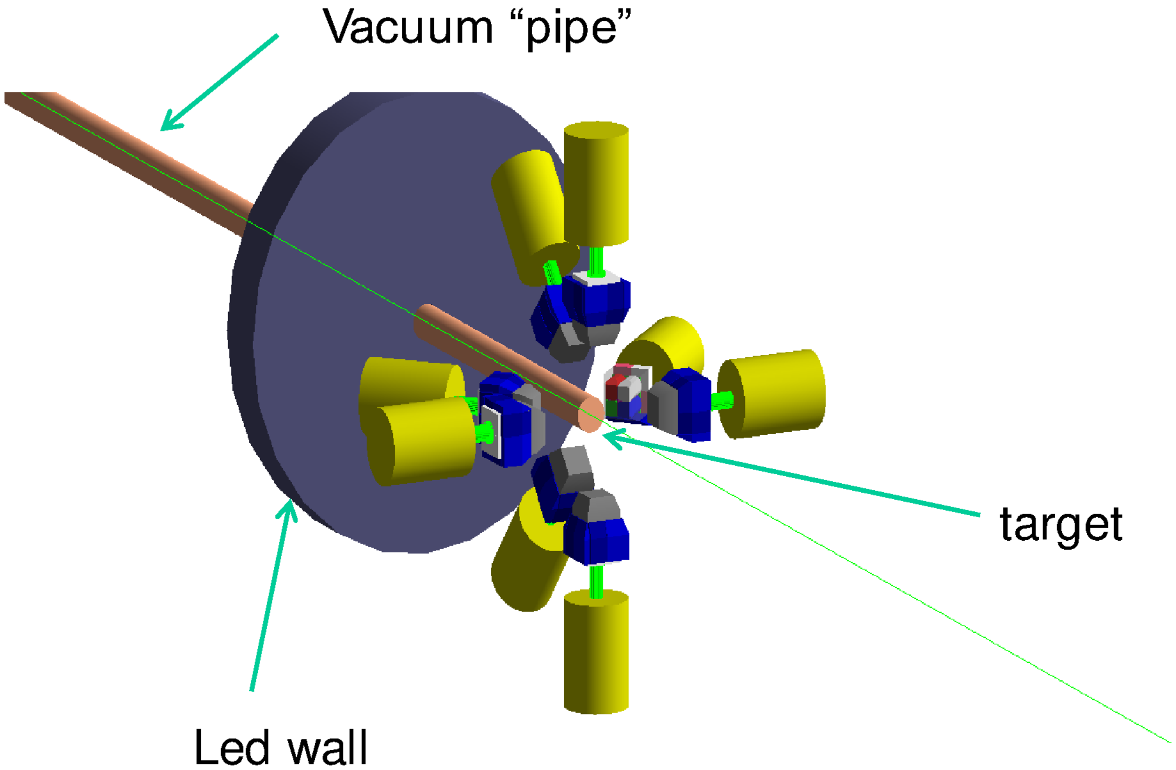


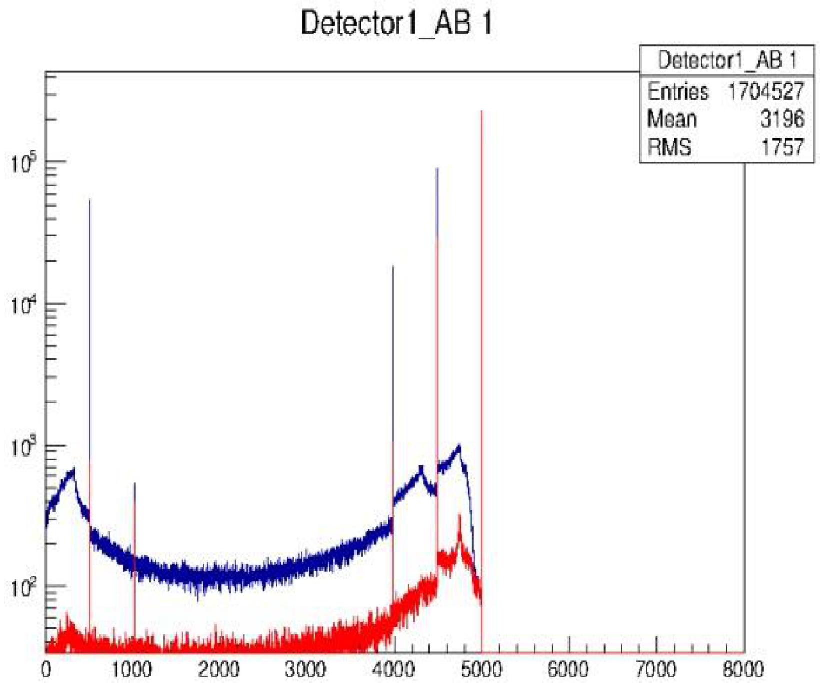
Tender ongoing

Anti-Compton shields

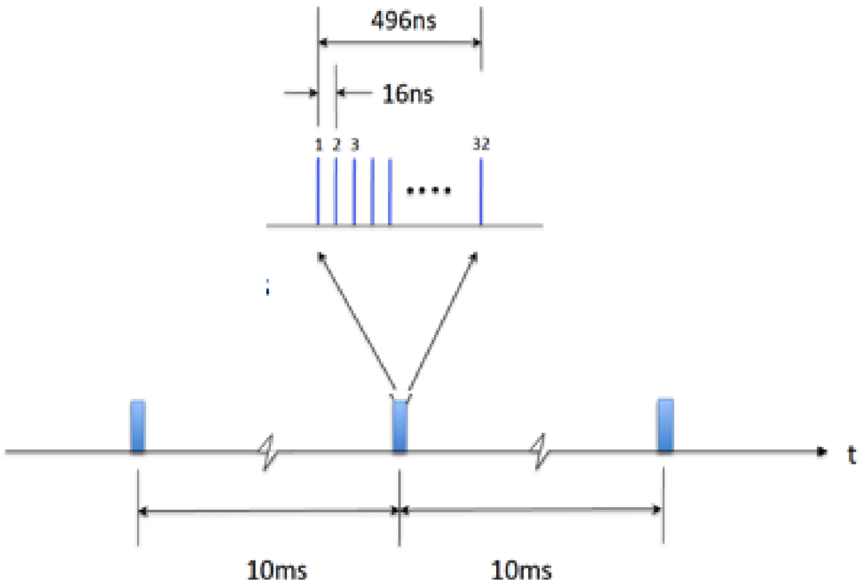
Mono-energetic point source:

Background reduction by a factor of 10





Anti-Compton shields

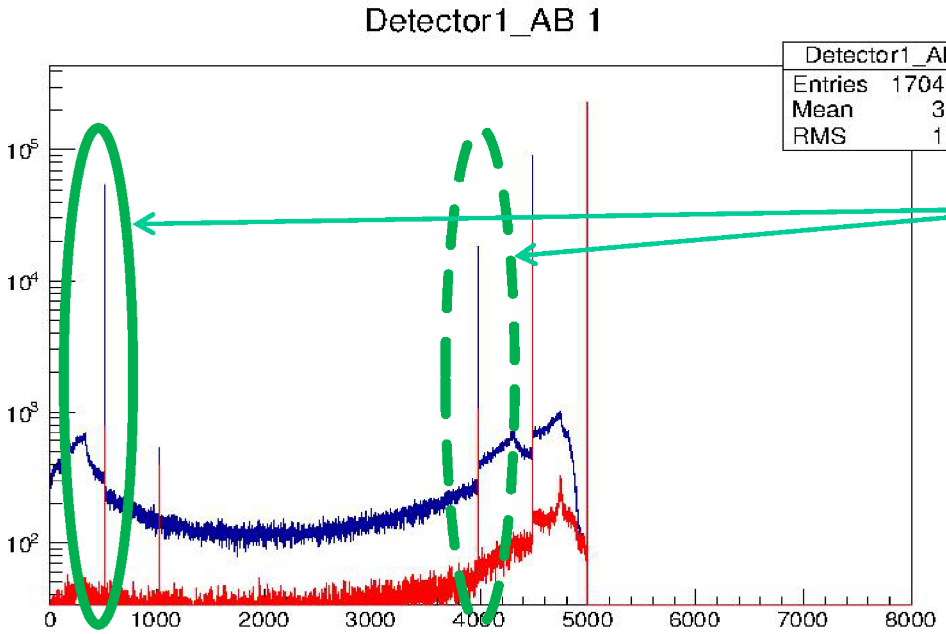


High intensity pulsed source (10^6 photons/pulse)

AC shield will always trigger -> either disregarded in analysis(sw veto) or we measure nothing(hw veto)

Anti-Compton shields

We measure in a sea of 511 keV photons:



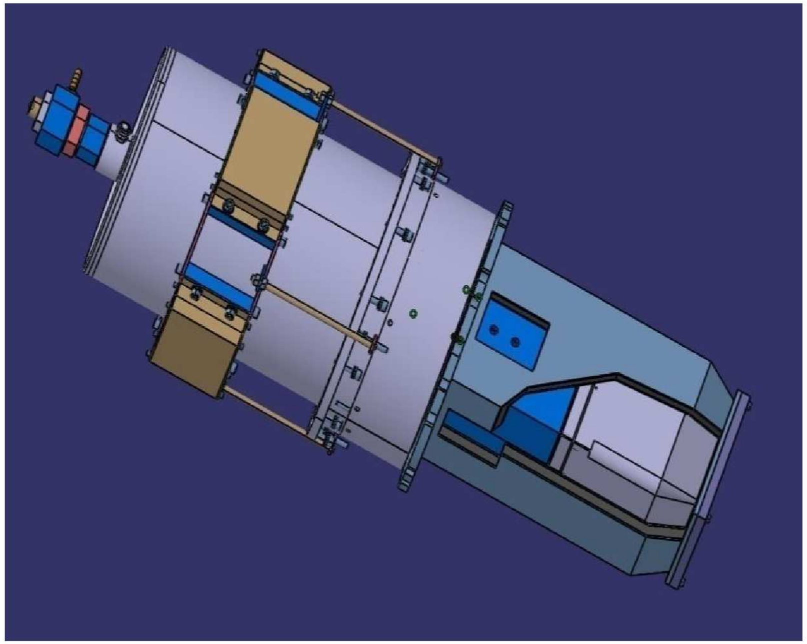
AC shield is thin for 511 keV photons

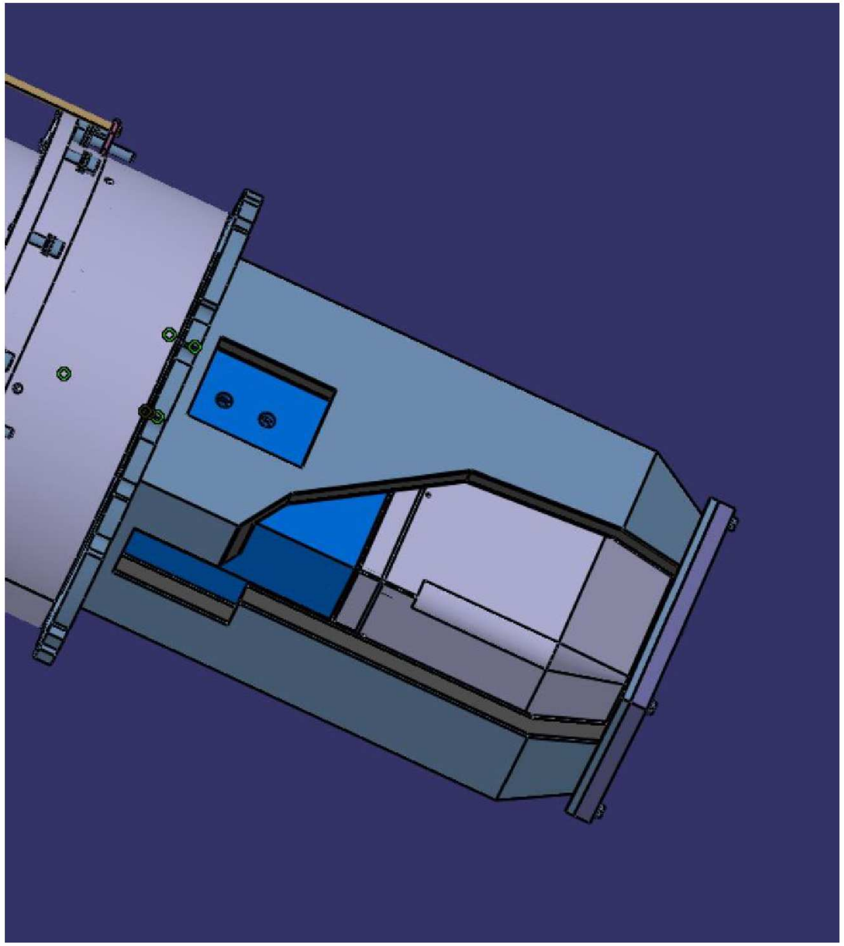
511 keV photons from “outside” the detector, not stopped by the AC shield

- 5 MeV point source, so 511 keV only originate from other detectors/AC shields

Anti-Compton shields

Replaced by 1 cm thick Pb screens.

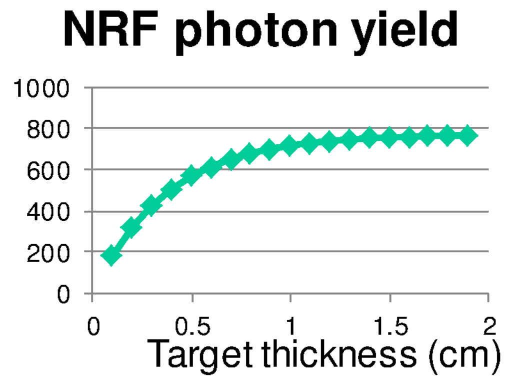




The need for segmentation

Target:

- ^{238}U
- 2 cm thick (0.5 g, 5 mm diameter)

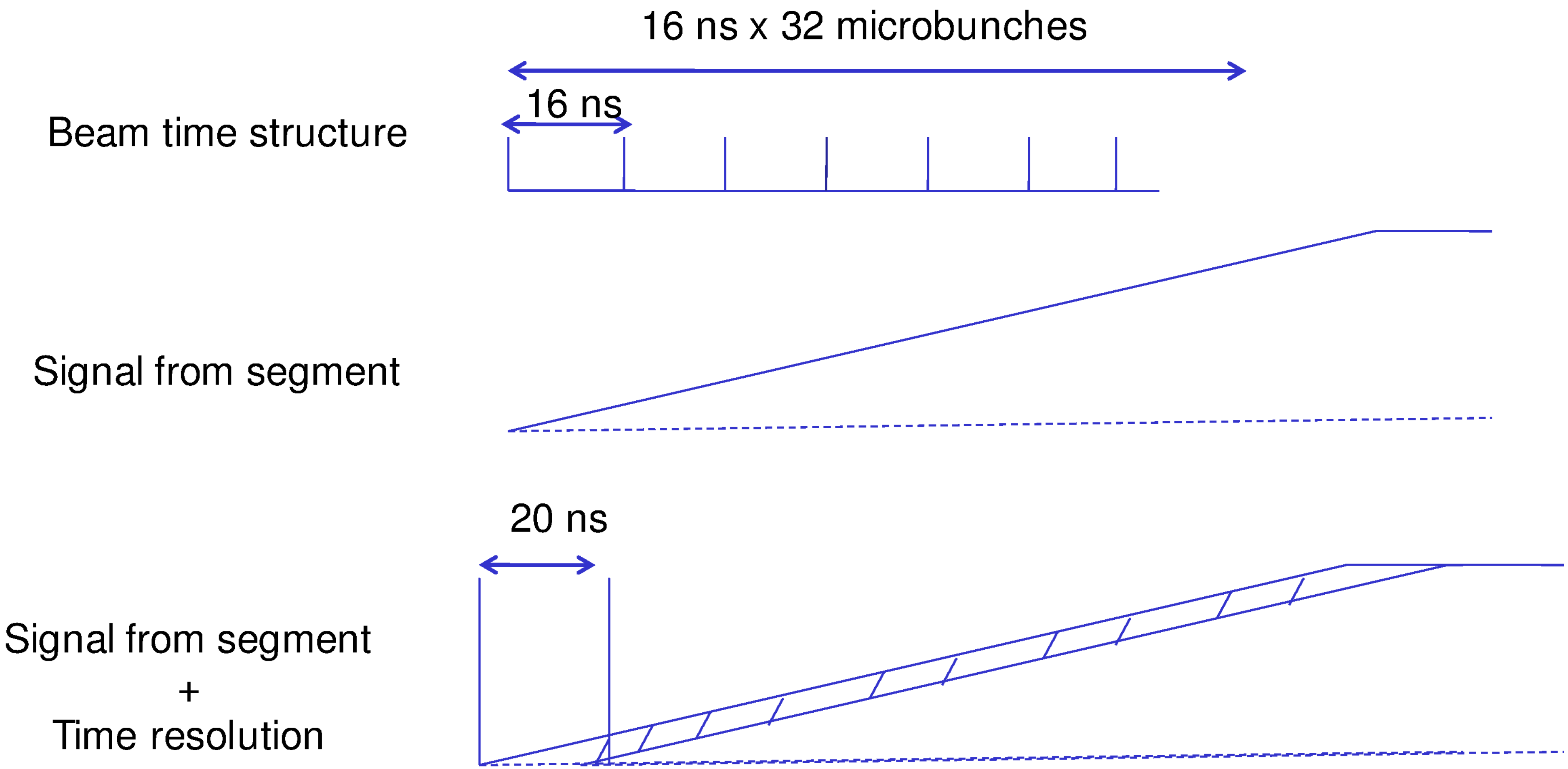


Source	Energy (MeV)	Number of photons/sec	Number of photons/sec (2 cm of lead)
NRF	2.1	566	199
Compton towards the ring at 90 deg	0.36	61966	1
Compton towards the ring at 135deg	0.26	43359	0
511 keV	0.511	59020	1521

The maximum rate for measurements is 100 Hz, one detected photon from each macropulse.

Detector segmentation

microbunch level analysis?



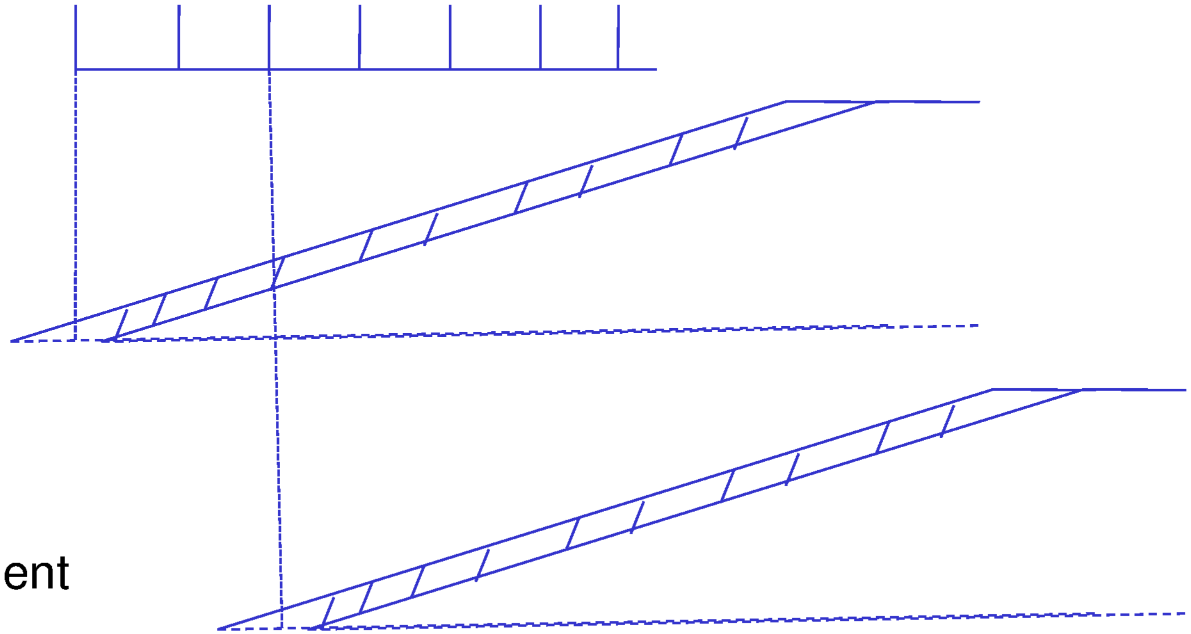
Detector segmentation

micro-bunch level analysis?

Beam time structure

Signal from one segment

Signal from another segment



Proper add-back: indentify the two segments as coming from different photons, even if they are 32 ns apart

Conclusion: we need to save the front of the traces!

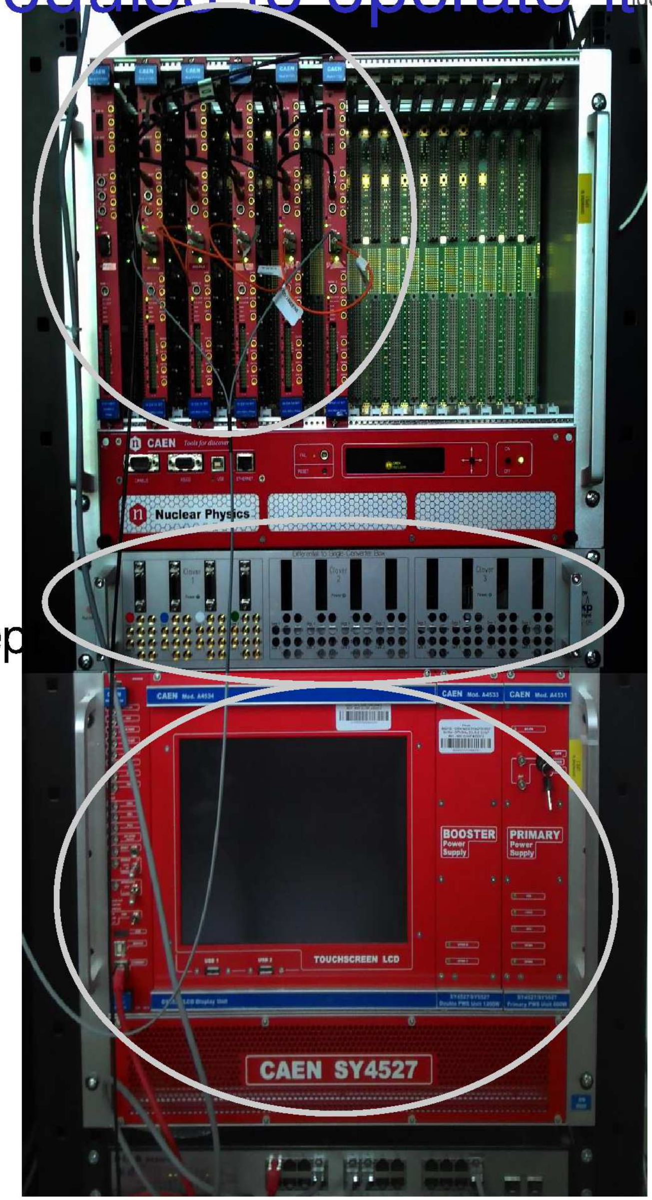
8 x CLOVER detector – delivered

- 32 x V1725 CAEN digitizers
  250 Msample/s
  16 channels per board
- 1 x V1730 CAEN digitizer
  500 Msample/s
  8 channels per board
  ($LaBr_3$)

- Diff-single proof-of-concep

- High voltage mainframe
  - (CAEN SY4527)

Part of the digital electronics, and the modules to operate it



Additional systems

- Single-differential-single signal transport (IKP Koeln)
- Low voltage distribution design (IKP Koeln)
- Liquid nitrogen filling:
  - National Instruments CompactRIO (prototype working since March 2015)
  - Valves/cables tender finishing soon
- Reaction chamber and target alignment (Univ. Transilvania Brasov)

DAQ software

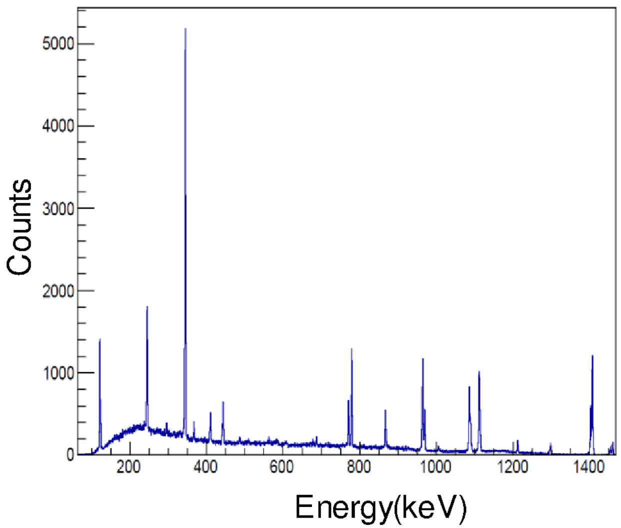
- MIDAS (STFC, Daresbury)
  - Our main DAQ system from August 2016
  - Very quick response from Vic Pucknell on any issue!

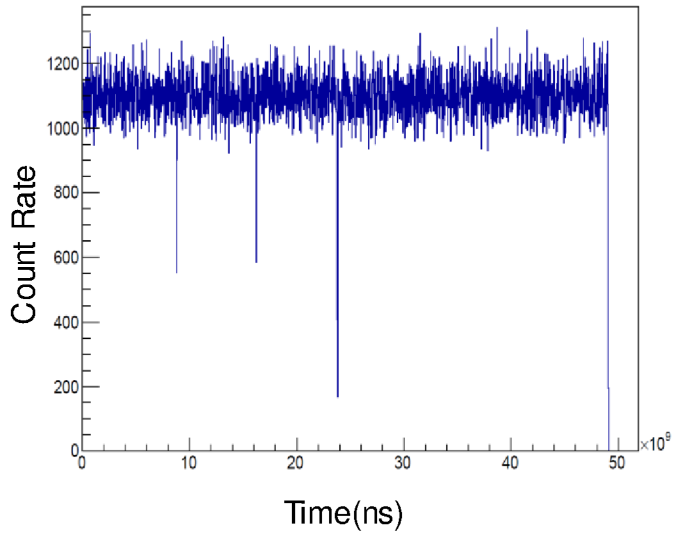
- digiTES (CAEN,Italy) – part of the DAQ tender procedure

- Wavedump (CAEN, Italy)

Data analysis

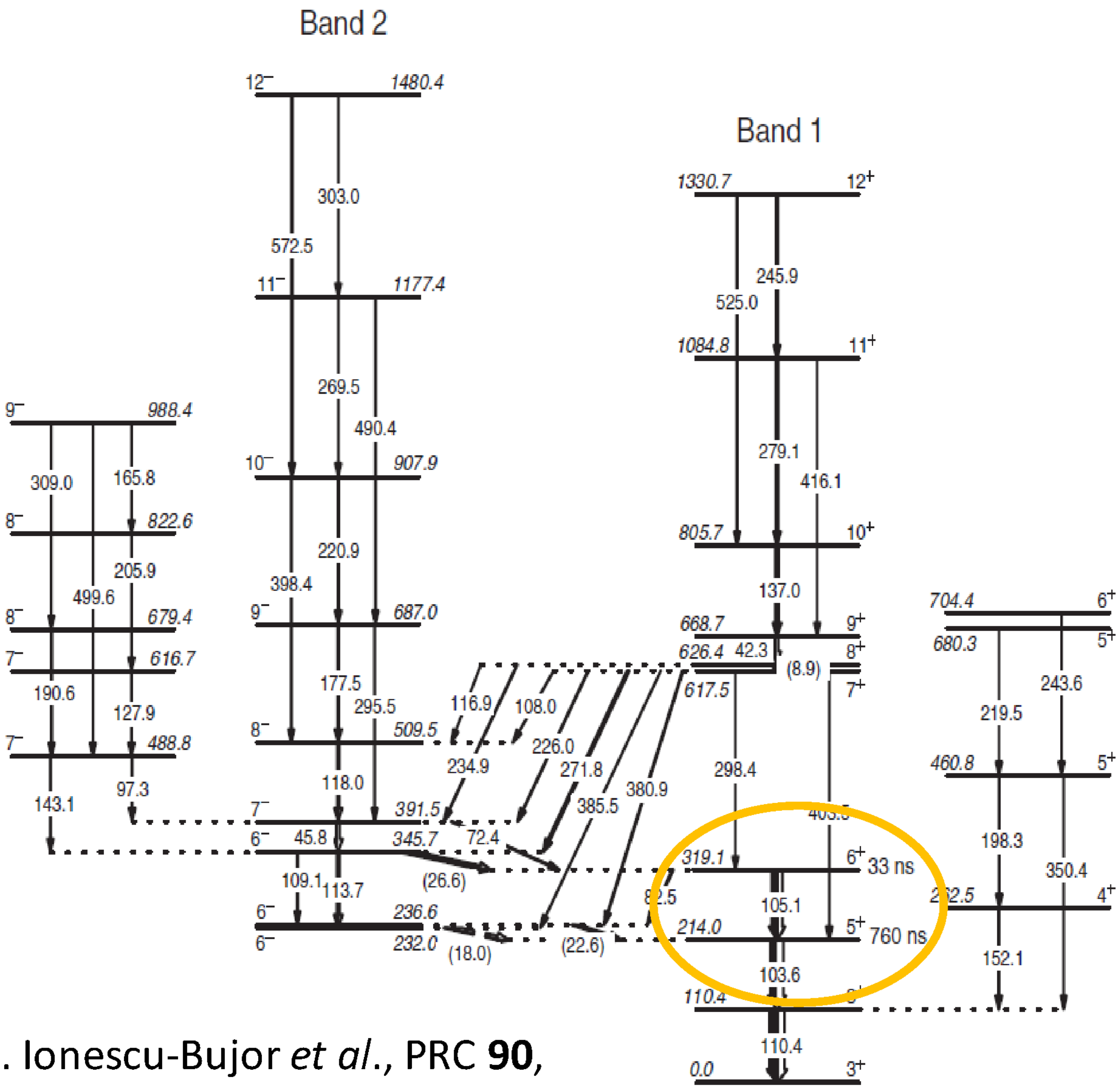
- Primary data converted to ROOT format
- ROOT/C++ for further analysis





- GRAIN from JYFL used for online and offline data analysis

Test experiment: The ^{130}La level scheme

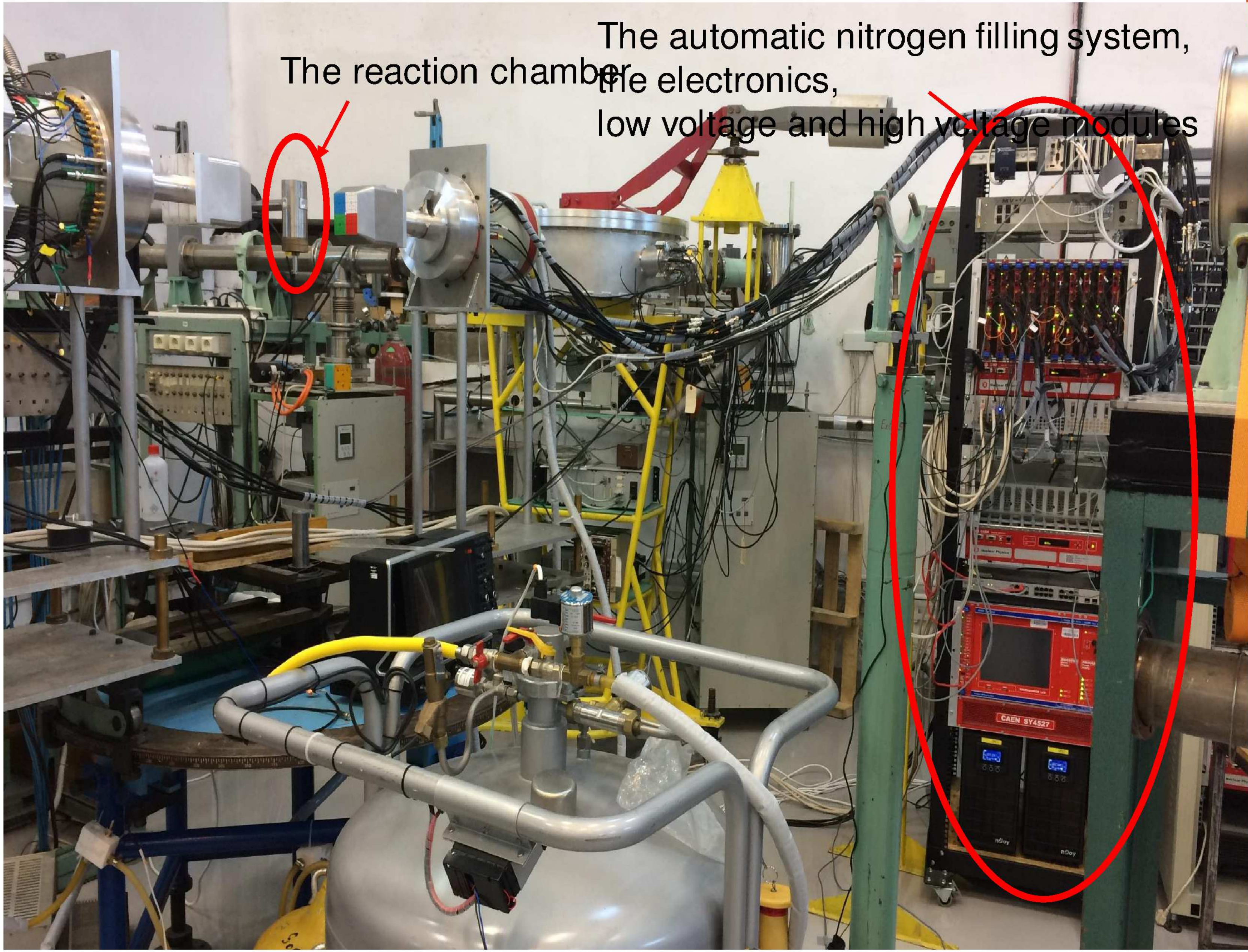


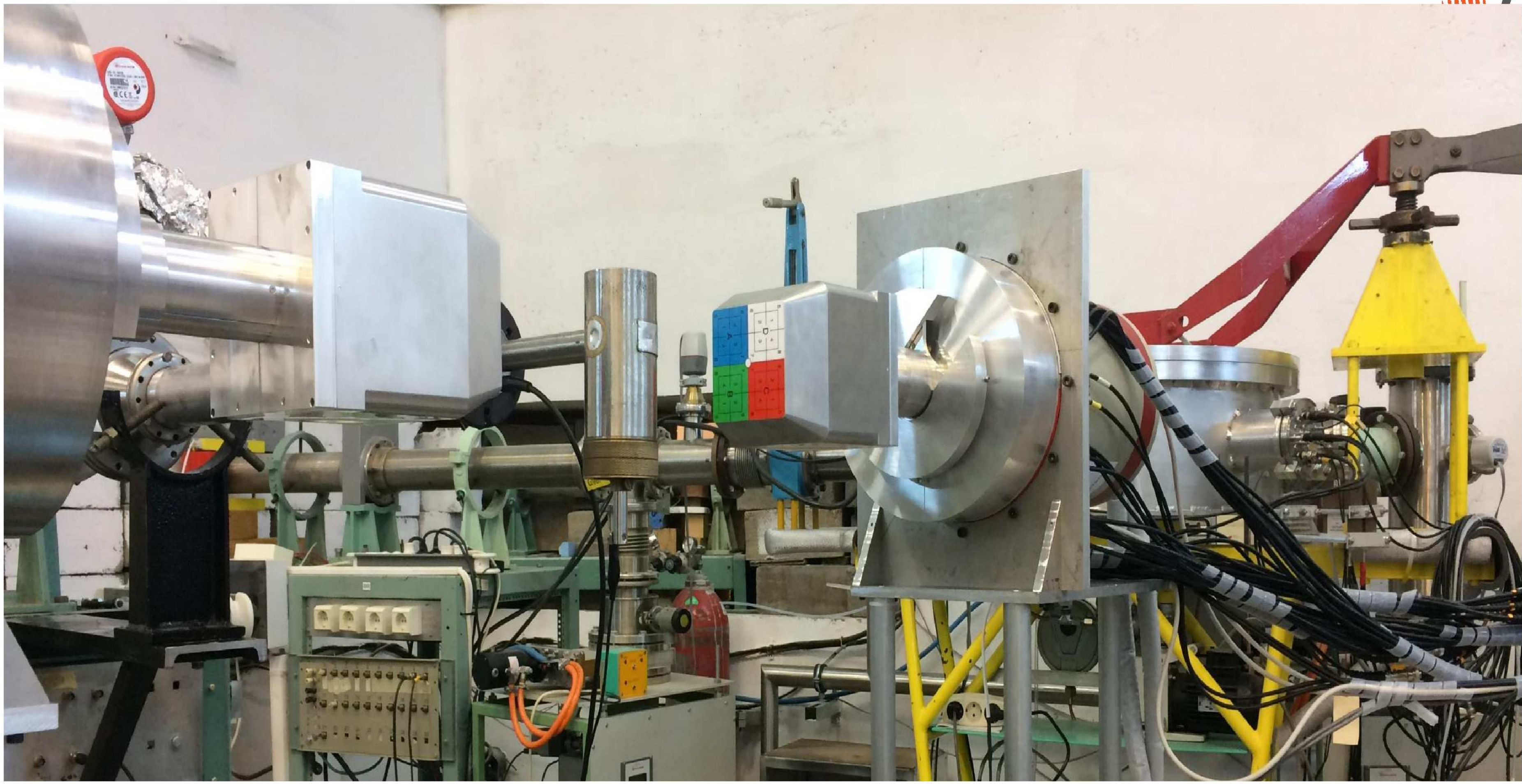
The most intense gamma ray transitions are concentrated at energies below 300 keV

The two isomeric states in ^{130}La:

J^π	E_{ex}(keV)	$T_{1/2}$(ns)
5^+	214	760(90)
6^+	319.1	33(1)

[M. Ionescu-Bujor *et al.*, PRC **90**, 014323 (2014)]

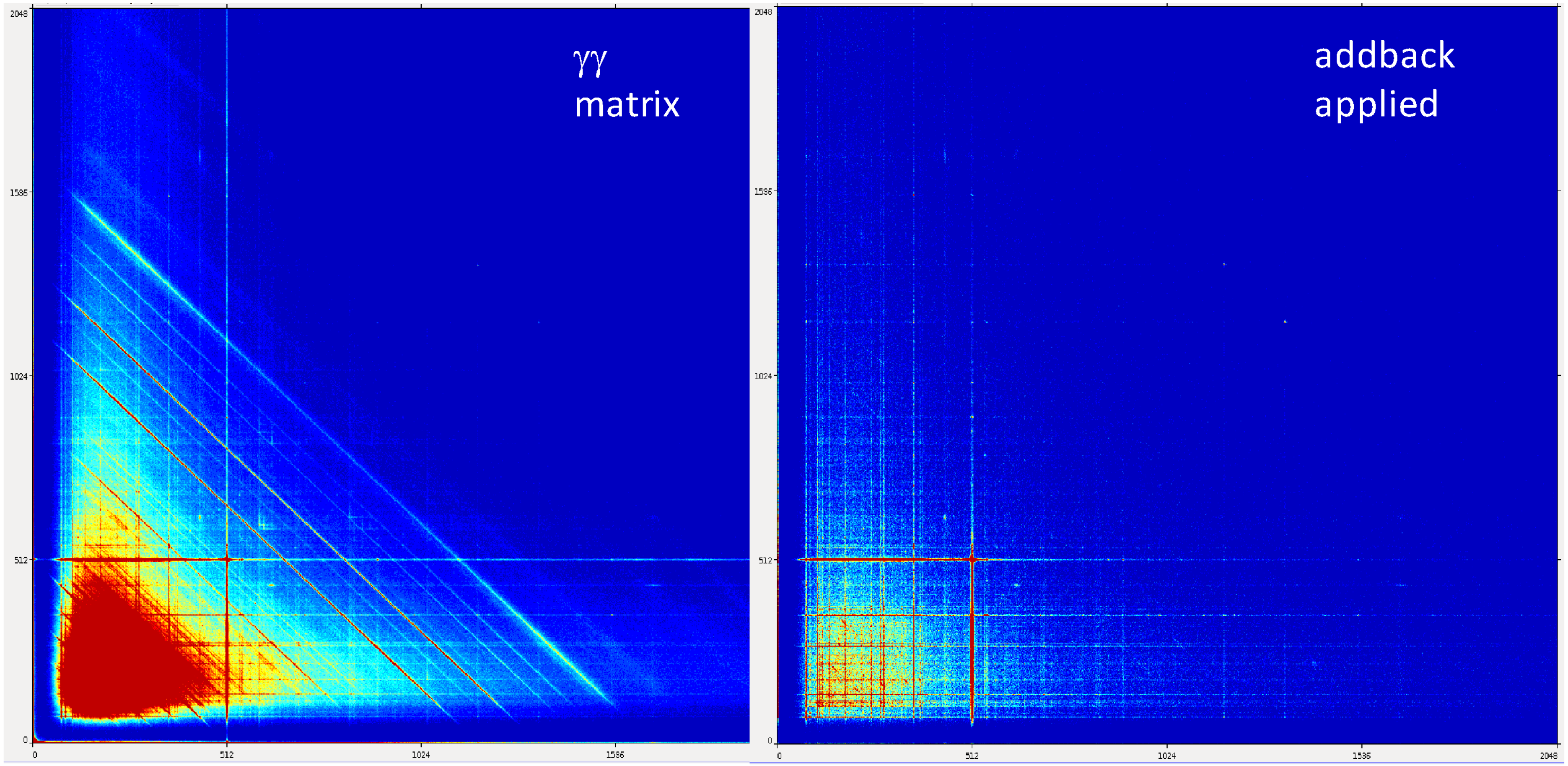

The reaction chamber
The automatic nitrogen filling system,
the electronics,
low voltage and high voltage modules
CAEN SY4527



A detail of the detectors facing the reaction chamber

Gamma rays in coincidence

GRAIN from JYFL can be used for online and offline data analysis



Future plans

- permanent set-up with as many detectors as possible
- Experiments at Tandem/IFIN-HH
- Get ready for the first beams
  - PSA of segment signals
  - “time-selective” add-back

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eli Nuclear Physics

IFIN-HH

Thank you!

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