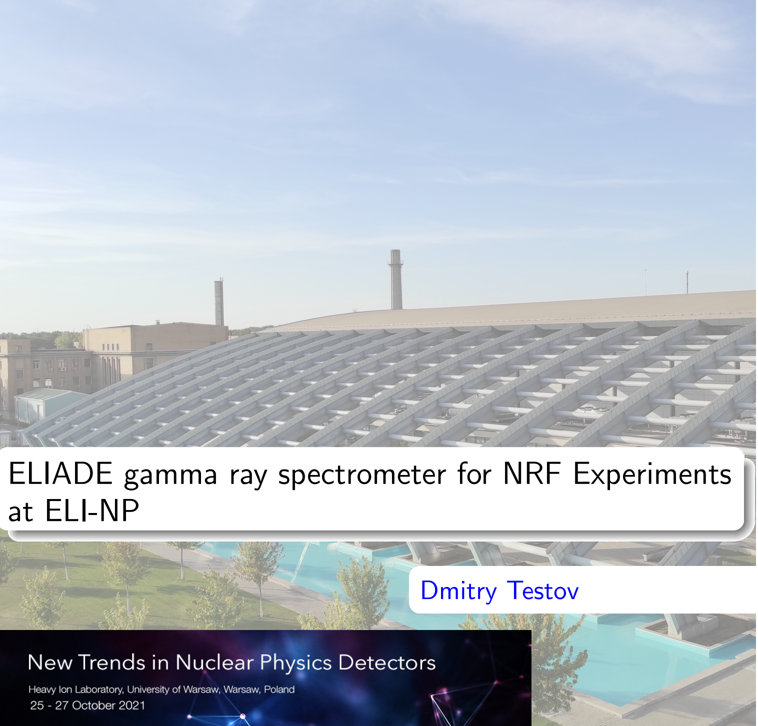
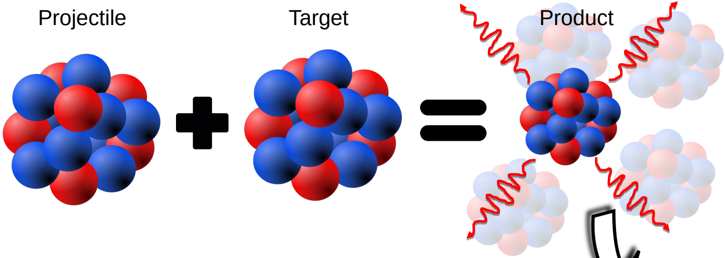


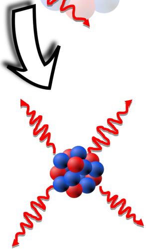
ELIADE gamma ray spectrometer for NRF Experiments at ELI-NP

Dmitry Testov

New Trends in Nuclear Physics Detectors
Heavy Ion Laboratory, University of Warsaw, Warsaw, Poland
25 - 27 October 2021

Photo-Nuclear Reactions





(Multi) Nucleon Transfer Reactions

Fusion (Evaporation) Reactions

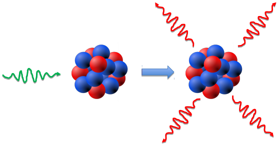
Decays

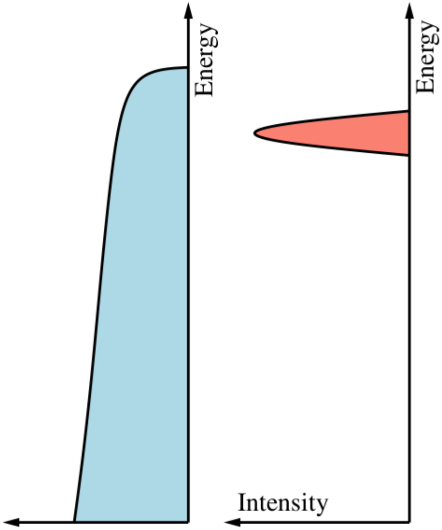
...

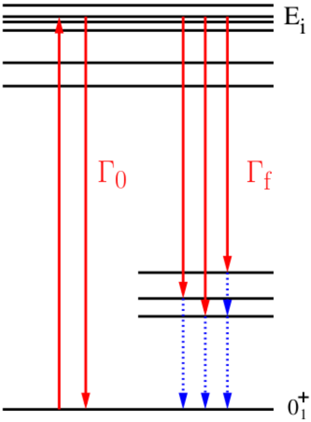
Photo-Nuclear Reactions

Bremsstrahlung

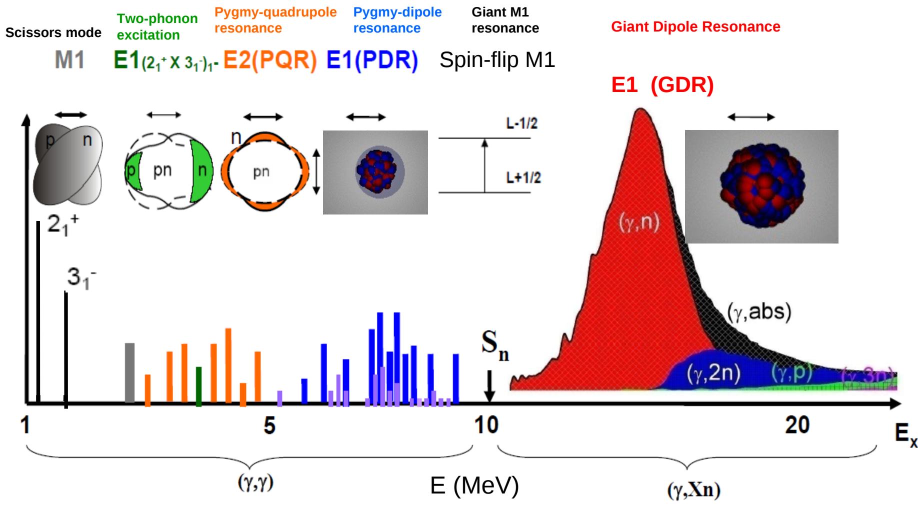
Mono-energetic source







Characteristic Response of Atomic Nucl. to EM Radiation

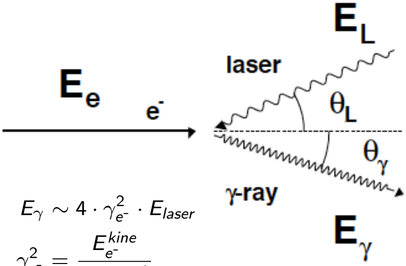


ELIADE spectrometer

ELIGANT array

P.-A. Söderström

Photons from Laser Compton Backscattering (LCB)



$$E_\gamma \sim 4 \cdot \gamma_{e^-}^2 \cdot E_{laser}$$

$$\gamma_{e^-}^2 = \frac{E_{e^-}^{kine}}{m_{e^-} \cdot c^2}$$

- ,,monoenergetic" γ-beam < 20 MeV
- bandwidth $\sim$0.5%
- 10^8photons/s
- tunable energy
- Almost 100% linearly polarized beam

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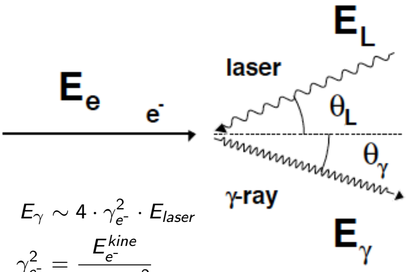

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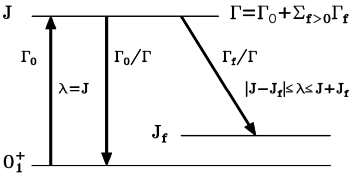
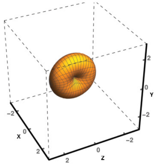


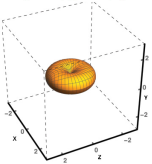
- Populate excited states by resonant scattering of γ rays
- Measure total (Γ) and partial (Γ_f) level widths following γ decay
- Narrow bandwidth: selective population
- Scan for new resonances
- Completely model independent measurements
- Very clean angular distributions for J^π measurements

Photons from Laser Compton Backscattering (LCB)

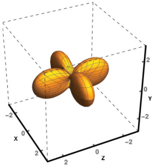
$0^+ \longrightarrow 1^- \xrightarrow{E1} 0^+$

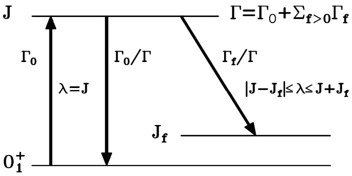


$0^+ \longrightarrow 1^+ \xrightarrow{M1} 0^+$



$0^+ \longrightarrow 2^+ \xrightarrow{E2} 0^+$





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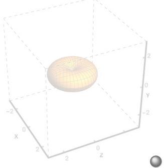

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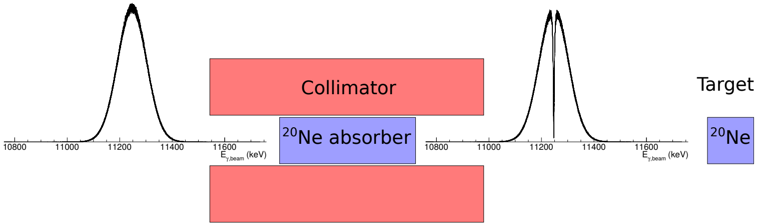
- 10^8photons/s
- tunable energy
- Almost 100% linearly polarized

- Access to the equation of the state (PDR)
- Constrains on matrix elements for $0\nu\beta\beta$-decay
- Parity violation in Nuclear excitations
- pn symmetry breaking
- Electric and dipole moments of nucleus
- Photo-response of weakly-abundant nuclei
- Self-absorption measurements
- Cultural heritage studies

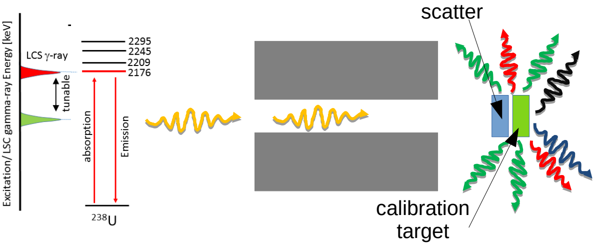
Parity violation in ^{20}Ne

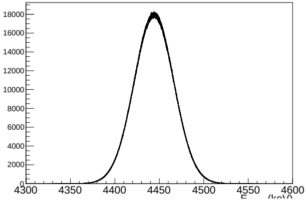
- Parity a fundamental symmetry in both the electromagnetic and strong force, but not in weak force
- In the effective nuclear force this can introduce a small parity violating term
- In ^{20}Ne, a $1^{\pm}$ parity doublet with $\Delta E = 3\text{-}4$ keV at 11.2 MeV $\beta \sim 10^{-4}$ as $|J^-\rangle = \alpha|\phi^-\rangle + \beta|\phi^+\rangle$
- Cross section for 1^+ ~ 50 times higher than 1^-
- Thick ^{20}Ne absorber to remove all 11.259 MeV beam γ-rays
- At ELI-NP: 100% linear polarization
- Measure β from angular distributions of 11.255 MeV γ-rays
- $\langle 0^+|T(E1) + T(M1)|1^-\rangle = \alpha\langle 0^+|T(E1)|\phi^-\rangle + \beta\langle 0^+|T(M1)|\phi^+\rangle$

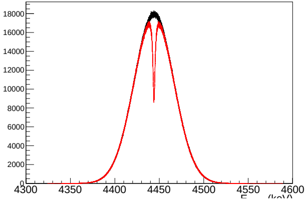


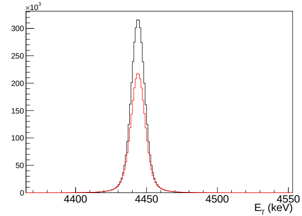
High-precision measurements: ^{11}B

- Concept of self-absorption can be used for high-precision measurements
- Example: ^{11}B used as a standard for photon flux calibrations
- Widths of the lowest lying states known only to precision of 3.4-9.1%
- Concept of self-absorption uses ratios of detected γ-rays with significantly lower systematic uncerainty









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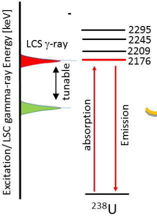
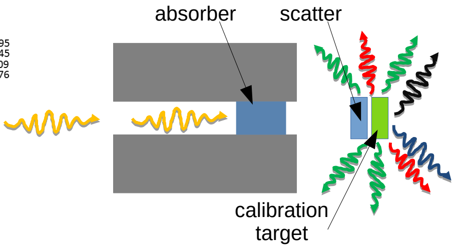
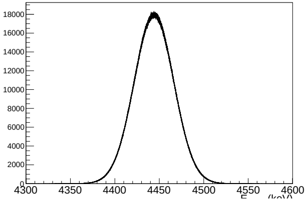
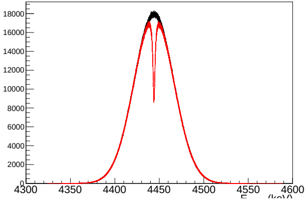
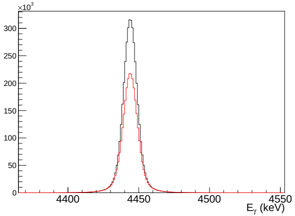




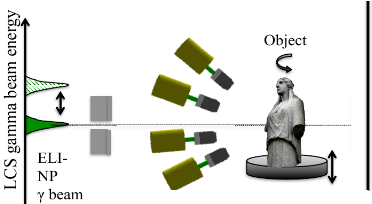




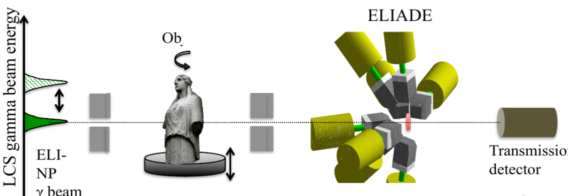


Active interrogation measurements at ELI-NP

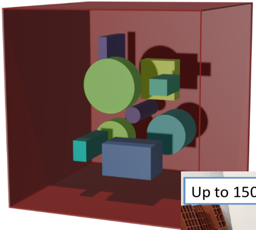
Self-absorption concept



Scattered NRF



Self-absorption/Transmission NRF



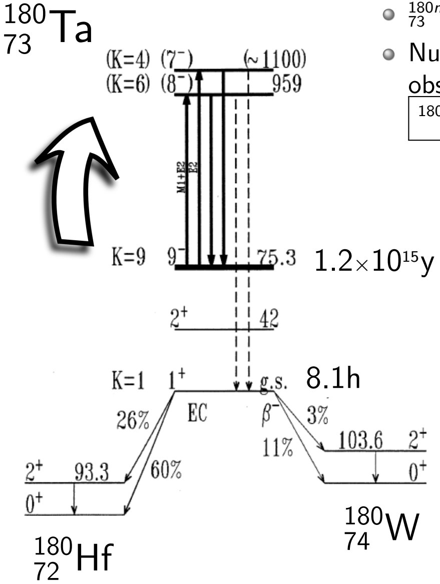
In-house developed control system and DAQ for 3D-radiography

G. V. Turturica et al, EPJ Plus (2020) 135:140

- Identification of elemental composition
- Noninvasive, nondestructive
- Spatial resolution less than mm in objects up 150 kg
- Nuclear waste management
- Cargo screening/Material identification
- Radioactive source identification
- Metal count in food and in plants
- Density screening in ill tissue
- Cultural heritage

Activation of ^{180m}Ta and decay study

Day One Experiment



- $^{180m}_{73}$Ta is the only naturally occurred isomer
- $^{180m}_{73}$Ta/$^{180}_{73}$Ta$\sim$0.012%
- Nucleosynthesis models fail to account for the observed abundance:

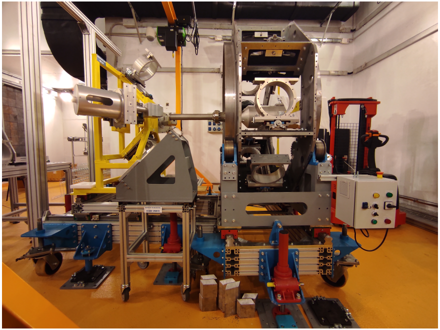
$\boxed{^{180m}\text{Ta}(\gamma, \gamma')^{180}\text{Ta}}$ $\boxed{T <<< 3{\cdot}10^8 K}$

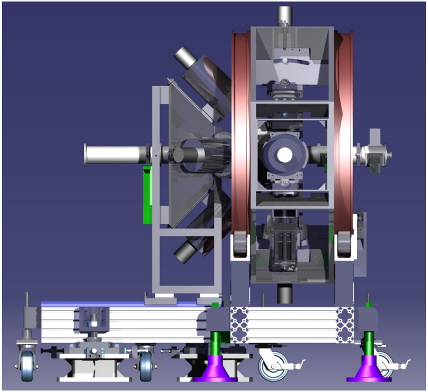
Experiment to find the doorway states, through which the $I^\pi = 9^-$ through which ^{180m}Ta deexcites (indications for doorway states from bremsstrahlung experiments)

Nine states are suggested in between 1 MeV and 3 MeV, the lowest 1.01 MeV

The detailed knowledge of the doorway states and the flux which passes through them provide a sensitive thermometer for studying the star conditions during the nucleosynthesis.

ELIADE γ-ray spectrometer





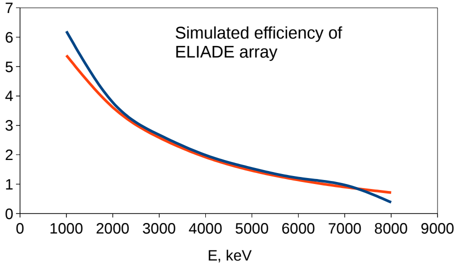
8 x HPGe Clover (4 x 90° and 4 x 135°)

d_{min}=15 cm d_{max}=30 cm

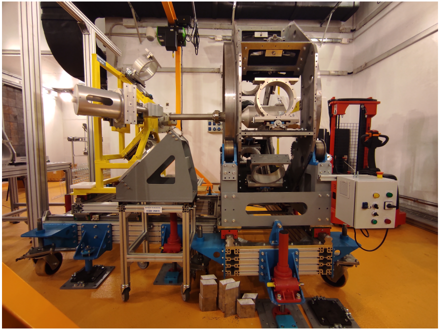
$\epsilon_{dmin} \approx 6\%$ $E_\gamma \sim 1.3$ MeV (GEANT4)

Compton Supressed ?!??

+ 4 x $LaBr_3$ at 90°



ELIADE γ-ray spectrometer



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ϵ_{dmin} ≈6% E_γ ∼1.3 MeV (GEANT4)

Compton Supressed ?!??

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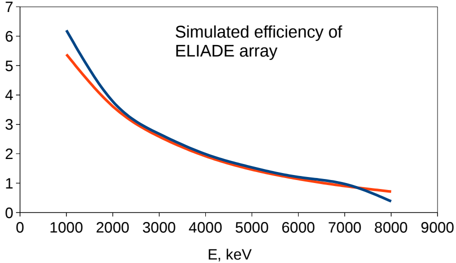
Mechanical structure - **completed**

LN2 system - **completed**

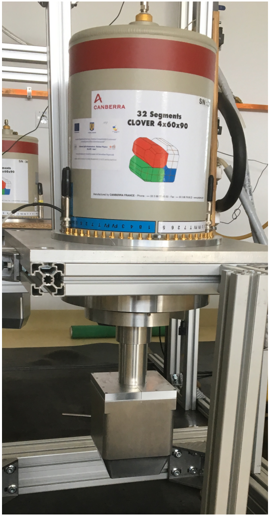
DAQ - **pending...**

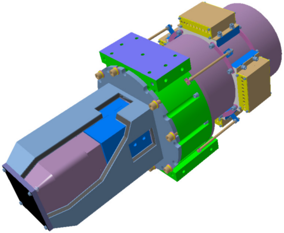
Detector characterisation - **pending...**

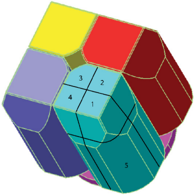
Phase 1 (4 clovers) **2021...**



Details of the ELIADE detectors







- 8 Canberra 4x60x90 Seg32 Clover detectors
- Interested in high-energy γ-rays
- Using segmented Clover detectors we can increase γ-ray count rate per detector
- Most low-energy γ-rays interact in the front segments

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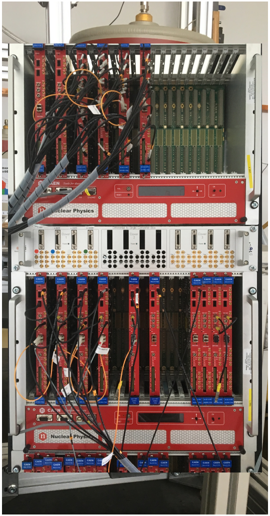

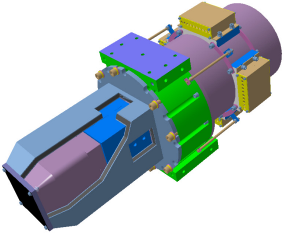

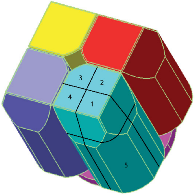

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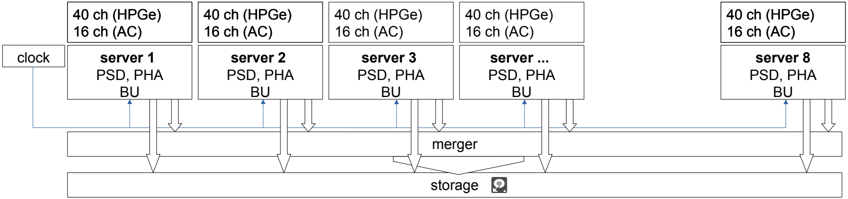
- Most low-energy γ-rays interact in the front segments

- AGATA core type preamplifiers
  dual gain: 5 MeV and 20 MeV/fast reset/
  differential output
- 32 v1725 CAEN 14 bit 250 MS/s 16 ch digitizers
- 2 v1730 CAEN 14 bit 500 MS/s 8 ch digitizers
- 8 front-end servers

DAQ: Conceptual architecture



320 ch (HPGe)

132 ch (CsI, BGO, $CeBr_3$)

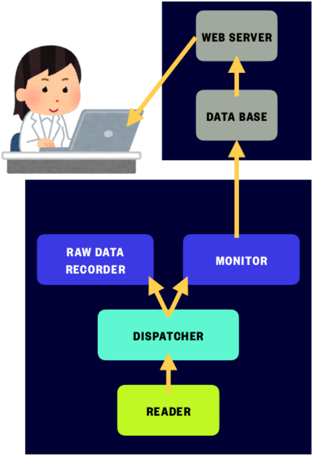
Sub-detector (domain) mechanism

DELILA data acquisition system at ELIADE

Digital Extreme Light infrastructure Listmode Acquisition

DAQ-Middleware

- Developed by KEK (High Energy Accelerator Research Organization
- Used many experiments at KEK, J-PARC
- Based on a robotics system, good real time operation and reliability
- CAEN digitizers PHA, PSD, waveform implemeted
- QDC (soon)
- Using ROOT to plot and store data
- Browser-based GUI

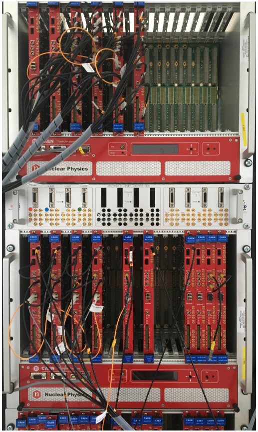


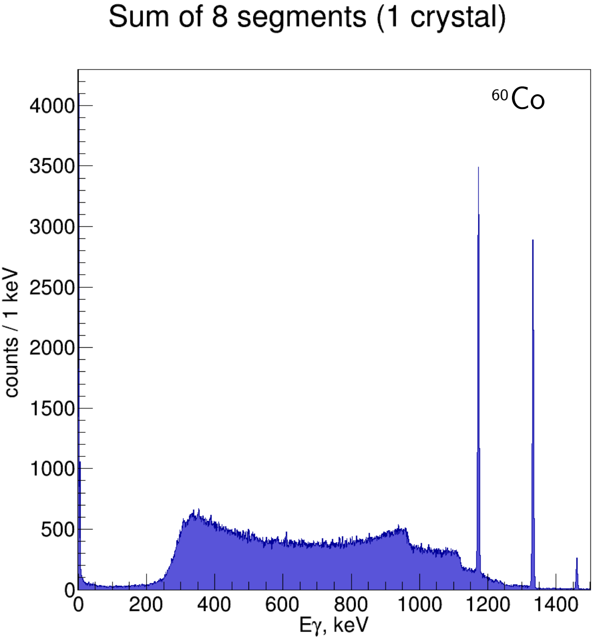
Soiciro Aogaki

DELILA at ELIADE

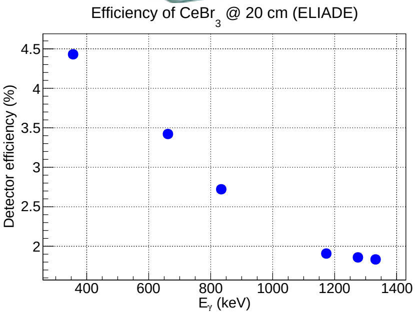
- One event in HPGe channel:
  Channel number: 1 Byte + digitizer number: 1 Byte;
  Energy (ADC value): 2 Bytes; Time stamp: 8 Bytes
- Waveform (250 samples): 500 Bytes
- Total: 512 Bytes
- Assuming 10^4 /s per ch 2.6 Gb/s including traces (waveformes)
- Assuming 10^4 /s per ch 61 Mb/s no traces ($\rightarrow$ 5 Tb/day)

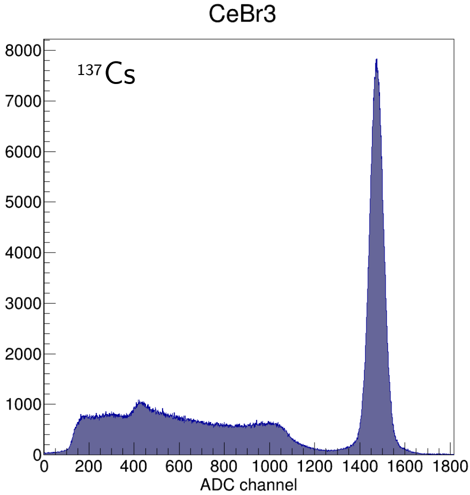
Details of the ELIADE detectors





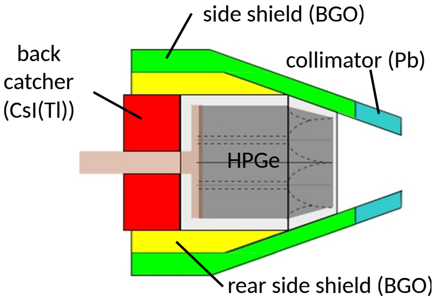
$CeBr_3$ scintillation detectors

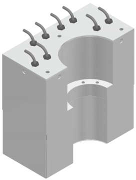


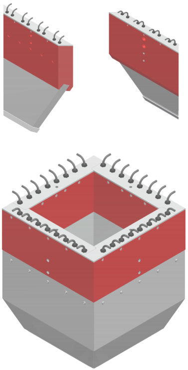


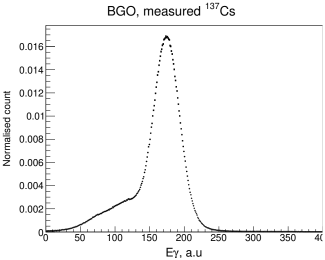
- ELIADE has 4 positions (4 x $LaBr_3$)
- High Efficiency
- good time resolution (ns)
- reduced pile up at higher countrates

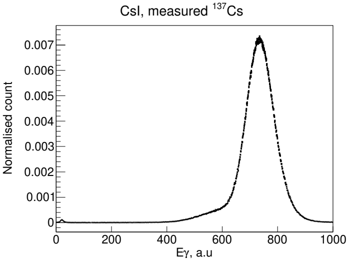
Anti-Compton shields







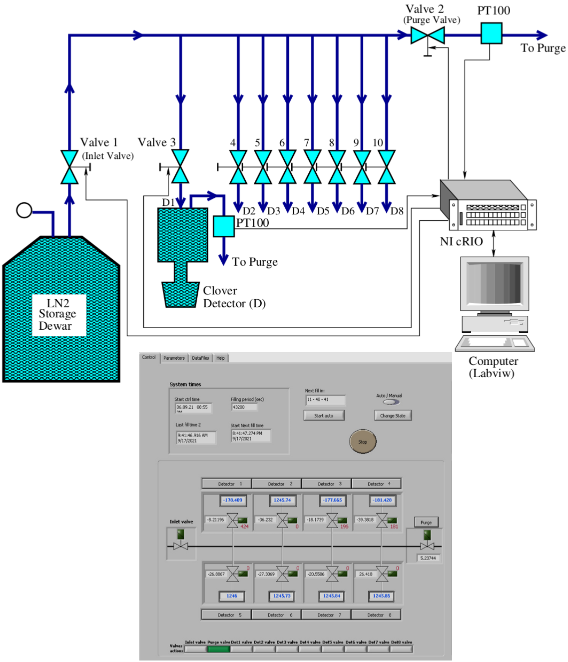




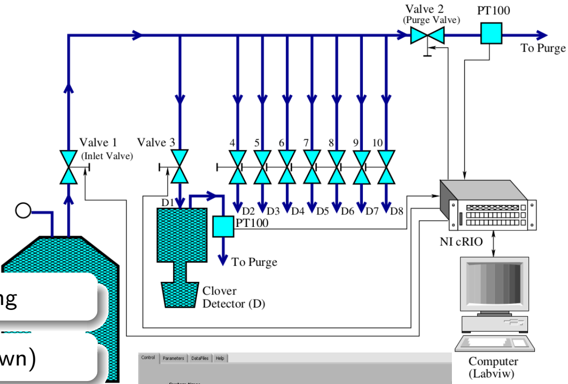
Laboratory (source) test

GEANT4 simulations are on-going

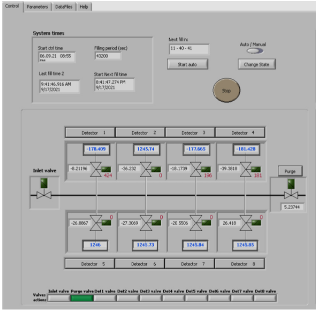
LN2-system


Valve 2
(Purge Valve)
PT100
To Purge
Valve 1
(Inlet Valve)
Valve 3
4
5
6
7
8
9
10
D1
D2
D3
D4
D5
D6
D7
D8
PT100
To Purge
Clover
Detector (D)
NI cRIO
LN2
Storage
Dewar
Computer
(Labviw)
Control
Parameters
DataFiles
Help
System times
Start ctrl time
Filling period (sec)
43200
Last fill time 2
Start Next fill time
Next fill in:
Auto / Manual
Start auto
Change State
Stop
Inlet valve
Purge
Detector 1
Detector 2
Detector 3
Detector 4
Detector 5
Detector 6
Detector 7
Detector 8

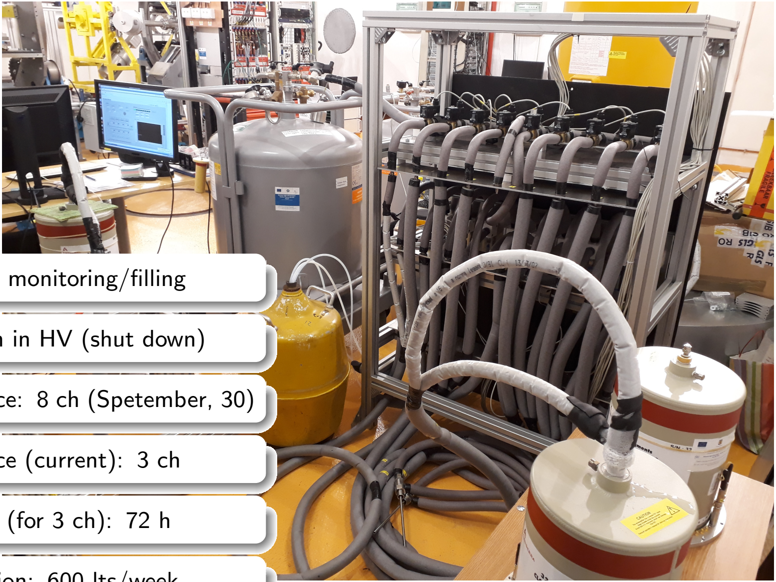
LN2-system



- Automatic monitoring/filling
- Integration in HV (shut down)
- Capacitance: 8 ch (Spetember, 30)
- Capacitance (current): 3 ch
- Autonomy (for 3 ch): 72 h
- Consumption: 600 lts/week



LN2-system



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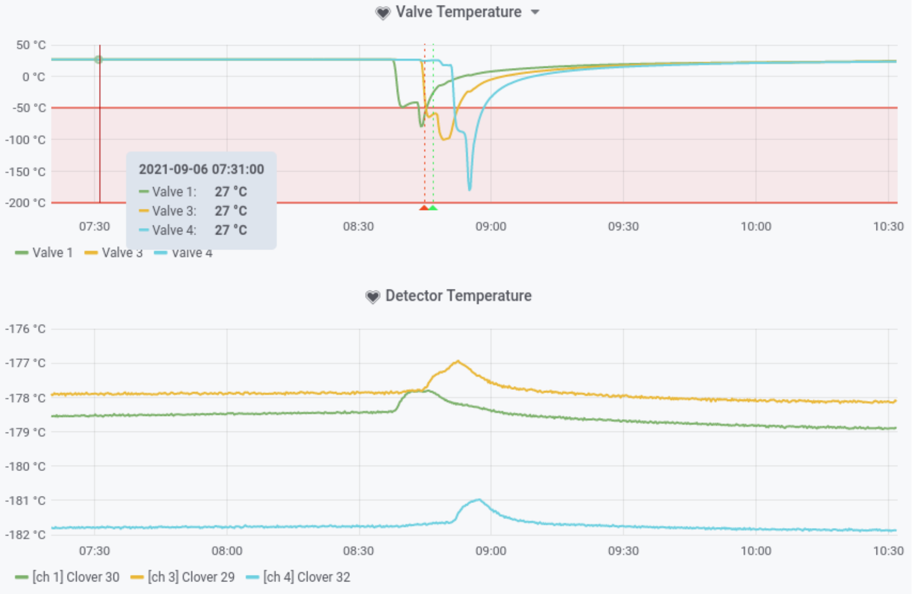
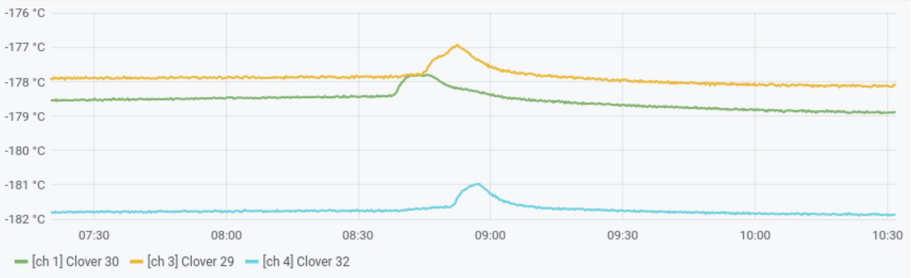
Monitoring, Alarming and Control for ELIADE (MACE)



Monitoring, Alarming and Control for ELIADE (MACE)

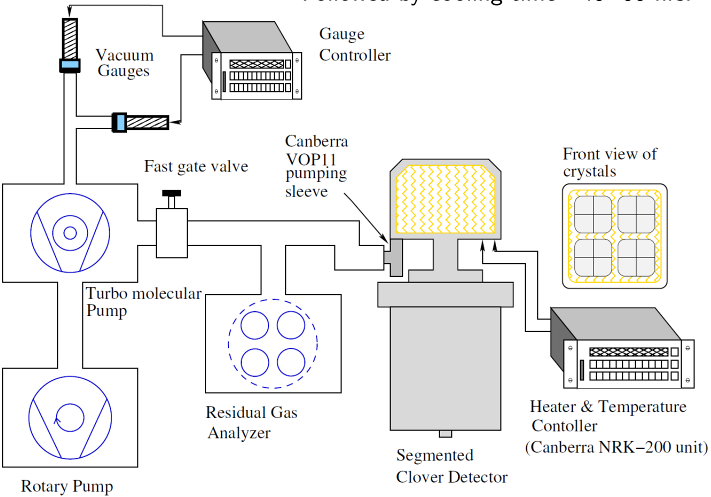
Functionalities

- **HV**, $\mathbf{I}_{leak}$ from the CAEN SY4527 High-Voltage Source;
- Temperature of the detectors is monitored via **PT100** sensors
- **CompactRIO** (cRIO) controller activates fillings, dispatches data
- **Python** (PyEpics library) updates **InfluxDB** data base with T, HV, I_{leak}
- **GRAFANA** monitoring interface (web, Android, iOS) provides on-line data base visualisation
- **Passive alarm**: messages via emails and **TELEGRAM**
- **Active alarm**: sim-calls, forced filling, HV shut down
- **browser GUI** for alarms configurations/settings



Annealing station

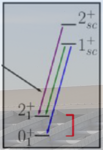
Heating the crystal 1000 °C for 40 hrs.
Followed by cooling time 40 -60 hrs.

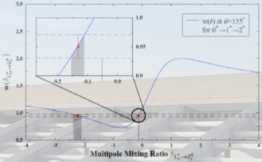


To take home

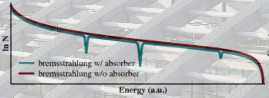
Discovery frontiers for NRF at ELI-NP

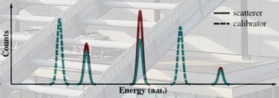
Availability frontier
(access to rare isotopes)





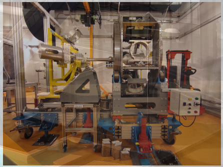
Sensitivity frontier
(weak channels)





Precision frontier
(high statistics)

ELIADE
(γ-ray spectrometer)
(from December 2021



Thank you for you attention

eli nuclear physics

JINR DUBNA

HIL Heavy Ion Laboratory

The ELIADE collaboration

EUROPEAN UNION

GUVERNUL ROMÂNIEI

Competitiveness Operational Programme

Structural Instruments 2014-2020

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- Violeta Iancu
- Gabriel Turturică
- Cristian Petcu
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- Emil Udup
- Frangil Ramirez
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- George Nitescu
- Andrei Vasile
- Sara Ban
- Maria Brezeanu
- ...and all the technical team!

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- Volker Werner, IKP, TU Darmstadt
- Julius Wilhelmy, IKP, University of Cologne
- ..., **JINR Dubna ???**

Matrix elements for $0\nu\beta\beta$-decay

- Decay rate ($\lambda_{0\nu\beta\beta}$) depends on neutrino mass (m_ν) and nuclear matrix element ($M^{(0\nu)}$)

  $$\lambda_{0\nu\beta\beta} = G_{0\nu} \left| M^{(0\nu)} \right|^2 \left(\frac{\langle m_\nu \rangle}{m_\mathrm{e}} \right)^2$$
- Matrix element needs to be calculated from nuclear structure physics and depends strongly on pn coupling
- Scissors mode particulary sensitive to pn coupling
- Example: ^{150}Sm with large $0\nu\beta\beta$ branching both to 0_1^+ and 0_2^+
- Ideal case to determine parities of $J = 1$ states and measure scissors branching to 0_2^+ using NRF