TDR on Nuclear Resonance Fluorescence Experiments

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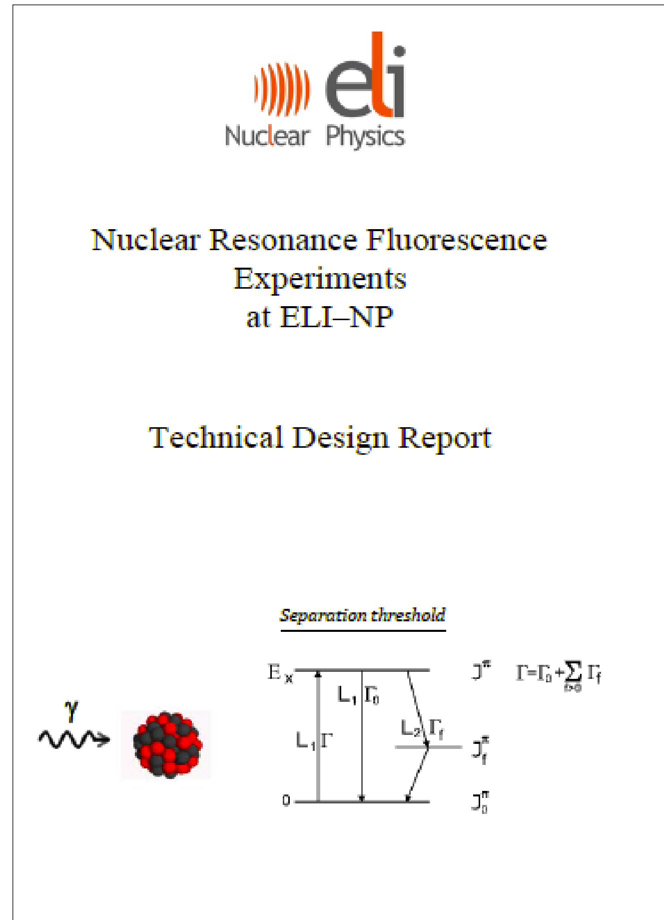


Nuclear Physics

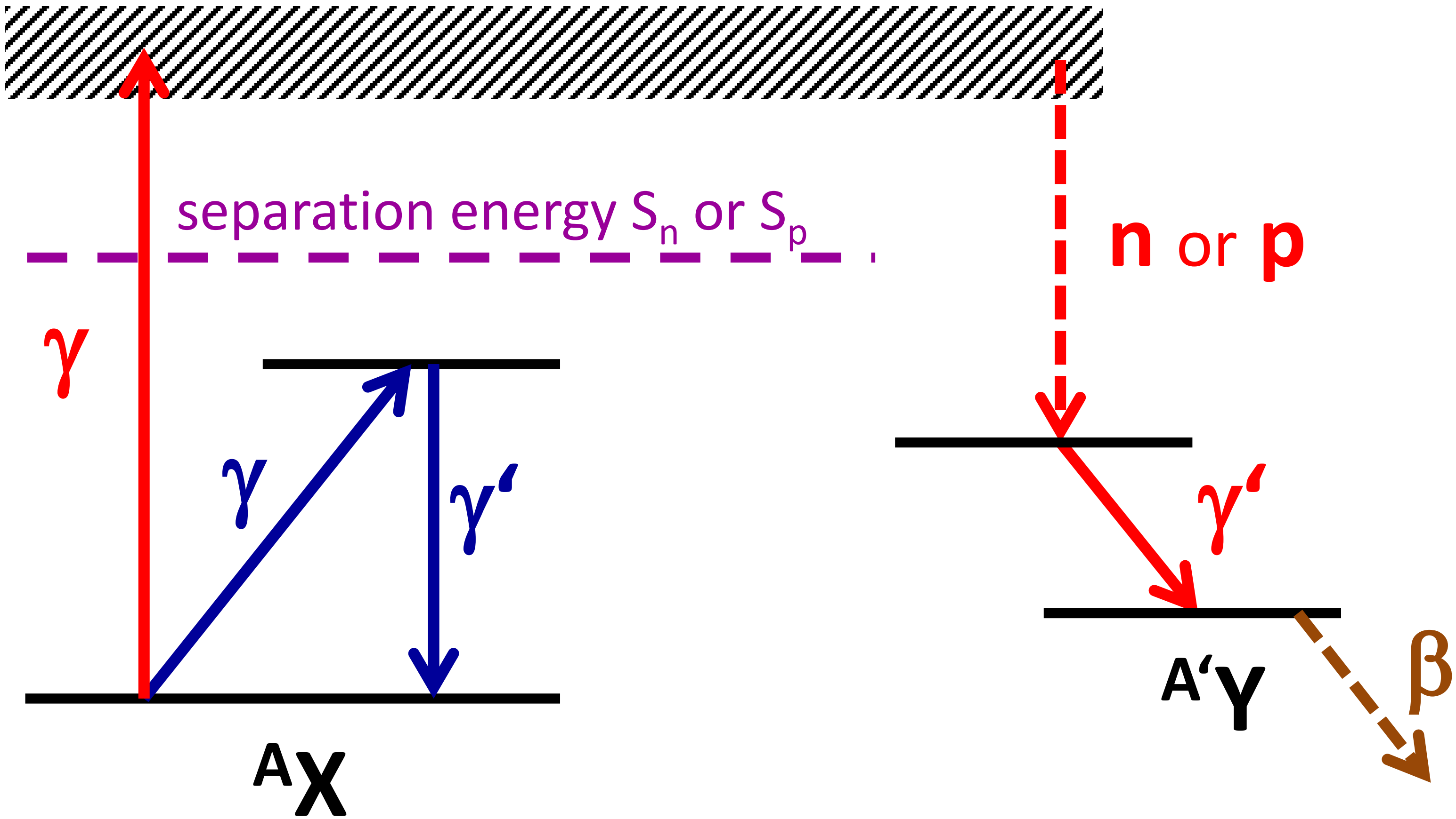
Nuclear Resonance Fluorescence Experiments at ELI–NP

Technical Design Report

Photonuclear Reactions

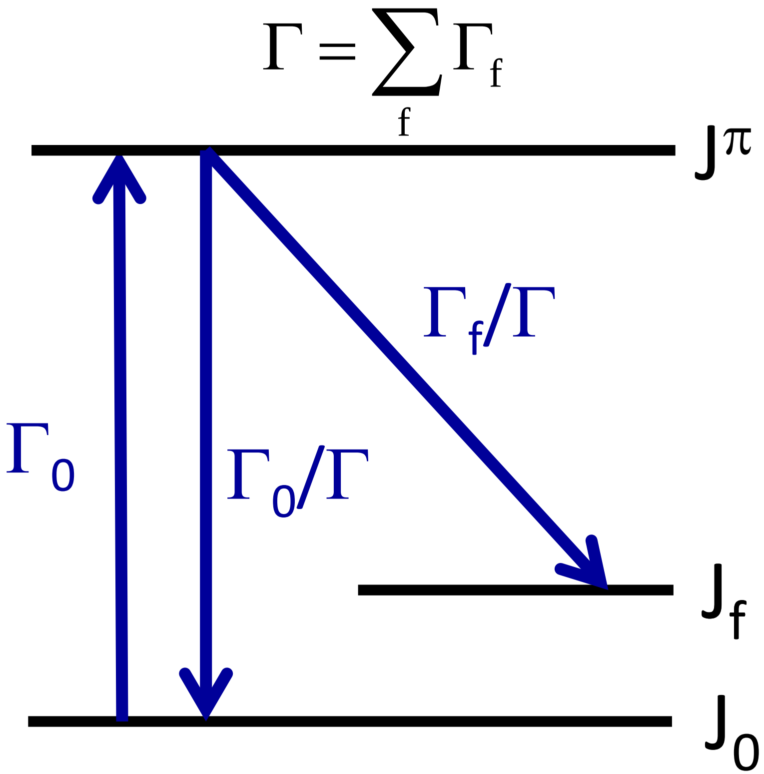
- Pure EM interaction
- Spin selectivity (mainly E1, M1, E2 transitions)
- Polarized beams
  $\rightarrow$ parity physics
- Tunable energy and narrow bandwidth
  $\rightarrow$ selective manipulation of nuclear states:
  ”Nuclear Photonics“

Photonuclear Reactions



- Photodisintegration, Photofission
- Nuclear Resonance Fluorescence - NRF

Nuclear Resonance Fluorescence



<u>Observables:</u>

- Excitation energies E_X
- Spins J
- Parities π
- Decay energies E_γ
- Level widths Γ (eV)
- Lifetimes τ (ps – as)
- Decay branchings Γ_f / Γ
- Partial widths Γ_f
- Multipole mixing ratios δ
- Decay strengths $B(\sigma\lambda)$

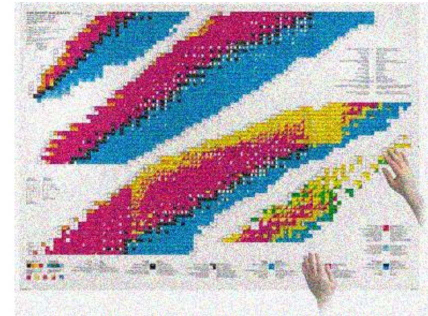
Nuclear Resonance Fluorescence

Special properties of ELI-NP photon beam for NRF:

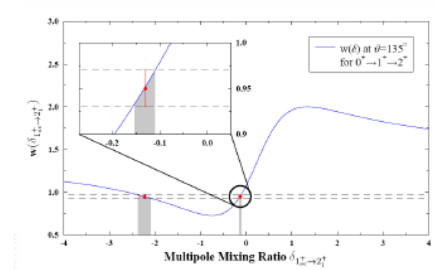
- very high intensity (10^4 photons/(s·eV))
- narrow bandwidth (down to 0.5%)
- high degree of polarization (> 99%)
- small beam diameter (mm range)
- low duty factor (100 Hz)

Discovery frontiers for NRF at ELI-NP

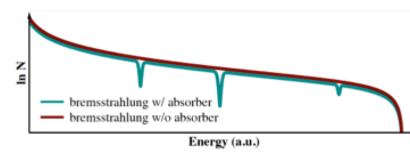
Availability frontier
(access to rare isotopes)

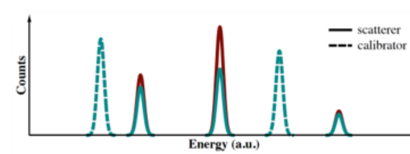


Sensitivity frontier
(weak channels)

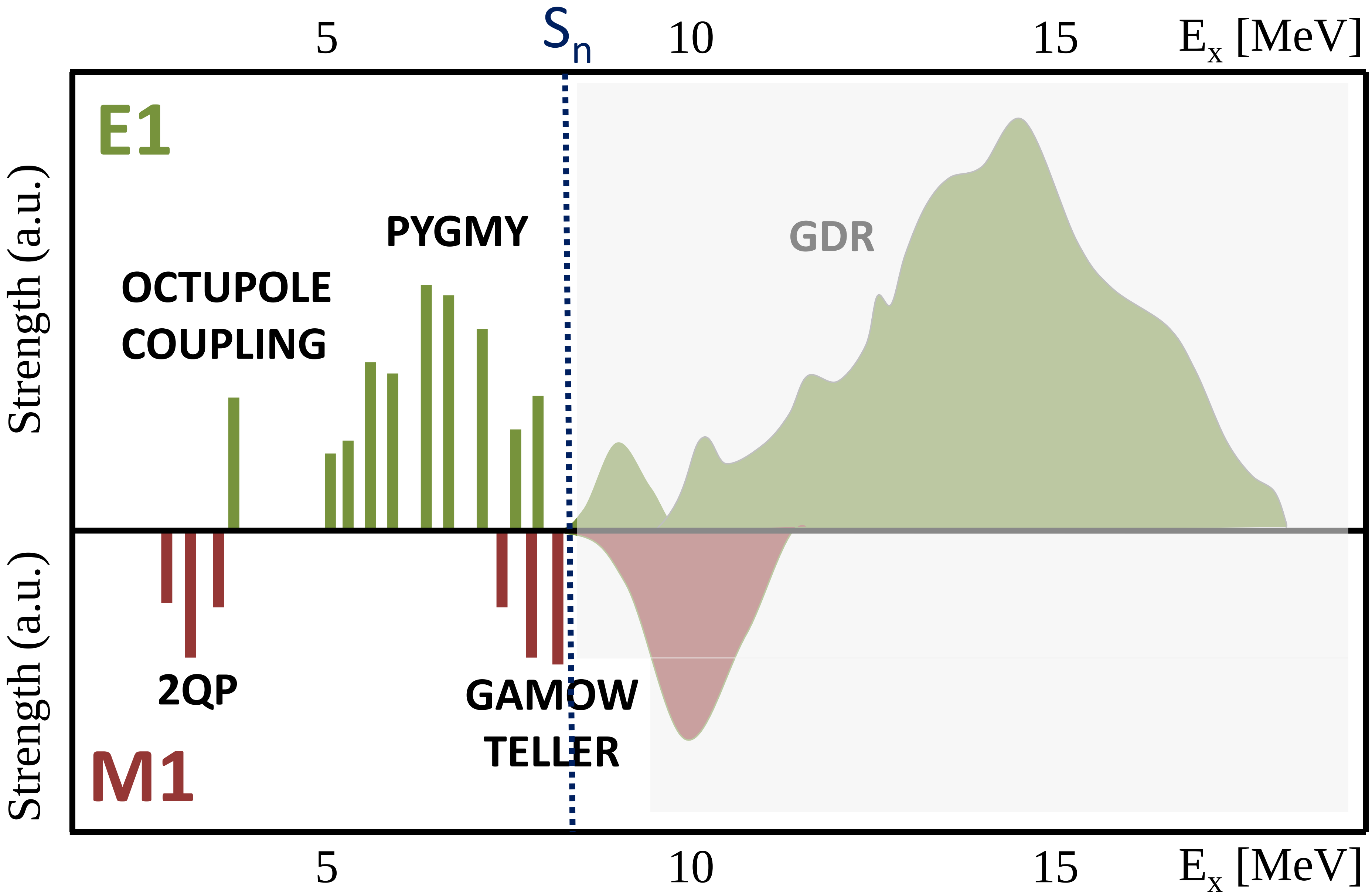


Precision frontier
(high statistics)





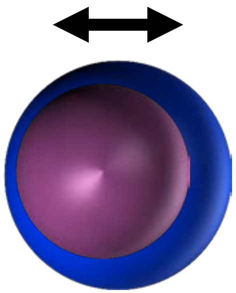
Dipole photoresponse of atomic nuclei



Physics cases for NRF at ELI-NP: Examples

- An access to the **equation of state** and to neutron-rich matter: Investigation of the Pygmy Dipole Resonance
- **Parity violation** in nuclear excitations: The case of ^{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 low-abundant *p* nuclei
- Photons and **radioactive isotopes**: Electric and magnetic dipole response of unstable nuclei

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

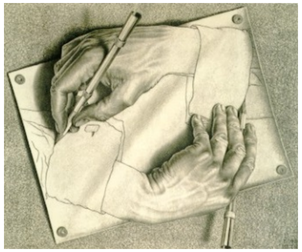
→ impact on EOS, Nucleosynthesis, neutron star radii

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*

Parity violation in nuclear excitations: The case of ^{20}Ne



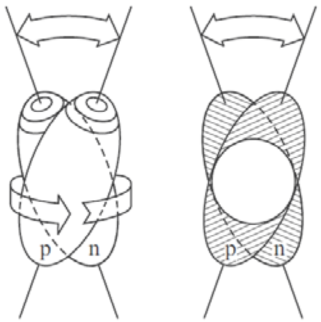
Parity doublet $1^+/1^-$ at 11.26 MeV in ^{20}Ne

$\rightarrow$ constrain weak meson-nucleon coupling

NRF@ELI-NP:

- nearly 100% polarized γ beam
- thick ^{20}Ne absorber removes photons to excite 1^+ state
- only 1^- state of doublet is excited
- measure NRF events in detector perpendicular to beam axis $\rightarrow$ M1 admixture

Constraints on neutrinoless double-beta decay matrix elements: A novel decay channel of the scissors mode



1^+ scissors mode observables are sensitive to parameters in the IBM-2 Hamiltonian

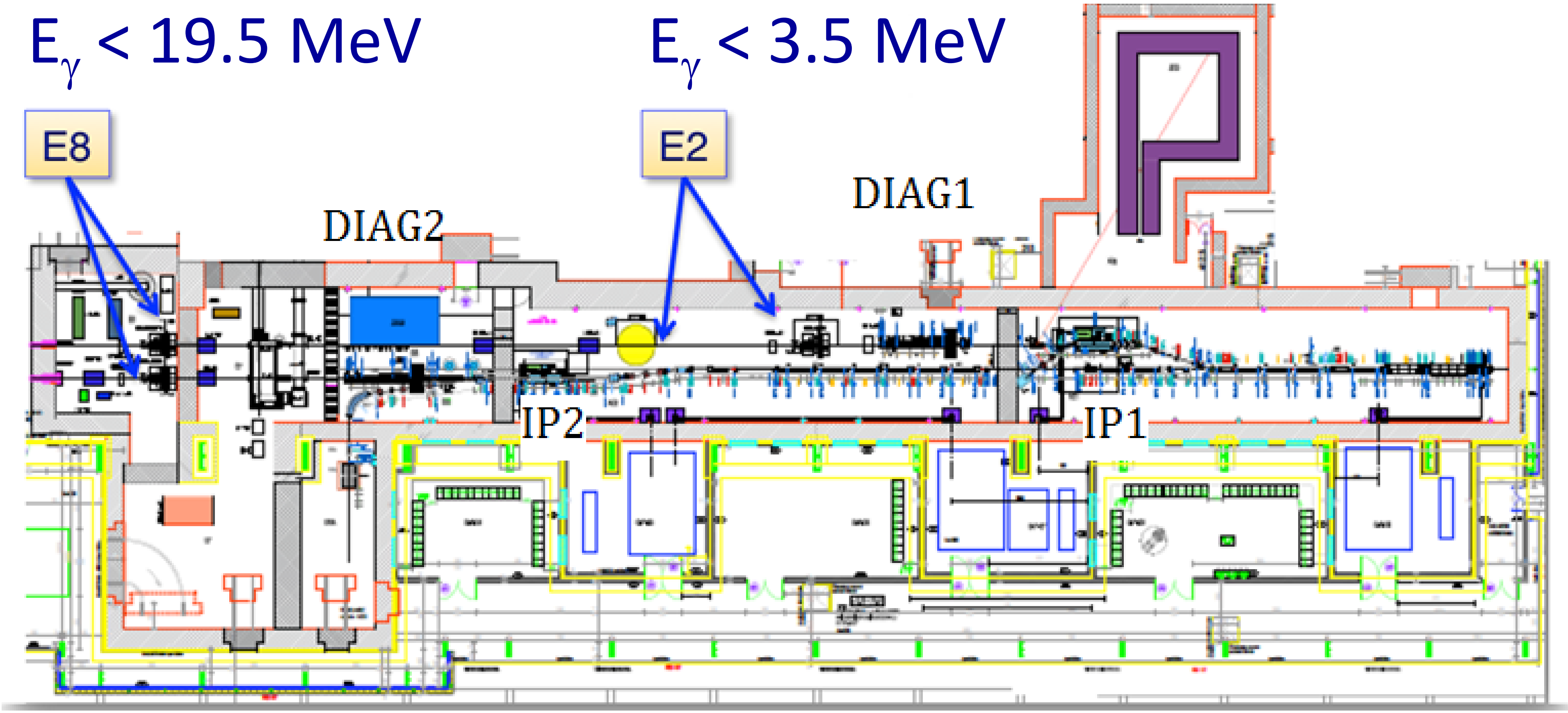
$\rightarrow$ constrain nuclear matrix element in $0\nu\beta\beta$ transition rate

NRF@ELI-NP:

- narrow bandwidth allows to detect weak decay channels of the scissors mode
- polarization allows to distinguish 1^+ and 1^- states

NRF: Technical Proposal

Combine unique properties of ELI-NP photon beam with an adapted but versatile experimental setup



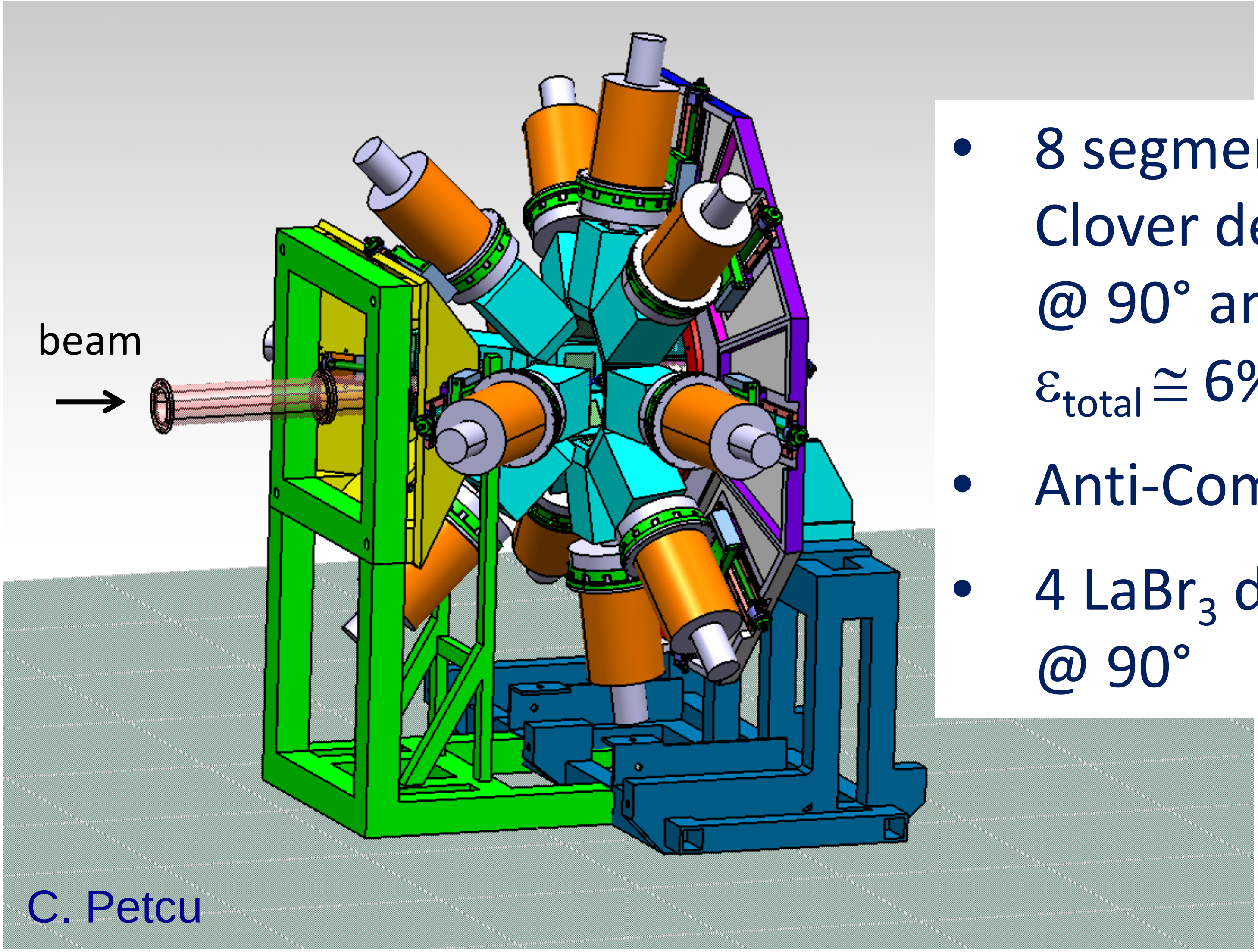
The γ-detector array

Requirements:

- high energy resolution ($\leq$ 1-2‰)
- high efficiency, even for E_γ > 5 MeV
- adequate $\gamma\gamma$-coincidence efficiency
- high granularity (angular distribution, parities)

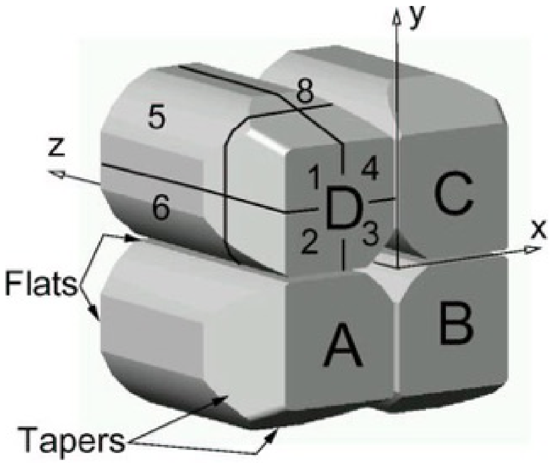
→ a combination of segmented HPGe and $LaBr_3$ detectors positioned around 90° and under backward angles

ELIADE: ELI-NP Array of DEtectors

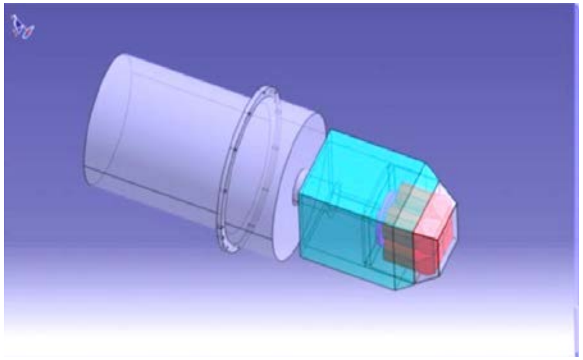


- 8 segmented HPGe Clover detectors @ 90° and 135°, $\varepsilon_{total} \cong 6\%$
- Anti-Compton shields
- 4 $LaBr_3$ detectors @ 90°

The Clover detectors



4 crystals („leaves“) per Clover,
8 segments per crystal,
tapered to allow close assembly
(similar to TIGRESS@TRIUMF)



Specifications:

- operational voltage: < 5000 V
- relative efficiency per leaf@1.3 MeV: ≥ 38%
- with addback mode: ε_{rel}(Clover) ~ 200 %

Why segmented Clovers?

Challenges for γ detection:

- low duty cycle of the photon beam
- high low-energy background

Statistics ratio (from case studies):
segmented/non-segmented = 1.6-1.8
(one saves beam time!)

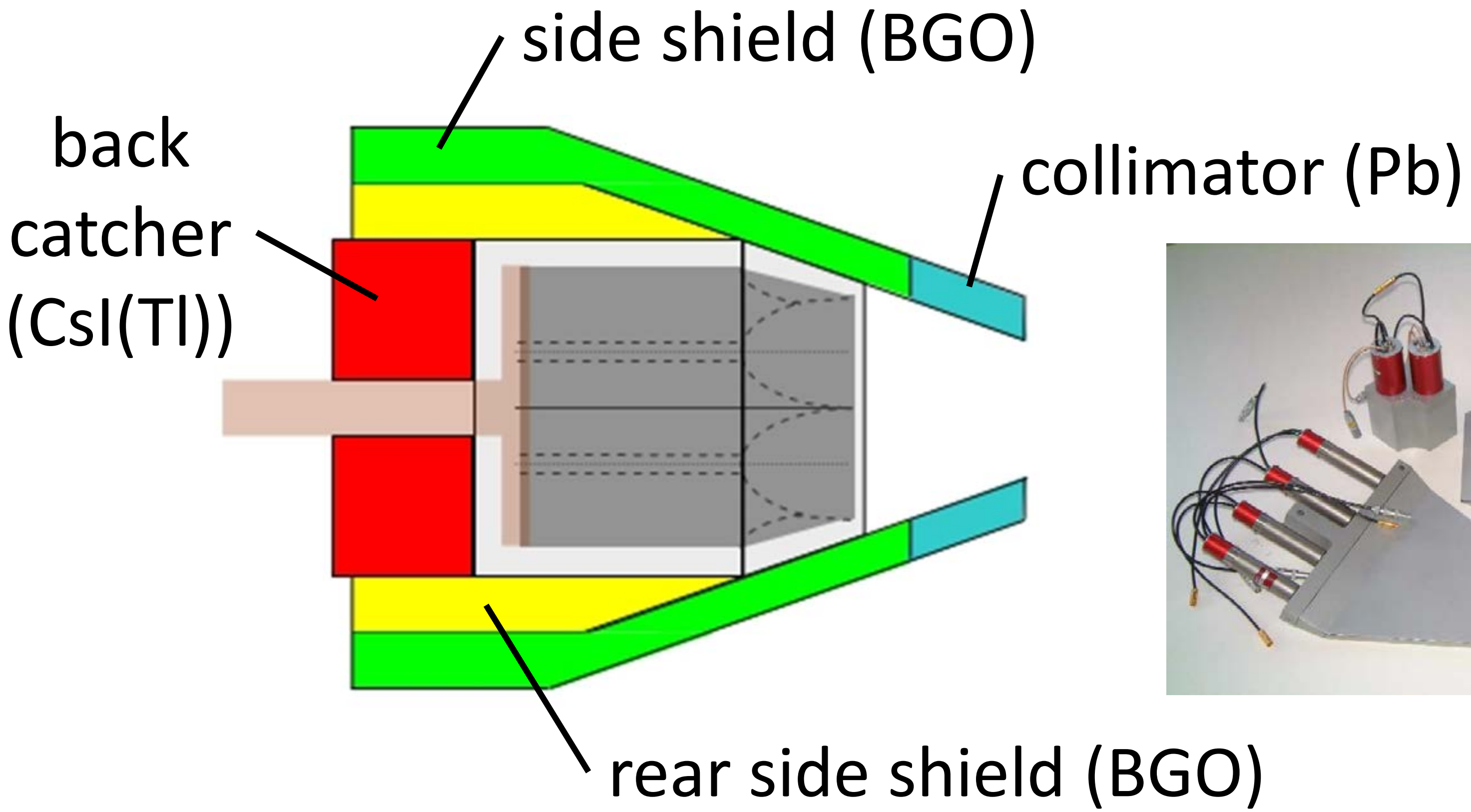
Cost ratio (including electronics, excluding beam time):
segmented/non-segmented = 1.5

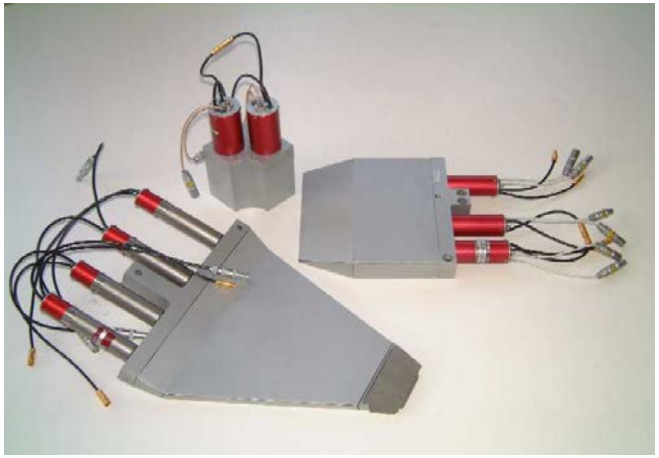
To reach the frontiers we need good statistics

$\rightarrow$ **we need segmented Clovers!**

Anti-Compton shields

(similar to shields for EXOGAM Clover)





$LaBr_3$ scintillation detectors

- ELIADE has four positions for $LaBr_3$ detectors
- high efficiency
- good time resolution (ns), reduced pile up at higher countrates

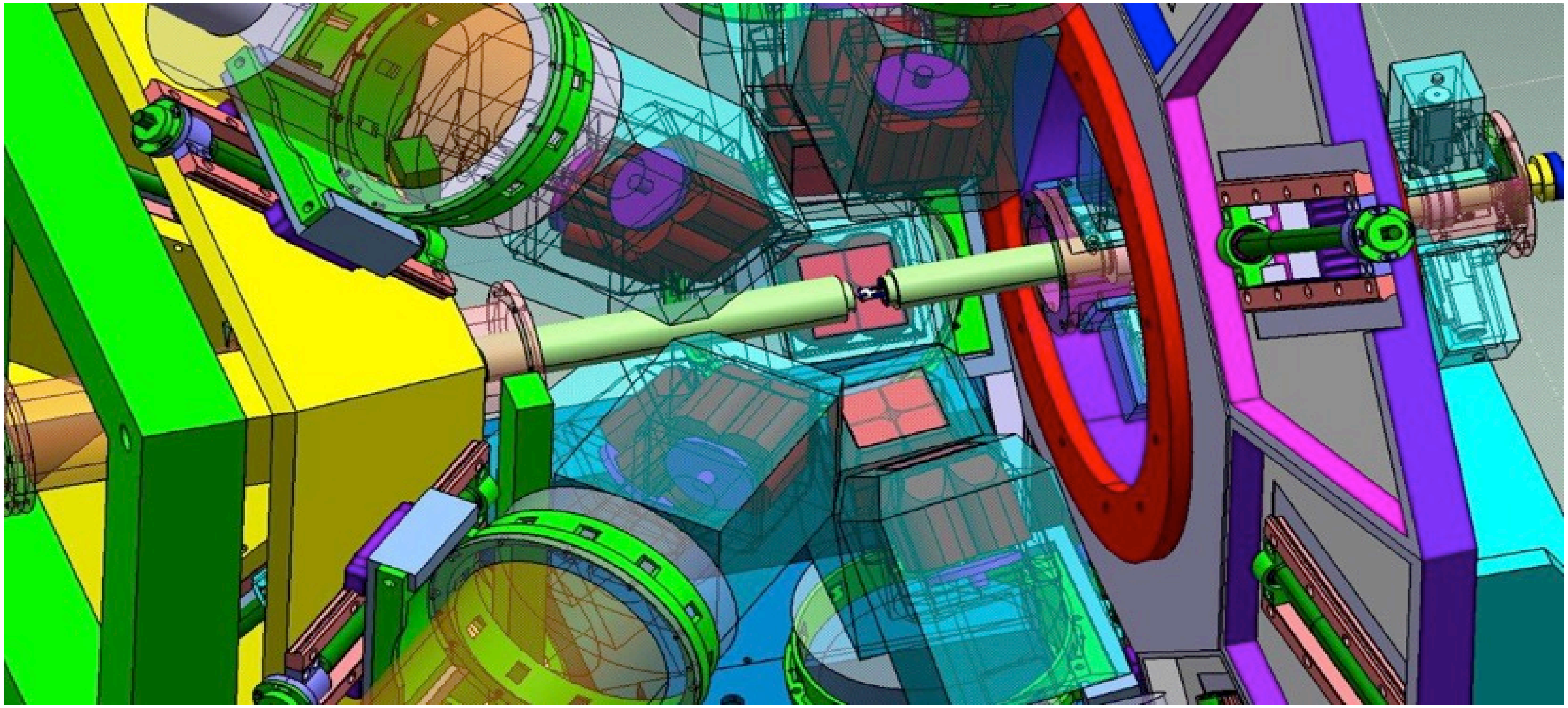
$\rightarrow$ ideal for $\gamma\gamma$-coincidence experiments

(proven by γ^3 setup at HIγS)

*B. Löher, V. Derya et al., NIM A **723** (2013) 136*

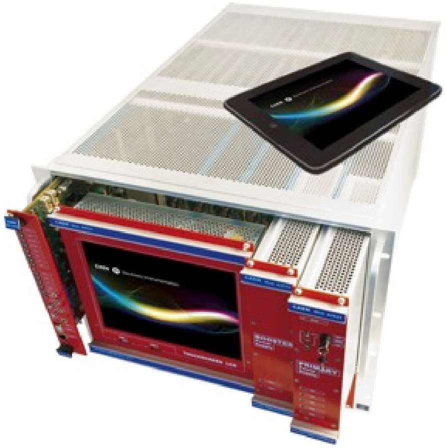
Mechanical support structure

- easy to move between E2 and E8
- 90° ring can be rotated (parity determination)
- accurate target-beam alignment in sub-mm range



HV and LV power supplies

- 32 independent HV channels for each HPGe crystal
- 4 HV supplies for $LaBr_3$
- 32 HV channels for Anti-Compton shields
- control system including LN_2 filling

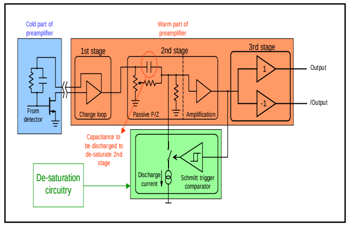


CAEN
SY4527 mainframe

- high quality, low noise LV for preamplifiers

Data acquisition

Front end:

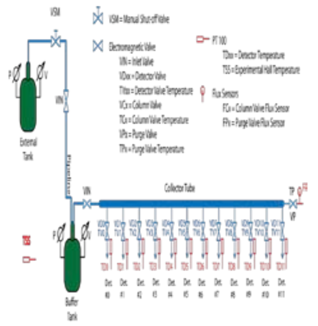


- AGATA core type preamplifiers
- dual gain: 5 MeV and 20 MeV
- fast reset
- differential output

Digital sampling:

- 250 MS/s @ 14 bit (HPGe, BGO)
- 500 MS/s @ 12 bit ($LaBr_3$)
- filtering on board
- commercial modules: XIA, Struck, CAEN
- trigger from RF macrobunch

LN_2 filling system and other aspects



- transfer lines for up to 12 HPGe in E2 and E8
- automatic control system for monitoring and filling
- integration in HV control system

Other aspects:

- cabling
- electronics cabinets
- vacuum control
- …

Work packages (I)

(1) γ detectors: HPGe, $LaBr_3$, Anti-Compton shields

- technical specifications for tender
- tender
- delivery, acceptance tests

(2) Front-end electronics

- design and prototyping
- production

(3) Digital readout and filters, storage, online control

- building prototype system $\rightarrow$ full system
- technical specifications for tender: digitizer, PC farm
- tender
- delivery and acceptance tests

Work packages (II)

(4) Mechanical support structure and shielding

- finalizing CAD drawings
- execution drawings
- tender
- delivery, acceptance tests

(5) LN_2 filling system

(6) Vacuum pumps and control

(7) GEANT 4 simulation of the setup

Transversal needs

- **Mechanics**
  - Alignment (laser tracker for the support structure, laser for the beam line, CCD camera for the target)
  - ‘universal’ type of support for all devices (alignment platform)
  - cranes for the handling of the detectors and other heavy materials
- **Vacuum**
  - control system (integrated in the general control and monitor system)
  - Pumps (vacuum level better than 10^{-3} mbar)
- **Electrical**
  - Clean power line
  - UPS
  - Grounding
  - Cable ducts (RF shielded)
- **Liquid nitrogen**
  - Use of the external tank, one local dewar in E2 and one in E8
  - Transfer lines

Transversal needs

- **Diagnostics devices**
  - CCD camera for the alignment
  - Gamma beam intensity monitor
  - Polarization control
  - Gamma beam energy monitor
- **Cabling**
  - Optical fibers from the experimental halls E2 and E8 to the Data Acquisition Room
- **Computing**
  - PC farm for data acquisition
  - Data storage
- **Experimental control**
  - One PC for experiment control
  - One PC for setup control

Safety requirements

- **Radioprotection**
  - General radioprotection system
  - E2 : electrons, gamma rays
  - E8 : gamma rays, neutrons
- **Hall access**
  - General interlock system
- **Vacuum**
  - Integration of the user part with the accelerator part (if it is the case)
- **LN_2 filling**
  - Exhausting nitrogen gas
  - Oxygen sensors
- **Shielding**
  - Pb walls in front of the experimental setup to remove scattered radiation

Formal collaborations

TU Darmstadt (MoU)

Physics cases, specifications for the setup

University of Cologne (MoU)

Physics cases, specifications for the setup

Department of Nuclear Physics, IFIN-HH

Detectors, electronics, DAQ

Budget estimate

ELIADE γ array: **3640 k€**

8 segmented HPGe Clover detectors	3040 k€
8 Anti-Compton shields	160 k€
4 $LaBr_3$ detectors, 3‘‘ x 3‘‘	240 k€
support structure	200 k€

Data acquisition: **420 k€**

332 channels digital electronics	332 k€
analog electronics, readout PC, cabling	88 k€

LN_2 filling system: **59 k€**

distribution system	35 k€
control system	24 k€

Budget estimate

Power supplies: **137 k€**

HV supply for HPGe Clover detectors	125 k€
HV supply for $LaBr_3$	7 k€
LV power supply	5 k€

Racks and crates: **62 k€**

Data storage RAID system: **50 k€**

Pb shielding: **50 k€**

Total cost for NRF setup
to reach the frontiers: **4418 k€**