Nuclear Resonant Scattering for γ-Beam Characterization procedure at ELI-NP

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ELI is a pan-European project involving over 40 institution from 13 EU countries that aims to host high-power lasers and extremely intense radiation beam lines devoted to scientific applications spacing from fundamental nuclear and molecular studies to applied biological and environmental researches.

Distributed into three specialized sites:

- Eli - Attoseconds (Hungary)
- Eli - Beamlines (Czech Republic)
- Eli - Nuclear Physics, **ELI-NP** (Romania) [1]

The ELI-NP building in Magurele, near Bucharest, Romania

The Gamma Beam System (ELI-NP-GBS) of ELI-NP will produce an intense γ-beam from Compton inverse scattering of pulsed laser light (at 550nm) from a (up to 720MeV) electron beam [2].

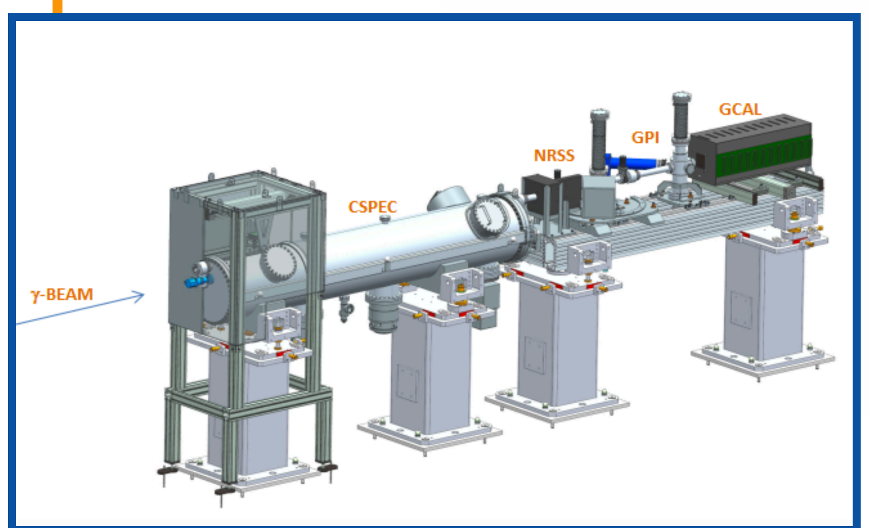
The design, manufacturing, delivery, installation, testing, and maintenance of the Gamma Beam System (GBS) is provided by the **EuroGammaS** association.

Photon energy	0.2-19.5 *MeV*
Spectral Density	$0.8\text{-}4\cdot10^4$ *ph/sec.eV*
Bandwidth (rms)	$\lesssim$ 0.5%
# photons per shot within FWHM bdw.	$\lesssim 2.6\cdot10^5$
# photons/sec within FWHM bdw.	$\lesssim 8.3\cdot10^8$
Source rms size	10 - 30 μm
Source rms divergence	25 - 200 μrad
Peak Brilliance ($N_{ph}/sec\, mm^2 mrad^2\, 0.1\%$)	10^{20} - 10^{23}
Radiation pulse length (rms, *psec*)	0.7 - 1.5
Linear Polarization	> 99 %
Macro rep. rate	100 *Hz*
# of pulses per macropulse	$\lesssim$ 32
Pulse-to-pulse separation	16 *nsec*

O. Adriani et al. arXiv:1407.3669 [physics.acc-ph] (2014)

The γ-Beam characterization system (EuroGammaS **WP09**) [3] will give a precise energy calibration of the γ beam and a continuous monitoring of its parameters (peak energy, energy and space profile, intensity…)

- Compton spectrometer (CSPEC)
- Nuclear Resonance Scattering system (NRSS)
- Beam Profile Imager (GPI)
- Sampling Calorimeter (GCAL)



3D view of the characterization systems and its subsystems.

The **Nuclear Resonant Scattering** (NRS) principle will be used to perform an absolute energy calibration of the CSPEC and the GCAL devices, and to give a redundant energy measurement.

Working principle: detect the resonant γ decays of properly detected target materials hit by a gamma beam with energy and bandwidth overlapping the selected nuclear level.

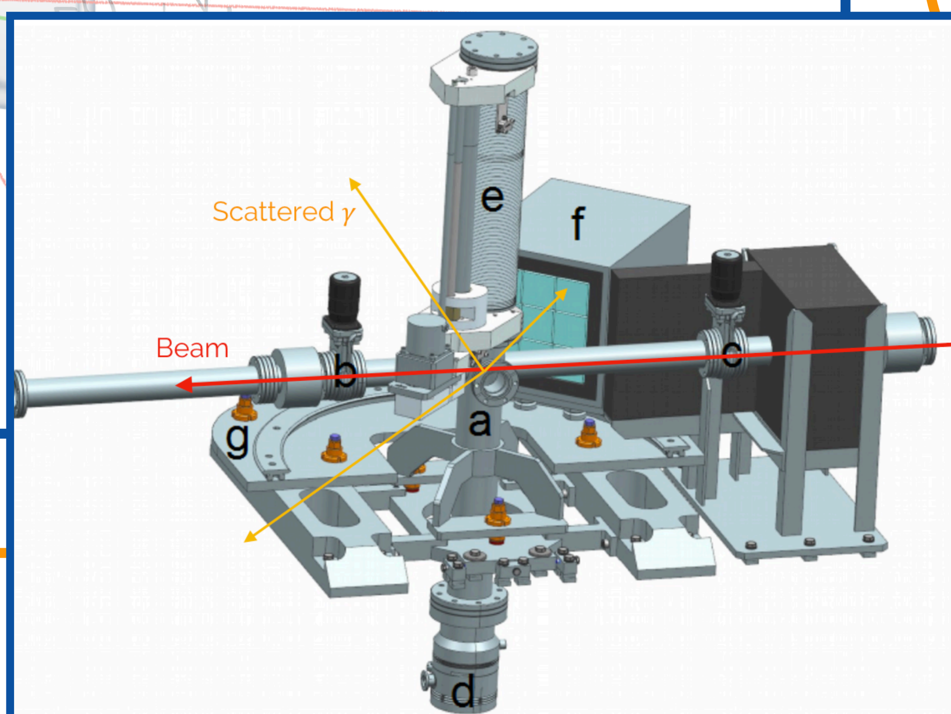
E = Er

Eb = Er

$$\sigma^0(E) = \pi\lambda^2 \frac{2J_1+1}{2(2J_0+1)} \frac{\Gamma^2}{(E-E_r)^2+\frac{1}{4}\Gamma^2}$$

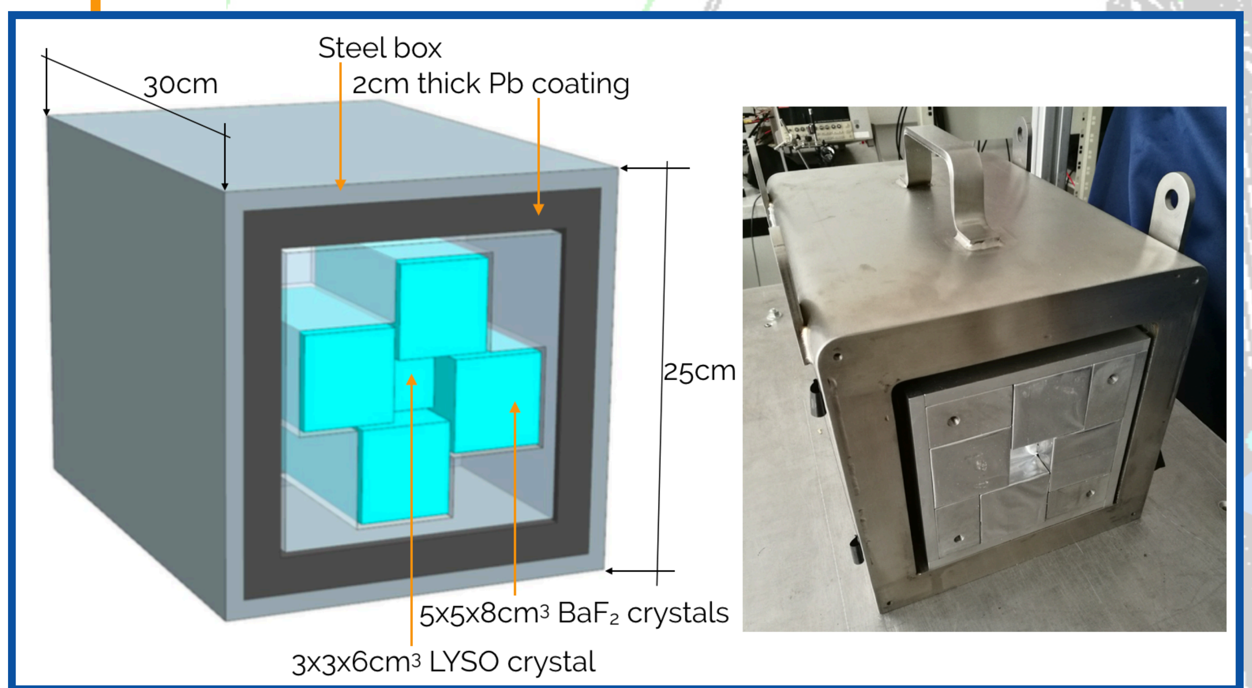
	^{6}Li	^{11}B	^{12}C	^{27}Al	^{27}Al
E_r(MeV)	3.56	2.12	4.43	2.21	2.98
σ_{int}(b*MeV)	8^*10^{-4}	5^*10^{-5}	1^*10^{-5}	2^*10^{-5}	4^*10^{-5}

Some nuclides with resonance levels between 2MeV and 3MeV suitable for low energy measurements in Eli-NP.



Layout of the NRSS: a) Al scattering chamber placed between two valves (b and c); d) vacuum pumps; e) target shifter; f) NRSS crystal detector; g) moving platform.

The **NRSS detector**[4] is made of a screened array of BaF_2 crystals surrounding a LYSO crystal. Two different designs have been implemented for low energy (0.2-3.5 MeV) and high energy (up to 19.5MeV) beam lines.



The design and final construction of the low energy line NRSS detector.

The system will operate in **two modes**:

(main) Fast Counting mode: Use the fast BaF2 response (<1ns) to count photons in resonance region. A dual readout technique is used to drastically reduce background from Pile-up;

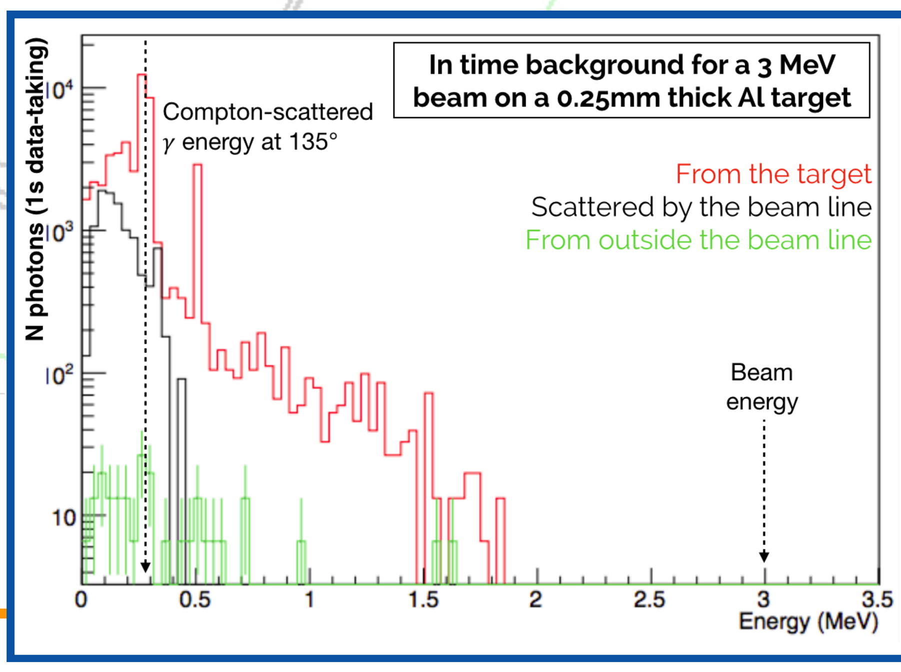
Crystal	$\rho(gr/cm^3)$	$\lambda(nm)$	$\tau(ns)$	$light_{output}(ph/MeV)$
BaF_2	4.88	220 310	0.88 600	12000
LYSO	7.2	420	45	32000

Energy mode: Use LYSO (slower but high resolution) and the BaF2s as Compton shields to perform a energy measurement.

Detailed **Background** studies have been performed using a dedicated **Geant4** simulation of geometry and realistic beams.

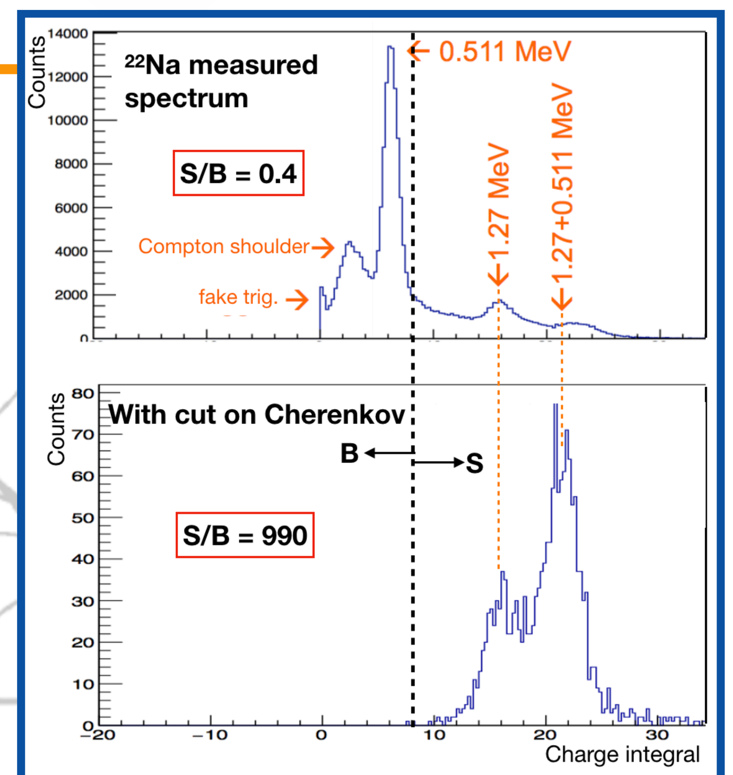
Main bkg source: Compton scattered γs at the NRS target → NRSS in backward region **(θ = 135°)** to move away from signal energy region.

Photons with energy comparable with signal showed from simulation to come out of time → **cut using fast BaF2 response.**

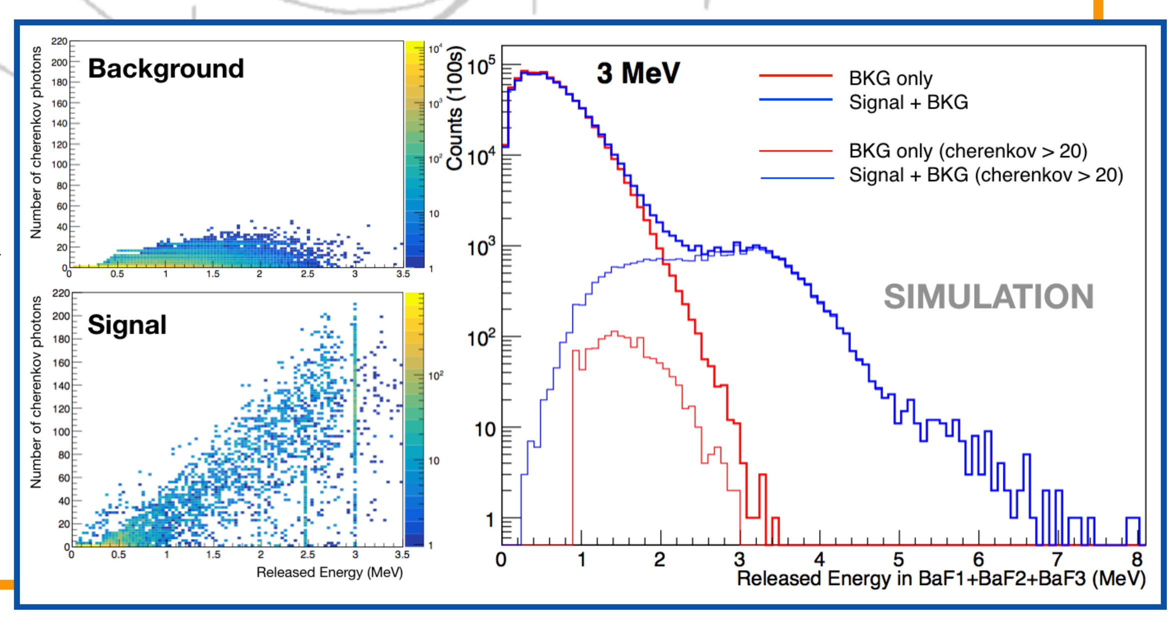


The pile-up rising from the big amount of Compton back-scattered photons make impossible to rely on an energy-only based rejection. For this reason a peculiar technique based on **dual readout of Cherenkov and Scintillation light** has been developed.

The power of this method have been measured with radioactive sources and investigated in simulation for usage with the ELI-NP beams.

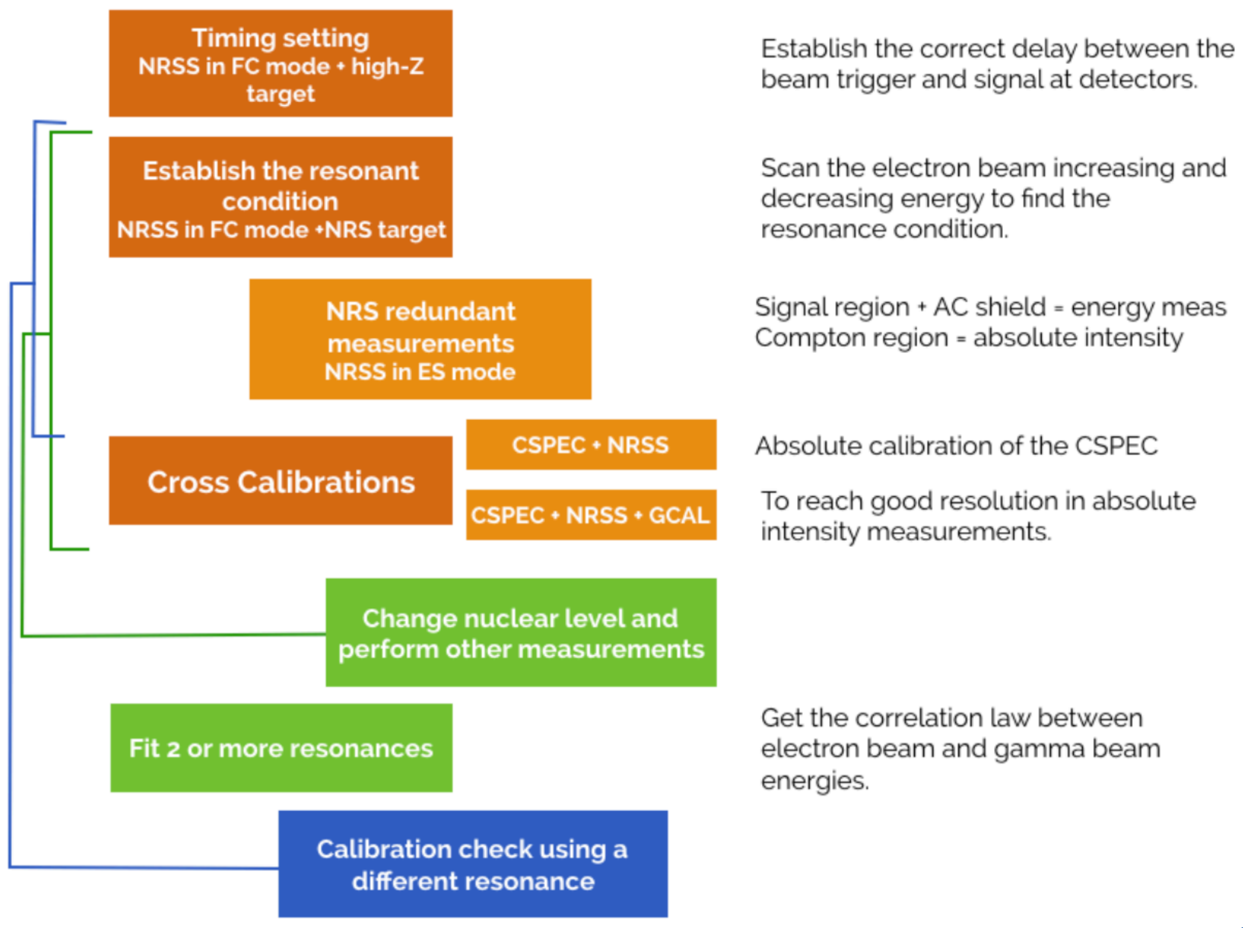


The rejection power of the dual readout technique has been tested with a ^{22}Na source.



Effects of the dual readout on the bkg and signal+bkg distributions. Left: Cherenkov light vs. Scintillation for bkg (incl. Pile up) and signal. Right: Energy distribution for bkg and signal+bkg with and with cut on cherenkov light.

The NRSS has a fundamental role in giving a **time and energy reference** to the whole beam characterization system, through an **inter-calibration procedure.**



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[4]M.G. Pellegriti et al., EuroGammaS gamma characterisation system for ELI-NP-GBS: The nuclear resonance scattering technique, Nucl. Instr. and Meth. in Phys. Res. A (2016).