A gamma calorimeter for the monitoring of the ELI-NP beam

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The ELI Project

- ELI: Extreme Light Infrastructure
- It is a large scale european project part of the ESFRI roadmap
- It will be devoted to the investigation of light–matter interactions
- Under construction, it will be implemented as a distributed facility over 3 sites

- ELI–NP – Romania
- Photonuclear physics and its applications

- ELI Beamlines – Czech Republic
- Production of short–pulse secondary sources driven by ultra intense lasers

- ELI Attoseconds – Hungary
- Production of laser driven secondary sources (extreme UV and X–rays) of ultra–short time duration

ELI–NP: Extreme Light Infrastructure–Nuclear Physics

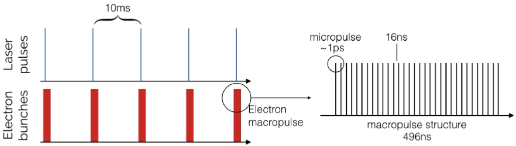
- ELI–NP will hosts two systems:
  - A very high intensity laser system with two 10 PW sources that combined can reach an intensity of 10^{23} W/cm^2
  - The Gamma Beam System (GBS)
    A very intense and monochromatic γ beam obtained by inverse Compton scattering of laser light off a high energy pulsed electron beam

- The expected performances will push the present limits and open a new field of investigation the "Nuclear Photonics"
- The GBS is being realized by the EuroGammaS Association lead by INFN
- Two energy lines are foreseen
  - Low energy: 0.2→3 MeV
  - High energy: 5→20 MeV

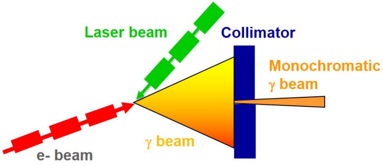
Gamma beam parameter	Value
Energy [MeV]	0.2 – 19.5
Spectral density [ph/s/eV]	$0.8 - 4\cdot10^4$
Bandwidth rms [%]	≤ 0.5
#Photons/shot within FWHM bdw.	$\leq 2.6\cdot10^5$
#Photons/s within FWHM bdw.	$\leq 8.3\cdot10^8$
Source rms size [μm]	10 – 30
Source rms divergence [μrad]	25 – 200
Peak brilliance [N_{ph}/s·mm^2·mrad^2·0.1%bdw]	$10^{20} - 10^{23}$
Pulse length rms [ps]	0.7 – 1.5
Linear polarization [%]	> 99
Macro repetition rate [Hz]	100
Number of pulses/macropulse	32
Pulse–to–pulse separation [ps]	16

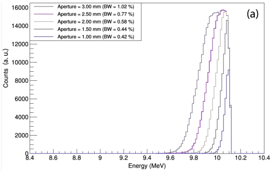
The ELI–NP γ beam

- The GBS will be operated in multibunches train mode at 100 Hz
- The single laser pulse will be recirculated 32 times to interact with the 32 e- bunches from the LINAC



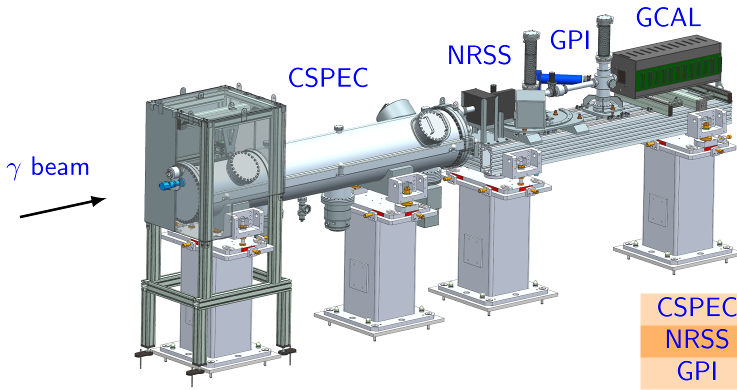
- The γ energy is tunable by adjusting the e^- beam energy
- In Compton backscattering the laser photons are scattered in a narrow cone around the e^- direction and the energy is amplified from eV$\rightarrow$MeV
- The radiation produced by Compton backscattering is not intrinsically monochromatic ➜ The γ energy is function of the emission angle
- The bandwidth can be controlled with proper collimation of the beam





The ELI–NP γ beam monitoring system

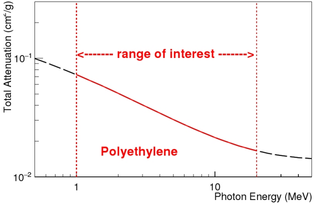
- CSPEC – Compton spectrometer (INFN–FI) ➜ Energy distribution
- NRSS – Nuclear Resonant Scattering Spectrometer (INFN–CT) ➜ Absolute energy calibration
- GPI – Gamma beam Profile Imager (INFN–FE) ➜ Spatial distribution
- GCAL – Gamma CALorimeter (INFN–FI) ➜ Average energy and intensity

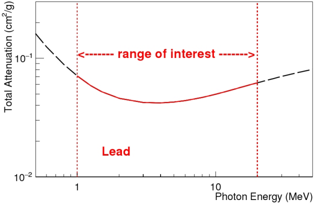


CSPEC	#136
NRSS	#338
GPI	#214

GCAL: Working principle

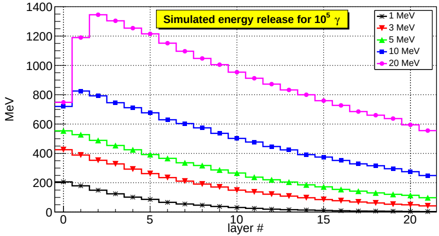
- The calorimeter has to provide a fast (➜ i.e. within a macro–pulse) measurement of the beam average energy and intensity
- Destructive measurement ➜ Cannot be used during normal data taking
  It is placed on a moveable platform
- GCAL is a sampling calorimeter with a low–Z absorber
- Low–Z absorber ➜ Dominated by Compton scattering at ELI energies
- High–Z absorber ➜ Pair production
- The Compton cross–section decreases rapidly with energy
- The longitudinal profile of the energy deposition retains the dependence on the beam energy





GCAL: Working principle

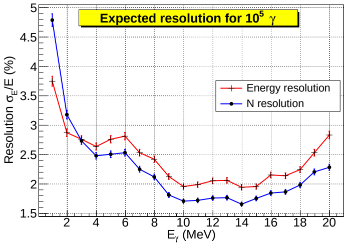
- The expected longitudinal profile of the energy distribution is parametrized by detailed Monte–Carlo simulations done with Geant4
- The average energy of the beam is determined by fitting the measured profiles against the simulated ones



- Low beam BW ➜ The beam intensity can be inferred from the measured total energy release

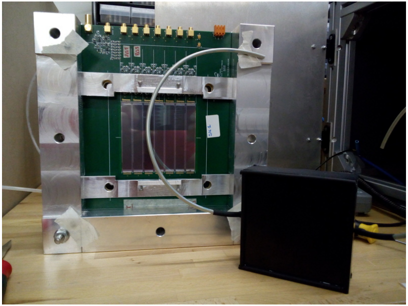
$$N_\gamma = \frac{\sum_{i=0}^{21} E_i^{meas}}{f(E_\gamma)E_\gamma}$$

- High beam intensity
  ➜ Low statistical error
  At nominal intensity in few seconds of operations the resolution is $\simeq 0.1\%$



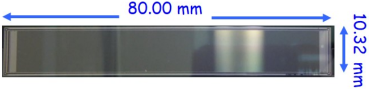
GCAL for the ELI–NP low energy line

- GCAL for the low energy ELI–NP beam is ready
- 22 layers:
  - 7 SiStrip pads with 128 strip each
  - FE board with 7 channels + SUM
  - PE target block with O-ring
  - Frame+spacers (and positioning bars)
- Ventilation system (dry air)
- LV/HV distribution systems
- Crate to hold and carry the device



Active layer

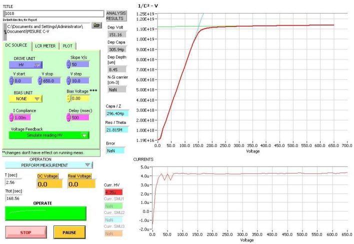
- Si Strip technology for the active layer
  - Fast response time
  - Radiation hardness
  - Linearity



- Cutting
- Cleaning
- Visual inspection
- C–V characterization
- Gluing 7 pads onto the read–out board
- The 7 pads have $\Delta C < 1$ pF

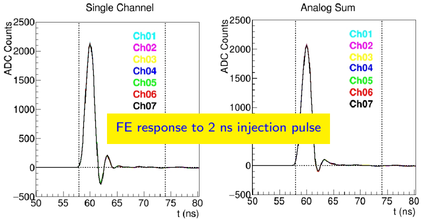
- Detectors developed by Hamamatsu
- Test structures of the CMS tracker
- Can sustain up to 100 kGy irradiation
- 128 strips all bonded together
- Depletion voltage: 200 V
- Operation voltage: 600 V

  ➜ Saturate the drift velocity and reduce the response time
- Large area but low capacitance ($\simeq$ 300 pF)

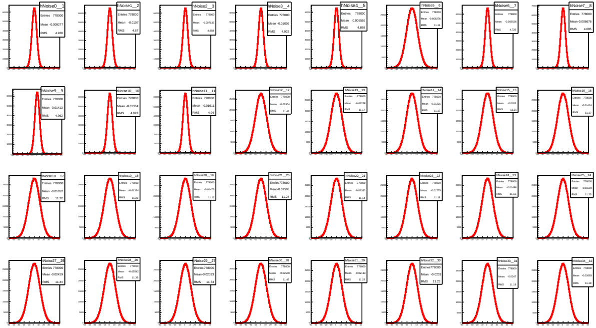


FE electronics

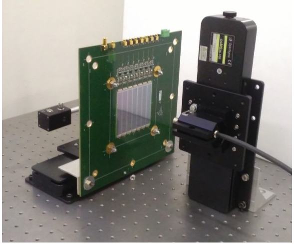
- Custom FE electronics
- Specifically designed to be very fast
- Individual read–out and analog sum
- The first two boards have connected the five central pads and the sum
- For the boards from 3 to 22 only the sum is acquired



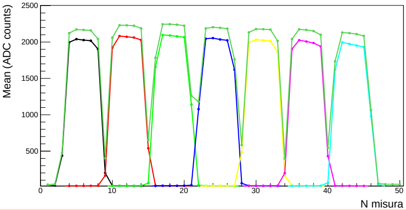
- Typical noise is 5 ADC ch for the single channel and the 12 for the sum



- Use an IR laser to test the time response of Si Strip devices
- Pulsed laser diode PicoQuant LDH–P
- IR Laser ➜ Can penetrate uniformly the whole depth of Si
- High Power ➜ Can reproduce the very large energy depositions expected at ELI–NP
- High Rate ➜ Can reproduce the same time structure of the ELI–NP beam
- Data Acquisition with CAEN digitizer V1742
- 1024 samples in a circular memory buffer
- To acquire the whole ELI–NP macro–pulse a 1 GHz sampling frequency will be used

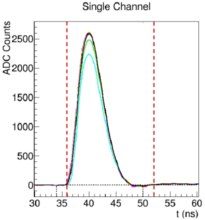


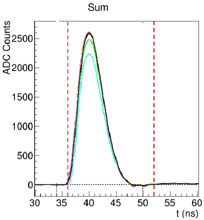
- λ=1060 nm
- MaxPower: 21 mW
- Rate: single→80 MHz
- FWHM $<$ 100 ps



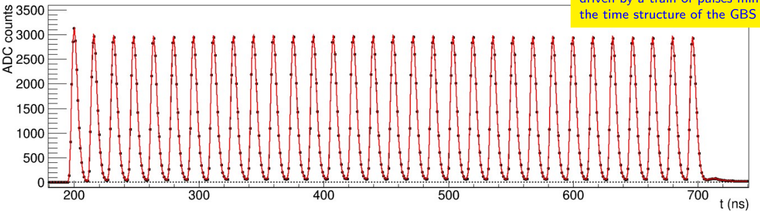
Time Response

- Very fast response of detector+electronics
- Well inside the 16 ns boundary
- These tests prove the capability of our system to cope with the demanding time structure of the ELI–NP beam



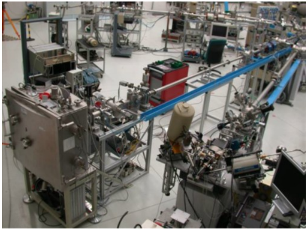


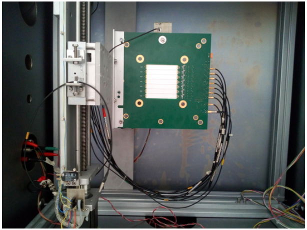
Detector response when the laser is driven by a train of pulses mimicking the time structure of the GBS



Energy Response

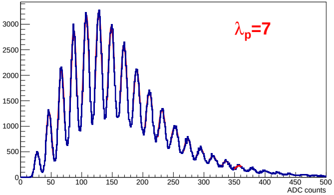
- The energy deposition in Si detectors was tested at DEFEL (ELectrostatic DEFlector) at the LABEC facility in Firenze
- Electrostatic chopper which produces a pulsed beam:
    - Particles: p
    - Short pulses: 0.2→1 ns
    - Adjustable average number of p/pulse
    - Energy: E_p=3 MeV
- Typical spectra contain equally spaced peaks at energies multiple of E_p

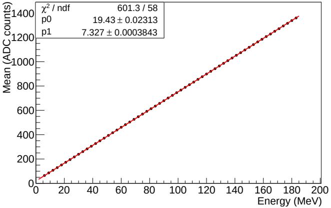


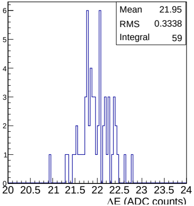


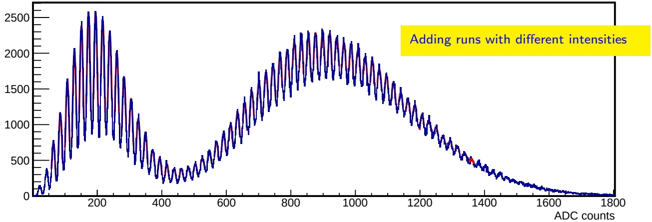
Energy Response

- Fit the spectrum with a Poisson convoluted with n gaussians
- Extract λ_p, mean$_i$, σ_i
- System linearity tested up to 200 MeV
- Energy calibration using ΔE









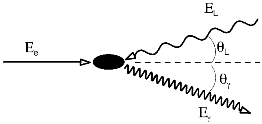
Summary

- A low–Z sampling calorimeter has been realized to meet the extraordinary properties of the ELI–NP γ beam
- It will measure the average energy and intensity of the beam exploiting the energy dependence of the γ absorption cross–section
- The active layer is made by Si detectors read out by a custom FE electronics
- Test performed with an IR laser have shown the capabilty of the device to cope with the time structure of the ELI–NP beam
- Test performed at the LABEC facility in Firenze show the excellent linearity of the device in the energy range relevant to ELI–NP beam

Additional Material

Gamma Beam System

$$E_\gamma = 2\gamma_e^2 \frac{1+cos\theta_L}{1+(\gamma_e\theta_\gamma)^2 + a_0^2 + \frac{4\gamma_e E_L}{m_0c^2}} E_L$$

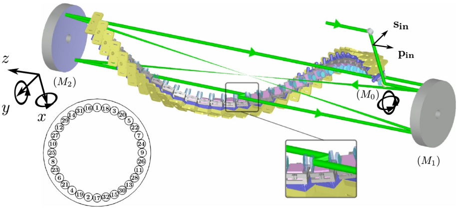


- The recirculator is needed to match the time structure of the e$^-$ beam with the laser one
- Mirror system to provide 32 collisions between the laser light and the e^- micro–bunches
- The laser pulses are focussed on the same IP
- Same incident angle

- For head–on collisions and the back–scattered γ in the e$^-$ direction

$$E_\gamma \simeq 4\gamma_e^2 E_L$$

- $\gamma_e = 1/\sqrt{(1-\beta^2)}$ and E_L energy of the laser photons



Absolute energy calibration with the NRSS

- NRSS is one of the four detectors which form the the monitoring system of the ELI–NP γ beam
- It detects the resonant condition between the beam energy and selected, well known, nuclear levels of given target nuclei
- ➜ Can provide an absolute energy calibration for GCAL and CSPEC
- External shell of BaF_2 crystals for fast counting to detect the establishment of the resonant condition
- Inner core made by a LYSO crystal for precise identification of the resonant energy (in this configuration the surrounding BaF_2 crystals act as Compton shield)