Tests of undoped CsI matrix with an extremely low intensity electron beam

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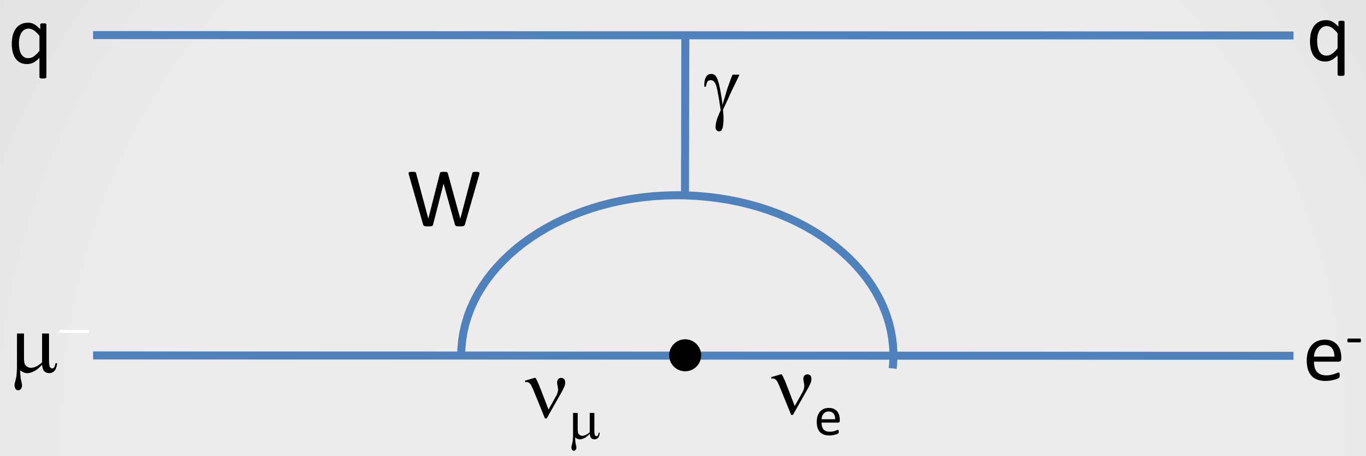
Outline

1. Introduction: CLFV and Mu2e experiment
2. Motivation
3. Extremely low intensity electron beam
4. Tests results
5. Conclusion

CLFV in the Standard Model



- Muon-electron conversion strictly speaking, forbidden in the SM
- Even in ν-SM, extremely suppressed (rate $\sim \Delta m_\nu^2 / M_w^2 < 10^{-50}$)
- However, many NP models predict rates observable at next generation CLFV experiments

What is Mu2e?

- Precision search for neutrinoless conversion of a muon to an electron, where muon is bound in atomic orbit on aluminum

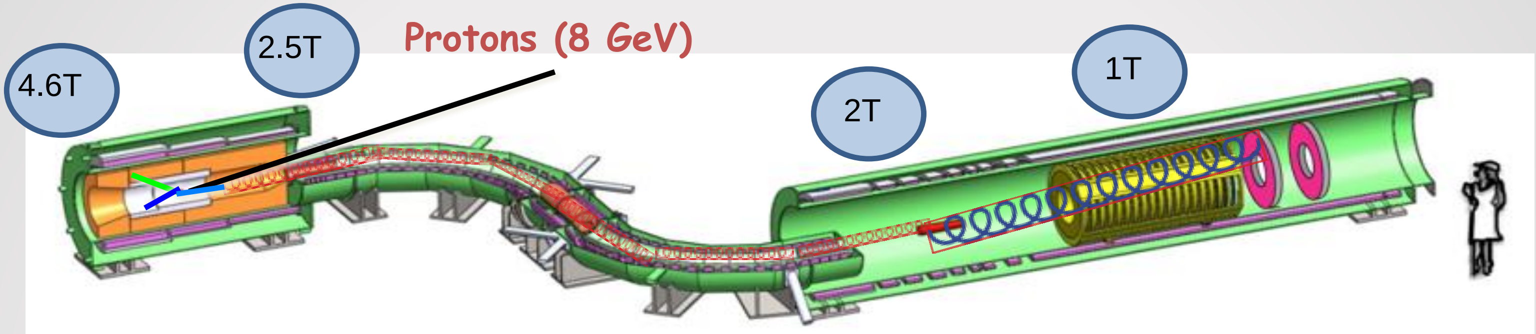
$$R_{\mu e} = \frac{\mu^- + {}^{27}_{13}Al \rightarrow e^- + {}^{27}_{13}Al}{\mu^- + {}^{27}_{13}Al \rightarrow \text{nuclear capture}}$$

- Example of Charged Lepton Flavor Violation (CLFV)
- Related but complementary to

$\mu^+ \rightarrow e^+ + \gamma,\ \mu^+ \rightarrow e^+ + e^+ + e^-,\ \tau \rightarrow e + \gamma\ ,\ \tau \rightarrow \mu + \gamma,\ \tau \rightarrow 3e....$

- LFV is observed experimentally (neutrino oscillations), but so far CLFV has not been seen
- Mu2e sensitivity goal x10000 improvement over previous best measurement

The Mu2e experiment



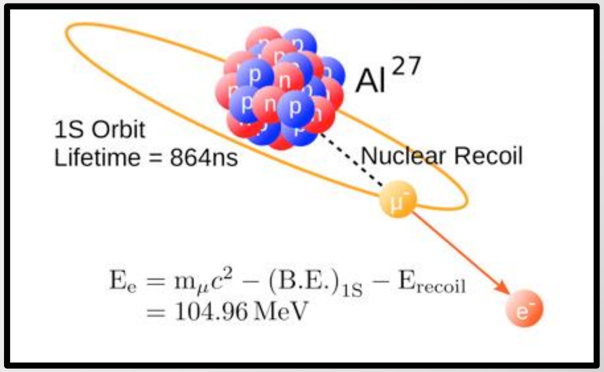
Production & Transport Solenoids

Production, selection and transport of low momentum muon beam stopped at 10 GHz on Al target
~ 10^{20} protons on production target
~ 10^{18} stopped muons on Al target

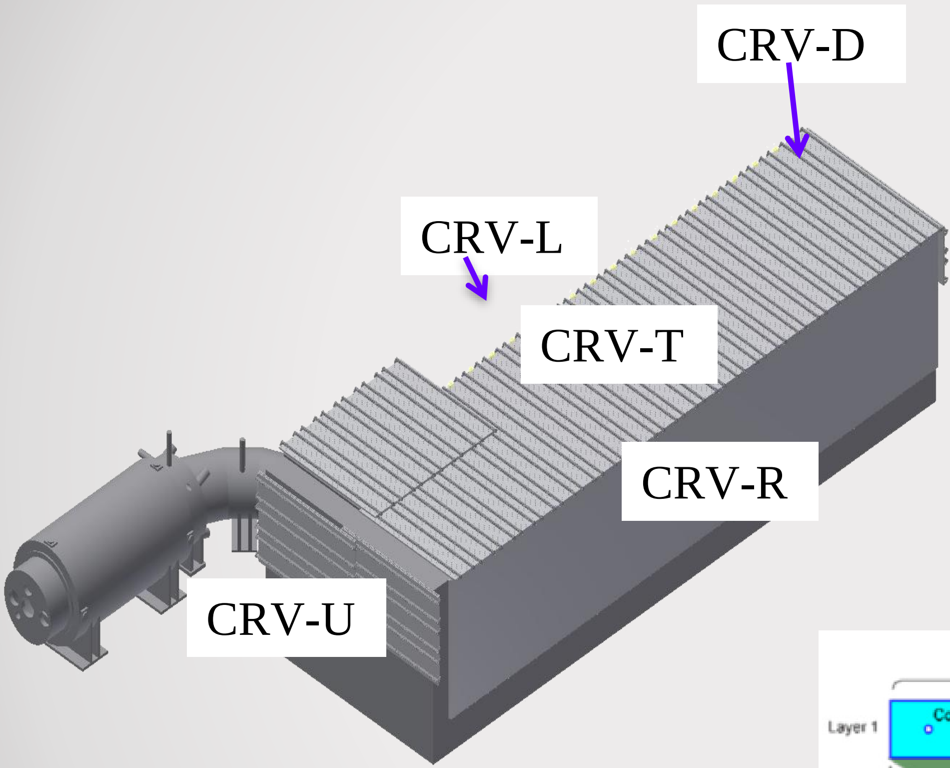
Detector Solenoid

- Muon capture on Al target
- High precision Tracker (180 keV res. at 105 MeV/C)
- **EM Calorimeter**
- **Cosmic Ray Veto system**

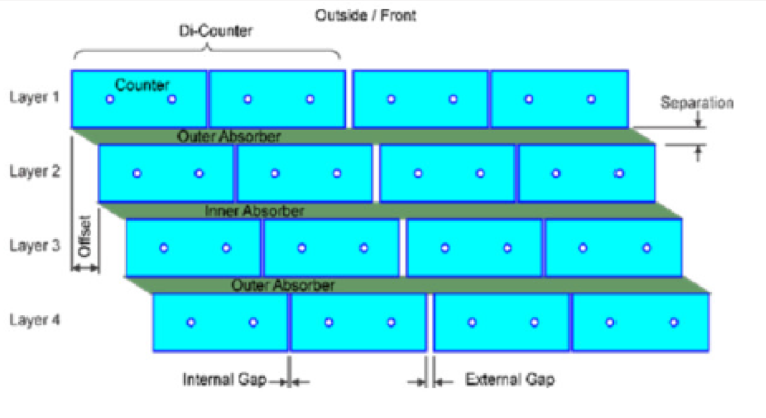
- Beam of low momentum muons stopped in Al target
- Muons trapped in orbit around the nucleus
- mN→*e*N events with signature → **single mono-energetic electron**



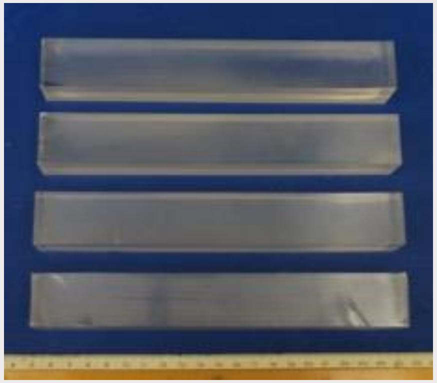
Mu2e Cosmic Ray Veto

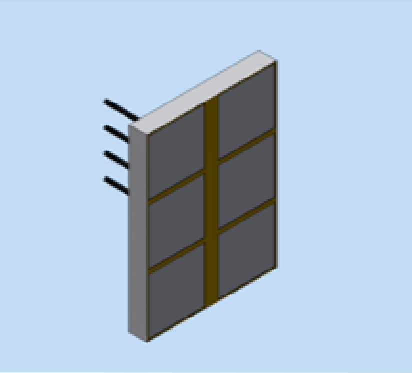


- Four layers of extruded plastic scintillators (~5000 counters)
- Fiber/SiPM readout (*neutron damage is an issue 1kHz neutrons/cm²*)
- Al and concrete shielding (*10^{10} neutrons/cm²/s from the stopping target*)

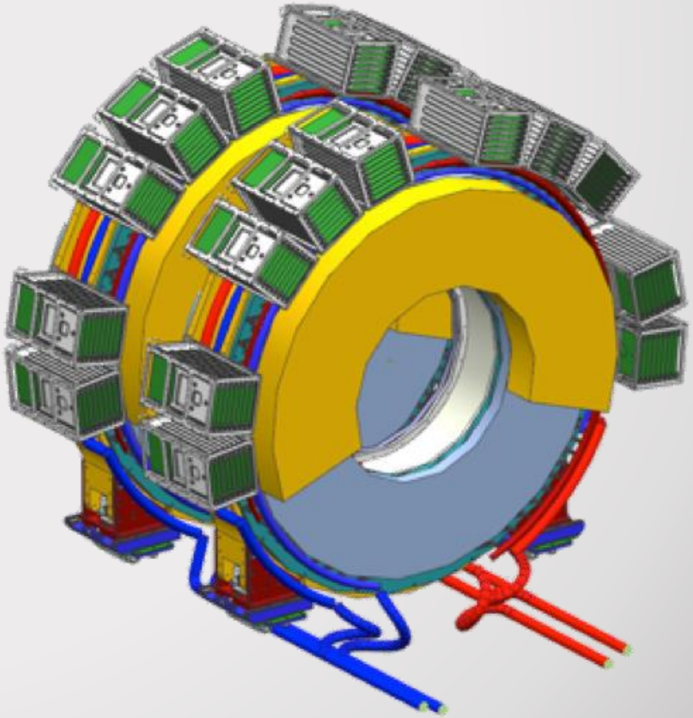


Mu2e electromagnetic calorimeter



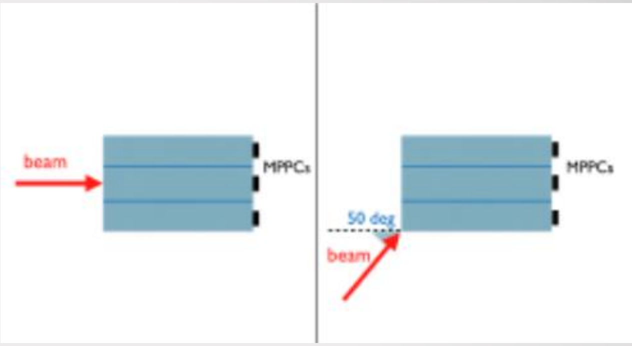


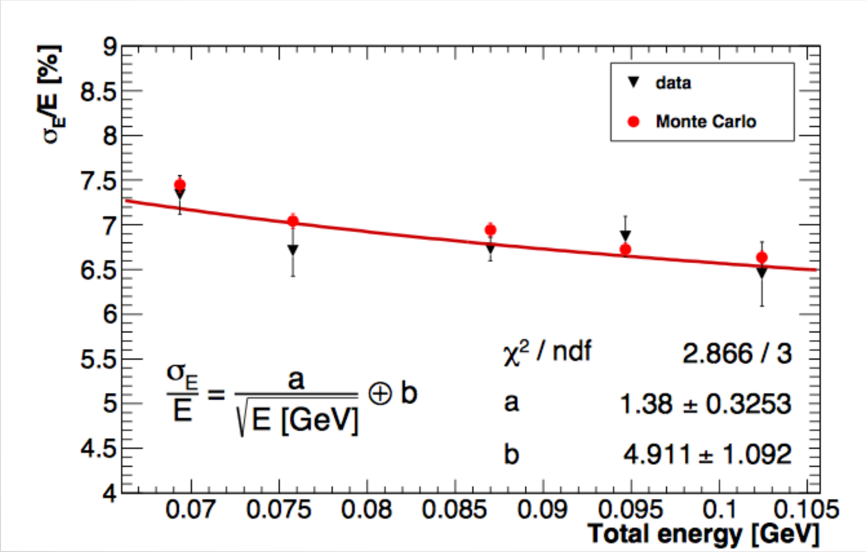
- Two annular disks separated by half a "wavelength" (70cm) of electron's helical path
- Maximize probability to hit at least one disk
- 0.5 ns time, 5% energy, 1 cm position resolution measurement independent of straw tracker
- Provides particle ID for track rejection
- Seed for tracking algorithm / trigger
- Each disk contains 674 undoped CsI 34x34x200 mm^3 crystals read out by SiPMs

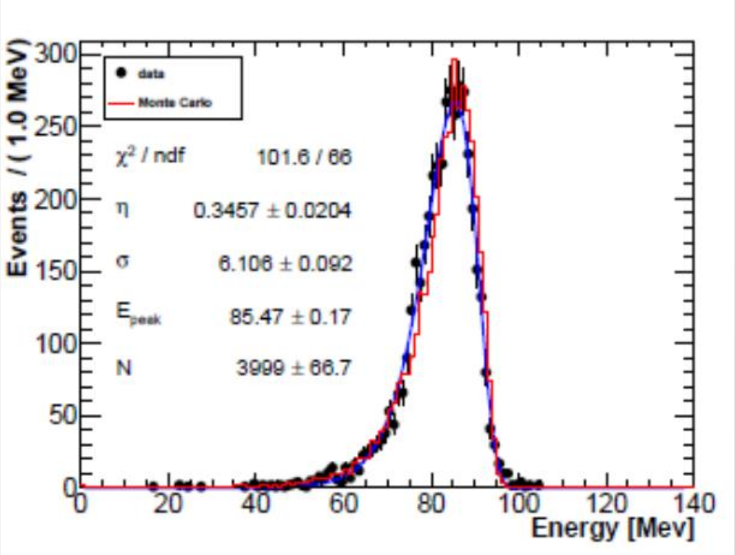


Tests of CsI matrix at LNF, Frascati

- Small prototype tested @ BTF (Frascati) in April 2015, 80-120 MeV secondary e^- beam
- 3×3 array of 30×30×200 mm^2 undoped CsI crystals coupled to UV-extended Hamamatsu SiPM array (12x12) mm^2 with Silicon optical grease
- DAQ readout: 250 Msps CAEN V1720 WF Digitizer







σ_E ~ 6.5% at 100 MeV

O.Atanova et al., 2017 JINST 12 P05007

LINAC of Yerevan Physics Institute (1)

Number of accel. sections	**4**
Total linac length	25 m
Field frequency	2.7973 GHz
RF power units, number, type	3 klystrons
RF power pick per unit	20 MW
Rep. rate	50 Hz
Currently output beam energy **Can be upgraded to**	10 – 50 MeV 75 MeV
Average beam intensity without collimation	10 μA
Bunch length	≤ 35 ps
ΔE/E (FWHM), measured with magnetic energy analyzer	≤ 2% with collimation at ordinary average beam currents I = 0.2 – 2 μA

Beam Pulse Structure

No. of bunches/pulse: *2800*

No. of particles/bunch: $5x10^7$

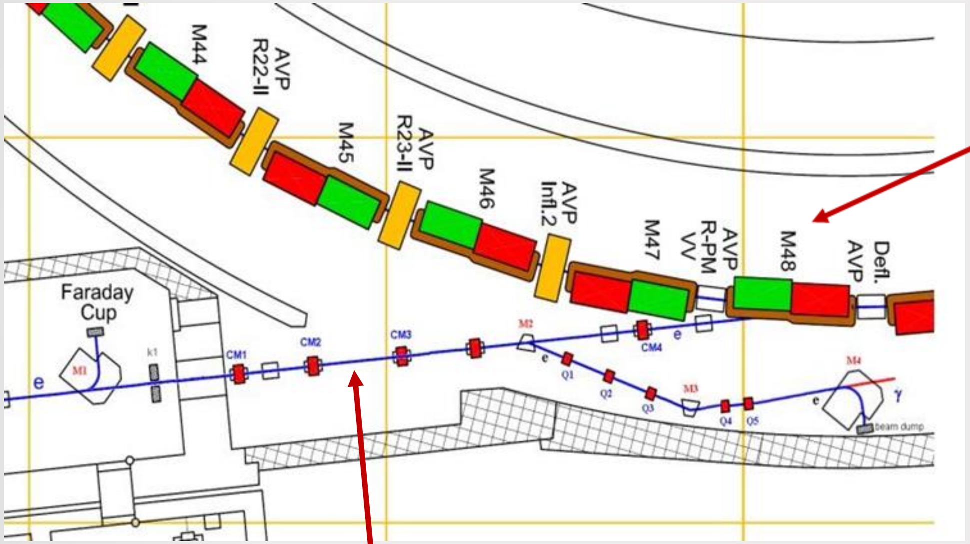
No. of particles/s: $50x2800x5x10^7 \approx 7x10^{12}$

Linear electron accelerator (linac) of Yerevan Physics Institute (currently A. Alikhanyan National Laboratory) designed as injector for synchrotron ARUS.

It was built in the 60s and partly renovated in the 80s and contains four accelerating sections.

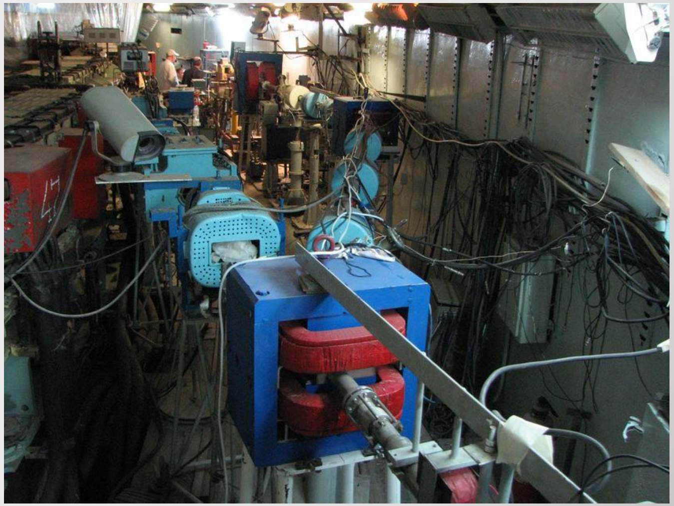
Currently, the complex of the linac and beam transport system makes it possible to carry out the work with the beam in the energy range from 10 to 50 MeV, with an intensity from a few electrons per second to 10 μA average current (without collimation).

LINAC of Yerevan Physics Institute (2)



Electron synchrotron ARUS,
up to 6 GeV

Linac LUE-75



Extremely low intensity beam

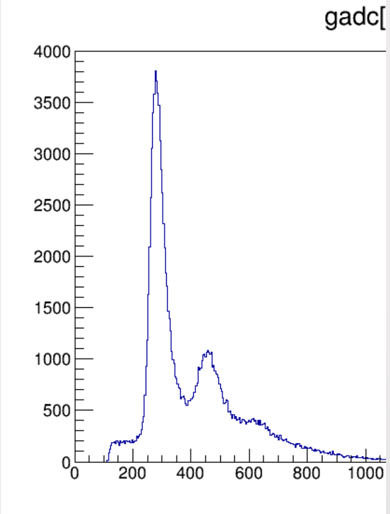
Linac designed to operate at 50 Hz, ~ $7x10^{12}$ electrons/s
Required measurement of matrix response on single electrons!

At first electron beam was transported through the beam line with high intensity. It allowed to control the beam intensity with a Faraday cup and check the beam position.

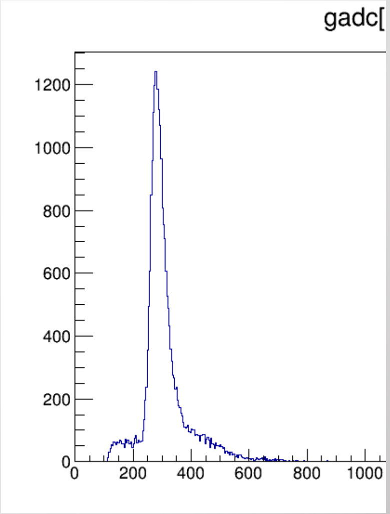
Intensity was decreased by different ways:

- by lowering high voltage on the cathode;
- by de-focusing and than collimating the beam;
- by decreasing temperature of the cathode.

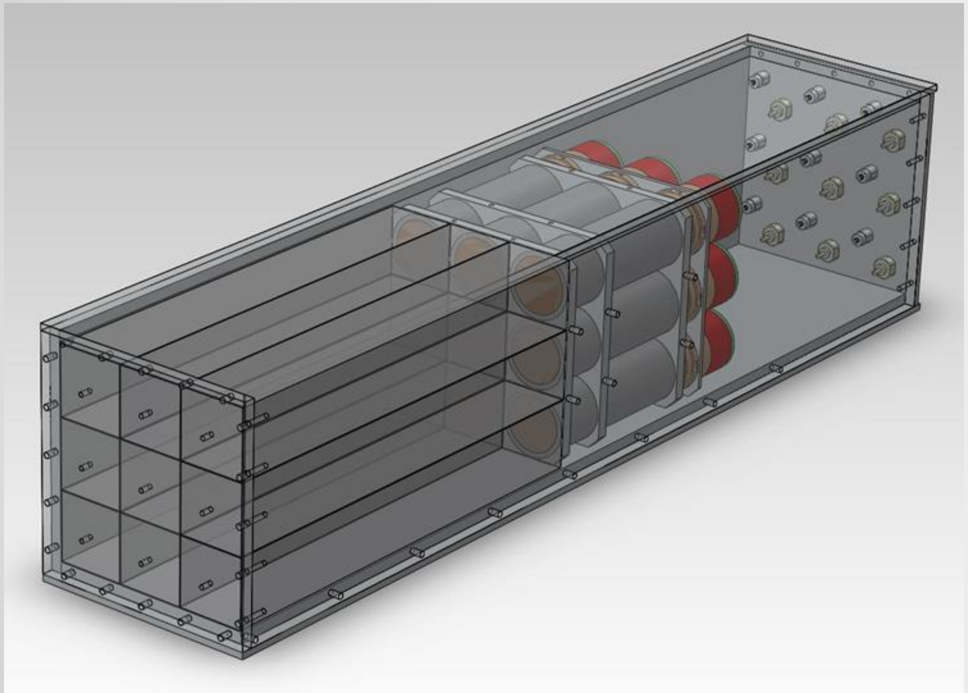
Rate ~30 e/s



Rate ~ 10 e/s

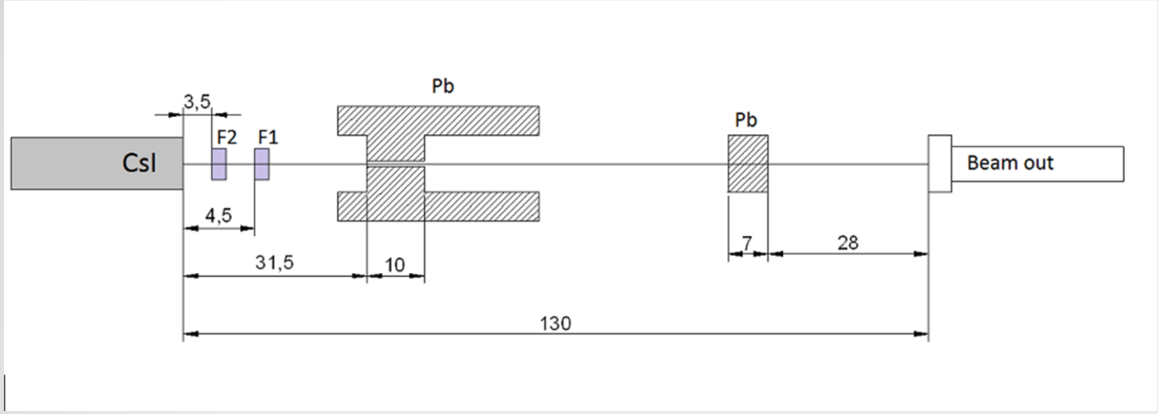


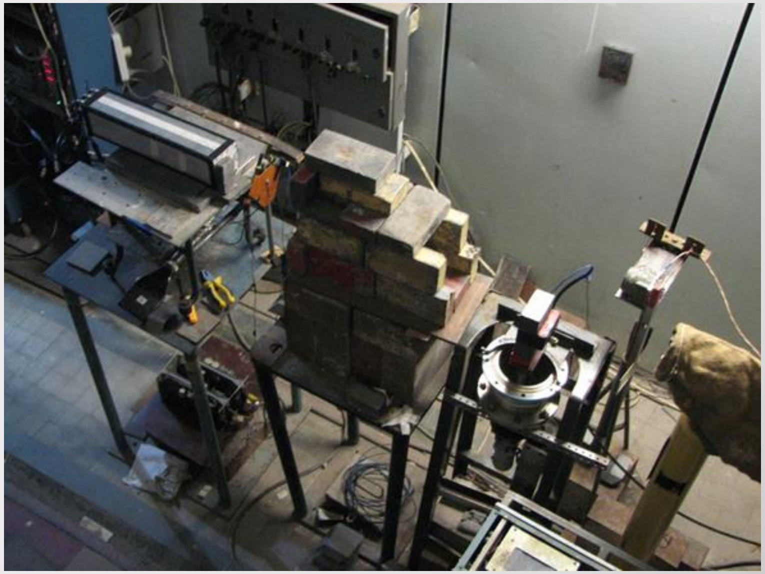
Test box



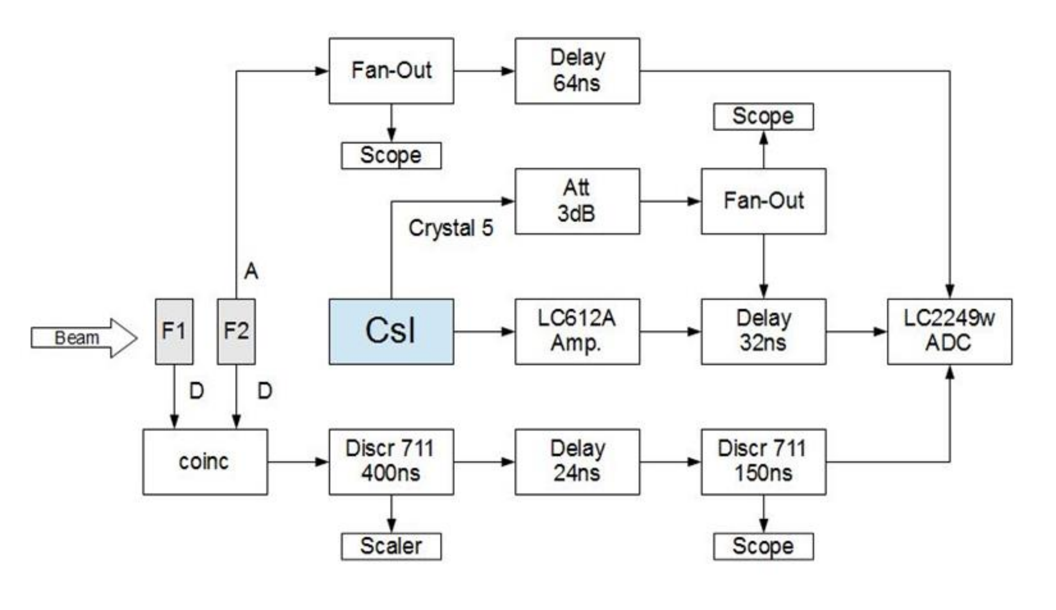
- 9 crystals of undoped CsI, 3x3x20 см
- Wrapped with Tywek
- Photo sensors: FEU-85

Geometry and position



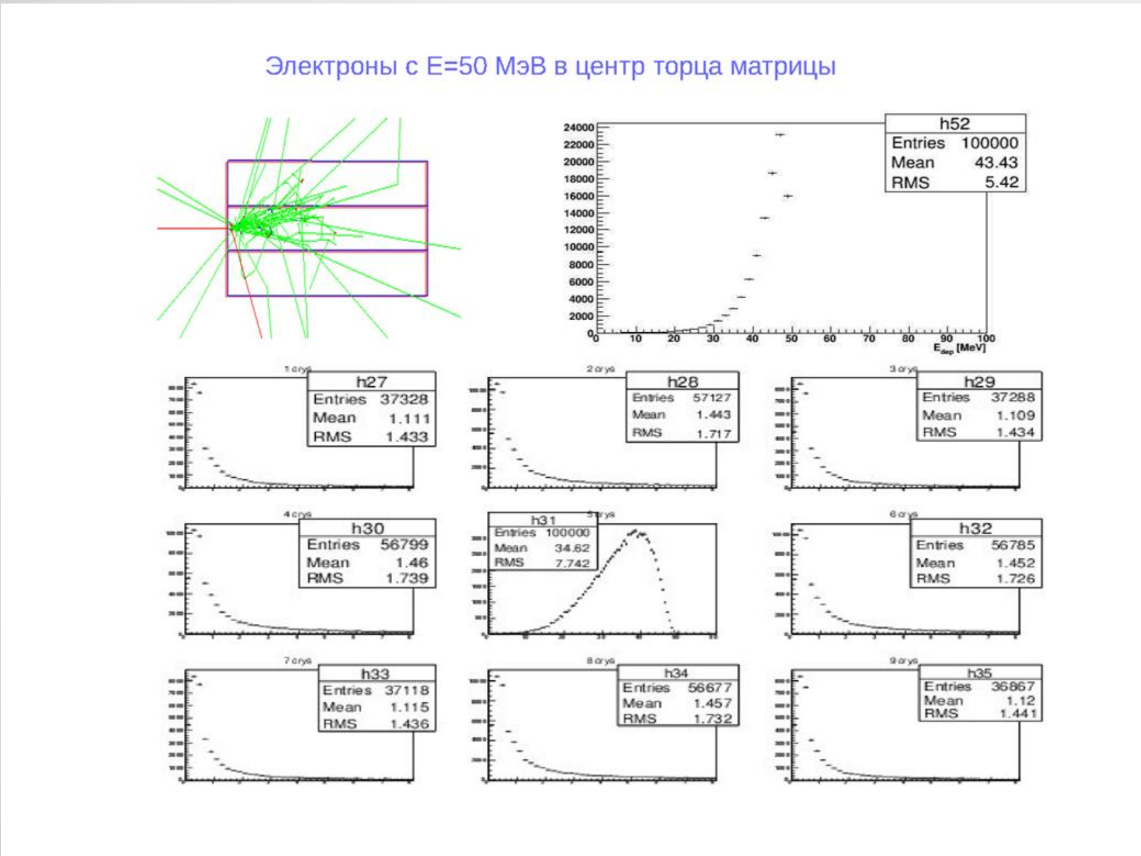


The block diagram of the setup



- Finger counters F1 and F2 provide the "gate" signal for ADC (150 ns)
- The central crystal signal goes to ADC input through 3 dB attenuator
- Signals from other 8 crystals are amplified by LeCroy612A (x10) and go to the ADC inputs
- Analog signal from the F2 feeds the ADC input as well to control electron multiplicity via energy loss in the counter

Simulated matrix response on 50 MeV beam

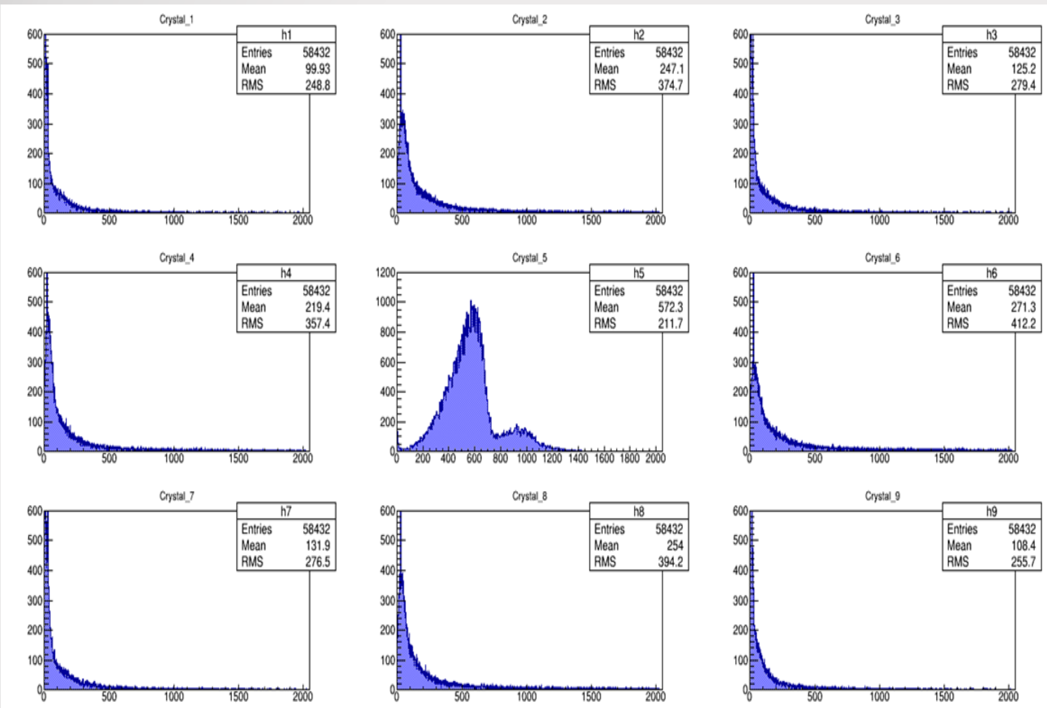


Sum of all 9 crystals

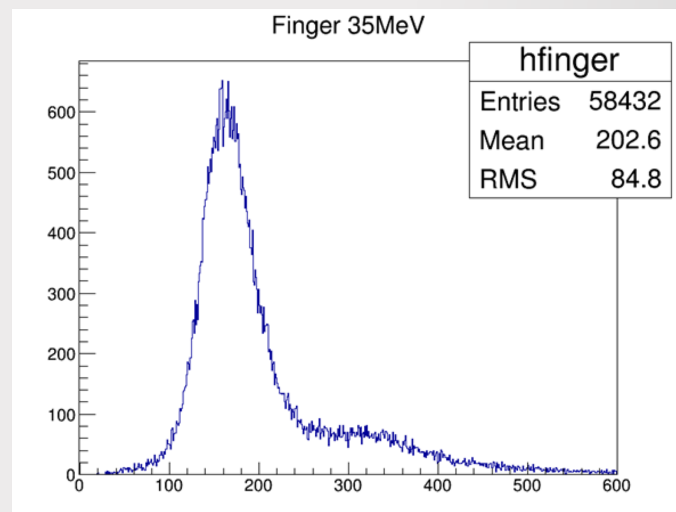
Response of each individual crystal on the 50 MeV electron beam pinging in the matrix center

Matrix response on the 35 MeV beam

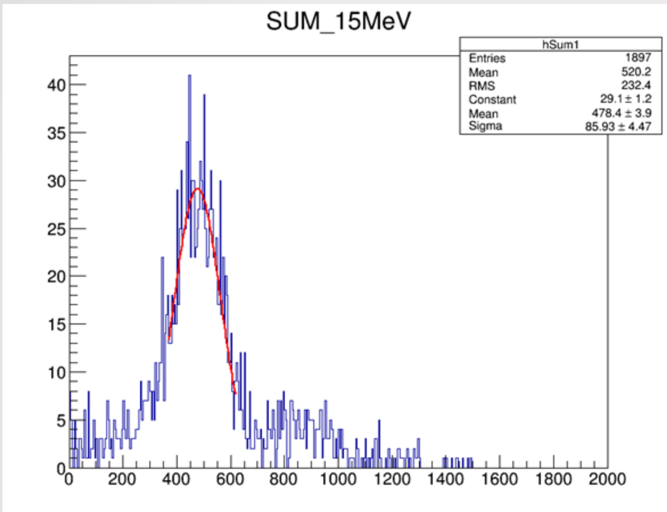
Individual crystals response on 35 MeV beam

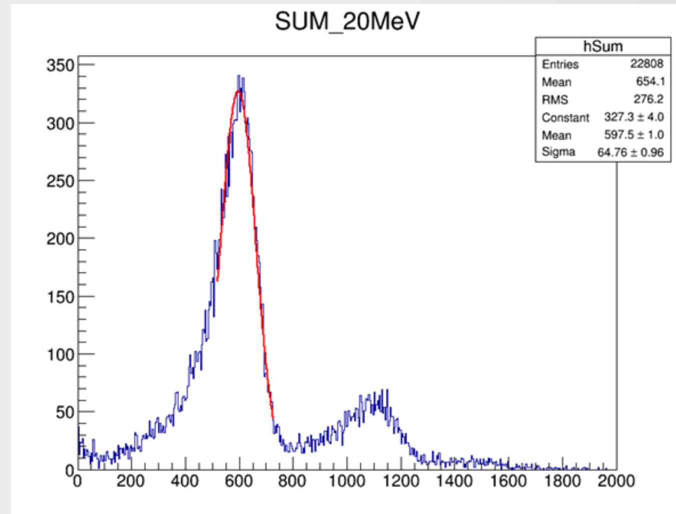


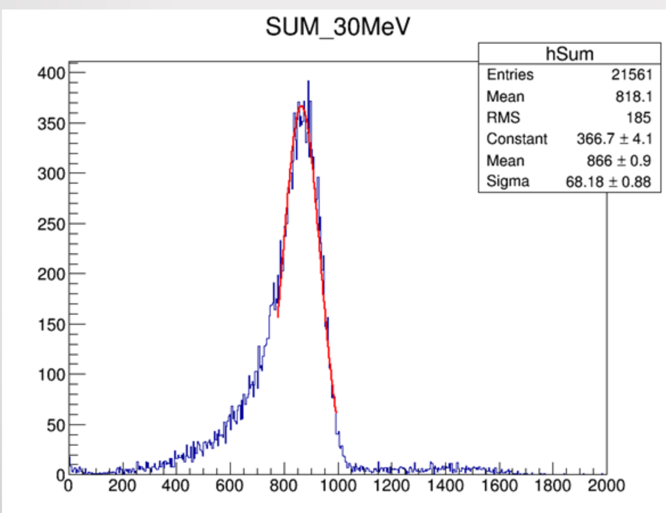
Electron energy loss in the trigger counter

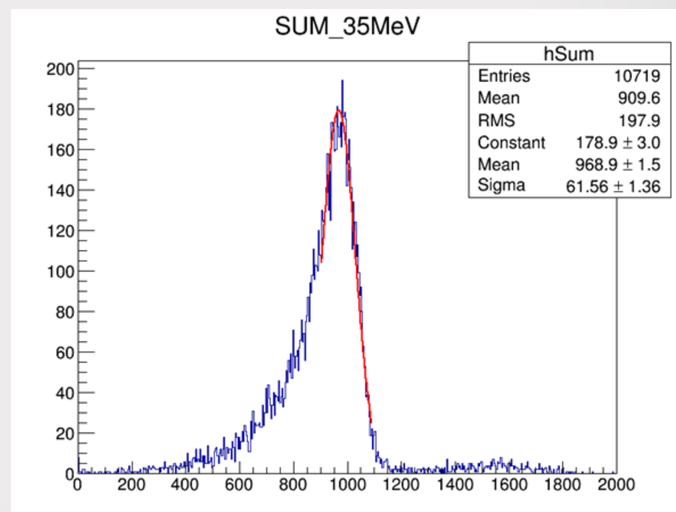


Matrix response on 15-35 MeV energy range

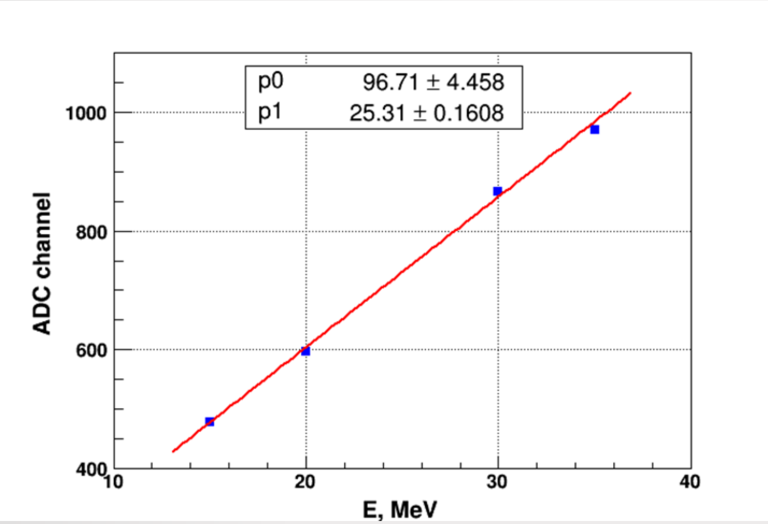


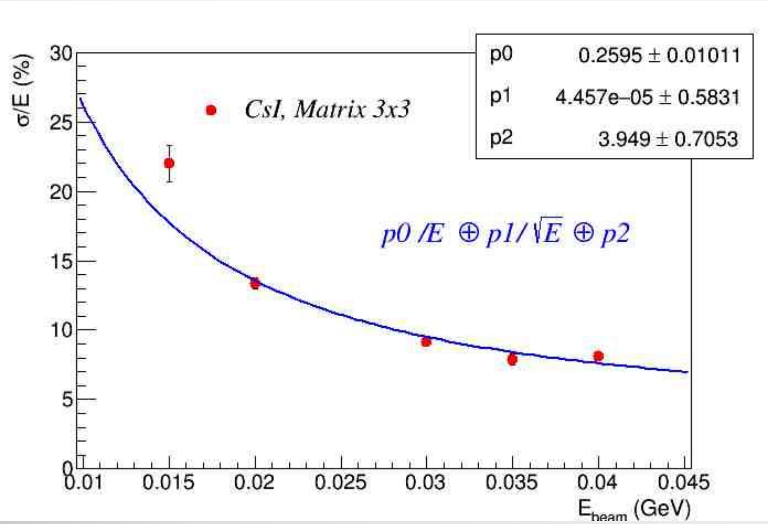


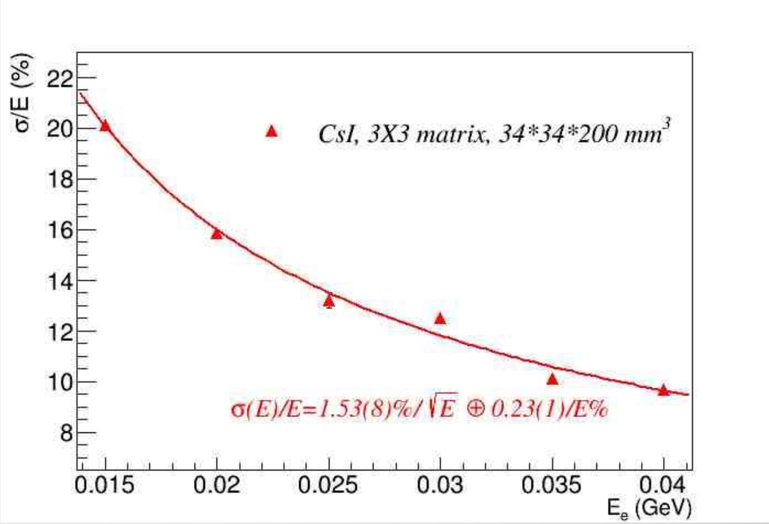




Linearity and energy resolution

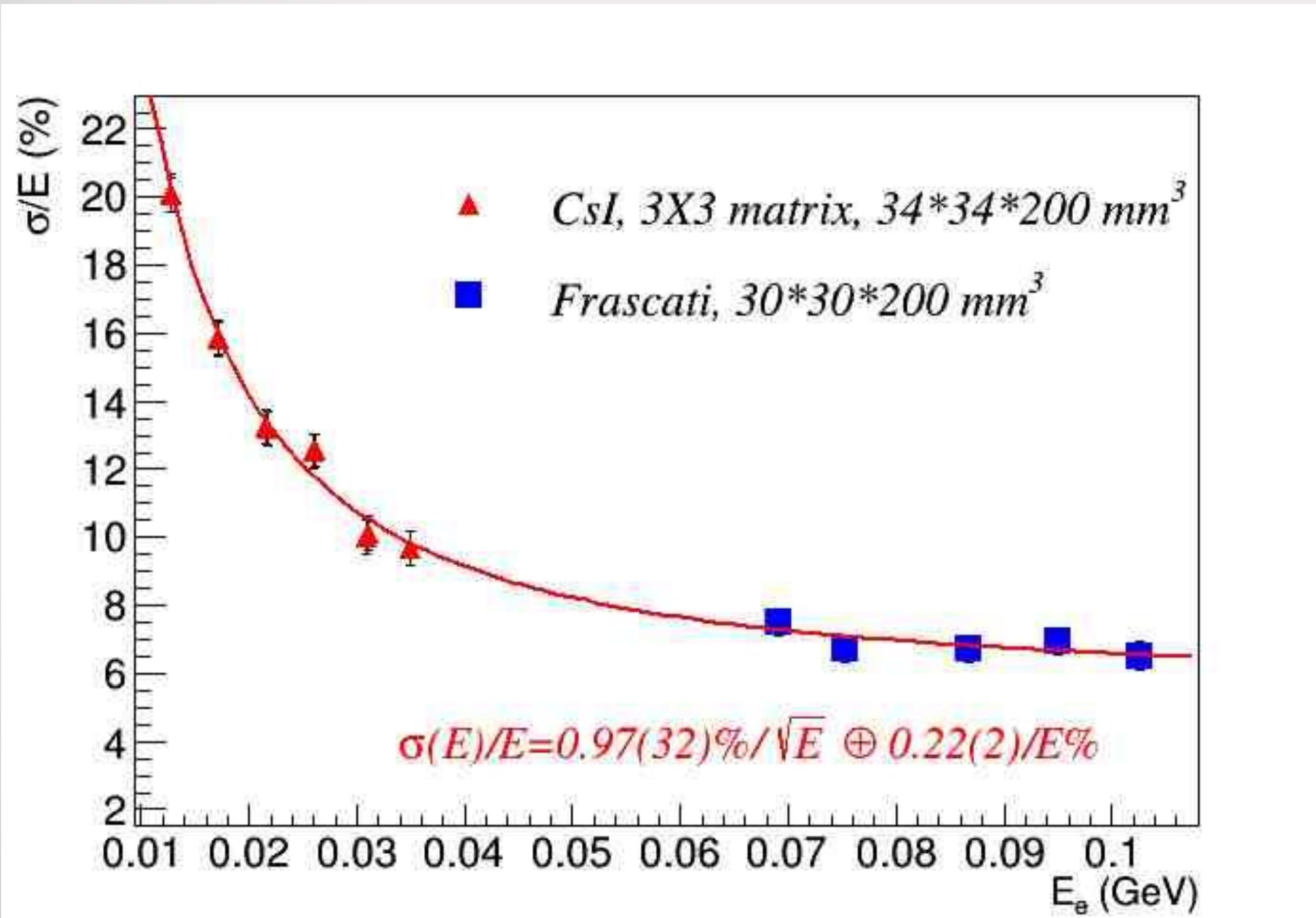




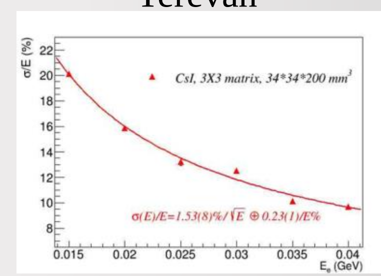


Combined Frascati + Yerevan data

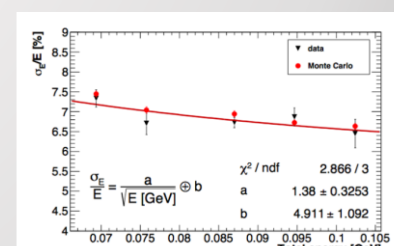
The results of Frascati and Yerevan measurements are consistent with each other



Yerevan

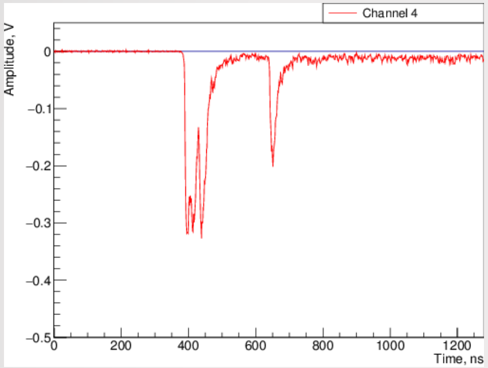


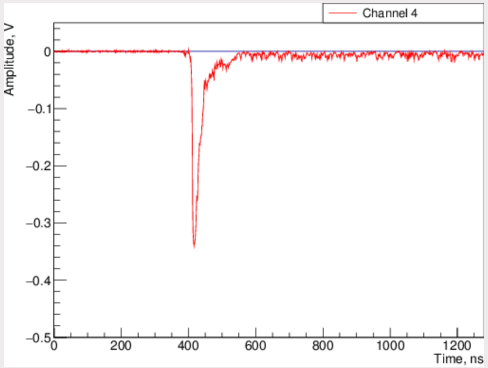
Frascati

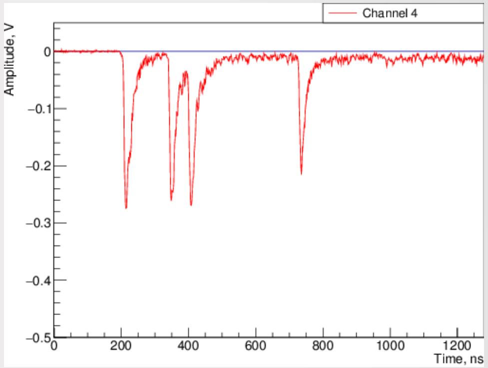


Future plans and prospects

- Recently we took data with DAQ based on FADC. That will allow us to better understand the beam







- Experts at Yerevan Physics Institute plan to increase the LUE-75 linac energy to 75 MeV very soon
- It is expected that electron accelerator Linac-200 will be launched at DLNP, JINR in the near future

Conclusion

- Test runs at Yerevan Physics Institute (Yerevan, Armenia) demonstrated possibility to obtain an extremely low intensity electron beam (a few tens of electrons per second) for testing of crystals in the energy range 10-50 MeV (however, better beam tuning required).

- 3x3 matrices of undoped CsI crystals (crystals 30x30x200 mm and 34x34x200 mm) were tested in the 15-40 MeV energy range. Crystal arrays demonstrated good linearity of energy response.

- Energy resolution results obtained for energy range of 15-40 MeV are consistent with our data taken in Frascati in the energy range 80-120 MeV

Acknowledgments

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