Irradiation tests at HZDR

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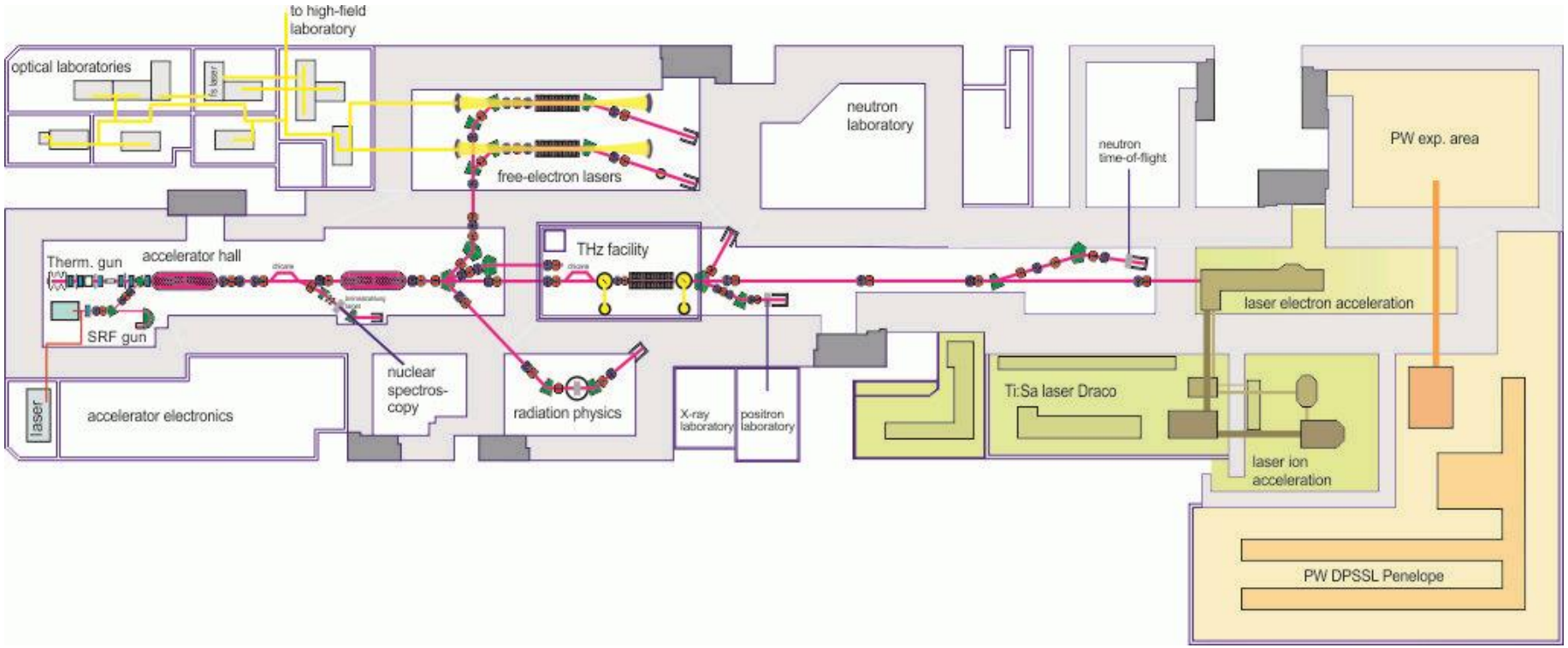
Helmholtz-Zentrum Dresden-Rossendorf

MUSE meeting, FERMILAB (Chicago), Oct 22, 2018

The ELBE radiation source

The ELBE “Electron Linac for beams with high Brilliance and low Emittance” delivers multiple secondary beams.

- $E_e \leq 40$ MeV; $I_e \leq 1$ mA; Micropulse duration 10 ps $< \Delta t < 1$ µs



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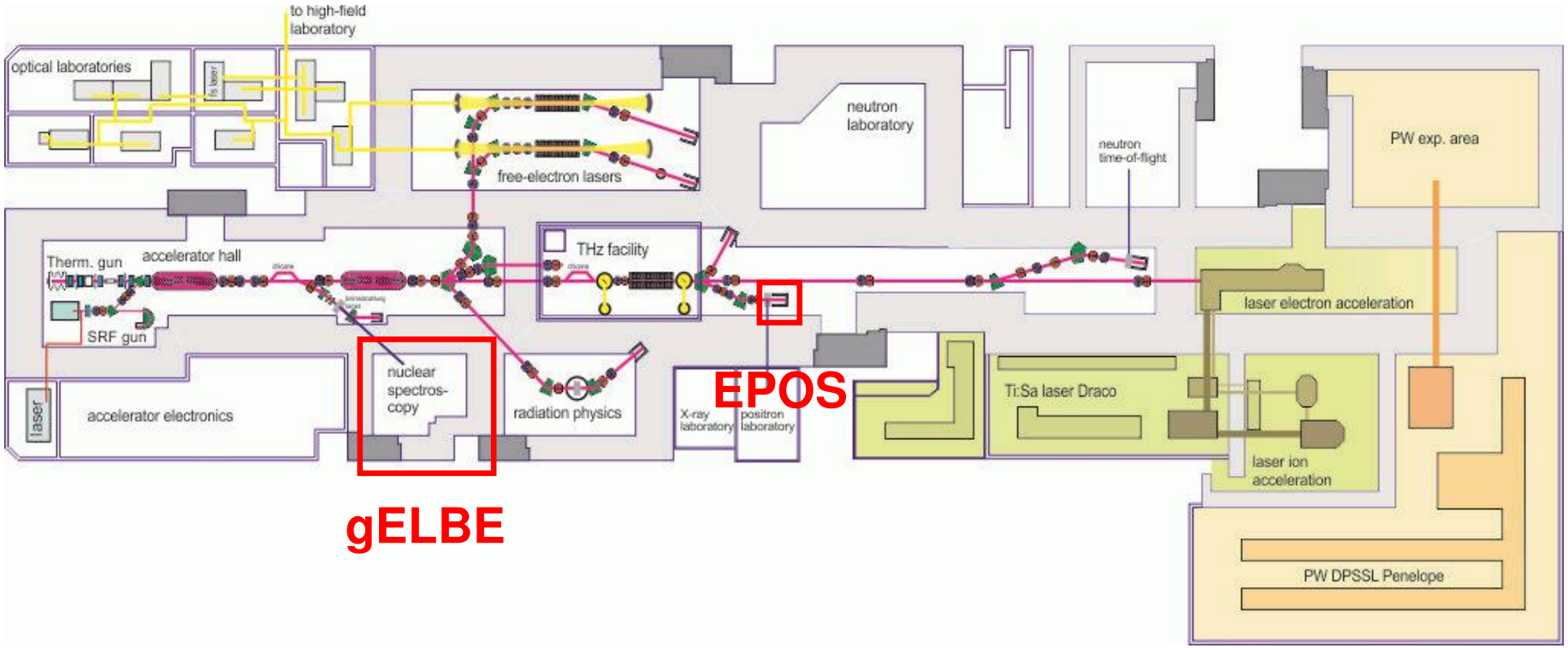
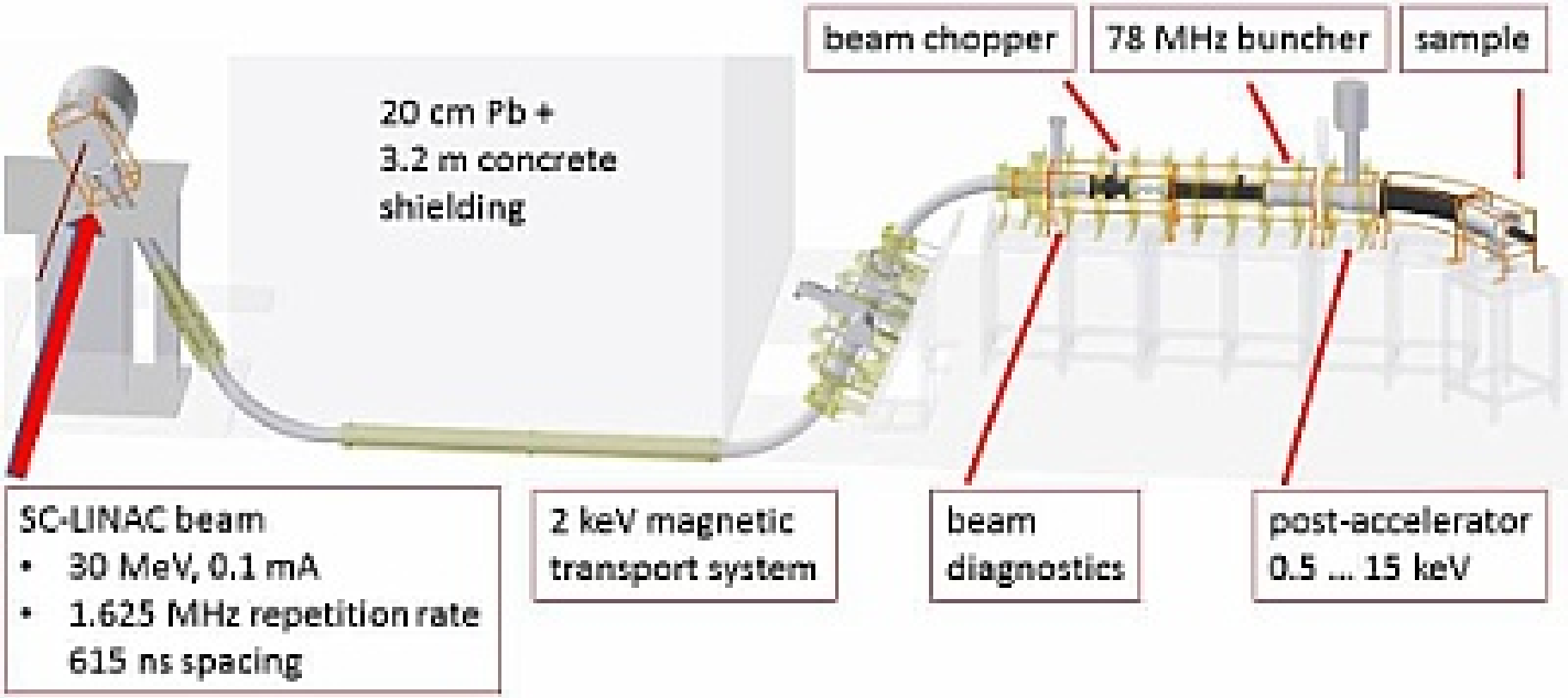


gELBE: Gamma beam facility

EPOS: Positron (+ Photoneutron) source

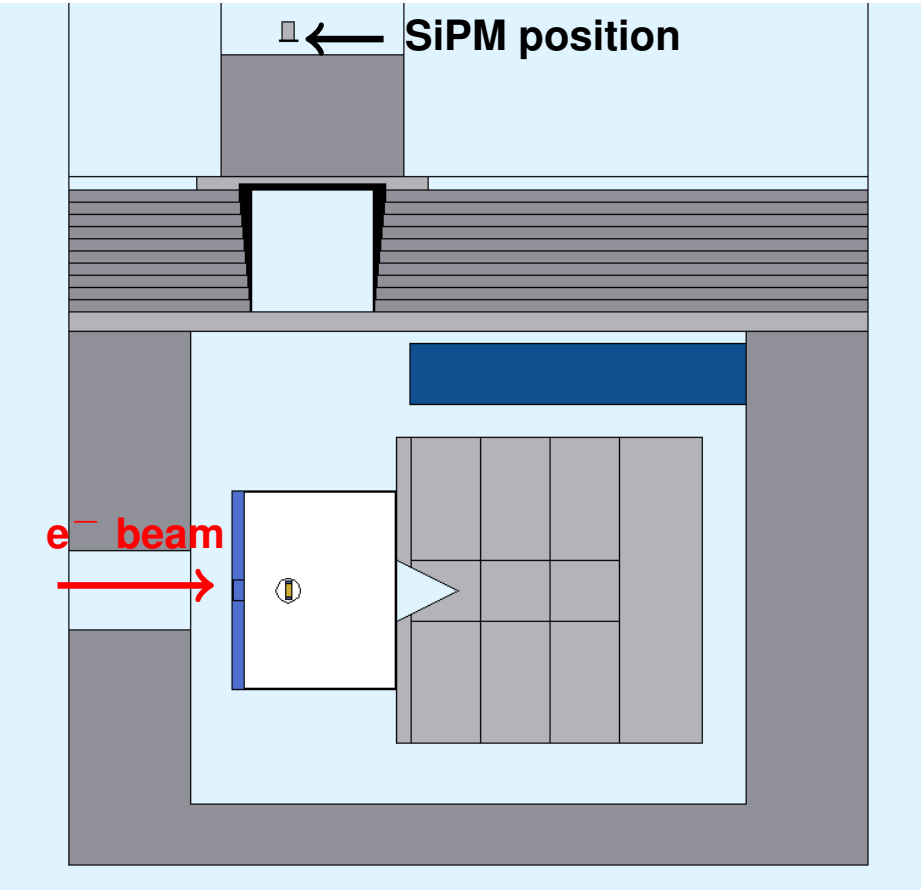
The EPOS positron source at ELBE

Positron extraction beamline:



The EPOS positron source at ELBE

Positron extraction beamline:



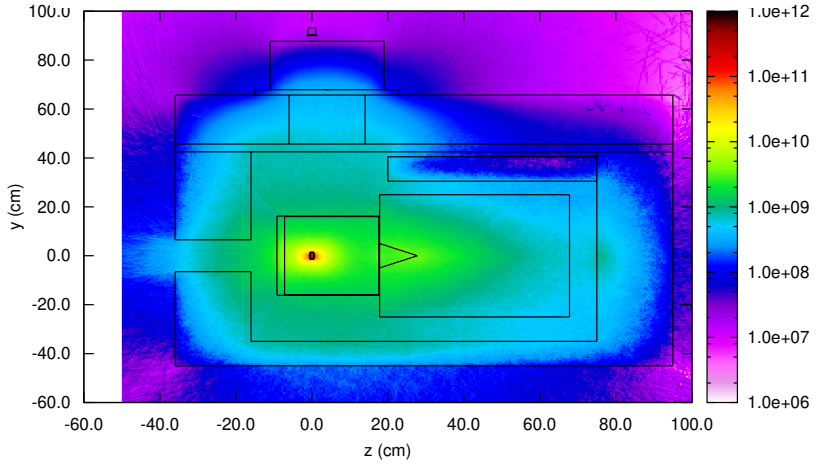
Only interested in production part (electron beam on water-cooled tungsten target inside lead castle)

EPOS beamtimes for MUSE

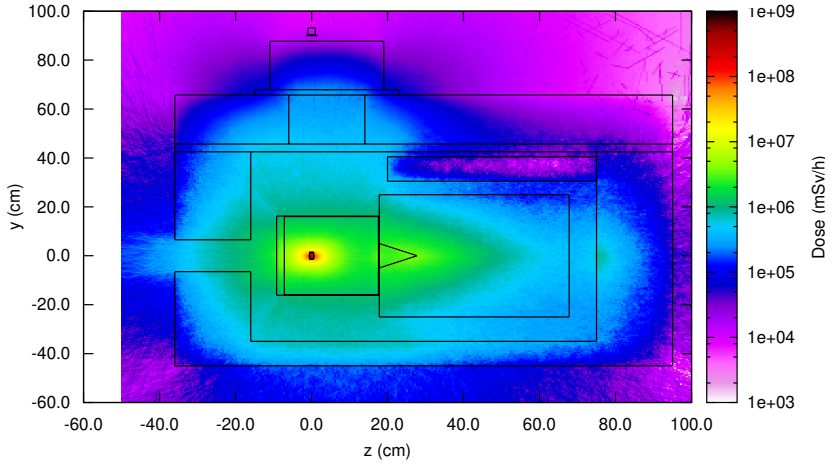
FLUKA simulations for EPOS neutron irradiation beamtimes:

- 30 MeV pencil beam ($\sigma_{x,y}$=0.3cm) of electrons

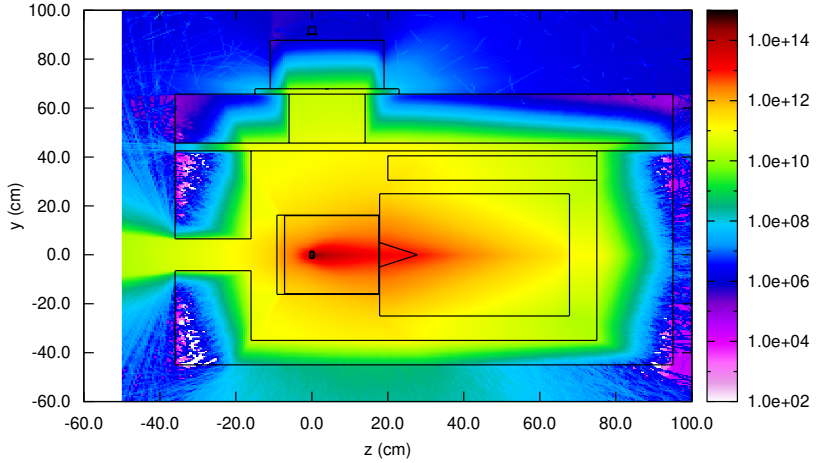
Neutron fluence (neutr/cm2/s) at 100 μA e- beam



Neutron dose (mSv/h) at 100 μA e- beam



Photon fluence (neutr/cm2/s) at 100 μA e- beam



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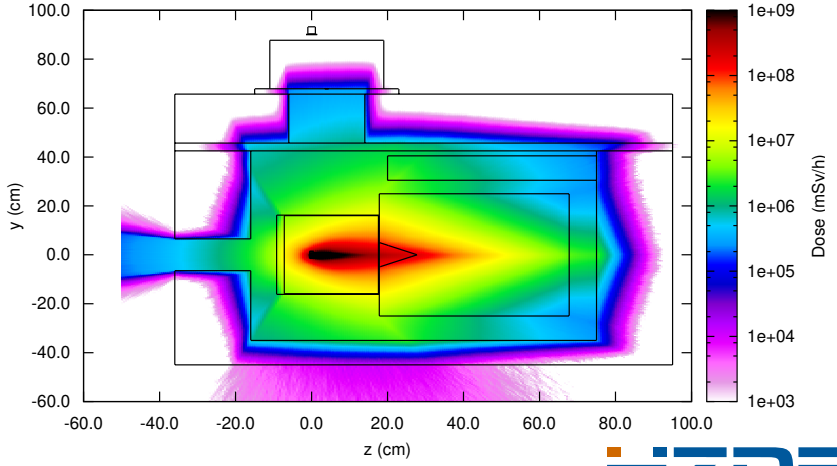
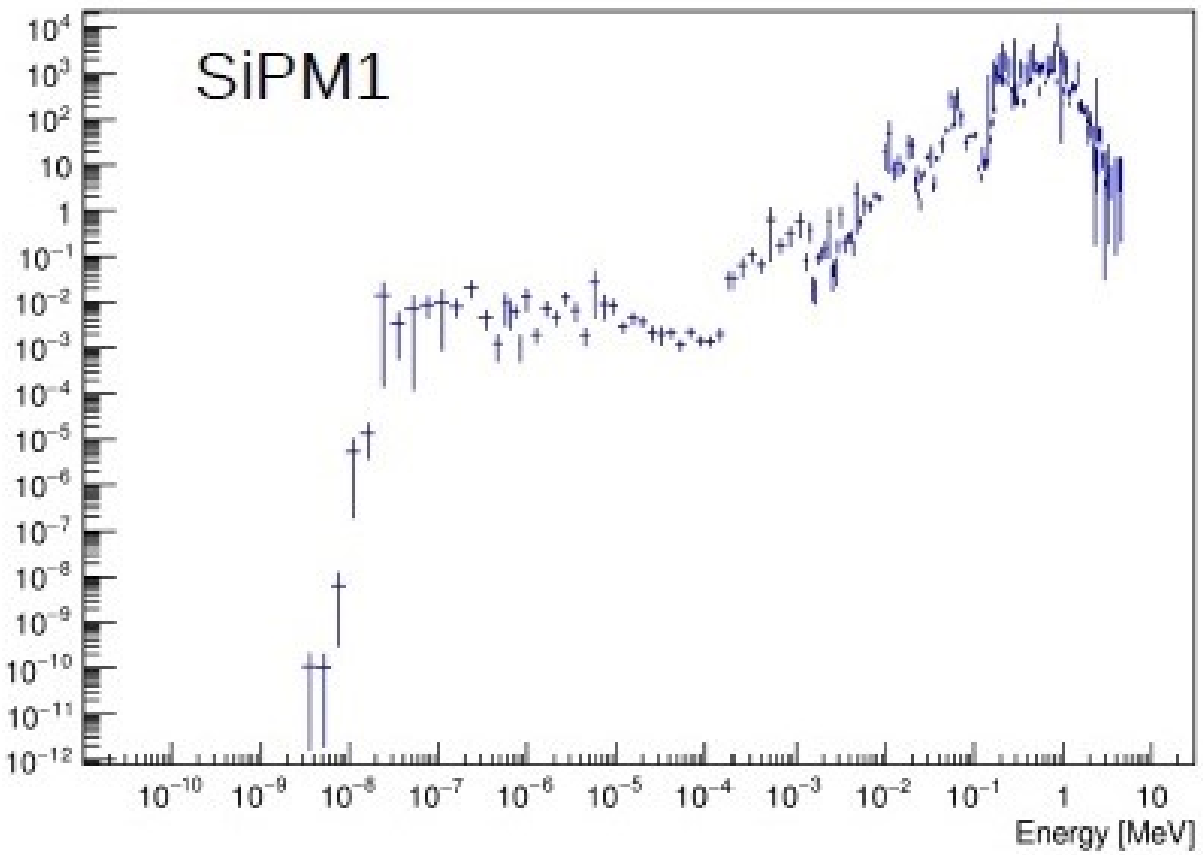


EPOS beamtimes for MUSE

FLUKA simulations for EPOS neutron irradiation beamtimes:

- 1 MeV-equiv.-neutron spectrum at SiPM position with peak around 1 MeV

  → this matches the expected radiation conditions at Mu2e

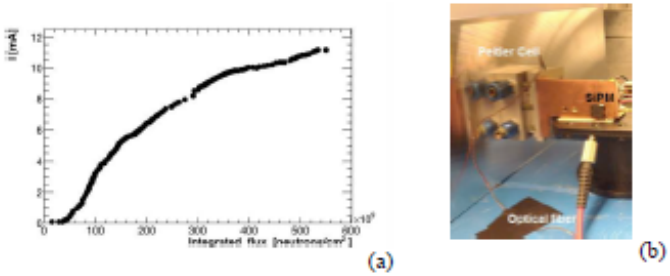


Total 1-MeV-eqiv. neutron rate at SiPM position: ∼70 000 neutr/s/μA

EPOS beamtimes for MUSE

(1) First irradiation in April 2016 (one SiPM tested)

Figure 1: (a) Leakage current vs integrated 1 MeV-equivalent neutron fluence, obtained at EPOS during the April 2016 parasitic run. The accumulated statistics corresponds to 6 years Mu2e operation (b) Photosensor position at the measurement place, at the top of the EPOS shielding cage.



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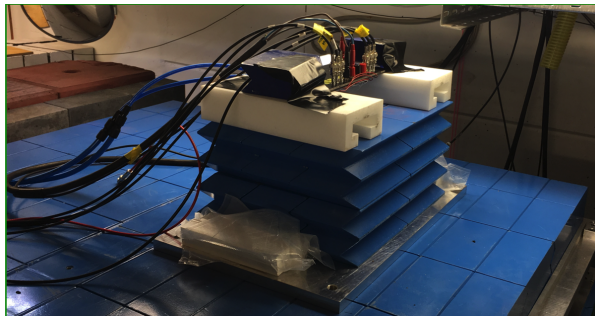
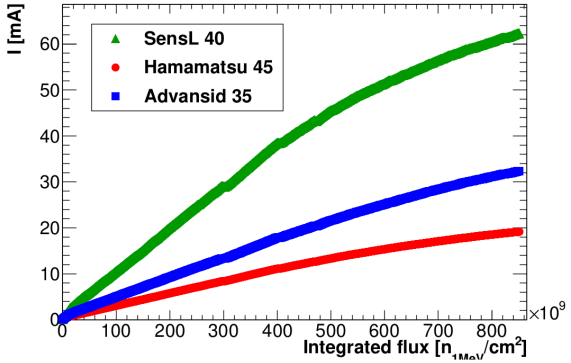
JINST 12 (2017) no.02 C02022

(2) Next step: Irradiation in March 2017 (three different SiPMs tested)





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JINST 13 (2018)

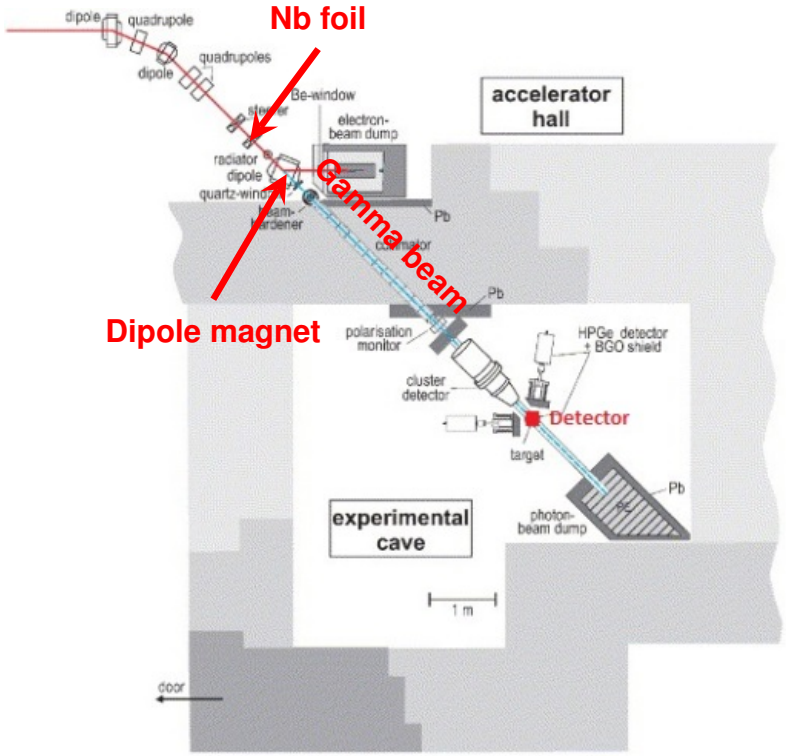
T03005

(3) Since then: Routinely parasitic irradiation of SiPMs

- batches 1-4 done (each $\sim 10^{12}$ 1MeV-equiv. neutrons accumulated)
- batches 5-7 currently under irradiation

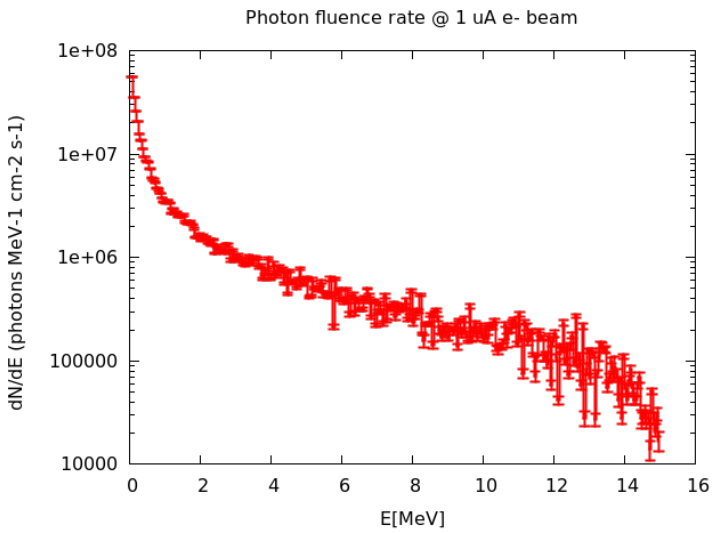
The gELBE gamma source

Bremsstrahlung production from electron beam impinging on niobium radiator foils



Time structure defined by electron beam (micropulses)

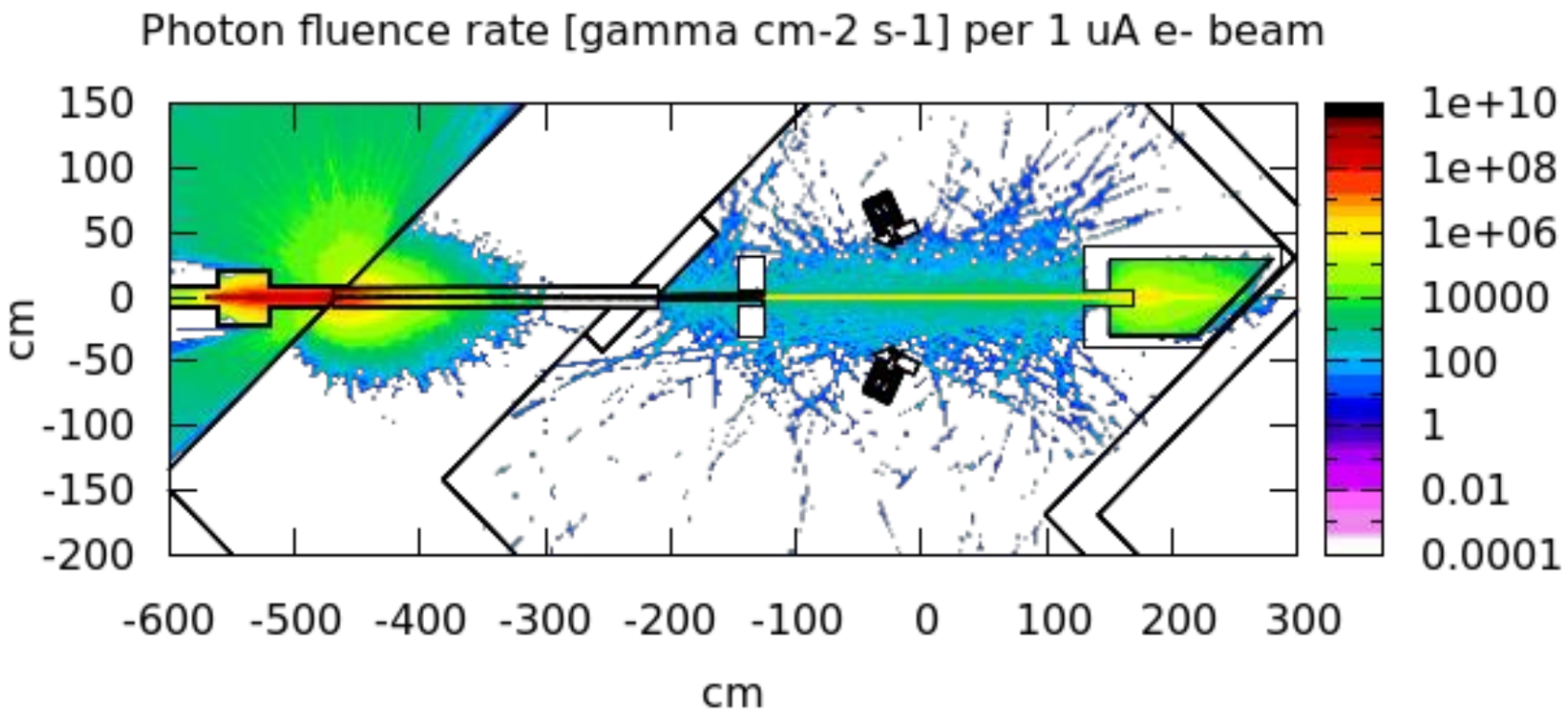
Diff. photon fluence rate@1μA electron beam:



Gamma rates up to 2.5 10^7 γ/cm^2/s per 1μA of electron beam at sample position

The gELBE gamma source

Photon fluence of gELBE with a 15 MeV electron beam simulated with the FLUKA code:



Studying HPGe detector response at gELBE

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Tests of HPGe performance in a high-flux pulsed gamma beam for the Mu2e Stopped Muon Flux Monitor

Proposers: Anna Ferrari, Laura Harkness-Brennan, Matt Jones, David Koltick, Mark Lancaster, Kevin Lynch, James Miller, Stefan Müller, James Popp, Nam Tran

Scientific Case

The Mu2e experiment [1] will search for neutrinoless muon-to-electron conversion, with the goal to test branching ratios up to 10^{-16}, which is a factor of 10000 more sensitive than any previous experiment. Observations of a signal would be an example lepton flavor violation, which would require physics beyond the Standard Model [2].

Mu2e will stop muons in an aluminum target, and will look for the mono-energetic electron produced in the reaction $\mu^- + {}^{27}_{13}Al \rightarrow e^- + {}^{27}_{13}Al$. In order to normalize the result, it is necessary to measure the number of stopped muons. A High-Purity Germanium detector (HPGe) will be employed to detect the number of characteristic muonic xrays, or gamma rays produced when the muon stops in the target, which is directly proportional to the number of stopped muons.

The HPGe is chosen for its excellent energy resolution (<2 keV FWHM at 1.33 MeV), which is required to resolve the desired photon lines from neighboring background gamma lines and to provide acceptable S/N above ambient background. However, the large flux (~150,000 per second) of gammas entering the detector will significantly challenge its rate-handling capability. When rates are too large, the energy resolution of the HPGe deteriorates and dead-time may also be introduced.

The Mu2e muon beam is delivered in 200 ns wide pulses spaced at 1700 ns intervals (~600 kHz). Almost all the background gamma rate occurs at the time of the muon injection (we call it the 'flash'), while the xrays and gamma rays of interest occur after that. The muonic xrays are produced about 100-200 ns after the flash, while the gamma rays are produced throughout the period between pulses. It is therefore necessary to

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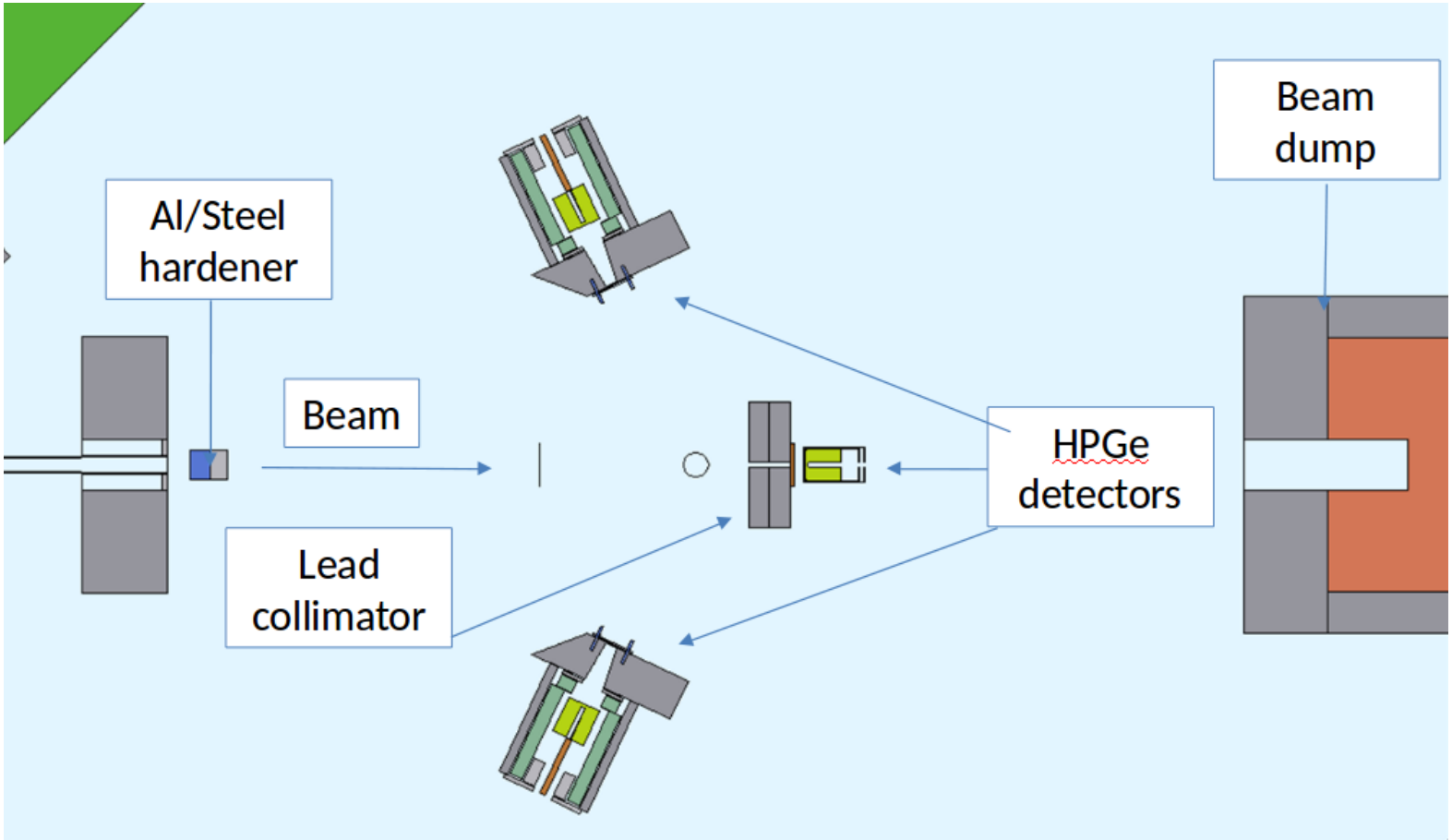
Studying HPGe detector response at gELBE

- Up to 125kHz of gamma rates expected for Mu2e Stopping-Target Monitor HPGe detector during beam pulse
  - high average γ energy ($\sim$ 5 MeV)
  - high beam pulse occupancy ($\sim$ 20%)
- gELBE pulse separation of 2.4μs close to Mu2e's 1.7μs proton pulse separation
- Goals of the beamtime:
  - Measure HPGe detector performance in the gELBE beam (energy resolution, radiation damage,...)
  - Understand best beam and detector geometry and position (including absorbers)
  - test signal-processing algorithms (DMA vs. MWD)
- Two HPGe detectors brought to ELBE by Purdue group, additional DAQ system from Liverpool group
- Using Cesium and Cobalt sources to study resolution in the presence of Bremsstrahlung tail
  - ^{137}Cs source right behind lead collimator (gamma beam passes source)
  - ^{60}Co source fixed to HPGe detector housing
- HZDR provided radiation transport simulations using the FLUKA code to estimate γ energy spectrum, energy deposit in crystal etc.

Studying HPGe detector response at gELBE

Setup during the gELBE beamtime:

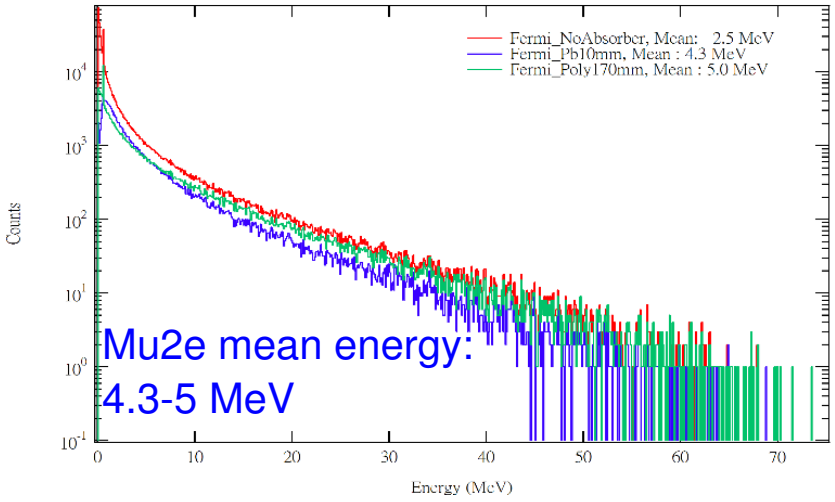


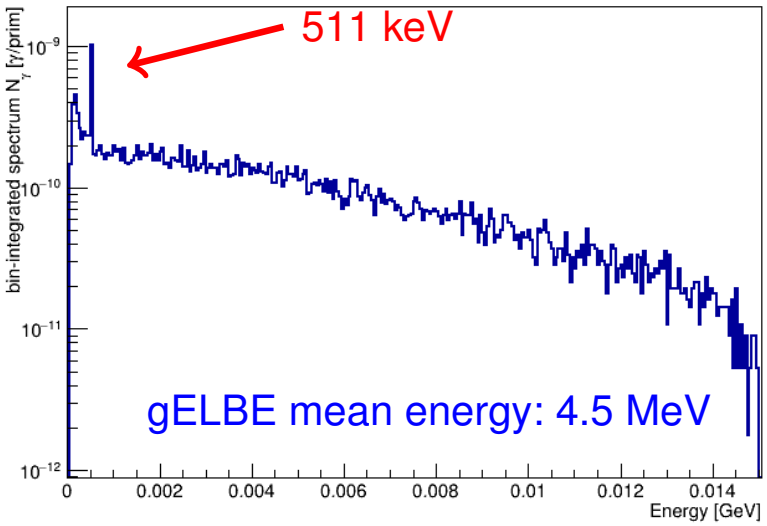
HPGe detector behind lead wall with 1cm^2 collimator hole and copper/aluminum absorber plates to shield from lead fluorescence.

Studying HPGe detector response at gELBE

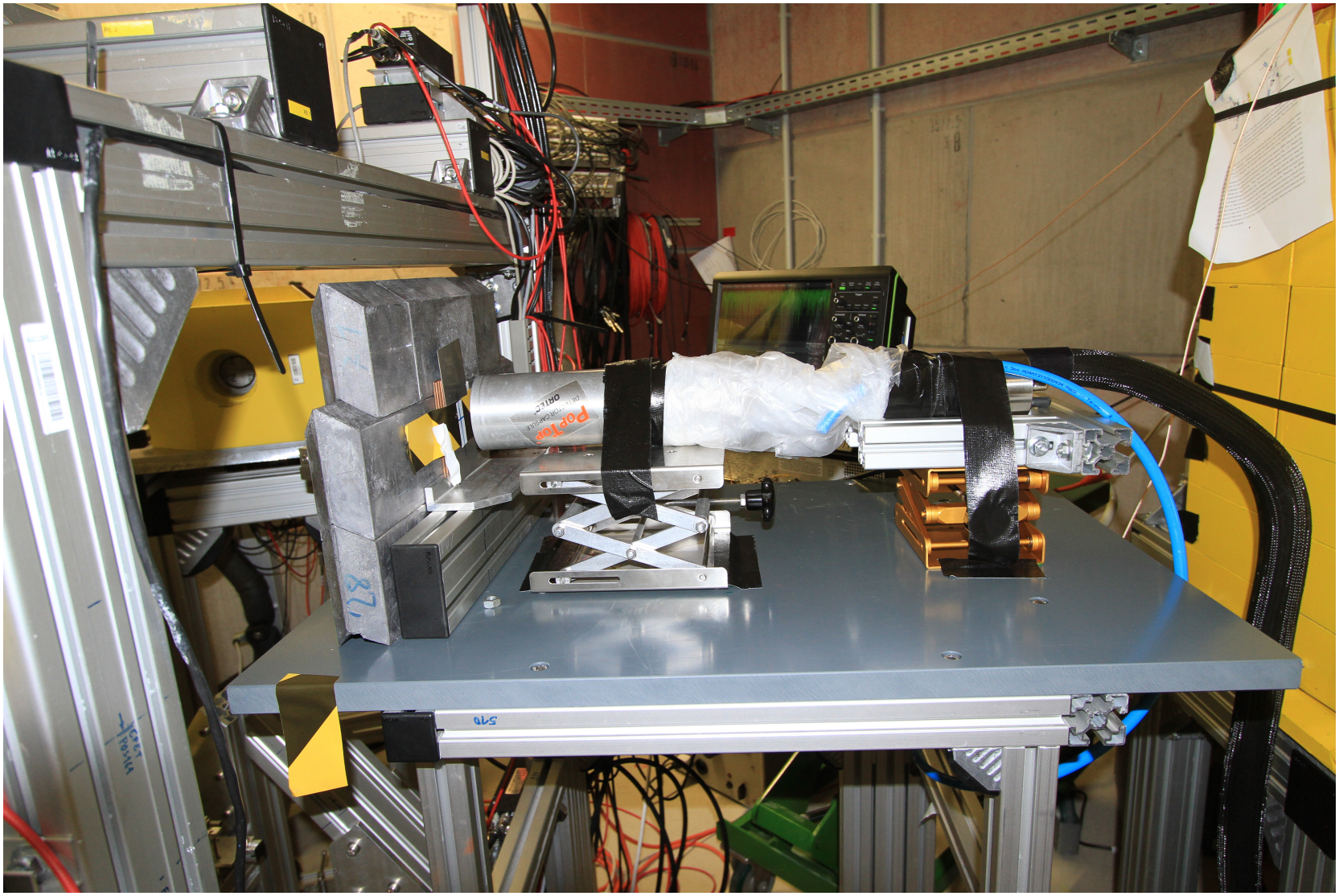
Simulated spectra for Mu2e photon flash and for gELBE are similar:

- Using proper absorbers, the mean energy of the spectrum becomes similar to the expected one for Mu2e (despite the fact that the Mu2e spectrum endpoint reaches 75 MeV compared to the gELBE one at 15 MeV)





Studying HPGe detector response at gELBE



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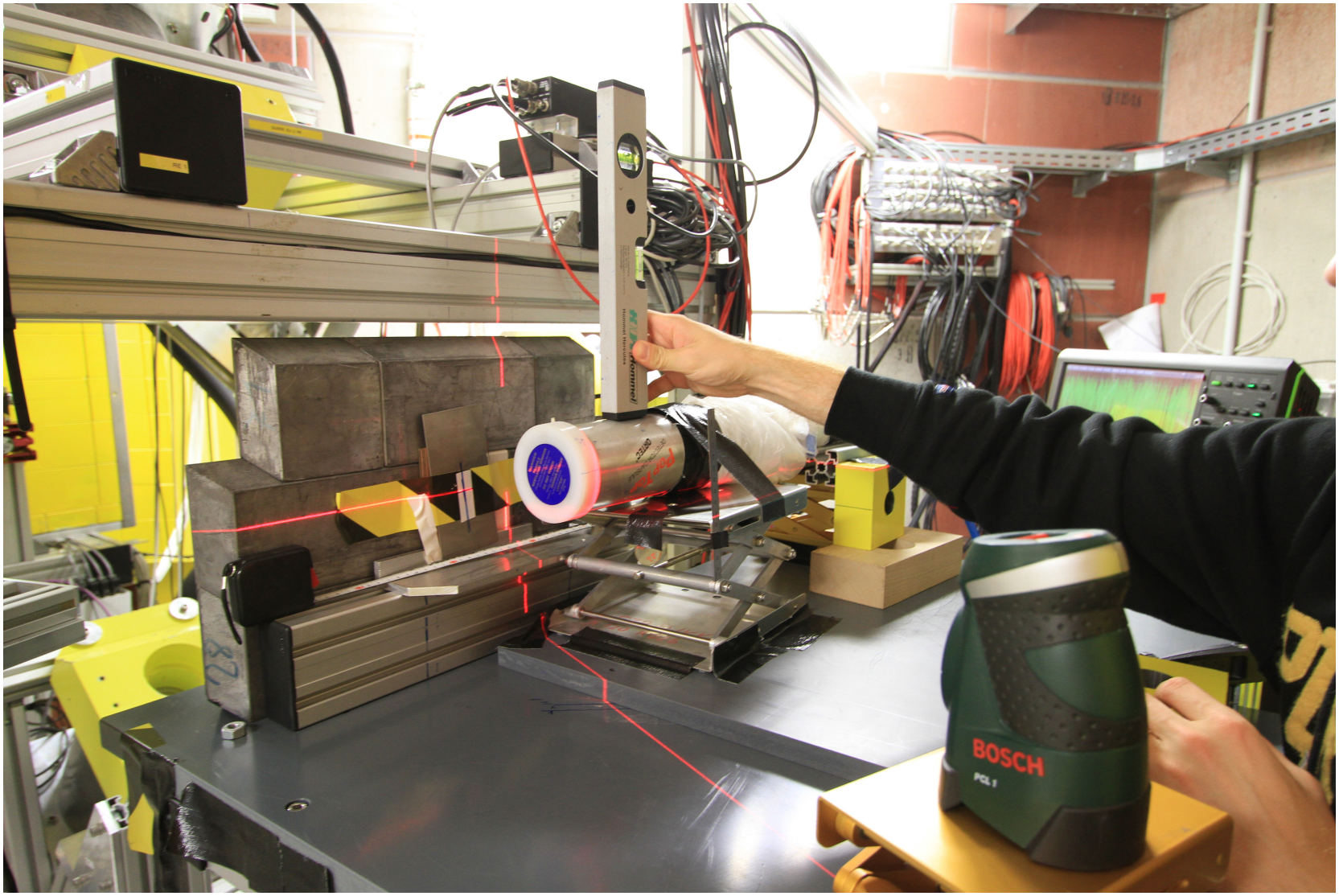

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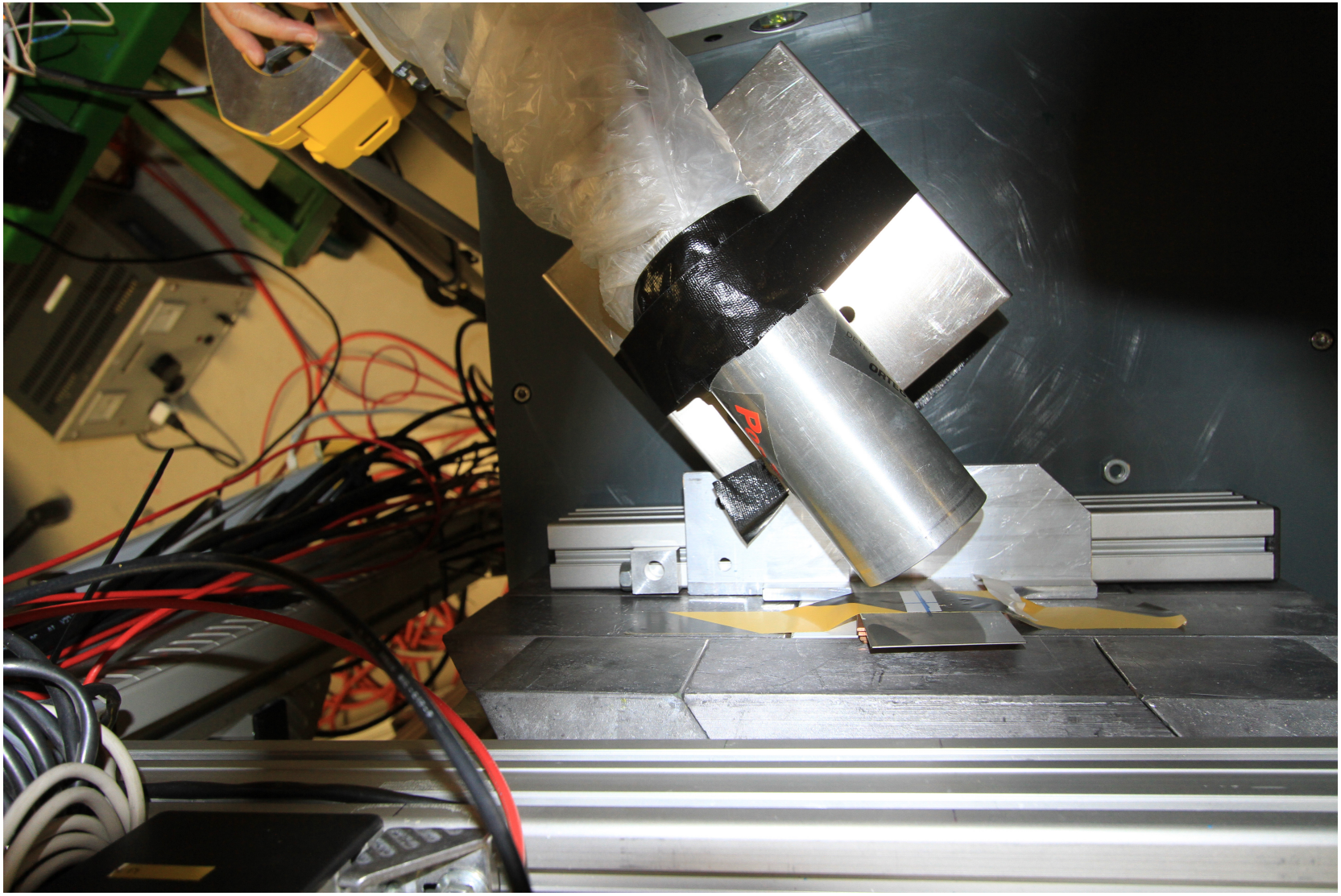
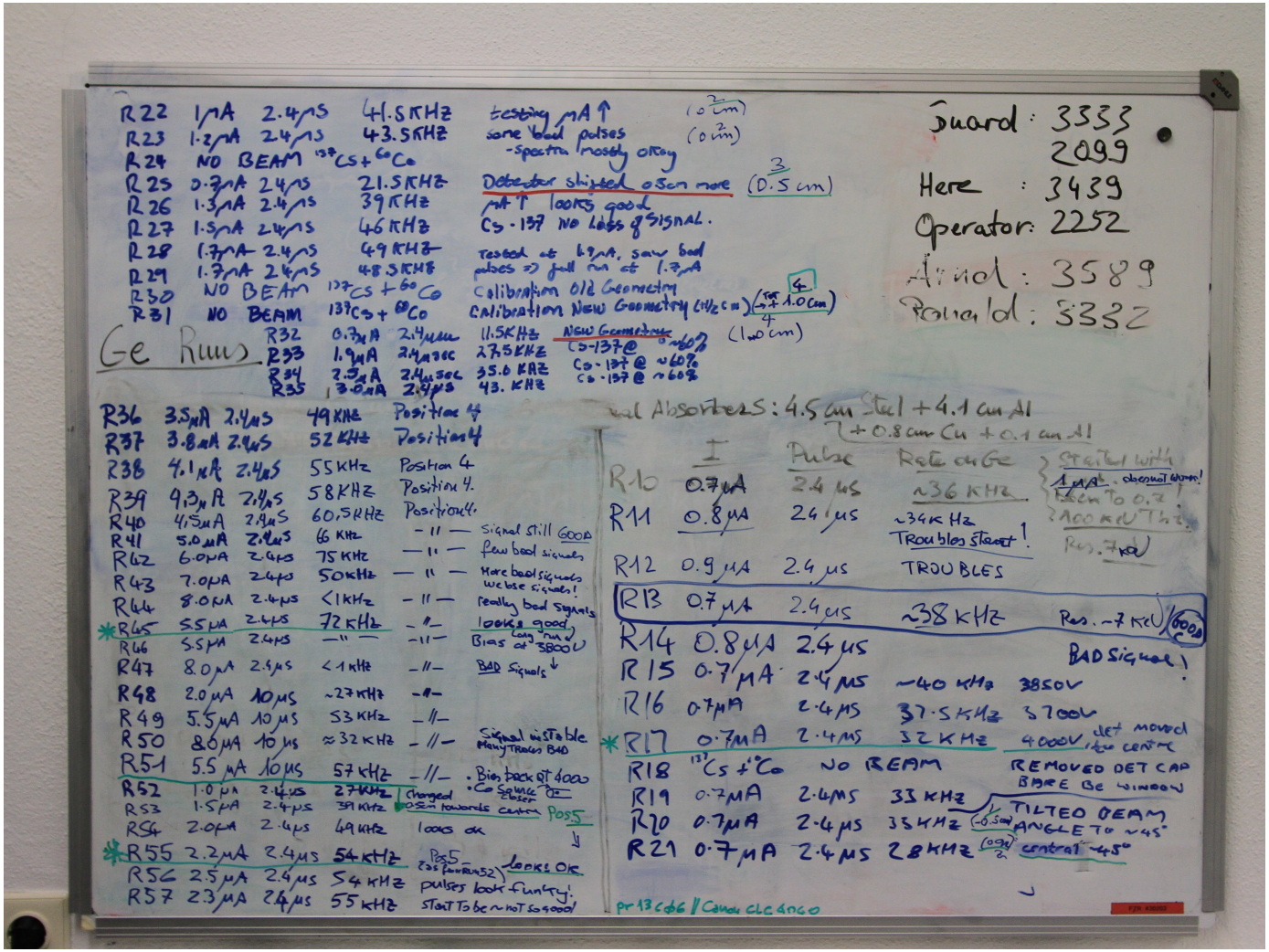


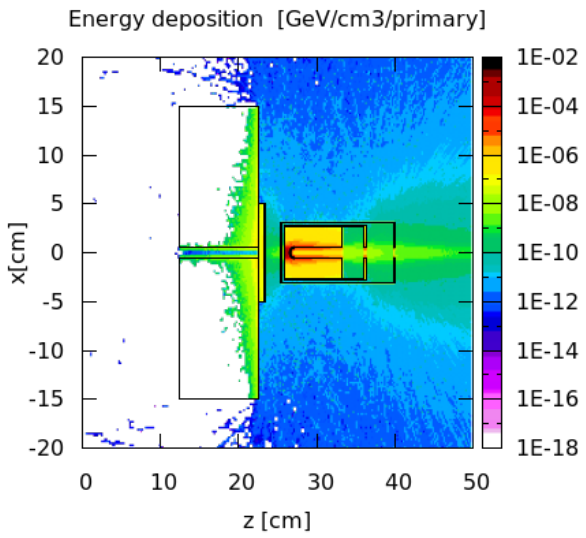
Studying HPGe detector response at gELBE

Runlist during beamtime:

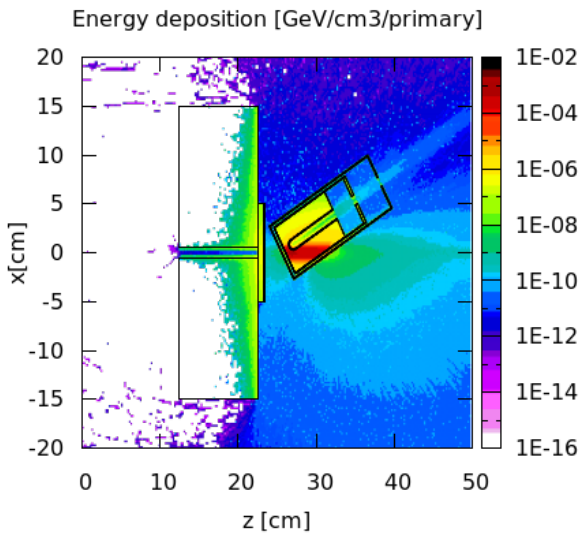


Studying HPGe detector response at gELBE

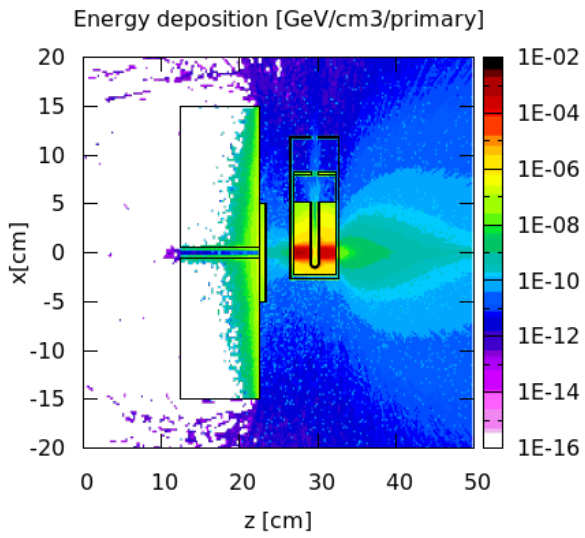
FLUKA studies on energy deposition for different detector positions:



Average energy deposition
(508.68±0.11) keV
per primary γ



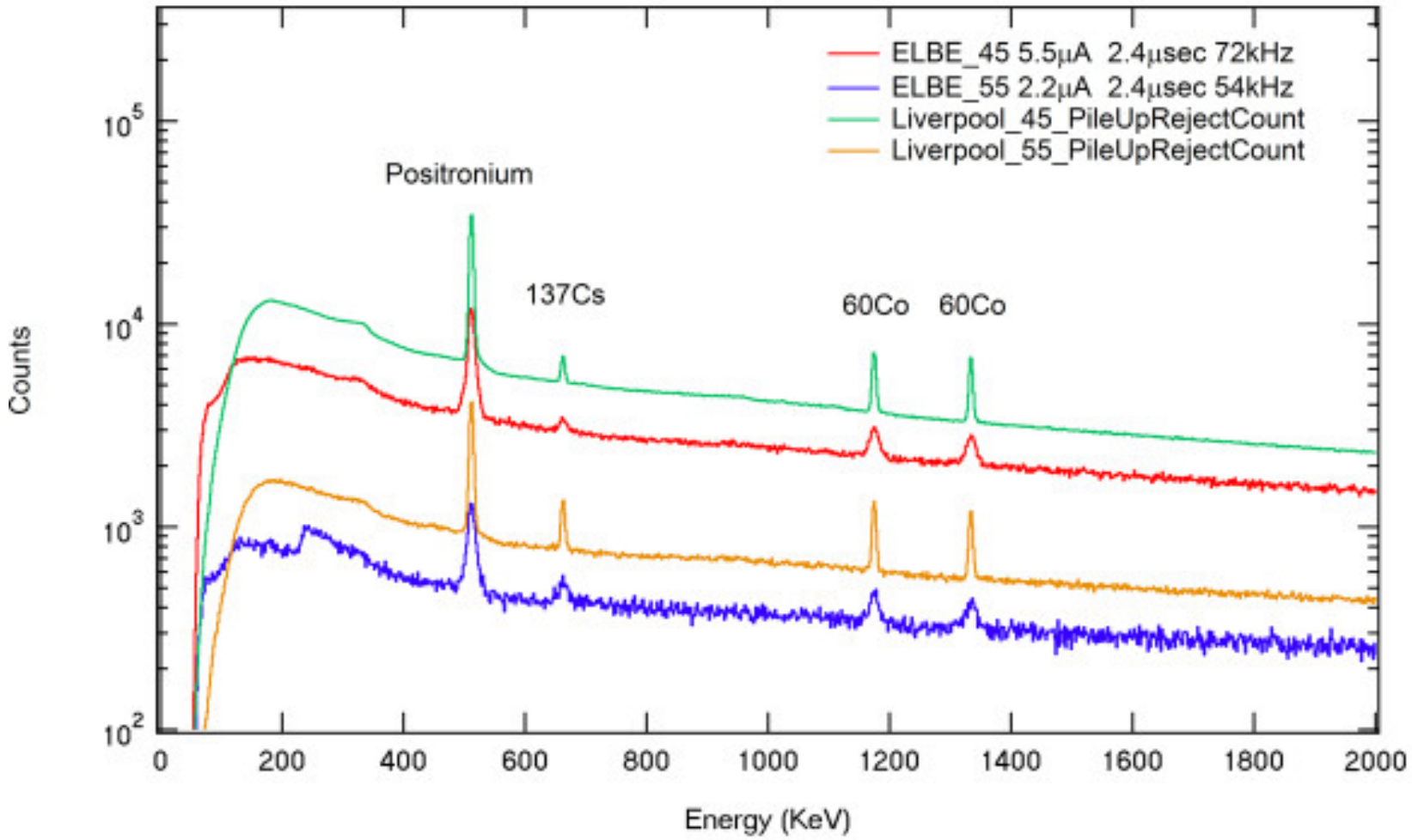
Average energy deposition
(1846.3±0.16) keV
per primary γ



Average energy deposition
(1759.4±0.08) keV
per primary γ

Studying HPGe detector response at gELBE

Analyzed spectra by applying Moving Window Deconvolution Algorithm:



Energy resolution from spectrum analysis between 3 KeV (Liverpool) and 6 KeV (Purdue).

Irradiation of DIRAC digitizer board at gELBE

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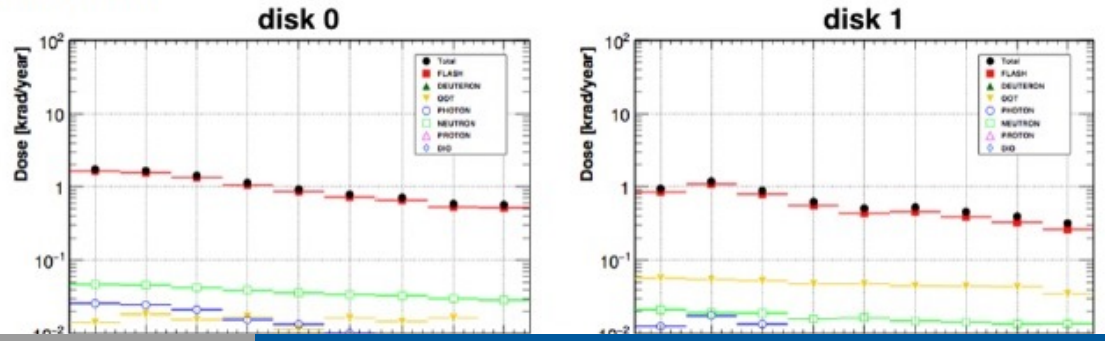
Photon irradiation of the digitizer board for the Mu2e electromagnetic calorimeter

Proposers: Stefano Di Falco, Anna Ferrari, Simona Giovannella, Stefano Miscetti, Stefan Müller, Gianantonio Pezzullo, Franco Spinella

Scientific Case

The Mu2e experiment [1] aims to increase of four orders of magnitude the sensitivity for the neutrino-less muon-to-electron conversion, with the goal to test branching ratios up to 10^{-16}. Observations of a signal would be a clear indication of physics beyond the Standard Model [2]. The Mu2e calorimeter system must provide an independent fast trigger, strong particle identification and a support to the track pattern recognition by providing a good timing [3, 4]. It is composed of 1400 un-doped CsI crystals coupled to large area UV extended Silicon Photomultipliers arranged in two annular disks, each readout by on-board preamplifiers and custom-based high frequency digitizer boards housed on crates located around the disks. The Mu2e calorimeter should also be fast enough to handle the high rate background and it must operate and survive in the high radiation environment. Simulation studies [5] estimated that, in the highest irradiated regions, the front end and the digitizer boards will be exposed to a total dose of ~ 6 krad in three years of run (Fig.1), with the dose largely dominated by the background gamma produced at the time of the beam injection ("flash").



HZDR

Irradiation of DIRAC digitizer board at gELBE

- 5 shifts (12h each) at the gELBE facility granted for June 2018 (“Open Lab-day” falls in between shifts - no beam possible!)
- Digitizer board placed after PE collimator (16mm diameter)
- Estimated dose from FLUKA simulatons: 3krad/h for 100μA electron beam
- 15 MeV electronbeam with 600μA on 12.4um niobium radiator foil (later increased to 700μA)
- Working plan:

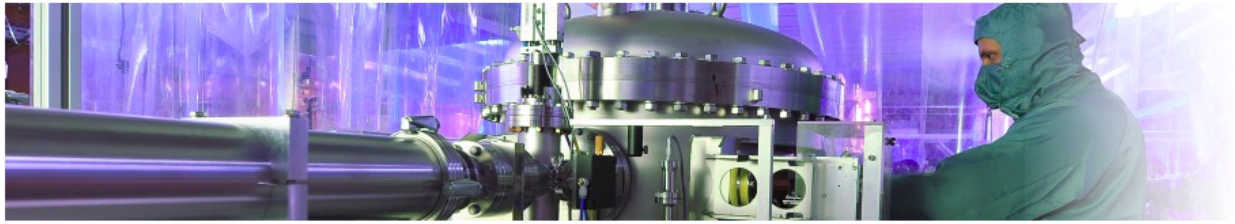
Date:	Time period	Component	Remarks
7.6 2018	7:00 -13:00	ADS 4229	
7.6.2018	16:00-19:00	Amplifier	
7.6. - 8.6.2018	20:00-06:00	DC-DC converter	200 kRad
8.6. - 9.6.2018	-	-	Open Lab Day - no irradiation
9.6.2018	18:00-23:30	VCXO (OSC1)	
10.06.2018	00:00-6:00	Termometro (U47)	
10.06.2018	7:00-12:30	LDO (U13)	problematic - max 4.2 V!
10.06.2018	14:00-20:00	Jitter-Cleaner (U2)	very problematic
10.06. - 11.06.2018	21:00-02.30	ADC Monitor (U39)	
11.06. - 12.06.2018	03:00-06:00	Traslatore di Livello (U38 or U40)	if there is time...

- No significant degradation of performance found (in contrast to CALLIOPE irradiation results!)
- suspicion that delivered dose was lower than predicted (factor 5 - 10)

Beamtime application via GATE

Dedicated beamtime is asked via the HZDR GATE page:

https://gate.hzdr.de/cgi-bin/gate



ELBE as a User Facility

ELBE

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ELBE is operated as user facility, providing more than 50% of the beamtime to external user groups.

The publications resulting from experiments at ELBE demonstrate the wealth of research fields covered by the activities at ELBE.

Application for beamtime and modalities of access

Two calls for proposals for experiments at ELBE are published per year. The next deadline for submission of beamtime applications for the 2nd term of 2018 will be

October 22nd, 2018

Proposals are submitted through the user portal GATE.

We strongly recommend discussing the feasibility of planned experiments with the responsible beamline scientist prior to the submission of a proposal, in particular, if you are a new user.

Access is free of charge for all non-proprietary research. User groups from outside Germany requesting access to beamlines involved in "Integrating activities" funded from the EU framework programme for Research and Innovation Horizon 2020 may apply for a reimbursement of travel costs. Please visit our specific website on Trans-national Access for details on this funding scheme.

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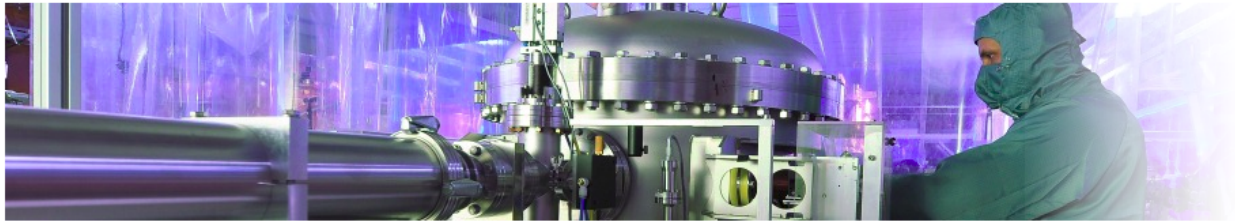

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We intend to submit another proposal for the irradiation of the DIRAC board at gELBE

Summary

Several beamtimes have been carried out at the ELBE facility to test detector components for the Mu2e experiment

- Beamtimes at the EPOS positron beam facility to understand effect of neutron radiation on SiPMs
  - Dark current tested as function of the absorbed neutron dose
  - Parasitic beamtimes for passive SiPM irradiation
- Beamtime at the gELBE gamma beam facility to study the behavior of a HPGe detector in an intensive gamma beam
  - It could be proven that a HPGe detector is suitable as a Stopping Target monitor for the Mu2e experiment
  - Detector managed to handle the gamma rates
  - No radiation damage on detector found after beamtime - energy resolution and calibration constants did not change.
  - Studies on reconstruction algorithms (MWD vs. DMA)
  - STM HPGe detectors have in the meantime been ordered by Liverpool
- Beamtime at the gELBE gamma beam facility to estimate radiation hardness of DIRAC digitizer board
  - Collimated gamma beam allows irradiation of individual components on the board
  - No significant degradation of components measured - suspicion that delivered dose was smaller than predicted
  - New proposal will be submitted to repeat beamtime