Novel detector systems for decay spectroscopy at FAIR/NUSTAR

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Objectives

Recently, the combination of the highly pixelated active DSSSD AIDA implanter and the compact, high-efficiency Ge array DEGAS-I has been commissioned and employed for first successful NUSTAR experiments at FAIR Phase-0. Based on the experience gained, a novel type of implanter, FIMP, aiming for highest efficiency, low-noise and ultimate timing characteristics is under development. For the first time, FIMP will be employing scintillating fibres. It will perfectly match to the future variants of the gamma array DEGAS-II and DEGAS-III. The latter one planned to be the first imaging grade gamma spectrometer, enabling the event-by-event distinction of gamma quanta emitted from the implantation zone versus quanta originating from the strong environmental background. The sensitivity gain of this set-up is estimated to be orders of magnitude, compared to conventional ones.

DEGAS realization in three phases

Phase I

-Use RISING (EUROBALL) crystals

-Replace preamps, detector pcbs, EDAQ

-Change configuration to adopt to extended AIDA implantation zone and structure

-Go for triple detectors to gain efficiency compared to 7-fold clusters

-add active/passive shielding to reduce background

Phase II

-include AGATA type doubles and/or triple detectors (downstream)

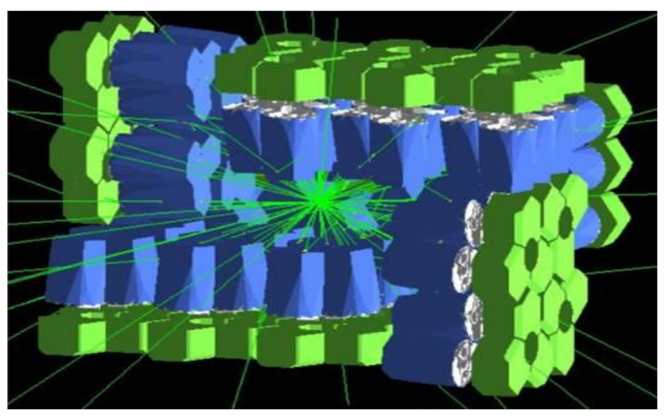
Phase III

-develop imaging array

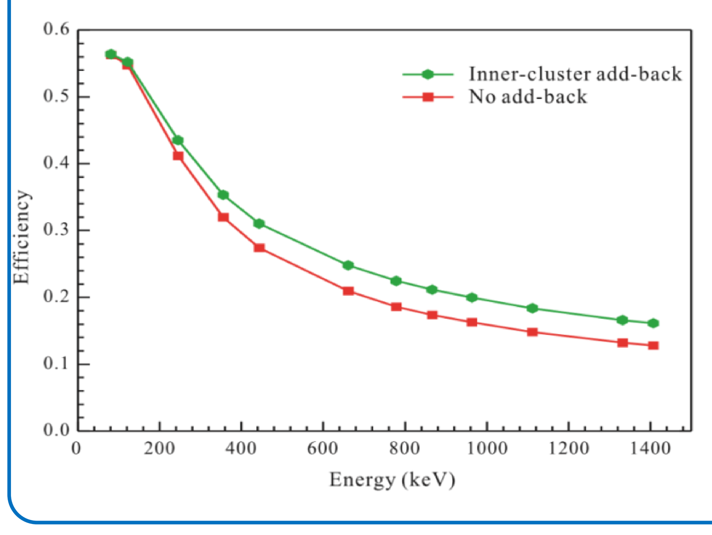
-develop Ge implanter

Property	RISING	Phase I	Phase II	Phase III
Array type	Composite Ge detector array	Composite Ge detector array	Phase I complem. by γ-tracking dets.	γ-imaging array
Energy range (keV)	50-5000	50-5000	50-5000	50-5000
Noise threshold (keV)	24	15	15	10
Energy resolution (at 1.3 MeV)	2.3 keV	2.3 keV	2.3 keV	2.0 keV
Full energy γ-detection efficiency (at 1 MeV)	16%	18%	20%	>20%
Effective full energy efficiency after prompt flash blinding	13.9%	15%	16%	20%
P/T-value	34%	34%	40%	>50%
Time resolution (at 1.3 MeV)	13 ns	10 ns	10 ns	< 10 ns
Overload recovery time	≤ 1ms	100 ns/MeV	100 ns/MeV	100 ns/MeV
Relative background suppression	1	5	10	100
Coverable implantation area	16 x 8 cm^2	24 x 8 cm^2	24 x 8 cm^2	24 x 8 cm^2
Max. acceptable event rate (kHz)	3.5	10	10	10

Phase I concept

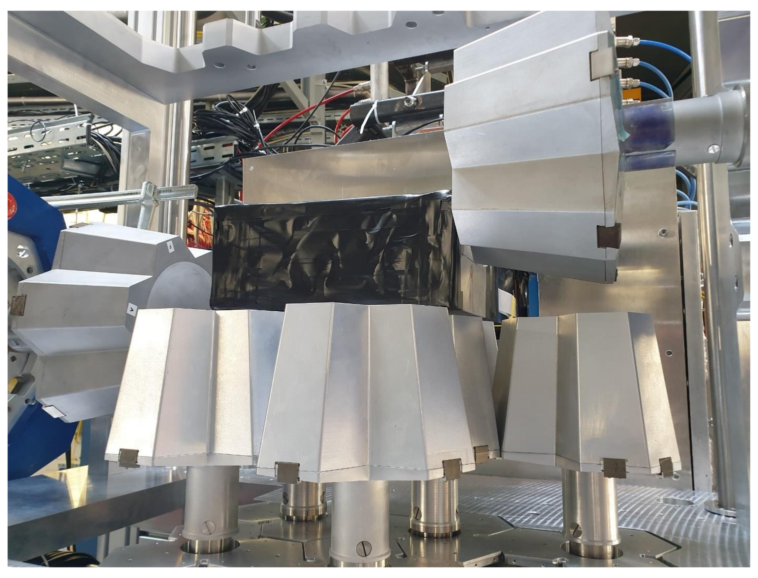


28 compact triple Ge detectors with BGO shields

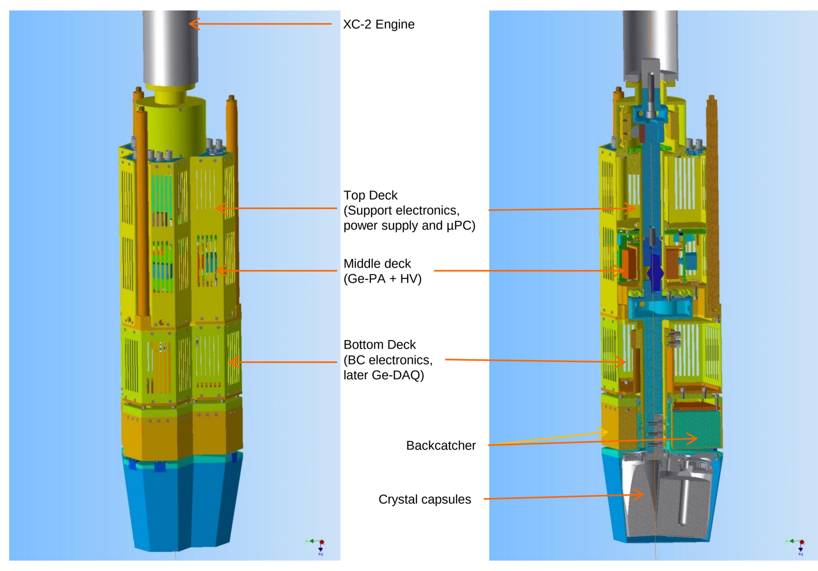


Phase I subsystem in use

First successful in-beam experiments were performed in spring 2022 at the SIS/FRS facility at GSI

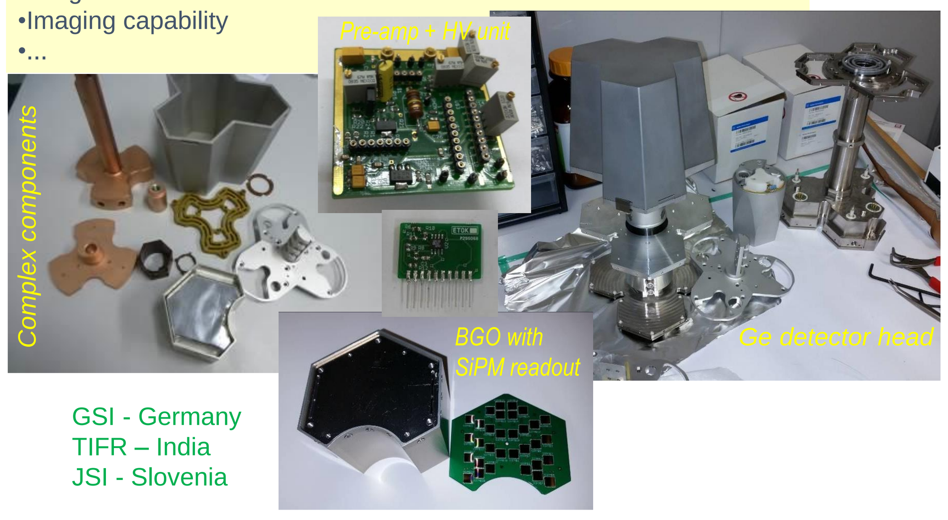


Phase I detector unit

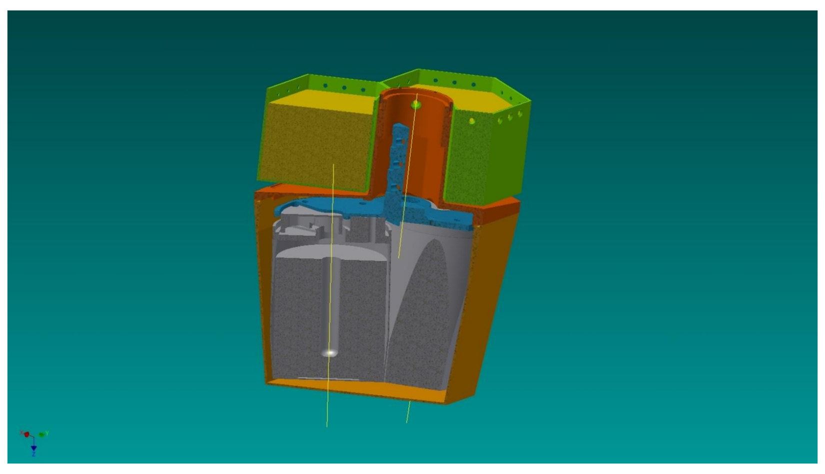


A very complex and complicated device

- Encapsulated HPGe crystals in a cryostat with electrical cooling.
- Minimal thermal losses
- High vacuum
- Integrated front-end and control electronics
- Imaging capability
- …



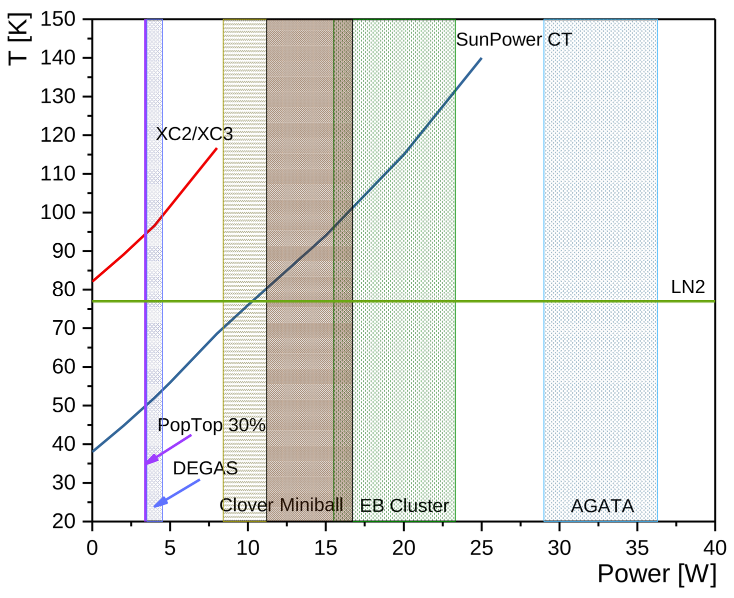
GSI - Germany
TIFR – India
JSI - Slovenia

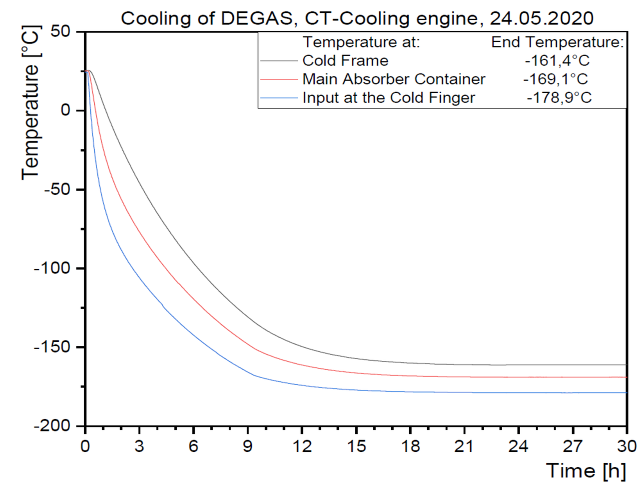


Phase I First of Series detector unit

Cryostat performance

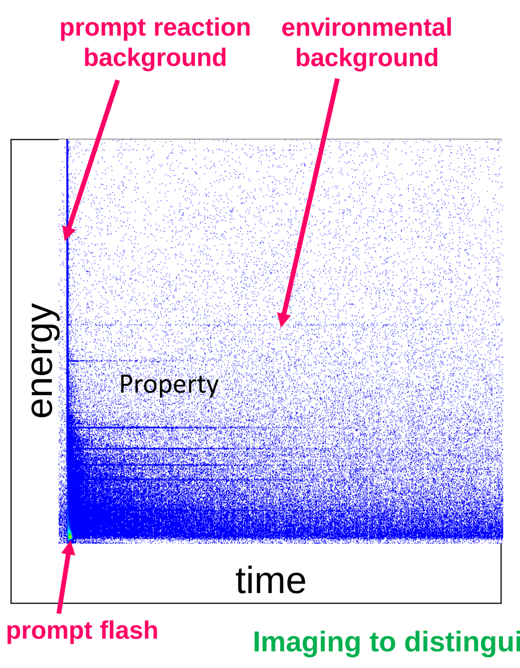
The DEGAS cryostat has ultra-low cooling power losses < 4.5 W

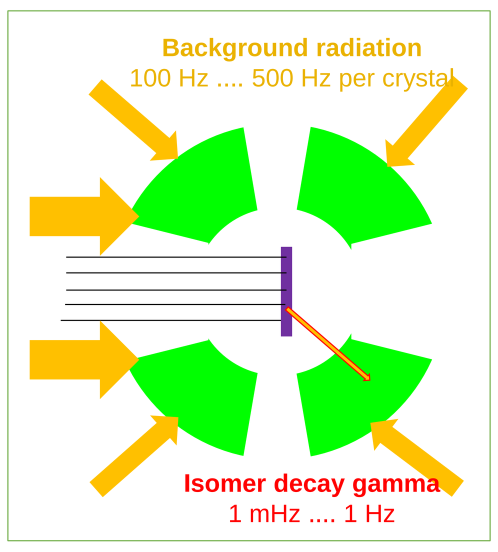




Challenges of DEGAS III

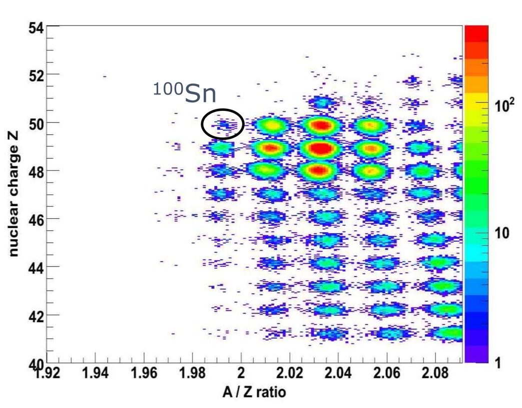
Rare decay experiments are hampered by severe background radiation from prompt beam interactions and environmental background. Imaging strongly reduces this background.

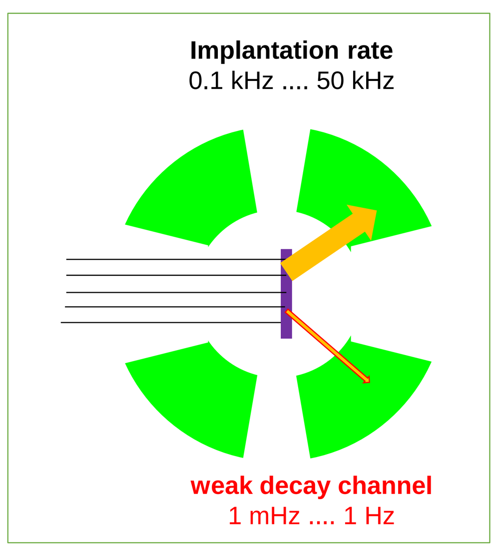




Imaging to distinguish isomeric from environmental γ rays

background from unwanted isotopes

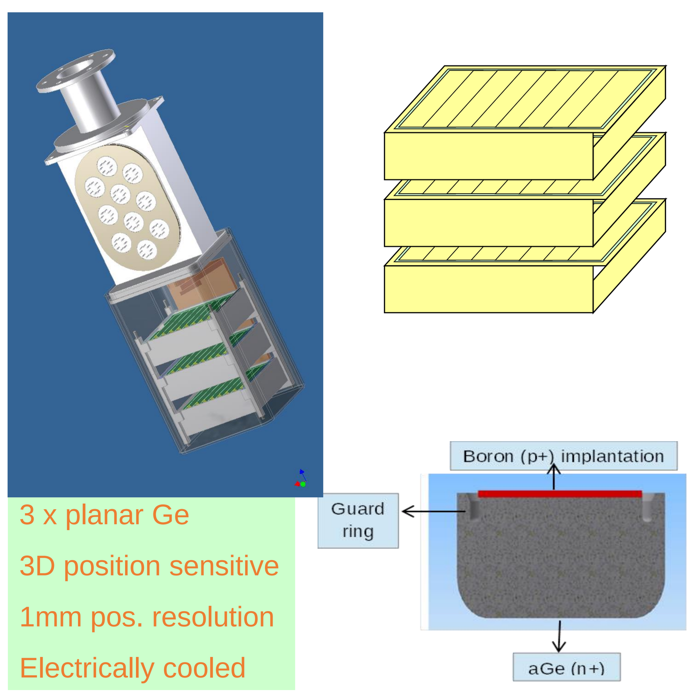




Imaging to localize the respective implantation points

DEGAS III Concept

Imaging-grade Ge detectors require planar type diode structures. While classical planar detectors suffer from large dead volumes the newly developed semi-planar detector overcomes this problem.



- Stack of 3 planar 2D stripe Ge detectors
- $68mm^2$ x $68mm^2$ x $20mm^2$ + 2mm guard ring
- 6mm gap between crystals
- 8x8 segmentation
- 1 – 3 mm 3D position resolution with PSA
- Energy resolution: 0.2%

dead volume destroys performance

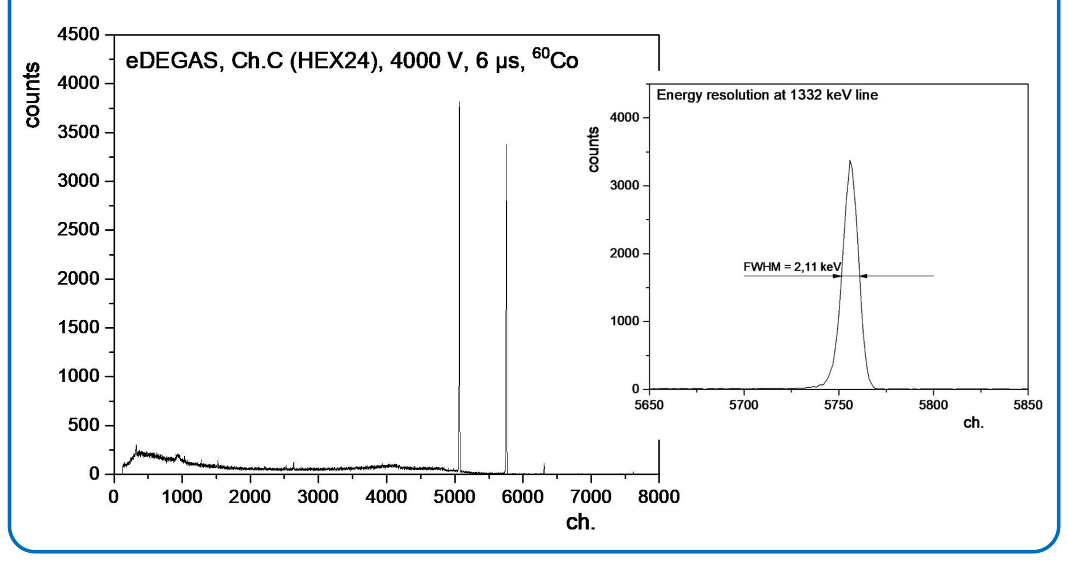
Semi-planar structure

Amorphous Ge (aGe) blocking contact

Negligible dead zone!

e-cooler performance

Using e-cooler enabled operation below liquid nitrogen temperature and resulted in a perfect energy resolution.

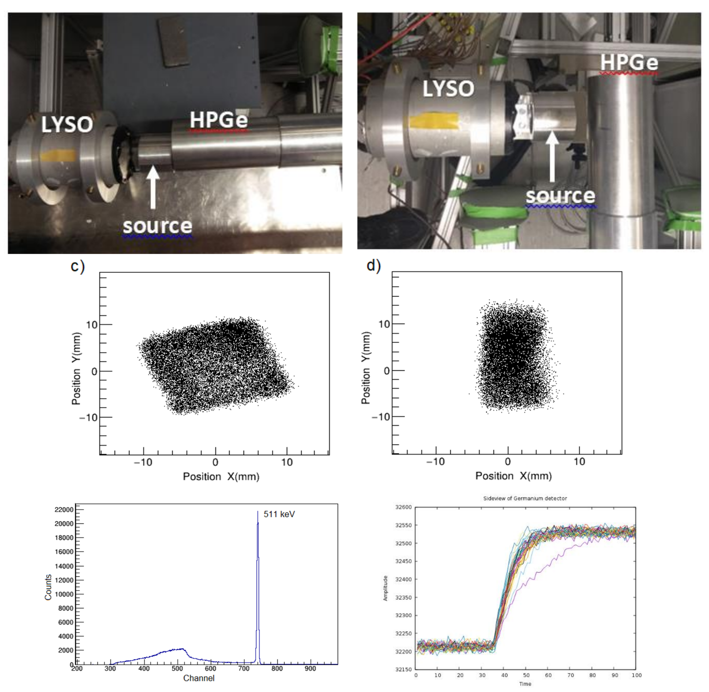


Semi-planar prototype for DEGAS III

First tests with a semi-planar crystal gave promising results.

Non-segmented p-type HPGe crystal Volume:
33.2x33.2x15.5 mm^3
Carrier concentration
3.3x10^9 atom/cm^3

Crystal processed by SEMIKON FZ-Jülich

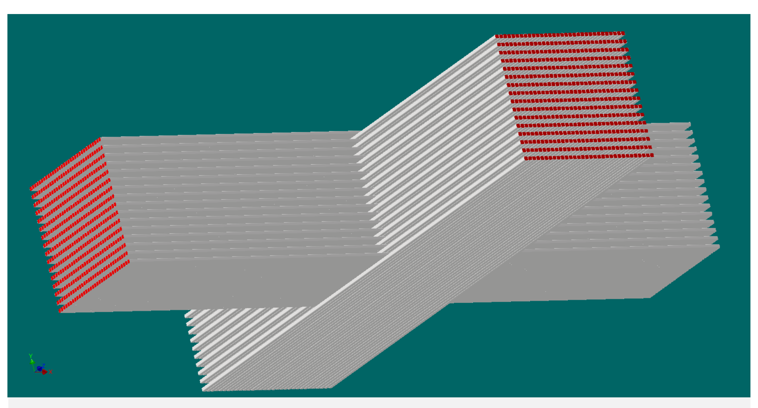


Conclusions

- The concept of DEGAS I has been proven to be viable
- The DEGAS cryostat has ultra-loow cooling losses enabling operation with either mini dewars or e-coolers
- Series production of Phase-I detector units has started
- First in-beam experiments with a sub-set of Phase-I units have been performed successfully
- γ imaging is able to reduce the huge background in rare decay experiments
- Imaging-grade semi-planar structure is under development for DEGAS III
- The concept of an active scintillating fiber implanter has been proven
- A prototype is under construction

FIMP concept

The idea of the FIMP Fiber IMPlanter is to build an active heavy ion implanter composed of orthogonal layers of scintillating polymer fibre mats, assuming that β and α particles (or their associated secondary electrons) will hit at least one x and one y fibre so that complete position information is available.

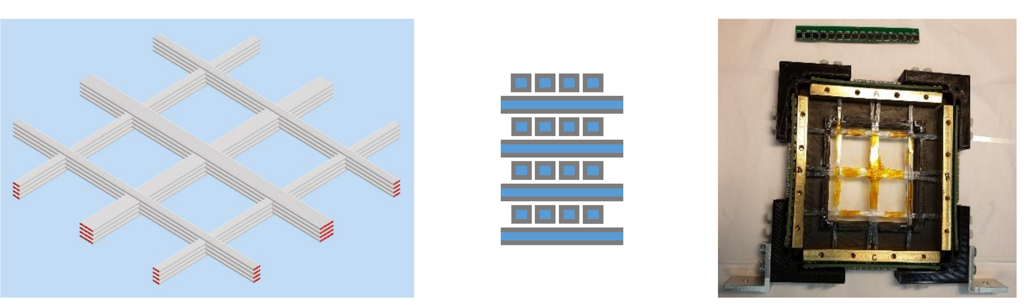


Geometry:
80x80x30 mm^3 respectively 240x80x30 mm^3

Expected specs:
-Efficiency: >80% at $E_\beta \geq 500$ keV
-Time resolution: <500 ps at $E_\beta \geq 500$ keV
-Energy resolution: <20% at $E_\beta = 1000$ keV
-Position resolution: 2mm voxels

FIMP demonstrator test

Based on GEANT simulations the optimal fiber thickness has been estimated to 0.5 mm. to proof the concept a demonstrator detector employing fibre bundles of 4x4 Kuraray fibres read out by SiPMs has been successfully tested in-beam at the FRS at GSI.



FIMP Prototype

A prototype with 19 orthogonal fiber mats and 81x81x12 mm3 active volume has been manufactured. It serves as testbench to investigate varies SiPM light read-out schemes and their associated frontend electronics.