Diamond detectors for life-time measurements of exotic nuclei

E.M. Gandolfo for the LISA collaboration

DeSyT-2025
February 25th, 2025

LISA Project & Physics goal

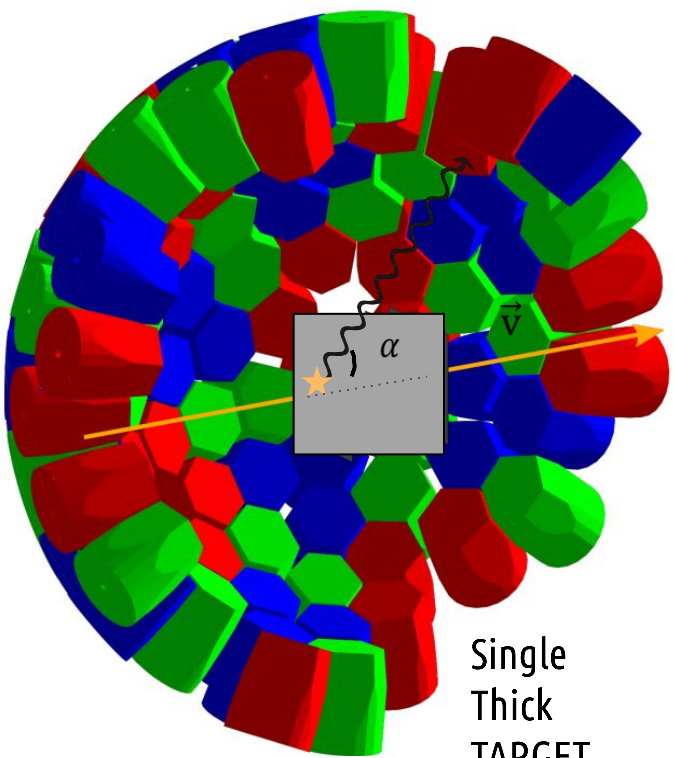
LIfe time measurement with Solid Active target

In-beam γ-rays spectroscopy experiments for life time measurements

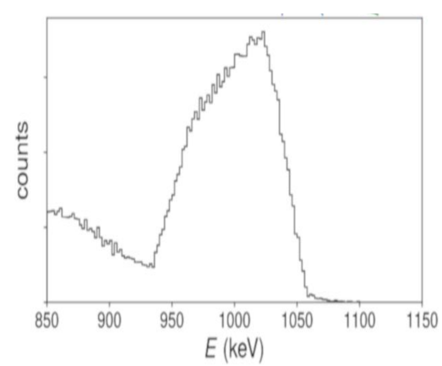
Energy resolution worsening due to:

- Doppler effect (emission angle and velocity)
- Thick targets (increase luminosity for exotic nuclei)

$$E_{lab} = E_0 \frac{\sqrt{1 - \beta^2}}{1 - \beta cos\alpha}$$



Single
Thick
TARGET



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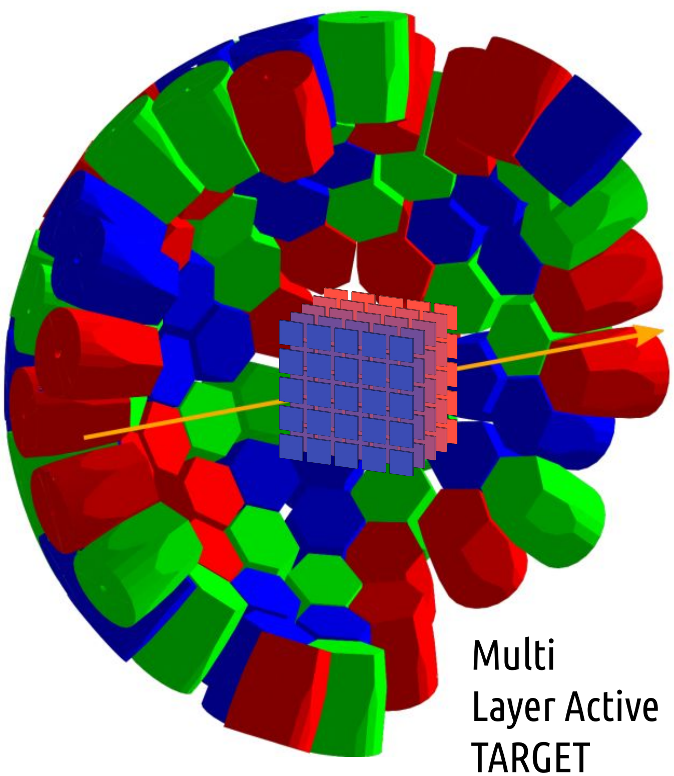
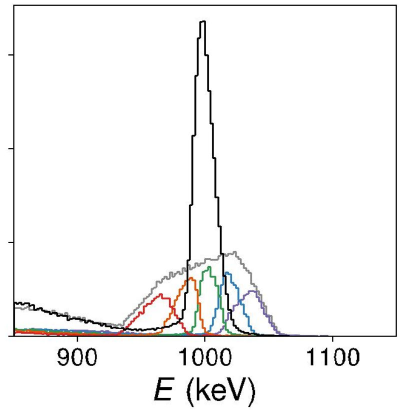
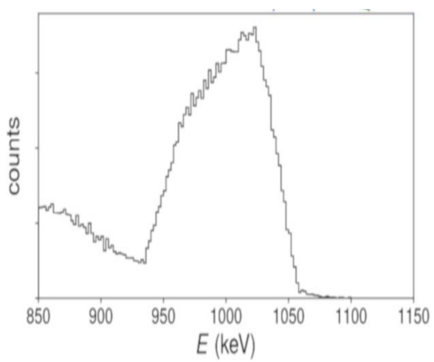


Multi Layer Active TARGET

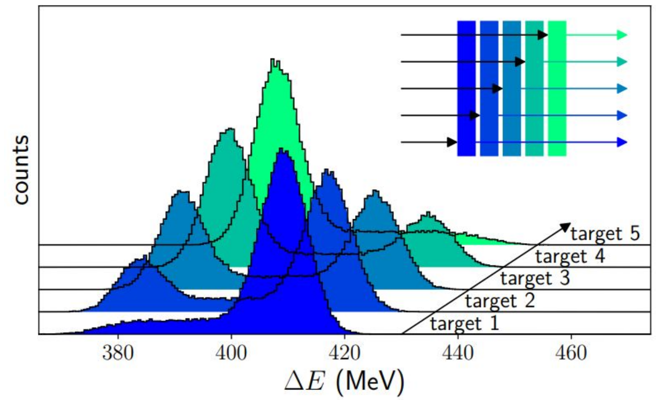




Increased sensitivity for **life-time measurement**

Detect change in energy loss (and Z) in each layer

Layer identification with neural network based on ML method



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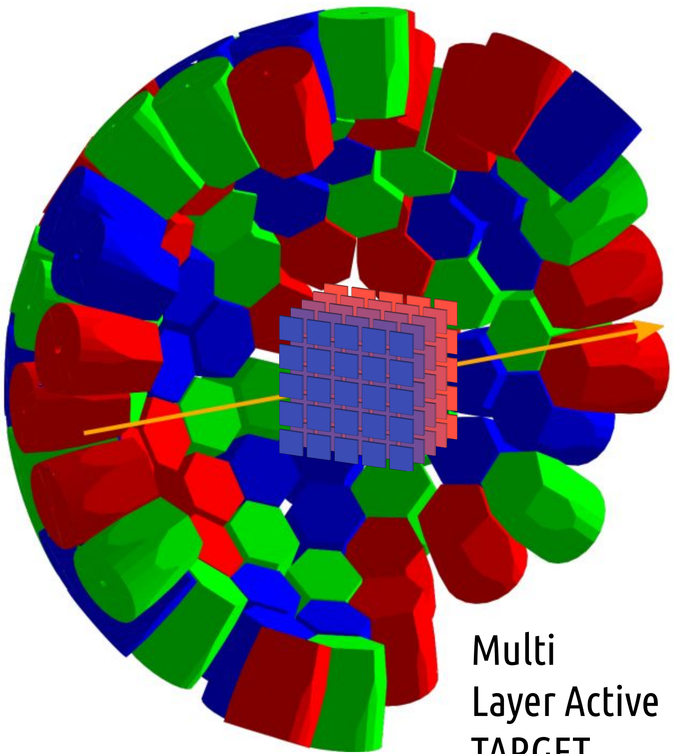

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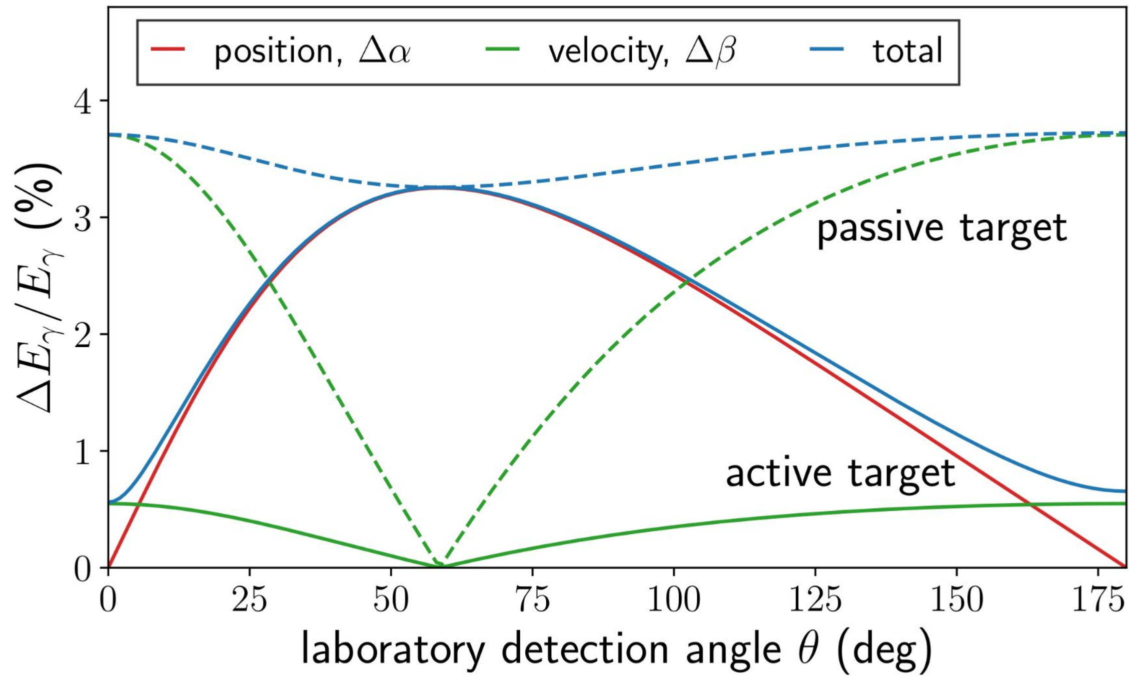


LIfe time measurement with Solid Active target

In-beam γ-rays spectroscopy experiments for life time measurements

Layers of single-crystalline CVD diamond detectors for energy deposition measurement

Timing properties

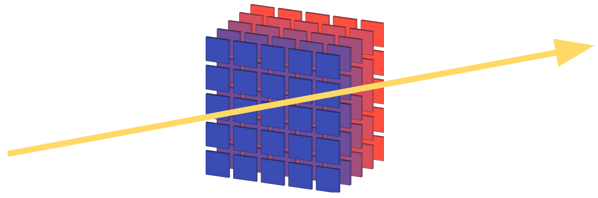
Bossini et al.[https://doi.org/10.3389/fphy.2020.00248]

Radiation hardness

Passeri et al. [https://doi.org/10.1016/j.nima.2021.165574]

Energy resolution 1% @GeV
(Z discrimination)

Berdermann et al. [https://doi.org/10.1002/pssa.200405170]



5 Layers each of
25 diamonds

LIfe time measurement with Solid Active target

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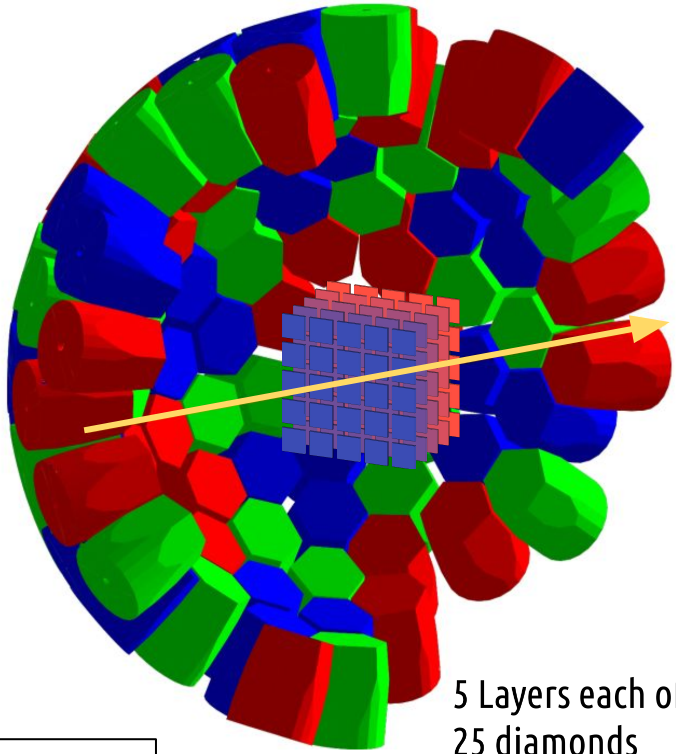


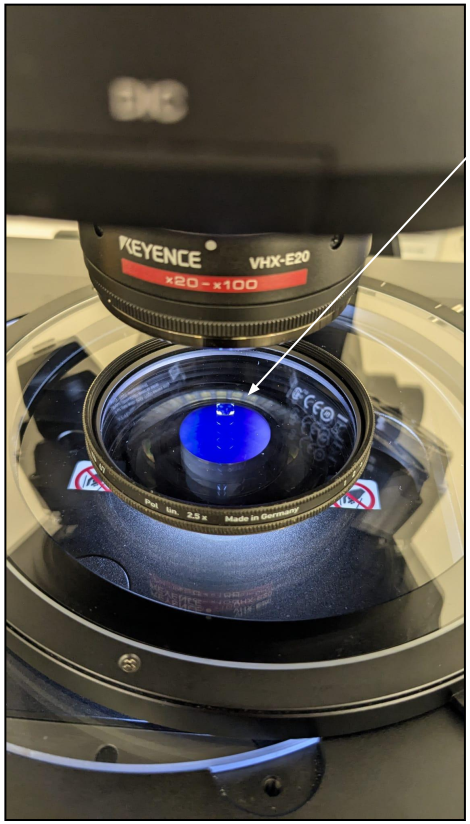
5 Layers each of 25 diamonds
+
Gamma-Ray detector

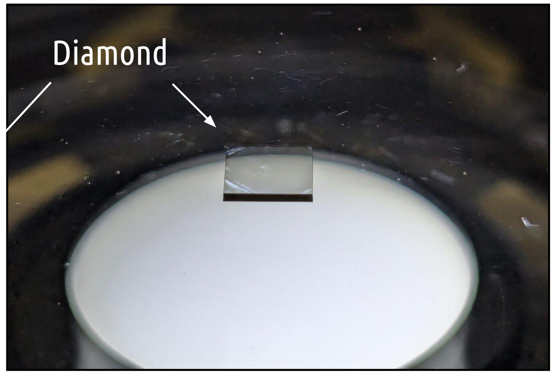
LISA coupled with state-of-the-art gamma detectors (i.e. AGATA) for the measurement of life-time for exotic nuclei

The Diamond Array

Diamond crystals

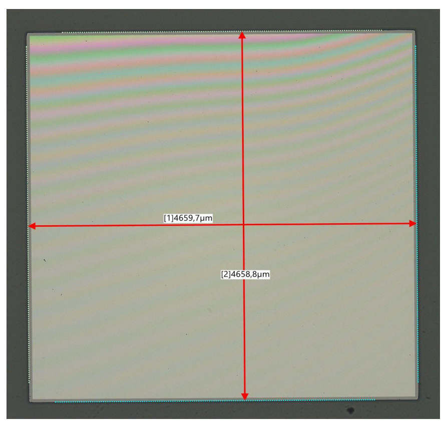
Visual characterization with high resolution microscope



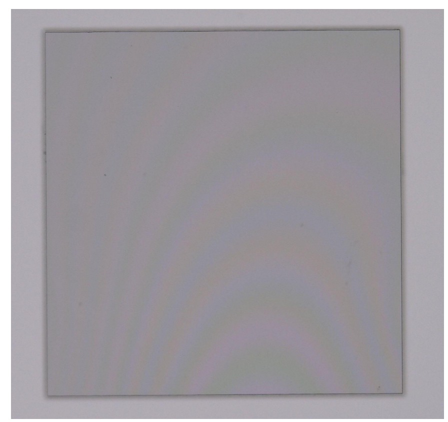


Monocrystalline, Chemical Vapour Deposition (SC-CVD) Diamonds

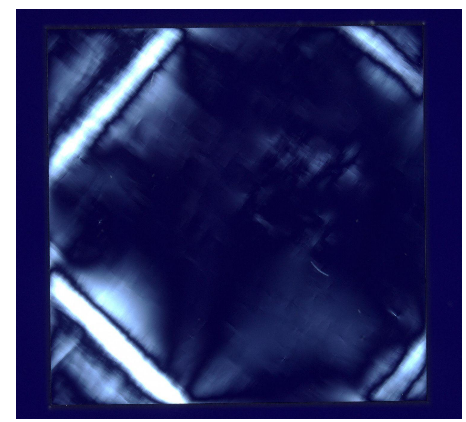
Thickness 500 µm - Area 4.5x4.5 mm^2



Coaxial



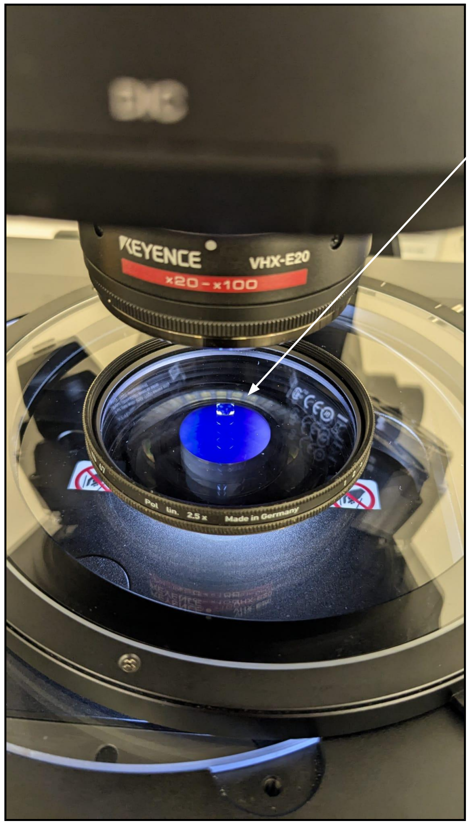
Transmission

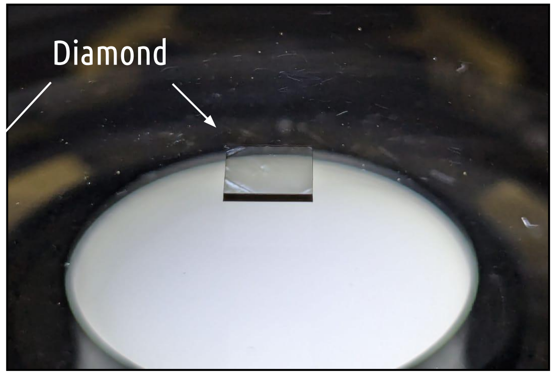


Cross-polarized

Diamond crystals

Visual characterization with high resolution microscope





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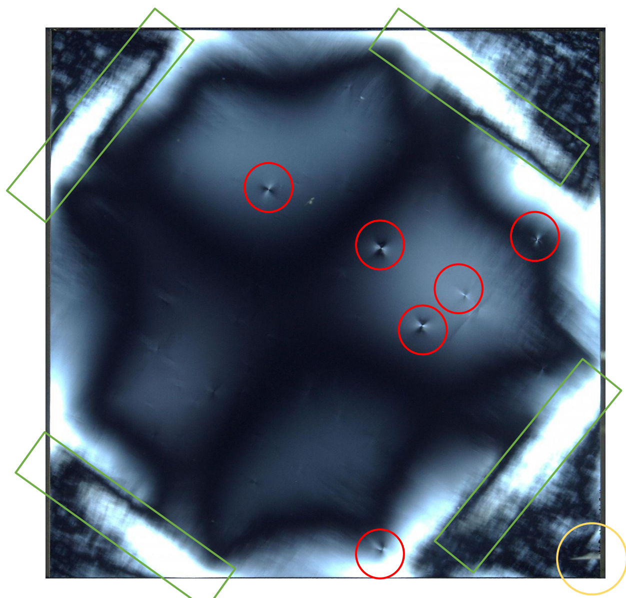
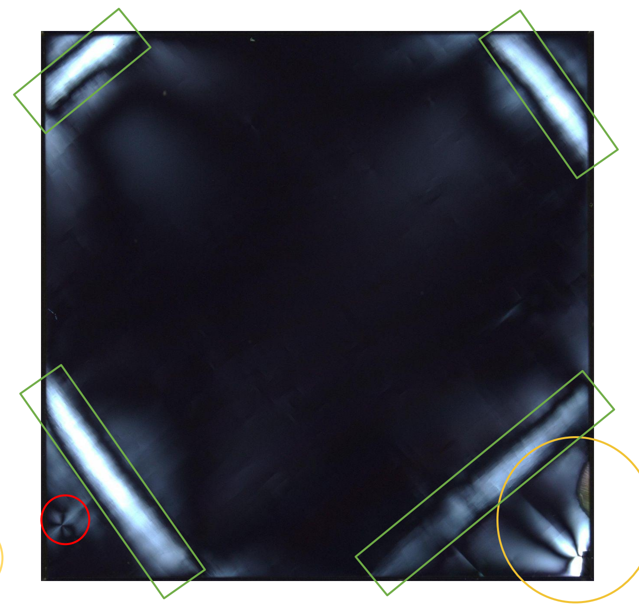
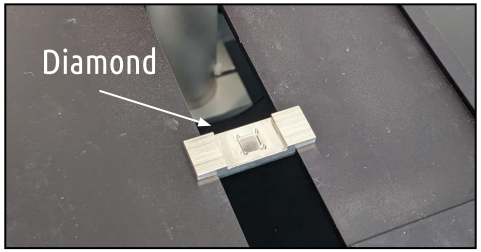
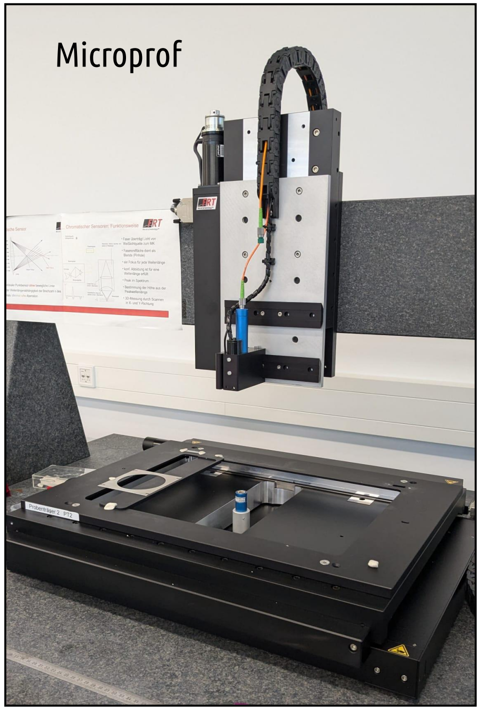




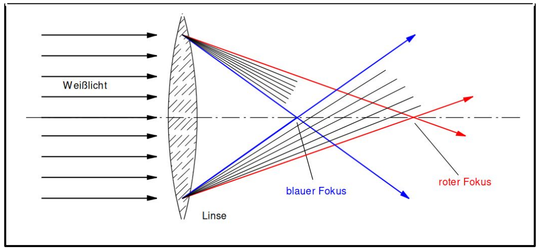
Diamond crystals

Thickness measurement with optical sensors

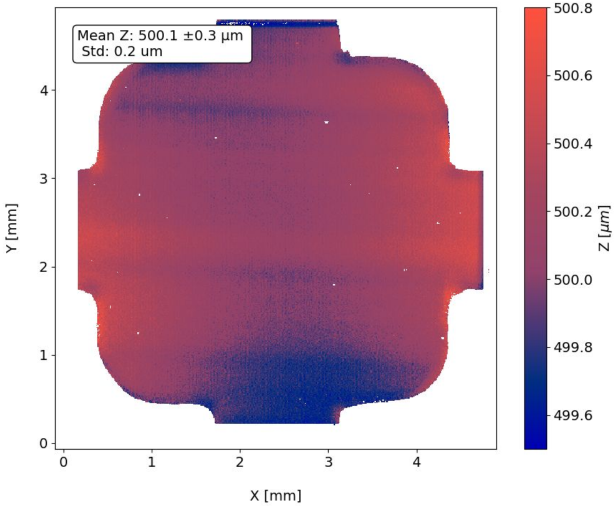




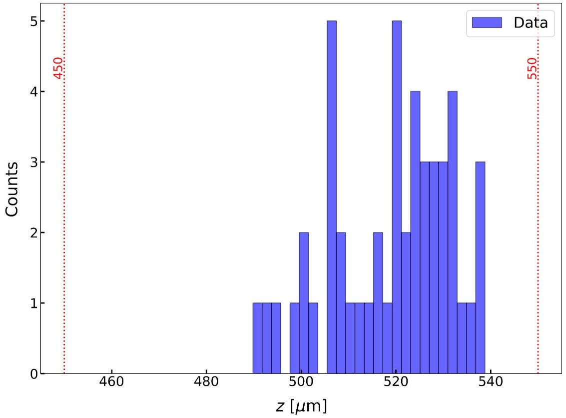
Optical Principle of Microprof



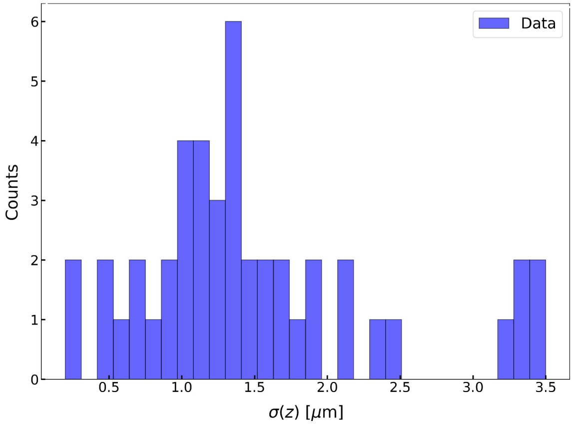
Thickness measurement



Thickness distribution



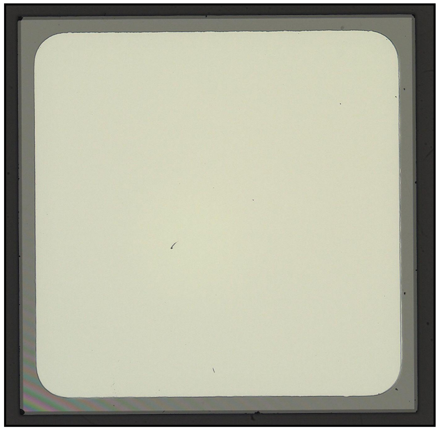
Std deviation distribution

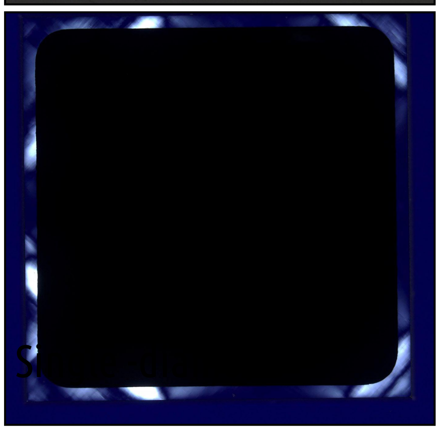


Diamond detectors

Metallization and assembling

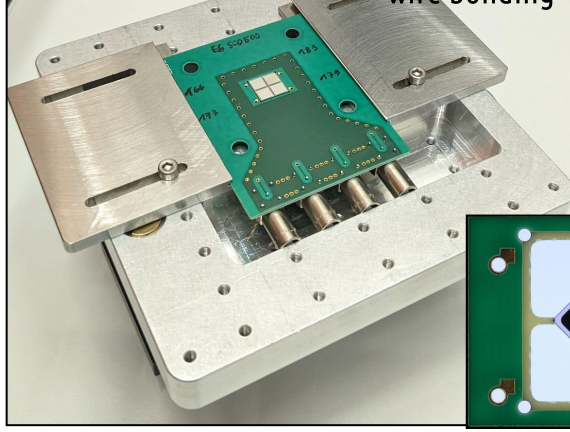
With metallization layer

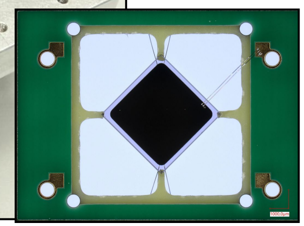


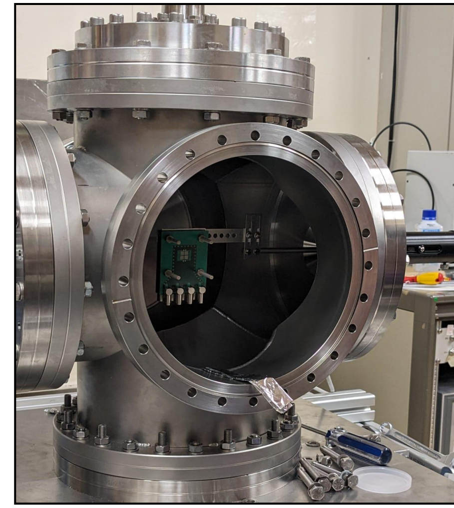


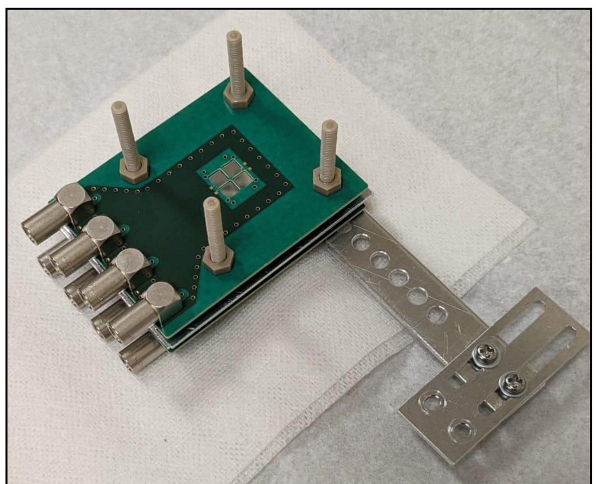
Active area
~0.18 cm^2 per diamond

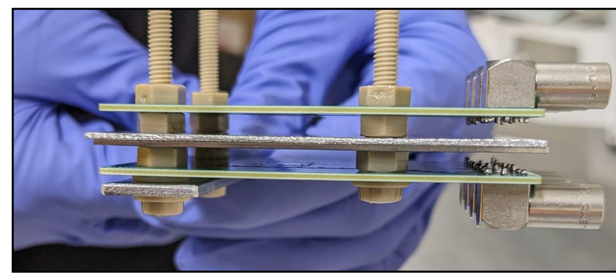
Preparation of PCB for wire bonding









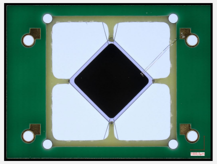


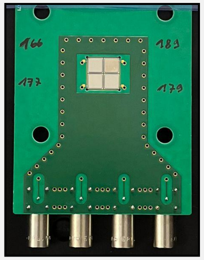
<u>Multi-Layer Prototype</u>

2 x 2 x 2 SC-CVD detector

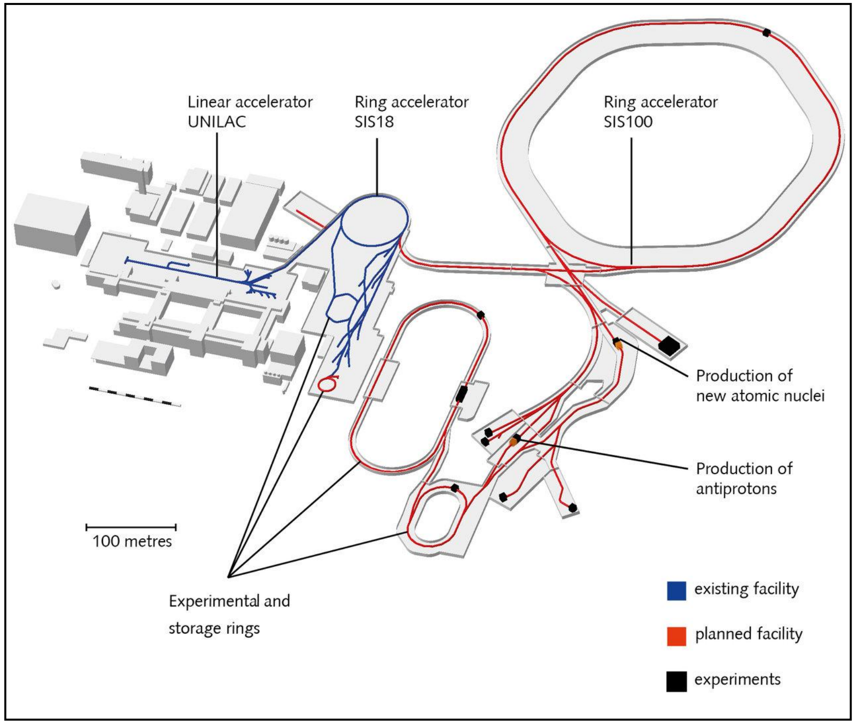
Active area of ~ 0.7 cm^2 per layer

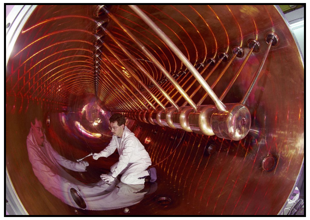
In-beam test @GSI


First in-beam test with single detector


Multi-layer test beam tracking and reactions identification

GSI facility (Darmstadt, DE)

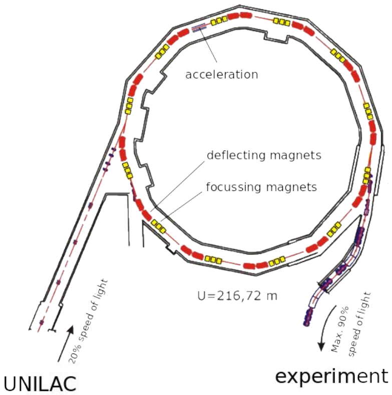




UNILAC

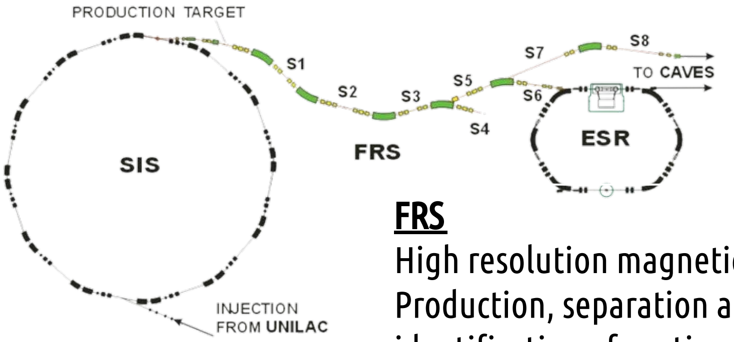
20 kV - 130 kV

v/c up to 16%



SIS18

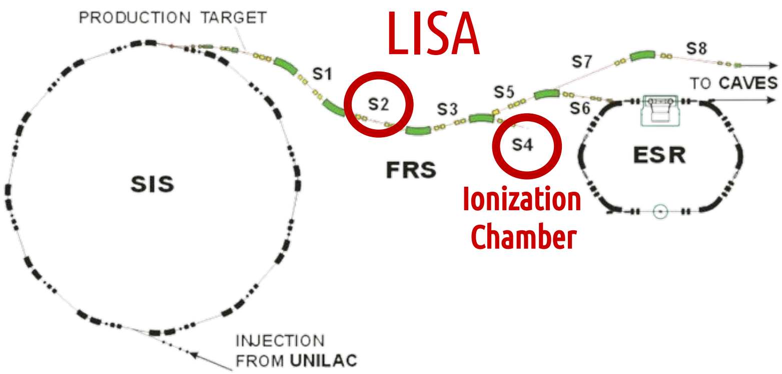
Energy of 4 GeV(p), 2 GeV/u (Ne), 1 GeV/u (U)
Max ion velocity 270 000 km/s (β = 90%)
Max B = 18 T
RF frequency = 0.85 - 6 MHz
Bending radius = 10 m
Intensity/ spill = 10^9 (i.e. for ^{238}U)

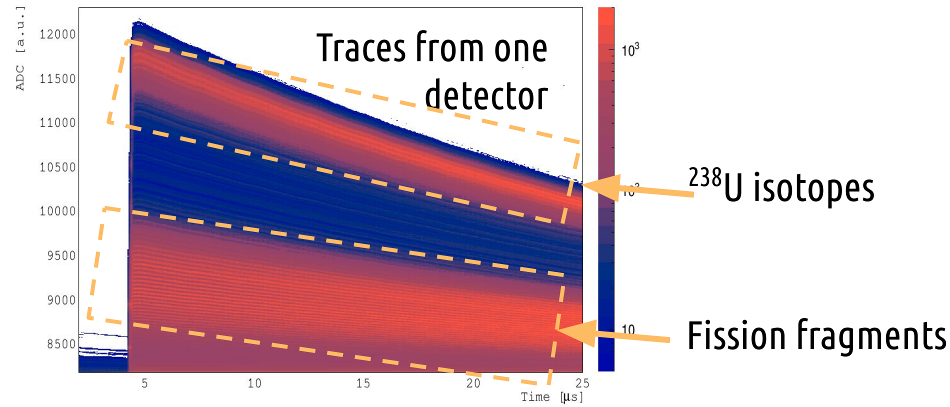


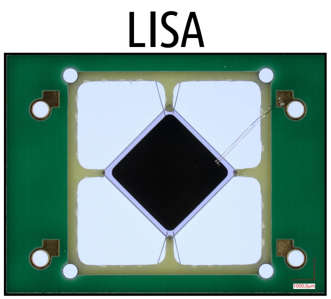
FRS

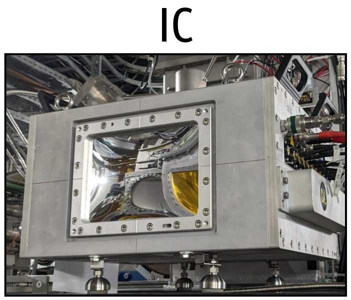
High resolution magnetic spectrometer
Production, separation and identification of exotic nuclei

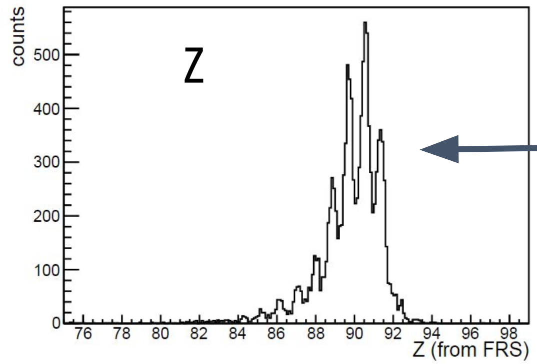
Single detector

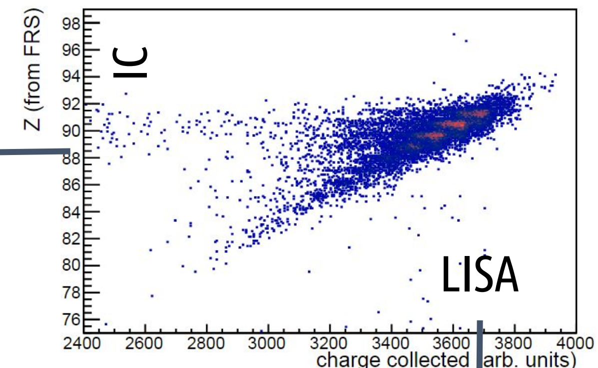






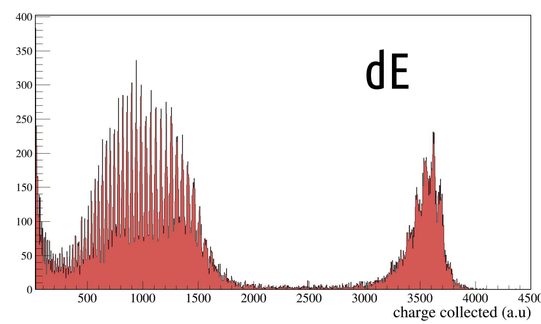


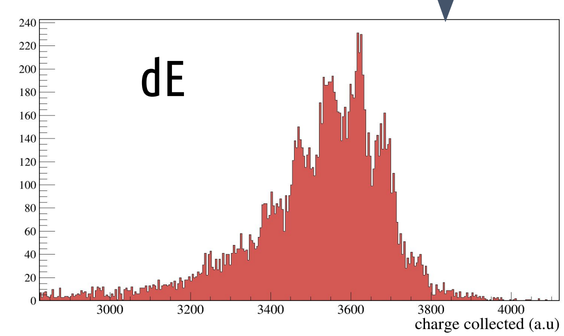




Test energy resolution and Z discrimination capabilities

^{238}U beam @1AGeV

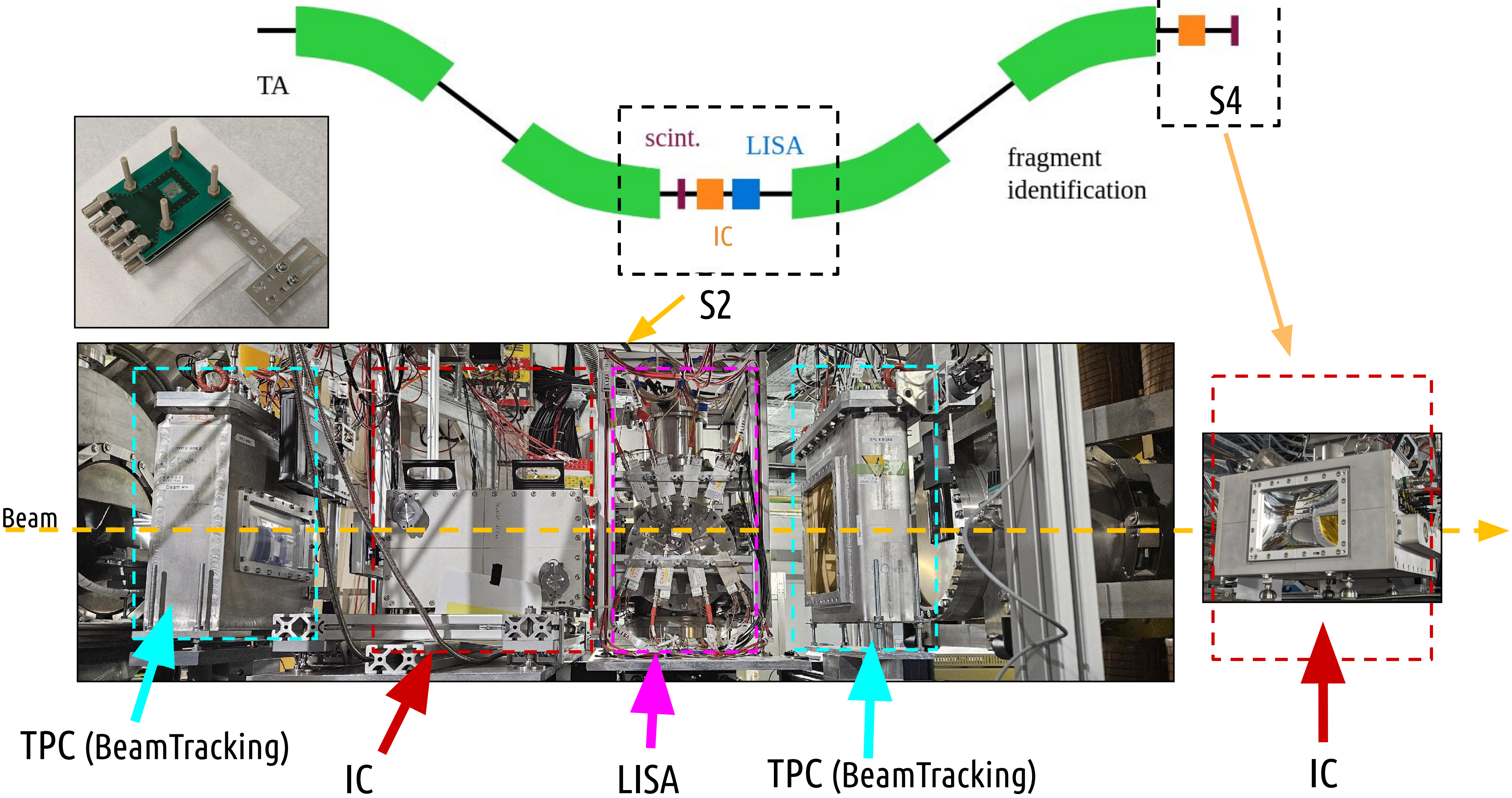




Multi-layer target

300, 500 AMeV ^{100}**Mo**

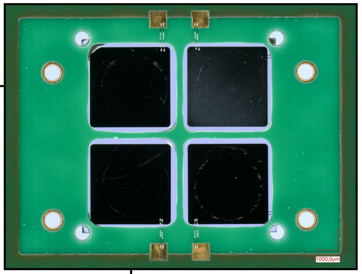
500 AMeV ^{100}**Mo fragments**



Multi-layer target

Prototype development

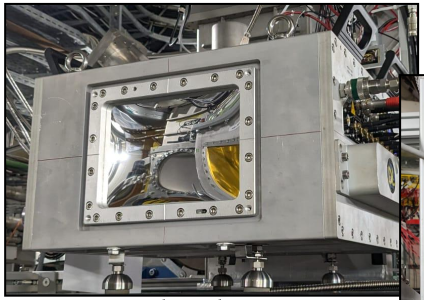
- Detector test and development (current monitor, HV test, metallization comparison)
- Electronics test (preamp and DAQ)
- Test of the whole experimental setup and data acquisition together with FRS



Layer prototype

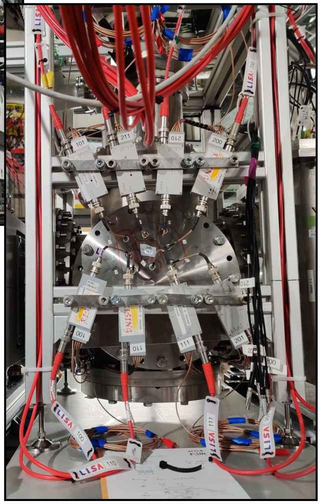
LISA multi-layer target test

- Comparison with detectors
  -> Z identification
- Correlation with FRS
  -> Reaction identification



Ionization Chamber

LISA chamber

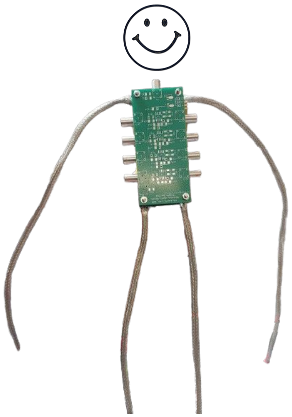


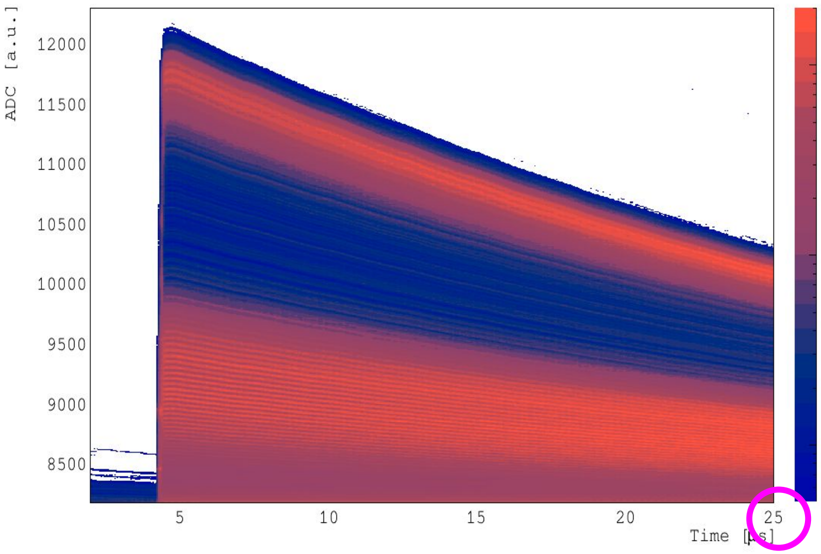
Preliminary results

LISA preamp prototype

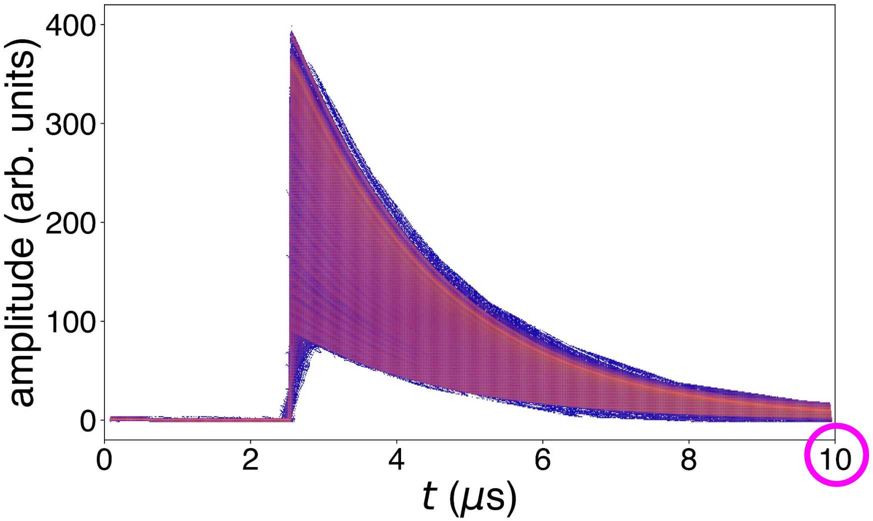
CSTA2
Charge Sensitive Preamplifier with fast Timing Output

preLISAmp
Charge Sensitive (only energy output)





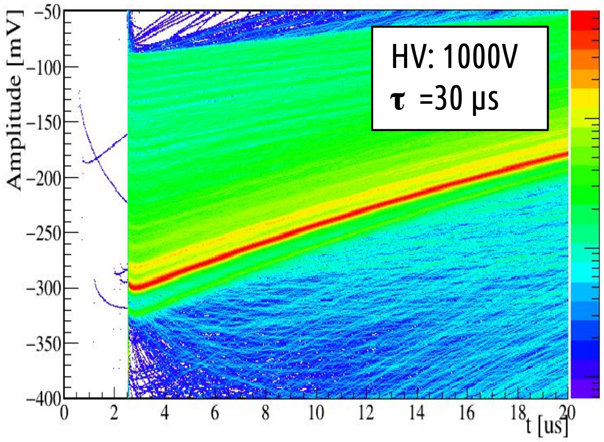
CSTA2 - Single detector test

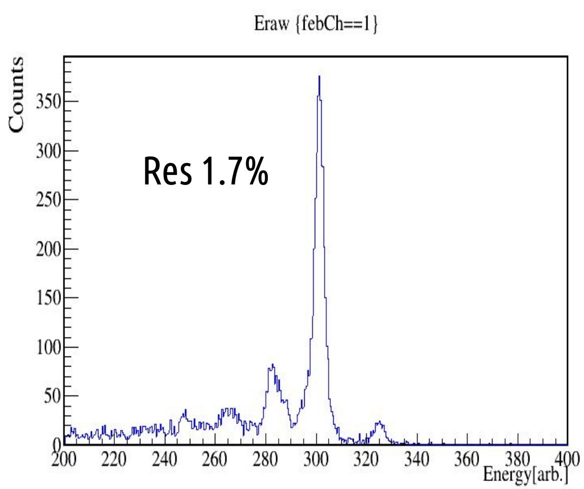


New LISA preamplifier (preLISAmp) - Multi-layer test

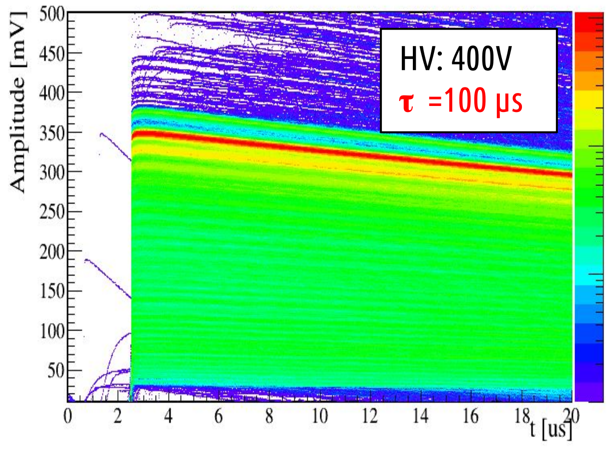
LISA preamp prototype

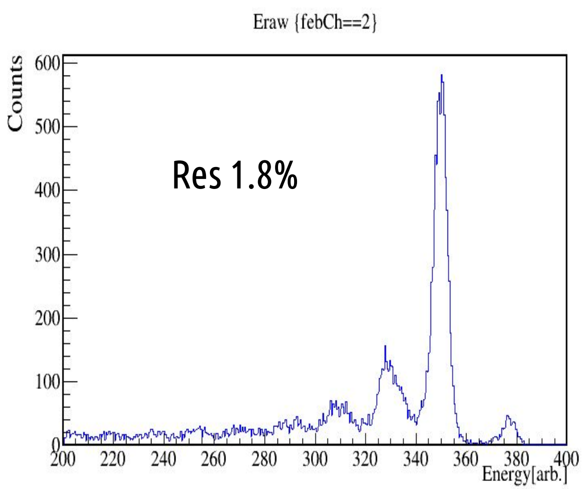
CSTA2



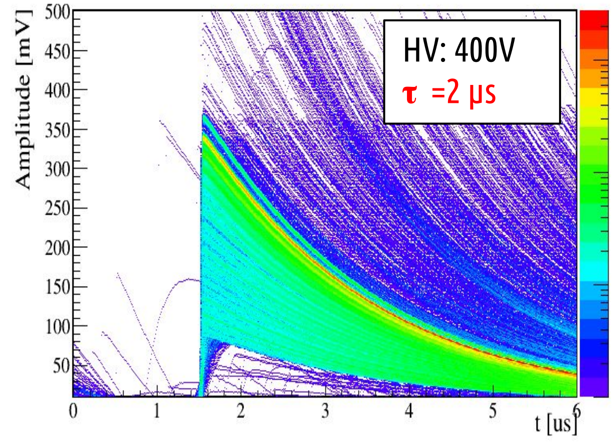


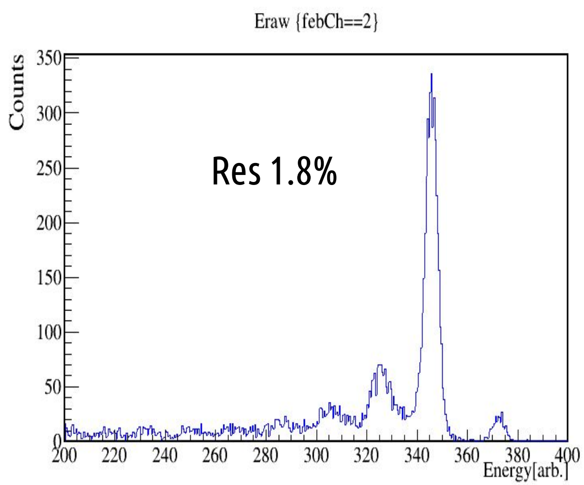
preLISAmp



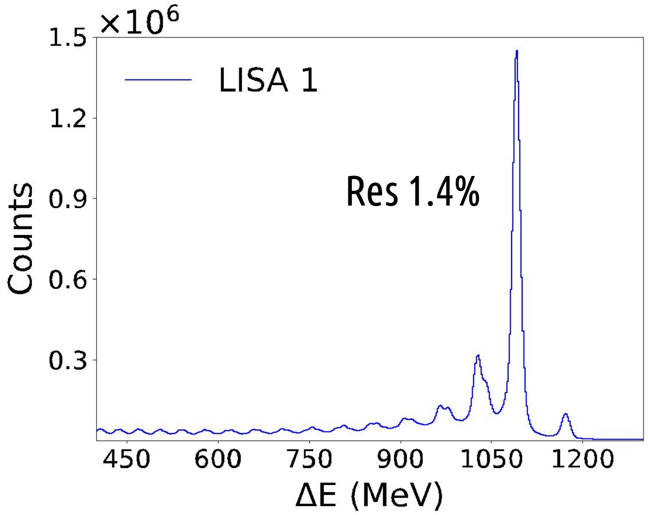


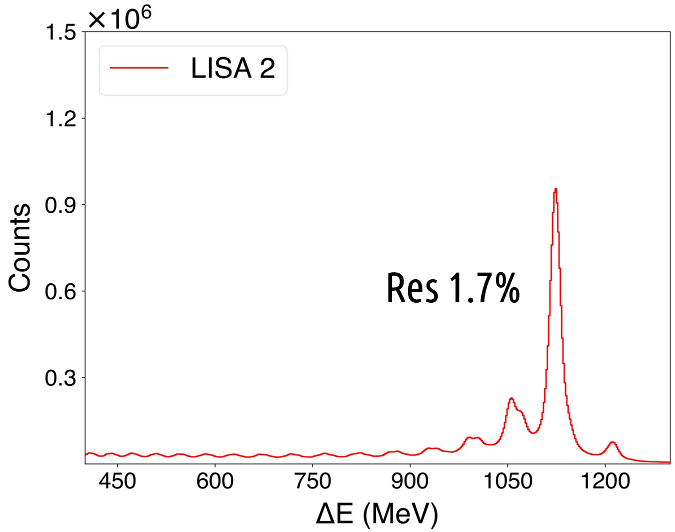
preLISAmp





Reaction identification - LISA





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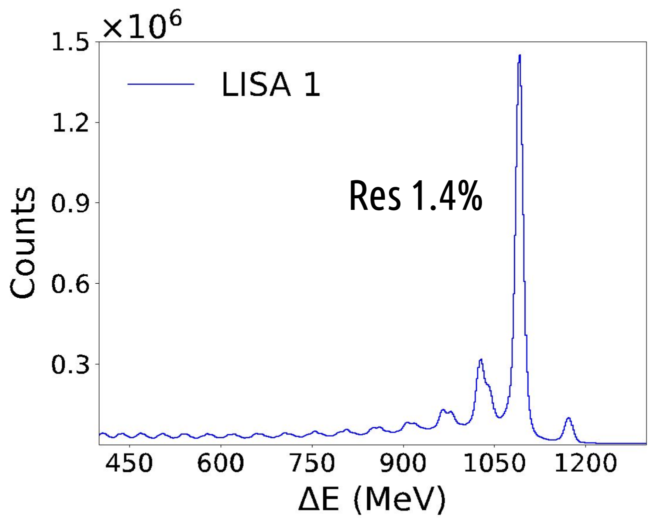
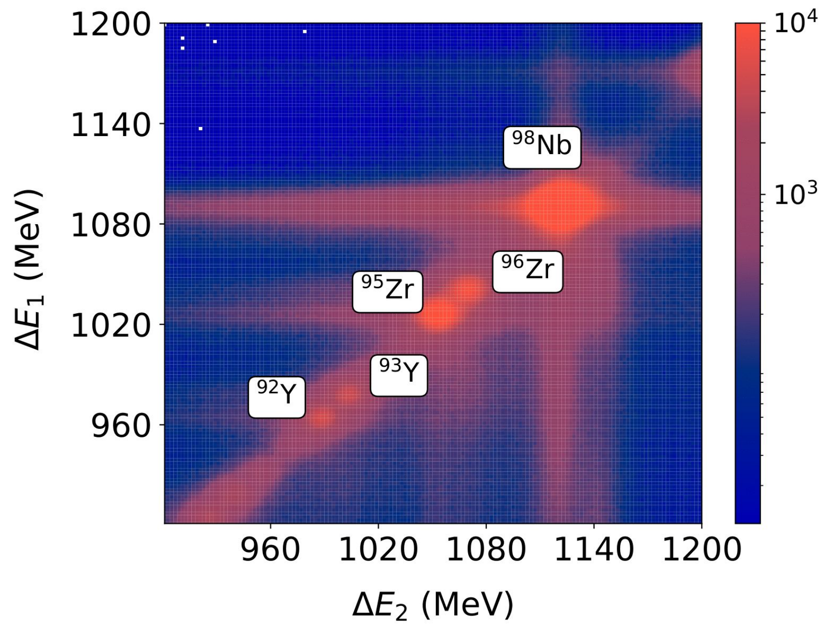
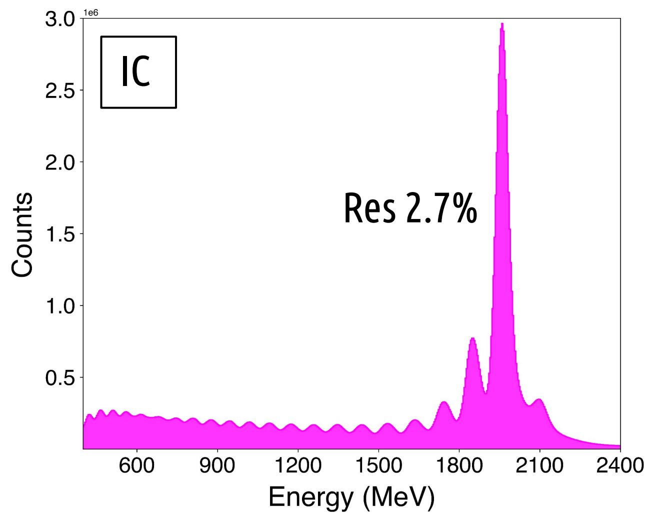
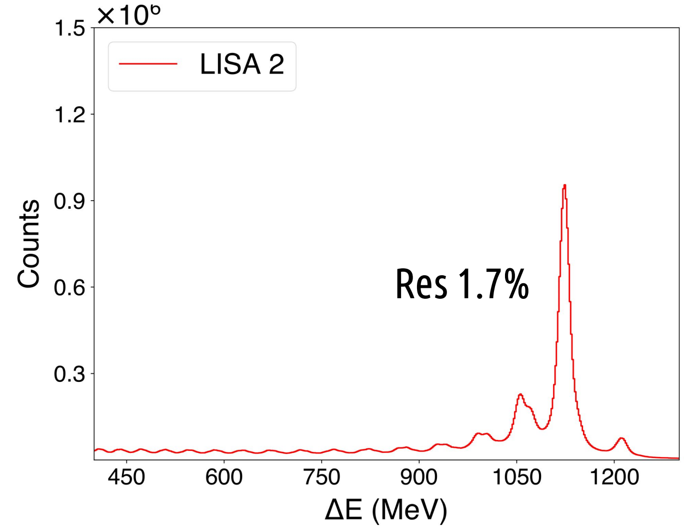
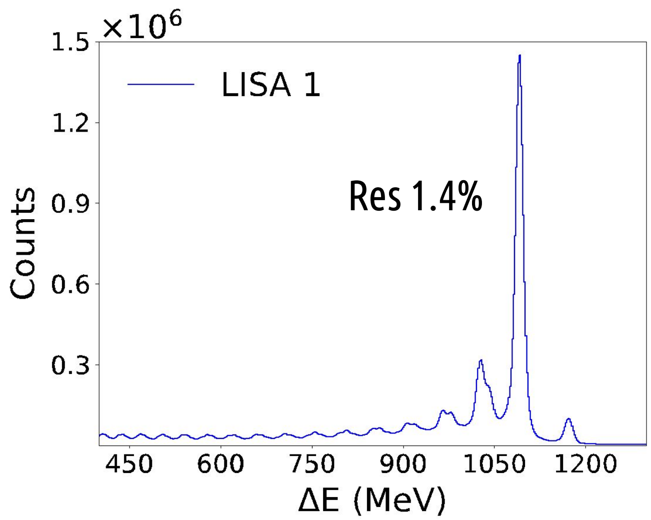


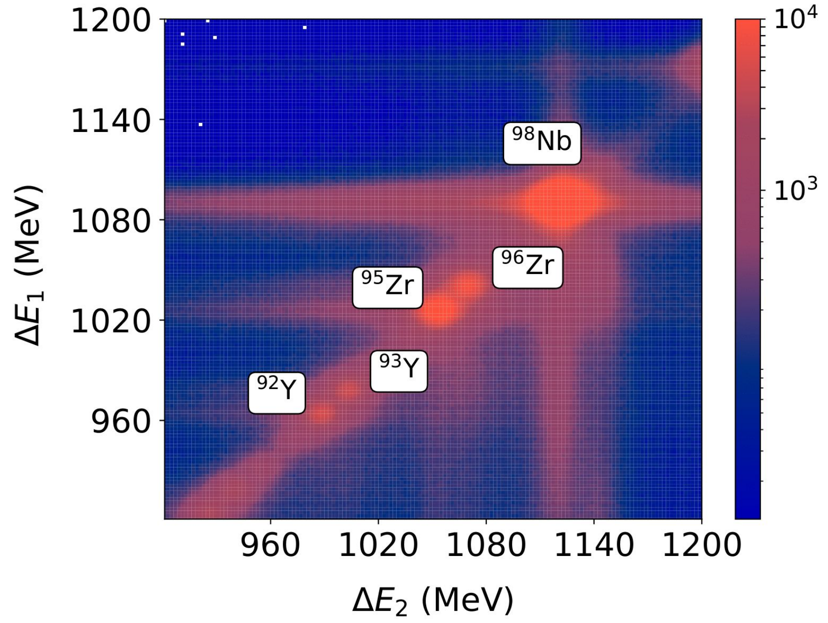


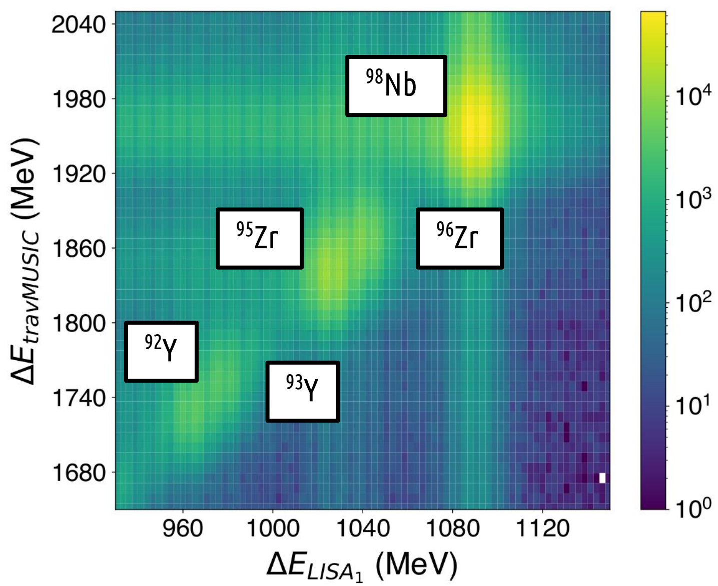


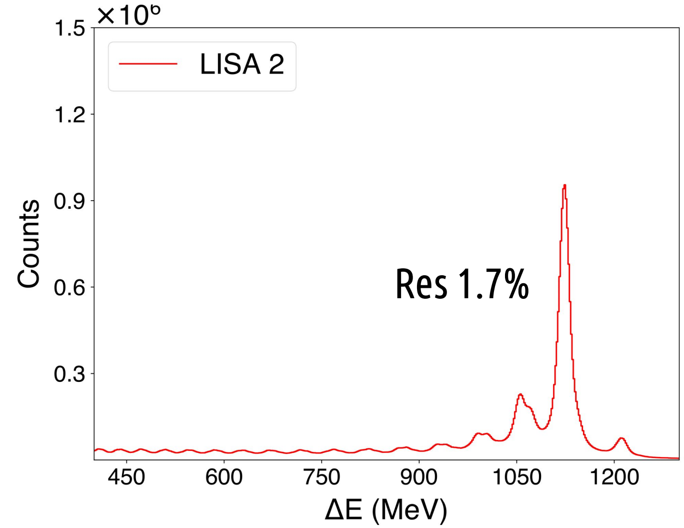


Reaction identification - LISA



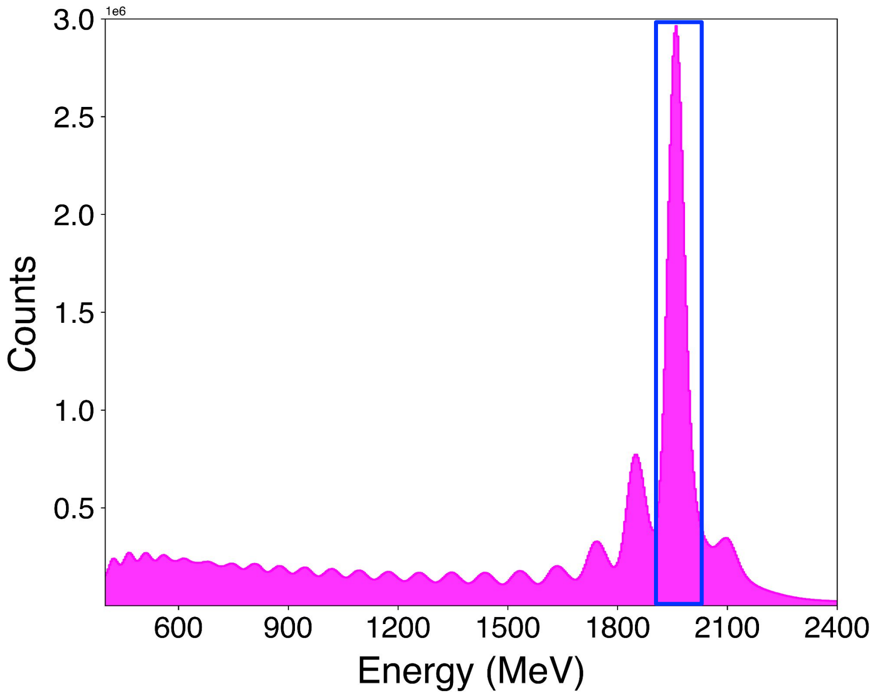




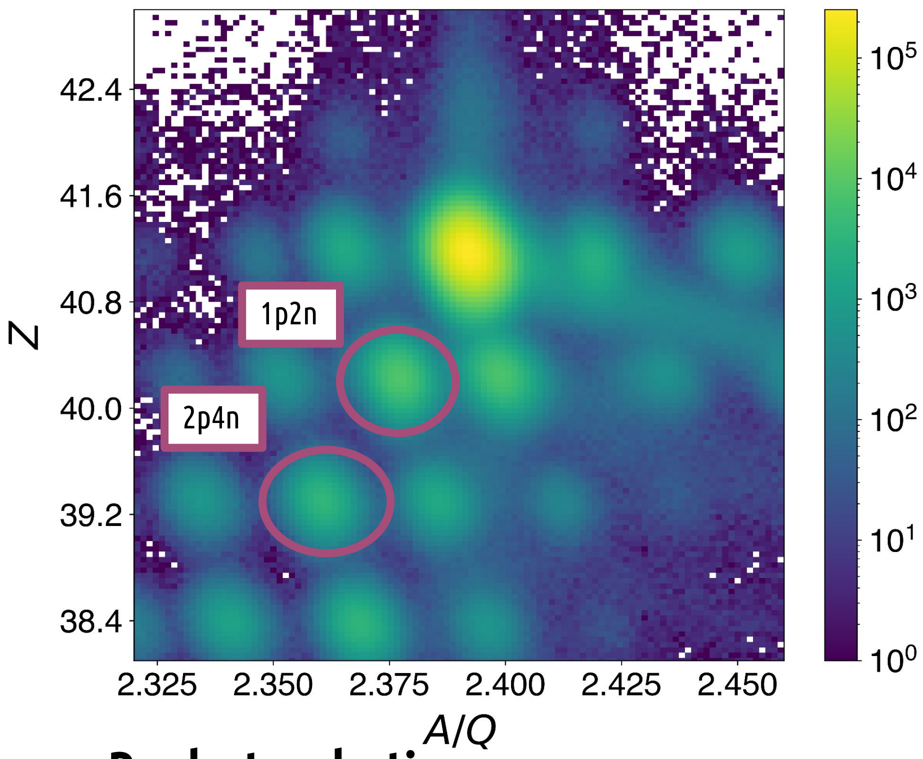


Correlation LISA-FRS

Before LISA



After LISA



Beam selection

Gates on IC in S2

^{98}Nb

Products selection

Gate on Z vs AoQ in S4

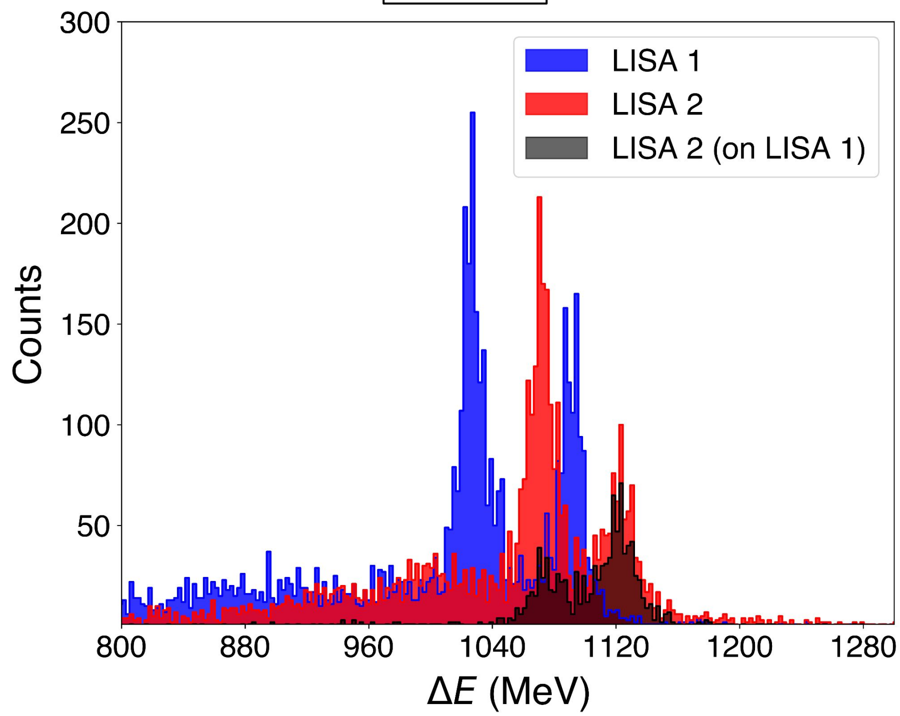
1p2n (^{95}Zr)

2p4n (^{92}Y)

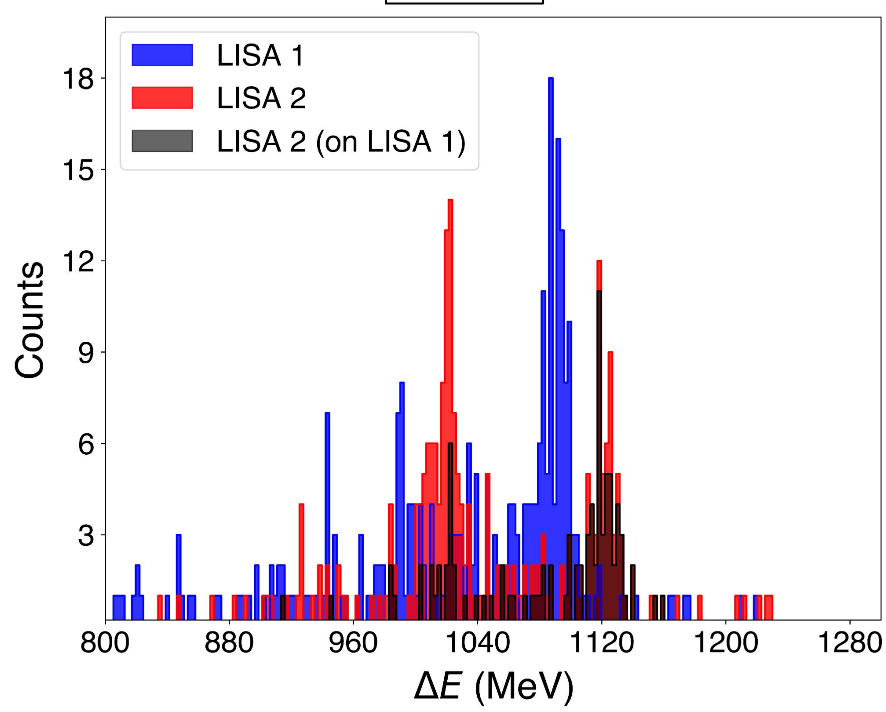
Correlation LISA-FRS

PRELIMINARY

1p2n



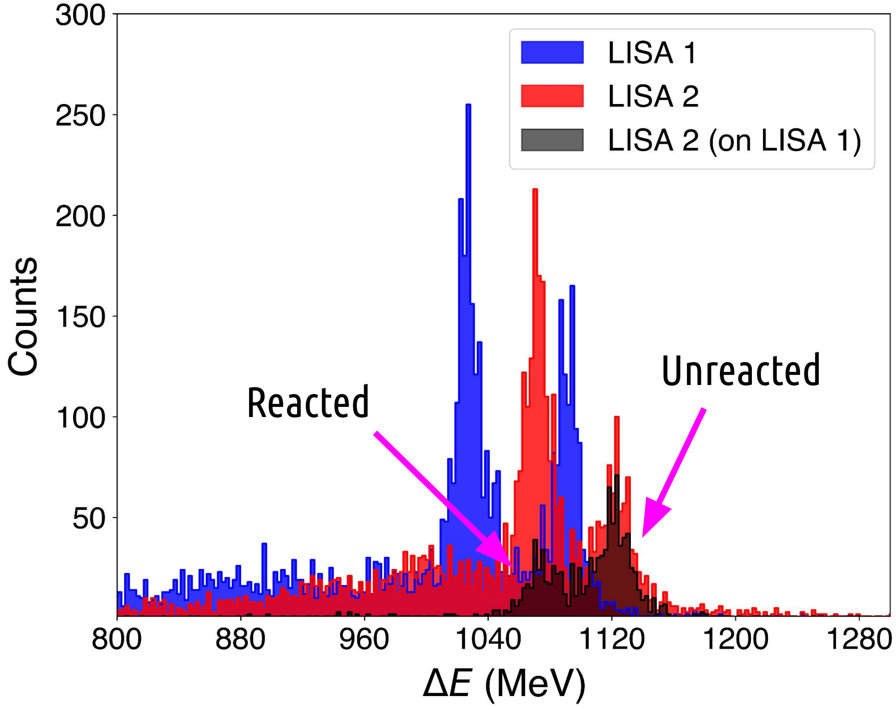
2p4n



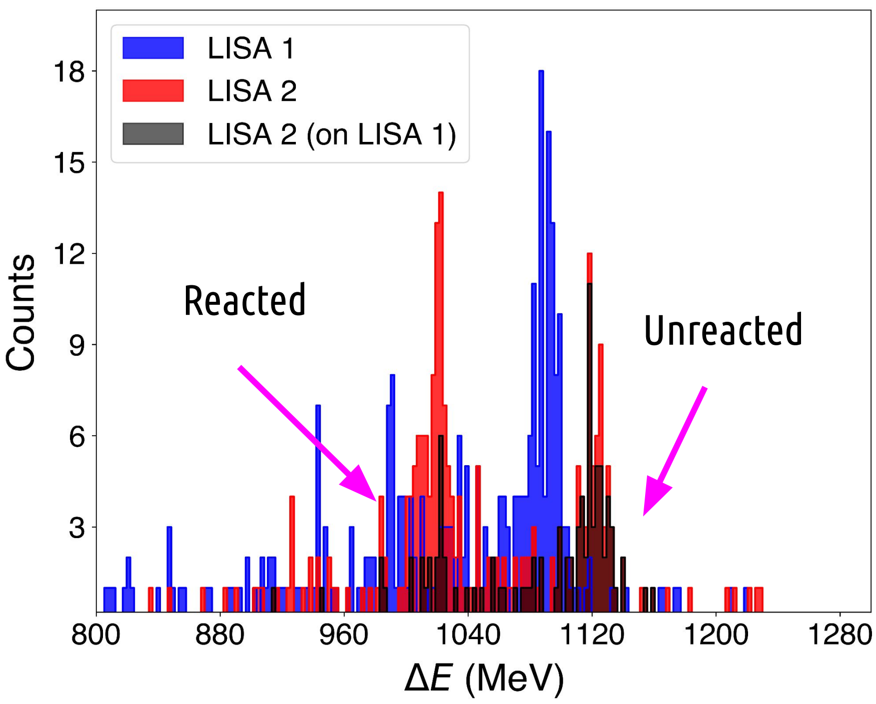
Correlation LISA-FRS

PRELIMINARY

1p2n



2p4n



Proof of the working principle for reactions identification!!

Current developments

Diamond characterization with X-ray tube

Upgrade of the whole system

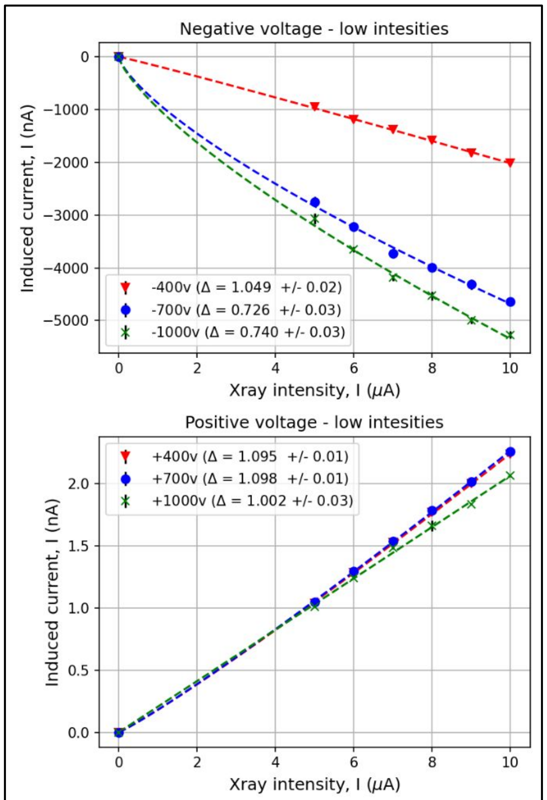
New preamp

Diamond characterization - Xray

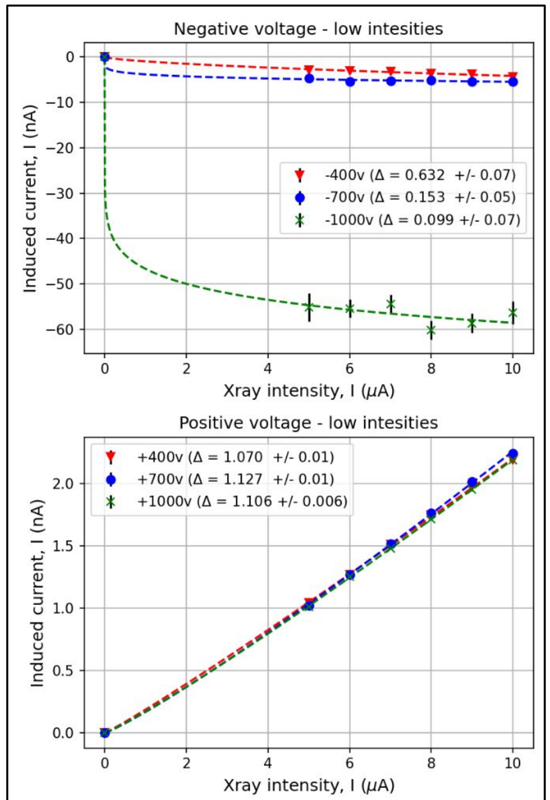
Current response under Xray irradiation vs $I_{(Xray)}$ and $HV_{(detector)}$

Linearity connected to diamond quality according to Fowler eq.:
[Ade et al. 2015] [Abdel-Rahman et al. 2019]

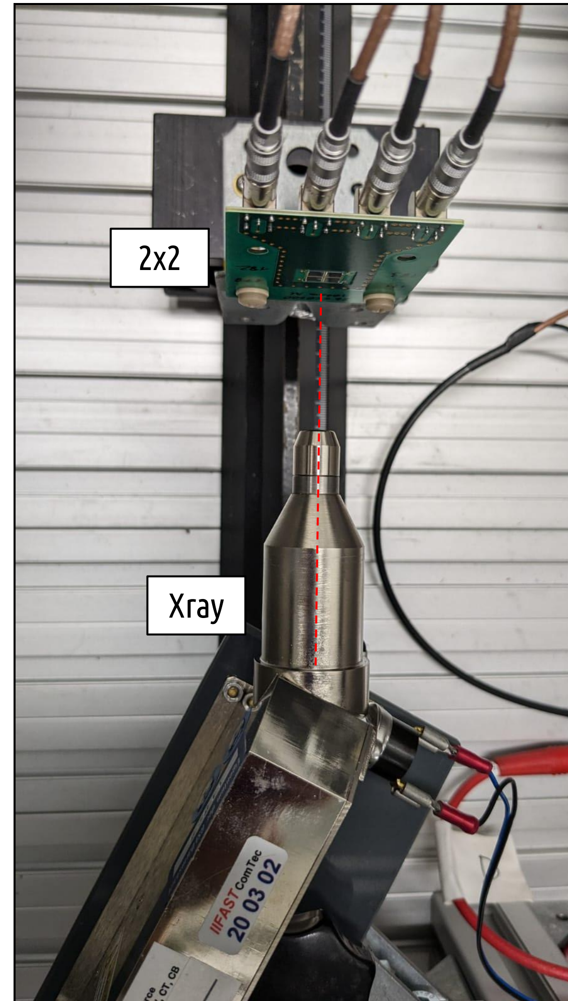
$$I = I_{dark} + RD^{\Delta}$$



171

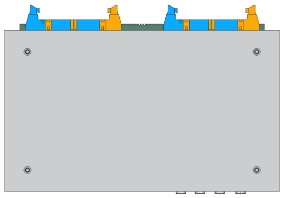


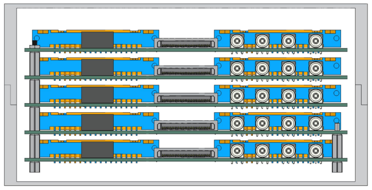
183

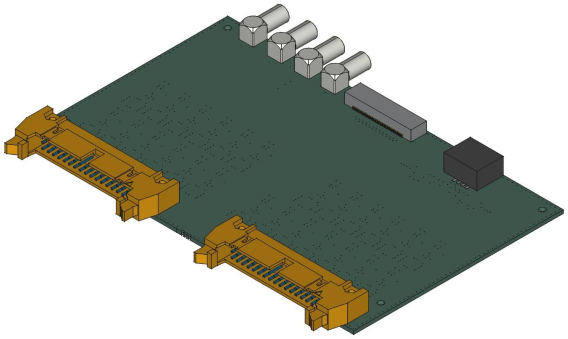


LISA preamp development

Charge-sensitive preamplifier for LISA

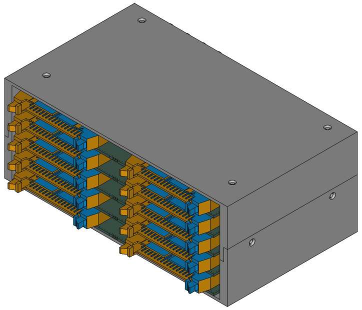






25 energy channels
Output independence: 100 ohm
Flexible dynamic range
(*high-gain* setting, 6 mV/MeV | *low-gain* setting, 300 mV/GeV)

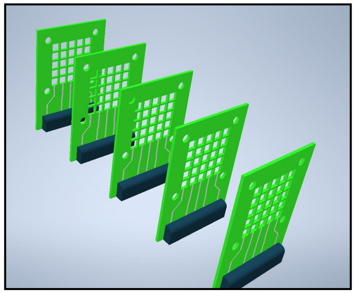
1GeV deposit on diamond:
10ns rising time; 6us decaytime, noise < 2mV

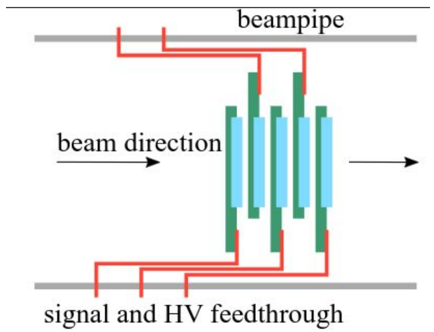


1x 30-pin input
(SAMTEC: FCS8-30,0.8mm pitch)
2x 34-pin output (2x17, 2.54mm pitch)

Upgrade of the system

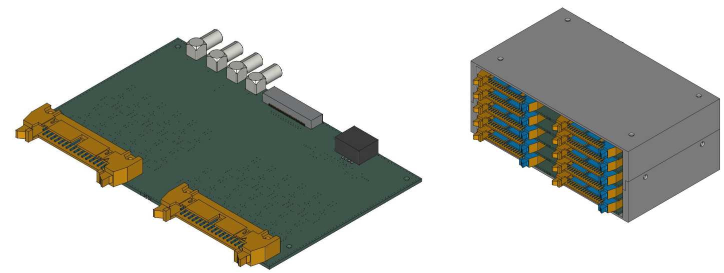
DETECTOR





5x5 layer
25x5 diamonds

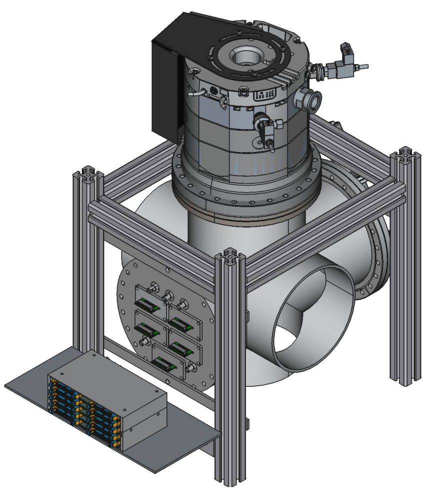
DAQ & ELECTRONICS

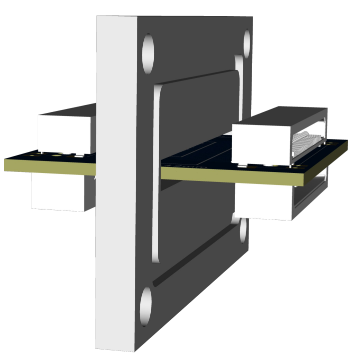


preLISA

10 FEBEX cards

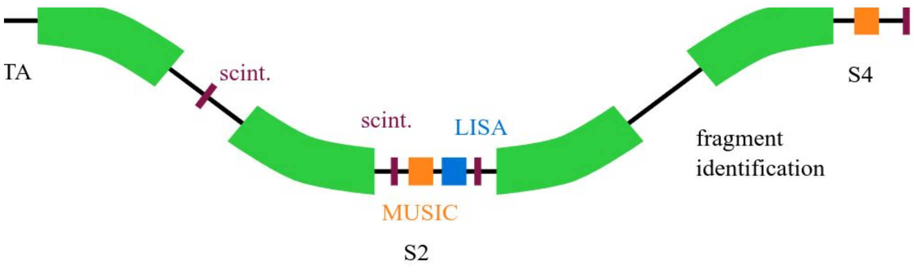
MECHANICS

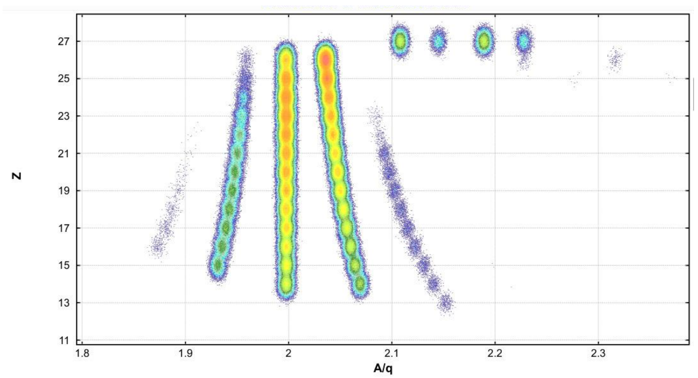




Future perspectives

Future perspectives





Goals for next beamtime in May

- First test with full system with 5 layers
- Commission the final LISA
- Reaction channel selectivity
- Develop cross-section measurement capability (charge changing cross-section)

FRS settings

- Secondary beam energy around 200 MeV/u
- N = Z setting for simplicity
- i.e. ^{52}Fe (kown charge radius, N=Z)

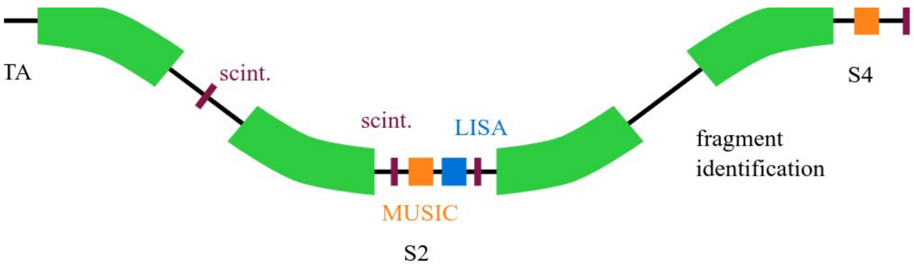
FRS upgrades

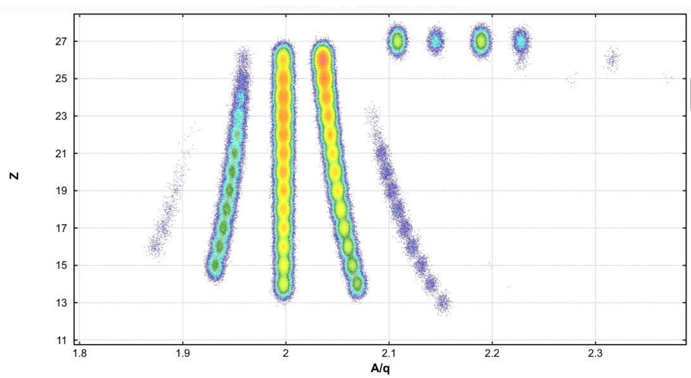
Full PID before and after LISA

Z calibration

Reaction identification

Future perspectives





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FRS upgrades

Full PID before and after LISA

Z calibration

Reaction identification

Future plans

Coupling with high precision gamma spectrometer for lifetime measurements at facilities like future FAIR and FRIB

THANK YOU FOR YOUR ATTENTION

G. Andretta, M. Bajzek, J. Bardak, B. Bles, G. Bruni-Campanella,
Z. Chen, D. Das, F. Drent, E.M. Gandolfo, E. Haettner, P. Hermann,
C. Hornung, N. Imai, C. E. Jones, N. Jovancevic, B. Lommel , M. Kis,
N. Kitamura, B. Kindler, H. Kleis, N. Kurz, D. Maletic, S. Michimasa,
C. Nociforo, W. Poklepa, M. Reece, M. Reese, M. Saifulin, H. Schaffner,
P. Schwarz, E. Takada, M. Trager, S.Walch, T. Weber, H.Werner
and K. Wimmer

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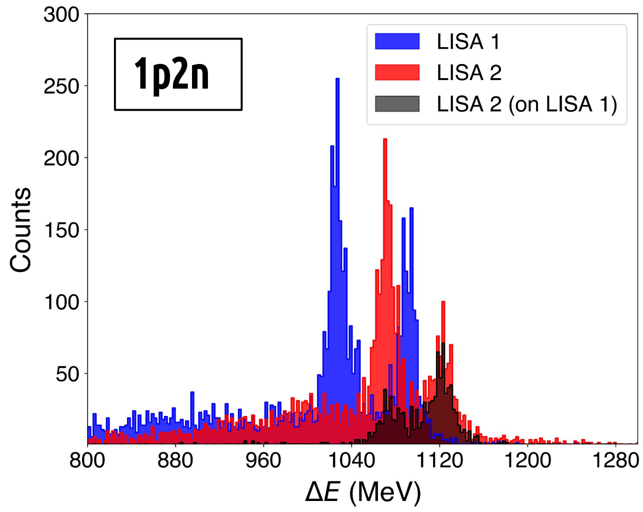
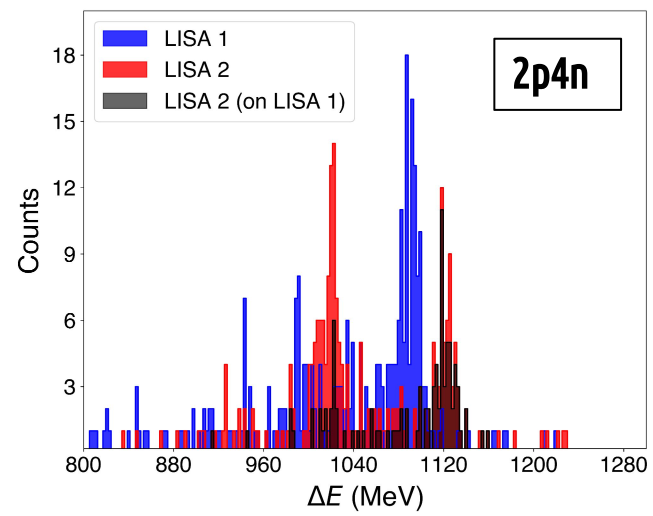
erc
European Research Council
Established by the European Commission

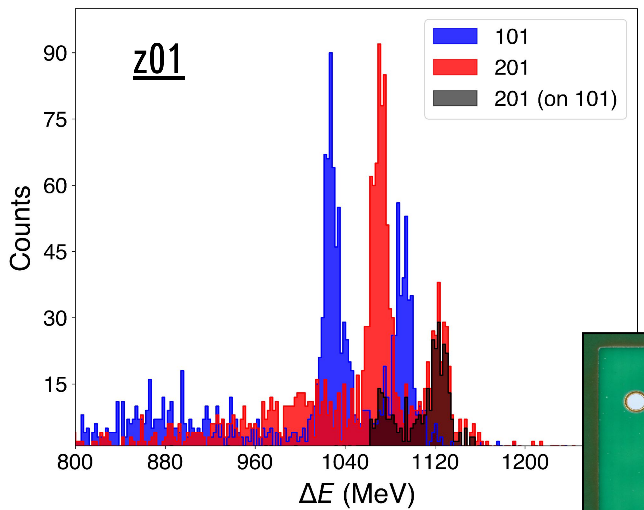
BACKUP

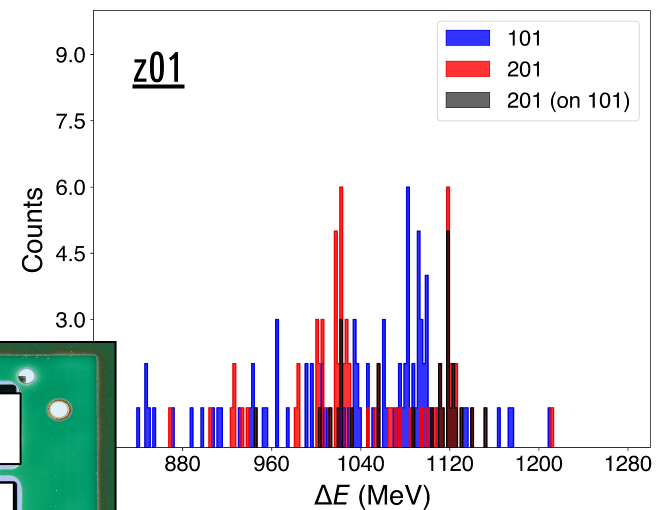
Correlation LISA-FRS

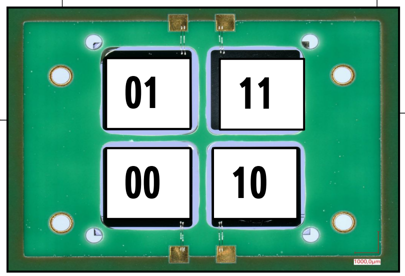
PRELIMINARY



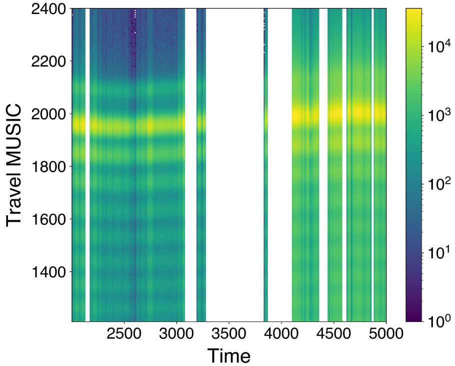


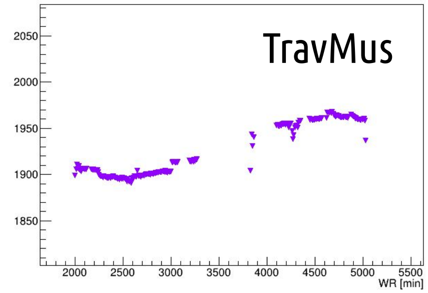


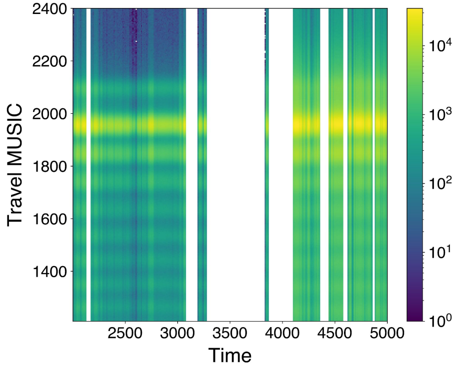


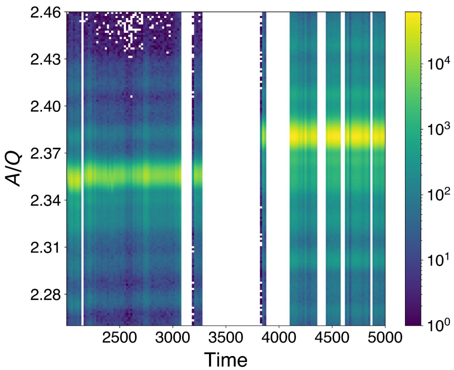


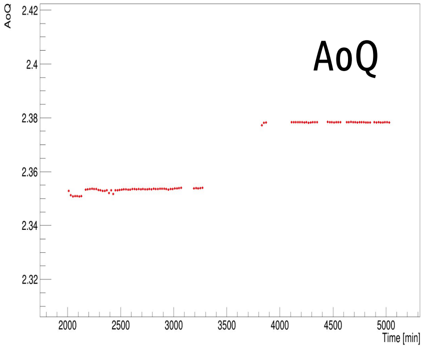
FRS

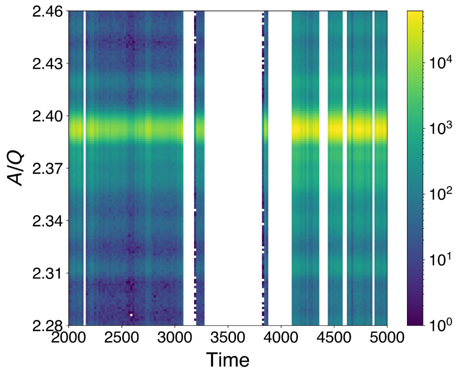

Travel MUSIC
Time

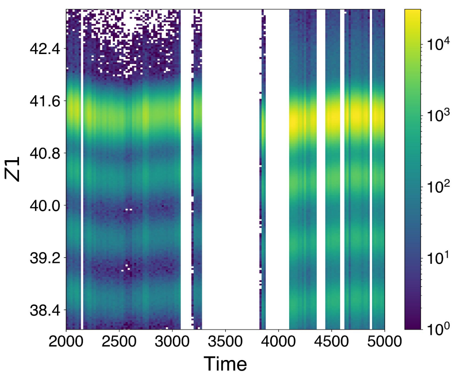

TravMus
WR [min]

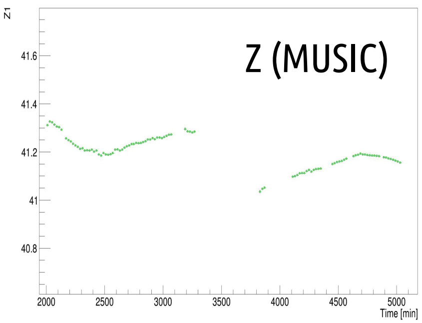

Travel MUSIC
Time

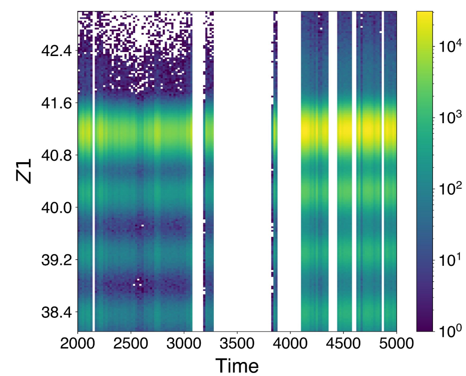

A/Q
Time


AoQ
Time [min]


A/Q
Time


Z1
Time

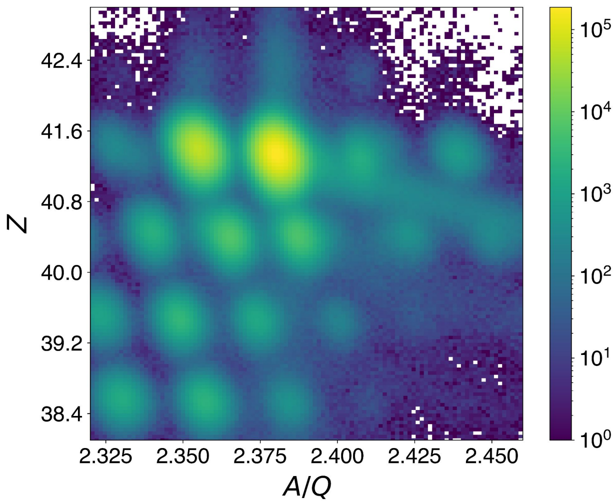

Z (MUSIC)
Z1
Time [min]

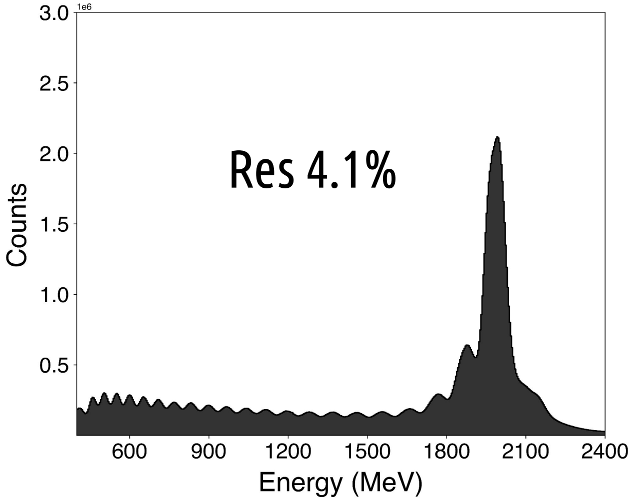

Z1
Time

FRS

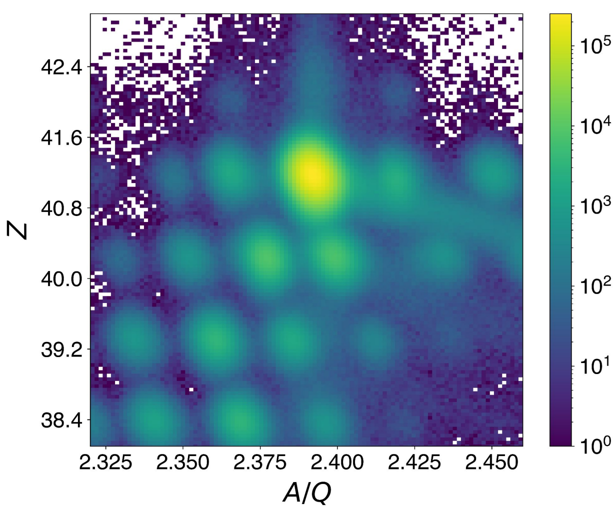
Z vs AoQ

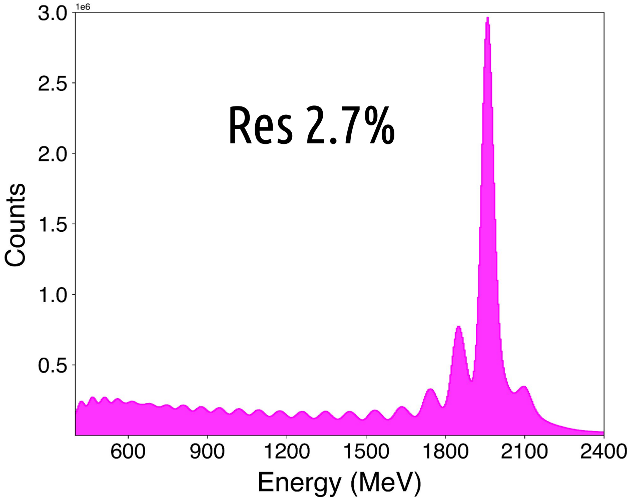
TravMUSIC dE





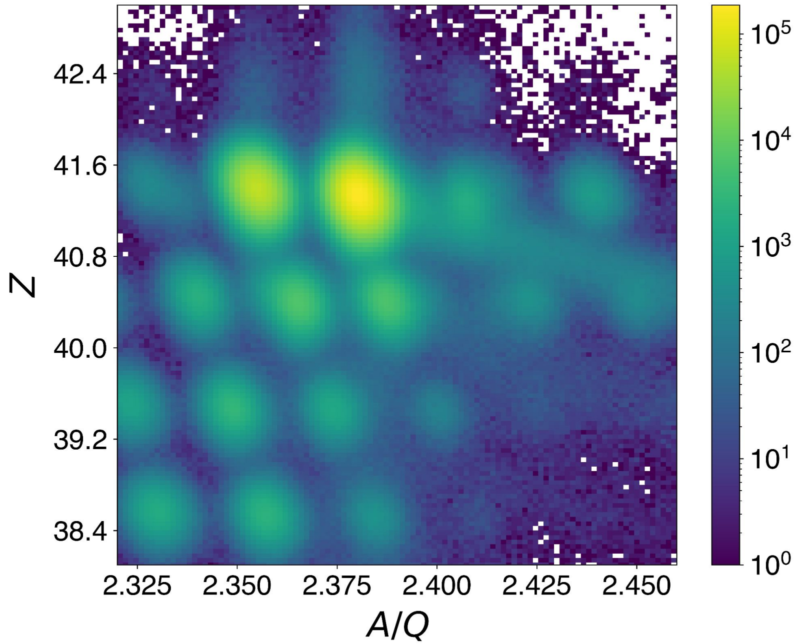
Corrected

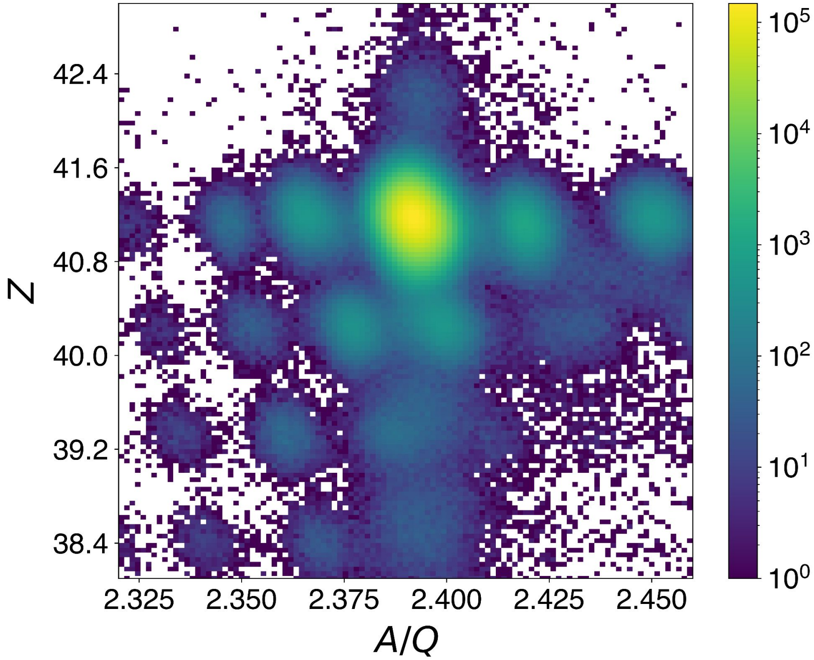




Correlation LISA-FRS

AoQ vs Z with and without
98Nb gate on TravMusic





Machine Learning for Reaction Layer Determination

Identify the layer where the reaction occurs

Geant4 simulations of energy spectra as training data-set

Multi-class classification problem:

- Artificial Network and Random-forest algorithm to train the model

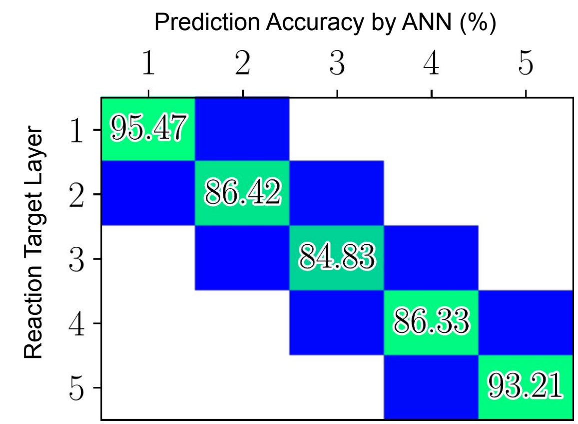
Current results show better performances with random-forest algorithm

Future plans

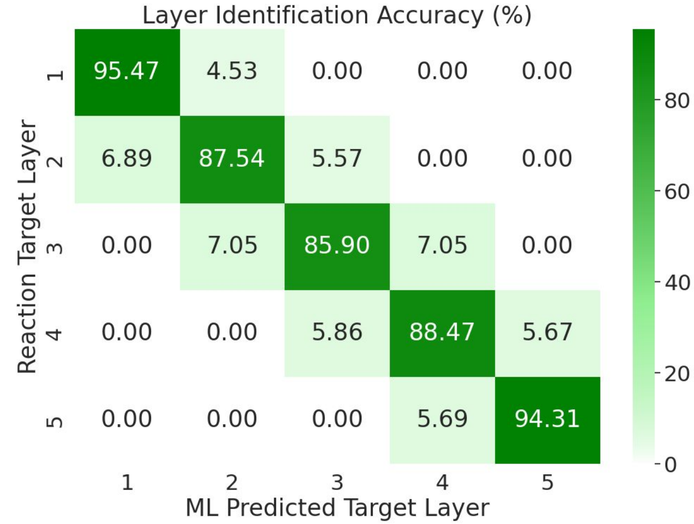
More accurate Geant4 simulation

Apply Deep Learning algorithm

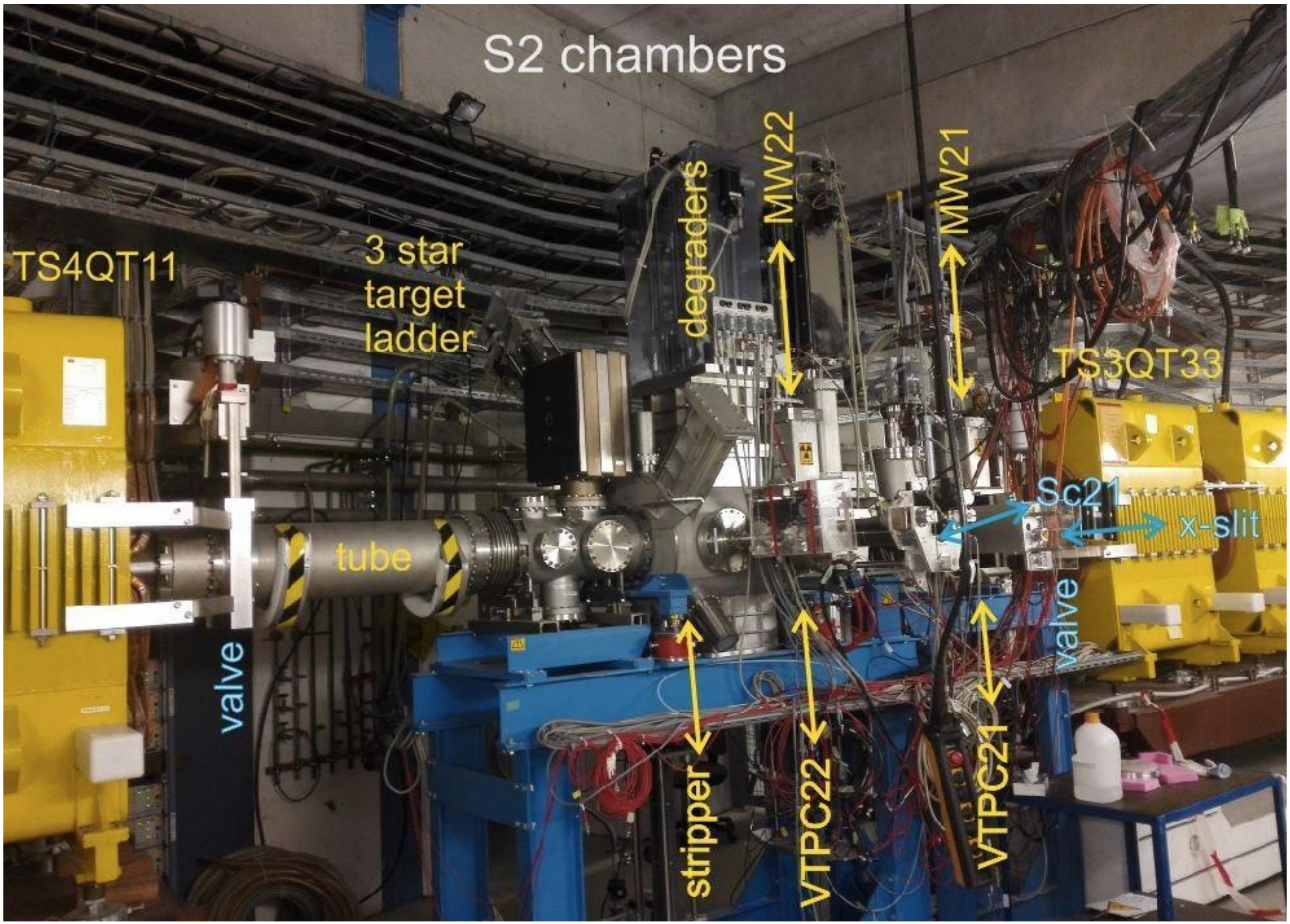
Artificial Network



Random-forest



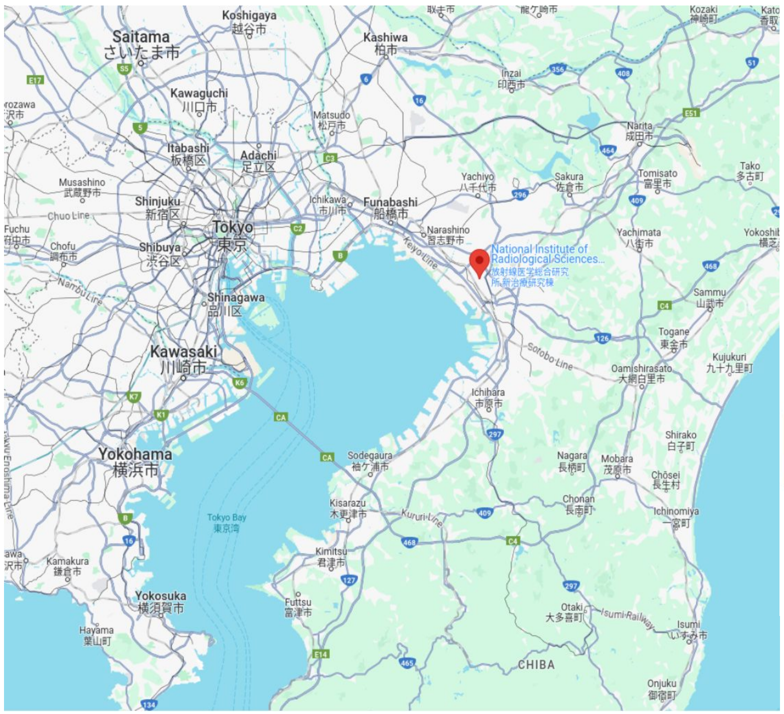
Pareeksha - Multi-layer target + FRS

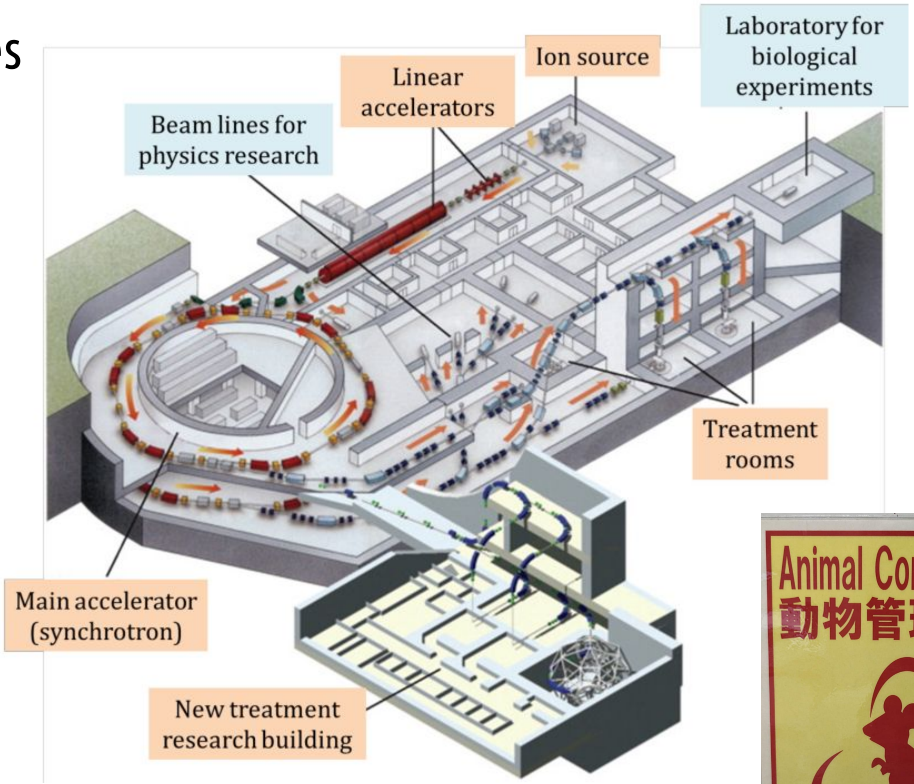


Jikken – Multi layer target

JIKKEN experiment @HIMAC

National Institute of Radiological Sciences
Heavy **I**on **M**edical **A**ccelerator in **C**hiba





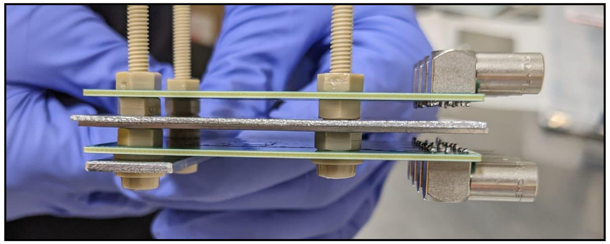
Synchrotrons for heavy ions
up to 800 AMeV

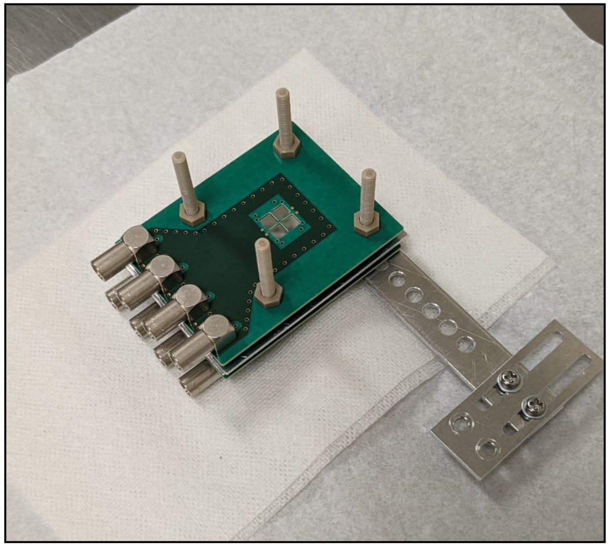
Jikken – Multi layer target

JIKKEN experiment @HIMAC

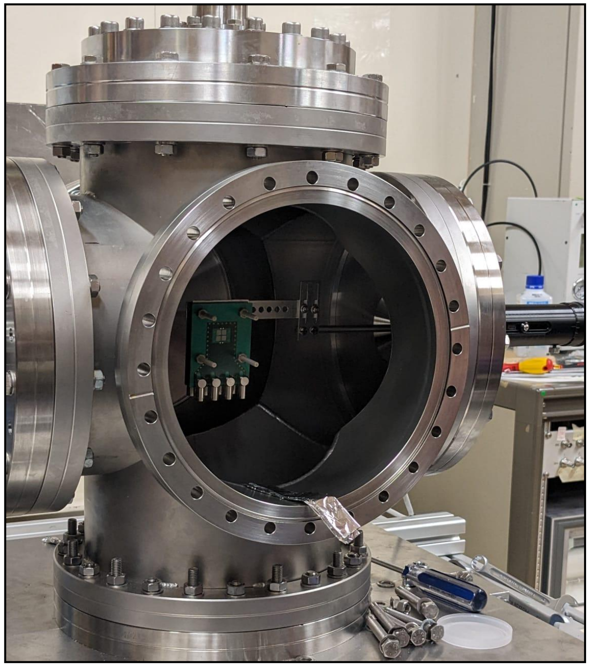
^{132}Xe beam @170 AMeV

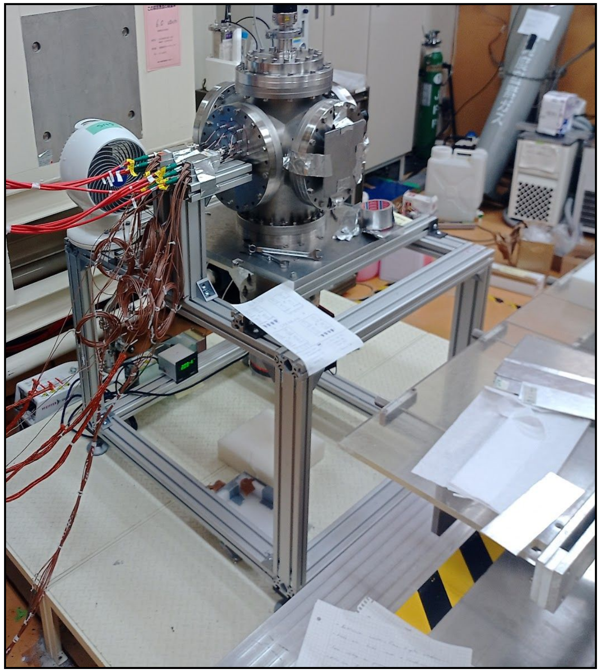
2 layers of 2x2 of SC-CVD





Test layer identification and tracking capabilities





Jikken – Multi layer target

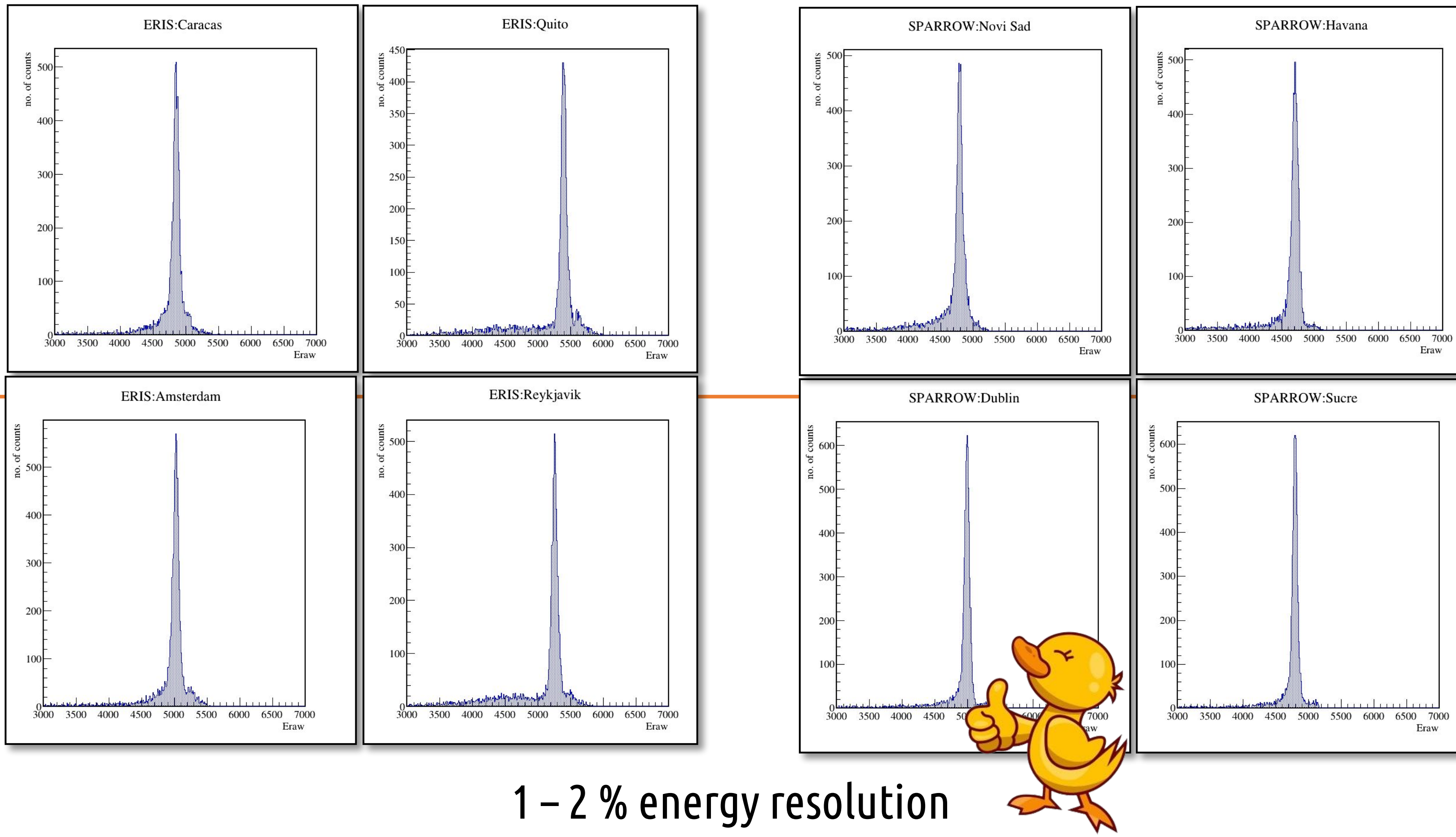
JIKKEN experiment @HIMAC

^{132}Xe beam @170 AMeV

Layer 1 (ERIS)

Layer 2 (SPARROW)

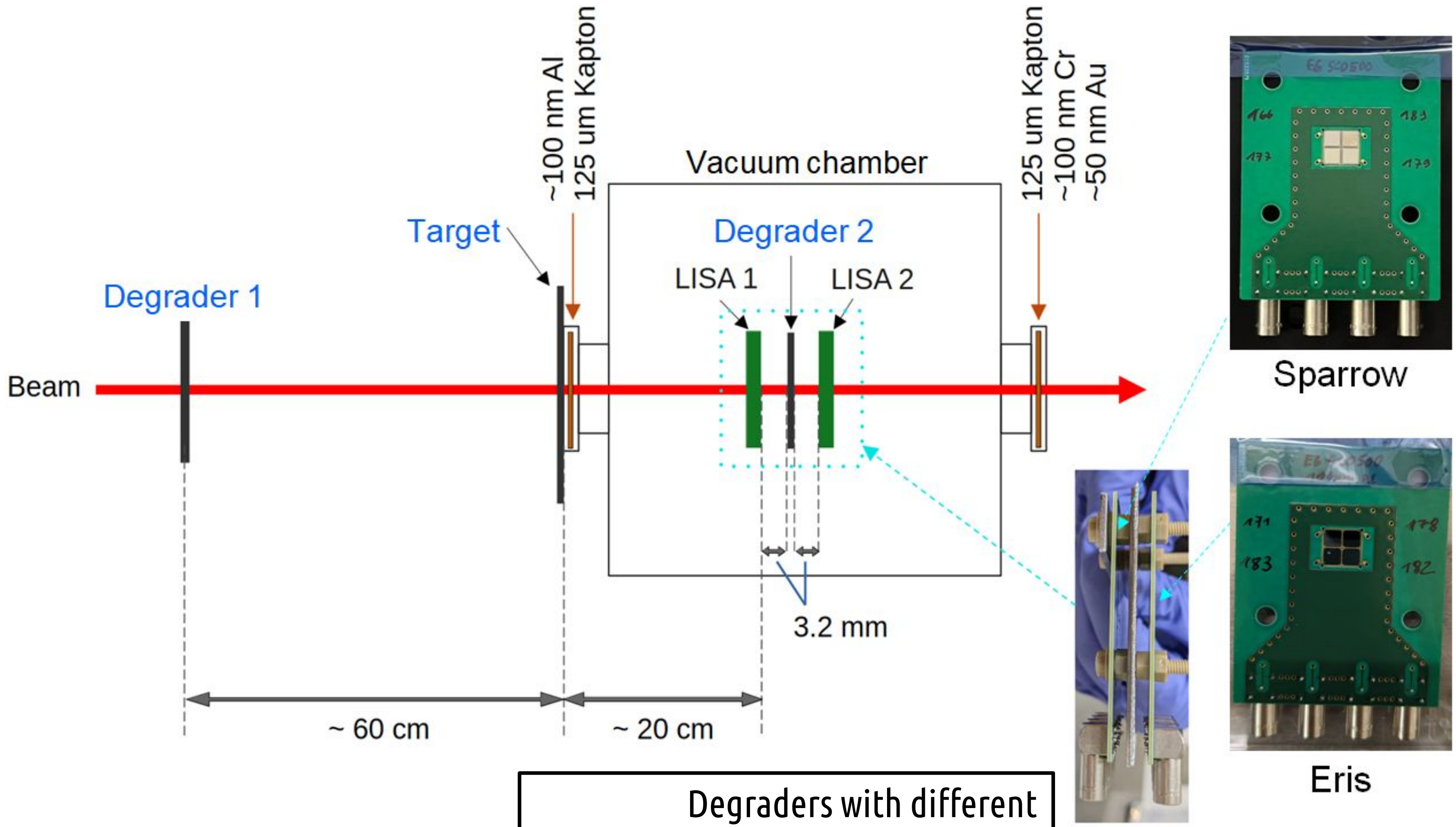
^{132}Xe



1 – 2 % energy resolution

Jikken – Multi layer target

JIKKEN experiment @HIMAC



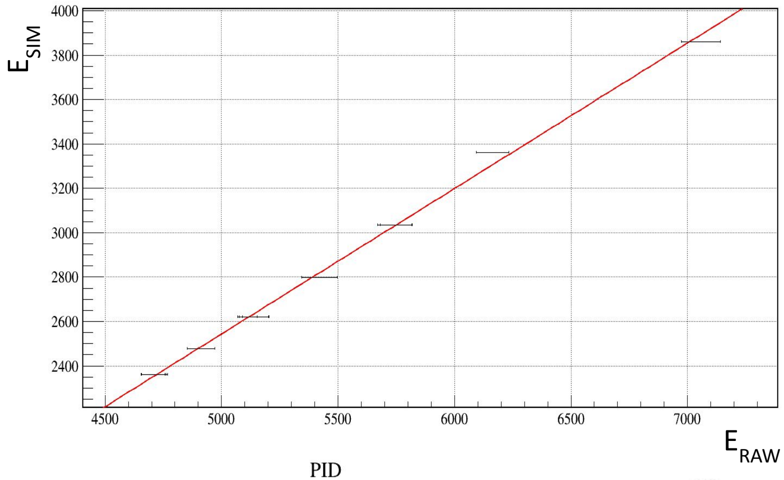
Degraders with different thickness t for energy calibration

Jikken – Multi layer target

JIKKEN experiment @HIMAC

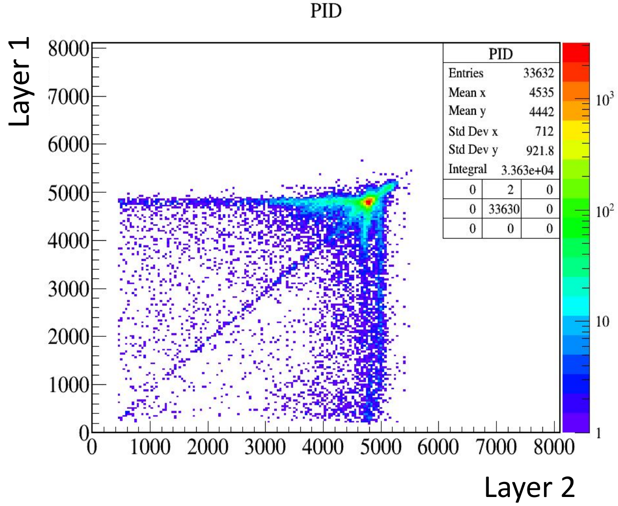
PRELIMINARY

Energy calibration

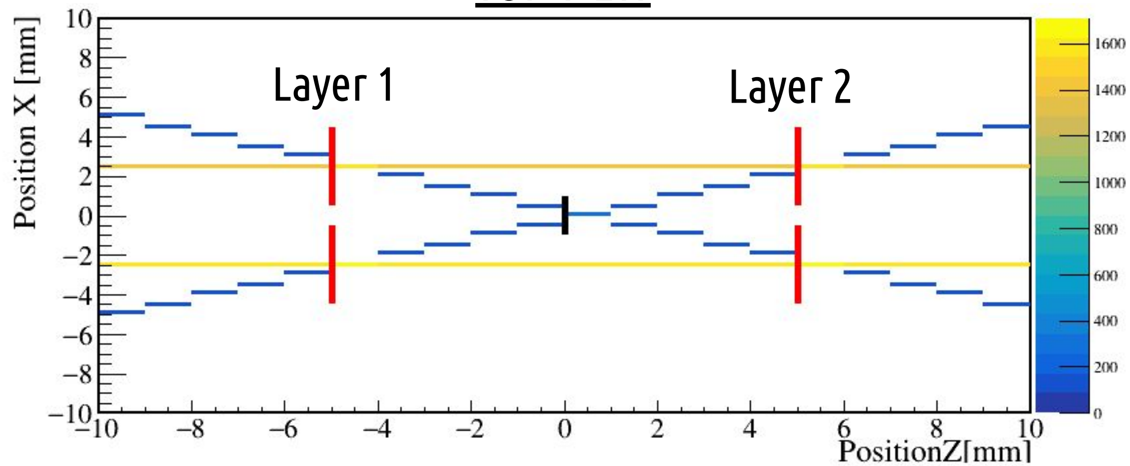


Energy calibration for run with different degraders

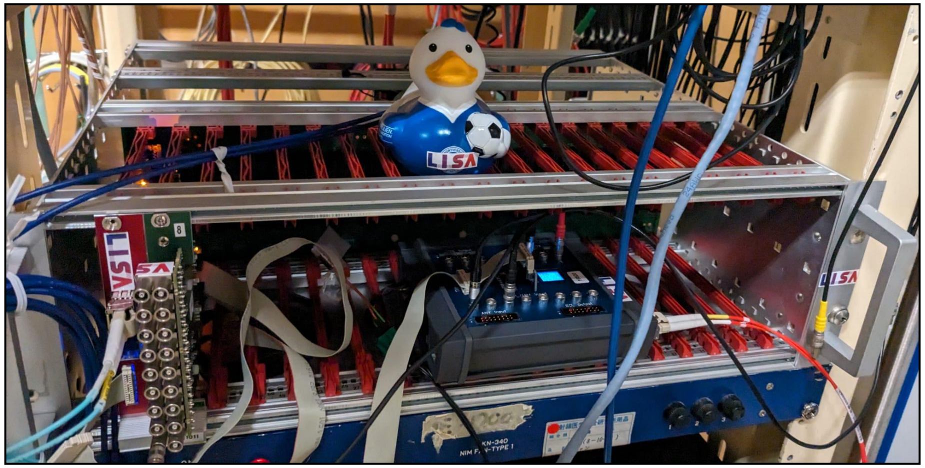
Layer correlation
Beam tracking



TOP VIEW



DAQ and data analysis



Low and High gain charge sensitive preamp

FEBEX4 digitizer from GSI
(14-bit-pipe-lining 100 MHz, block data transfer 2 GBit/s)

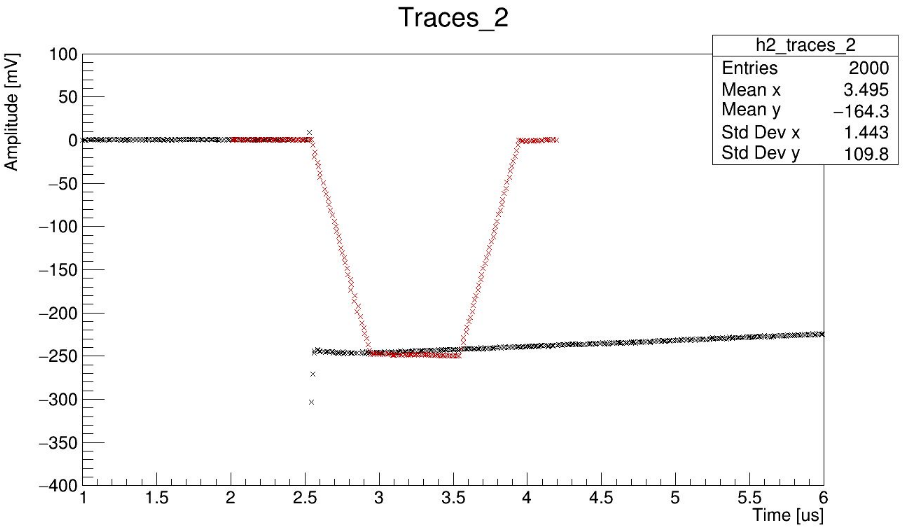
MBS acquisition system

Offline analysis of traces

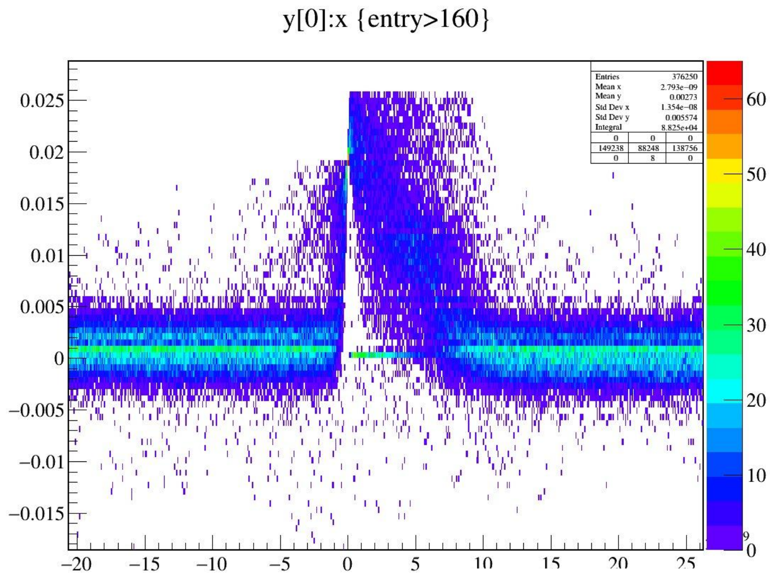
Moving Window Deconvolution (MWD)

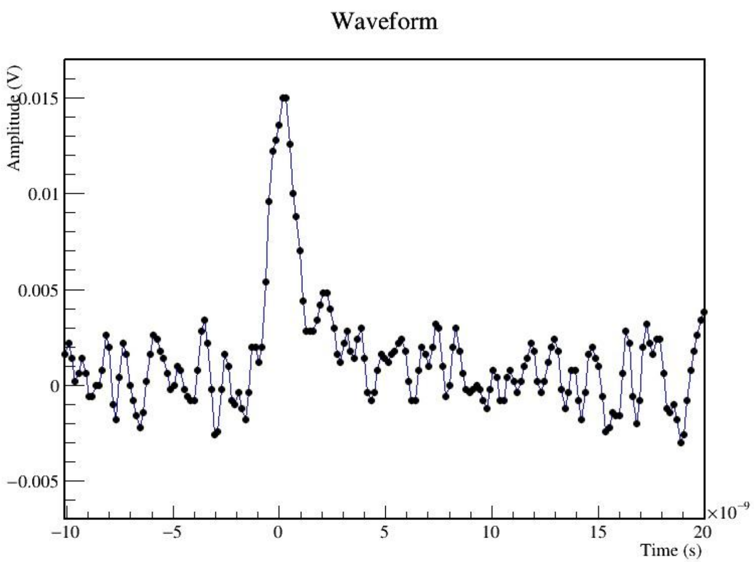
$$MWD(i) = \frac{1}{L} \sum_{j=i-L}^{i-1} D_M(j)$$

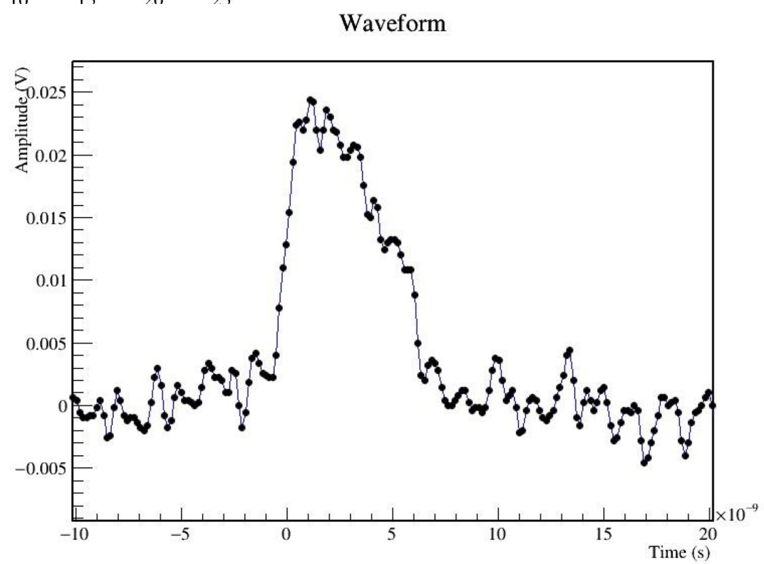
$$D_M(j) = x(j) - x(j-M) + \frac{1}{\tau} \sum_{k=j-M}^{j-1} x(k)$$



Fast timing output







Outline

LISA Project & Physics goal

The Diamond Array

In-beam tests

Preliminary results

Current developments

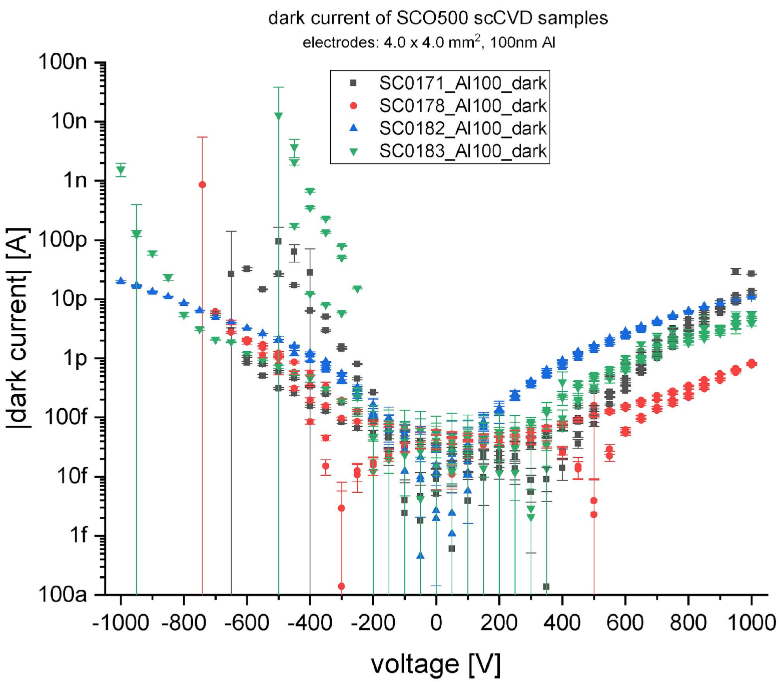
Future perspectives

Layer characterization

I-V curves

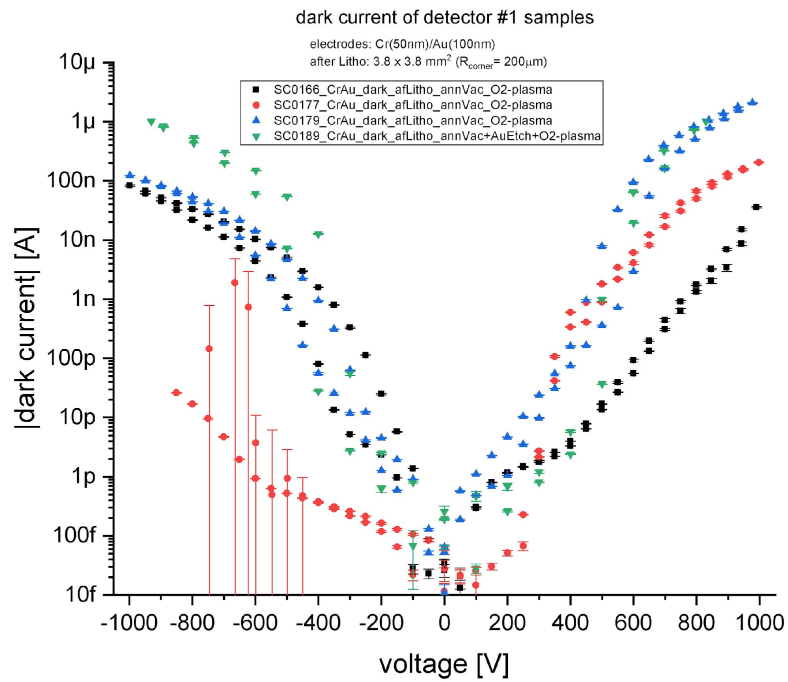
ERIS

Al(100 nm) metallization



SPARROW

Cr+Au(50+100 nm) metallization with annealing



From detector Lab @GSI