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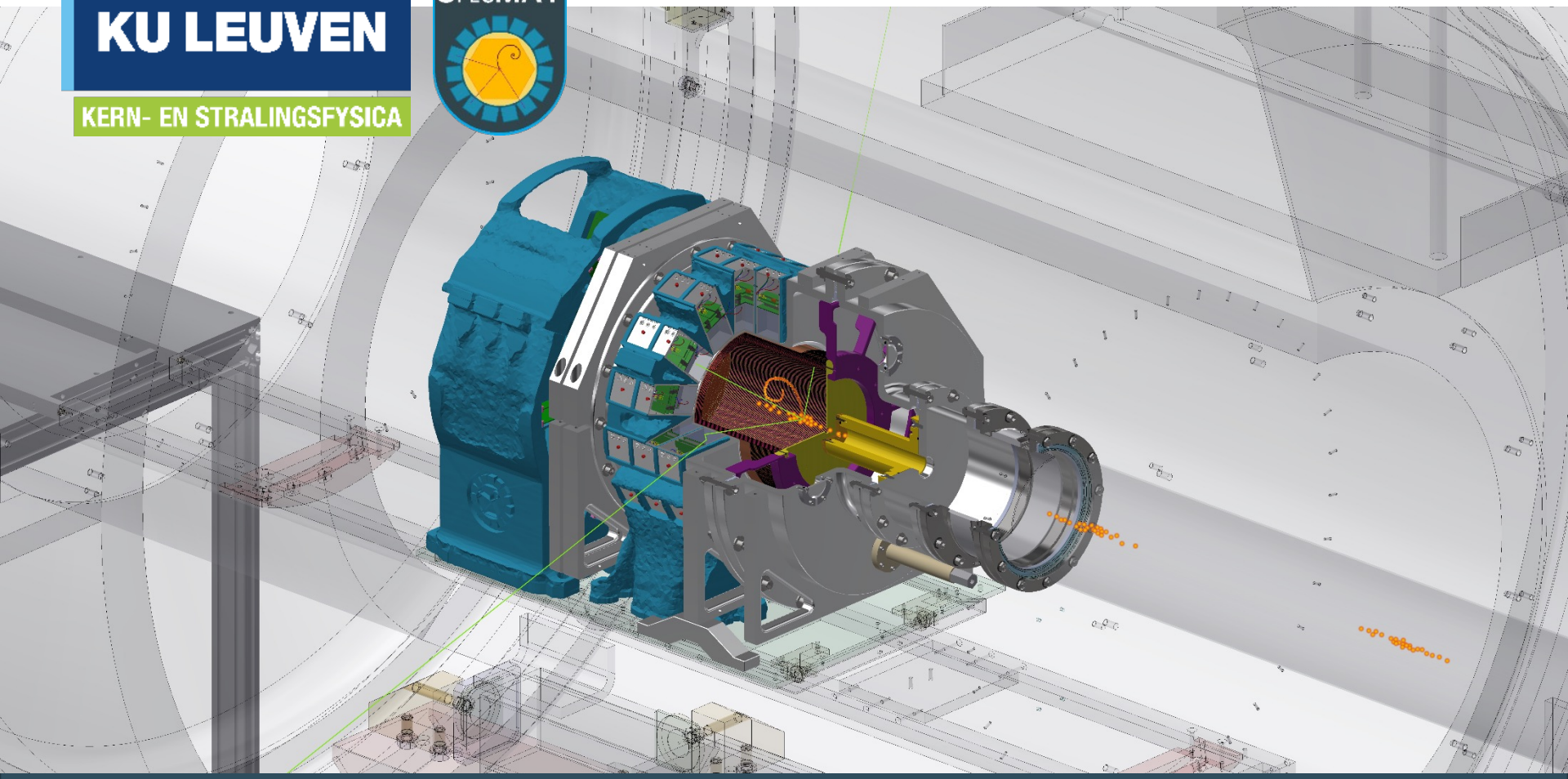
SpecMAT

ISOLDE Solenoidal Spectrometer

ISOLDE

CERN

erc European Research Council



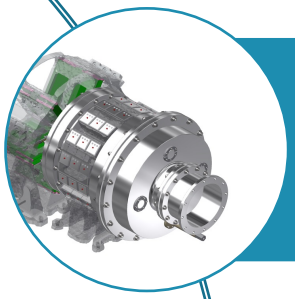
SpecMAT, the active target for nuclear transfer reactions studies at ISOLDE, CERN

Oleksii Poleshchuk

TIPP2023

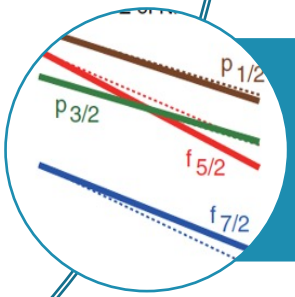
Cape Town, 8 September 2023

Outline



Motivation to build SpecMAT and its overview

Characterisation of the SpecMAT active target



A (d,^{3}He) reaction for SpecMAT

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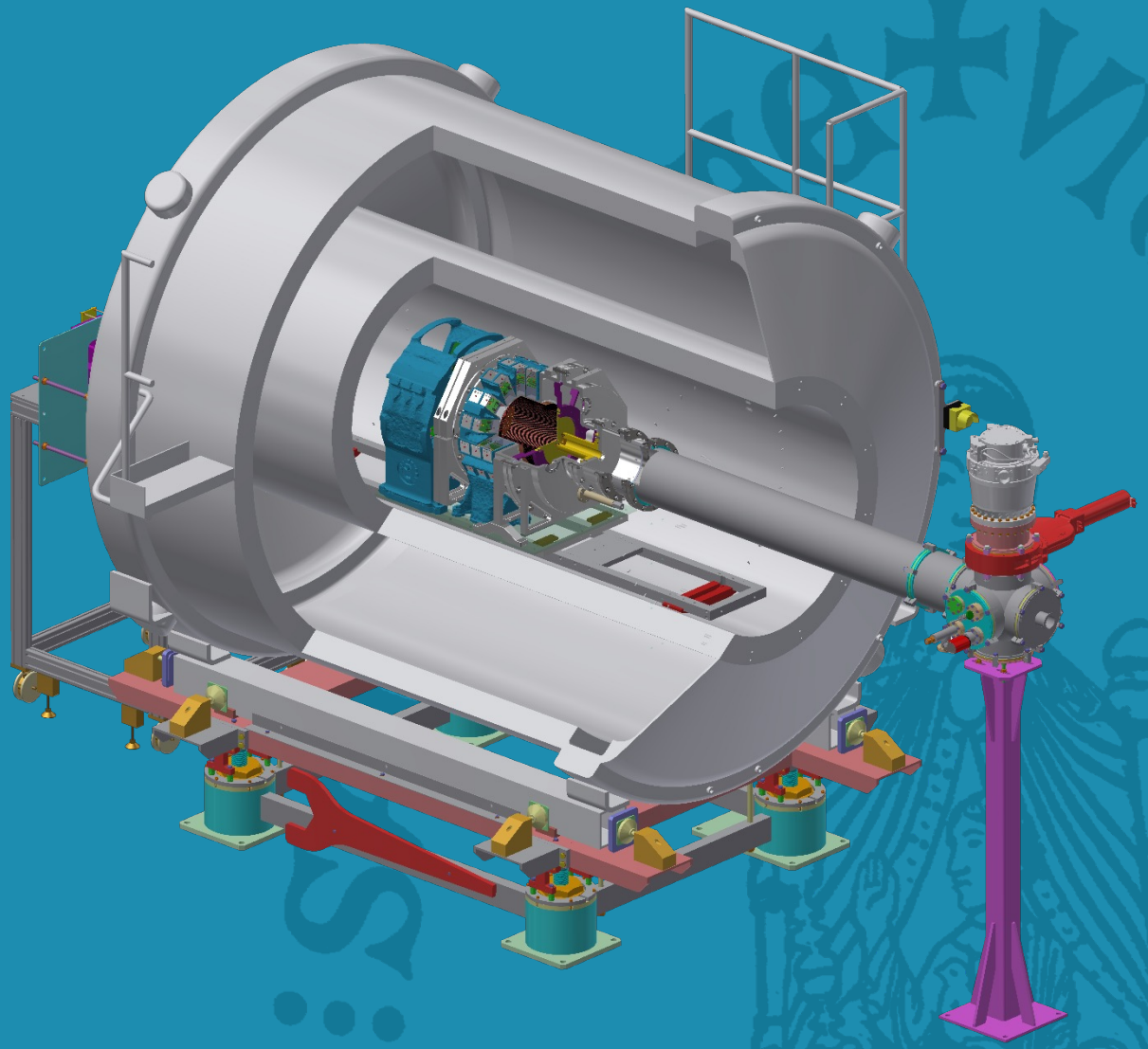
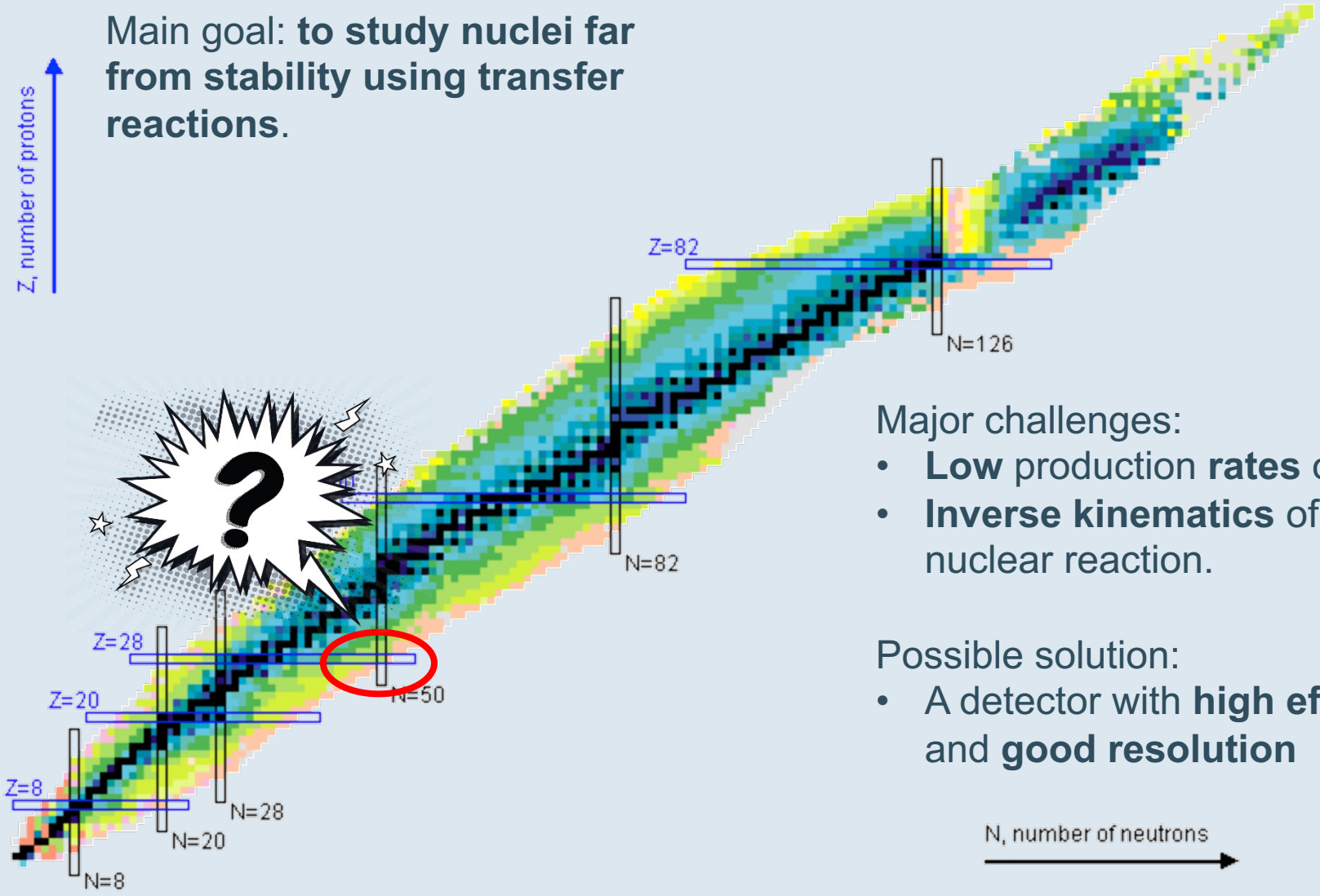
SpecMAT

Motivation and Overview



Physics motivation

Main goal: **to study nuclei far from stability using transfer reactions**.



Major challenges:

- **Low** production **rates** of RIBs
- **Inverse kinematics** of the nuclear reaction.

Possible solution:

- A detector with **high efficiency** and **good resolution**

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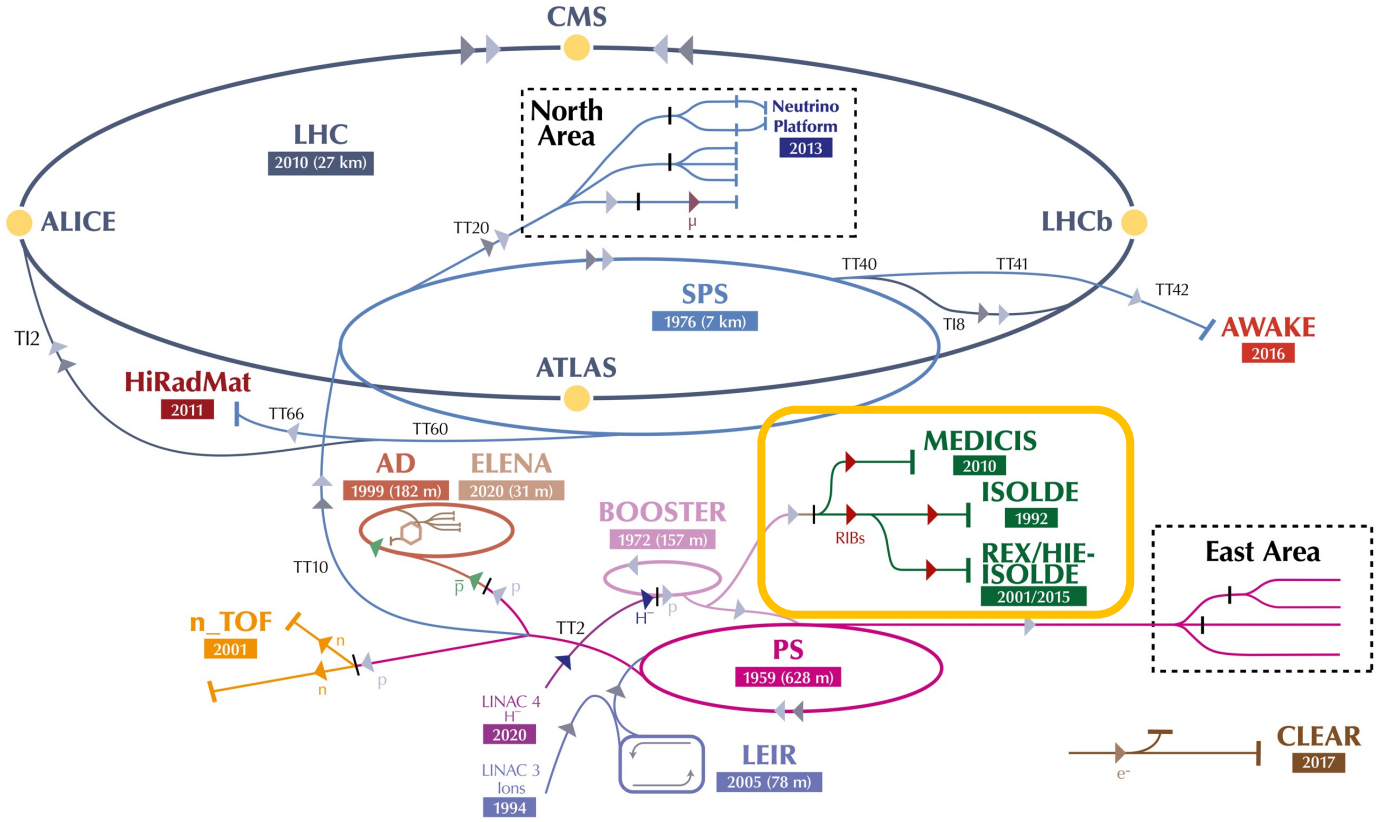
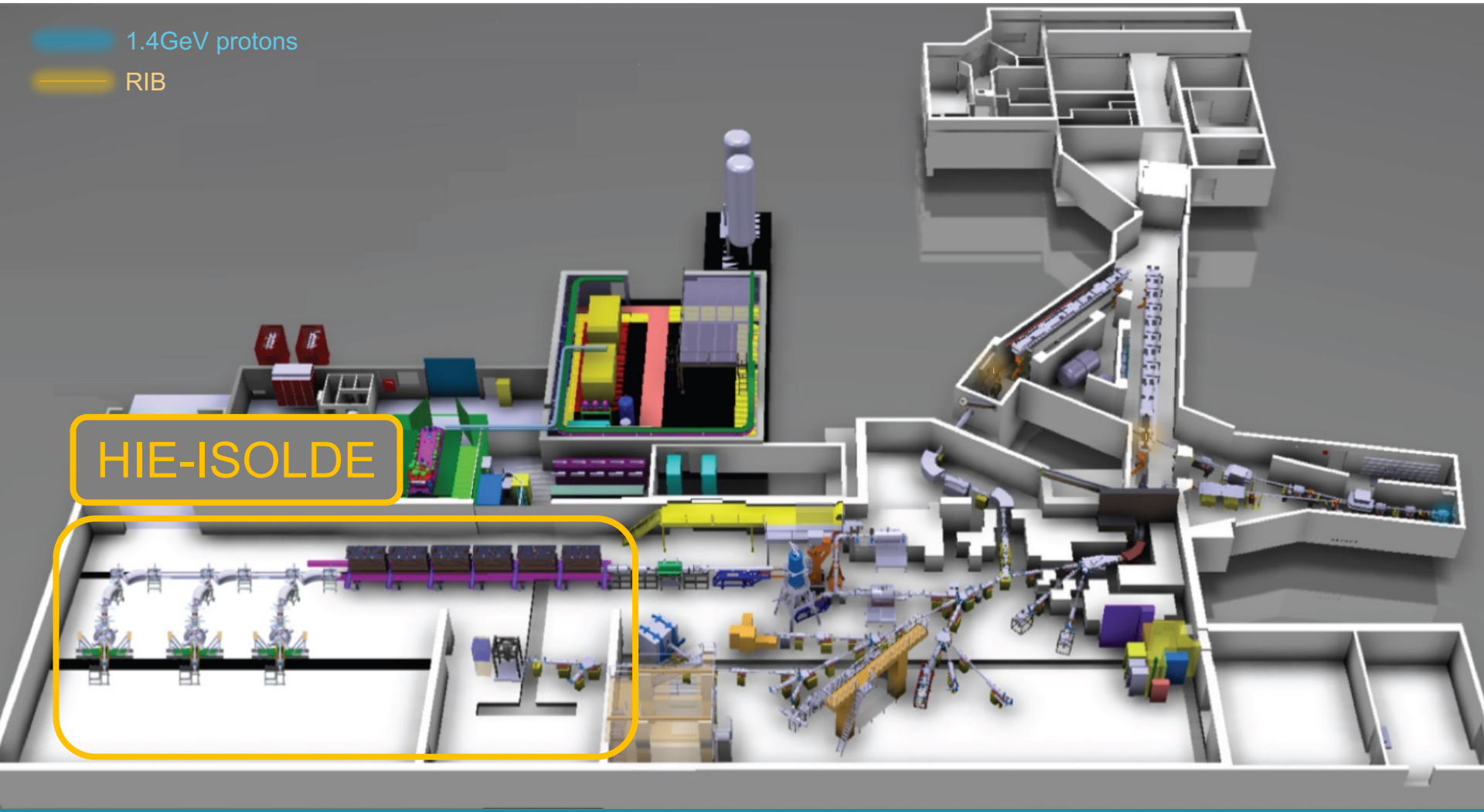
The CERN accelerator complex
Complexe des accélérateurs du CERN



H⁻ (hydrogen anions) · p (protons) · ions · RIBs (Radioactive Ion Beams) · n (neutrons) · $\bar{p}$ (antiprotons) · e^- (electrons) · μ (muons)

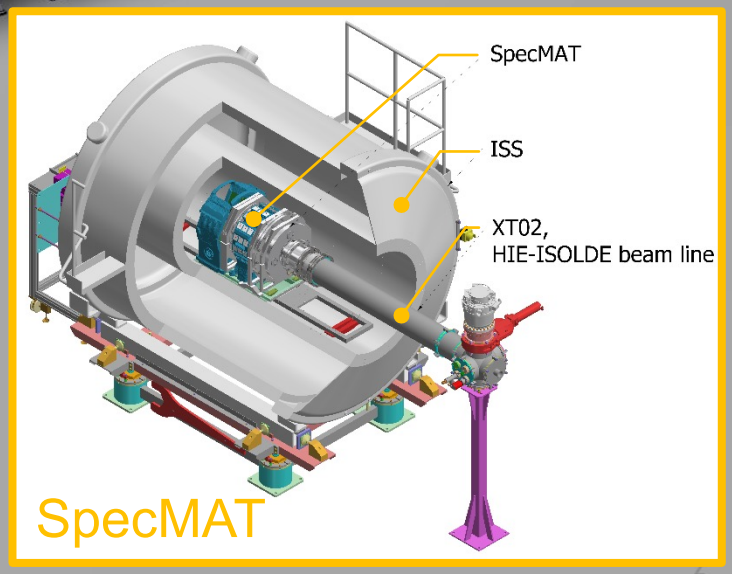
LHC - Large Hadron Collider // SPS - Super Proton Synchrotron // PS - Proton Synchrotron // AD - Antiproton Decelerator // CLEAR - CERN Linear Electron Accelerator for Research // AWAKE - Advanced WAKefield Experiment // ISOLDE - Isotope Separator OnLine // REX/HIE-ISOLDE - Radioactive EXperiment/High Intensity and Energy ISOLDE // MEDICIS // LEIR - Low Energy Ion Ring // LINAC - LINear ACcelerator // n_TOF - Neutrons Time Of Flight // HiRadMat - High-Radiation to Materials // Neutrino Platform


1.4GeV protons
RIB
HIE-ISOLDE

RIB

ISS

Currently: 2.5T
Perspective: 4T



ISS = ISOLDE Solenoidal Spectrometer

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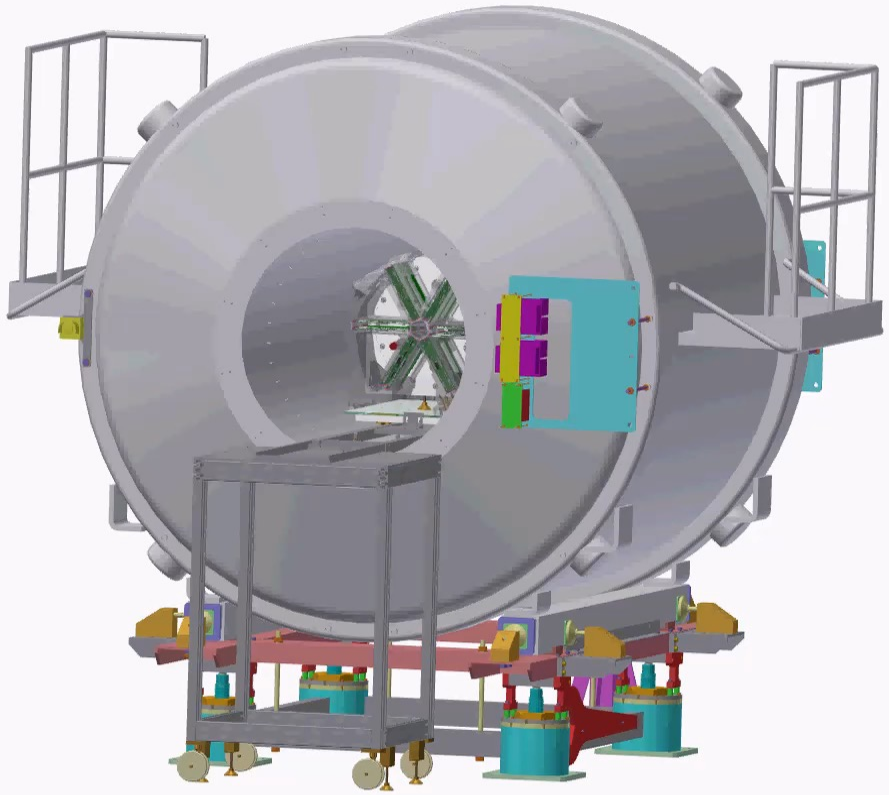
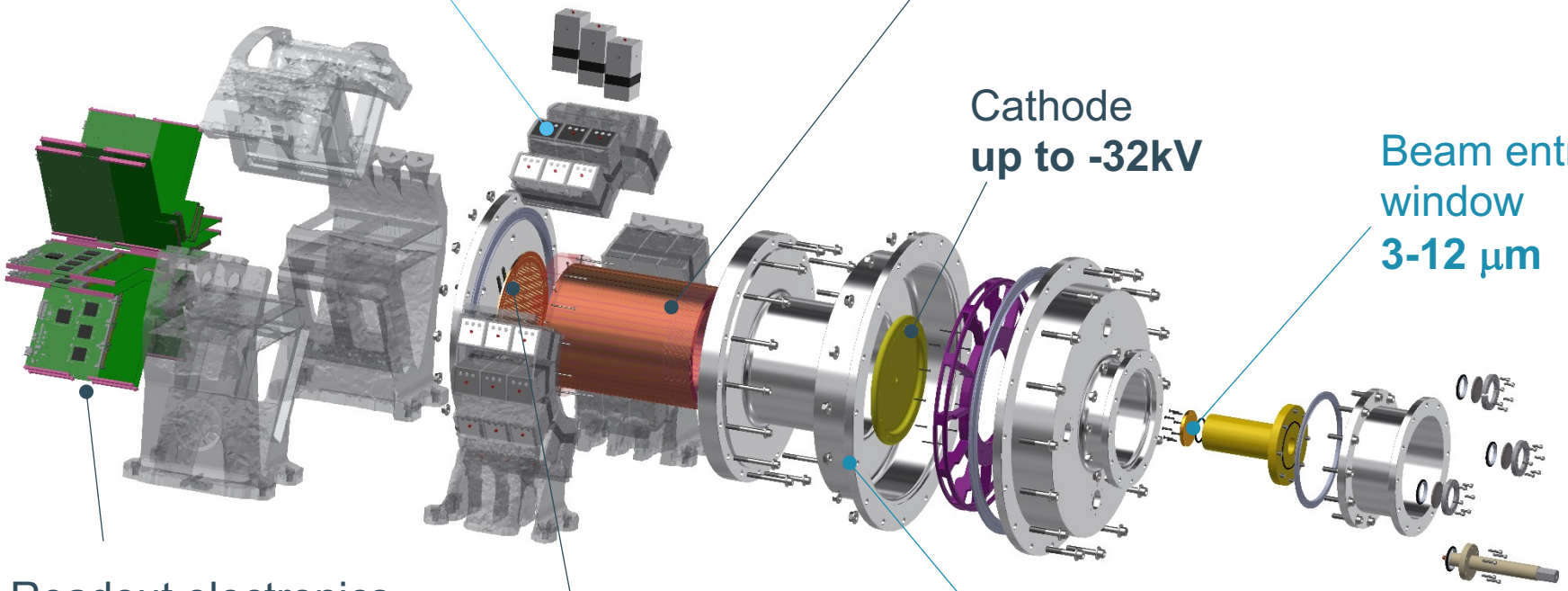


45 $CeBr_3$
48×48×48mm
scintillation
detectors

Field cage
homogeneous
electric field ~2%

Cathode
up to -32kV

Beam entrance
window
3-12 μm



Readout electronics
1-100MS/s 12bit
3072+256 channels

MICROMEGAS detector
2916 channels

Gas chamber
up to 1 atm
min wall thickness 3mm

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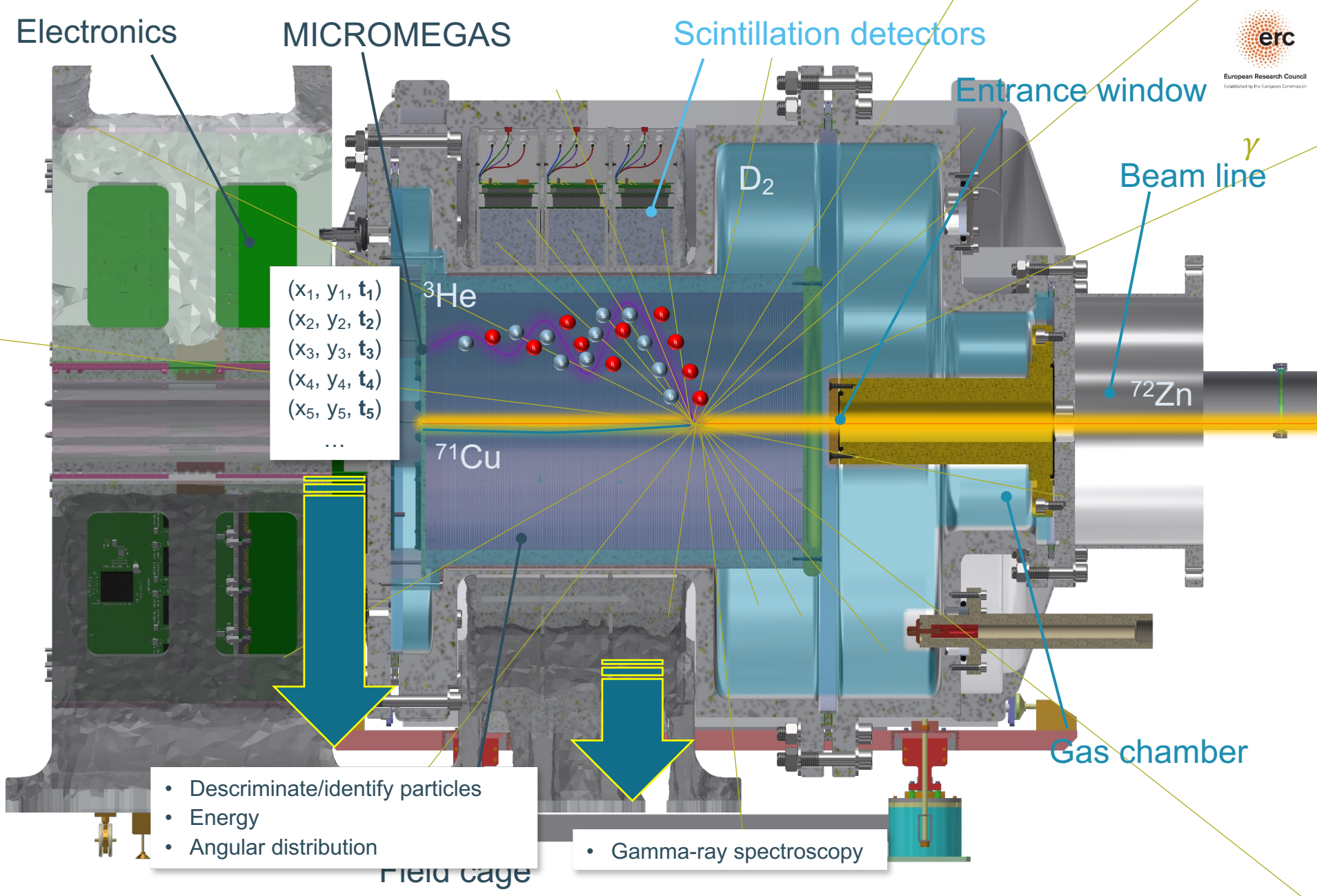
Electronics
MICROMEGAS
Scintillation detectors
Entrance window
γ
Beam line
D_2
^3He
(x_1, y_1, t_1)
(x_2, y_2, t_2)
(x_3, y_3, t_3)
(x_4, y_4, t_4)
(x_5, y_5, t_5)
…
^{71}Cu
^{72}Zn
Gas chamber
• Descriminate/identify particles
• Energy
• Angular distribution
• Gamma-ray spectroscopy
Field cage

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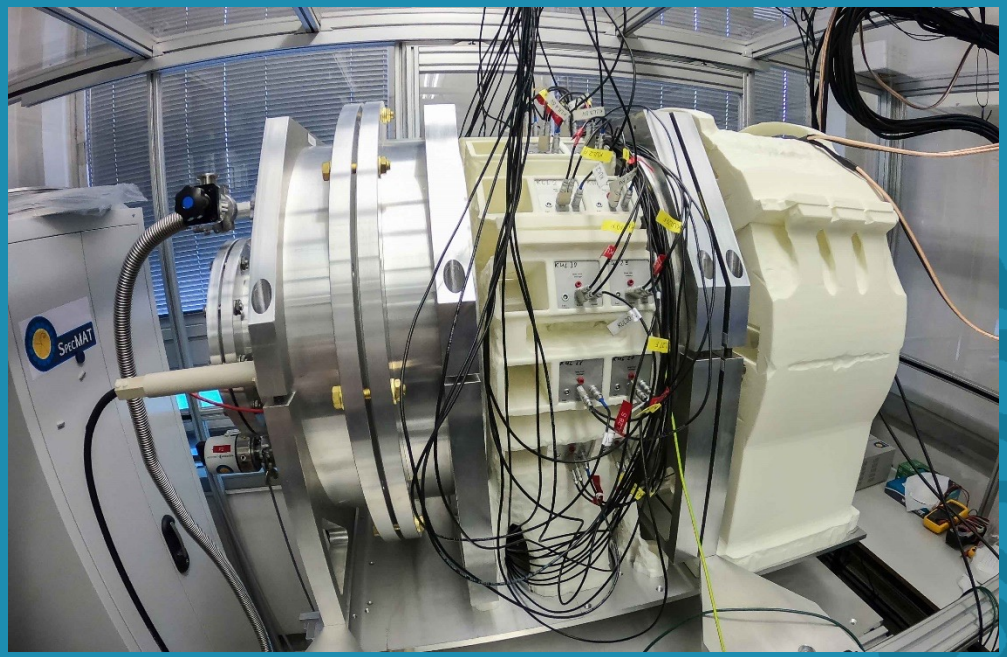
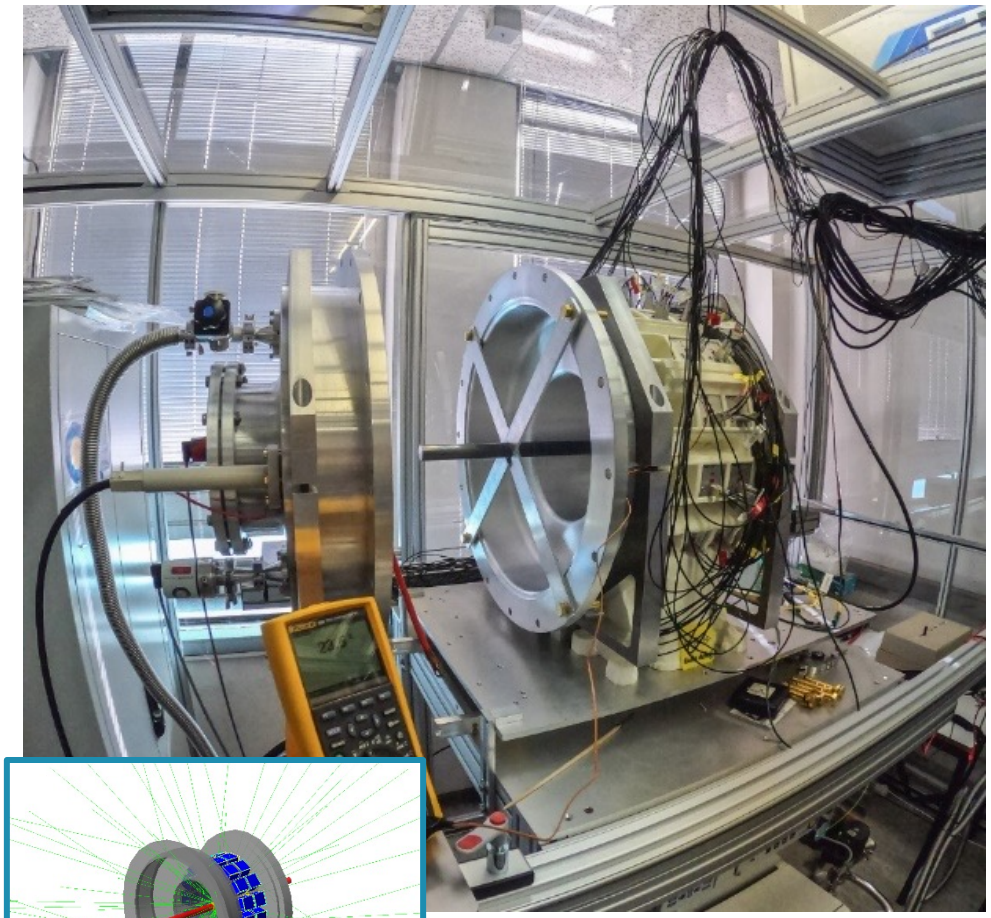
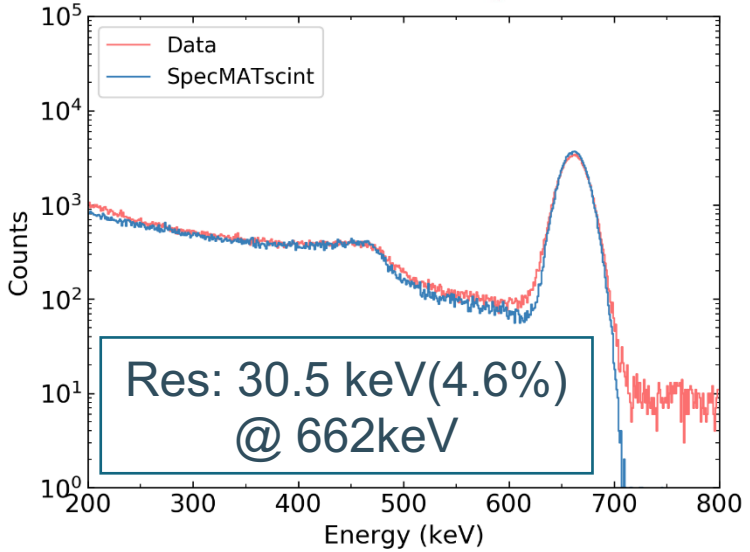
Characterisation of the SpecMAT active target

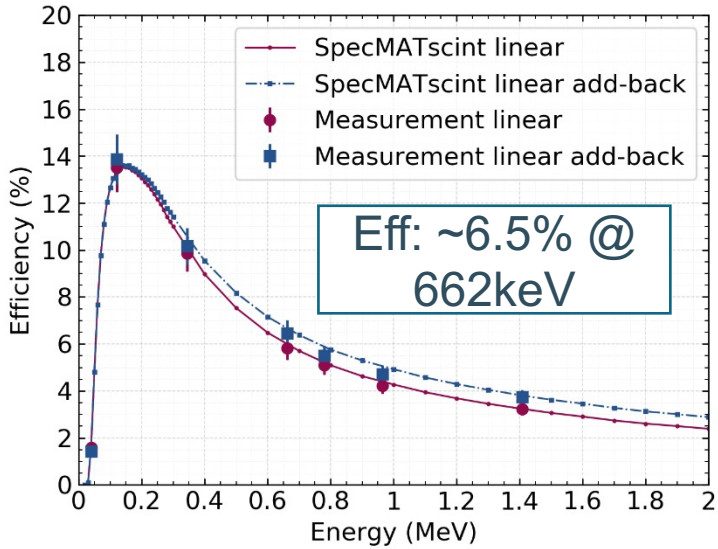


Characterisation of the array with 30 detectors, Measurement vs G4

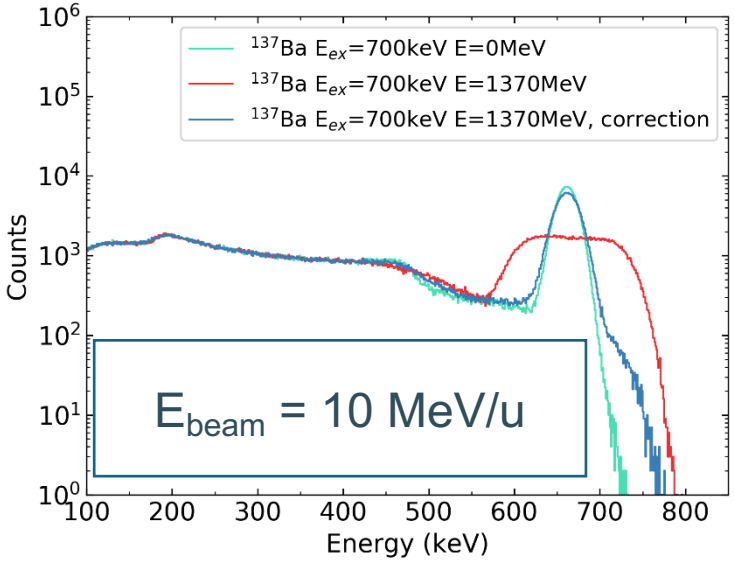


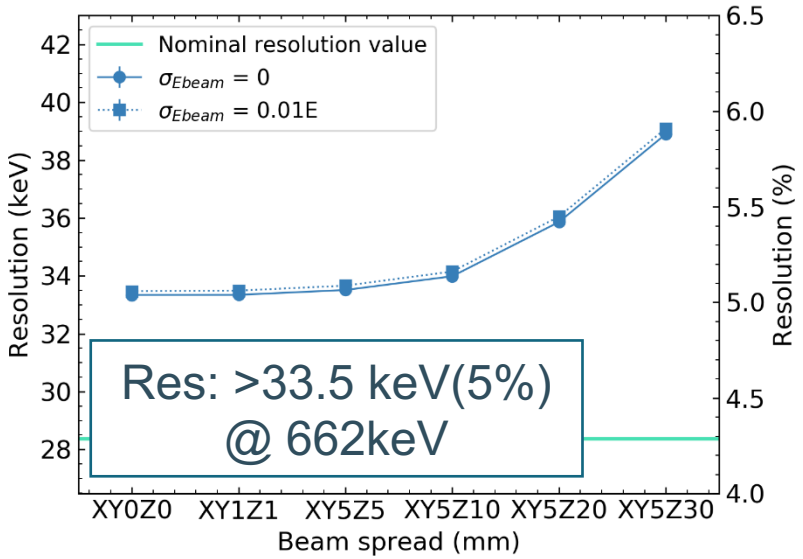


Linear source (Experimental condition)



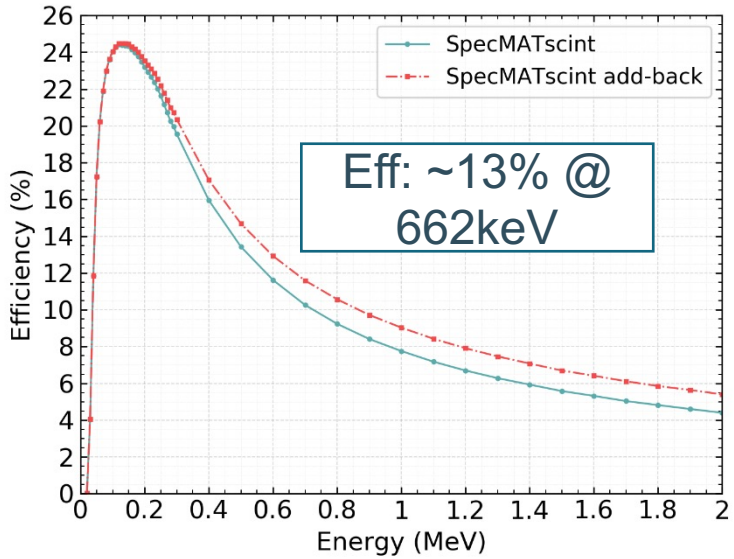
Characterisation of the array with 45 detectors, G4



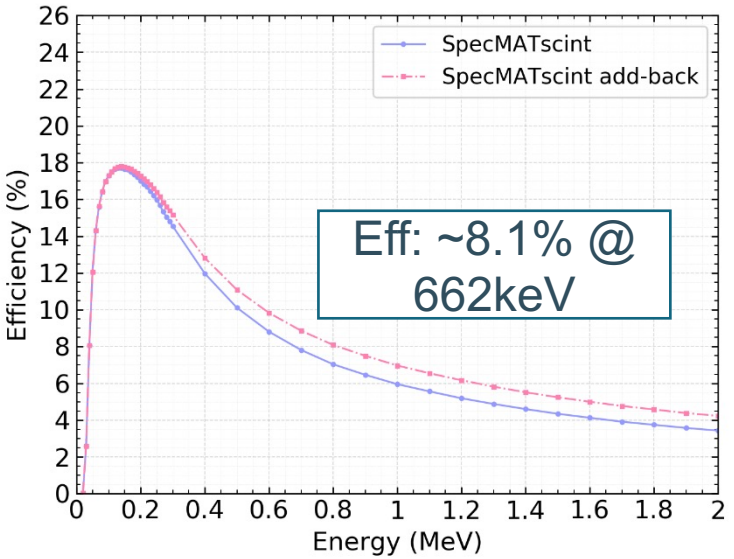


x45
$CeBr_3$
detectors

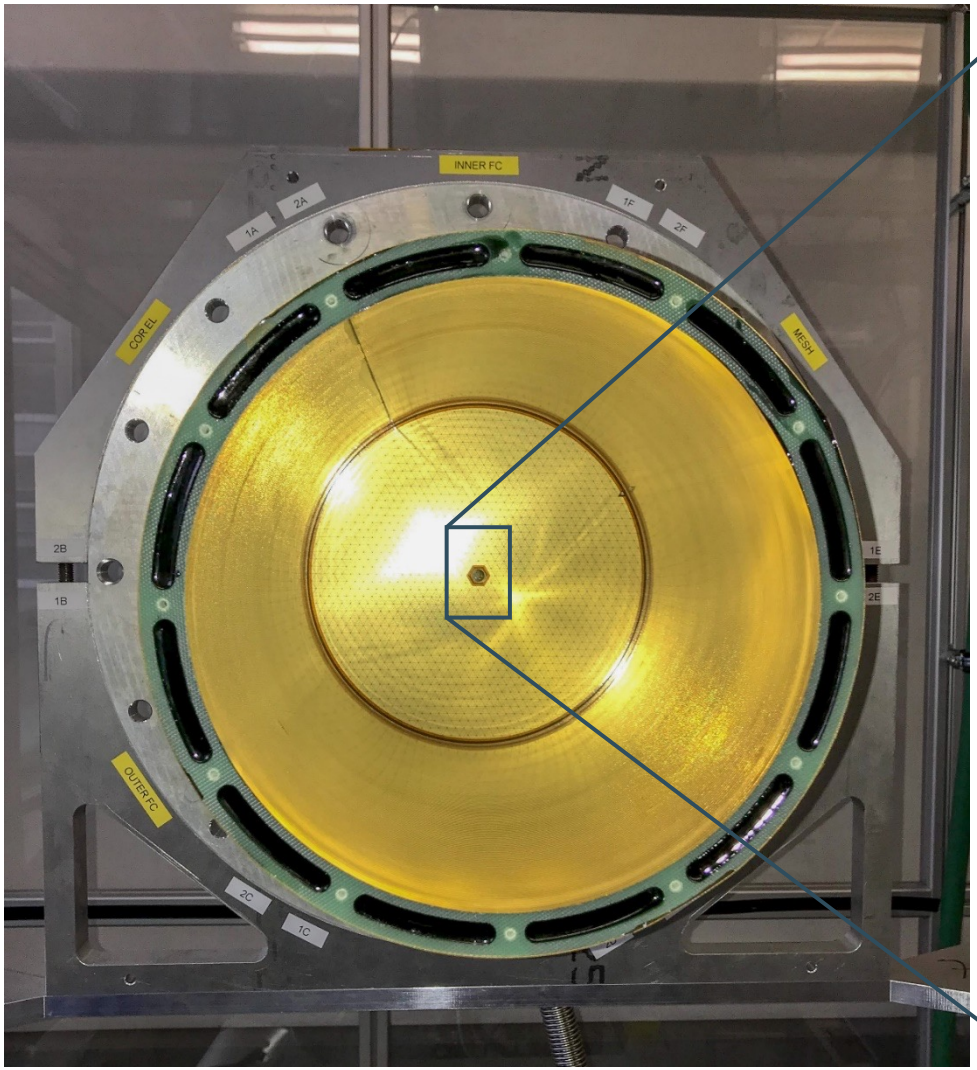
Point source

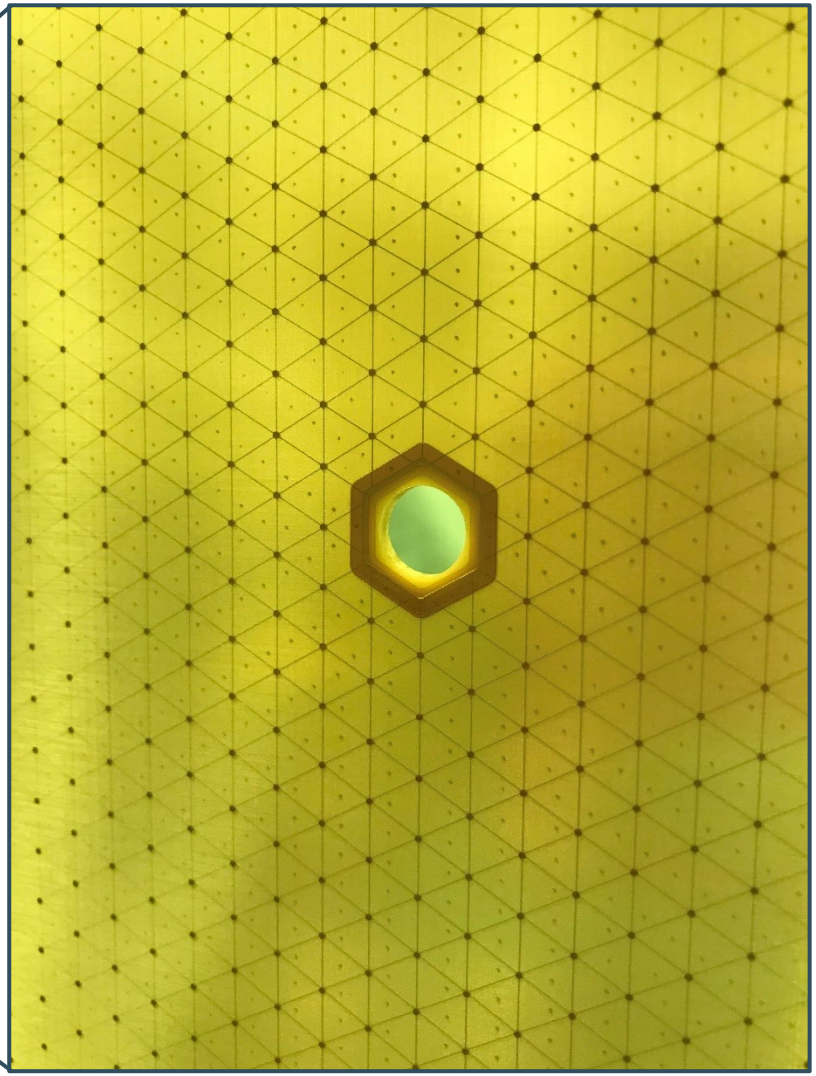


Linear source (Experimental condition)

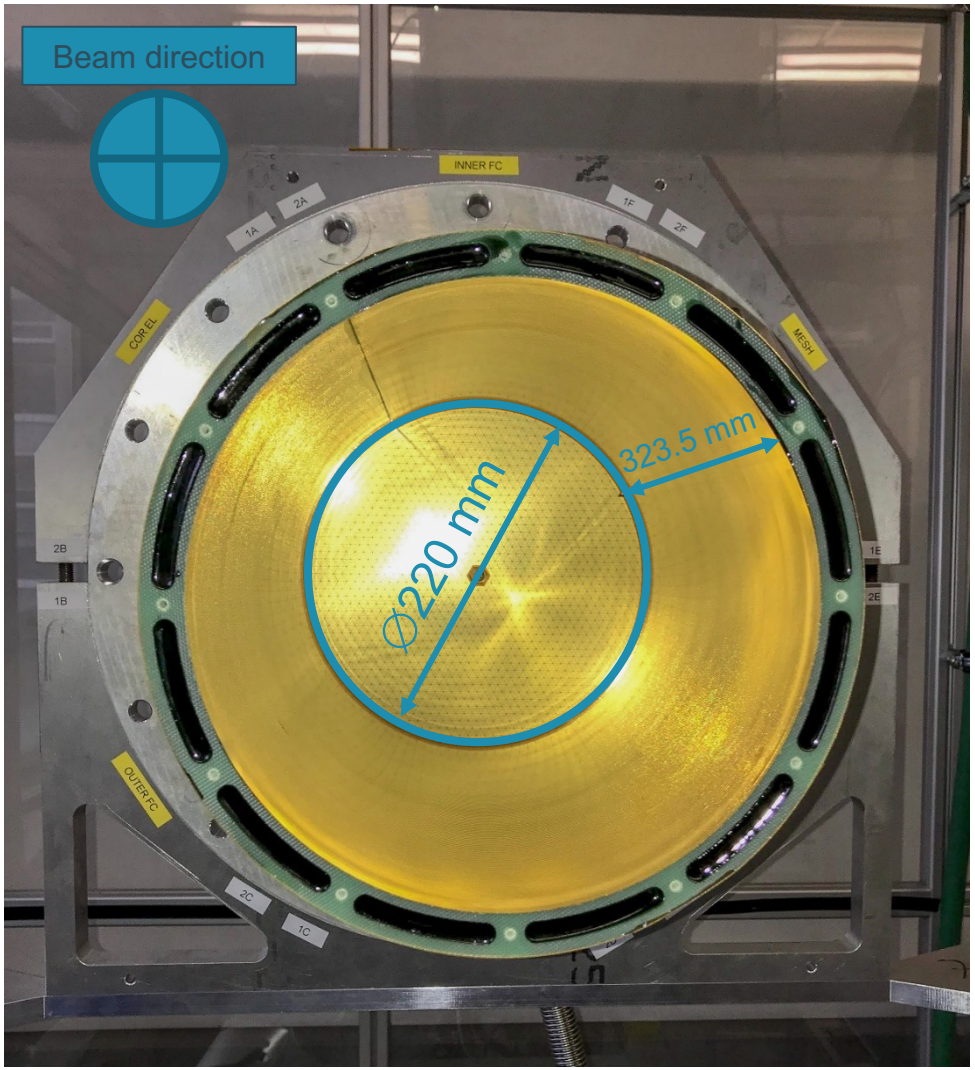


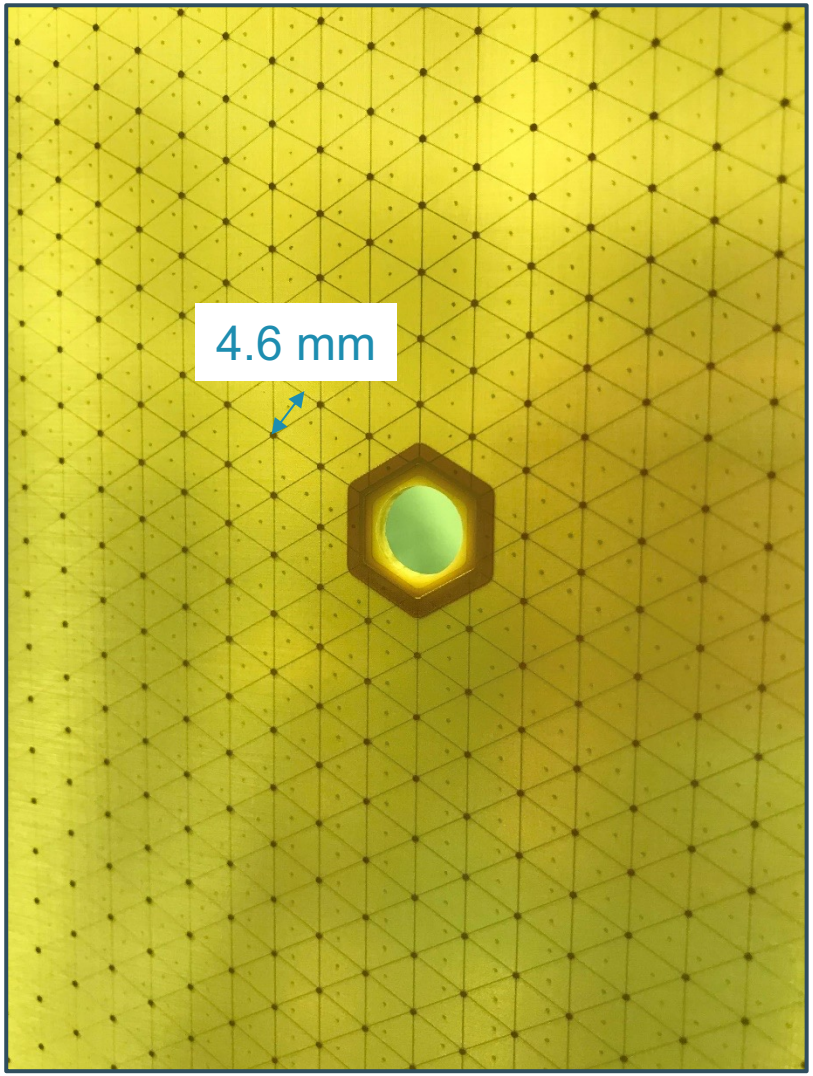
SpecMAT field cage



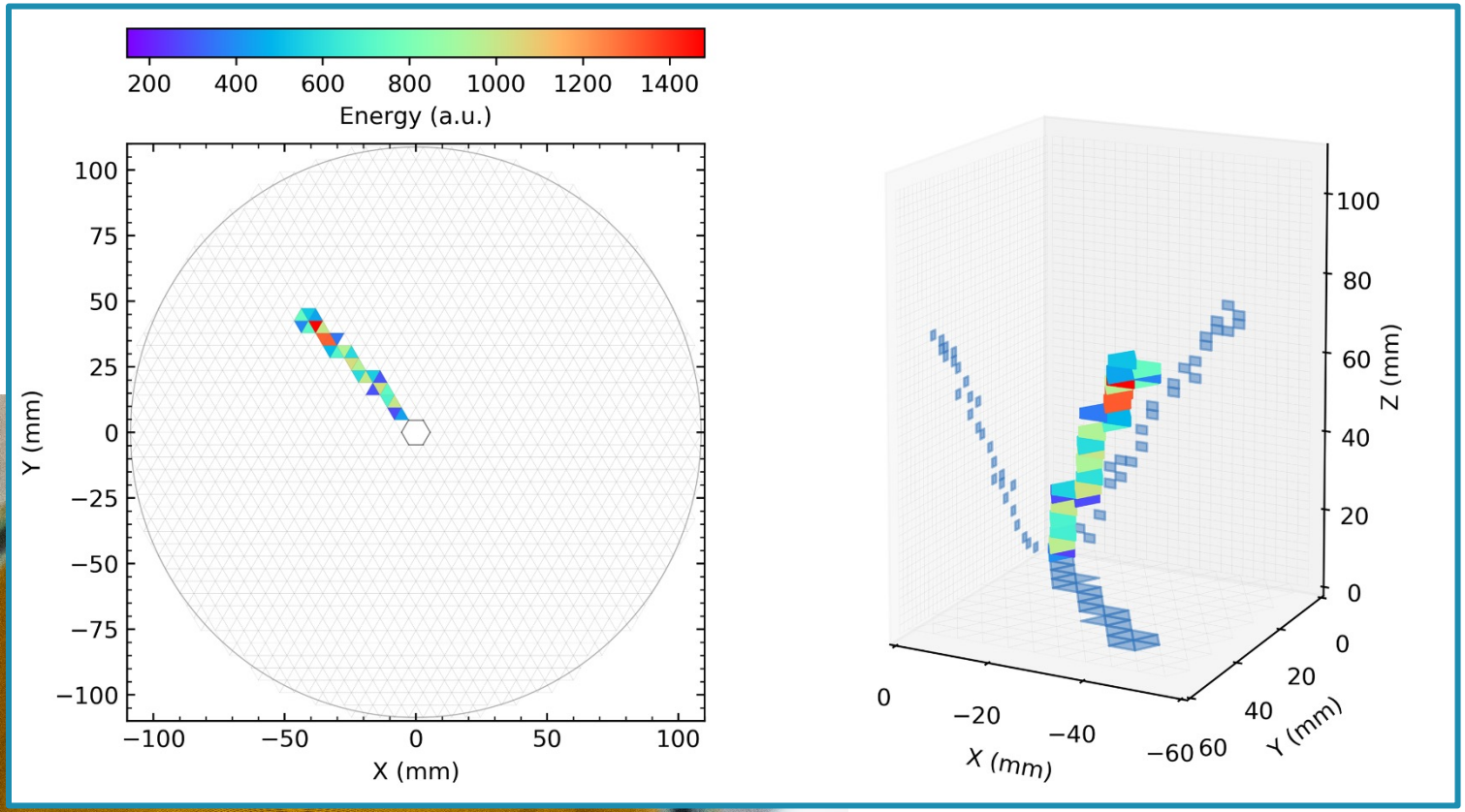


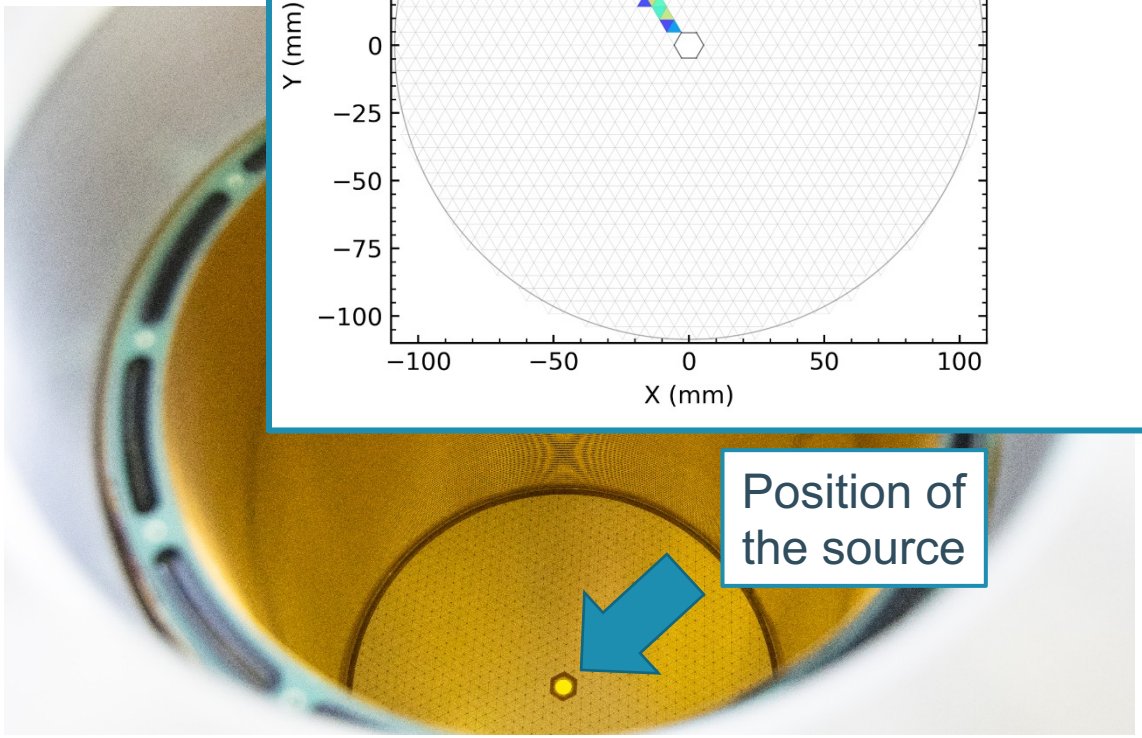
SpecMAT field cage



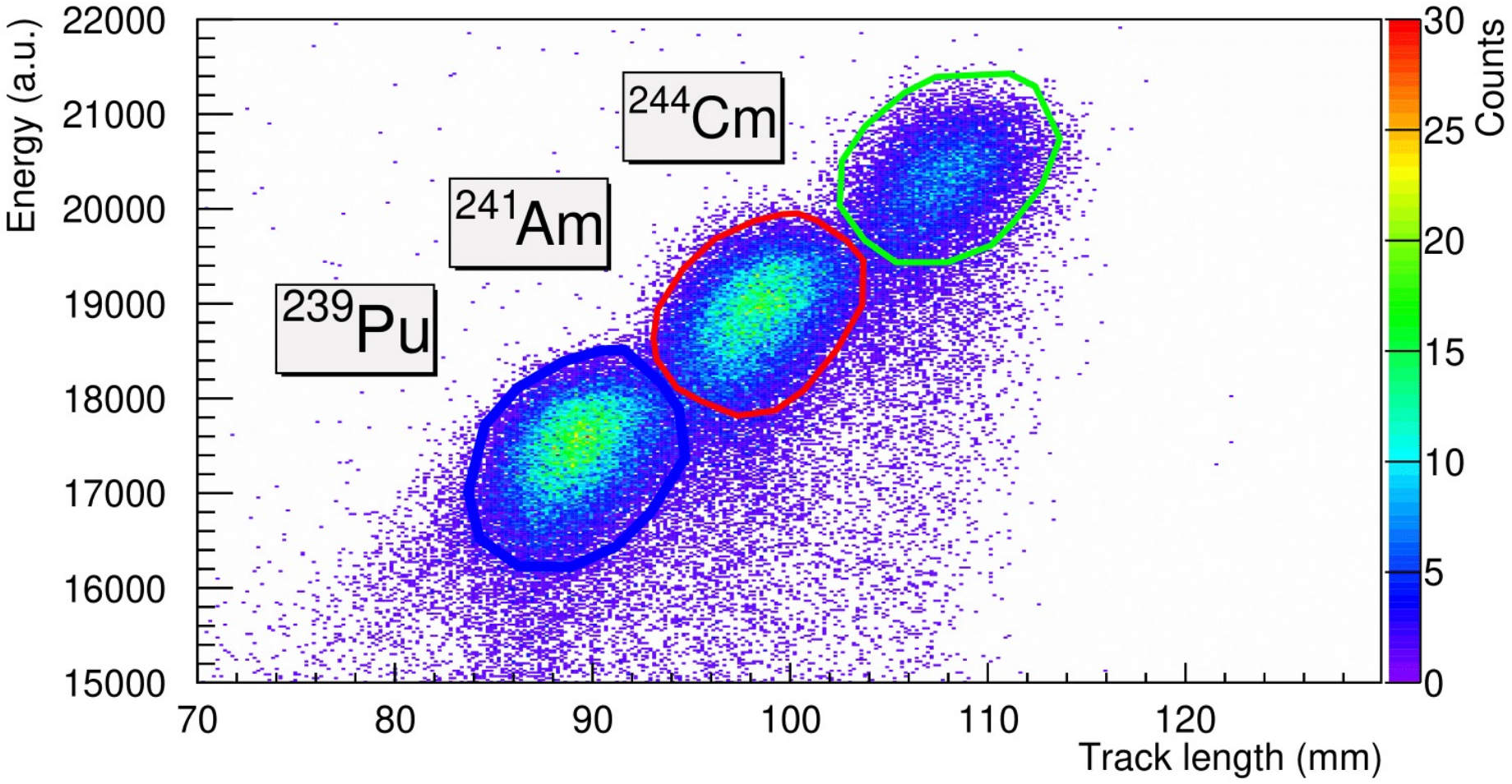


Measured α-particle track in **Ar95%$CF_4$5% @ 0.4mbar**

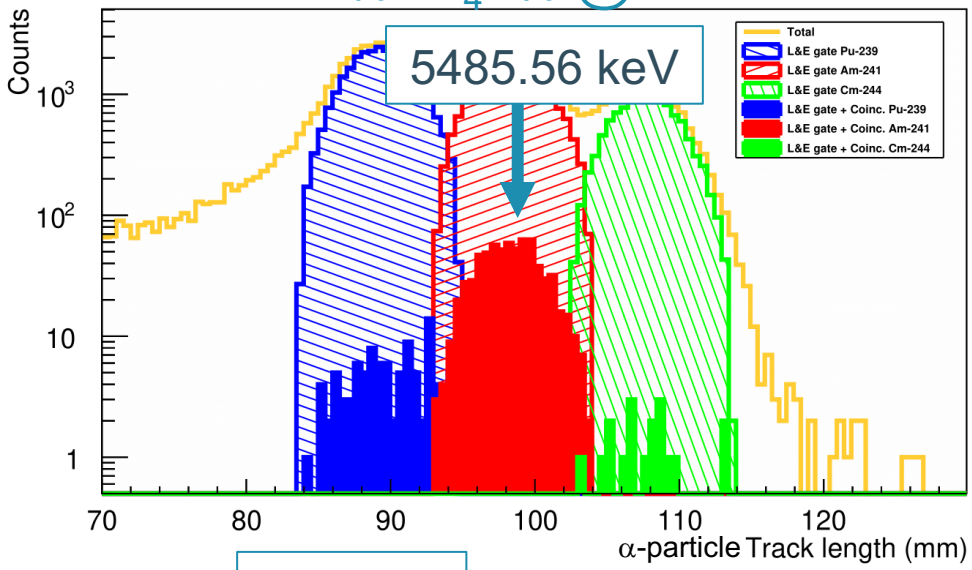


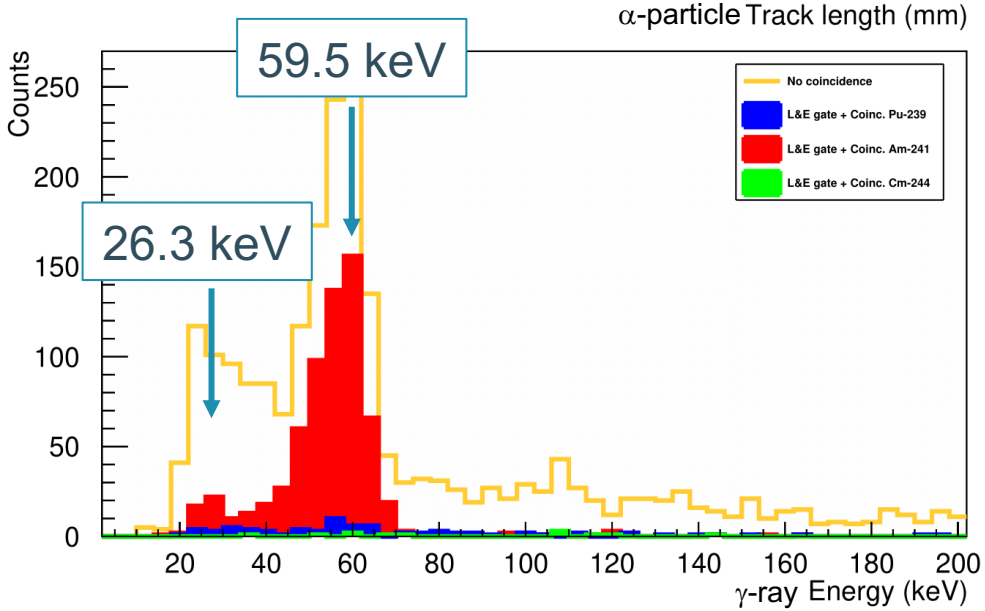


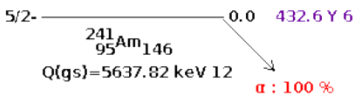
Measured α-particle spectra in Ar95%$CF_4$5% @ 0.4mbar

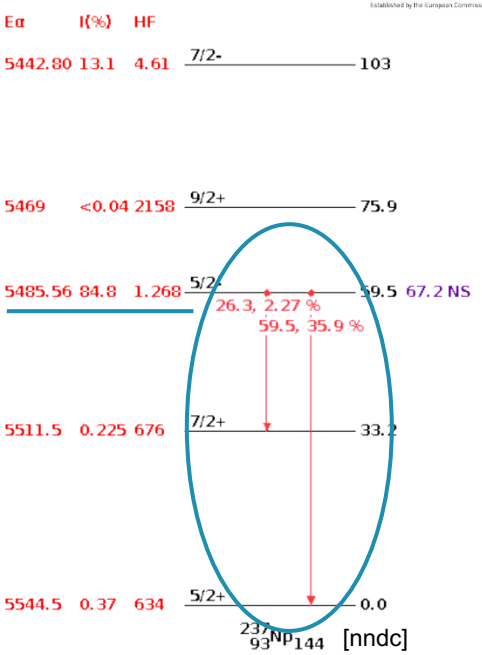


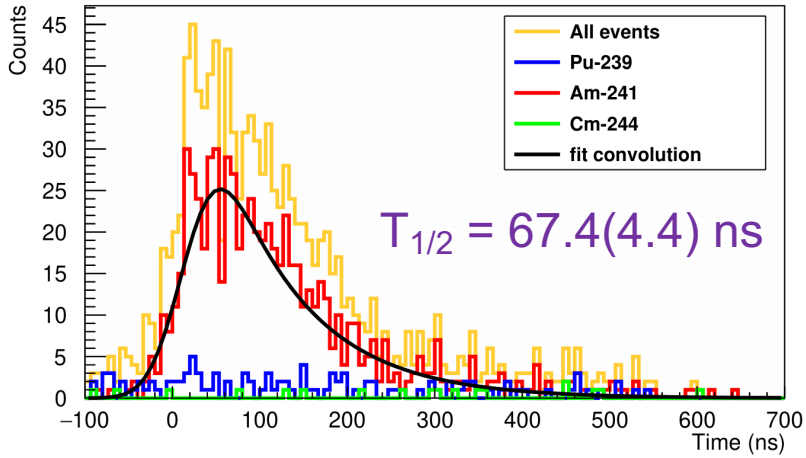
Measured α-γ correlation spectra in Ar95%$CF_4$5% @ 0.4mbar











O. Poleshchuk, R. Raabe, et.al., NIM A "The SpecMAT active target" Volume 1015, 1 November 2021, 165765

Offline tests of the SpecMAT active target in ISS 2022

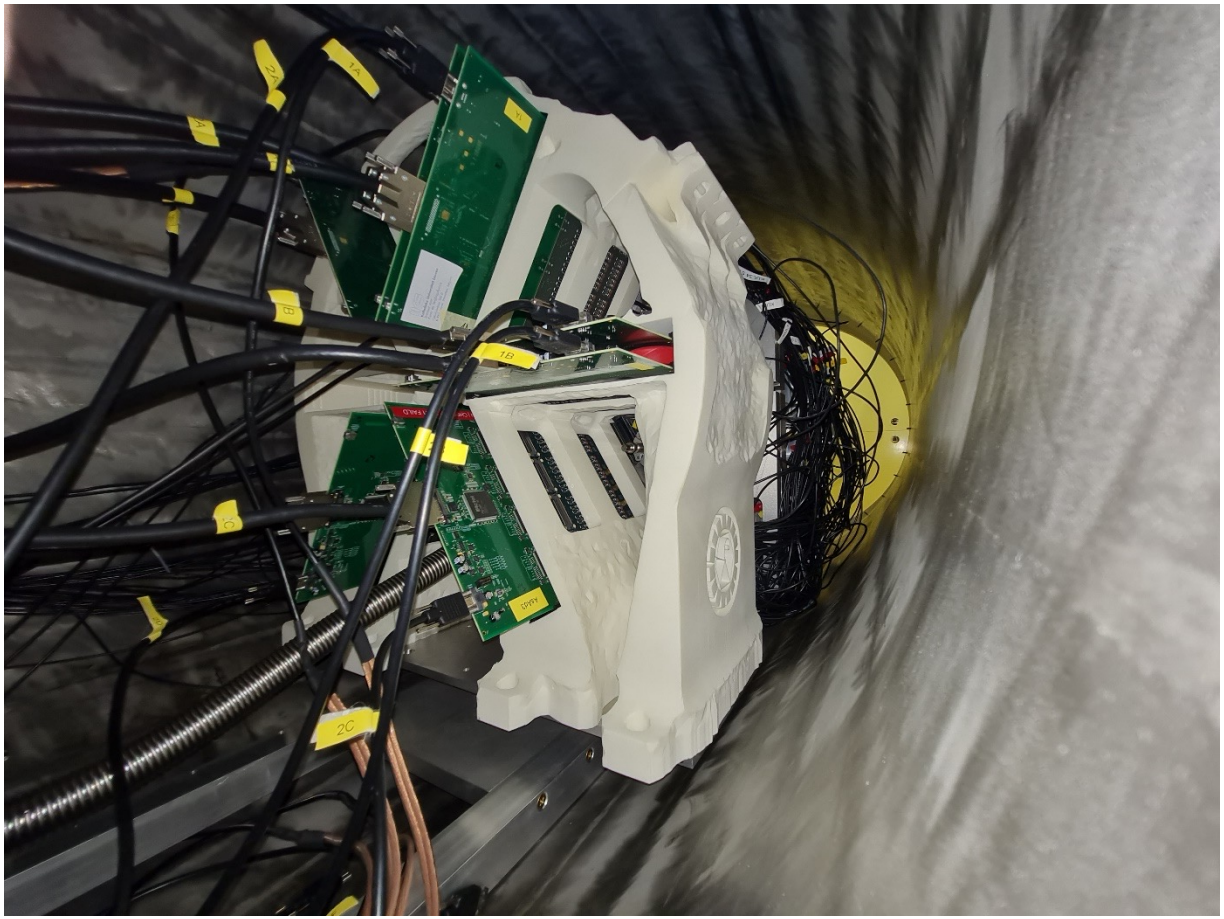
A 4-alpha source was used for the characterisation: ^{148}Gd, ^{239}Pu, ^{241}Am, ^{244}Cm

Ar(90%)CF_4(10%)

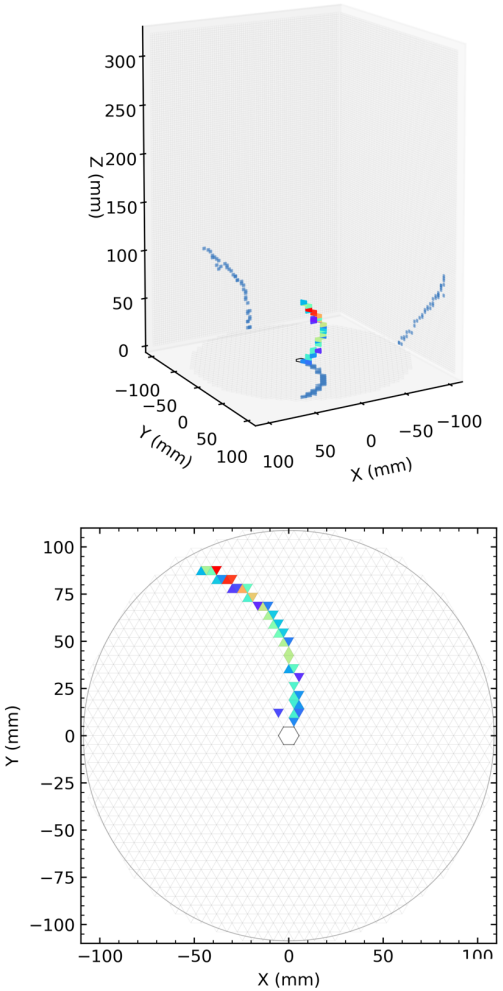
Detector configuration	Pressure of ArCF4(10%), mbar
3 sectors + scint. in 2.5T	100 / 250 / 350
3 sectors + scint. in 0T	

Pressure, mbar	^{148}Gd 3182 keV	^{239}Pu 5155 keV	^{241}Am 5488 keV	^{244}Cm 5805 keV
	Range, mm			
100	190	369.7	404.496	438.848
250	76.84	147.9	161.797	175.537
350	54.73	105.63	115.568	125.38

Tests of the SpecMAT active target in ISS



SpecMAT installed in ISS



Measured α-particle track in B=2.5T

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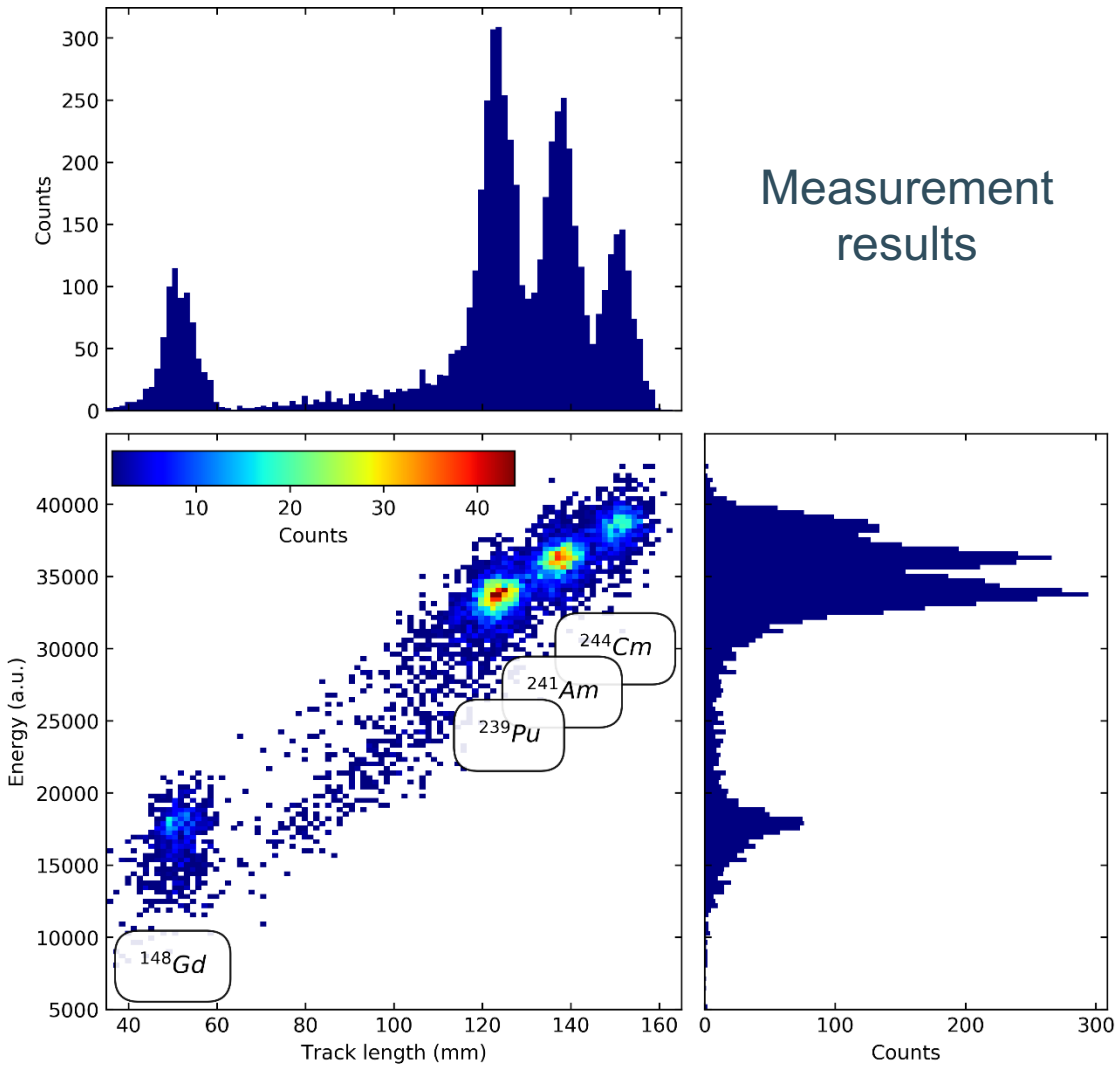
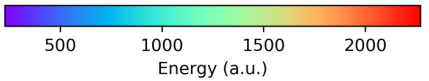
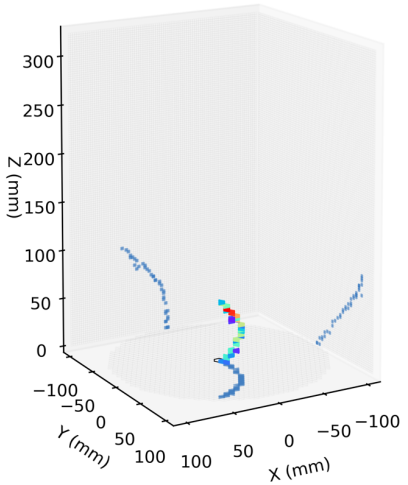
Tests of the SpecMAT active target in ISS

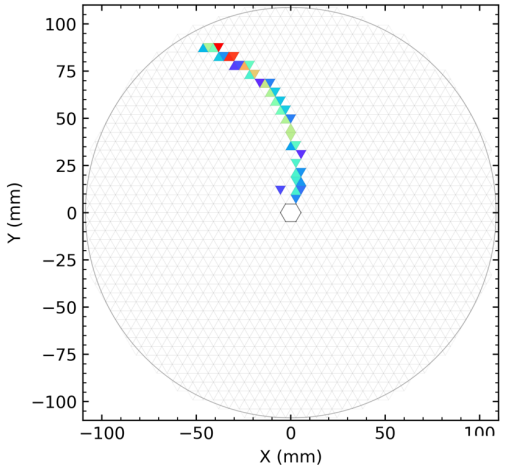
Comparison of the SpecMATscint G4 simulation
with preliminary analysis of the measurement
(Ar90%$CF_4$10% @ 250 mbar)



Measurement results







Measured α-particle track in B=2.5T

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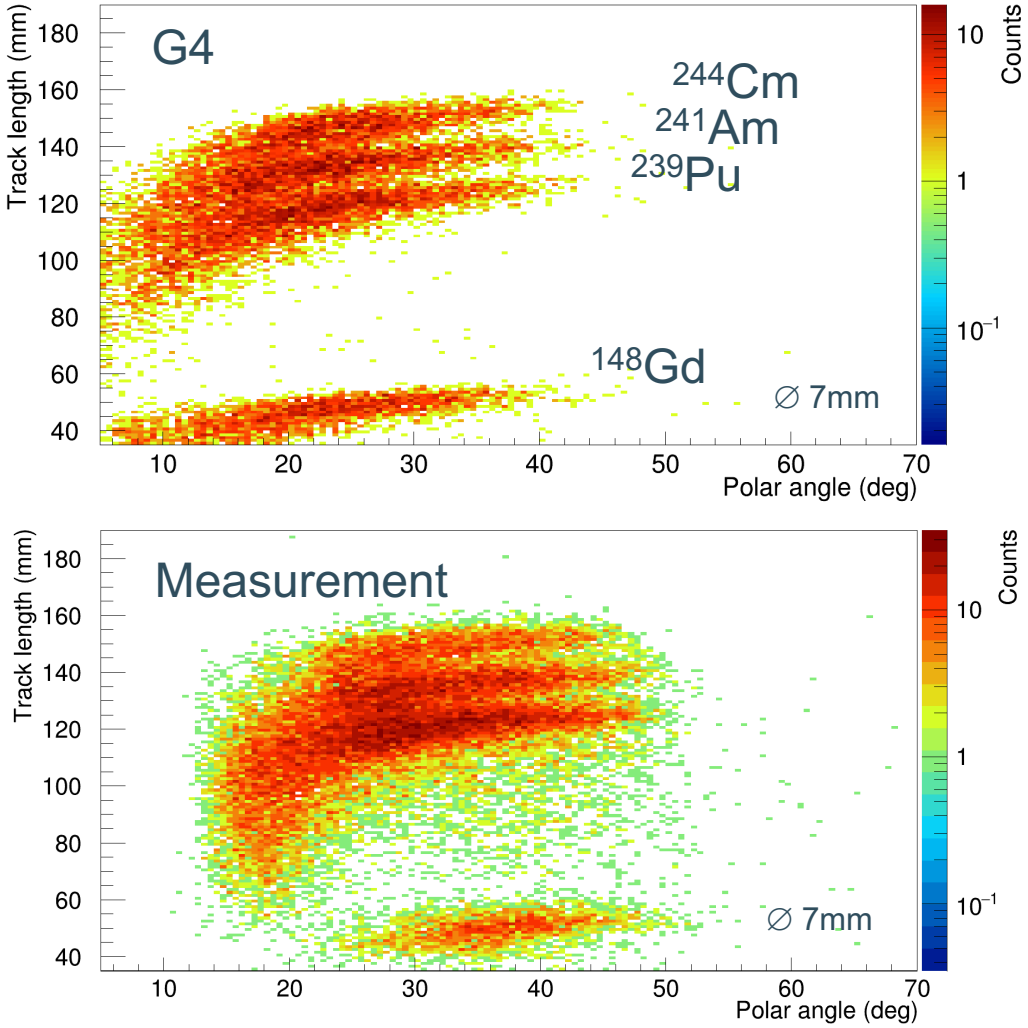

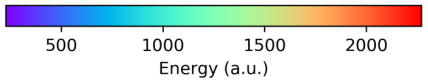

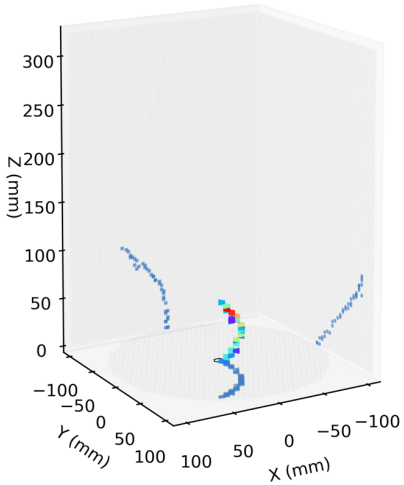

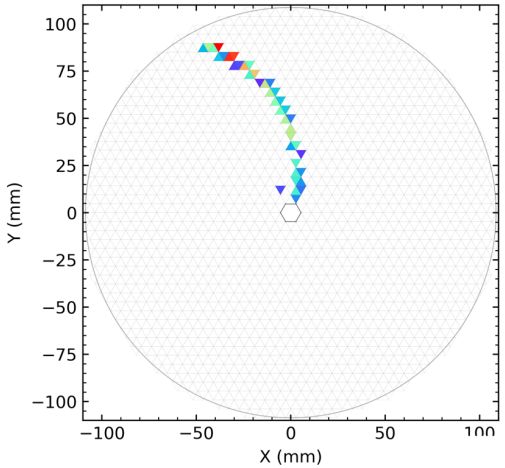

Measured α-particle track in B=2.5T

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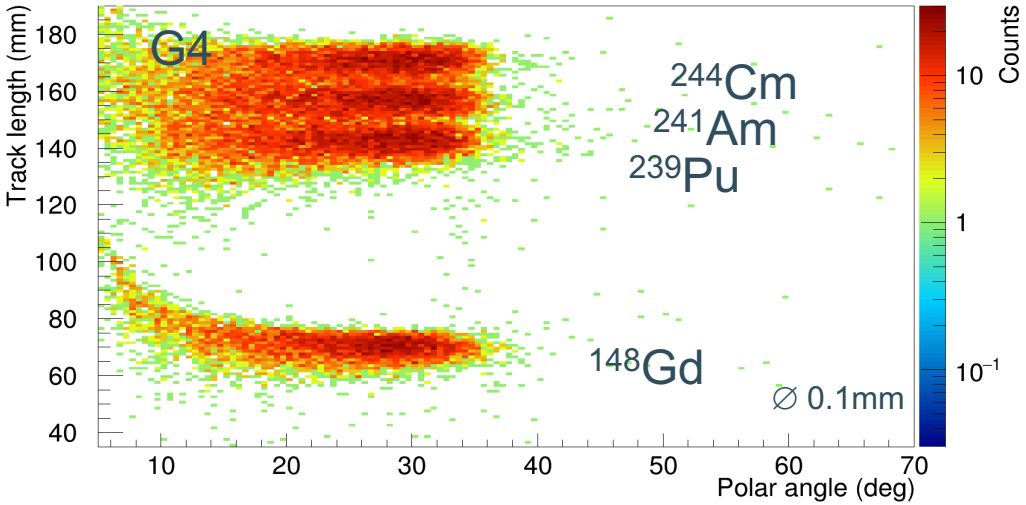

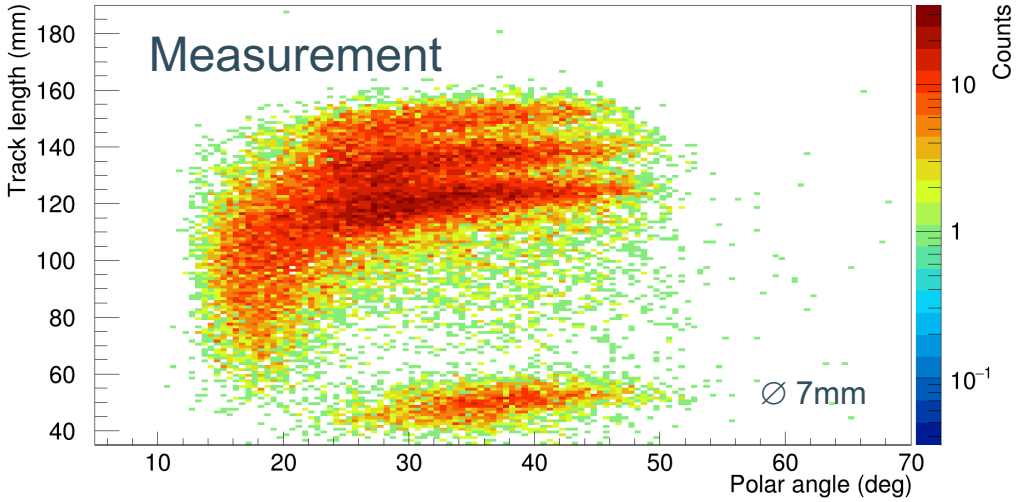

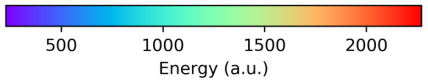

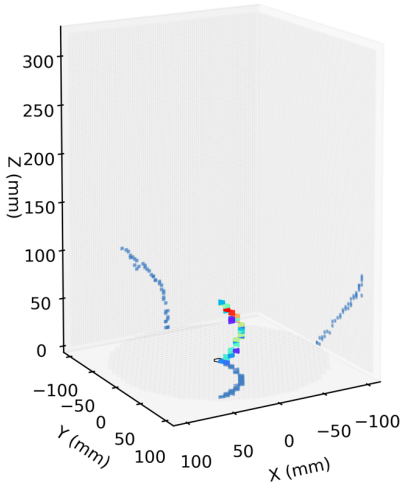

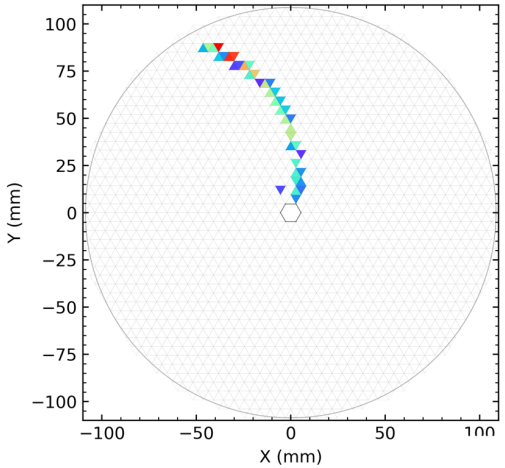

Measured α-particle track in B=2.5T

SpecMAT

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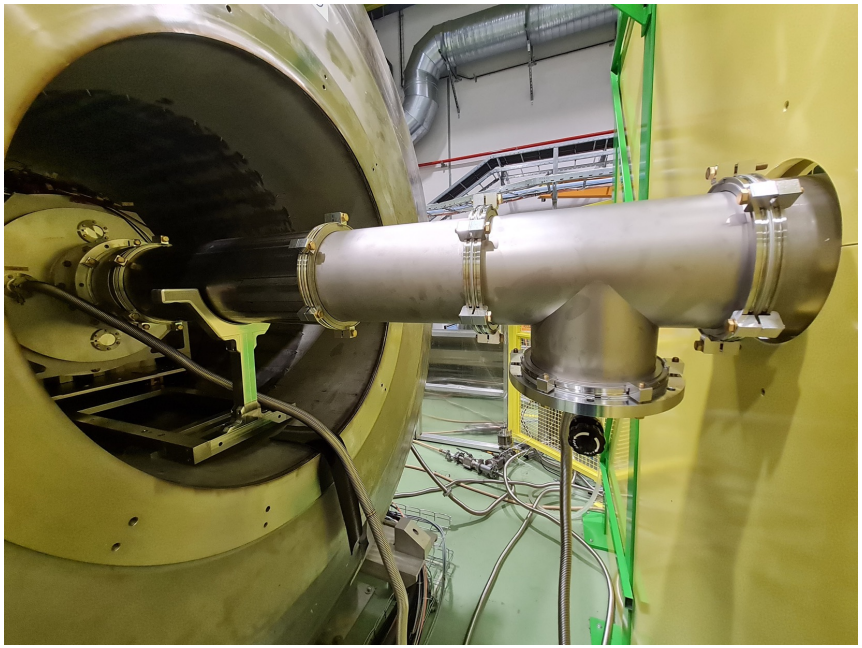
Online commissioning of SpecMAT at HIE-ISOLDE 2023

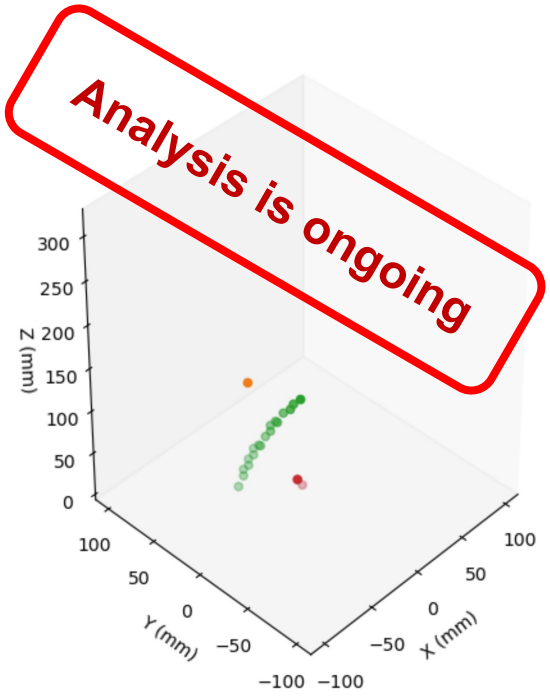
^{22}Ne @ 7.58 MeV/u on **D_2 @ 800 mbar**

8 μm Mylar window → Beamline 8×10^{-8} mbar | Detector 800 mbar

Main reaction branches expected to observe:

- ^{22}Ne(d,d)
- ^{22}Ne(d,p)
- ^{22}Ne(d,^{3}He)
- ^{22}Ne(d,t)





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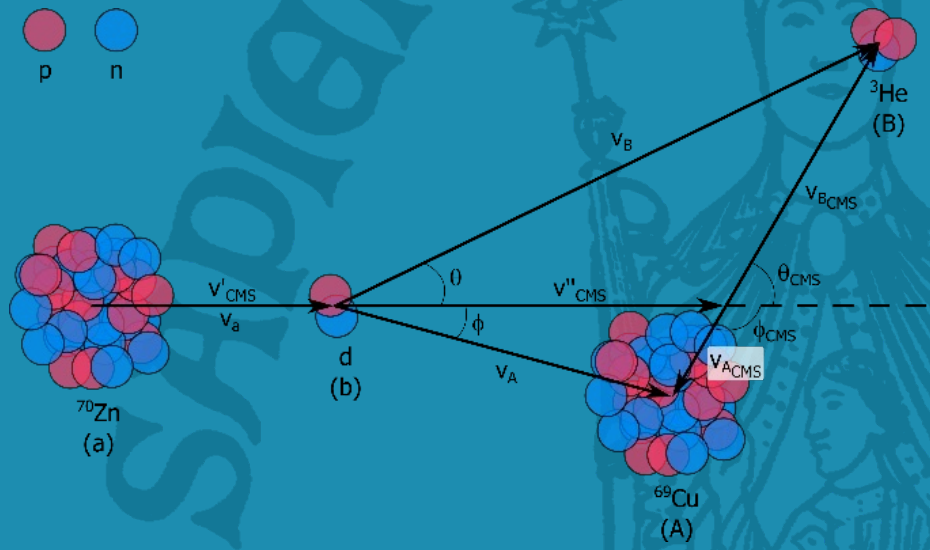
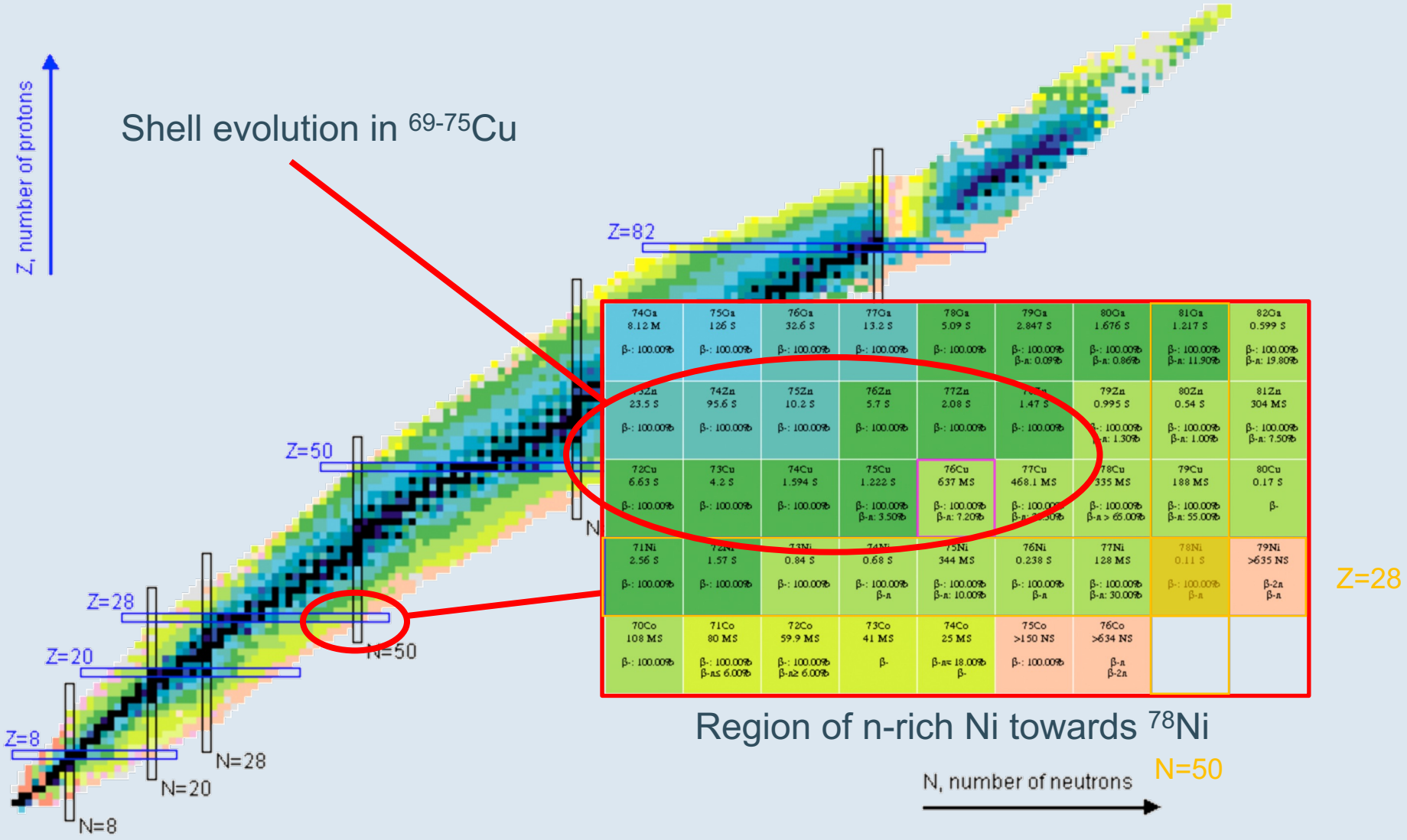
Physics perspectives

Simulation of a $^{70}Zn(d, {}^{3}He)^{69}Cu$ reaction



Physics case



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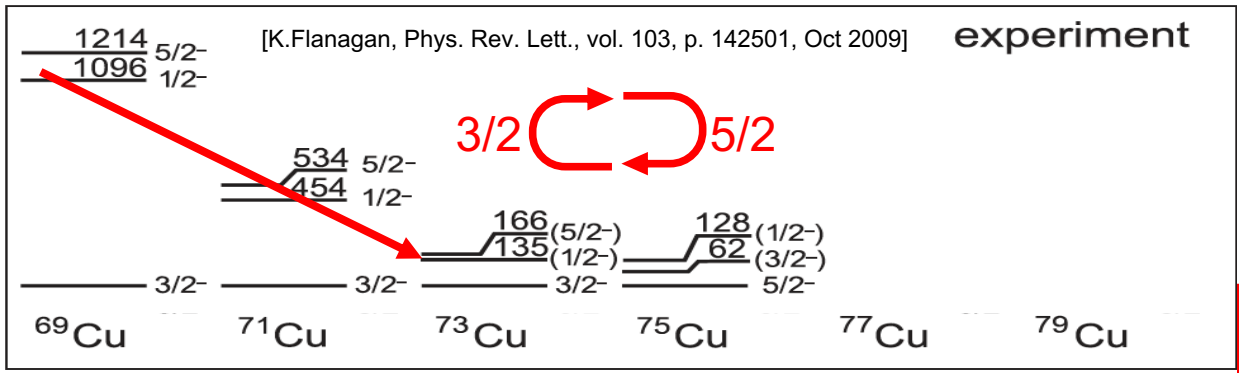
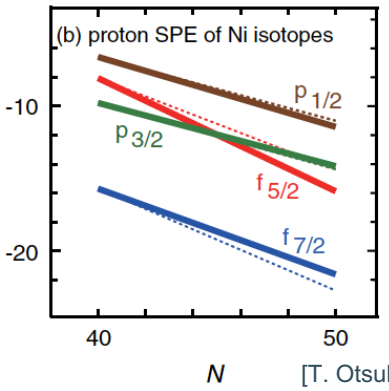
Physics case

Shell structure of odd Cu isotopes via nucleon transfer reactions on Zn:

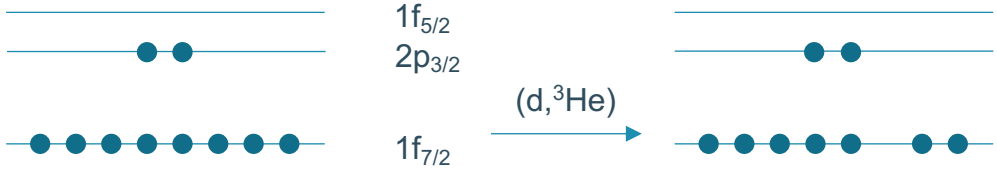
- ^{70}Zn(d,^{3}He)^{69}Cu
- ^{72}Zn(d,^{3}He)^{71}Cu
- ^{74}Zn(d,^{3}He)^{73}Cu
- ^{76}Zn(d,^{3}He)^{75}Cu





[T. Otsuka, *et al.*, PRL, 104, 012501 (2010)]

Region of ^{78}Ni



Protons in ^{72}Zn

Protons in ^{71}Cu*

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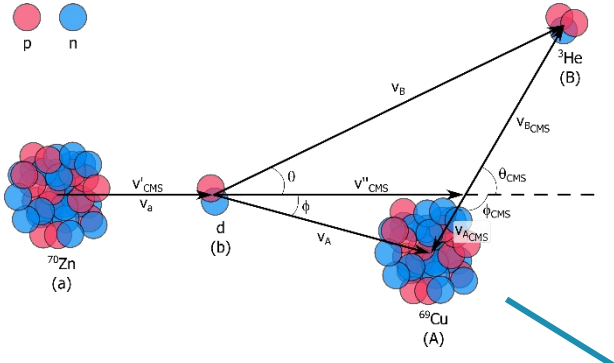
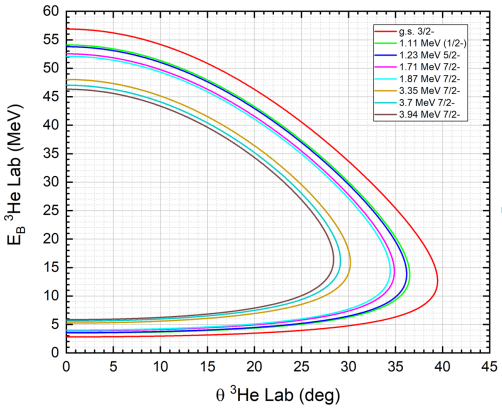
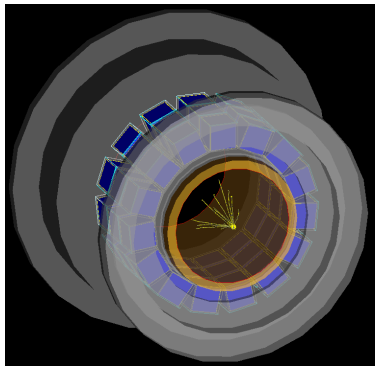
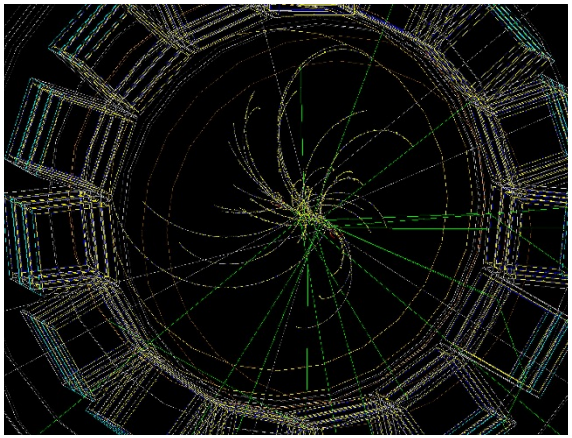
^{70}Zn(d, ^{3}He)^{69}Cu reaction simulation in G4 for SpecMAT

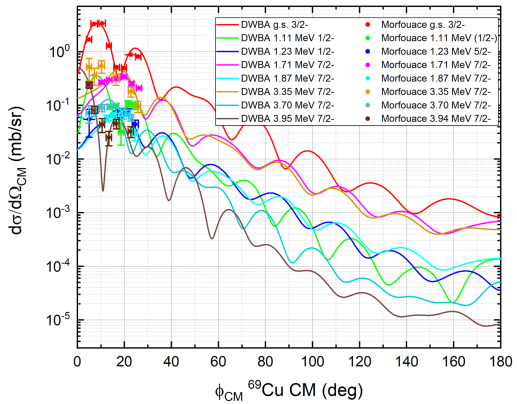






+ B-field = 4T



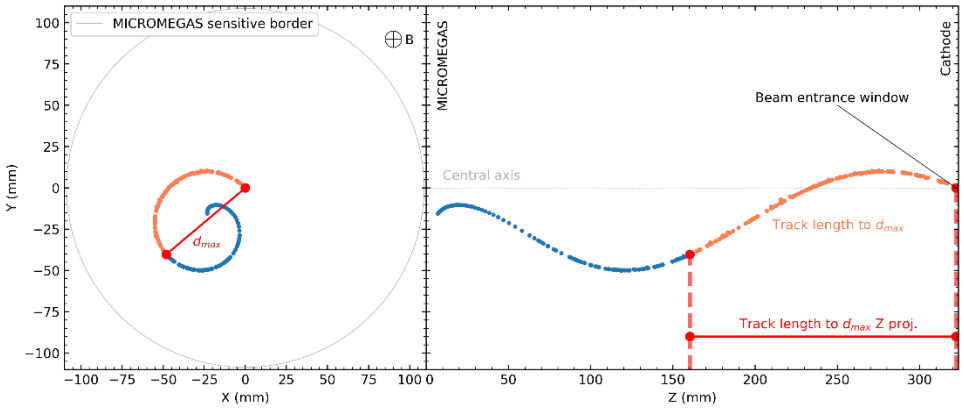


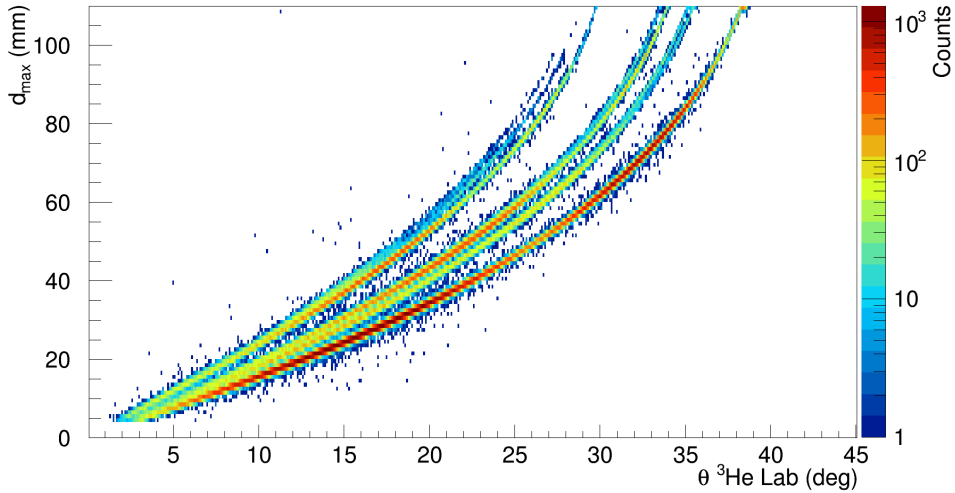
Cross section data from [P. Morfouace https://doi.org/10.1103/PhysRevC.93.064308], DWBA by J.C. Yang

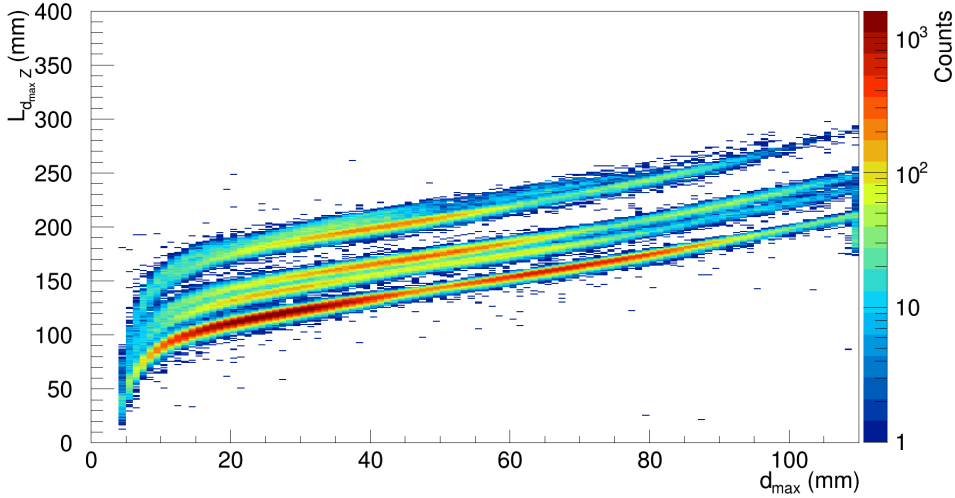
Table 5.1: Estimated total cross section of the low-lying states in ^{69}Cu.

State	Energy (MeV)	Estimated σ_{tot} (mb)
$3/2^-$	g.s. 0	1.506
$(1/2^-)$	1.11	0.14
$5/2^-$	1.23	0.083
$7/2^-$	1.71	0.349
$7/2^-$	1.87	0.074
$7/2^-$	3.35	(0.387)
$7/2^-$	3.7	0.066
$7/2^-$	3.94	0.046

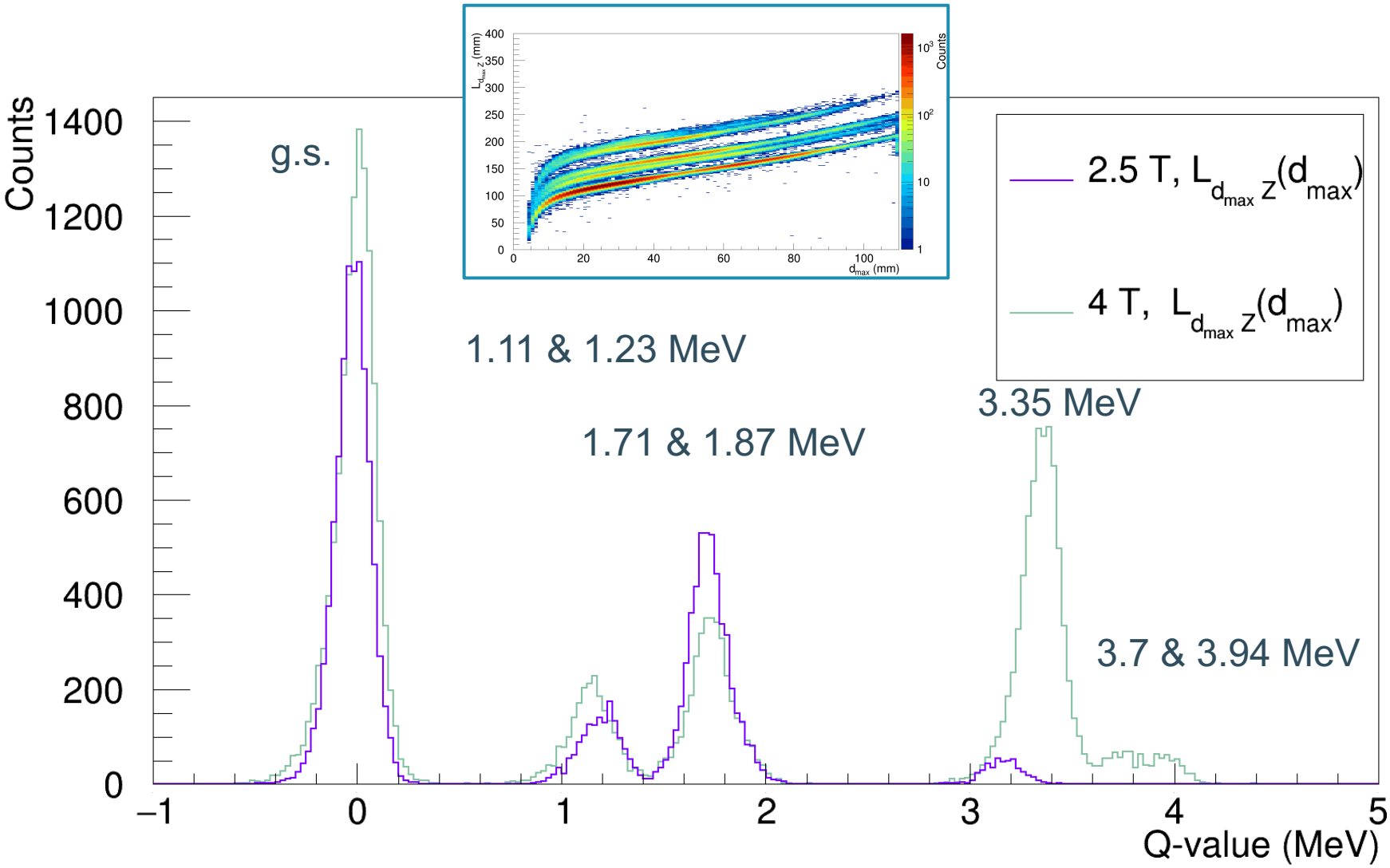
4T no MICROMEGAS binning



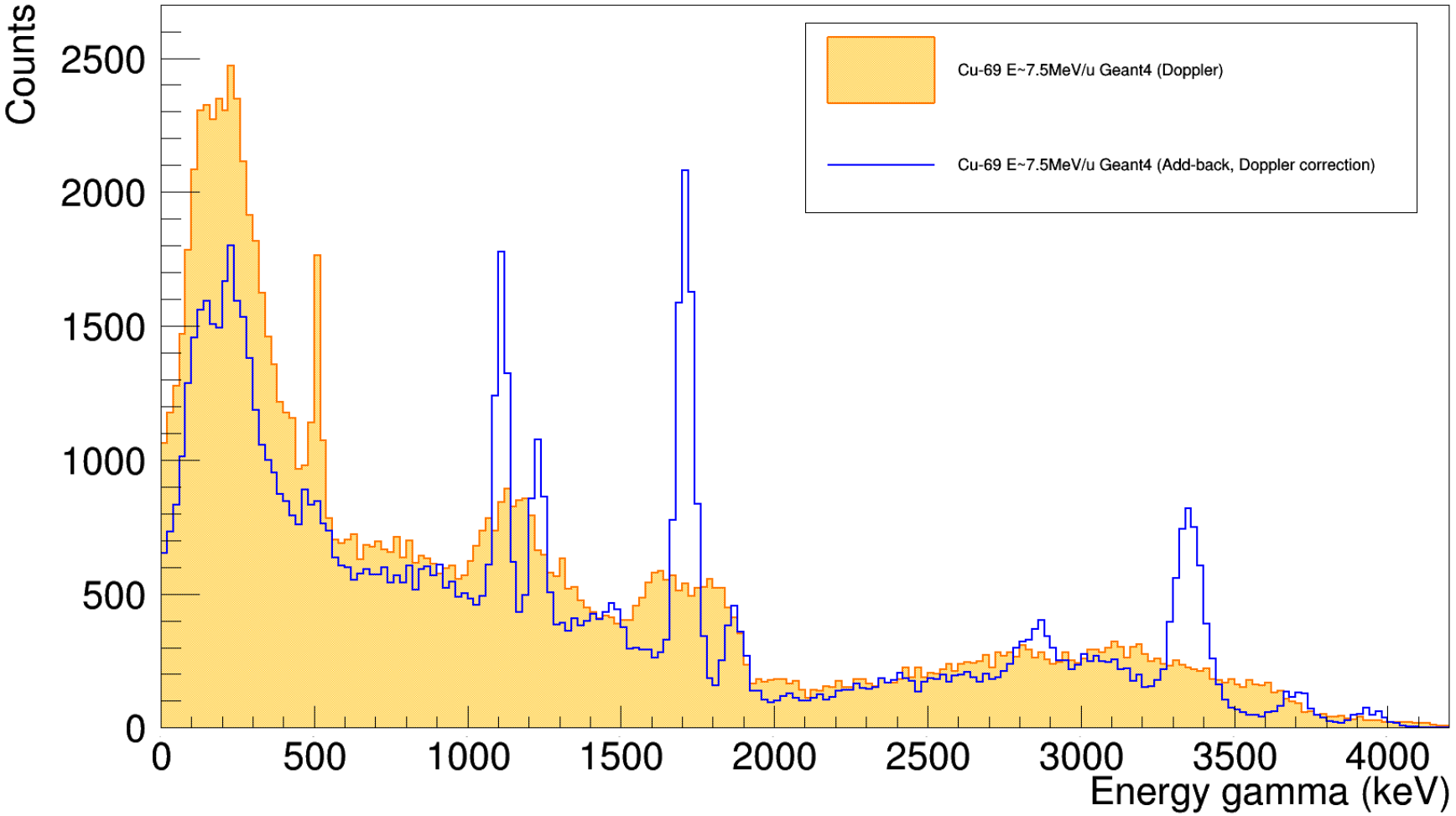


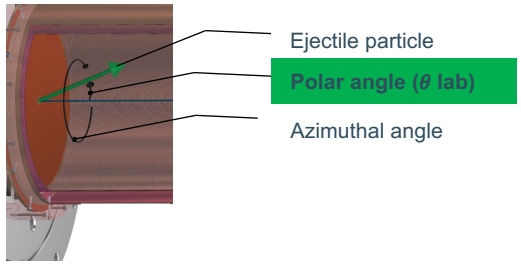


Excitation spectra obtained with the new analysis method

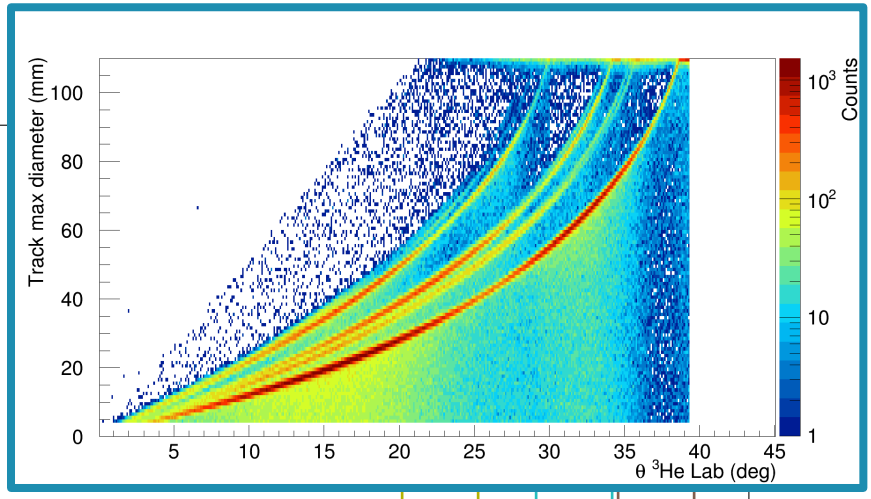


Analysis based on (full+partial)-track length
Gating on the gamma-ray spectrum





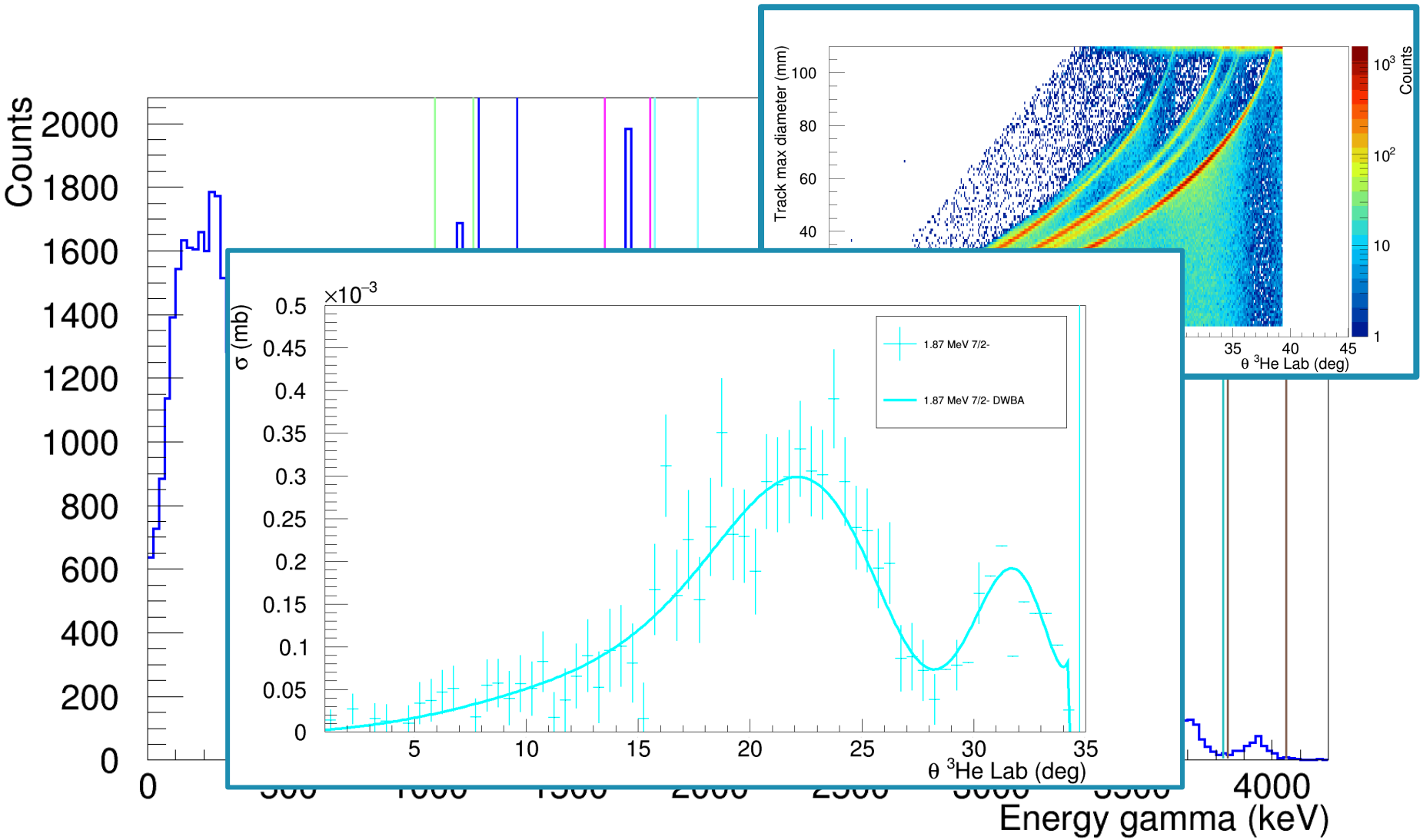
Analysis based on (full+partial)-track length
Gating on the gamma-ray spectrum



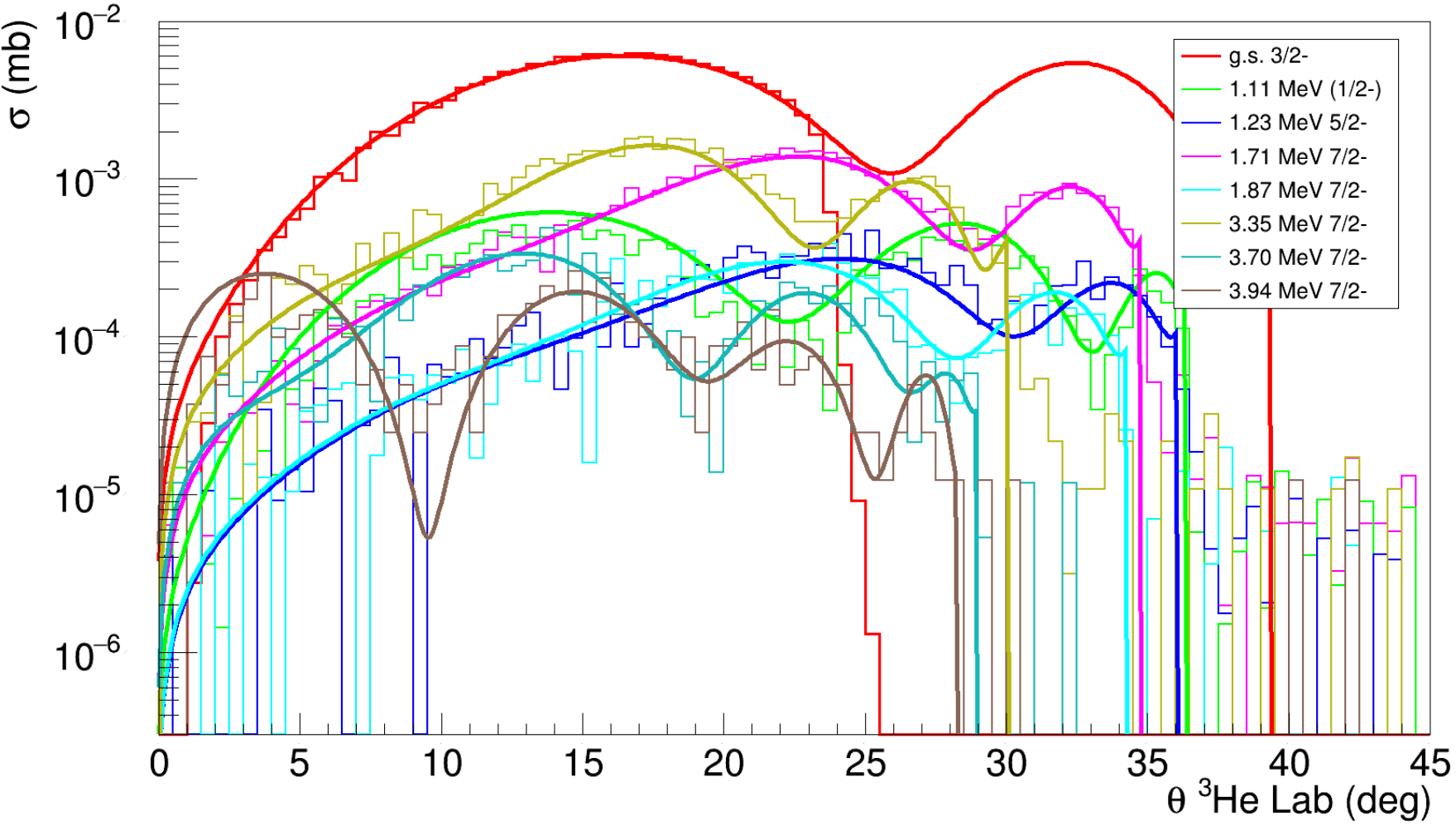
Counts

Energy gamma (keV)

Analysis based on (full+partial)-track length
Gating on the gamma-ray spectrum

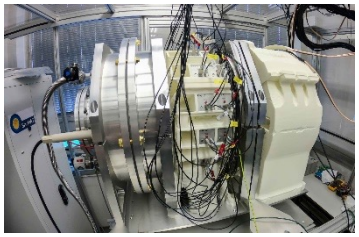


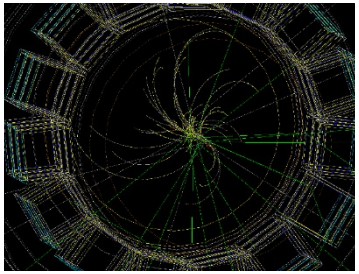
Analysis based on (full+partial)-track length
Gating on the gamma-ray spectrum

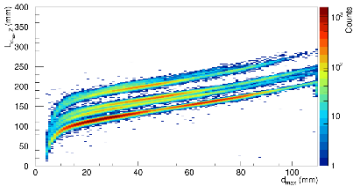


Summary

- ✓ The SpecMAT active target was designed, built and tested.
- ✓ The active target was characterised in 0T and in 2.5T.
- ✓ An experimentally verified set of simulations was developed.
- ✓ A novel analysis method of the spiral tracks was proposed.
- ✓ Online commissioning of the detector with a ^{22}Ne beam was successful.
- ✓ We are upgrading the detector with THGEMs and preparing to the first experimental campaign with exotic RIBs.







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Thank you for your attention!

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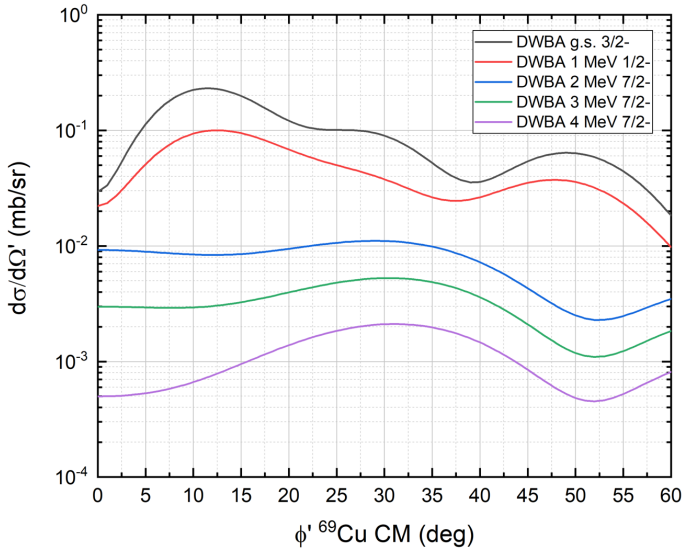
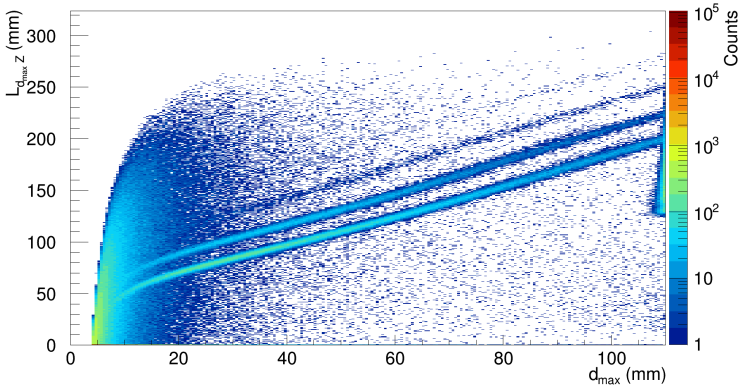
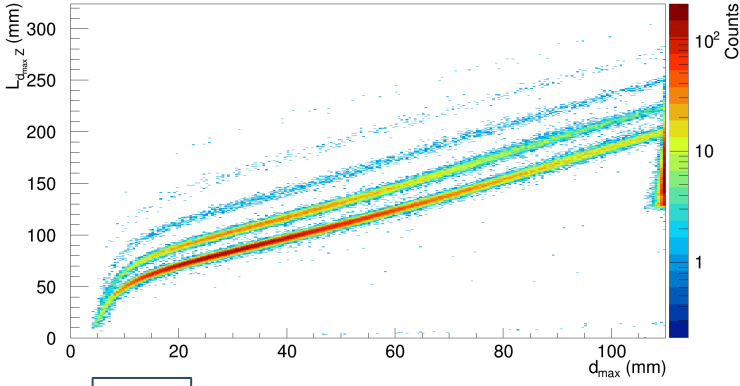
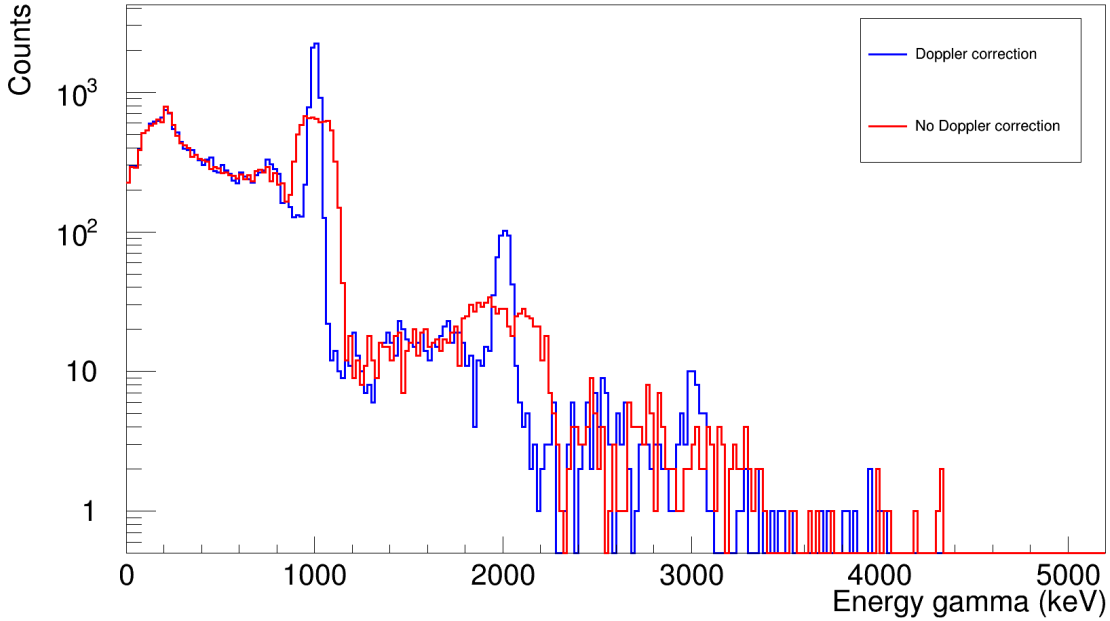
Backup slides

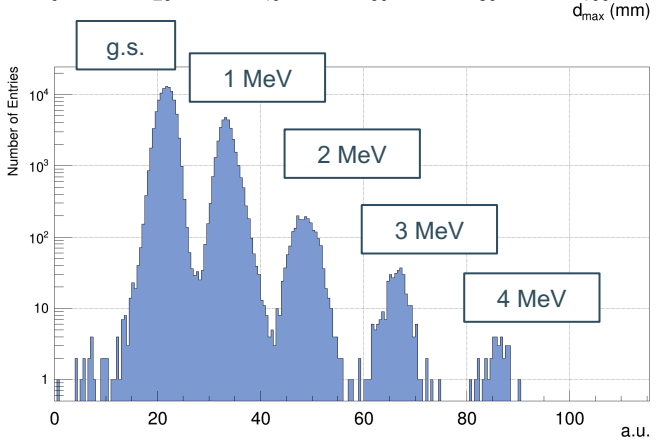
$^{70}Zn(d, ^{3}He)^{69}Cu$--9.5MeV/u--2.5T--$D_2$@1bar











DWBA by B. Kay

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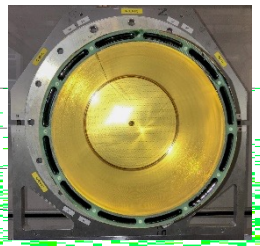
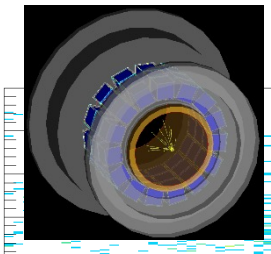
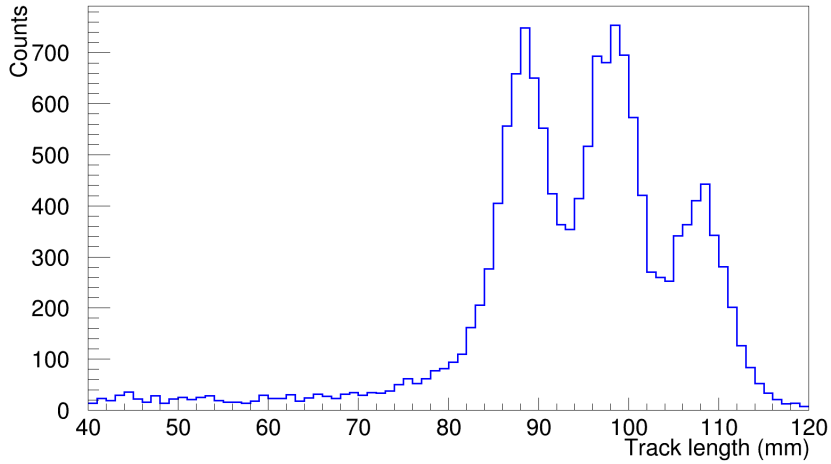
Measurement vs G4
α-particle length spectra

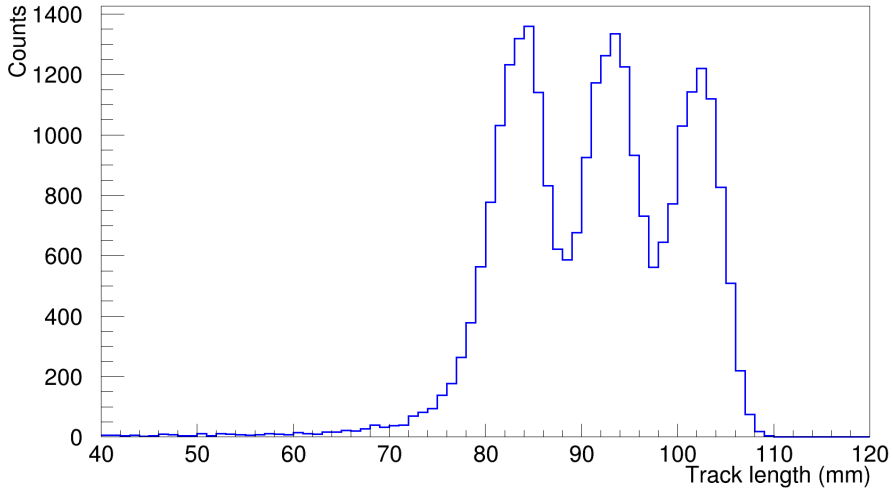


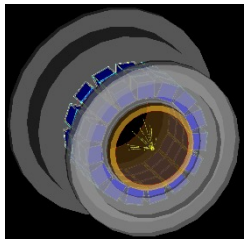
Measurement



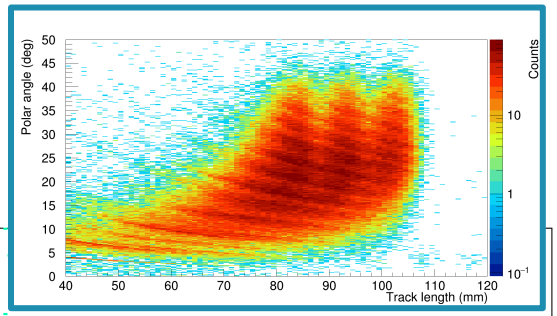
Geant4

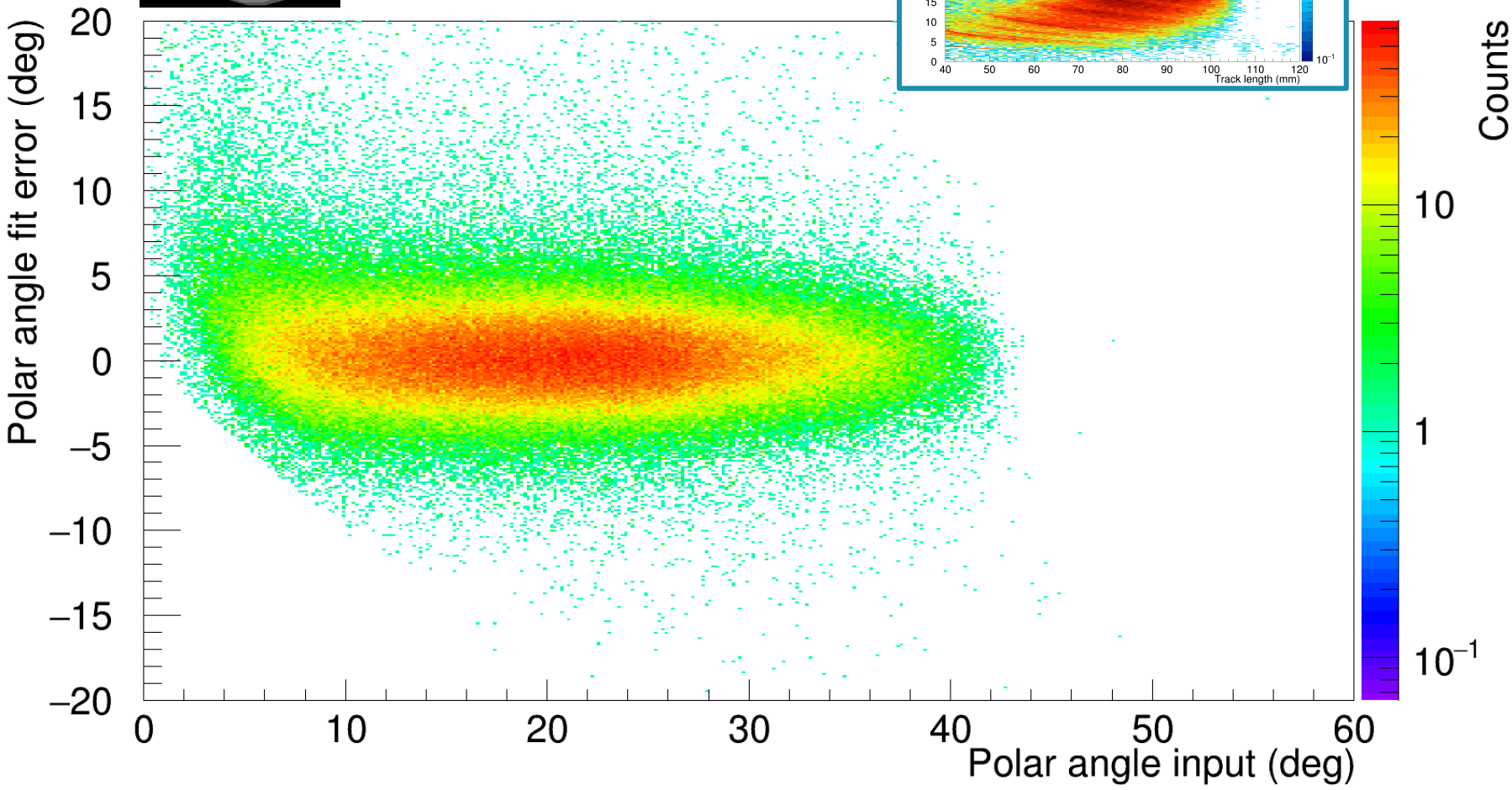


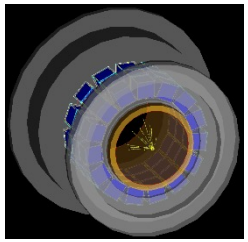




Geant4

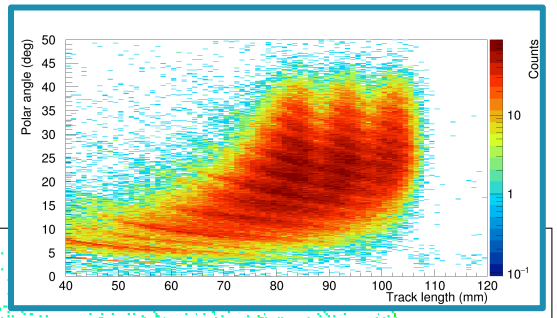

Polar angle (deg)
Track length (mm)
Counts

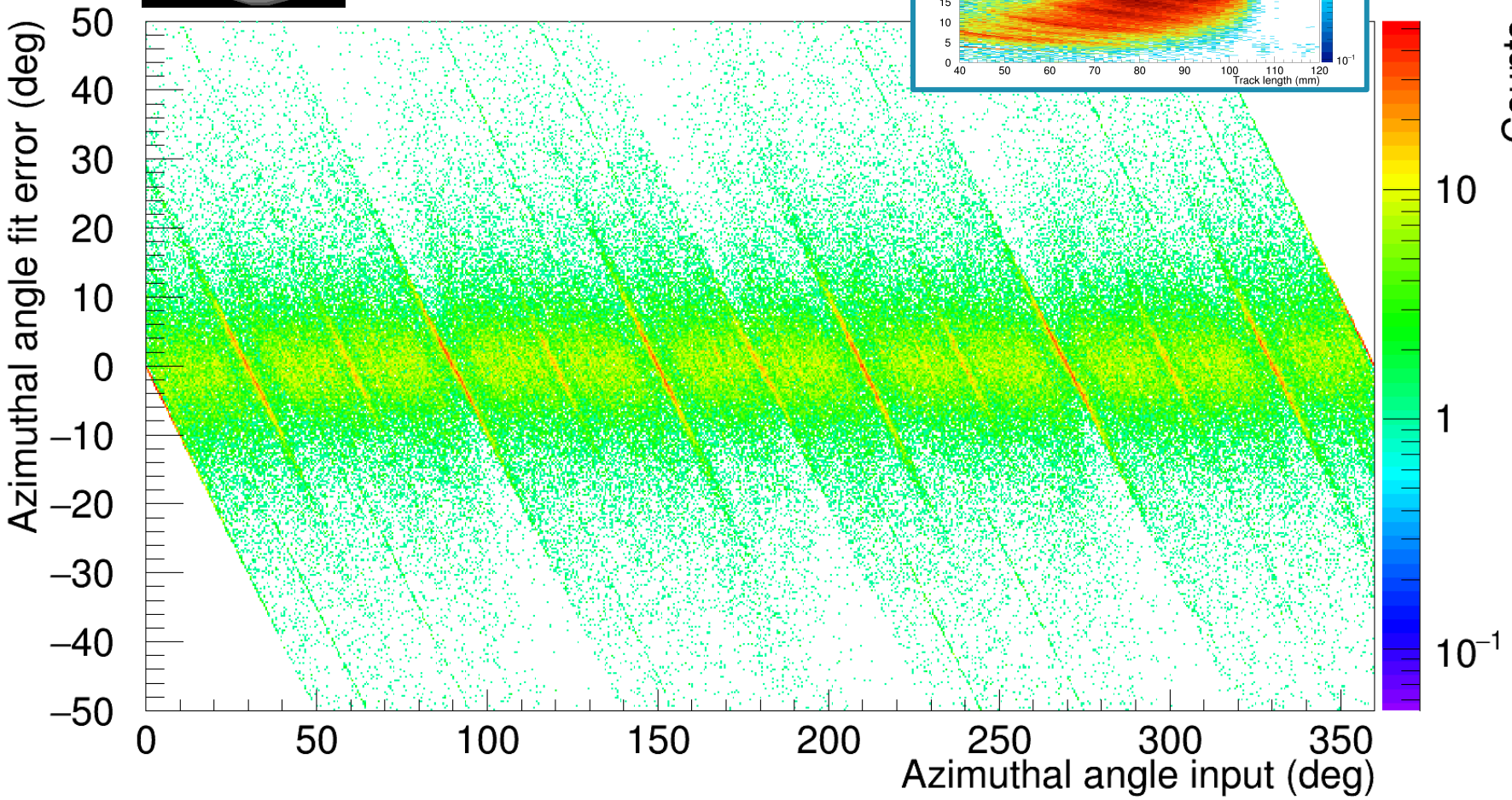

Polar angle fit error (deg)
Polar angle input (deg)
Counts

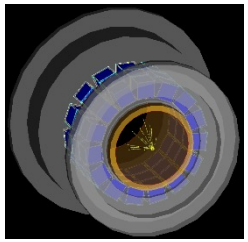


Geant4

Phi > 0 deg

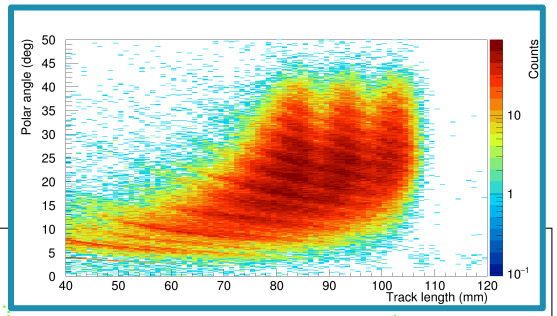


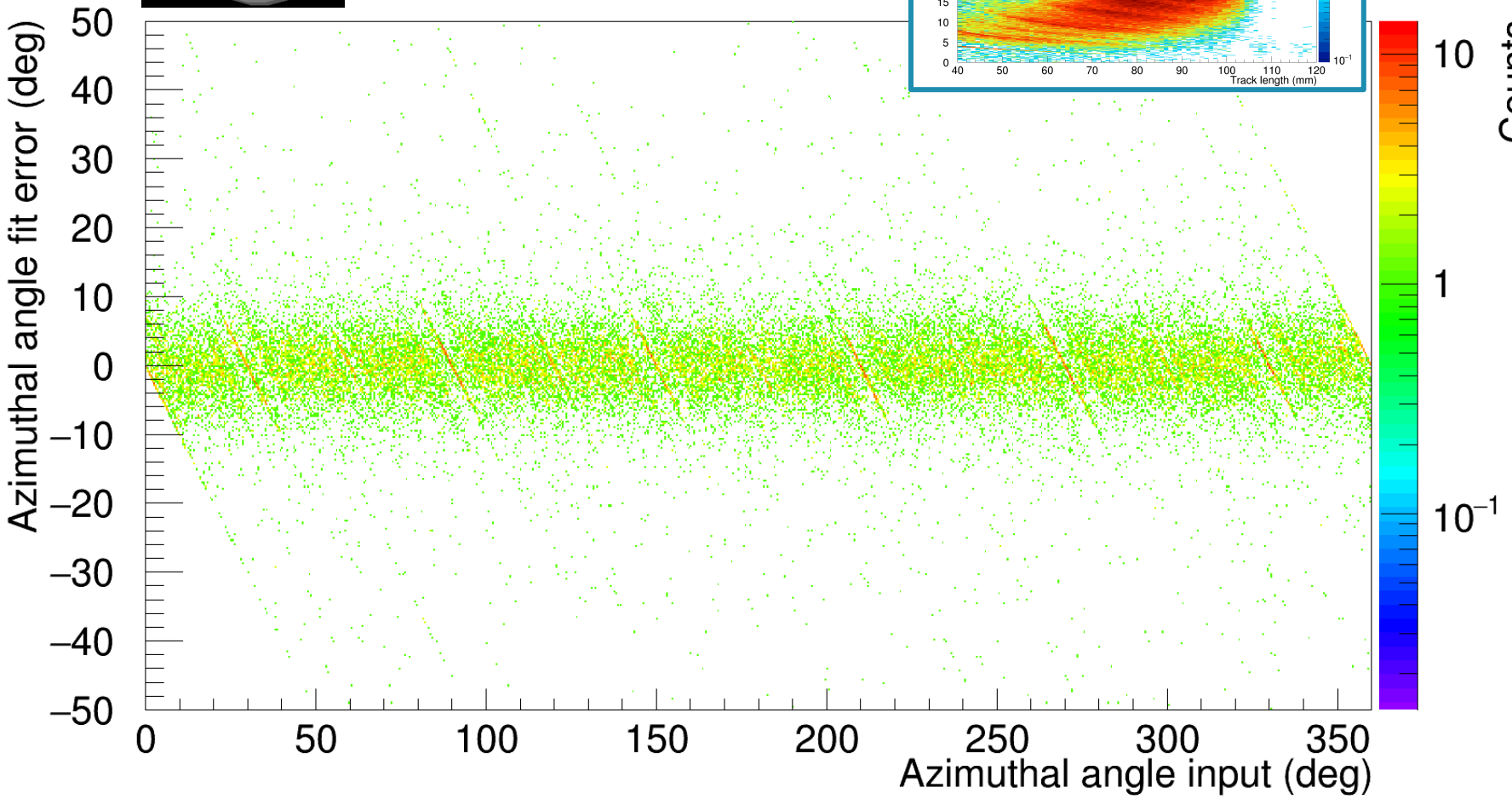




Geant4

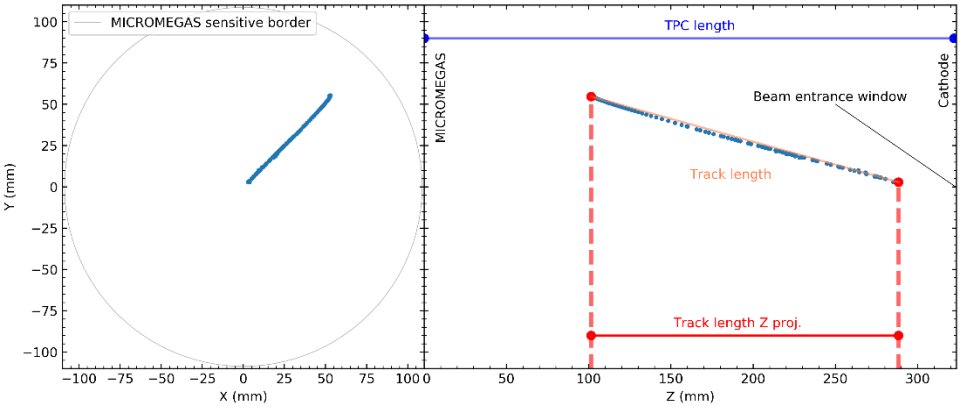
Phi > 30 deg

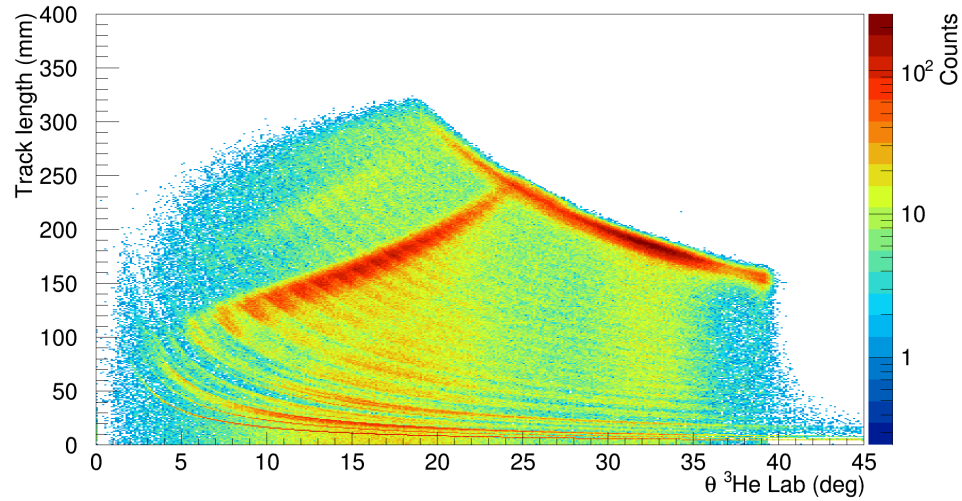




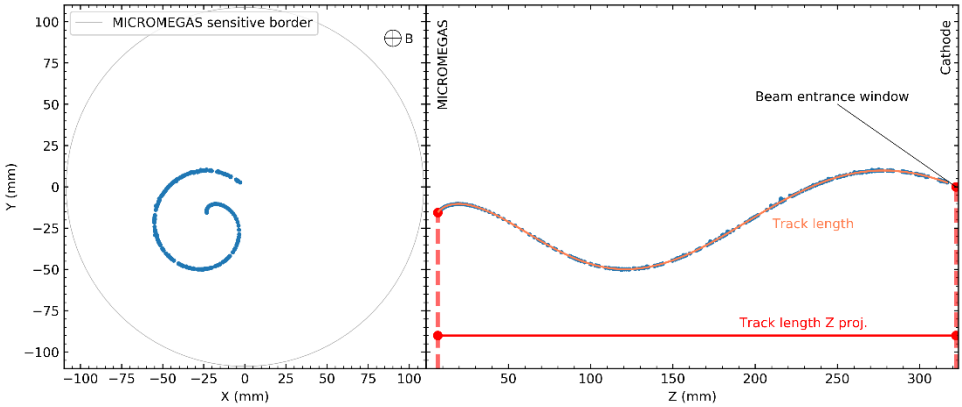
Analysis based on full-track length

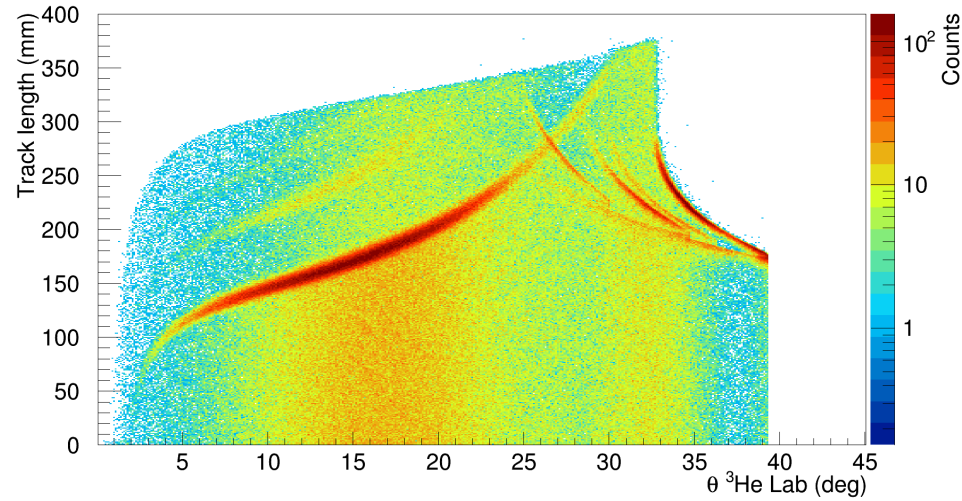
0T with MICROMEGAS binning
Track parameters (θ, L) from fitting





4T no MICROMEGAS binning
Track parameters from G4

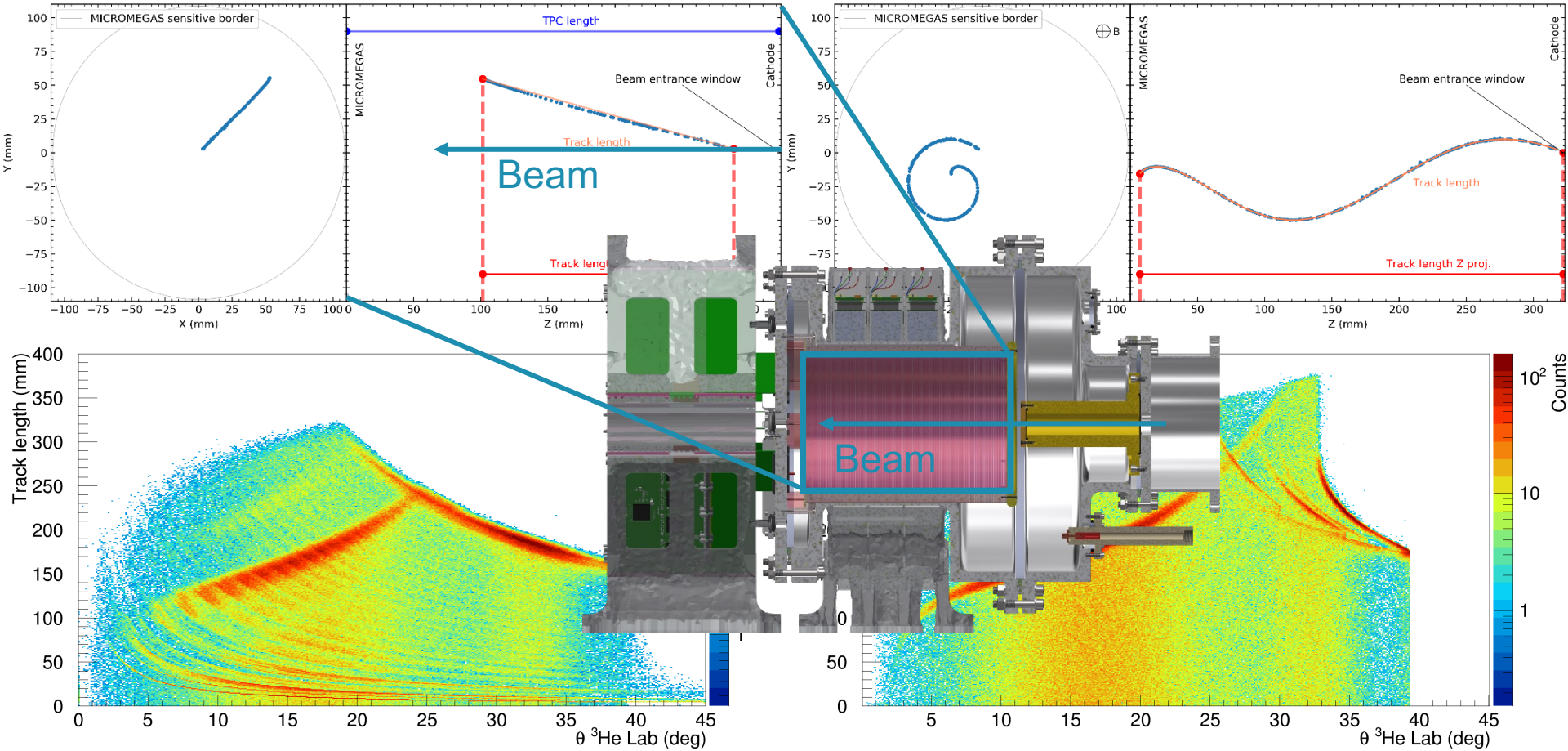




Analysis based on full-track length

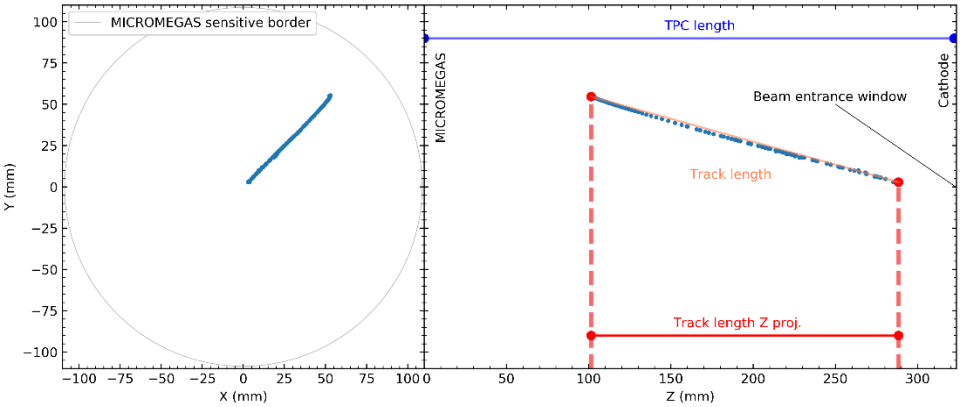
0T with MICROMEGAS binning
Track parameters (θ, L) from fitting

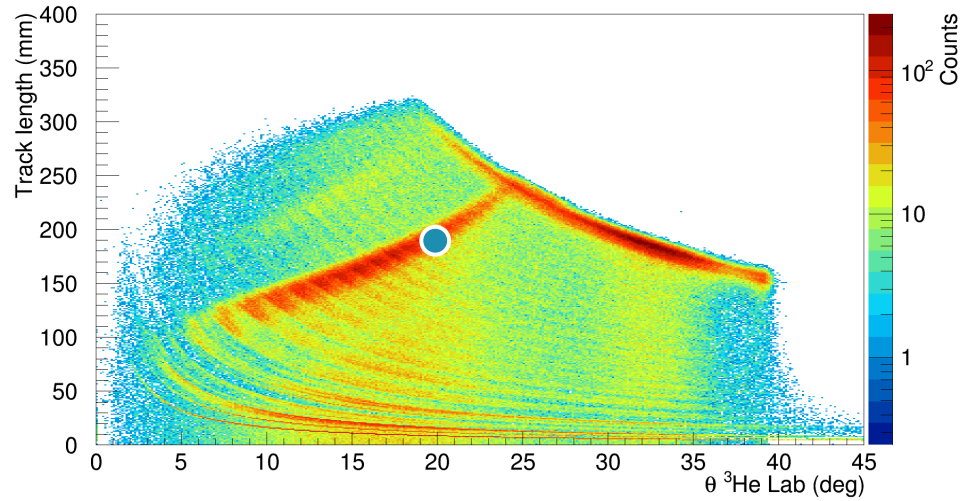
4T no MICROMEGAS binning
Track parameters from G4



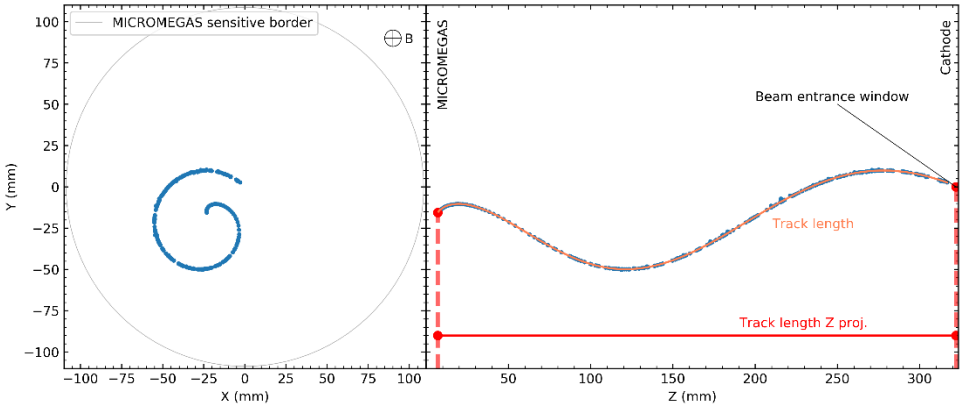
Analysis based on full-track length

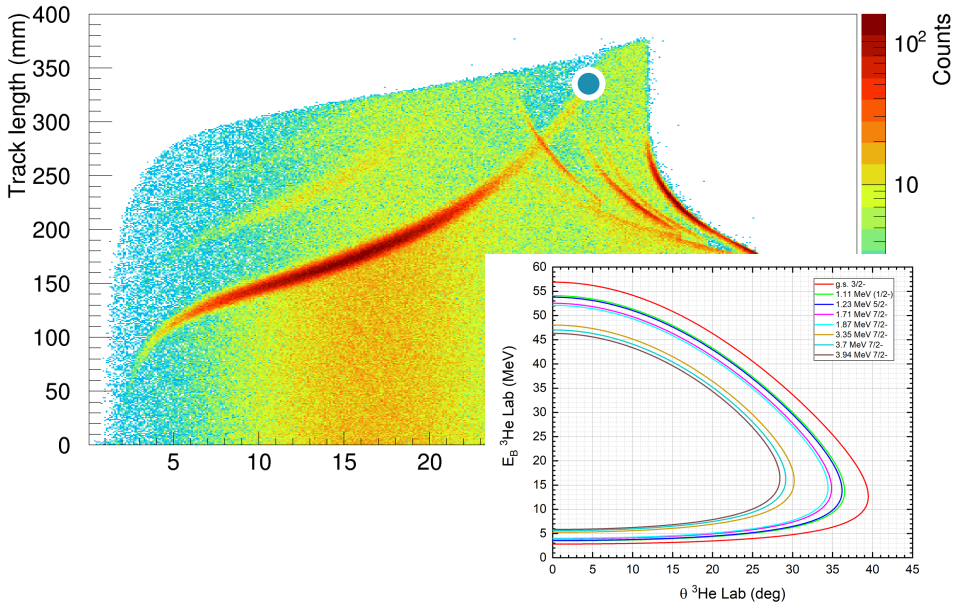
0T with MICROMEGAS binning
Track parameters (θ, L) from fitting





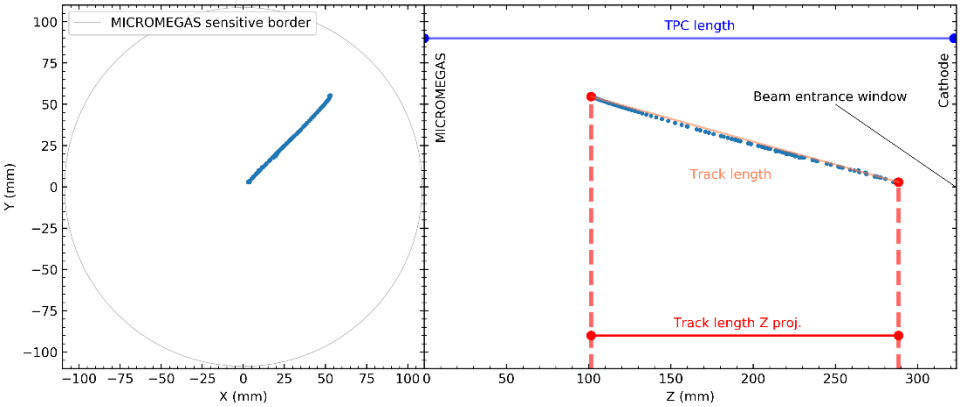
4T no MICROMEGAS binning
Track parameters from G4

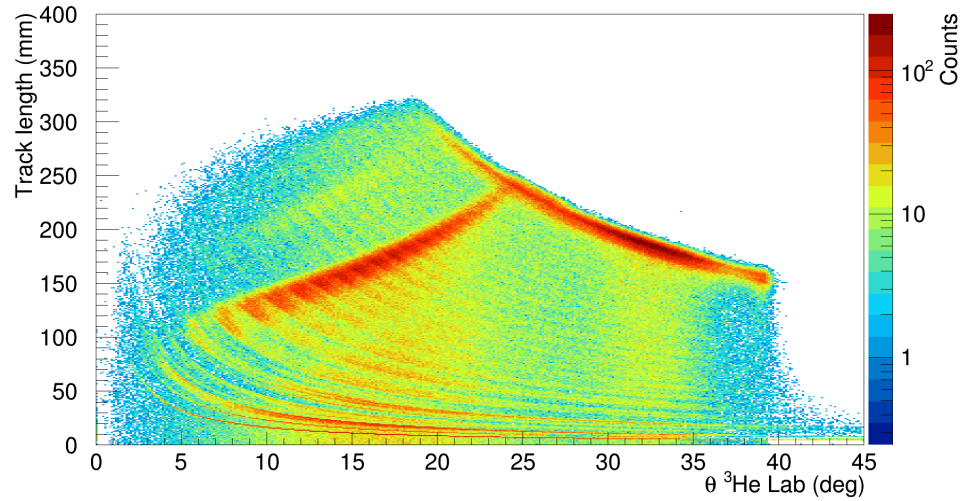




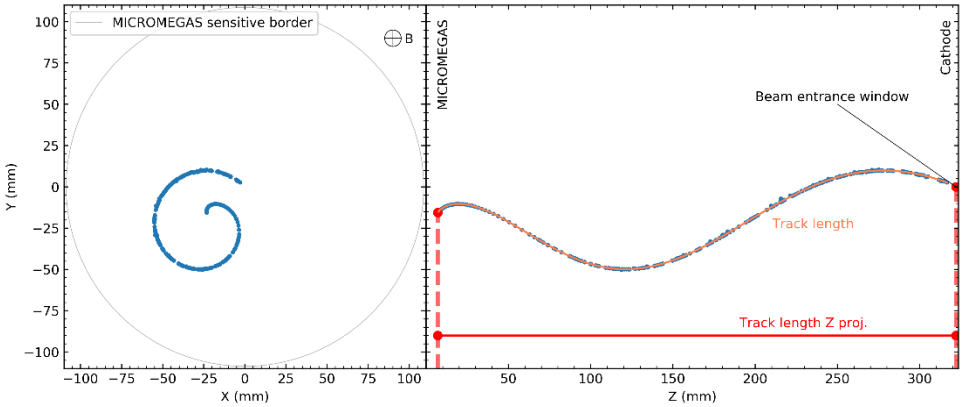
Analysis based on full-track length

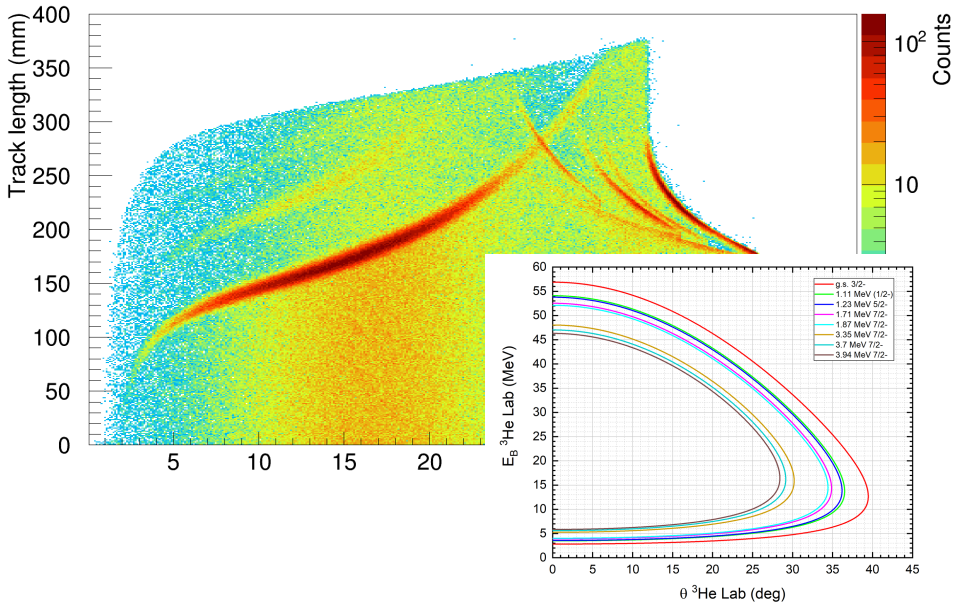
0T with MICROMEGAS binning
Track parameters (θ, L) from fitting





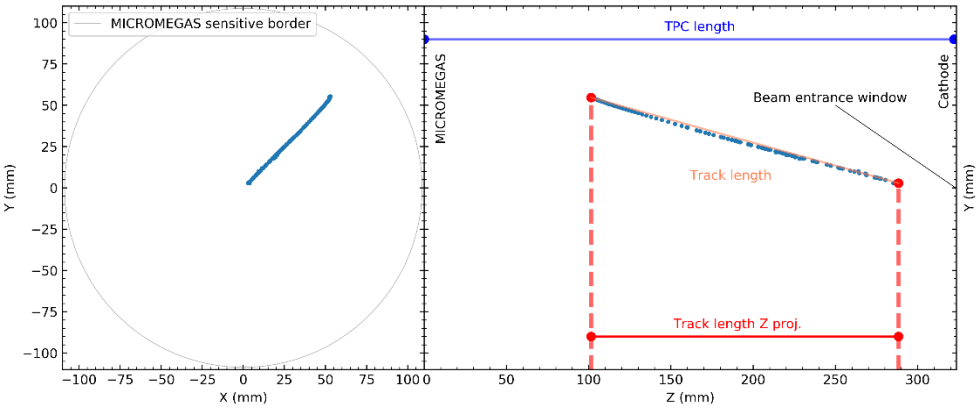
4T no MICROMEGAS binning
Track parameters from G4

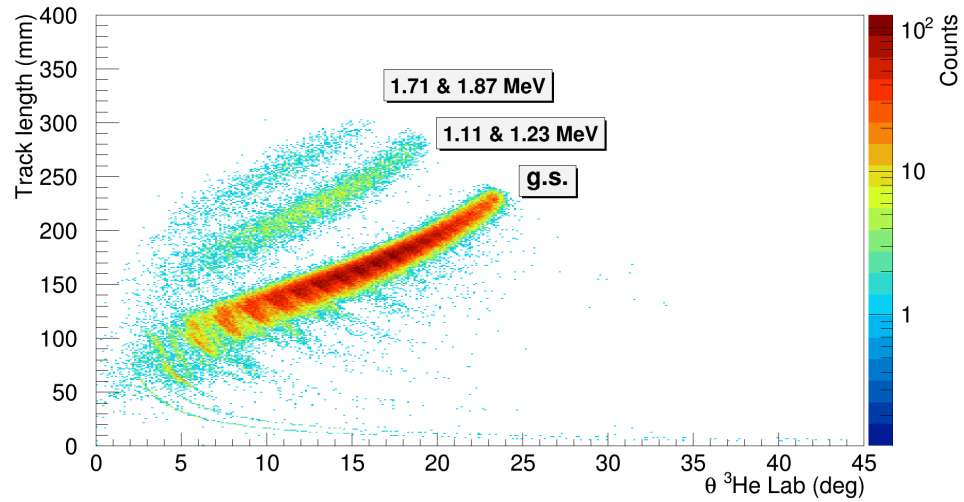




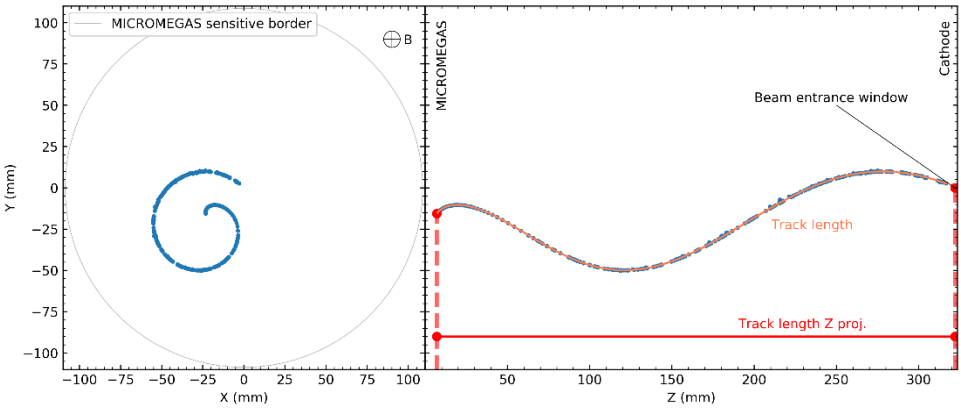
Analysis based on full-track length

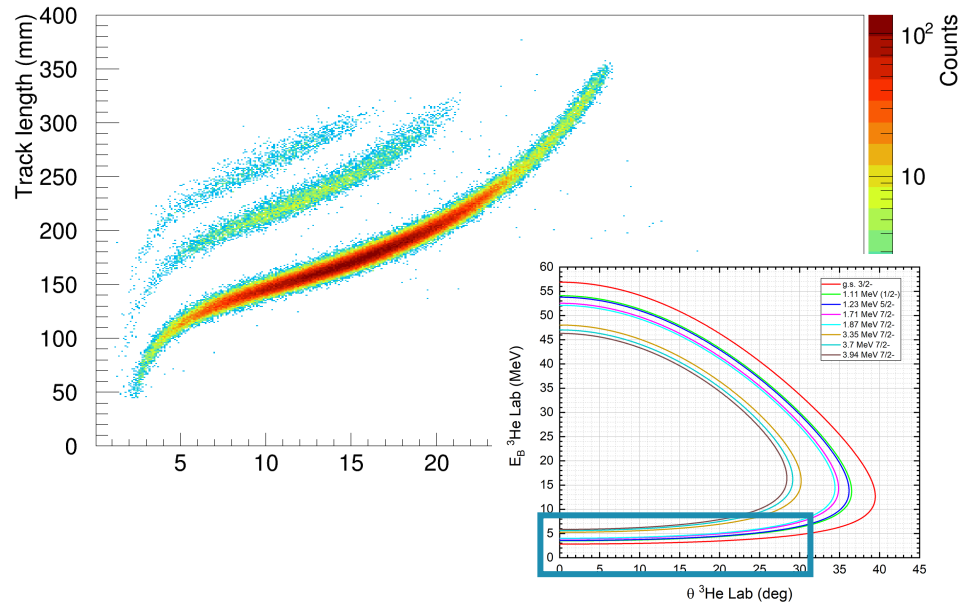
0T with MICROMEGAS binning





4T no MICROMEGAS binning





Analysis based on full-track length
Excitation spectra