Status report on in-flight recoil separators RITU and MARA

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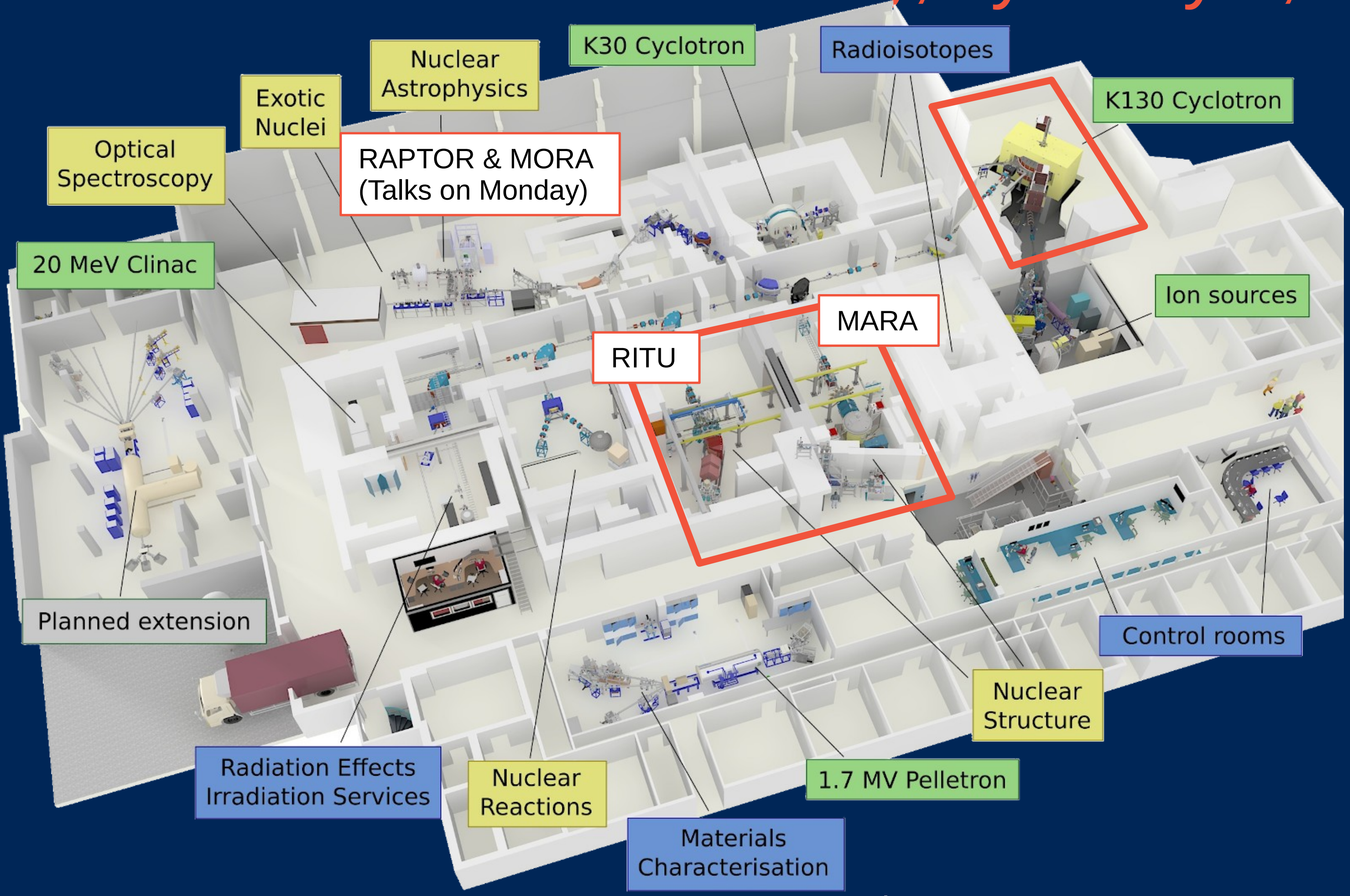
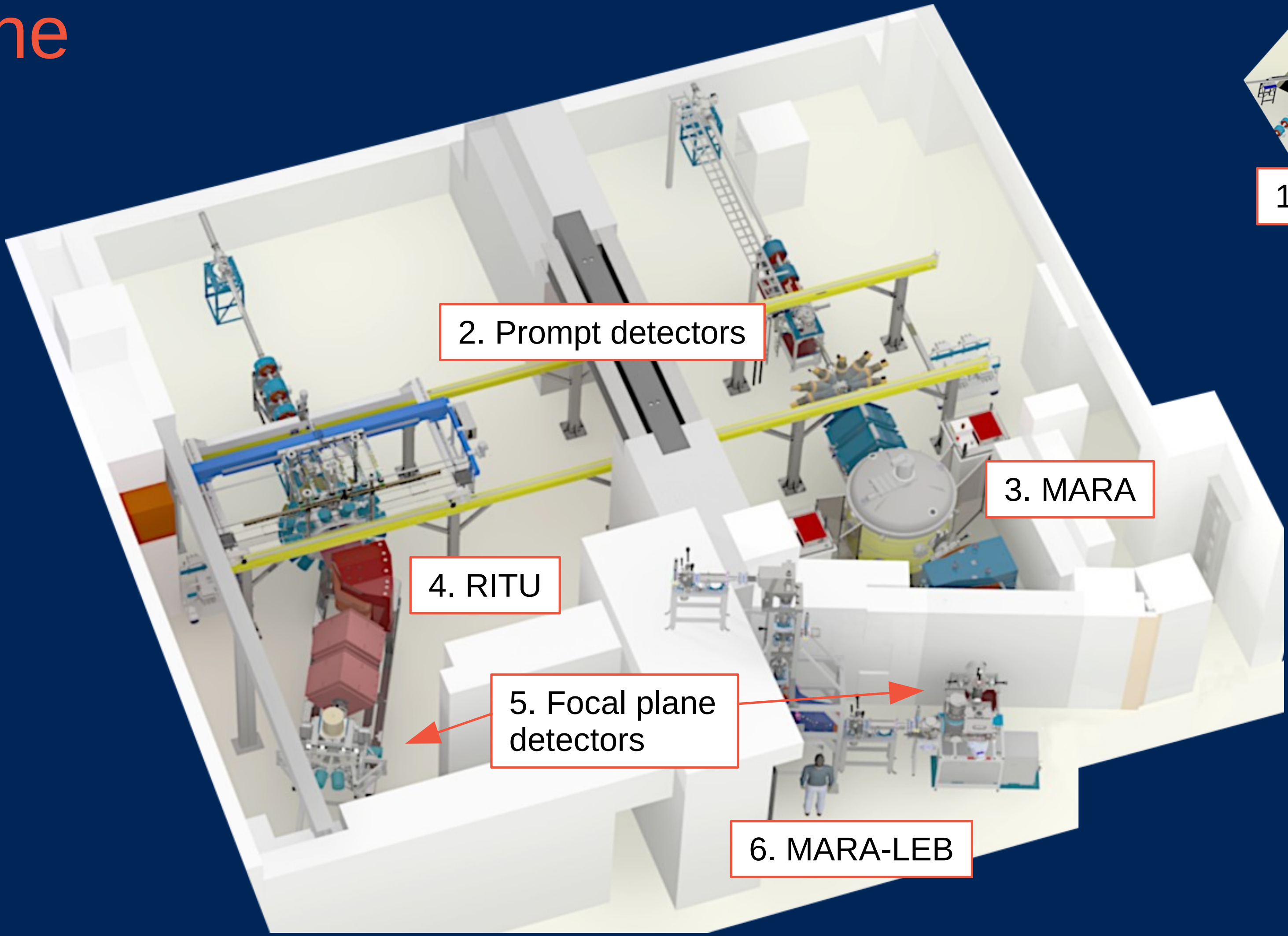
EMIS2022, Daejeon, South-Korea

JYFL Accelerator laboratory, Jyväskylä, Finland

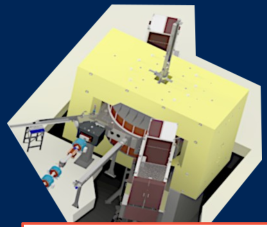


This presentation consentrates to describe the **instrumentation** used by **Nuclear Spectroscopy group**. Most of the experiments relies on **fusion evaporation reactions**.

Outline



2. Prompt detectors
3. MARA
4. RITU
5. Focal plane detectors
6. MARA-LEB



1. K130 cyclotron

K130 Cyclotron – news

K130 cyclotron – news

- K130 just had 30th anniversary…
  - there are some maintenance backlog – especially in water cooling.
- Serius maintenance started recently.
  - This summer the second RF was dismantled and all critical water piping was replaced.
  - The first RF will face the same threatment next summer.
- New spare ”dee” will be assembled. Old ones cannot be fixed due to their activation.

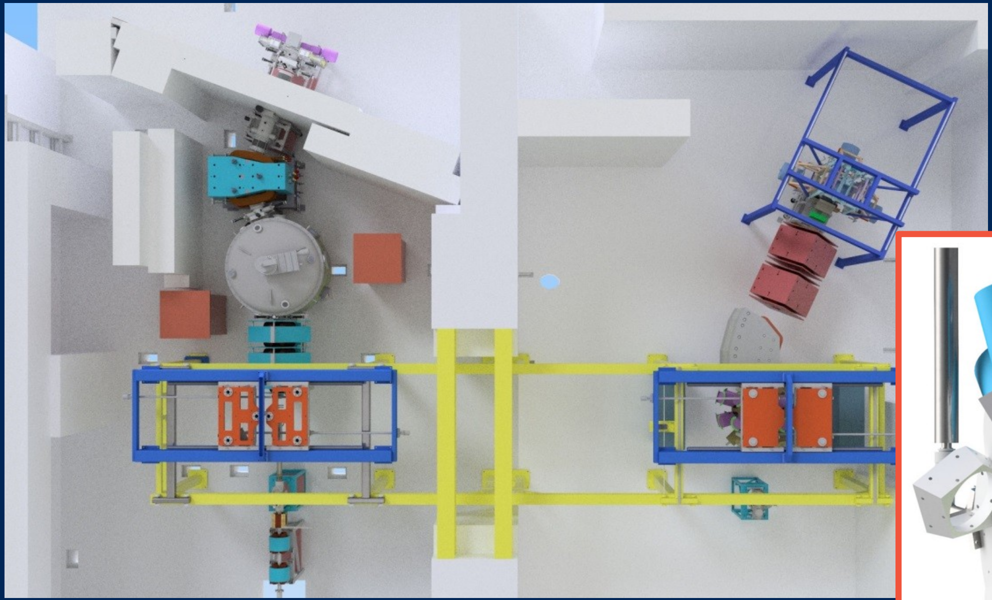
source: Taneli Kalvas, responsible for JYFL cyclotrons among others

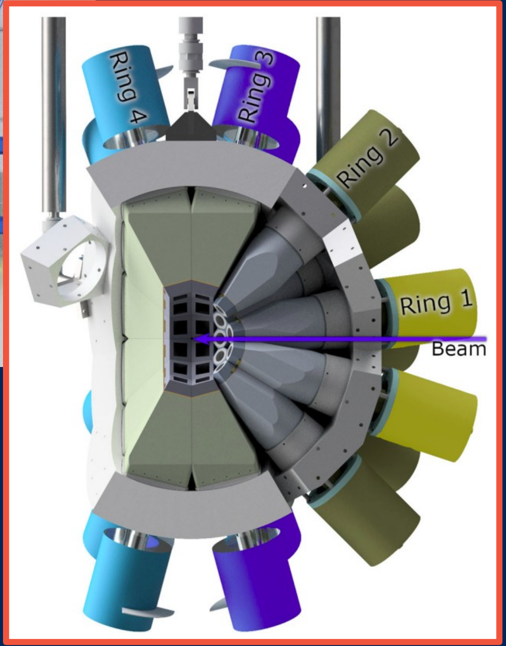
Taneli explaining the RF maintenance operation

Prompt detectors and target area instrumentation

Jurogam – Ge array around RITU/MARA target

- Majority of the experiments last years has been in-beam high spin studies utilizing recoil gating or recoil decay tagging with RITU/MARA focal plane.
- Consists currently on 15 single chrystal phase-one detectors in two rings (backward angles).
- 24 Clover detectors currently at Orsey.
- Rail system ables the move of Jurogam between the separators while the dectors are biased.



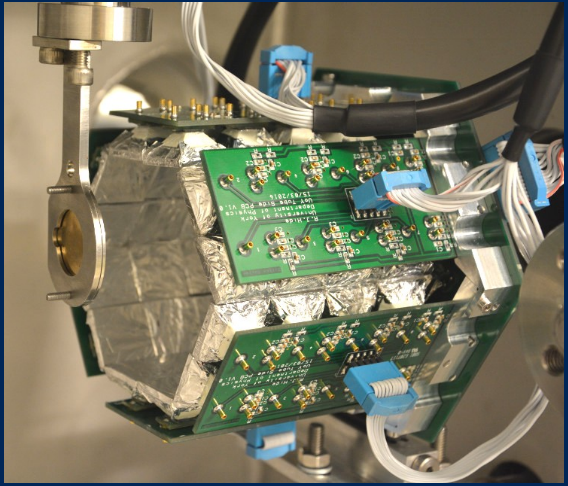


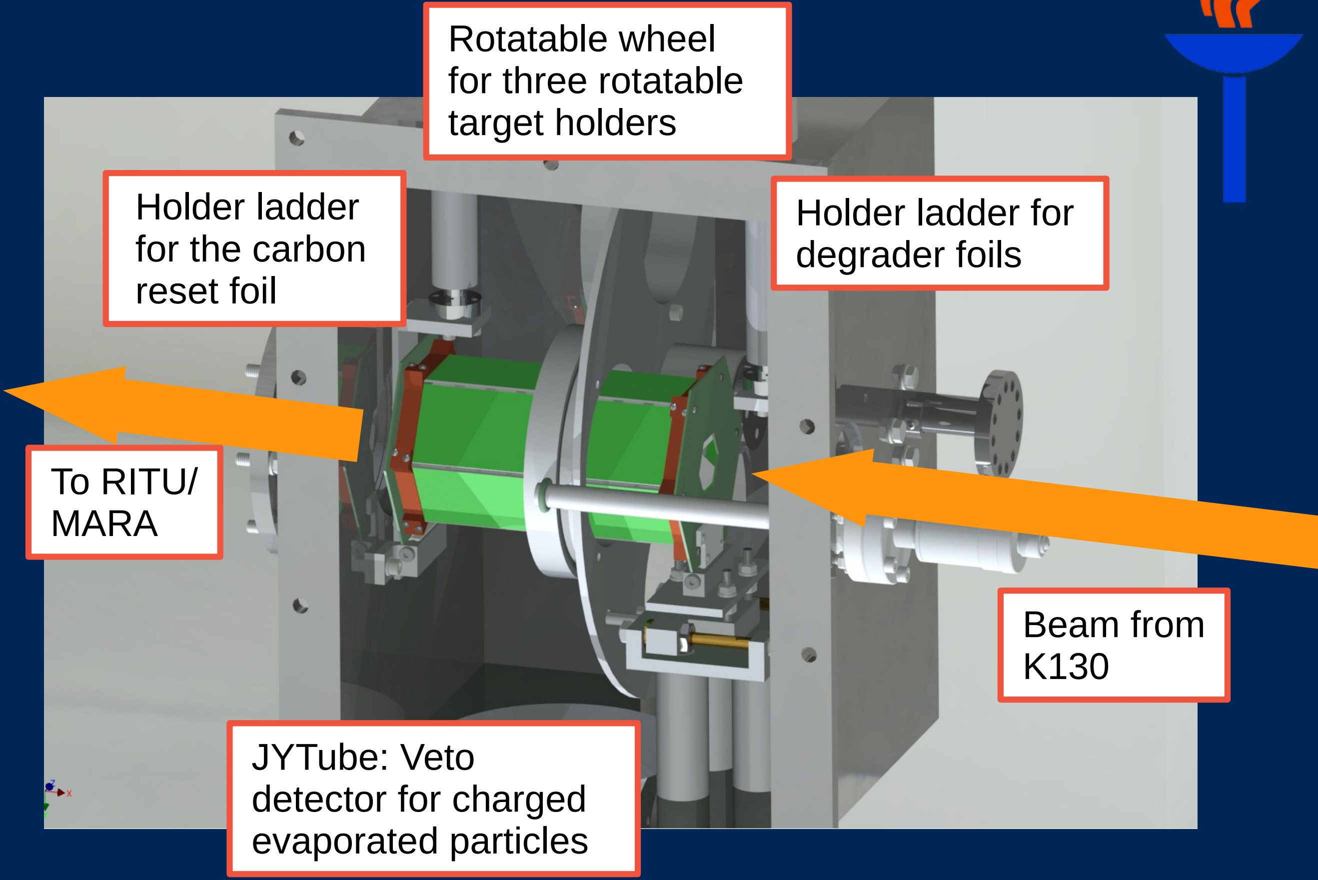
J. Pakarinen et al. EPJ A 56 (2020) 149

JYTube – charged particle veto

JYTube

- almost 100 plastic scintillators read out with SiPMs.
- Signal is typically used to veto proton and alpha evaporation channels.
- Consists of two hemispheres.
- Can be used also with JUROGAM inside a small spherical target chamber.

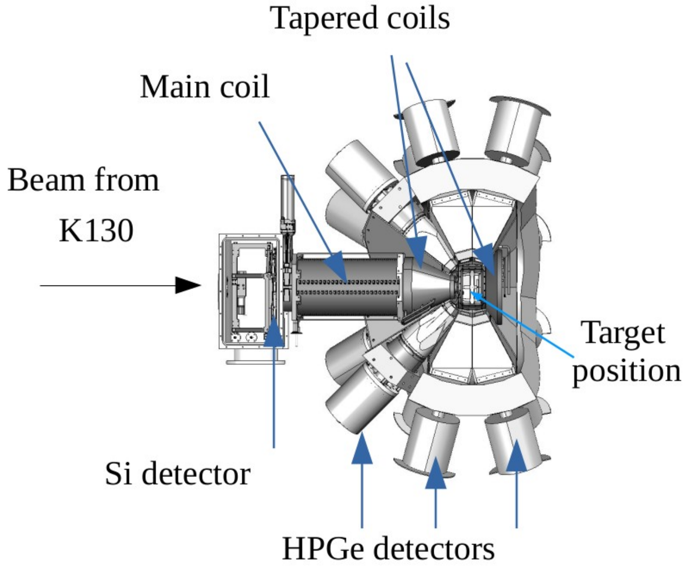


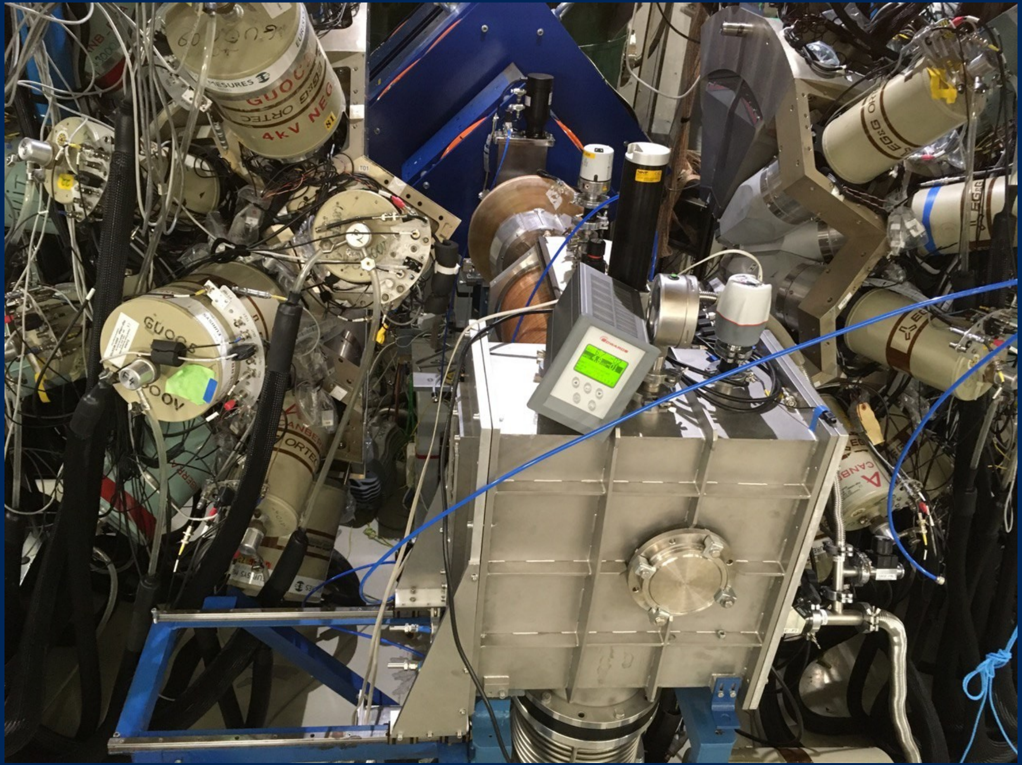


Person behind JYTube is Panu Ruotsalainen

Sage – electron spectrometer

- Solenoidal B-field transports conversion electrons from the target to the cooled Si-detector.
- HV-barrier shields for delta electrons.
- Fits INSIDE Jurogam if the most backward ring of Jurogam is removed →gamma electron coincidences!

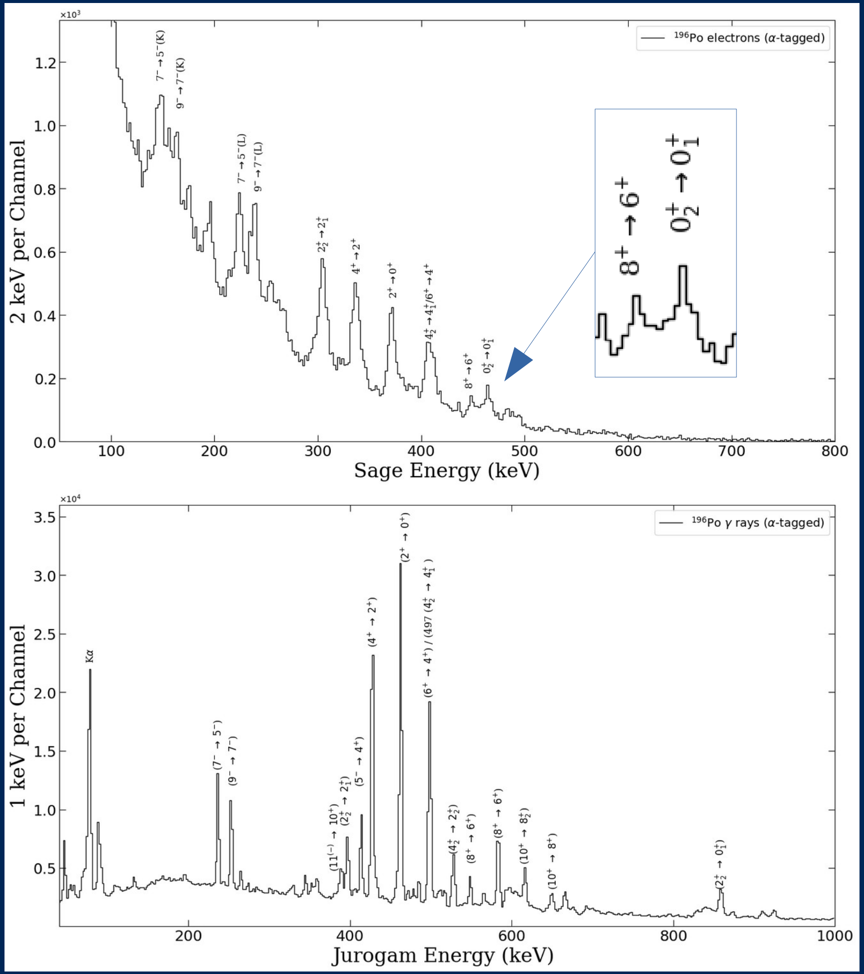




Sage in front of MARA. Jurogam is still open.

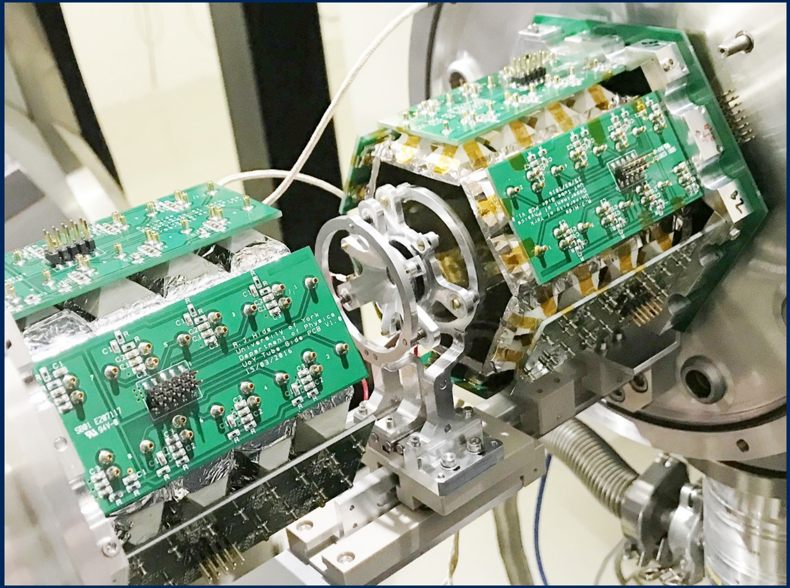
Sage – electron spectrometer

- Example of projected gamma-electron coincidence matrix.
  - Figure: Prompt electrons and gammas followed by ^{196}Po alpha decay at the MARA focal plane in a last year experiment.
  - There is a 0+→0+ candidate.
  - Reaction: ^{165}Ho(^{35}Cl,4n)^{196}Po
- This reaction would have slightly better transmission with RITU gas-filled separator but Sage benefits MARA since MARA is in vacuum.



APPA, Plunger device – lifetime measurements

- New plunger device APPA
  - Designed to operate inside JYTube and Jurogam.
  - Lifetime measurements of lowest exited states based on measurement of ratios between doppler shifted and unshifted gamma rays as a function of degrader foil distances from the target.
  - Designed to measure lifetimes of certain N~Z nuclei (for example 66As, 62Ga).
  - Ask Panu Ruotsalainen for more information.
  - Designed together with colleagues in Cologne.
- APPA is a new device. Most of the plunger experiments has been carried out with other (visiting) plunger devices.



APPA plunger in the middle of the opened JYTube

Charge plunger method

- Idea:
  - Internal conversion leads to Auger cascade and the fusion product ends up to high atomic charge state.
  - Ratio between normal and high charge states is related to the lifetime of the level and target-reset foil distance.
  - Charge states are measured with recoil separator (MARA).
- In practice
  - Demonstrated to work (see the publication).
  - No real experiment run (with unknown lifetimes) yet.

Eur. Phys. J. A (2021) 57:132
https://doi.org/10.1140/epja/s10050-021-00425-8

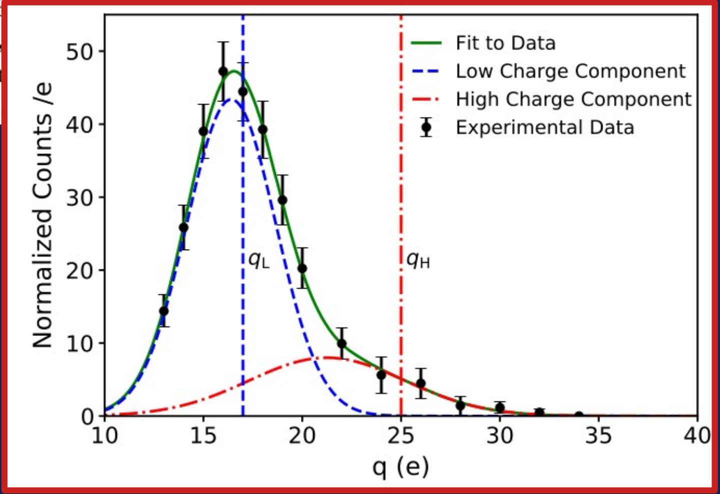
The European Physical Journal A

Check for updates

Regular Article - Experimental Physics

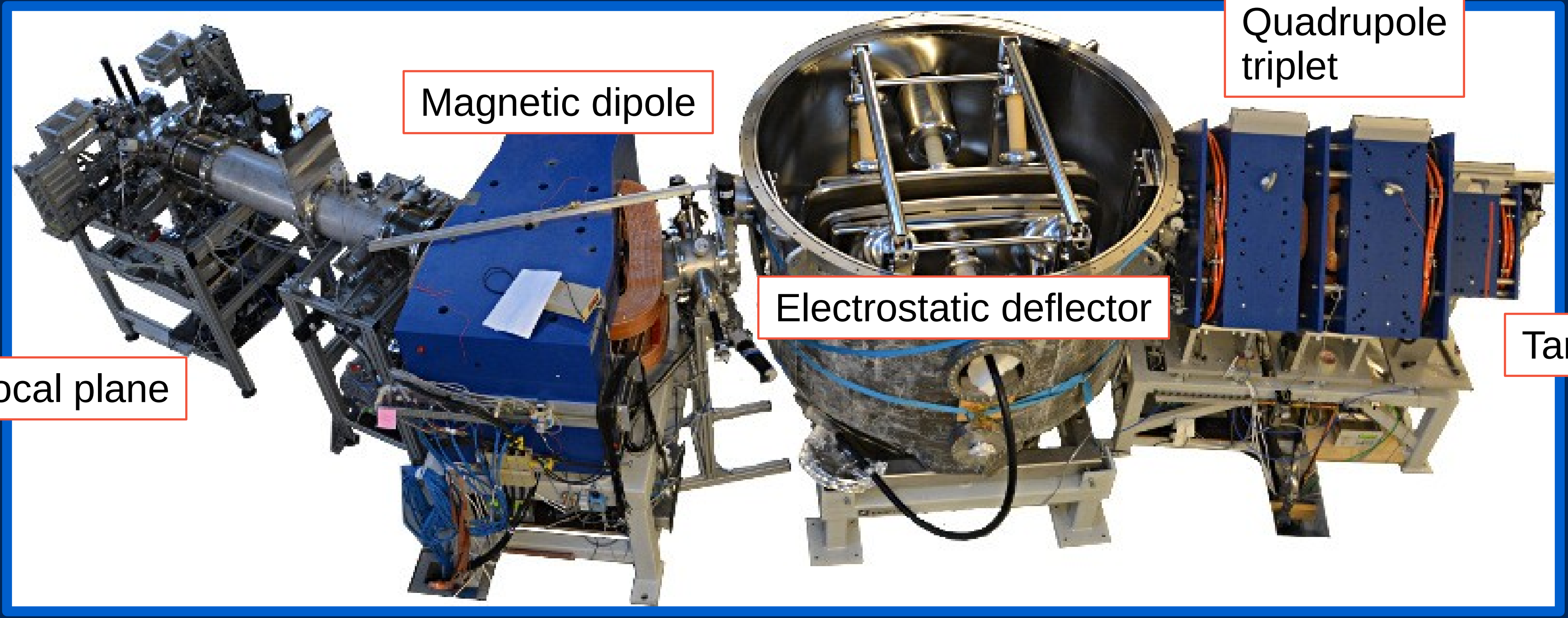
Lifetime measurements of yrast states in ^{178}Pt using the charge plunger method with a recoil separator

J. Heery[1,a], L. Barber[2], J. Vilhena[3], B. S. Nara Singh[3], R.-D. H
G. Beeton[3], M. Bowry[3], A. Dewald[4], T. Grahn[5], P.T. Greenlees[5],
M. Leino[5], M. Luoma[5], D. O'Donnell[3], J. Ojala[5], J. Pakarinen
J. Sarén[5], J. Sinclair[3], J. F. Smith[3], J. Sorri[6,8], P. Spagnoletti[3,9]



MARA

MARA



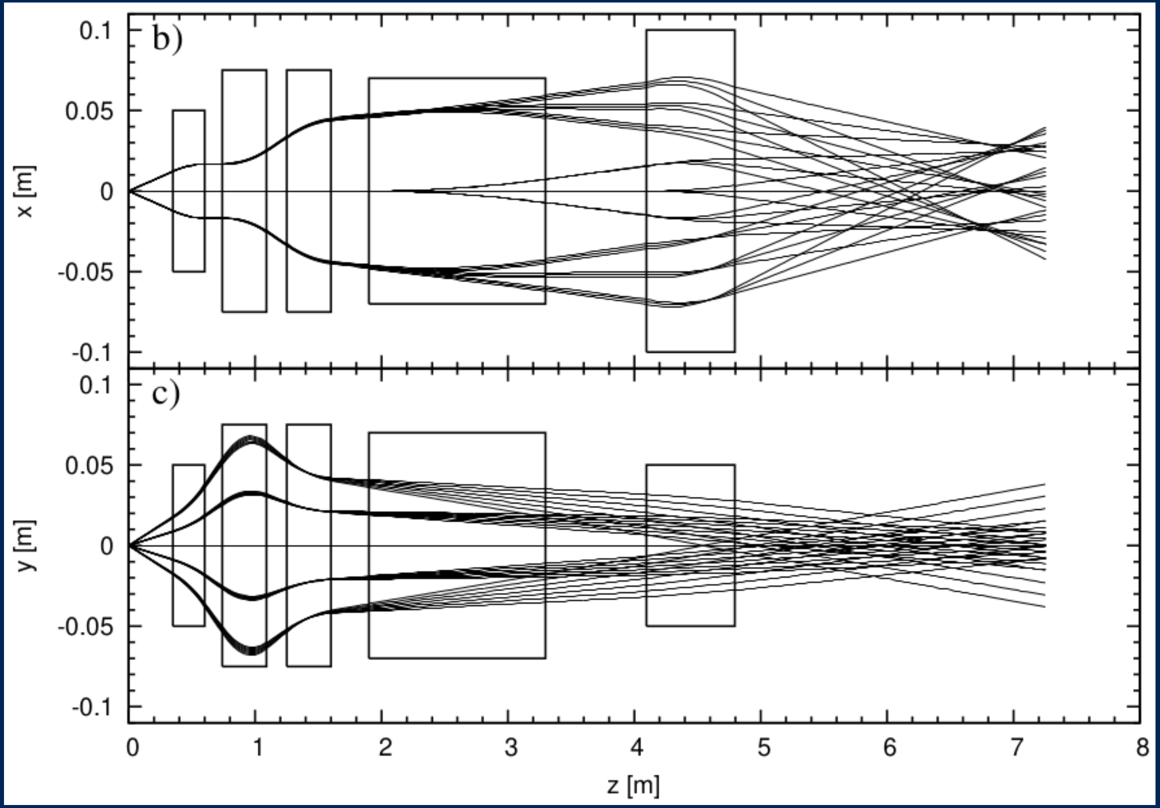
Best reference this far: Juha Uusitalo, J. Saren et al., Acta Physica Polonica B 50(3)319

MARA

because this is EMIS conference:

MARA vacuum mode separator:

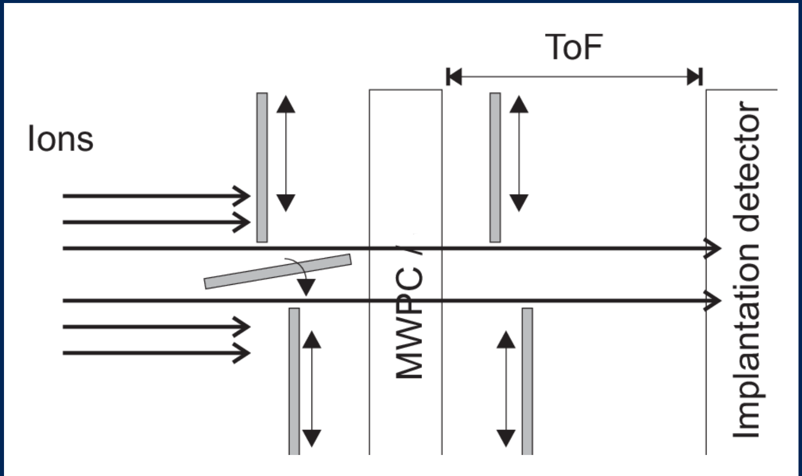
- In operation since 2016.
- Built to extent the physics program (from RITU) to nuclei around N~Z and to use symmetric/inverse kinematics.
- Symmetric angular acceptance (±50)x(±50) mrad^2
- Products are physically separated along their m/q values (typical mass resolving power: 150–200)
- Highly abundant neighboring masses can be cut down with mass slits.

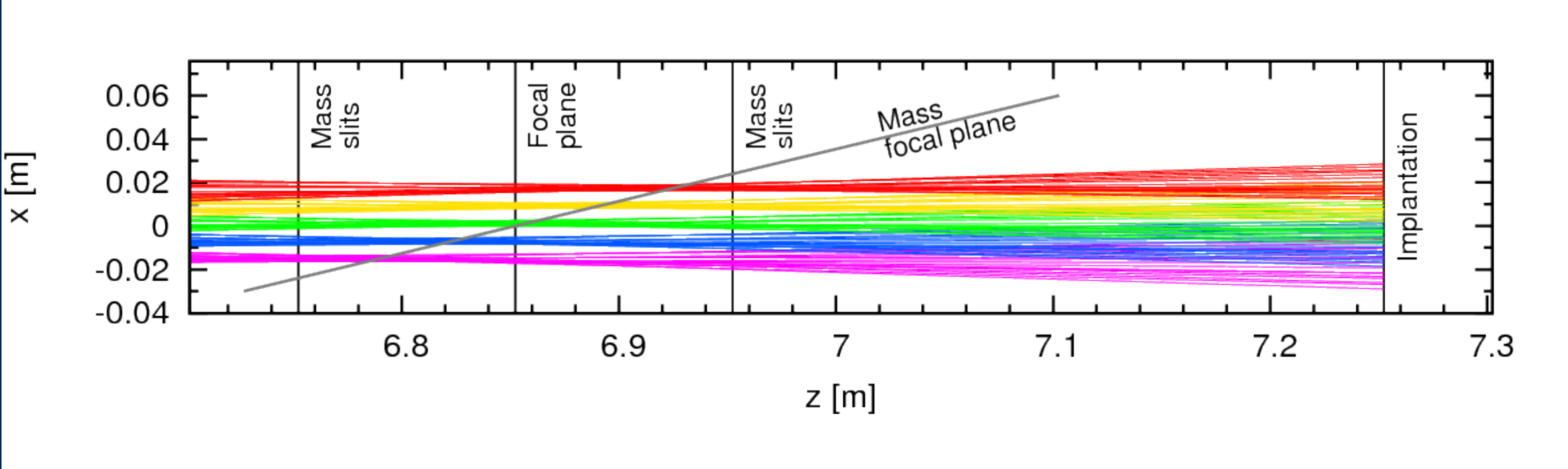


MARA

Mass slits at the focal plane:

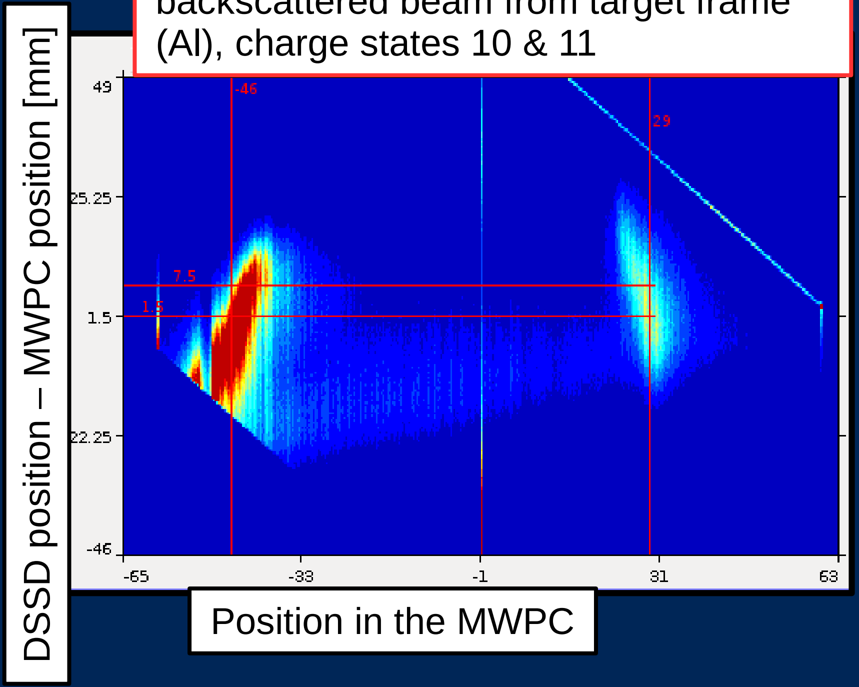
- To select two charge states of isobar under interest to reduce DSSD rates and false decay correlations.
- Placed 10 cm before AND after the focal point due to the heavily tilted focal plane.
- System of two mass slits works very well.

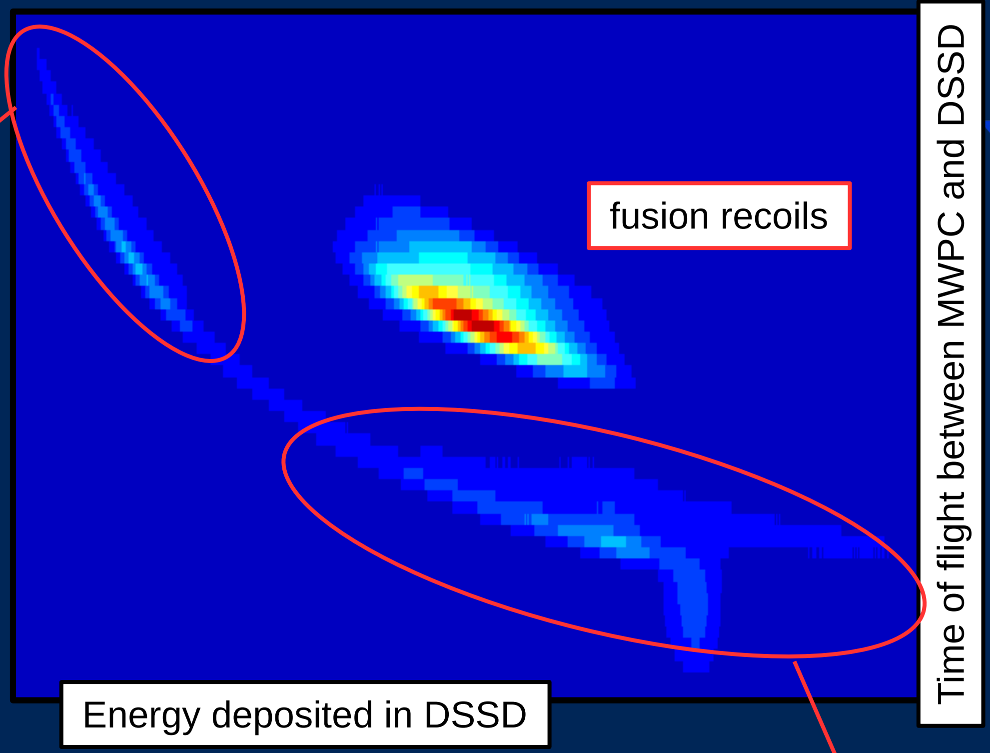


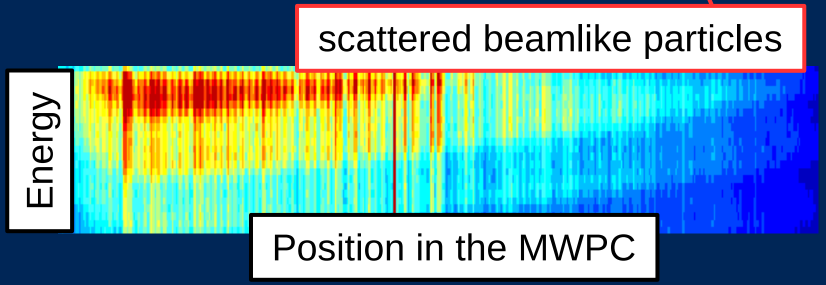


MARA – background

Commissioning: 58Ni + 106Cd → 164Os*



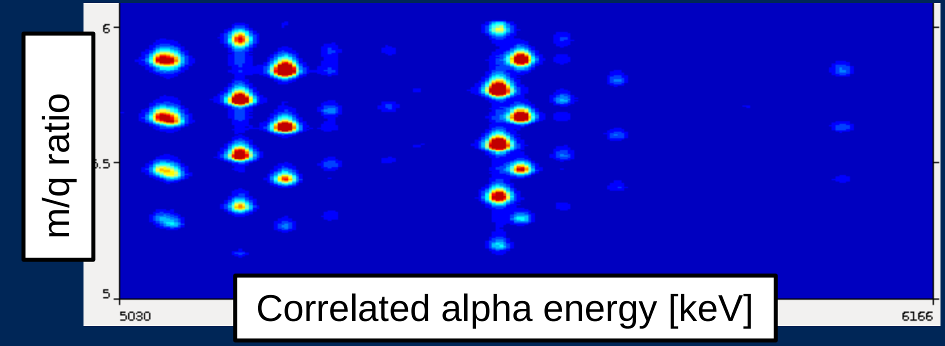


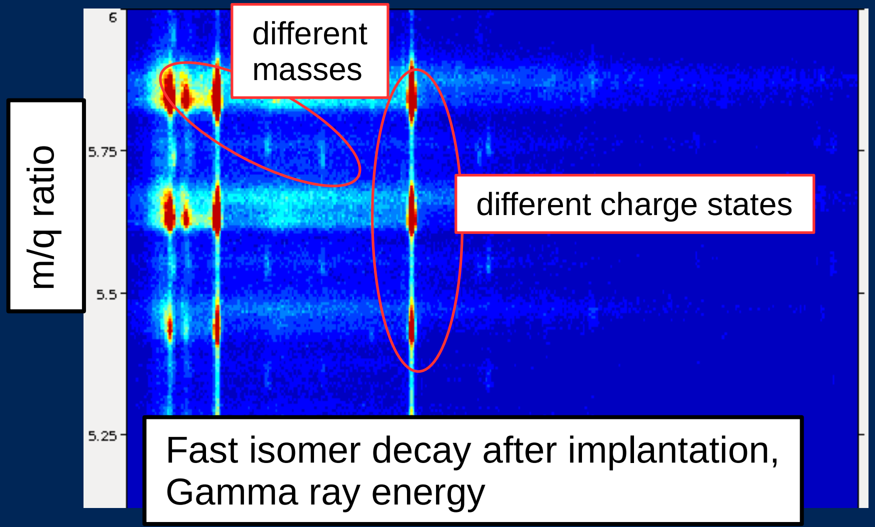


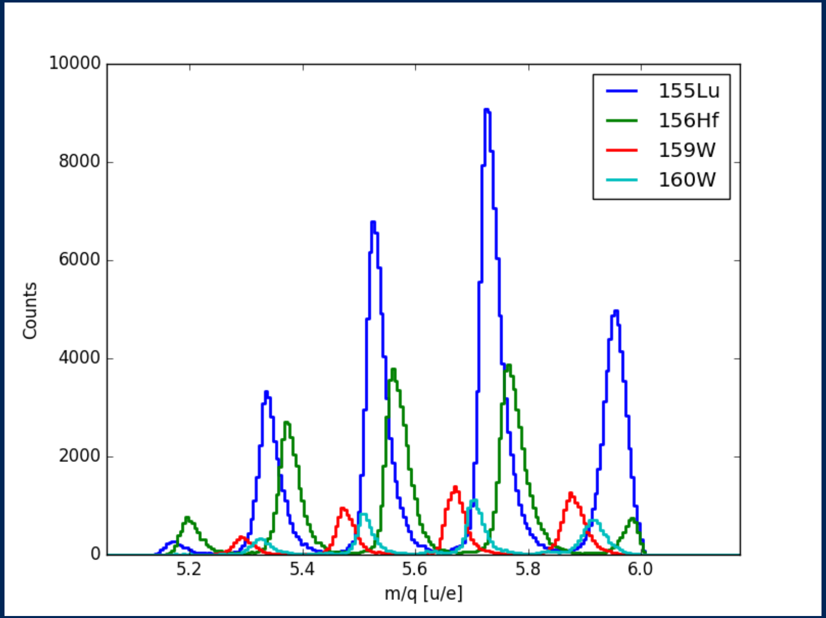
These are the main background types seen in the experiments. Rates have been tolerable in all experiments. Beam suppression factor around 10^7.

MARA – M/Q resolving power

Commissioning: 58Ni + 106Cd → 164Os*







Mass resolving power (MRP) of 140-150 is very typical in the experiments. Mass gates in phase phase (x,x') results slightly higher MRP. By careful tuning one can reach value around 200. MRP is affected by beam spot size and aberrations. If required, mass resolving power can be increased by apertures or by using a so called high resolution mode.

New isotopes observed at MARA

- and
  - ^{169}Au, p emitter
  - ^{160}Os, α emitter
  - ^{156}W, β emitter
- Strong collab. of Univ. of Liverpool and JYFL

PHYSICAL REVIEW C **100**, 014305 (2019)

α-spectroscopy studies of the new nuclides ^{165}Pt and ^{170}Hg

J. Hilton,[1,2,*] J. Uusitalo,[1] J. Sarén,[1] R. D. Page,[2] D. T. Joss,[2] M. A. M. AlAqeel,[2,3] H. Badran,[1] A. D. Briscoe,[2] T. Calverley,[1,2] D. M. Cox,[1,†] T. Grahn,[1] A. Gredley,[2] P. T. Greenlees,[1] R. Harding,[4] A. Herzan,[5,2,‡] E. Higgins,[2] R. Julin,[1] S. Juutinen,[1] J. Konki,[1,§] M. Labiche,[6] M. Leino,[1] M. C. Lewis,[2] J. Ojala,[1] J. Pakarinen,[1] P. Papadakis,[1,‖] J. Partanen,[1,¶] P. Rahkila,[1] P. Ruotsalainen,[1] M. Sandzelius,[1] C. Scholey,[1] J. Sorri,[1,7] L. Sottili,[1] S. Stolze,[1,**] and F. Wearing[2]
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[7]Sodankylä Geophysical Observatory, U

(Received 13 May

The new nuclides ^{165}Pt and ^{170}Hg were produ
at bombarding energies of 418 MeV and 390 Me

PHYSICAL REVIEW LETTERS **128**, 112501 (2022)

Editors' Suggestion

Nanosecond-Scale Proton Emission from Strongly Oblate-Deformed ^{149}Lu

K. Auranen,[1,*] A. D. Briscoe,[1] L. S. Ferreira,[2] T. Grahn,[1] P. T. Greenlees,[1] A. Herzáň,[3] A. Illana,[1] D. T. Joss,[4] H. Joukainen,[1] R. Julin,[1] H. Jutila,[1] M. Leino,[1] J. Louko,[1] M. Luoma,[1] E. Maglione,[2] J. Ojala,[1] R. D. Page,[4] J. Pakarinen,[1] P. Rahkila,[1] J. Romero,[1,4] P. Ruotsalainen,[1] M. Sandzelius,[1] J. Sarén,[1] A. Tolosa-Delgado,[1] J. Uusitalo,[1] and G. Zimba[1]
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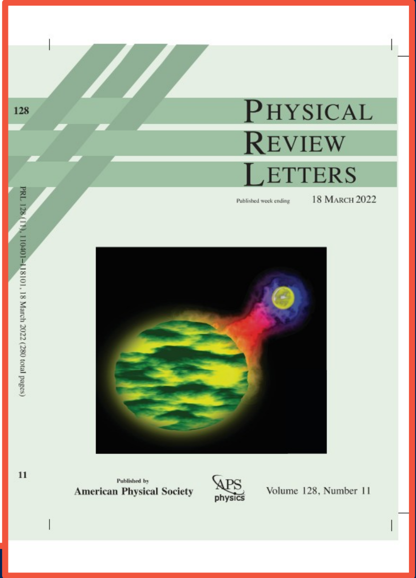
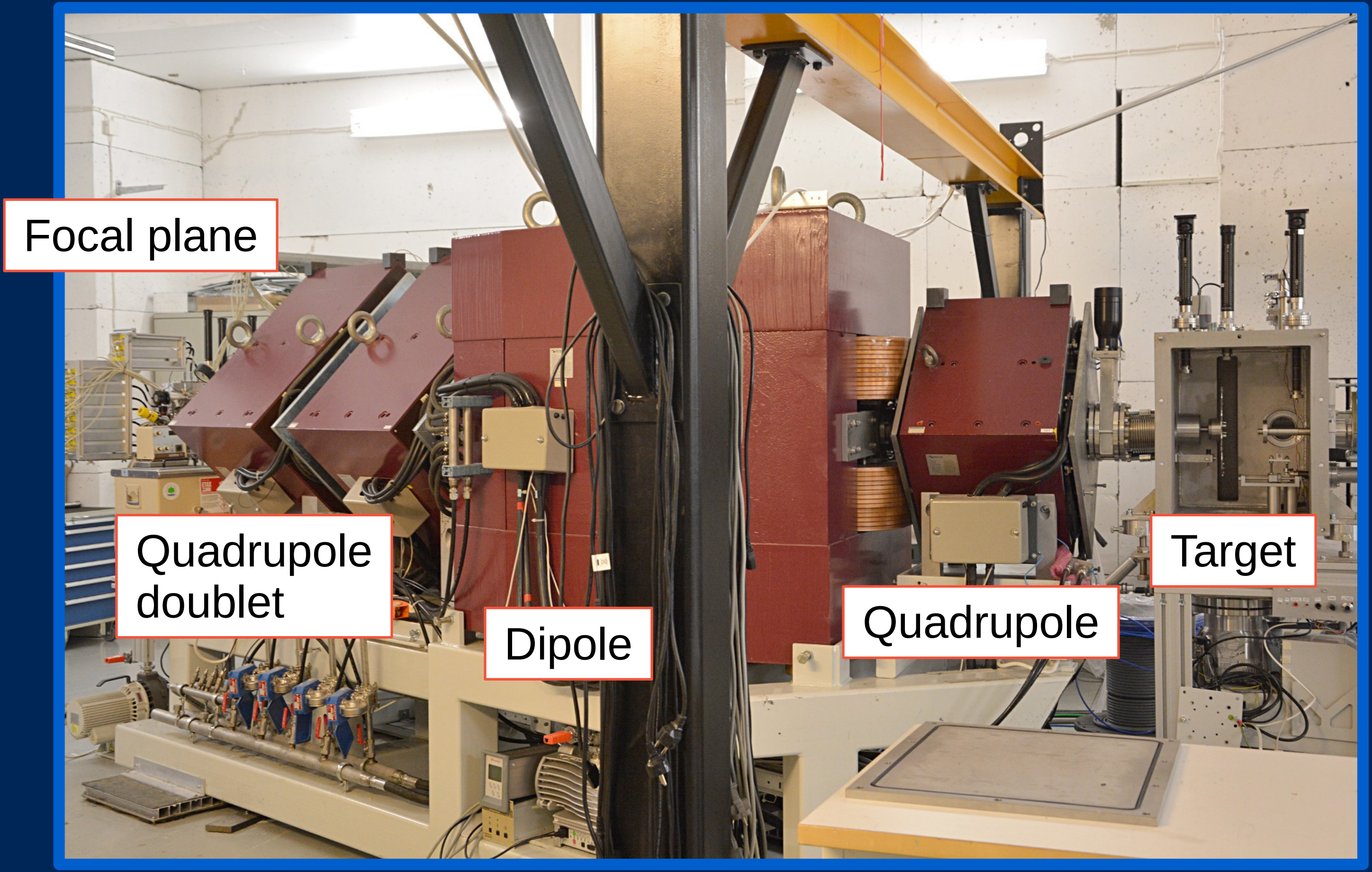
(Received 15 December 2021; revised 2 February 2022; accepted 22 February 2022; published 16 March 2022)

Using the fusion-evaporation reaction ^{96}Ru(^{58}Ni, $p4n$)^{149}Lu and the MARA vacuum-mode recoil separator, a new proton-emitting isotope ^{149}Lu has been identified. The measured decay Q value of 1920(20) keV is the highest measured for a ground-state proton decay, and it naturally leads to the shortest *directly* measured half-life of 450^{+170}_{-100} ns for a ground-state proton emitter. The decay rate is consistent with $l_p = 5$ emission, suggesting a dominant $\pi h_{11/2}$ component for the wave function of the proton-emitting state. Through nonadiabatic quasiparticle calculations it was concluded that ^{149}Lu is the most oblate deformed proton emitter observed to date.



RITU

RITU

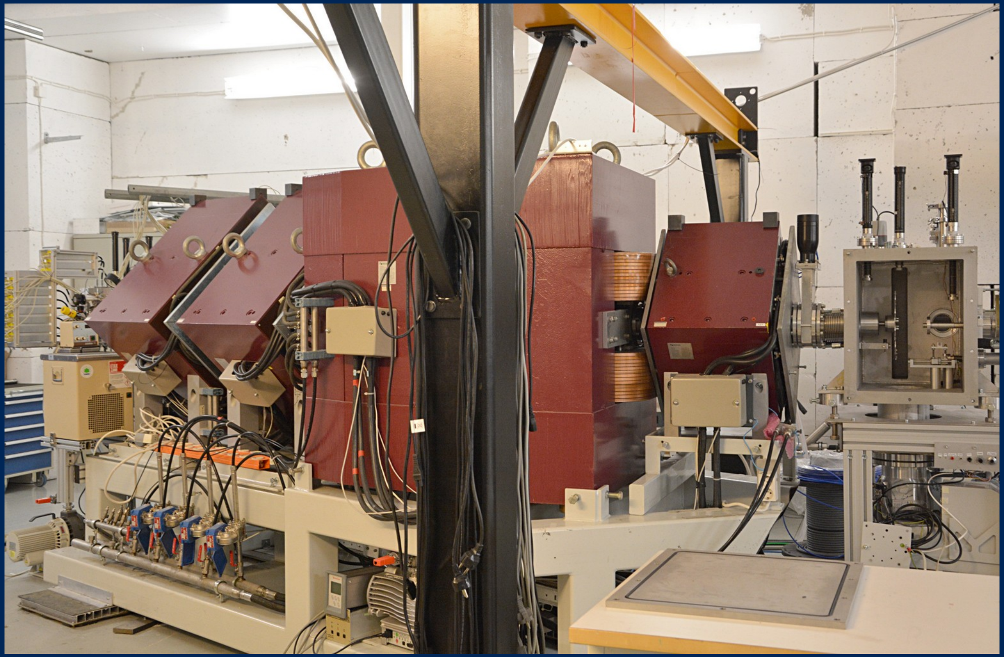


Jan Sarén et al., NIMA 654 (2011) 508

RITU

RITU *gas-filled separator*:

- Old and reliable since 1993!
- Filled with helium (typically 0.5 – 1.5 mbar).
- Transmission independent of original charge state and kinetic energy.
- Asymmetric angular acceptance (±25)x(±85) $mrad^2$.
- Good for asymmetric fusion reactions, where beam is lighter than the target.
- Ideal for transactinide fusion products
  - Suppression factor typically better than $5 \cdot 10^{10}$!



Jan Sarén et al., NIMA 654 (2011) 508

RITU

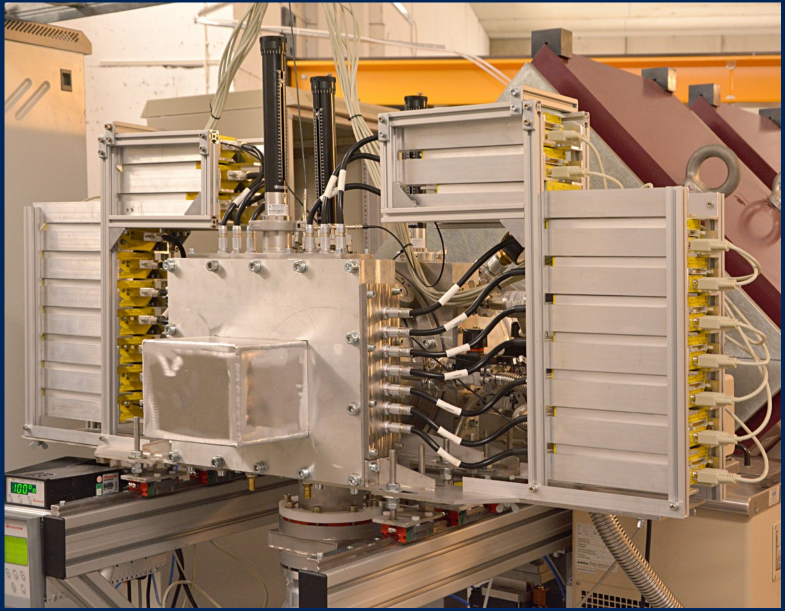
- Recommissioned after a long break (~5 years).
  - ^{40}Ar + ^{165}Ho, ^{169}Tm, ^{175}Lu
  - ^{40}Ca + ^{159}Tb
- New focal plane (~copy of MARA fp).
- New MWPC detectors (in collab. with slovakian colleagues)
- New He-gas handling system.
- New control system (Rockwell).
- Shared DAQ with MARA. All ~600 channels are digital and self-triggering.

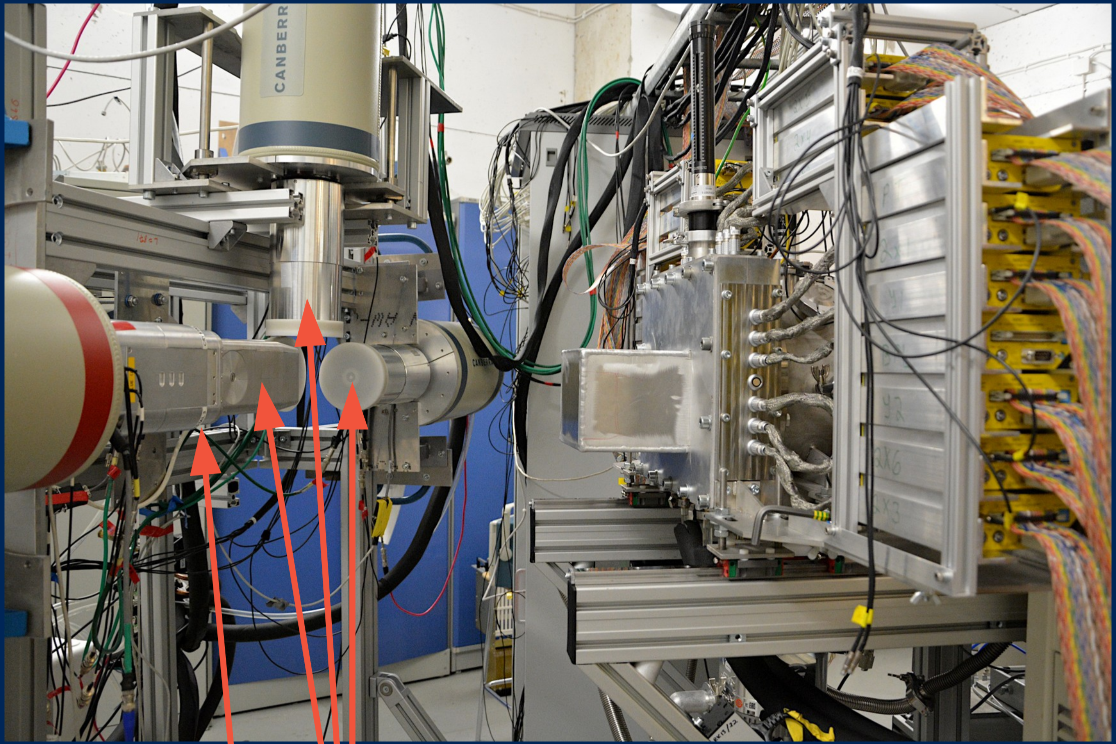
RITU was observed to work as earlier. Old and reliable and very clean for asymmetric fusion reactions.

RITU/MARA focal planes

RITU/MARA focal planes

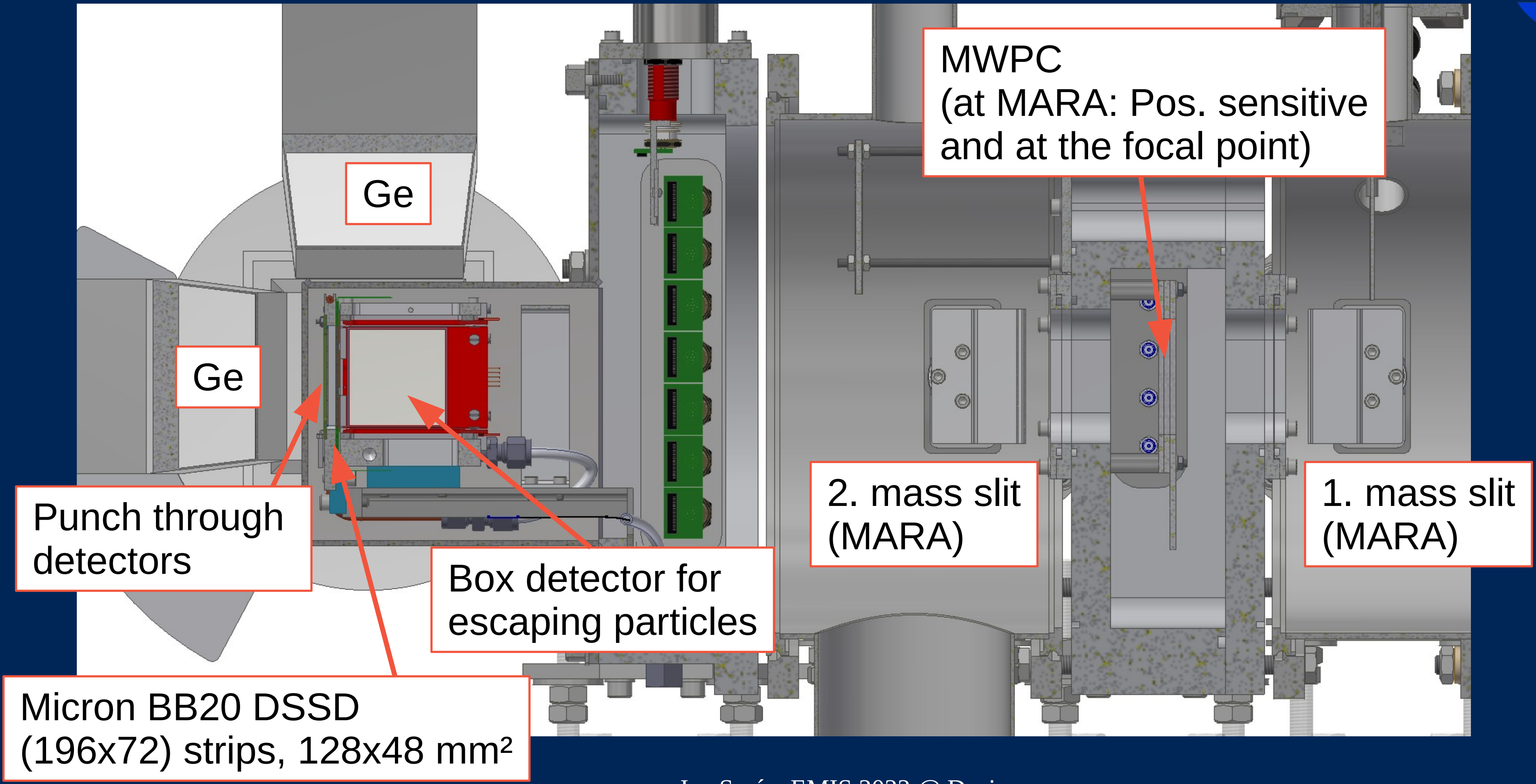
The focal planes are almost identical (mass slits only at MARA). Same detectors can be easily used in both.





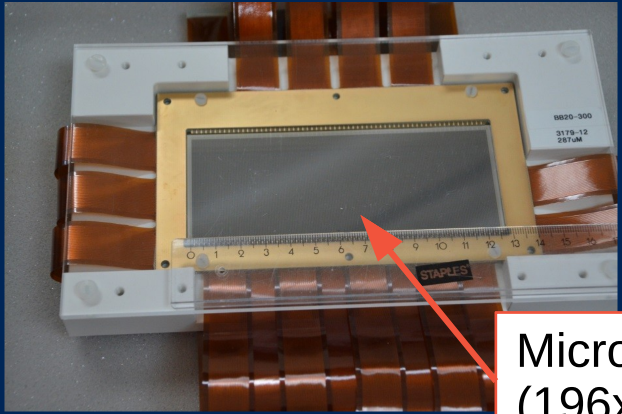
efficient gamma ray setup with three BEGe detectors and one Clover detectors

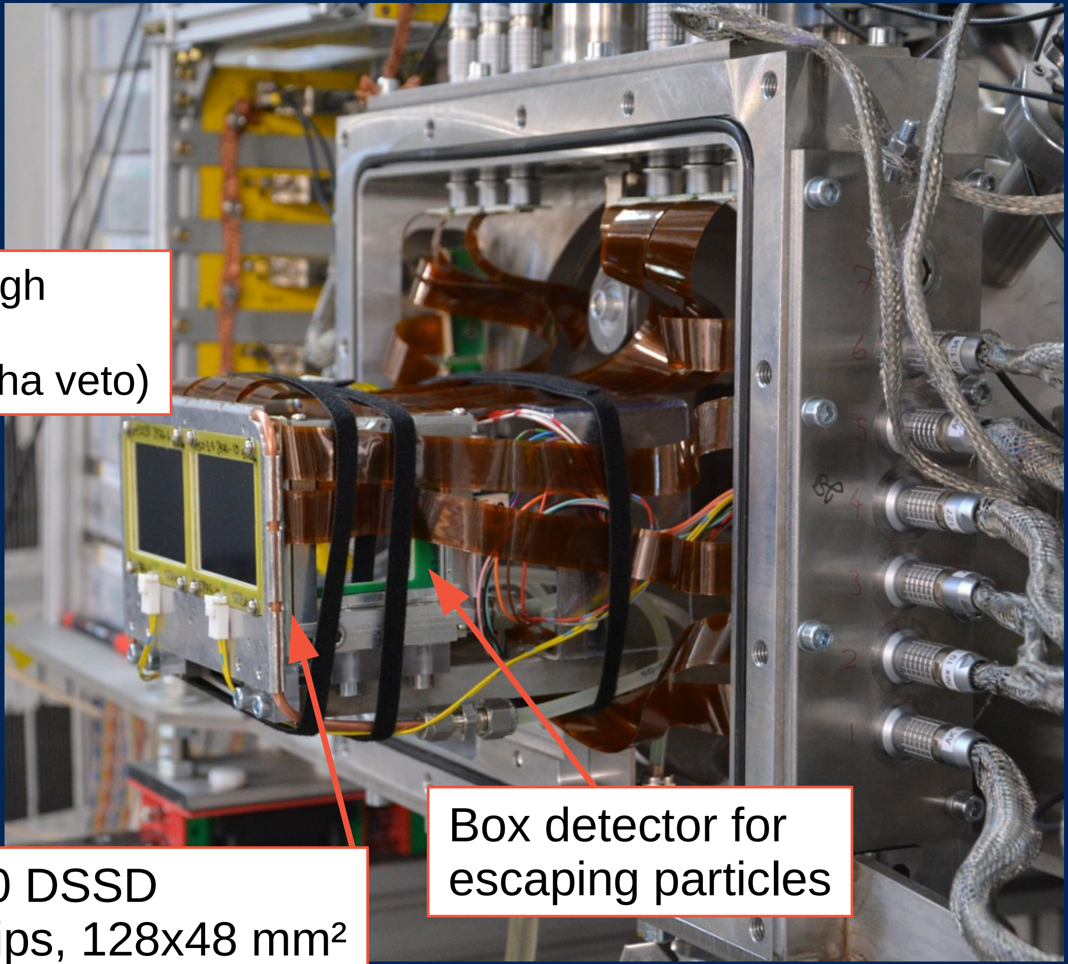
RITU/MARA focal planes



RITU/MARA focal planes

In real life...





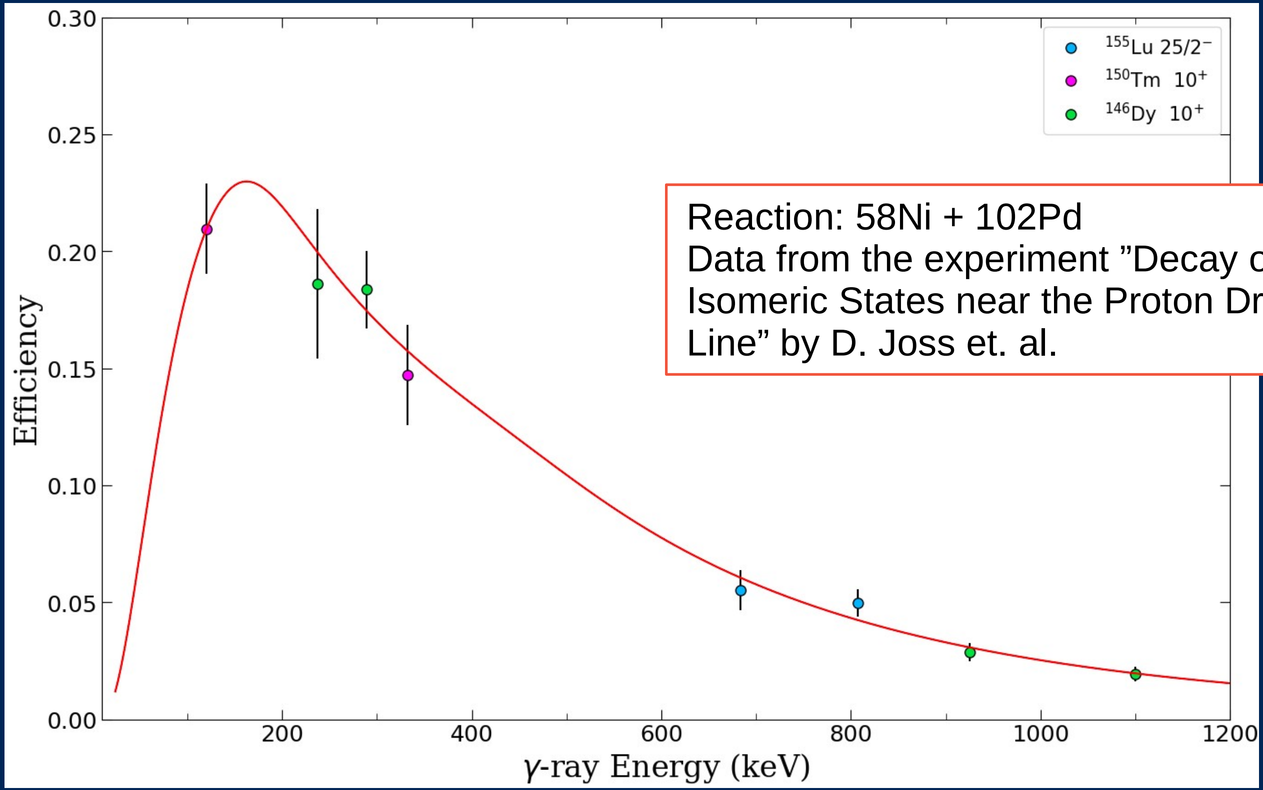
Punch through detectors
(for p/d/t/alpha veto)

Micron BB20 DSSD
(196x72) strips, 128x48 mm²

Box detector for
escaping particles

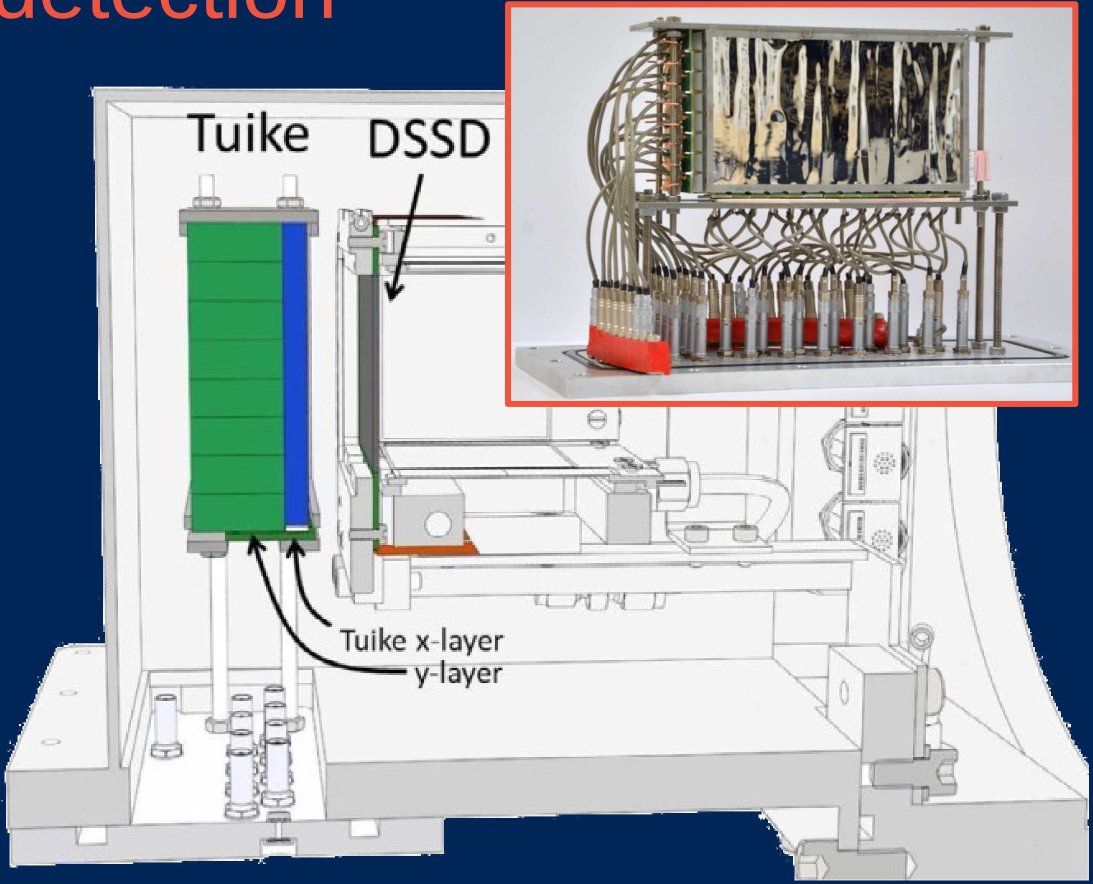
RITU/MARA focal planes

- Absolute gamma ray efficiency over 20 % around 200 keV.
- Efficiency and setup will be described in detail in coming publication.



Reaction: 58Ni + 102Pd
Data from the experiment ”Decay of Isomeric States near the Proton Drip Line” by D. Joss et. al.

TUIKE – plastic scintillator for high energy beta detection

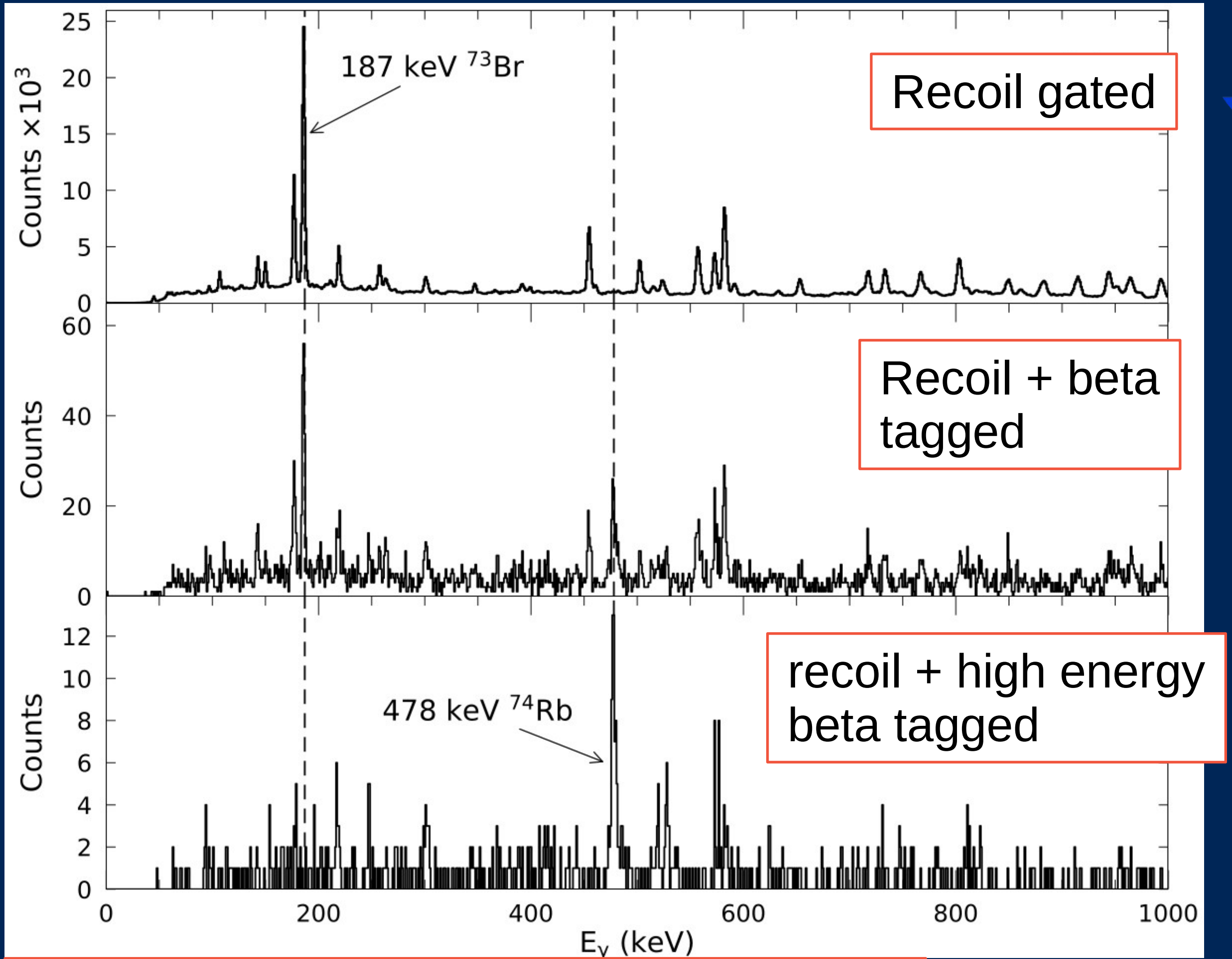


- For studies of N~Z nuclei.
- Two layers (in total the size is 140x80x30 mm^3)
  - x layer: 14 scintillator bars of size 10x80x6 mm^3
  - y layer: 8 scintillator bars of size 140x10x24 mm^3
  - Thickess of 30 mm is enough to stop 6 MeV beta.
- Light readout with SiPMs separately from all 22 scintillator bars.
- Simultaneous signals summed together to get the full beta energy.

Henna Joukainen, Jan Sarén and Panu Ruotsalainen, NIMA 1027 (2022) 166253

TUIKE

- High energy beta decay tagging, meaning the correlation chain:
  - prompt gamma at Jurogam
  - Recoil at DSSD
  - Beta at same pixel + high energy beta at TUIKE).
- Very useful for N~Z studies where the beta decay of the interesting nucleus is between Isobaric Analogue States providing the fast and high energy beta decays.



Prompt gamma spectra, $^{40}Ca(^{36}Ar,pn)^{74}Rb$

MARA-LEB

MARA-LEB

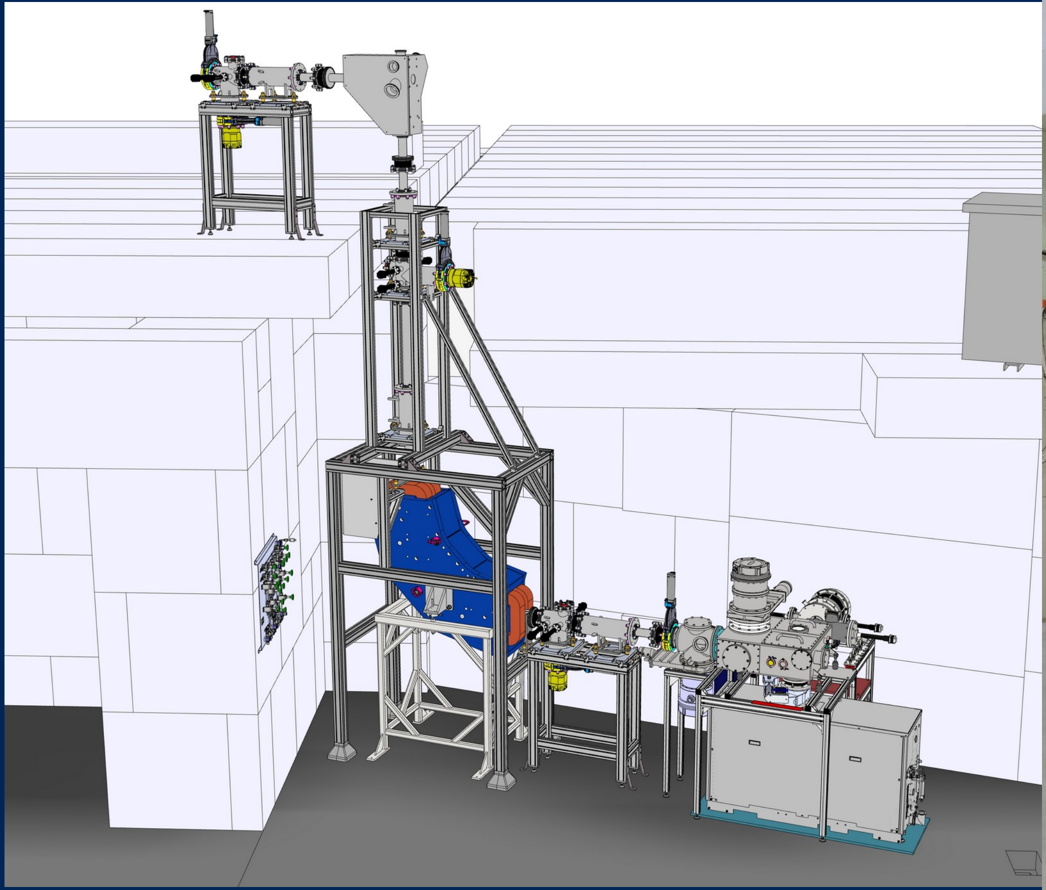
What it is?

- MARA-LEB is the low energy branch after the MARA recoil separator.
- In-gas cell / in-gas jet resonant laser ionization (Ar gas)
- Mass measurements and beam purification (He gas, MR-TOF-MS)
- Decay station (Kalle Auranen, Academy of Finland Fellowship 2022)

Motivation:

- Laser spectroscopy towards the N=Z line
- Mass measurements towards the N=Z line

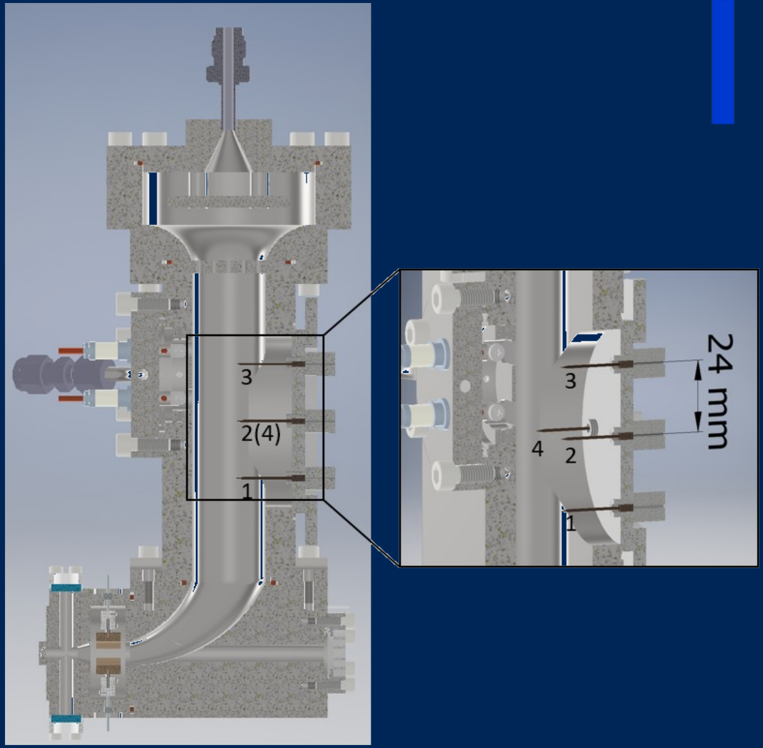
MARA-LEB



MARA-LEB

Gas cell test have been performed with ^{223}Ra α-recoil source on a needle

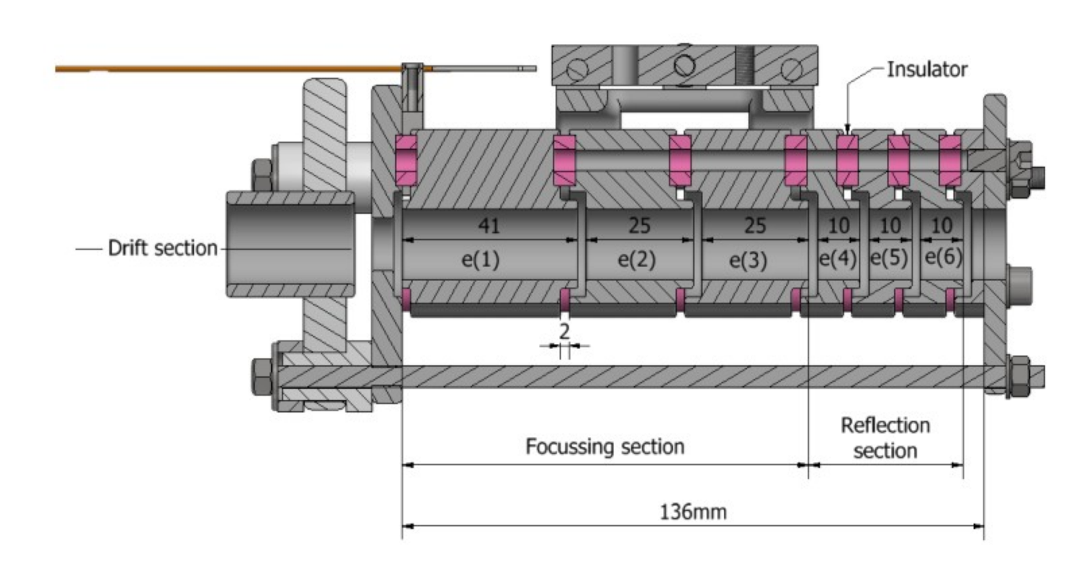
- Four different source positions
- Measured ^{219}Rn α spectra with a Si detector at different gas cell pressures
- Ion survival and transport efficiency @300mbar helium:
  - ~9% at centre of gas cell (position 2)
  - ~13% closest to the exit hole (position 1)
- Evacuation time measurements for He and Ar

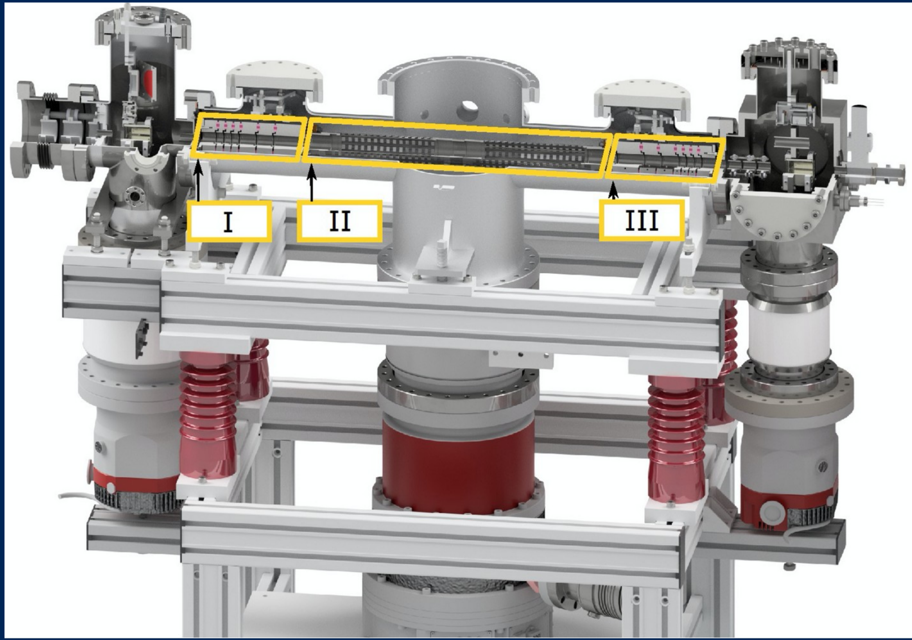


A. Zadvornaya, J. Romero et al., submitted to NIMB (2022)

MARA LEB

- RFQ cooler and buncher based on FAIR cooler
  - Under construction at IGISOL, A. Jaries PhD
- MR-TOF-MS based on IGISOL design
  - Constructed at IGISOL, V. Virtanen PhD





MARA-LEB

UKRI Science and Technology Facilities Council

P. Papadakis, R. Smith, M. Cordwell

UNIVERSITY OF JYVÄSKYLÄ

K. Auranen, T. Eronen, **W. Gins**, J. Liimatainen, I. Moore, J. Partanen†, I. Pohjalainen, M. Reponen, S. Rinta-Antila, J. Sarén, J. Tuunanen, J. Uusitalo, **S. Zadvornaya**

UNIVERSITY OF LIVERPOOL

J. Romero

Funding

ACADEMY OF FINLAND

MARIE CURIE ACTIONS

SEVENTH FRAMEWORK PROGRAMME

UKRI Science and Technology Facilities Council

In collaboration with

UKRI Science and Technology Facilities Council

KU LEUVEN

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

MARA LEB

Summary

- Observation of weak channels requires complex concidences in multiple detectors.
- Many detector systems have been designed and used around in-flight separators for different physics cases.
- About 14 experiments carried out every year.

Thank you

Nuclear spectroscopy group