Nuclear and applied research at JYFL-accelerator laboratory

Ari Jokinen

- Accelerator Laboratory
- IGISOL
- Gamma/RITU/MARA
- Pelletron Laboratory
- Commercial activities

JYFL Accelerator Laboratory

NuPECC Long Range plan 2010

Current Nuclear Research Facilities in Europe.

- Over 6000 beam-time hours a year
- Part of the Department of Physics
- Basic funding from Ministry of Education
- EU- Access Laboratory (ENSAR)
- Centre of Excellence (Academy of Finland)
- Accredited European Space Agency (ESA) test facility

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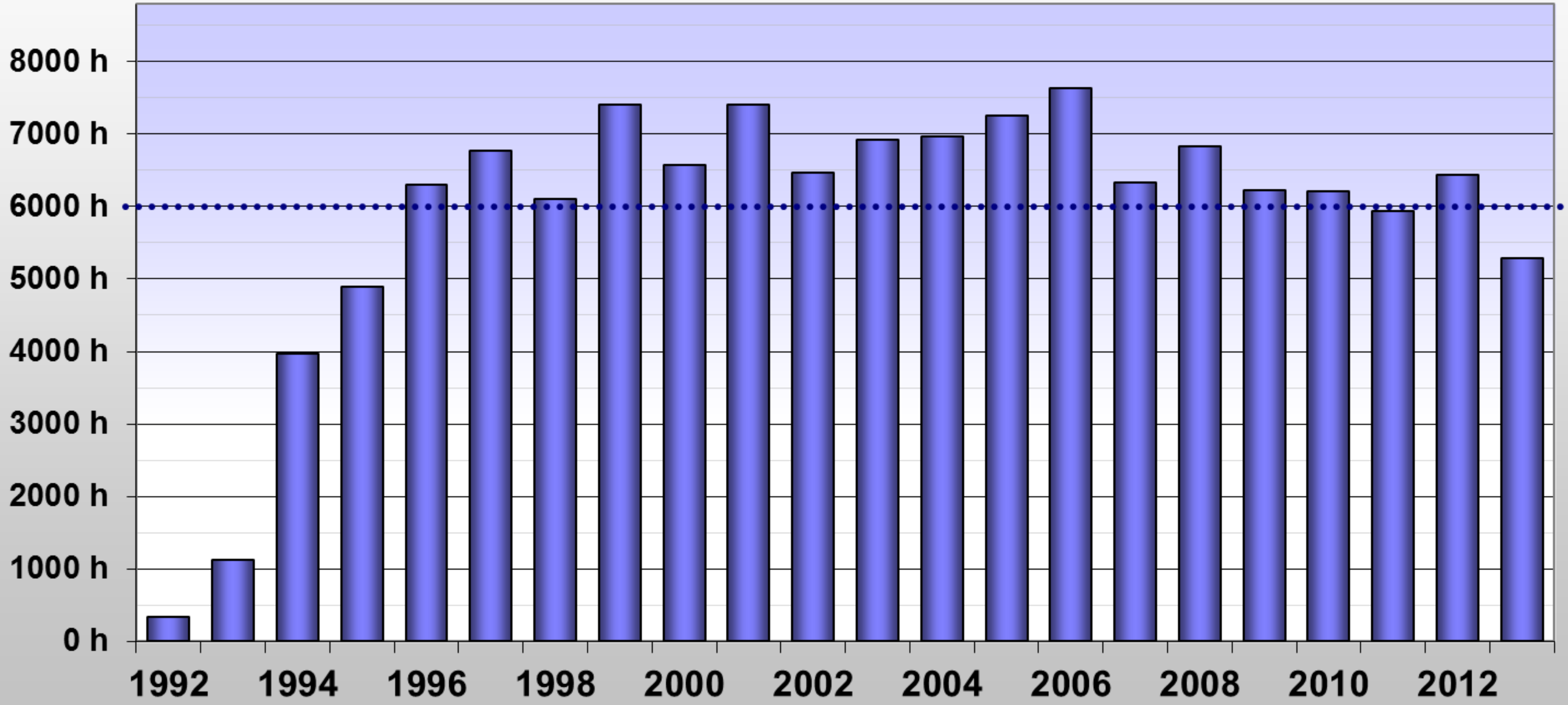
K130

Accelerated elements:
p – Xe
E = Q^2/A 130 MeV

Ion sources:
6.4 GHz ECRIS
14 GHz ECRIS
Multicusp (H^-, D^-)

Last week:
Funding approved for new 18GHz ECR !

Operation of the Jyväskylä Cyclotron



Charts

Run time as of 12.11.2013 at 14:40 is 129 424 hours. The average per year (after 1.1.1996) is 6 667 hours.

MCC30/15

H^-	18 – 30 MeV
d^-	9 – 15 MeV
beam current	200/62 μA

Users:

- IGISOL
- Radioisotope production

New RF ion source

- Intensity increase
- Continuous operation

Accelerator laboratory

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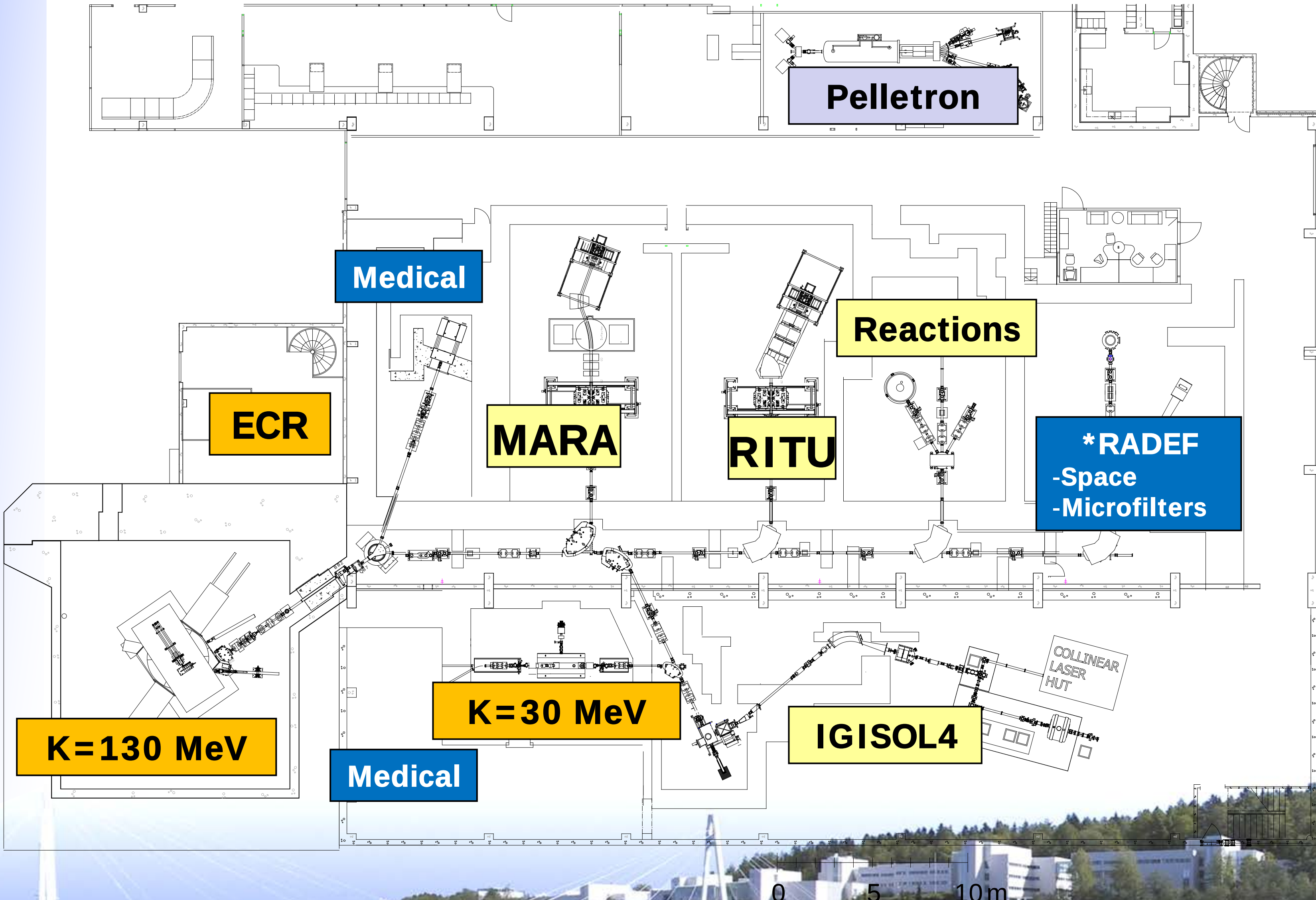

IGISOL

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IGISOL - 3

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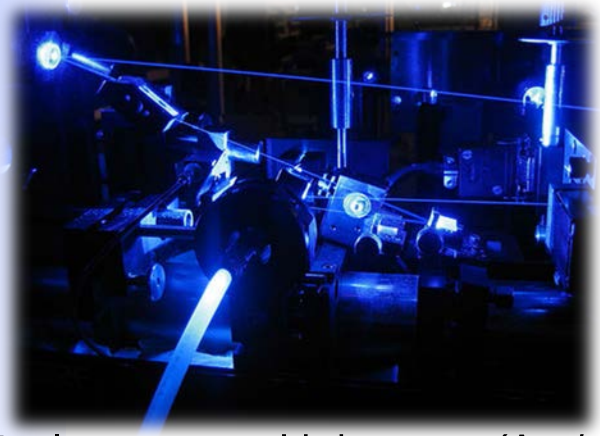
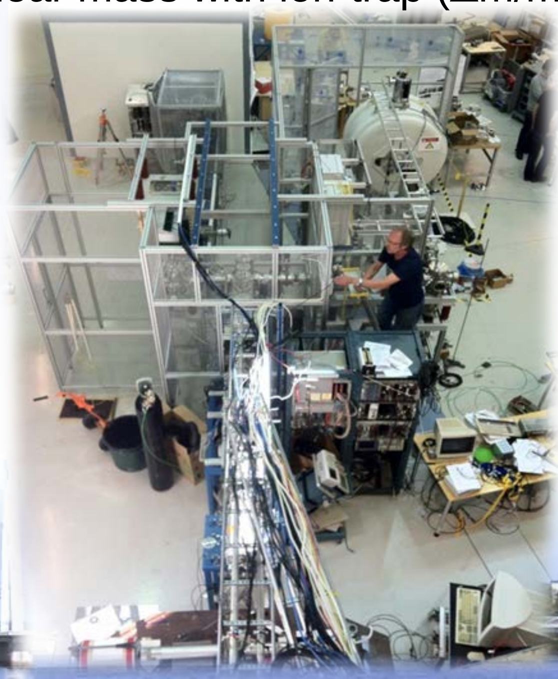
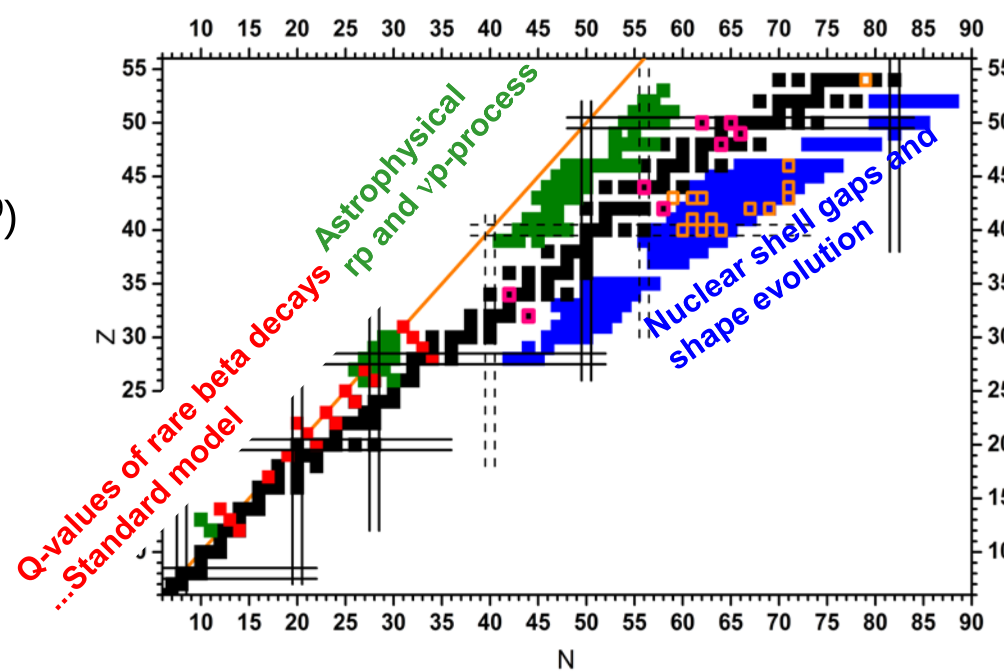
Isotope shifts with lasers → nuclear radia



Nuclear mass with ion-trap ($\Delta m/m = 10^{-9}$)

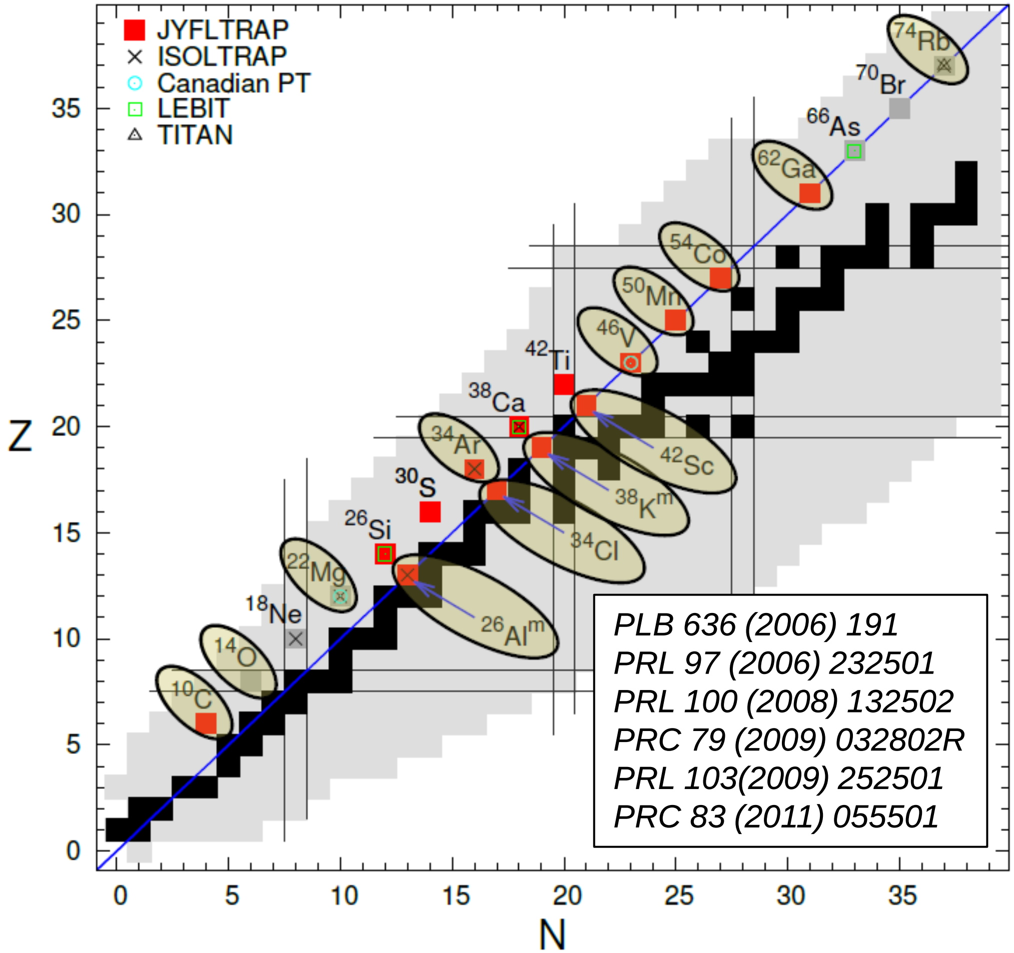


Accurate measurements of nuclear masses and radia provide input and critical test for nuclear models, nuclear astrophysics and standard model



Superallowed Q_{EC} values

$$\mathcal{F}t = f\frac{T_{1/2}}{B}(1+\delta'_R)(1+\delta_{NS}-\delta_C) = \frac{K}{2G_V^2(1+\Delta_V^R)}$$



2005:
- ^{62}Ga

2006:
- ^{46}V, ^{42}Sc, ^{26}Al^{m}
- ^{26}Si, ^{42}Ti

2006-2007:
- ^{50}Mn, ^{54}Co

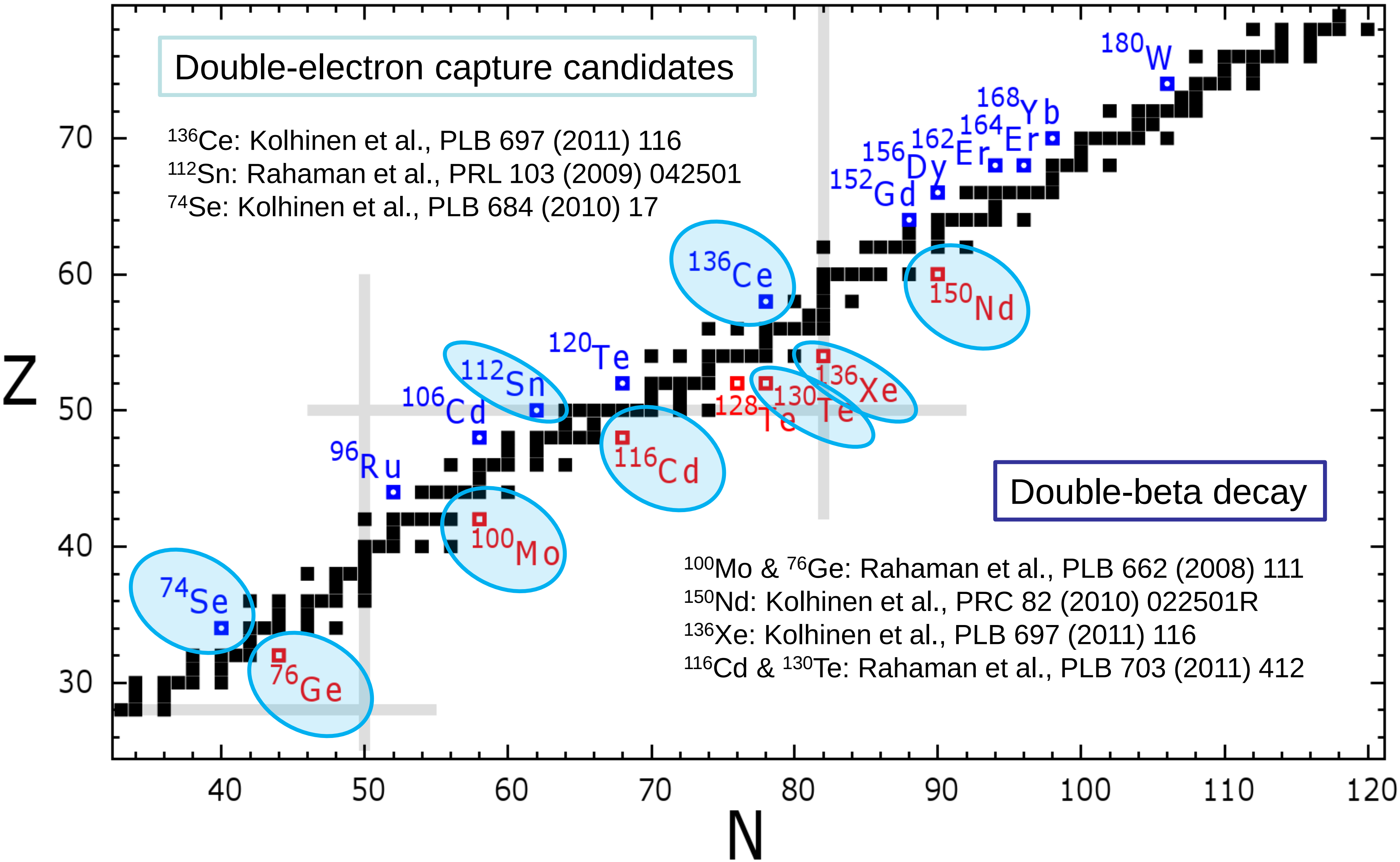
2009:
- ^{38}K^{m}, ^{34}Cl
- ^{30}S

2010:
- ^{10}C, ^{34}Ar, ^{38}Ca

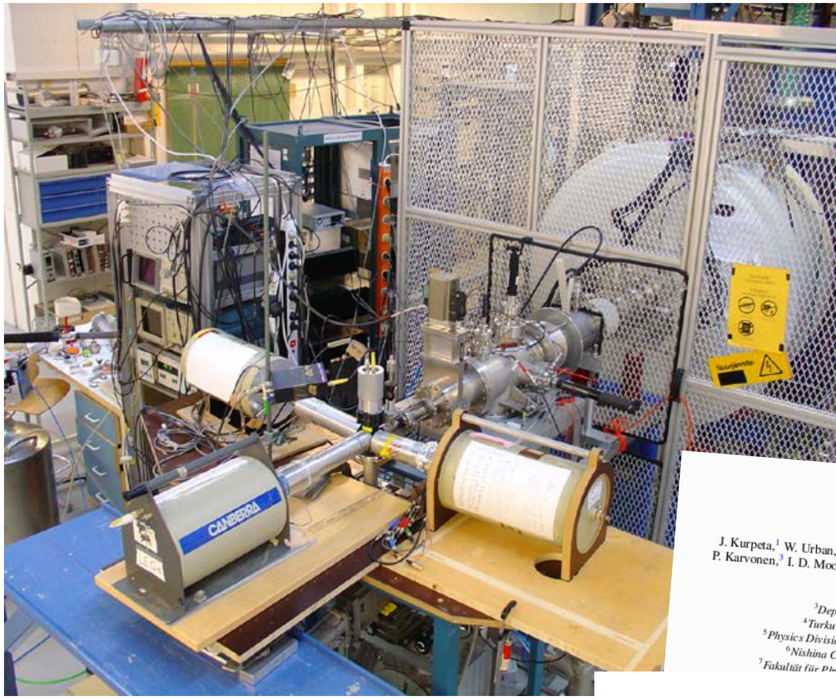
^{34}Ar, ^{38}K^{m} by using interleaved parent and daughter measurement !

^{14}O: IGISOL-4

JYFLTRAP harvest...



Trap-assisted spectroscopy



Eur. Phys. J. A **31**, 1–7 (2007)
DOI 10.1140/epja/i2006-10158-9
THE EUROPEAN PHYSICAL JOURNAL A
Regular Article – Nuclear Structure and Reactions

Decay study of ne... Penning trap as a...

Eur. Phys. J. A **31**, 263–266 (2007)
DOI 10.1140/epja/i2007-10009-3
THE EUROPEAN PHYSICAL JOURNAL A
Letter

Letter

Penning trap assisted decay spectroscopy of neutron-rich ^{115}Ru

Eur. Phys. J. A (2011) **47**: 97
DOI 10.1140/epja/i2011-11097-0
THE EUROPEAN PHYSICAL JOURNAL A
Reply

Penning-trap–assisted study of ^{115}Ru beta decay

PHYSICAL REVIEW C **83**, 011301(R) (2011)
RAPID COMMUNICATIONS

Decay study of ^{114}Tc with a Penning trap

PHYSICAL REVIEW C **82**, 027306 (2010)

Excited states in ^{115}Pd populated in the β^- deca...

IOP PUBLISHING
JOURNAL OF PHYSICS G: NUCLEAR AND PARTICLE PHYSICS
J. Phys. G: Nucl. Part. Phys. **39** (2012) 015101 (6pp)
doi:10.1088/0954-3899/39/1/015101

Trap-assisted separation of nuclear states for gamma-ray spectroscopy: the example of ^{100}Nb

C Rodríguez Triguero[1], A M Bruce[1], T Eronen[2], I D Moore[2], M Bowry[3], A M Denis Bacelar[1], A Y Deo[3], V-V Elomaa[2], D Gorelov[2], J Hakala[2], A Jokinen[2], A Kankainen[2], P Karvonen[2], V S Kolhinen[2], J Kurpeta[4], T Malkiewicz[5], P J R Mason[3], H Penttilä[2], M Reponen[2], S Rinta-Antila[2], J Rissanen[2], A Saastamoinen[2], G S Simpson[5] and J Äystö[2]

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Received 9 May 2011
Published 24 November 2011

PHYSICAL REVIEW C **80**, 035502 (2009)

Half-life, branching-ratio, and Q-value measurement for the superallowed $0^+ \rightarrow 0^+ \beta^+$ emitter ^{42}Ti

PRL **105**, 202501 (2010) PHYSICAL REVIEW LETTERS week ending 12 NOVEMBER 2010
Selected for a Viewpoint in *Physics*

Reactor Decay Heat in ^{239}Pu: Solving the γ Discrepancy in the 4–3000-s Cooling Period

A. Algora,[1,2,*] D. Jordan,[1] J. L. Taín,[1] B. Rubio,[1] J. Agramunt,[1] A. B. Perez-Cerdan,[1] F. Molina,[1] L. Caballero,[1] E. Nácher,[1] A. Krasznahorkay,[2] M. D. Hunyadi,[2] J. Gulyás,[2] A. Vitéz,[2] M. Csatlós,[2] L. Csige,[2] J. Äysto,[3] H. Penttilä,[3] I. D. Moore,[3] T. Eronen,[3] A. Jokinen,[3] A. Nieminen,[3] J. Hakala,[3] P. Karvonen,[3] A. Kankainen,[3] A. Saastamoinen,[3] J. Rissanen,[3] T. Kessler,[3] C. Weber,[3] J. Ronkainen,[3] S. Rahaman,[3] V. Elomaa,[3] S. Rinta-Antila,[3] U. Hager,[3] T. Sonoda,[3] K. Burkard,[4] W. Hüller,[4] L. Batist,[5] W. Gelletly,[6] A.L. Nichols,[6] T. Yoshida,[7] A.A. Sonzogni,[8] and K. Peräjärvi[9]
[1]IFIC (CSIC-Univ. Valencia), Valencia, Spain
[2]Institute of Nuclear Research, Debrecen, Hungary
[3]University of Jyväskylä, Jyväskylä, Finland
[4]GSI, Darmstadt, Germany
[5]PNPI, Gatchina, Russia
[6]University of Surrey, Guildford, United Kingdom
[7]Tokyo City University, Setagaya-ku, Tokyo, Japan
[8]NNDC, Brookhaven National Laboratory, Upton, New York, USA
[9]STUK, Helsinki, Finland
(Received 13 May 2010; published 8 November 2010)

The β feeding probability of ^{102,104,105,106,107}Tc, ^{105}Mo, and ^{101}Nb nuclei, which are important contributors to the decay heat in nuclear reactors, has been measured using the total absorption technique. We have coupled for the first time a total absorption spectrometer to a Penning trap in order to obtain sources of very high isobaric purity. Our results solve a significant part of a long-standing discrepancy in the γ component of the decay heat for ^{239}Pu in the 4–3000 s range.

DOI: 10.1103/PhysRevLett.105.202501 PACS numbers: 23.40.–s, 27.60.+j, 28.41.Fr, 29.30.Kv

IGISOL - 4

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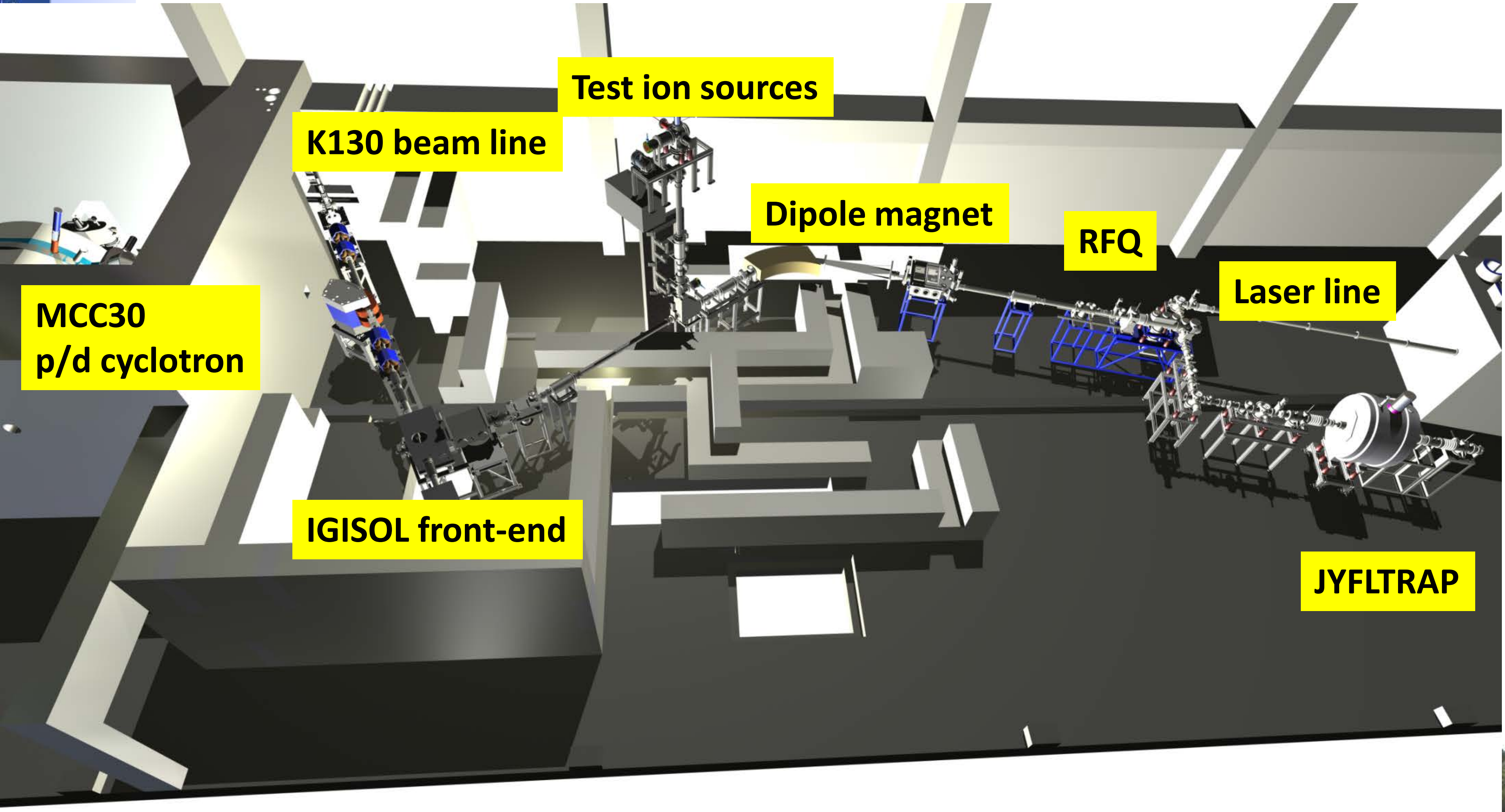


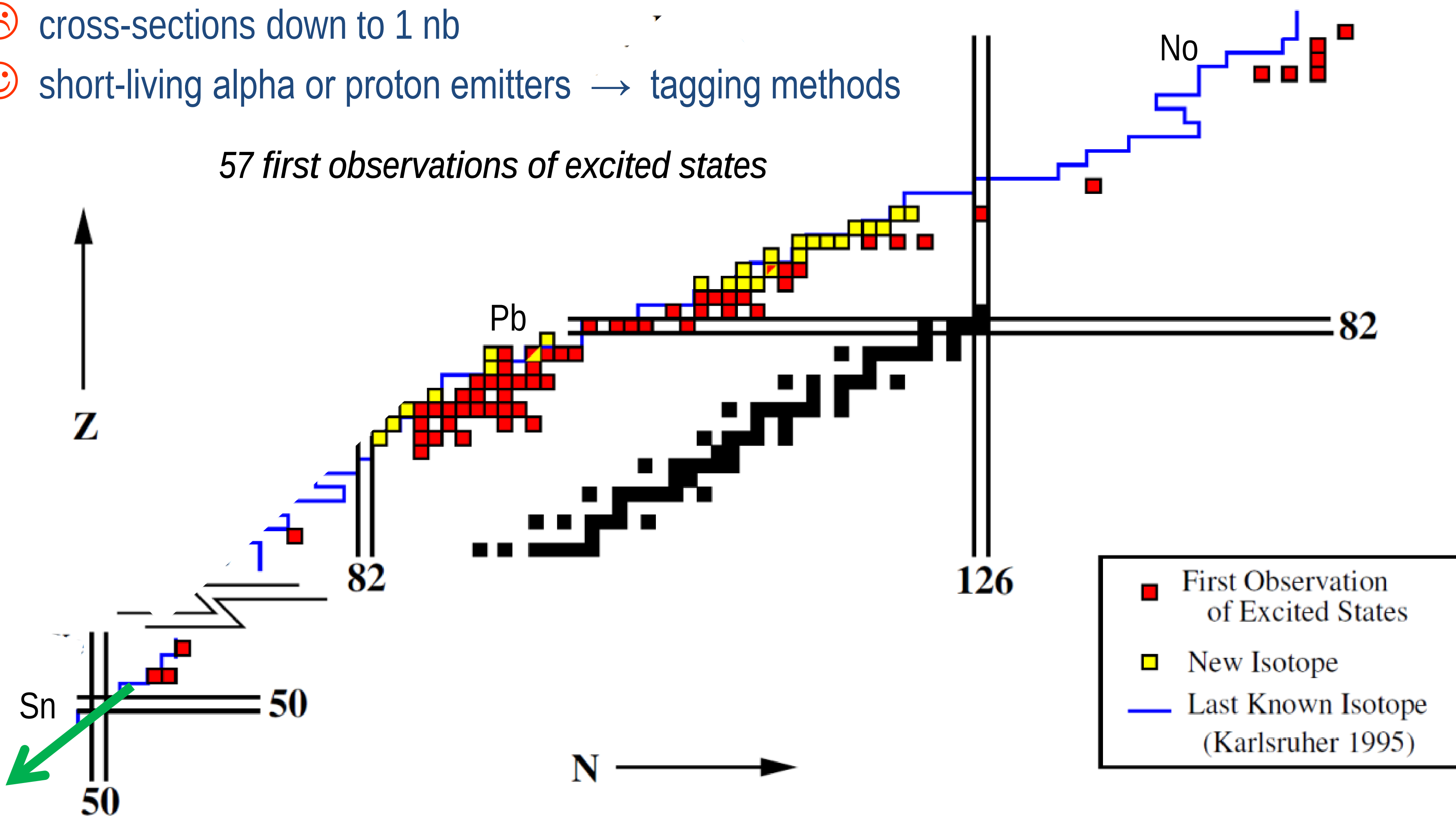
Gamma/RITU

Probing proton-rich and heavy nuclei with Recoil - Decay - Tagging (RDT)

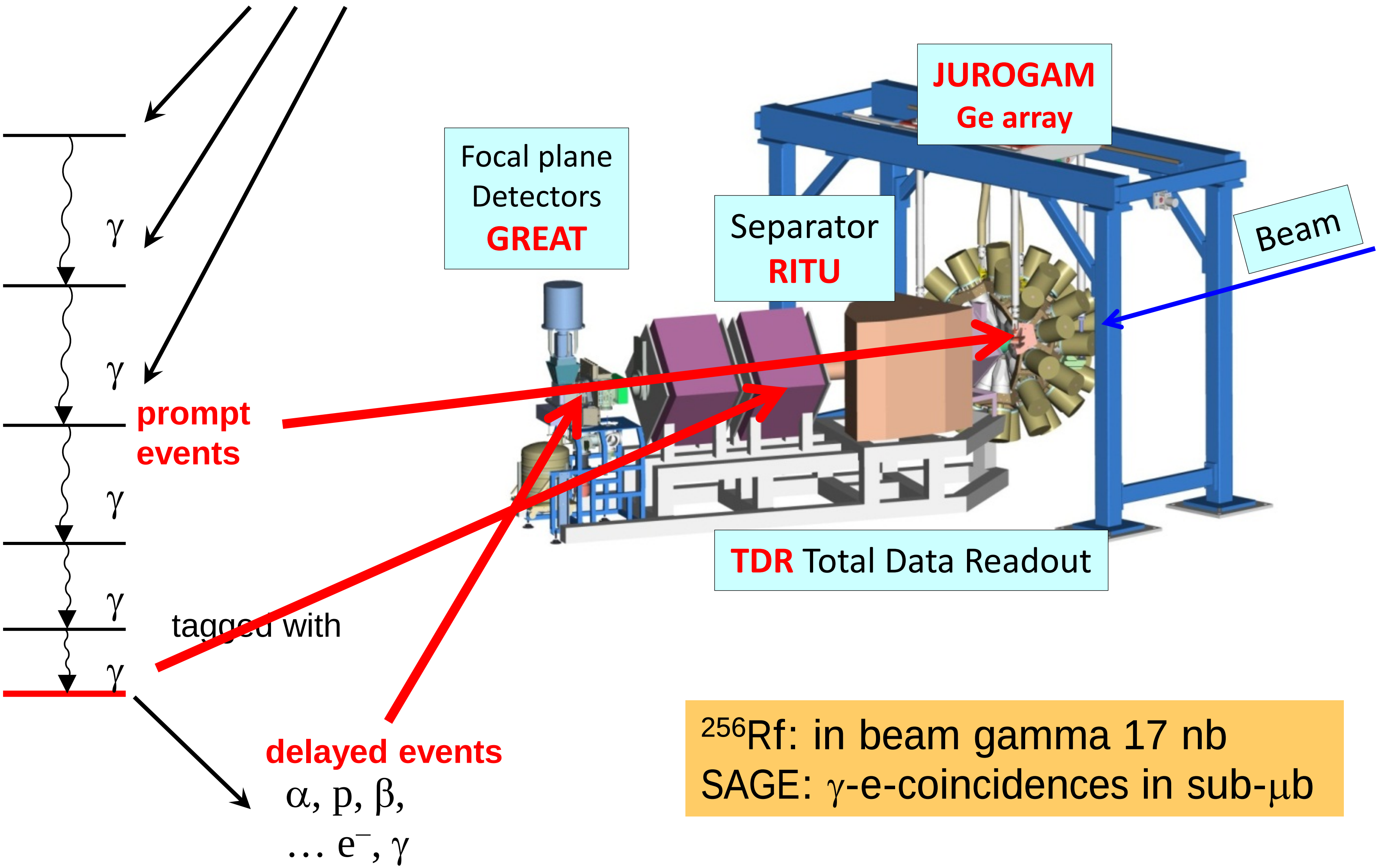
very neutron deficient heavy nuclei

- ☺ can be produced via fusion evaporation with stable-ion beams and stable targets
- ☹ cross-sections down to 1 nb
- ☺ short-living alpha or proton emitters → tagging methods

57 first observations of excited states



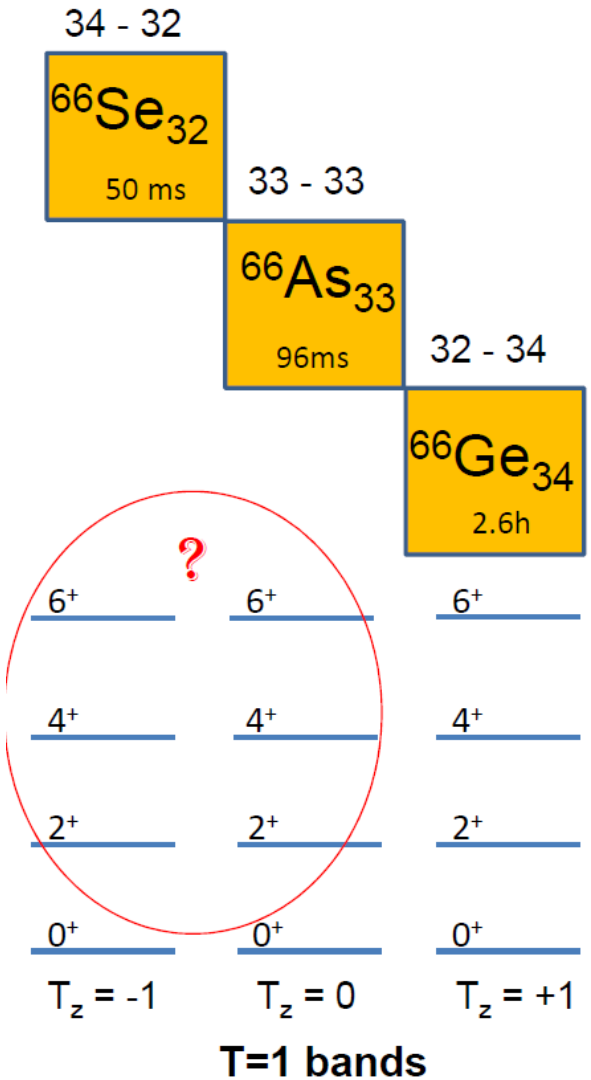
RDT WITH JUROGAM + RITU + GREAT



^{256}Rf: in beam gamma 17 nb
SAGE: γ-e-coincidences in sub-μb

RECOIL – β – TAGGING

Application: Energy Differences
between Isobaric Analog States of T=1 bands in A = 66 nuclei



MED = Mirror Energy Differences

TED = Triple Energy Differences

☺

- *High-energy β decays (compared to other reaction products)*
- *Relatively fast super-allowed Fermi β decays*:

☹

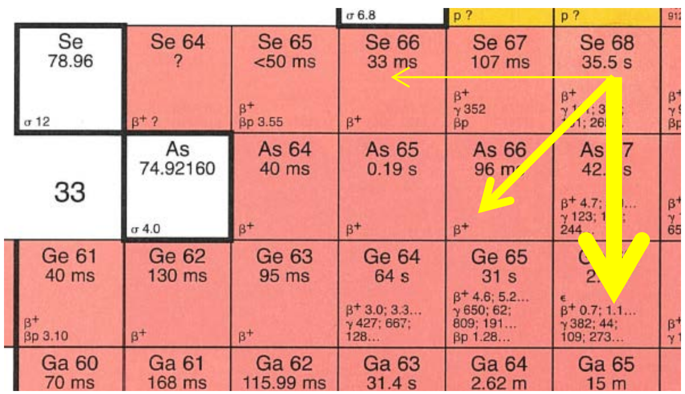
- *Continuous β- spectrum overlapping with those from uninteresting evaporation channels*

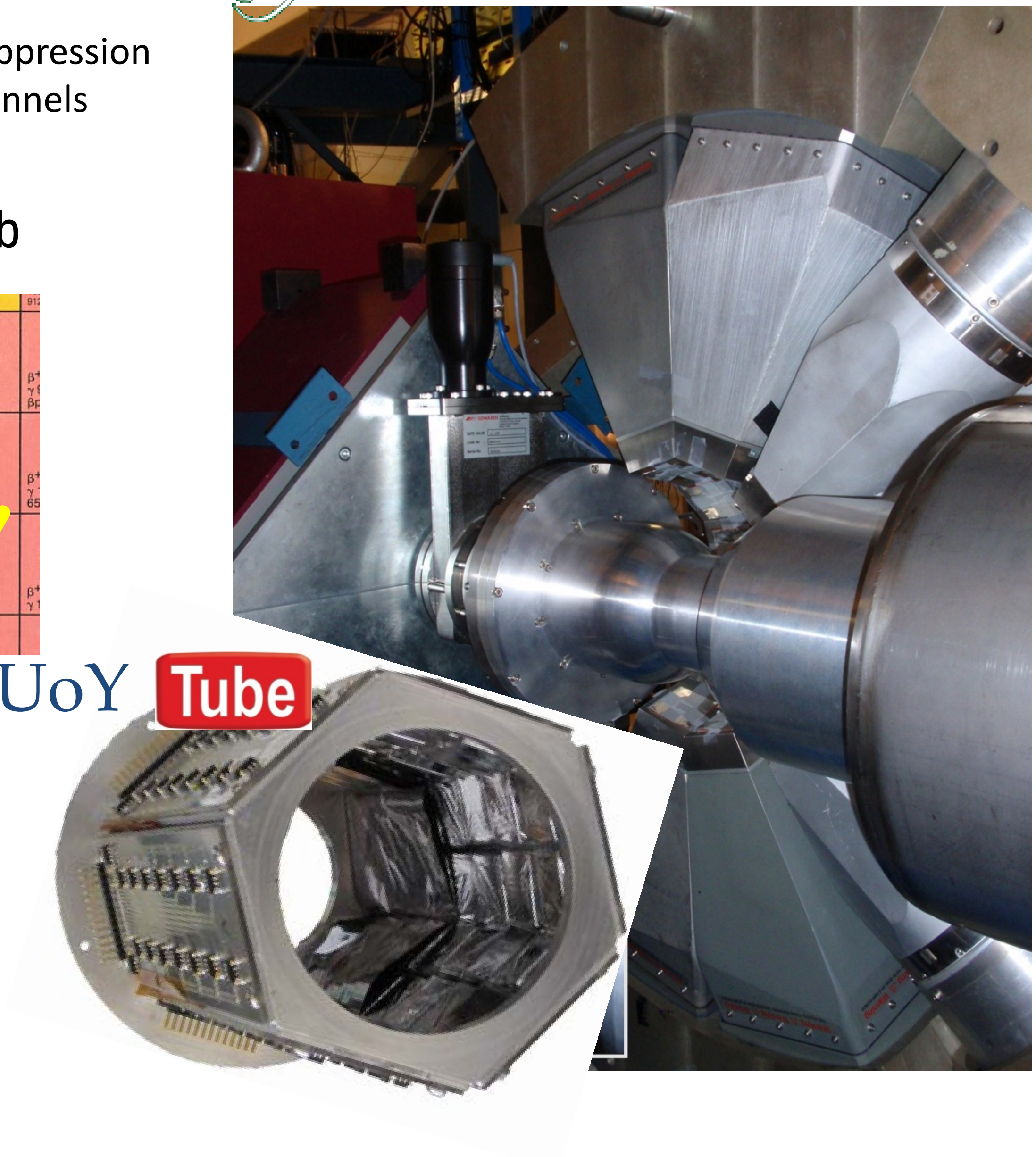
^{66}Se(Z = 32, N = 34)

UoY Tube THE UNIVERSITY *of York*

Charged particle veto → efficient suppression of disturbing proton-evaporation channels

^{40}Ca(^{28}Si,2n) ^{66}Se ~ 200nb





UoY Tube

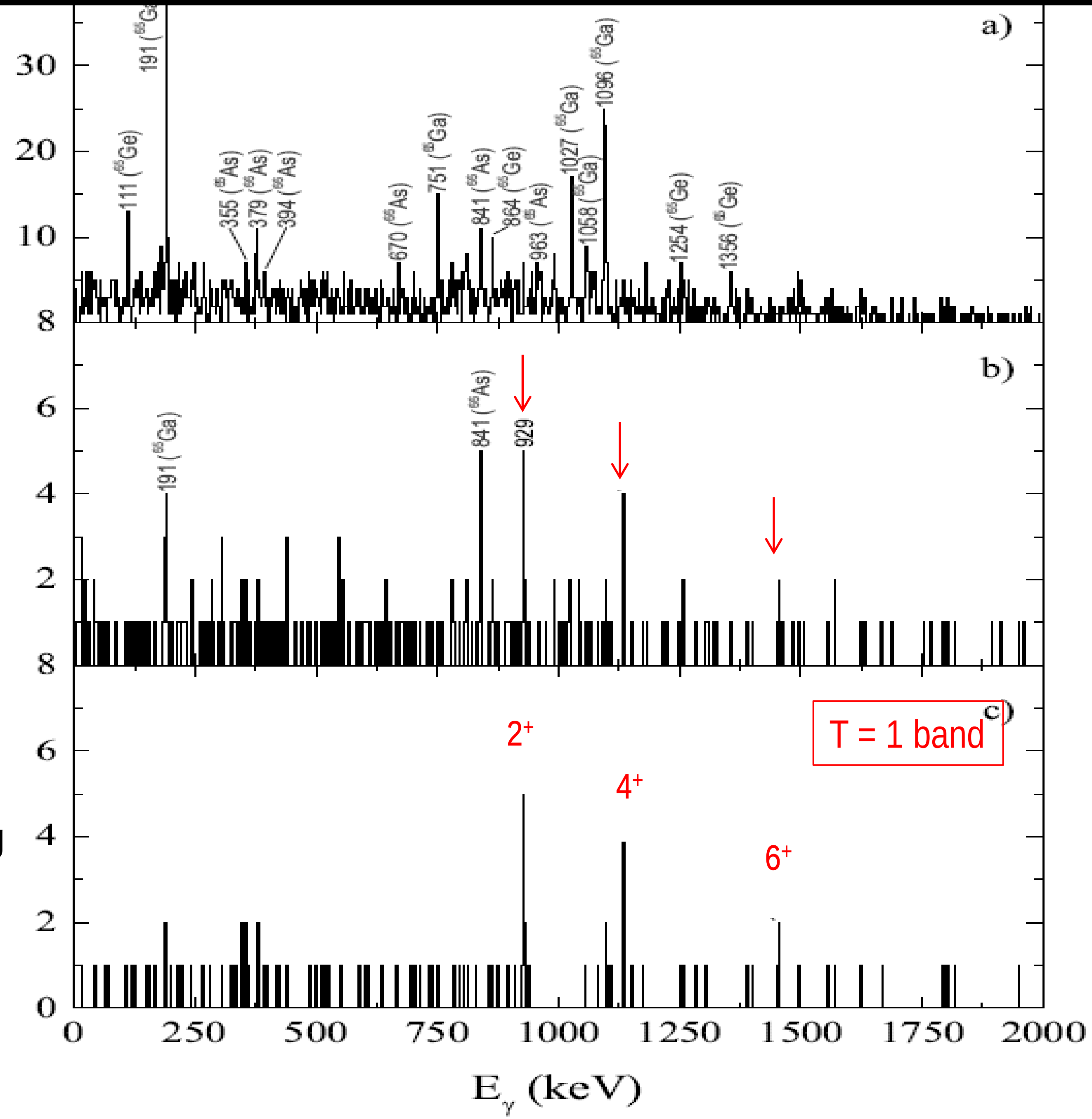
96 20 x 20 mm CsI crystals

^{66}Se (Z = 32, N = 34)

γ-rays from $^{66}Se_{32}$ tagged with its 50ms β decay

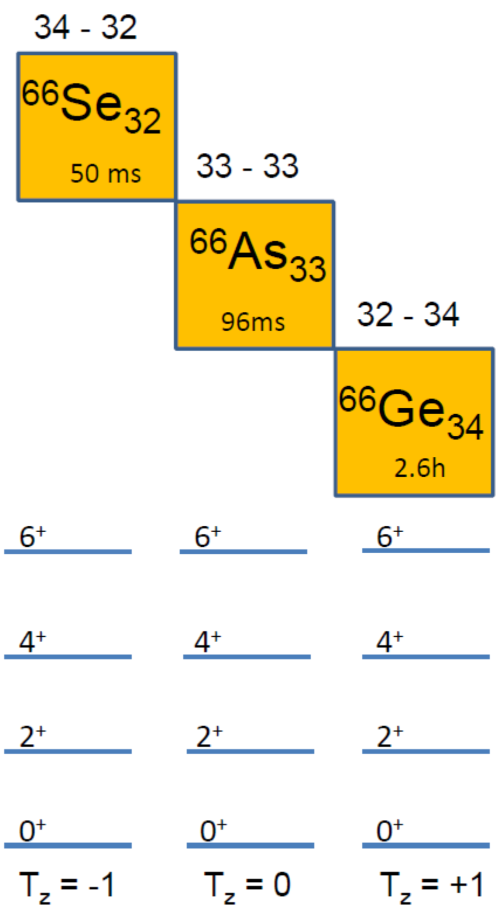
+ UoY Tube veto

+ ^{66}As isomer veto-tagging



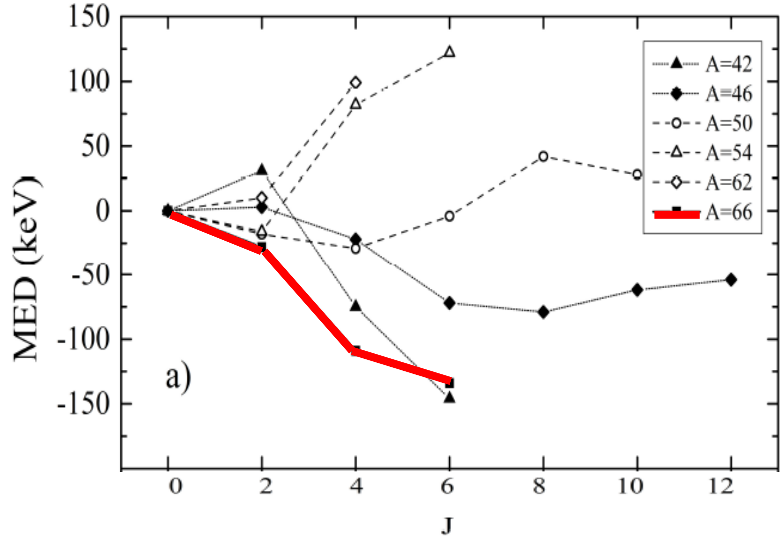
MED AND TED

A=66 is the heaviest
triplet of T = 1 bands up to 6+



T=1 bands

MED=Mirror Energy Differences

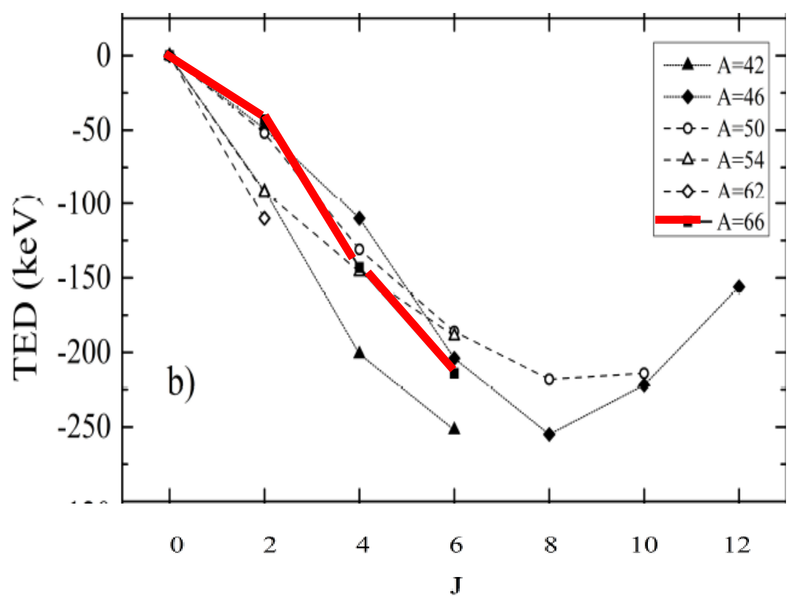


MED=
$E_x(T_z= -1) – E_x(T_z= +1)$

$V = v_{pp} – v_{nn}$

Charge symmetry
Sign of MED defined by particle type of active pair

TED=Triple Energy Differences



TED=
$E_x(T_z= -1) + E_x(T_z= +1) - 2 E_x(T_z= 0)$

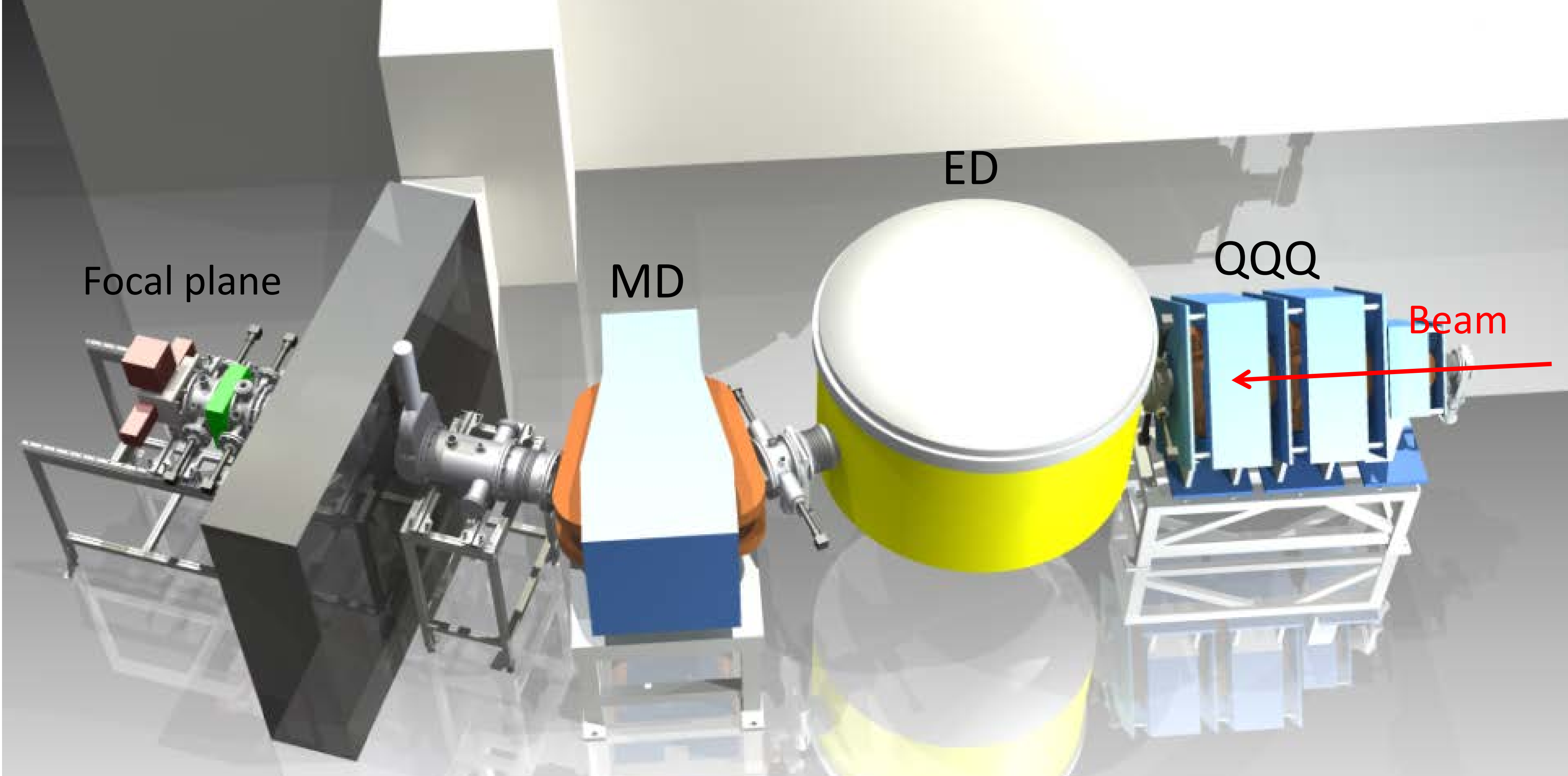
$V = v_{pp} + v_{nn} - 2v_{pn}$
Charge independence

Single-particle effects cancel out

TED behaviour ?
→ exp's
→ theory

FUTURE

The new vacuum mode separator – MARA
→ better mass selection in RDT experiments

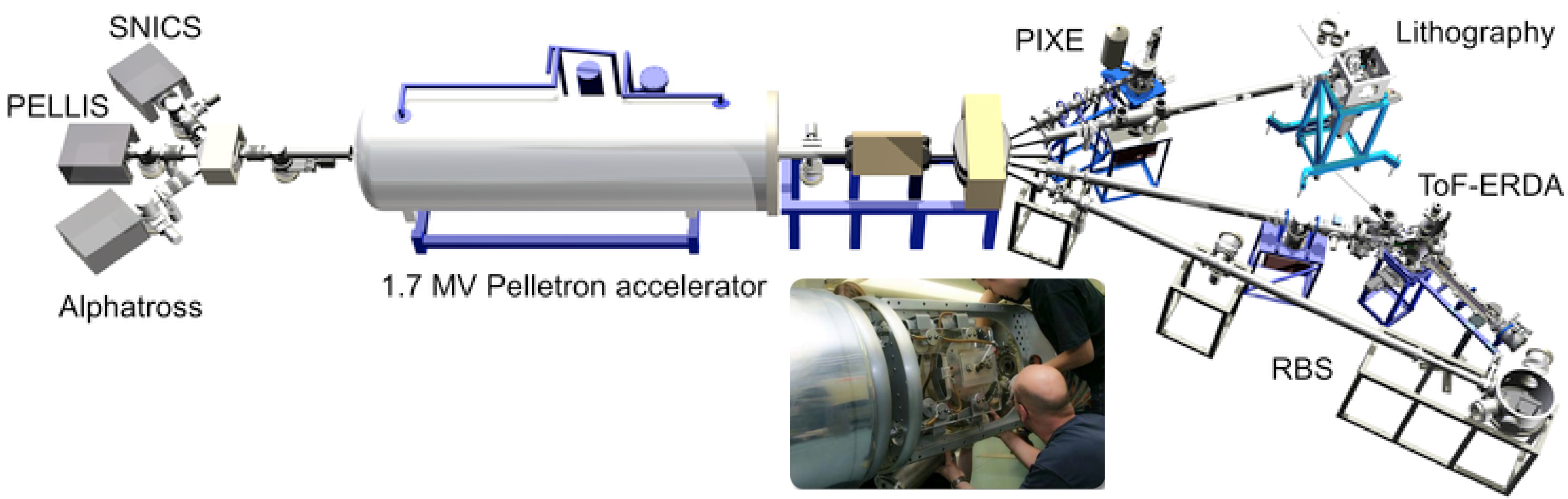


- Solid angle acceptance (central m/q and energy) 10 msr
- Typical transmission ~12% per charge state

Pelletron

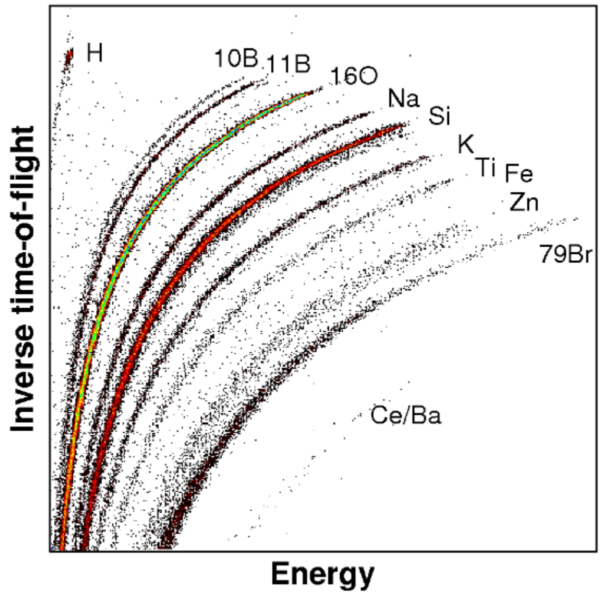
Materials physics at Pelletron laboratory

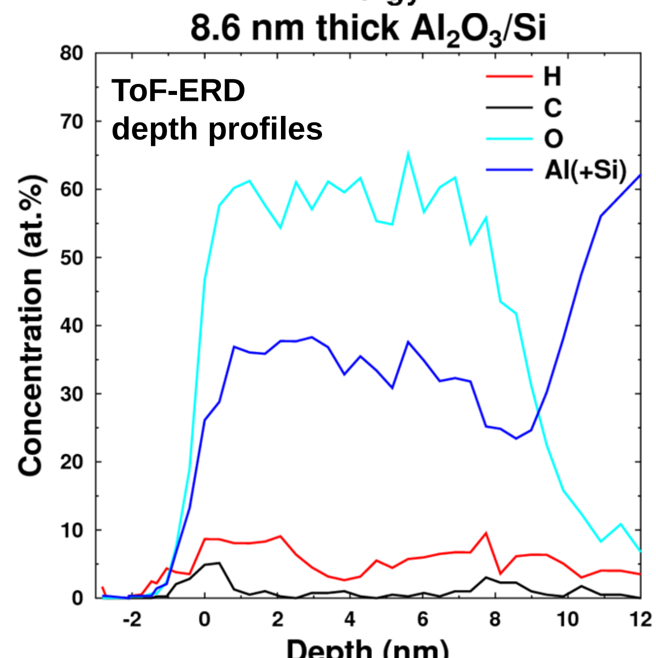
- Main research fields
  - Fundamental ion-matter interactions (cross sections, stopping forces, straggling)
  - Ion beam analysis (IBA) for thin film samples
  - Development of IBA techniques (detectors, data acquisition, simulations)
  - Thin film processing (ALD, proton beam writing, irradiation)
  - Materials research applications
- Key facilities
  - 1.7 MV Pelletron accelerator (in Jyväskylä since 2006)
    - Three ion sources, four beam lines
    - H, He, Cl, Cu, Br, I, and other heavy ion beams, 0.2 – 20 MeV
    - RBS, ToF-ERD, PIXE, and proton beam writing facilities
  - Atomic layer deposition (ALD) tool for thin film research
  - K130 cyclotron used for fundamental research and ion track production

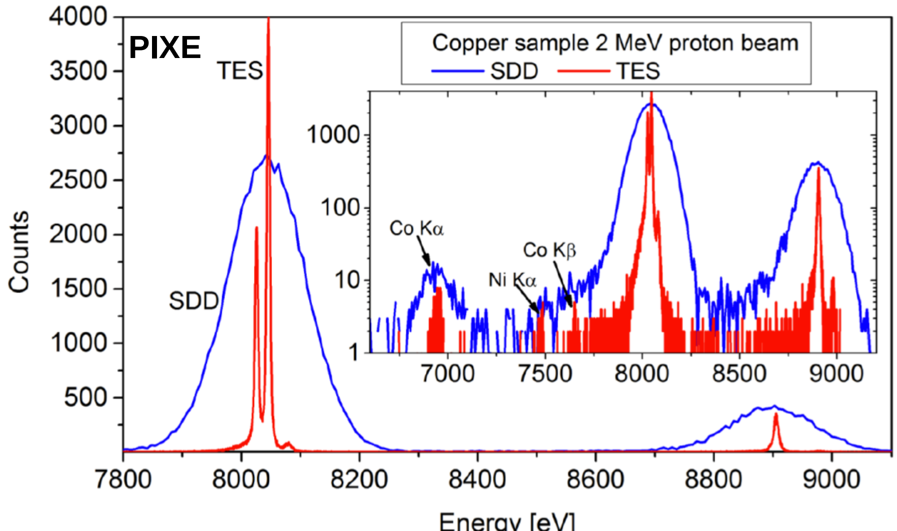


Development of ion beam analysis techniques

- ToF-ERD (Time-of-flight Elastic Recoil Detection)
  - Quantitative depth profiling for all elements (H-Au), sensitivity < 0.1 at.%, depth resolution < 2 nm
  - Optimized timing gate design for improved energy resolution
  - Development of gas-ionization detector to improved mass separation
  - Digital data acquisition to improve high count rate perfomance and detection of low energy signals
- PIXE (Particle Induced X-ray Emission)
  - High sensitivity (ppm) for elements heavier than Al, no depth information
  - Superconductive transition edge sensor (TES) with 3 eV resolution @ 5.9 keV

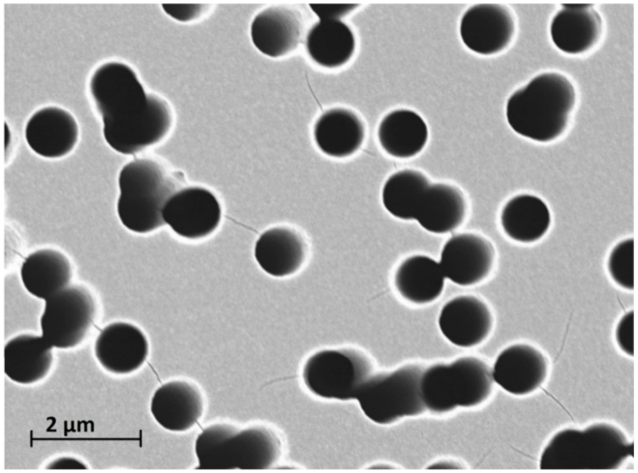


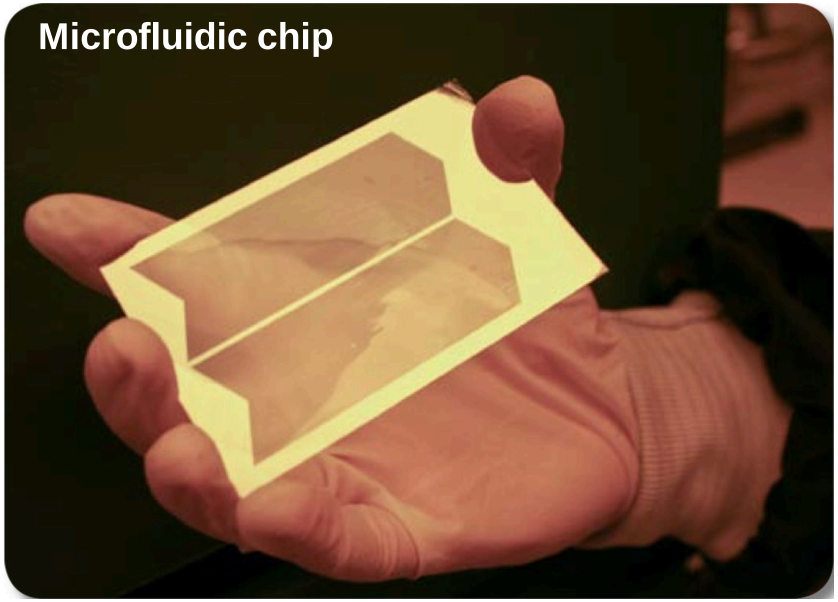




Thin films processing and applications

- Atomic layer deposition (ALD)
  - Oxides, nitrides, carbides, fluorides, sulphides and metals with excellent control of film thickness and high conformality for 3D structures
  - Mechanical properties of thin films on MEMS structures
  - Biomimetic materials (hydroxyapatite)
  - Hydrophilic/hydrophobic surfaces
- Lithography with proton beam writing
  - Large area exposures for high-aspect ratio structures
  - Microfluidic chips for borrelia infection diagnostics
- Functionalized ion tracks
  - Enhanced electron multiplication in ALD coated pores





Commercial activity

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for

space, microfilter and medical industry

RADEF; test laboratory of ESA since 2005

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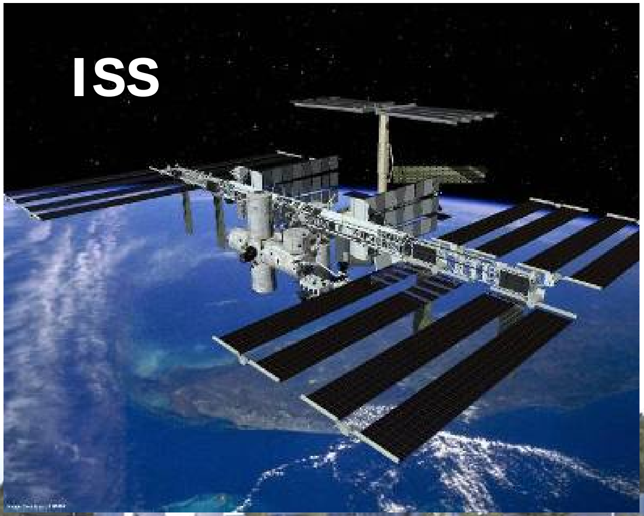
ESA/ESTEC/Contract No. 18197/04/NL/CP
"Utilisation of the High Energy Heavy Ion Test Facility for Component Radiation Studies"

Tested satellite electronics in RADEF for ESA, NASA, JAXA (Japan), CNES (France) and more than 30 satellite companies

- International Space Station
- Telecommunication satellites
- Global Positioning System, GPS
- Mission satellites
- Earth observation, i.e. EO- satellites
  - Global warming
  - Weather etc…



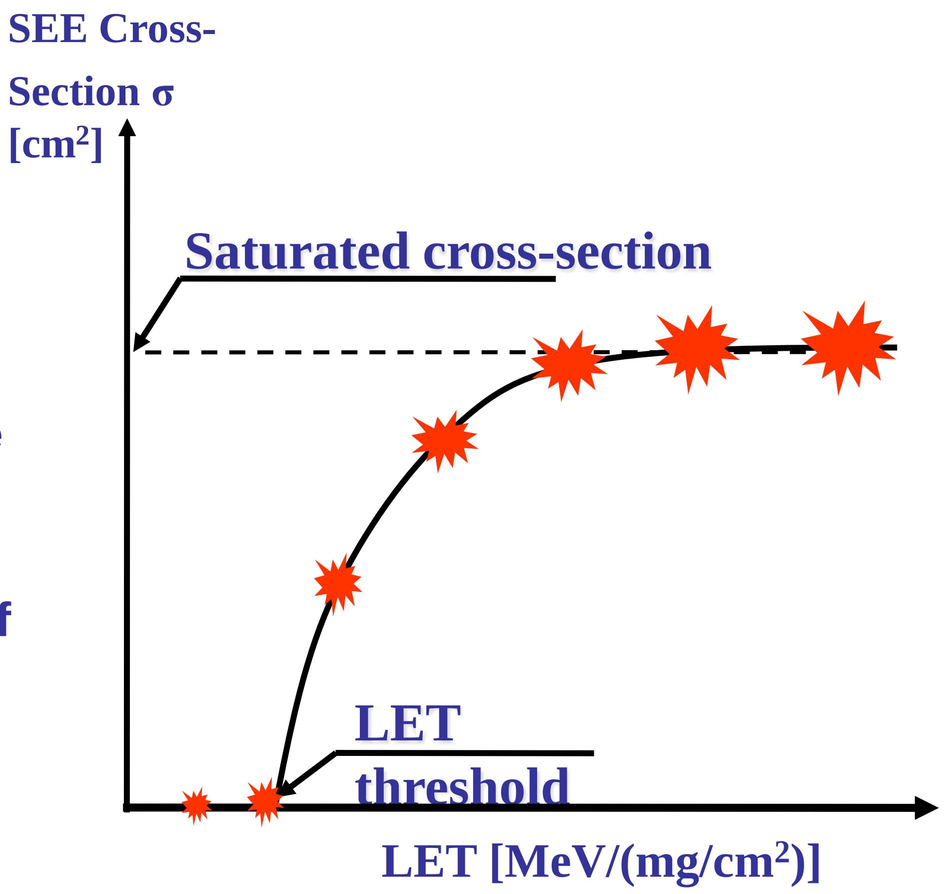
How do we test?

By determining the error cross-section σ as a function of LET* we define the LET threshold and Saturated cross-section.

The higher LET_{th} and lower σ_{sat} the more RadHard the component

The increase in LET is done by increasing the mass (i.e. charge) of the ions

* LET = Linear Energy Transfer



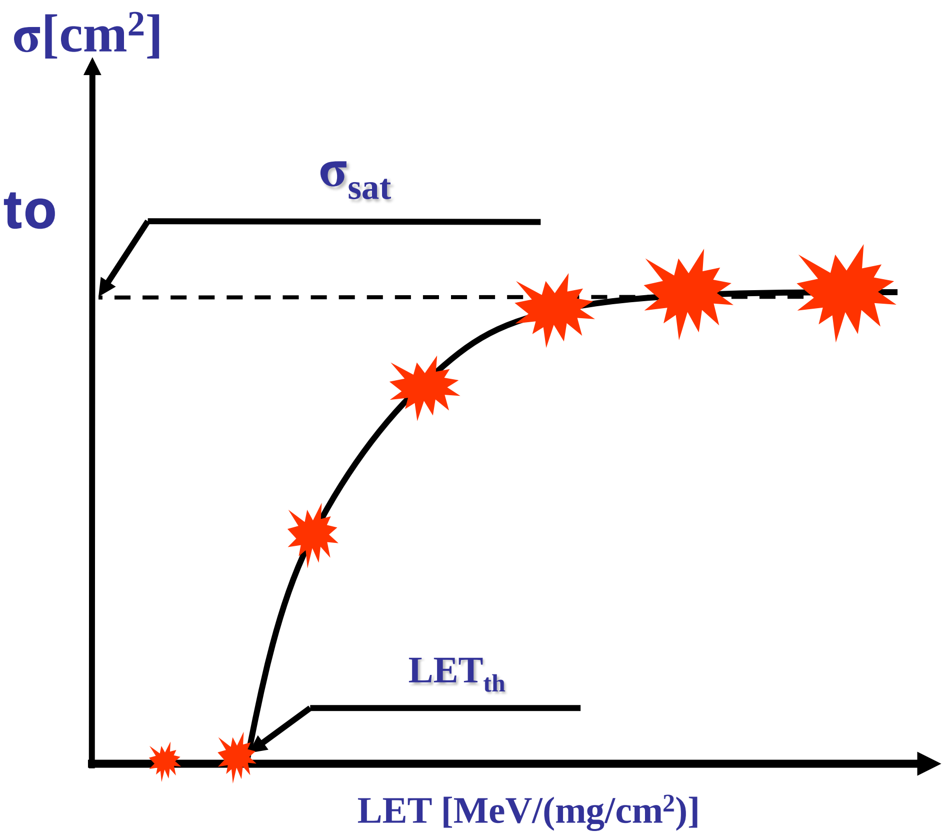
Two major problems

Technical:

In order to define LET_{th} and σ_{sat}, we need several ions up to twice of the LET-value of Fe, *i.e. LET ~ 60 MeV·cm²/mg*

Business related:

In order to keep project costs low we have to do this in as short time as possible, *i.e. the change of ions must be fast*



Solution: Ion cocktail 9.3·*A* MeV

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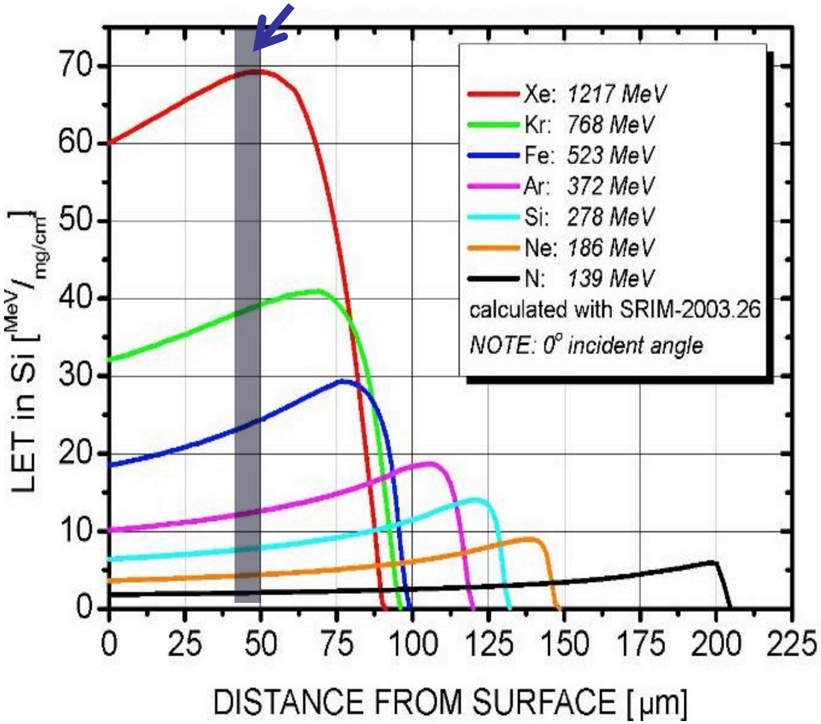
$^{A}Ion^{q+}$ q/A≈ 0.27	E [MeV]	Range [μm]	LET @surface [MeV·cm²/mg]	LET @bragg [MeV·cm²/mg]
$^{15}N^{4+}$	139	202	2	6
$^{20}Ne^{6+}$	186	146	4	9
$^{30}Si^{8+}$	278	130	6	14
$^{40}Ar^{12+}$	372	118	10	19
$^{56}Fe^{15+}$	523	97	19	21
$^{82}Kr^{22+}$	768	94	32	41
$^{131}Xe^{35+}$	1217	89	60	69



1. LET > 60 MeV/(mg/cm²)
2. Fast ion change with 7 ions
3. Bragg peak behind 50μm in silicon → this cocktail allows backside irradiation and do it also in air

Note: ECR type ion source and cyclotron type accelerator is the necessary combination

Irradiation of polymer films

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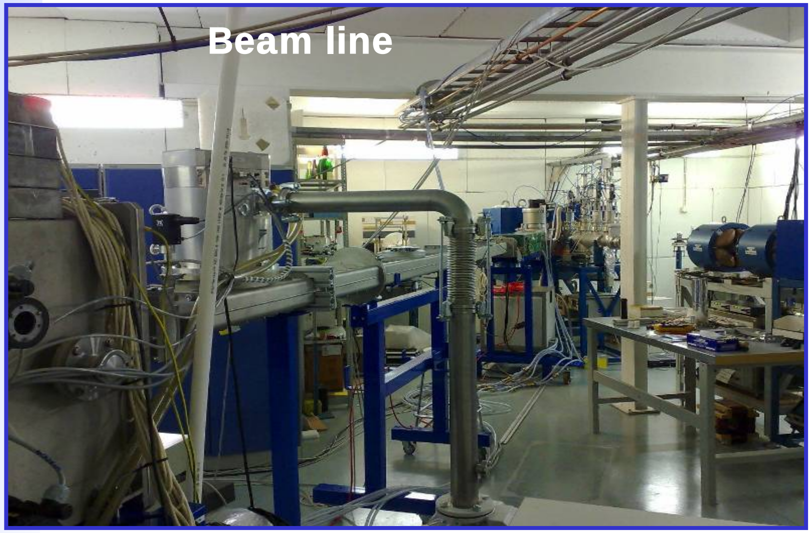
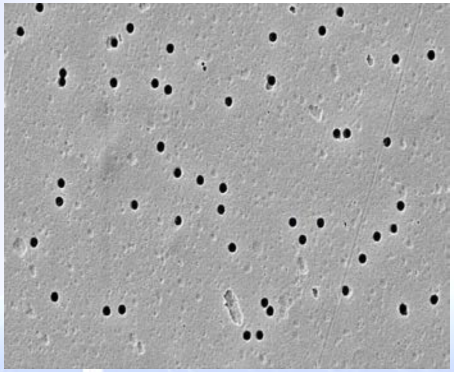
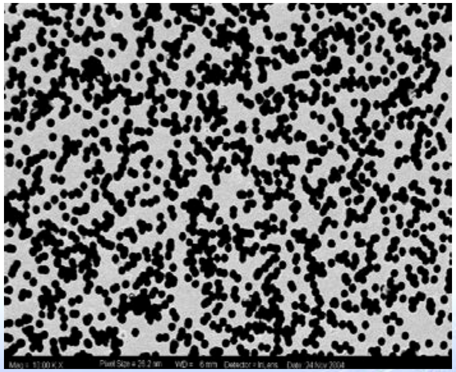


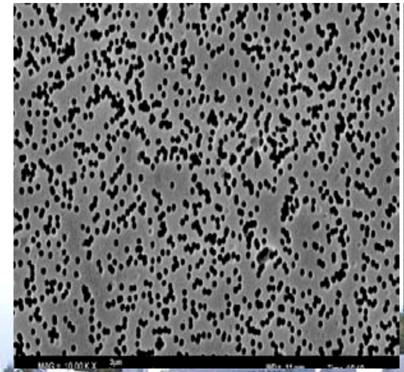
to etching →

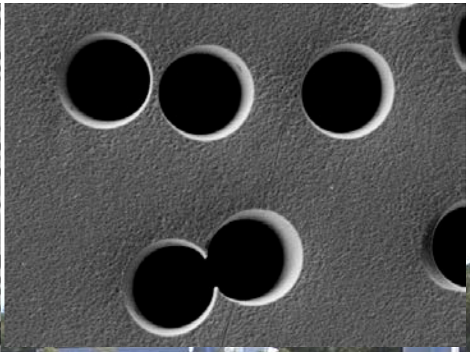
10^5 pores / cm^2 → **10^9 pores / cm^2**

0.1 µm → **10 µm**









Production of radiopharmaceuticals

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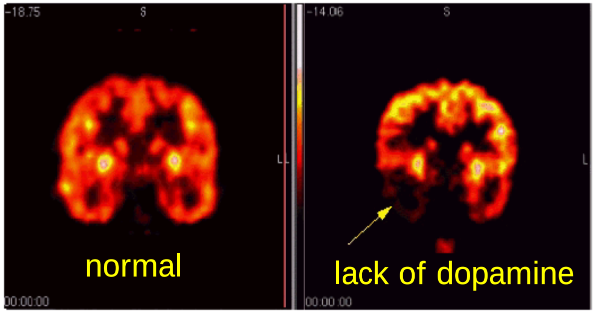
K-130 accelerator:

- Weekly production of 123-iodine ($T_{1/2}$=13 h)
- Local company fabricates a compound and “fly” it to hospitals
- The last iodine irradiation was done in September, 2008.

Used for diagnosing brain based diseases in largest hospitals in Finland

Gamma - camera picture



SPECT= Single Photon Emission Computer Tomography

Plans for the K-30 cyclotron

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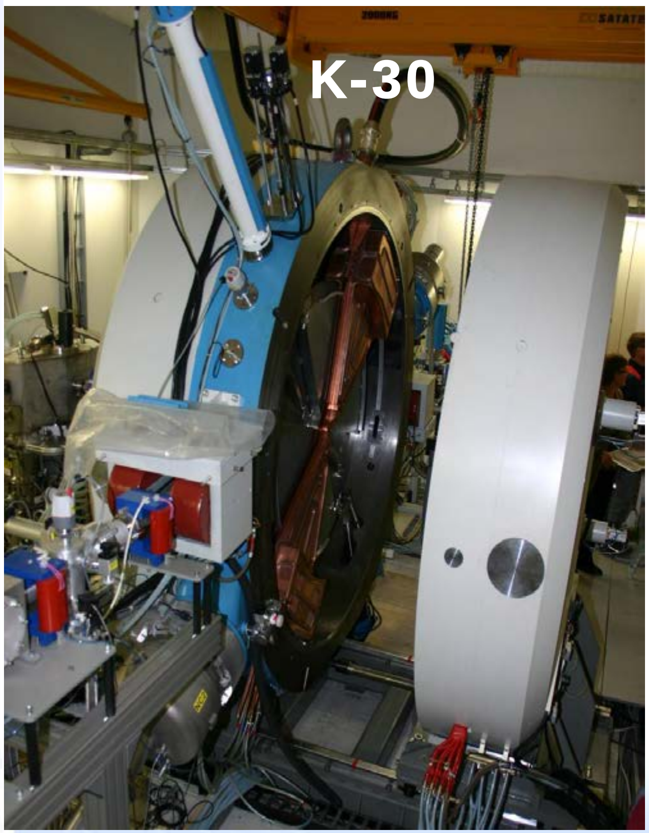
Start 18-Fluorine (ß$^{+}$-emitter with$T_{1/2}$=110 min!) production?

Used for early stage diagnosis of cancer with PET camera



The latest update at RADEF

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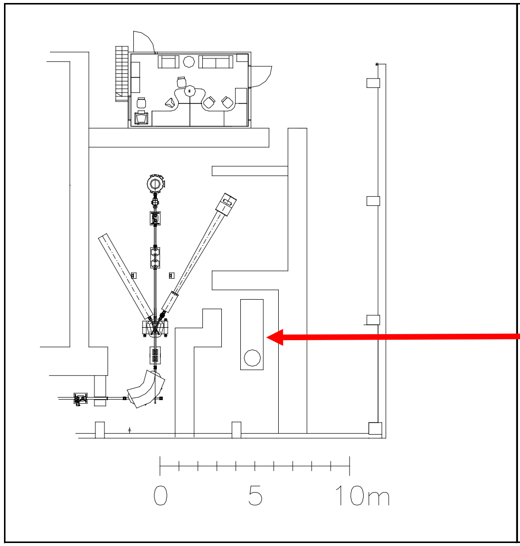
Old Varian Clinac 2100CD radiation therapy accelerator from Kuopio University Hospital

- **Provides very intense electron and x-ray beams up to 20 MeV and 15 MeV, respectively**
- **Installed during the summer**



- Will be used for irradiation studies of semiconductor materials and devices
- Especially foreseen is the next large-scale satellite mission of ESA, JUICE = Jupiter Icy moon Explorer, aimed to be launched in 2022
- The data from previous missions indicate extremely severe electron fluxes and x-ray doses

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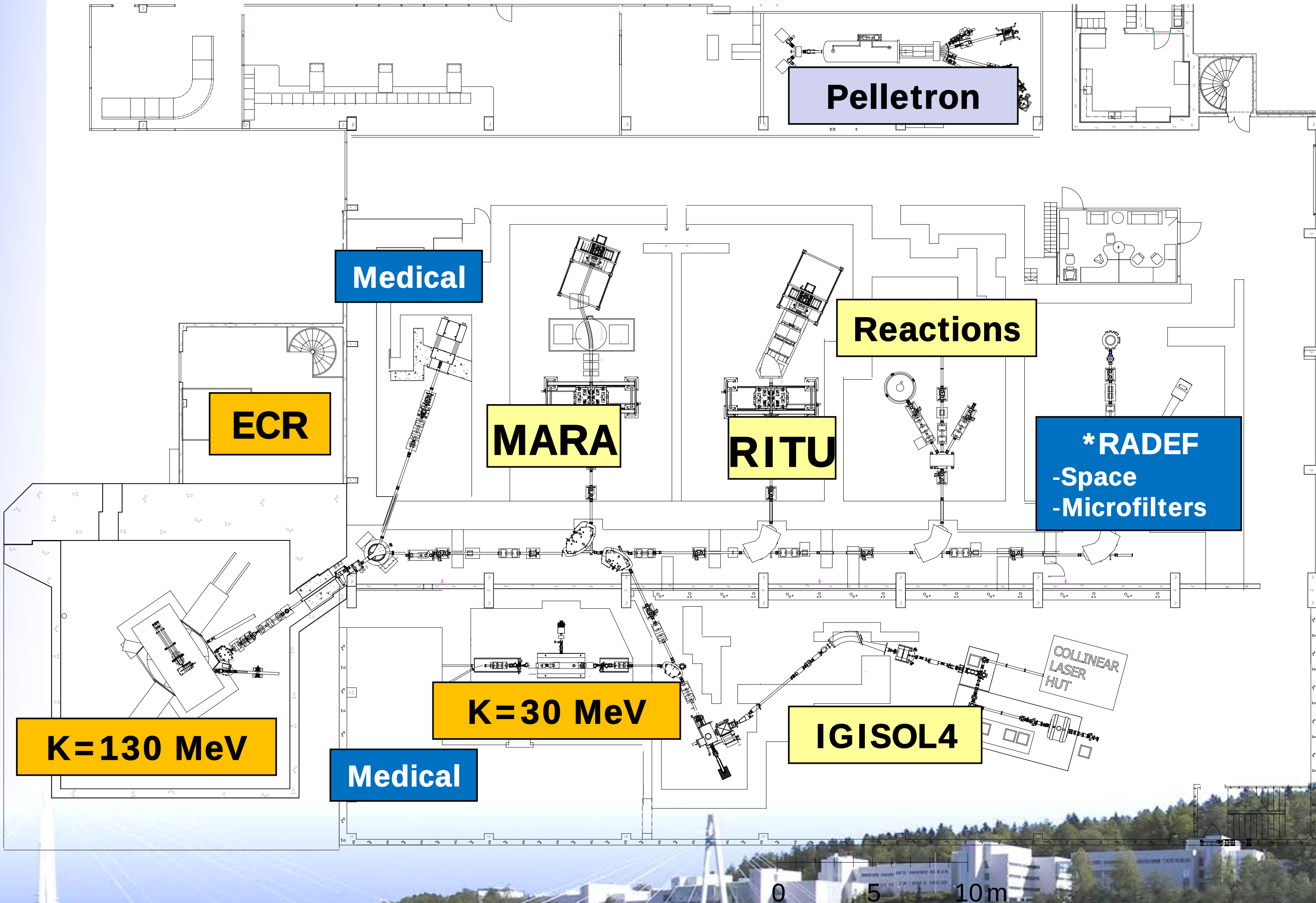

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Thank you for your attention !