

Nuclear and applied research at JYFL-accelerator laboratory

Ari Jokinen

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



NuPECC Long Range plan 2010



- 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



K130

Accelerated elements:

p – Xe

$E = Q^2/A$ 130 MeV

Ion sources:

6.4 GHz ECRIS

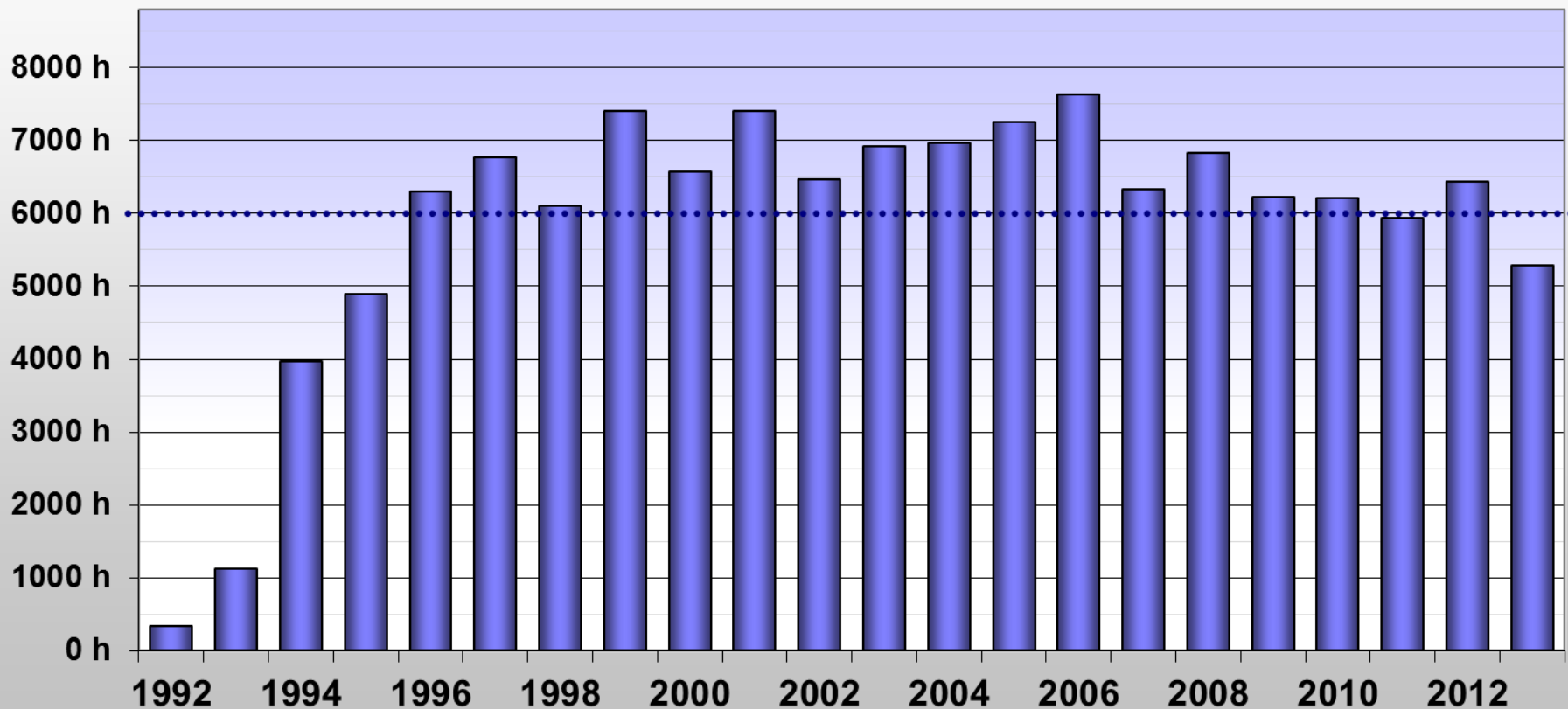
14 GHz ECRIS

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 μ A

Users:

- IGISOL
- Radioisotope production

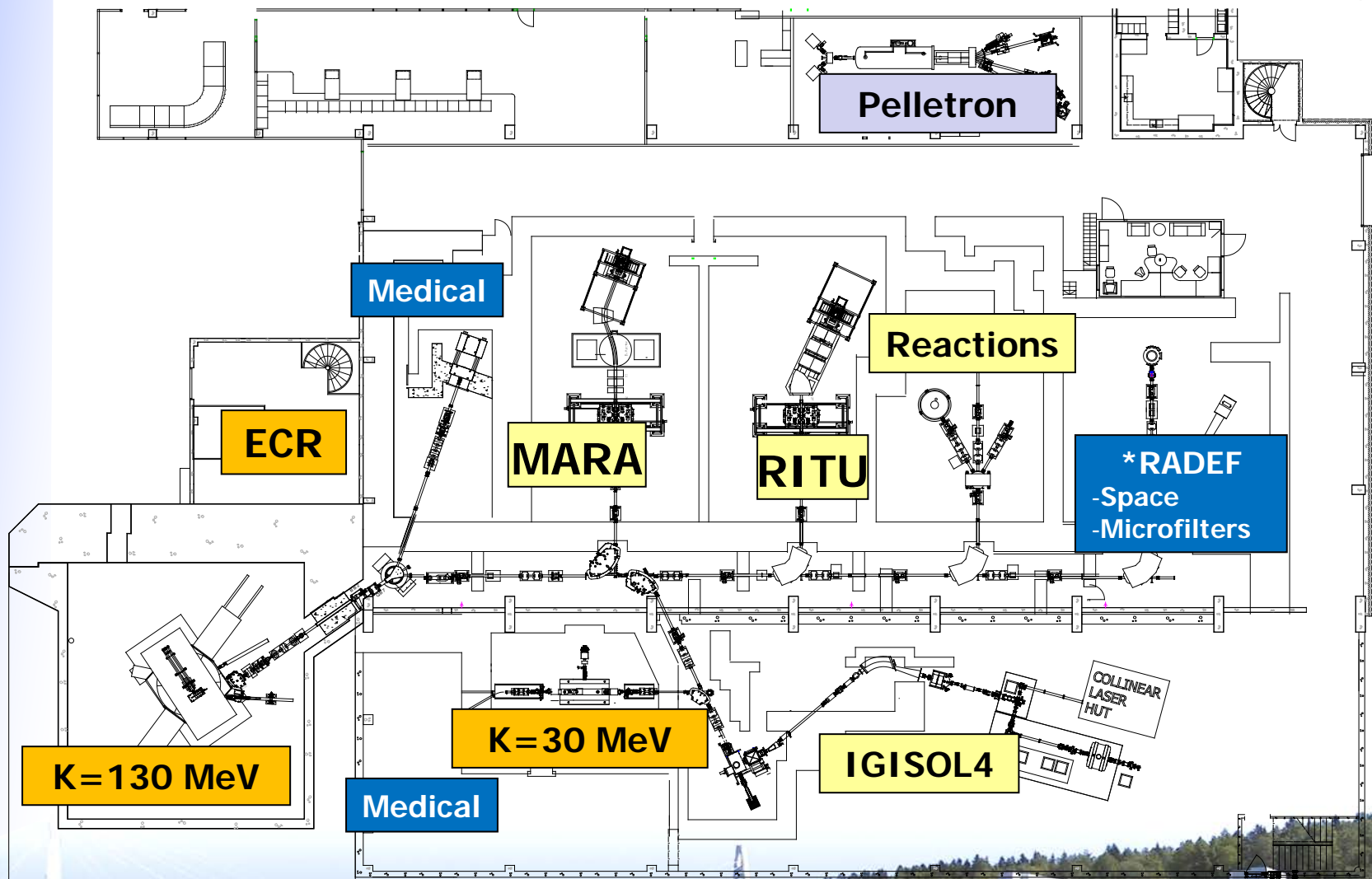
New RF ion source

- Intensity increase
- Continuous operation

Accelerator laboratory



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0 5 10m

IGISOL

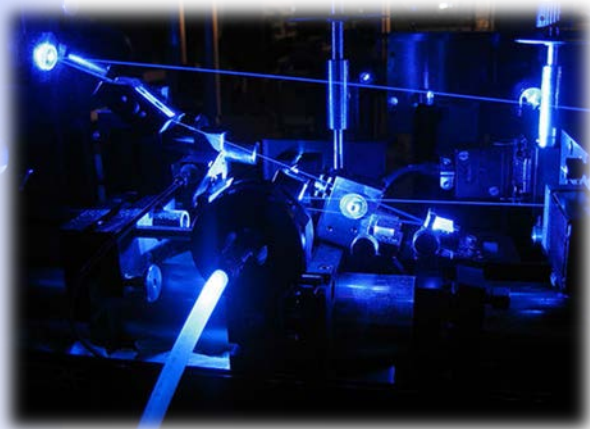


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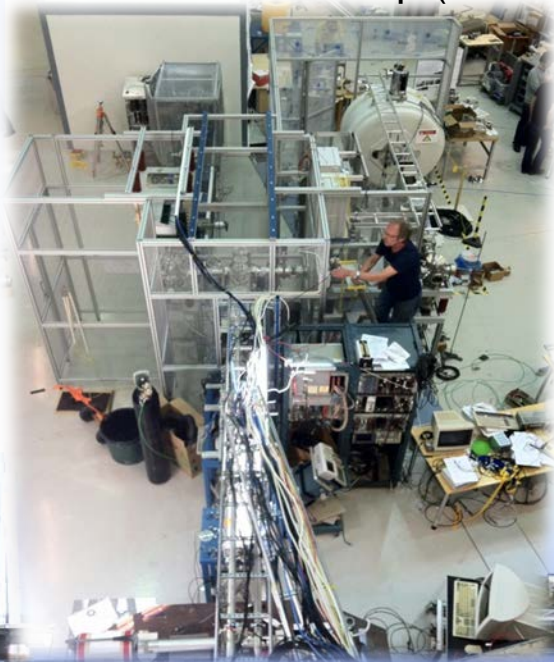


IGISOL - 3

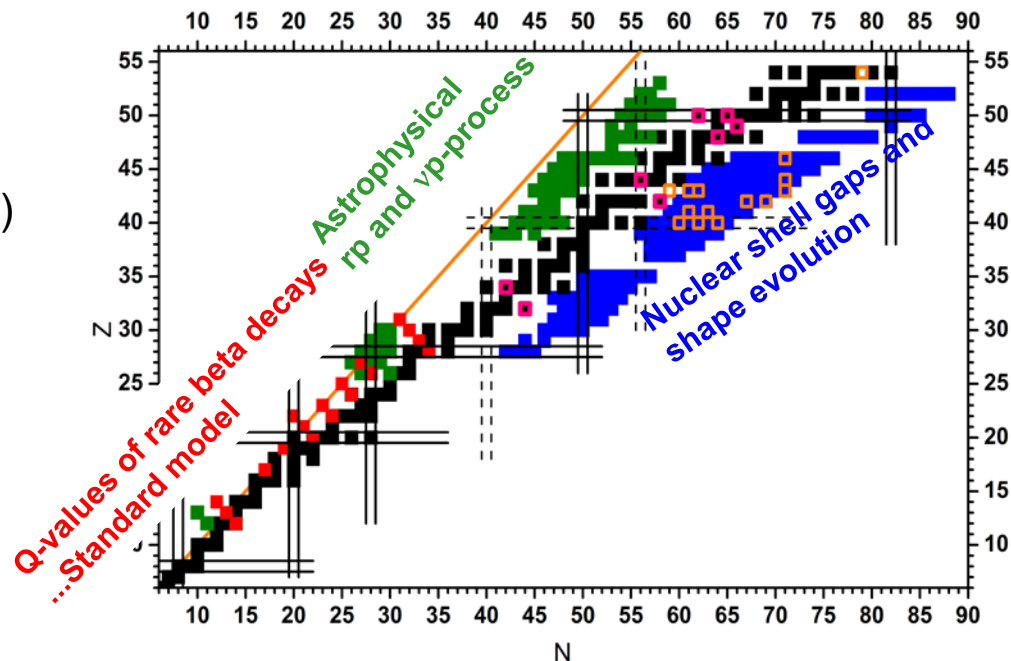
Isotope shifts with lasers → nuclear radii



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

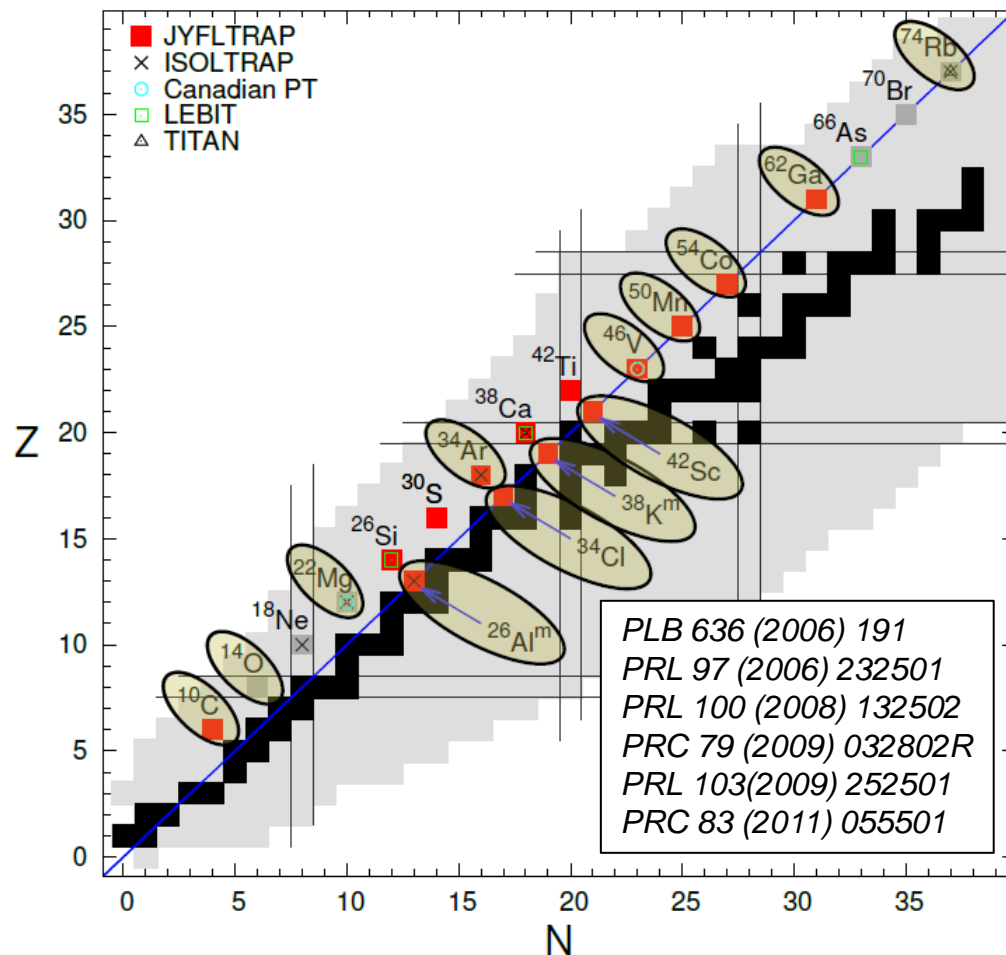


Accurate measurements of nuclear masses and radii provide input and critical test for nuclear models, nuclear astrophysics and standard model



Superaligned 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 , $^{26}\text{Al}^m$

^{26}Si , ^{42}Ti

2006-2007:

^{50}Mn , ^{54}Co

2009:

$^{38}\text{K}^m$, ^{34}Cl

^{30}S

2010:

^{10}C , ^{34}Ar , ^{38}Ca

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

^{14}O : IGISOL-4

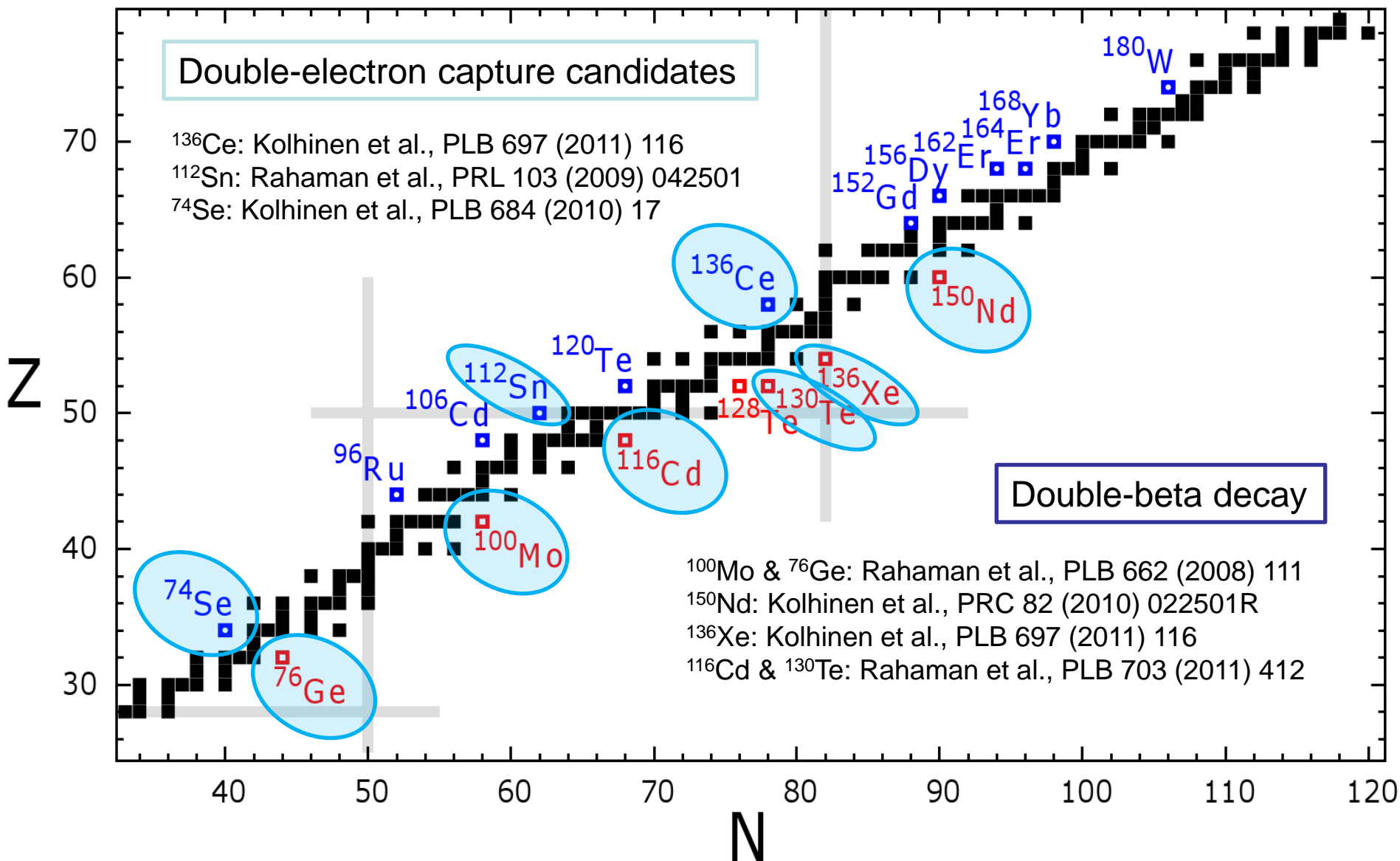
JYFLTRAP harvest...

Double-electron capture candidates

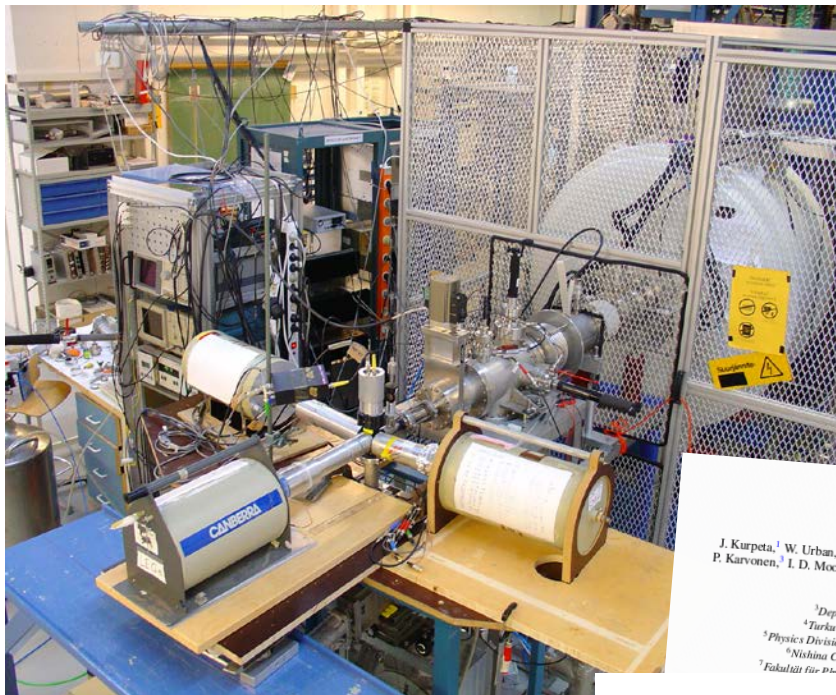
^{136}Ce : Kolhinen et al., PLB 697 (2011) 116
 ^{112}Sn : Rahaman et al., PRL 103 (2009) 042501
 ^{74}Se : Kolhinen et al., PLB 684 (2010) 17

Double-beta decay

^{100}Mo & ^{76}Ge : Rahaman et al., PLB 662 (2008) 111
 ^{150}Nd : Kolhinen et al., PRC 82 (2010) 022501R
 ^{136}Xe : Kolhinen et al., PLB 697 (2011) 116
 ^{116}Cd & ^{130}Te : Rahaman et al., PLB 703 (2011) 412



Trap-assisted spectroscopy



Eur. Phys. J. A 31, 1-7 (2007)
DOI 10.1140/epja/2006-10158-9

Regular Article – Nuclear Structure and Reactions

THE EUROPEAN
PHYSICAL JOURNAL A

Decay study of ne Penning trap as a

S. Rinta-Anttila¹, T. Eronen², V.-A.
T. Sonoda³, A. Saastamoinen⁴, and
University of Jyväskylä, Department

Eur. Phys. J. A 31, 363-366 (2007)
DOI 10.1140/epja/2007-10009-3

Letter

Letter

Penning trap assisted decay spectroscopy of neutron-rich ¹¹⁵Ru

J. Kurpeta^{1,2}, V.-V. Elomaa³, T. Eronen², J. Hakala², A. Jokinen², P. Karvonen², I. Moore², H. Penttilä²,
Saastamoinen², T. Sonoda²

THE EUROPEAN
PHYSICAL JOURNAL A

Finland
Aug 2007

Penning-trap-assisted study of ¹¹⁵Ru beta decay

J. Rissanen^{1,2}, J. Kurpeta², A. Plochowski²,
P. Karvonen¹, I. D. Moore¹

¹ Department of Phys
² Faculty of Physics,
³ Institut Laue-Langevin

Received: 8

PHYSICAL REVIEW C 82, 027306 (2010)

Excited states in ¹¹⁵Pd populated in the β^- decay

J. Kurpeta,¹ W. Urban,² A. Plochowski,¹ J. Rissanen,³ V.-V. Elomaa,⁴ T. Eronen,³ J. I.
P. Karvonen,¹ I. D. Moore,¹ H. Penttilä,¹ S. Rahaman,⁵ A. Saastamoinen,² T. Sonoda,⁶

¹ Faculty of Physics, University of Warsaw, ul. Heca 69, PL-00-681 V
² Institut Laue-Langevin, 6 rue J. Horowitz, F-38042 Grenoble

³ Department of Physics, University of Jyväskylä, P.O. Box 35, FIN-40351,
⁴ Turku PET Centre, Accelerator Laboratory, Abo Akademi University, FIN-
⁵ Physics Division, P-23, Mail Stop HB03, Los Alamos National Laboratory, Los Alamos,
⁶ Nishina Center for Accelerator Based Science, RIKEN, Wako, Japan

⁷ Fakultät für Physik, Universität Wien, A-1040 Wien, Austria

PHYSICAL REVIEW C 80, 035502 (2009)

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

U. Hager,¹ T. Eronen,² L. Audrac,³ J. Äystö,² B. Blank,¹ V.-V. Elomaa,² J. Giovannazzo,¹ U. Hager,²
Kankainen,² P. Karvonen,² T. Kessler,² I. D. Moore,² H. Penttilä,² S. Rahaman,² M. Reponen,²
Rinta-Anttila,² J. Rissanen,² A. Saastamoinen,² T. Sonoda,² and C. Weber⁴
vaires de Bordeaux Gradignan-Université Bordeaux I-UMR 5797 CNRS/IN2P3, Chemin du Solarium,
BP 120, F-33175 Gradignan, France
¹ment of Physics, University of Jyväskylä, P. O. Box 35, FI-40014 Jyväskylä, Finland
²Physics, Oliver Lodge Laboratory, University of Liverpool, Liverpool L69 7ZE, United Kingdom
(Received 26 July 2009; published 8 September 2009)

the branching ratio, and the decay Q value of the superallowed β^+ emitter ⁴²Ti were measured in
formed at the JYFLTRAP facility of the Accelerator Laboratory of the University of Jyväskylä.
at $T_2 = -1$ nucleus for which high-precision measurements of these quantities have been tried.
 $Q = 208.14 \pm 0.45$ (ms) and the Q value [$Q_{EC} = 7016.83(25)$ keV] are close to or reach the
of about 0.1%. The branching ratio for the superallowed decay branch [BR = 47.7(12)%], a
c half-life measurement, does not reach the necessary precision yet. Nonetheless, these results
emine the experimental f value and the corrected F value to be 3114(79) and 3122(79), s.

15RevC.80.035502

PACS number(s): 23.40.Bw, 21.10.Tg, 27.40.+z

ODUCTION

ved nuclear β decays provides
the standard model of particle
 $0^+ \rightarrow 0^+ \beta$ decay between $T = 1$
 $\rightarrow 0$ on the vector part of the weak
to the conserved vector current
imental f value is related to the
a fundamental constant that is

the statistical rate function, f , whereas the half-life and the
branching ratio yield the partial half-life, t .

The aim of the present piece of work is to measure the
half-life of ⁴²Ti and the decay Q value with a precision close
to or better than 0.1%. In addition, the branching ratio for
the superallowed decay is measured with less precision. ⁴²Ti
decays by superallowed β^+ emission to its isobaric analog
state ($J^\pi = 0^+$, $T = 1$), the ground state of ⁴²Sc. Before the
measurement reported here, the accepted value for the half-life

Selected for a Viewpoint in Physics
PHYSICAL REVIEW LETTERS

PRL 105, 202501 (2010)

week ending
12 NOVEMBER 2010

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

A. Algorta,^{1,2,*} D. Jordan,¹ J. L. Tain,¹ B. Rubio,¹ J. Agramunt,¹ A. B. Perez-Cerdan,¹ F. Molina,¹ L. Caballero,¹
E. Nücher,¹ A. Krasznahorkay,² M. D. Hunyadi,² J. Gulyás,² A. Viñe,² M. Csatlós,² L. Csige,² J. Äystö,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-Anttila,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. Peräjärvi⁹

¹IFIC (CSIC-UVn), Valencia, Spain

²Institute of Nuclear Research, Debrecen, Hungary

³University of Jyväskylä, Jyväskylä, Finland

⁴GSI, Darmstadt, Germany

⁵PNPI, Gatchina, Russia

⁶University of Surrey, Guildford, United Kingdom

⁷Tokyo City University, Setagaya-ku, Tokyo, Japan

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(Received 13 May 2010; published 8 November 2010)

The β feeding probability of ¹⁰²Mo, ¹⁰⁵Mo, ¹⁰⁷Tc, ¹⁰⁵Mo, and ¹⁰⁸Nu 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 isotopic purity. Our results solve a significant part of a long-standing discrepancy in
the γ component of the decay heat for ²³⁹Pu in the 4–3000 s range.

DOI: 10.1103/PhysRevLett.105.202501

PACS numbers: 23.40.+z, 27.60.+g, 28.41.Fr, 29.30.Kv

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

C Rodríguez Triguero¹, A M Bruce¹, T Eronen², I D Moore²,
M Bowry³, A M Denis Bacelar⁴, A Y Deo⁵, V.-V. Elomaa², D Gorelov²,
J Hakala², A Jokinen², A Kankainen², P Karvonen², V S Kolhinen²,
J Kurpeta², T Malkiewicz², P J R Mason², H Penttilä², M Reponen²,
S Rinta-Anttila², J Rissanen², A Saastamoinen², G S Simpson²

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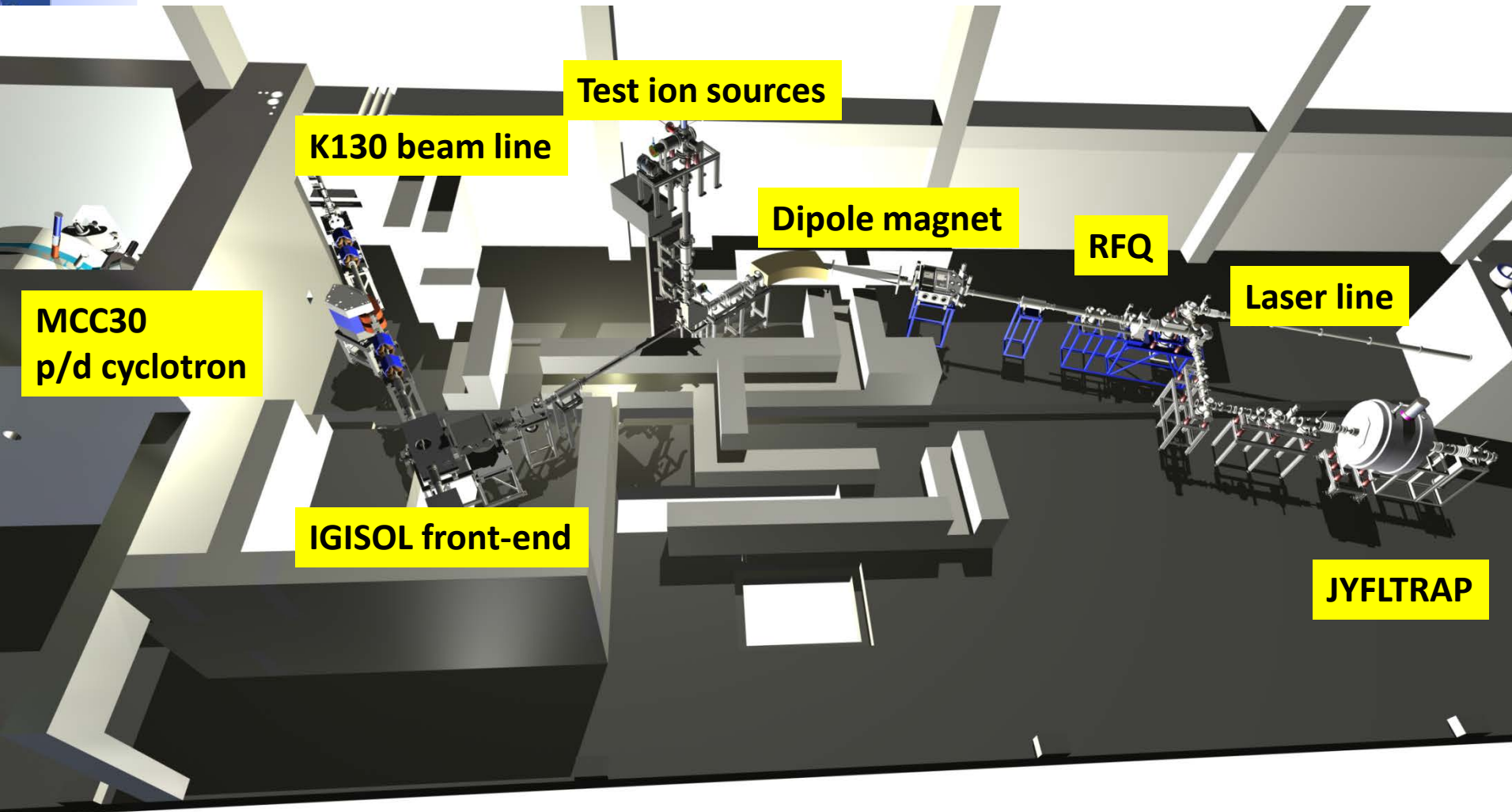
Received 9 May 2011

Published 24 November 2011

IGISOL - 4



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Test ion sources

K130 beam line

Dipole magnet

RFQ

Laser line

MCC30
p/d cyclotron

IGISOL front-end

JYFLTRAP

Gamma/RITU



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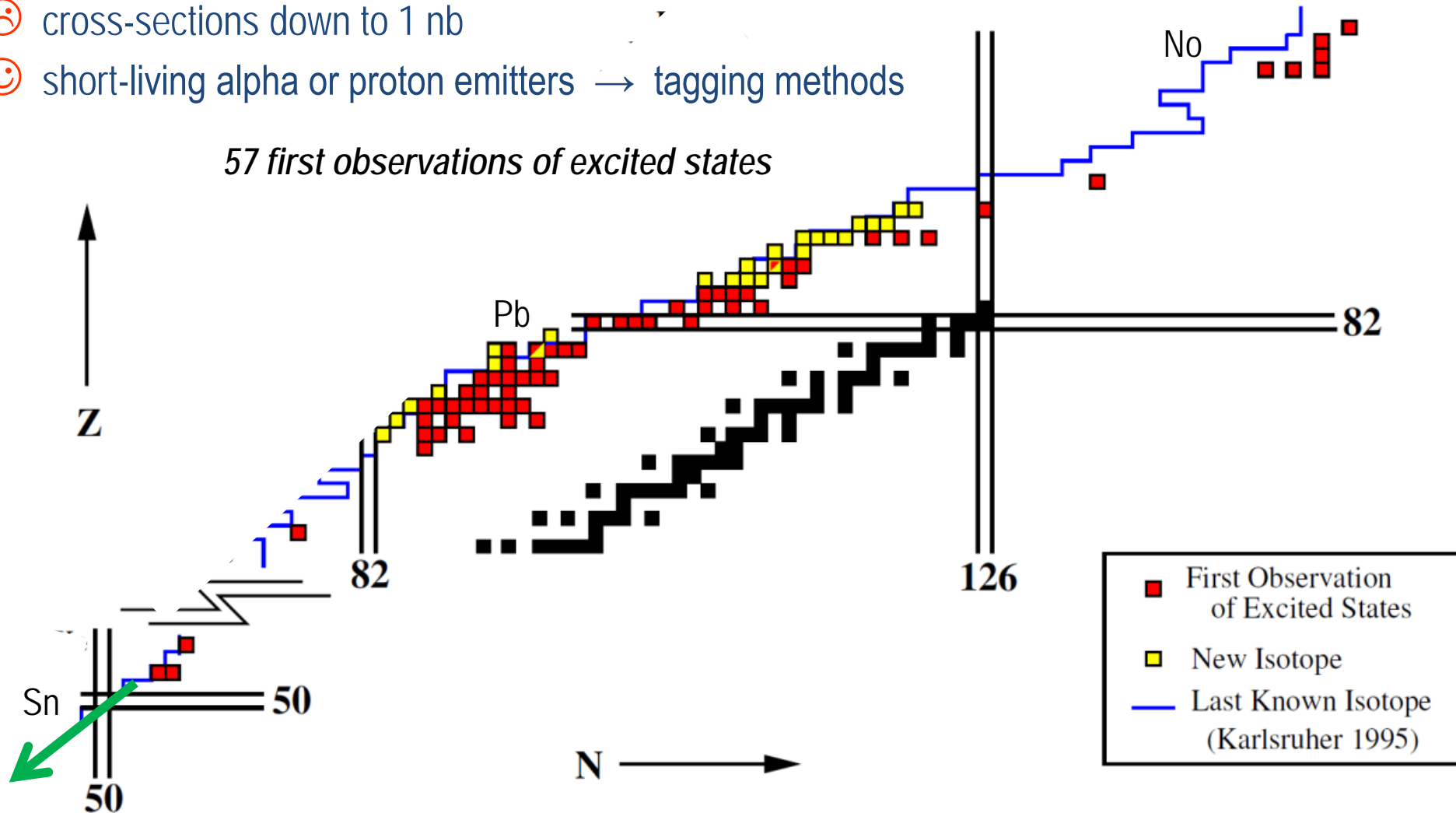


PROBING PROTON-RICH AND HEAVY NUCLEI WITH RECOIL - DECAY - TAGGING (RDT)

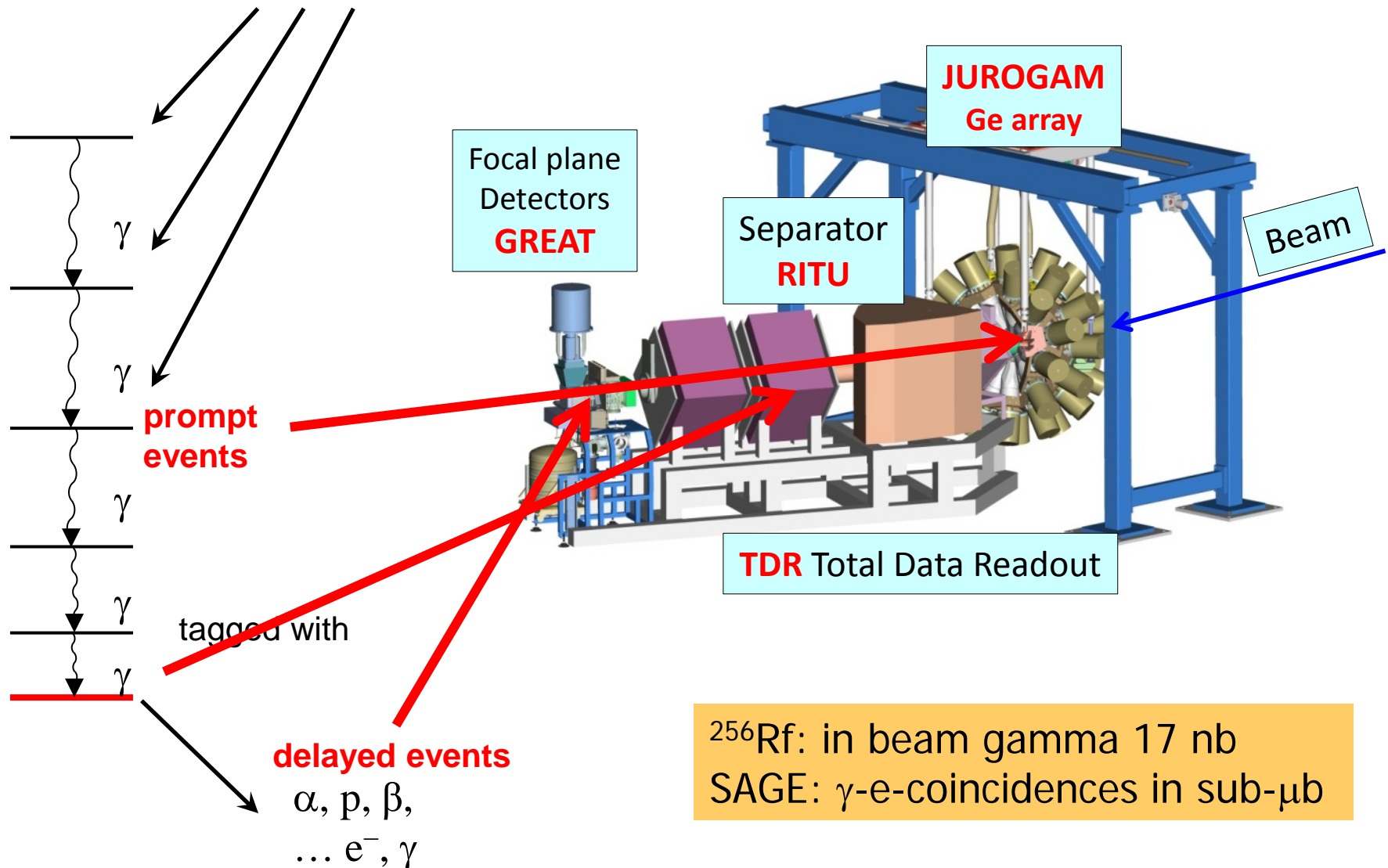
very neutron deficient heavy nuclei

- ☺ 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

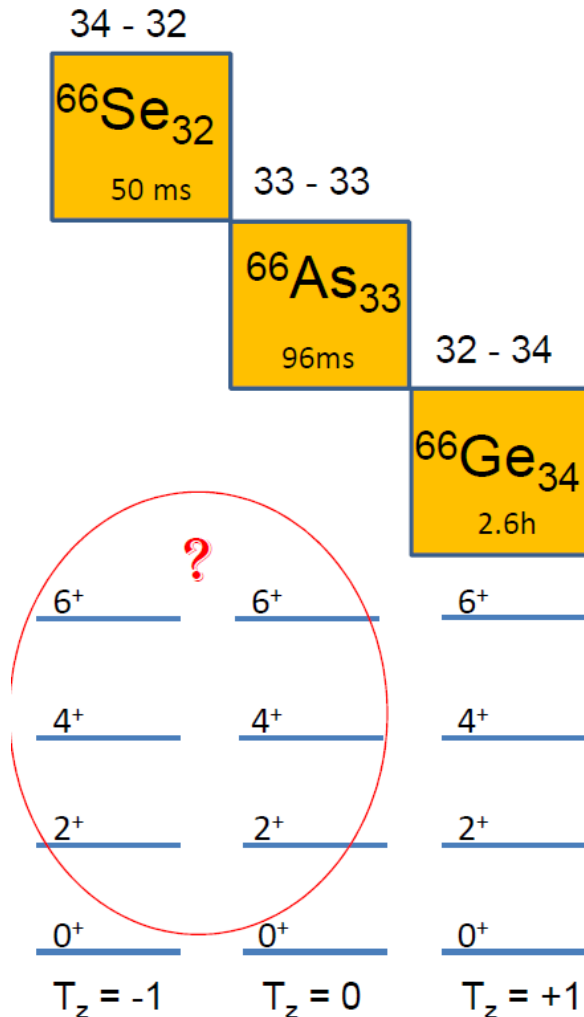


RDT WITH JUROGAM + RITU + GREAT



RECOIL – β – TAGGING

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



$T=1$ bands

MED = Mirror Energy Differences
TED = Triple Energy Differences



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

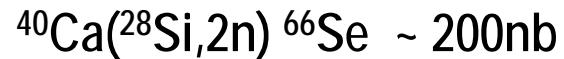


- *Continuous β - spectrum overlapping with those from uninteresting evaporation channels*

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

UoY Tube THE UNIVERSITY of York

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



Se 78.96	Se 64 ?	Se 65 <50 ms	Se 66 33 ms	Se 67 107 ms	Se 68 35.5 s	99
$\alpha 12$	$\beta^+ ?$	$\beta^+ \beta p 3.55$	β^+	$\beta^+ \gamma 352 \beta p$	$\beta^+ \gamma 14; 3; 21; 26$	$\beta^+ \gamma \beta$
33	As 74.92160	As 64 40 ms	As 65 0.19 s	As 66 96 m	As 67 42 s	
	$\alpha 4.0$	β^+	β^+	β^+	$\beta^+ 4.7; 123; 1244$	$\beta^+ \gamma 65$
Ge 61 40 ms	Ge 62 130 ms	Ge 63 95 ms	Ge 64 64 s	Ge 65 31 s	C 60 2.6 s	
$\beta^+ \beta p 3.10$	β^+	β^+	$\beta^+ 3.0; 3.3; 427; 667; 128...$	$\beta^+ 4.6; 5.2; 650; 62; 809; 191; \beta p 1.28...$	$\epsilon \beta^+ 0.7; 1.1; 382; 44; 109; 273...$	$\beta^+ \gamma$
Ga 60 70 ms	Ga 61 168 ms	Ga 62 115.99 ms	Ga 63 31.4 s	Ga 64 2.62 m	Ga 65 15 m	



UoY Tube

96 20 x 20 mm CsI crystals

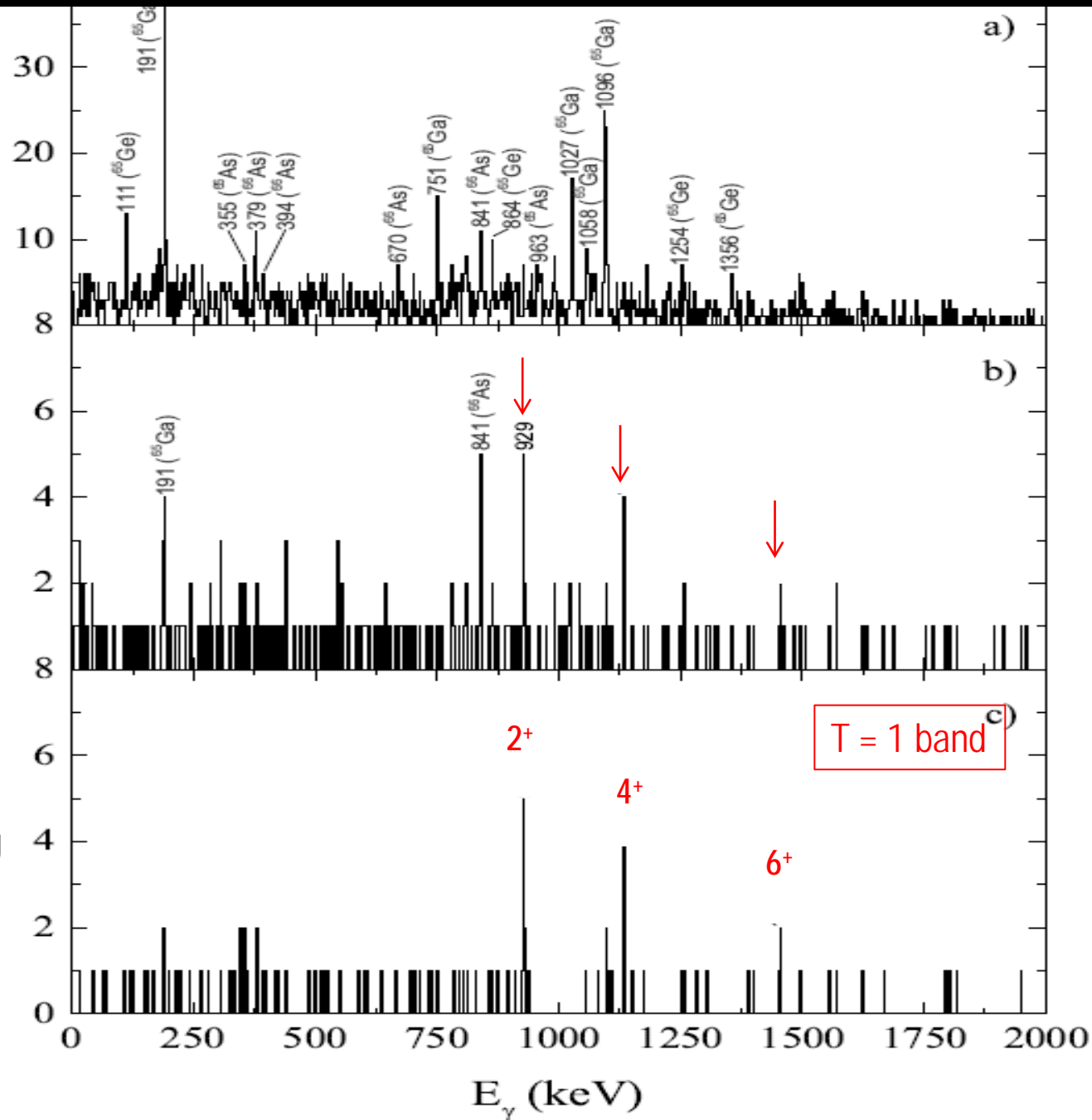


^{66}Se ($Z = 32$, $N = 34$)

γ -rays from $^{66}\text{Se}_{32}$ tagged
with its 50ms β decay

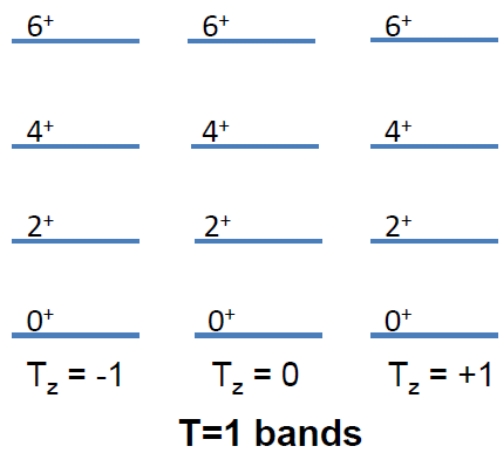
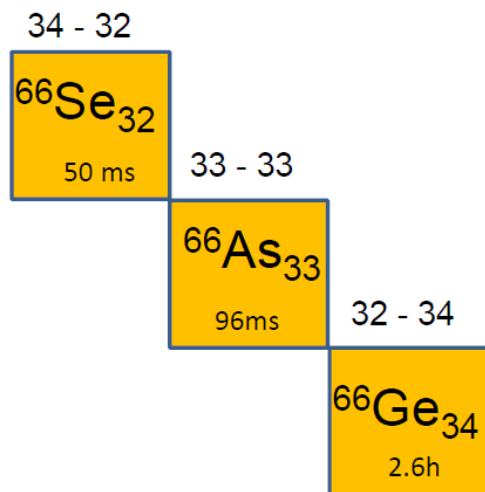
+ UoY Tube veto

+ ^{66}As isomer veto-tagging

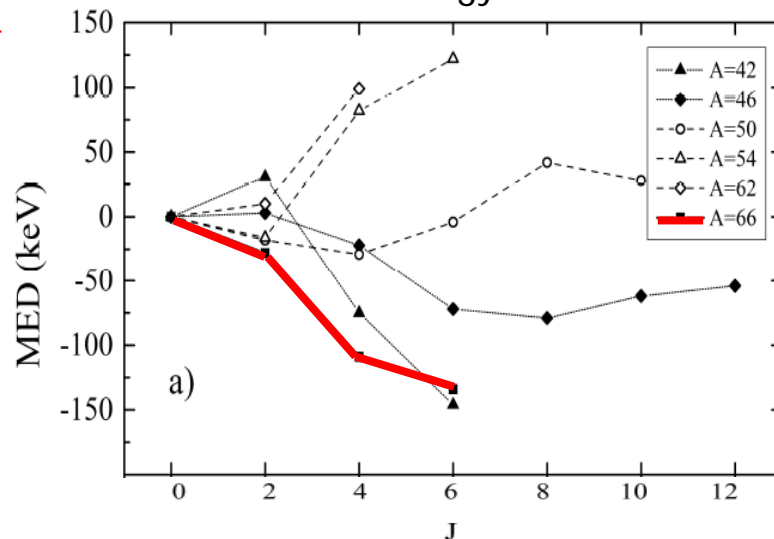


MED AND TED

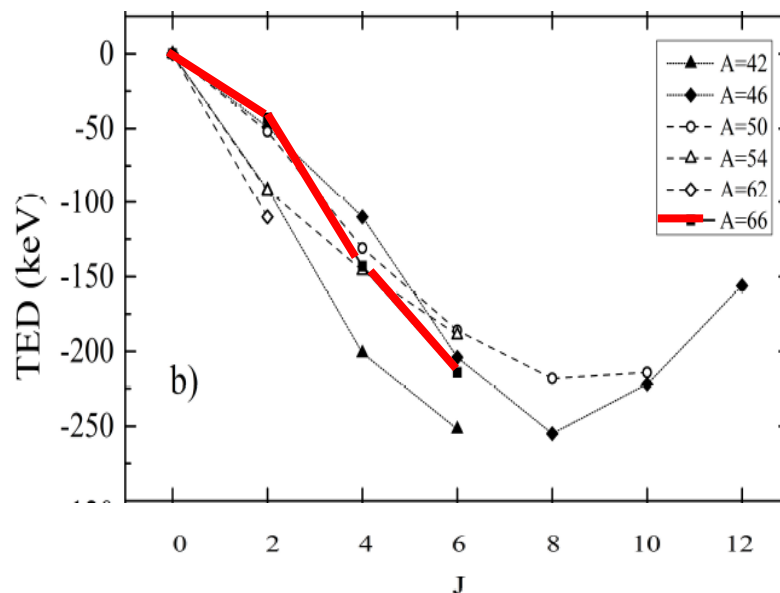
A=66 is the heaviest triplet of T = 1 bands up to 6+



MED=Mirror Energy Differences



TED=Triple 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=

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

$$V = V_{pp} + V_{nn} - 2V_{pn}$$

Charge independence

Single-particle effects cancel out

TED behaviour ?

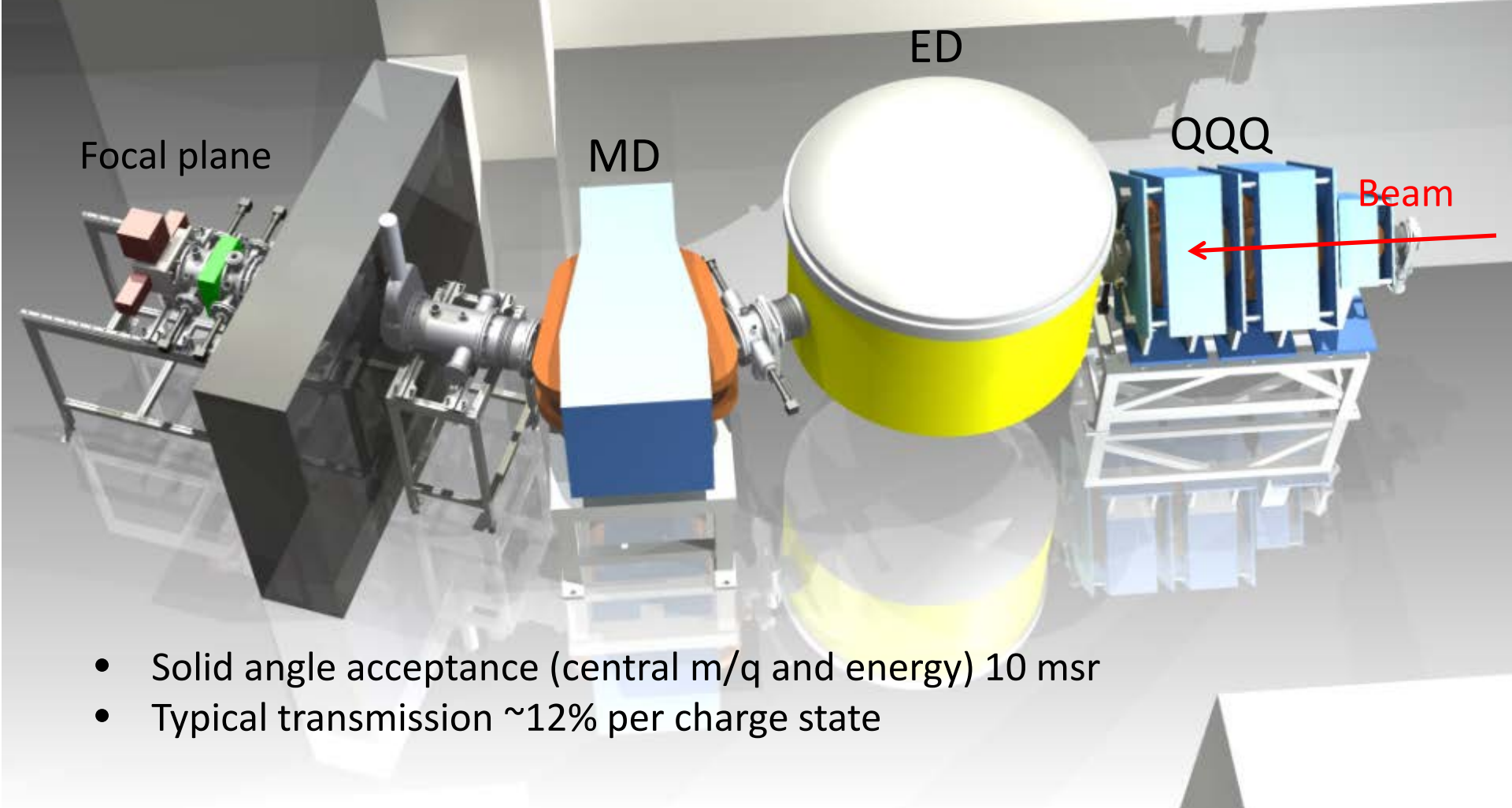
→ exp's

→ 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 $\sim 12\%$ per charge state

Pelletron

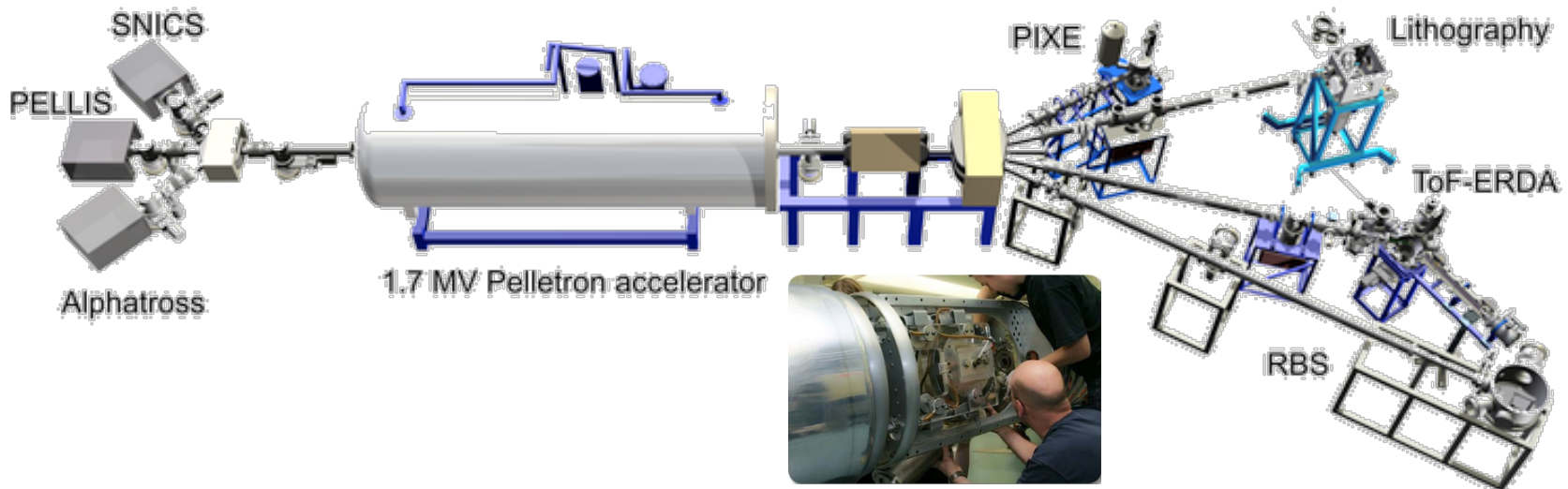


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Materials physics at Pelletron laboratory

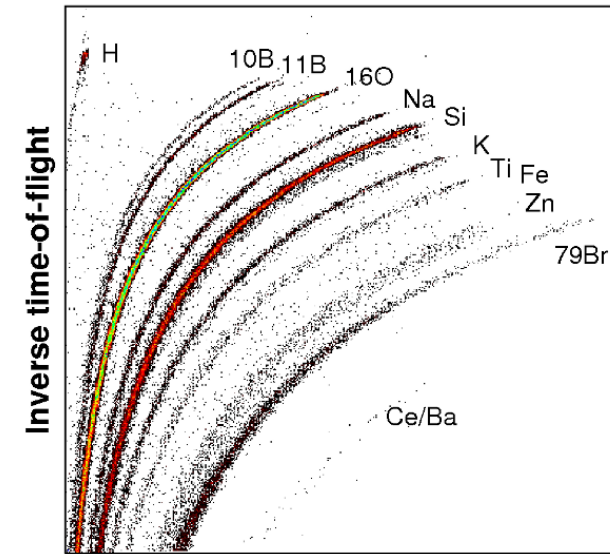
- Main research fields
 - Fundamental ion-matter interactions (cross sections, stopping forces, straggling)
 - Ion beam analysis (IBA) for thin film samples
 - Development of IBA techniques (detectors, data acquisition, simulations)
 - Thin film processing (ALD, proton beam writing, irradiation)
 - Materials 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-ERDA, 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

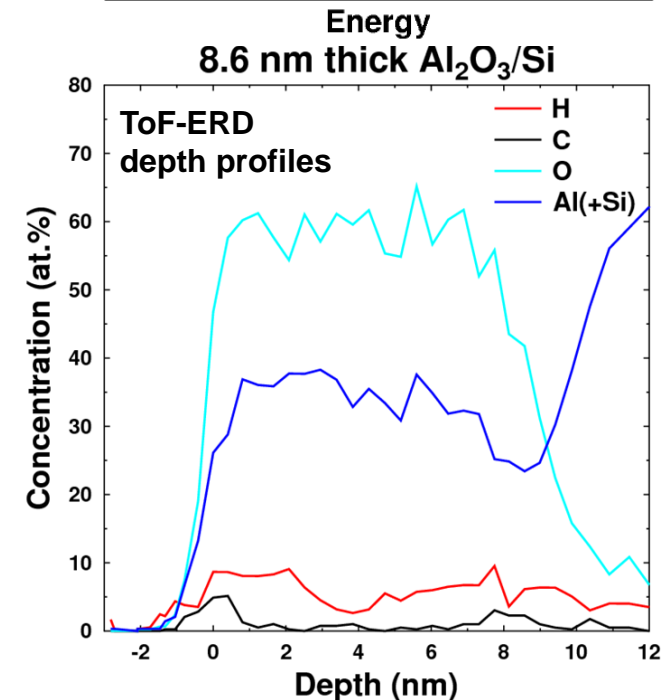
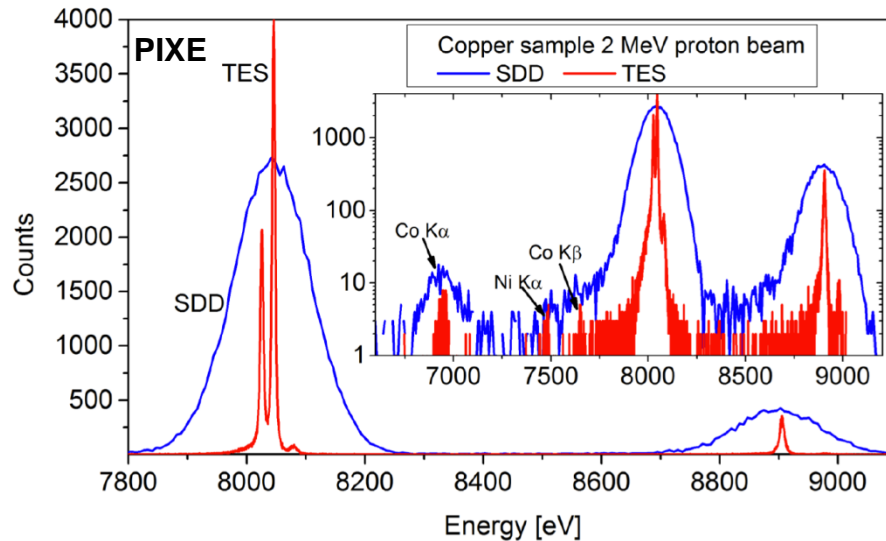
■ ToF-ERD (Time-of-flight Elastic Recoil Detection)

- 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 performance and detection of low energy signals



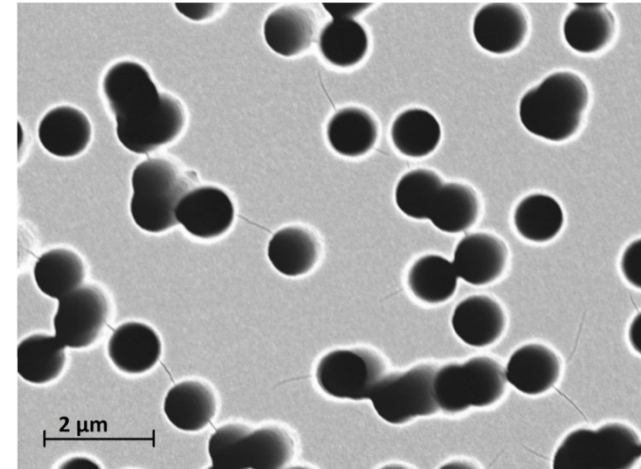
■ PIXE (Particle Induced X-ray Emission)

- High sensitivity (ppm) for elements heavier than Al, no depth information
- Superconductive transition edge sensor (TES) with 3 eV resolution @ 5.9 keV

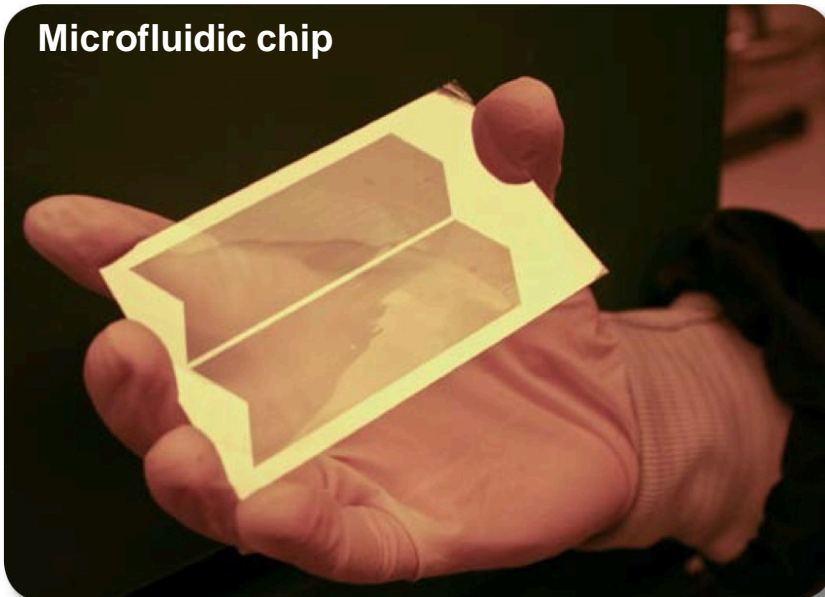


Thin films processing and applications

- 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



Microfluidic chip



ALD tool



Commercial activity



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**for
space, microfilter and
medical industry**



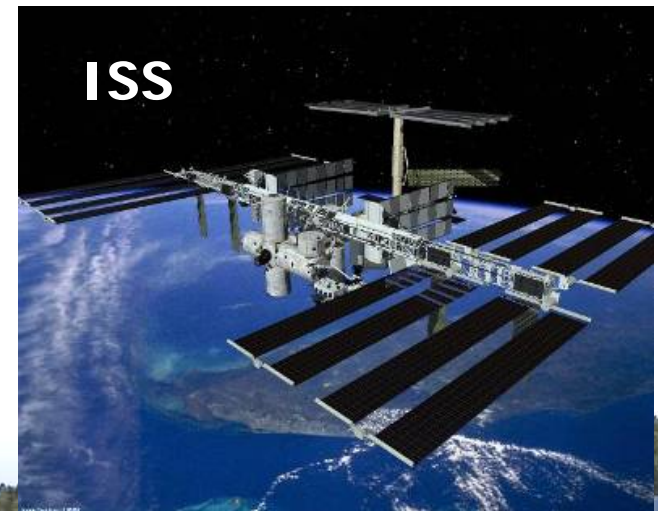
RADEF; test laboratory of ESA since 2005

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...



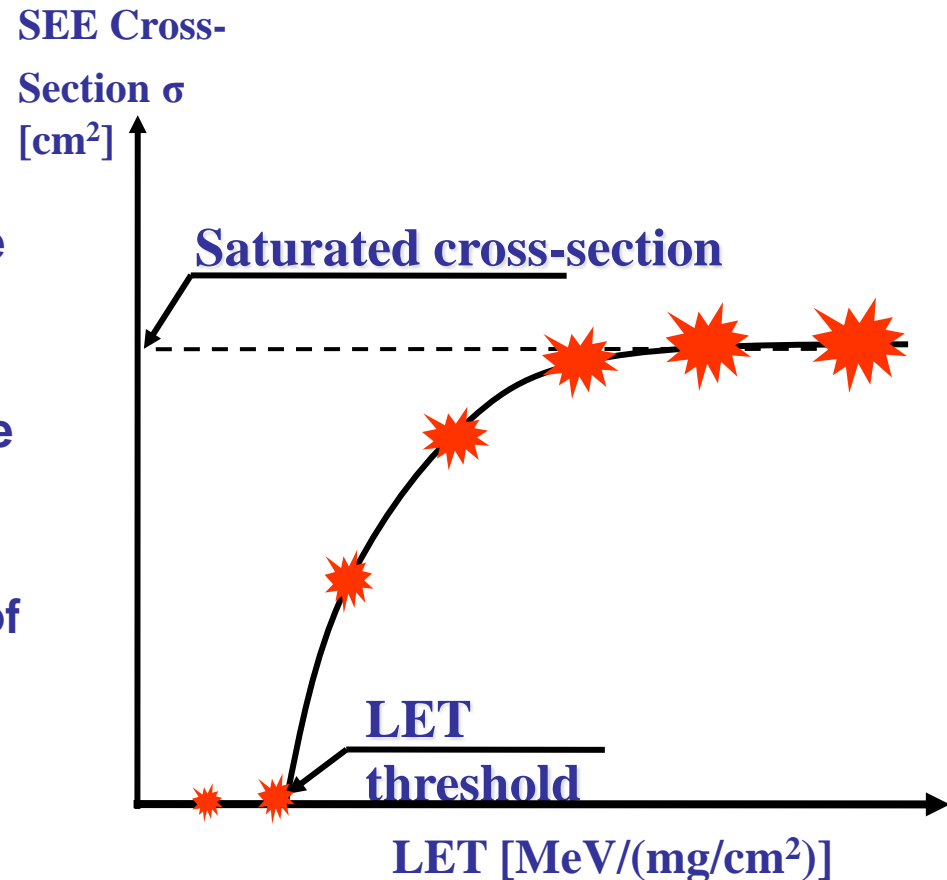
How do we test?

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



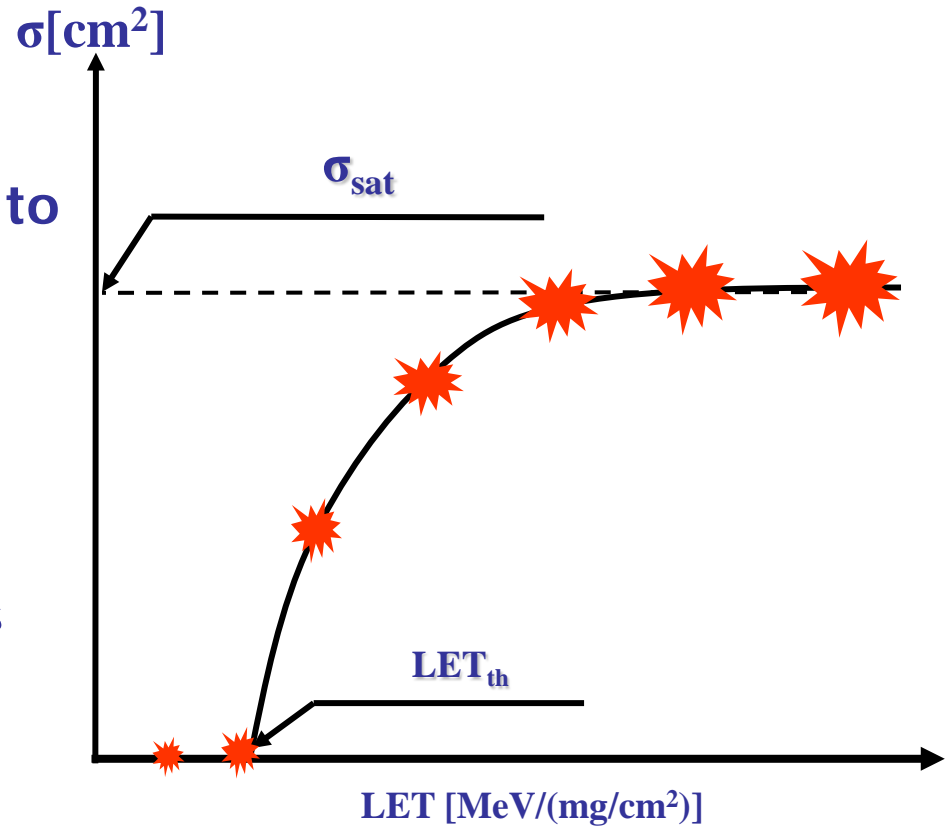
Two major problems

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.* $LET \sim 60 \text{ MeV}\cdot\text{cm}^2/\text{mg}$

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

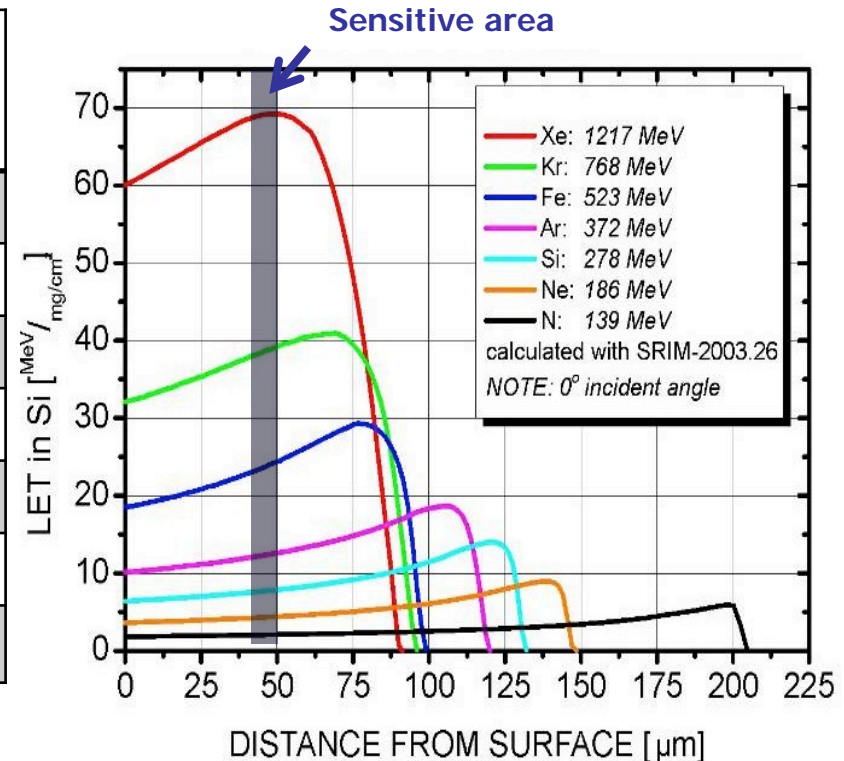


Solution: Ion cocktail 9.3·A MeV



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A Ion ^{q+} q/A ≈ 0.27	E [MeV]	Range [μm]	LET @surface [MeV·cm ² /mg]	LET @bragg [MeV·cm ² /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

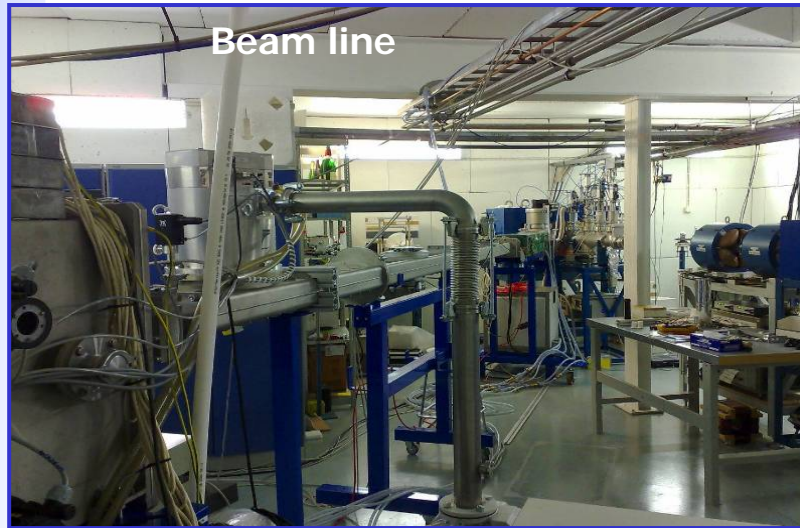


1. LET > 60 MeV/(mg/cm²)
2. Fast ion change with 7 ions
3. Bragg peak behind 50μm in silicon → this cocktail allows backside irradiation and do it also in air

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



Irradiation of polymer films

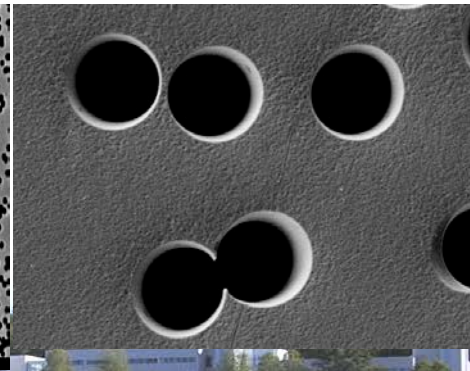
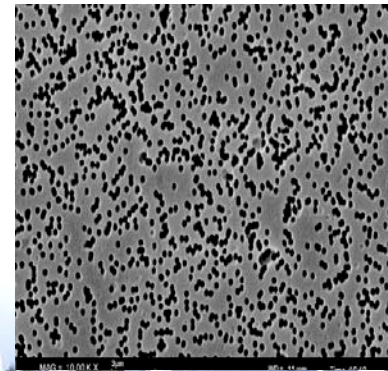
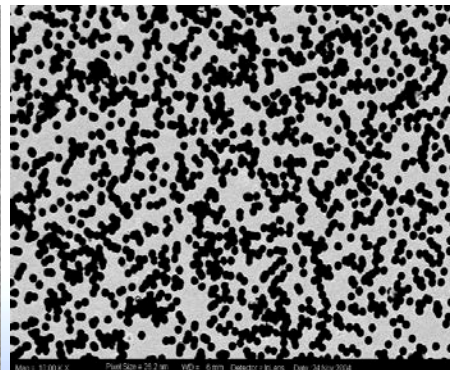
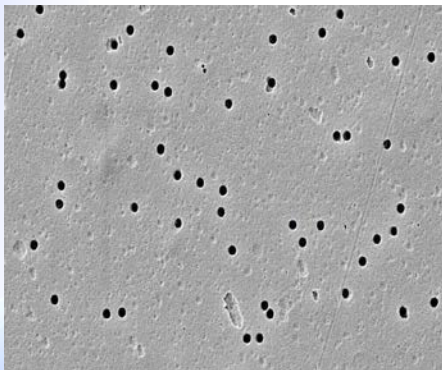


to
etching
→



10^5 pores / cm^2 → 10^9 pores / cm^2

$0.1 \mu\text{m}$ → $10 \mu\text{m}$



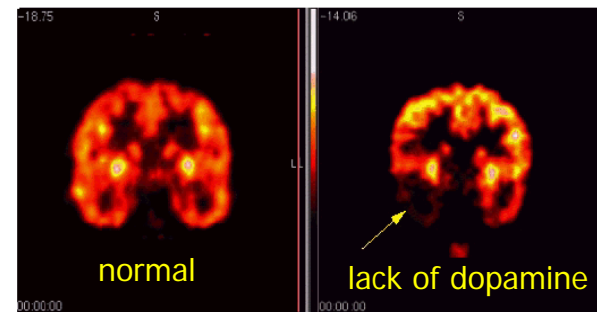
Production of radiopharmaceuticals

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

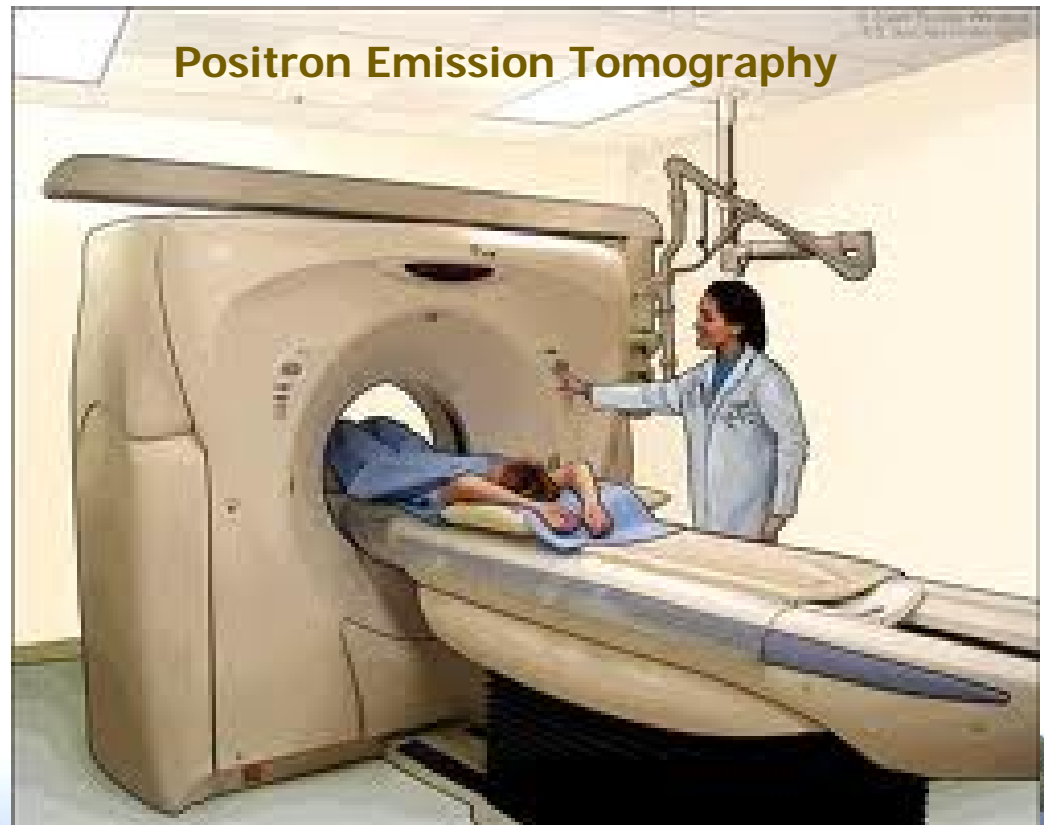
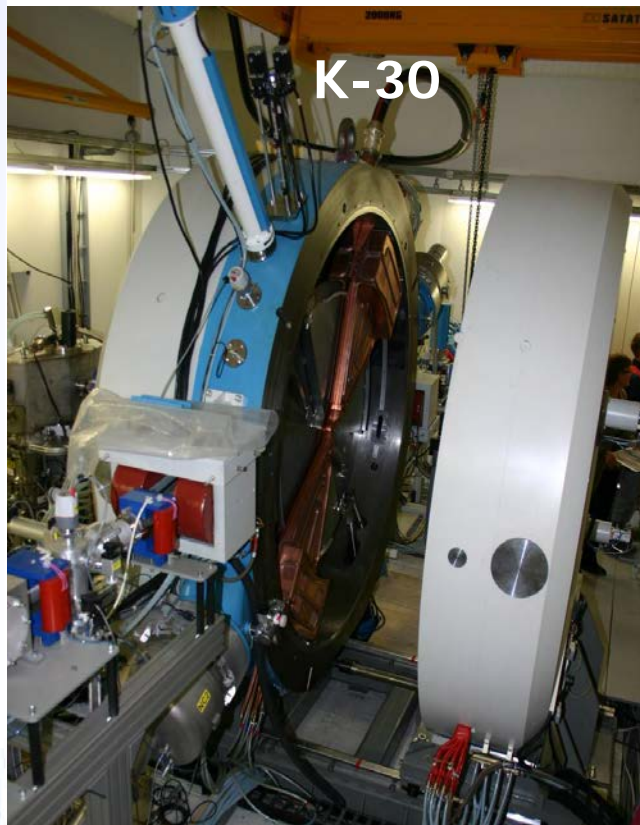


SPECT= Single Photon Emission Computer Tomography



Plans for the K-30 cyclotron

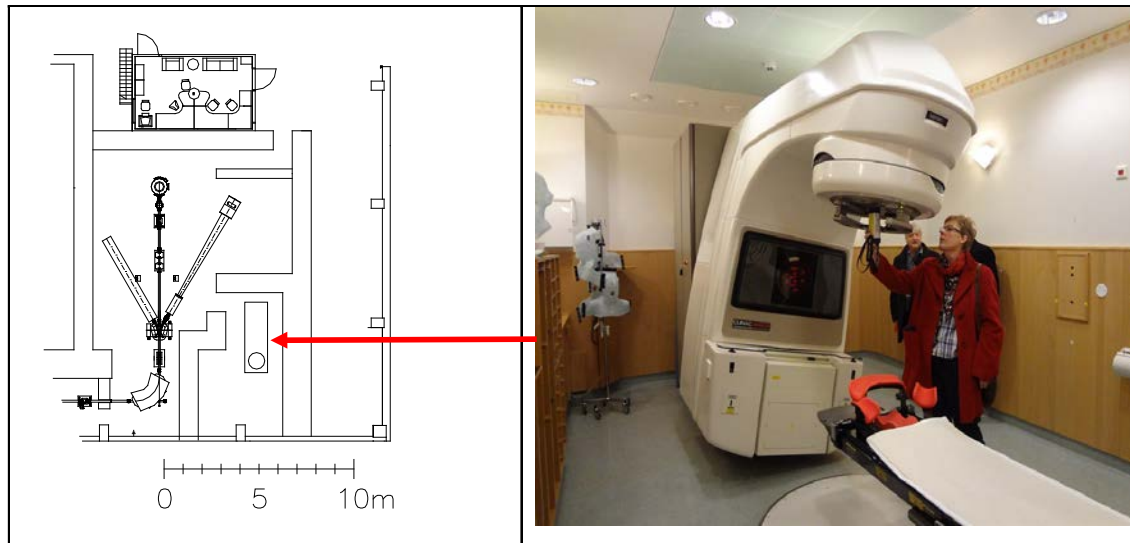
Start 18-Fluorine (β^+ -emitter with $T_{1/2}=110$ min!) production?
Used for early stage diagnosis of cancer with PET camera



The latest update at RADEF

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



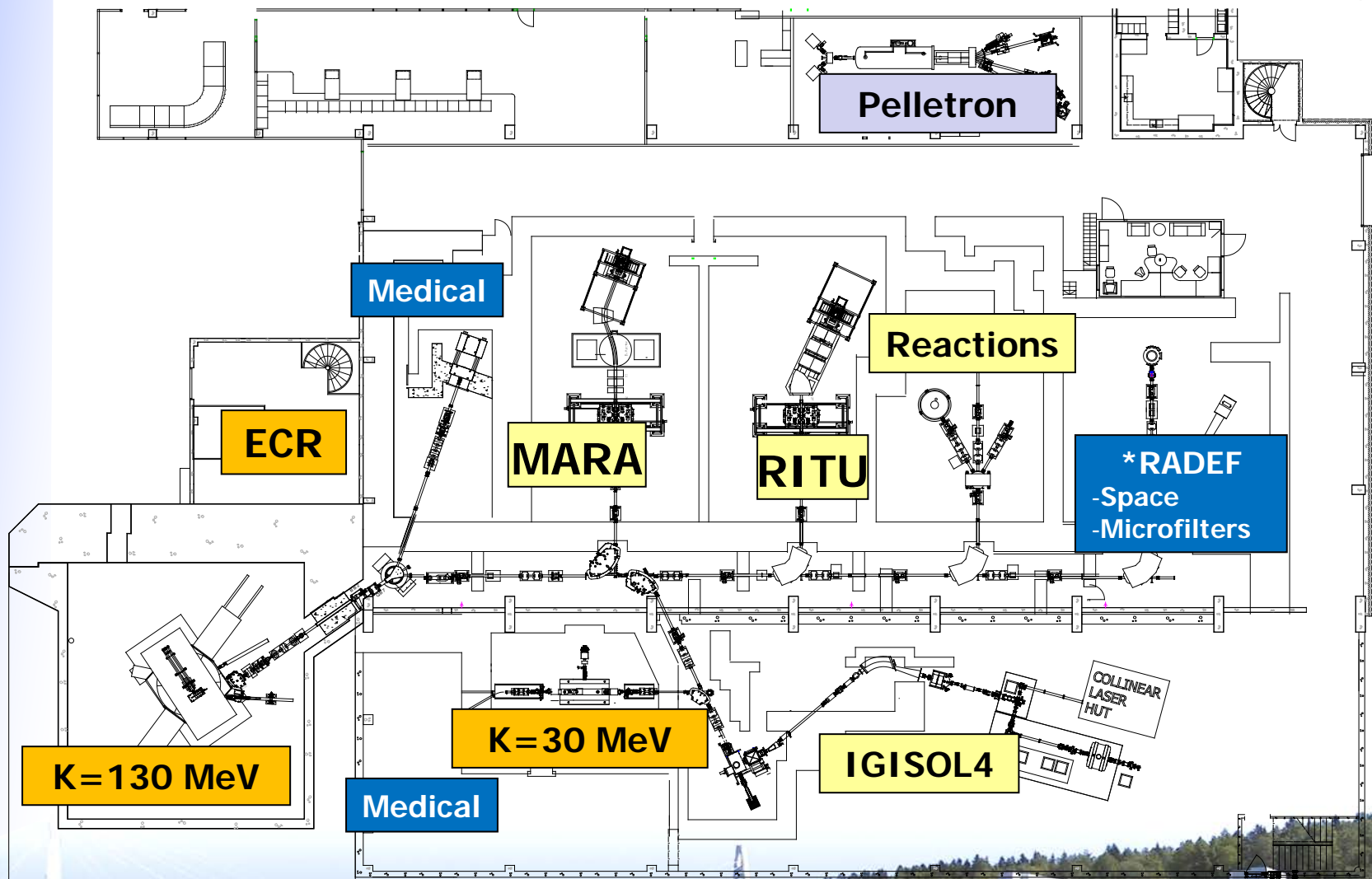
- Will be used for irradiation studies of semiconductor materials and devices
- Especially foreseen is the next large-scale satellite mission of ESA, JUICE = Jupiter Icy moon Explorer, aimed to be launched in 2022
- The data from previous missions indicate extremely severe electron fluxes and x-ray doses



Accelerator laboratory today



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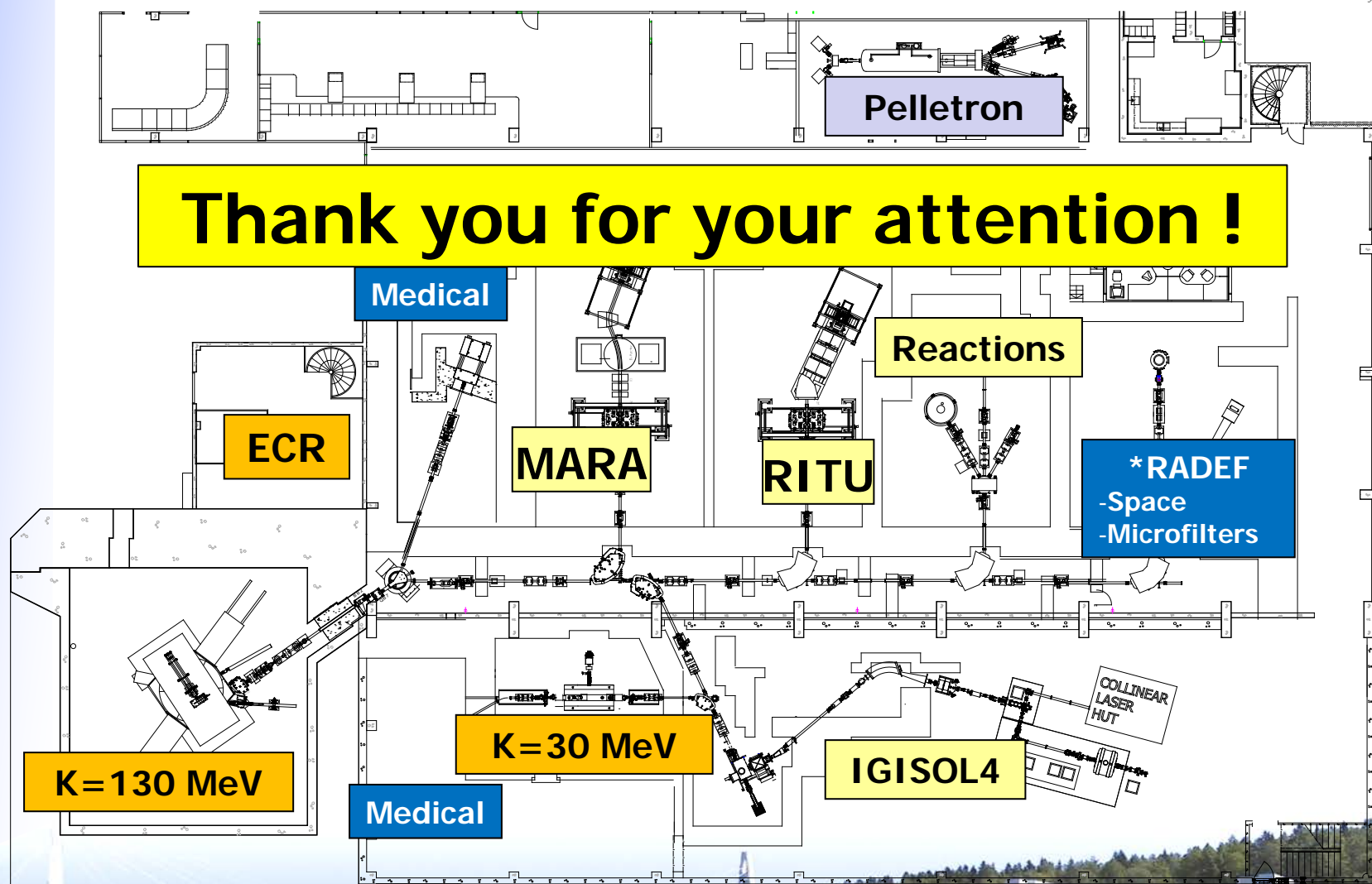
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Accelerator laboratory today



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Thank you for your attention !



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