Nuclear physics at JYFL-ACCLAB, NUSTAR-FAIR and ISOLDE-CERN

Ari Jokinen

"Nuorison parasta tässä harrastetaan"

Seinäteksti Jyväskylän yliopiston vanhassa juhlasalissa (1882)

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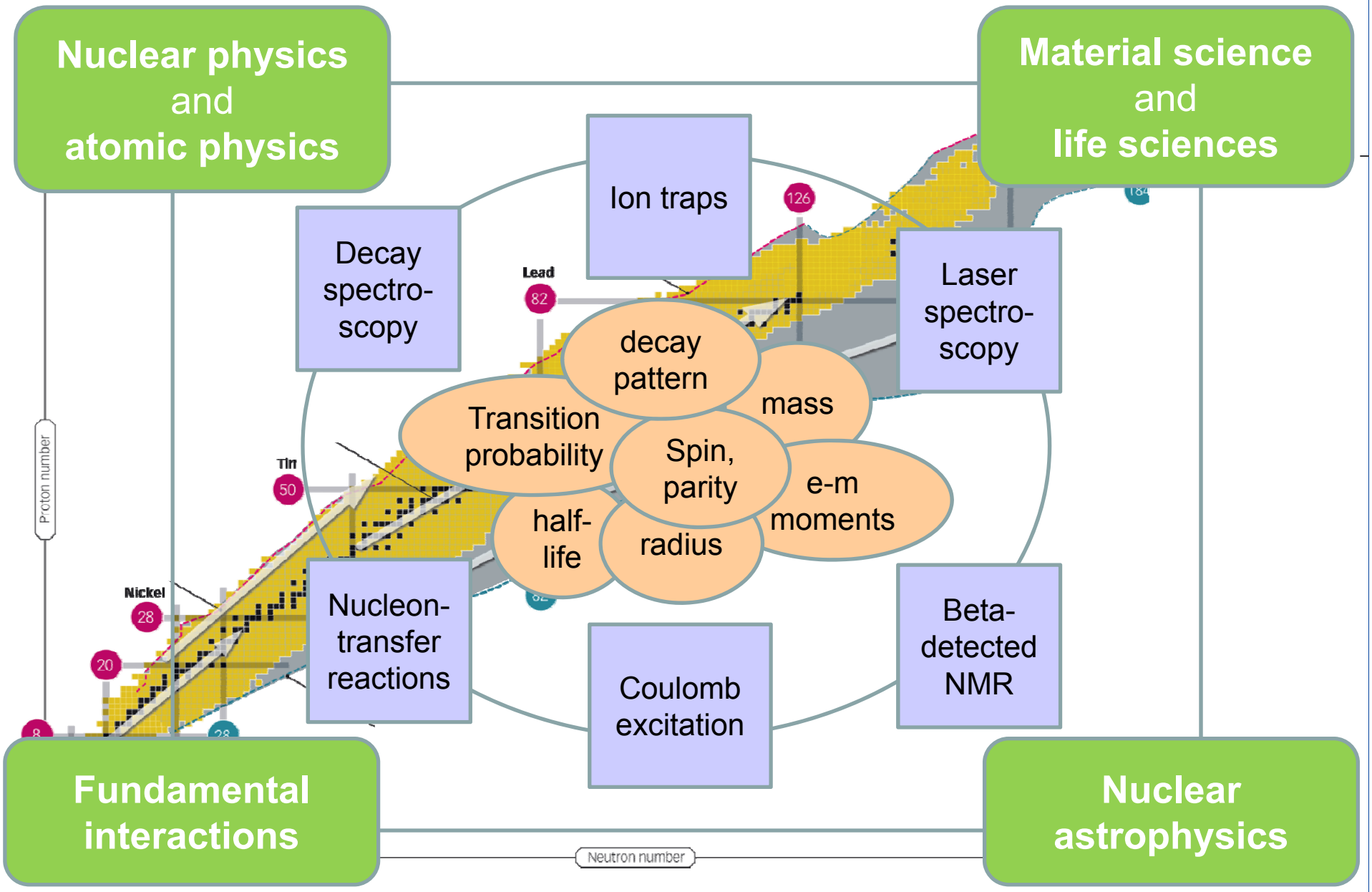
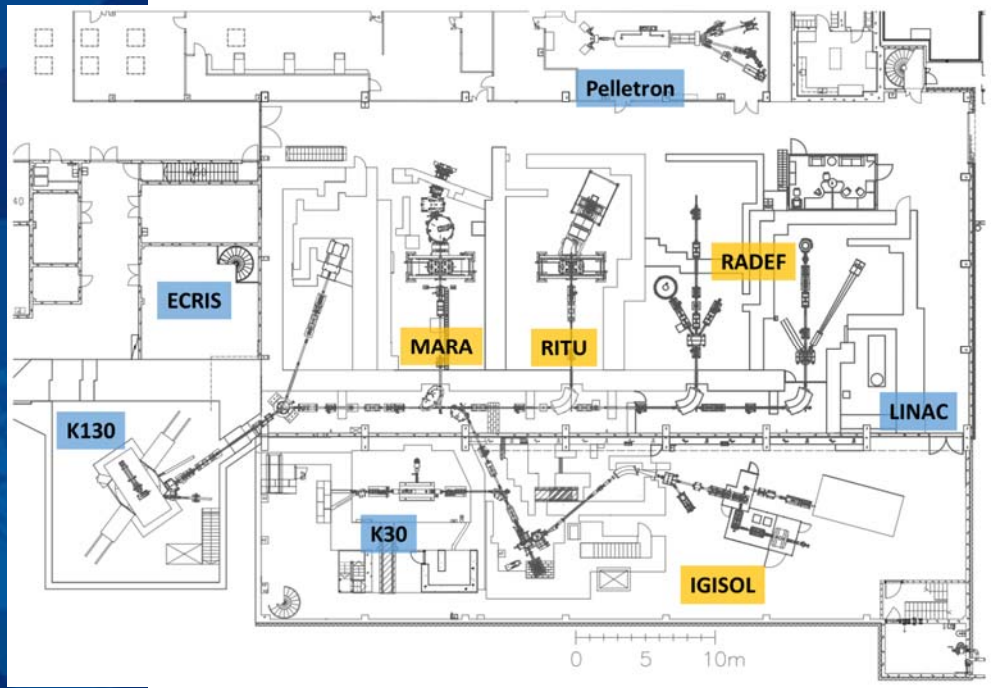
Research with radioactive nuclides



JYFL-ACCLAB

Physics-driven international research infrastructure

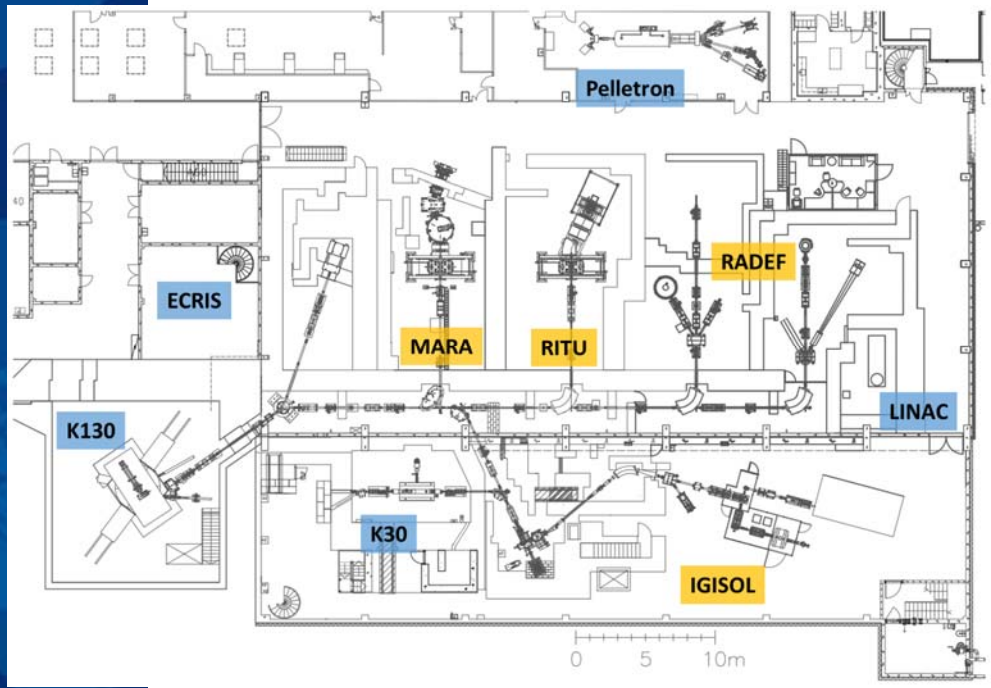


BASIC INSTRUMENTATION

- **Four accelerators** serving international users for basic research, applications and commercial services:
  - K130 heavy ion cyclotron (+ three ECR ion sources and light ion source) (1992)
  - 1.7 MV Pelletron for ion beam analysis and modification of materials (2007)
  - K30 light ion cyclotron (2012)
  - Electron LINAC (2015)
- 2000 m^2 of laboratory space
- International instrumentation worth of 10+ M€

JYFL-ACCLAB

Physics-driven international research infrastructure



STATUS:

- Integral part of the **Department of Physics (JYFL)**
- **EU access laboratory** (FP4→Horizon2020)
- More than **250 foreign users** annually
- One of the three recognized test laboratories of **European Space Agency (ESA)** since 2005
- In the **2014-2020 roadmap** of research infrastructure in Finland → access to **FIRI-funding** → important upgrades and investments for the future research and operation
- **Center of Excellence** of the Academy of Finland 2012-2017 (application for 2018-2025)
- National collaborations:
  - Nanoscience Center in the University of Jyväskylä
  - Detector Laboratory of Helsinki Institute of Physics
  - CSC: IT Center for Science
  - STUK: Finnish radiation safety authority
- International:
  - CERN (ISOLDE)
  - FAIF (NUSTAR)

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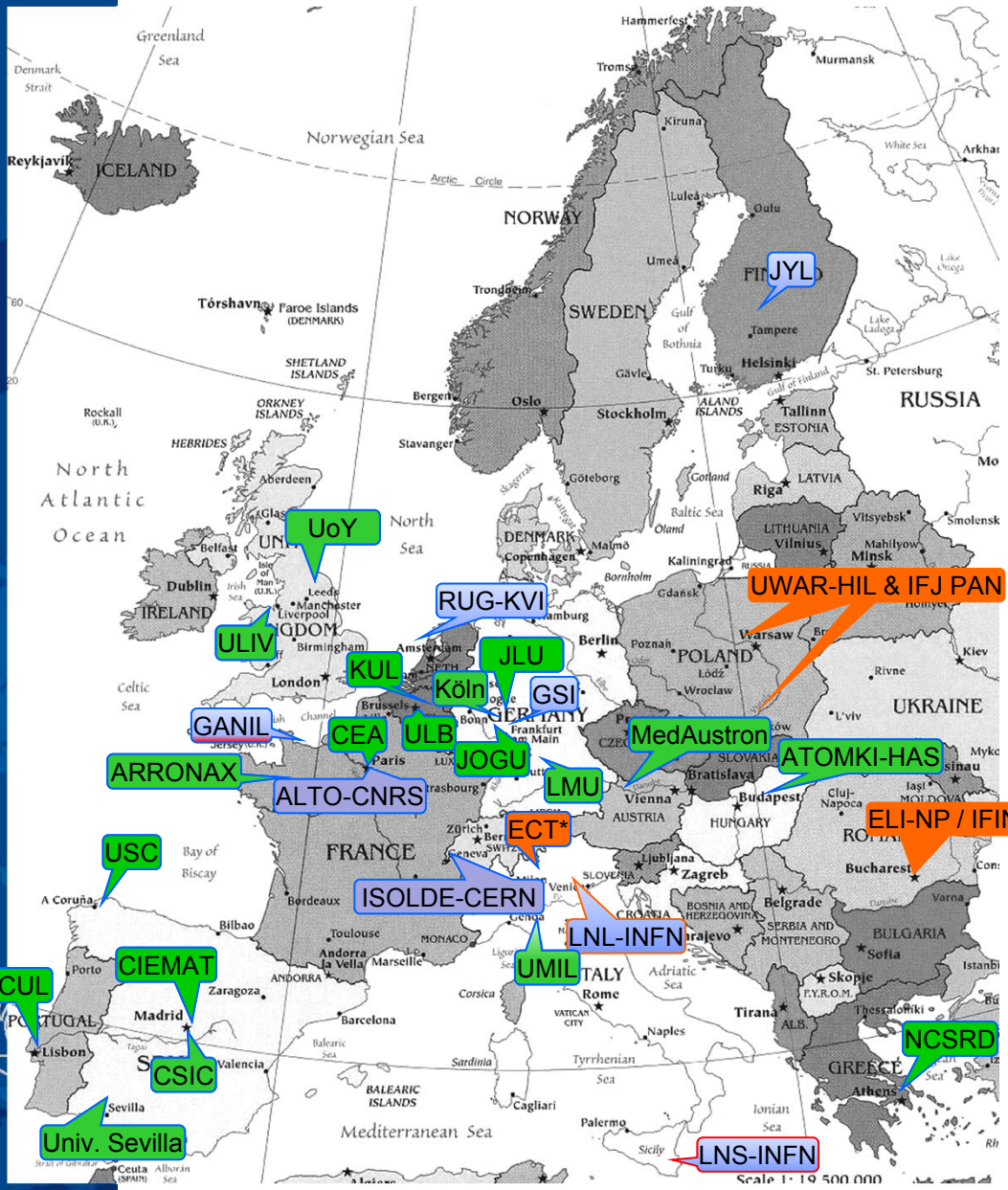
Map of European facilities



European Nuclear Science and Applications Research – 2

1.3.2016 - 1.3.2020

10 TNA Facilities

30 beneficiaries
15 countries

Community: 2700-3000 scientists and highly qualified engineers

ENSAR2 is funded by the European Commission within its HORIZON2020 Programme under the specific programme 'Infrastructures'.

Active participation in EU-projects

- CHANDA “CHAllenges in Nuclear DAta for the Safety of European Nuclear Facilities” (2013 – 2017) (H. Penttilä)
- NuClock (2015-2017): Horizon 2020 FET-OPEN (I. Moore)
- ENSAR2 (2016-2019) HORIZON 2020 (A. Jokinen, I. Moore, H. Koivisto, C. Scholey)
- EURISOL-DF proposal (A. Jokinen, I. Moore) 2017-
- RADSAGA is an Innovative Training Network under the Marie Skłodowska-Curie Actions (A. Virtanen)
- “COST Action ChETEC “Chemical Elements as Tracers of the Evolution of the Cosmos” (http://www.cost.eu/media/newsroom/cost-network-to-trace-evolution-universe and http://www.cost.eu/COST_Actions/ca/CA16117) (A. Kankainen)
- This European Researchers' Night project is funded by the European Commission under the Marie Skłodowska-Curie actions under contract number 722854 (Janne Pakarinen, Philippos Papadakis)

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K130 heavy ion cyclotron

K130

p – Au beams
E = 130 x Q^2/A MeV

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

2014-2017 upgrade:
18 GHz ECR ”HIISI”

Program Advisory Committee

PAC meeting twice a year following fixed deadlines of proposals (15.3. and 15.9.)

- Michael Bender (Université de Bordeaux)
- Jon Billowes (University of Manchester)
- Bertram Blank (CEN Bordeaux-Gradignan) (Chair)
- Bo Cederwall (KTH Stockholm)
- Fadi Ibrahim (IPN Orsay)
- Silvia Lenzi (University of Padova)

- Mikael Sandzelius, Scientific Secretary (JYFL)

- Paul Greenlees (JYFL)
- Ari Jokinen (JYFL)

PAC statistics 2006-2015

Requested days	2833
Given days	2026
Success rate	71,5%
No. of proposals	389
Average number of proposals	17
Average number of pending days	383 (15.3.2017 323 days)

March 2017 PAC:
23 exp's, of which 20 includes international collaboration
232 days requested altogether

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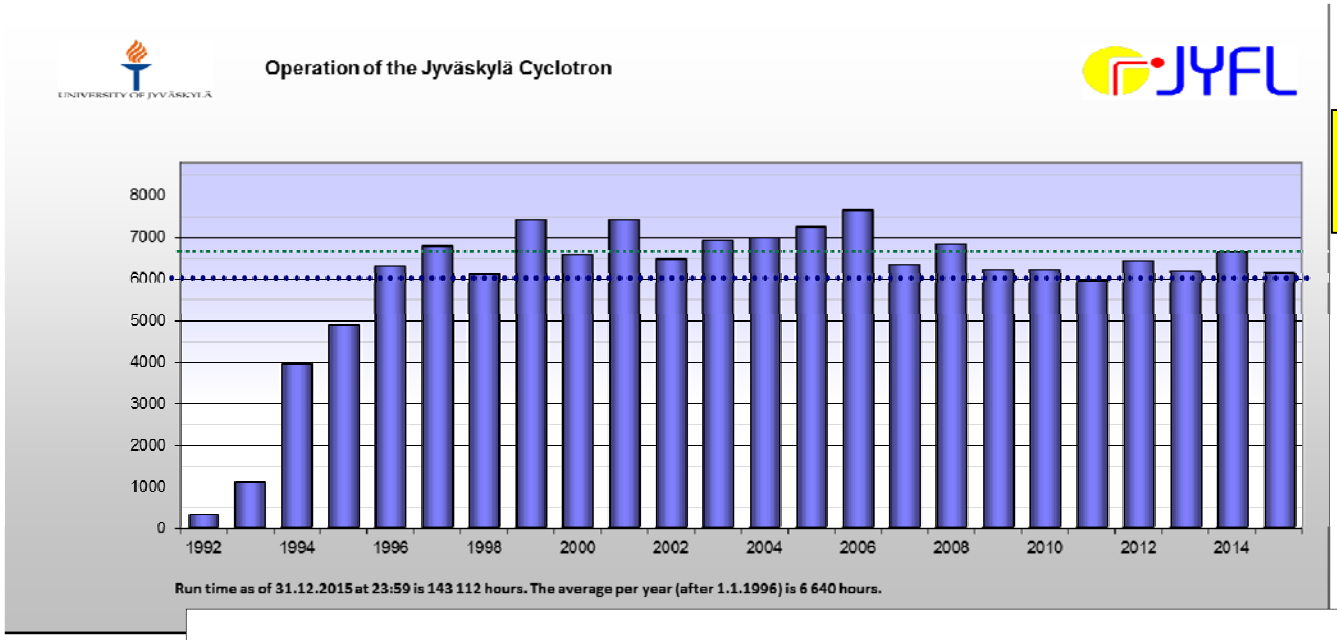
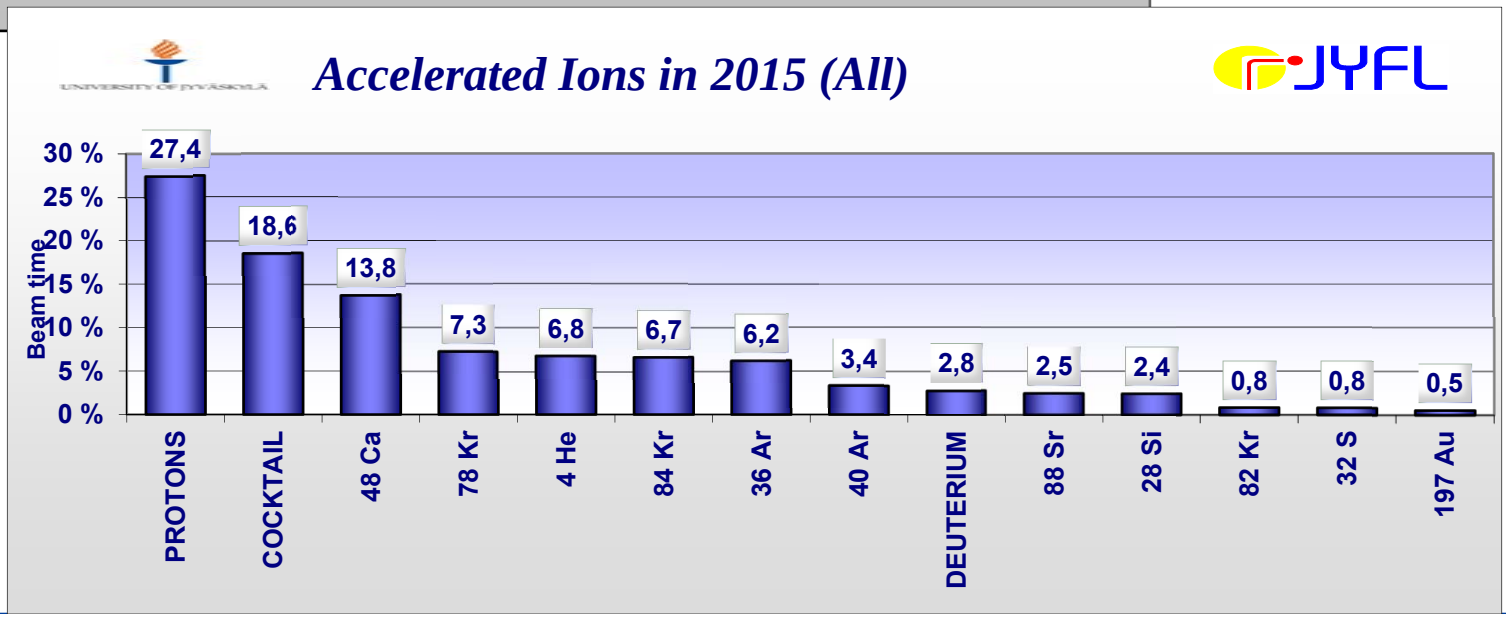
Operation of K130



2015:
6135 h



Human resources

CoE:	**N (Int.)**	
Professors	6 (2)	
Senior researchers	17 (3)	
Post doctoral researchers	9 (5)	
Graduate students	27 (8)	
Technical staff	2	
	61 (18)	(30%)

JYFL-ACCLAB (accelerator and technical staff):

Senior researchers	4
Post doctoral researchers	1
Graduate students	4
Technical staff	17
	26

+ 250 foreign users annually

Training and career development

Status:

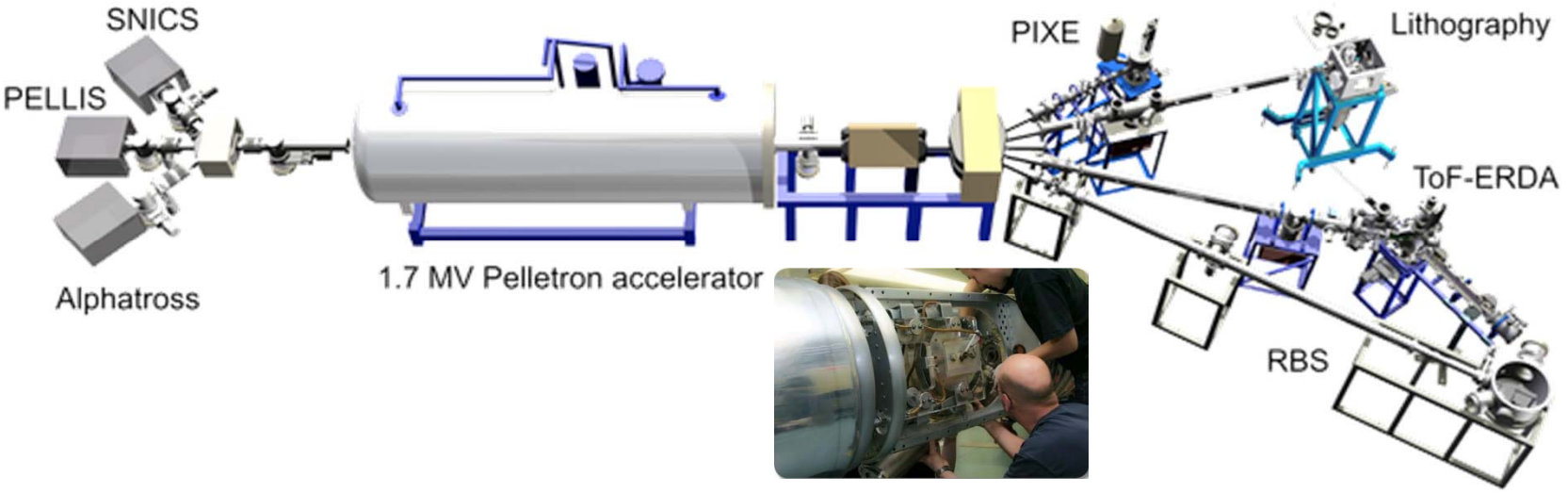
- 28 PhD's in 2009-2013
- 27 PhD's in other universities in 2008-2012 based on data obtained at JYFL-ACCLAB
- Presently 27 PhD students

Added value for researcher training:

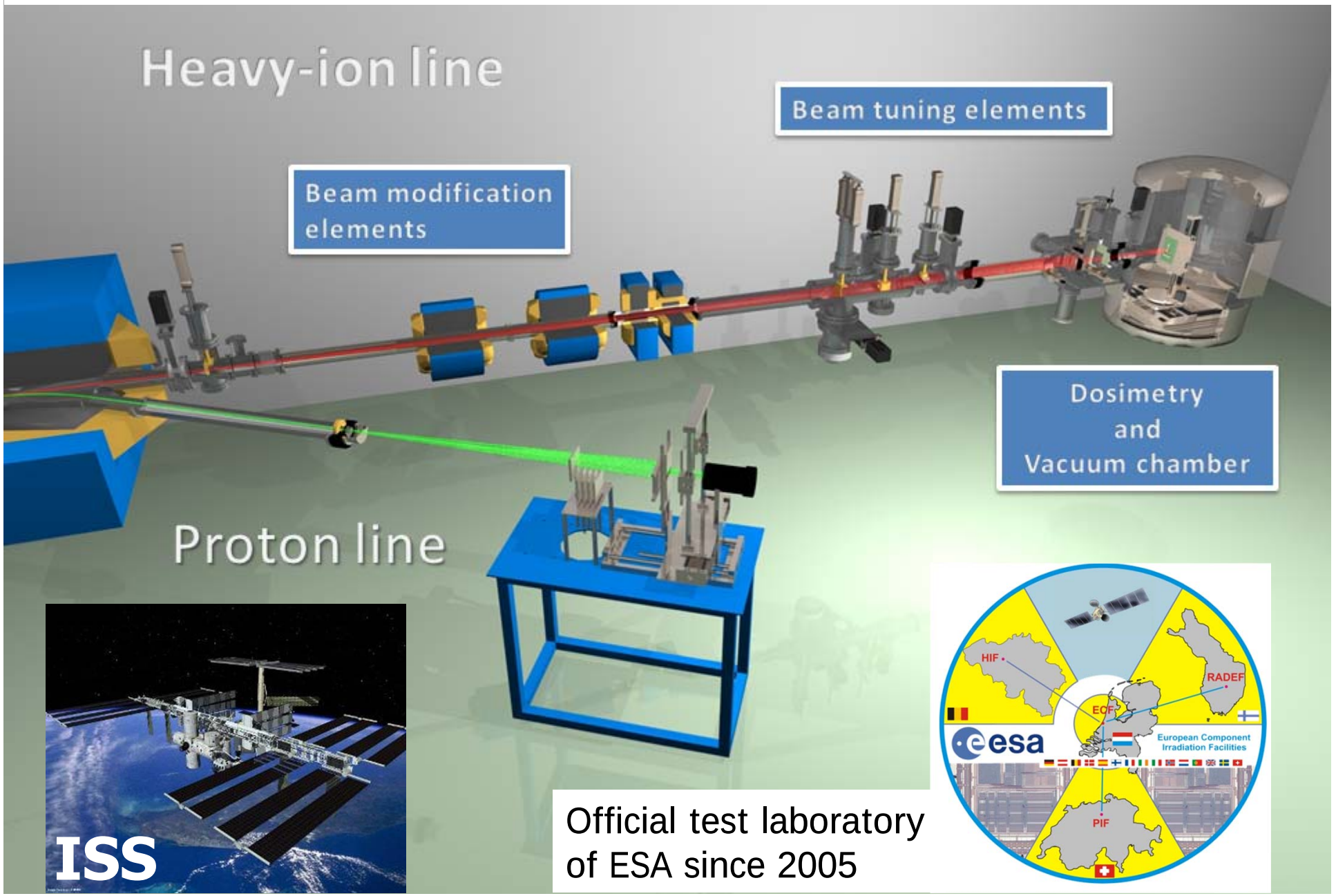
- International, multidisciplinary research environment
- Project management skills
- Better competitiviness of our PhD's in competition of post-doctoral and academic positions

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
  - Helium Ion Microscope



RADiation Effects Facility RADEF



Official test laboratory of ESA since 2005

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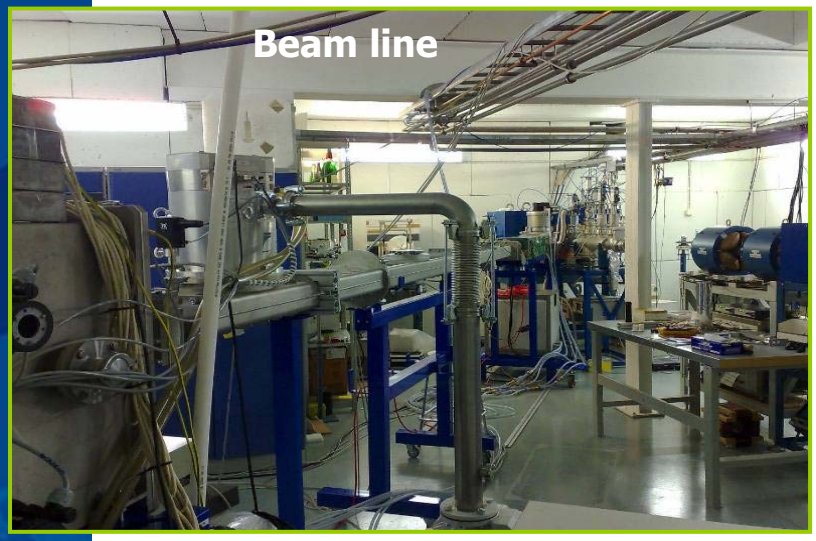
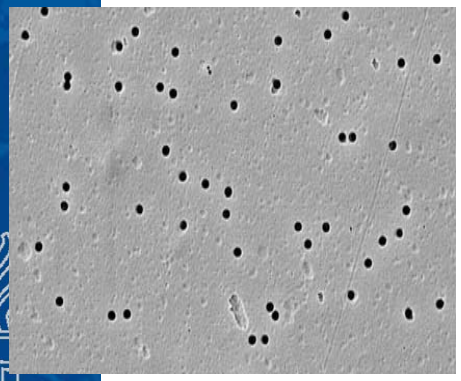
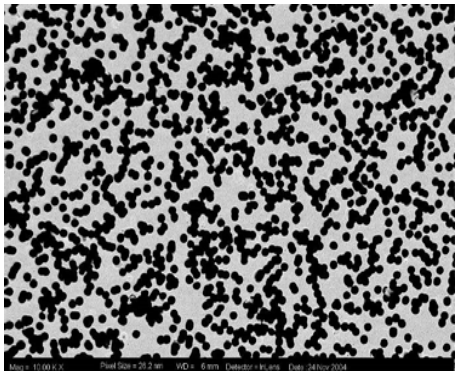
Irradiation of polymer films



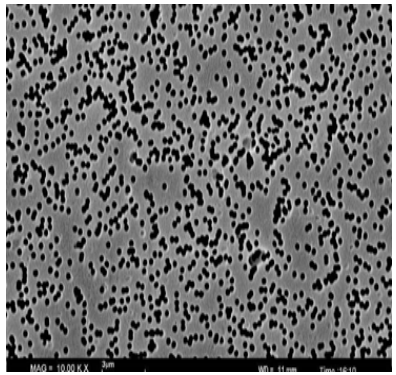
to etching

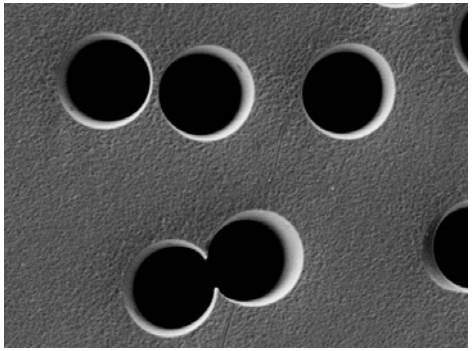
10^5 pores / cm^2 → 10^9 pores / cm^2





0.1 µm → 10 µm

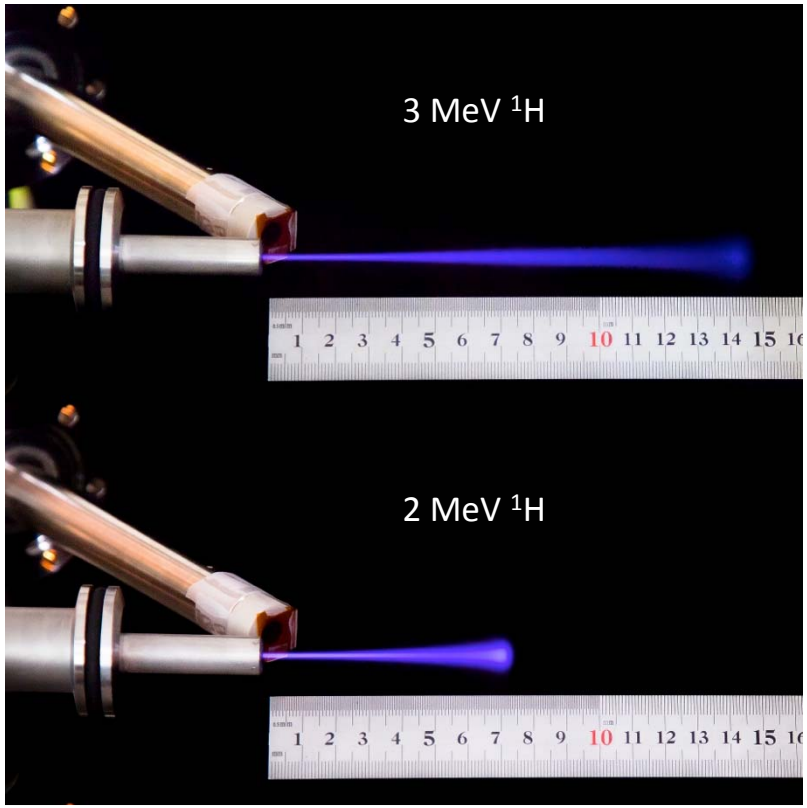


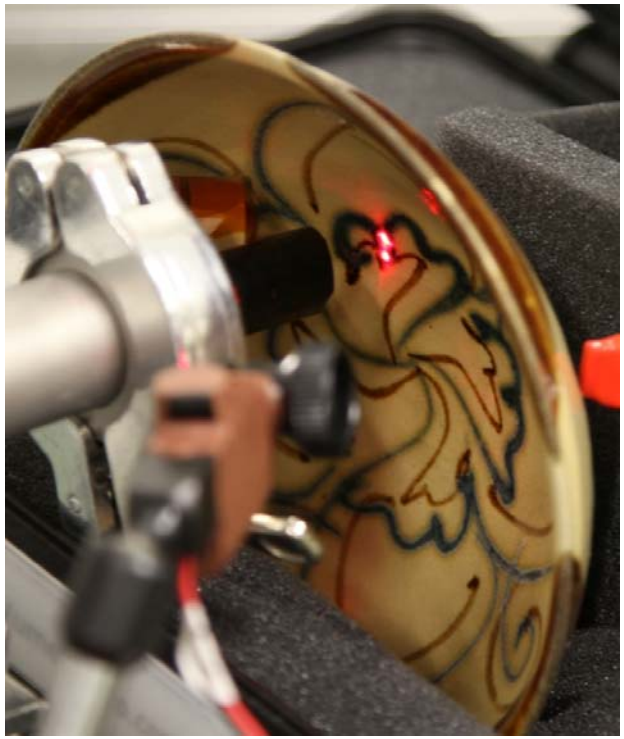


New developments at Pelletron Laboratory

RECENART - Research Center for Artestablished in Jyväskylä in 2014
Company founded in May 2016

Pilot study: Chinese bowl from Tang Dynasty (618–907 AD) period, composition of colors, glazing and body

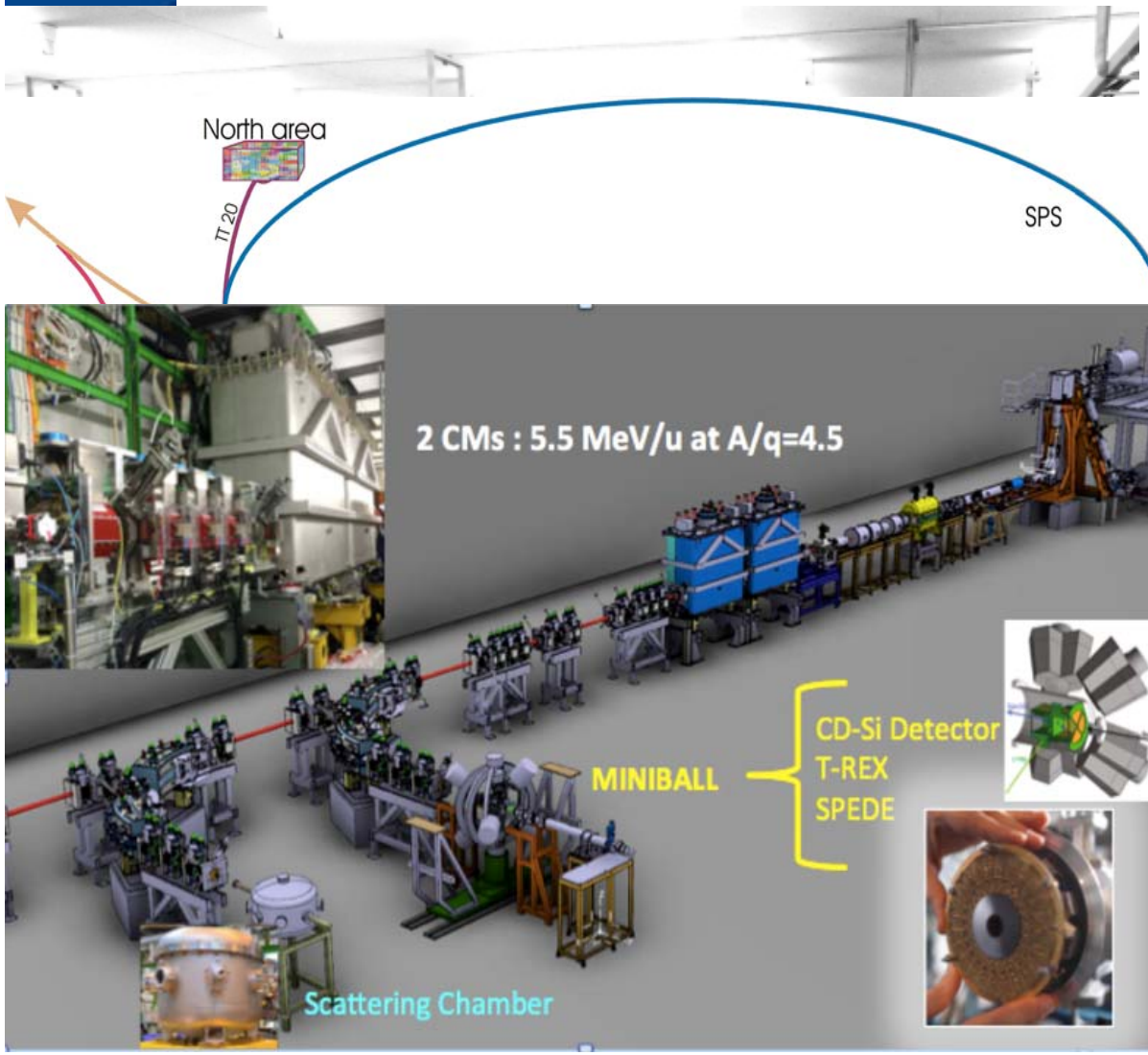




PIXE spectrum from blue color shows high Cu content and the absence of Co: both typical findings for porcelain originating from Changsha kiln active during the Tang period

The ISOLDE facility

- radioactiove ion beam factory -



First beam October 1967

Upgrades 1974 and 1988

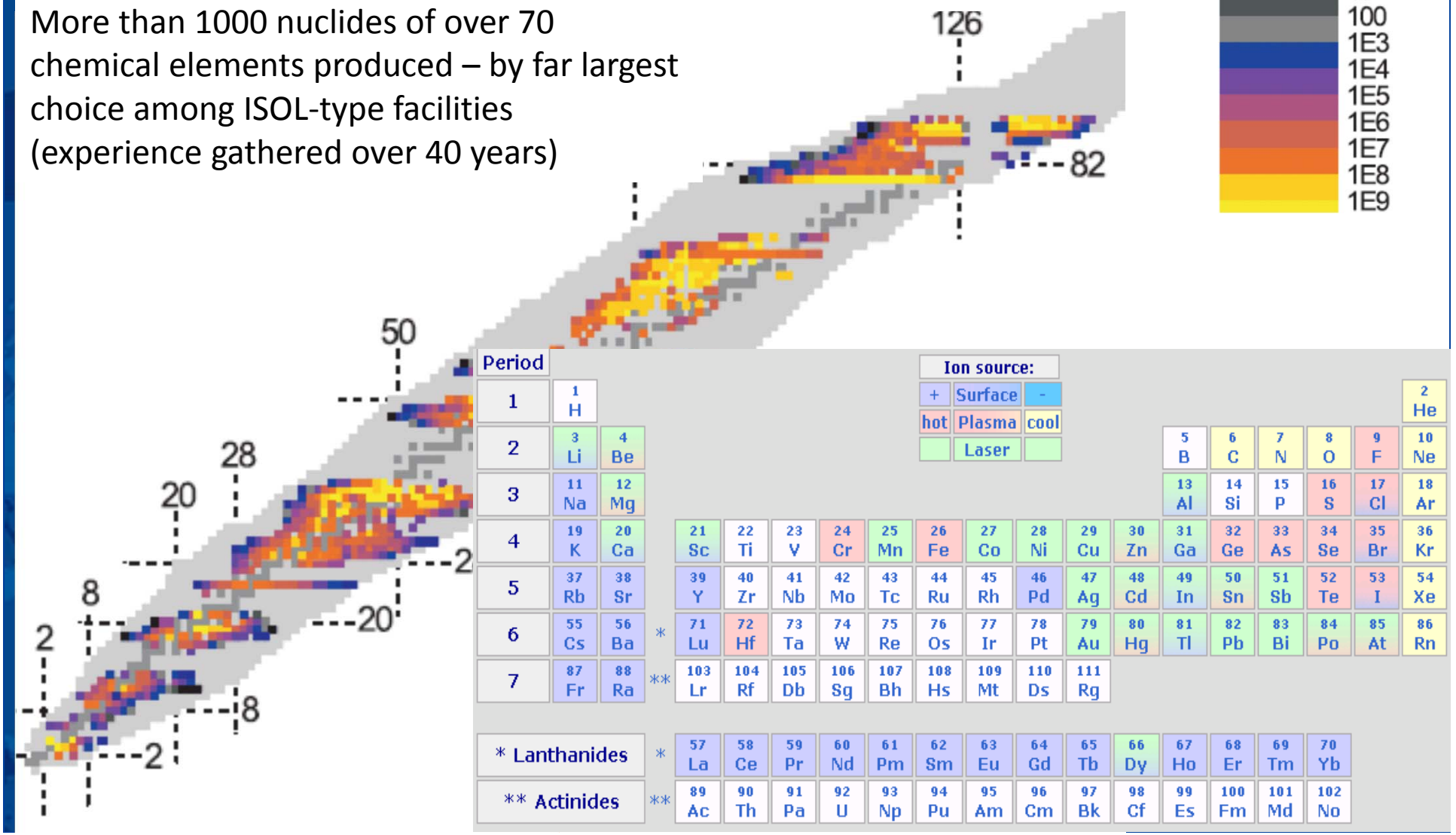
New facility June 1992

Post-accelerated beams 2001

Produced nuclides

complementary to IGISOL at JYFL-ACCLAB

More than 1000 nuclides of over 70 chemical elements produced – by far largest choice among ISOL-type facilities (experience gathered over 40 years)



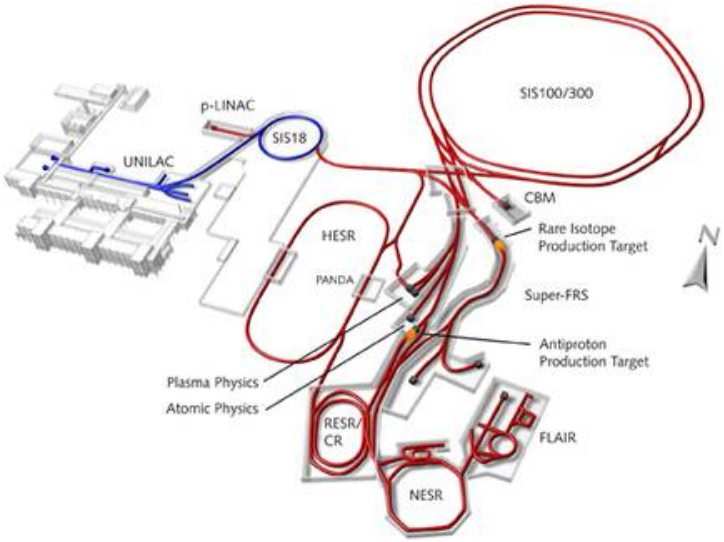
Finnish activities at ISOLDE

Active participation since mid 90's
Nuclear physics and material physics

- ISCC representative: *Prof. P. Greenlees - JYU*
- ISOLDE project leader: *Dr. J. Pakarinen - JYU*
- Adjoint scientists:
  - *Prof. I. Moore - JYU*
  - *Dr. D. Cox- JYU*
  - *Dr. T. Grahn- JYU*
  - *Dr. K. Helariutta - HU*
  - *Dr. U. Jakobsson - HU*
  - *Dr. P. Papadakis - JYU*
  - *Dr. P. Rahkila - JYU*
  - *Mr. J. Konki – JYU*
- Typically two summer trainees annually

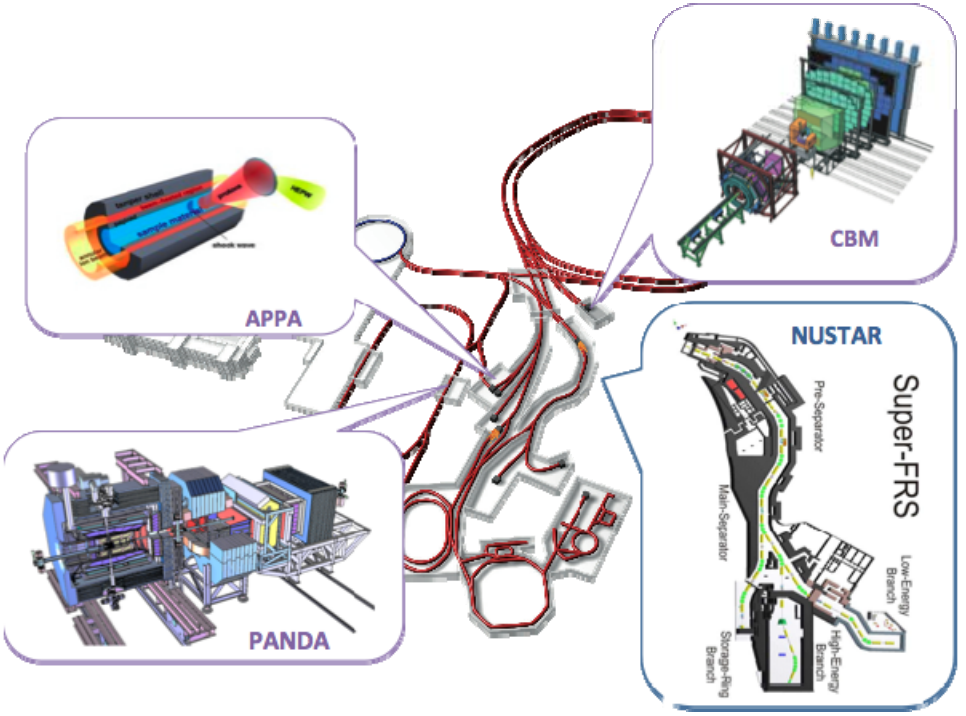
FAIR GmbH (Facility for Antiproton and Ion Research in Europe)

- ESFRI landmark project under construction in Darmstadt, Germany
- Budget: 1.678 M€ (2022)
- Finland and Sweden in consortium have 1% share
- Will be based on the existing GSI GmbH facility
- Globally complements the heavy-ion ring accelerators RHIC at BNL, LHC at CERN and NICA & HIAF (under construction)



Four science pillars of FAIR

- APPA–atomic and plasma physics, applications
- CBM–baryon rich matter
- NUSTAR–nuclear structure, astrophysics and reactions
- PANDA–high-energy antiprotonphysics



Finnish resources – instrumentation at FAIR

- 5 M€ (2005) initial funding, including in-kind contributions (1.5 cash + 2.8 accel. + 0.7 exps M€)
- Coordinated through the FAIR operations project in the nuclear matter programme of the Helsinki Institute of Physics (HIP).
- Finnish speciality in instrumentation: Ion-beam tracking and identification in the Super-FRS fragment separator, mainly:
  - GEM-TPC tracking detectors
  - MUSIC dE detectors
  - SEM-Grid beam profile detectors
- Contributions to the NUSTAR experiments: detectors and beam-line components

Finnish resources FAIR science

- Science case and methodologies complementary to those in JYFL-ACCLAB
- NUSTAR: Super-FRS Experiment Collaboration, HISPEC/DESPEC, MATS, LaSpec, Superheavy elements
- Experimental research complemented by theory
  - HIP nuclear structure project (M. Kortelainen, JY)
  - FiDiPro professorship (J. Dobaczewski) at JYFL
- Finland has a strong position in the FAIR NUSTAR science programme ⇒ potential for science breakthroughs !

International activity

- **Nuclear Matter program** at HIP (ALICE,ISOLDE,FAIR) (Ari Jokinen)
- **FAIR project** (T. Grahn)
  - NUSTAR experiments
    - Super-FRS collaboration (J. Äystö, T. Grahn, A. Jokinen,…)
    - LASPEC (Iain Moore) and MATS (T. Eronen, …)
    - HISPEC/DESPEC (H. Penttilä, S. Rinta-Antila, P. Greenlees, …)
    - SHE (J. Uusitalo, …)
  - IKRB (A. Jokinen)
  - FAIR RRB (T. Grahn, A. Jokinen), NUSTAR RB (I. Moore)
- **ISOLDE project** (J. Pakarinen)
  - ISCC representative P. Greenlees
  - SPEDE-electron spectrometer for HIE-ISOLDE (Acad. Res. J. Pakarinen). [funded by the Academy of Finland and through a Marie Curie grant]

- **EURISOL:** EURISOL-UG (I.Moore), EURISOL-DF (A. Jokinen)
- **NuPECC** (P. Greenlees)
- **Euroschool** (A. Jokinen)
- Individual research projects:
  - ANL, GANIL, LBL, MSU, RIKEN, Texas A&M, TRIUMF, Leuven, …

Communication, outreach

JYFL Accelerator News

Accelerator Laboratory, Department of Physics
University of Jyväskylä, Finland

Volume 25, No. 1 March 2017

Next Call for Proposals
Deadline: March 15, 2017

Significant infrastructure funding granted by Academy of Finland

JYFL-ACCLAB was selected as one of the Research Infrastructures on the Roadmap 2014-2020 of the Ministry of Education and Culture, and has since been successful in securing competitive infrastructure funding via the Academy of Finland's FIRI program. The results of the latest call for applications were published on 19th January. JYFL-ACCLAB was awarded funding totalling 1.31M€, of which the Academy contribution is 0.92M€. The funding will be used to overhaul the vacuum system of IGISOL, to purchase germanium detectors for use at MARA and IGISOL, to develop a novel Auger electron spectrometer for use with the Helium Ion Microscope previously funded via FIRI and to equip beam lines for reaction studies. The funding granted will also allow procurement of an AGATA module, representing the Finnish contribution to the next generation gamma-ray tracking spectrometer.

MARA Low-Energy Branch: first infrastructure arrives

The MARA Low-Energy Branch (MARA-LEB), currently under development at JYFL-ACCLAB, will provide the isotopic selectivity required for the study of proton-rich nuclei which will be accessible with MARA. Infrastructure funding (FIRI), secured from the Academy of Finland at the end of 2015, has been used for the purchase of the first parts of the facility. Three state-of-the-art solid state Ti:Sapphire lasers (see picture) were delivered to JYFL from the University of Mainz in February 2017 and will be assembled by the IGISOL laser team. The tendering process for the vacuum system required for the gas cell and differential pumping stage has just been completed. Other components of the facility are currently in the design phase and we soon expect to make the order for the gas cell as well as the dipole magnet required for MARA-LEB.

Three newly-designed Ti:sapphire lasers delivered from the University of Mainz which will be used in connection with MARA-LEB

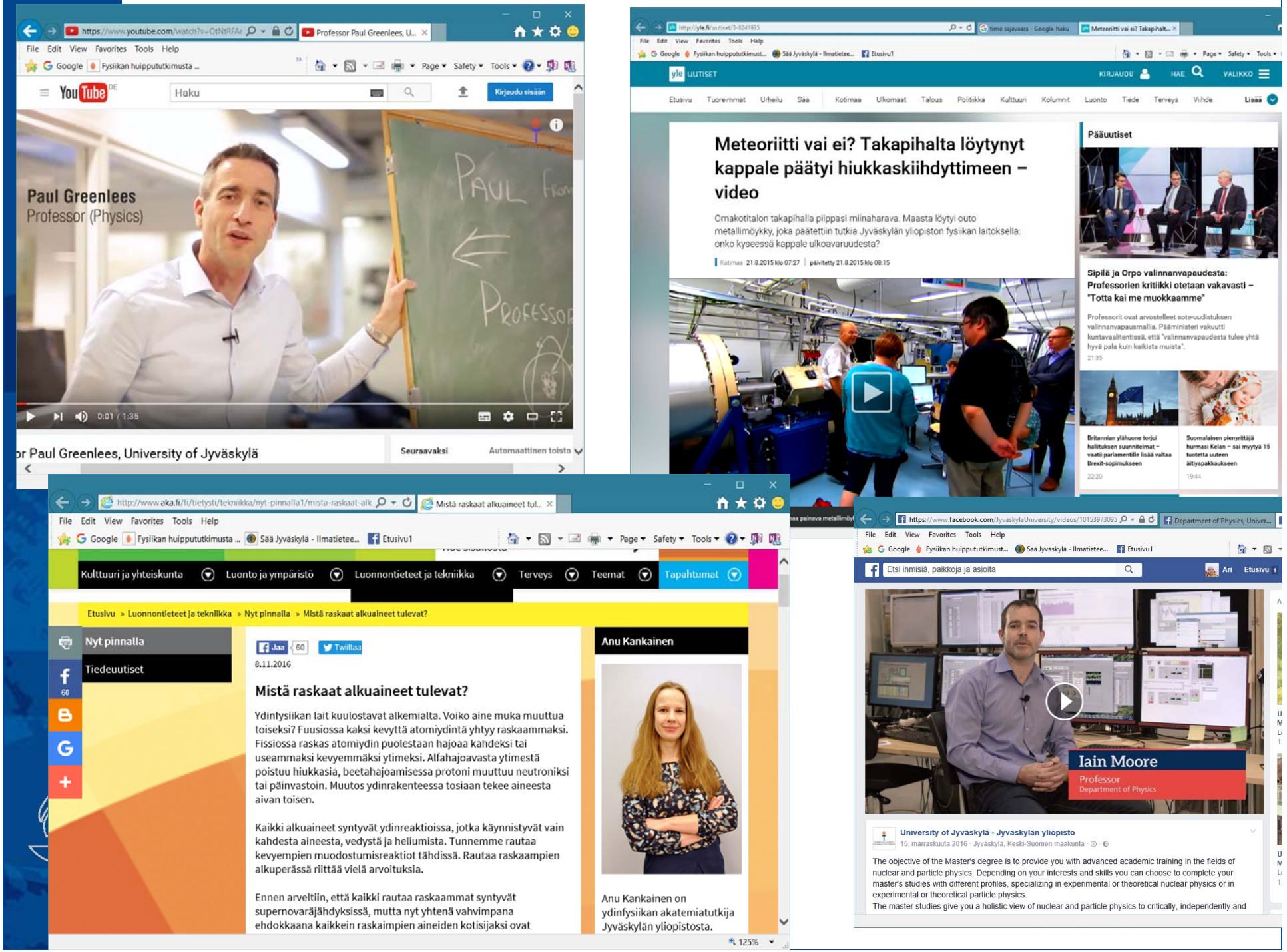
March 2017 JYFL Accelerator News 3

RADSAGA offers 15 positions for PhD studies in the field of radiation effects in electronics. Application open!
https://jobs.web.cern.ch/job/12243
http://radsaga.web.cern.ch/

European Researchers' Night at the Department of Physics, 30 September 2016

The European Researchers' Night took place across Europe on the 30th of September 2016. Almost 6000 people attended the event at the University of Jyväskylä with more than 1000 visiting the Accelerator Laboratory. There they participated in a number of tours around the experimental facilities, lectures and interactive demonstrations organised by 60 local researchers. The European Researchers' Night event will be organized in the laboratory also in 2017. The Accelerator Laboratory activities were coordinated by Arto Javanainen, Philippos Papadakis was the coordinator for the University of Jyväskylä and Janne Pakarinen for the national consortium. Photos: W.T. Trzaska.

European Researchers' Night project is funded by the European Commission under the Marie Skłodowska-Curie actions under contract number 722854.
Initiated by Janne Pakarinen (co-ordinator)
JyU co-ordination: Philippos Papadakis


Paul Greenlees
Professor (Physics)
Meteoriitti vai ei? Takapihalta löytynyt kappale päätyi hiukkaskiihdyttimeen – video
Mistä raskaat alkuaineet tulevat?
Anu Kankainen
Iain Moore
Professor
Department of Physics

Summary

- JYFL ACCLAB
  - International continuously upgraded infrastructure with a rich program of basic and applied research at Jyväskylä University
    - Host institute support (strategy and profiling)
    - National task given by the Ministry of Education to act as a Centre of Expertise in radiation- and ion-beam research, education and applications
    - EU access laboratory
    - National infrastructure roadmap
    - CoE of the Academy of Finland
    - A broad international user community
- Close ties with NUSTAR-FAIR and ISOLDE-CERN

Thank you !

https://www.jyu.fi/fysiikka/tutkimus/kiihdytin/

https://www.jyu.fi/fysiikka/en/research/accelerator

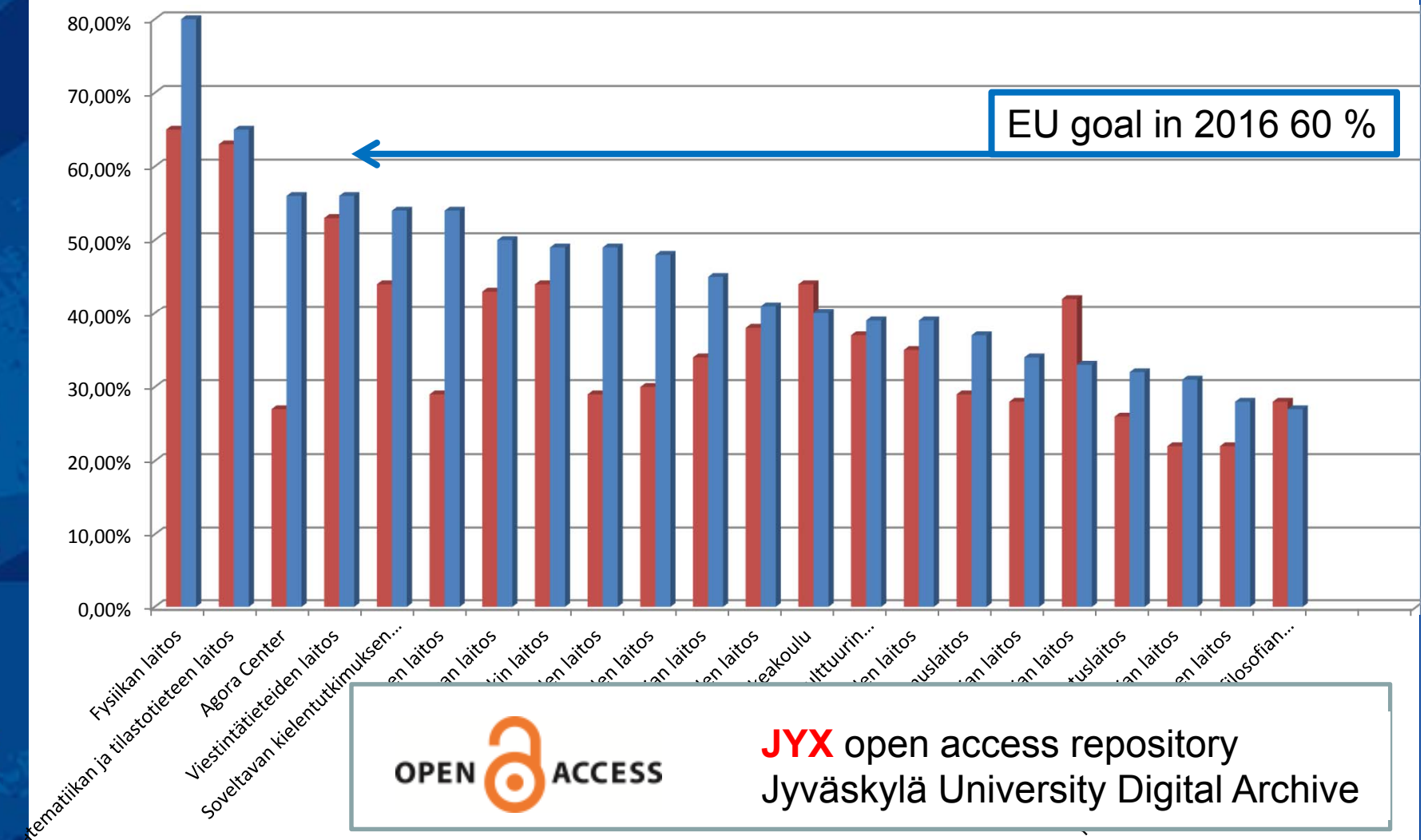
EXTRA’s

Data management + open access

- Intellectual property issues treated according to a common policy of University of Jyväskylä.
- Open Access policy: University guidelines and positive view on open access.
- Open access and basic laboratory services guaranteed for PAC-approved experiments.
- More than 80 % of publications openly accessible in JyX-database in 2016.

JYX open access repository
Jyväskylä University Digital Archive

Archiving percentages in 2015 and 2016



Budget details

Salaries (JY)*	2.4	Salaries	(51.7%)
OKM budget (JY)*	0.5	Research groups	
FIRI	0.5		
Commercial	0.6	Infrastructure, operation	
ESA	0.1	maintenance, …	(26.8%)
EU	0.2		
Academy grants	0.2	Salaries, travels	
CoE	1.1	Salaries, travels	(19.6%)
	5.6 M€		

* These items include profiling and national task

FIRI funding

Finnish Roadmap of the major research infrastructures 2014-2020:
JYFL ACCLAB is the only operational research infrastructure in the Natural Sciences and Technology category

- **New infrastructure for the accelerator and separator facilities of the Accelerator Laboratory of the Department of Physics, University of Jyväskylä (JYFL-ACCLAB)**
  - Decision No. 141395, Duration 09.12.2010 – 30.06.2013, Academy contribution 670600€
  - PI: Professor Rauno Julin
- **State-of-the-art ion beam developments for JYFL-ACCLAB**
  - Decision No. 273526, Duration 01.01.2014 – 31.07.2016, Academy contribution 927418€
  - PI: Professor Rauno Julin
- **Helium-Ion Microscope Centre for Interdisciplinary Materials Research (HIM)**
  - Decision No. 283399, Duration 01.01.2015 – 31.12.2016, Academy contribution 874305€
  - PI: Professor Timo Sajavaara. (Joint project with Department of Biological and Environmental Science, JyU)
- **Implementation of new research infrastructure at JYFL-ACCLAB and an upgrade of the cyclotron control system**
  - Decision No. 293408, Duration 01.01.2016 – 31.12.2017, Academy contribution 1011500€
  - PI: Professor Ari Jokinen
- **Upgrades of Research Infrastructure at JYFL-ACCLAB**
  - Funding period 01.01.2017 – 31.12.2019, Academy contribution 920150€
  - PI: Professor Paul Greenlees

How do we test?

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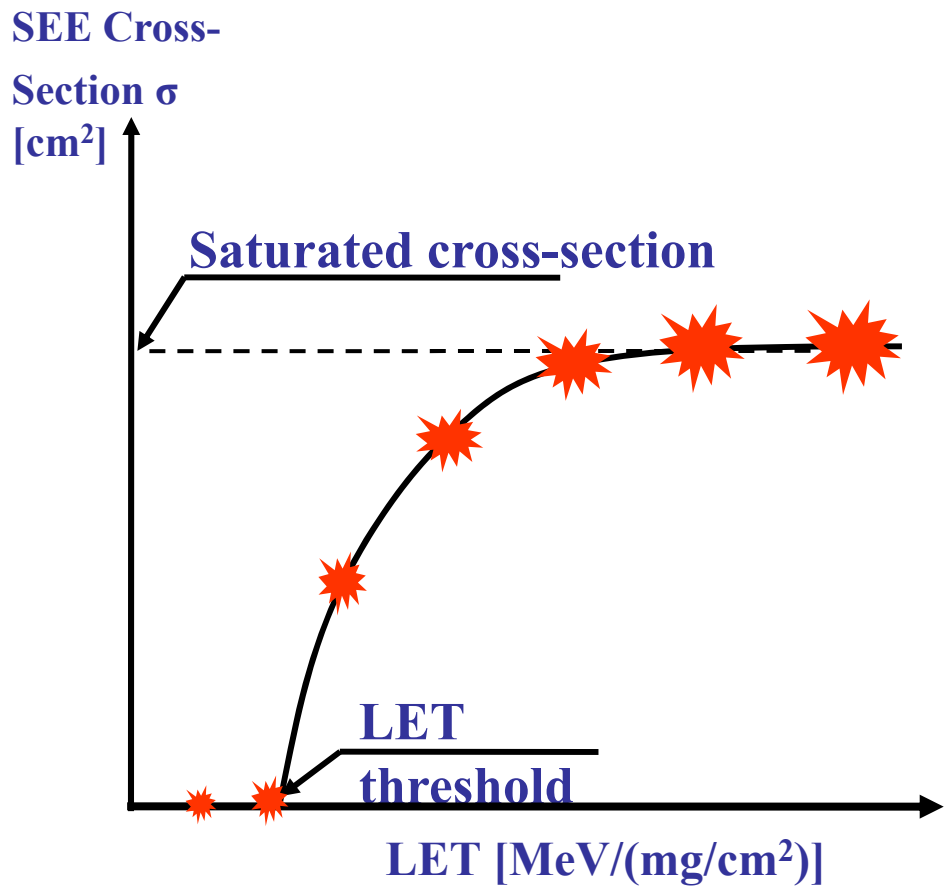
By determining the error cross-section σ as a function of LET* we define the LET threshold and Saturated cross-section.

The higher LET_{th} and lower σ_{sat} → the more radiation-hard component

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



* LET = Linear Energy Transfer

Solution: Ion cocktail 9.3·*A* MeV

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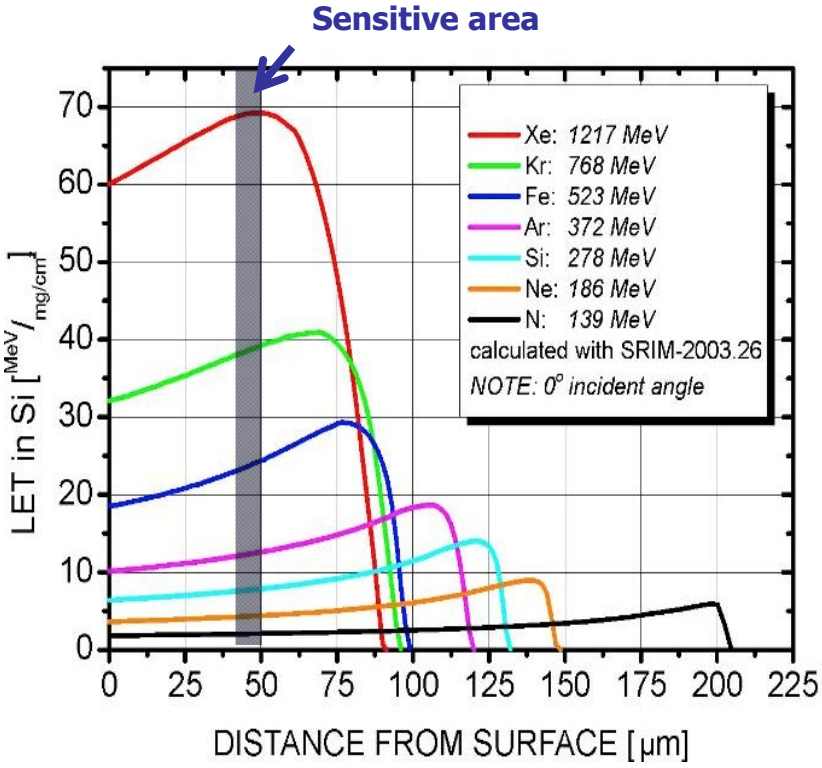
$^{A}Ion^{q+}$ q/A≈ 0.27	E [MeV]	Range [µm]	LET @surface [MeV·cm²/mg]	LET @bragg [MeV·cm²/mg]
$^{15}N^{4+}$	139	202	2	6
$^{20}Ne^{6+}$	186	146	4	9
$^{30}Si^{8+}$	278	130	6	14
$^{40}Ar^{12+}$	372	118	10	19
$^{56}Fe^{15+}$	523	97	19	21
$^{82}Kr^{22+}$	768	94	32	41
$^{131}Xe^{35+}$	1217	89	60	69



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 also irradiation in air

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

Host Institute support

- **University strategy.** In the strategy of JyU for the years 2015-2020, natural sciences and mathematical thinking is one of the five central research fields with accelerator-based physics one of the key areas.
- **University profiling.** “Structure of matter with accelerator-based methods” was selected as one of the three profiling actions in 2015, strengthening further the role of JYFL-ACCLAB in JyU. As a result, two new professors were hired, Iain Moore and Timo Sajavaara; Team leaders of the new CoE application.
- **National task** for accelerator-based research and education

Science objectives at JYFL-ACCLAB

- How do properties of atomic nuclei evolve far from stability?
- What are the limits of nuclear existence in terms of proton and neutron numbers?
- What is the role of nuclear physics in stars and in the chemical evolution of the universe?
- Can nuclear and atomic physics contribute to neutrino physics and to the physics beyond the Standard Model?
- How can nuclear and accelerator-based physics research contribute to a healthy and secure society?
- How can fundamental ion-material interactions be exploited for materials characterization and for studying radiation damage in electronics components?

Impact

- Research and education
- Education (Horizon2020 RADSAGA and Nupia)
- National task given by the Ministry of Education to act as a Centre of Expertise in radiation- and ion-beam research, education and applications
- High-profile international user facility
- Commercial and industrial collaboration (ESA, Oxyphen)
- Ion beam analysis and nuclear data for IAEA
- CORES (Consortium for Radiation Safety Research) working for “Healthy and Secure Societies”
- A partner in the new RECENART company (a spin-off of JyU, founded in May 2016)
- Teachers training + high school visits
- Outreach

New 18 GHz ECRIS (HIISI)

UNIVERSITY OF JYVÄSKYLÄ

Motivation:

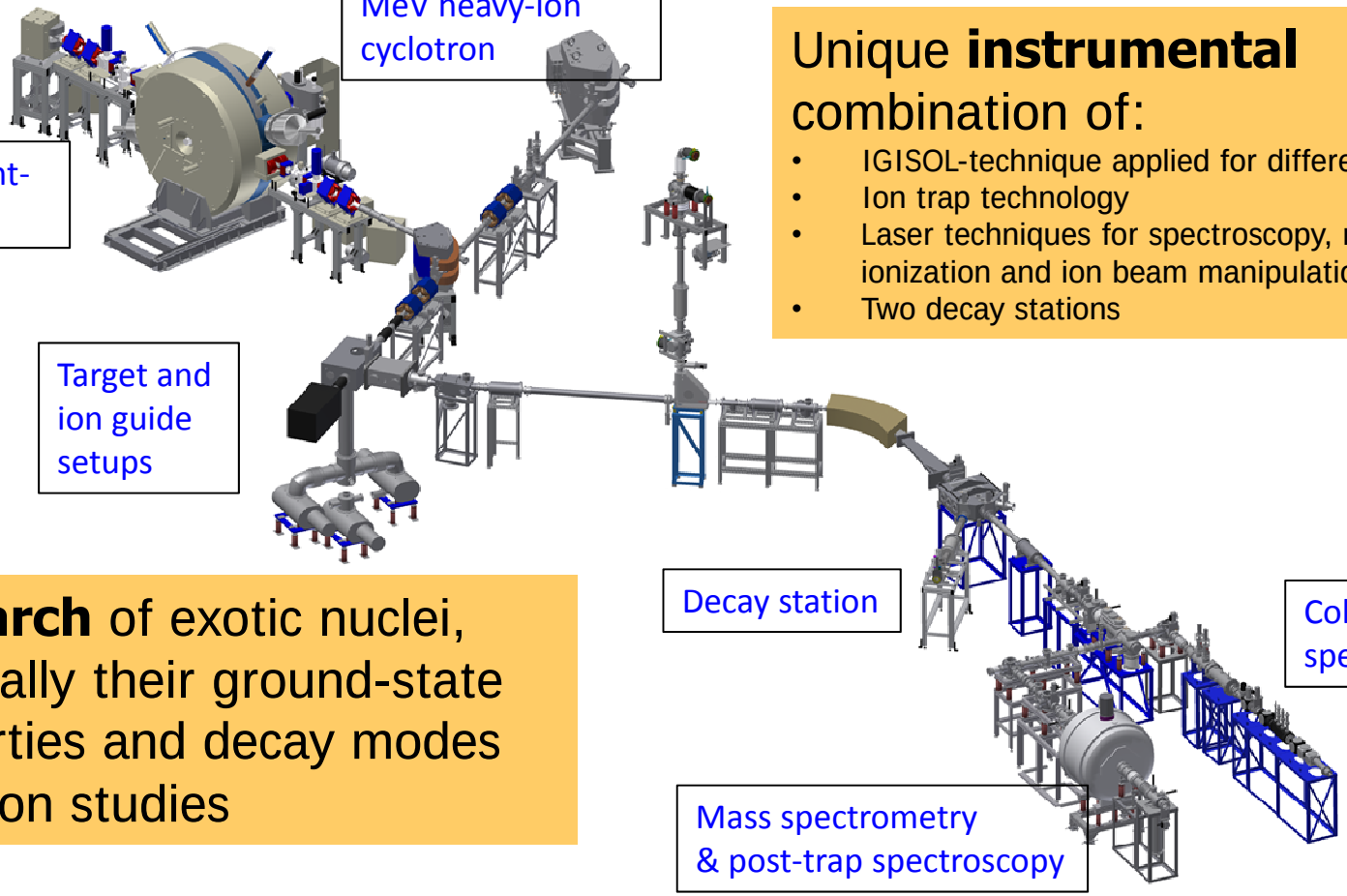
1. **Nuclear physics experiments**, especially studies of super-heavy elements, would benefit from **higher intensities at medium charge states**, such as Ar^{8+} and Xe^{26+} (energy > 5 MeV/u).
2. **European space industry** and radiation effects community need **higher-energy**, higher-intensity beams in the future. The ion beam cocktail energy should be increased from present 9.3 MeV/u to about **15 MeV/u**.
   - → deeper penetration in silicon
   - → irradiations in air with possibility to tilt

Infrastructure funding (Academy of Finland) + ESA financial support.

IGISOL – 4th generation

Ion Guide Isotope Separator On-Line

https://www.jyu.fi/fysiikka/en/research/accelerator/igisol

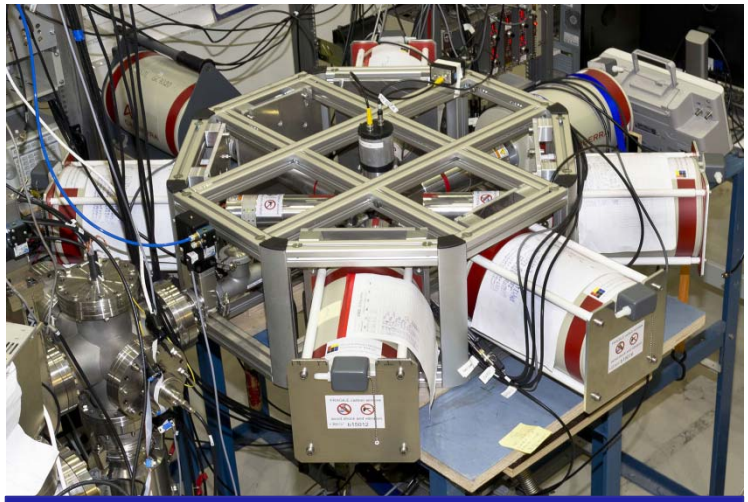


Unique **instrumental** combination of:

- IGISOL-technique applied for different reactions
- Ion trap technology
- Laser techniques for spectroscopy, resonant ionization and ion beam manipulation
- Two decay stations

Research of exotic nuclei, especially their ground-state properties and decay modes + fission studies

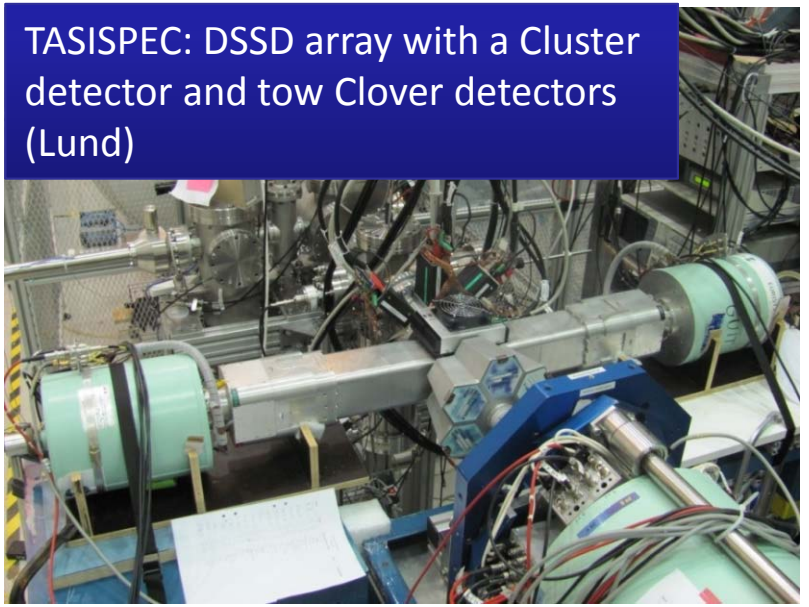
Post-trap spectroscopy experiments at JYFLTRAP & IGISOL



Low-energy Ge array (Univ. of Warsaw)

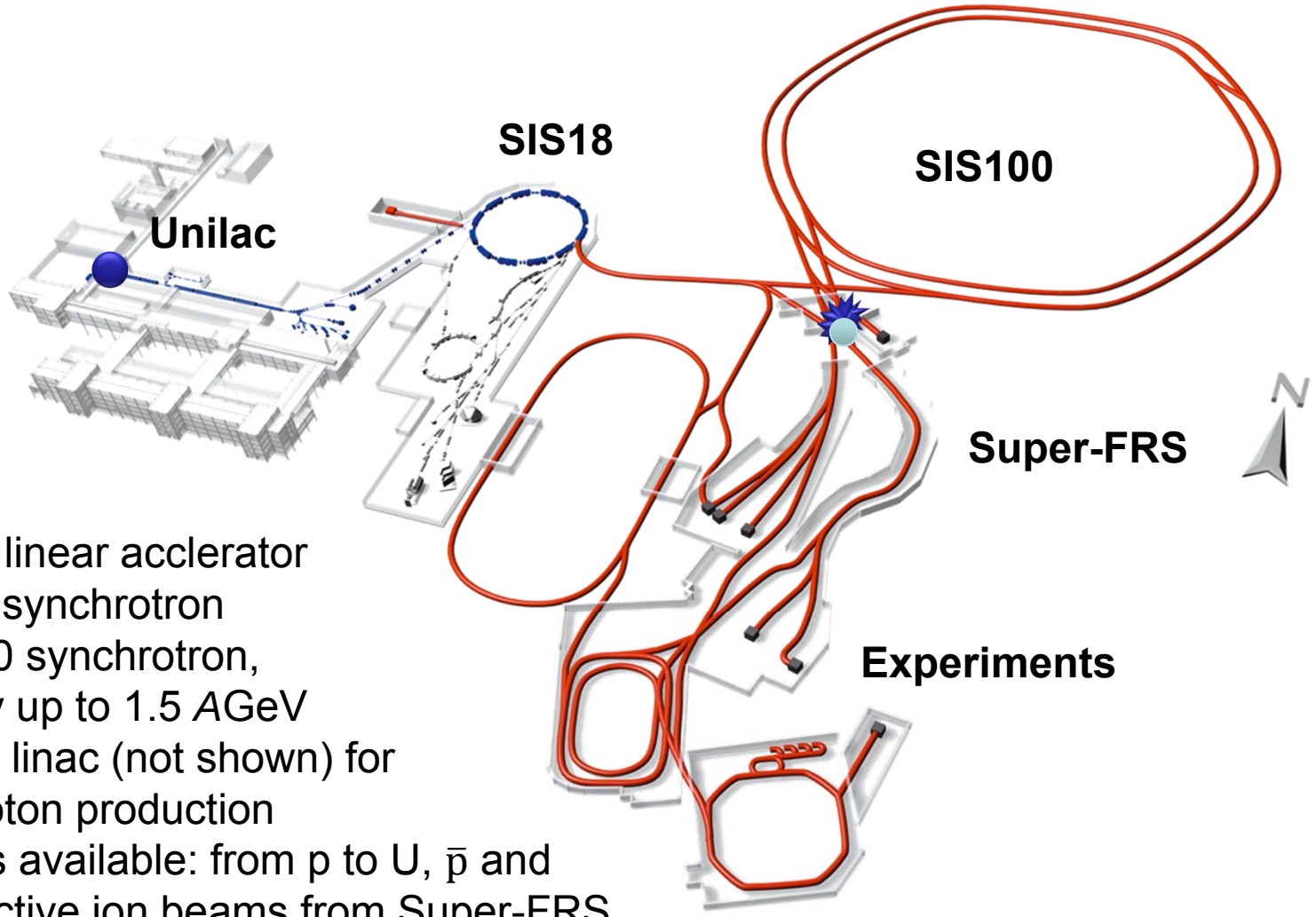
DTAS (total absorption decay spectroscopy) (Valencia)

TASISPEC: DSSD array with a Cluster detector and tow Clover detectors (Lund)



BELEN-48 for beta-delayed neutrons (FAIR)

FAIR accelerators



- Unilac linear acclerator
- SIS18 synchrotron
- SIS100 synchrotron, energy up to 1.5 *A*GeV
- Proton linac (not shown) for antiproton production
- Beams available: from p to U, $\bar{p}$ and radioactive ion beams from Super-FRS