Applied research and commercial services at JYFL Accelerator Laboratory

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Ari Jokinen

- Accelerator Laboratory
- Centre of excellence
- Pelletron Laboratory
- RADiation Effects Facility

JYFL Accelerator Laboratory

- 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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NuPECC Long Range plan 2010

Current Nuclear Research Facilities in Europe.

Department of Physics

- Nuclear and accelerator based physics
  - Accelerator laboratory
  - Theory
- Materials physics
  - from nanophysics, nanoelectronics and low-temperature physics to the soft condensed matter and statistical physics.
  - Mainly performed in the multidisciplinary Nanoscience Center
- High energy physics
  - particle cosmology
  - the physics of ultra-relativistic heavy ion collisions
  - theoretical particle physics (neutrinos, beyond the SM).
- Teacher's education

Accelerator laboratory

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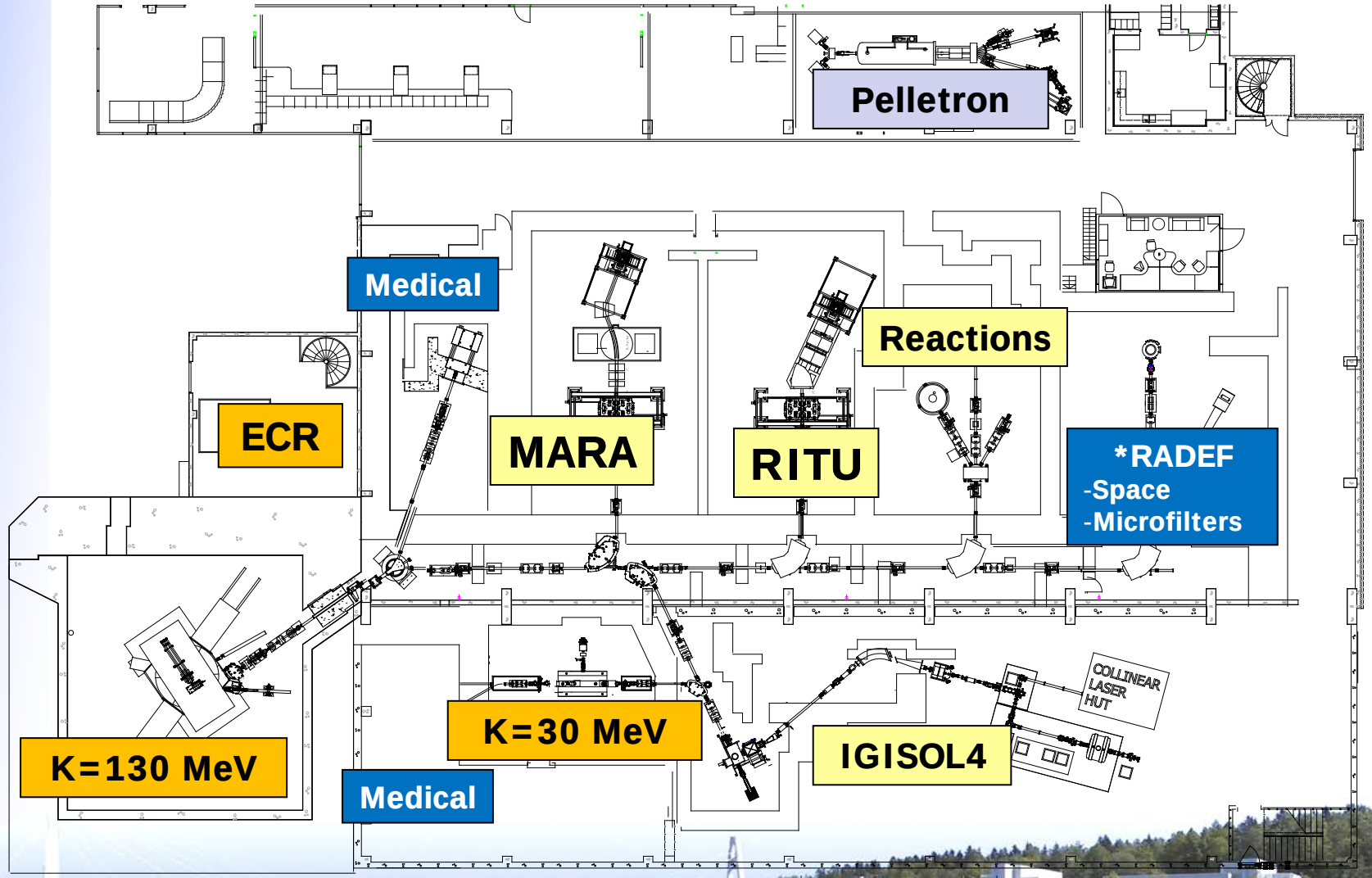

K130

Accelerated elements:

p – Xe

$E = Q^2/A$ 130 MeV

Ion sources:

6.4 GHz ECRIS

14 GHz ECRIS

Multicusp (H^-, D^-)

2014-2016 upgrade:

18 GHz ECR

Operation of K130

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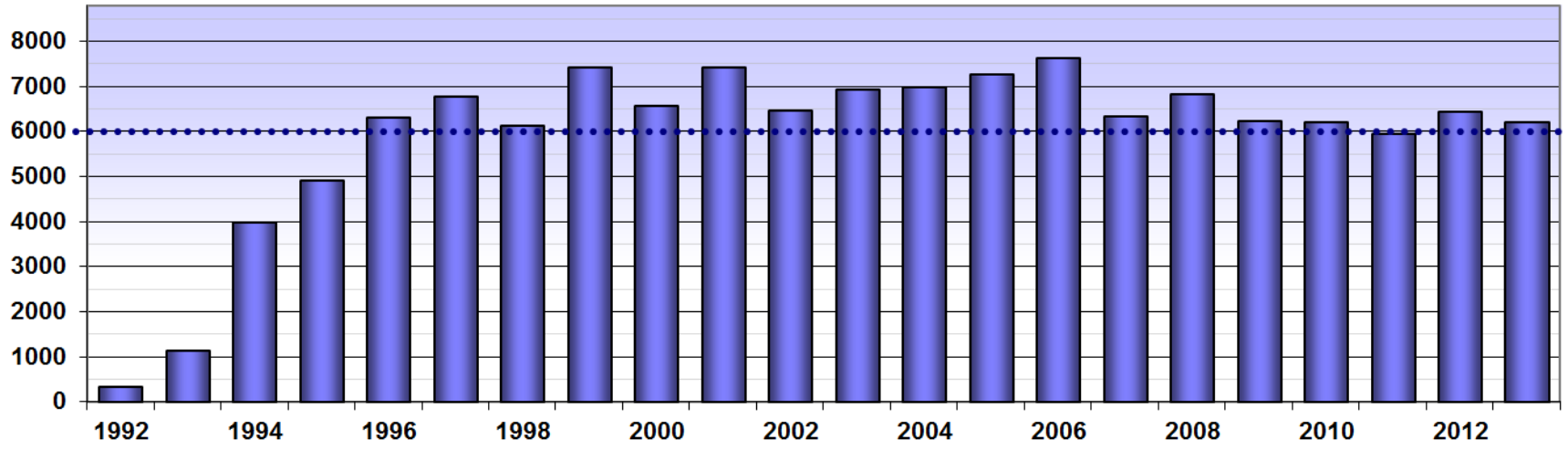
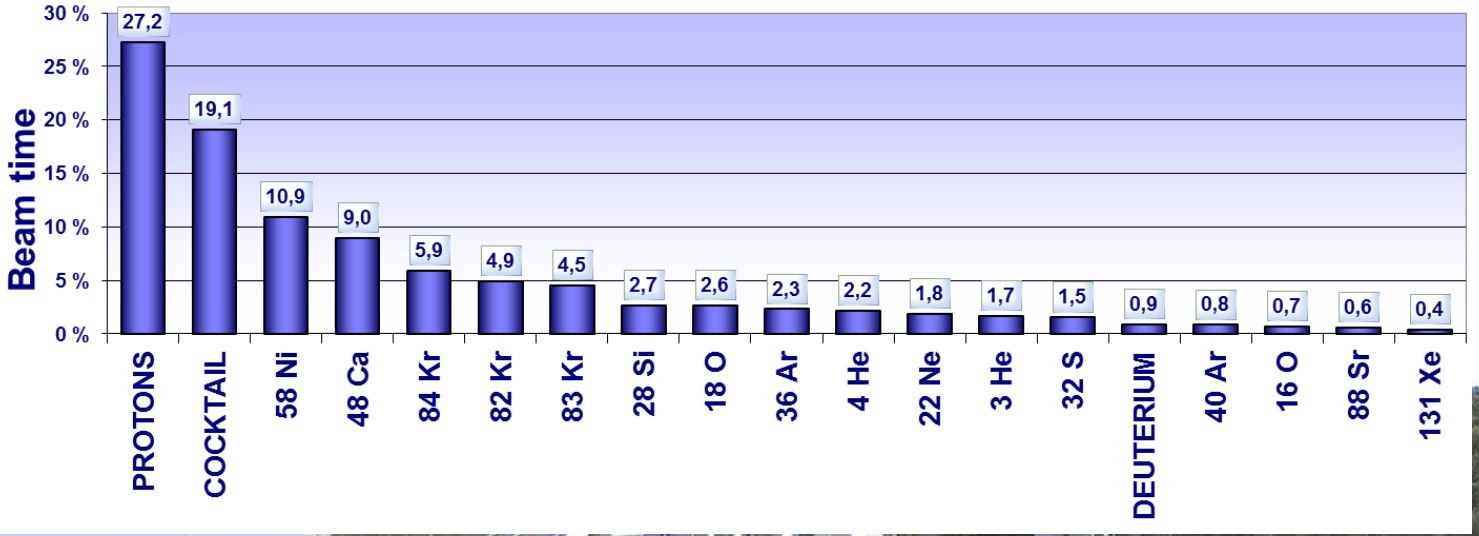


Accelerated ions in 2013



MCC30/15

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

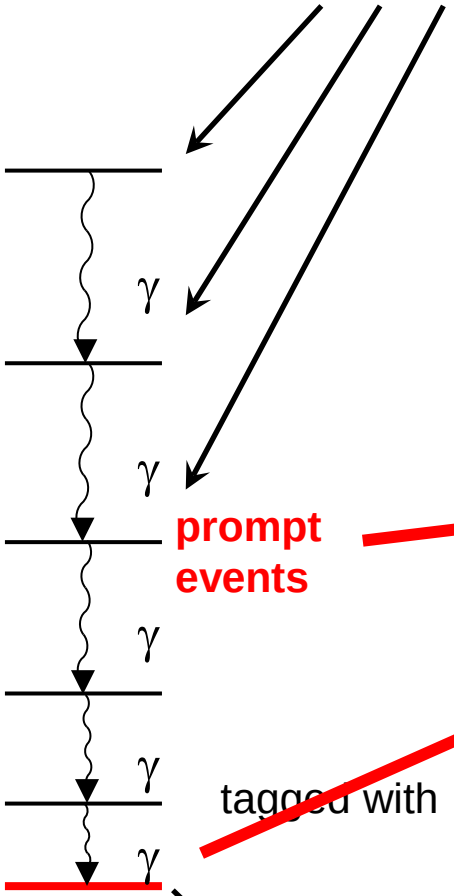
Users:

- IGISOL
- Radioisotope production

New RF ion source

- Intensity increase
- Continuous operation

RDT WITH JUROGAM + RITU + GREAT



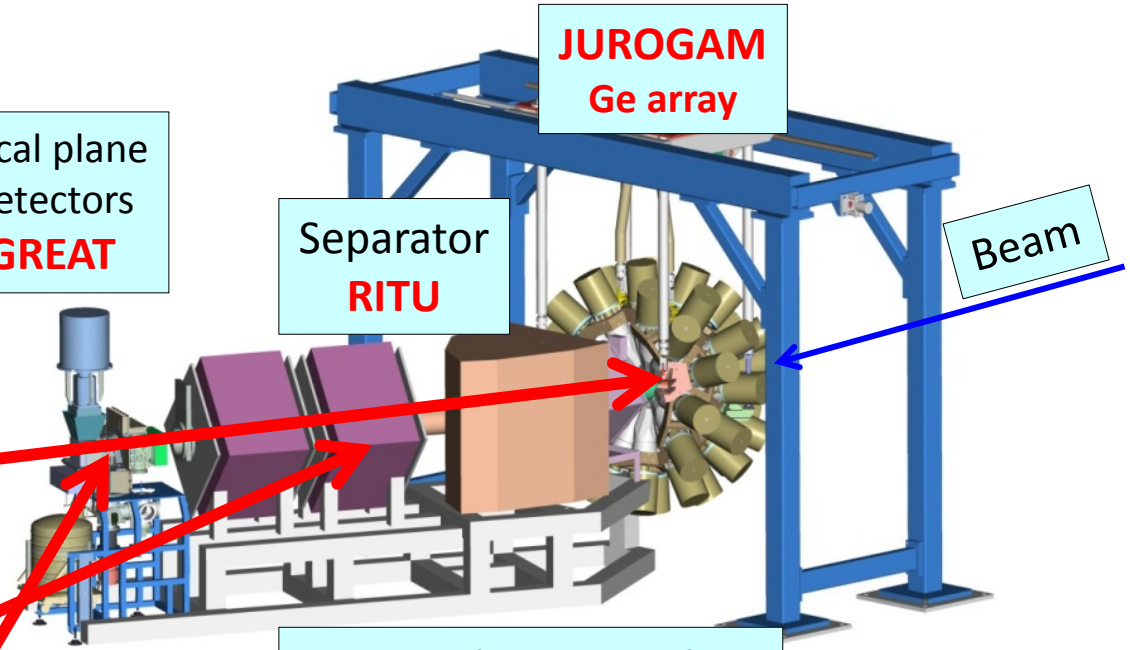
prompt events

tagged with

delayed events

α, p, β,

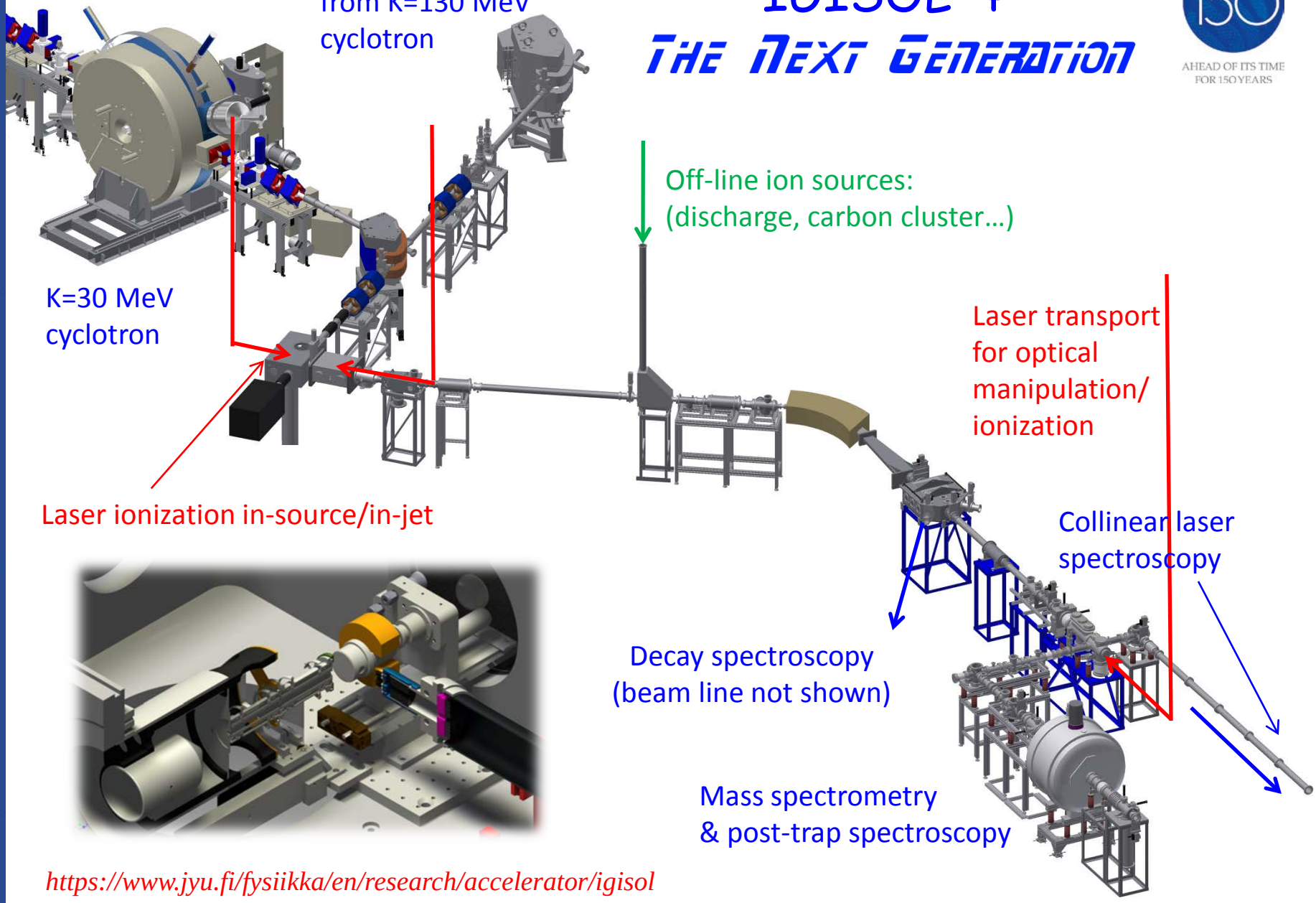
… e^-, γ



^{256}Rf: in beam gamma 17 nb

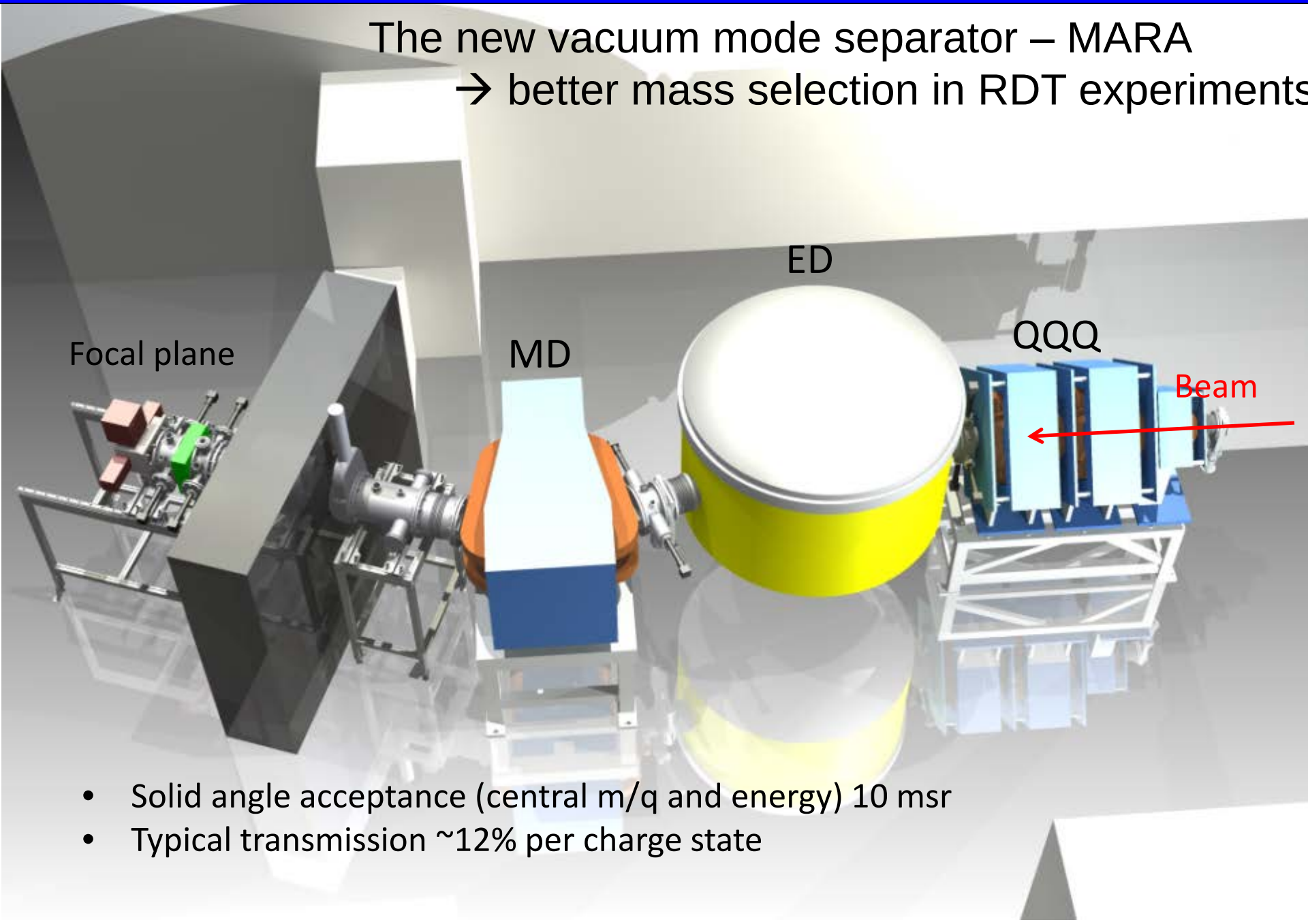
SAGE: γ-e-coincidences in sub-μb

IGISOL-4
The Next Generation



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

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

Interdisciplinary research

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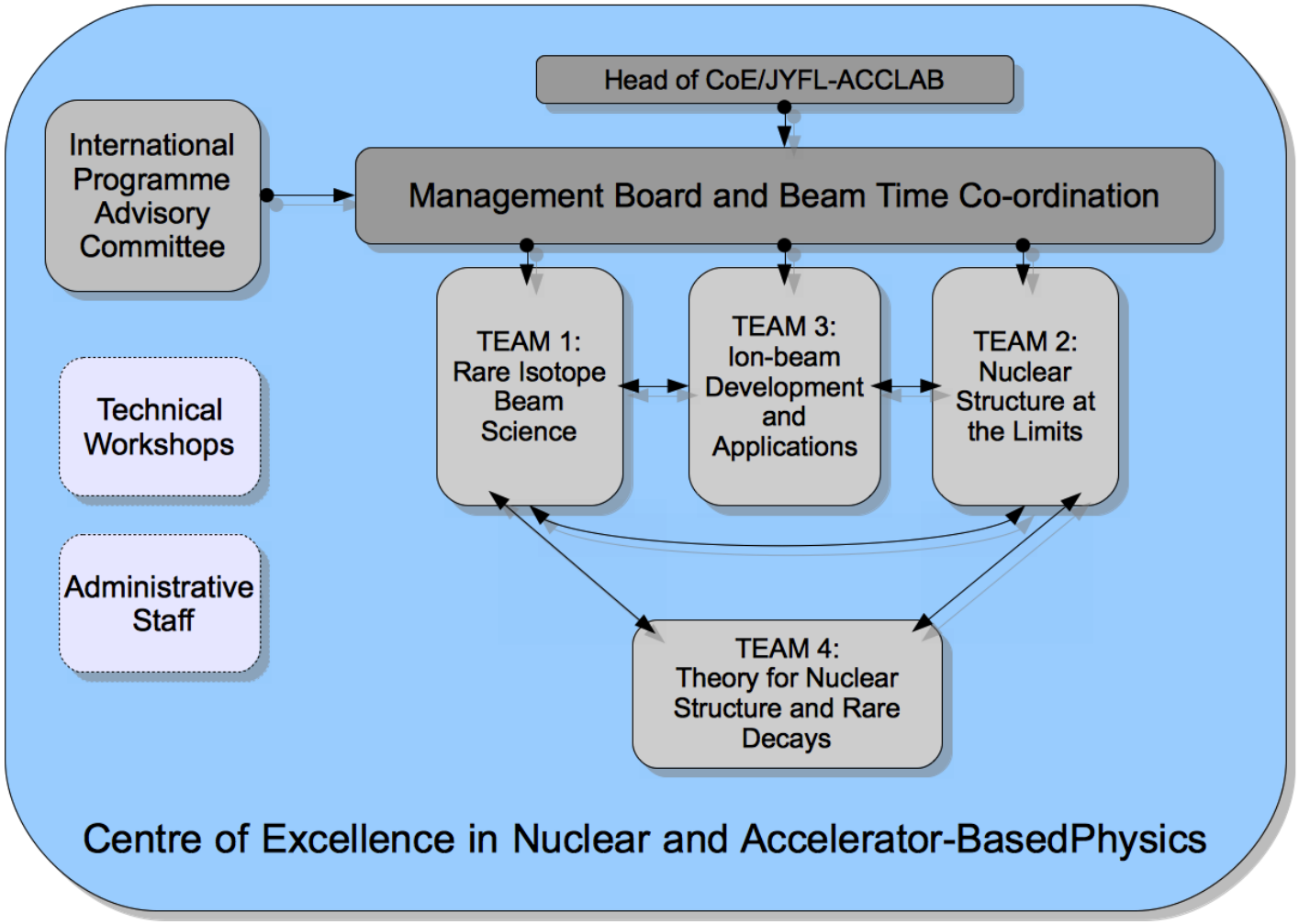
IGISOL:

- Fission yield studies (nuclear energy)
- Decay heat measurements (reactor technology)
- Proliferation (neutrino spectra determination through TAS measurements)
- Comprehensive Test Ban Treaty Organization (calibration of world-wide monitoring network)
- Material studies with implanted radiotracers

Other recent examples:

- Lake sediment dating development (^{210}Pb)
  - Center for environmental studies
  - Dating laboratory of Finnish National Museum
- Implementation of modern detection and DAQ techniques in radiation monitoring.
  - Finnish Radiation Safety Authority
- Development of non-invasive analysis methods
  - Finnish Radiation Safety Authority
  - Ministry of Defense

Finnish Centre of Excellence (CoE) of the Academy of Finland in Nuclear and Accelerator Based Physics Research



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Finnish Centre of Excellence (CoE) of the Academy of Finland in Nuclear and Accelerator Based Physics Research

5 professors + FiDiPro professor
16 senior researchers or professors
11 post doctoral researchers
27 PhD students
6 laboratory engineers
3 operators
2 technicians

71 in total (30 % from overseas)

35 % of salary costs covered by the Academy of Finland CoE funds

+ auxiliary personnel (~ 10) shared with JYFL and
~ 250 foreign user collaborators annually

JYFL-PAC

	Pending days before the PAC	No. of proposals	Days requested	Days approved	Success rate [%]	Total pending after the PAC
Apr 2012	352	11	97	42	43	394
Oct 2012	331	15	131	70	53	401
Apr 2013	319	16	145	106	73	432
Oct 2013	373	11	106	58	54	431
Apr 2014	313	21	198	123	62	462

Program Advisory Committee:

Wolfram Korten, Chairman, CEA, Saclay, France
Gerda Neyens , KU Leuven , Belgium
Thomas Nilsson, Chalmers Univ. of Techn., Sweden
Marek Pfützner, Warsaw University, Poland
Philip M. Walker, University of Surrey, UK
Dario Vretenar, University of Zagreb, Croatia
Mikael Sandzelius, Scientific Secretary (JYFL)

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Beam time distribution

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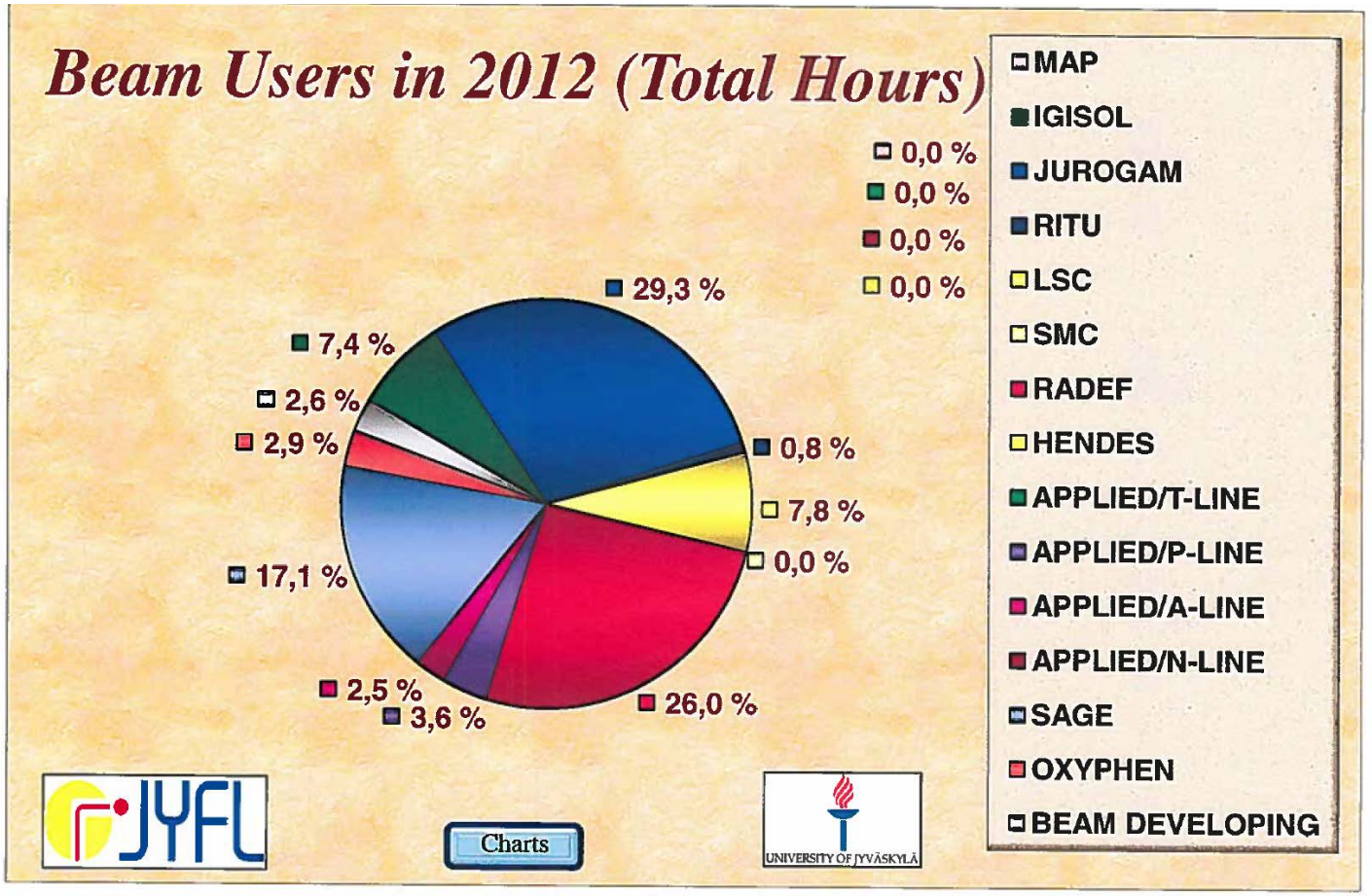
72 days out of 268 effective running days of K-130



National Infrastructure Roadmap 2014-2020

	INAR RI	Ilmakehä- ja ympäristötutkimuksen tutkimusinfrastruktuuri	X
	oGIIR**	Avoin paikkatiedon tutkimusinfrastruktuuri**	
Bio- ja terveystieteet	BBMRI.fi	Biopankki-infrastruktuuri	X
	Biokeskus Suomi		
	EATRIS Suomi	Euroopan translationaalisen tutkimuksen infrastruktuuri	X
	ELIXIR Suomi	Euroopan luonnontieteiden infrastruktuuri biologiselle tiedolle	X
	EuBI Suomi	Euro-BioImaging. Eurooppalainen bioalojen ja lääketieteen kuvantamisteknologioiden tutkimusinfrastruktuuri	X
	EU-OPENSCREEN Suomi	European infrastructure of screening platforms for chemical biology	X
	INFRAFRONTIER Suomi	Euroopan geenimuunneltujen hiirten analysoinnin, säilyttämisen ja jakelun tutkimusinfrastruktuuri	X
	Instruct Suomi	Integroidun rakenteellisen biologian infrastruktuuri	X
	NaPPI	Kansallinen kasvien fenotyyppaus Infrastruktuuri	
	NVVL	Kansallinen virusvektorilaboratorio	
Materiaalitiede ja analytiikka	MAX IV	Synktrotronisäteilylaitos Lundissa, MAX IV Laboratorio	
	OMN	Otaniemen mikro- ja nanoteknologioiden tutkimusinfrastruktuuri	
	XFEL ja XBI	Eurooppalainen röntgen-vapaaeletronilaser, XFEL, ja biologinen infrastruktuuri, XBI	X
Luonnontieteet ja tekniikka	BIOECONOMY	Huippuallianssi kestävään biomassan jalostukseen	
	CTA	Cherenkov-teleskooppijärjestelmä	X
	Euclid	Euclid-kosmologiamissio	
	JYFL-ACCLAB	Jyväskylän yliopiston fysiikan laitoksen Kiihdytinlaboratorio	
E-tutkimus-infrastruktuurit ja matematiikka	CSC RI	Tieteen tietotekniikan keskus – kansallinen infrastruktuuri	
	PRACE Suomi	Eurooppalainen superlaskentainfrastruktuuri	X
	FGCI**	Suomen hila- ja pilvilaskennan infrastruktuuri**	

* Kumppanuudet ESFRI-tutkimusinfrastruktuureissa
** Potentiaalinen hanke

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Infrastructure funding

Academy of Finland

2011-2013 (~ 1 M€)

New infrastructure for the accelerator and separator facilities of the Accelerator Laboratory of the Department of Physics, University of Jyväskylä (JYFL-ACCLAB)

- MARA deflector (Team 2)
- IGISOL Solid state laser and Ge-detectors (Team 1)

2014-2015 (~ 1,3 M€)

State-of-the-art ion beam developments for JYFL-ACCLAB

- New 18 GHz ECR ion source “HIISI” (Team 3)
- MR-TOF spectrometer (Team 1 and Team 2)

2015-2017 (call open)

Helium ion microscope

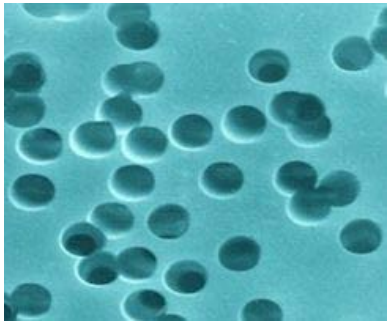
- Team 3

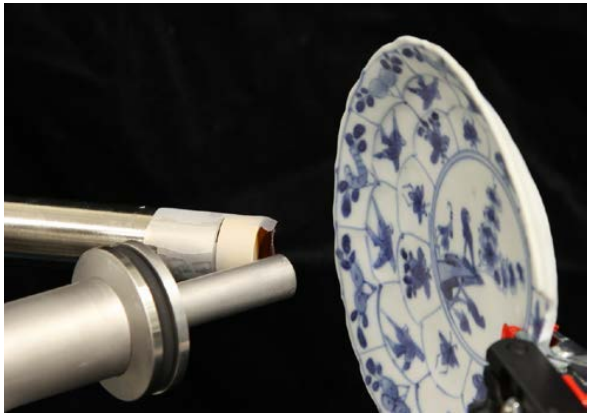
Detector development for CERN and FAIR (HIP+HY+JY consortium)

- Teams 1 and 2

Societal impact

- 16-25 % of the beam time is used for commercial services
- ESA accredited laboratory
- Collaboration with Finnish Radiation Safety Authorities
- Spin-off companies with strong contribution from the JYFL-ACCLAB
- High school visits and visitor groups (ACCLAB and NanoCenter)
- Open days for the public
- Radioisotope production
- Education of talented researchers for private sector and national research centers
- Cultural heritage program to investigate origin of art objects





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Research training in the ACCLAB

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

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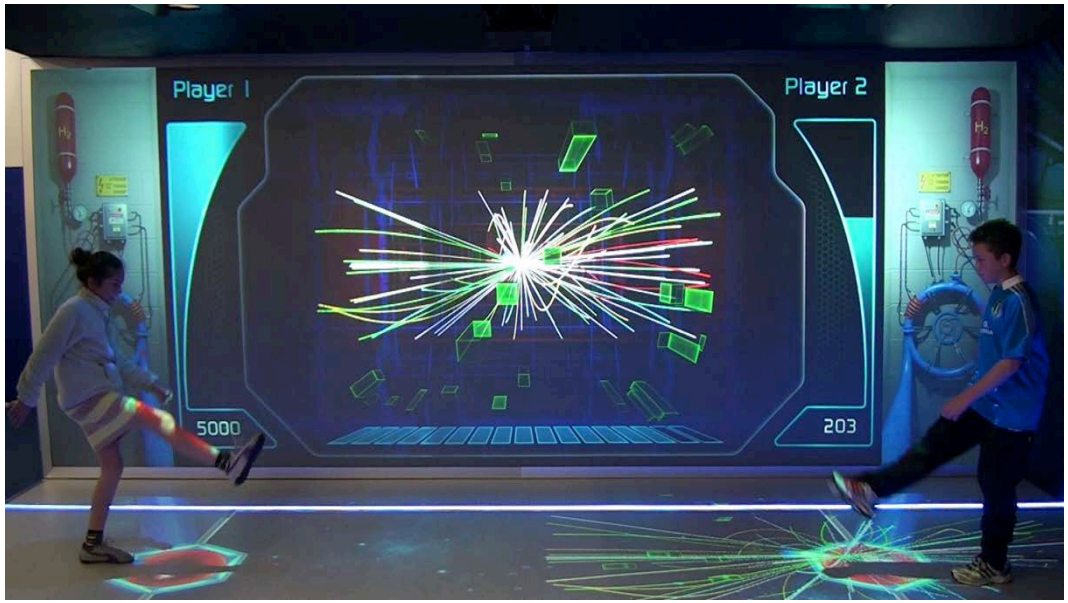
European Researchers' Night

Janne Pakarinen
Filippos Papadakis

- Open doors event
- 2 nights, September 2014 and September 2015
- Aiming to have more than 1500 visitors each year
- Visibility through printed and audio-visual media
- Collaboration with internationally acknowledged "Jyväskylä City of Light" event
- Involvement of all research staff
- Invitations to high schools

Events will include:

- Tours of the facility
- Demonstrations/Exhibitions
- LHC-tunnel
- Models of satellites
- Public lecture
- Illumination of experimental equipment



Marie-Sklodowska-Curie actions
Call: H2020-2014-MSCA-NIGHT

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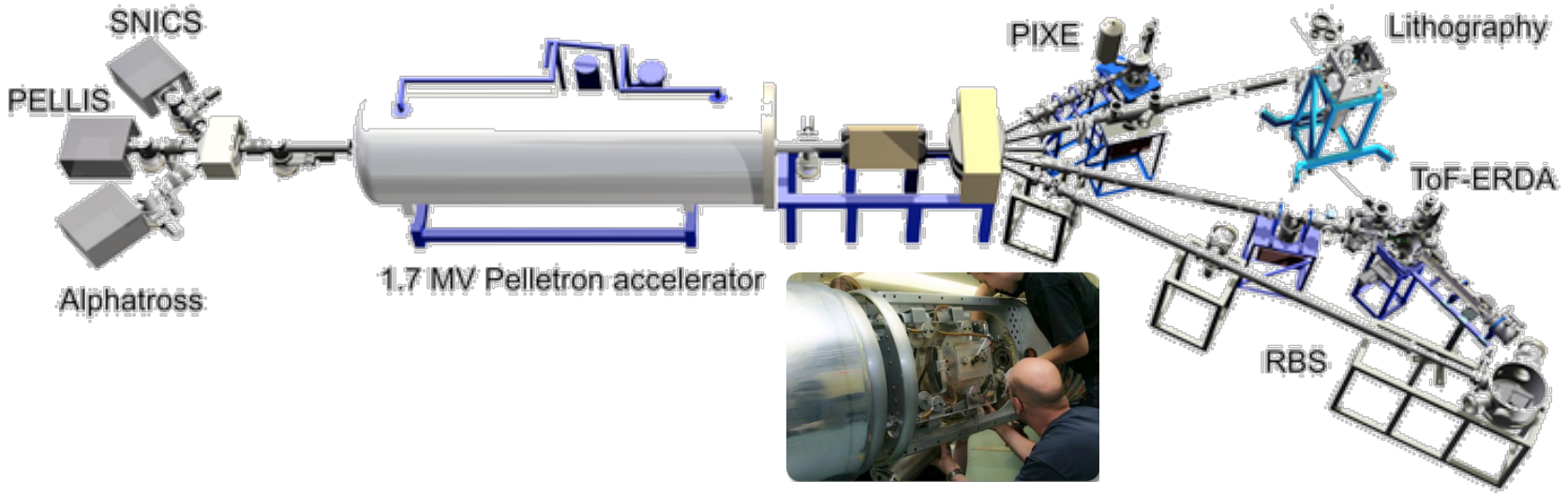
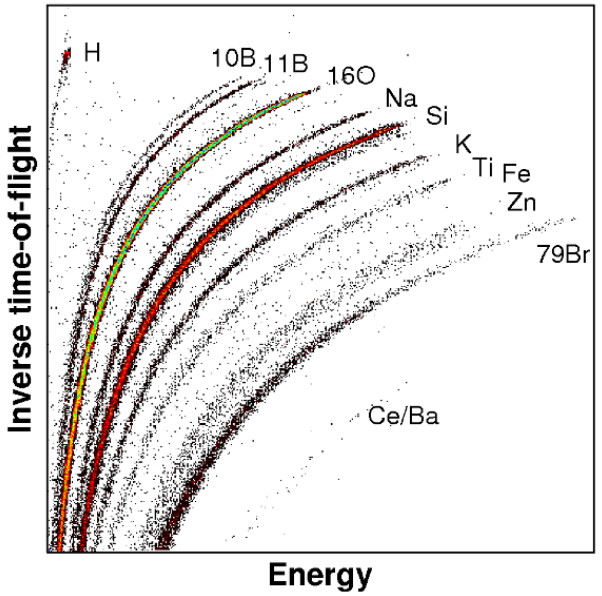
Materials physics at Pelletron laboratory

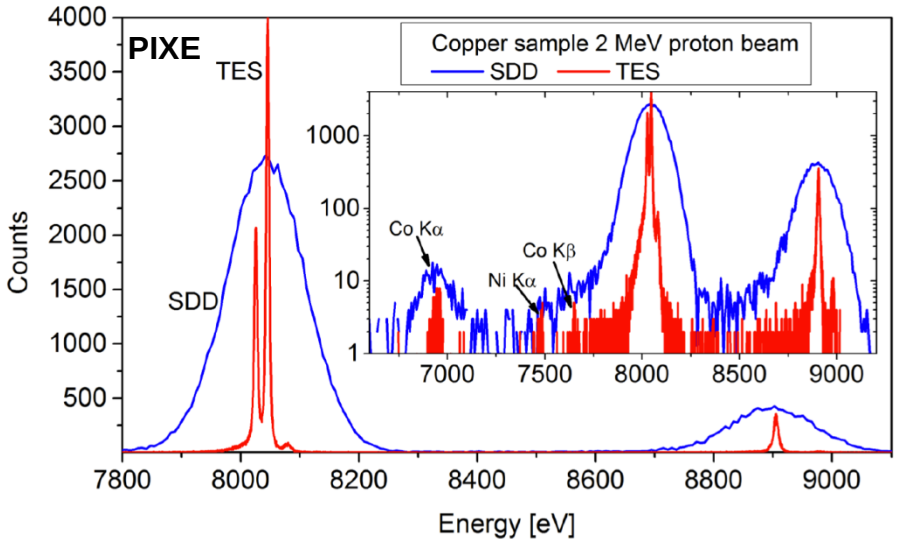
- Main research fields
  - Fundamental ion-matter interactions (cross sections, stopping forces, straggling)
  - Ion beam analysis (IBA) for thin film samples
  - Development of IBA techniques (detectors, data acquisition, simulations)
  - Thin film processing (ALD, proton beam writing, irradiation)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

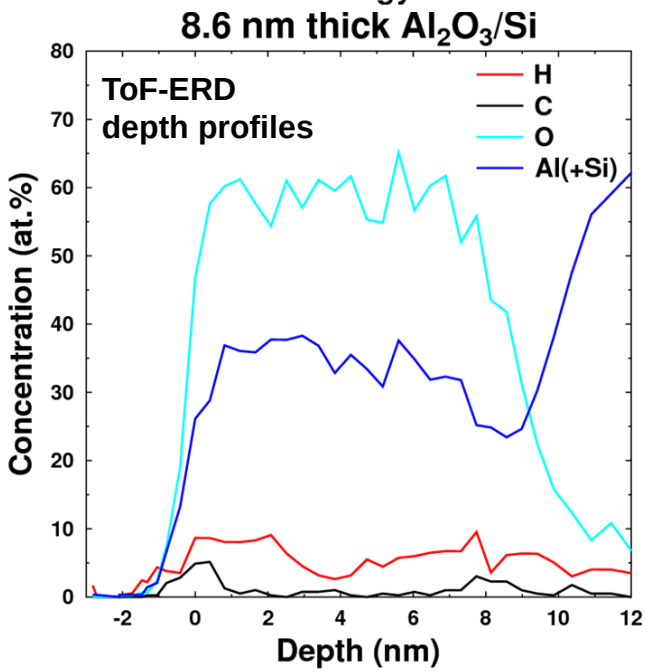


Development of ion beam analysis techniques

- 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 to observe chemical shifts

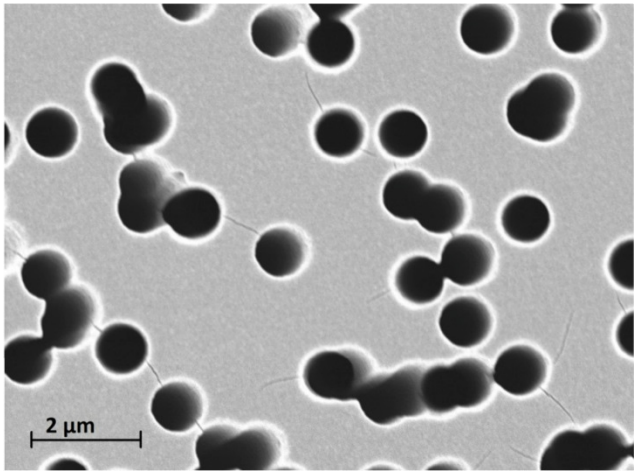


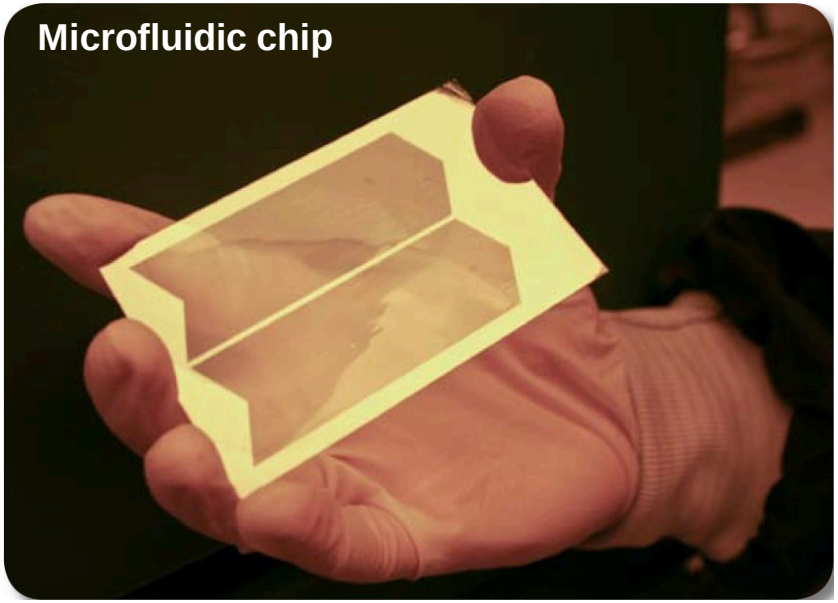




Thin films processing and applications

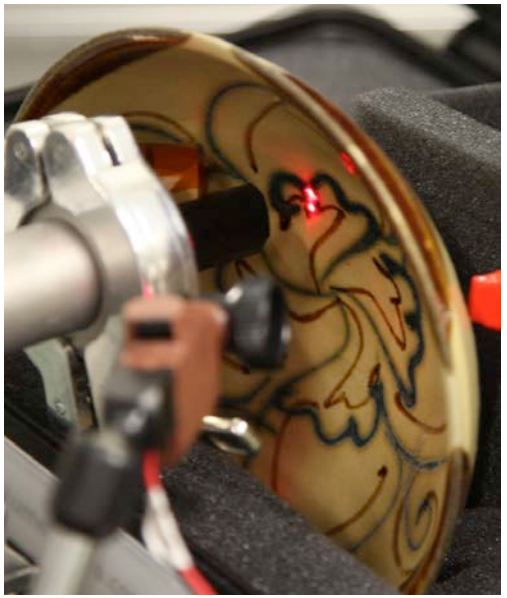
- Atomic layer deposition (ALD)
  - Oxides, nitrides, carbides, fluorides, sulphides and metals with excellent control of film thickness and high conformality for 3D structures
  - Mechanical properties of thin films on MEMS structures
  - Biomimetic materials (hydroxyapatite)
  - Hydrophilic/hydrophobic 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

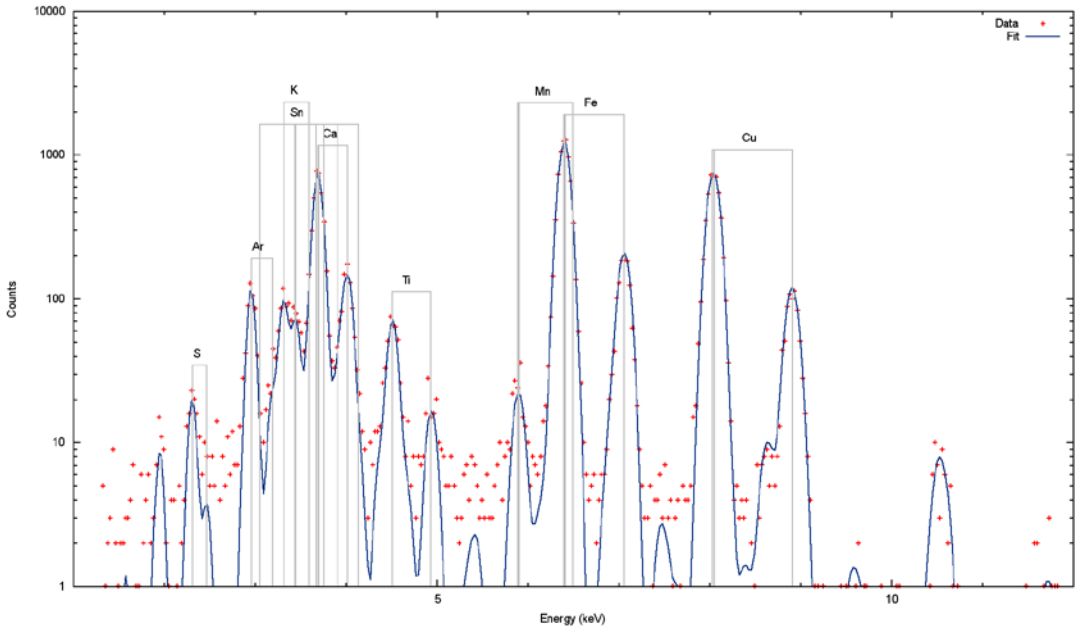




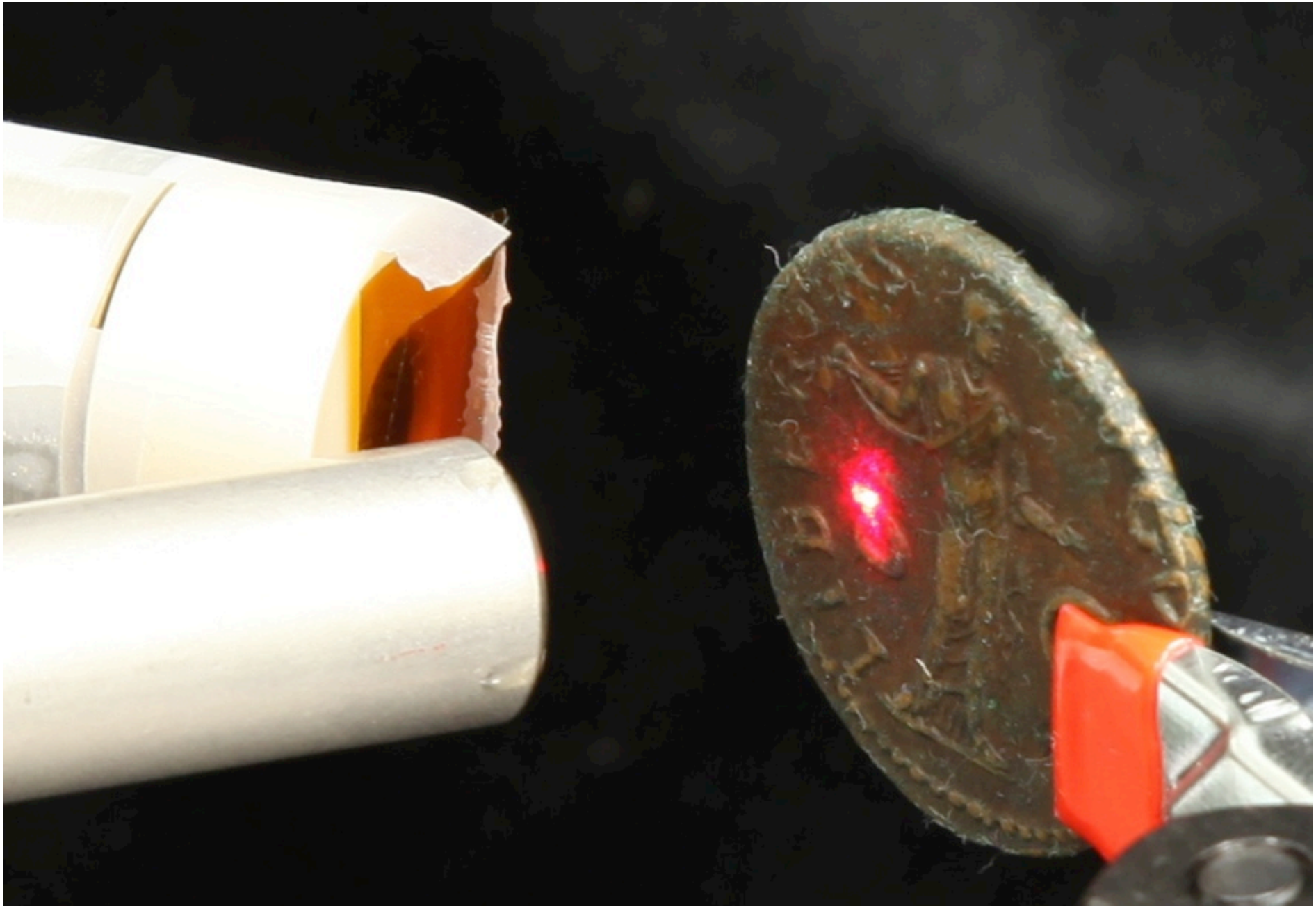
New ion beam application at JYFL: cultural heritage artefact studies with external beam

- RECENART – Research Center for Art established in Jyväskylä in 2014
  - Combines traditional and scientific methods to study art and artefacts
  - One of the analysis tools: External 3 MeV proton beam from 1.7 MV Pelletron accelerator used for particle induced x-ray emission (PIXE) measurements
  - Pilot study: Chinese bowl from Tang Dynasty (618–907 AD) period, composition of colors, glazing and body

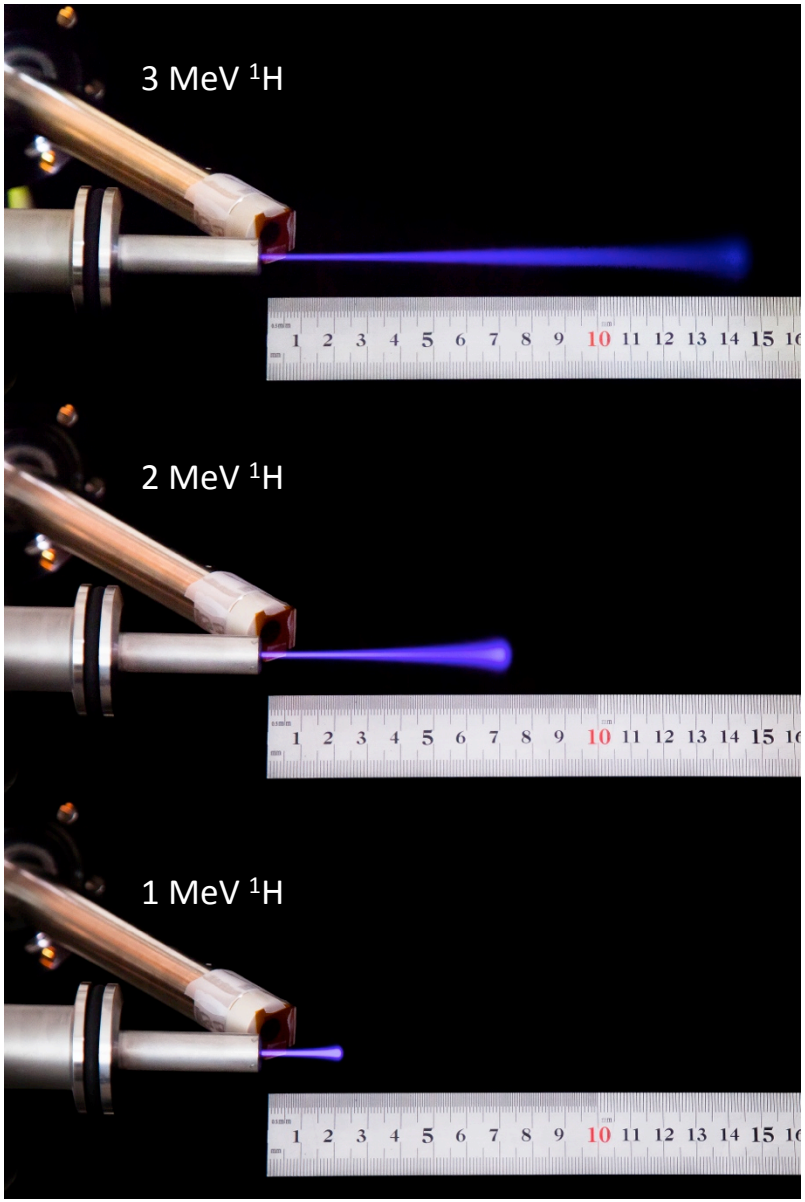


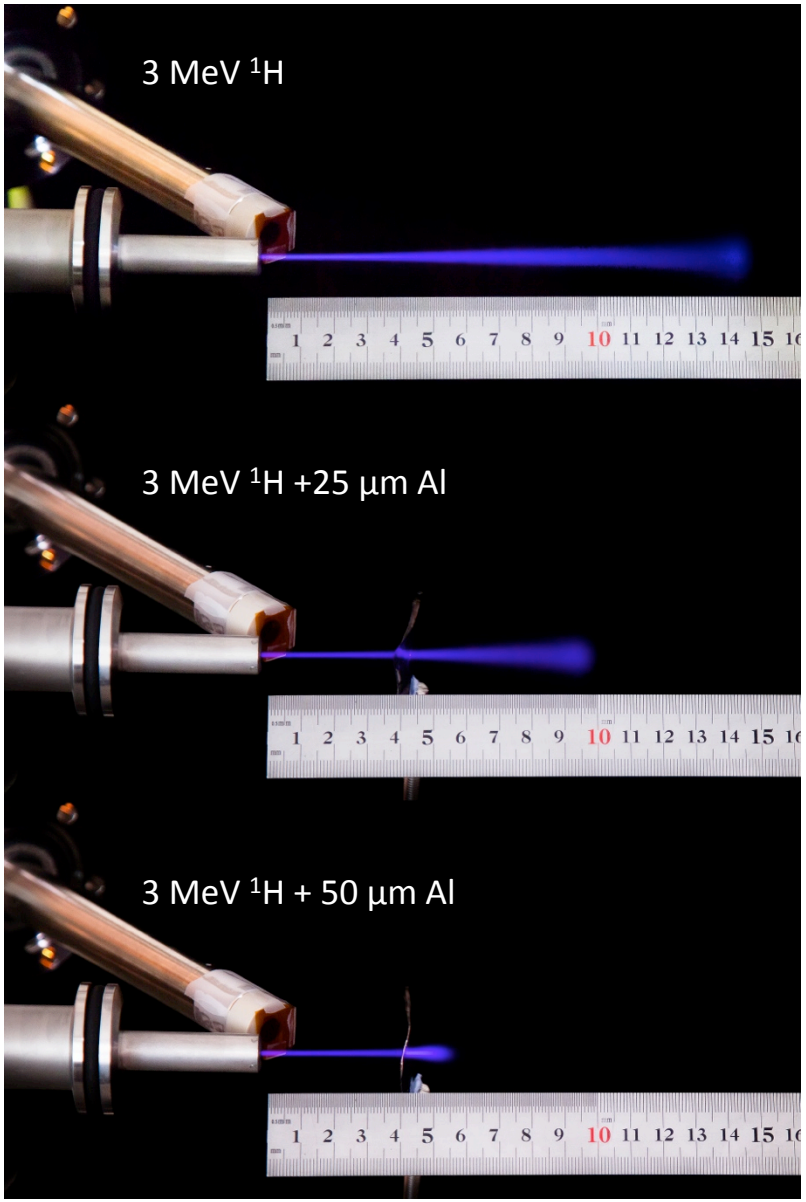


PIXE spectrum from blue color shows high Cu content and the absence of Co: both typical findings for porcelain originating from Changsha kiln active during the Tang period



External beam





RADiation Effects Facility (RADEF)

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Commercial activity
for
space industry

Official test laboratory of ESA; since 2005

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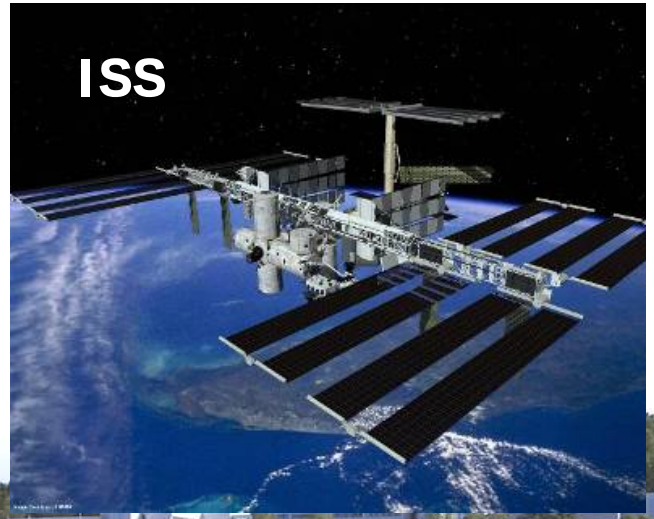
ESA/ESTEC/Contract No. 18197/04/NL/CP
”Utilisation of the High Energy Heavy Ion Test Facility for Component Radiation Studies”

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?

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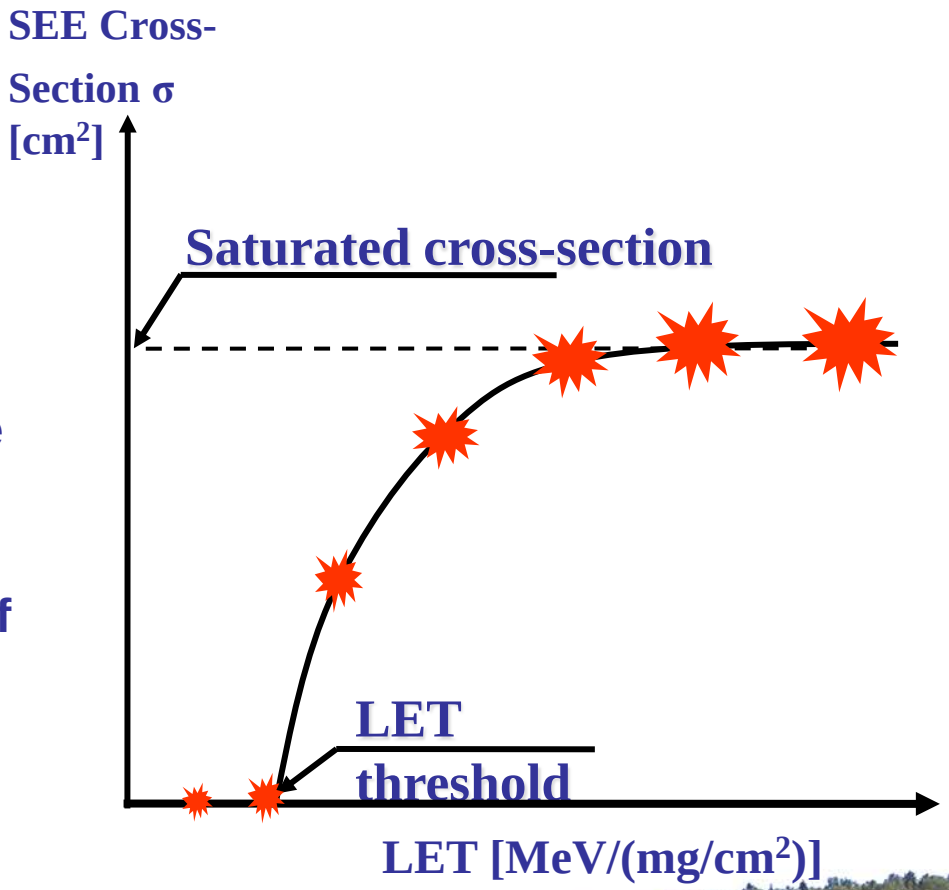
By determining the error cross-section σ as a function of LET* we define the LET threshold and Saturated cross-section.

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

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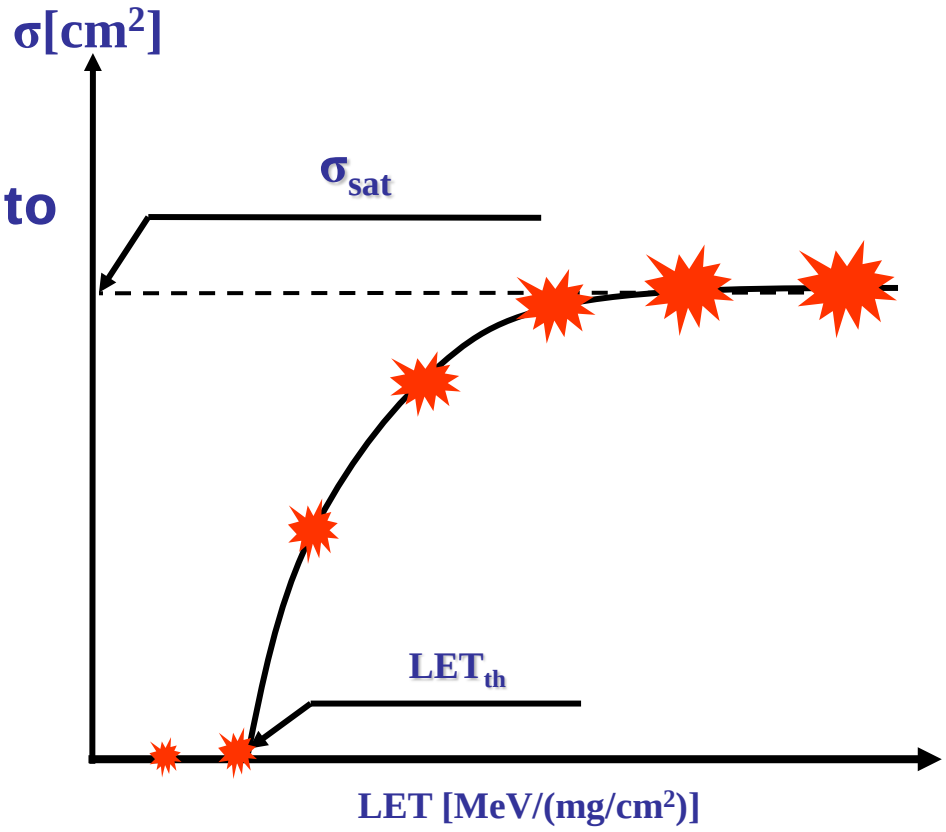
Technical:

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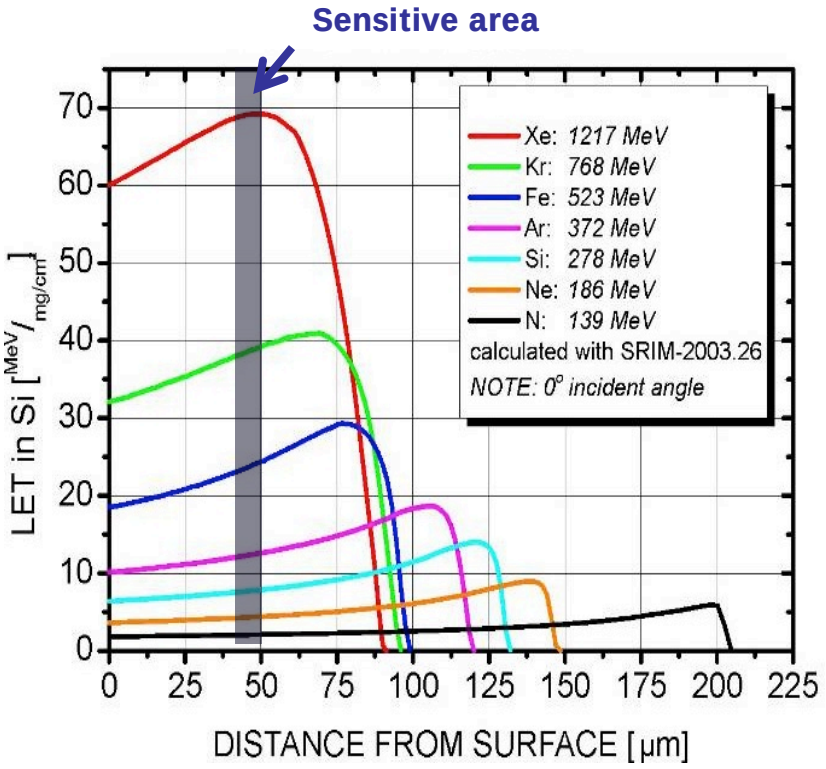
$^{A}Ion^{q+}$ q/A≈ 0.27	E [MeV]	Range [µm]	LET @surface [MeV·cm²/mg]	LET @bragg [MeV·cm²/mg]
$^{15}N^{4+}$	139	202	2	6
$^{20}Ne^{6+}$	186	146	4	9
$^{30}Si^{8+}$	278	130	6	14
$^{40}Ar^{12+}$	372	118	10	19
$^{56}Fe^{15+}$	523	97	19	21
$^{82}Kr^{22+}$	768	94	32	41
$^{131}Xe^{35+}$	1217	89	60	69



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

Customers in 2013

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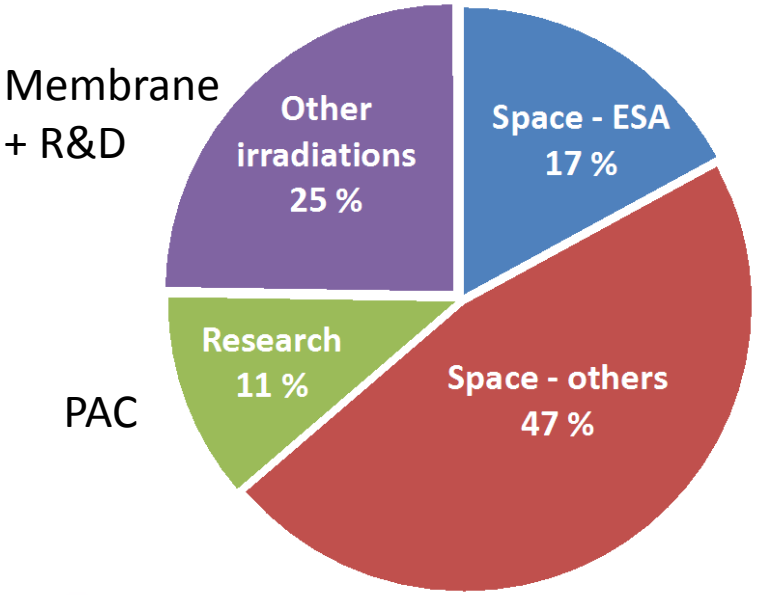
- 46 test campaigns by 28 individual users
- ~25% of K=130 beam time



AEROFLEX, Gothenburg, Sweden
ASRO, Turku, Finland
ATMEL, Nantes, France
CEA, Gif-sur-Yvette, France
CNES, Toulouse, France
Cypress Semiconductor, San Jose, CA, USA
DLR, German Aerospace Center, Wessling, Germany
EADS ASTRIUM, Elancourt, France
EADS ASTRIUM, Portsmouth, UK
ESA/ESTEC, Noordwijk, The Netherlands
HIREX Engineering, Toulouse, France
MapRAD, Peruga, Italy
Naval Research Laboratory, Washington DC, USA
Oxyphen, Wetzikon, Switzerland
Paul Scherrer Institute, Villigen, Switzerland
RedCat Devices, Milan, Italy
RUAG Sweden, Gothenburg
Saphyrion, Bioggio, Switzerland
STUK, Radiation and Nuclear Safety Authority of Finland
ST Microelectronics, Catania, Italy
Synergy Health, Oxfordshire, UK
Thales Alenia Space, Toulouse, France
TRAD, Labege, France
University of Bergen, Norway
University of Cyprus, Nicosia, Cyprus
University of Milan, Italy
University of Montpellier, France
University of Palermo, Italy

Commercial activity for microfilter industry

Irradiation of polymer films

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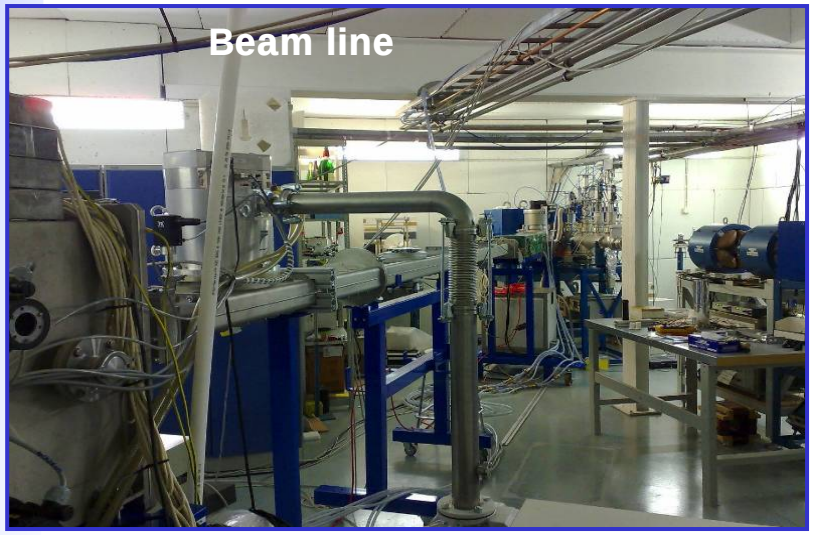
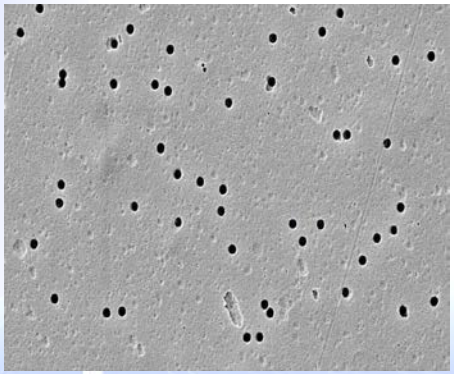
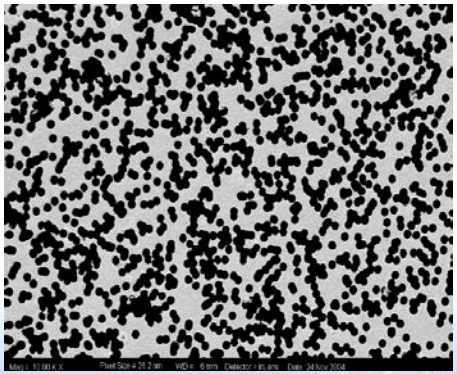


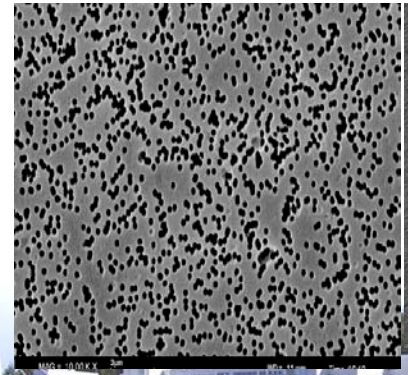
to etching

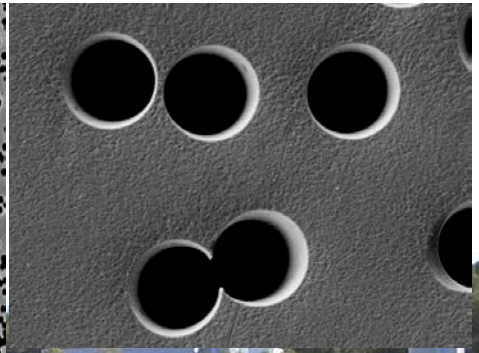
10^5 pores / cm^2 → 10^9 pores / cm^2



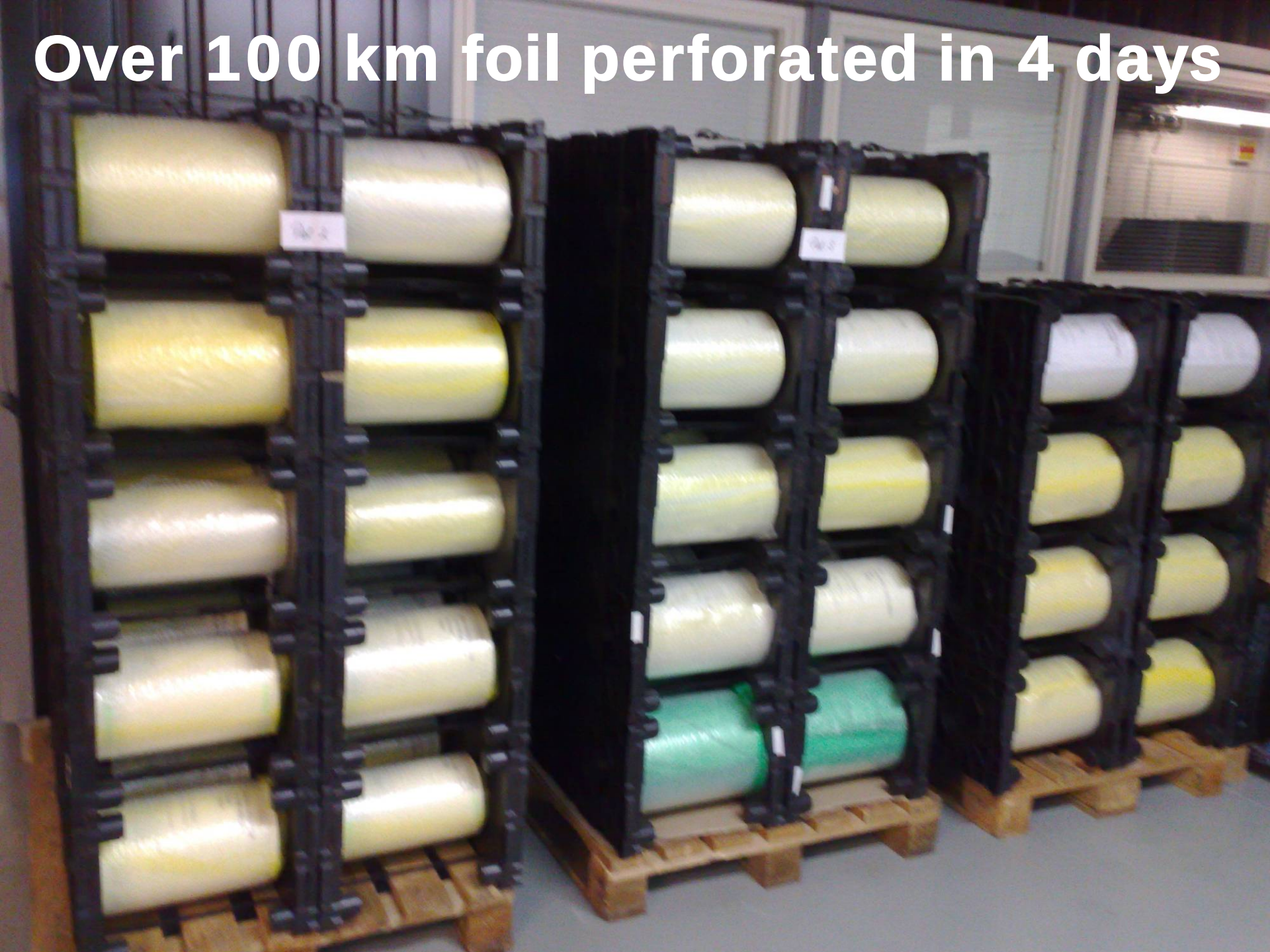


0.1 µm → 10 µm





Over 100 km foil perforated in 4 days



Used in e.g. car industry

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Modern headlamps are transparent systems with complex thermal characteristics; moisture, dust and heat affect function and appearance

Cayenne

Solution:
Filter, using Oxyphen **RoTrac®** capillary pore membrane, removes moisture, vents the headlamp and stops water and dust, c.f. GoreTex

- highlights

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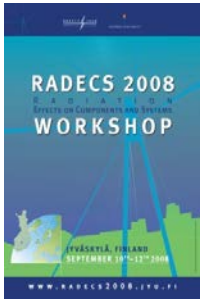
2005, ESTEC/Contract No. 18197/04/NL/CP

- Utilisation of the High Energy Heavy Ion Test Facility For Component Radiation Studies

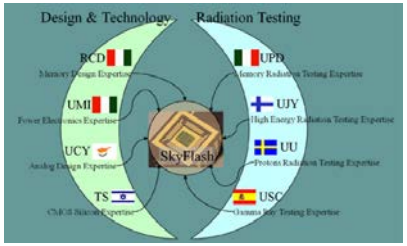
RADECS 2008 in Jyväskylä:



- 232 participants from 29 countries, 93 presentations, 13 exhibitors
- best conference of the year awarded by Jyväskylä Convention Bureau

EU's FP7-SPACE-10 Program:

- SkyFlash - Development of RadHard non volatile Flash memories for space applications



First prize in the Academic Entrepreneurship Competition 2011 for Finnish universities

In 2012 1st PhD - thesis

- By Arto Javanainen: Particle radiation in microelectronics

Future activities

New 18 GHz ECRIS (HIISI)

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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.

→ RADEF competitive with e.g. Texas A&M Univ.

HORIZON 2020

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- Proposals for H2020-COMPET-2014 (RADEF as partner)
  - SPES (SOI PLL for Earth hostile environment and Space applications)
  - SOLIS (SOI Library for Space Applications)
  - SpaceMIST (Space Mixed Signal Circuits and Technologies)
  - R2RAM (Radiation Hard Resistive Random-Access Memory)
  - LIRARSUP (Light weight, Radiation Resistant SUPerconductiong wires for space applications)

Electron LINAC (Varian)

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- Energetic electrons for radiation hardness assurance (RHA) testing
- 100 k€ from ESA
- E_e = 6-18 MeV
- JUICE-mission

NASA/JPL

(Jupiter Icy Moon Explorer)

  - "The most dominant trapped particle constituents at Jupiter are electrons with energy in the 1>E>100 MeV range." (NASA, Norman *et al.*)
- All ESA's MEO-satellites (2000 – 35 000 km)
  - Navigation (GPS), communication, and geodetic/space environment science
  - Van Allen electron belt (tens of MeV)

Summary

UNIVERSITY OF JYVÄSKYLÄ

- University laboratory
- Three accelerators for basic and applied research:
  - Commercial and industrial usage of K130 25 % (Heavy ions)
  - MCC30 (Intense light ions)
  - Pelletron accelerator and ALD
- Solid international and national status
- Interdisciplinary program, especially at IGISOL
- RADEF; RADiation Effects Facility
  - ESA accredited since 2005
  - Annual revenue increasing
- New projects coming (electrons, α-therapy,...)

Contacts:

UNIVERSITY OF JYVÄSKYLÄ

RADEF: Ari Virtanen
Pelletron: Timo Sajavaara

Head of the Accelerator Laboratory: Ari Jokinen
Accelerators: Pauli Heikkinen
Ion Sources: Hannu Koivisto
IGISOL: Ari Jokinen
Gamma/RITU: Paul Greenlees and Juha Uusitalo

Firstname.lastname@jyu.fi

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


Thank you for your attention !