

Jožef Stefan Institute

**F2 / Department of Low
and Medium Energy Physics**

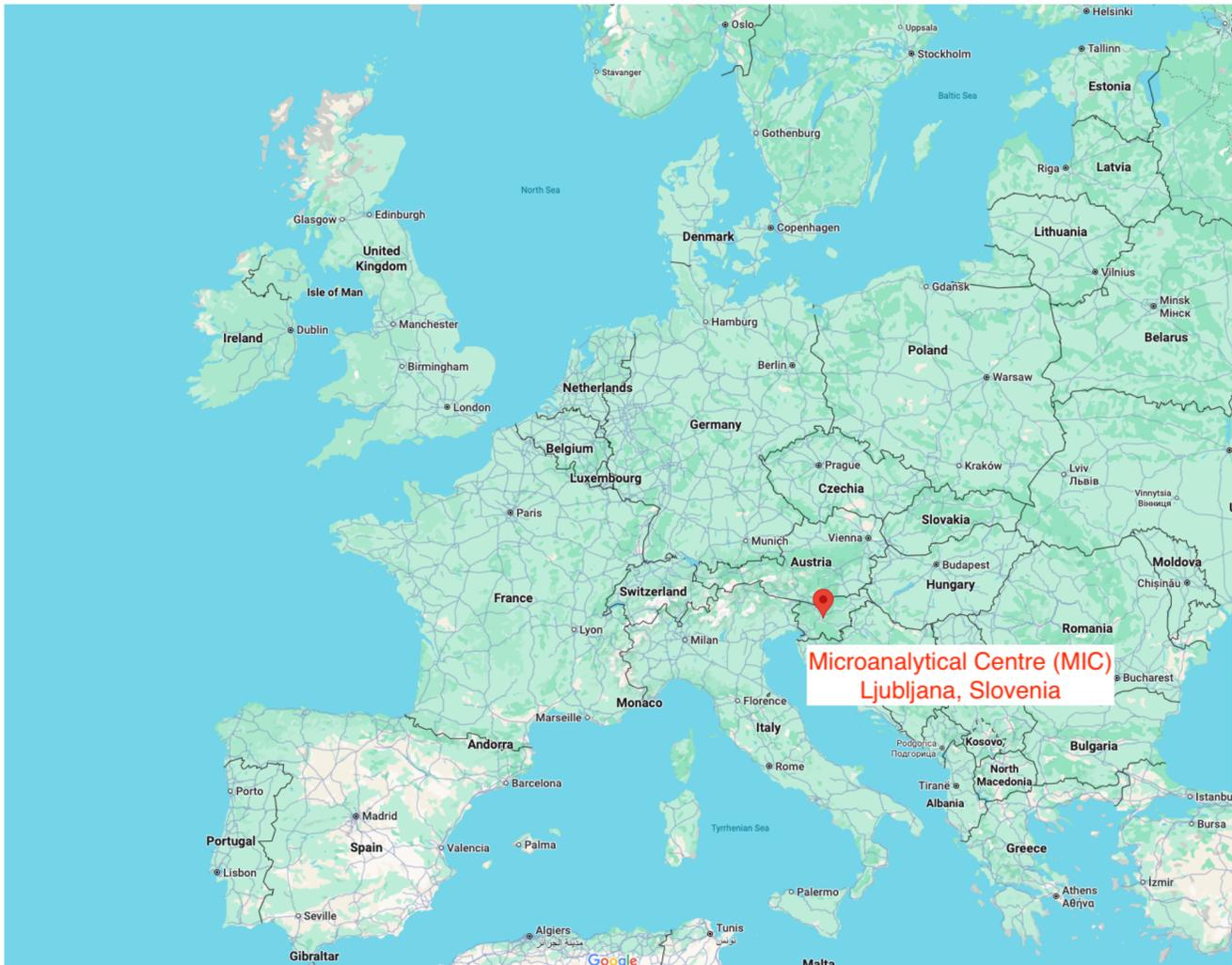
JSI ion implantation group's path to EDF

Ž. Brenčič, M. Kelemen, Ž. Gosar, R. Podlipec, M. Skobe, A. Šestan, and P. Pelicon

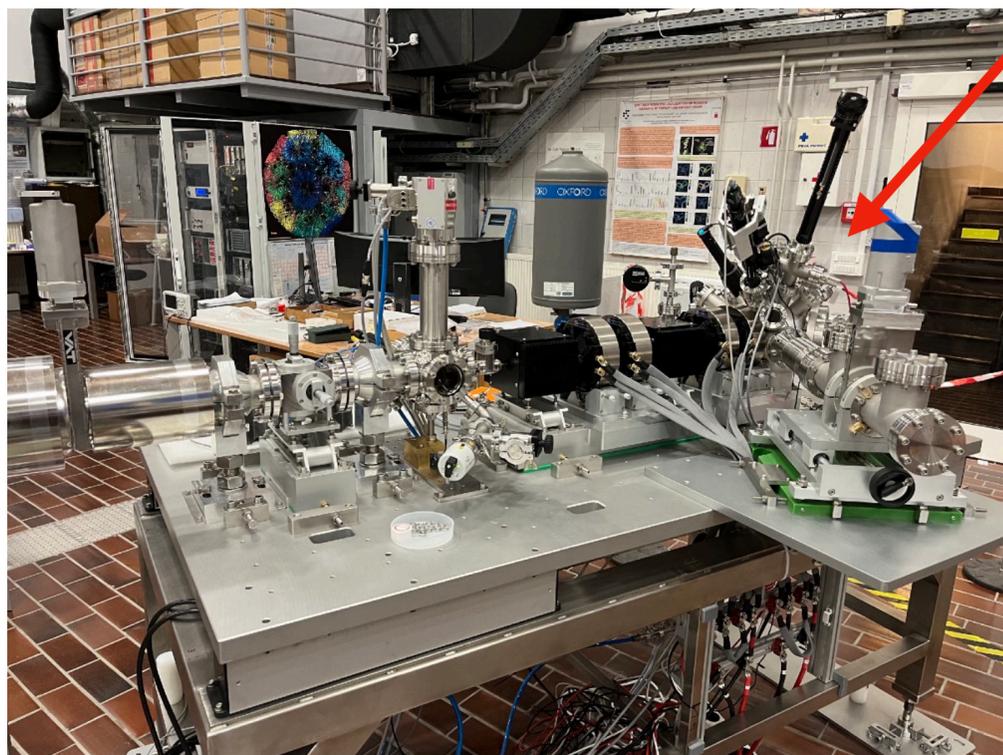
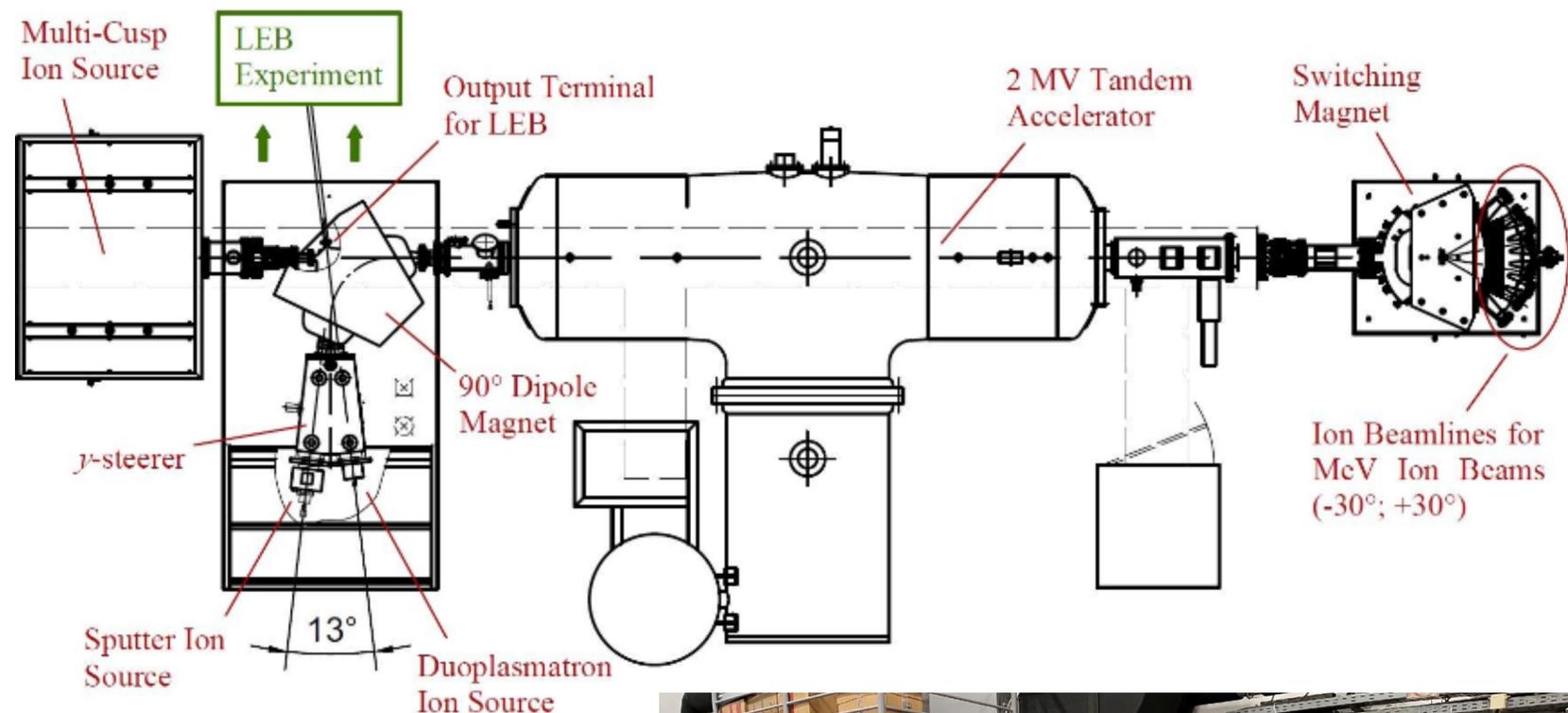
Jožef Stefan Institute, Ljubljana, Slovenia

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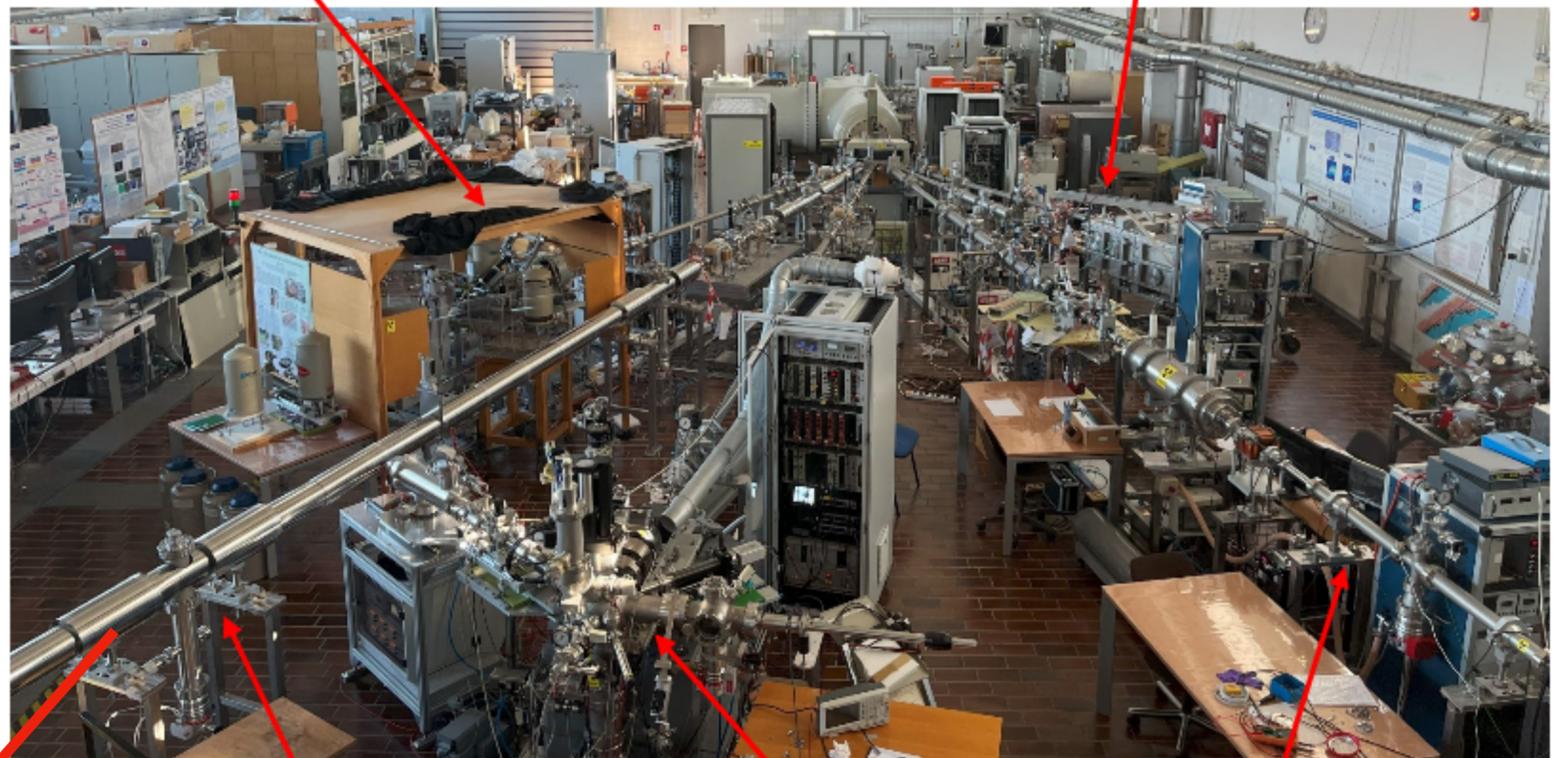


Microanalytical Center (MIC)



External ion beamline (-30°)

High-resolution x-ray spectroscopy (+30°)

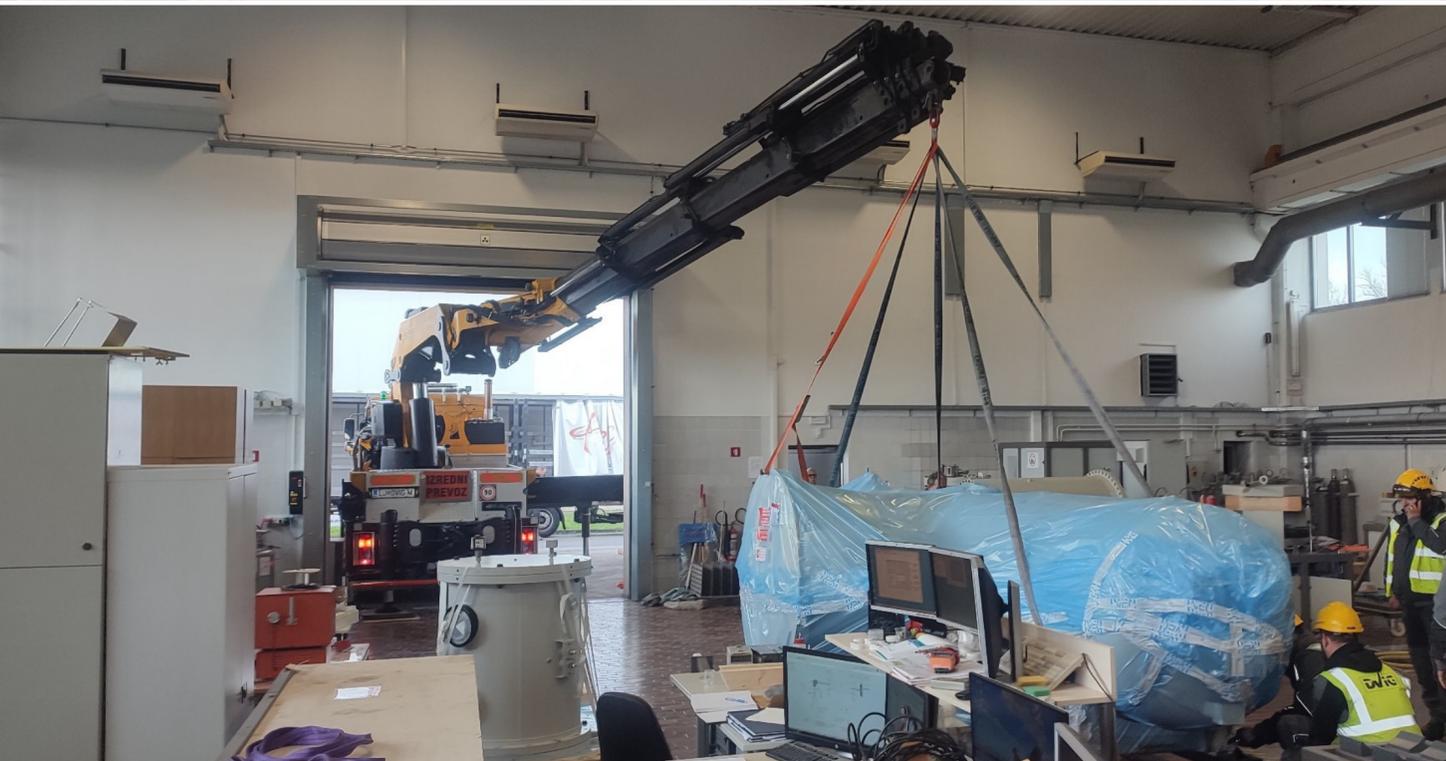


Nanobeam (-20°)

Microbeam (-10°)

INSIBA (+10°)

New accelerator



Particle Implantation and Quantum science Laboratory (PIQsL)

F2



Matevž Skobe

(Mechanical design, control system)



Mitja Kelemen

(Accelerator operation, RSF PI)



Klemen Bučar

(Control system)



Žiga Brenčič

(Ion Optics, SQORPION PI)



Primož Pelicon

(Nano beam)



Andreja Šestan

(Microscopy)

F5



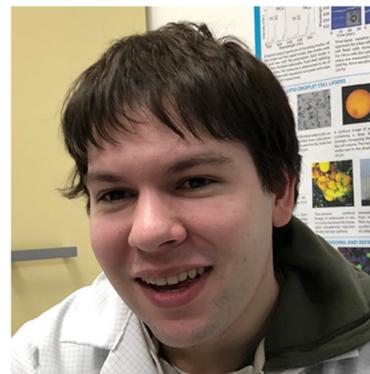
Žiga Gosar

(N-V center verification)



Rok Podlipec

(Confocal microscope)



Gregor Pirnat

(Fluorescence microscope)

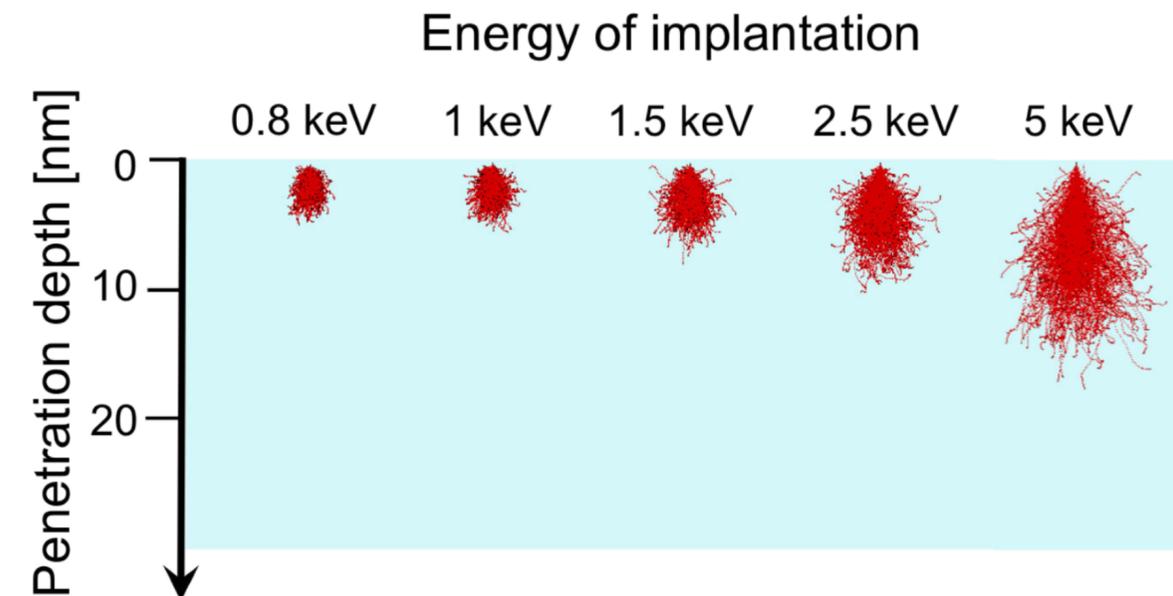
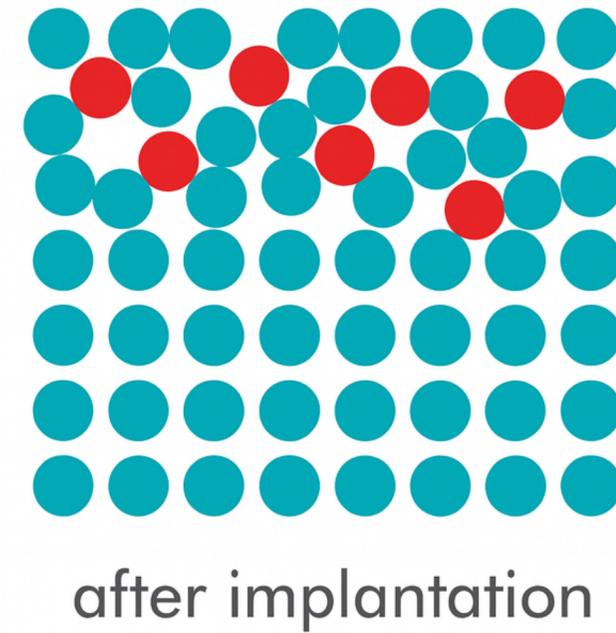
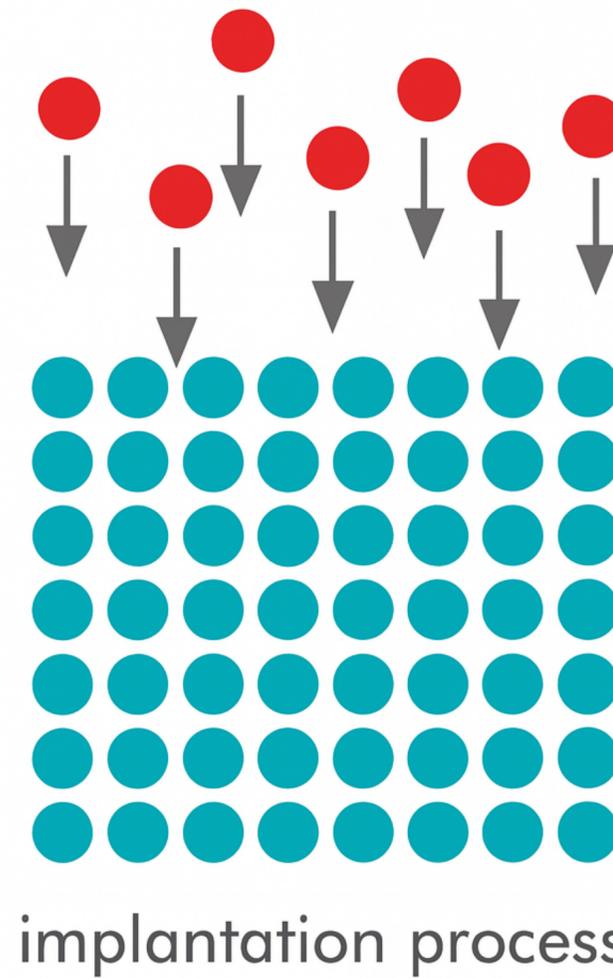


Before EDF

Why ion implantation?

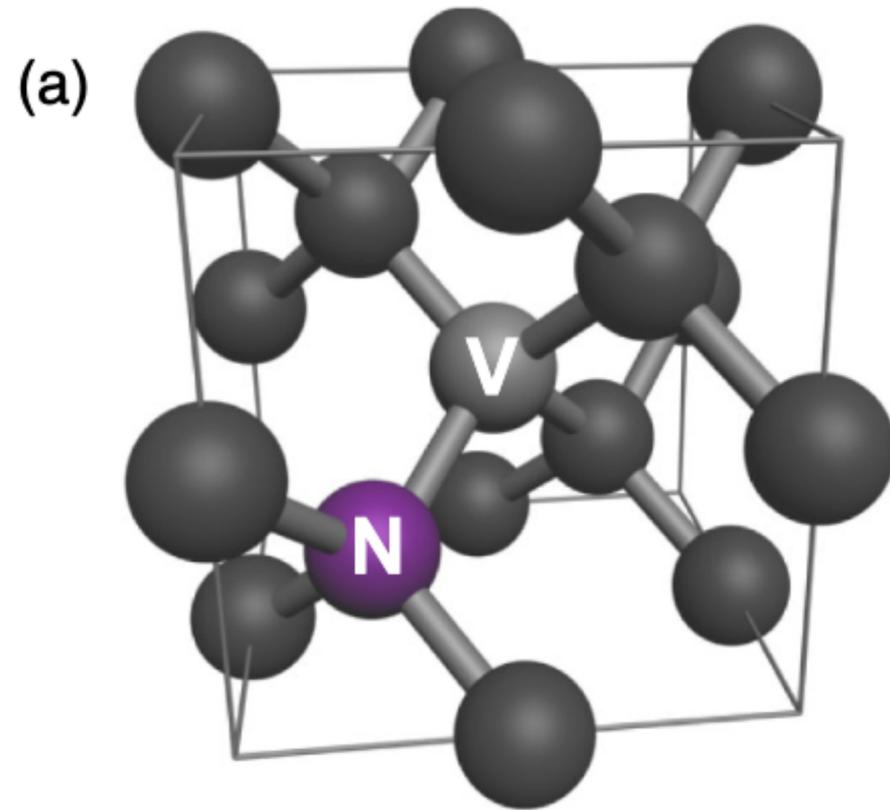
Missing facility capability!

- For material analysis.
- For basic physics studies.
- For semiconductor research, doping, since 1960s.
- Lastly creation of NV centres.

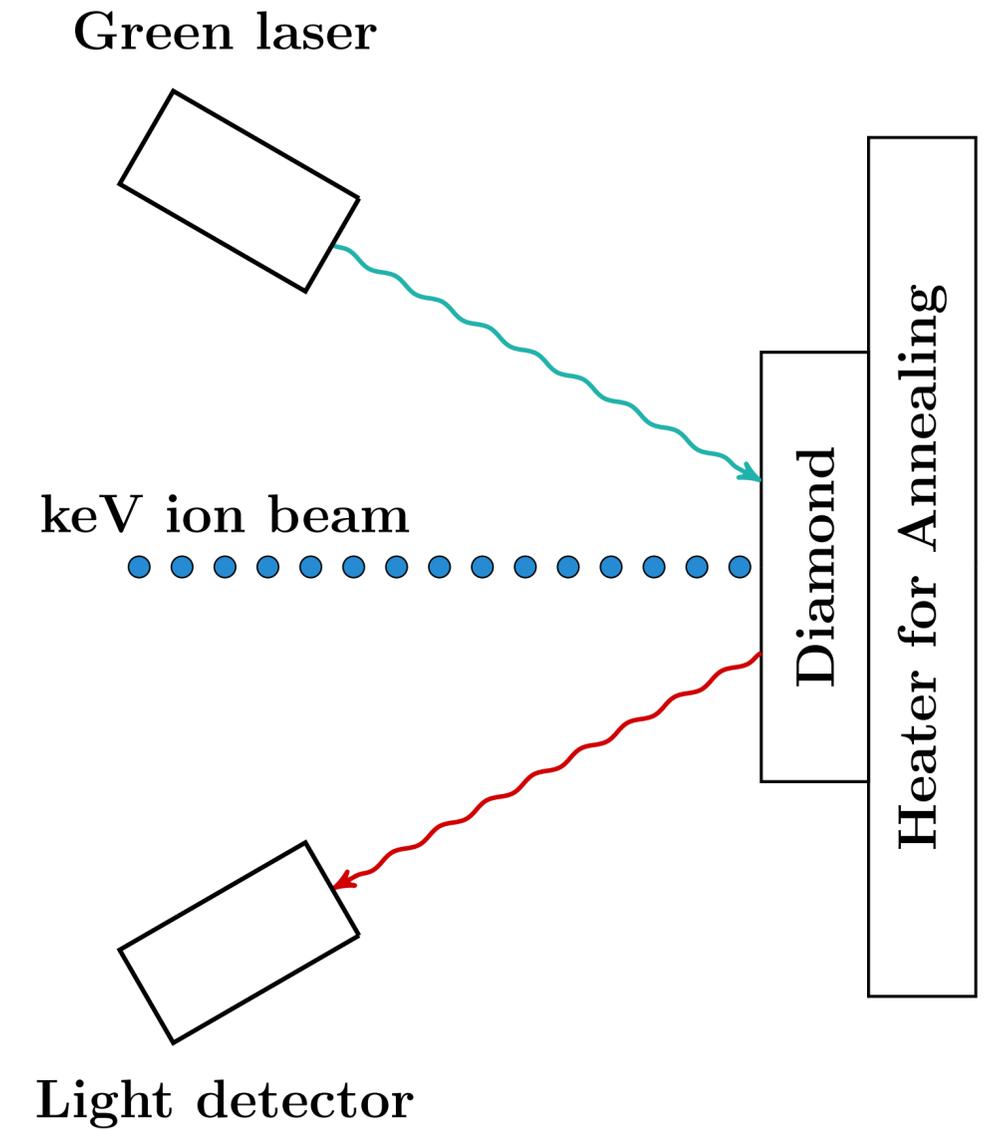


Nitrogen-vacancy centres

Solid state qubits



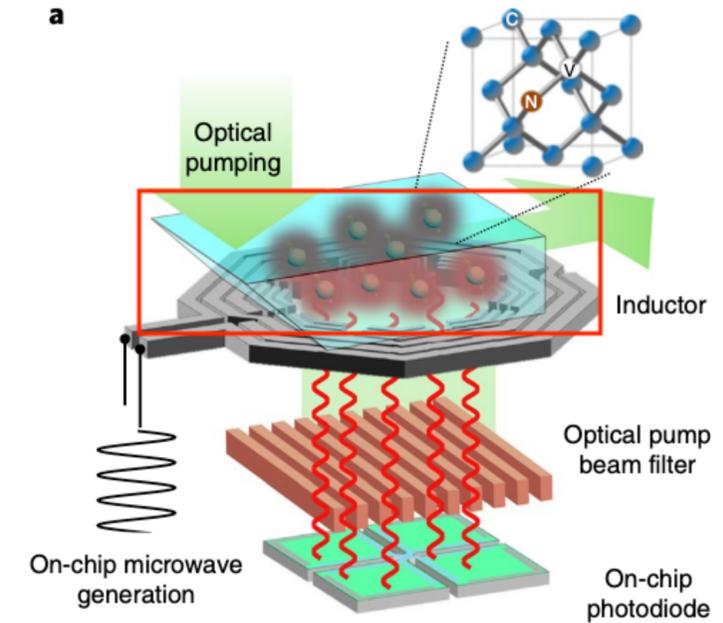
Du et al. RMP, 025001-1 (2024)

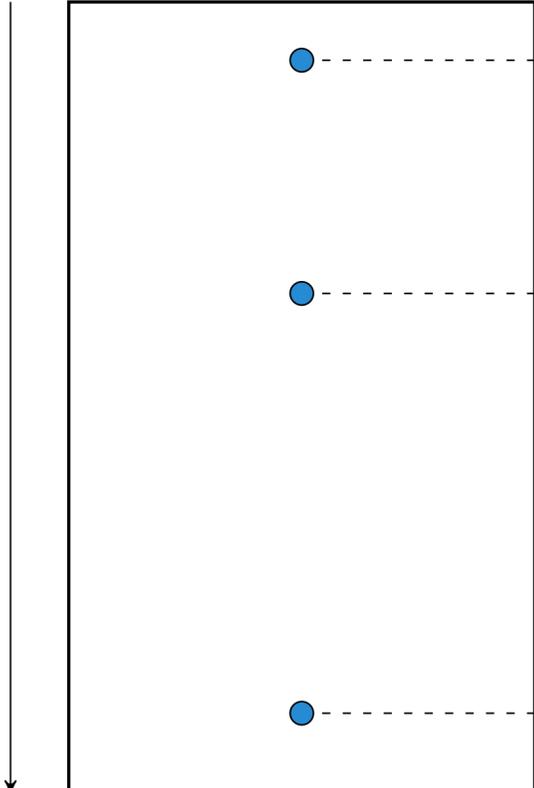
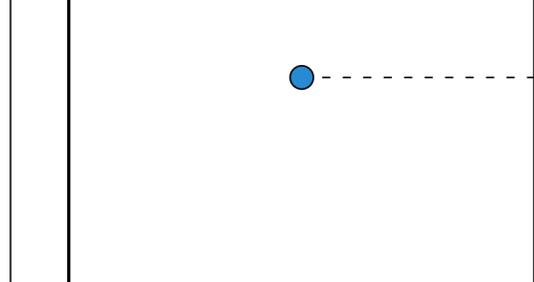
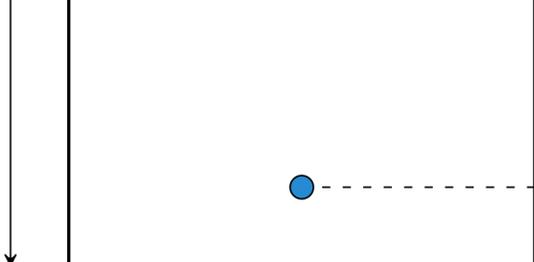


Colour centre: Crystal defect that acts as a quantum state that emits light upon excitation.

N-V centre based quantum sensors

- Goal is to sense small magnetic fields.
- Fridge magnet: (10 mT)
- Earth's magnetic field (25 - 65 μT), nT accuracy needed for navigation.

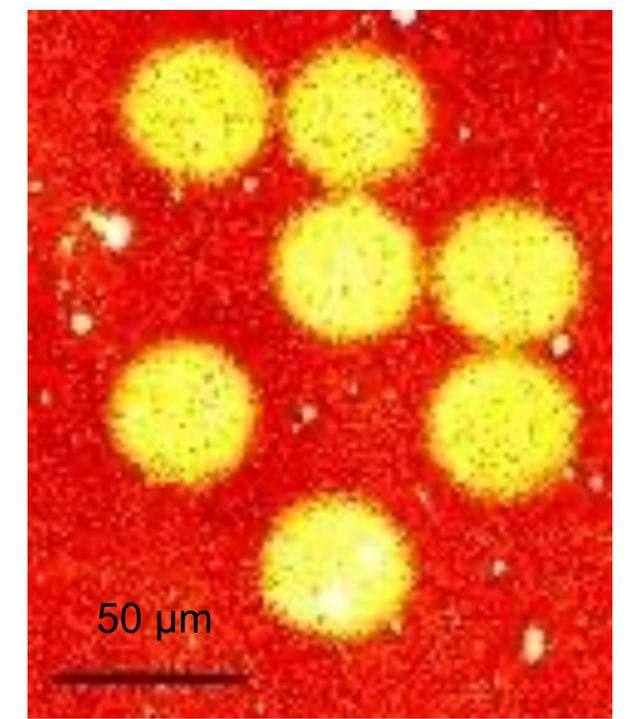
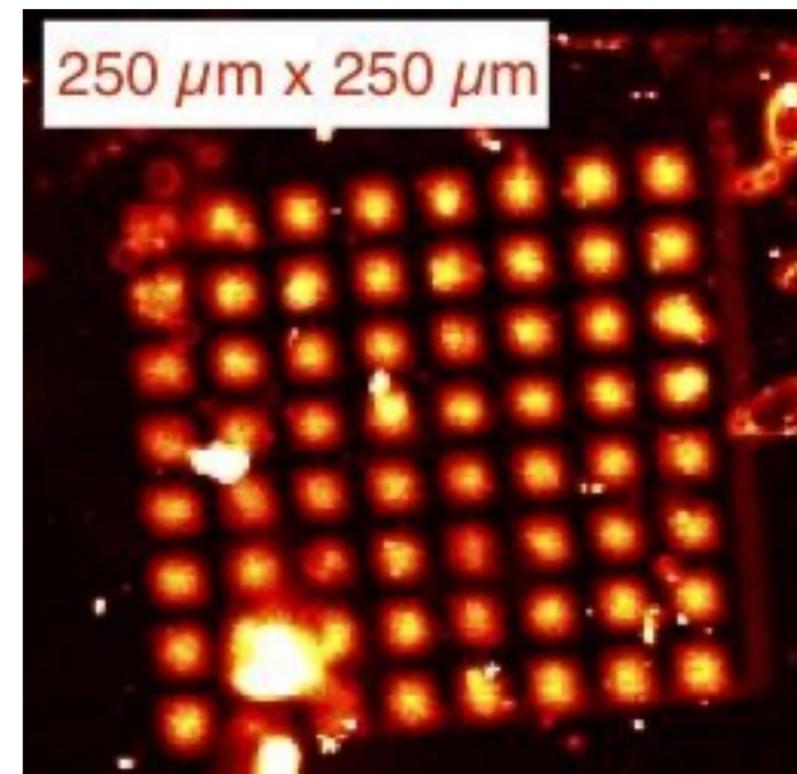


Diamond	Depth	Beam Energy	Magnetometer application	Sensitivity	Equipment
	< 20 nm	< 5 KeV	Nuclear spin sensing, anti-ferromagnetism, superconductors	\sim mT	Low Energy Branch
	100 nm	\sim 40 KeV	Ferromagnetism	\sim 30 mT	Low Energy Branch
	3 μm	5 MeV	Gyroscope resistant to external perturbations. Orientation using Earth's magnetic field.	\sim 30 μT	Nano beam

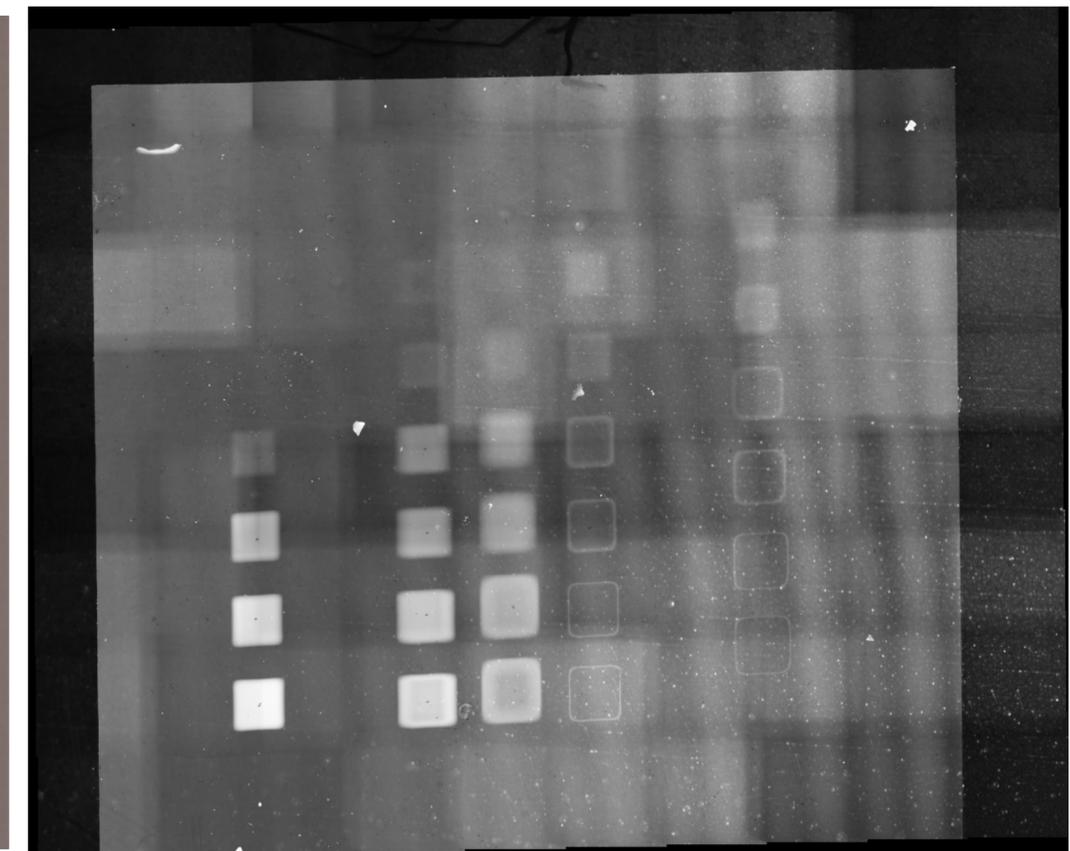
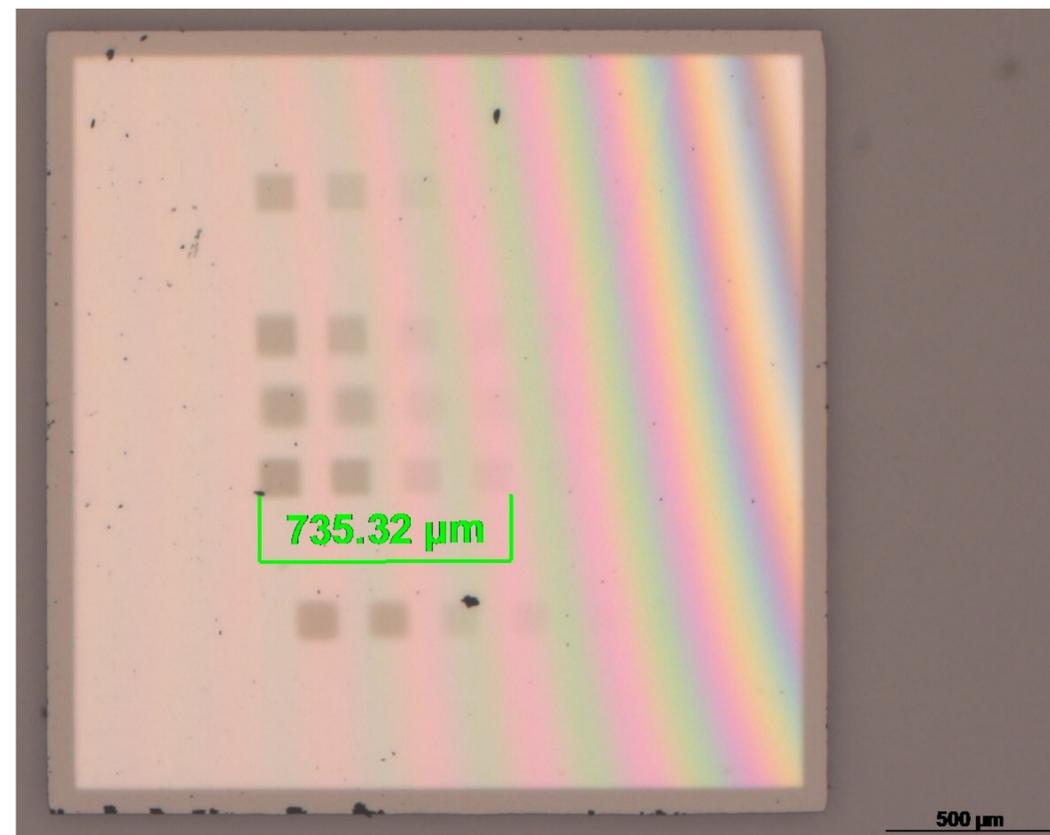
^{15}N implantation

First N-V centres in diamond:

- Started in 2023,
- Diamonds: 2 mm x 2 mm x 0.5mm,
- Low N ppb, by Element Six,
- Ion beam ^{15}N with high energy 3.8 MeV,
- Exposure time, depth variation studies a.t.m.



Optical response of implanted areas under the confocal microscope (F5). Barba, Kokot.



Application process

2024-10

- 2022: First implantation project at JSI.
- 2023: Collaboration with SAL, Austria started.
- 2024: Internal JSI project to develop the implantation capabilities.

- Oct 2024 SAL invited us into EDF consortium. => Nov 2024 submission.
 - Hectic application for us, due to last minute consortium integration.
 - Not clear for Slovenian partners how local MOD has to be included.
 - We were informed that local MOD doesn't need to approve our application.



SQORPION

Spin-based Quantum Optics for Robust and Precise Inertial Sensing, Orientation and Navigation

SQORPION deals with the development of solid-state spin based quantum sensors for defence applications based on magnetic anomaly detection.

The project aims to provide a miniature position, navigation timing system based on a solid-state spin-based quantum system-on-a-chip approach. The nuclear spin-based quantum gyroscope's sensitivity to magnetic fields allows for magnetic anomaly detection and magnetic crustal field navigation, which will support positioning for defence systems in global navigation satellite system denied environments.

- Solid-state room temperature,
- Spin-based qubit,
- Leverage sensitivity to magnetic field for navigation that doesn't rely on GPS.

NAME OF THE ENTITY	COUNTRY
SILICON AUSTRIA LABS GMBH (Coordinator)	Austria
COSYLAB LABORATORIJ ZA KONTROLNE SISTEME DD	Slovenia
IHP GMBH - LEIBNIZ INSTITUTE FOR HIGH PERFORMANCE MICROELECTRONICS	Germany
INSTITUT JOZEF STEFAN	Slovenia
JOHANNES GUTENBERG-UNIVERSITAT MAINZ	Germany
NORTHROP GRUMMAN ITALIA S.P.A.	Italy
SCHIEBEL ELEKTRONISCHE GERATE GMBH	Austria



"(The SQORPION project is) funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Commission. Neither the European Union nor the granting authority can be held responsible for them."

Project approved

2025-05-01



- Approved in May 2025.
- Most of the consortium was blindsided by all of the security requirements.
- Quite time till Sep 2025.
 - EU EDF, PO, Security officer, project coordinator ping-pong.

Paperwork

Security clearance

- Security assessment letter (SAL) was a bit dumped on us.
 - Another MOD demanding the restriction of specific JSI results, without explanation.
- Obtaining:
 - Facility Security Clearance (FSC) => JSI has it,
 - Personal security Clearance (PSC) => in progress,
 - Luckily JSI has a security officer, but still took us weeks to sort this out.

Paperwork

- How to properly establish the background IP?
 - Which is key!
 - Everything you can't prove you did before the project is then restricted, ...
 - JSI has some experience, but we struggled here, ...
 - GA, CA again ping-pong with EU EDF, etc.
 - As a result project got pushed to 1.12.
 - 6 months :(
- => 1y of work already and we didn't even start ...

So allocate time for this process, for sorting out the execution details with project partners.

JSI Implanter menue



- General (non-radioactive) ion of choice.
- Substrate: diamond, silicon carbide, Si, etc.
- Implantation depths: 100 nm - 5 um.
- Good position control um and below.

=> Feel free to reach out: ziga.brencic@ijs.si

The periodic table is color-coded by groups: Alkali metals (light blue), Alkaline earth metals (red), Transition metals (purple), Post-transition metals (green), Metalloids (yellow), Reactive non-metals (blue), Noble gases (pink), and Lanthanides (light blue). Elements are numbered 1-118. Specific elements are highlighted with colored boxes: Na, Mg, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Kr, Rb, Sr, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Te, I, Xe, Cs, Ba, La, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, Tl, Pb, Bi, Po, At, Rn, Fr, Ra, Ac, Rf, Db, Sg, Bh, Hs, Mt, Ds, Rg, Cn, Nh, Fl, Mc, Lv, Ts, Og, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr.

- Alkali metals
- Alkaline earth metals
- Transition metals
- Post-transition metals
- Metalloids
- Reactive non-metals
- Noble gases
- Lanthanides
- Actinides
- Unknown properties

Generated by thinking in the 