First ion source at ISOL@MYRRHA with an improved thermal profile
From prototype to the first experimental validation

by Sophie Hurier[1,2]

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21 September, 2023

0 Outline

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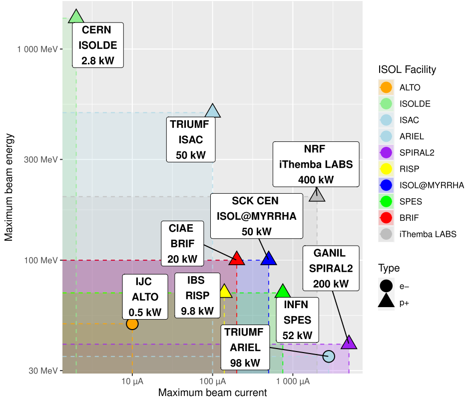
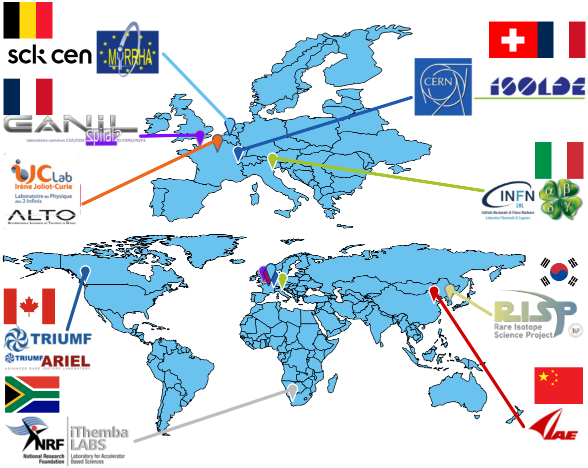
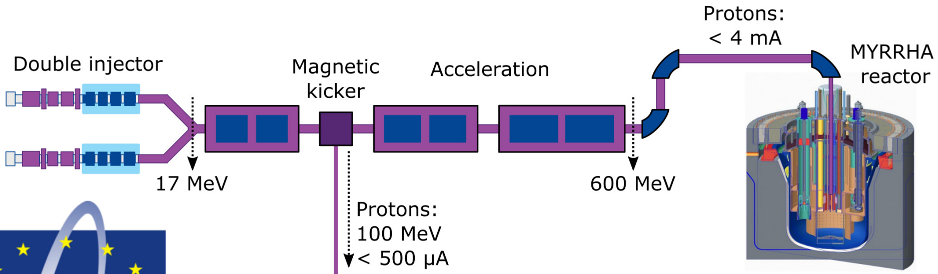
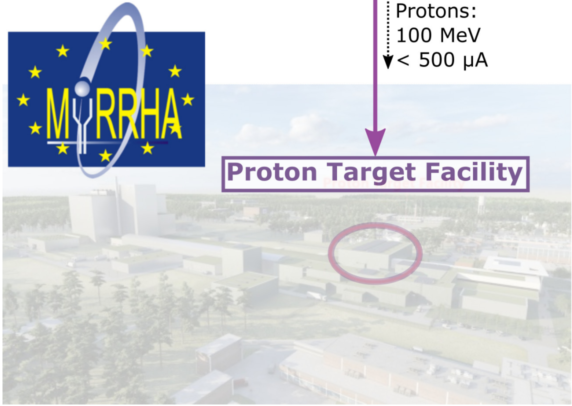
1 Outline

1 Isotope Separation On-Line (ISOL) facility landscape



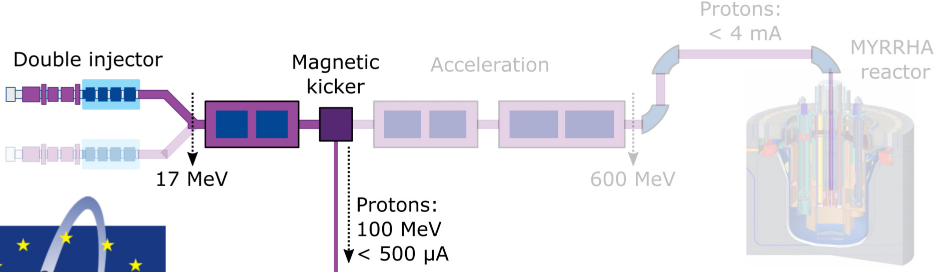


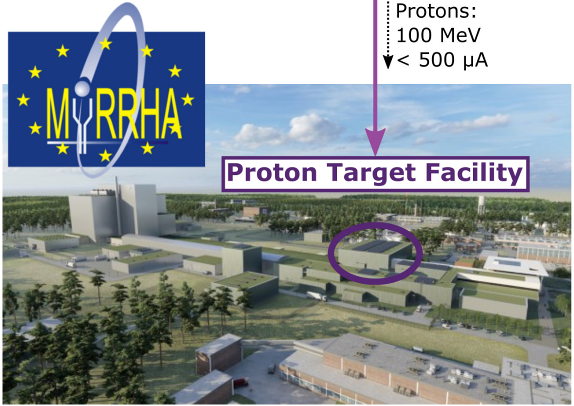




Proton Target Facility ISOL@MYRRHA

- Multi-purpose research infrastructure
- **100 MeV proton beam** up to **0.5 mA**
- Production **R**adioactive **I**on **B**eam (**RIB**)





Proton Target Facility ISOL@MYRRHA

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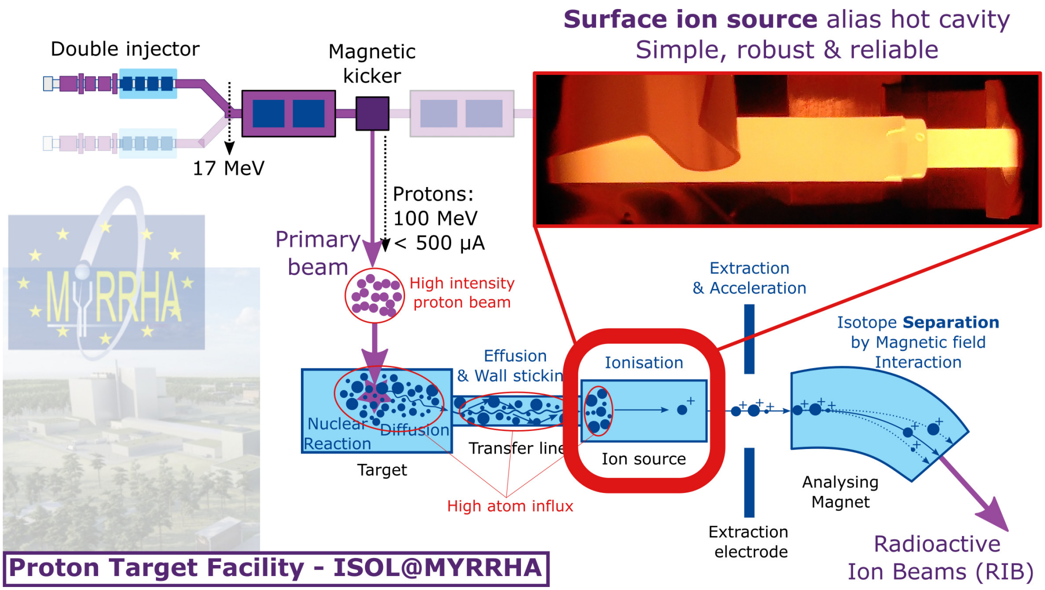
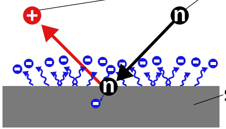

Surface ion source alias hot cavity
Simple, robust & reliable
Double injector
Magnetic kicker
17 MeV
Protons:
100 MeV
< 500 μA
Primary beam
High intensity proton beam
Extraction & Acceleration
Isotope Separation by Magnetic field Interaction
Effusion & Wall stickin
Ionisation
Nuclear Reaction
Diffusion
Transfer line
Ion source
Target
High atom influx
Analysing Magnet
Extraction electrode
Radioactive Ion Beams (RIB)
MYRRHA
Proton Target Facility - ISOL@MYRRHA

2 Outline

2 Surface ionisation principle

At the surface:



Element:

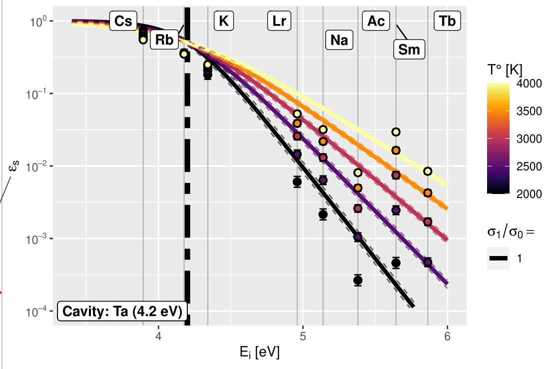
E_i: Ionisation energy

$\frac{\sigma_i}{\sigma_0}$: Statistical weight

Surface:

φ: Work function

T: Temperature



Ion to neutral ratio at the surface:

$$\alpha_s = \frac{n_i}{n_n} = \frac{\sigma_i}{\sigma_0} e^{\frac{\varphi - E_i}{k_B T}}$$

Ionisation "efficiency" at the surface:

$$\varepsilon_s = \frac{n_i}{n_i + n_n} = \frac{\alpha_s}{1 + \alpha_s}$$

(Saha-Langmuir equations)

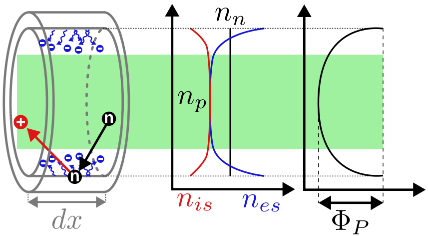
Thermionic emission:

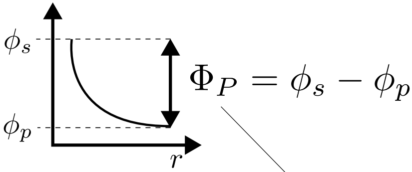
$$n_{es} = 2 \left(\frac{2\pi m_e k_B T}{h^2} \right)^{3/2} e^{-\frac{\varphi}{k_B T}}$$

(Richardson's law)

[Kirchner, 1990] and [Huyse, 1983]

In a tube section:





Plasma sheath potential:

$$\Phi_P = \frac{k_B T}{2e} \ln\left(\frac{n_{is}}{n_{es}}\right) = \frac{k_B T}{2e} \ln\left(\frac{\alpha_s n_n}{n_{es}}\right)$$

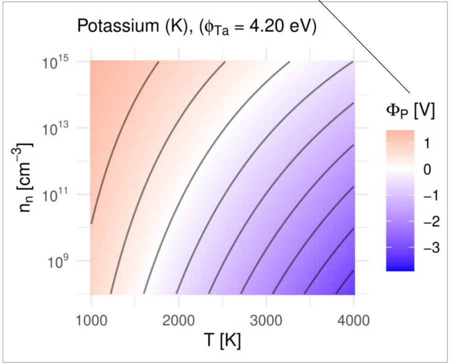
Ion to neutral ratio in the plasma:

$$\alpha_p = \alpha_s \exp\left(-\frac{q_e \Phi_P}{k_B T}\right) = \sqrt{\frac{\alpha_s n_{es}}{n_n}}$$

Ionisation "efficiency" in the plasma:

$$\varepsilon_p = \frac{\alpha_p}{1+\alpha_p}$$

[Kirchner, 1990] and [Huyse, 1983]



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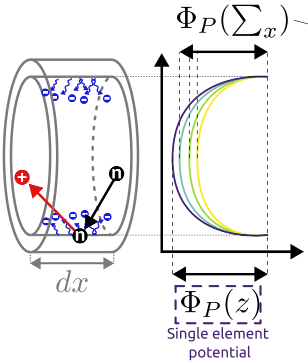
Multi-elements equations:



Plasma sheath potential of **x elements**:

$$\Phi_P = \frac{k_B T}{2q_e} \ln\left(\frac{\sum_x \alpha_{sx} n_{nx}}{n_{es}}\right)$$

Ion to neutral of the an element **z**:

$$\alpha_{pz} = \alpha_{sz} \exp\left(-\frac{q_e \Phi_P}{k_B T}\right) = \sqrt{\frac{\alpha_{sz} n_{es}}{n_{nz}}} \times \sqrt{\frac{1}{1+\sum_{x\neq z} \frac{n_{ix}}{n_{iz}}}}$$

Single element equation — Multi-element factor

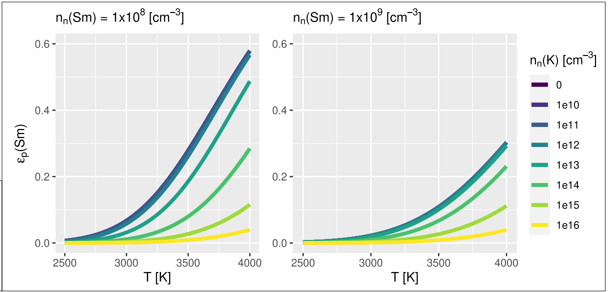
Ionisation "efficiency" of the an element **z**:

$$\varepsilon_{pz} = \frac{\alpha_{pz}}{1+\alpha_{pz}}$$

[Kirchner, 1990] and [Huyse, 1983]

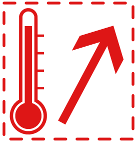
Example:

Samarium (Sm) ionisation
in a Potassium (K)
+ Samarium (Sm) plasma



2 Surface ionisation principle: Hot cavity

Temperature impact:



What is the ioniser tube temperature impact?

Ion to neutral ratio:

$$\alpha_s = \frac{n_i}{n_n} = \frac{\sigma_i}{\sigma_0} e^{\frac{\varphi - E_i}{k_B T}}$$

Thermionic emission:

$$n_{es} = 2\left(\frac{2\pi m_e k_B T}{h^2}\right)^{3/2} e^{-\frac{\varphi}{k_B T}}$$

Plasma sheath potential of **x elements**:

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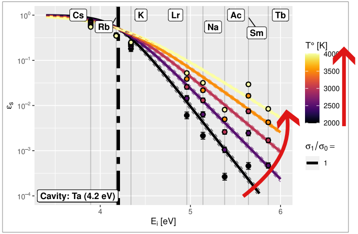
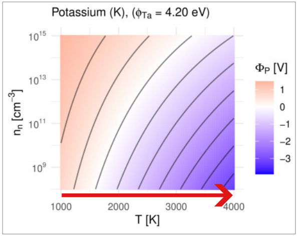
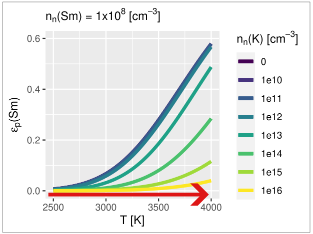
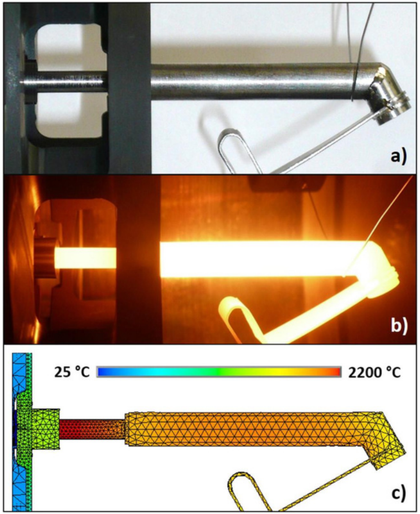
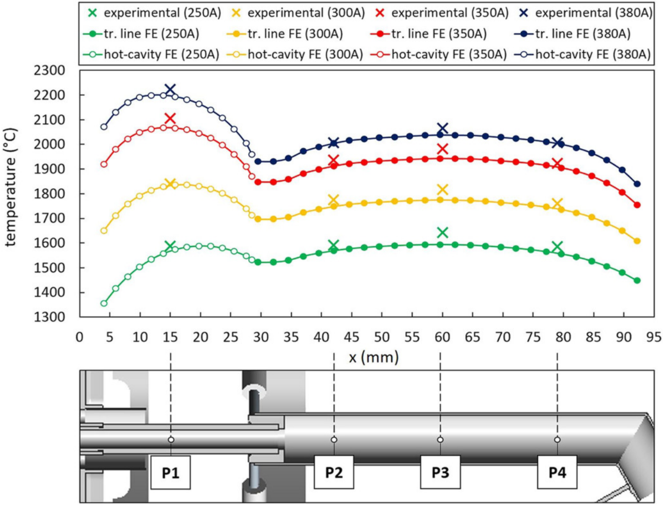






2 Thermal-electric simulation: SPES results



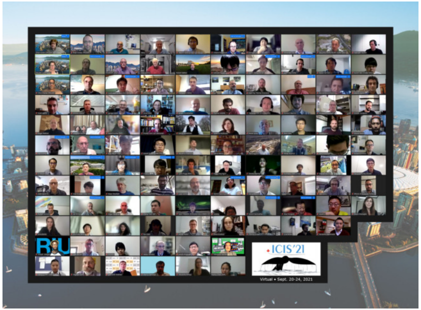


[Manzolaro et al., 2017]

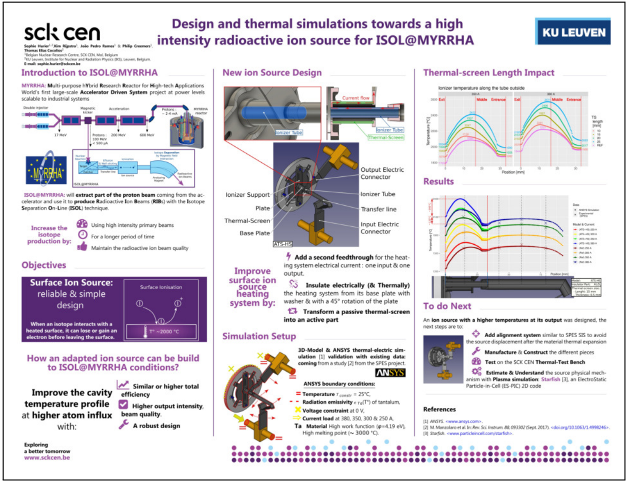
3 Outline

1. Introduction - ISOL@MYRRHA
2. Surface ionisation
3. ISOL@MYRRHA first prototype
4. First tests at CERN
5. Conclusion & Outlook

3 ICIS 2021



ICIS'21



Poster & Proceeding [Hurier et al., 2022]

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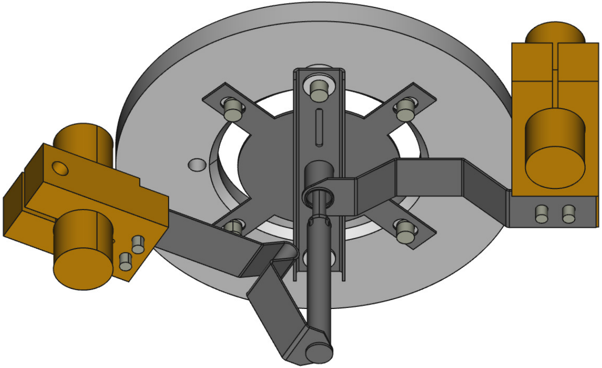
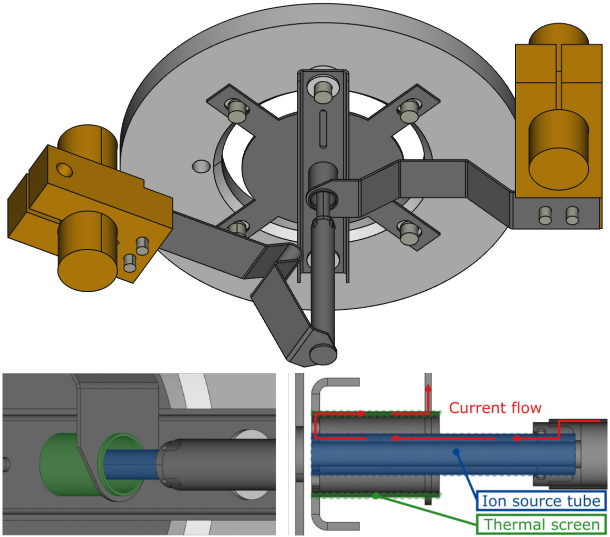
3 New design: ATS-HS



Active Thermal Screen Heating System (ATS-HS):

- **Add a second feedthrough** for electrical current of the heating system:
  One input & one output
- **Insulate electrically (& thermally)** the heating system from its main support system
- **Transform a passive thermal-screen into an active part**

3 New design: ATS-HS



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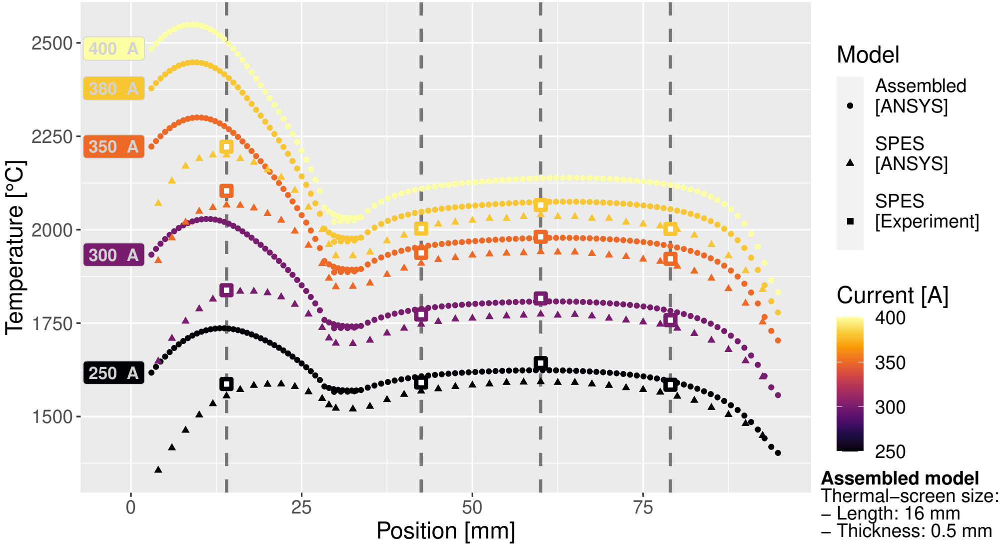
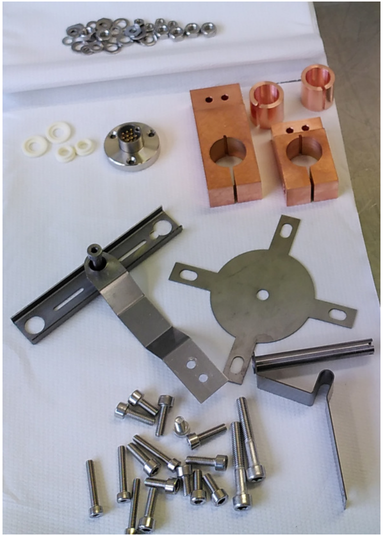
3 New design: ANSYS simulation

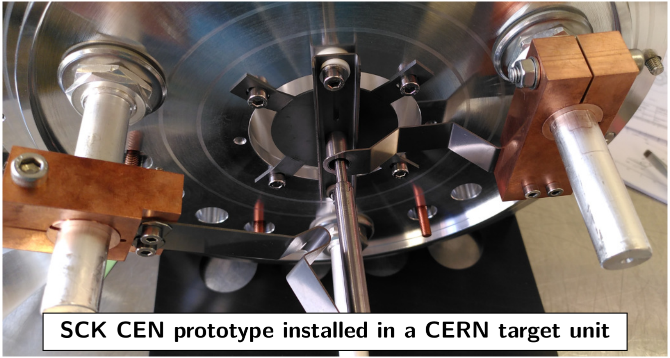


Assembled model
Thermal–screen size:
– Length: 16 mm
– Thickness: 0.5 mm

4 Outline

4 Final assembly and preparation made at CERN





SCK CEN prototype installed in a CERN target unit

Design to be made as simple as possible:
No weld, Only press fit & tight fit

Install two holes for two independent mass markers:

K Potassium ($E_i = 4.3\ eV$)   Sm Samarium ($E_i = 5.6\ eV$)

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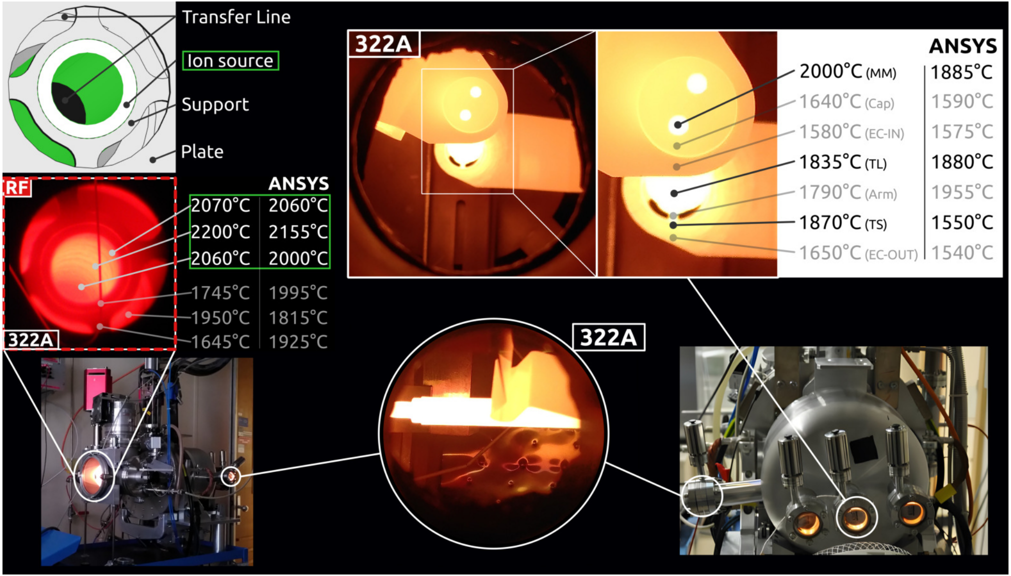
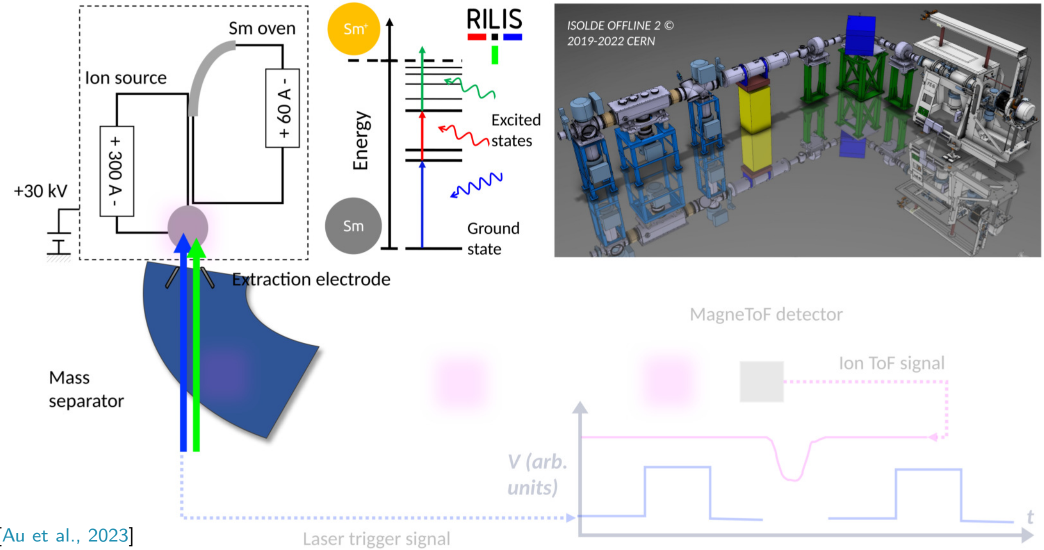


Image: Prototype and setup views on the pumpstand at CERN (RF: red filter)

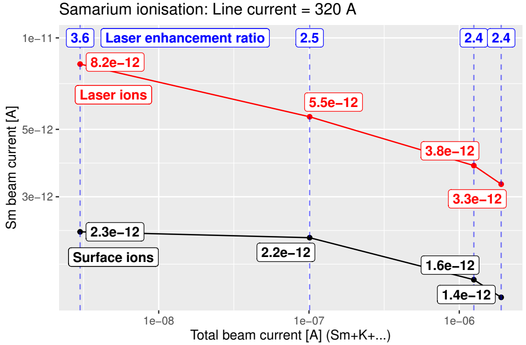
Values: Temperature measured with an optical pyrometer and simulated with ANSYS

4 CERN-ISOLDE's OFFLINE 2 - Laser ionisation

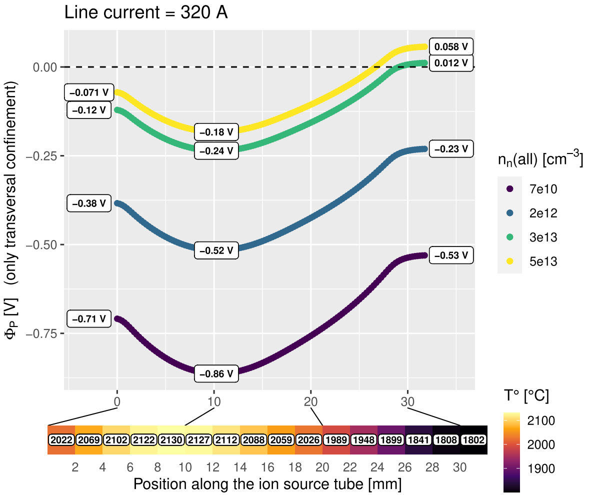


[Au et al., 2023]

4 Ion load impact: Increased potassium load



Laser on/off **measurements**
at Offline 2 (CERN)



Plasma sheath potential $\Phi_P(T_{ANSYS})$ **estimations**

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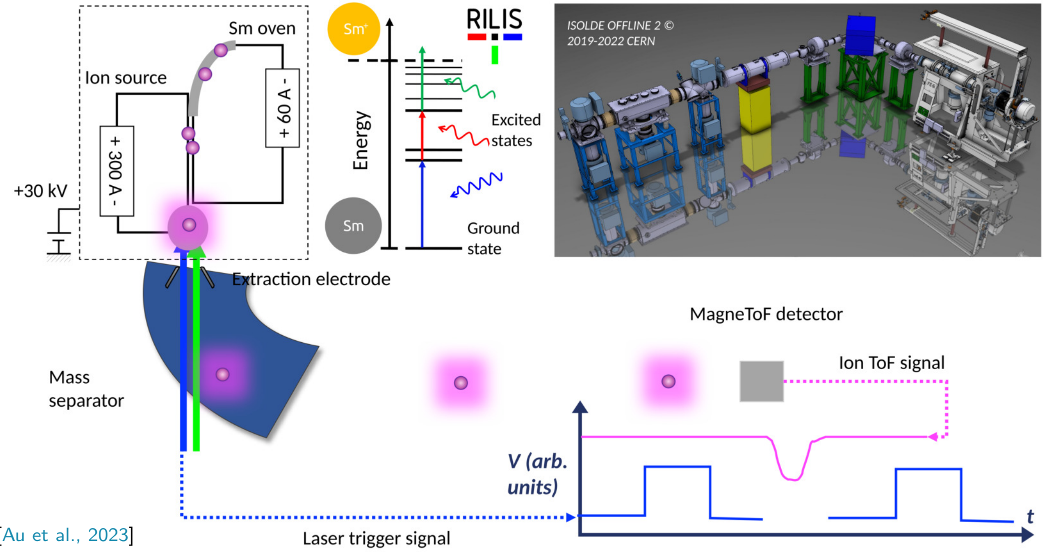
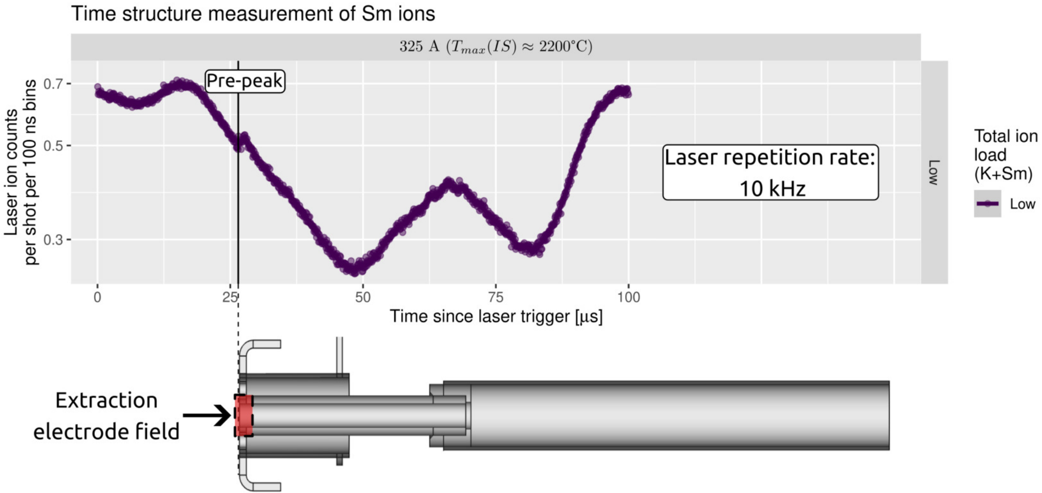
4 Time structure measurement



[Au et al., 2023]

4 Time structure: Principle



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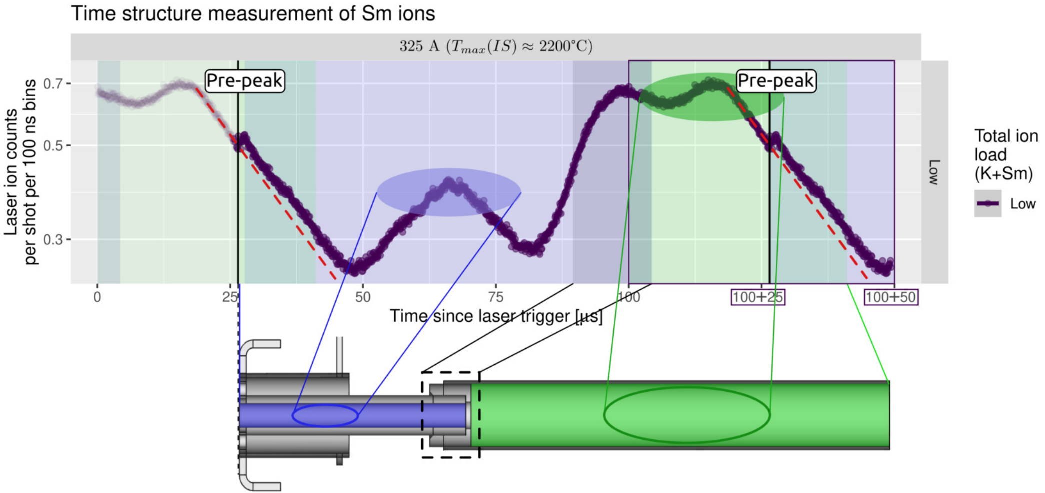

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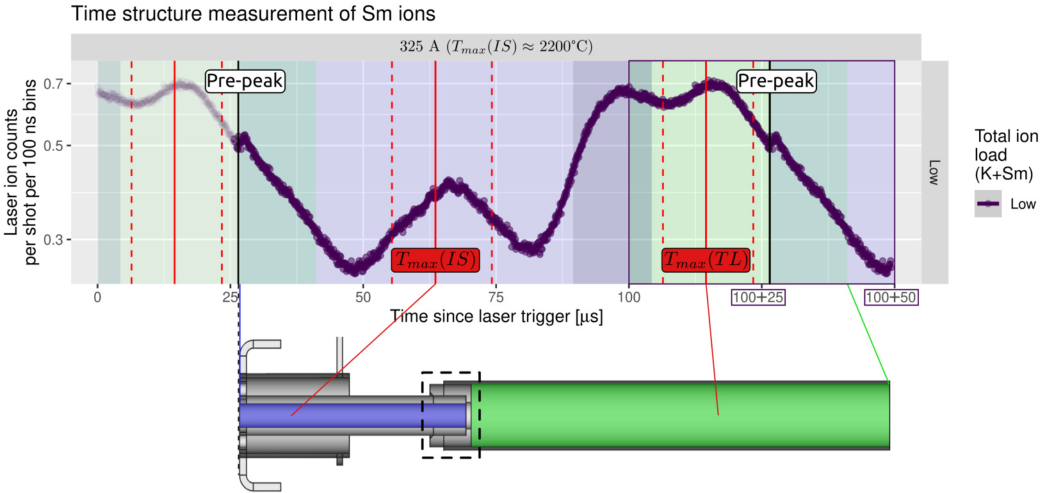
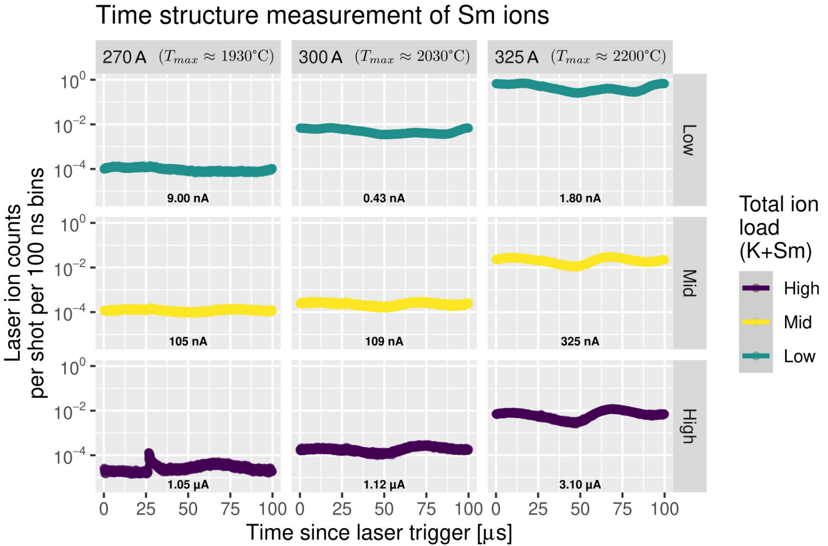
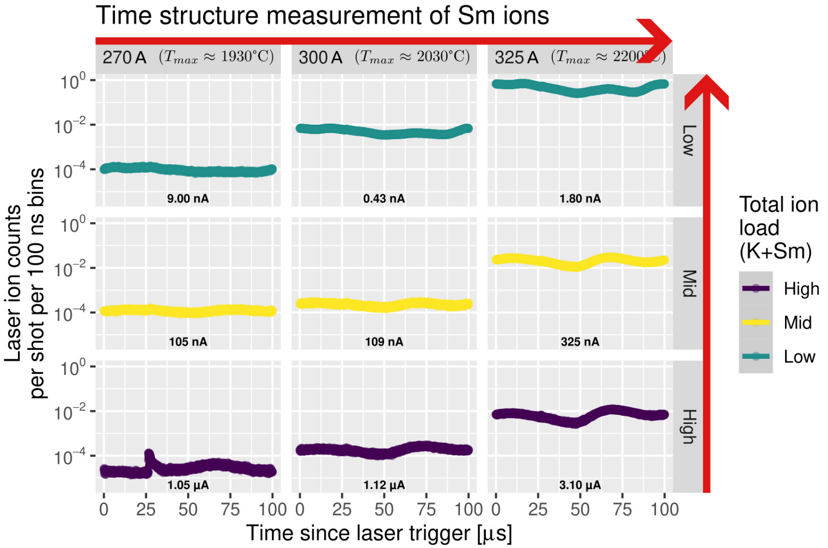


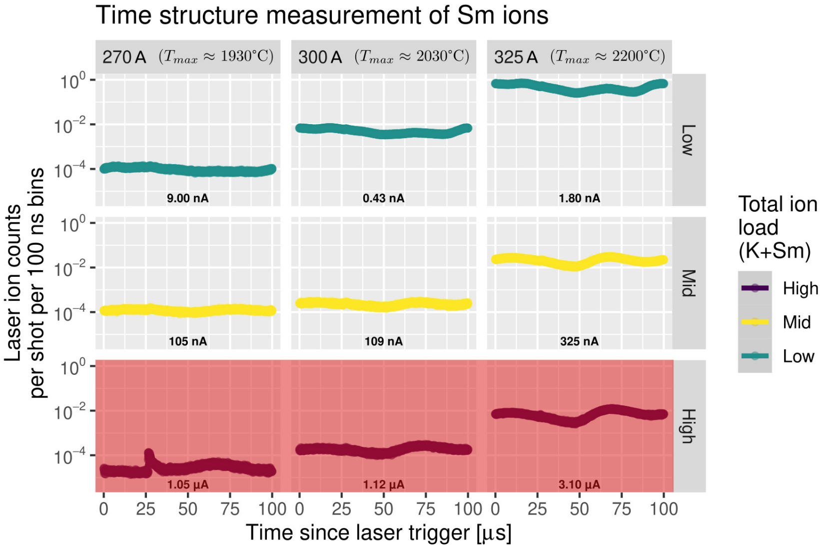
4 Time structure: 3 T° vs 3 ion loads



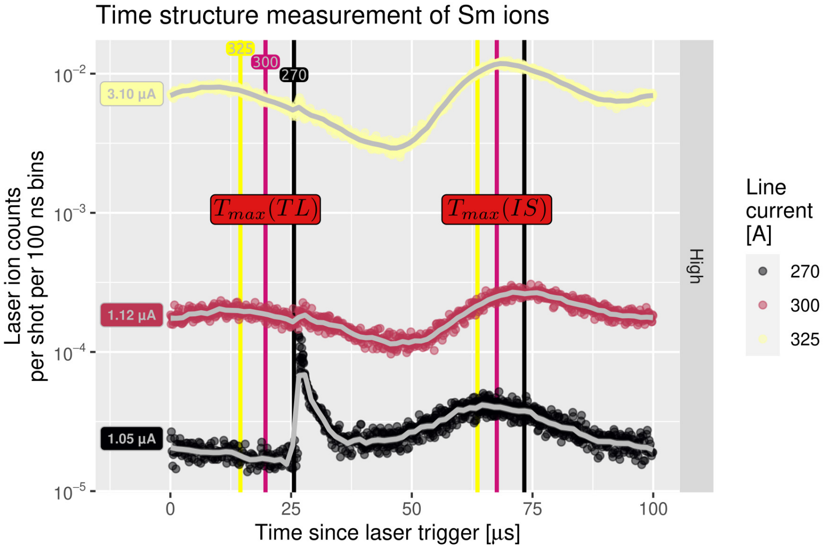
4 Time structure: 3 T° vs 3 ion loads



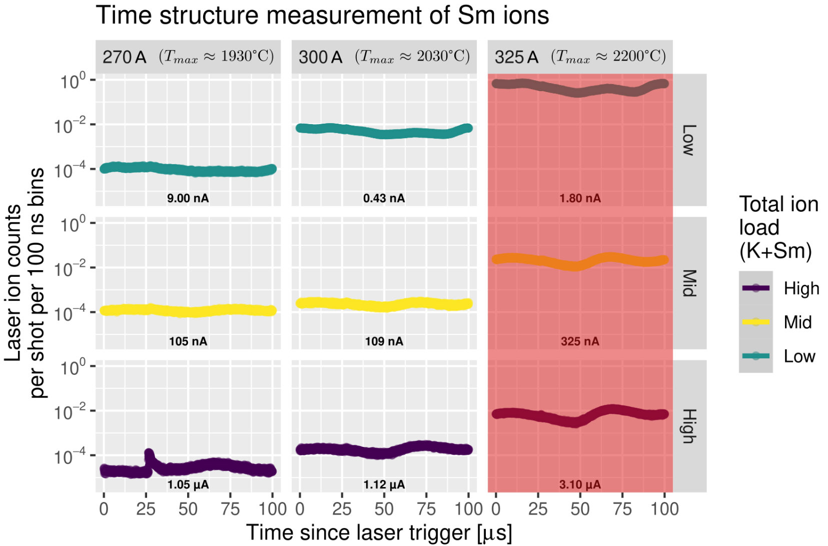
4 Time structure: 3 T° vs 3 ion loads



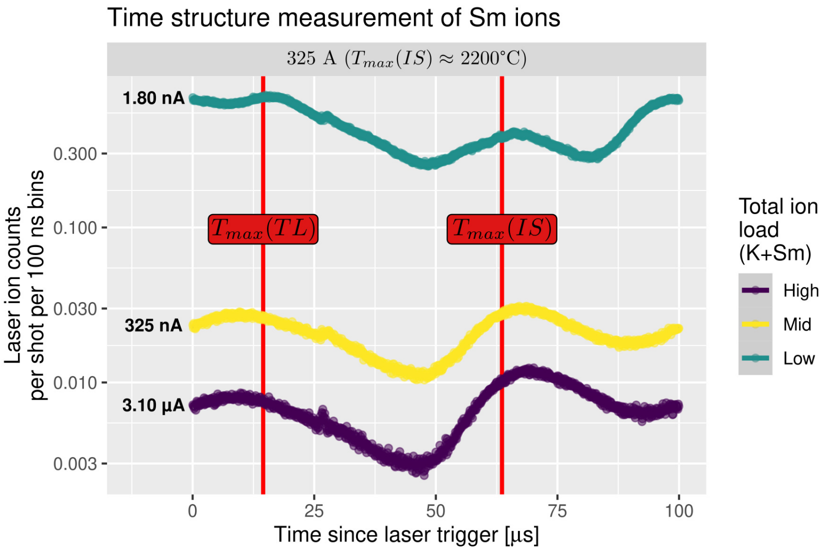
4 Time structure: High load ($\approx \mu A$)



4 Time structure: 3 T° vs 3 ion loads



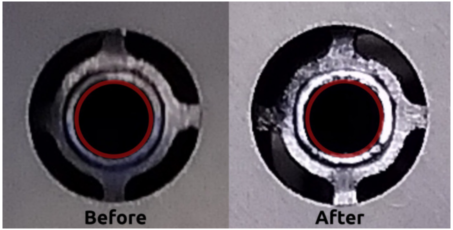
4 Time structure: High T° (325A)

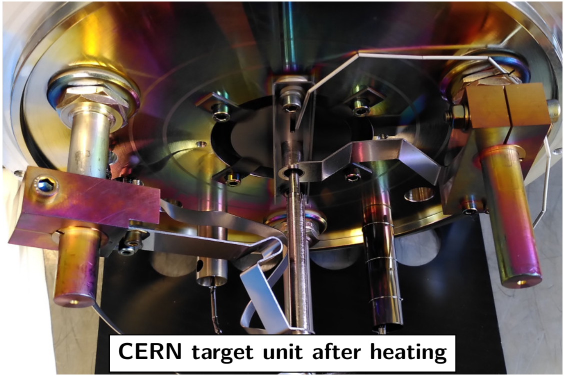


4 Dismounting the target unit

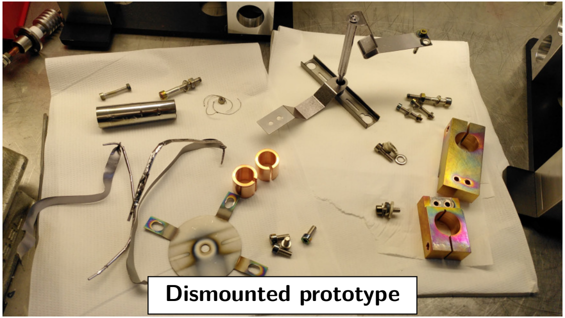
#814 Target: Total heating time

- **Pumpstand:** 2d 6h ∼ 54h (25%)
- **Offline 2:** 6d 22h ∼ 166h (75%)
- **Total: 9d 4h ∼ 220h**





CERN target unit after heating



Dismounted prototype

5 Outline

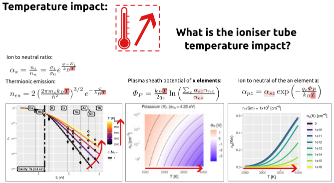
5 Conclusion & Outlook

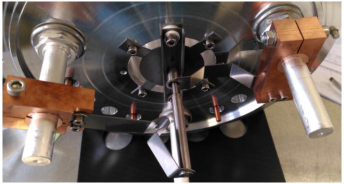
Conclusion

- **Surface ionisation key element:**
  Temperature & Potential
- **ISOL@MYRRHA first source**: surface ion source
- **Prototype design and construction:**
  Focus on the simplicity
- **Test at CERN: Prototype first validation**
  Importance of the heating (ion source AND transfer line)
  Maximum laser ionisation position shift along the tube, because of temperature, potential and ion loads

Outlook

- **Continue thermal test on the prototype at SCK CEN:**
  "Stress" test, ...
- 2^{nd} **prototype under construction** to be tested at ISOLDE (thermal-electric, efficiency, ...)





5 Acknowledgements

SCK CEN
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KU Leuven
Institute for Nuclear and Radiation Physics (IKS)
Interdisciplinary Research group

Special thanks to the CERN collaborators

Thank you for your attention!

6 Reference

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