

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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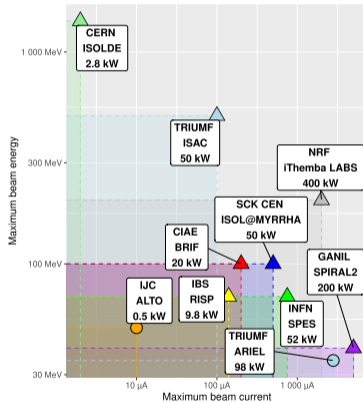
0 Outline

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

1 Outline

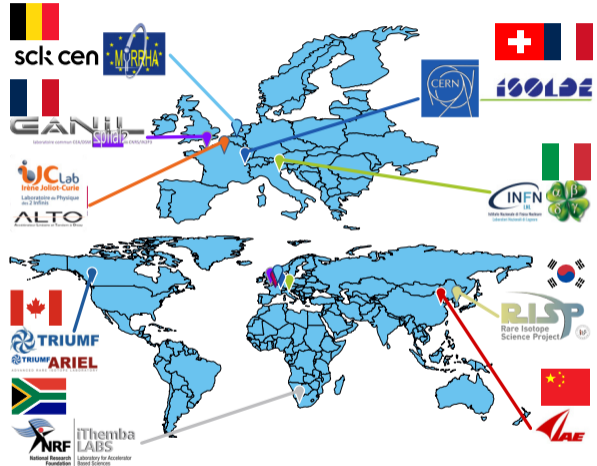
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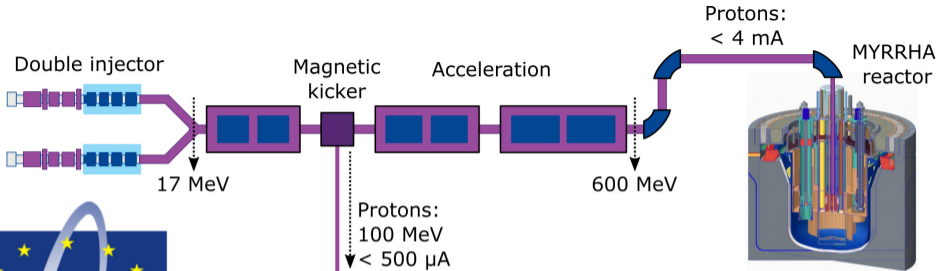
1 Isotope Separation On-Line (ISOL) facility landscape



- ISOL Facility
- ALTO
 - ISOLDE
 - ISAC
 - ARIEL
 - SPIRAL2
 - RISP
 - ISOL@MYRRHA
 - SPES
 - BRIF
 - iThemba LABS

- Type
- e⁻
 - ▲ p⁺





Proton Target Facility

Proton Target Facility ISOL@MYRRHA



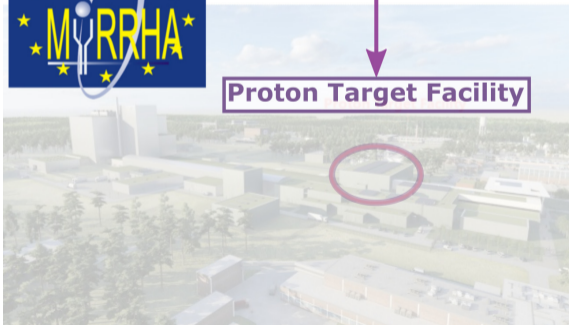
Multi-purpose research infrastructure

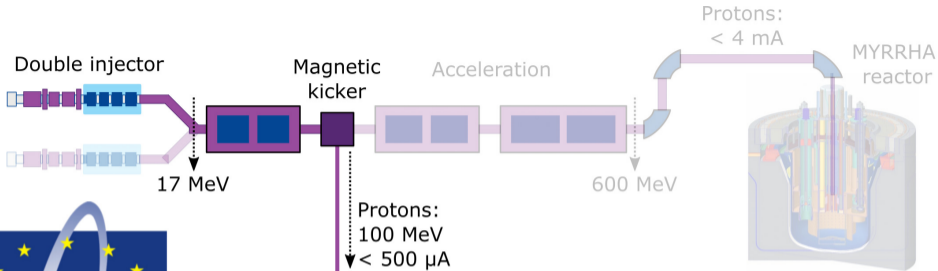


100 MeV proton beam up to 0.5 mA



Production **R**adioactive **I**on **B**eam (**RIB**)





Proton Target Facility



Proton Target Facility ISOL@MYRRHA



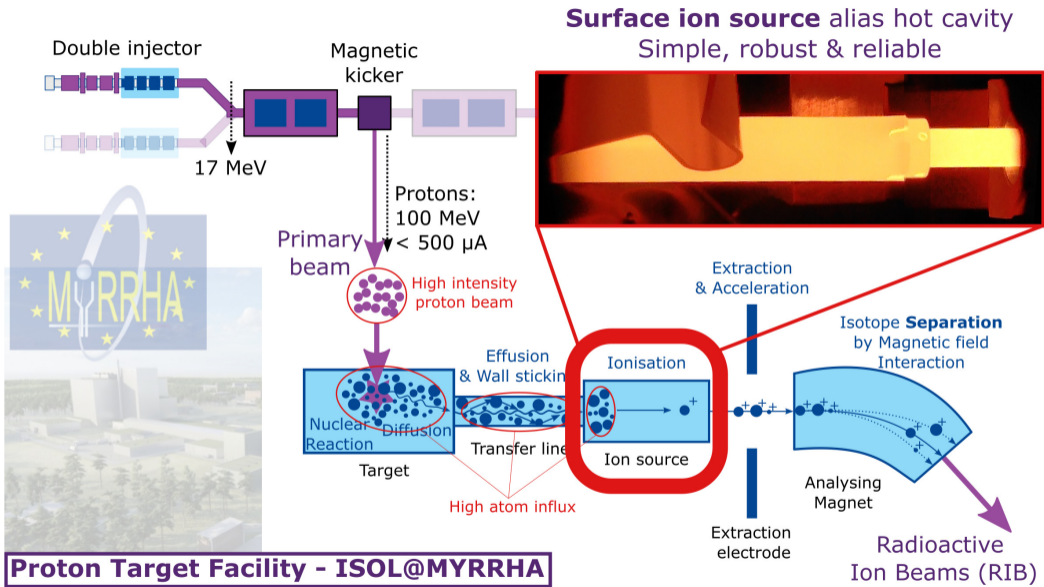
Multi-purpose research infrastructure



100 MeV proton beam up to 0.5 mA



Production **R**adioactive **I**on **B**eam (**RIB**)

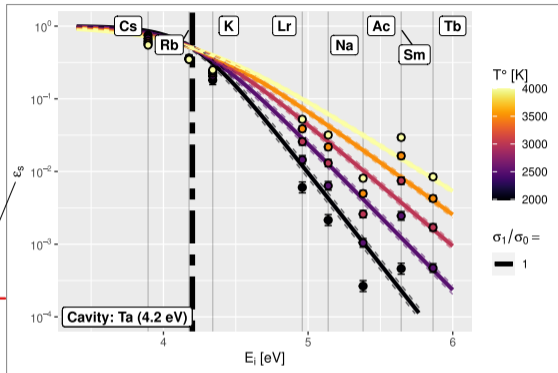
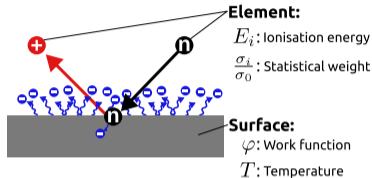


2 Outline

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2 Surface ionisation principle

At the surface:



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:

$$\varepsilon_s = \frac{n_i}{n_i + n_n} = \frac{\alpha_s}{1 + \alpha_s} \quad \text{(Saha-Langmuir equations)}$$

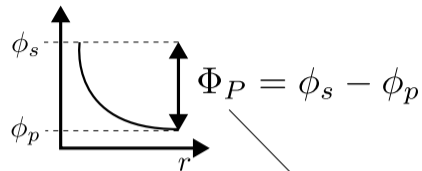
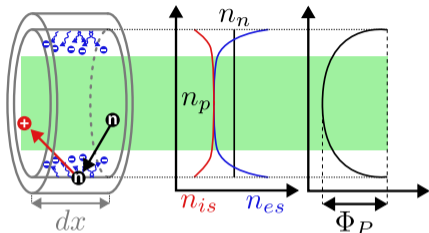
Thermionic emission:

$$n_{es} = 2 \left(\frac{2\pi m_e k_B T}{h^2} \right)^{3/2} e^{-\frac{\varphi}{k_B T}} \quad \text{(Richardson's law)}$$

[Kirchner, 1990] and [Huyse, 1983]

2 Surface ionisation principle

In a tube section:



Plasma sheath potential:

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

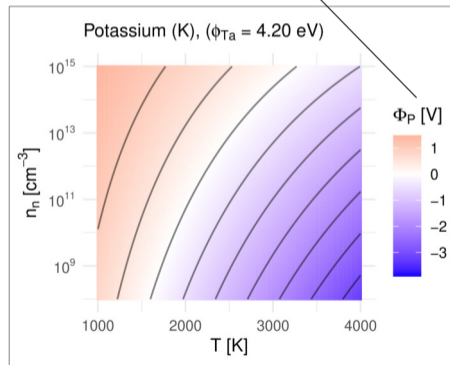
Ion to neutral ratio in the plasma:

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

Ionisation "efficiency" in the plasma:

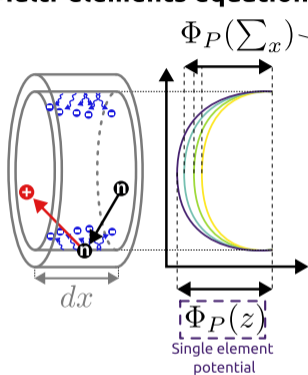
$$\varepsilon_p = \frac{\alpha_p}{1 + \alpha_p}$$

[Kirchner, 1990] and [Huysse, 1983]



2 Surface ionisation principle: Multi-elements

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 :

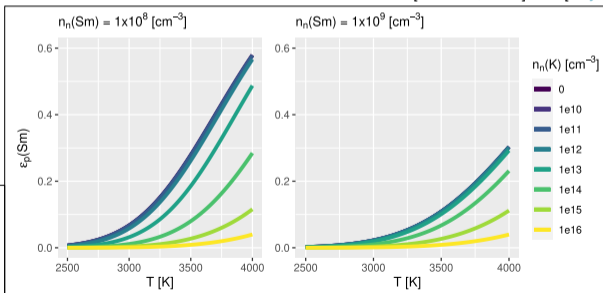
$$\alpha_{pz} = \alpha_{sz} \exp \left(-\frac{q_e \Phi_P}{k_B T} \right) = \underbrace{\sqrt{\frac{\alpha_{sz} n_{es}}{n_{nz}}}}_{\text{Single element equation}} \times \underbrace{\sqrt{\frac{1}{1 + \sum_{x \neq z} \frac{n_{ix}}{n_{iz}}}}}}_{\text{Multi-element factor}}$$

Ionisation "efficiency" of the an element z :

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

[Kirchner, 1990] and [Huysse, 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:

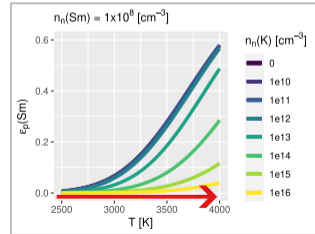
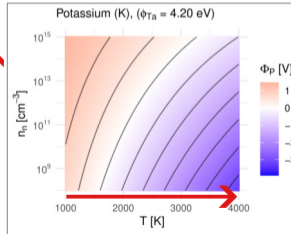
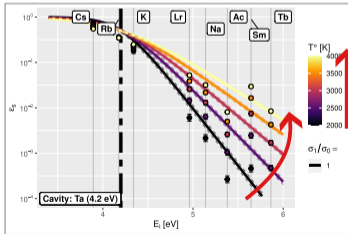
$$n_{es} = 2 \left(\frac{2\pi m_e k_B T}{h^2} \right)^{3/2} e^{-\frac{\varphi}{k_B T}}$$

Plasma sheath potential of **x** elements:

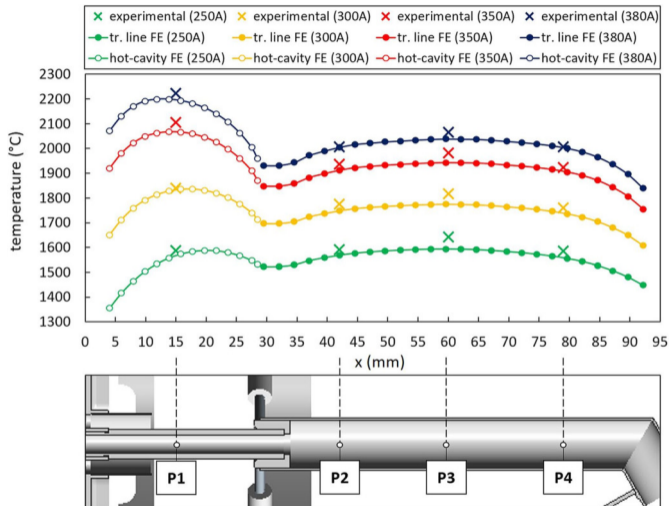
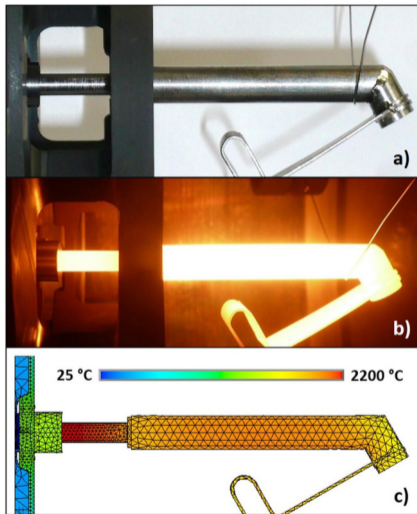
$$\Phi_P = \frac{k_B T}{2q_e} \ln \left(\frac{\sum_x \alpha_{sx} n_{nx}}{n_{es}} \right)$$

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

$$\alpha_{pz} = \alpha_{sz} \exp \left(-\frac{q_e \Phi_P}{k_B T} \right)$$



2 Thermal-electric simulation: SPES results

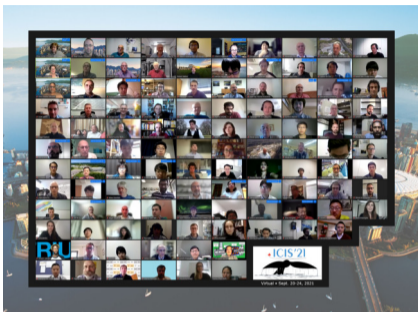


[Manzolaro et al., 2017]

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3 ICIS 2021



ICIS'21



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Design and thermal simulations towards a high intensity radioactive ion source for ISOL@MYRRHA

Introduction to ISOL@MYRRHA

MYRRHA: Multi-purpose (World) Research Reactor for High-tech Applications. World's first large-scale Accelerator Driven System project at power levels scalable to industrial systems.

ISOL@MYRRHA: will extract part of the proton beam coming from the accelerator and use it to produce Radioactive Ion Beams (RIB) with the Isotope Separation On-Line (ISOL) technique.

- Increase the isotope production by:
 - Using high intensity primary beams
 - For a longer period of time
 - Maintain the radioactive ion beam quality

Objectives

Surface Ion Source: reliable & simple design

When an isotope interacts with a heated surface, it can lose or gain an electron before leaving the surface.

How an adapted ion source can be built to ISOL@MYRRHA conditions?

- Similar or higher total efficiency
- Higher output intensity, beam quality.
- A robust design

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New ion Source Design

- Improve surface ion source heating system by:
 - Add a second feedthrough for the heating system electrical current: one input & one output.
 - Insulate electrically (& Thermally) the heating system from its base plate with washer & with a 45° rotation of the plate
 - Transform a passive thermal-screen into an active part

Simulation Setup

3D Model & ANSYS thermal-electric simulation [1] validation with existing data: coming from a study [2] from the SPES project.

ANSYS boundary conditions:

- Temperature $T_{cavity} = 25^{\circ}\text{C}$.
- Radiation emissivity $\epsilon = \epsilon_{\text{ref}}(T)$ of tantalum.
- Voltage constraint at 0 V.
- Current load at 300, 350, 400 & 250 A.
- T_0 Material High work function (sp=4.19 eV), High melting point ($\approx 3000^{\circ}\text{C}$).

Thermal-screen Length Impact

Results

To do Next

An ion source with a higher temperature at its output was designed, the next steps are to:

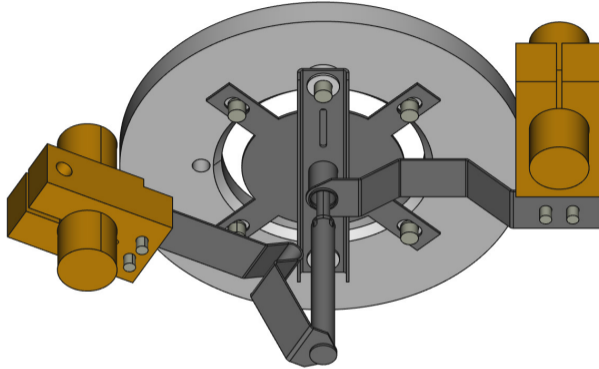
- Add alignment systems similar to SPES SIS to avoid the source displacement after the material thermal expansion
- Manufacture & Construct the different pieces
- Test on the SCK-CEN Thermal-Test Bench
- Estimate & Understand the source physical mechanism with Plasma simulation: Starfish [3], an ElectroStatic Particle-in-Cell (ES-PIC) 2D code

References

[1] ANSYS - www.ansys.com
 [2] M. Marnett et al. In: Rev. Sci. Instrum. 88, 083302 (2017). doi:10.1063/1.4986246
 [3] Starfish - www.particlein-cell.com/starfish/

Poster & Proceeding [Hurier et al., 2022]

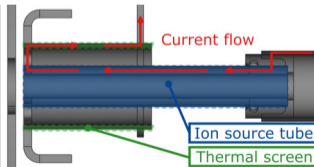
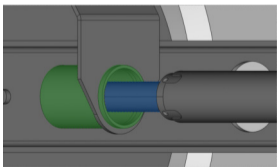
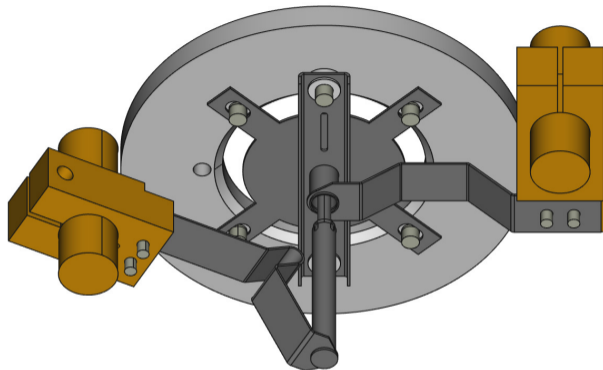
3 New design: ATS-HS



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

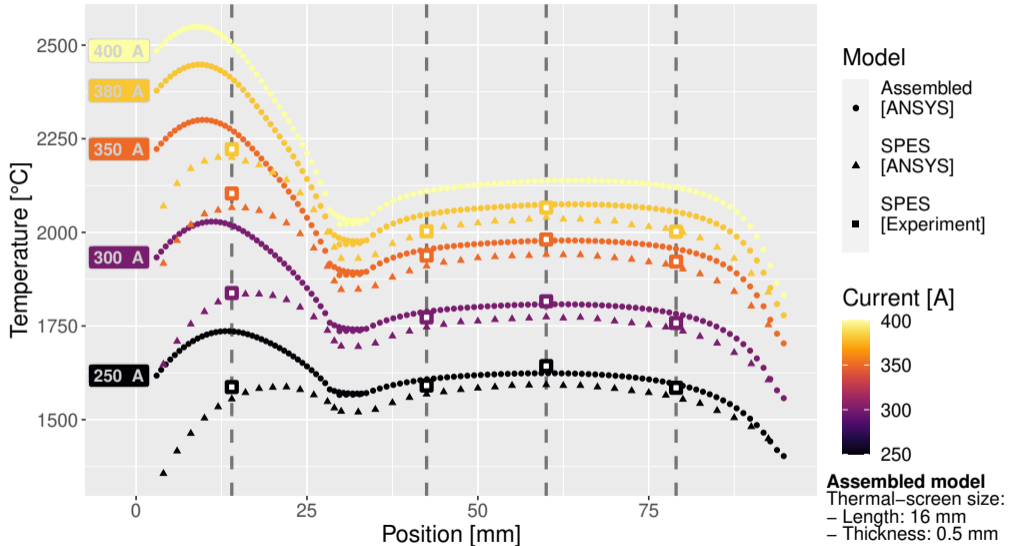
3 New design: ATS-HS



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
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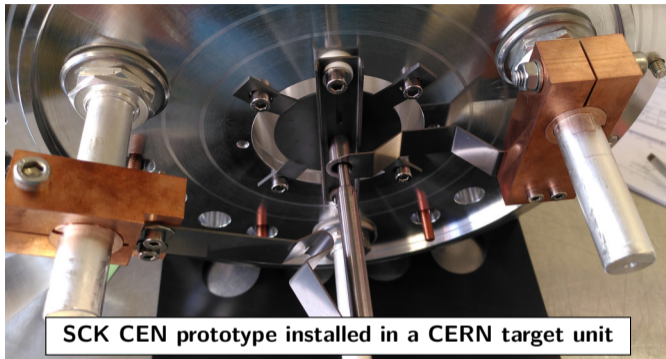
3 New design: ANSYS simulation



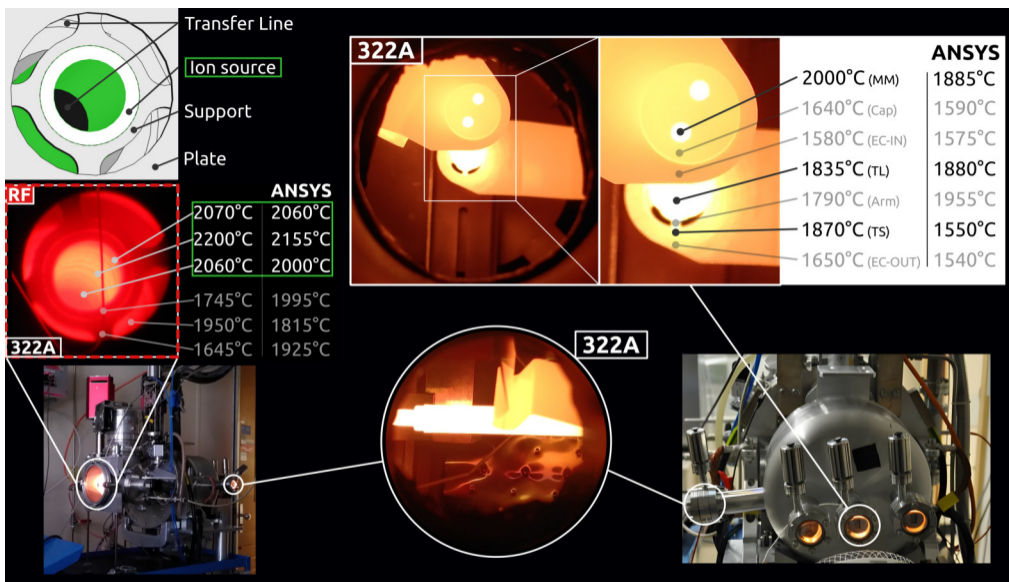
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4 Final assembly and preparation made at CERN



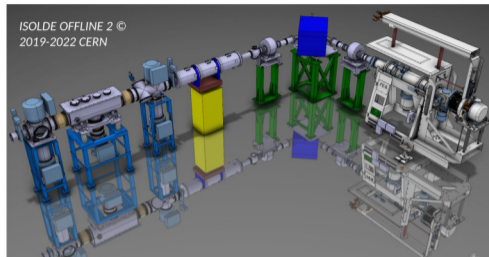
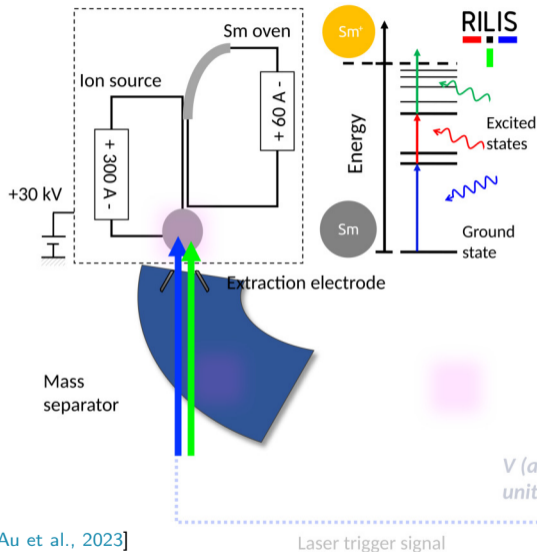
- 🔧 **Design to be made as simple as possible:**
No weld, Only press fit & tight fit
- ⊕ **Install two holes for two independent mass markers:**
K Potassium ($E_i = 4.3 \text{ eV}$) Sm Samarium ($E_i = 5.6 \text{ eV}$)



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

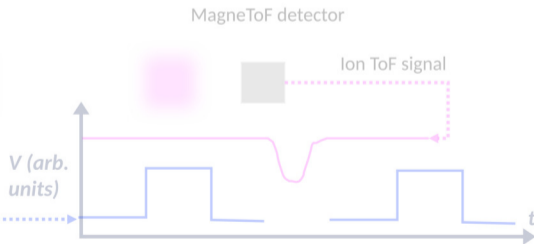
 **Values:** Temperature measured with an optical pyrometer and simulated with ANSYS

4 CERN-ISOLDE's OFFLINE 2 - Laser ionisation

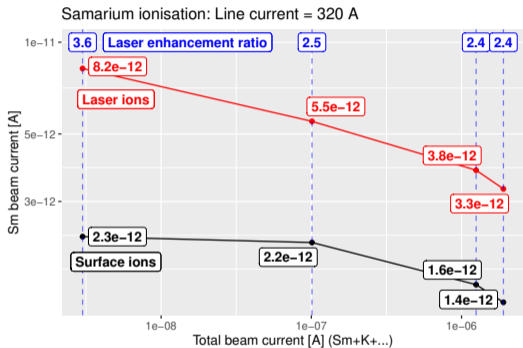


[Au et al., 2023]

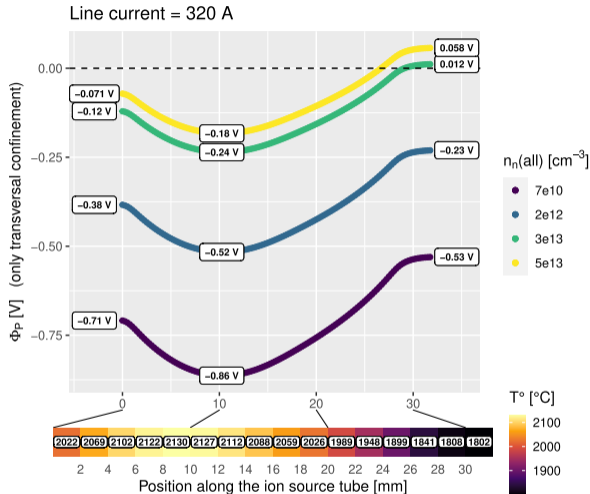
Laser trigger signal



4 Ion load impact: Increased potassium load

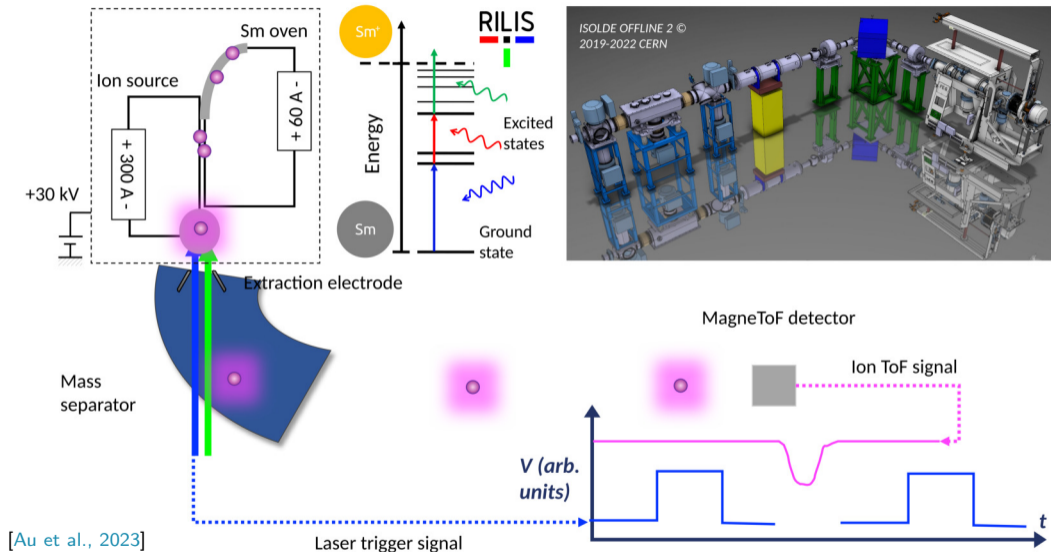


Laser on/off measurements
at Offline 2 (CERN)



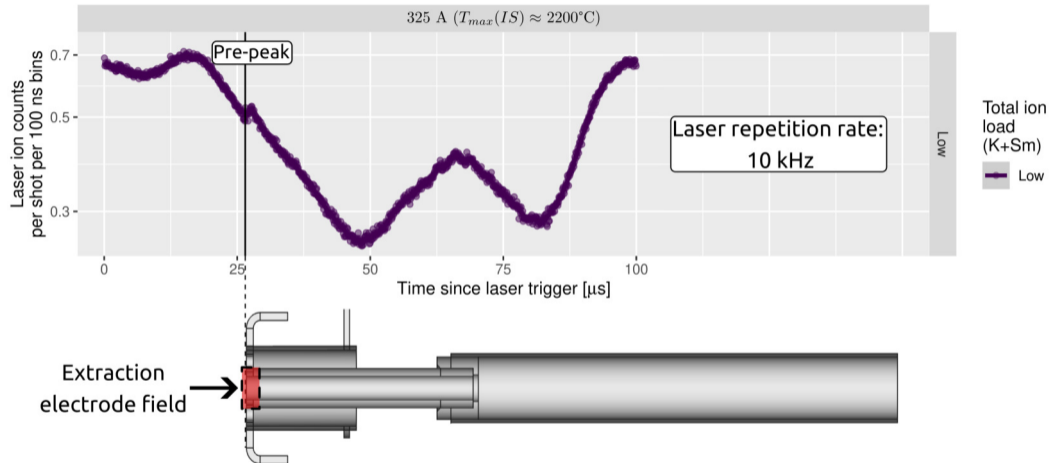
Plasma sheath potential $\Phi_P(T_{ANSYS})$ estimations

4 Time structure measurement



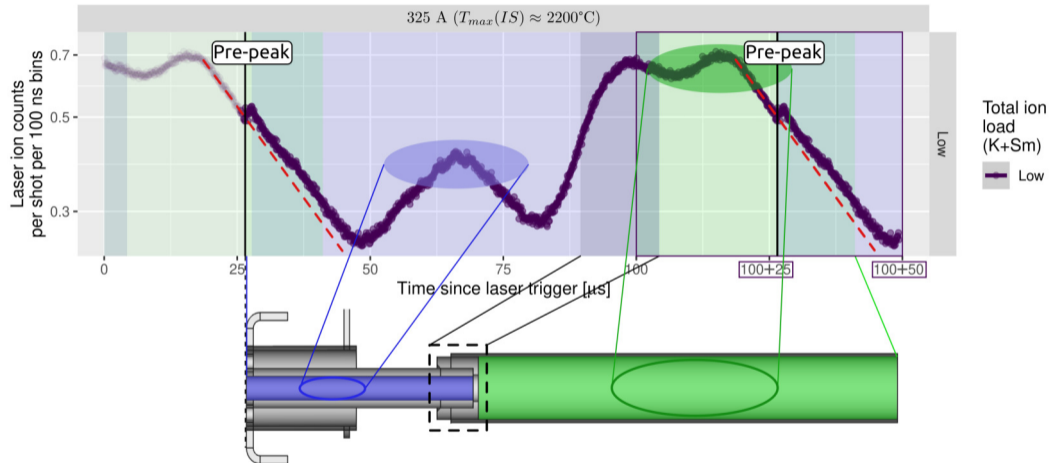
4 Time structure: Principle

Time structure measurement of Sm ions



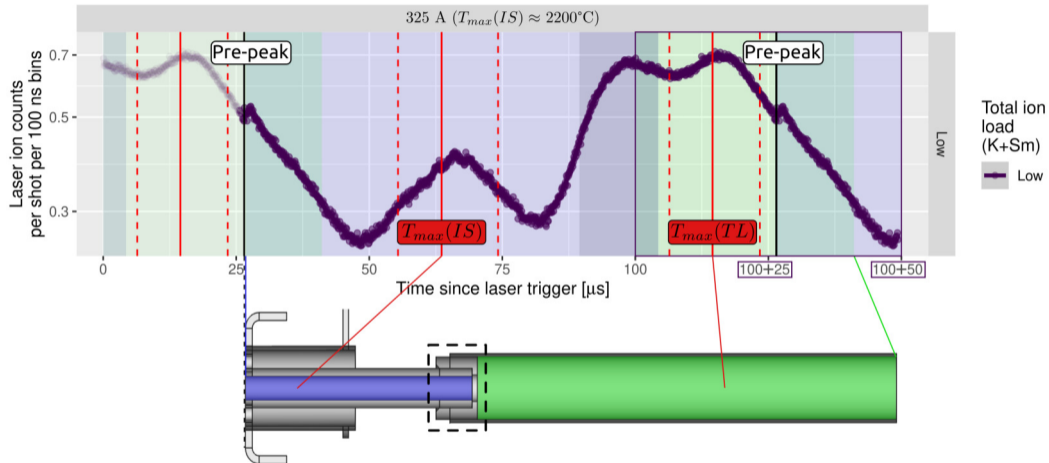
4 Time structure: Principle

Time structure measurement of Sm ions

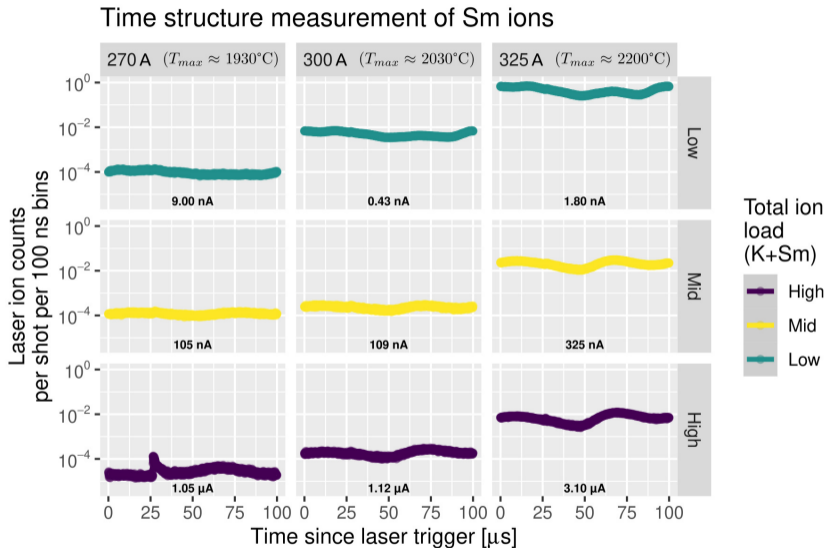


4 Time structure: Principle

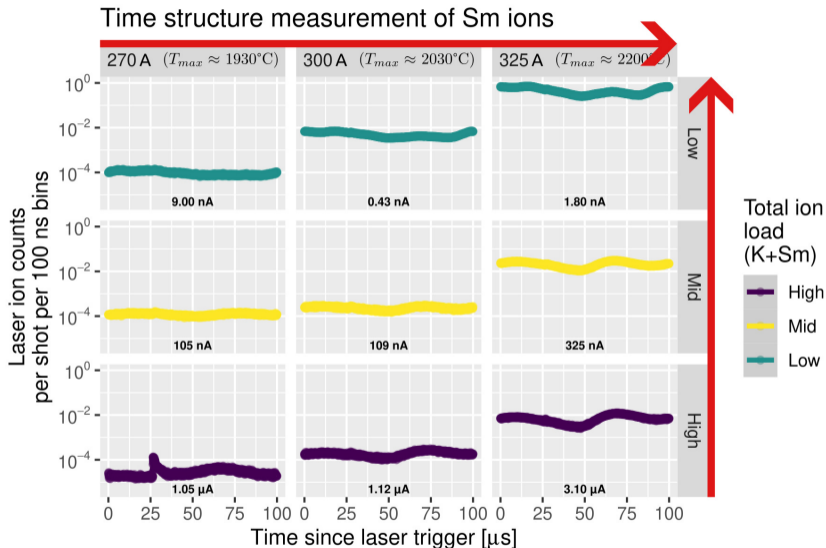
Time structure measurement of Sm ions



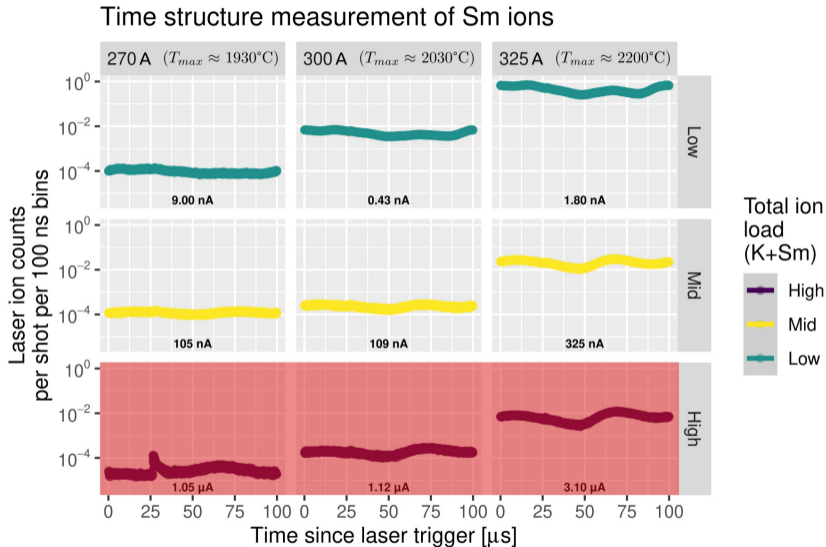
4 Time structure: 3 T° vs 3 ion loads



4 Time structure: 3 T° vs 3 ion loads

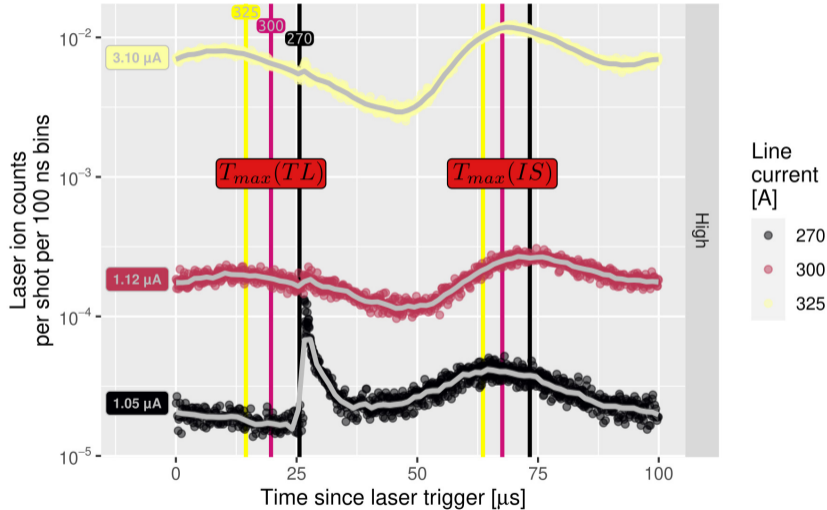


4 Time structure: 3 T° vs 3 ion loads



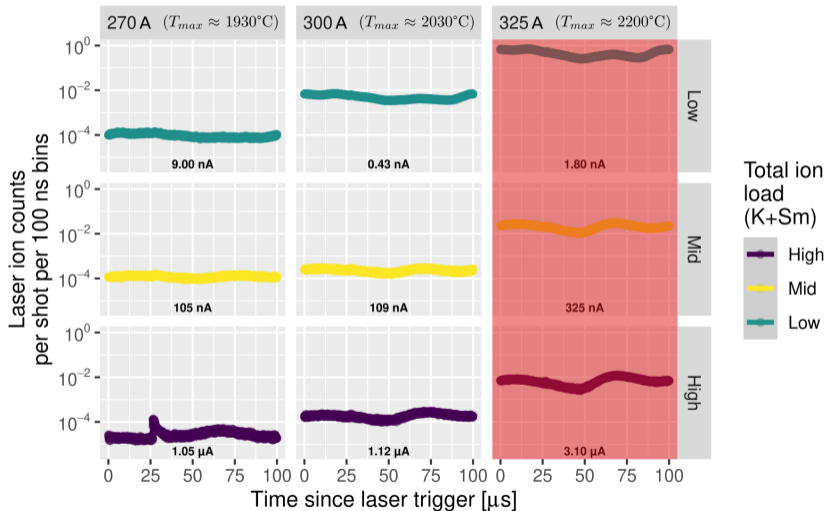
4 Time structure: High load ($\approx \mu A$)

Time structure measurement of Sm ions



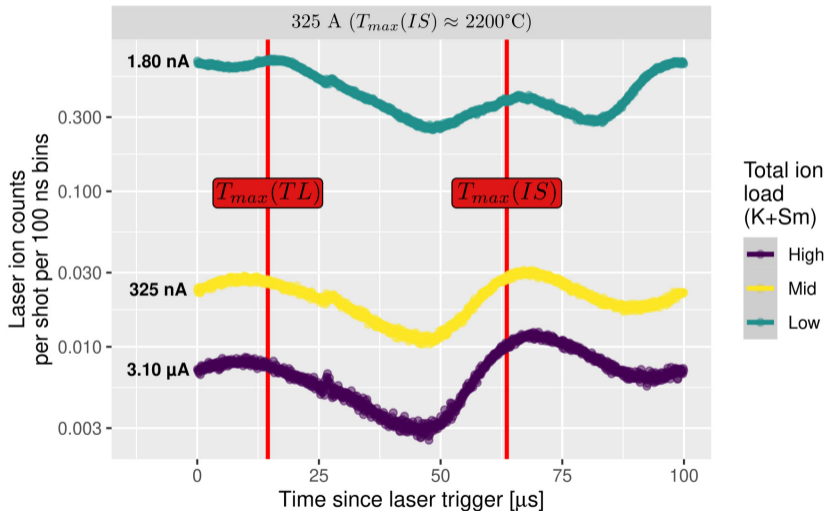
4 Time structure: 3 T° vs 3 ion loads

Time structure measurement of Sm ions



4 Time structure: High T° (325A)

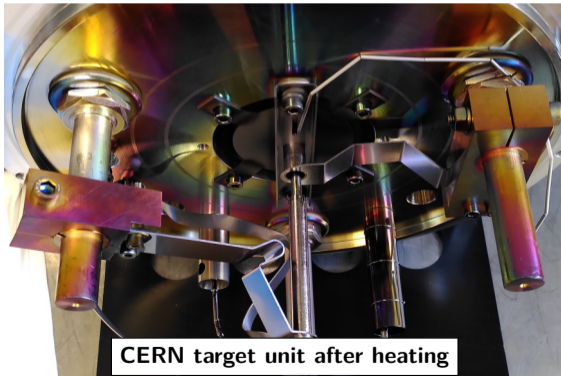
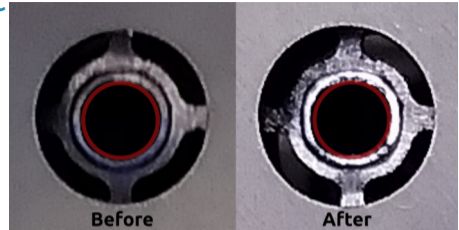
Time structure measurement of Sm ions



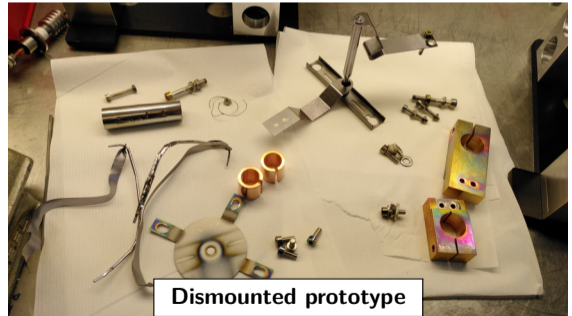
4 Dismounting the target unit

#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

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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

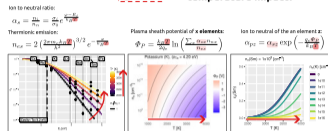
Outlook

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

Temperature impact:



What is the ioniser tube temperature impact?



SCK CEN thermal-test bench

5 Acknowledgements



SCK CEN

Physics and Target Research group



KU Leuven

Institute for Nuclear and Radiation Physics (IKS)
Interdisciplinary Research group



Special thanks to the CERN
collaborators


sck cen
Academy



KU LEUVEN

Thank you for your attention!

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