High throughput Ion Sources for the production of medical radionuclides

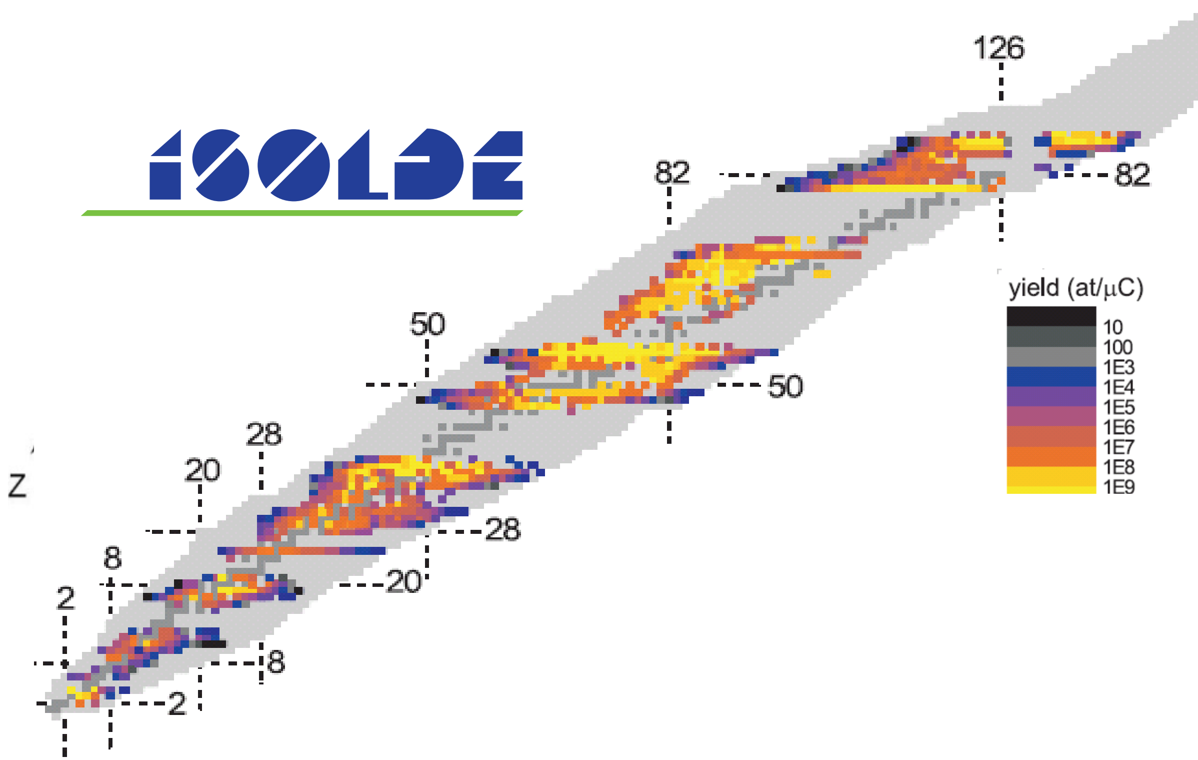
Ralitsa Mancheva on behalf of the RILIS team

The ISOL method

Transport to experimental setup

Mass separation for isotope selectivity

Ionization



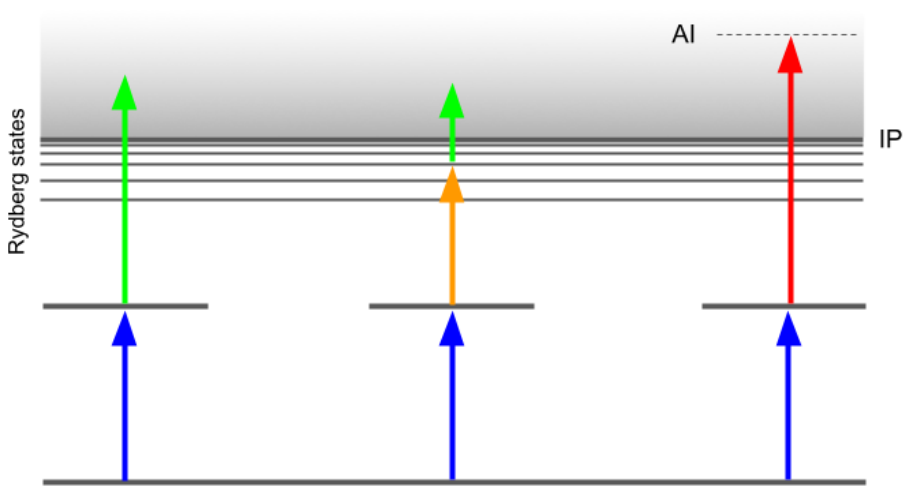
Target preparation

Target irradiation

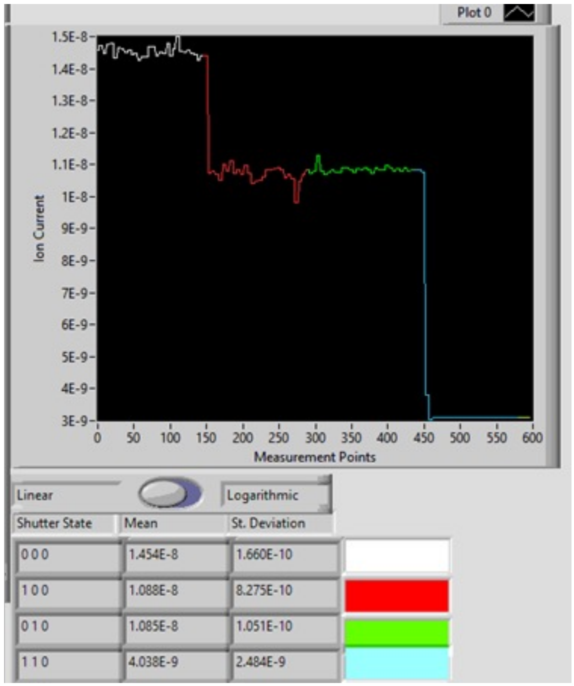
Diffusion through transfer line

The RILIS principle

- Stepwise excitation and subsequent ionization
- Selectivity due to unique atomic structure of each element
- Excitation with tunable lasers



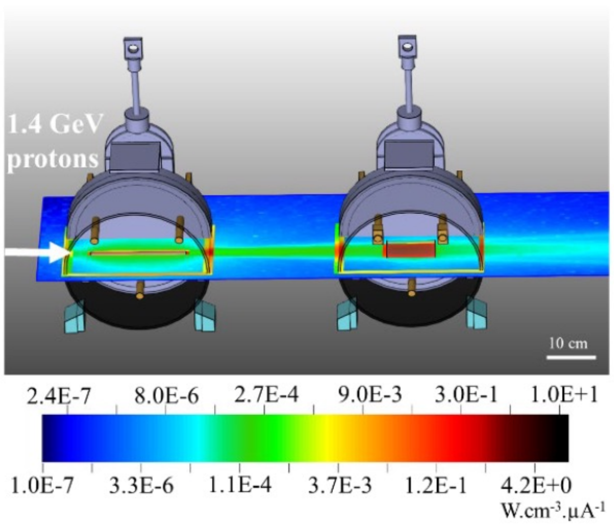
Example of laser enhancement for Sm laser ionization



MEDICIS

- **MED**ical **I**sotopes **C**ollected from **IS**OLDE
- Medically relevant isotopes of Tb, Tm, Cs, Yb, Er, Ac, Sm, Ba and more*
- Commissioned in 2017
- Target irradiated at ISOLDE or external source
- Up to µA ion beams
- Fast collection and extraction required

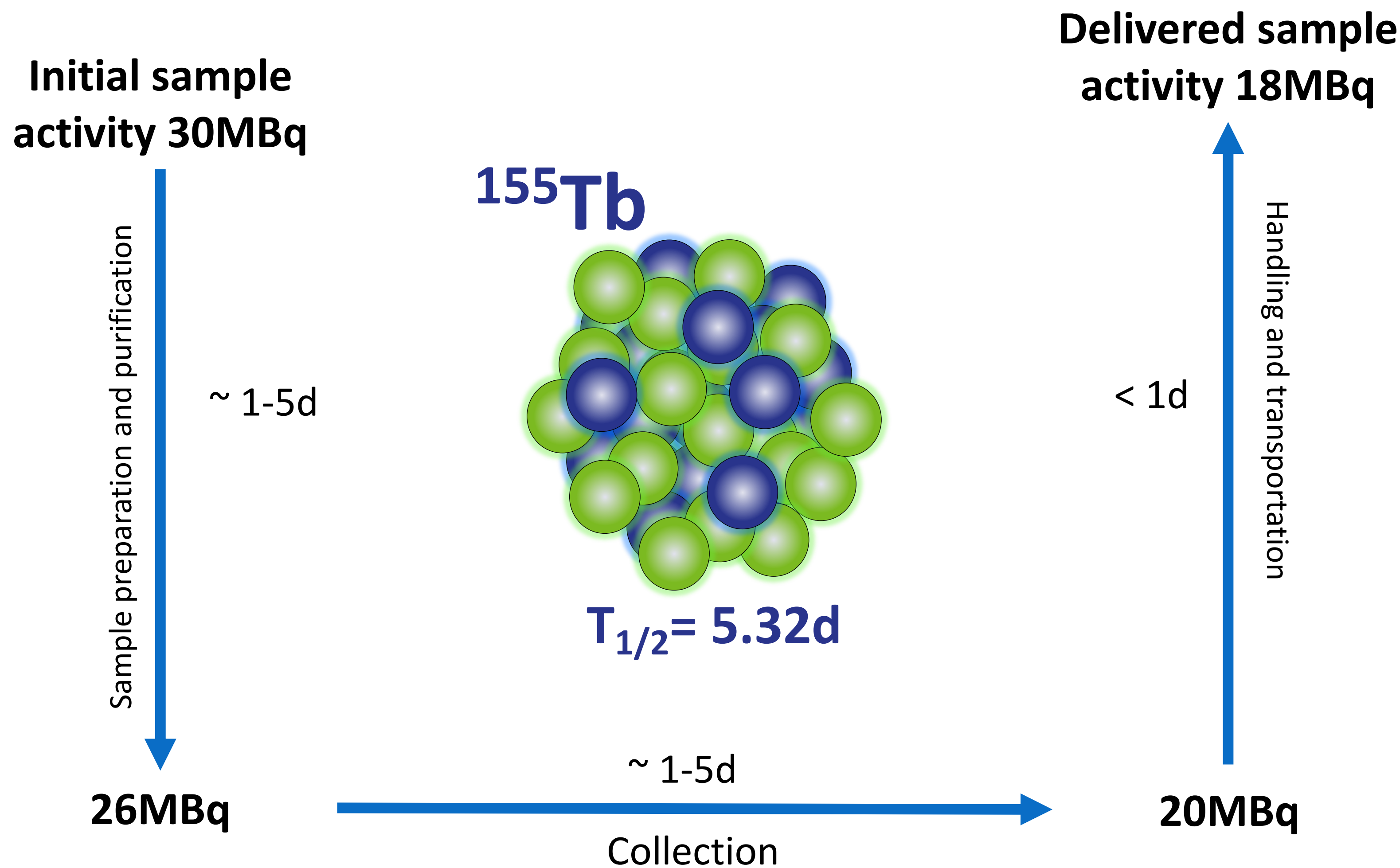
C. Duchemin et al. CERN-MEDICIS: A Review Since Commissioning in 2017. Front Med (Lausanne). 2021 Jul 15;8:693682. doi: 10.3389/fmed.2021.693682. PMID: 34336898; PMCID: PMC8319400.



C. Duchemin et al. CERN-MEDICIS: A Unique Facility for the Production of Non-Conventional Radionuclides for the Medical Research

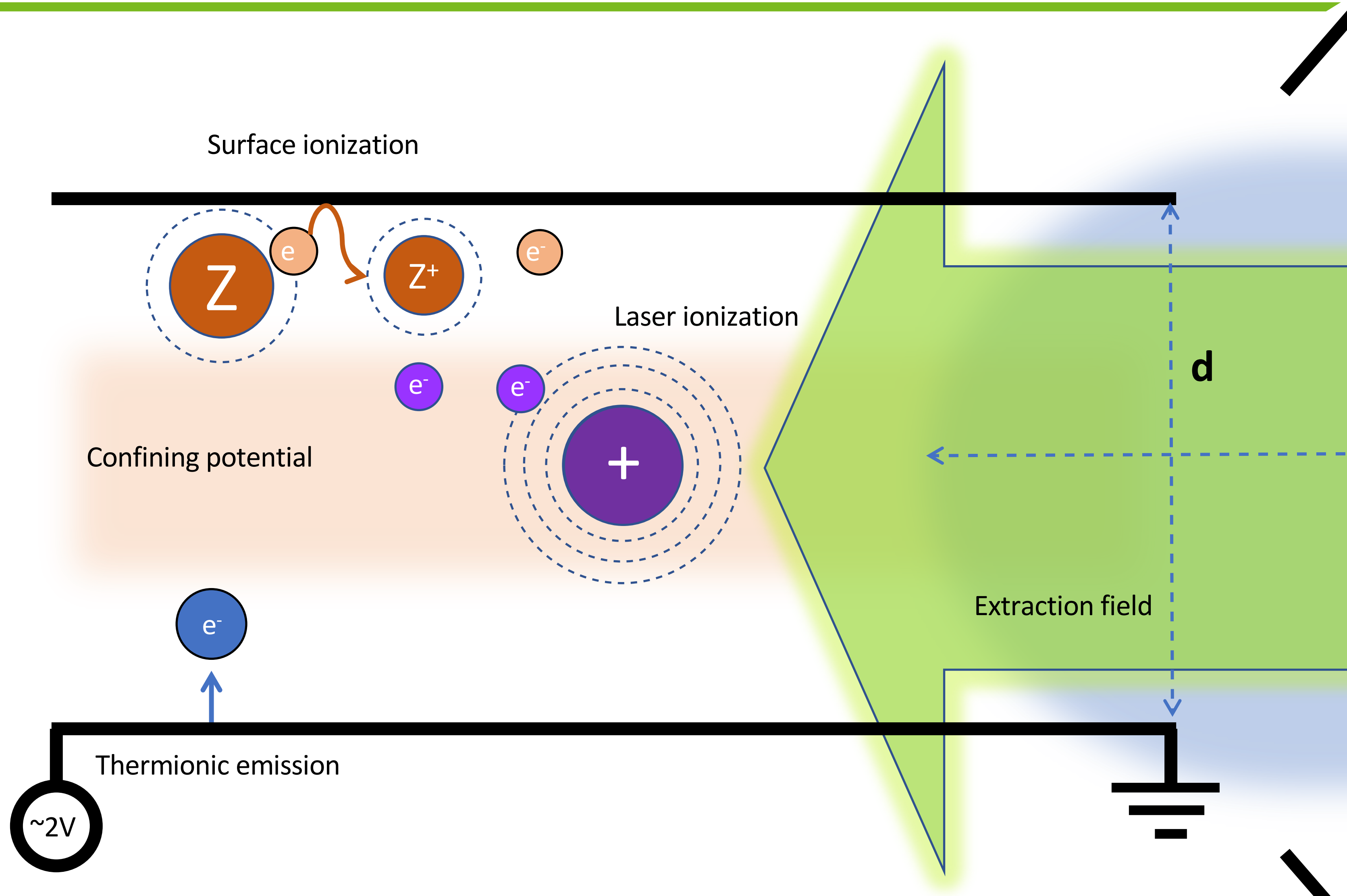
* C. Duchemin et al. CERN-MEDICIS: A review since commissioning in 2017 .

Production cycle of medical radionuclides



B. Webster et al. Chemical Purification of Terbium-155 from Pseudo-Isobaric Impurities in a Mass Separated Source Produced at CERN

Laser ion source up-close

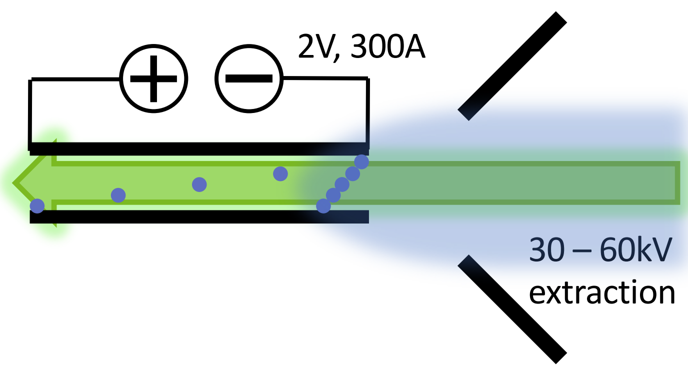


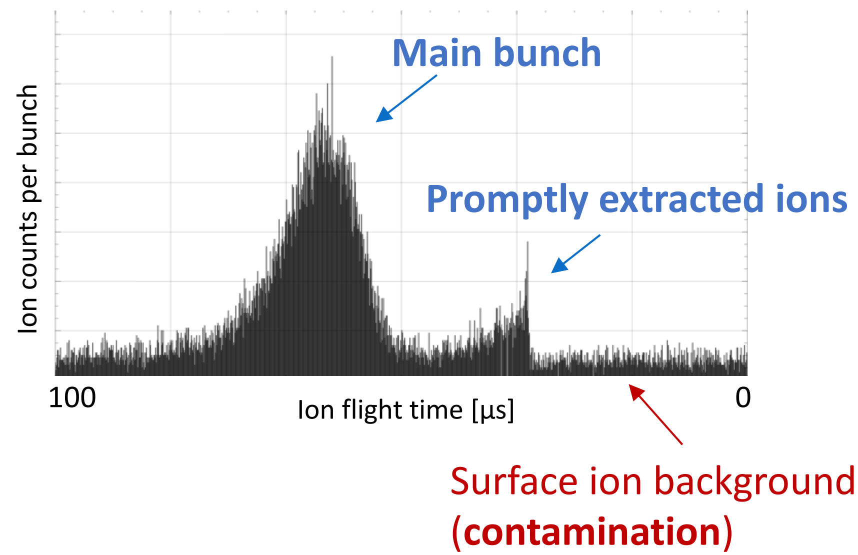
Laser ion source up-close

- Time structure shows extracted ions within one laser pulse (100 µs)
- Prebunch from ions created in the extraction potential
- Main bunch from ions extracted along the source

➢ Requires single ion detector, fast beam gating/time tagger card, power supply

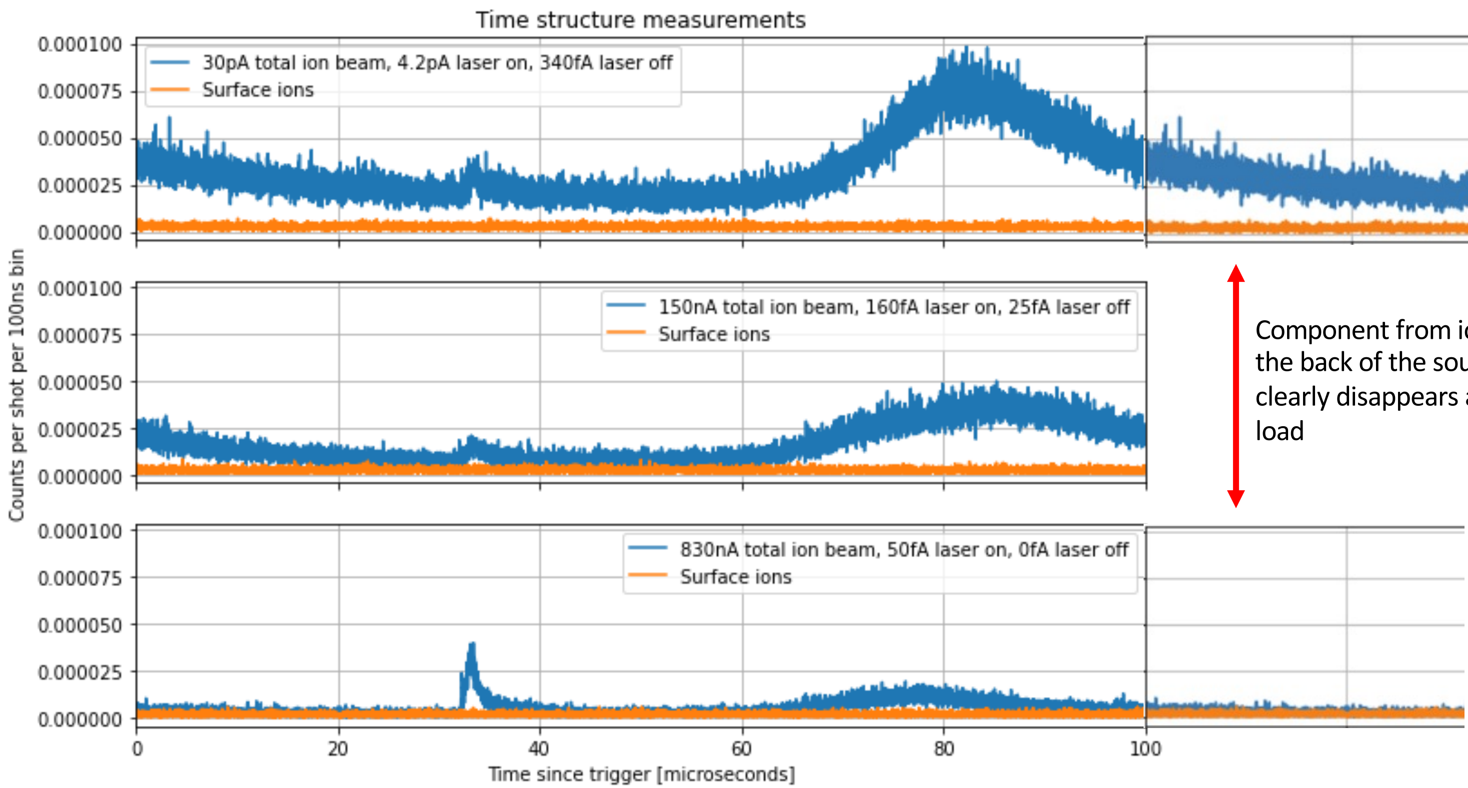
➢ Can be a good measurement to test the ion source limits by probing the laser ion extraction





The problem with high ion load

Time structures of a Ta ion source for low, medium and high ion currents



Component from ions from the back of the source clearly disappears at high ion load

Laser extraction is compromised at high ion loads due to confinement potential breakdown!

The ideal laser ion source for MEDICIS

Dear Santa,

~~*I want an iPad.*~~

Please build us an ion source:

- From a material with a low work function
- With good ion survival
- With good temperature distribution
- With fast ion extraction

Sincerely,

The RILIS team

Ion source material

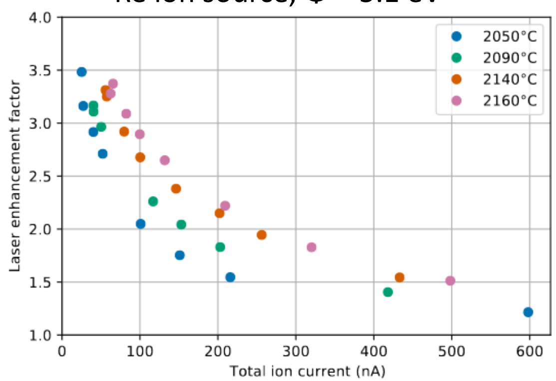
- Low work function materials are favored
  - Less surface ionization
  - More electron emission (better confinement)
- High melting point materials are required
  - Ion source heating ≈1600-2300°C
- Material has to fit machining requirements

Surface ionization efficiency

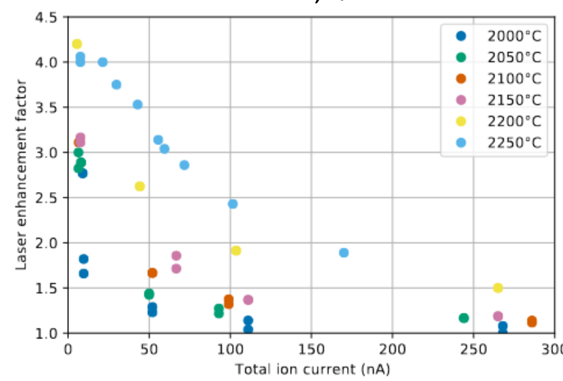
$$\frac{n_i}{n_0} = \frac{g_i}{g_0} \exp\left(\frac{\Phi - E_{IP}}{k_B T}\right)$$

Ion density (n_i), Neutral density (n_0), Statistical weights (g_i, g_0), Work function (Φ), Ionization potential (E_{IP}), Boltzmann constant (k_B), Temperature (T)

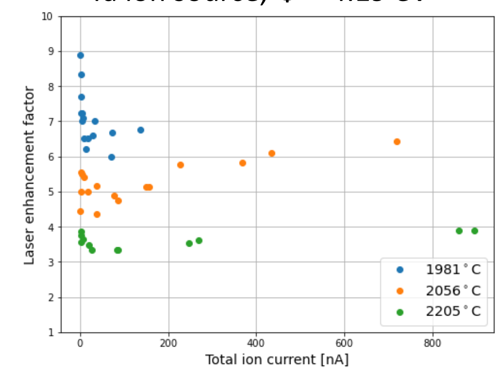
Re ion source, Φ = 5.1 eV



W ion source, Φ = 4.53 eV



Ta ion source, Φ = 4.19 eV



Ion survival

- Confining potential due to thermionic emission improves laser ion survival and reduces wall-sticking
- Confining potential breaks down at high ion loads
- Applying an external magnetic fields may improve confinement*

Confining potential**

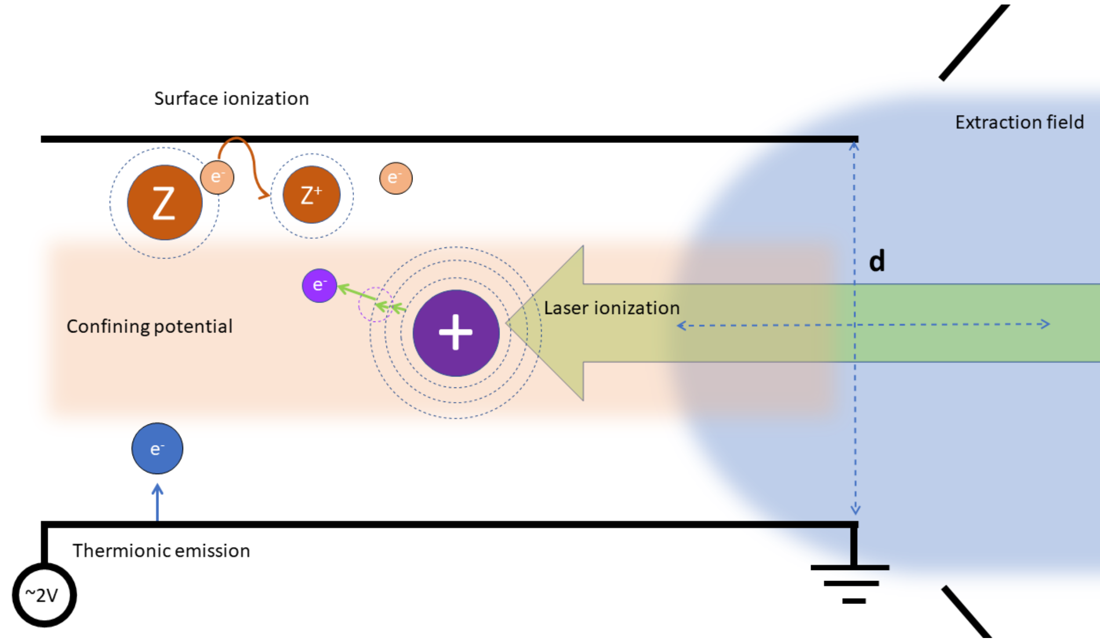
Plasma potential with respect to plasma enclosure

$$\Phi_p = \frac{k_B T}{\mathrm{e}} \ln \left[\frac{n_i}{n_e} \right]$$

Ion density

Electron charge

Electron density

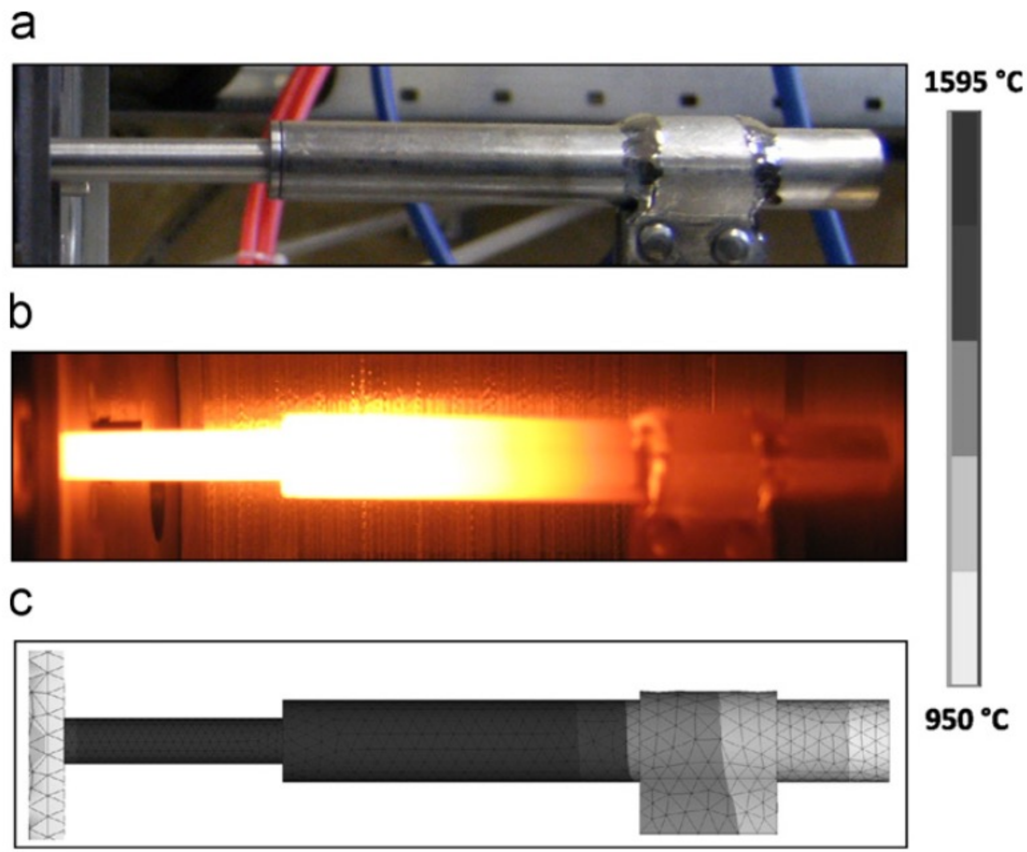


* V. Panteleev et al. Enhancement of ionization efficiency of surface, electron bombardment and laser ion sources by axial magnetic field application

** R. Kirchner. Progress in ion source development for on-line separators.

Temperature distribution

- Back of the transfer line is typically colder
- Condensation in so-called “cold spots”
- Decreased extraction of ions created in colder areas
- Uneven distribution of electrons emitted from the walls

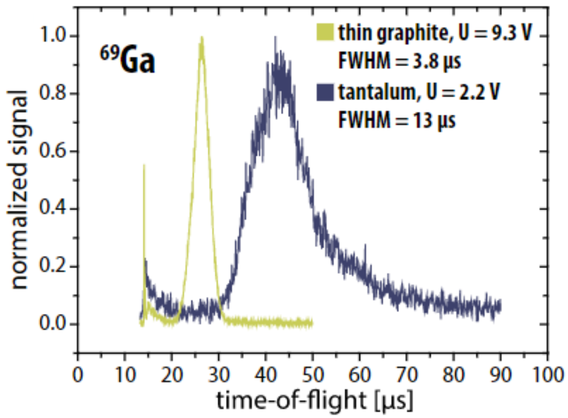


SPES ion source and transfer line*. (a) Source at room temperature. (b) Source at 300A line current. (c) Simulated model

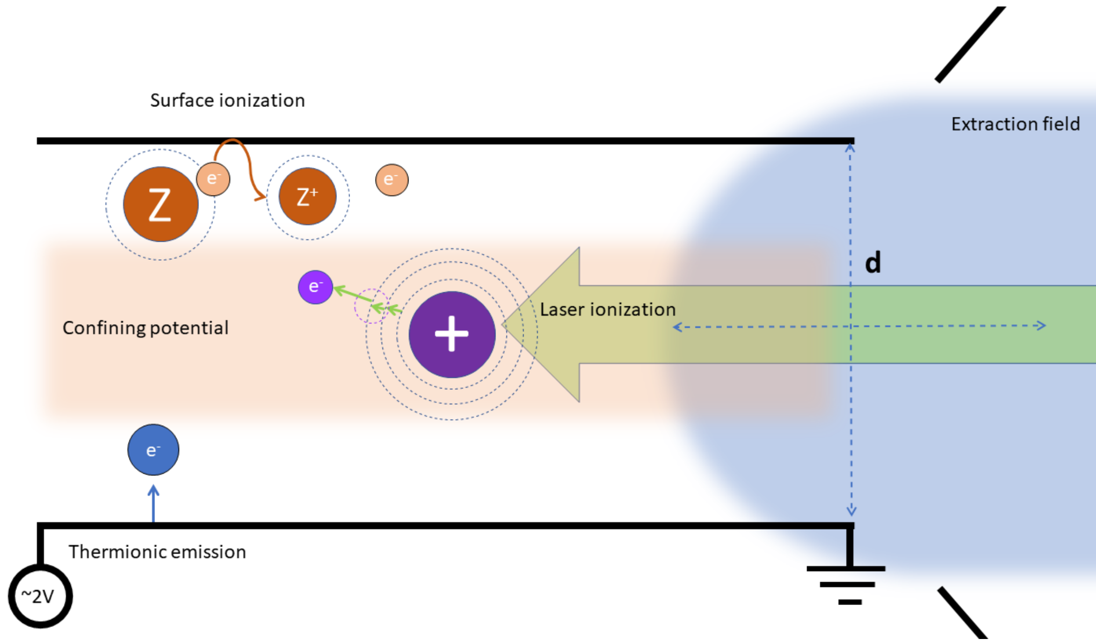
* M. Manzolaro et al. Thermal–electric numerical simulation of a surface ion source for the production of radioactive ion beams.

Ion extraction

- Fast extraction is favored in order to reduce dependence on ion survival requirements
- Extraction depends on longitudinal potential (2V for typical RILIS source)
- Longitudinal voltage depends on the line heating and resistivity of ion source
- Faster extraction corresponds to a more “narrow” time structure



Time structures of Ga for two different ion source materials*.



*S. Rothe et al. Advances in surface ion suppression from RILIS: Towardsthe Time-of-Flight Laser Ion Source (ToF-LIS)

Conclusion

- Fast extraction and collection of radioactive samples can decrease losses through decay in medical radioisotope production.
- A laser ion source specifically designed for MEDICIS can improve collection times.
- Ion source material, temperature distribution as well as ion survival and ion extraction are important parameters which are studied in order to design a new ion source.
- Decoupling these parameters and meeting machining requirements for an “ideal” laser ion source for MEDICIS is difficult even for Santa (which is why we need physicists)