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Towards a high throughput ion source for medical radioisotope production at MEDICIS

ISOLDE Workshop and Users meeting 2023

Ralitsa Mancheva on behalf of the RILIS team

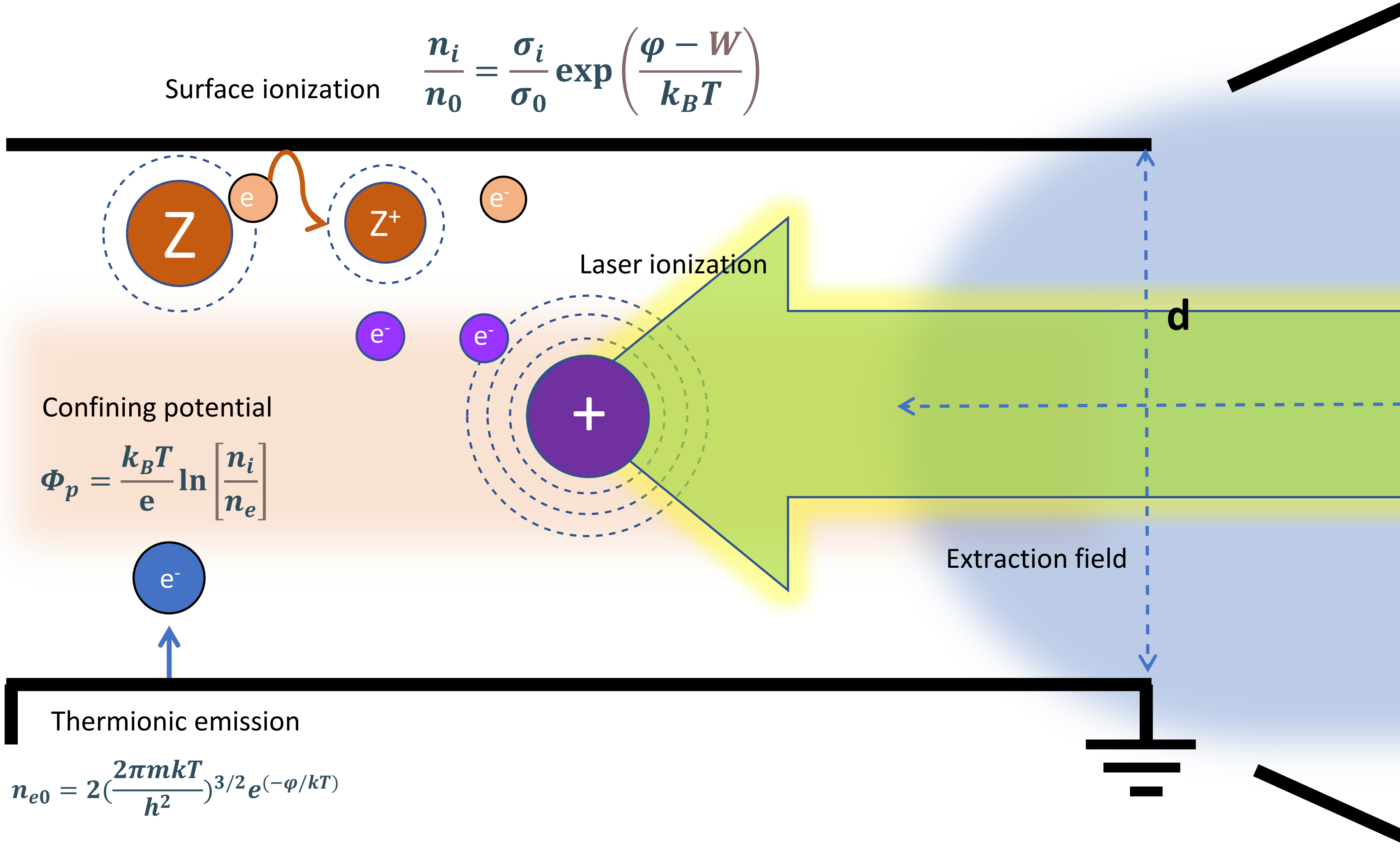
Outline

- What is a laser ion source?
- A new laser ion source for MEDICIS
- What have we tested so far?
- Discussion and outlook

What is a laser ion source?

The ion source up-close

- Ion survival?
- Mean number of wall collisions?
- Electron impact ionization from electrons in the extraction potential?
- Neutral density distribution?
- Neutral density influence on ions?

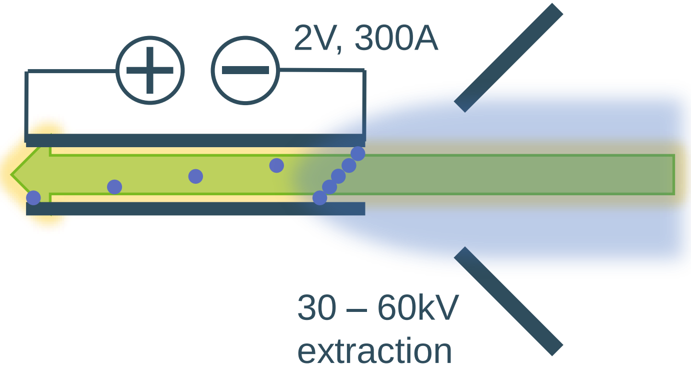


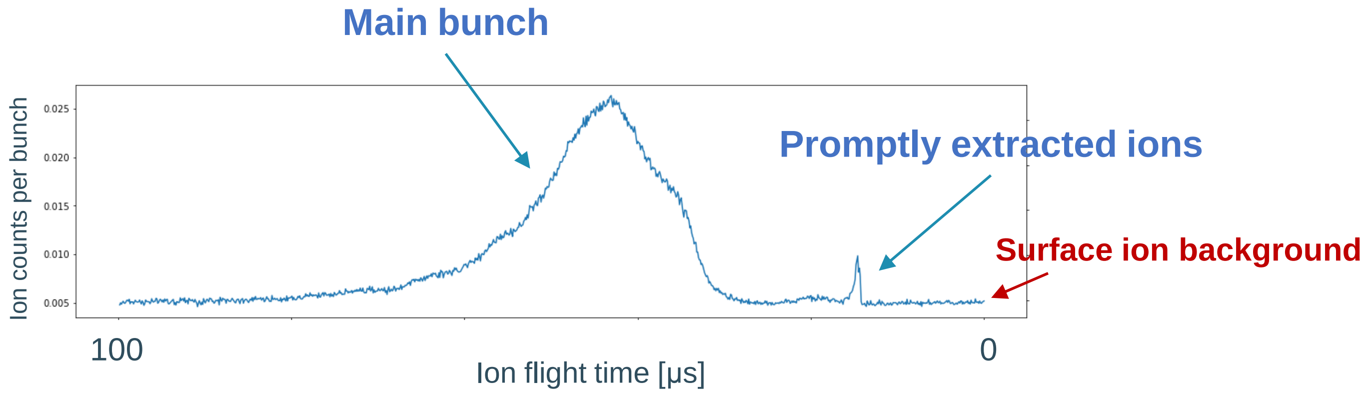
Φ_p - Plasma potential with respect to plasma enclosure
k_B – Boltzmann constant
e - Electron charge
T – Plasma temperature
n_i - Ion density
n_e - Electron density
φ – Work function of cavity material
W – First ionization potential of atomic species
σ_i - Statistical weight of ionic/atomic ground state

Time structure of extracted ions

- Time structure shows histogram of extracted ions within one laser pulse (100 μs)
- Narrow peak from ions created in the extraction potential
- Main peak from ions extracted along the source

➢ Good qualitative way to “probe” the ion source





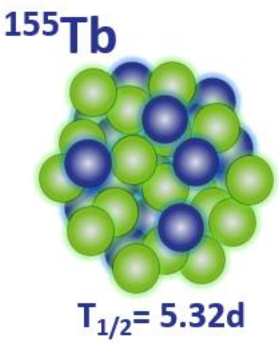
A new laser ion source for MEDICIS

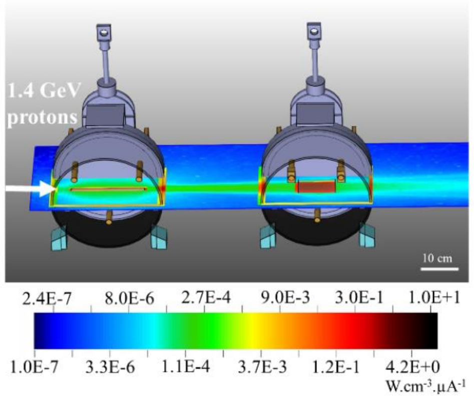
Radioisotope production at MEDICIS

Initial sample activity 30MBq

Sample preparation

~ 1-5d



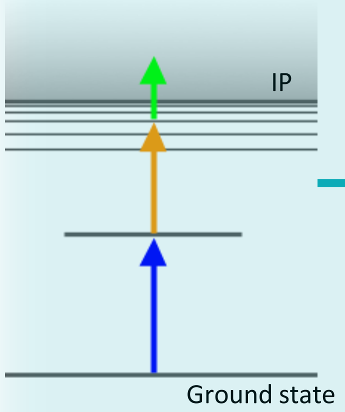


16-26 MBq

Target irradiation

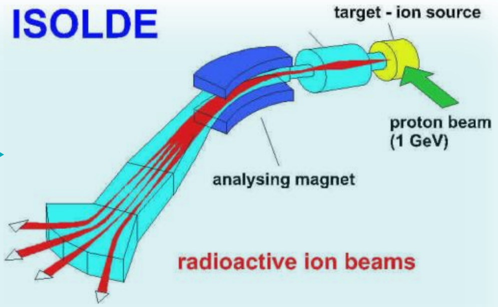
< 1d

RILIS



16-26 MBq

ISOLDE



Mass separation + Ionization = ~50% efficiency

Collection at MEDICIS

~ 1-5d

8-23 MBq

Handling and transportation

< 1d

Delivered sample activity 7-20MBq

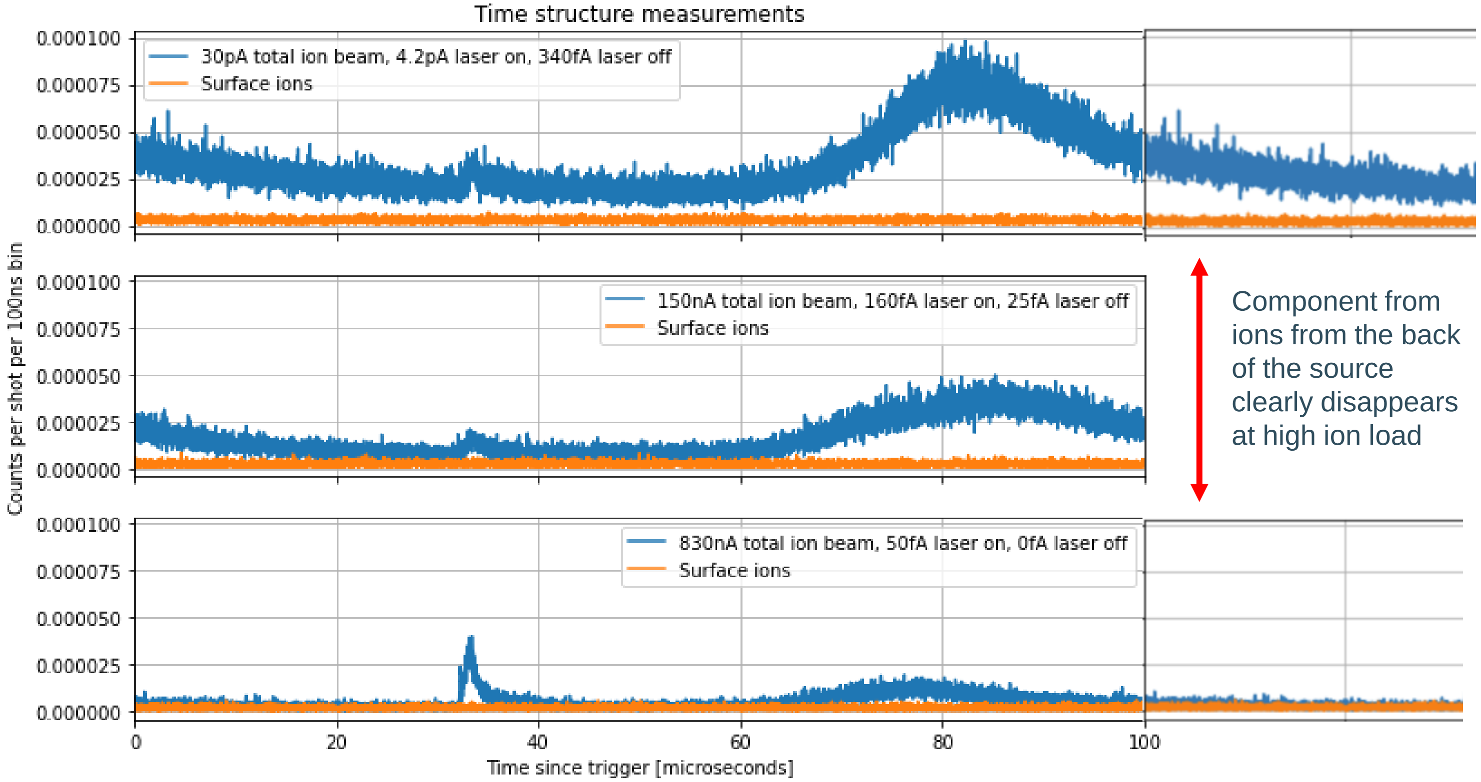
ISOLDE vs. MEDICIS

	ISOLDE	MEDICIS
Half-life of extracted species	Down to ms	A few days
Ion beam magnitude	nA	µA
Production and extraction	Simultaneously (steady-state)	Separate with compressed extraction time
Ion load limit on ion source reached	Sometimes	Often
Ion source designed for specific requirements	Yes	No

The high ion throughput problem

- Laser ion extraction reduced at high ion load
- In some cases, no laser effect is present
- Confinement potential breakdown
- Ions from the back of the source are not extracted efficiently
- MEDICIS operates at high ion loads

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



An ideal high-throughput laser ion source

Fast ion extraction

Good temperature distribution
- Homogenous temperature profile
- No cold spots

Good ion survival
- Strong confinement
- Low wall collision probability

Appropriate material
- Low work function
- Easy to machine or 3D print
- Robust

What have we tested so far?

OFFLINE 2 measurements

SPES

Time structures

Sm+K, 10kHz

1800 °C	2050 °C	2200 °C
Ion load:	**Ion load:**	**Ion load:**
4nA	**2nA**	**60nA**
60nA	**450nA**	**470nA**
230nA	**730nA**	**1000nA**

Ga+K, 1kHz

Low ion load:
1800 °C
1940 °C
2050 °C
2200 °C

Efficiency

First set:
3 LIS
1 SIS

Second set:
2 SIS

SCK

Time structures

Sm+K, 10kHz

1800 °C	2030 °C	2200 °C
Ion load:	**Ion load:**	**Ion load:**
9nA	**0.4nA**	**2nA**
100nA	**110nA**	**500nA**
1000nA	**1100nA**	**3100nA**

Efficiency

1 LIS
1 SIS

MLIS

Time structures

2000 °C
5A magnet current
Ion load: 400nA

RILIS threaded

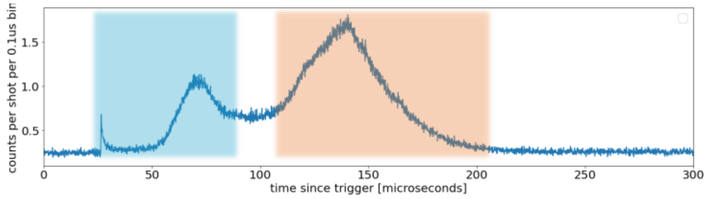
Efficiency

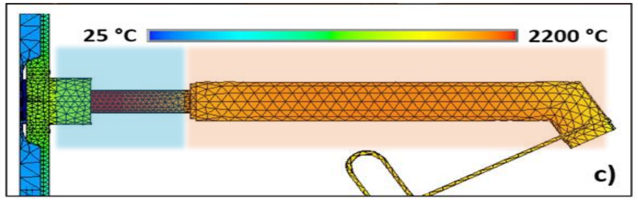
1 measurement with standard source

1 measurement with threaded source

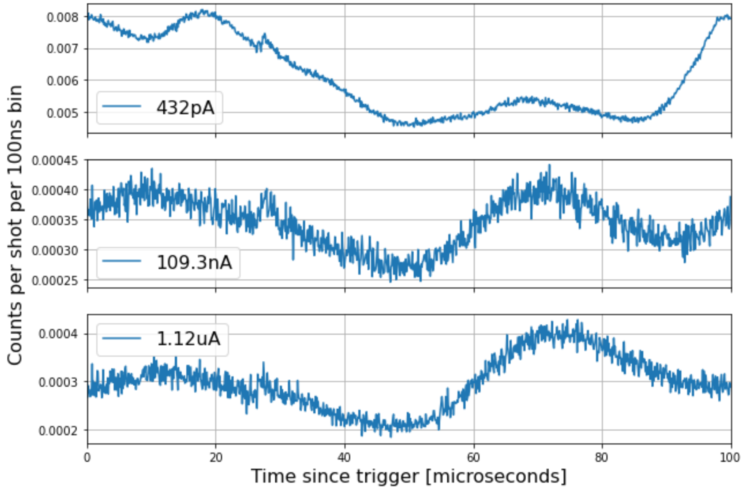
Back-of-the-line heating, a state-of-the-art solution?

	RILIS standard design	SPES	SCK
Ion source length	34 mm	33 mm	33 mm
Transfer line length	32 mm	65.2 mm	65 mm
Heated back of transfer line	No	Yes	Yes

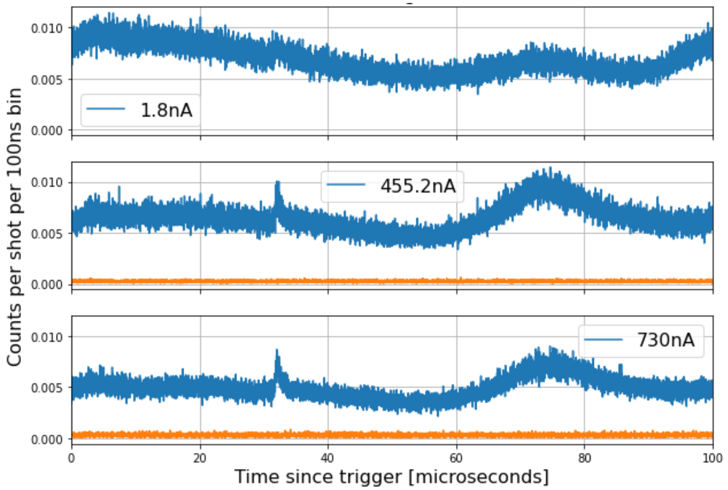




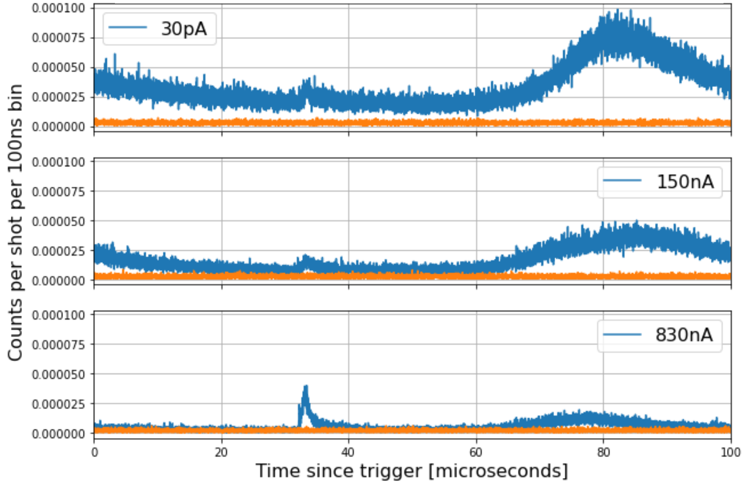
SCK – 2000°C



SPES - 2050°C



RILIS standard - 2064°C



Conclusions and outlook

- A high ion throughput decreases laser ion extraction in laser ion sources
- A new laser ion source design is in development for MEDICIS to improve collection time
- The processes and parameters inside a laser ion source are various and difficult to decouple
- Heating the back of the transfer line improves ion confinement and extraction

Various measurements are planned to further study ion source parameters:

- Injection of neutrals
- Electron emission measurements
- Alternative ion source configurations (e.g. threaded source)
- More measurements with external magnetic field

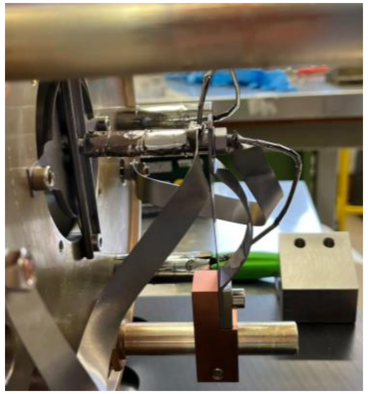
Thank you for the laser focused attention!

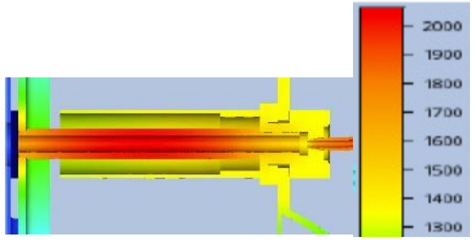
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008571 (PRISMAP).

Backup slides

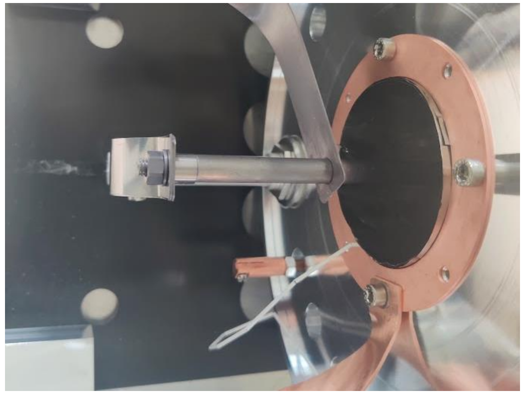
Design comparison

RILIS standard



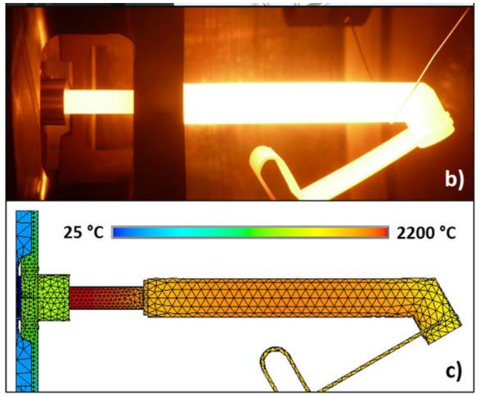


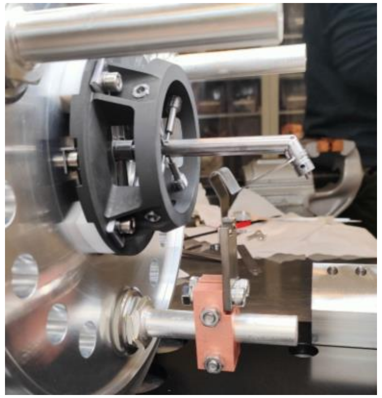
MLIS



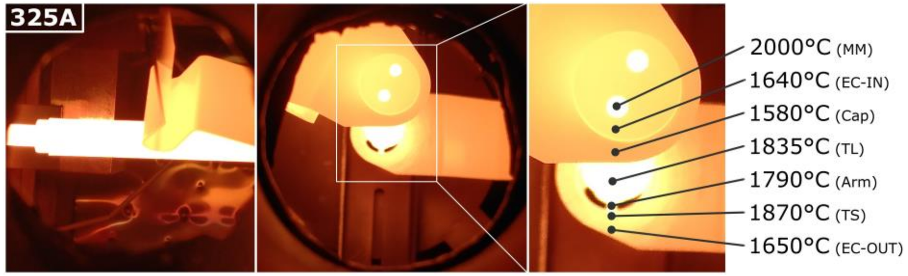
	RILIS standard design	SPES	SCK	RILIS with magnet (MLIS)
Ion source length	34 mm	33 mm	33 mm	34 mm
Transfer line length	32 mm	65.2 mm	65 mm	75 mm
Heated back of transfer line	No	Yes	Yes	Yes

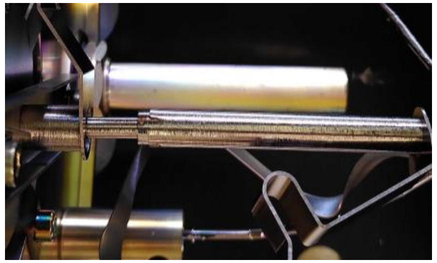
SPES

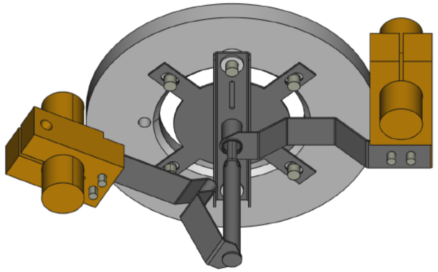




SCK







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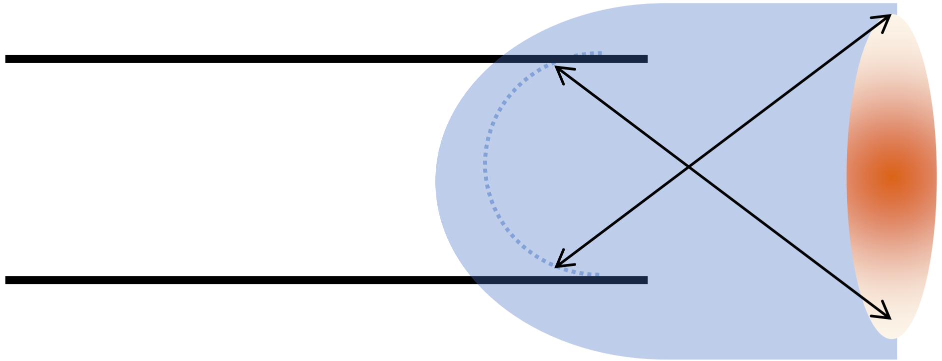
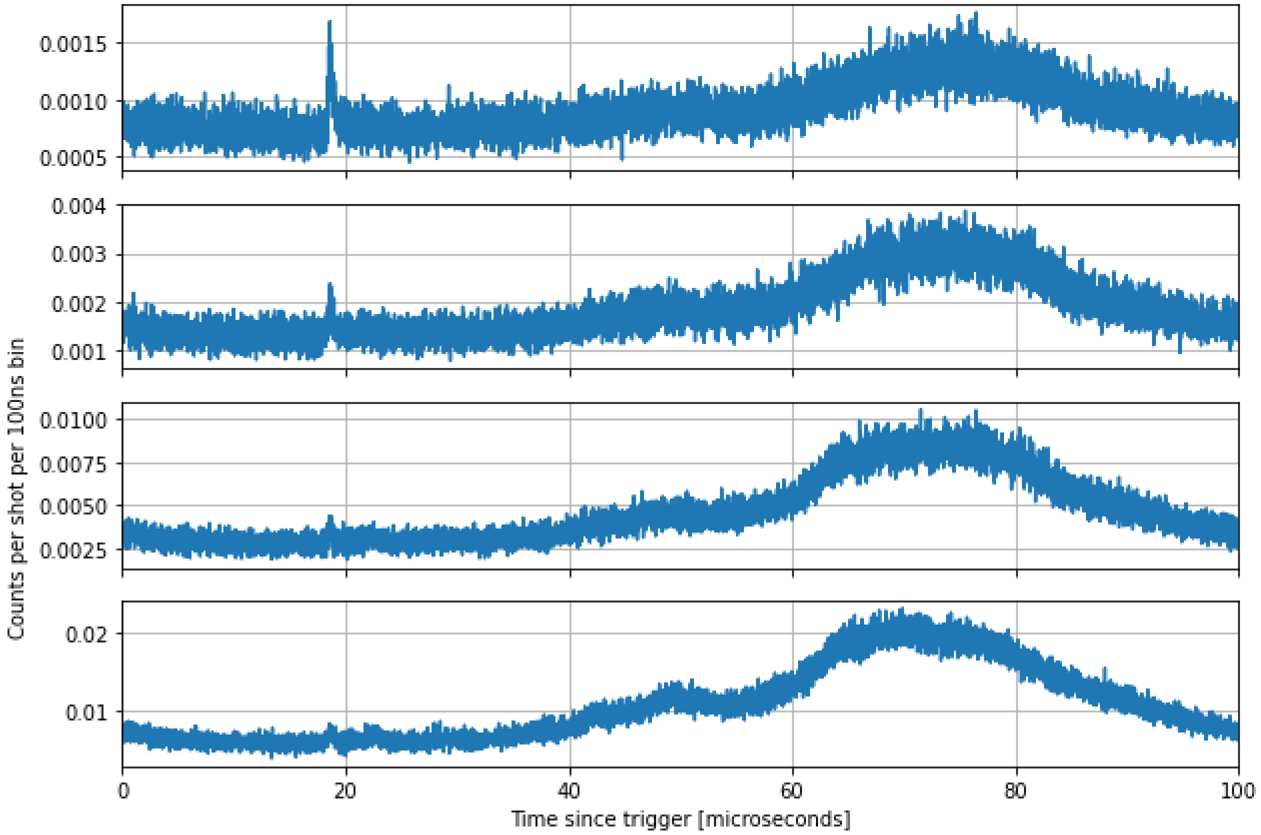
Ga timestructures – beam not centered on magnetof

- Decentering beam to reduce current on magnetof
  - ➢ Shows overpronounced prompt peak
  - ➢ Possibly due to larger energy spread at edges of beam



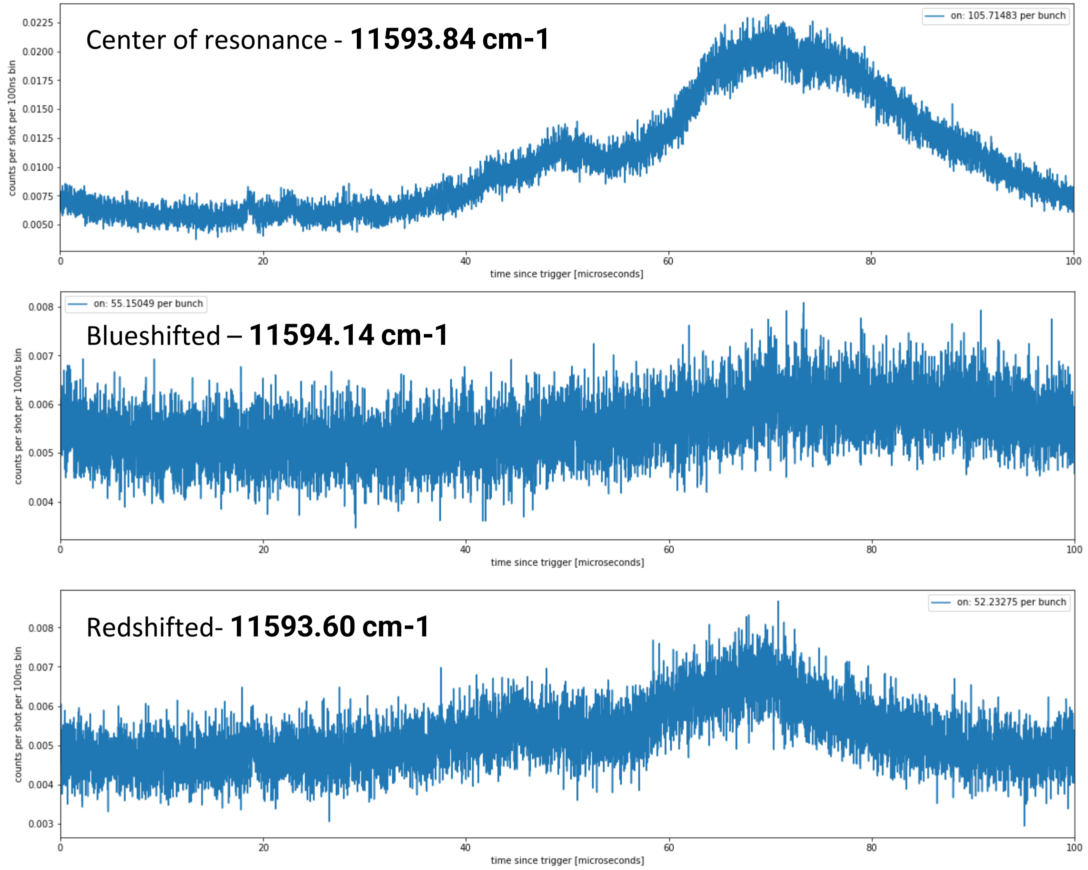
2200°C, 5nA total beam



Ga timestructures – wavelength detuned

- Detuned wavelength to reduce current on magnetof
    - ➢ Clear difference from Doppler effect

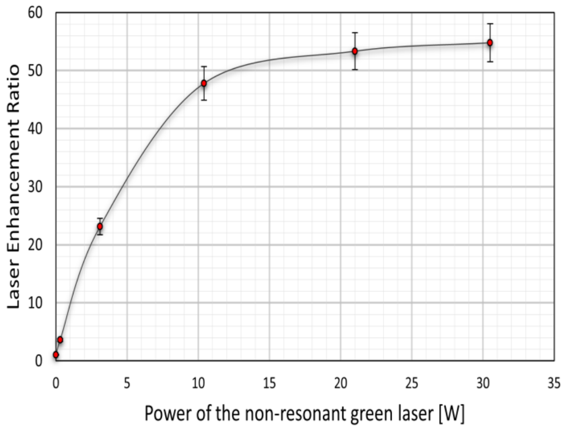
2200°C, 5nA total beam

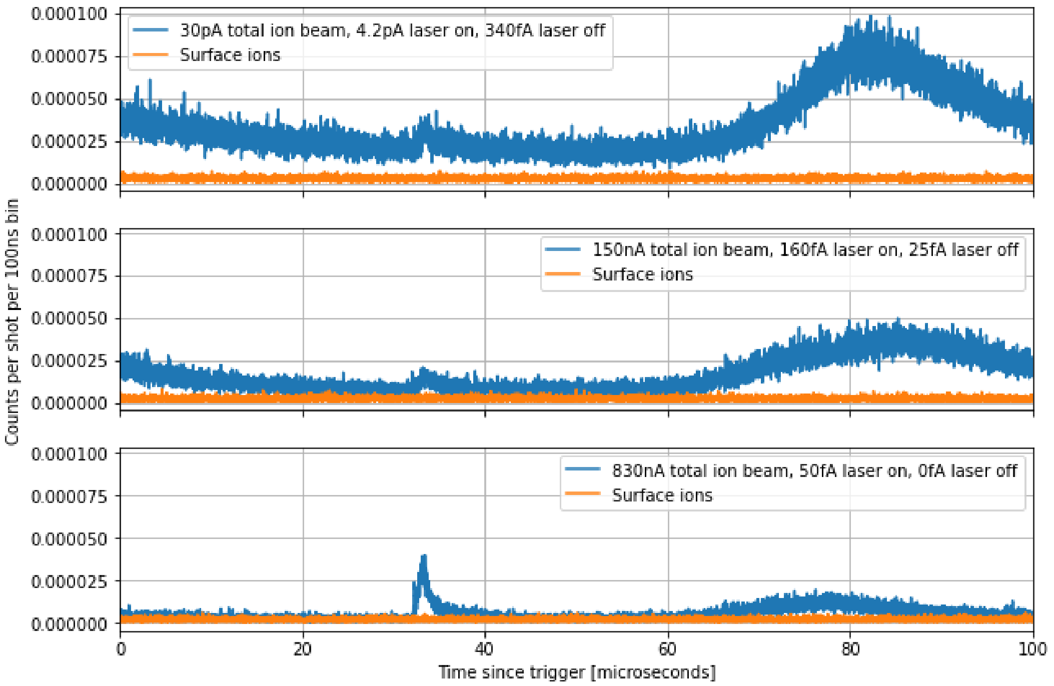


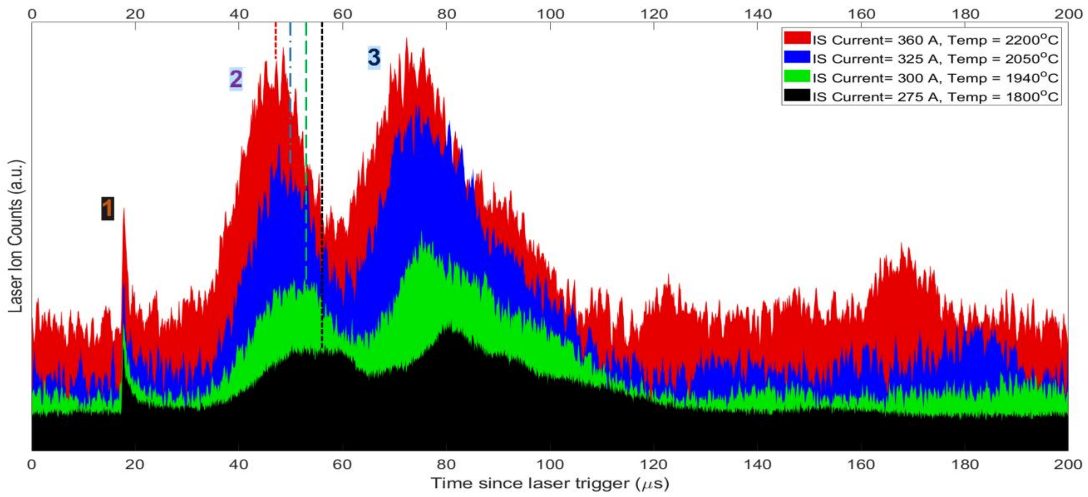
More SPES

Table 2: Measured ionization efficiency values of gallium at ion source temperature 2200°C

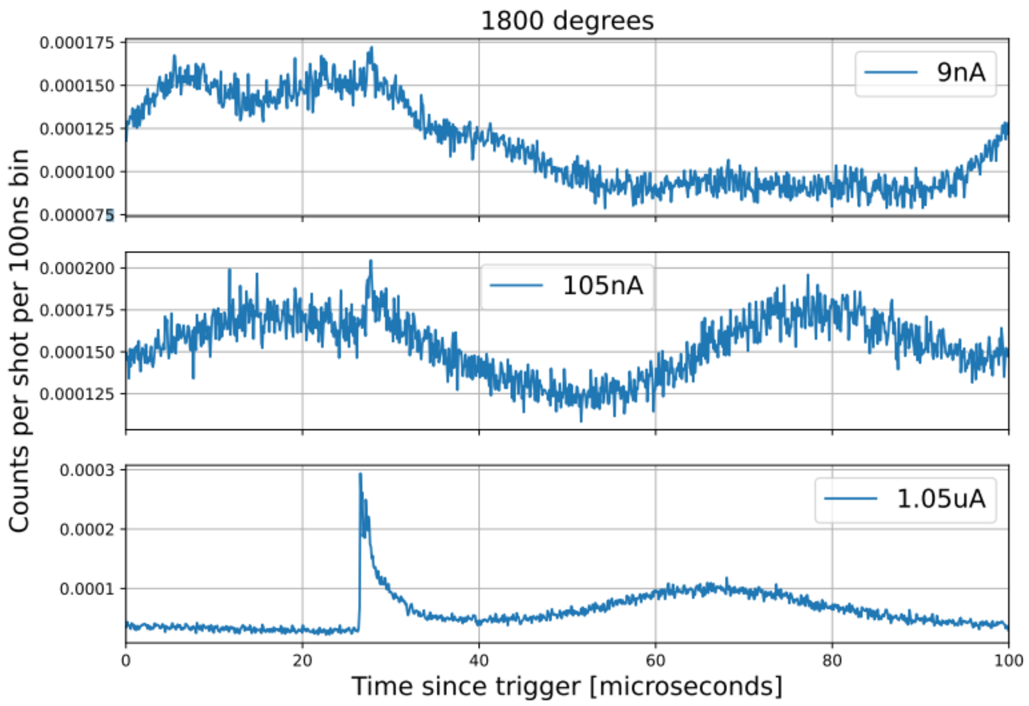
Test no.	Type	Efficiency(%)	Mean Efficiency(%)
1	Surface	0.49 ±0.04	0.49 ±0.04
2	Laser	27.66 ±2.07	27.18 ±1.18
3	Laser	27.64 ±2.07	
4	Laser	26.23 ±1.97	

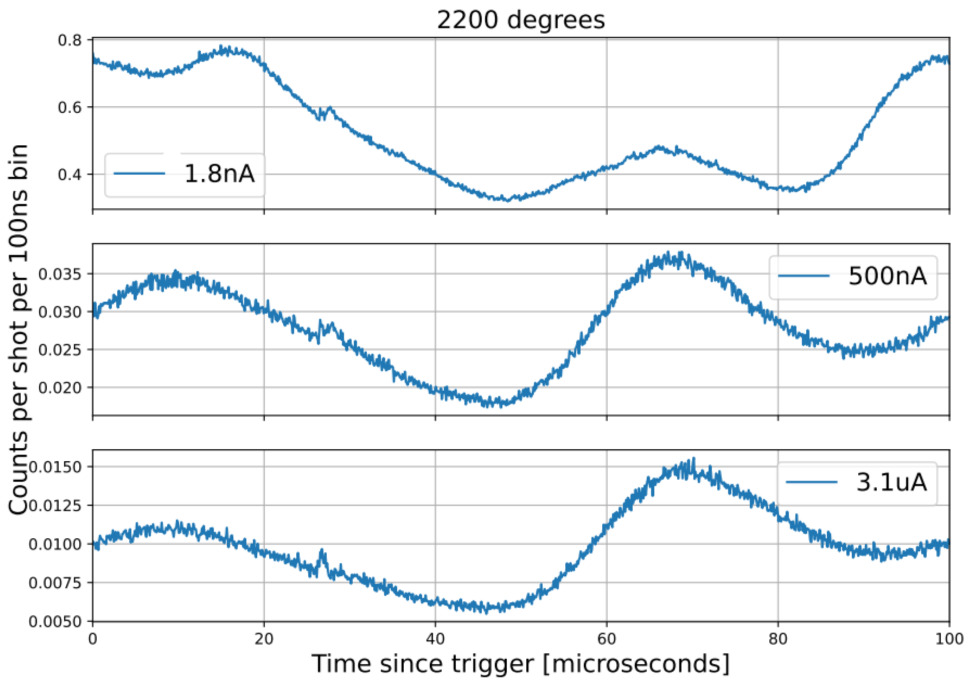






More SCK


1800 degrees
9nA
105nA
1.05uA
Counts per shot per 100ns bin
Time since trigger [microseconds]
0.000175
0.000150
0.000125
0.000100
0.000075
0.000200
0.0003
0.0002
0.0001
0
20
40
60
80
100


2200 degrees
1.8nA
500nA
3.1uA
Counts per shot per 100ns bin
Time since trigger [microseconds]
0.8
0.6
0.4
0.035
0.030
0.025
0.020
0.0150
0.0125
0.0100
0.0075
0.0050
0
20
40
60
80
100

RILIS with heated transfer line (Sb -23.10.2023)