

# Towards chemistry beyond moscovium (Mc, $Z = 115$ )

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for TASCA collaboration

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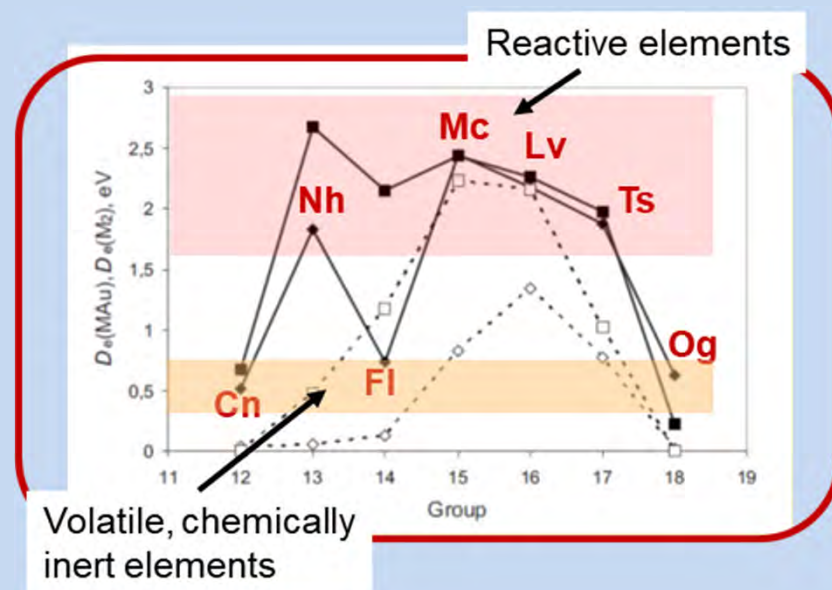
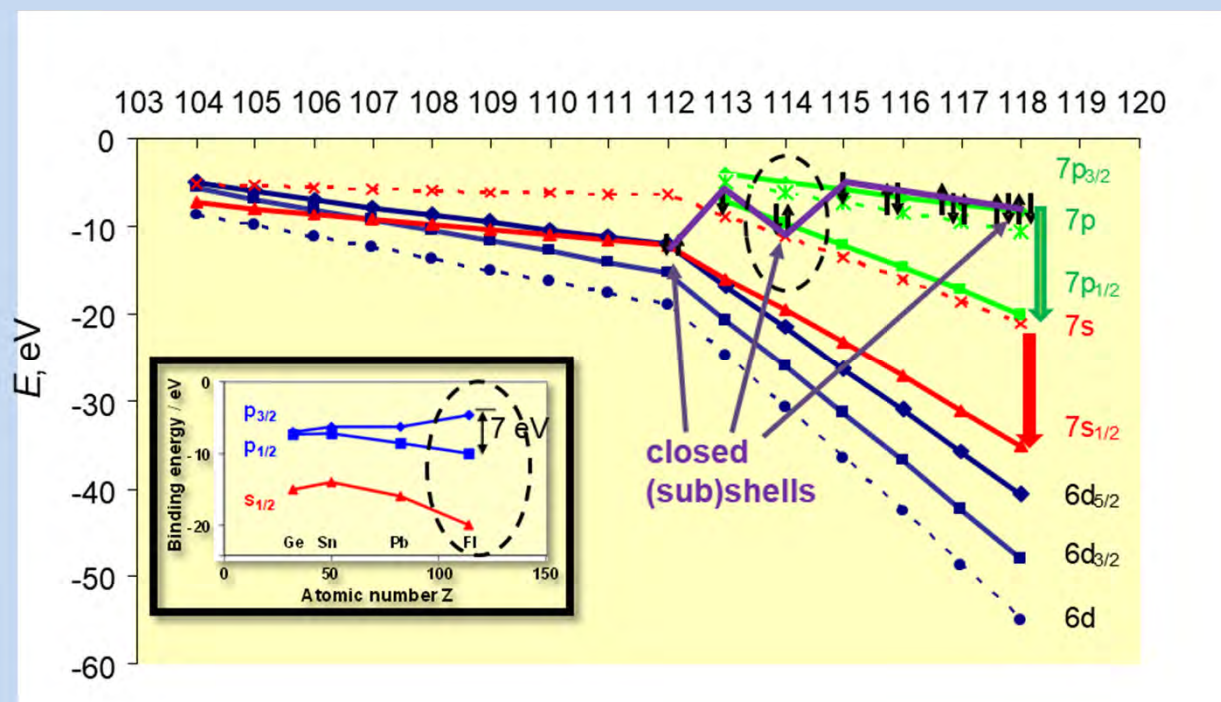


GEFÖRDERT VOM



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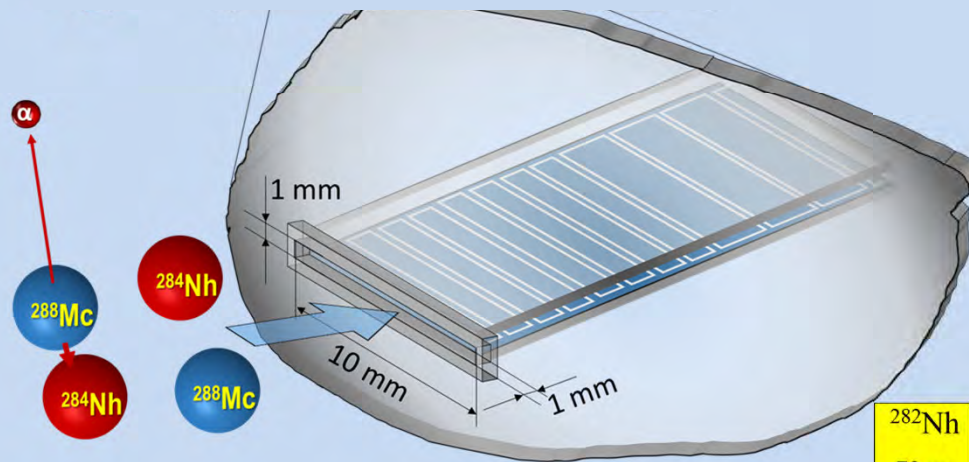
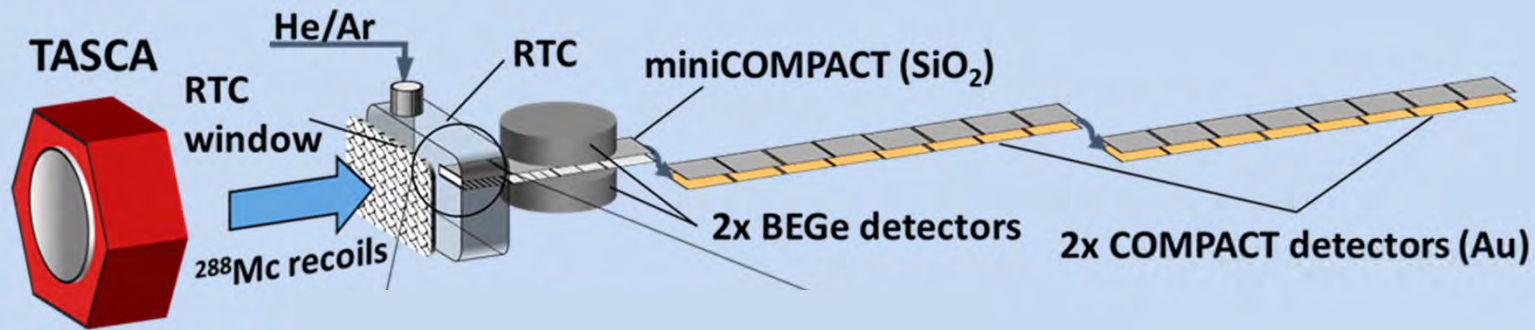
## Superheavy element (SHE) chemistry : current status



- Strong relativistic effects influence on the chemical properties of SHE
- First chemical studies with Cn, Nh, Fl and Mc are performed
- Closed-shell elements Cn and Fl are volatile metals; odd-Z elements Nh and Mc are reactive



# SHE chemistry at TASCA : current status



		294Og	
		0.69 ms	
	293Ts		294Ts
		22 ms	51 ms
290Lv	291Lv	292Lv	293Lv
8.3 ms	19 ms	13 ms	57 ms

	287Mc	288Mc	289Mc	290Mc
	42 ms	170 ms	330 ms	650 ms
285Fl	286Fl	287Fl	288Fl	289Fl
0.13 s	0.12 s	0.48 s	0.66 s	1.9 s
282Nh	283Nh	284Nh	285Nh	286Nh
73 ms	82 ms	1.02 s	4.2 s	9.5 s

***A new faster transport technique is needed for elements beyond Mc***

# Solution: gas stopping cell

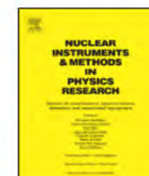
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## Concept of a new Universal High-Density Gas Stopping Cell Setup for study of gas-phase chemistry and nuclear properties of Super Heavy Elements (UniCell)



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### ARTICLE INFO

#### Keywords:

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Superheavy elements  
Gas-phase chemical reactor  
RF-funnels  
RF-buncher  
Gas dynamic and Monte Carlo ion-trajectory simulations

### ABSTRACT

Here we propose a concept of a new universal high-density gas stopping cell setup (UniCell), whose advantages are based on use of the ultra-compact RF ion-funnel technique. It will allow for the fast (~2 ms) and highly efficient (up to 100%) extraction of ions in a wide range of masses from high-density gas stopping cells and, in particular, ions of superheavy elements (SHE) for gas-phase chemical studies and nuclear property (high-precision mass spectrometry, laser and decay spectroscopy) measurements. The gas cell consists of a traditional DC-cage and (RF+DC)-funnel of a novel compact design.

For physical researches, the UniCell is equipped with the additional system of three RF-funnels placed on the axis downstream the gas cell exit, which will allow for a high-efficient and fast extraction of ions into high-vacuum with production of continuous and pulsed ion beams having a record small transverse and longitudinal emittance.

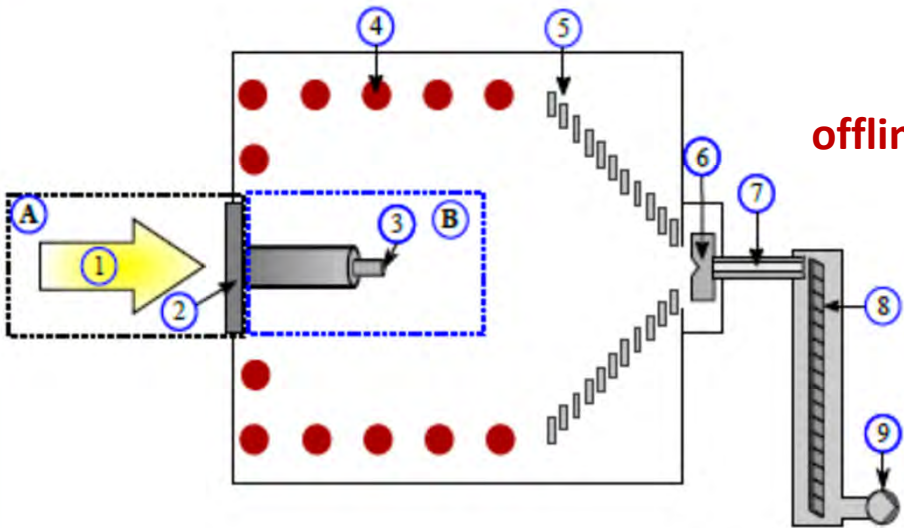
For the gas-phase chemistry studies, the system of three extraction RF-funnels can be replaced by a gas chromatography detector array with an original gas ejector-interface, which will allow, when it will be necessary for ions neutralization, to add different reactive gases into the helium flow.

The operation regimes of the proposed UniCell have been explored by detailed gas dynamic and Monte Carlo ion-trajectory simulations, whose results are presented and discussed.

# Solution: gas stopping cell

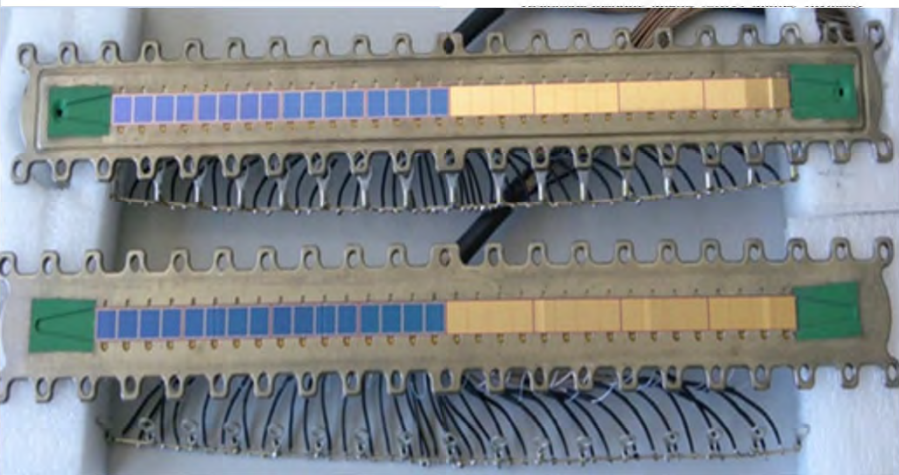
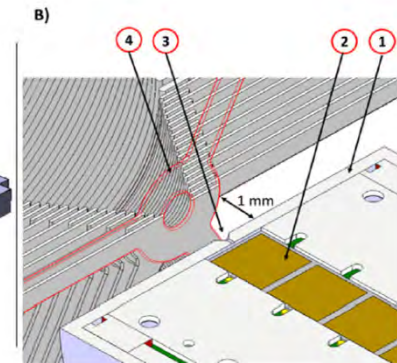
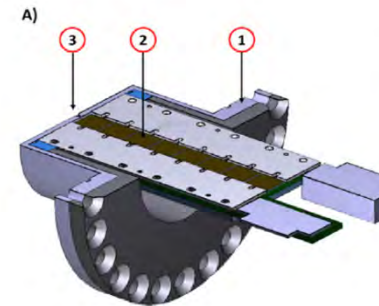
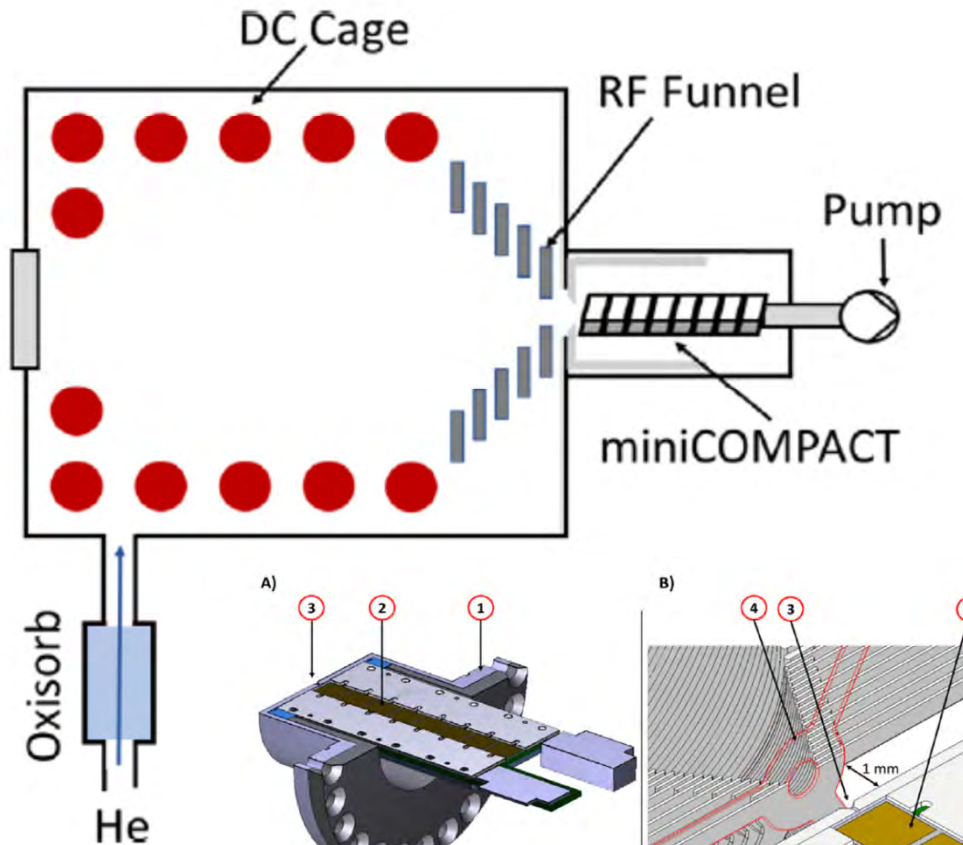
S. Götz et al., *Nuclear Inst. and Methods in Physics Research, A* 995 (2021) 165090

S. Götz et al., *Nuclear Inst. and Methods in Physics Research, B* 507 (2021) 27–35



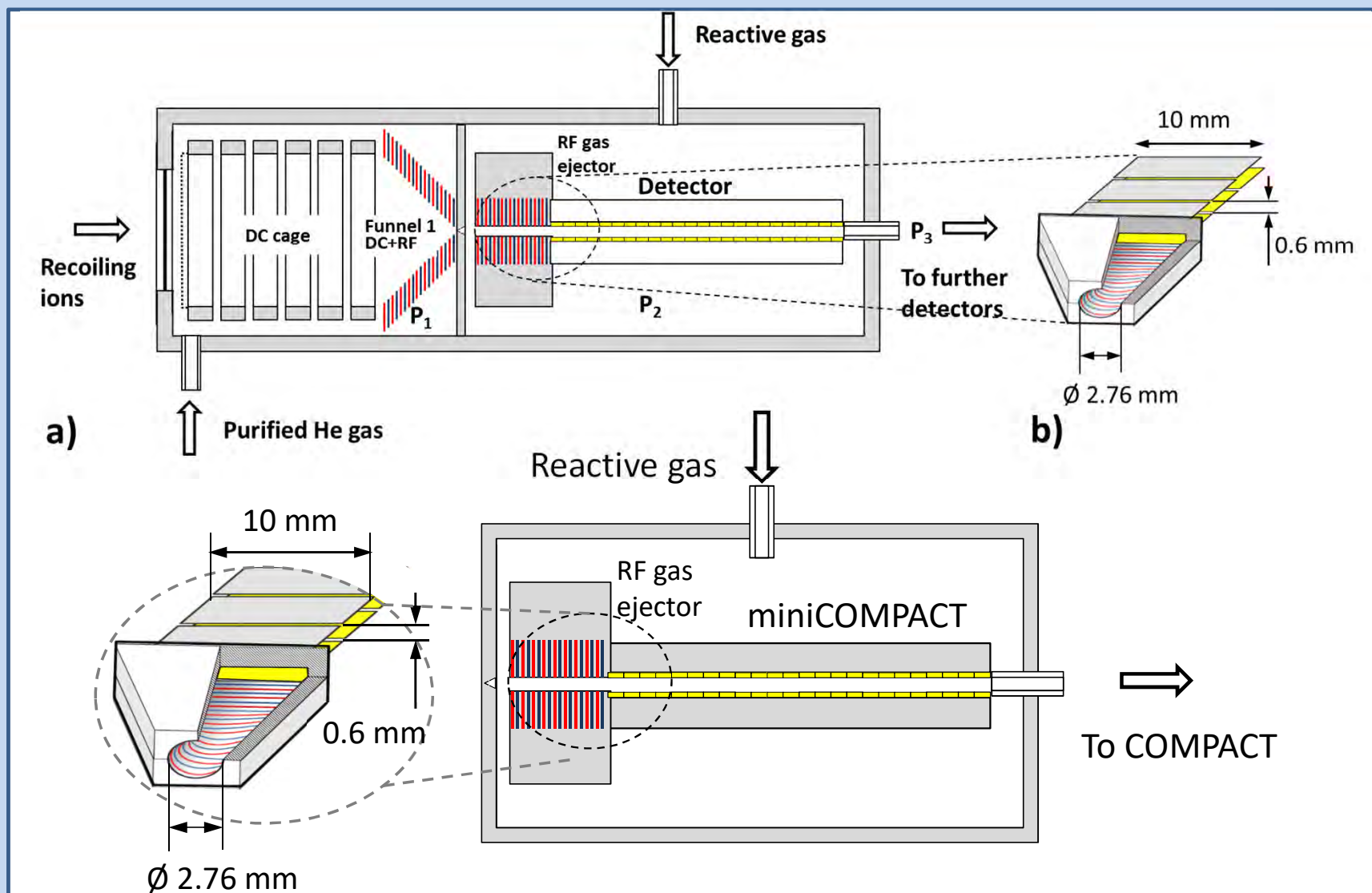
offline online

Entrance Window

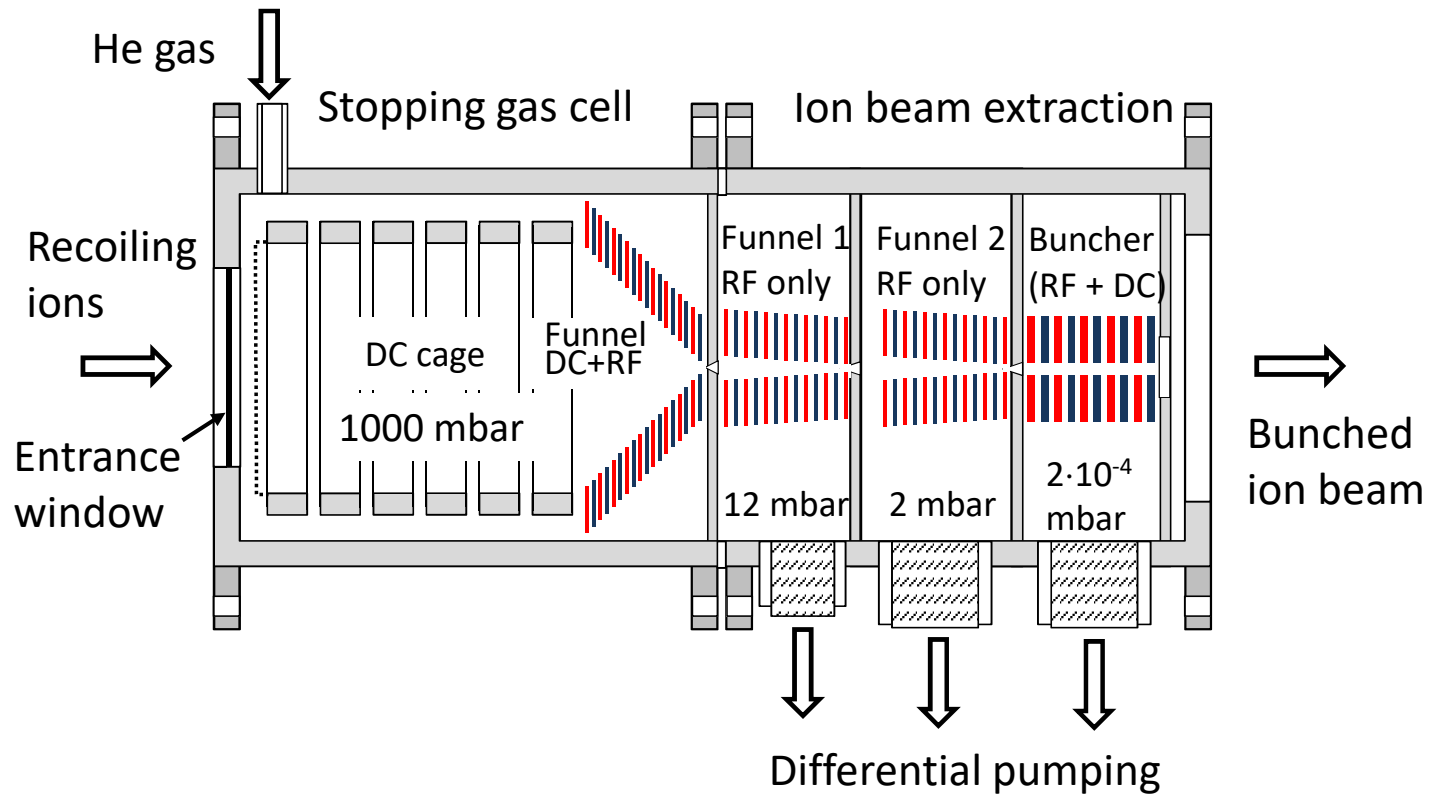


Carlo ion-trajectory simulations, whose results are present

# UniCell for SHE chemistry...



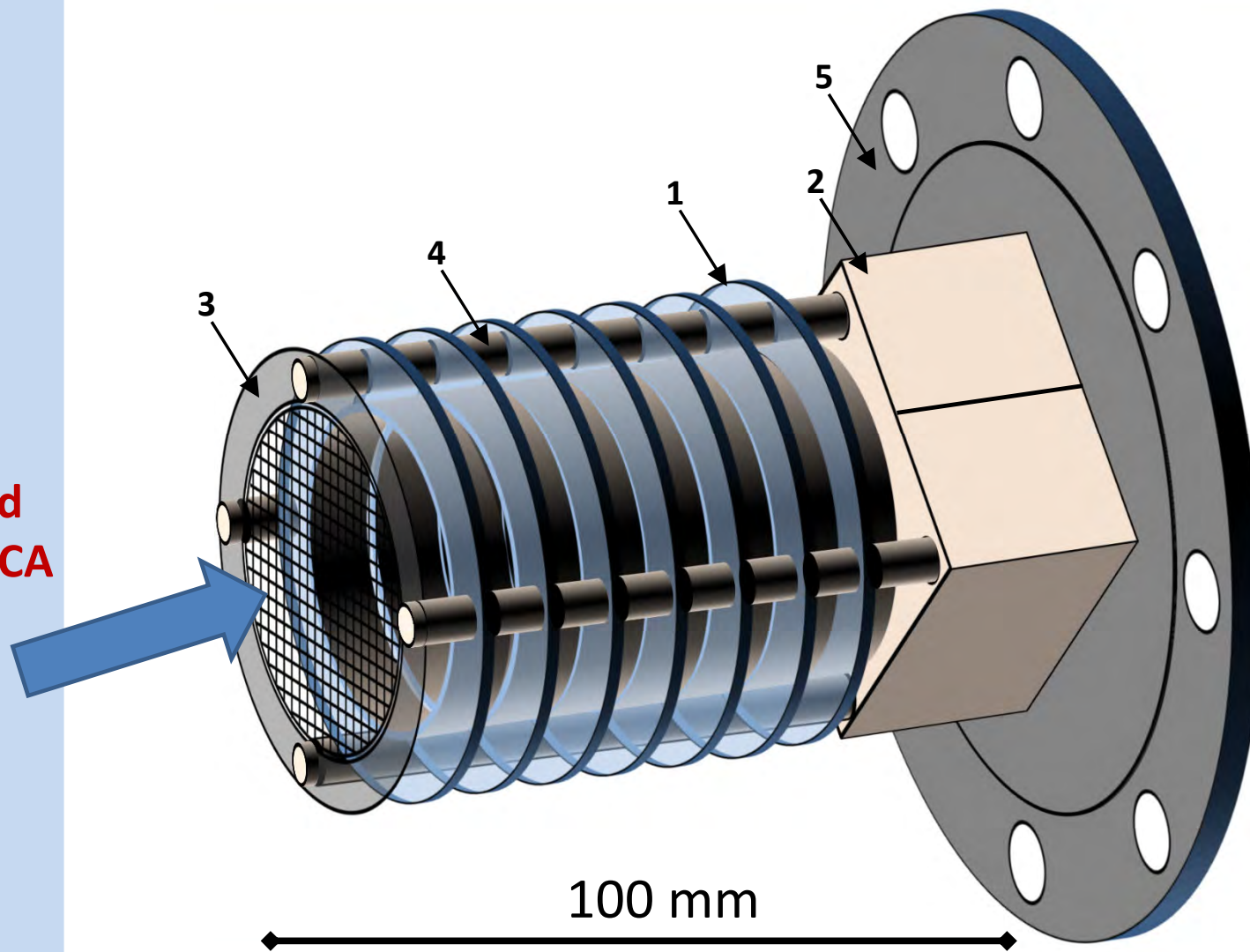
## ... and physics





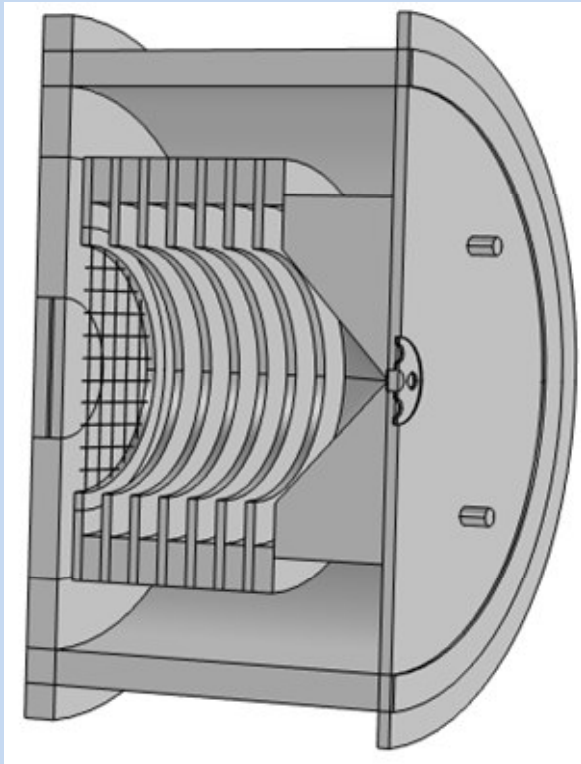
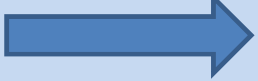
## UniCell concept: *compact* DC cage and RF funnel

**SHE ions  
separated  
with TASCA**

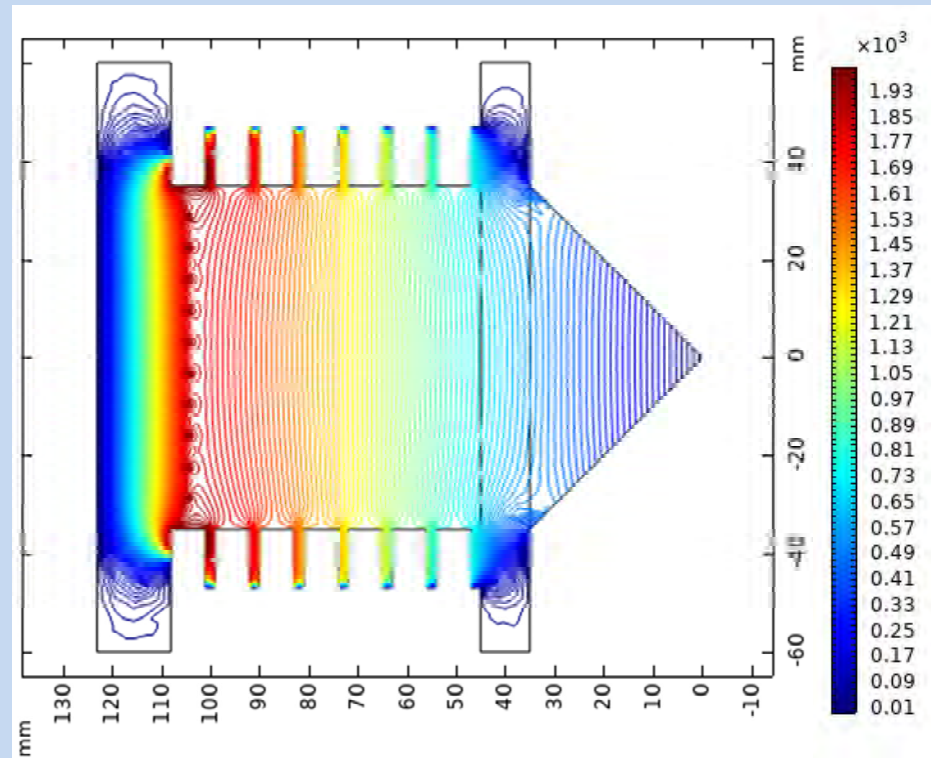


## Design and COMSOL simulations

SHE ions  
separated  
with TASCA

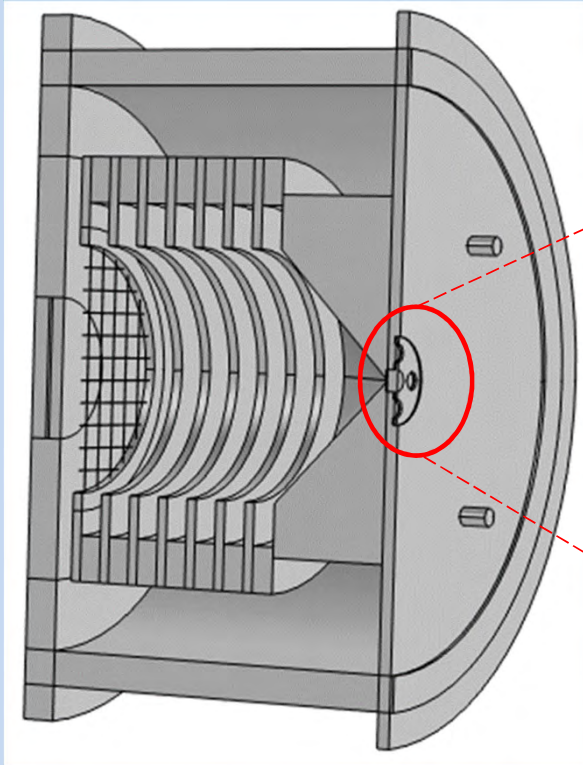


Mechanical design  
(by Gleb Vorobyev, Jörg  
Krier & Dimitar Simonovsky)



COMSOL simulations: electrical field distribution  
(by Dimitar Simonovsky)

## RF funnel is a key part of UniCell

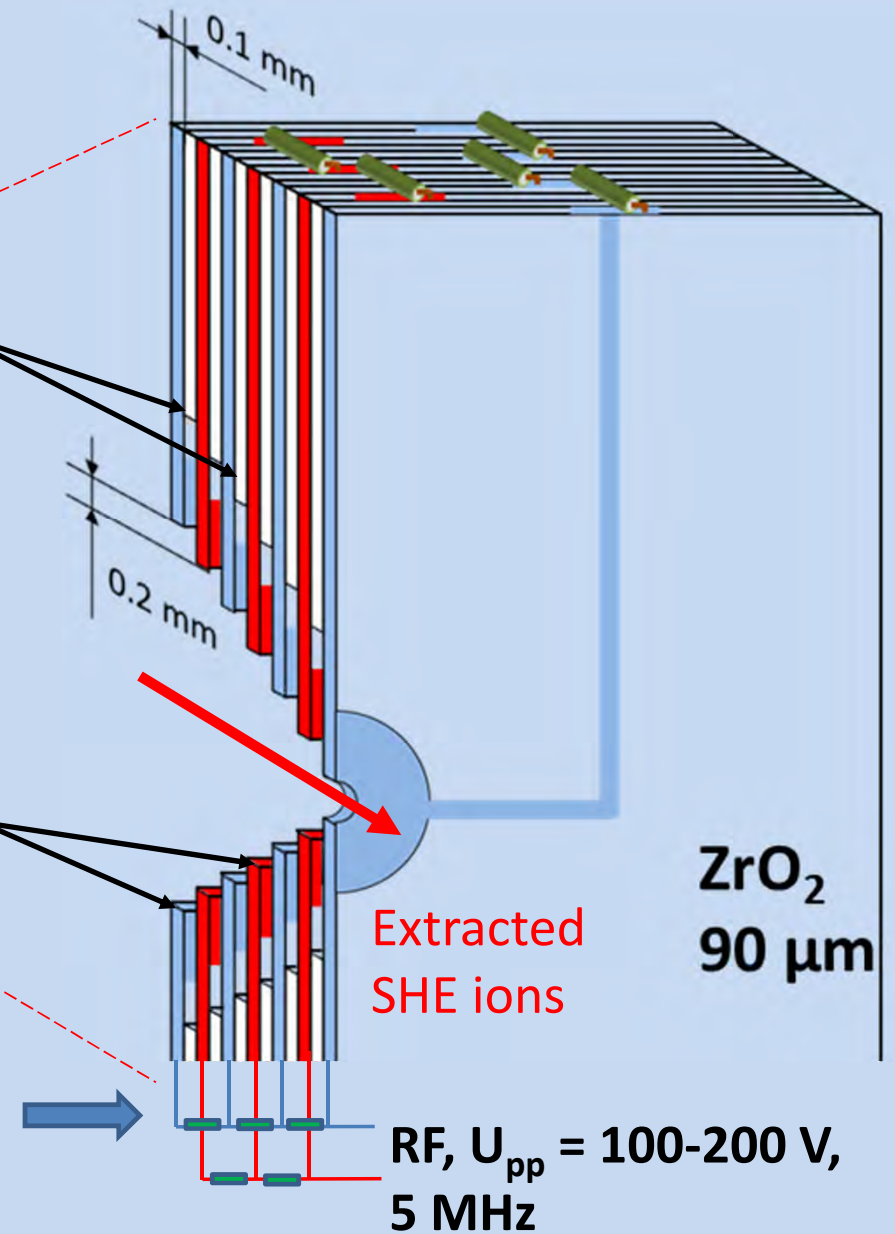


Ceramic plates –  
insulators

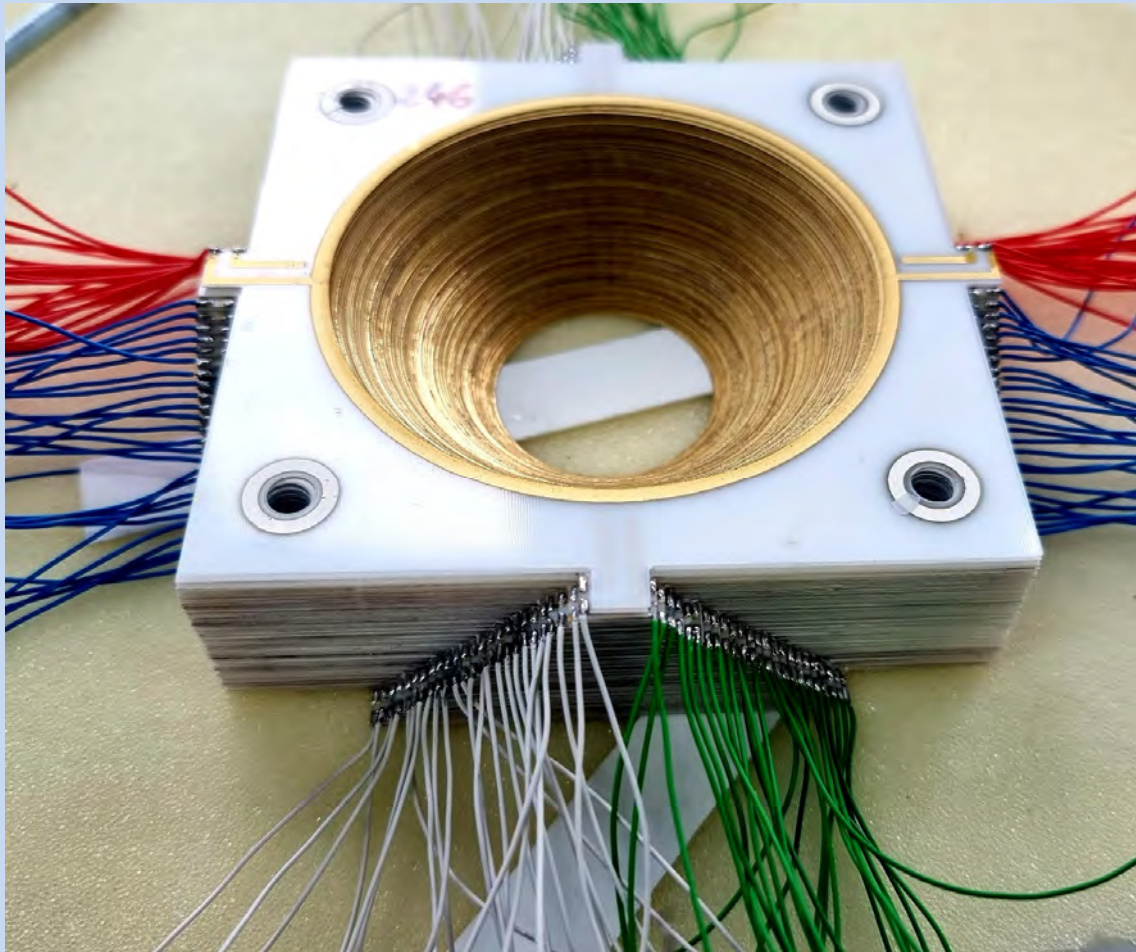
Ceramic plates  
with electrodes

DC gradient  
100-200 V

DC gradient with high values  
is possible due to high pressure



## Production of the ceramic RF funnel: current status



Dr. Jan Kulawik and coworkers; ITE Cracow, Poland

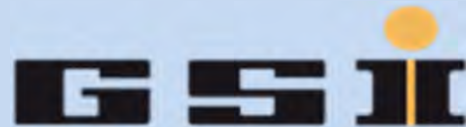
# Simulation Studies on UniCell for Extraction of Ions

Alexander Yakushev<sup>1,2</sup>, **Yeqiang Wei**<sup>1,3</sup>, Ch. E. Düllmann<sup>1,2,3</sup>  
for TASCA collaboration

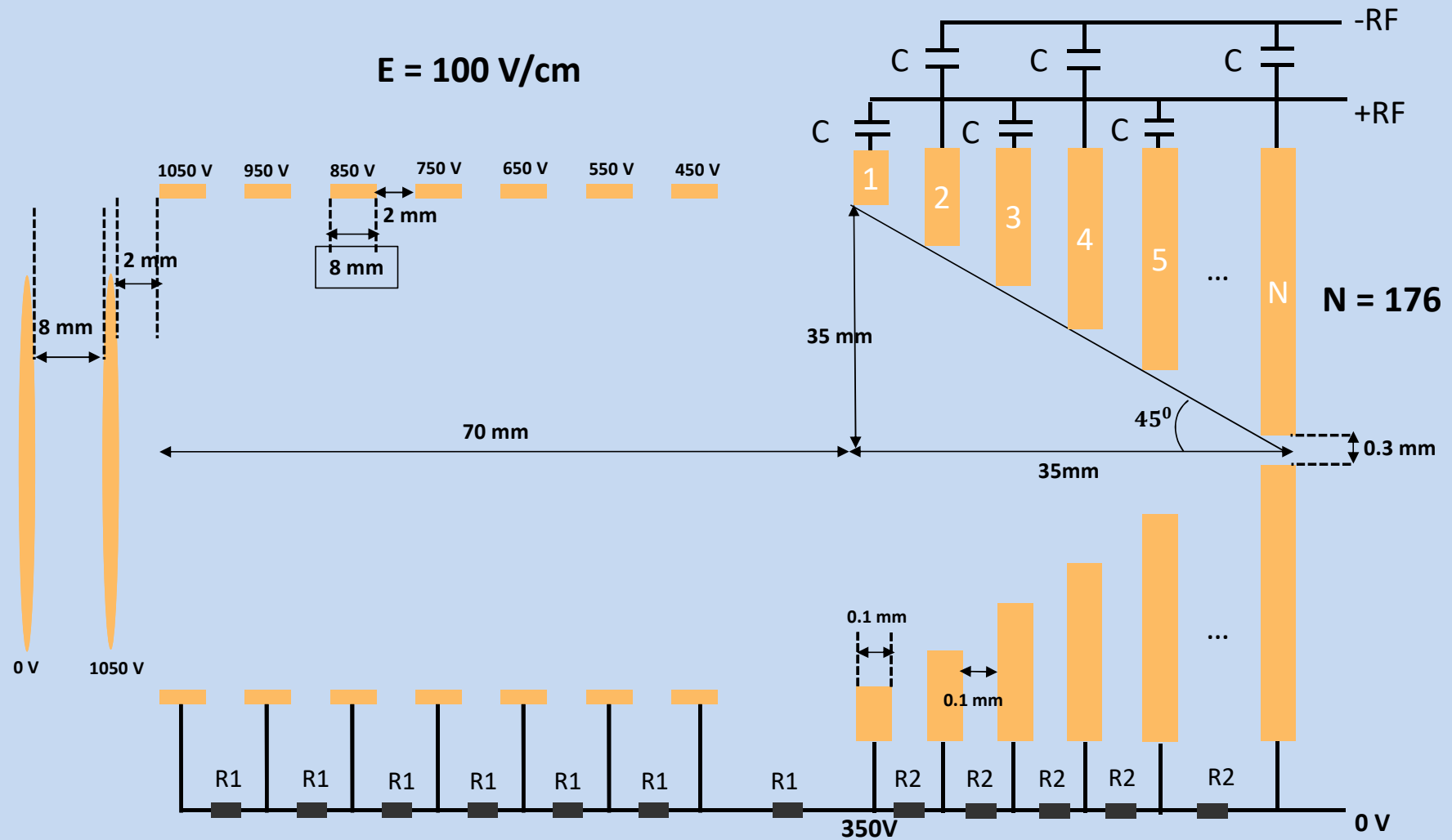
<sup>1</sup>GSI Helmholtzzentrum für Schwerionenforschung GmbH

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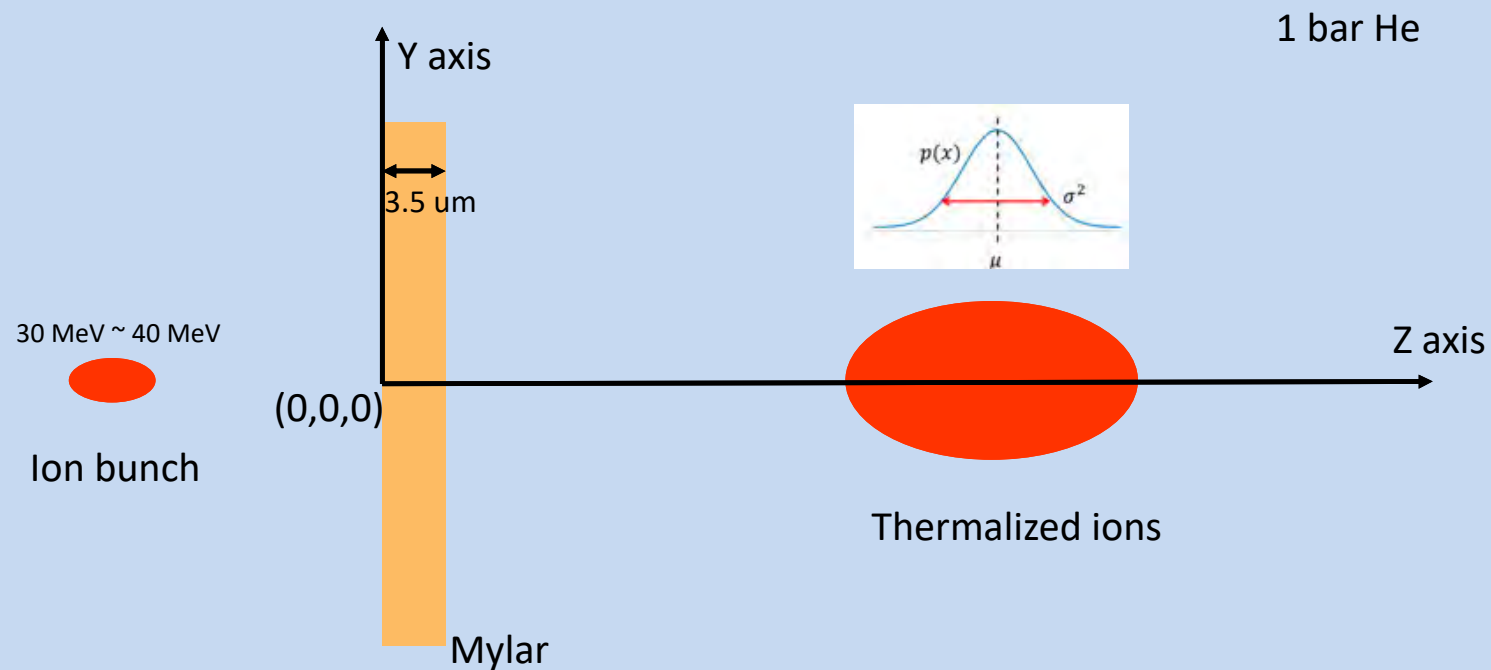


# Circuit Layout Board of the DC Cage + RF Funnel



# SRIM Code

- **Stopping and Range of Ions in Matter (SRIM)** is a group of computer programs which calculate interaction of ions with matter.



# SRIM Code (examples)

The screenshot displays the SRIM-2013.00 software interface. The main window shows simulation parameters and a plot of ion stopping range. The plot, titled "XY Longitudinal" and "Depth vs. Y-Axis", shows a fan-shaped distribution of ions starting from a target depth of 0 Å and extending to 40.0 mm. The y-axis ranges from -20.0 mm to 20.0 mm. The plot includes buttons for Save, Save As, Print, Label, and Clear.

**Simulation Parameters:**

- Ion Type: U (238.05 amu)
- Ion Energy: 24.1 MeV
- Ion Angle: 0 degrees
- Completed: 535 of 99999

**TARGET DATA:**

Layer Name	Width [Å]	Density	H (1.008)	C (12.011)	O (15.999)	He (4.0026)
1 Layer 1	35000	1.309	0.36364	0.45455	0.18182	0.0
2 Layer 2	400000000	0.000179	0.00000	0.00000	0.00000	1.0
Lattice Binding Energy			3	3	3	

**ION STATS:**

	Range	Straggle
Longitudinal	21.6 mm	2.57 mm
Lateral Proj.	1.29 mm	1.62 mm
Radial	1.99 mm	1.02 mm

**SPUTTERING YIELD:**

	Atoms/ion	eV/Atom
TOTAL		
H	0.000000	0.00
C	0.000000	0.00
O	0.000000	0.00

**Other Statistics:**

- Backscattered Ions: 0
- Transmitted Ions: 0
- Vacancies/ion: 107056.5
- % ENERGY LOSS: Ionization (66.71%), Vacancies (0.07%), Phonons (0.05%)
- Recoils: 25.04 (Ionization), 1.03 (Vacancies), 7.09 (Phonons)

For recoiling energy is 30 MeV, the longitudinal (z-axis) ion stopping range is (13.89 mm, 29.31 mm), the lateral projected range along x-axis or y-axis is (-3.57 mm, 6.15 mm)



# SRIM Code (examples)

The screenshot displays the SRIM-2013.00 software interface. The main window shows simulation parameters for a Uranium (U) ion beam. The ion type is U (238.05 amu) with an energy of 32.2 MeV and an angle of 0 degrees. The simulation is completed 599 of 99999 ions. The target consists of two layers: Layer 1 (35000 atoms, density 1.309) and Layer 2 (4000000000 atoms, density 0.000179). The plot window shows a 'Depth vs. Y-Axis' graph with a target depth of 40.0 mm. The plot shows a fan-shaped distribution of ions originating from the surface and spreading as they penetrate the target. The x-axis represents the lateral displacement in mm, ranging from -20.0 to 20.0. The y-axis represents the depth in mm, ranging from 0 to 40.0. The plot is titled 'Depth vs. Y-Axis' and includes a 'Target Depth' indicator at 40.0 mm. The plot window also has buttons for 'Save', 'Save As', 'Print', 'Label', and 'Clear'.

**Simulation Parameters**

Layer Name	Width [A]	Density	H (1.008)	C (12.011)	O (15.999)	He (4.0026)
1 Layer 1	35000	1.309	0.36364	0.45455	0.18182	0.0
2 Layer 2	4000000000	0.000179	0.00000	0.00000	0.00000	1.0
Lattice Binding Energy			3	3	3	

**ION STATS**

	Range	Straggle
Longitudinal	33.9 mm	2.49 mm
Lateral Proj.	1.48 mm	1.90 mm
Radial	2.45 mm	1.32 mm

**% ENERGY LOSS**

	Ions	Recoils
Ionization	71.84	21.46
Vacancies	0.07	0.91
Phonons	0.04	5.68

**SPUTTERING YIELD**

	Atoms/ion	eV/Atom
TOTAL		
H	0.000000	0.00
C	0.000000	0.00
O	0.000000	0.00

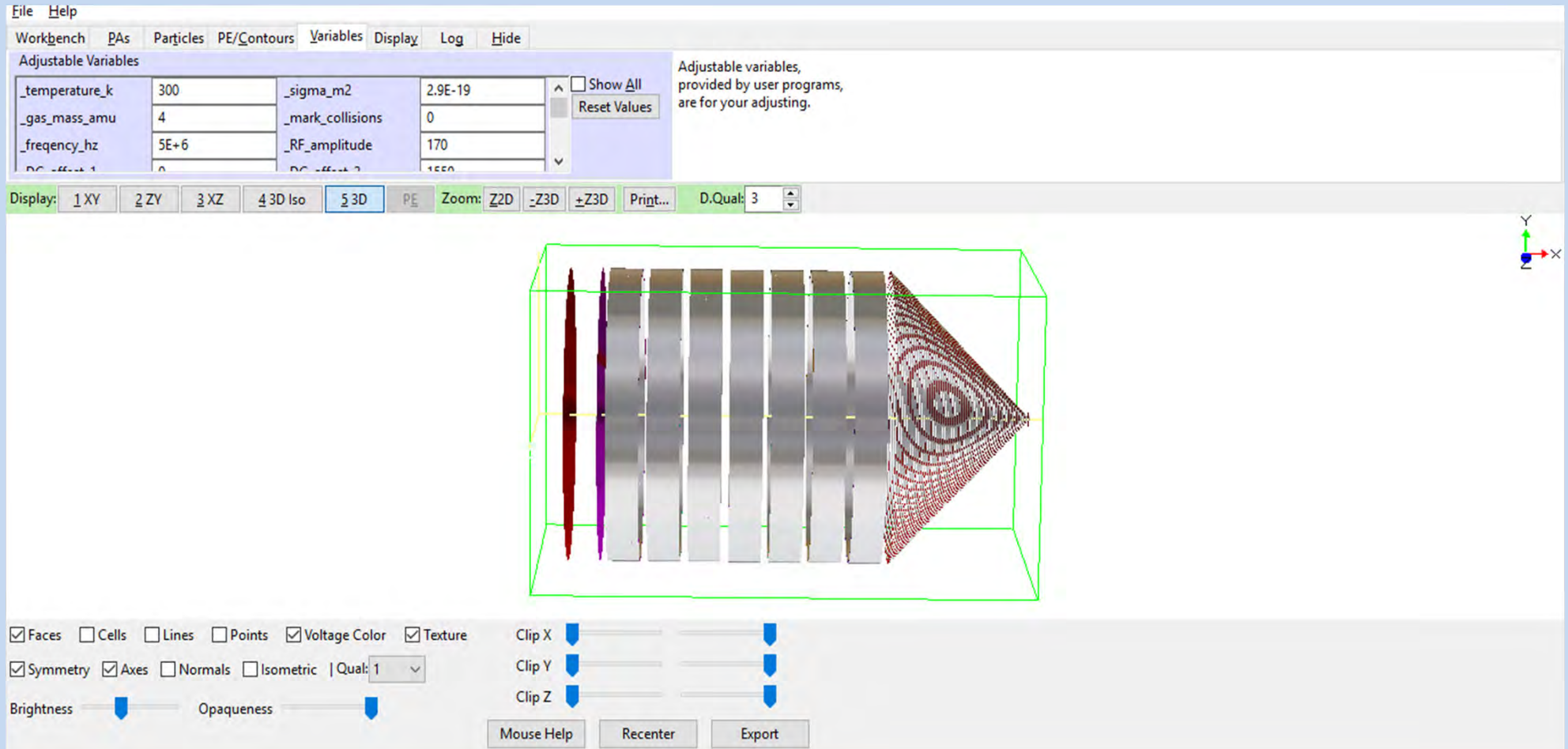
**Backscattered Ions**: 0  
**Transmitted Ions**: 0  
**Vacancies/ion**: 127122.0

**Type of Damage Calculation**: Quick: Kinchin-Pease  
**Stopping Power Version**: SRIM-2008

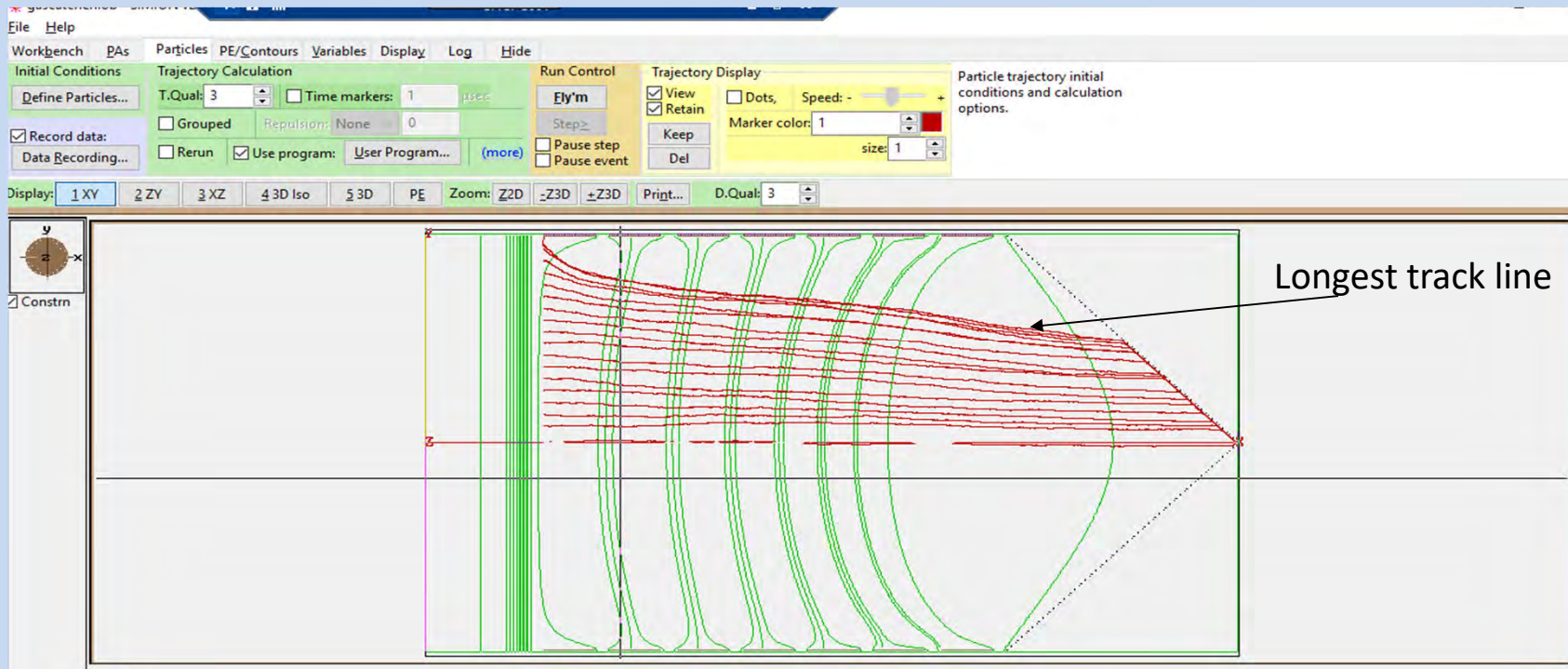
**Save every**: 10000 ions  
**Random Number Counter**: 25489363

For recoiling energy is 40 MeV, the longitudinal (z-axis) ion stopping range is (26.43 mm, 41.37 mm), The lateral range along x-axis or y-axis is (-4.22 mm, 7.18 mm)

# 3D Model for SIMION Simulations

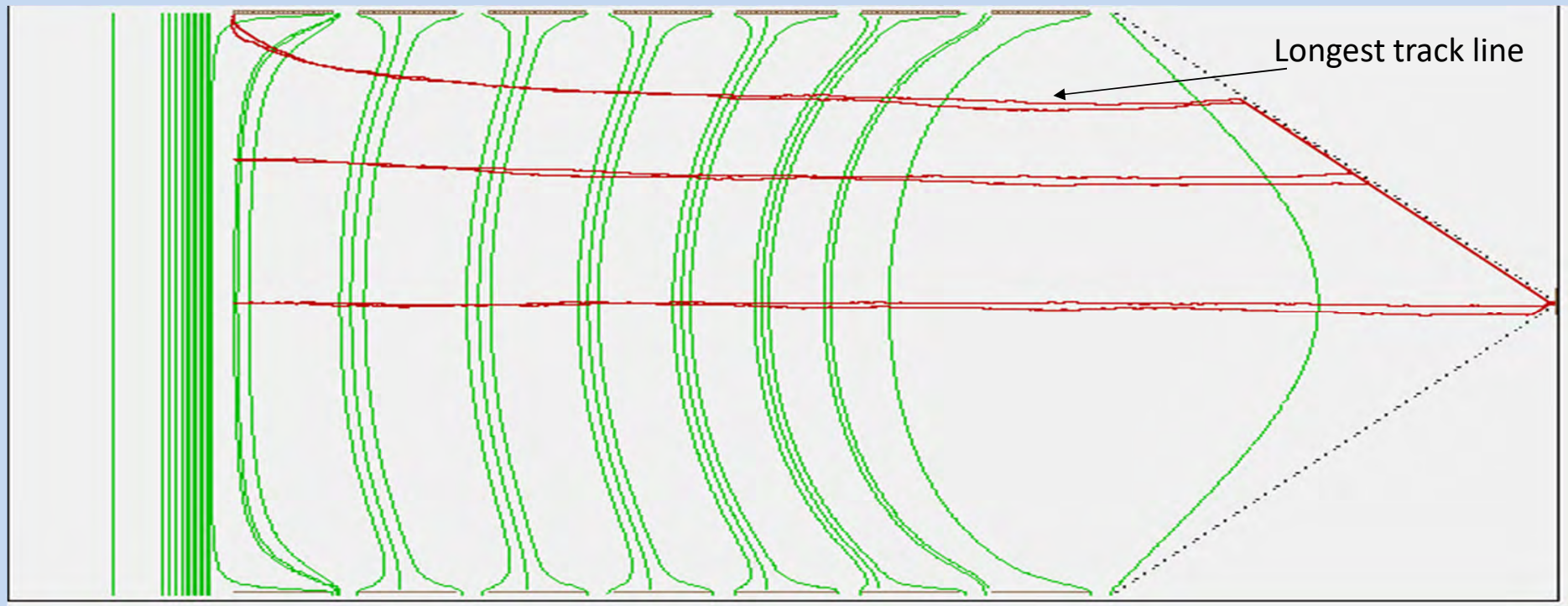


# SIMION Simulations of the UniCell



$E = 100 \text{ V/cm}$ ,  $T = 300 \text{ K}$ , He gas,  $P = 0.1 \text{ bar}$ ,  $f = 5 \text{ MHz}$ ,  $V_{PP} = 200 \text{ V}$ . The extraction time is about 0.7 ms and 0.35 ms for ions with charge +1 and +2, respectively (ion with mass = 293). The extraction efficiency is about 100 %.

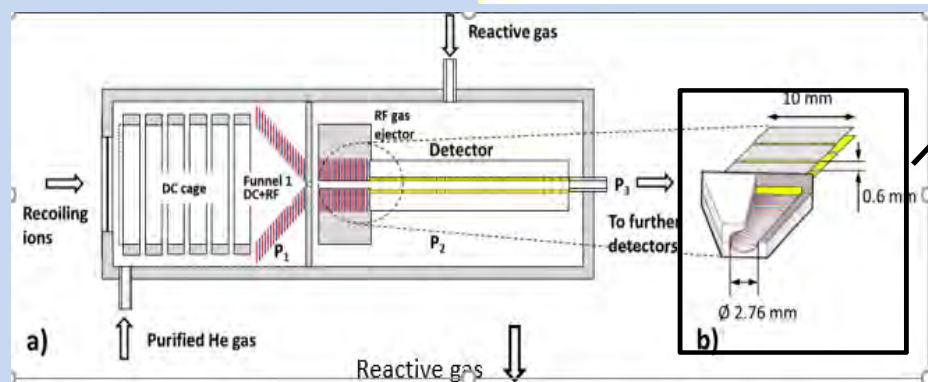
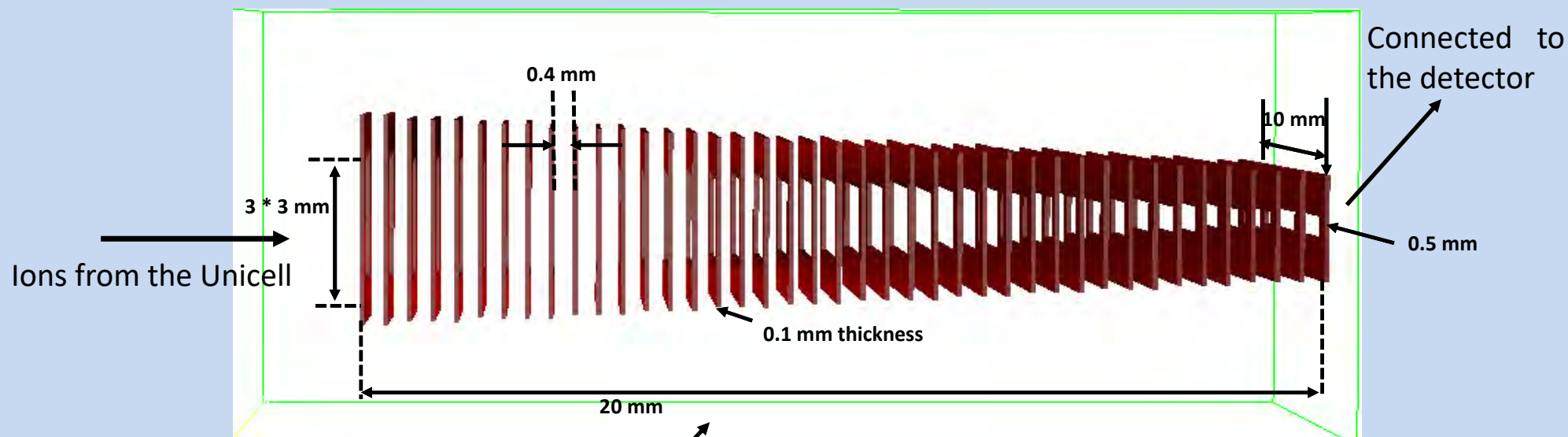
# SIMION Simulations of the UniCell



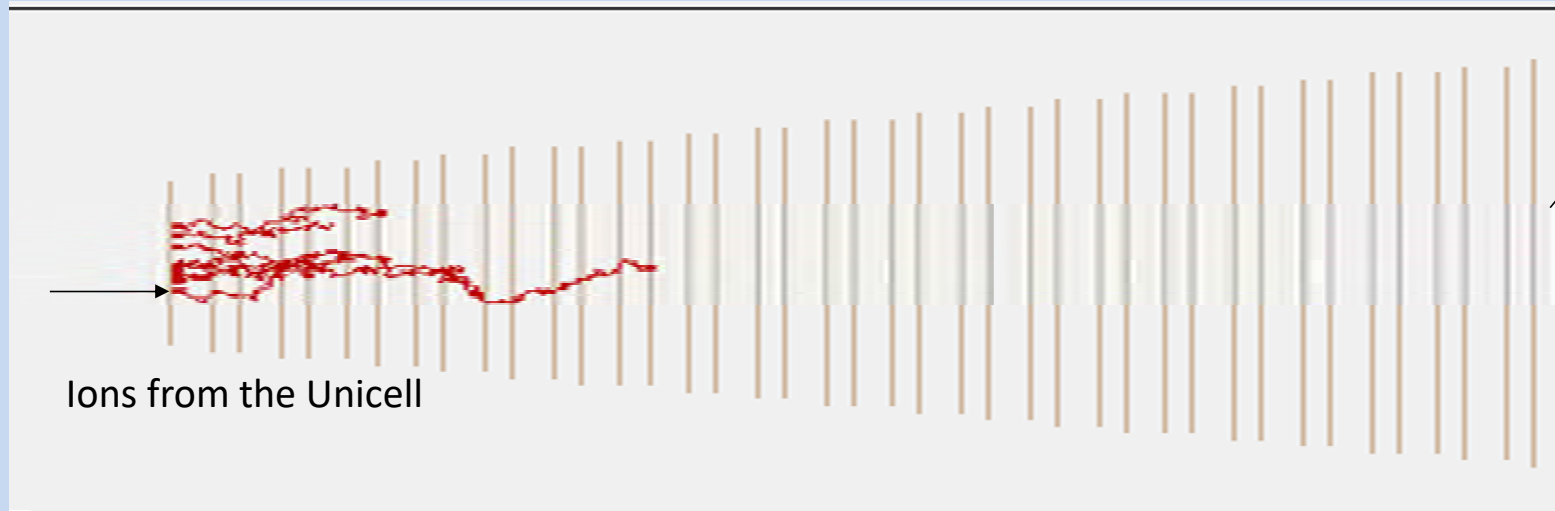
$E = 100 \text{ V/cm}$ ,  $T = 300 \text{ K}$ , He gas,  $P = 1 \text{ bar}$ ,  $f = 5 \text{ MHz}$ ,  $V_{PP} = 340 \text{ V}$ . The extraction time is about 7 ms and 3.5 ms for ions with charge +1 and +2, respectively (ion with mass = 293).

The extraction efficiency is about 100 %.

# SIMION Simulations – Ejector Geometry

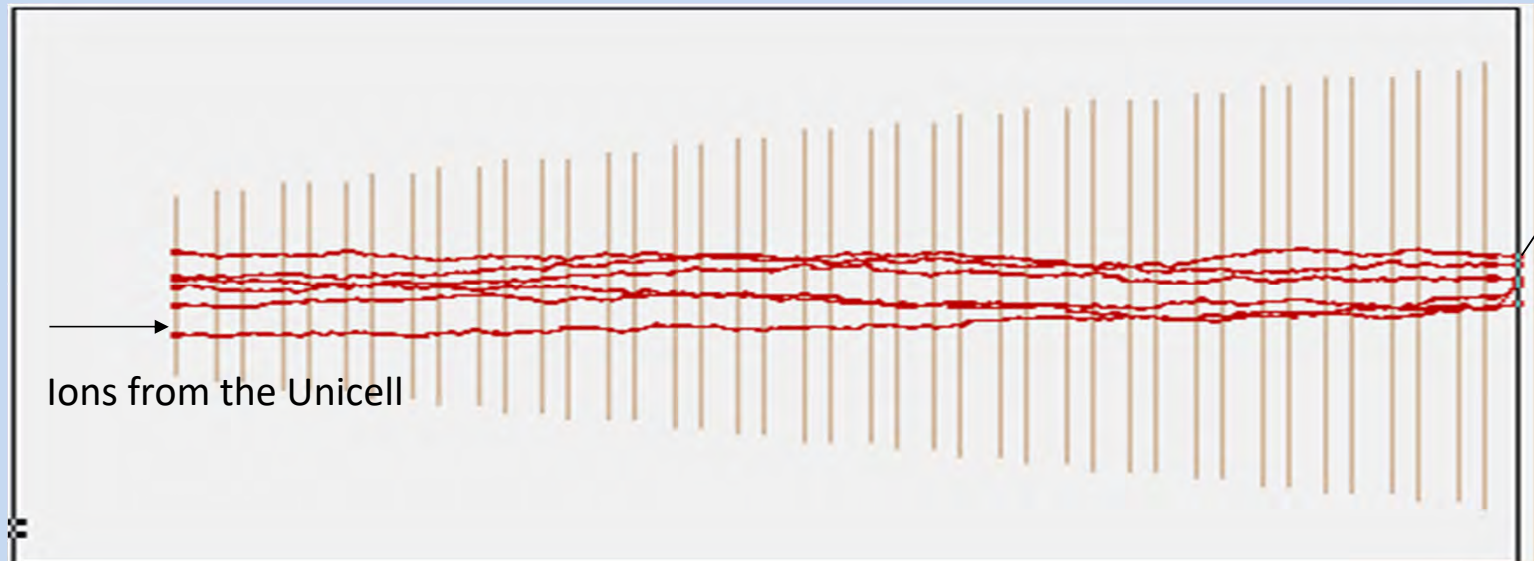


# SIMION Simulations – Ion Trajectory



Gas flow is 10 m/s, the initial velocity of ions is also 10 m/s,  $f = 5 \text{ MHz}$ ,  $V_{pp} = 0 \text{ V}$ ,  $T = 300 \text{ K}$ ,  $P = 0.98 \text{ bar}$ . For ions we used in the simulation, extraction efficiency without RF power is about zero.

# SIMION Simulations – Ion Trajectory



Gas flow is 10 m/s, the initial velocity of ions is also 10 m/s,  $f = 5 \text{ MHz}$ ,  $V_{pp} = 200 \text{ V}$ ,  $T = 300 \text{ K}$ ,  $P = 0.98 \text{ bar}$ . For ions we used in the simulation, the efficiency is about 100%, the flight time is about 2 ms and 4 ms for ions with charge +1 and +2, respectively (ion mass = 293).

# Summary

Very high efficiency and fast extraction from UniCell for Lv and Ts ions are expected at  $T = 300 \text{ K}$ ,  $P = 1 \text{ bar}$

This makes chemical studies of superheavy elements beyond Mc promising

- For ions with charge = +1 , the total transport time to a detector is about **9 ms** = 7 ms + 2 ms.
- For ions with charge = +2, the total transport time to a detector is about **7.55 ms** = 3.55 ms + 4 ms.

## Acknowledgements

Many thanks to TASCA workshop for offering me a chance to present this talk, to SHE groups for helpful discussions, to Gleb Vorobyev and Dimitar Simonovsky for useful suggestions, and to Dr. Jan Kulawik from ITE Cracow, Poland for the fabrication of the ceramic RF funnel. The project is supported by German BMBF (Project Number is 05P18UMFN2).

