Towards chemistry beyond moscovium (Mc, Z = 115)

Alexander Yakushev[1,2], Yeqiang Wei[1,3], Ch. E. Düllmann[1,2,3]
for TASCA collaboration

[1]GSI Helmholtzzentrum für Schwerionenforschung GmbH
[2]Helmholtz-Institute Mainz
[3]Johannes Gutenberg-University Mainz

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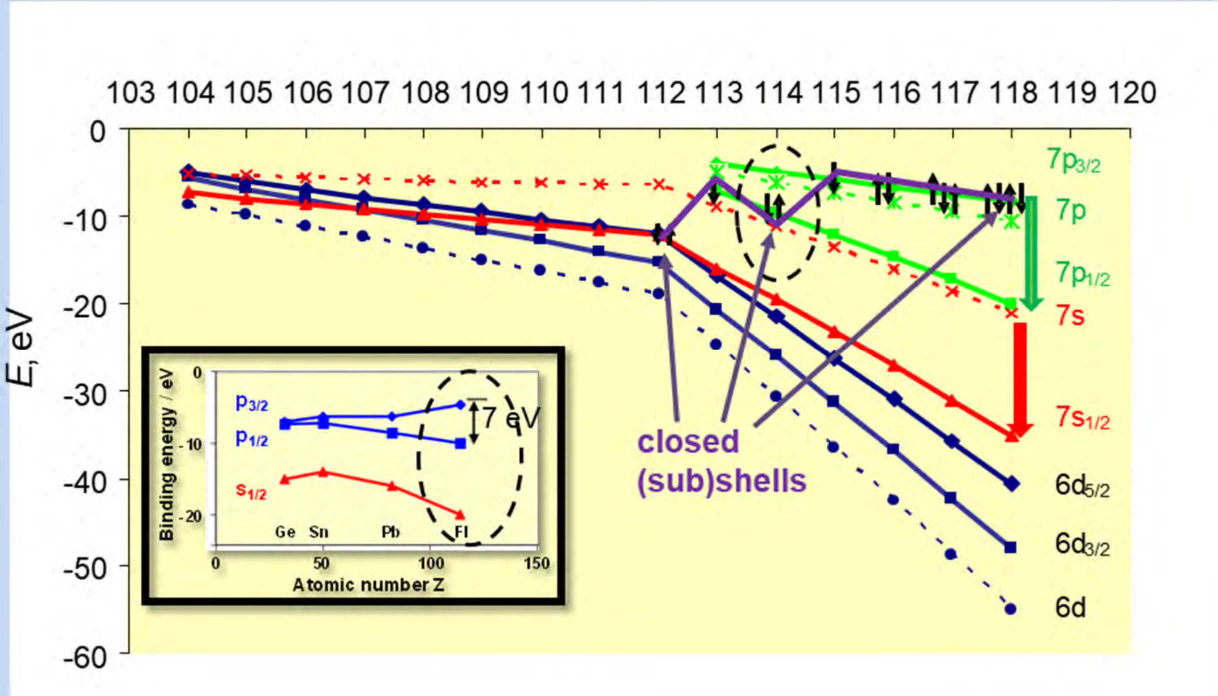
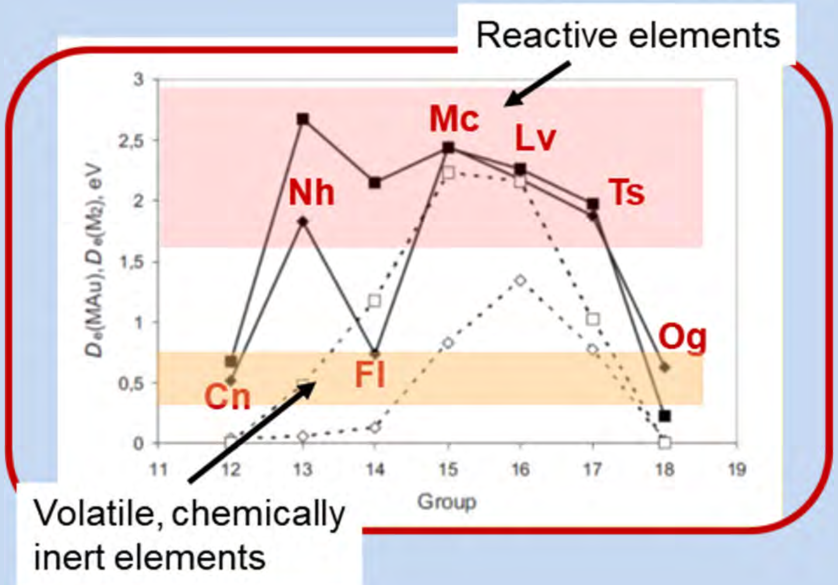
Superheavy element (SHE) chemistry : current status

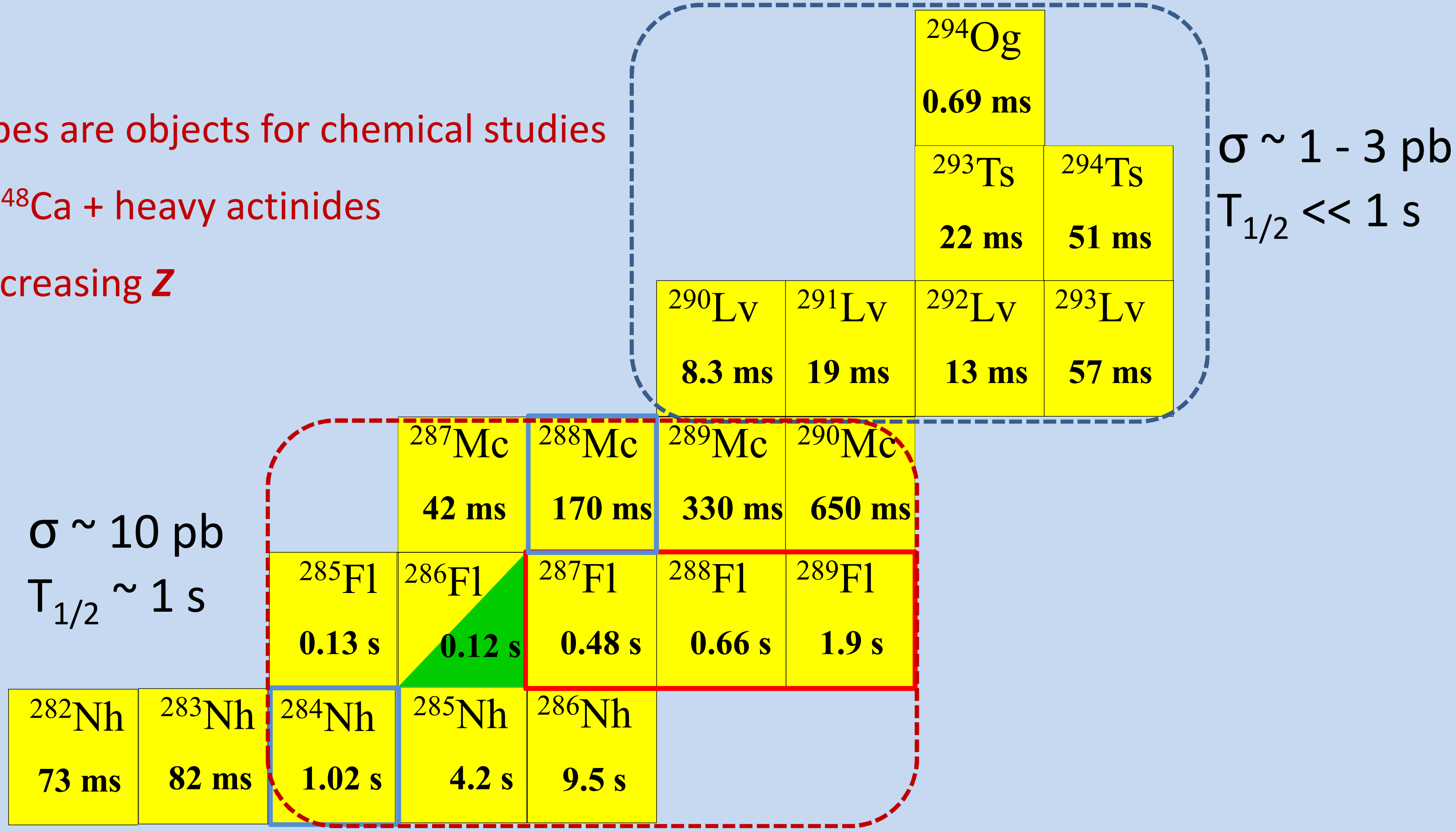




- Strong relativistic effects influence on the chemical properties of SHE
- First chemical studies with Cn, Nh, Fl and Mc are performed
- Closed-shell elements Cn and Fl are volatile metals; odd-Z elements Nh and Mc are reactive

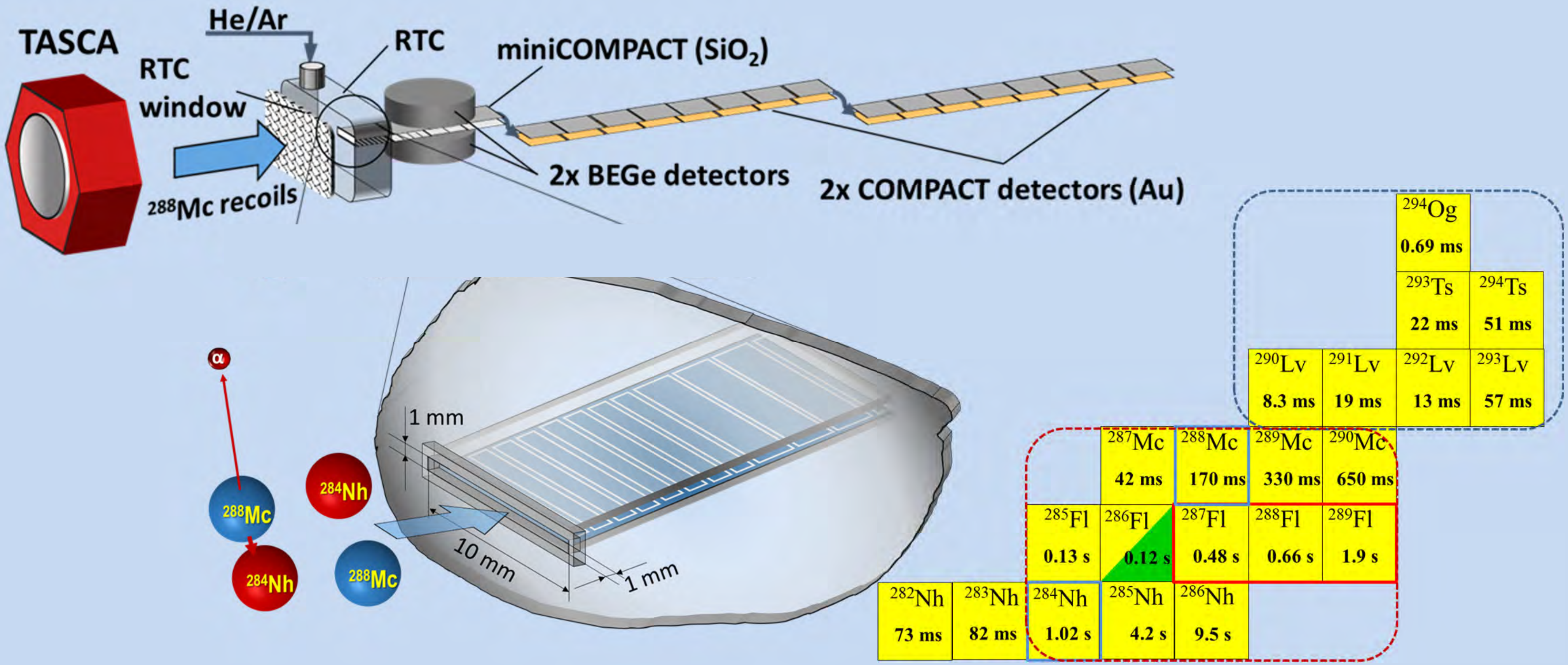
Superheavy element (SHE) chemistry : current status

- Most neutron-rich SHE isotopes are objects for chemical studies
- Fusion products of reactions ^{48}Ca + heavy actinides
- Decreasing ***σ*** and $\boldsymbol{T_{1/2}}$ with increasing ***Z***



Yu. Ts. Oganessian, V. K. Utyonkov. *Rep. Prog. Phys*. 78 (2015) 036301
D. Rudolph, L.G. Sarmiento, U. Forsberg *AIP Conf. Proc.* **1681**, 030015 (2015).

SHE chemistry at TASCA : current status



A new faster transport technique is needed for elements beyond Mc

Solution: gas stopping cell

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH

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

Check for updates

Victor Varentsov [a,b,*], Alexander Yakushev [c,d]

[a] *Institute for Theoretical and Experimental Physics, B. Cheremushkinskaya 25, 117218 Moscow, Russia*
[b] *Facility for Antiproton and Ion Research in Europe (FAIR), Planckstraße 1, 64291 Darmstadt, Germany*
[c] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany*
[d] *Helmholtz-Institute Mainz, 55099 Mainz, Germany*

A R T I C L E I N F O

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

A B S T R A C T

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.

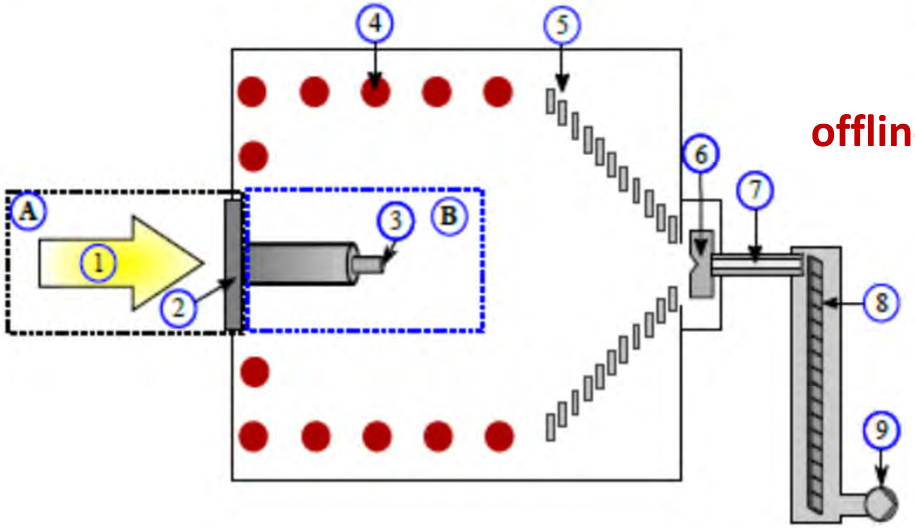
For physical researches, the UniCell is equipped with the additional system of three RF-funnels placed on the axis downstream the gas cell exit, which will allow for a high-efficient and fast extraction of ions into high-vacuum with production of continuous and pulsed ion beams having a record small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

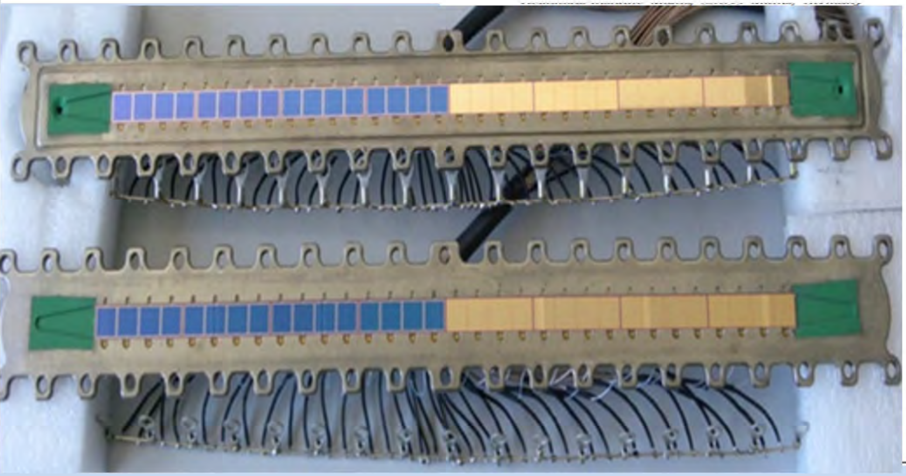
For the gas-phase chemistry studies, the system of three extraction RF-funnels can be replaced by a gas chromatography detector array with an original gas ejector-interface, which will allow, when it will be necessary for ions neutralization, to add different reactive gases into the helium flow.

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

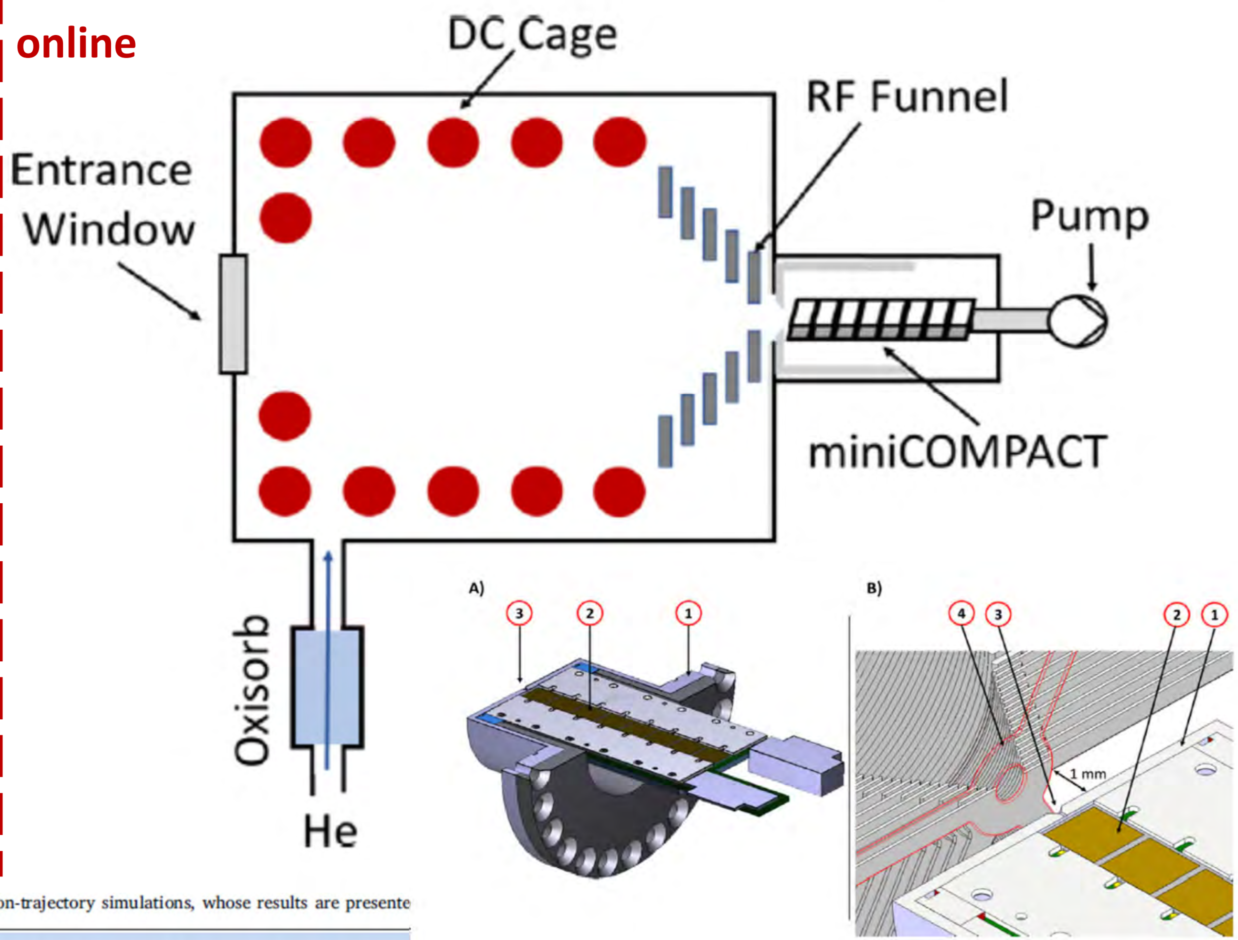
S. Götz *et al.*, *Nuclear Inst. and Methods in Physics Research, A 995 (2021) 165090*





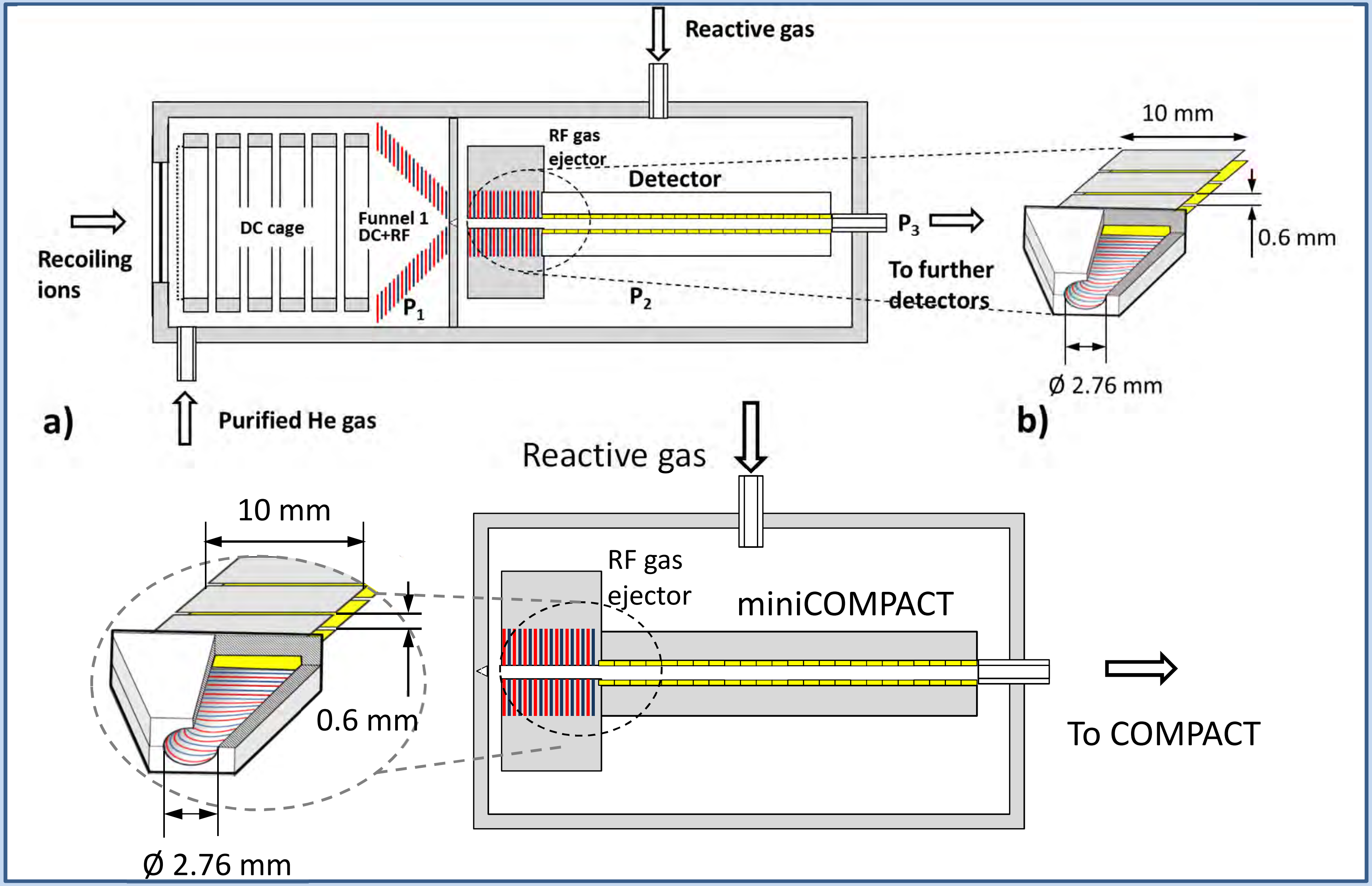
offline | **online**

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

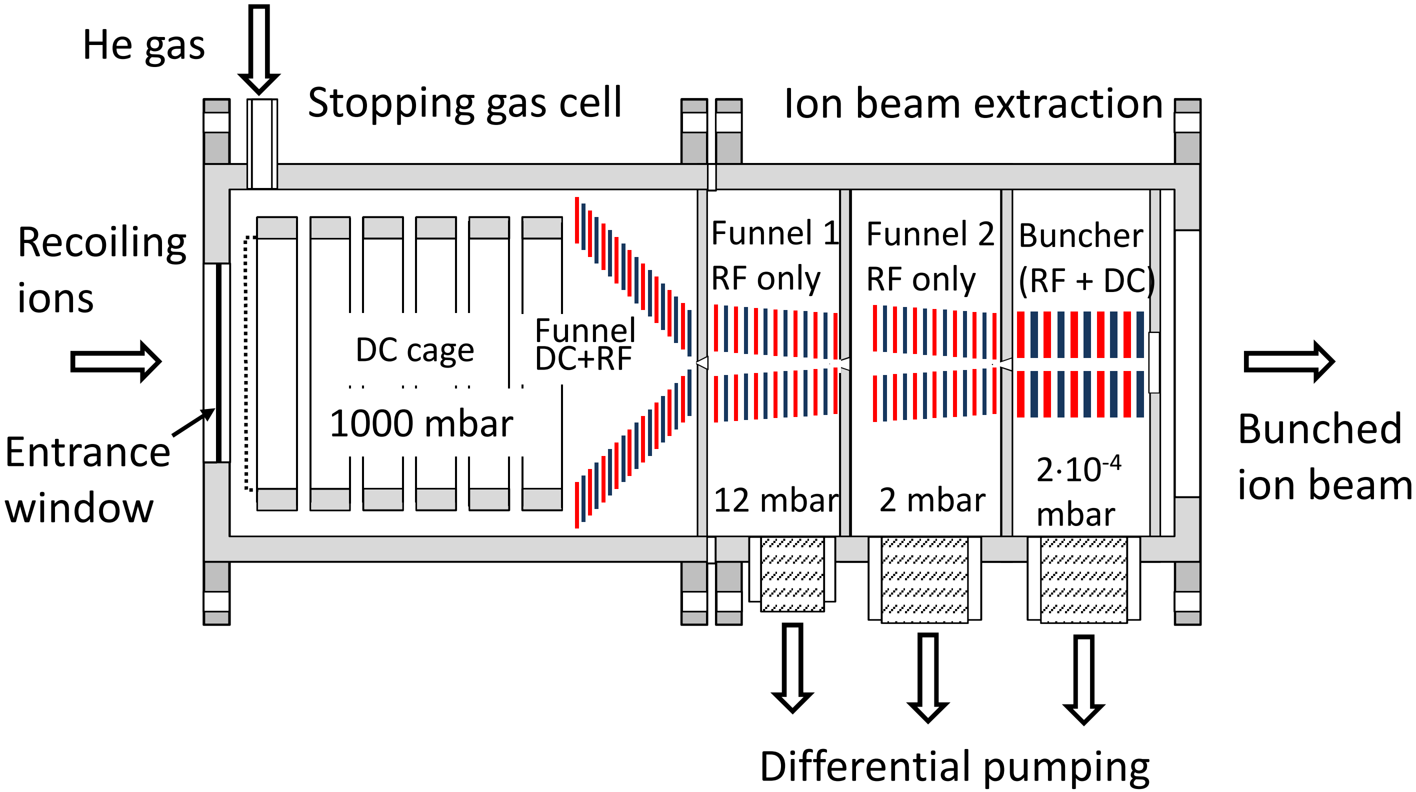


Carlo ion-trajectory simulations, whose results are presente

UniCell for SHE chemistry…



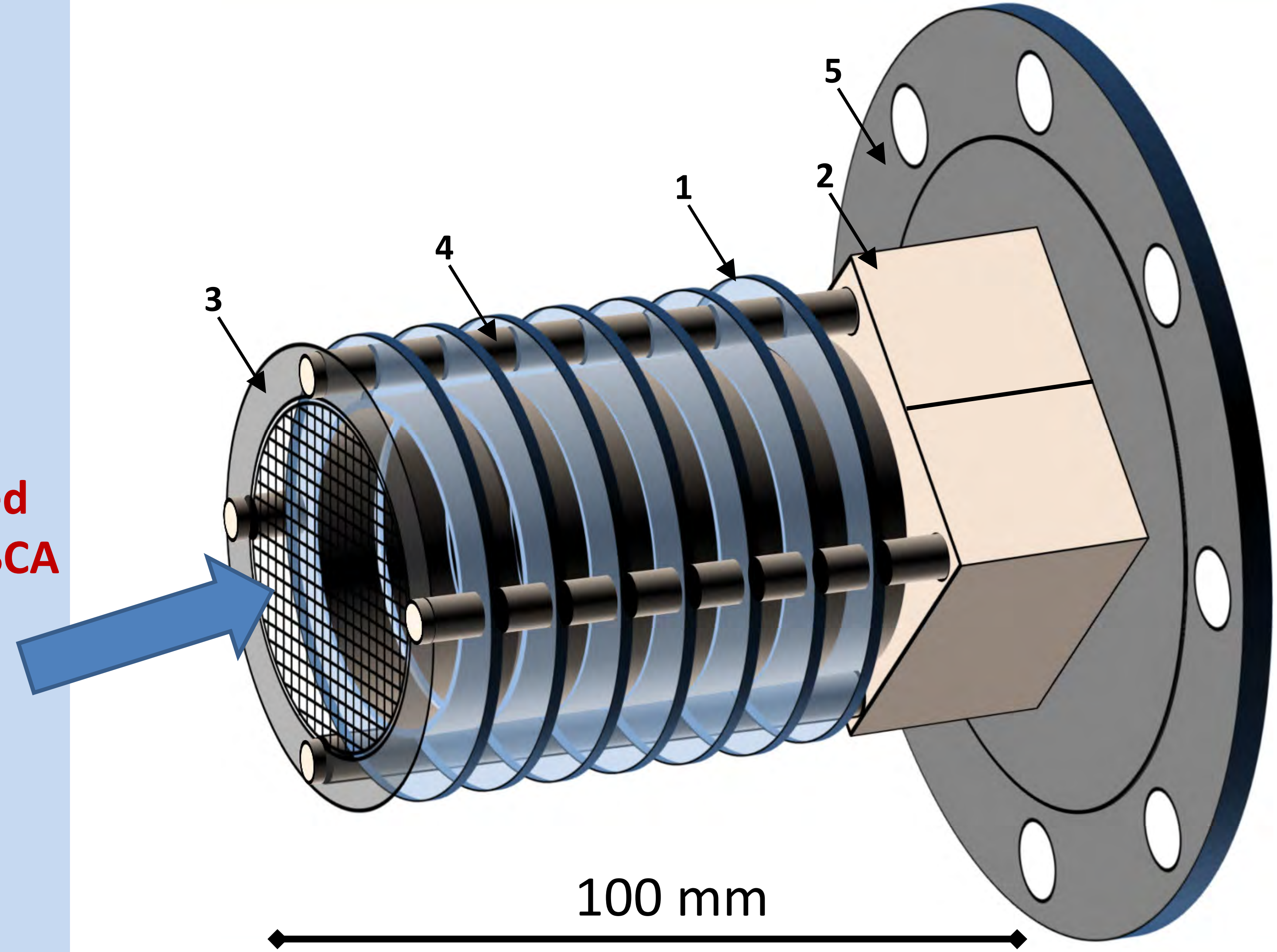
… and physics



He gas
Stopping gas cell
Ion beam extraction
Recoiling ions
Entrance window
DC cage
1000 mbar
Funnel DC+RF
Funnel 1 RF only
12 mbar
Funnel 2 RF only
2 mbar
Buncher (RF + DC)
2·10-4 mbar
Bunched ion beam
Differential pumping

UniCell concept: *compact* DC cage and RF funnel

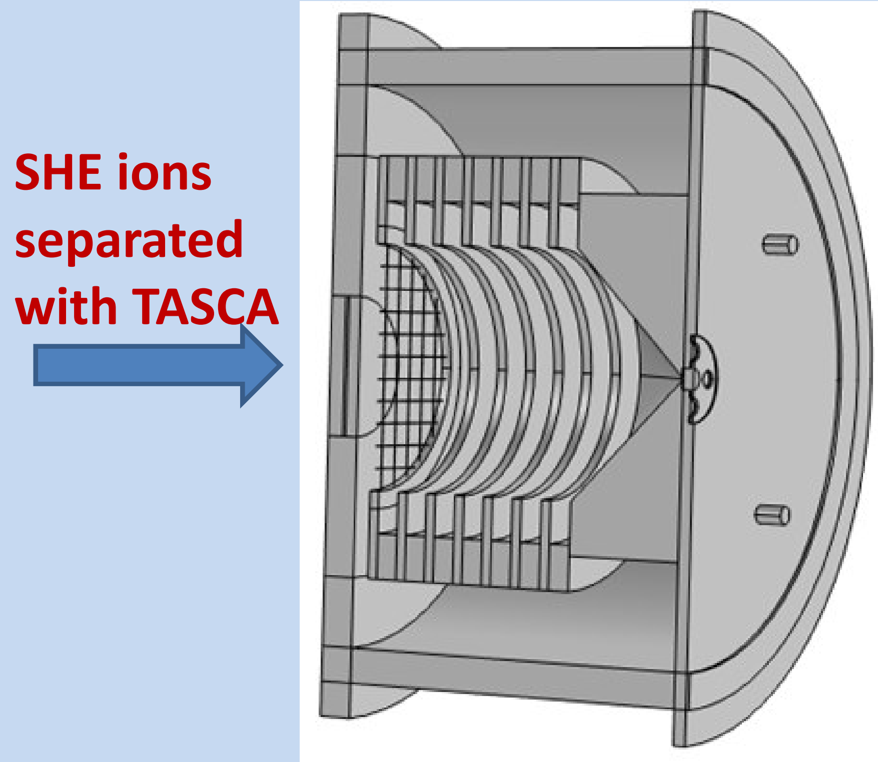
SHE ions separated with TASCA



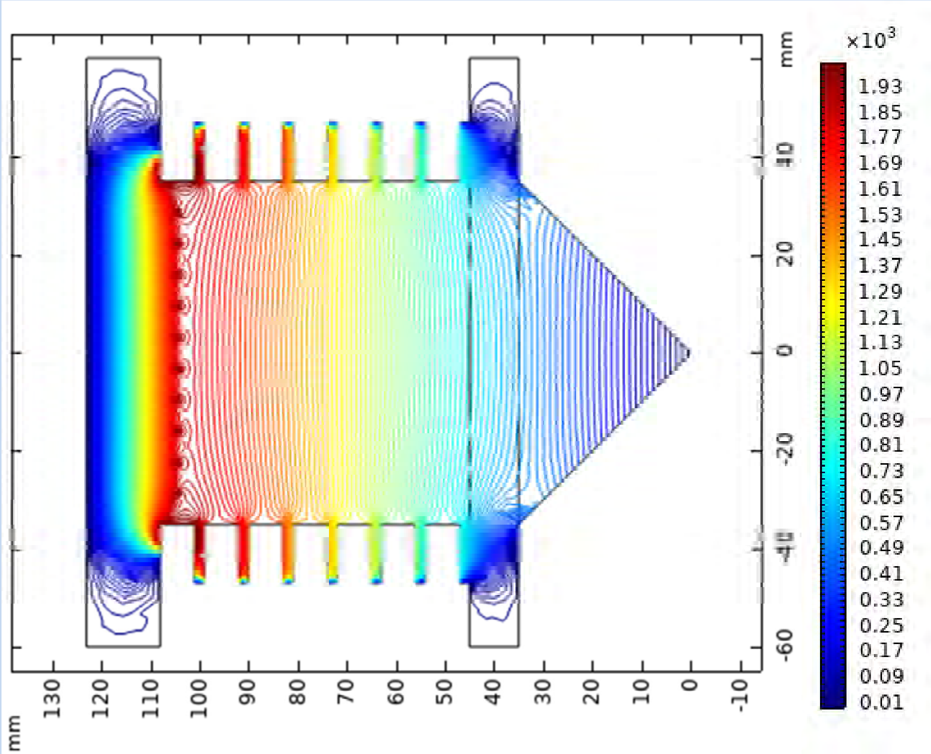
1) DC cage electrodes
2) RF funnel
3) HV entrance grid
4) Ceramic insulators
5) Flange with a nozzle

Design and COMSOL simulations

SHE ions separated with TASCA

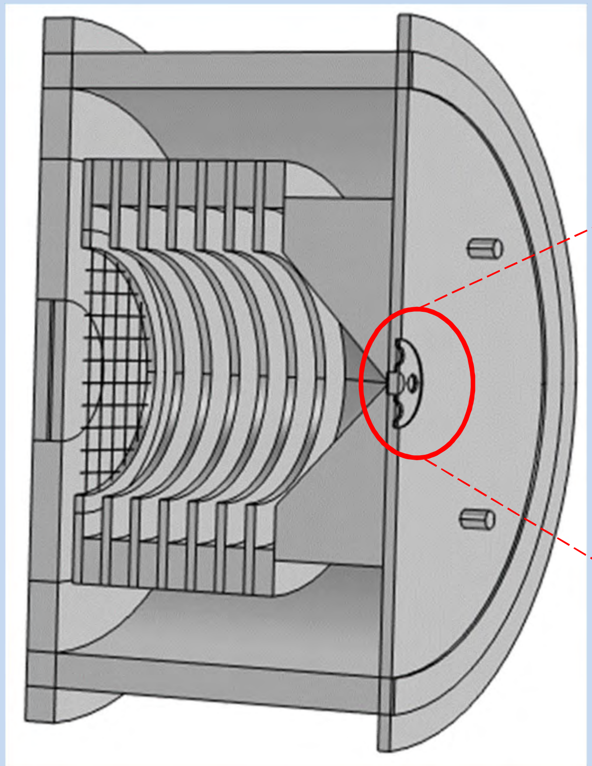


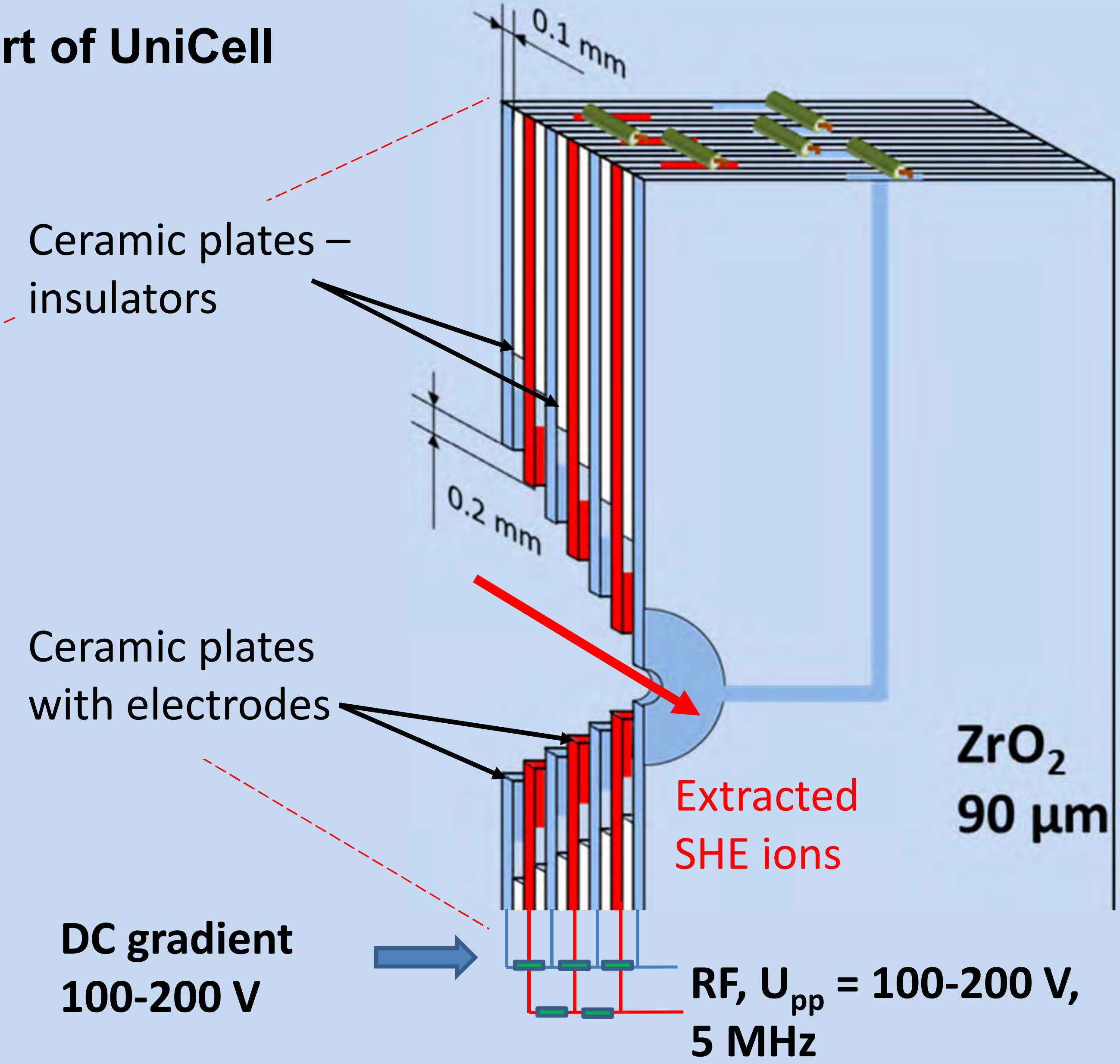
Mechanical design
(by Gleb Vorobyev, Jörg Krier & Dimitar Simonovsky)



COMSOL simulations: electrical field distribution
(by Dimitar Simonovsky)

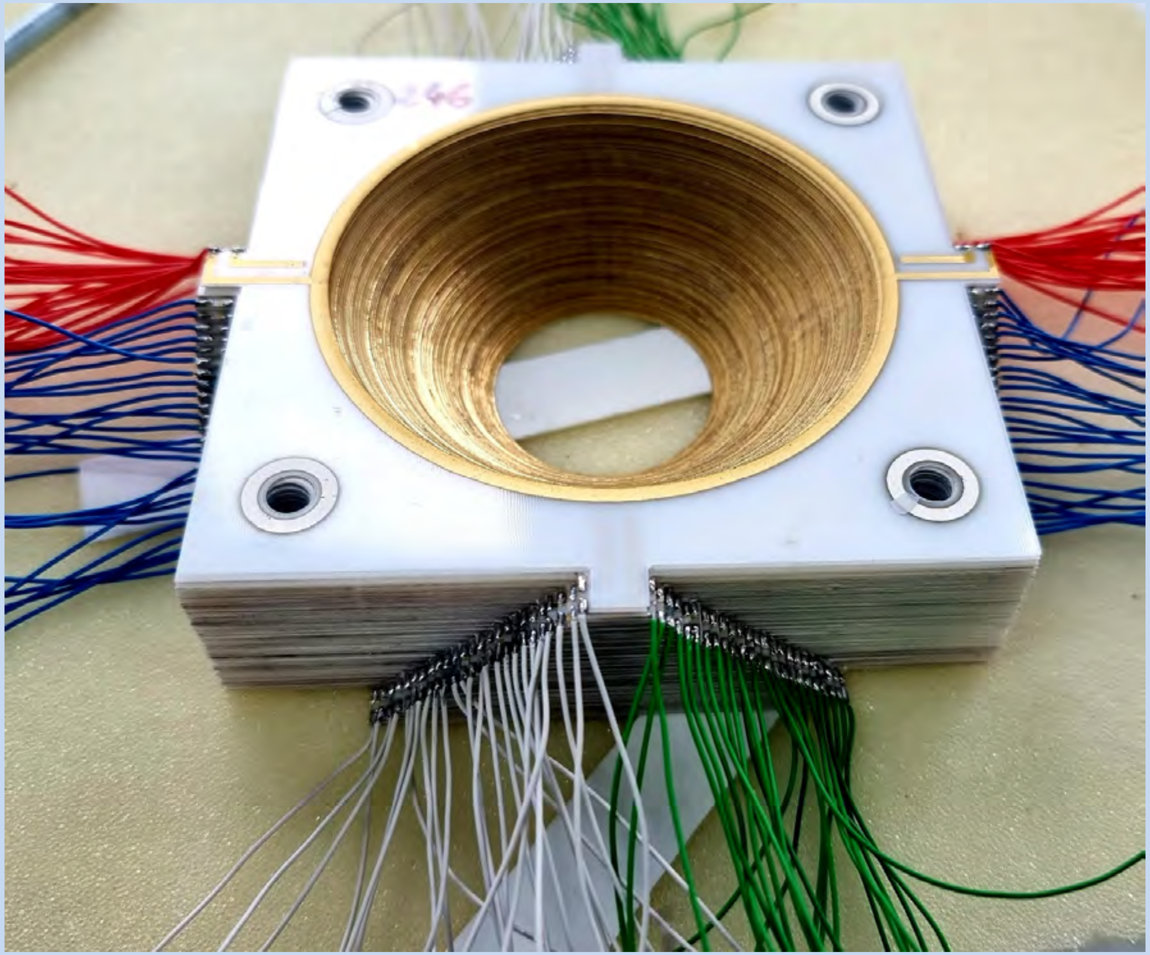
RF funnel is a key part of UniCell





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[1,2], **Yeqiang Wei**[1,3], Ch. E. Düllmann[1,2,3]
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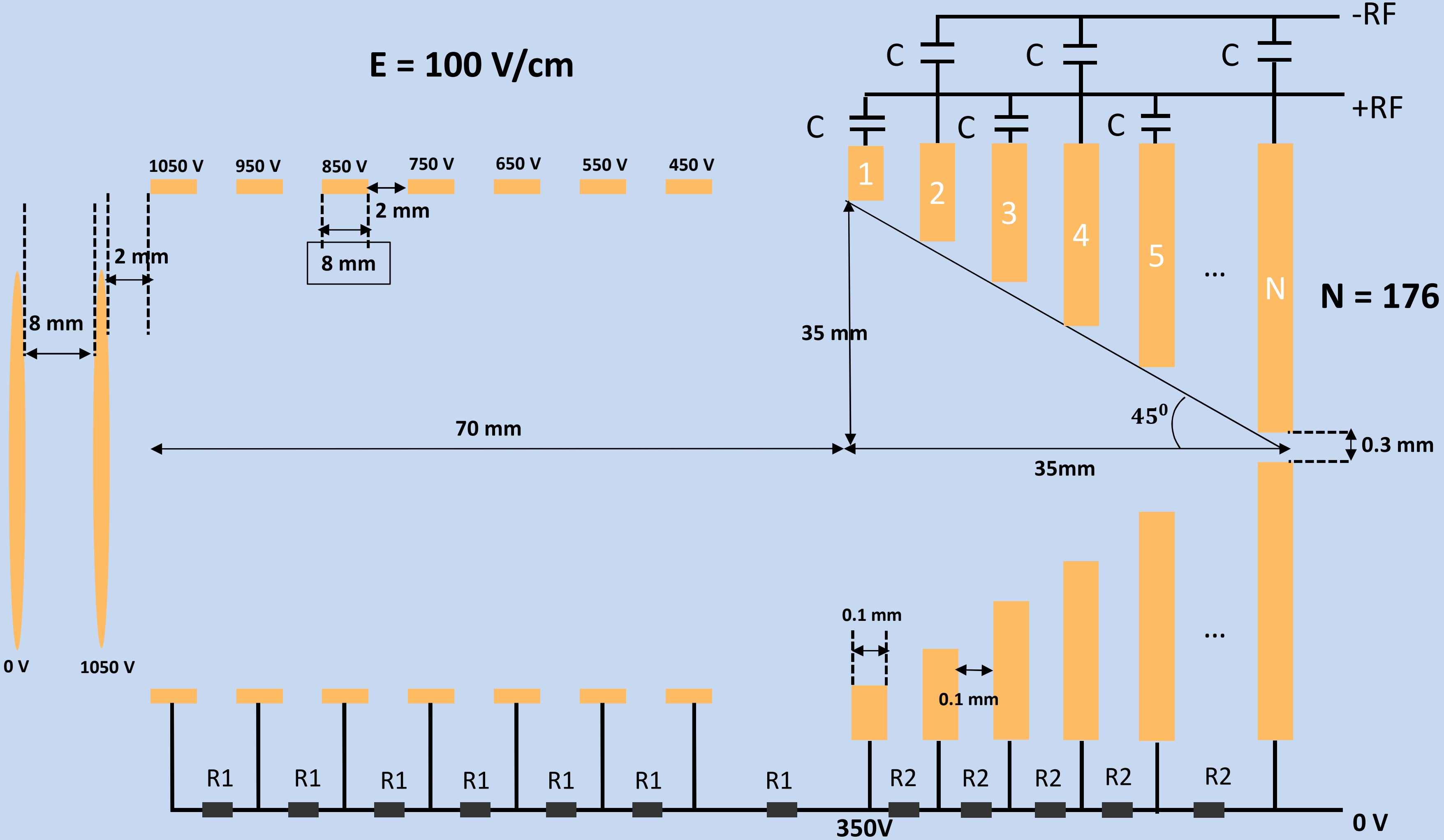
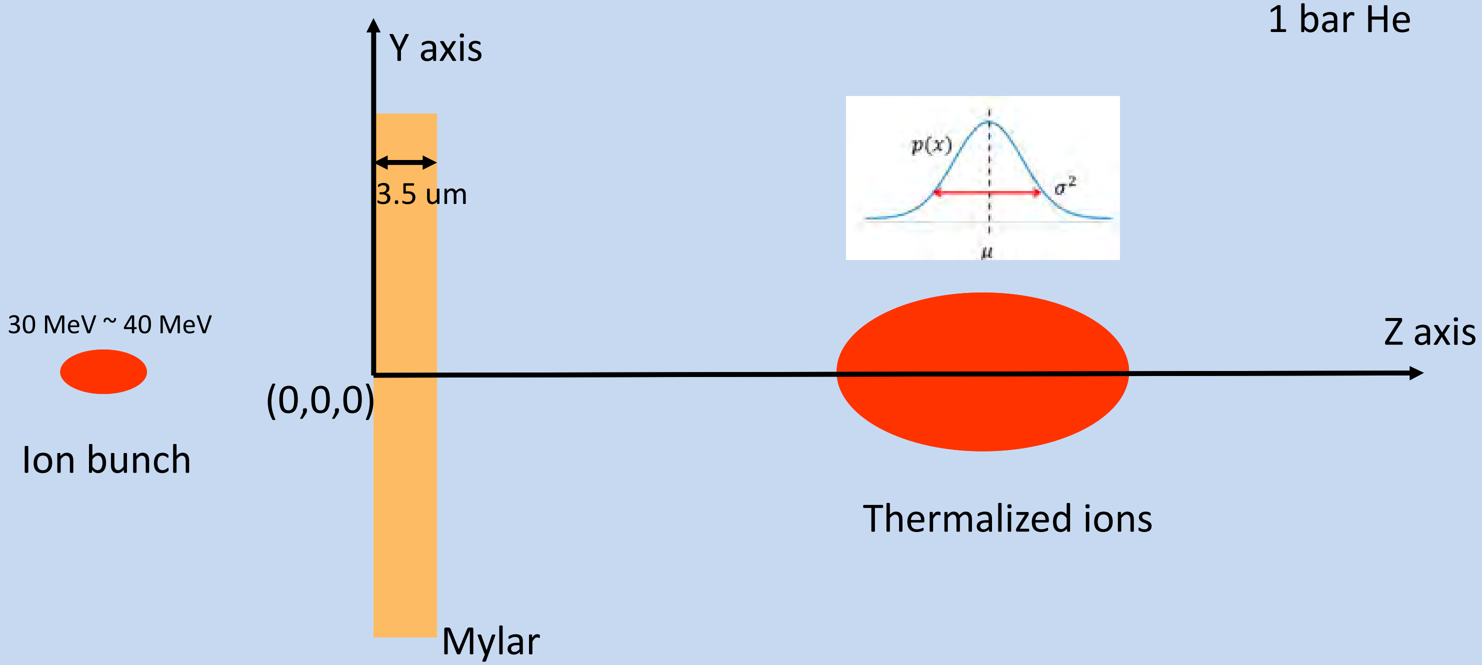
Circuit Layout Board of the DC Cage + RF Funnel

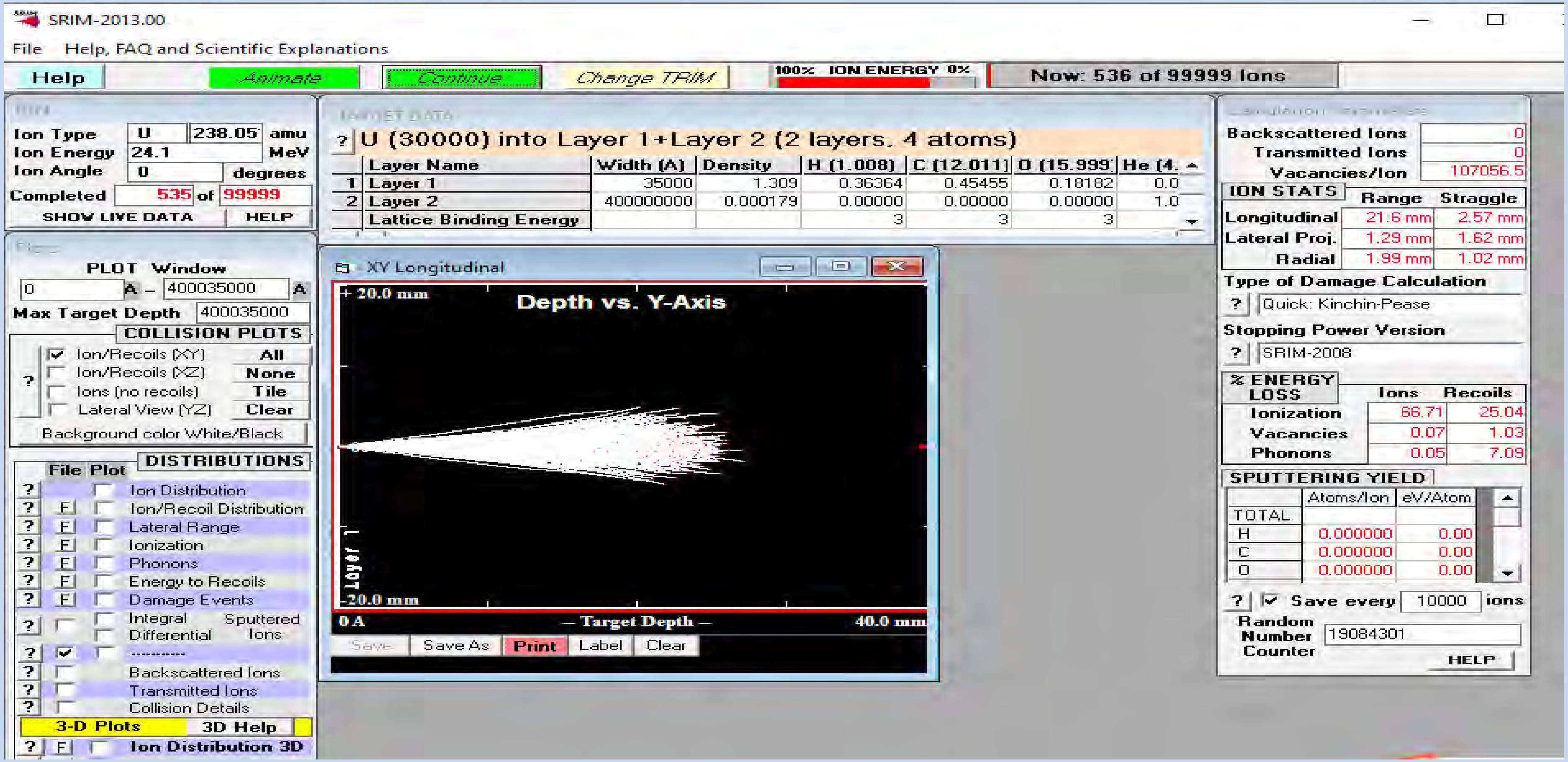


SRIM Code

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

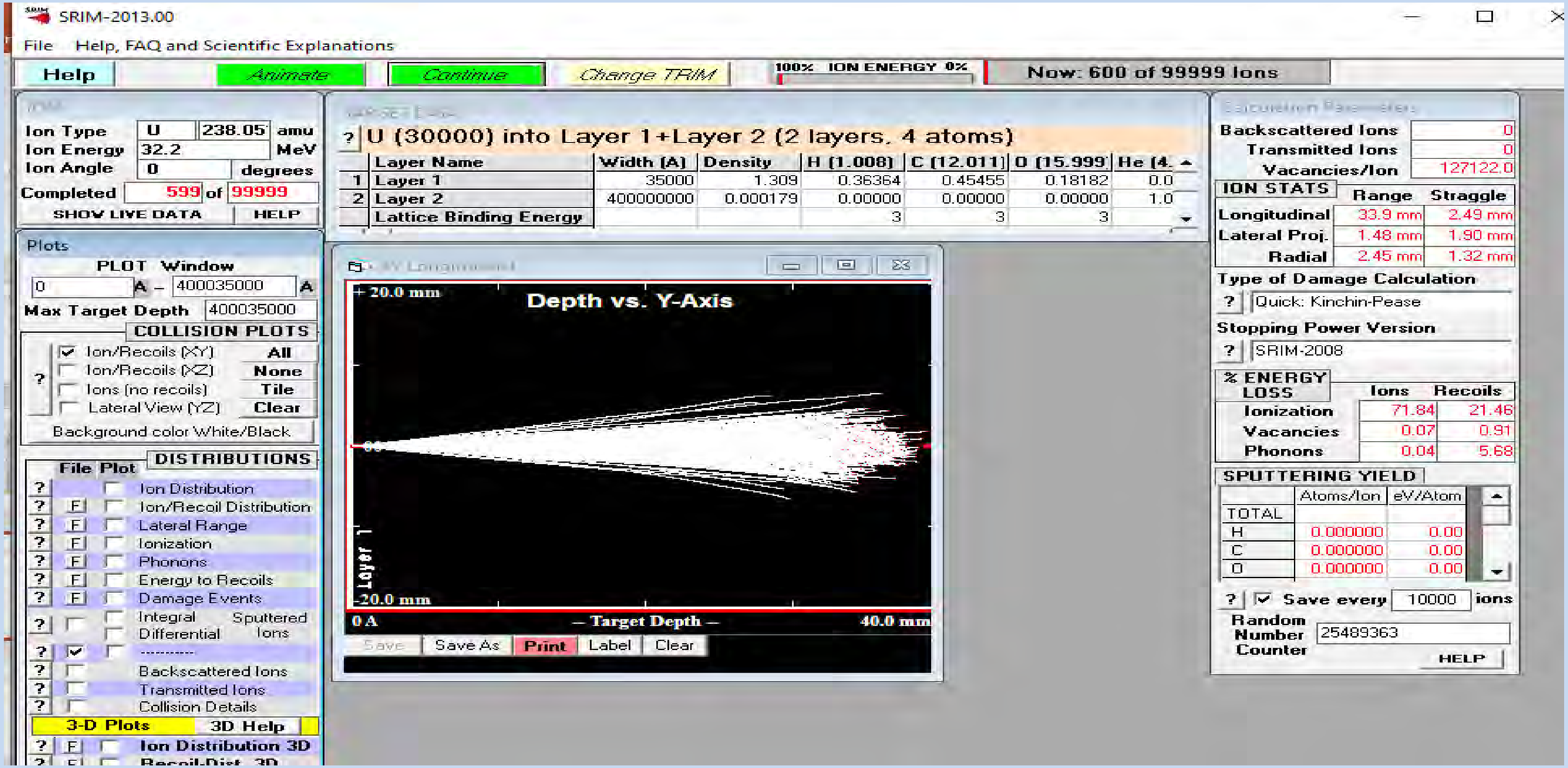


SRIM Code (examples)



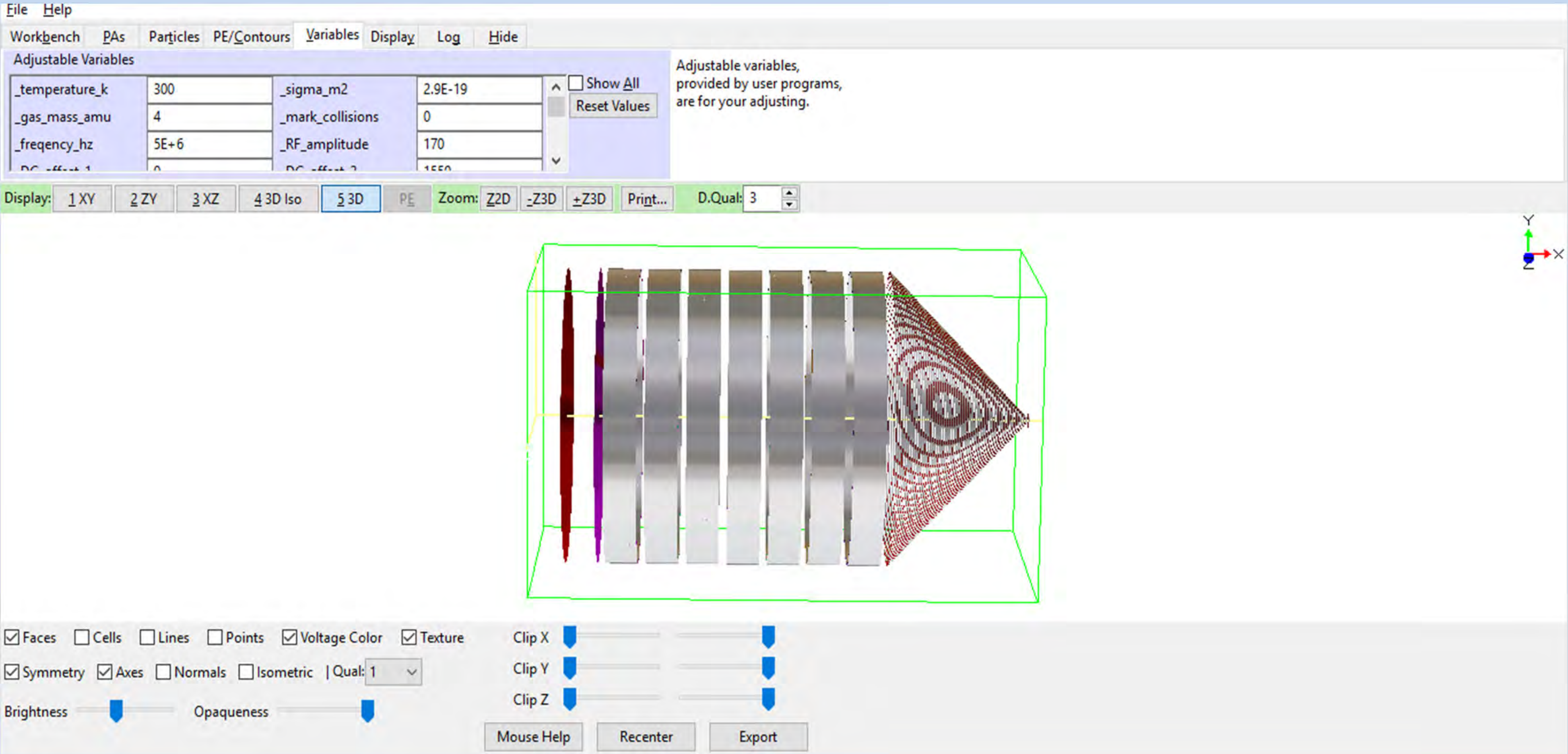
For recoiling energy is 30 MeV, the longitudinal (z-axis) ion stopping range is (13.89 mm, 29.31 mm), the lateral projected range along x-axis or y-axis is (-3.57 mm, 6.15 mm)

SRIM Code (examples)

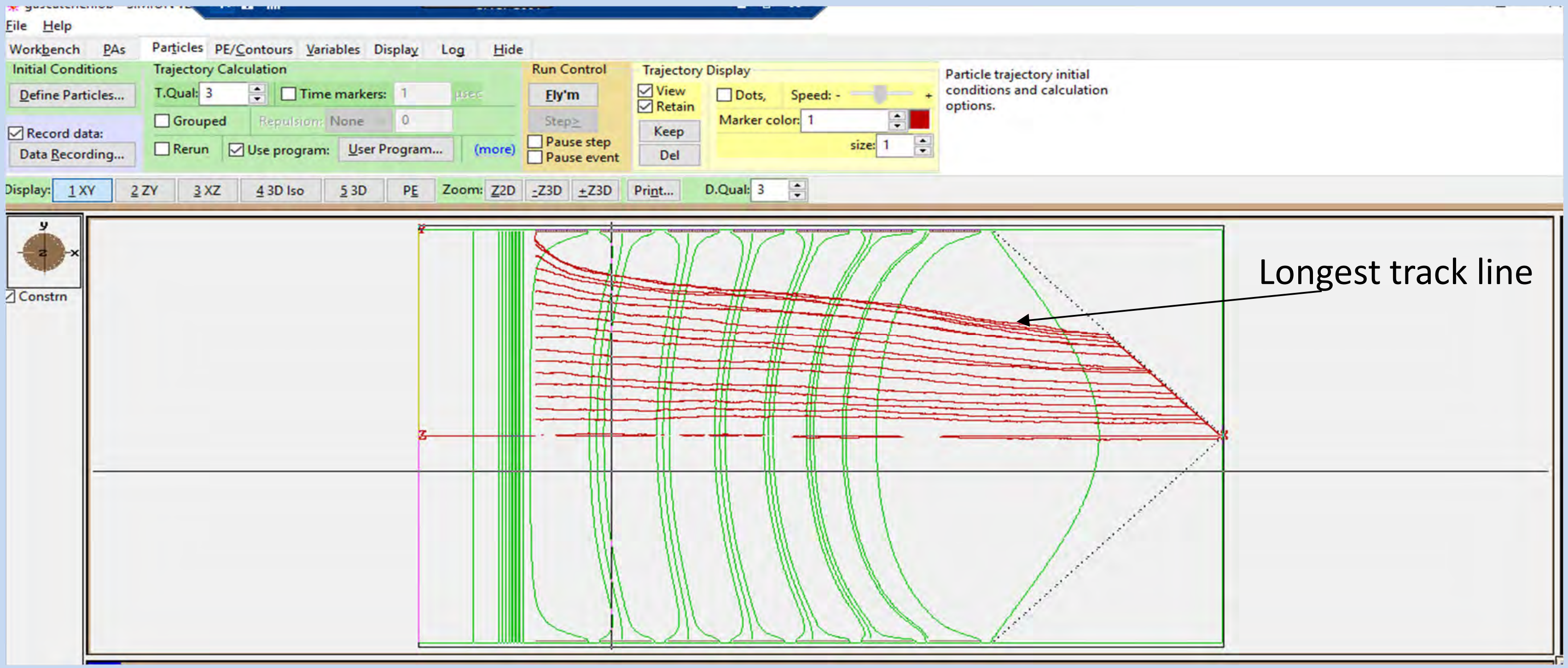


For recoiling energy is 40 MeV, the longitudinal (z-axis)ion stopping range is (26.43 mm, 41.37 mm), The lateral range along x-axis or y-axis is (-4.22 mm, 7.18 mm)

3D Model for SIMION Simulations

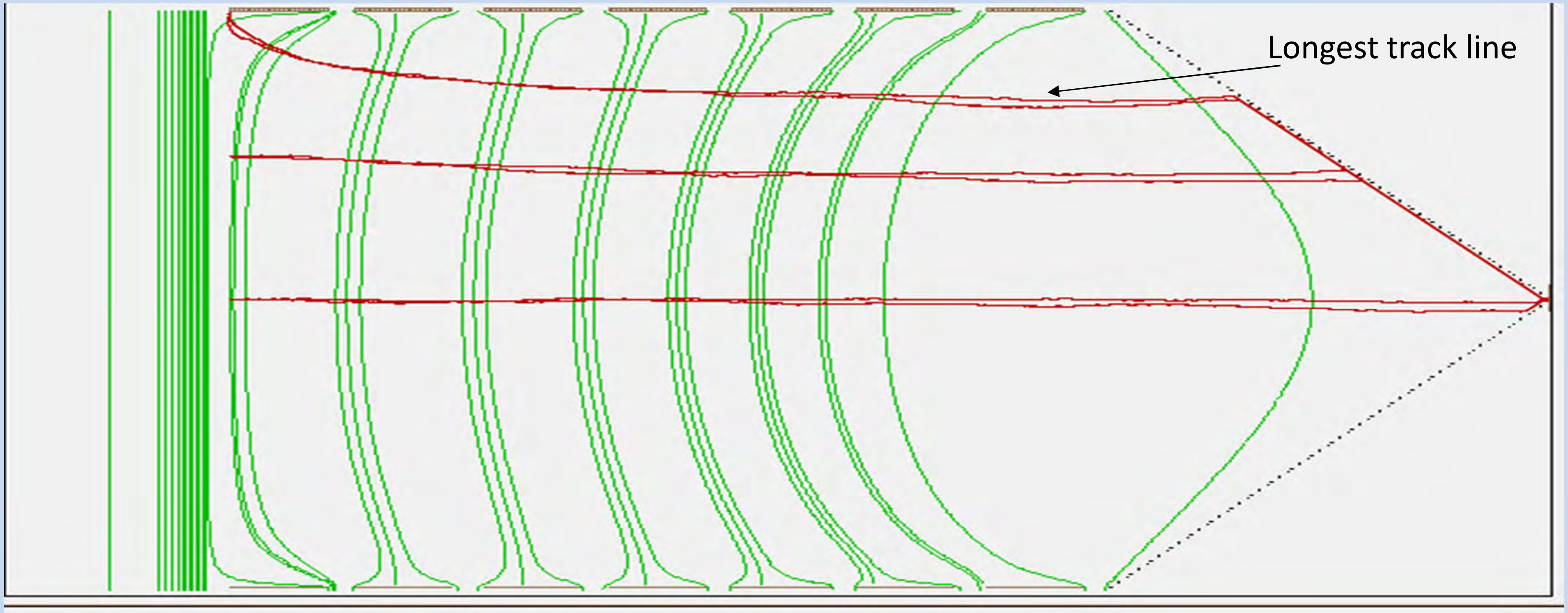


SIMION Simulations of the UniCell



E = 100 V/cm, T = 300 K, He gas, P = 0.1 bar, f = 5 MHz, V_{PP} = 200 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 %.

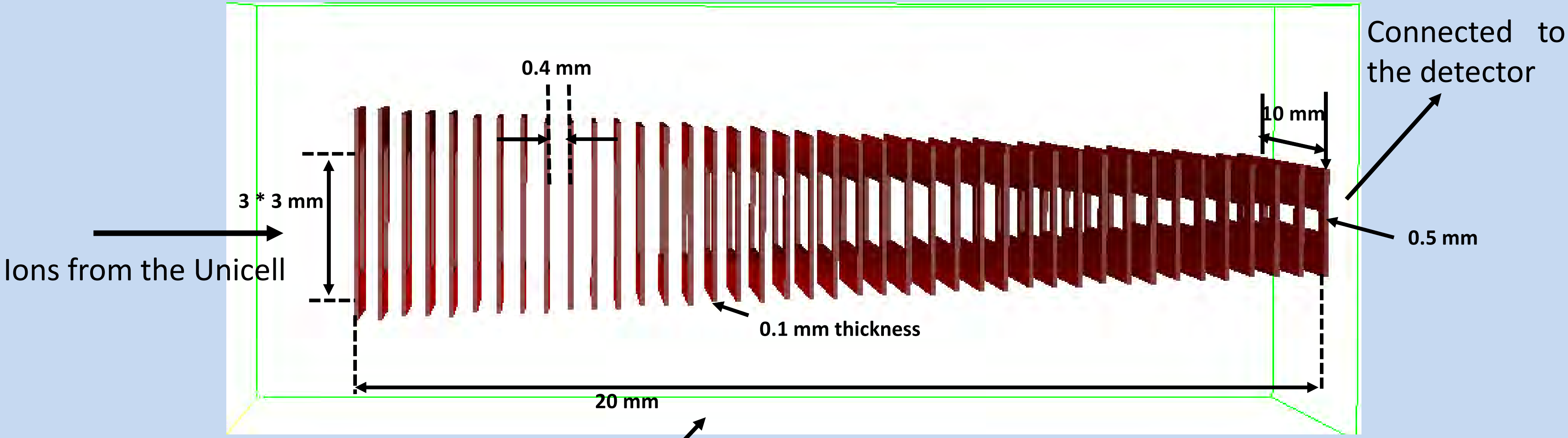
SIMION Simulations of the UniCell

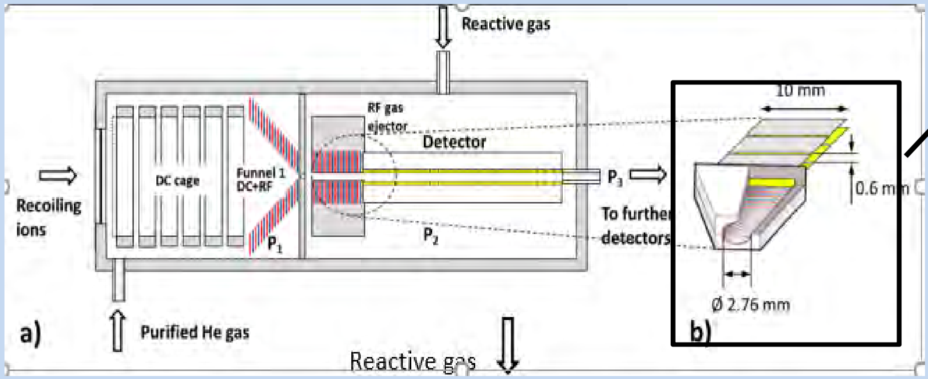


E = 100 V/cm, T = 300 K, He gas, P = 1 bar, f = 5 MHz, V_{PP} = 340 V. The extraction time is about 7 ms and 3.5 ms for ions with charge +1 and +2, respectively (ion with mass = 293).

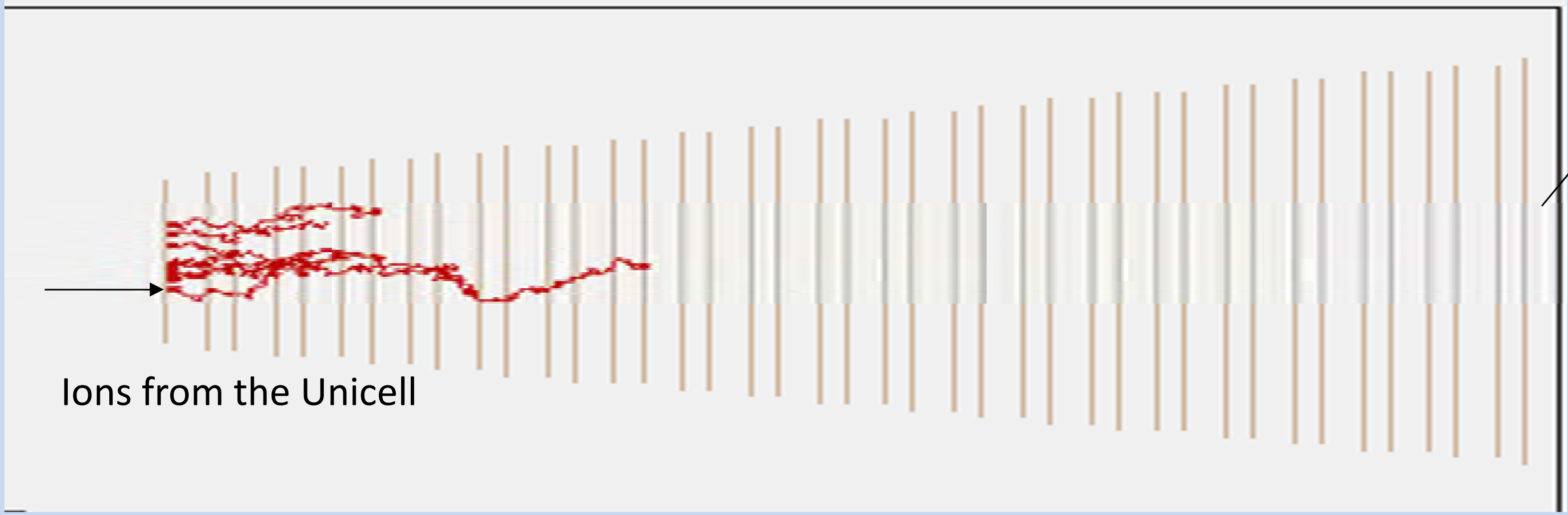
The extraction efficiency is about 100 %.

SIMION Simulations – Ejector Geometry





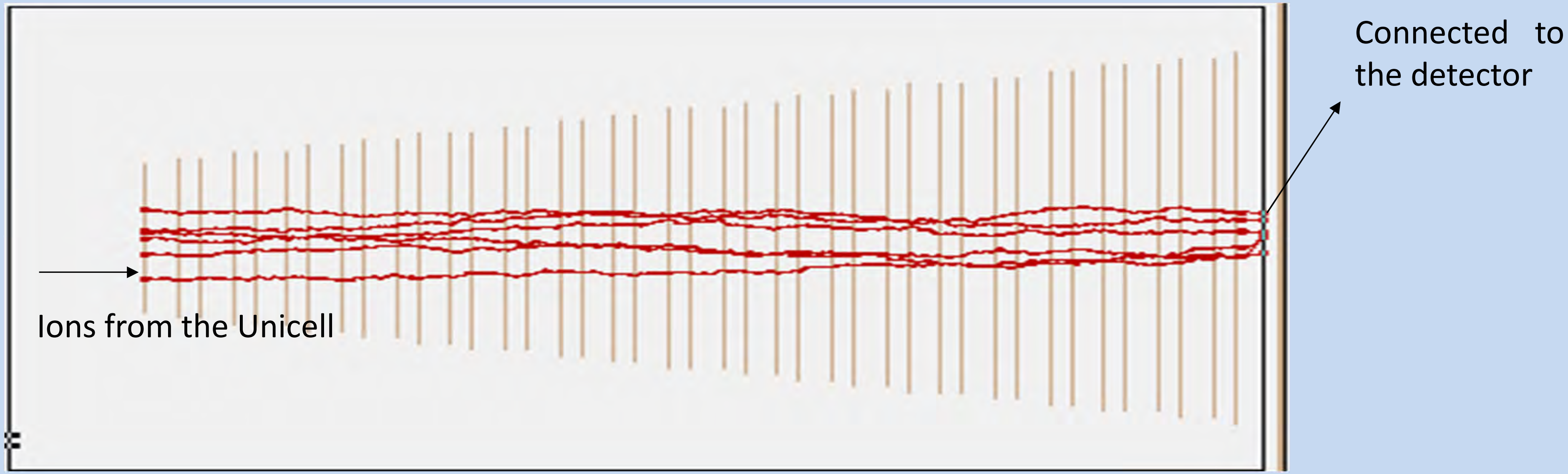
SIMION Simulations – Ion Trajectory



Connected to the detector

Gas flow is 10 m/s, the initial velocity of ions is also 10 m/s, **f = 5 MHz, V_{pp} = 0 V** , T = 300 K, P = 0.98 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 MHz, V_{pp} = 200 V** , T = 300 K, P = 0.98 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 K, P = 1 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

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International Cooperation on the TASCA Recoil Separator for Transactinide Chemistry and Physics