Update of the FRIENDS^3 project

FRIENDS^3: Fast radioactive ion extraction and neutralization device for S^3

Wenling Dong

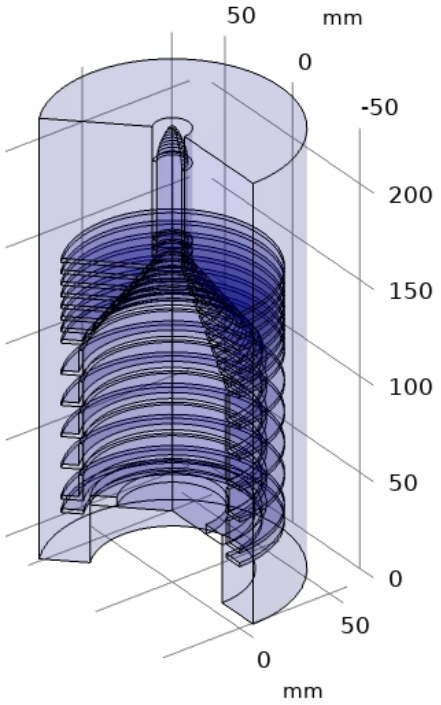
IJCLab, Orsay, France
March 10, 2022

Outline

Motivation

FRIENDS³ project objectives and methodology

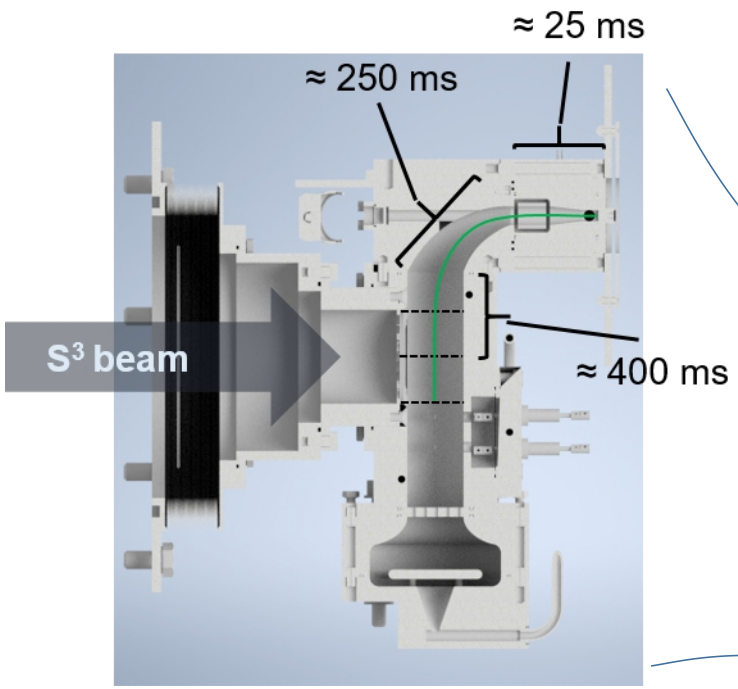
Preliminary results

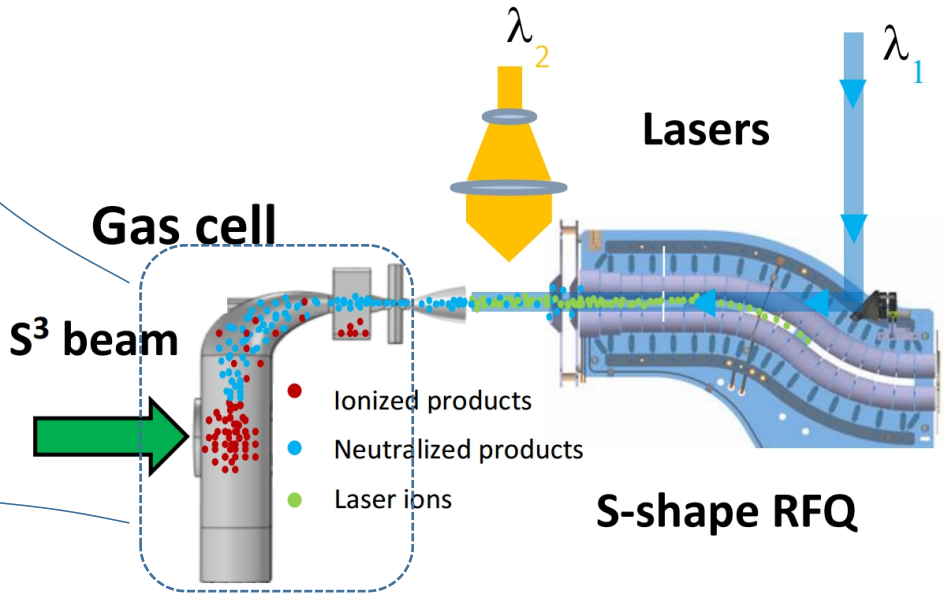


Motivation: the existing S³-LEB gas cell

Radioactive ions to be studied by laser spectroscopy:

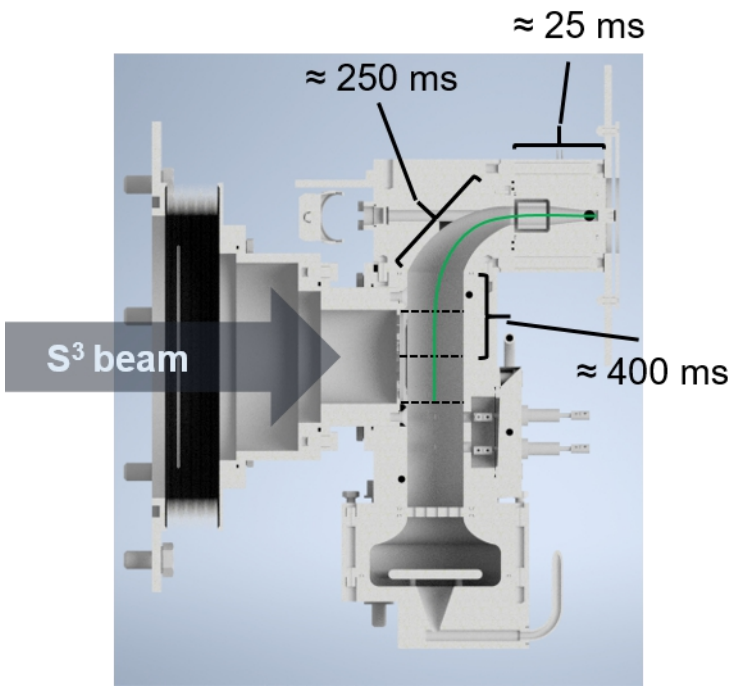
- stopped, thermalized and neutralized in the gas cell.
- extracted through a de Laval nozzle in a supersonic gas jet.
- ionized by the combined turnable pulsed lasers.





Radioactive ions are extracted out of the stopping volume solely relies on the gas flow.

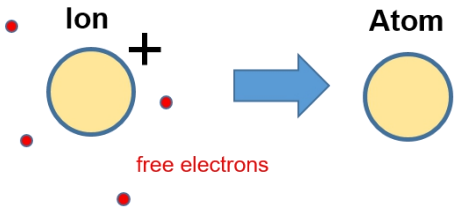
Motivation: the existing S³-LEB gas cell

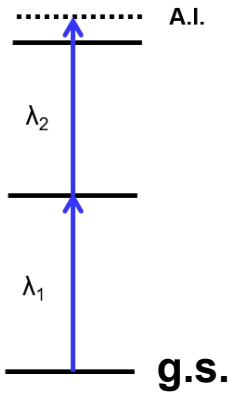


Radioactive ions are extracted out of the stopping volume only relies on the gas flow.

Limitations:

- Long extraction time: ~ 500 ms.
- Current neutralization mechanism cannot work with electric field.





➡ A **fast** gas cell with **high-efficient neutralization** techniques is necessary for short-lived S³ products with $T_{1/2}$ in 100 ms range.

FRIENDS³ Project Objectives and Methodology

Objectives:

- Reduce the extraction time for nuclei with $T_{1/2}$ ~ 100 ms.
- Efficient and fast neutralization mechanism for the gas cell.
- Maximize the ion extraction efficiency.

FRIENDS³ Project Objectives and Methodology

Objectives:

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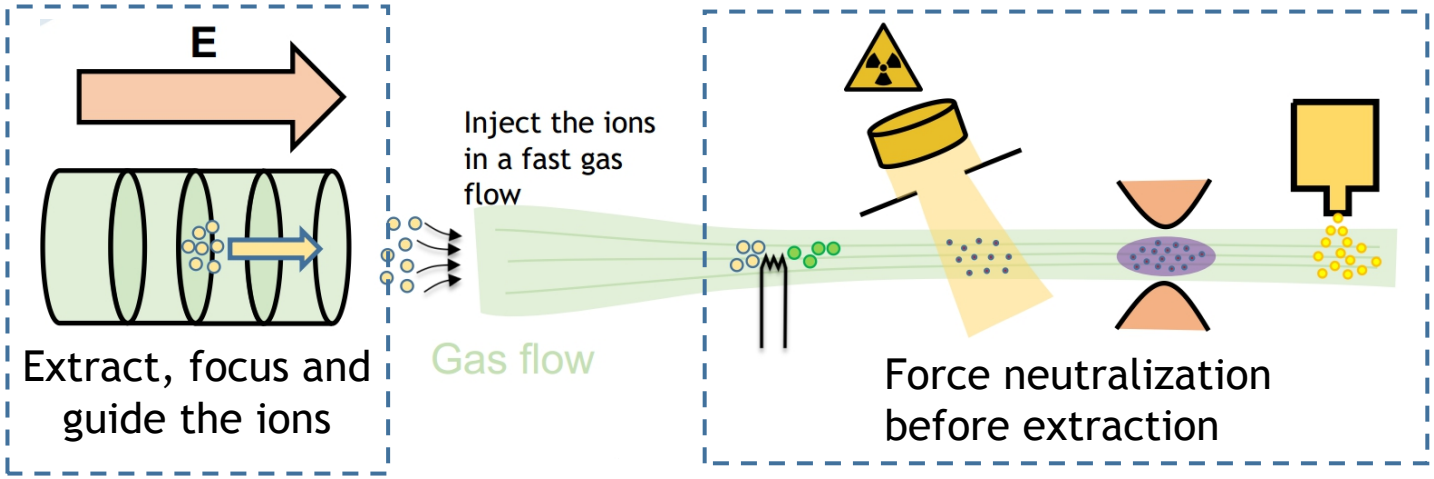
- Efficient and fast neutralization mechanism for the gas cell.
- Maximize the ion extraction efficiency.

Idea:

Two functional sections
- Electrical field applied region (extraction time & efficiency improvement).
- Long no-field region before the nozzle (ensure sufficient time for neutralization).



FRIENDS³ Project Objectives and Methodology

Multiphysics Simulation:

Fundamental effects due to the combined action of the electric fields and the gas flow:

Electric force + Collisions

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Drag force (Deterministic component)

Diffusion (Random thermal motion)

$$F_{combined} = F_E + F_{drag} + diffusion$$

Simulate collisions one by one at high pressure is not possible for optimization.

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◎ First stage optimization by COMSOL:

$$F_{combined} = F_E + F_{drag}$$

- Electrostatics interface F_E.
- Effecitve user-defined Stokes type viscous damping force in laminar flow interface:

$$F_{drag} = -m \cdot \delta \cdot (v - u) = -\frac{e}{k}(v - u) \ ,$$

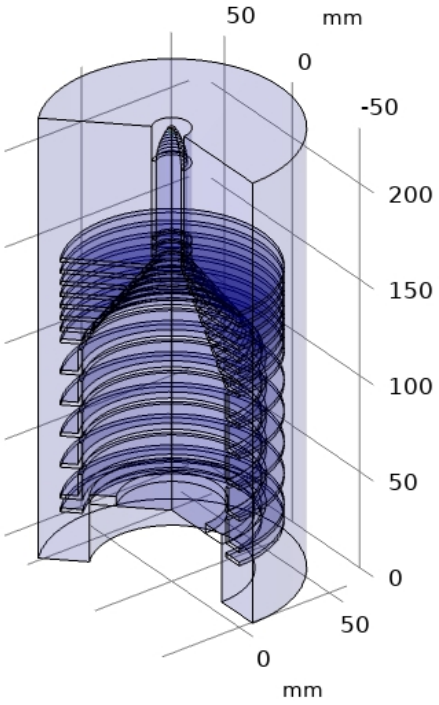
ion mobility : $k = k_0 \frac{T/T_0}{P/P_0}$

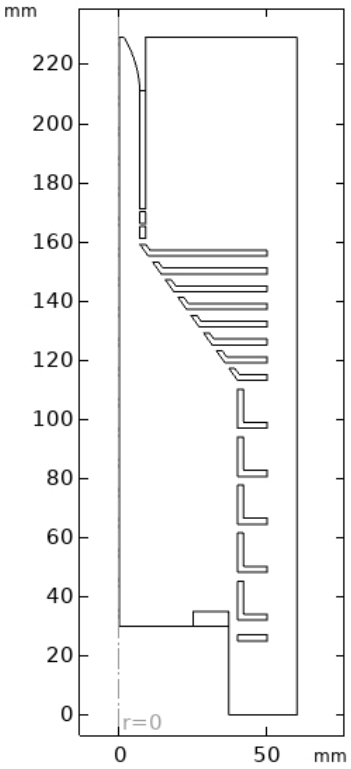
◎ Statistical modeling of diffusion effect by SIMION:

$$F_{combined} = F_E + F_{drag} \quad + diffusion$$

Preliminary Results: COMSOL simulation

Preliminary design: a cylindrically symmetric gas cell.





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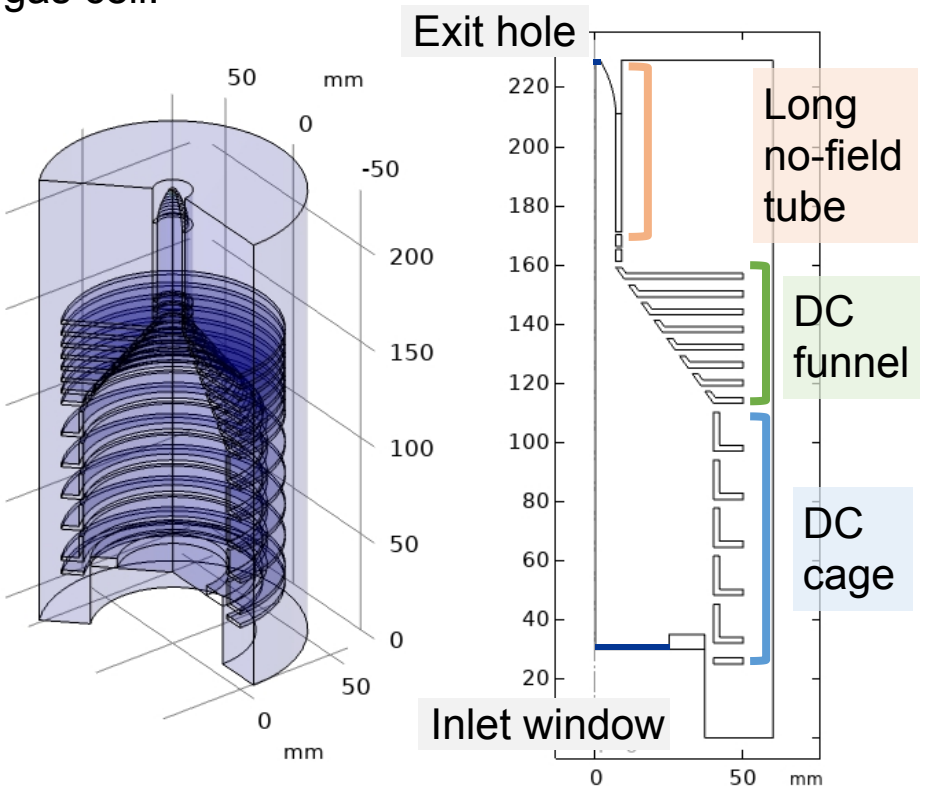


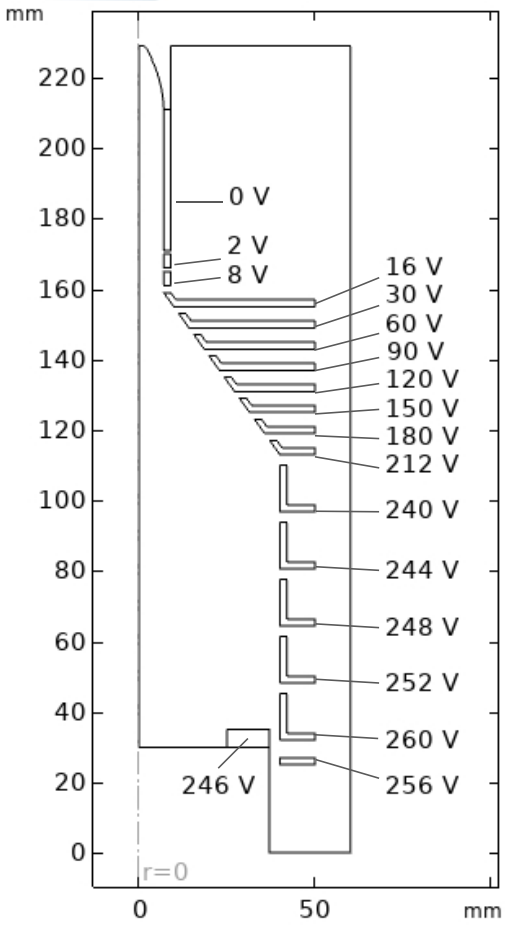
- Sufficient flight time for ions to be neutralized

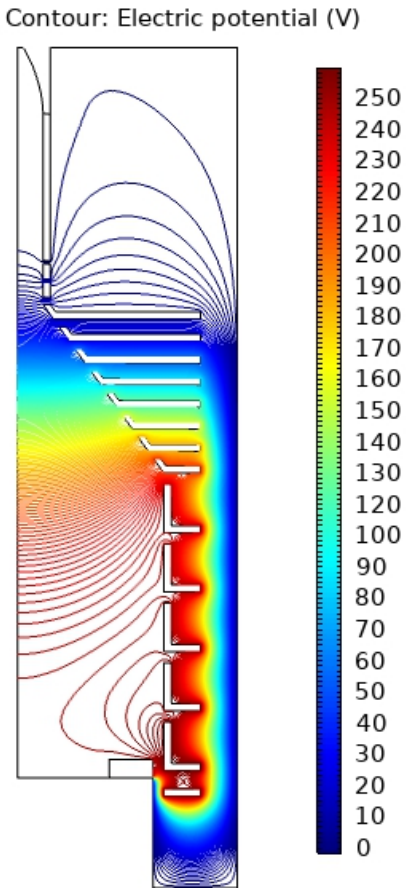
- Fast extraction
- Good extraction efficiency (focus and guide)

Dimension adapted to S^3 beam shape and layout

Optimized voltage configurations

$F_E >> F_{drag}$, next step optimization: align the electric field with the desirable ion trajectory.





Optimized voltage configurations

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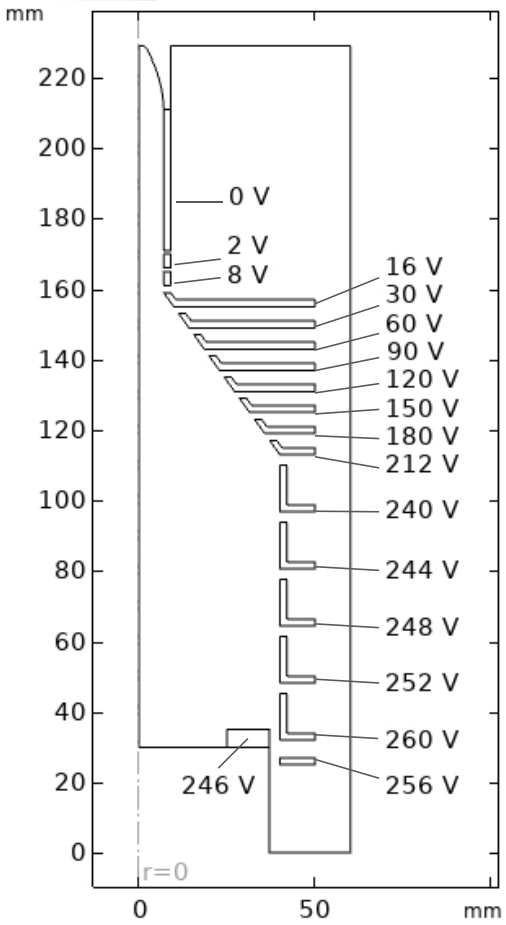
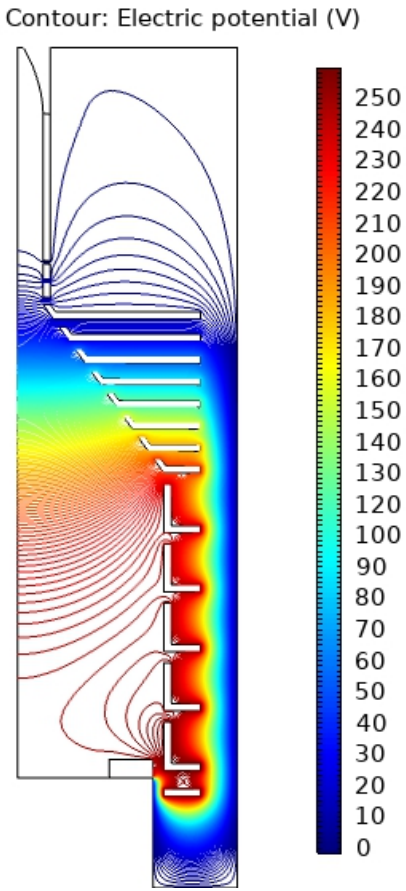
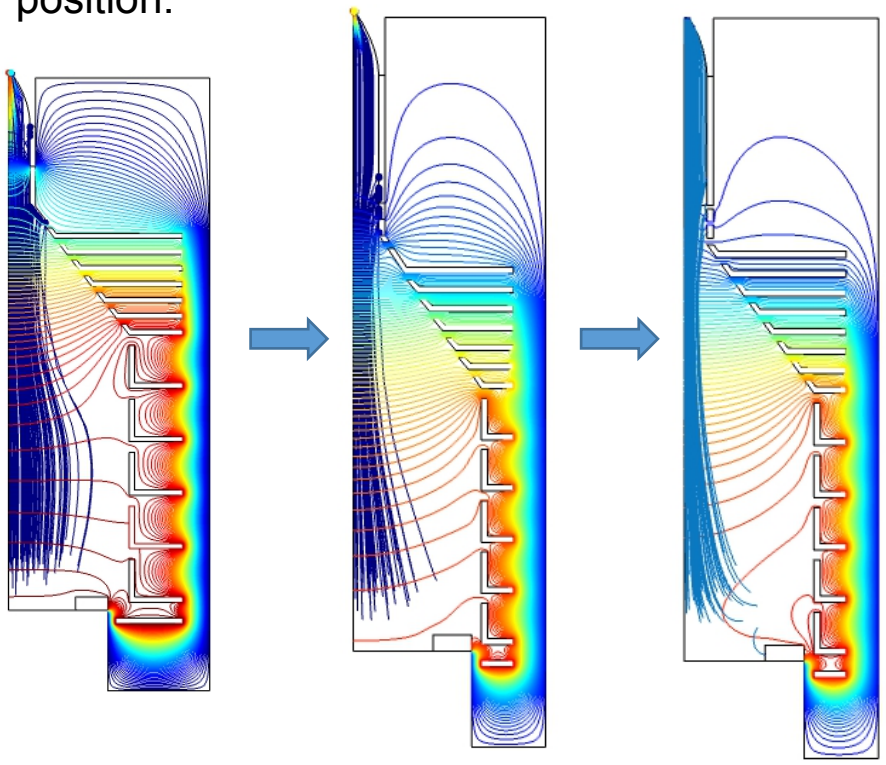


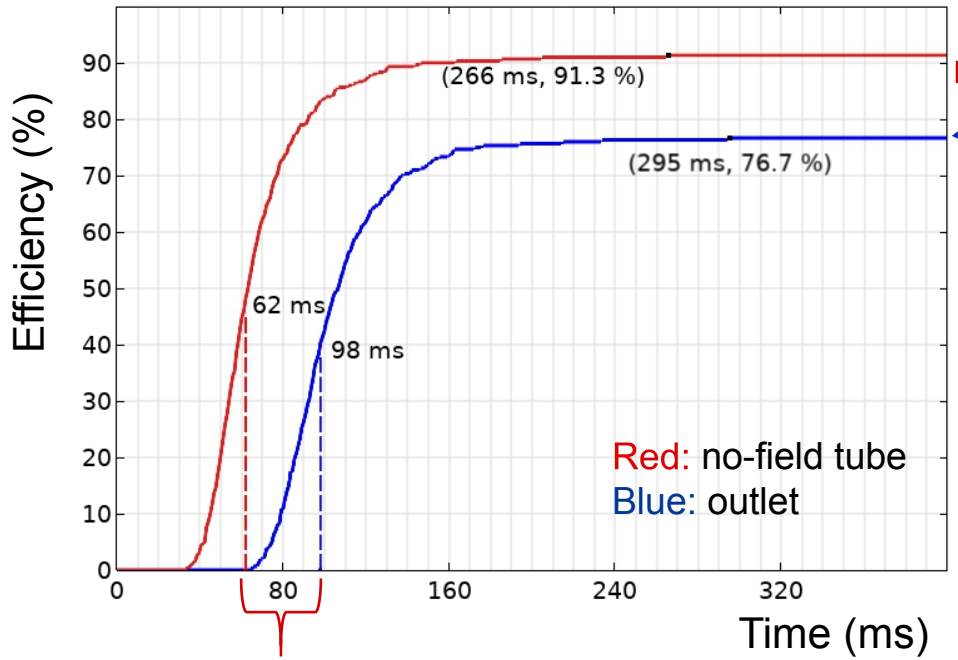


Trajectories of $^{133}Cs^{+}$ released at the same position:

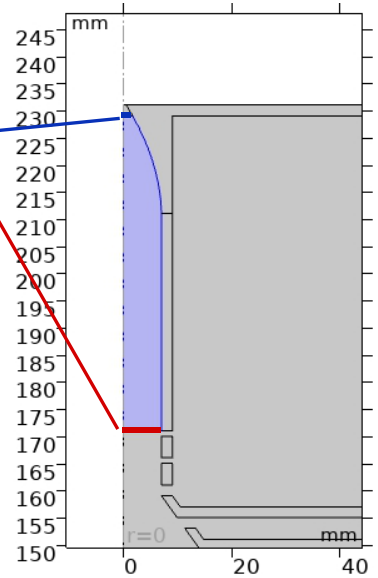


Ions extraction and neutralization

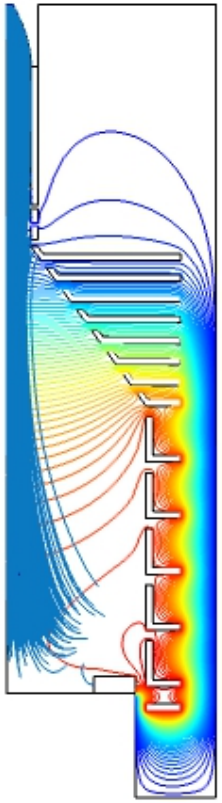
100 mbar



Time available for neutralization (ms)

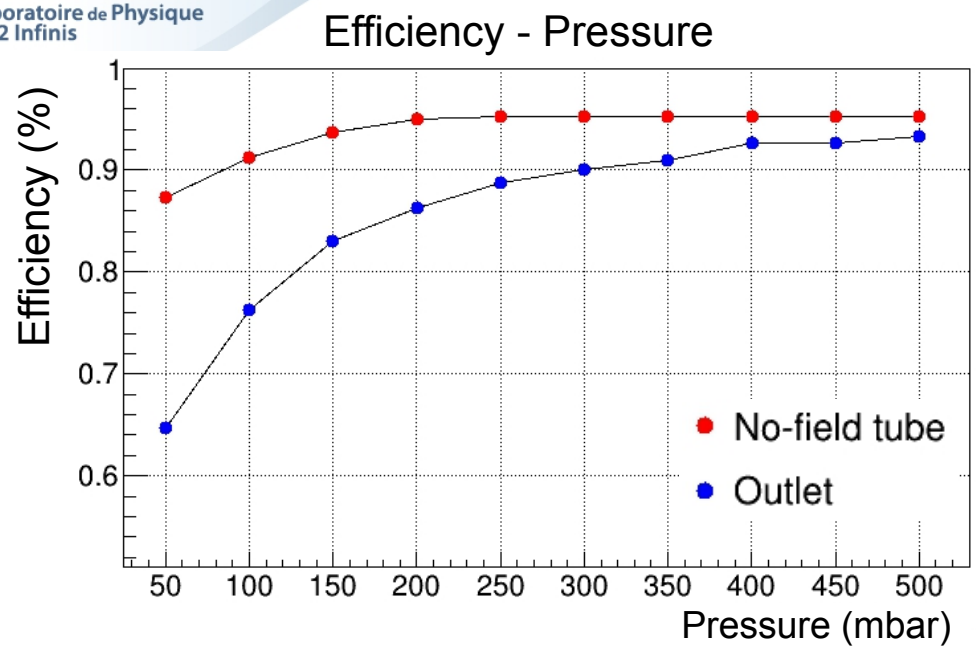


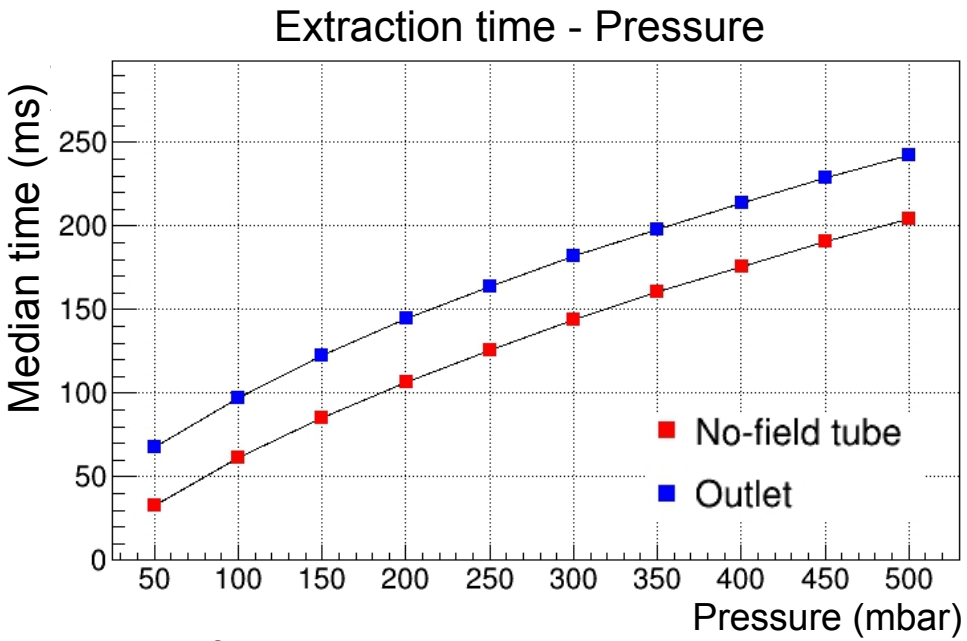
Ions trajectories



Efficiency is much higher than reality since diffusion is not considered in COMSOL.

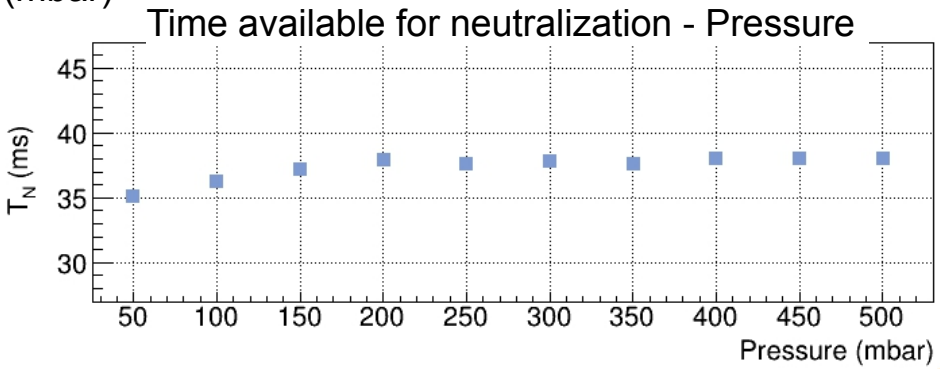
Performance of the designed gas cell





COMSOL simulation results

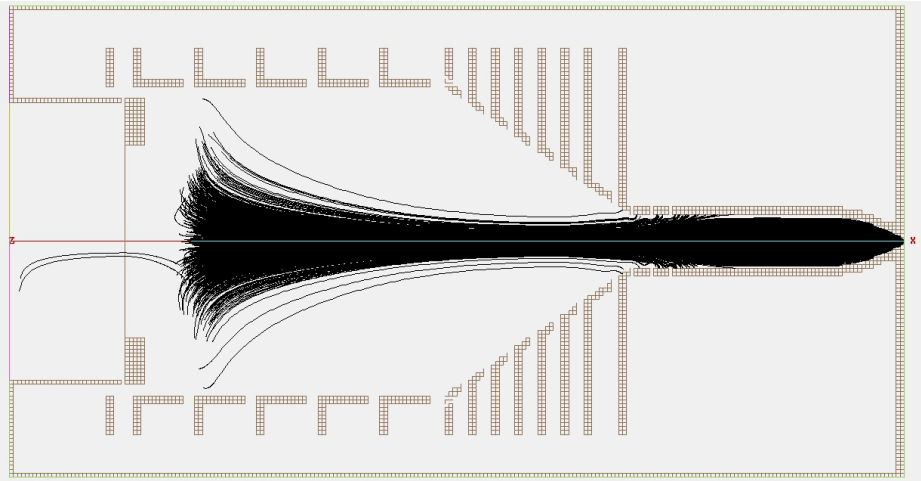
- For 100 mbar, extraction time below 100 ms.
- With this design, around 35 ms for neutralization.



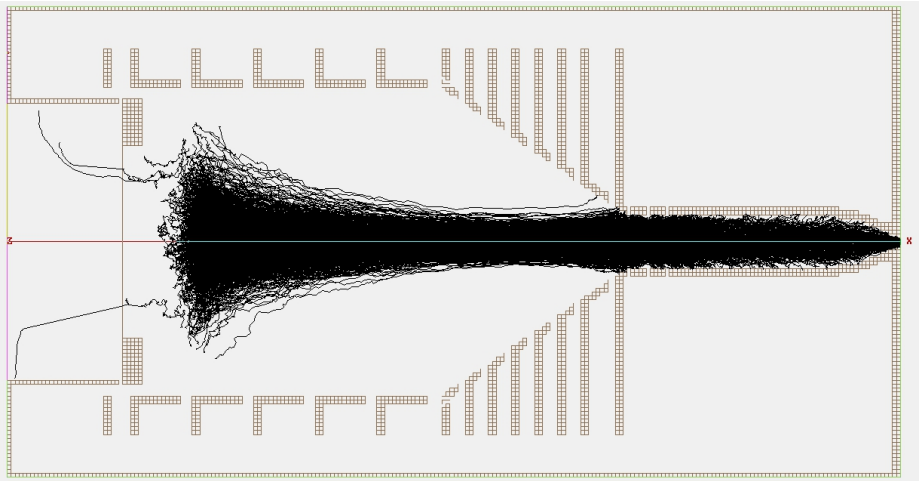
Diffusion simulation in SIMION

- Transfer the optimized parameters (pressure, voltage gradient) and geometry by COMSOL to SIMOIN.
- Coupling the diffusion effect.

$$F_{combined} = F_E + F_{drag}$$

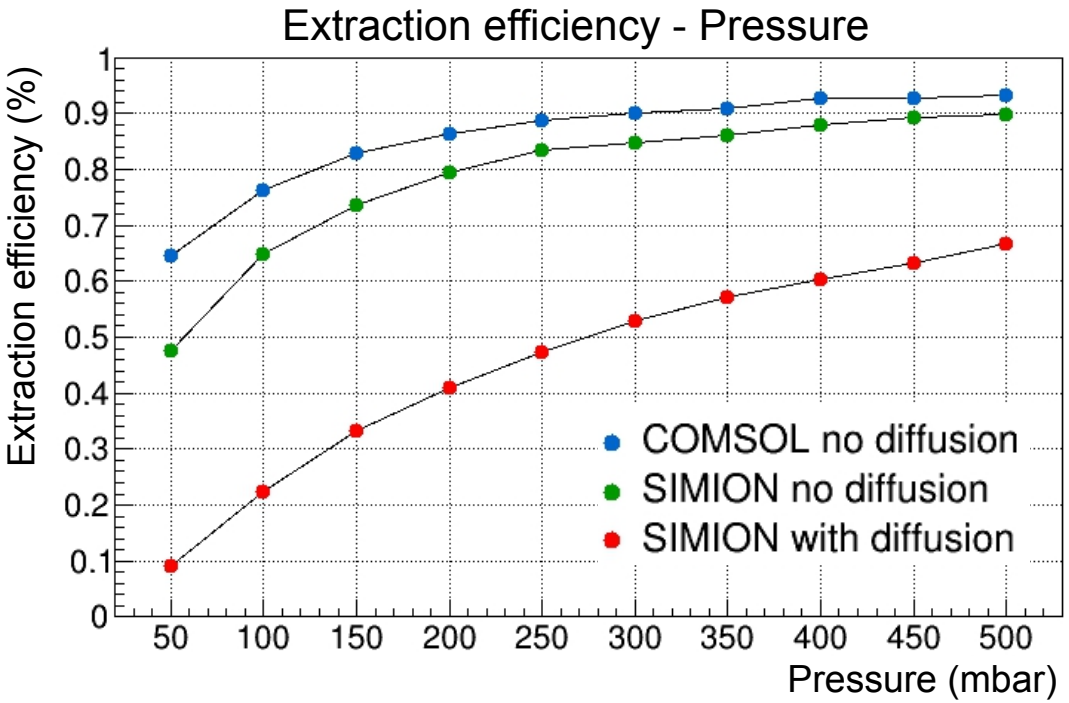


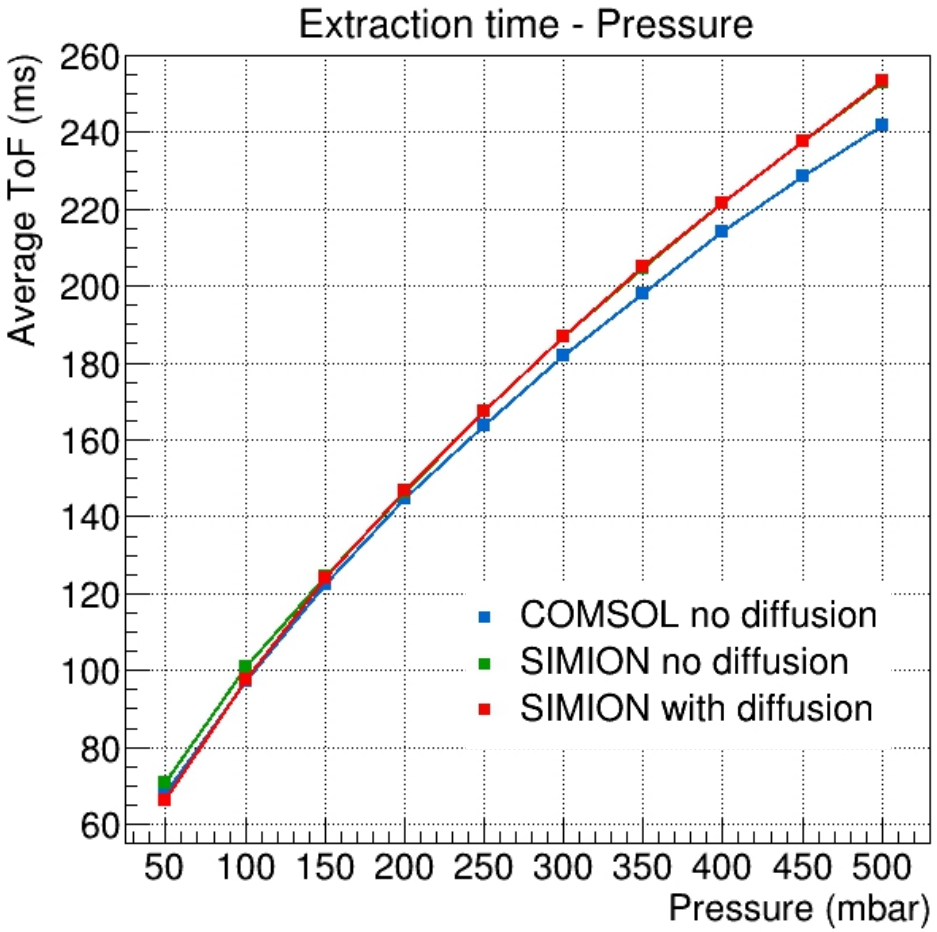
$$F_{combined} = F_E + F_{drag} + diffusion$$



Cross check with COMSOL.

COMSOL/SIMION results comparison



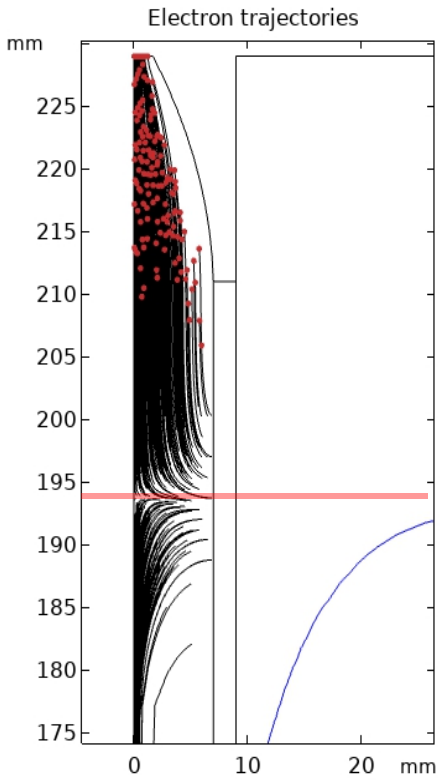


- Calculations without diffusion gives similiar efficiencies.
- Diffusion significantly reduces the efficeincy.
- Extraction time almost identical between two softwares.

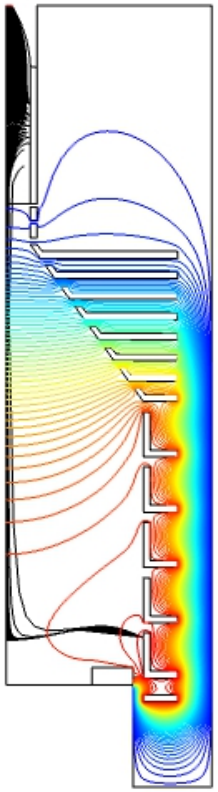
Electrons generated for neutralization

- Check the dynamics of the free electrons in the neutralization tube:

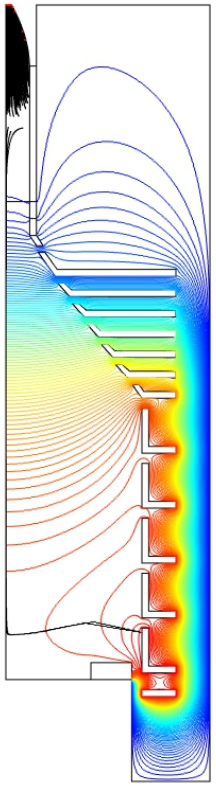
Electrons released in the tube:



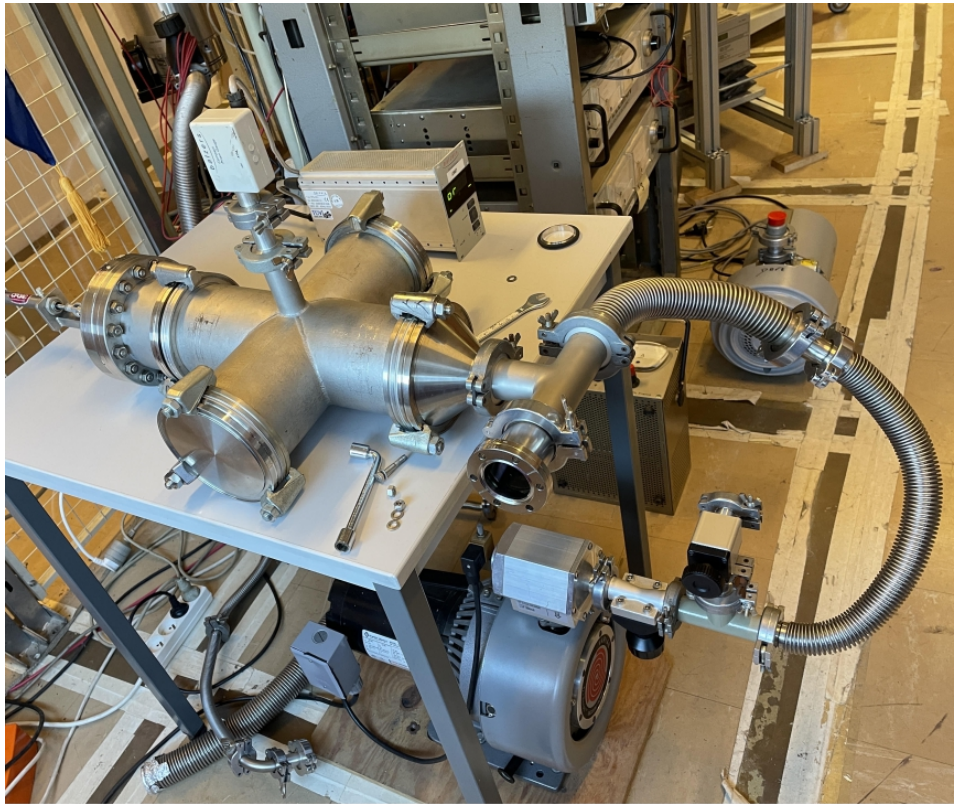
Release at z=195 mm:



Release at z=205 mm:

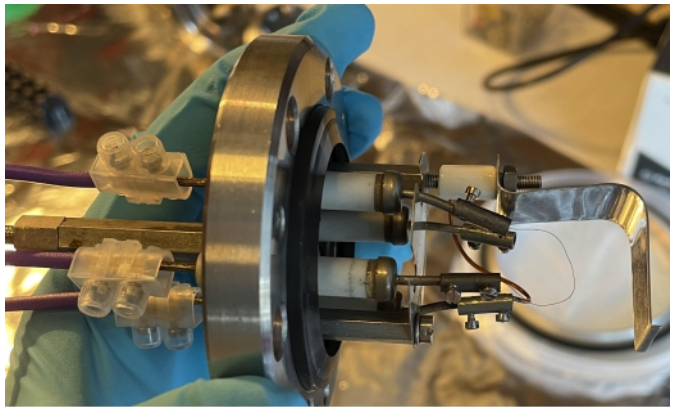


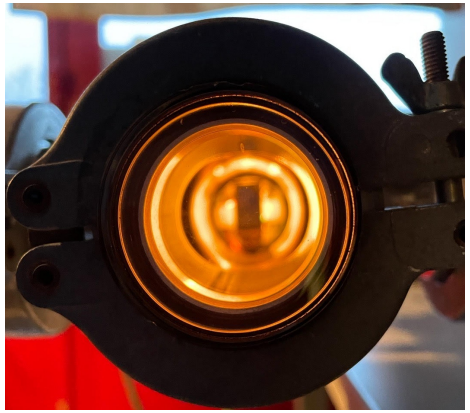
FRIENDS³ test bench



An off-line simplified test bench:

- To study electron emission mechanisms, already done by filament heating. (beta source, electrical discharge will be tested)
- Beta source ionize the gas.





Conclusion and perspectives

- Clear view of how to simulate and optimize the gas cell.
- Plasma module of COMSOL will be used to simulate the more precise electron generation/motion in the neutralization tube.
- A preliminary report is being writen with the first simulation results.
- Preperations for test bench have started.

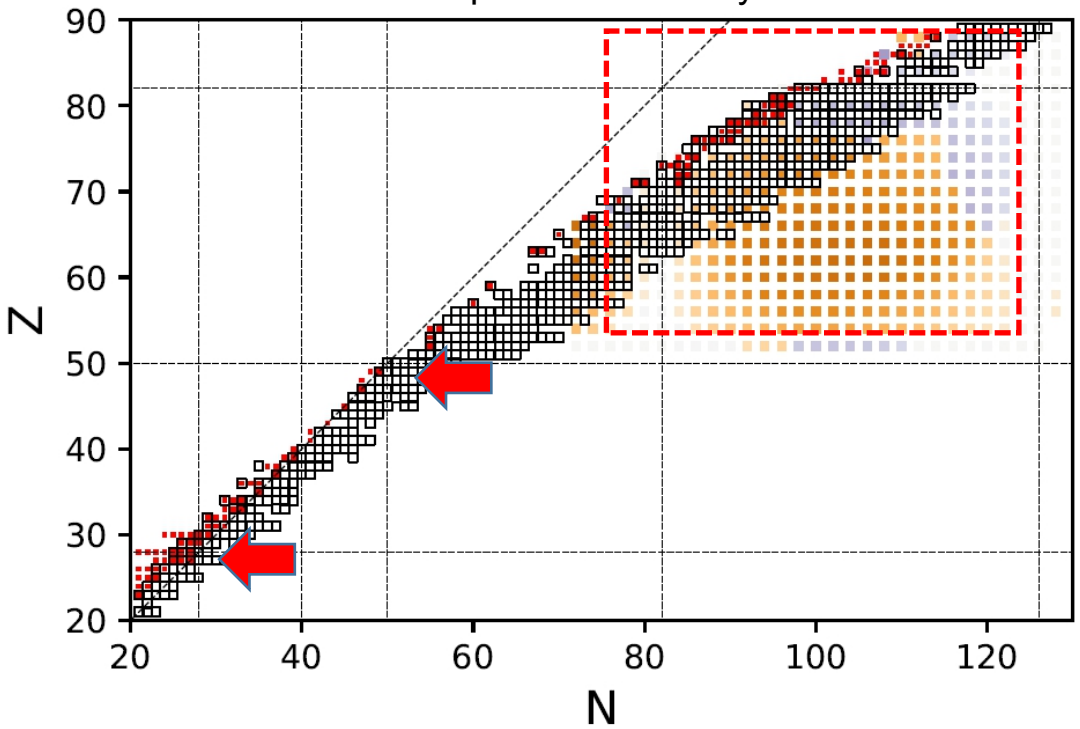
Thank you for your attention !

Project team:
Vladimir Manea[1,2], Serge Franchoo[1],
David Lunney[1], Enrique Minaya -Ramirez[1],
Samuel Roset[1], Wenling Dong[1]

[1]IJCLab CNRS-IN2P3, Orsay, France
[2]GANIL CEA-DSM/CNRS-IN2P3, Caen, France

Overview: S³ physics

Producible isotopes from the S³ yield database



Empty squares: S³ products
Red squares: $T_{1/2}$ < 250 ms

Particular interest of this project:
Laser spectroscopy for short-lived S³-LEB products (in the 100 ms range) around the N = 82 shell closure up to the proton dripline.

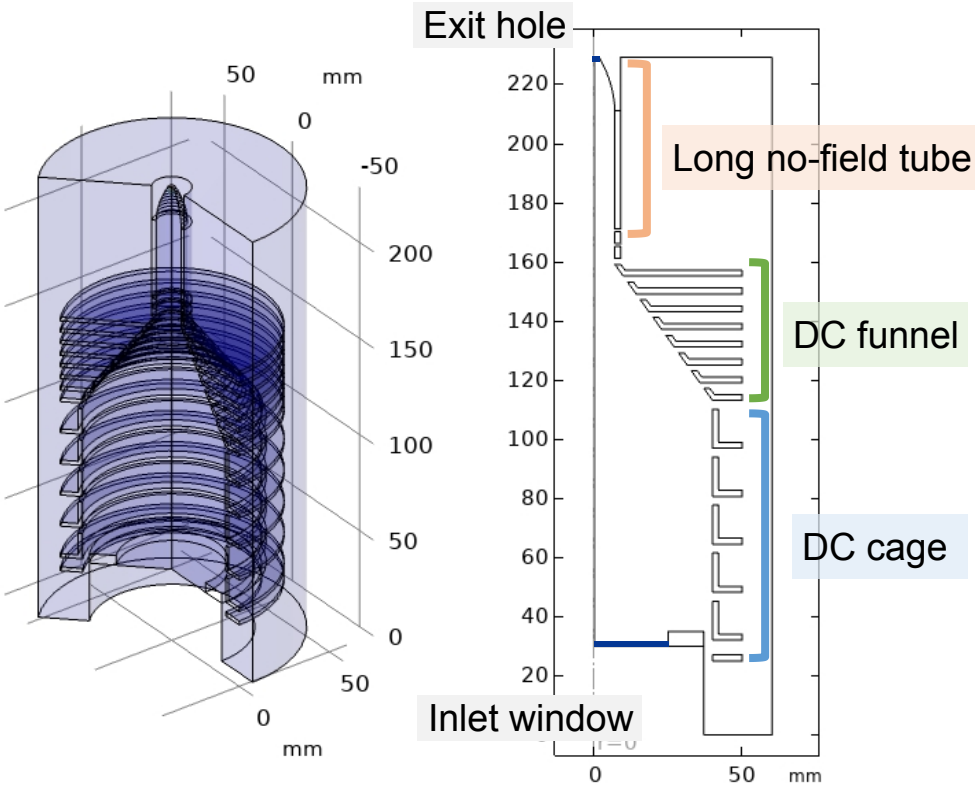
Long-term expectation:
short-lived isotopes at the region

- "beyond" N = Z
- near the N = Z = 50 shell closures.

https://u.ganil-spiral2.eu/chartbeams/
M. Kortelainen et al., Phys. Rev. C 82, 024313 (2010)

Preliminary Results: COMSOL simulation

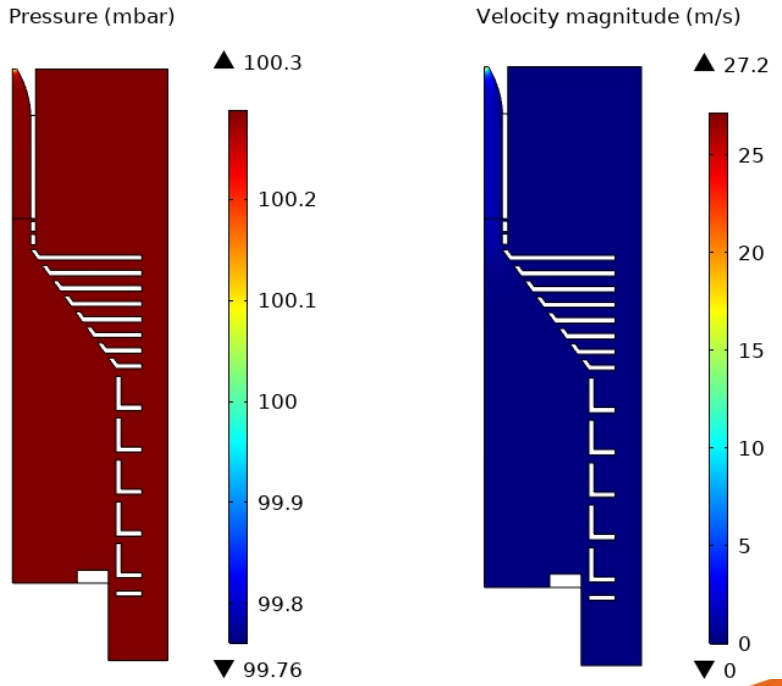
Preliminary design: a cylindrically symmetric gas cell.



COMSOL simulation results are studied by two steps:

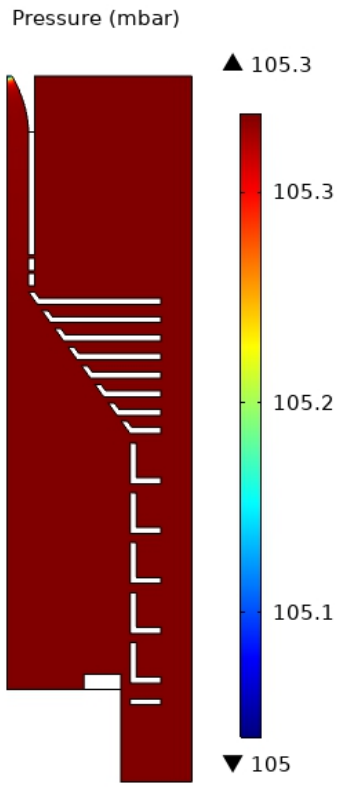
- Stationary study of the gas flow.
- Time-dependent study of the particle motion.

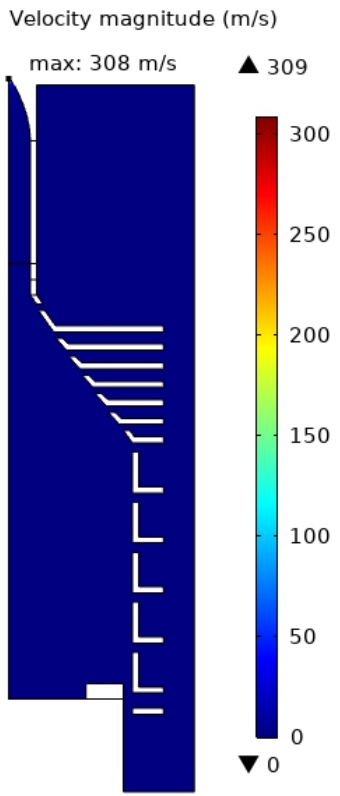
Gas properties at equilibrium state by laminar flow interface:



COMSOL simulation of the gas flow

Gas properties at equilibrium state: stationary study by laminar flow interface (Mach number < 0.3) in COMSOL.



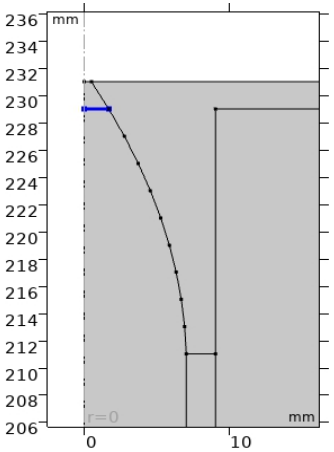


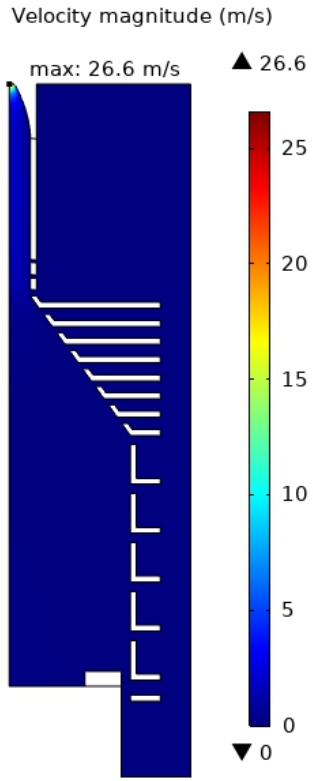
Redefinition of simulation volume:

Exit hole: Constant pressure boundary (p = 0)

New outlet: constant volume flow condition

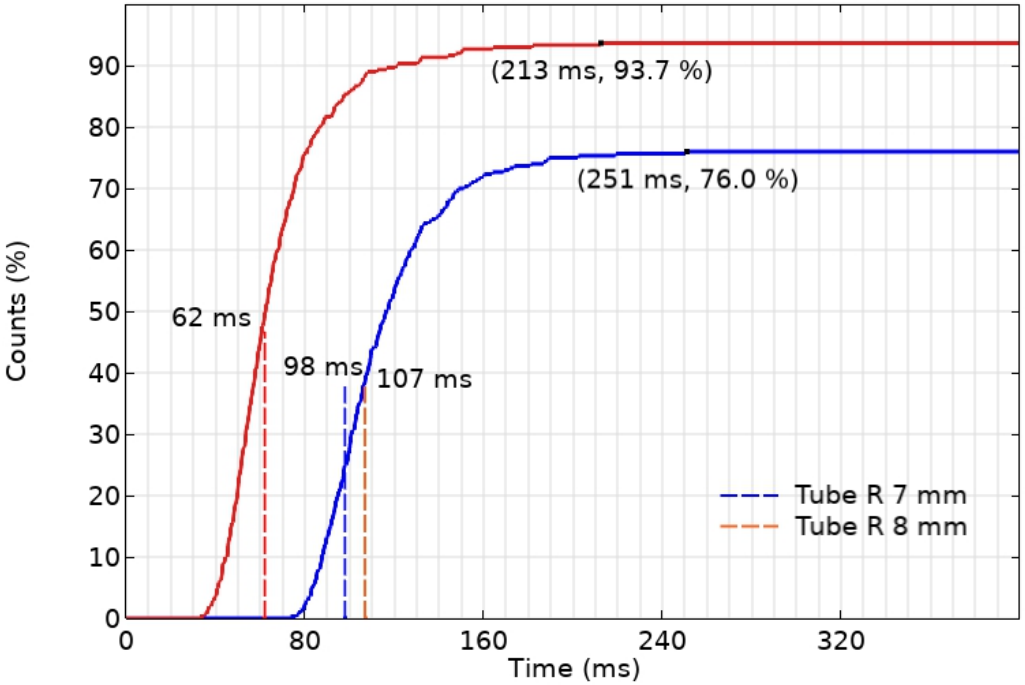
$$Q_V = \sqrt{\frac{\gamma R T}{M}} \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}} \frac{\pi}{2} d^2$$

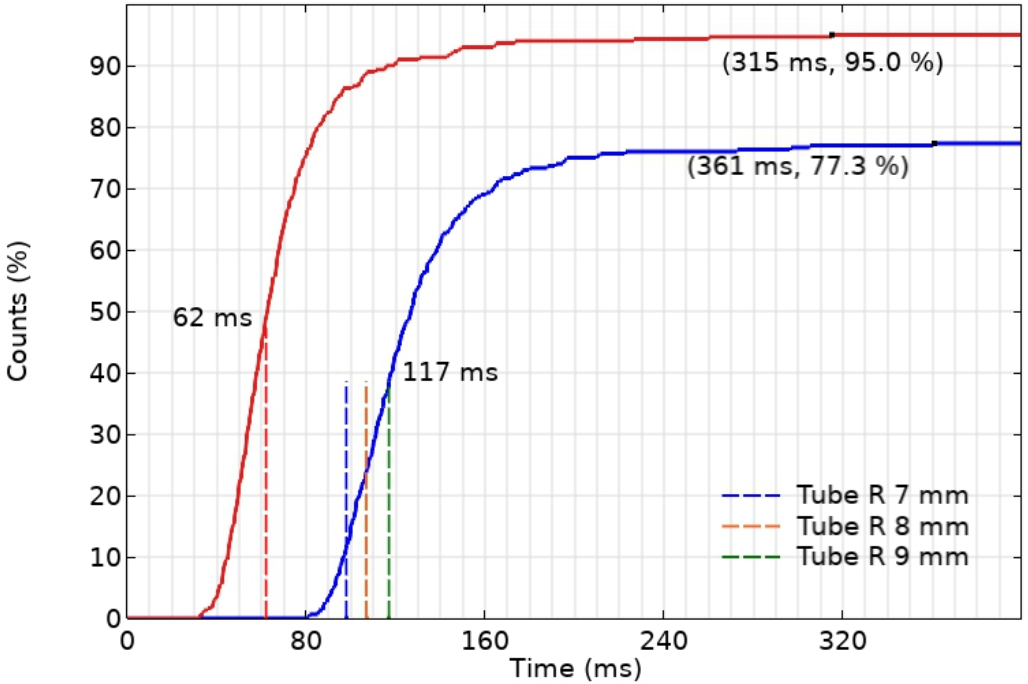




[1] E. Mogelevskiy, 'Diffusion inside the gas cell for laminar flow', Tech. rep., KU Leuven(2013).
[2] Y. Kudryavtsev, et al., Nucl. Instrum. Meth. B (2016)

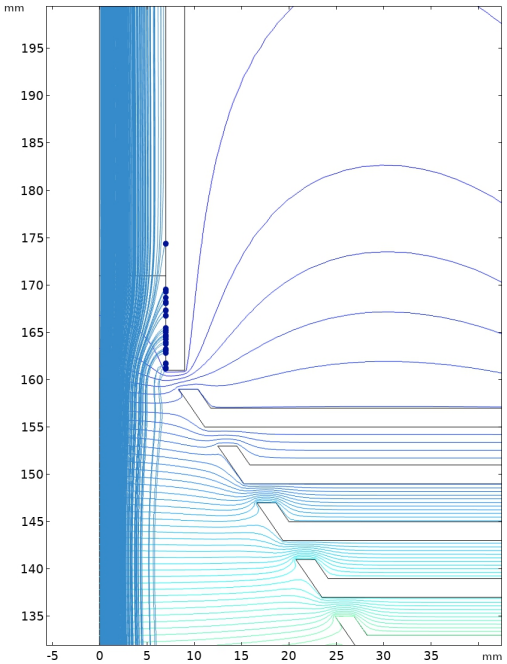
Feasibility of neutralization time improvement

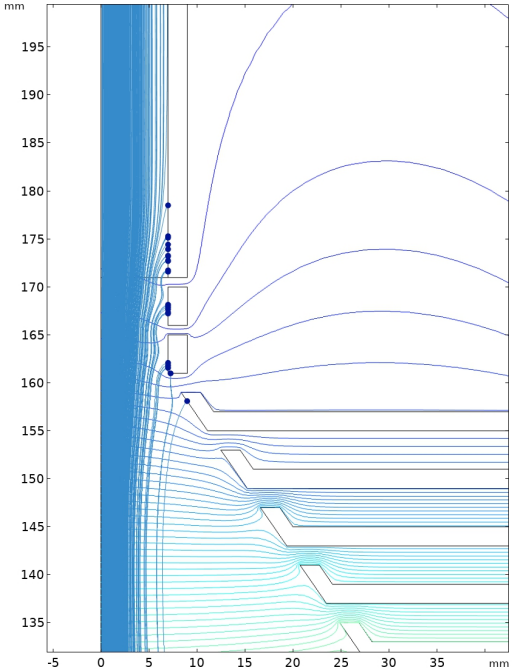




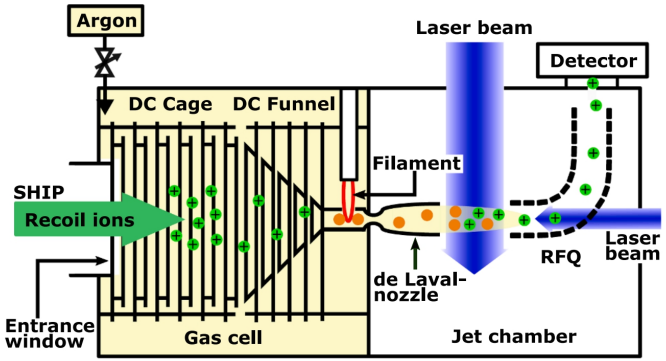
Tube segmentation and Nozzle diameter

Tube is segmented: avoid large voltage drop. Acceleration on a particle is normal to the contour.





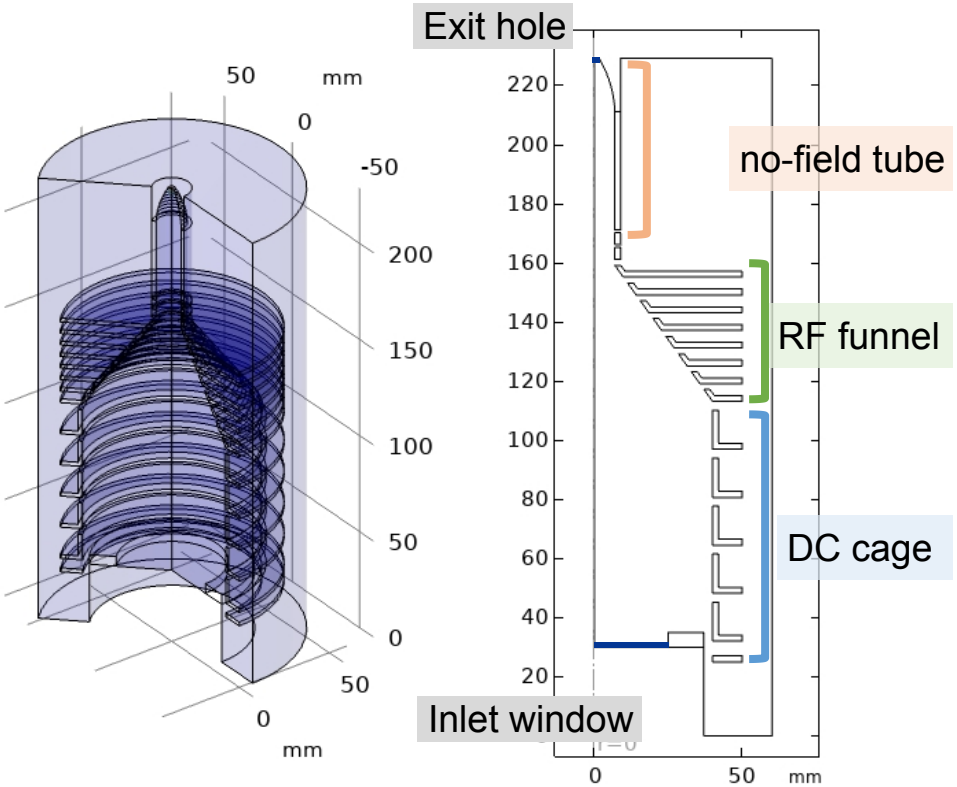
Gas cell using at Mainz/GSI:



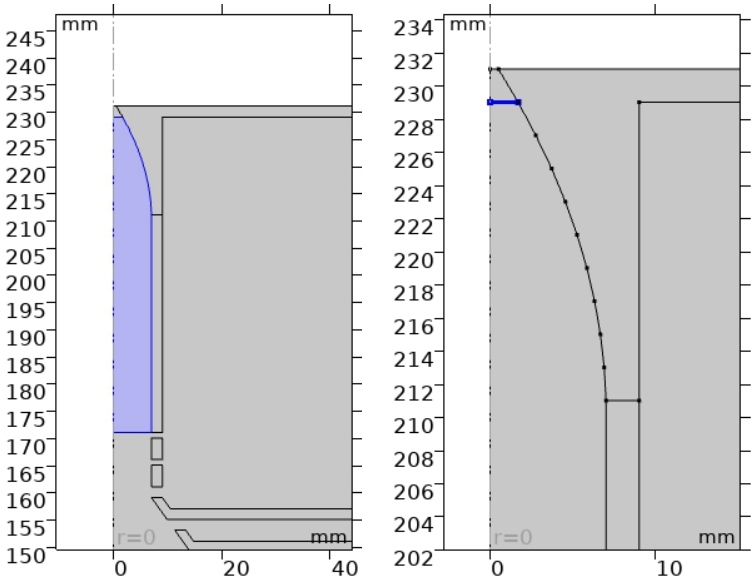
S. Raeder et al., NIM B 463, 272-276 (2020)

RF funnel

Preliminary design: a cylindrically symmetric version gas cell.



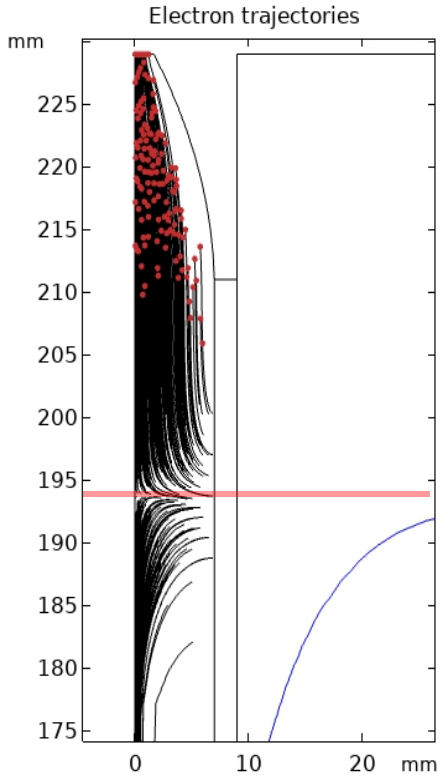
Particle counters:

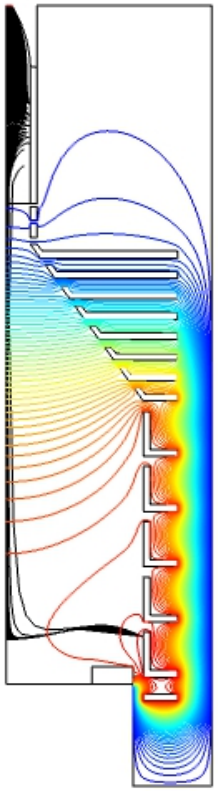


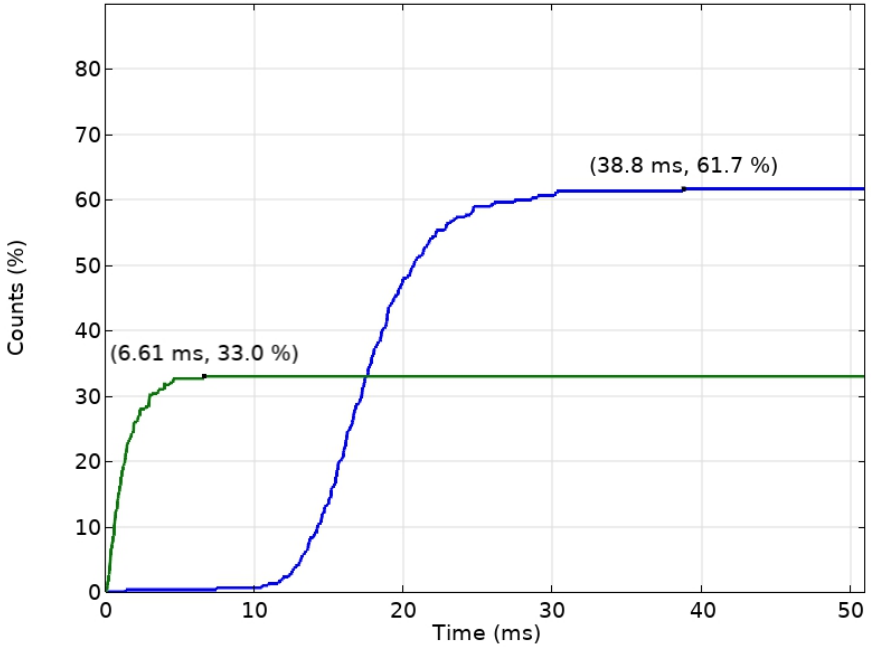
Dynamics of the electron cloud

Free electrons will be produced in the neutralization tube:

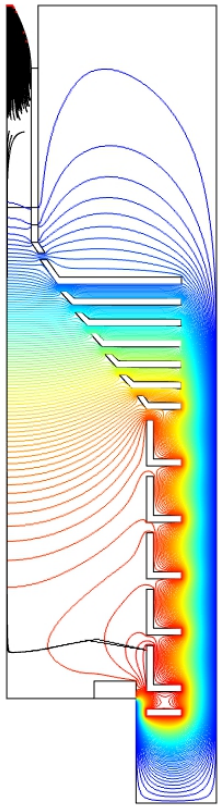
300 electrons released in Gaussian distribution at z = 195 mm in the tube of the optimized gas cell:







Release at z=205 mm:



Mesh size choosen for optimization