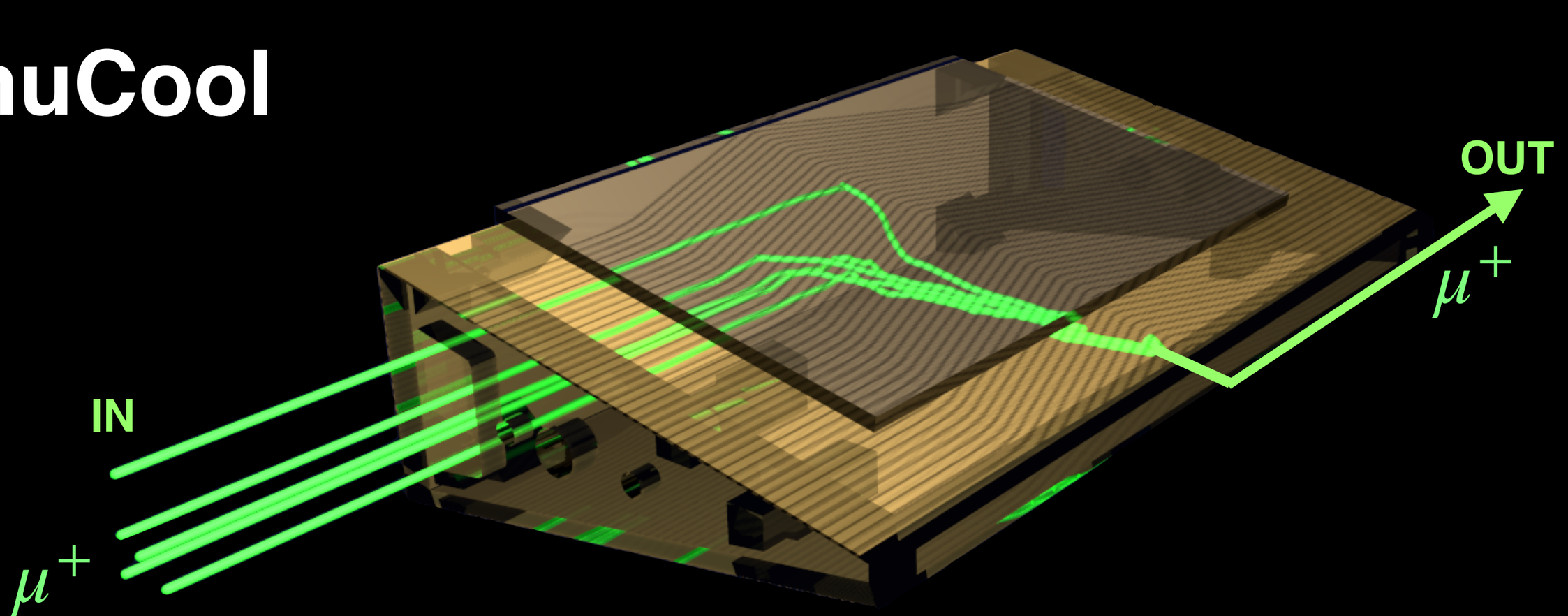
muCool



R. Iwai, R. Koch, G. Lospalluto, P. Mullan,
J. Peszka, M. Sakurai, I. Solovyev, D. Taqqu, T. Yan

Institute for Particle Physics and Astrophysics, ETH Zurich, Switzerland

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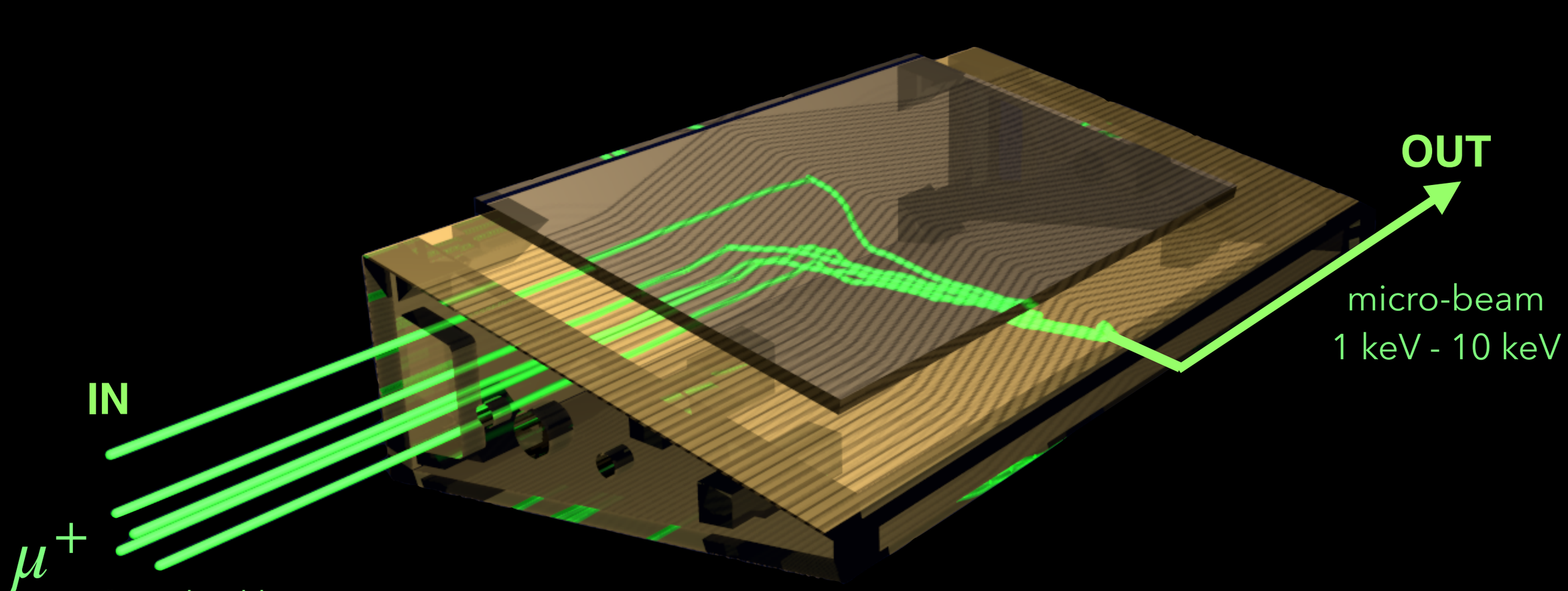
Paul Scherrer Institute, 5232 Villigen-PSI, Switzerland

* also at the ETH

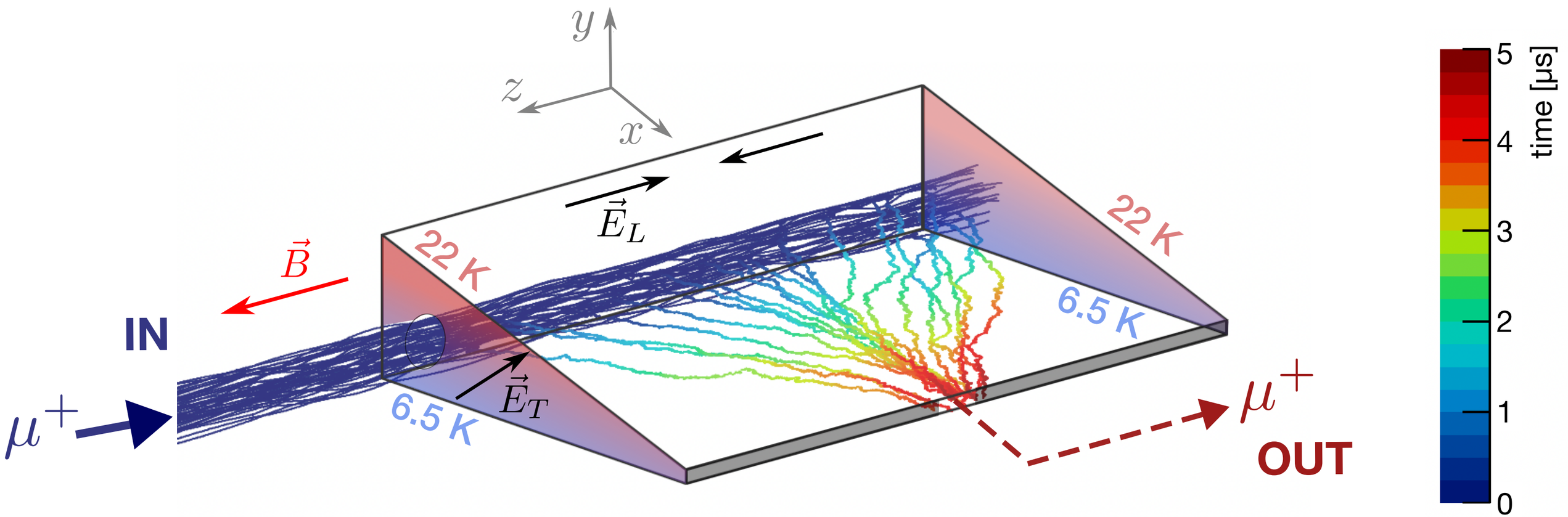
§ also at the INFN and university of Pisa



Goal

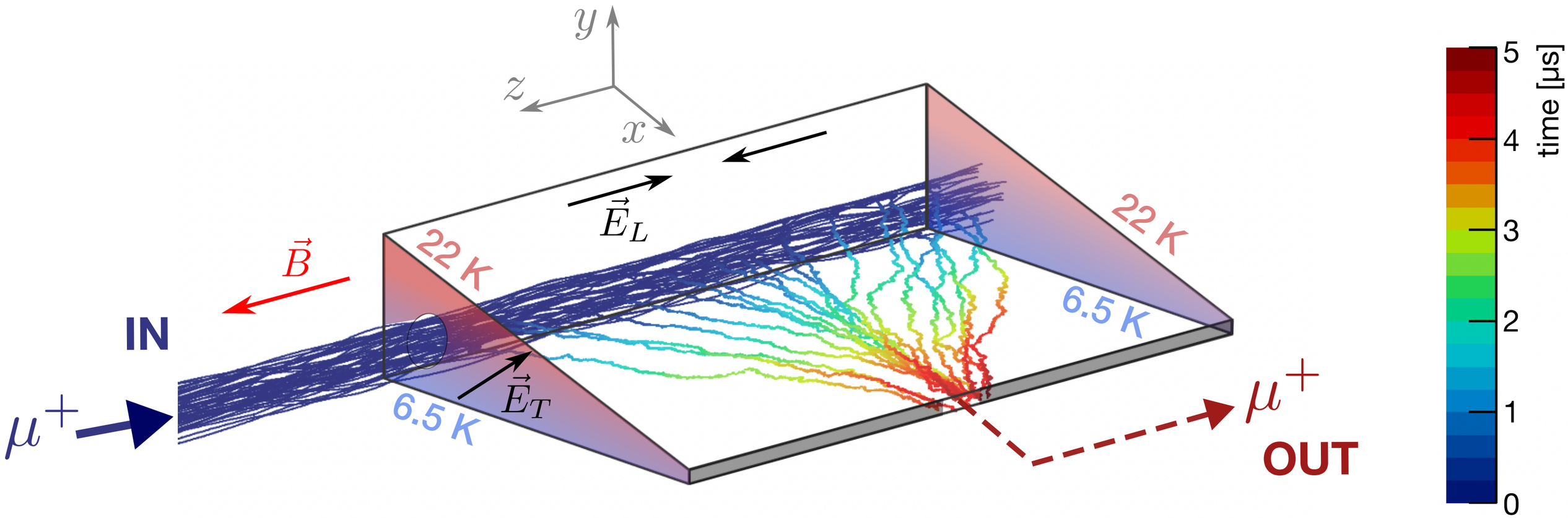
Produce a micro-beam:
decreasing by 10^8 - 10^9 the 6D phase space
in an He gas target with an efficiency of 10^{-4} - 10^{-5}

Muon compression



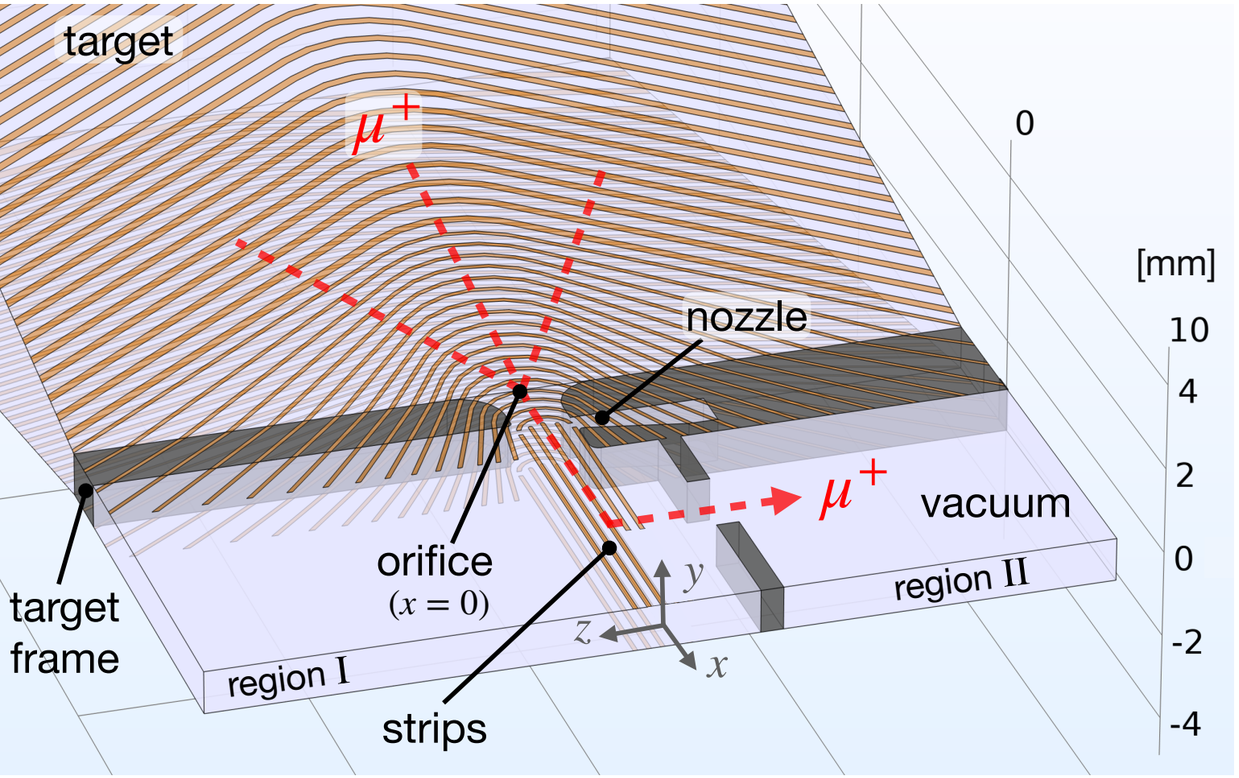
$$\vec{v}_D = \frac{\mu E}{1+\omega^2\tau_c^2}\left[\hat{E} + \omega\tau_c\left(\hat{E}\times\hat{B}\right) + \omega^2\tau_c^2(\hat{E}\cdot\hat{B})\hat{B}\right]$$

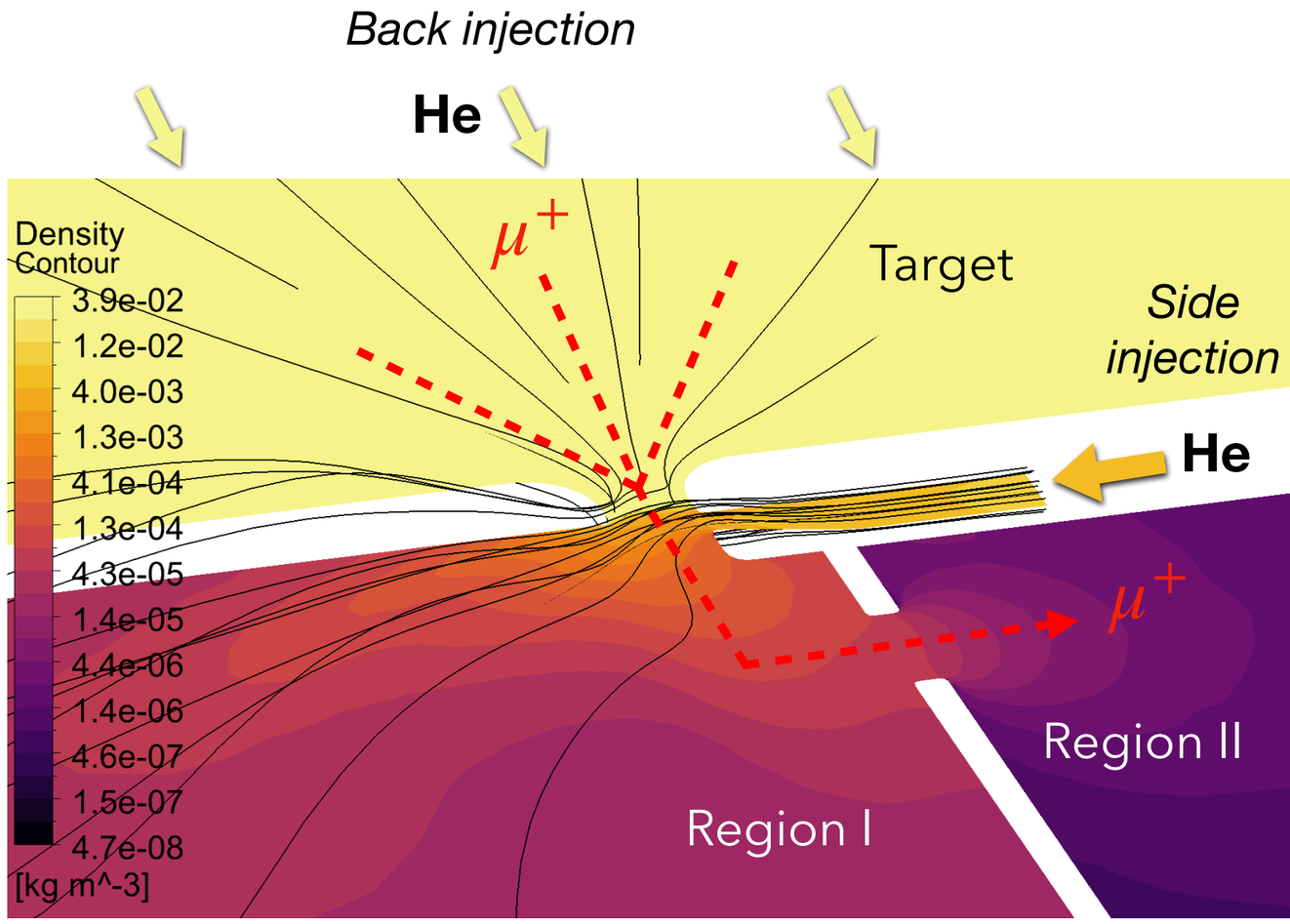
Muon compression



Efficient compression in target demonstrated

Next step: Extraction from the target

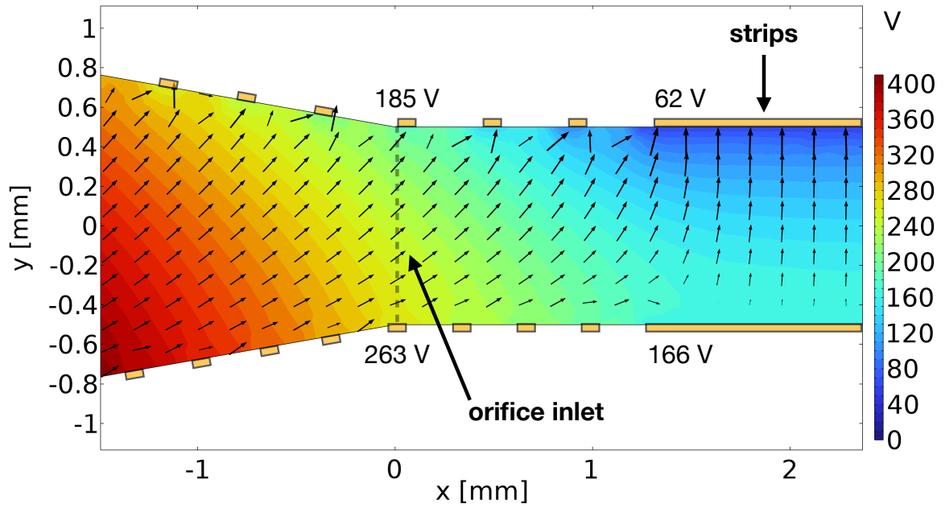


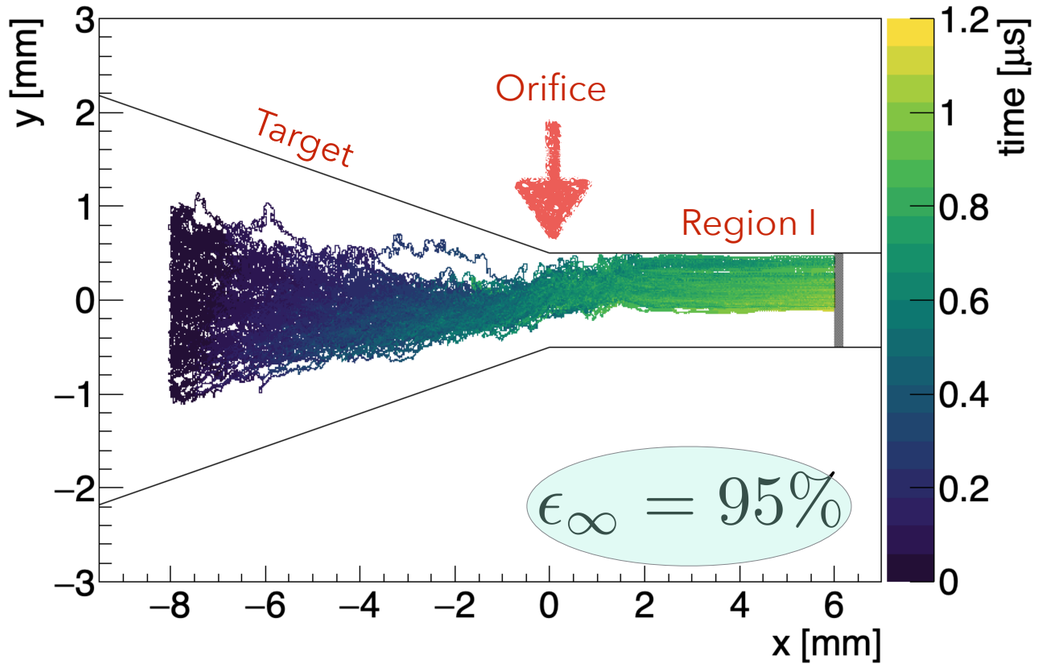


- ☑ Re-inject the He gas without disrupting the vertical density gradient
- ☑ Low He density in the re-acceleration region
- ☑ Matching between gas density and E-field

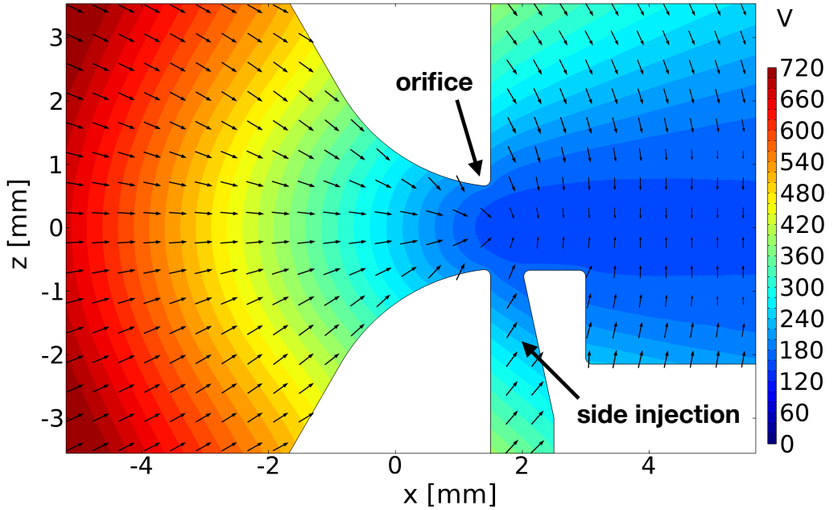
Electric field and muon trajectories at the orifice

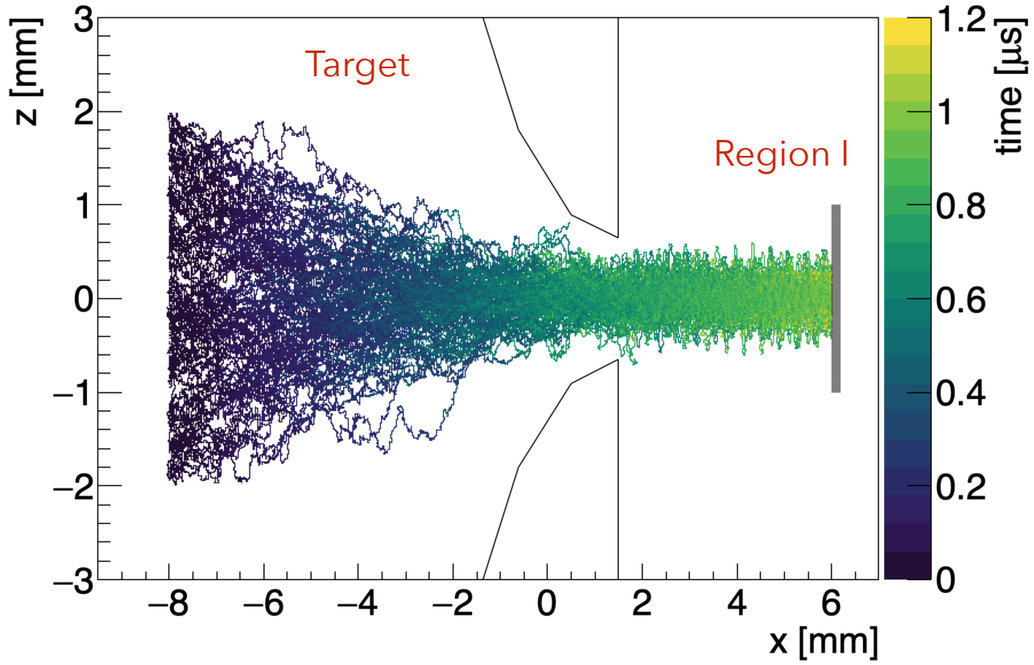
Side-view (transverse)



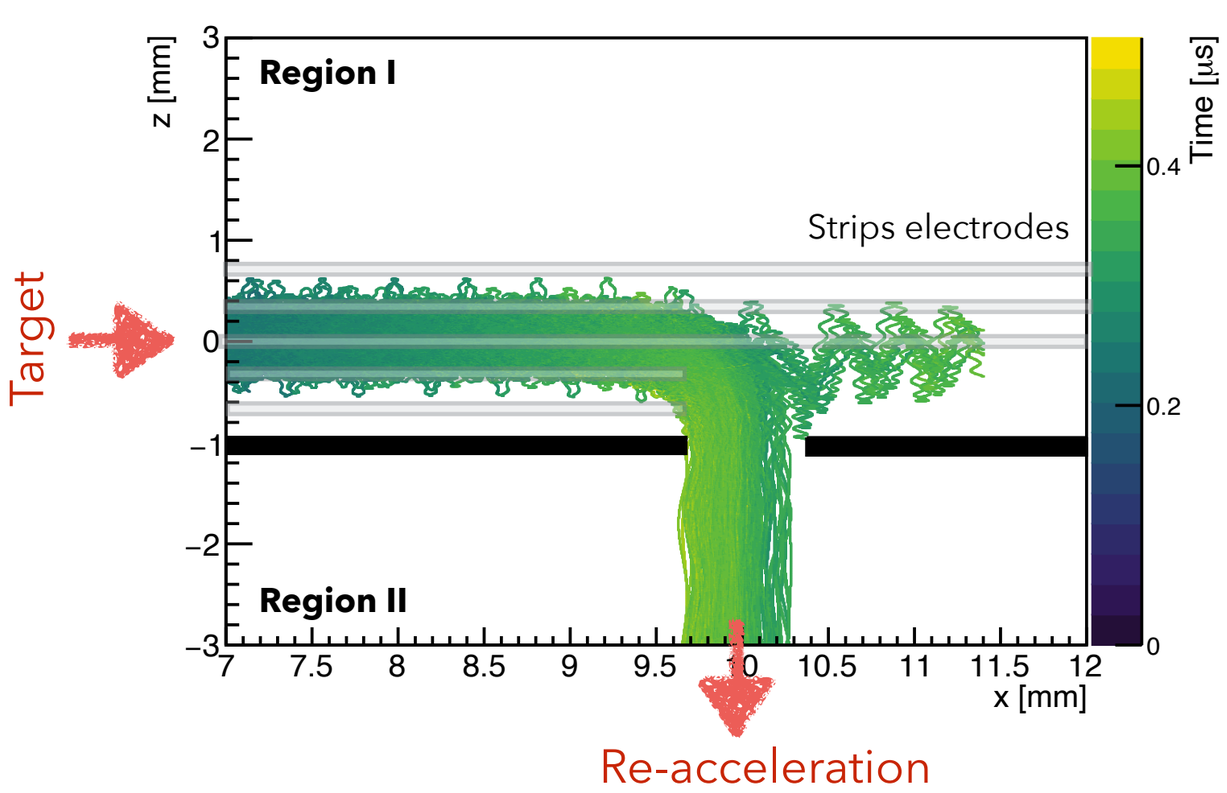


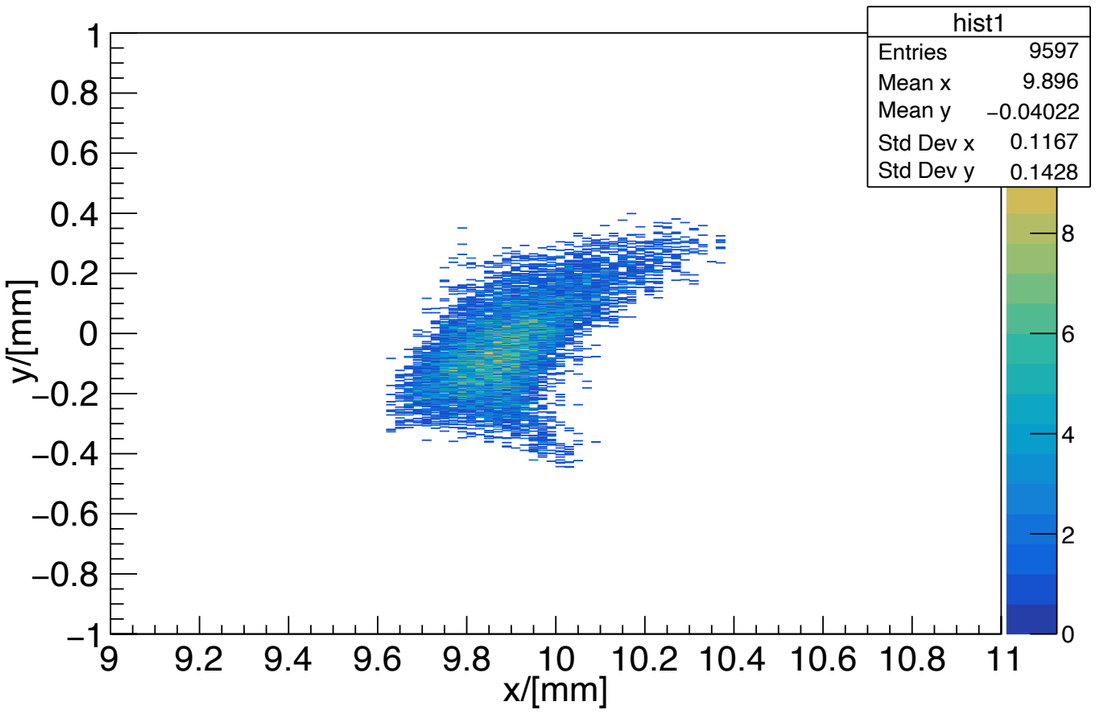
Top-view (longitudinal)





Coupling into re-acceleration region & beam quality





☑ Efficient coupling

$\epsilon_\infty = 96\,\%$

$\epsilon_\infty = 80\,\%$ (eliminating energy tail)

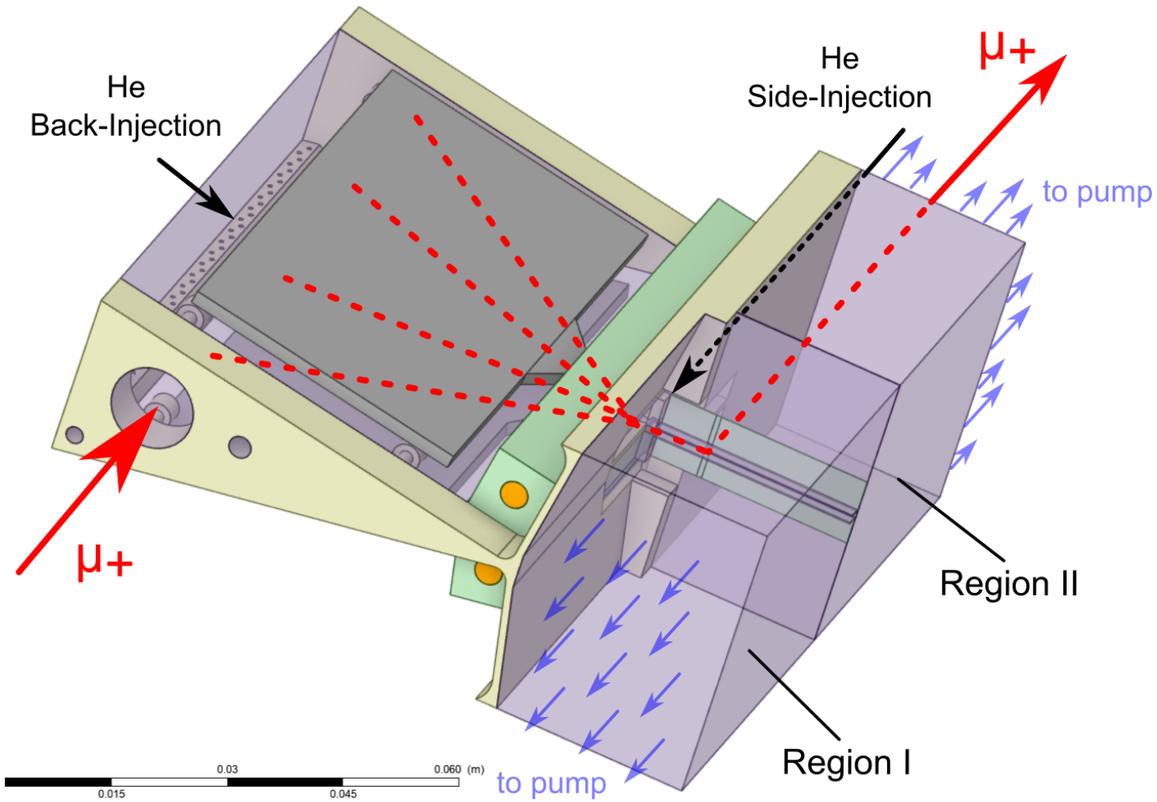
☑ Excellent beam quality after bending

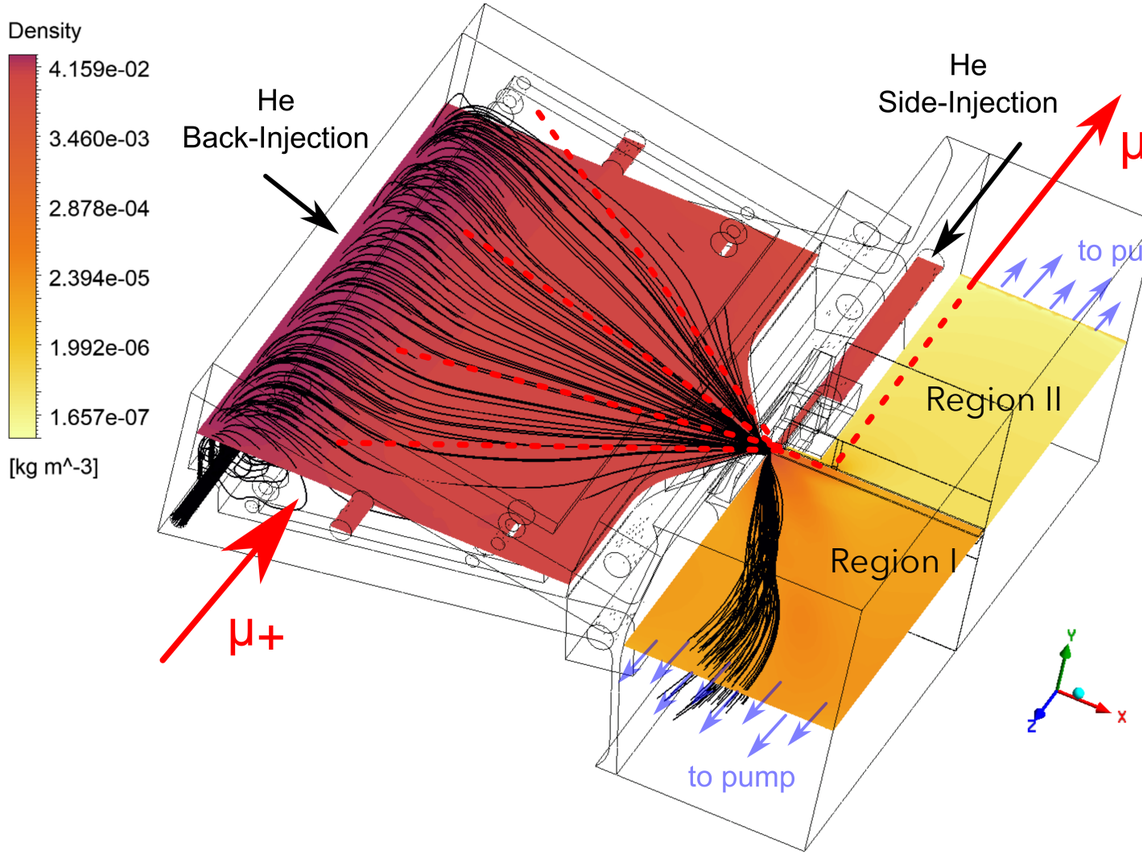
$\sigma_x = 0.12$ mm

$\sigma_y = 0.14$ mm (in 5T B-field, $E = 1$ keV)

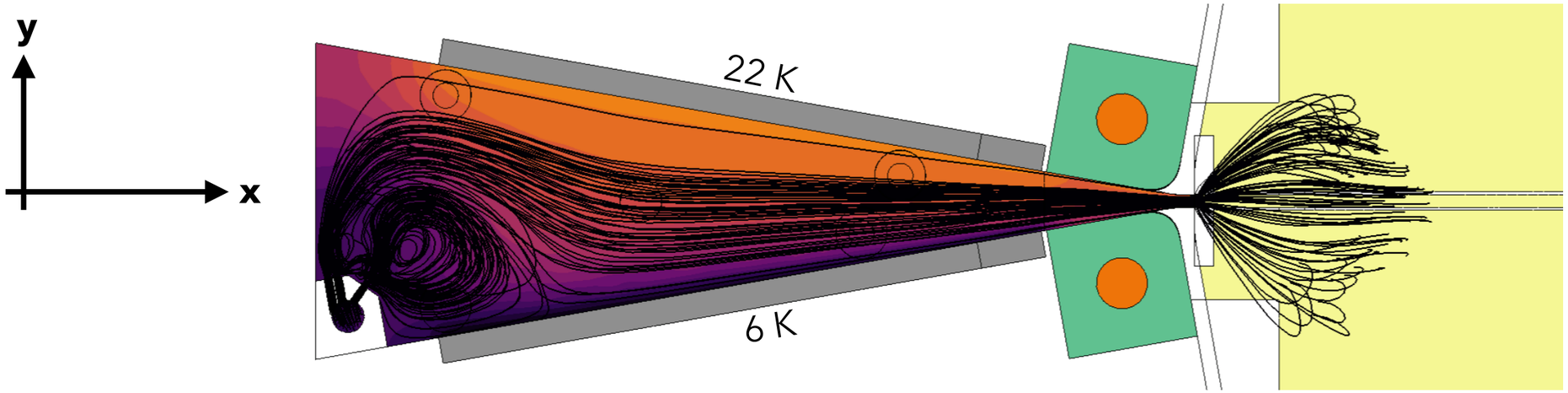
$\sigma_E = 25$ eV

He gas injection scheme

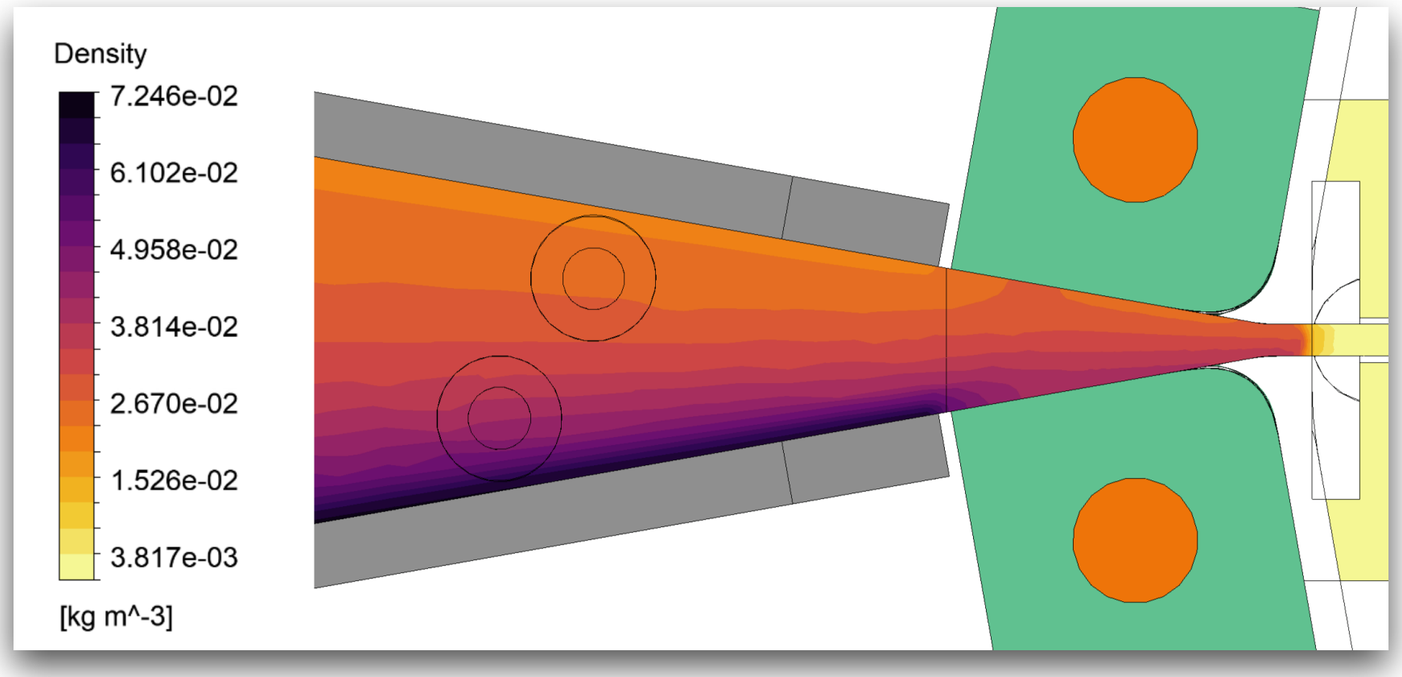




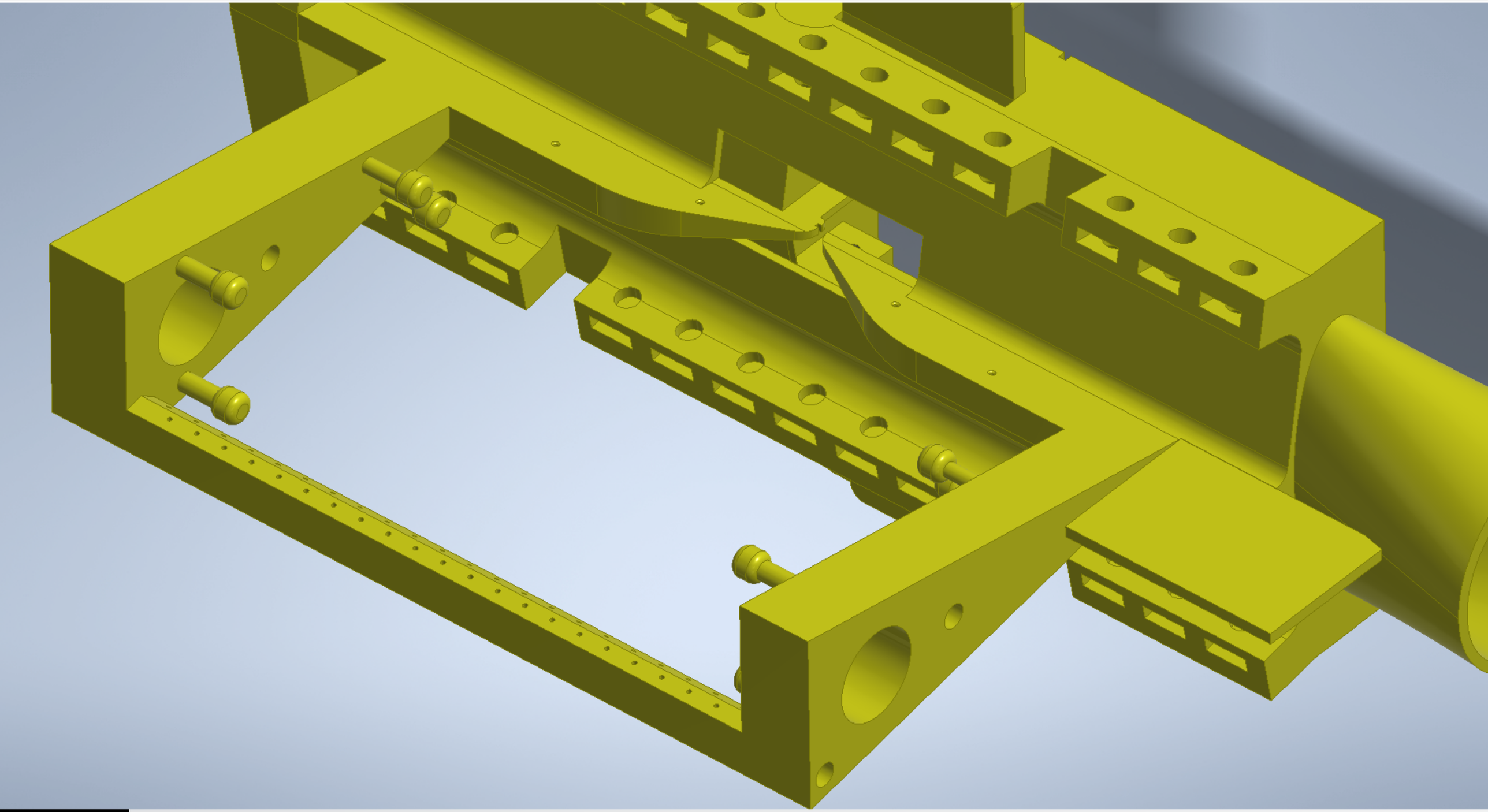
Density distribution and streamlines in transverse plane



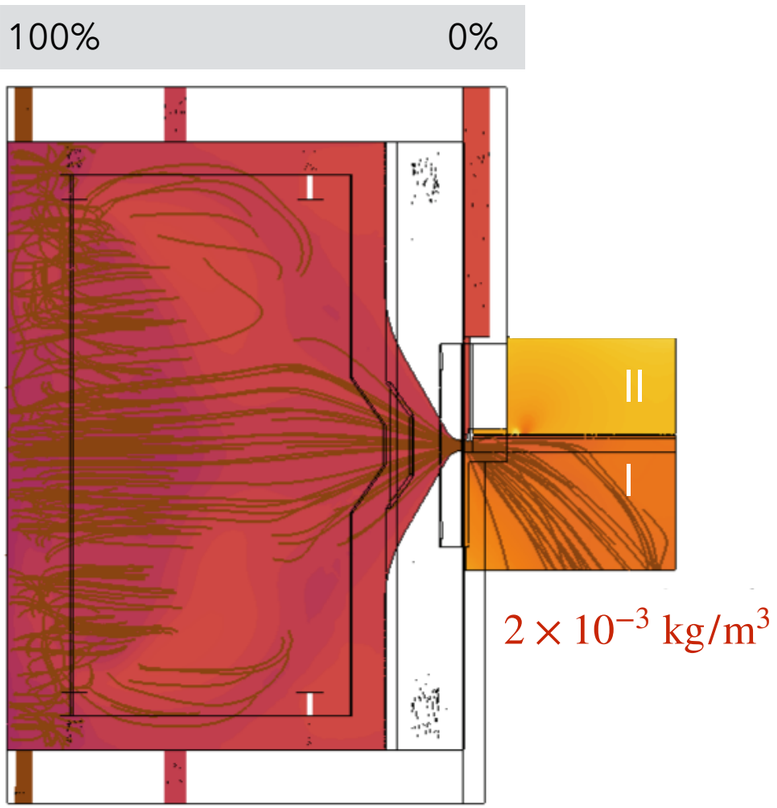
Zoom in orifice region

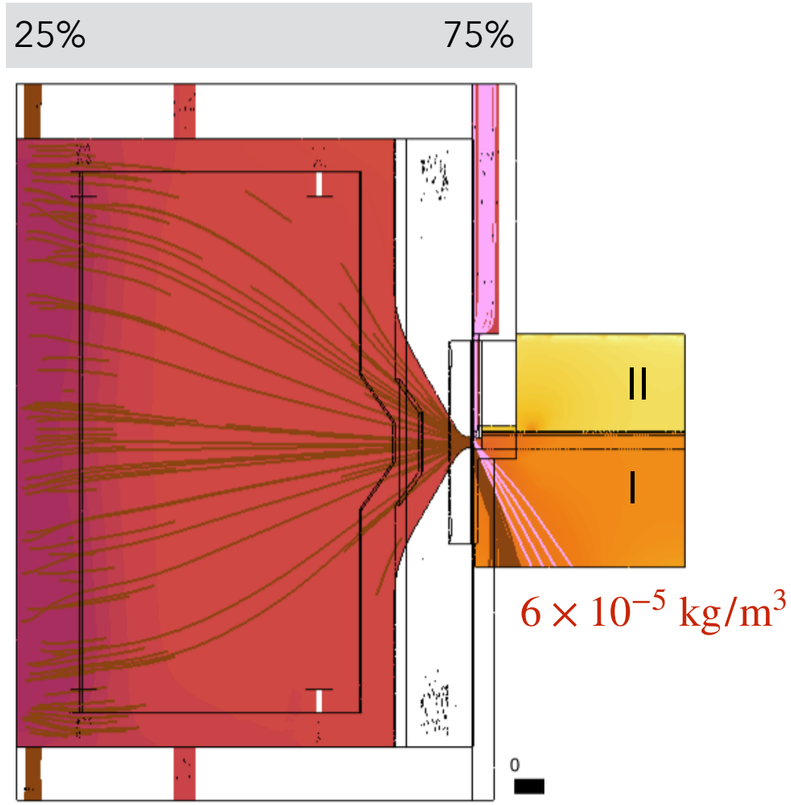


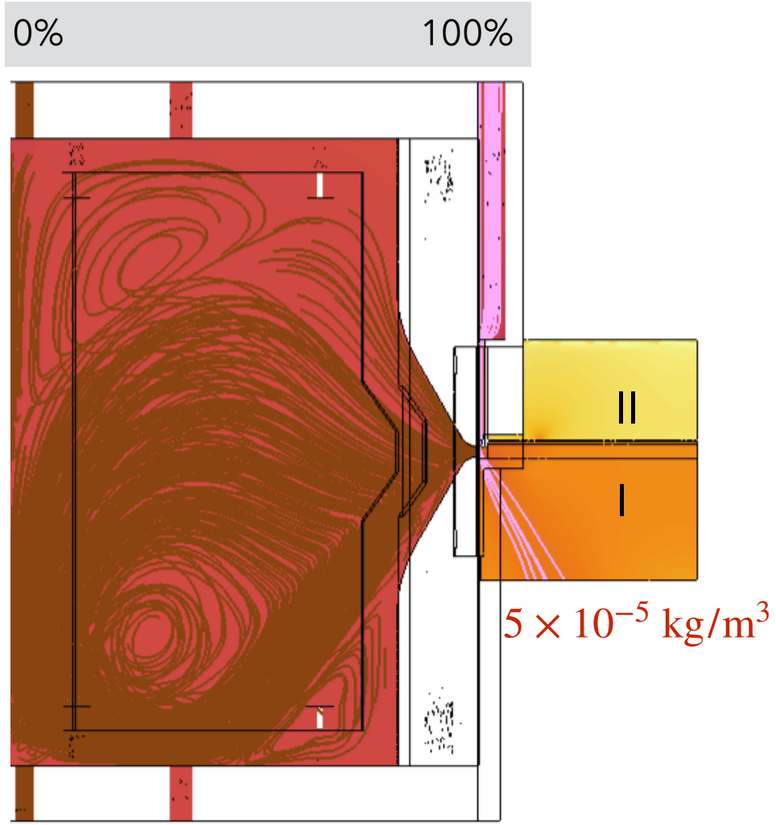
Target frame



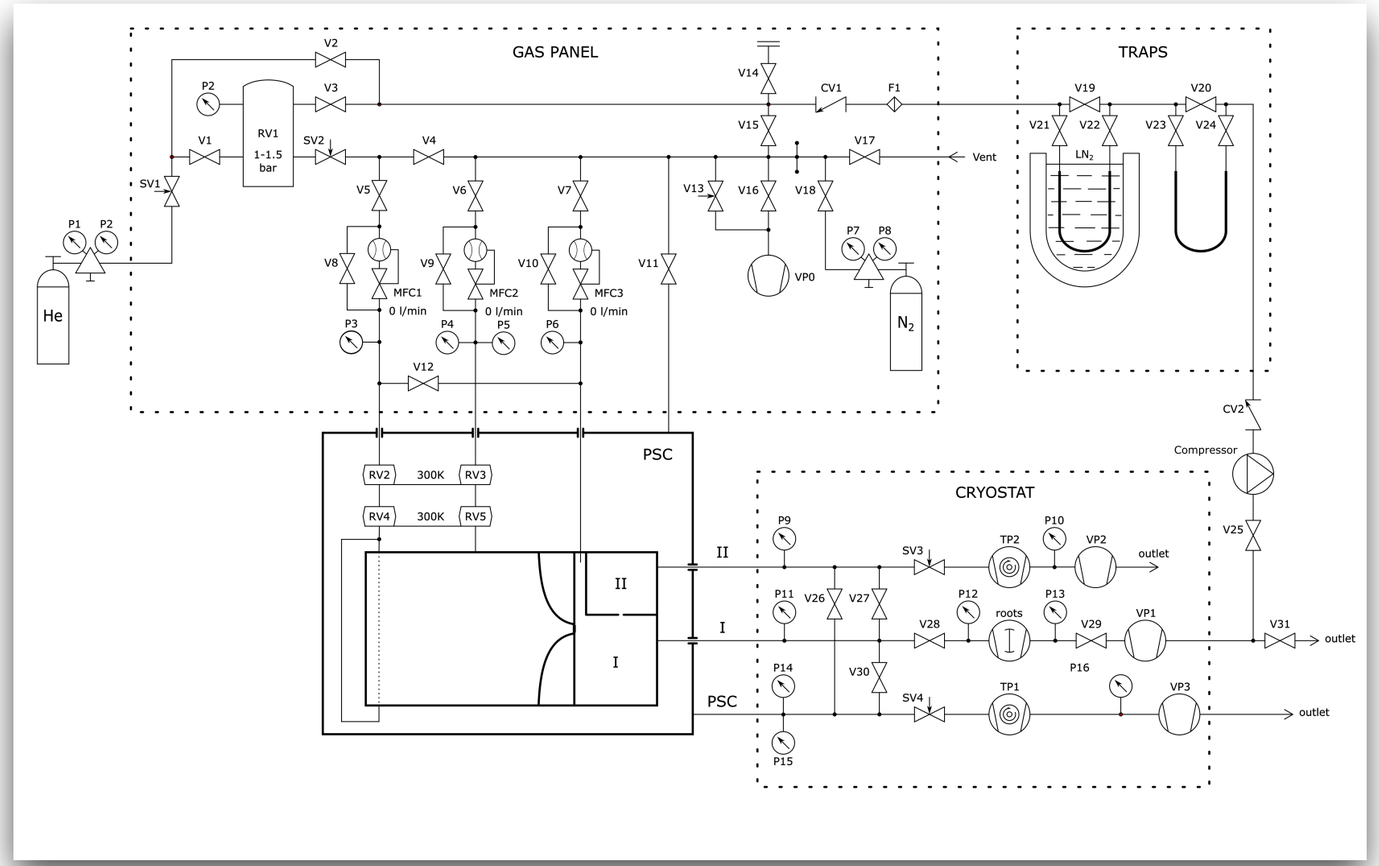
Why complicating our lives with back- and side-injections?

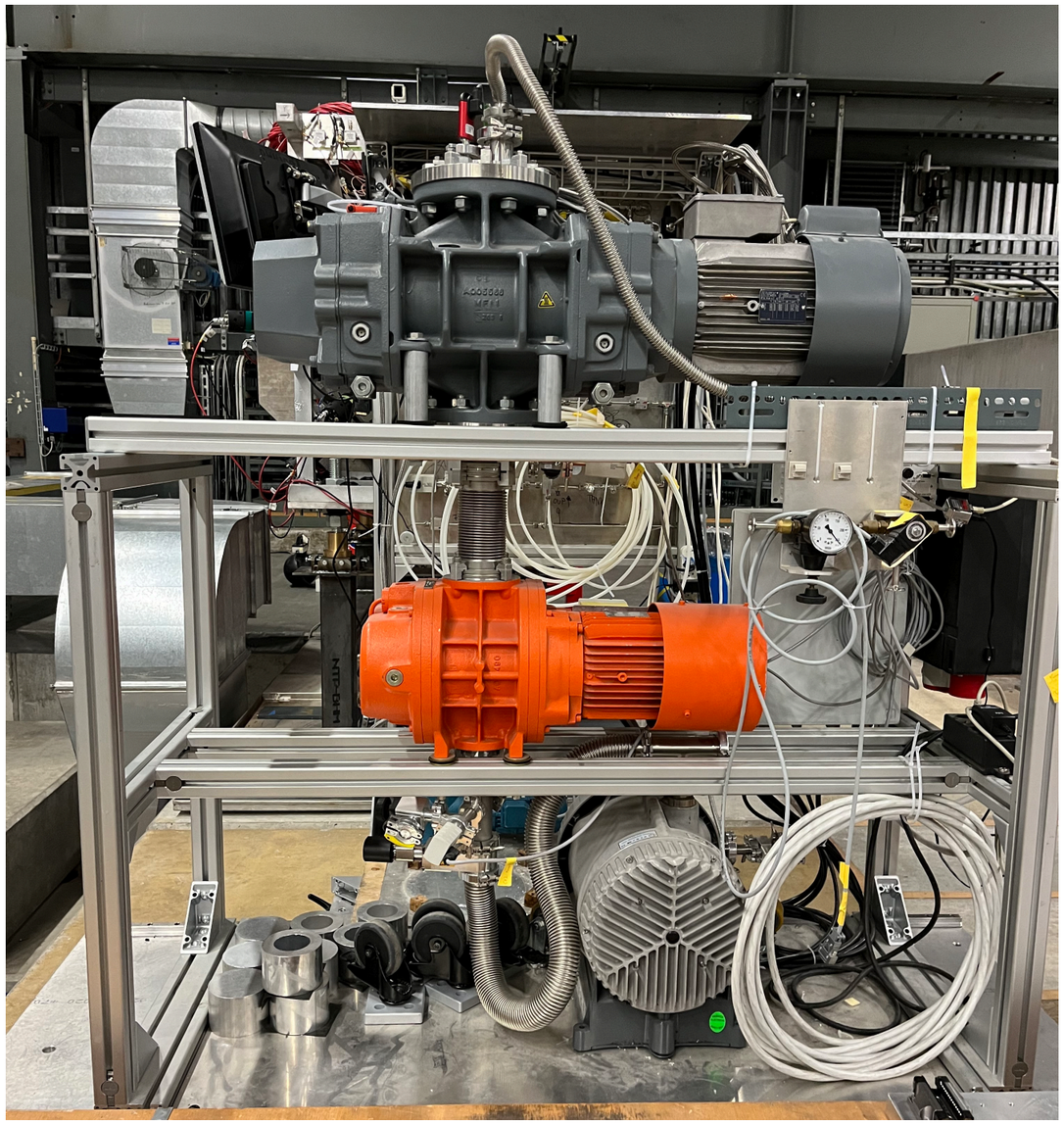






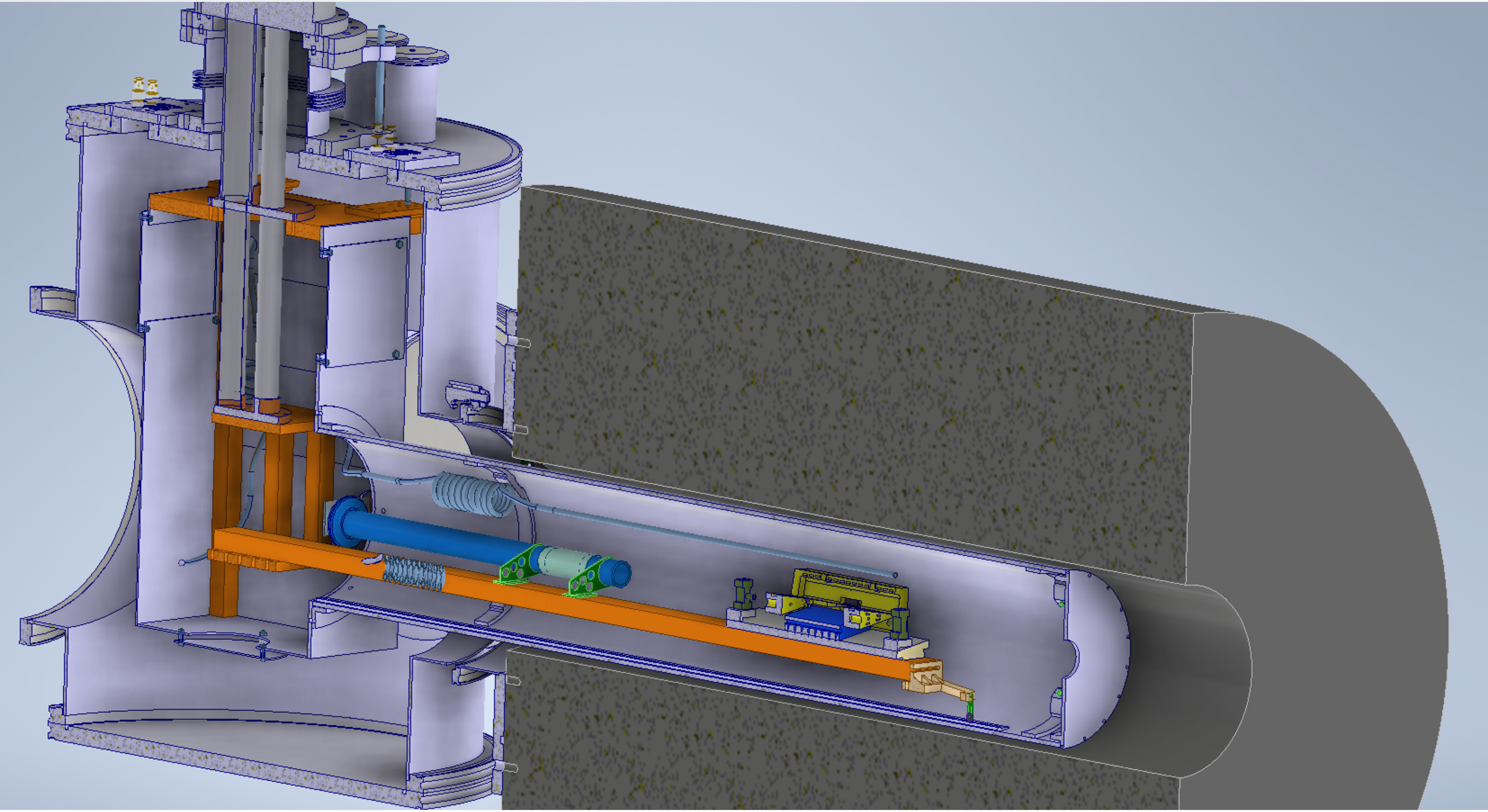
Started to develop the gas system hardware



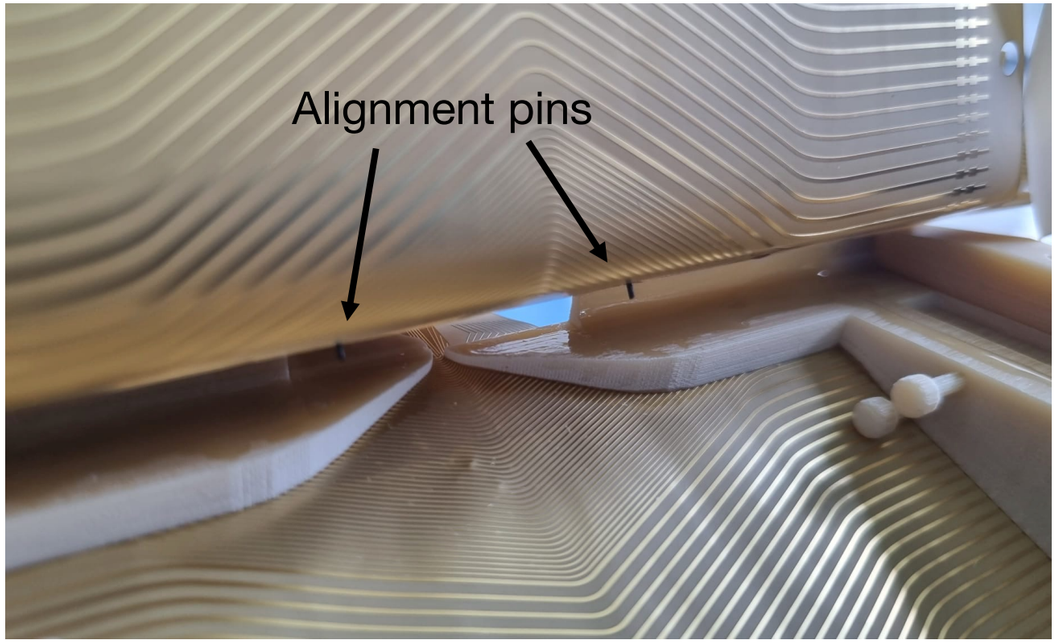


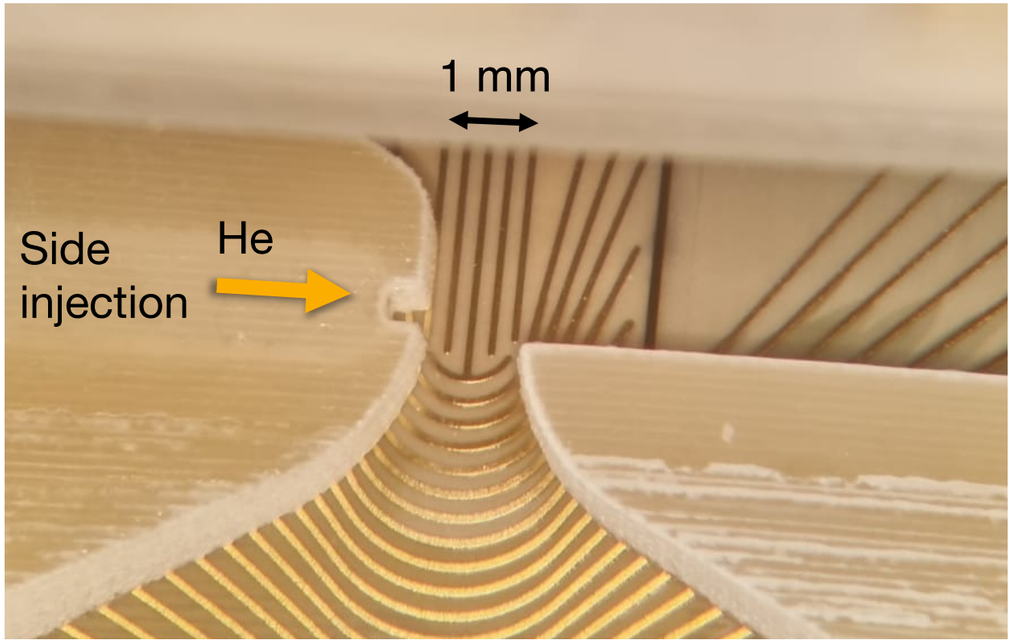
- [x] Conceptional design
- [x] Calibration method
- [x] Roots pump for region I
- [ ] Construction of gas system

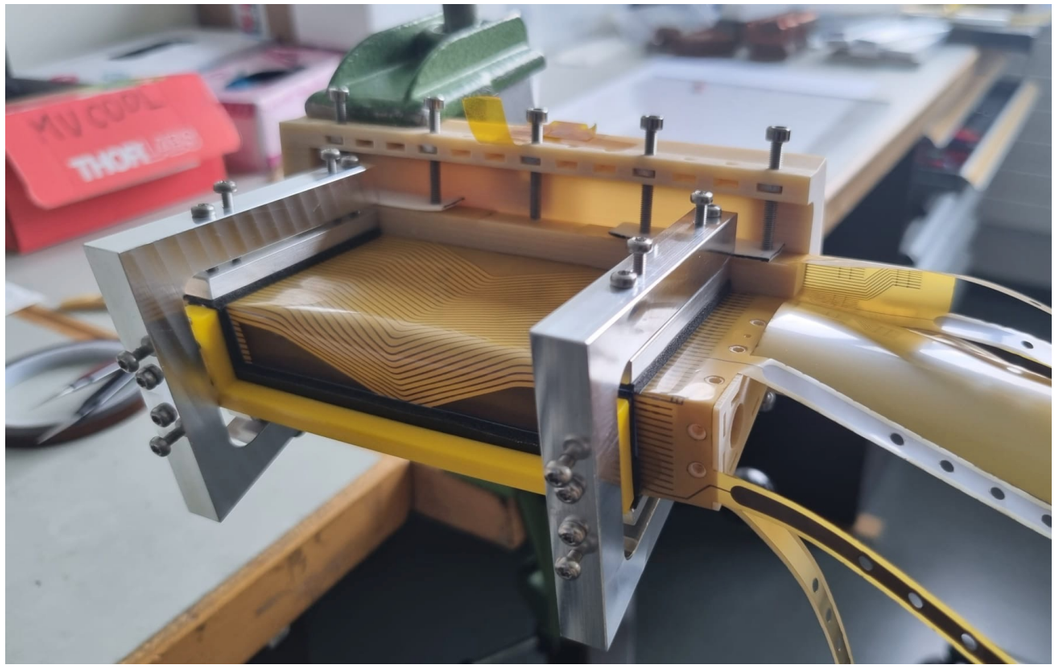
Conceptional drawing of the new cryogenic system

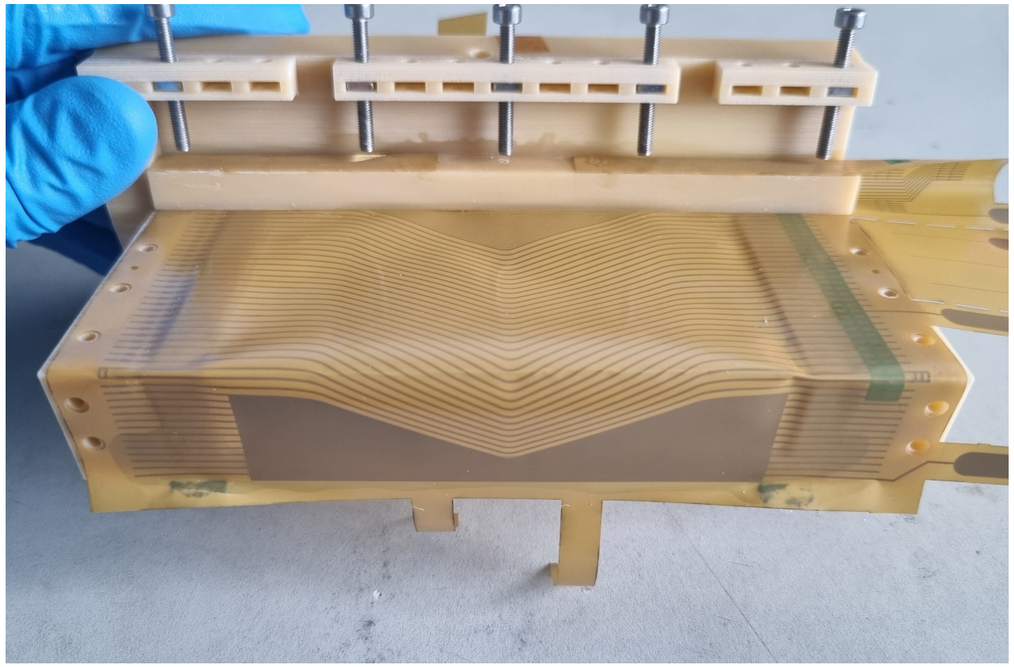


Pictures of the target during the gluing process



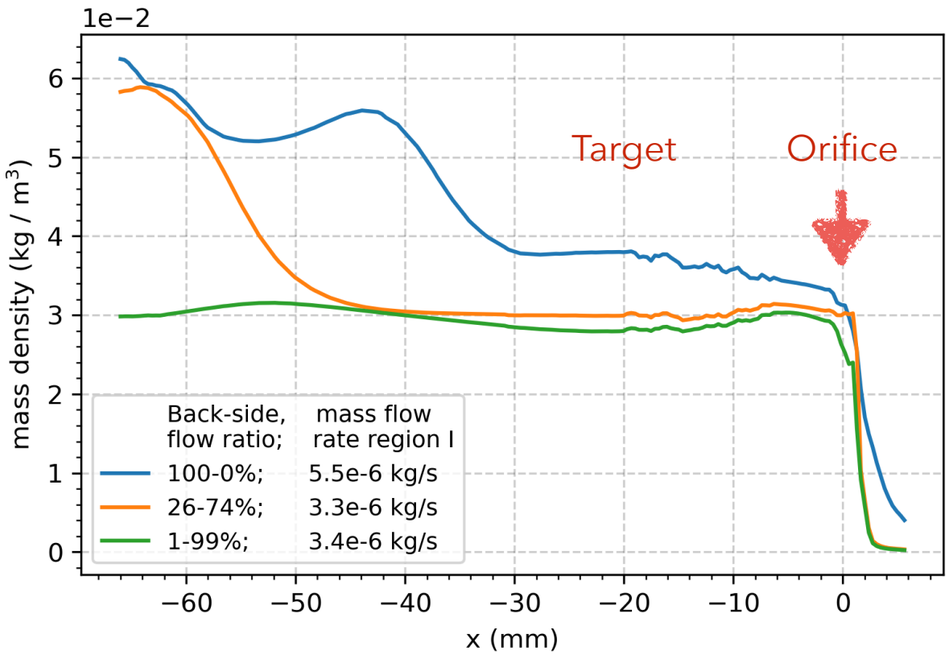






Robustness: back-to-side injection fractions

He density

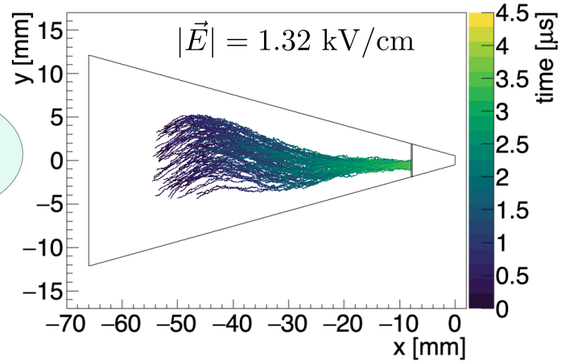


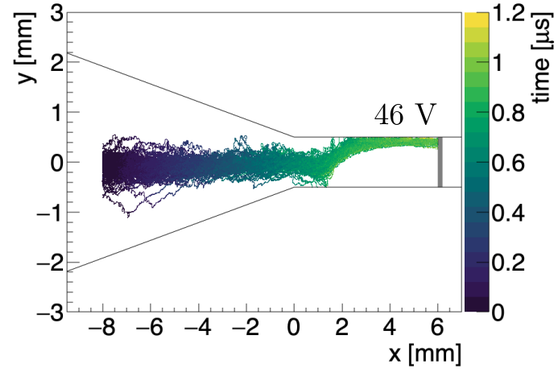
Requires tuning two parameters only

Target

Orifice

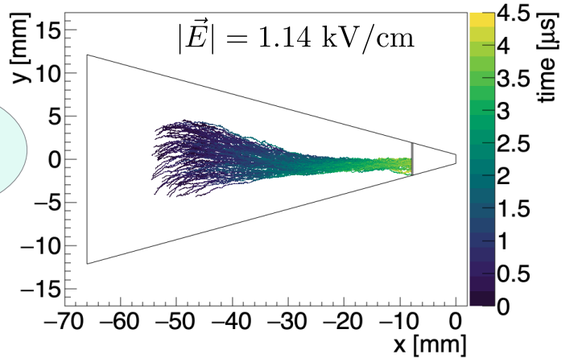
100%
0%

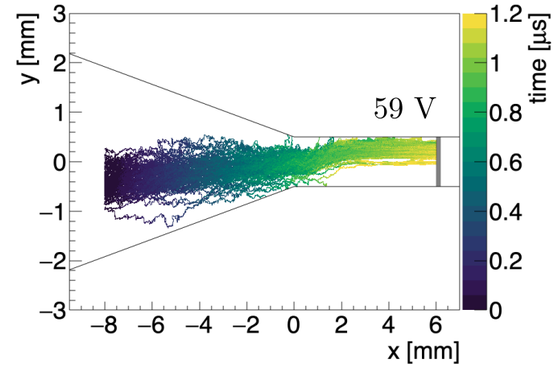




$\epsilon_\infty = 20\%$
$\epsilon_\tau = 2.8\%$

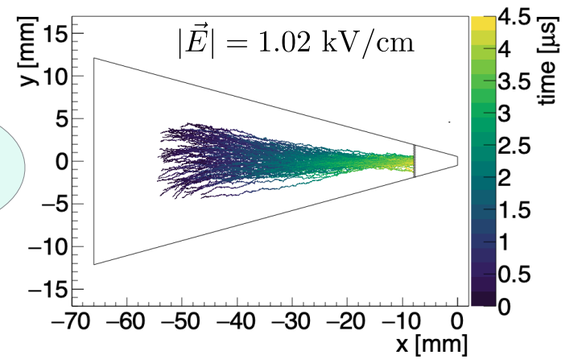
26%
74%

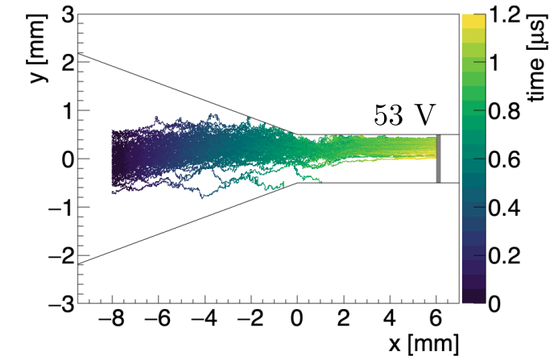




$\epsilon_\infty = 85\%$
$\epsilon_\tau = 9.0\%$

1%
99%

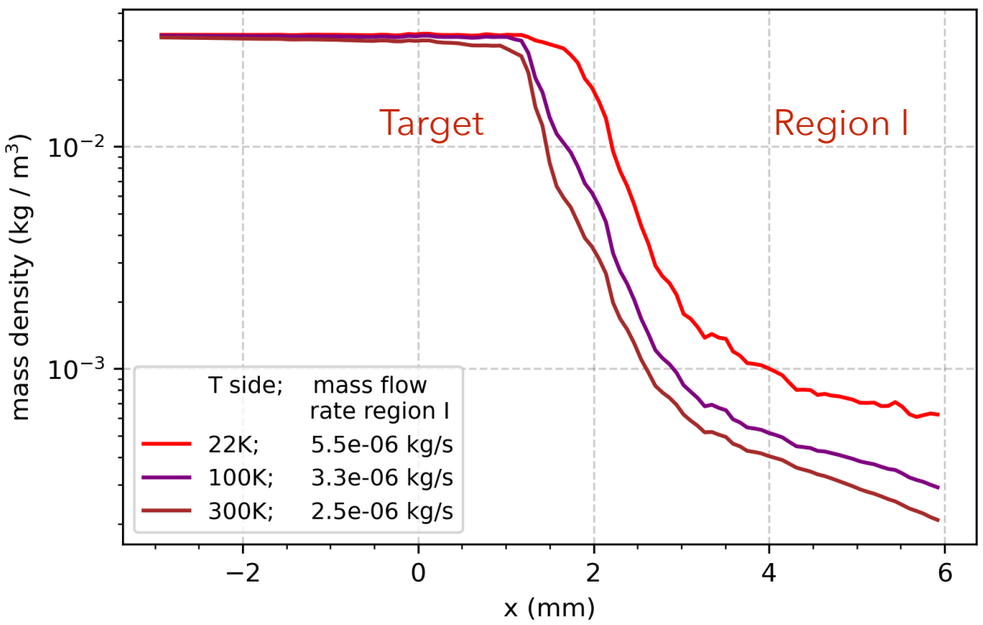




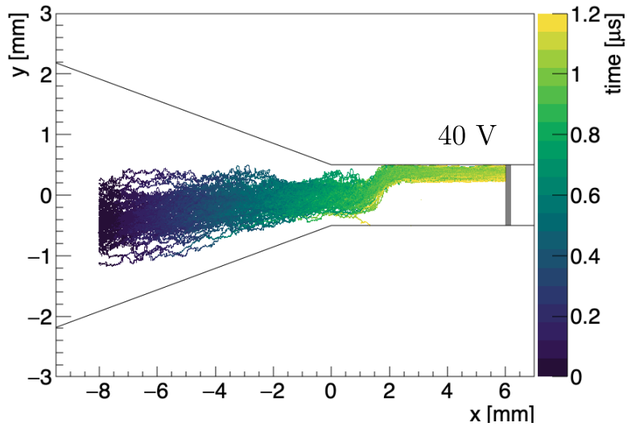
$\epsilon_\infty = 64\%$
$\epsilon_\tau = 6.3\%$

Robustness: side-injection temperature

He density

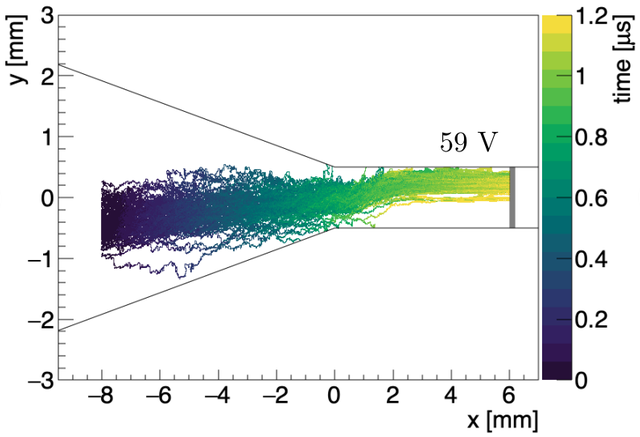


22 K



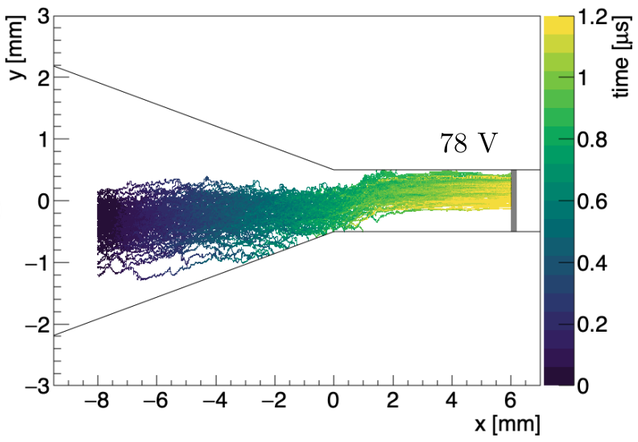
$\epsilon_\infty = 52\%$
$\epsilon_\tau = 5.6\%$

100 K



$\epsilon_\infty = 85\%$
$\epsilon_\tau = 9.0\%$

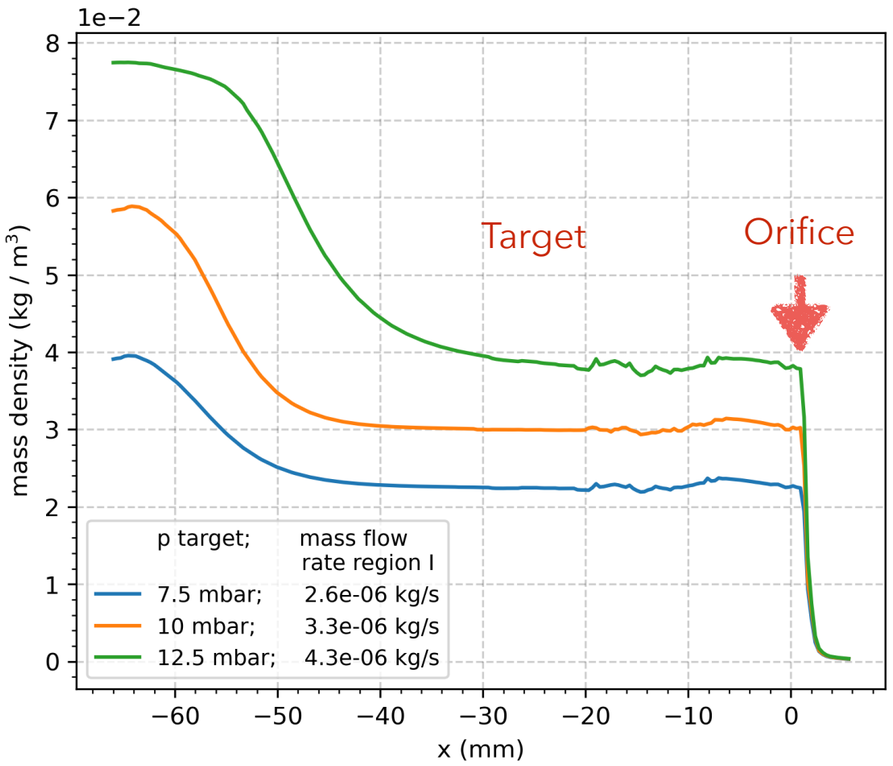
300 K



$\epsilon_\infty = 67\%$
$\epsilon_\tau = 7.0\%$

Robustness: target pressures

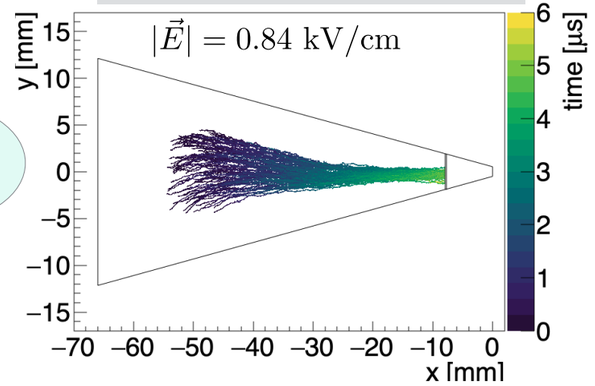
He density

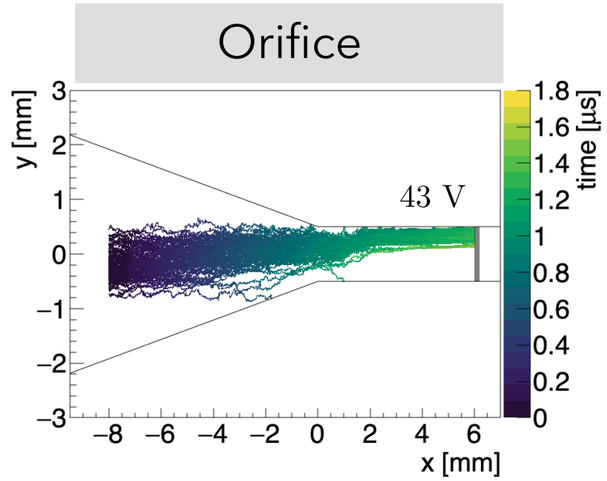


Target

Orifice

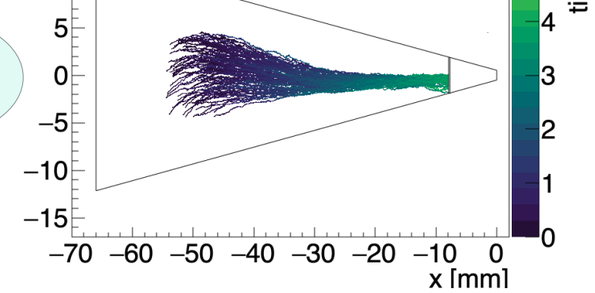
7.5 mbar

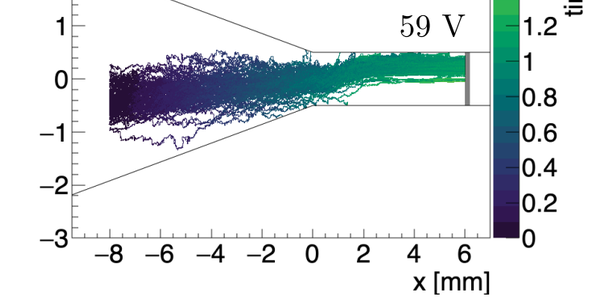




$\epsilon_\infty = 86\%$
$\epsilon_\tau = 5.6\%$

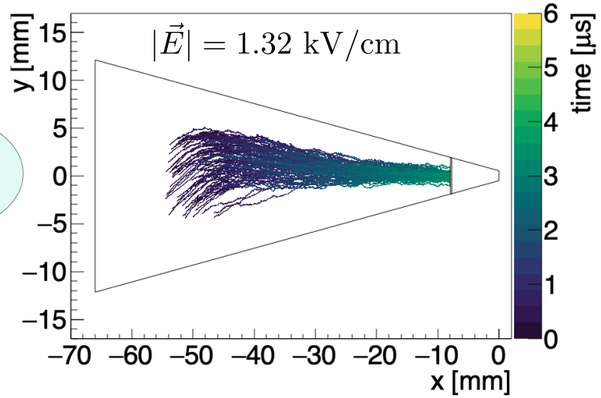
10 mbar

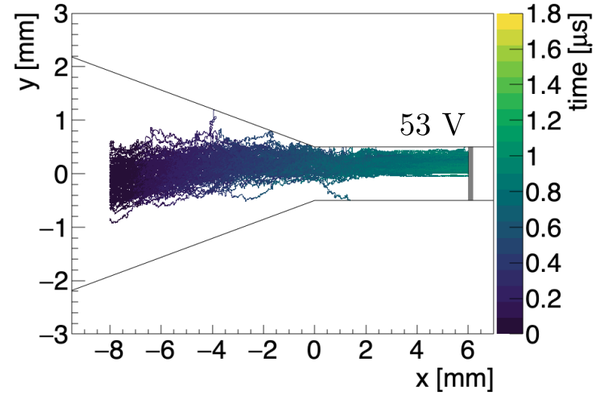




$\epsilon_\infty = 85\%$
$\epsilon_\tau = 9.0\%$

12.5 mbar

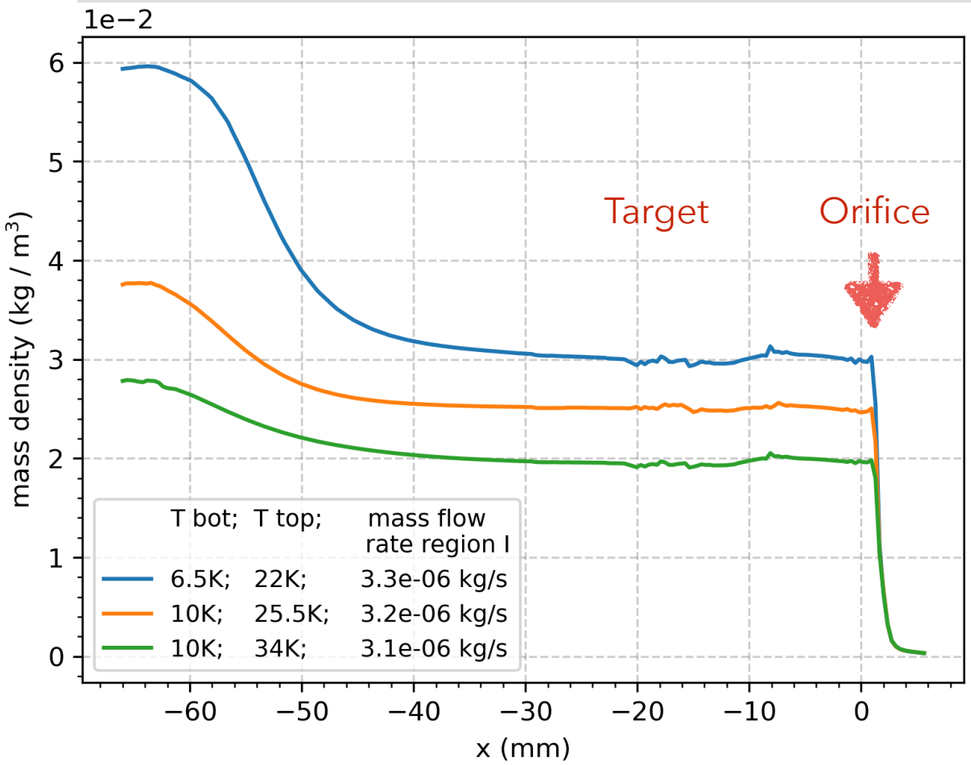




$\epsilon_\infty = 67\%$
$\epsilon_\tau = 10.0\%$

Robustness: top-bottom sapphire temperatures

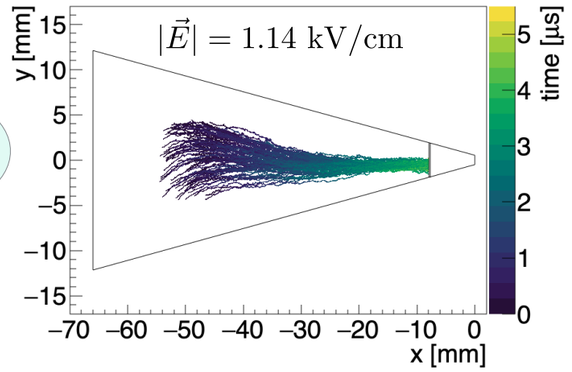
He density

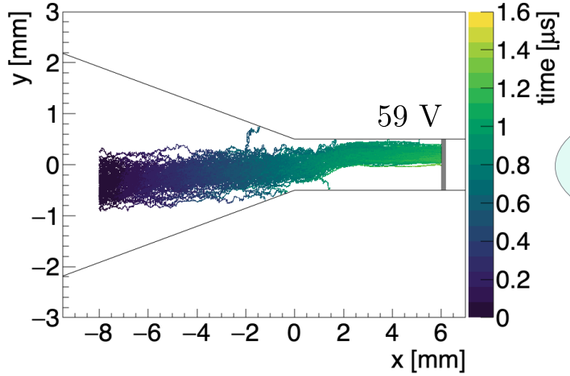


Target

Orifice

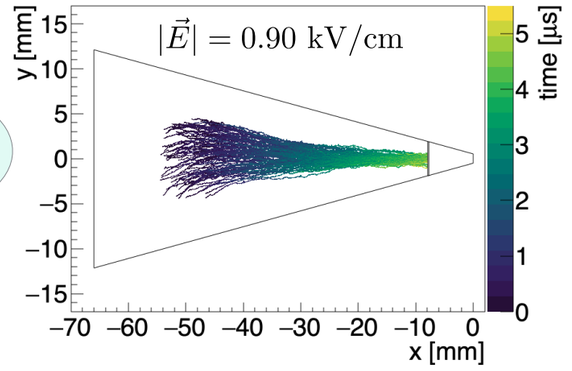
22 K
6.5 K

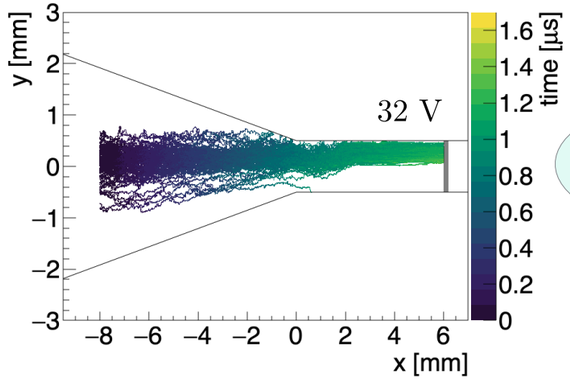




$\epsilon_\infty = 80\%$
$\epsilon_\tau = 8.5\%$

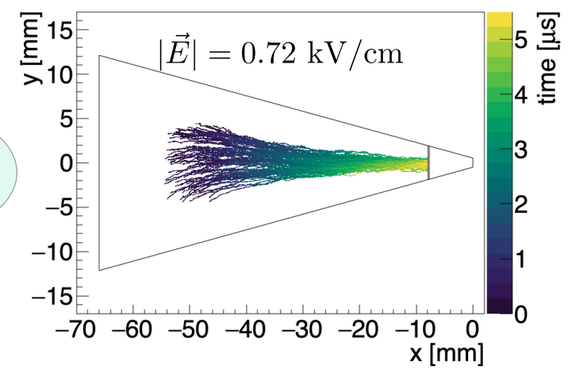
25.5 K
10 K

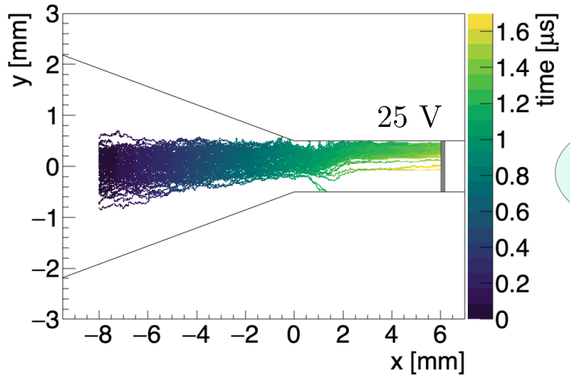




$\epsilon_\infty = 73\%$
$\epsilon_\tau = 5.8\%$

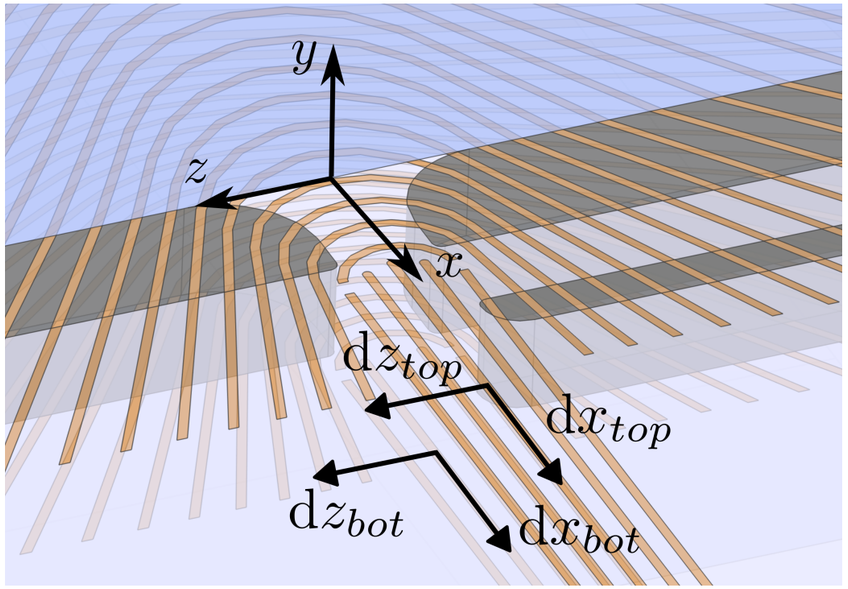
34 K
10 K



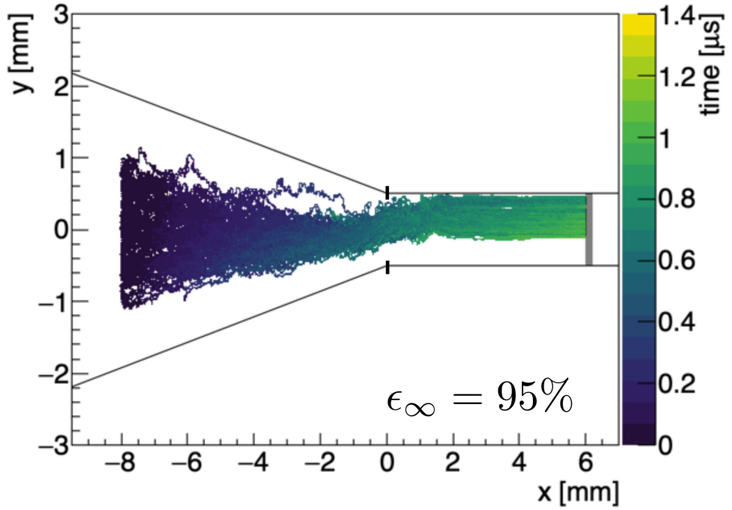


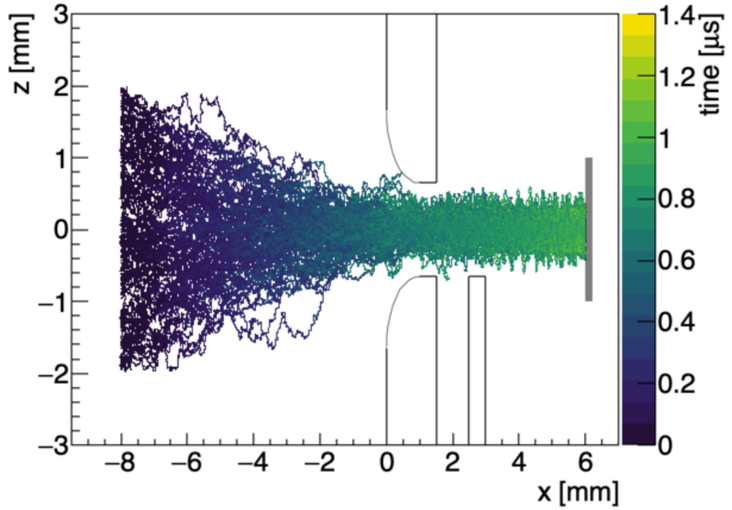
$\epsilon_\infty = 76\%$
$\epsilon_\tau = 5.2\%$

Robustness: alignment of Kapton foils

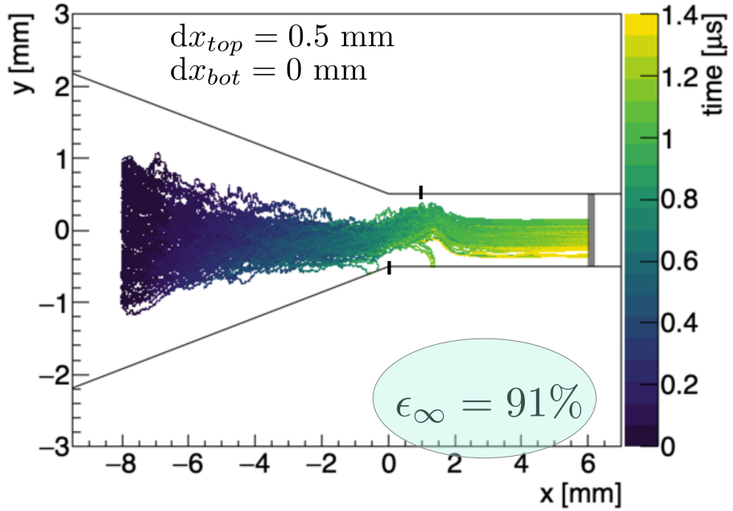


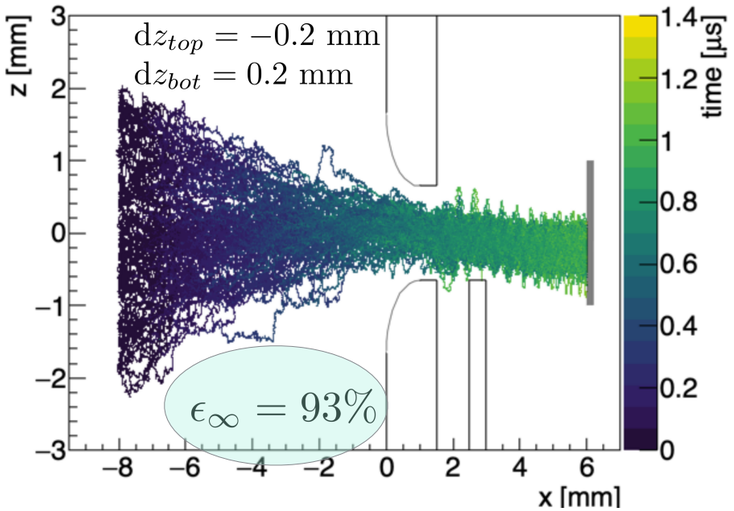
Perfect alignment





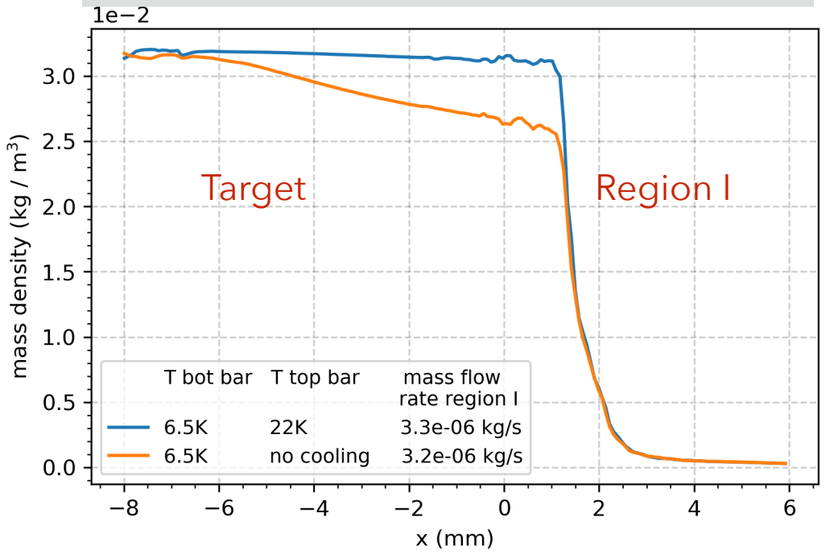
Misaligned





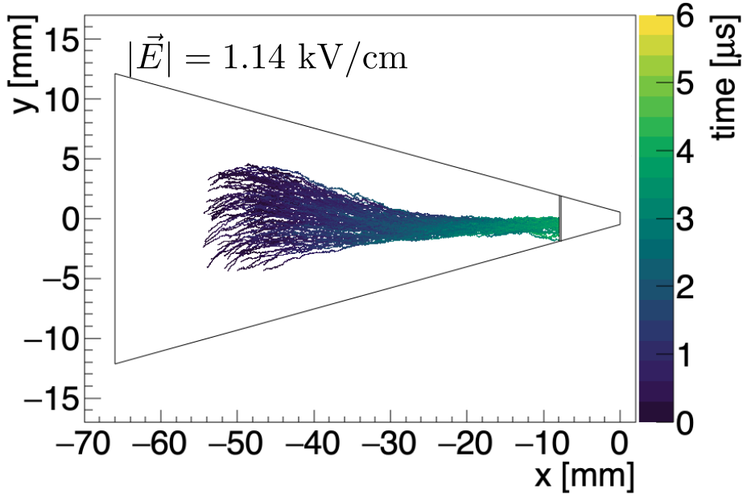
Robustness: Temperatures of top/bottom bars

He density

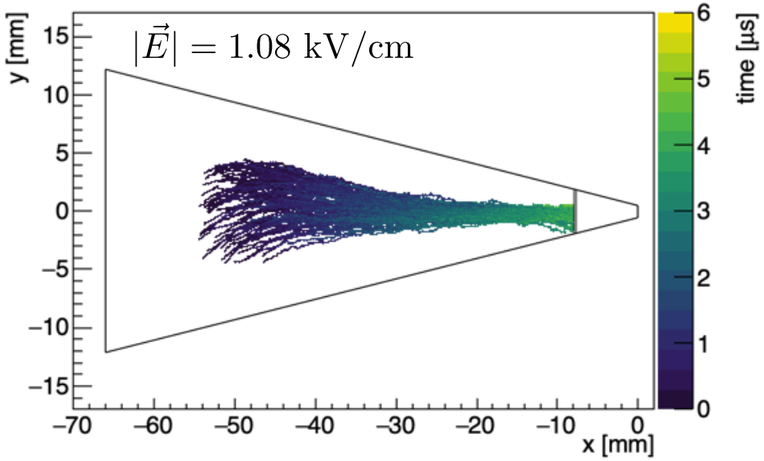


Target

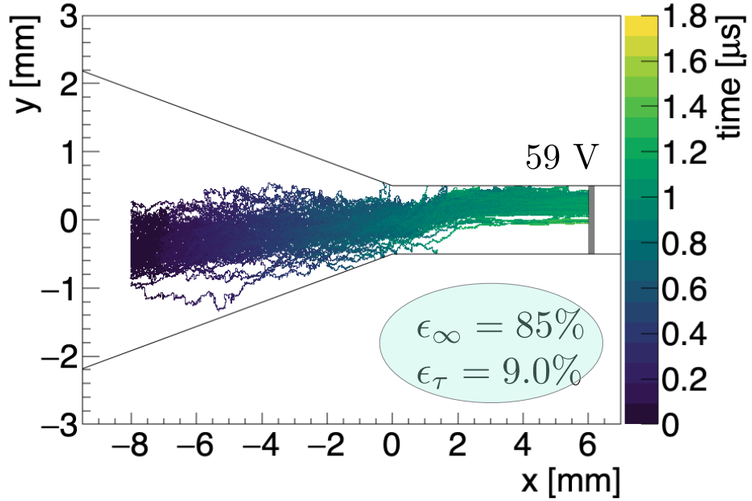
Cooling top and bottom bars

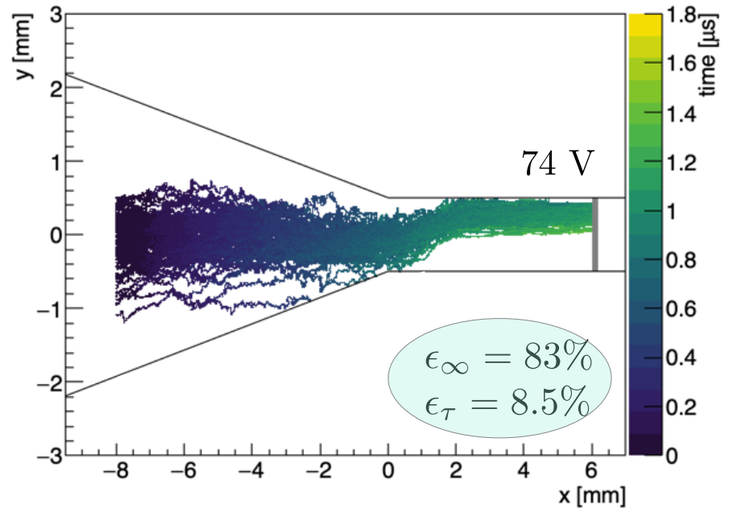


Cooling bottom bar only



Orifice





Status

- ☑ Robust extraction scheme
- ☑ Target mechanical model
- ☑ Target gluing procedure
- ☑ Target tight at cryogenic temperatures
- ☑ Pump system for evacuating the Region I
- ☑ Preliminary HV test with simplified target
- ☑ Gas scheme and cryostat concept

2024

- ☐ Realize complete target mechanics and test it under gas flow
- ☐ Electrical stability of full target with 18 independent electrodes
- ☐ Patch charges loading effects

- ☐ Design and construct vacuum chamber, cryostat, gas system, target region
- ☐ New 2.5W (@4K) pulse tube

- ☐ Design and construct positron detectors and entrance counter

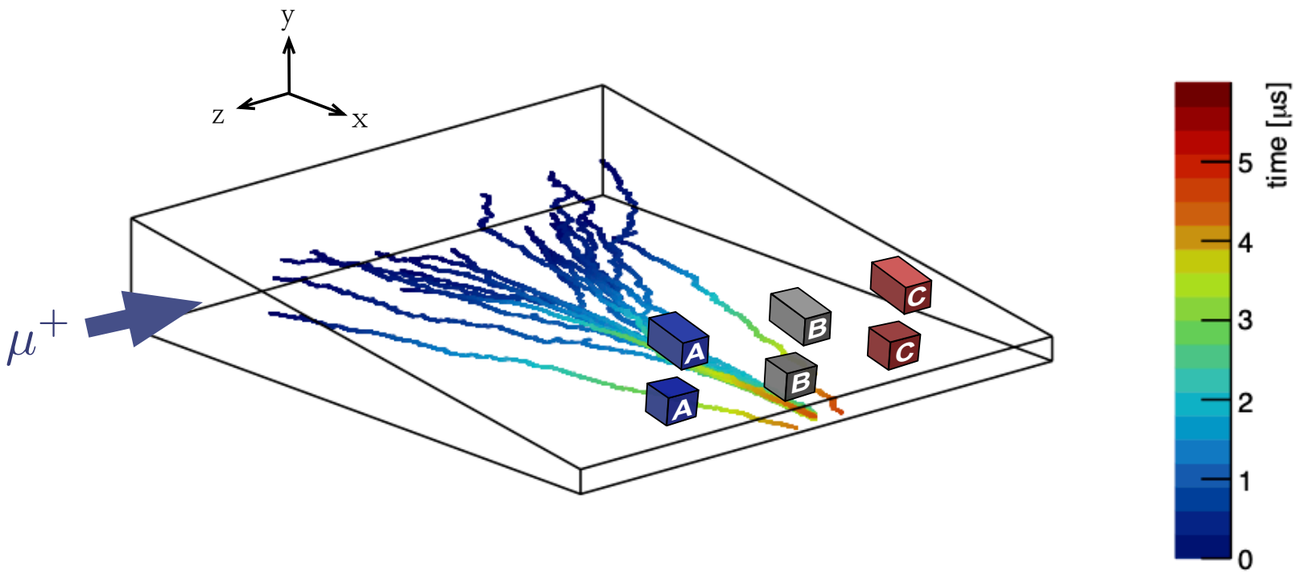
Goals for 2024 and beam time request

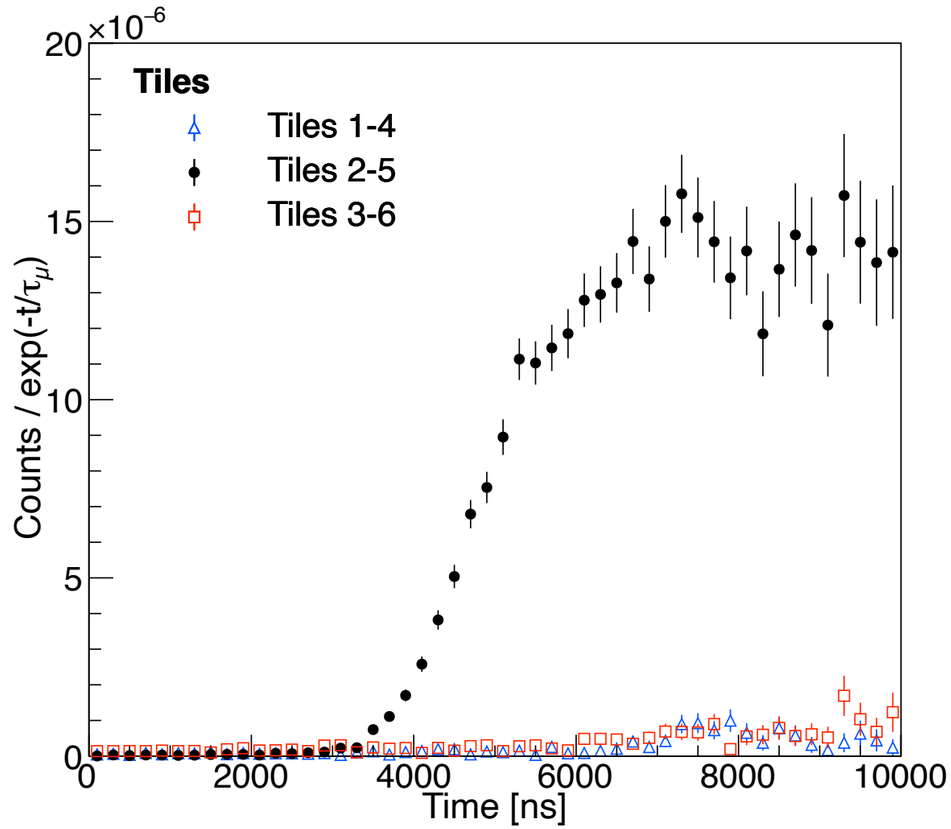
- ☐ Test mixed compression while injecting and evacuating He gas
- ☐ Test extraction of the compressed beam from the target

4.5 weeks of beamtime in piE1, very preferably in December

Back-up

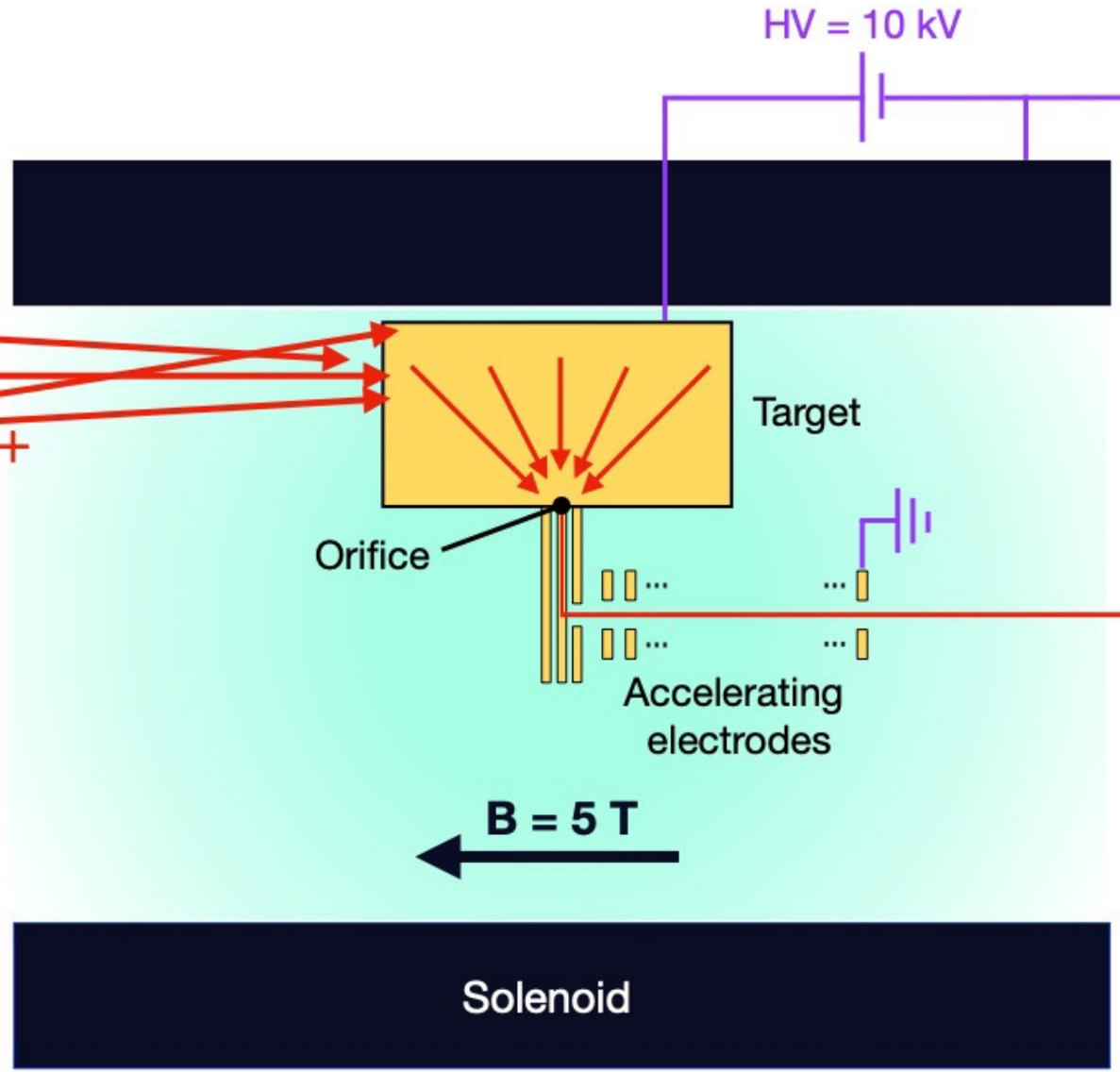
Mixed longitudinal-transverse compression demonstrated





- ☑ Efficient compression demonstrated
- ☑ Small discrepancy with simulation (2 μs longer drift) explained with tilt between beam and target axis

The full muCool scheme



IN

$\sigma_x\sigma_x' \approx 2000$ mm · mrad
$\sigma_y\sigma_y' \approx 2000$ mm · mrad
$E \approx 4$ MeV
$\Delta E \approx 0.4$ MeV ($1\,\sigma$)

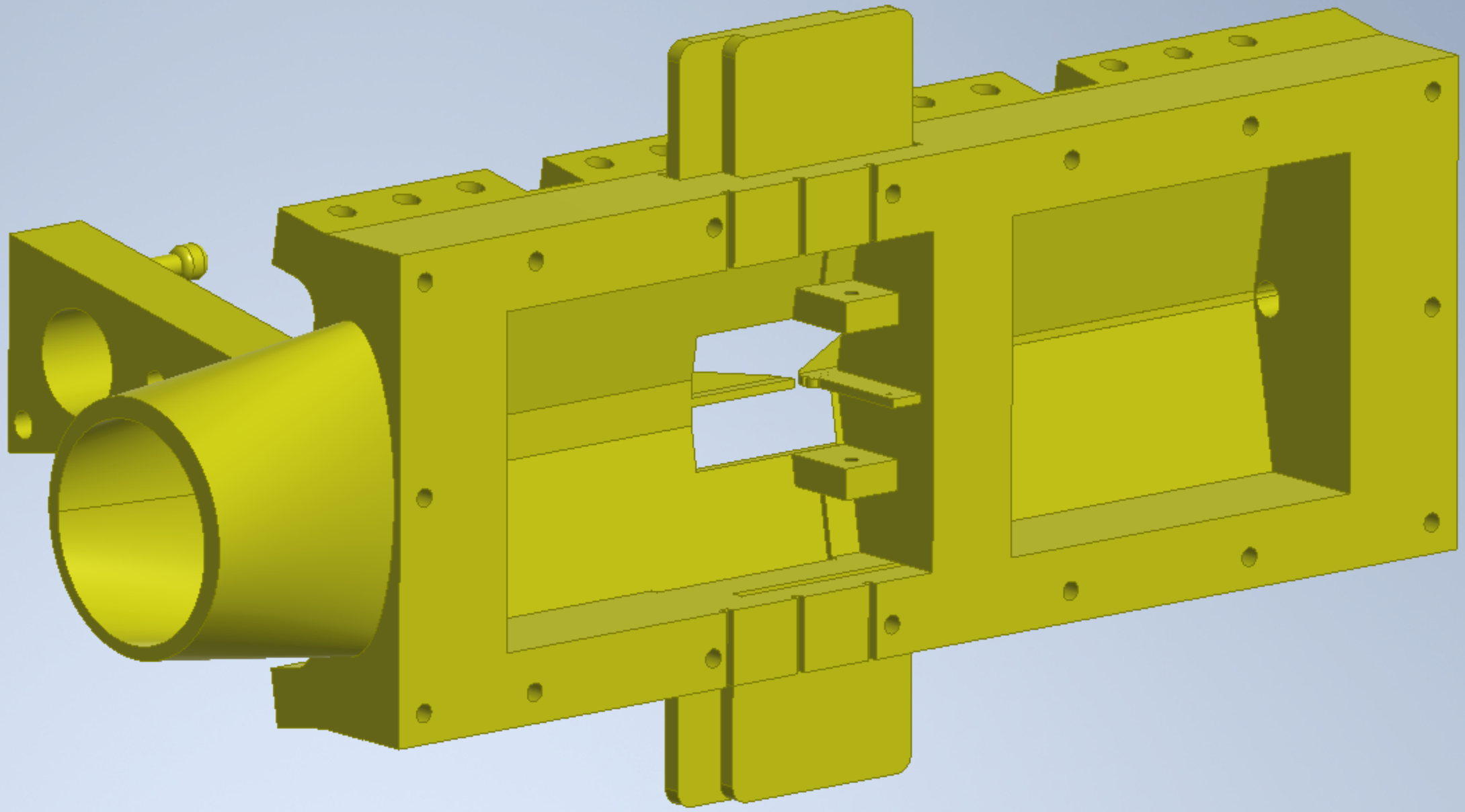
OUT

$\sigma_x\sigma_x' \approx 2$ mm · mrad
$\sigma_y\sigma_y' \approx 10$ mm · mrad
$E \approx 10$ keV
$\Delta E \leq 100$ eV ($1\,\sigma$)

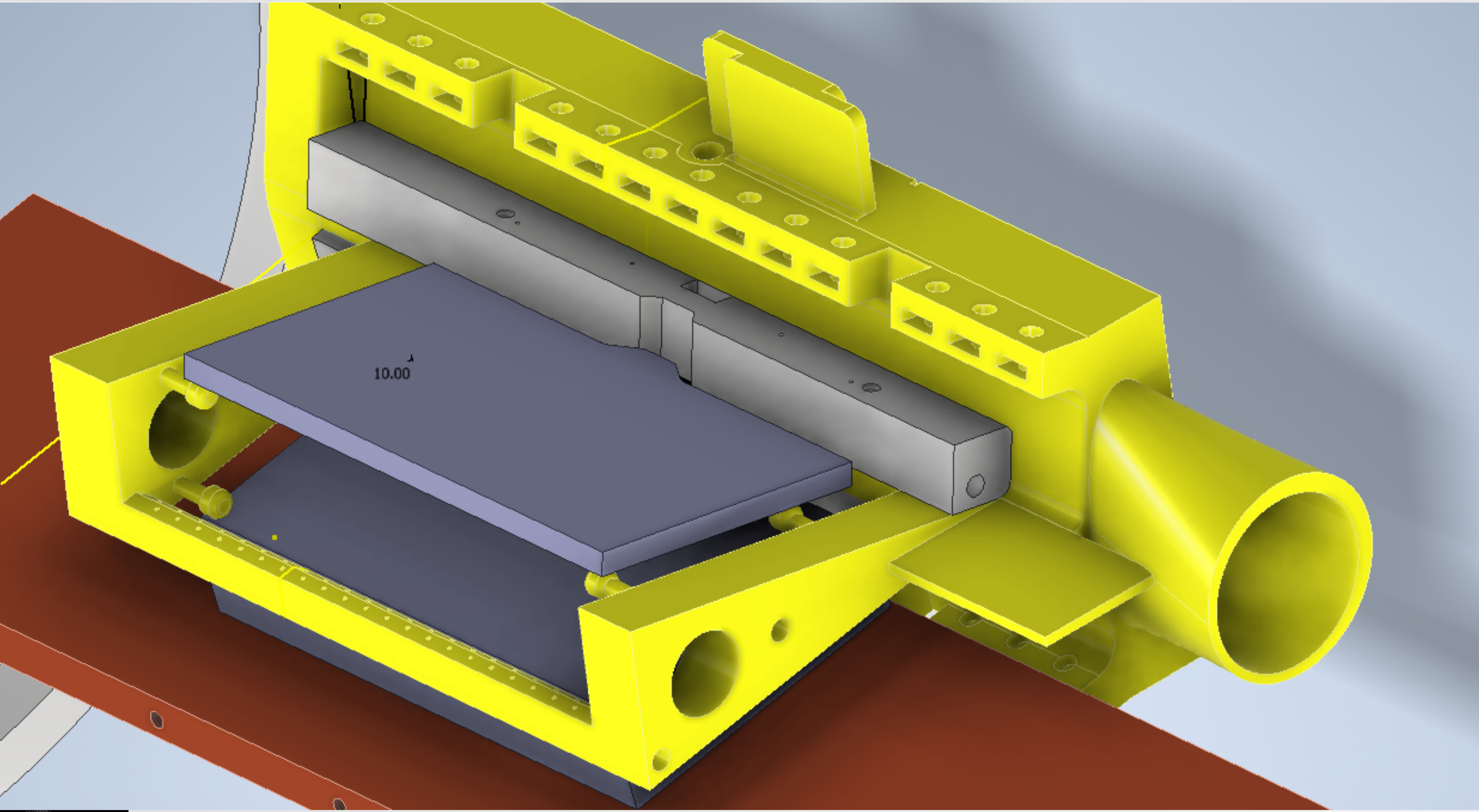
Preliminary

6D phase space decreased by 10^8- 10^9 with an efficiency of few 10^{-5}

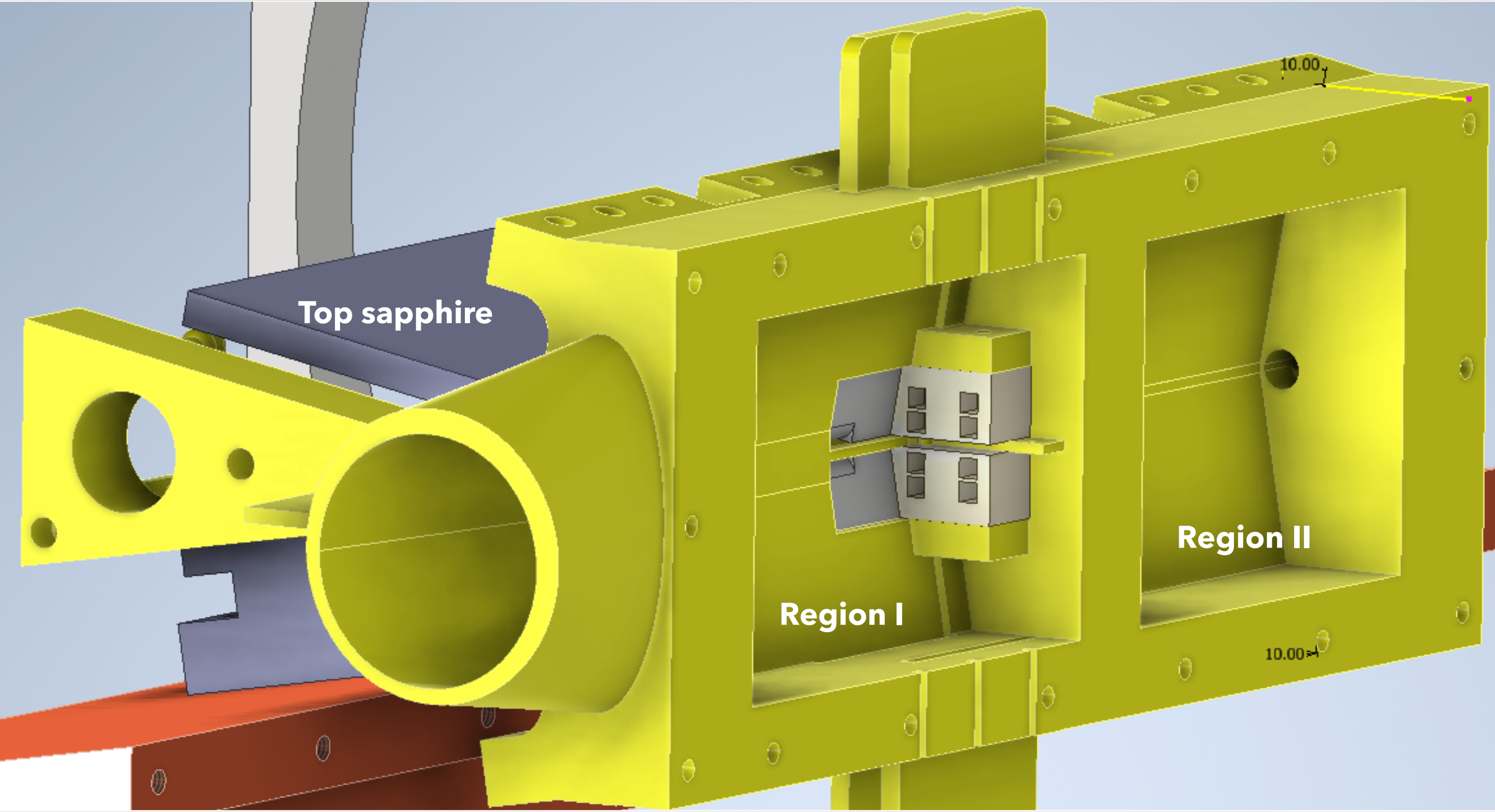
Target frame



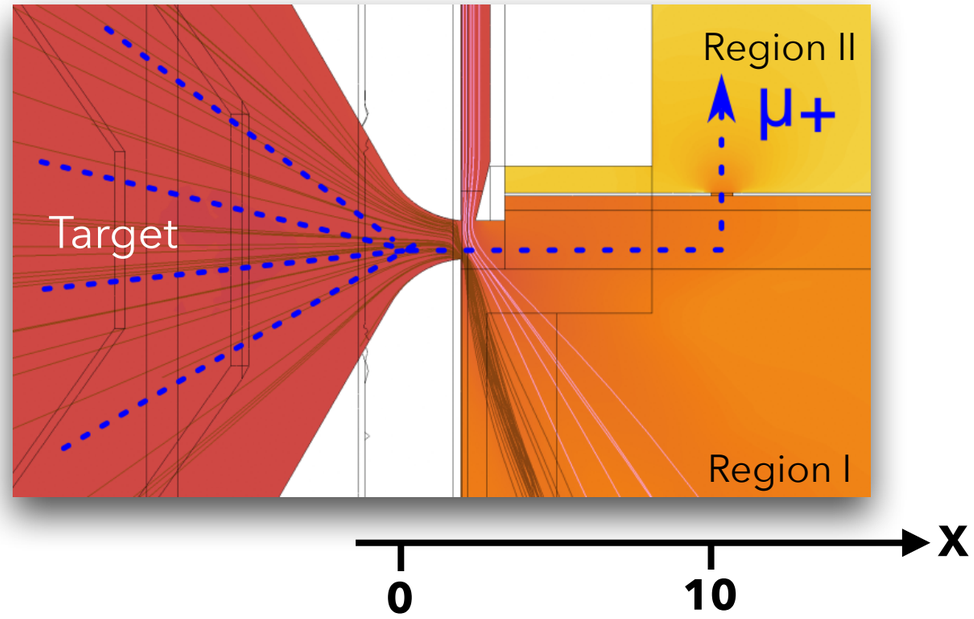
Target without Kapton foils

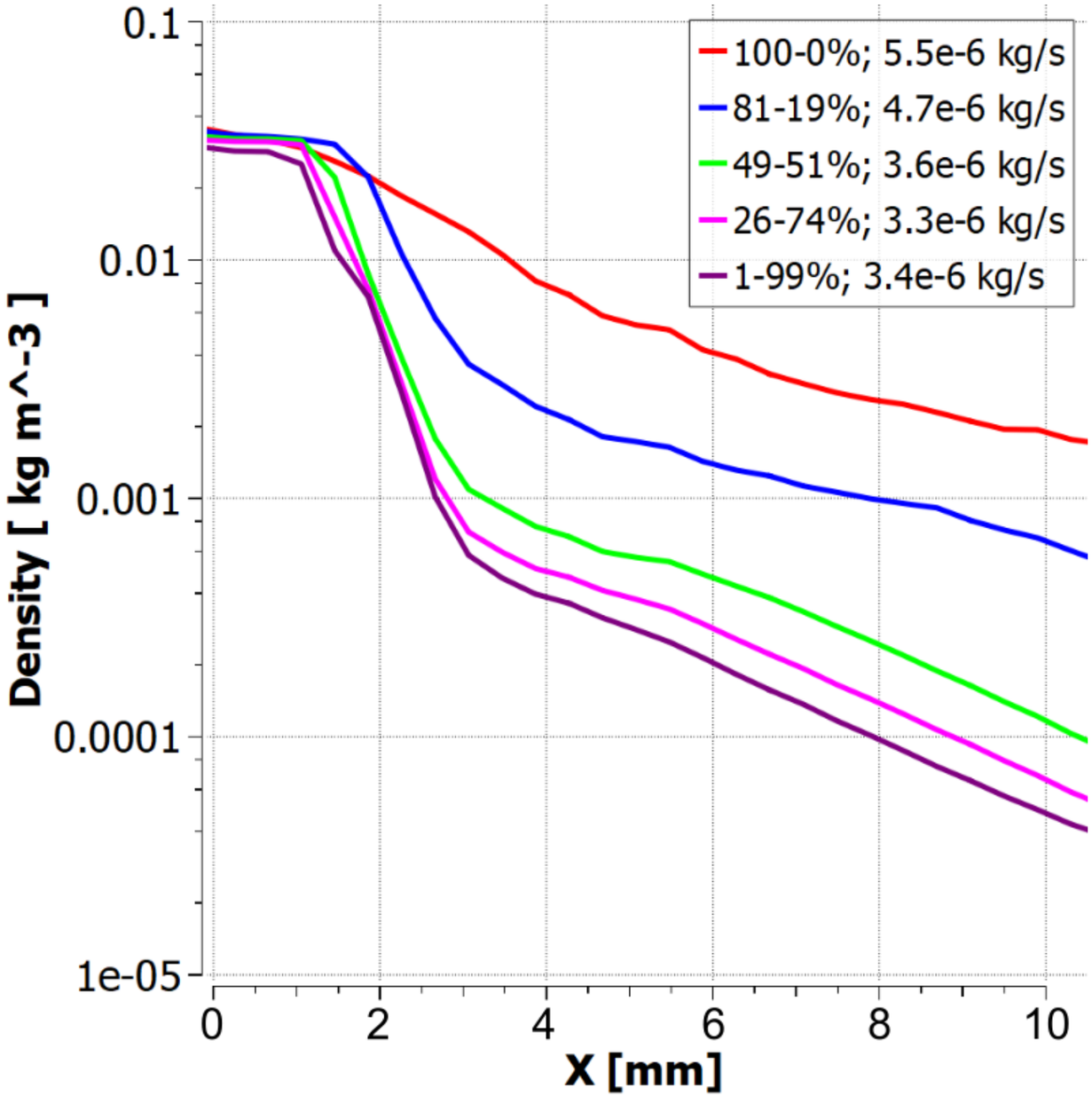


Extraction region



Density vs back-to-side injection fractions





Density versus side-injection temperatures