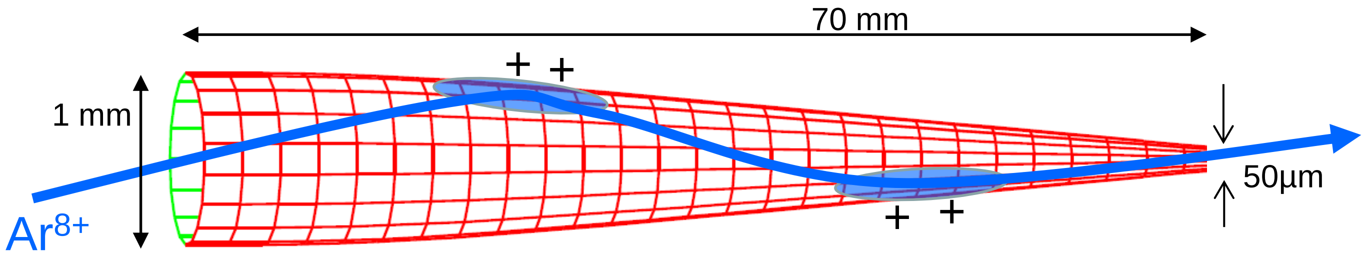
CAPILLARIES AS SELF-ORGANIZED ELECTROSTATIC LENSES ?

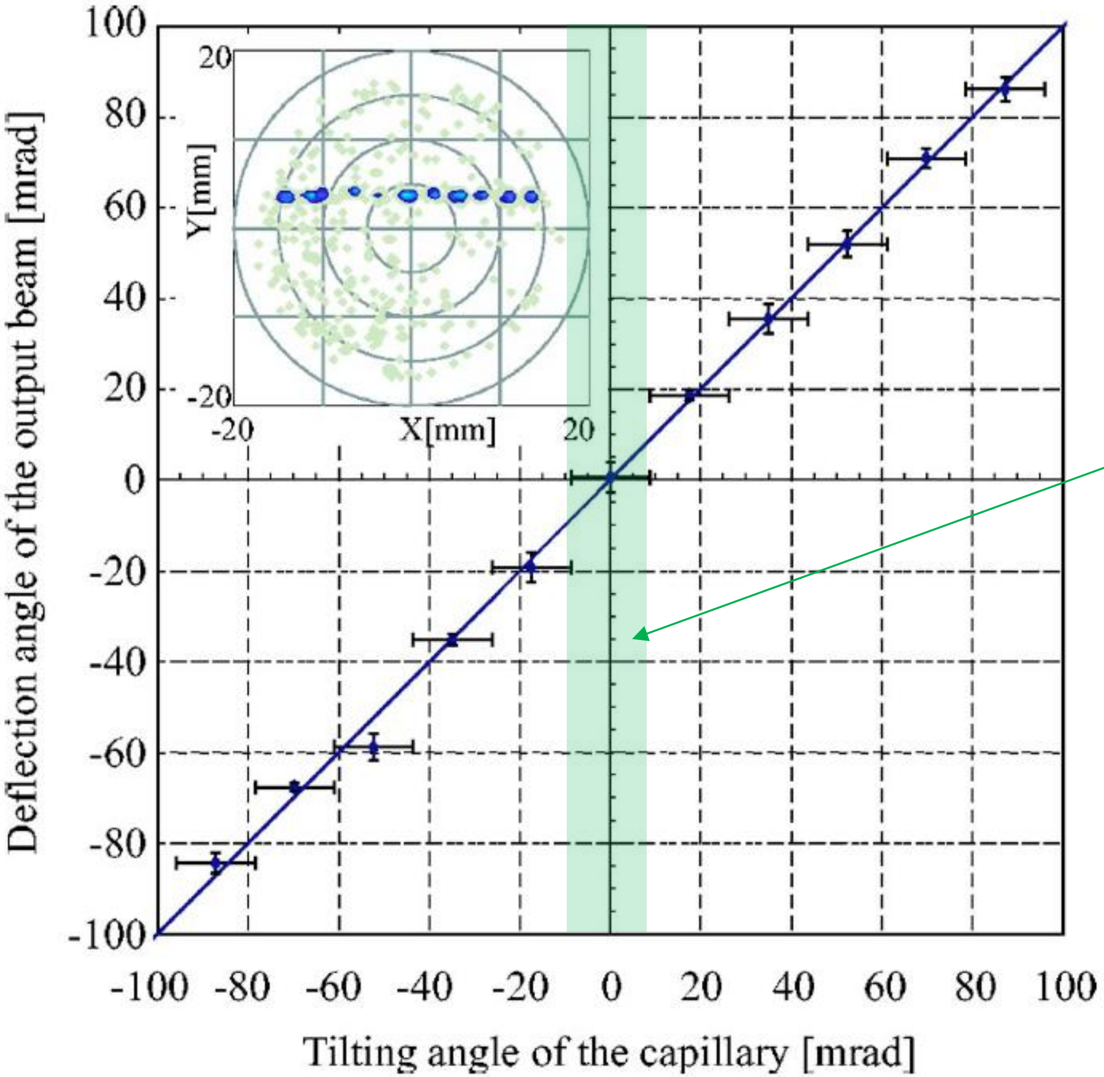


Giglio Eric

giglio@ganil.fr

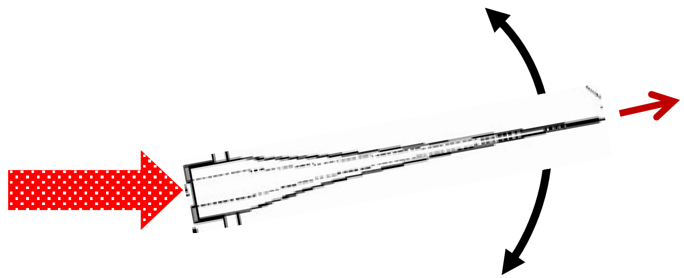
Centre de Recherche sur les Ions, les Matériaux et la Photonique (CIMAP), F-14000, Caen

Guiding power of insulating capillaries

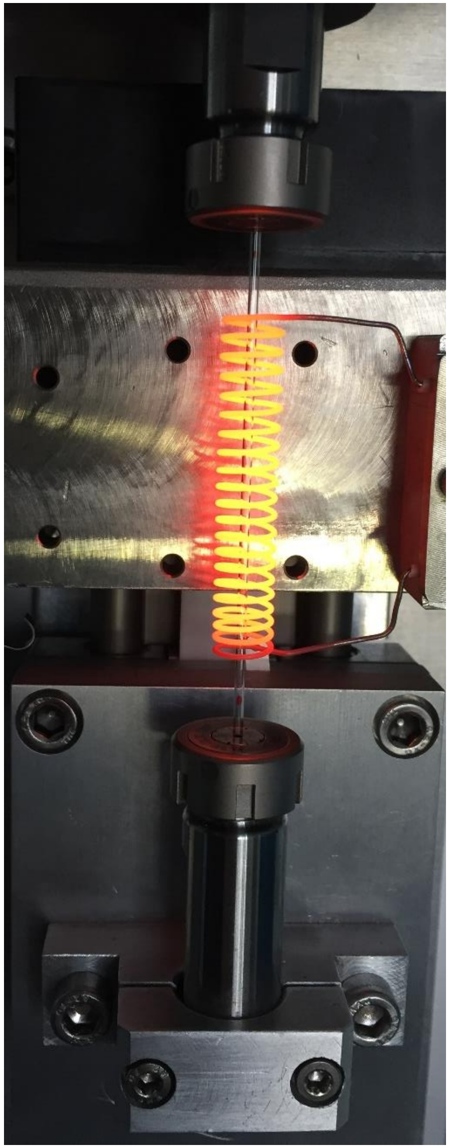


Extracted from T. Ikeda , Appl. Phys. Lett. **89**, 163502 (2006)

Geometrical transmission



Home-made conical glass capillaries, obtained by pulling a softened capillary glass tube tube



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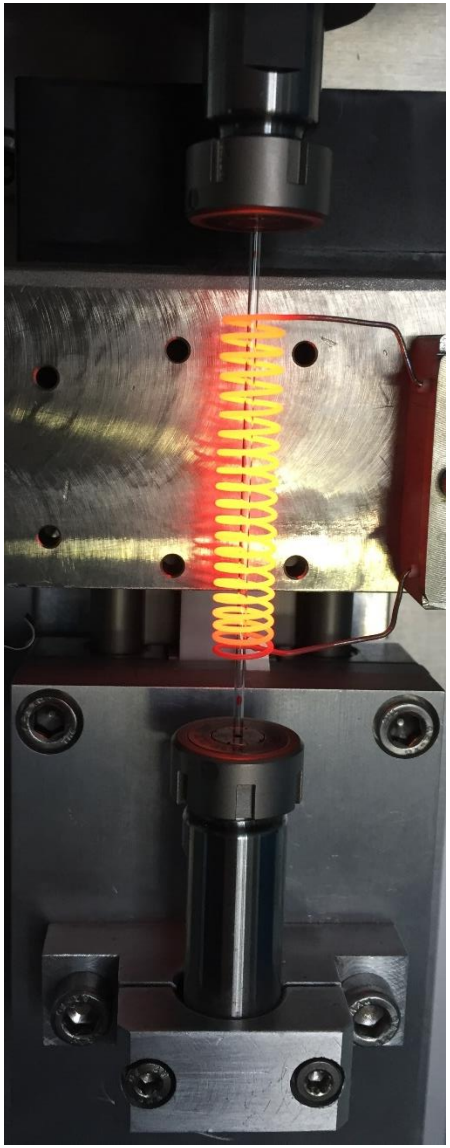


Can tapered capillaries be used to focus an ion beam?

(Einzel lens)

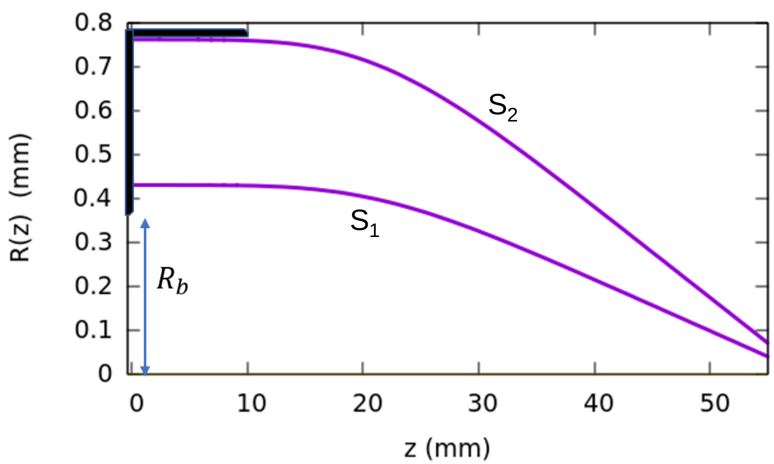
1) Write a numerical code that makes reliable, quantitative predictions for the beam transport through capillaries

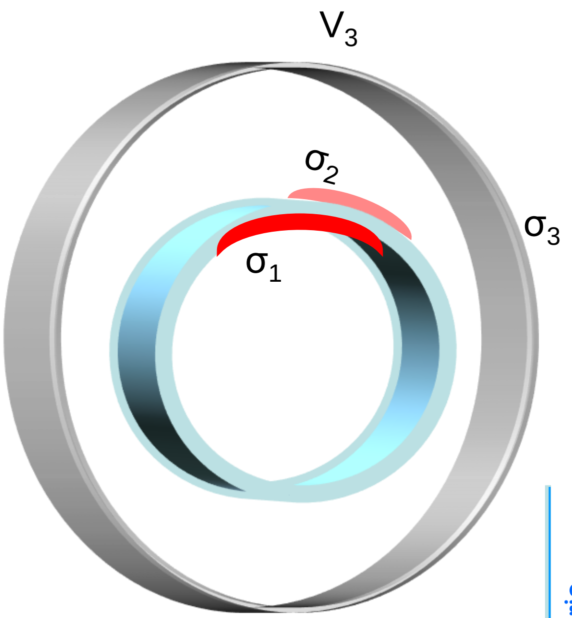
2) Design new capillary holder in order to show experimentally the lens effect

Numerical code for simulating the beam transport through glass capillaries, accounting for the charge dynamics in the glass wall

InCa4D

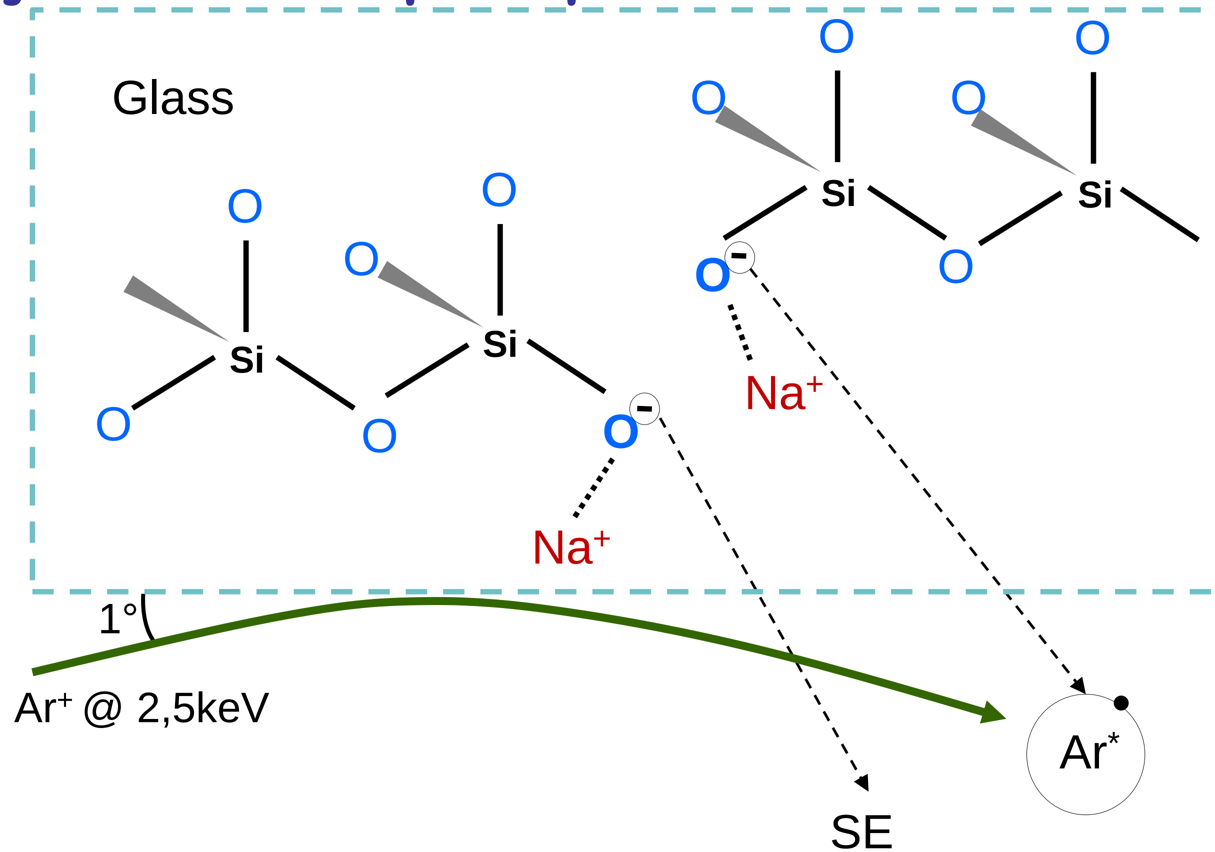
- Capillary is described by the inner S_1 and outer S_2 glass-vacuum interfaces
- Capillary is surrounded by a conducting interface S_3 **
- Charges accumulate only at the interfaces S_1 , S_2 and S_3
- Entrance and 10 first mm are grounded





Charge Injection at impact point

Non-bridging oxygens (NBO) are the most common hole centers (hole traps)



- At grazing angles, a low energy particle of charge **q** injects **$q+N_{se}$** holes at the impact point, which are quickly trapped by hole centers.
- The projectile is neutralized and N_{se} electrons are emitted

+ Features of InCa4D

1) Accounts for non-linearity of the bulk and surface conductivity …
2) Accounts for image charge of the projectile
3) Accounts for secondary electrons generated at S_1
4) Accounts for stray electrons at S_2
5) Control over emittance and divergence of the injected beam by simulating the ion source upstream
6) Follows the trajectory of neutralized projectiles
7) CPU efficient ! 10^6 trajectories in 24h on 1 CPU

Surface charge dynamics

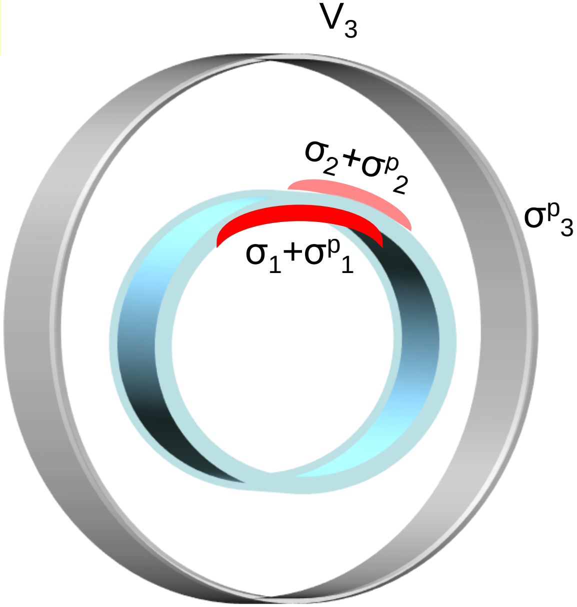
[] Giglio, E., Phys. Rev. A **101**, 052707 (2020)

$$\begin{cases} \dfrac{\partial \sigma_1}{\partial t} = \kappa_s \vec{\nabla}_s \cdot \vec{E}_1 - \kappa_b E^+_{n,1} + \gamma^h + \gamma^e_{se} \\ \dfrac{\partial \sigma_2}{\partial t} = \kappa_s \vec{\nabla}_s \cdot \vec{E}_2 + \kappa_b E^-_{n,2} + \gamma^e_{str} \end{cases}$$

Charge dynamics is controlled by the ratio $\dfrac{\kappa_b U_s}{I}$

Source potential

Beam current



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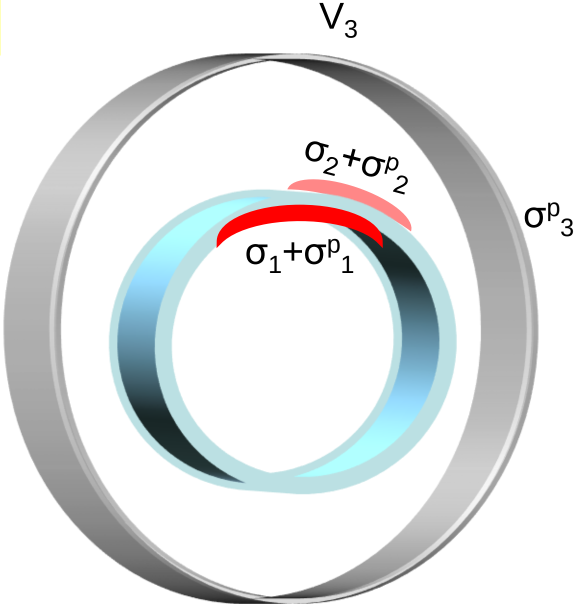
Charge dynamics is controlled by the ratio $\dfrac{\kappa_b U_s}{I}$

Source potential (U_s)

Beam current (I)



Pyrex glass

κ_b (20°C)	κ_s
(10^{-13} S/m)	(10^{-16} S)

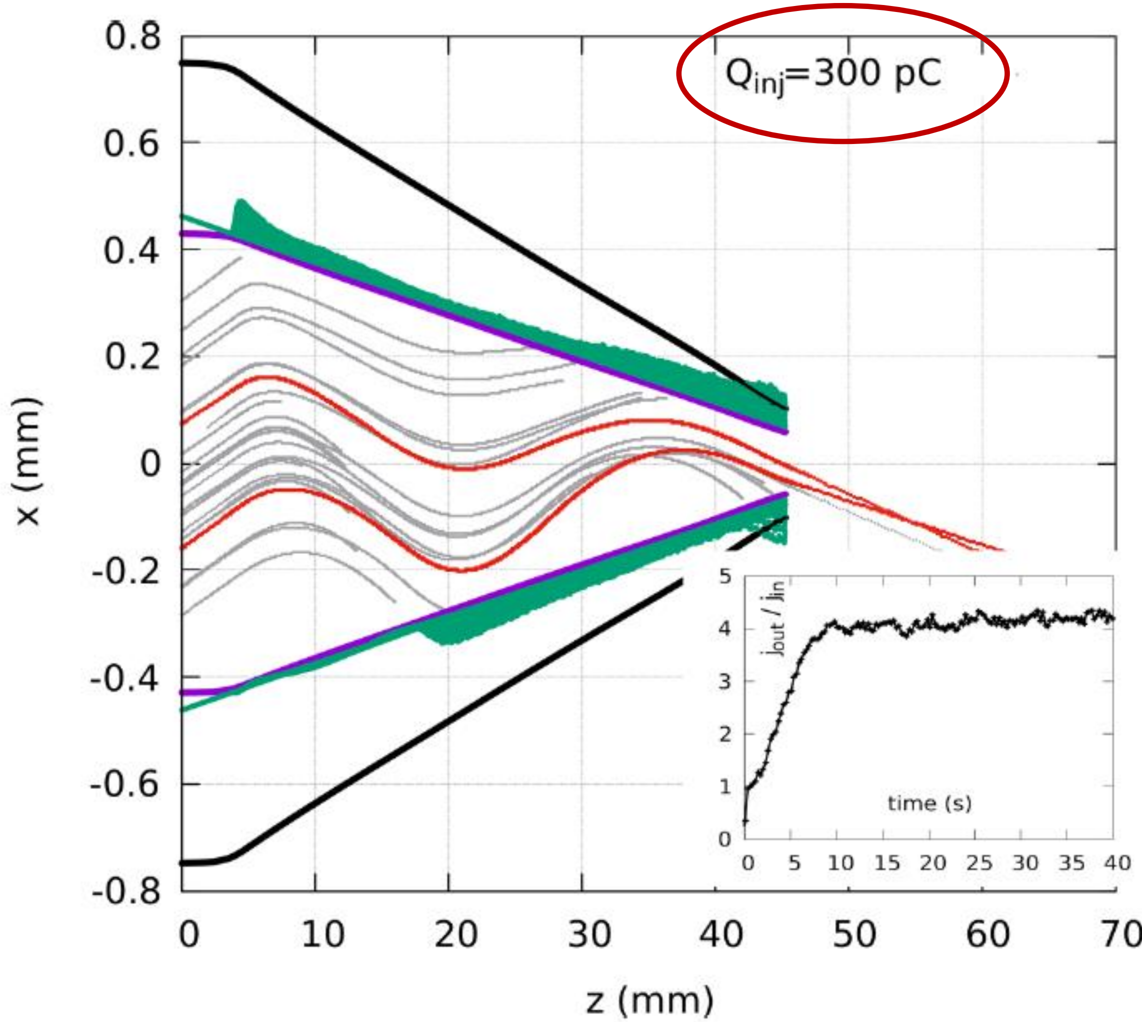
Relevant Numerical Results

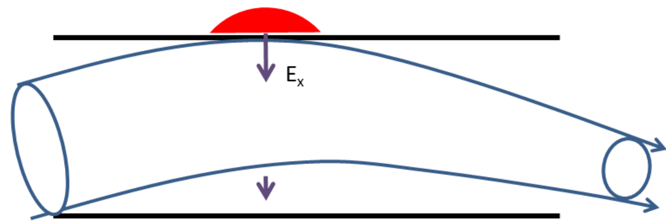
Two mechanism that result in a denser transmitted beam have been identified

1. Transverse compression (non-zero tilt angle)

2. Self-Organized Radial focusing (zero tilt angle)

1) Beam compression by transverse fields for tilted capillaries





$$\frac{j_{\mathrm{out}}}{j_{\mathrm{in}}} \simeq 4$$

Relevant Numerical Results

Two mechanism that result in a denser transmitted beam have been identified

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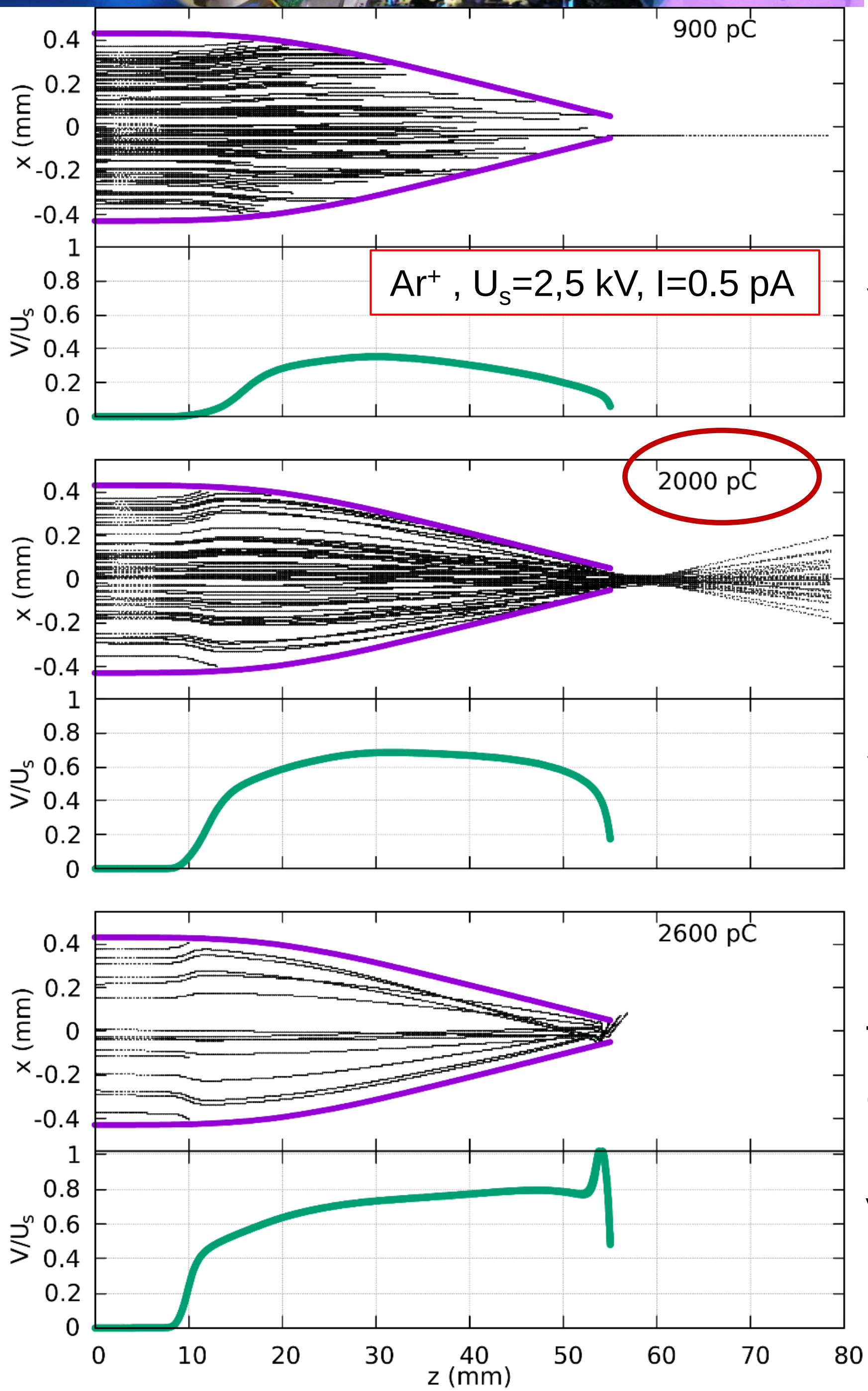
Self-Organized Radial Focusing



Geometrical transmission

$V < 0.4\ U_s$

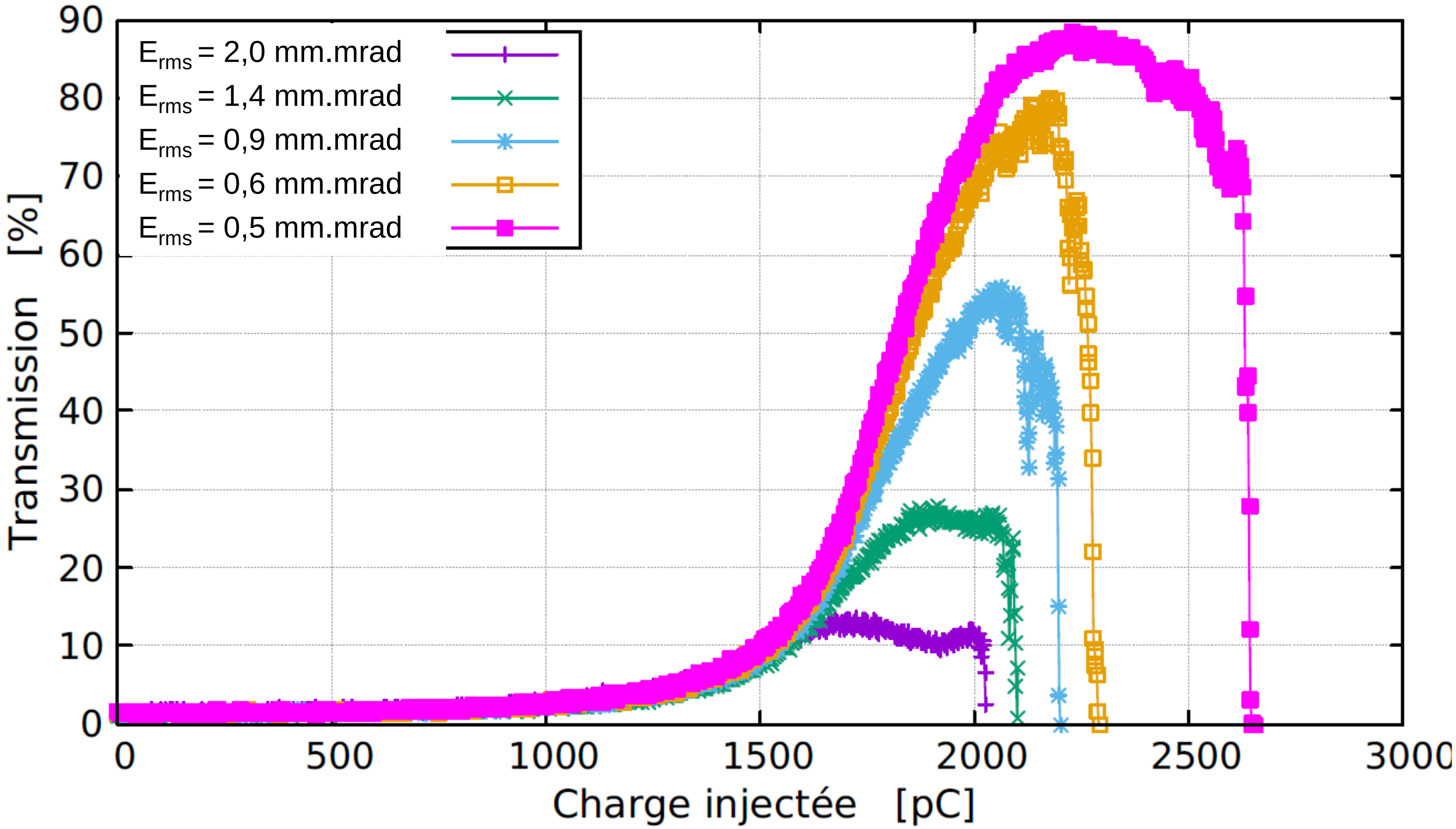
Focused beam,
maximal transmission rate

$V \sim 0.7\ U_s$

Transmission is
Coulomb blocked,

$V > U_s$

Influence of the beam emittance



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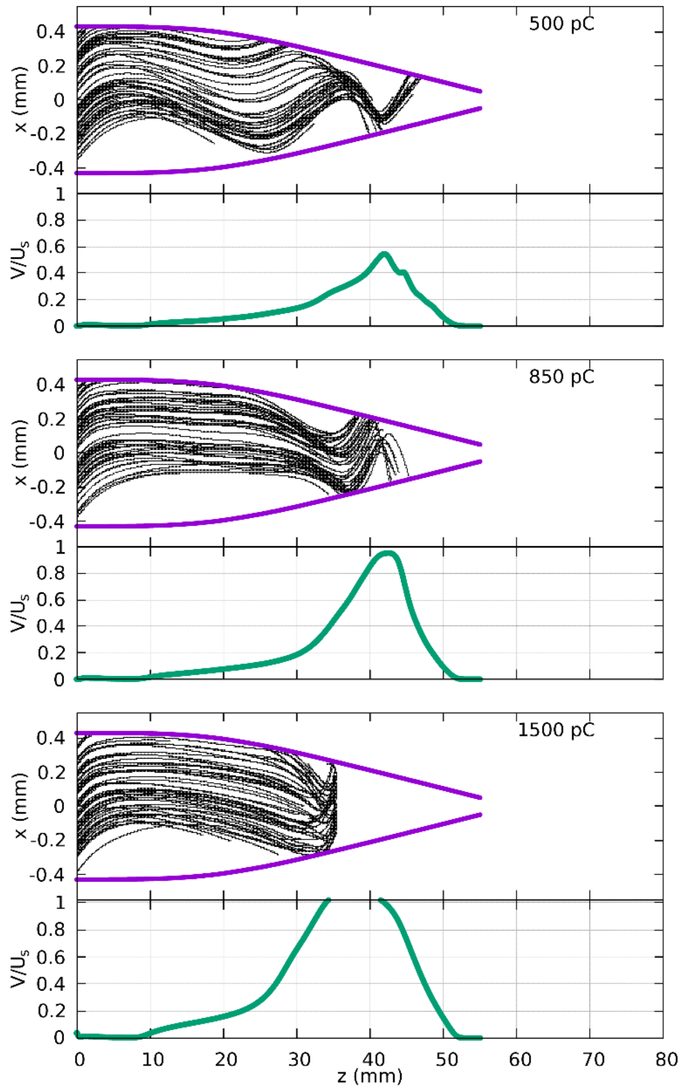
Giglio Eric

Influence of the tilt angle



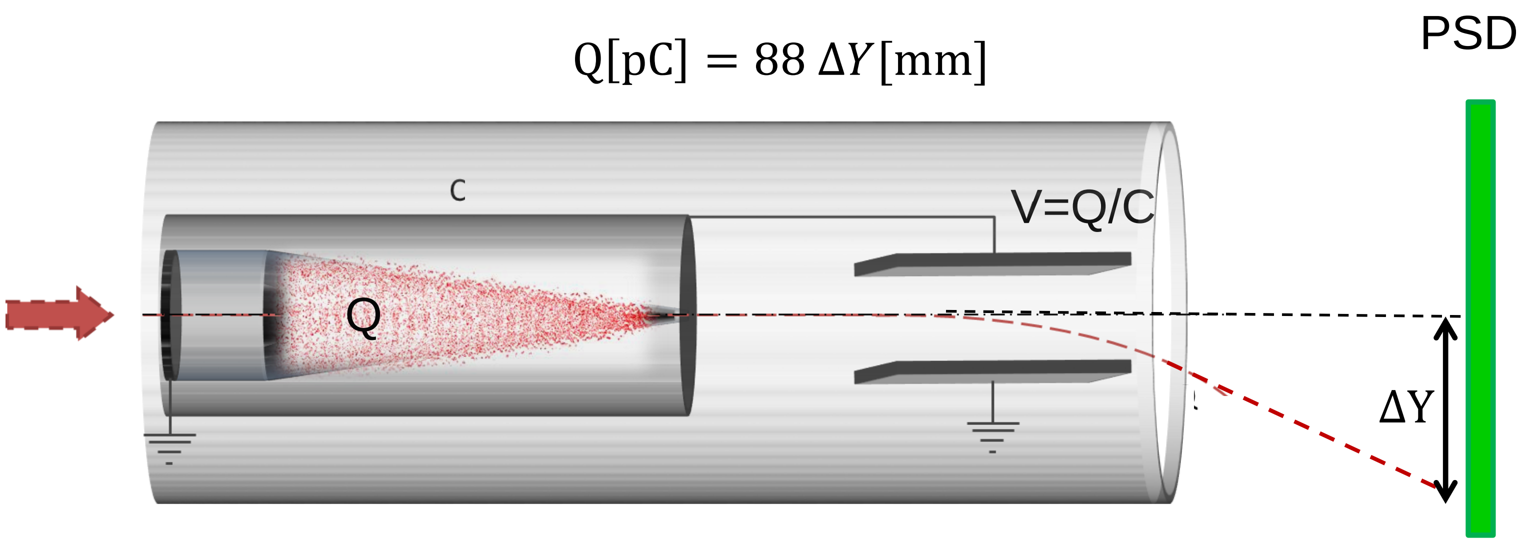
1) Write a numerical code that makes reliable quantitative predictions for the beam transport through capillaries

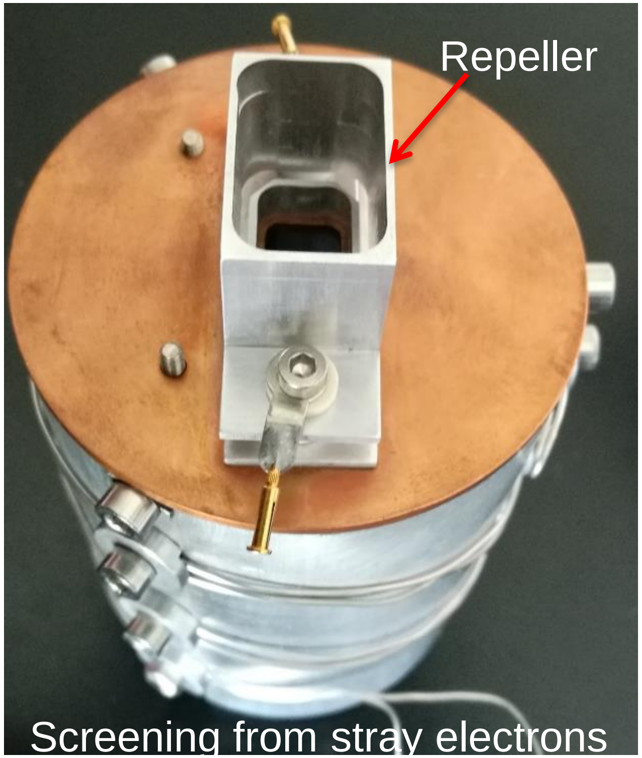
2) Design new capillary holder in order to show experimentally the lens effect

Features of new capillary holder

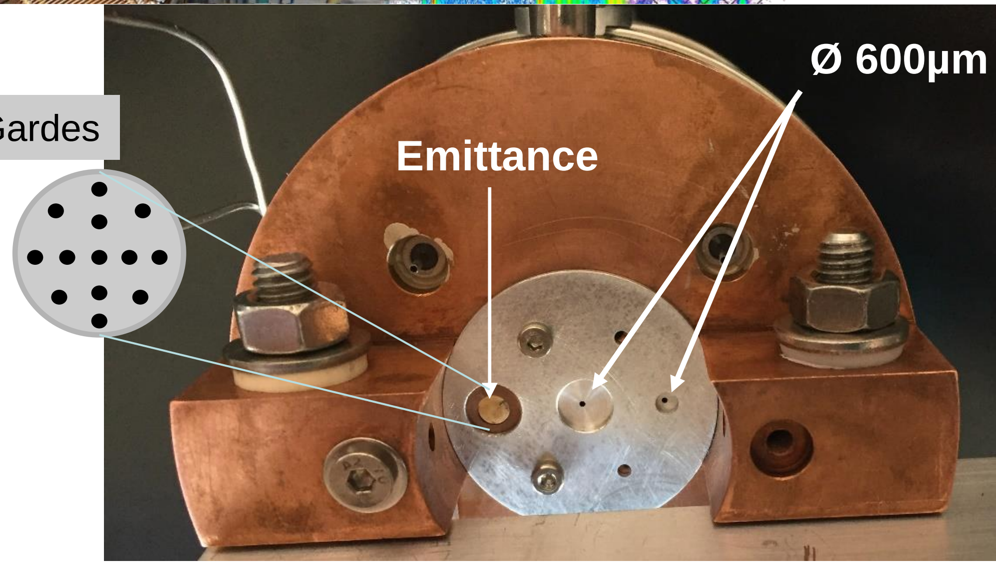
- Allow measuring the emittance and intensity of the injected beam
- Screen capillary from stray electrons
- Heat capillary up to 70°C
- Axis symmetric geometry that can be truthfully simulated by InCa4D
- Allow measuring the charge stored in the capillary as a function of time

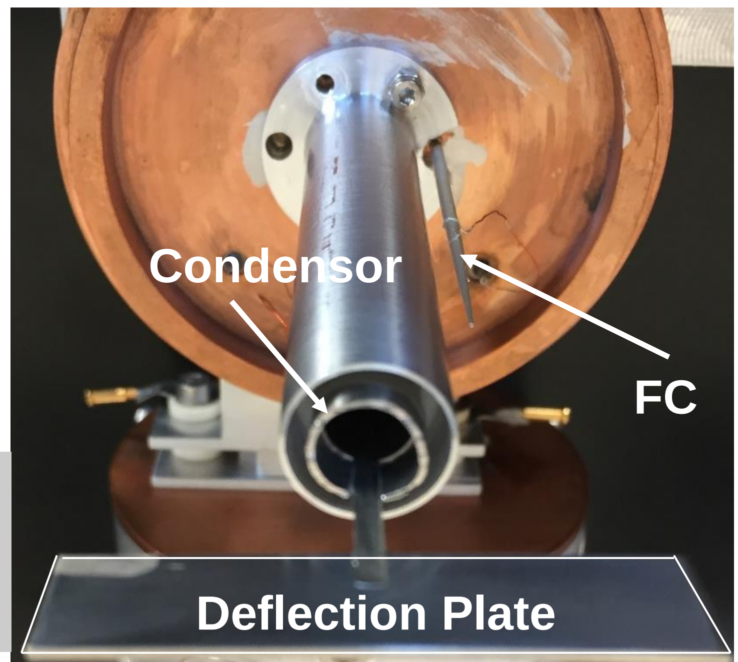
$$Q[\mathrm{pC}] = 88\,\Delta Y\,[\mathrm{mm}]$$





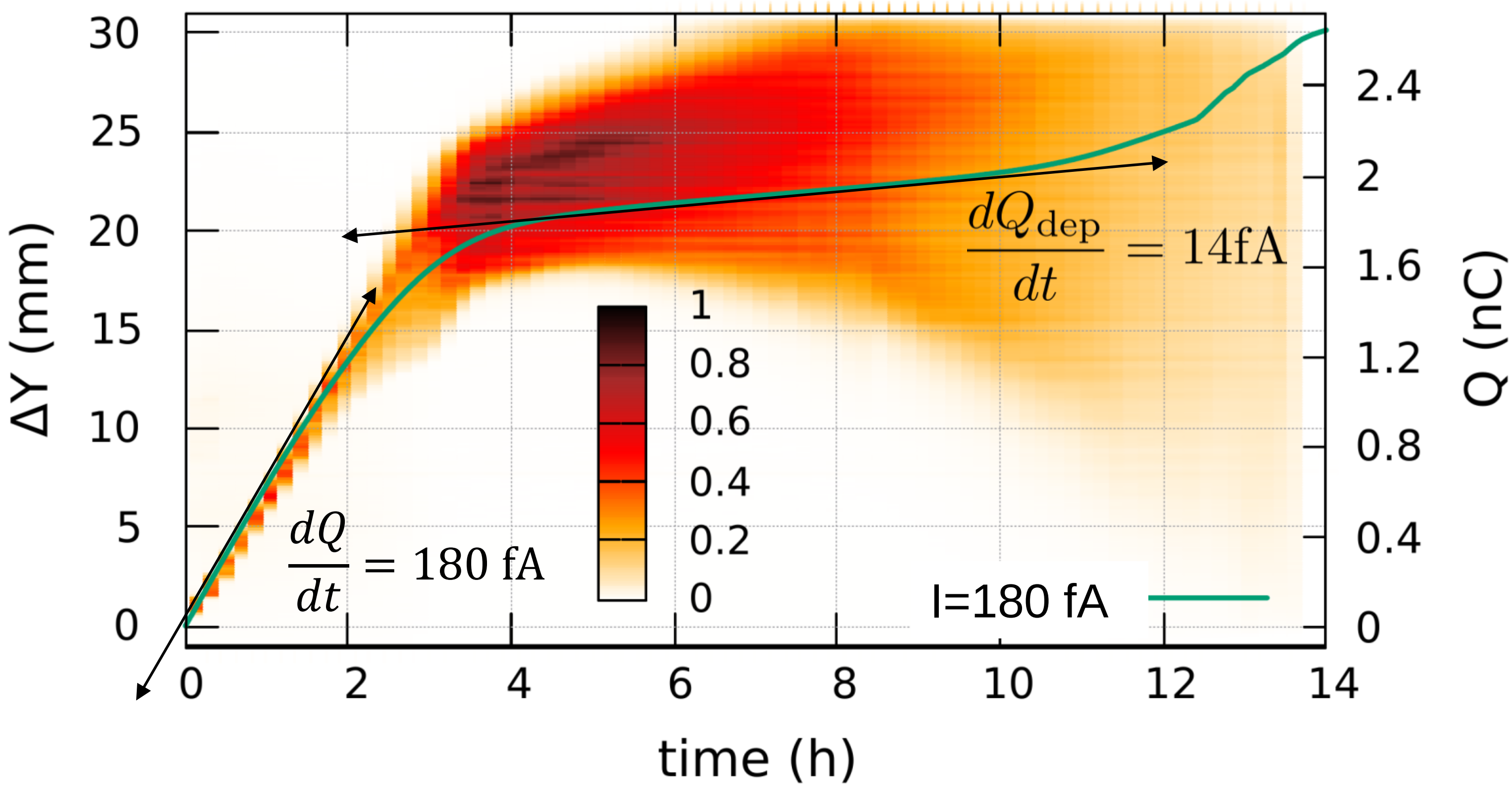
E. Gardes



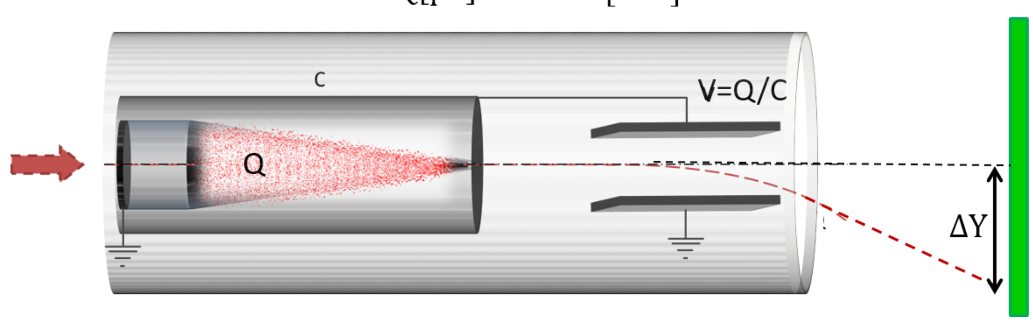


S. Guillous

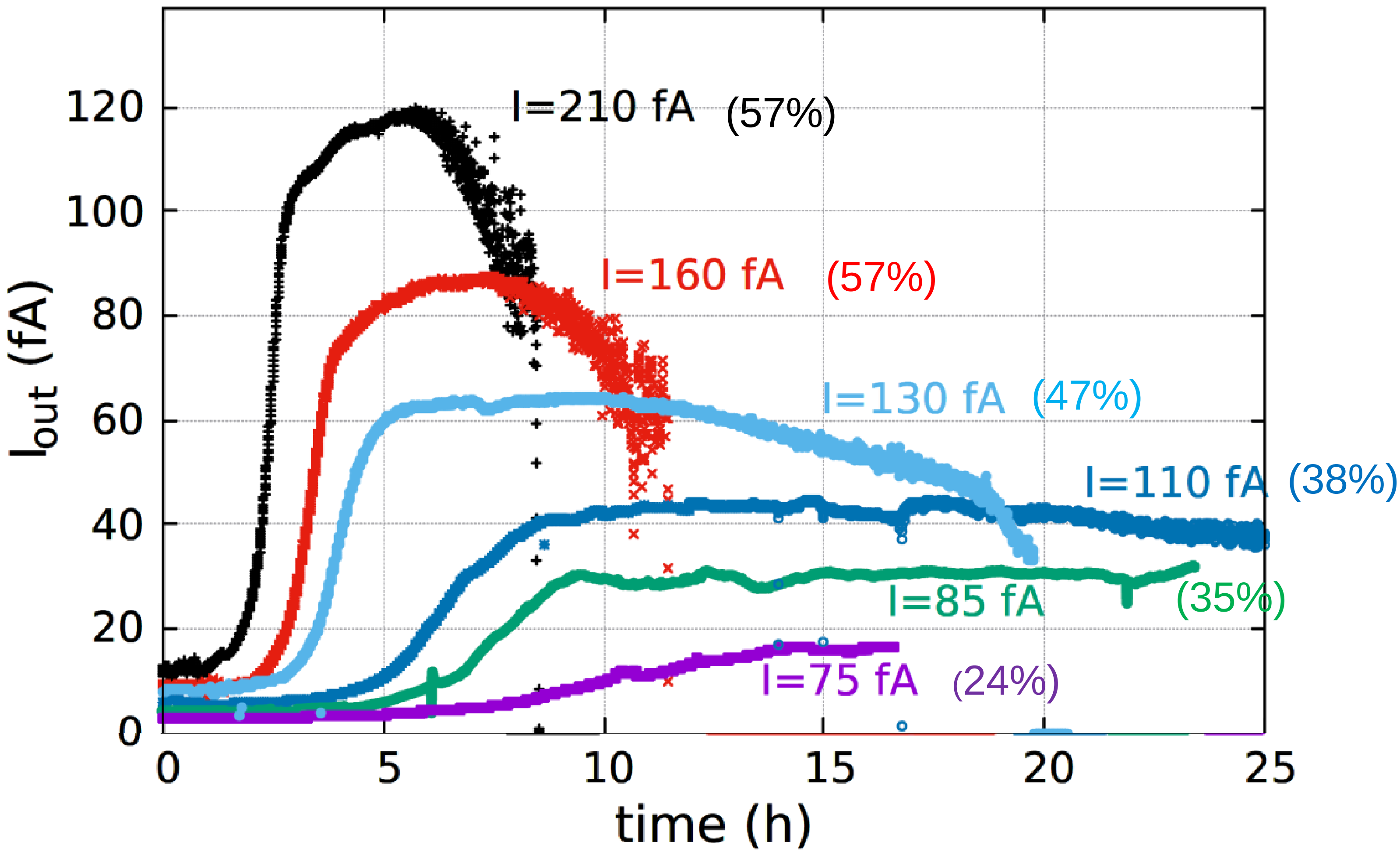
Big Thank to our mechanics
T. Been,
P. Guinement,
J.-M. Ramillon

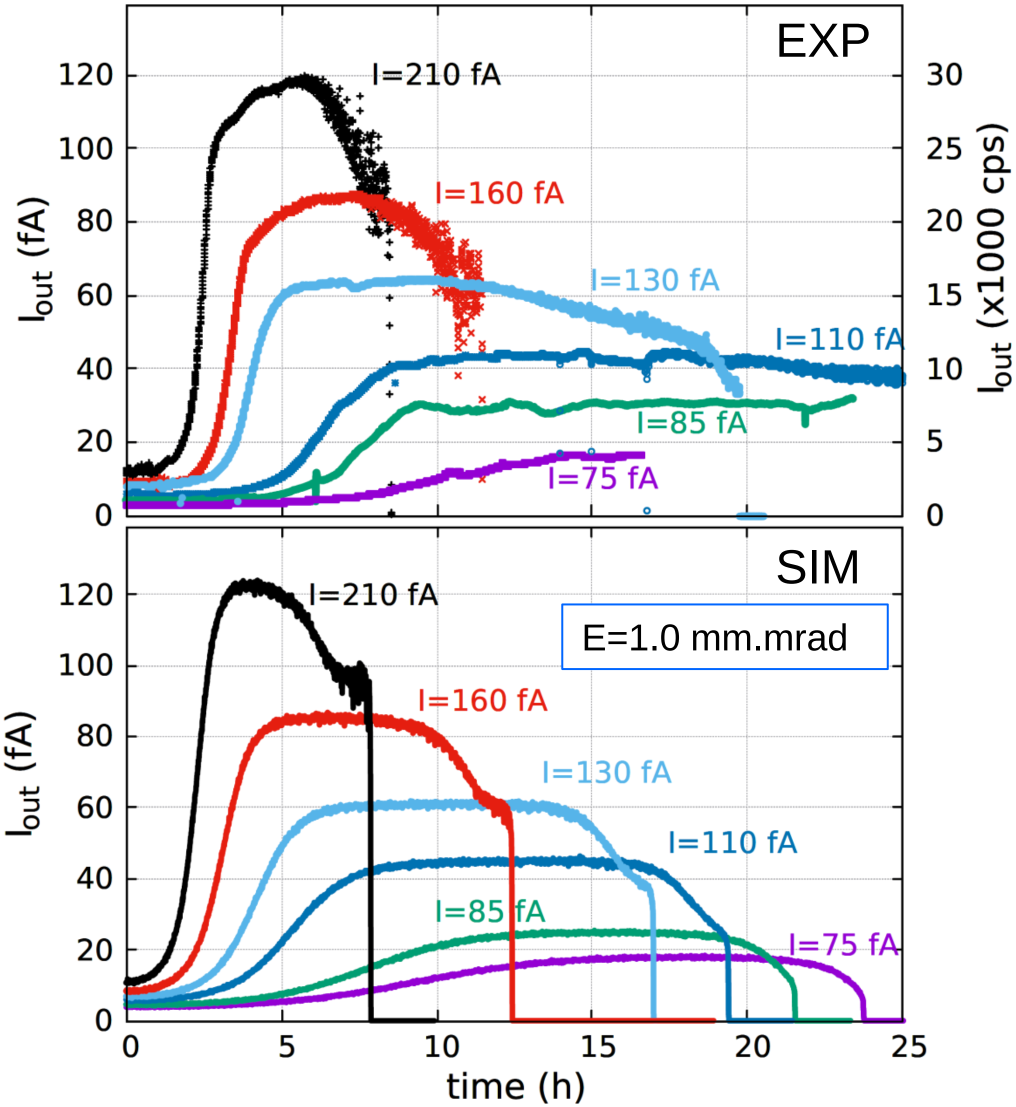


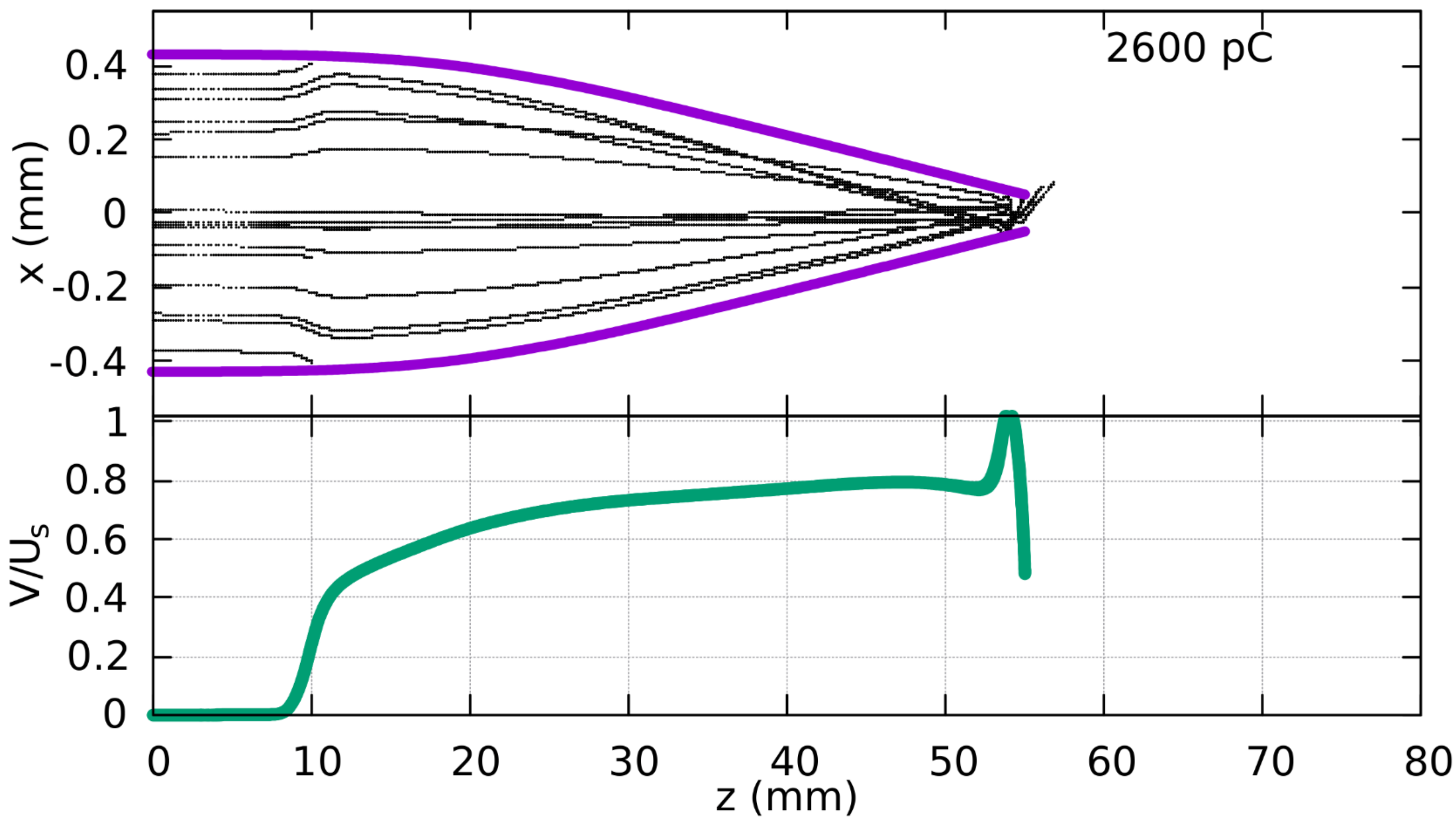
$$Q[pC] = 88\,\Delta Y[mm]$$



Transmitted Intensity as a function of time

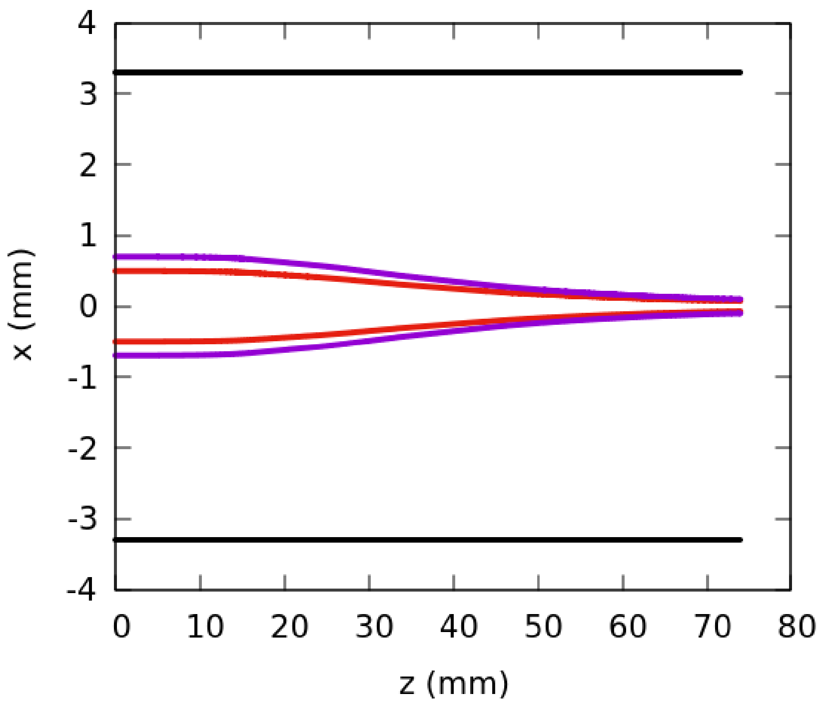



EXP
I=210 fA
I=160 fA
I=130 fA
I=110 fA
I=85 fA
I=75 fA
I_{out} (fA)
I_{out} (x1000 cps)
SIM
E=1.0 mm.mrad
I=210 fA
I=160 fA
I=130 fA
I=110 fA
I=85 fA
I=75 fA
I_{out} (fA)
time (h)

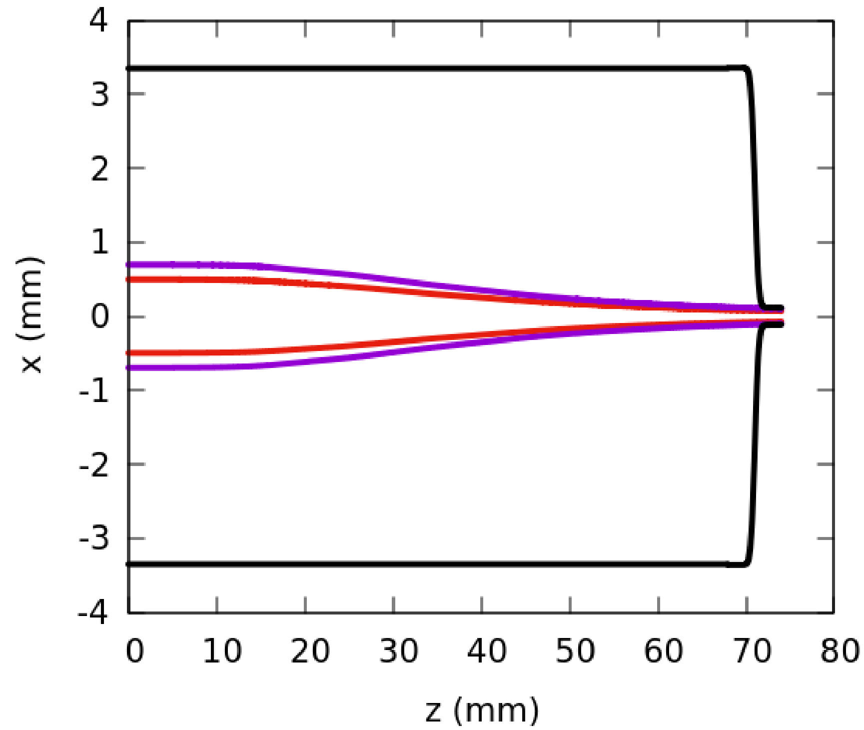

2600 pC
0.4
0.2
0
-0.2
-0.4
x (mm)
1
0.8
0.6
0.4
0.2
0
V/U_s
0
10
20
30
40
50
60
70
80
z (mm)

Avoid Coulomb blocking

Old setup

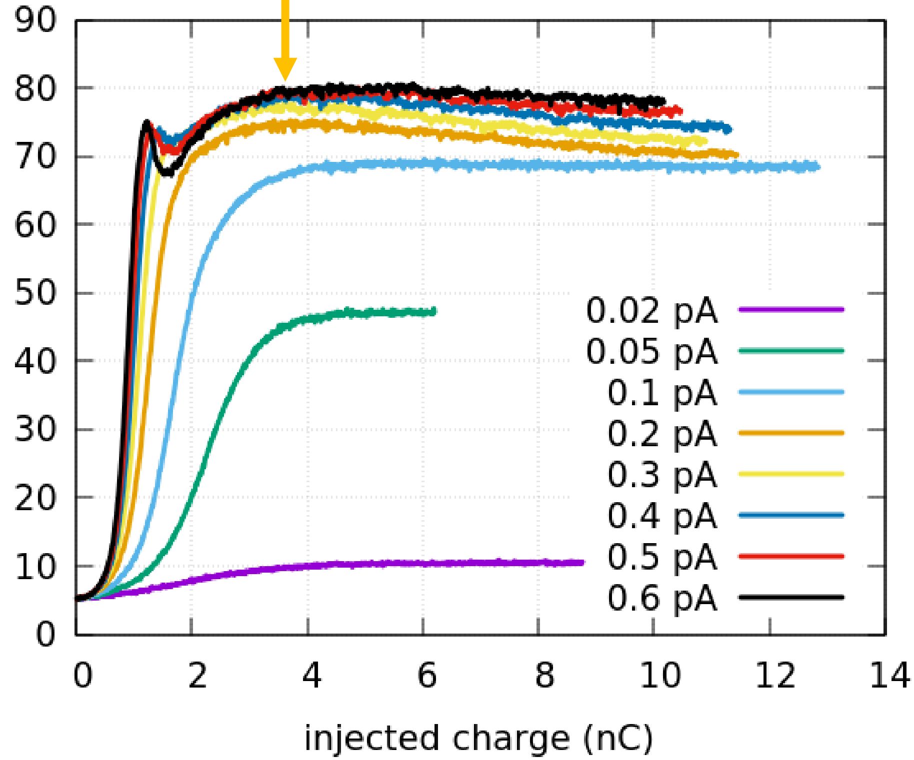


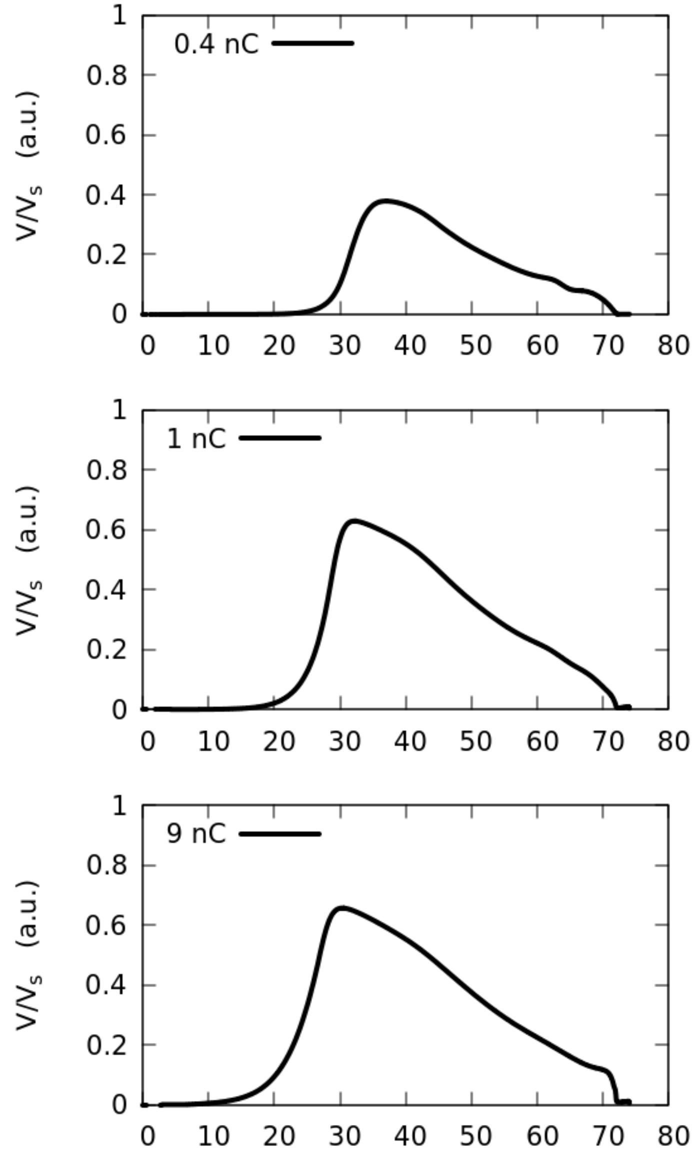
New setup



Avoid Coulomb blocking

Coulomb blocking
without GND tip





Giglio Eric

Conclusion and Persepectives

- Tapered capillaries are able to focus ion beams like electrostatic lenses.
- Coulomb blocking seems unavoidable for capillaries because of the non-zero emittance of the beam.
- Simulations suggest that Coulomb blocking can be delayed or even hindered if the tip is grounded.
- This open up a new application for using tapered capillaries for producing micro-beams
- Experimental evidence for stable micro-beams will be the next step (which was unfortunately delayed and could ne be shown here due to the confinement)

Co-Workers

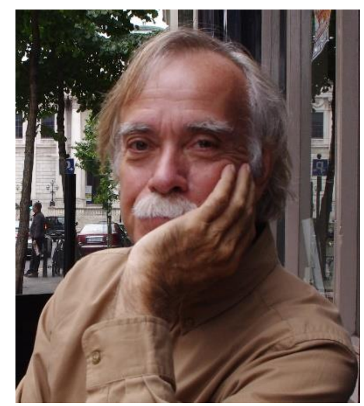
S. Guillous
A. Cassimi

Centre de Recherche sur les Ions, les Matériaux et la Photonique (CIMAP), F-14000, Caen, France, EU

HongqiangH.Q. Zhang
School of Nuclear Science and Technology, Lanzhou University, Lanzhou, China

Karoly Tökési

G.U.L. Nagy
Institute for Nuclear Research, Hungarian Academy of Sciences (ATOMKI), Hungary, EU



R. D. DuBois
Missouri University of Science and Technology, Rolla MO 65409 USA