Zajfman's Electrostatic Ion Beam Trap

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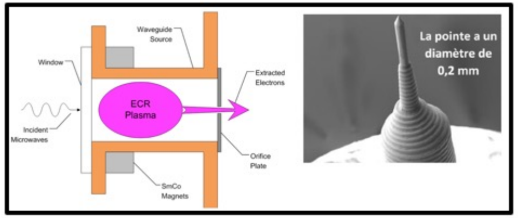
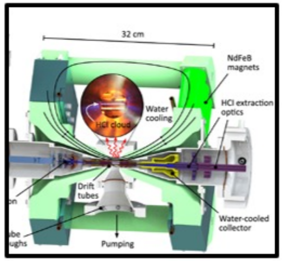
- Developpement of ion traps at Orsay :
  - HINA (Highly charged Ions for Nuclear physics and Astrophysics)

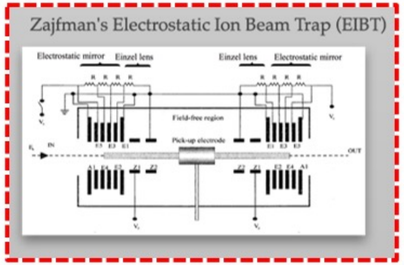
Sarah Naimi

mosaic

Production (ECR/LMIS) → Charge breeding → Trapping Observation







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Amelle Khamkham (M1)

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David Lunney

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Sarah Hussein (M1)

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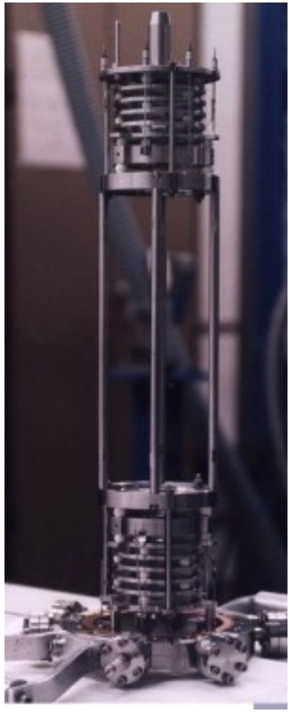
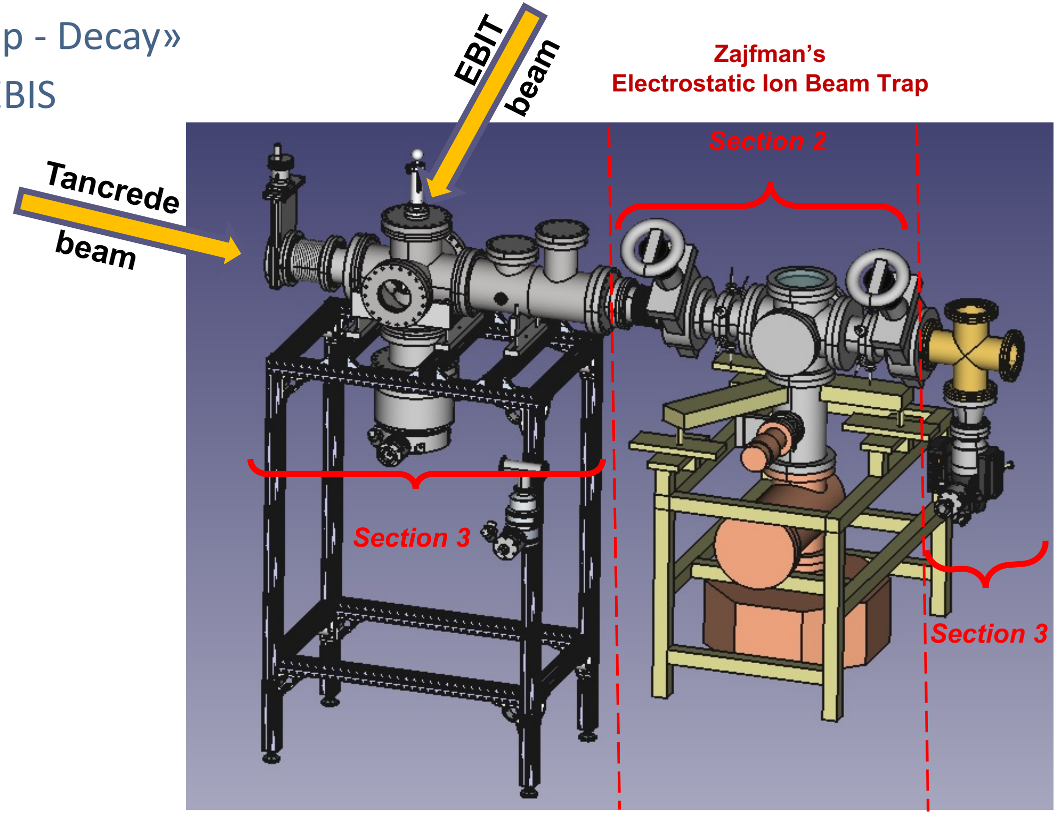
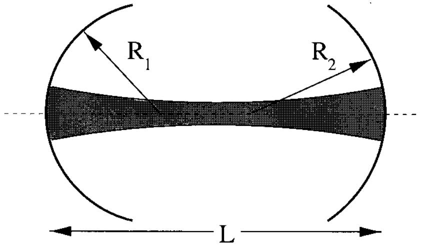
- What is it?
  - Electrostatic ion trap
  - Observation of the decay inside the trap «InTrap - Decay»
  - Multicharged ions from Tancred or from EBIT/EBIS



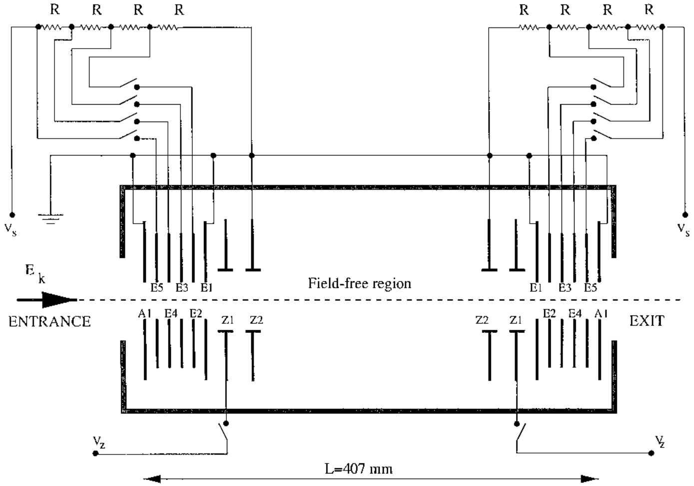
Picture of the inside of the trap



- How does it work ?
  - Charged particle in electrostatic field ➔ Light in medium (with n α √E)
    - stability condition : $0 \leq \left(1 - \frac{L}{R_1}\right)\left(1 - \frac{L}{R_2}\right) \leq 1$
    - trapping conditions :
      - ➔ transverse : $\frac{L}{4} \leq f \leq \infty$
      - ➔ Longitudinal : $V_s > \frac{E_k}{q}$

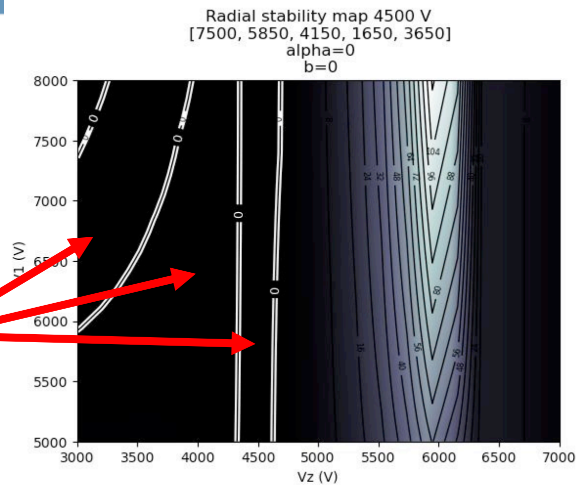


  - Zajfman's Trap ➔ Optical resonator
    - longitudinal trapping with mirrors ➔ Electrodes (V1,V2,V3,V4, V0)
    - radial trapping with Einzel lens ➔ Electodes (Vz + 2 V0)



Simulations

- Tunning the trap:
  - PyTrap :
    - python program developped by Alexandre Vallette in 2011(LKB)
    - analytical calculations for potentials inside trap and ions trajectories

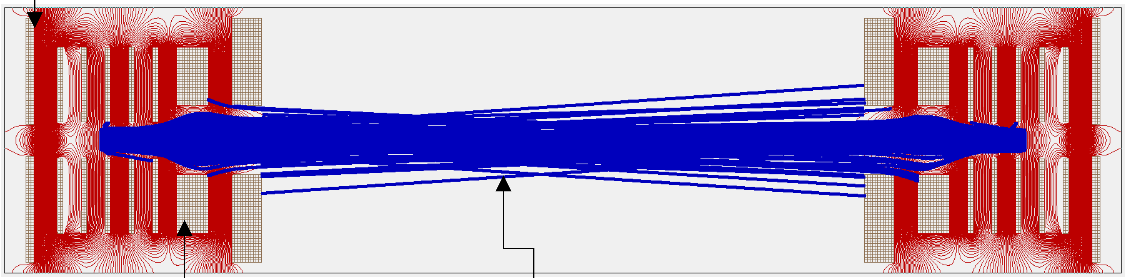


zone of interest
(radial motion is stable)

  - SIMION :
    - charged particles behaviour in electrostatic and magnetic fields
    - for A_r^+ at $E_k = 4{,}5$KeV: $V1 = 6750V,\ \ V2 = 5850V,\ \ V3 = 4150V,\ \ V4 = 1650V,\ \ Vz = 3650V$

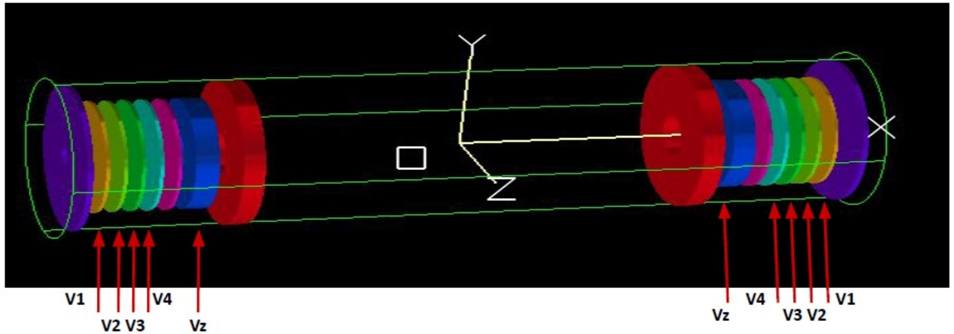
      ➔ *57% trapped up to 0,6ms*

$\vec{E}$ field lines

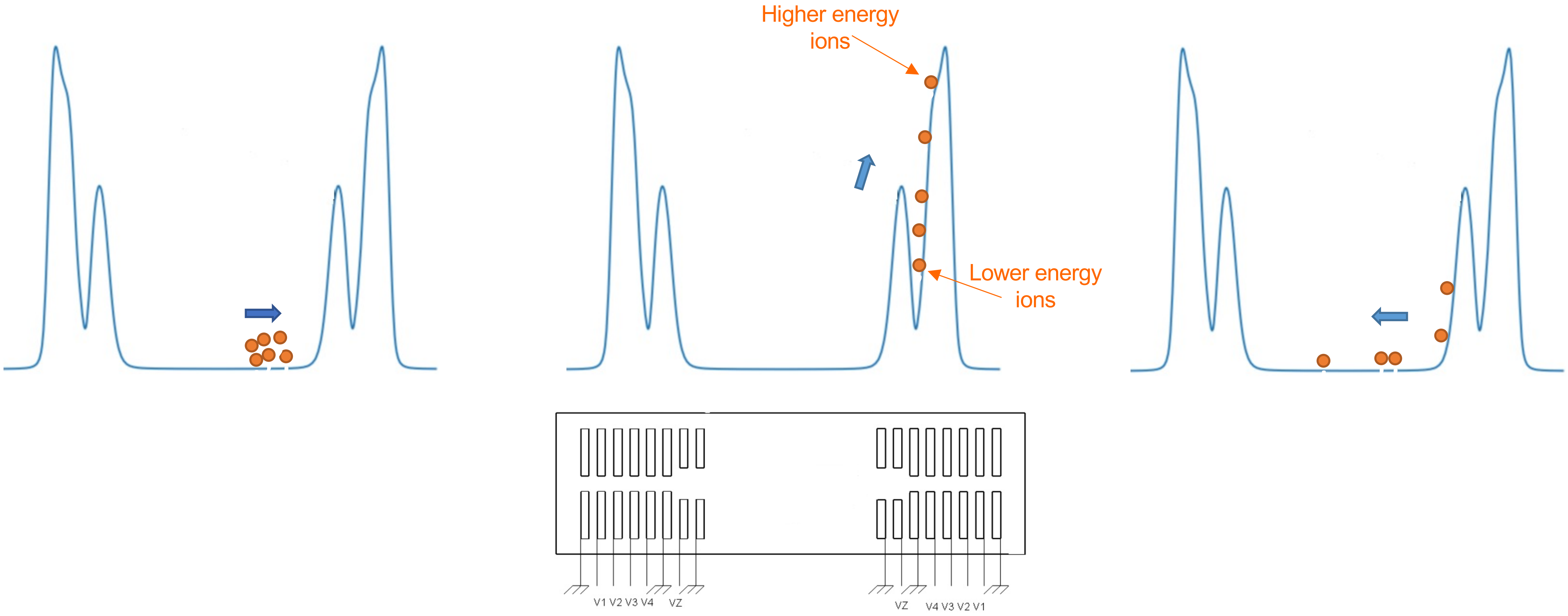


Electrode with applied potential

Ions trajectory

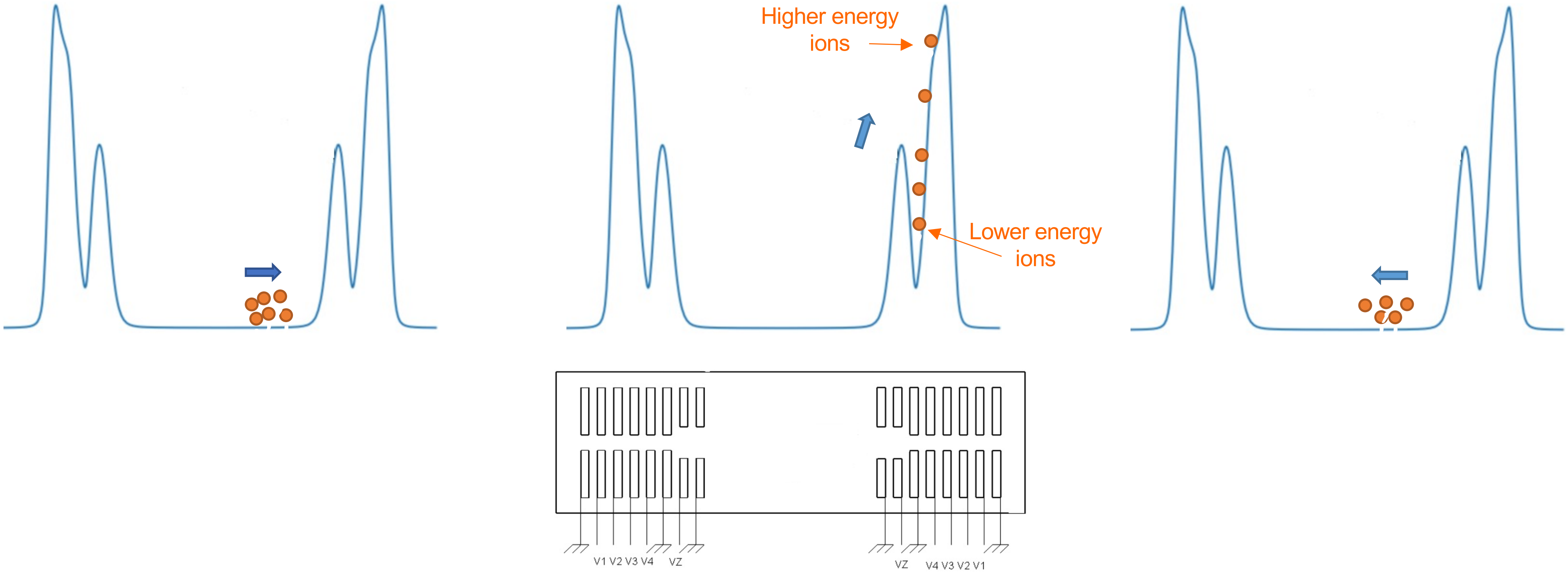


- Tunning the trap:
  - Energy spread ➔ enlargement of the ion bunch longitudinally



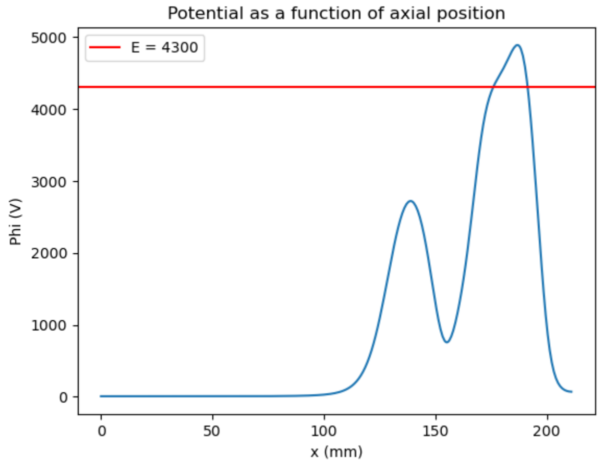
- Tunning the trap:
  - Slip factor η:
    - $\eta = \frac{\Delta f / f}{\Delta E / E}$, express the separation of the ions in the bunch
    - Condition to maintain bunch compactness : $\eta < 0$ & $\eta \sim 0$

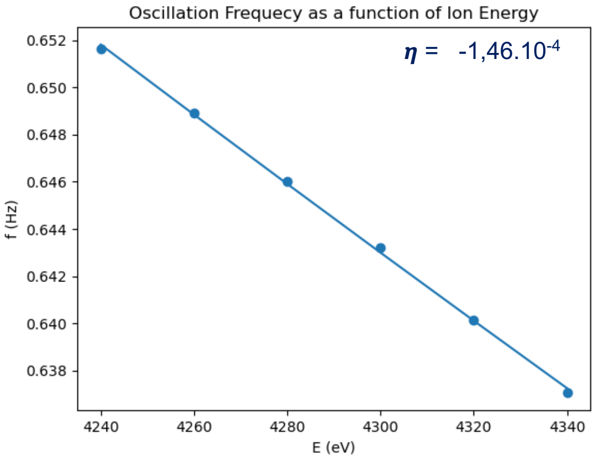
f : ions oscillation frequency in the trap
E : energy of the ions



- Tunning the trap:
  - for A_r^+ at $E_k = 4{,}3\text{KeV}$: $V1 = 5800V,\ V2 = 4450V,\ V3 = 4450V,\ V4 = 1356V,\ Vz = 3796V$
    ➔ *100% trapped for over 80ms*

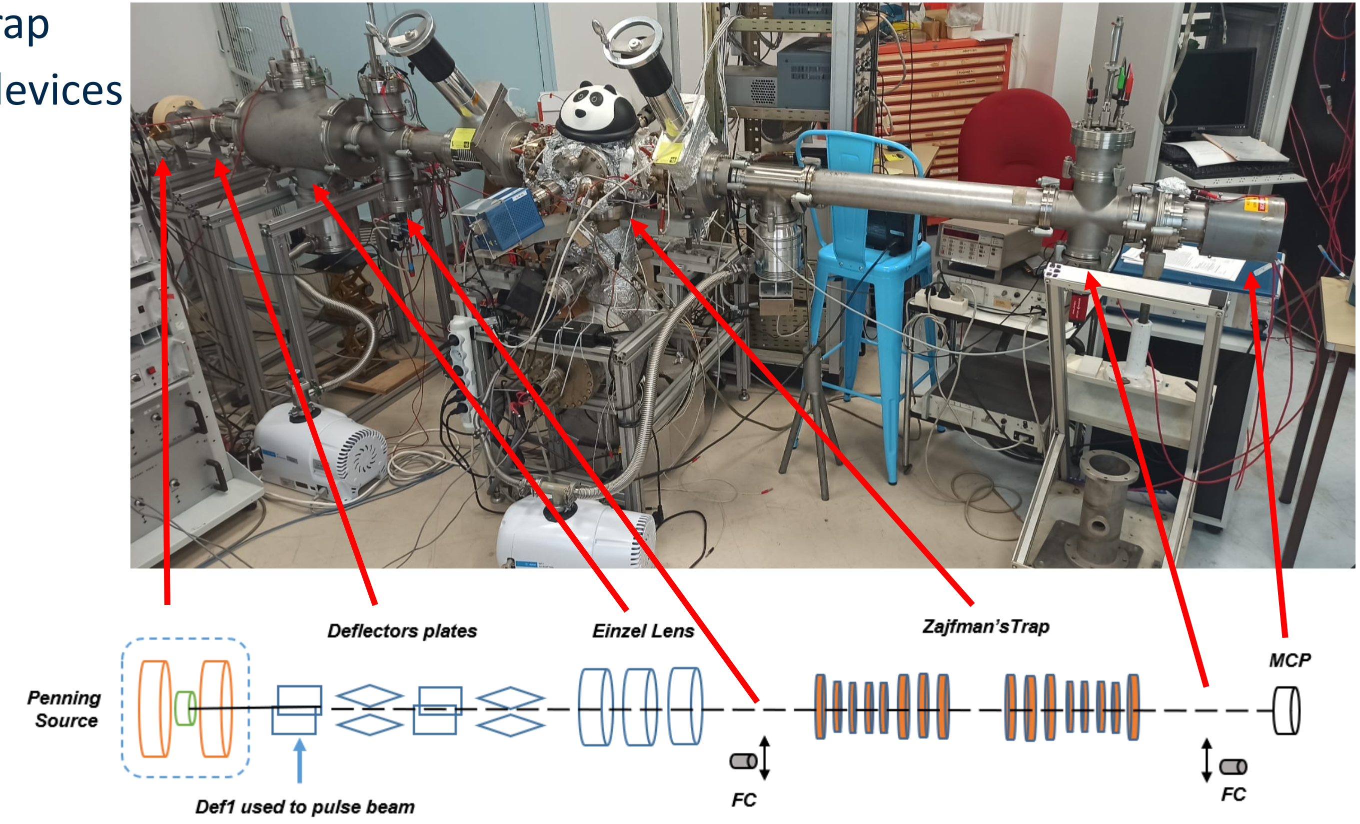
Reminder : $\eta = \frac{\Delta f/f}{\Delta E/E}$





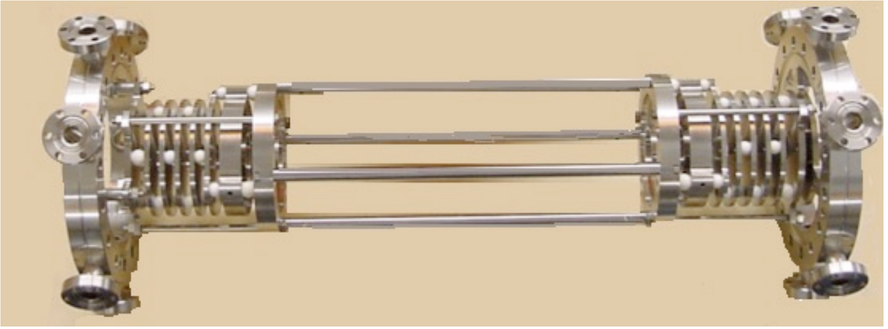
Applications

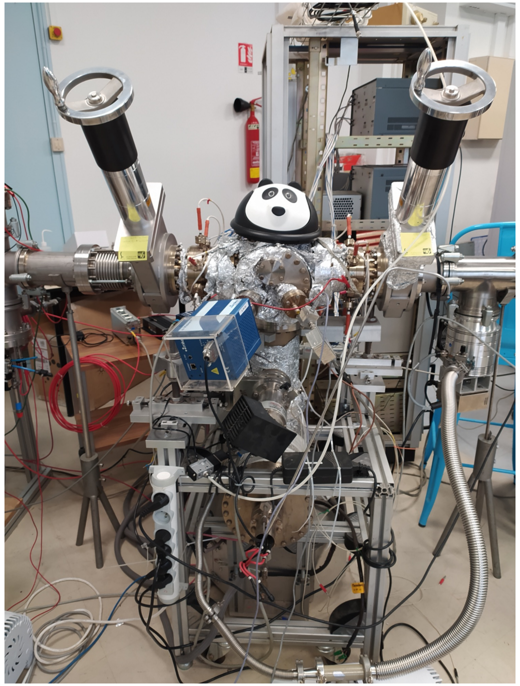
- Developement Set up:
  - penning source to create ions (energy spread ~100eV)
  - different optical devices to pulse and optimise ion beam
  - Zajfman's Trap
  - diagnostic devices

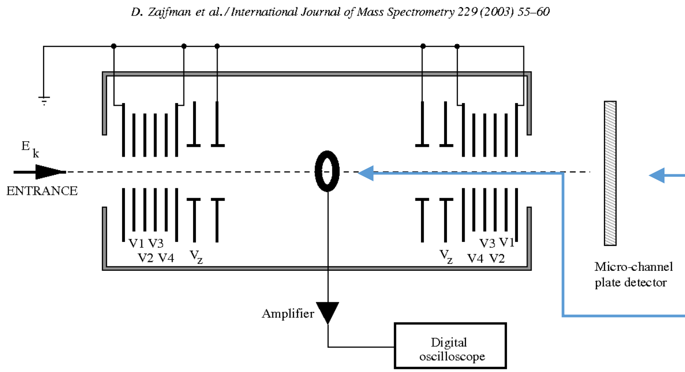


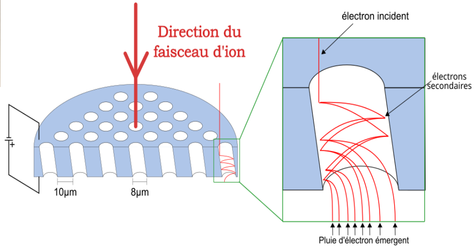
Applications

- Prototype: made by Dina Attia in 2007 (LKB)
  - MCP detector for TOF (destructive)
  - Pick up electrode for TOF (non destructive)



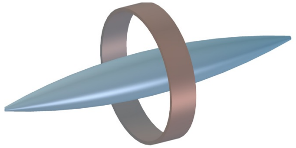






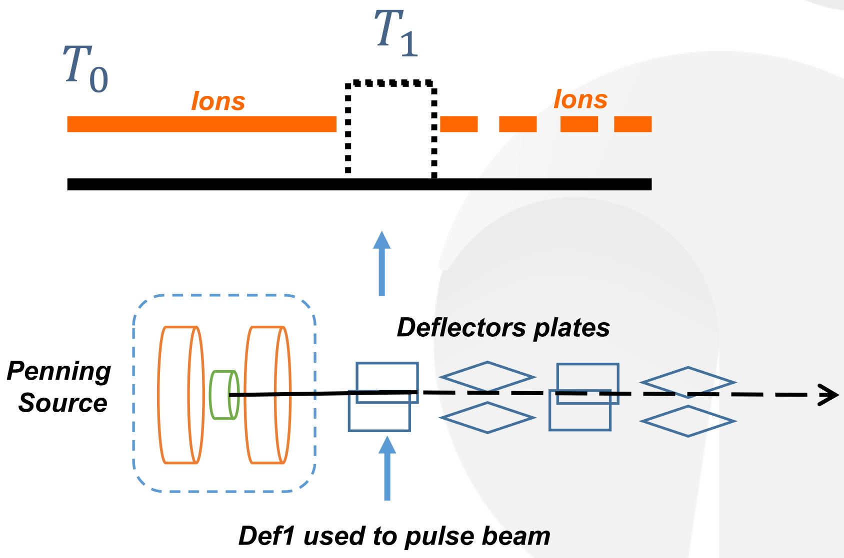
MCP

Pickup electrode

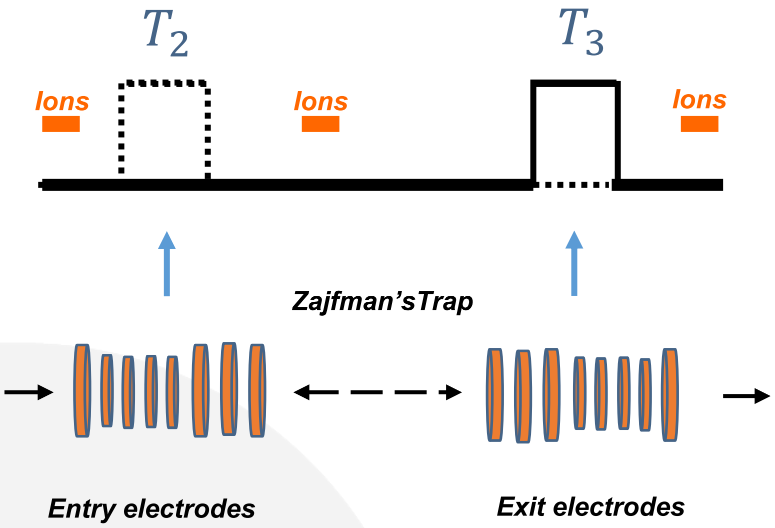


Timing

- Beam gate (deflector plate)
  - Potential applied to «cut» the beam
    - If no switch : potential to 0V



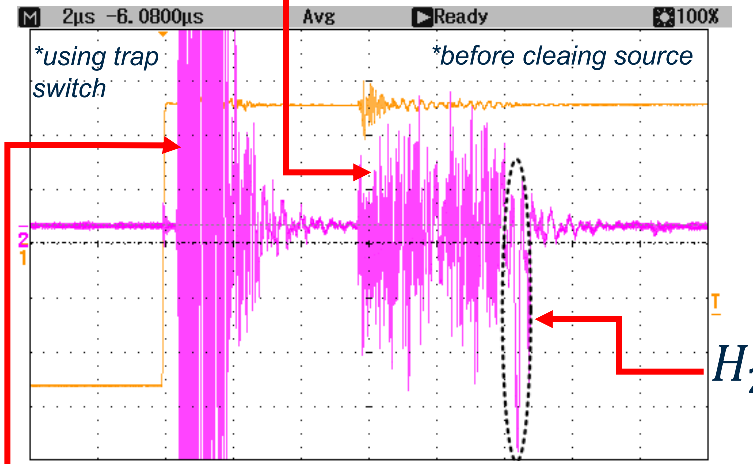
- Trap
  - Potential applied to trap de ions
  - Two separate switches :
    - If no switch at entry : potentials to 0V
    - If no switch at exit : potentials to V1,V2V3,V4,Vz



- With H_2^+:
  - at E_k≈2KeV:
    - *V1 = 2826V, V2 = 2168V, V3 = 2168V, V4 = 661V, Vz = 1850V*
    - *Trapping time up to 80us ~ 40 revolutions (very low signal)*

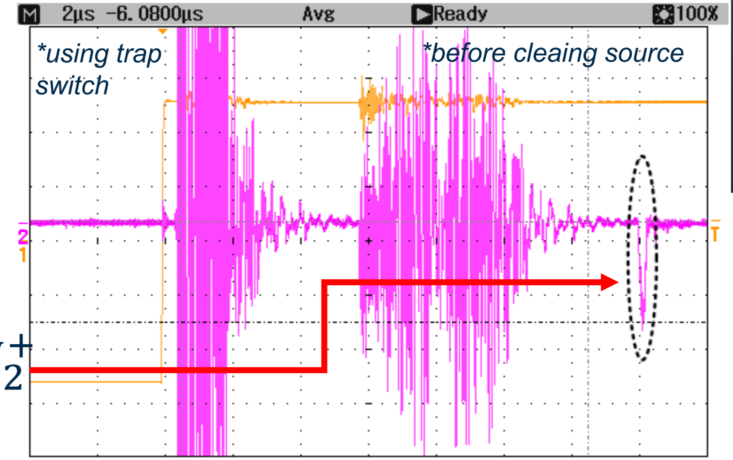
Trap switch noise

Buncher switch noise

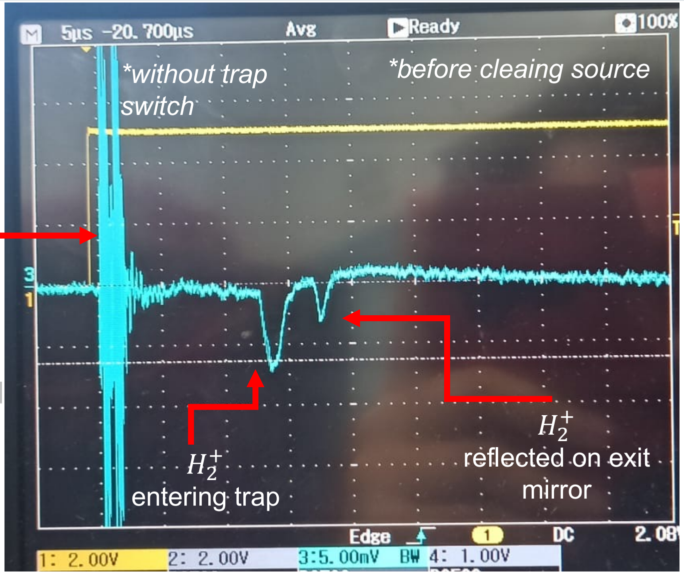


Signal on MCP for a shoot throught, ToF = 10,85us.

H_2^+



Signal on MCP for one revolution, ToF = 13,69us.



Signal on MCP for one revolution, ToF = 13,69us.

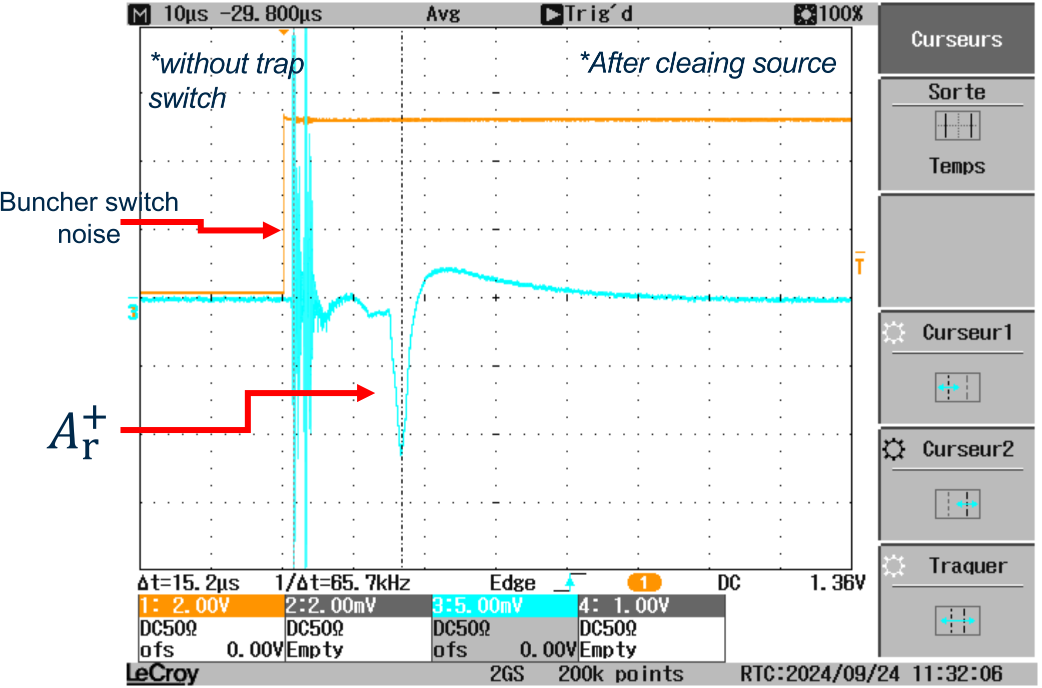
Buncher switch noise

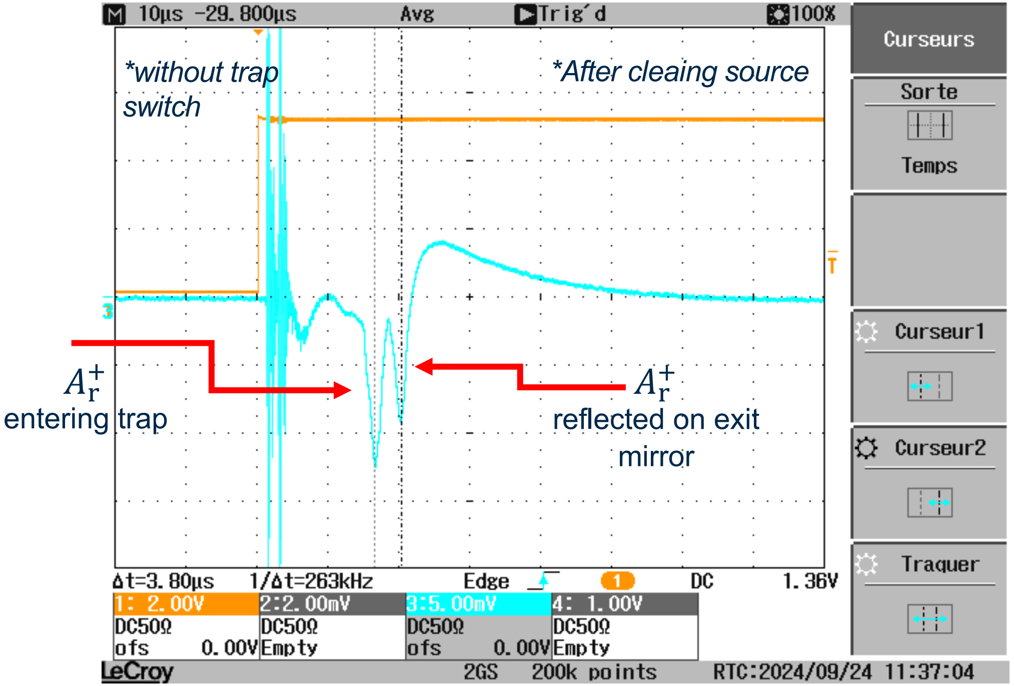
- Detection on PickUp
- Detection on MCP

Courtesy of Maxime

- With Ar^{+}:
  - at E_k≈3KeV:
    - *Trap entry : V1 = 4760V, V2 = 3528V, V3 = 3535V, V4 = 959V, Vz = 2908V*
    - *Trap exit : V1 = 4754V, V2 = 3543V, V3 = 3510V, V4 = 930V, Vz = 2916V*
    - *Trapping for half a revolution (~ 4us)*

Detection on PickUp

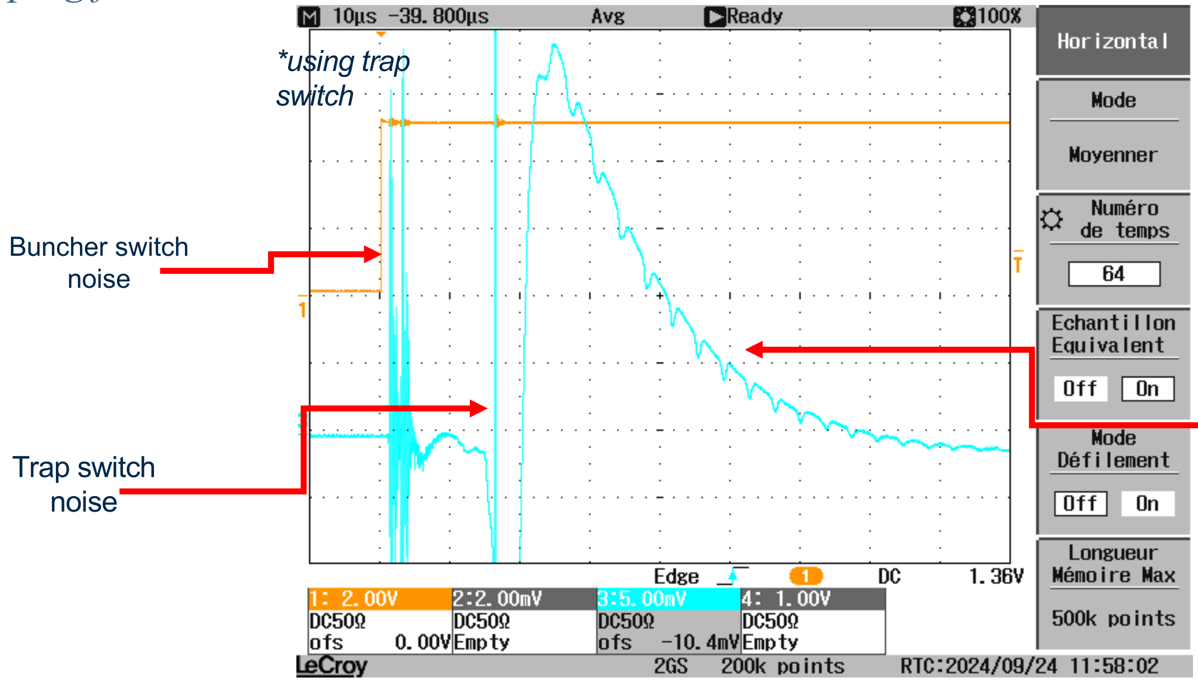




Courtesy of Michele

Measurements

- With Ar^+:
  - at $E_k \approx 3\text{KeV}$:
    - *Trap entry : V1 = 4756V, V2 = 3570V, V3 = 3399V, V4 = 925V, Vz = 2663V*
    - *Trap exit : V1 = 4730V, V2 = 3553V, V3 = 3345V, V4 = 928V, Vz = 2699V*
    - *Trapping for ~ 80us, 10 revolutions*

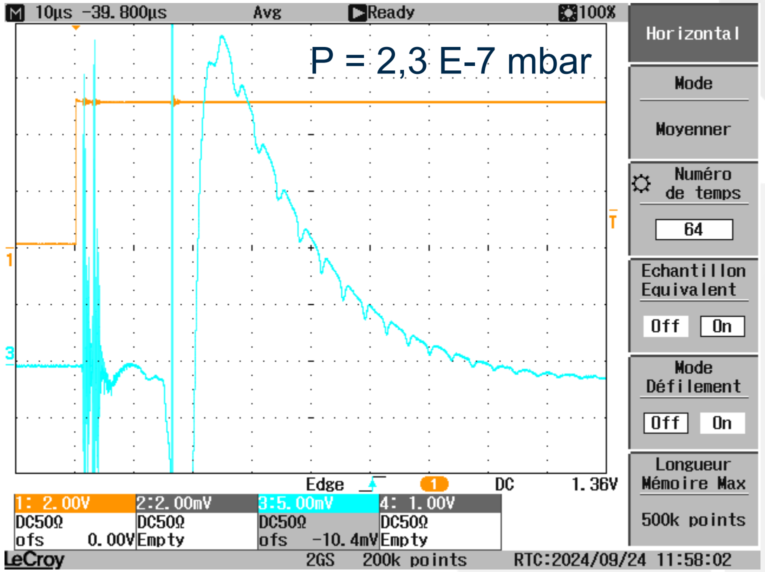


Detection on PickUp

A_r^+ ion bunch decaying over time !

Courtesy of Michele

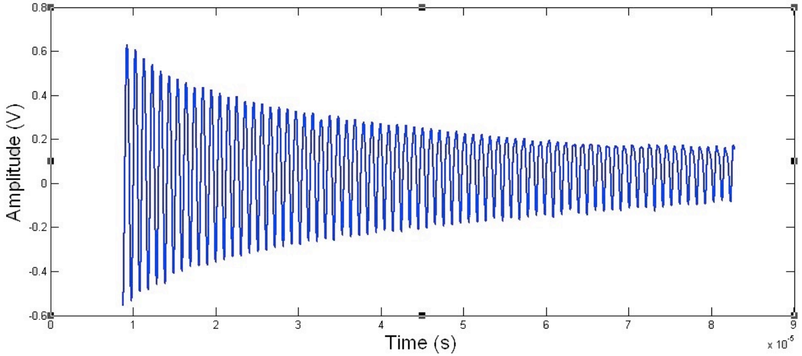
- Our's



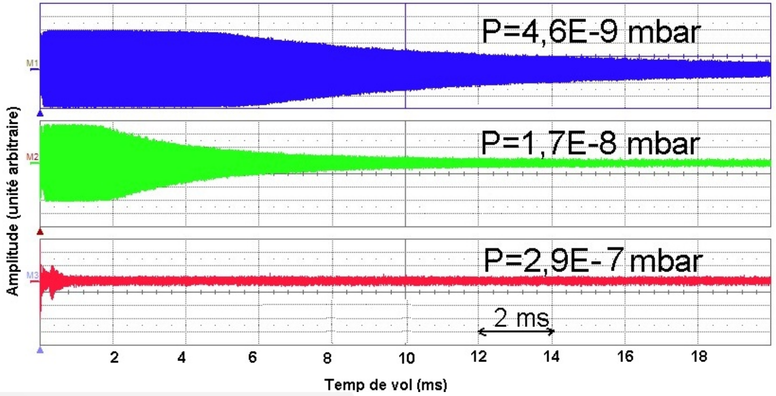
Trapping of A_{r}^{+} ions

clean signal
and
higher vaccum
needed !!!

- Dina's

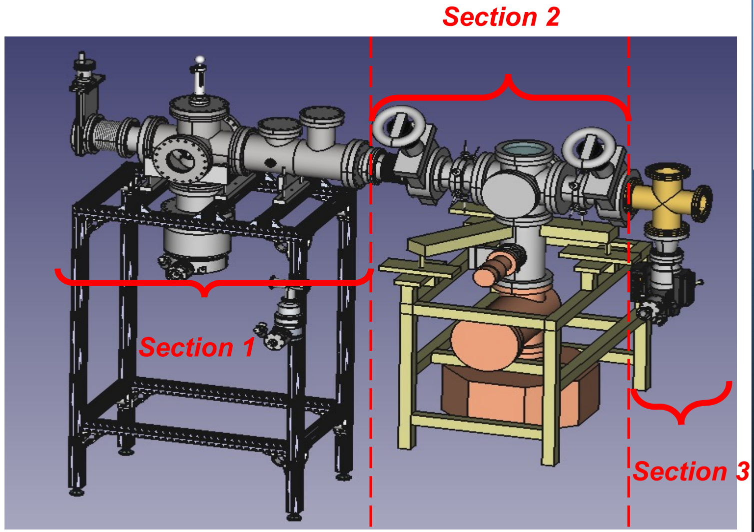


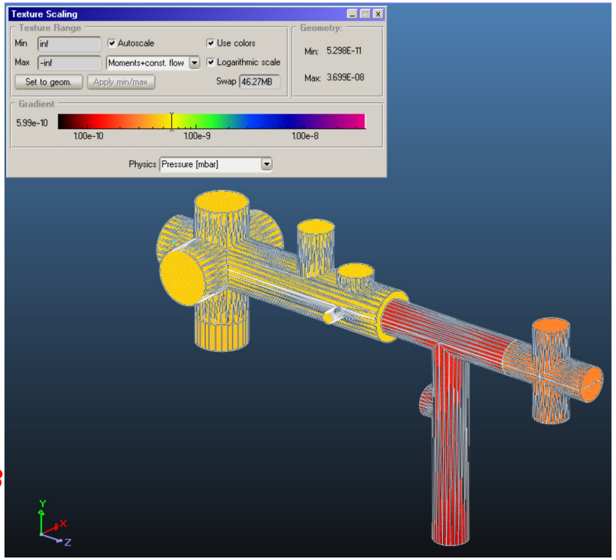
Trapping of A_{r}^{10+} ions

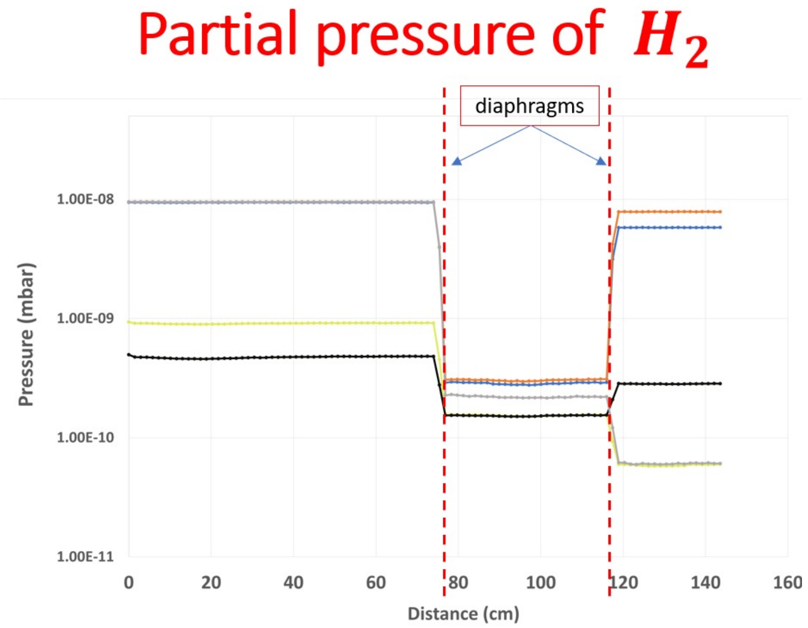


Trapping of A_{r}^{11+} ions

Simulation for vacuum (Molflow)







500 l/s

TMP (Section 1)

Ionic (Section 2)

250 l/s

TMP (Section 3)

100 l/s

Back pressure (pumps on):
$1.3 \cdot 10^{-4}$ mbar

Back pressure (pumps on):
$1.3 \cdot 10^{-4}$ mbar

TMP (Common forepump)

50 l/s

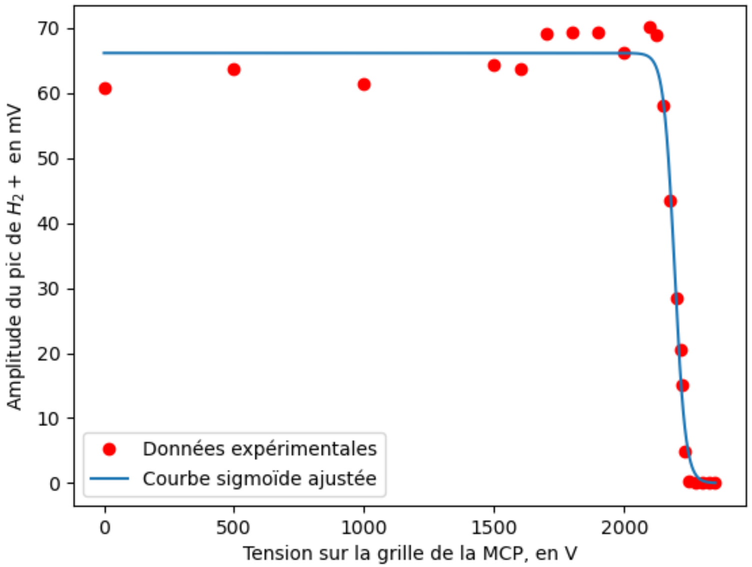
Perspectives

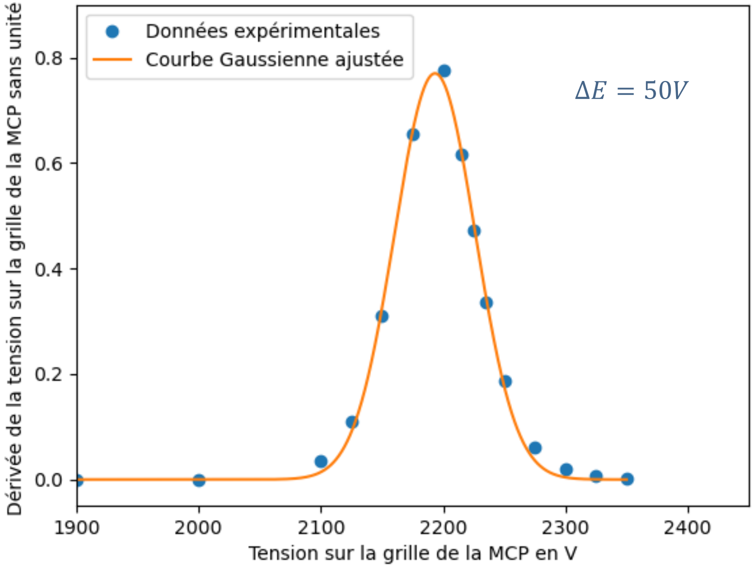
- What next ?

  - Tests : (end 2024)
    - Applying simulations results for Ar+ on prototype
  - Improvements : (2024-2025)
    - General optimisations of the trapping parameters
    - Solving noises issues on Pick-Up and MCP
    - Attaining higher vaccum
    - New electronic for switches
  - Multicharged ions : (Tancrede commissioning 2025)
    - Simulations and tests
  - InTrap Decay : (2026)
    - Developing and implementing decay detection devices

Thank you for your attention !

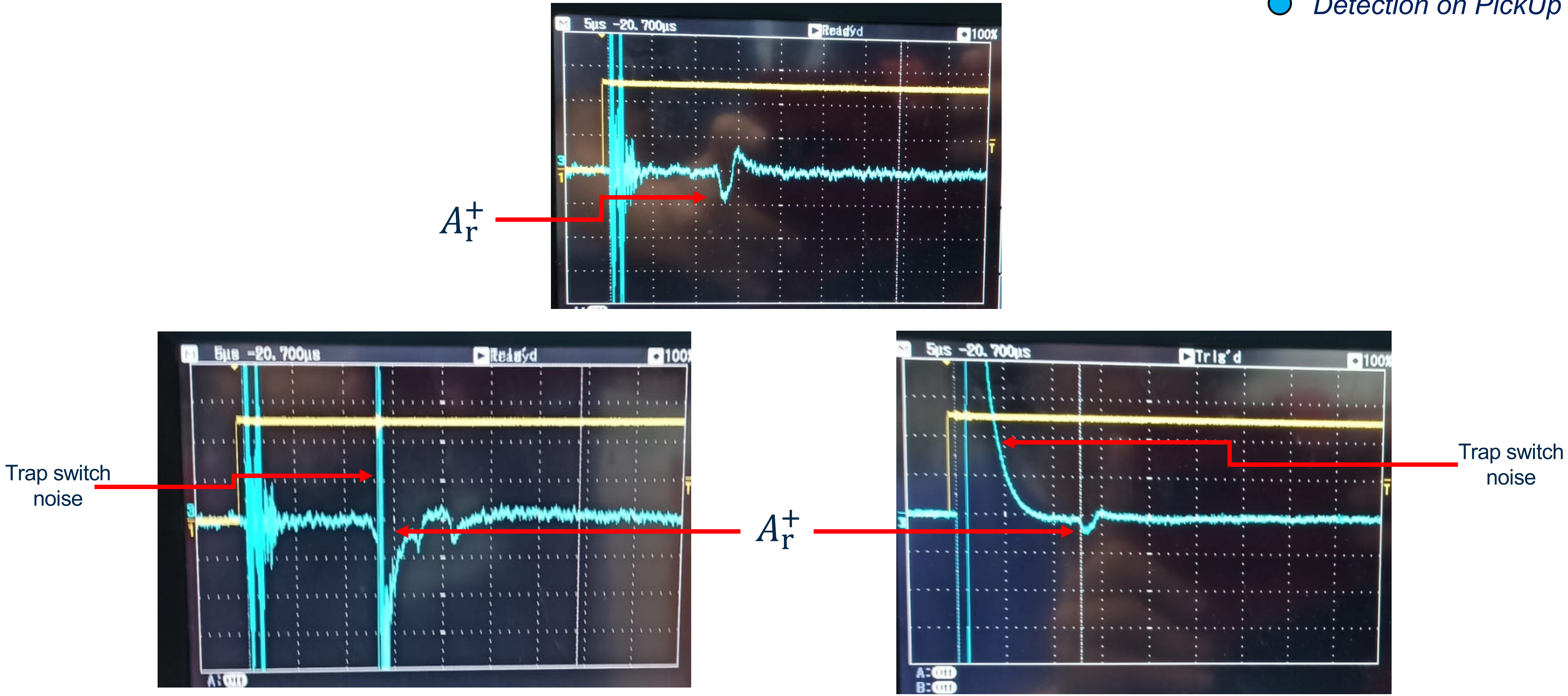
- Energy spread from Penning ion source:





- Noises induced from switches :

Detection on PickUp



Physical context

- Study of highly charged ions for nuclear astrophysics:
  - Stelar medium full of highly charged / bare nuclei
  - Decay path of instable nuclei important for nucleosynthesis
    - ➢ Can change with charge state
  - Beta bound decay (predicted in 1947, observed in 1992)
    - ➢ Explain abundunces of some elements
    - ➢ s – process (slow neutron capture)