17 > 21 OCTOBER
CAEN
GANIL COMMUNITY MEETING
2022

PIPERADE
PIEGES DE PENNING POUR LES RADIONUCLEIDES A DESIR

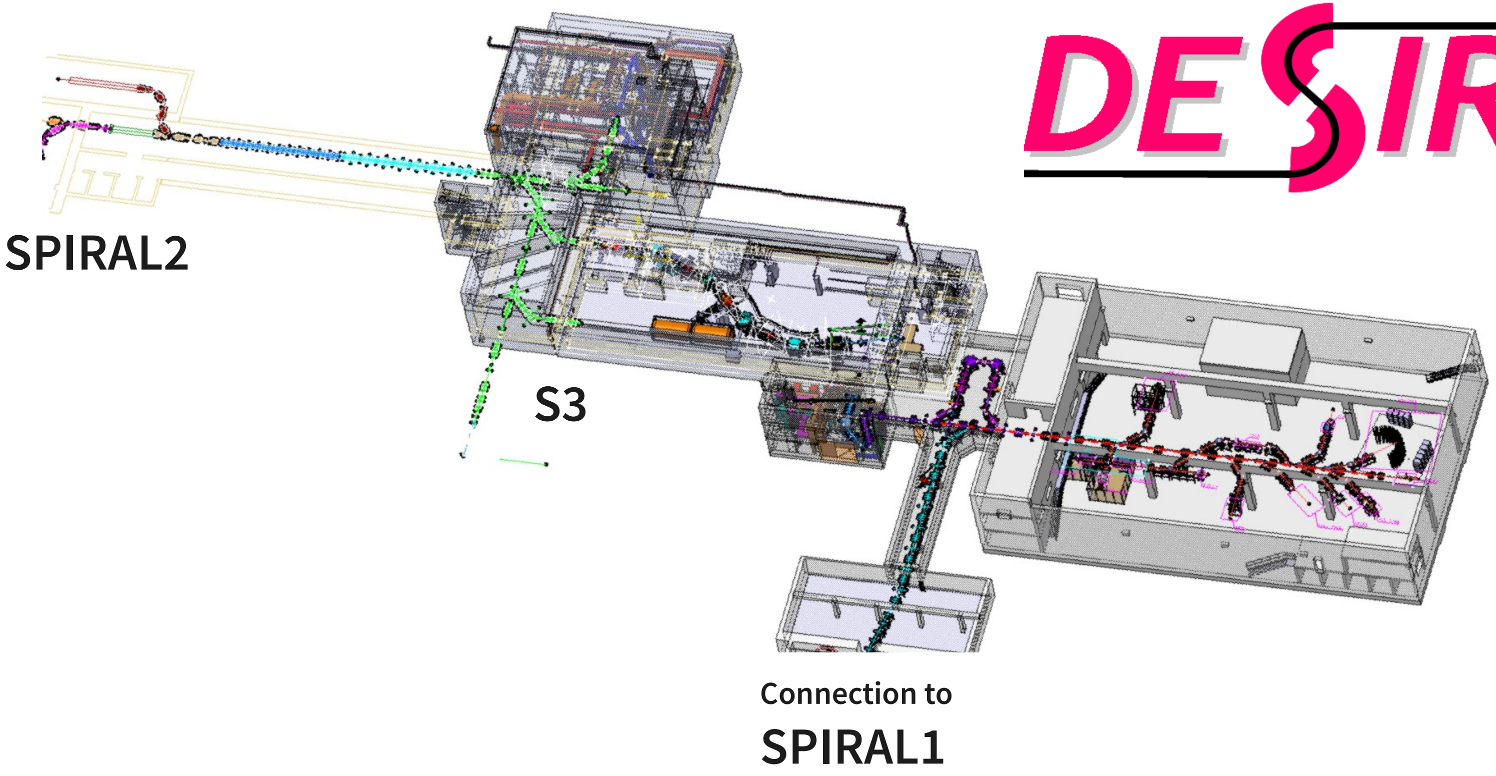
Status & first results of GPIB & PIPERADE beamline

Audric HUSSON, LP2i Bordeaux, GANIL Community Meeting 2022,

DESIR
université de BORDEAUX
cnrs
LP2i Bordeaux

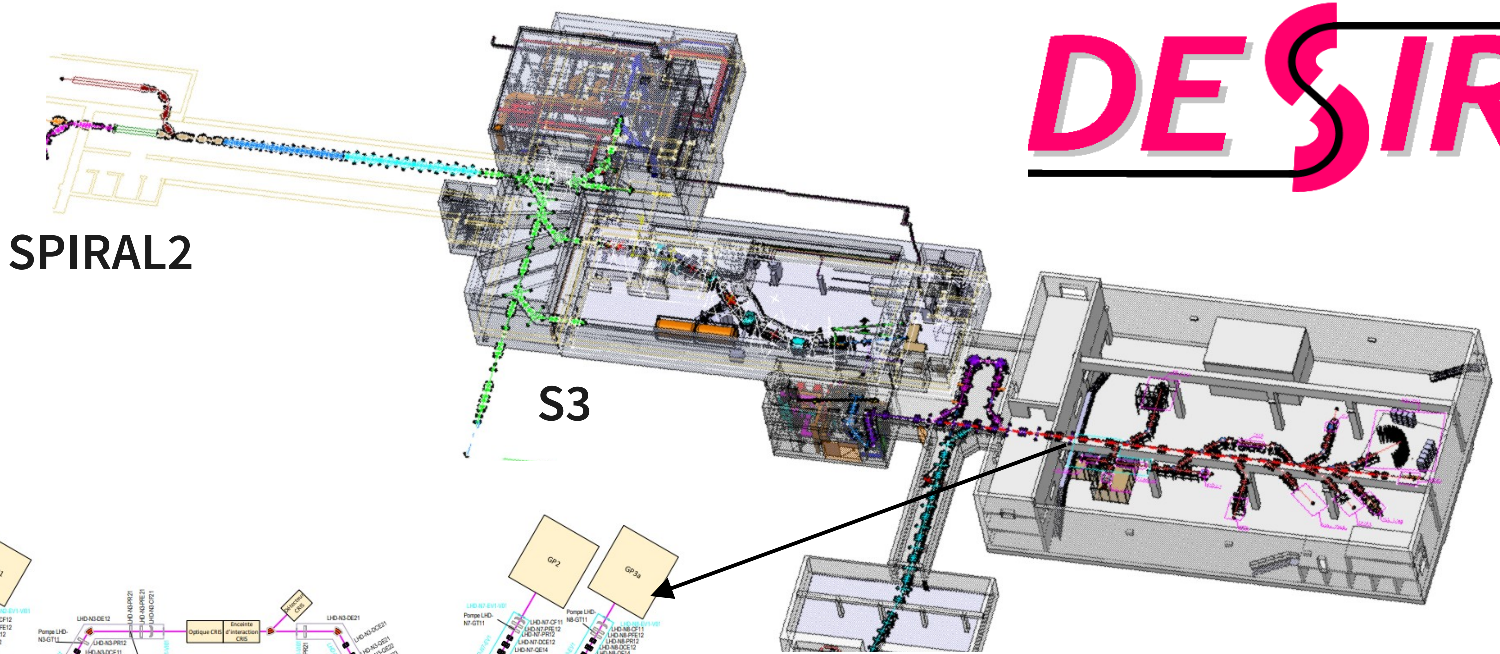
Context

DESIR



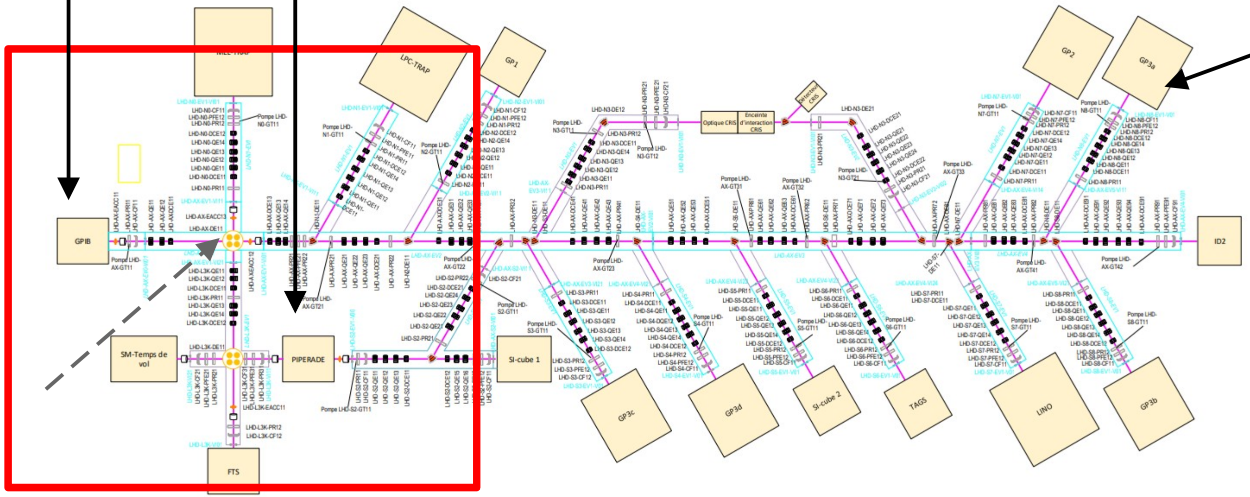
Context

- Dedicated to beam purification and preparation



Connection to

SPIRAL1



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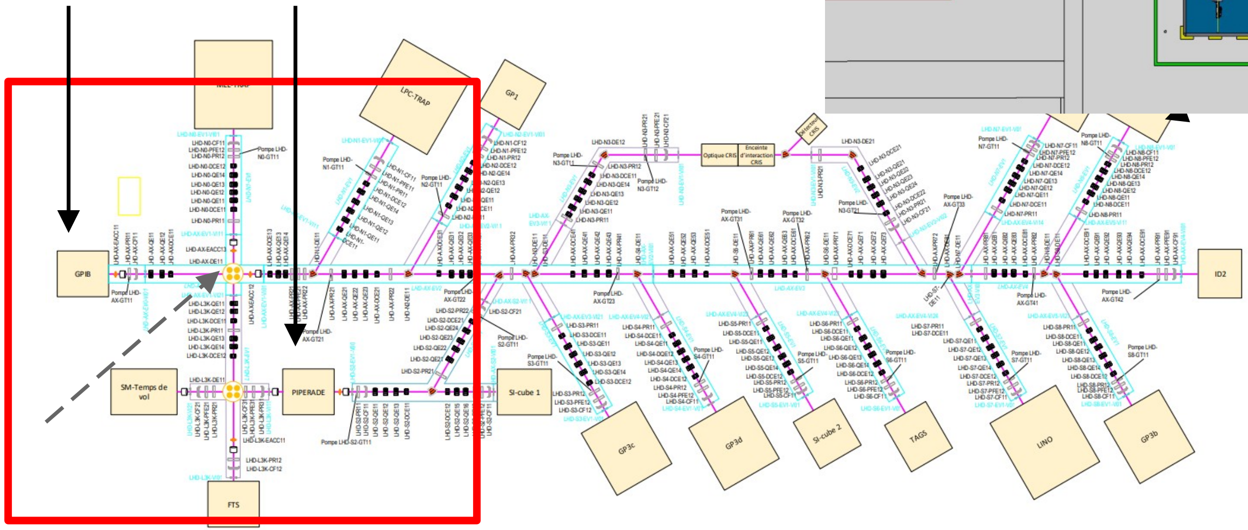
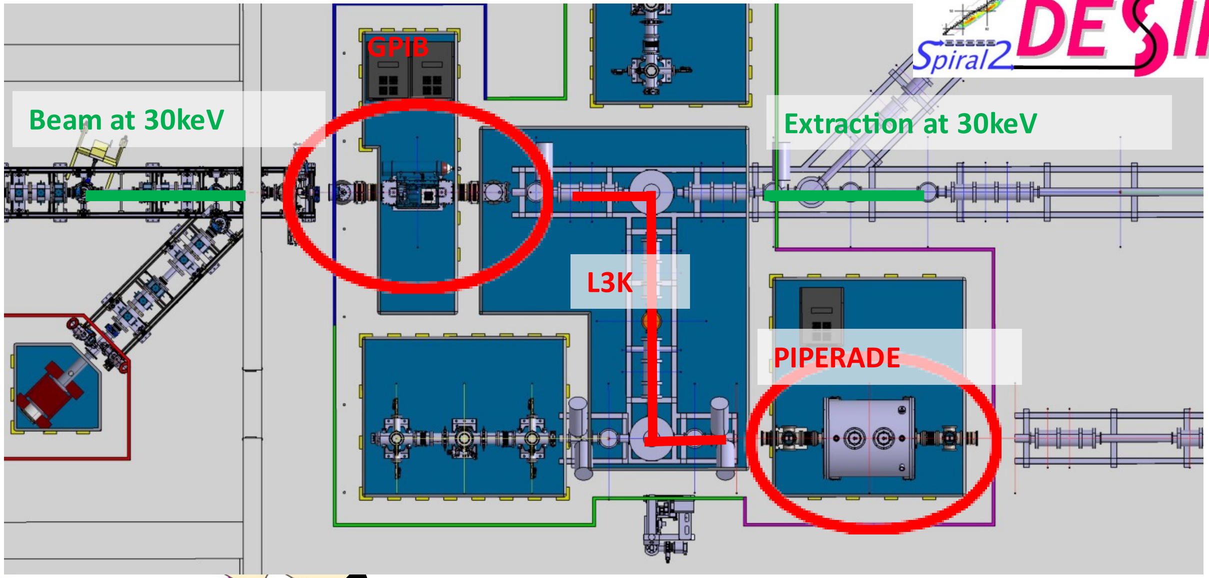


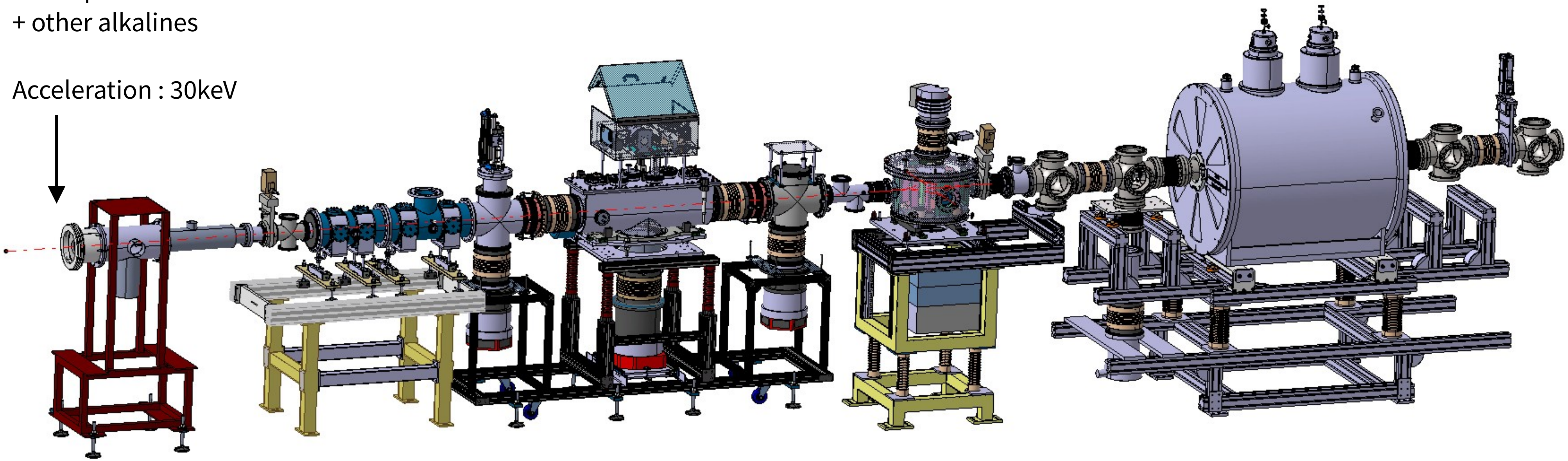


At LP2i Bordeaux

FEBIAD source
Produce alkaline
(surface ionization)

Main species – ^{39}K
+ other alkalines

Acceleration : 30keV



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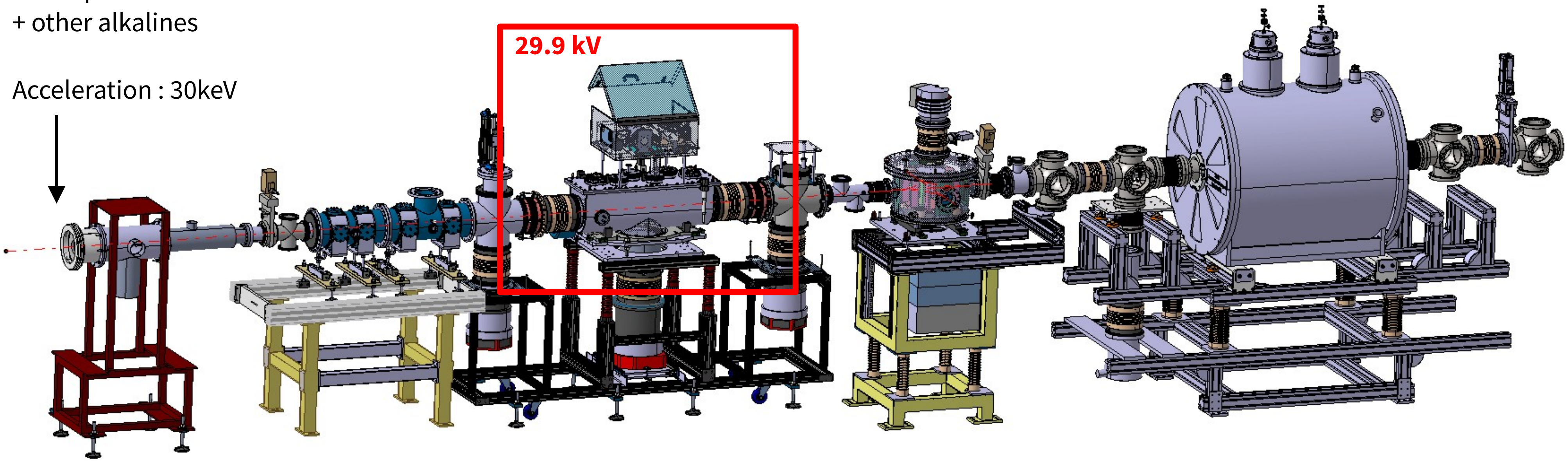
GPIB Cooler-Buncher

RFQ trap filled with He gas

- cooling via gas interaction
- bunching



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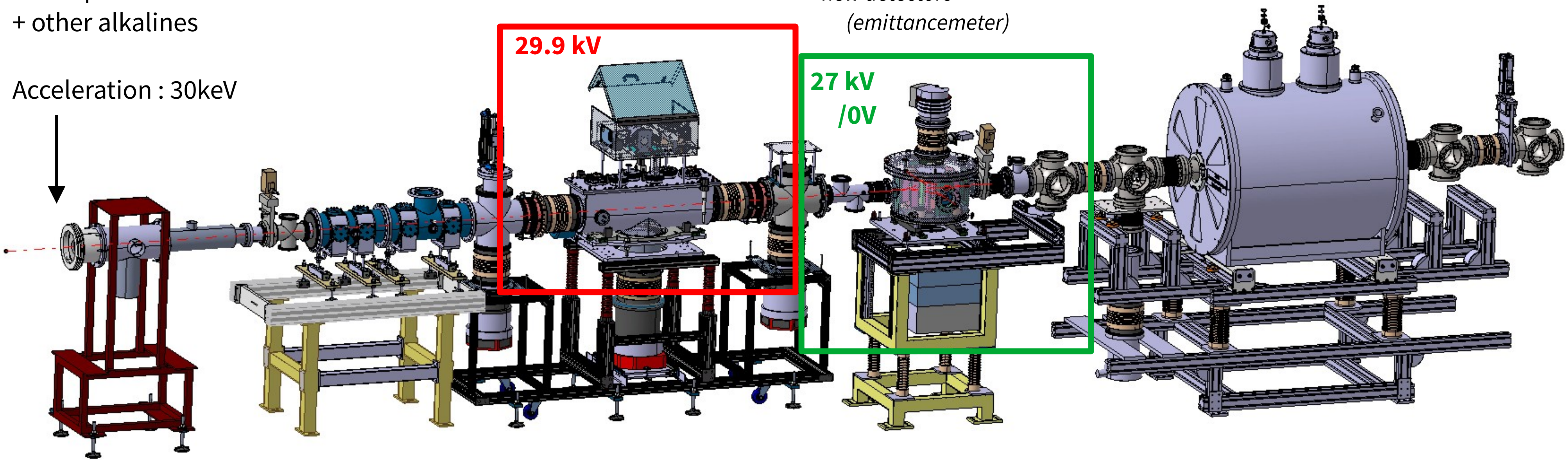
L3keV line

90° electrostatic deflector

- *new alkaline source*
- *new detectors (emittancemeter)*



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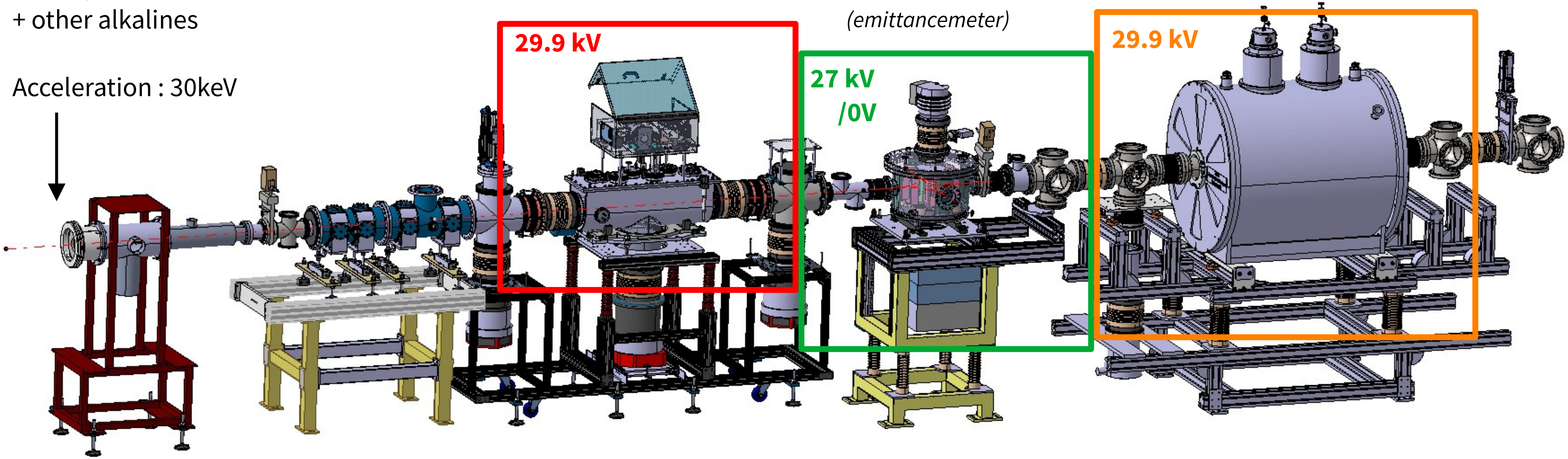
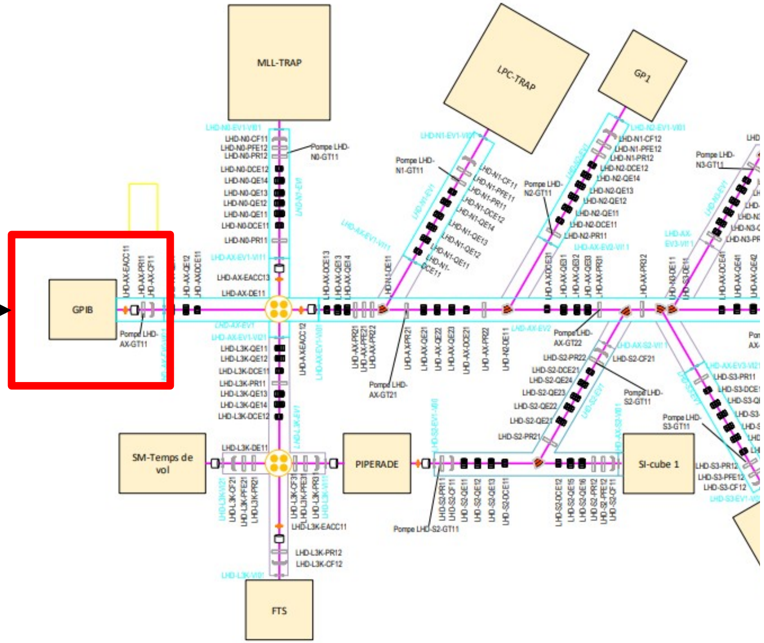
PIPERADE
double Penning trap

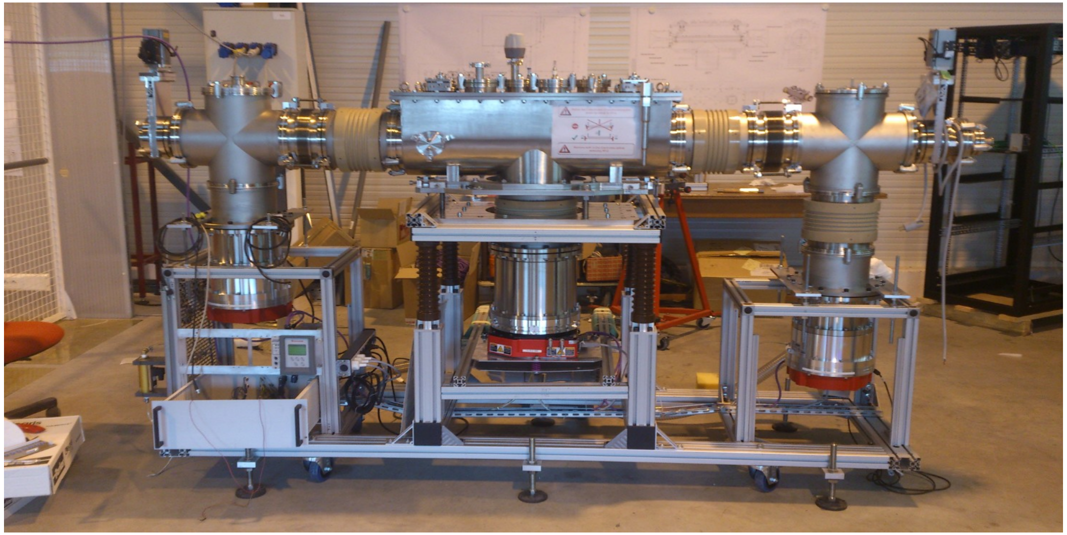
- *7T superconducting magnet*
- *beam purification*
- *mass measurement*



GPIB Cooler-Buncher

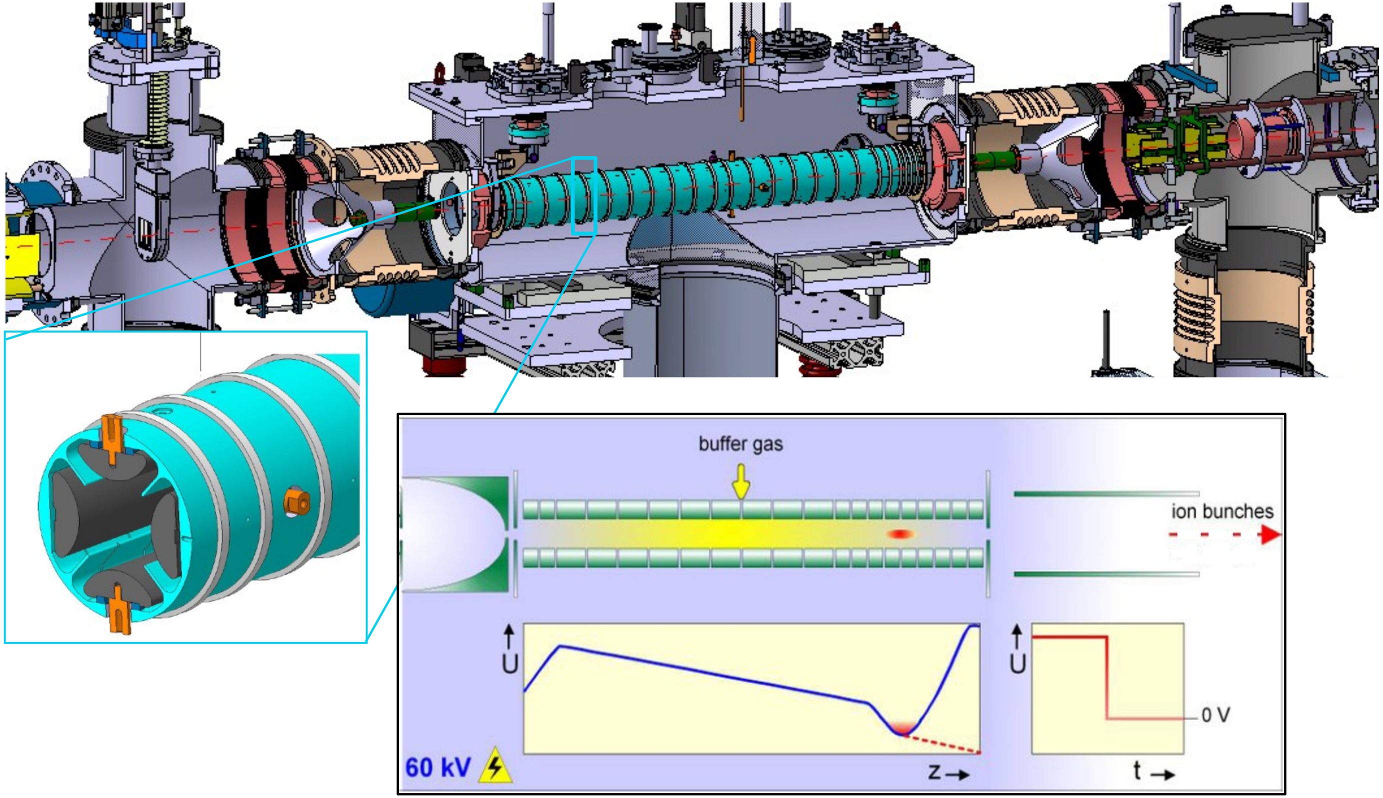


RIB from S3
or SPIRAL1



GPIB in the Hall de Montage before installation on the PIPERADE beamline

GPIB Cooler-Buncher ~~(chiller-gatherer)~~



RadioFrequency Quadrupole trap
(linear Paul trap)

Ion confined :

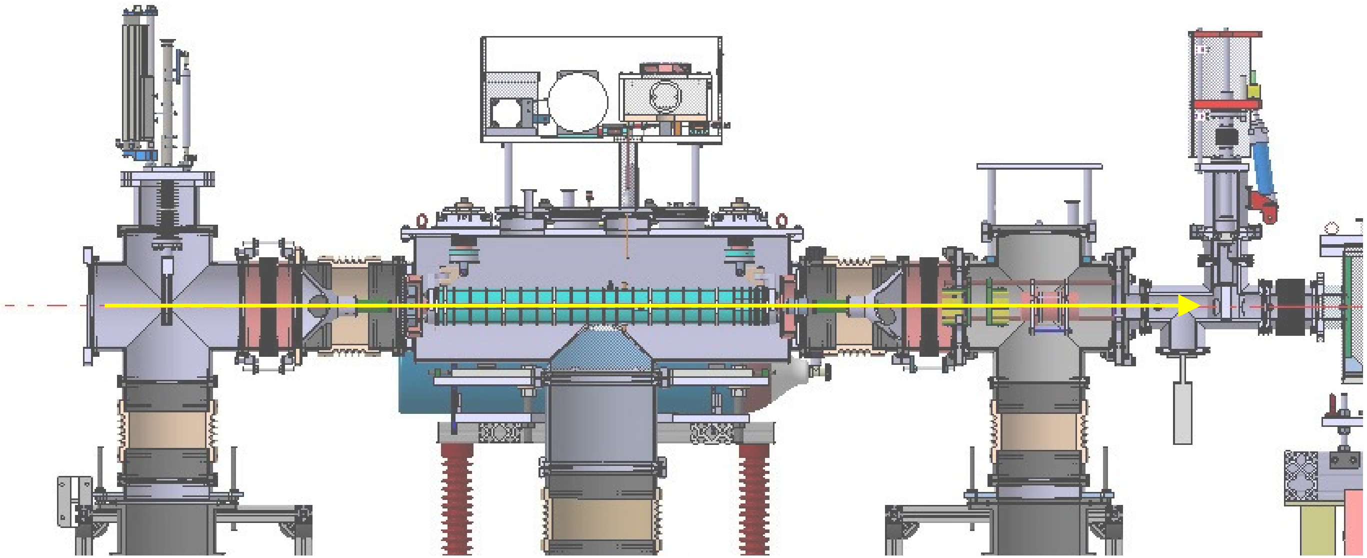
- radially : RF oscillating potential
  (saddle shape potential)
- longitudinal : arbitrary potential slope
  potential well at the extraction

Objectives :

- Cool down the ion beam
  emittance reduction down to
  10π mm.mrad @ 3keV
  4.5π mm.mrad @ 30keV
- Make bunches/packets of ions with specific characteristics
  bunch length < 1µs
  energy spread < 1eV

M. Gerbaux et al., The General Purpose Ion Buncher: a radiofrequency quadrupole cooler-buncher for DESIR at SPIRAL2, ***2022*** *(NIM), accepted*

GPIB Cooler-Buncher



RadioFrequency Quadrupole trap
(linear Paul trap)

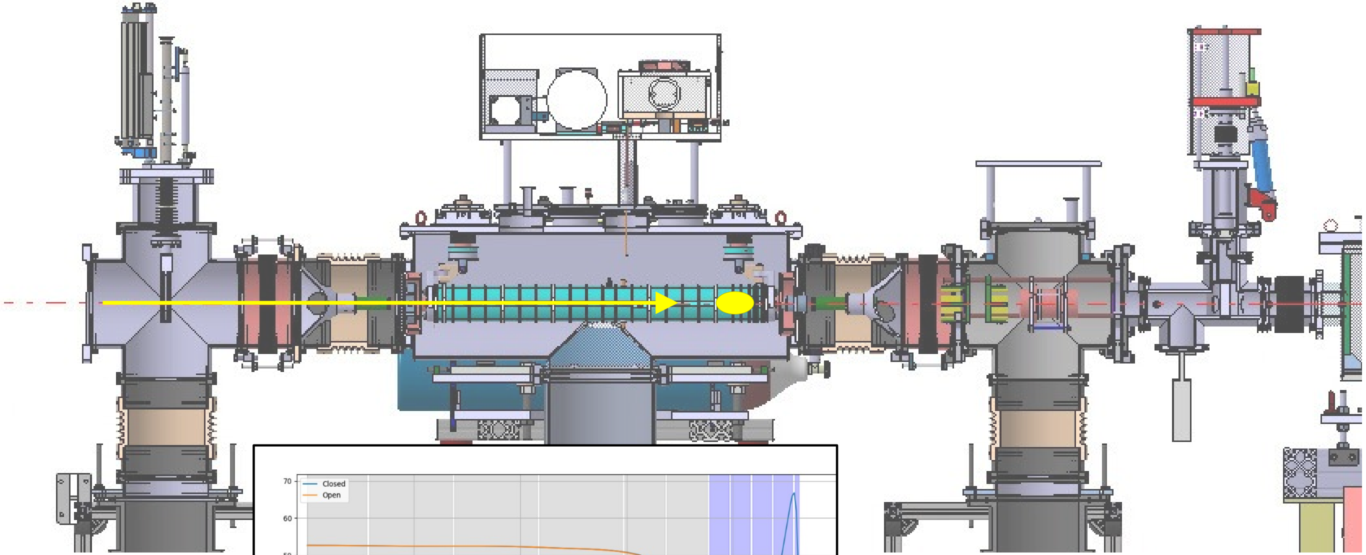
Two operation modes :

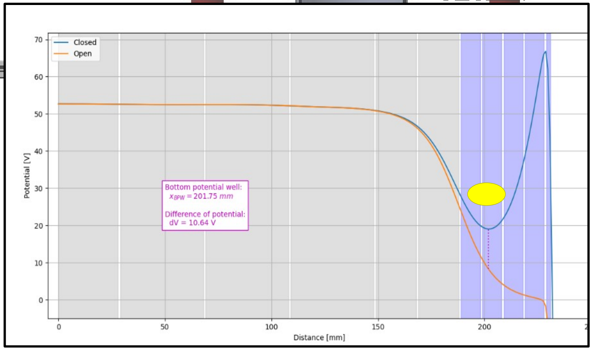
- continuous beam (CW)

→ *transmission*

→ *(later) emittance – spot size / divergence*

GPIB Cooler-Buncher





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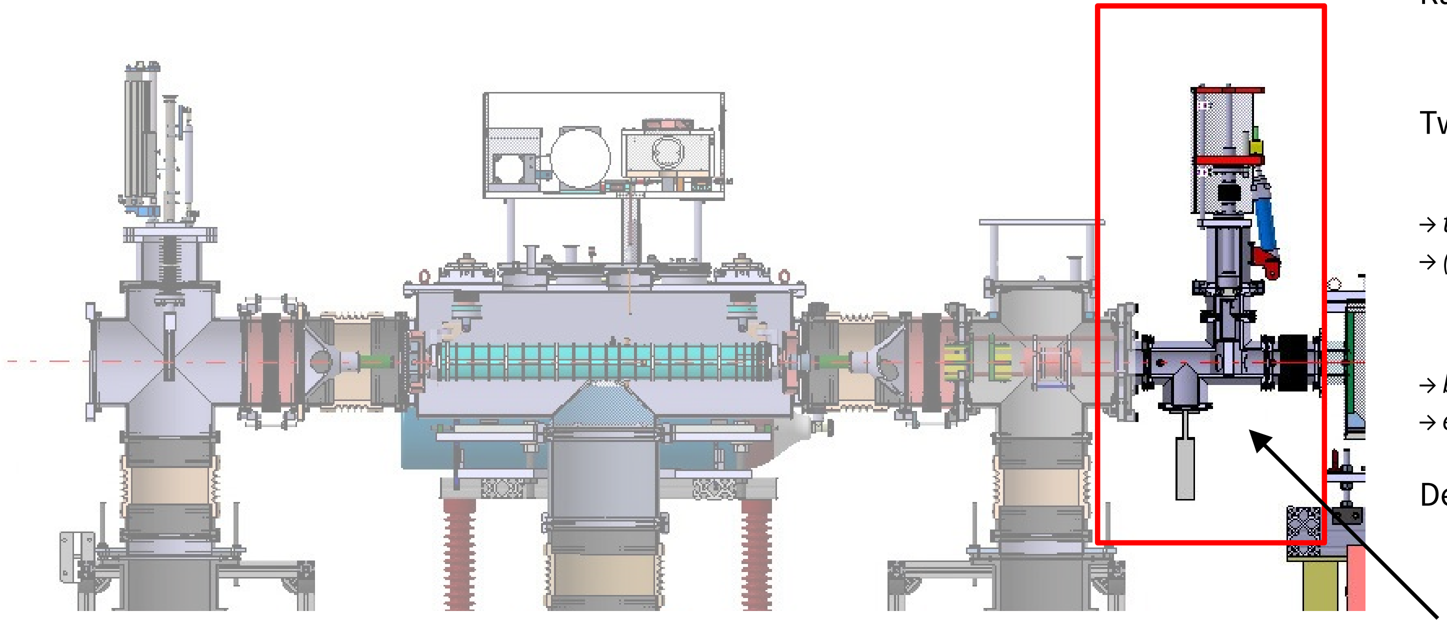
- bunch(ing) mode

→ *bunch length*
→ *energy spread*

GPIB Cooler-Buncher



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Two operation modes :

- continuous beam (CW)

→ *transmission*
→ *(later) emittance – spot size / divergence*

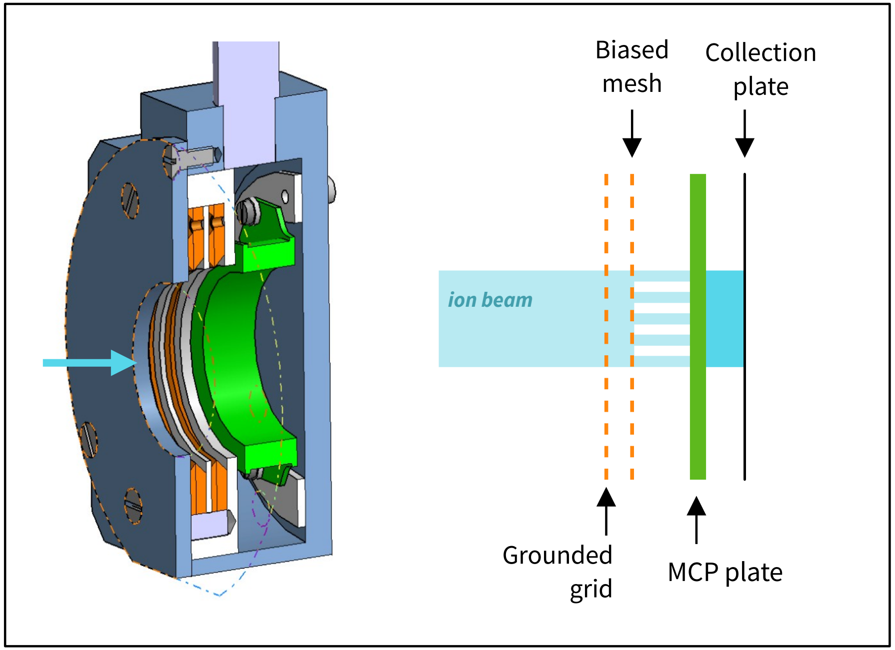
- bunch(ing) mode

→ *bunch length*
→ *energy spread*

Detectors :

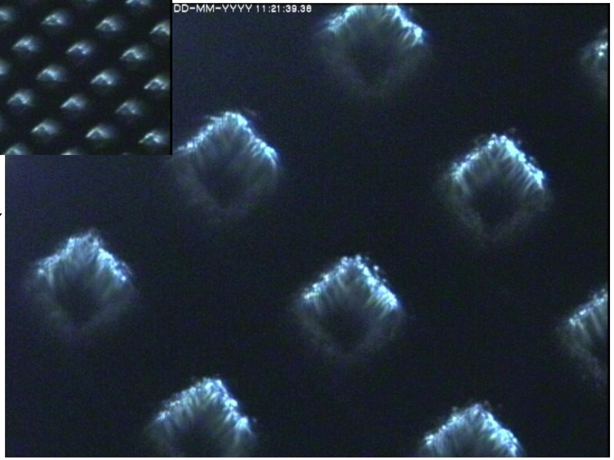
- Faraday cup → *beam current*
- MCP (micro-channel plate)
  + retarding grid
  → *detect bunch profile over time*
  → *scan the energy*
  → *longitudinal emittance*

GPIB Cooler-Buncher - MCP + Retarding grid



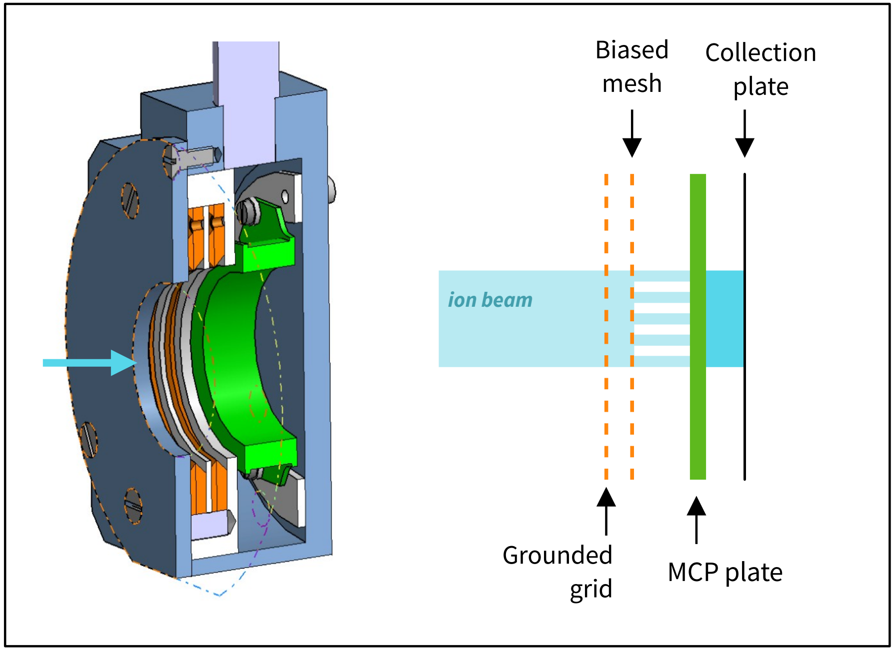
Electroformed Ni/Nickel mesh, *Transmission 10 %*

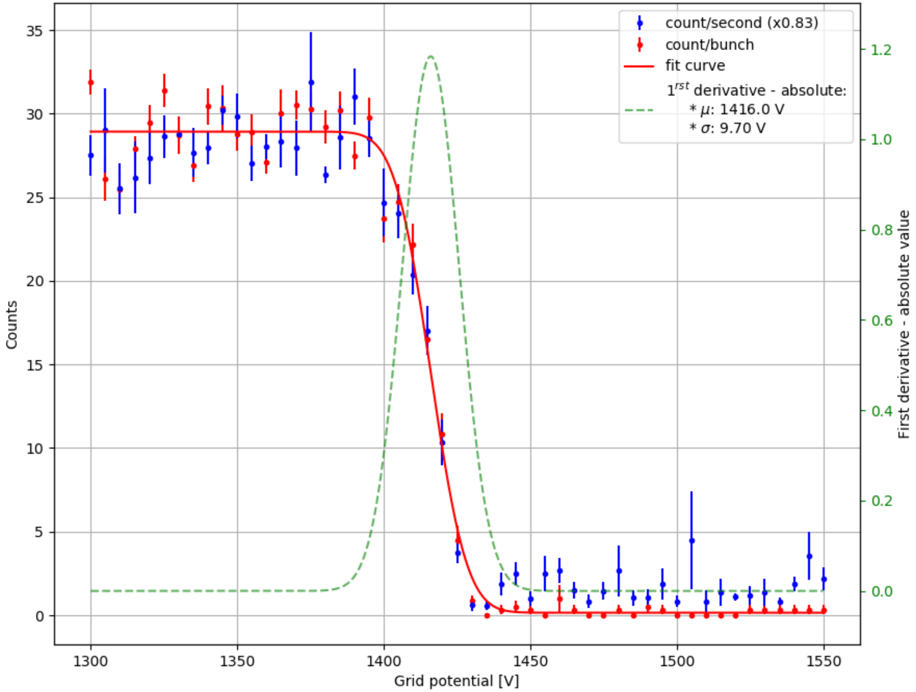
Cie : 10 %
Image : 13,6 %
Measure : 11,8 %



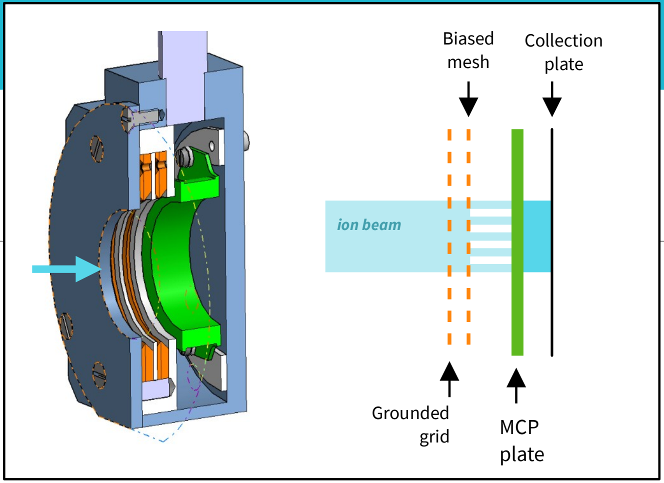
Micro-beam scan
AIFIRA facility, LP2I Bordeaux

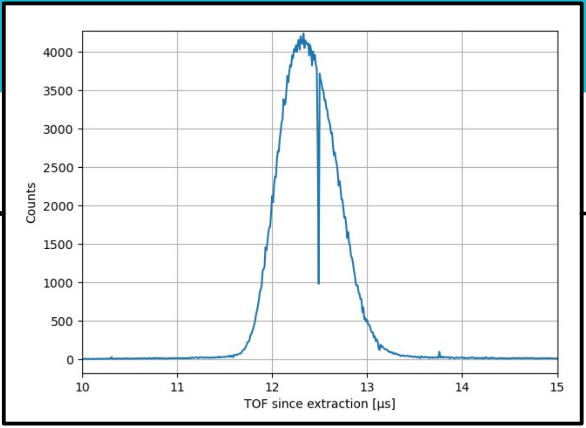
GPIB Cooler-Buncher - MCP + Retarding grid





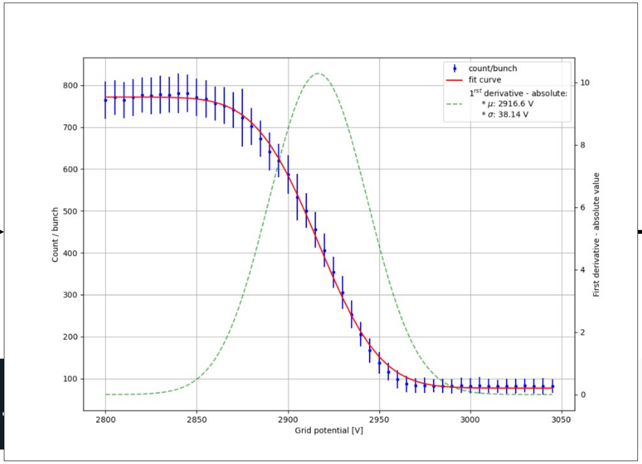
GPIB Cooler-Buncher - MCP + Retarding grid

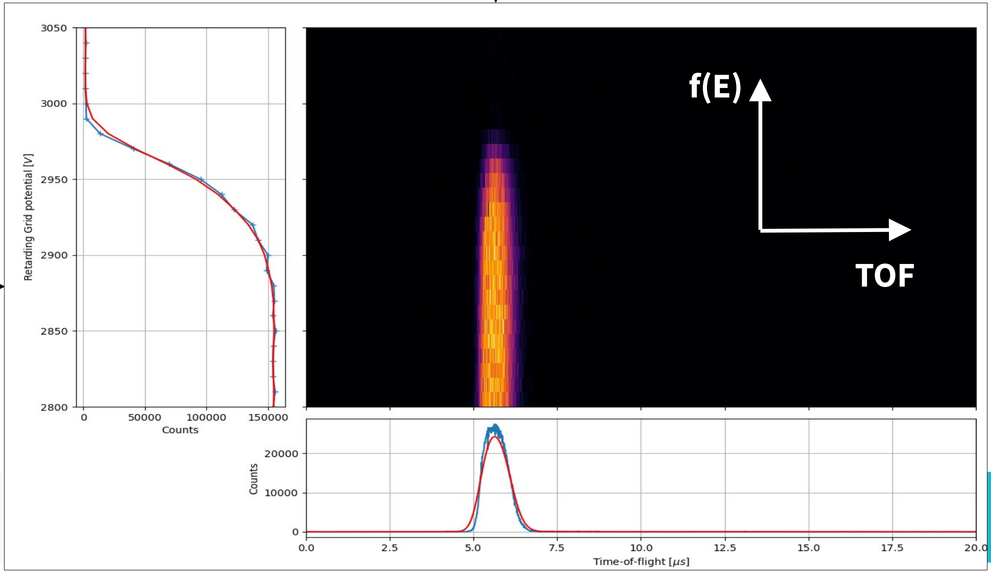




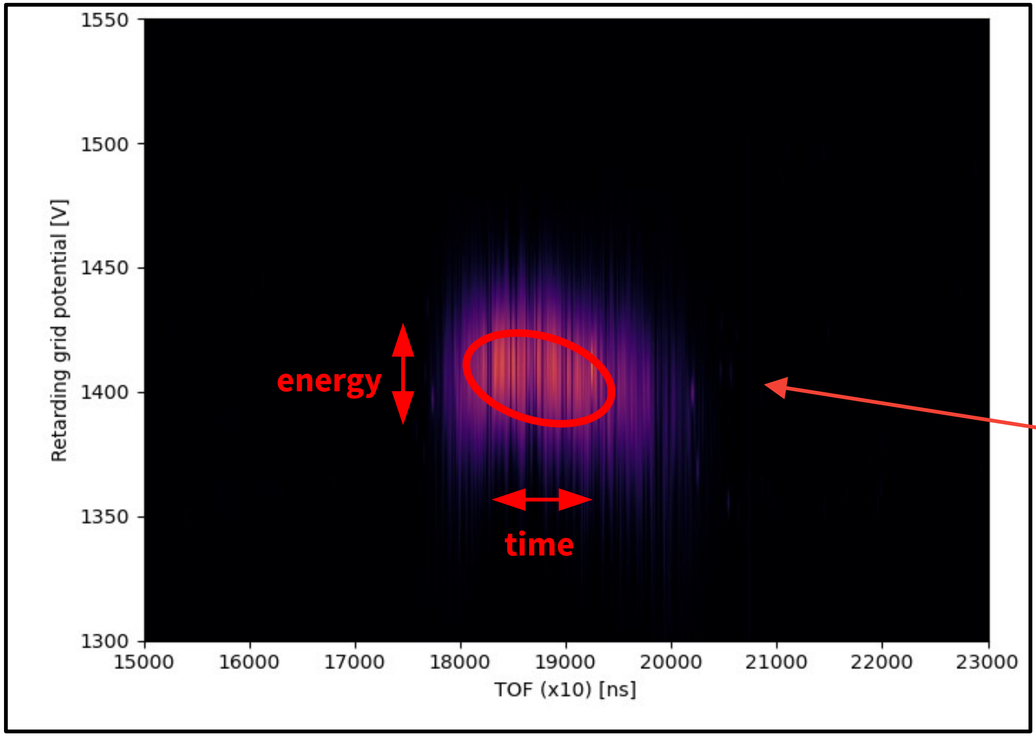
Time

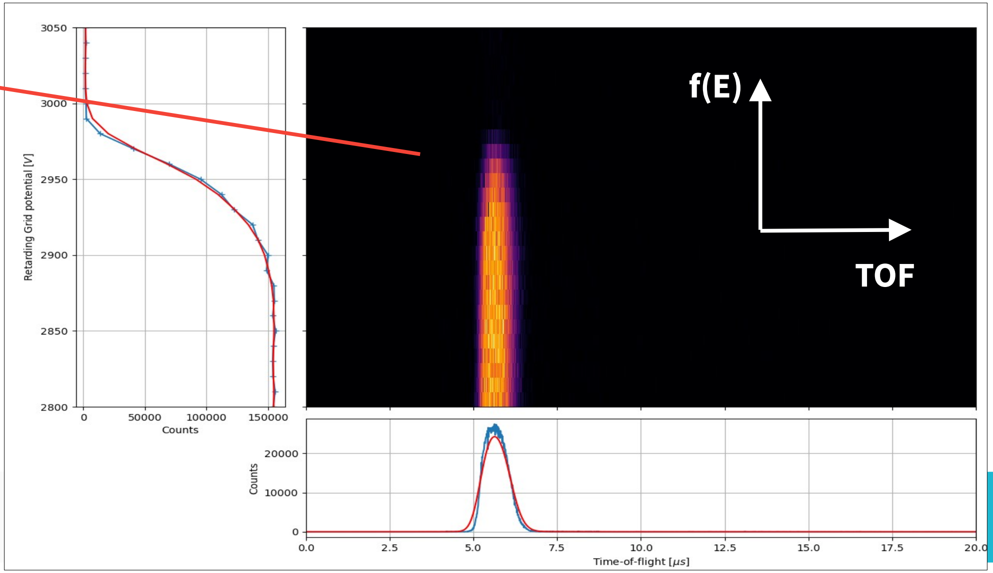
Energy





GPIB Cooler-Buncher - MCP + Retarding grid





GPIB Cooler-Buncher – *First results*

CW mode:

Intensity up to 10^{10}pps (~1nA)

Transmission with K^+ ions :

80% @ 30 keV

routinely **70-75 % @ 3 keV**

Record transmission obtained after careful Tuning - **92% @ 3keV**

Bunch mode:

Rep. Rate : 1 – 100 Hz

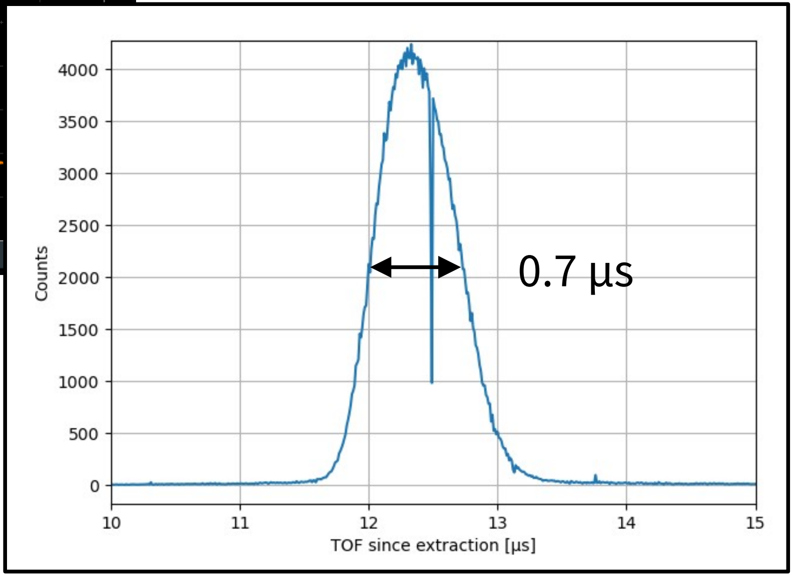
Measured bunch length :

- Extraction 30keV : ~ **1-2 µs FWHM**
- Extraction 3keV : **0.7µs FWHM**

→ Extraction potential to be optimized for bunch compression

MCP signal downstream of the GPIB

TOF spectrum – extraction 30keV



GPIB Cooler-Buncher *– First results*

CW mode:

Intensity up to 10^8pps (~20pA)

Transmission:

80% @ 30 keV
92% @ 3keV

Bunch mode:

Rep. Rate : 1 – 100 Hz

Measured bunch length :

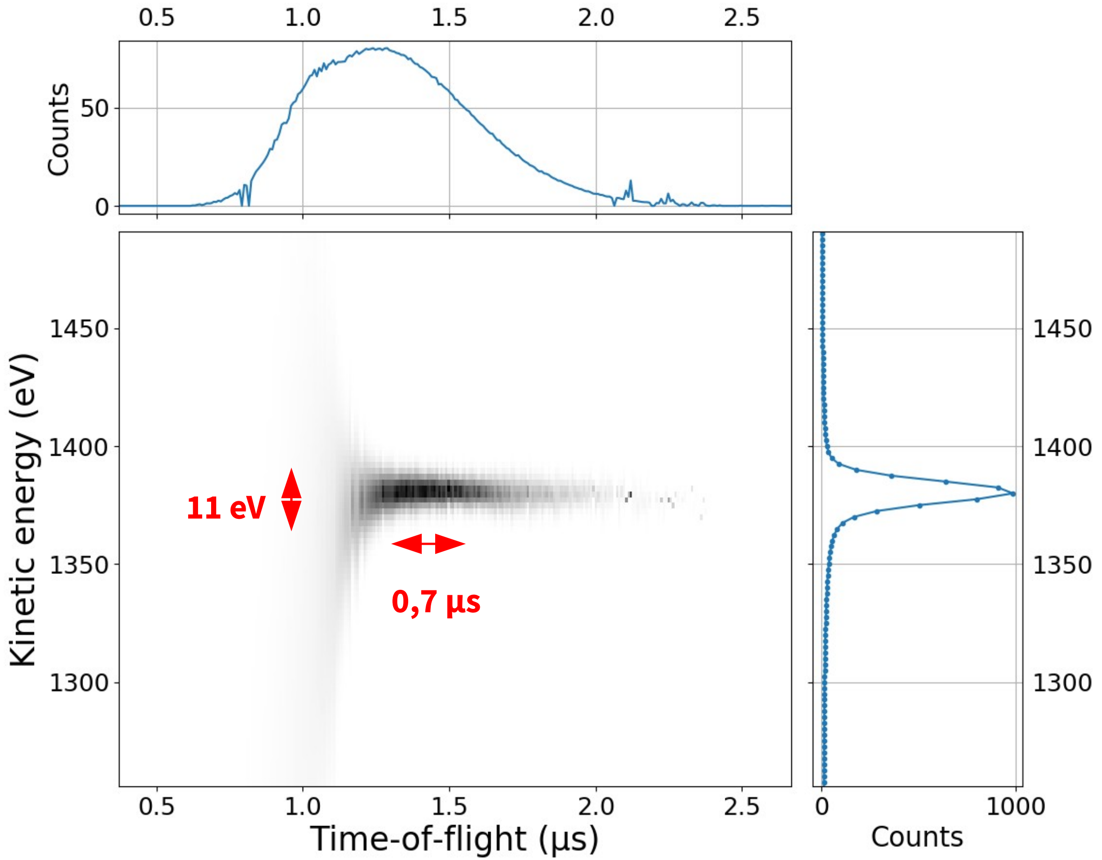
- Extraction 30keV : ~ 1-2 µs FWHM
- Extraction 3keV : 0.7 µs FWHM

→ Extraction potential to be optimized for bunch compression

Technical limitation in the energy spread measurement :

6 eV for 10ms cooling

→ Cooling sequence/time to be optimized
→ Technical developments required

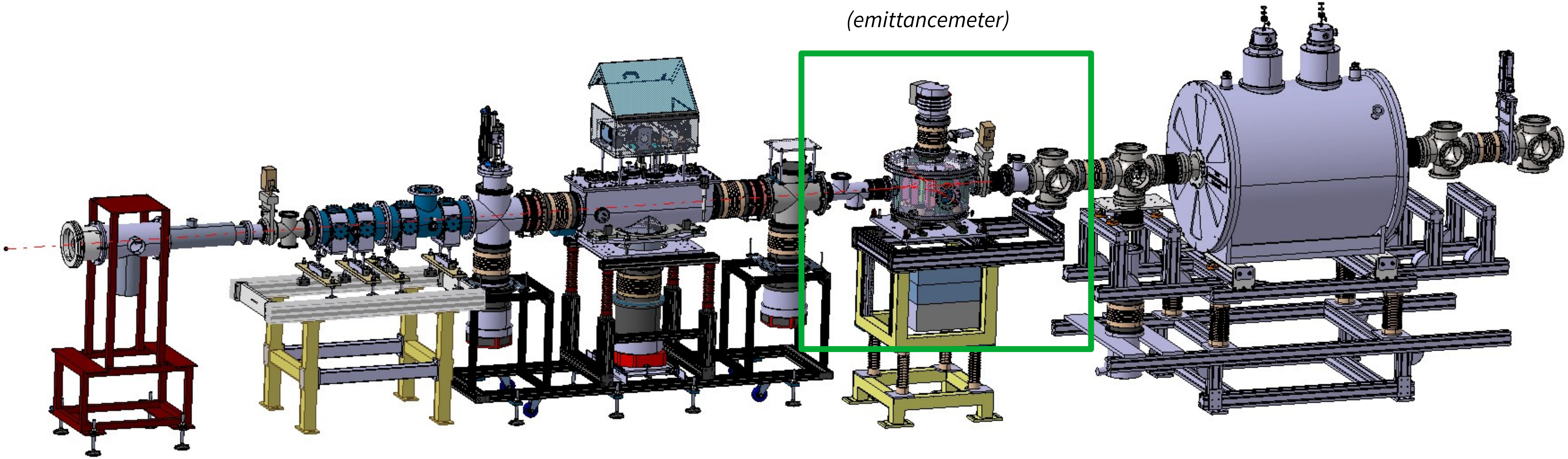


90° electrostatic deflector

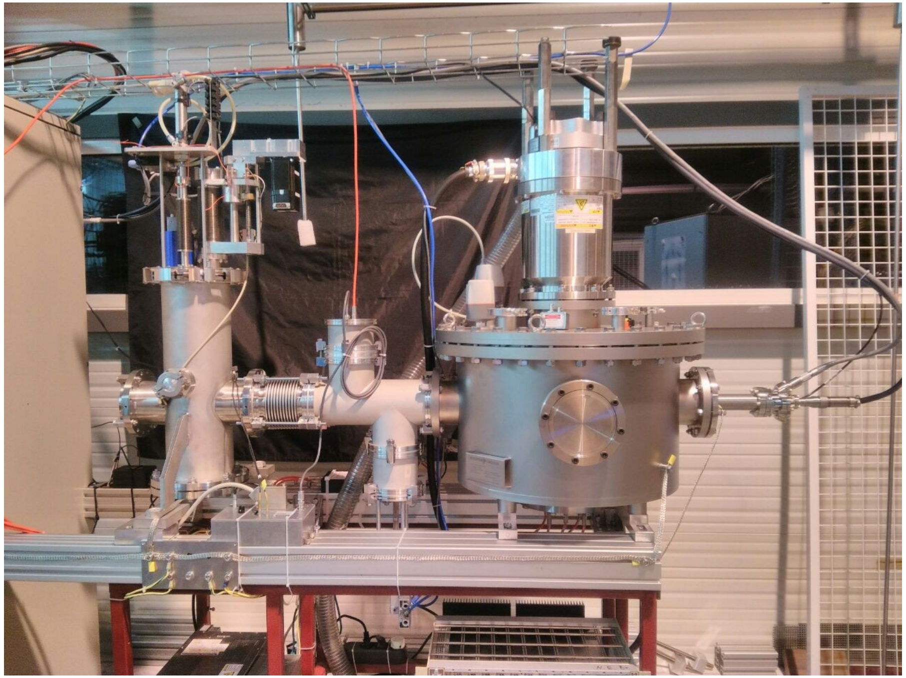
L3-keV line

90° electrostatic deflector

- *new alkaline source*
- *new detectors*
  (emittancemeter)



90° electrostatic deflector



Test bench for the 90° electrostatic deflector

- Characterize the 90° deflector

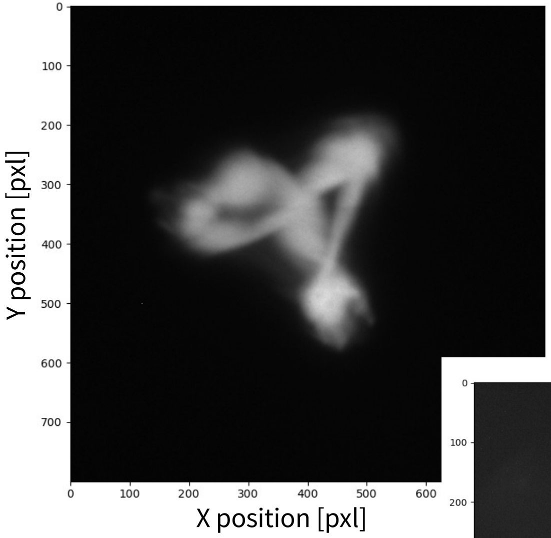
- CW mode :
  - Energy measurement – Faraday cup
  - Transverse emittance measurement
    → optimization & characterization of an emittance-meter for GPIB

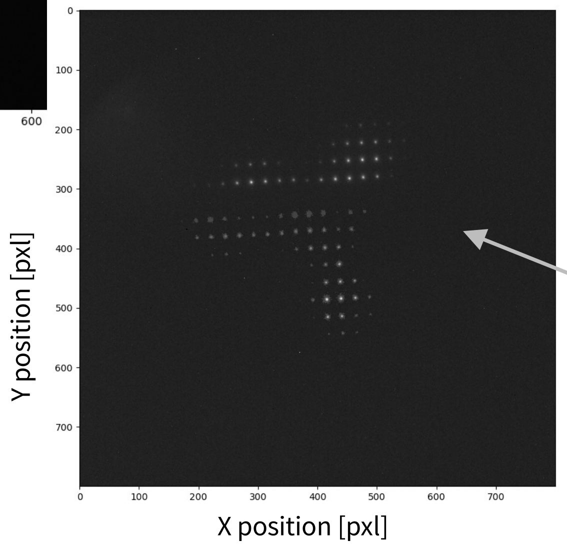
- Bunch mode :
  - Test the transmission measurement with a low number of ions,
  - Optimize the energy dispersion measurement,
  - Guarantee feasibility of TOF/energy measurement over all intensity range

High intensity (>10^4 evts) → CF with trans-impedance FEMTO
Low intensity (<1000 evts) → MCP

Properties with medium intensity hard to evaluate ???

90° electrostatic deflector





Test bench for the 90° electrostatic deflector

Rubidium source

- source CC unders EPICS ✓

– upgrade to Phoebus made on the testbench

- beam properties measured, still problem with the energy

* intensity ✓
* beam spot size ✓
* energy dispersion ✗

- bunch delivery implemented & tested : bunch down to 250ns ✓

– CC EPICS ✓

- Pantechnik pepper-pot emittance-meter modified to be EPICS compatible ✓

GPIB summary

Extraction

30 keV

CW beam

Transmission		Transverse emittance		Energy dispersion	
low	high	low	high	low	high
> 93%		*estimation: ~3 π mm.mrad*		Not accessible	
		to be repeated		*HRS coupling ?*	

Bunched beam

Transmission		Transverse emittance		Energy dispersion		TOF distribution	
low	high	low	high	low	high	low	high
x	x	should come soon		Not accessible		< 10 μs	x
		need further developments		*HRS coupling ?*			*RF limit*

Low = low intensity
High = high intensity
(10^8 ions/bunch or CW 100pA)

3 keV

CW beam

Transmission		Transverse emittance		Energy dispersion	
low	high	low	high	low	high
70 - 80 %		coming soon		x	x
(elements to improve it)		*EMT limit*			

Bunched beam

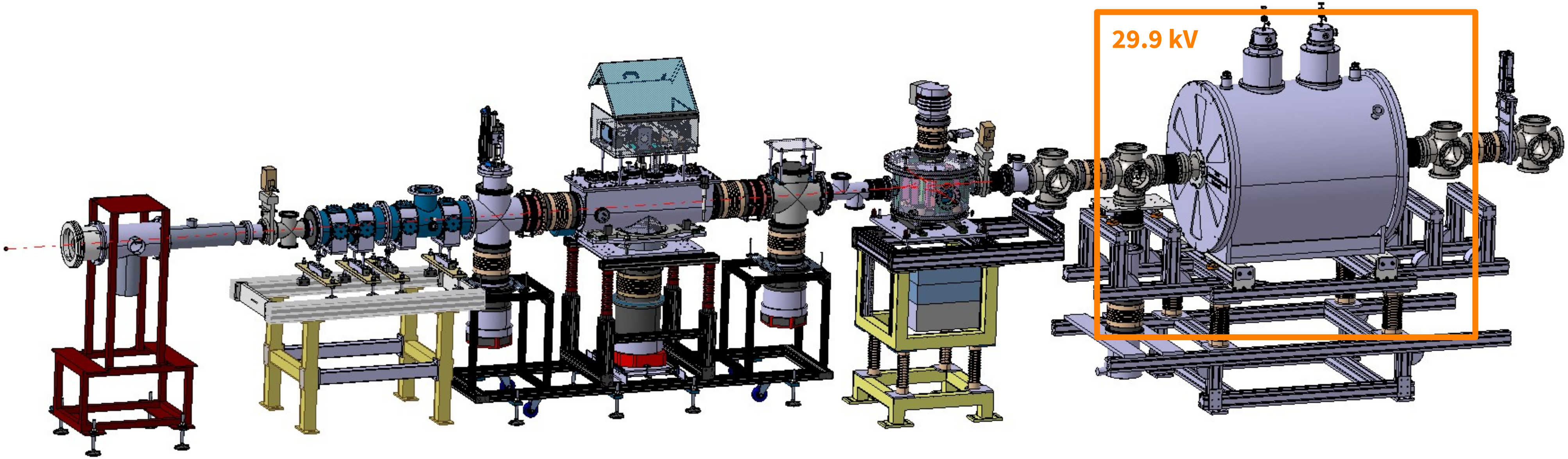
Transmission		Transverse emittance		Energy dispersion		TOF distribution	
low	high	low	high	low	high	low	high
x	x	should come soon		< 6 eV	?	< 1 μs	< 10 μs
		need further developments				*RF limit - to be repeated*	

PIPERADE

PIPERADE

double Penning trap

- *7T superconducting magnet*
- *beam purification*
- *mass measurement*



PIPERADE trap

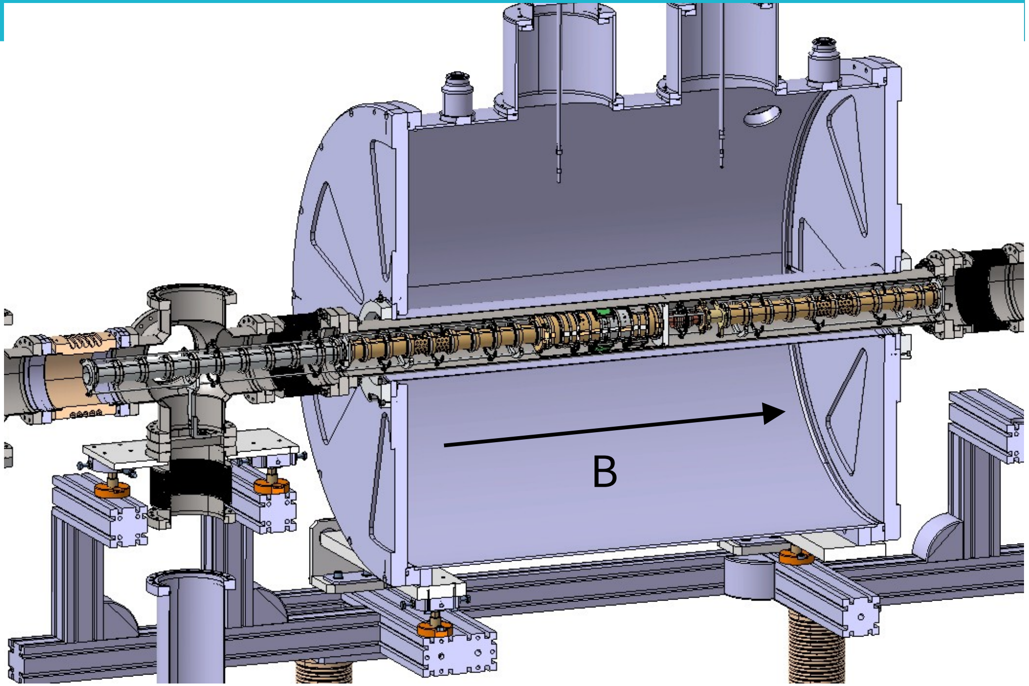
Double Penning Trap

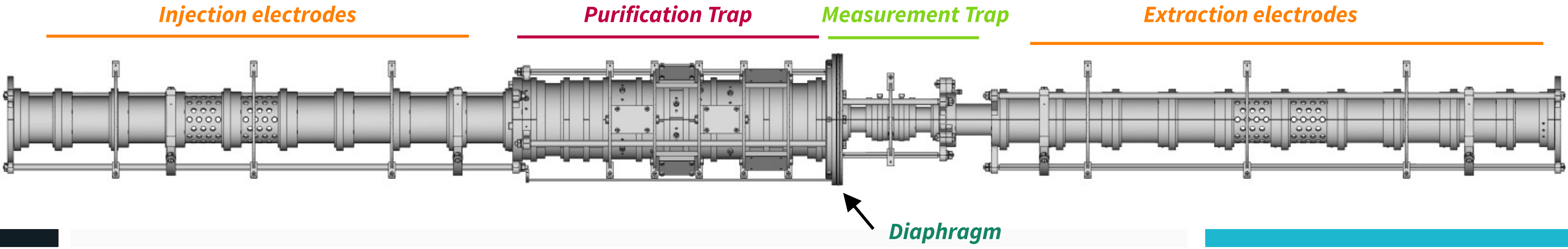
Magnetic field 7T, 2 homogeneous regions *(<1ppm over 1cm^3 volume)*

Two traps in one :

1. Purification trap : large inner radius (>10^4 ions/bunch)
2. Measurement trap : ion stacking/ mass measurements

P. Ascher et al., PIPERADE: A double Penning trap for mass separation and mass spectrometry at DESIR/SPIRAL2, published end of 2021 (NIM A)





PIPERADE trap

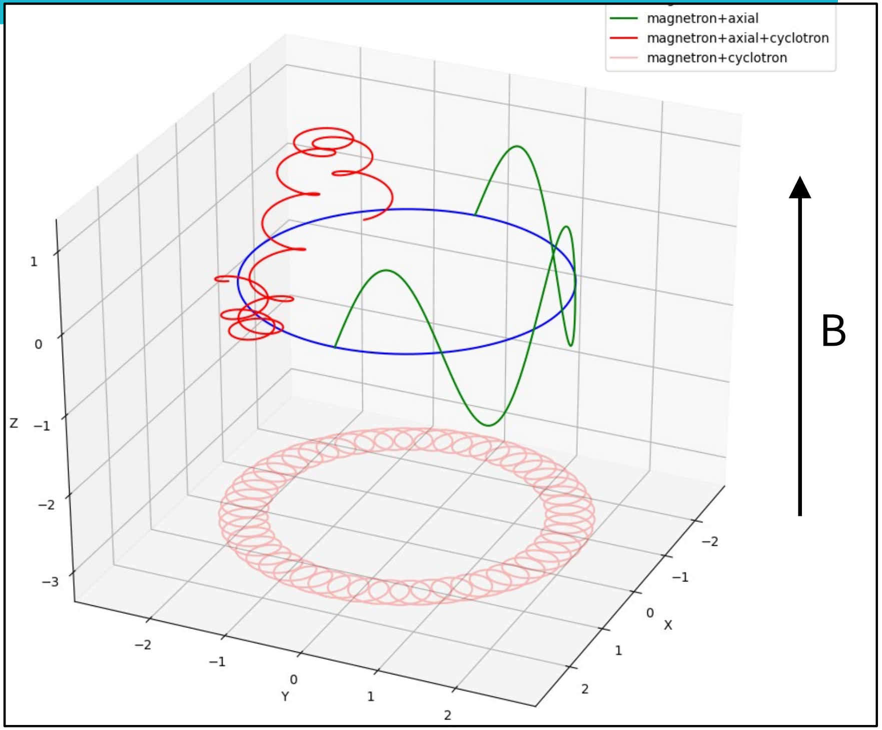
Double Penning Trap

Magnetic field 7T, homogeneous *(<1ppm over 1cm^3 volume)*

Ion confined :

- radially : magnetic field
- longitudinal : electrostatic quadrupolar field

Confinement leads to 3 cumulated eigen motions :



Axial motion
along the optical axis
~100 kHz

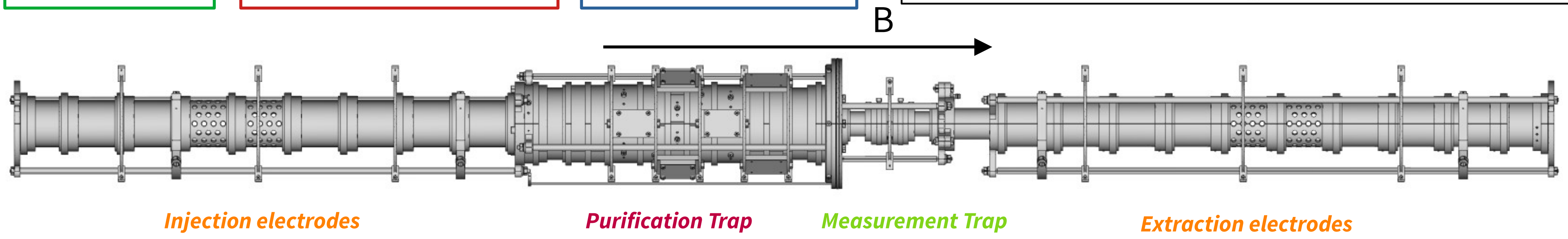
$$\omega_z = \sqrt{\frac{qU}{md^2}}$$

Reduced cyclotron motion
fast circular motion
~ MHz

$$\omega_p = \frac{\omega_c}{2} + \sqrt{\frac{\omega_c^2}{4} - \frac{\omega_z^2}{2}}$$

Magnetron motion
slow circular motion around trap axis
~ kHz

$$\omega_m = \frac{\omega_c}{2} - \sqrt{\frac{\omega_c^2}{4} - \frac{\omega_z^2}{2}}$$



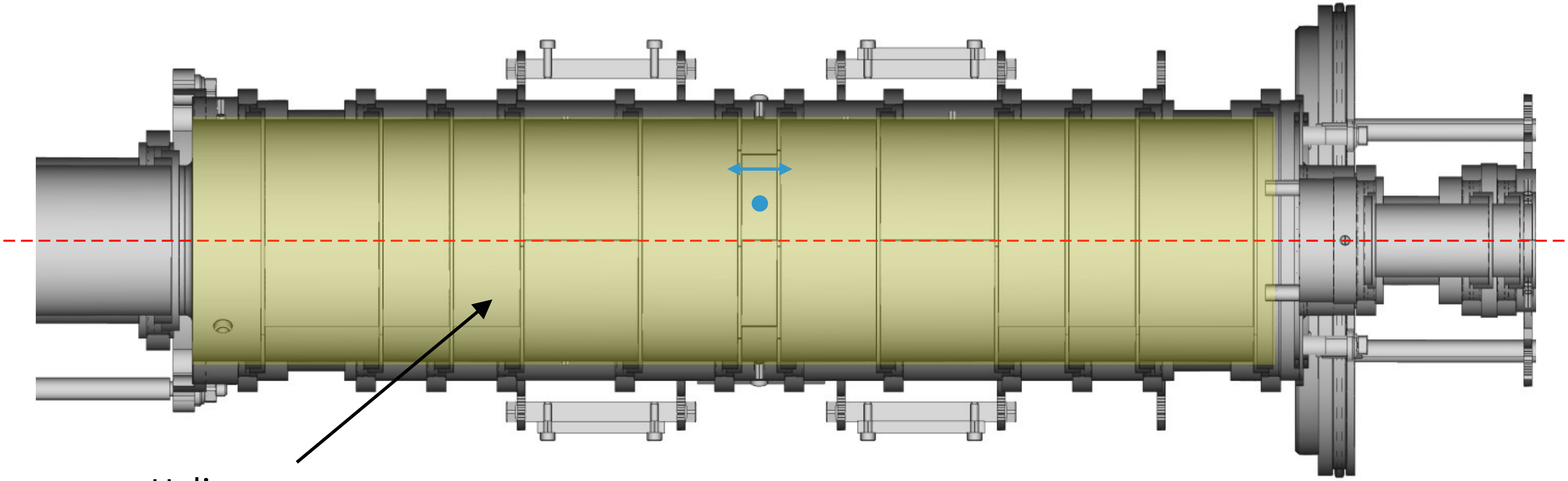
PIPERADE trap - Principle

First Penning Trap

- central « ring » electrode 8-fold segmented

<u>Two types of excitation applied</u> :

- Dipolar @ magnetron freq. : *change the magnetron radius* ← *almost* **mass independent**
- Quadrupolar @ cyclotron freq. : *conversion magnetron/cyclotron* ← **mass dependent**



Helium gas ← axial and modified cyclotron motion damped by collisions with gas

PIPERADE trap - Principle

First Penning Trap

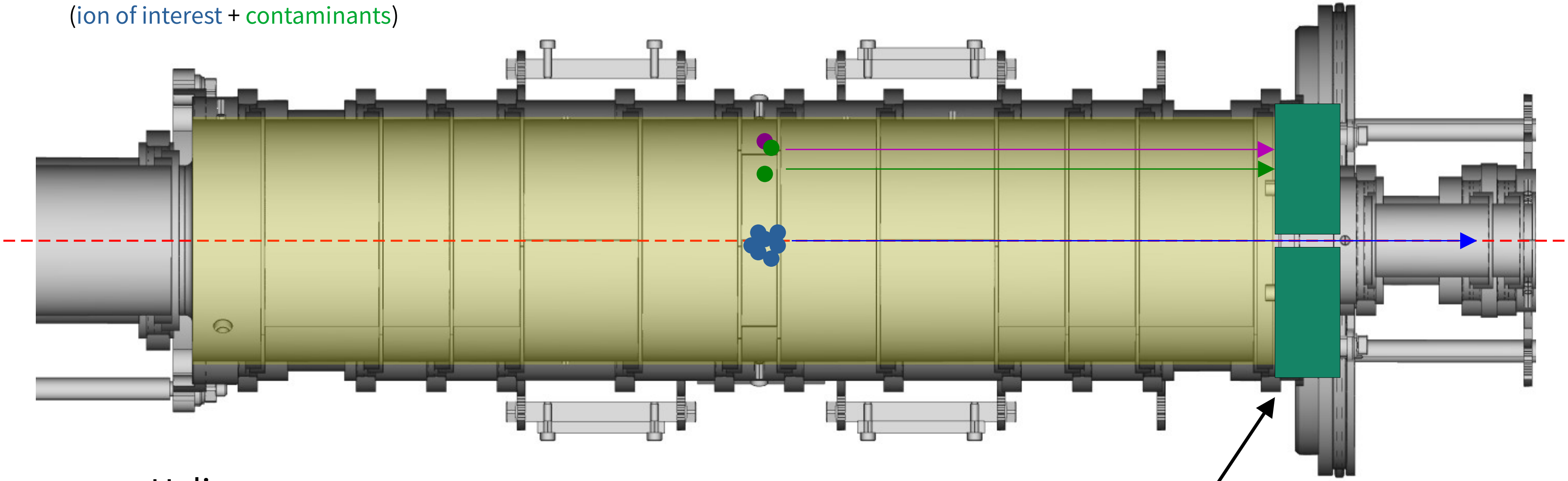
- central « ring » electrode 8-fold segmented

- magnetron excitation ← **mass independent**
- cyclotron excitation ← **mass dependent**
- buffer gas cooling

→ now with multiple species
(ion of interest + contaminants)

Ion of interest : centered
Contaminants : off-center

=> Ejection through the diaphragm to complete the selection



Helium gas ← axial and modified cyclotron motion damped by collisions with gas

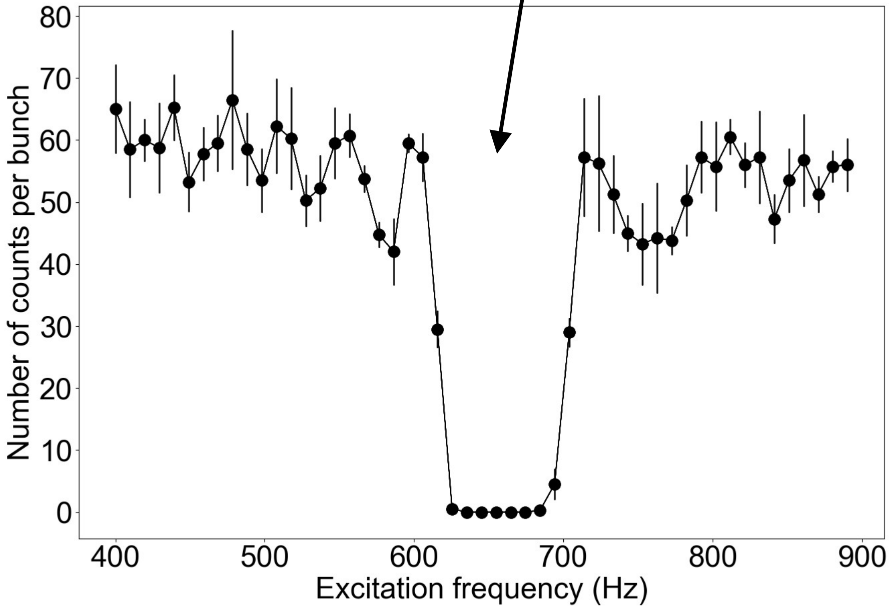
PIPERADE trap – First results

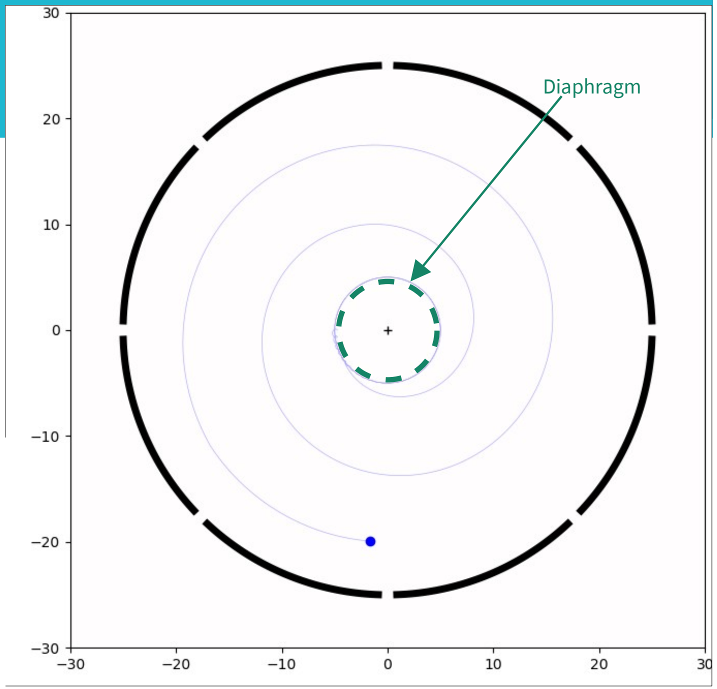
First Penning Trap

- first ion trapping ← September 2020

- first magnetron excitation seen – March 2021
  measured frequency ~660 Hz
  calculated frequency → 669 Hz

Ions out of the diaphragm - disappearance



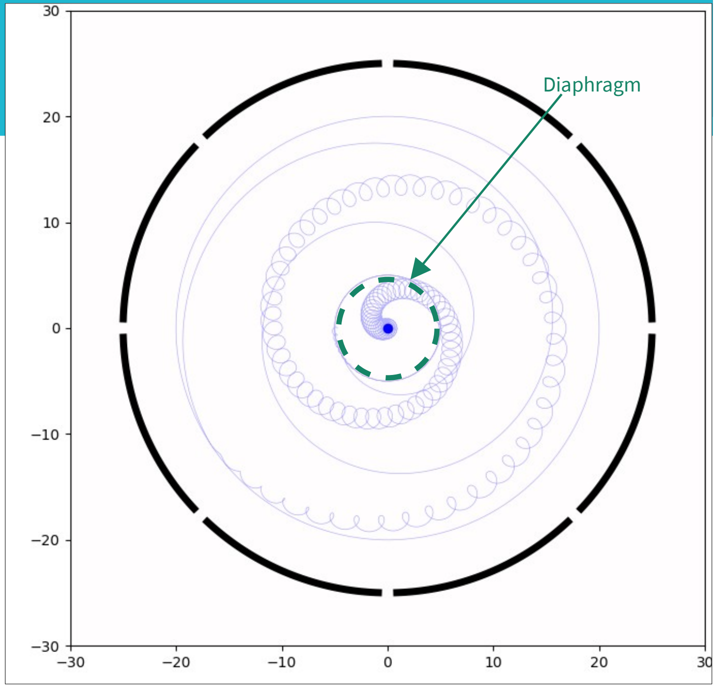


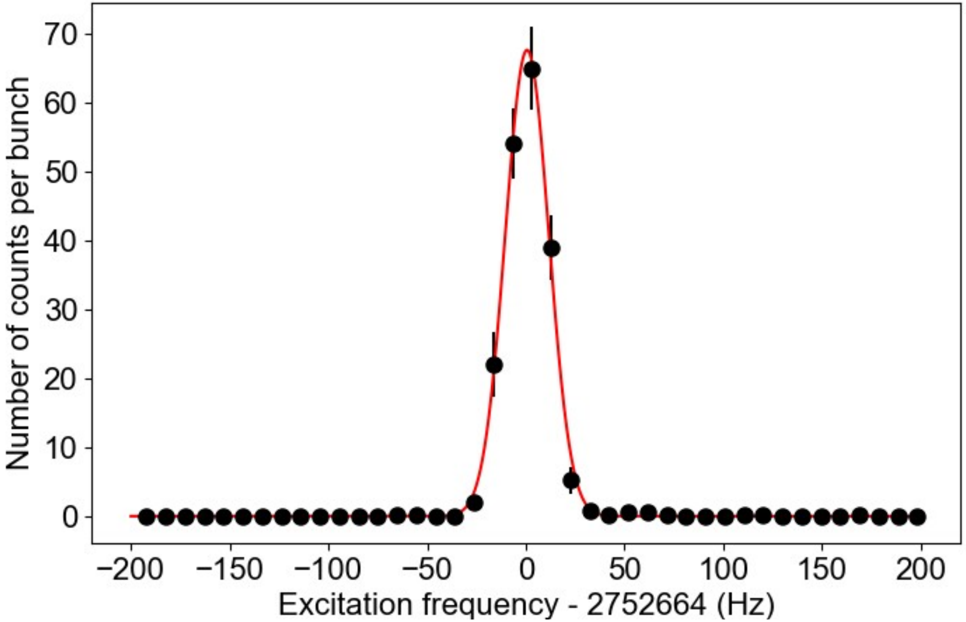
PIPERADE trap – First results

First Penning Trap

- first ion trapping ← September 2020

- first magnetron excitation seen – March 2021 (660 Hz)
- first cyclotron excitation applied – April 2021
  buffer gas cooling recentering of ^{39}K ions – 2.75283 MHz





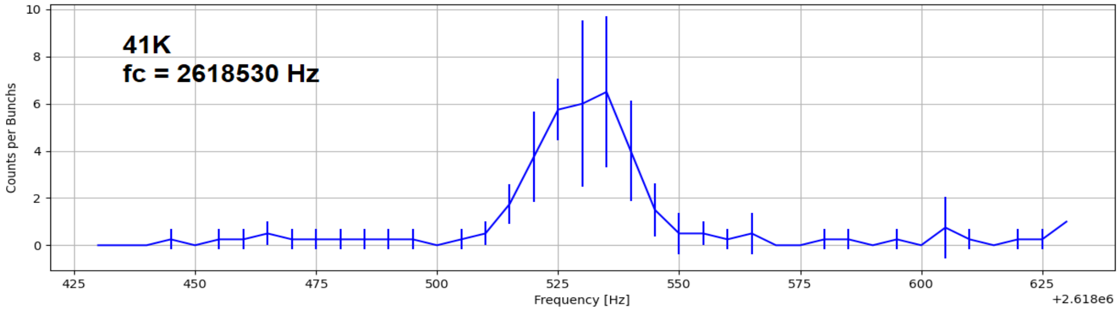
PIPERADE trap – First results

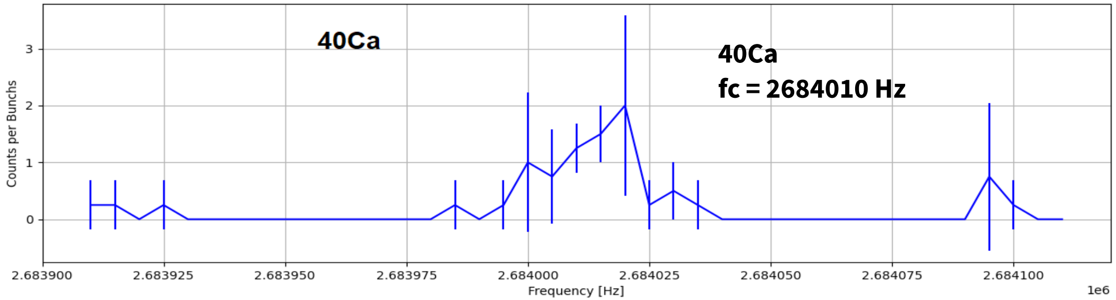
First Penning Trap

- first ion trapping ← September 2020

- first magnetron excitation seen – March 2021 (660 Hz)
- first cyclotron excitation applied – April 2021
  buffer gas cooling recentering of ^{39}K ions (2.75 MHz)

- 3 other species found during a '*massive day*'
  no more species found due to the GPIB selectivity





40Ca
fc = 2684010 Hz

PIPERADE trap – First results

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  buffer gas cooling recentering of ^{39}K ions (2.75 MHz)

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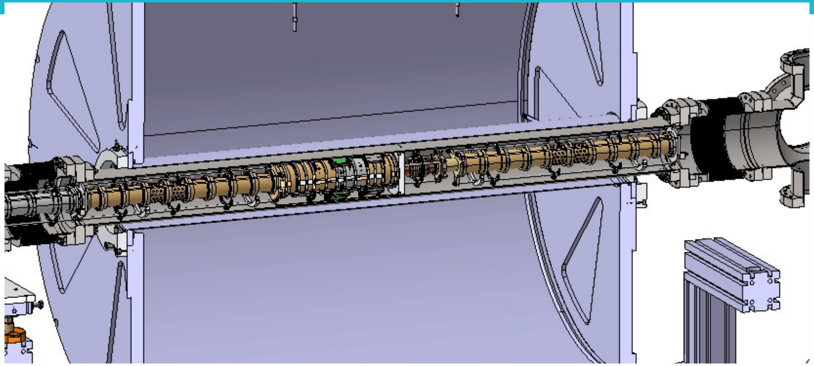
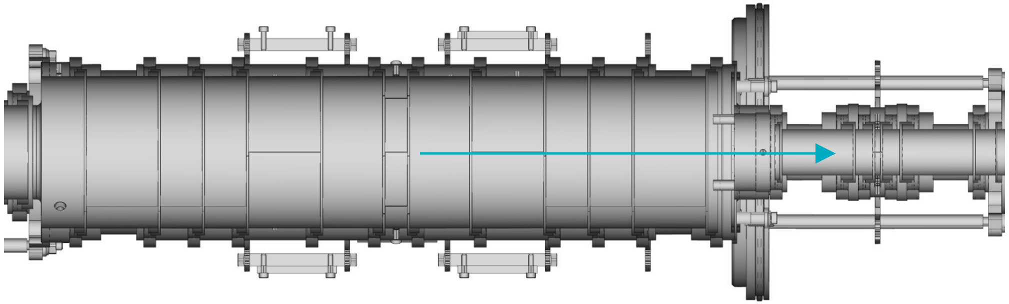
- transfer and trapping in the second trap (Accumulation/Measurement Trap)

- apply excitations in the Accumulation/Measurement Trap + extraction





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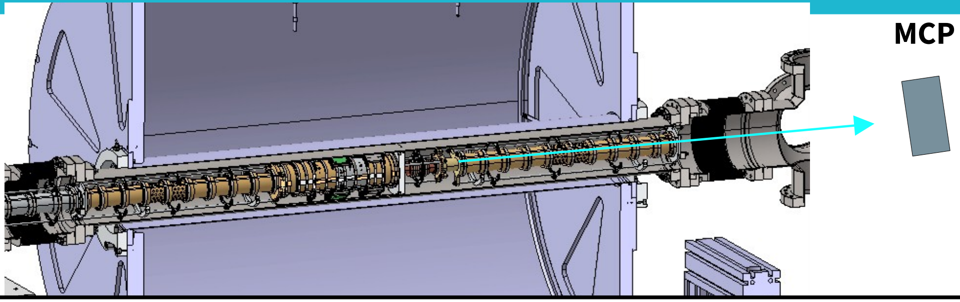
- first cyclotron excitation applied – April 2021
  buffer gas cooling recentering of ^{39}K ions (2.75 MHz)

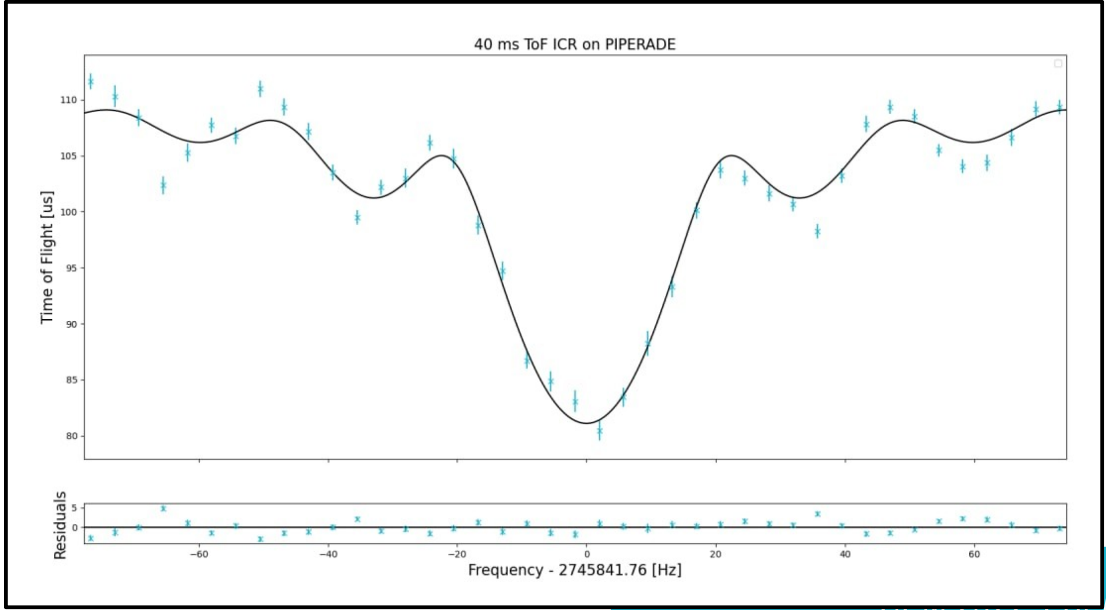
- 3 other species found during a ‘*massive day*’
  no more species found due to the GPIB selectivity

- transfer and trapping in the second trap (Accumulation/Measurement Trap)

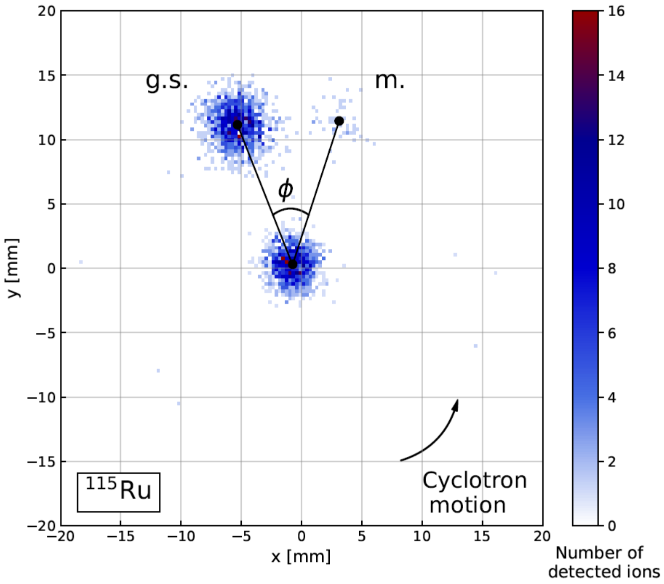
- apply excitations in the Accumulation/Measurement Trap + extraction

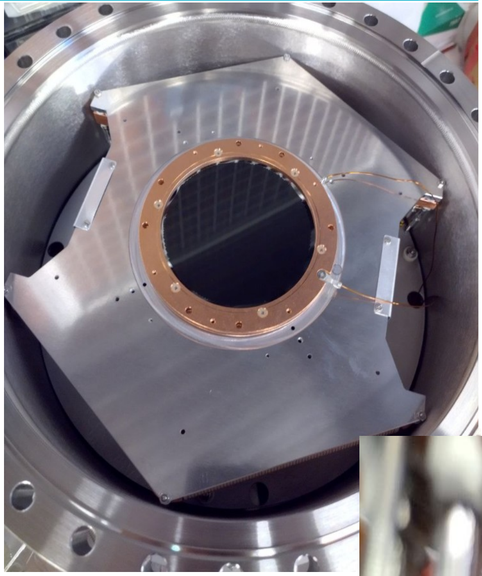
- first ToF-ICR resonance
  → meas. Time-of-flight of the ions

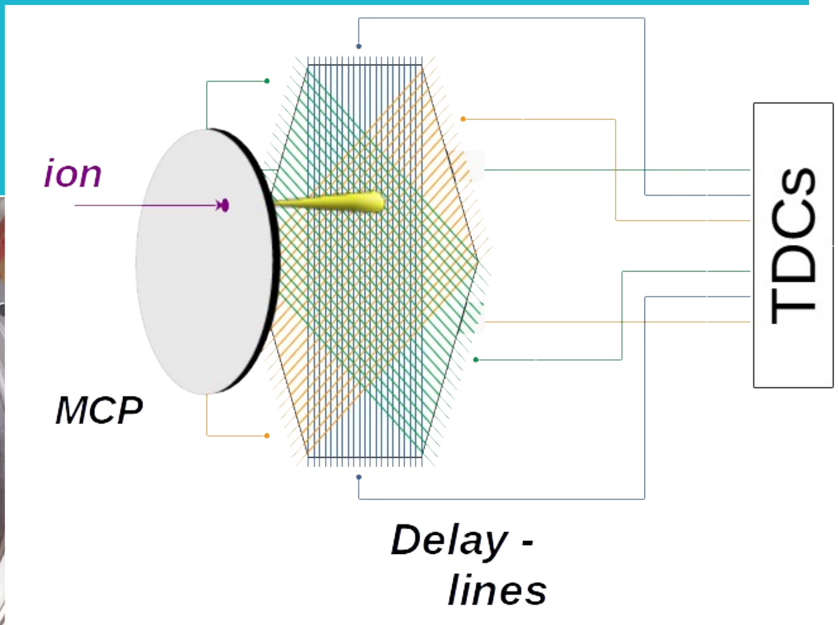


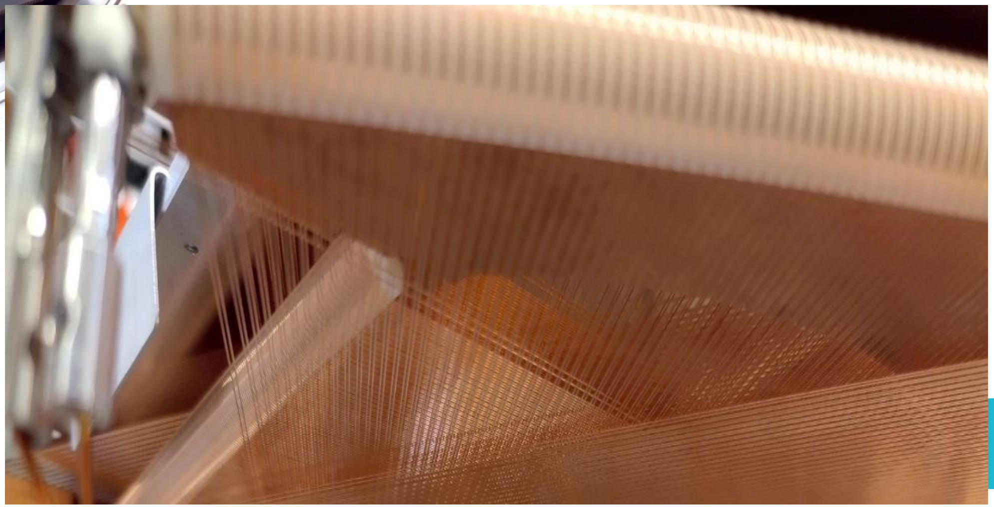


PIPERADE trap – Perspectives









Currently preparing a 2D sensitive detector to perform PI-ICR technique (Phase Imaging) – *also a very good debugging device*

THANK YOU

PIPERADE TEAM

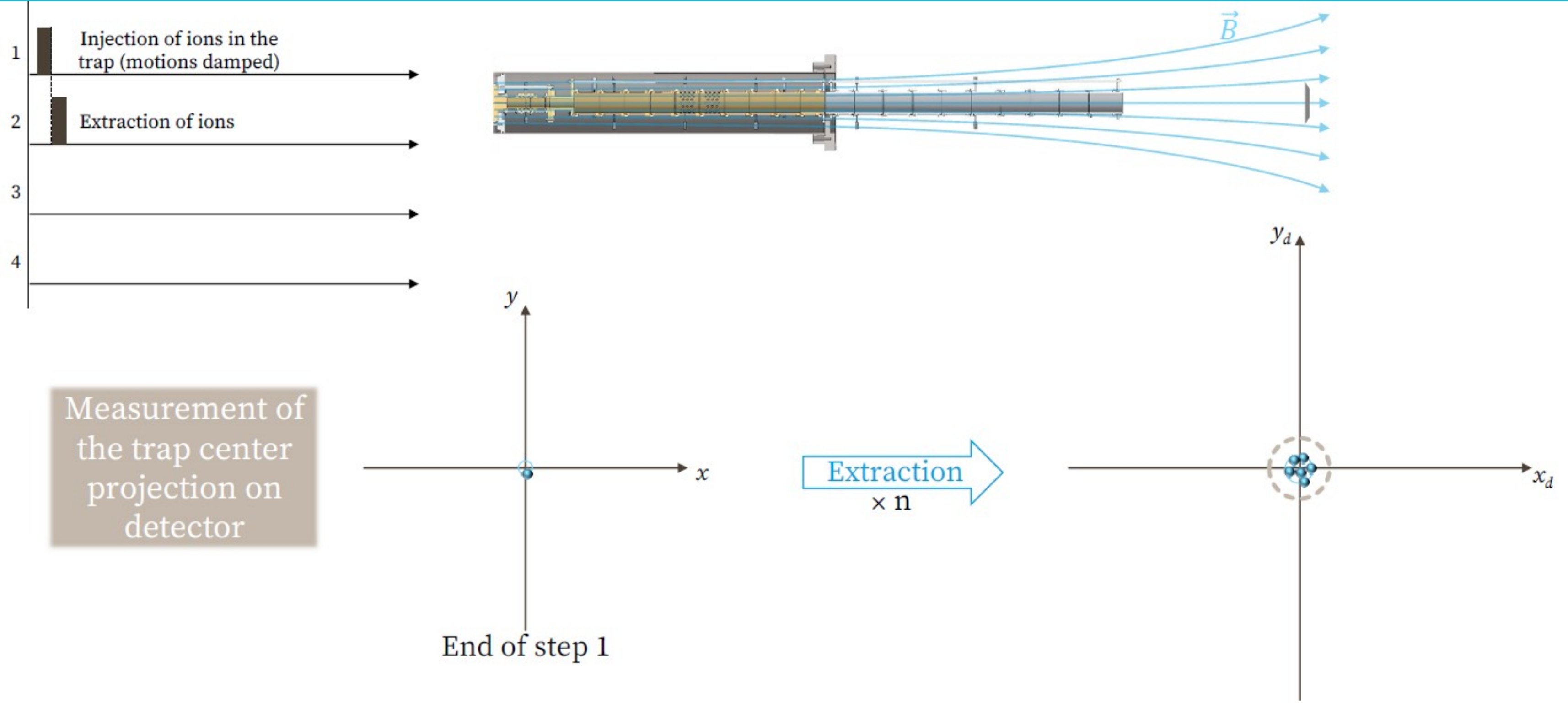
Permanent physicists
P. Ascher, B. Blank, M.Gerbaux, S. Grévy

Instrumentation
P. Alfaurt, L. Daudin, B. Lachacinski

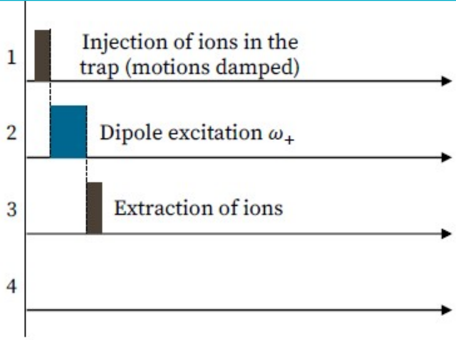
Mechanics (‘*BE*’)
S. Perard

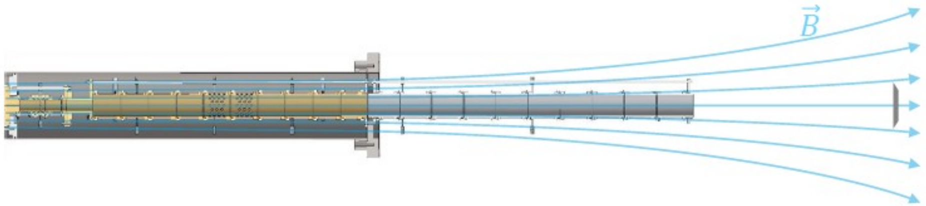
PhDs
M. Flayol, M. Hukkanen

Postdocs
D. Atanasov, A. Husson

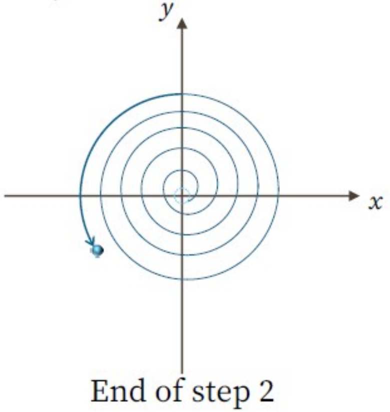


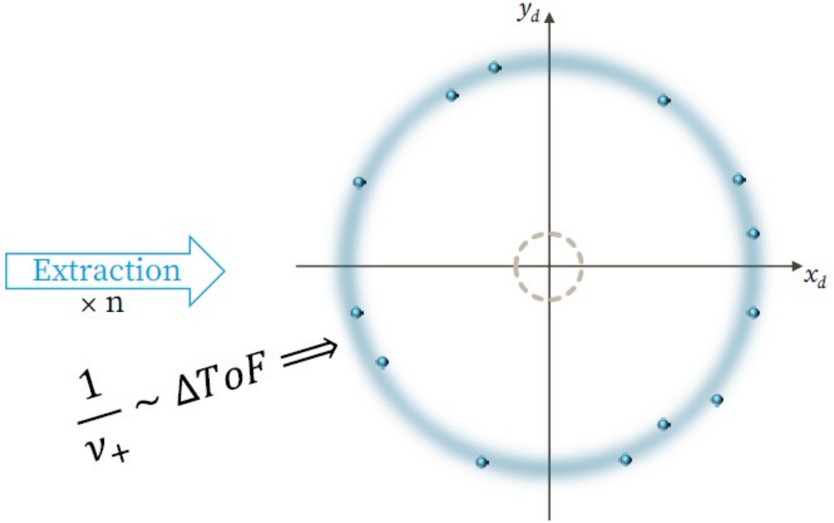
Courtesy: Mathias GERBAUX





What not to do !





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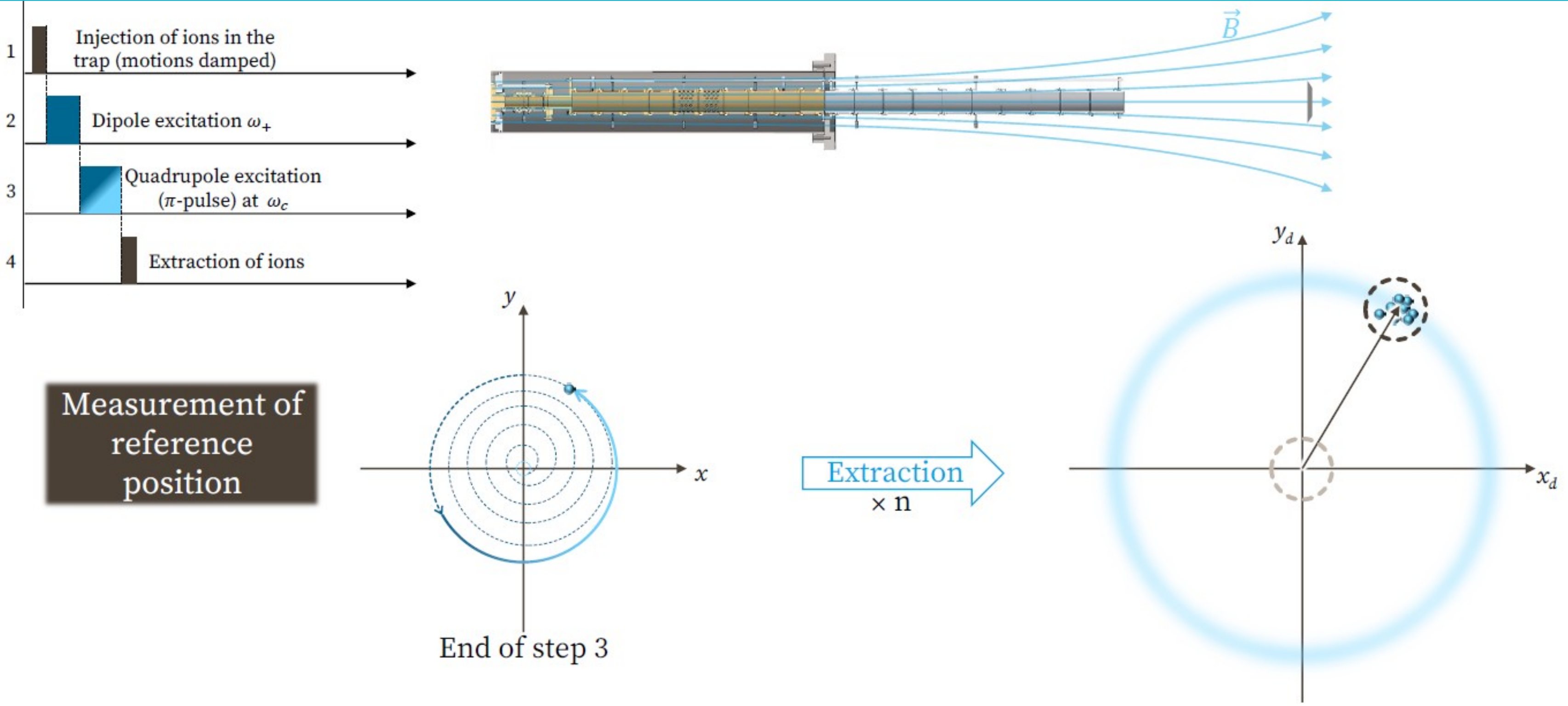
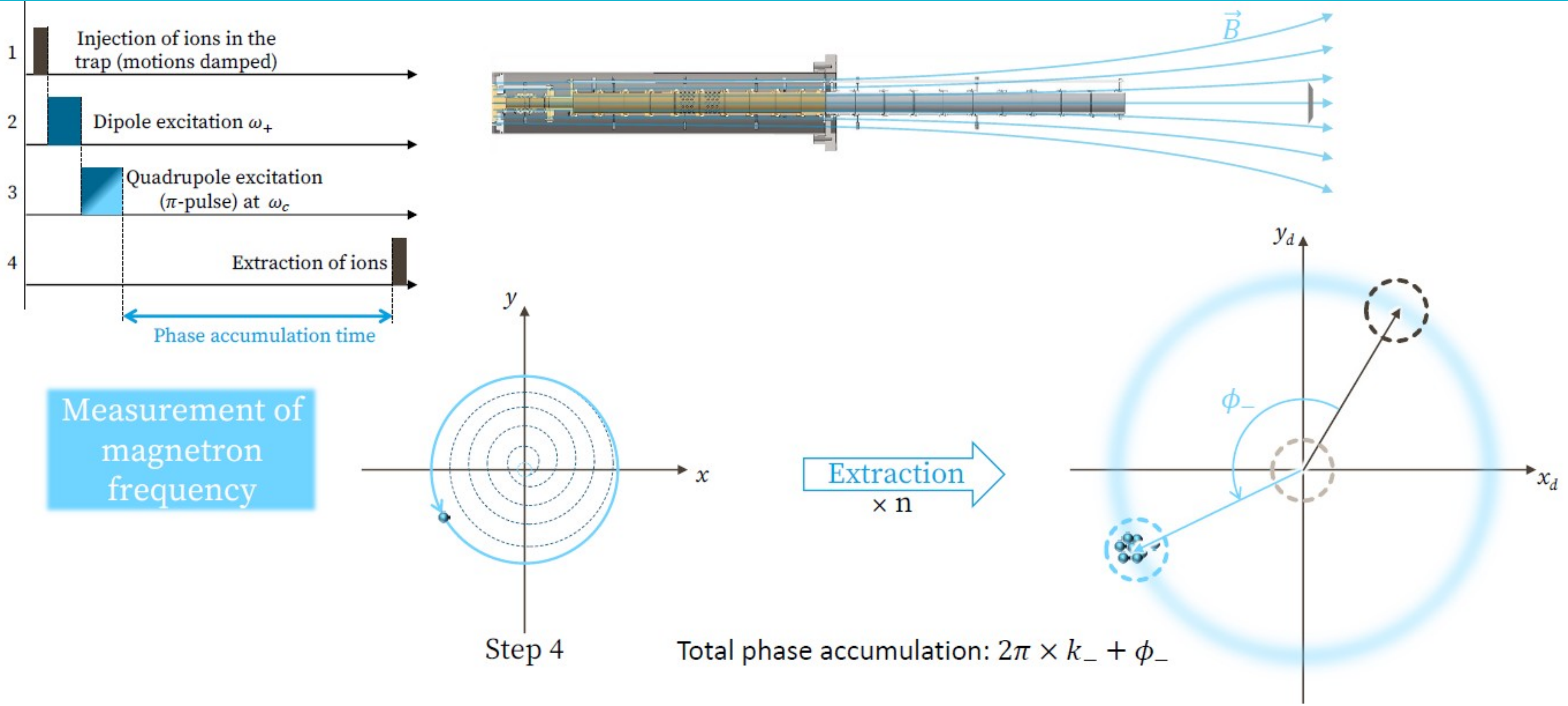
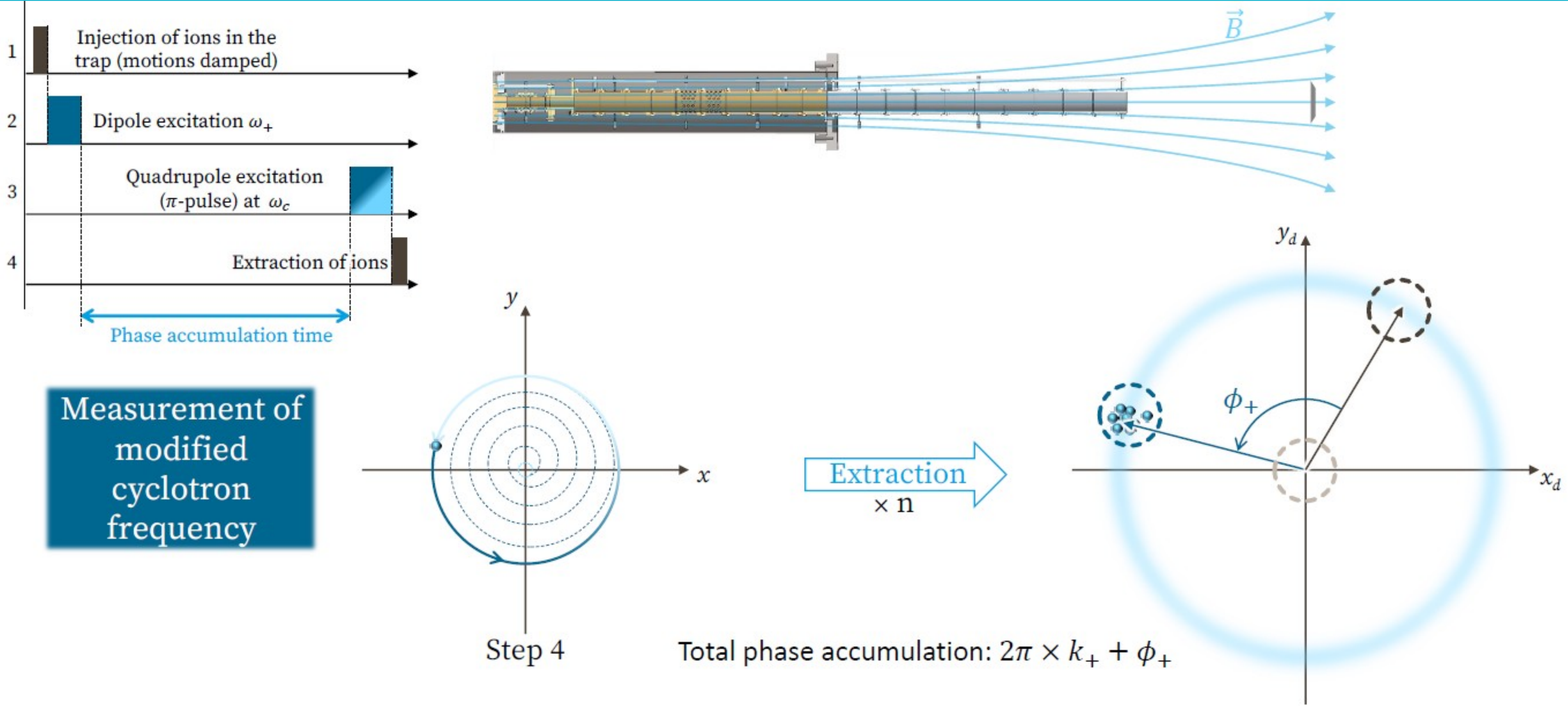


Courtesy: Mathias GERBAUX

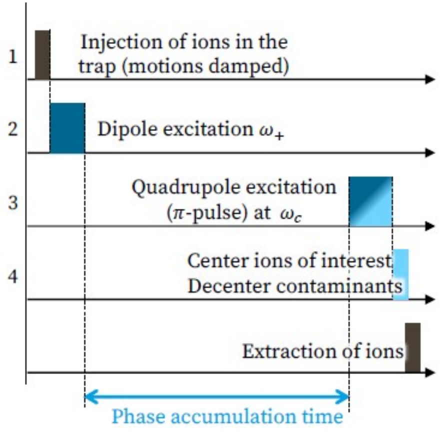
Measurement of magnetron frequency

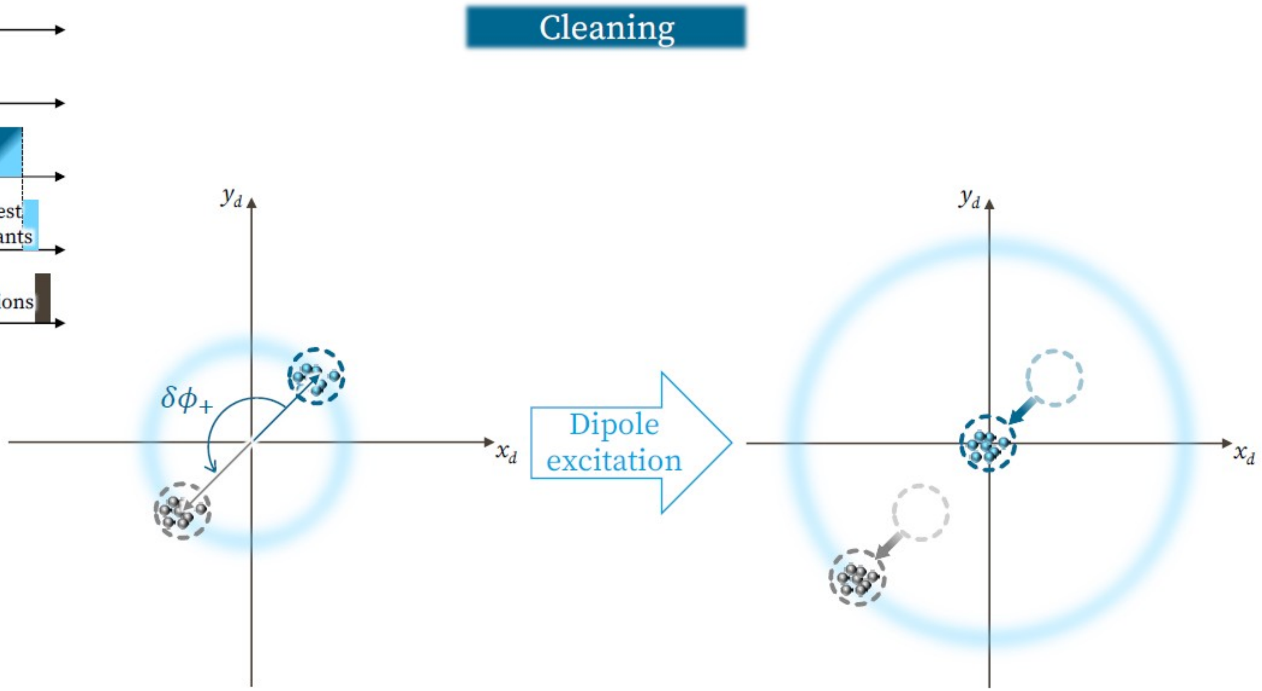


Courtesy: Mathias GERBAUX



Courtesy: Mathias GERBAUX





Courtesy: *Mathias GERBAUX*

THANK YOU

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