Commissioning and recent achievements of ion beam purification devices under development at CENBG

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cnrs

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Spiral2 DESIR

MAX-PLANCK-INSTITUT
FÜR KERNPHYSIK

PIPERADE
PIEGES DE PENNING POUR LES RADIONUCLEIDES A DESIR

The DESIR hall

Three main setup categories

- β-decay spectroscopy
- Laser spectroscopy
- Mass spectrometry

To study

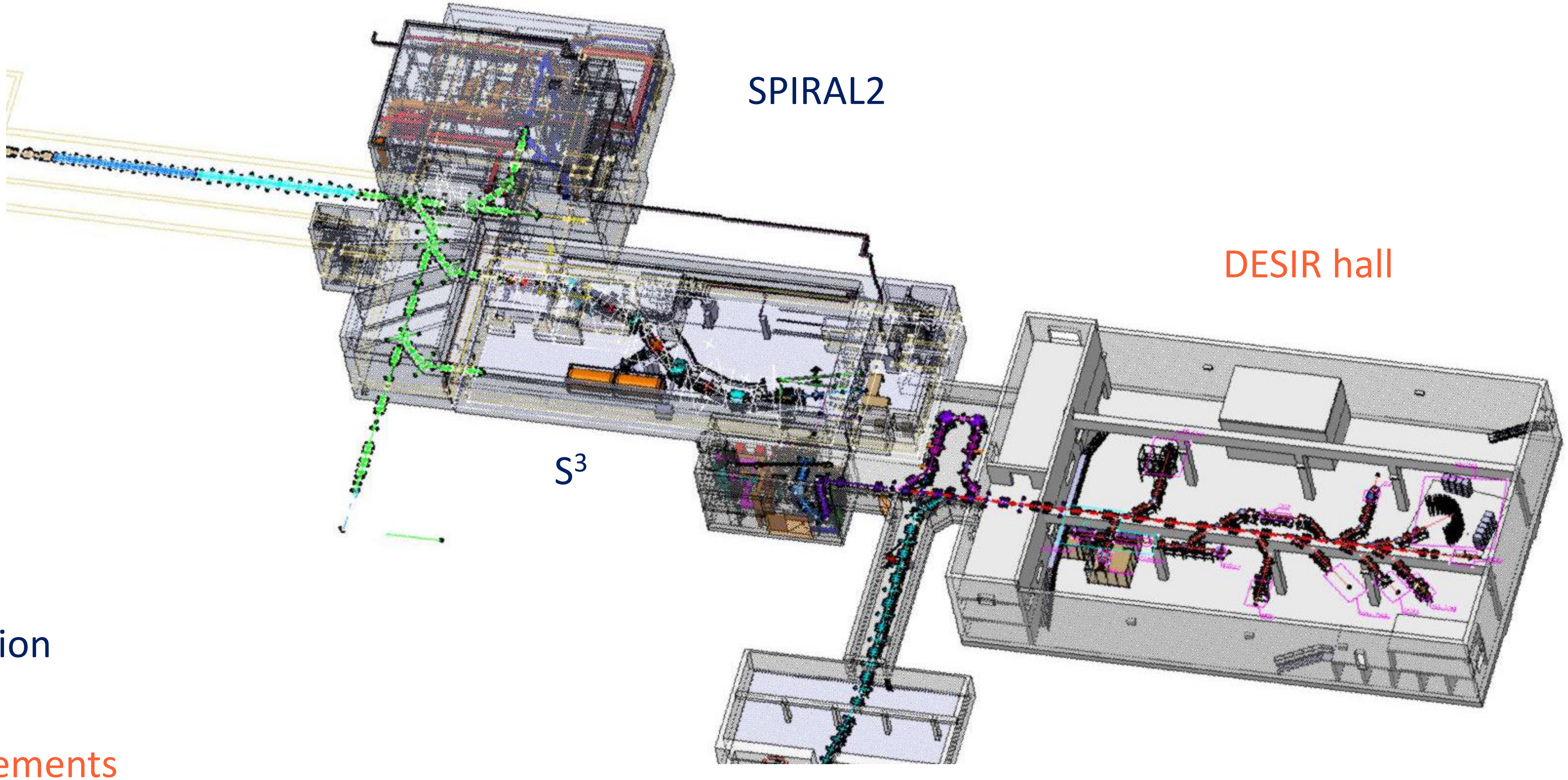
- Nuclear structure
- Astrophysics
- Weak interaction
- Application…

Ion beams from

- SPIRAL1 → fragmentation
- S^3 → fusion

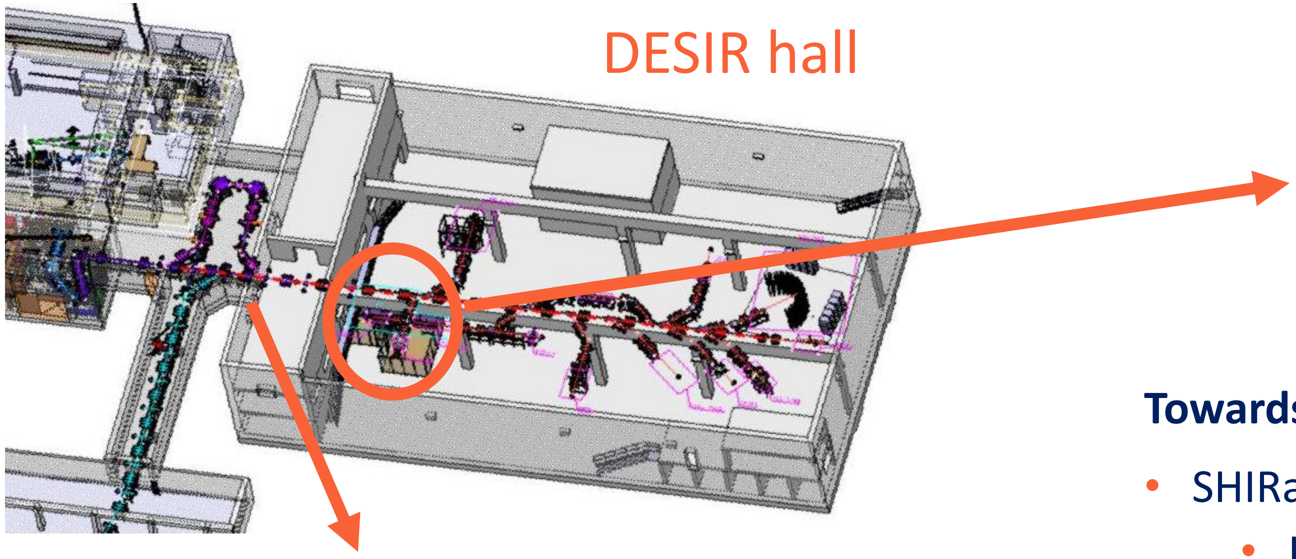
Aim for high precision measurements

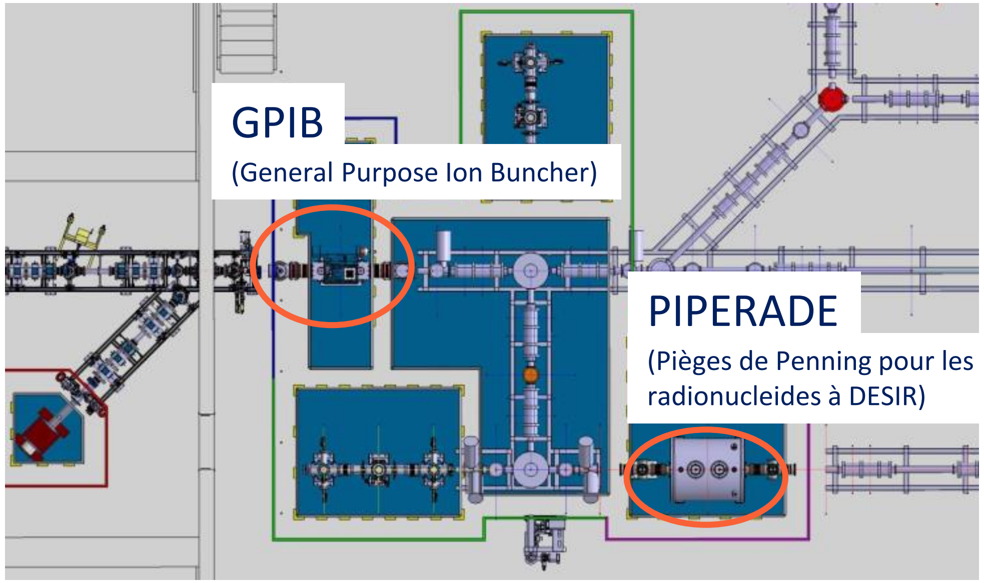
- High purity beam
  - ➢ We need to purify isobars (up to isomers)
- High quality beam
  - ➢ Low longitudinal and transverse emittance



SPIRAL1 transfer beam line

HRS, GPIB & PIPERADE


DESIR hall

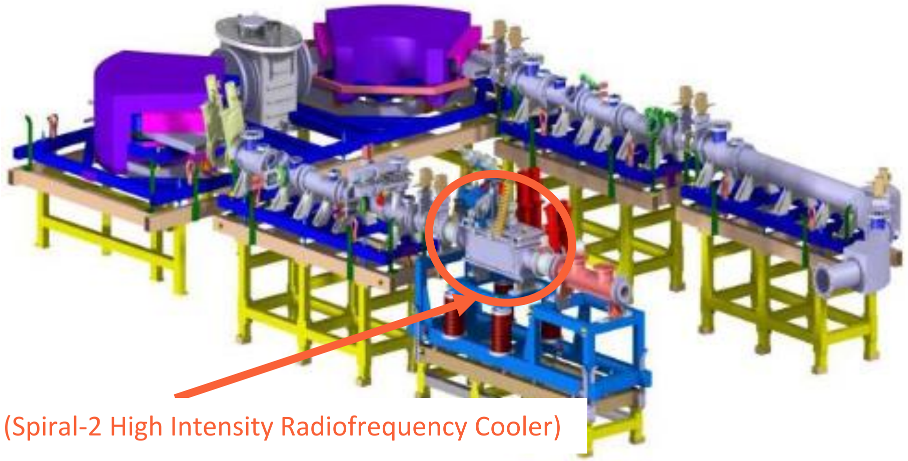

GPIB

(General Purpose Ion Buncher)

PIPERADE

(Pièges de Penning pour les radionucleides à DESIR)

HRS (high resolution separator)

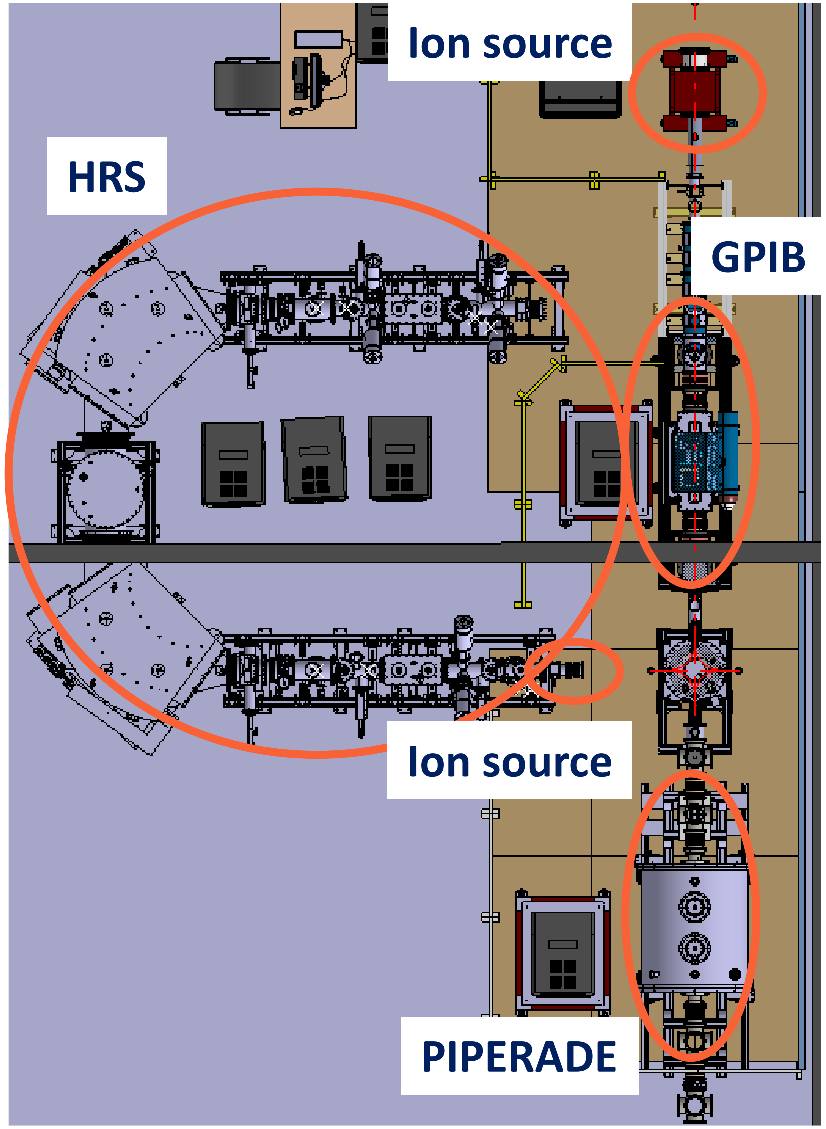

SHIRaC (Spiral-2 High Intensity Radiofrequency Cooler)

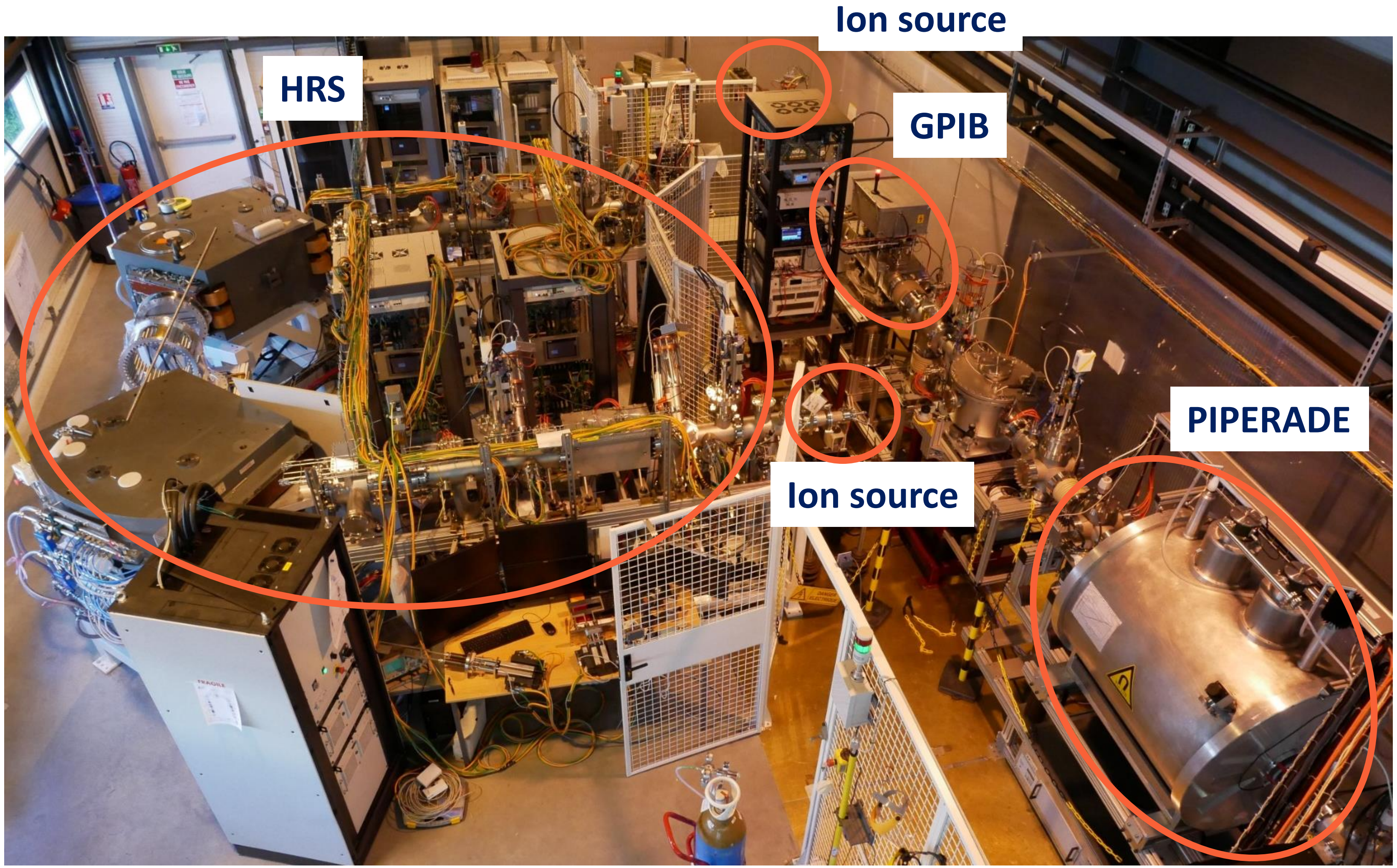
Towards high beam purity

- SHIRaC + HRS
  - Located in front of DESIR
  - SHIRaC → beam cooling + HRS → in-flight mass separation
- GPIB + PIPERADE
  - Located at the entrance of DESIR
  - GPIB delivers cooled ion bunches to the hall
  - PIPERADE: large isobarically pure ion bunches

HRS, GPIB and PIPERADE are being commissioned at CENBG

HRS, GPIB & PIPERADE at CENBG



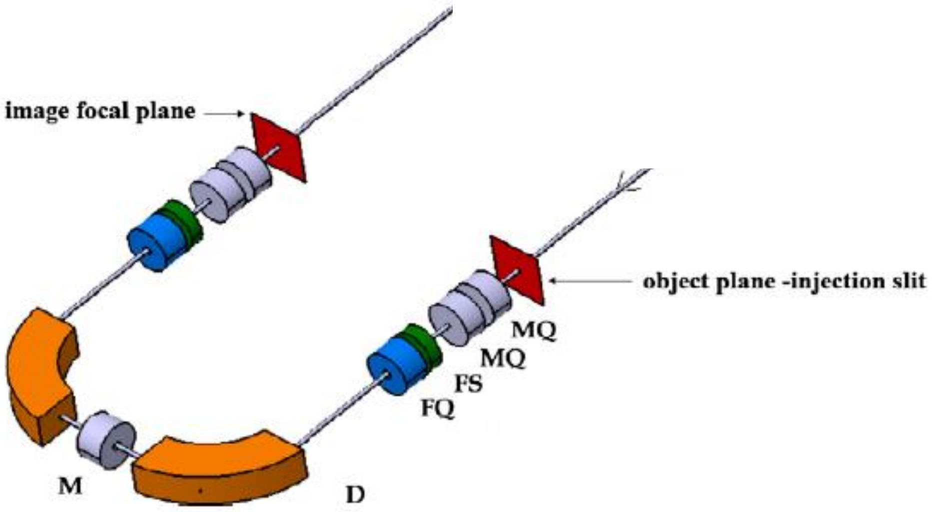


HRS: High Resolution Separator

Lattice and elements :

- **D** : Two 90° *magnetic* dipoles (36° entrance/exit angles)
- **MQ** : Matching quadrupoles
- **FQ** : Focusing quadrupoles
- **FS** : Focusing sextupoles
- **M** : A multipole (up to 5th order)

Configuration: MQ-MQ-FS-FQ-D-M-D-FQ-FS-MQ-MQ



Main objective: Decrease isobaric contamination for high-intensity beams with a resolution $\mathrm{R} = \frac{M}{\Delta M} \approx 20\,000$

ISOLDE's HRS → $\mathrm{R} \approx 5000$

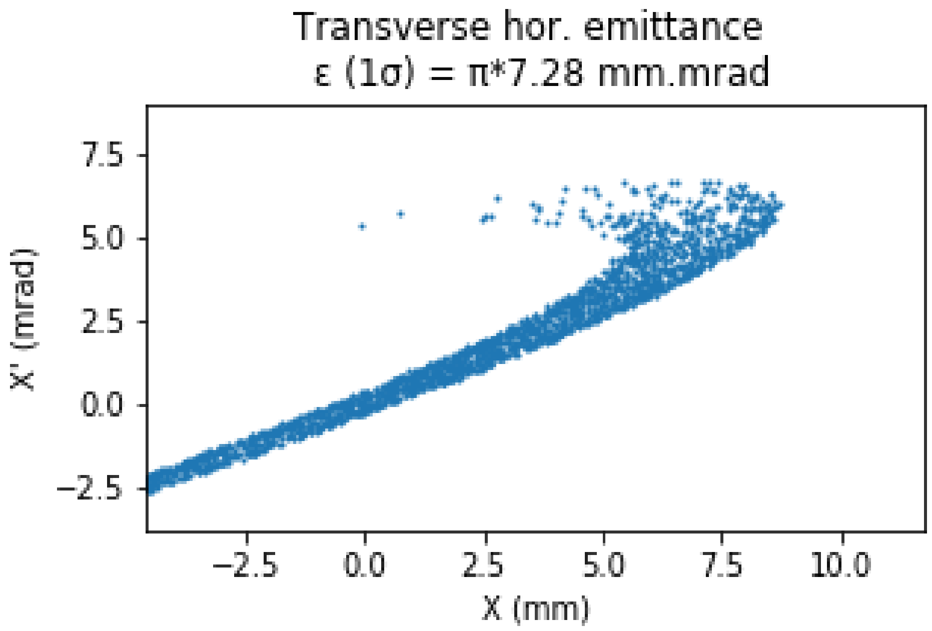
Requirements and constrains:

- Transmission efficiency close to $100\ \%$ for $R \approx 20\,000$ to provide mono-isobaric exotic beams
- Beam emittance $\varepsilon < 3\pi$ mm.mrad and $\Delta E < 1$ eV at 60 keV (beam emittance from RFQ cooler SHIRaC)

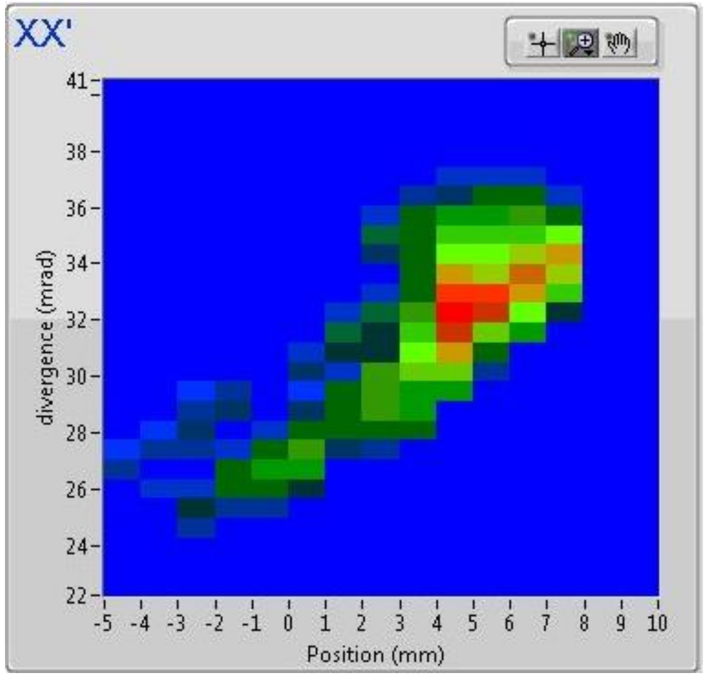
T. Kurtukian et al., Nucl. Instrum. Methods Phys. Res. B 317 (2013) 284-289

Current work: correction of aberrations with the multipole

Higher order aberrations will lead to distortions of the beam (spatial space or phase space)



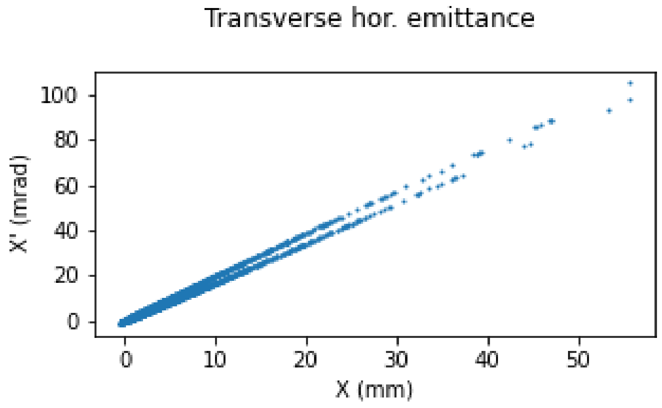
Simulated emittance with second order aberration (COSY)



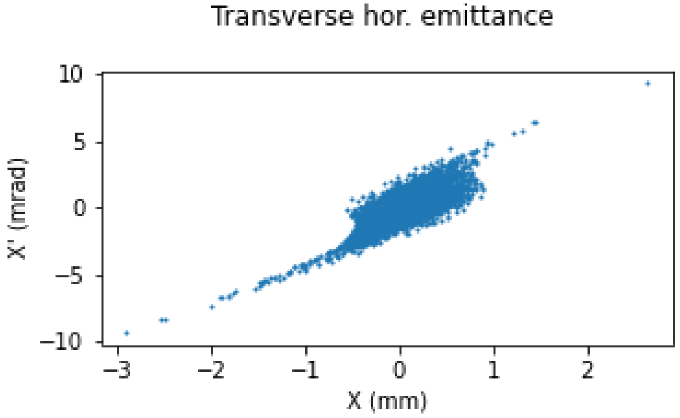
Measured emittance

Solution → correction of the aberration with the multipole !

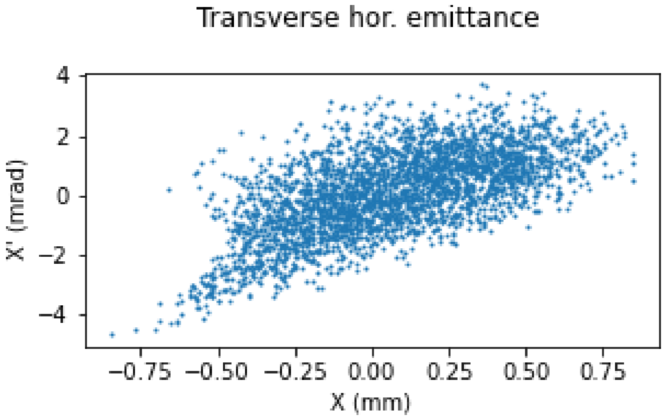
Current work: correction of aberrations with the multipole



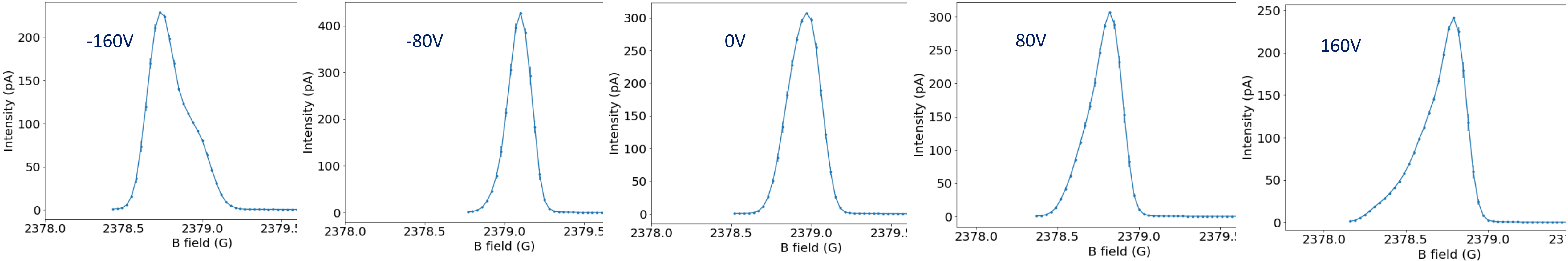
No corrections (hexapolar aberration)



2nd order correction (octupolar aberration)



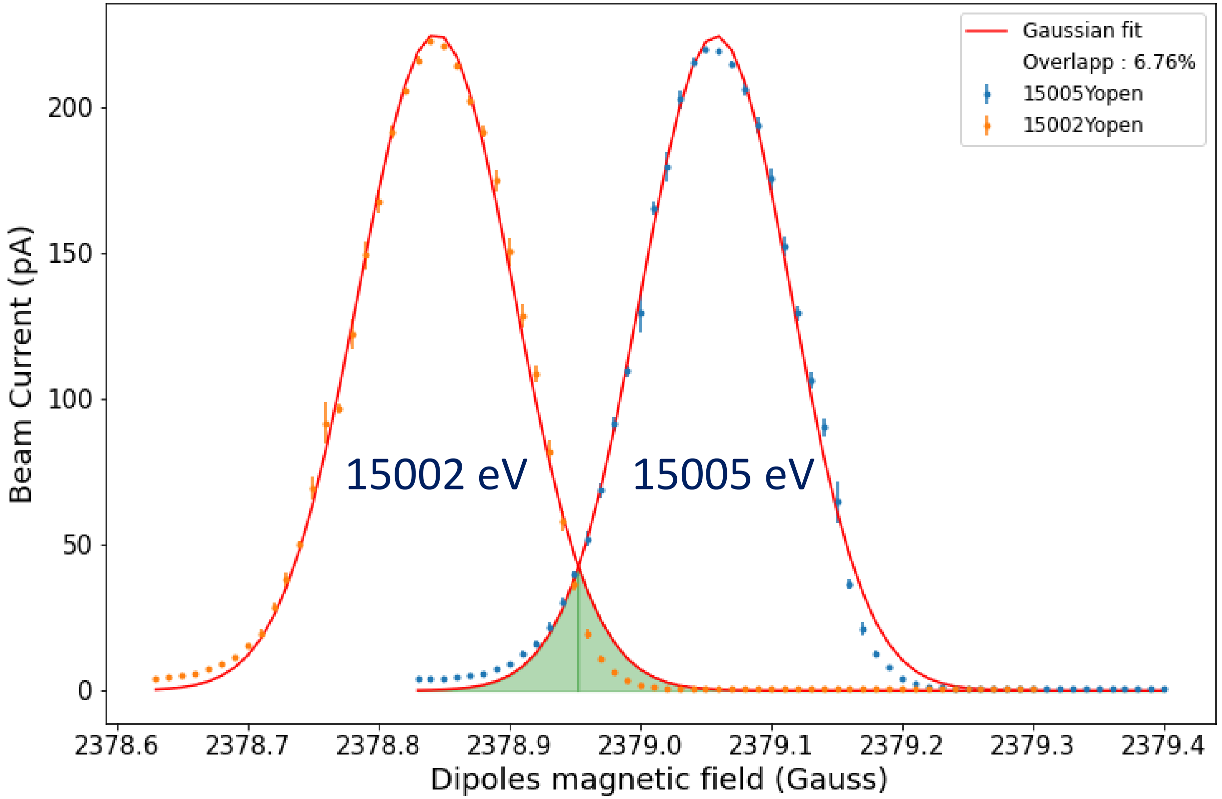
2nd and 3rd order correction (higher order aberrations)



Beam profiles for different multipole voltages (hexapolar)

HRS resolution

- Transfer functions of the spectrometer are identical for $\frac{\Delta M}{M}$ and $\frac{\Delta E}{E}$ ($\Delta E \ \rightarrow$ FWHM)
- We can estimate the resolution of the HRS by measuring two beams with close energy



One can extrapolate to a FWHM separation of:

$$\frac{\Delta E}{E} = \frac{1}{12000}$$

Next steps:

- Correct to next aberration orders (3^{rd}, 4^{th}, 5^{th} …)
- Increase the beam energy
- Aim to achieve the design resolution of $R = 20000$

More details on poster from J. Michaud !

J. Michaud et al., Proc. IPAC’21, to be published

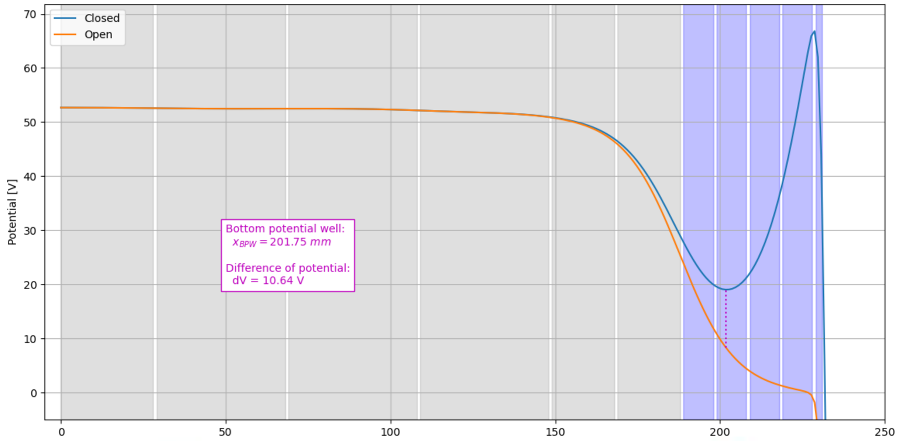
GPIB – General Purpose Ion Buncher

- ISCOOL mechanical design
  - Larger $r_0 = 20$ mm for high intensity beam
  - New development: increased U_{rf} up to 4 kV_{pp}
  - Frequency → 220 kHz – 2 MHz
- Control command → EPICS/Python based
- Homemade switches developed

Two operation modes:

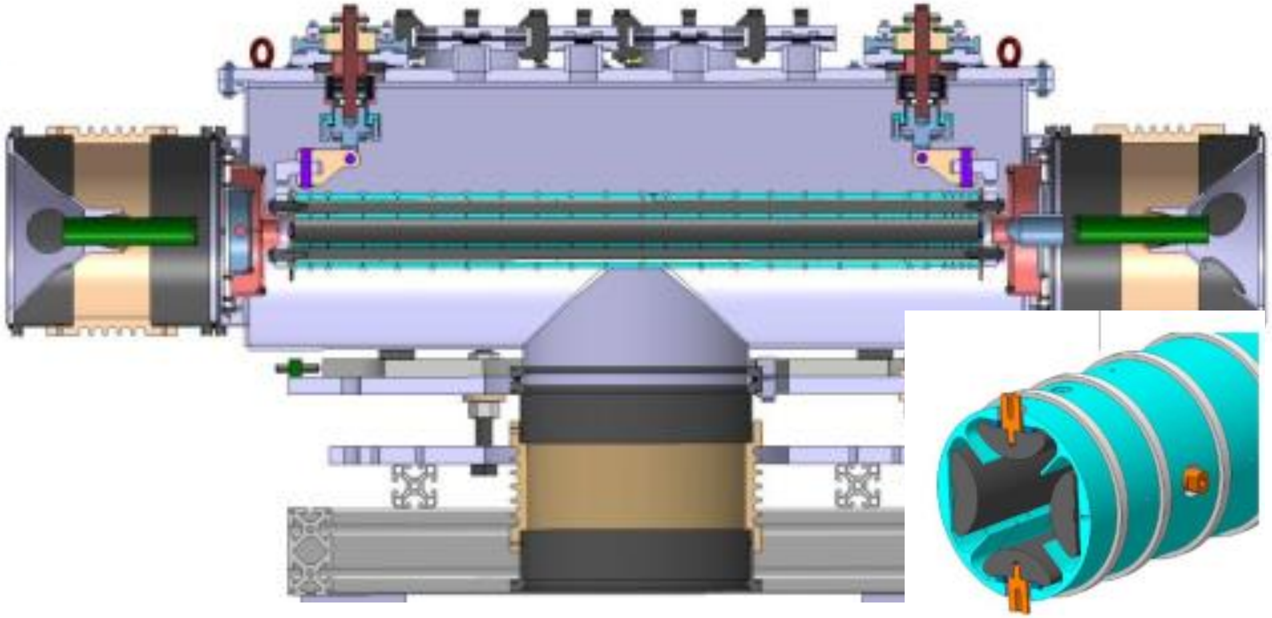
- CW mode
  - Test and characterization with ^{39}K (+ ^{41}K)
  - Beam cooling: $2.9(5)\pi$ mm.mrad @ 30 keV
  - Transmission → 80 % @ 30 keV
    92 % @ 3 keV
- Bunching mode

M. Gerbaux et al., to be submitted



Bottom potential well: $x_{BPW} = 201.75\ mm$

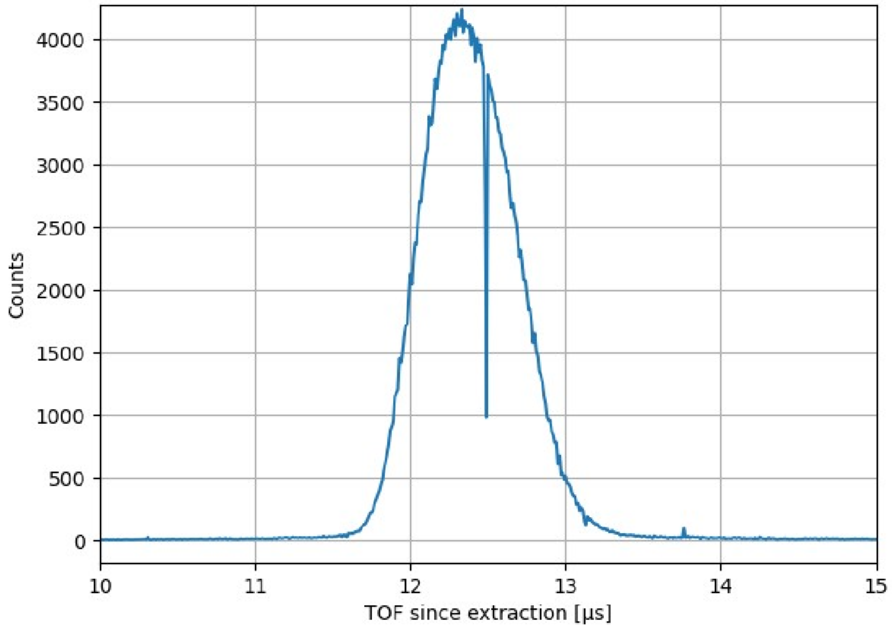
Difference of potential: dV = 10.64 V



Bunching mode

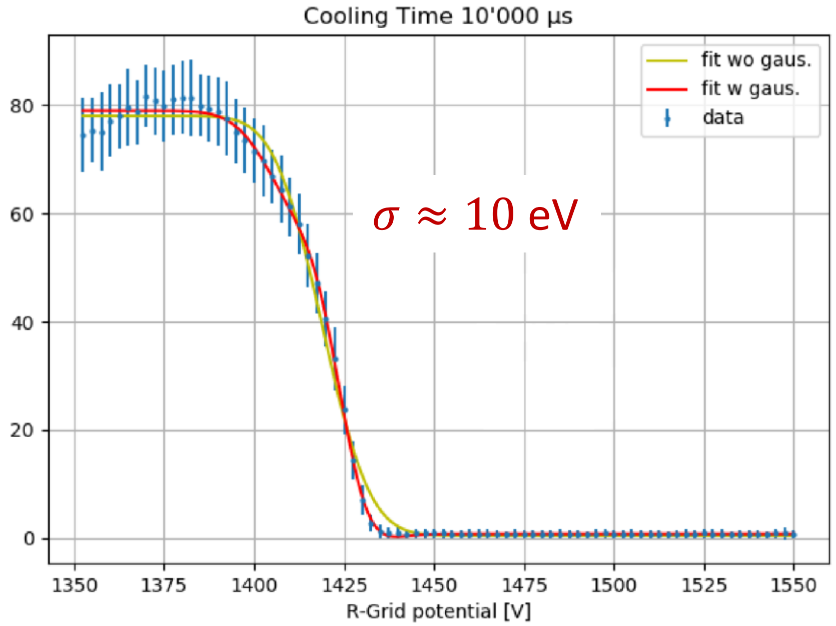
Time-of-flight dispersion:

- 1 – 2 µs FWHM at 30 keV
- 0.5 – 0.7 µs FWHM at 3 keV
- Extraction potentials can still be optimized for better bunch compression



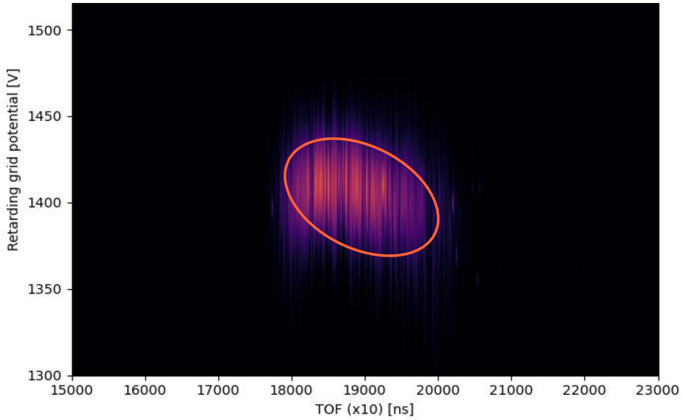
Energy dispersion

- ≈ 10 eV in 10 ms cooling time
- Cooling sequence optimization in progress



Next steps:

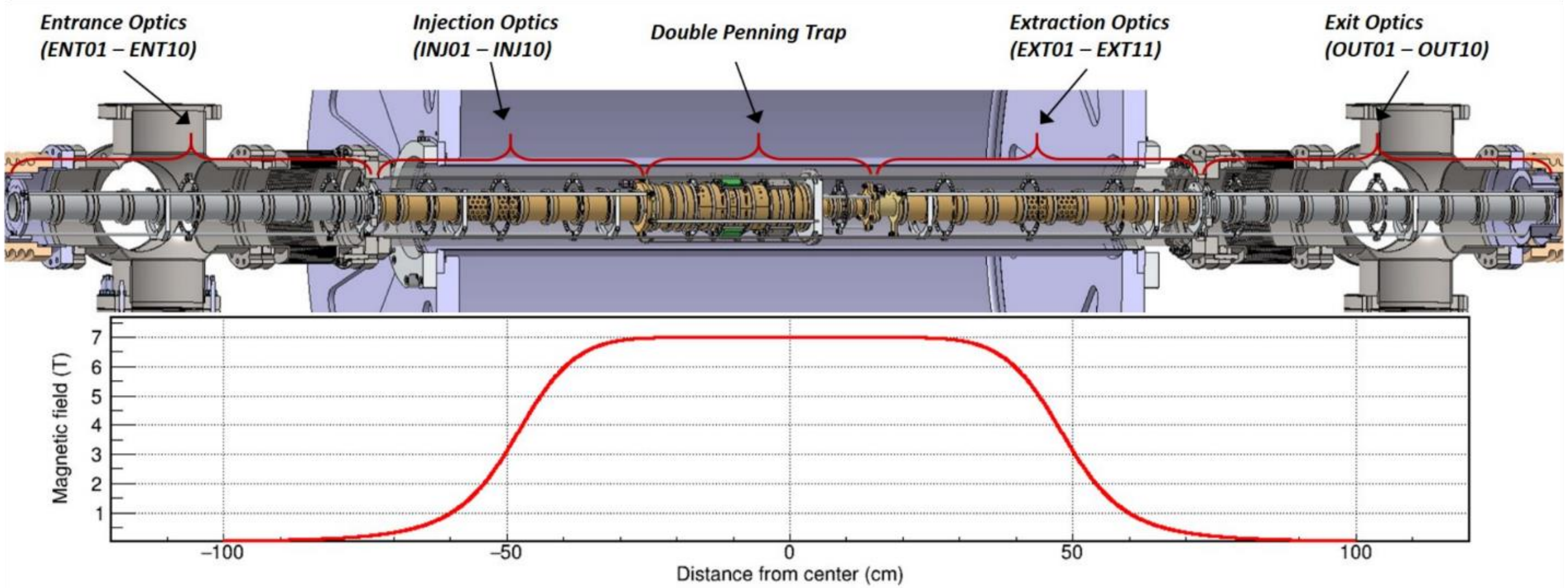
- Transverse emittance measurements at 3 keV and 30 keV
- Longitudinal emittance measurements



⇨ Longitudinal emittance test measurement

M. Gerbaux et al., to be submitted

PIPERADE



PIPERADE double Penning trap:

- 7 T superconducting magnet
- Homemade switches
- Control command
    - ➢ EPICS/Python

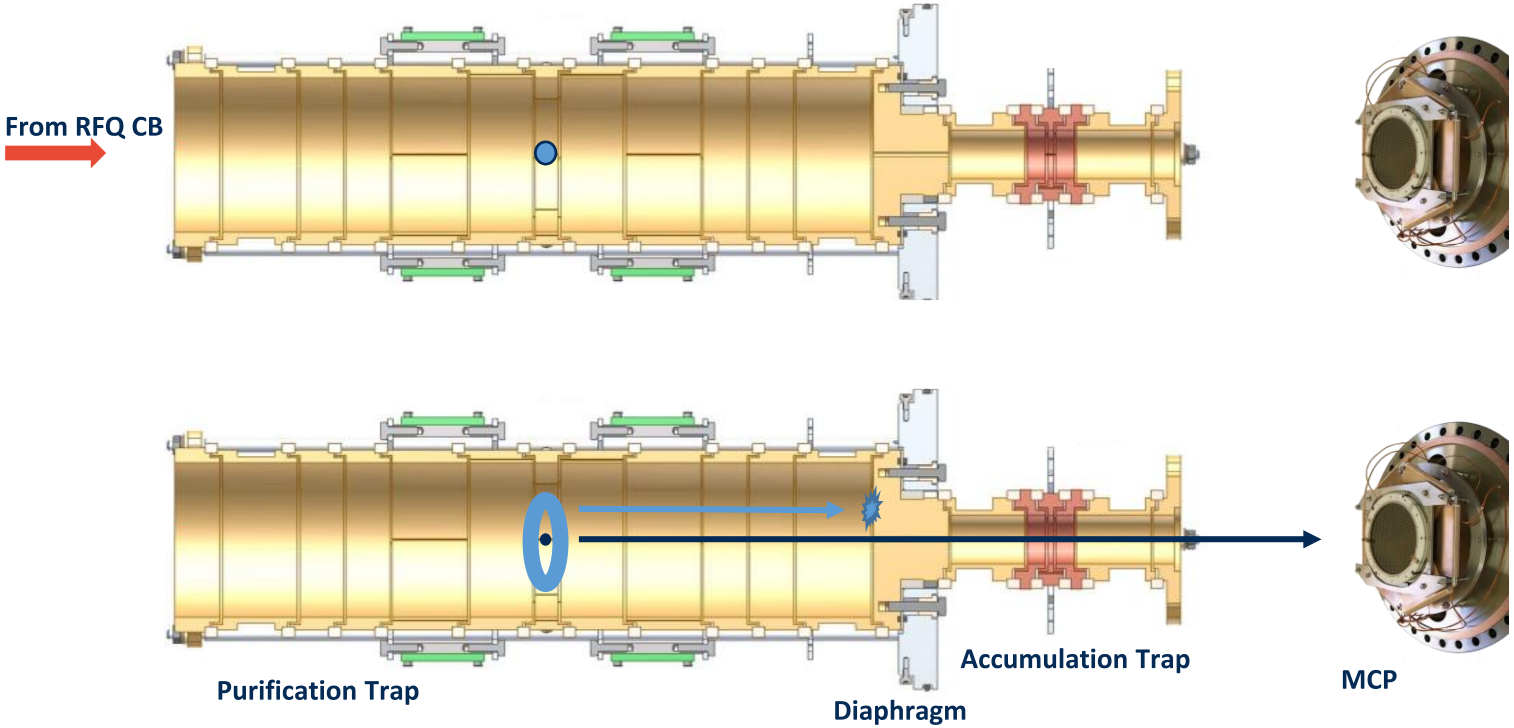
First trap – Purification trap

- Beam purification
- Large inner radius
    - Minimize space charge effects
    - > 10^4 ions per bunch

Second trap – Measurement trap

- Accumulation
- Isomeric purification
- Mass measurements

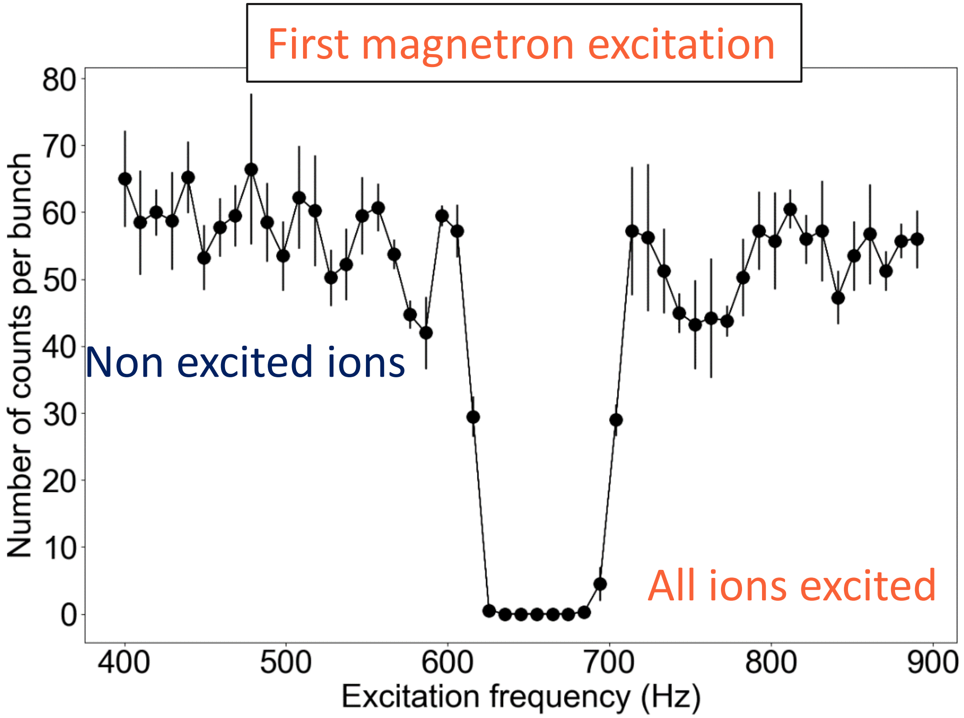
Buffer gas cooling technique



- Gas filled purification trap
- Separation → 2 main steps:
  - 1st bring all ions off axis
    - ➢ Magnetron excitation
  - 2nd center back only the ions of interest
    - ➢ Cyclotron excitation
- Cooling

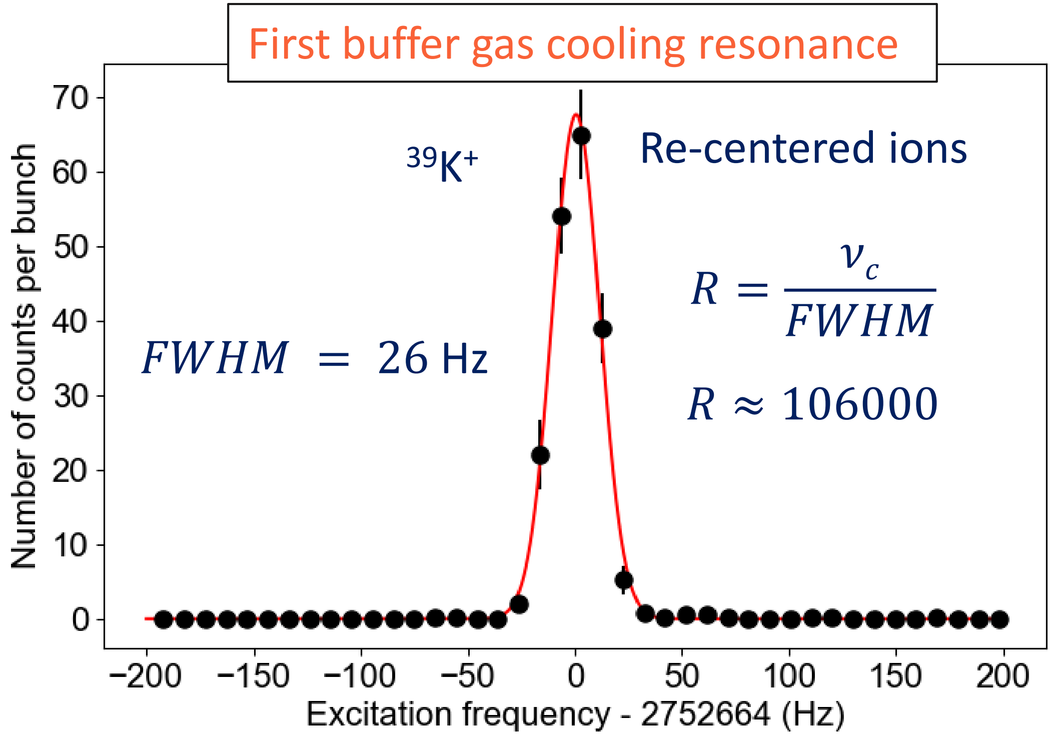
First buffer gas cooling achieved with PIPERADE !!!!

Buffer gas cooling technique


First magnetron excitation

Non excited ions

All ions excited


First buffer gas cooling resonance

$^{39}K^+$

Re-centered ions

$FWHM = 26$ Hz

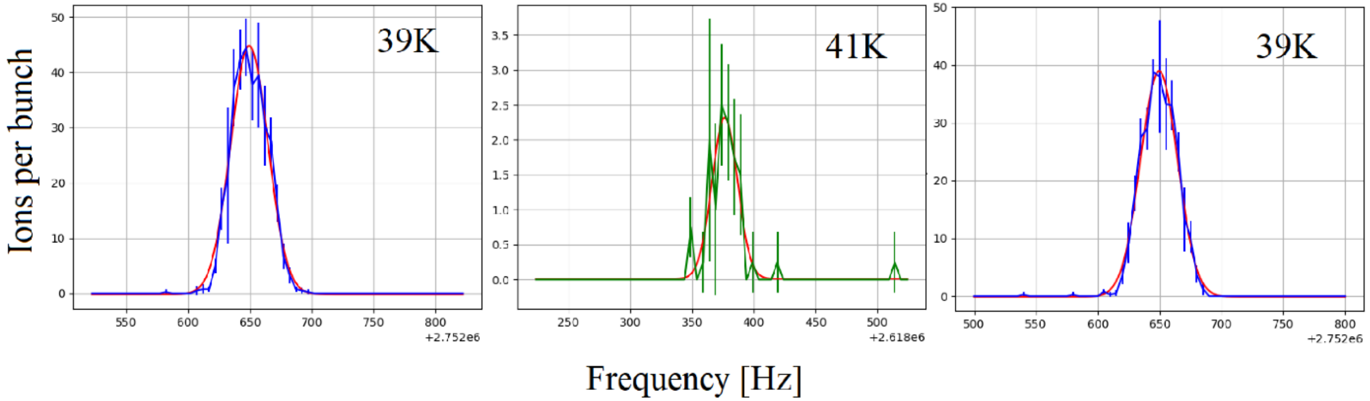
$$R = \frac{\nu_c}{FWHM}$$

$$R \approx 106000$$

- Technique tested on
  - ^{39}K
  - ^{40}Ca
  - ^{41}K
- Resolving power of 10^5 reached
- On-going studies to improve the resolution and the re-centering efficiency

P. Ascher et al., Nucl. Instrum. Methods Phys. Res. A, accepted for publication

Buffer gas cooling technique



1^{st} rough mass measurement of ^{41}K vs ^{39}K

- ME(^{41}K) = -35523 ± 3 keV
- Deviation of ≈ 40 keV with the AME
- Study of systematics ongoing

See poster from M. Flayol !

Next steps:

- Mass measurements with the 2^{nd} trap (first ion trapping achieved during summer)
- Implementation of PI-ICR

Thank you for your attention

Local team

Physicists
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S. Perard

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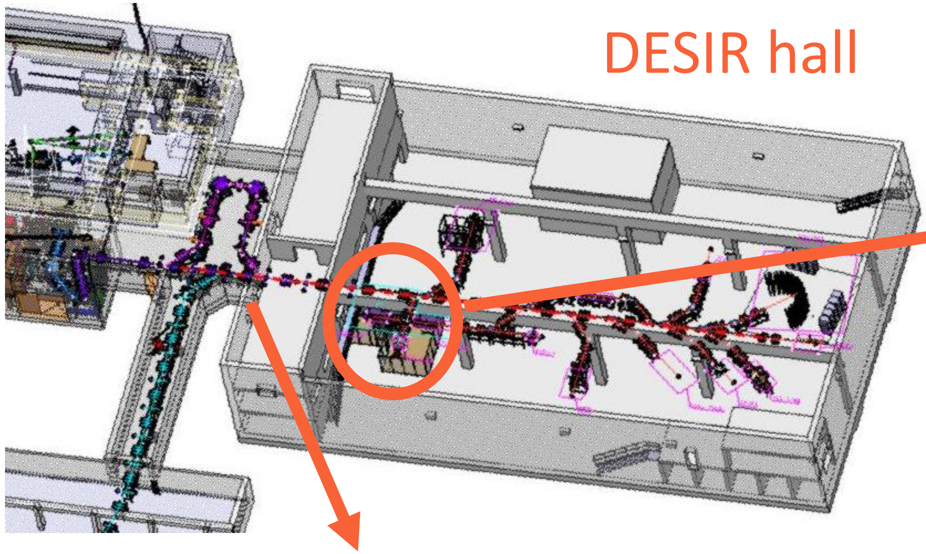
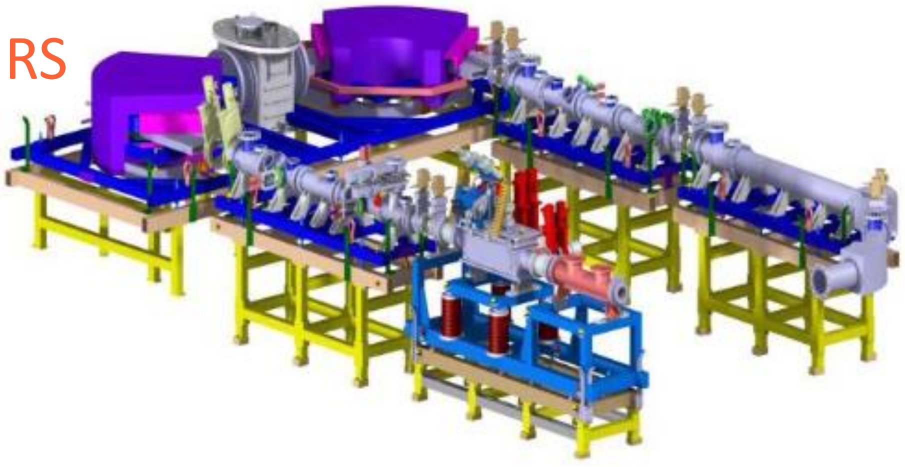
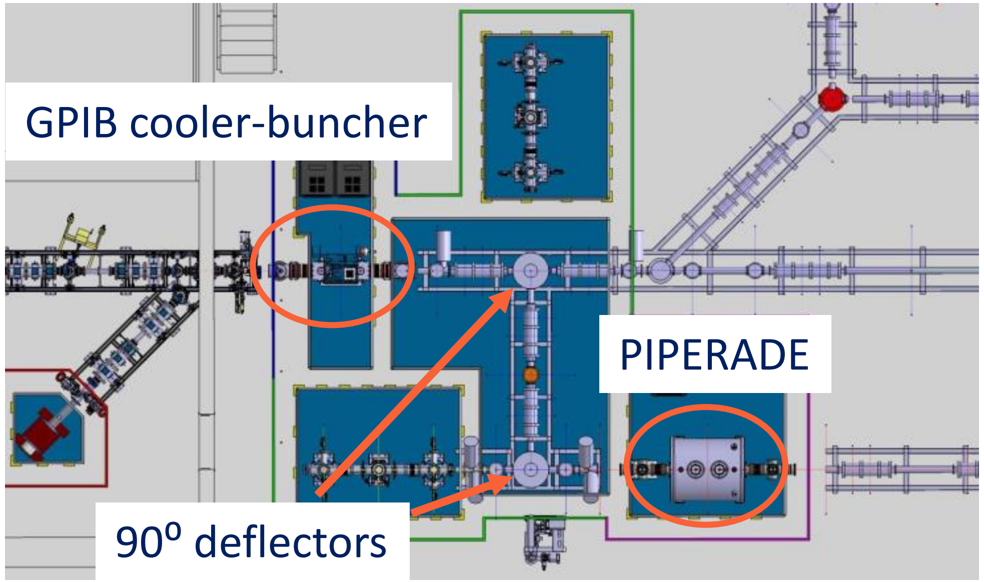
- *T. Kurtukian et al., Nucl. Instrum. Methods Phys. Res. B 317 (2013) 284-289*
- *P. Ascher, et al., EPJ Web of Conf. 66 (2014) 537 11002*
- *E. M. Ramirez, et al., 539 Nucl. Instrum. Methods Phys. Res. B 376 (2016) 298*
- *P. Ascher et al., Nucl. Instrum. Methods Phys. Res. A, accepted for publication*
- *J. Michaud et al., Proc. IPAC'21, to be published*
- *M. Gerbaux et al., to be submitted*

HRS, GPIB & PIPERADE





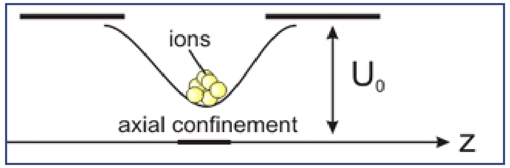


Towards high beam purity

- HRS
  - Beam emittance reduction via SHIRaC
  - Located in front of DESIR
  - Resolving power of ≈ 10^4
- GPIB + PIPERADE
  - Located at the entrance of DESIR
  - GPIB delivers ion bunches to the hall
  - Resolving power higher than 10^6

All are being commissioned at CENBG

PIPERADE



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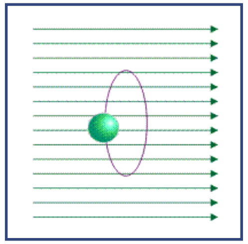
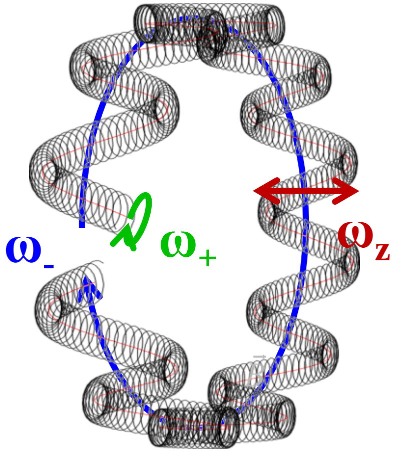


Confinement in 3D:

- 3 independent motions
- 3 eigen frequencies



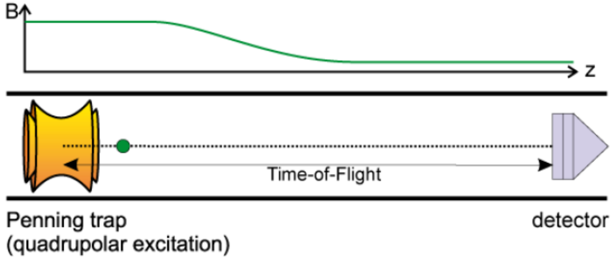
Axial motion
$\omega_z \sim$ 100 kHz

Modified cyclotron motion
$\omega_+ \sim$ 10 MHz

Magnetron motion
$\omega_- \sim$ kHz

⇨

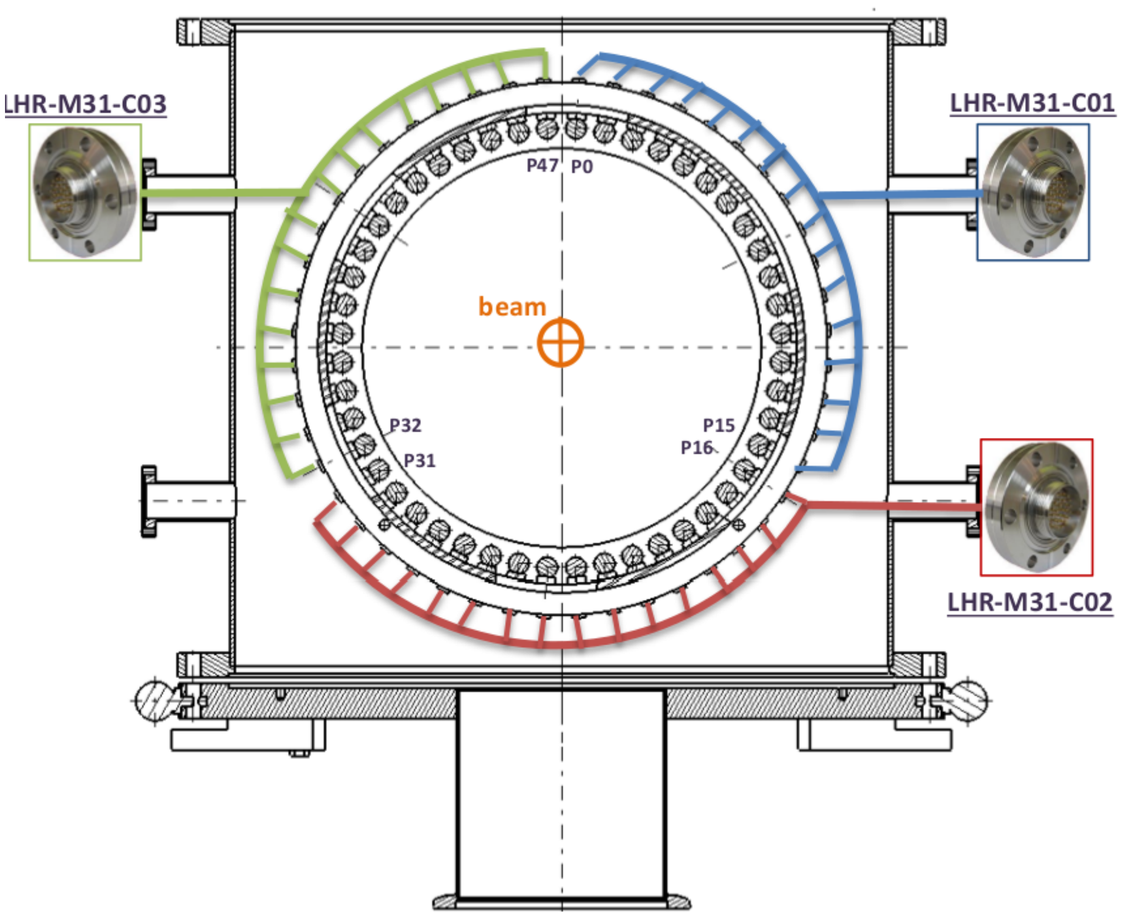
$$\boxed{\begin{aligned} \omega_c &= \omega_+ + \omega_- \\ \omega_c &= \frac{q}{m} B \end{aligned}}$$

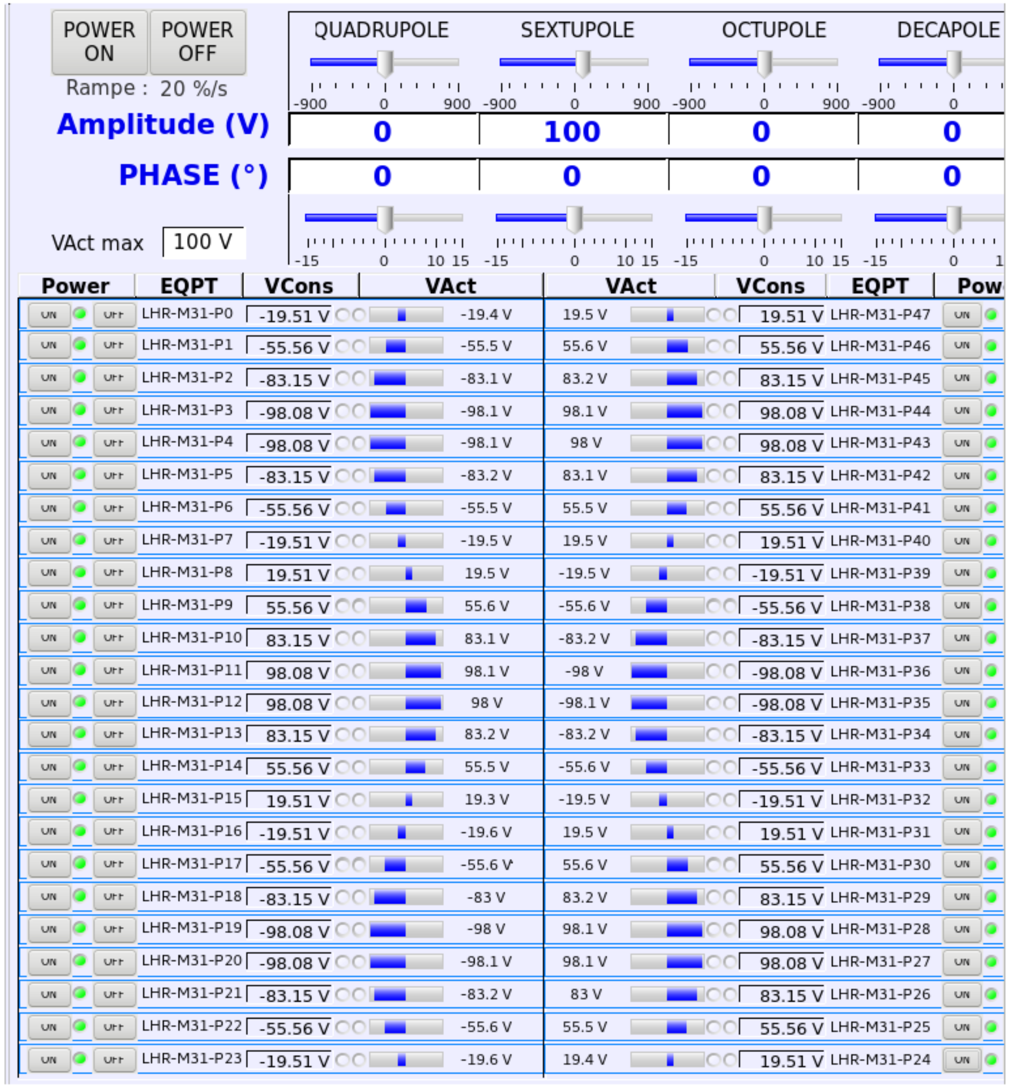


Mass measurement:

- Scan around ω_c
- Extraction of ions
- Measurement of their ToF

Current work: correction of aberrations with the multipole





Rampe : 20 %/s

	QUADRUPOLE	SEXTUPOLE	OCTUPOLE	DECAPOLE
Amplitude (V)	0	100	0	0
PHASE (°)	0	0	0	0

VAct max 100 V

Power	EQPT	VCons	VAct	VAct	VCons	EQPT	Pow
ON ● OFF	LHR-M31-P0	-19.51 V	-19.4 V	19.5 V	19.51 V	LHR-M31-P47	ON ●
ON ● OFF	LHR-M31-P1	-55.56 V	-55.5 V	55.6 V	55.56 V	LHR-M31-P46	ON ●
ON ● OFF	LHR-M31-P2	-83.15 V	-83.1 V	83.2 V	83.15 V	LHR-M31-P45	ON ●
ON ● OFF	LHR-M31-P3	-98.08 V	-98.1 V	98.1 V	98.08 V	LHR-M31-P44	ON ●
ON ● OFF	LHR-M31-P4	-98.08 V	-98.1 V	98 V	98.08 V	LHR-M31-P43	ON ●
ON ● OFF	LHR-M31-P5	-83.15 V	-83.2 V	83.1 V	83.15 V	LHR-M31-P42	ON ●
ON ● OFF	LHR-M31-P6	-55.56 V	-55.5 V	55.5 V	55.56 V	LHR-M31-P41	ON ●
ON ● OFF	LHR-M31-P7	-19.51 V	-19.5 V	19.5 V	19.51 V	LHR-M31-P40	ON ●
ON ● OFF	LHR-M31-P8	19.51 V	19.5 V	-19.5 V	-19.51 V	LHR-M31-P39	ON ●
ON ● OFF	LHR-M31-P9	55.56 V	55.6 V	-55.6 V	-55.56 V	LHR-M31-P38	ON ●
ON ● OFF	LHR-M31-P10	83.15 V	83.1 V	-83.2 V	-83.15 V	LHR-M31-P37	ON ●
ON ● OFF	LHR-M31-P11	98.08 V	98.1 V	-98 V	-98.08 V	LHR-M31-P36	ON ●
ON ● OFF	LHR-M31-P12	98.08 V	98 V	-98.1 V	-98.08 V	LHR-M31-P35	ON ●
ON ● OFF	LHR-M31-P13	83.15 V	83.2 V	-83.2 V	-83.15 V	LHR-M31-P34	ON ●
ON ● OFF	LHR-M31-P14	55.56 V	55.5 V	-55.6 V	-55.56 V	LHR-M31-P33	ON ●
ON ● OFF	LHR-M31-P15	19.51 V	19.3 V	-19.5 V	-19.51 V	LHR-M31-P32	ON ●
ON ● OFF	LHR-M31-P16	-19.51 V	-19.6 V	19.5 V	19.51 V	LHR-M31-P31	ON ●
ON ● OFF	LHR-M31-P17	-55.56 V	-55.6 V	55.6 V	55.56 V	LHR-M31-P30	ON ●
ON ● OFF	LHR-M31-P18	-83.15 V	-83 V	83.2 V	83.15 V	LHR-M31-P29	ON ●
ON ● OFF	LHR-M31-P19	-98.08 V	-98 V	98.1 V	98.08 V	LHR-M31-P28	ON ●
ON ● OFF	LHR-M31-P20	-98.08 V	-98.1 V	98.1 V	98.08 V	LHR-M31-P27	ON ●
ON ● OFF	LHR-M31-P21	-83.15 V	-83.2 V	83 V	83.15 V	LHR-M31-P26	ON ●
ON ● OFF	LHR-M31-P22	-55.56 V	-55.6 V	55.5 V	55.56 V	LHR-M31-P25	ON ●
ON ● OFF	LHR-M31-P23	-19.51 V	-19.6 V	19.4 V	19.51 V	LHR-M31-P24	ON ●

GPIB and PIPERADE at CENBG