PIPERADE @ DESIR

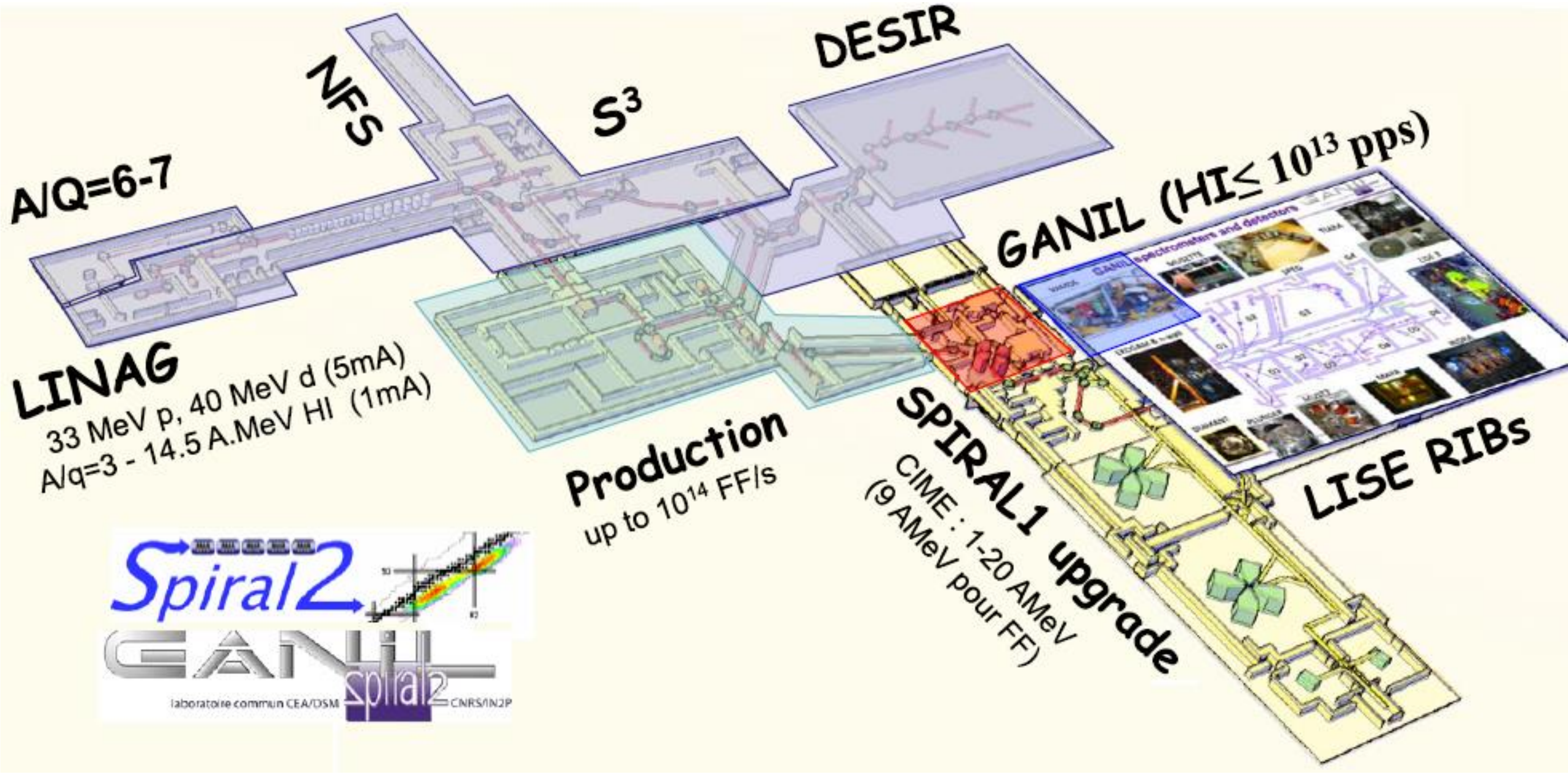
PIEGES DE PENNING POUR LES RADIOISOTOPES A DESIR

- The DESIR facility
- Why PIPERADE? Example of physics cases
- The PIPERADE set-up
    - GPIB (General Purpose Ion Buncher)
    - Double Penning trap

Pauline Ascher - ISOLDE Seminar - 3d September 2015

SPIRAL2 at GANIL

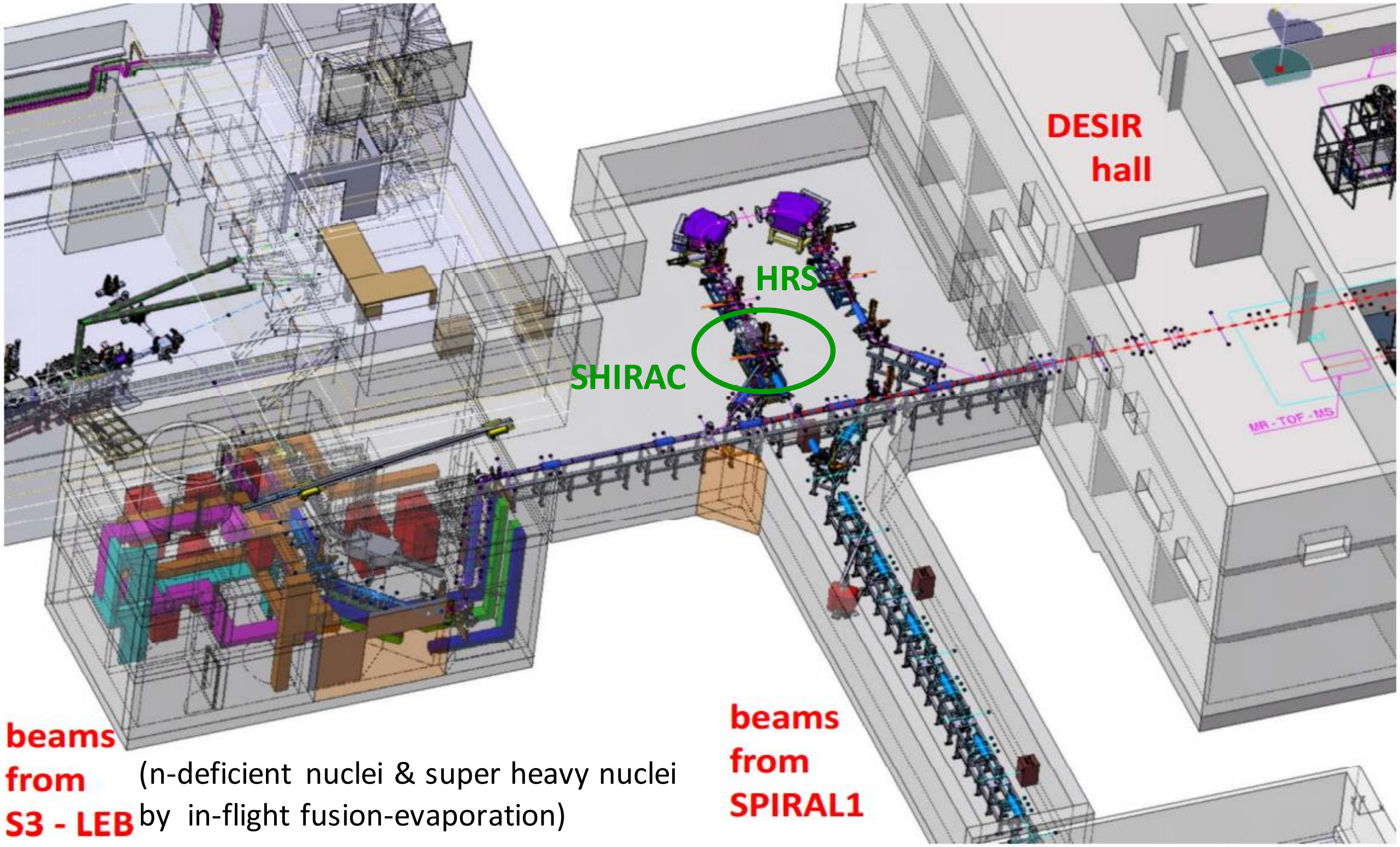
Phase 1	LINAC + NFS + S3	→	Constructed Commissioning of LINAC and NFS this year, of S3 in 2016-2017
Phase 1+	DESIR	→	Construction mid-2017 Commissioning mid- 2019
Phase 2	Production building	→	> 2025?



Collaboration Spokesperson: *B. Blank, CENBG*
Facility coordinator: *J.-C. Thomas, GANIL*

DESIR

Beams from SPIRAL1 and S3



(n-deficient & n-rich nuclei by ISOL fragmentation,
up to mass ~ 90)

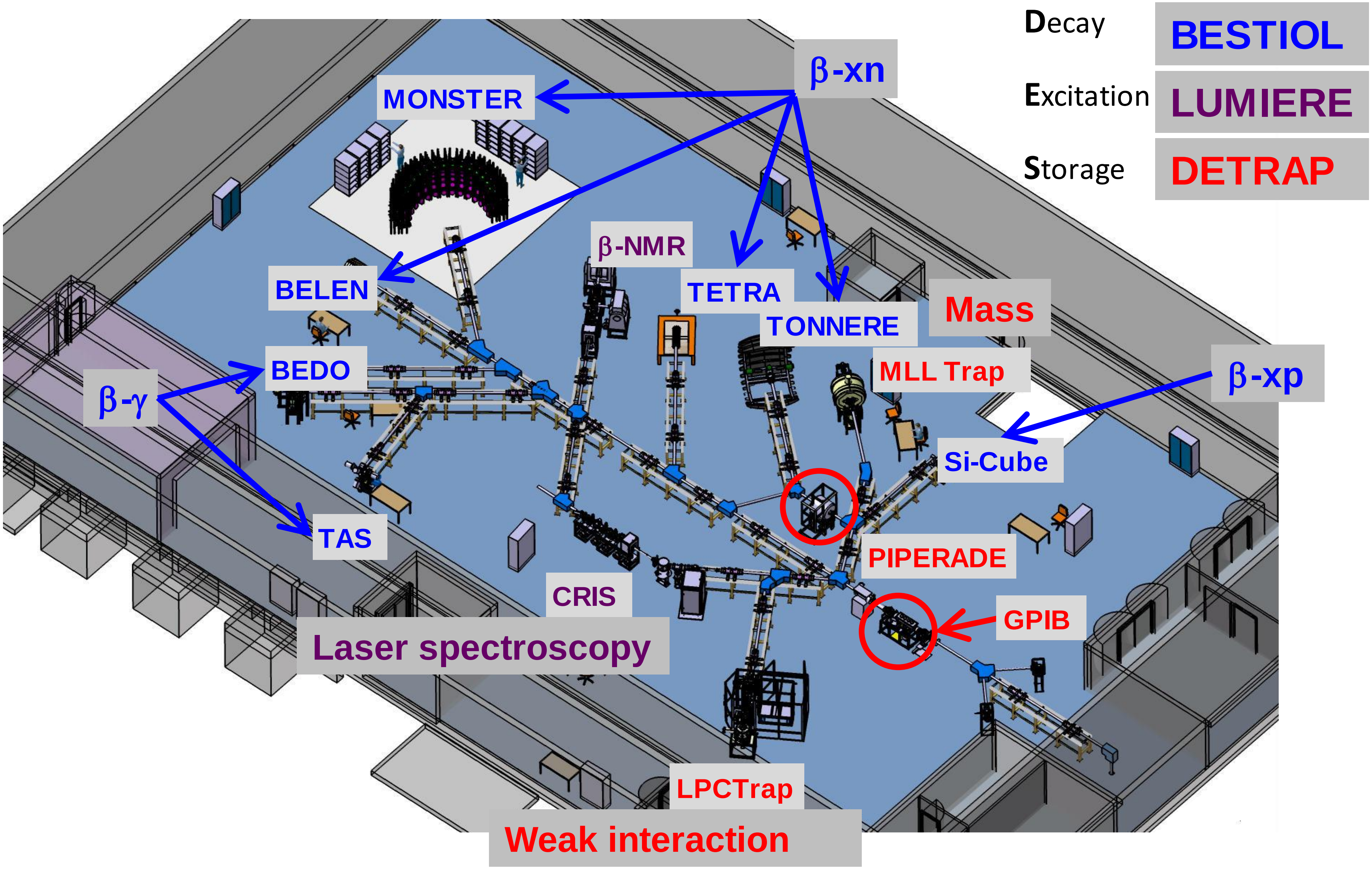
News

New location of SHIRAC and HRS due to the delay of the phase 2

DESIR is now fully funded! ~14M€ from Germany, ~ 8 M€ from EQUIPEX and ~ 2M€ from CPER

total 24 M€

Experimental equipment



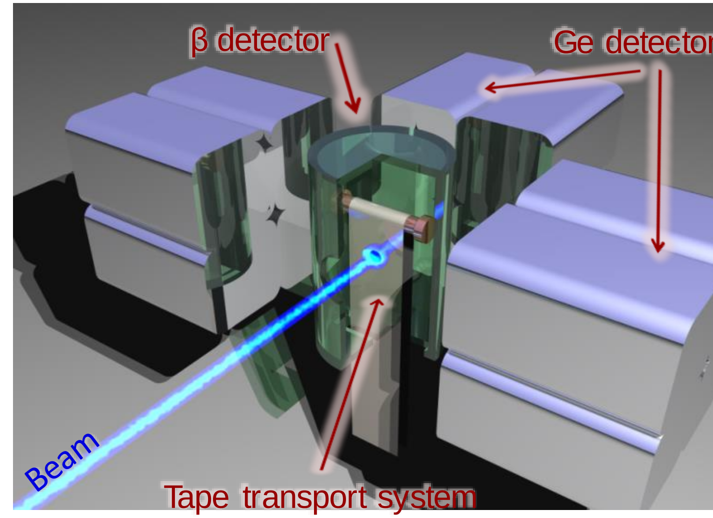
Examples of DESIR experiments

Trap assisted $\beta-\gamma$ spectroscopy

High-precision measurements of $T_{1/2}$ and BR of super-allowed Fermi beta decay and mirror transitions

→ test the CVC hypothesis and the unitarity of the CKM matrix (V_{ud} element)

(^{66}As, ^{70}Br, ^{74}Rb, ^{94}Ag, ^{98}In, ….)



TAS (Total Absorption Spectroscopy)

Reconstruction of a nucleus level scheme
Avoid the « Pandemonium » effect but need to get rid of any contaminant

→ nuclear structure, astrophysics, nuclear power

($^{80\text{-}82}$Zn, $^{98\text{-}101}$In, $^{97\text{-}99}$Cd, $^{130\text{-}132}$In, ^{130}Ag, …)

High-precision mass measurements

→ shell closures evolution, r-process studies

(^{80}Zr, ^{100}Sn, ^{83}Zn, $^{131\text{-}133}$In, $^{129\text{-}133}$Cd, …)

→ Q values for super-allowed transitions

(^{66}As, ^{70}Br, …)

Requirements of PIPERADE

Goal of PIPERADE (Pièges de Penning pour les ions radioactifs à DESIR) : deliver **very pure** and **large samples** of exotic nuclei to the DESIR set-ups

Requirements

→ **Mass resolution > 10^5** (to clean isobars not cleaned by the HRS + isomers)

Ions of interest usually less produced than contaminants

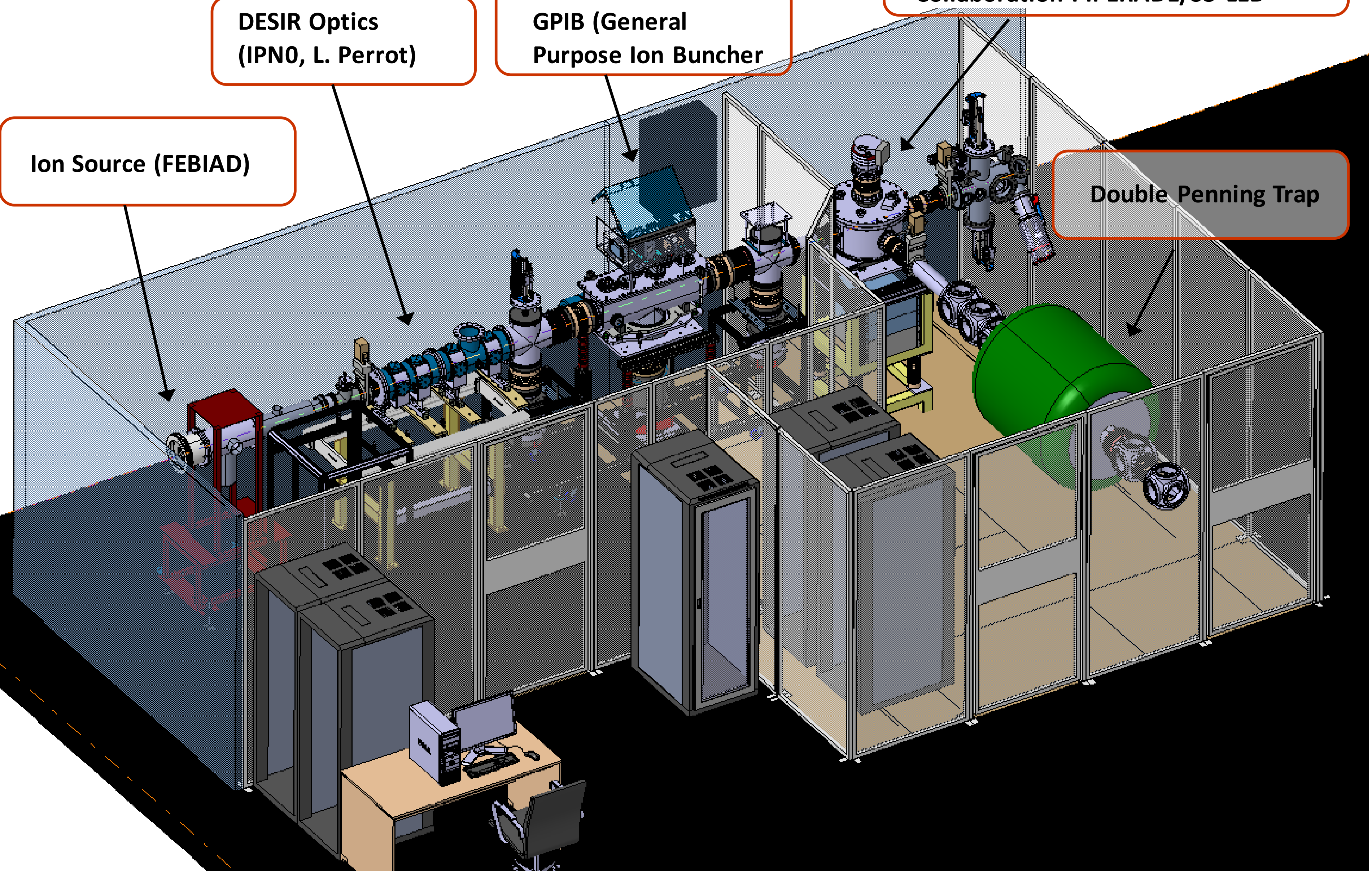
→ Purification of large samples **(> 10^4 ions/bunch)**

→ "**Fast**" cleaning process

→ High transmission efficiency

→ **Double Penning trap (1 for purification, 1 for accumulation)**

PIPERADE @ CENBG



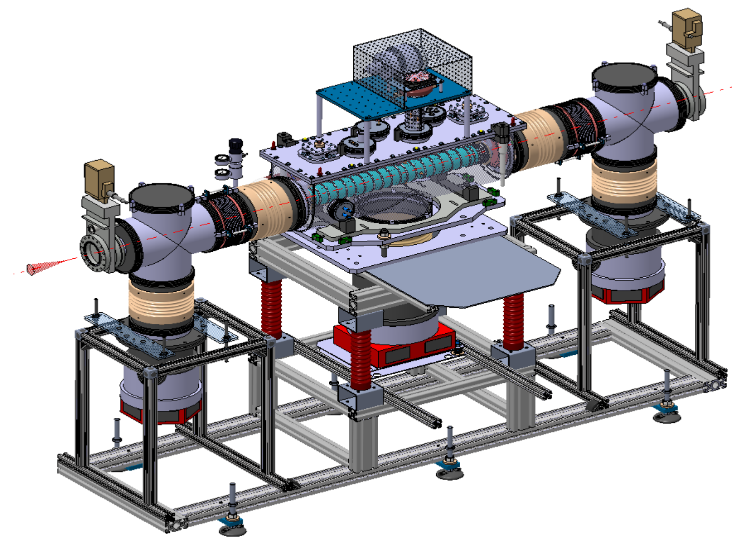
GPIB (General Purpose Ion Buncher)

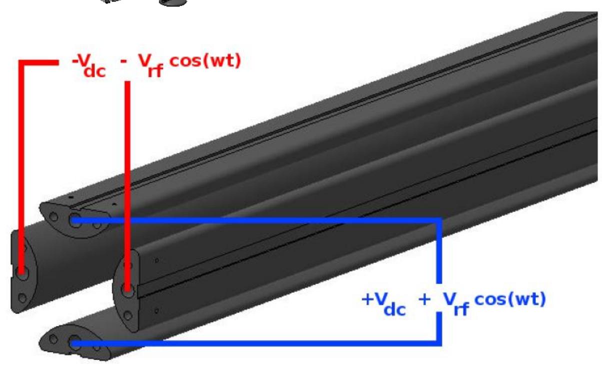
Aim: cool and bunch the beam

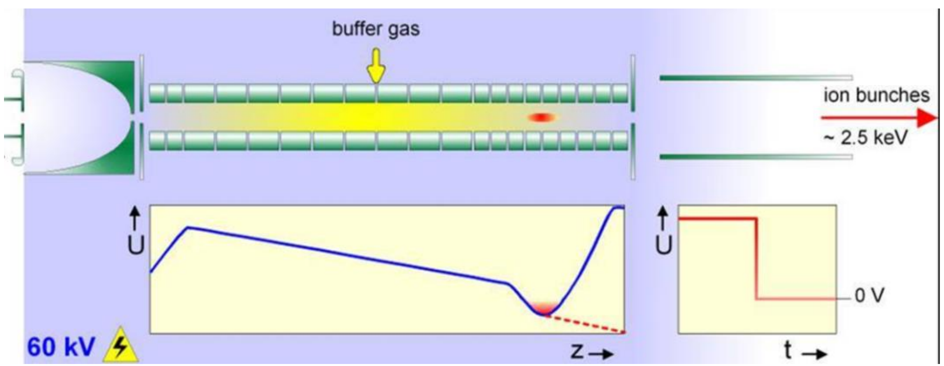
- for injection into Penning trap
- DESIR experiments might need bunched beam (e.g. collinear laser spectroscopy, LPCTrap)
- will be placed in the central beam line

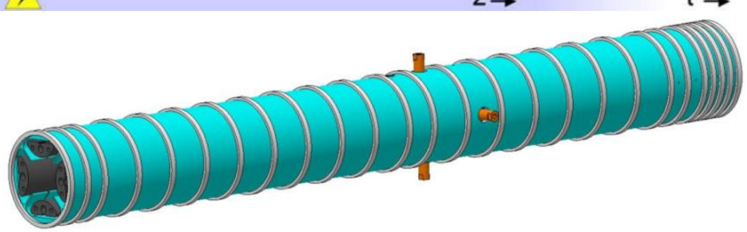
RFQ Principle

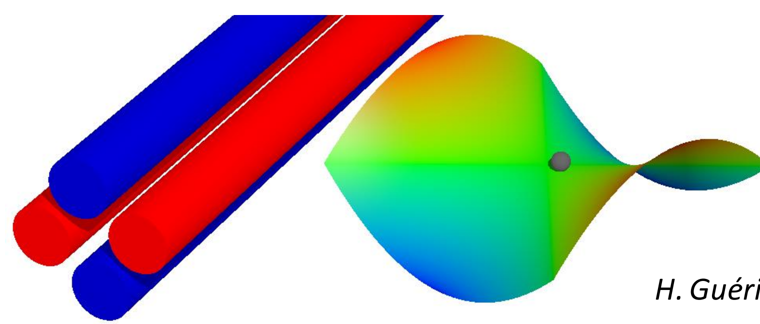
- Cooling via collisions wit buffer gas
- RF field on the 4 rods for radial confinement
- DC gradient for guiding the ions
- DC switching for bunching









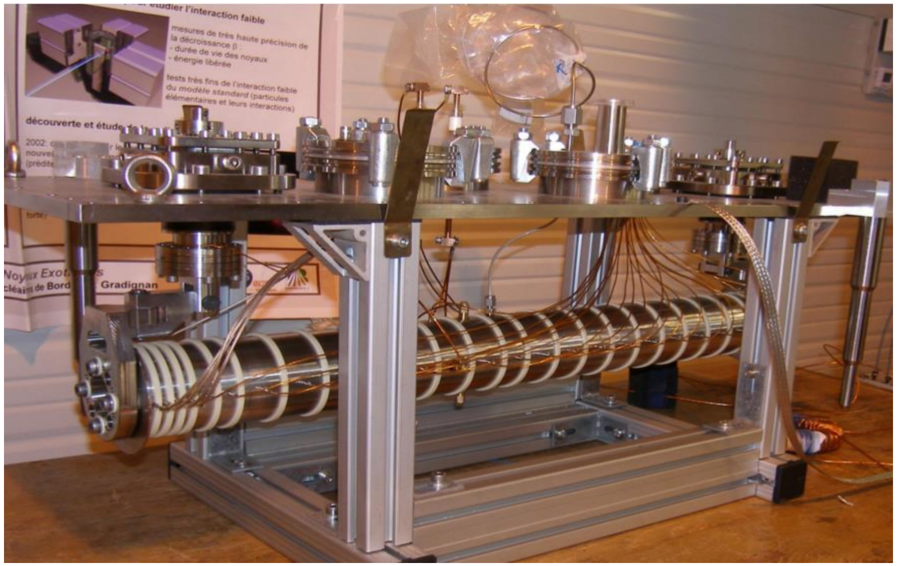


H. Guérin

GPIB (General Purpose Ion Buncher)

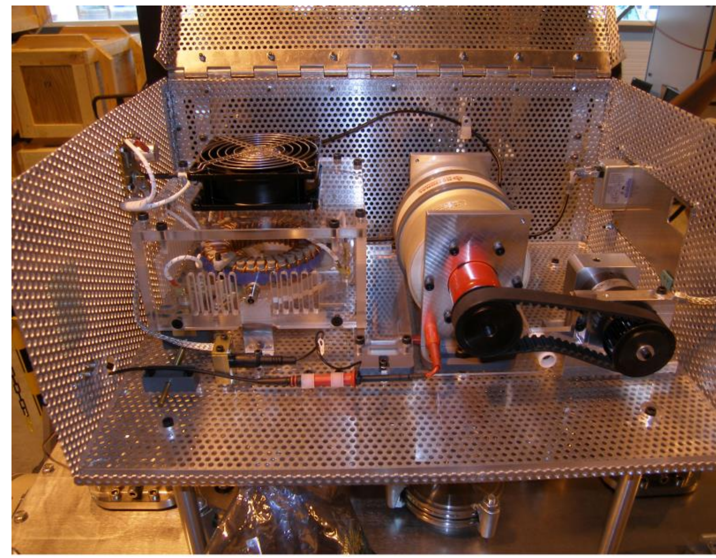
- Constructed at CENBG
- ISCOOL Mechanical design

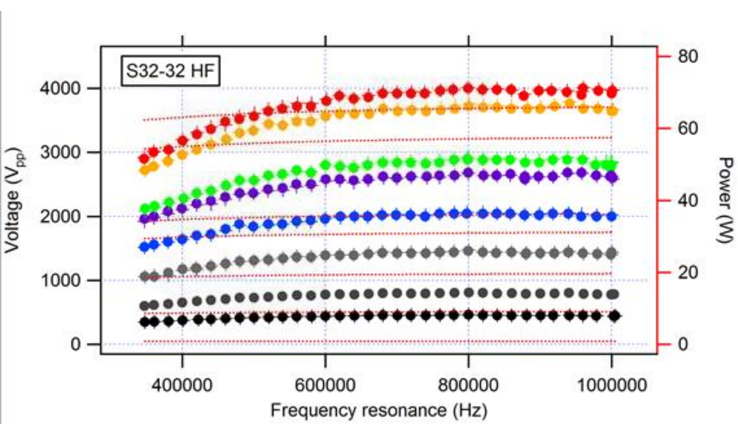
Large r_0 (=20 mm) to handle high-intensity beam

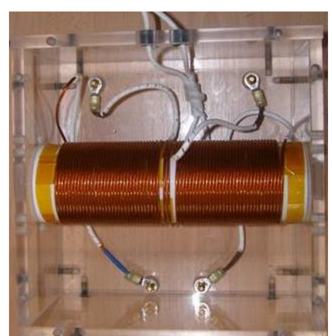


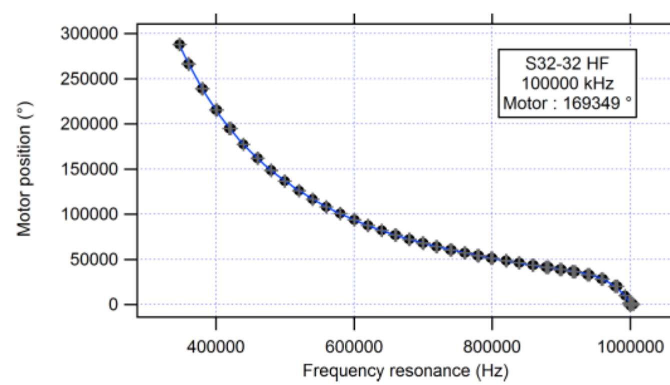
New RF circuit developed to reach high U_{RF} for better confinement

Motor to tune a capacitance to adjust the resonance frequency





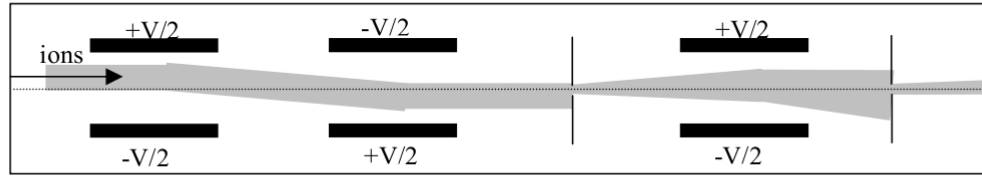


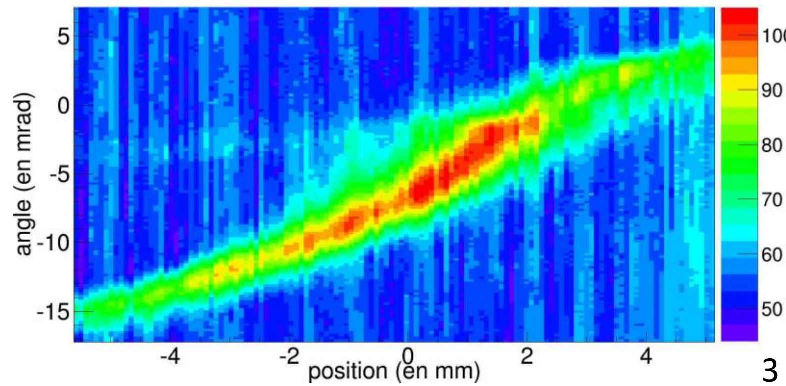


Coll. LPCCaen

Reference emittance measurements

Emittancemeter with vertical and horizontal slits



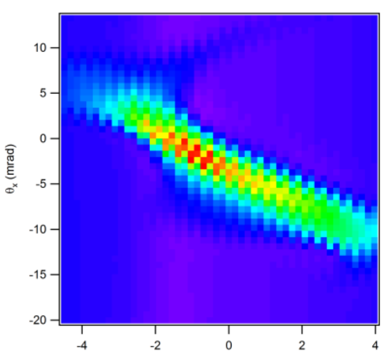


Source emittance
ε = 26 π mm mrad
at 30 keV

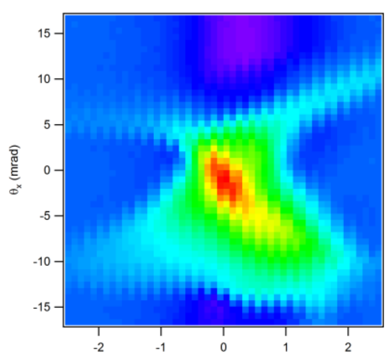
(Aim of GPIB:
3 π mm mrad at 30 keV)

With different focusing parameters
(Q12 and Q3 quadrupole triplet voltages)

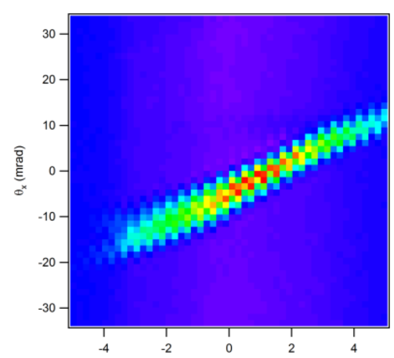
Q_{12}=337 V
Q_3=333 V



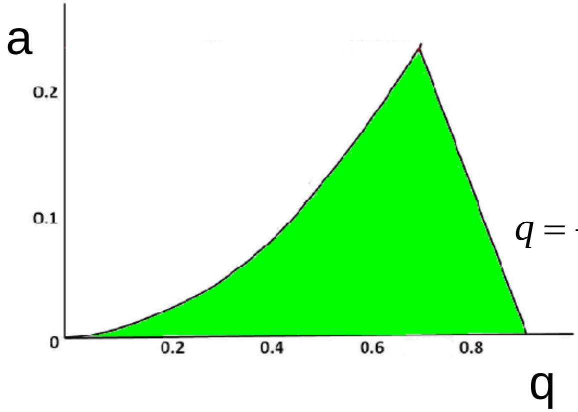
Q_{12}=356 V
Q_3=347 V



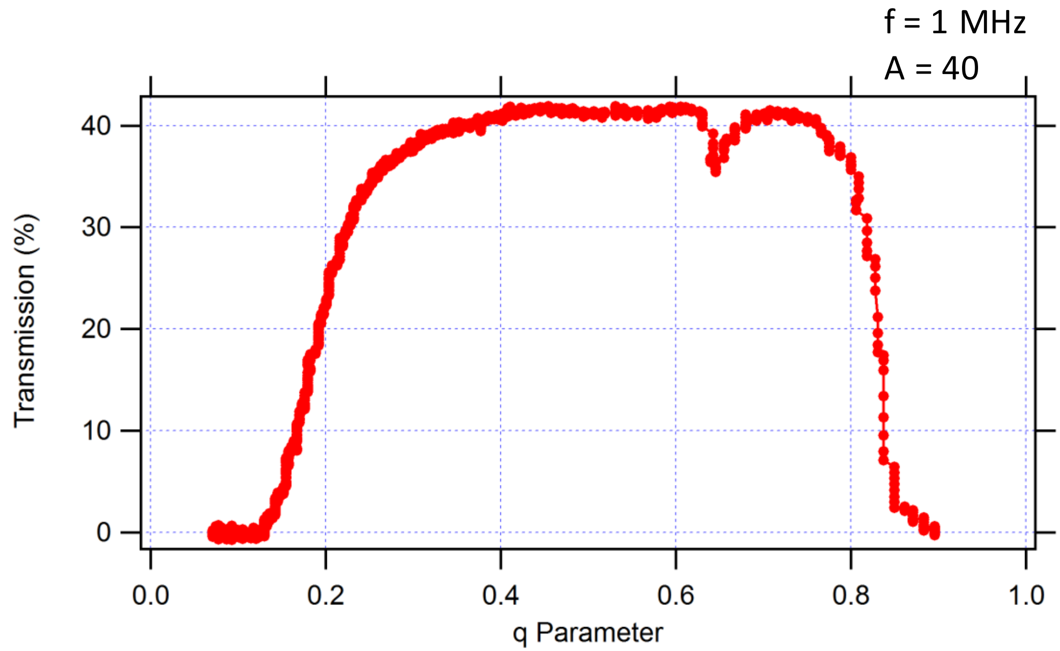
Q_{12}=381 V
Q_3=365 V



First GPIB transmission measurements

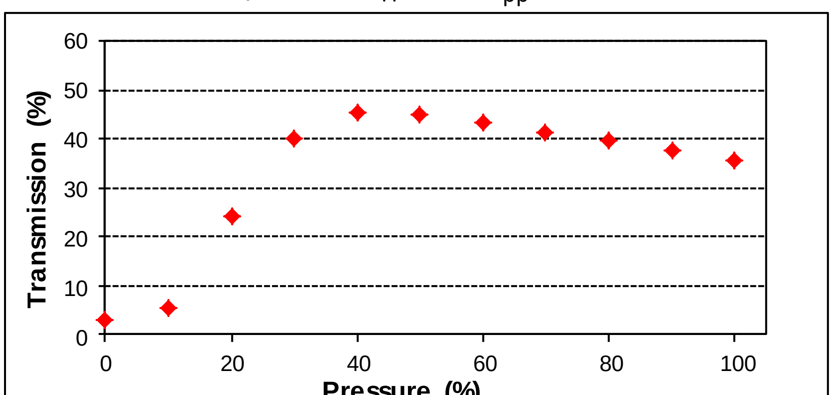


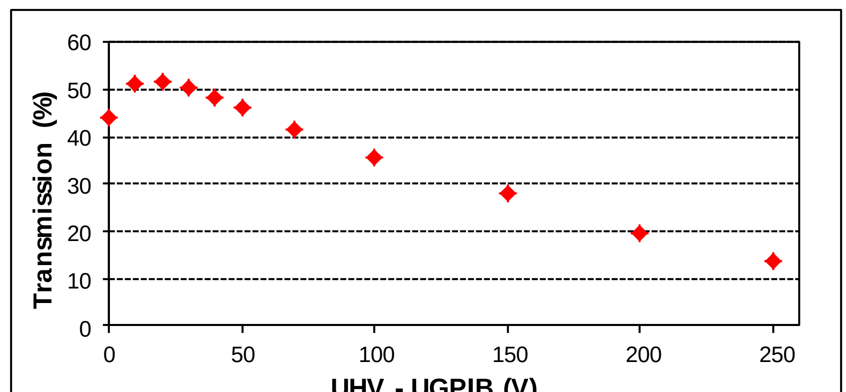
$$q = \frac{4QV_{RF}}{mr_0^2\omega_{RF}^2}$$



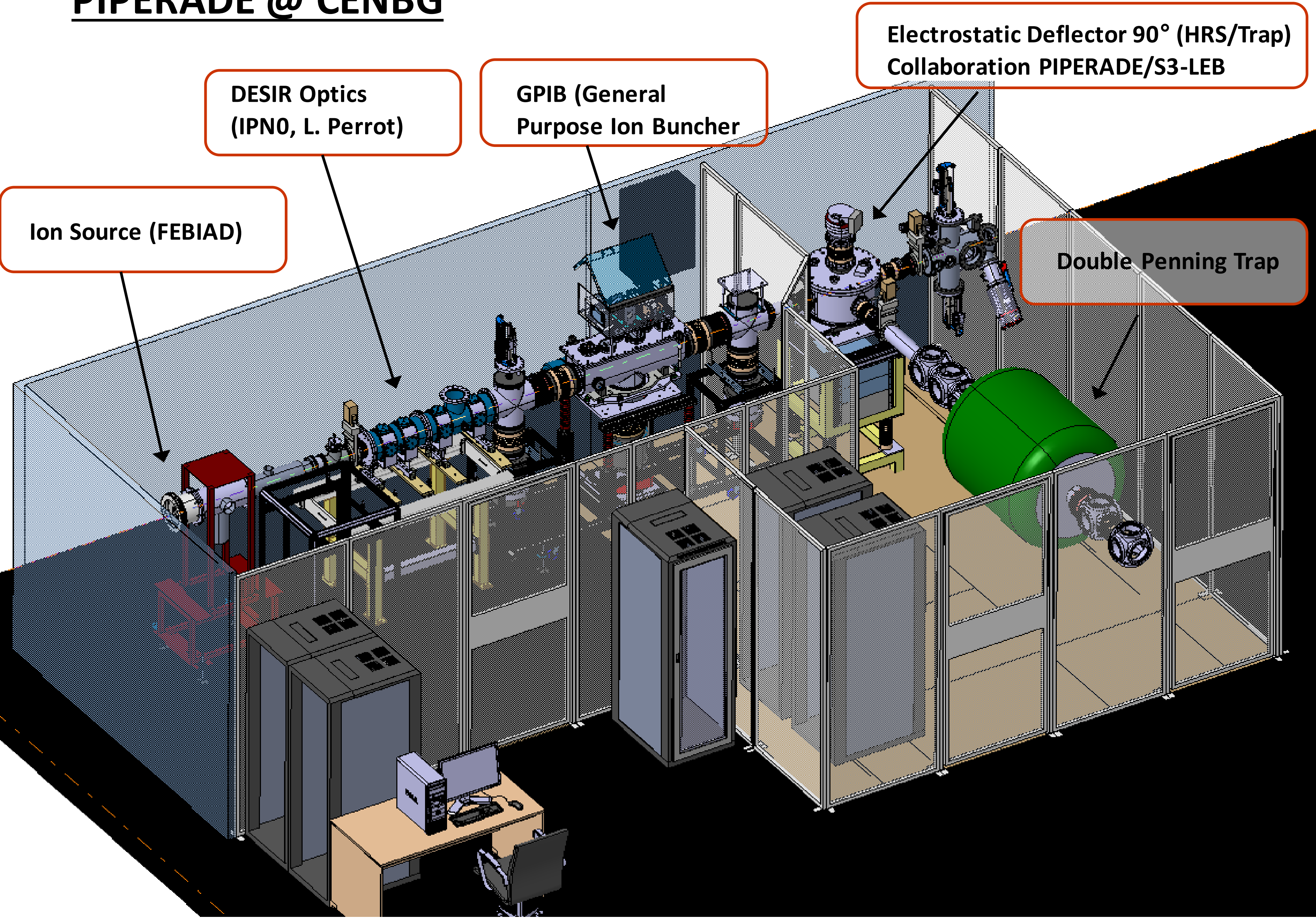
- Transmission to be improved
- Probably not ^{40}Ar, compatible with ^{39}K
  Under investigation….

with f=1MHz, q=0.35 (U_{rf}=1.2kV_{pp})





PIPERADE @ CENBG

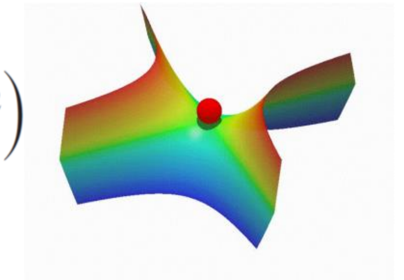


Penning trap

Trapping (i.e. confinement in all 3 dimensions) obtained by:

- electrostatic quadrupolar field (axial confinement)
- homogeneous magnetic field (radial confinement)

$$\Phi(z,r) = \frac{U_{\mathrm{dc}}}{2d^2}\left(z^2 - \frac{1}{2}r^2\right)$$



3 independent motions at 3 eigenfrequencies

axial motion

$$\omega_z = \sqrt{\frac{qU_{\mathrm{dc}}}{md^2}}$$

ω_z ~ 100 kHz

modified cyclotron motion

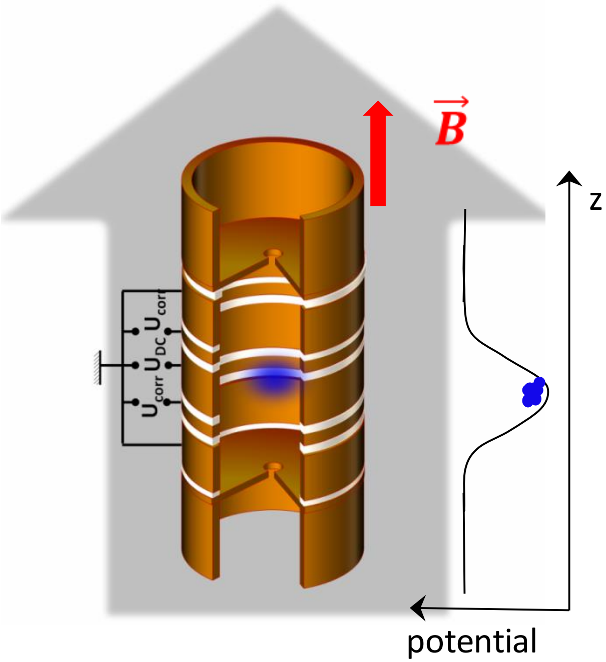
$$\omega_+ = \frac{\omega_c}{2} + \sqrt{\frac{\omega_c^2}{4} - \frac{\omega_z^2}{2}}$$

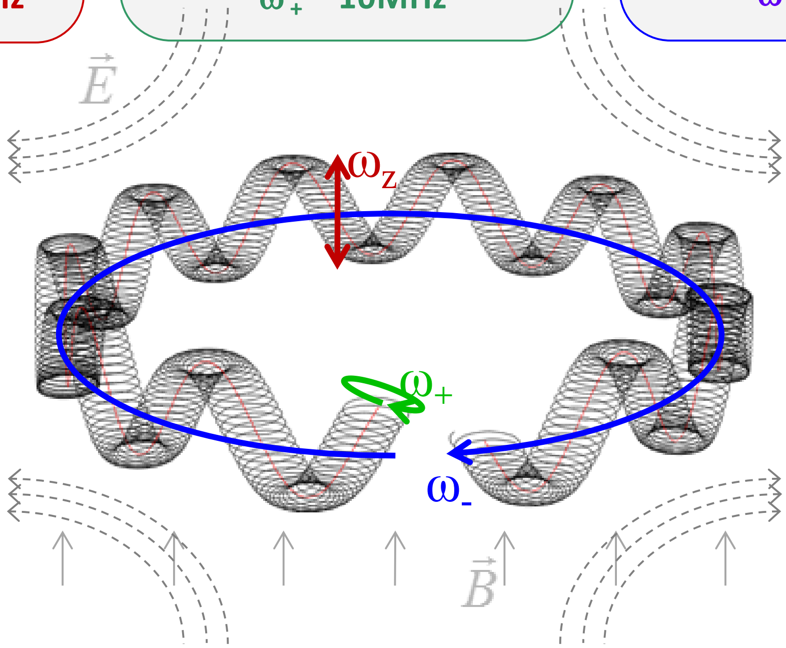
ω_+ ~ 10MHz

magnetron motion

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

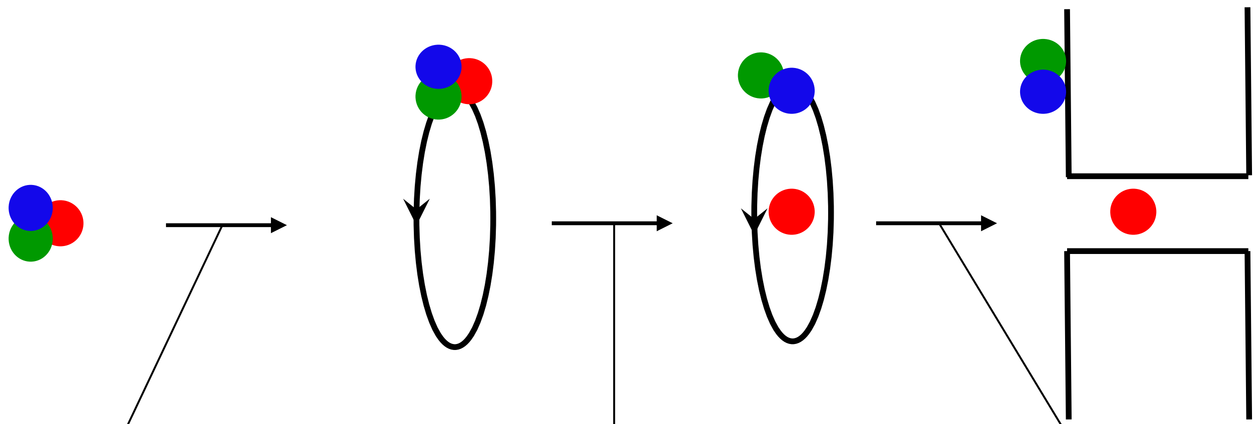
ω_- ~ kHz





Isobaric separation in a Penning trap

Resonant buffer gas cooling



Dipolar excitation at the magnetron frequency ν_-
(in first order mass independent)

$$\omega_- \approx \frac{U_{\mathrm{dc}}}{2d^2 B}$$

Buffer gas cools cyclotron motion

Quadrupolar excitation at $(\nu_+ + \nu_-)$ to convert the magnetron motion into cyclotron motion only for the ions of interest

→ Ions of interest are recentered

Ejection through a diaphragm : selection

→ Resolution up to 10^5

→ Time ~ 100-300 ms

Space charge effects

Increasing the number of ions makes the re-centering inefficient

Additional potential created by the cloud itself

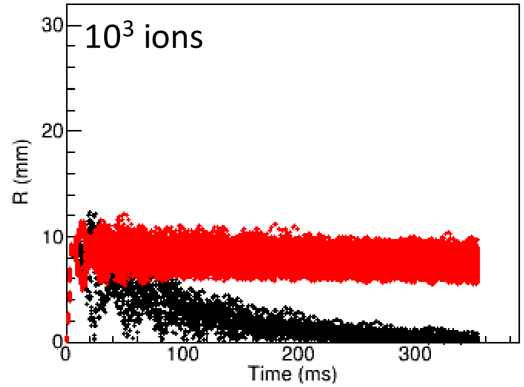
SIMBUCA code, *S. Van Gorp et al., NIM A 638, 192200 (2011)*

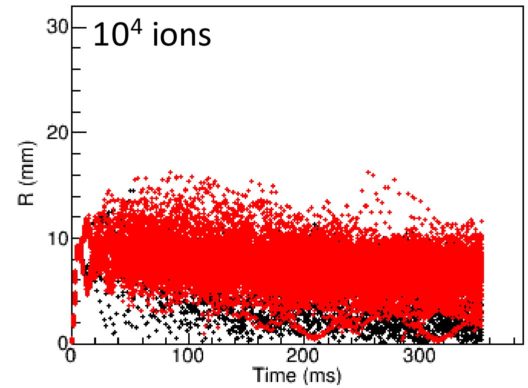
- → frequency-shifts
- → peak broadening
- → screening effects

90% ^{136}Te, 10% ^{136}Sb

P = 10^{-4} mbar, B = 7 T

r_0 = 20 mm





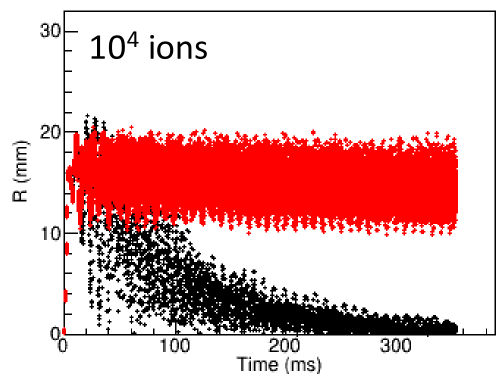
Large inner radius

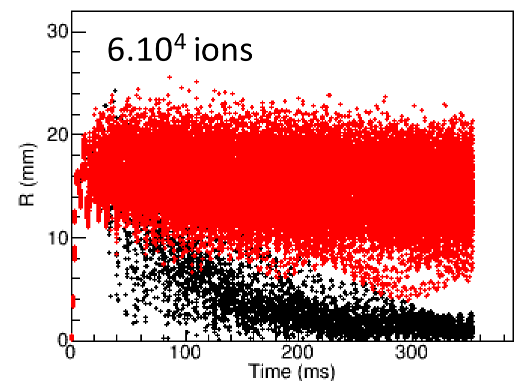
- ✓ Decrease the cloud density (anharmonicities further from center)
- ✓ Limit space charge effects

90% ^{136}Te, 10% ^{136}Sb

P = 10^{-4} mbar, B = 7 T

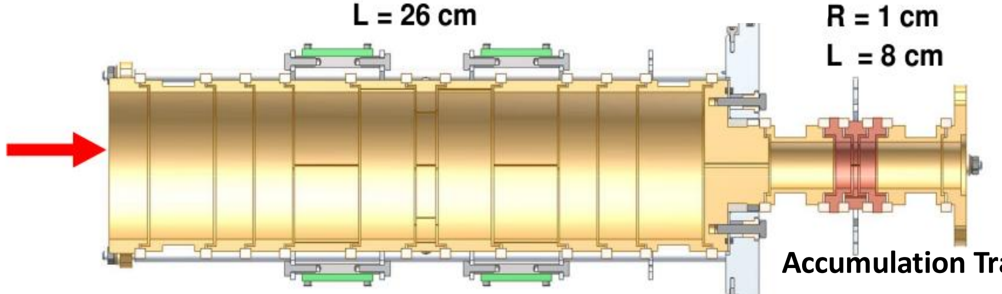
<u>r_0 = 32mm</u>



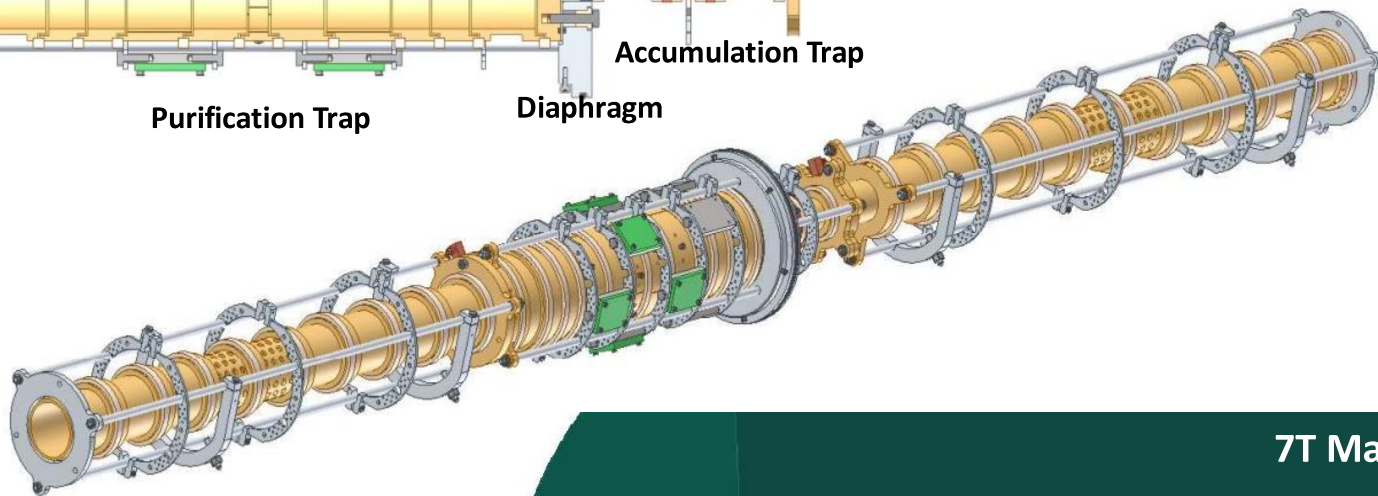


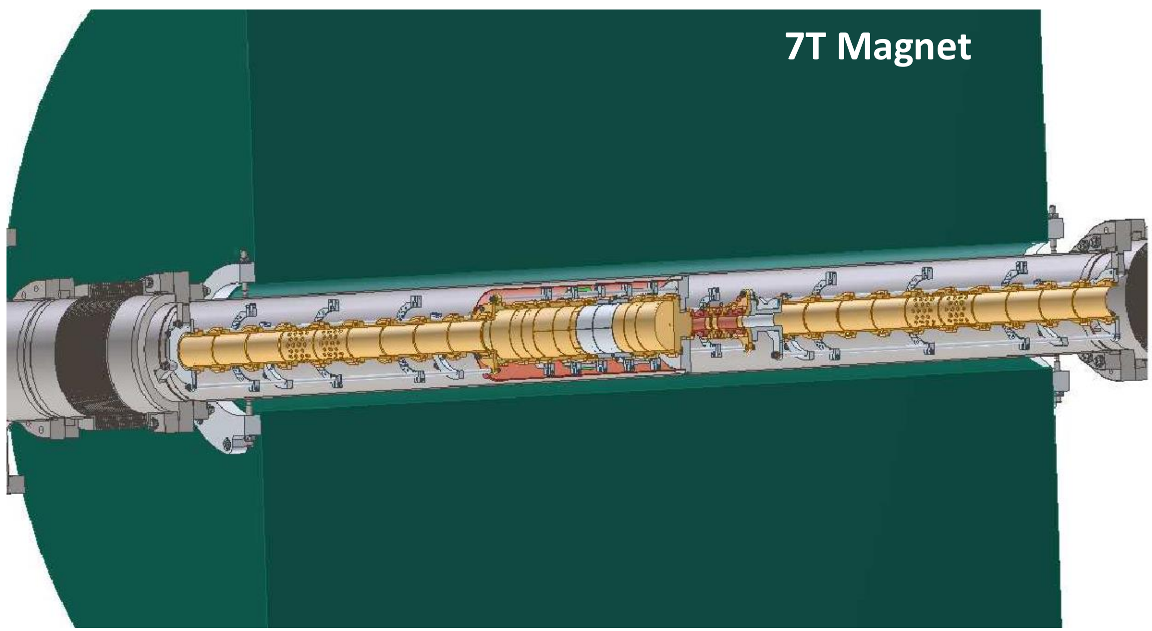
Other idea: increase the axial dispersion to decrease even more the cloud density. Under study…

Design of the double Pening trap

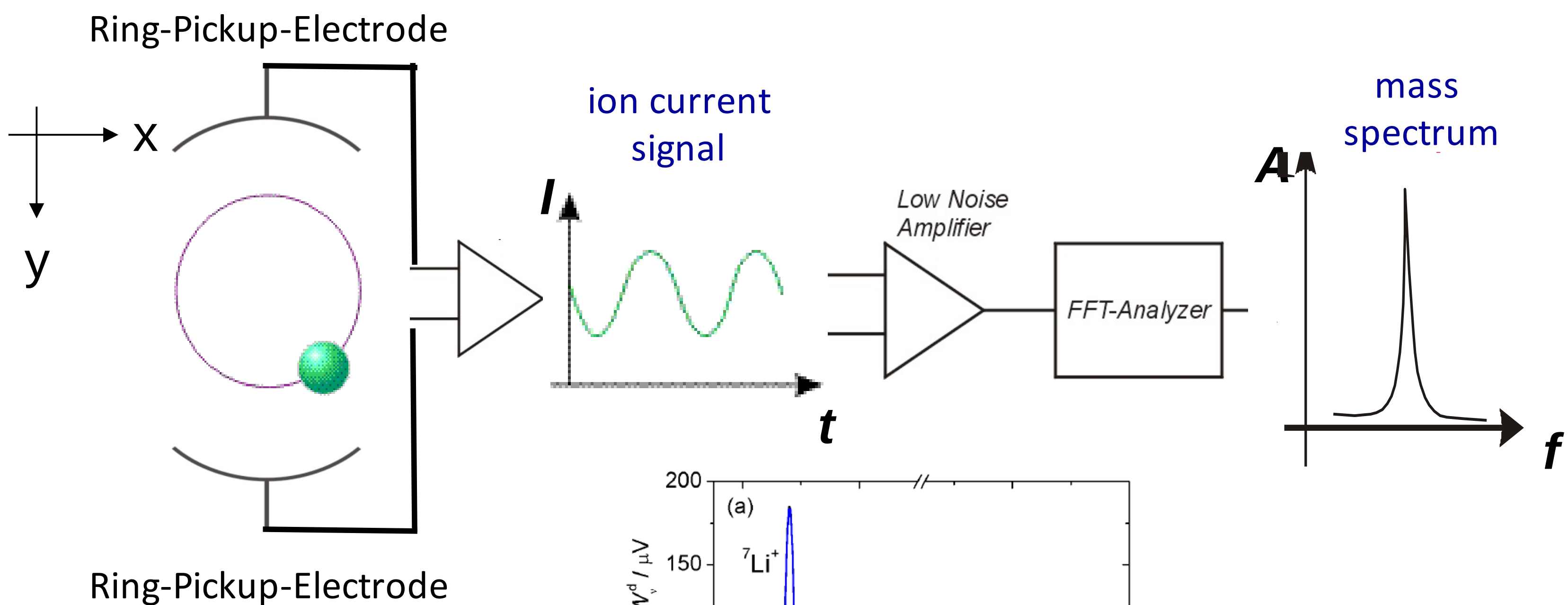


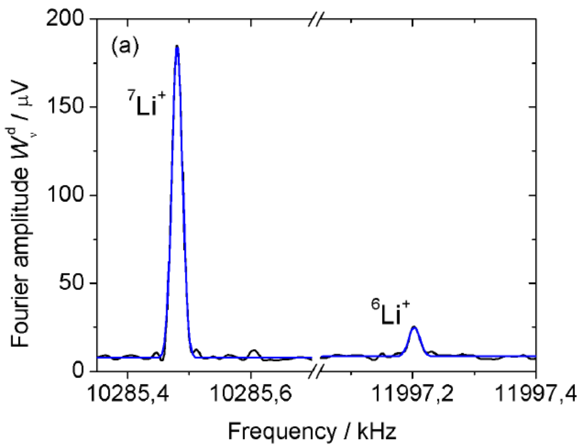
Performed at MPIK-Heidelberg

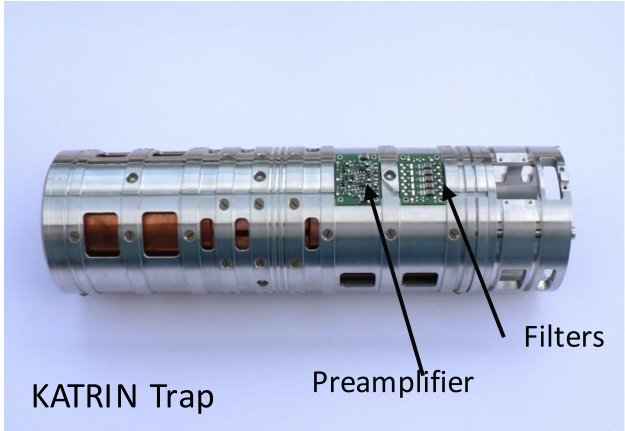




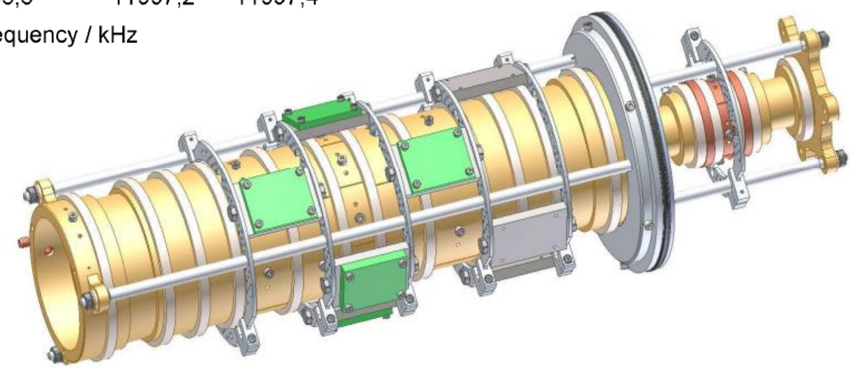
FT-ICR detection (Fourier Transform Ion Cyclotron Resonance)







Identify online the high-abundant contaminants



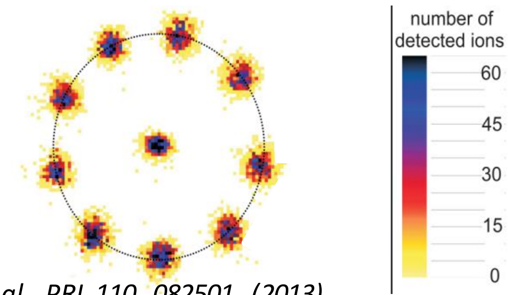
Other separation methods for Piperade

Not only space charge effects have to be faced, other methods have to be very fast and have to reach a very high resolving power (isomeric cleaning)

- no gas
- few ions

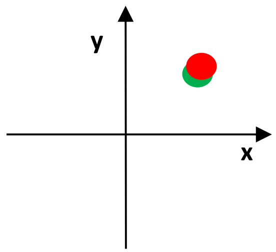
➢ **<u>Phase splitting</u> (inspired by the PI-ICR technique)**

Never been tested for purification, used for mass measurements at SHIPTRAP

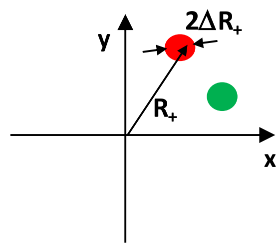


S. Eliseev et al., PRL 110, 082501 (2013)

Non-selective dipole excitation at ν+



After a number of turns: phase splitting



$$\frac{\nu_+}{\Delta\nu_+} = \frac{\pi\nu_+ t R_+}{\Delta R_+}$$

with ν_+ = 800 kHz, ΔR_+= 0.5 mm and R_+ = 5 mm

for t =100 ms → **R = 2,5.10^6** **SELECTIVITY**

for R=10^5 → **t = 4 ms** **RAPIDITY**

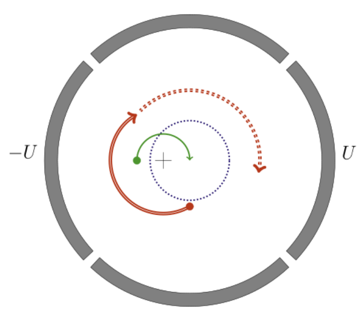
How to select the ions of interest?

Ejection through a special diaphragm with a shifted hole

OR

π-pulse to convert cyclotron to magnetron

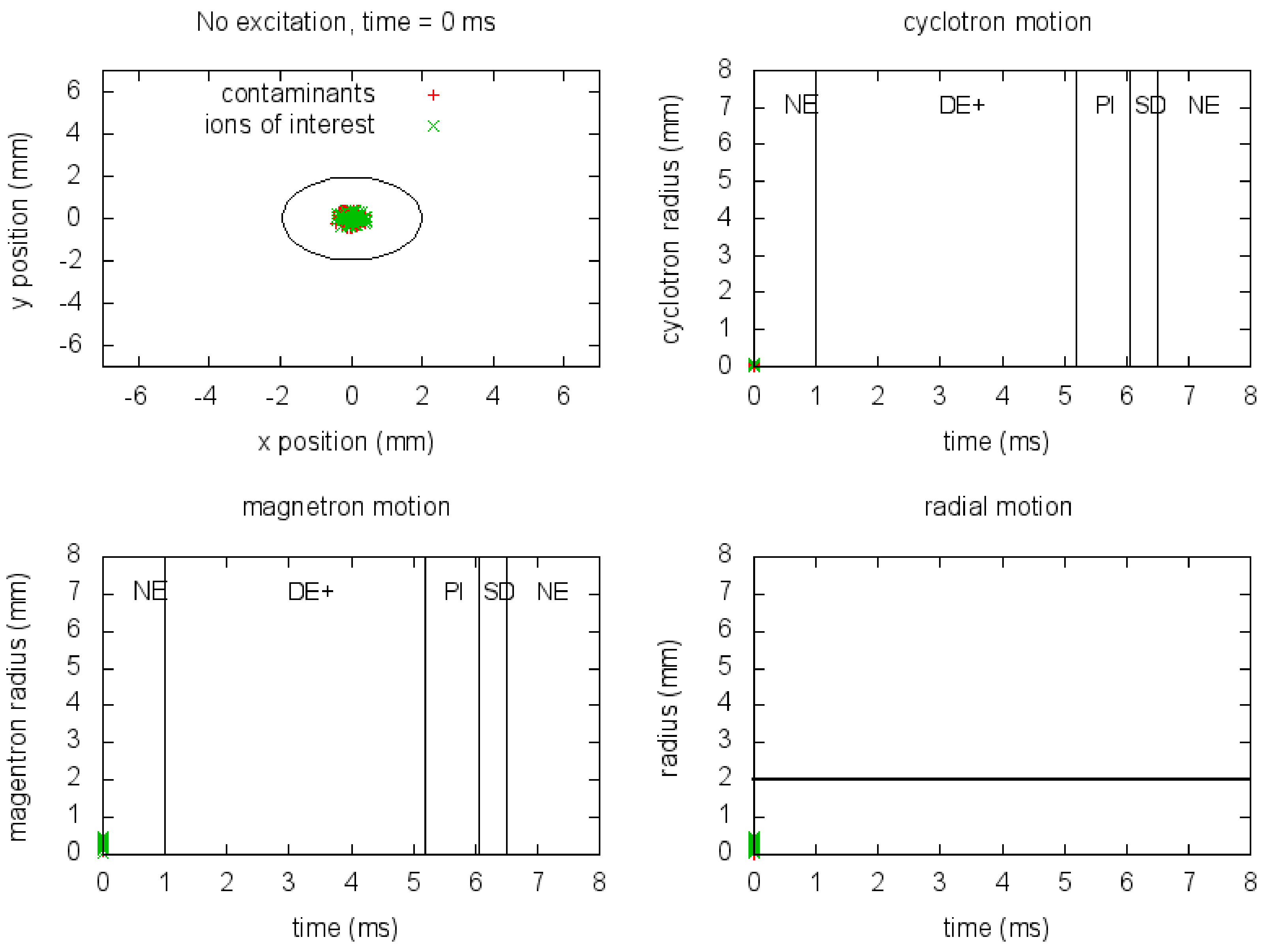
→ Static excitation to recenter the ions of interest and ejection through a diaphragm



High-resolution mass separation by phase splitting and fast centering of ion motion in a Penning trap
P. Dupré, D. Lunney, IJMS 379, 33–45 (2015)

Manipulation of the magnetron orbit of a positron cloud in a Penning trap
T. Mortensen et al., Phys. Plasmas 20, 012124 (2013)

Simulations of phase splitting technique



^{78}Ge ^{78}As

$\Delta M/M = 76000$

Simulations performed with SIMBUCA by Pierre Dupré

Other separation methods for Piperade

Not only space charge effects have to be faced, other methods have to be very fast and have to reach a very high resolving power (isomeric cleaning)

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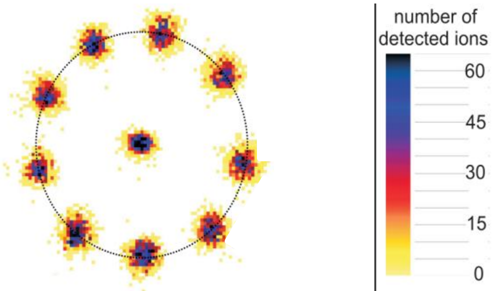
- few ions

➢ **Phase splitting (inspired by the PI-ICR technique)**

Never been tested for purification, used for mass measurement at SHIPTRAP



➢ **Ramsey cleaning:**

Routinely used at JYFLTRAP/IGISOL for isomeric cleaning (*T. Eronen, NIM B 266, 4527-4531 (2008)*)

Dipolar excitation at ν_+ of the contaminant using time-separated oscillatory fields

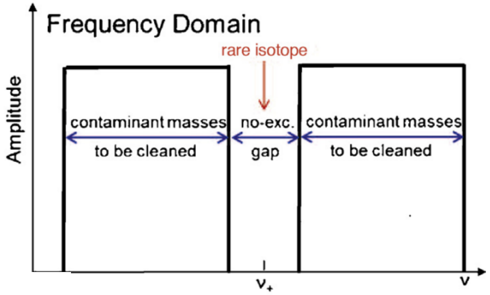
→ Resolution up to 5.10^5 with a time excitation of the order of 100 ms

➢ **SWIFT technique**

Recently used at LEBIT/MSU (*A. A. Kwiatkowski et al., IJMS 379, 9-15 (2015)*)

Dipolar excitation at ν+ of all the contaminants using a specified excitaiton scheme in frequency space. M/ΔM of the order of 10^4-10^5 and very fast (< 50ms)

→ Advantage: does not require the exact identification of each contaminant ion



➢ **SIMCO Excitation (**First tests at ISOLTRAP, need to be further investigated) (*M. Rosenbusch, IJMS 325–327 (2012)*)

These methods will be implemented and tested at PIPERADE for a flexible purification system that can be adapted to any cases

Status and timeline of the PIPERADE project

GPIB

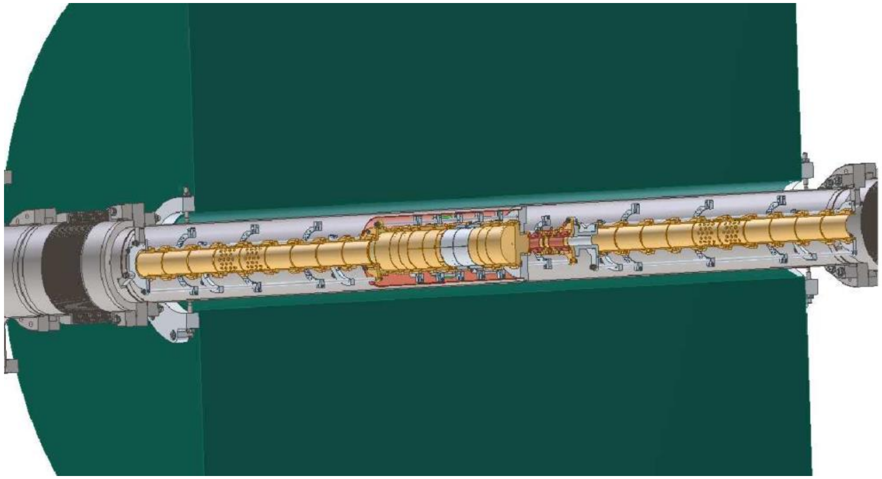
- First transmission measurement done, to be continued, better optimised
- Transverse emittance measurements
- Bunching mode, characterisation of the bunches (time, energy spread)

TRAPS

@ MPIK

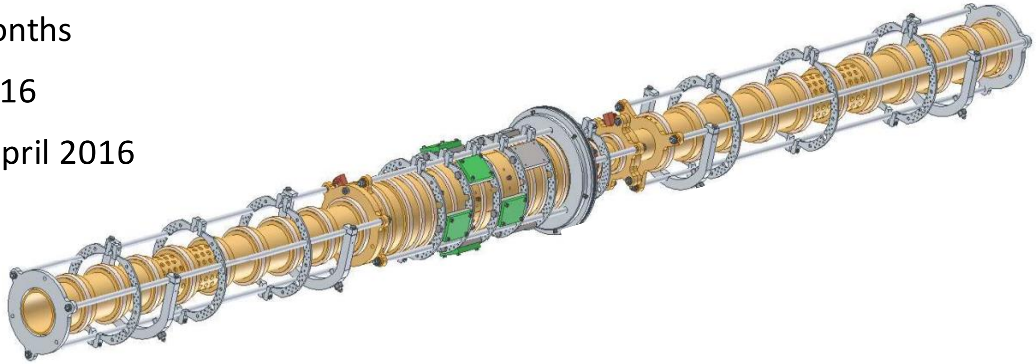
- Mechanical design of the tower completed
- Construction in progress at MPIK-Heidelberg

  All the pieces will be ready in november
- Mechanical design of the injection/ejection parts under study



@ CENBG

- Installation of the 90° deflector in the next months
- Delivery of the traps fro MPIK beginning of 2016
- Delivery of the magnet from CRYOGENICS in april 2016
- Commissioning with beam end of 2016
- Move to GANIL in 2019



PIPERADE @ DESIR

PIEGES DE PENNING POUR LES RADIOISOTOPES A DESIR

Thanks for your attention and to the PIPERADE collaboration

M. Aouadi, G. Ban, B. Blank, K. Blaum, J.- F. Cam, P. Delahaye, L. Daudin, F. Delalee, P. Dupré, S. El Abbeir, M. Gerbaux, S. Grévy, H. Guérin, E. Liénard, D. Lunney, S. Naimi, L.Perrot, A. de Roubin, L. Serani, B. Thomas, J.-C. Thomas

CENBG · MAX-PLANCK-INSTITUT FÜR KERNPHYSIK · CSNSM · lpc caen · GANIL spiral2 laboratoire commun CEA/DSM CNRS/IN2P3 · IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY