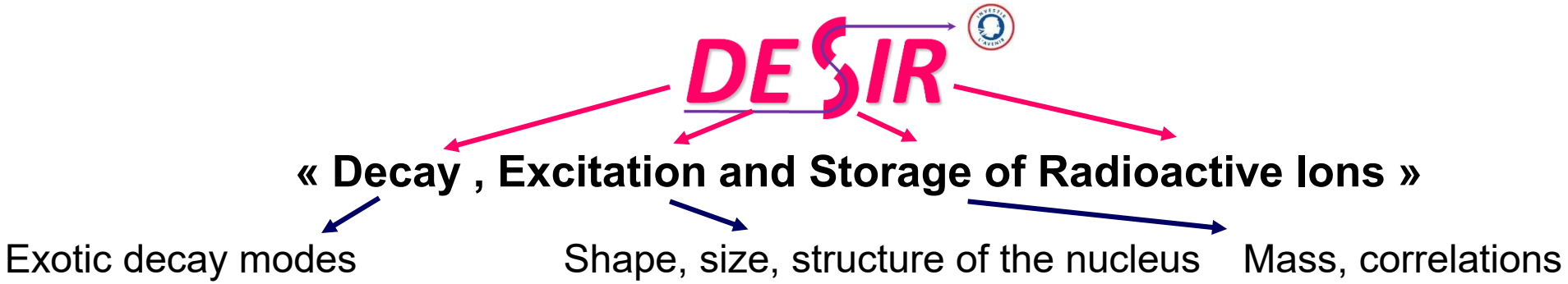
The DESIR facility at GANIL/SPIRAL2

Bertram Blank

L2Pi Bordeaux

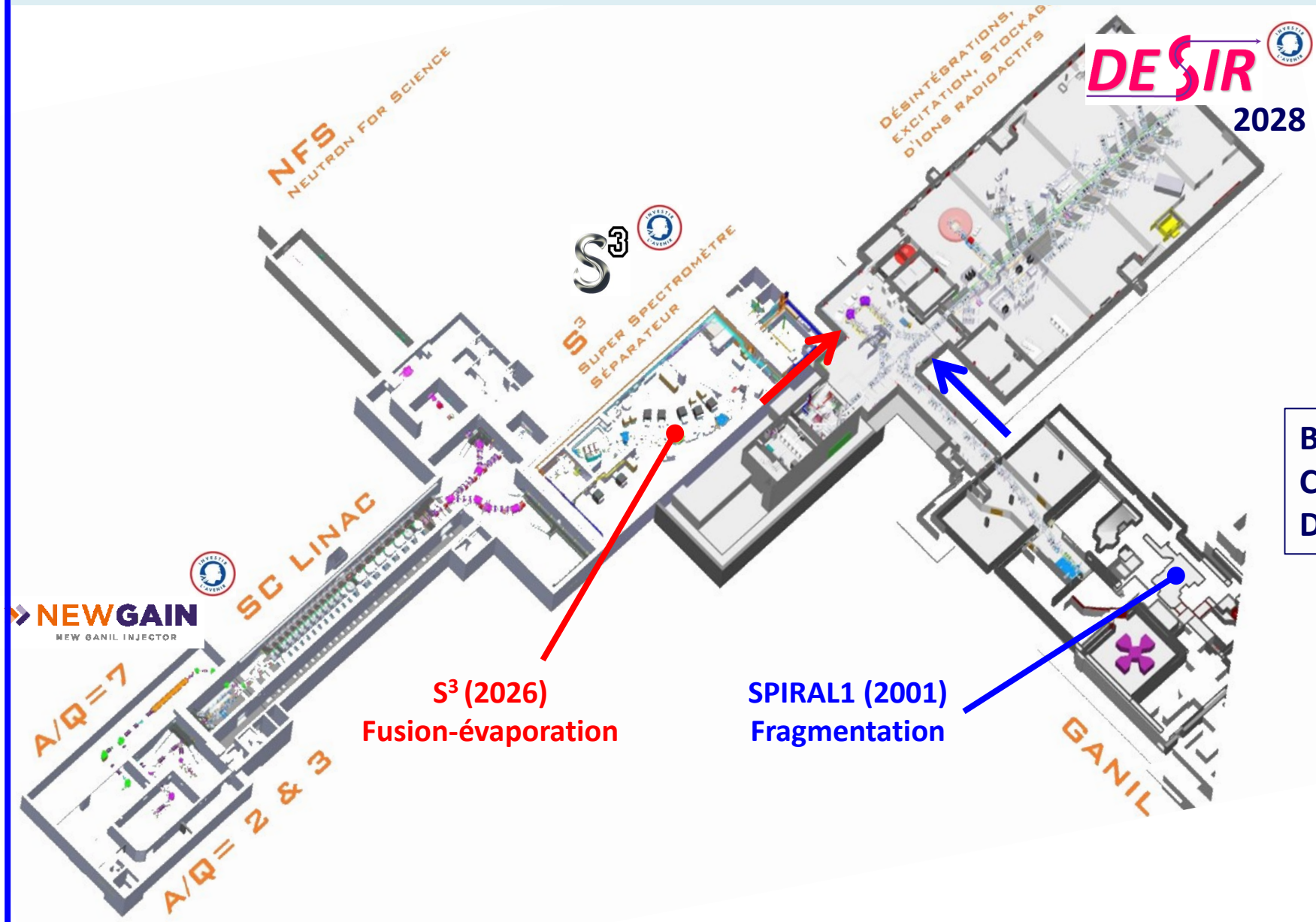
Séminaire IJCLab, 13/12/2024



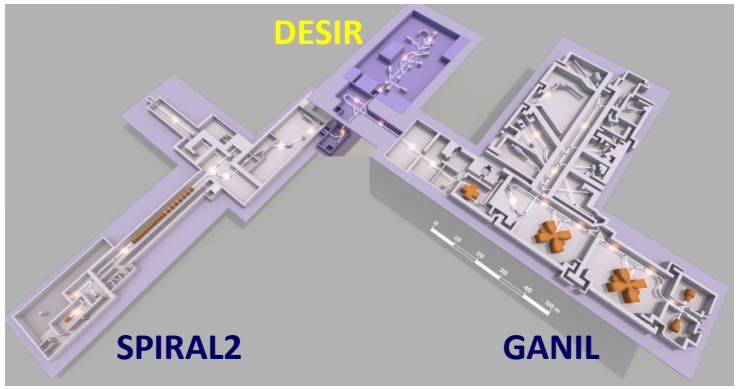
A new GANIL users facility

- Study of the fundamental properties of atomic nuclei and underlying forces
- With a high precision using ultra-pure samples of radioactive ions manipulated at very low energy
- Taking advantage of the various RIBs production methods
- In complementarity to S^3(-LEB) and other GANIL installations

DESIR at GANIL



Building delivery: mid-2025
Commissioning (stable beams): 2027
Day 1 experiments (RIBs): 2028



DESIR physics programme

- Collinear laser-spectroscopy — **LUMIERE**
- Correlations in β decay (MORA)
- Mass meas. (PIPERADE, MLLTrap) — **DETRAP**
- (Trap-assisted) decay spectroscopy — **BESTIOL**

(Super) Heavy nuclei

✓ Size & Shape
✓ Deformation

✓ Exotic decay modes

✓ Nuclear structure

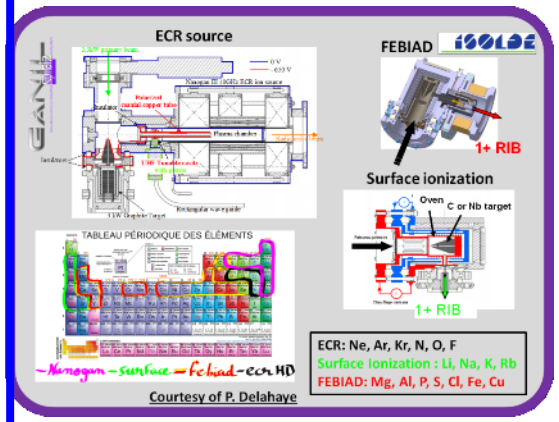
✓ Fundamental interactions

N≈Z

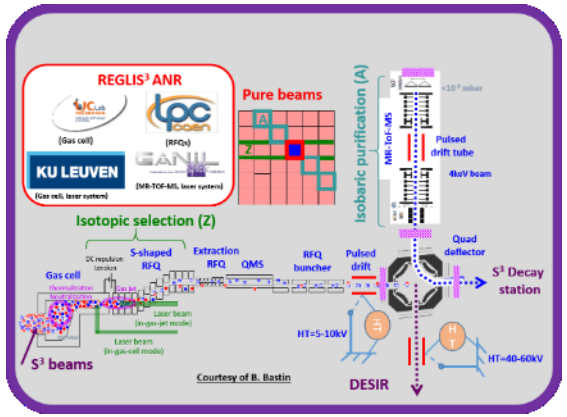
Z=82
N=126
Z=50
N=82
Z=28
N=50
Z=20
N=28
Z=8
N=20
N=8

SPIRAL 1

Fragmentation

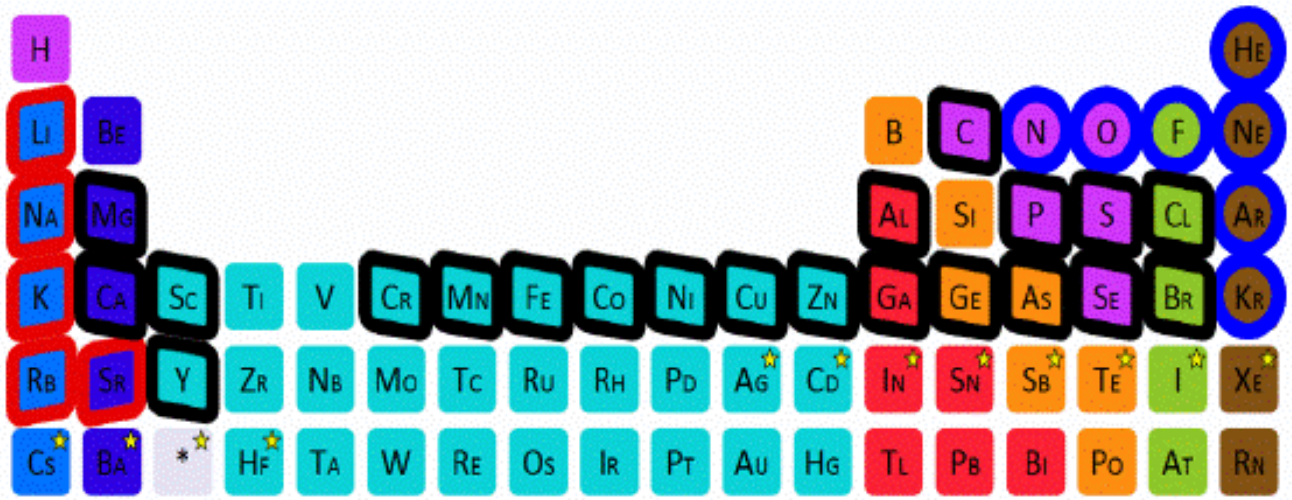


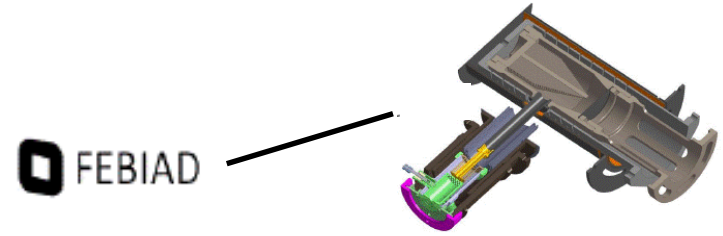
Fusion-evaporation



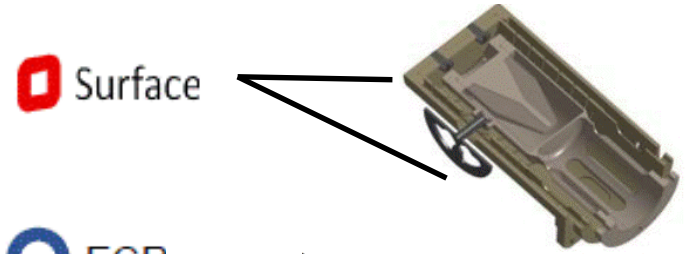
Beam production

SPIRAL1 beams

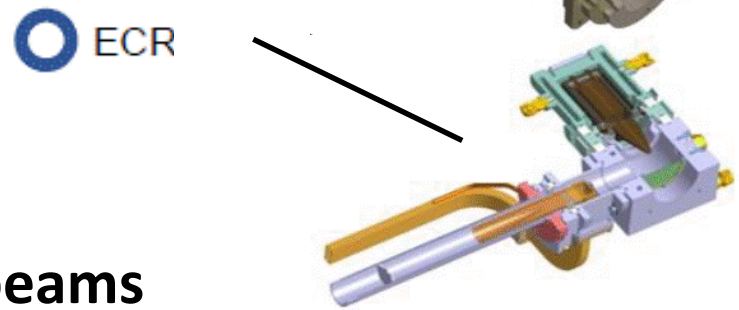




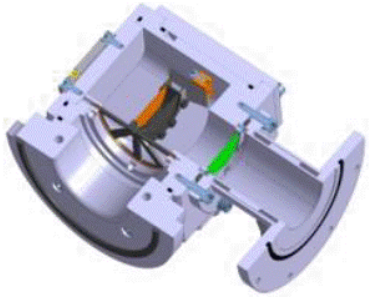
FEBIAD
for condensables



MonoNaKe
for alkalines



Nanogan
for gases



TULIP
for proton-rich isotopes

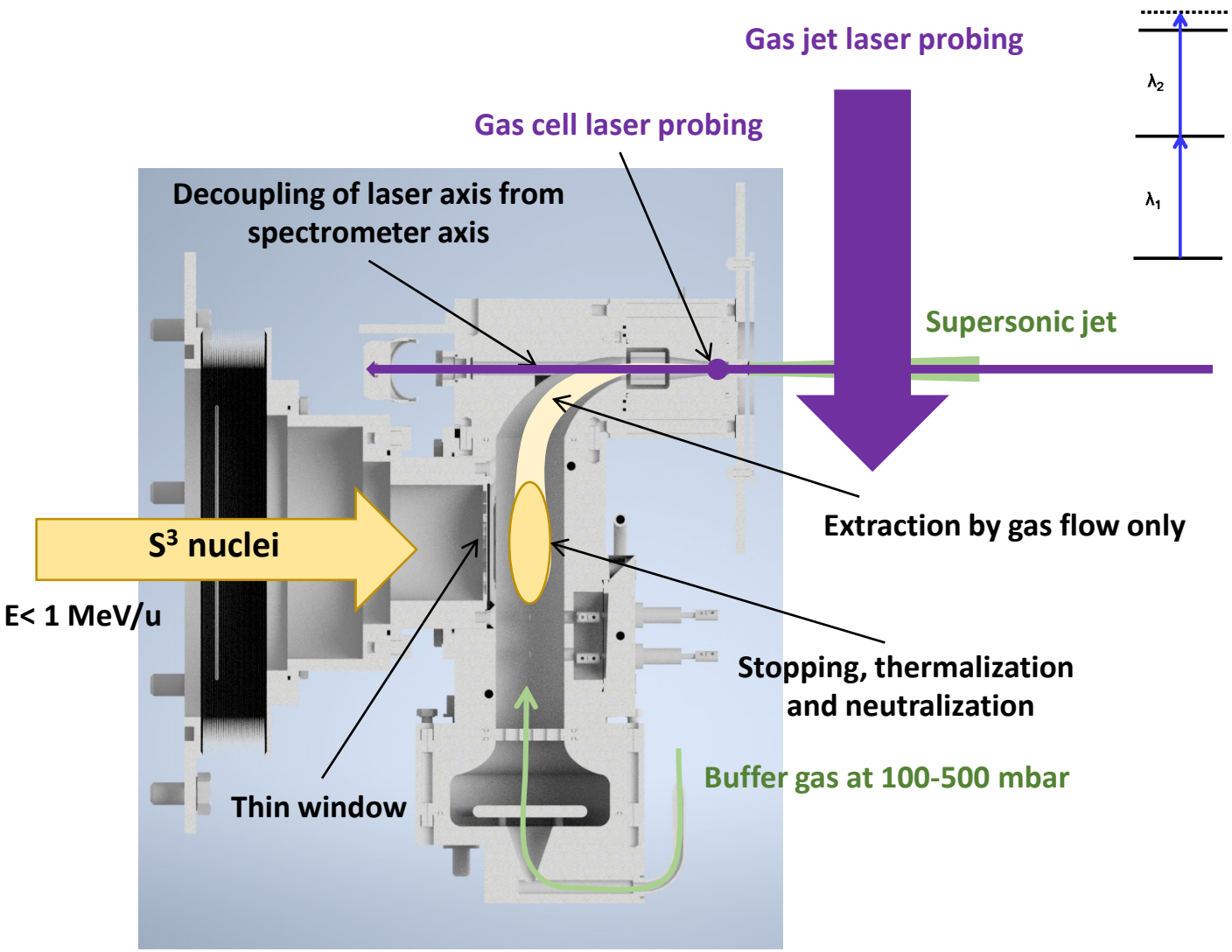
Fragmentation (and fus-eva) of heavy primary beams

Limitations:

- primary beam power
- fragmentation cross sections
- diffusion/effusions times (refractory elements, short half-lives)
- ionisation efficiency
- operational issues (stability, resilience etc.)

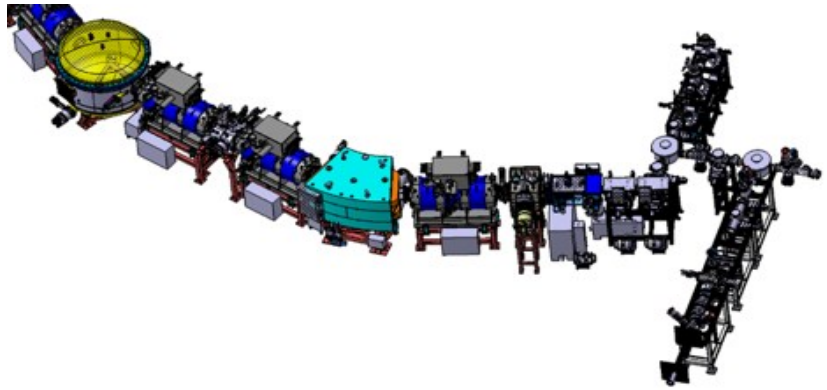
Courtesy P. Chauveau

S3-LEB beams



- Critical performance criteria :
  - Stopping efficiency
  - Extraction efficiency and time
  - Chemical survival/neutralization efficiency

S³-LEB
(Low Energy Branch)



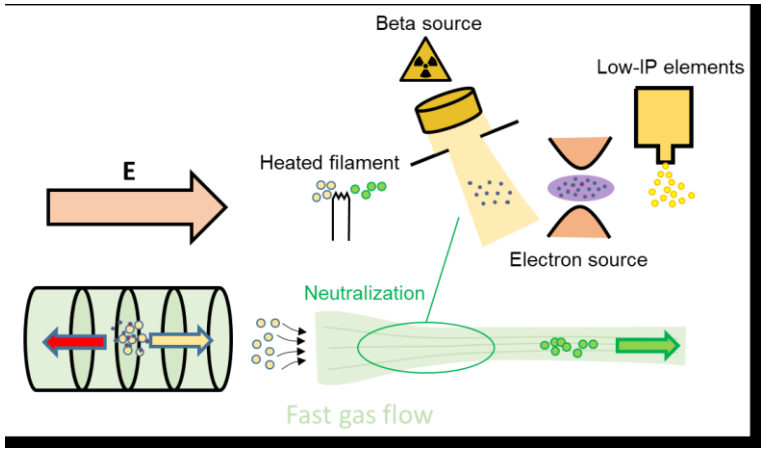
DESIR

R. Ferrer, Nature Comm. 8 14520 (2017)

Courtesy V. Manea

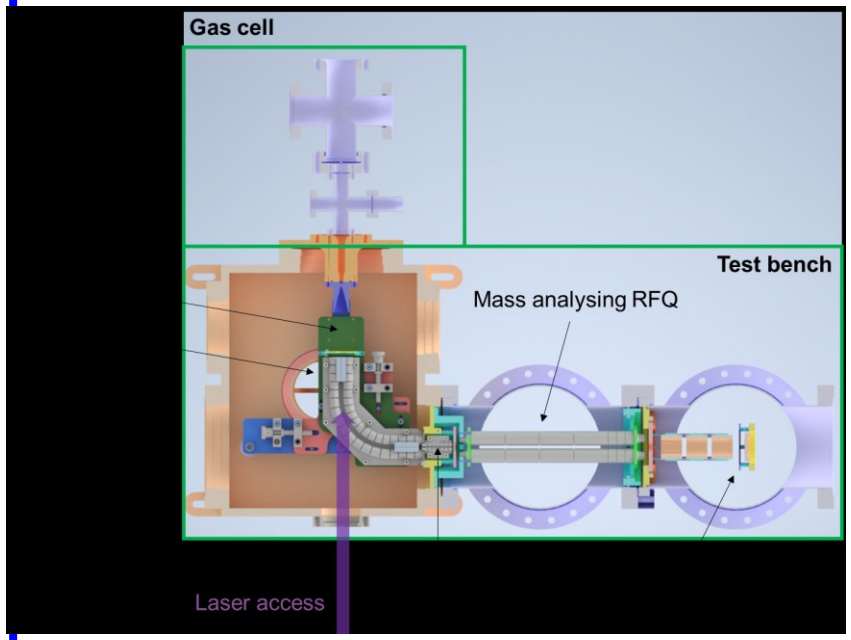
S3-LEB beams: FRIENDS^3

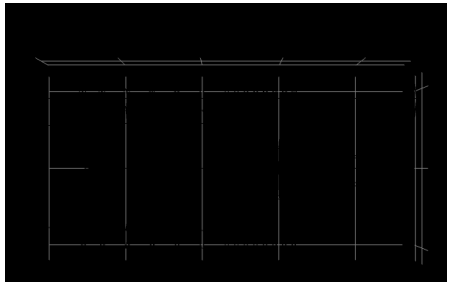
- ANR JCJC project FRIENDS^3 aimed at improving the S^3-LEB gas cell:
  - Reduce extraction time
  - Improve neutralization efficiency
  - Ideally both at the same time

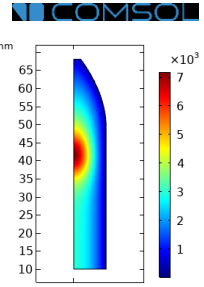


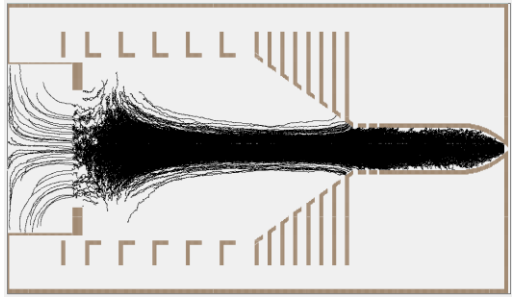
Construction of test bench

Simulations





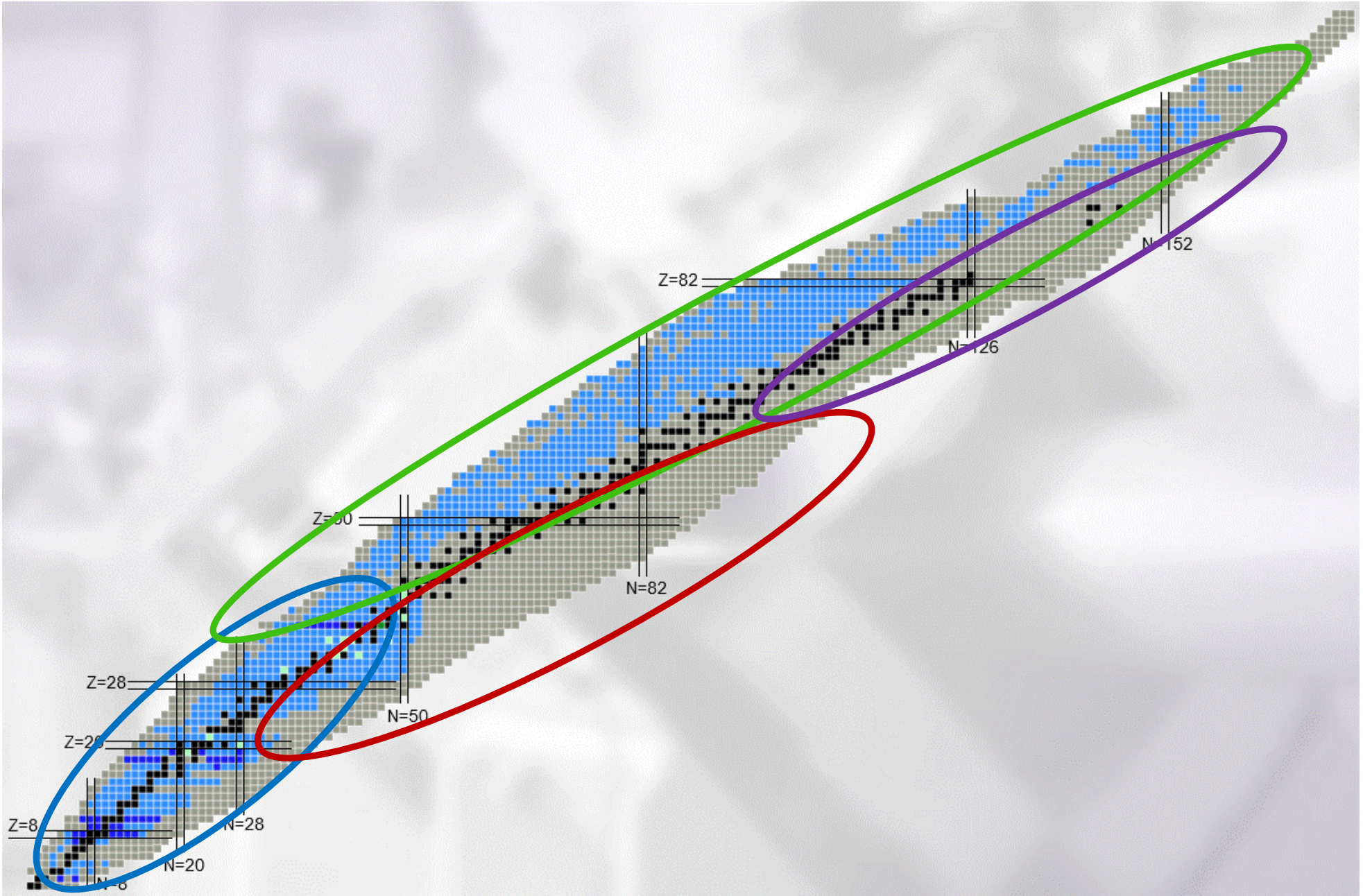




- Test-bench design study finalized, constructed in 2024
- Will be installed at GANIL for laser access
- Exploration of direct ion extraction by electrical field

Courtesy V. Manea

DESIR beams: S1 & S3 (& S2)



DESIR beams:

S1: fragmentation

S3: fusion-evaporation

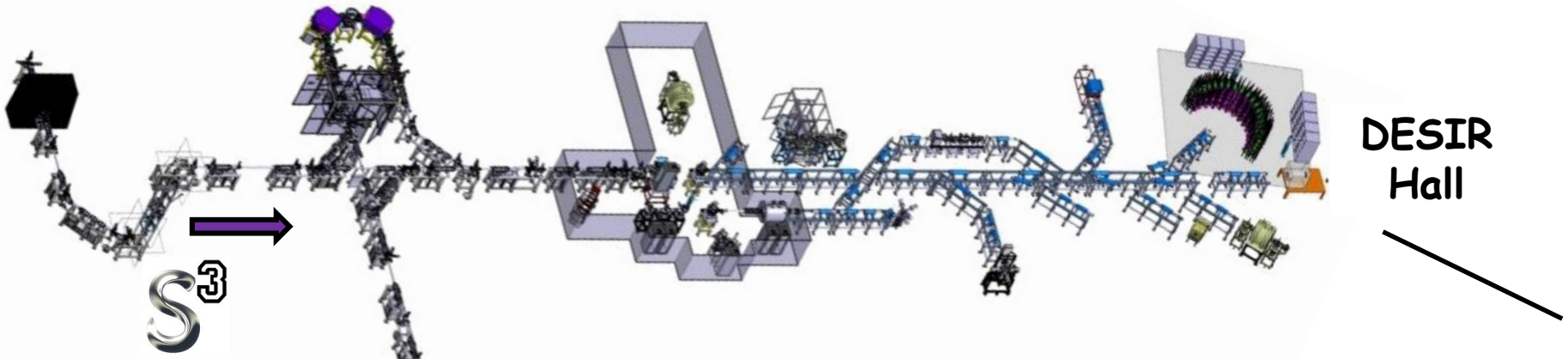
S2: fission

Multi-nucleon transfer reactions

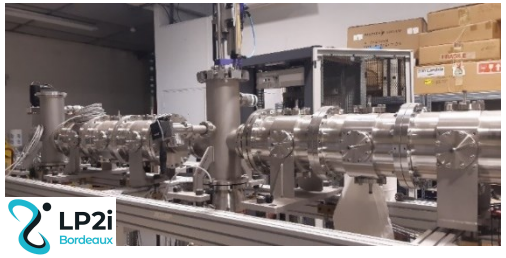
Beam transport

Transport beam lines

1+ ions, < 60 keV, < 80 π.mm.mrad – fully electrostatic



Test bench



Ph. Alfaurt, LP2iB

- Junction beam lines from SPIRAL1 and S3-LEB to the DESIR Hall: ~100 m
- Installation starting by the end of 2025

SP1 -> DESIR beam line

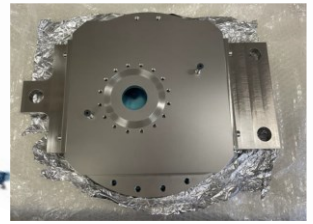
V. Watt-Morel, GANIL

L. Perrot et al., IJCLab

SPIRAL1

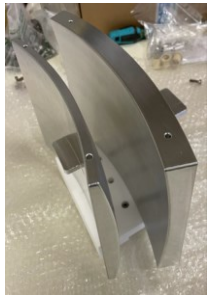
Example: 45° deflector assembly

Base assembly

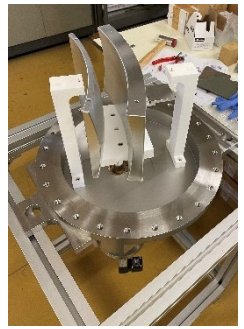


Insertion

Pole assembly



Internal part

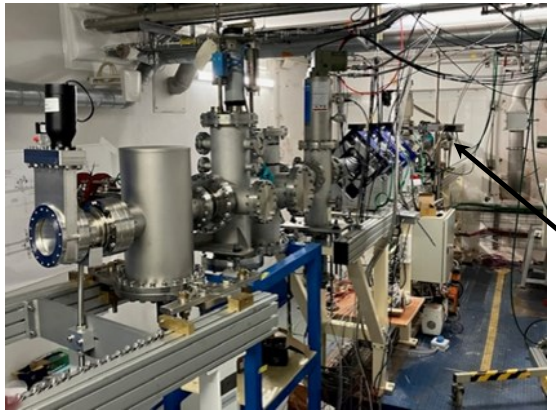


Upper part

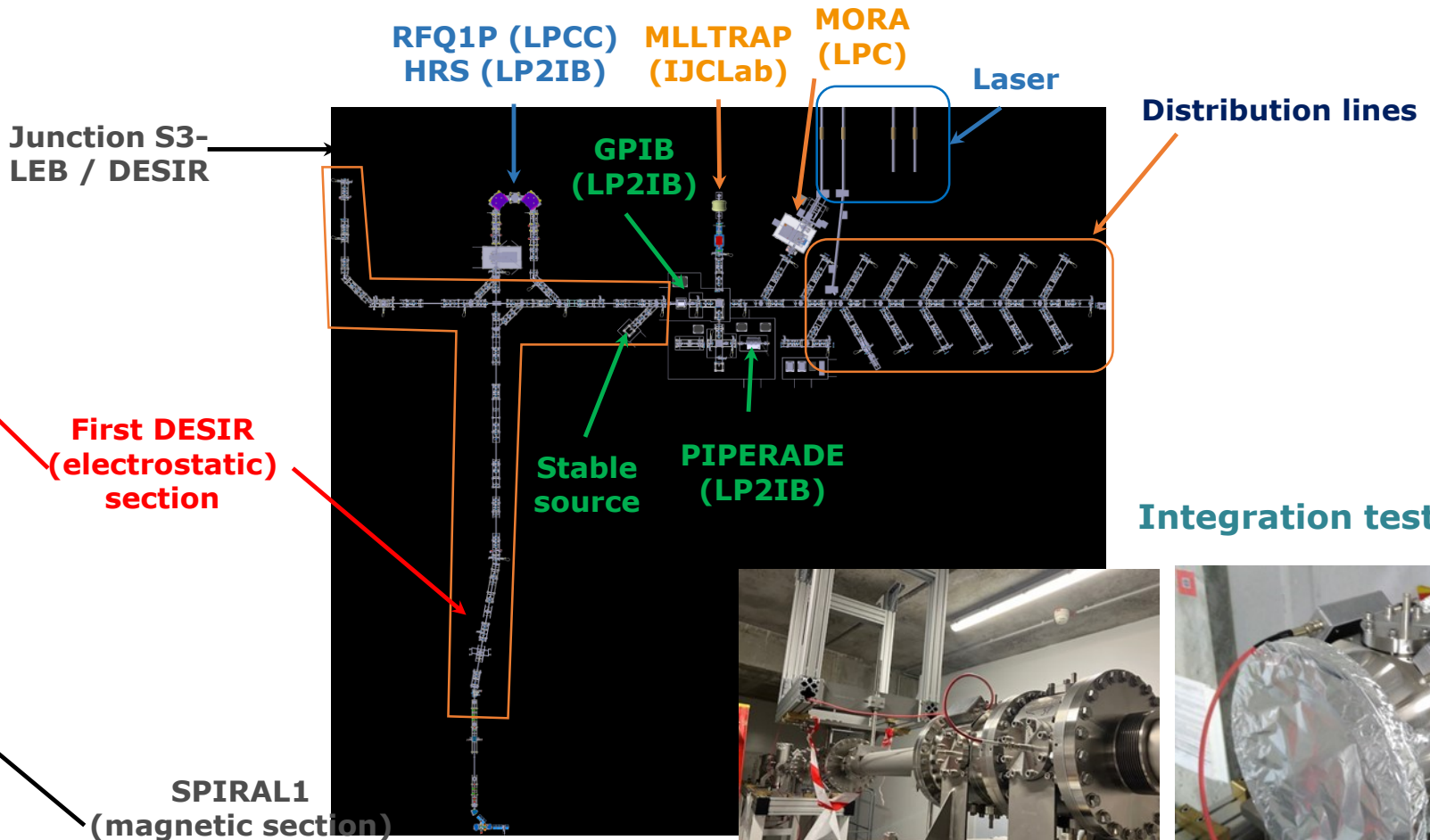
Transport beam lines

SPIRAL -> DESIR section

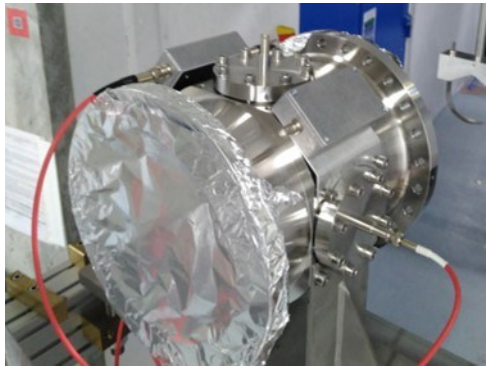
- Ongoing installation (mechanical assembly, supply integration tests, …)
- Operation tests scheduled middle of 2025
- LP2IB/GANIL: process supplies, remote control systems…



Courtesy V. Watt-Morel, GANIL

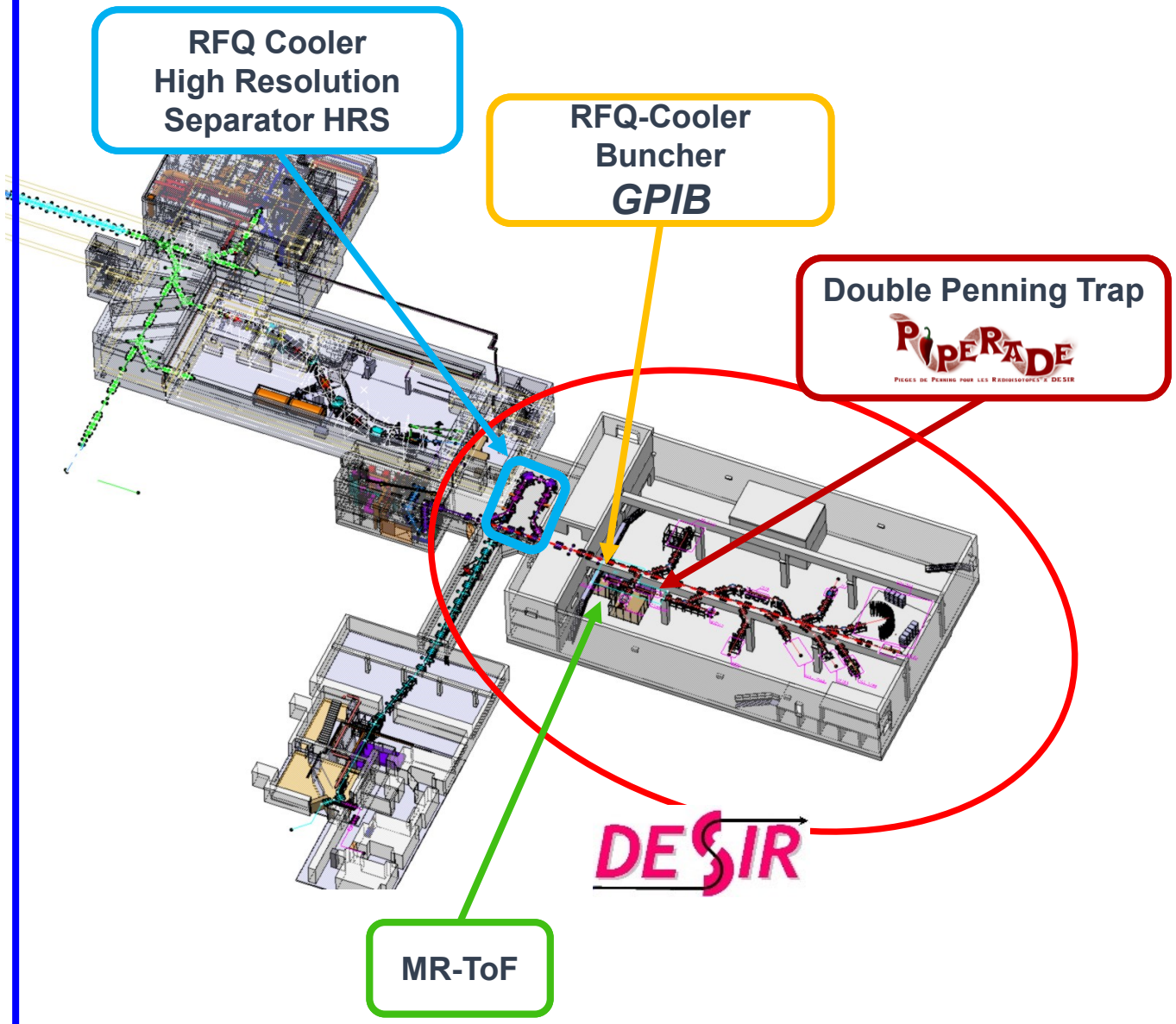


Integration tests



Beam preparation and purification

Beam preparation and purification



Mass separation/beam purification:

- RFQ+HRS: $\frac{M_0}{\Delta M} = \sim 20\,000$
- MR-ToF: $\frac{M_0}{\Delta M} = \sim 200\,000$
- Piperade 1st trap: $\frac{M_0}{\Delta M} \leq 10^5$
- Piperade 2nd trap: $\frac{M_0}{\Delta M} \approx 10^6 - 10^7$

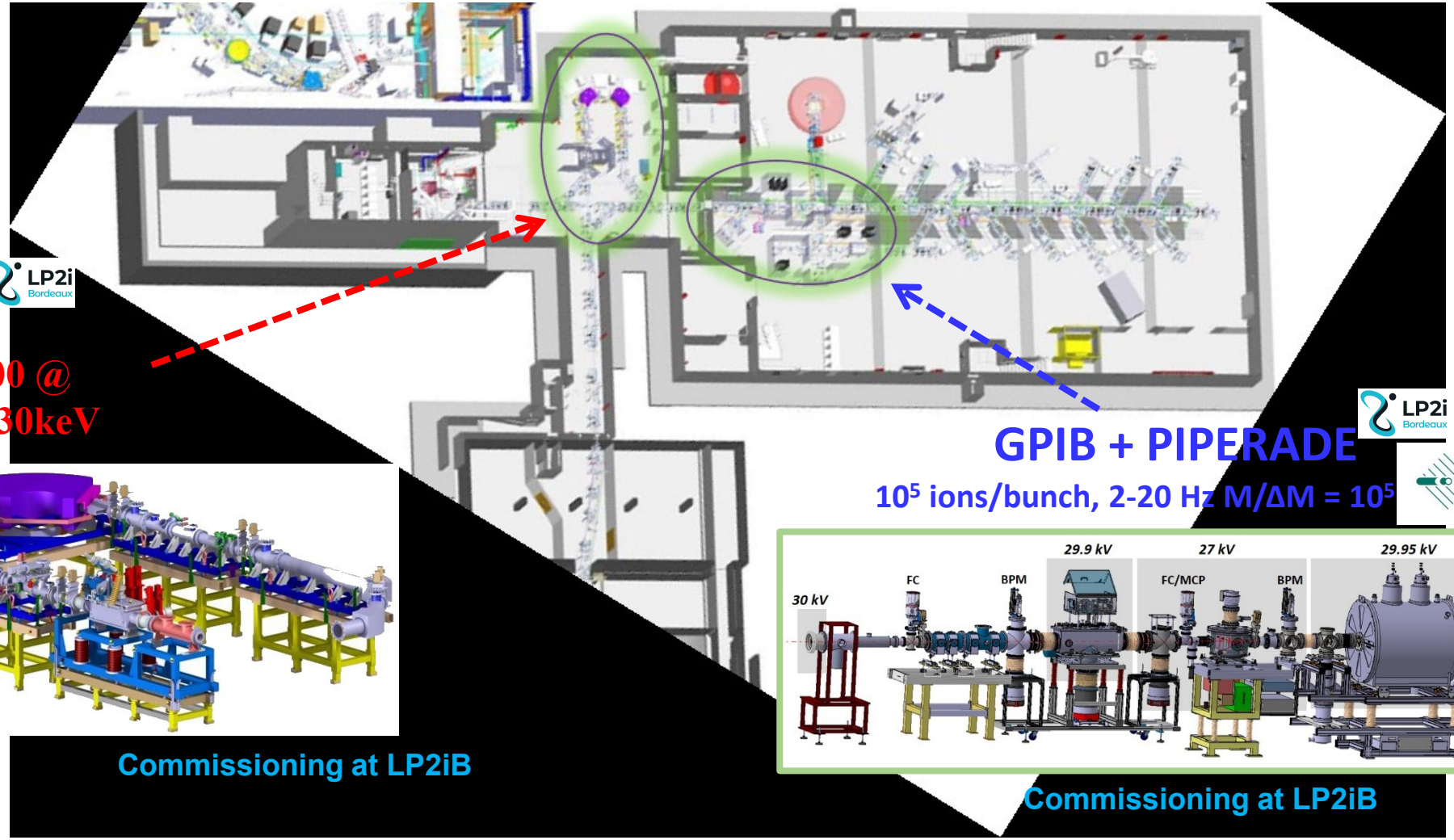
Beam preparation:

- GPIB: Cooling and bunching
- Piperade 2nd trap: Accumulation trap

Mass measurements:

- Piperade 2nd trap: Mass precision: 10^{-8} – 10^{-9}

Beam purification



RFQ + HRS

M/ΔM =20,000 @
3π mm.mrad / 30keV

Refurbishment at LPC Caen

Commissioning at LP2iB

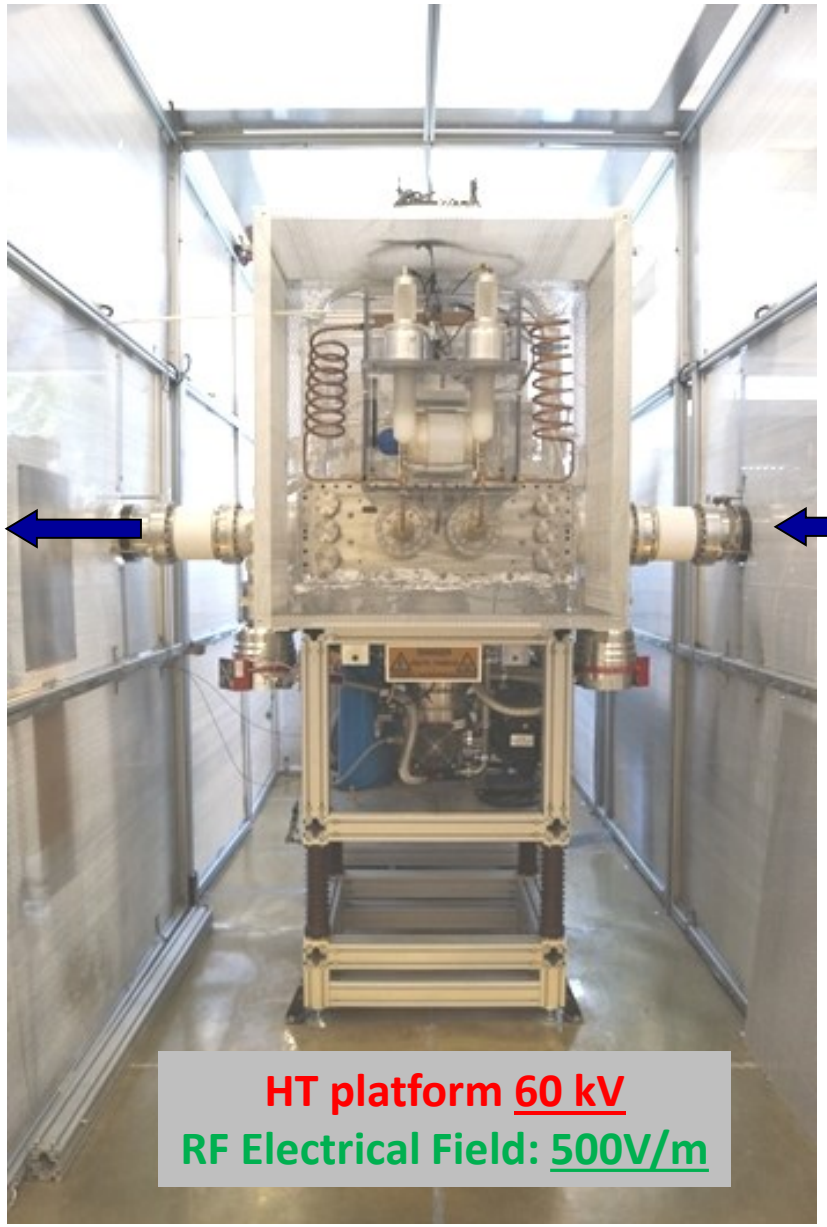
GPIB + PIPERADE

10^5 ions/bunch, 2-20 Hz M/ΔM = 10^5

Commissioning at LP2iB

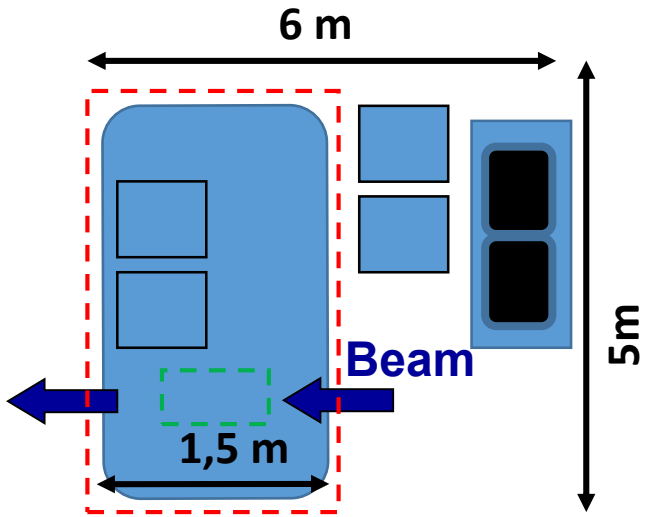
- Installation and commissioning: 2026-2027
- MR-ToF-MS for mass measurements and beam purification: 2026-2028

Beam purification: RFQ SHIRaC



R. Boussaid et al., PRCST 18 (2015) 072802

SHIRaC : Construction and test @ LPC Caen



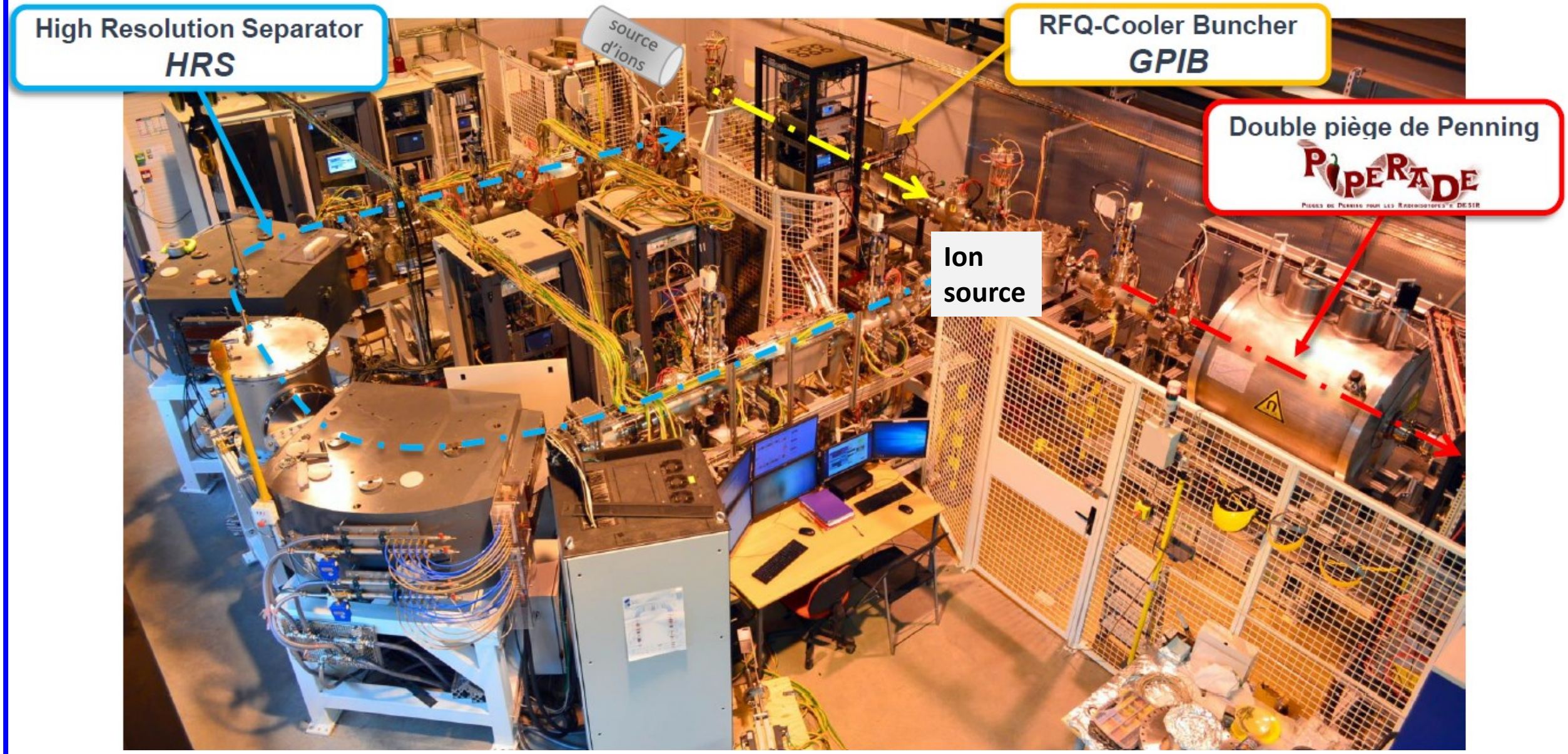
SHIRaC

RF: 2.1-4.9 MHz; V_{pp}: 8kV
Emittence: ~3π mm.mrad
ΔE ~eV

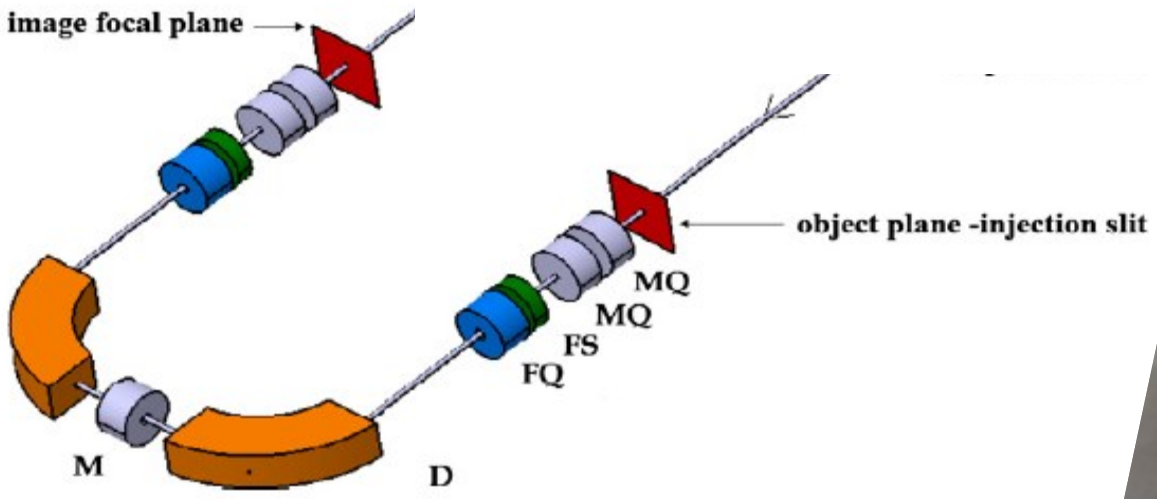
Transmission ~70 % for 1eμA beam

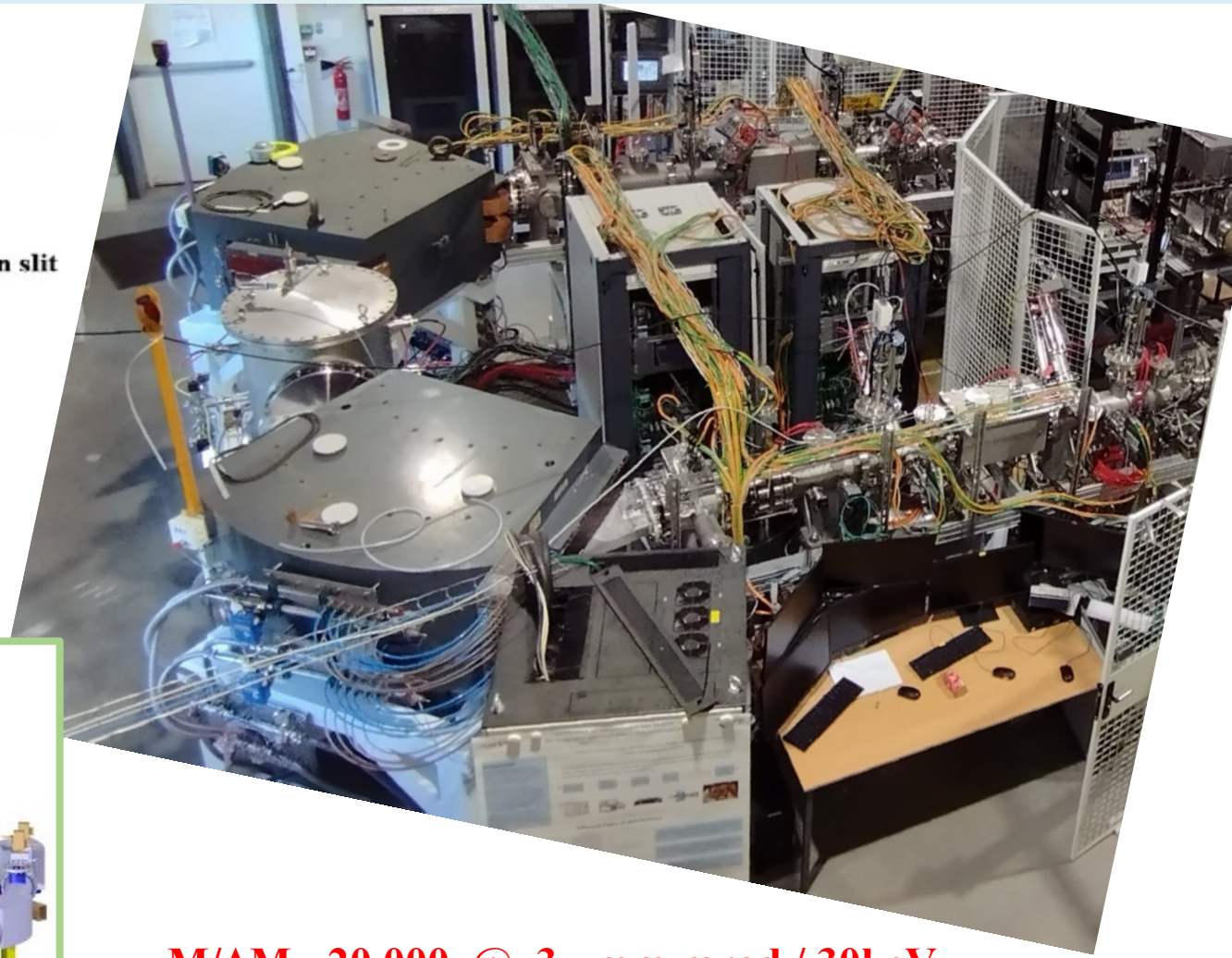
…presently refurbished at LPC
(according to RFQ cooler of SPES)

Beam purification: Ion source, GPIB, PIPERADE and HRS at LP2i Bordeaux

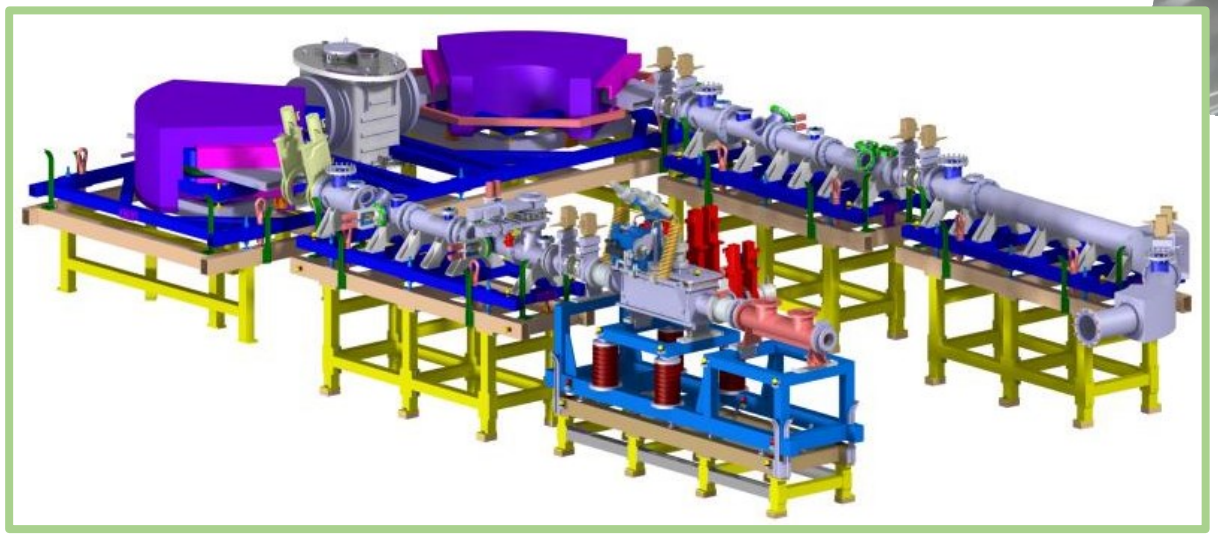


Beam purification: High-resolution separator HRS





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

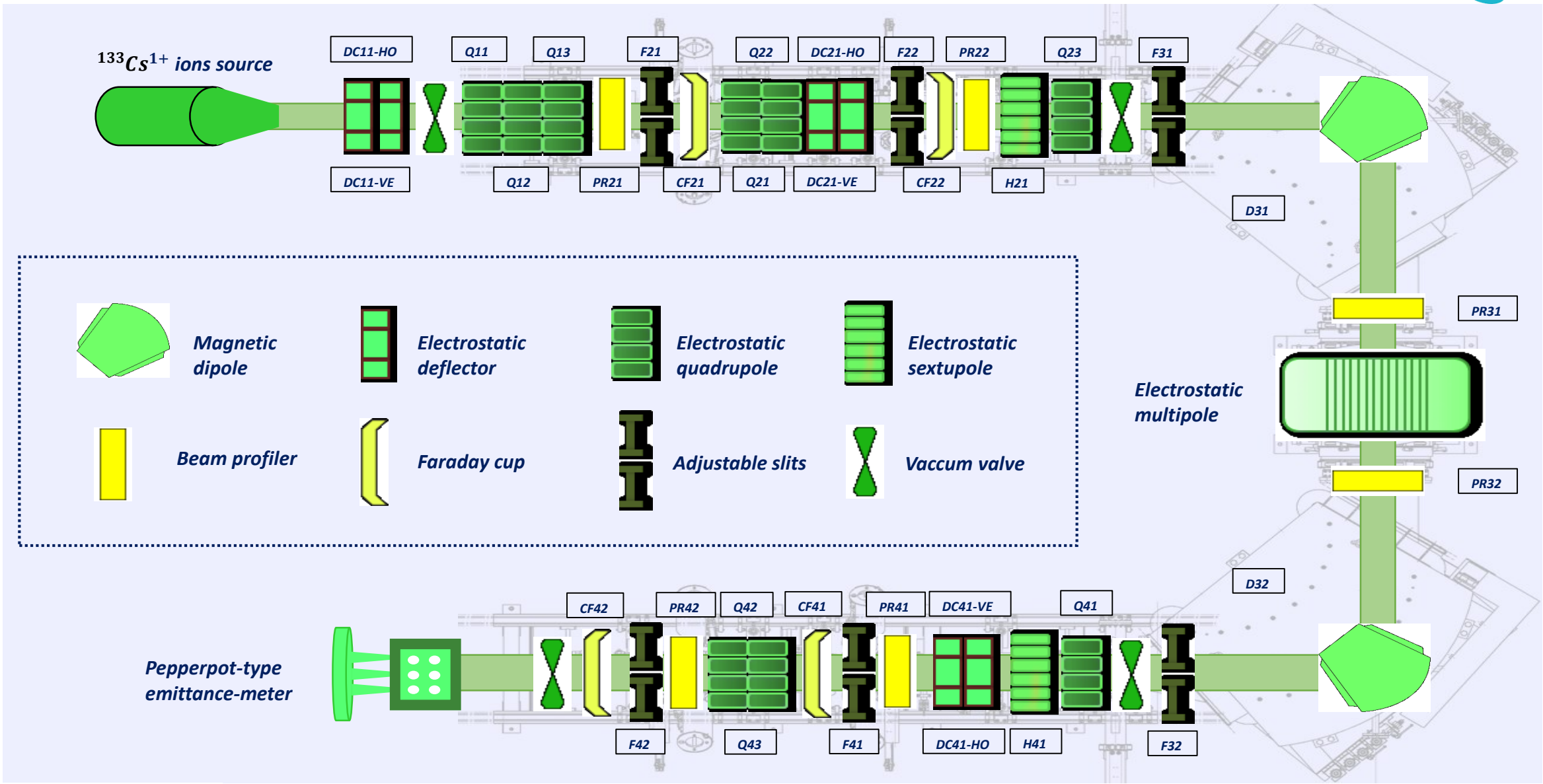


M/ΔM =20 000 @ 3π mm.mrad / 30keV

T. Kurtukian Nieto et al., NIMB 317 (2013) 284

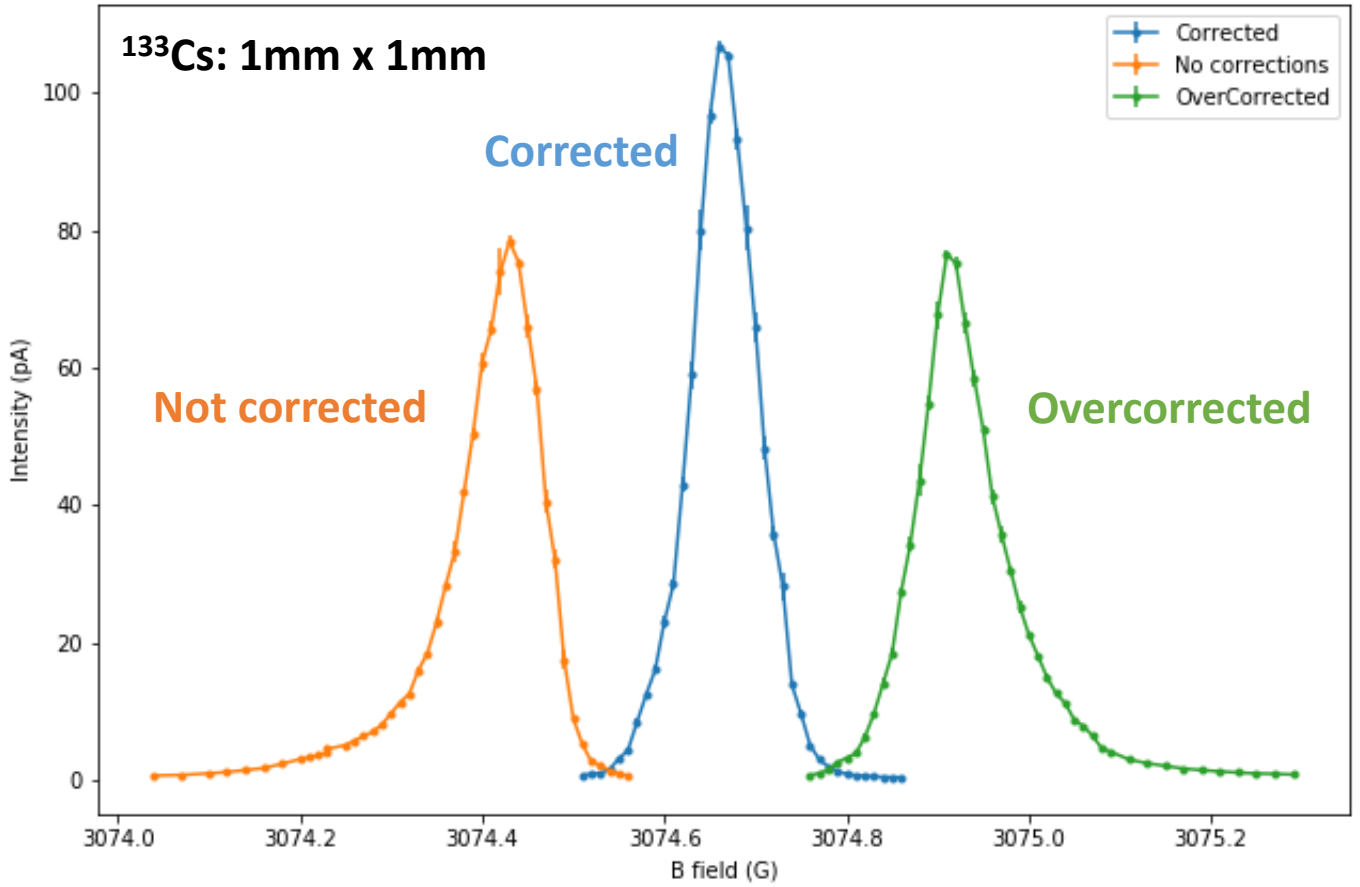
J. Michaud et al., LP2iB & IJCLab

Beam purification: High-resolution separator HRS



J. Michaud et al., LP2iB & IJCLab

High-resolution separator 2nd order correction measurements



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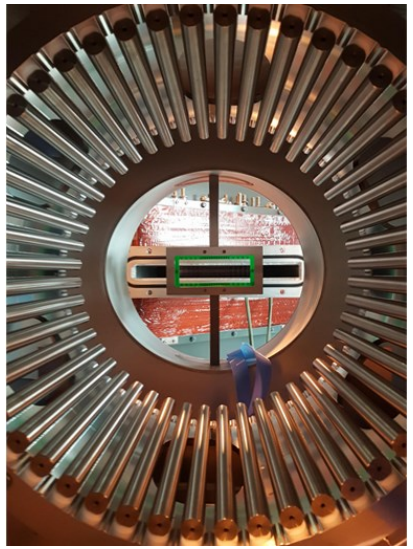
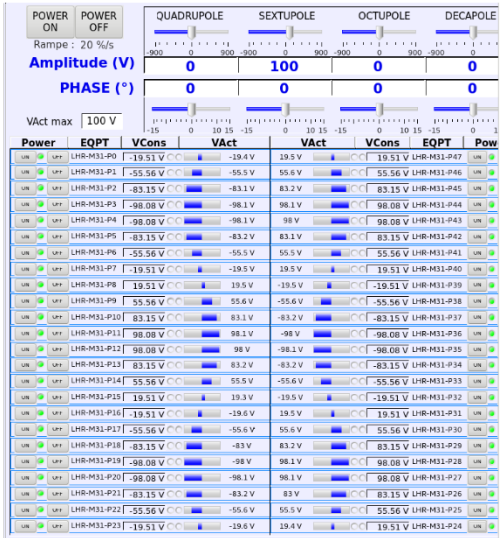
Beam can be scanned with the dipoles through end slits to obtain a precise beam profile

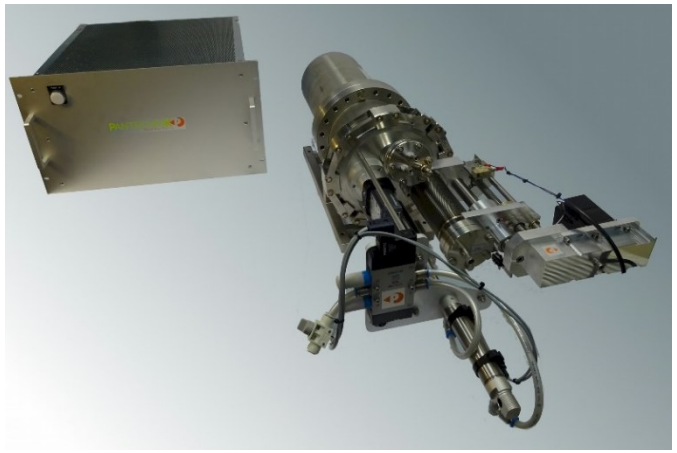
48-rod multipole

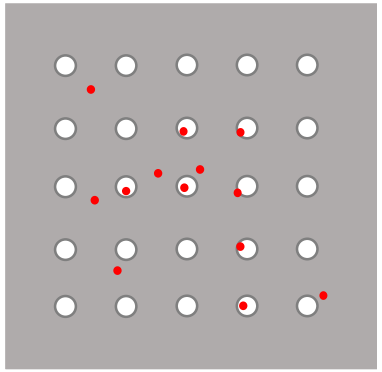




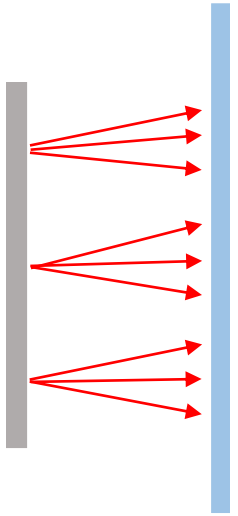
J. Michaud et al., NIMB 541 (2023) 161

High-resolution separator HRS: emittance meter

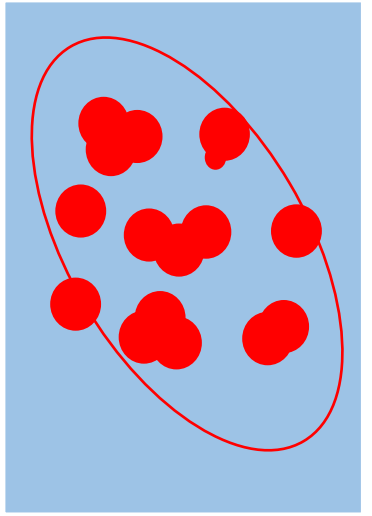




Front view:
tantal mask

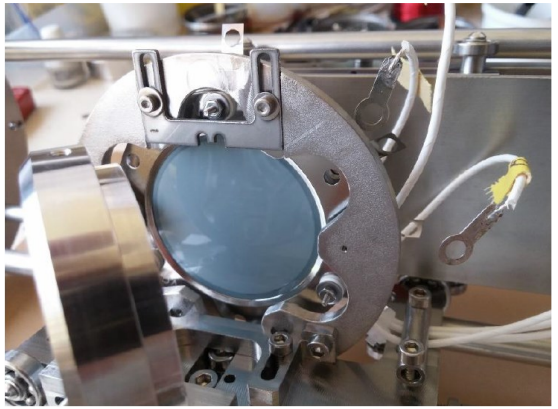


Side view:
Phosphore screen + MCP



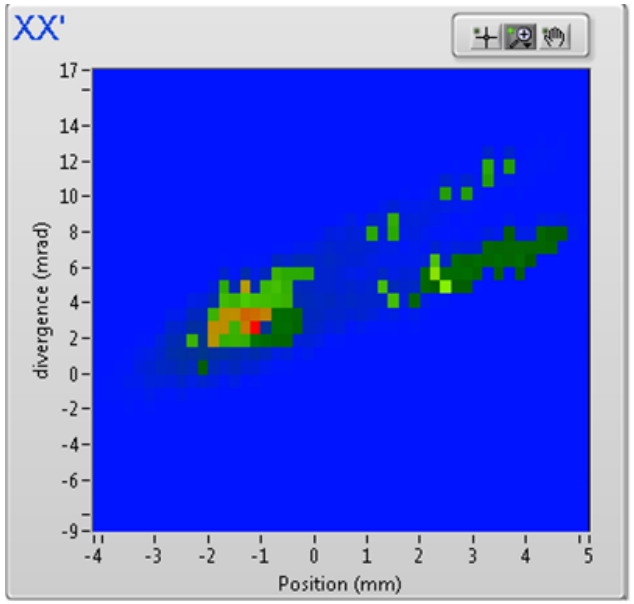
Front view:
CCD camera

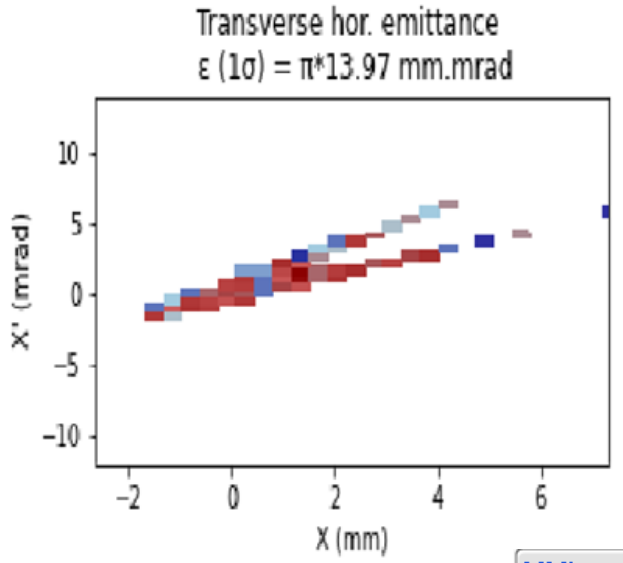
Pepperpot
emittance-meter



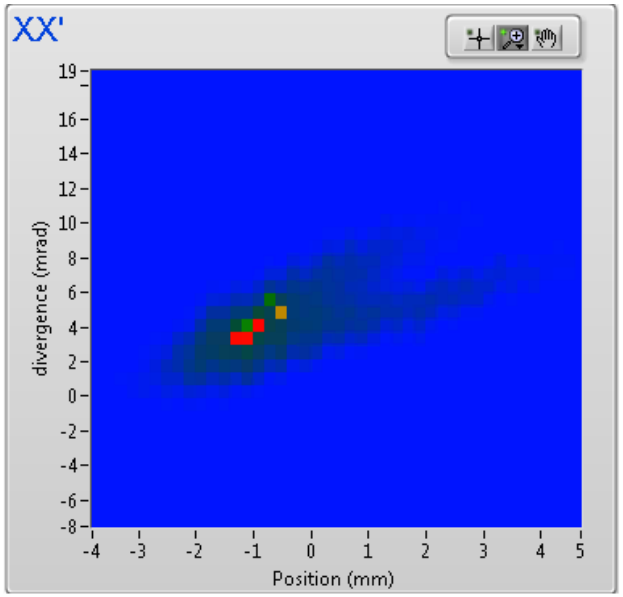
J. Michaud et al., LP2iB & IJCLab

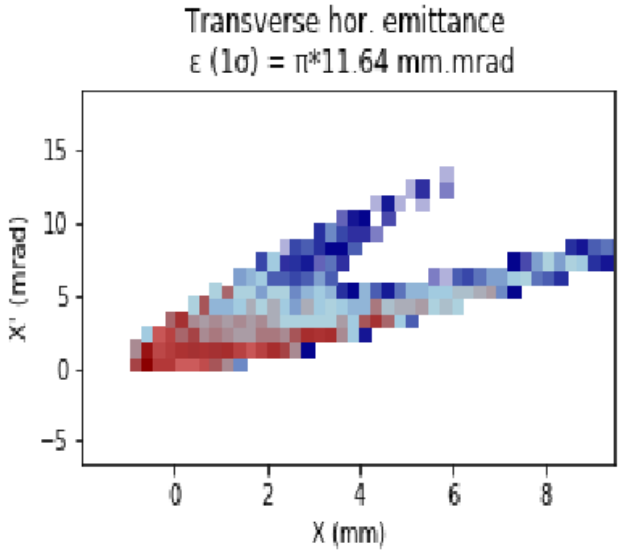
High-resolution separator HRS: emittance figures





Experimental measurements correspond to simulations





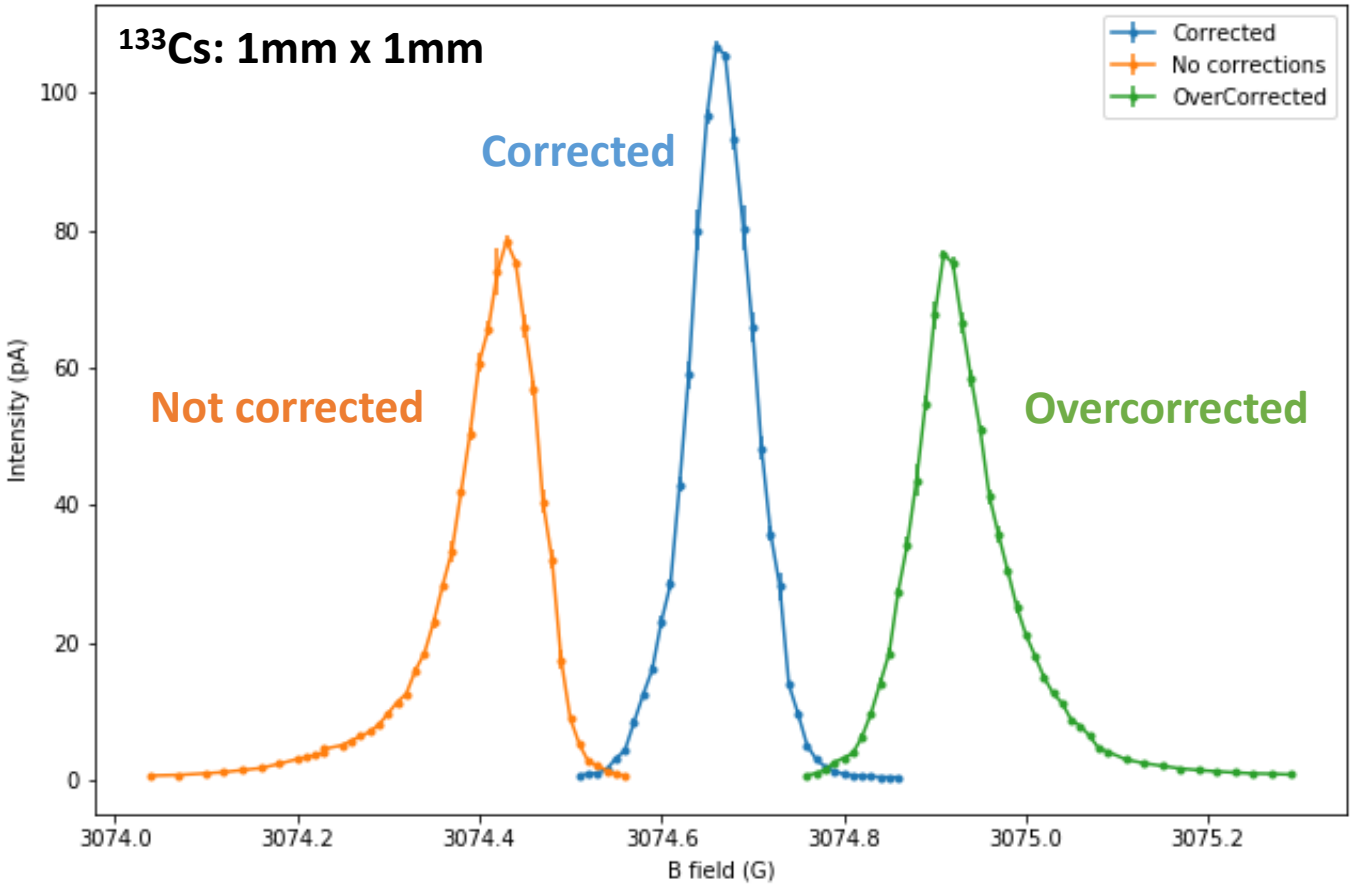
2nd order aberrations can be observed with the emittance-meter

➔ Order 3: Not by eye, but a computer could

➔ Image analysis software under development (A. Balana)

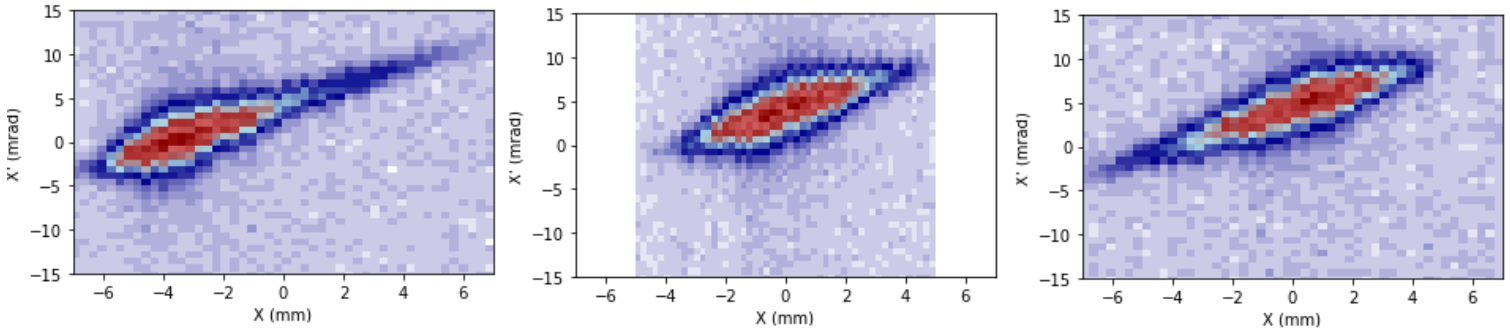
J. Michaud et al., NIMB 541 (2023) 161

High-resolution separator 2nd order correction measurements



> Shifted left -0,2G
> Shifted right +0,2G

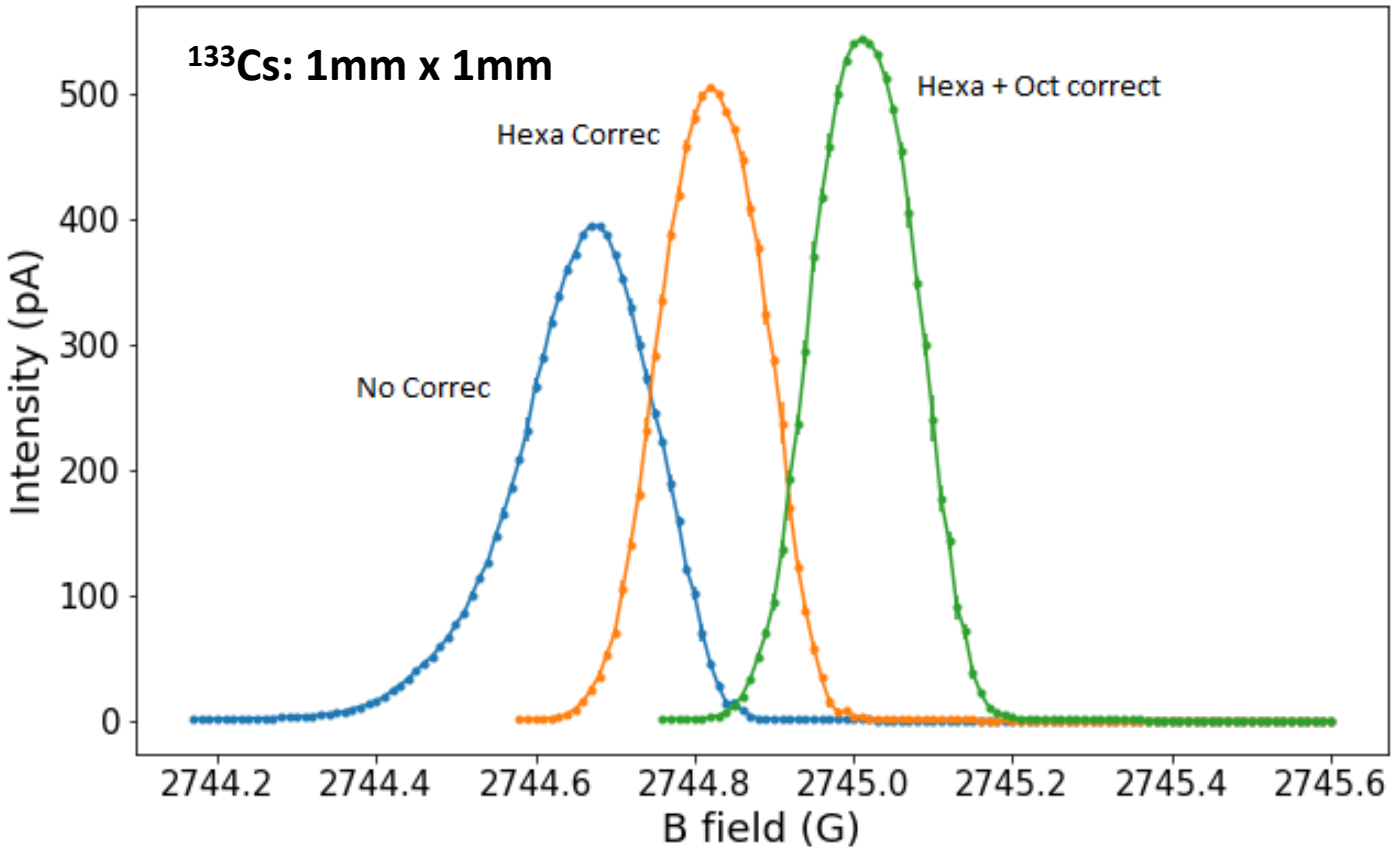
Beam (1mm x 1mm) can be scanned with the dipoles through exit slits to obtain a precise beam profile



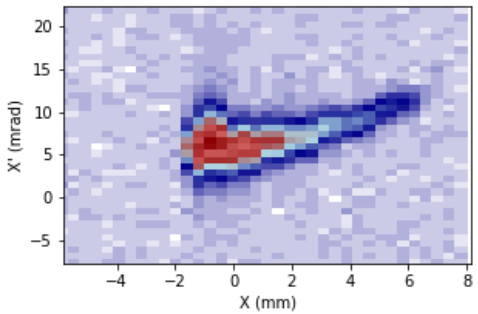
Pepperpot emittance figures

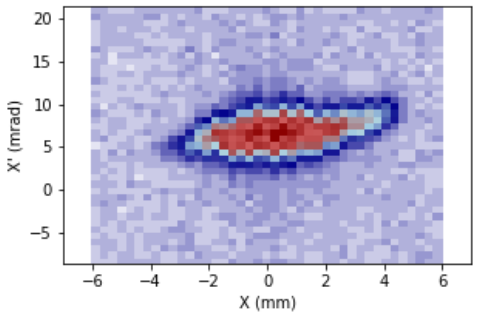
J. Michaud et al., LP2iB & IJCLab

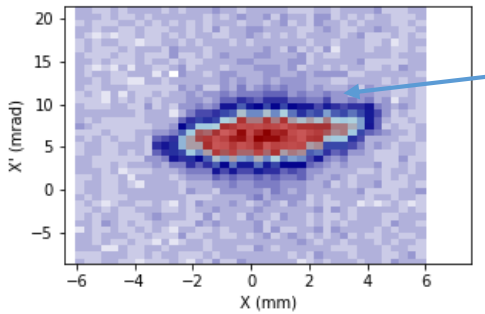
High-resolution separator 3rd order correction measurements



Beam (1mm x 1mm) can be scanned with the dipoles through exit slits to obtain a precise beam profile



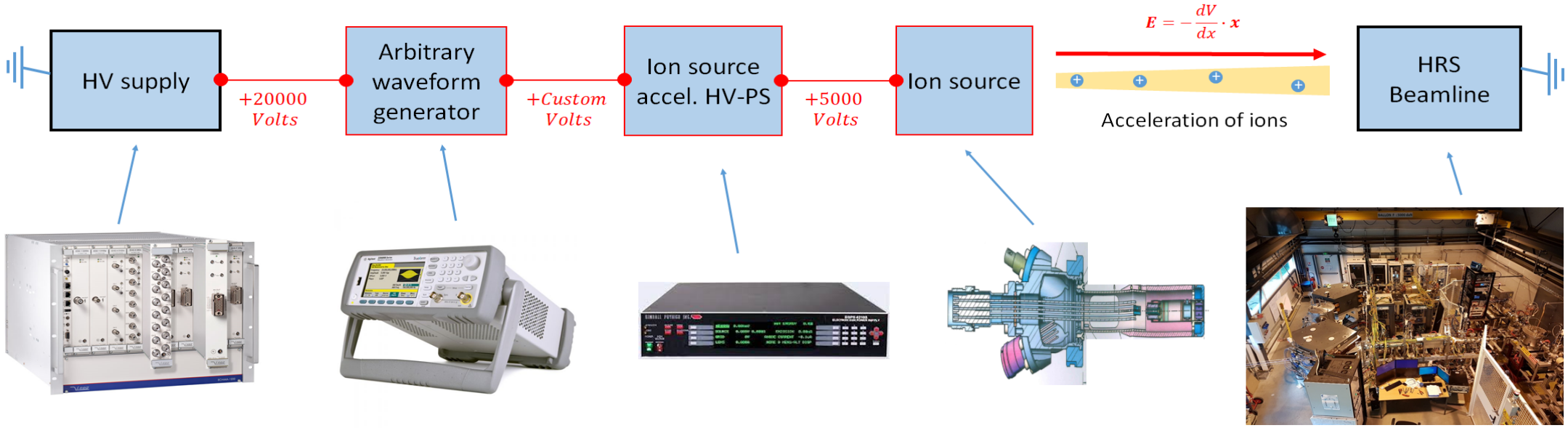




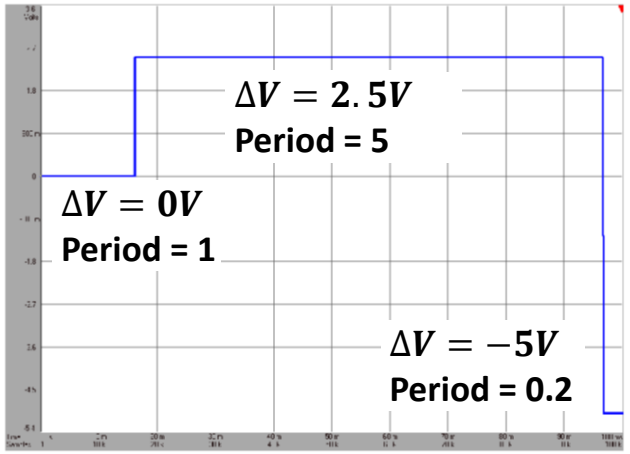
Hard to see a change, but a computer should

J. Michaud et al., LP2iB & IJCLab

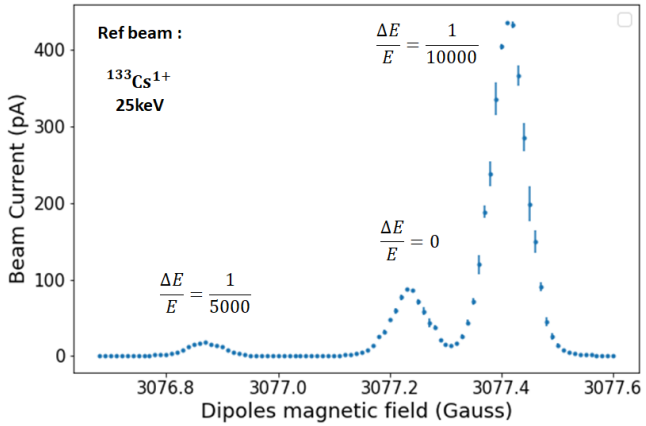
High-resolution separator HRS: arbitrary waveform generator



$$Energy_{total} = 25000eV + custom\ distribution\ (\pm 5eV)$$



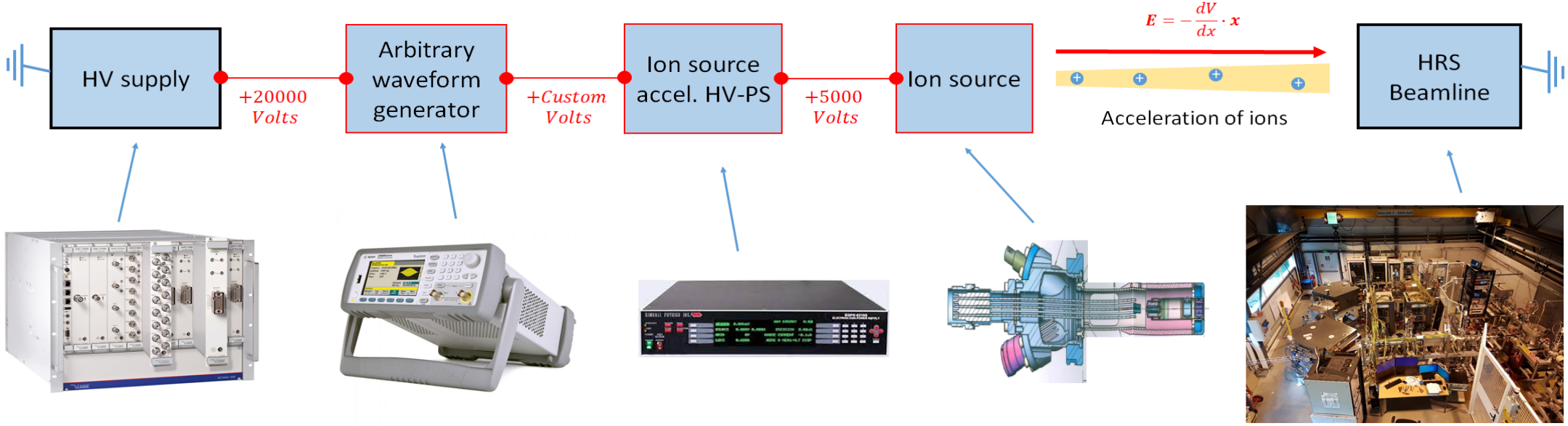
Create custom beam contaminants



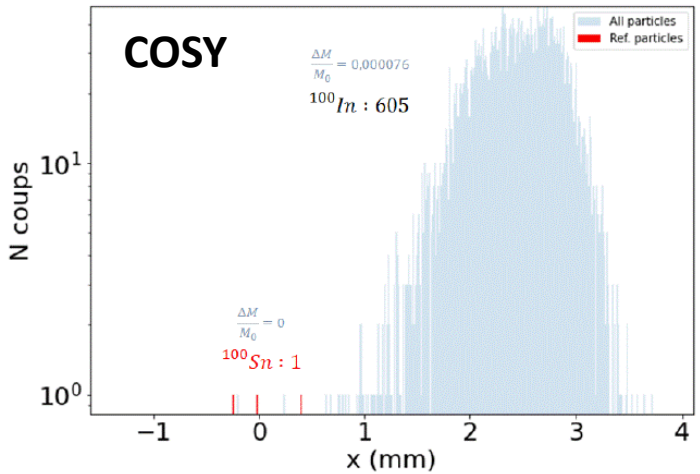
The HRS can be commissioned in almost real operating conditions, with no radioactive beam and (relatively) high intensities

J. Michaud et al., NIMB 541 (2023) 243

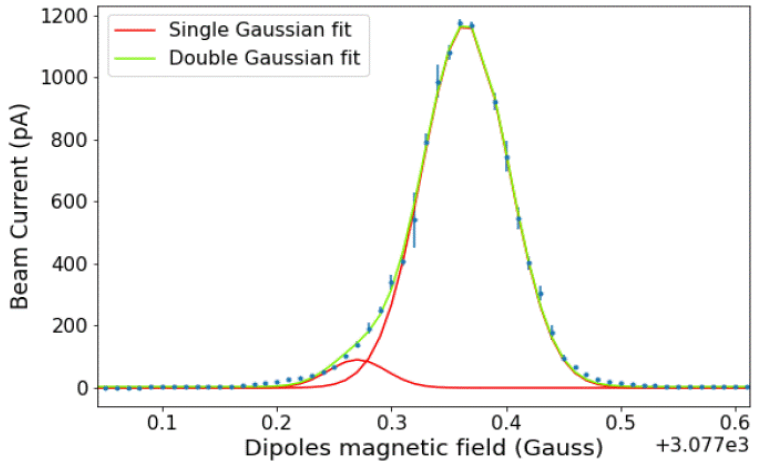
High-resolution separator HRS: arbitrary waveform generator



$$Energy_{total} = 25000eV + custom\ distribution\ (\pm 5eV)$$



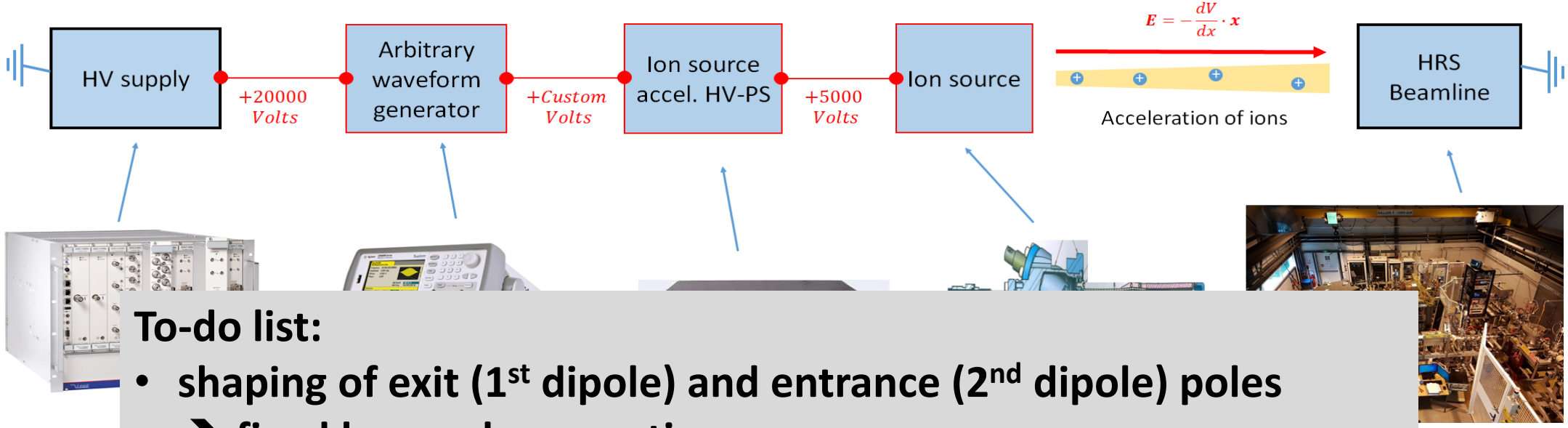
^{100}Sn/^{100}In separation: simulation and measurement



J. Michaud et al., NIMB 541 (2023) 243

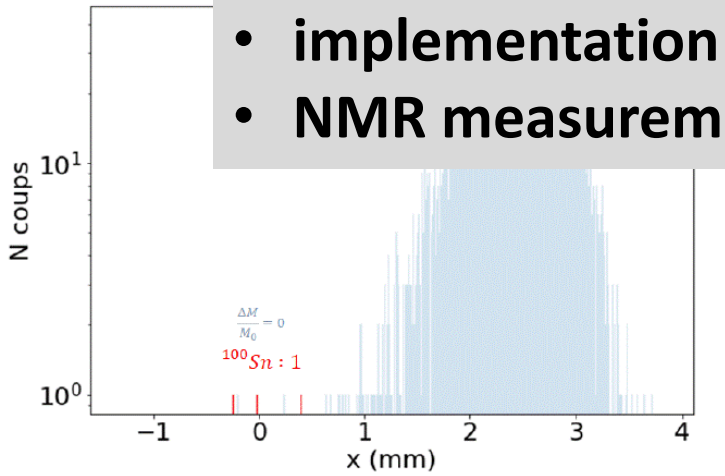
J. Michaud et al., LP2iB & IJCLab

High-resolution separator HRS: arbitrary waveform generator

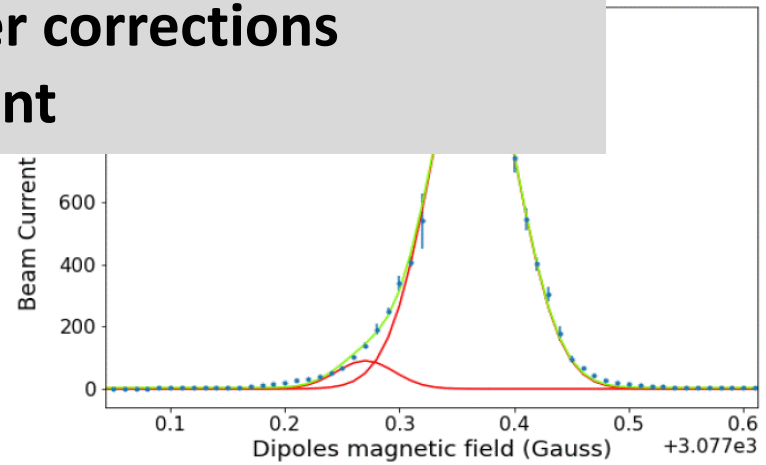


To-do list:

- **shaping of exit (1st dipole) and entrance (2nd dipole) poles**
  ➔ fixed hexapole corrections
- **optimising of 3rd and higher orders**
- **implementation of automatic higher-order corrections**
- **NMR measurement reliability improvement**

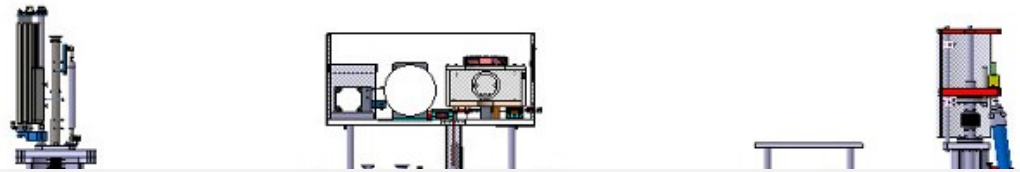


^{100}Sn/^{100}In separation: simulation and measurement

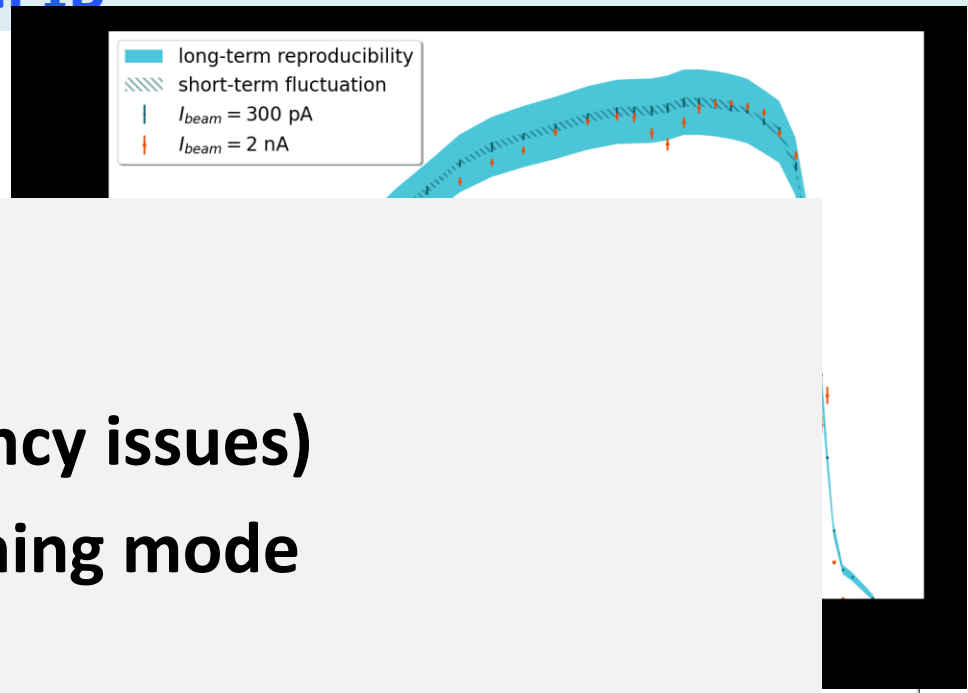


J. Michaud et al., NIMB 541 (2023) 243

Beam preparation: General purpose ion buncher GPIB

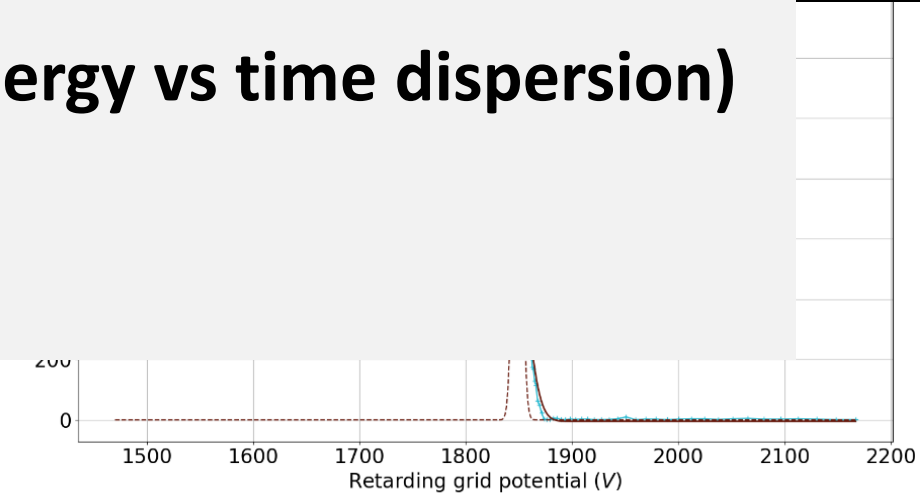


LP2i Bordeaux



To-do list:

- Magnetof for energy dispersion (avoid efficiency issues)
- Transverse emittance measurements in bunching mode
- RF phase dependence for the bunches
- Bunching mode to be investigated in detail (energy vs time dispersion)
- Space charge effects
- coupling to HRS ?

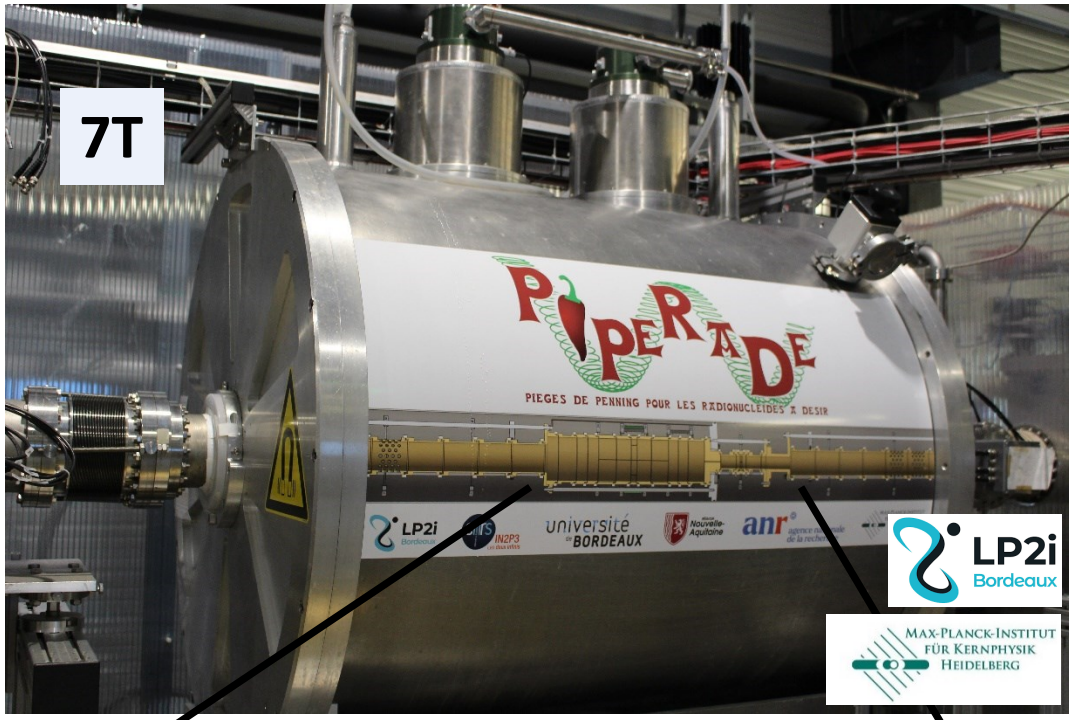


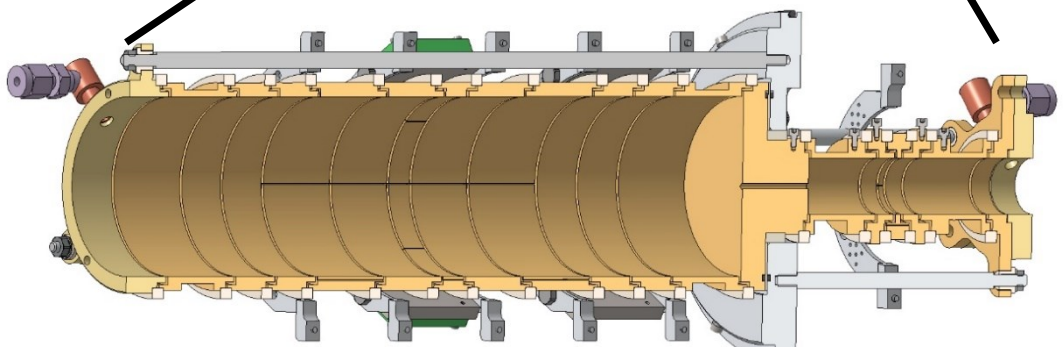
Energy and time dispersion:

- Energy dispersion measurement currently limited by detection system (< 6 eV) ➔ Magnetof
- Minimum time dispersion currently down to ≈ 250 ns (FWHM) at 3 keV

M. Gerbaux, C. Roumegou et al., LP2iB
M. Gerbaux et al., NIMA 1046 (2023) 167631

Beam purification: PIPERADE, 1st trap



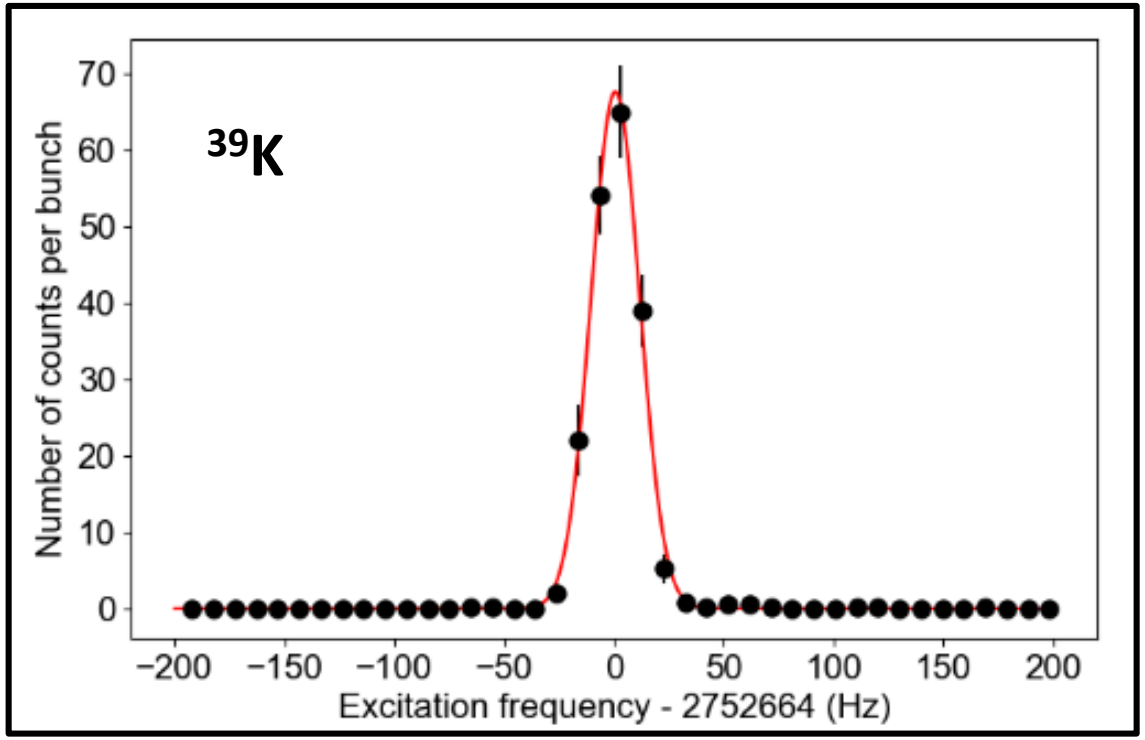


purification trap

accumulation & measurement trap

P. Ascher et al., NIMA1019 (2021) 165857

First trap:

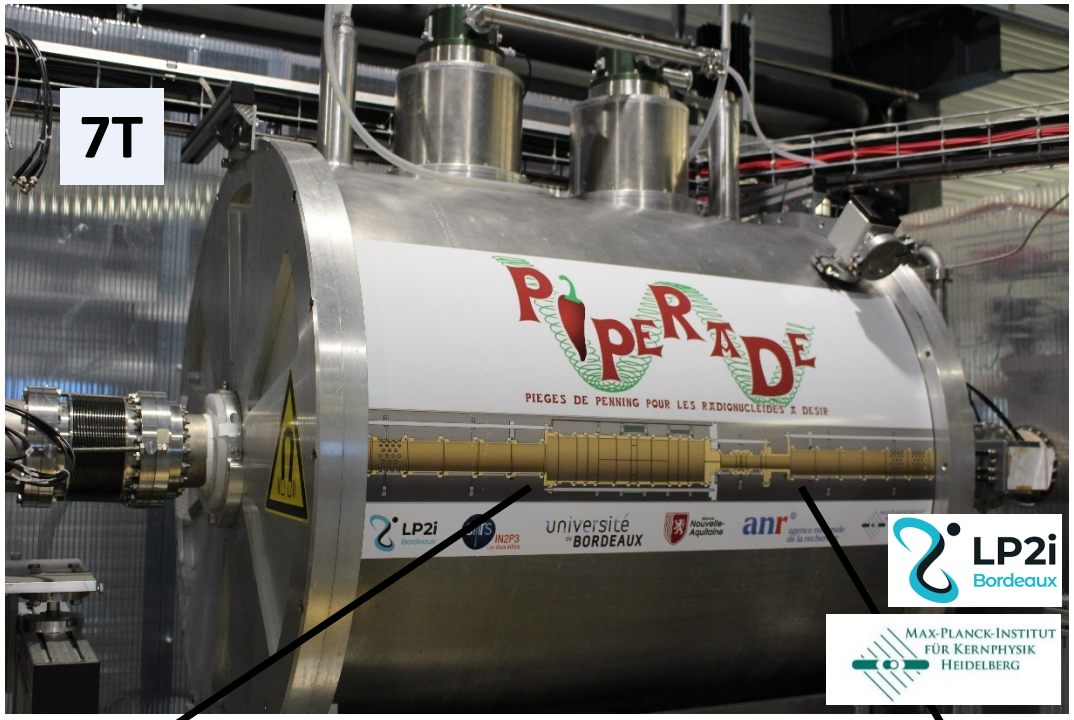


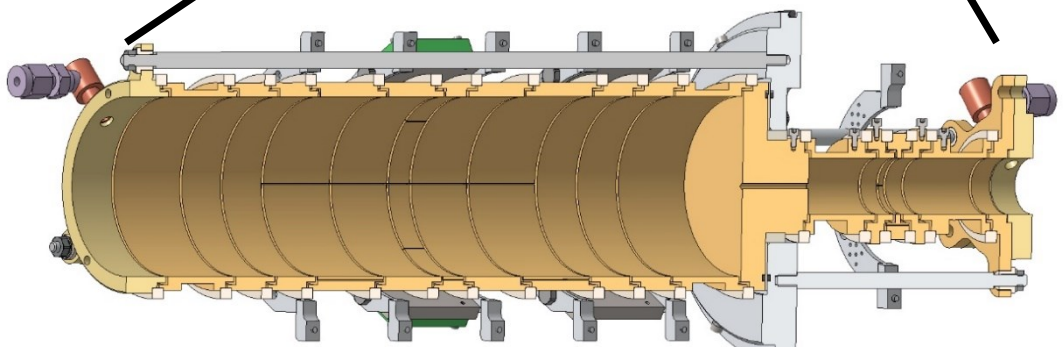
Resolving power:

$$\frac{\nu_c}{\Delta\nu_c} \propto \frac{m}{\Delta m} \approx 2 \times 10^5$$

P. Ascher, M. Flayol, D. Atanasov,
E. Rey-herme, G. Guignard et al., LP2iB

Beam purification: PIPERADE, 2nd trap

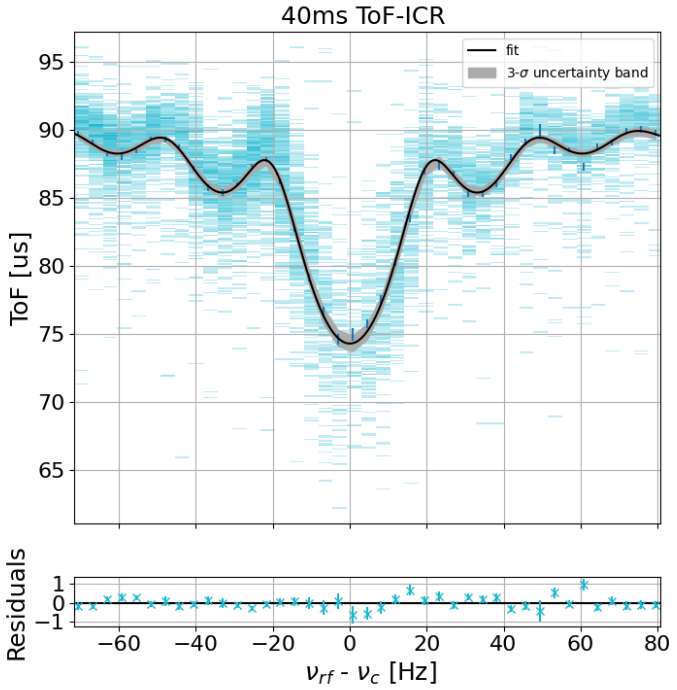




purification trap

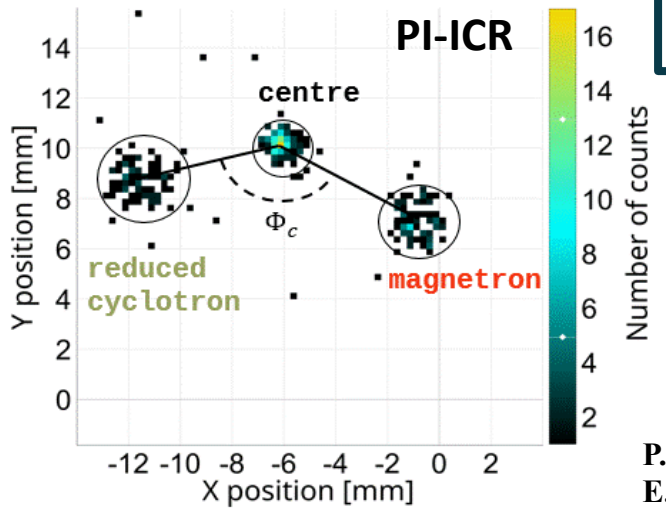
accumulation & measurement trap

P. Ascher et al., NIMA1019 (2021) 165857



accuracy: $\frac{\Delta m}{m} \approx 9.5 \times 10^{-10}$

precision: $\frac{\delta m}{m} \approx 3 \times 10^{-9}$



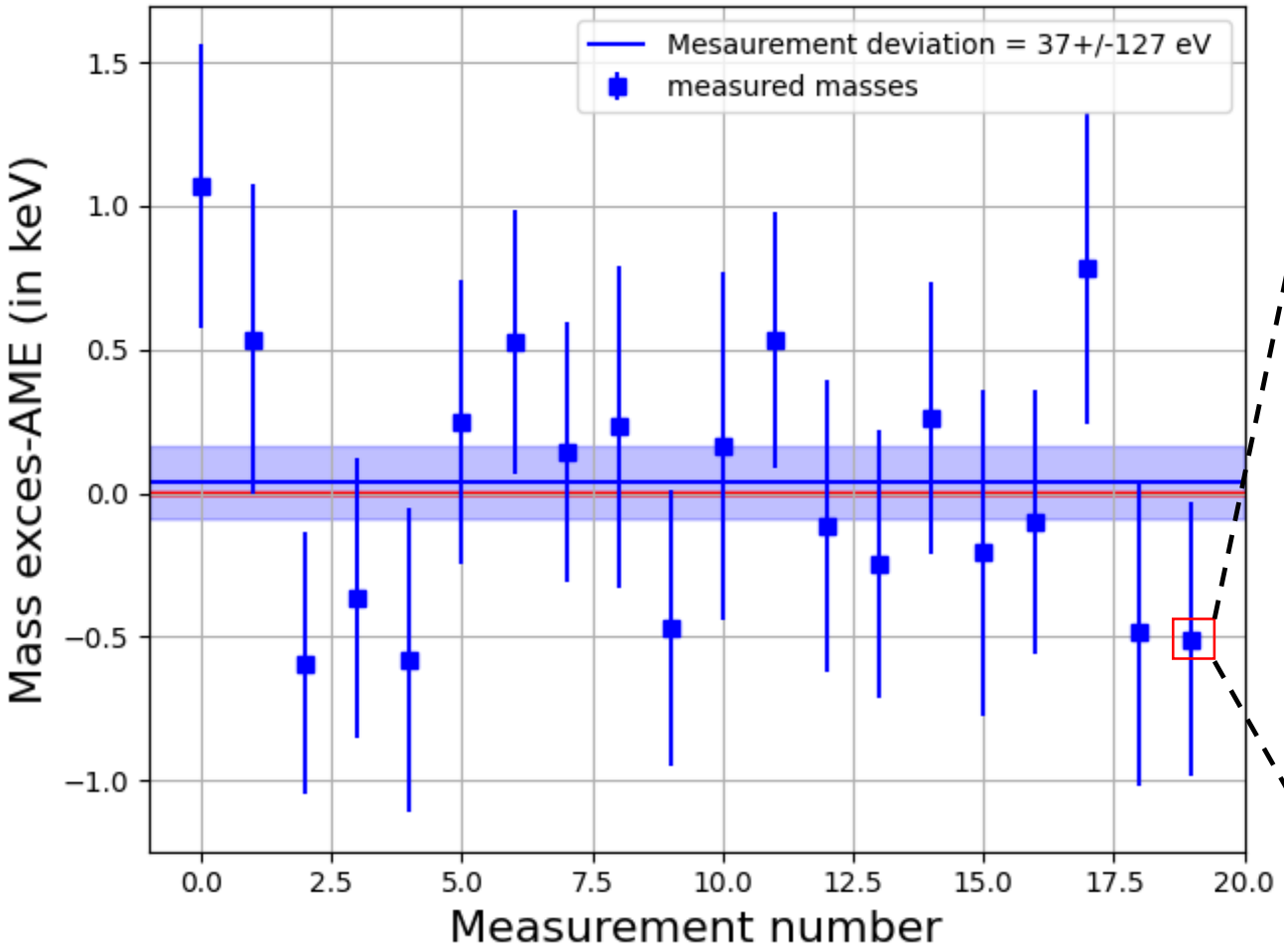
$$\nu_c = \frac{\phi_c + 2\pi n}{2\pi t} = \frac{qB}{2\pi m}$$

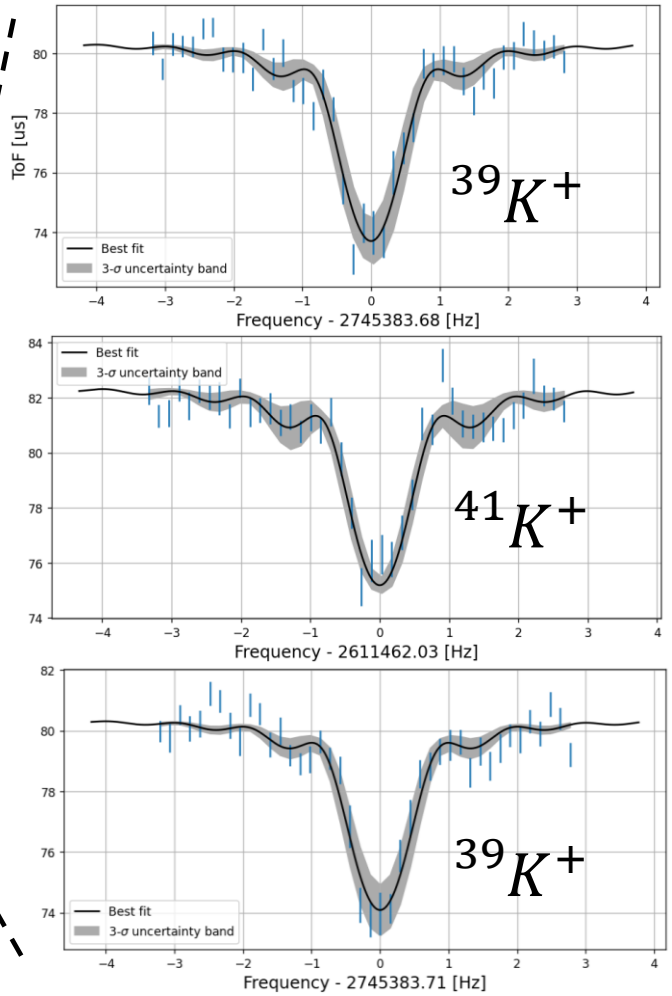
accuracy: $\frac{\Delta m}{m} * 5$

precision: $\frac{\delta m}{m} * 40$

P. Ascher, M. Flayol, D. Atanasov, E. Rey-herme, G. Guignard et al., LP2iB

PIPERADE: Mass measurement of ^{41}K with ToF-ICR





$$\nu_c = \frac{qB}{2\pi m}$$

- measured with ^{39}K as reference
- ToF-ICR of 1 s

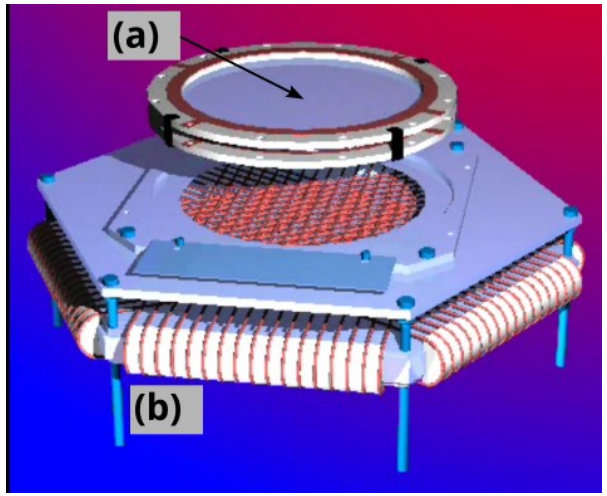
P. Ascher, M. Flayol, D. Atanasov,
E. Rey-herme, G. Guignard et al., LP2iB

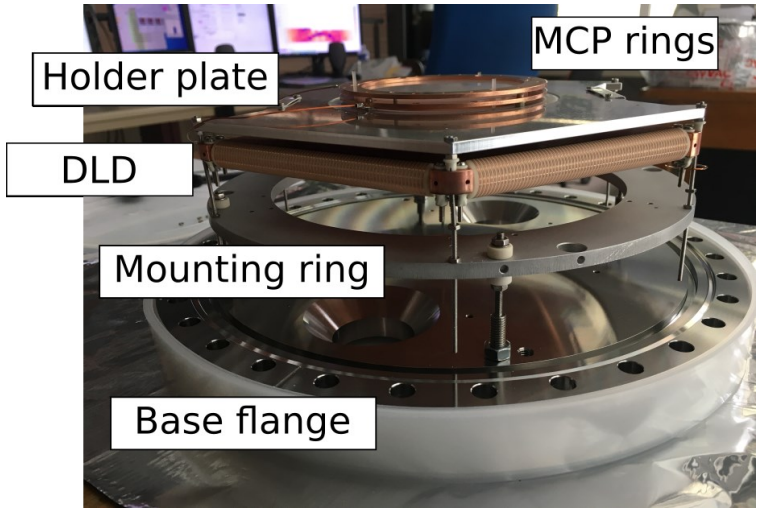
$$\nu_c = \frac{\phi_c + 2\pi n}{2\pi t} = \frac{qB}{2\pi m}$$

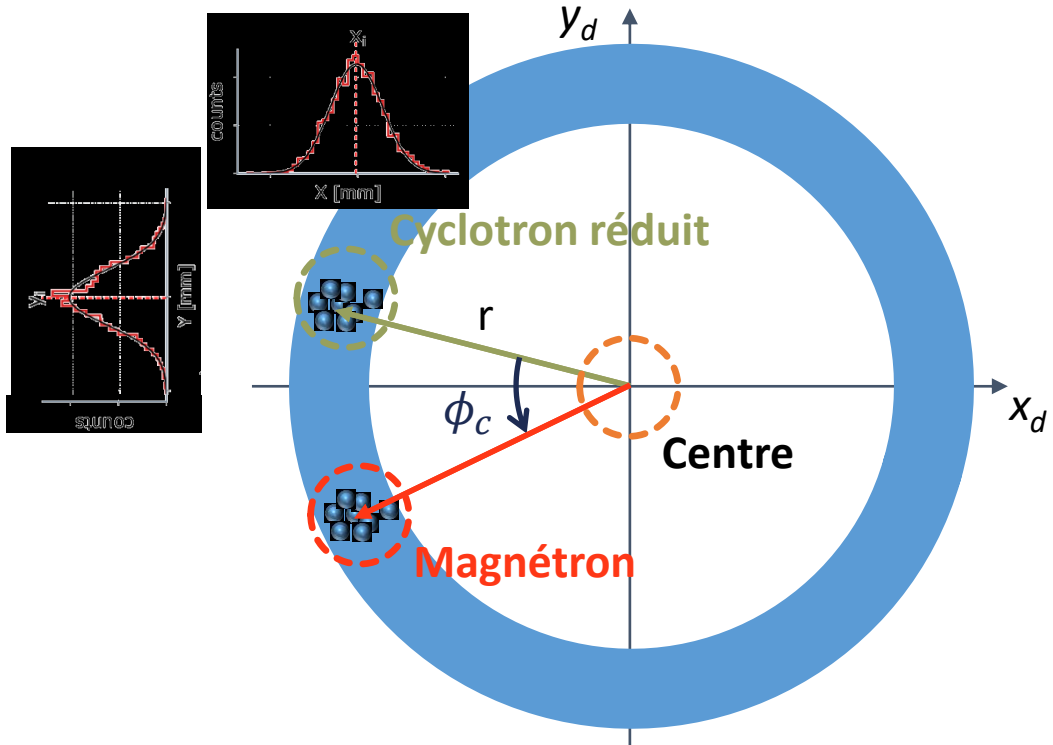
$$\delta\nu_c = \frac{\delta\phi_c}{2\pi t} = \frac{\delta r}{2\pi r t\sqrt{N}}$$

Précision $\frac{\delta m}{m} \approx 10^{-8}$ **à** 10^{-10}

position-sensitive MCP







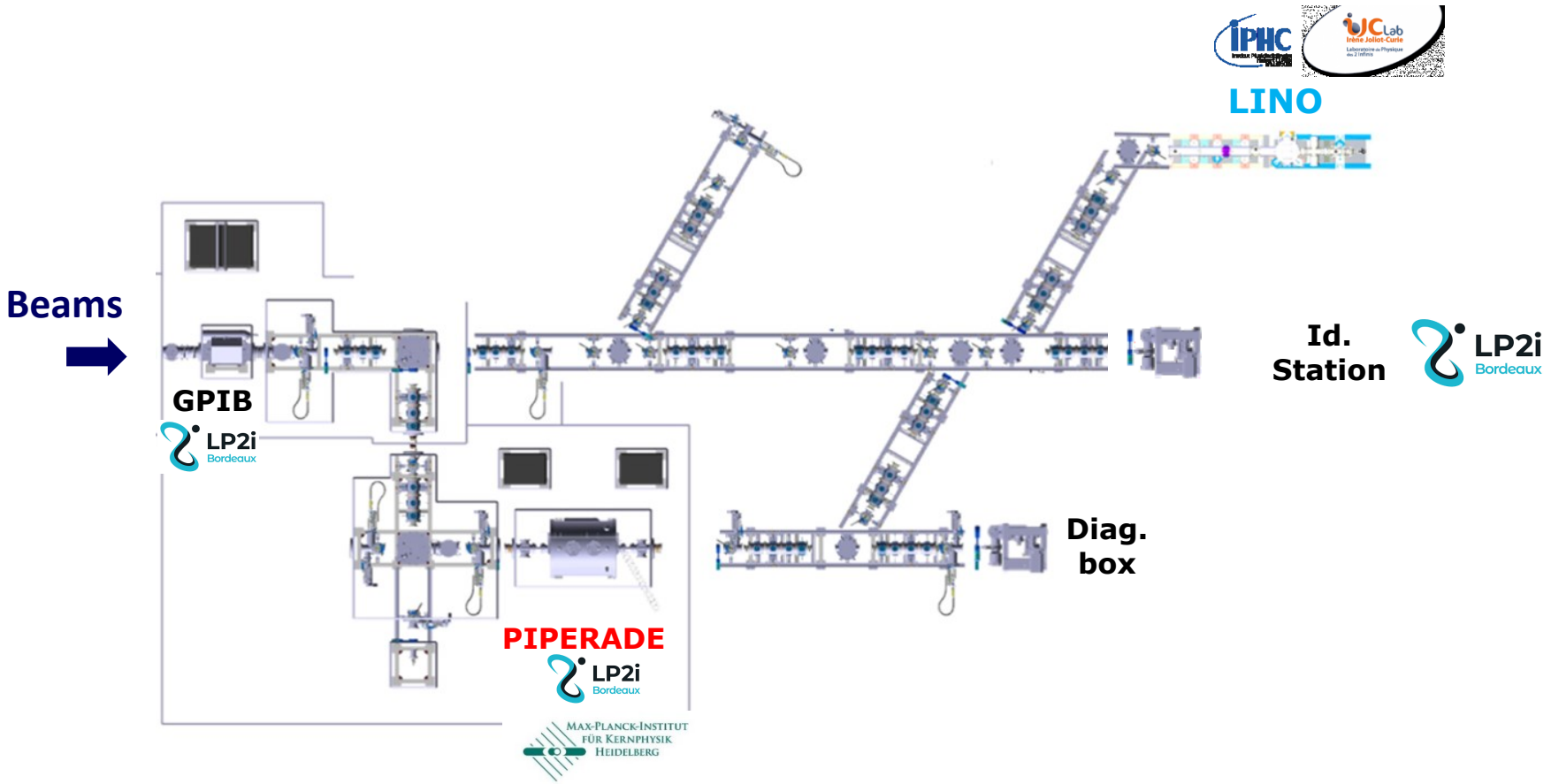
To-do list:

- January 2025: diaphragm change for a smaller diameter hole (reduction of gas leaking from PT to MT)
- before moving to DESIR:
  - systematic studies of ToF-ICR, impact of field imperfections (anharmonicities of E-field and fluctuations of B-field) on mass precision, mass-dependent errors, ion-ion interaction
  - PI-ICR mass measurement and systematic studies (imperfections E/B fields + image distortion + extraction optimisation)
  - PI-ICR cleaning: installation of an iris to select the ion of interest
  - Buffer gas cooling technique: limits in terms of trapping times and investigation vs number of ions
- if AC not OK at DESIR: pressure/temp stabilisation system to implement
- commissioning at DESIR: all systematics to study again

Installation of experimental equipment

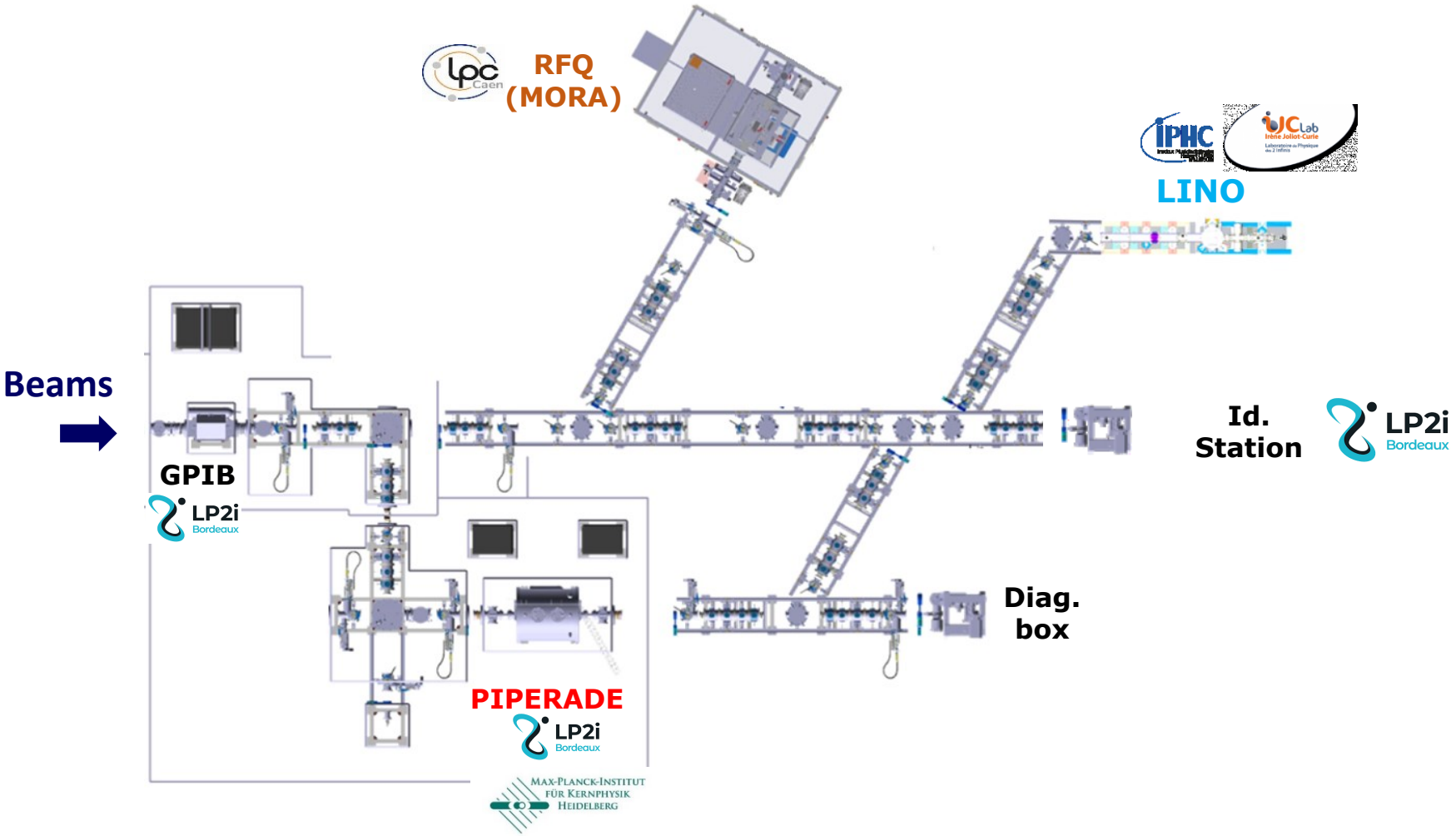
Experimental equipment: time line

S2 - 2026: GPIB + PIPERADE + fluorescence laser line (LINO)



Experimental equipment: time line

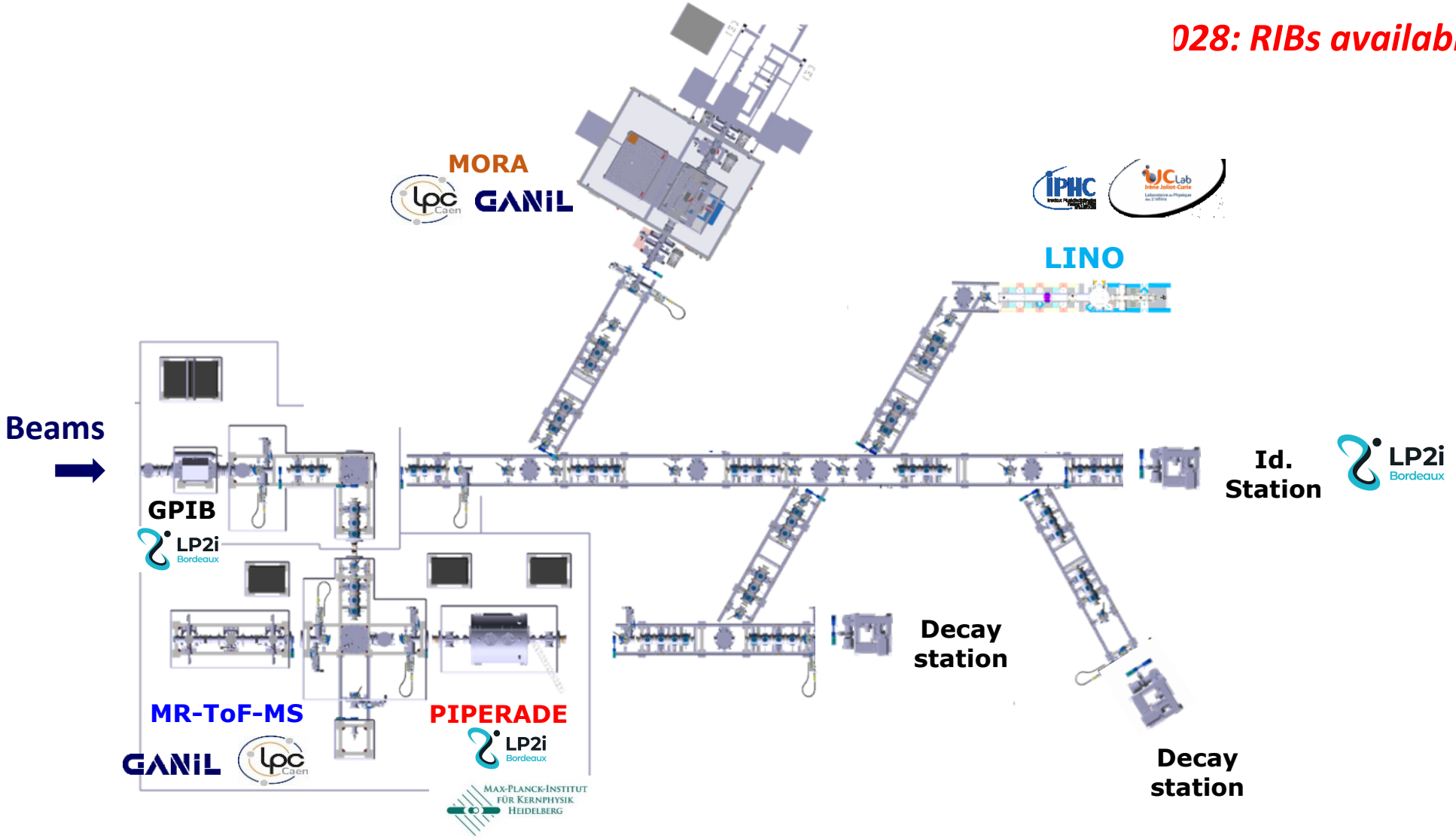
S1 - 2027: MORA cooler-buncher (RFQ)



Experimental equipment: time line

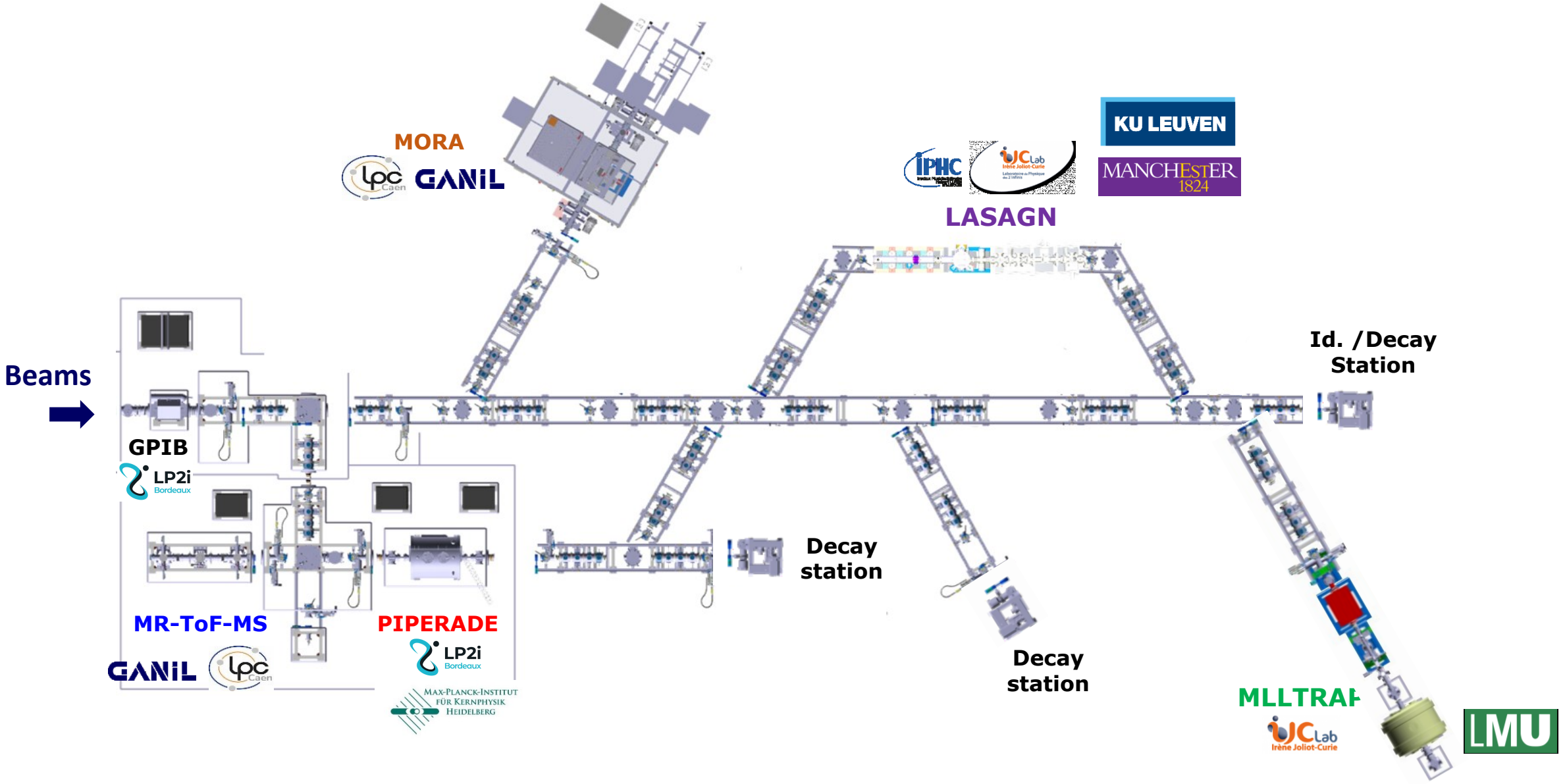
2028: MORA completed, MR-ToF-MS, decay stations

028: RIBs available



Experimental equipment: time line

2029: collinear laser spectroscopy (LASAGN) completed, MLLTrap



The DE$_{sir}$TRAP$_{ping}$ facility

MORA

P. Delahaye, GANIL, L. Hayen, X. Fléchard, LPC Caen

- RFQ-CB associated with a Paul trap

-> β-ν angular correlation coefficient
-> D correlation with laser polarized beams

P. Delahaye et al., Hyperfine Interaction 240 (2019) 63

⇒ Fundamental interaction physics
- exotic currents, CVC, V_{ud}, CP-violation

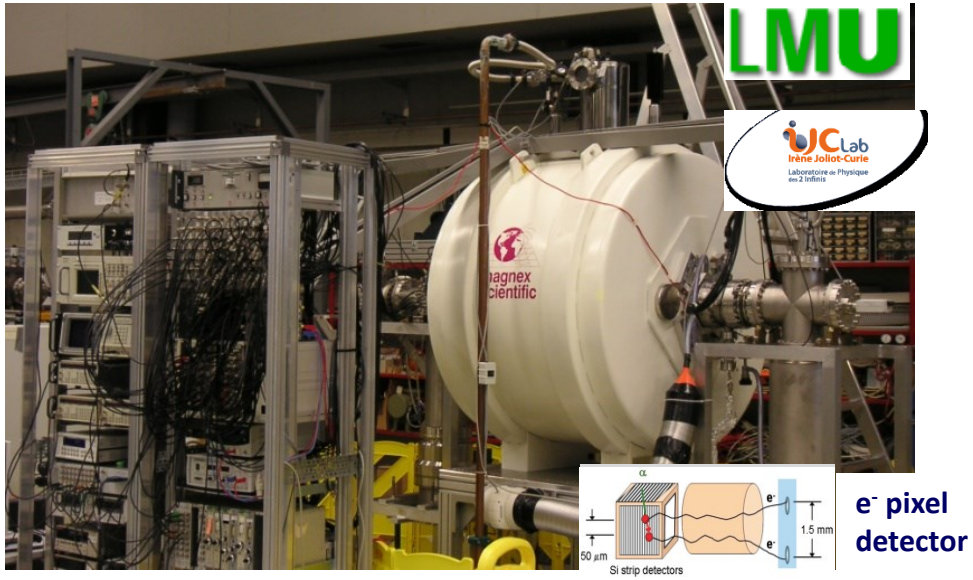
Commissioning at JYFL

MLLTrap

P. Thirolf, LMU Munich – E. Minaya Ramirez, IJClab

- Double Penning trap

-> high precision mass measurements
-> in-trap decay



e⁻ pixel detector

E. Minaya-Ramires et al., NIM B 463 (2020) 315
P. Chauveau et al., NIMB 463 (2020) 371

⇒ Nuclear structure & Decay properties
- shell evolution, deformation
- (super-) heavy nuclei decay spectroscopy

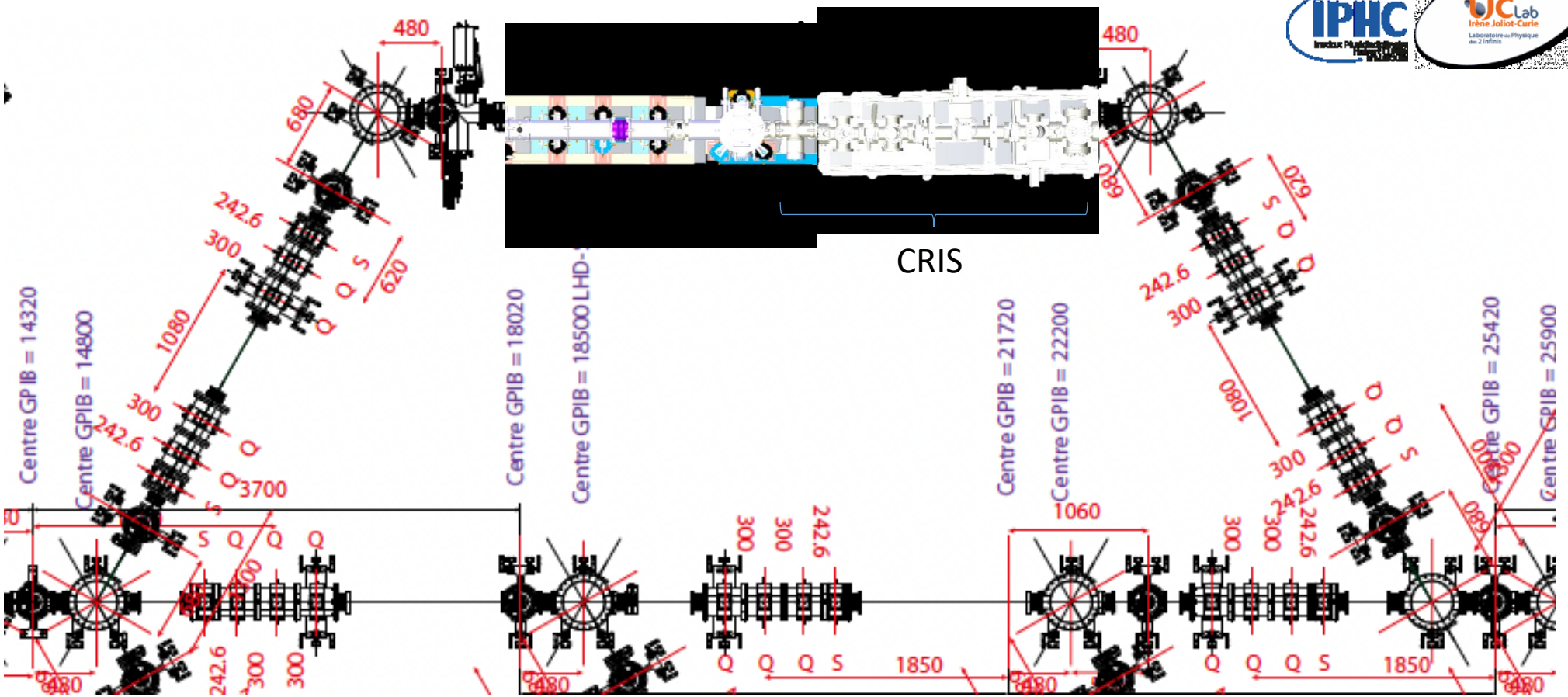
Commissioning at ALTO (IJCLab)

The LUMIERE facility

Laser Utilization for Measurement and Ionization of Exotic Radioactive Elements

LASAGN (*L. Lalanne, IPHC*)

- **Collinear laser spectroscopy (CRIS like)**
  - **-> hyperfine structure (magnetic and quadrupole moments, mean square charge radii)**
- **LINO commissioned at ALTO, IJCLab, *D. Yordanov et al.***



The BESTIOL facility

BEta decay STudies at the SPIRAL2 IsOL facilty

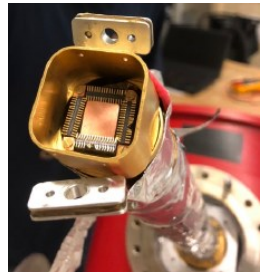
Beam cooling and purification using PIPERADE for (trap-assisted) decay spectroscopy
-> High-precision measurements with ultra-pure samples for fundamental interaction, nuclear structure, nuclear astrophysics etc

- β-γ decay stations (BEDO, …)
- total absorption spectrometers (DTAS)
- neutron detection arrays (BELEN, MONSTER, …)
- electron and proton detection (COeCO, SiCube, b-STILED
- recoil detection (ASGARD)

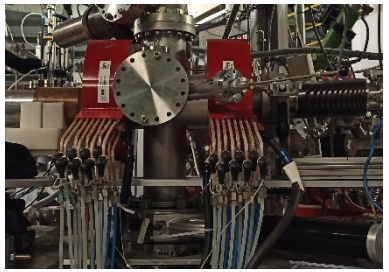
for

- CVC, V_{ud}
- beta shapes
- lifetimes, $P_{(2)n}$
- exotic decays (β-2p, cluster emission)
- Gamow-Teller strength

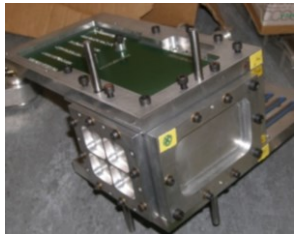
BELEN



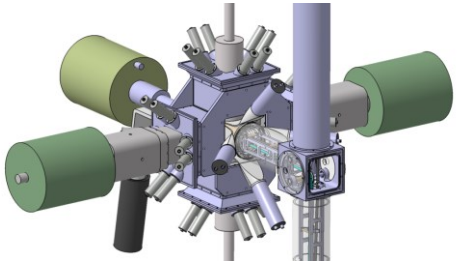
ASGARD



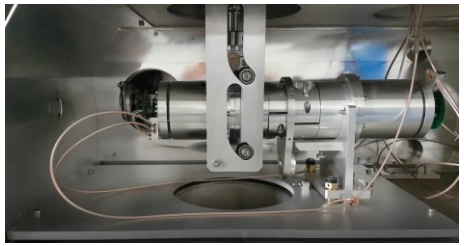
COeCO



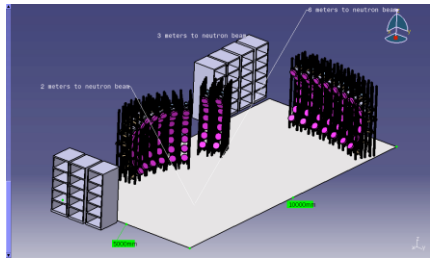
SiCube



BEDO



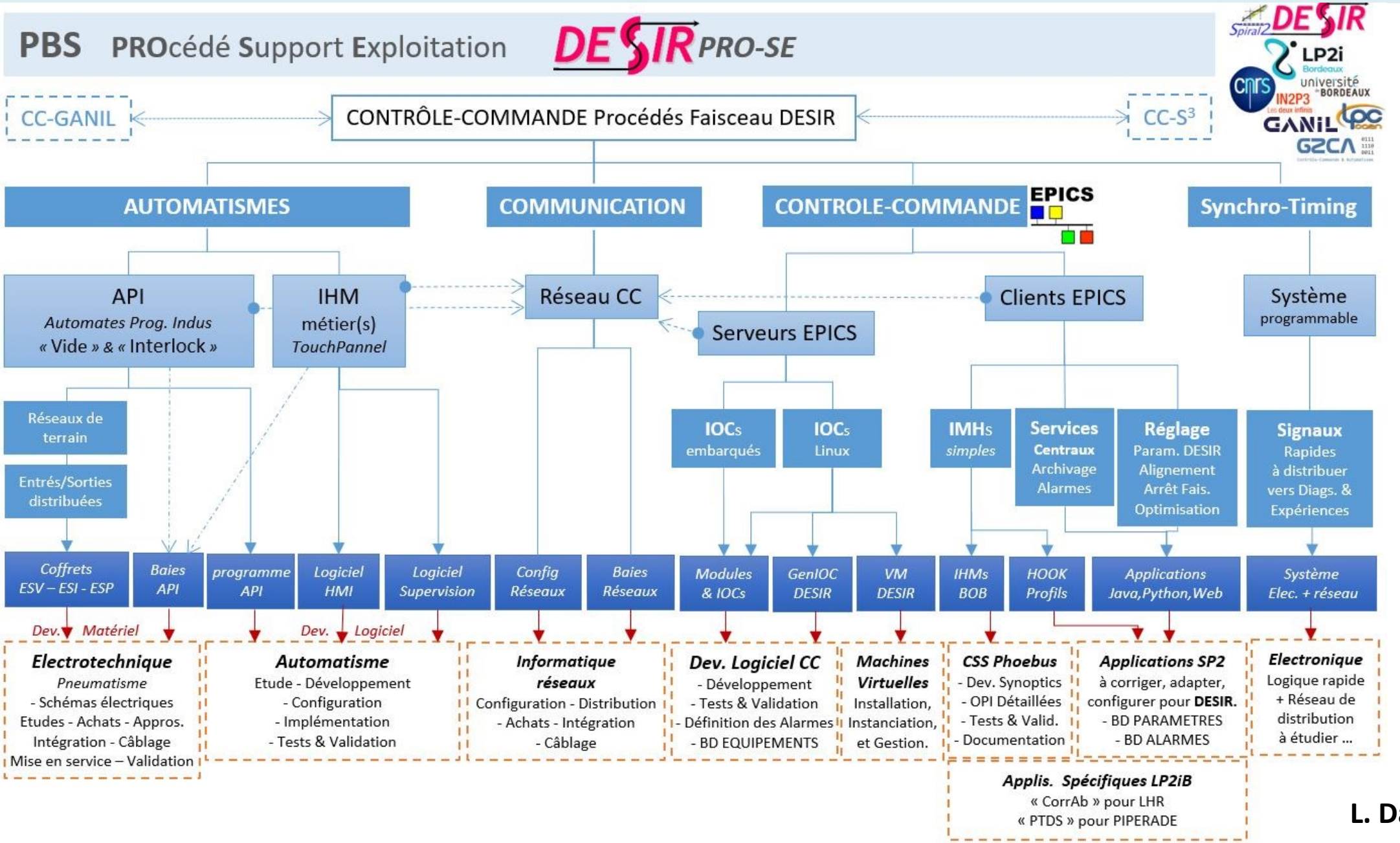
b-STILED



MONSTER

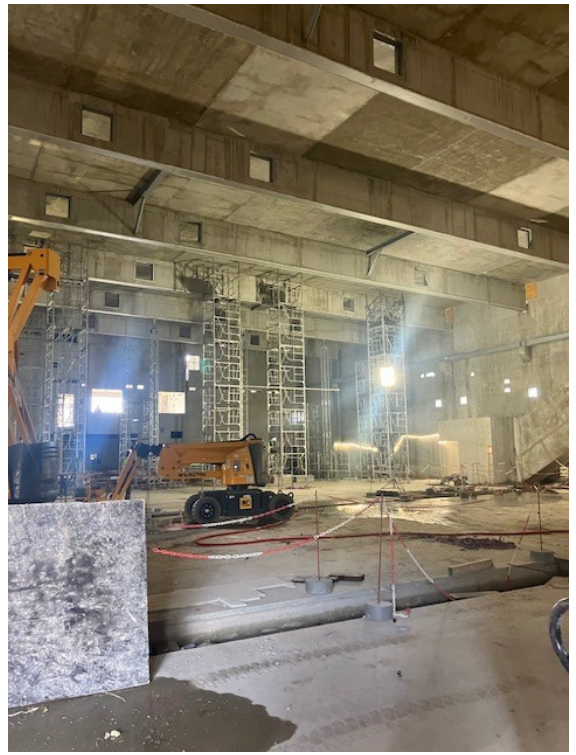
DTAS

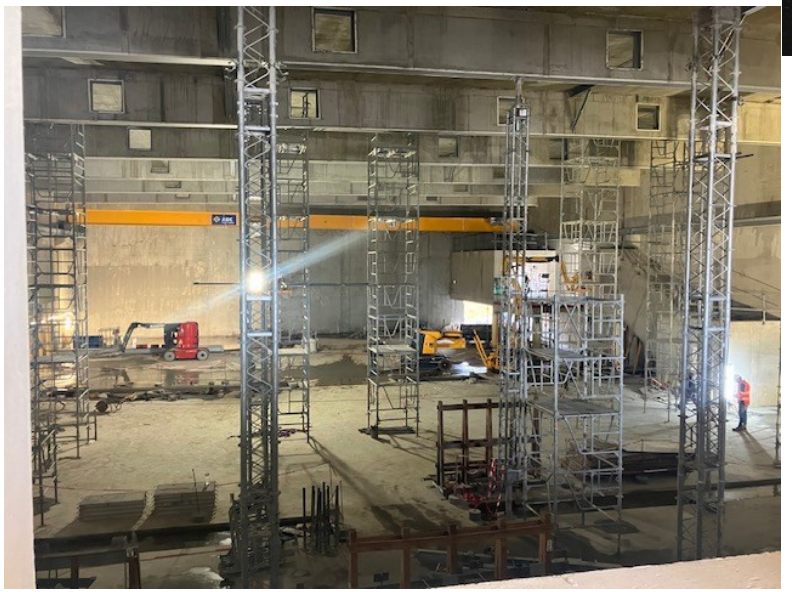
DESIR C/C



L. Daudin et al.

The DESIR building





- Building delivery: September 2025
- October 2025 to September 2026: Beam line & experiment installation
- June 2026 to January 2027: Cabling
- October 2026 to June 2027: Technical commissioning
- March to October 2027: Stable beam commissioning
- November 2027: Facility ready for radioactive beams

DESIR construction

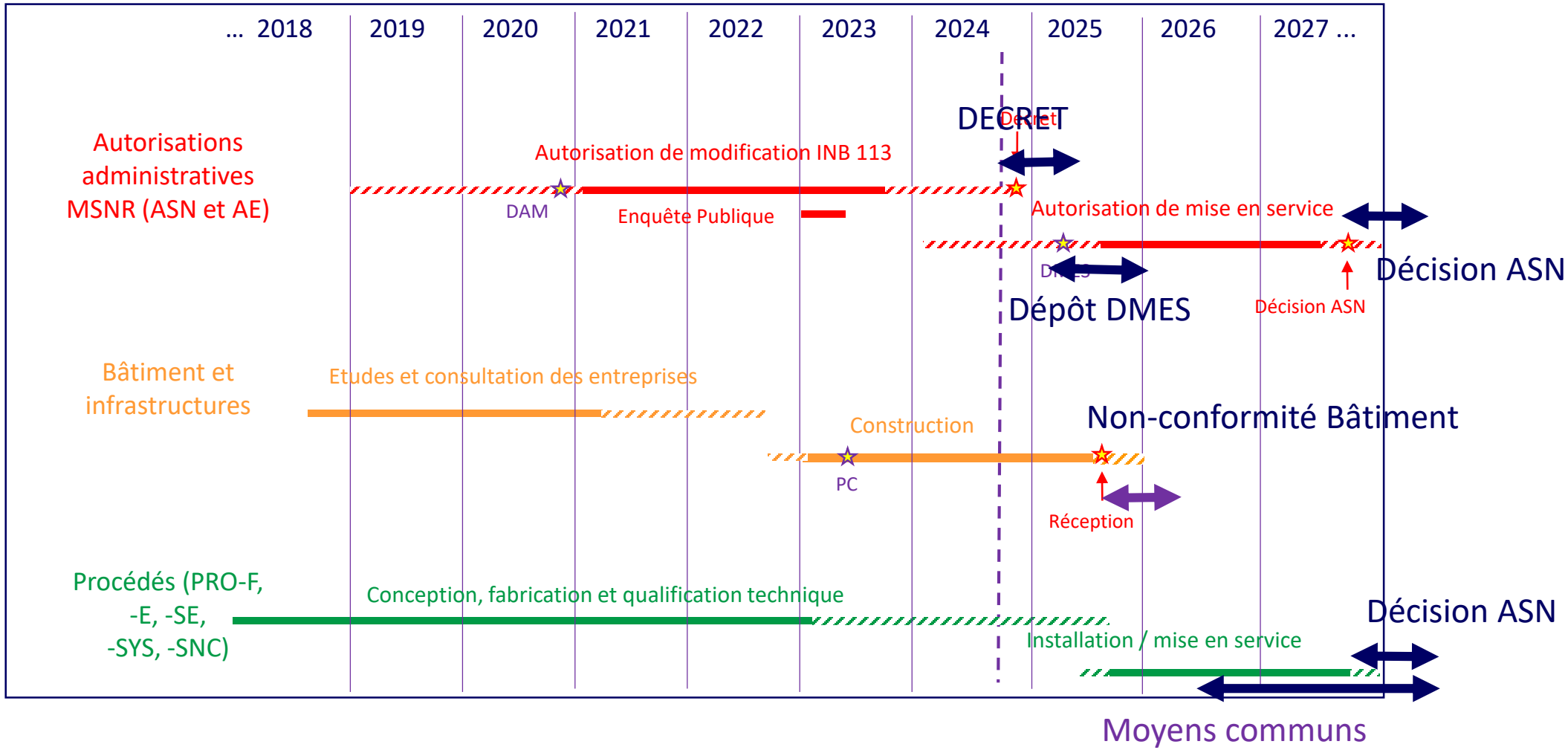
HRS room

DESIR hall

Thermal isolation of roof

Soil refilling

DESIR time line



Thanks for your attention