Implementation of the double Penning trap mass spectrometer MLLTRAP at ALTO

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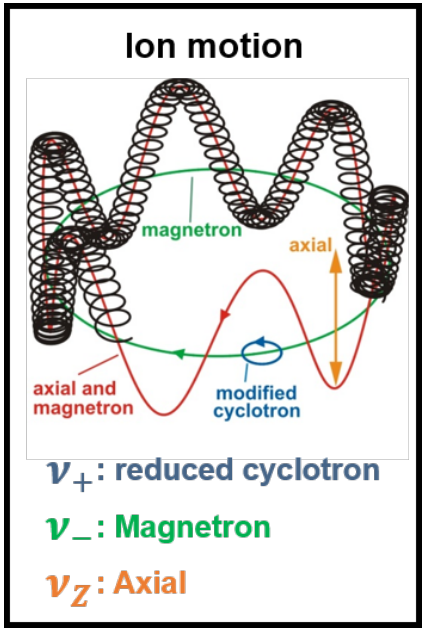
Penning trap mass spectrometer (PTMS)

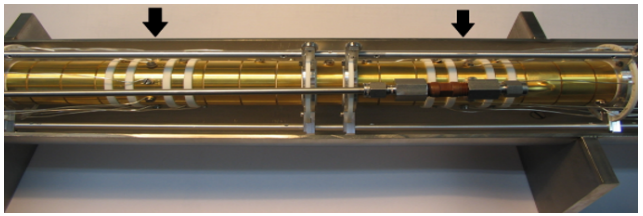
MLLTRAP : Two cylindrical Penning traps in a 7 T superconducting magnet

- Penning trap : superposition of high intensity magnetic field with low electrostatic field
- Application of quadrupolar field : 3 eignemotions appear :
  - An axial motion : ν_z
  - A slow radial motion, the magnetron motion : ν_-
  - A fast radial motion, the modified cyclotron motion : ν_+
  - $\rightarrow \nu_c^2 = \nu_+^2 + \nu_-^2 + \nu_z^2; \nu_c = \nu_+ + \nu_-$
- Ion manipulation by exciting their eigenmotions
  - Isobaric purification with buffer gas cooling in preparation trap
  - Cyclotron frequency measurements in a measurement trap

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



Measurement trap Preparation trap



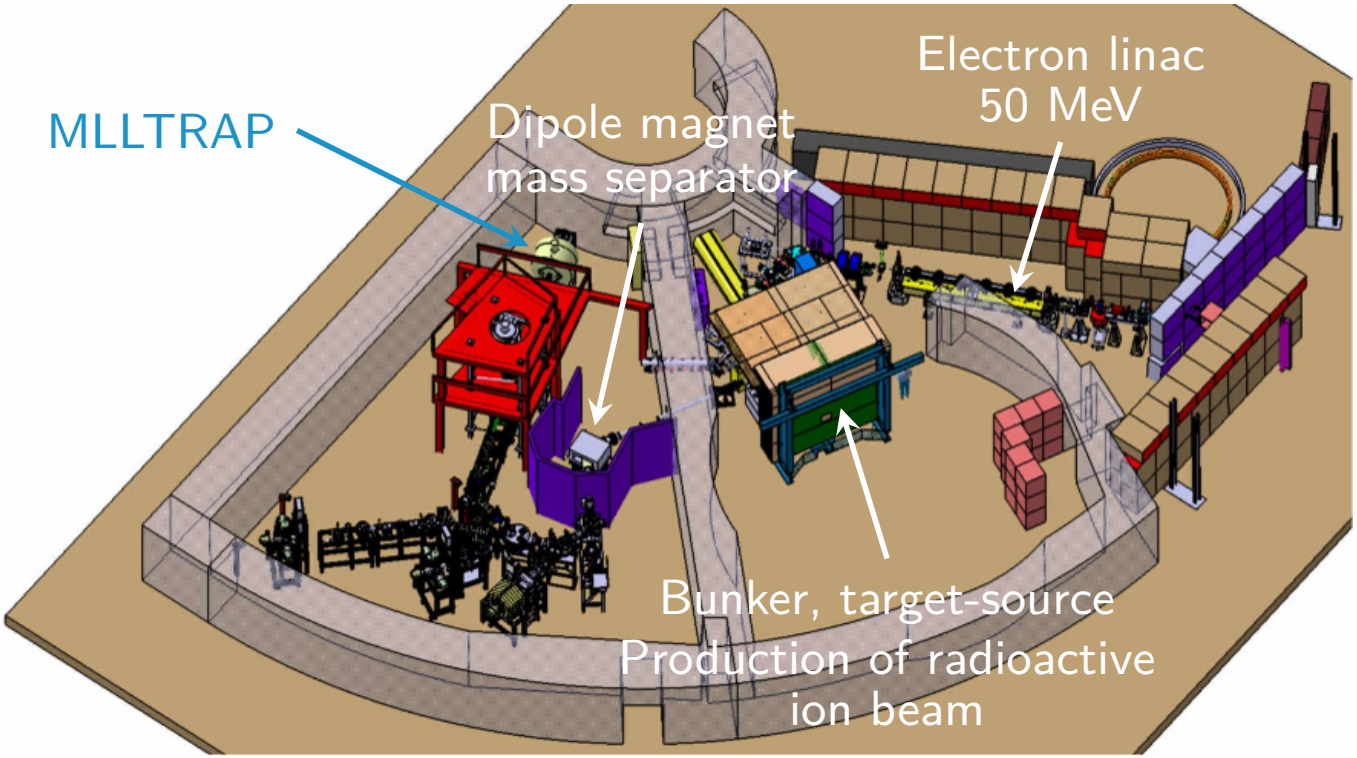
L. S. Brown, G. Gabrielse, Rev. Mod. Phys., 58 (1986) 233

ALTO facility at Orsay

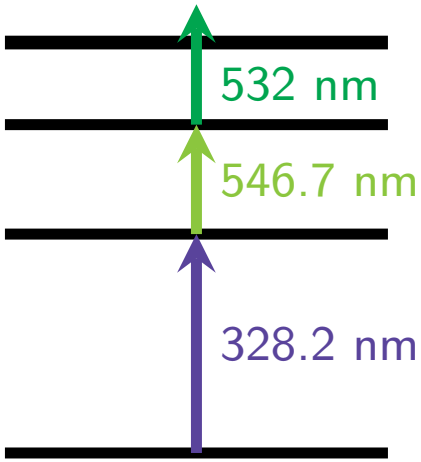
ALTO (Accélérateur Linéaire et Tandem à Orsay)

- Ions accelerated with Tandem for High energy experiments
- Electrons accelereted in the linac :
  - Production of radioactive species by photofission in C_xU targets
  - Ionization with a surface ion source or a laser ion source (e.g. Ag case)

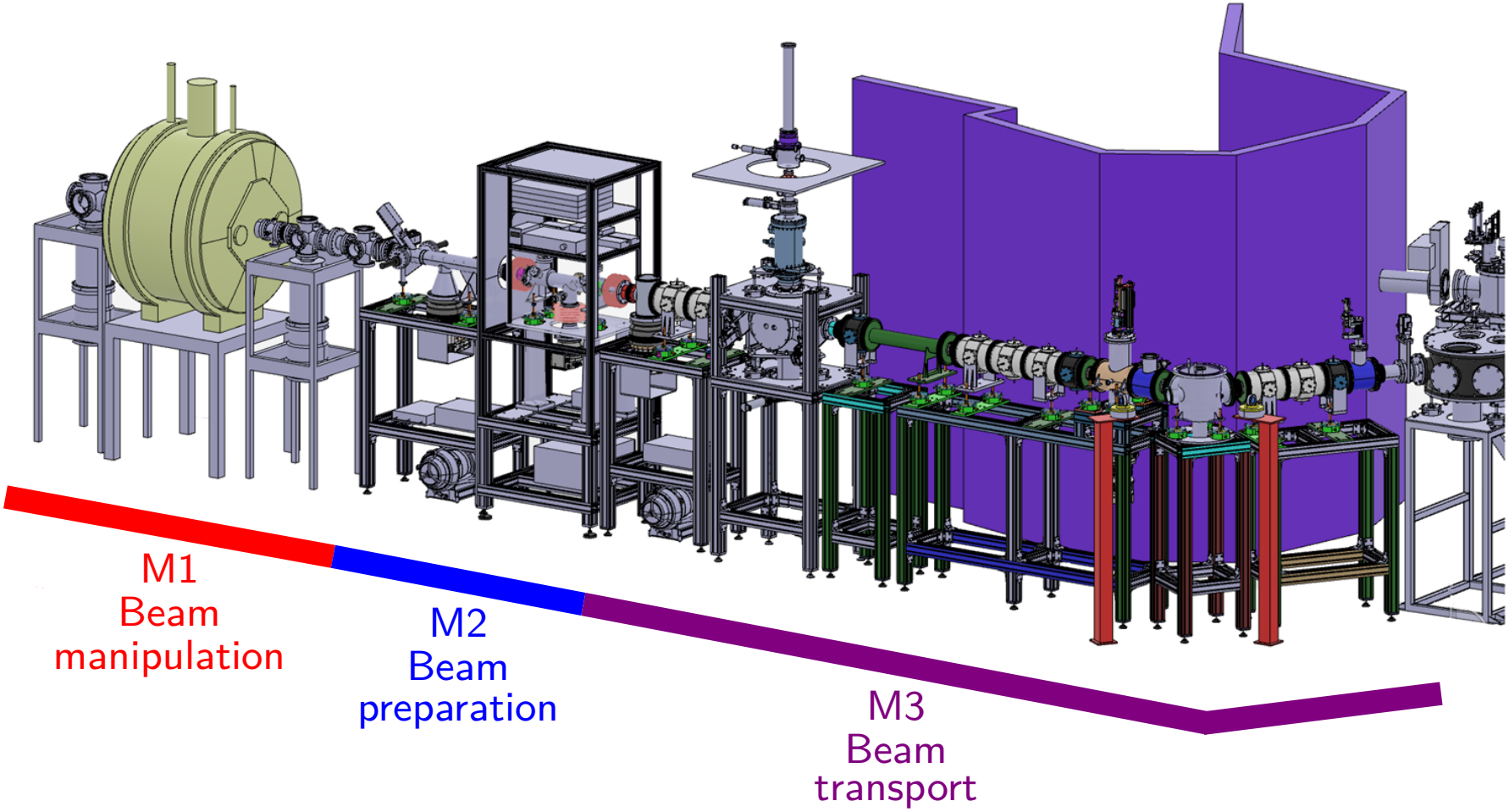
Observation Production



Ag ionisation scheme



MLLTRAP@ALTO



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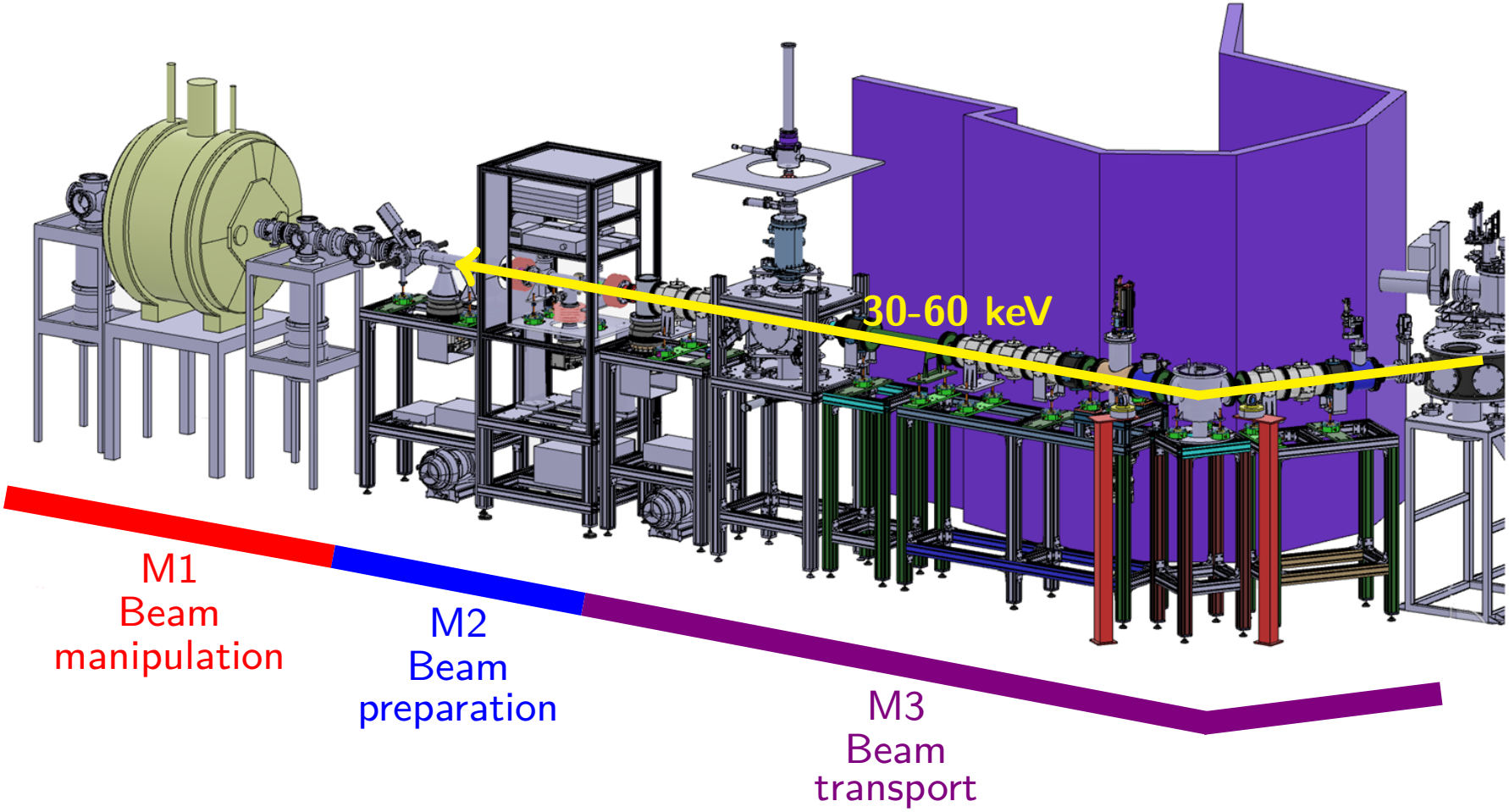

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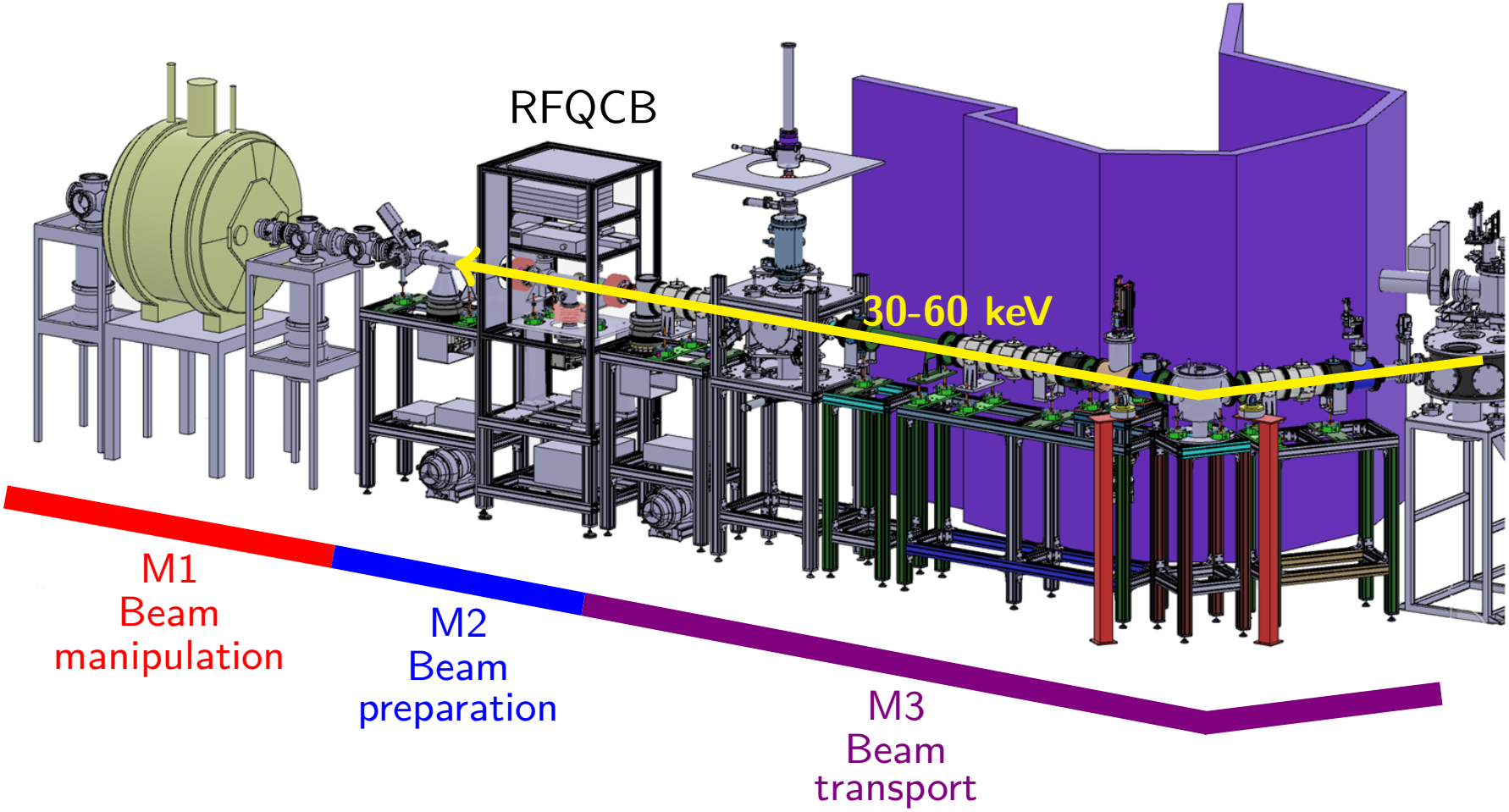
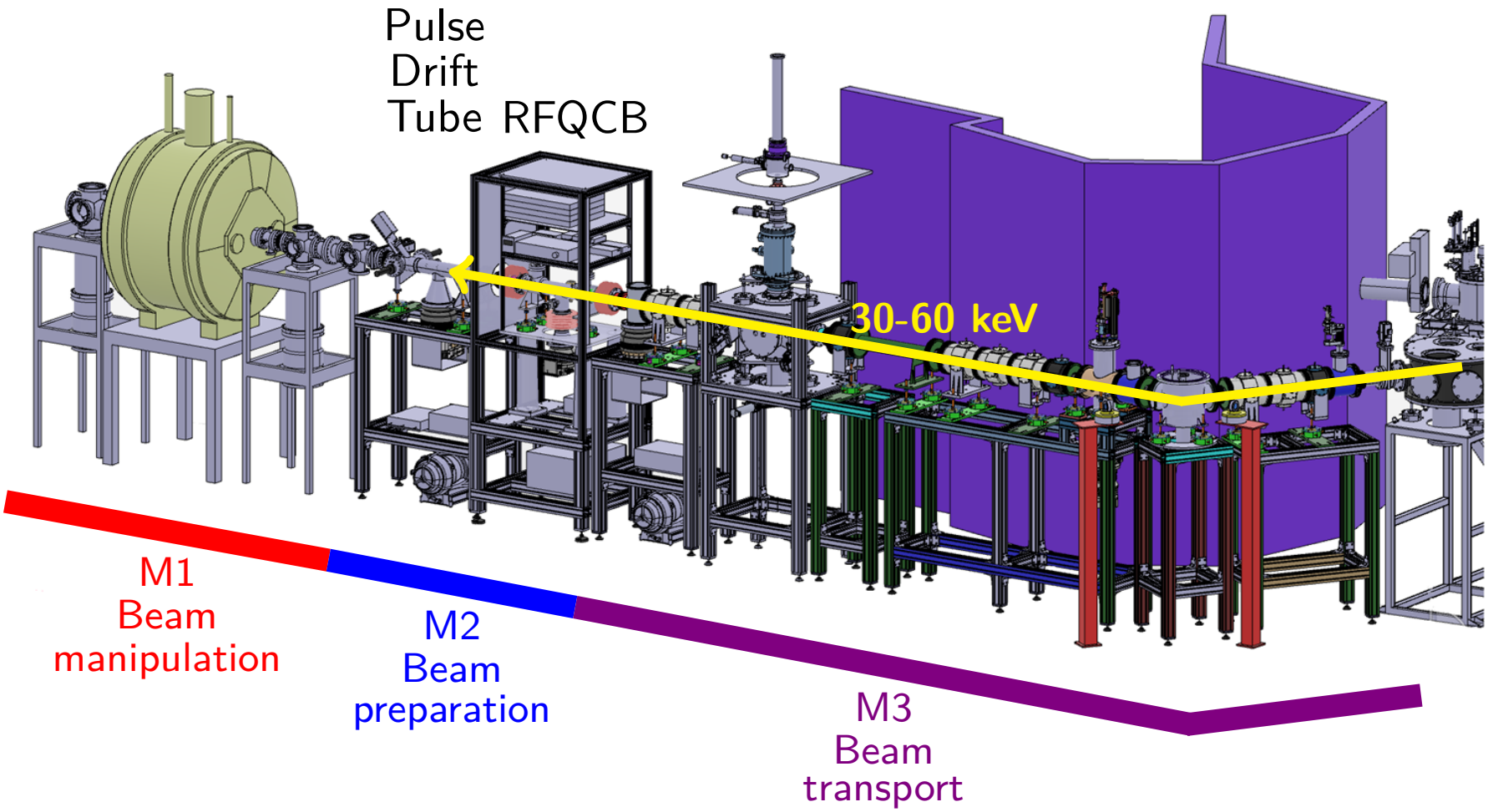
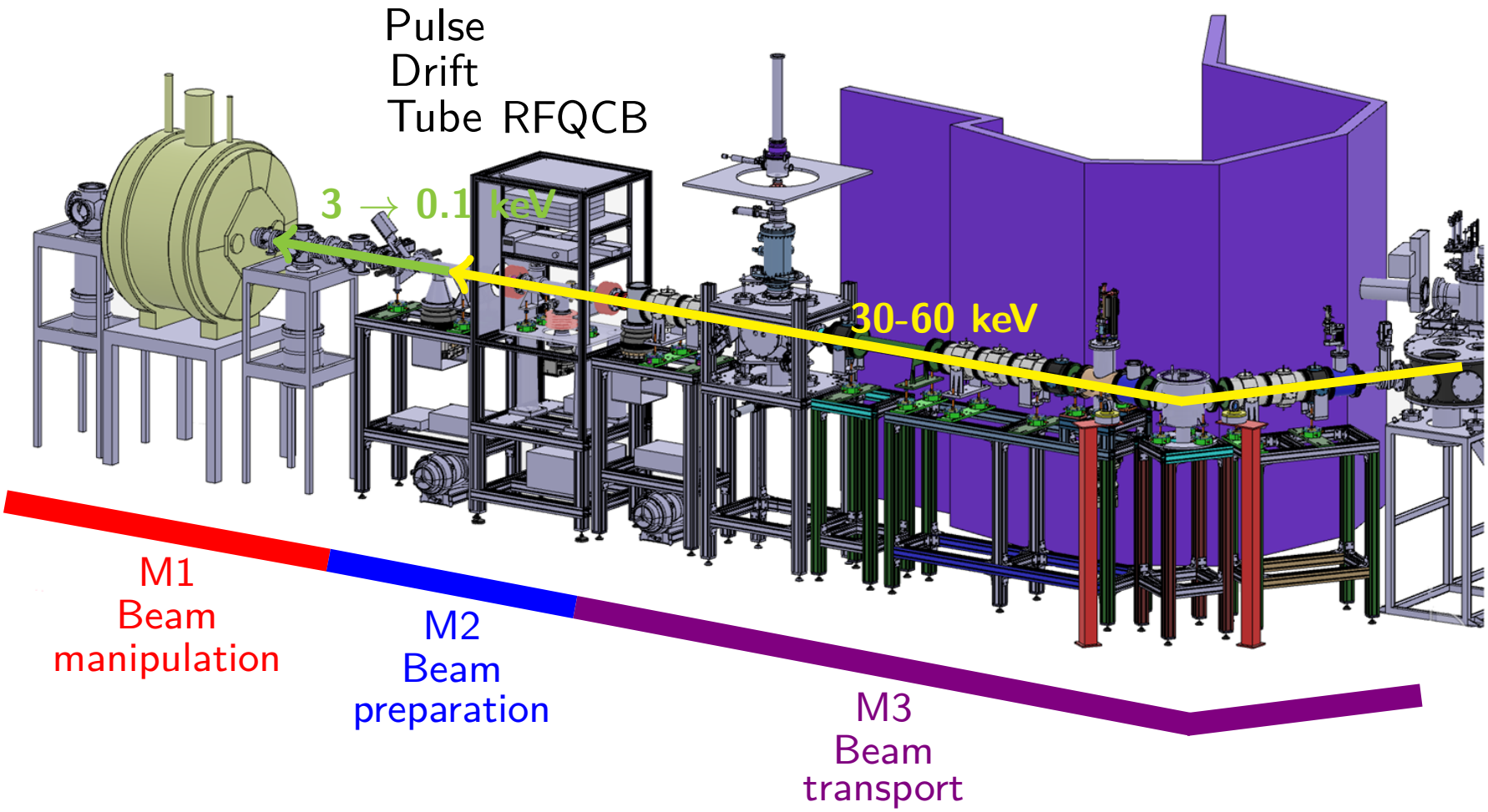


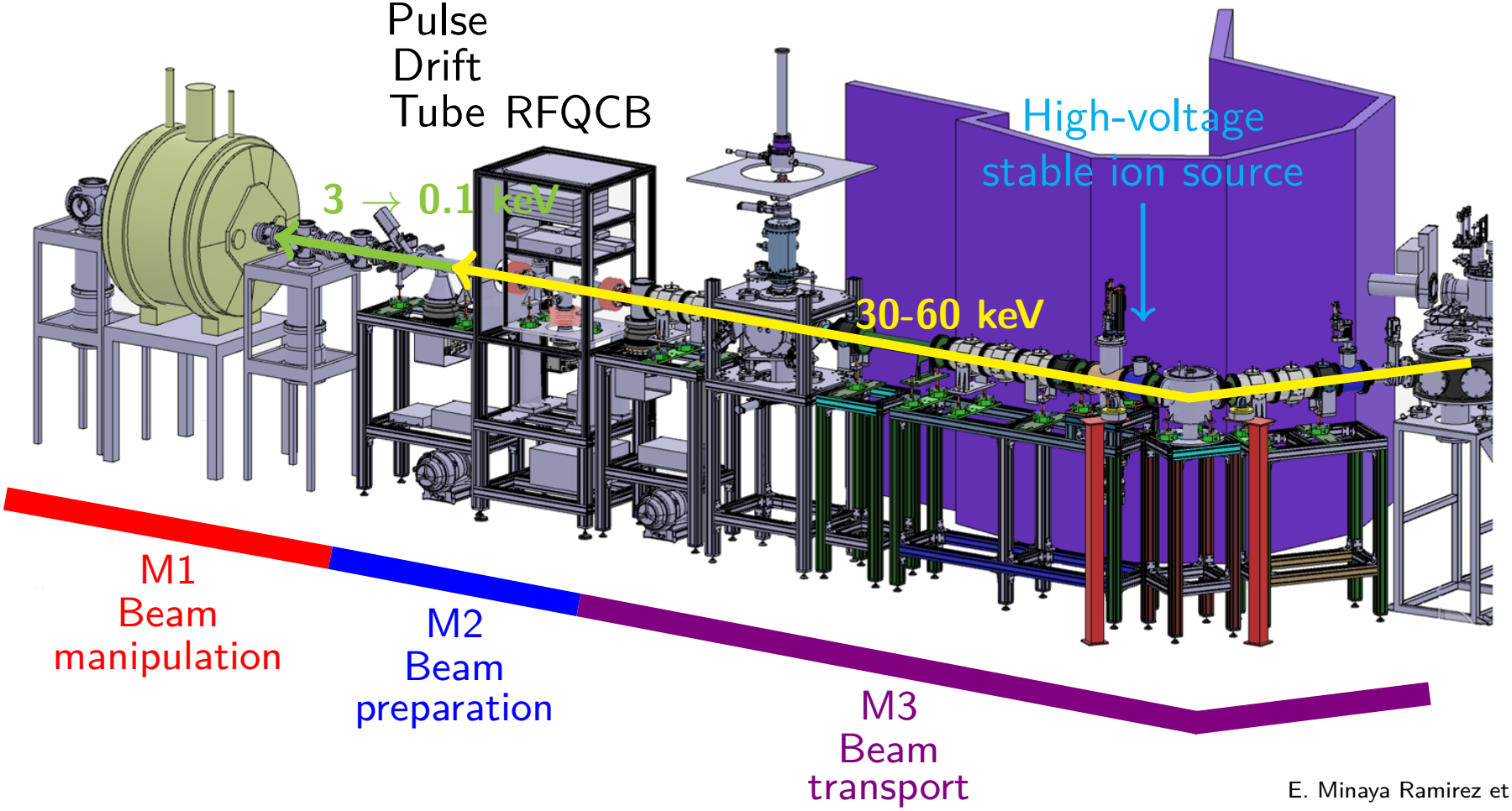
MLLTRAP@ALTO



MLLTRAP@ALTO



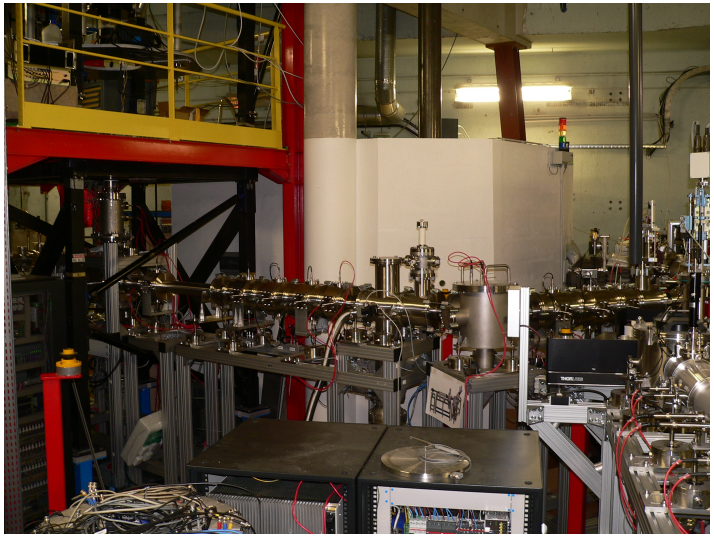
MLLTRAP@ALTO

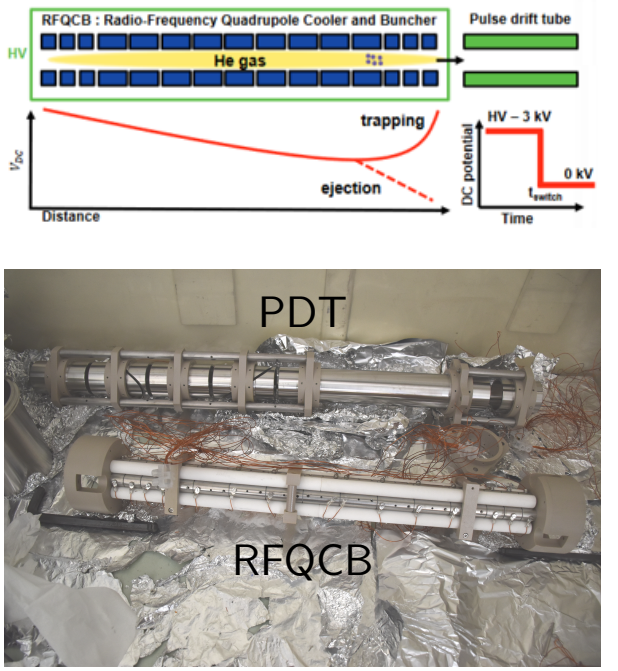


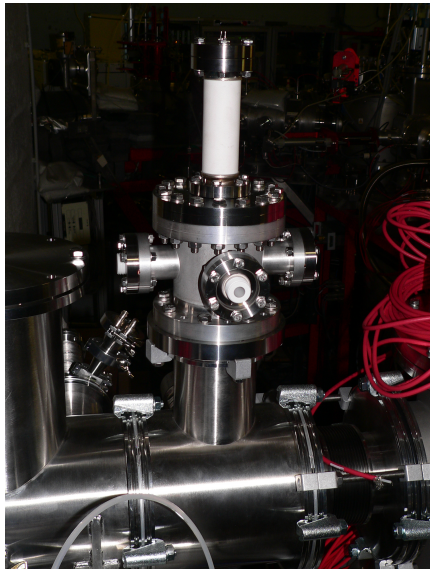
E. Minaya Ramirez et al.,
NIM B, 463 (2020) 315-319

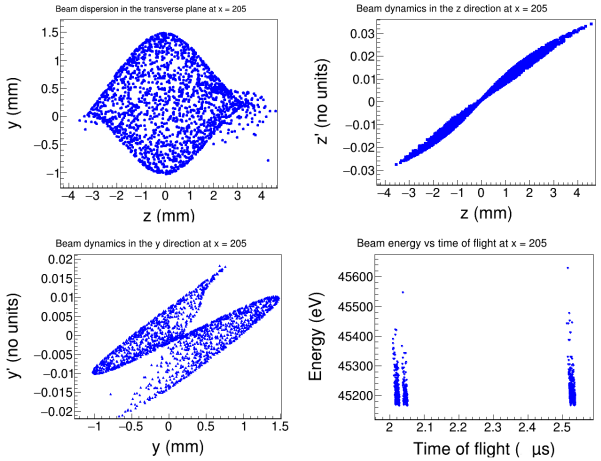
M3 and M2 sections

- Transport section and control system operationnal
- High-voltage ion source
  - Provide alkali ions ^{133}Cs and $^{85-87}Rb$
  - Traps caracterization and reference for magnetic field calibration
- RFQCB (Radiofrequency Cooler and Buncher)



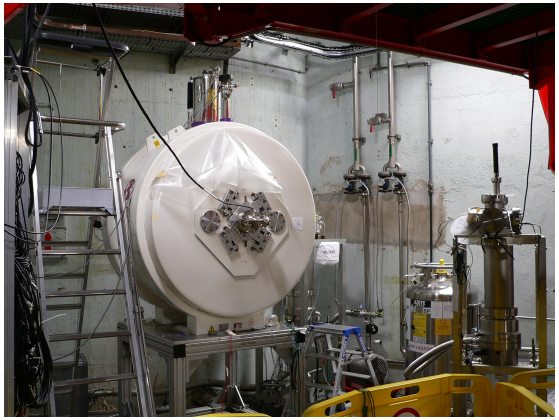


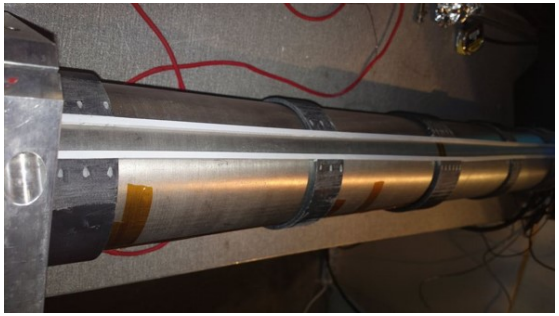


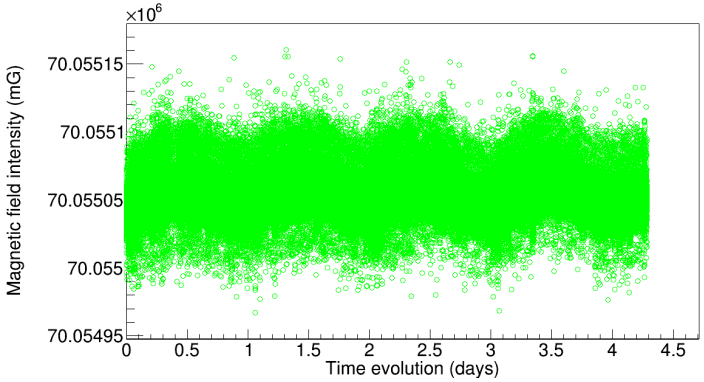


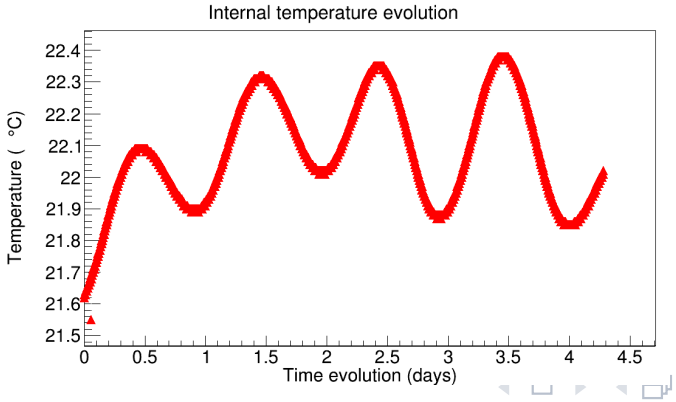
M1 section and Control System

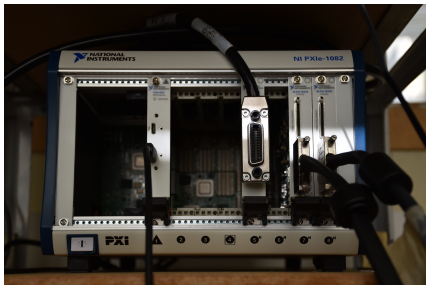
- Injection system operational
- Vacuum tube aligned with a 1.1 ± 0.1 mrad $\rightarrow$ insertion of Penning traps soon
- Magnetic probe : monitoring during measurements
- New C++ control system (CS++) developped by the Control System Framework from GSI (https ://wiki.gsi.de/CSframework/WebHome)
  - All MLLTRAP equipment controled by only one computer via PXIe-1082 chassis
  - PI-ICR method compatible with the new CS++







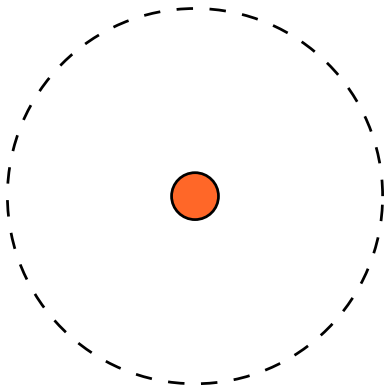




PI-ICR : Phase Imaging Ion Cyclotron Resonnance

- Based on the projection of ions eigenmotions on a position-sensitive detector, a MCP delay-line

S. Eliseev et al., Appl. Phys. B, 114 (2014) 107-128



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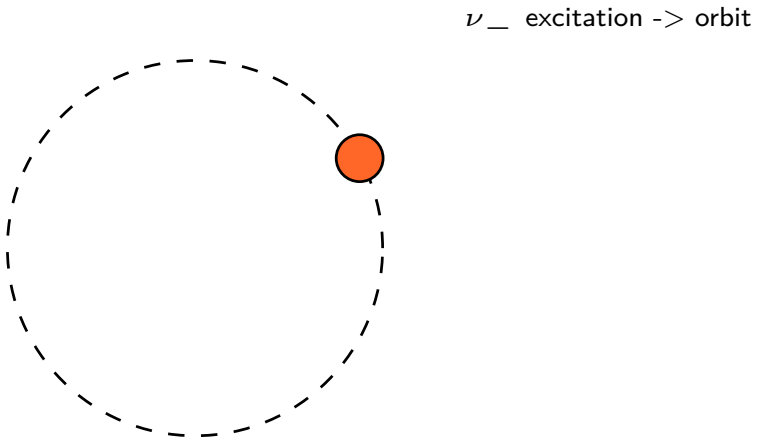

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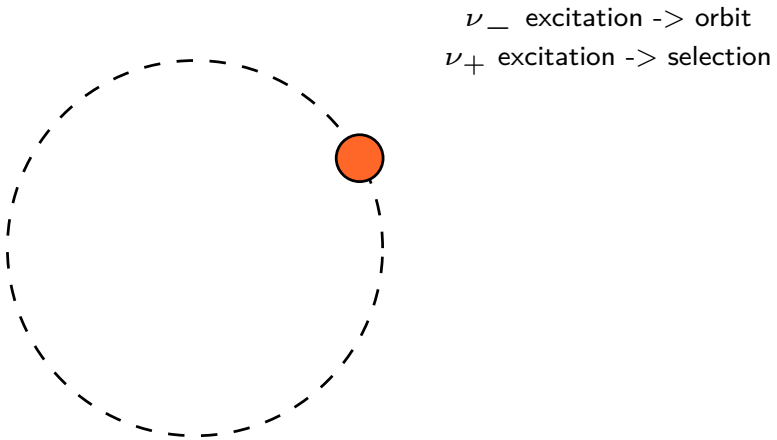

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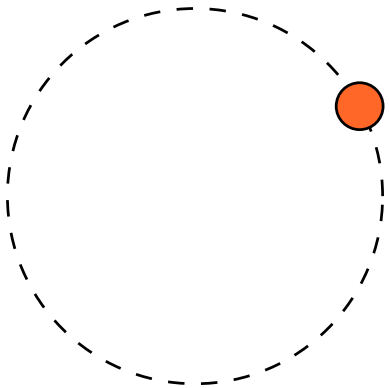

ν_- excitation -> orbit
ν_+ excitation -> selection
ν_c excitation -> conversion

PI-ICR : Phase Imaging Ion Cyclotron Resonnance

- Based on the projection of ions eigenmotions on a position-sensitive detector, a MCP delay-line

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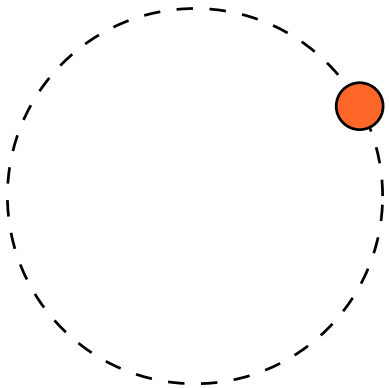
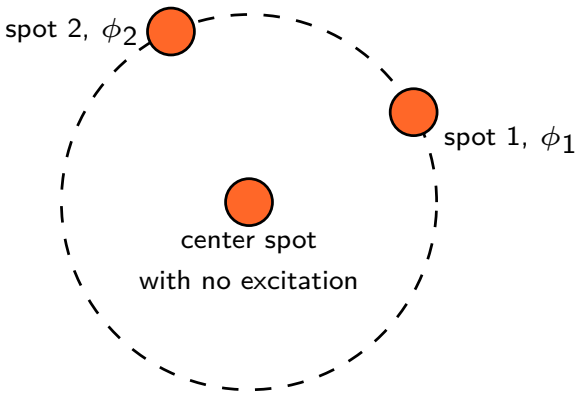


ν_- excitation -> orbit
ν_+ excitation -> selection
ν_c excitation -> conversion
Phase accumulation :
spot positioning, resolution

PI-ICR : Phase Imaging Ion Cyclotron Resonnance

- Based on the projection of ions eigenmotions on a position-sensitive detector, a MCP delay-line

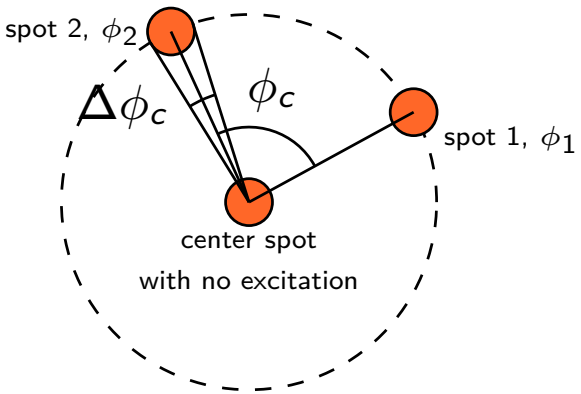
S. Eliseev et al., Appl. Phys. B, 114 (2014) 107-128

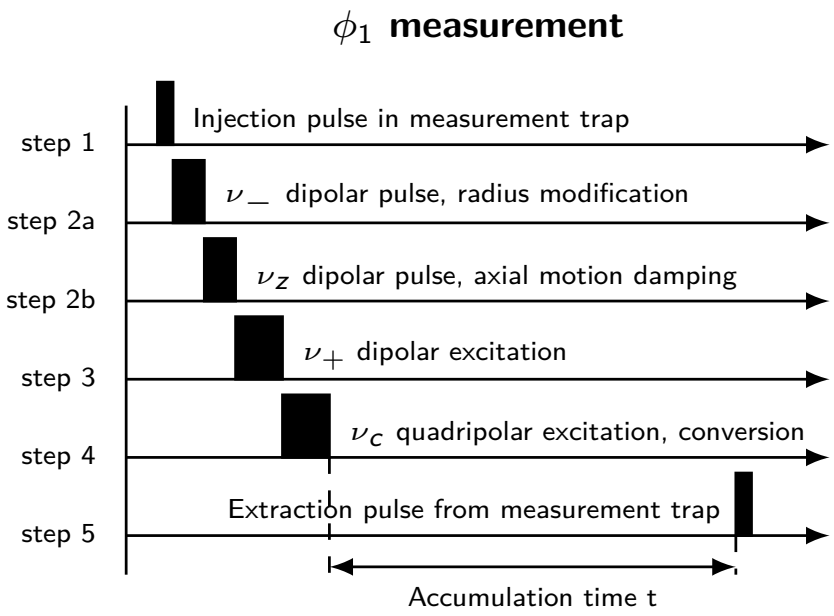


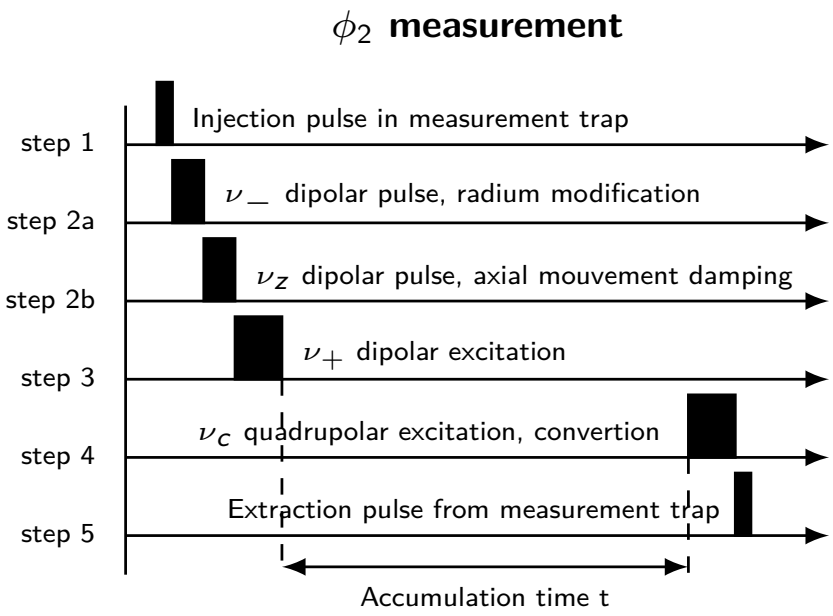
PI-ICR : Phase Imaging Ion Cyclotron Resonnance

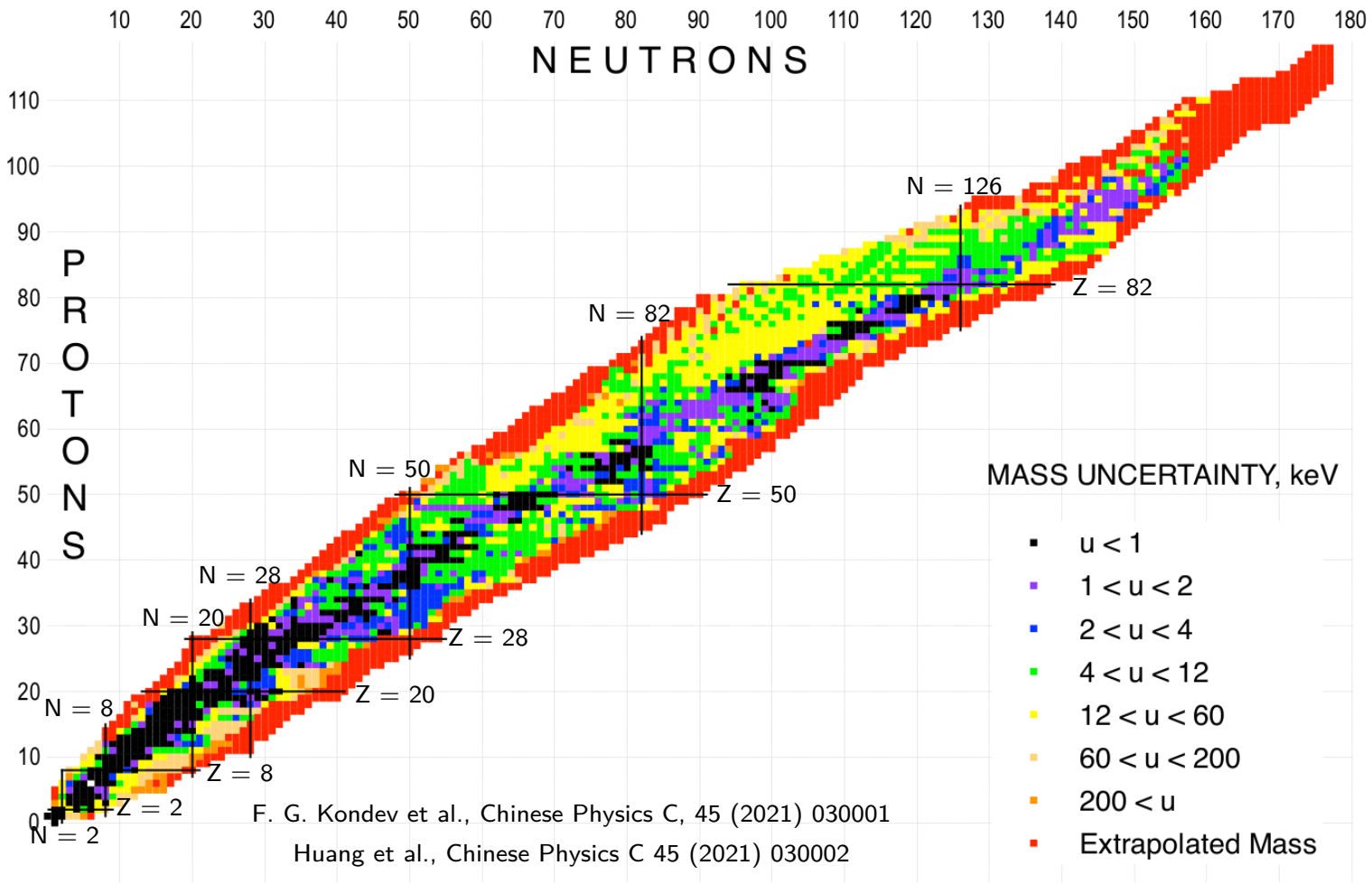
- Based on the projection of ions eigenmotions on a position-sensitive detector, a MCP delay-line
- $\phi_c + 2\pi(n_+ + n_-) = 2\pi\nu_c t$

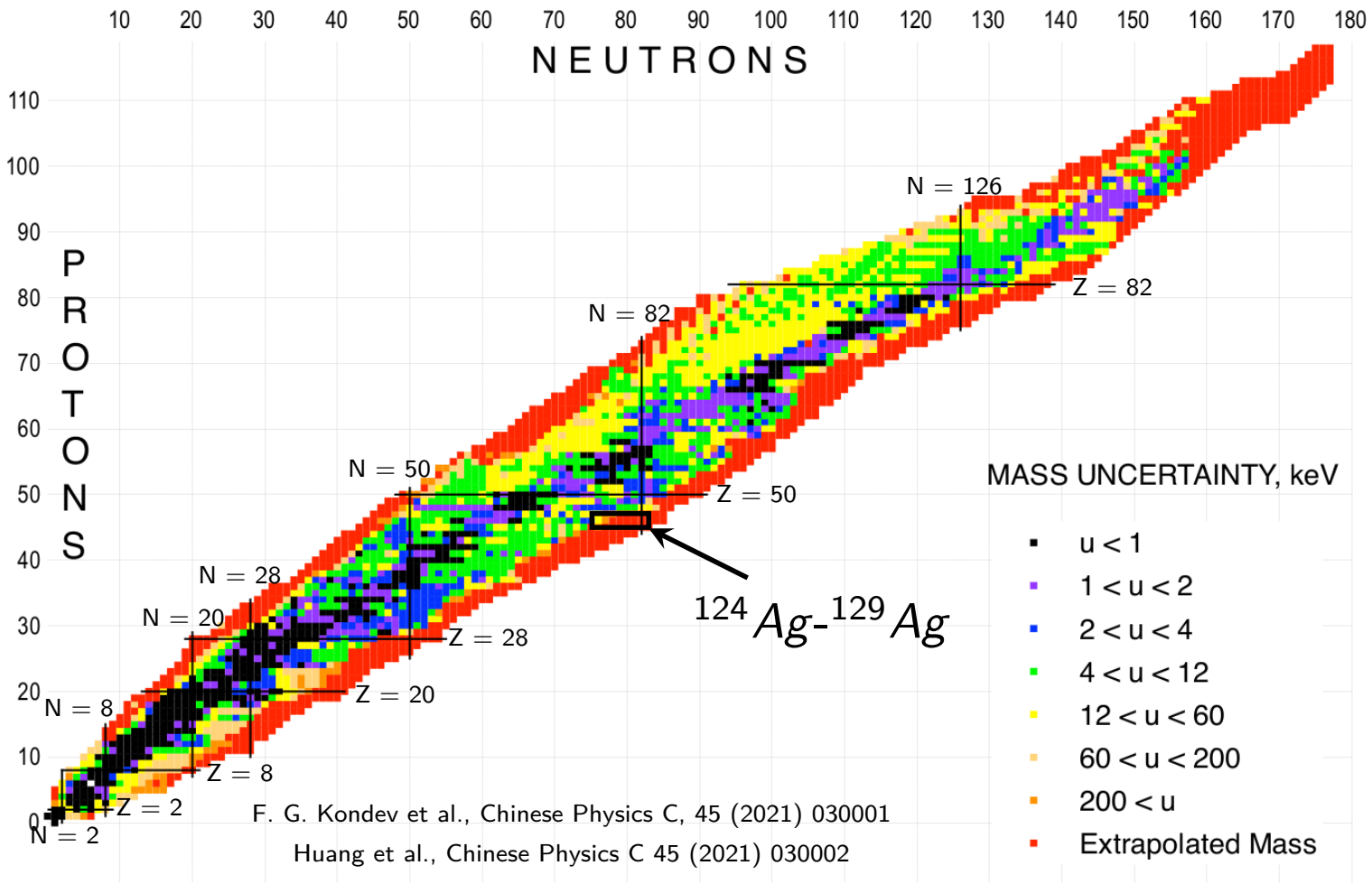
S. Eliseev et al., Appl. Phys. B, 114 (2014) 107-128








NEUTRONS
PROTONS
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
0 10 20 30 40 50 60 70 80 90 100 110
N = 2
N = 8
N = 20
N = 28
N = 50
N = 82
N = 126
Z = 2
Z = 8
Z = 20
Z = 28
Z = 50
Z = 82
MASS UNCERTAINTY, keV
u < 1
1 < u < 2
2 < u < 4
4 < u < 12
12 < u < 60
60 < u < 200
200 < u
Extrapolated Mass
F. G. Kondev et al., Chinese Physics C, 45 (2021) 030001
Huang et al., Chinese Physics C 45 (2021) 030002


NEUTRONS
PROTONS
N = 2
N = 8
N = 20
N = 28
N = 50
N = 82
N = 126
Z = 2
Z = 8
Z = 20
Z = 28
Z = 50
Z = 82
^{124}Ag-^{129}Ag
MASS UNCERTAINTY, keV
u < 1
1 < u < 2
2 < u < 4
4 < u < 12
12 < u < 60
60 < u < 200
200 < u
Extrapolated Mass
F. G. Kondev et al., Chinese Physics C, 45 (2021) 030001
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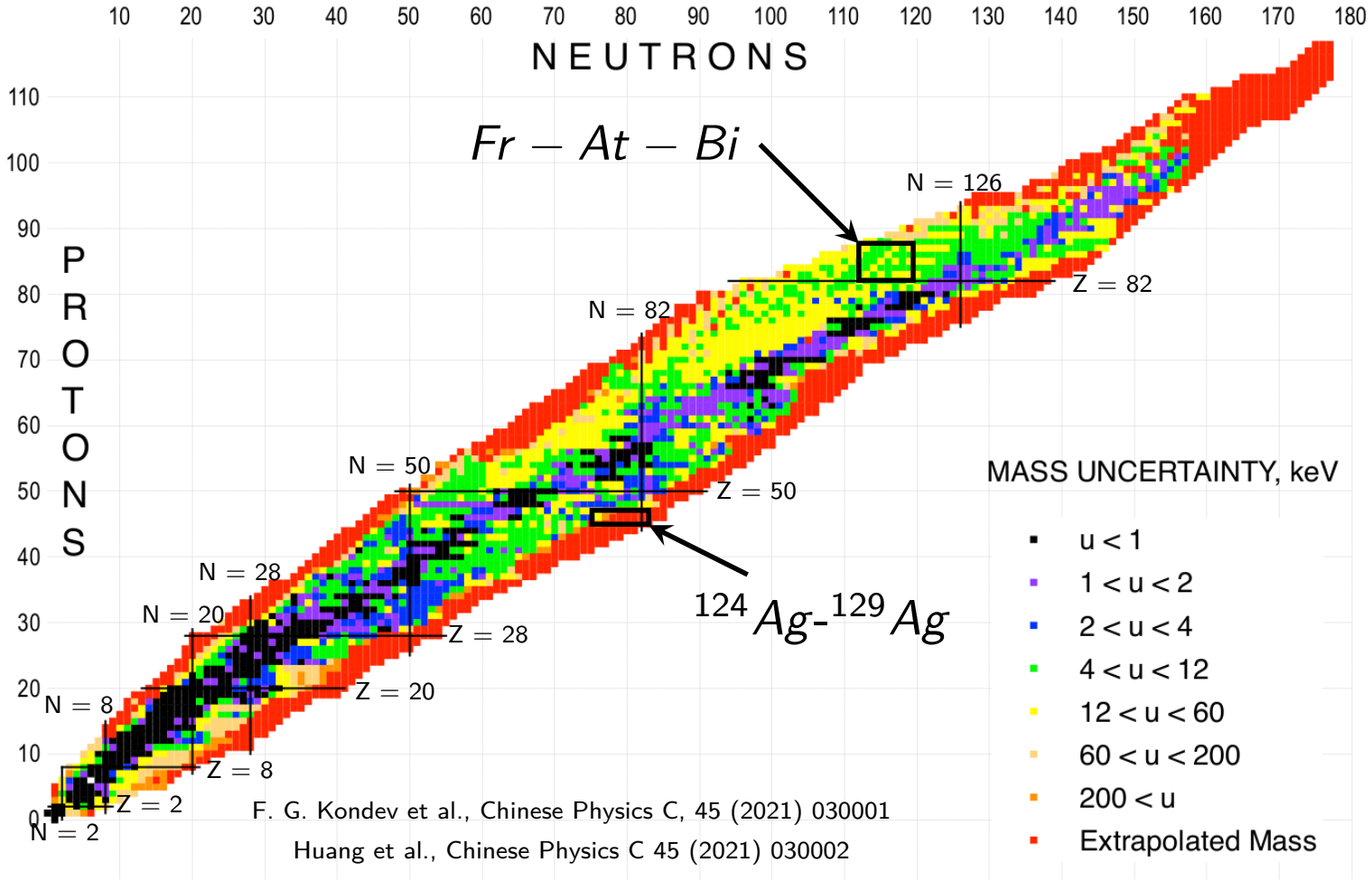
NEUTRONS
PROTONS
Fr − At − Bi
124Ag-129Ag
N = 126
Z = 82
N = 82
N = 50
Z = 50
N = 28
N = 20
Z = 28
Z = 20
N = 8
Z = 8
Z = 2
N = 2
MASS UNCERTAINTY, keV
u < 1
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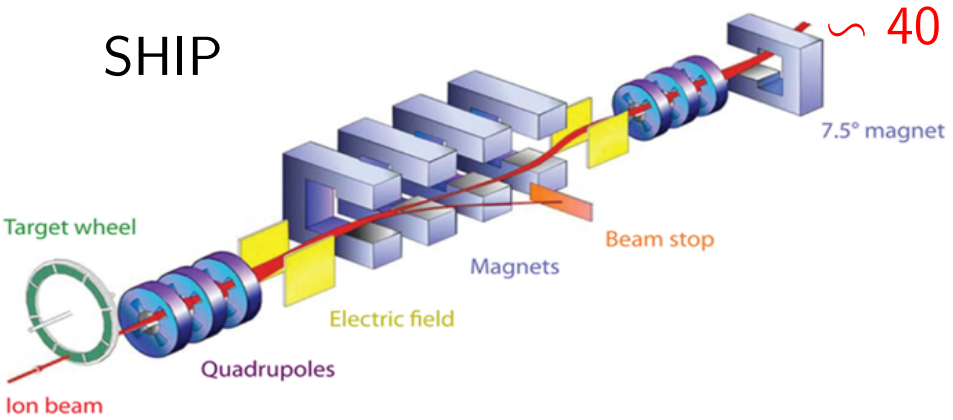
200 < u
Extrapolated Mass
F. G. Kondev et al., Chinese Physics C, 45 (2021) 030001
Huang et al., Chinese Physics C 45 (2021) 030002

SHIPTRAP experiment at GSI (Darmstadt, Germany)

SHIP

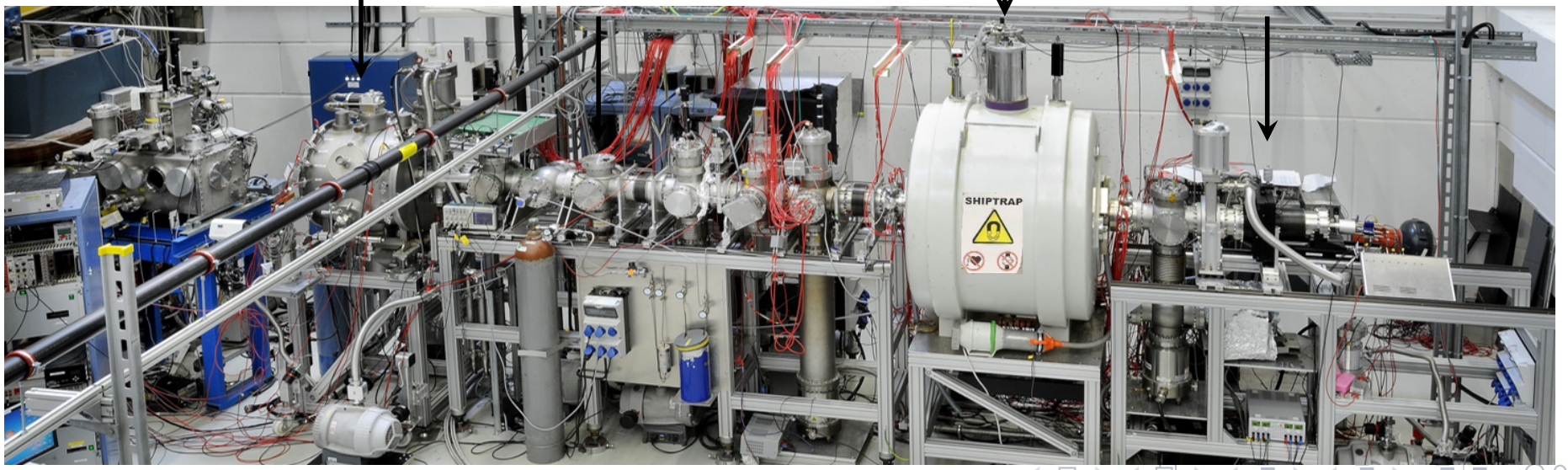


Cryogenic gas cell to stop ions provided by SHIP

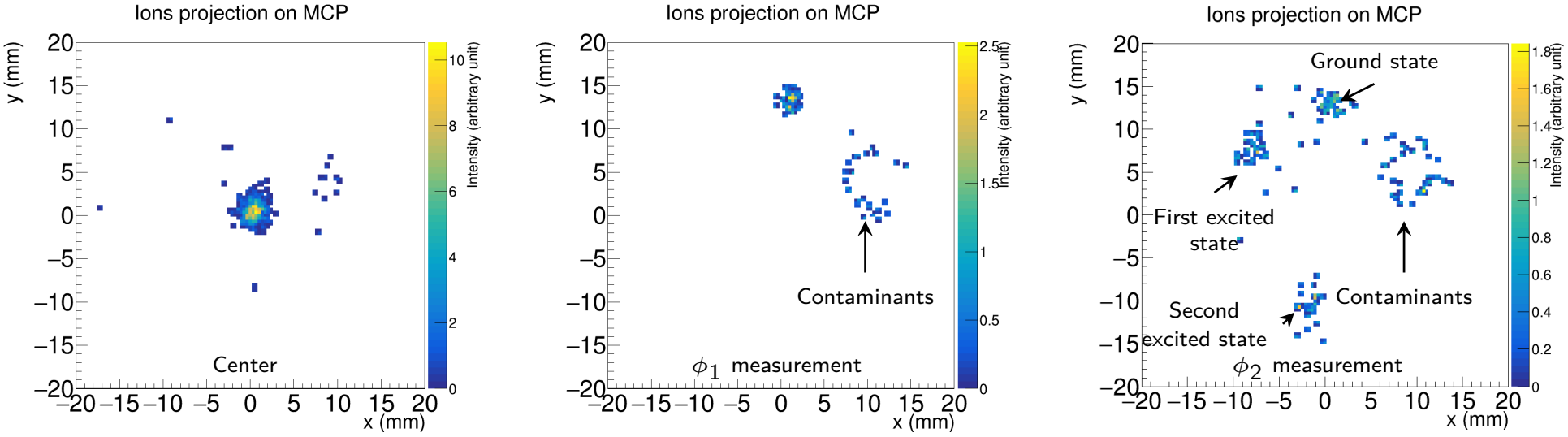
7 T superconducting magnet with two Penning traps

RFQCB

Detection

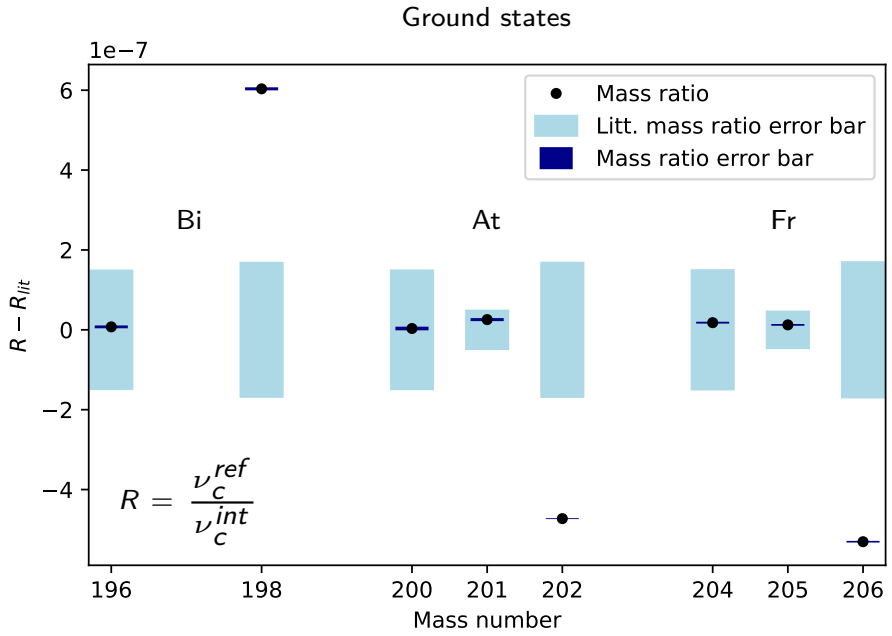


PI-ICR example with ^{200}At



- Isomers and contaminants resolved

Preliminary results



Excited states

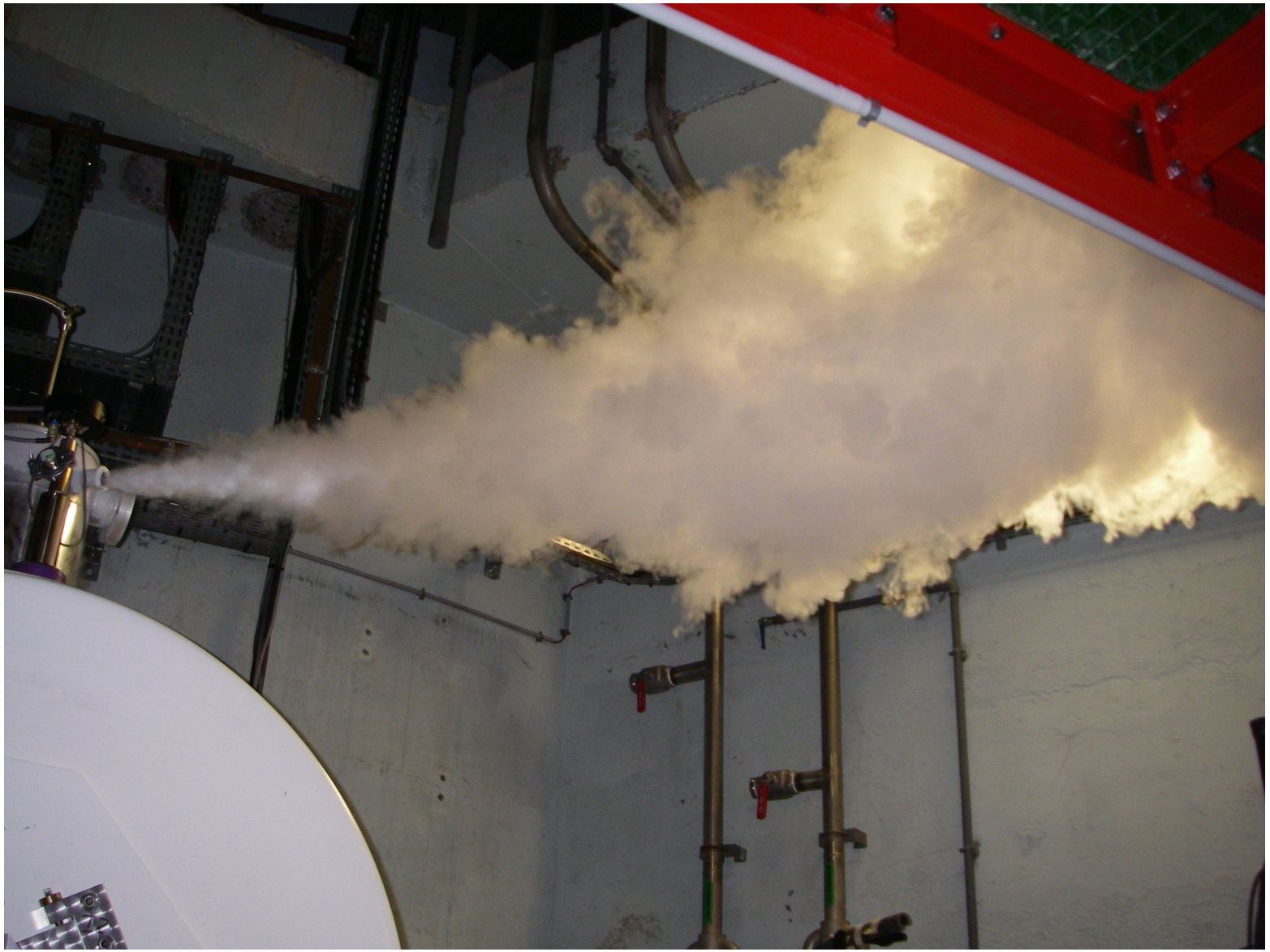
Species	Litterature value (keV)	measured value (keV)
^{m196}Bi	166.4 ± 2.9	171.9 ± 1.6
^{n196}Bi	272 ± 3	271.7 ± 0.7
^{m198}Bi	280 ± 40	173.7 ± 0.8
^{m200}At	112.9 ± 2.9	118.9 ± 1.1
^{n200}At	343.8 ± 3.0	375.1 ± 1.0
^{m202}At	190 ± 40	144.1 ± 0.5
^{n202}At	590 ± 40	414.3 ± 0.4
^{m204}Fr	50 ± 4	49.6 ± 0.7
^{n204}Fr	326 ± 4	330.1 ± 0.7
^{m206}Fr	190 ± 40	196.1 ± 0.7
^{n206}Fr	730 ± 40	548.5 ± 1.1

Only statistical uncertainties, work on systematics estimation in progress

- Center spot scaterring
- Mass difference dependent shift
- Time-dependent non linear magnetic field drift
- Excitation frequency detuning (excited states or isobar studies)

Conclusion

- A new Penning trap setup is being implemented at Orsay at the ALTO facility
- Stable ion source developped for tests and magnetic field calibration to send a beam with same initial conditions as ALTO's beam
- Development and implementation of the new CS++ at MLLTRAP
- Data analysis ongoing for SHIPTRAP experiments, also allows improvements for MLLTRAP developpements (PI-ICR systematics characterisation, improvement of CS++)
- Extensive study on the analysis and systematics to understand discrepancies with litterature
- In the framework of DESIR/SPIRAL2 (GANIL, Caen) : Making MLLTRAP operationnal before moving to DESIR experimental Hall



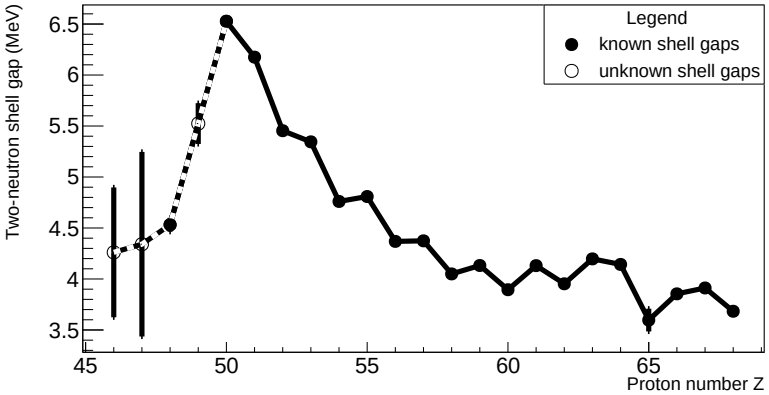
Thank you for your attention !

Backup

Nuclear physics impacts of MLLTRAP mass measurements at ALTO

Nuclear structure

- Access to binding energies → interactions inside the nucleus
- Neutron separation energies and shell gaps
- → Shell quenching for N = 82 ?



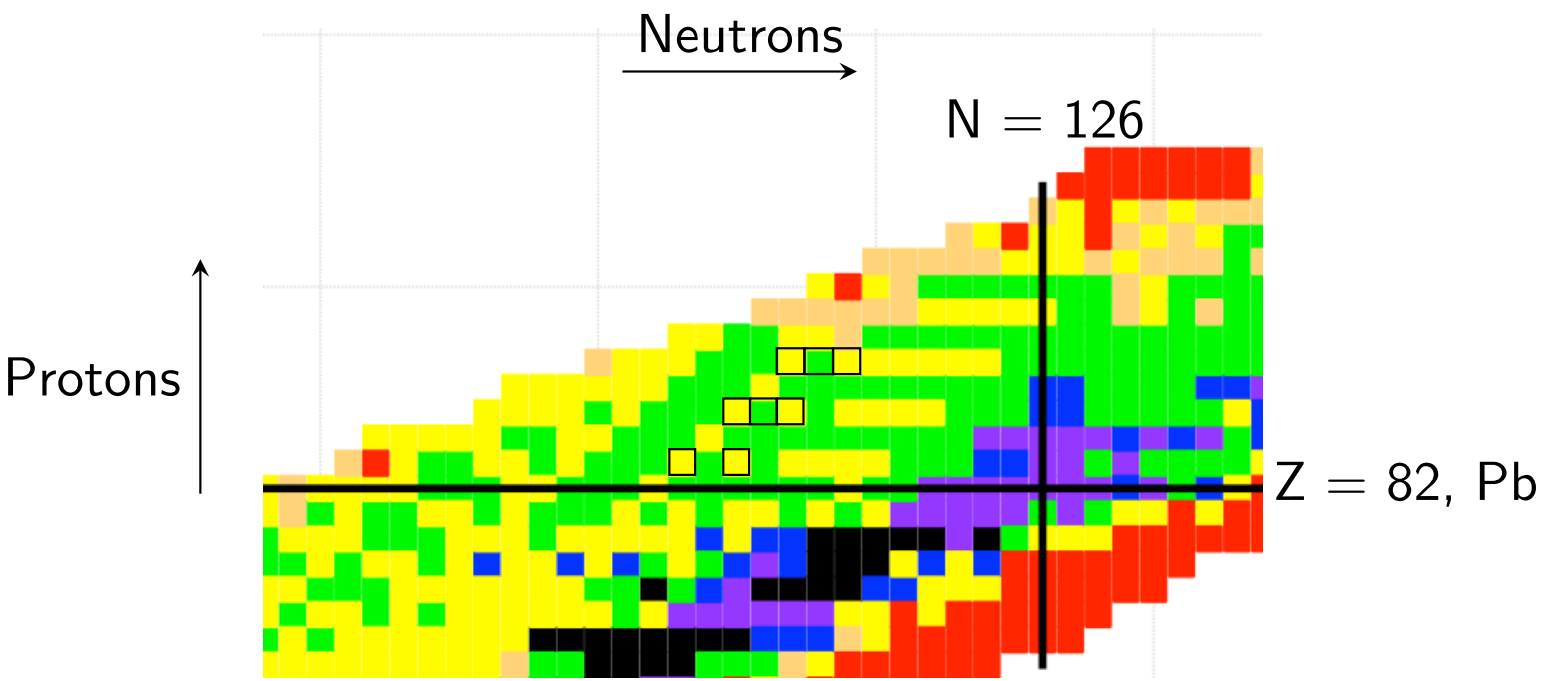
Huang et al.,
Chinese Physics C 45 (2021) 030002

Nuclear astrophysics

- Nuclear informations (including nuclear masses) are important inputs for r-process path evolution models
- N = 82 could be linked to A = 130 r-process solar abundance peak
- Non-negligible impact of Ag masses close to N = 82 on r-process simulations for at least 4 different scenarios

Mumpower et al,
Prog. Part. Nucl. Phys., 86 (2016)

SHIPTRAP Experimental campaign in 2021

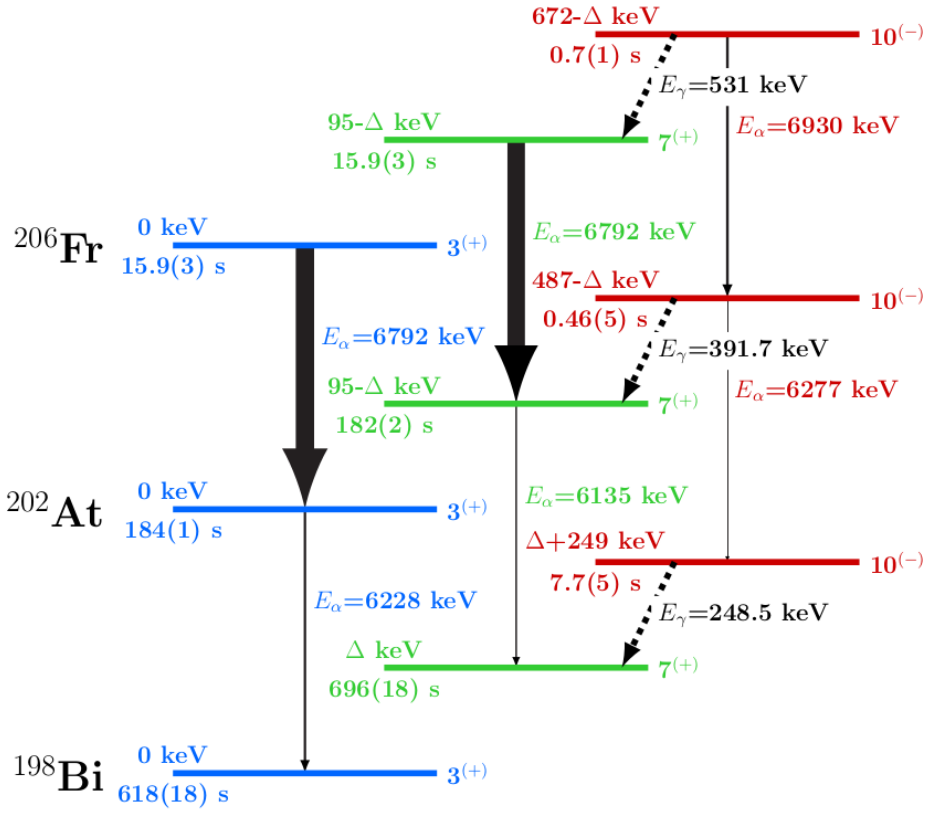


- Main beamtime focused on Super-Heavy ^{257}Rf and ^{258}Db
- 12 days of parasitic ^{48}Ca beam, 7 days of parasitic ^{50}Ti beam, 14 days of main ^{50}Ti beam
- More than 20 isotopes above Z = 82 investigated, including $^{206}Fr -^{202} At -^{198} Bi$ decay chain
- New isomers observed and their masses precisely measured

Physical case

Study of $^{206}Fr -^{202} At -^{198} Bi$ α decay chain

- Odd-Z and odd-N, Z > 82 neutron-deficient nuclei
- Main motivation in this region of nuclear chart : shape coexistence, need of excitation energies for calculations
- For $^{206}Fr -^{202} At -^{198} Bi$:
  - Hyperfine structure and isotopic shift determined for ground and excited states
  - But excitation energies not directly accessed so far
- Direct mass measurement performed using PI-ICR methods at SHIPTRAP



M. Huyse, Phys. Rev. C, 46 (1992) 1209

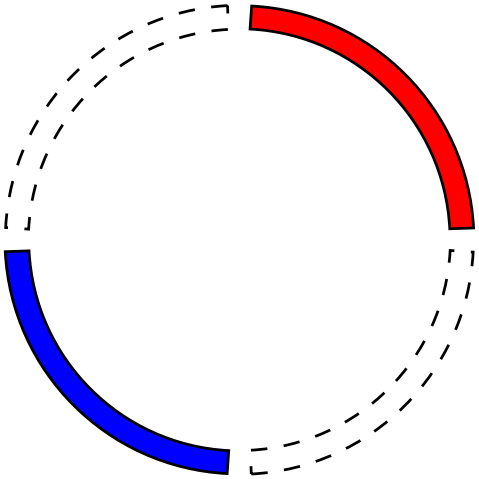
J. Uusitalo, Phys. Rev. C, 71 (2005) 024206

K. M. Lynch, Phys. Rev. C, 93 (2016) 014319

Ion manipulation

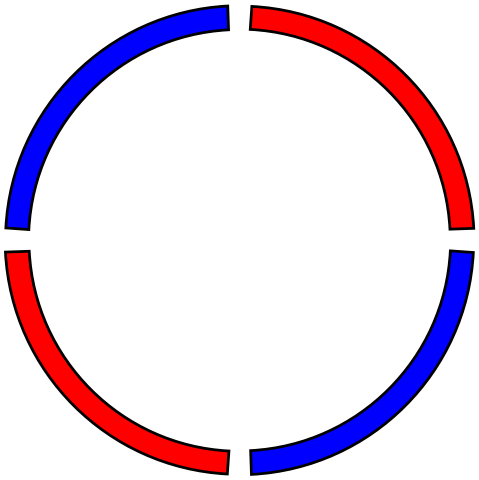
Manipulation of the eigenmotions performed by dipolar and quadrupolar excitation applied on the segmented ring electrode

- Dipolar excitation :



Applied at eigen frequencies, modifies the amplitude of the eigenmotions

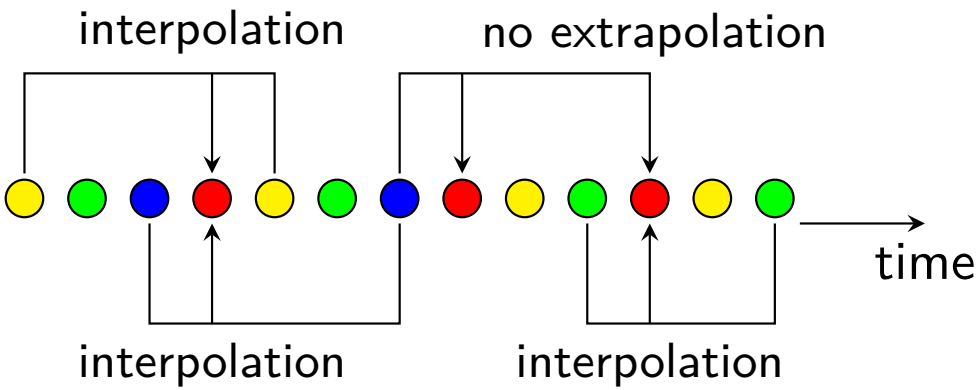
- Quadrupolar excitation :



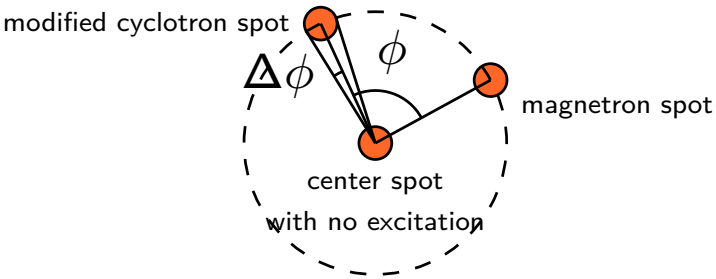
Applied at the sum of eigenfrequencies, couples the eigenmotions and converts one eigenmotion to the other

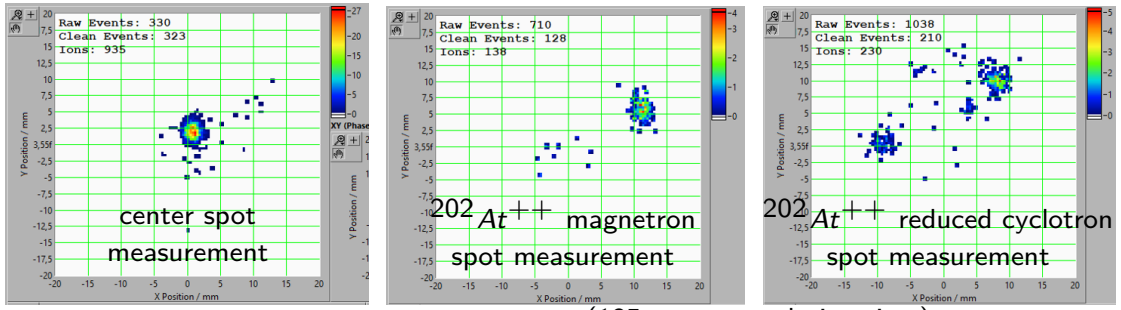
Data taking

- Alternation of data acquisition on an interest ion, center spots and a reference ion
- The way data are taken influences the way the data will be analysed :



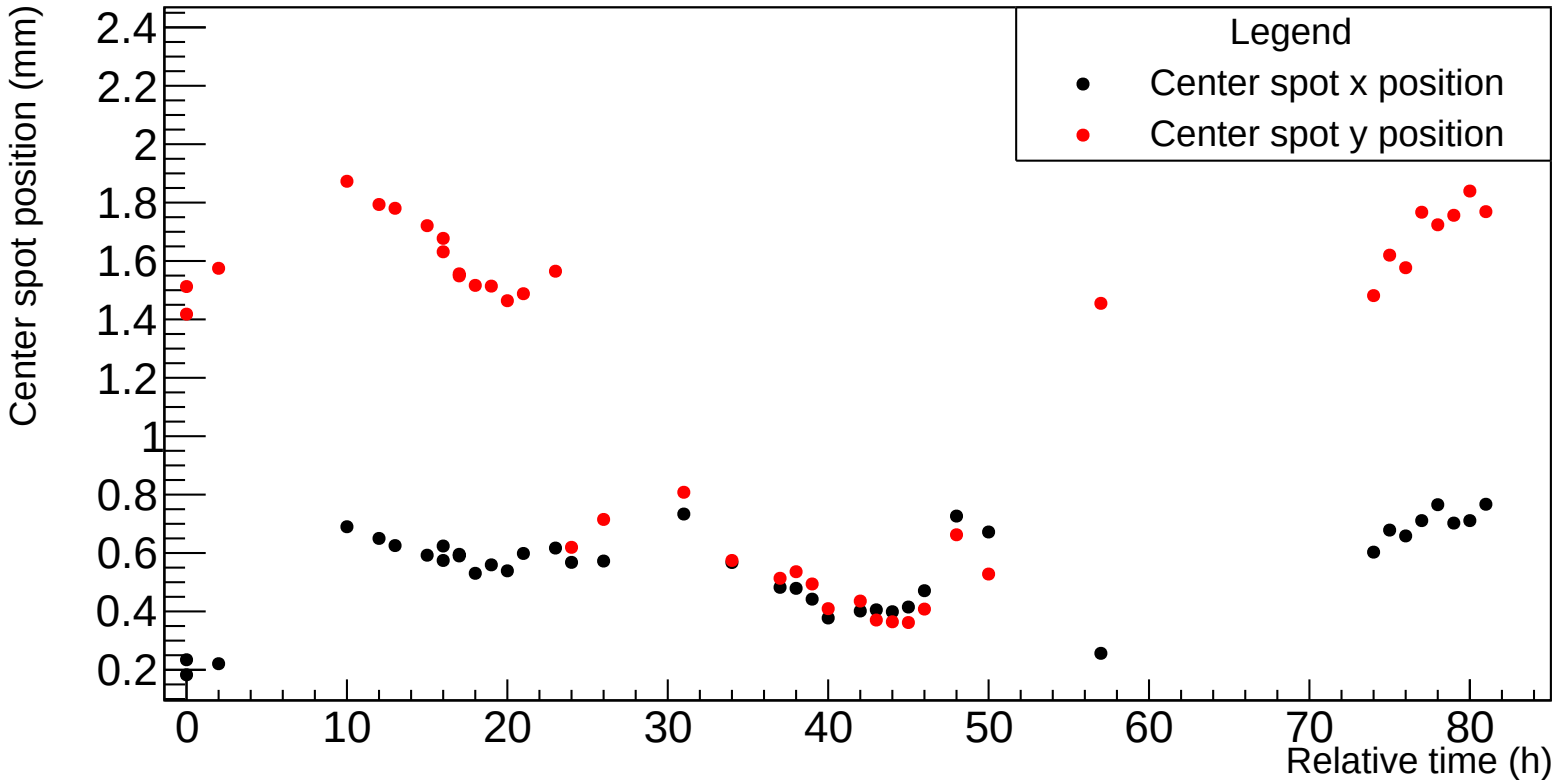
- Reference phases measurements
- Center spot measurements
- Magnetron phases measurements
- Reduced cyclotron phase measurements





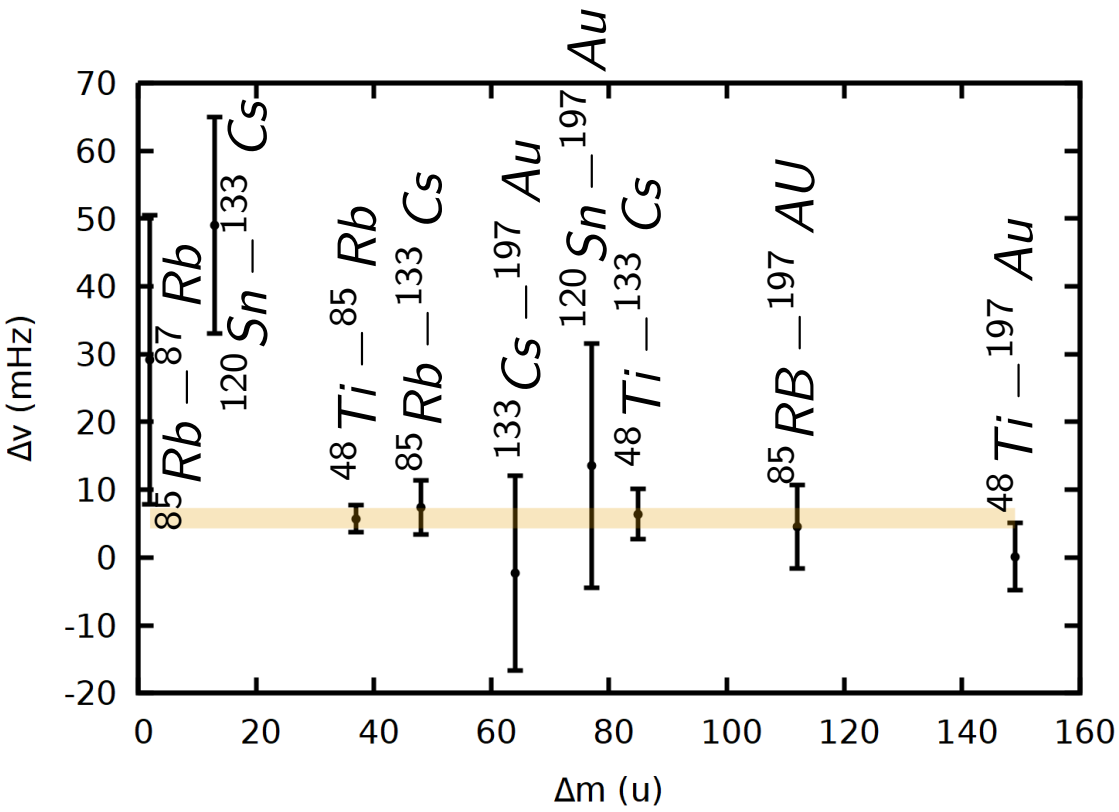
(185 ms accumulation time)

Center spot scattering



Position of the center moves from one run to another
Estimation of uncertainties with standard deviation

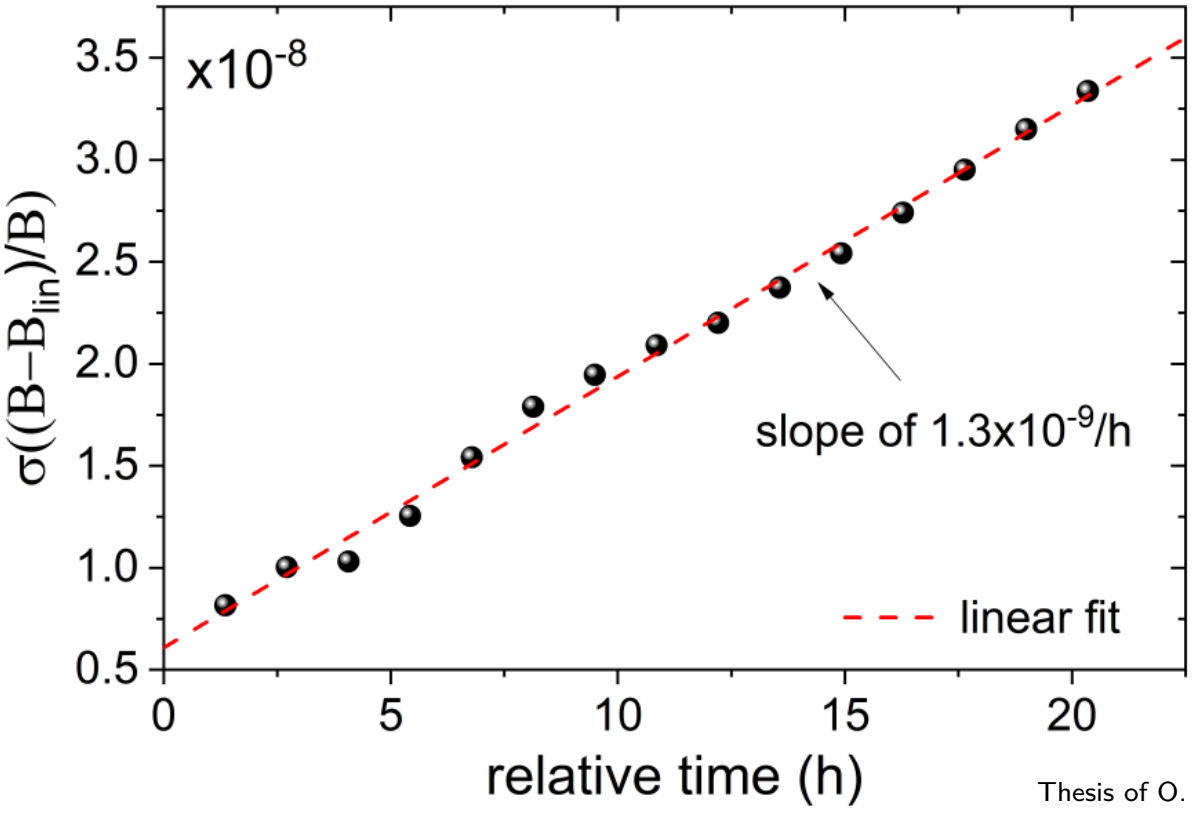
Mass difference dependent shift



Courtesy to M. J. Gutiérrez

- $R_{lit} = \frac{\nu_{c,t}^{exp} - \Delta\nu}{\nu_{c,r}^{exp} - \Delta\nu}$
- Imperfection of the electric-quadrupole field
- Misalignment of electrostatic trapping field with respect to magnetic field

Time-dependent non-linear magnetic fields drift



Thesis of O. Kaleja, JGU Mainz

- Magnetic field intensity of such superconducting magnets drifts over years
- This drift can be linearly estimated by a campaign of equal time spaced measurements on a reference ion during a couple of days