JYVÄSKYLÄN YLIOPISTO

Q-value measurement for neutrino physics at JYFLTRAP

Antoine de Roubin

Low Q-value measurements in the framework of neutrino physics

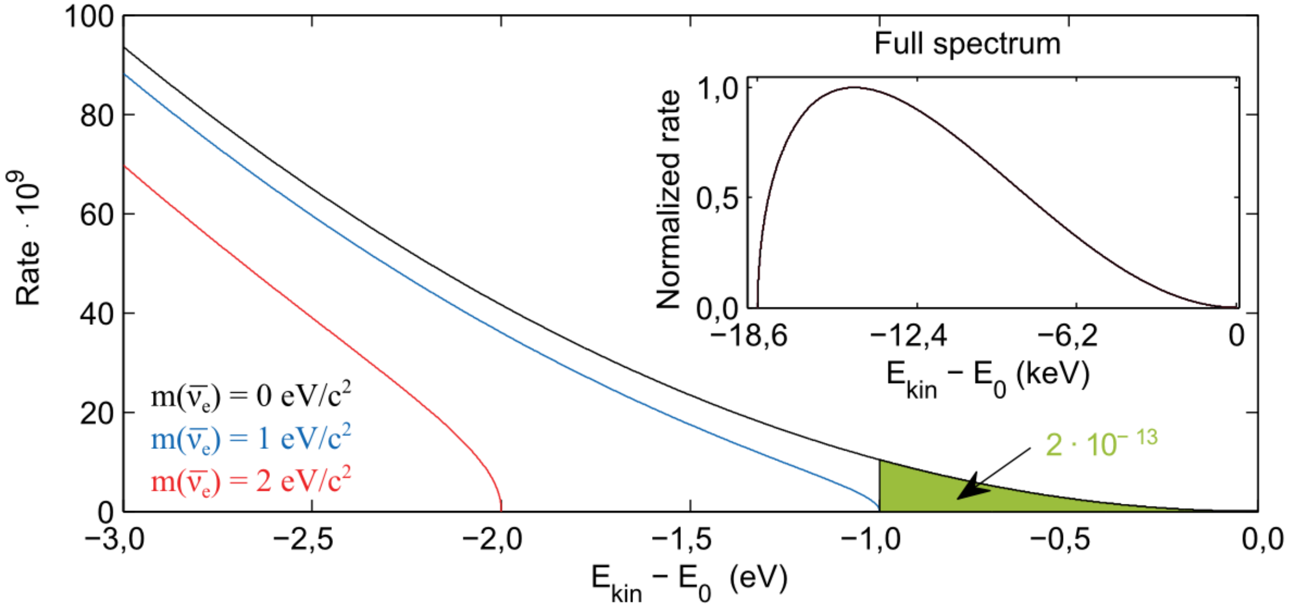
The determination of the absolute mass scale of the neutrino is of extreme importance in particle physics

- β decay via the mass of the electron antineutrino
  → A slight distortion of the β decay spectrum relates directly to the electron-neutrino mass

- KATRIN [1] experiment
  → $^{3}H(1/2^{+}) \xrightarrow{\beta^{-}} {}^{3}He(1/2^{+})$
  → Allowed decay
  → $Q = 18.5920(3)\ keV$

- Low Q → higher sensitivity

Tritium β decay electron spectrum



[1] *C. Weinheimer, Prog. Part. Nucl. Phys.* ***48****, 141 (2002)*

Low Q-value measurements in the framework of neutrino physics

The determination of the absolute mass scale of the neutrino is of extreme importance in particle physics

- β decay via the mass of the electron antineutrino
  → A slight distortion of the β decay spectrum relates directly to the electron-neutrino mass

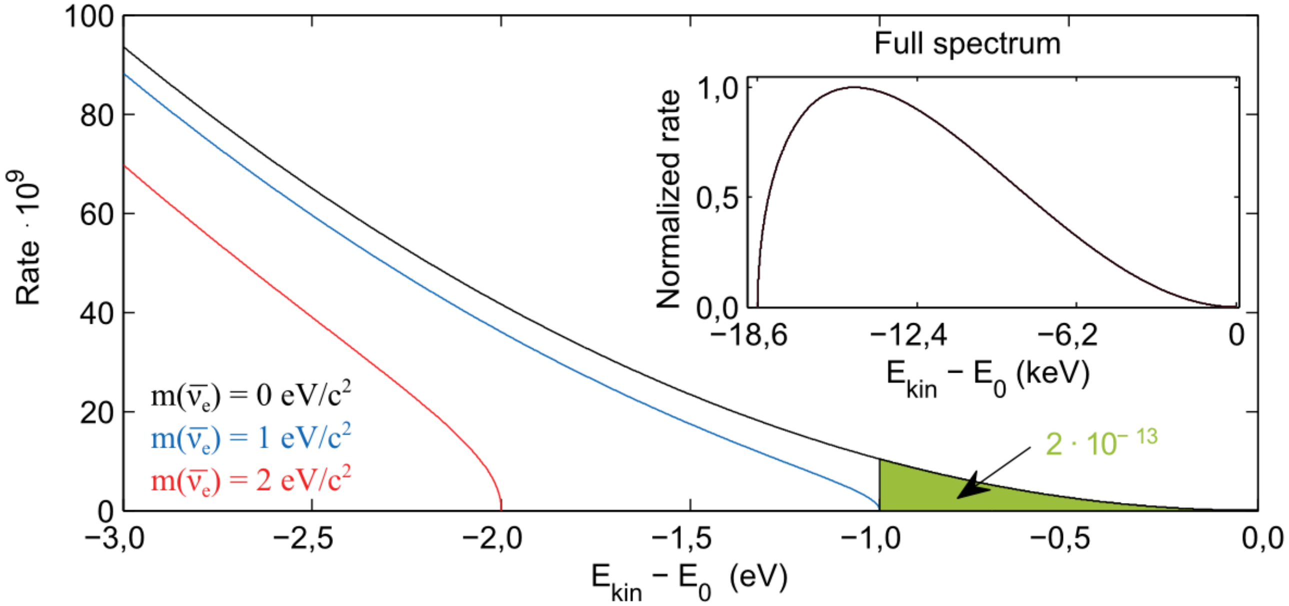
- KATRIN [1] experiment
  → $^3H(1/2^+) \xrightarrow{\beta^-} {}^3He(1/2^+)$
  → Allowed decay
  → $Q = 18.5920(3)\ keV$

- Low $Q \rightarrow$ higher sensitivity

- **Other possible low Q-values**

  → Not very well known
  → Need to identify them with Penning traps

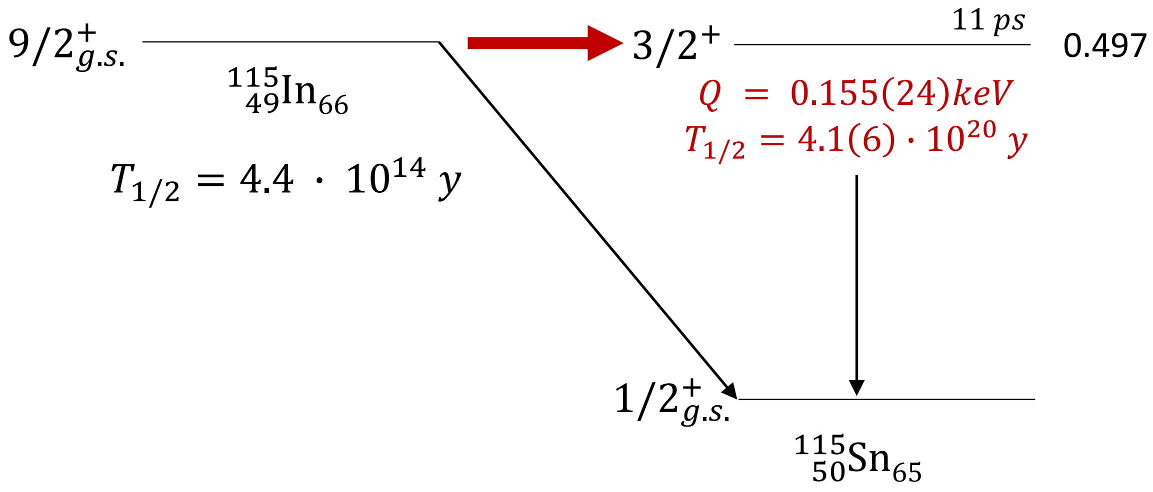
Tritium β decay electron spectrum



[1] *C. Weinheimer, Prog. Part. Nucl. Phys.* ***48****, 141 (2002)*

Low Q-value measurements in the framework of neutrino physics

- **Possibility to use even weaker Q-values**
  - → $^{115}In(9/2^+) \xrightarrow{\beta^-} {}^{115}Sn(3/2^+)$
  - → Q = 0.155(24) keV → weakest Q-value ever measured
  - → **A « detector » for the neutrino mass ?**



B.J. Mount, M. Redshav, E.G. Myers, 2009 Phys. Rev. Lett. 103 122502
J. S. E. Wieslander, Phys. Rev. Lett. 103, 122501 (2009)
C.M. Cattadori, Nucl. Phys. A, 748, 333-347 (2005)

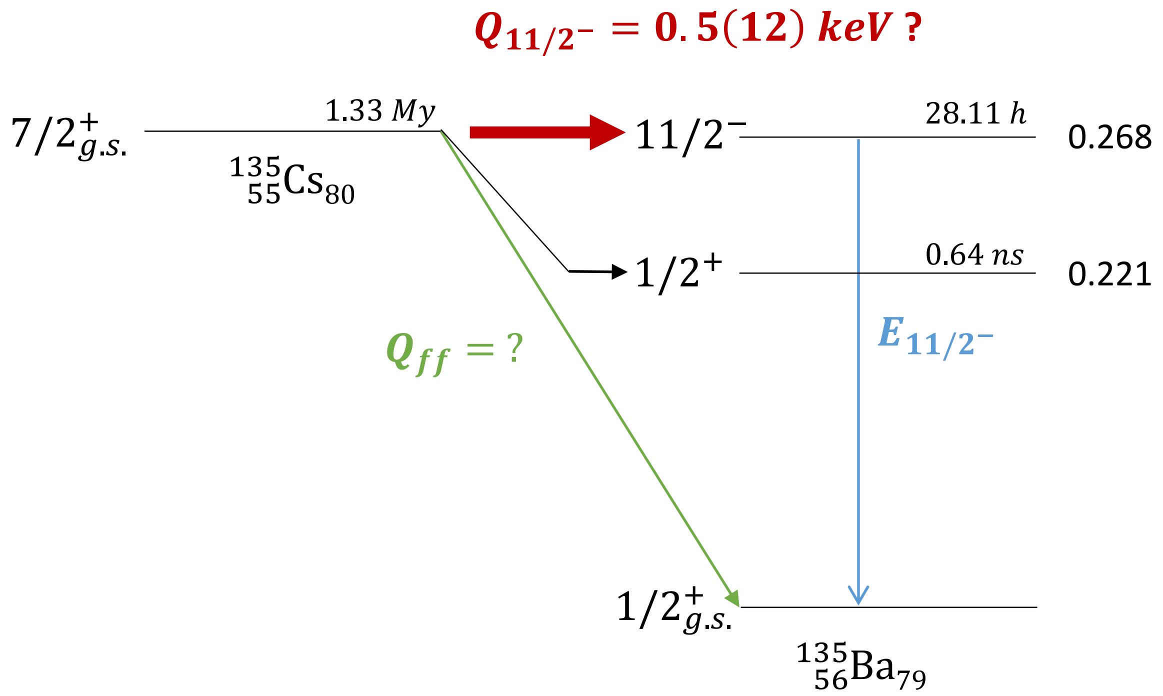
$^{135}Cs(7/2^+) \xrightarrow{\beta^-} {}^{135}Ba(11/2^-)$

But : The transition is poorly known!

- Not yet proven that it is energetically possible : $Q_{11/2^-} < 0$ **?**
- Decay never observed directly

To determine $Q_{11/2^-}$ we need:

- The excitation energy $E_{11/2^-} = 268.218(20)\ keV$
- The ground-state-to-ground-state Q-value Q_{ff}
- $Q_{ff} = 268.9(1.1)\ keV$ [1]



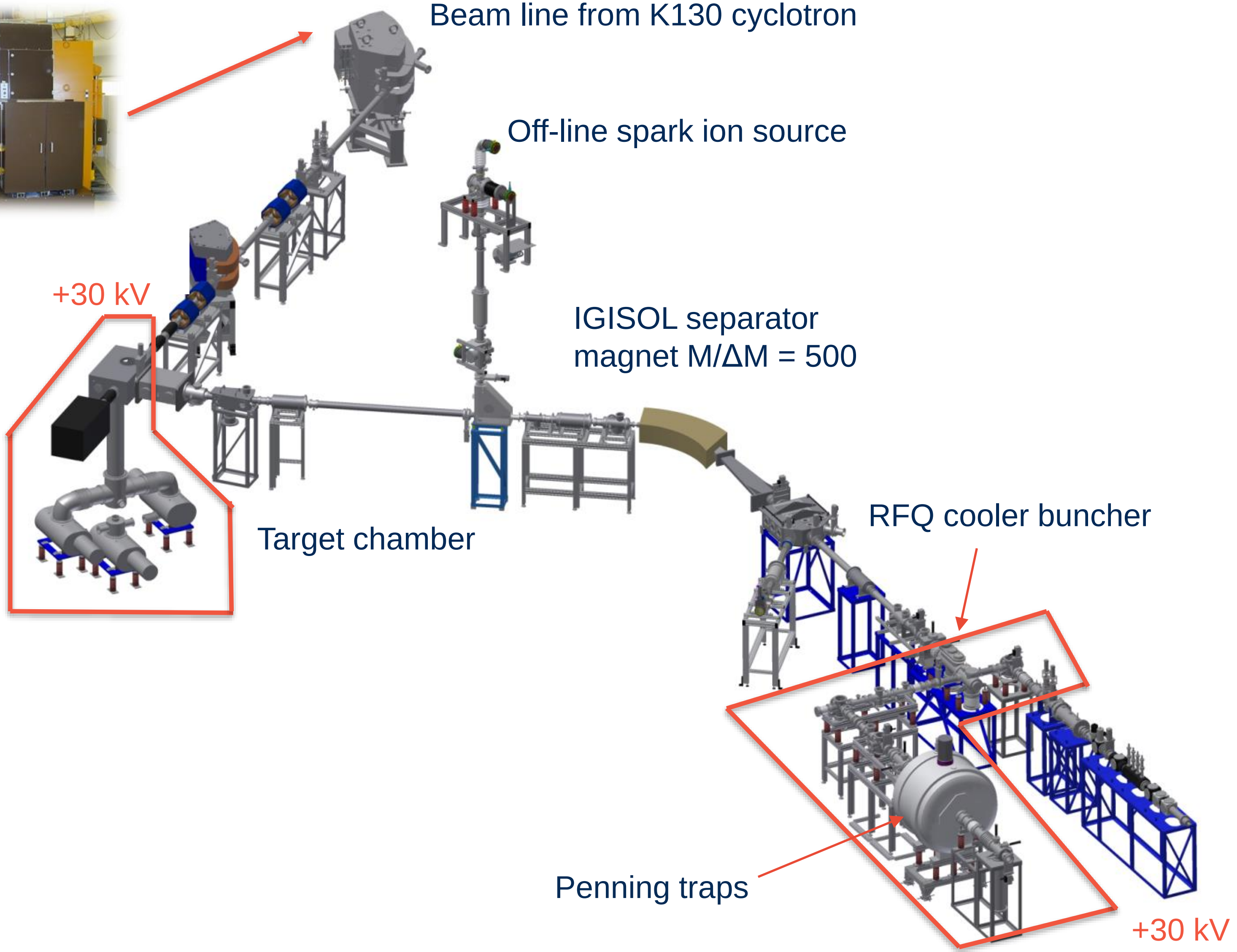
$$Q_{ff} = 268.9(1.1)\ keV \rightarrow Q_{11/2^-} = 0.5(1.2)\ keV$$

New measurement of Q_{ff} with Penning traps!!

[1] *M. Wang et al., Chin. Phys. C 41, 030003 (2017)*

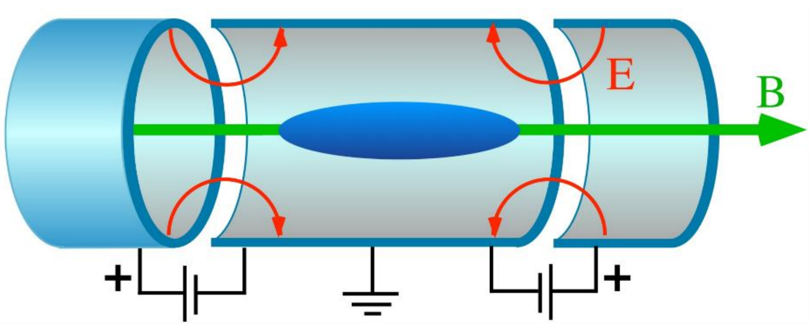
The IGISOL-4 facility

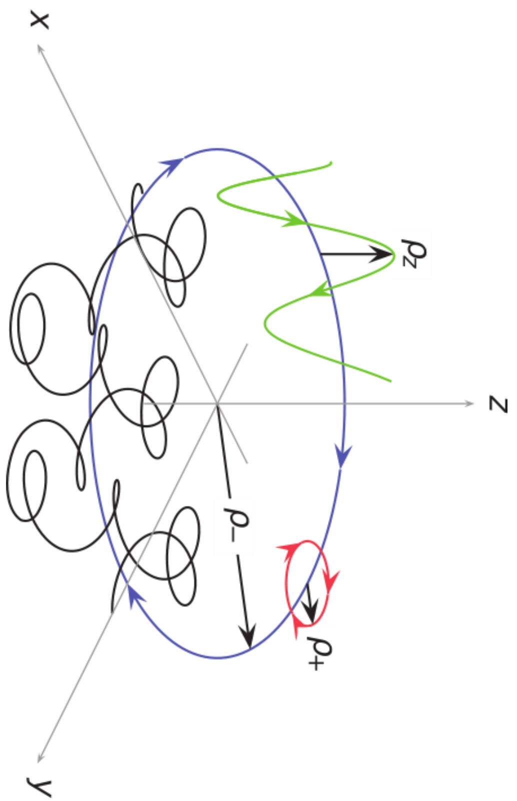
- Production of ^{135}Cs:
  - Proton beam of 50 MeV
  - Target of ^{nat}U → 15mg/cm^2
  - The fission reaction is less likely to produce $^{135}Ba(11/2^{-})$
- Production of ^{135}Ba:
  - Electrode of Ba installed in the spark source



Penning trap

- Radial confinement
  - strong homogeneous magnetic field
- Axial confinement
  - electric field





3 ion motions ⟷ 3 ion frequencies

- Axial — ν_z
- Magnetron — ν_-
- Reduced cyclotron — ν_+

- Invariance theorem

$$\nu_c^2 = \nu_-^2 + \nu_+^2 + \nu_z^2$$

- Cyclotron frequency

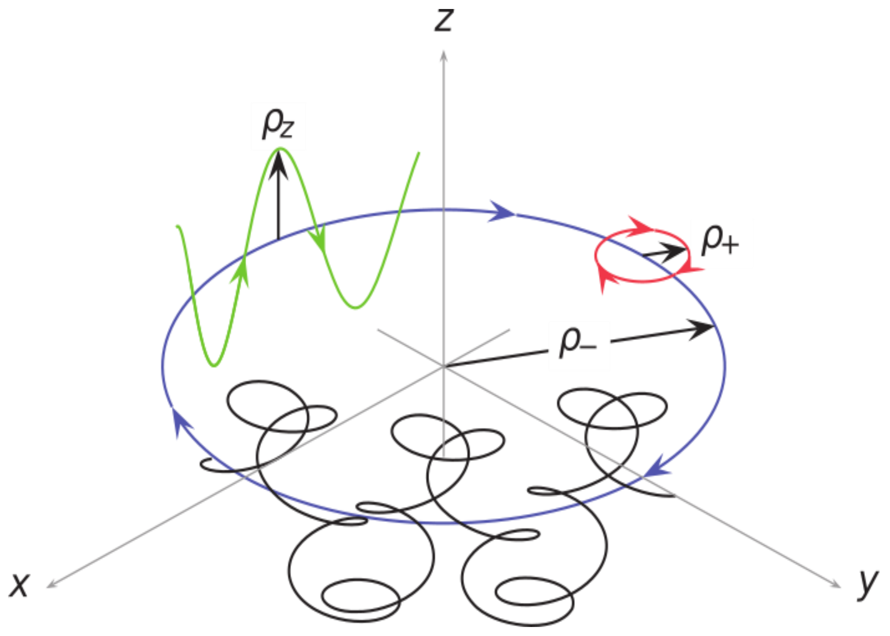
$$\nu_c = \nu_- + \nu_+$$

Cyclotron frequency

$$\nu_c = \frac{1}{2\pi}\frac{q}{m}B$$

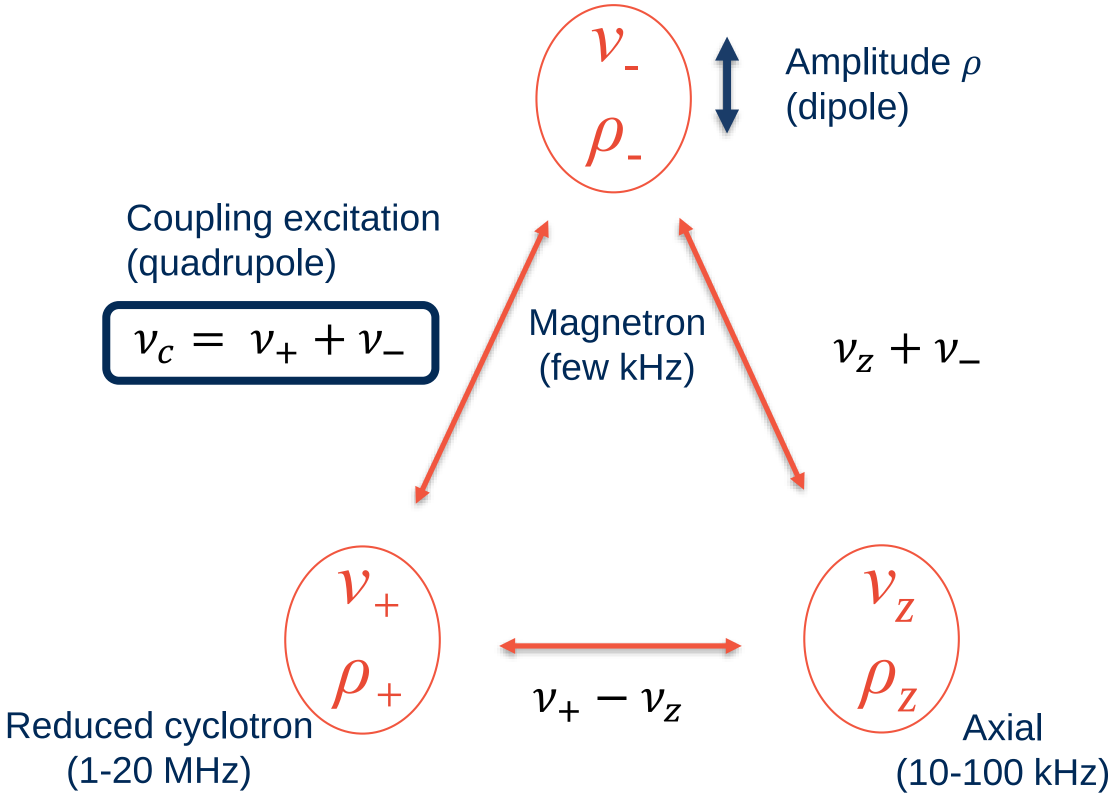
q : electric charge
B : magnetic field
m : mass

Penning trap



Control amplitudes

Convert motions



3 ion motions ↔ 3 ion frequencies

- Axial — ν_z
- Magnetron — ν_-
- Reduced cyclotron — ν_+

- Invariance theorem

$$\nu_c^2 = \nu_-^2 + \nu_+^2 + \nu_z^2$$

- Cyclotron frequency

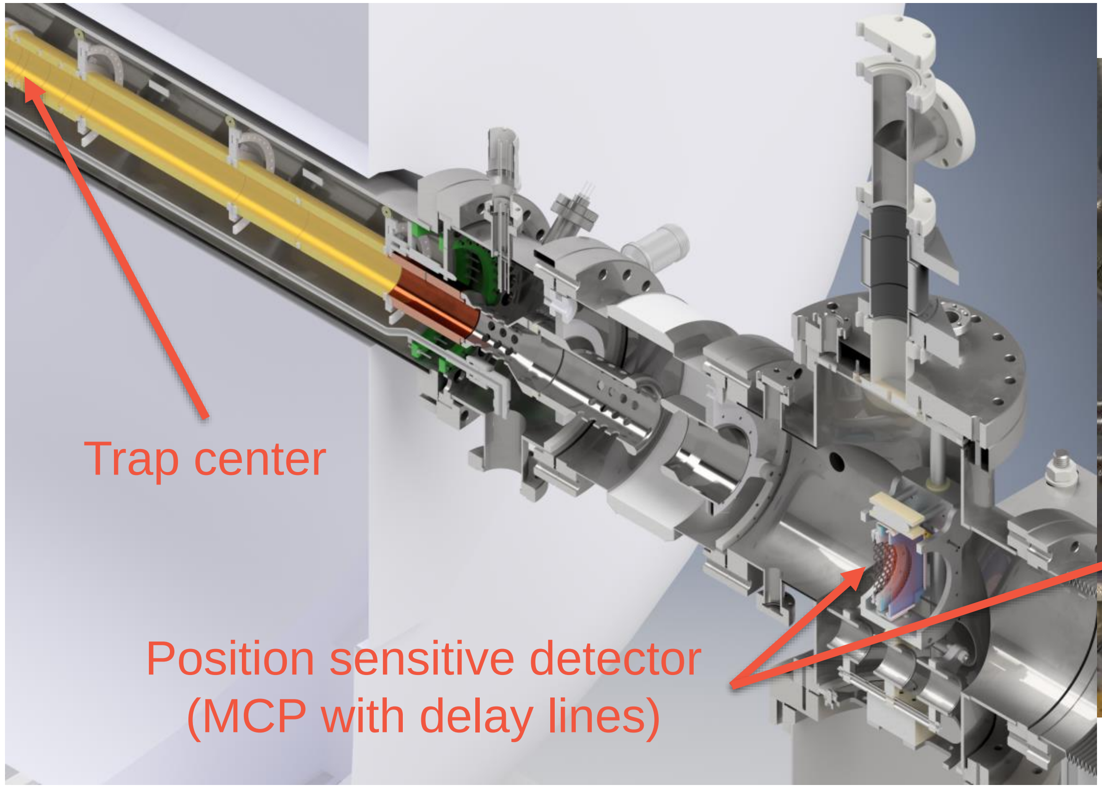
$$\nu_c = \nu_- + \nu_+$$

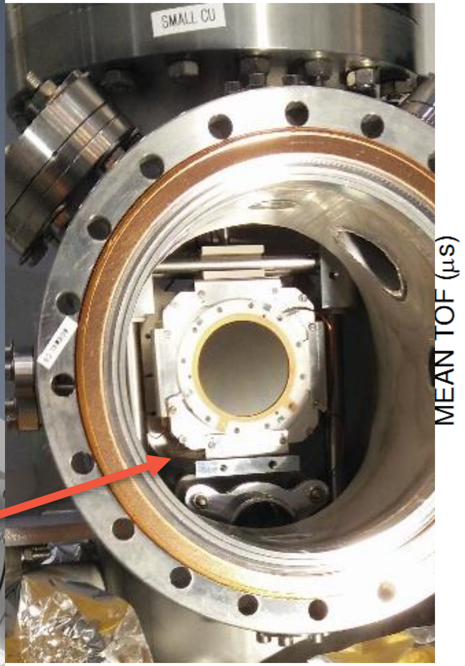
Cyclotron frequency

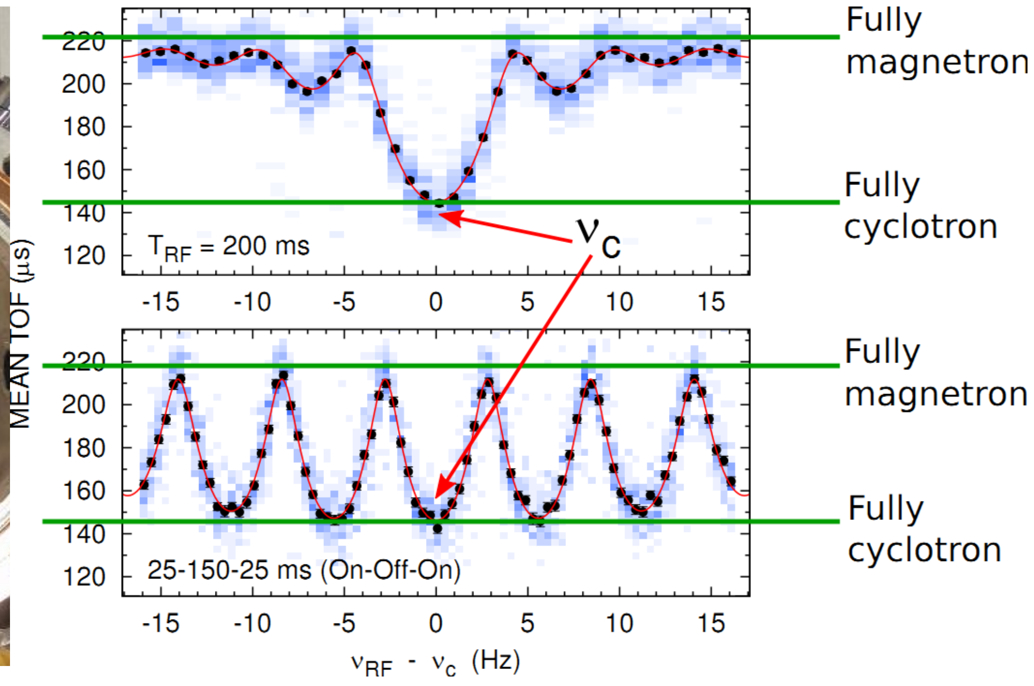
$$\nu_c = \frac{1}{2\pi}\frac{q}{m}B$$

q : electric charge
B : magnetic field
m : mass

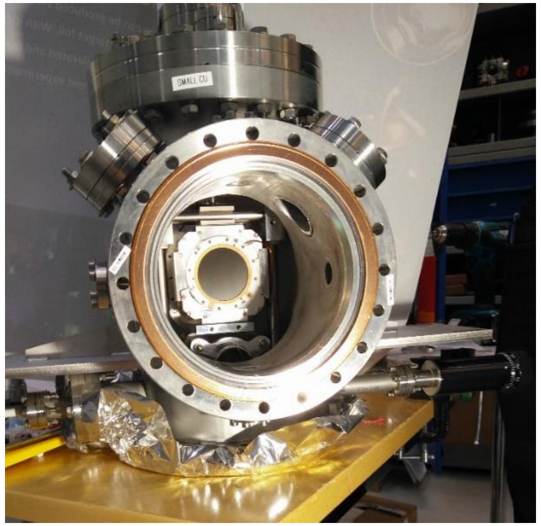
Position sensitive detector

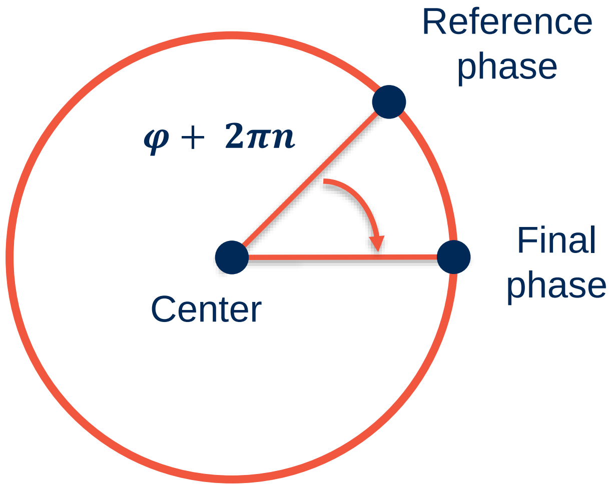




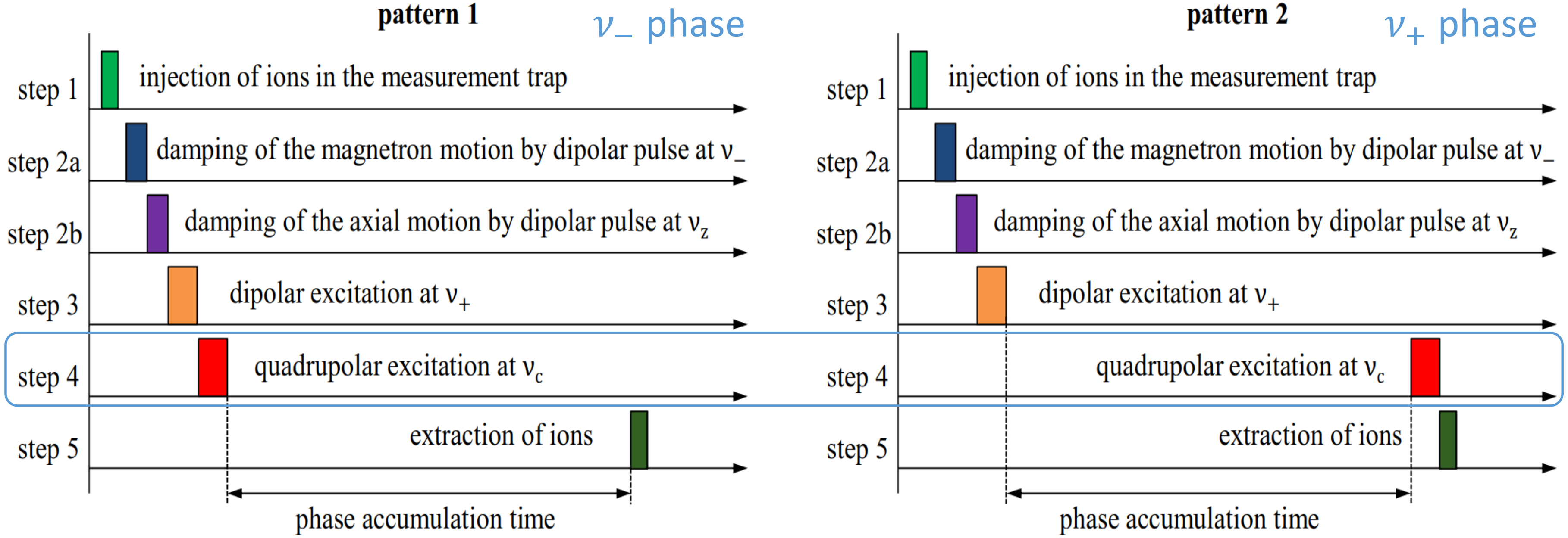


Phase-imaging ion cyclotron resonance technique (PI-ICR)

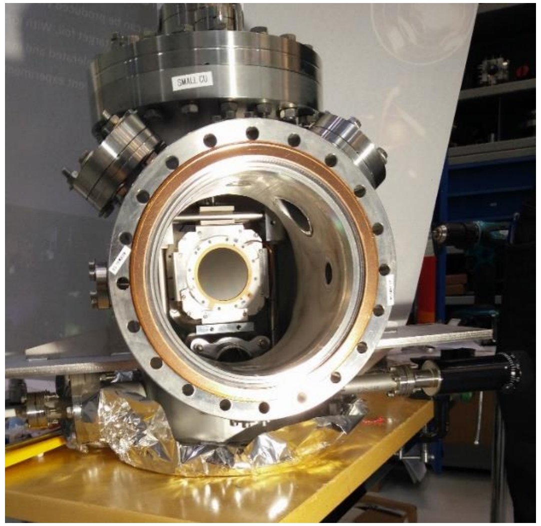


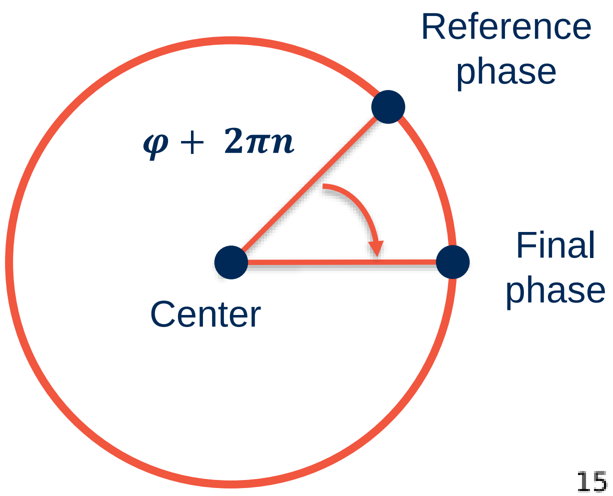


$$\nu = \frac{\varphi + 2\pi n}{2\pi t}$$

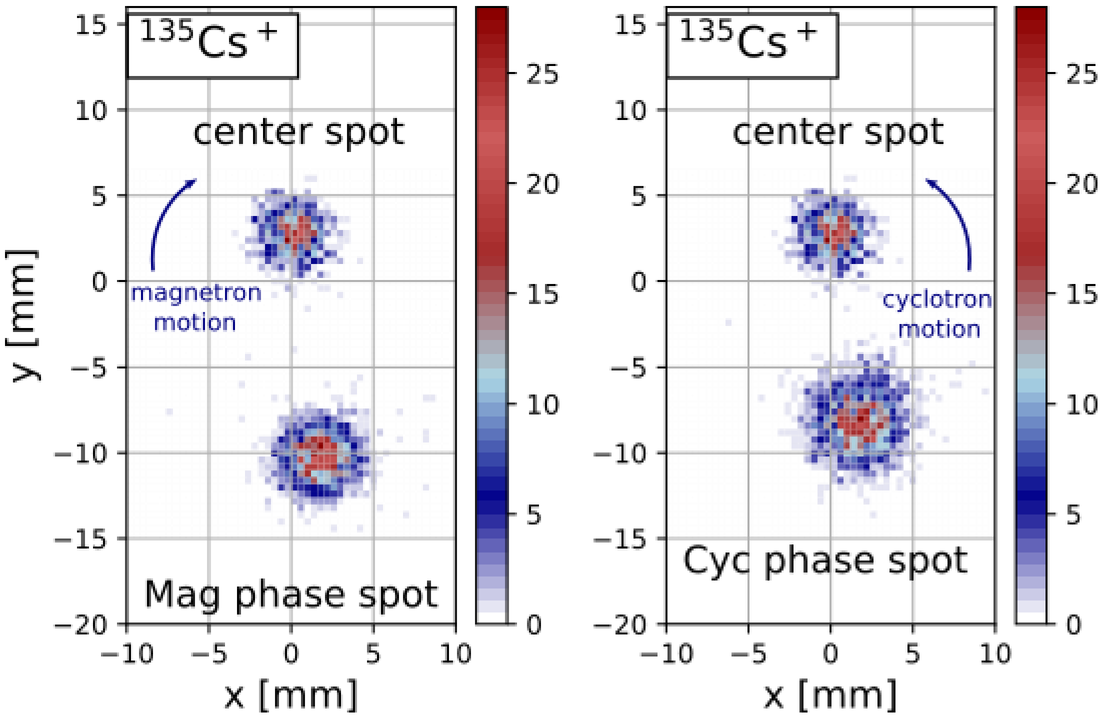


Phase-imaging ion cyclotron resonance technique (PI-ICR)





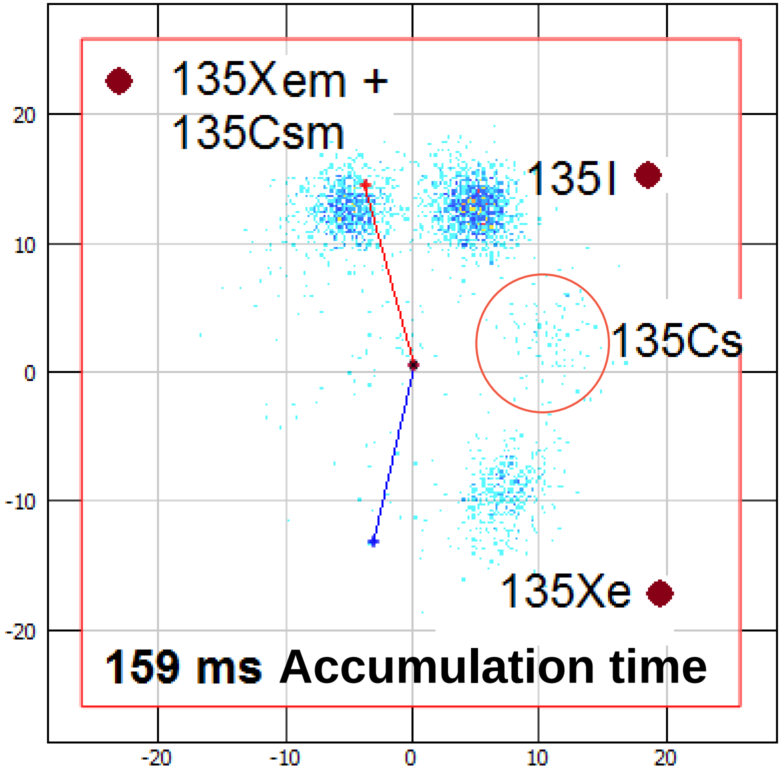
$$\nu = \frac{\varphi + 2\pi n}{2\pi t}$$



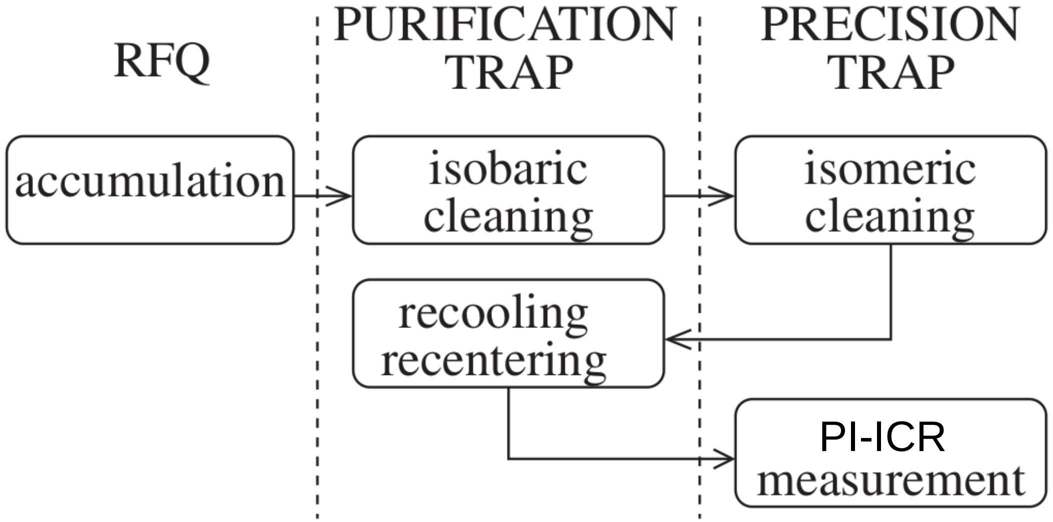
Advantages of PI-ICR:
- No scan data collection to one spot
- x40 faster x5 increase in precision

But:
- Need to prepare the ion more carefully
- Damping of ion motions; longer setting up time
- Sensitive to voltage fluctuations

Isomeric cleaning



Ramsey cleaning

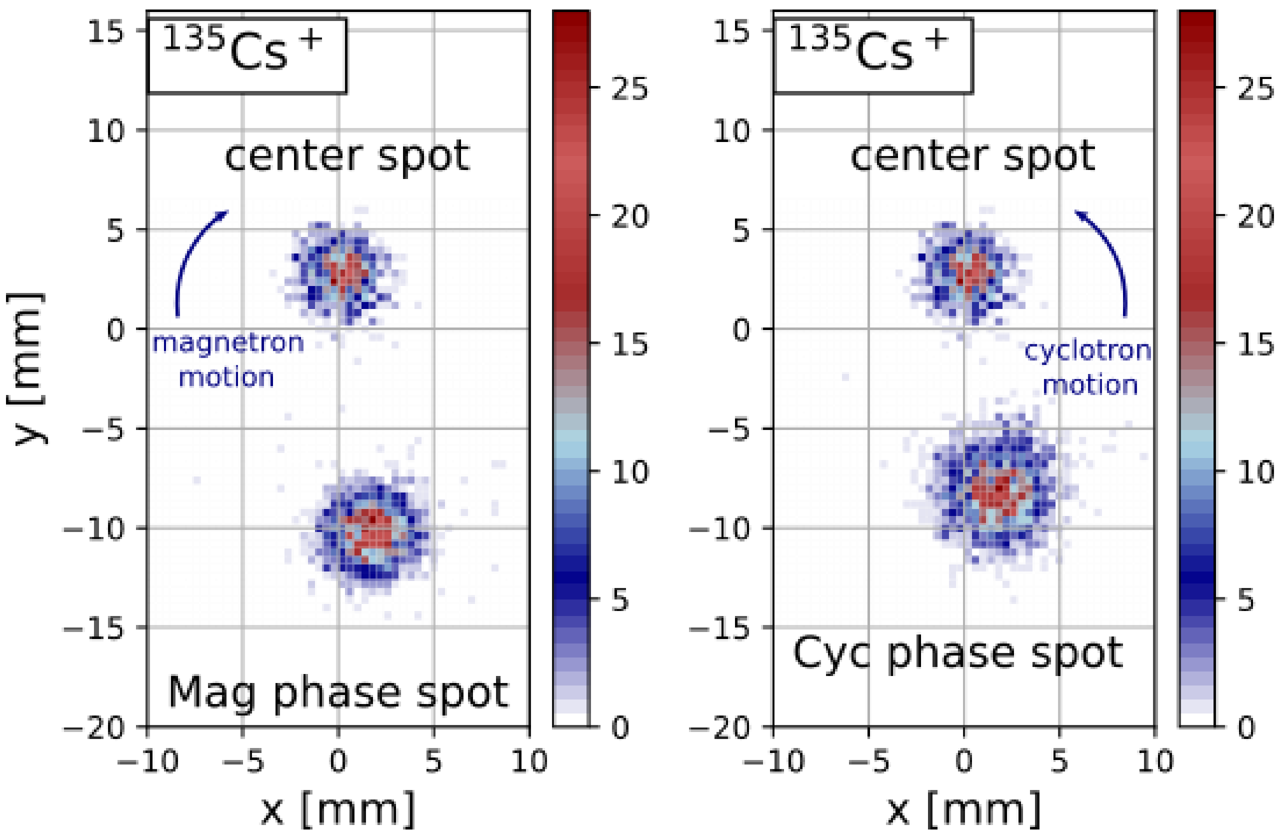


With the Ramsey cleaning we could get rid of the contaminants:

- $^{135}Xe^{m}$
- $^{135}Cs^{m}$
- ^{135}I
- ^{135}Xe

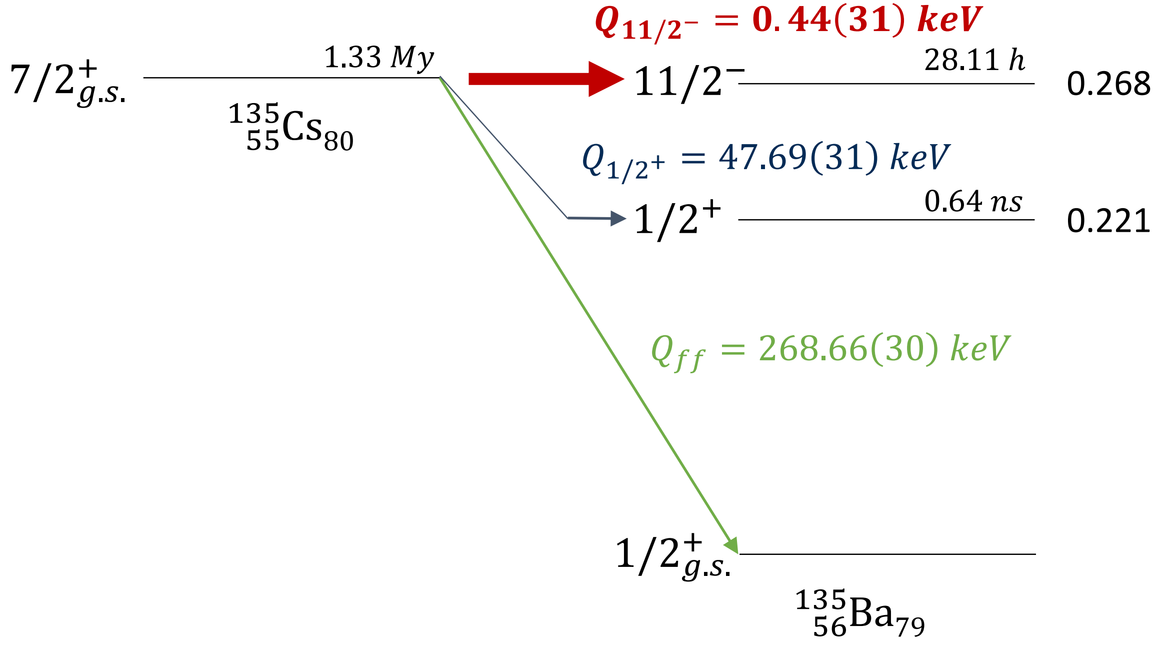
PI-ICR measurements

- Pure sample of ^{135}Cs sent in the measurement trap
- Every few rounds, switched between ^{135}Cs from IGISOL and ^{135}Ba from the off-line spark source
- Measurement of the GS-to-GS *Q*-value performed with
  - TOF-ICR Ramsey technique
  - PI-ICR technique



Result and conclusion

$Q_{ff} = 268.66(30)\ keV$
→ $Q_{11/2^-} = 0.44(31)\ keV$
→ $Q_{1/2^+} = 47.69(31)\ keV$



Half-lives calculations computed with NuShell@MSU

- $T_{1/2}$ (^{135}Ba($11/2^-$)) = $8.2(32) \cdot 10^{11}\ y$
- $T_{1/2}$ (^{135}Ba($1/2^+$)) = $6.5(17) \cdot 10^{13}\ y$

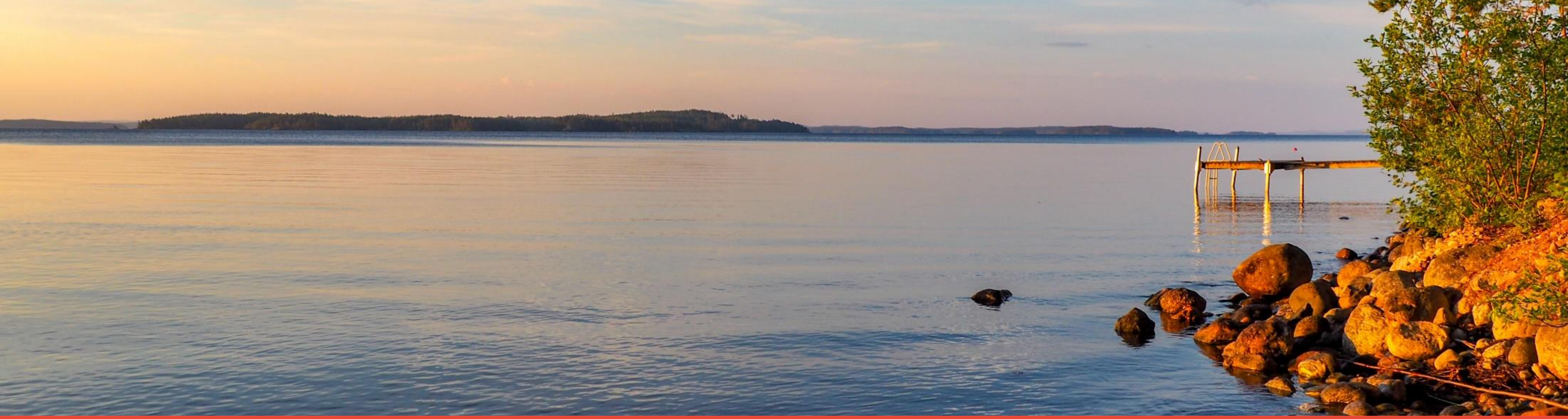
⇩

Branching ratio $(0.04 - 16) \cdot 10^{-6}$

A. de Roubin et al., Phys. Lett. A **124** (2020) 222503

Conclusion

- $^{135}Cs(7/2^+) \xrightarrow{\beta^-} {}^{135}Ba(11/2^-) > 0$
- First direct measurement
- Direct measurement of the antineutrino mass?
- $^{72}As \rightarrow {}^{72}Ge$ → Z. Ge *et al.* Submitted to PRC
- 17 new candidates proposed (Z. Ge et al.)



Thanks a lot for your attention

O. Beliuskina, L. Canete, **T. Eronen**, **Z. Ge**, S. Geldhof, W. Gins, R. de Groote, M. Hukkanen, A. Jokinen, A. Kankainen, J. Kostensalo, Á. Koszorús, J. Kotila, I. D. Moore, D. A. Nesterenko, A. Raggio, S. Rinta-Antila, J. Suhonen, M. Vilen, V. Virtanen, A. P. Weaver, A. Zadvornaya