# ISOLTRAP Status Report 2014-2018

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for the ISOLTRAP collaboration

*62nd INTC Meeting - CERN – 6 November 2019*

# Outline :

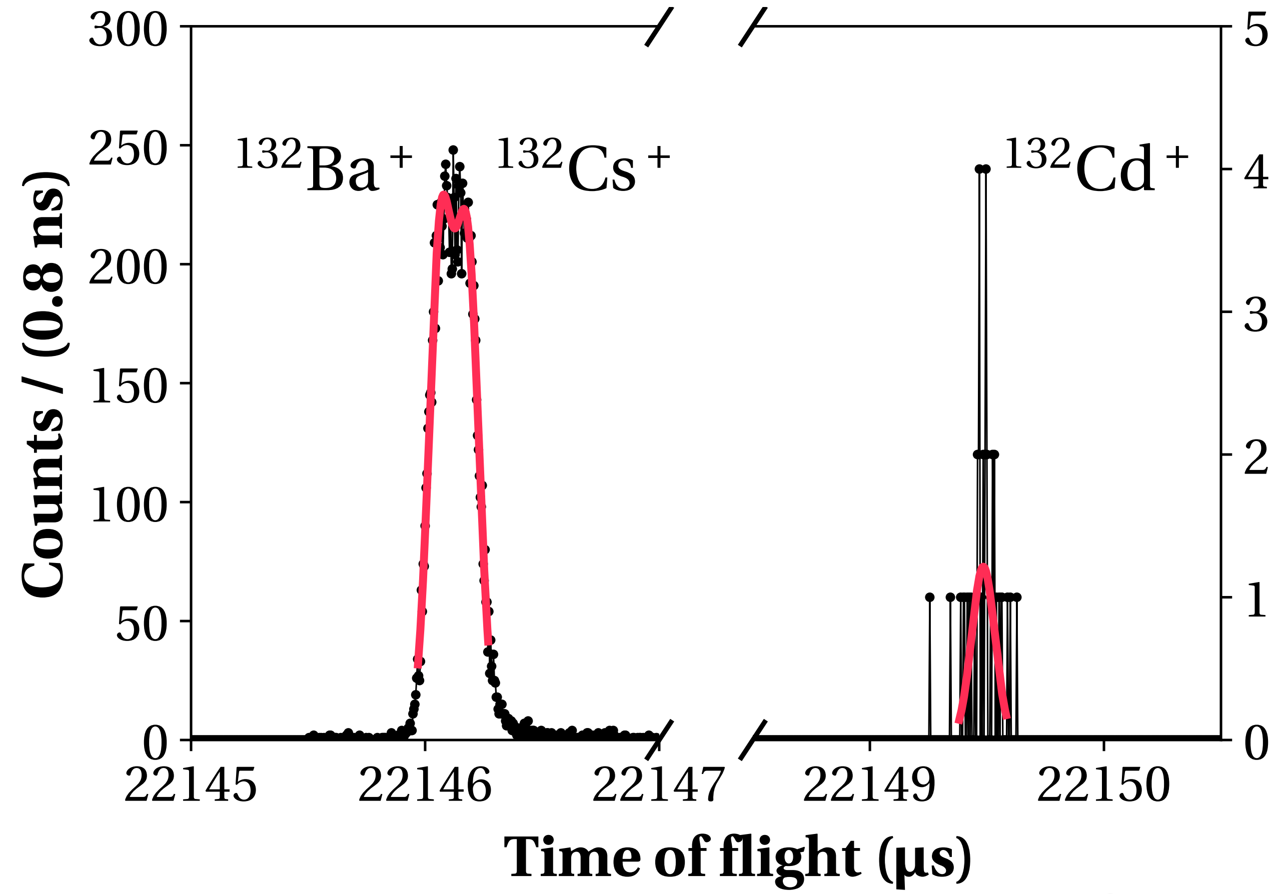
- Introduction
- Recent measurements with the ISOLTRAP mass spectrometer
- Status report for IS542,IS592,IS625,IS642
- Conclusion

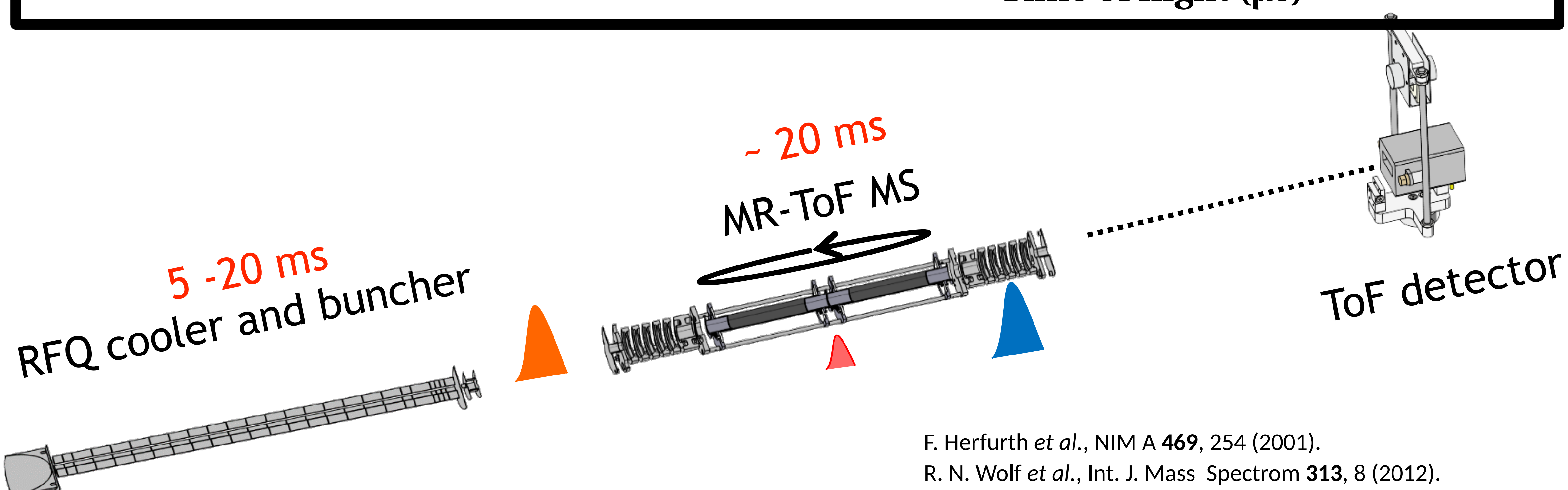
# INTRODUCTION

# MR-ToF mass spectrometry :

- $^{m}/_{\Delta m} \approx 10^5$ in ~20 ms
- $^{\delta m}/_{m} \approx 10^{-6}$

$$t_i = a \cdot \sqrt{\frac{m_i}{q_i}} + b$$





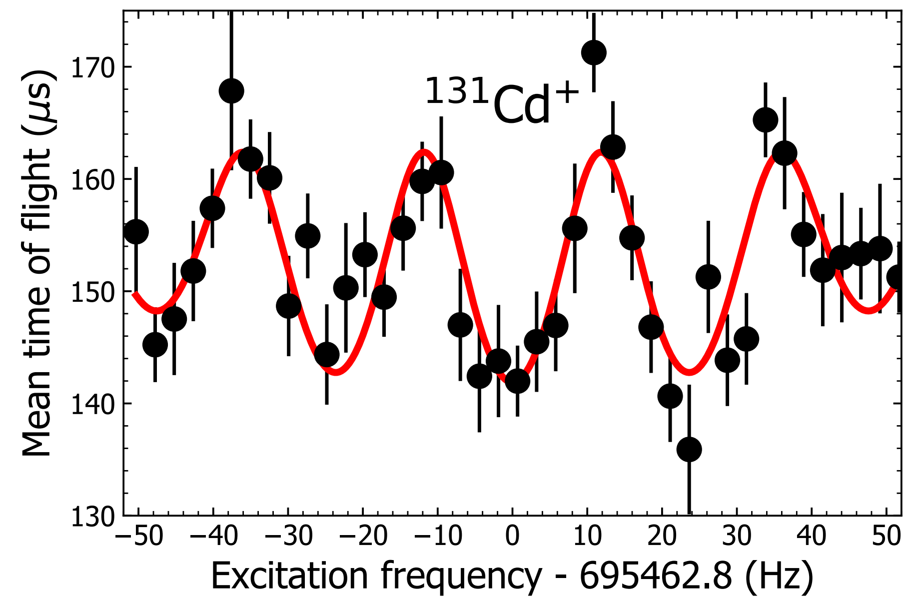
F. Herfurth *et al.*, NIM A **469**, 254 (2001).
R. N. Wolf *et al.*, Int. J. Mass Spectrom **313**, 8 (2012).
V. Manea, J. Karthein *et al.*, Submitted to Phys. Rev. Lett. (2019).

# Penning-trap mass spectrometry :

ToF-ICR:

- Scanning
- $t_{meas}$ ~ 50 - 2000 ms
- $\delta m/m$ ~ $10^{-7}$ - $10^{-9}$
- $m/\Delta m$ ~ $10^4$ - $10^6$

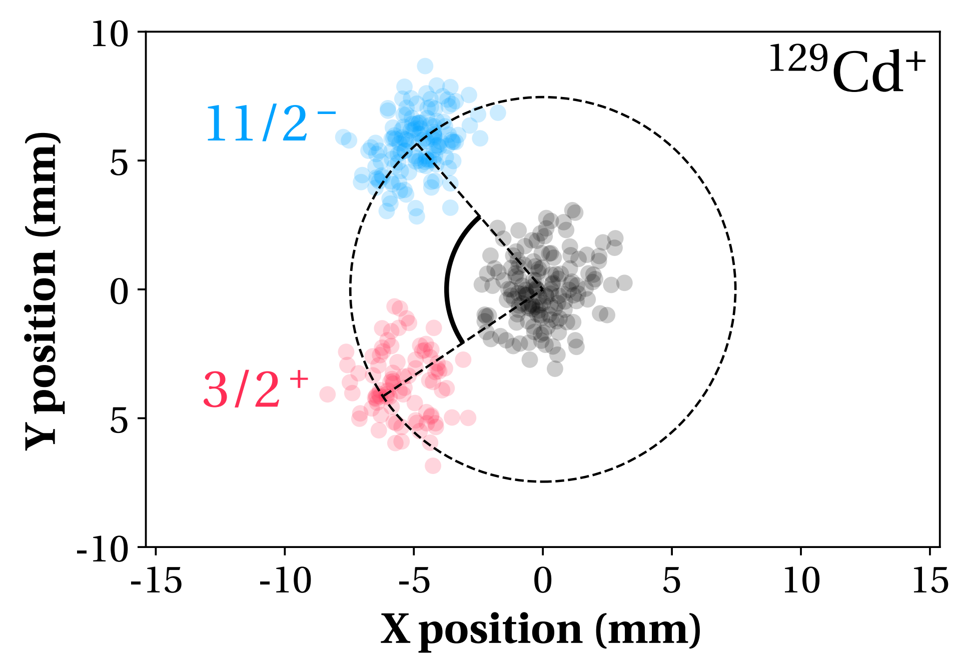
$$\nu_c = \frac{qB}{2\pi m_{ion}}$$



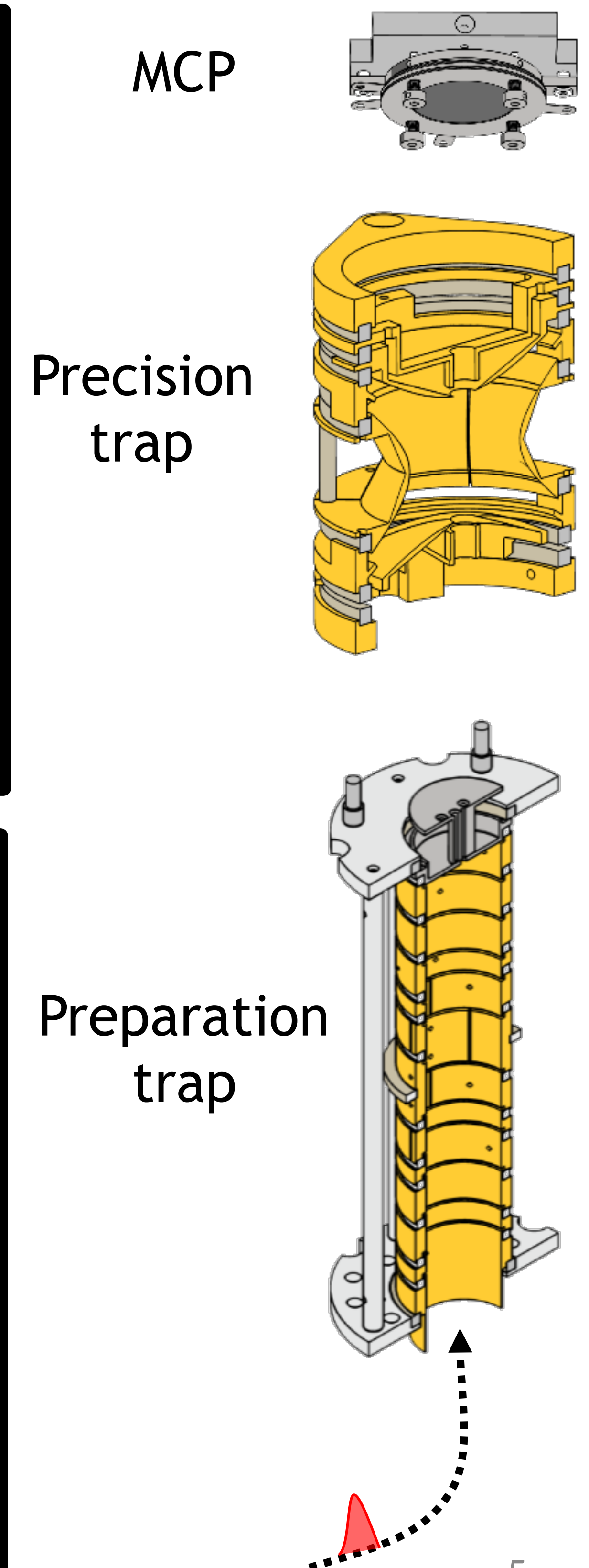

PI-ICR :

- **Non**-scanning
- $t_{meas}$ ~ 50 - 2000 ms
- $\delta m/m$ ~ $10^{-7}$ - < $10^{-9}$
- $m/\Delta m$ ~ $10^6$ - > $10^7$

$$\nu = \frac{\phi + 2\pi n}{2\pi t_{meas}}$$

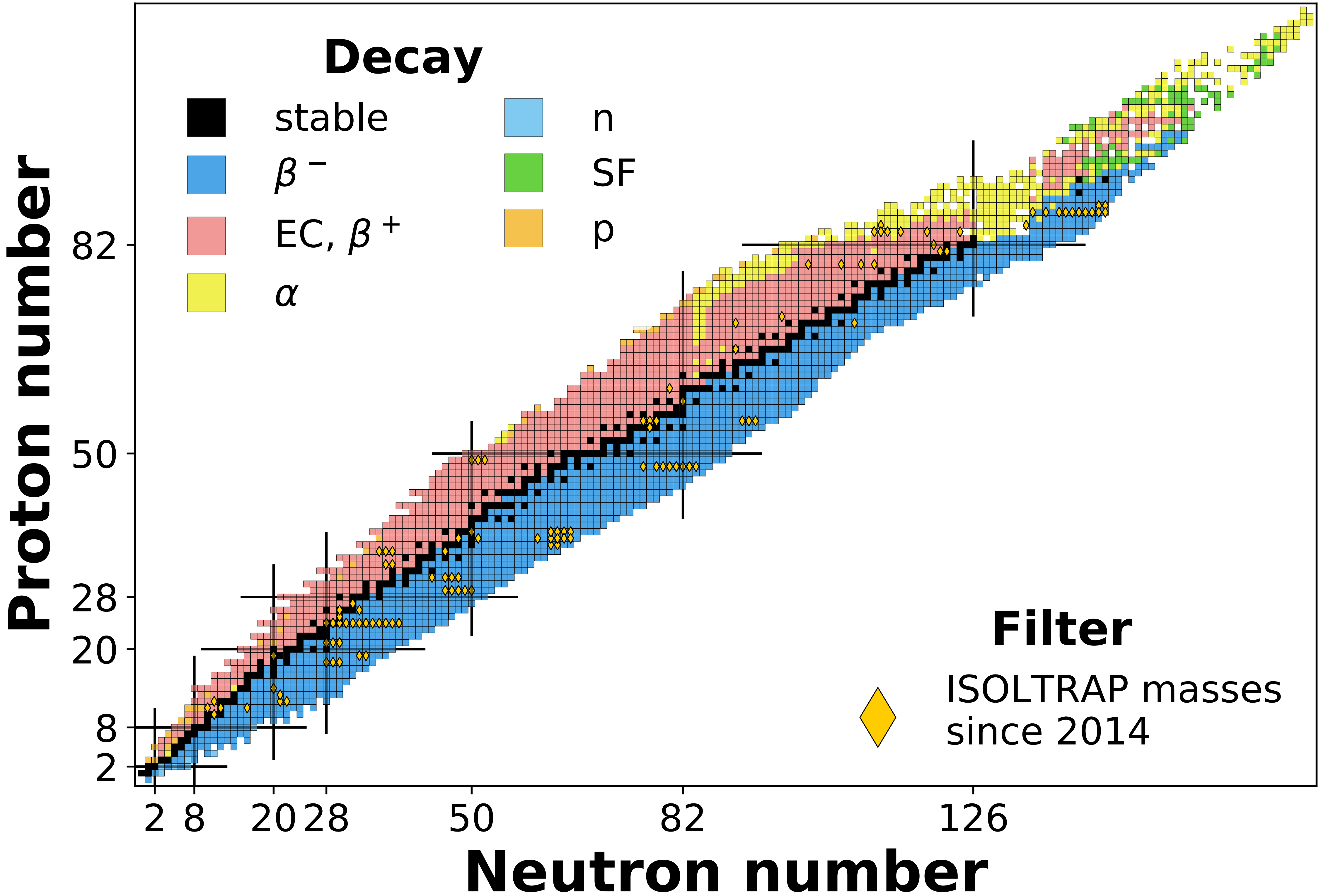



V. Manea, J. Karthein *et al.*, Submitted to Phys. Rev. Lett. (2019).

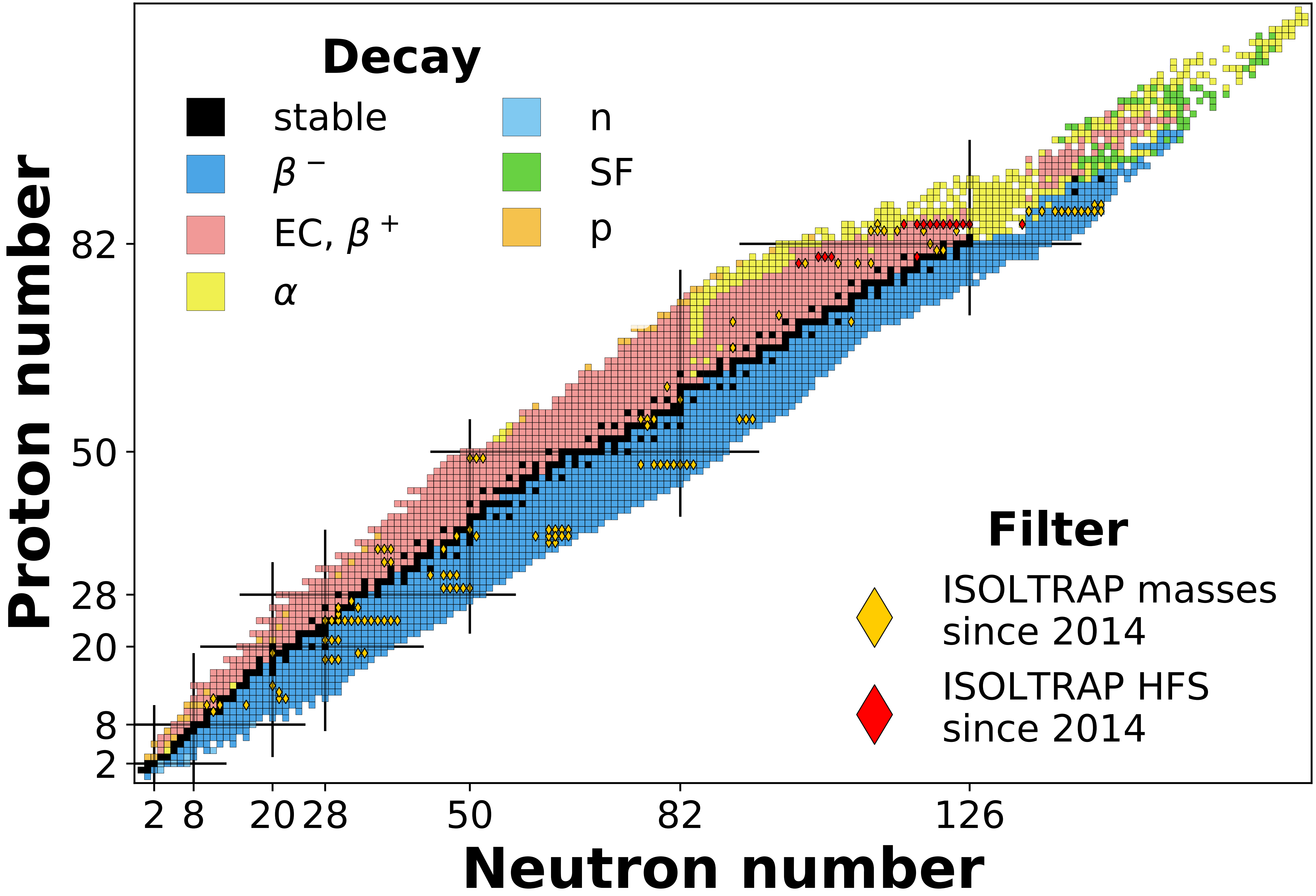


# Recent measurements with the ISOLTRAP

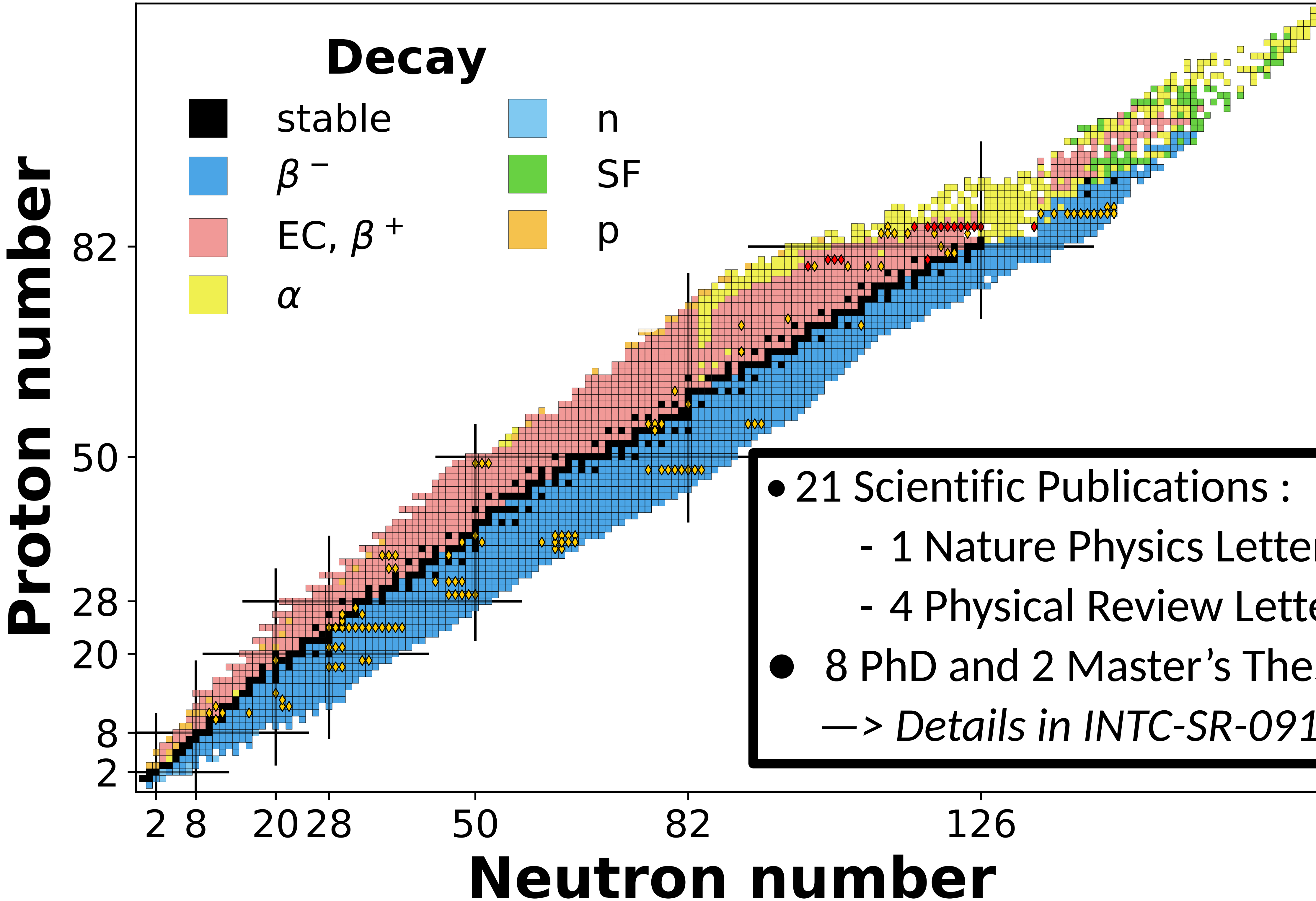
# Mass measurements since 2014:



# MR-ToF assisted HFS:



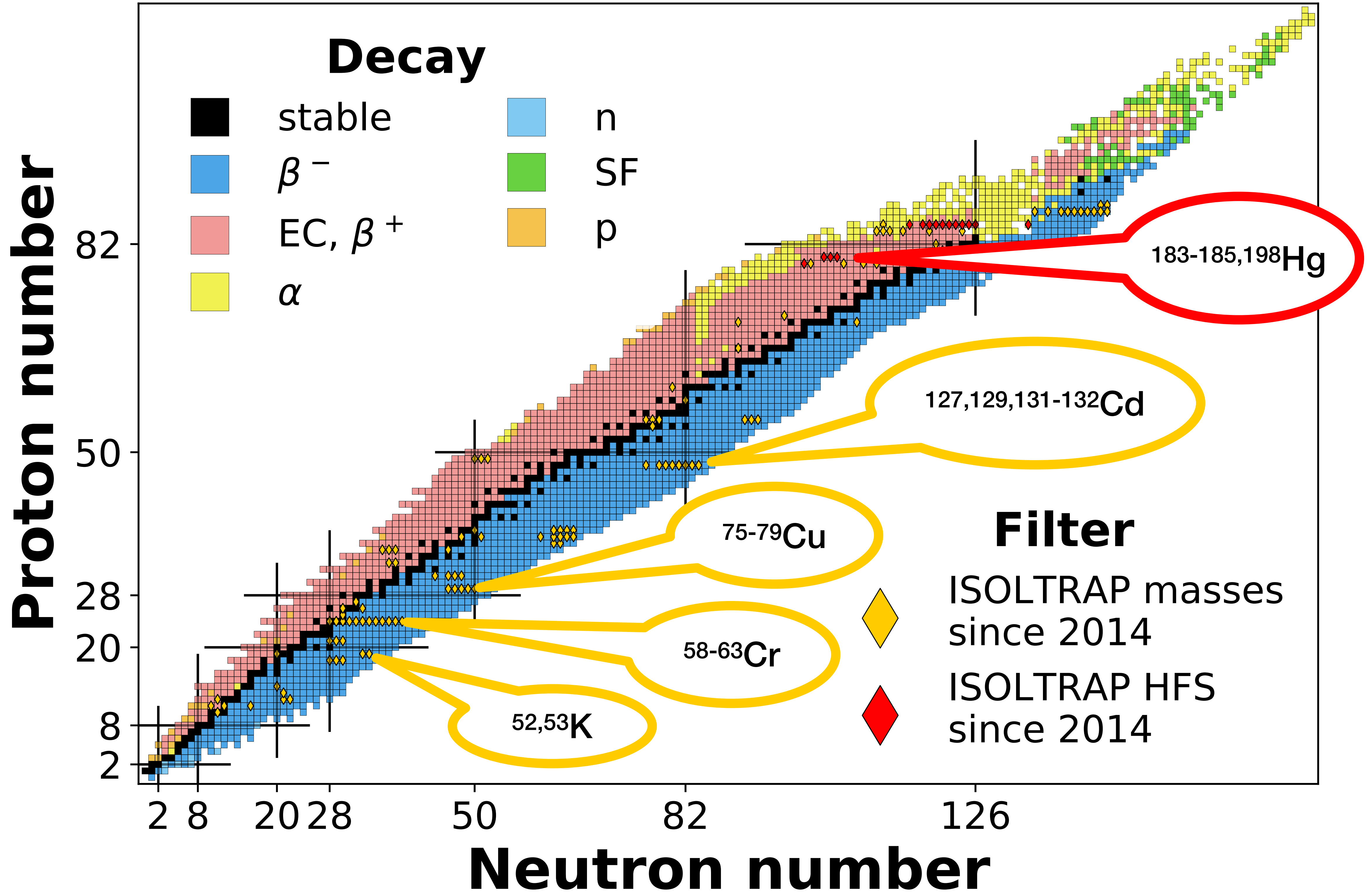
# Publication highlights:




- 21 Scientific Publications :
  - 1 Nature Physics Letter
  - 4 Physical Review Letters
- 8 PhD and 2 Master's Thesis

—> *Details in INTC-SR-091*

# Publication highlights:




M. Rosenbusch *et al.*, *Phys. Rev. Lett. 114, 202501 (2015)*
D. Atanasov *et al.*, Phys. Rev. Lett. **115**, 232501 (2015)
A. Welker *et al.*, *Phys. Rev. Lett. 119, 192502 (2017)*
M. Mougeot *et al.*, Phys. Rev. Lett. 120, 232501 (2018)
B. Marsh *et al.*, Nature Physics 14, 1163 (2018)
V. Manea, J. Karthein *et al.*, Submitted to Phys. Rev. Lett. (2019)

# Status Report for IS542,IS592,IS625,IS642

# Status report

| Exp. | Total shifts | Used shifts/Remaining shifts in 2018 | Accepted isotopes | Last scheduled in | Remaining shifts in 2019 | Proposed status after LS2 |
|---|---|---|---|---|---|---|
| IS490 | 28 | 0/0 | $^{46-48}$Ar, $^{96-98}$Kr | 2017 | 0 | Close |
| IS532 | 27 | 11/11 | $^{52-55}$Sc | 2018 | 0 | Close |
| IS542 | 9 | 0/9 | $^{32}$Ar | 2014 | 9 | Open |
| IS565 | 8 | 0/0 | $^{23}$Mg/Na, $^{21}$Na/Ne | 2016 | 0 | Close |
| IS567 | 17 | 0/0 | $^{34}$Mg/Al | 2015 | 0 | Close |
| IS574 | 19 | 0/0 | $^{127-132}$Cd | 2017 | 0 | Close |
| IS592 | 12 | 0/10 | $^{131}$Cs/Xe | 2017 | 10 | Open |
| IS625 | 12 | 0/12 | $^{56}$Cu, $^{58}$Zn | | 12 | Open |
| IS642 | 12 | 6/12 | $^{70}$Br/Se | 2018 | 6 | Open |
| **Total Shifts in 2018 : 54** | | | **Total Shifts in 2019 : 37** | | | |

# Status report IS542 : Physics case

- Testing accuracy of the IMME :

$$m(T_Z) = c_0 + c_1 T_Z + c_2 T_Z^2$$

- A = 32 *T*=2 quintet —> $^{32}$Ar,$^{32}$Cl,$^{32}$S,$^{32}$P,$^{32}$SI

- Mass excess uncertainty
  - $^{32}$Cl —> 0.6 keV
  - $^{32}$Cl —> 0.3 keV
  - $^{32}$P —> 0.2 keV
  - $^{32}$Si —> 0.7 keV
  - $^{32}$Ar —> 1.8 keV (Aim factor 10 reduction)

- Reduced $\chi^2 \geq$ 6.6 with quadratic fit

# Status report IS542 : Shift request

| Isotope | Half-life | Yield (ions/$\mu$C$^{-1}$) | Target | Ionisation Method | Shifts (8H) |
|---|---|---|---|---|---|
| $^{32}$Ar | 98.0 ms | 800 | nano-CaO | Hot Plasma | 8 |
| | | | | | **Total Shifts: 8(+1 for tuning)** |

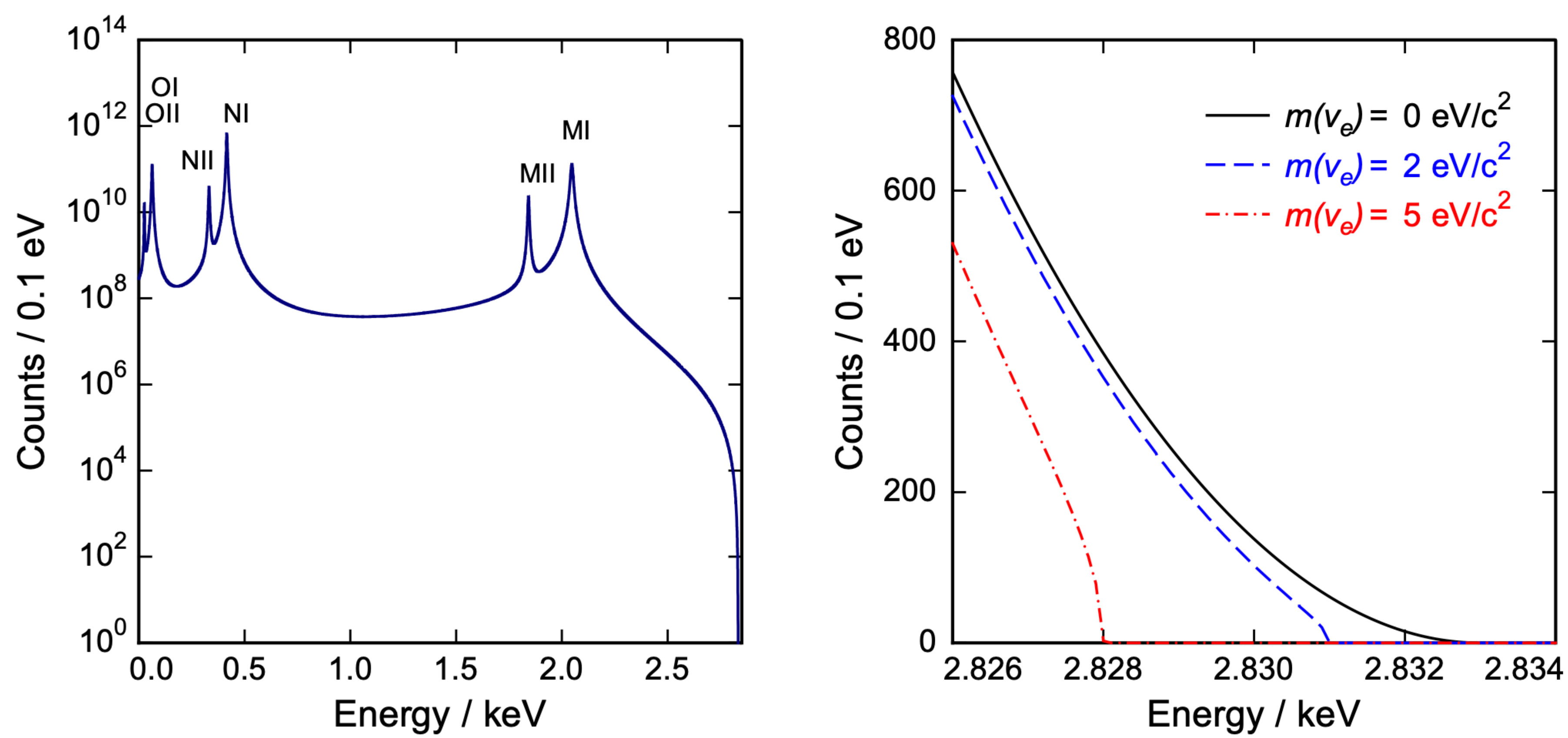
- nano-CaO standard target unit
- $^{32}S$ or $^{32}O_2$ stable isobaric contamination
- Required R = $\frac{m}{\Delta m}$ ~ 1000 or 4000 respectively

# Status report IS592 : Physics case

- Search for $\beta$-decay transitions with the lowest possible decay-energy
- Direct determination of the neutrino mass (micro-calorimeter)
- $Q_{EC} = (M_p - M_d)c^2$

$$^{163}\text{Ho} + e^- \rightarrow {}^{163}\text{Dy}^* + \nu_e$$

$$^{163}\text{Dy}^* \rightarrow {}^{163}\text{Dy} + E_C$$



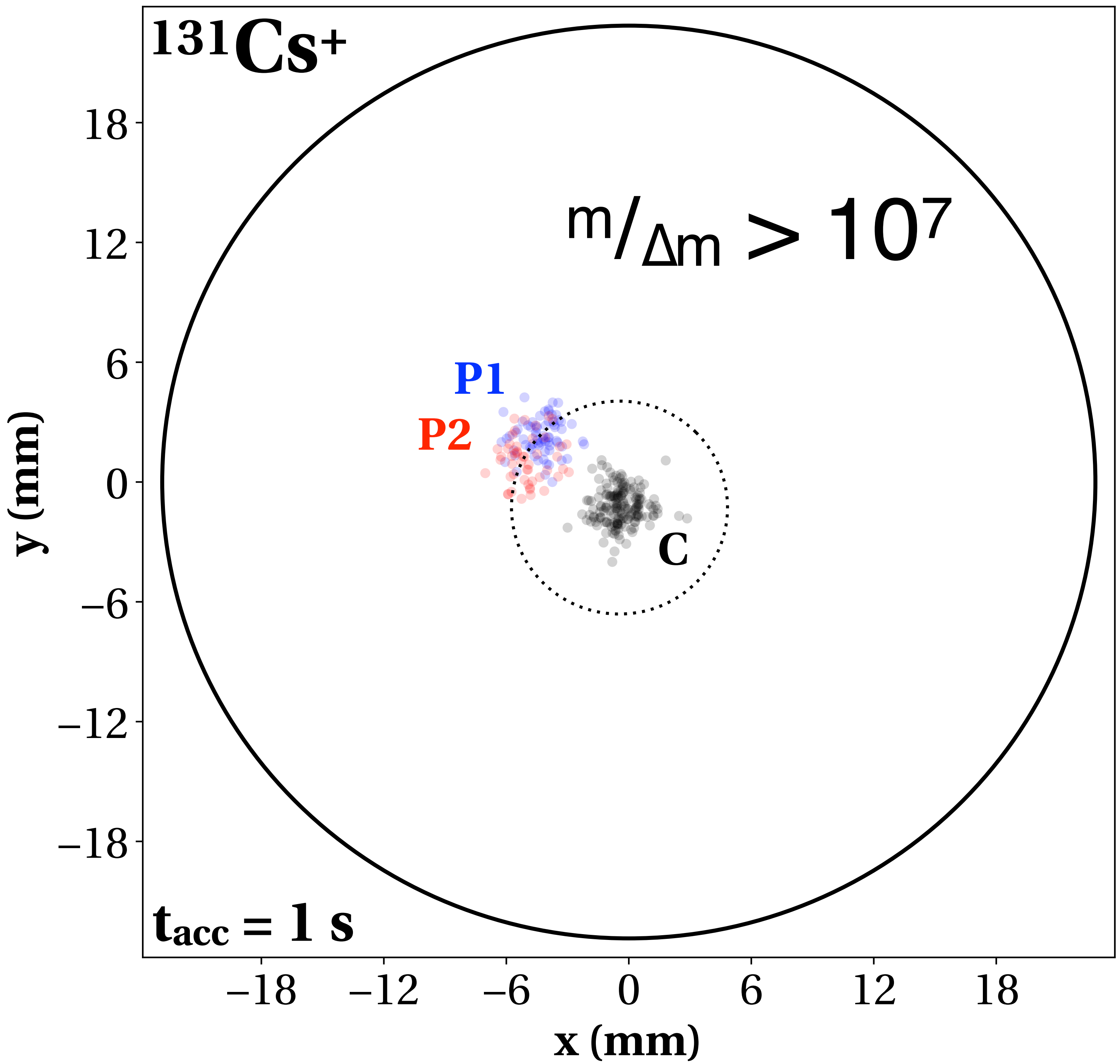

L. Gastaldo *et al.*, Eur. Phys. J. Special Topics 226, 1623–1694 (2017)

# Status report IS592 : Physics case

- Search for $\beta$-decay transitions with the lowest possible decay-energy
- Direct determination of the neutrino mass

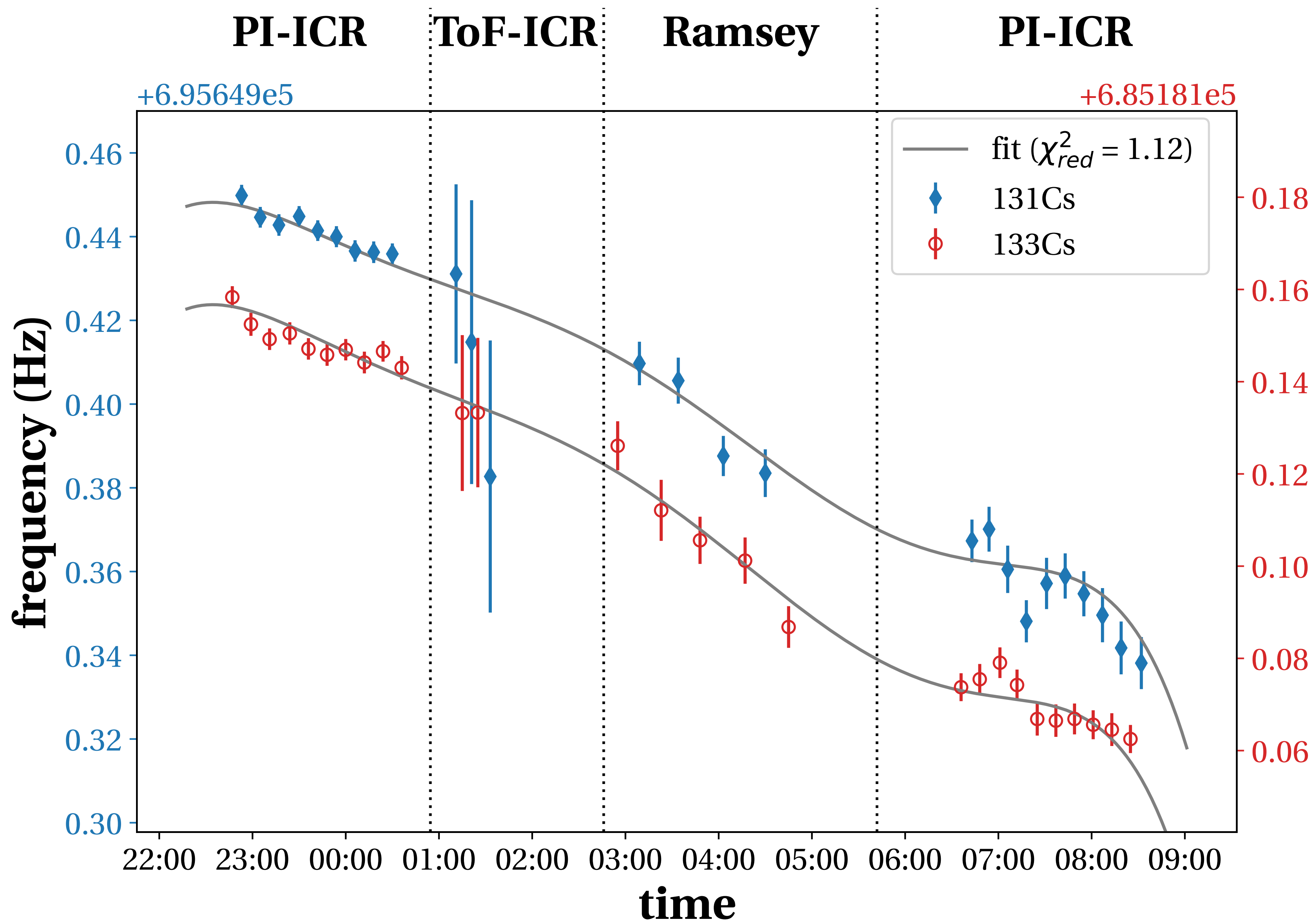
| Mother | $T_{1/2}$ | Stable Daughter | $Q_{ge}$ / keV | $\delta Q_{ge}$ / keV | Decay |
|---|---|---|---|---|---|
| $^{131}Cs$ | 9.7 d | $^{131}Xe$ | -15<br>-11 | 5<br>5 | $EC_L$<br>$EC_M$ |
| $^{134}Ce$ | 3.2 d | $^{134}La$ | -8.4 | 29 | $EC_K$ |
| $^{159}Dy$ | 144 d | $^{159}Tb$ | -0.21 | 2.0 | $EC_M$ |
| $^{175}Hf$ | 70 d | $^{175}Lu$ | 0.20<br>-5.94 | 2.6<br>2.6 | $EC_L$<br>$EC_K$ |

# Status report IS592 : Status




J. Karthein *et al.*, Hyperfine Interact (2019) 240:61

# Status report IS592 : Status




- very good agreement with well-established PTMS techniques
- 4 hrs beam time: $^{\delta m}/_{m} < 1.4 \cdot 10^{-9}$ with $\delta m < 200$ eV

J. Karthein *et al.*, Hyperfine Interact (2019) 240:61

# Status report IS592 : Status

- Improve $Q_{ec}$ uncertainty by factor 25
- Preclude $^{131}$Cs as possible candidate for $\nu_e$-mass determination
- Successful PI-ICR online test (1st ISOLTRAP publication on PI-ICR)

| Mother | $T_{1/2}$ | Daugh. | $Q_{ge}$ / keV | $\delta Q_{ge}$ / keV | Decay |
|---|---|---|---|---|---|
| $^{131}$Cs | 9.7 d | $^{131}$Xe | -15<br>-11 | 5<br>5 | $EC_L$<br>$EC_M$ |
| $^{131}$Cs | 9.7 d | $^{131}$Xe | -11.5<br>-7.2 | 0.2<br>0.2 | $EC_L$<br>$EC_M$ |

J. Karthein *et al.*, Hyperfine Interact (2019) 240:61

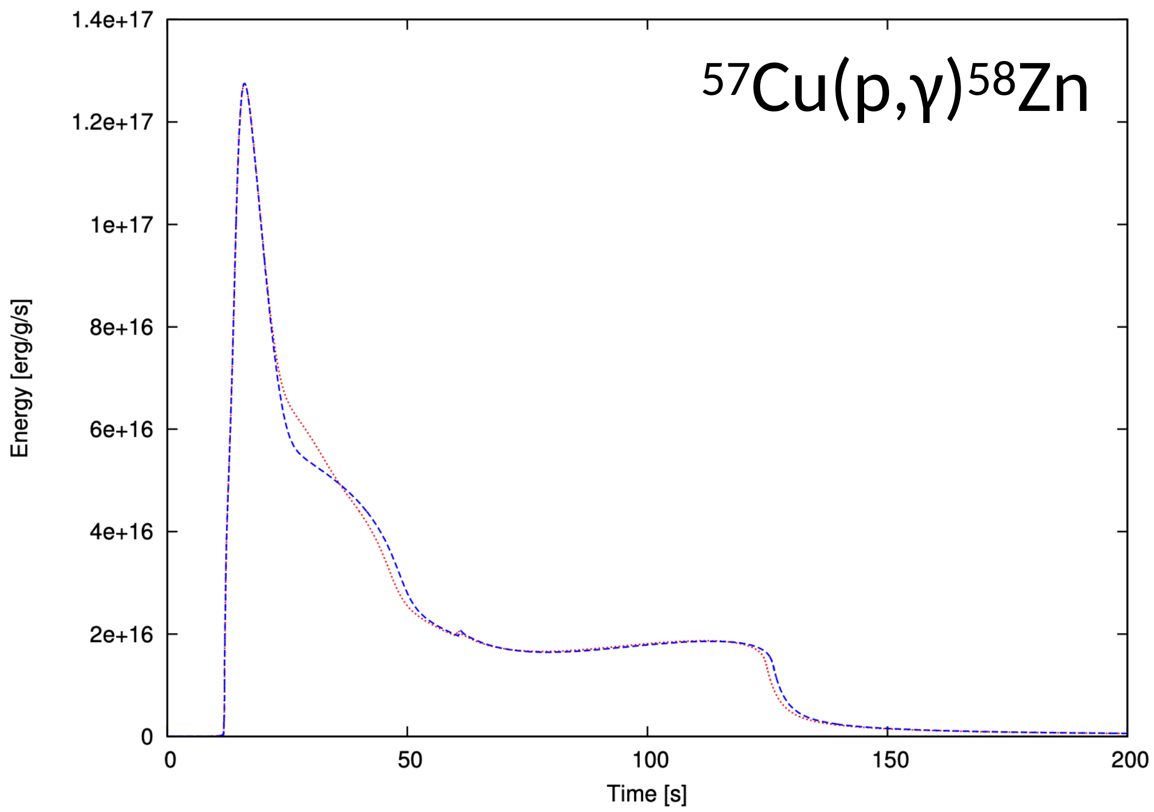
# Status report IS592 : Shift request

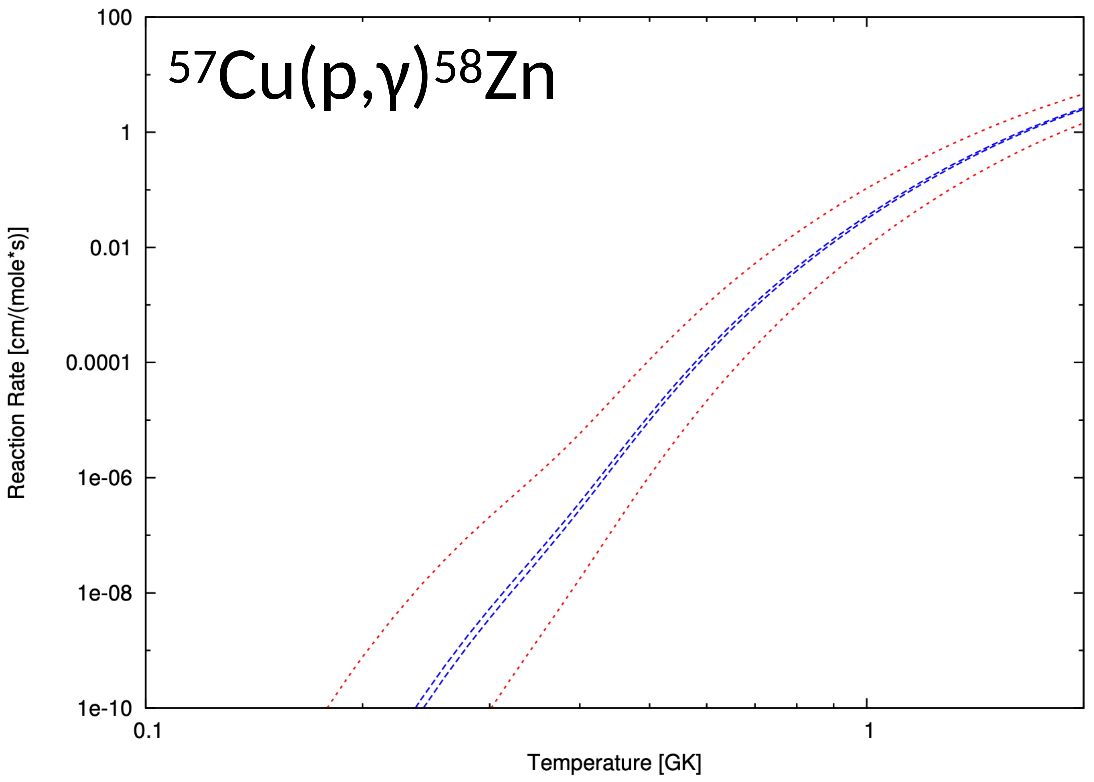
| Isotope | Half-life(d) | Yield (ions/$\mu C^{-1}$) | Target | Ionisation Method | Shifts (8H) |
|---|---|---|---|---|---|
| $^{159}Dy$ | 144 | $10^8$ | Ta | Surface | 12 |
| $^{159}Tb$ | Stable | $10^7$ | | | |
| $^{175}Hf$ | 70 | $>10^7$ | Ta | Hot Plasma | 12 |
| $^{175}La$ | Stable | Plenty | | | |
| | | | | | **Total Shifts: 24** |

| Mother | $T_{1/2}$ | Daugh. | $Q_{ge}$ / keV | $\delta Q_{ge}$ / keV | Decay |
|---|---|---|---|---|---|
| $^{131}Cs$ | 9.7 d | $^{131}Xe$ | -15<br>-11 | 5<br>5 | $EC_L$<br>$EC_M$ |
| $^{134}Ce$ | 3.2 d | $^{134}La$ | -8.4 | 29 | $EC_K$ |
| $^{159}Dy$ | 144 d | $^{159}Tb$ | -0.21 | 2.0 | $EC_M$ |
| $^{175}Hf$ | 70 d | $^{175}Lu$ | 0.20<br>-5.94 | 2.6<br>2.6 | $EC_L$<br>$EC_K$ |

# Status report IS625 : Physics case

- How does the *rp*-process proceed beyond $^{56}$Ni in Type-I X-Ray bursts ?
- Ratio of (p,γ) to (γ,p) reaction rate $\propto exp(\frac{-Q(p,\gamma)}{kT})$
- Two reactions to consider :
  - $^{55}$Ni(p,γ)$^{56}$Cu —> measured in [1] by the LEBIT group
  - $^{57}$Cu(p,γ)$^{58}$Zn
- $^{58}$Zn mass excess uncertainty 50 keV —> aimed at factor 5 reduction



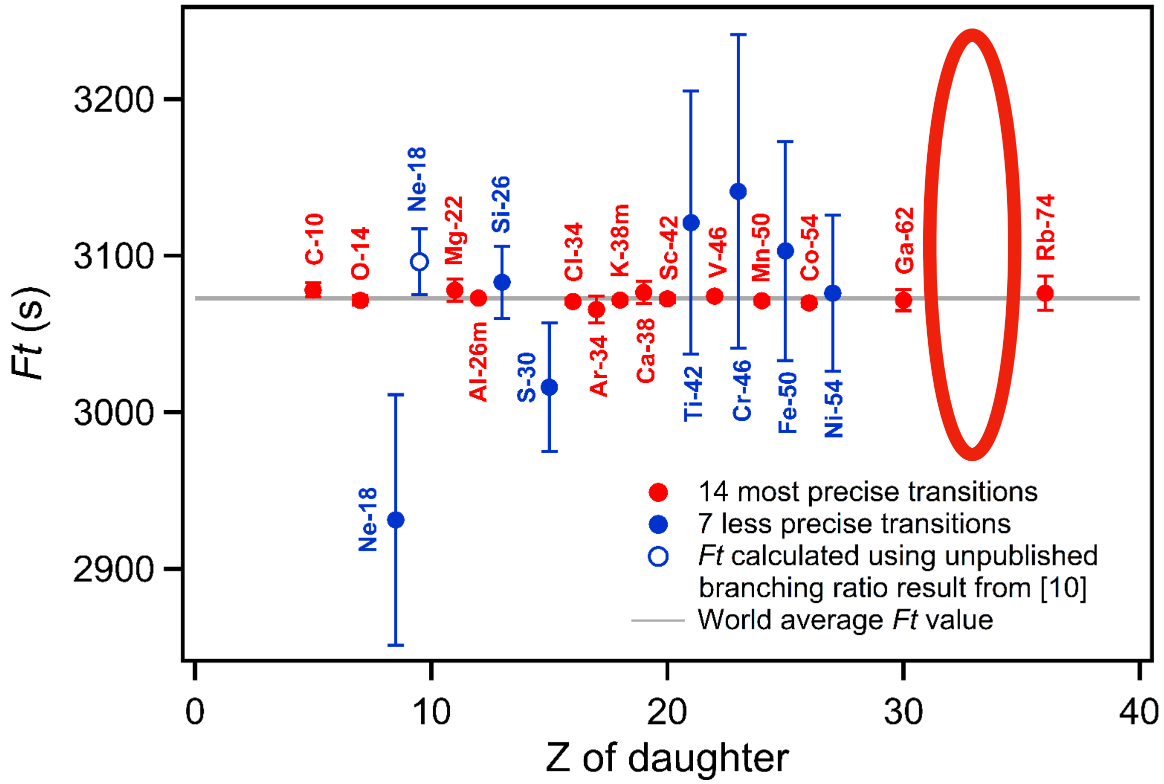

[1] A. A. Valverde et al., Phys. Rev. Lett. **120**, 032701 (2018)

# Status report IS625 : Shift request

| Isotope | Half-life (ms) | Yield (ions/$\mu C^{-1}$) | Target/ion source | Shifts (8H) |
|---|---|---|---|---|
| $^{58}Zn$ | 86.7 (24) | 10 | $ZrO_2$/RILIS | 3+9 |
| | | | | **Total Shifts: 12** |

- Stable Fe and/or Ni isobaric contaminants
- Required R = $\frac{m}{\Delta m}$ ~ 3000 —> HRS should be sufficient
- Should be feasible but difficult to guarantee (target variability)

# Status report IS642 : Physics case




$$\mathscr{F}t = ft(1+\delta'_R)(1+\delta_{NS}-\delta_C) = \frac{K}{2G_V^2(1+\Delta_R^V)}$$

- $ft$ depends on 3 experimental quantities
- $f$ statistical rate function ∝ $Q_{EC}{}^5$

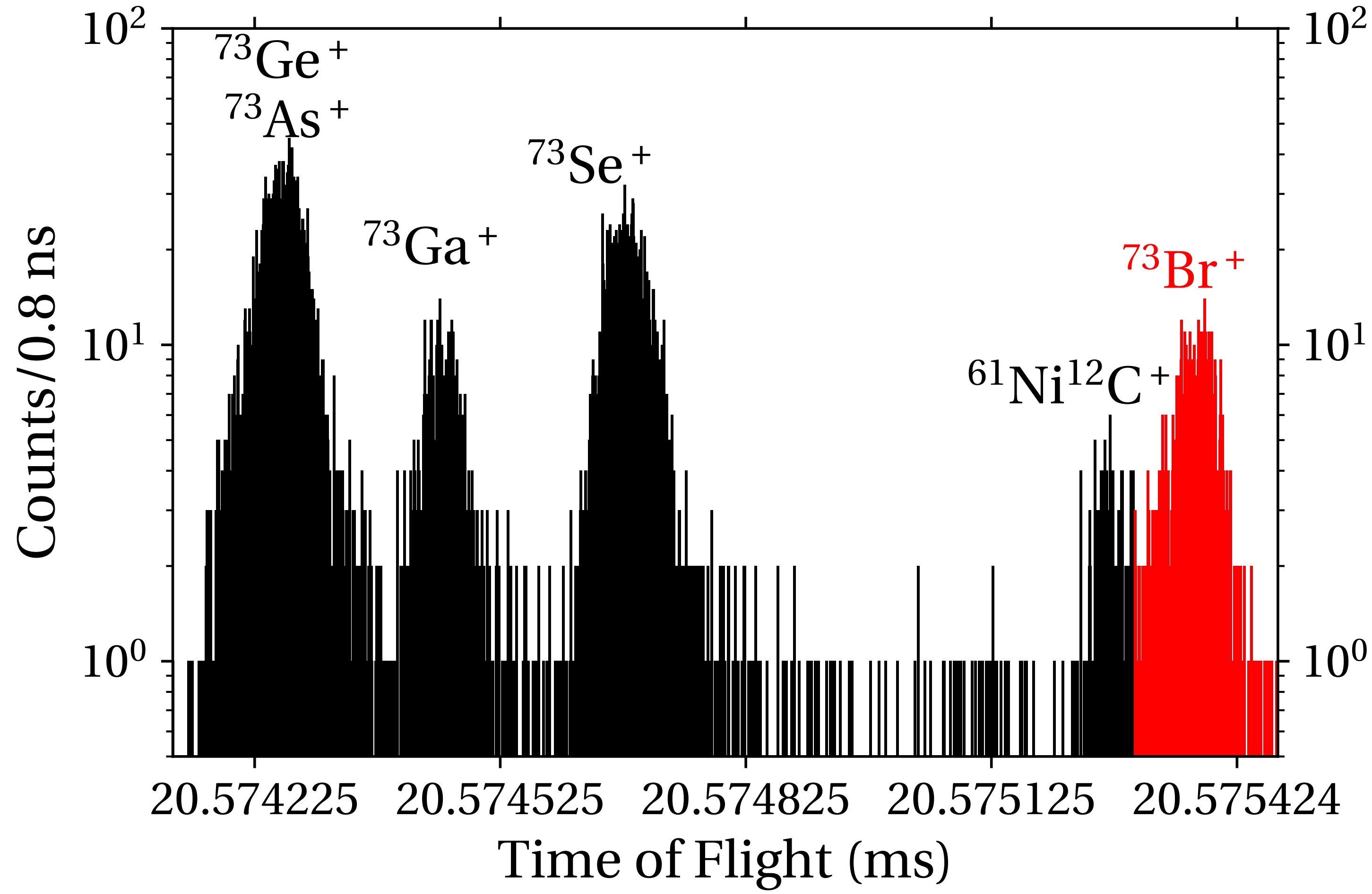
$$\overline{\mathcal{F}t} = 3072.27 \pm 0.72 \text{ s}$$

| $Q_{EC}$ (keV) | f | $P_{EC}$ (%) | ft (s) | *Ft*(s) |
|---|---|---|---|---|
| 9970 ± 170[1] | 38600 ± 3600 | 0,173 | 3096 ± 293 | **3086 ± 293** |
| 10504 ± 15[2,3] | 50979 ± 385 | 0,133 | 4087 ± 83 | **4078 ± 83** |

**12 sigma deviation —> Redetermination of $^{70g}$Br, $^{70m}$Br and $^{70}$Se**


[1] J. Savory, et al., Phys. Rev. Lett. 102, 132501 (2009).
[2] D.G. Jenkins et al., Phys. Rev. C 65. 064307 (2002)
[3] C. N. Davids, Atomic Masses and Fundamental Constants 6, edited by J. A. Nolen and W. Benenson (Plenum, New York) p. 419 (1980).

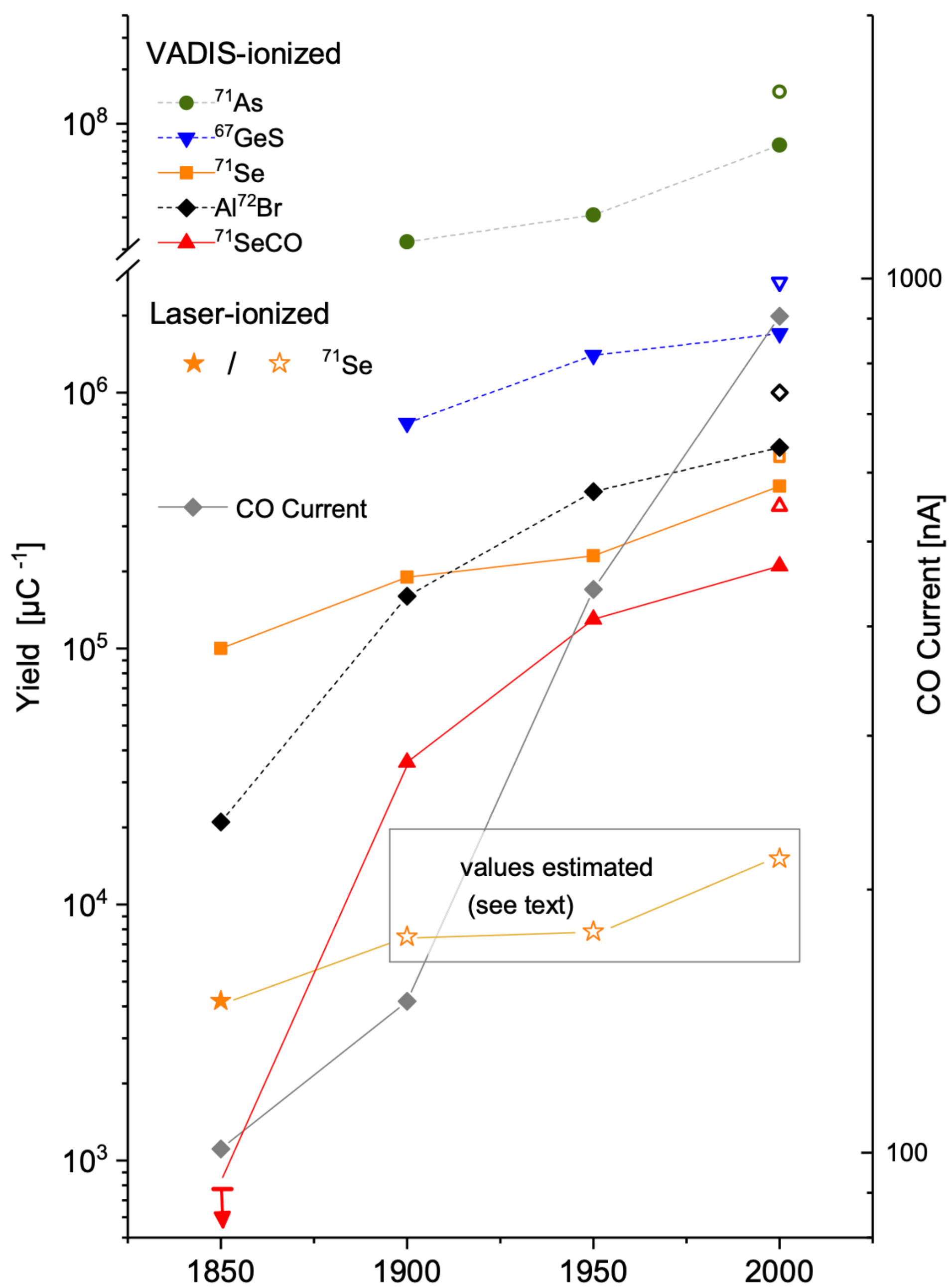
# Status report IS642 : Status



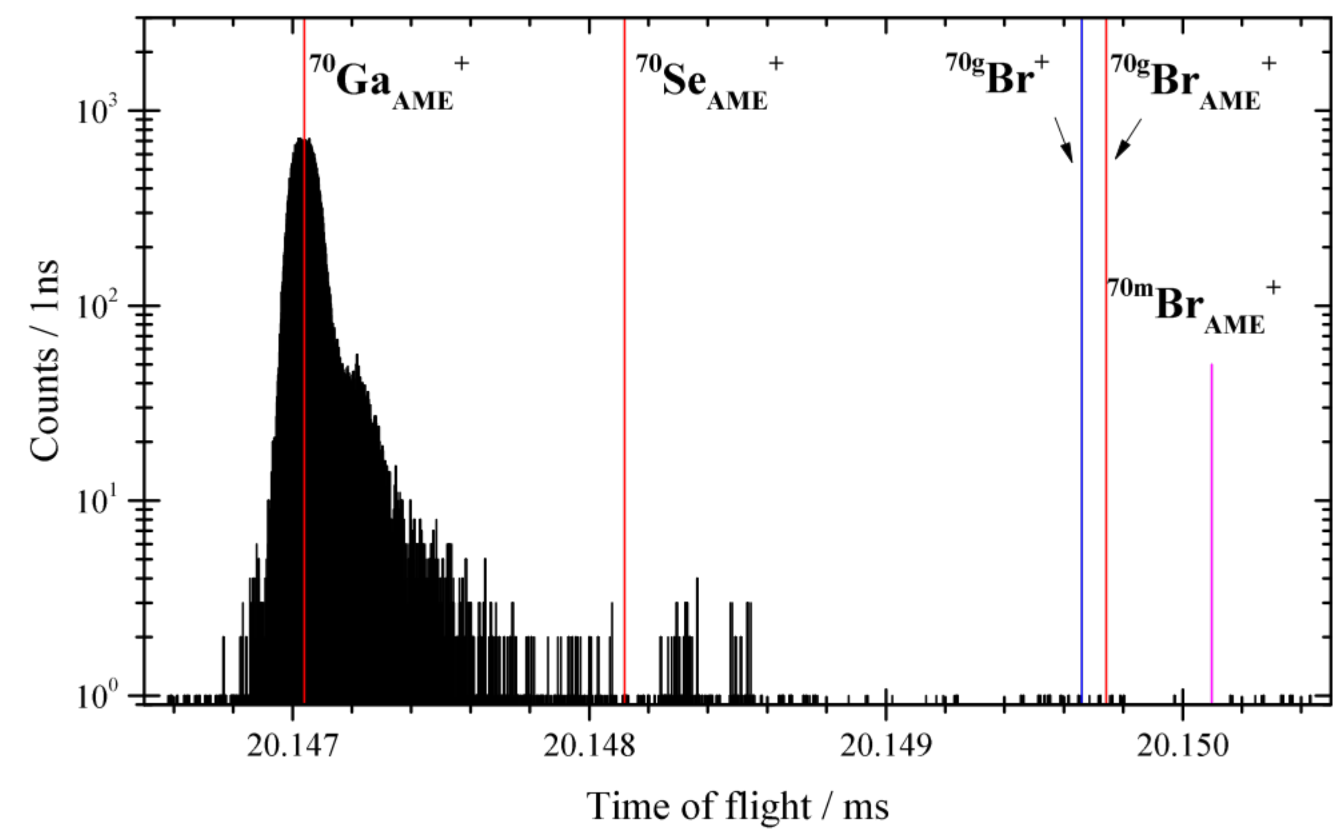

- $^{73}Br^+$ —> already one order of magnitude less than contaminants
- *A*=70 strong Ga and As beams but **NO** $^{70}$Br/Se seen
- **No** $^{27}Al^{70}Br^+$ sideband observed

# Status report IS642 : Shift request

| Isotope | Half-life | Yield (ions/$\mu$C$^{-1}$) | Target | Ionisation Method | Shifts (8H) |
|---|---|---|---|---|---|
| $^{70}$Br | 79.1 ms | $10^{3-4}$ | ZrO or Nb foil | Hot Plasma | 2.5 |
| $^{70}$Se | 41.1 days | | | | |
| | | | | | **Total Shifts: 5(+ 1 for tuning)** |




K. Chrysalidis *et al.*, Eur. Phys. J. A (2019) 55: 173




- Se beam production with VADLIS could be tried
- Br should be feasible
- TISD requested before scheduling

# Summary :

- 21 Scientific publications in the period 2014-2019
- Major technical development —> PI-ICR
  - First isomeric separation of $^{129g,m}Cd$
- MR-ToF MS is a flexible tool :
  - First mass measurement of $^{132}Cd$
- Close 5 proposals with no shifts remaining
- Request to keep 4 proposals open :
  - Total shift starting 2019 : 37
  - Total requested shift :
    37 (remaining) + 14 (new) = 51

# Acknowledgment :


D. Atanasov, K. Blaum, T. Cocolios, S. Eliseev, F. Herfurth, A. Herlert, J. Karthein, I. Kulikov, Y. A. Litvinov, D. Lunney, V. Manea, M. Mougeot, D. Neidherr, L. Schweikhard, A. Welker, F. Wienholtz, K. Zuber

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ISOLTRAP

https://isoltrap.web.cern.ch

Federal Ministry of Education and Research

Grants No.: 05P15ODCIA 05P15HGCIA

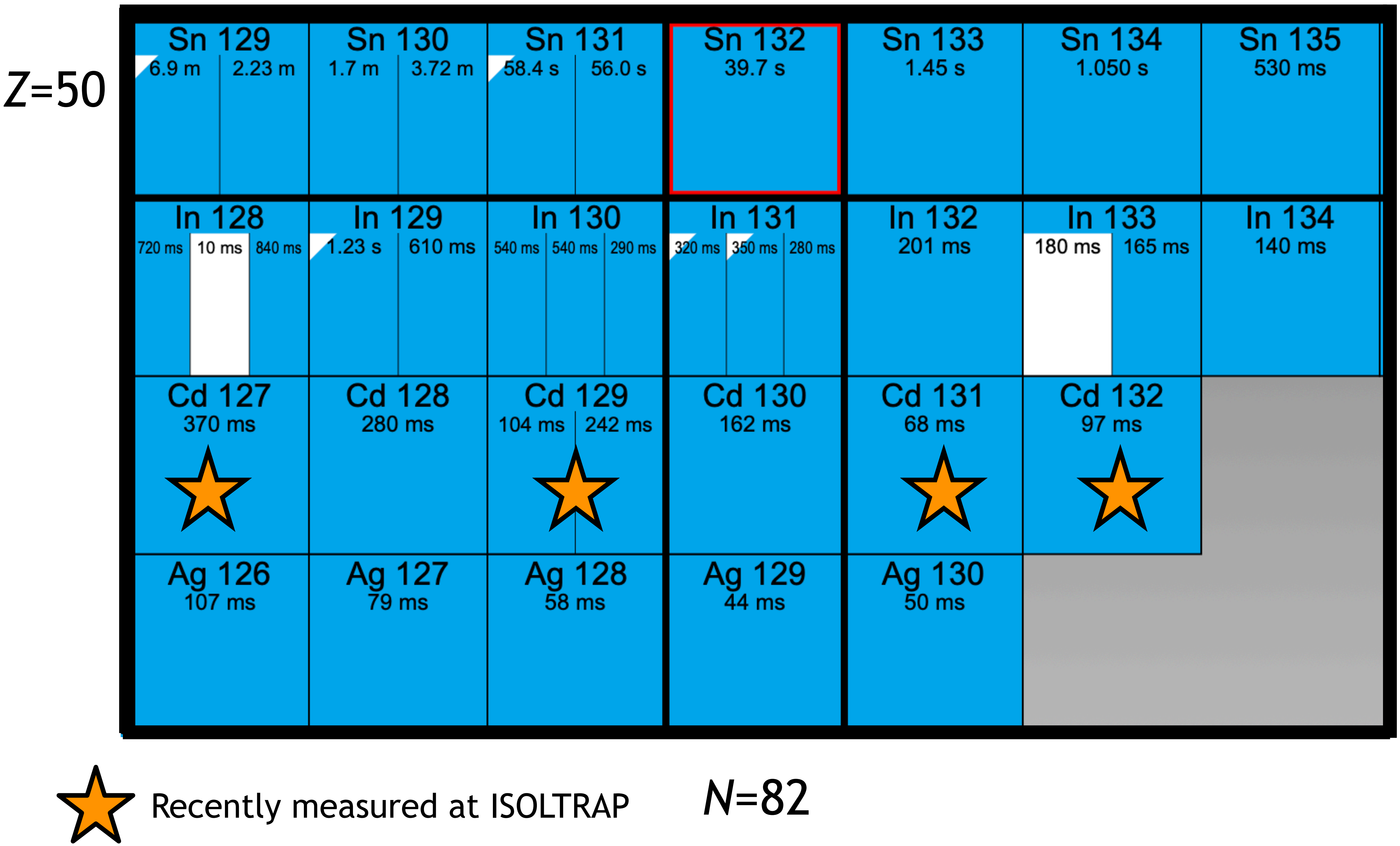
CNRS — dépasser les frontières

IN2P3 — Les deux infinis

Max-Planck-Gesellschaft

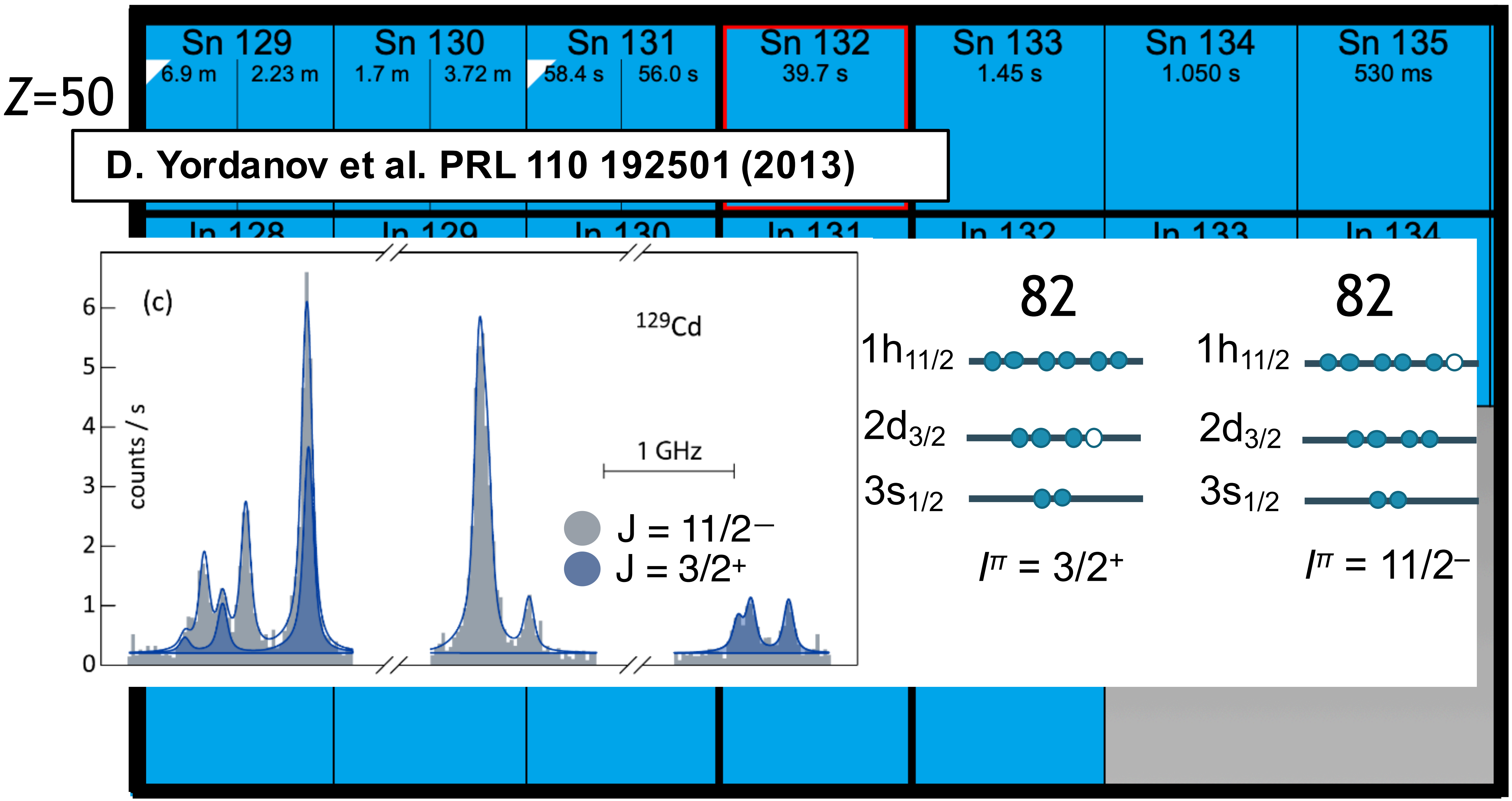
ENSAR

# $^{127-132}$Cd : Strength *N* = 82 shell-gap ?




V. Manea, J. Karthein *et al.*, Submitted to Phys. Rev. Lett. (2019)

# HFS study of odd-A < 130 isotopes :

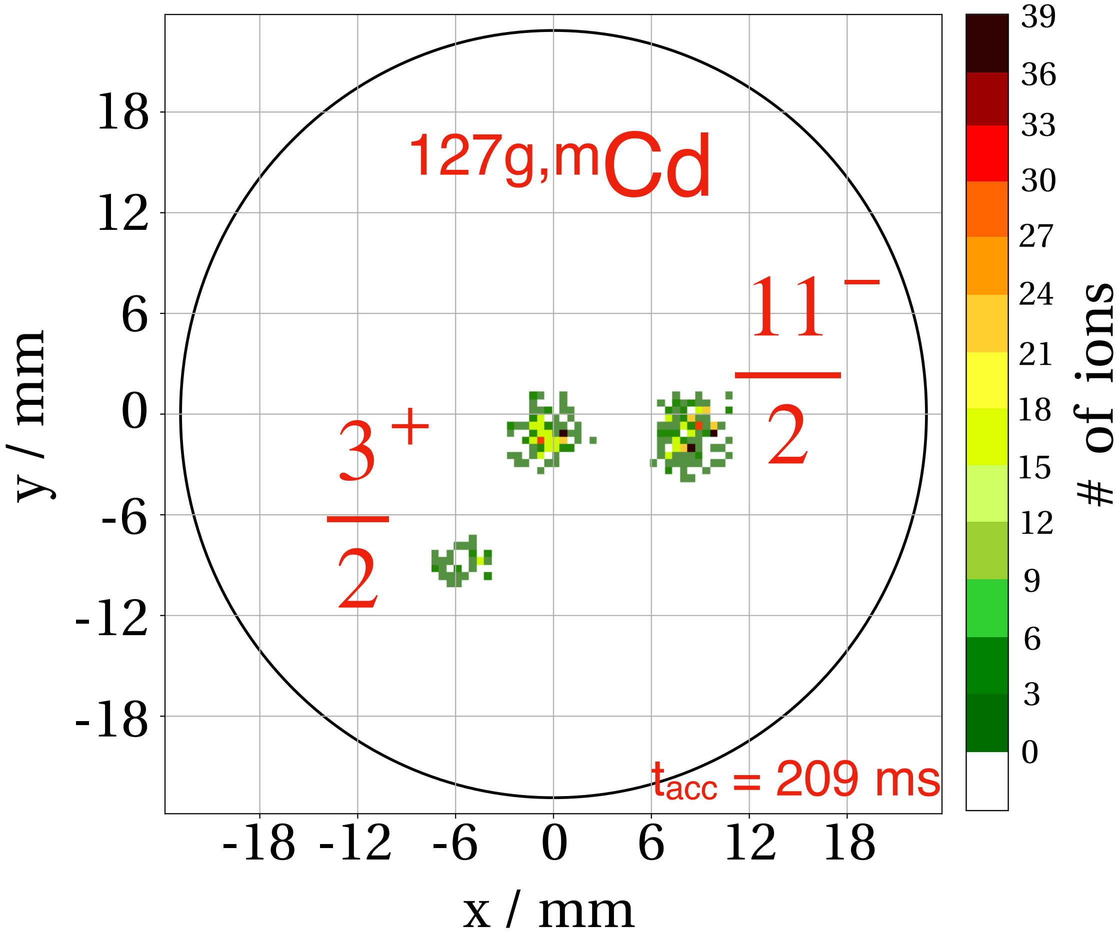


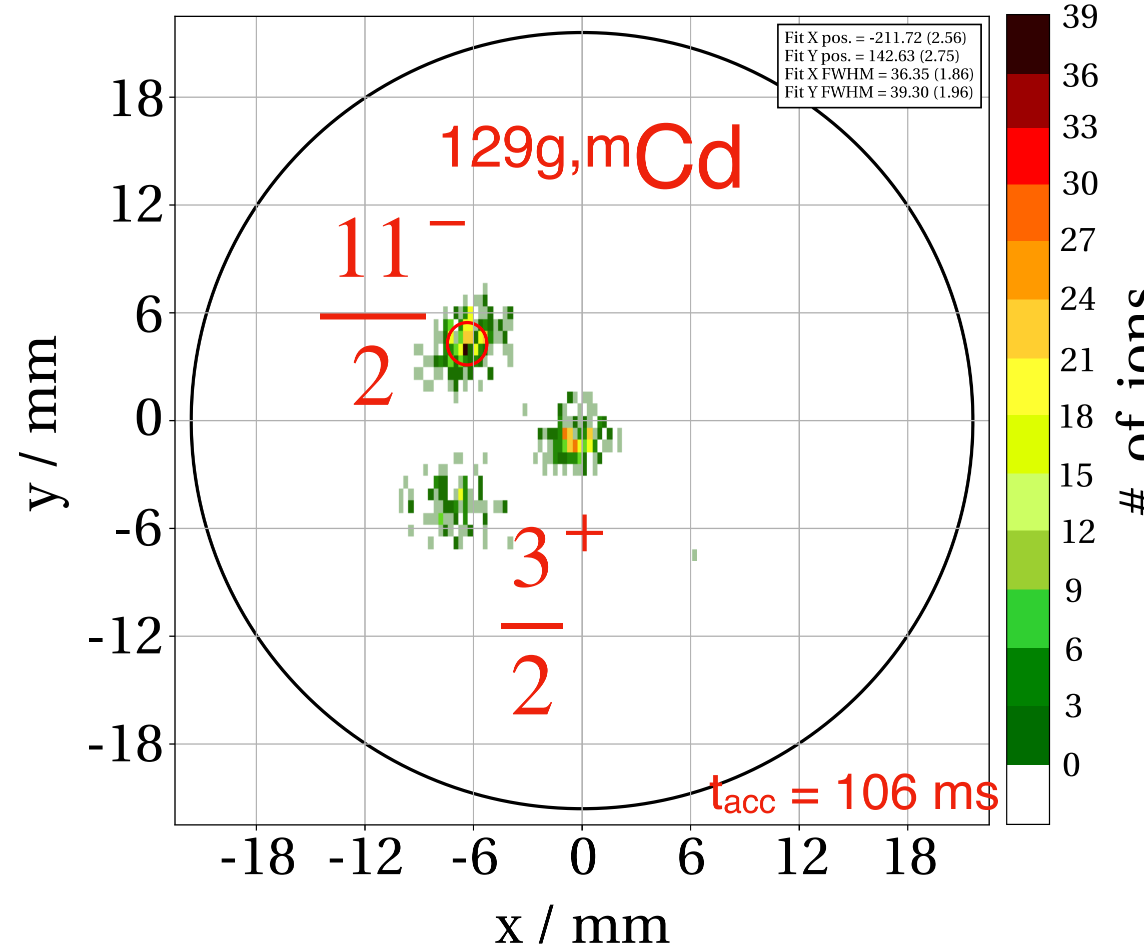

Recently measured at ISOLTRAP

*N*=82

V. Manea, J. Karthein *et al.*, Submitted to Phys. Rev. Lett. (2019)

# $^{129g,m}$Cd Spin assignment :

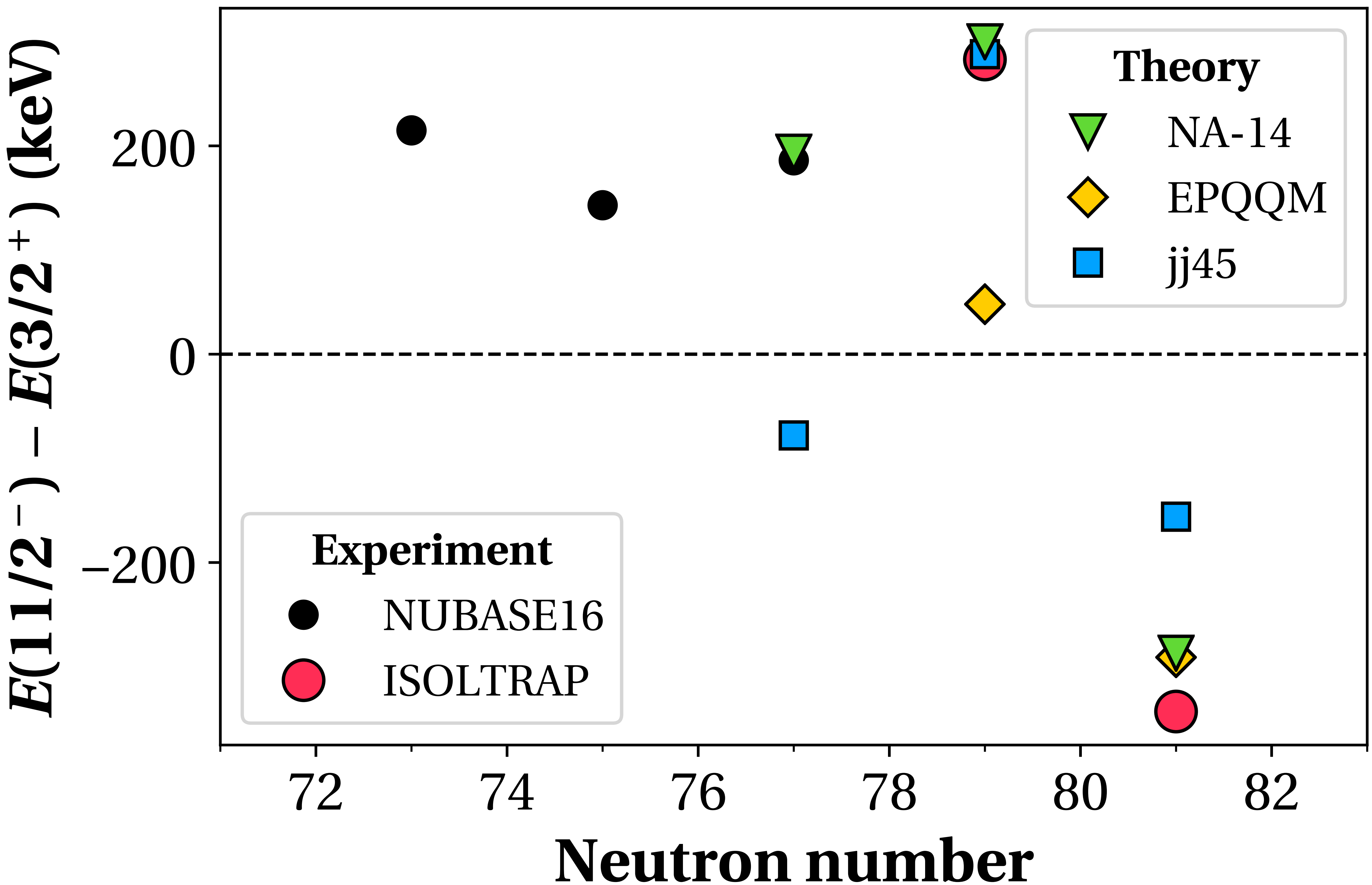



- Resolving power $R = \dfrac{m}{\Delta m} > 10^6$ in 106 ms
- $^{129m}$Cd excitation energy measured for the first time

V. Manea, J. Karthein *et al.*, Submitted to Phys. Rev. Lett. (2019)

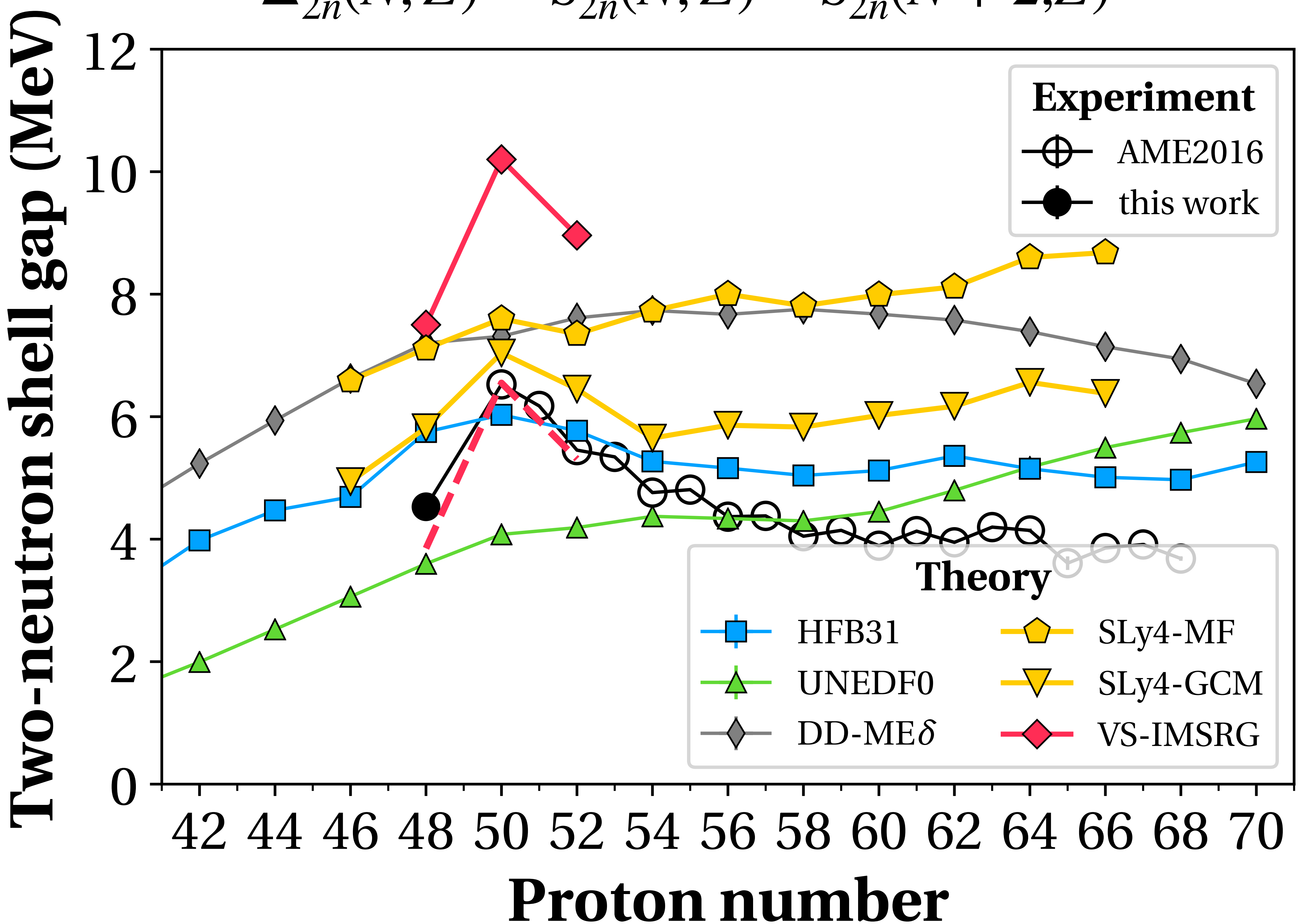
# $^{129g,m}$Cd state inversion




V. Manea, J. Karthein *et al.*, Submitted to Phys. Rev. Lett. (2019)

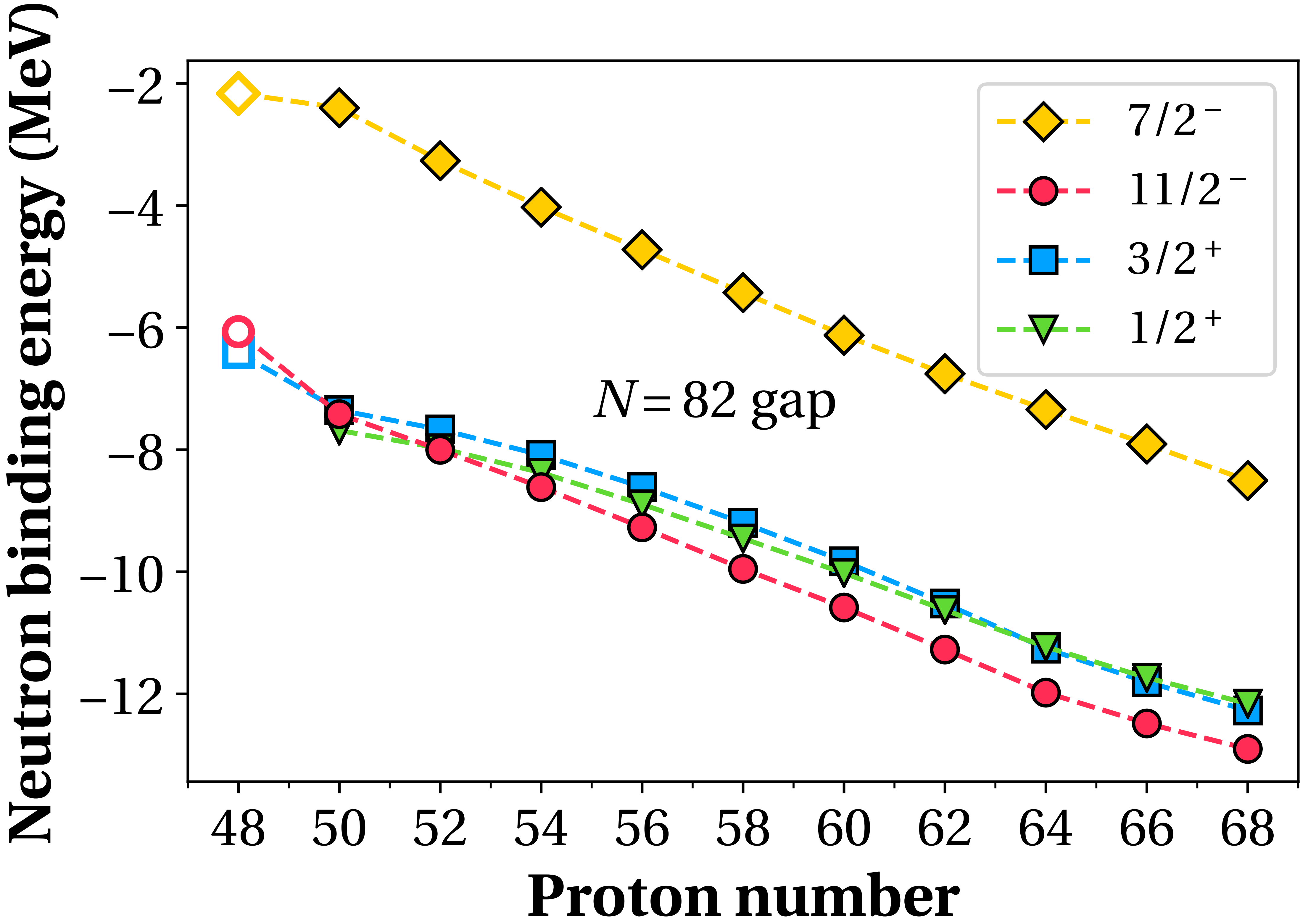
# N=82 two-neutron shell-gap ?

$$\Delta_{2n}(N,Z) = S_{2n}(N,Z) - S_{2n}(N+2,Z)$$




V. Manea, J. Karthein *et al.*, Submitted to Phys. Rev. Lett. (2019)

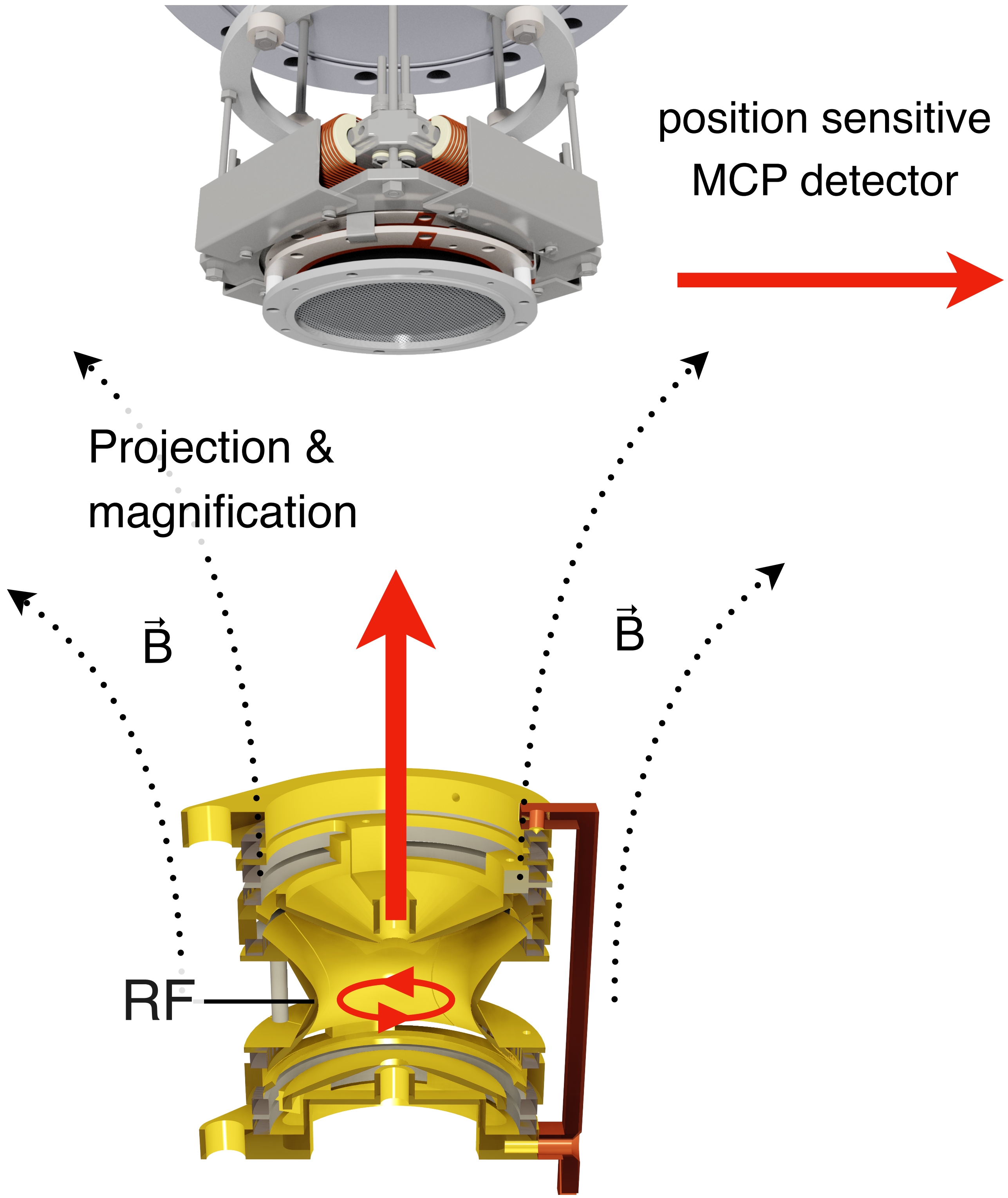
# First point below Z = 50

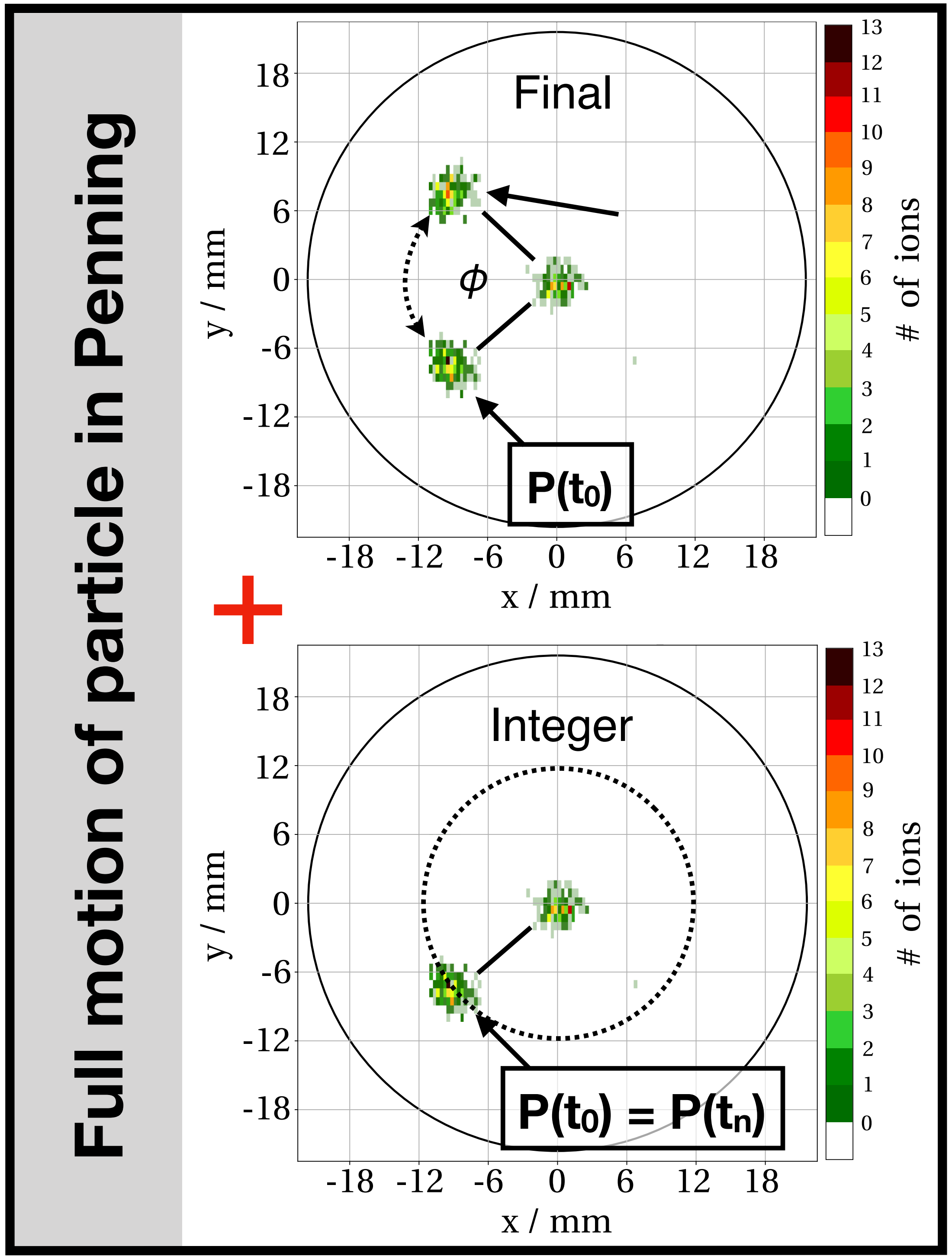



V. Manea, J. Karthein *et al.*, Submitted to Phys. Rev. Lett. (2019)

# PI-ICR :

S. Eliseev et al., Phys. Rev. Lett. 110, 082501

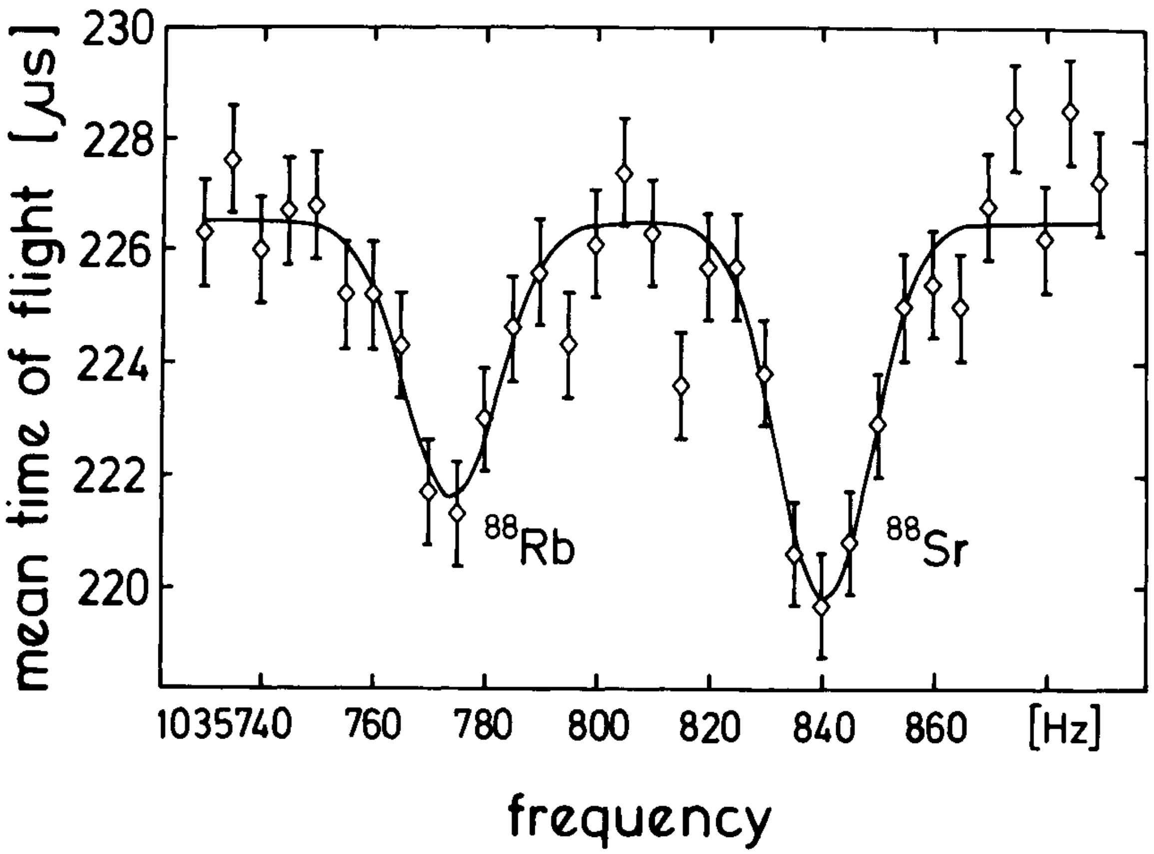


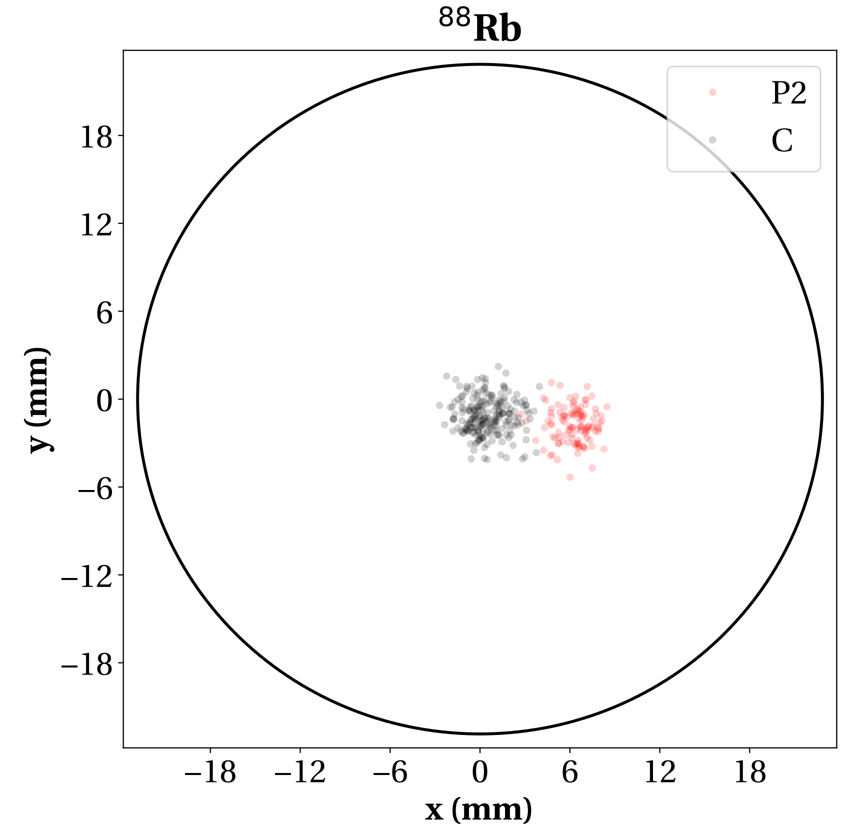
# PI-ICR: commissioning

F. Kern, *AIP Conf. Proc.* **164**, 22 (1987)

in 1987:




in 2017:




- $Q(^{88}Sr \rightarrow {}^{88}Rb)$ = -5300(180) keV
- $Q(^{88}Sr \rightarrow {}^{88}Rb)_{AME16}$ = -5312.62(16) keV
- $Q(^{88}Sr \rightarrow {}^{88}Rb)$ = -5312.68(13) keV

# Need for more than one $Q_{EC}$

$Q$-value of EC in $^{163}$Ho