*Proposal to the ISOLDE and Neutron Time-of-Flight Committee*

77th Meeting – 12.11.2024

# Precise mass measurement of light and heavy neutron-rich noble-gas isotopes for nuclear structure studies

INTC-P-715

**Daniel Lange[1,2] for the ISOLTRAP collaboration**

[1]Max-Planck-Institute for Nuclear Physics, Heidelberg

[2]Heidelberg University

# Motivation

**Mass filters:**

**Neutron Binding Energy $S_{1n}$**

$$S_{1n}(Z,N) = B(Z,N) - B(Z,N-1)$$

**Two-Neutron Separation Energy $S_{2n}$**

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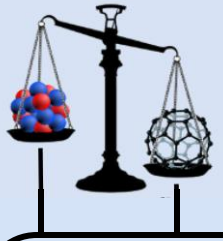

$$M_{atom}(Z,N) = M_{nuc}(Z,N) + Z \cdot m_e - B_e(Z)$$

$$M_{nuc}(Z,N) = Z \cdot m_p + N \cdot m_n + B(Z,N)/c^2$$

$$M_E(Z,N) = M_{atom}(Z,N) - (Z+N)u$$

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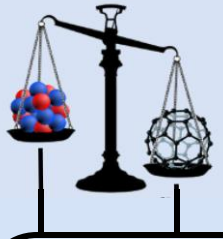

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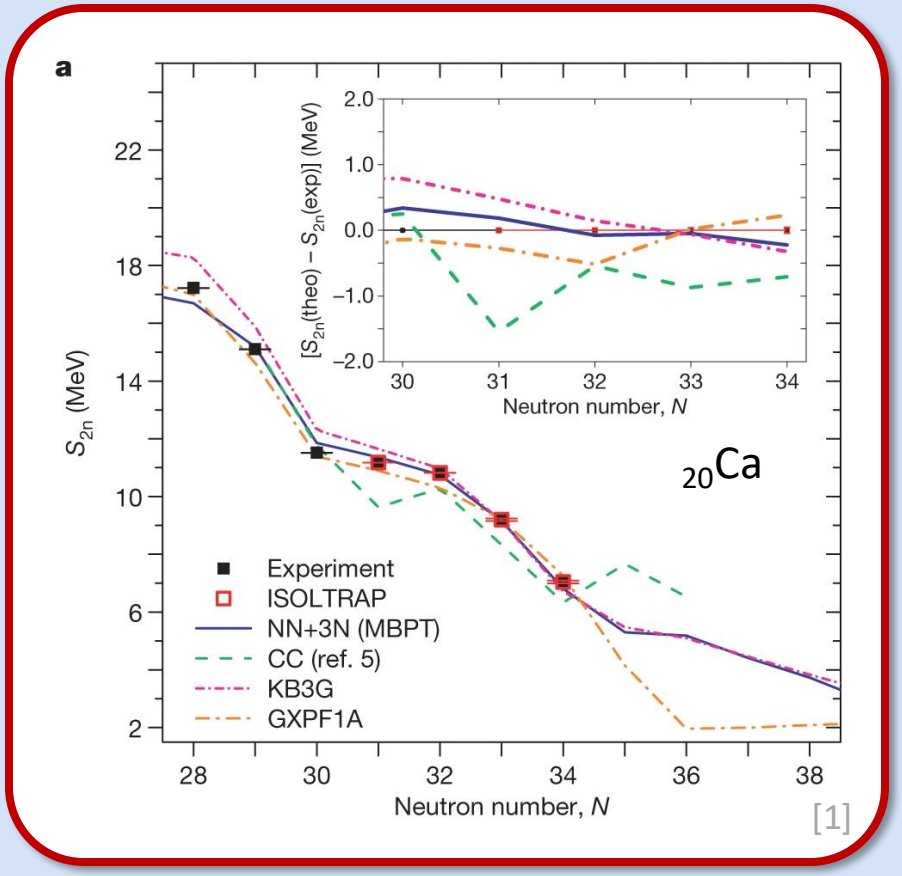


[1]

LETTER

doi:10.1038/nature12226

**Masses of exotic calcium isotopes pin down nuclear forces**

F. Wienholtz[1], D. Beck[2], K. Blaum[3], Ch. Borgmann[3], M. Breitenfeldt[4], R. B. Cakirli[3,5], S. George[1], F. Herfurth[2], J. D. Holt[6,7], M. Kowalska[8], S. Kreim[3,8], D. Lunney[9], V. Manea[9], J. Menéndez[6,7], D. Neidherr[2], M. Rosenbusch[1], L. Schweikhard[1], A. Schwenk[7,6], J. Simonis[6,7], J. Stanja[10], R. N. Wolf[1] & K. Zuber[10]

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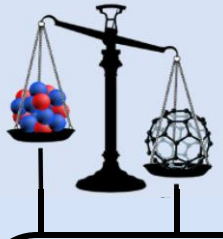
**Proton-Neutron Interaction $\delta V_{pn}$**

$$\delta V_{pn}^{ee}(Z,N) = {}^1/_4 \cdot [S_{2n}(Z,N) - S_{2n}(Z-2,N)]$$
$$\delta V_{pn}^{oe}(Z,N) = {}^1/_2 \cdot [S_{2n}(Z,N) - S_{2n}(Z-1,N)]$$



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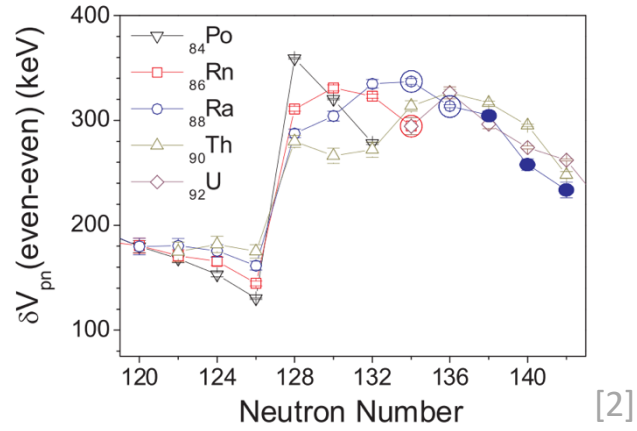
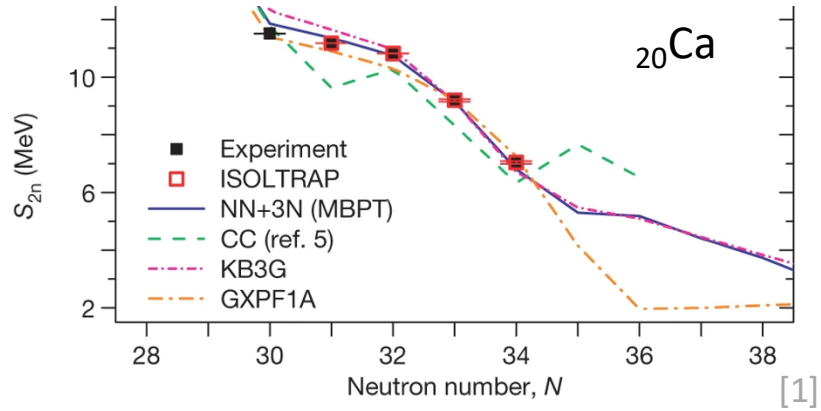


[2]



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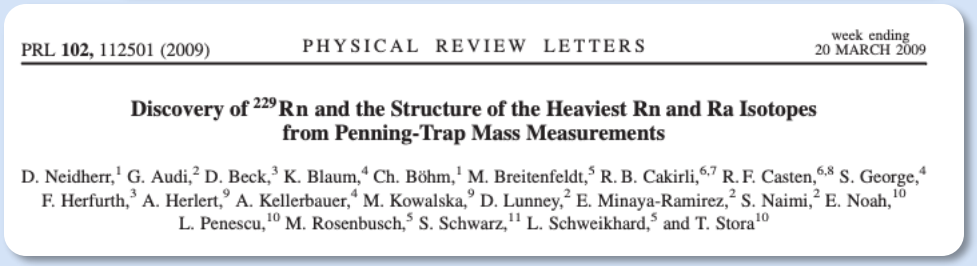


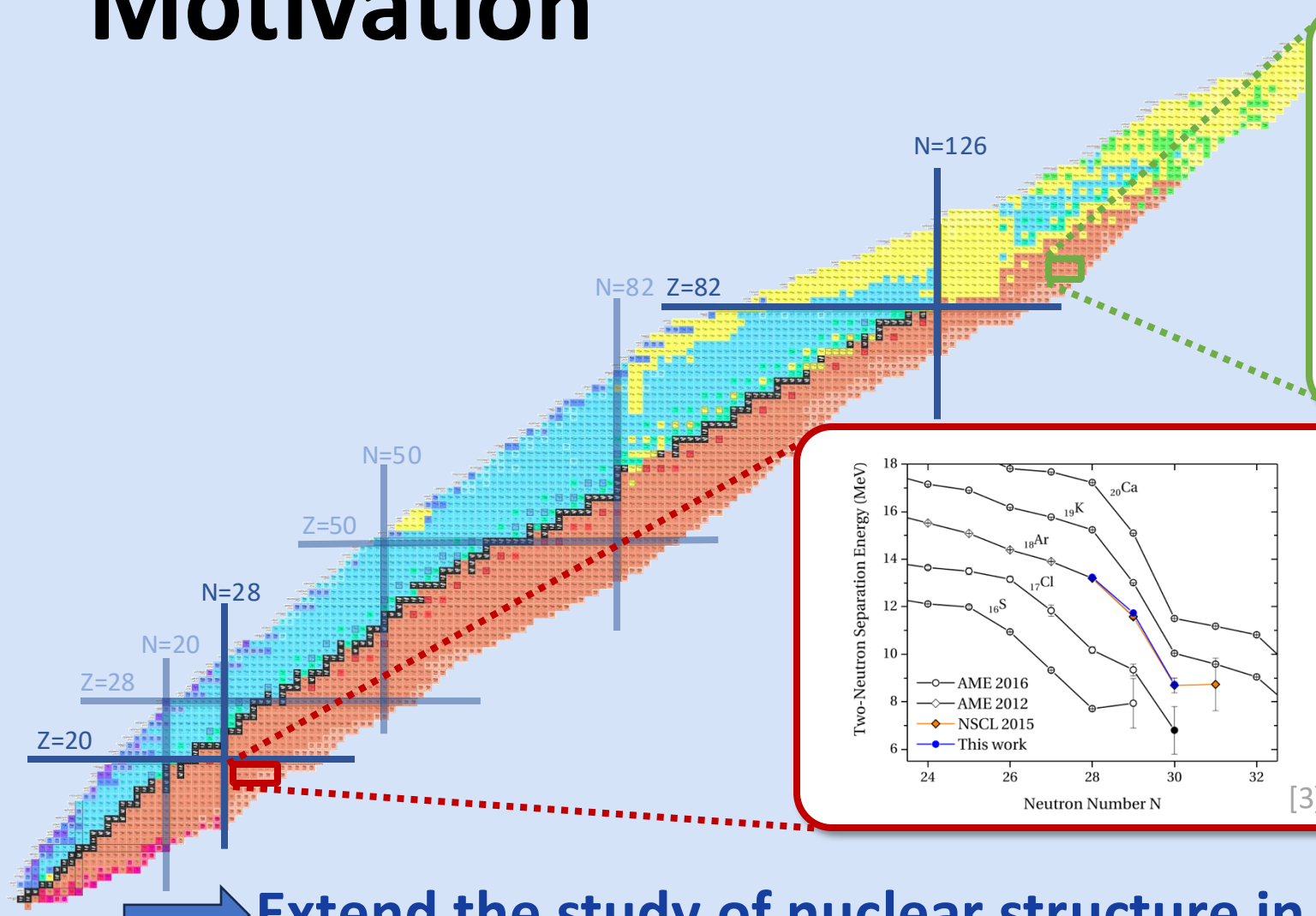
PRL 102, 112501 (2009) PHYSICAL REVIEW LETTERS week ending 20 MARCH 2009

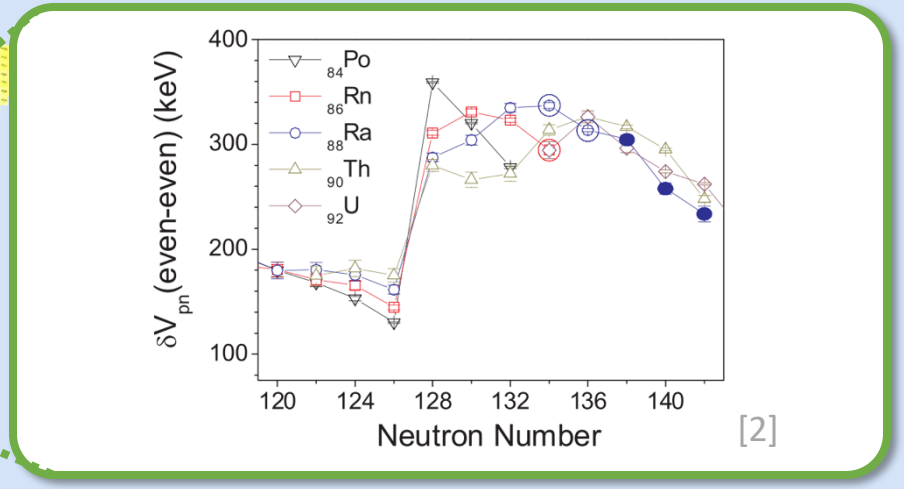
**Discovery of $^{229}$Rn and the Structure of the Heaviest Rn and Ra Isotopes from Penning-Trap Mass Measurements**

D. Neidherr,[1] G. Audi,[2] D. Beck,[3] K. Blaum,[4] Ch. Böhm,[1] M. Breitenfeldt,[5] R. B. Cakirli,[6,7] R. F. Casten,[6,8] S. George,[4] F. Herfurth,[3] A. Herlert,[9] A. Kellerbauer,[4] M. Kowalska,[9] D. Lunney,[2] E. Minaya-Ramirez,[2] S. Naimi,[2] E. Noah,[10] L. Penescu,[10] M. Rosenbusch,[5] S. Schwarz,[11] L. Schweikhard,[5] and T. Stora[10]


[1] F. Wienholtz *et al.*, Nature **498** (2013)
[2] D. Neidherr *et al.*, PRL **102**, 112501 (2009)

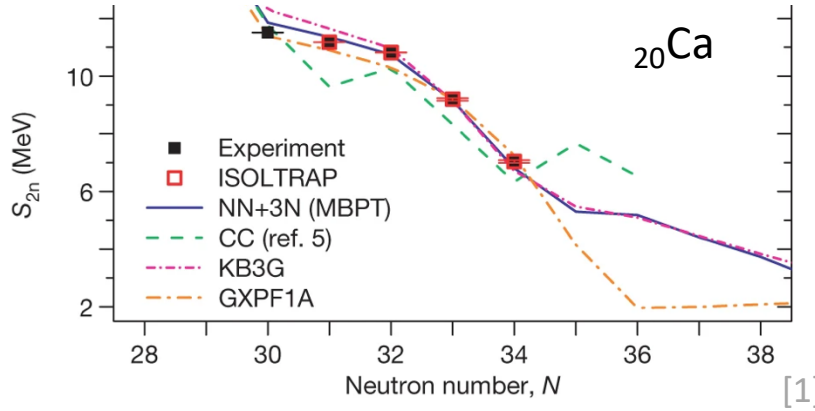
# Motivation







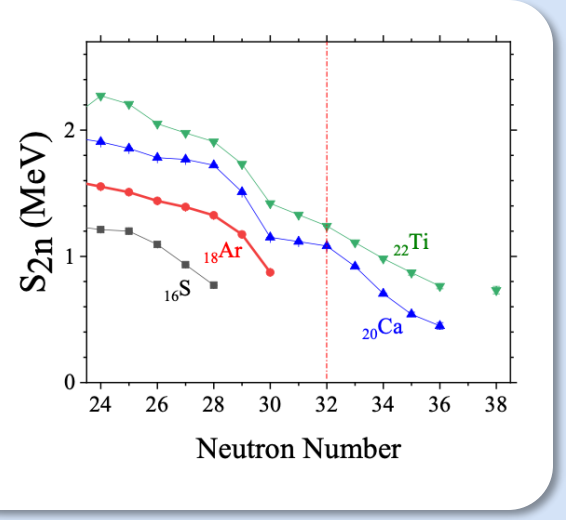



**Extend the study of nuclear structure in neutron-rich noble-gas isotopes**


[1] F. Wienholtz *et al.*, Nature **498** (2013)
[2] D. Neidherr *et al.*, PRL **102**, 112501 (2009)
[3] M. Mougeot *et al.*, PRC **102**, 014301 (2020)

# Motivation

## Neutron-rich argon:




- **First direct mass measurement** of $^{49,50}$Ar

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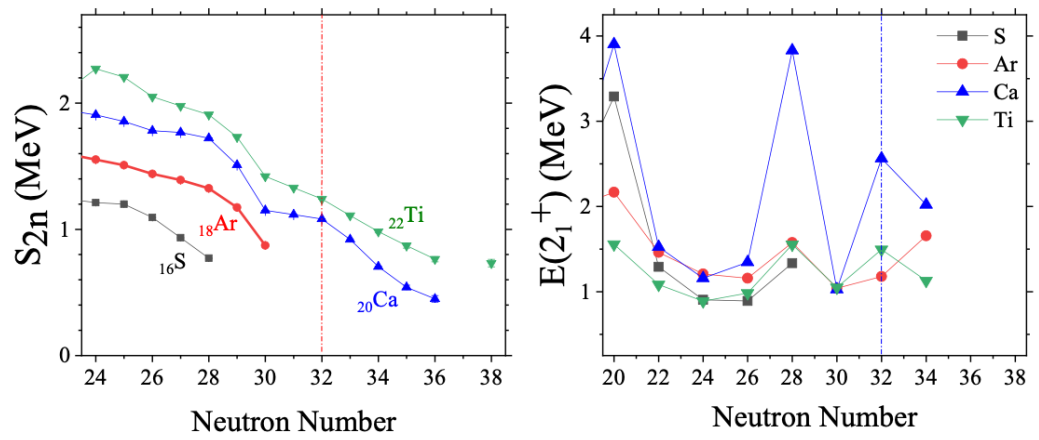


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- extract single and **two neutron binding energy $S_{2n}$** in $^{49,50}$Ar
  → **probe possible shell-closure at N=32**

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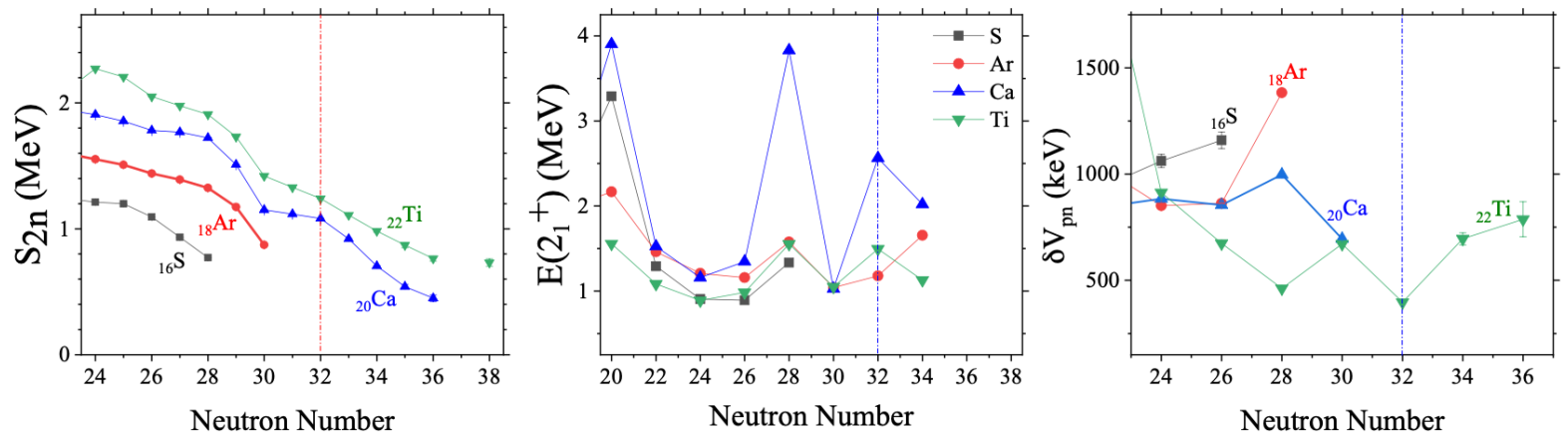


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- Precise mass measurement of $^{50}$Ar allows to probe the **proton-neutron interaction** in $_{20}$Ca at the **shell-closure N=32** ($\delta V_{pn}^{ee}(^{52}\mathrm{Ca})$)

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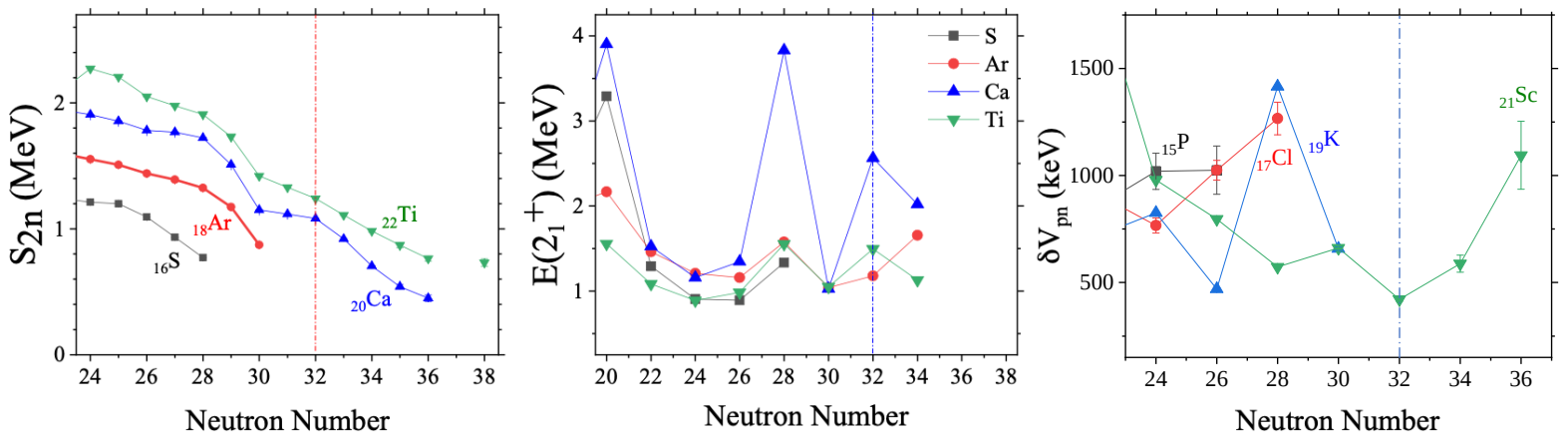


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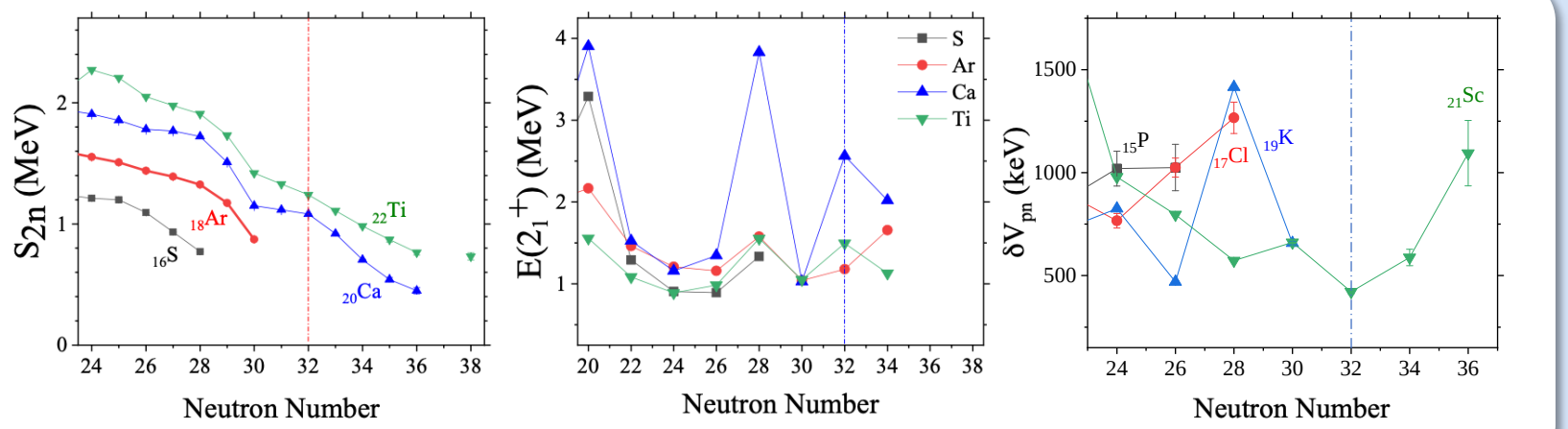


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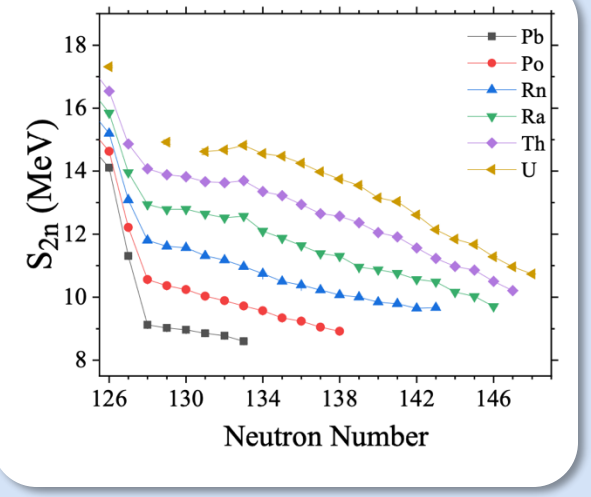
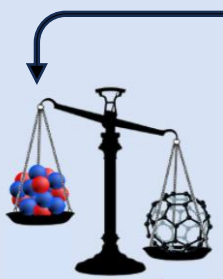
## Neutron-rich radon:

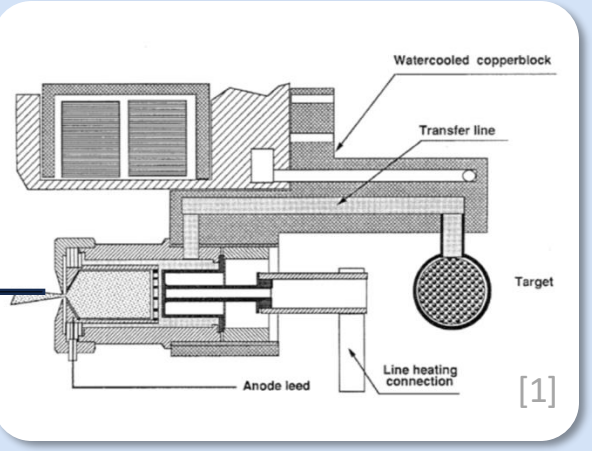



- **First discovery and direct mass measurement** of $^{230,231}$Rn
- study opposite inflection, **$S_{2n}$**
- refinement of mass models for nucleosynthesis, r-process [1,2,3]


[1] E. M. Holmbeck *et al.*, EPJ A **59**, 28 (2023)
[2] S. Brett *et al.*, EPJ A **48**, 184 (2012)
[3] J. Clark *et al.*, *EPJ* A. **59**, 204 (2023)

# Experimental Techniques

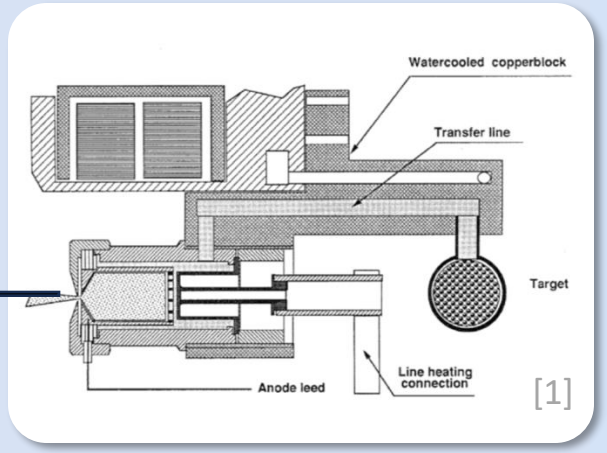




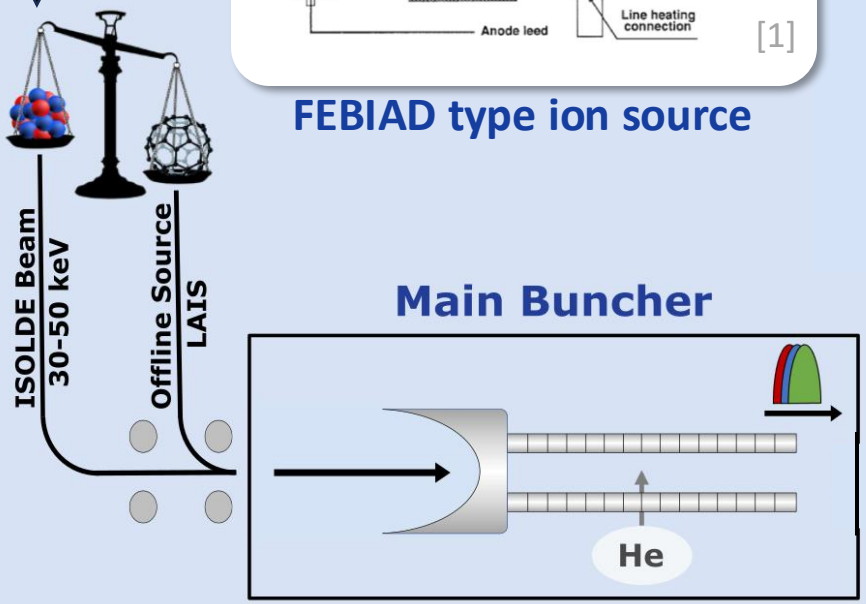

FEBIAD type ion source

- **uranium carbide target** (2000°C)
- effusion via a low-temperature, **water-cooled transfer line** to a **FEBIAD type plasma ion source**
- cold transfer line efficiently condensate possible isobaric contamination

# Experimental Techniques




FEBIAD type ion source



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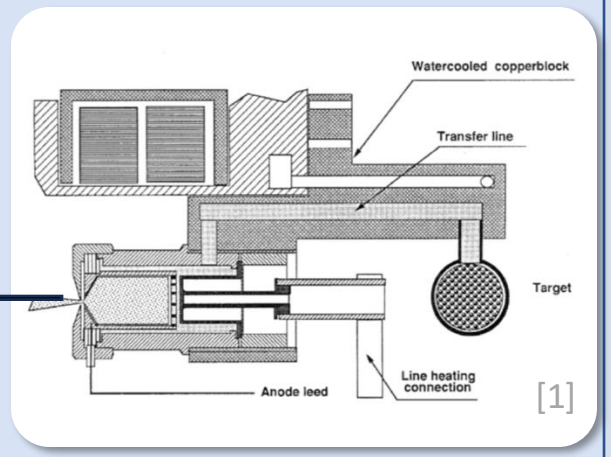


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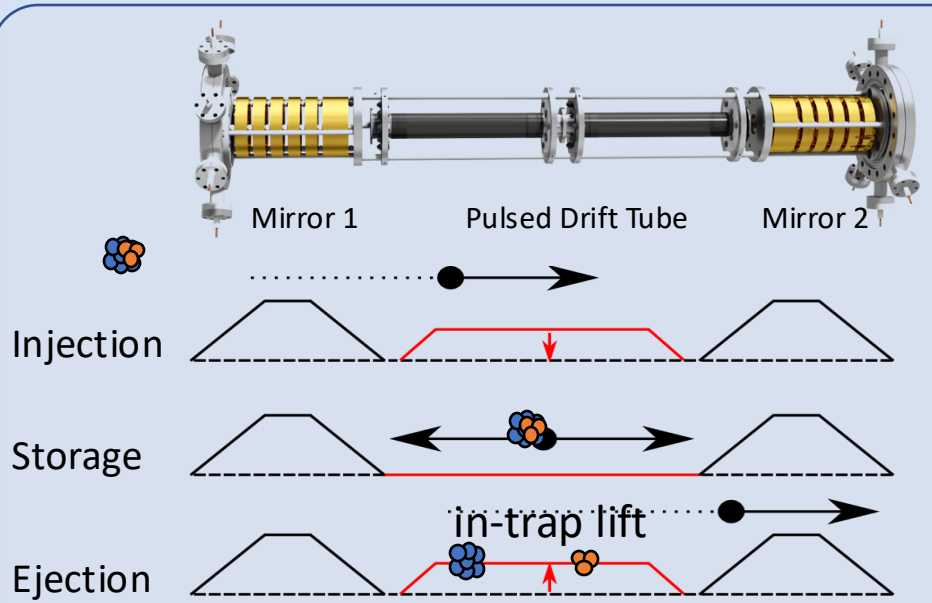
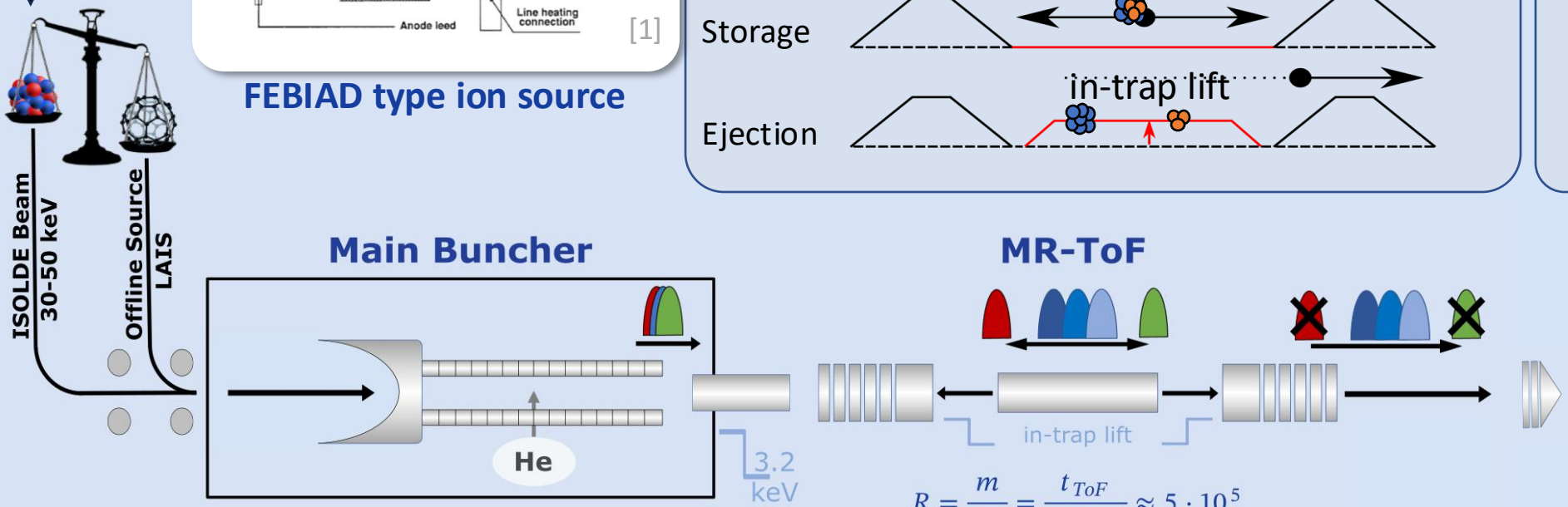



**MR-ToF MS:** [2,3]

- versatile and fast
- Mass separation or spectrometry
- **low yield and/or short half-life of ion of interest**
- isobaric contamination as calibrants



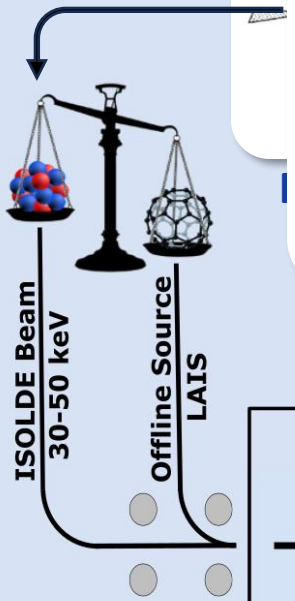

$$t_0 = A\sqrt{m_0/q} + B$$

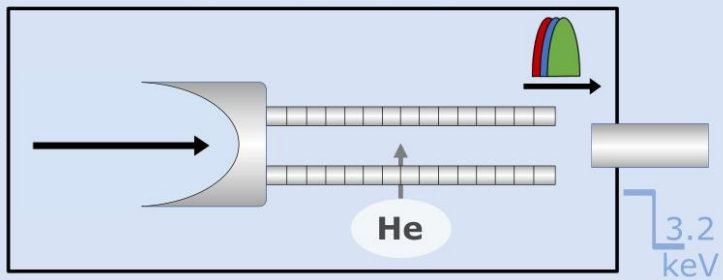
$$R = \frac{m}{\Delta m} = \frac{t_{ToF}}{2\Delta t_{ToF}} \approx 5 \cdot 10^5$$

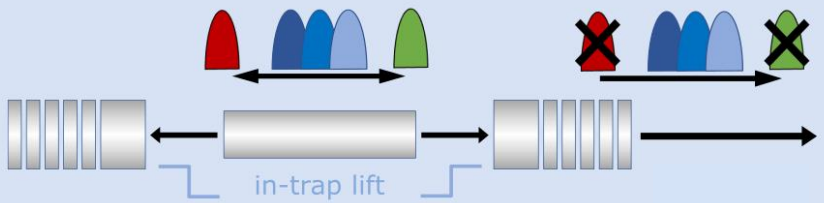

[1] S. Sundell *et al.*, NIM-B **70**, 160-164 (2023)
[2] R. N. Wolff *et al.*, Int. J. of Mass Spectr. 349–350 (2013)
[3] F. Wienholtz *et al.*, NIM B. 463 (2019)

# Experimental Techniques

- high first ionization potential
- **charge-exchange (CE)** reactions with neutral impurities in buffer gas of the RFQ-CB
- $^{38}Ar^{+}$ **CE life-time 23(2) ms** [1]
- with **cold trap** CE life-time of $^{38}Ar^{+}$ improved to **50(13) ms** [1]

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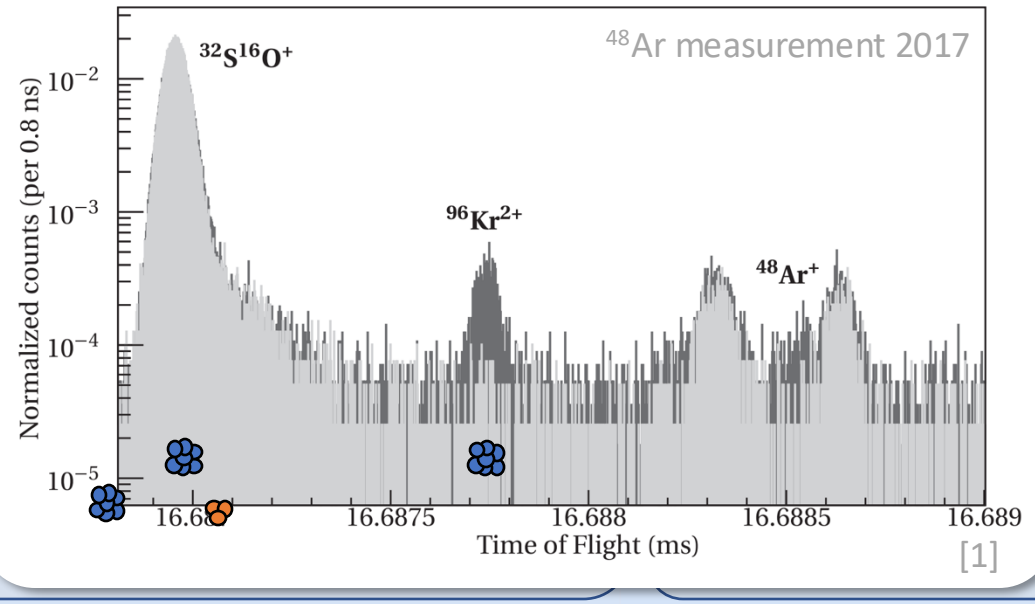

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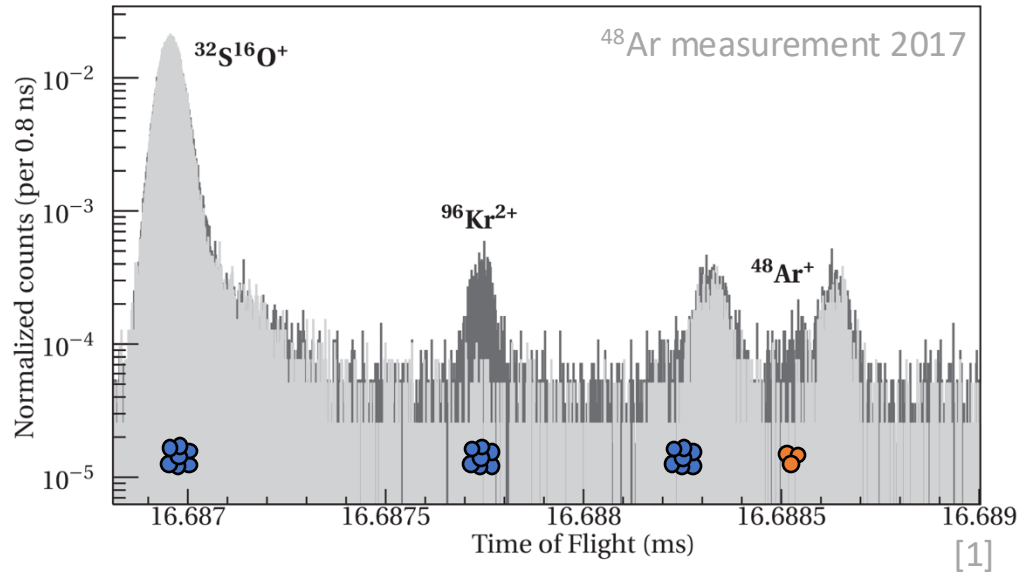


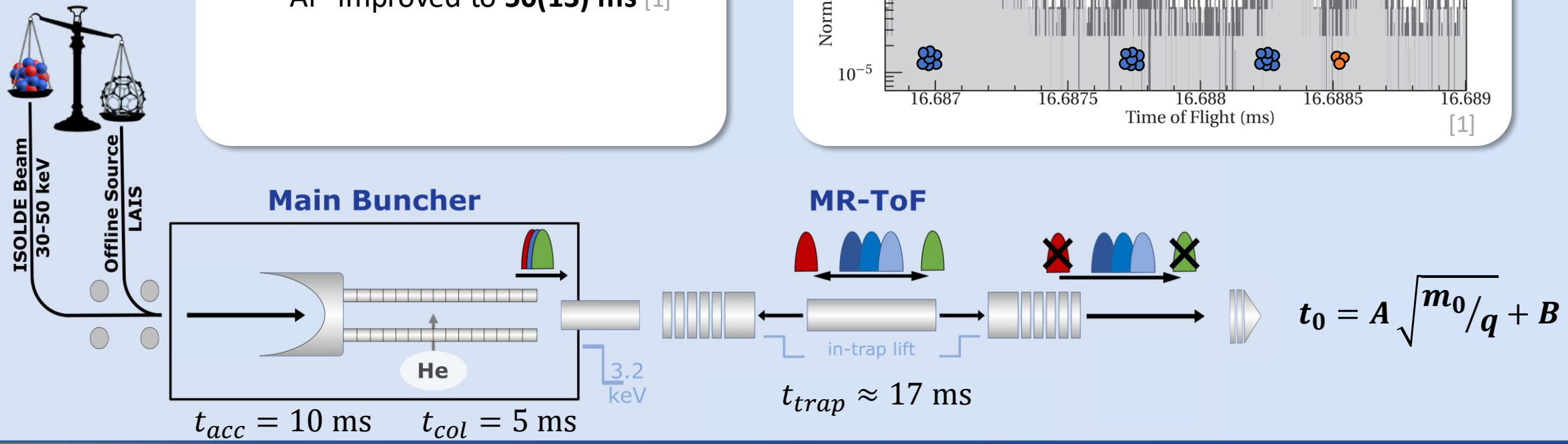

# Experimental Techniques

- high first ionization potential
- **charge-exchange (CE)** reactions
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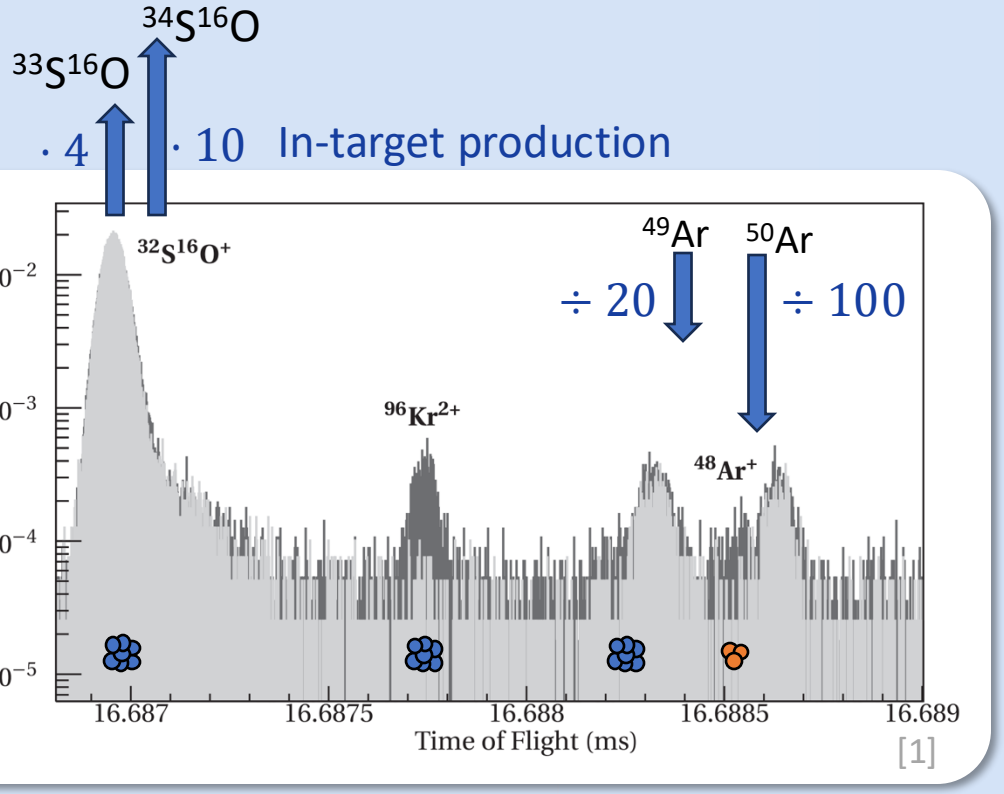
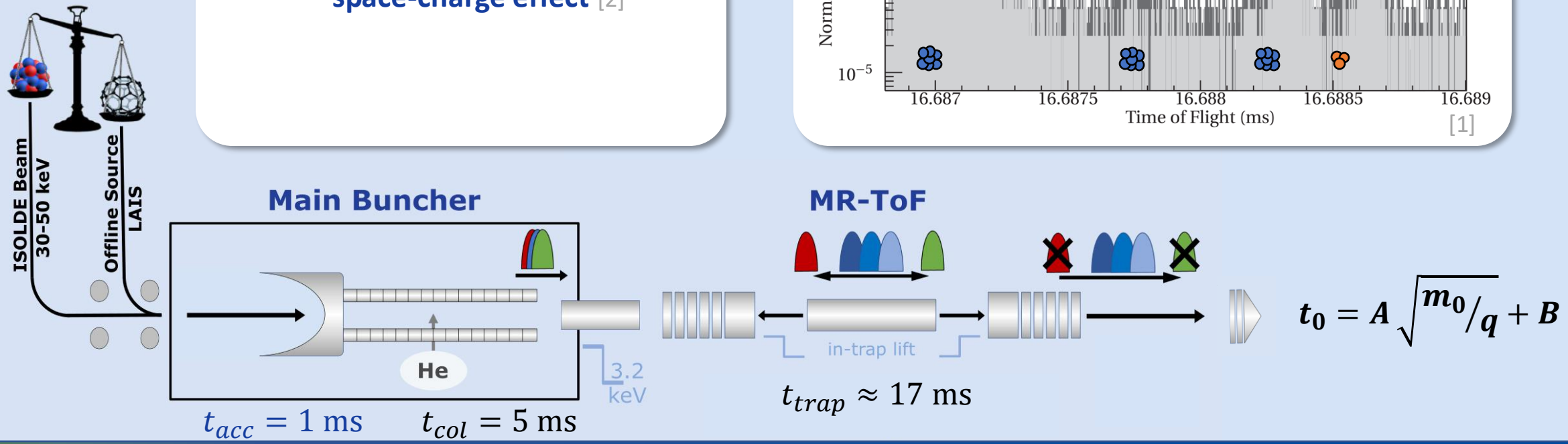
- $^{38}Ar^{+}$ **CE life-time optimization**
- **Challenges:**
  - **CE life-time**
  - **space-charge effect** [2]





[1] M. Mougeot *et al.*, PRC **102**, 014301 (2020)
[2] F. M. Maier *et al.*, NIM-A **1056**, 168545 (2023)

# Experimental Techniques

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- **Challenges:**
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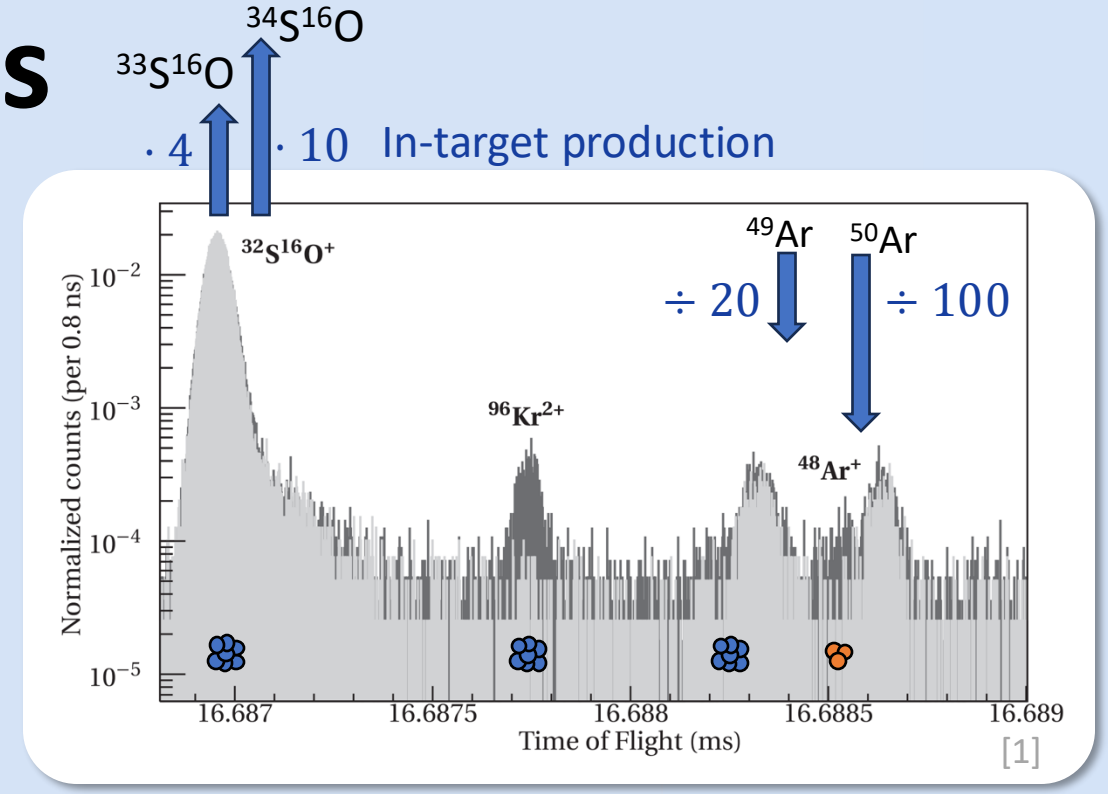
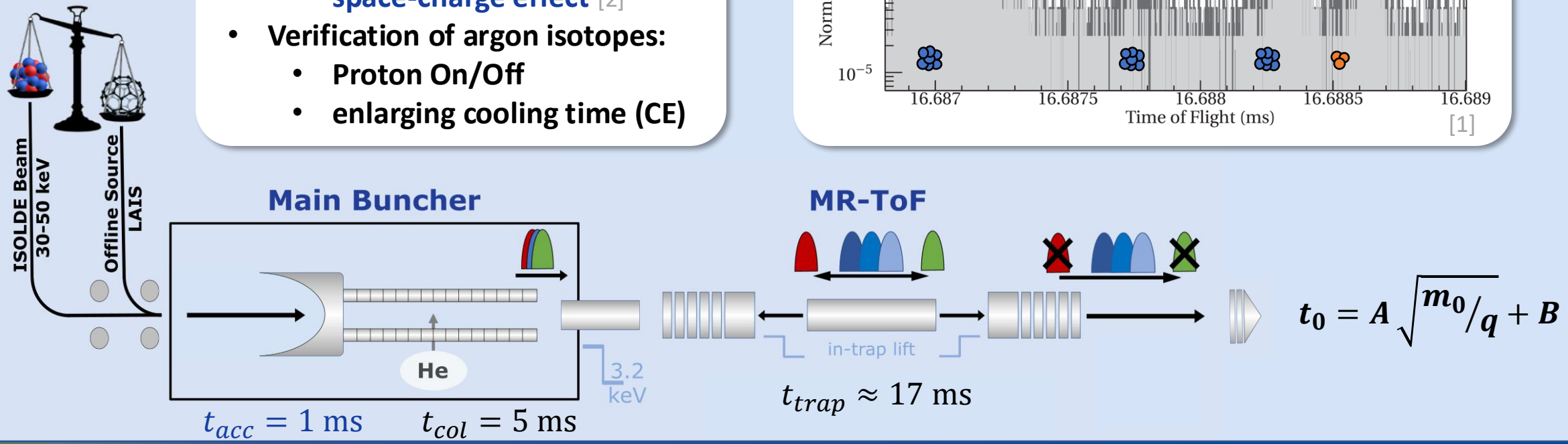
- **Verification of argon isotopes:**
  - **Proton On/Off**
  - **enlarging cooling time (CE)**





[1] M. Mougeot *et al.*, PRC **102**, 014301 (2020)
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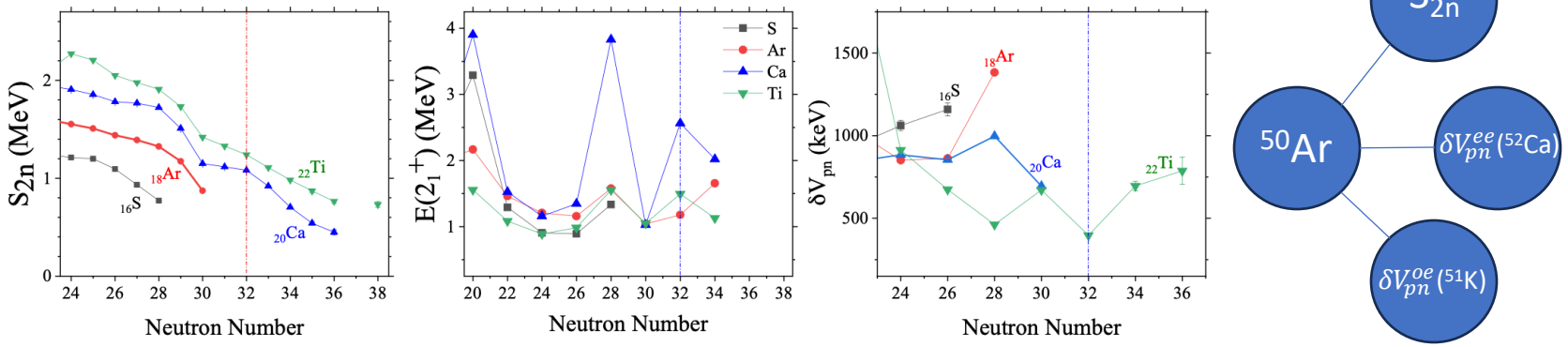
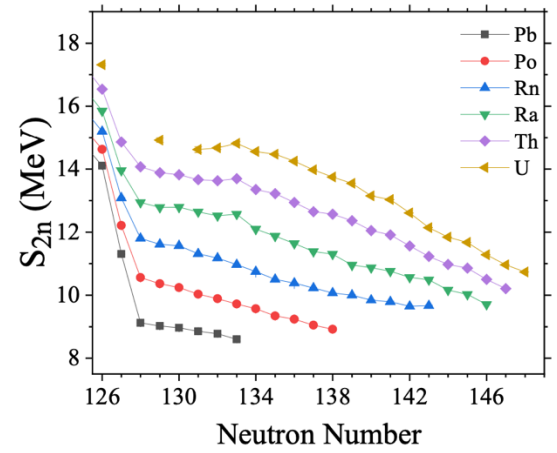
# Summary

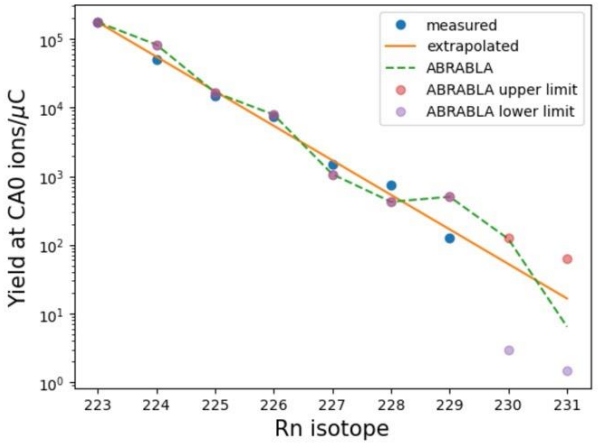
## Neutron-rich Ar




| Isotope | Half-life | Yield in CA0 [μC$^{-1}$] | Target | Ion Source | Method | Shifts |
|---|---|---|---|---|---|---|
| $^{49}$Ar | 170(50) ms | $1.1 \cdot 10^{1}$ [1,2] | UC$_x$ | FERBIAD type | MR-ToF | 3 |
| $^{50}$Ar | 106(6) ms | $2.0 \cdot 10^{0}$ [1,2] | | | | 12 |
| $^{230}$Rn | - | $\approx 5 \cdot 10^{1}$ # | | | | 1 |
| $^{231}$Rn | - | $\approx 2 \cdot 10^{1}$ # | | | | 2 |
| Target optimization, Charge-exchange half-life optimization | | | | | | 2 |
| **Total Shifts** | | | | | | **20** |

## Neutron-rich Rn





[1] L. Weissman *et al.*, PRC **67**, 054314 (2003)
[2] ISOLDE Yield Database

# extrapolated

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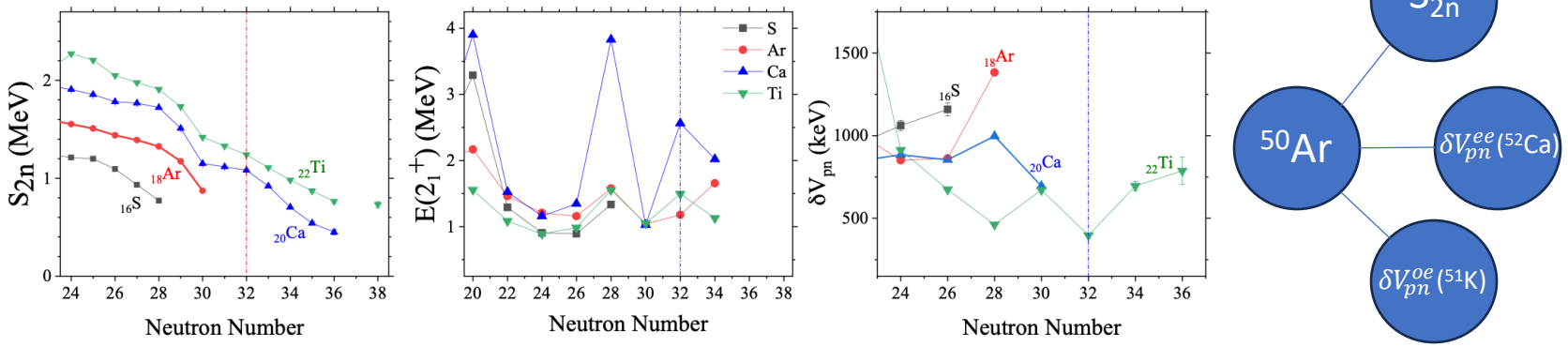


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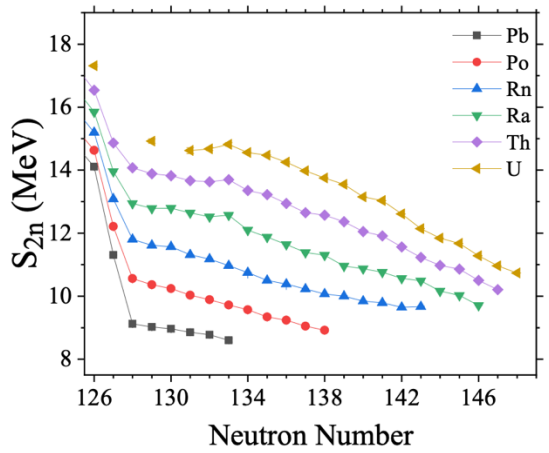
| $^{49}$Ar | 170(50) ms | $1.1 \cdot 10^1$ [1,2] | $UC_x$ | FERBIAD type | MR-ToF | 3 |
| $^{50}$Ar | 106(6) ms | $2.0 \cdot 10^0$ [1,2] | | | | 12 |
| $^{230}$Rn | - | $\approx 5 \cdot 10^1$ # | | | | 1 |
| $^{231}$Rn | - | $\approx 2 \cdot 10^1$ # | | | | 2 |
| Target optimization, Charge-exchange half-life optimization | | | | | | 2 |
| **Total Shifts** | | | | | | **20** |

## Neutron-rich Rn




The TAC does not see any particular issues with this proposal

**Thank you for your attention!**