Binding energy studies of shell closures in exotic nuclei with ISOLTRAP

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for the ISOLTRAP collaboration

Outline:

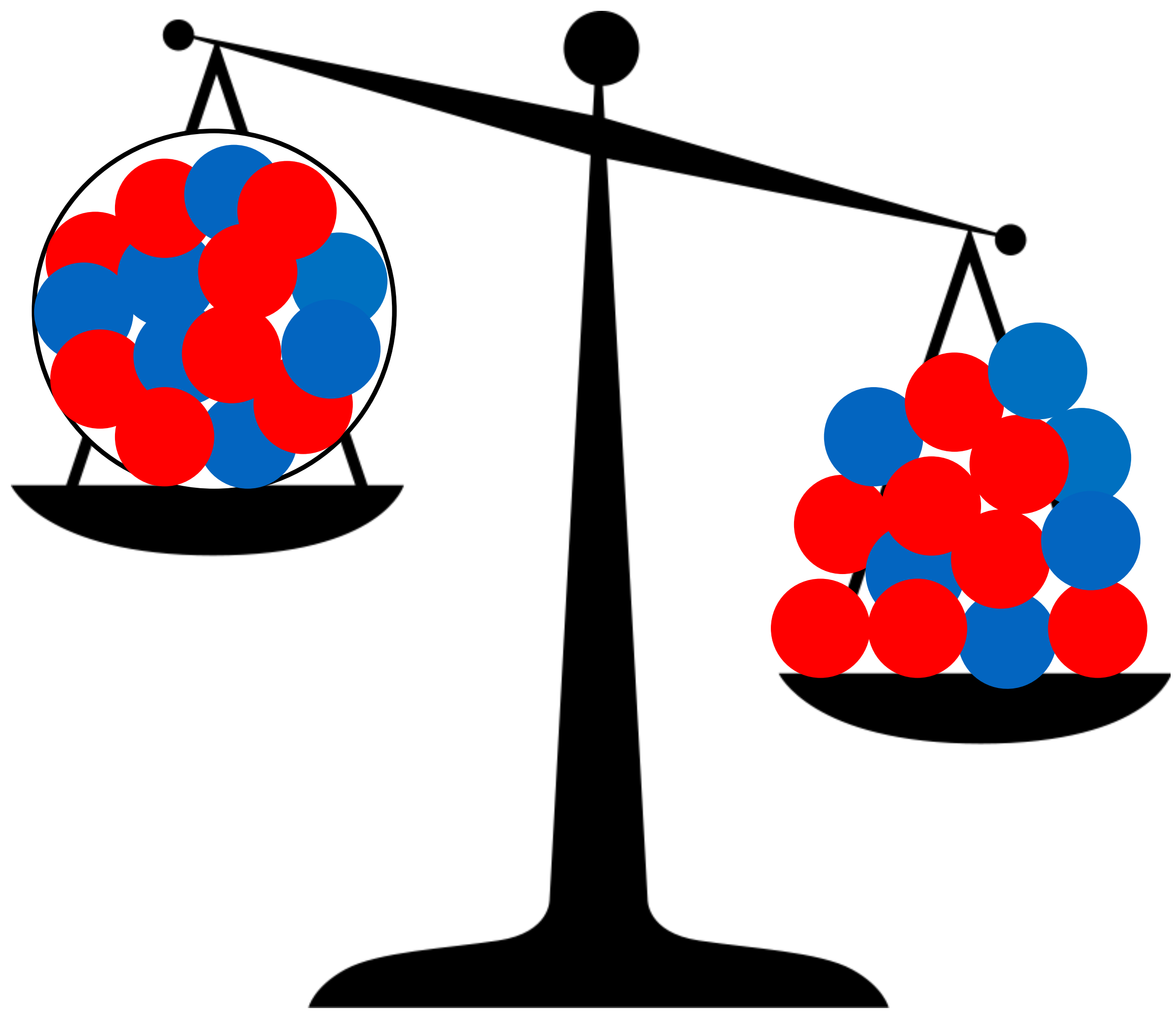
- Introduction
- Neutron-rich Argon isotopes
- Evolution of $N=28$ shell gap
- Conclusion and perspectives

INTRODUCTION

The nuclear binding energy

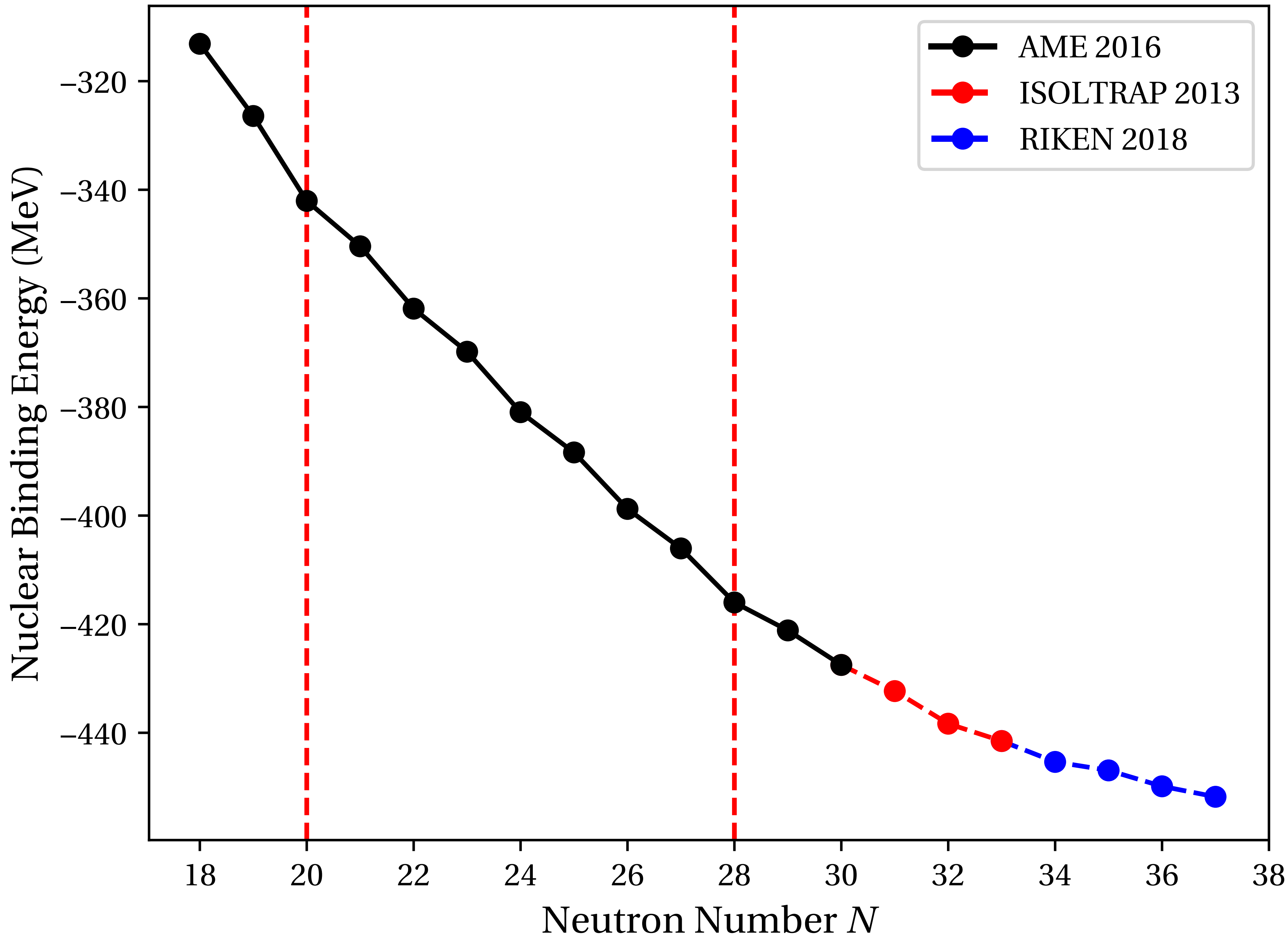
- Reflects the interaction of **ALL** the nuclear constituents

$$M_{nuc}(Z,N) = Zm_p + Nm_n + E(Z,N)/c^2$$



Example : Calcium chain

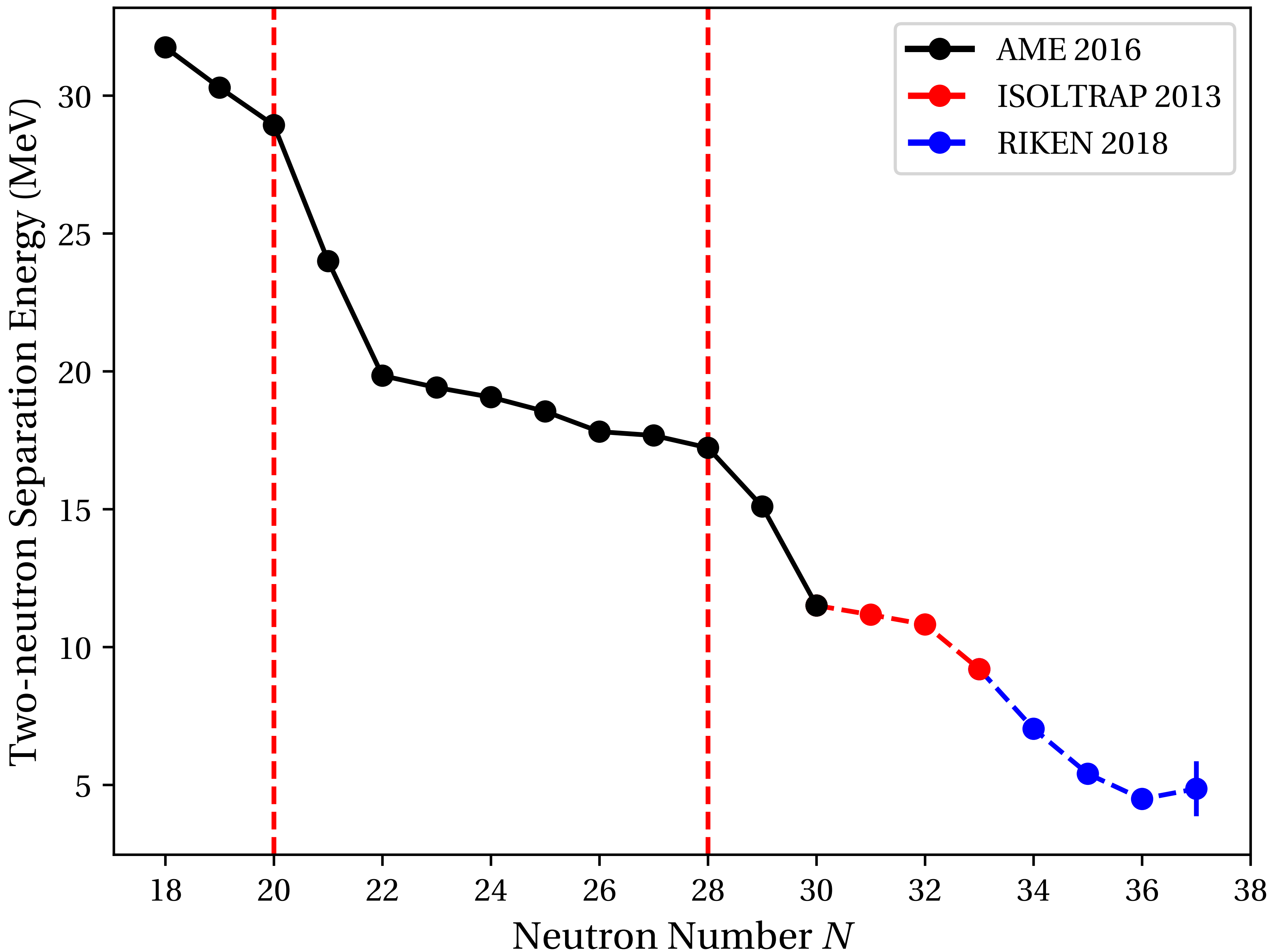
$$M_{nuc}(Z,N) = Zm_p + Nm_n + E(Z,N)/c^2$$



G. Audi *et al.*, Chinese Phys. C **41**, 3 (2017) F. Wienholtz *et al.*, Nature **498**, 346 (2013) S. Michimasa *et al.*, Phys. Rev. Lett. ***121,*** *022506 (2018)*

New features far from stability

$$S_{2n}(Z,N) = E(Z-2,N) - E(Z,N)$$



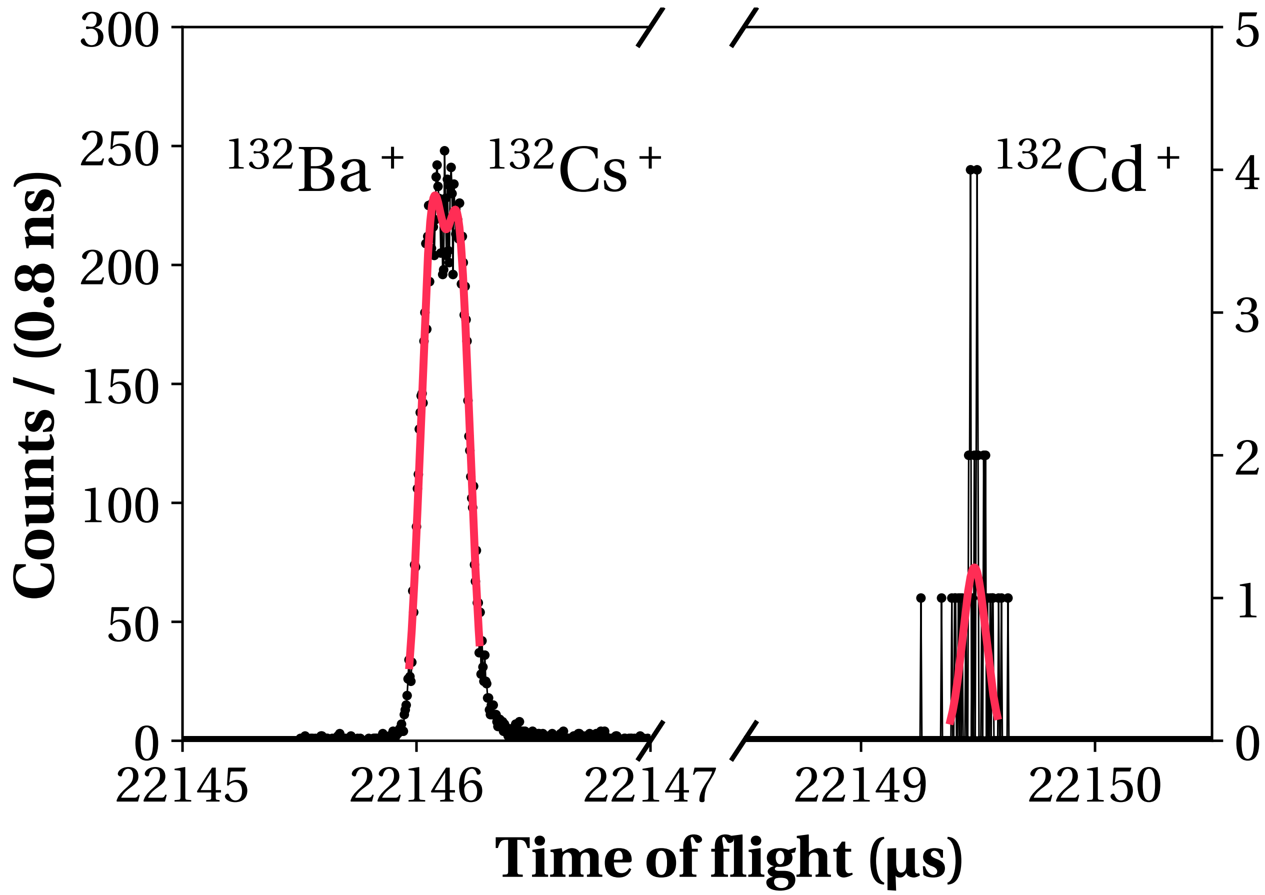
G. Audi *et al.*, Chinese Phys. C **41**, 3 (2017) F. Wienholtz *et al.*, Nature **498**, 346 (2013) S. Michimasa *et al.*, Phys. Rev. Lett. ***121,*** *022506 (2018)*

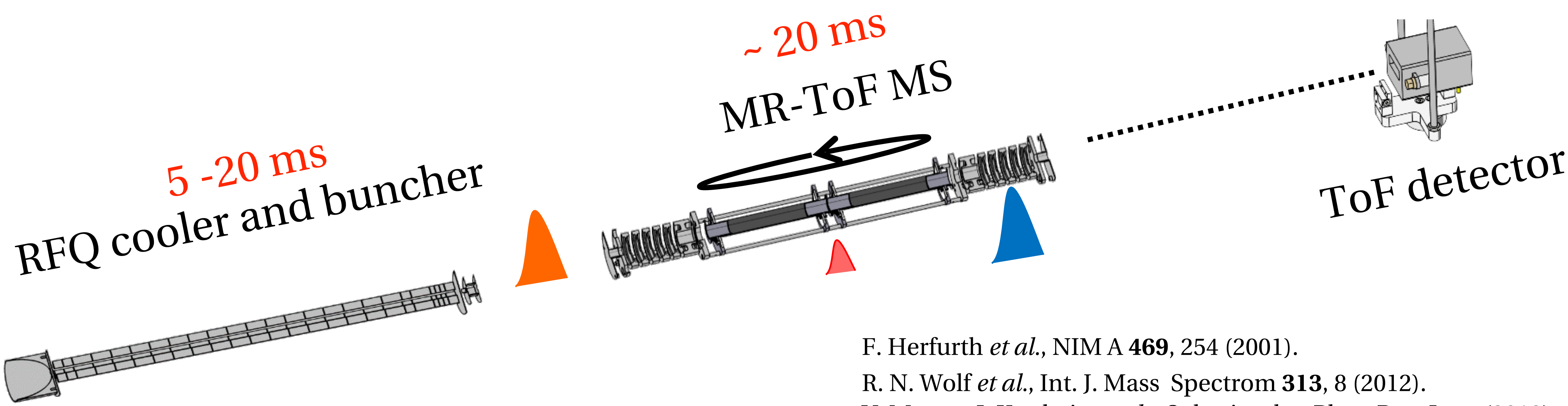
MR-ToF mass spectrometry

MR-ToF MS:

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

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





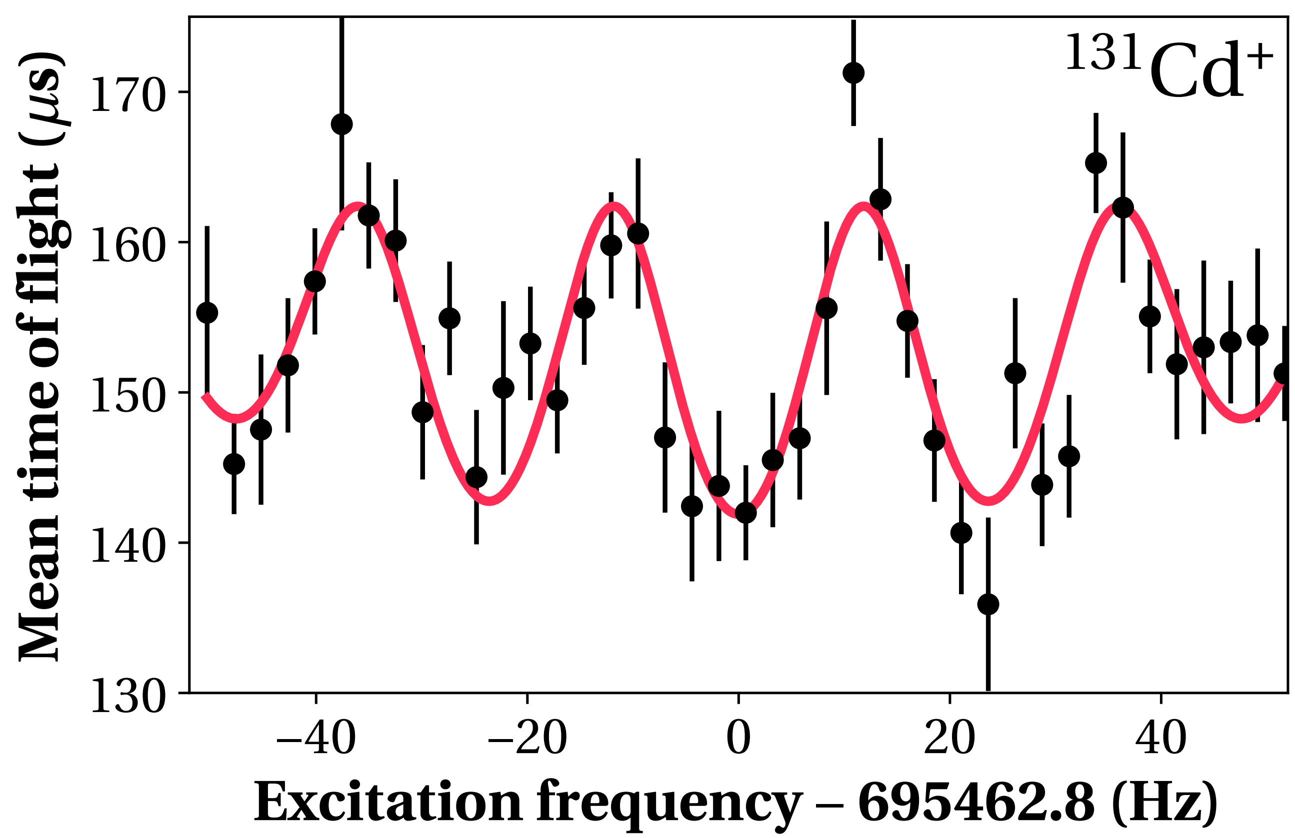
F. Herfurth *et al.*, NIM A **469**, 254 (2001).
R. N. Wolf *et al.*, Int. J. Mass Spectrom **313**, 8 (2012).
V. Manea, J. Karthein *et al.*, Submitted to Phys. Rev. Lett. (2019).

Penning-trap mass spectrometry

ToF-ICR:

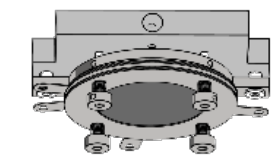
- Scanning
- t_{meas} ~ 50 - 2000 ms
- $\delta m/m$ ~ 10^{-7} - 10^{-9}
- $m/\Delta m$ ~ 10^{4} - 10^{6}

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

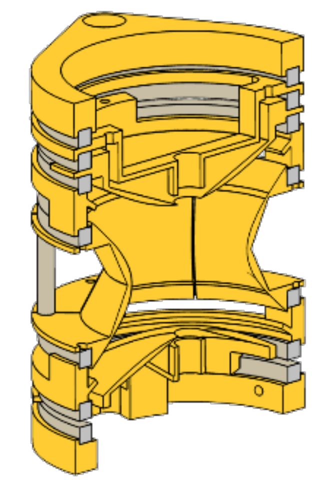


V. Manea, J. Karthein *et al.*, Submitted to Phys. Rev. Lett. (2019).

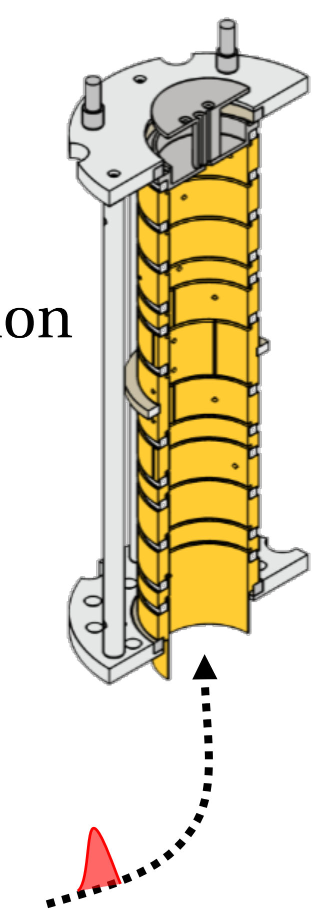
MCP



Precision trap



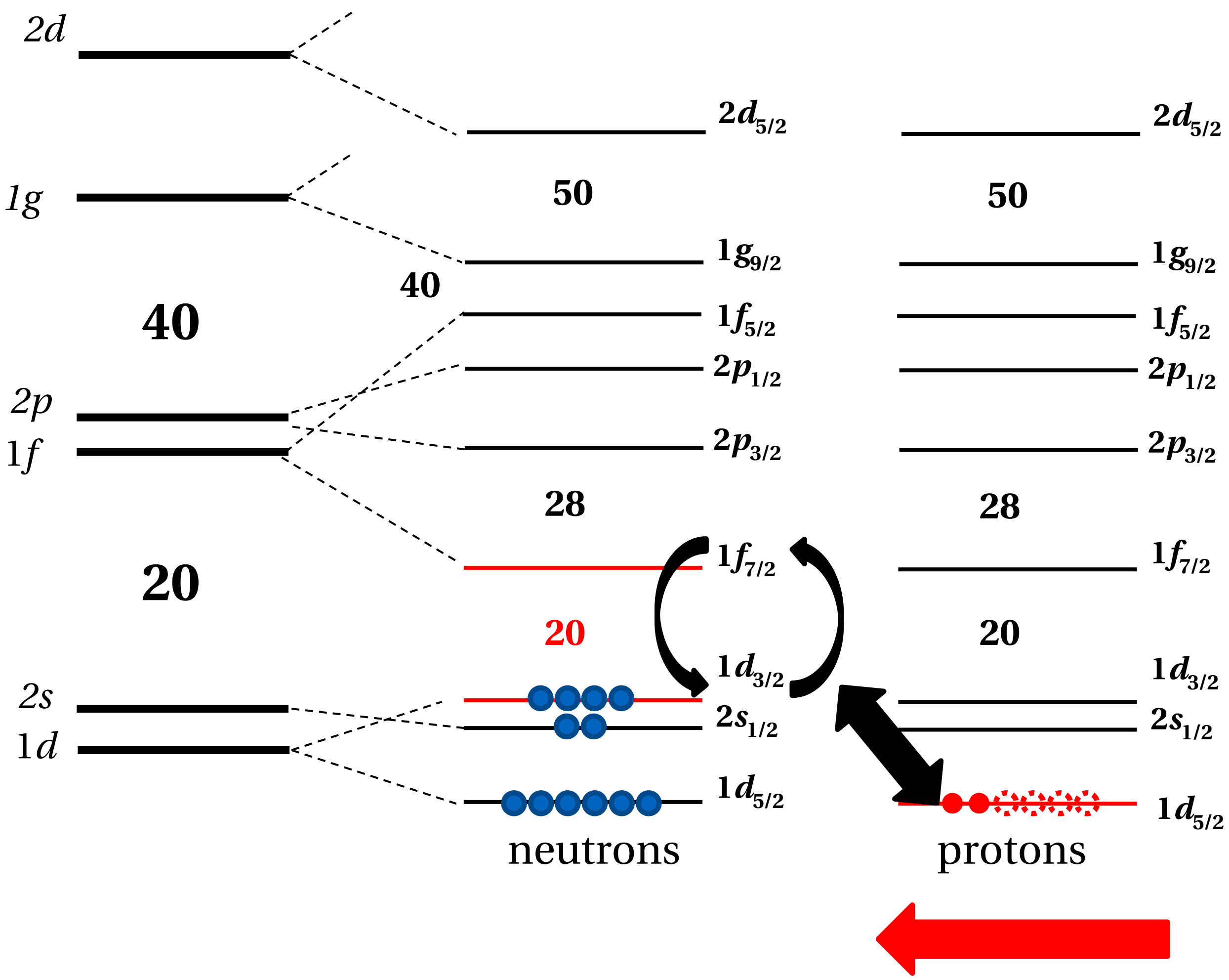
Preparation trap

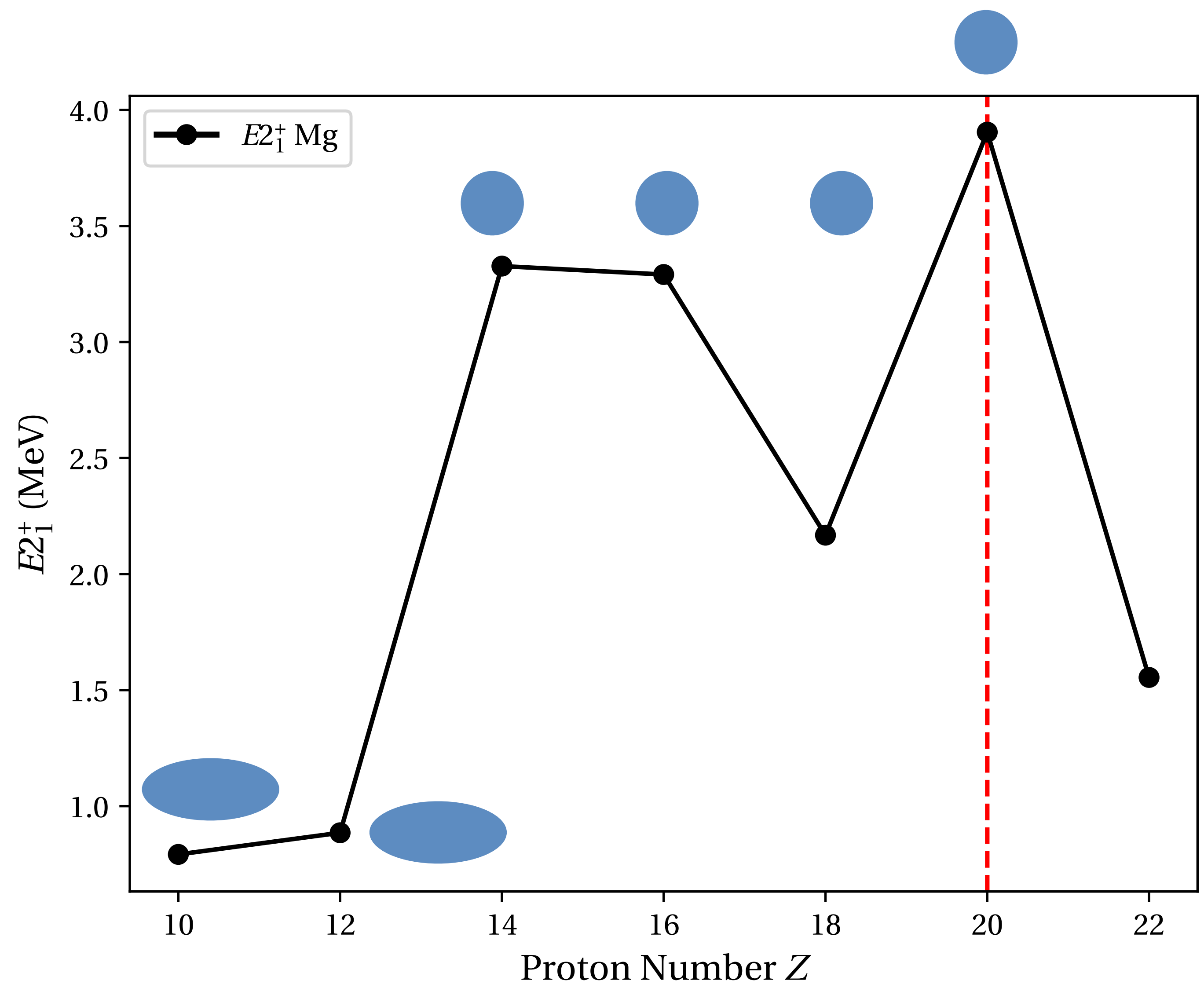


Neutron-rich Argon isotopes

The vanishing of nuclear shells

- Example: $N = 20$ “Island of Inversion”



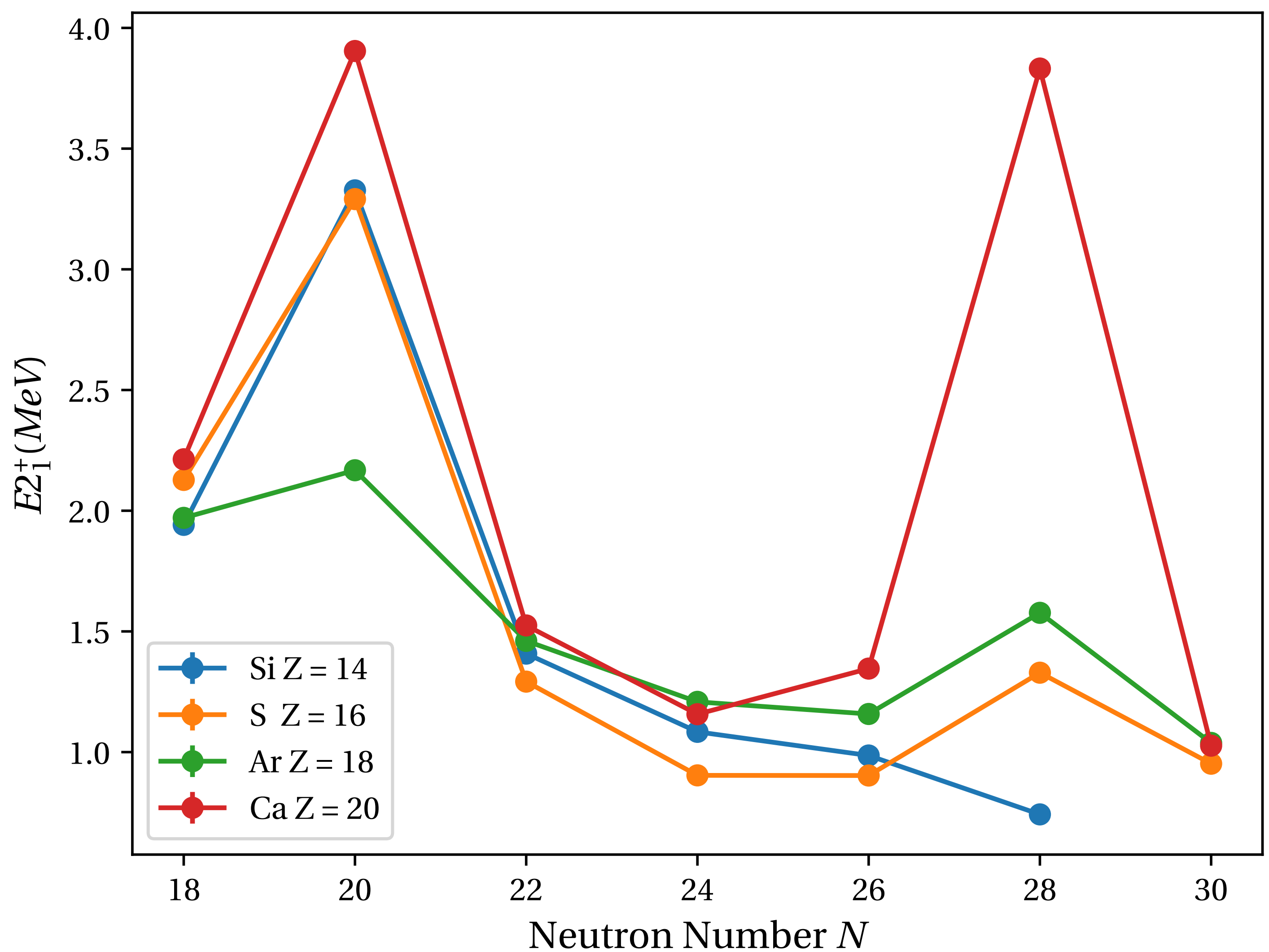


ENSDF (2015)

What happens for $N = 28$?

- Fast reduction of $E2_1^+$ below ^{48}Ca
- Collapse of the N=28 shell-closure

Ca 47 4.538 d	Ca 48 0.187 5.3E+19 y	Ca 49 8.72 m	Ca 50 13.9 s	Ca 51 10.0 s	Ca 52 4.6 s	Ca 53 90 ms
K 46 1.75 m	K 47 17.5 s	K 48 6.8 s	K 49 1.26 s	K 50 472 ms	K 51 365 ms	K 52 105 ms
Ar 45 21.48 s	Ar 46 8.4 s	Ar 47 580 ms	Ar 48 500 ms	Ar 49 170 ms	Ar 50 85 ms	Ar 51 60 ms
Cl 44 560 ms	Cl 45 400 ms	Cl 46 220 ms	Cl 47 200 ms	Cl 48 100 ms	Cl 49 50 ms	Cl 50 20 ms
S 43 260 ms	S 44 123 ms	S 45 82 ms	S 46 30 ms	S 47 20 ms	S 48 10 ms	S 49 200 ns



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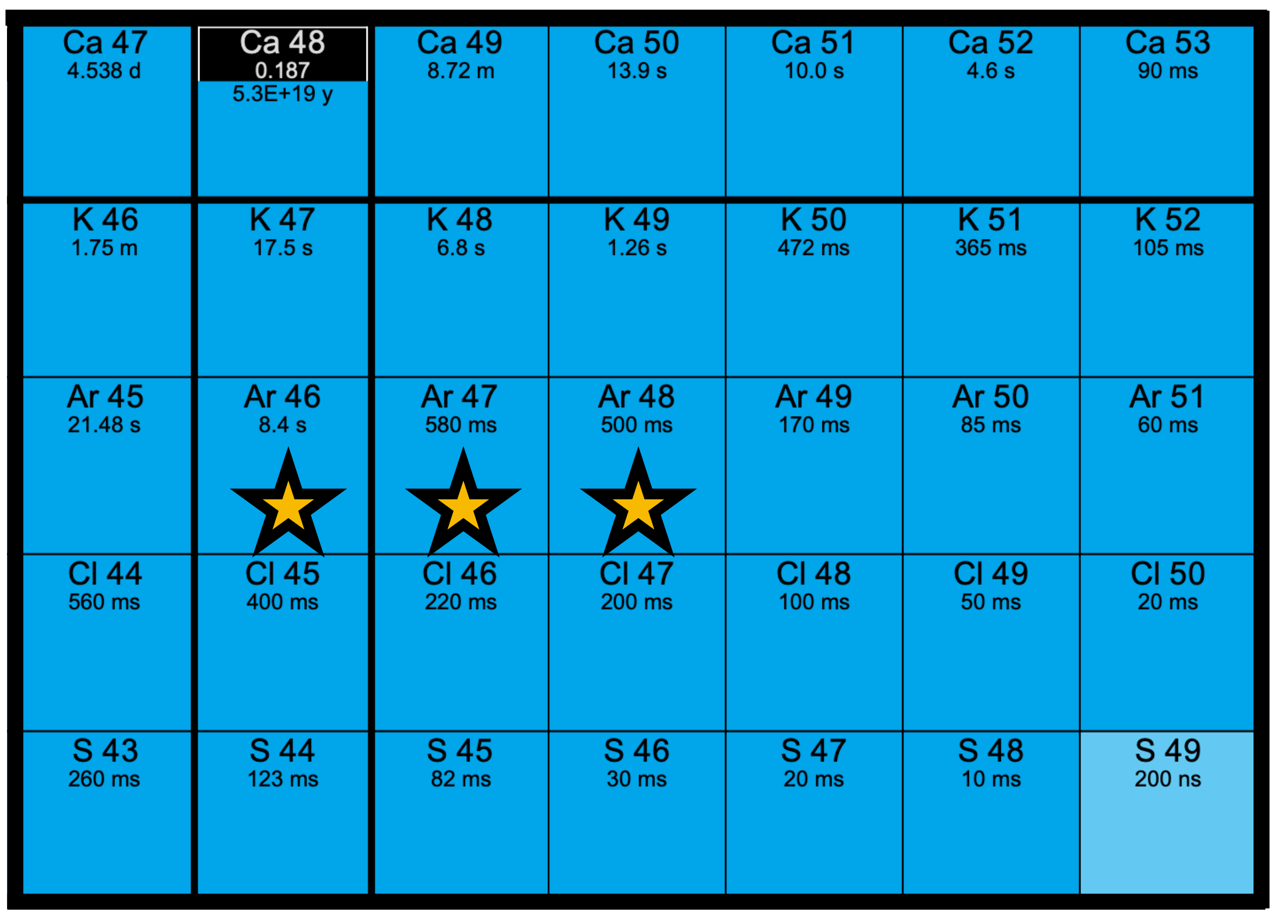
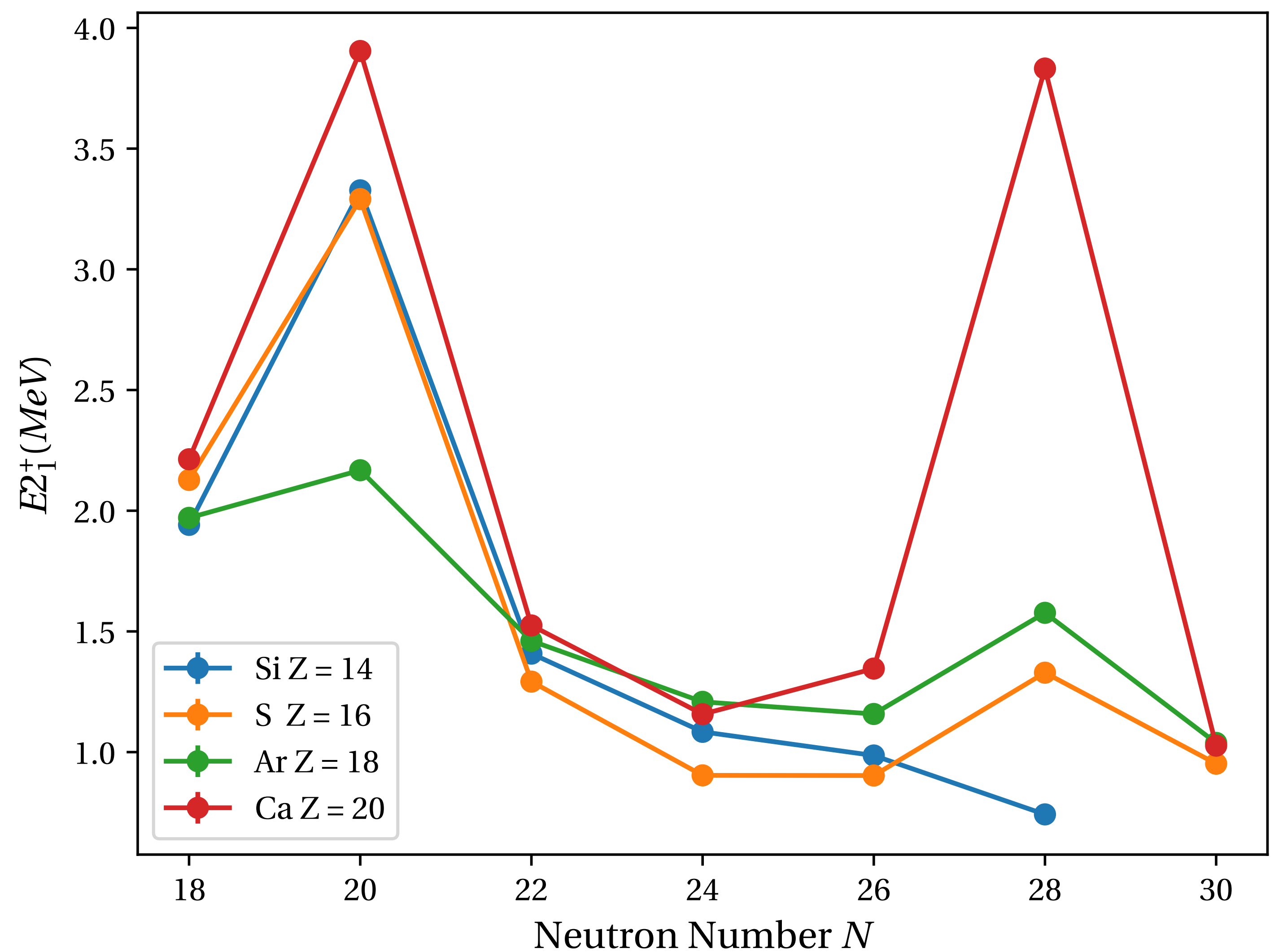
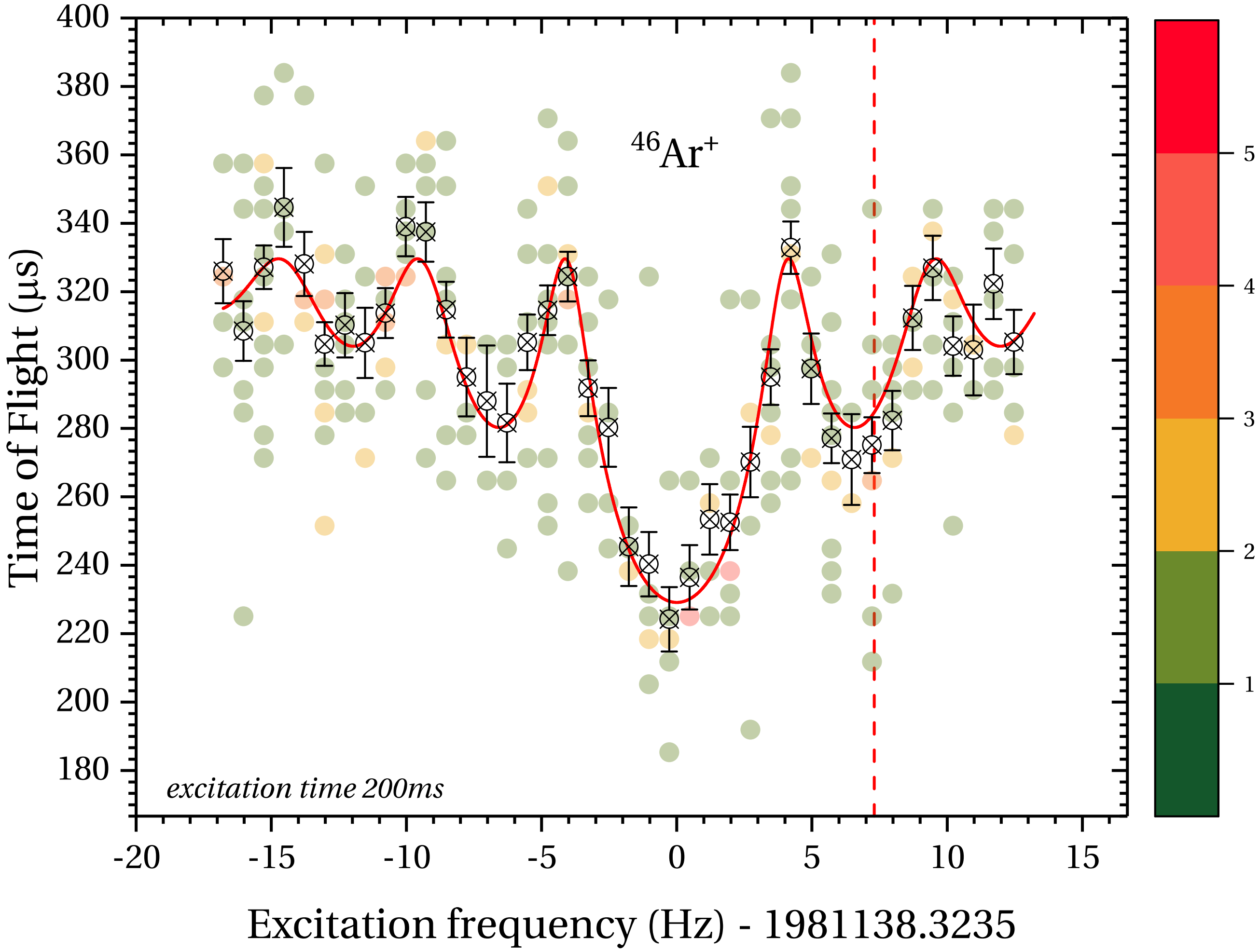
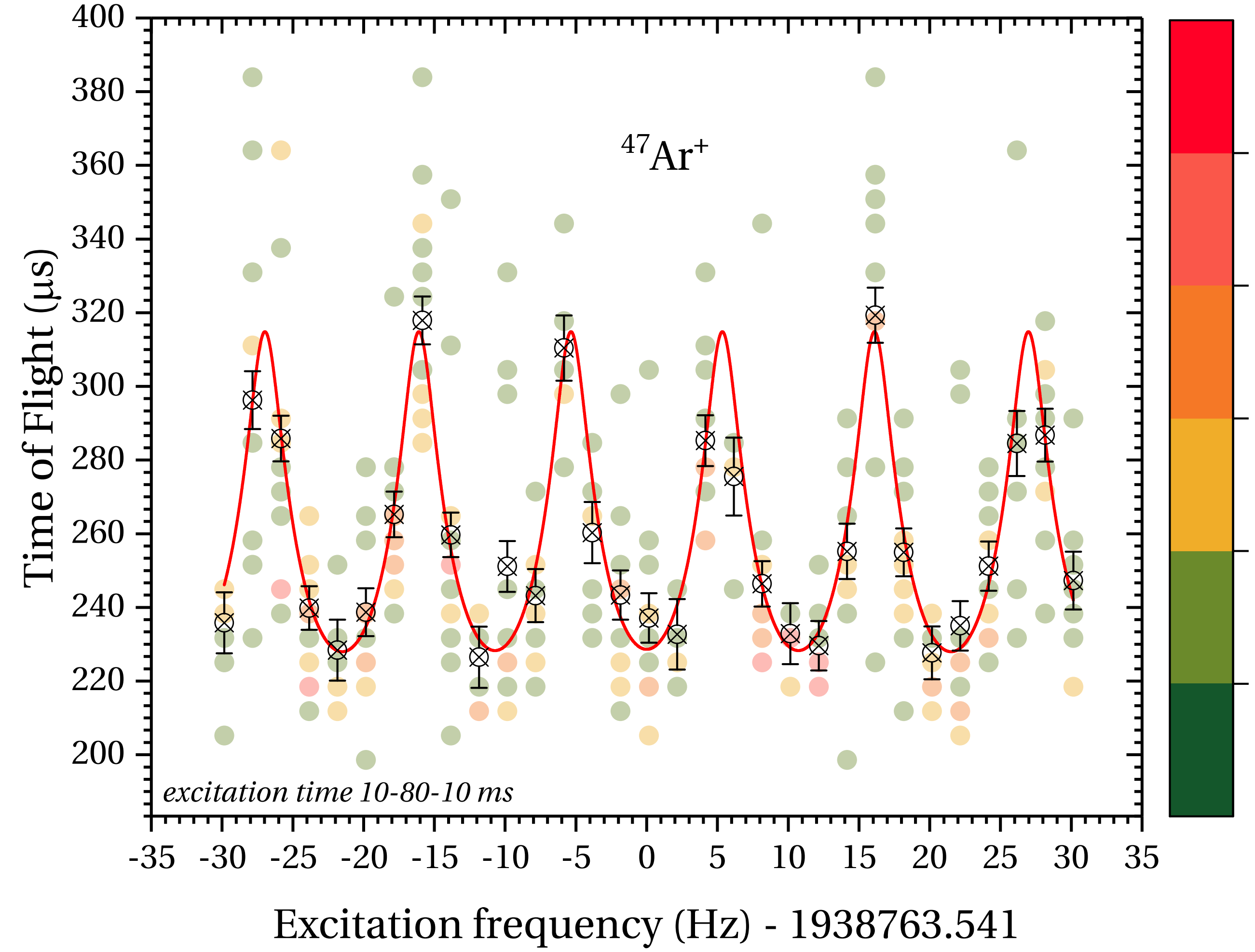




ENSDF (2015)

Mass measurements of $^{46-47}Ar$



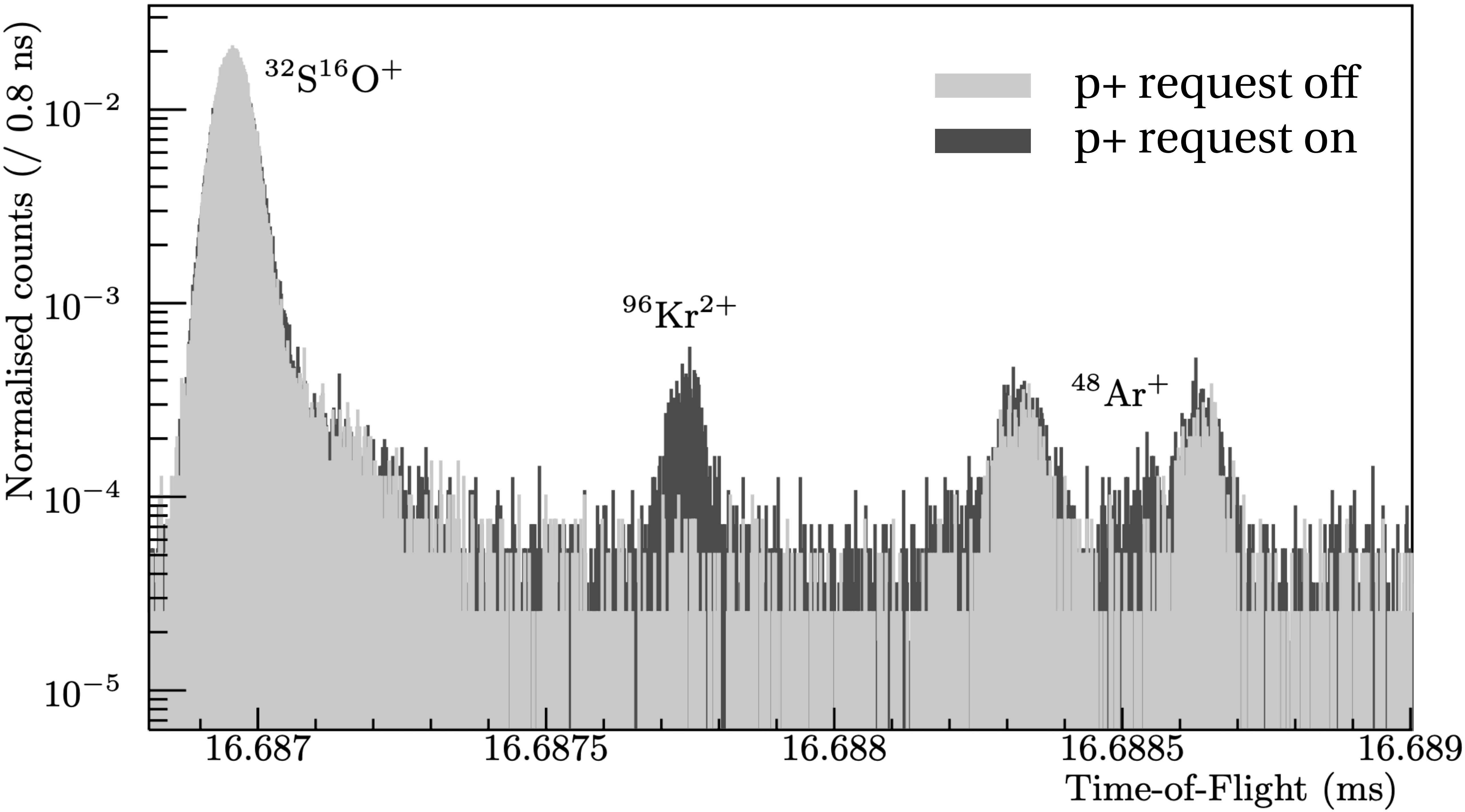


- ~ 40 keV more bound
- ~ 40 times more precise

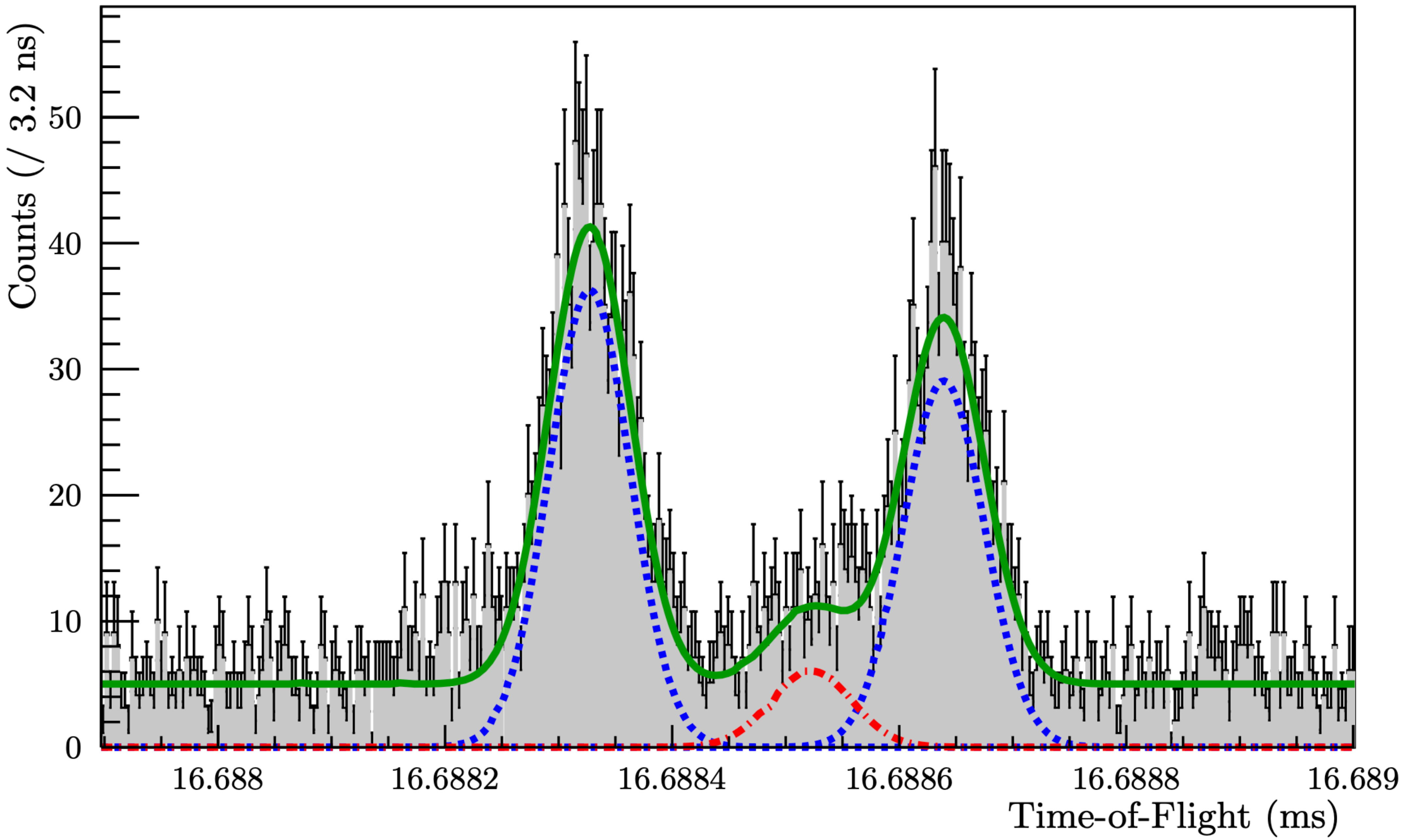
- ~ 160 keV more bound
- ~ 90 times more precise

M. Wang *et al.*, Chinese Physics C **36**, 1603 (2012).
Z. Meisel *et al.*, Phys. Rev. Lett. **94**, 022501 (2015).

Mass measurements of ^{48}Ar



Mass measurements of ^{48}Ar



- ~ 75 keV more bound
- ~ 19 times more precise

Background comp.

Signal comp.

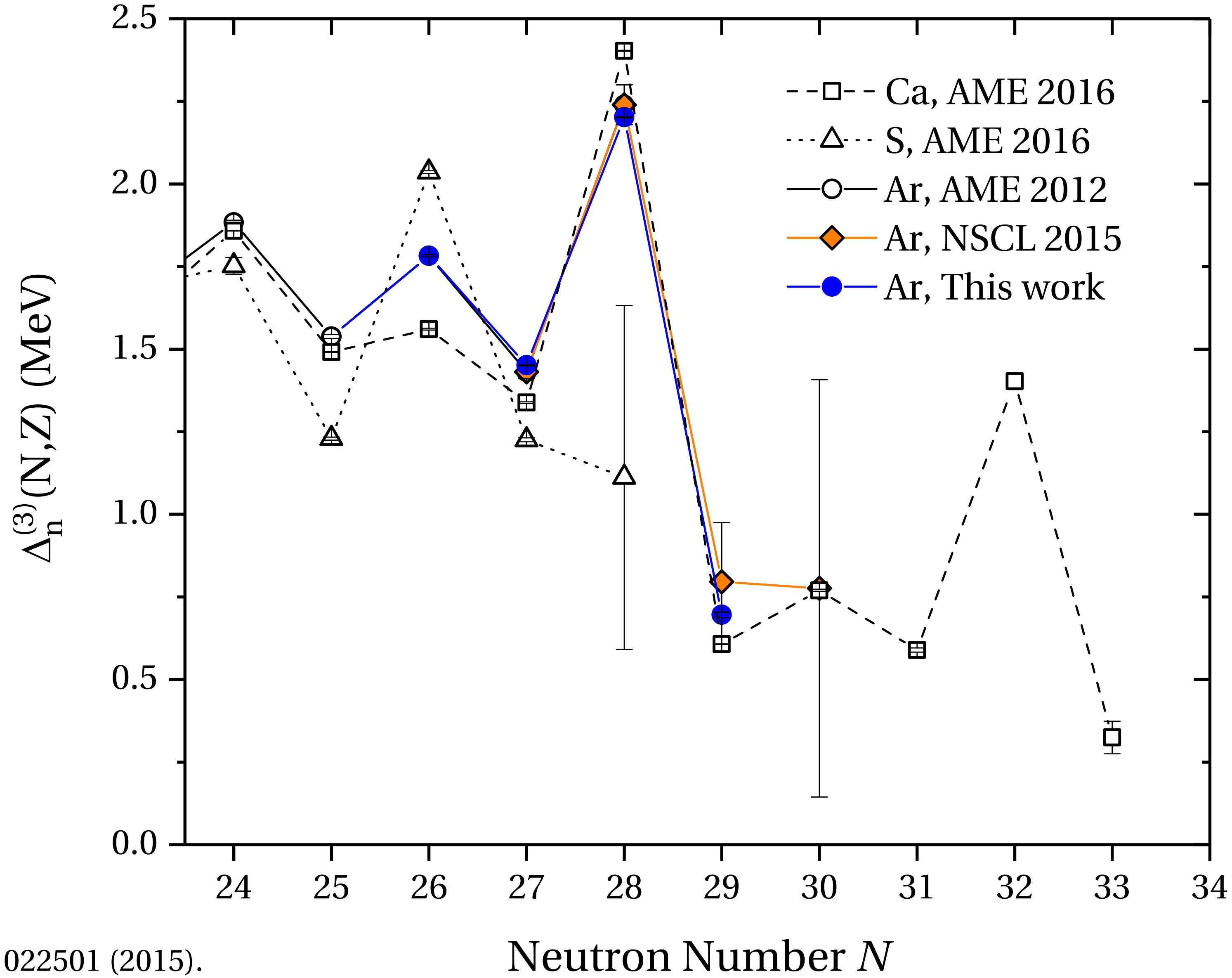
Sum + Uniform comp.

Evolution of the $N = 28$ empirical shell gap

Strength of the $N = 28$ shell gap

- Rapid collapse of the N=28 one-neutron empirical shell gap for Z <18
- From Ca to Ar, ~400keV reduction

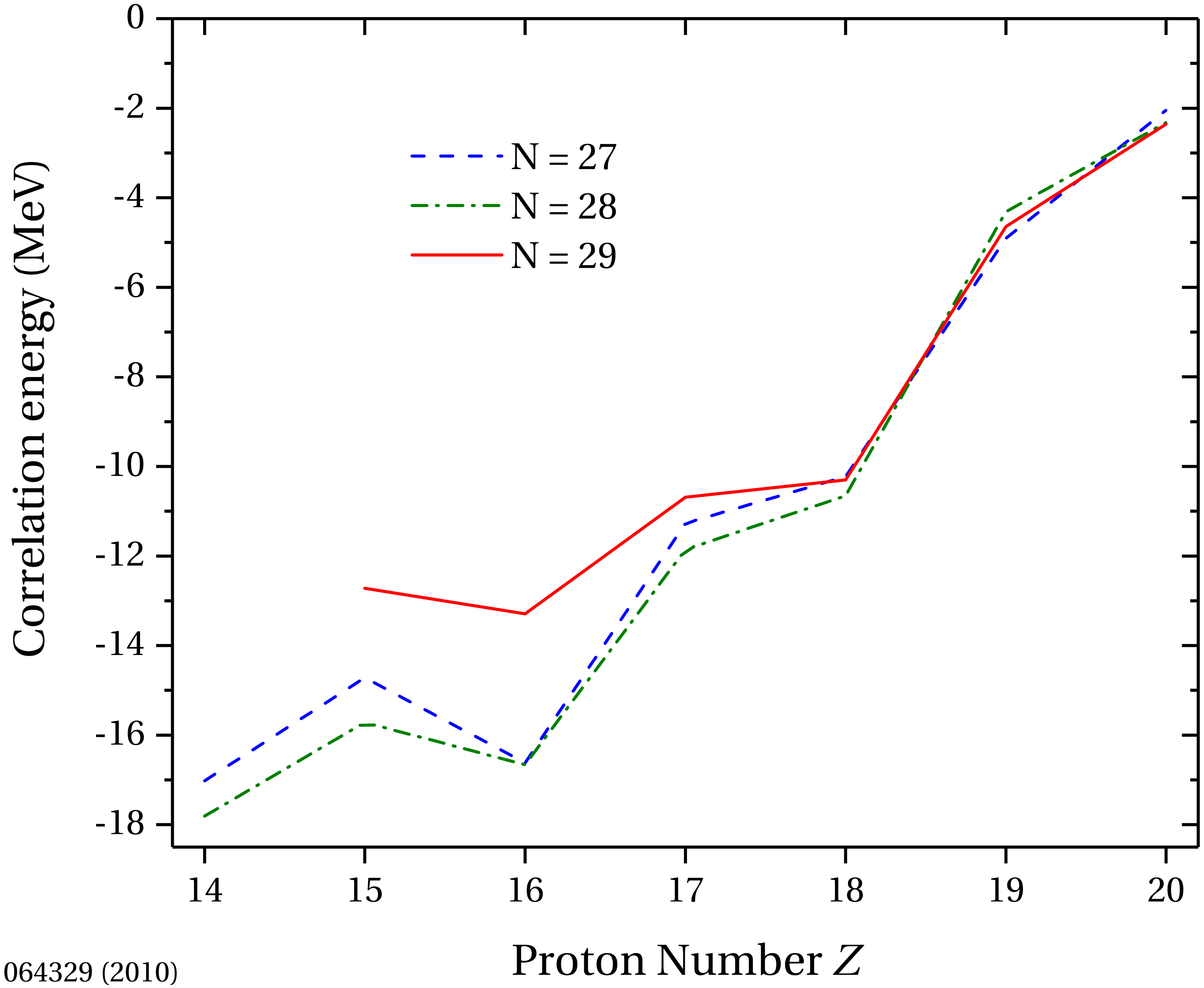
$$\Delta_{3n}(N,Z) = \frac{-1^{N}}{2}[E(Z,N+1) - 2E(Z,N) + E(Z,N-1)]$$



Z. Meisel *et al.*, Phys. Rev. Lett. **94**, 022501 (2015).

Correlations south of ^{48}Ca

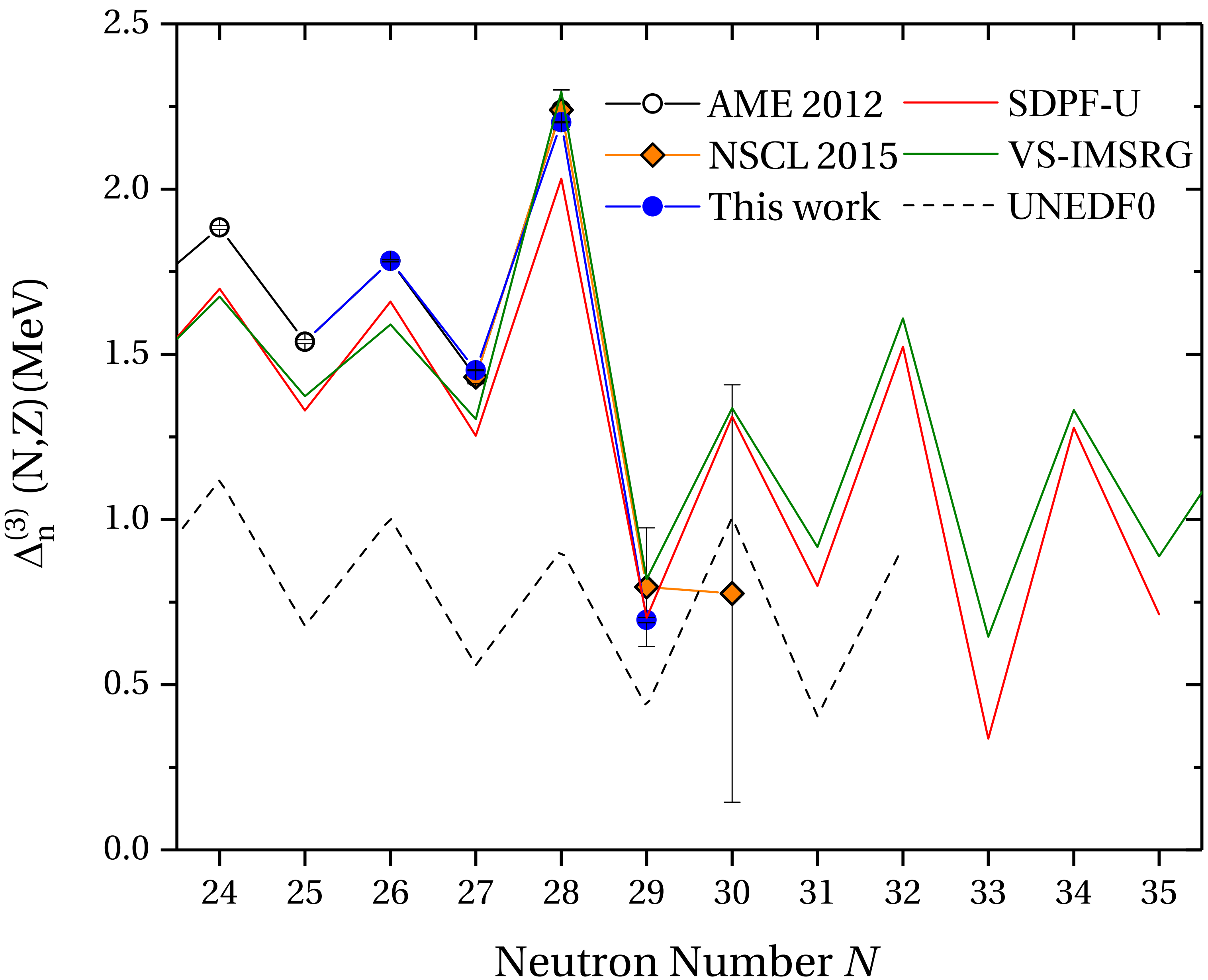
- Multipole energy extracted from calculated g.s
- ANTOINE code using *SDPF-U* interaction



L. Gaudefroy *et al.*, Phys. Rev. C. **81**, 064329 (2010)

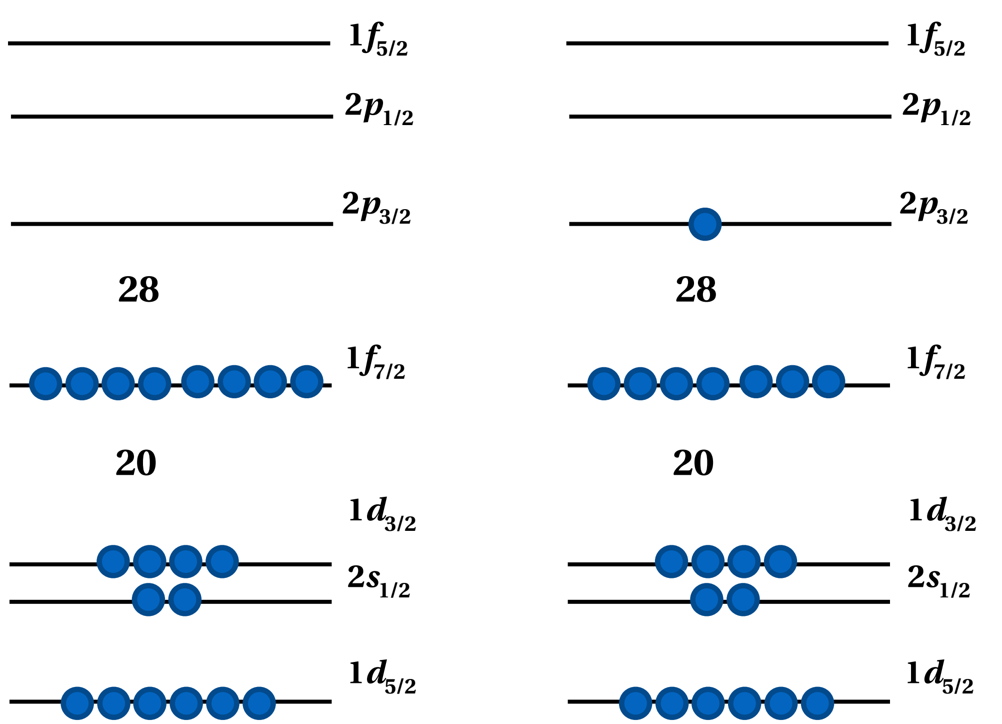
Theoretical trends

- *SDPF-U* phenomenological interaction –> good agreement
- *VS-IMSRG ab-initio* approach –> also good agreement
- UNEDF0 –> strength of pairing too low



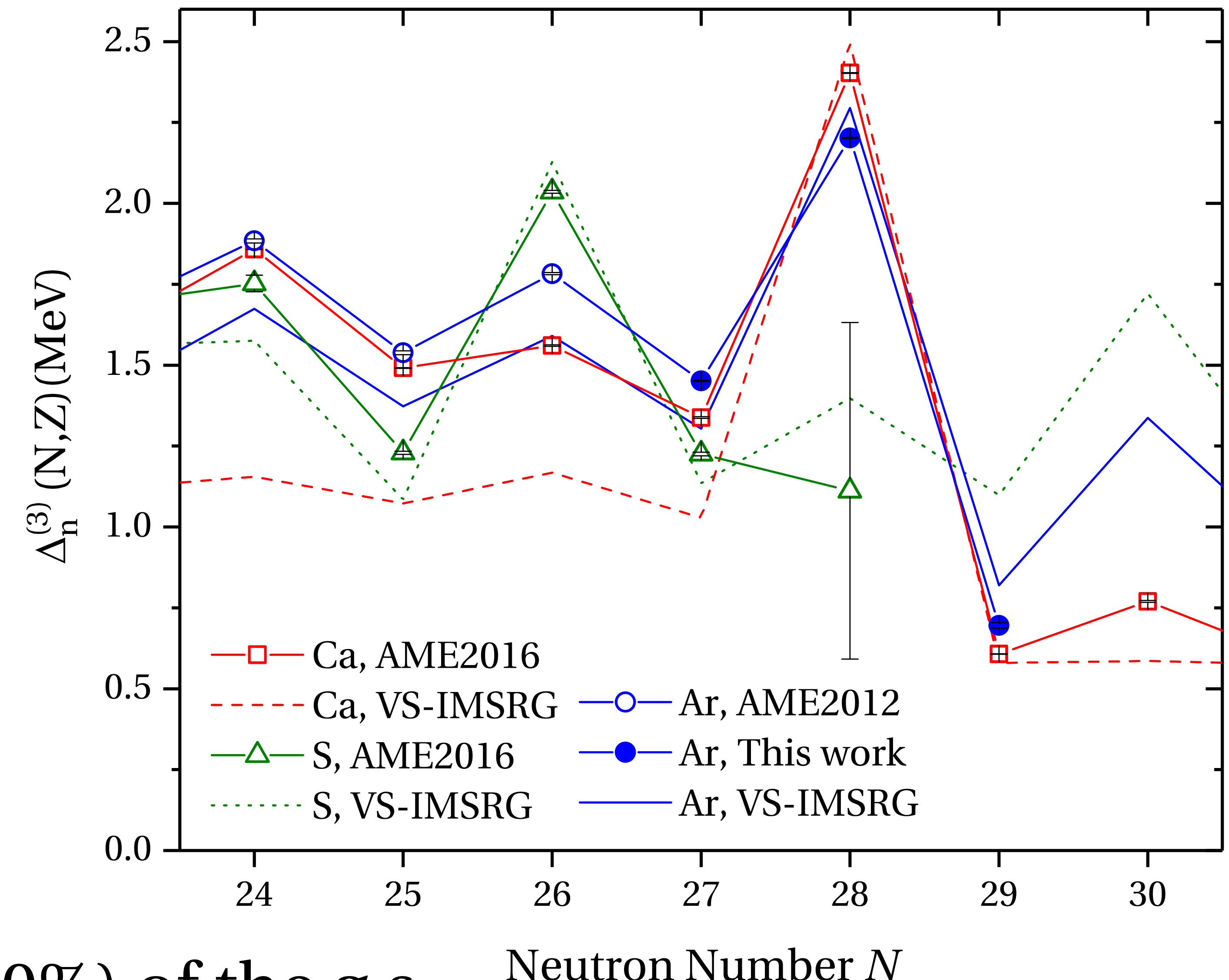
VS-IMSRG in the region

- *VS-IMSRG ab-initio* approach extended down to S
- Predicts erosion of $N = 18$ shell gap
- Need for more precise mass data below $Z < 18$



Neutron
Natural conf.

Neutron
Intruder conf.
1p-1h, 2p-2h …

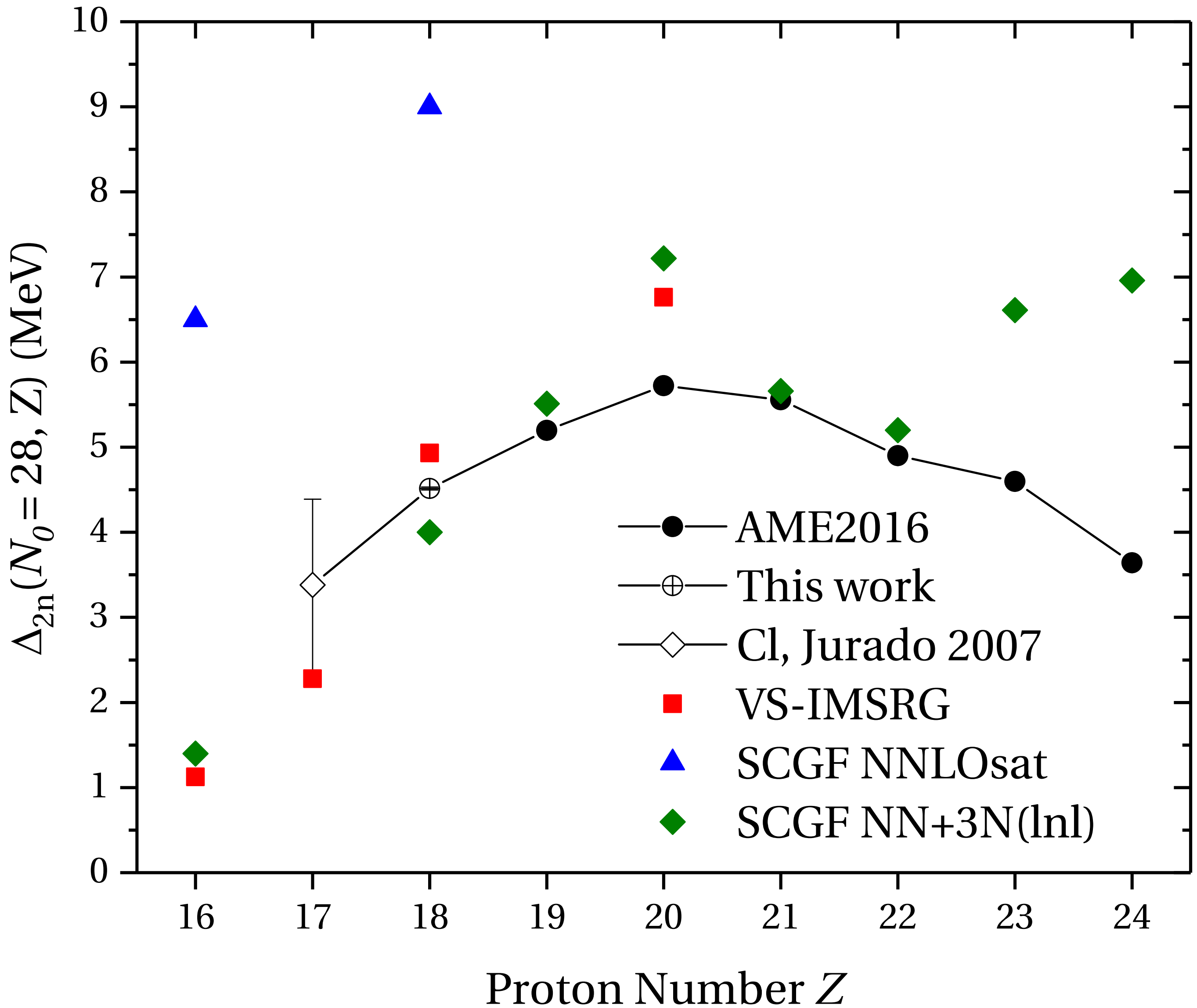


- *SDPF-U* –> ^{48}Ca (90%), ^{46}Ar(50%) of the g.s
- VS-IMSRG –> ^{48}Ca (90%), ^{46}Ar(40%) of the g.s

SCGF predictions :

- *ab-initio* calculations using Self Consistant Green's Function
- Two nuclear interactions
- Good agreement with experiment
- Also predicts a reduction of the N=28 shell gap $Z < 18$

$$\Delta_{2n}(N_0, Z) = S_{2n}(N_0 = 28, Z) - S_{2n}(N_0 = 30, Z)$$



Conclusion

In summary:

- Improved precision for $^{46-48}$Ar
- ~ 400 keV reduction of the one-neutron empirical shell-gap
- Apparently strong shell gap
- Argon rather a transitional chain
- Ab-initio (VS-IMSRG,SCGF) results in good agreement
- Need for high-precision measurements of isotopes with $Z < 18$

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