3 February 2016

Addendum to the ISOLDE and Neutron Time-of-Flight Committee

IS532 experiment

# Mass spectrometry of neutron-rich chromium isotopes into the *N* = 40 "island of inversion"


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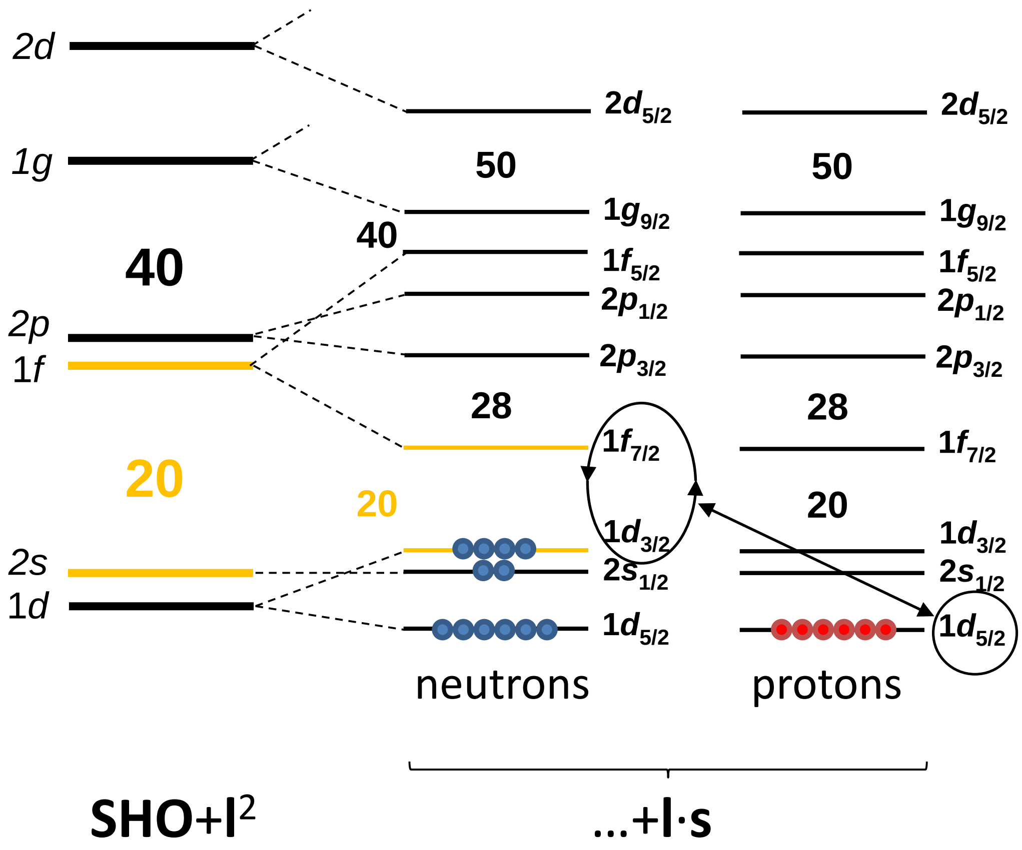
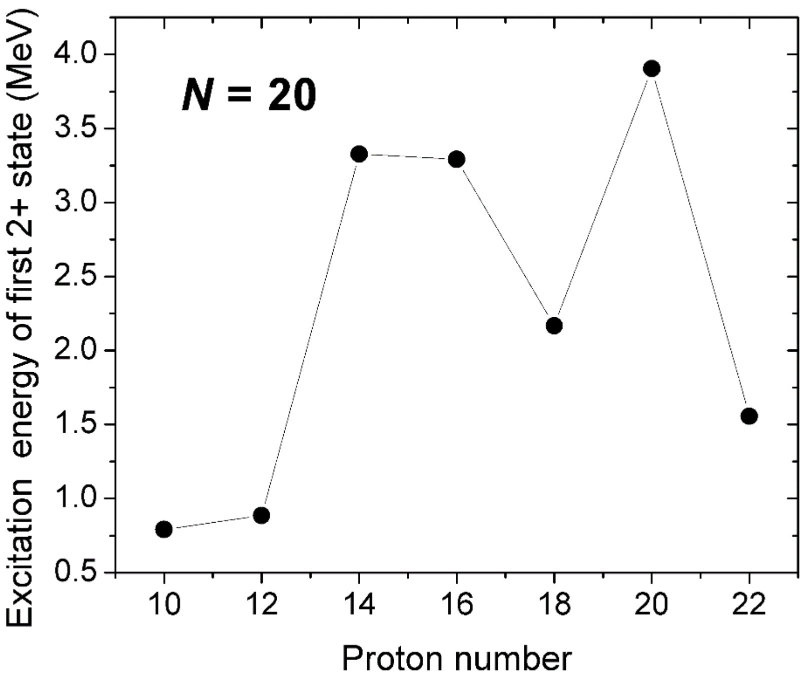
D. Atanasov, K. Blaum, S. George, F. Herfurth, M. Kowalska, S. Kreim, D. Lunney, Z. Meisel, M. Mougeot, D. Neidherr, M. Rosenbusch, L. Schweikhard, A. Welker, F. Wienholtz, R. Wolf, K. Zuber

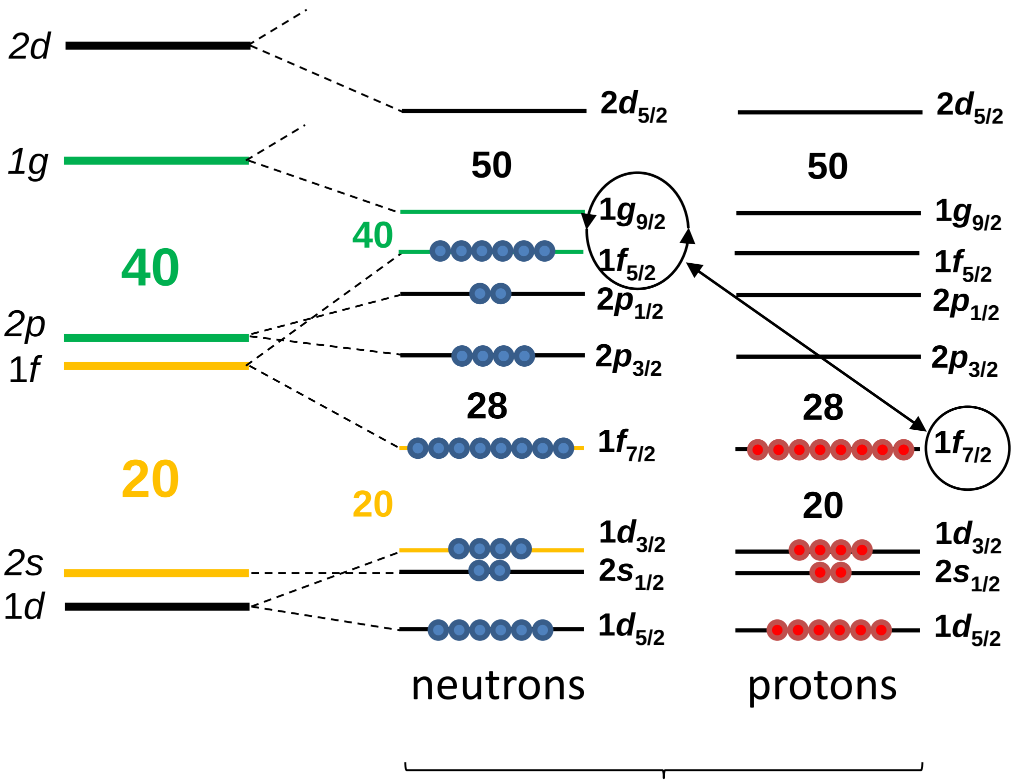
# $N$ = 20 "island of inversion"

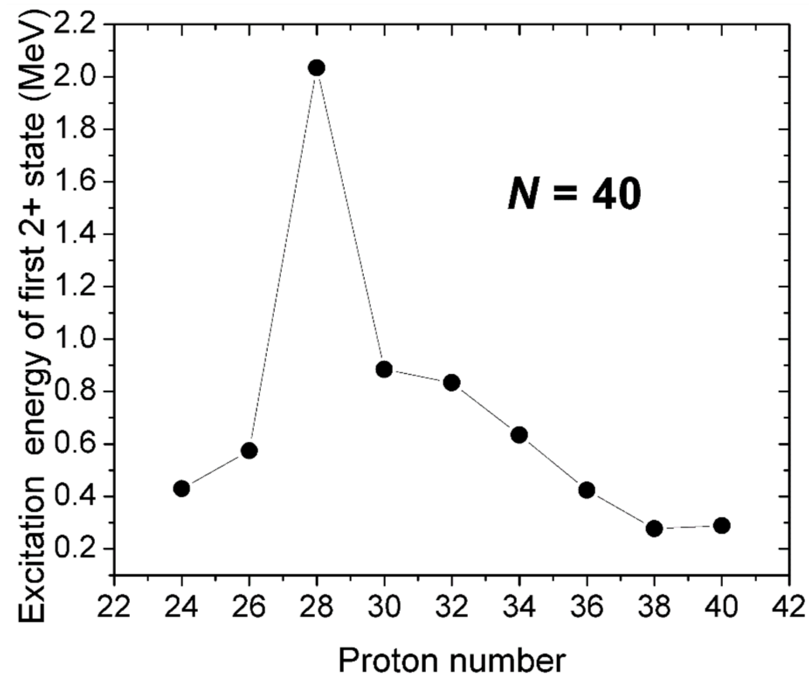



S. M. Lenzi *et al.*, Phys. Rev. C **82**, 054301 (2010).
ENSDF database (2015).

# $N$ = 40 "island of inversion"




**SHO+l$^2$**

**...+l·s**

**What does the mass surface look like?**

S. M. Lenzi *et al.*, Phys. Rev. C **82**, 054301 (2010).
ENSDF database (2015).

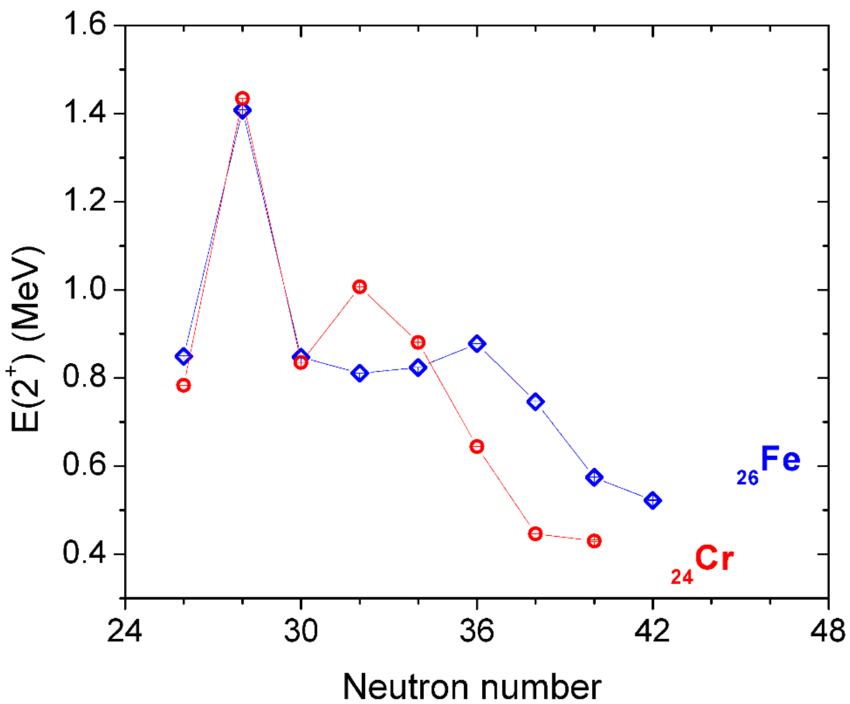
# Previous chromium addendum

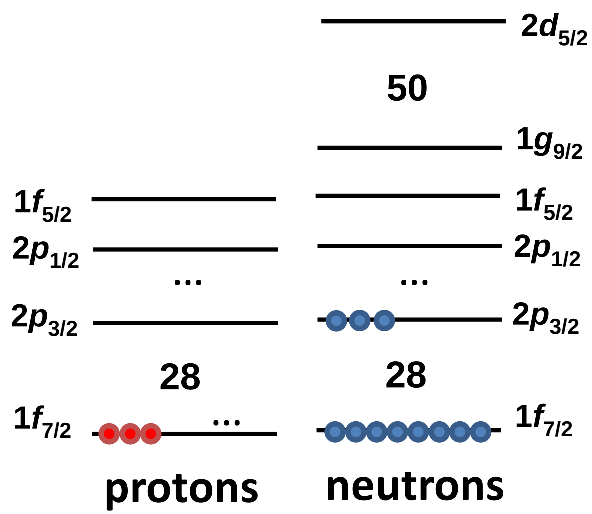
"The neutron-rich chromium isotopes in the region around N=40 are known to show an onset of collectivity based on recent data obtained, for example in Coulomb excitation experiments, providing B(E2) values and E2+ energies. Based on this experimental information it is however **not evident how more accurate mass measurements will change the picture of the nuclear structure** in Cr significantly. The Cr measurements are technically less challenging than that of n-rich Ca, but **the masses up to 63Cr are already known** even though with low precision. However, **the authors have not provided reasons why to doubt the previous measurement**s or why the higher precision is critical. "

*Minutes of 49th INTC Meeting 11-12 February 2015*

**How complete is the picture of nuclear structure at *N* = 40?**

# Nuclear structure at *N* = 40 in the shell-model framework




LNPS model space

- E($2^+$) and B(E2) suggest an onset of collectivity at N = 40.
- Large scale interaction (LNPS) devised to describe the data.

S. M. Lenzi *et al.*, Phys. Rev. C **82**, 054301 (2010).
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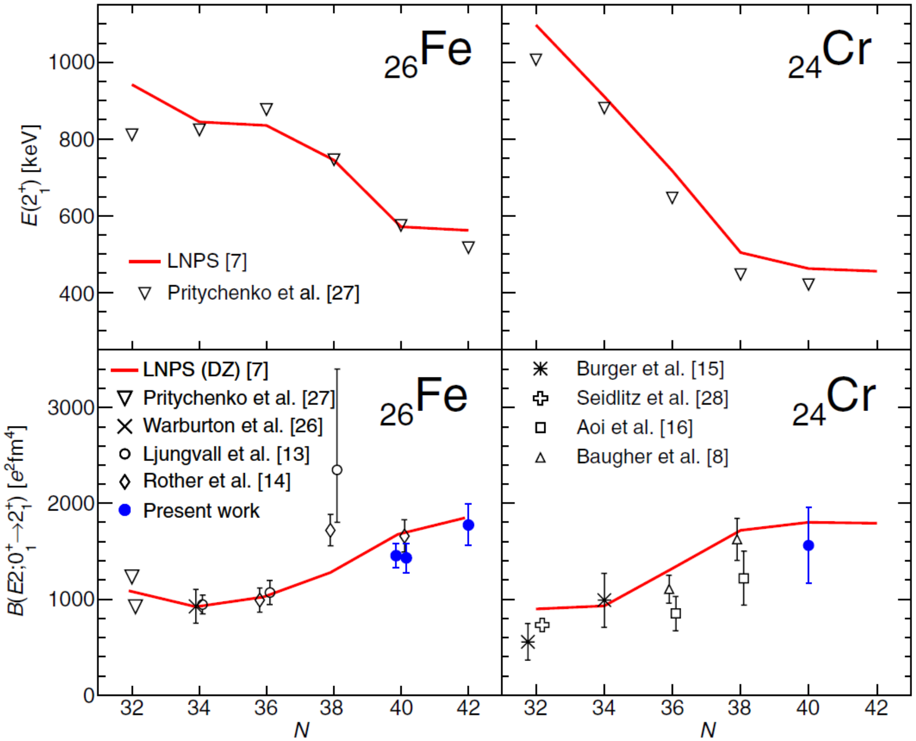
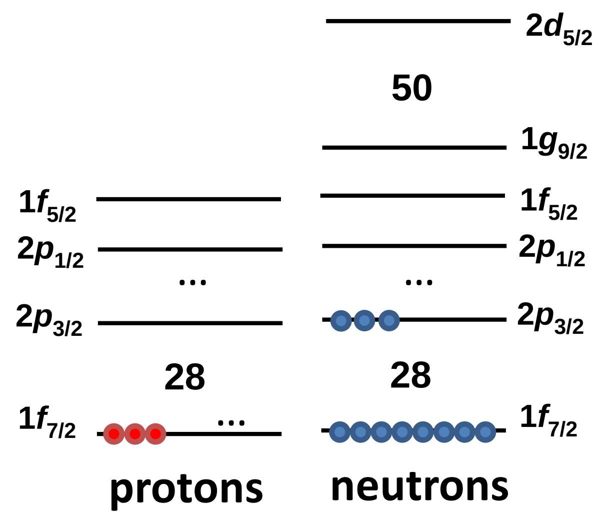
# Nuclear structure at *N* = 40 in the shell-model framework



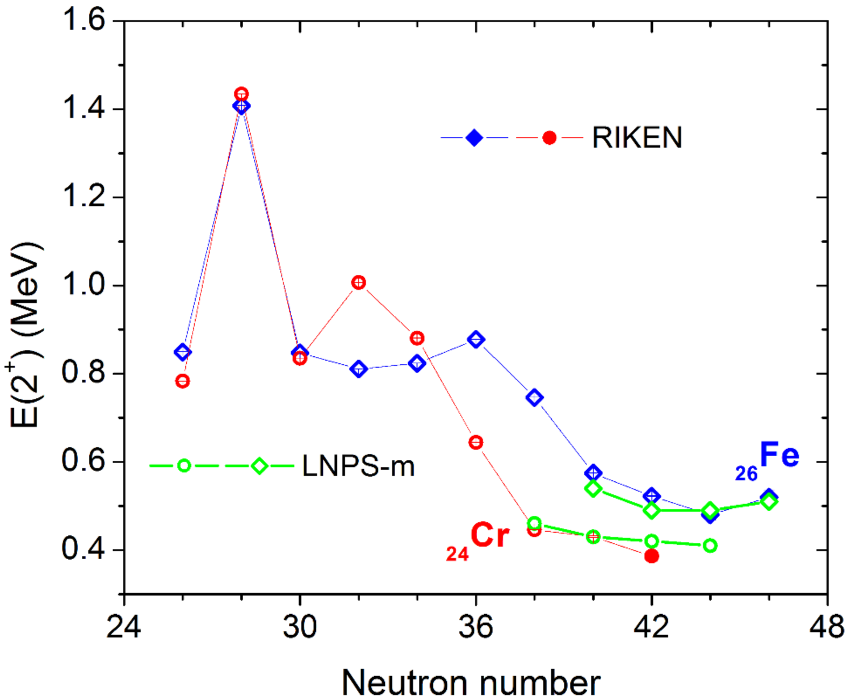



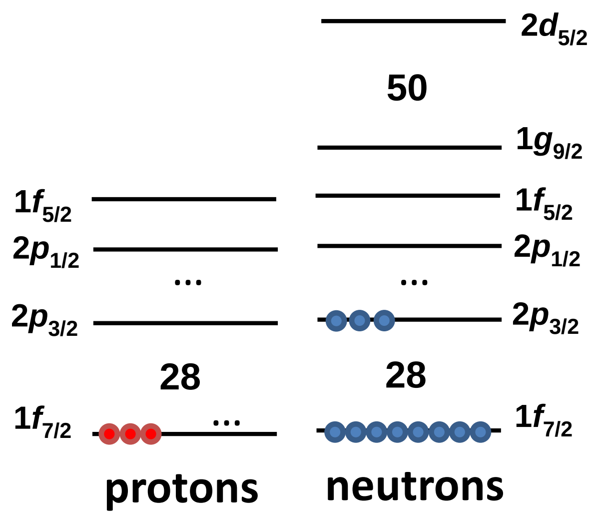

LNPS model space

- E(2⁺) and B(E2) suggest an onset of collectivity at *N* = 40.
- Large scale interaction (LNPS) devised to describe the data.
- Authors speak of an onset of deformation.


S. M. Lenzi *et al.*, Phys. Rev. C 82, 054301 (2010).
H. L. Crawford et al., Phys. Rev. Lett. 110, 242701 (2013).
ENSDF database (2015).

# Nuclear structure at $N$ = 40 in the shell-model framework



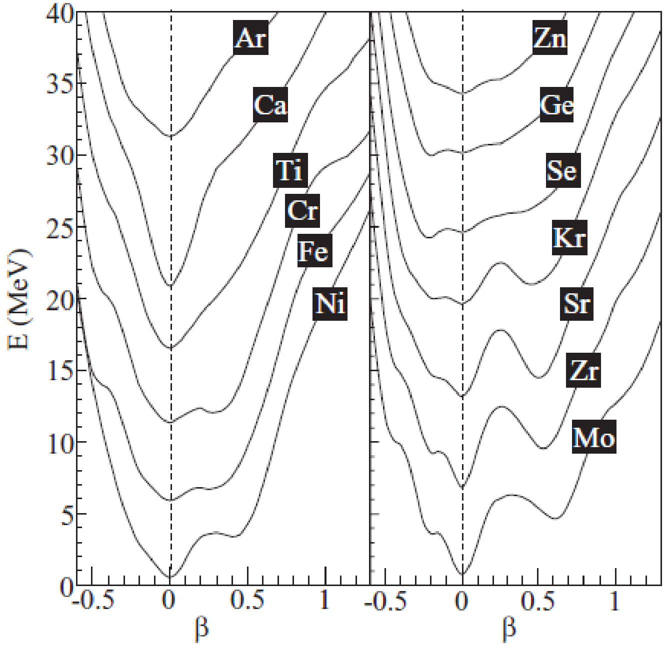



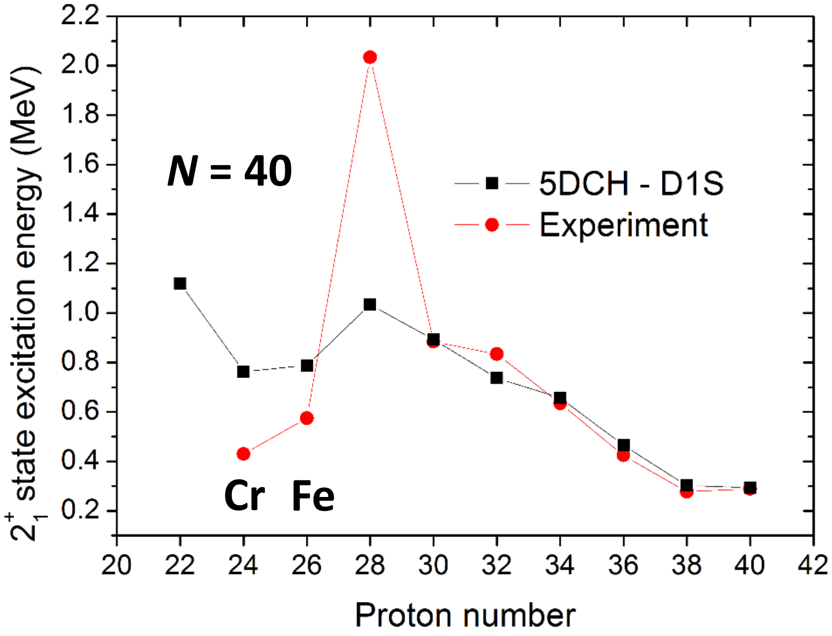

LNPS model space

- E(2⁺) and B(E2) suggest an onset of collectivity at $N$ = 40.
- Large scale interaction (LNPS) devised to describe the data.
- Authors speak of an onset of deformation.
- New RIKEN data published in 2015 impose a readjustment of the interaction (LNPS-m).


ENSDF database (2015).
C. Santamaria *et al.*, Phys. Rev. Lett. 115, 191501 (2015).

# Nuclear structure at *N* = 40 in the mean-field framework

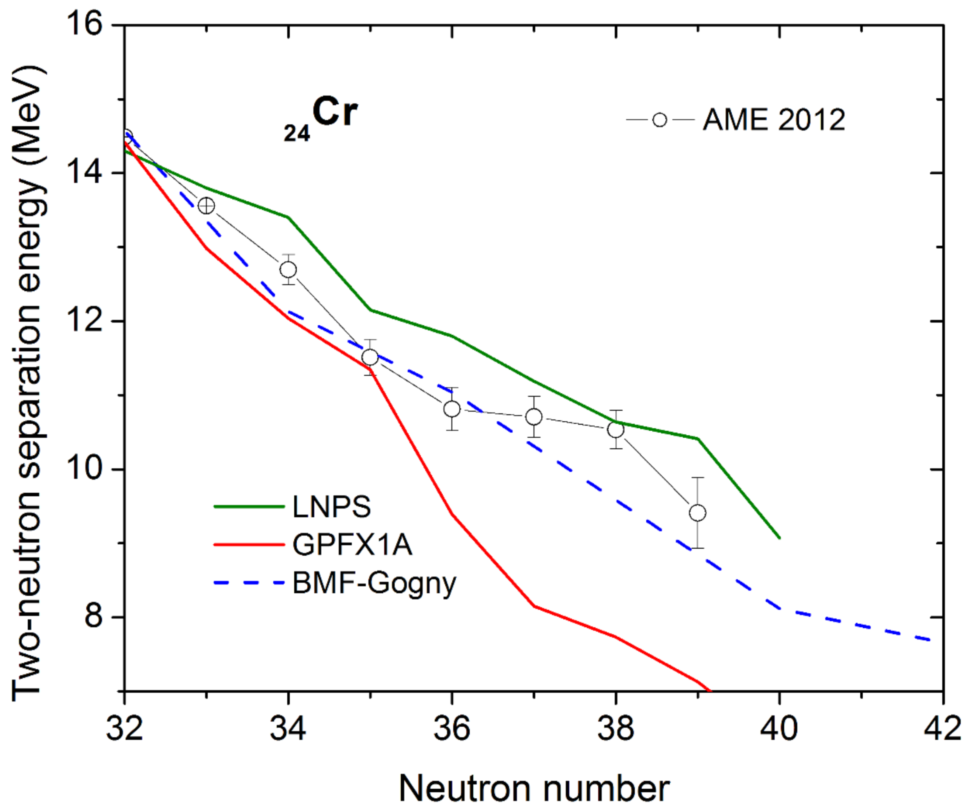



- "Islands of inversion" excellent phenomena for beyond-mean-field dynamics.
- All *N* = 40 isotones predicted to be spherical at the mean-field level.
- Excellent agreement of BMF-Gogny calculations with E($2^+$) values of *N* = 40 isotones for *Z*>28, but significant overestimation for *Z*<28.
- Ground-state binding energies are observables more reliable to compute in mean-field-based approaches.


L. Gaudefroy *et al.*, Phys. Rev. C. 80, 064313 (2009).
J.-P. Delaroche *et al.*, Phys. Rev. C 81, 014303(2010).
ENSDF database (2015).

# *N* = 40 "island of inversion"

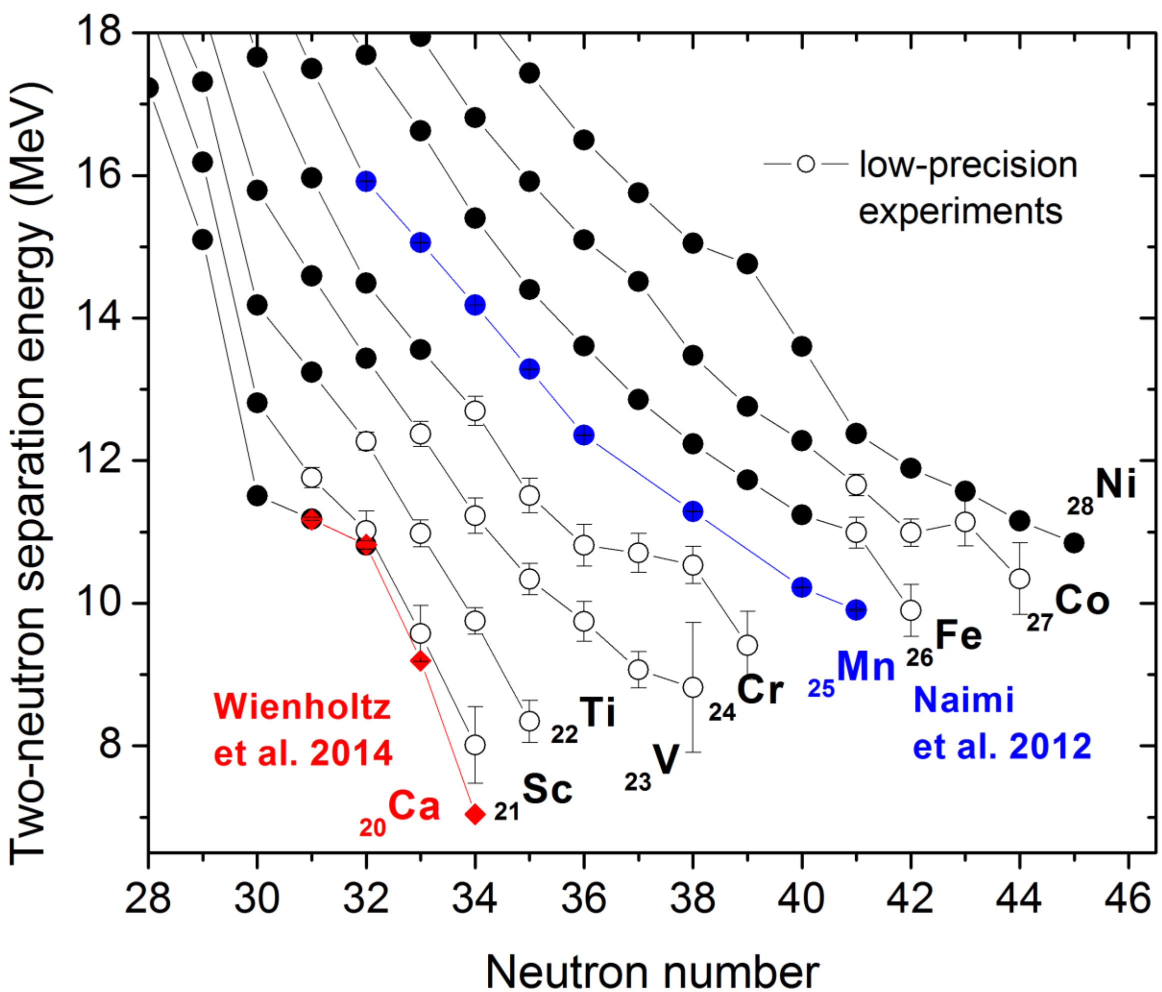



- AME2012 trend in disagreement with all predictions.
- It only confirms that LNPS model space is necessary.


K. Sieja, private communication.
J.-P. Delaroche *et al.*, Phys. Rev. C 81, 014303(2010).
M. Wang *et al.*, Chinese Physics C **36**, 1603 (2012).

**How reliable is the knowledge of binding energies across *N* = 40?**

# Existing mass surface



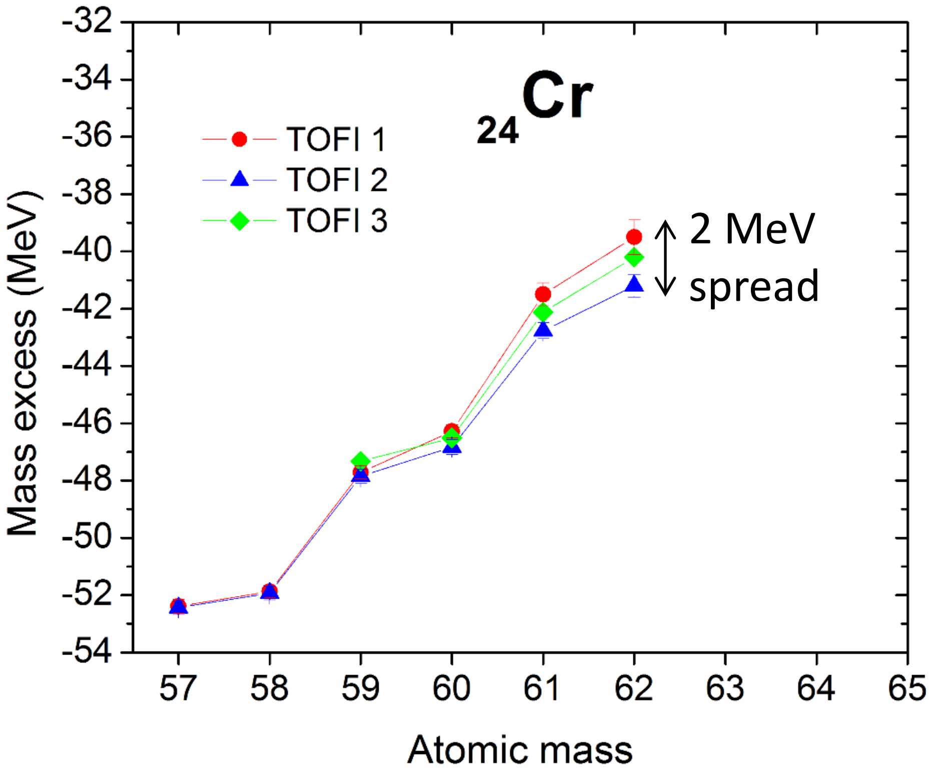


S. Naimi *et al.,* Phys. Rev. C **86**, 014325 (2012).

M. Wang *et al.*, Chinese Physics C **36**, 1603 (2012).

F. Wienholtz *et al*., Nature **498**, 346 (2013).

# Previous chromium measurements




- Three measurements with the same apparatus give three different trends.
- Systematic errors increase further one moves from the references.

X. Tu, et al., Z. Phys. A 337, 361 (1990).
H. Seifert, et al., Z. Phys. A 349, 25 (1994).
Y. Bai, D. J. Vieira, H. L. Seifert, J. M. Wouters, AIP Conf. Proc. 455, 90 (1998).

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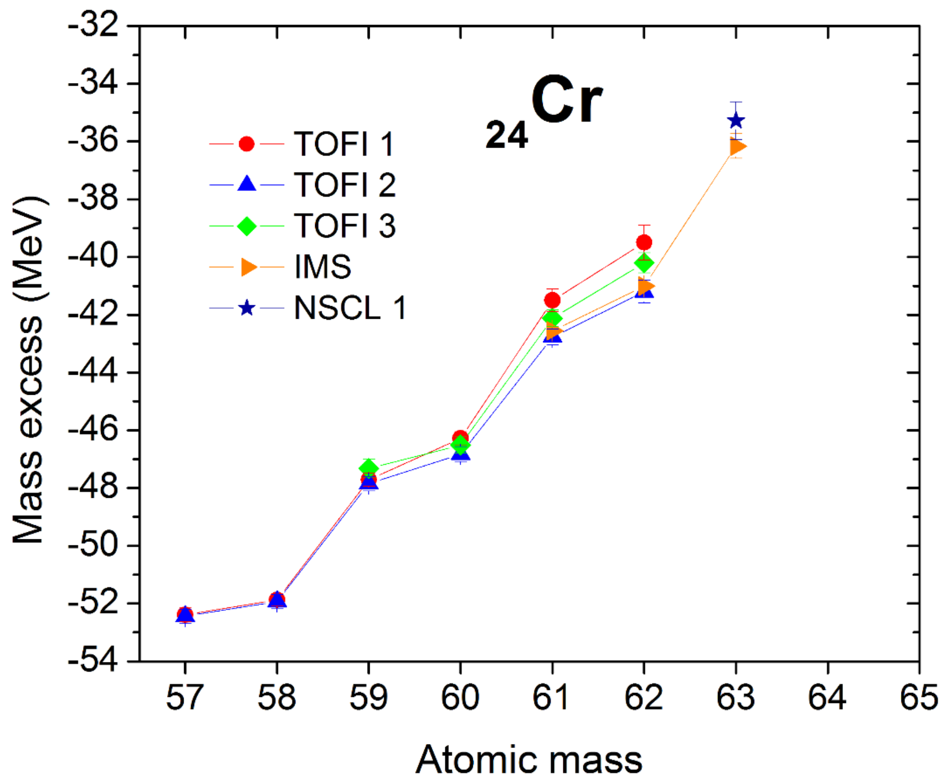


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Y. Bai, D. J. Vieira, H. L. Seifert, J. M. Wouters, AIP Conf. Proc. 455, 90 (1998).
A. Estrade, Phys. Rev. Lett. 107, 172503 (2011)
M. Matos, PhD thesis, Giessen (2004)

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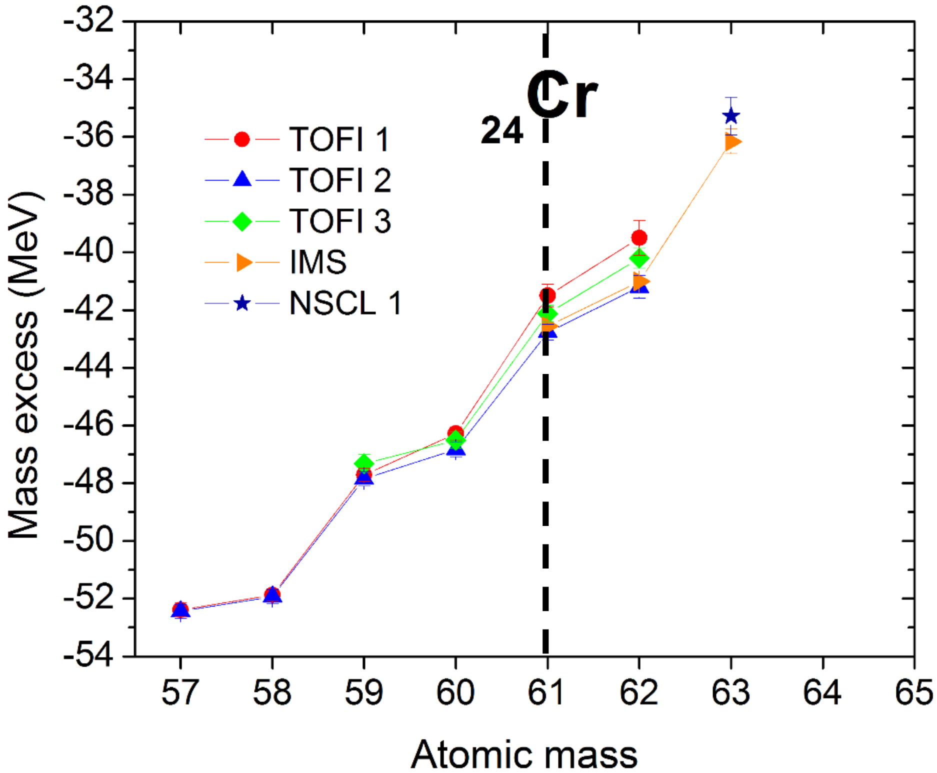


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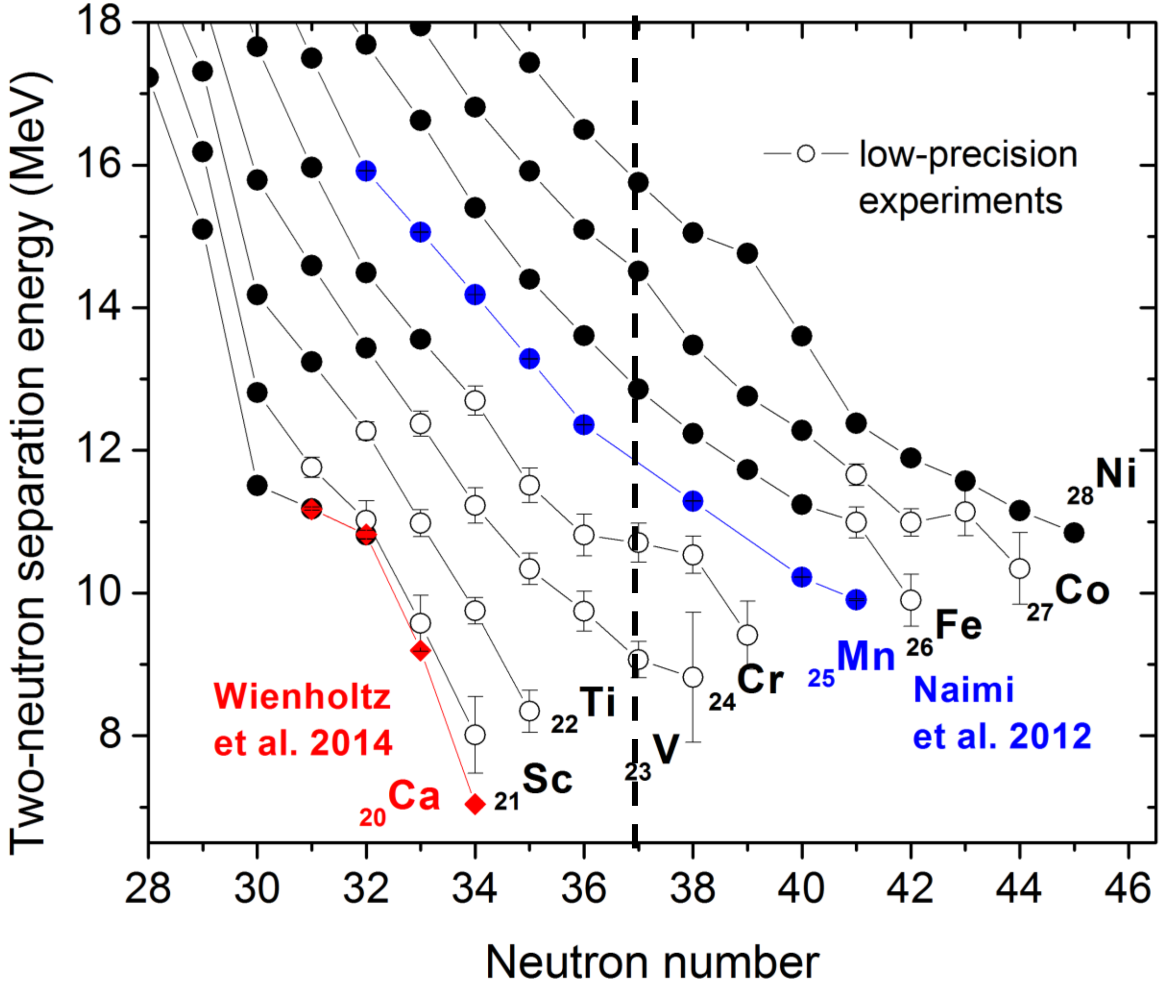
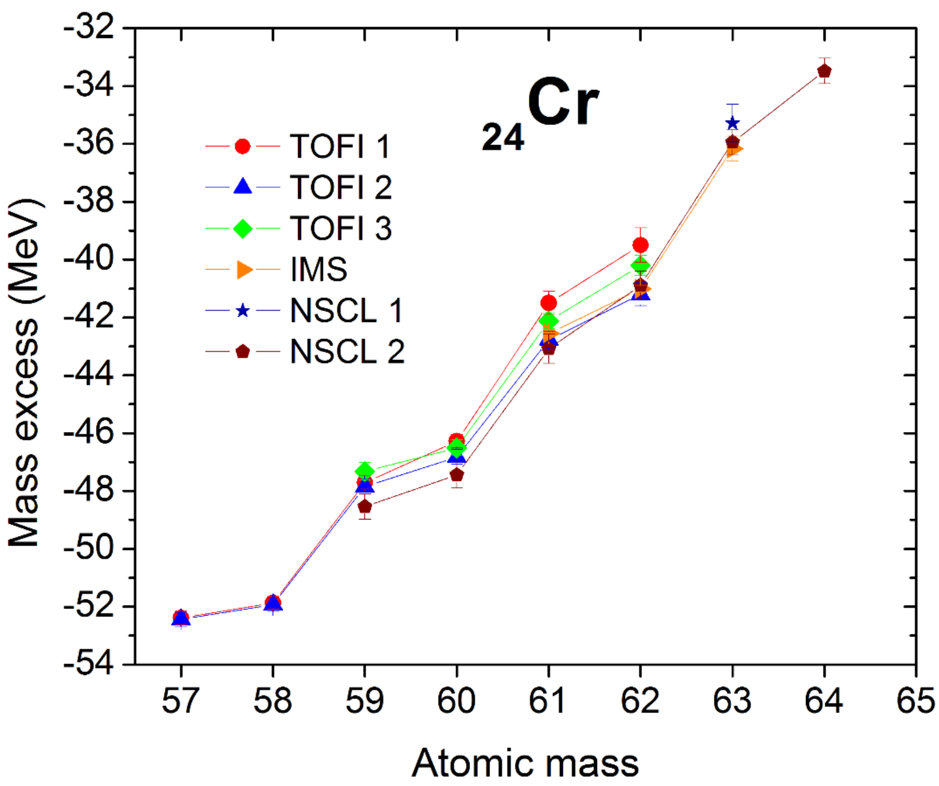



S. Naimi *et al.,* Phys. Rev. C **86**, 014325 (2012).
M. Wang *et al.*, Chinese Physics C **36**, 1603 (2012).
F. Wienholtz *et al.*, Nature **498**, 346 (2013).

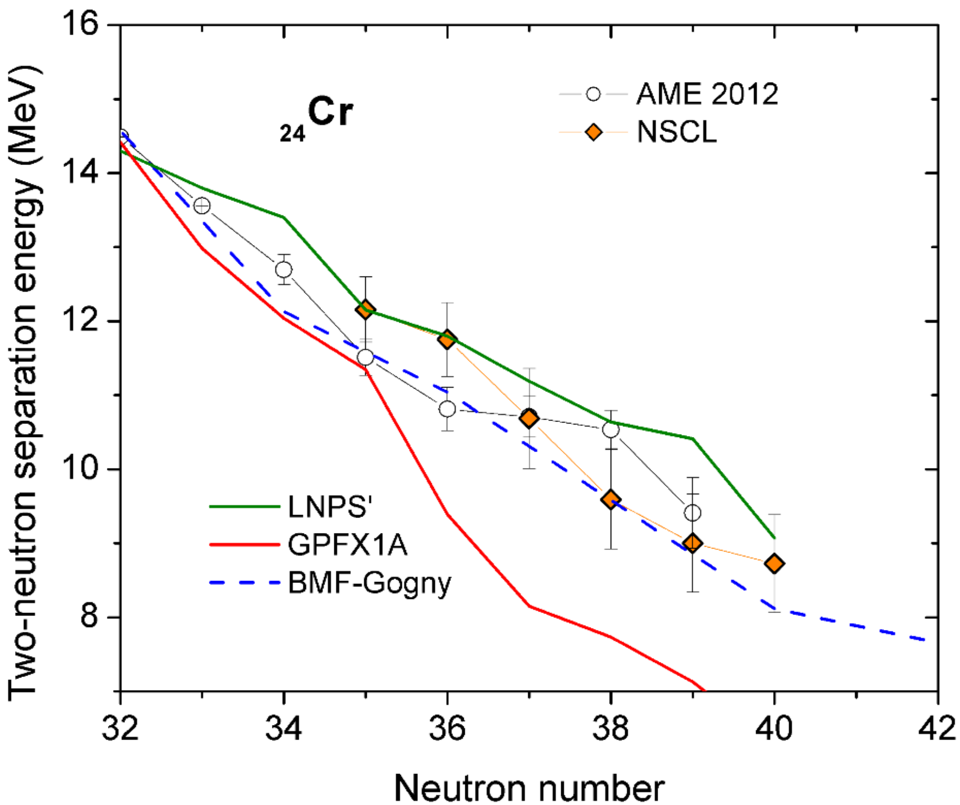
# Recent chromium measurements




- Three measurements with the same apparatus give three different trends.
- Systematic errors increase further one moves from the references.
- Artefact in $S_{2N}$ is expected to occur where new data set begins.
- Recent data set (NSCL2, 2015) completely off-set from old one.


X. Tu, et al., Z. Phys. A 337, 361 (1990).
H. Seifert, et al., Z. Phys. A 349, 25 (1994).
Y. Bai, D. J. Vieira, H. L. Seifert, J. M. Wouters, AIP Conf. Proc. 455, 90 (1998).
Z. Meisel, private communication (2016).
A. Estrade, Phys. Rev. Lett. 107, 172503 (2011)
M. Matos, PhD thesis, Giessen (2004)

# The recent masses



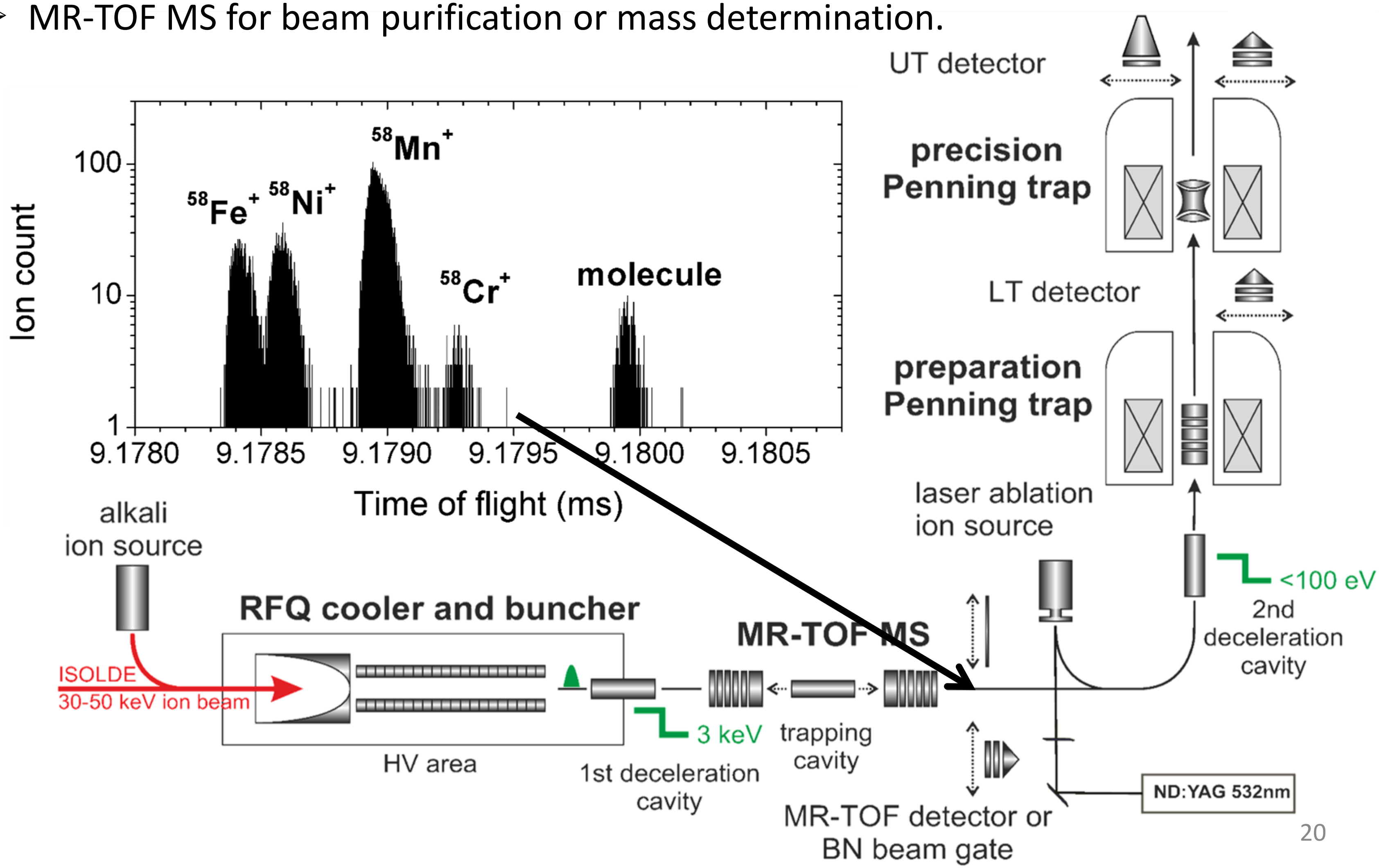

- LNPS interaction modified to better describe $S_{2N}$ values (LNPS').
- Precise and accurate measurements are required to compare theory to.
- New Penning-trap masses would also become more reliable references for future TOF spectrometer mass measurements.


K. Sieja, private communication (2016).
J.-P. Delaroche *et al.*, Phys. Rev. C 81, 014303(2010).
M. Wang *et al.*, Chinese Physics C **36**, 1603 (2012).
Z. Meisel *et al.*, private communication (2016).

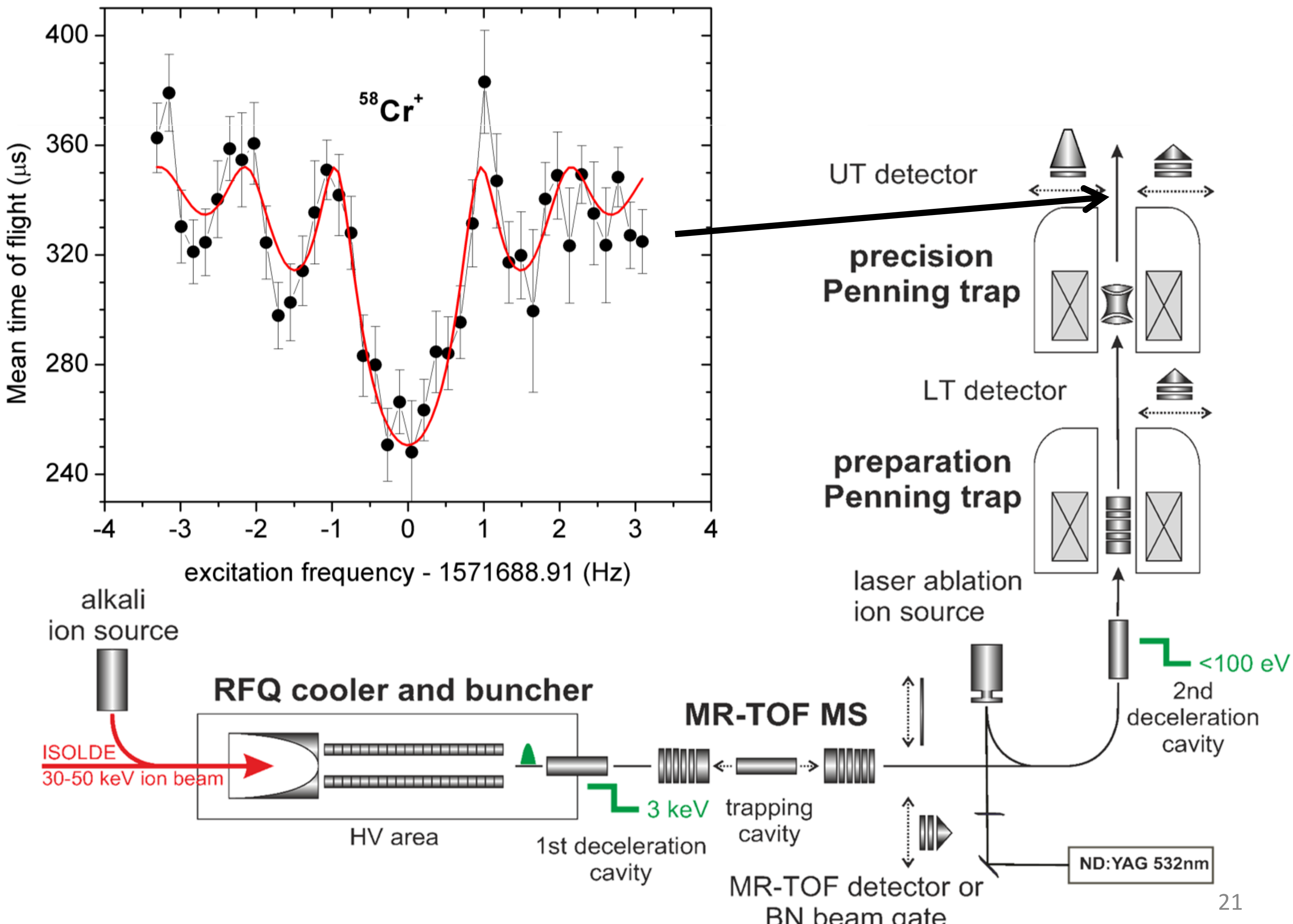
**How feasible is the experiment?**

# IS532 measurements – $^{52,55-59}Cr$

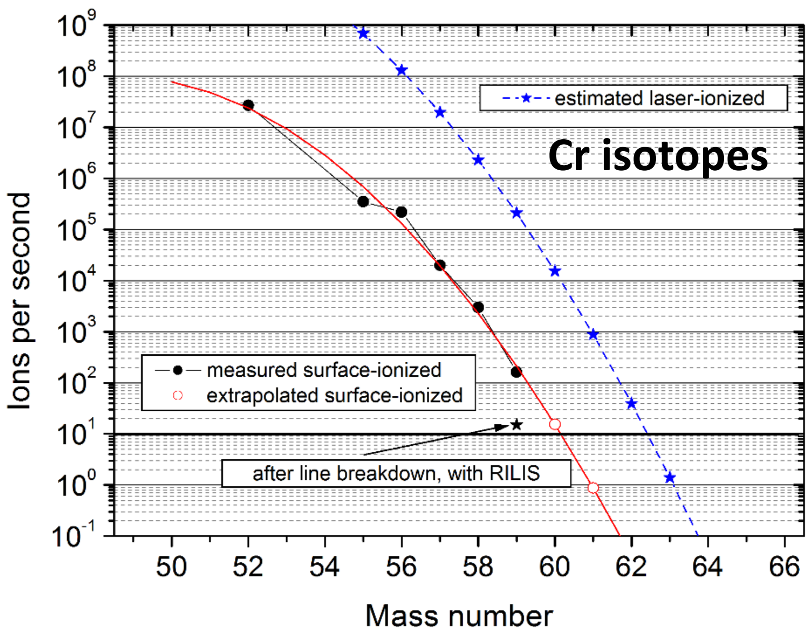
- Scandium beam time, no scandium observed (even from oven).
- Intense chromium beams observed: measured $^{52,55-59}Cr$.
- MR-TOF MS for beam purification or mass determination.



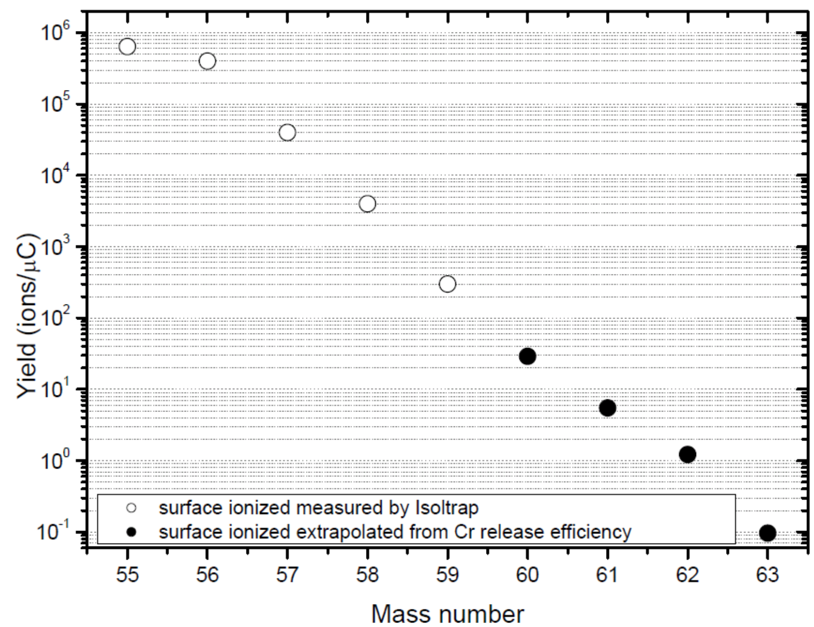
# IS532 measurements – $^{52,55-59}Cr$



# Beam-time request




Courtesy Tania Mendonca




| Isotope | Half-life (ms) | Target | Yield† (ions/μC) | Method | Ion source | Shifts |
|---|---|---|---|---|---|---|
| **$^{60}$Cr** | 490(10) | $UC_x$ | $10^4$ | Penning trap | RILIS | **2** |
| **$^{61}$Cr** | 243(9) | | $10^3$ | Penning trap/ MR-TOF MS | | **3** |
| **$^{62}$Cr** | 206(2) | | $10^1$-$10^2$ | MR-TOF MS | | **3** |
| **$^{63}$Cr** | 129(2) | | 1-10 | MR-TOF MS | | **5** |
| | | | | | **Total shifts of radioactive beam** | **13** |

- Factor 500 enhancement from RILIS tested with stable chromium.



T. D. Goodacre *et al.*, arXiv:1512.07875 (2015)

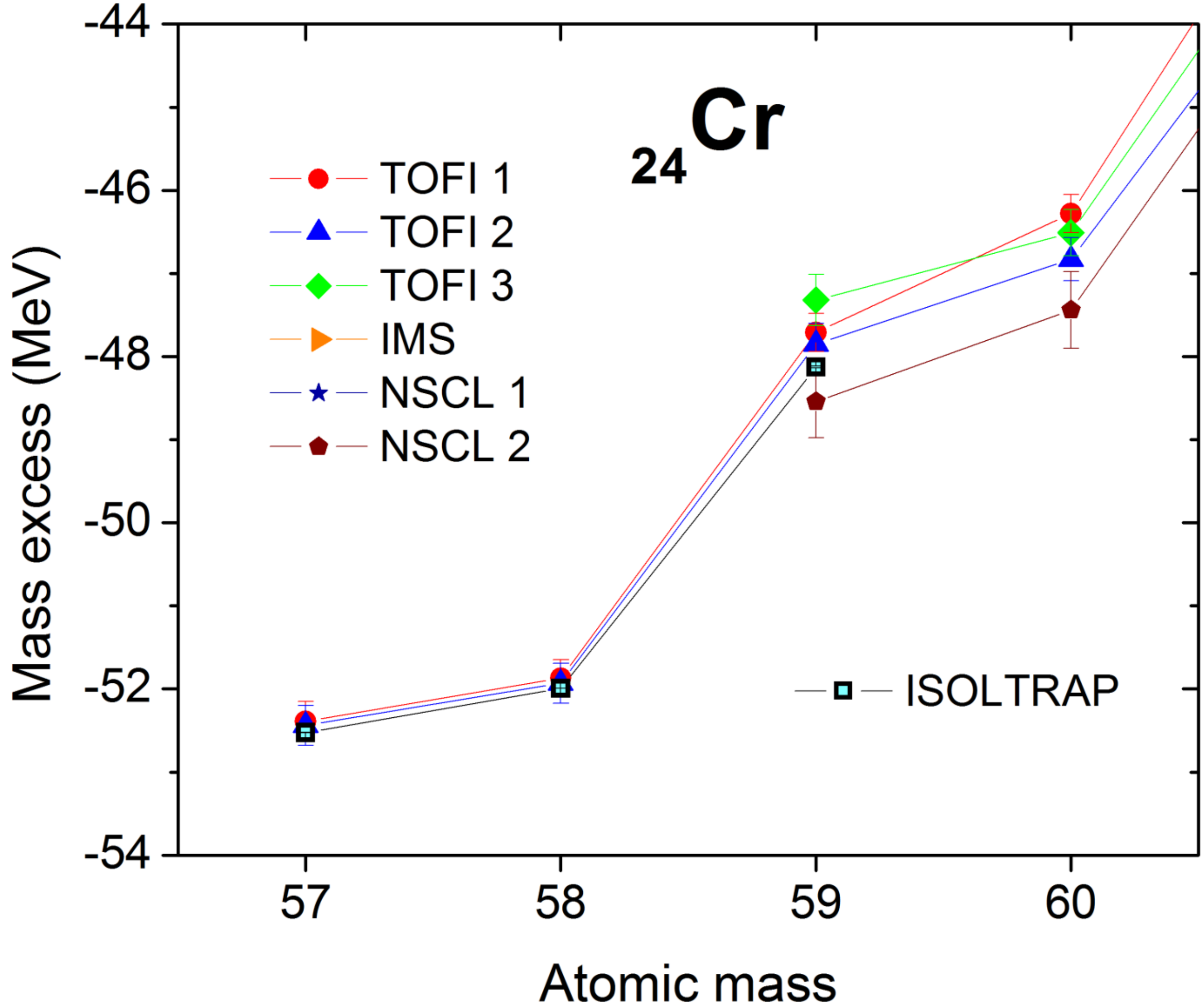
# Appendices

“The largest discrepancy is found for the $S_{2N}$ value of $^{63}$Cr, which is severely overestimated. This is surprising as the present model accurately reproduces the known excitation energies of chromium isotopes, with the visible drop of the yrast $2^+$ excited state energies between $N$ = 36 and $N$ = 38, indicating that chromium isotopes undergo a shape change at $N$ = 38. **However, nothing is known about the spectroscopy of $^{63}$Cr and the ground-state spin assignments of both $^{63}$Cr and $^{61}$Cr are tentative, making it difficult to evaluate whether these nuclides have the correct degree of collectivity in the present shell-model calculations.** This in turn prevents us from determining why the $S_{2N}$ trend from this experiment does not drop smoothly between $N$ = 38 and $N$ = 39, as expected in the deformation region. In spite of this discrepancy, the LNPS' shell-model trend points clearly to the development of collectivity around $N$ = 40 and predicts continuation of the deformation onset towards higher neutron numbers.”

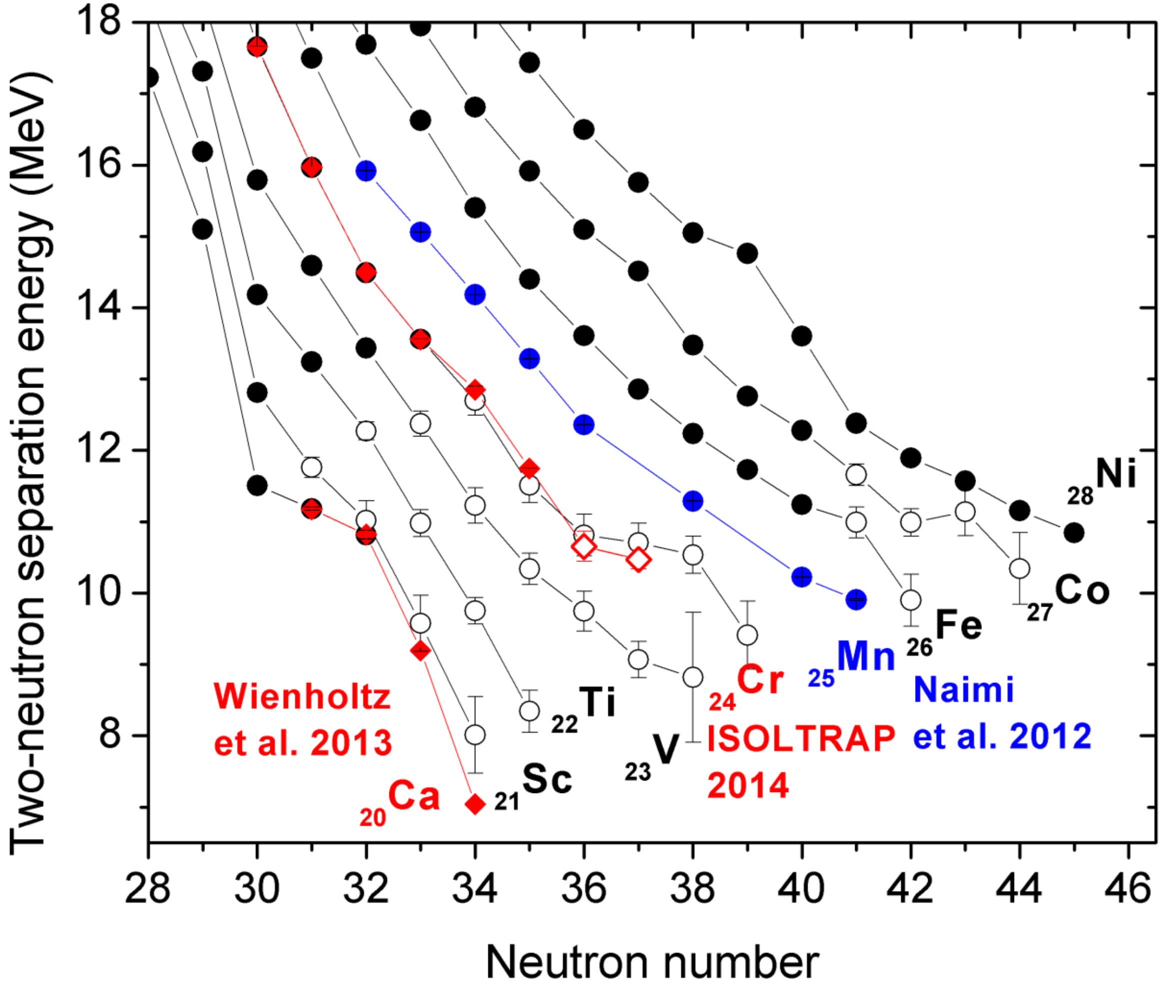


Z. Meisel *et al.*, private communication (2016).

# Chromium masses



# Chromium binding energies





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