

Future exploitation of optical pumping in manganese

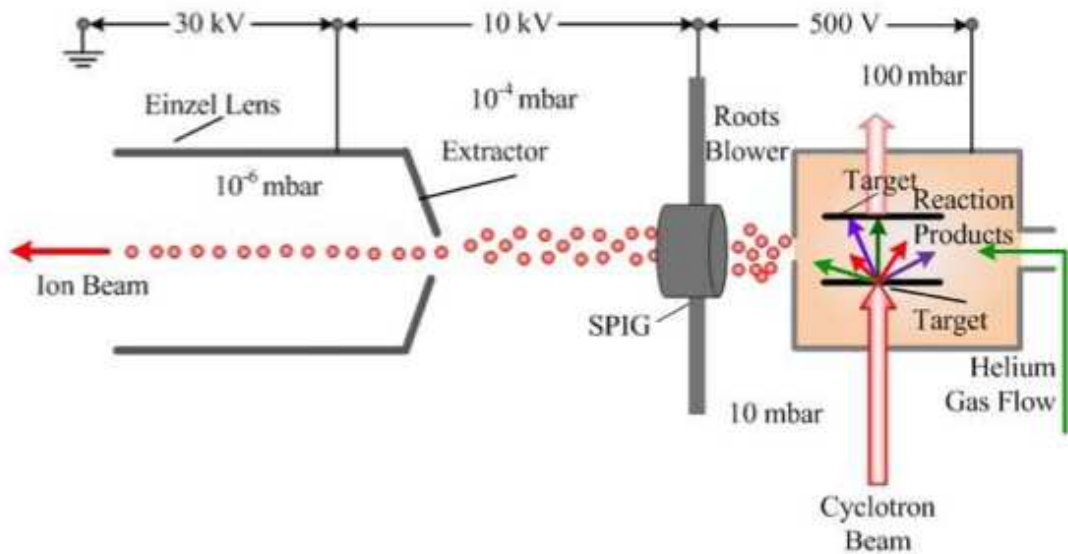
Frances Charlwood

DESIR workshop

May 2010

Introduction

- ✿ Laser spectroscopy at JYFL
- ✿ History of the $N=28$ shell closure
- ✿ Manganese isotope shifts and charge radii
- ✿ Future experiments at JYFL, ISOLDE and DESIR

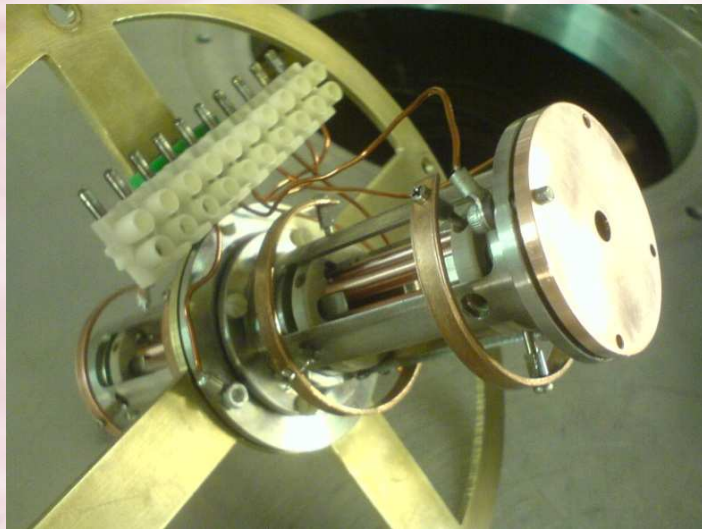


- ✱ Refractory Mn can only be produced at separators such as the IGISOL, JYFL (and now ISOLDE!)

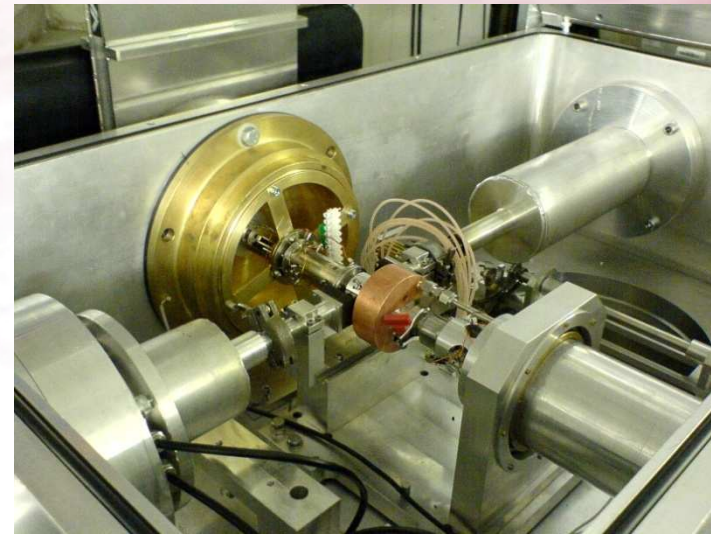
- ✱ Radioactive isotopes with short half lives can also be studied

- ✱ Reaction products quickly extracted from the target region via a helium buffer gas

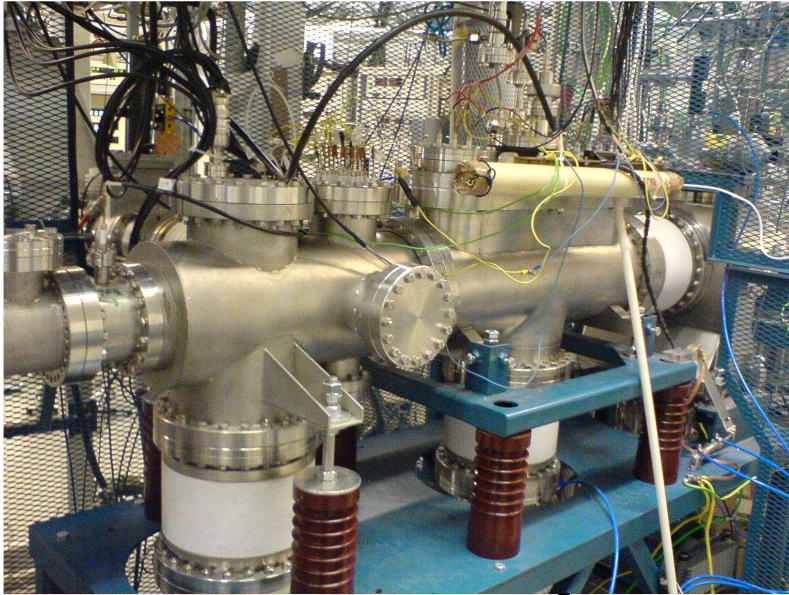
- ✱ Ions formed into a beam and injected into the cooler-buncher



Copper Sextupole Ion Guide (SPIG)



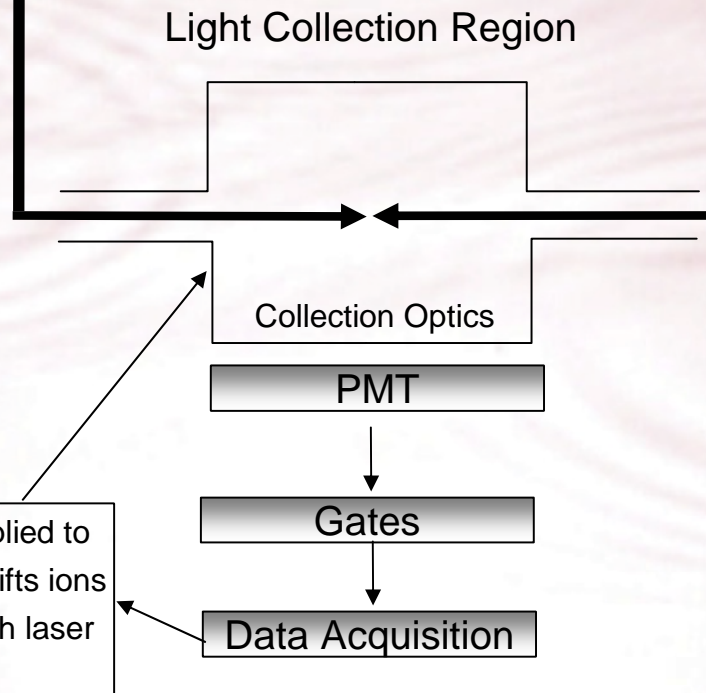
Fusion guide



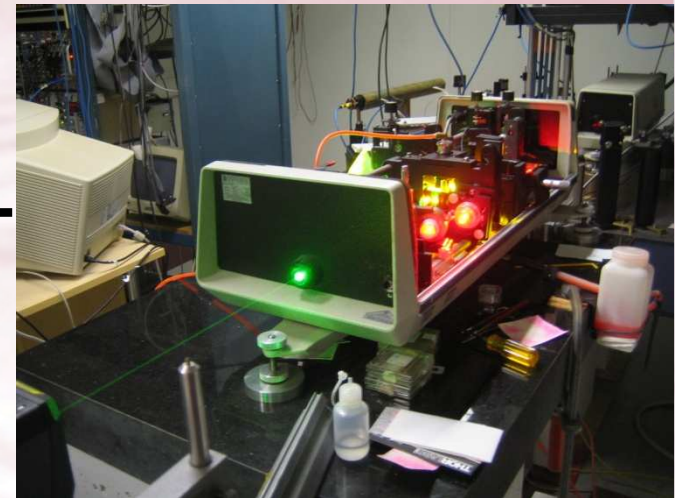
Ions through cooler-buncher on +30kV platform

Laser Spectroscopy at JYFL

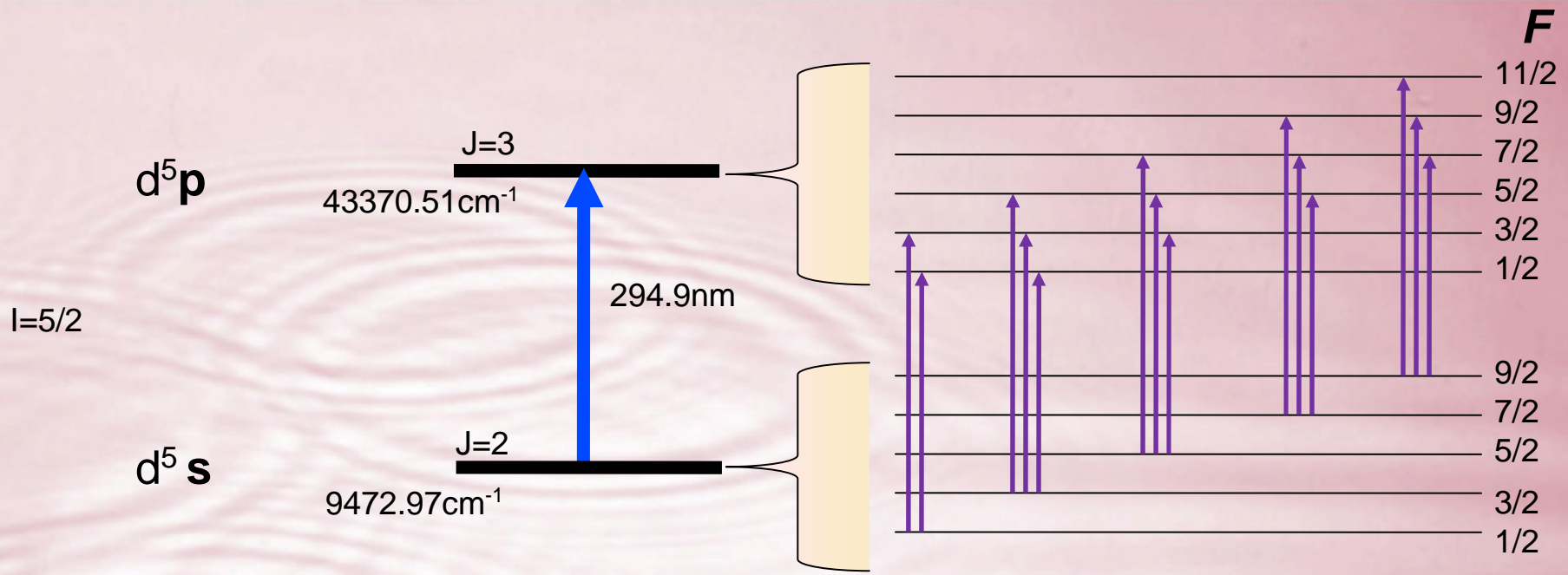
- ✱ Overlapping of an ion beam with a counter propagating, fixed frequency, CW laser at 30kV to reduce the energy spread
- ✱ Photon detection when resonantly excited ions decay to their ground states



CW laser



- ✱ Gating decreases background by factor 10^4

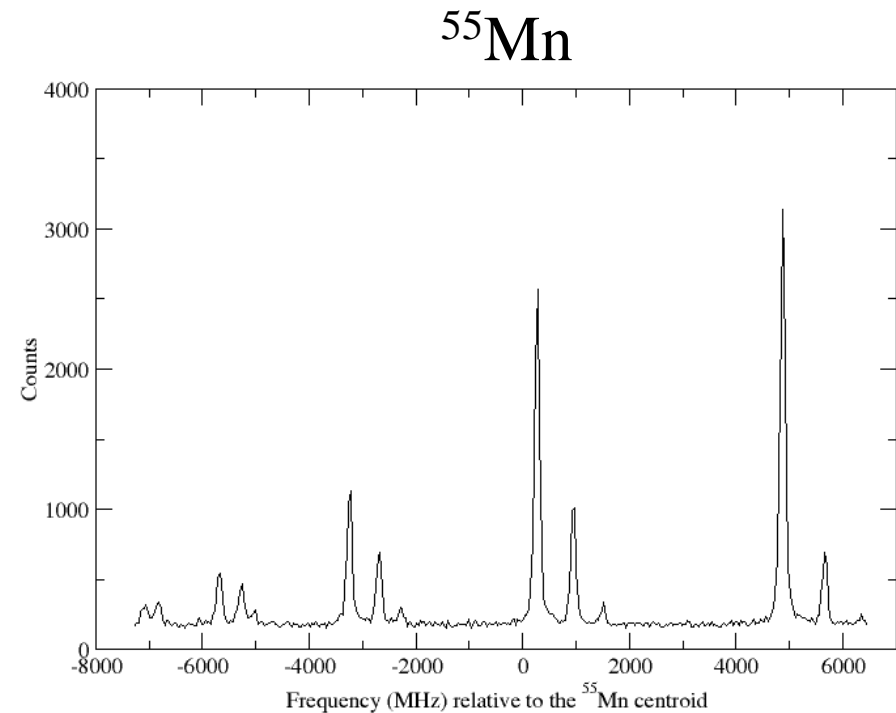


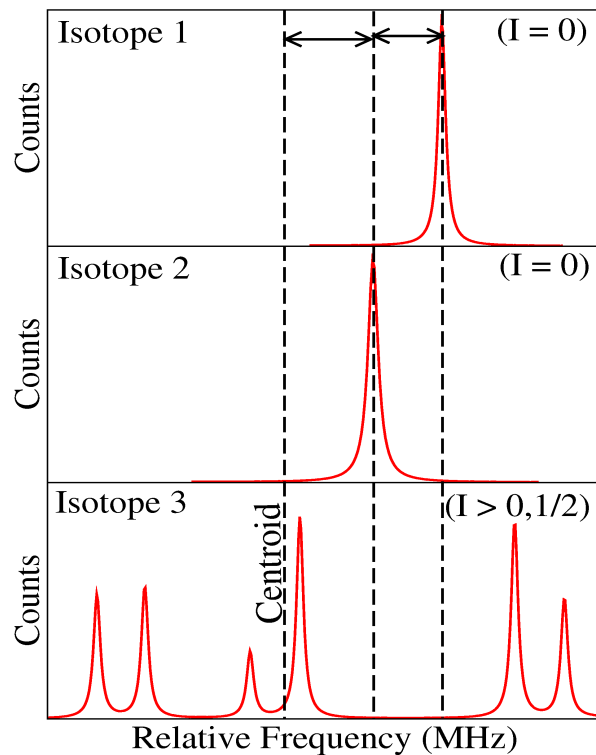
★ Hyperfine structure – interaction of nuclear charge distribution and EM field at the nucleus produced by electrons.

$$F = I + J$$

Nuclear Spin I
 Magnetic Dipole Moment μ_I
 Electric Quadrupole Moment Q_s
 Hyperfine Anomaly

μeV splitting





IS measurements
yield information on:

- $\delta \langle r^2 \rangle^{AA'}$ Size
- $\delta \langle \beta_2^2 \rangle$ Shape
- $\delta \sigma$ Diffuseness

☀ Isotope shift measurements

Arises due to the finite size and mass of the nucleus

Causes a shift in centroid of the hyperfine multiplet along an isotope chain

Divided into the mass shift and field shift:-

Mass shift – the relative centre of mass changes between isotopes

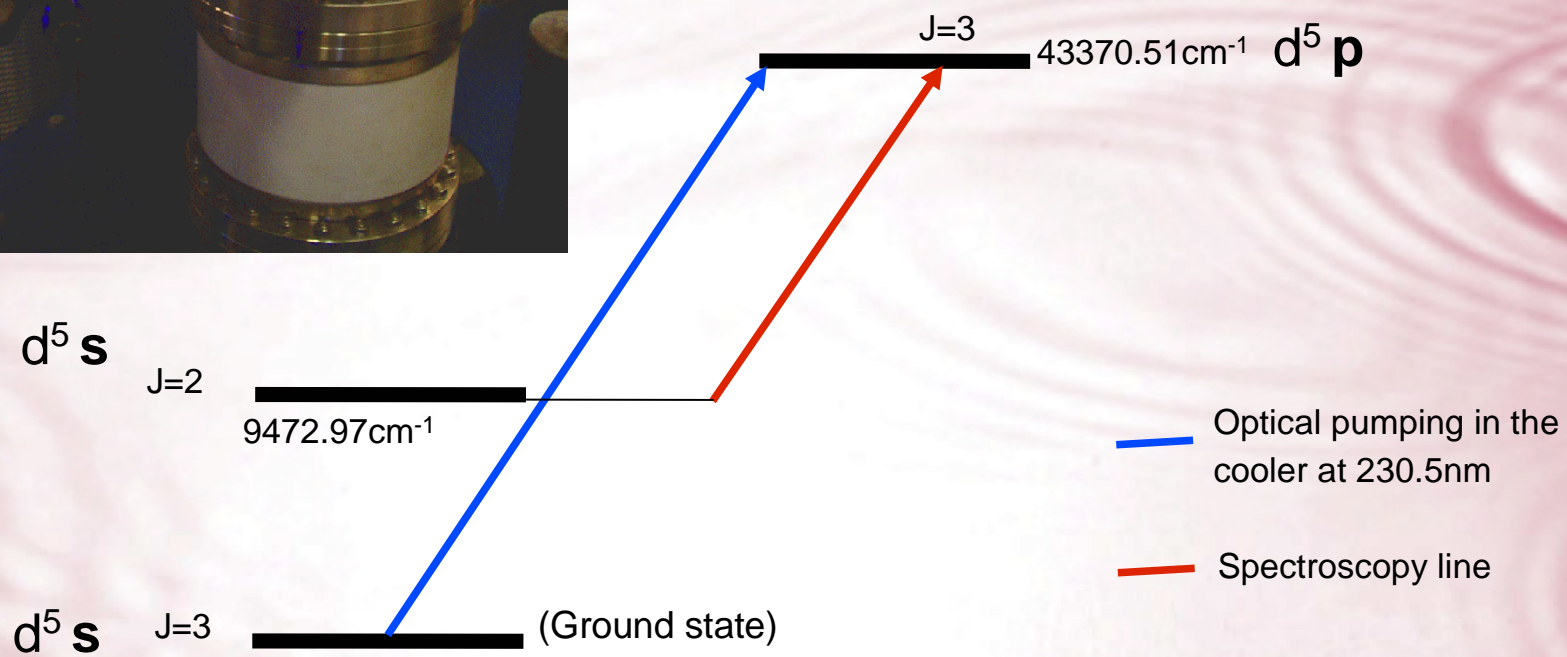
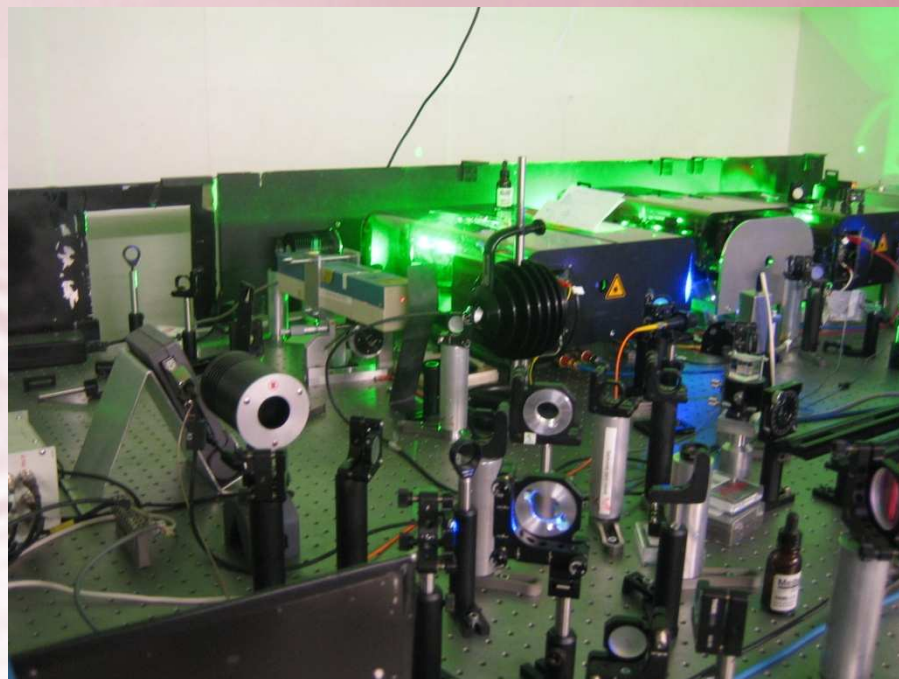
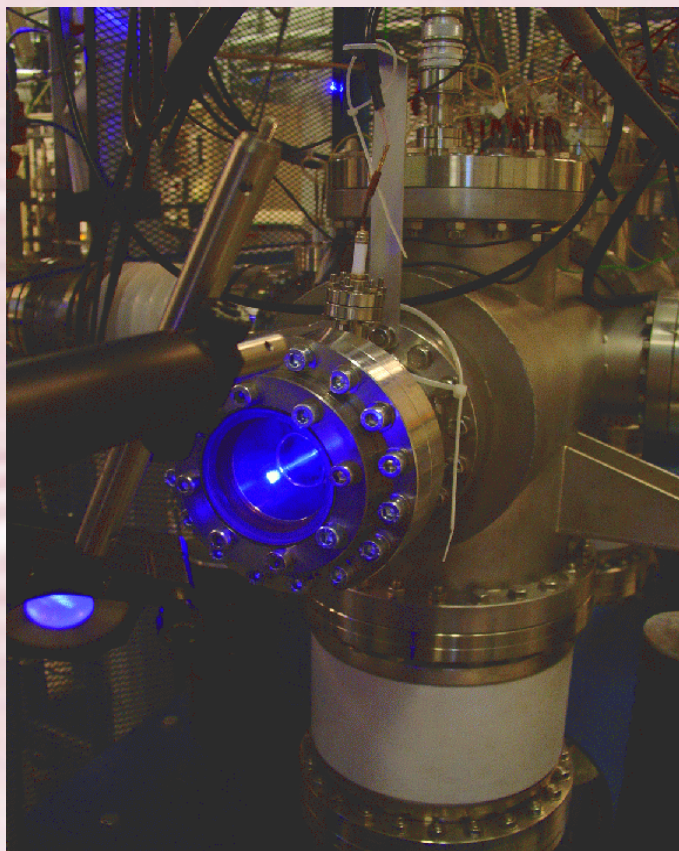
Field shift – Orbital electron experiences an electrostatic potential due to the nuclear charge and distribution of that charge. This changes between isotopes.

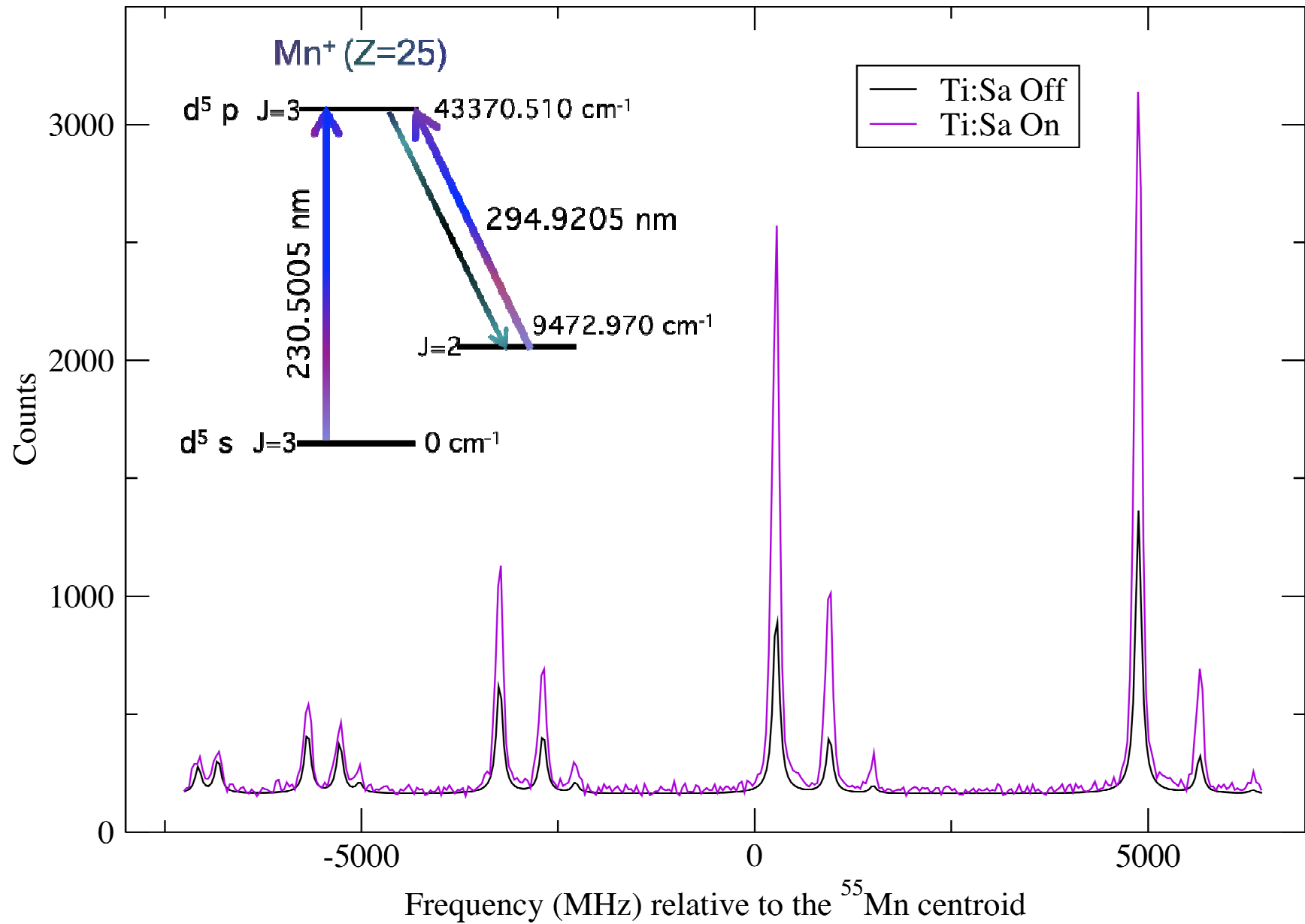
$$\delta \nu^{A,A'} = M_i \frac{A' - A}{AA'} + F_i \delta \langle r^2 \rangle^{A,A'}$$

Mass shift

Field shift

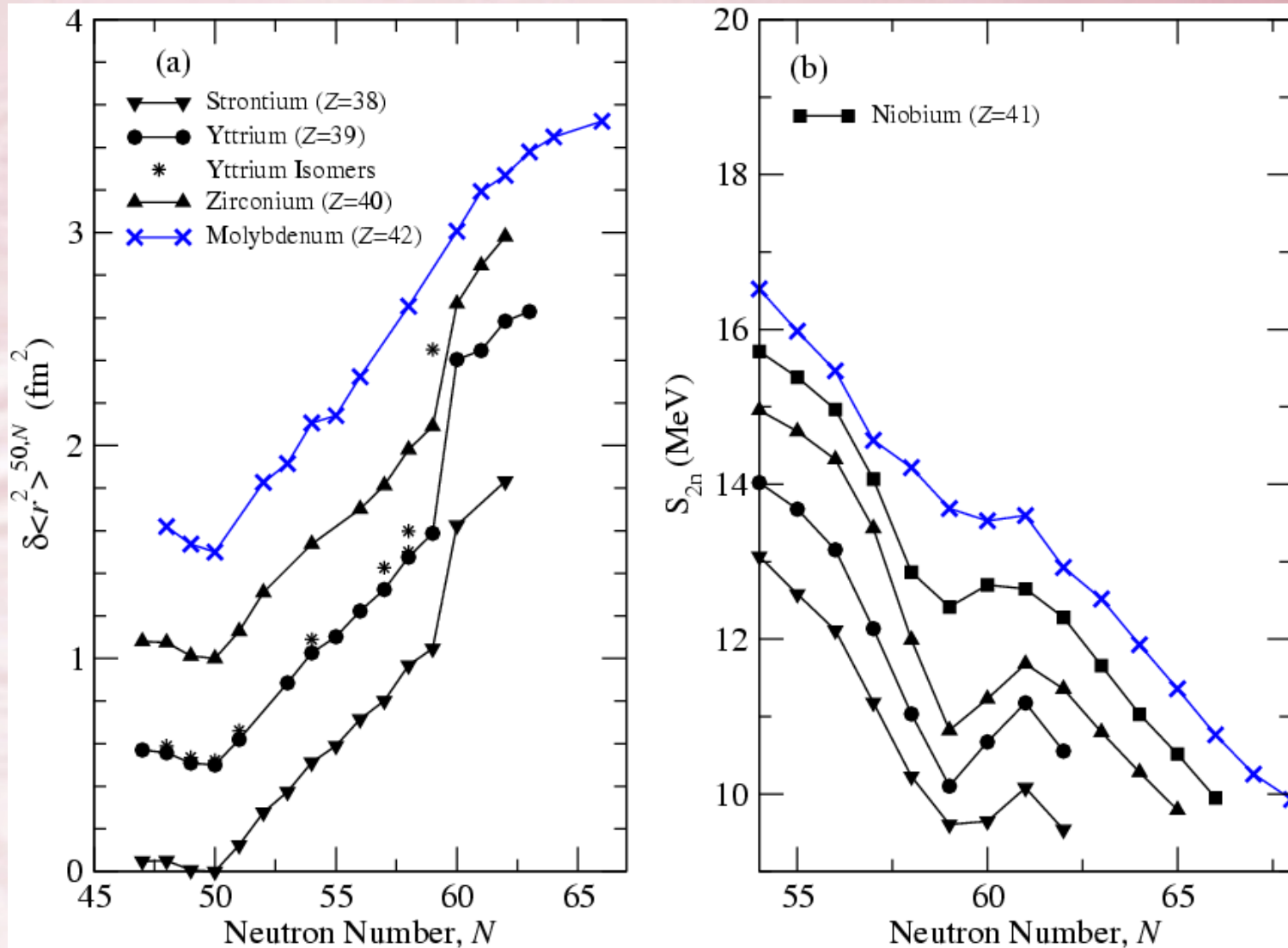
✱ Optical pumping in cooler-buncher



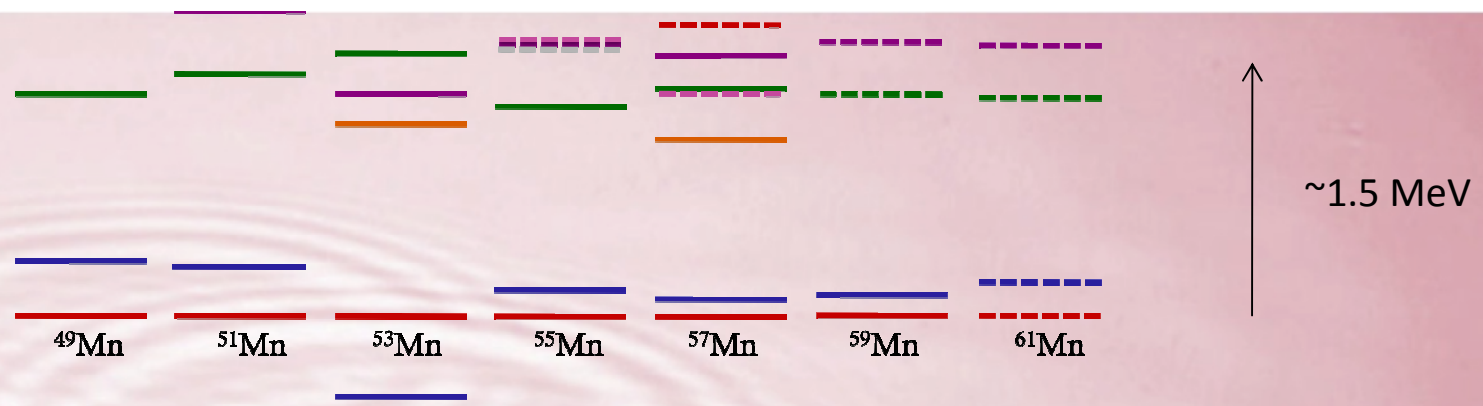


✱ Improvement in efficiency from 1 in 250,000 to 1 in 4,000 after bunching ions in cooler

Previously in the $Z \sim 40$ region...

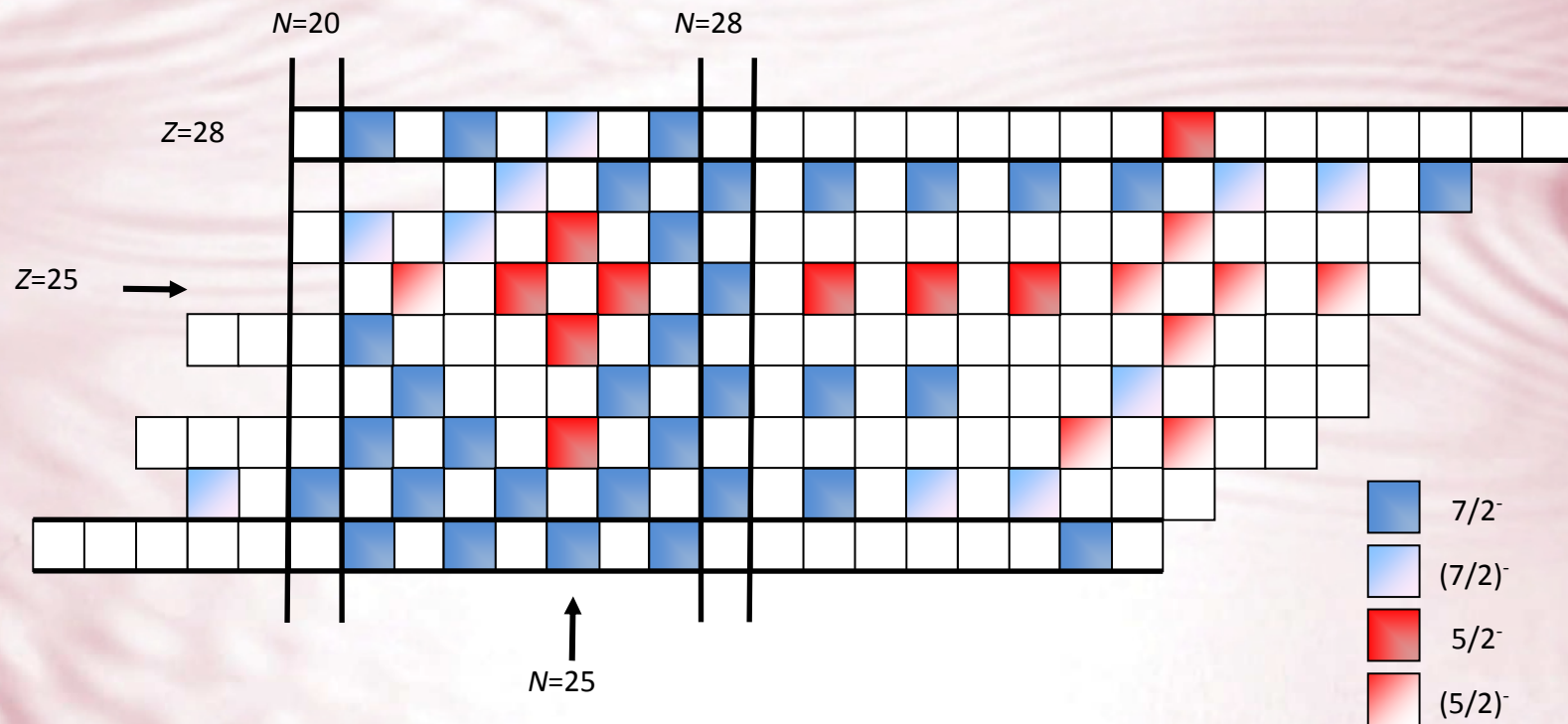


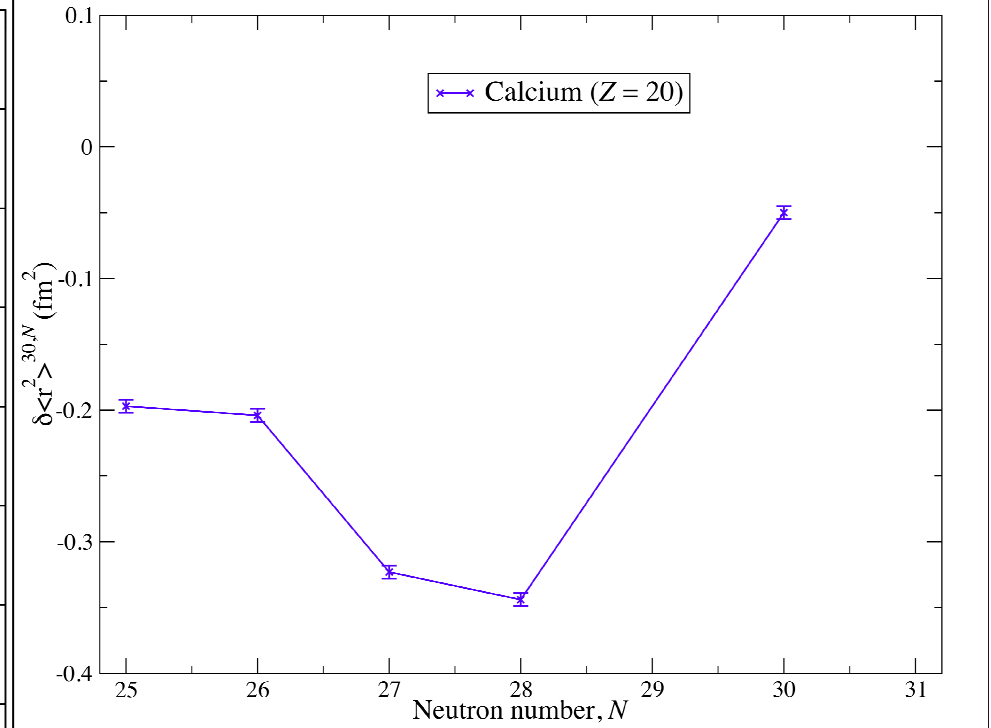
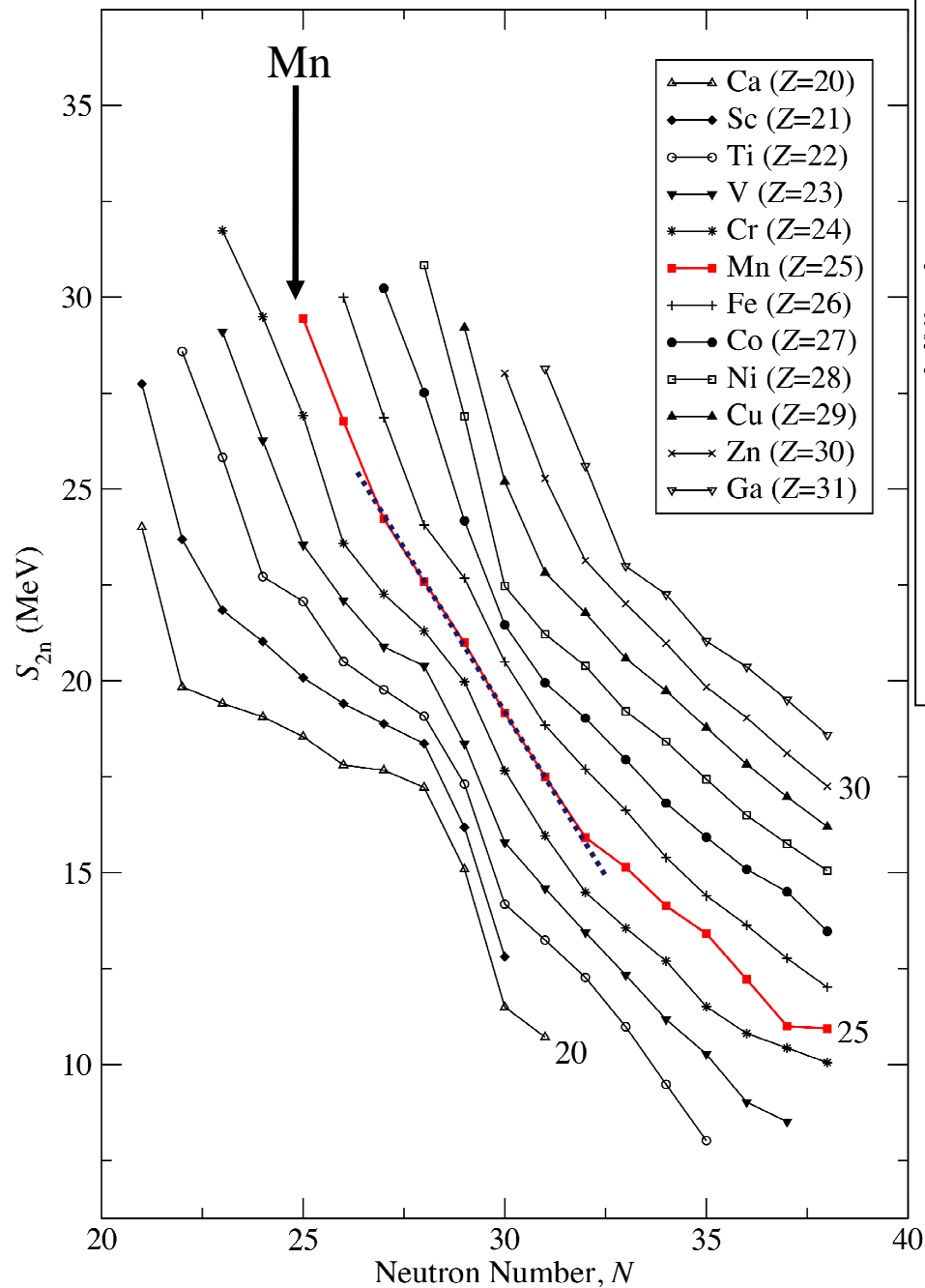
★ Near perfect agreement in $\delta \langle r^2 \rangle$ and S_{2n} measurements at $N=50$ and $N=60$



^{53}Mn 'allegedly' has a dominant single particle character associated with the $f_{7/2}$ shell.

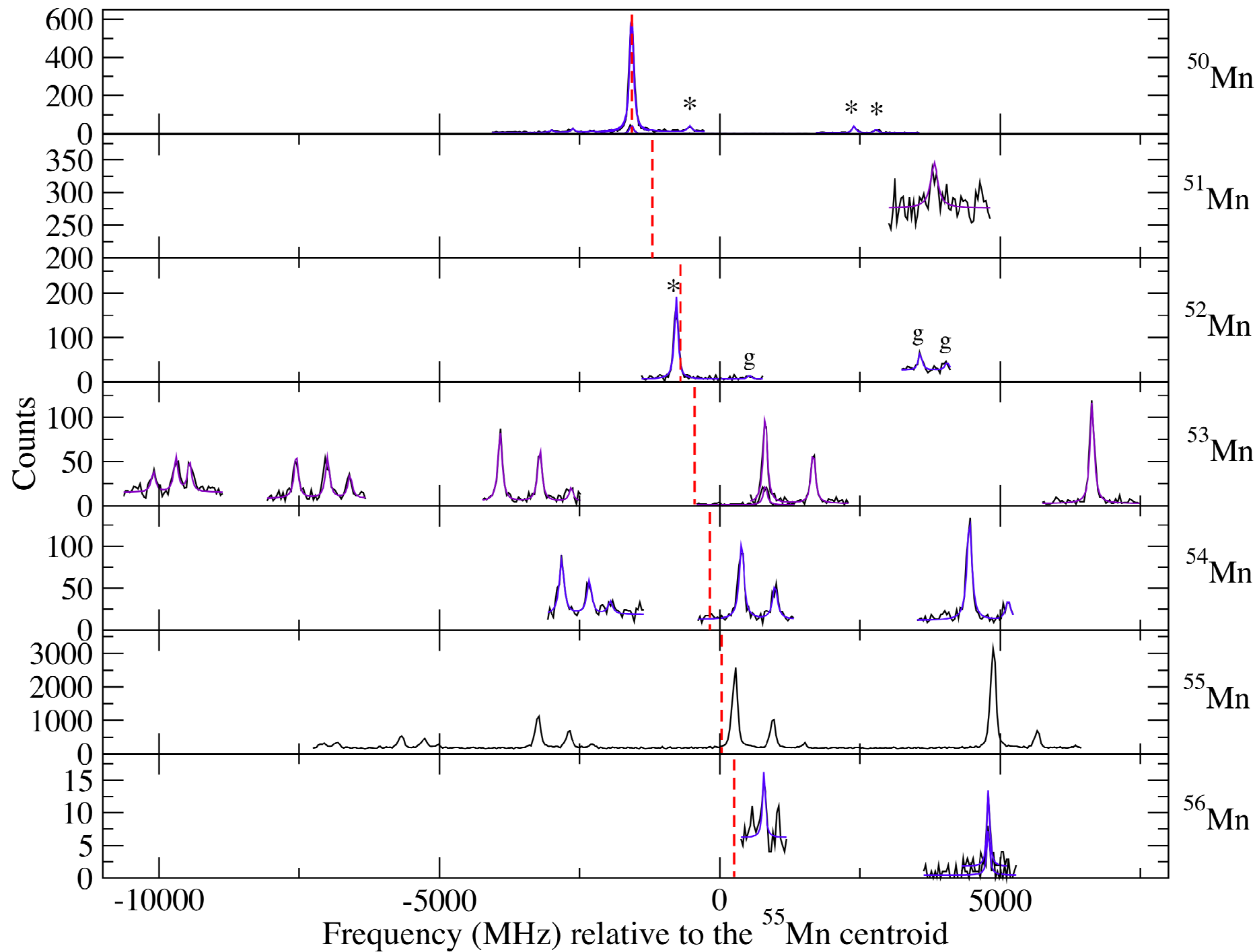
The other odd isotopes in this region have more complicated neutron and proton configurations with $l=5/2$ ground states, also seen in the odd proton isotones.





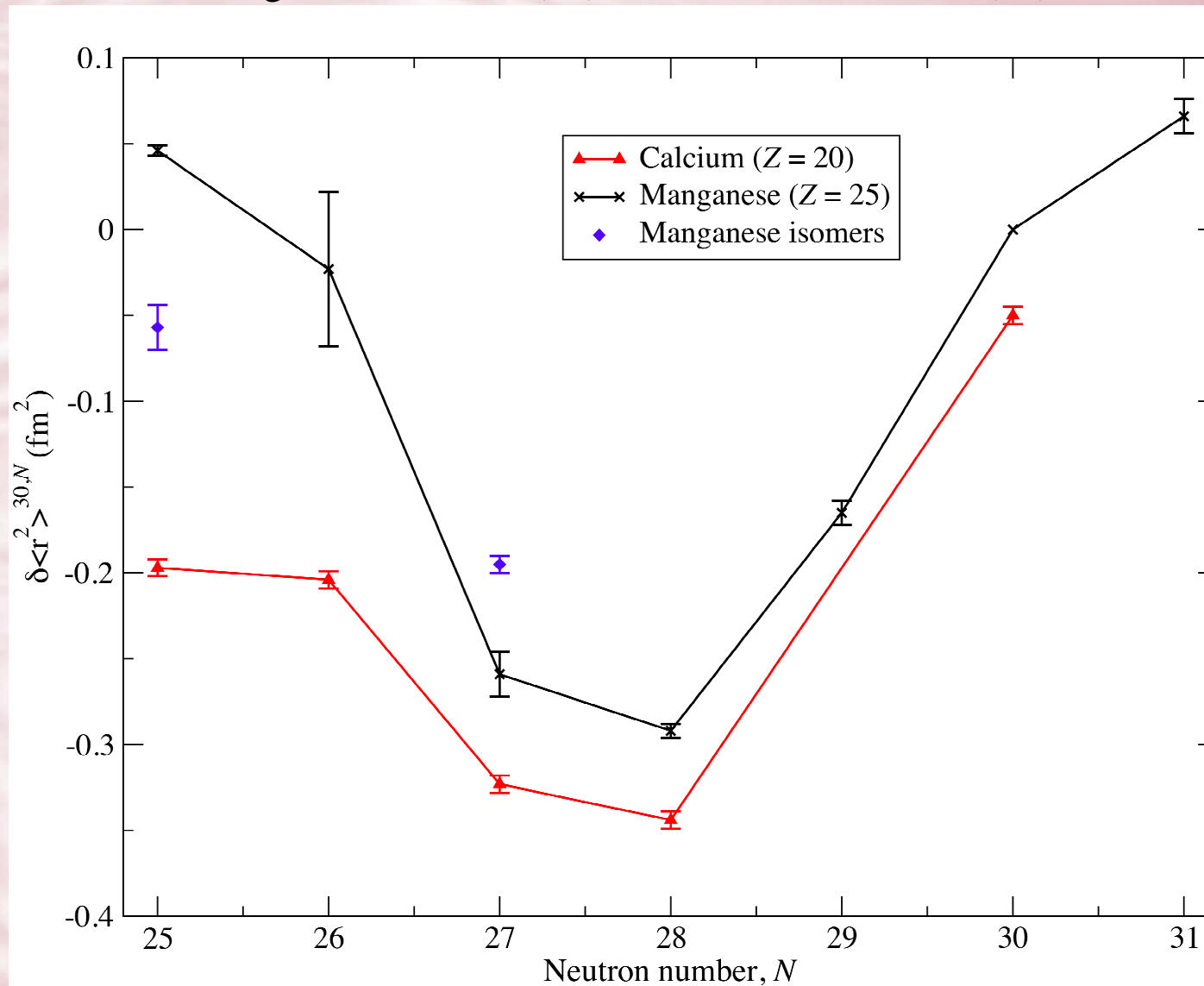
S_{2n} in Mn shows a steady linear trend across the shell closure – uncharacteristic!

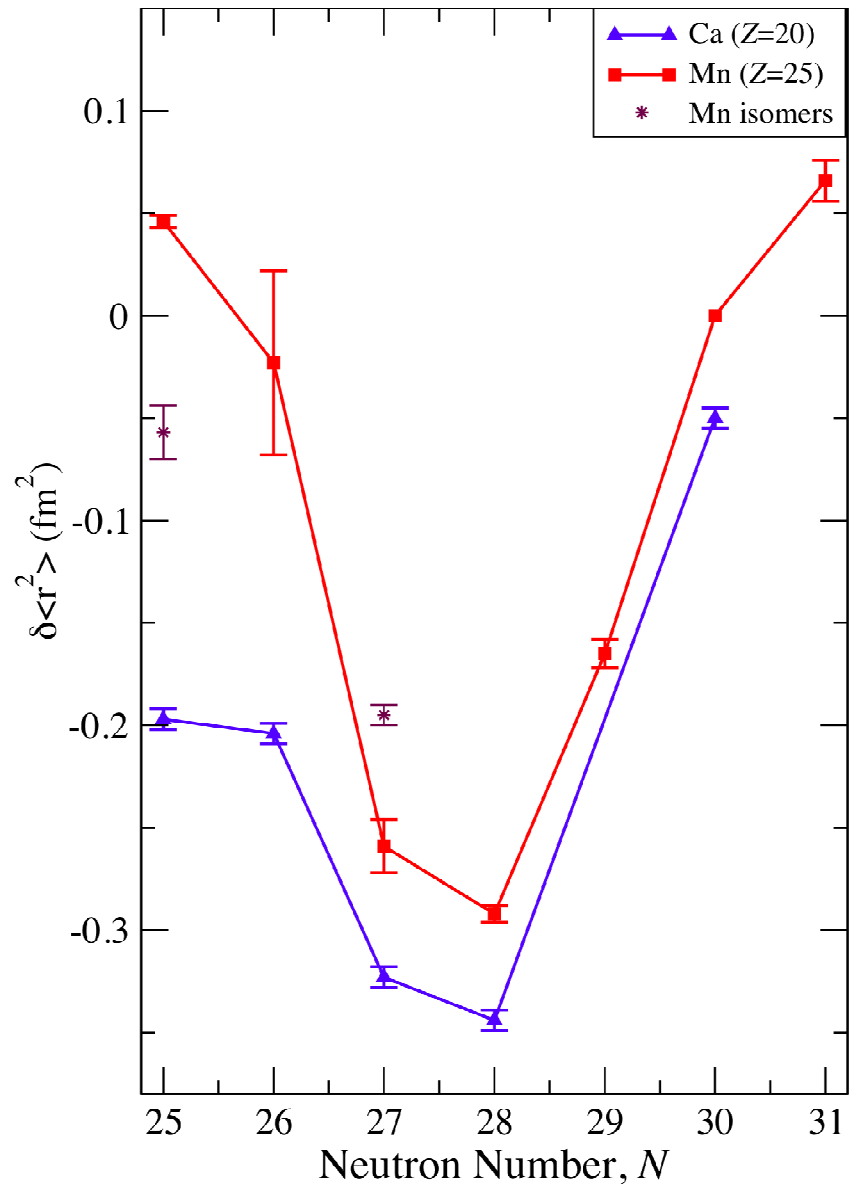
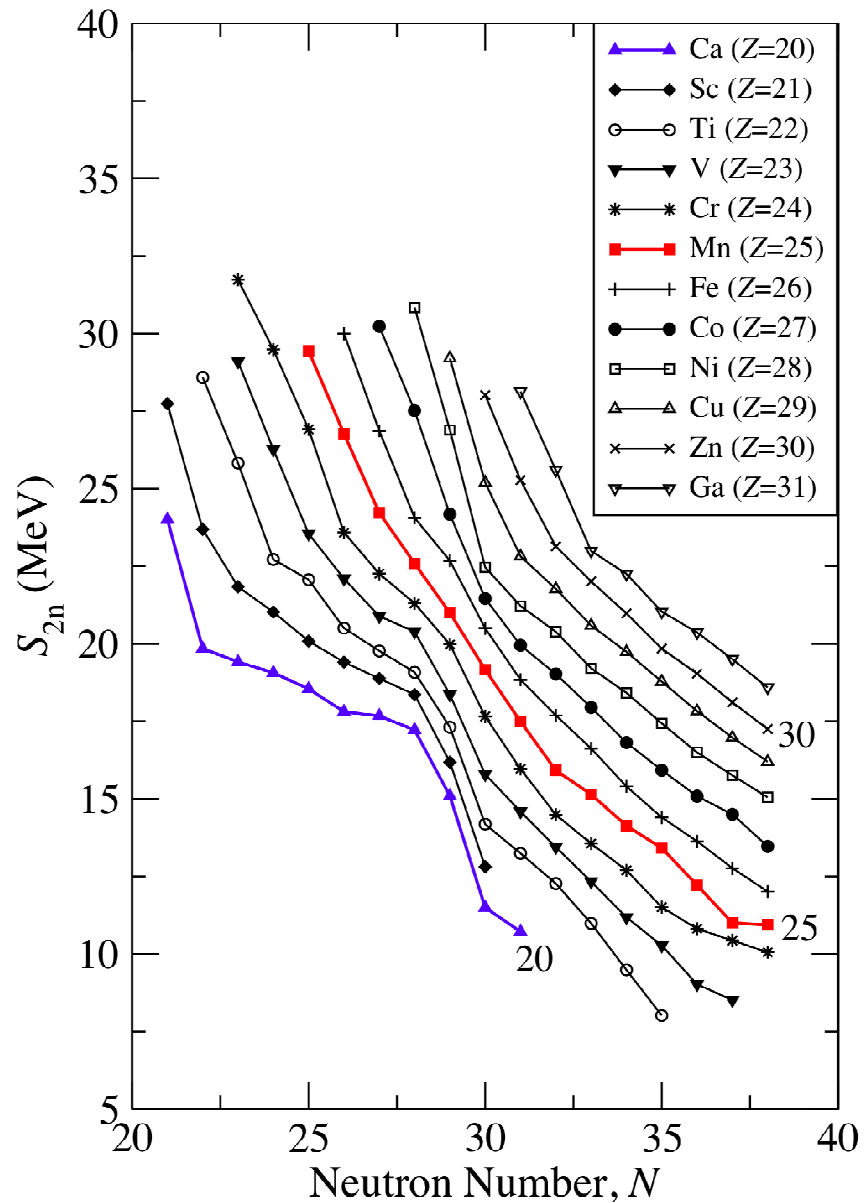
Is a shell closure observed in the charge radii measurements around $N=28$ (like in Ca)?



$$\delta\nu^{A,A'} = M_i \frac{A' - A}{AA'} + F_i \delta\langle r^2 \rangle^{A,A'}$$

New atomic calculations based on MCDF method:
Manganese $F = -572(86)\text{MHz fm}^{-2}$ and $M = 852(45)\text{GHz.u}$

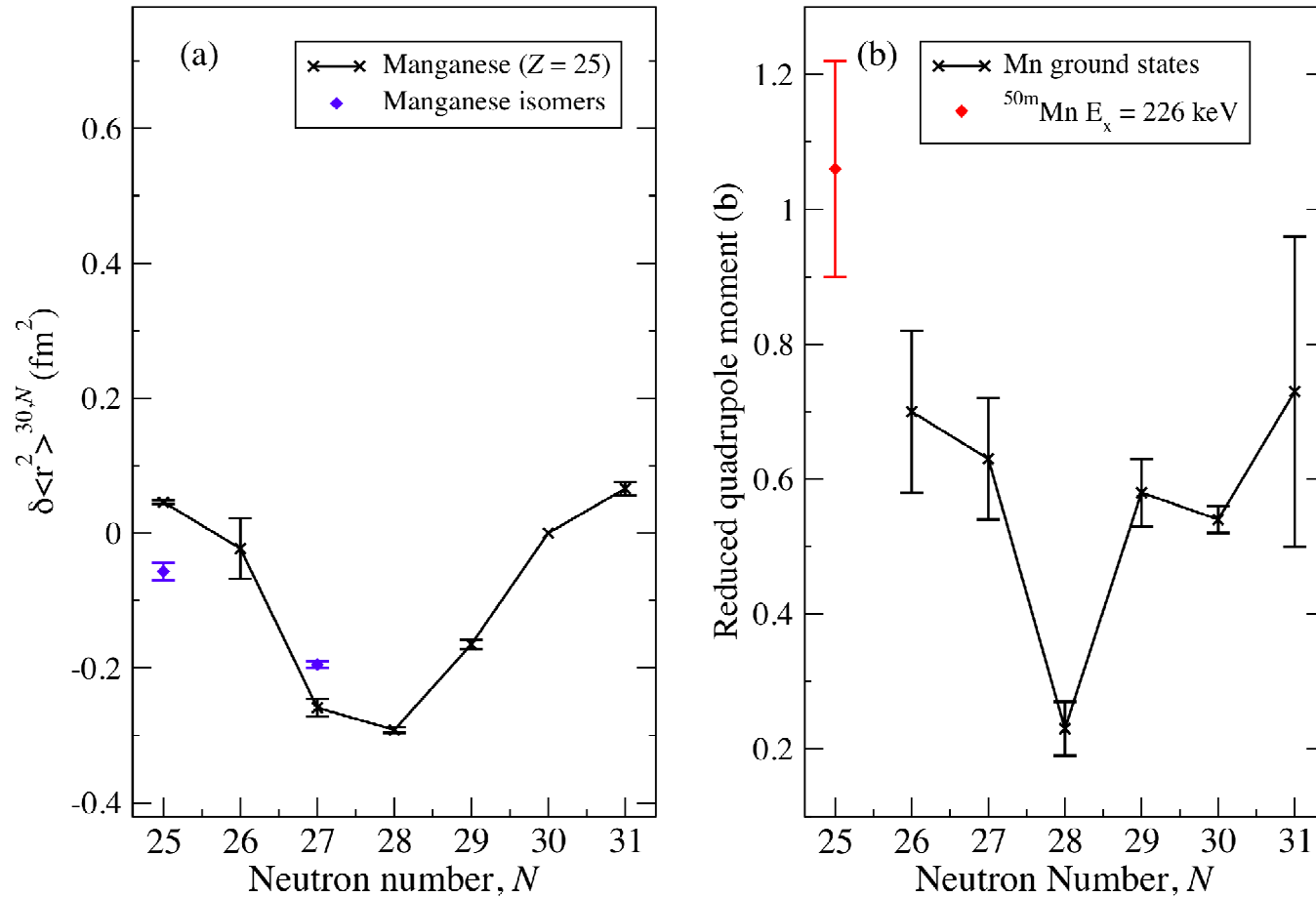




* Charge radii follow trends in Υ -ray spectroscopic studies, not S_{2n}

* Very different to perfect agreement in two sets of measurements at $Z \sim 40$.

Quadrupole moments of Mn – characteristic of shell model

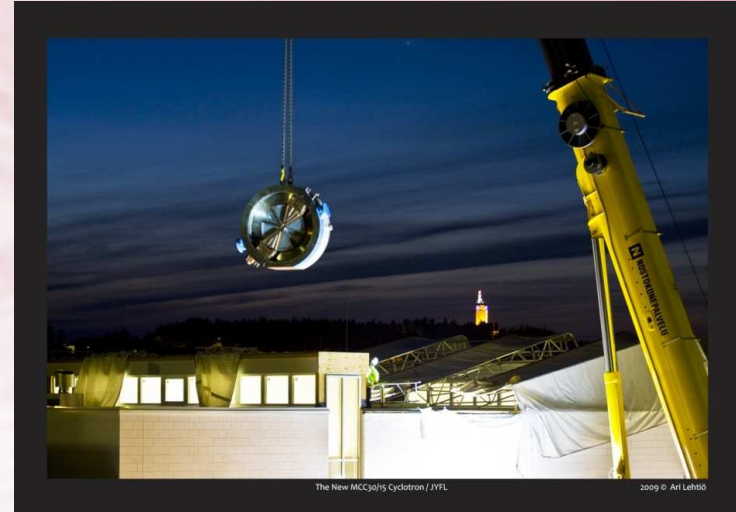


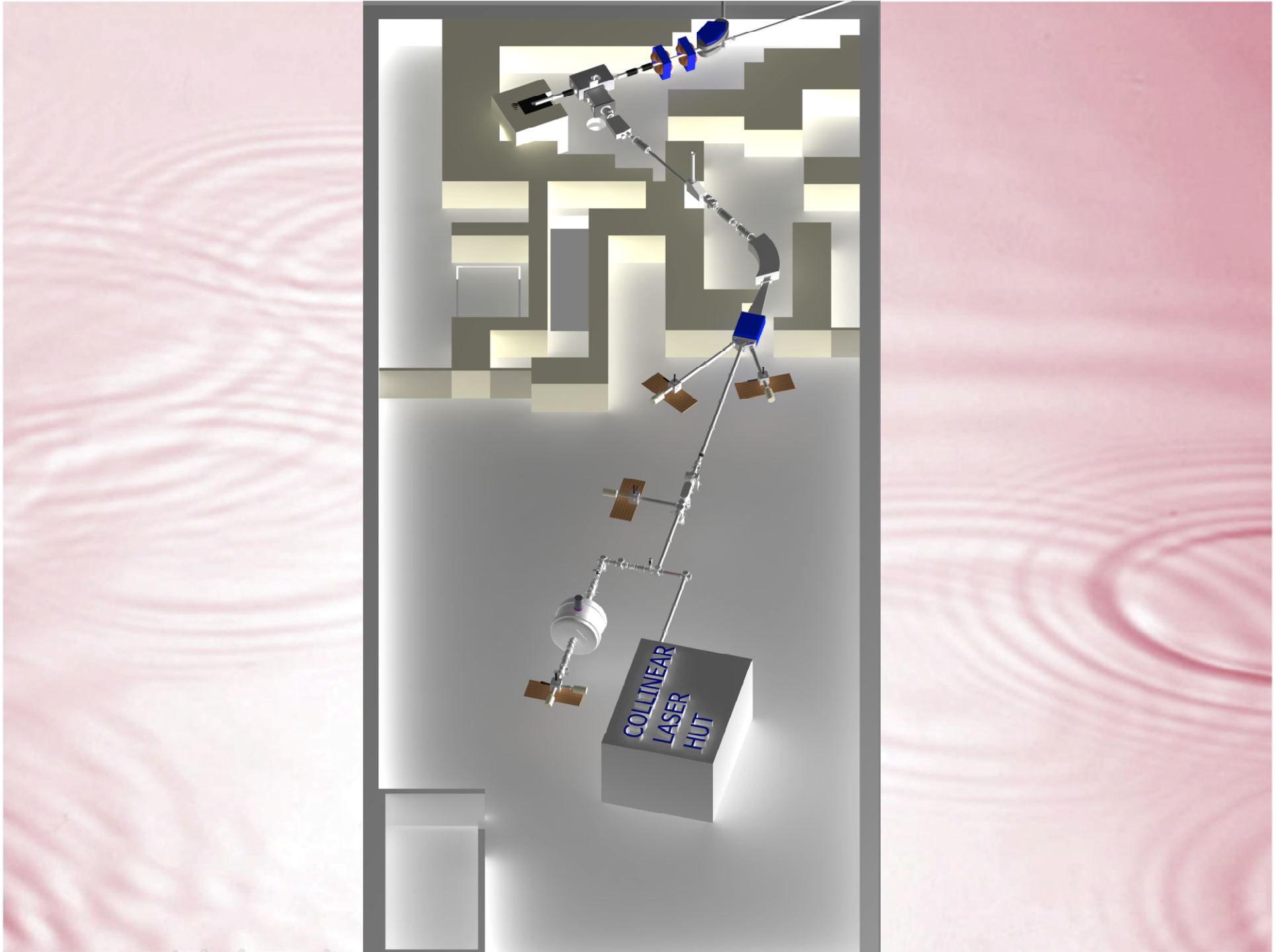
✱ Known moments of ^{55}Mn used to calibrate magnetic and quadrupole moments of $^{50m,53,54,56}\text{Mn}$.

✱ Not collective nor single particle states. GXPF1A shell model calculations suggest a highly mixed g.s

New Lab at JYFL!

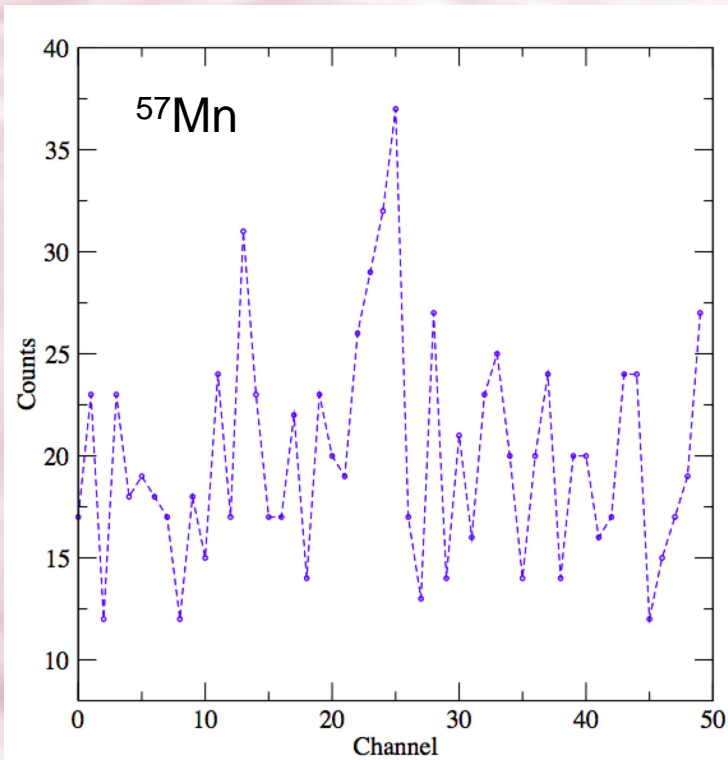
- ✿ New mini cyclotron dedicated to IGISOL experiments
- ✿ IGISOL and laser line move from summer 2010.





Future work at JYFL

- ☀ (d,2p) reaction on $^{57,58}\text{Fe}$ target
- ☀ Cross section $\sim 100\text{mb}$



^{55}Ni 212.1 ms 7/2- EC	^{56}Ni 6.077 d 0+ EC	^{57}Ni 35.60 h 3/2- EC	^{58}Ni 0+ 68.077	^{59}Ni 7.6E+4 y 3/2- EC	^{60}Ni 0+ 26.223	^{61}Ni 3/2- 1.140	^{62}Ni 0+ 3.634	^{63}Ni 100.1 y 1/2- β^-	^{64}Ni 0+ 0.926
^{54}Co 193.23 ms 0+ EC	^{55}Co 17.53 h 7/2- EC	^{56}Co 77.27 d 4+ EC	^{57}Co 271.79 d 7/2- EC	^{58}Co 70.82 d 2+ EC	^{59}Co 1.0 2- β^-	^{60}Co 5.2714 y 5+ β^-	^{61}Co 1.650 h 7/2- β^-	^{62}Co 1.50 m 2+ β^-	^{63}Co 27.4 s (7/2)- β^-
^{53}Fe 8.51 m 7/2- EC	^{54}Fe 0+ 5.8	^{55}Fe 2.73 y 3/2- EC	^{56}Fe 0+ 91.72	^{57}Fe 1/2- 2.2	^{58}Fe 0+ 0.28	^{59}Fe 44.503 d 3/2- β^-	^{60}Fe 1.5E+6 y 0+ β^-	^{61}Fe 5.98 m 3/2-,5/2- β^-	^{62}Fe 68 s 0+ β^-
^{52}Mn 5.591 d 6+ EC	^{53}Mn 3.74E+6 y 7/2- EC	^{54}Mn 312.3 d 3+ EC, β^-	^{55}Mn 5/2- 100	^{56}Mn 2.5785 h 3+ β^-	^{57}Mn 8.46 s 5/2- β^-	^{58}Mn 3.0 s 0+ β^-	^{59}Mn 4.6 s 3/2-,5/2- β^-	^{60}Mn 51 s 0+ β^-	^{61}Mn 0.71 s (5/2)- β^-
^{51}Cr 27.702 d 7/2- EC	^{52}Cr 0+ 83.789	^{53}Cr 3/2- 9.501	^{54}Cr 0+ 2.365	^{55}Cr 3.497 m 3/2- β^-	^{56}Cr 5.94 m 0+ β^-	^{57}Cr 21.1 s 3/2-,5/2-,7/2- β^-	^{58}Cr 7.0 s 0+ β^-	^{59}Cr 0.74 s β^-	^{60}Cr 0.57 s 0+ β^-
^{50}V 1.4E+17 y 6+ EC, β^-	^{51}V 7/2- 99.750	^{52}V 3.743 m 3+ β^-	^{53}V 1.61 m 7/2- β^-	^{54}V 49.8 s 3+ β^-	^{55}V 6.54 s (7/2)- β^-	^{56}V	^{57}V	^{58}V	^{59}V
^{49}Ti	^{50}Ti	^{51}Ti 5.76 m	^{52}Ti 1.7 m	^{53}Ti 32.7 s	^{54}Ti	^{55}Ti	^{56}Ti	^{57}Ti	^{58}Ti

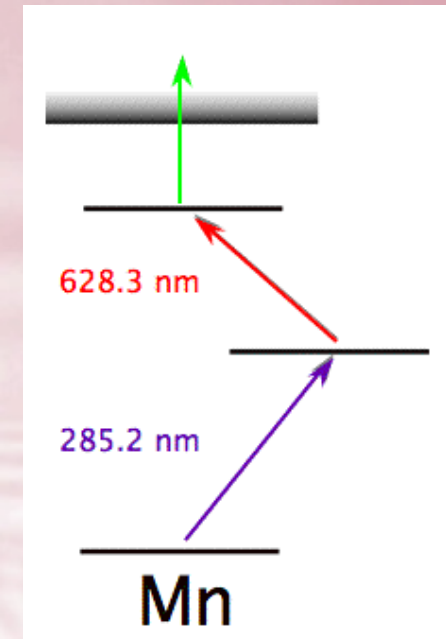
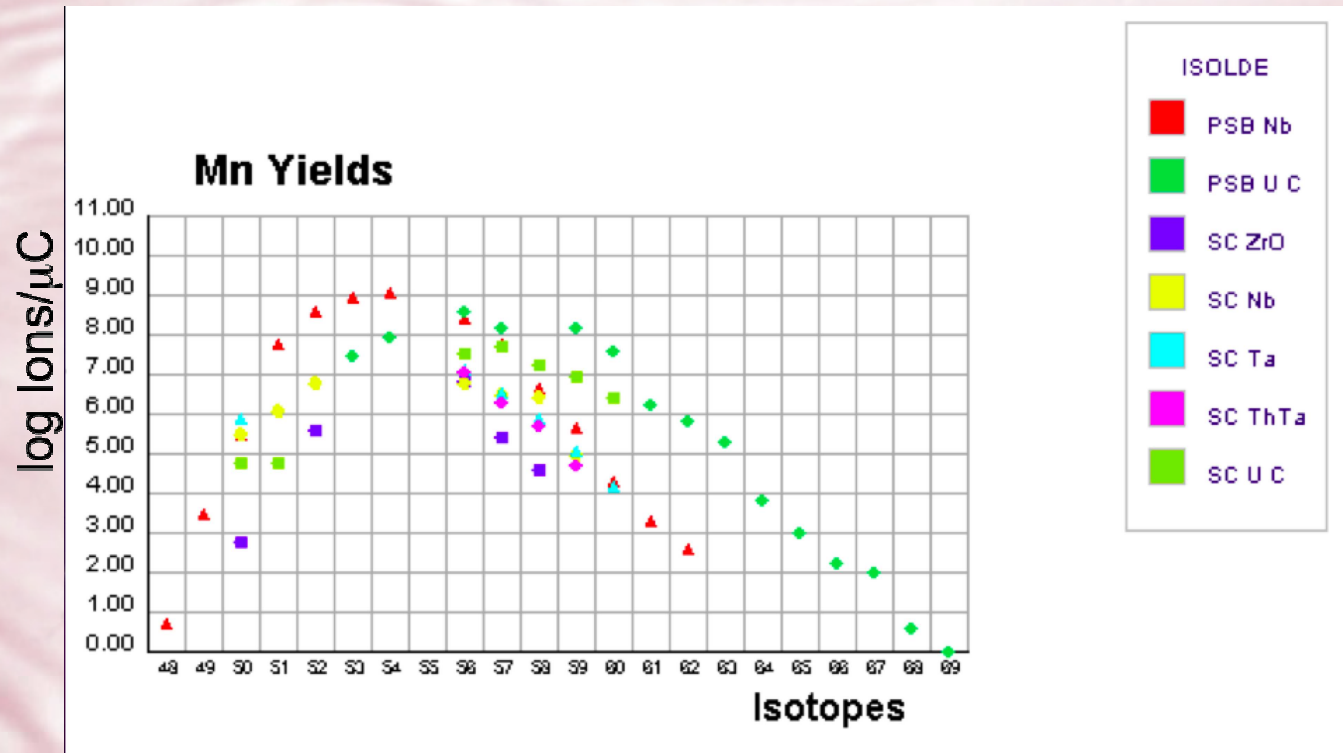
Easter 2010

- $\sim 400/\text{s}$
- $\sim 650,000/\text{s}$ background

Improve vacuum by factor of 10
(d,2p) applicable for other $Z=20-30$ nuclei

Future work at ISOLDE

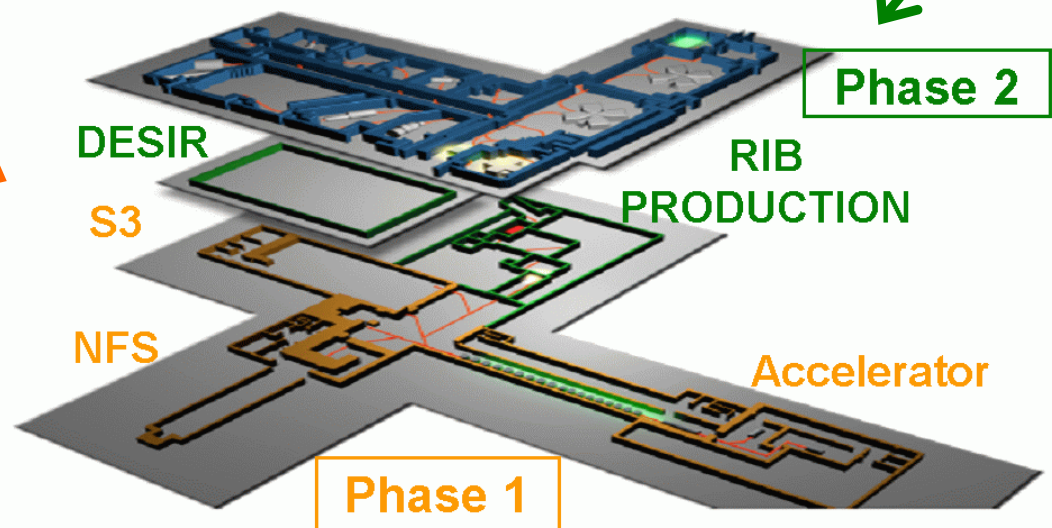
- ✱ Isotope production possible from $^{48-69}\text{Mn}$ with Nb foil or UCx target
- ✱ RILIS scheme
- ✱ Optical pumping in the cooler yet to be established
- ✱ New ISOLTRAP Mn mass measurements across N=40



Future work at DESIR

Ni55 212.1 ms 7/2- EC	Ni56 6.077 d 0+ EC	Ni57 35.60 h 3/2- EC	Ni58 0+ 68.077	Ni59 7.6E+4 y 3/2- EC	Ni60 0+ 26.223	Ni61 3/2- 1.140	Ni62 0+ 3.634	Ni63 100.1 y 1/2- β	Ni64 0+ 0.926	Ni65 2.5172 h 5/2- β	Ni66 54.6 s 0+ β	Ni67 21 s (1/2-) β	Ni68 19 s 0+ β	Ni69 11.4 s β	Ni70 0+ β	Ni71 1.86 s β	Ni72 2.1 s 0+ β	Ni73 0.90 s β
Co54 193.23 ms 0+ EC	Co55 17.53 h 7/2- EC	Co56 77.27 d 4+ EC	Co57 271.79 d 7/2- EC	Co58 70.82 d 2+ EC	Co59 7/2- 100	Co60 5.2714 y 5+ β	Co61 1.650 h 7/2- β	Co62 1.50 m 2+ β	Co63 27.4 s (7/2-) β	Co64 0.30 s 1+ β	Co65 1.20 s (7/2-) β	Co66 0.23 s (3+) β	Co67 0.42 s (7/2-) β	Co68 0.18 s β	Co69 0.27 s β	Co70 β	Co71 β	Co72 β
Fe53 8.51 m 7/2- EC	Fe54 0+ 5.8 EC	Fe55 2.73 y 3/2- EC	Fe56 0+ 91.72	Fe57 1/2- 2.2	Fe58 0+ 0.28	Fe59 44.503 d 3/2- β	Fe60 1.5E+6 y 0+ β	Fe61 5.98 m 3/2- β	Fe62 0+ β	Fe63 6.1 s (5/2-) β	Fe64 2.0 s 0+ β	Fe65 0.4 s β	Fe66 0+ β	Fe67 β	Fe68 0.10 s 0+ β	Fe69 β	44	
Mn52 5.591 d 6+ EC	Mn53 3.74E+6 y 7/2- EC	Mn54 312.3 d 3+ EC,β	Mn55 5/2- 100	Mn56 2.5785 h 3+ β	Mn57 85.4 s 5/2- β	Mn58 3.0 s 0+ β	Mn59 4.6 s 3/2- β	Mn60 51 s 0+ β	Mn61 0.71 s (5/2-) β	Mn62 0.88 s (3+) β	Mn63 0.25 s β	Mn64 β	Mn65 β	Mn66 β	Mn67 β	42		
Cr51 27.702 d 7/2- EC	Cr52 0+ 83.789	Cr53 3/2- 9.501	Cr54 0+ 2.365	Cr55 3.497 m 3/2- β	Cr56 5.94 m 0+ β	Cr57 21.1 s 3/2- β	Cr58 7.4 s 0+ β	Cr59 0.74 s β	Cr60 0.57 s 0+ β	Cr61 β	Cr62 0+ β	Cr63 β	Cr64 0+ β	Cr65 β	40			
V50 1.4E+17 y 6+ EC,β	V51 7/2- 99.750	V52 3.743 m 3+ β	V53 1.61 m 7/2- β	V54 49.8 s 3+ β	V55 6.54 s (7/2-) β	V56 β	V57 β	V58 β	V59 β	V60 β	V61 β	V62 β	V63 β					
Ti49 β	Ti50 β	Ti51 5.76 m β	Ti52 1.7 m β	Ti53 32.7 s β	Ti54 β	Ti55 β	Ti56 β	Ti57 β	Ti58 β	Ti59 β	Ti60 β	Ti61 β						

- ☀ Problems at ISOLDE
- ☀ Reactions such as ^{48}Ca on $^{13,14}\text{C}$ at S3
- ☀ ISOL facility required for production of Cr, Fe, Ni at reasonable beam intensity.



Summary

- ✱ $\delta\langle r^2 \rangle$ extracted for Mn isotope chain from $^{50}\text{Mn} - ^{56}\text{Mn}$
- ✱ First observation of differing mass and charge radii measurements
- ✱ Quadrupole moment at the shell closure and moments for $^{50}\text{Mn}^m$
- ✱ Charge radii and quadrupole moments correspond
- ✱ Future experiments towards the n-rich ^{58}Mn utilising (d,2p) in JYFL new lab
- ✱ $^{48-69}\text{Mn}$ beams available at ISOLDE
- ✱ Beam production at DESIR provides the possibility to study n-rich dripline nuclei in the $Z = 20-30$ region.

University of Manchester

**J Billowes, P Campbell, B Cheal,
F. Charlwood and D. Johnson**

University of Birmingham

**G Tungate, D H Forest
and R Powis**



THE UNIVERSITY
OF BIRMINGHAM



University of Jyväskylä, Finland

**J Äystö, T Eronen, A Jokinen, ID Moore, H Pentillä,
M. Reponen and A. Saastamoinen**



University of Oulu, Finland

S. Fritzsche



University of Aizu, Japan

M. Honma