MANCHESTER
1824

The University
of Manchester

Future exploitation of optical pumping in manganese

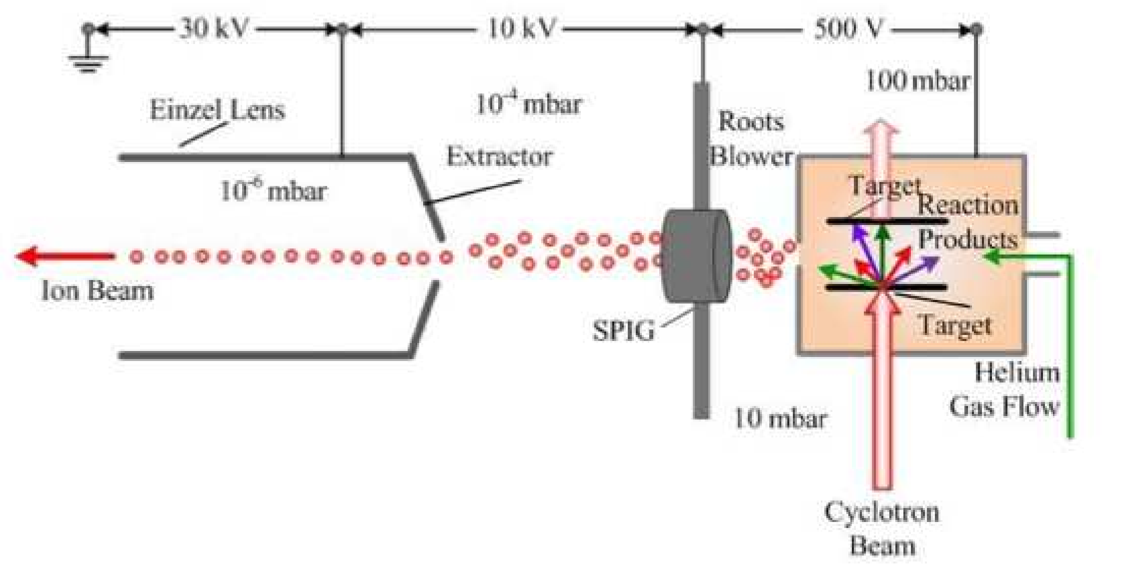
Frances Charlwood

DESIR workshop

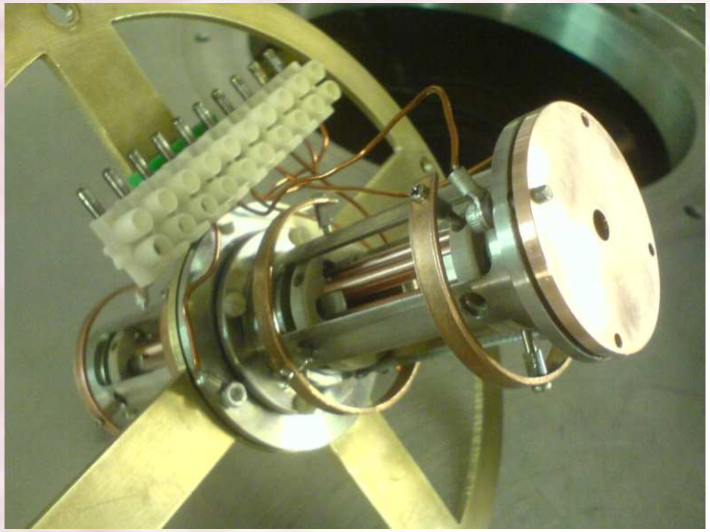
May 2010

Introduction

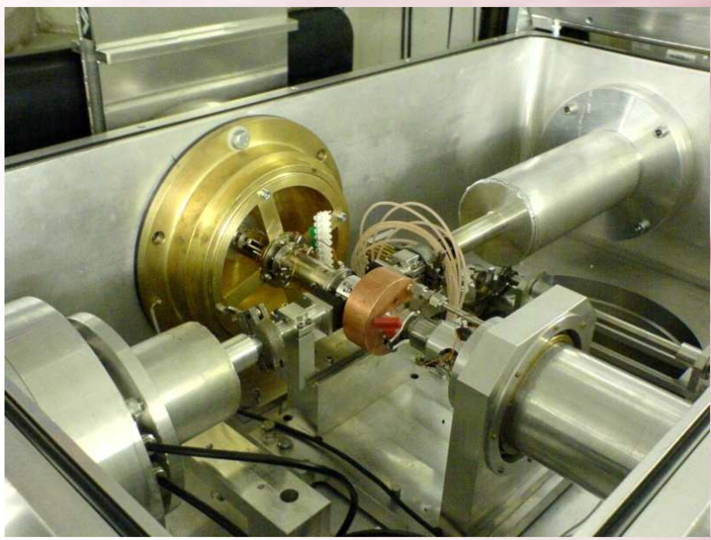
- Laser spectroscopy at JYFL
- History of the *N*=28 shell closure
- Manganese isotope shifts and charge radii
- Future experiments at JYFL, ISOLDE and DESIR



- 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)

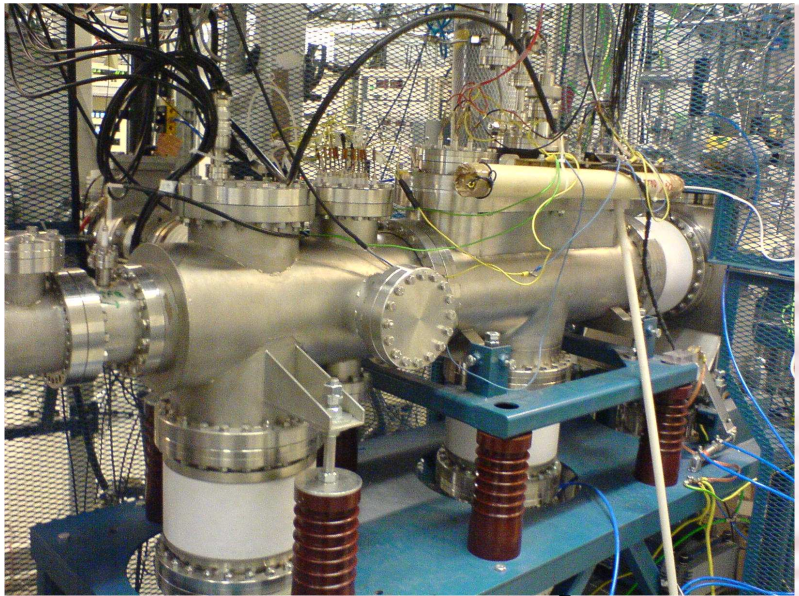


Fusion guide

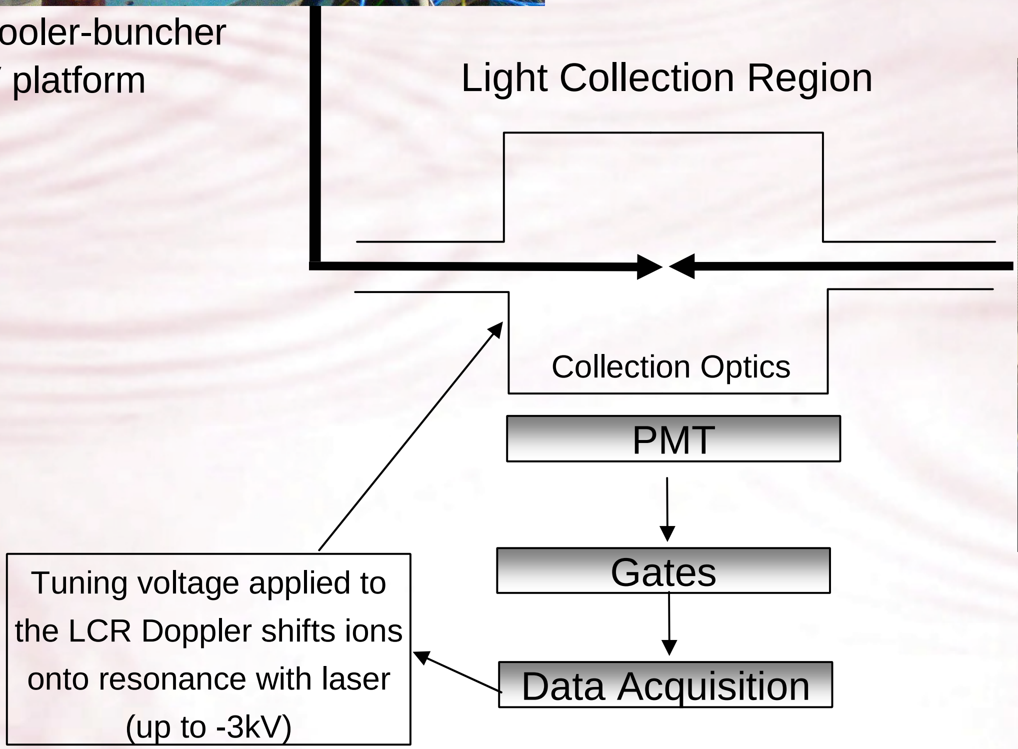
Laser Spectroscopy at JYFL

- Overlapping of an ion beam with a counter propagating, fixed frequency, CW laser at 30kV to reduce the energy spread

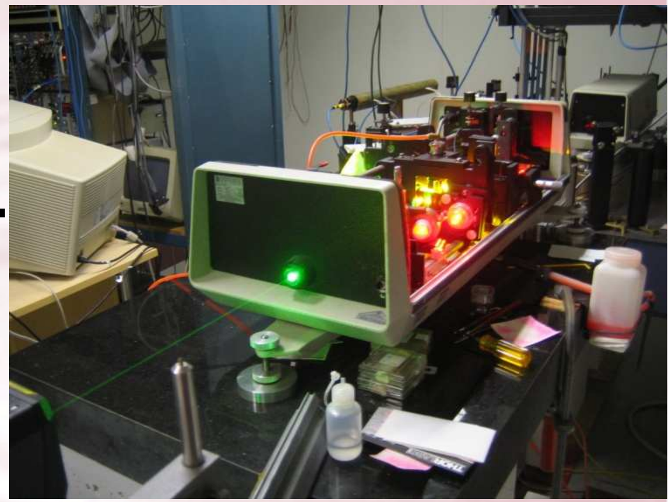
- Photon detection when resonantly excited ions decay to their ground states



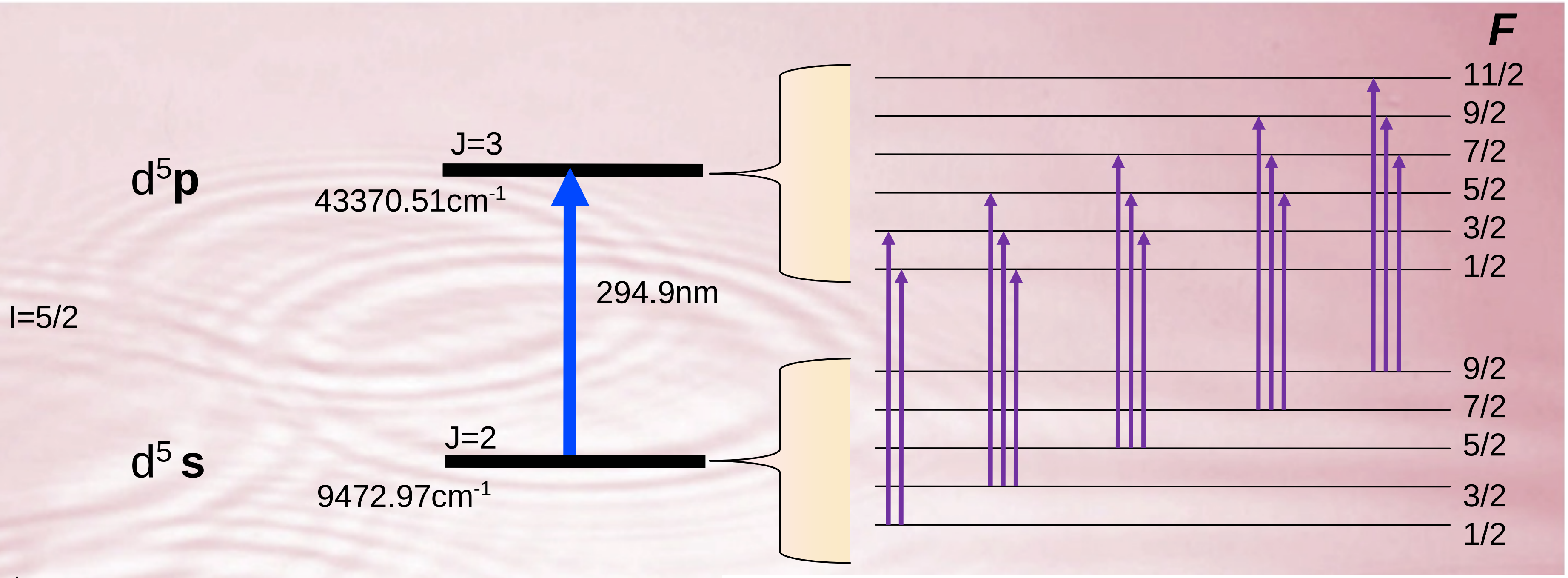
Ions through cooler-buncher on +30kV platform



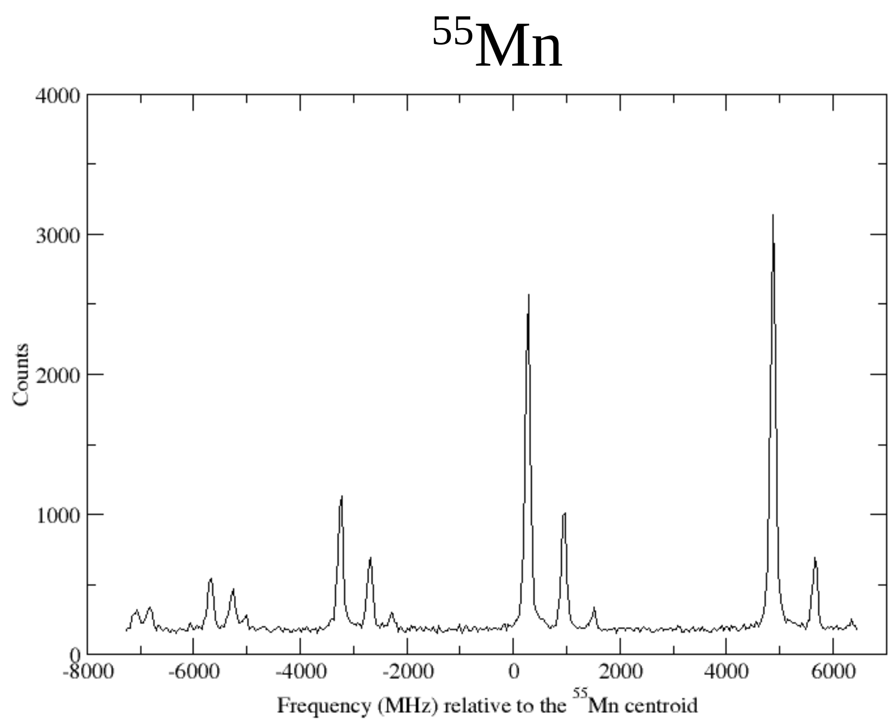
CW laser



- Gating decreases background by factor 10^4



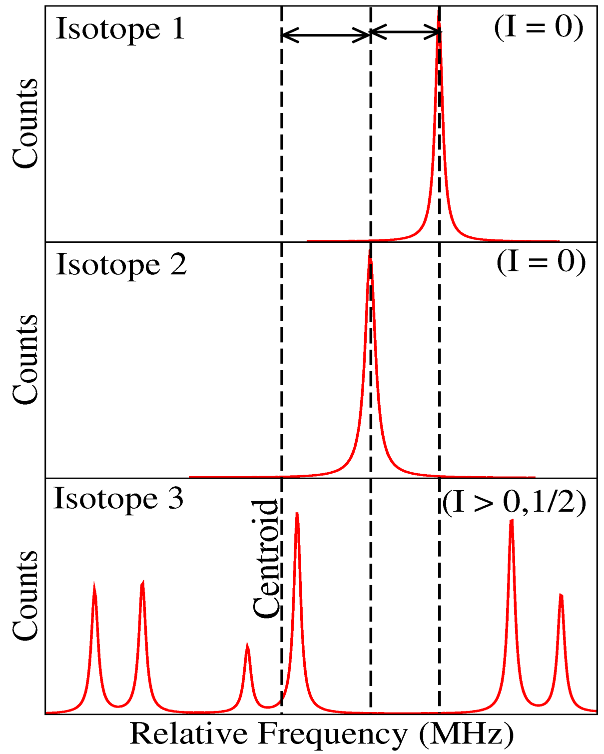
✹ Hyperfine structure – interaction of nuclear charge distribution and EM field at the nucleus produced by electrons.



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:-

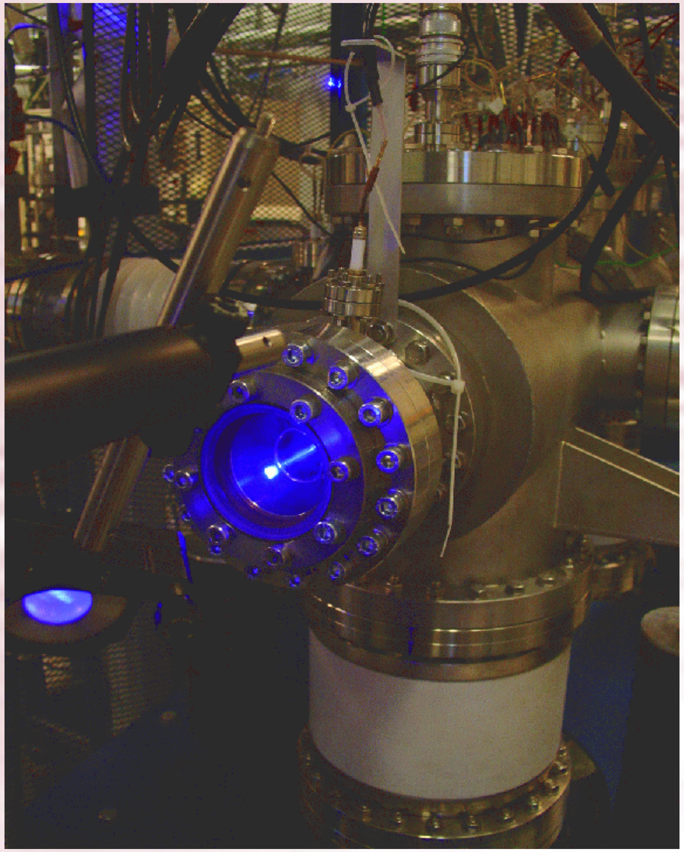
Mass shift – the relative centre of mass changes between isotopes

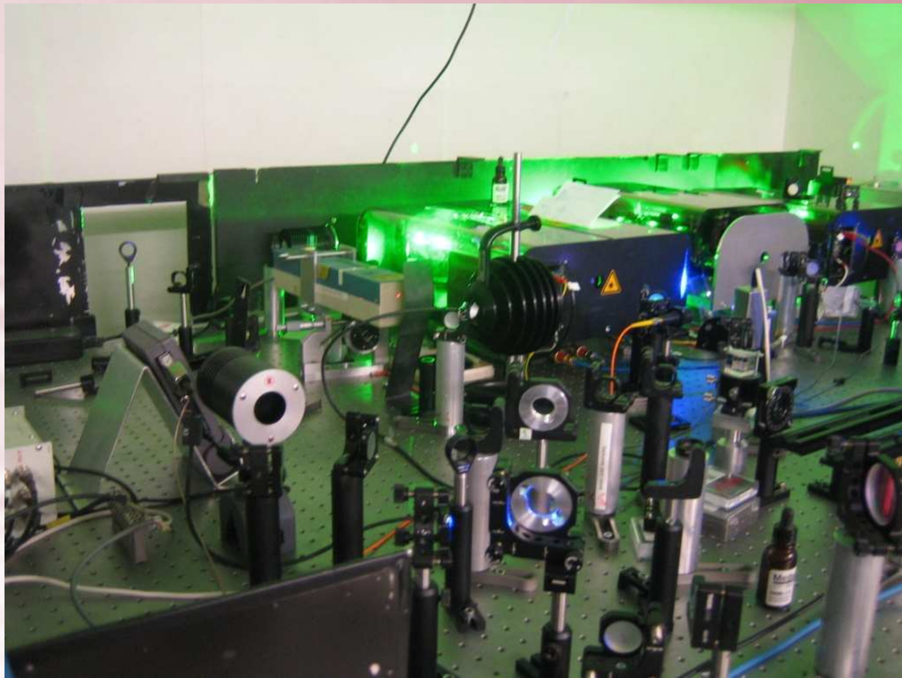
Field shift – Orbital electron experiences an electrostatic potential due to the nuclear charge and distribution of that charge. This changes between isotopes.

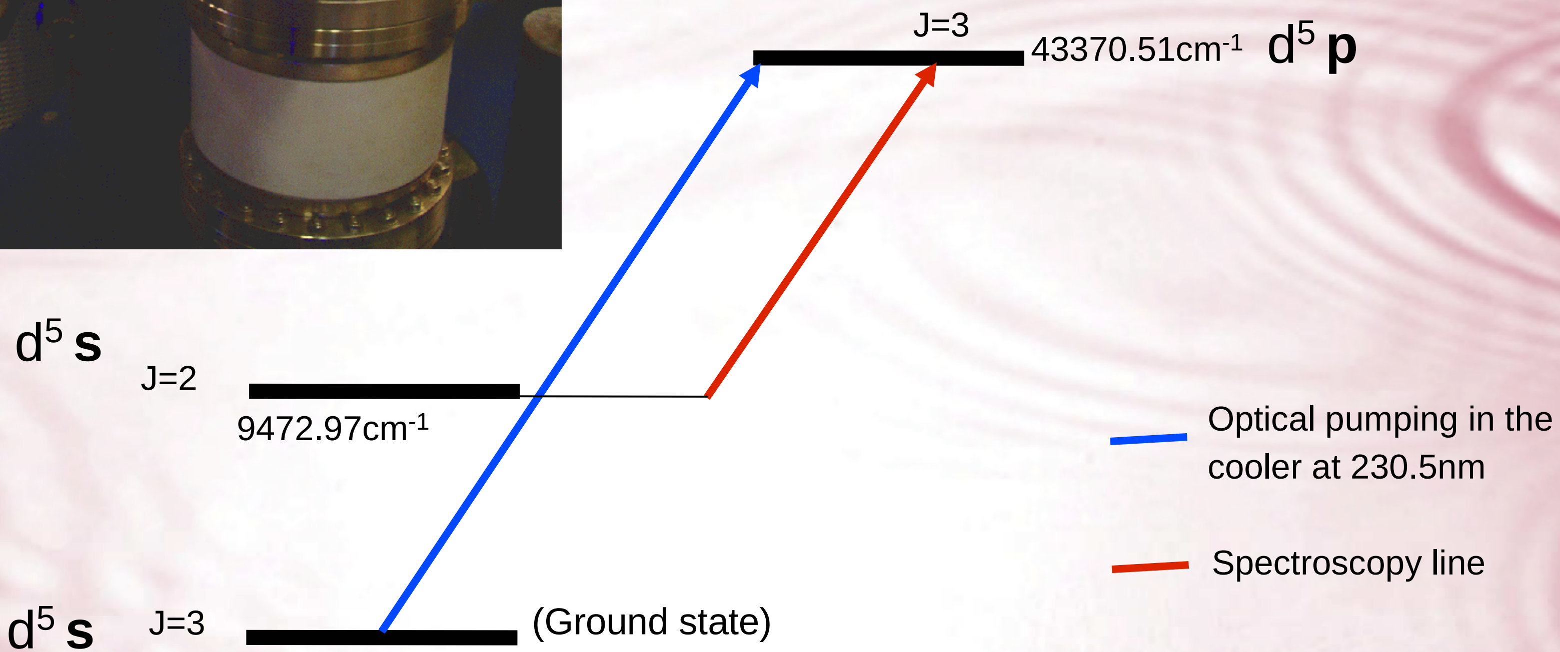
$$\delta\nu^{A,A'} = M_i \frac{A'-A}{AA'} + F_i \delta\langle r^2\rangle^{A,A'}$$

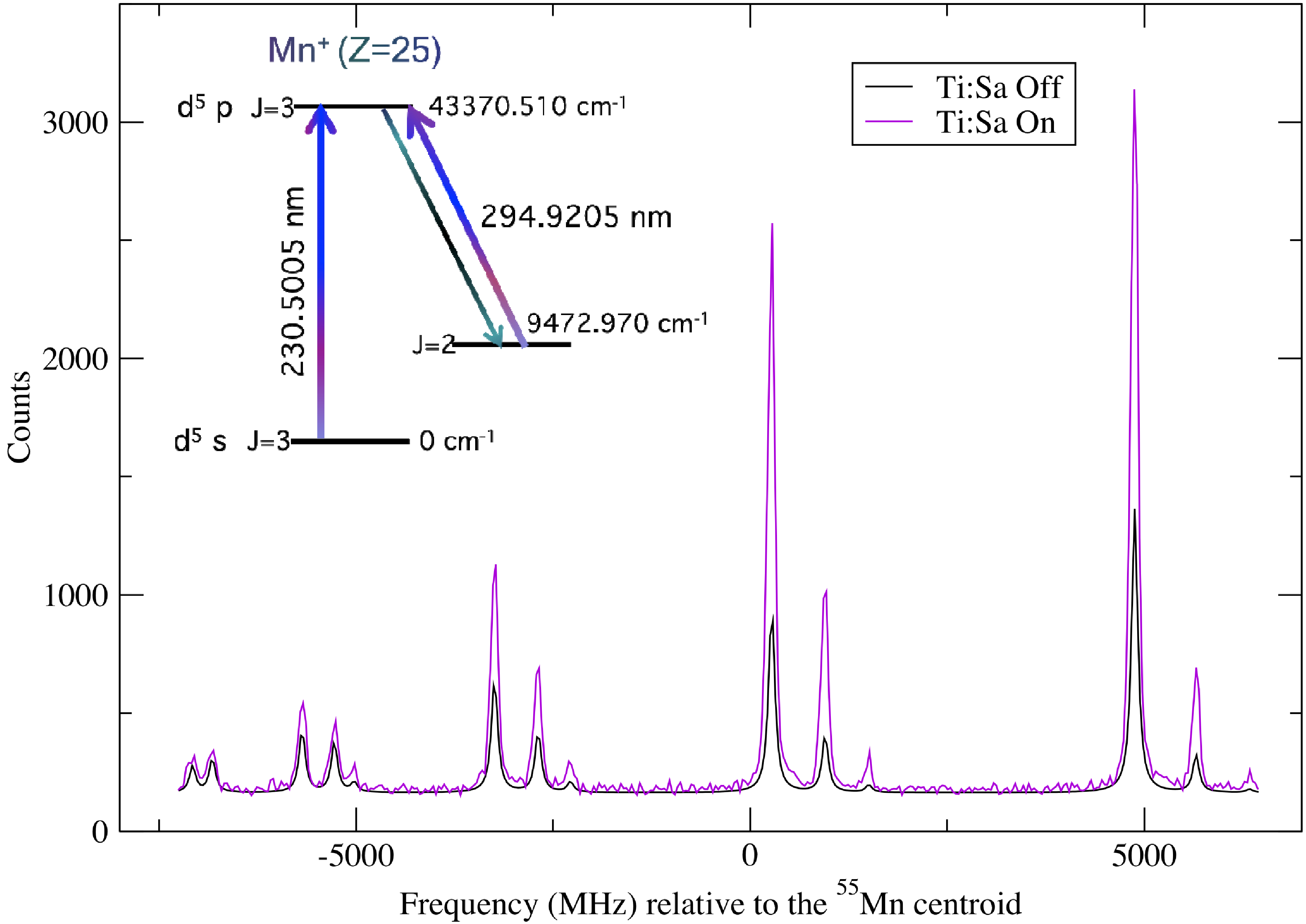
Mass shift　　　　Field shift

- Optical pumping in cooler-buncher



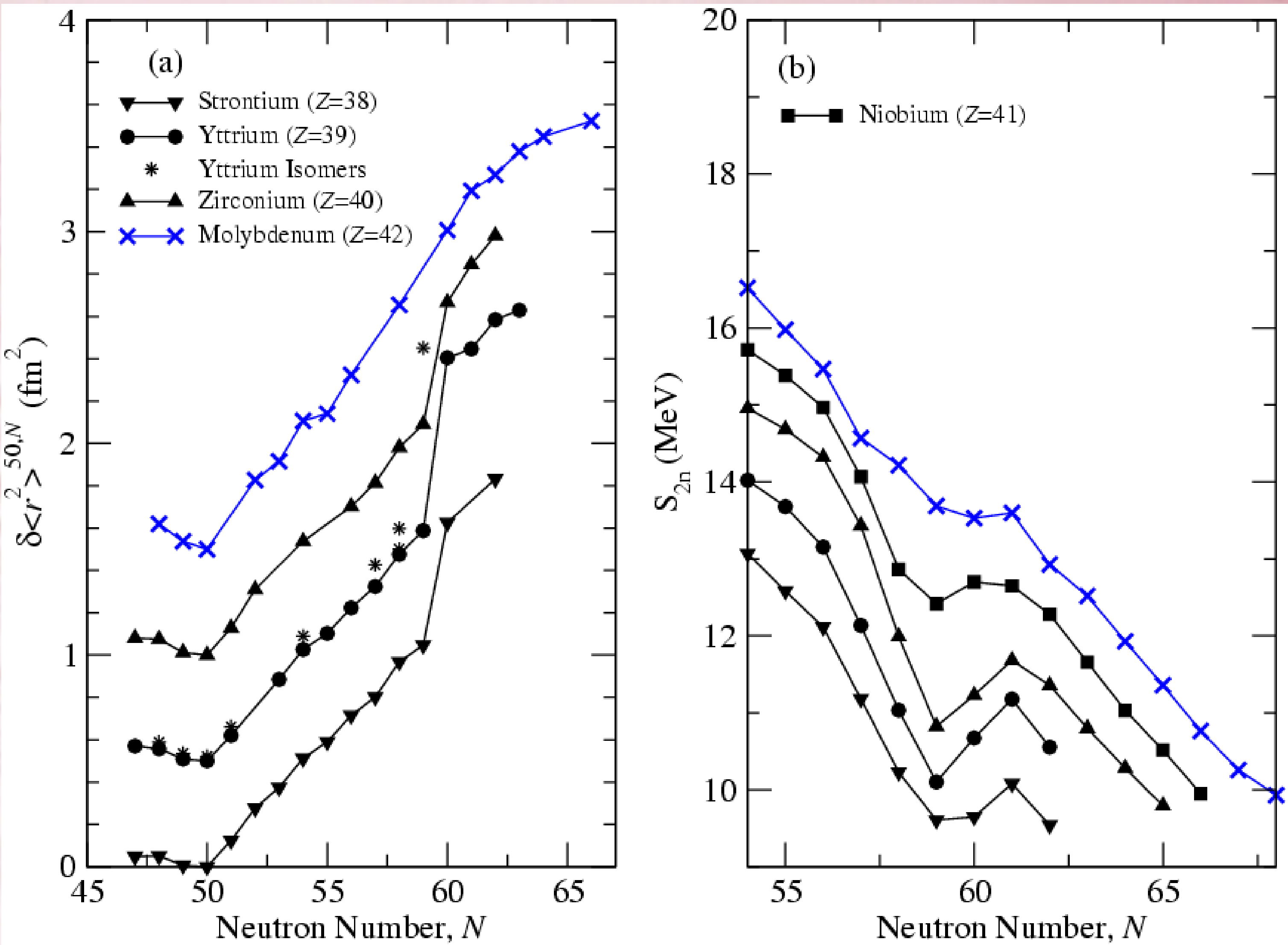




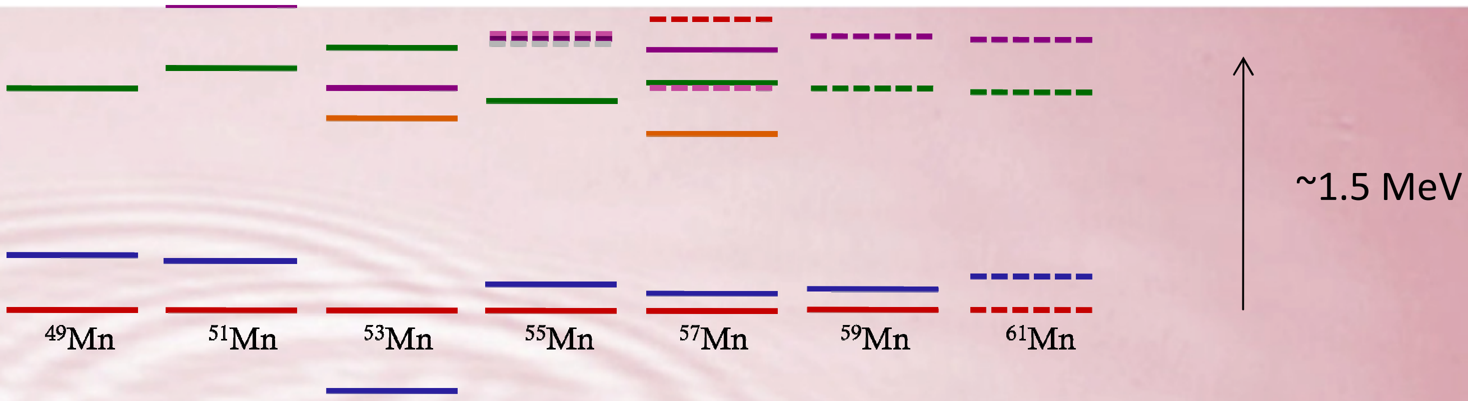


- Improvement in efficiency from 1 in 250,000 to 1 in 4,000 after bunching ions in cooler

Previously in the *Z*~40 region…

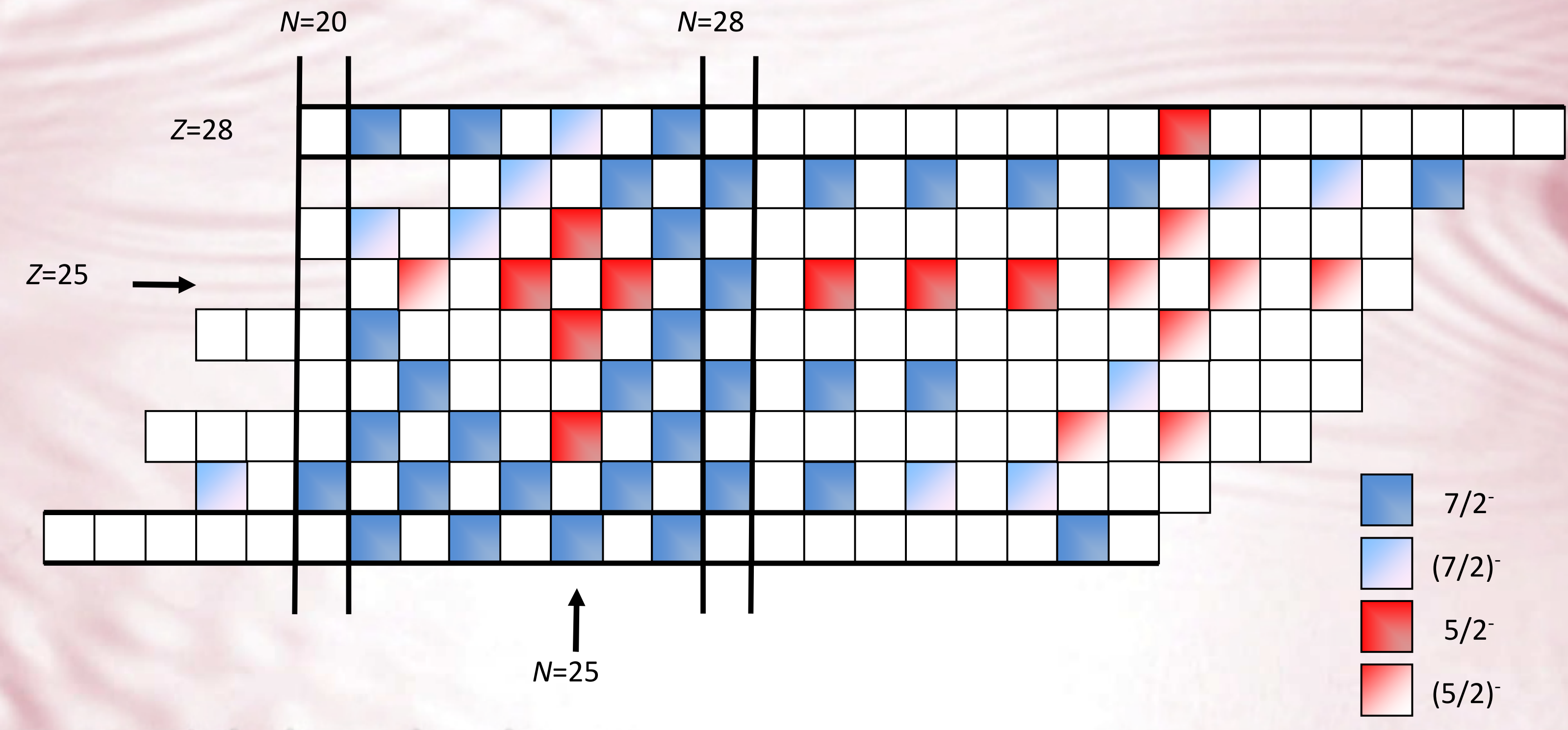


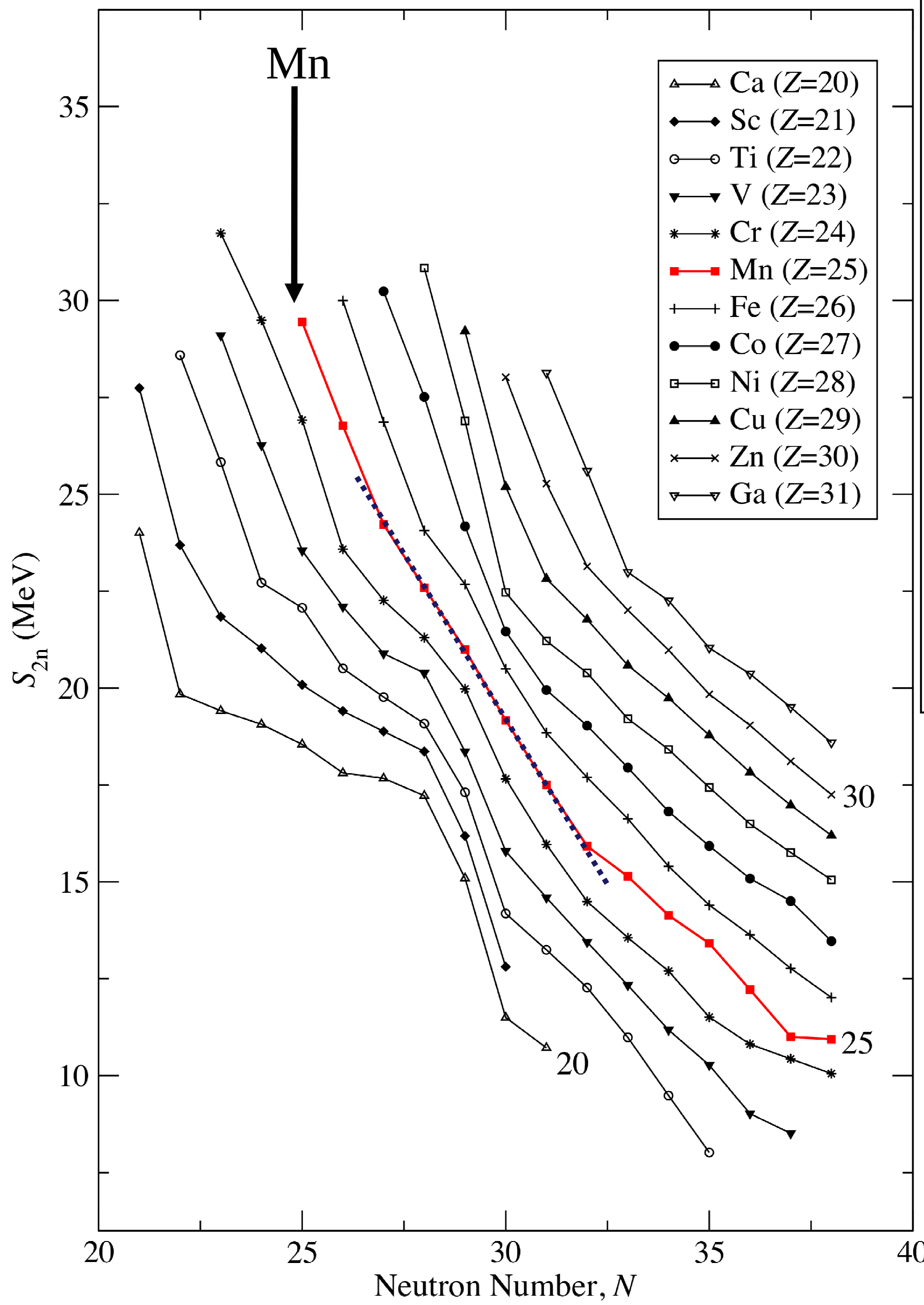
- Near perfect agreement in $\delta<r^2>$ and S_{2n} measurements at *N*=50 and *N*=60

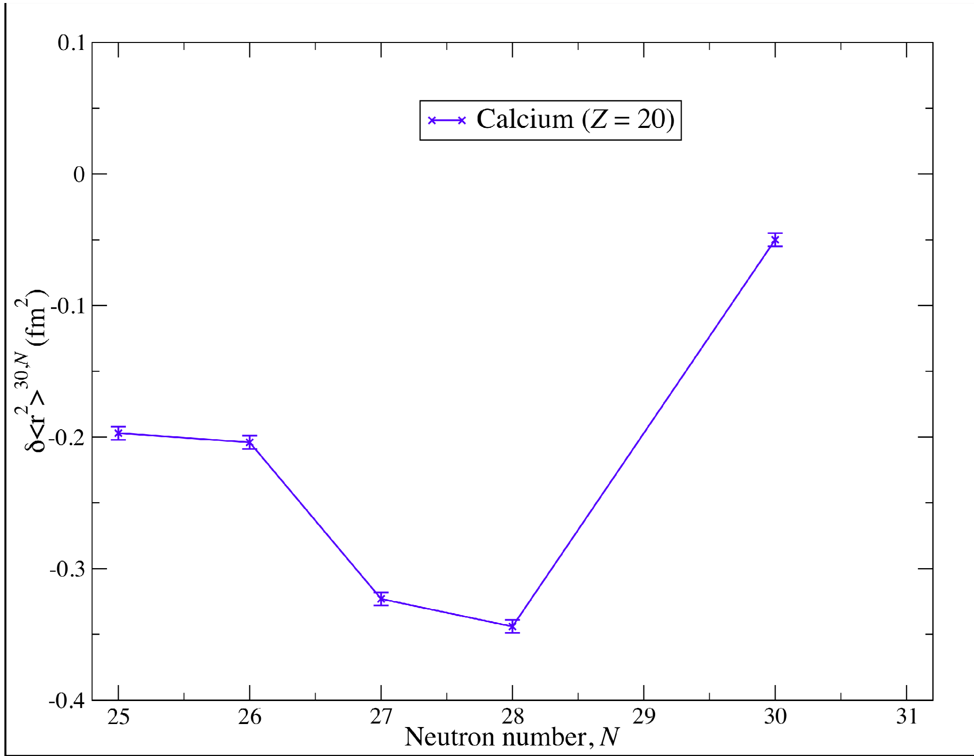


^{53}Mn 'allegedly' has a dominant single particle character associated with the $f_{7/2}$ shell.

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

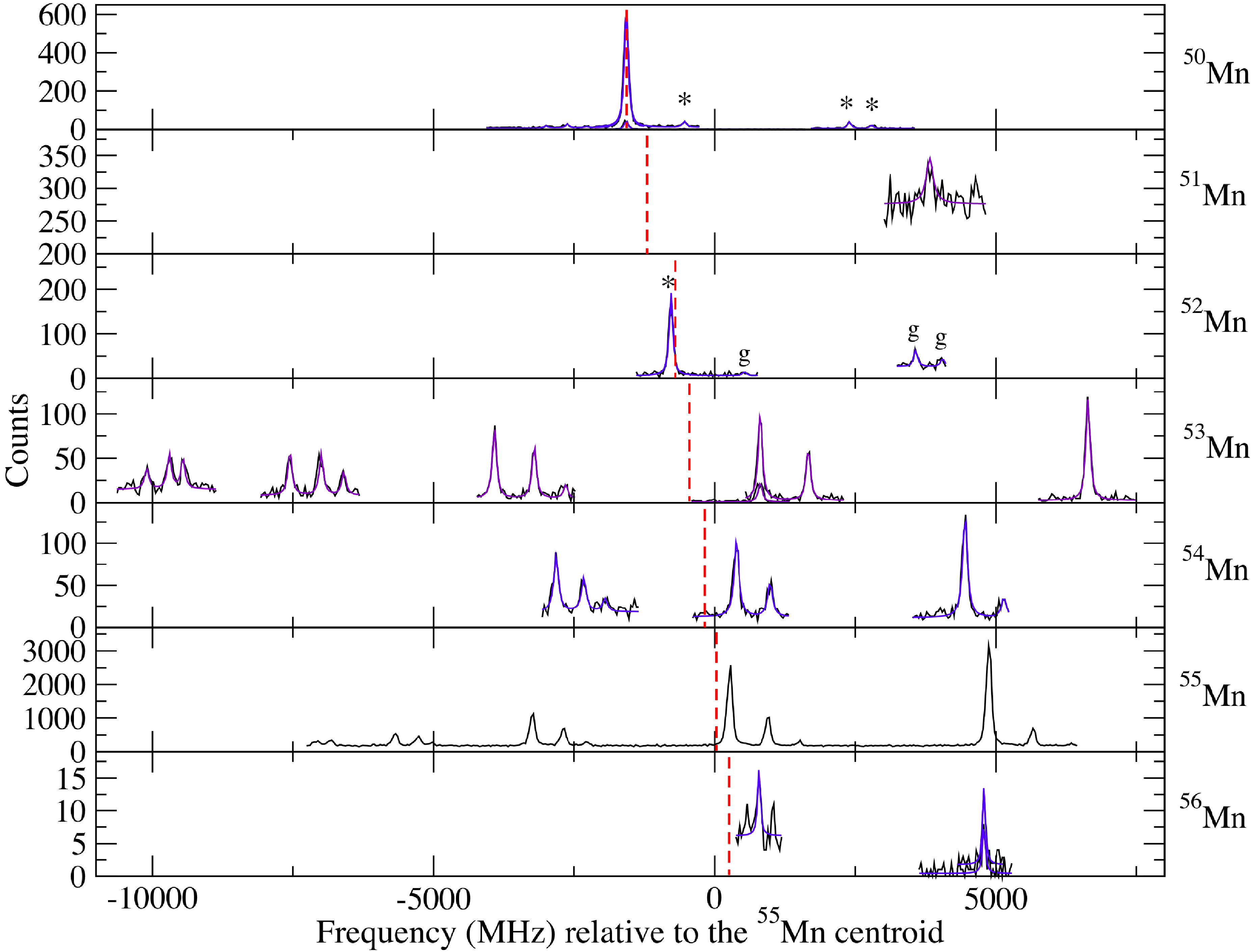






S_{2n} in Mn shows a steady linear trend across the shell closure – uncharacteristic!

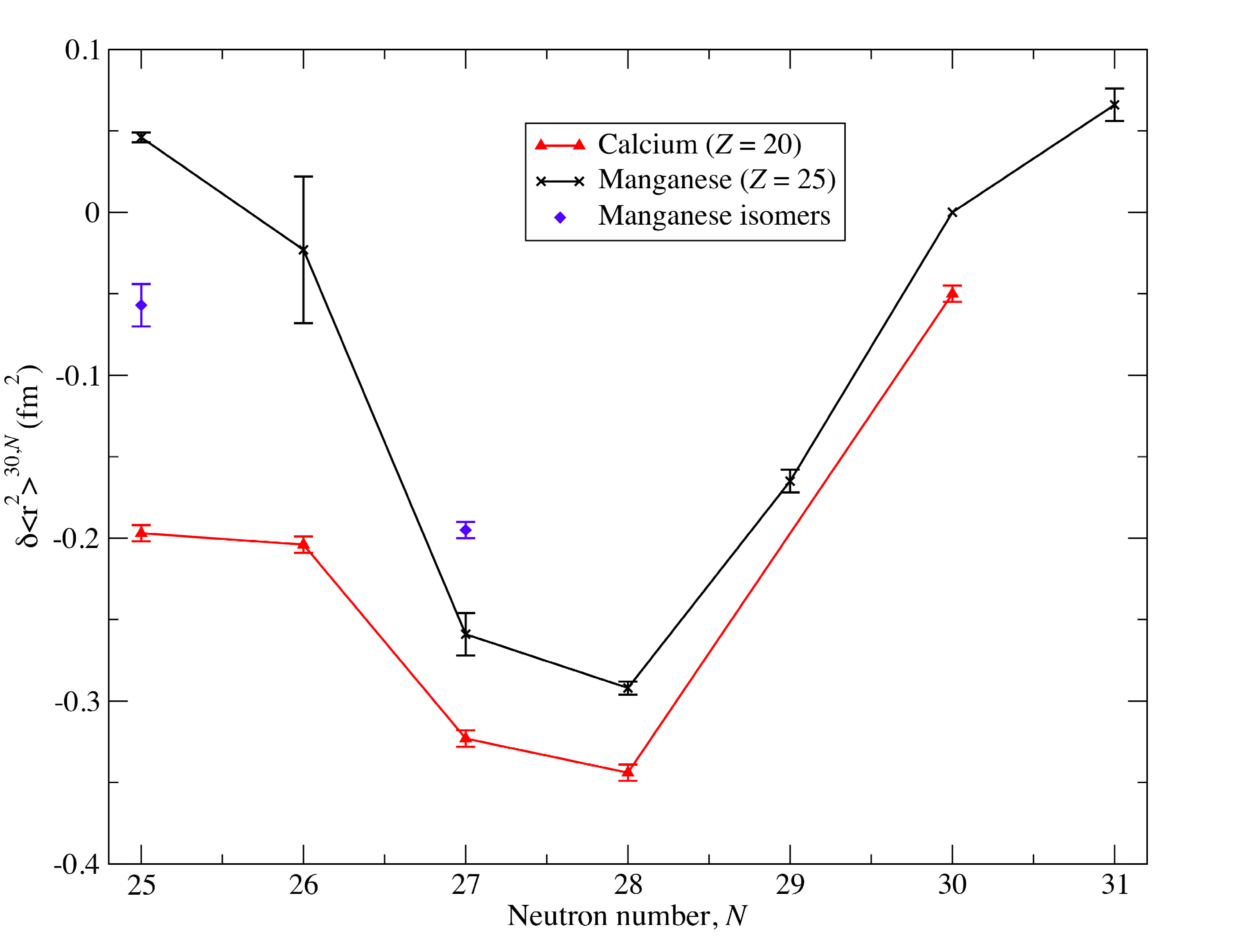
Is a shell closure observed in the charge radii measurements around *N*=28 (like in Ca)?

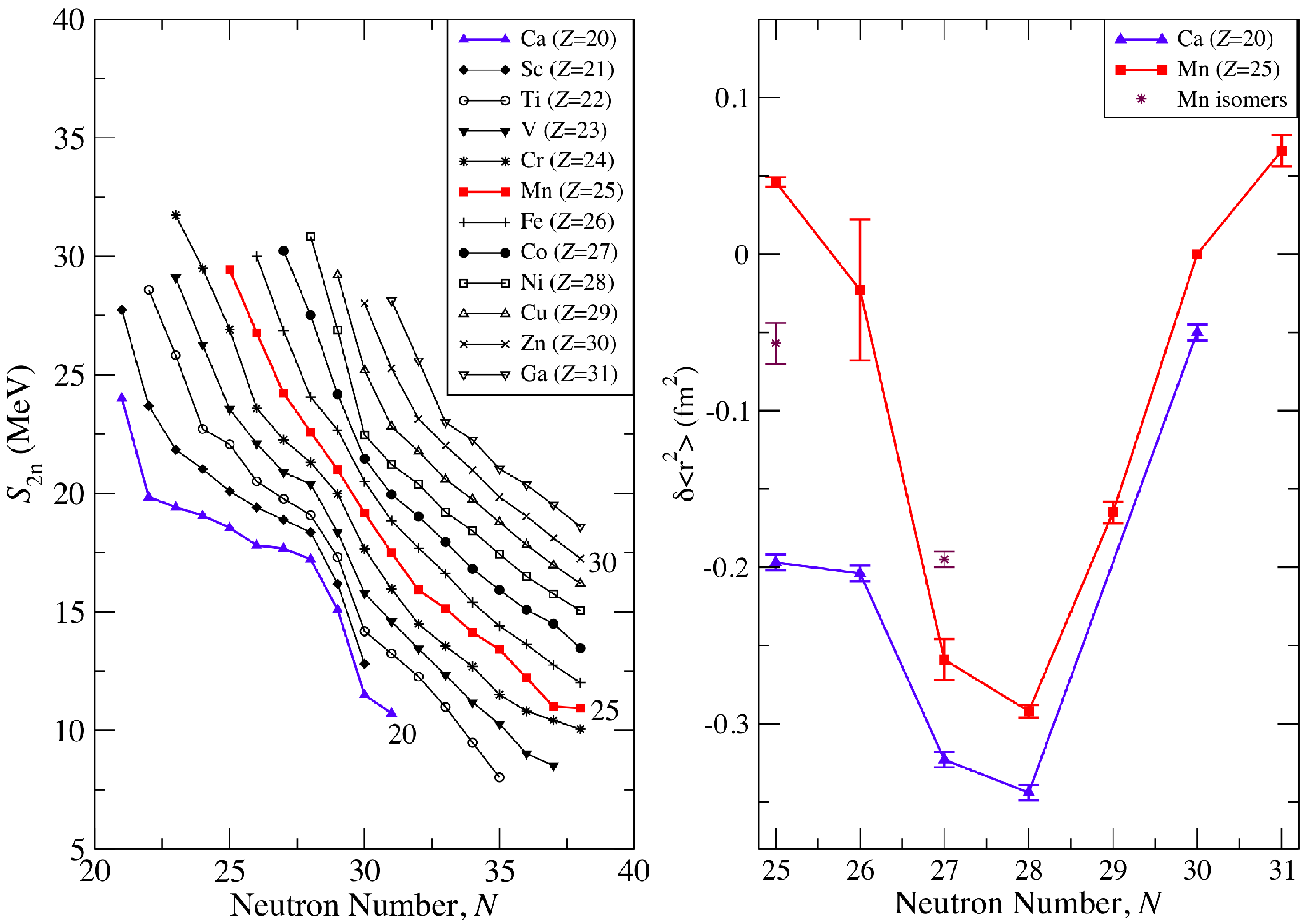


Counts
Frequency (MHz) relative to the 55Mn centroid
-10000
-5000
0
5000
50Mn
51Mn
52Mn
53Mn
54Mn
55Mn
56Mn
*
g

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

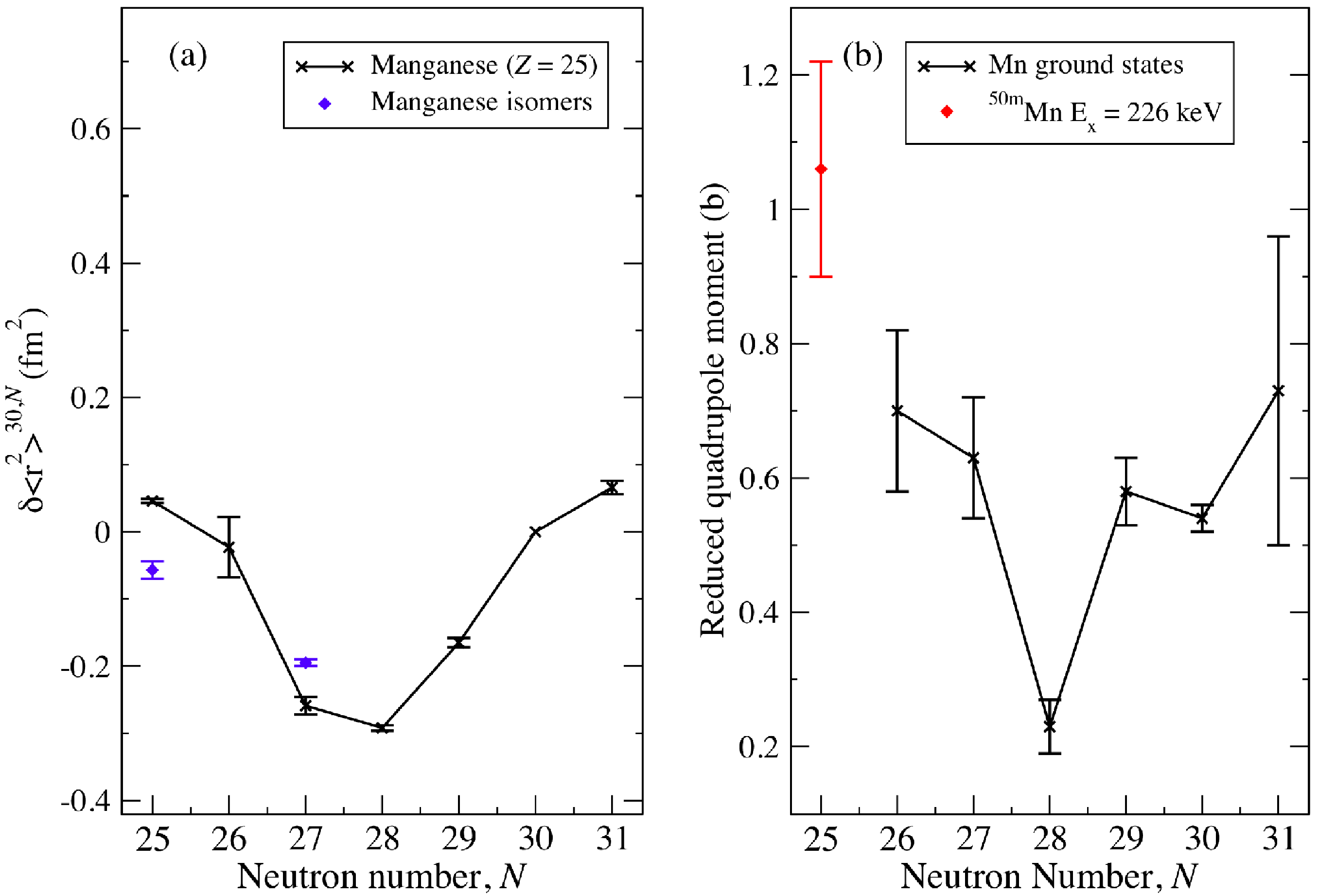
New atomic calculations based on MCDF method:
Manganese F = -572(86)MHz fm^{-2} and M = 852(45)GHz.u





- Charge radii follow trends in ϒ-ray spectroscopic studies, not S_{2n}
- Very different to perfect agreement in two sets of measurements at Z~40.

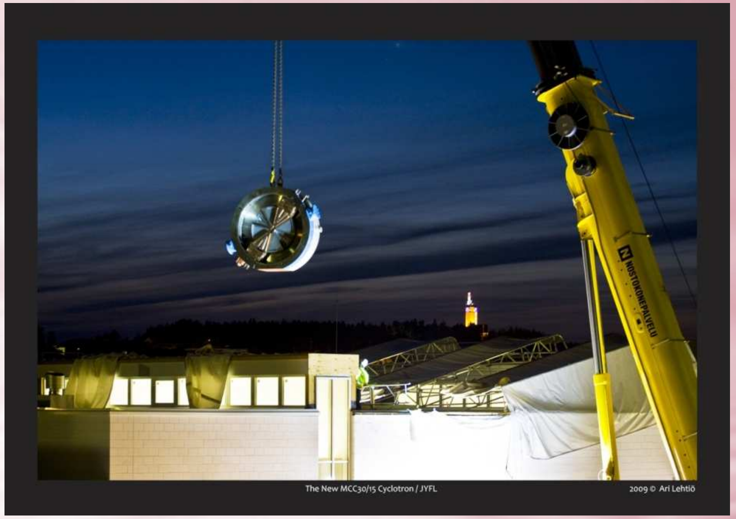
Quadrupole moments of Mn – characteristic of shell model

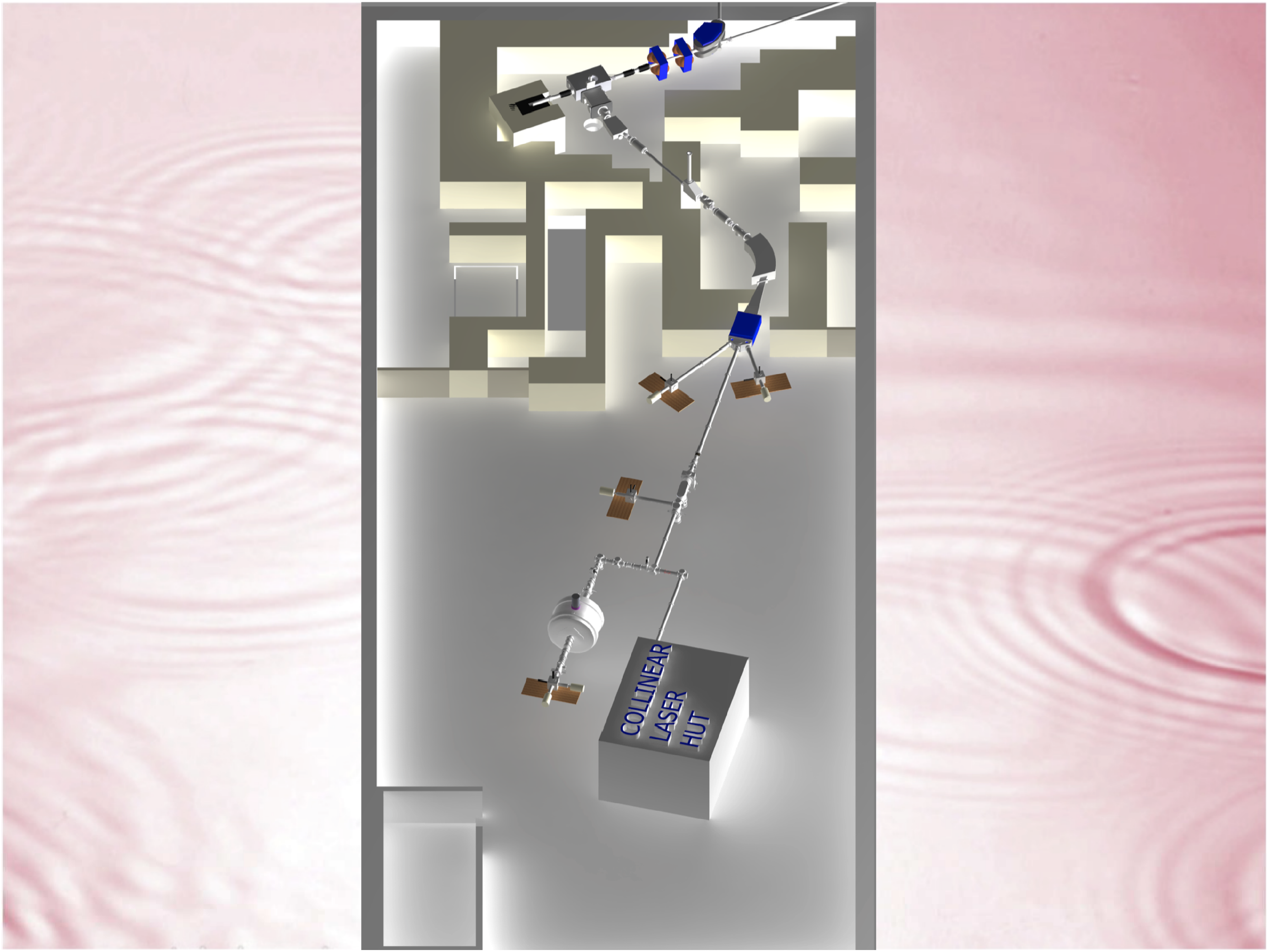


- Known moments of ^{55}Mn used to calibrate magnetic and quadrupole moments of ^{50m,53,54,56}Mn.
- Not collective nor single particle states. GXPF1A shell model calculations suggest a highly mixed g.s

New Lab at JYFL!

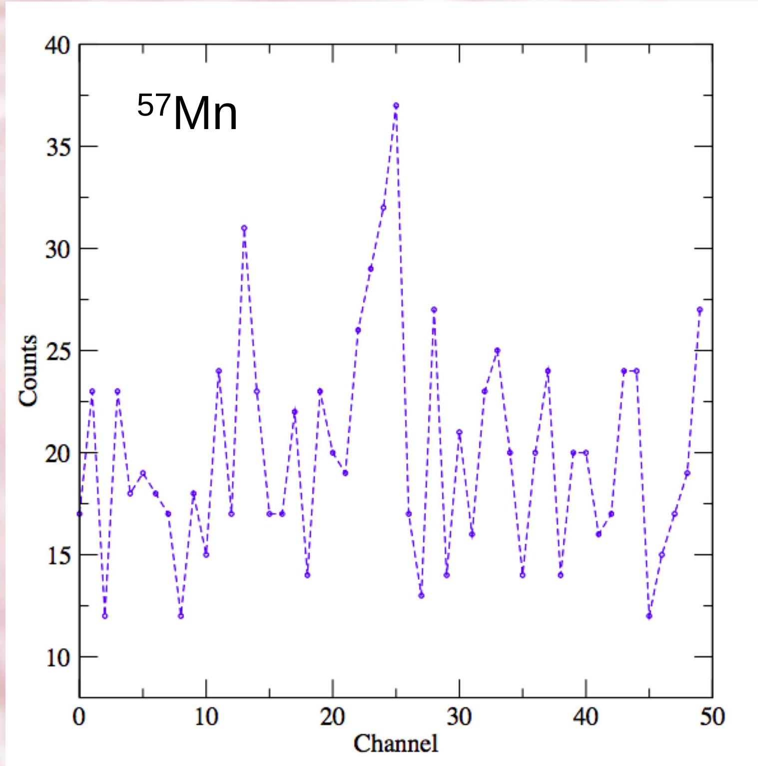
- New mini cyclotron dedicated to IGISOL experiments
- IGISOL and laser line move from suummer 2010.




COLLINEAR
LASER
HUT

Future work at JYFL

- (d,2p) reaction on ^{57,58}Fe target
- Cross section ~100mb



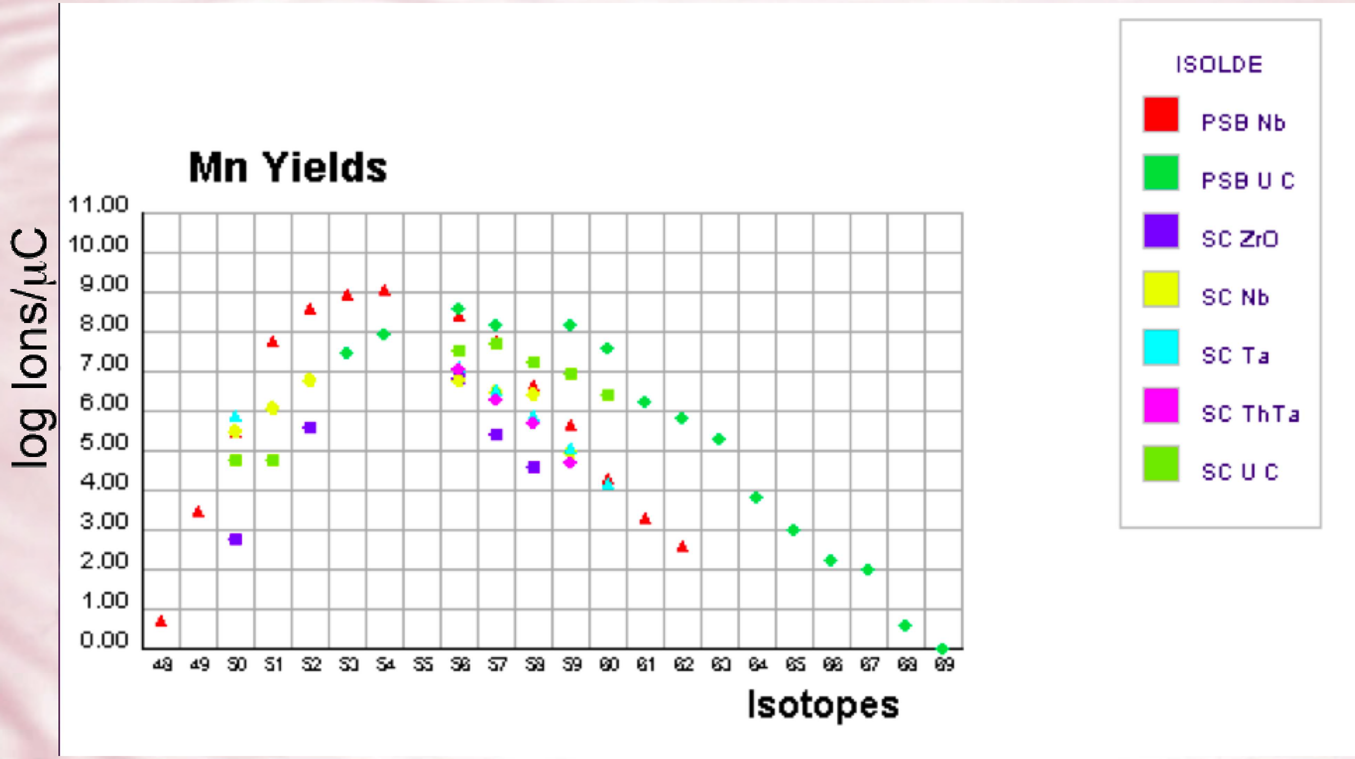
Easter 2010

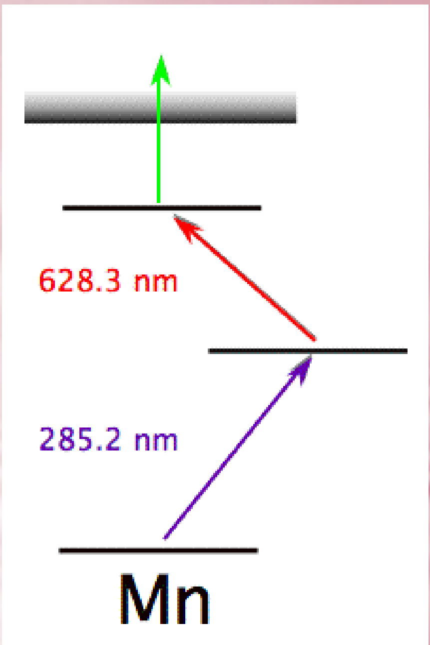
~ 400/s
~ 650,000/s background

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

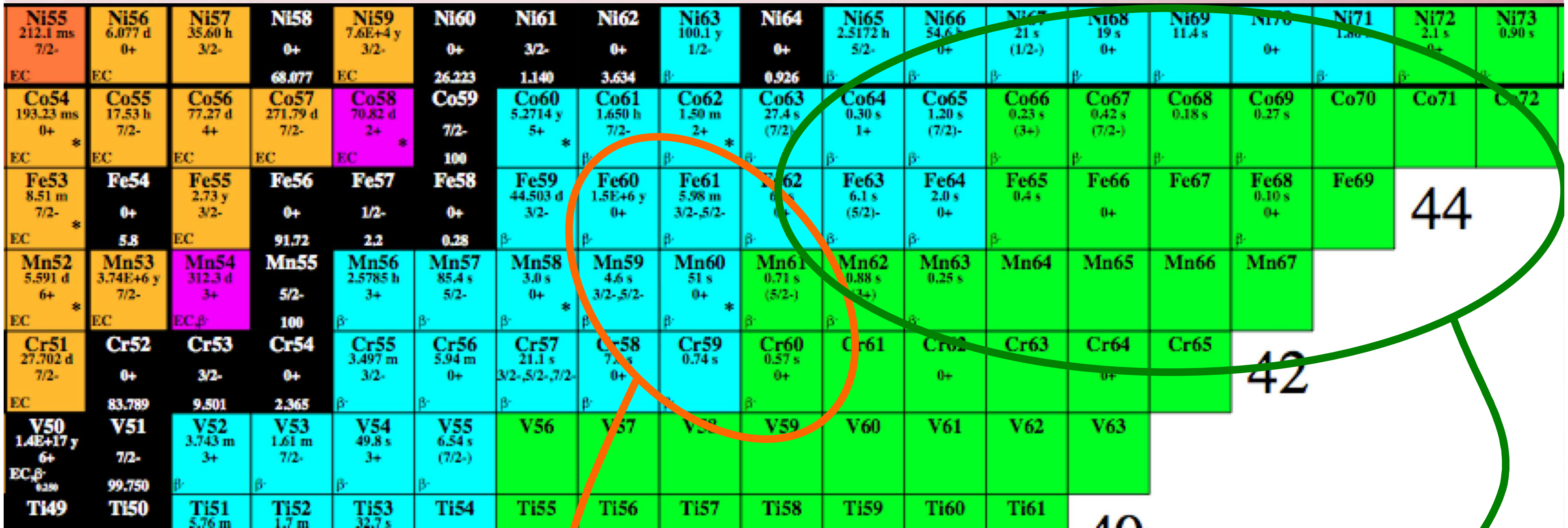
Future work at ISOLDE

- Isotope production possible from $^{48\text{-}69}Mn$ 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

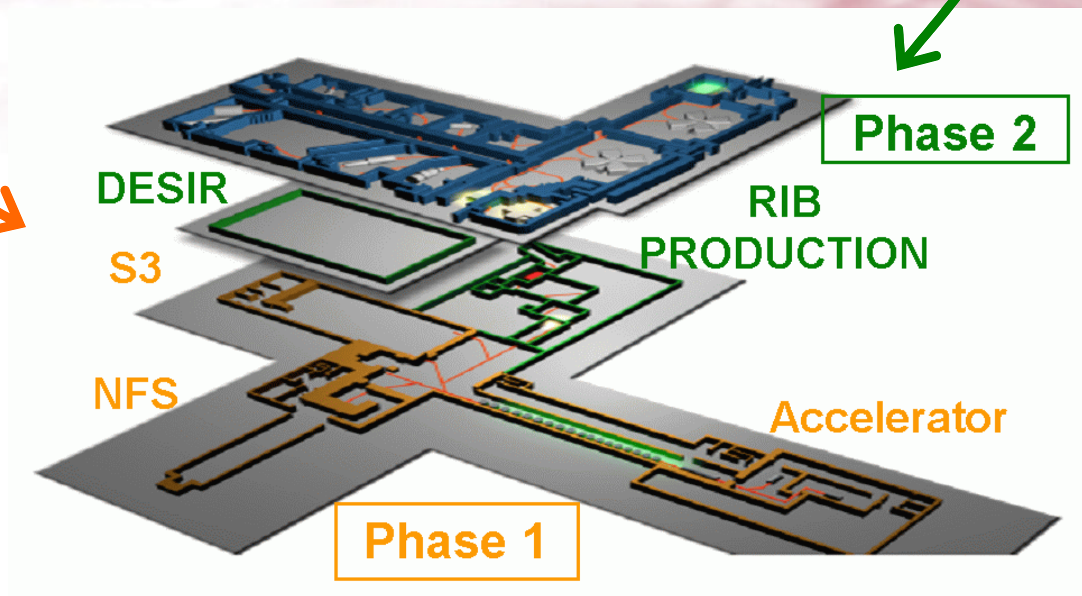




Future work at DESIR



- Problems at ISOLDE
- Reactions such as ^{48}Ca on ^{13,14}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}Mn – ^{56}Mn
- First observation of differing mass and charge radii measurements
- Quadrupole moment at the shell closure and moments for ^{50}Mn^{m}
- Charge radii and quadrupole moments correspond
- Future experiments towards the n-rich ^{58}Mn utilising (d,2p) in JYFL new lab
- $^{48-69}$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**

University of Jyvaskyla, 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