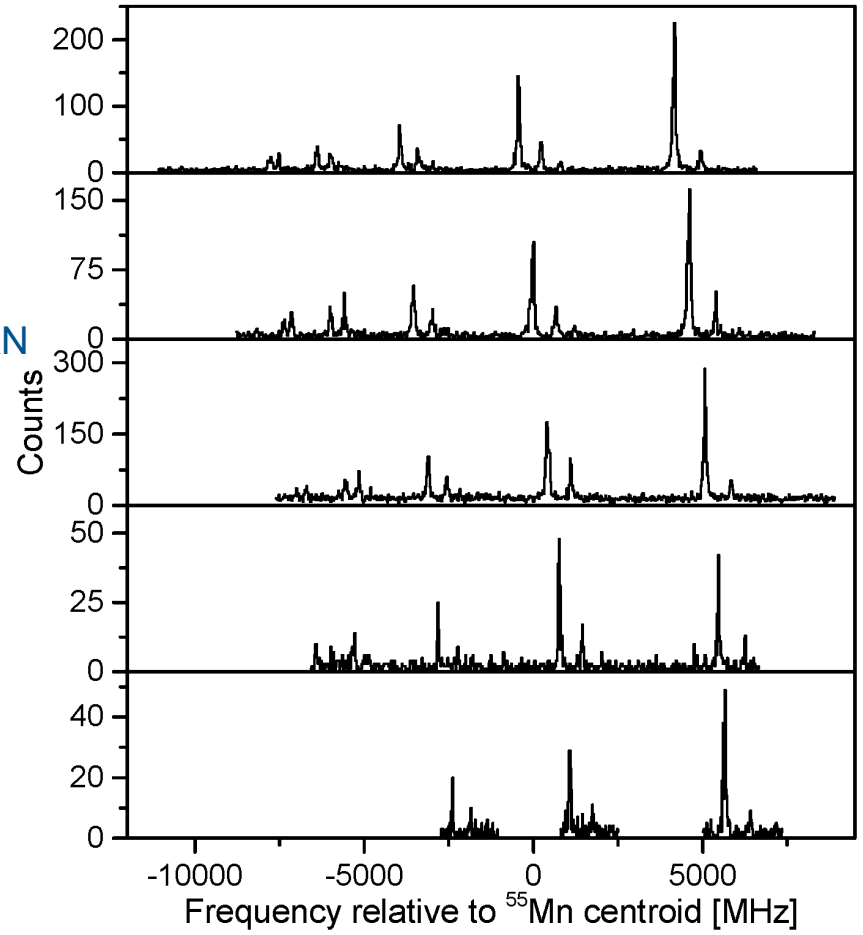
Nuclear moments of Mn, the first application of optical pumping in the ISCOOL RFQ

Hanne Heylen
NUSTAR Week, 29/09/2015

BriX
KU LEUVEN
NUCLEAR AND RADIATION PHYSICS

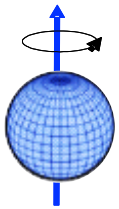
Introduction

- Quadrupole moments of odd $^{53\text{-}63}$Mn
- Collinear laser spectroscopy at ISOLDE, CERN
- Optical pumping in ISCOOL RFQ

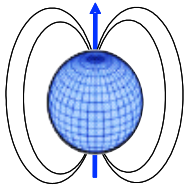


Collinear laser spectroscopy

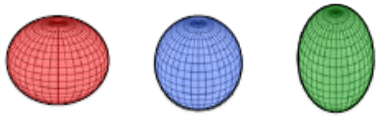
Measure **nuclear** ground state properties



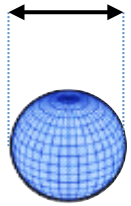
Spin I



Magnetic moment μ

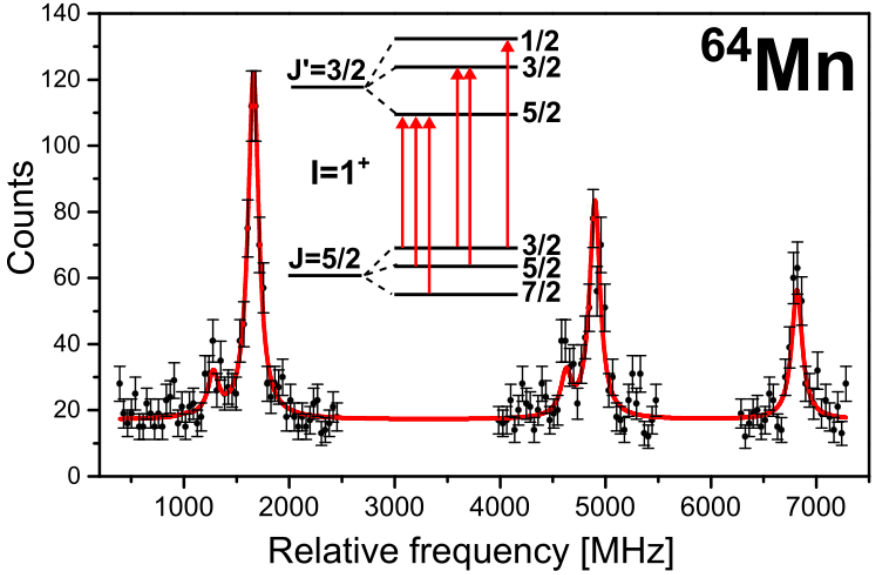


Quadrupole moment Q_s



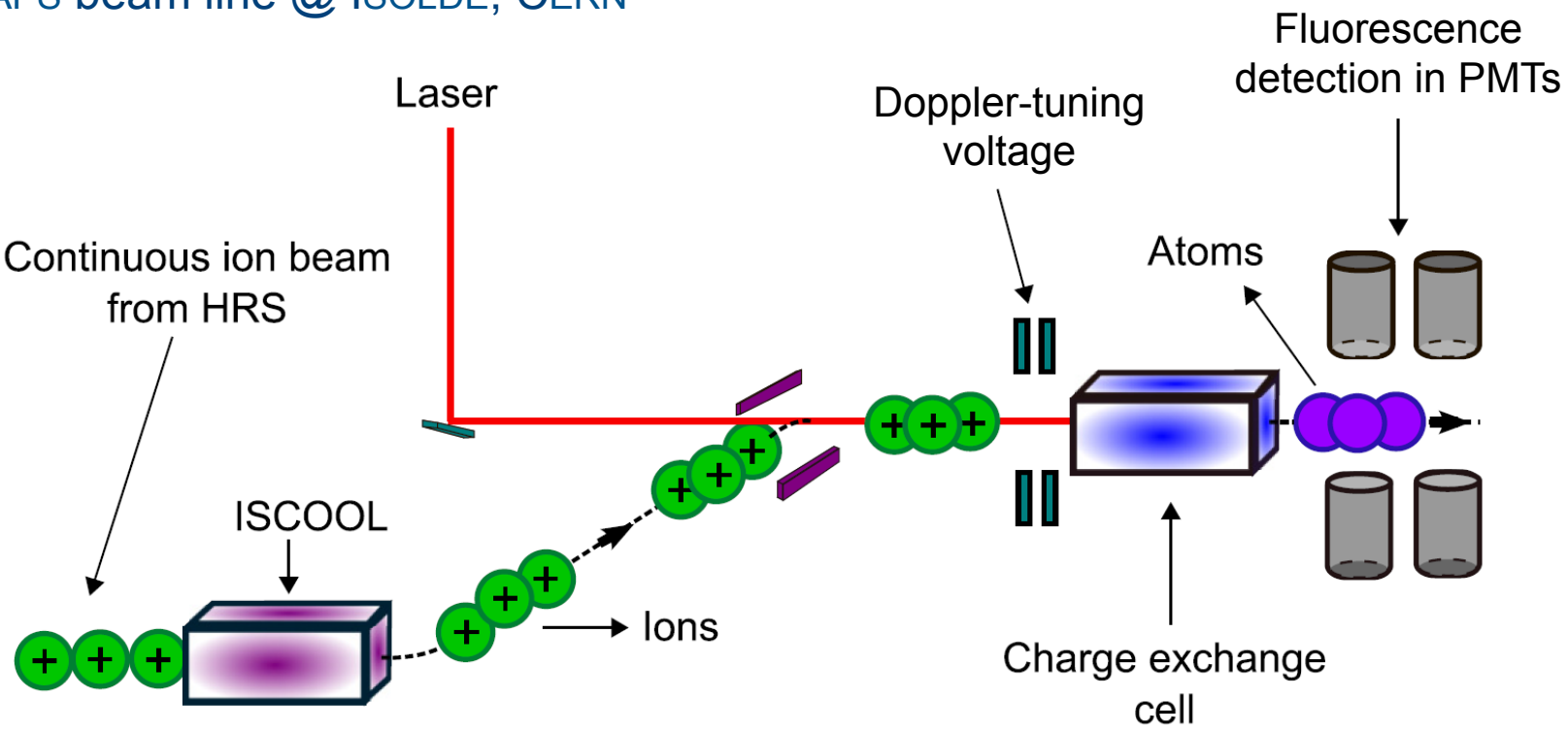
Mean square charge radii $\delta\langle r^2\rangle$

via **atomic** hyperfine splitting: interaction between electrons and nucleus



Collinear laser spectroscopy

COLLAPS beam line @ ISOLDE, CERN



Collinear laser spectroscopy

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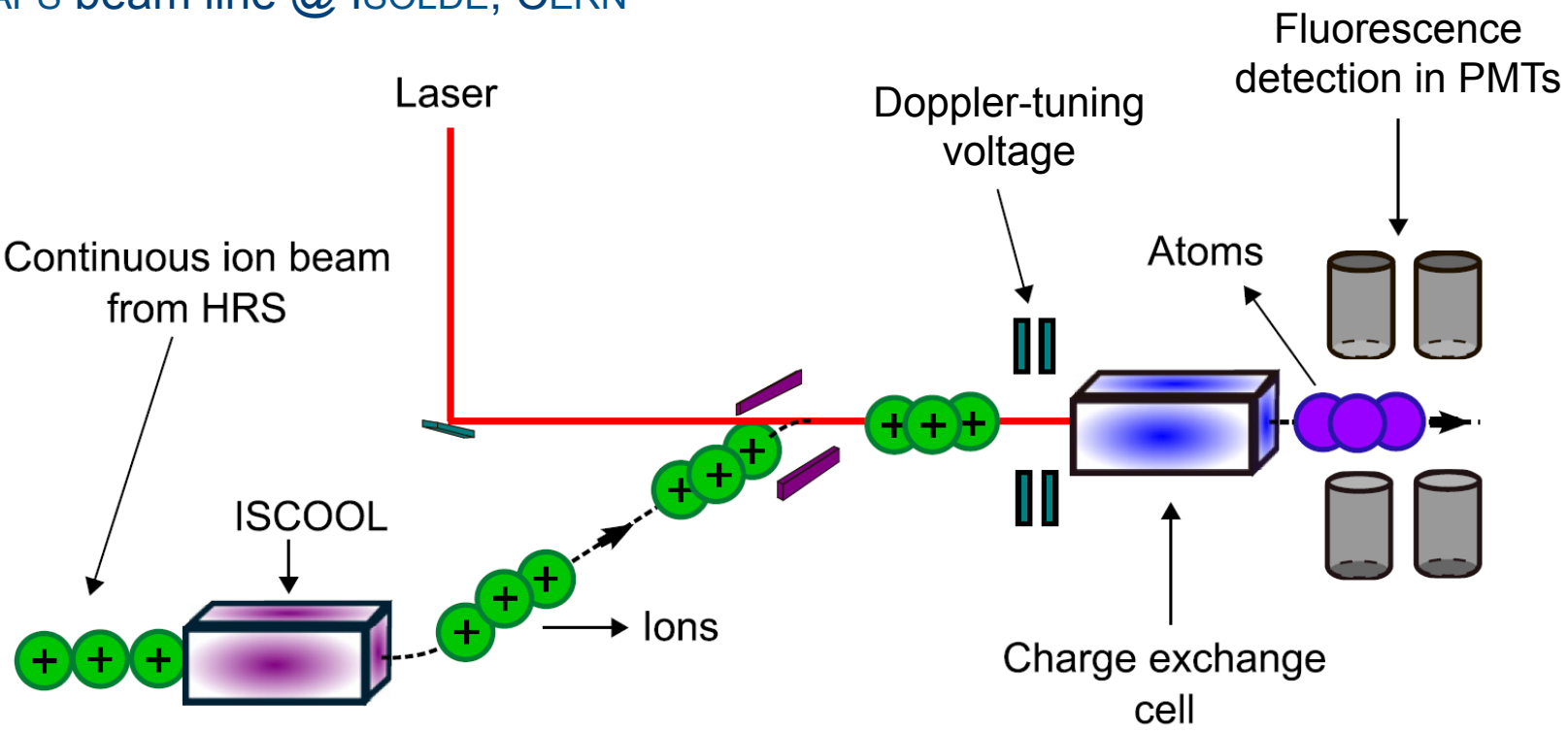
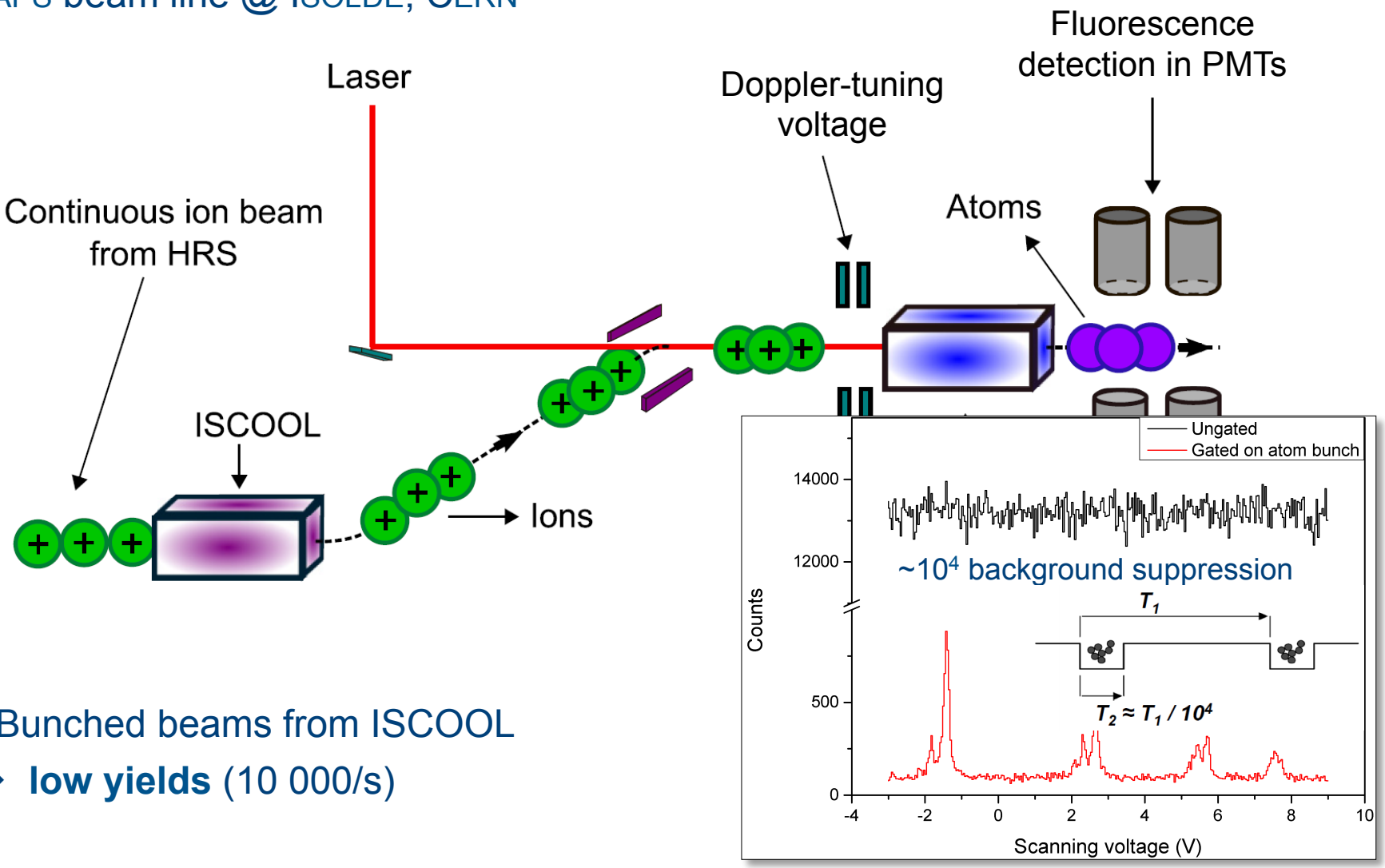


- 30 – 40 keV beams → **High-resolution**
  Doppler broadening ∝ $1/\sqrt{V_{acc}}$

Collinear laser spectroscopy

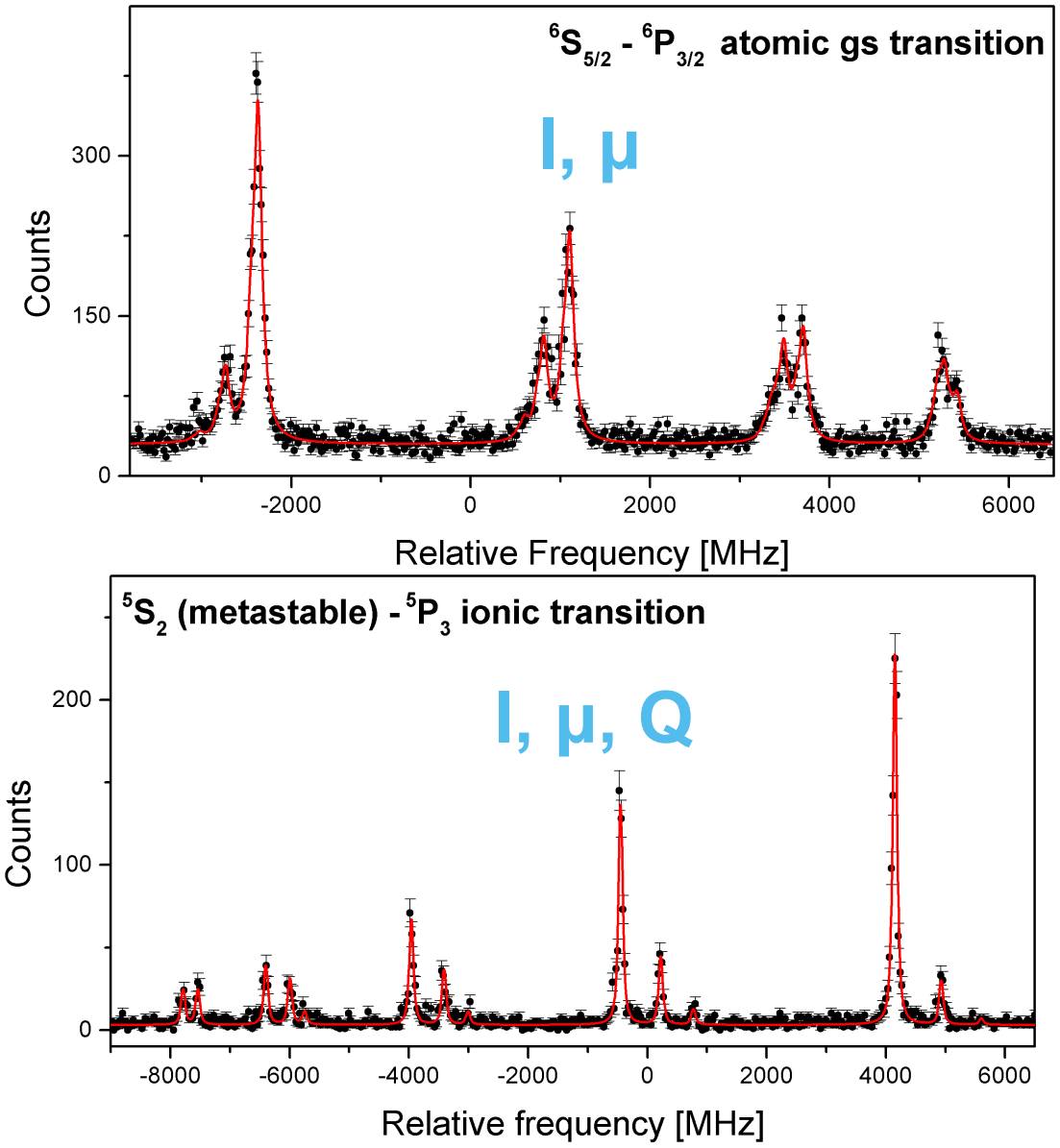
COLLAPS beam line @ ISOLDE, CERN



- Bunched beams from ISCOOL

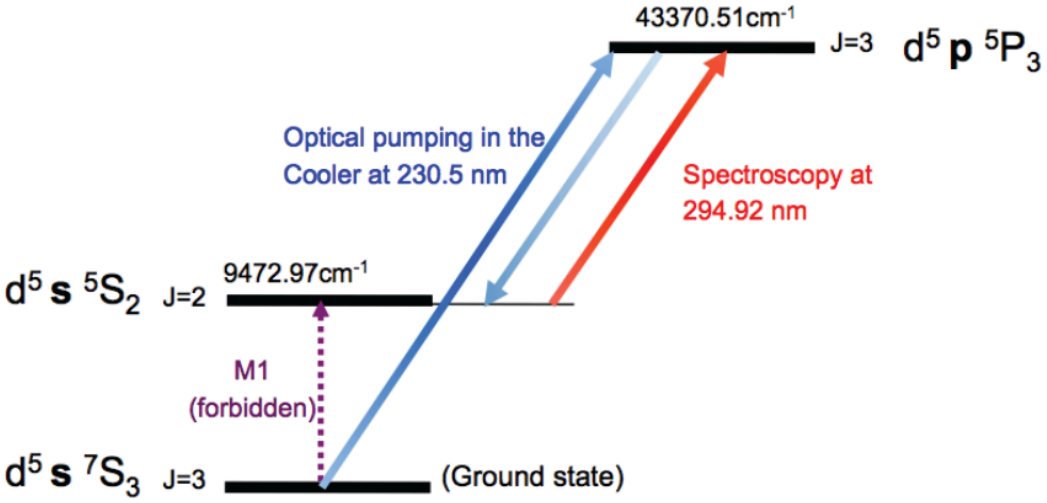
→ **low yields** (10 000/s)

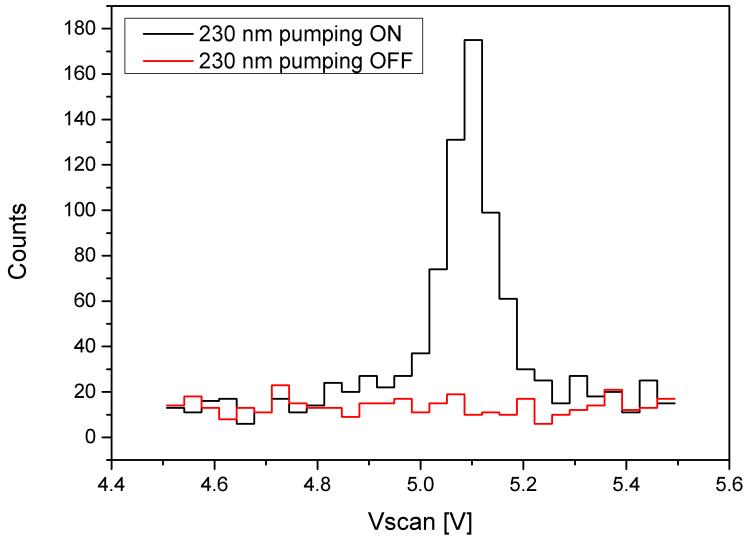
Collinear laser spectroscopy



In-cooler optical pumping

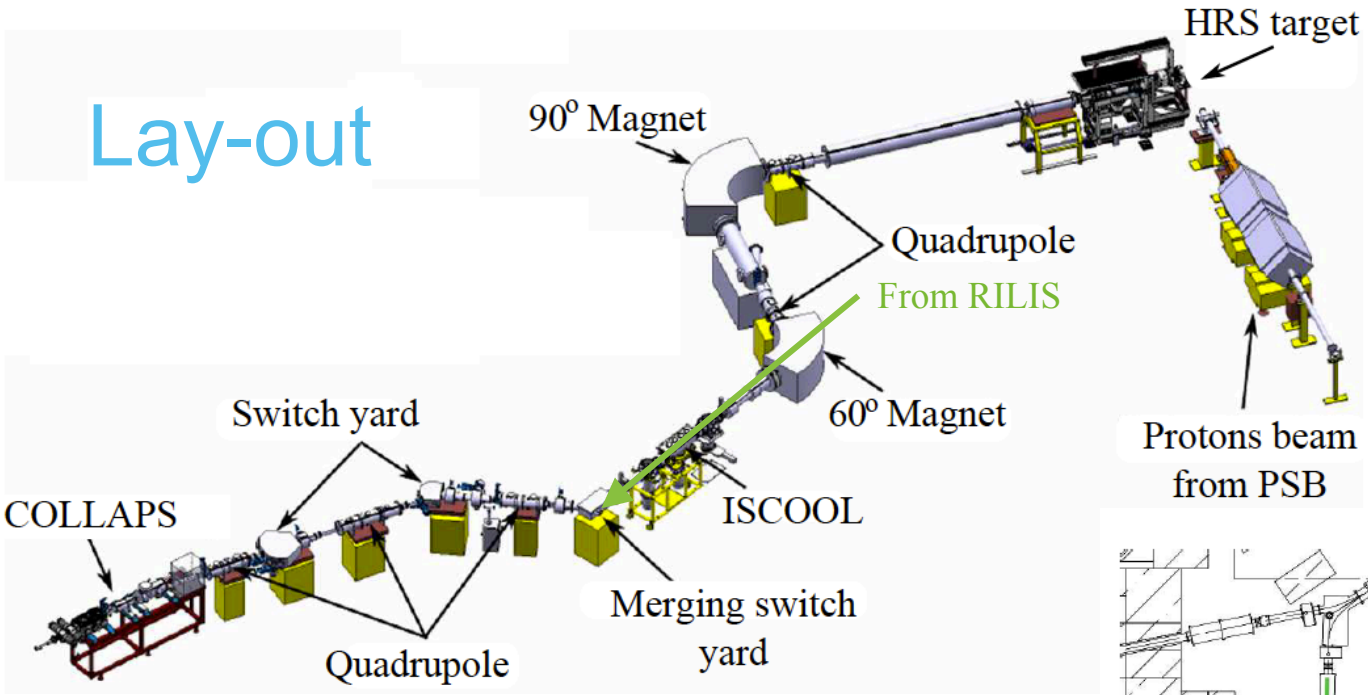
- Enhancement of metastable ionic state
  - Long laser-ion interaction time (200 ms) in ISCOOL RFQ

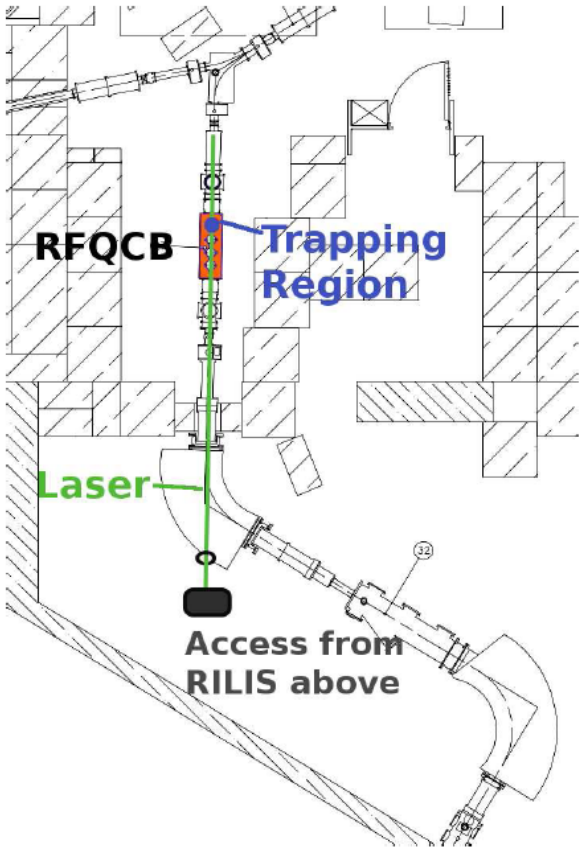




- Proof of principle in Jyväskylä Cheal et al., PRL 102 (2009); Charlwood,et al. PLB 690 (2010);
- Challenges at ISOLDE PhD work, Carla Babcock
  - Alignment of laser with ISCOOL

Lay-out


HRS target
90° Magnet
Quadrupole
From RILIS
60° Magnet
Protons beam
from PSB
Switch yard
COLLAPS
ISCOOL
Merging switch
yard
Quadrupole


RFQCB
Trapping
Region
Laser
Access from
RILIS above

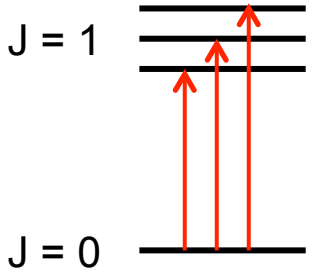
In-cooler optical pumping: future?

Suitable optical transitions

- Inefficiencies in charge exchange process

- Accessible with narrow-band lasers Mn, Mo

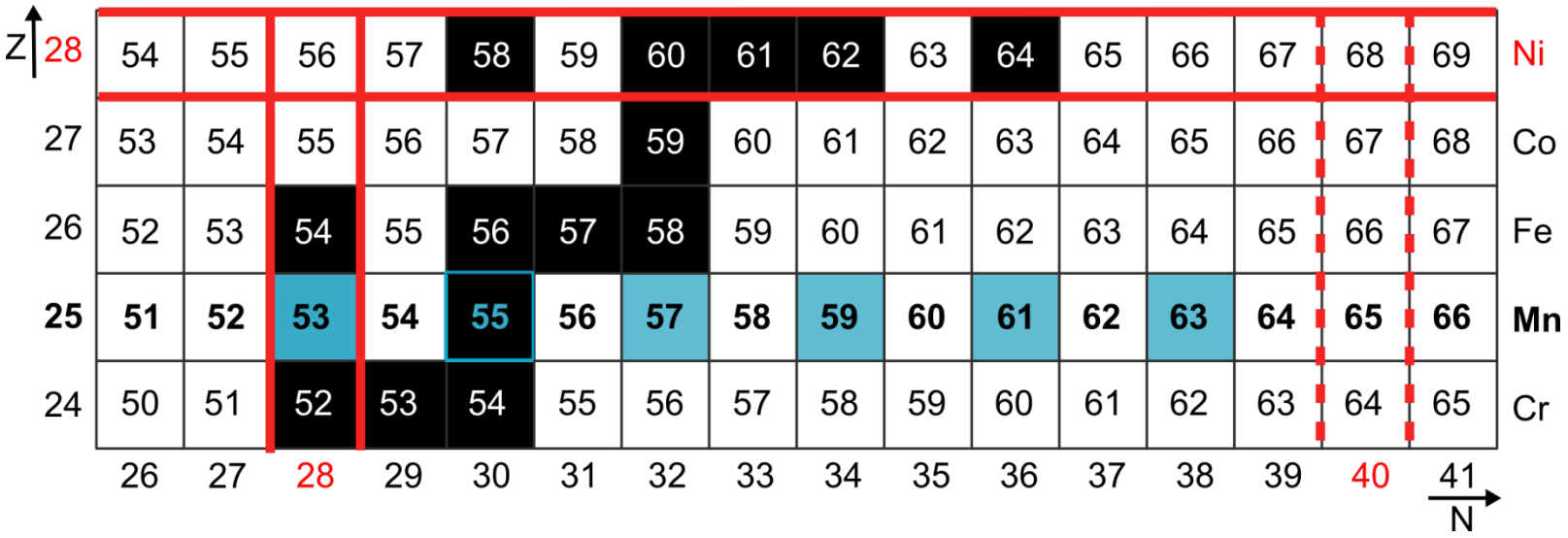
- Sensitive to all nuclear parameters Mn, Y, Lu
  - Small quadrupole splitting
  - Ionic gs J = 0 → J = 1 does not provide spin



3 transitions,
4 observables: μ, Q, δ<r^2>, I
Extracted values depend on I

→ Optical pumping to ionic metastable state

Quadrupole moments of exotic Mn



- Why?
- What did we learn?

Onset of deformation below ^{68}Ni

VOLUME 88, NUMBER 9 PHYSICAL REVIEW LETTERS 4 MARCH 2002

$^{68}_{28}Ni_{40}$: Magicity versus Superfluidity

O. Sorlin,[1] S. Leenhardt,[1] C. Donzaud,[1] J. Duprat,[1] F. Azaiez,[1] F. Nowacki,[2] H. Grawe,[3] Zs. Dombrádi,[4] F. Amorini,[5] A. Astier,[6] D. Baiborodin,[7] M. Belleguic,[1] C. Borcea,[8] C. Bourgeois,[1] D. M. Cullen,[9,*] Z. Dlouhy,[7] E. Dragulescu,[8] M. Górska,[3] S. Grévy,[10] D. Guillemaud-Mueller,[1] G. Hagemann,[11] B. Herskind,[11] J. Kiener,[12] R. Lemmon,[13] M. Lewitowicz,[14] S. M. Lukyanov,[15] P. Mayet,[3] F. de Oliveira Santos,[14] D. Pantalica,[7] Yu.-E. Penionzhkevich,[15] F. Pougheon,[1] A. Poves,[16] N. Redon,[6] M. G. Saint-Laurent,[14] J. A. Scarpaci,[1] G. Sletten,[11] M. Stanoiu,[14] O. Tarasov,[15,†] and Ch. Theisen[17]

PRL 102, 012502 (2009) PHYSICAL REVIEW LETTERS week ending 9 JANUARY 2009

Development of Large Deformation in ^{62}Cr

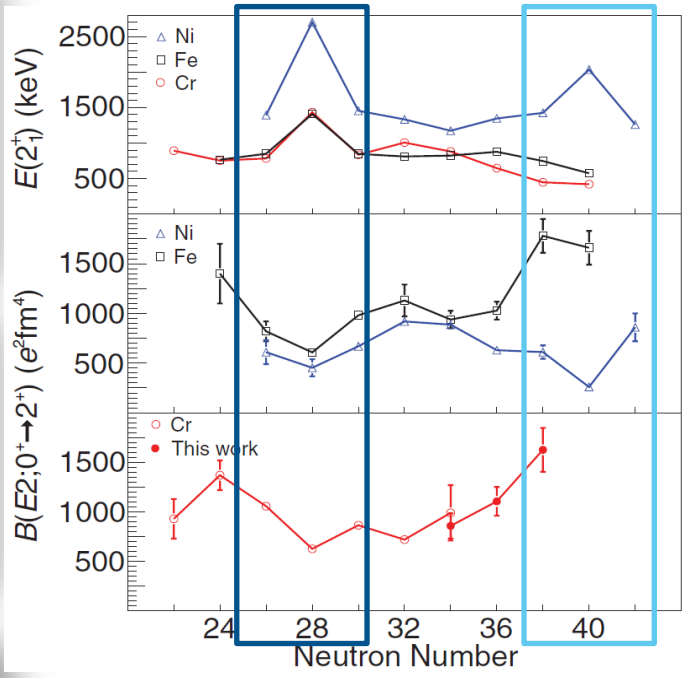
N. Aoi,[1] E. Takeshita,[1,2] H. Suzuki,[3] S. Takeuchi,[1] S. Ota,[4] H. Baba,[1] S. Bishop,[1] T. Fukui,[4] Y. Hashimoto,[5] H. J. Ong,[6] E. Ideguchi,[7] K. Ieki,[2] N. Imai,[8] M. Ishihara,[1] H. Iwasaki,[6] S. Kanno,[2] Y. Kondo,[5] T. Kubo,[1] K. Kurita,[2] K. Kusaka,[1] T. Minemura,[8] T. Motobayashi,[1] T. Nakabayashi,[5] T. Nakamura,[5] T. Nakao,[6] M. Niikura,[7] T. Okumura,[5] T. K. Ohnishi,[6] H. Sakurai,[6] S. Shimoura,[7] R. Sugo,[2] D. Suzuki,[6] M. K. Suzuki,[6] M. Tamaki,[7] K. Tanaka,[1] Y. Togano,[2] and K. Yamada[1]

PRL 110, 242701 (2013) PHYSICAL REVIEW LETTERS week ending 14 JUNE 2013

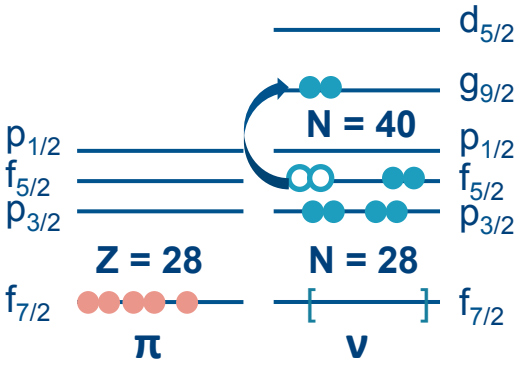
Quadrupole Collectivity in Neutron-Rich Fe and Cr Isotopes

H. L. Crawford,[1] R. M. Clark,[1] P. Fallon,[1] A. O. Macchiavelli,[1] T. Baugher,[2,3] D. Bazin,[2] C. W. Beausang,[4] J. S. Berryman,[2] D. L. Bleuel,[5] C. M. Campbell,[1] M. Cromaz,[1] G. de Angelis,[6] A. Gade,[2,3] R. O. Hughes,[4] I. Y. Lee,[1] S. M. Lenzi,[7] F. Nowacki,[8] S. Paschalis,[1] M. Petri,[1] A. Poves,[9] A. Ratkiewicz,[2,3] T. J. Ross,[4] E. Sahin,[6] D. Weisshaar,[2] K. Wimmer,[2,10] and R. Winkler[2]

Baugher, PRC 86 (2012)



Onset of deformation below ^{68}Ni



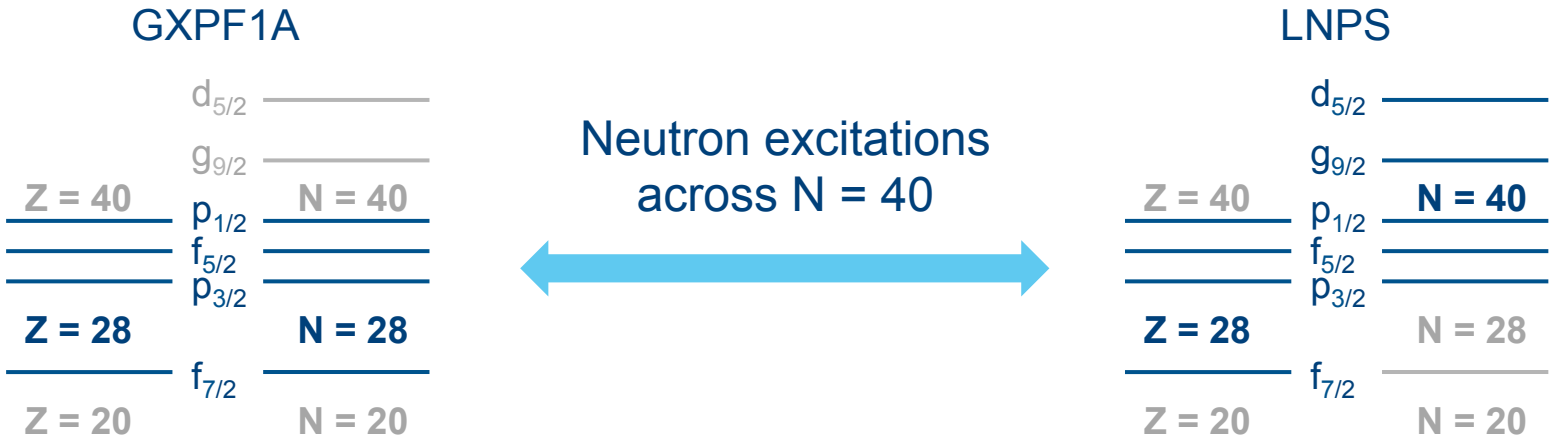
Onset of deformation towards N = 40

- Stabilizing proton shell closure at Z = 28
  - Spherical ^{68}Ni ground state
- Quadrupole correlations for Z < 28
  - Deformation
  - Particle-hole excitations across N = 40

Understand dynamics of shape transition:
Interplay between single-particle nature and collectivity

Onset of deformation below ^{68}Ni

Large-scale shell model interactions



. Honma, EPJ A 25 (2005)

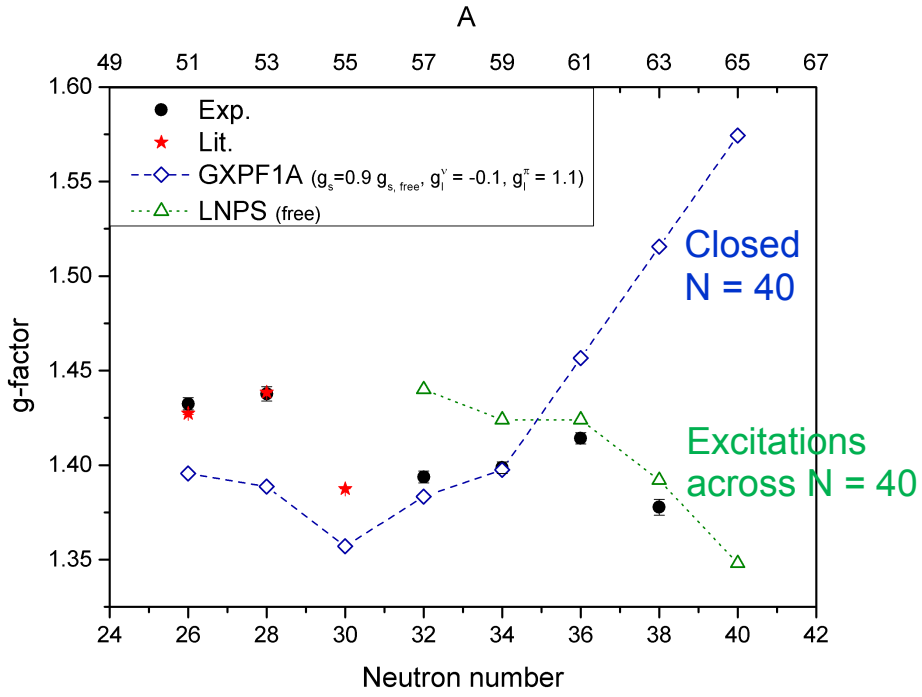
Lenzi, PRC 82 (2010)

Nuclear moments

- Magnetic moments: nuclear configuration of valence nucleons
- Quadrupole moments: deformation

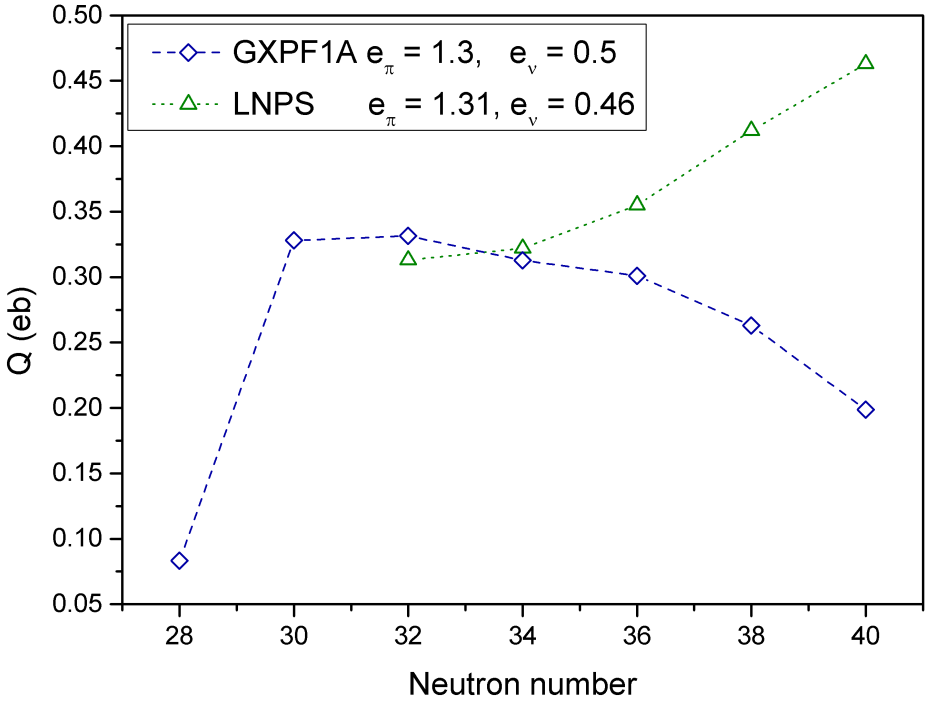
Magnetic moments of exotic Mn

C. Babcock et al., PLB 750 (2015); H. Heylen et al., accepted for publication in PRC

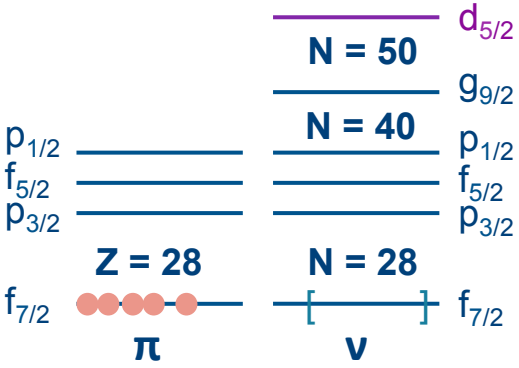


- Excitations of protons across Z = 28 and neutrons across N = 40 (4p – 4h at ^{65}Mn)
- Limited sensitivity to 2p – 2h, 4p – 4h neutron excitations (< 20 % effect)

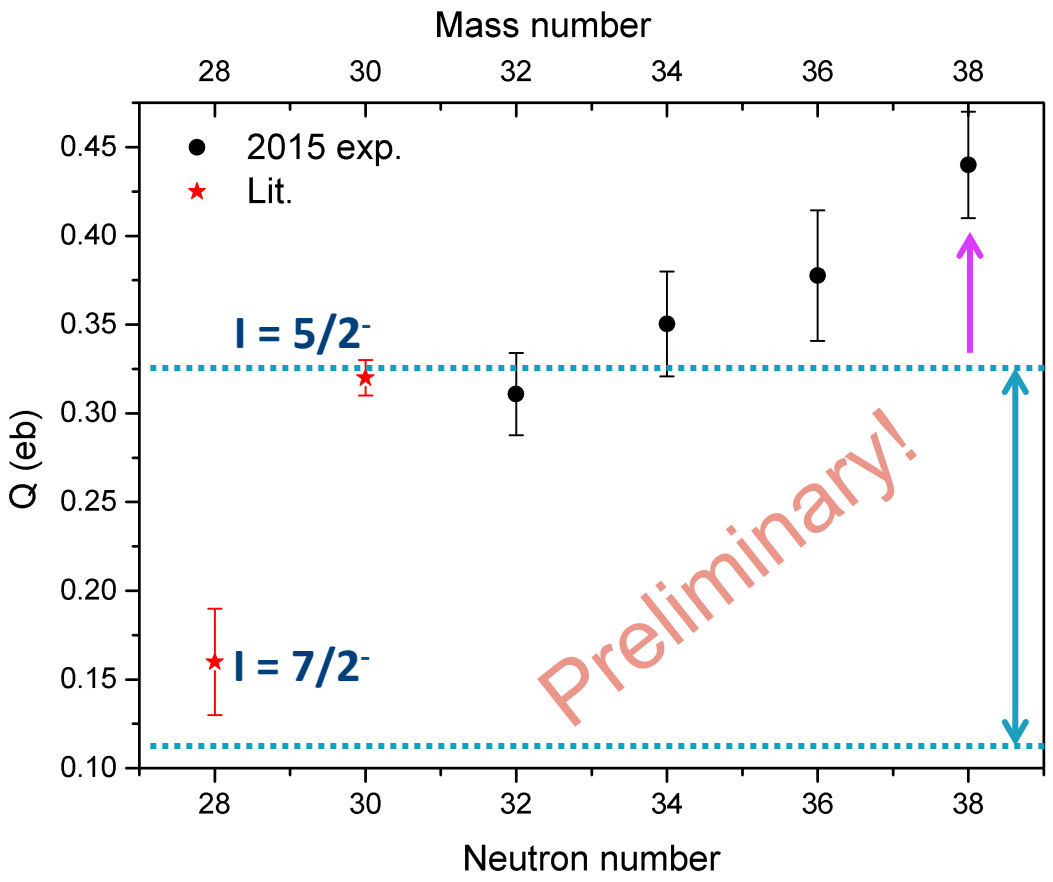
Quadrupole moments of exotic Mn

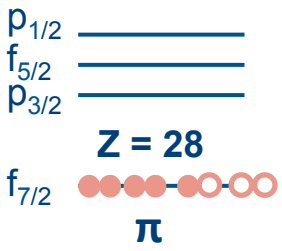


- Factor 2 difference at N = 40
- Influence of $d_{5/2}$ neutron orbital?
- Experimentally limited to N = 38 due to target problems



Quadrupole moments of odd-even Mn



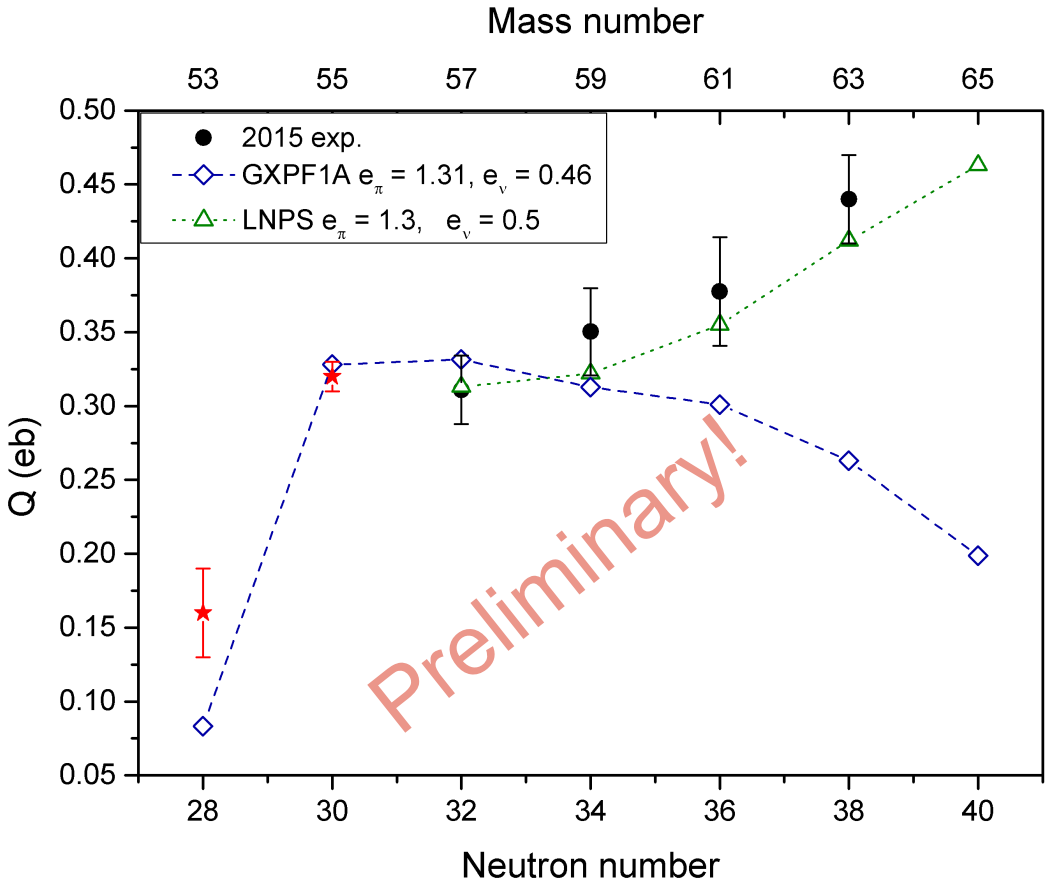


Increased deformation β ~ 0.27

$Q(f_{7/2}^{-3})_{I=7/2} = 0.35Q(f_{7/2}^{-3})_{I=5/2}$

Mayer and Jensen, *Elementary theory of nuclear shell structure* (1957)

Quadrupole moments of odd-even Mn



Summary

- Hyperfine structures of $^{53\text{-}63}$Mn (up to N = 38)
  - I, μ (2012)
  - Odd-even isotopes: Q_s
- Optical pumping in ISCOOL was performed successfully at ISOLDE
- g and Q_s suggest change in nuclear structure at N = 38
  - Neutrons across N = 40, protons across Z = 28
  - Increased deformation

Next?

- Mean square charge radii

Last evening 2015 run

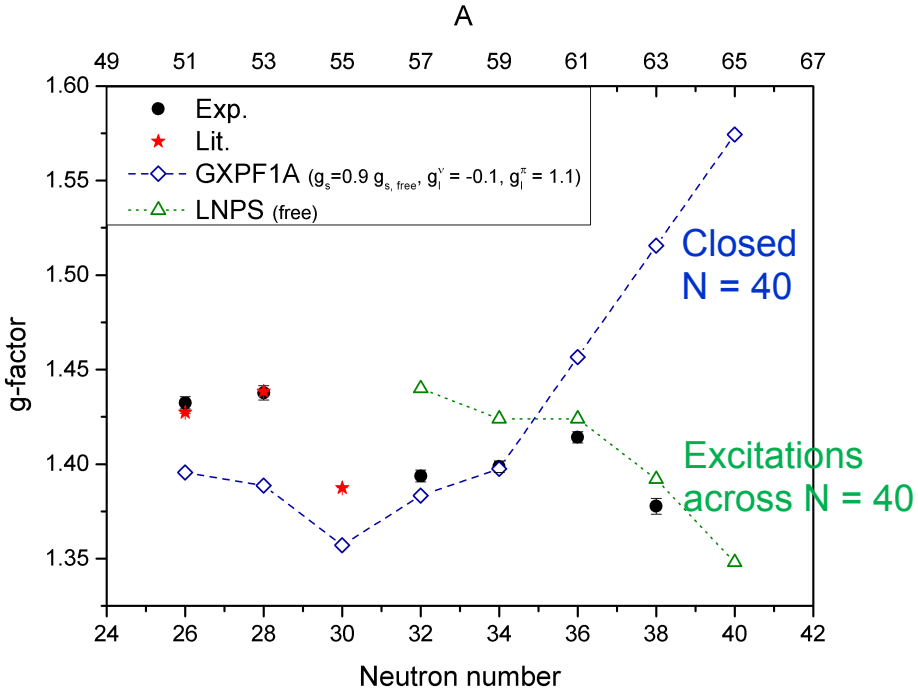
COLLAPS collaboration (2014)

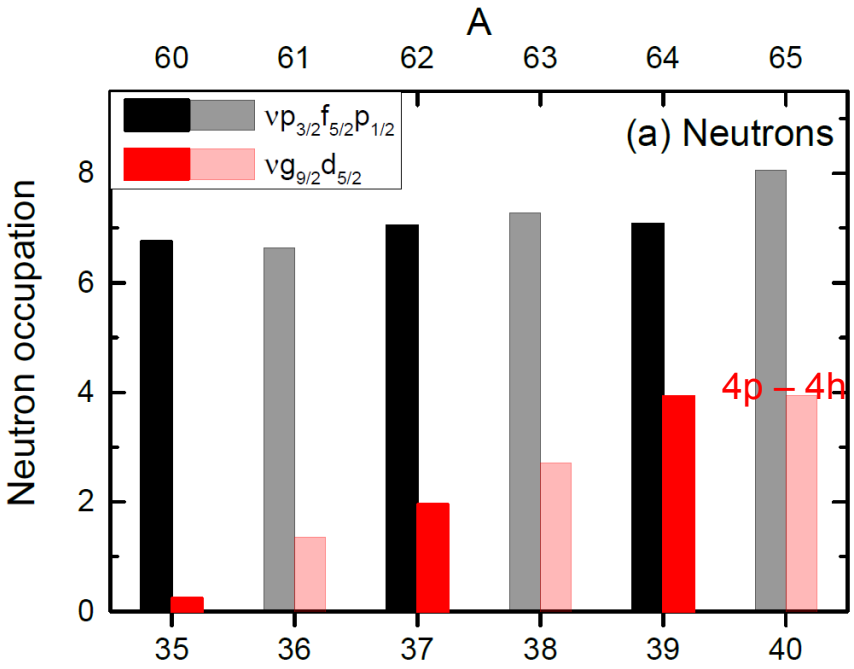
C. Babcock, M.L. Bissell, K. Blaum, P. Campbell, B. Cheal, R.F. Garcia Ruiz, W. Geithner, W. Gins, M. Kowalska, S.M. Lenzi, B. Maaß, S. Malbrunot-Ettenauer, B. Marsh, R. Neugart, G. Neyens, W. Nörtershäuser, R. Rossel, S. Rothe, R. Sanchez, C. Wraith, L. Xie, X. Yang

Thanks to our collaborators!

Magnetic moments of exotic Mn

C. Babcock et al., PLB 750 (2015); H. Heylen et al., accepted for publication in PRC





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