β-decay of ^{68}Mn: Probing the *N*=40 Island of Inversion

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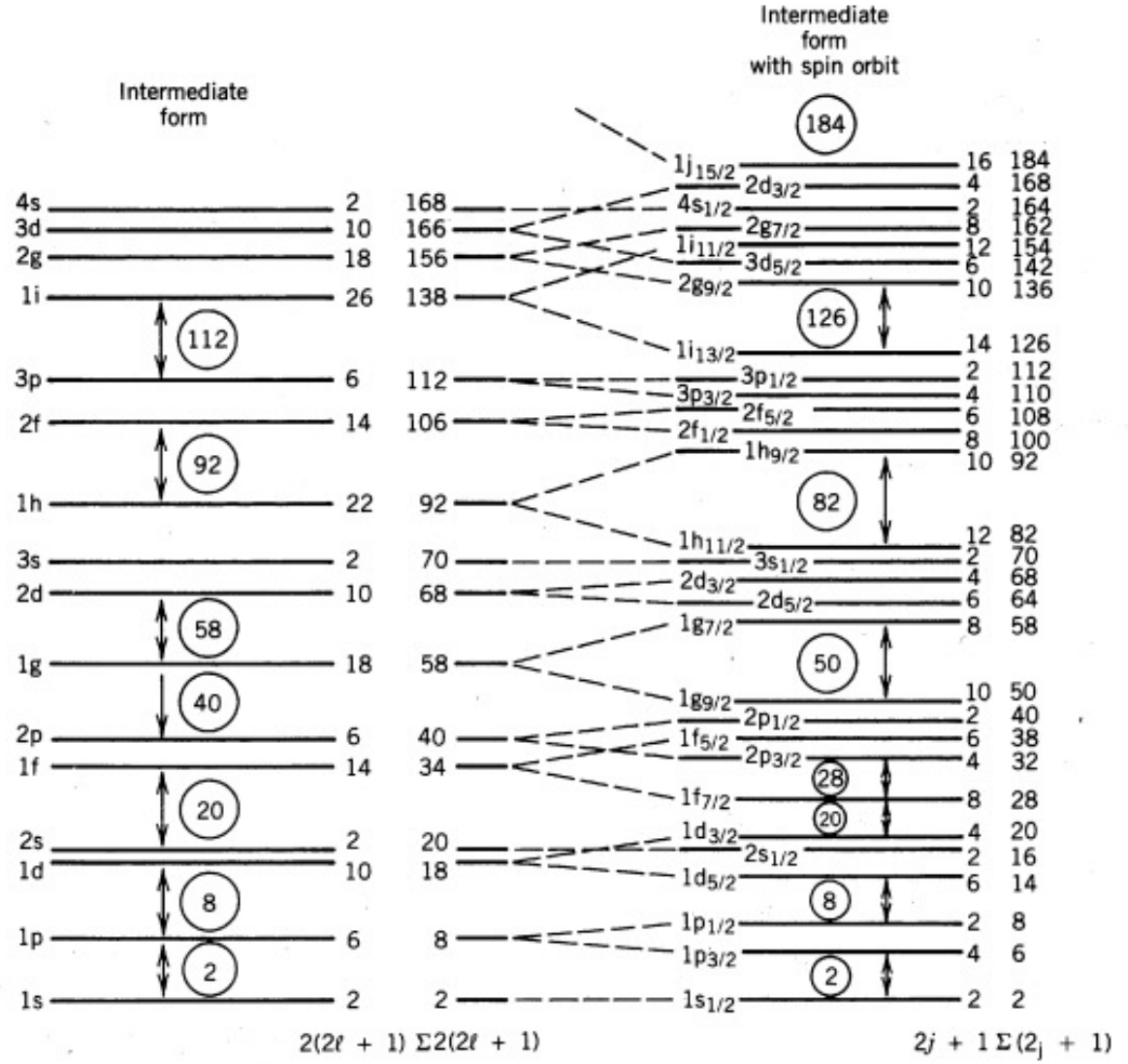
Nuclear Shell Model

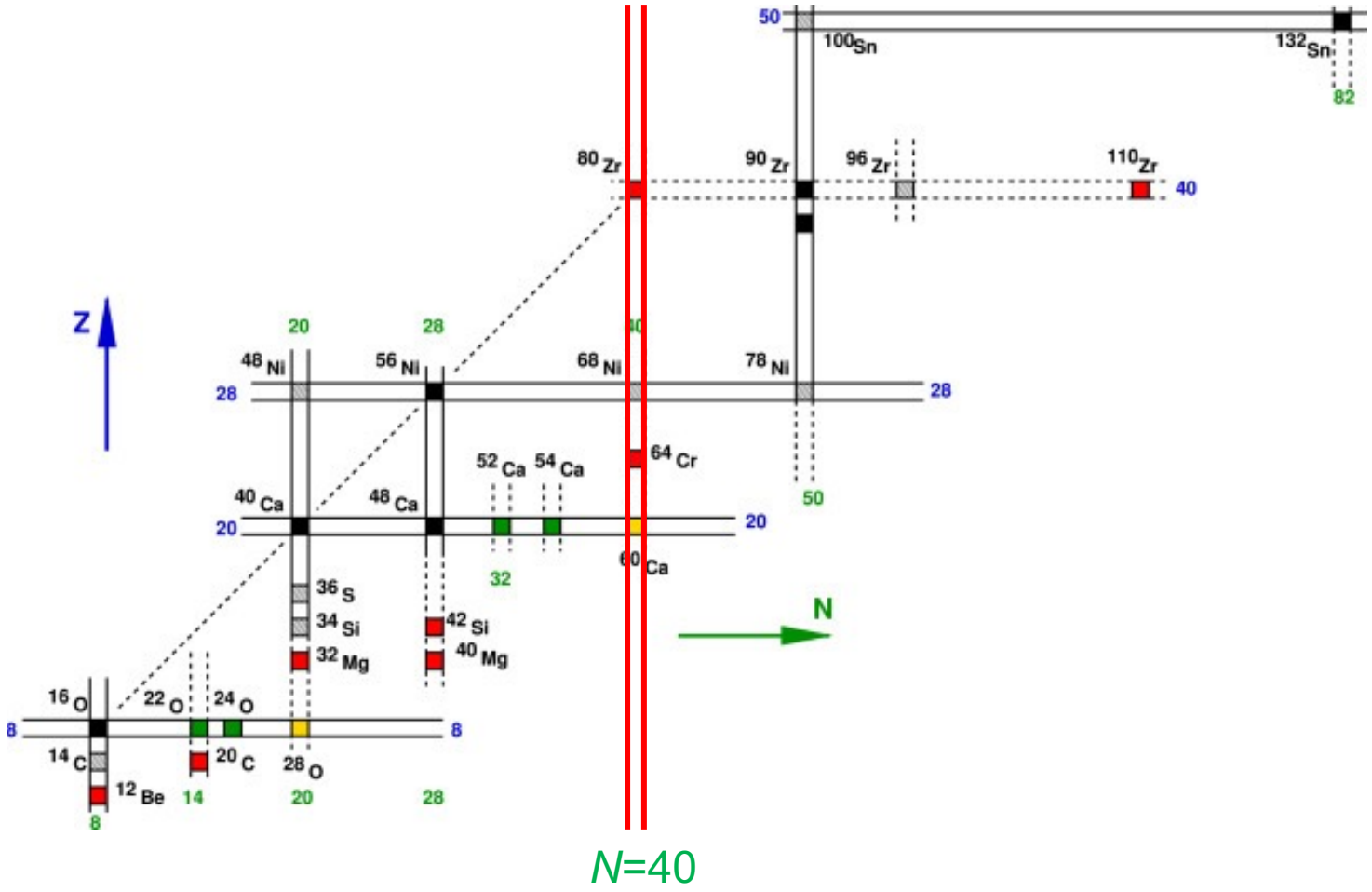
- Each nucleon moves independently in a mean-field describing the average interaction with the other nucleons
- Reproduces magic numbers obtained empirically



Kenneth S. Krane, Introductory Nuclear Physics (1988)
E. Caurier, G. Martínez-Pinedo, F. Nowacki, A. Poves, and A. P. Zuker. Rev. Mod. Phys. 77, 427 (2005)

Islands of Inversion

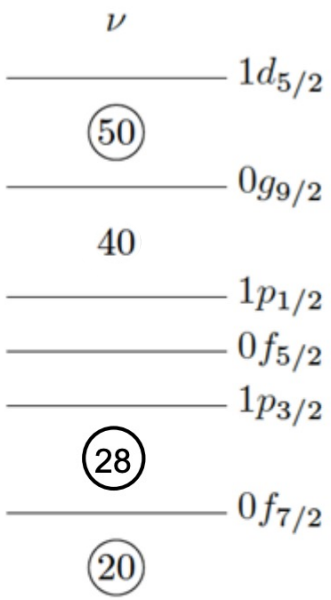
- Ground states dominated by deformed *n*p*n*h configurations instead of *0*p*0*h
- Shell and subshell closure features disappear
  - $E(2^+)$
  - $B(E2)$: Transition probability
- N=8, 14, 20, 28, 40: Archipelago of islands of shell breaking

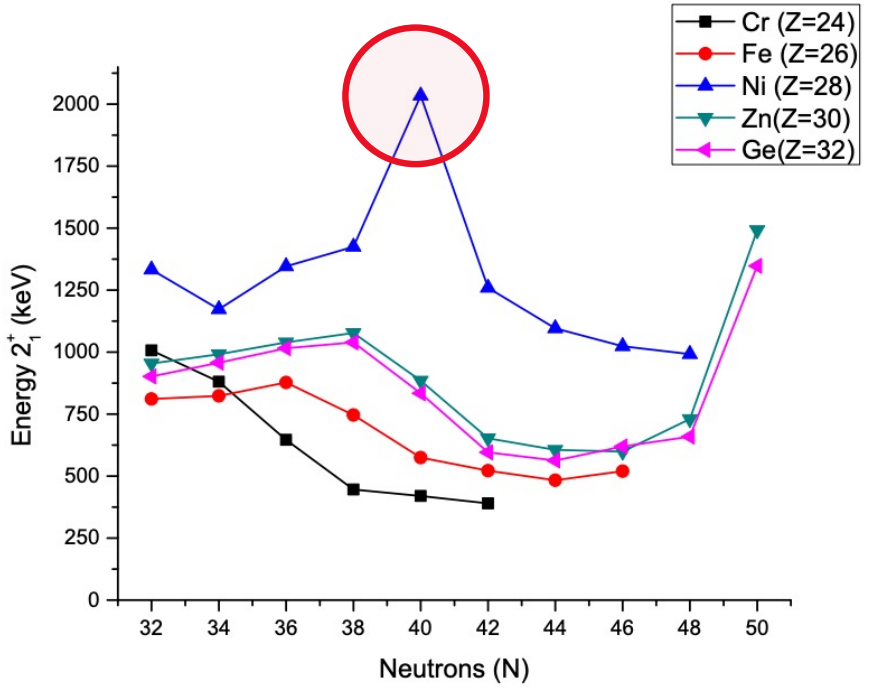


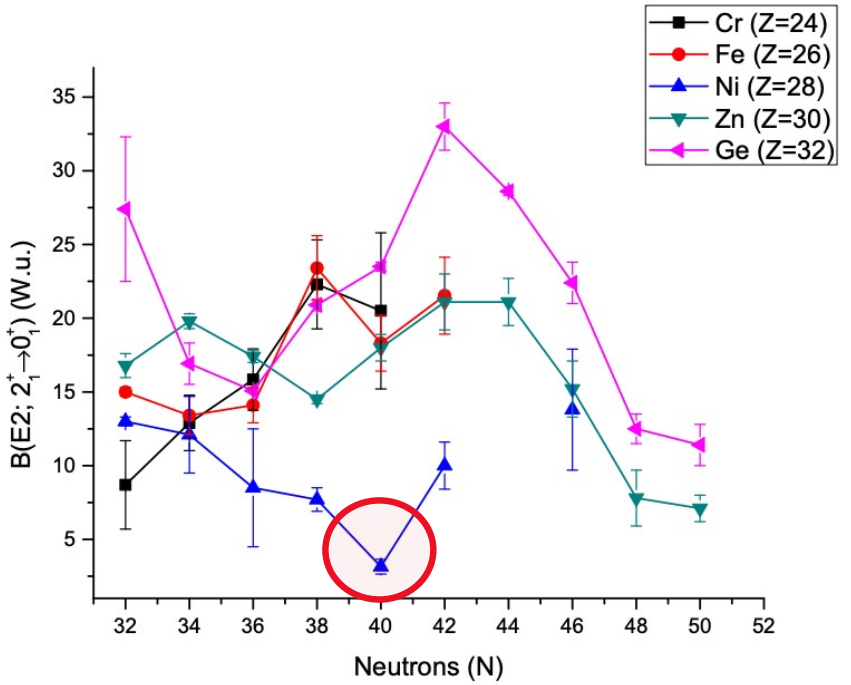
F. Nowacki, A. Obertelli, A. Poves. Progress in Particle and Nuclear Physics 120, 103866 (2021)

Suggested magicity of *N*=40

- Large energy gap between the *pf* shell and neutron $0g_{9/2}$ shell
- Sub-shell closure at *N*=40
- Evidenced by ^{68}Ni (*Z*=28):
  - Doubly magic behavior
  - Large $E(2^+)$ = 2.033 MeV
  - Small $B(E2; 0^+ \rightarrow 2^+)$ = 3.2 (7) W.u







However,

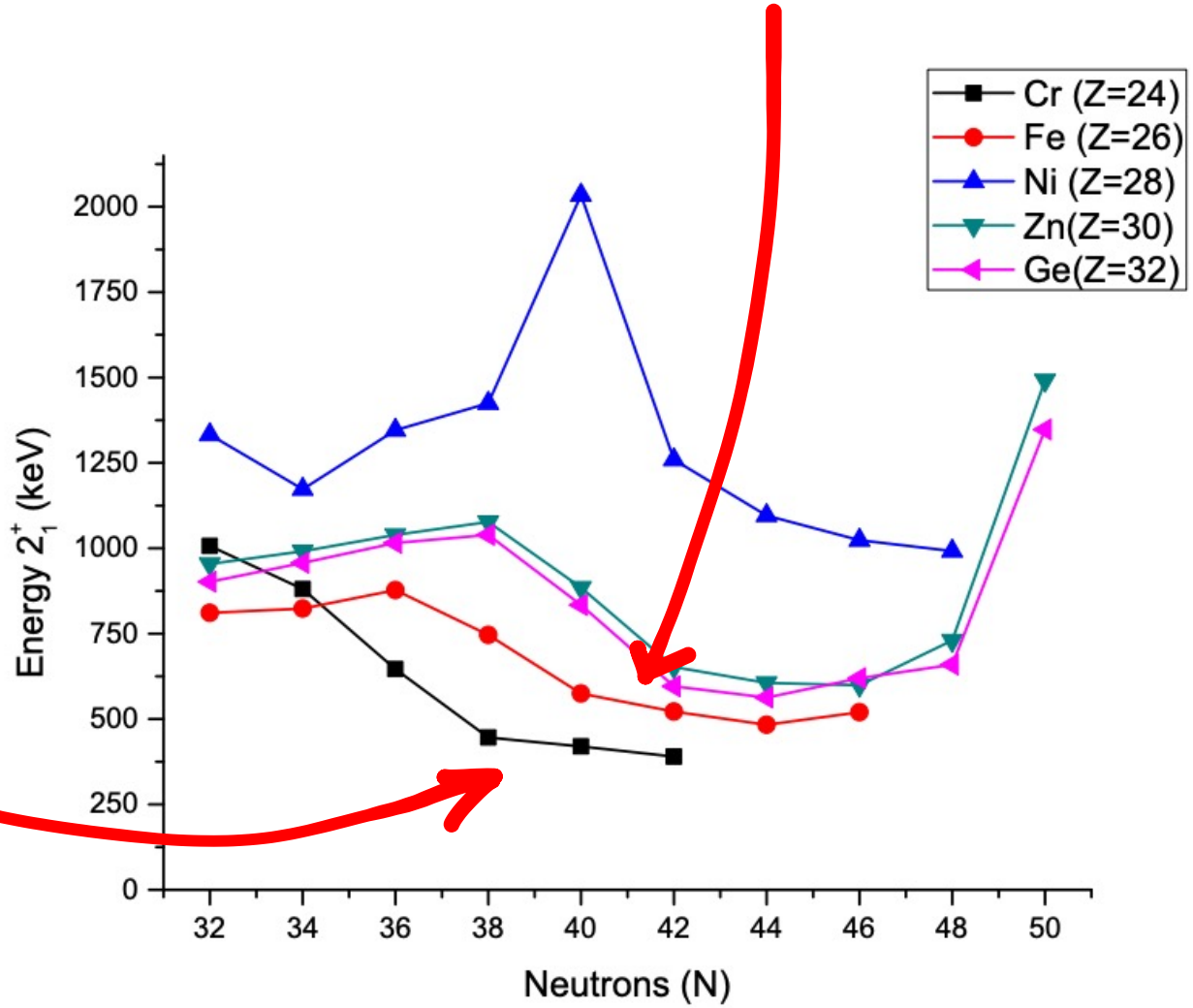
O. Sorlin et al., Phys. Rev. Lett. 88, 092501 (2002).

N=40 Island of Inversion

Energy of the 2_1^+ state changes from 2033 keV in ^{68}Ni to 573 and 517 keV in ^{66}Fe and ^{68}Fe, respectively

- Systematics indicate a sudden increase in collectivity around *N*=40 and *Z*<28

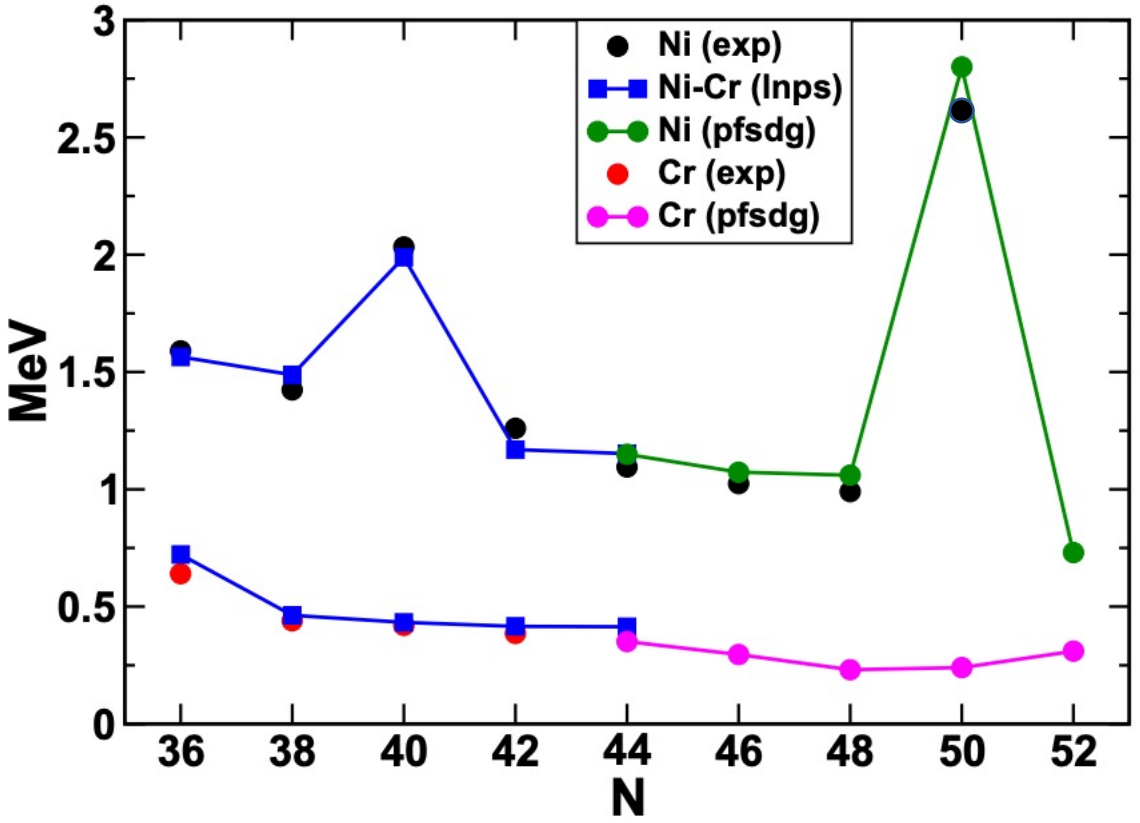
Cr isotopes: 2_1^+ energies decrease gradually beyond *N*=32 with lowest $E(2_1^+)$ measured at 390 keV for ^{66}Cr



C. Santamaria et al. Phys. Rev. Lett.115 (2015)
S. Naimi et al. Phys. Rev. C 86 (2012)

Merging the *N*=40 and *N*=50 Islands of Inversion

- Suggested extension of the island of inversion at *N*=40 for more neutron-rich isotopes towards *N*=50
- Supported by large-scale shell-model calculations using the PFSDG-U interaction
- Spectroscopic information required to understand this bridge

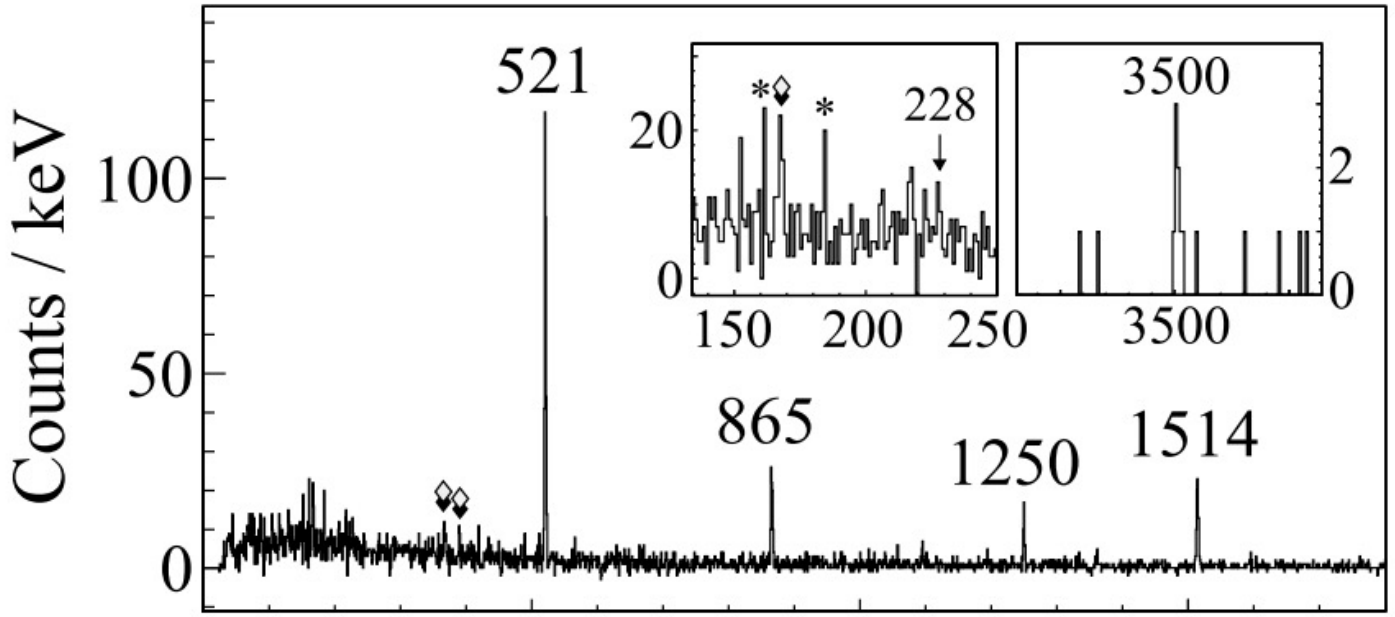


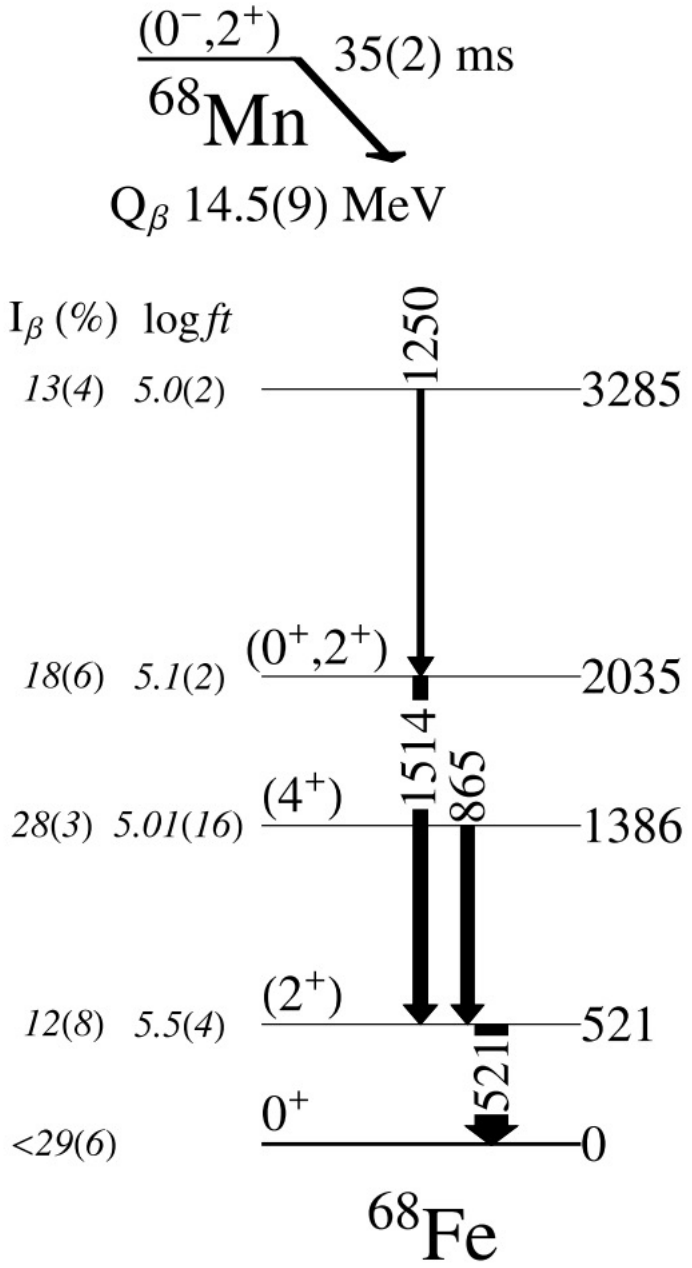
2^+ energy systematics in Ni and Cr isotopic chains

Santamaria, et al., PRL 115, 192501 (2015)
Nowacki, et al., PRL 117, 272501 (2016)
Taniuchi, R., Santamaria, C., Doornenbal, P. et al. *Nature* 569, 53–58 (2019)

Existing Literature

- ^{68}Fe populated through β-decay of ^{68}Mn
- Preliminary level scheme
- Tentative spin-parity assignments for (2^+) and (4^+) states in ^{68}Fe
- 2035 keV level assigned either (0^+) or (2^+)

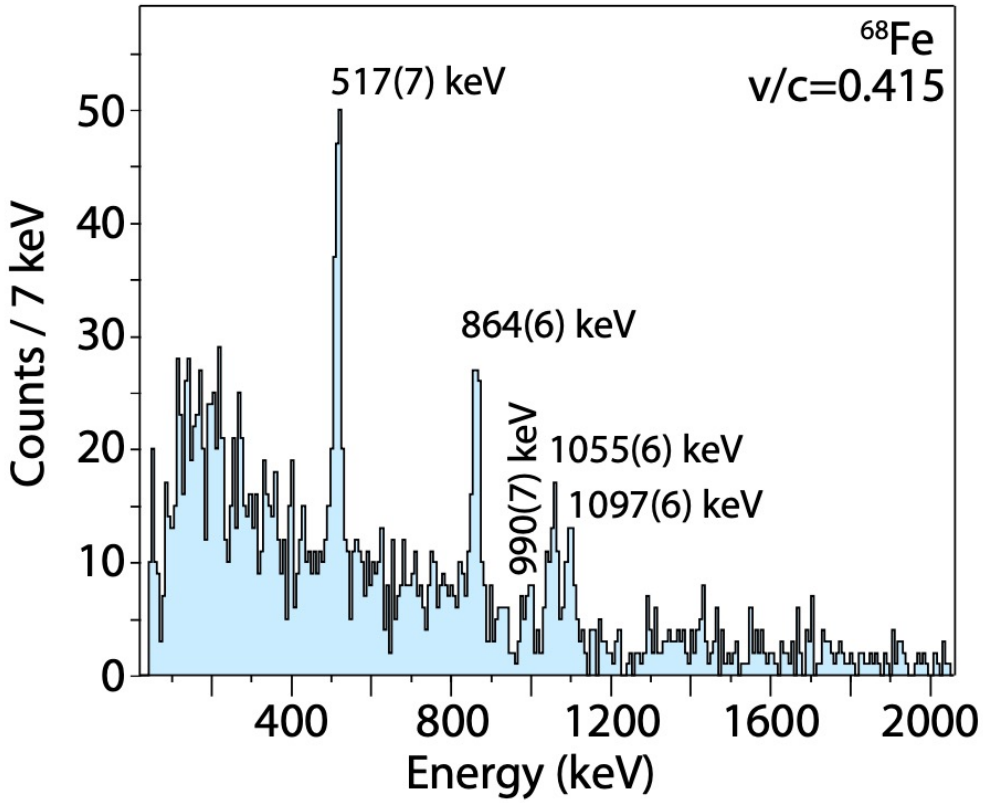


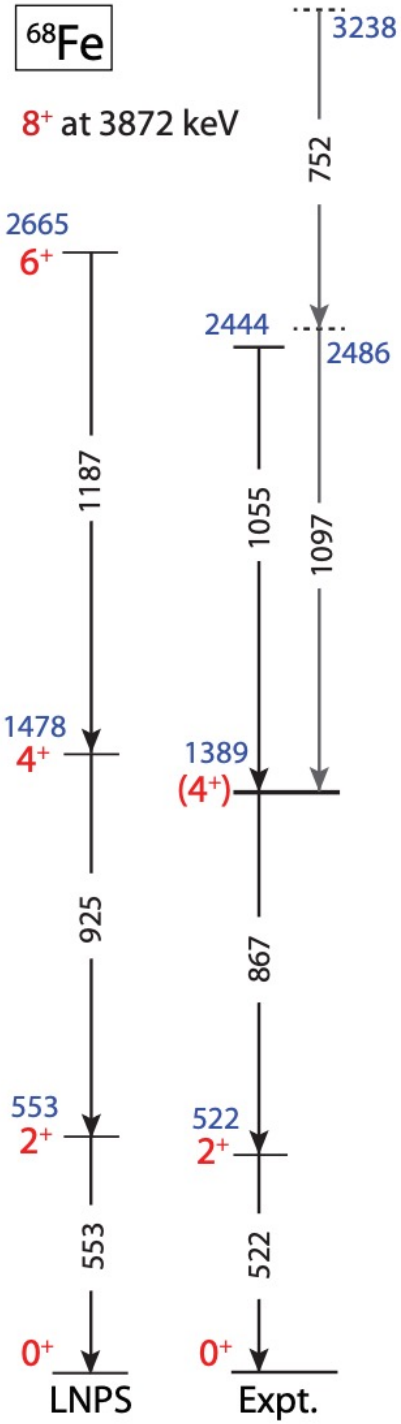


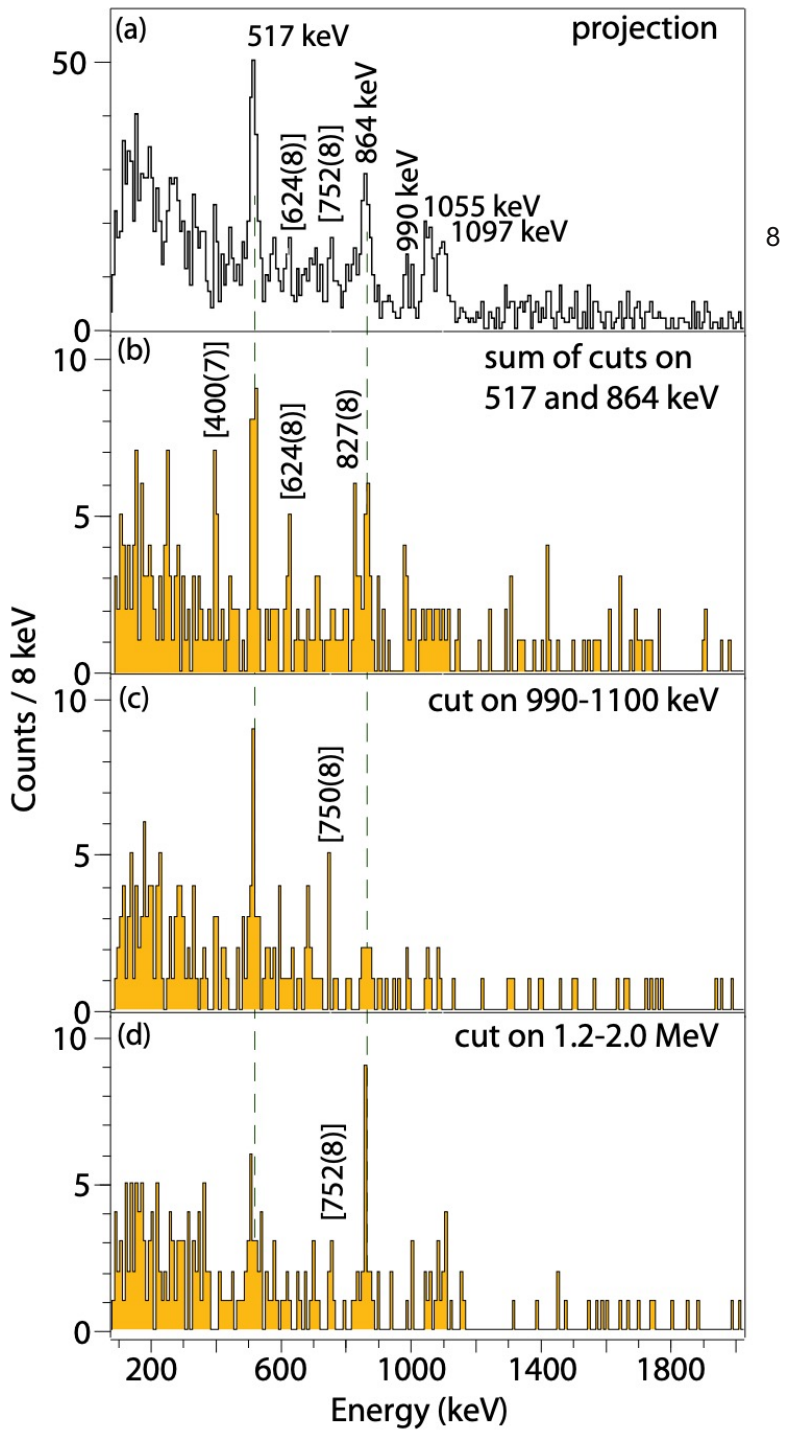
G. Benzoni, et al. Physics Letters B, 751:107–112 (2015).

Existing Literature

- Populated using a ^{9}Be(^{68}Co, ^{68}Fe + γ)X charge-exchange reaction
- Expansion of level scheme through coincidence analysis



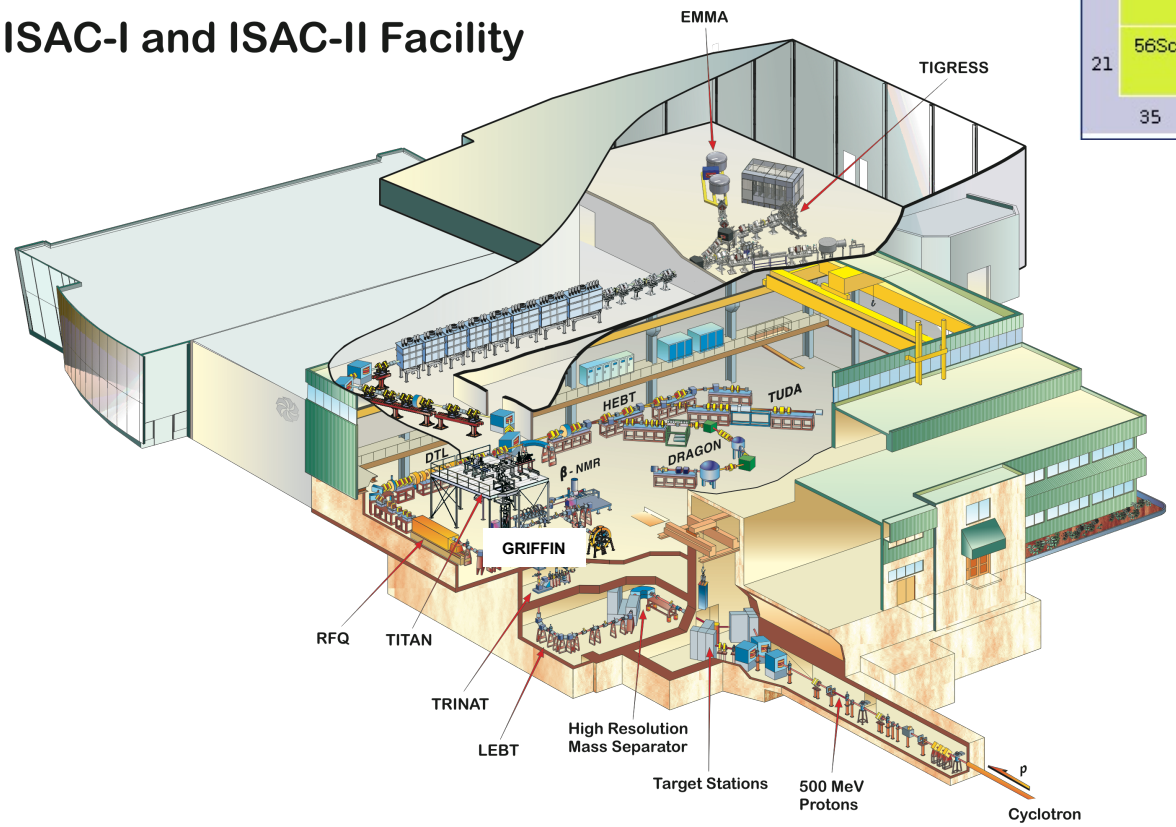


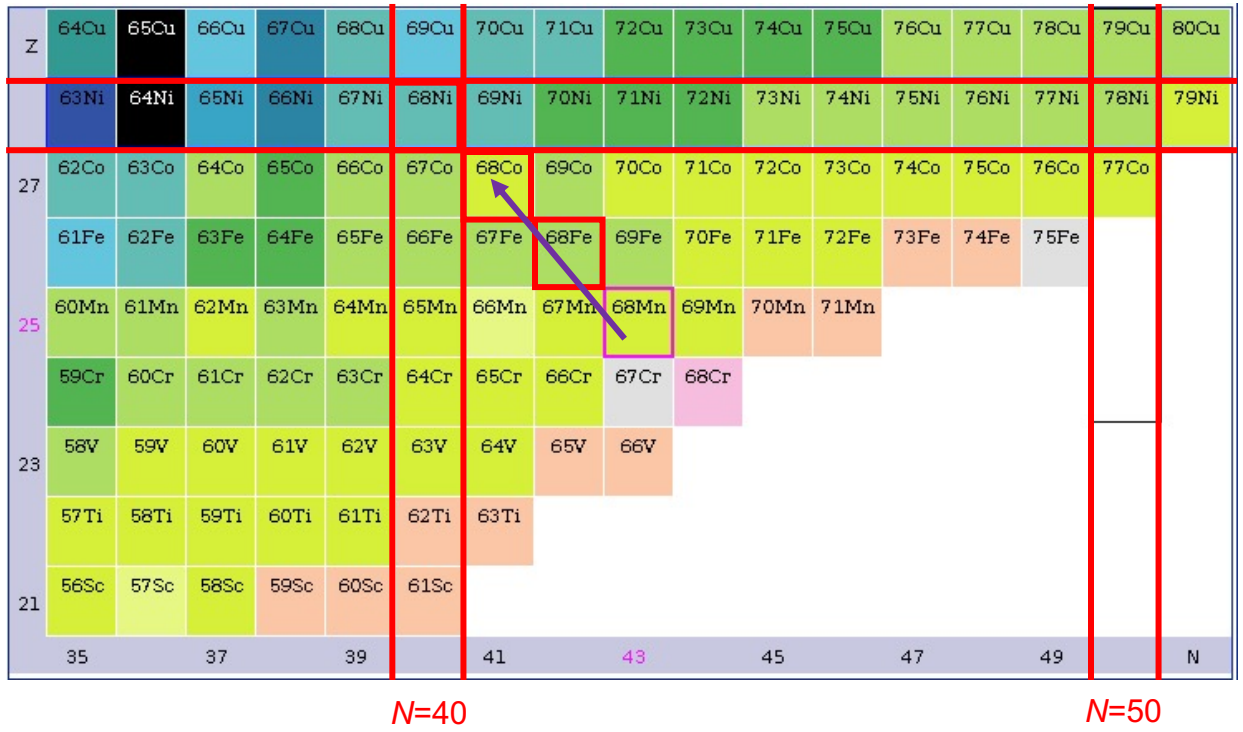


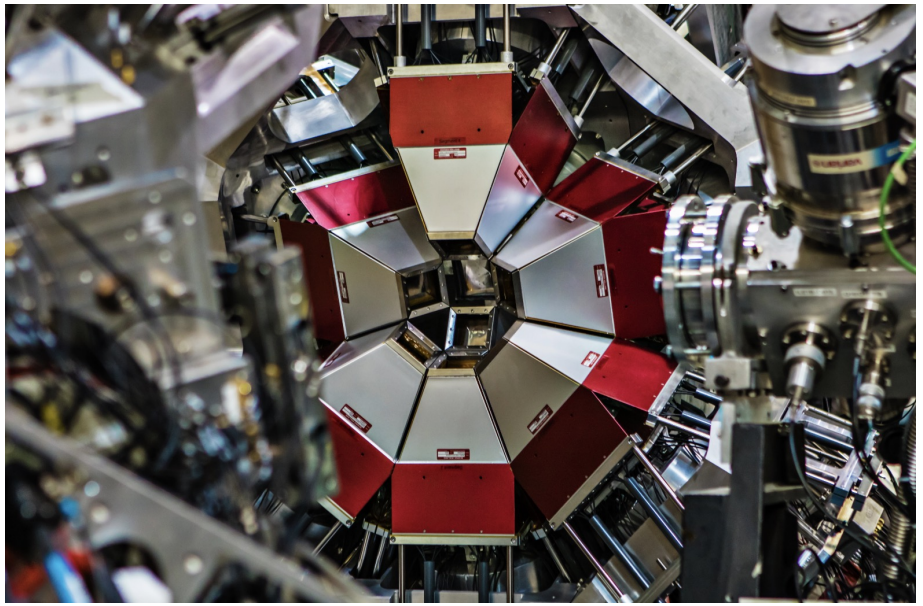
A. Gade, et al. Phys. Rev. C. 104,0243 (2021) 31

Experimental Setup

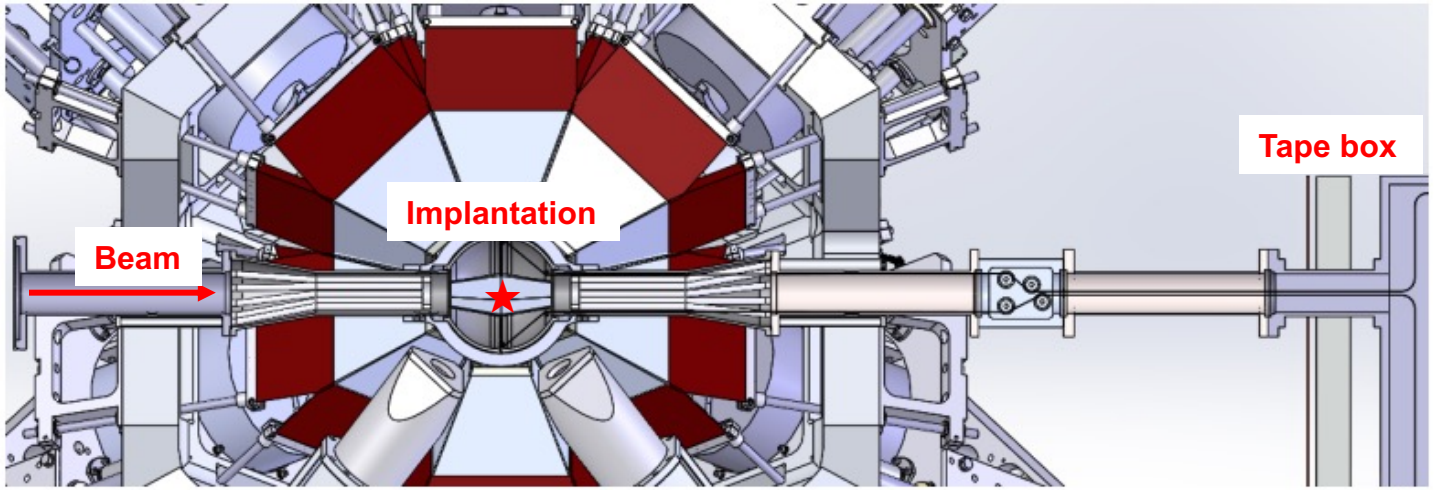
- S1723 at TRIUMF, Vancouver
- β-decay of ^{68}Mn

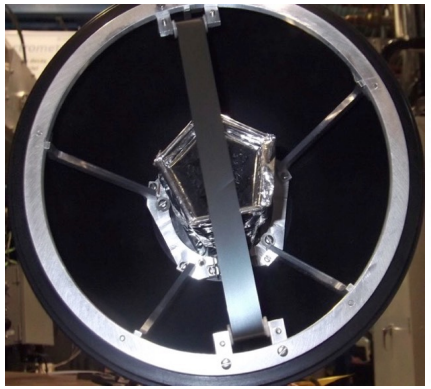




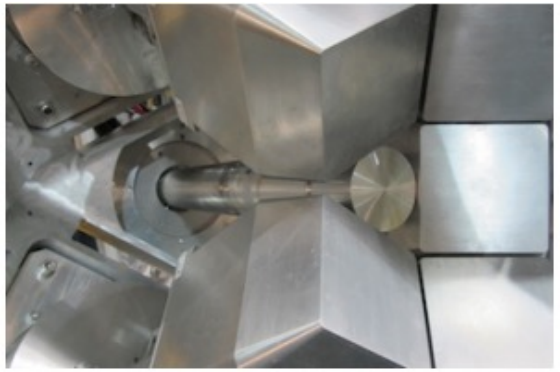


Experimental Setup

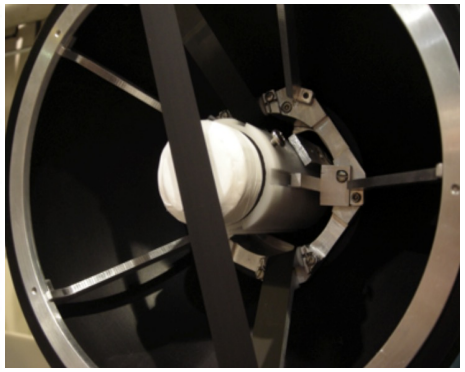




SCEPTAR



$LaBr_3(Ce)$



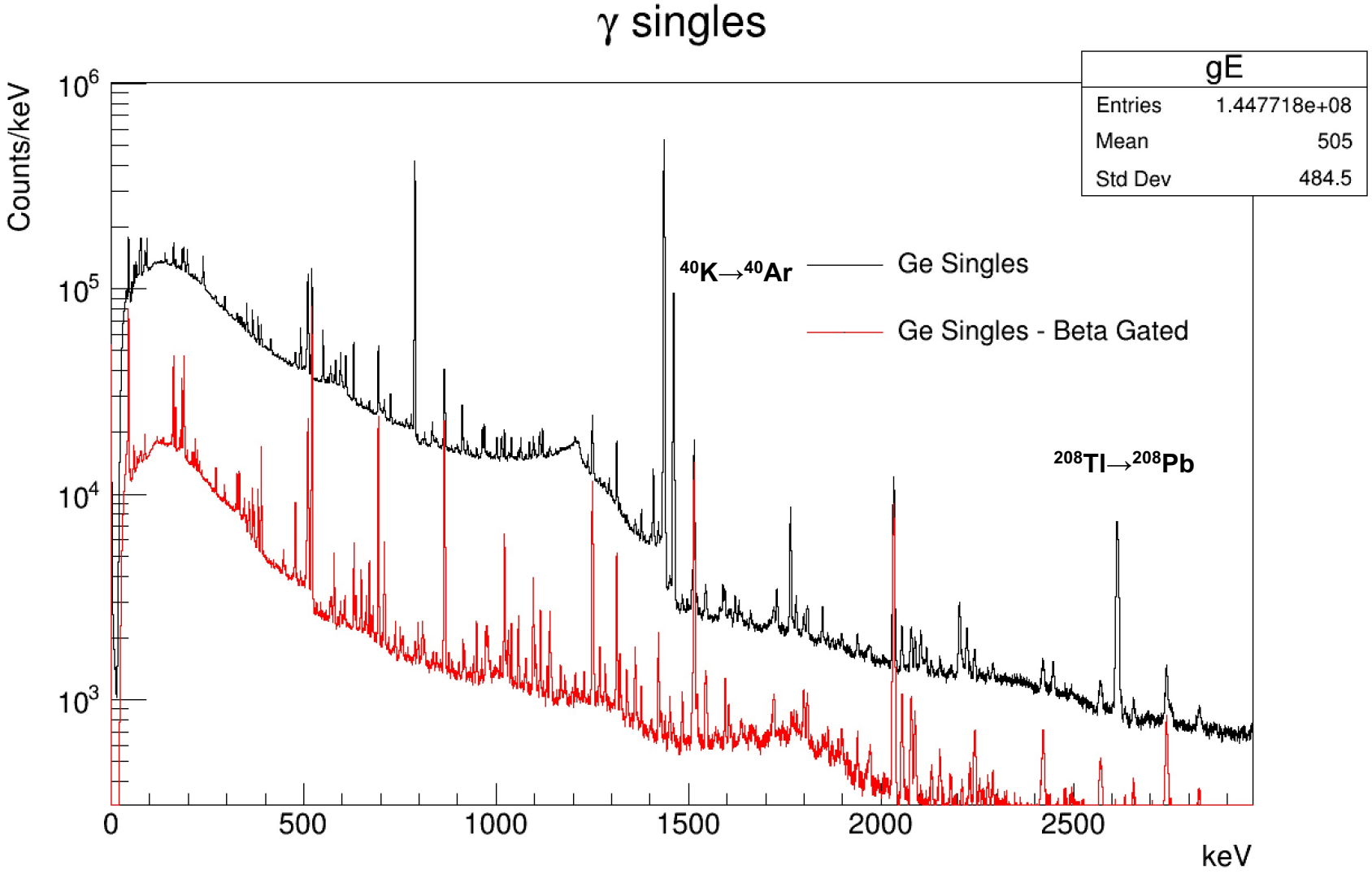
ZDS

- 16 BGO Suppressed HPGe clovers
  - 15% efficiency at 1332 keV
  - 4096 crystal pairs at 52 unique angles for γ-γ angular correlation studies
- SCEPTAR and ZDS
  - β tagging scintillators
- 8 BGO Suppressed $LaBr_3(Ce)$
  - Lifetime measurements via fast-timing techniques

A.B. Garnsworthy et al. Nucl. Inst. Meths. A 918, 9 (2019)

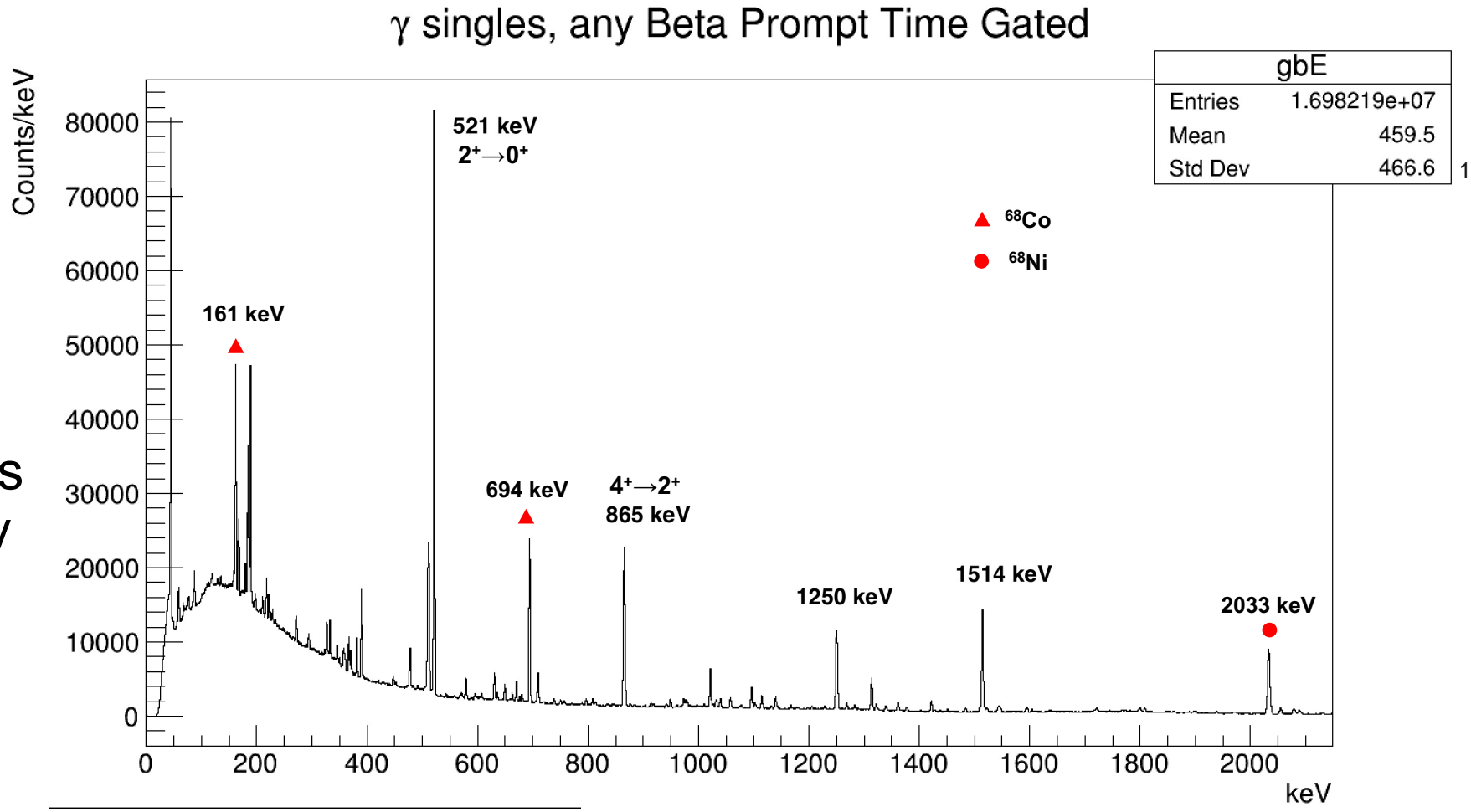
Analysis

- ~50 hours of beam at ~20 pps → x10^5 more statistics than Benzoni et al.
- β-tagging reduces room background



Analysis

- Confirm γ-ray energies from previous β-decay studies
- Plenty of new γ lines



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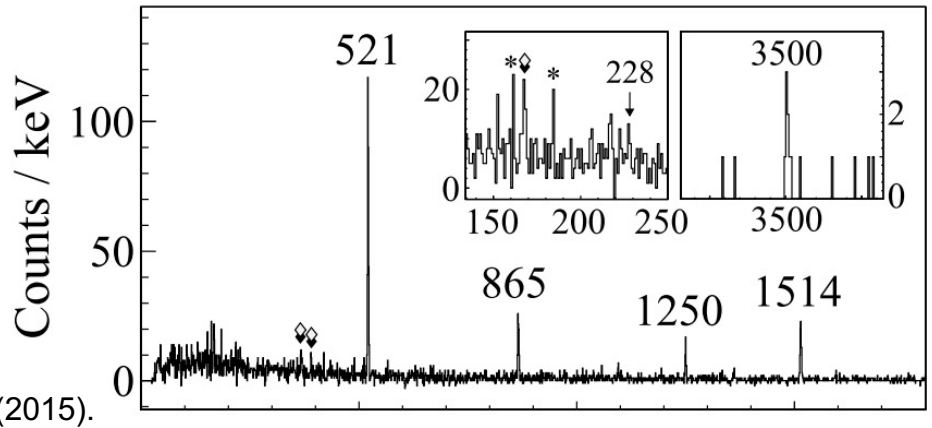
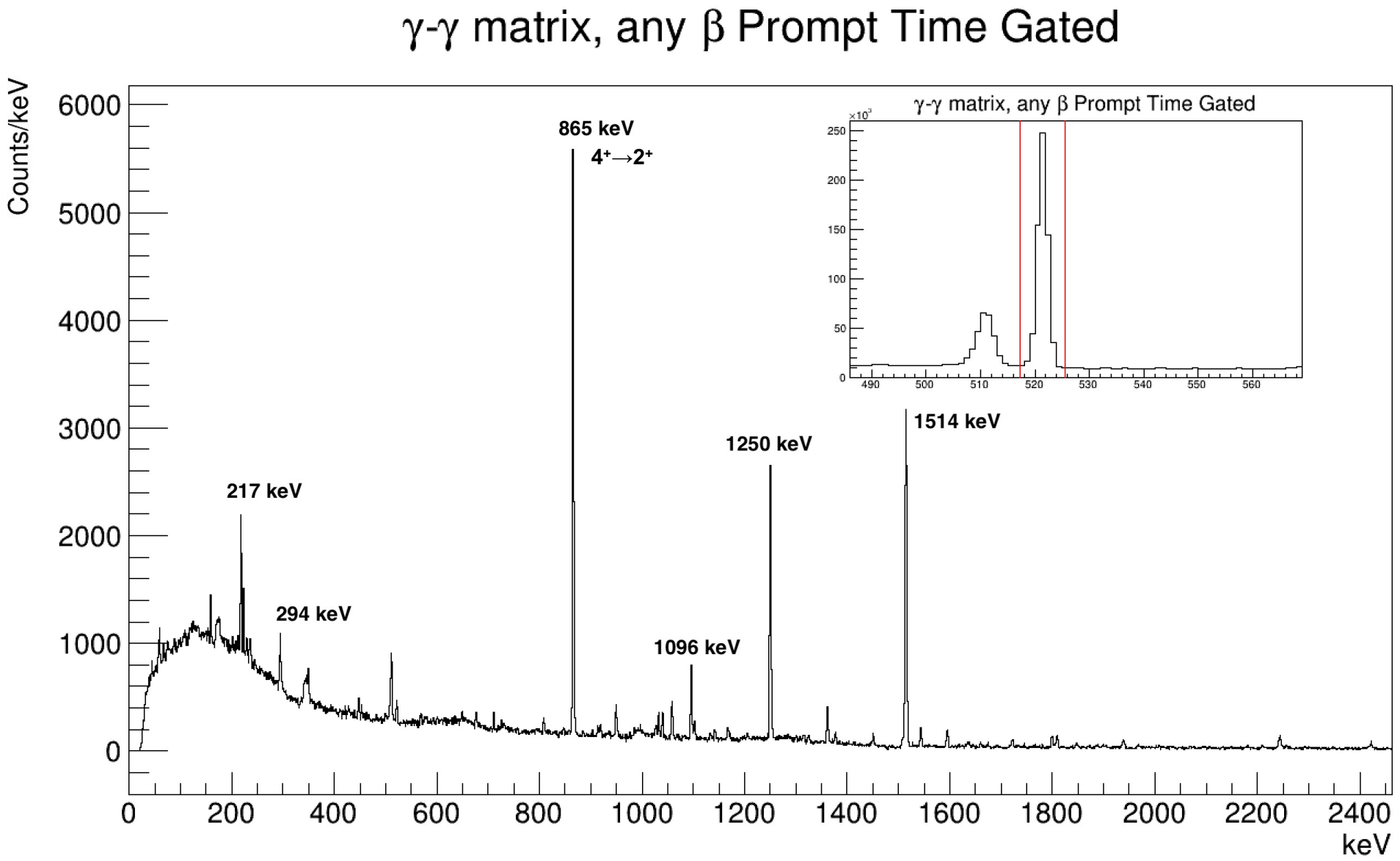
$^{68}Mn \rightarrow {}^{68}Fe$		
E_γ [keV]	I_{rel} [%]	Coincidences
228.5*	3(2)	521, 1514
521	100(10)	865, 1250, 1514
865	38(7)	521
1250	16(6)	228.5, 521
1514	46(8)	521, 1250
3500*	11(3)	



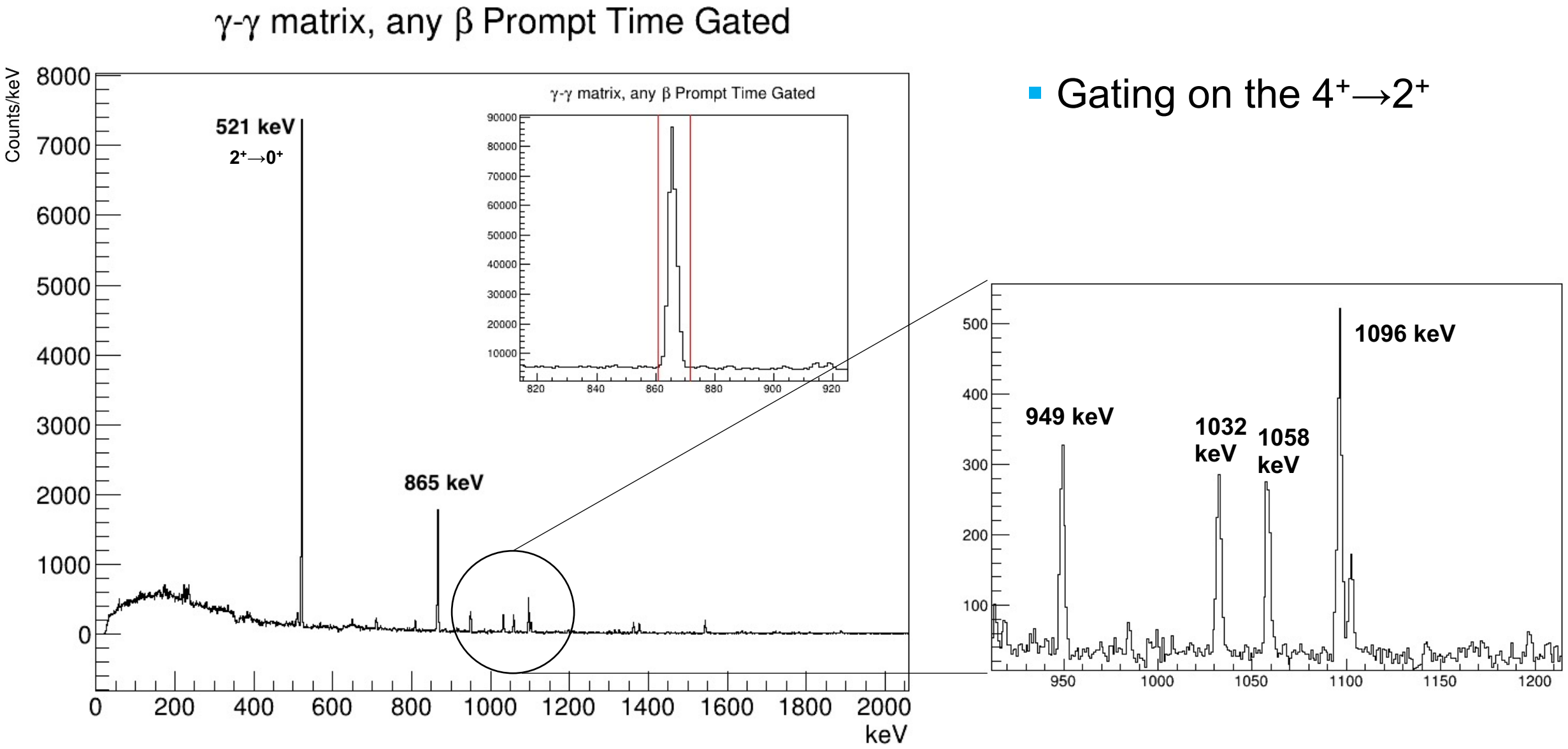
G. Benzoni, et al. Physics Letters B, 751:107–112 (2015).

Coincidence Analysis

- Gating on the most intense transition ($2^+ \rightarrow 0^+$)



Coincidence Analysis



- Gating on the $4^+ \rightarrow 2^+$

Future Work

- Complete the analysis
  - Expand level scheme
  - Firm spin assignments through angular correlation analysis
  - Lifetime measurements
- Full decay chain analysis (^{68}Co, ^{68}Ni, ^{67}Fe, ^{67}Co, ^{67}Ni)
- Further insight into the nuclear structure in/around *N*=40 and study its connection with *N*=50 IoI

Thank you
Merci

R. Umashankar[1,2], B. Olaizola[3], V. Vedia[1], A.B. Garnsworthy[1], C. Andreoiu[4], G.C. Ball[1], S.S. Bhattacharjee[5], S. Buck[6], R. Caballero-Folch[1], I. Dillman[1], E. Dunling[1], E.G. Fuakye[4], F.H. Garcia[4], P.E. Garrett[6], S. Georges[1], C. Griffin[1], G. Grinyer[7], G. Hackman[1], K. Kapoor[7], G. Leckenby[1,2], R.S. Lubna[1], M. Martin[4], C. Natzke[8], M. Rocchini[6], N. Saei[7], Y. Saito[1,2], M. Satrazani[9], D. Shah[7], J. Smallcombe[9], P. Spagnoletti[4], C.E. Svensson[6], D. Yates[1,2], T. Zidar[6]

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Discovery, accelerated