Addendum to IS587:

Characterising excited states in and around the semi-magic nucleus ^{68}Ni using Coulomb excitation and one-neutron transfer

Spokespersons:

Liam Gaffney *– University of the West of Scotland, UK*

Piet Van Duppen – KU Leuven, Belgium

Freddy Flavigny – IPN Orsay, France

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Kay Kolos – Lawrence Livermore Nat. Lab., USA

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ACCEPTED

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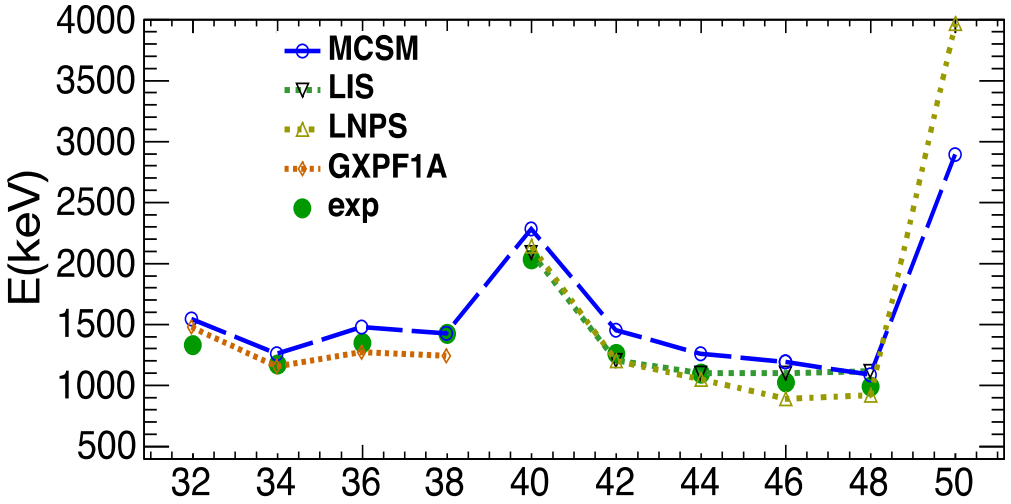
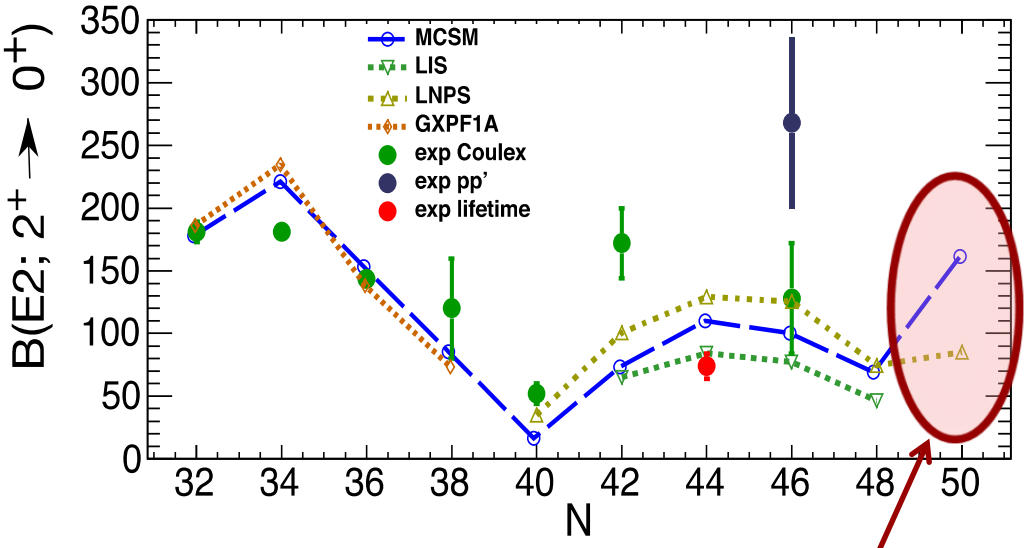
^{68}Ni and *N*=40

- Low B(E2) + high E(2^+_1)…
  - Indicator of subshell closure.
- Shell model theory reproduces general trend, but interpretations differ.
- Do we understand N=40?
  - Electromagnetic properties more revealing of structure.
  - Low precision B(E2) values at N=38 and N=42; i.e ^{66,70}Ni.



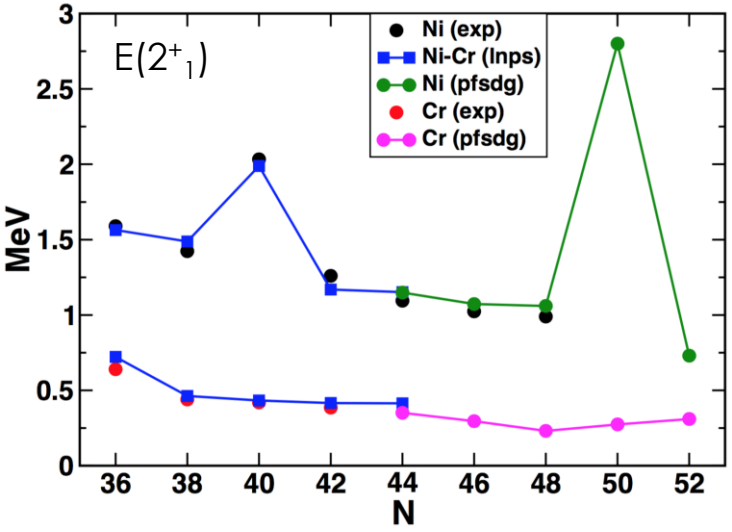


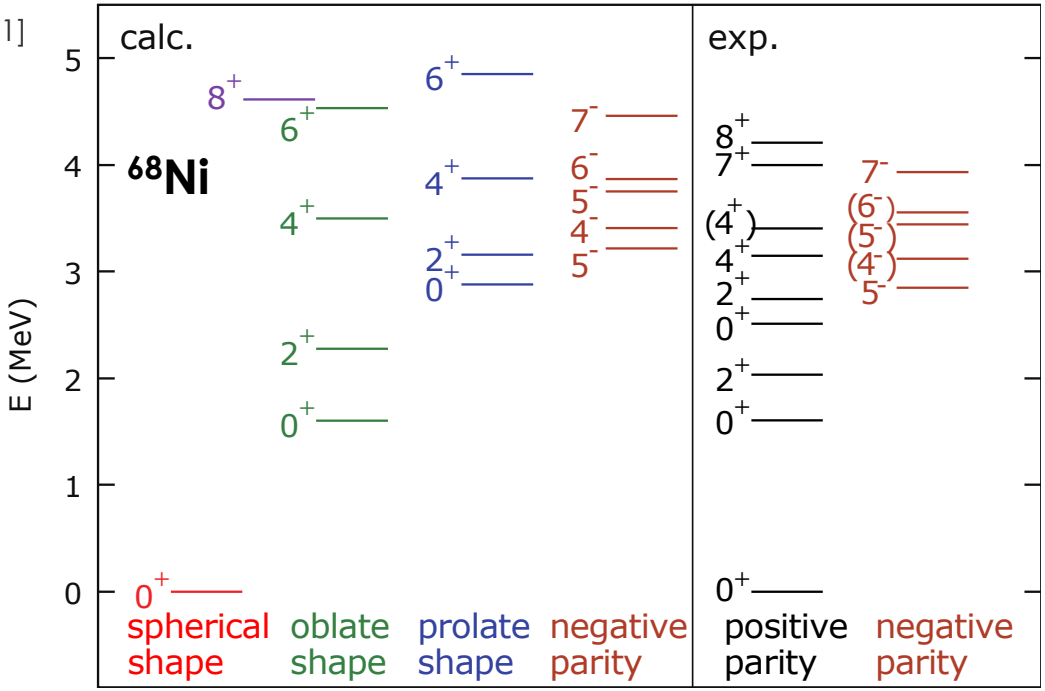
Divergence of theories at ^{78}Ni!

K. Kolos et al., Phys. Rev. Lett. 116, 122502 (2016)

Shell model calculations

- Monte-Carlo Shell Model (MCSM)[1]
- Interpreted as "Type-II" shape coexistence.
  - Intruder structures:
    - Oblate and prolate
  - Detailed EM properties – testable!



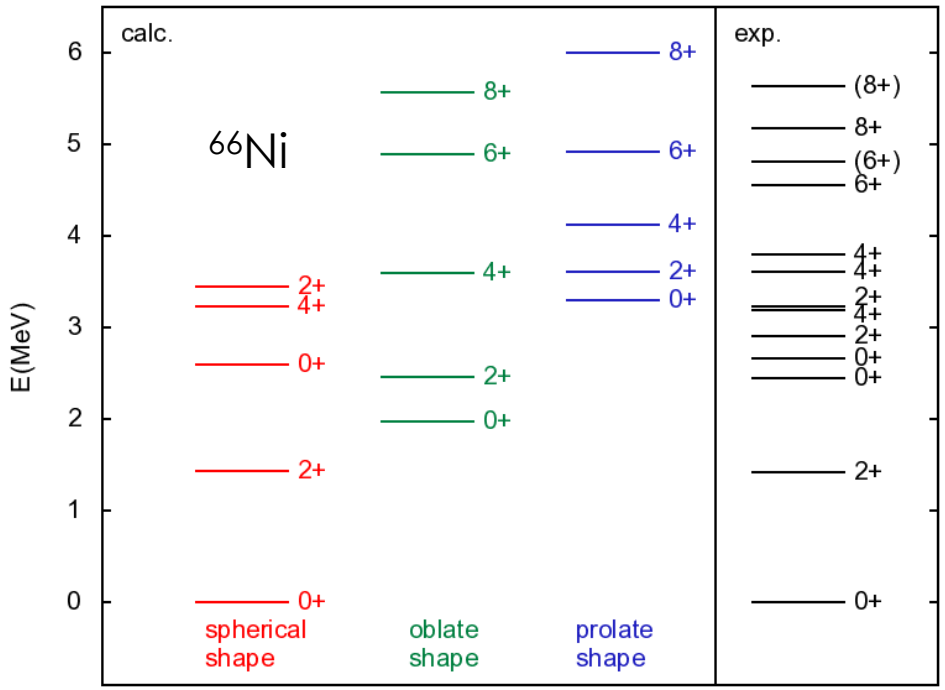


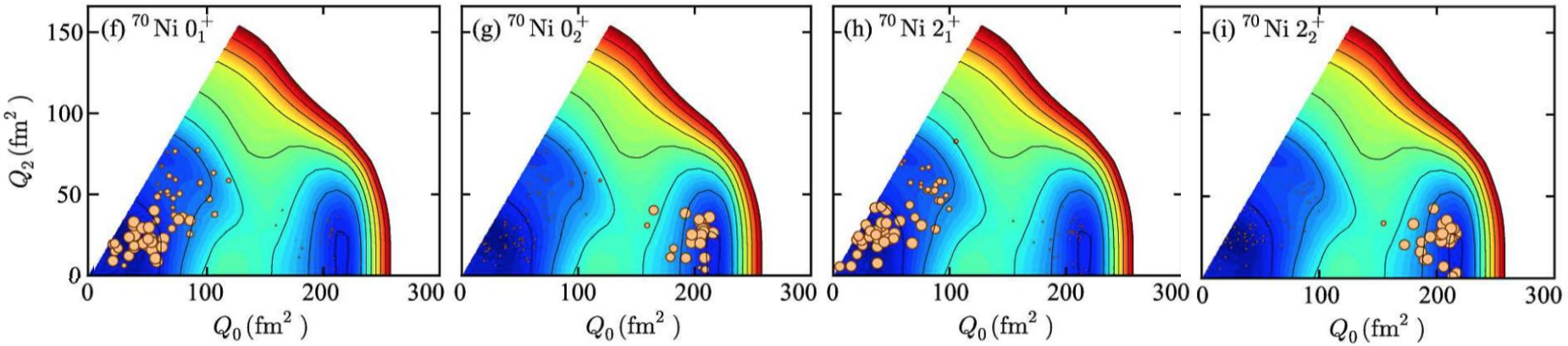
- LNPS[2] & pfsdg[3] – new "island of inversion":
  - Originally ^{64}Cr/^{68}Ni and similarly about ^{74}Cr/^{78}Ni[3].
    - Precision data near N=40 → extrapolate reliably to N=50!

[1] Y. Tsunoda et al., Phys. Rev. C 89, 031301 (2014)
[2] S.M. Lenzi, F. Nowacki, A. Poves, and K. Sieja, Phys. Rev. C 82, 054301 (2010)
[3] F. Nowacki, A. Poves, E. Caurier, and B. Bounthong, arXiv preprint arXiv:1605.05103 (2016)

MCSM extended to ^{66}Ni and ^{70}Ni

- Similar prolate and oblate intruder configurations.
- Characterisation can only come from electromagnetic properties → B(E2) and Q_s.
- Previous description of large B(E2) in ^{70}Ni – core polarisation[2].





[1] Y. Tsunoda et al., Phys. Rev. C 89, 031301 (2014)
[2] O. Perru et al., Phys. Rev. Lett. 96, 232501 (2006)

INTC response to original proposal

- The Committee finds points (i) and (ii) not urgent, since newer measurements on ^{70}Ni and ^{72}Ni have been made at NSCL@MSU but not yet published. It might be therefore prudent to wait for these results before approving this part of the experiment.

- The use of multiple Coulex, which will explore shape coexistence and compare the transition probabilities with large-scale shell model calculations, is complex in the experiment and particularly in the analysis. This makes this also less urgent and it would benefit from the successful completion of the other measurement proposed in ^{68}Ni at this INTC meeting.

^{72}Ni now published

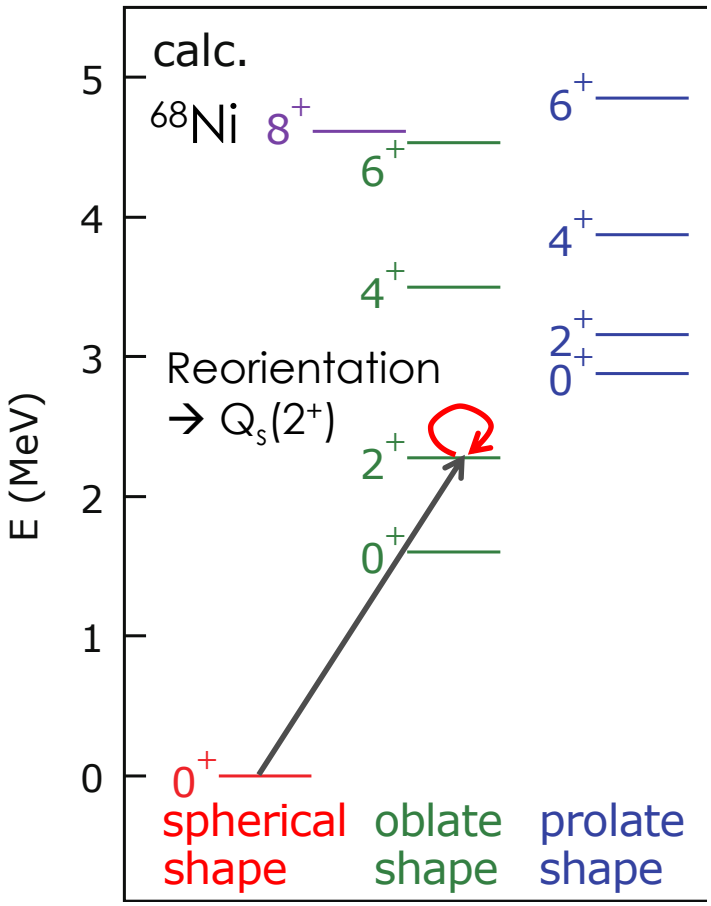
^{70}Ni difficult analysis ongoing

Simplified experimental procedure

^{68}Mn→ ^{68}Ni β decay completed

Complementary experiments

- ^{68}Mn → ^{68}Ni beta-decay @ ISODLE Decay Station[1]
  - No B(E2) values.
- Intermediate energy Coulex @ GANIL[2] (^{66,68}Ni) and NSCL[3] (^{74}Ni)
  - Potential unobserved feeding.
  - Low precision and inconsistent with SM.
- RDDS lifetimes at NSCL[4]
  - Direct τ in ^{72}Ni, but ^{70}Ni data imprecise.



[1] C. Sotty et al., IS590, to be published
[2] O. Sorlin et al., Phys. Rev. Lett. 88, 092501 (2002)
[3] T. Marchi et al., Phys. Rev. Lett. 113, 182501 (2014)
[4] K. Kolos et al., Phys. Rev. Lett. 116, 122502 (2016)

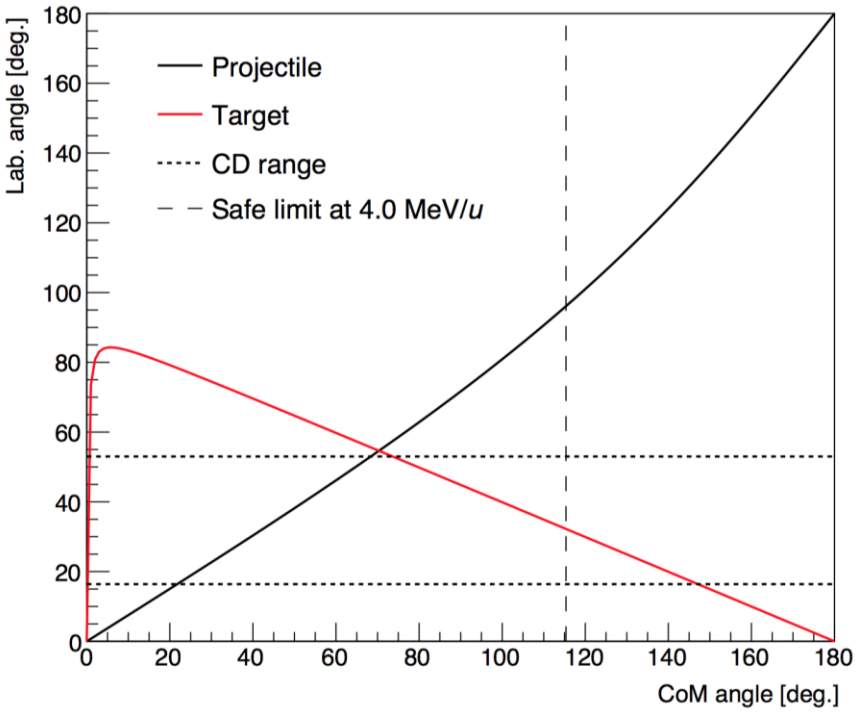
Experimental setup - Miniball

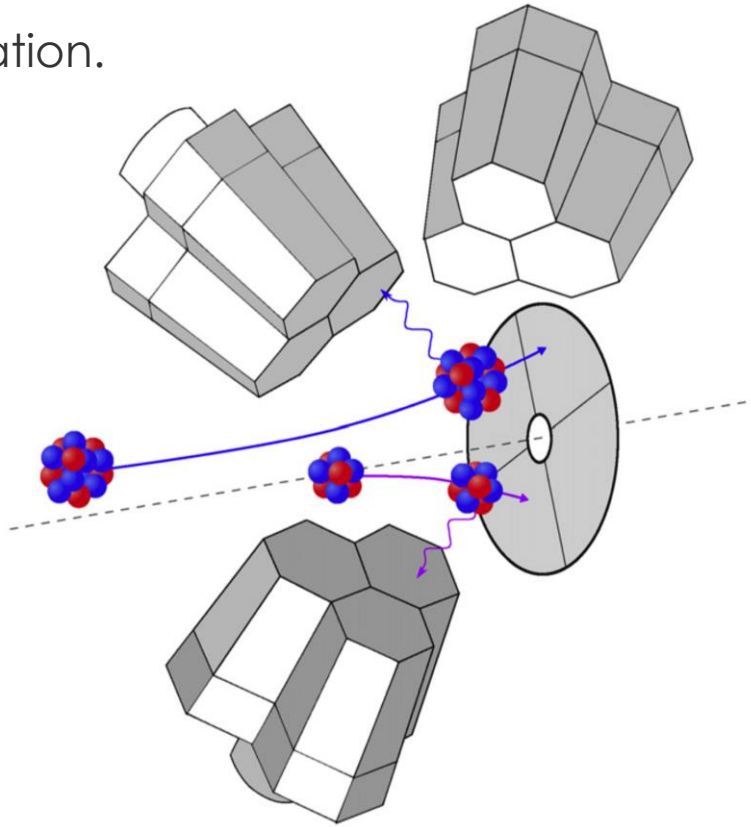
- Miniball Ge array coupled to either T-REX chamber or CD+SPEDE → Flexibility.
- Angular coverage ~17˚-55˚ → Optimum kinematics for CoM coverage.
- Ionisation chamber can monitor contamination.

^{206}Pb(^{66}**Ni**) @ 4.0 MeV/*u*

^{206}Pb(^{68}**Ni**) @ 4.0 MeV/*u*

^{206}Pb(^{70}**Ni**) @ 3.5 MeV/*u*





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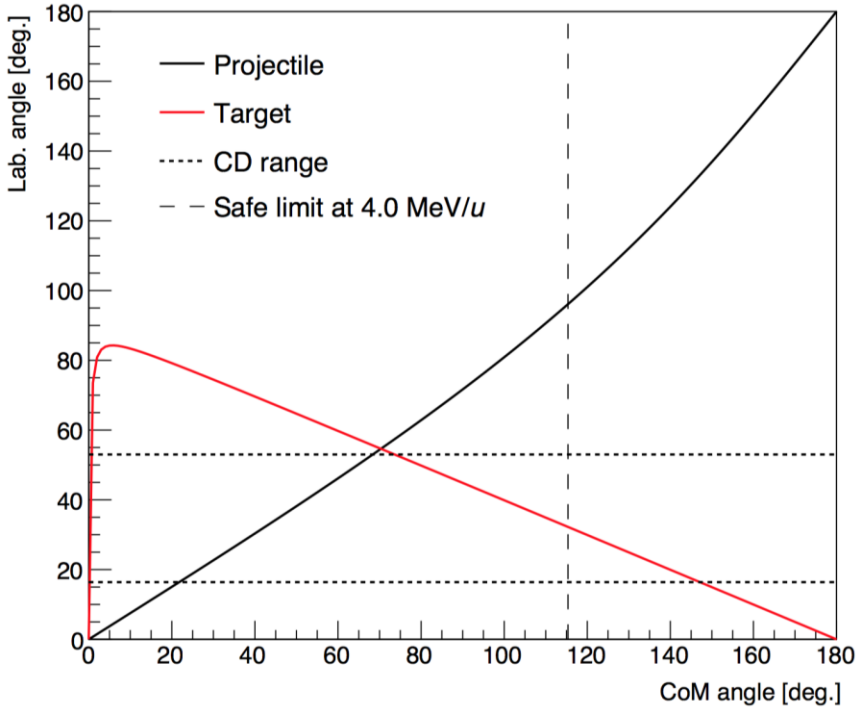
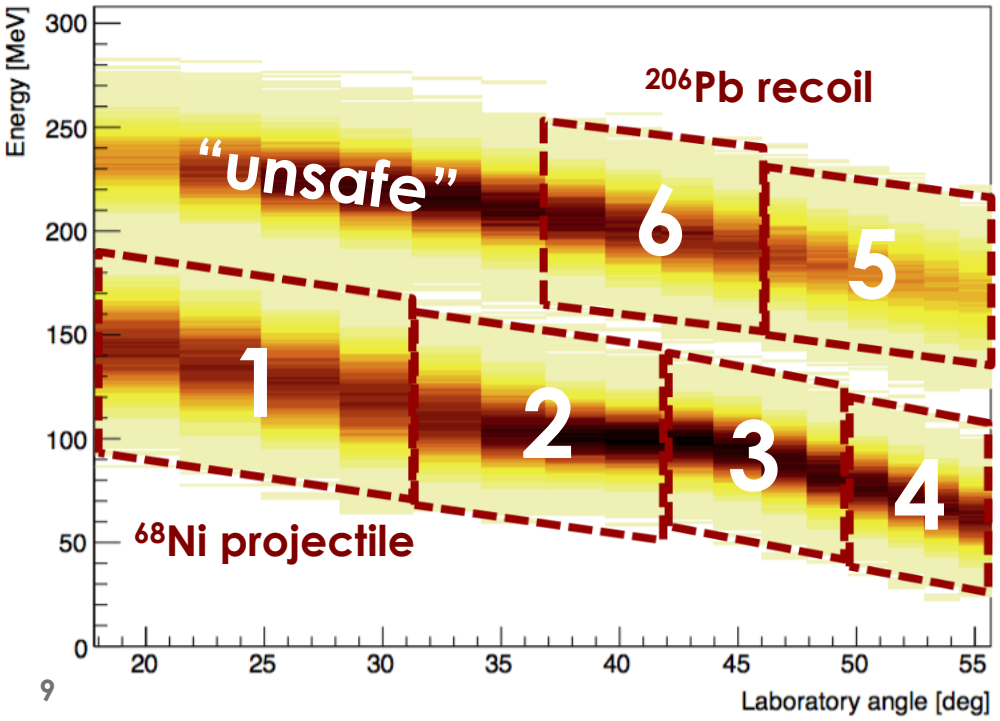
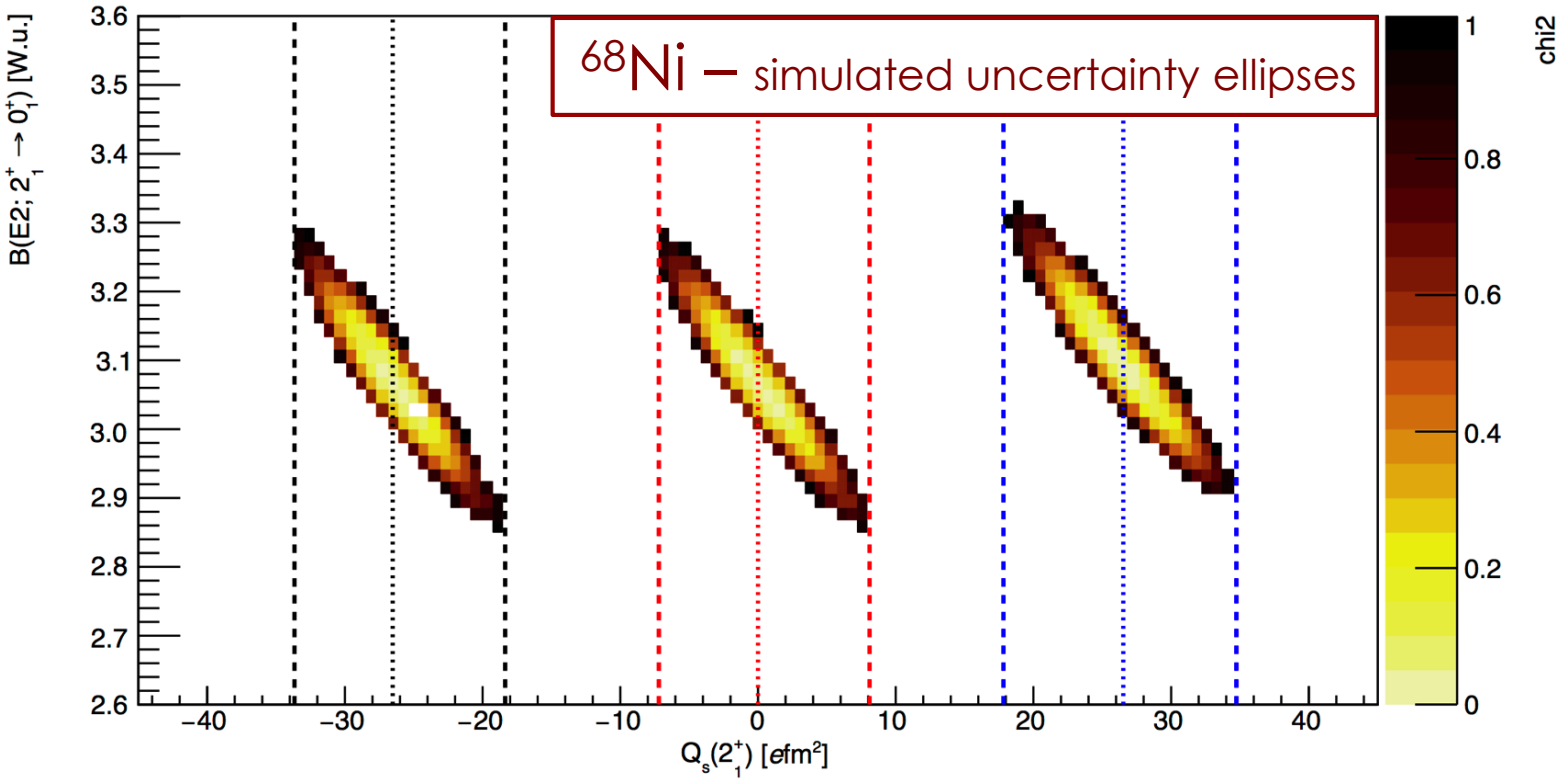




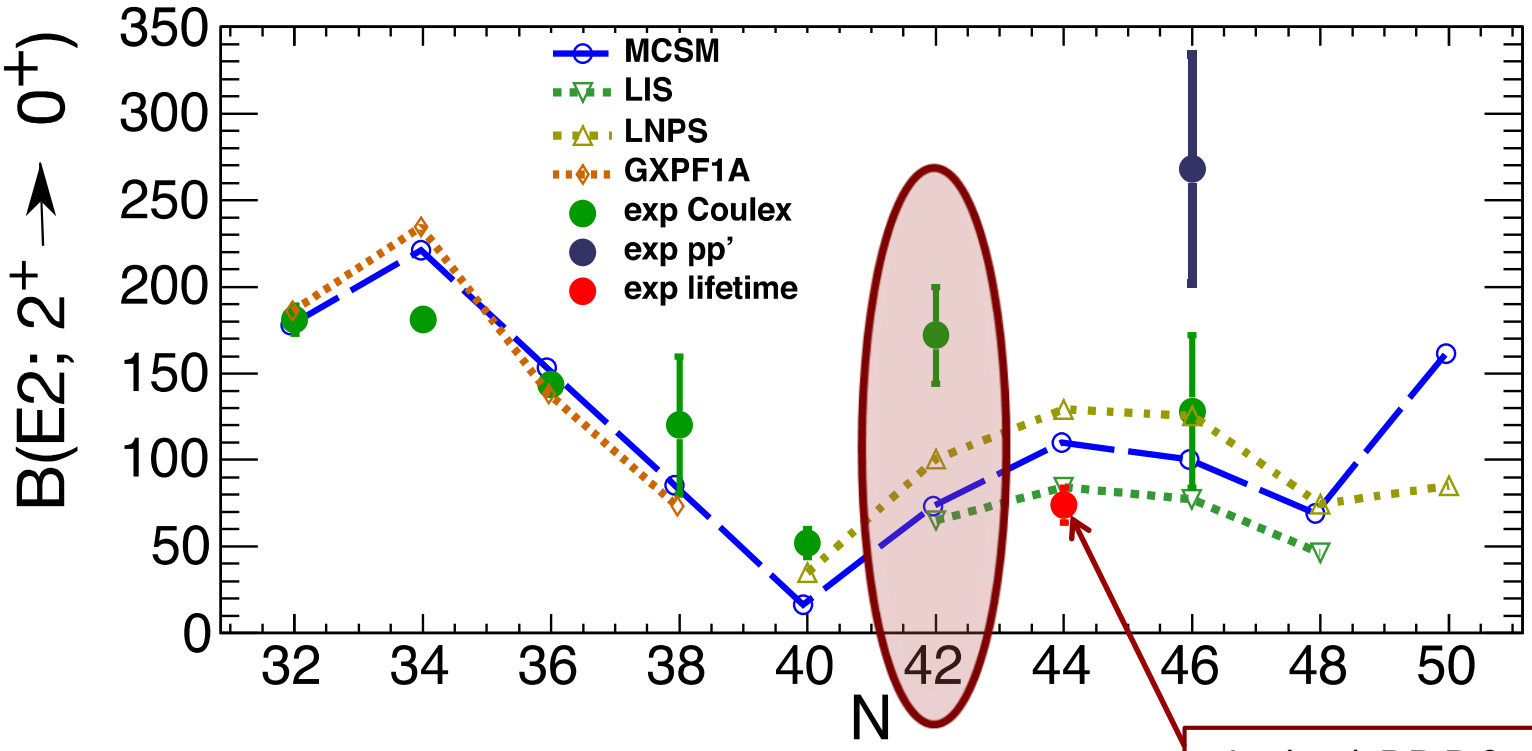
Desired outcomes

- ^{66}Ni and ^{68}Ni:
  - Simultaneous determination of B(E2; $0^+_1 \rightarrow 2^+_1$) and Qs(2^+_1) [*oblate?*]



Desired outcomes

- ^{70}Ni:
  - Unambiguous measurement of B(E2; $0^+_1 \rightarrow 2^+_1$).
  - Resolve discrepancy between τ and intermediate-energy Coulex.



K. Kolos et al., Phys. Rev. Lett. 116, 122502 (2016)

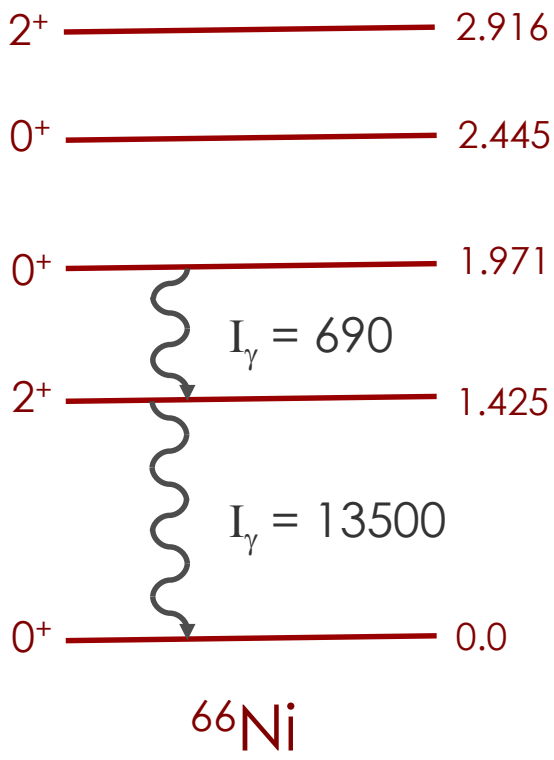
Beam time request

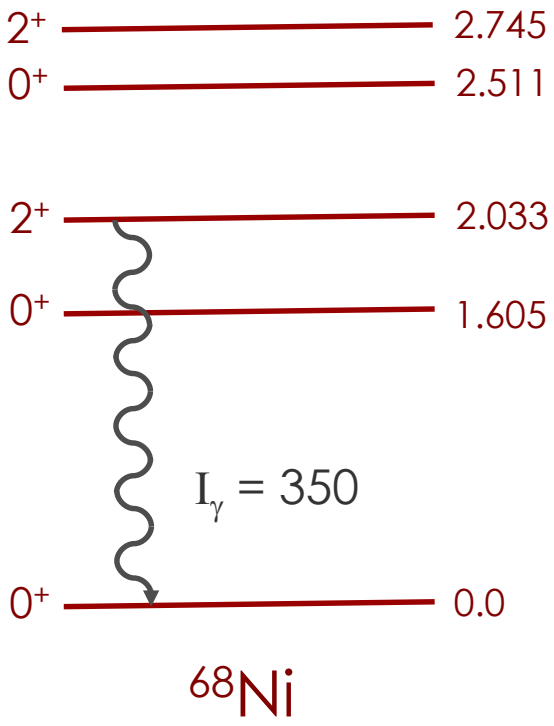
^{68}Ni previous "safe" Coulex –
N. Bree et al., PRC **78**, 047301 (2008)
Yield > 5 x 10^5 ions/μC – 8 shifts – 11 counts!

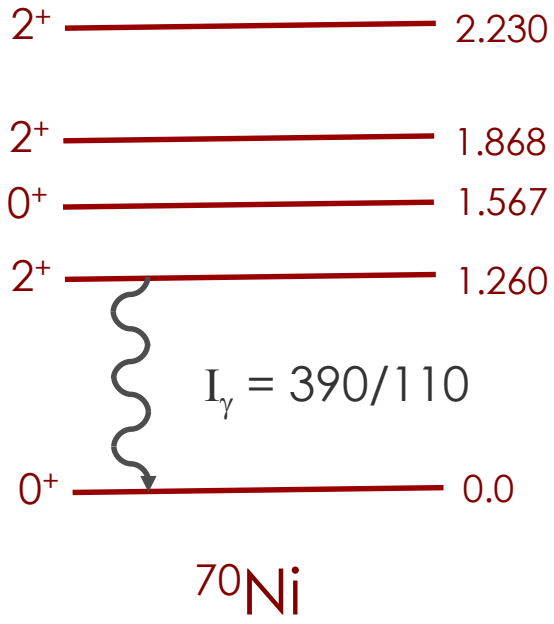
	$T_{1/2}$	Primary yield	Beam Energy	$E_\gamma(2_1^+ \to 0_1^+)$	$I_\gamma(2_1^+ \to 0_1^+)$	$I_\gamma(^{206}\mathrm{Pb})$	Shifts
^{66}Ni	54.6 h	1×10^8 ions/μC	4.0 MeV/u	1.425 MeV	3400/shift	5000/shift	4
^{68}Ni	29 s	1×10^6 ions/μC	4.0 MeV/u	2.033 MeV	24/shift	250/shift	15
^{70}Ni	6 s	1×10^5 ions/μC	3.5 MeV/u	1.260 MeV	9 or 32/shift	15/shift	12

+ setup: 2

= total: **33**







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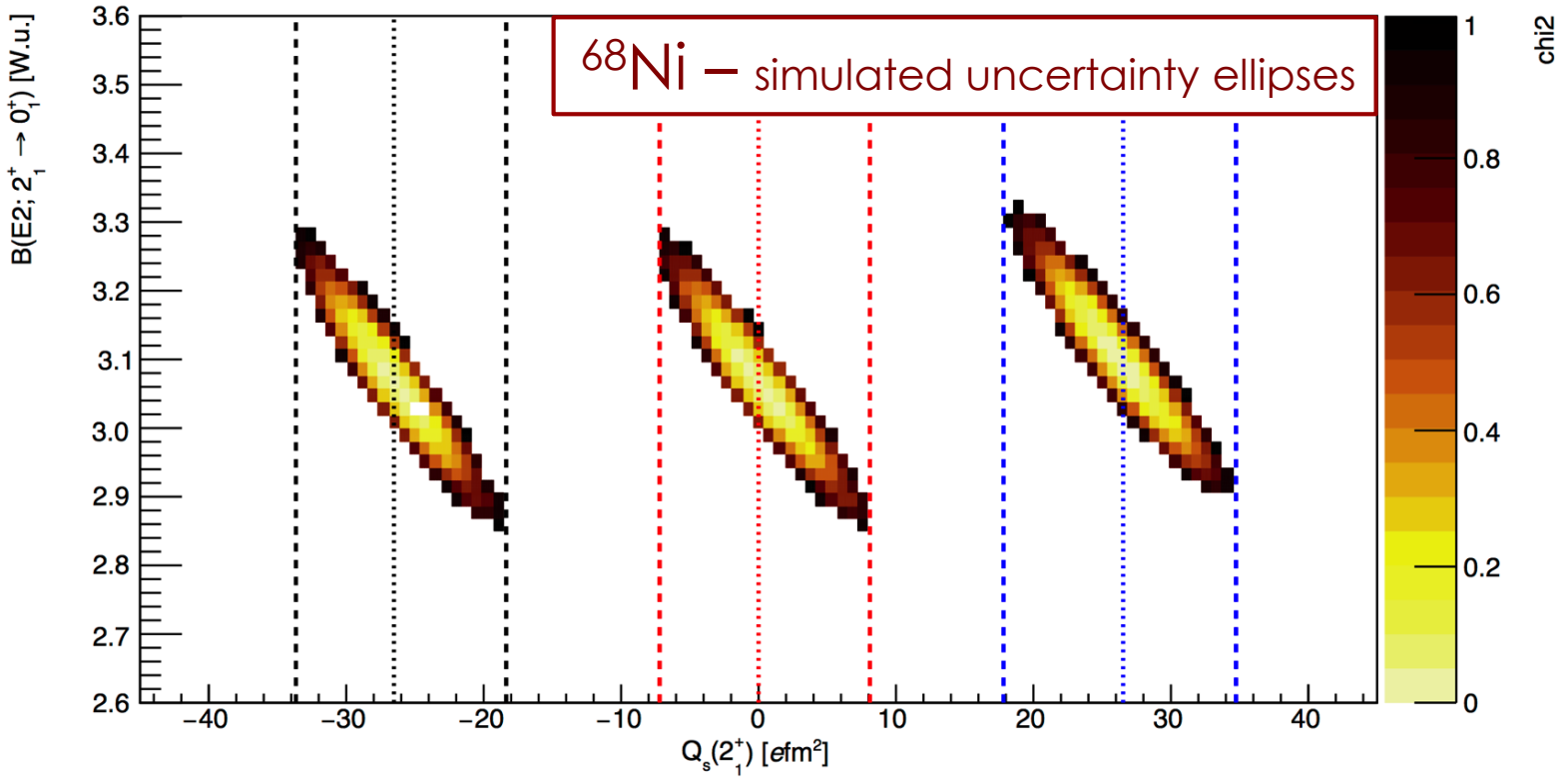

Collaboration

L. P. Gaffney[1], P. Van Duppen[2], F. Flavigny[3], M. Zielińska[4], K. Kolos[5], A. N. Andreyev[6], M. Axiotis[7], D. L. Balabanski[8], A. Blazhev[9], J. Cederkäll[10], T. E. Cocolios[11], E. Clément[12], T. Davinson[13], G. De France[12], H. De Witte[2], D. Di Julio[10], T. Duguet[4], C. Fahlander[10], S. J. Freeman[11], G. Georgiev[14], R. Gernhäuser[15], A. Gillibert[4], S. Go[16], T. Grahn[17], P. T. Greenlees[17], R. K. Grzywacz[16,18], S. Harissopulos[7], M. Huyse[2], A. Illana[2], D. G. Jenkins[6], J. Jolie[9], R. Julin[17], M. Komorowska[4,19], W. Korten[4], Th. Kröll[20], A. Lagoyannis[7], C. Louchart[4], T. Marchi[2], T. J. Mertzimekis[21], D. Miller[21], D. Mücher[22,23], P. Napiorkowski[19], K. Nowak[15], F. Nowacki[24], D. O'Donnell[1], A. Obertelli[4], R. Orlandi[24], T. Otsuka[26], J. Pakarinen[17], P. Papadakis[17], N. Patronis[27], N. Pietralla[20], P. Rahkila[17], R. Raabe[2], G. Rainovski[28], E. Rapisarda[29], P. Reiter[9], M. Scheck[1], M. Seidlitz[9], B. Siebeck[9], K. Sieja[24], D. K. Sharp[11], J. F. Smith[1], C. Sotty[2], O. Sorlin[12], J. Srebrny[19], M. J. Taylor[11], Y. Tsunoda[26], N. Warr[9], R. Wadsworth[6], F. Wenander[29], K. Wimmer[26], P. J. Woods[13], K. Wrzosek-Lipska[19]

[1] *University of the West of Scotland, U.K.* | [2] *KU Leuven, Belgium* | [3] *IPN Orsay, France* | [4] *CEA-Saclay, France* | [5] *Lawrence Livermore National Laboratory, U.S.A.* | [6] *University of York, U.K.* | [7] *NCSR-Demokritos, Greece* | [8] *INRNE-BAS, Bulgaria* | [9] *University of Köln, Germany* | [10] *University of Lund, Sweden* | [11] *University of Manchester, U.K.* | [12] *GANIL, France* | [13] *University of Edinburgh, U.K.* | [14] *CSNSM, France* | [15] *TU-München, Germany* | [16] *University of Jyväskylä and Helsinki Institute of Physics, Finland* | [17] *University of Tennessee, Knoxville, U.S.A.* | [18] *Oak Ridge National Laboratory, U.S.A.* | [19] *HIL, University of Warsaw, Poland* | [20] *TU-Darmstadt, Germany* | [21] *University of Athens, Greece* | [22] *TRIUMF, Canada* | [23] *University of Guelph, Canada* | [24] *Université de Strasbourg, France* | [25] *JAEA, Tokai, Japan* | [26] *University of Tokyo, Japan* | [27] *University Of Ioannina, Greece* | [28] *St. Kl. Ohridski University of Sofia, Bulgaria* | [29] *CERN-ISOLDE, Switzerland*


Thank (E)U!

Supplementary slides

Beam time request – TAC comments

	$T_{1/2}$	Primary yield	Beam Energy	$E_\gamma(2_1^+ \rightarrow 0_1^+)$	$I_\gamma(2_1^+ \rightarrow 0_1^+)$	$I_\gamma(^{206}\mathrm{Pb})$	Shifts
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= total: **33**

^{68}Ni: 1e6/uC requested.
Ga in;
^{66}Ni : 1e8/uC
^{70}Ni : 1e5/uC laser on/off ok.
2016: low yld were found:

2013 yields = 1 x 10^5 ions/μC

e.g. Target/line 590A/430A (2100C/2000C):
^{69}Ni: 9.8e2 /uC
^{70}Ni: 1.6e3 /uC (on betas) / 2.6e3 /uC (on gammas)
^{70}Ga: 2.4e3 /uC (on betas only due to low branching ratios of gammas)

Target/line 590A/440A (2100C/2050C):
^{70}Ni: 1.2e3 /uC (on betas)
^{70}Ga: 4e3 /uC (on betas)
Ga contamination?
Sigradur unit would help? Testing worthwhile to confirm yields

Factor 50 drop in ^{70}Ni is too much.
Was higher in 2013 → Testing OK.

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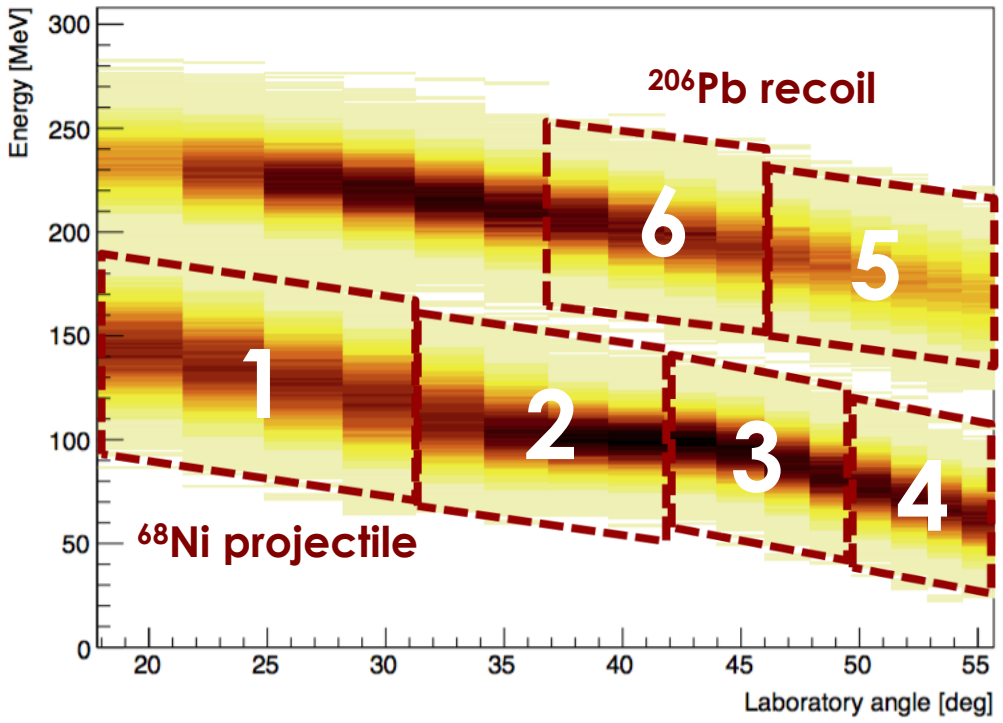
Exp	Iγ
1	32
2	72
3	66
4	57
5	124
6	146



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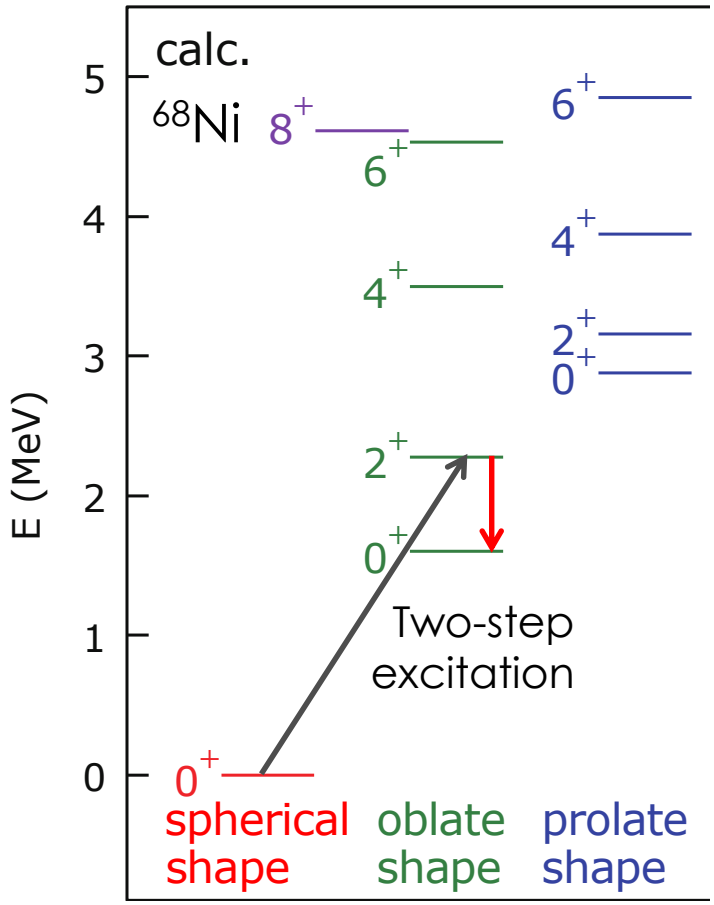

Ω(E0; 1605 keV):
K = 1.878 x 10^8
IPF = 1.542 x 10^8

Pair production = 45%