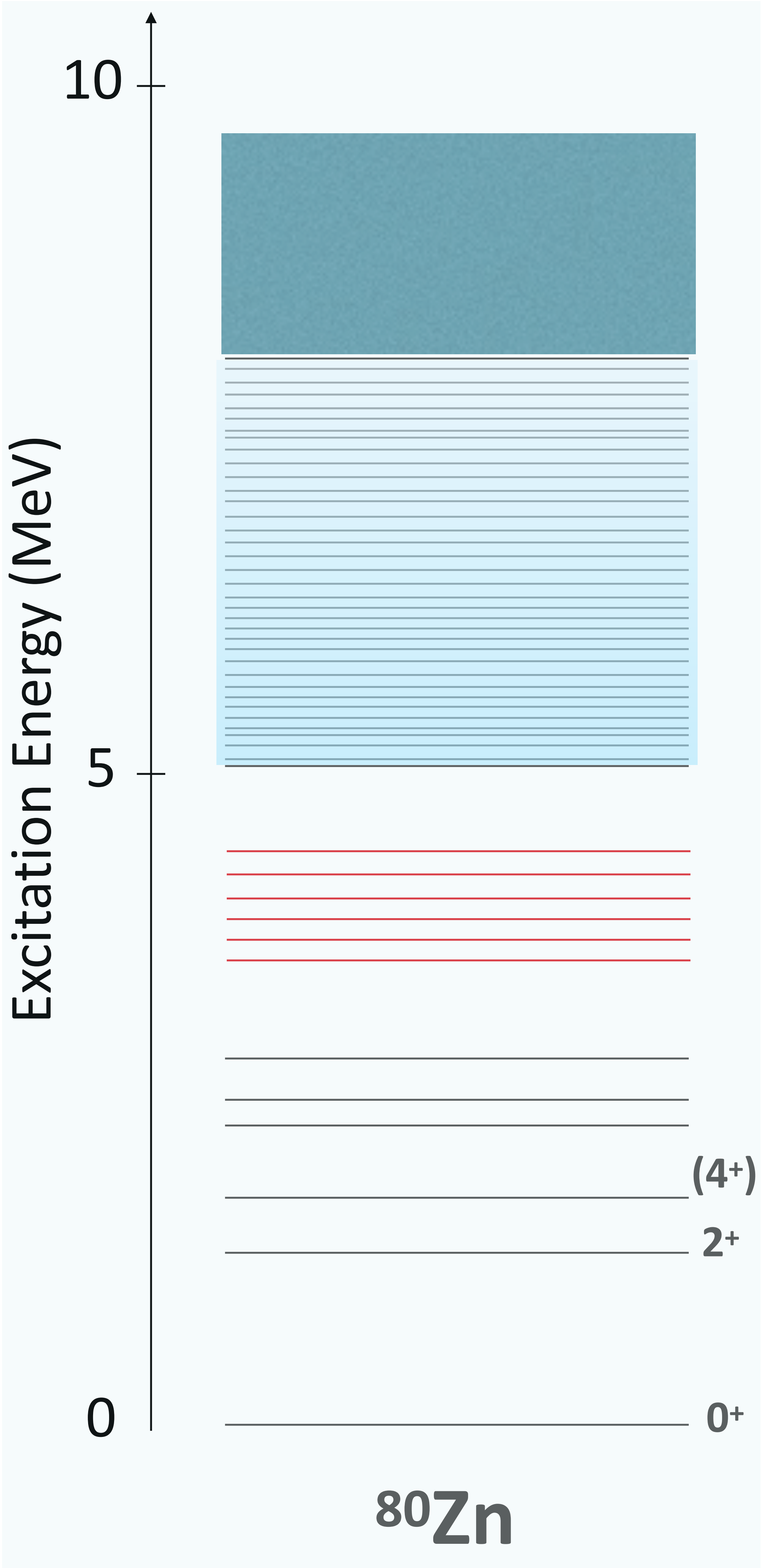
Neutron single-particle states and neutron-capture cross sections towards ^{78}Ni: ^{79}Zn(d,p)^{80}Zn

Spokesperson: E. Sahin,
University of Oslo, Oslo, Norway

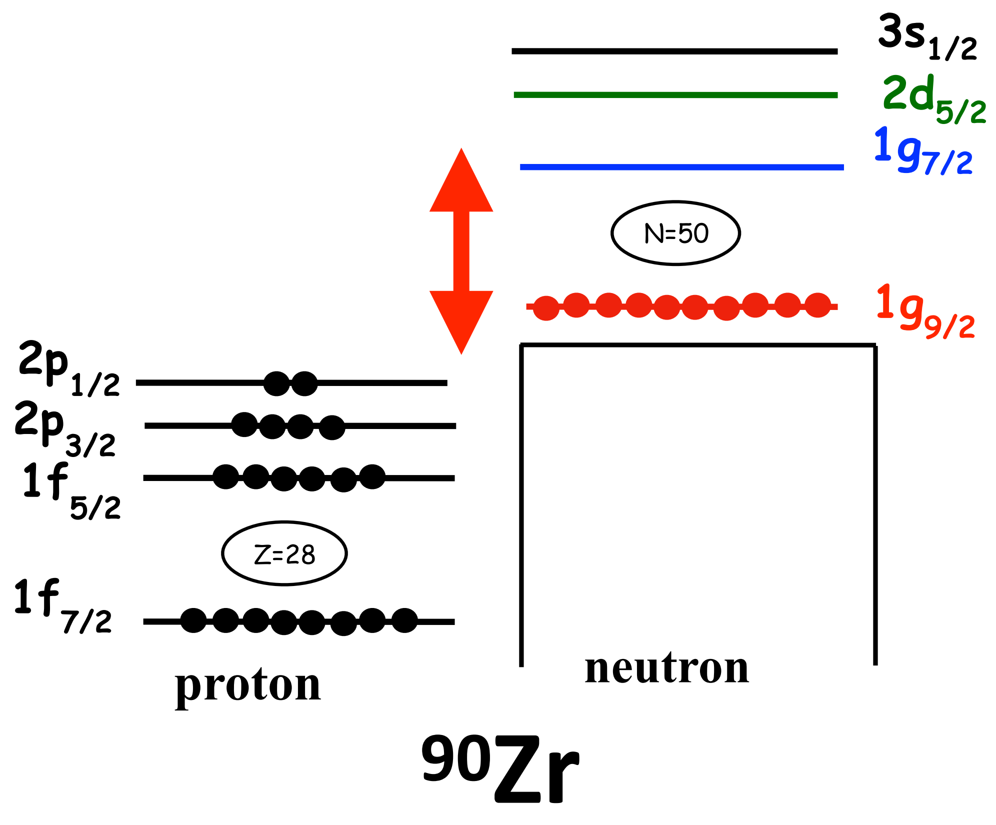


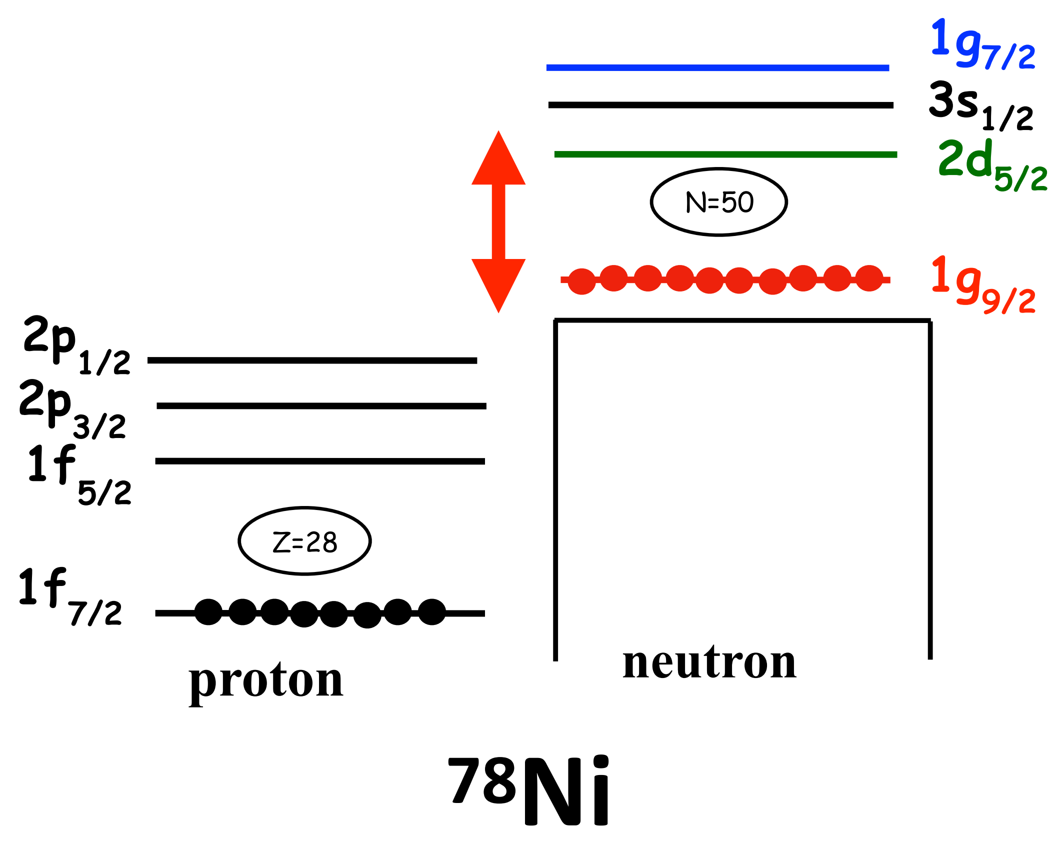
Objective 2:
(Weak) r-process around the A=80 mass region

Objective 1:
Evolution of the N = 50 shell gap

2 PhD projects

Evolution of the N = 50 shell gap





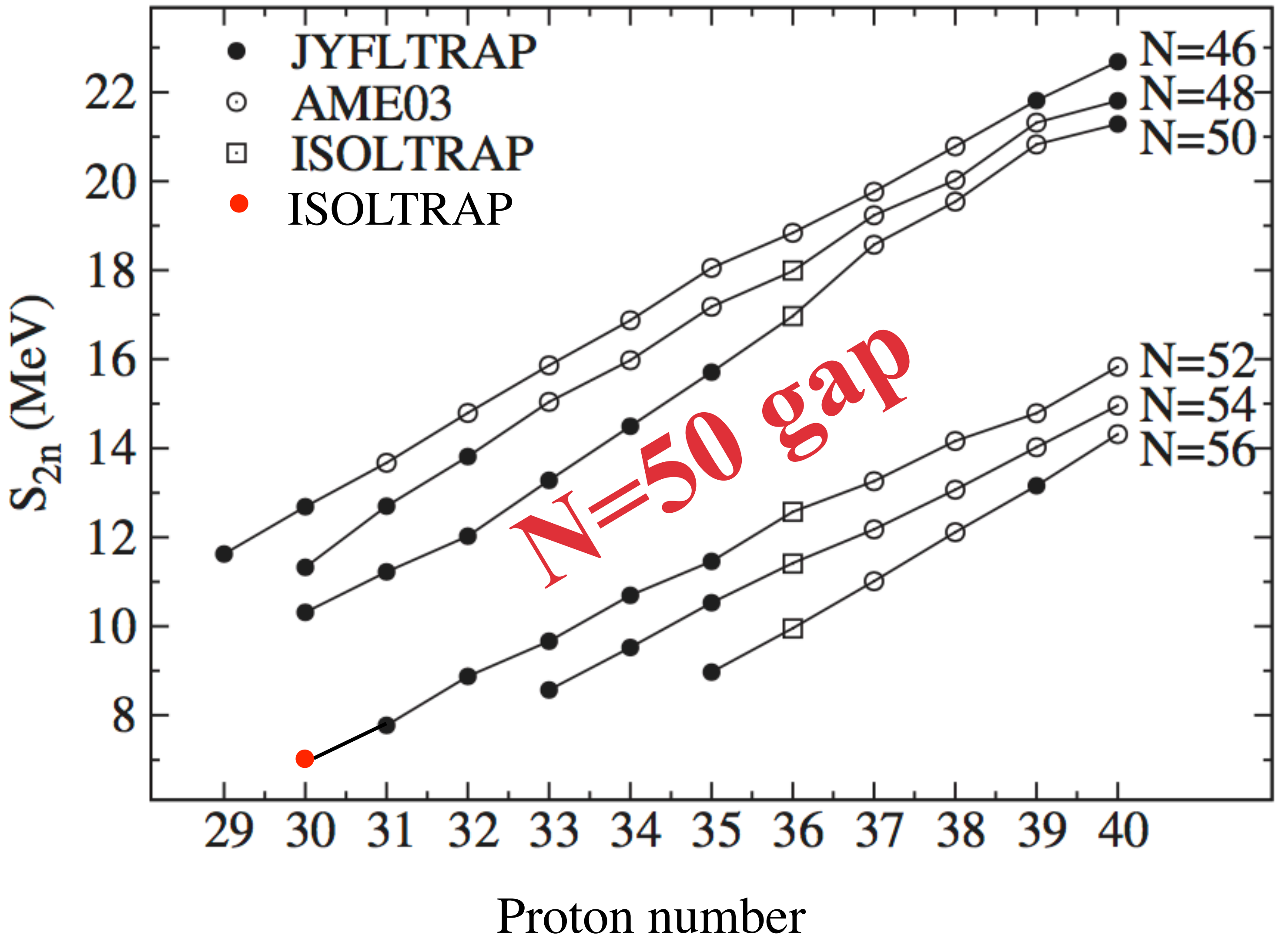
- Monopole tensor component of the *NN* interaction
- Changes in the location of the neutron single particle orbitals
- Changes in the size of the N=50 gap from Z=40 (^{90}Zr) to Z=28 (^{78}Ni)

- Evolution of the N = 50 gap from 1p–1h states

Evolution of the N = 50 shell gap

J. Hakala et al., PRL 101, 052502 (2008)

^{82}Zn: R. N. Wolf et al., PRL 110, 041101 (2013)



Shell gap from mass is correlated.

SM approach:

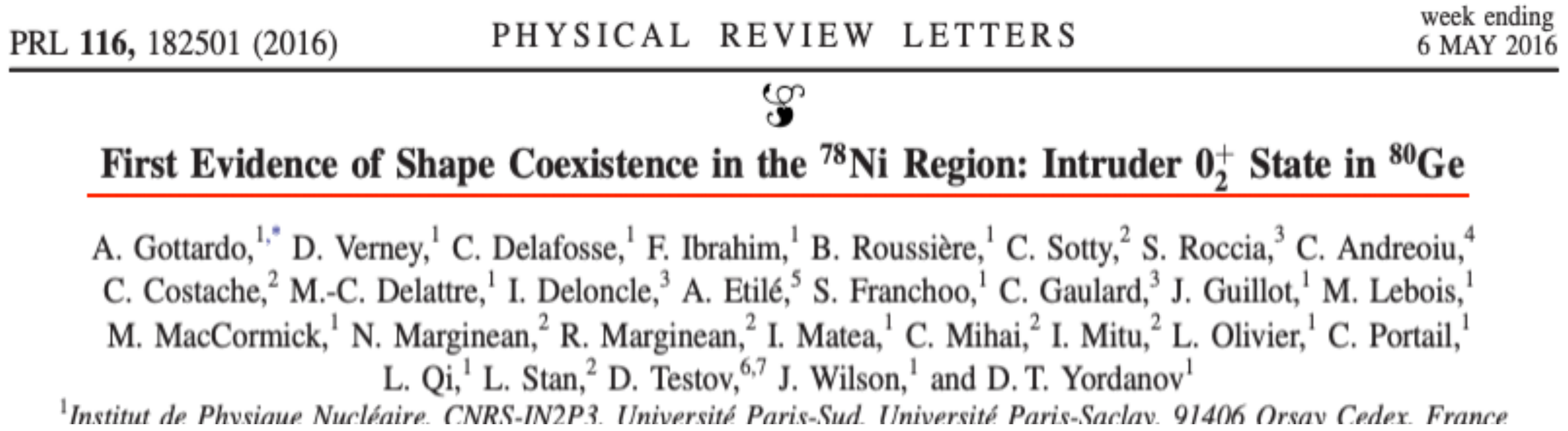
K. Sieja and F. Nowacki , PRC85 051301(R) (2012)

F. Nowacki et al., PRL 117, 272501 (2016)

A. Welker et al., PRL 119, 192502 (2017).

Mean-field approach:

M. Bender et al. PRC78, 054312 (2008)

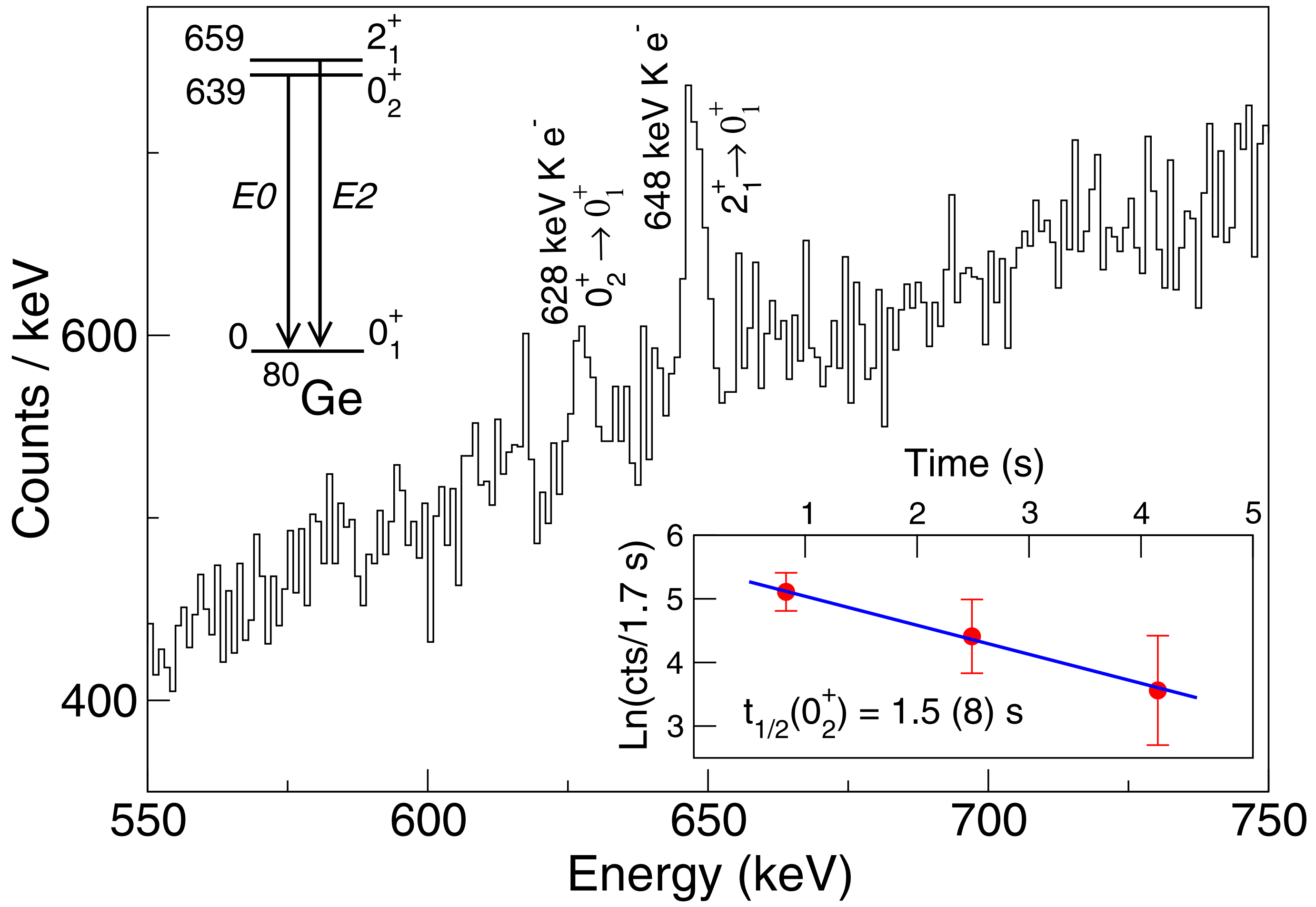


PRL 116, 182501 (2016) PHYSICAL REVIEW LETTERS week ending 6 MAY 2016

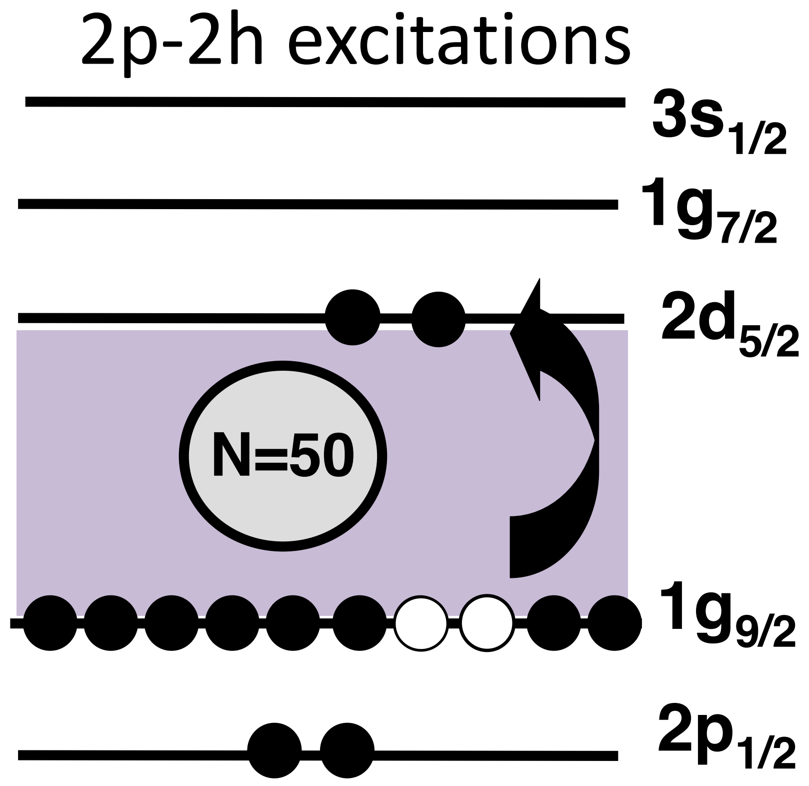
First Evidence of Shape Coexistence in the ^{78}Ni Region: Intruder 0_2^+ State in ^{80}Ge

A. Gottardo,[1,*] D. Verney,[1] C. Delafosse,[1] F. Ibrahim,[1] B. Roussière,[1] C. Sotty,[2] S. Roccia,[3] C. Andreoiu,[4] C. Costache,[2] M.-C. Delattre,[1] I. Deloncle,[3] A. Etilé,[5] S. Franchoo,[1] C. Gaulard,[3] J. Guillot,[1] M. Lebois,[1] M. MacCormick,[1] N. Marginean,[2] R. Marginean,[2] I. Matea,[1] C. Mihai,[2] I. Mitu,[2] L. Olivier,[1] C. Portail,[1] L. Qi,[1] L. Stan,[2] D. Testov,[6,7] J. Wilson,[1] and D. T. Yordanov[1]

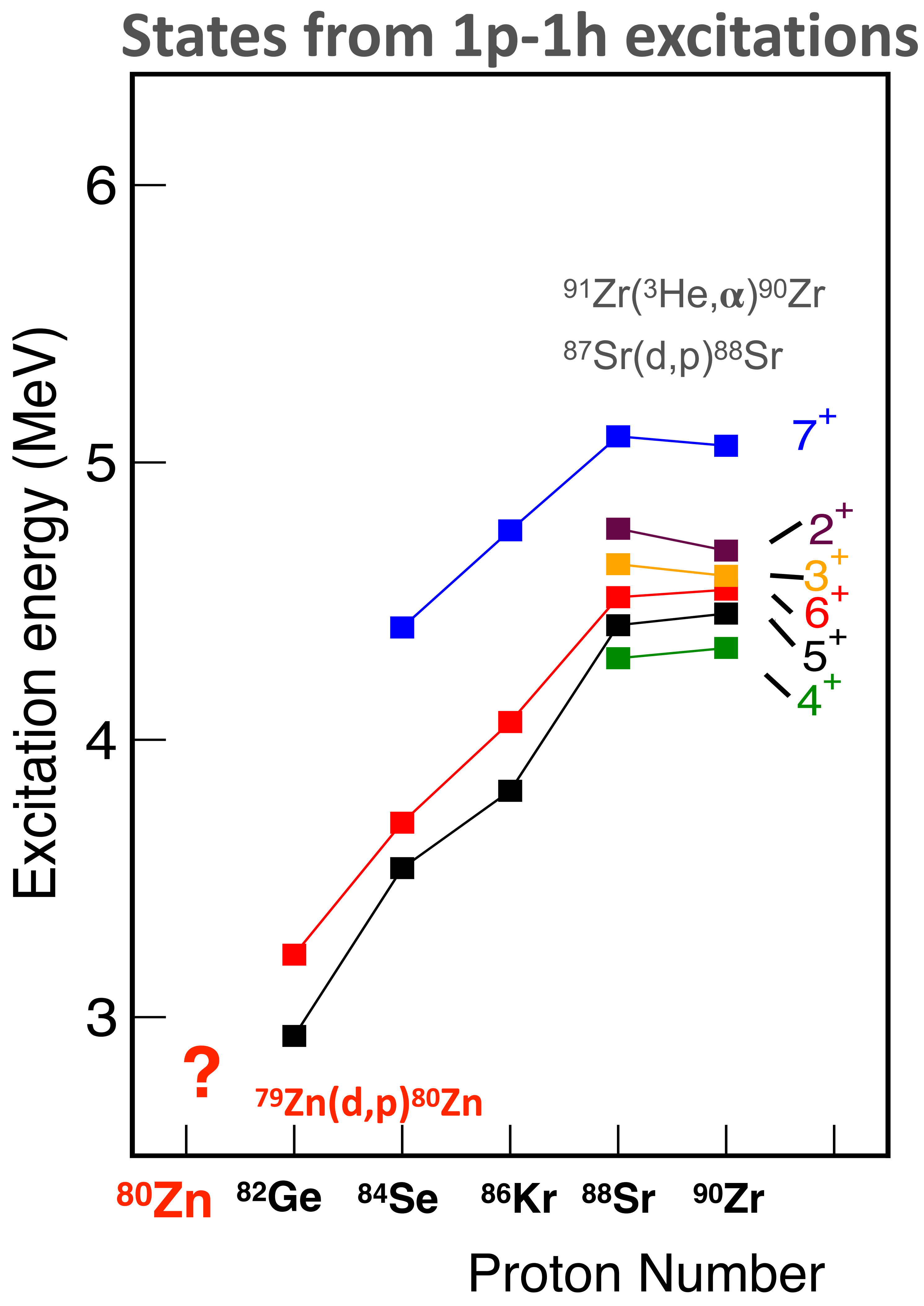
[1]Institut de Physique Nucléaire, CNRS-IN2P3, Université Paris-Sud, Université Paris-Saclay, 91406 Orsay Cedex, France

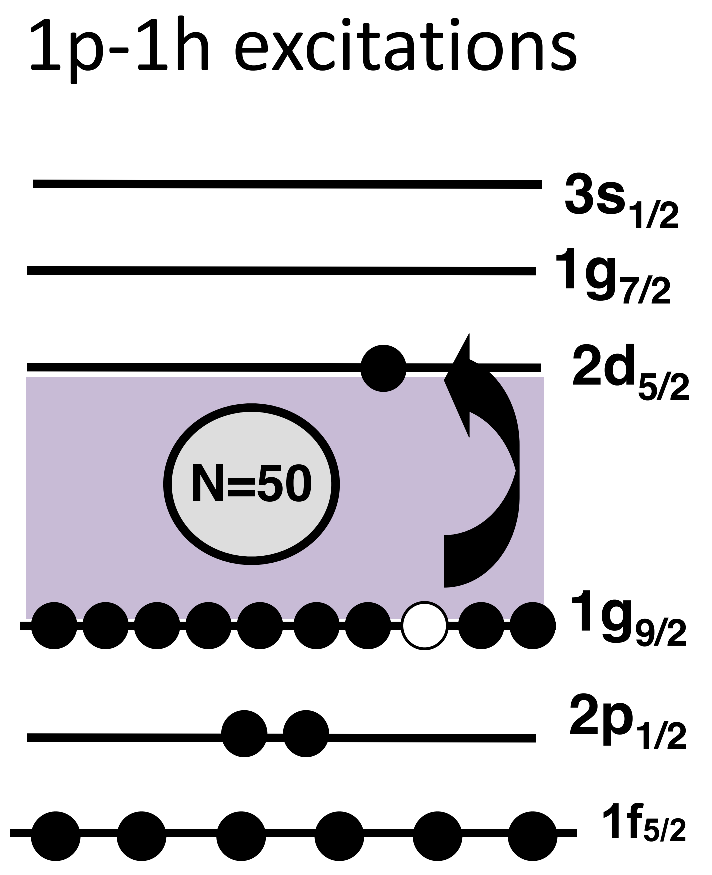


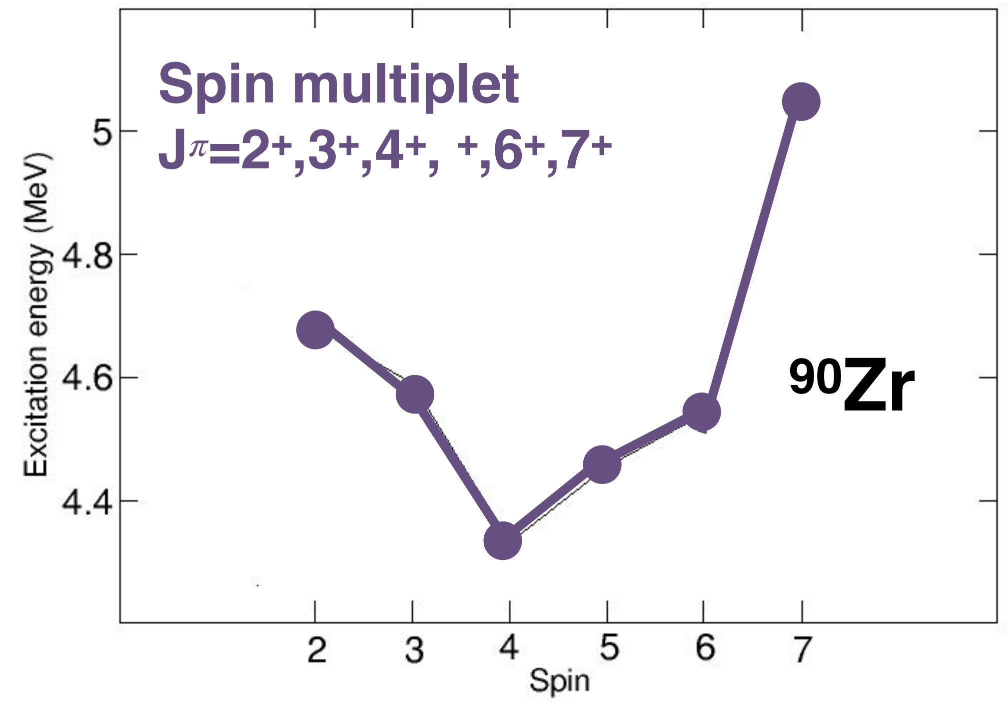
$$E_{0_2^+} = 2(E_{\nu d_{5/2}} - E_{\nu g_{9/2}}) + \Delta E^{\nu\nu}_{\text{pair}} + \Delta E^{\pi\nu}_{M} + \Delta E^{\pi\nu}_{Q},$$



Present proposal:
1p-1h excitations across N=50







pairing corr. energy
S_{2n} at Z=40,42

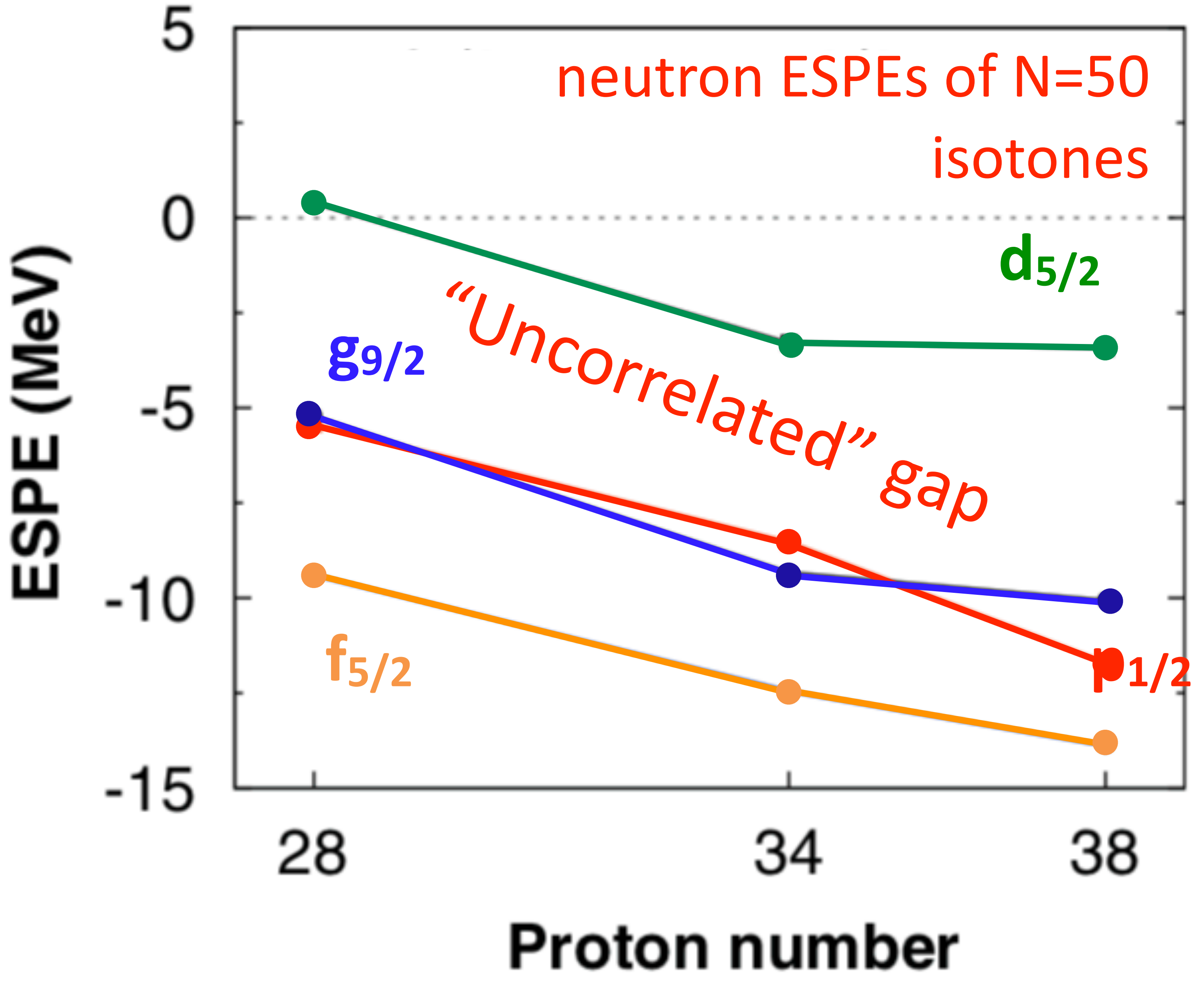
monopole
comp.

quadrupole
comp.

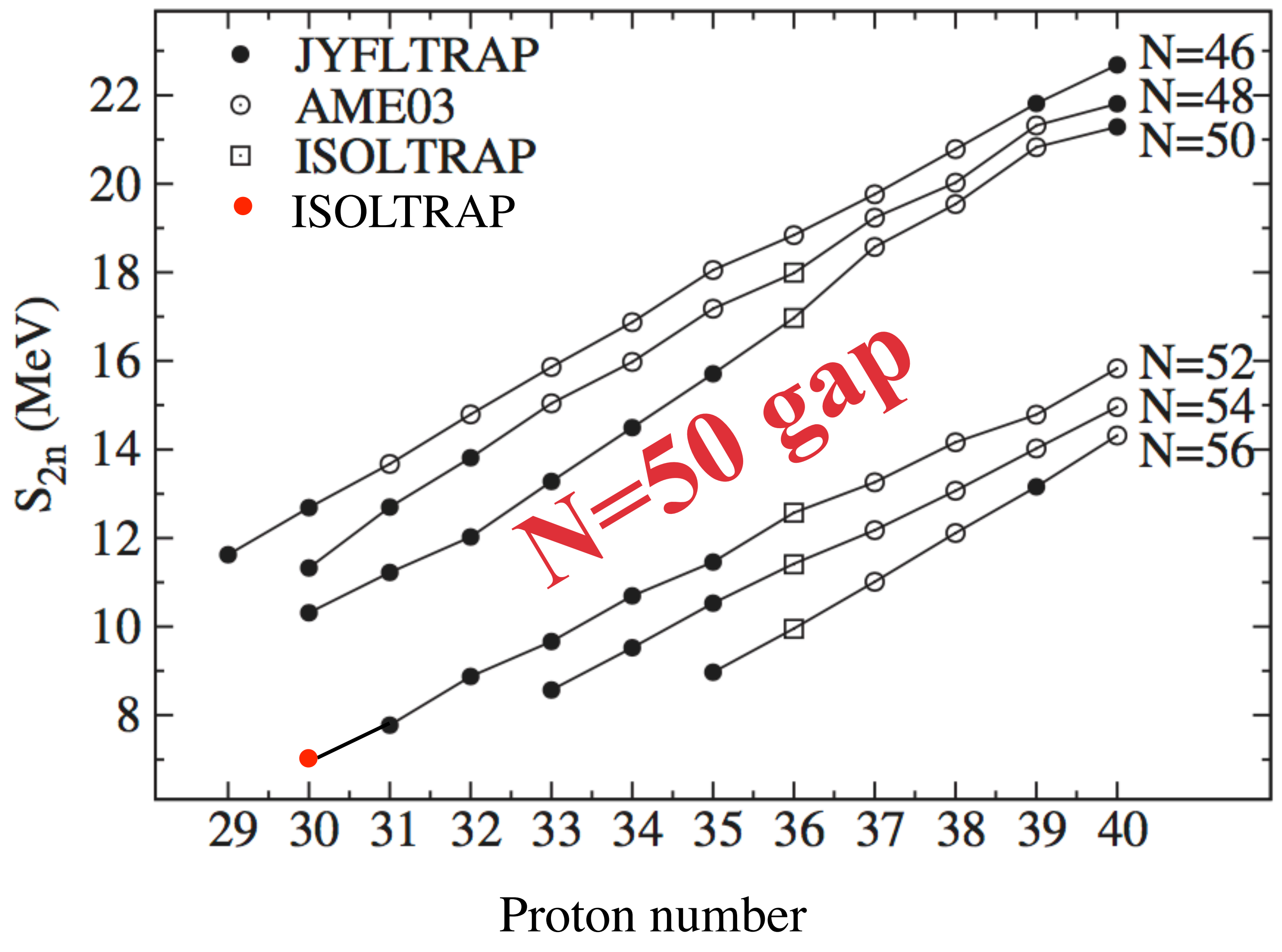
$$E_{0_2^+} = 2(E_{\nu d_{5/2}} - E_{\nu g_{9/2}}) + \Delta E^{\nu\nu}_{\rm pair} + \Delta E^{\pi\nu}_{M} + \Delta E^{\pi\nu}_{Q}$$

Unperturbed N gap
S_n at Z=40,41

(1p-1h) states



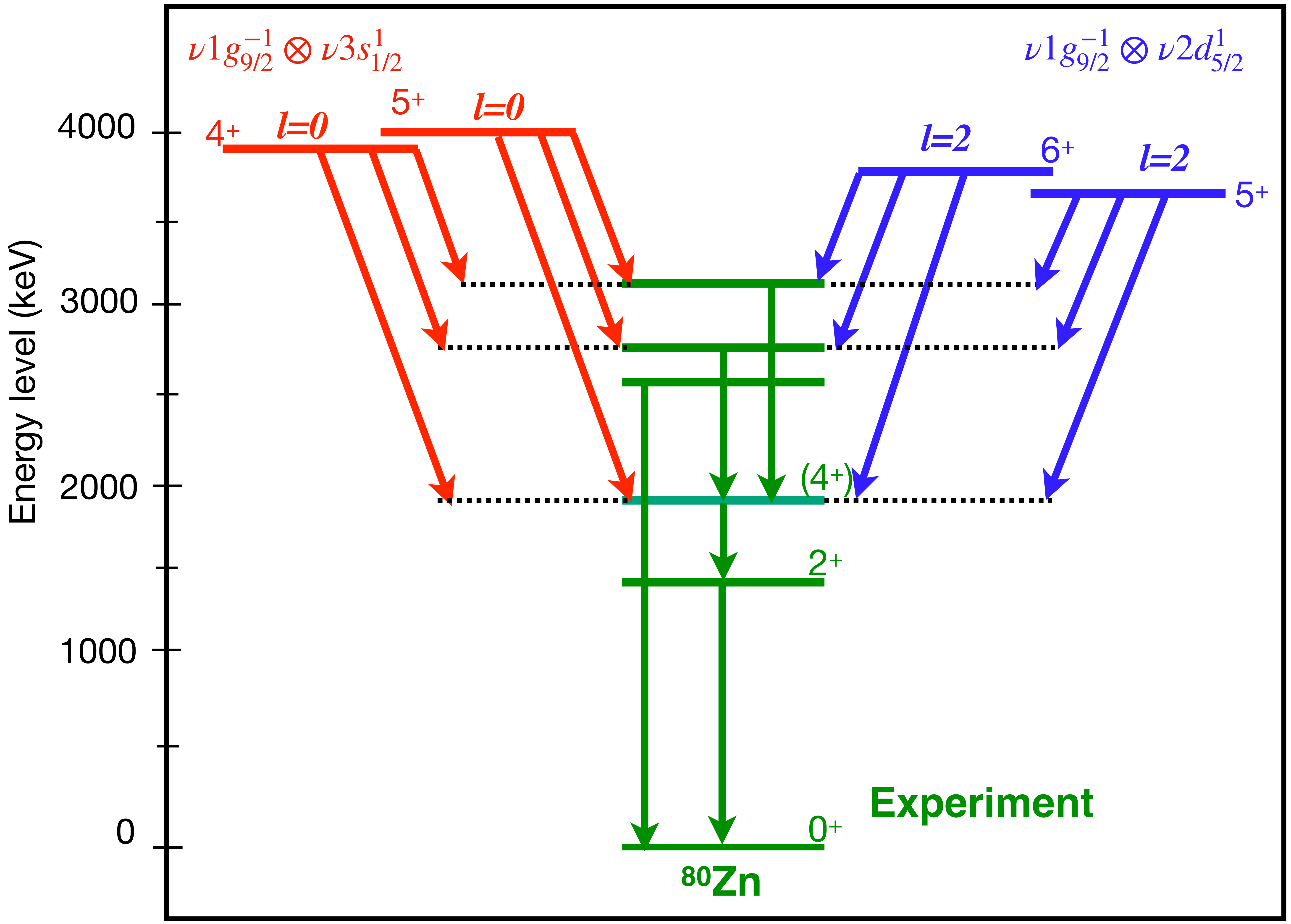
K. Sieja and F. Nowacki , PRC85 051301(R) (2012)



0_2^+ in ^{80}Ge: A. Gottardo et al., PRL 116, 182501 (2016).

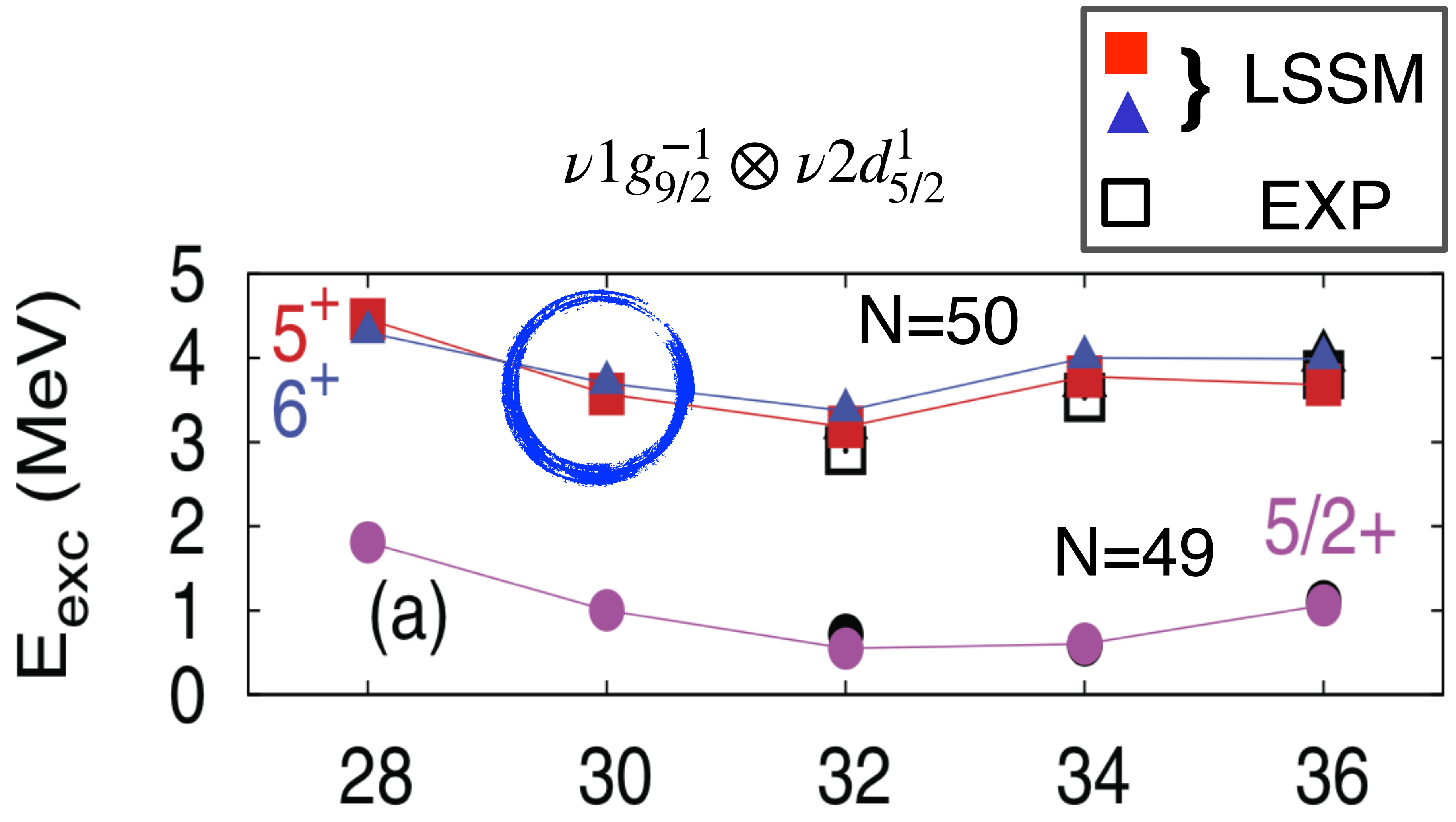
J. L. Wood et al., Phys. Rep. 215, 101 (1992).

^{80}Zn and 1p-1h states

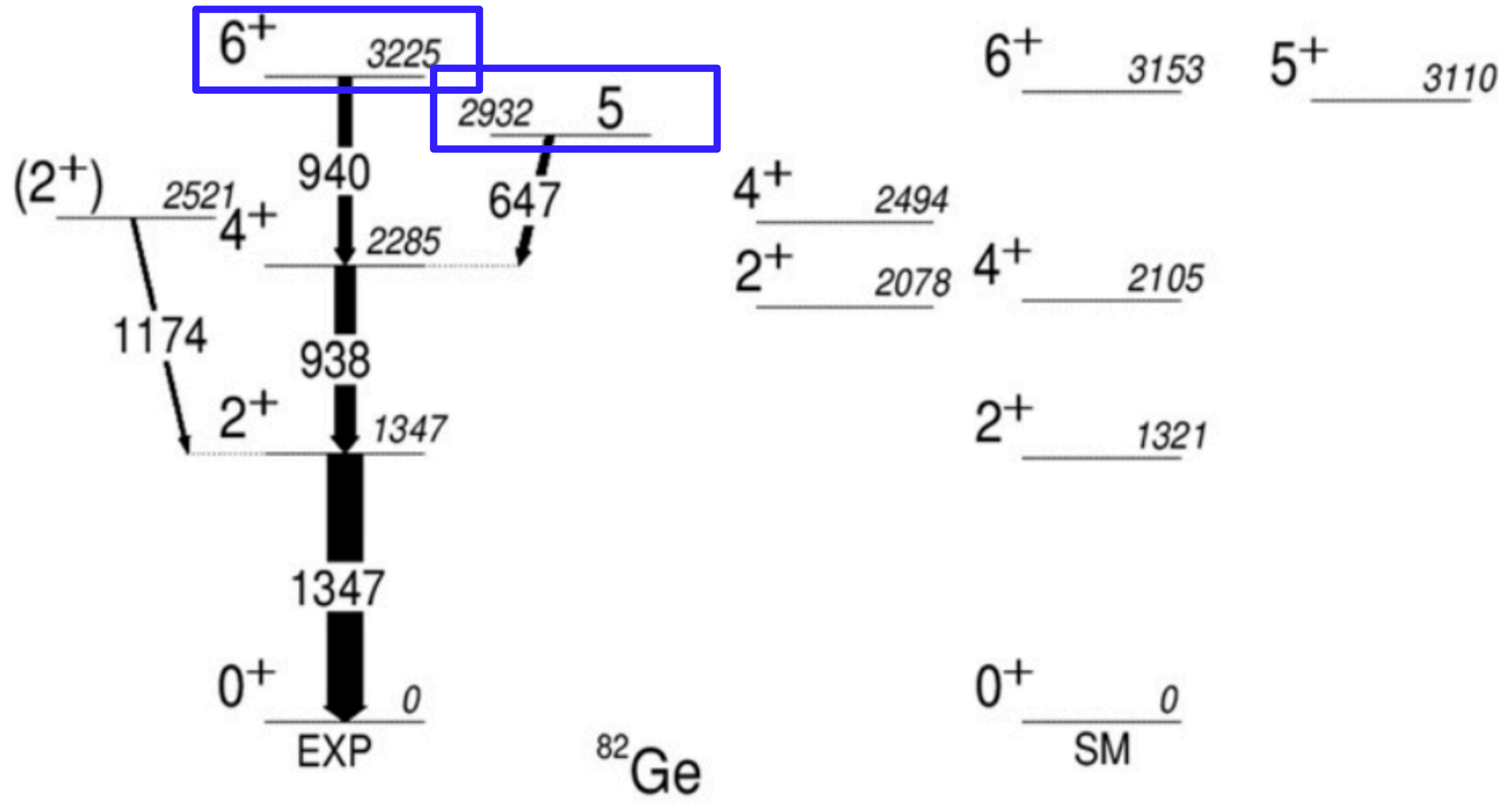


2+ state at ISOLDE Coulomb excitation : J. Van de Walle et al., PRL 99, 142501 (2007).

RIKEN inelastic scattering and proton removal: ^{9}Be(^{80}Zn,^{80}Zn) and ^{9}Be(^{81}Ga,^{80}Zn) :
Y. Shiga et al., PRC 93 024320 (2016).



K. Sieja and F. Nowacki , PRC85 051301(R) (2012)



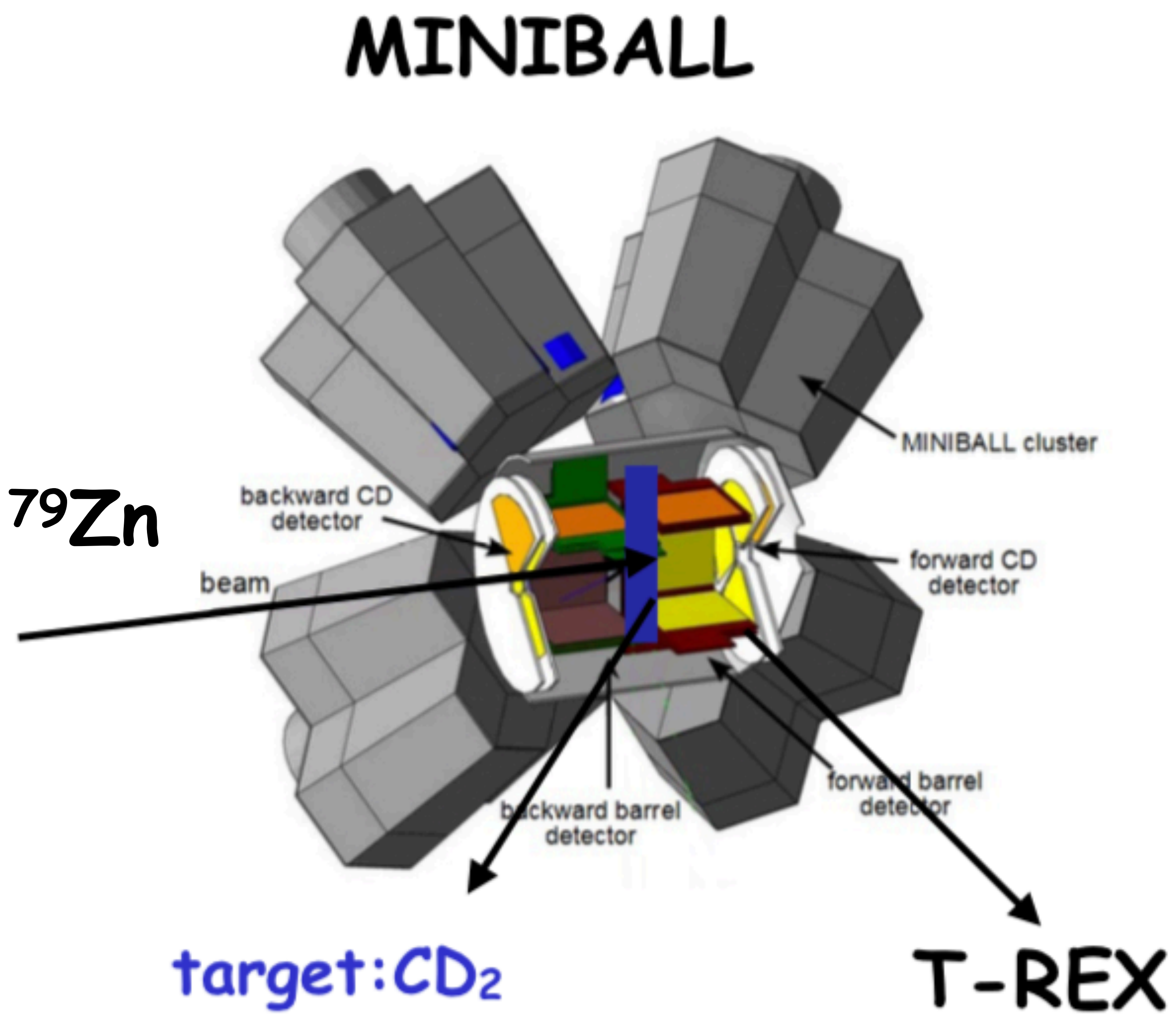
ES et al.,Nucl. Phys. A 893, 1-12 (2012)

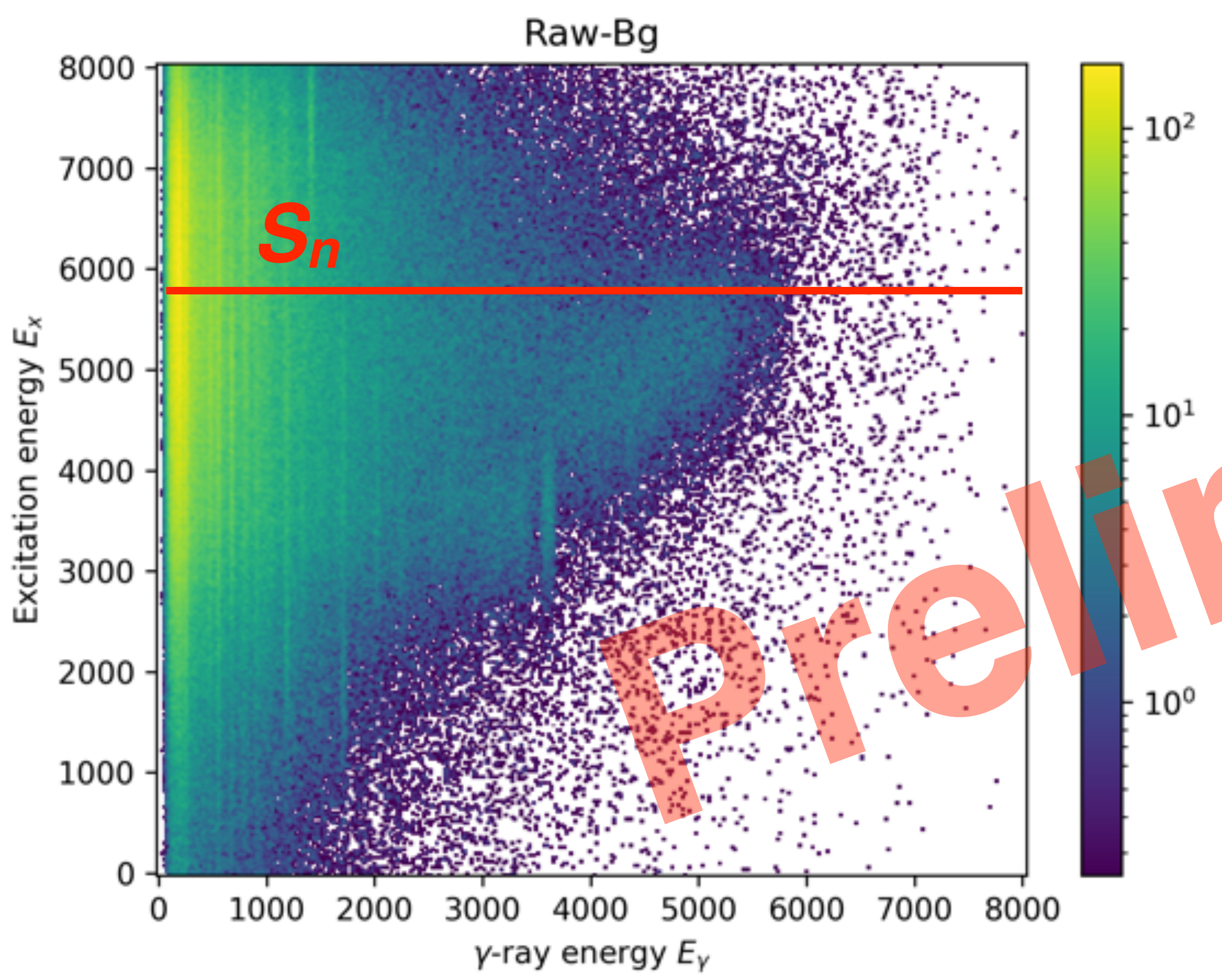
(Weak) r-process around the A~80 mass region

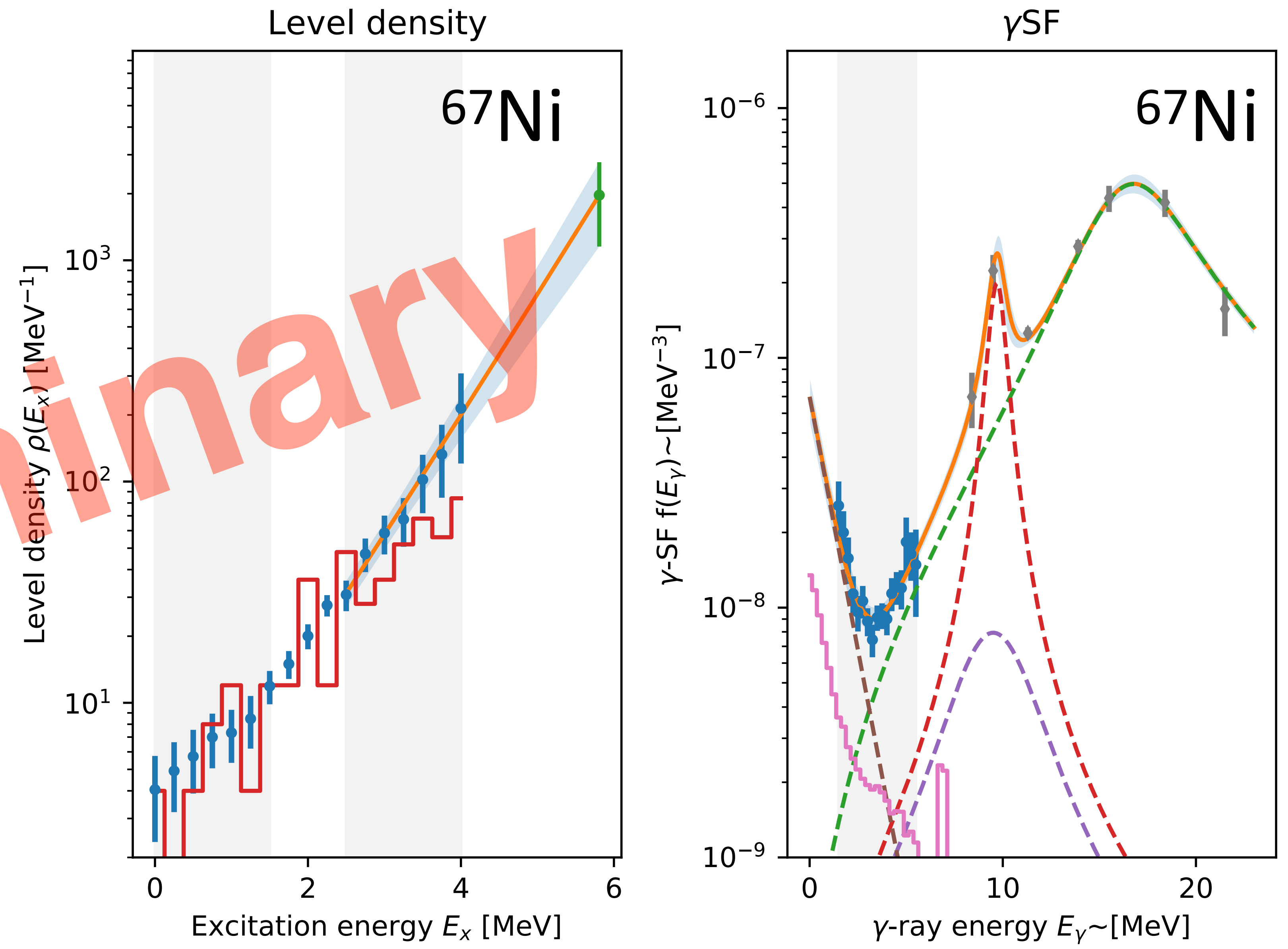
Oslo method in inverse kinematics

^{86}Kr(d,p)^{87}Kr iThemba
V. W. Ingeberg, Master thesis 2016
V.W.Ingeberg et al. Eur. Phys. J. A (2020) 56:68.

Experiment at ISOLDE (IS559): ^{66}Ni(d,p)^{67}Ni







$$P(E_\gamma, E_x) \propto \rho(E_f)\mathscr{T}(E_\gamma)$$

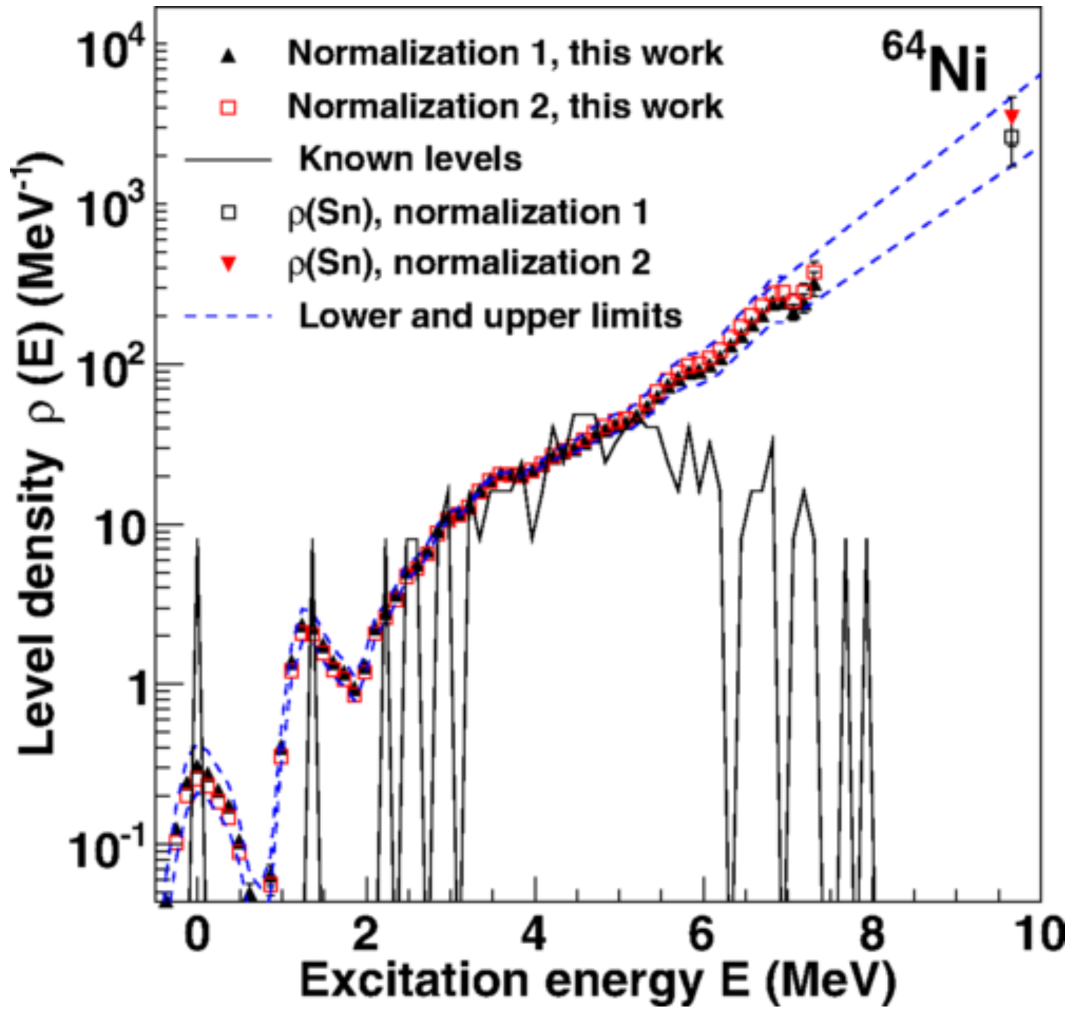
NLD gSF

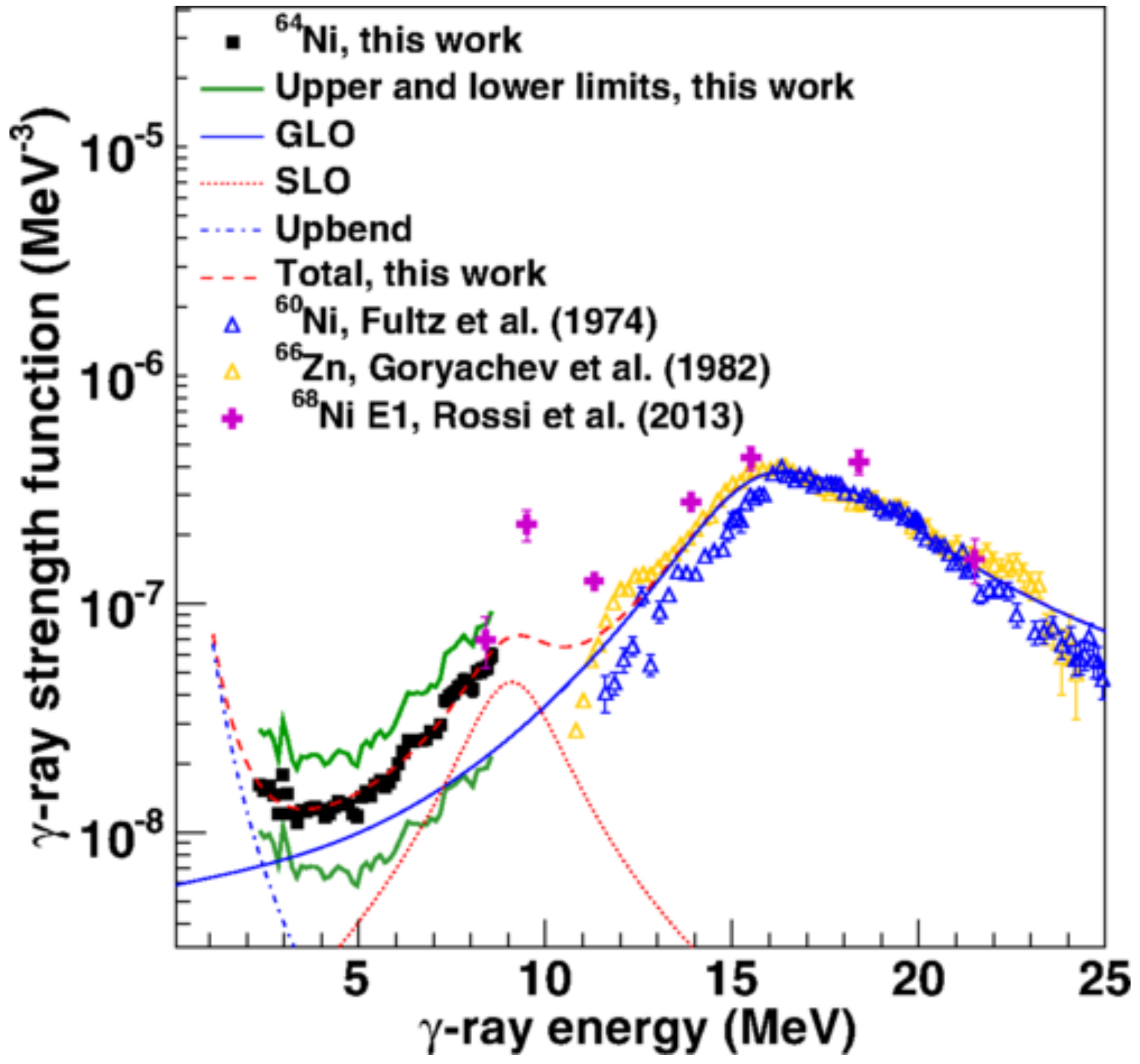
Data analysis: V. W. Ingeberg, Univ. of Oslo

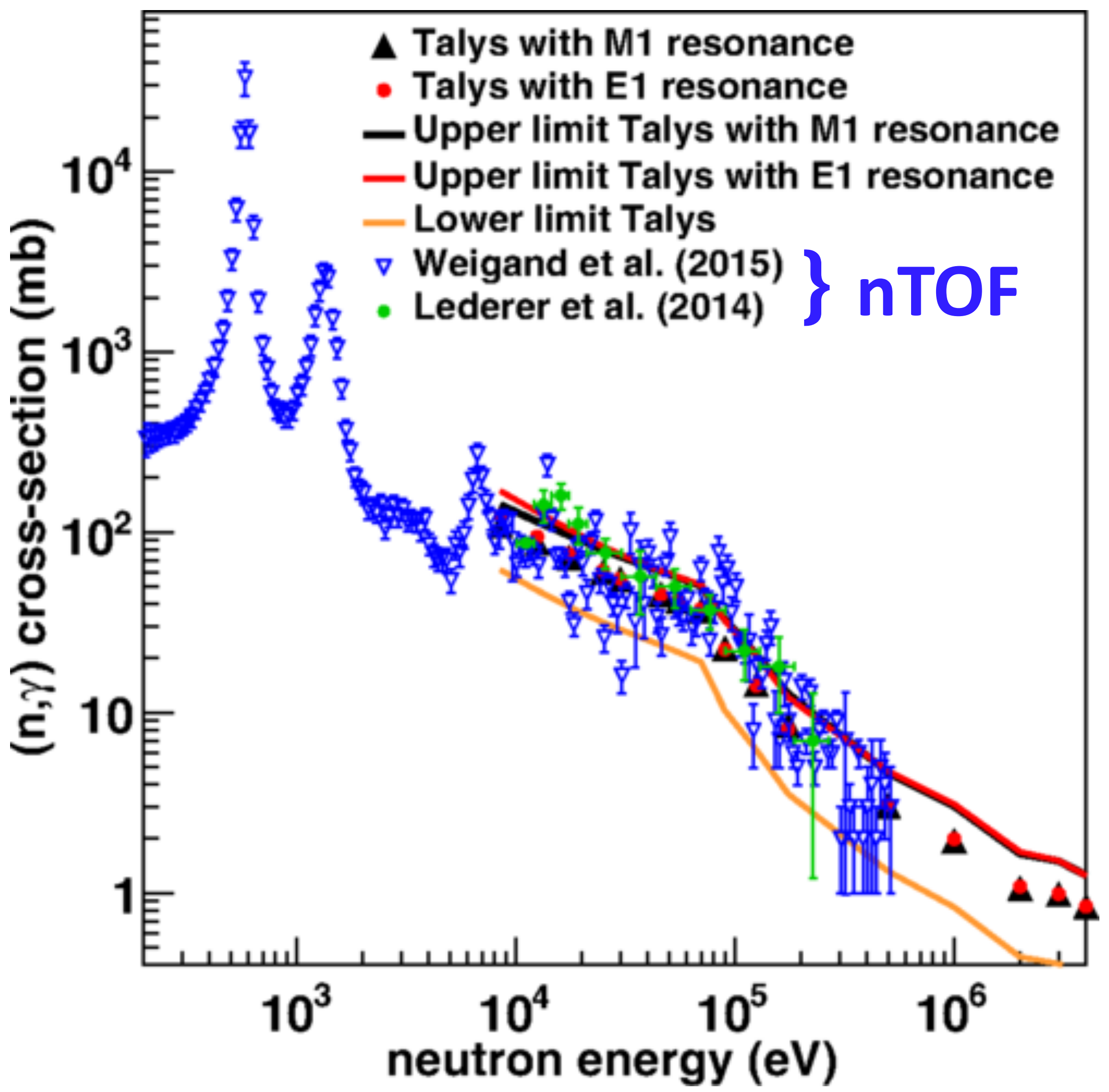
L. Crespo Campo, PRC 94, 044321 (2016)

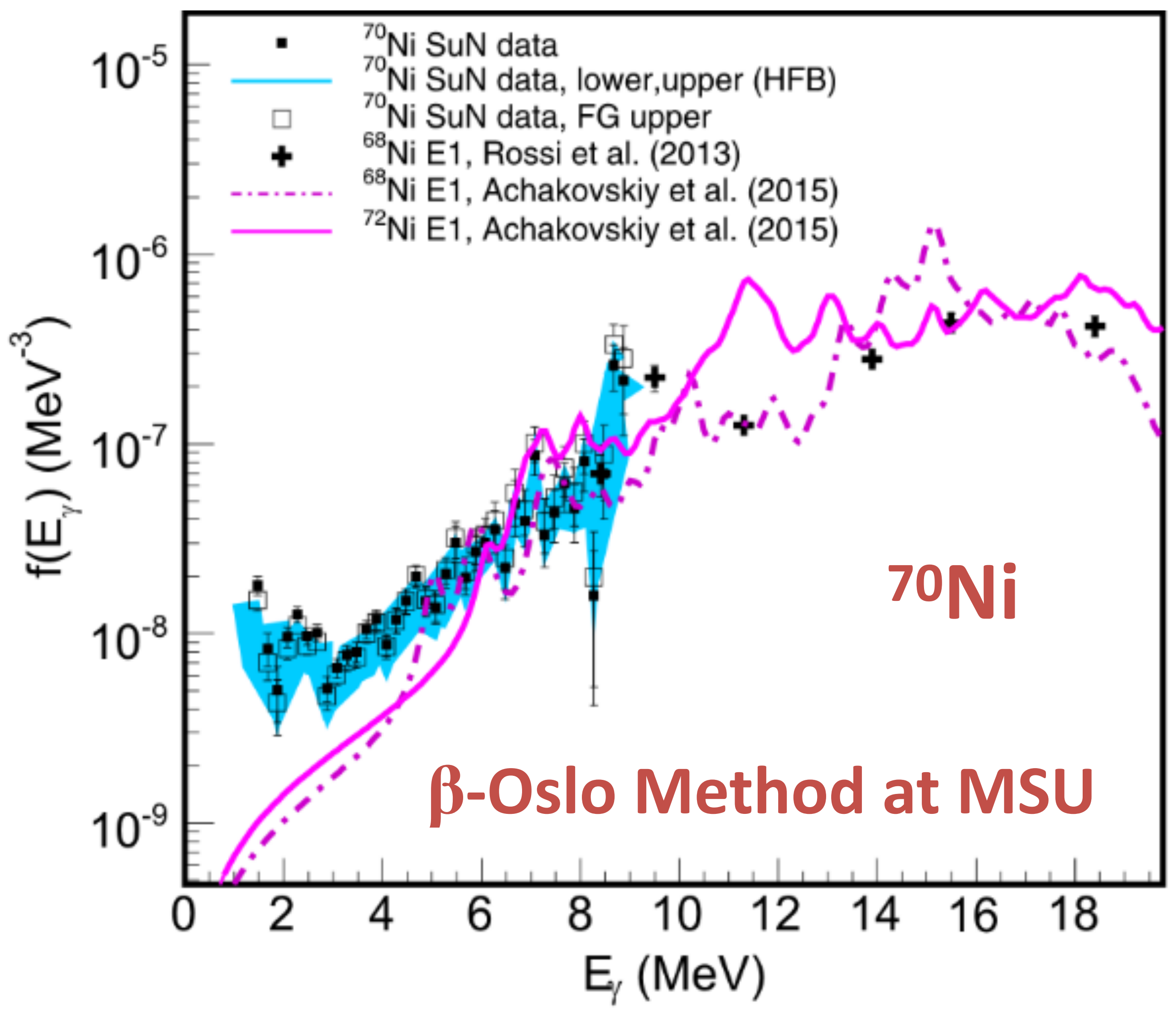
constrain ^{63}Ni(n,γ)^{64}Ni cross section for radioactive ^{63}Ni

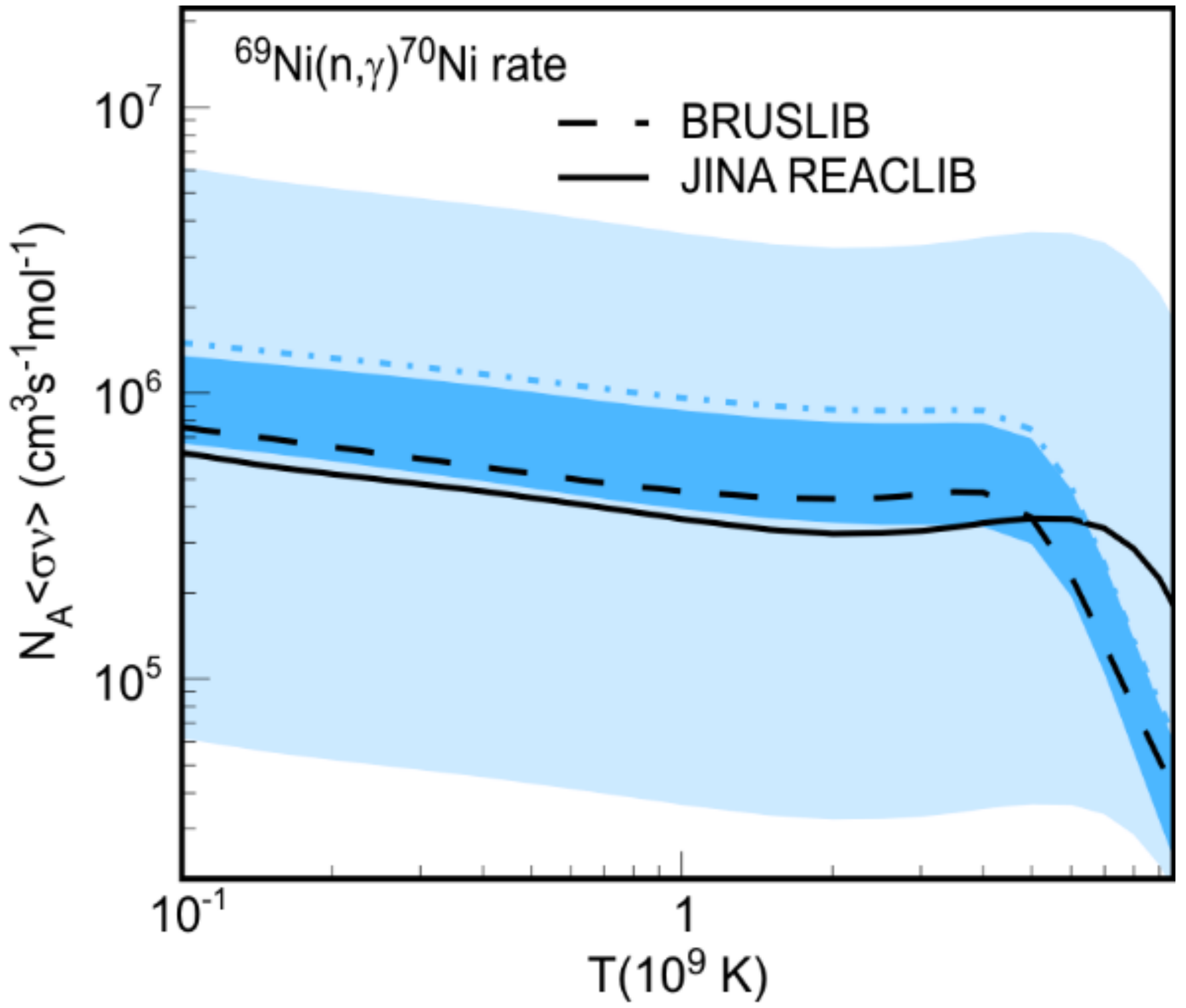
^{64}Ni(p,p')^{64}Ni





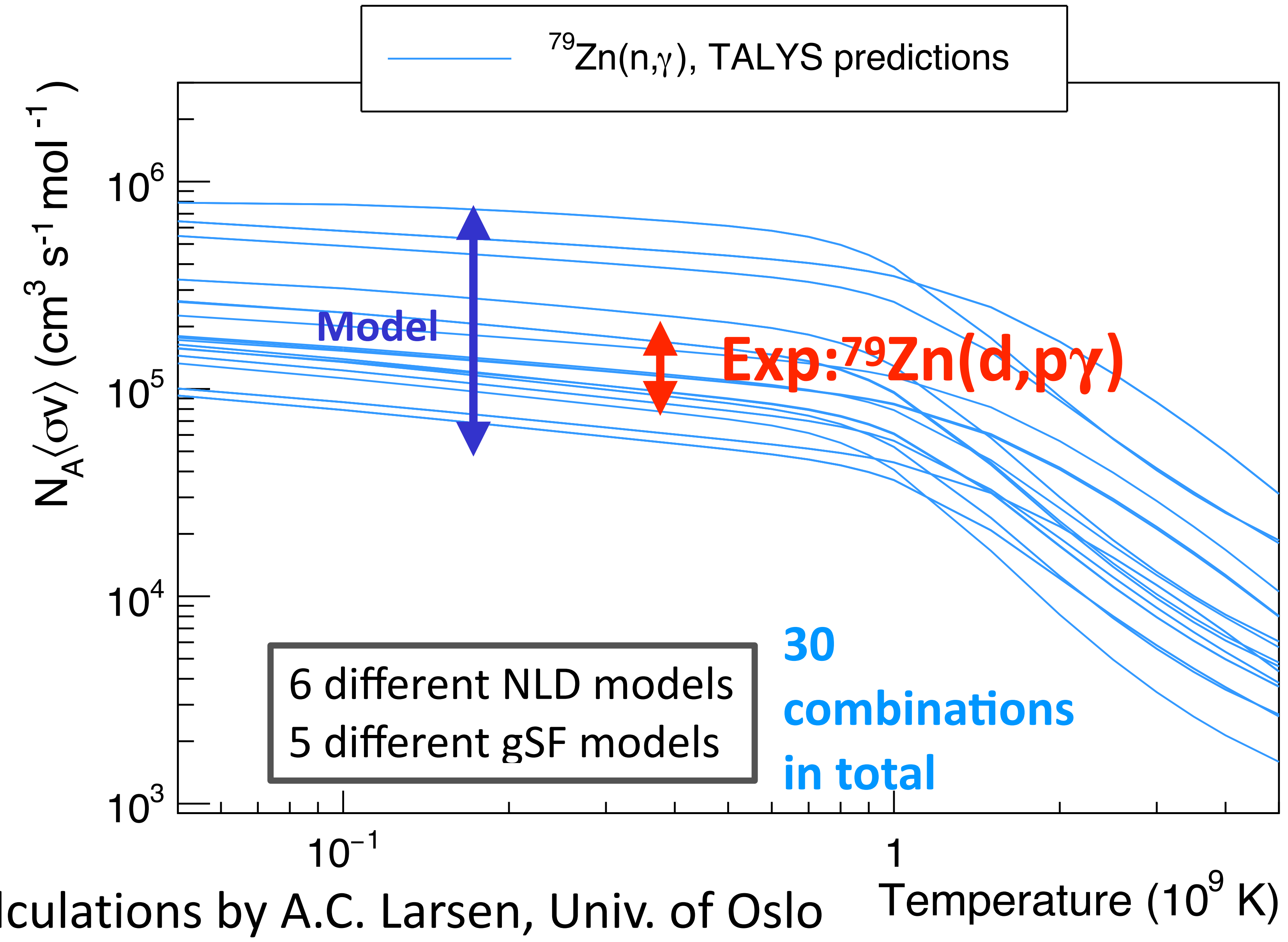






S. N. Liddick et al., PRL 116, 242502 (2016)

Aim: (n,γ) cross section for ^{79}Zn(d,pγ)



Calculations by A.C. Larsen, Univ. of Oslo

Objective 1:

Experiment
^{79}Zn(d,p)^{80}Zn inverse kinematics

Beam energy (^{79}Zn)	435 MeV (5.5 MeV/nuc)
Beam intensity on MINIBALL	**5x10^4 pps** (with n converter & quartz line)
Target thickness (CD_2)	**1 mg/cm^2**
Cross sections	DWBA via FRESCO

- TREX angular coverage: 50%
- MINIBALL efficiency on average 8%

	(particle-γ)/day	(particle-$\gamma\gamma$)/day
Average cross section for $\nu 1g_{9/2}^{-1} \otimes \nu 2d_{5/2}^{1}$ states : 120 mb	6200	500
Average cross section for $\nu 1g_{9/2}^{-1} \otimes \nu 3s_{1/2}^{1}$ states : 300 mb	15000	1200

Beam time request **TOTAL: 18 shifts for physical runs + 3 shifts for beam preparation**

Objective 2:

Previous experiment (IS559)

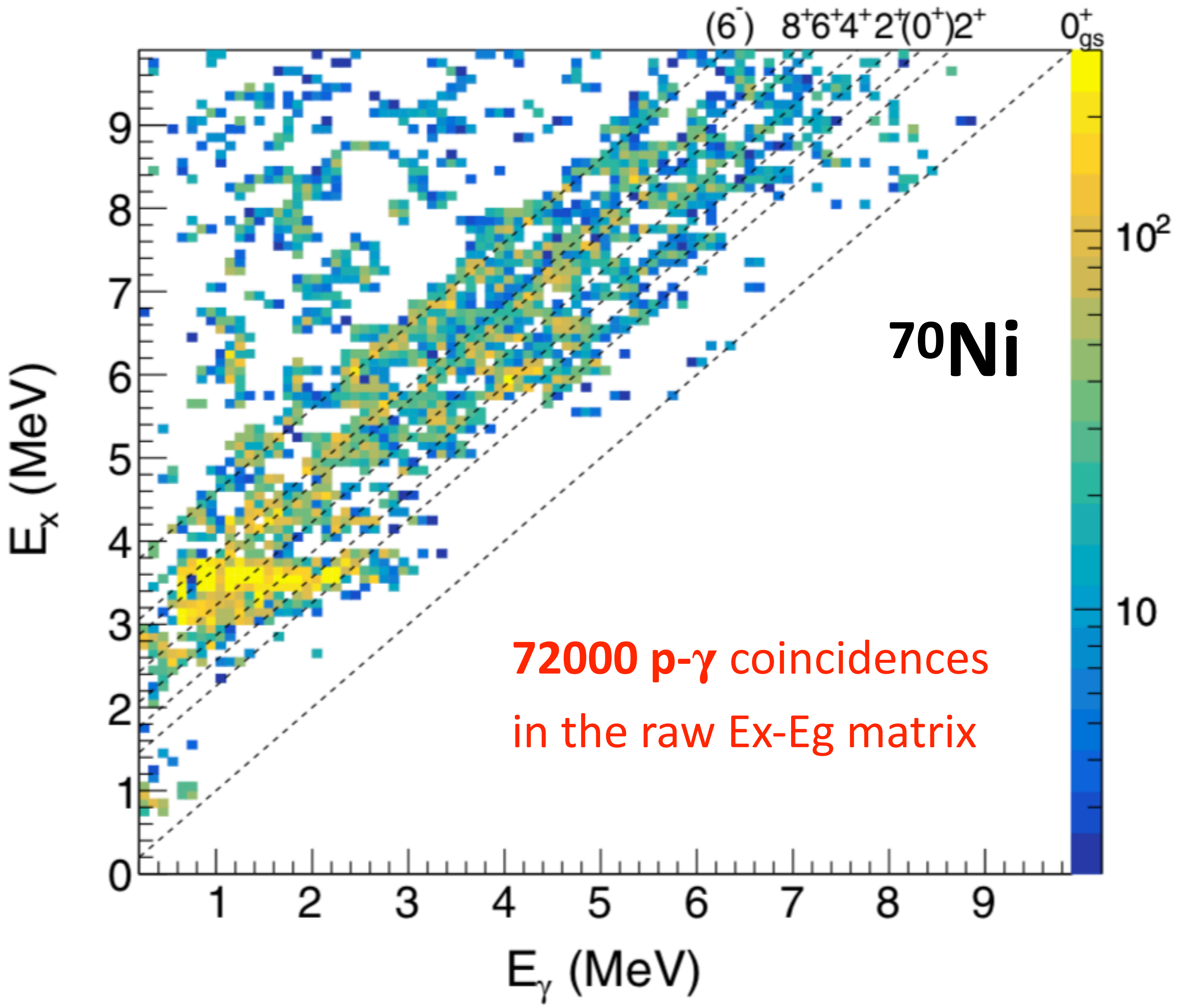
- ^{66}Ni + CD_2 —> ^{67}Ni +p
- E(^{66}Ni)=300 MeV (~4.5 MeV/u)
- I_{beam}= 4x10^6 pps at MINIBALL
- d_{target}= 0.6 mg/cm^2
- 6 days of beam time
- 6 LaBr3 were far from the target position
- CREX with only forward CD detector covering 25∘-49∘

Present case

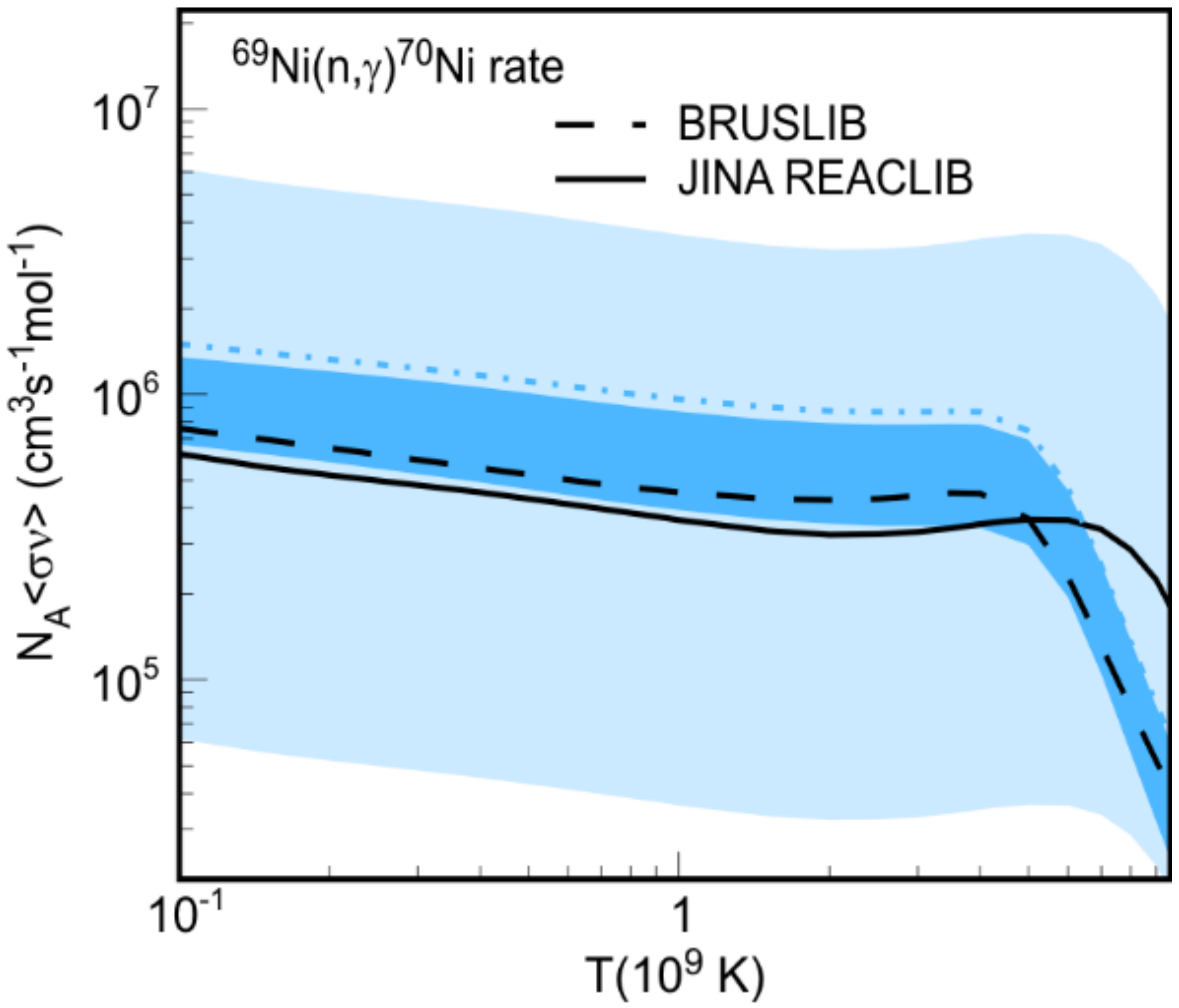
• ^{79}Zn+ CD_2 —> ^{80}Zn +p	
• **E(^{79}Zn)=435 MeV (~5.5 MeV/u)**	**Larger σ(CN)**
• I_{beam}= 5x10^4 pps at MINIBALL	**1/80**
• d_{target}= 1.2 mg/cm^2	**2**
• 6 days of beam time	
• 6 LaBr3 can be at least 5 cm closer	**Larger ε**
• TREX with CD and barrel detectors	**2**
Loss:	**1/20**

1.5 M p-γ events in ^{66}Ni(d,p)^{67}Ni

~75 K p-γ events in ^{79}Zn(d,p)^{80}Zn



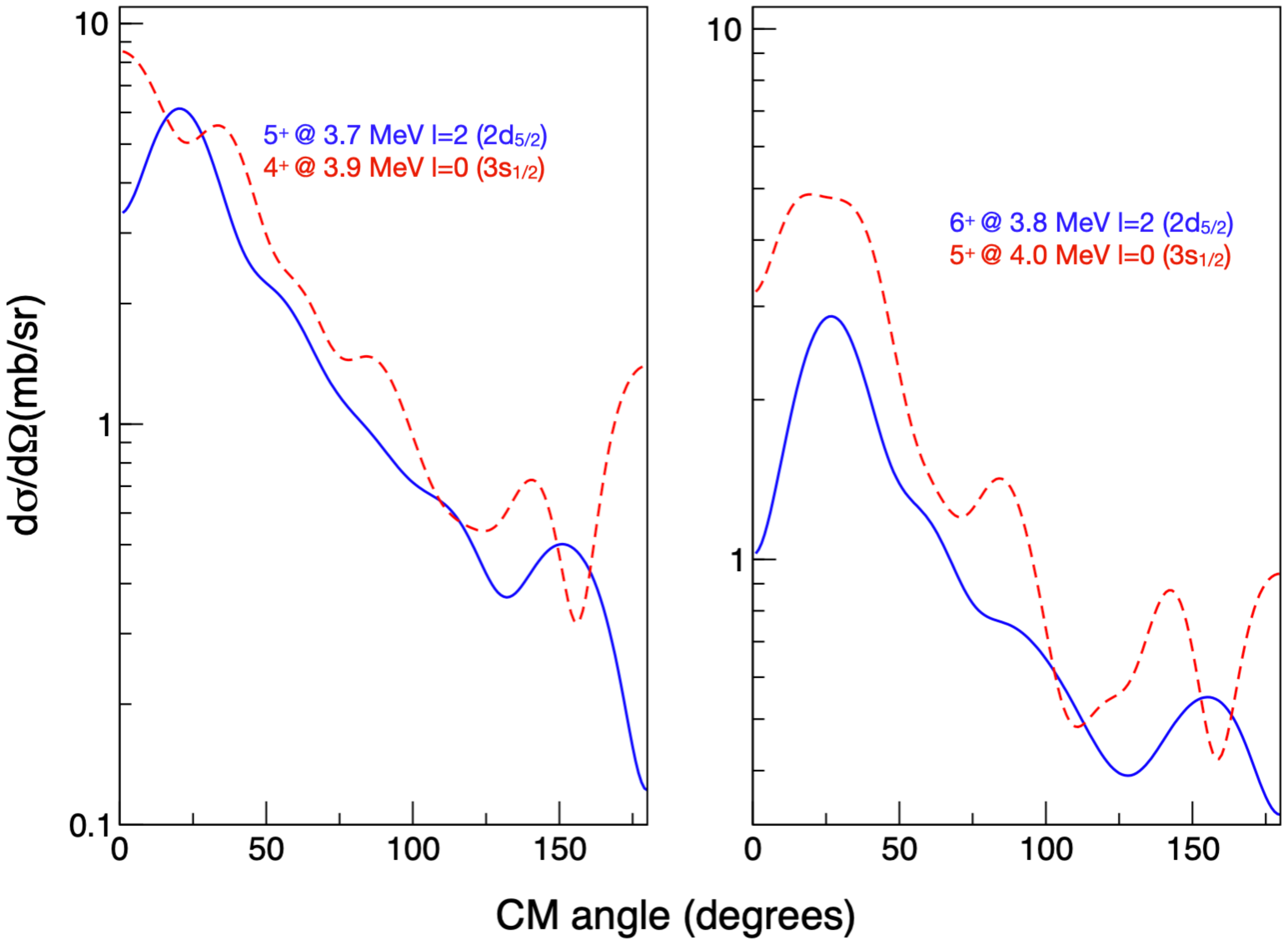
A.C. Larsen et al., PRC **97**, 054329 (2018)



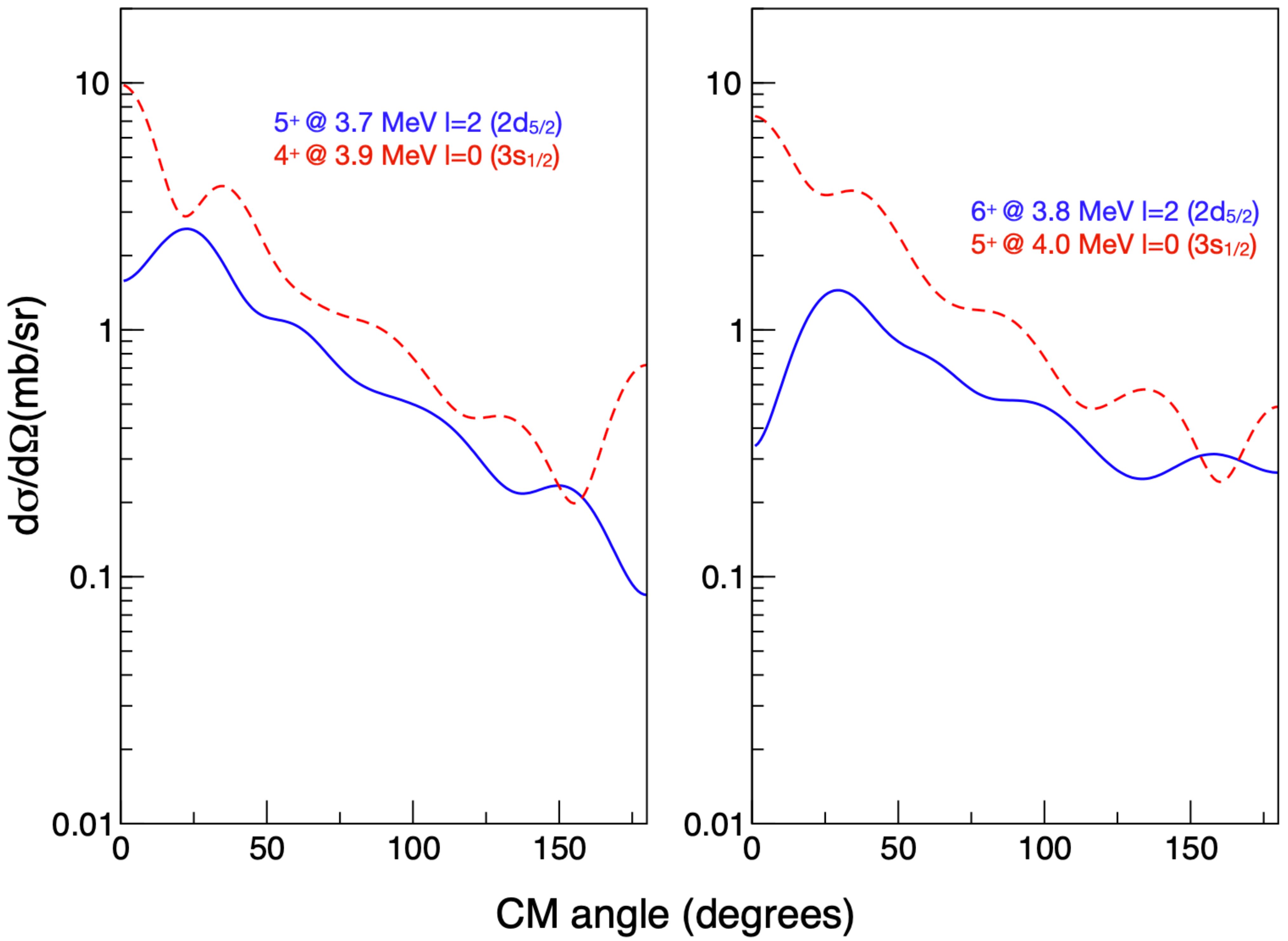
Thank you

Additional slides

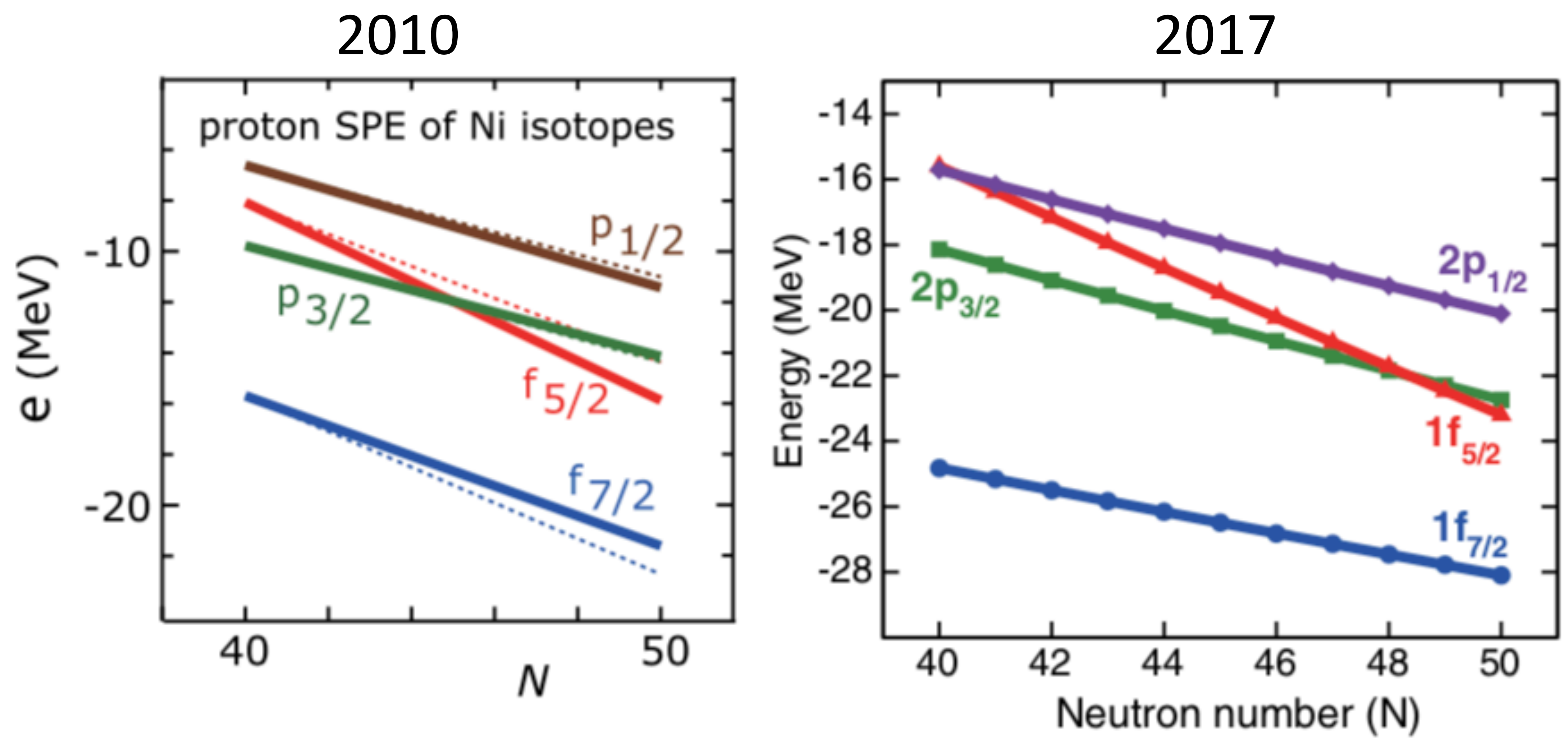
In the proposal



In the presentation after correcting the bug in Fresco



Evolution of Z=28 from N=40 to N=50



^{75}Cu:

K. Flanagan et al., PRL 103, 142501 (20109.

MCSM calc. : Monopole + Multipole comp.

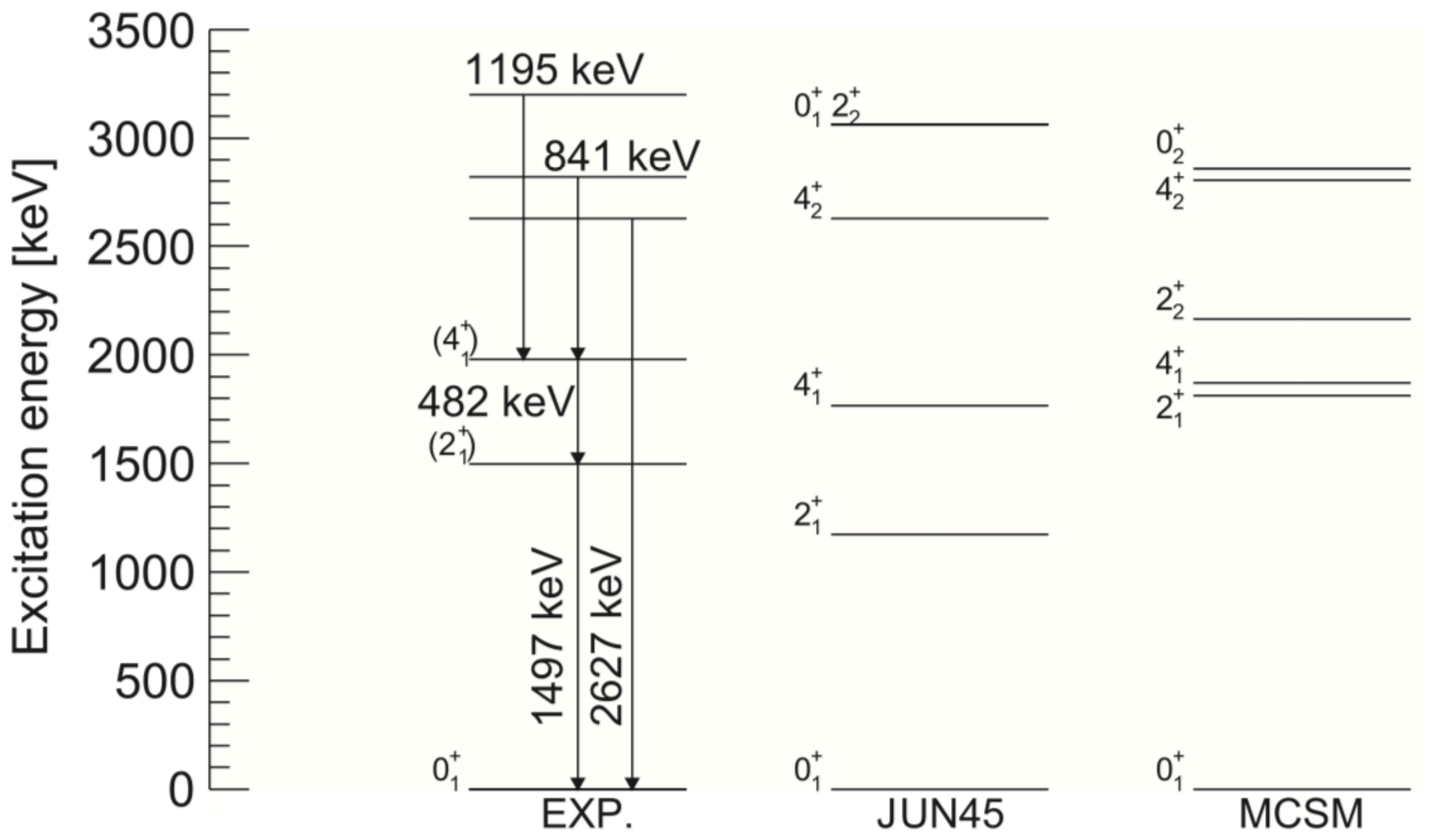
^{77}Cu

E.S. et al., PRL 118, 242502 (2017).

MCSM:Monopole + improved Multipole

Figure:

T. Otsuka, A. Gade, O. Sorlin, T. Suzuki, Y. Utsuno Rev. Of Mod. Phys. 92, (2020)

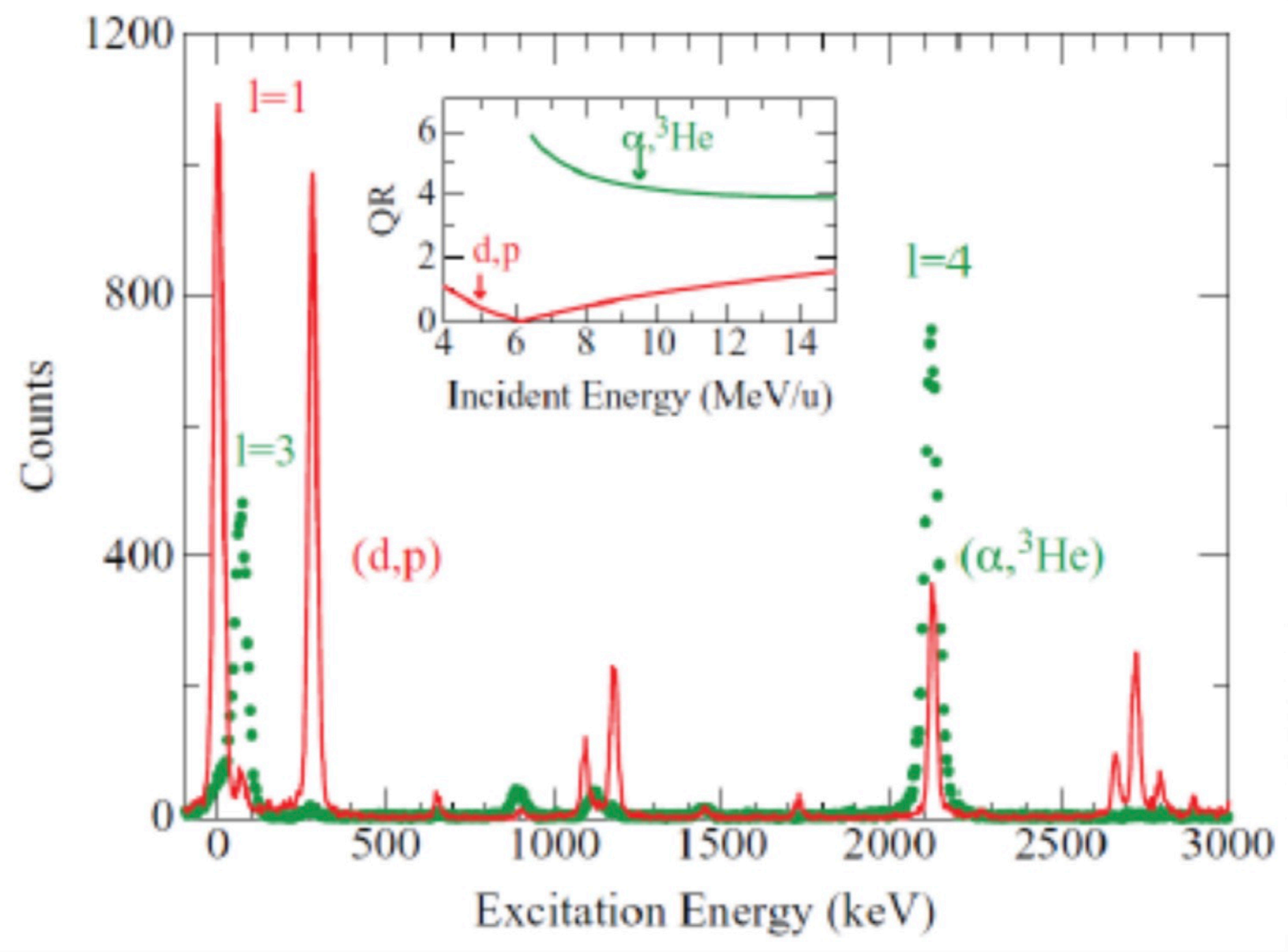


Excitation energy [keV]
3500
3000
2500
2000
1500
1000
500
0
1195 keV
841 keV
482 keV
1497 keV
2627 keV
(4+1)
(2+1)
0+1
EXP.
0+1 2+2
4+2
4+1
2+1
0+1
JUN45
0+2
4+2
2+2
4+1
2+1
0+1
MCSM

Momentum matching in transfer reactions

^{60}Ni(α,^{3}He): $Q_{g.s.}$= -12.8 MeV -> high momentum transfers

^{60}Ni(d,p): $Q_{g.s.}$= 5.6 MeV -> low momentum transfers



^{79}Zn(d,p)^{80}Zn

$Q_{g.s.}$=4.064 MeV

(example borrowed from C. Hoffman)

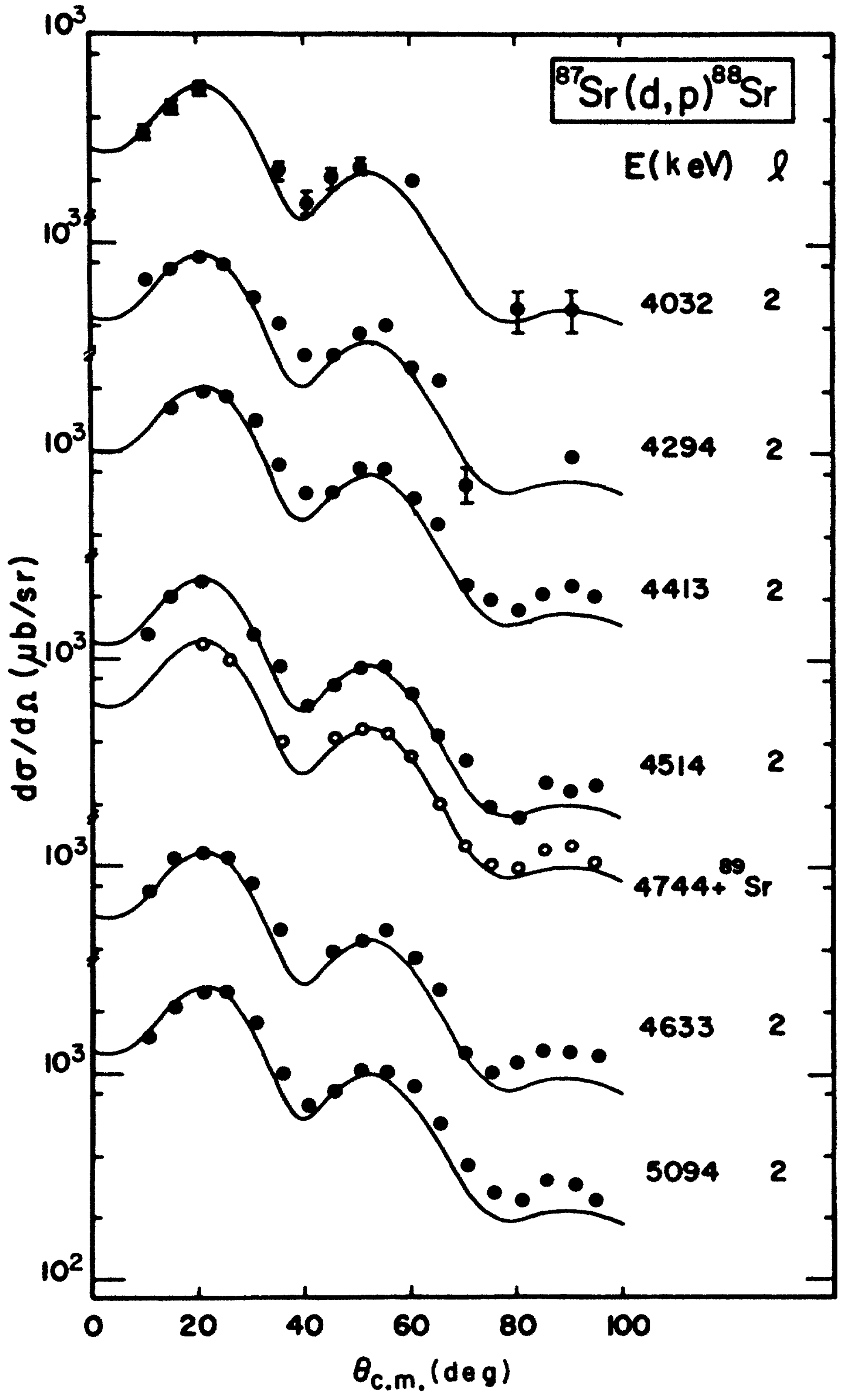


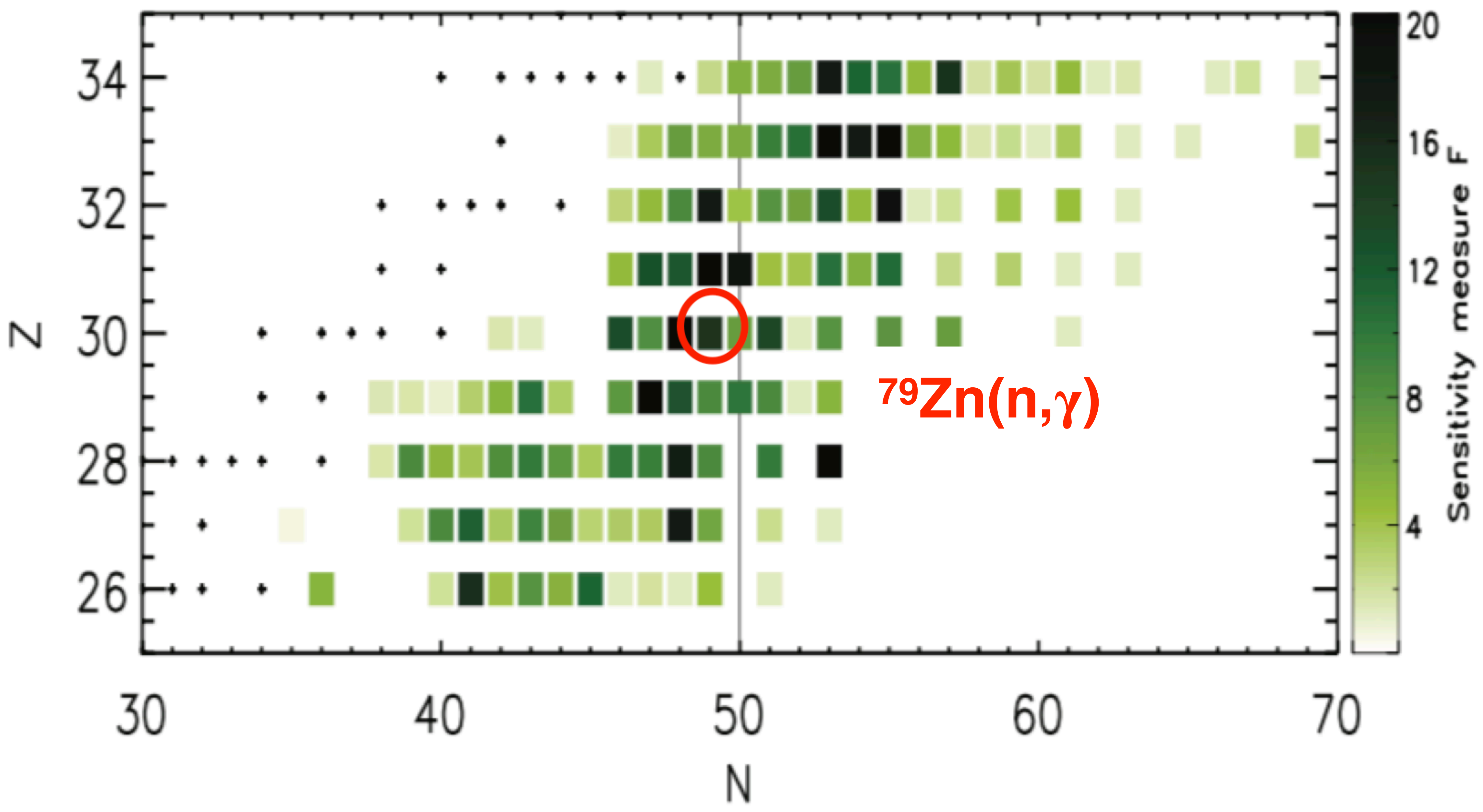
FIG. 8. Measured differential cross sections and DWBA fits for $l = 2$ transitions. All fits are based on NLFR calculations using L/B parameters.

TABLE V. Summary of (d,p) results for levels in ^{88}Sr.

Level No.[a]	E^* (keV)	Cosman and Slater[a] l	G_{lJ}[c]	This experiment[b] l	G^{88}_{lj}	G^{89}_{lj}	J^π (assumed)[d]	S^{88}_{lj}
1	(1836)	2	0.126	2	(0.13)		2^+	0.25
5	4032	2	0.279	2	0.35		2^+	0.71
6	4294	2	0.376	2	0.53		4^+	0.59
7	4413	2	0.875	2	1.18		$[5]^+$	1.07
8	(4450)	2	0.083	(2)	(~0.10)		$[4]^+$	(0.11)
10	4514	2	1.080	2	1.31		$[6]^+$	1.00
12	4633	2	0.564	2	0.68		$[3]^+$	0.97
13	4744	2	0.805	2	0.14	5.86	$[4]^+$	0.28(0.16)
17	5094	2	1.040	2	1.33		$[7]^+$	0.89
			5.228		5.75	5.86		
15	4873[e]	0	0.230	0	0.24[e]		$[4]^+$	0.26[e]
21	5416	0	0.105	0	0.13		$[5]^+$	0.12
22	5466	0	0.563	0	0.61		4^+	0.67
23	(5506)	0	0.027	(0)	<0.01			
25	5729	0	0.789	0	0.94		$[5]^+$	0.85
26	(5780)	0	0.405	0	0(±0.03)	1.92		
32	(6214)	0	0.031	(0)	(~0.03)			
			2.150		1.95	1.92		

Weak r-process

Sensitivity study to the n-capture process in the context of neutron-rich supernova and collapsar accretion disk winds.

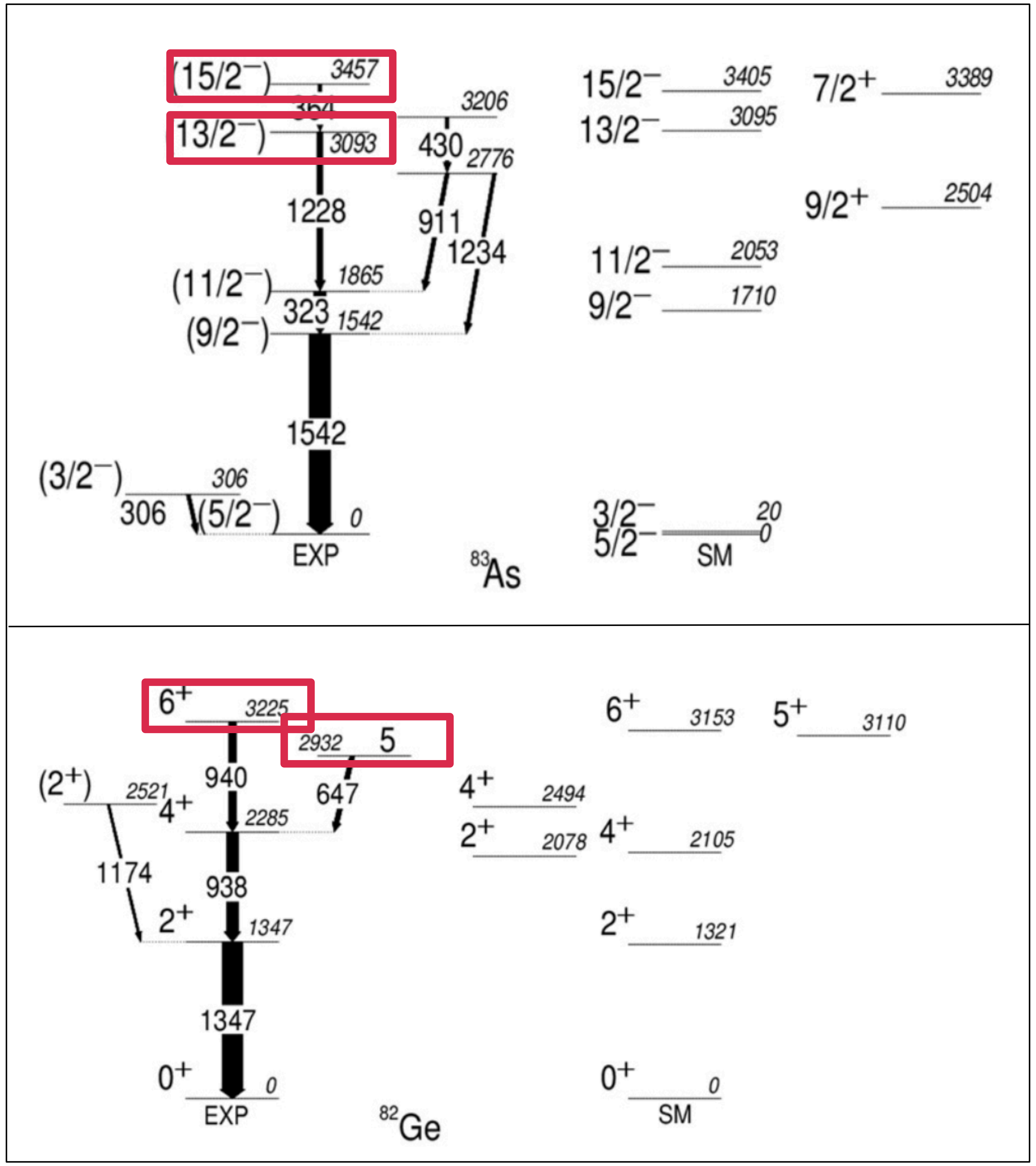


weak *r* process—a rapid neutron capture process that forms a solar-type *A* ~ 80 *r*-process peak and potentially nuclei up to the *A* ~ 130 peak.

Nuclear data relevant to r-process calculations are (pin-parity assignments, excitation energies, spectroscopic factors and can be extracted from transfer reactions, such as (d, p).

R. Surman et al., AIP Advances 4, 041008 (2014)

Equivalent of $5^+,6^+$ states in ^{82}Ge is found to be $13/2^-$, $15/2^-$ in ^{83}As



SM Calculations:

A.F. Lisetskiy, B.A. Brown, M. Horoi, H. Grawe, Phys. Rev. C 70 (2004) 044314.

Interaction: JJ4B + SDI

Model spaces: *pfg9+sdg*

Inert Core nucleus: ^{56}Ni

Tensor interactions are included

The SPEs relative to the ^{56}Ni core have been derived from the SPEs with respect to the doubly-magic ^{78}Ni core.

Model Space	Single-Particle Energy			
pfg	$E(1f_{5/2})$	$E(2p_{3/2})$	$E(2p_{1/2})$	$E(1g_{9/2})$
	-9.28590	-9.65660	-8.26950	-5.89440
sdg	$E(2d_{5/2})$	$E(3s_{1/2})$	$E(1g_{7/2})$	
	-1.19440	-0.16800	0.2700	

$$E(\nu d_{5/2} - \nu g_{9/2}) = \text{parameter}$$

ES et al.,Nucl. Phys. A 893, 1-12 (2012)