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

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[1]KU Leuven, Belgium; [2]CEA-Saclay, France; [3]CERN-ISOLDE, Switzerland; [4]University of Kentucky, U.S.; [5]University of York, U.K.; [6]NCSR-Demokritos, Greece; [7]INRNE-BAS, Bulgaria; [8]University of Köln, Germany; [9]University of Lund, Sweden; [10]Univeristy of Manchester, U.K.; [11]GANIL, France; [12]University of Edinburgh, U.K.; [13]CSNSM, France; [14]TU-München, Germany; [15]University of Jyväskylä; Helsinki Institute of Physics, Finland; [16]Oak Ridge National Laboratory, U.S.; [17]TU Darmstadt, Germany; [18]Univeristy of Athens, Greece; [19]TRIUMF, Canada; [20]HIL University of Warsaw, Poland; [21]Universite de Strasbourg, France; [22]University of Ioannina, Greece; [23]Central Michigan University, U.S.

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[1]KU Leuven, Belgi… … of York, U.K.; [6]NCSR-Demokritos… …[10]Univeristy of Manchester, U.K.; … …[15]University of Jyväskylä; Helsinki… …[18]Univeristy of Athens, Greece; … …[22]University of Ioannina, Greece; [23]…

^{68}Ni beam @ 4.0, 4.5, 5.0 MeV/u → Coulomb excitation – ^{68}Ni

^{68}Ni beam @ 4.0, 4.5, 5.0 MeV/u → One-neutron transfer – ^{69}Ni

^{70}Ni beam @ 3.5 MeV/u → Coulomb excitation – ^{70}Ni

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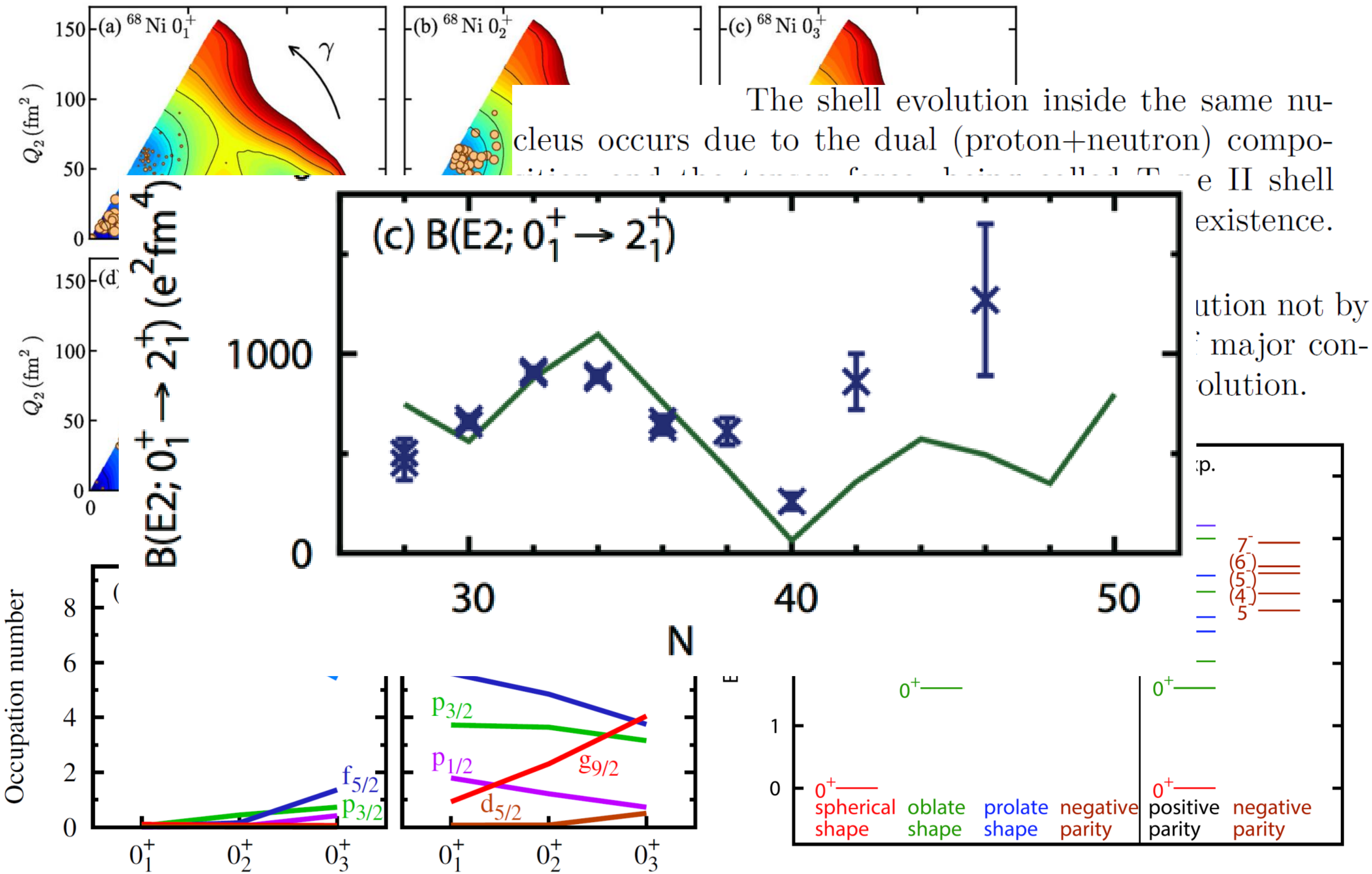
Monte Carlo Shell Model calculations

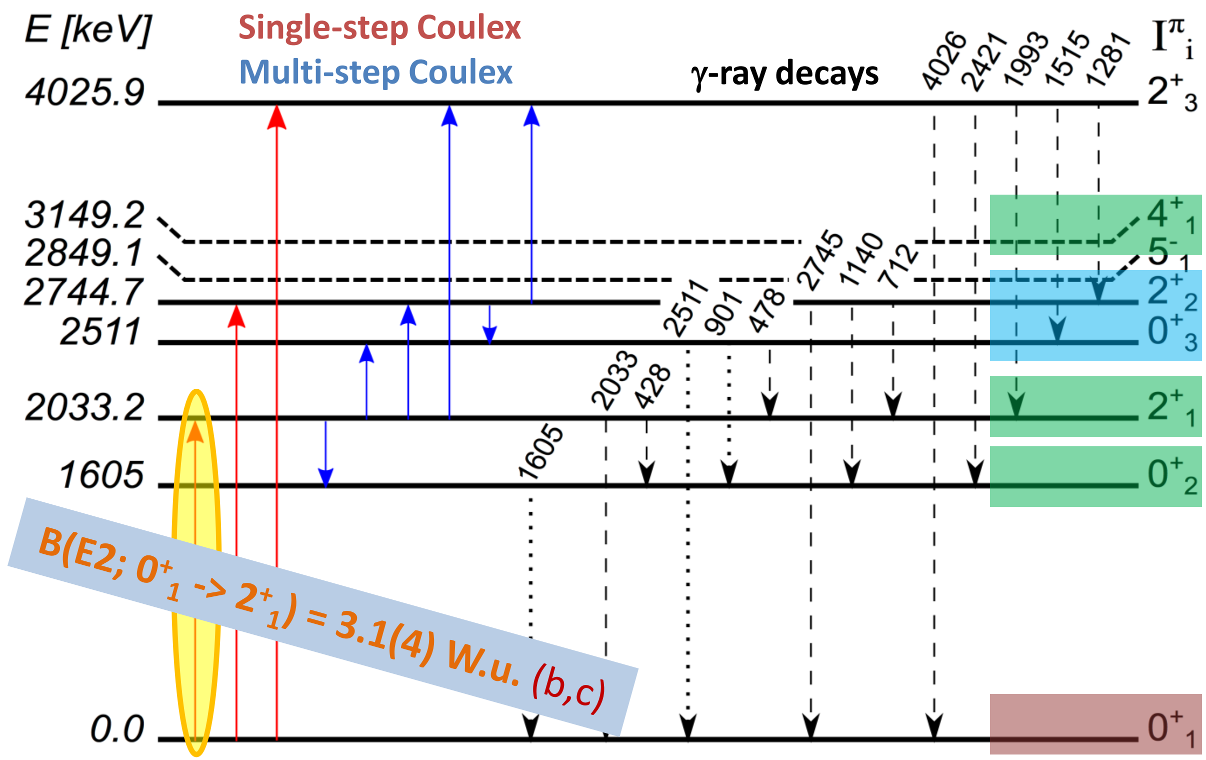


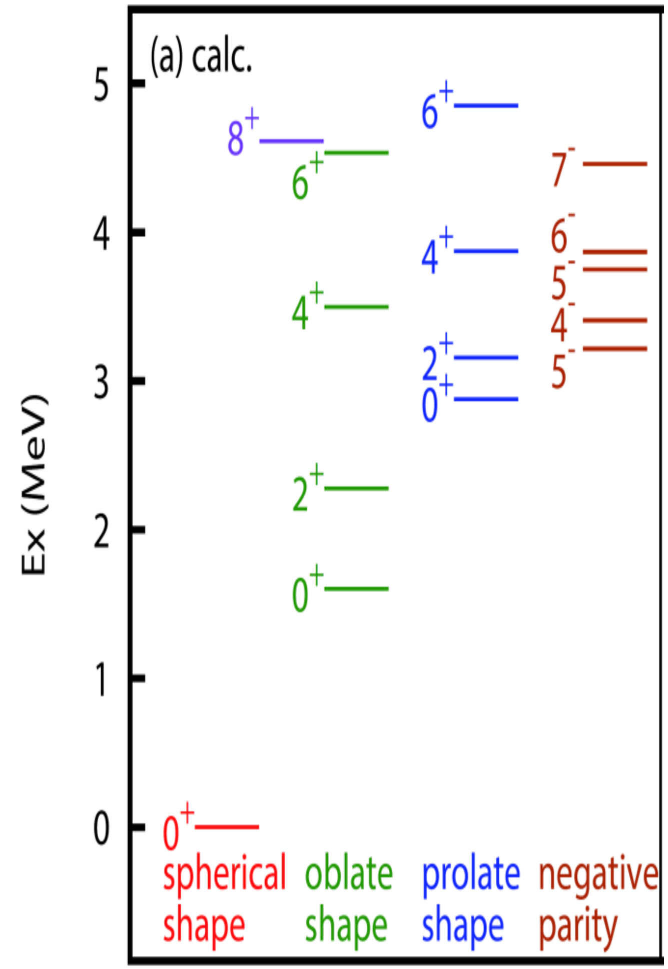
The shell evolution inside the same nucleus occurs due to the dual (proton+neutron) composition ... e II shell ... existence.

... ution not by ... major con- ... olution.

Y. Tsunoda JPG (2013), arXiv [nucl-th] 1309.5851v1

Excited states in ^{68}Ni (Z=28; N=40)





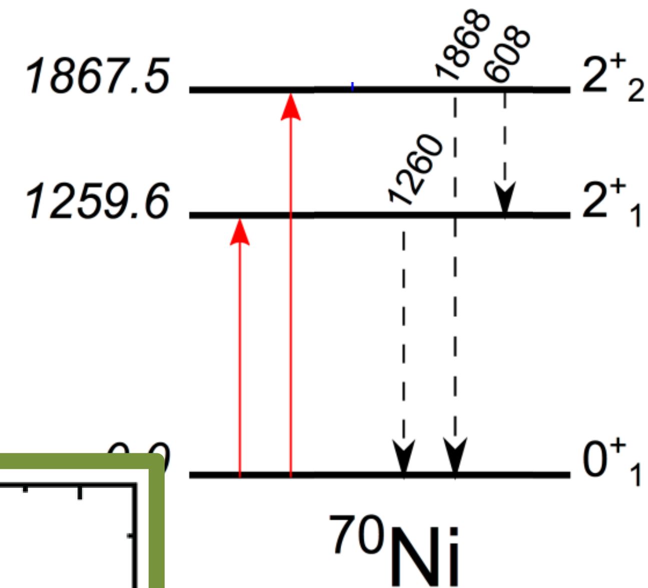
- Re-measure B(E2; 0^+_1 -> 2^+_1) at safe energy and higher precision with respect to ^{196}Pt target excitation.

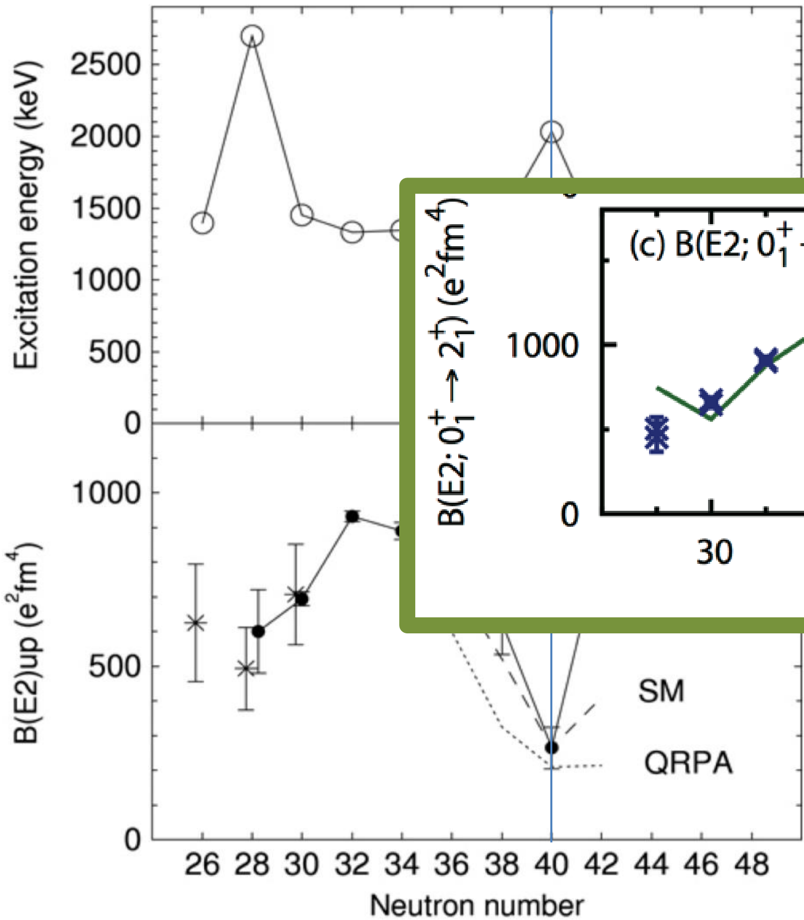
- Determine if higher-order transitions are of collective nature or not, using “clean” ^{208}Pb target.

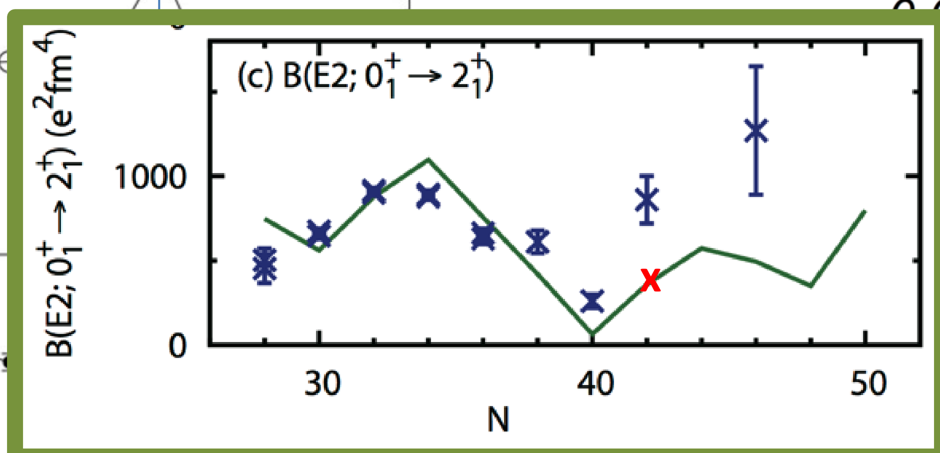
(a) Y. Tsunoda *J. Phys. G.* (2013), arXiv [nucl-th] 1309.5851v1
(b) O. Sorlin, et al., *Phys. Rev. C* **88**, 092501 (2002) – Intermediate energy Coulomb excitation
(c) N. Bree, et al., *Phys. Rev. C* **78**, 047301 (2008)

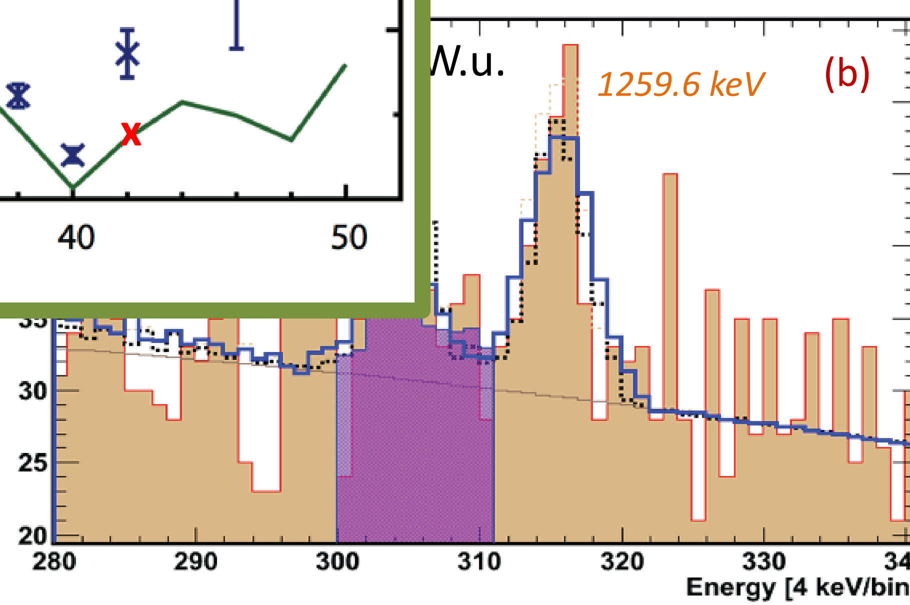
^{70}Ni: A discrepancy

- Intermediate energy Coulex gives large B(E2) = 10.0 W.u.
- Large B(E2) explained as proton-core polarisation (a)
- New RDDS Lifetime gives B(E2) = 2.7 W.u. (b)
- Consistent with latest shell-model calculations (c)









Reproduced from: O. Sorlin & M. Porquet, *Prog. Part. Nucl. Phys.* **61**, 602 (2008).
(a) O. Perru et al., *Phys. Rev. Lett.* **96**, 232501 (2006).

(b) D. Miller et al., *Bull. Am. Phys. Soc.* **55**, DC.00001 (2010).
(c) Y. Tsunoda JPG (2013), arXiv [nucl-th] 1309.5851v1.

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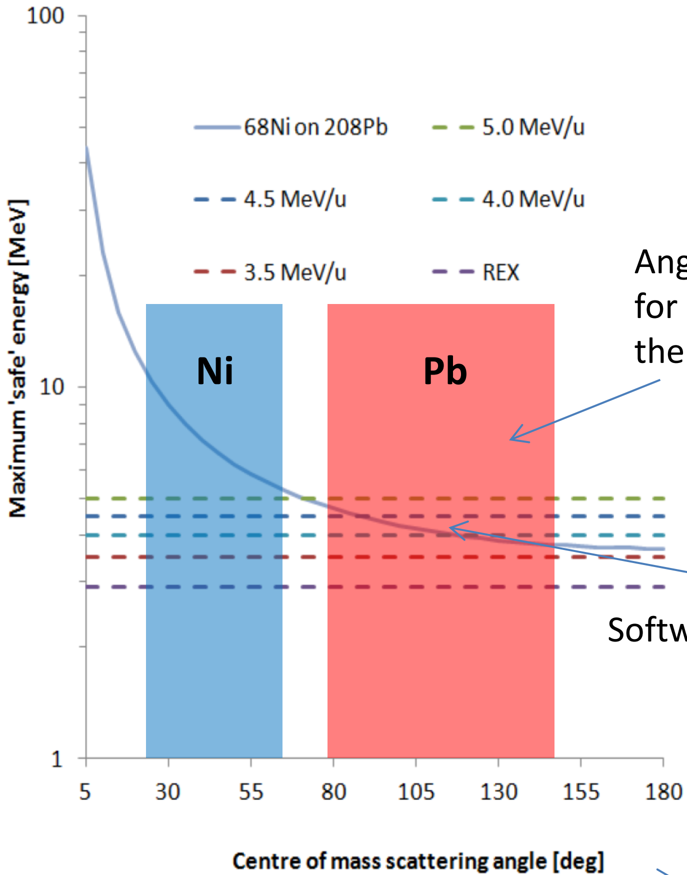
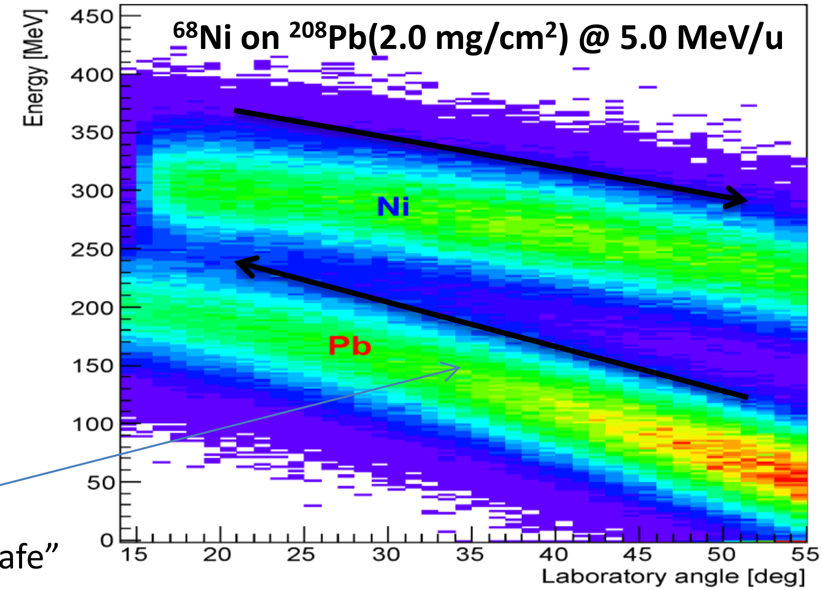
Coulex experiment and simulations



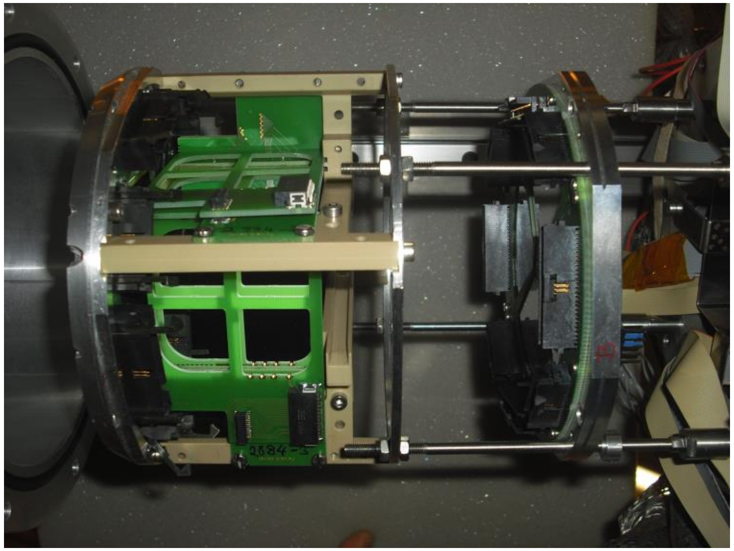
Increasing multi-step probability

Angles of detection for projectile/recoil in the T-REX setup

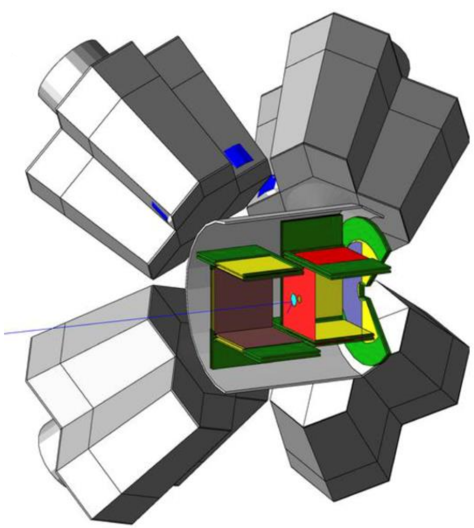
Software cut to make “safe”



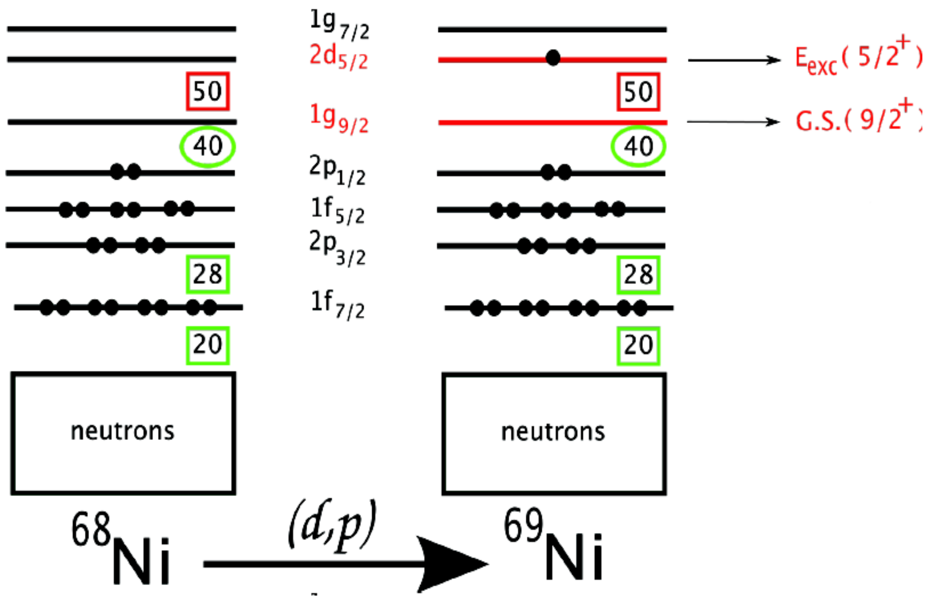
- Front CD (150 μm thick) without barrels
- Adjustable target CD-distance to optimise angles
- Rear CD + rear barrels (not used for Coulex)



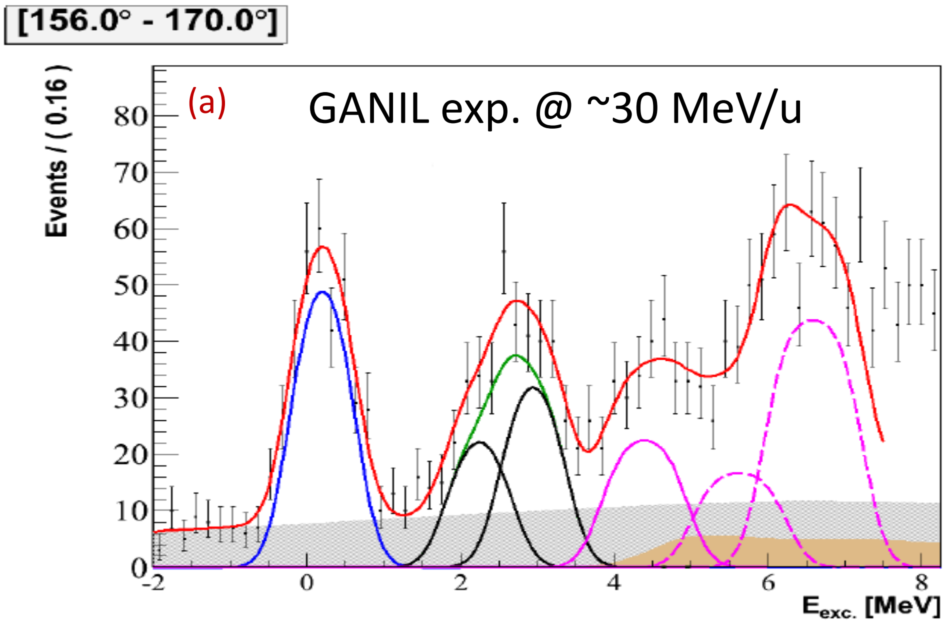
T-REX + Miniball



One-neutron transfer: ^{69}Ni

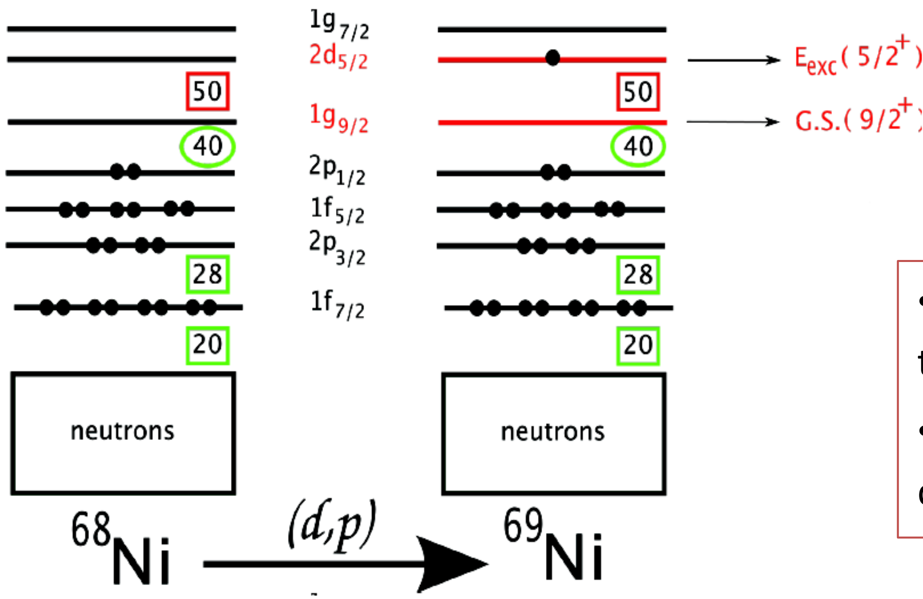


- Identification of 5/2⁺ -> info on *N*=50 shell gap.
- Previous experiment fits two states; one "bump"



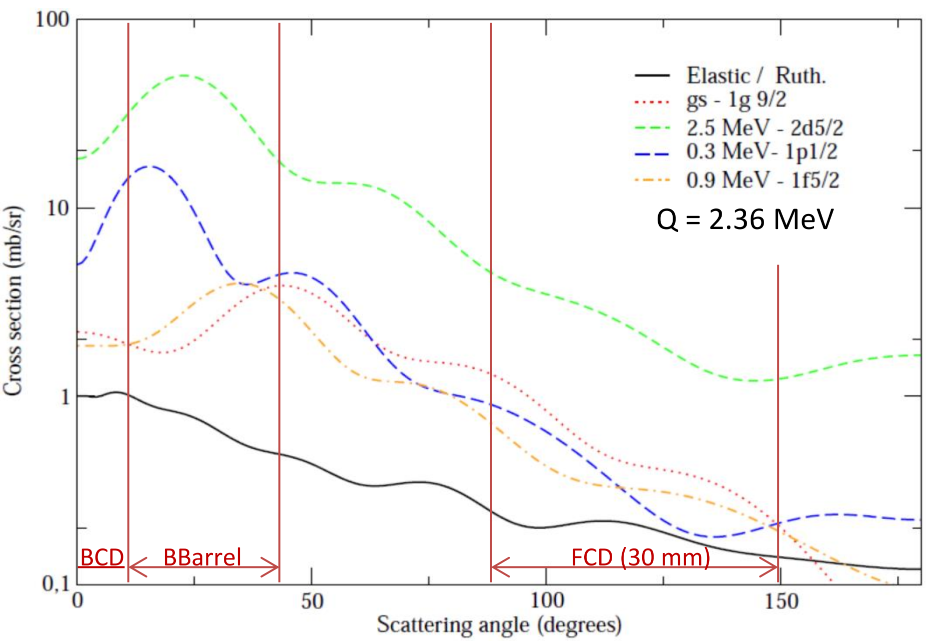
(a) M. Moukaddam. Thesis: *Évolution de la structure en couches dans les noyaux de masse moyenne: Recherche de l'orbitale $2d_{5/2}$ neutron dans le ^{69}Ni*. Strasbourg (2012)

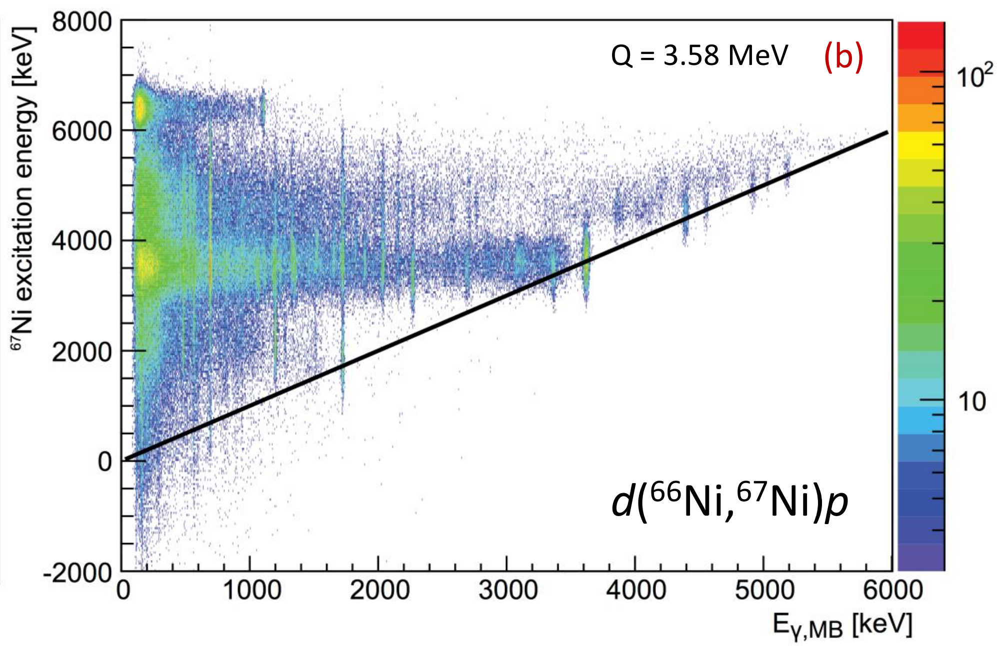
One-neutron transfer: ^{69}Ni



- Identification of $5/2^+$ -> info on *N*=50 shell gap.
- Previous experiment fits two states; one “bump”

- New experiment better energy matched for *l*=2 transfer => large cross-section for $5/2^+$ state(s).
- High resolution and efficiency of gamma-ray detection will give precise energy of $5/2^+$ states(s).





(b) J. Diriken. Thesis: *Probing positive-parity states in ^{67}Ni through one-neutron transfer reactions*. KU Leuven (2013)

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Beam-time request: ^{68}Ni

BriX

Beam rate

^{68}Ni beam – 2.1 x 10^5 ions/s @ Miniball
Primary yield – 1 x 10^6 ions/μC (estimated)

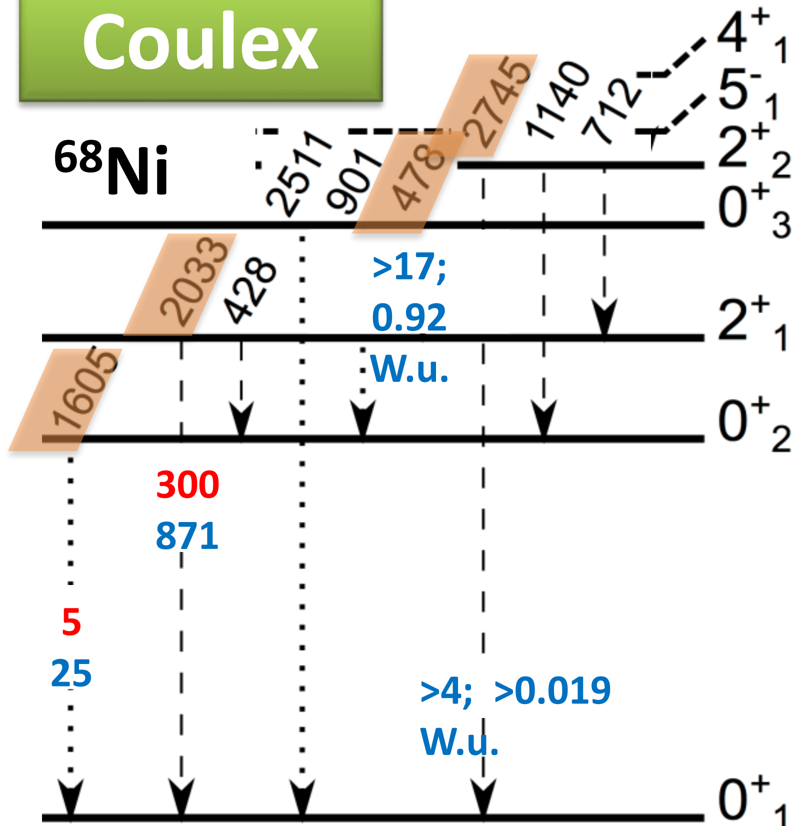
^{70}Ni beam – 2 x 10^4 ions/μC @ Miniball (assumed)
Primary yield – 2 x 10^5 ions/μC

Transfer – 5.0 MeV/u

Target (thickness)	σ (5/2$^+$) [mb]	SF (5/2$^+$)	Run time
CD_2 (0.2 mg/cm^2)	122	0.6	72 h

γ-ray efficiency	Angular coverage	Total p$^+$-γ coincidences
4% @ 2.5 MeV	~40%	**840** (Σ^i 5/2^+_i → g.s.)

Coulex



^{196}Pt (2.0 mg/cm^2) @ 4.5 MeV/u; 3 shifts
^{208}Pb (2.0 mg/cm^2) @ 4.0 MeV/u; 15 shifts
+ regular ionisation chamber runs with laser ON/OFF to accurately monitor contamination + beam dump γ rays

~50% ^{70}Ga contamination = ~50% Laser OFF runs

^{70}Ni

If 2.7 W.u.; I_γ(2$^+$ -> 0$^+$) = **117** counts per day
Or 10 W.u.; I_γ(2$^+$ -> 0$^+$) = **407** counts per day

^{196}Pt (2.0 mg/cm^2)
@ 3.5 MeV/u

Summary

^{68}Ni beam @ 4.0, 4.5, 5.0 MeV/u → Coulomb excitation – ^{68}**Ni** → 18 shifts

^{68}Ni beam @ 4.0, 4.5, 5.0 MeV/u → One-neutron transfer – ^{69}**Ni** → 9 shifts

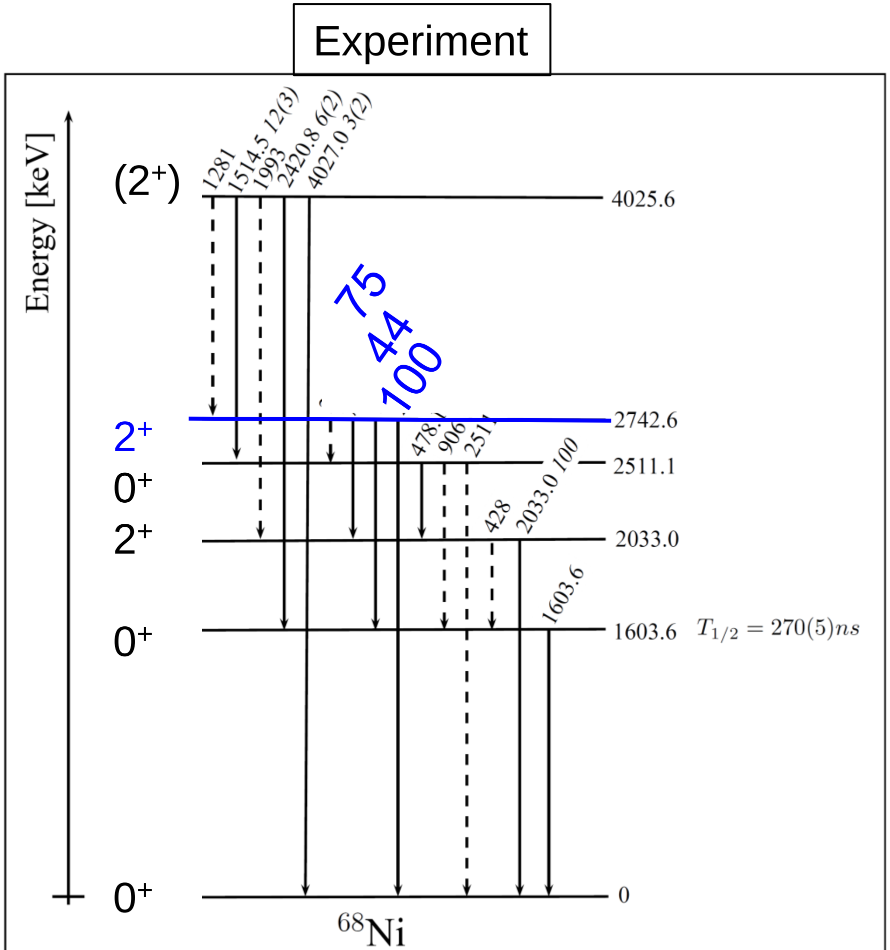
^{70}Ni beam @ 3.5 MeV/u → Coulomb excitation – ^{70}**Ni** → 12 shifts

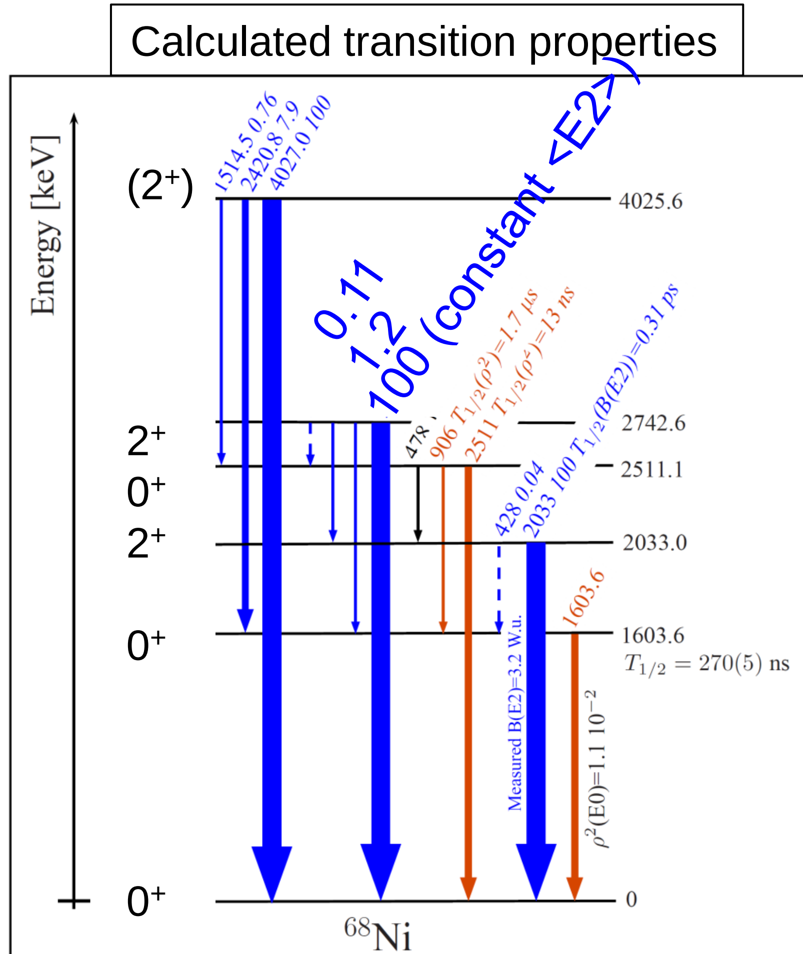
+1 shift for setup of each beam

41 shifts

^{68}Ni (Z=28, N=40)

- **β-decay proposal :**
  - obtain precise gamma- and electron transition intensities between the 0^+ and 2^+ states





Mueller PRC (2000), Flavigny (2013, IS467)

^{69}Ni (Level Scheme)

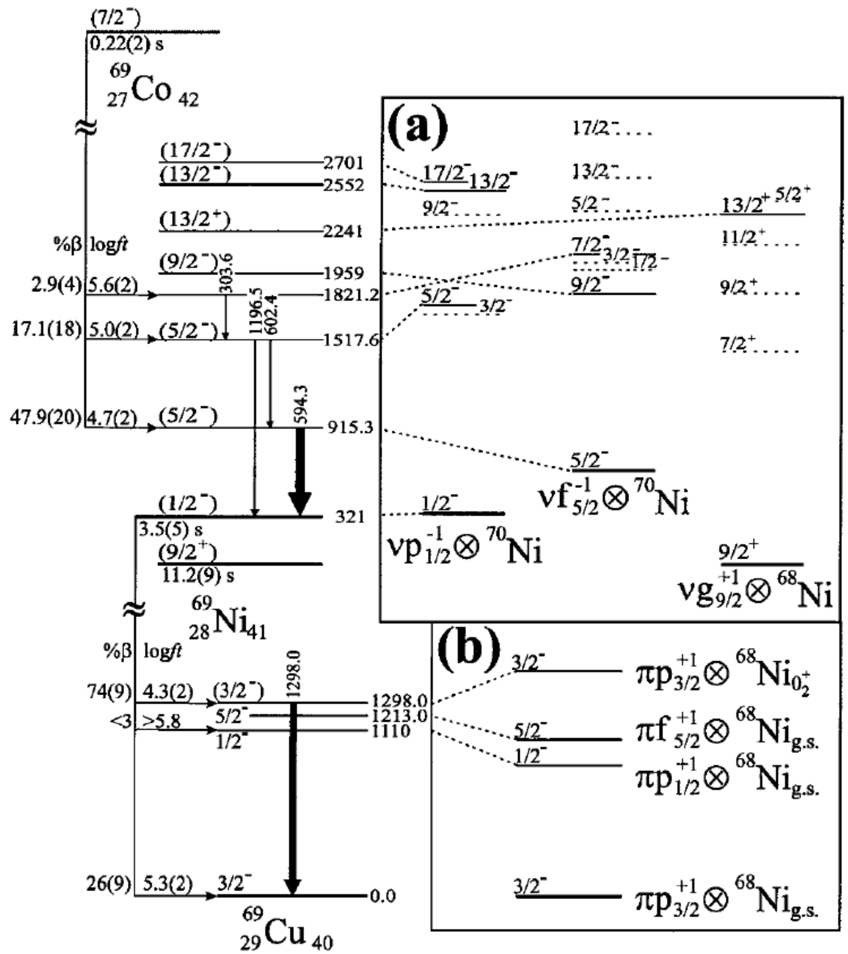


FIG. 2. The experimental decay scheme of ^{69}Co and ^{69}Ni, with comparative shell-model calculations for (a) ^{69}Ni and (b) ^{69}Cu. Theoretical levels that can be associated with experimental levels are indicated by solid levels and larger fonts. Details are provided in the text.

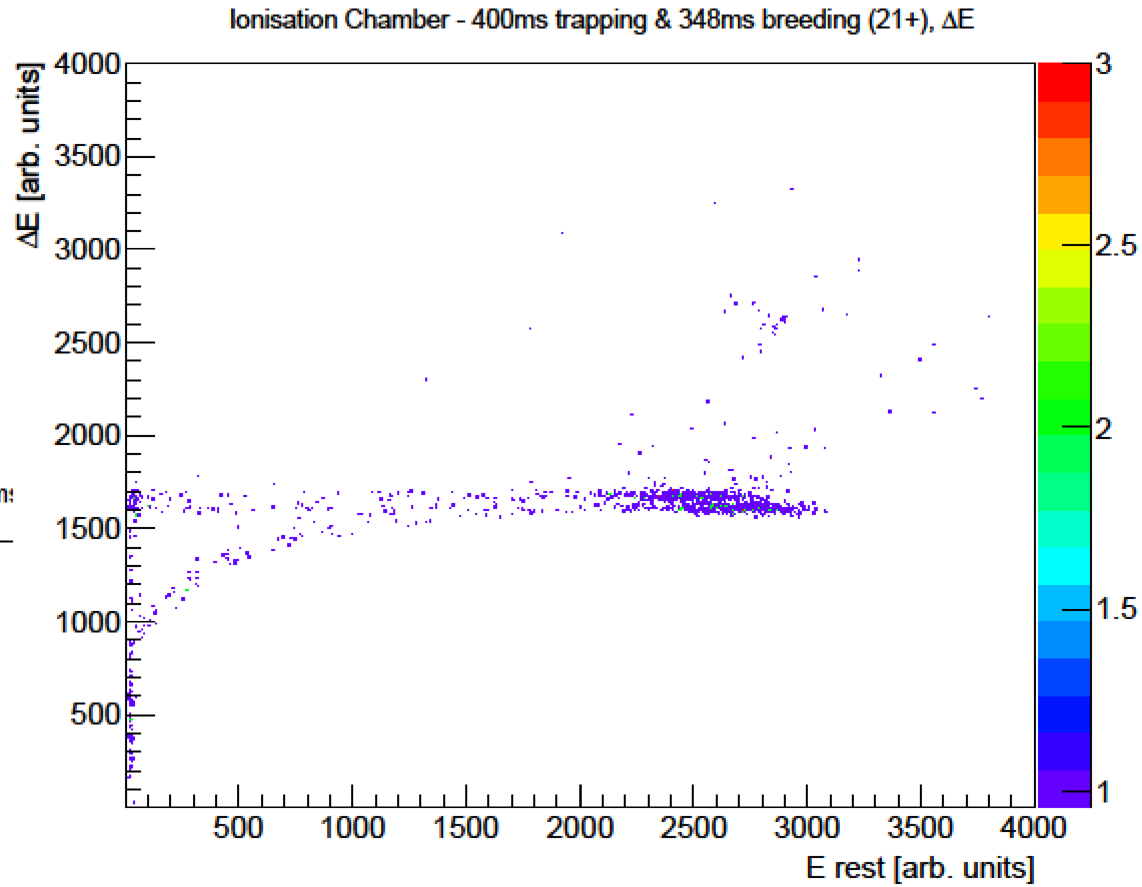
Beam contamination

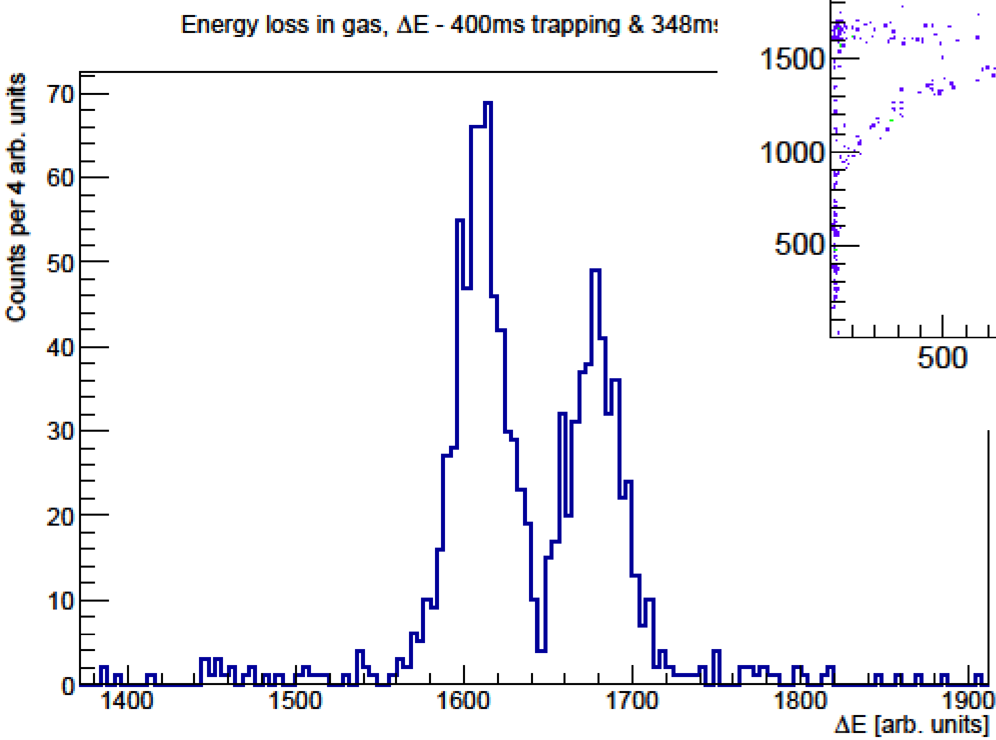
Ionisation chamber:

Mn/Fe (Z=25/26) previously separable[a]

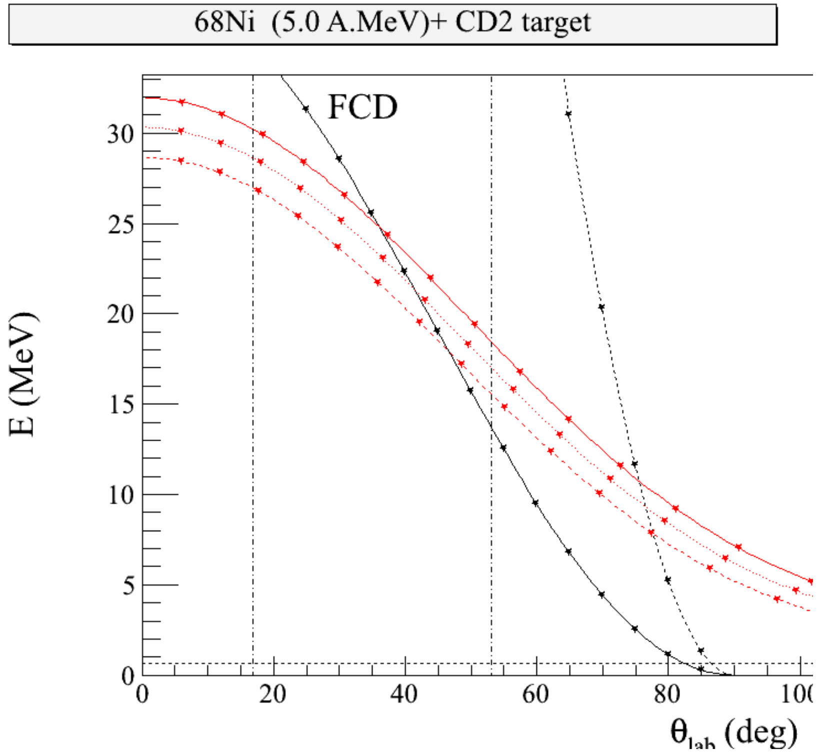
Easy to separate Ni/Ga (Z=28/31)…

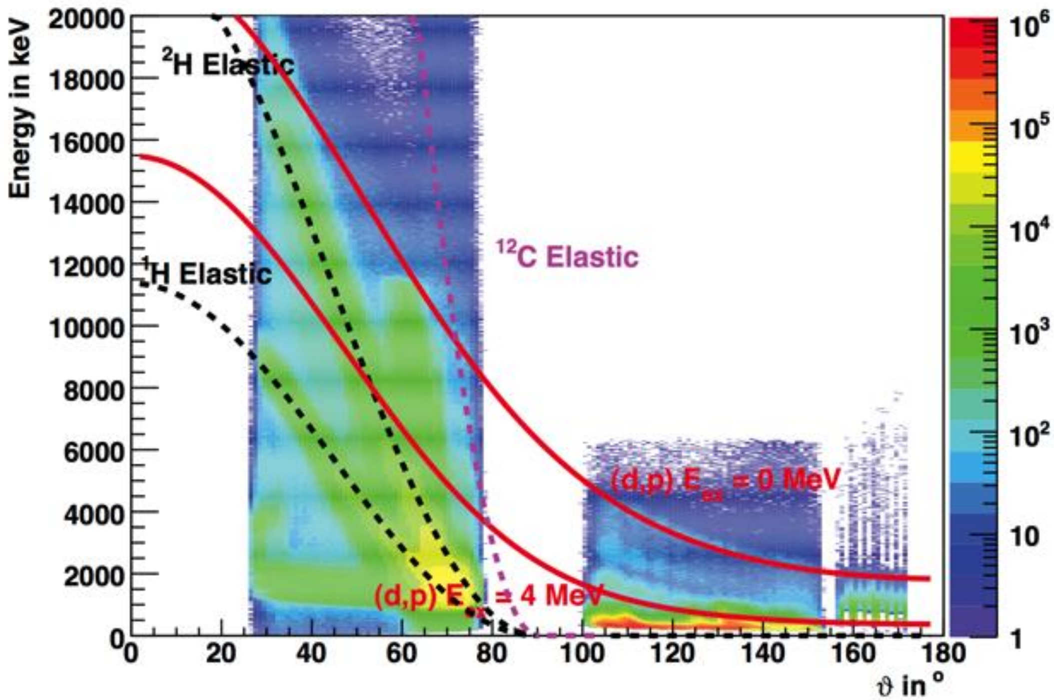
Advantage of direct beam measurement, high statistics quickly = short runs





(a) J. Van de Walle, et al., *Eur. Phys. J* **42**, 401-406 (2009).





Integrated cross section :

Gs = 3 mb

State at 2.5 MeV($d_{5/2}$) = 13 mb

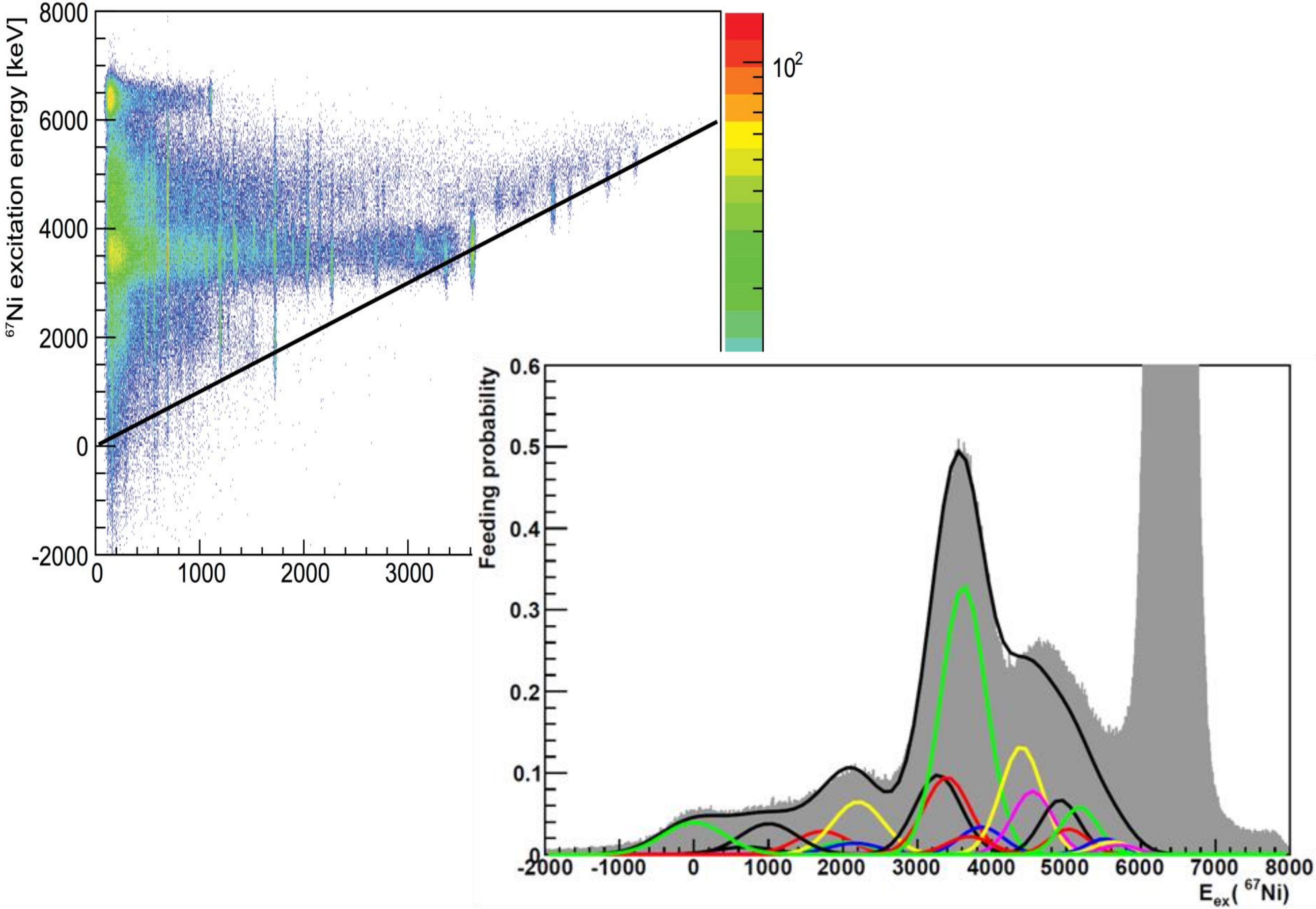
Proton stopped in dE
BCD and Barrel for GS
BBarrel used alone for 2.5 MeV states

Integrated cross section (Barrel only) :

Gs = 3.5 mb

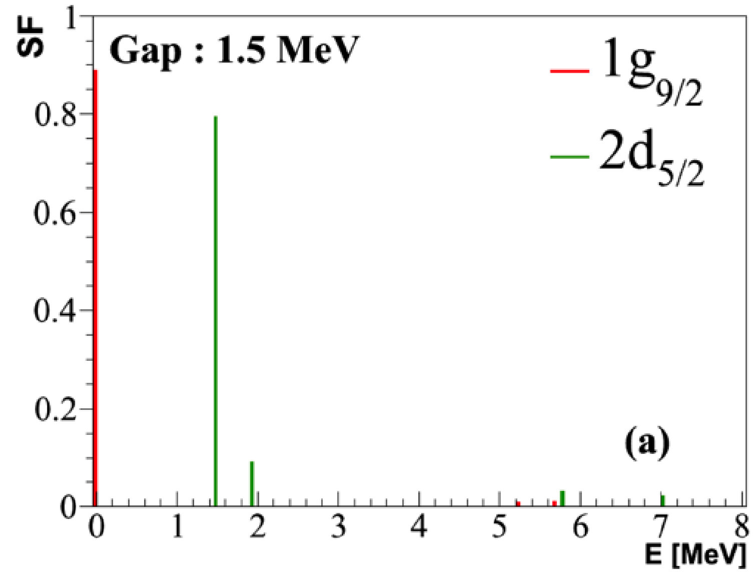
State at 2.5 MeV($d_{5/2}$) = 54 mb

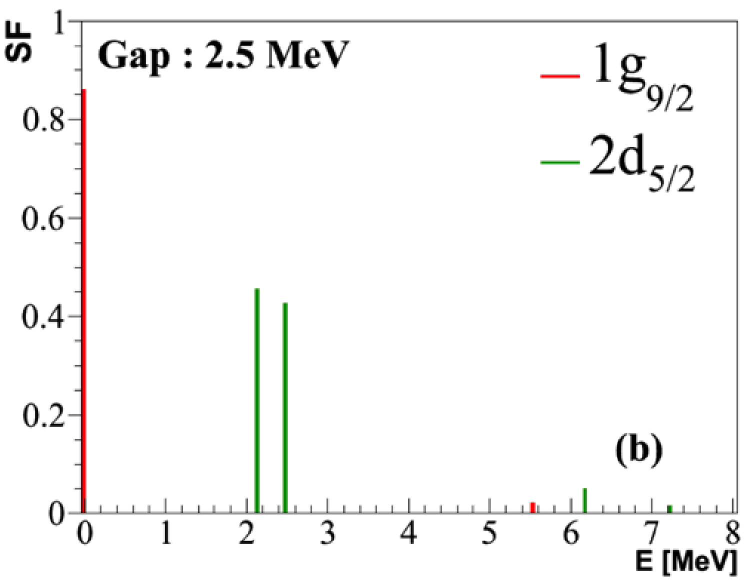
RatioTREX(gs) = 6,5/17 *0,95 ~ 37%
RatioTREX(d5/2) = 67/122 *0,95 ~ 47%

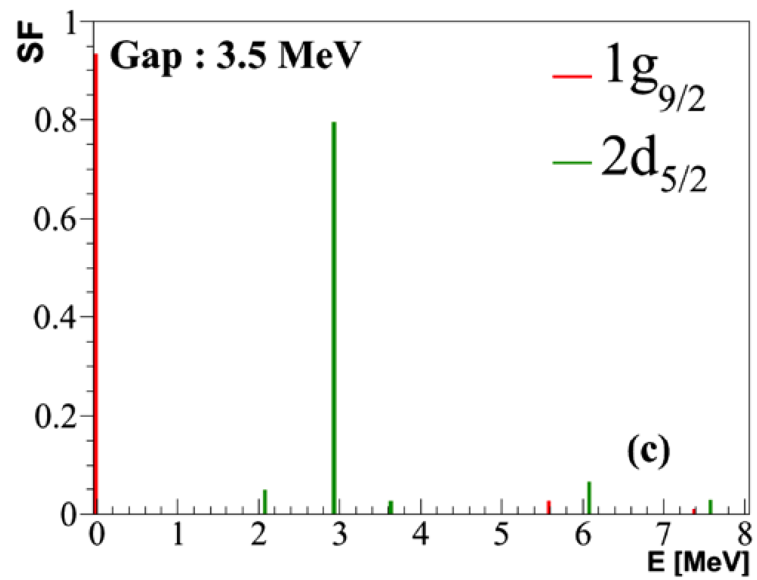

^{67}Ni excitation energy [keV]
8000
6000
4000
2000
0
-2000
0
1000
2000
3000
10^2
Feeding probability
0.6
0.5
0.4
0.3
0.2
0.1
0
-2000
-1000
0
1000
2000
3000
4000
5000
6000
7000
8000
E_{ex}(^{67}Ni)

^{69}Ni: updated motivation

- *N*=50 gap size influences energy and strength distribution of 5/2+ states.
- LNPS shell model calculations with 3 different assumed gaps.
- ~50/~50 distribution of 2 states at 2.0-2.5 MeV consistent with observation.
- Precise measurement will constrain calculations.





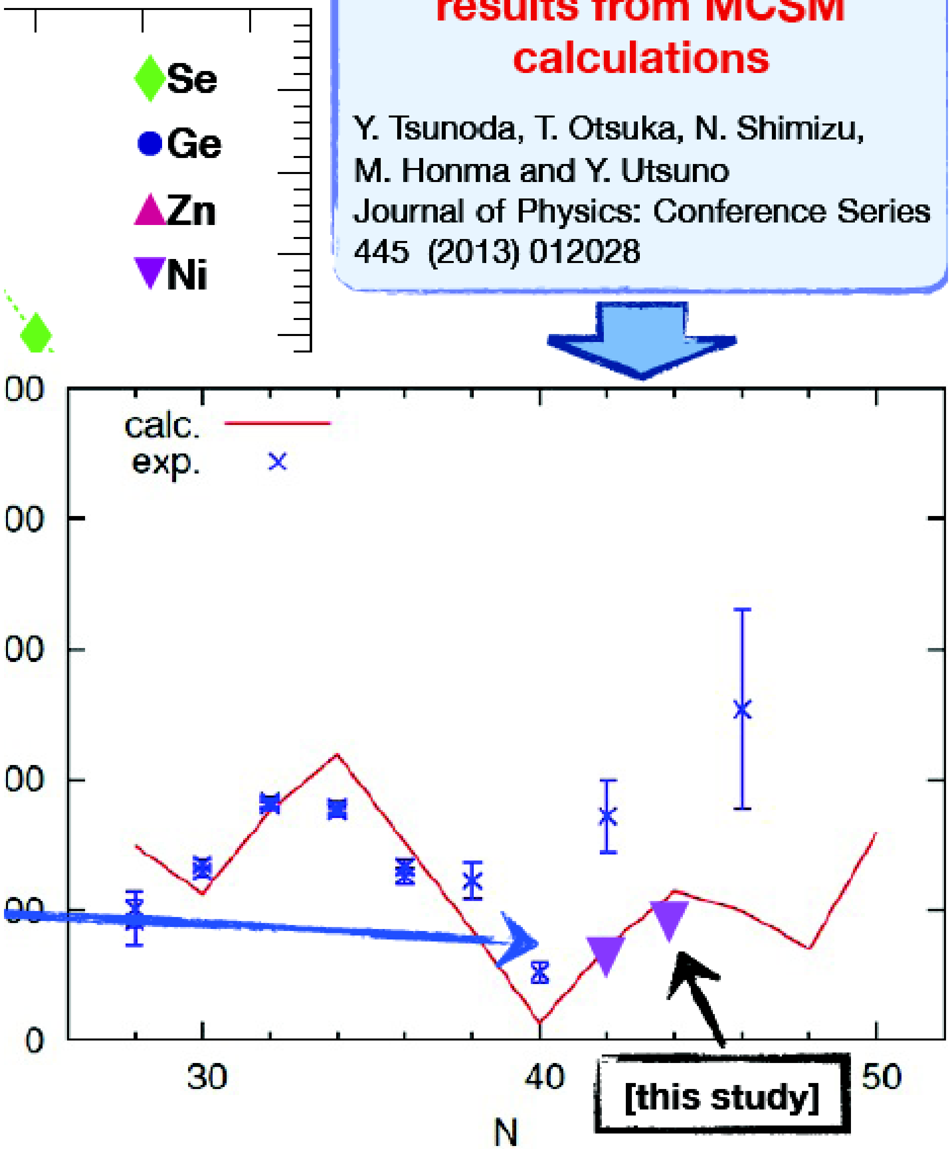


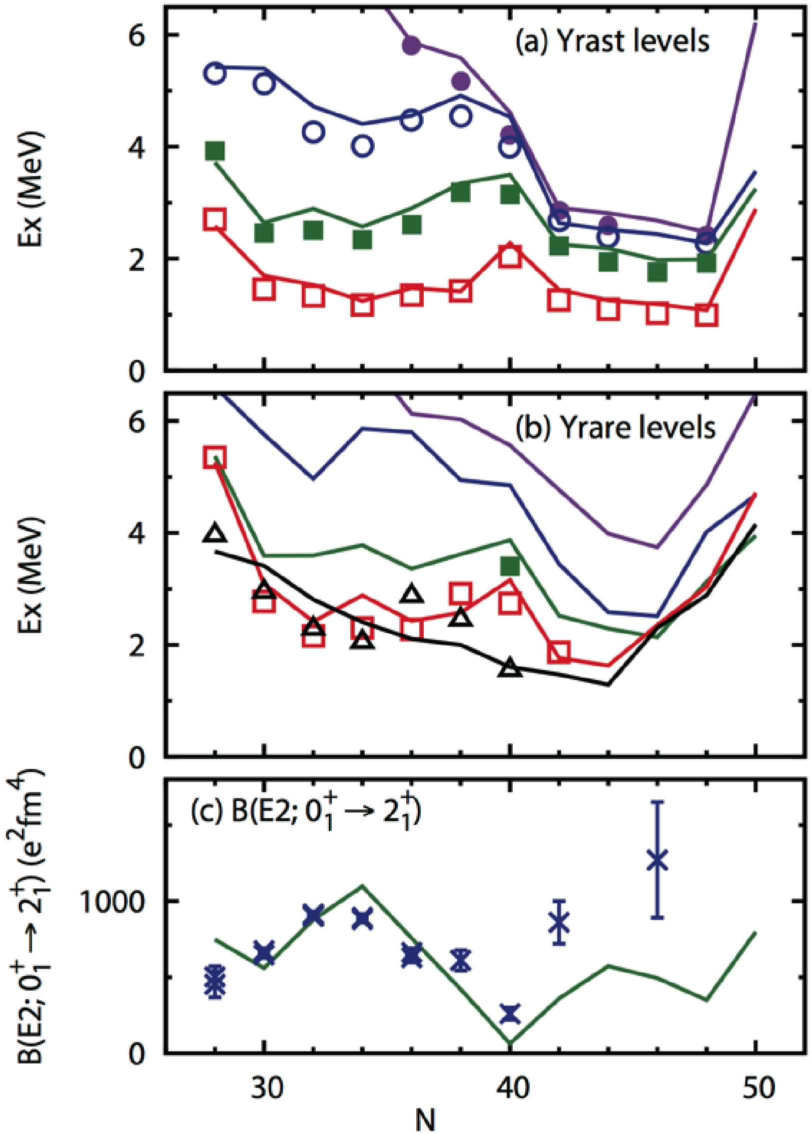
(a) M. Moukaddam. Thesis: *Évolution de la structure en couches dans les noyaux de masse moyenne: Recherche de l'orbitale 2d$_{5/2}$ neutron dans le ^{69}Ni*. Strasbourg (2012)

^{70}Ni: updated motivation

results from MCSM calculations

Y. Tsunoda, T. Otsuka, N. Shimizu, M. Honma and Y. Utsuno
Journal of Physics: Conference Series 445 (2013) 012028





Y. Tsunoda JPG (2013), arXiv [nucl-th] 1309.5851v1

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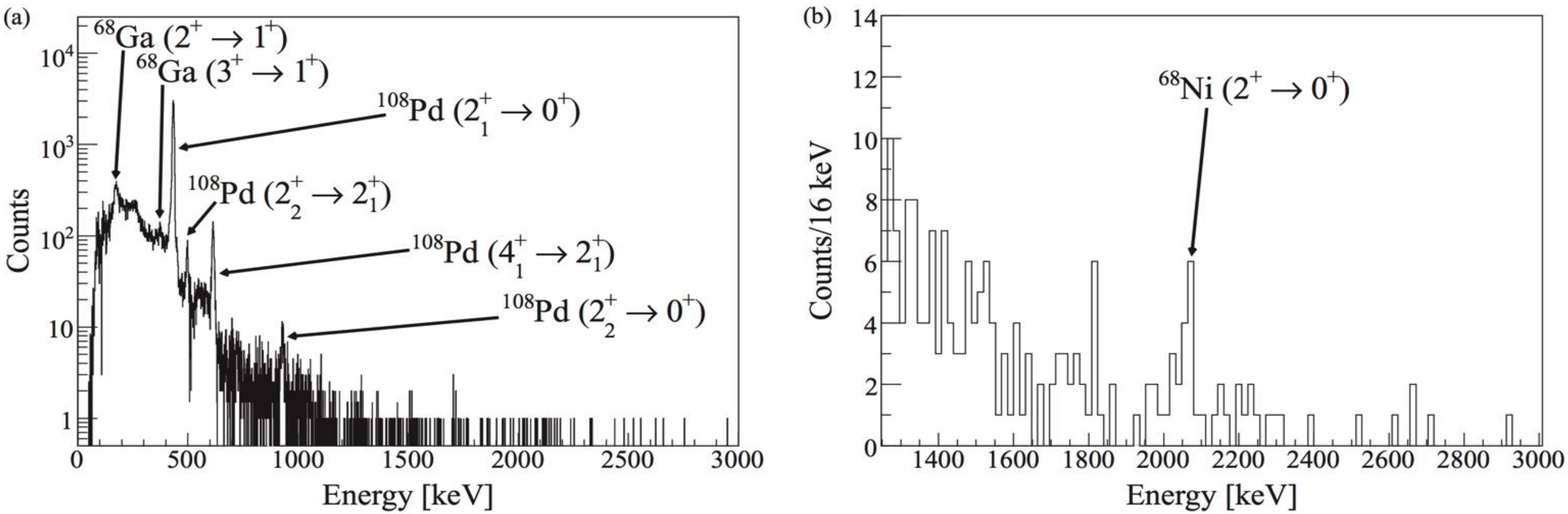
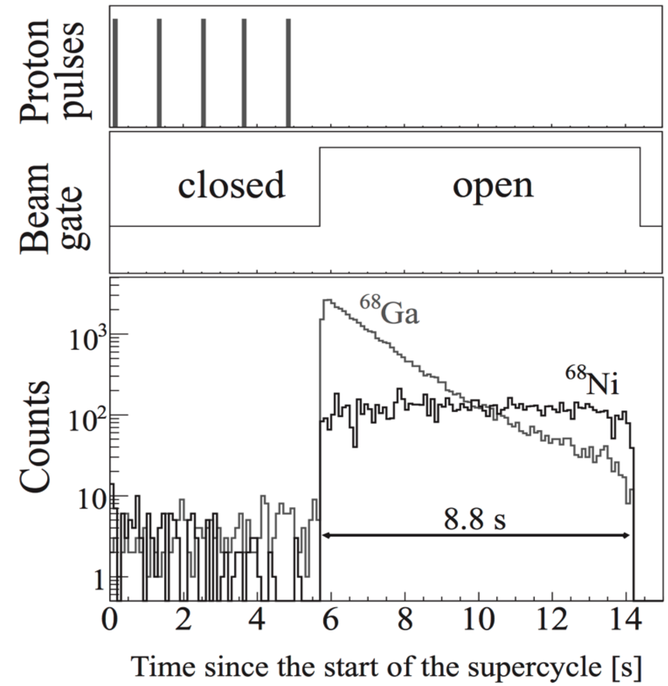
Previous ^{68}Ni Coulex at ISOLDE

BriX



$B(E2; 0^+_1 \rightarrow 2^+_1) = 2.8^{+1.2}_{-1.0} \times 10^2\ e^2\ fm^4$



Transfer – 5.0 MeV/u

Scenario	Target (thickness)	σ (5/2⁺) [mb]	SF (5/2⁺)	Run time	γ-ray efficiency	Angular coverage	Total p⁺-γ coincidences
Current	CD_2 (0.2 mg/cm²)	122	0.6	72 h	4% @ 2.5 MeV	~40%	840
Worst	CD_2 (0.2 mg/cm²)	"	0.5	"	3% @ 2.5 MeV	20%	280
Compensate	CD_2 (1.0 mg/cm²)	"	0.5	"	3% @ 2.5 MeV	20%	1420
Most recent simulation	**CD_2 (1.0 mg/cm²)**	**"**	**0.6**	**"**	**3.2% @ 2.5 MeV**	**47%**	**5370**

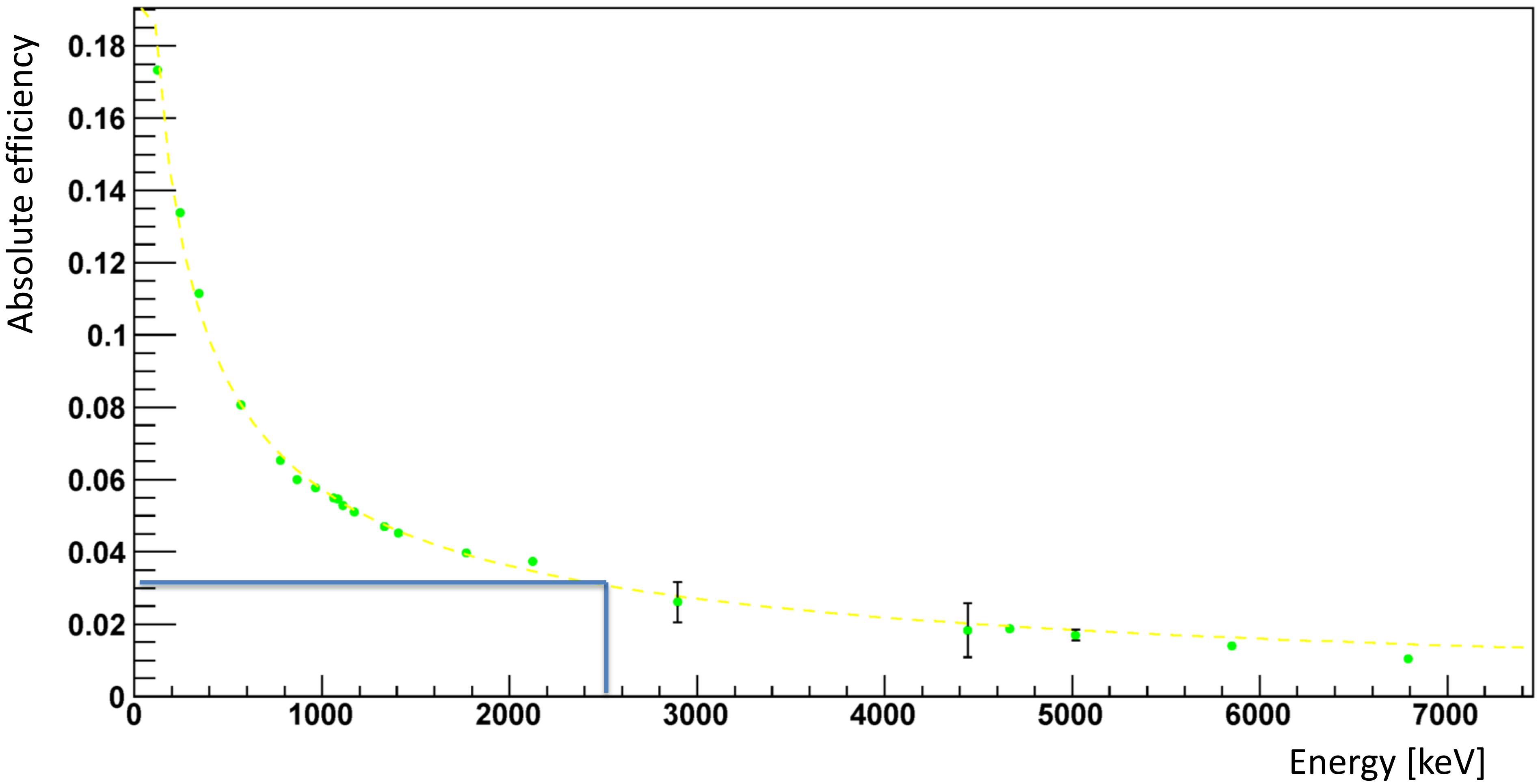
E_{loss} ~100 keV

Other states?

- Negative parity states not 1n configuration, hence SF << 1.
- Cross-section small regardless.

	Cross Sections (mb)	SF
GS(1g9/2)	17	1
2.5 MeV (2d5/2)	122	1
0.312 MeV (2p1/2)	25	1
0.915 MeV (1f5/2)	14	1

Miniball + TREX: Ge efficiency



Beam rates

Nucleus	^{68}Ni (ions/μC)	^{70}Ni (ions/μC)
Requested yields	**1 x 10^{6}**	**2 x 10^{5}**
Database values	4 x 10^{5}	1 x 10^{4}
Recent measurements	8 x 10^{5}	2 x 10^{5}
N. Bree Coulex	~10^{6}	