Experimental status of the N=20 region around ^{32}Mg

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DSM - DAM

Shape coexistence and electric monopole transitions in atomic nuclei

23-27 October 2017 – CEA-Saclay

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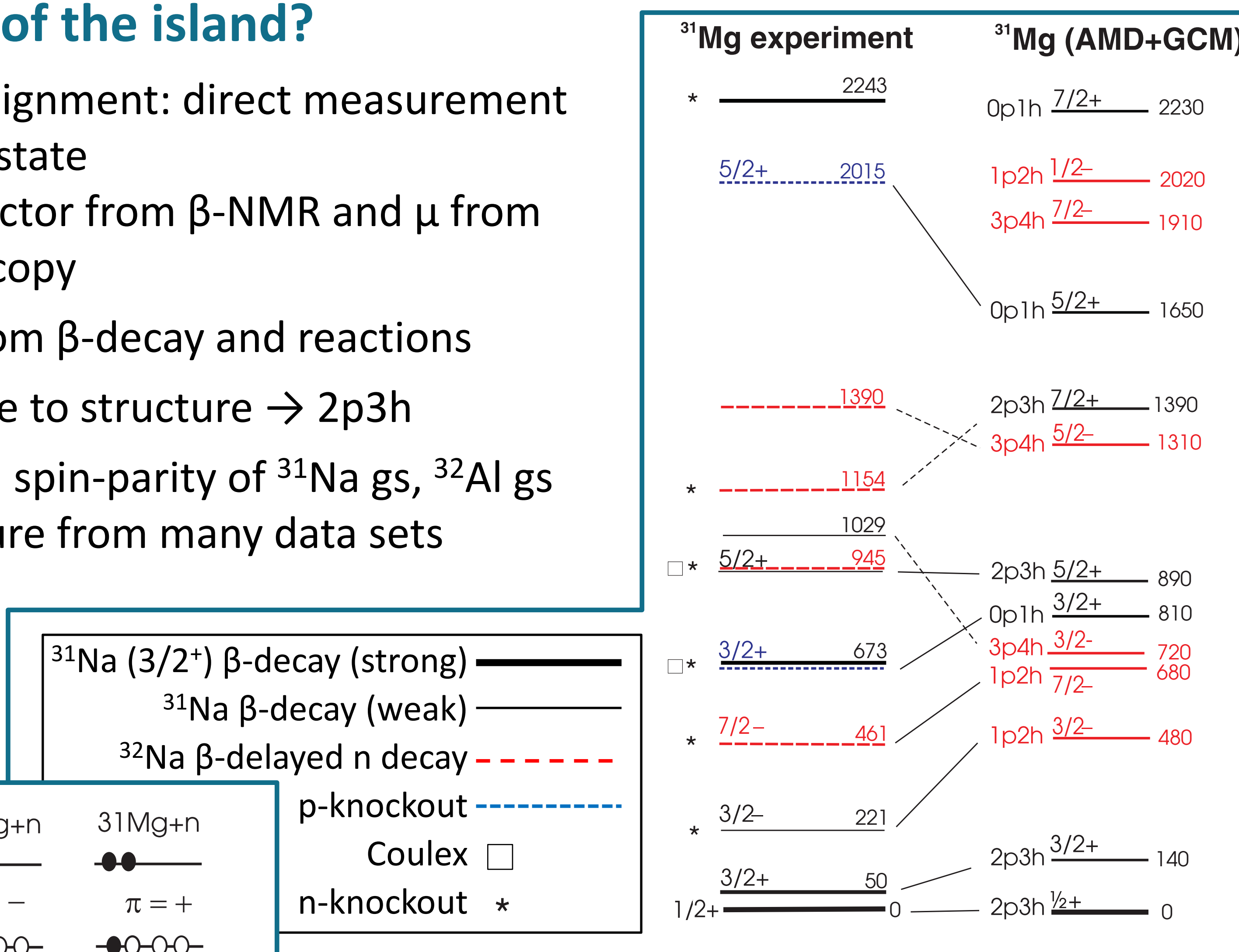
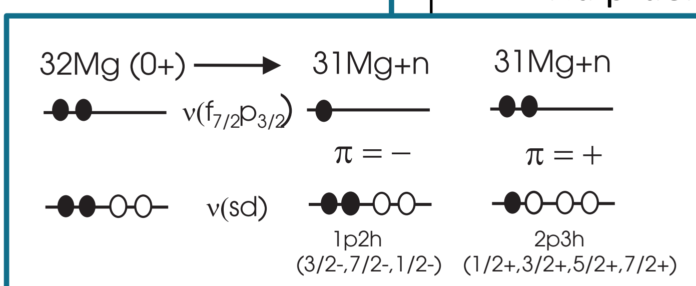
The evidence in ^{31}Mg

G Neyens et al, PRC 84 (2011) 064310

At the border of the island?

- Spin-parity assignment: direct measurement of the ground state
  combined *g*-factor from β-NMR and μ from laser spectroscopy
- Other spins from β-decay and reactions
- μ very sensitive to structure → 2p3h
- Anchor points: spin-parity of ^{31}Na gs, ^{32}Al gs
  Coherent picture from many data sets





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The evidence in ^{33}Mg

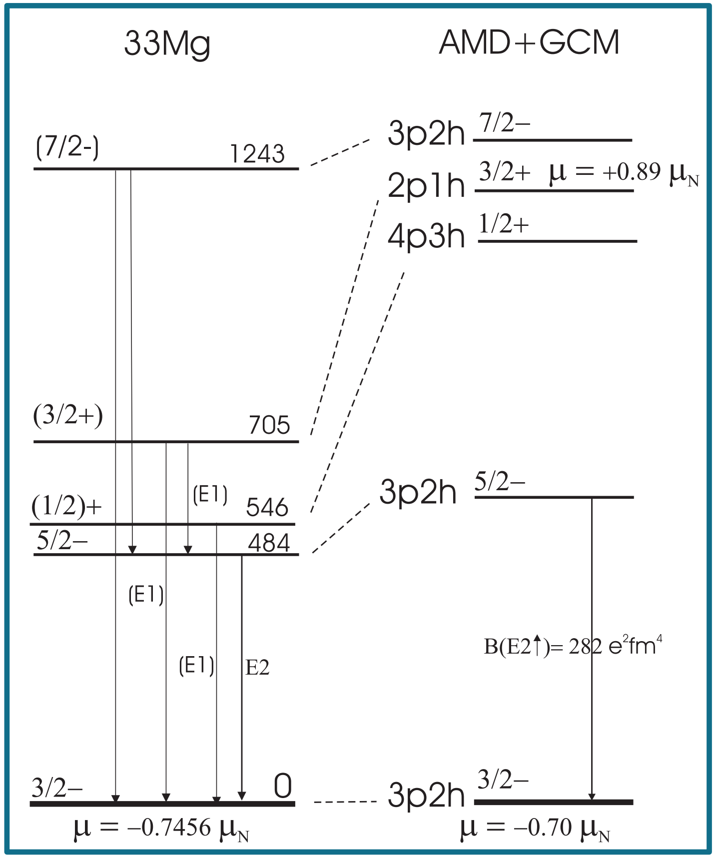
G Neyens et al, PRC 84 (2011) 064310

The ground-state parity puzzle

- *I* = 3/2 by β-NMR and from laser spectroscopy
- Combined β-decay, in-beam spectroscopy, Coulex, laser spectroscopy, n-knockout suggest negative parity
- Theory indicates 3p2h configuration for the gs and 484-keV state

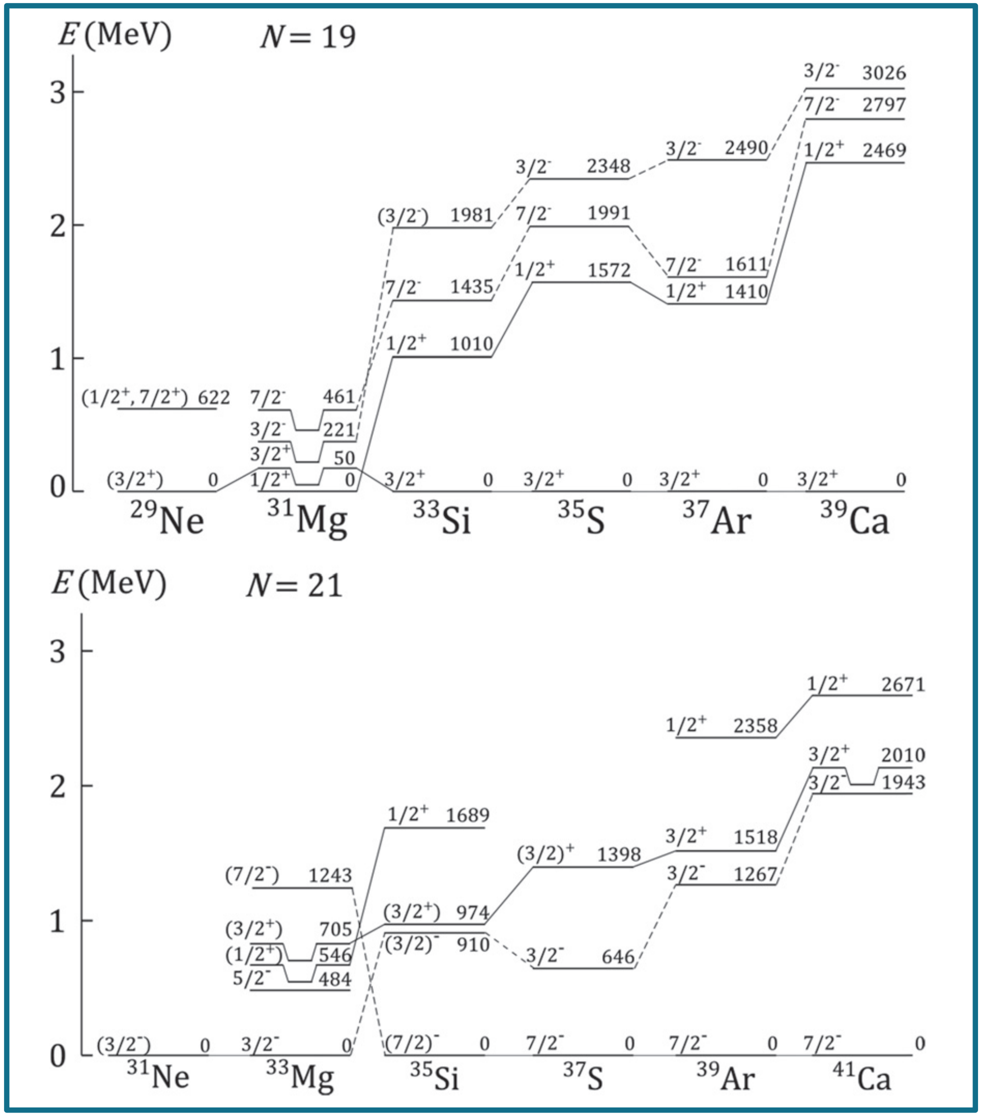
Ground state has 2 neutrons across N = 20 as in ^{31,32}Mg

- Suggestion to use transfer reactions to constrain spins

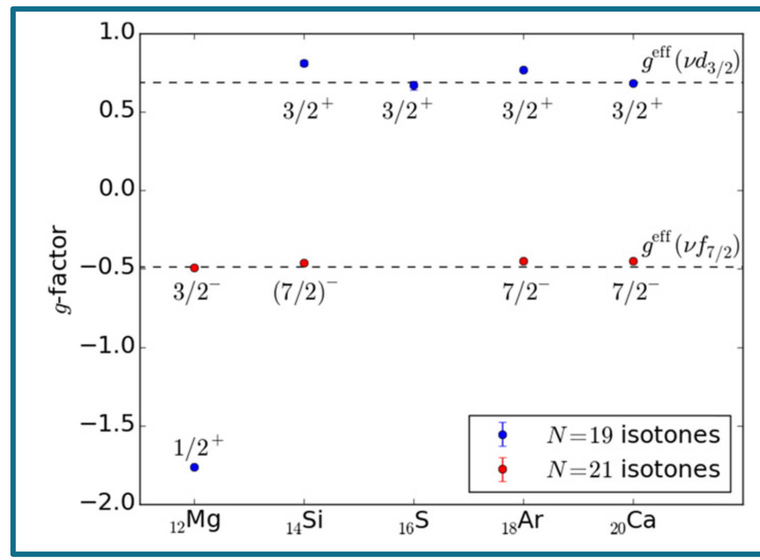


The shape coexistence picture

G Neyens et al, JPG 43 (2016) 024007



- Coexistence (and mixing) of configurations
- No shell collapse
  but enormous gain in correlation energy

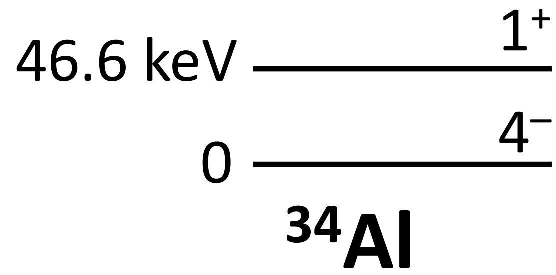


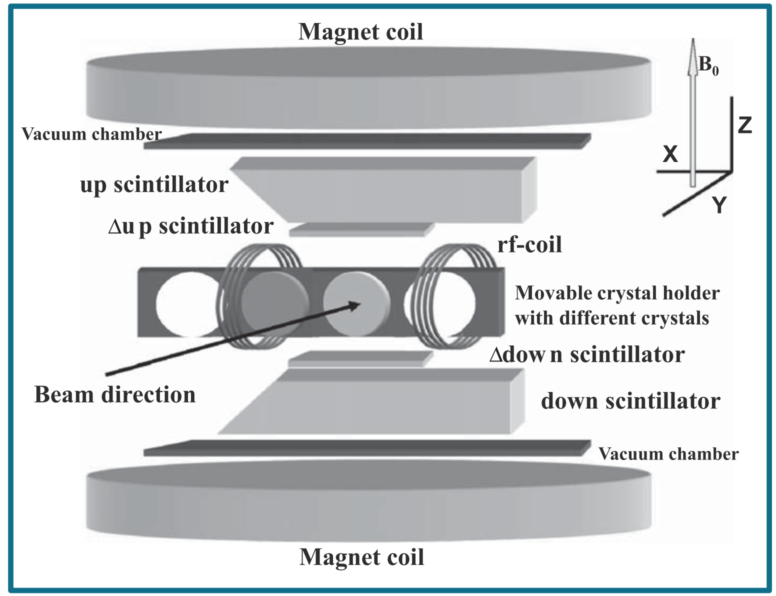
g-factor and quadrupole moment in $^{34}Al^{m}$

Z.Y. Xu et al, in preparation

^{34}Al: transitional nucleus?

- *g*-factor in $^{34}Al^{g}$ suggests 0p0h-2p2h mixing
  P. Himpe et al., PLB 658 (2008) 203
- 1^{+} predicted with a 2p1h structure
- Recently observed at 46 keV
  R. Liča et al. PRC 95 (2017) 021301(R)
- β-NMR/NQR at GANIL/LISE
  → *g*-factor and quadrupole moment

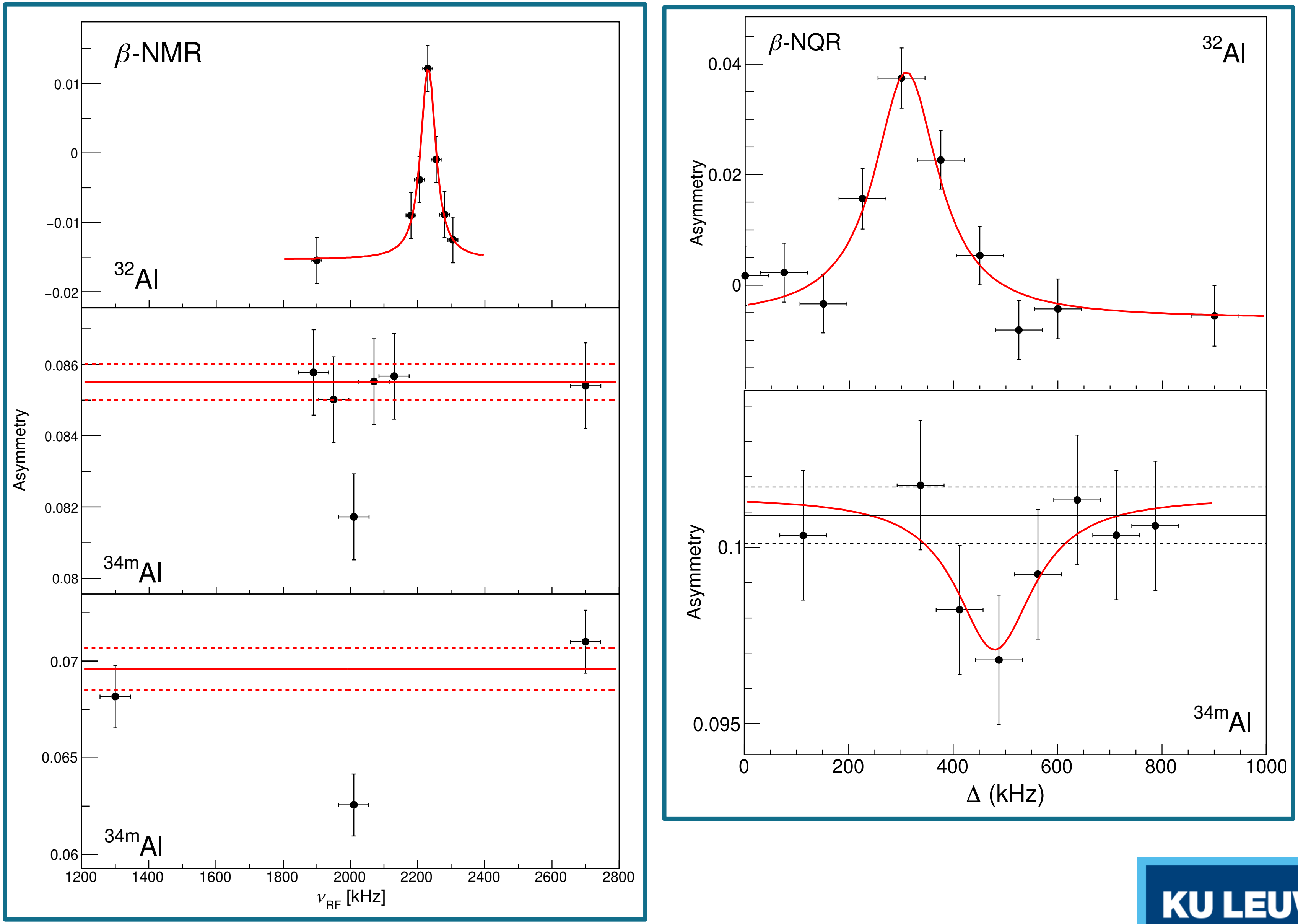




M. De Rydt et al NIMA 612 (2009) 112

g-factor and quadrupole moment in $^{34}Al^m$

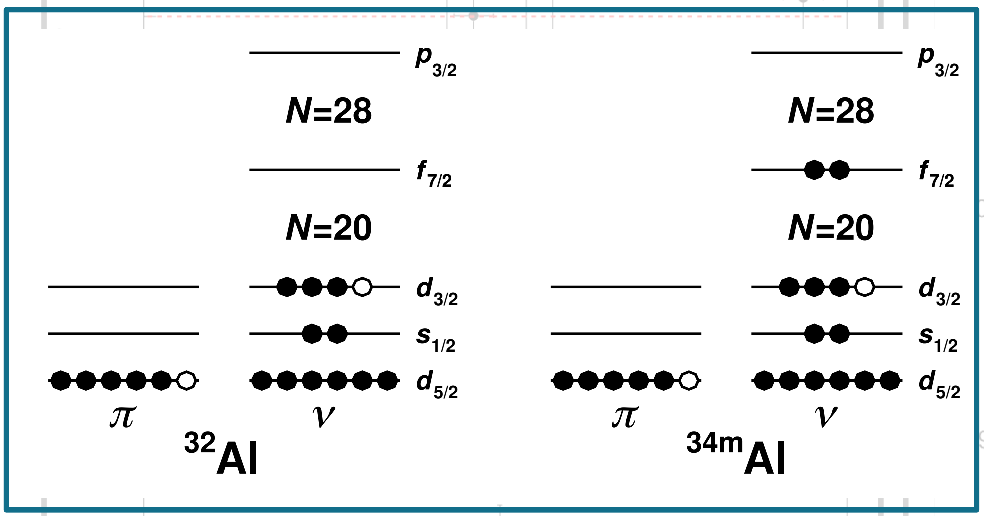
Z.Y. Xu et al, in preparation



g-factor and quadrupole moment in ^{34}Al^{m}

Z.Y. Xu et al, in preparation

				g factor			Q_s (mb)		
	N	I^π	$T_{1/2}$	ν_L (kHz)	This work	Lit.	ν_Q (kHz)	This work	Lit.
^{32}Al	19	1^+	33.0 ms	2240.5(7)	1.958(1)(7)$_{\rm sys}$	1.9516(22)	418(4)	25.5(3)	24(2)
^{34m}Al	21	1^+	26 ms	2010±15	1.756±0.014		627(83)	38(5)	



Dominant $\pi(d_{5/2})^{-1} \otimes \nu\,(d_{3/2})^{-1}(f_{7/2})^2$ configuration as in ^{32}Al

but larger Q_s

→ extra correlation and deformation

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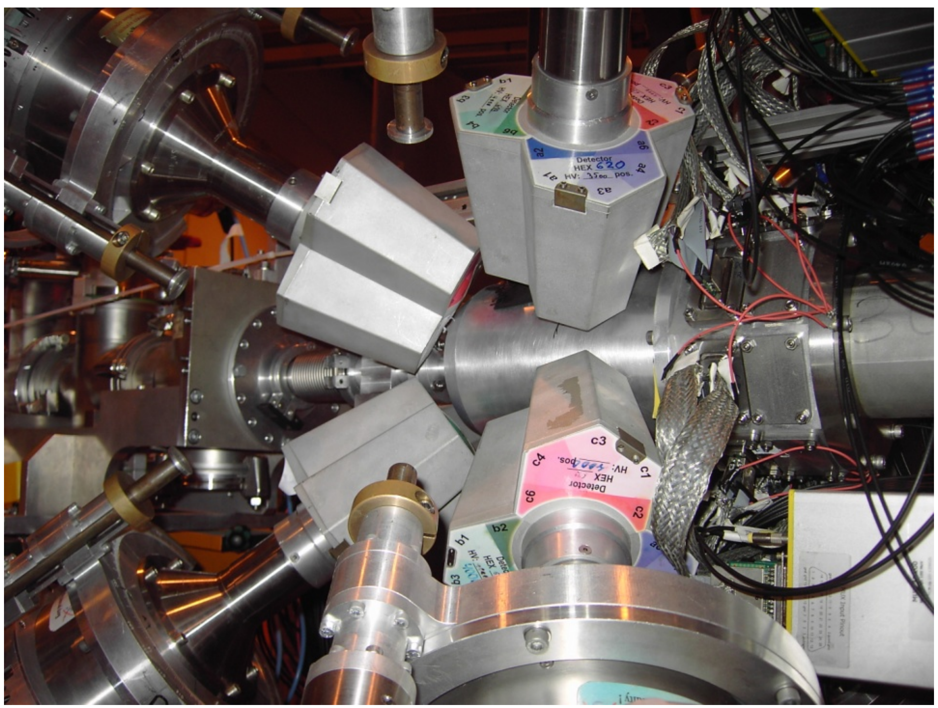
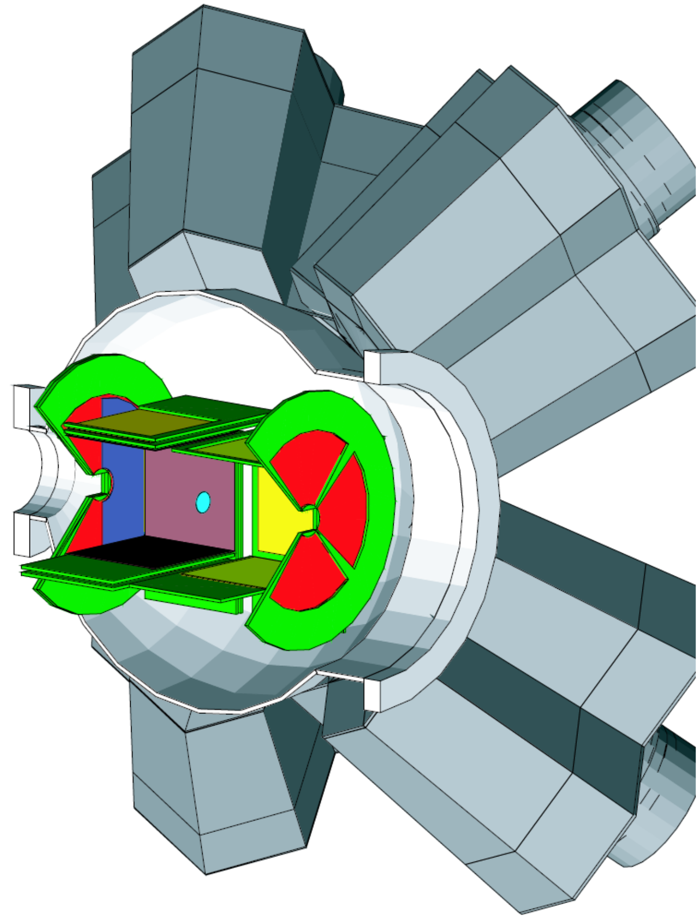
Transfer reactions in Mg: ^{30}Mg(d,p)

V Bildstein, PhD thesis, TUM (2010)

- ^{30}Mg beam at REX-ISOLDE, 3 MeV/nucleon
- T-REX charged-particle detector
- Miniball γ-ray array





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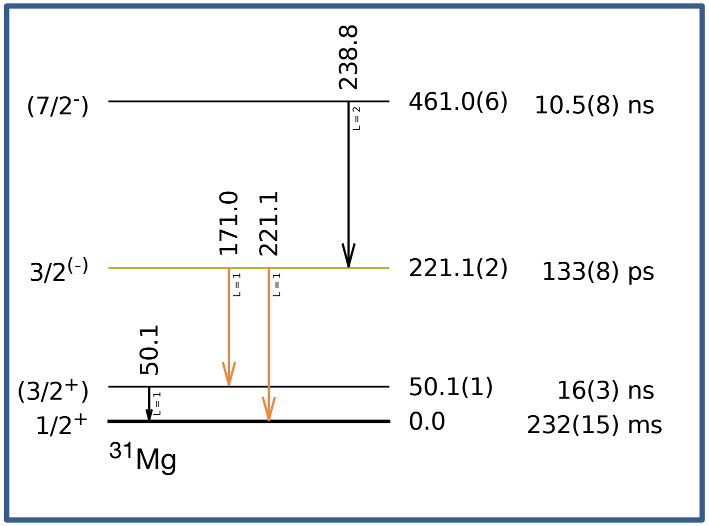
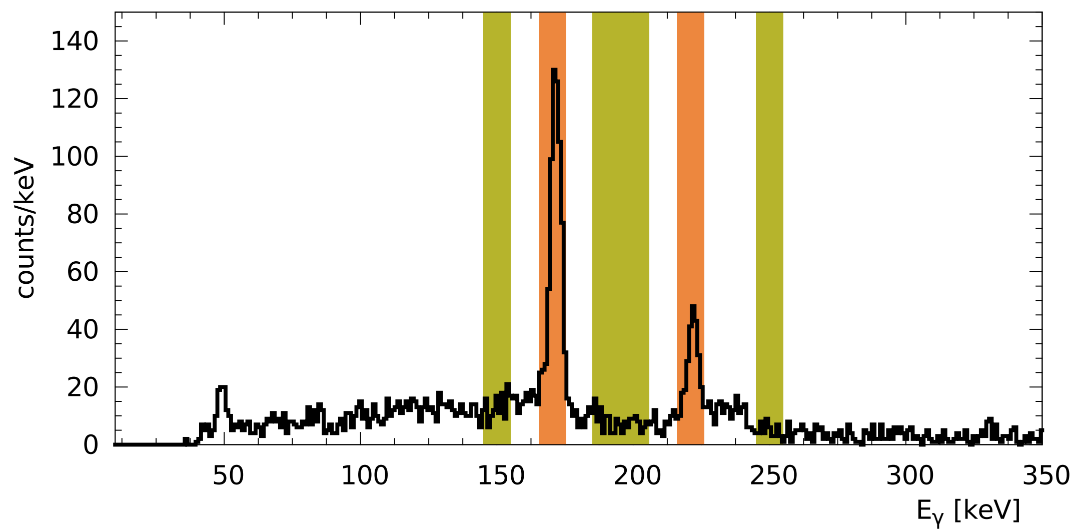
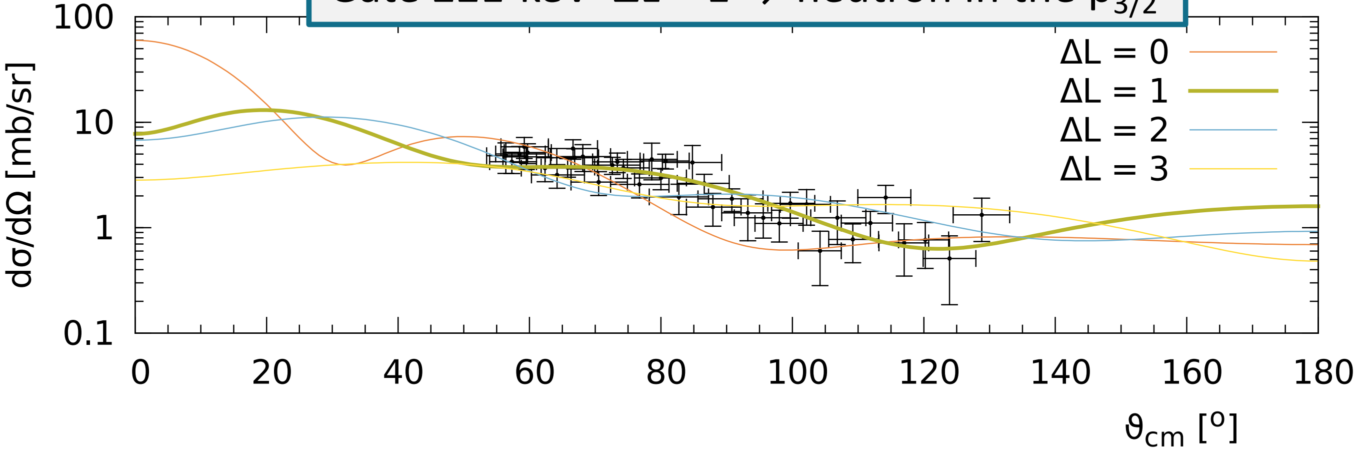




Gate 221-keV ΔL = 1 → neutron in the $p_{3/2}$



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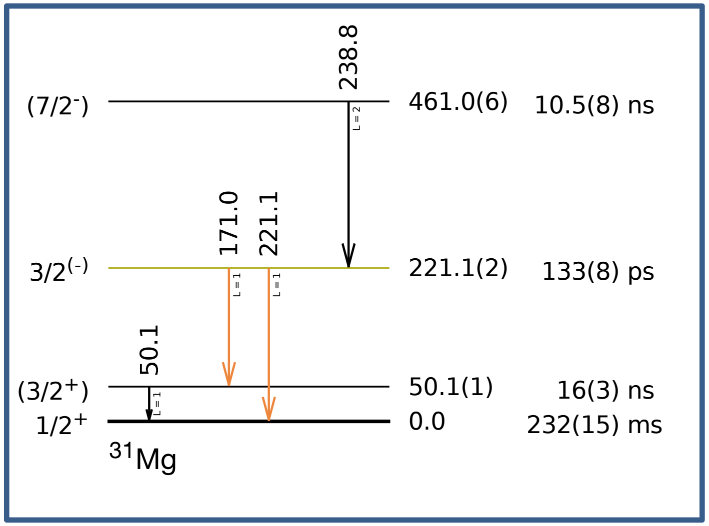
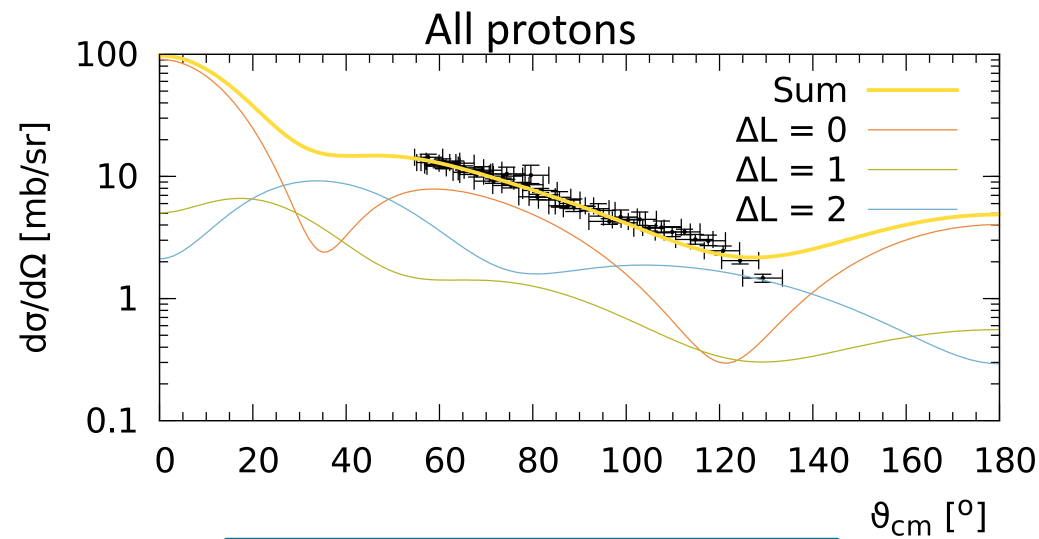
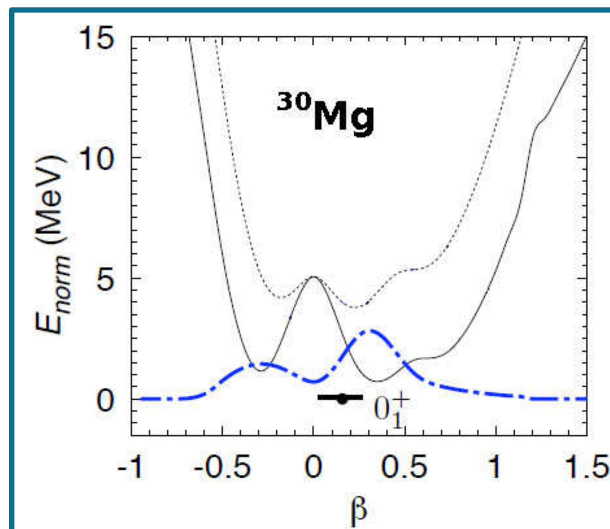




	[Per76]	[Kon03] & [Loh74]	[Kon03] & [Boj88]	fitted parameters
a) free fit of all transfer protons				
$S_{\Delta L=0}$	0.111(9)	0.27(2)	0.144(10)	0.312(18)
$S_{\Delta L=1}$	0.084(4)	0.096(10)	0.087(5)	0.046(16)
$S_{\Delta L=2}$	0.124(14)	0.21(2)	0.142(17)	0.32(2)
$S_{\Delta L=1}/S_{\Delta L=0}$	0.76(2)	0.36(5)	0.60(5)	0.15(5)
$S_{\Delta L=1}/S_{\Delta L=2}$	0.68(8)	0.46(6)	0.61(8)	0.14(5)
$S_{\Delta L=2}/S_{\Delta L=0}$	1.12(16)	0.78(9)	0.99(14)	1.00(8)
b) fit of all transfer protons with $S_{\Delta L=1}$ fixed				
$S_{\Delta L=0}$	0.160(8)	0.326(15)	0.206(8)	0.272(7)
$S_{\Delta L=1}$ (fixed)	0.0401	0.066	0.0411	0.084
$S_{\Delta L=2}$	0.234(9)	0.25(2)	0.279(10)	0.274(13)
$S_{\Delta L=1}/S_{\Delta L=0}$	0.251(13)	0.202(9)	0.200(8)	0.309(8)
$S_{\Delta L=1}/S_{\Delta L=2}$	0.171(7)	0.26(2)	0.147(5)	0.307(15)
$S_{\Delta L=2}/S_{\Delta L=0}$	1.46(9)	0.77(7)	1.35(7)	1.01(5)



T. Rodriguez and J. Egido, priv comm (2008)

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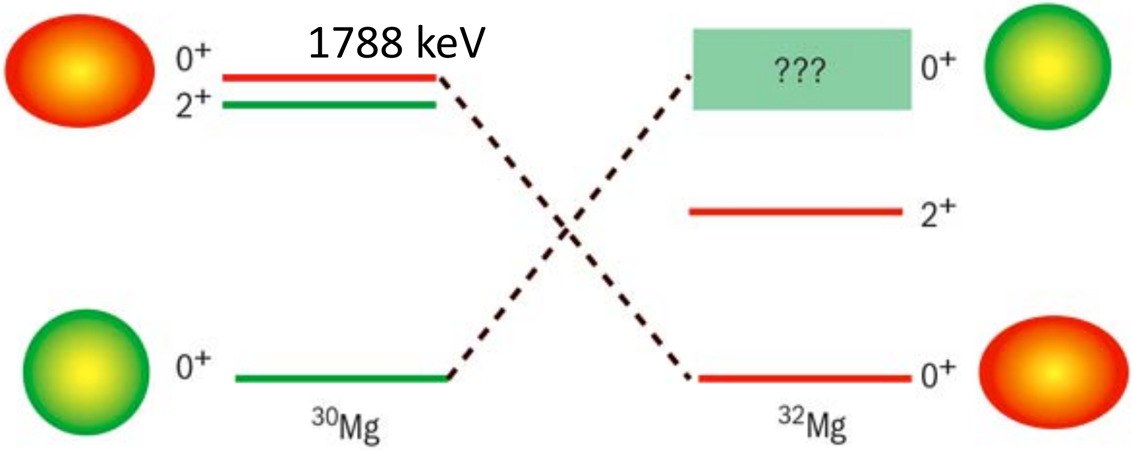
Two-neutron transfer to ^{32}Mg

K Wimmer et al., PRL 105 (2010) 252501

Looking for the second, spherical 0^+ in ^{32}Mg:

^{30}Mg(t,p)^{32}Mg

- ^{30}Mg beam at REX-ISOLDE, 1.8 MeV/nucleon (below fusion barrier for Ti)
- Tritium-implanted Ti foil (t: 40 µg/cm^2)
- T-REX charged-particle detector
- Miniball γ-ray array

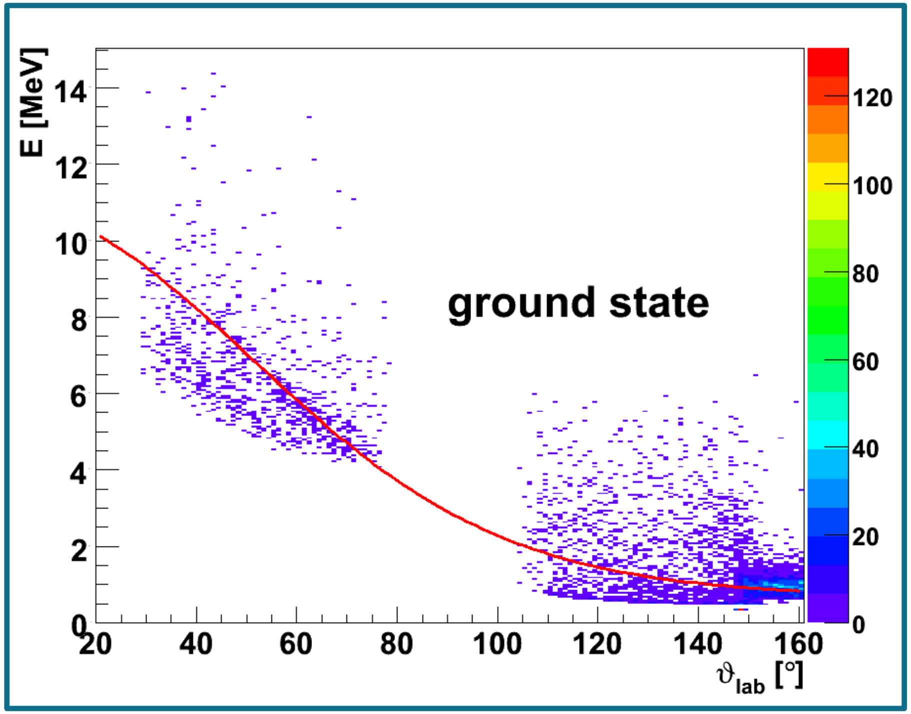


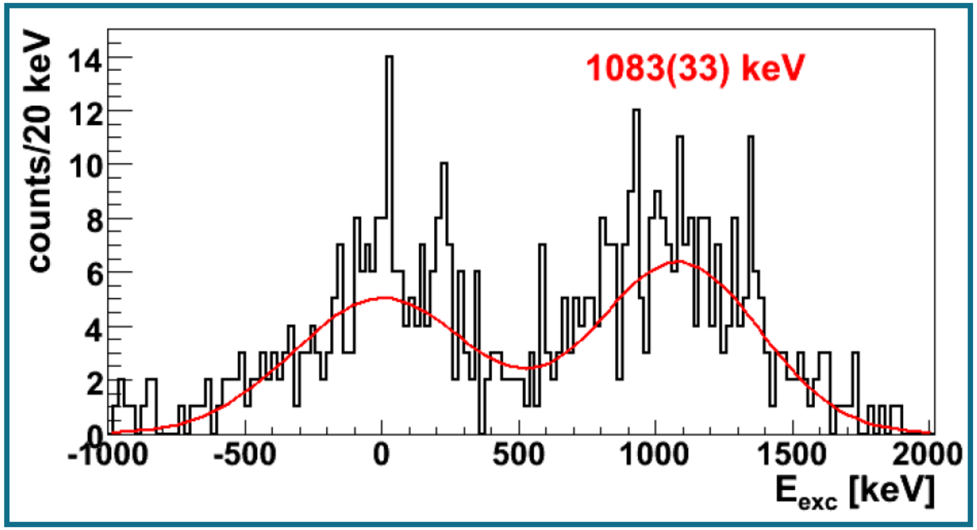
Two-neutron transfer to ^{32}Mg

K Wimmer et al., PRL 105 (2010) 252501

^{30}Mg(t,p)^{32}Mg

Two states identified, well separated
(despite poor resolution)





Two-neutron transfer to ^{32}Mg

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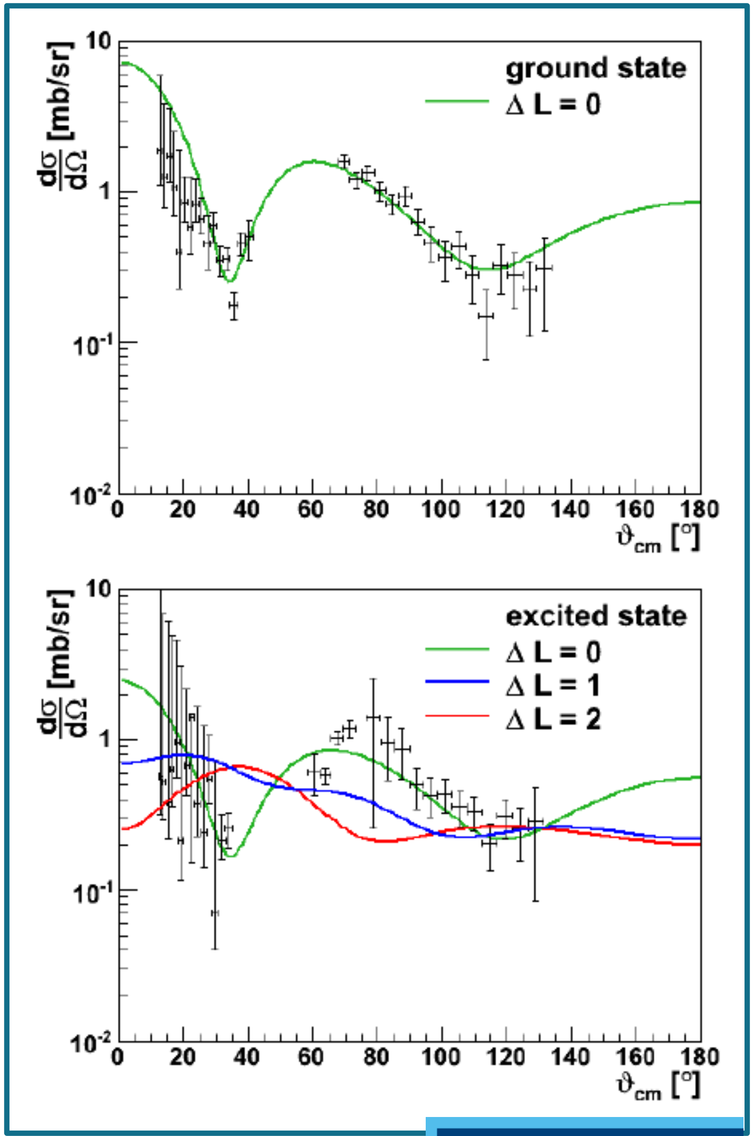
^{30}Mg(t,p)^{32}Mg

- Angular distributions: l=0

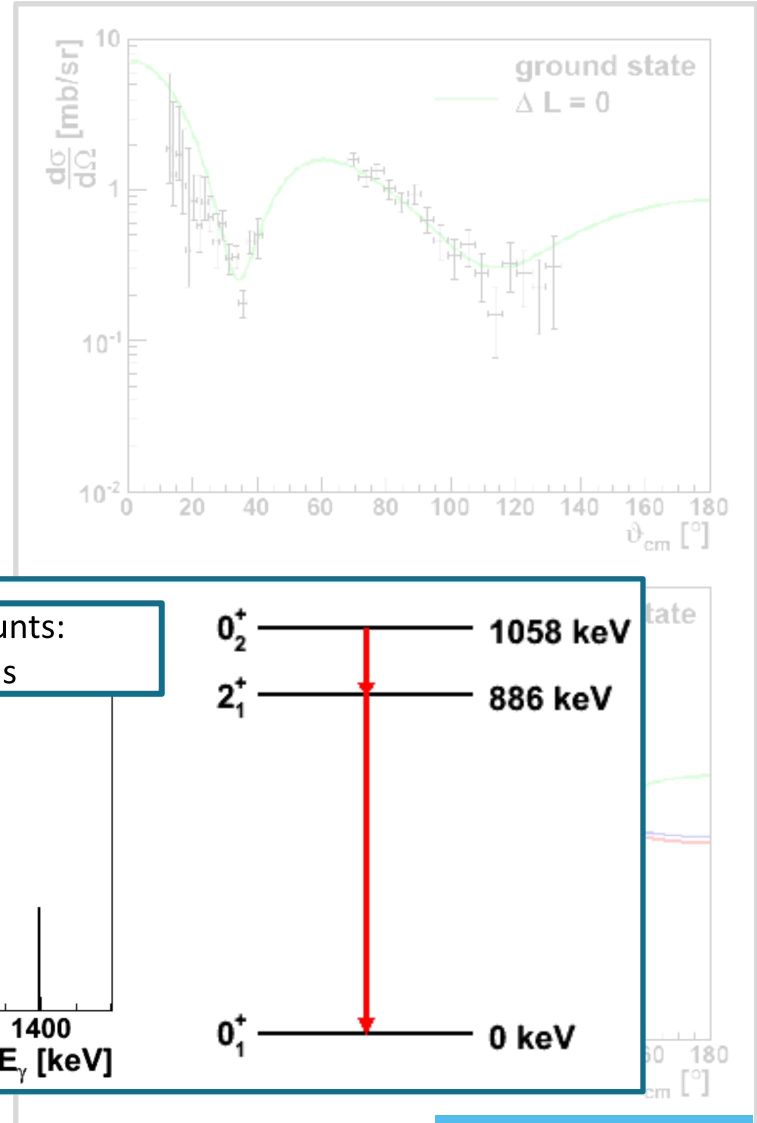


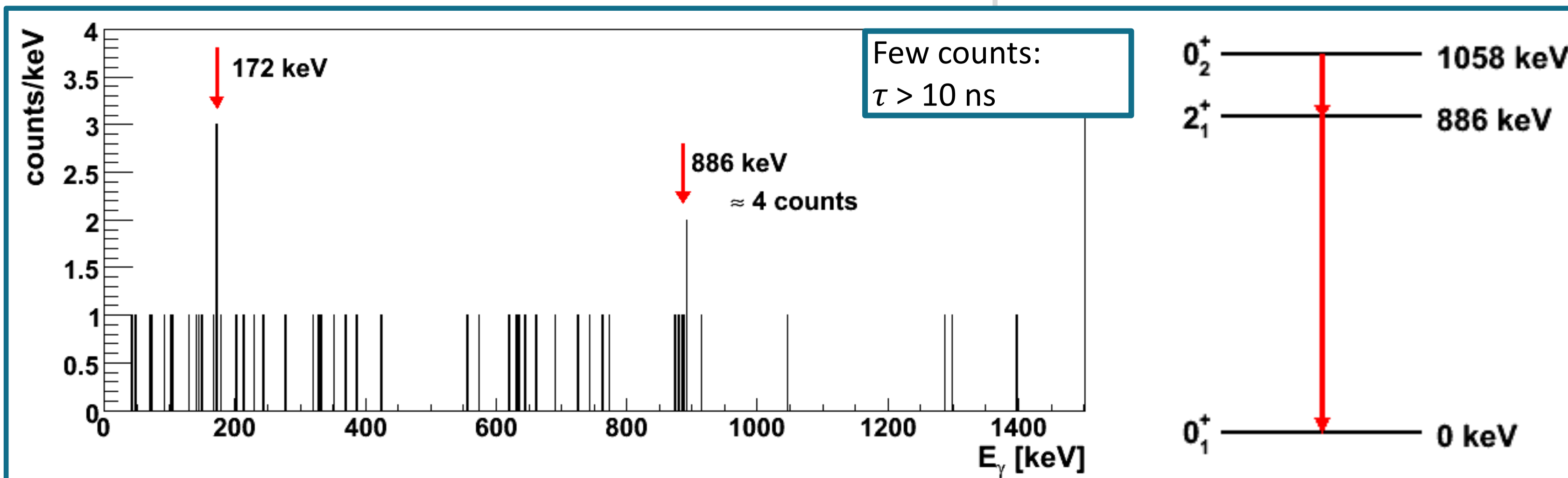
Two-neutron transfer to ^{32}Mg

K Wimmer et al., PRL 105 (2010) 252501

^{30}Mg(t,p)^{32}Mg

- Angular distributions: l=0
- γ-ray coincidences with excited state: no 2^+ (18 cts expected from 2^+ at 886 keV)





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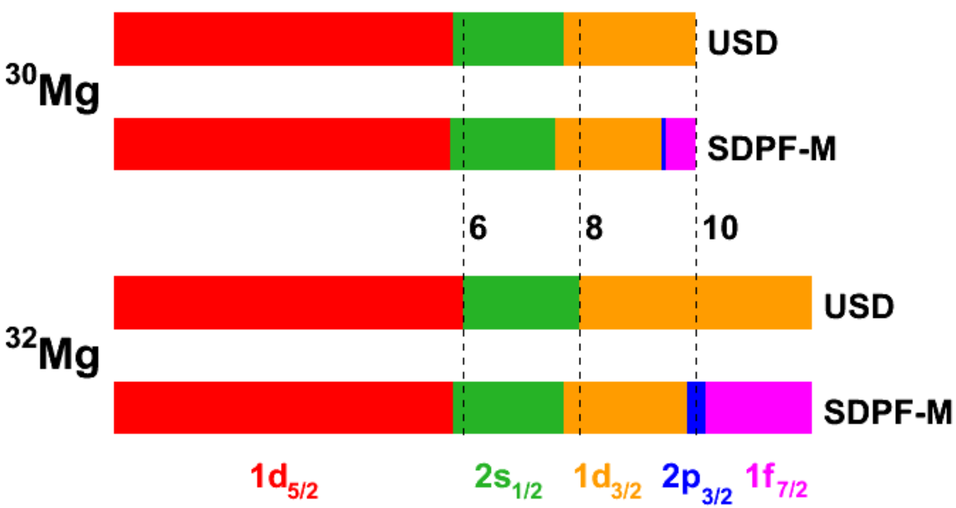
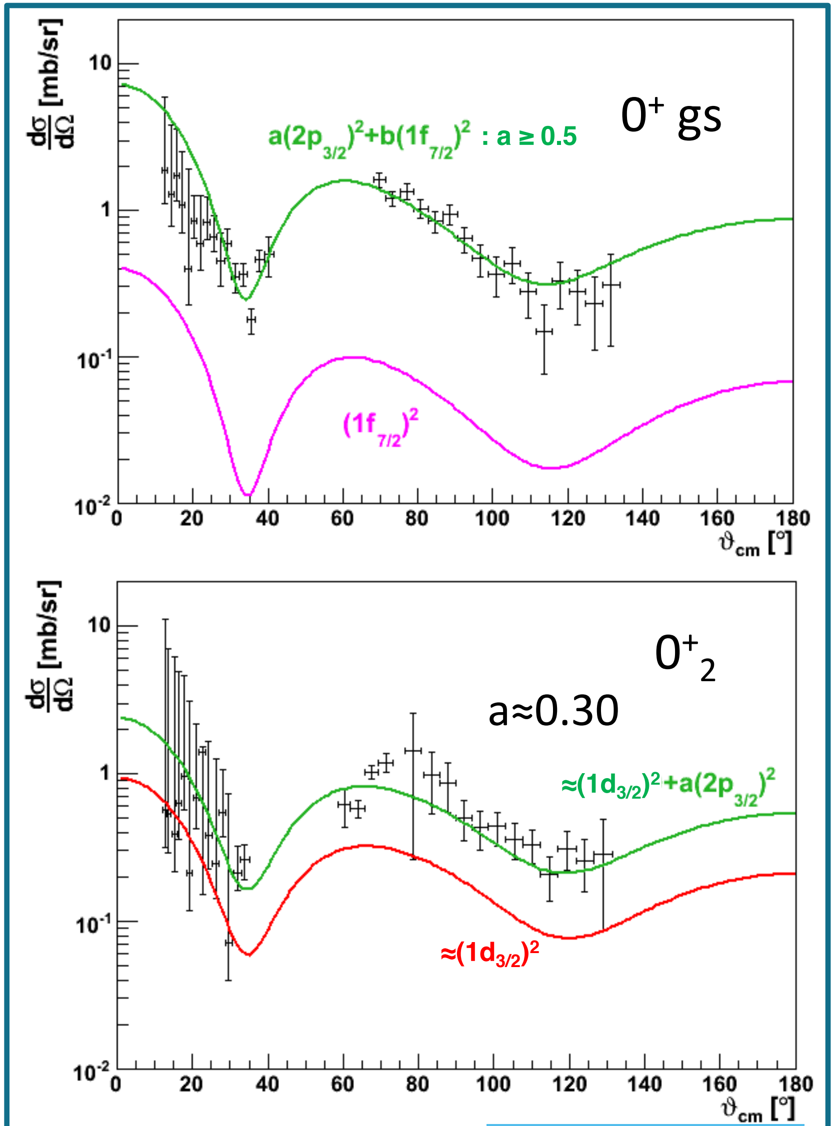


“naïve” 2-level no-mixing does not work

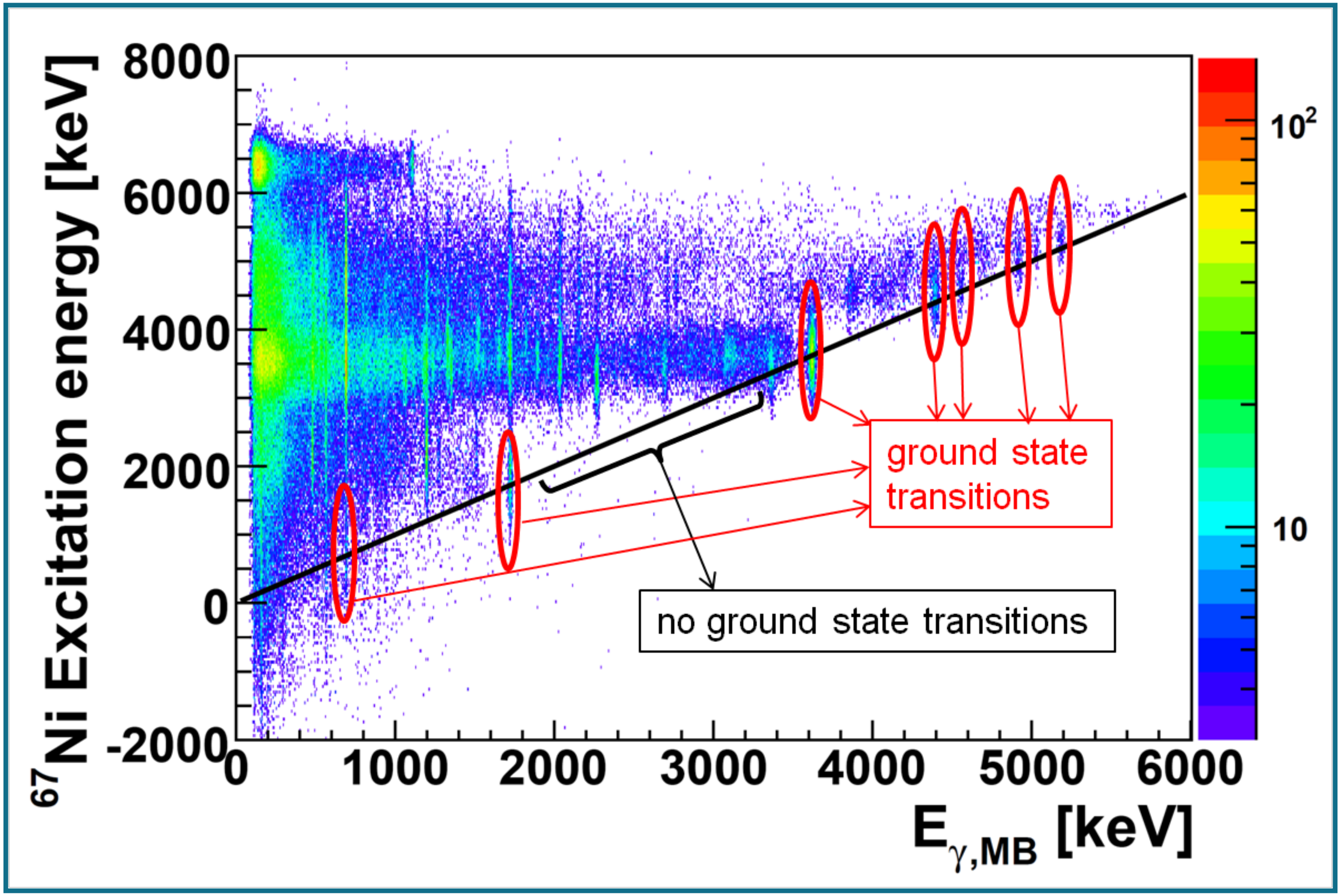
> $(p_{3/2})^2$ component both in the gs and excited state



Transfer reactions towards ^{68}Ni: ^{66}Ni(d,p)

J. Diriken et al, PLB 736 (2014) 533
PRC 91 (2015) 054321

^{66}Ni(d,p) 2.85 MeV/nucleon



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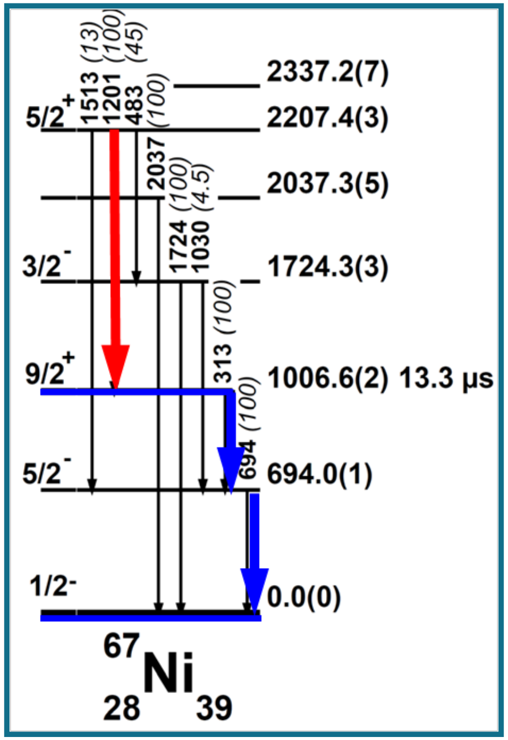

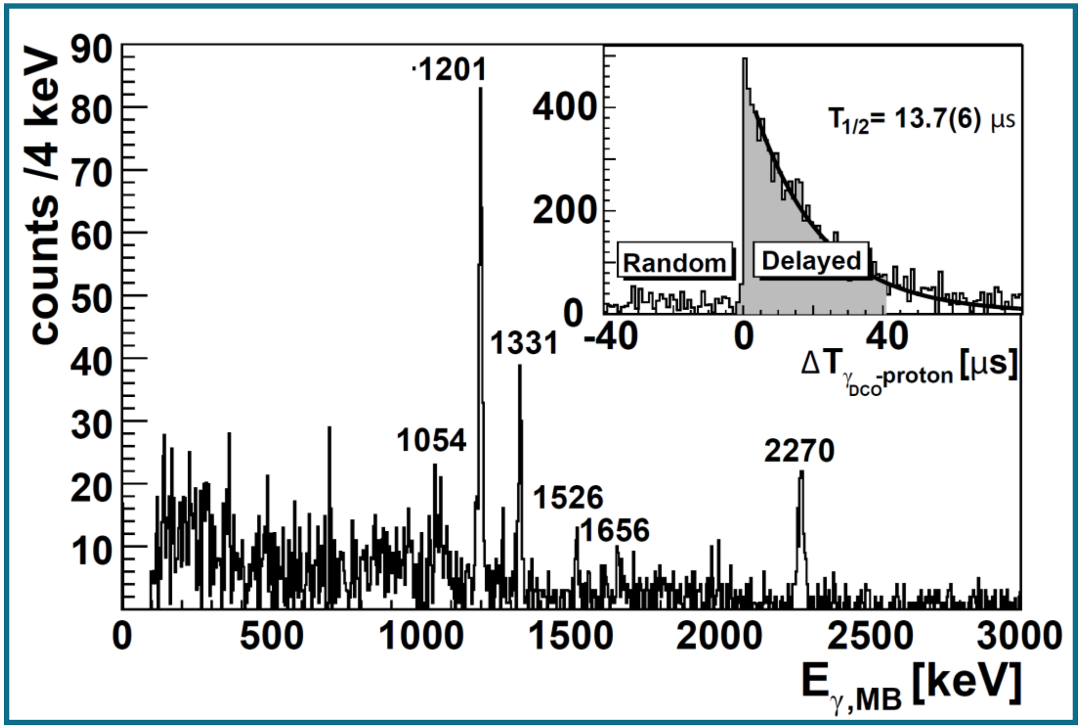

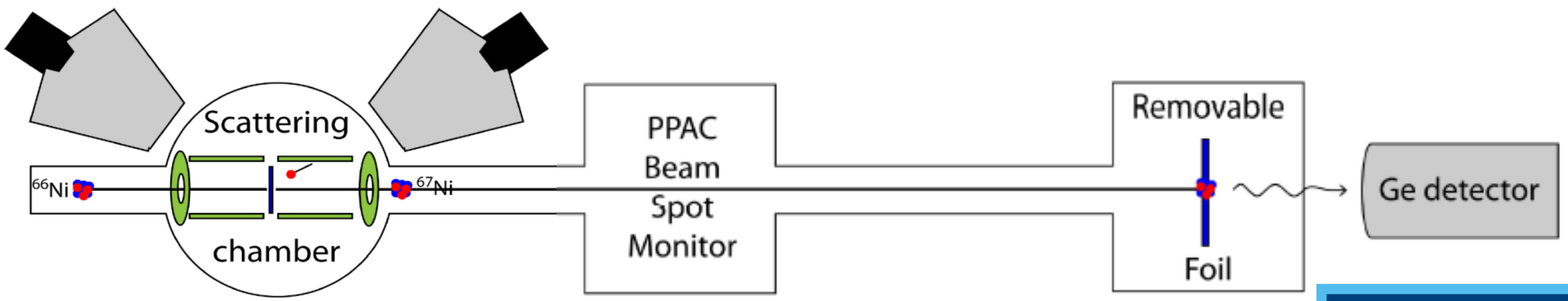

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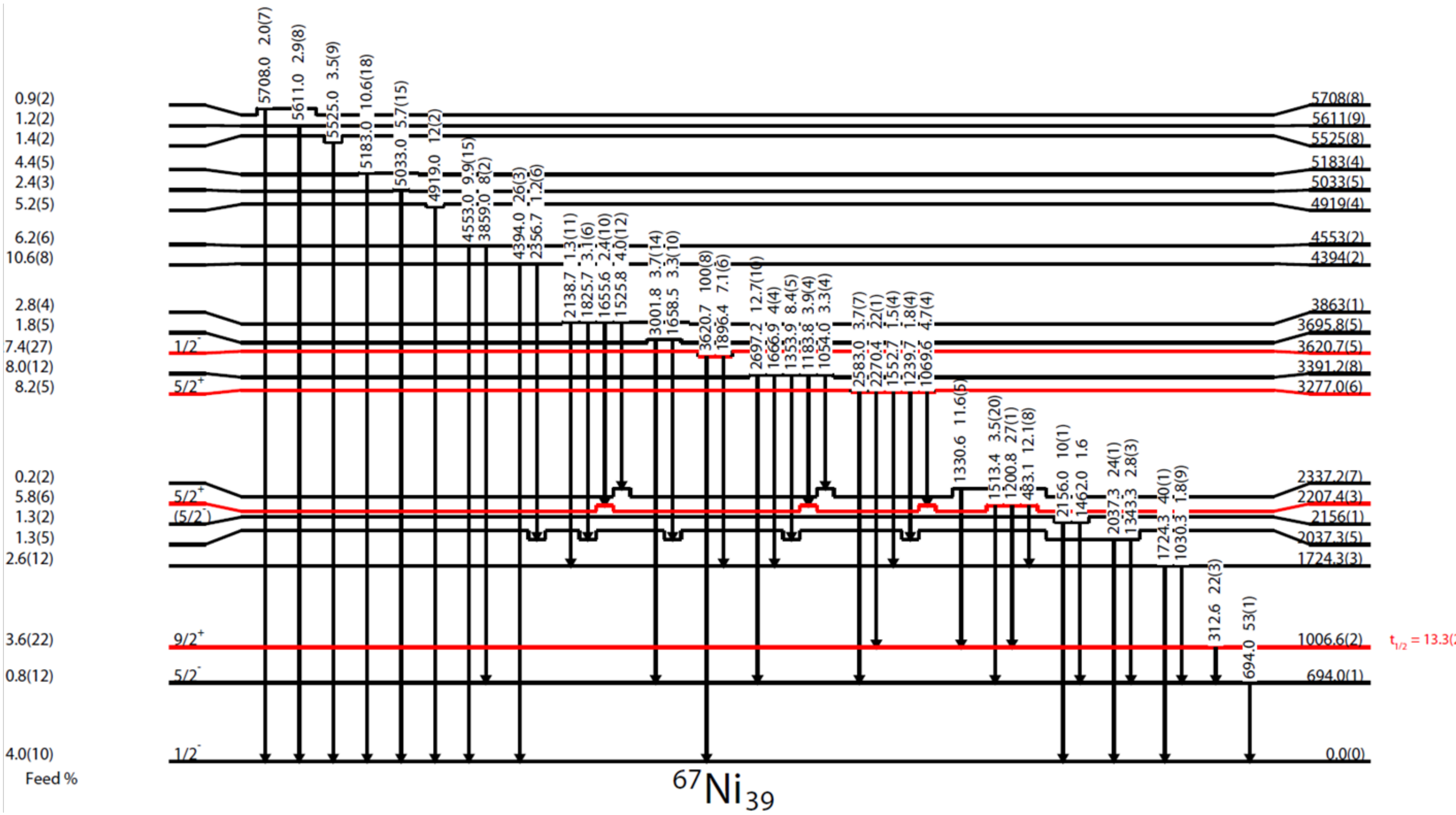

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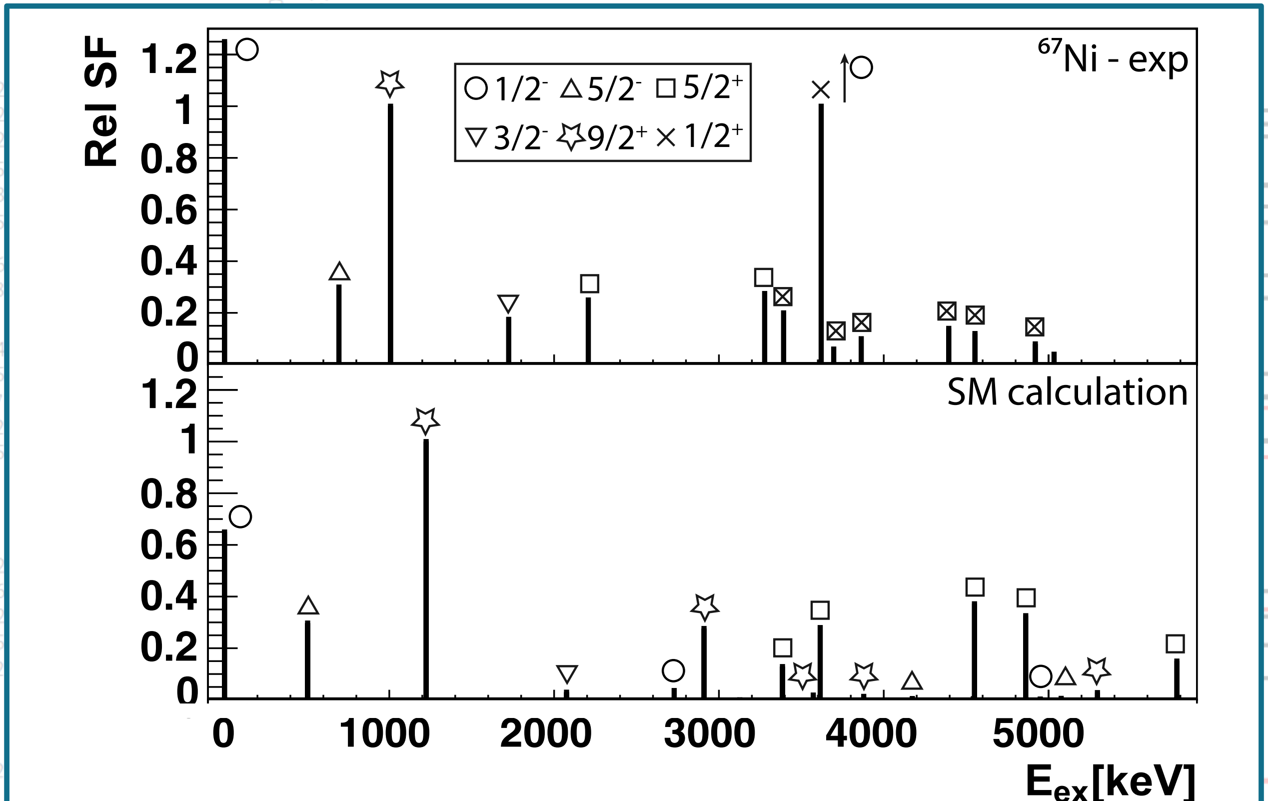

- Identification of $d_{5/2}$ (and $s_{1/2}$) strength
- $g_{9/2}$-$d_{5/2}$ gap at ≈2.5 MeV, reproduced by large-scale SM (F. Nowacki and collaborators)

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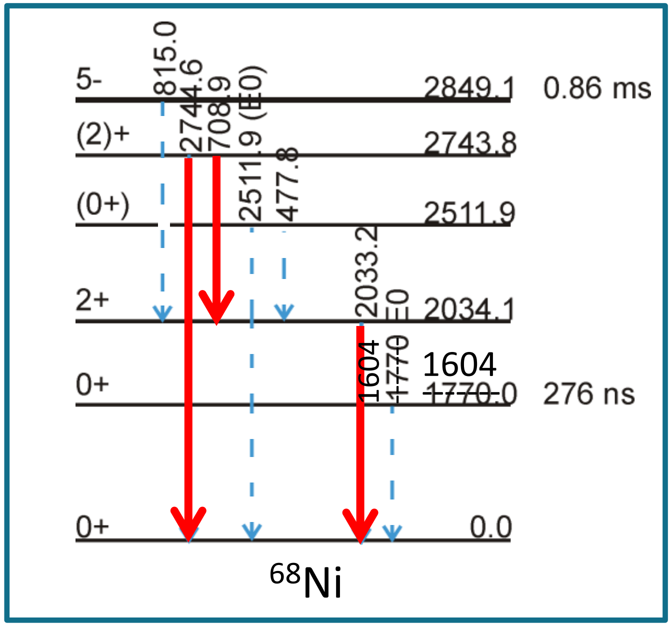
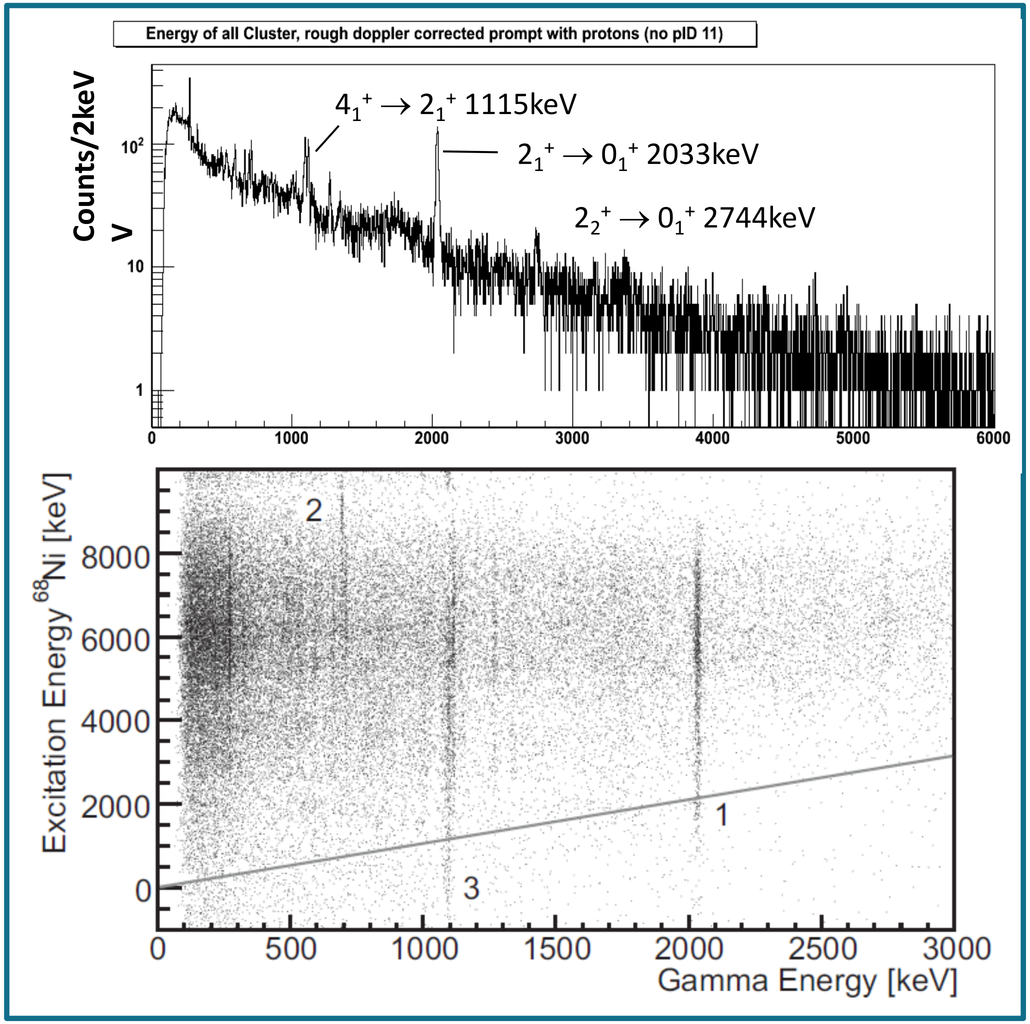
Transfer reactions towards ^{68}Ni: ^{66}Ni(t,p)

J Elseviers, PhD Thesis, KUL, 2014

^{66}Ni(t,p)^{68}Ni at 2.6 MeV/nucleon

- Few γ's to ground state
- No p-γ-γ coincidences





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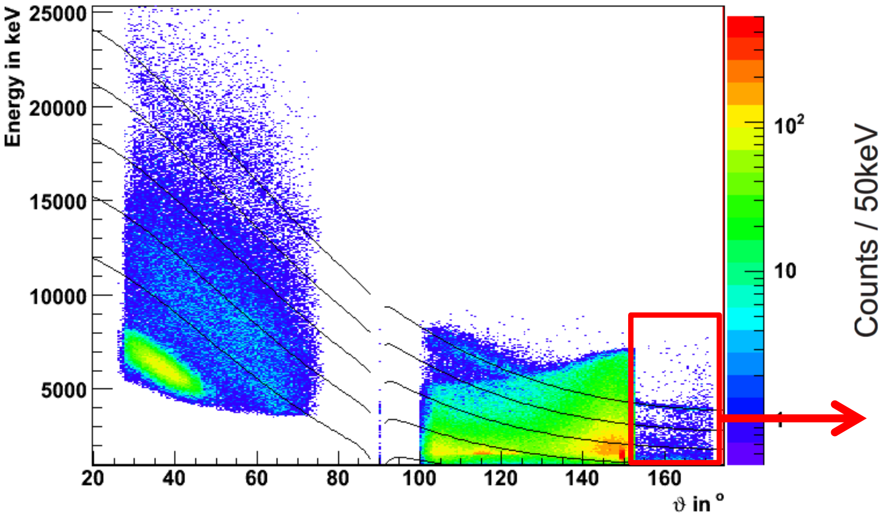

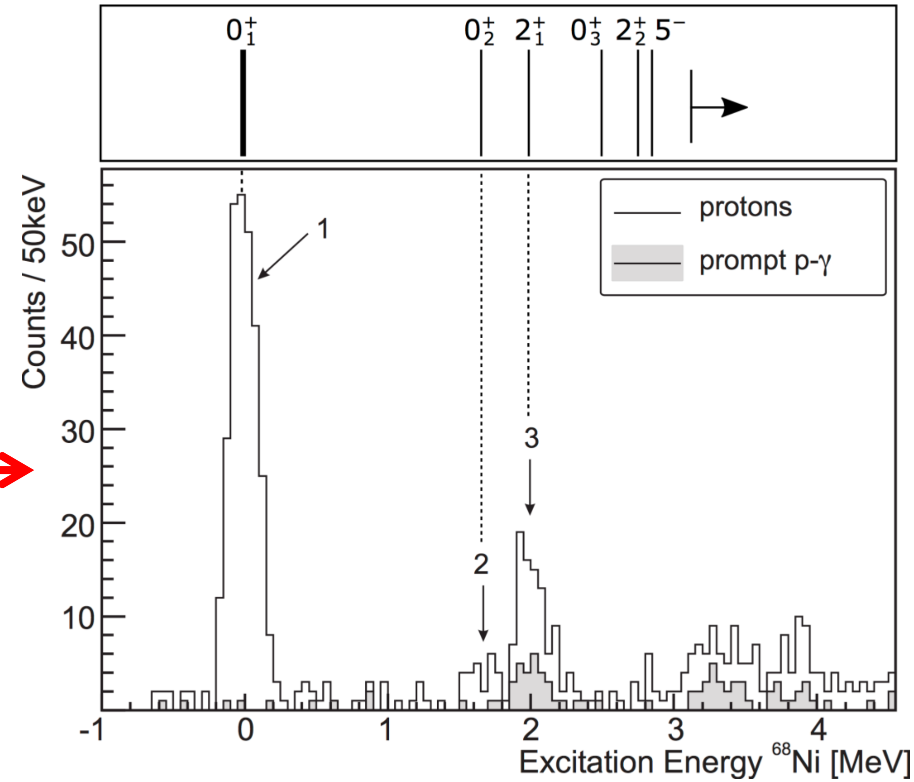

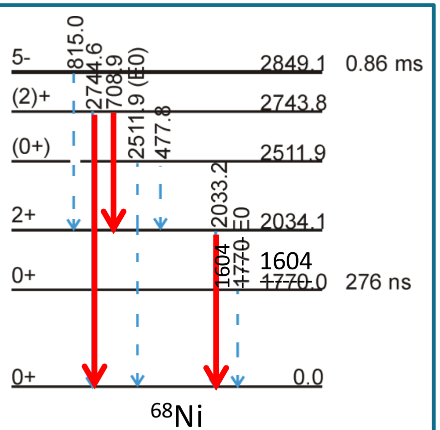

- Population of 0^+_2 : 5.4(11)% of g.s.
- Upper limits (<4%) on population of 0^+_3 and 2^+_2

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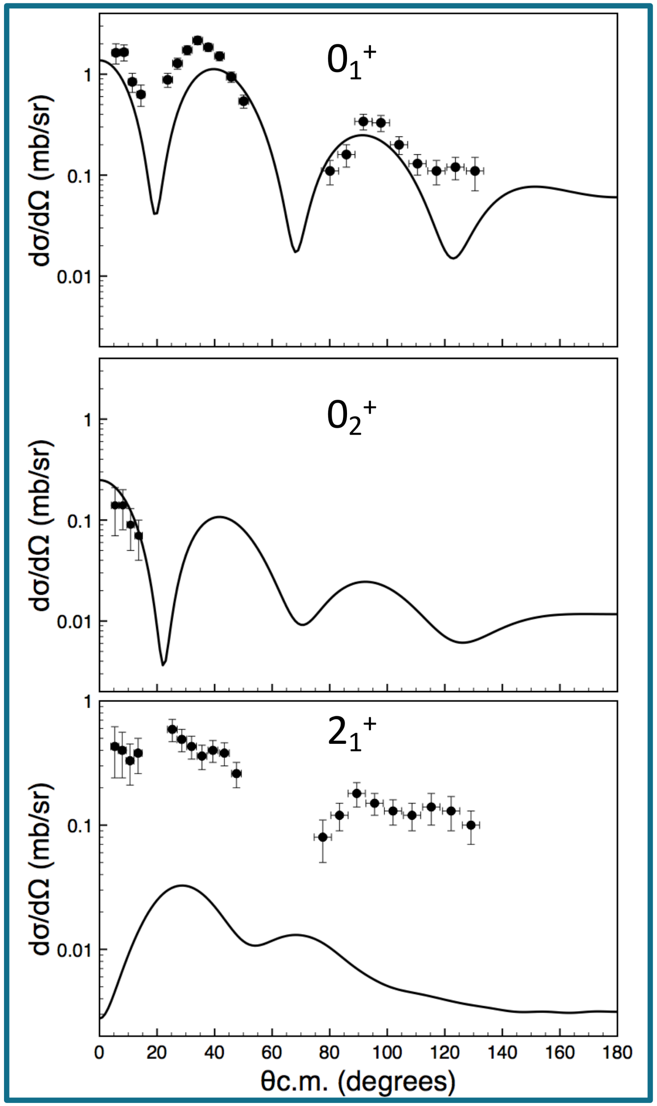
Transfer reactions towards ^{68}Ni: ^{66}Ni(t,p)

J Elseviers, PhD Thesis, KUL, 2014

^{66}Ni(t,p)^{68}Ni at 2.6 MeV/nucleon

- Two-neutron overlap amplitudes from MCSM (T. Otsuka) pf+$g_{9/2}$+$d_{5/2}$ both protons and neutrons
- Works well for the 0^+s does not reproduce the 2^+_1



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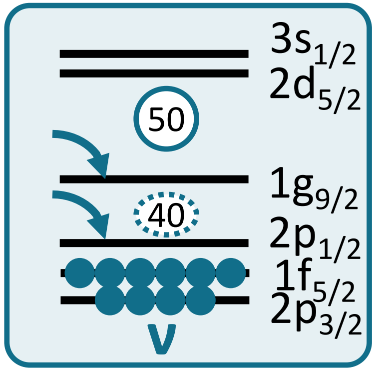
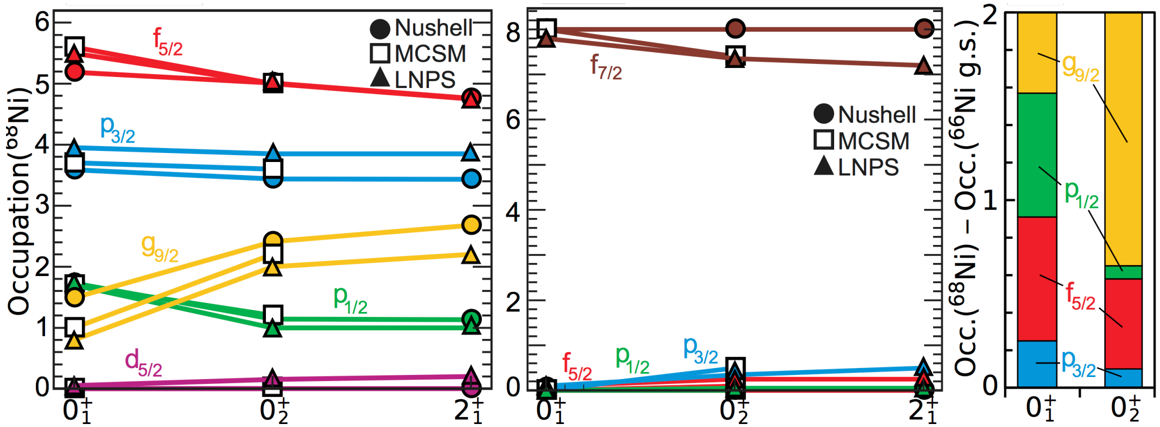


- Two-neutron overlap amplitudes
  from MCSM (T. Otsuka)
  pf+$g_{9/2}$+$d_{5/2}$ both protons and neutrons

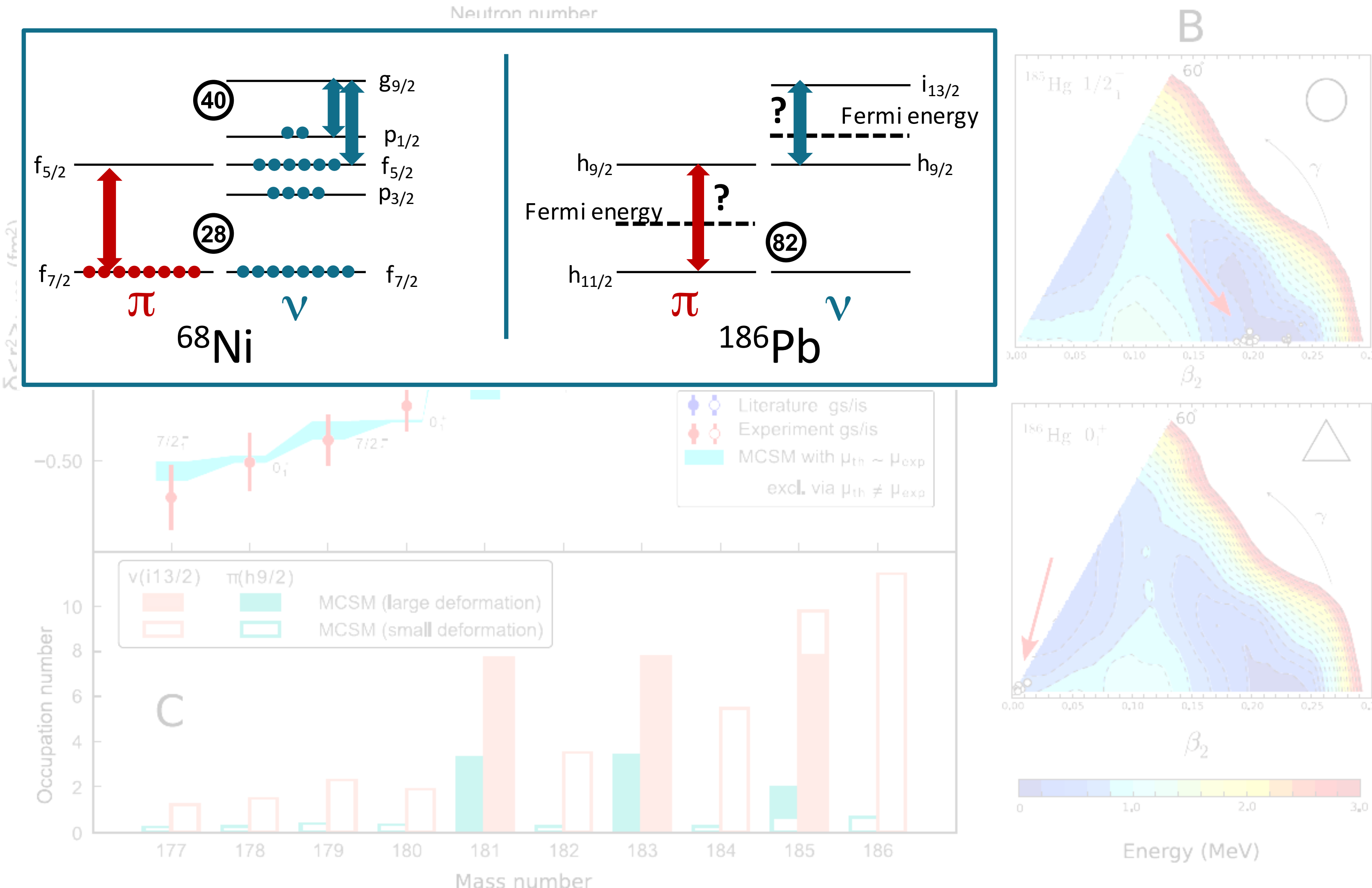
neutron - **occupation numbers** - protons



Agreement for $0^+_{1,2}$ states
0^+_1 state populated by transfer filling N=40
0^+_2 state populated by transfer across N=40

To the Pb region

T Otsuka and Y Tsunoda, JPG 43 (2016) 024009



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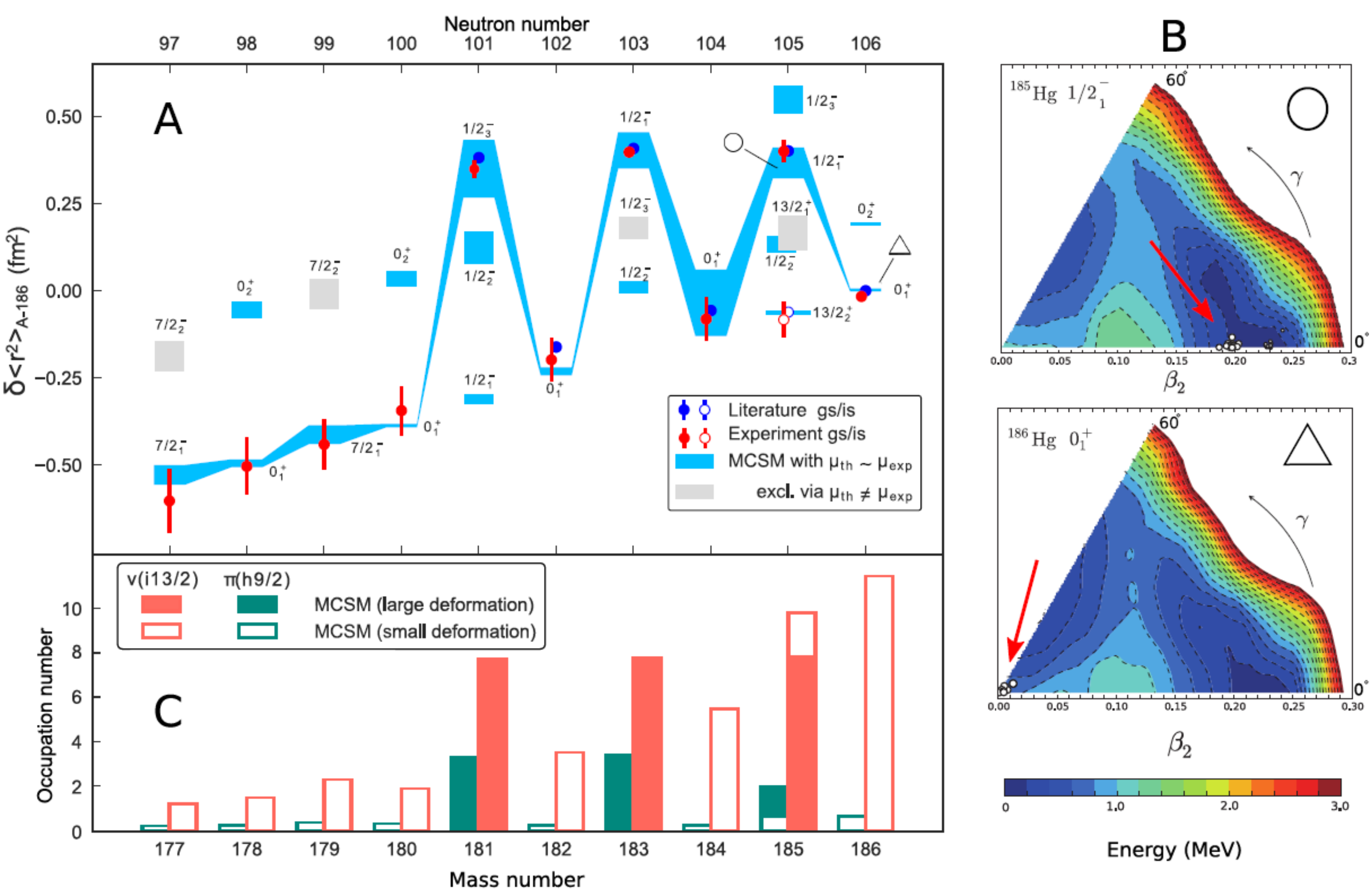
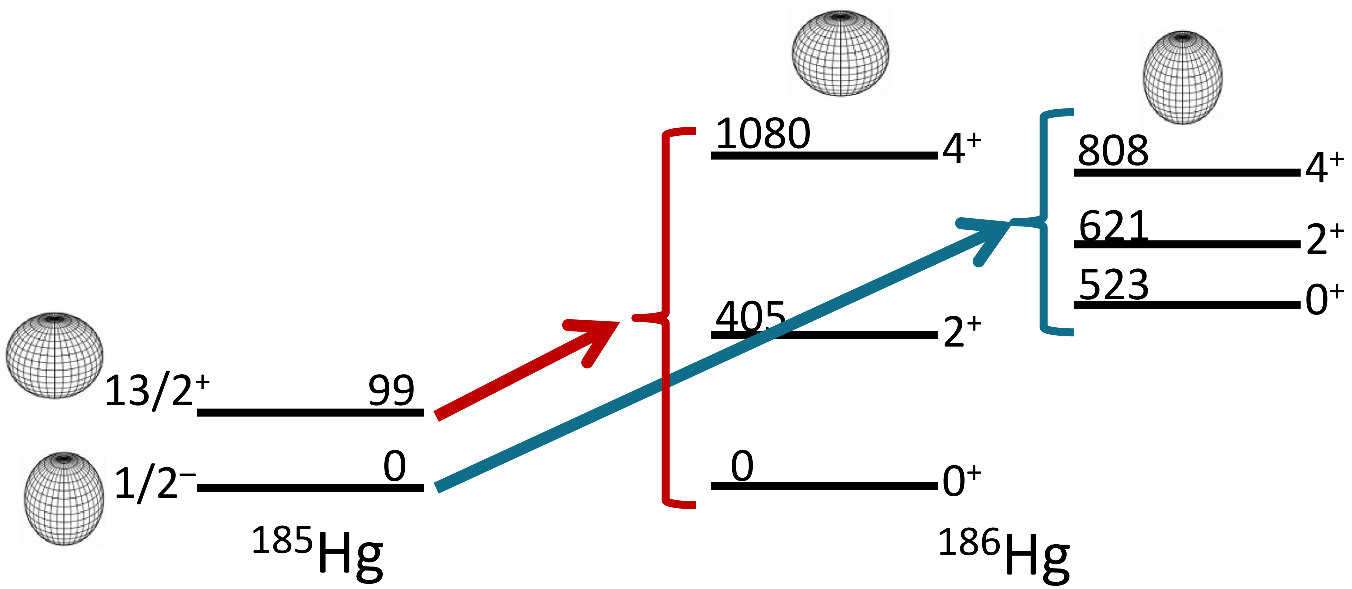


To the Pb region

T Otsuka and Y Tsunoda, JPG 43 (2016) 024009

1-n transfer in Hg

- ^{185g,m}Hg (d,p) and (p,d)
- Beam intensity ≈ 10^5 pps → feasible!



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1-n transfer in Hg

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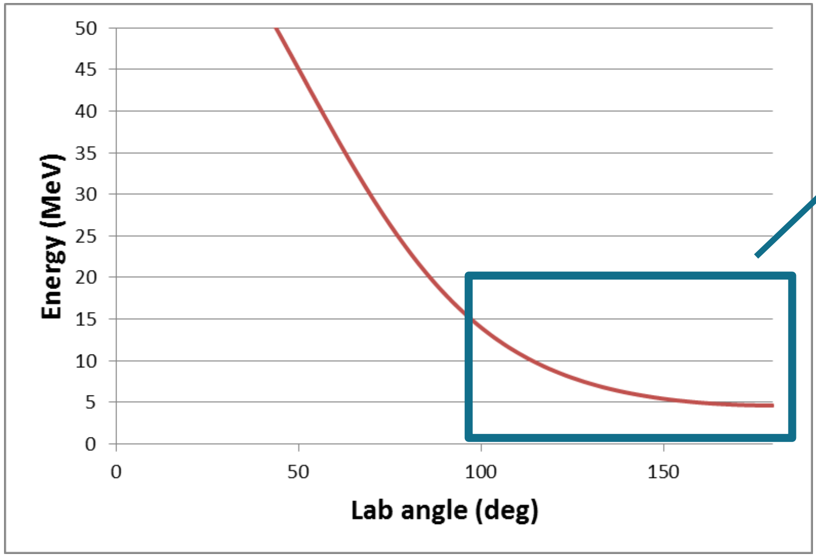
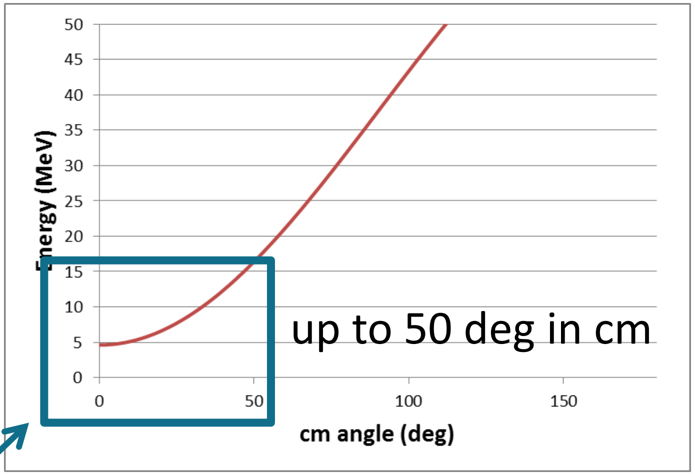
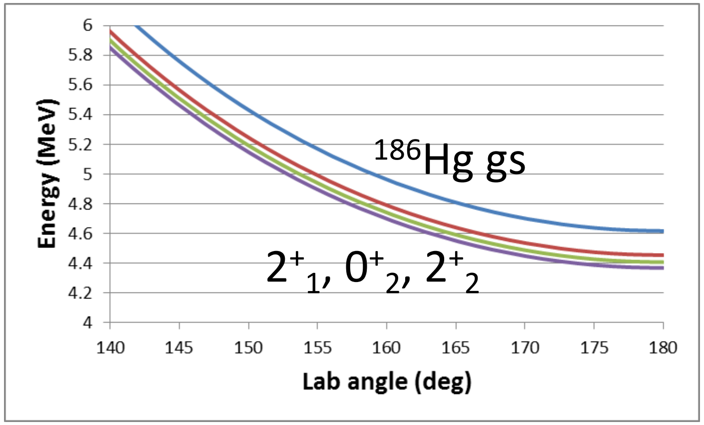
(d,p)^{186}Hg 10 MeV/nucleon, *Q*-value +8.2 MeV







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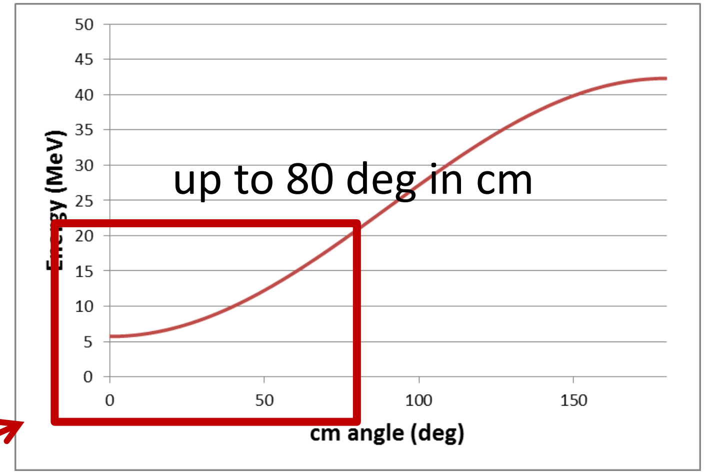
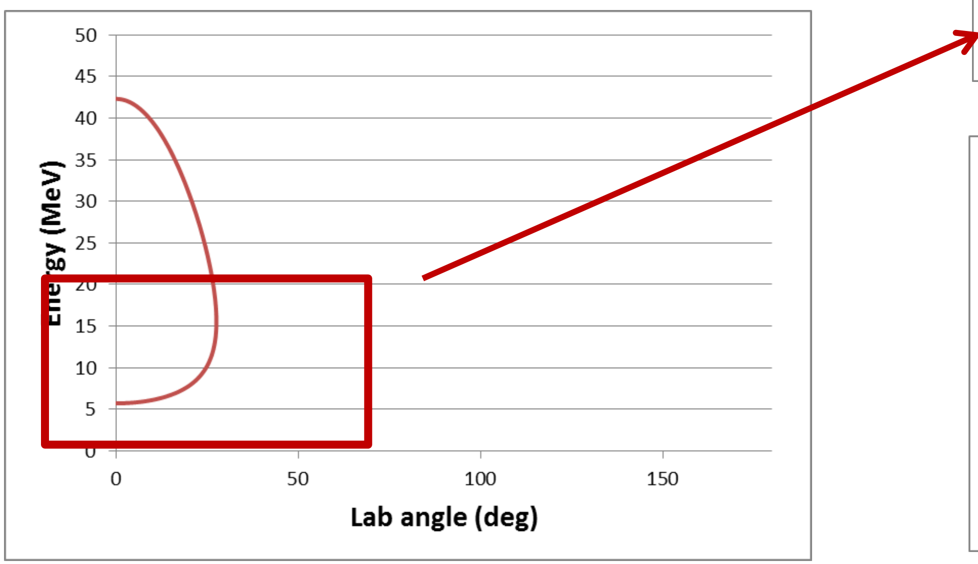
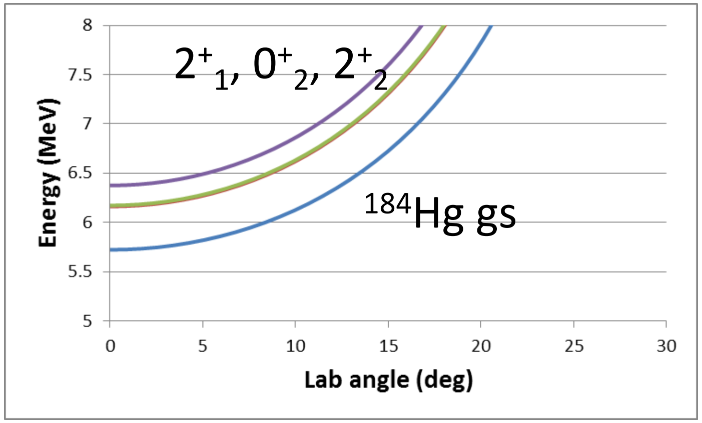


(p,d)^{184}Hg 10 MeV/nucleon, *Q*-value –5.7 MeV





Summary

- Data from all sort of techniques are necessary
  Importance of "anchor points"
- Transfer reactions with radioactive beams are feasible,
  but they remain very challenging!
- Choose cases accurately
  Aim for good-quality data on accessible nuclei
- γ-ray detection often essential
  Resolution vs efficiency
- Spectroscopic factors not always reliable
  (unknown reaction mechanism)
  Use relative quantities to interpret cross sections

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