EGAN Workshop, Padova, June, 26-30, 2011

EXOGAM: recent results and near future perspectives

- EXOGAM at GANIL
- A few recent physics highlights
- EXOGAM2
- EXOGAM at the ILL

G de France, GANIL

A few recent physics highlights

1. Lifetime measurement:
   - $^{62,64}Fe$
   - $^{63,65}Co$
2. Prompt and delayed gamma-ray spectroscopy: ^{68}Ni

   → A. Dijon
3. Fission fragments γ-ray spectroscopy
4. MED in the A=58, T=1 triplet: ^{58}Zn
5. Search for T=0 np pairing: ^{92}Pd, ^{91}Ru
6. The ^{34}Si(d,p) reaction to probe the spin orbit interaction

1. Lifetime measurement:

Onset of collectivity in the ^{68}Ni region. The case of $^{62,64}Fe$.

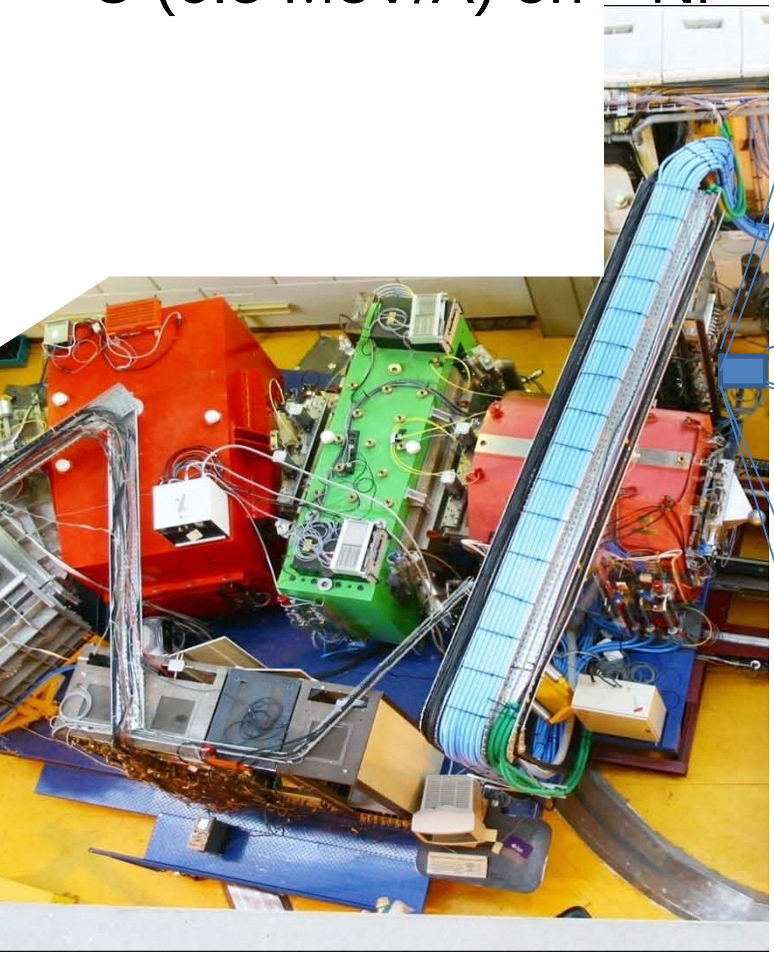
The case of $^{63,65}Co$:

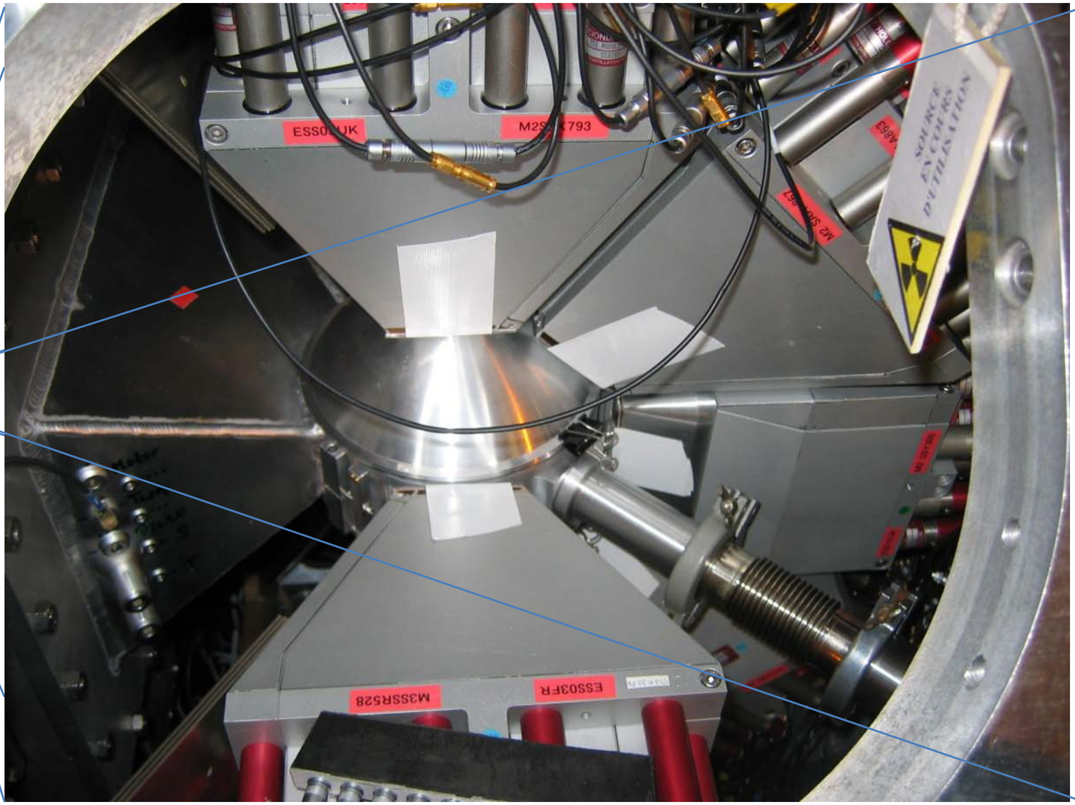
A. Dijon’s talk

E553

Differential plunger at VAMOS+EXOGAM

^{238}U (6.5 MeV/A) on ^{64}Ni

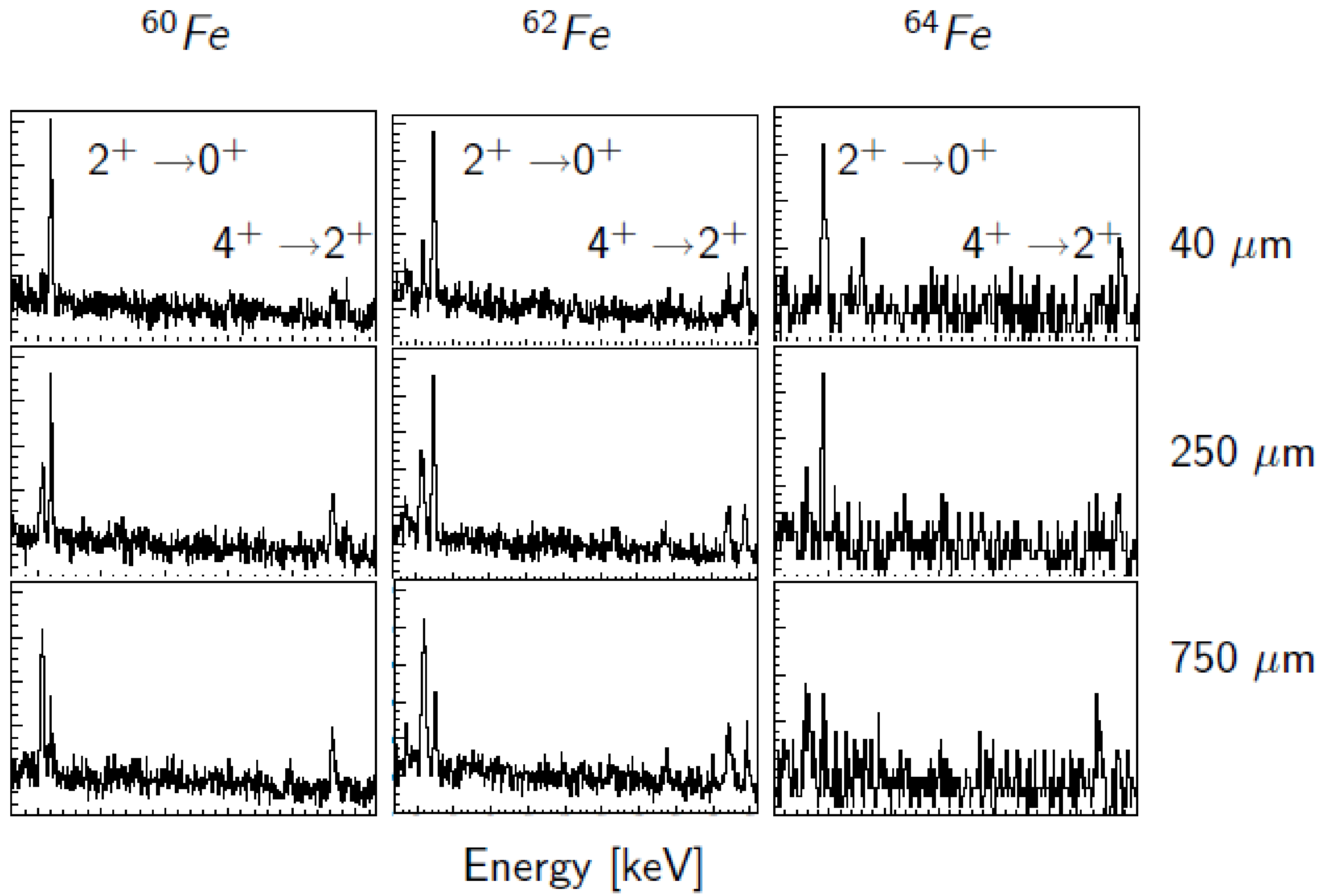




EXOGAM

VAMOS close to the grazing angle (45°)

Results: the iron isotopes



Lifetime of irons

Isotope (A)	τ (ps)		E_{exc} (keV)	B(E2; $2^+ \rightarrow 0^+$) (e^2fm^4)
	NNDC	This work		
60	11.6(22)	11.4(12)	823.6	190(20)
62	-	7.4(9)	876.8	214 (26)
64	-	7.4(26)	746.4	470 $_{(-110)}^{(+210)}$

Check: ^{60}Fe: $t_{1/2}$ ($2^+ \rightarrow 0^+$) = 11.4 (12) ps (this work)

(11.6 (22) ps in Warburton et al, PRC 16 (1977) 1027)

PHYSICAL REVIEW C **81**, 061301(R) (2010)

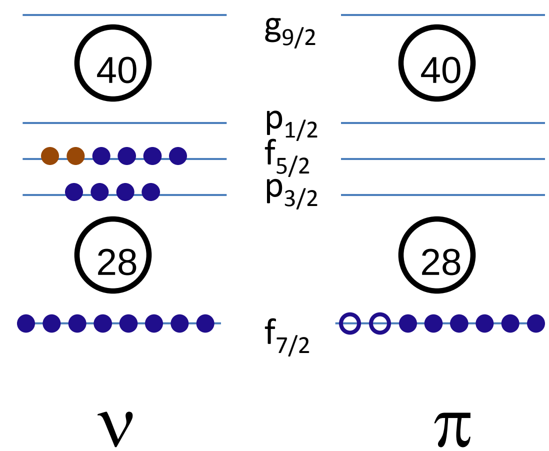
Onset of collectivity in neutron-rich Fe isotopes: Toward a new island of inversion?

J. Ljungvall,[1,2,3] A. Görgen,[1] A. Obertelli,[1] W. Korten,[1] E. Clément,[2] G. de France,[2] A. Bürger,[4] J.-P. Delaroche,[5] A. Dewald,[6] A. Gadea,[7] L. Gaudefroy,[5] M. Girod,[5] M. Hackstein,[6] J. Libert,[8] D. Mengoni,[9] F. Nowacki,[10] T. Pissulla,[6] A. Poves,[11] F. Recchia,[12] M. Rejmund,[2] W. Rother,[6] E. Sahin,[12] C. Schmitt,[2] A. Shrivastava,[2] K. Sieja,[10] J. J. Valiente-Dobón,[12] K. O. Zell,[6] and M. Zielińska[13]

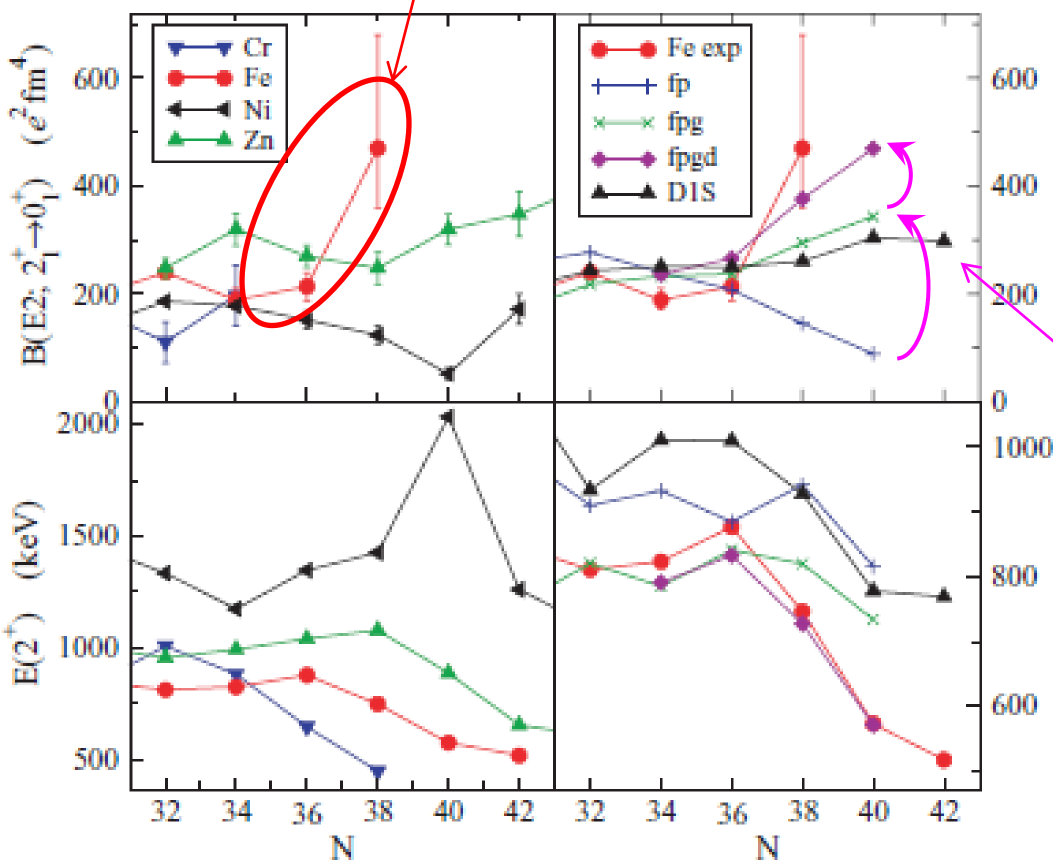
Iron results

$B(E2;2^+_1 \rightarrow 0^+_1) = 214(26)\ e^2.fm^4$ ^{62}Fe

$B(E2;2^+_1 \rightarrow 0^+_1) = 470(+210/-110)\ e^2.fm^4$ ^{64}Fe



- Increase of collectivity



- Role of g9/2 and d5/2

2. Prompt and delayed gamma-ray spectroscopy around ^{68}Ni

A. Dijon’s talk

3. Fission fragments gamma-ray spectroscopy at VAMOS

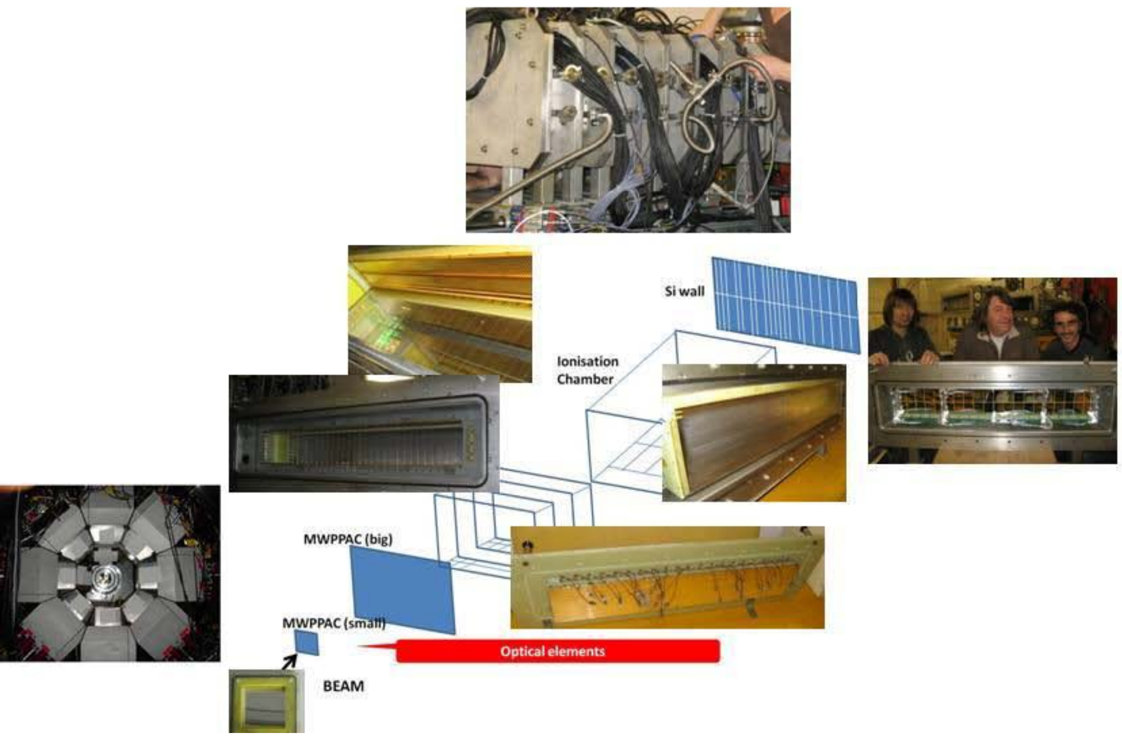
E585

Slides from A .Navin, M. Rejmund and Ch. Schmitt

Nuclear Instruments and Methods in Physics Research A 646 (2011) 184–191

Performance of the improved larger acceptance spectrometer: VAMOS++

M. Rejmund [a], B. Lecornu [a], A. Navin [a,*], C. Schmitt [a], S. Damoy [a], O. Delaune [a], J.M. Enguerrand [a], G. Fremont [a], P. Gangnant [a], L. Gaudefroy [b], B. Jacquot [a], J. Pancin [a], S. Pullanhiotan [c], C. Spitaels [a]



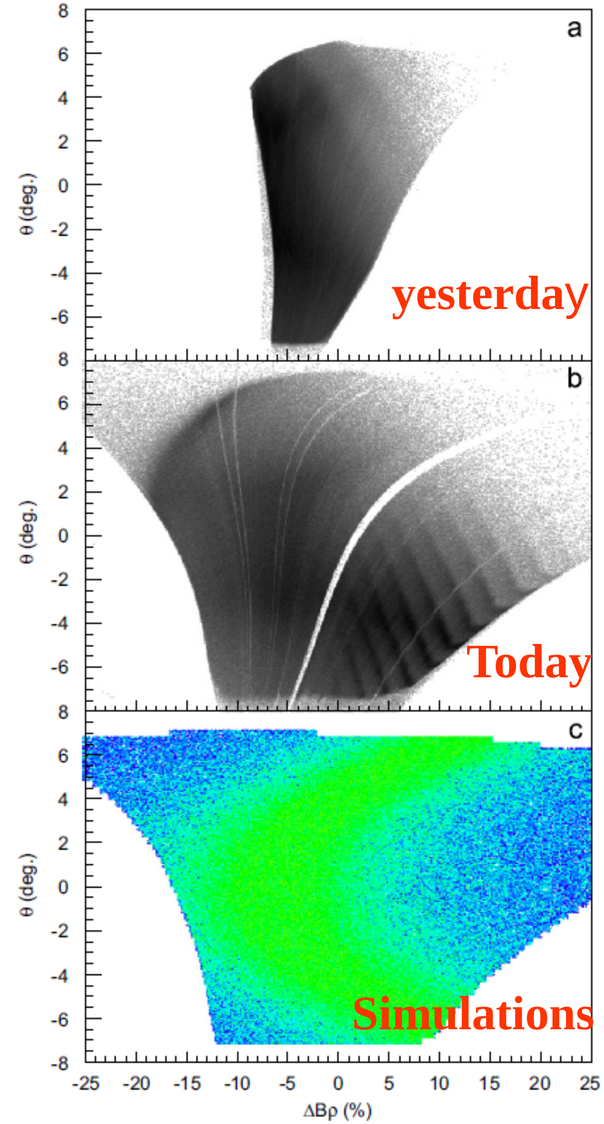


Fig. 11. Two-dimensional plot of θ as a function of relative rigidity for transmitted trajectories. (a) Same as in Fig. 2(b) for a detector size of 400 mm × 110 mm. (b) From the present measurement with a detector size of 1000 mm × 150 mm. (c) Simulation for an isotropic distribution of particles entering the spectrometer, for a detector size of 1000 mm × 150 mm.

4. Mirror energy differences in the A=58, T=1 triplet: ^{58}Zn

Slides from T. Hüyük and A. Gadea

Mirror energy differences beyond the $f_{7/2}$-shell

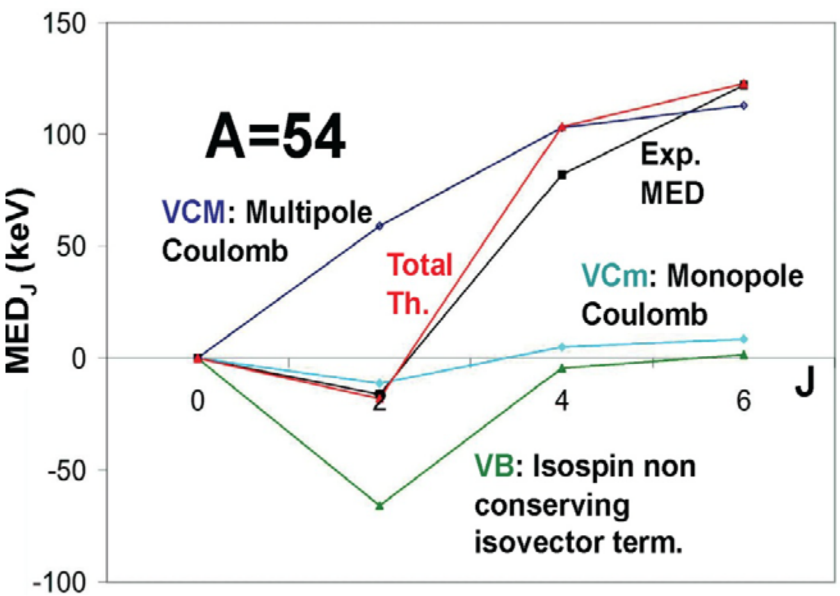
For a T=1 triplet:

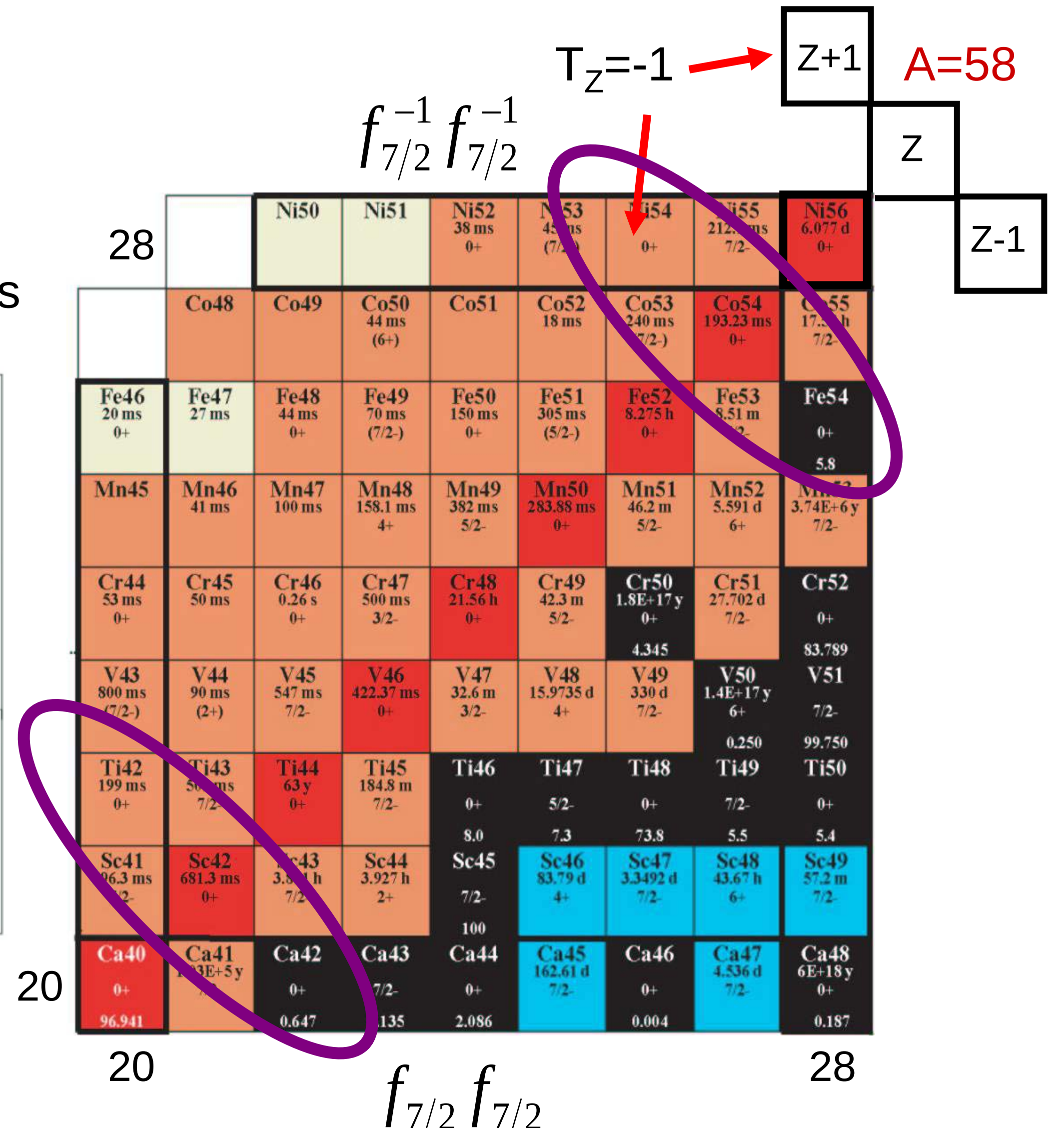
$$\mathbf{MED}_J = E_J(Z+1) - E_J(Z-1)$$

information on CSB terms (V^{pp}-V^{nn})

$$\mathbf{TED}_J = E_J(Z+1) + E_J(Z-1) - 2E_J(Z)$$

information on CSB & CIB (V^{pn}) terms



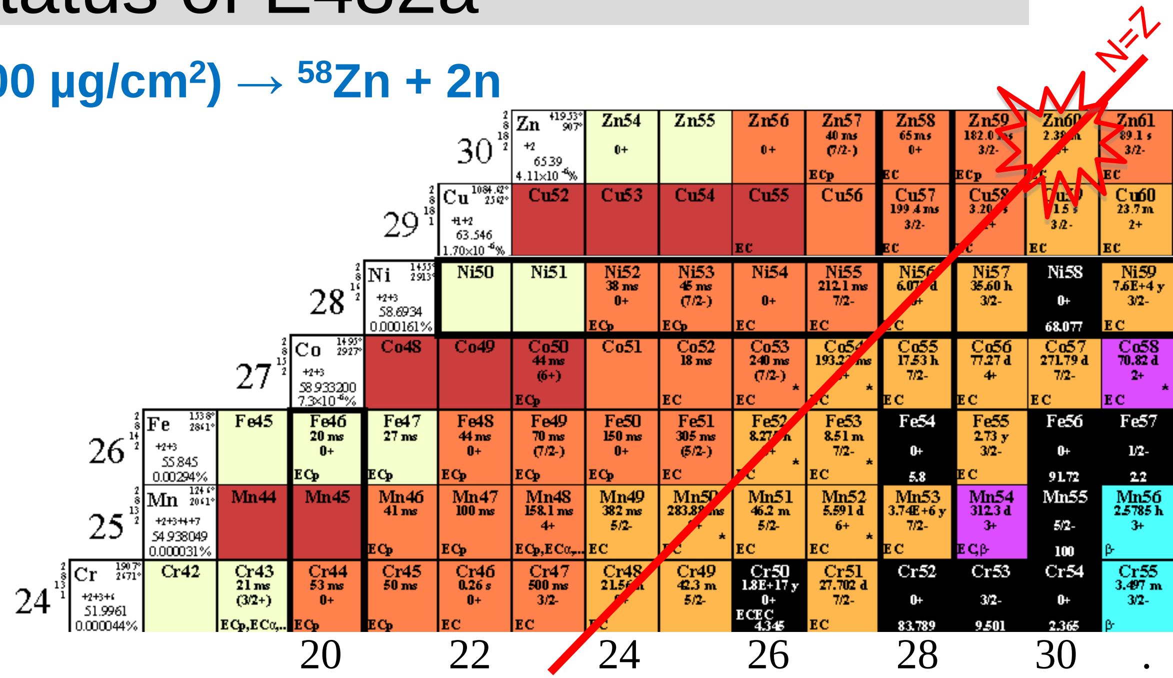


A=54 A.Gadea et al. , Phys.Rev.Lett. 97 (2006) 152501

Theory: A.Zuker et al., Phys.Rev.Lett.89 (2002)142502

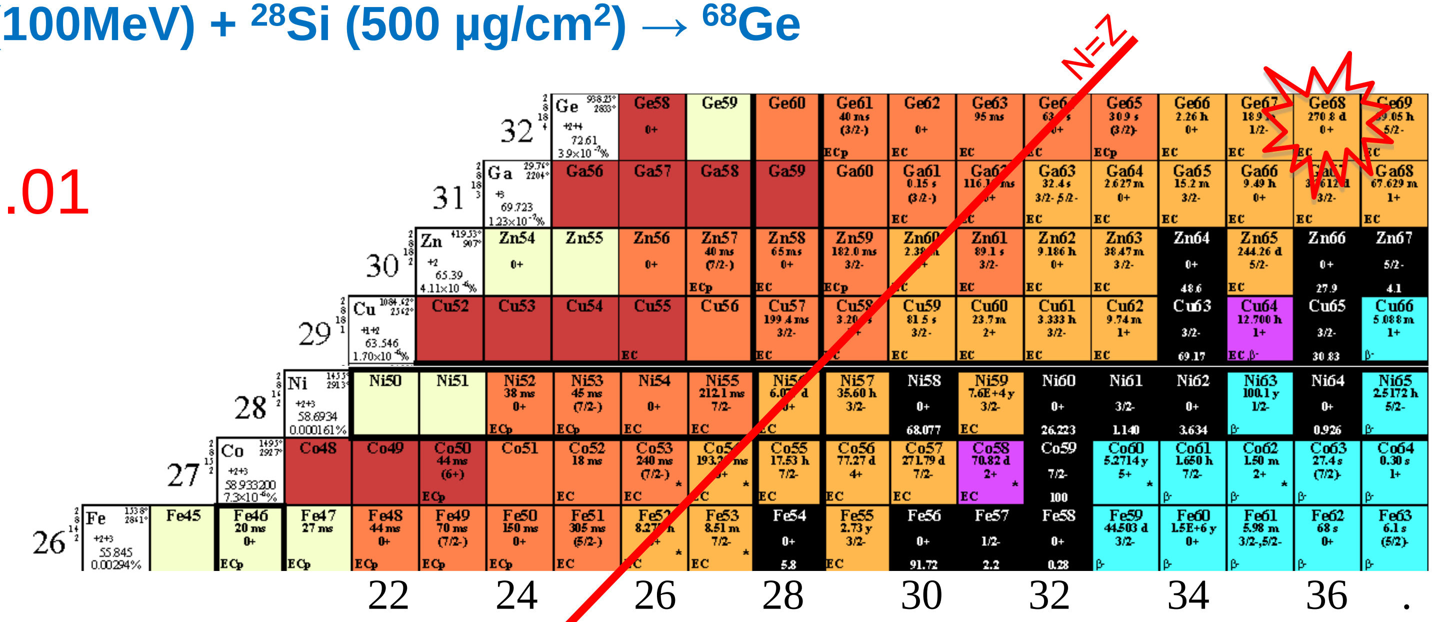
Status of E482a

Reaction: ^{32}S (80MeV) + ^{28}Si (500 μg/cm^2) → ^{58}Zn + 2n



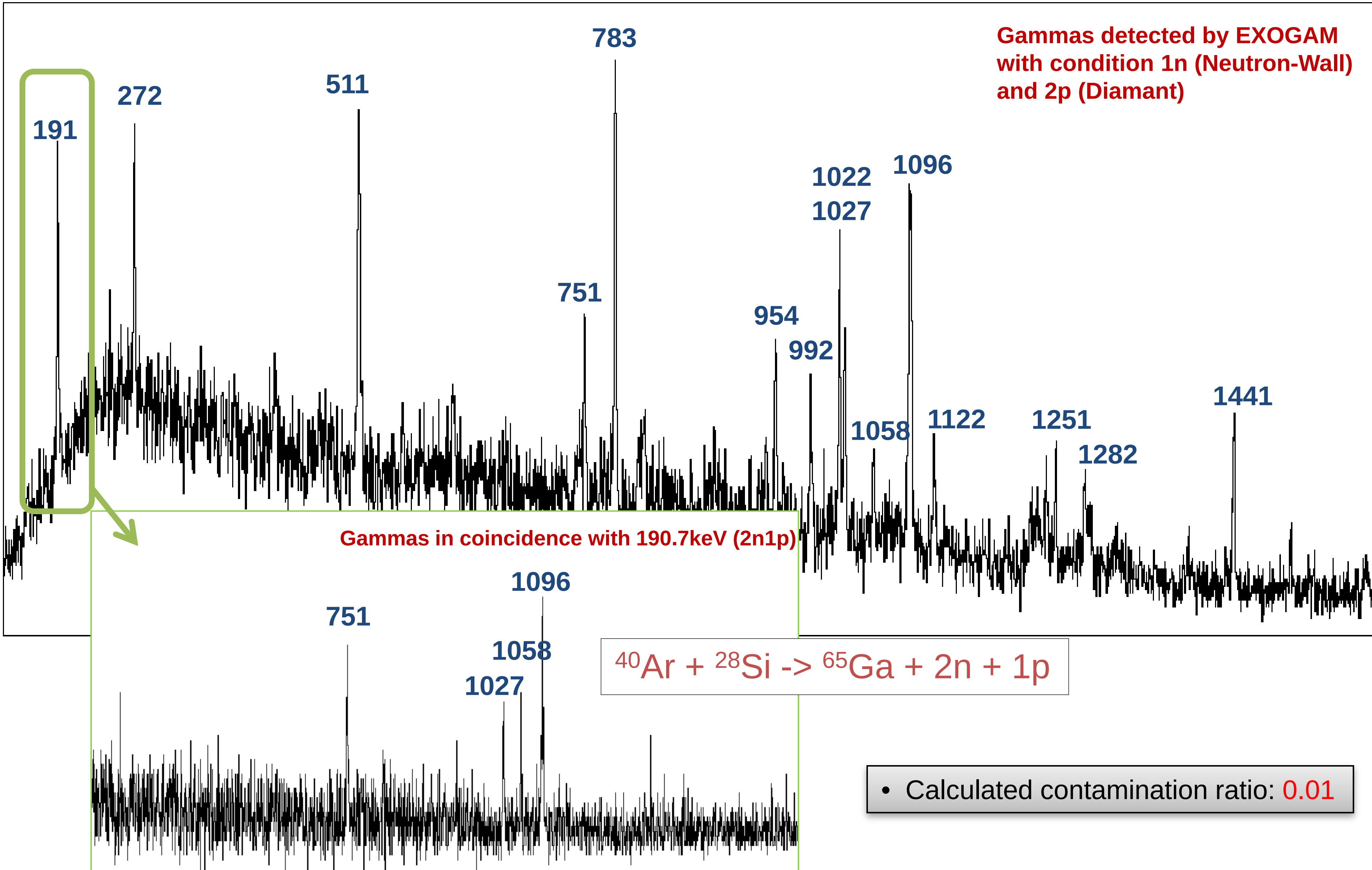
Contamination: ^{40}Ar (100MeV) + ^{28}Si (500 μg/cm^2) → ^{68}Ge

$^{40}Ar/^{32}S = 0.01$



Status of E482a

Neutron and Charged Particle gates and ^{40}Ar contamination in the ^{32}S beam



$^{40}Ar + ^{28}Si \rightarrow ^{65}Ga + 2n + 1p$

- Calculated contamination ratio: 0.01

Mirror energy differences beyond the $f_{7/2}$-shell

Silvia Lenzi, Gilles de France, Emmanuel Clement, Aurore Dijon,
Jean Ropert, Barna Nyako, Katalin Juhász, József Molnár, János Timár,
Alejandro Algora, János Gál, Gábor Kalinka Marcin Palacz, Pier Giorgio Bizzeti, Antonio di Nitto, Giovanni La Rana, Renata Moro, Giacomo de Angelis,
Francesco Recchia, Calin A. Ur, Jose Javier Valiente, Eda Sahin, Andrea Gottardo, Daniel R. Napoli, Johan Nyberg, Pär-Anders Söderström, Ayse Atac, Ayse Kaskas, Menekse Senyigit, **Tayfun Hüyük**, Bo Cederwall, Torbjörn Bäck,
Farnaz Ghazi Moradi, **Andres Gadea**

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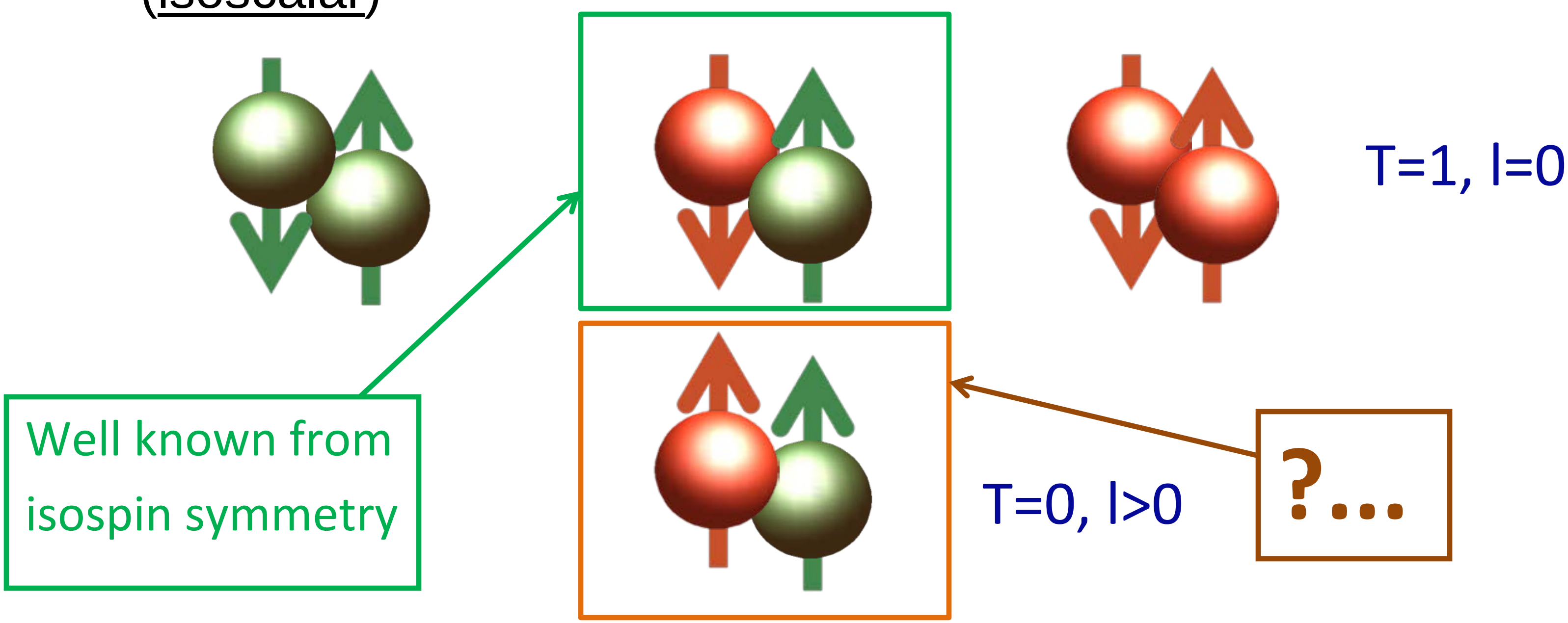
Department of Physics, Faculty of Science, Ankara University, Turkey
Department of Physics ,The Royal Institute of Technology (KTH) Stockholm, Sweden
GSI Darmstadt, Germany
Dipartimento di Fisica, Università di Firenze and INFN, Firenze, Italy
Dipartimento di Scienze Fisiche, Università di Napoli and INFN, Napoli, Italy

5. Search for T=0 np pairing: ^{92}Pd. By-product: ^{91}Ru

Motivations

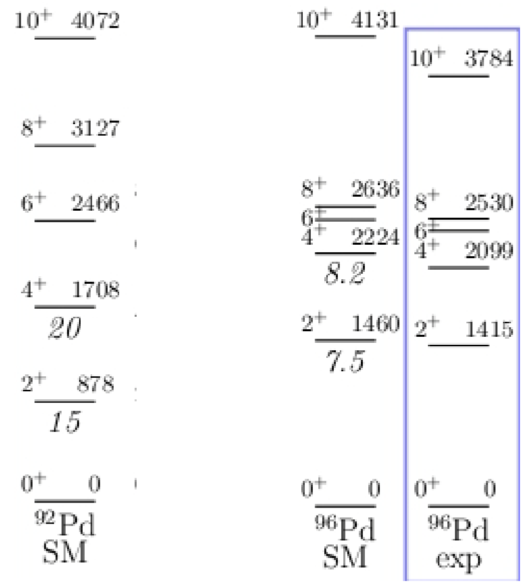
- Study of pairing (short range) correlations is a central topic in nuclear structure.
- In heavy nuclei, like nucleon pairing dominates: identical particles in time reversed orbits are coupled to T=1, l=0 <u>isovector</u> nn and pp Cooper pairs
- In N ≈ Z nuclei, neutrons and protons occupy the same orbitals ➔ maximum spatial overlap ➔ np pairs with T=1, l=0 and also T=0, l>0 (<u>isoscalar</u>)



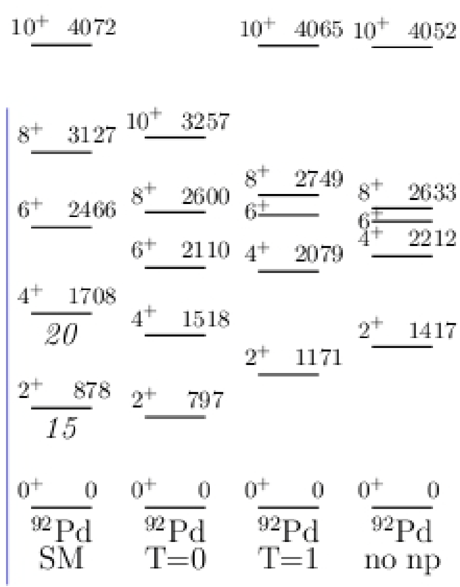
How to look for this?

- Profound modification of the level scheme:

Regular spacing



Seniority type

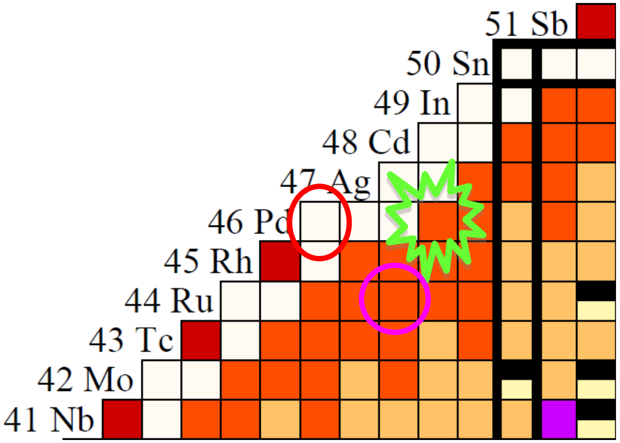


- Predicted effect of the T=0 and T=1 channels
- **The major influence of T=0**

J. Blomqvist et al

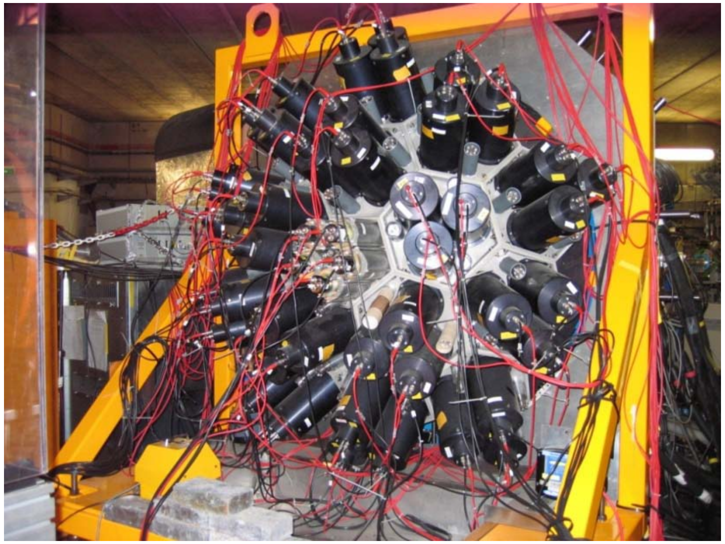
EXOGAM-NWall-DIAMANT:

The power of the coupling

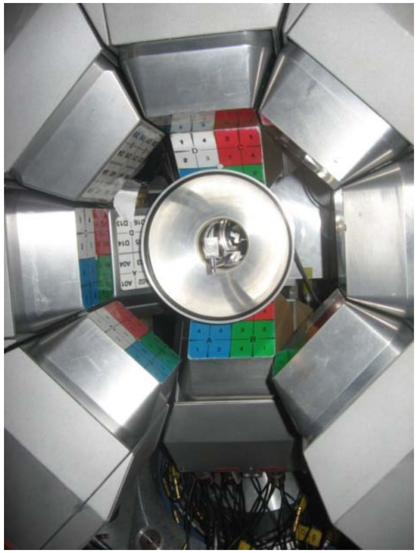


^{36}Ar (111 MeV) + ^{58}Ni ⟶ ^{94}Pd* ⟶

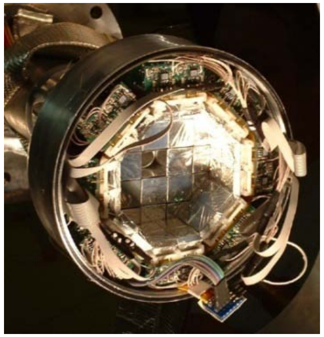
^{91}Tc + 3p
^{91}Ru + 2p1n
^{90}Mo + 4p
^{88}Mo + 4p2n
^{90}Tc + 3p1n
^{92}Rh + 2p
...
^{92}Pd + 2n



- The Neutron Wall: 50 liquid scintillator detectors. ε_{1n} ~ 23%



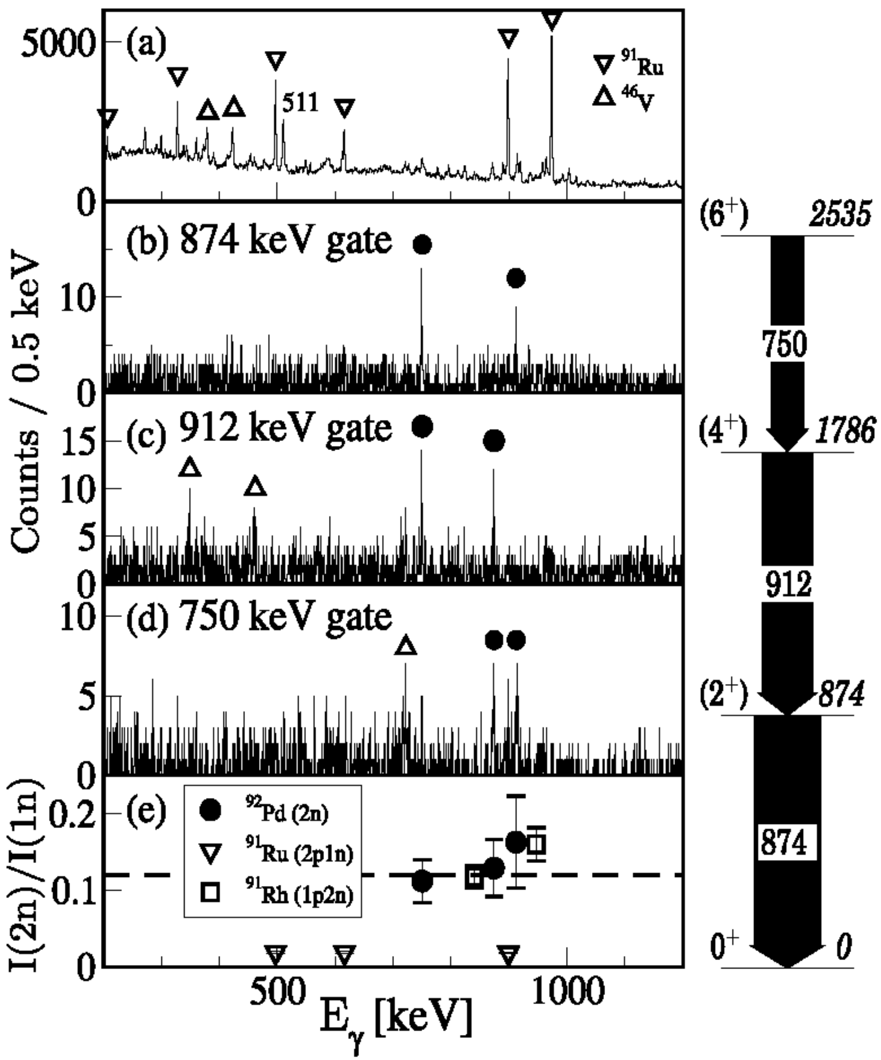
- EXOGAM: 11 Clovers with partial shield. $\varepsilon_p\omega$ ~ 10% for E_g=1.3 MeV



- DIAMANT: 80 CsI(Tl) dets. $\varepsilon_{p \text{ or } \alpha}$ ~ 66%

EXOGAM:

First identification of γ-rays in ^{92}Pd



- Three γ-rays firmly identified
- In coincidence with 2n
- Not in coincidence with charged particles
- Mutually coincident
- All possible contaminants excluded
- ➔ Unambiguously assigned to ^{92}Pd

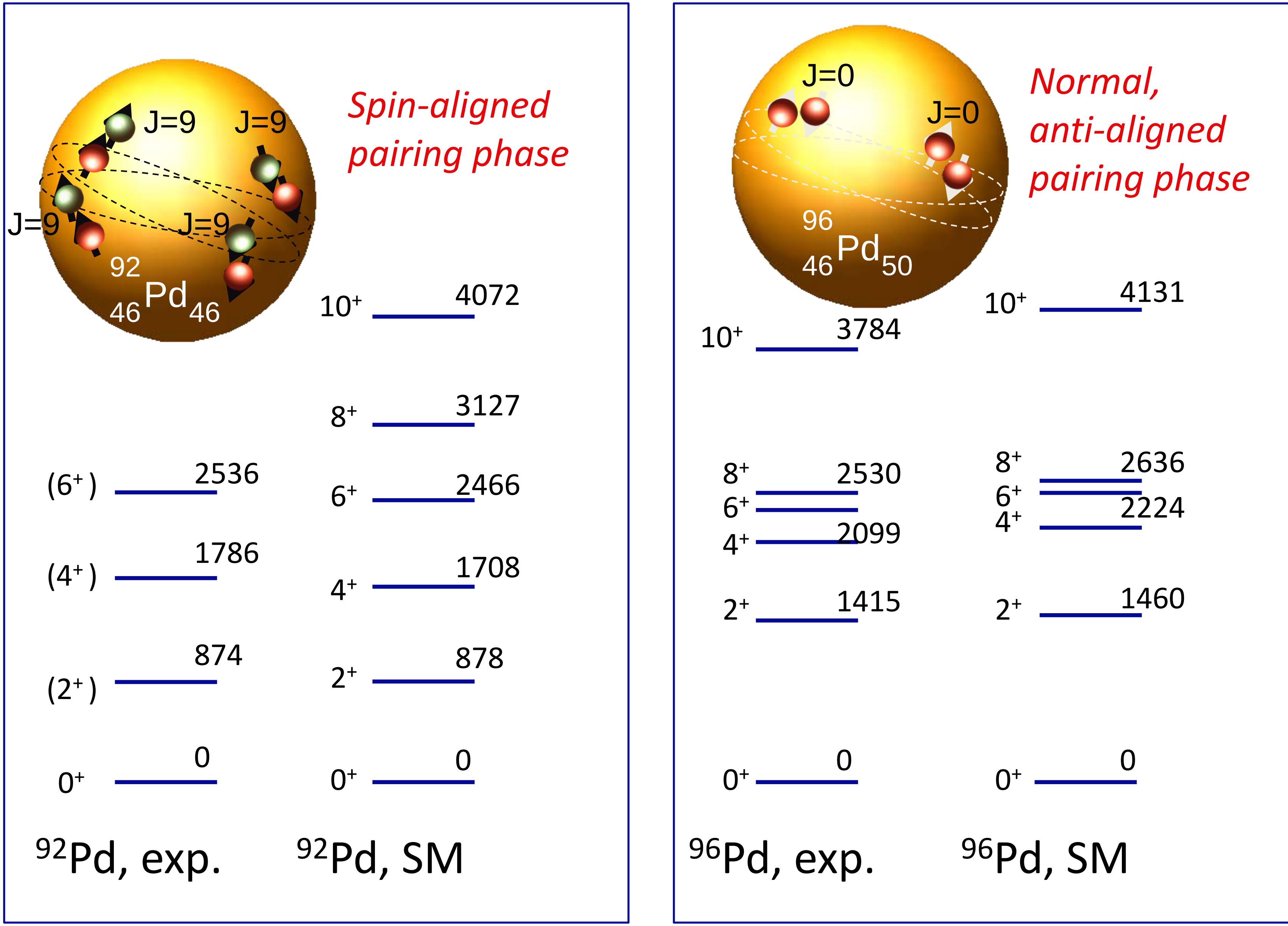
Production cross section ~ 0.5 μb

B Cederwall, F. Ghazi-Moradi, T Back, A Johnson, J. Blomqvist, E Clément, G. de France, R Wadsworth et al,

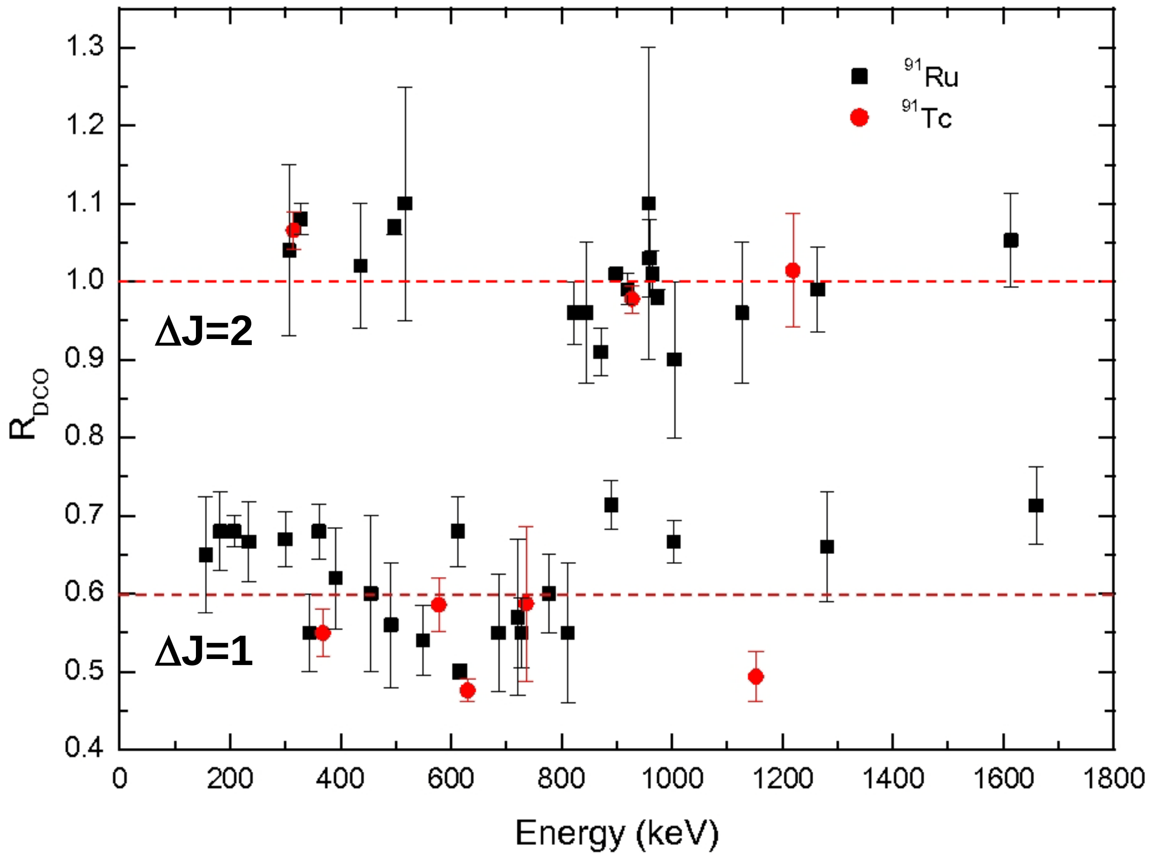
Nature 469, 68-71 (2011)

See J Nyberg's talk for the 2n selection procedure

^{92}Pd:A new spin aligned np coupling scheme



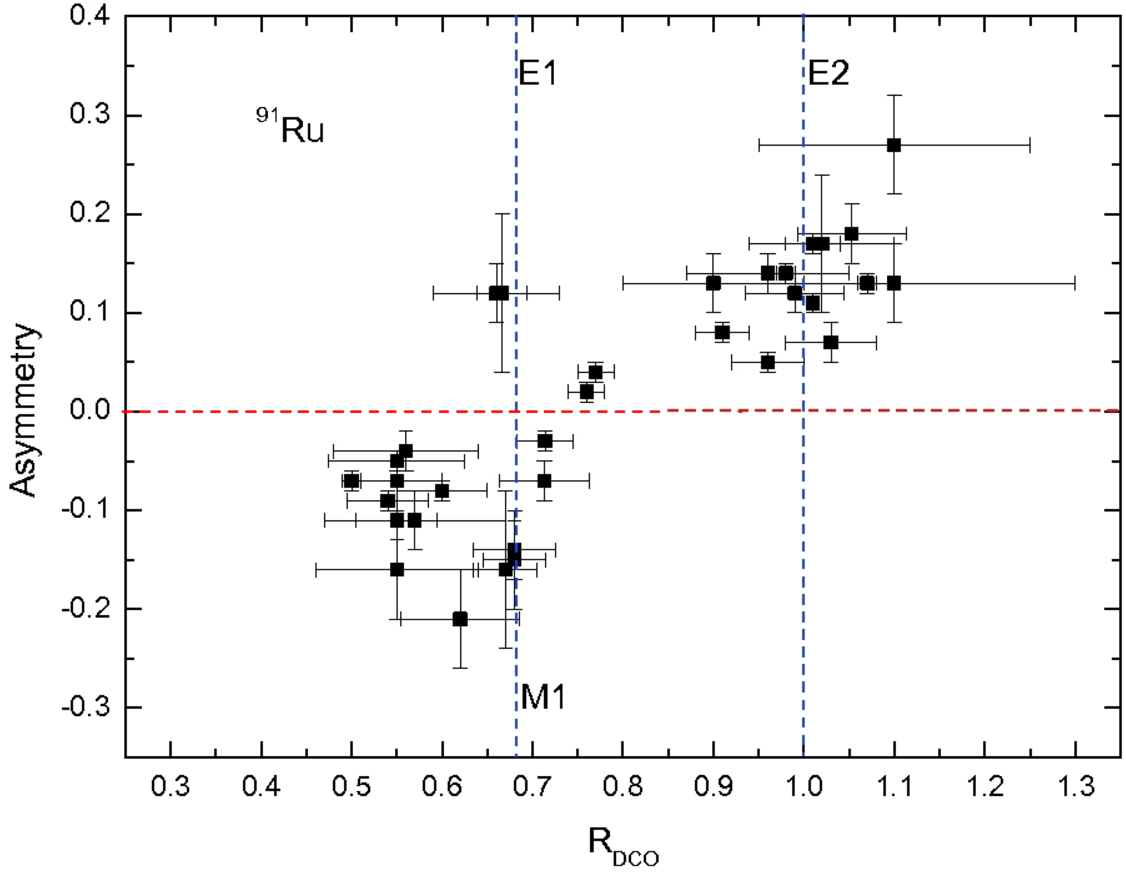
DCO ratios in ^{91}Ru



$$R_{DCO} = \frac{I_{\gamma 1} \text{ at } 135° \text{ gated by } \gamma 2 \text{ at } 90°}{I_{\gamma 1} \text{ at } 90° \text{ gated by } \gamma 2 \text{ at } 135°}$$

Y Zheng et al

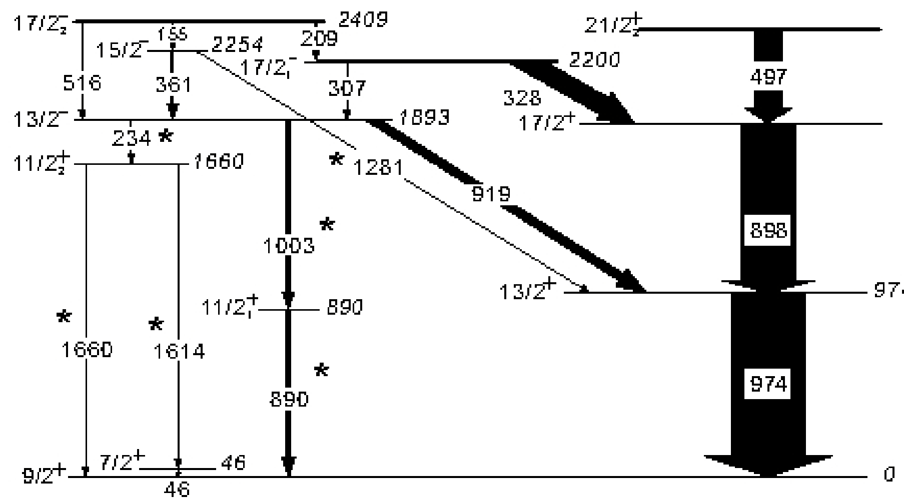
Asymmetry vs DCO ratios in ^{91}Ru



$$A = \frac{[a(E_\gamma)N_\perp - N_{//}]}{[a(E_\gamma)N_\perp + N_{//}]} \qquad a(E_\gamma) = \frac{N_{//}(\textit{unpolarized})}{N_\perp(\textit{unpolarized})}$$

Y Zheng et al

New transitions in ^{91}Ru



^{91}Ru

- Three neutron-hole excitations in ^{91}Ru
- First DCO ratios and asymmetry measurements with EXOGAM!

Y Zheng et al

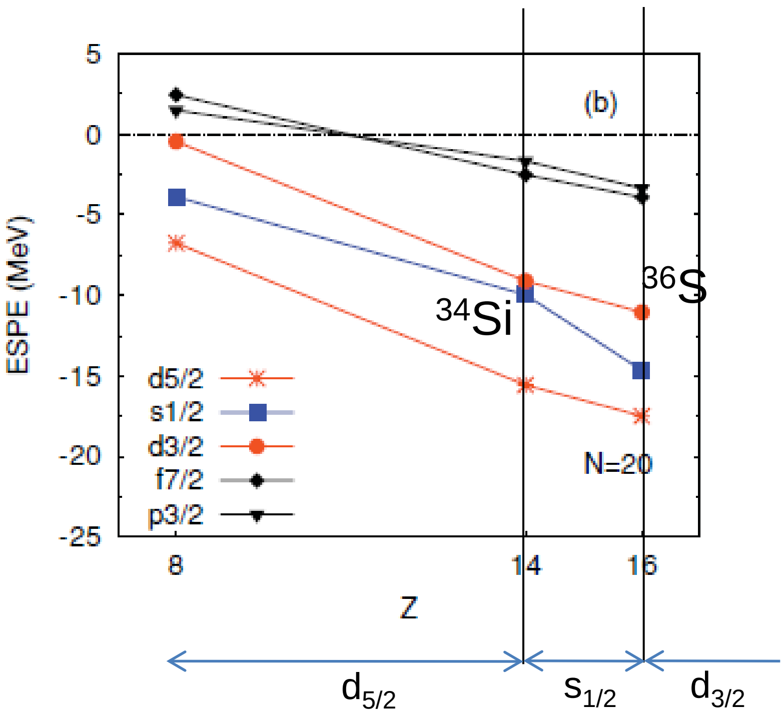
6. The $^{34}Si(d,p)$ reaction to probe the spin orbit interaction.

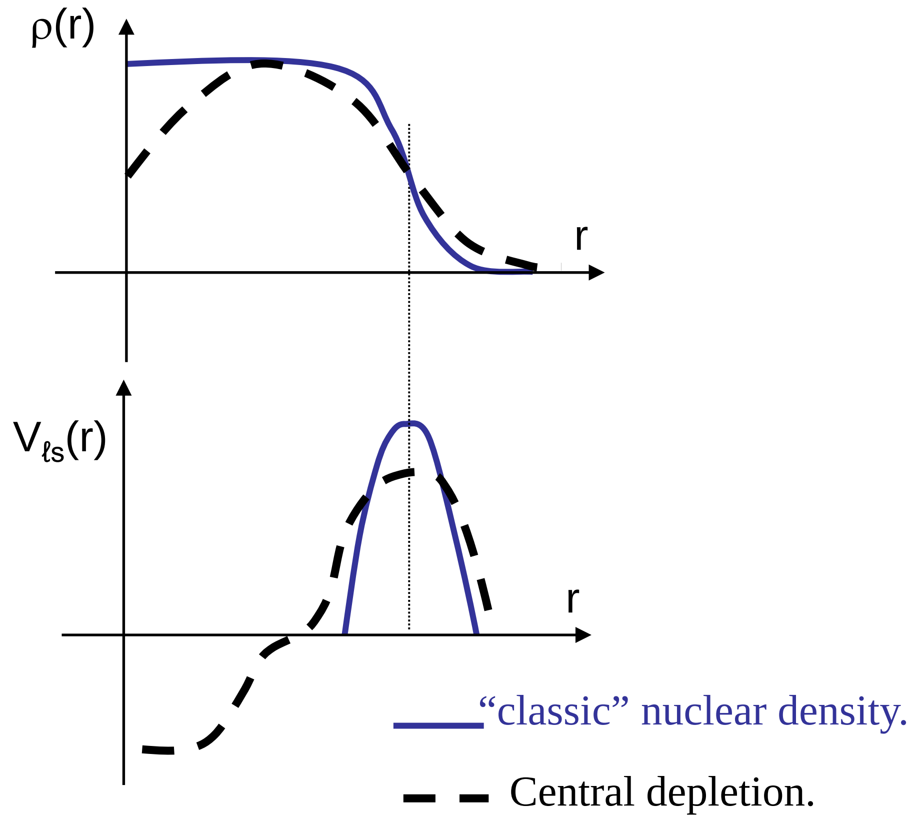
Slides from G. Burgunder and O Sorlin

The spin-orbit interaction

Density dependence of the spin-orbit interaction:

$$V_{ls}(r) \propto \frac{1}{r}\frac{d}{dr}\left[A\rho_n(r) + B\rho_p(r)\right]\cdot\left(\vec{l}\cdot\vec{s}\right)$$





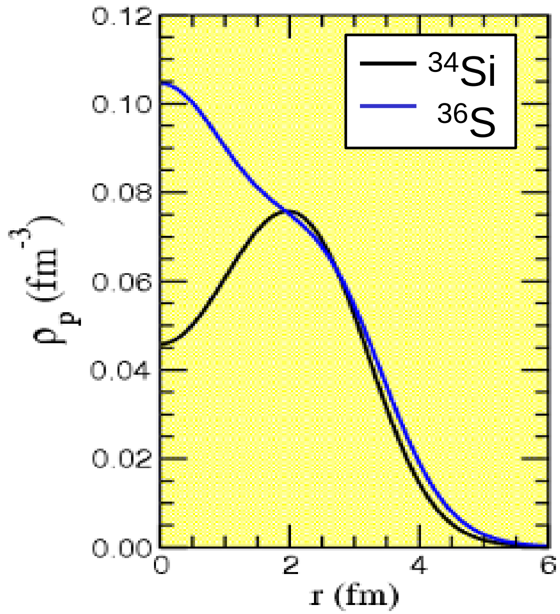
➔ Probe filling of $s_{1/2}$ going from ^{34}Si to ^{36}S

SM Lenzi et al PRC82, 054301 (2010)

(d,p) reactions to probe π density

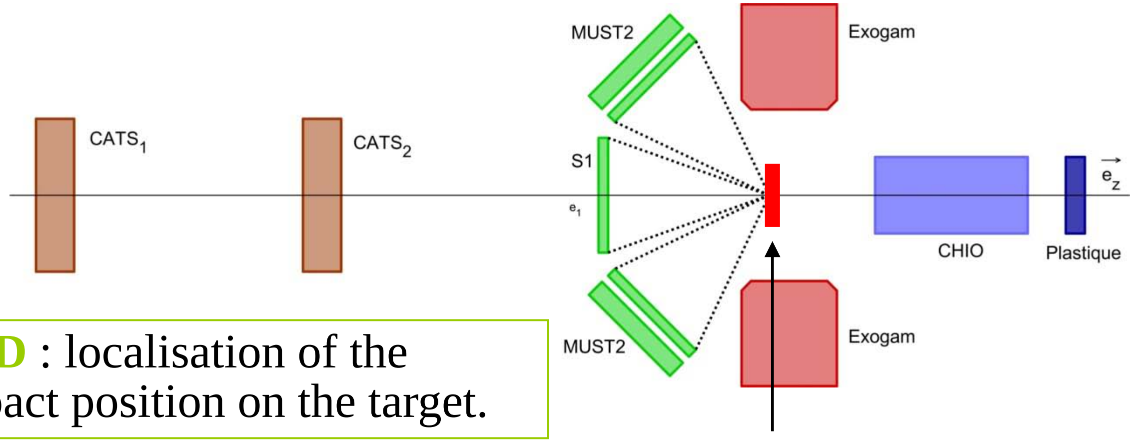
Probing $s_{1/2}$ occupancy ⇔ probing the central proton density

➔ Transfer reactions



Grasso et al. Phys. Rev. C 79 (2009).

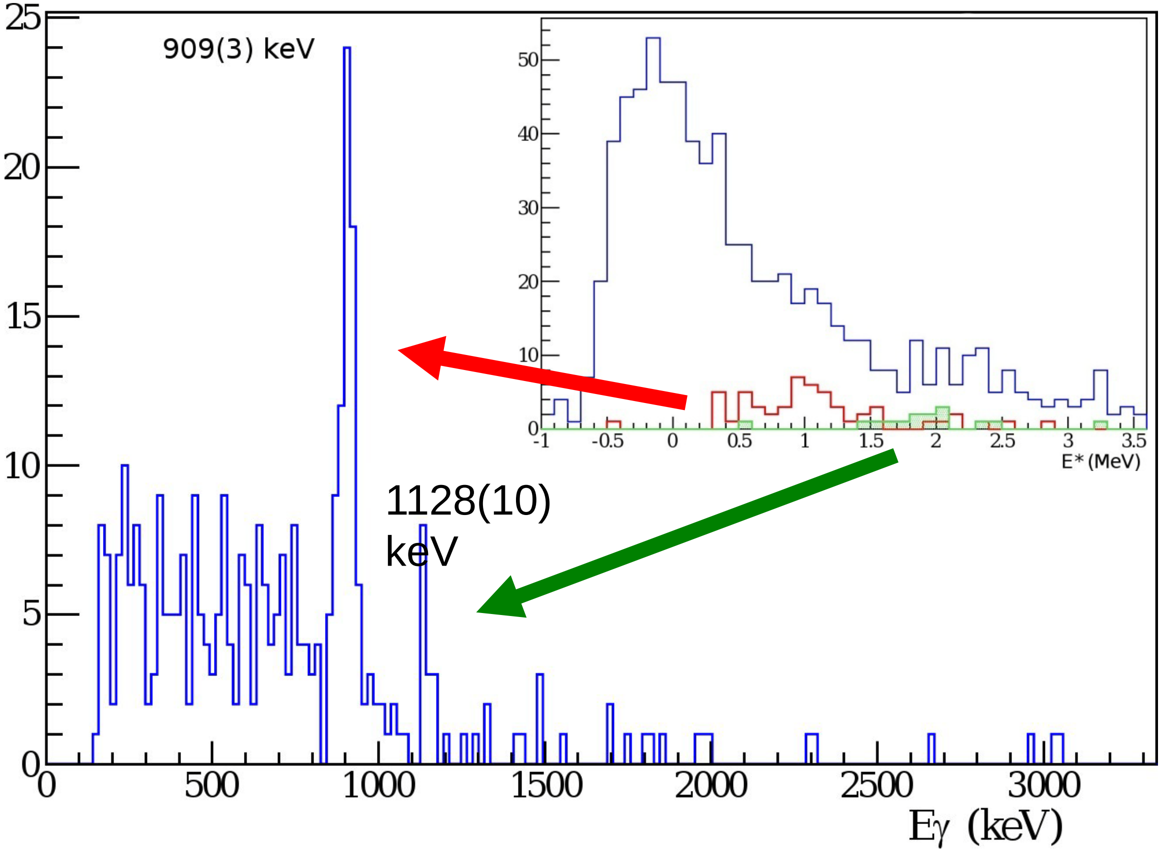
Beam : ^{36}S or ^{34}Si, 20 MeV/A 10^5 pps

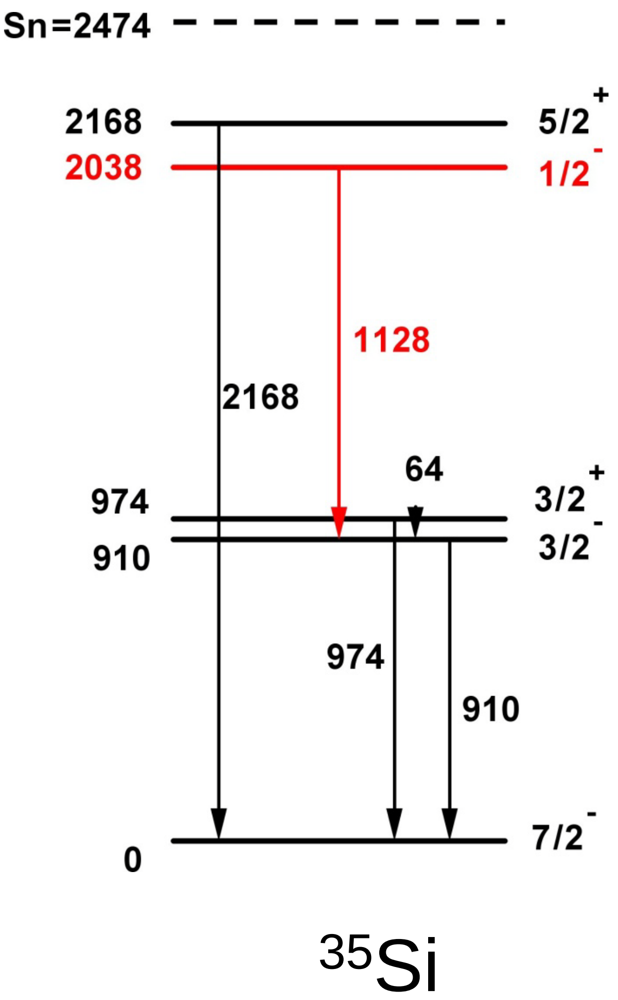


BTD : localisation of the impact position on the target.

Target : CD_2 (2,6 mg/cm^2).

E* (MUST) in coinc. with EXOGAM





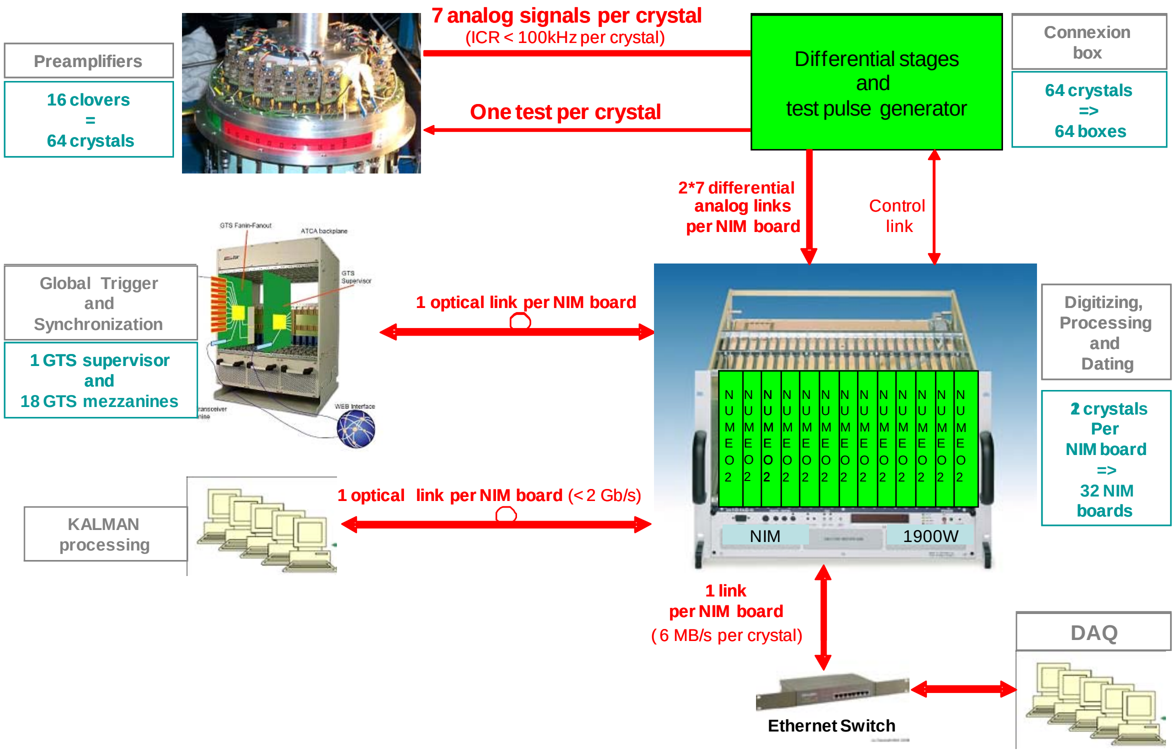
The near future of EXOGAM:

EXOGAM2

EXOGAM at the ILL

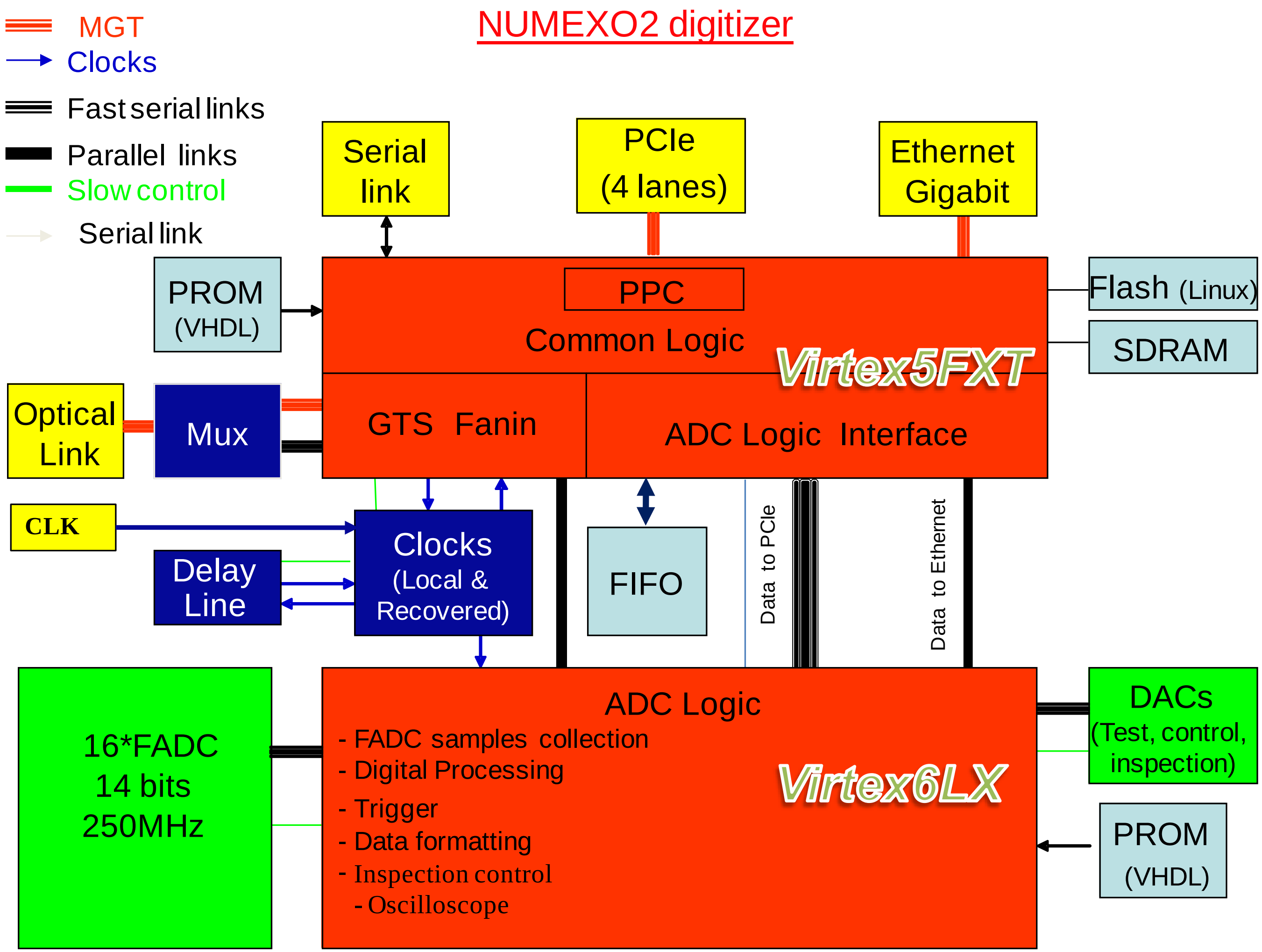
EXOGAM2

- Aging D-Size VXI electronics
- Severe rate limitations (use far beyond original specs)



EXOGAM2

- The NIM digitizer



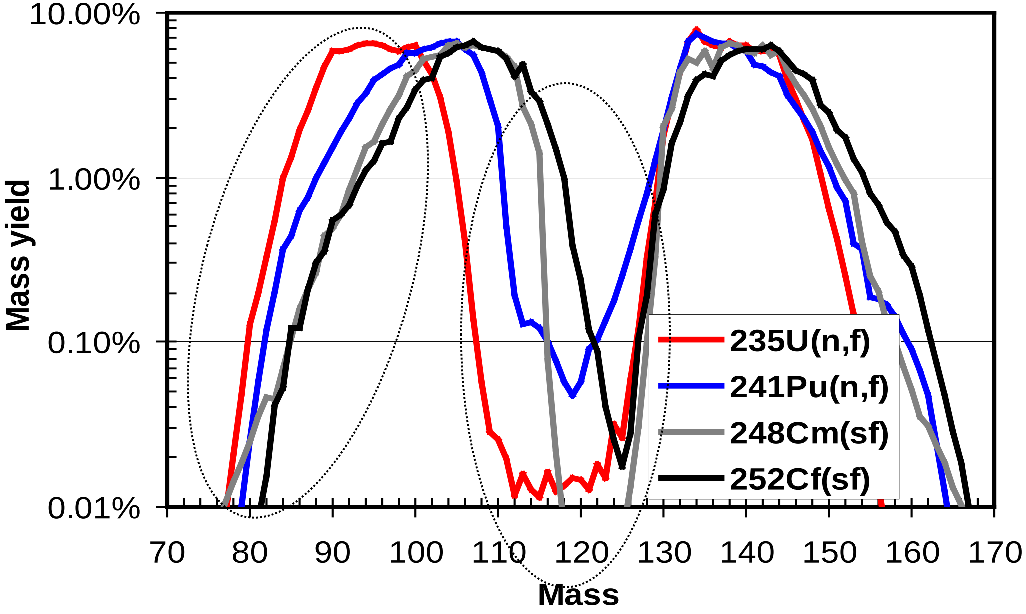
The collaboration, etc.

- Timescale: ready when AGATA will be at GANIL (early 2014)
- Collaboration: GANIL, IPNO, CSNSM, Krakow, UIAC New Delhi, TIFR Mumbai, ATOMKI, KTH Stockholm, Nigde Univ. + NEDA synergy: IFIC-Valencia, Padova, SLCJ Warsaw. Coll. Agreement being signed.
- Cost: ~580 k€ for 448 channels
- Current status: design of the full prototype. Should be available for test early 2012.

EXOGAM at the ILL

Exploit differences in the spontaneous and thermal neutron-induced fission yields to study:

- Nuclear structure around ^{78}Ni and beyond ^{132}Sn
- Nuclear astrophysics and the r-process
- The fission mechanism: angular momentum generation and the fragment mass distribution
- Reactor physics and nuclear data



The method and requirements

use γ–γ–γ or γ–γ–γ–γ coincidences

Need efficiency (~10 %) and the ability to resolve M~6 cascades

Typically 5×10^4-10^5 fissions per/s x 6 γ rays=3 – 6 x 10^5 γ rays emitted per second

Fission rate required ~10^5 fissions/s

Cross-sections ^{235}U=584 b, ^{241}Pu=1009 b

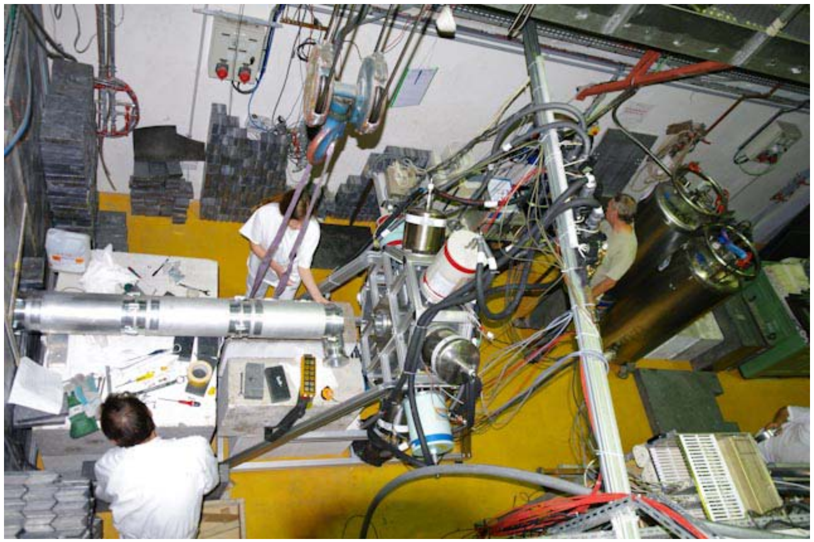
PF1B flux up to 1.8×10^{10} n/cm^2/s

Typical Lohengrin target ~400 μg/cm^2

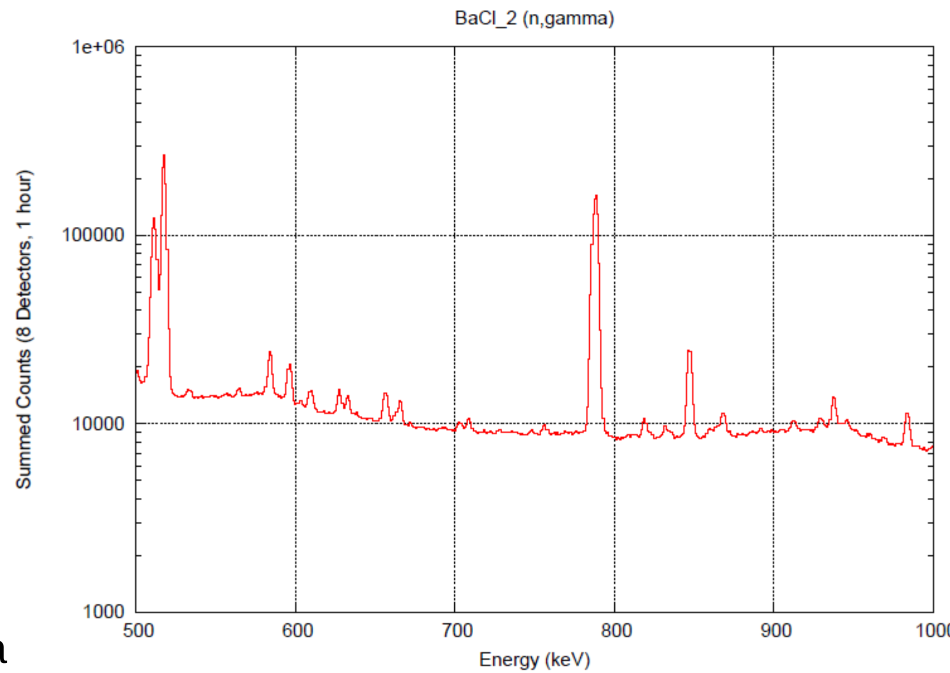
Fission rate (1 cm^2 ^{241}Pu target) = 1.8 x10^7 fissions/s

reduce by 200 (neutron beam collimation)

Test of the neutron collimator at PF1B



M Jentshel, W Urban, G Simpson et al



γ-ray spectrum of the energy range 500-1000 keV for a one hour in-beam measurement of a $BaCl_2$ target at PF1B

➔ No (n,n'γ) (broad peak around 600 keV)

➔ Very clean spectrum for (n,γ) reaction

Summary

- EXOGAM is intensively used at GANIL: working horse for high-resolution gamma-ray spectroscopy
- New and important physics results in various mass regions
- The upgrade of the electronics is going on
- ILL campaign expected 2012-13 (tbc). Workshop postponed by the end of the year.