Neutron-proton interaction in ^{92}Pd

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Agenda

- Introduction
- Experiment
- Results
- Interpretation
- Continuation

Nuclear pairing

Theory of the pairing mechanism in nuclei followed the Baardeen Cooper and Schriefer explanation of superconductivity in metals

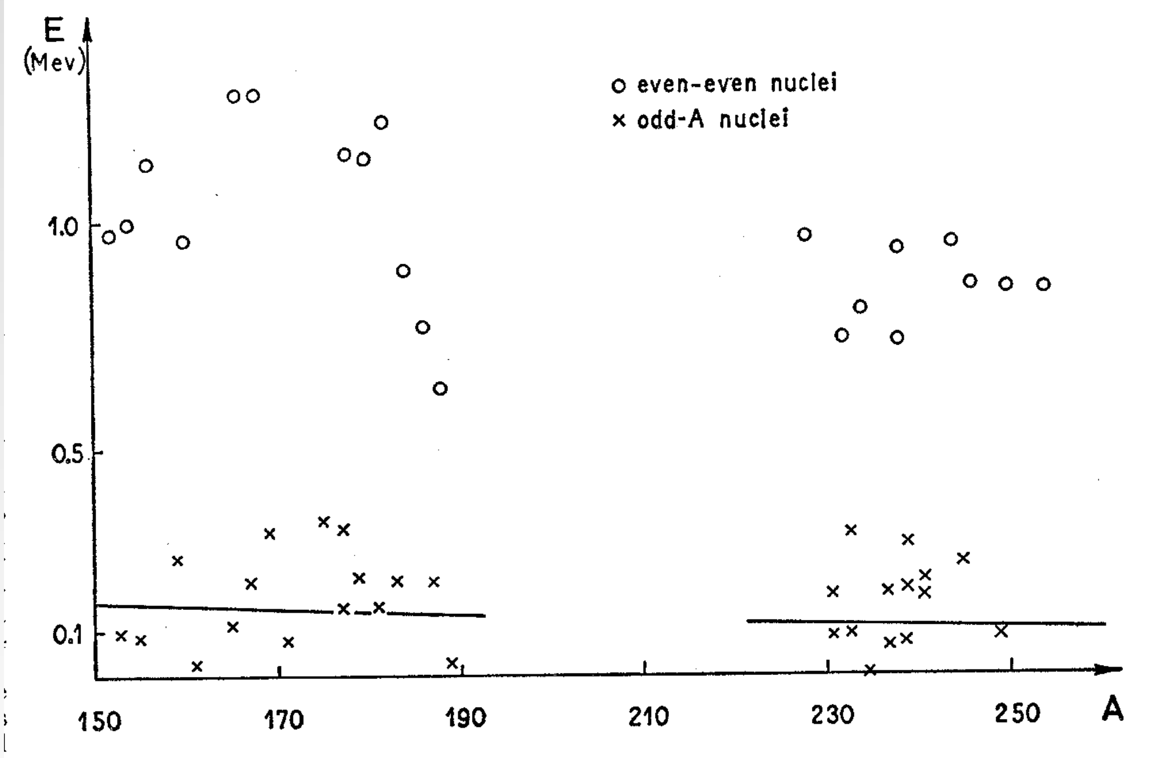
PHYSICAL REVIEW VOLUME 110, NUMBER 4 MAY 15, 1958

Possible Analogy between the Excitation Spectra of Nuclei and Those of the Superconducting Metallic State

A. Bohr, B. R. Mottelson, and D. Pines*
Institute for Theoretical Physics, University of Copenhagen, Copenhagen, Denmark, and Nordisk Institut for Teoretisk Atomfysik, Copenhagen, Denmark

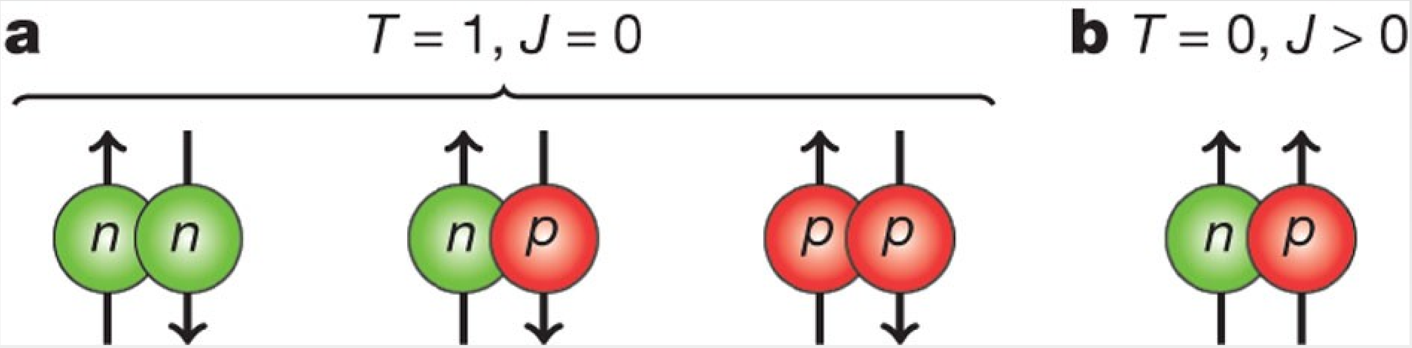
(Received January 7, 1958)

The evidence for an energy gap in the intrinsic excitation spectrum of nuclei is reviewed. A possible analogy between this effect and the energy gap observed in the electronic excitation of a superconducting metal is suggested.



Possible pairing schemes

- In most (N>Z) nuclei pp and nn pairing dominates
- Charge indepedence => pp, nn, np coupling possible
- Pauli principle: for pp, nn must couple with opposite spins
- np can also form T=0, J>0 pairs



- For N>Z, np coupling difficult to observe due the different spatial wave functions of valence nucleons,

Examples of the np pairing evidence

- Ground states of odd-odd N=Z nuclei:

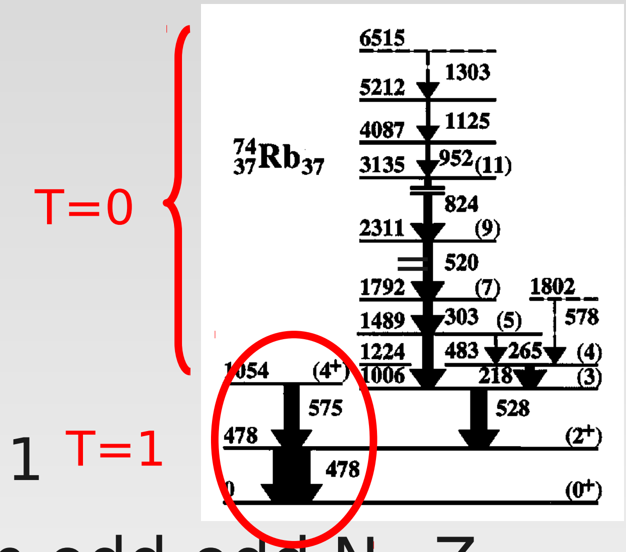
  A≤40 (except ^{34}Cl): T=0, J>0 ⇨ dominating isoscalar np pairing

  A>40 (except ^{58}Cu): T=1, J=0 ⇨ dominating isovector np paring

- Rotational properties of N≈Z nuclei:

  T=1/T=0 band crossing (^{74}Rb$_{37}$)

  D.Rudolph et al. PRL 76 (1996) 376,
  D.J.Dean et al. Phys.Lett. B399 (1997) 1

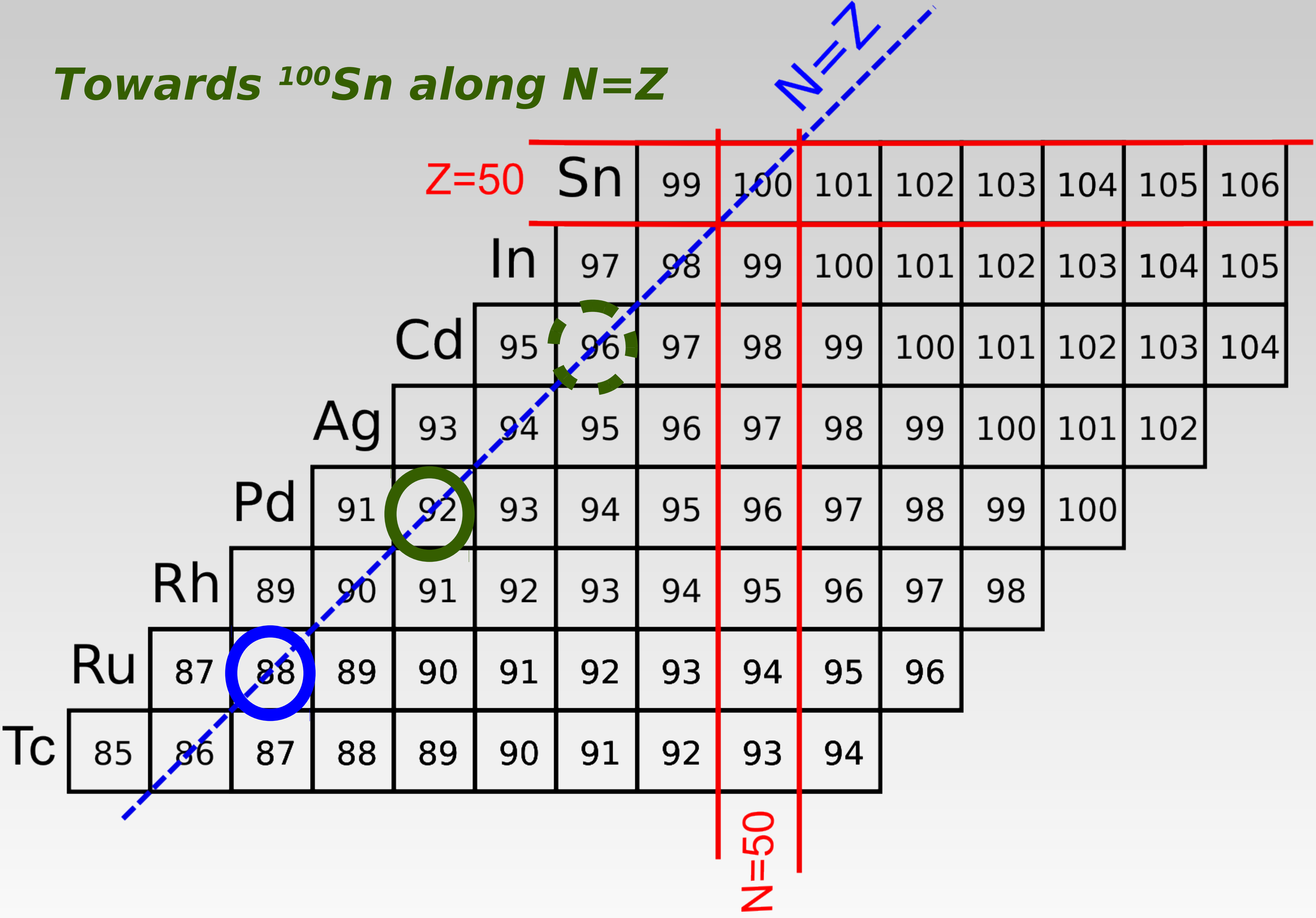


- Evidence for strong isovector pairing in odd-odd N=Z nuclei seen in the double binding energy differences

  Macciavelli et al. PRC 61 (2000) 041303(R)

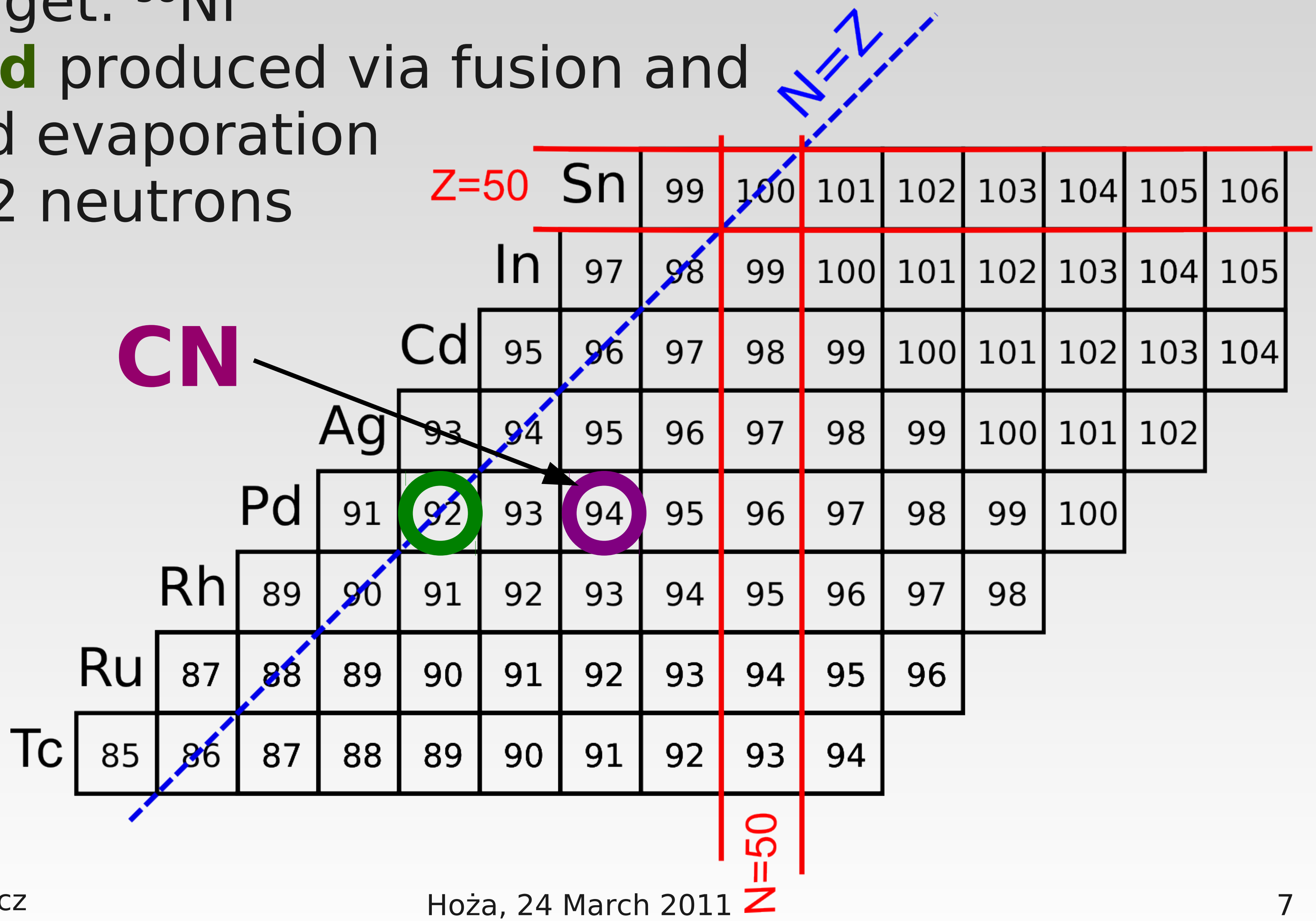
- **Are there signatures of np pairing in the ground and low lying states of even-even nuclei at N=Z?**

Towards ^{100}Sn along N=Z



The experiment at GANIL

- Beam: ^{36}Ar
- Target: ^{58}Ni
- **^{92}Pd** produced via fusion and and evaporation of 2 neutrons

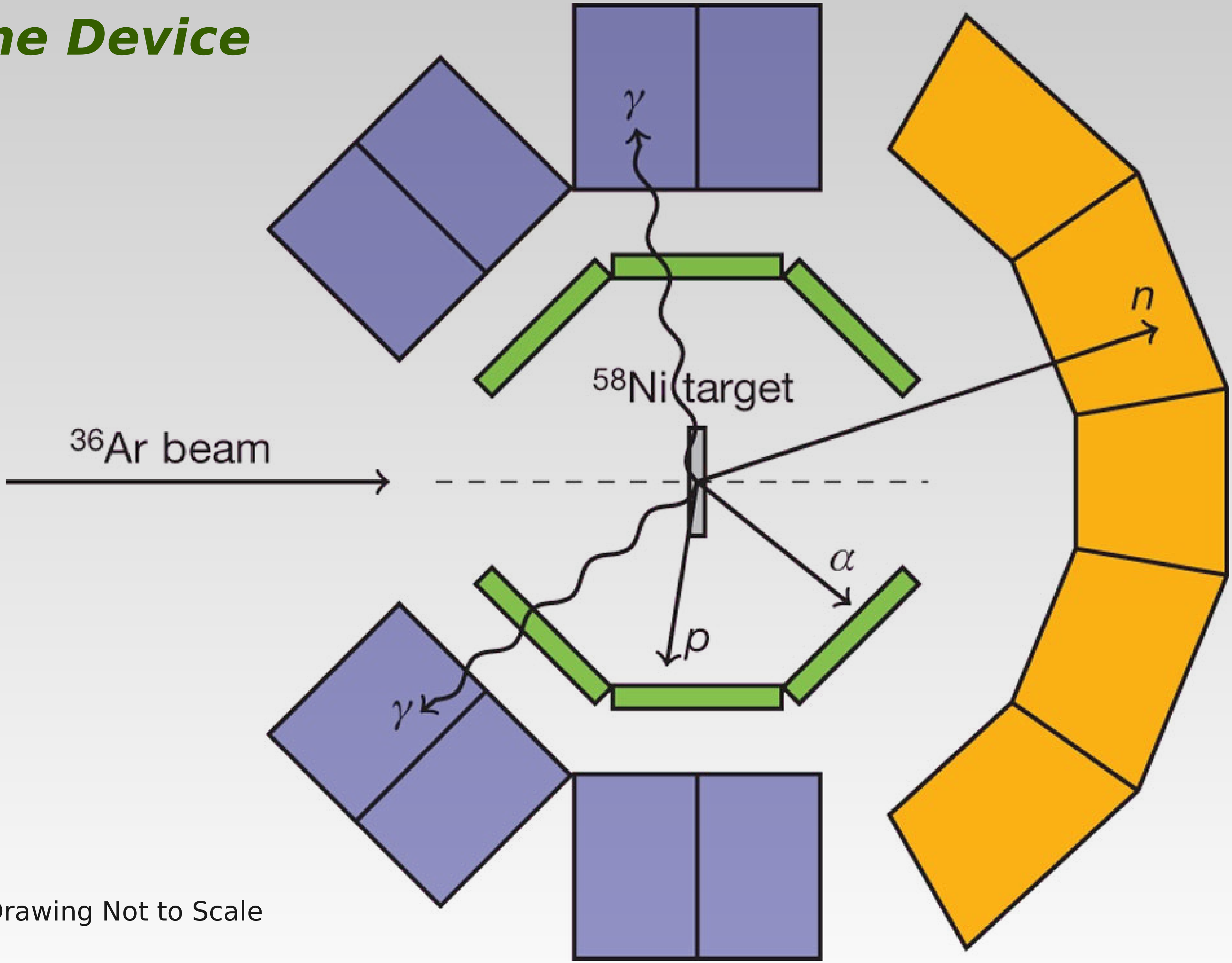


The experiment - details

- EXOGAM + Neutron Wall + DIAMANT at GANIL
- Beam: ^{36}Ar, 111 MeV , 10 pnA
  isotopic purity, precise energy tuning very close to the Coulomb barrier, timing resolution 3.5 ns, optimum pulse distance, good collimation
- Target: ^{58}Ni, 6.0 mg/cm^2, 99.83% enriched

  purity of the target material and good vacuum are essential,
  thick enough to stop recoils, but not thicker
- 14 days of beam time in September 2009
  $3.9 \cdot 10^9$ 1n trigger preselected events

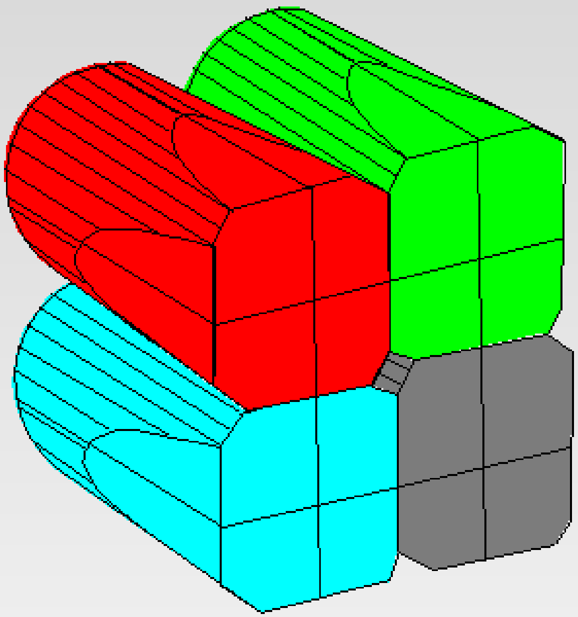
The Device

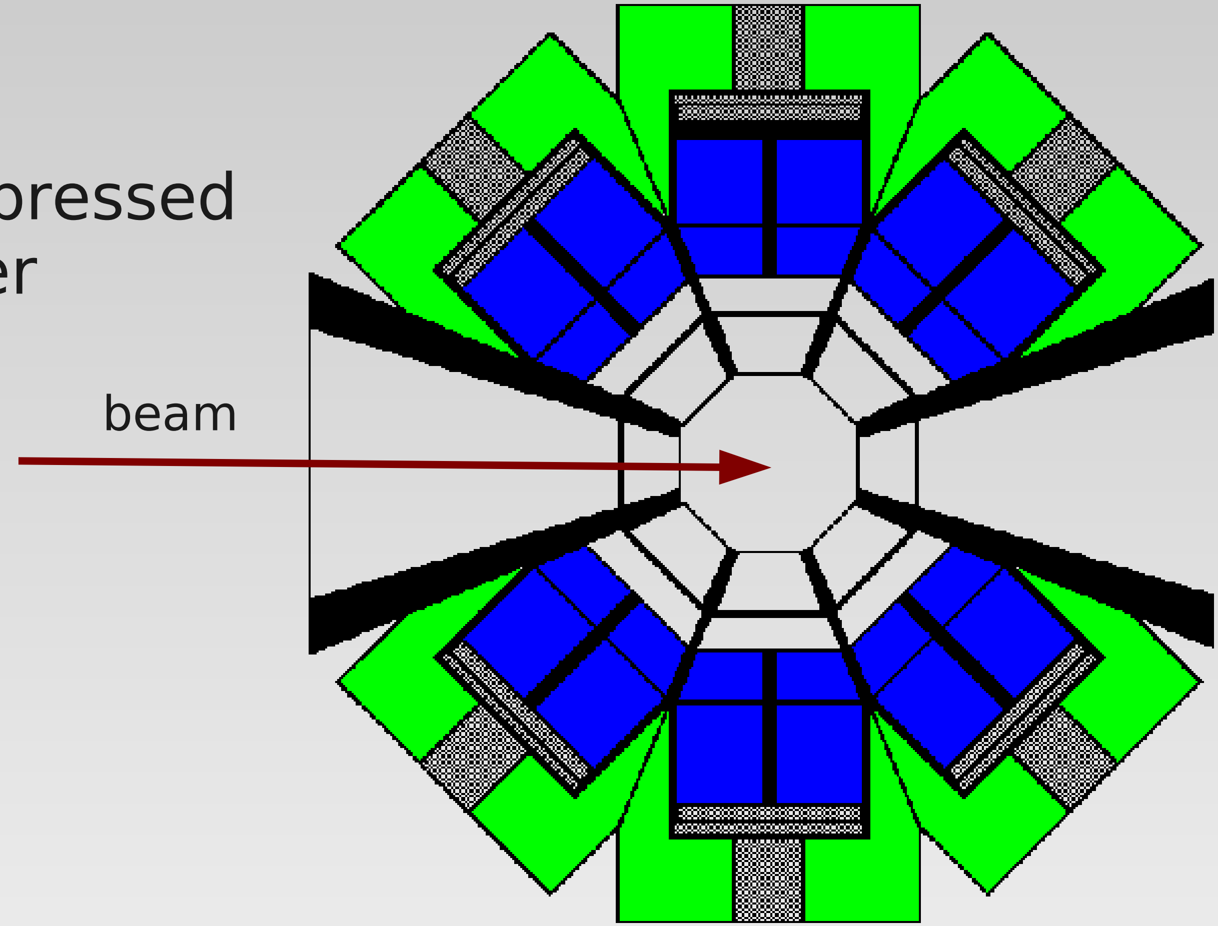


Drawing Not to Scale

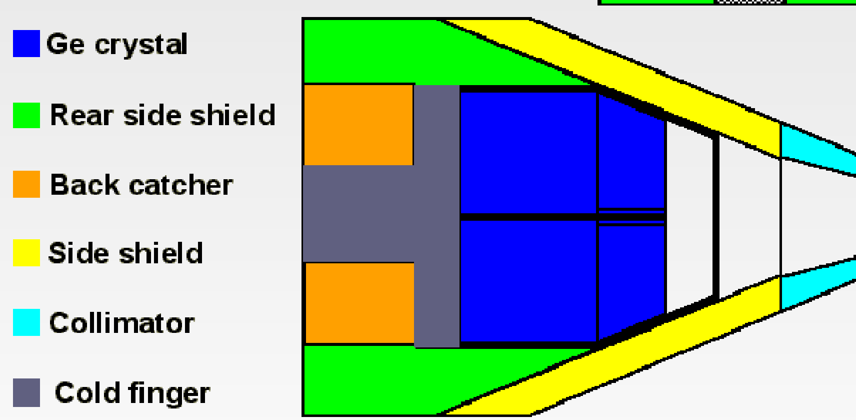
EXOGAM

Up to 16 Compton suppressed segmented HPGe clover detectors



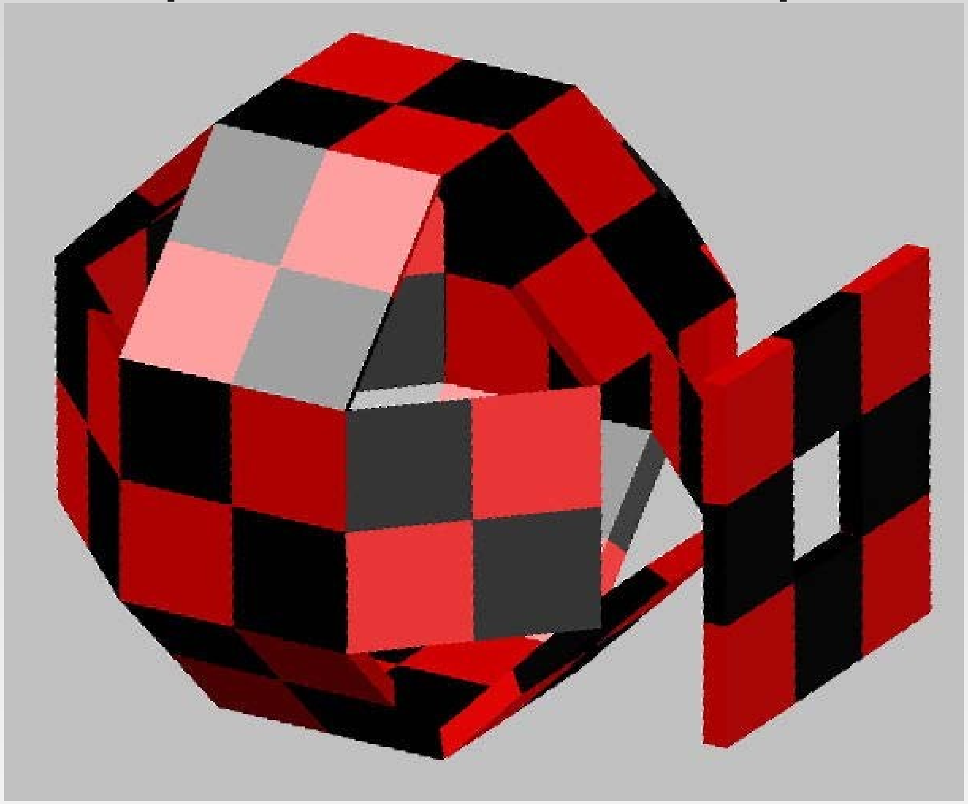


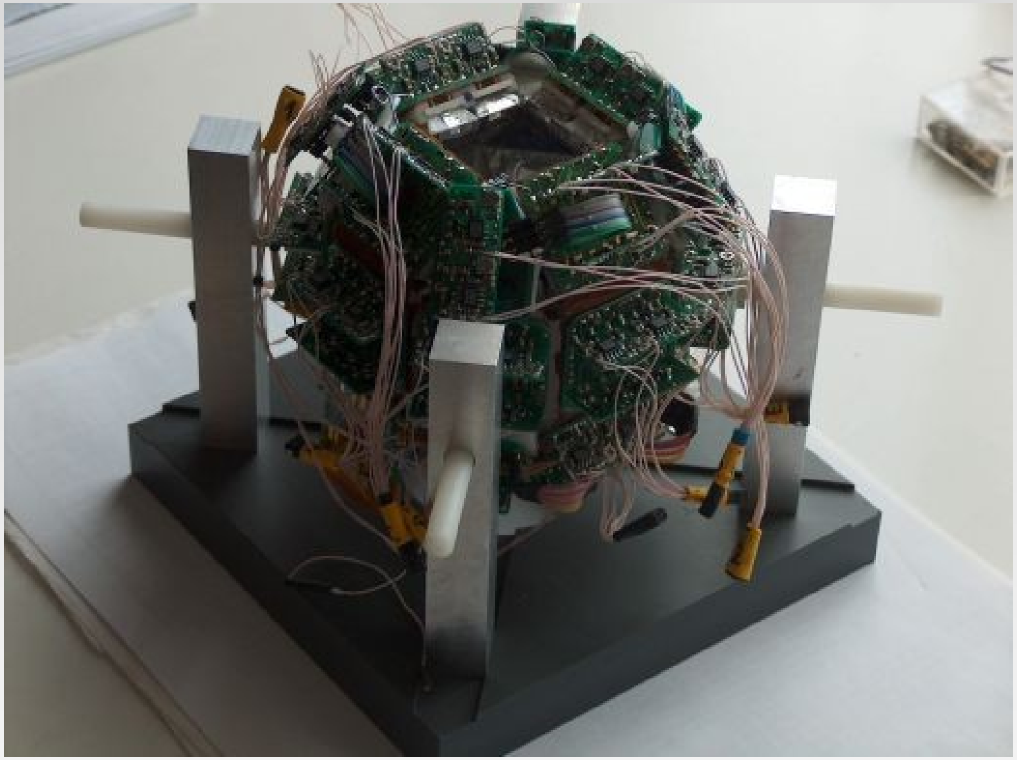
$E_{\gamma} \sim 10\%$ (1.3 MeV)
(11 detectors in a closed packed configuration)



DIAMANT

- 80 CsI scintillators
- Efficiency
  protons: 55%, alpha: 48%, veto: 66 %





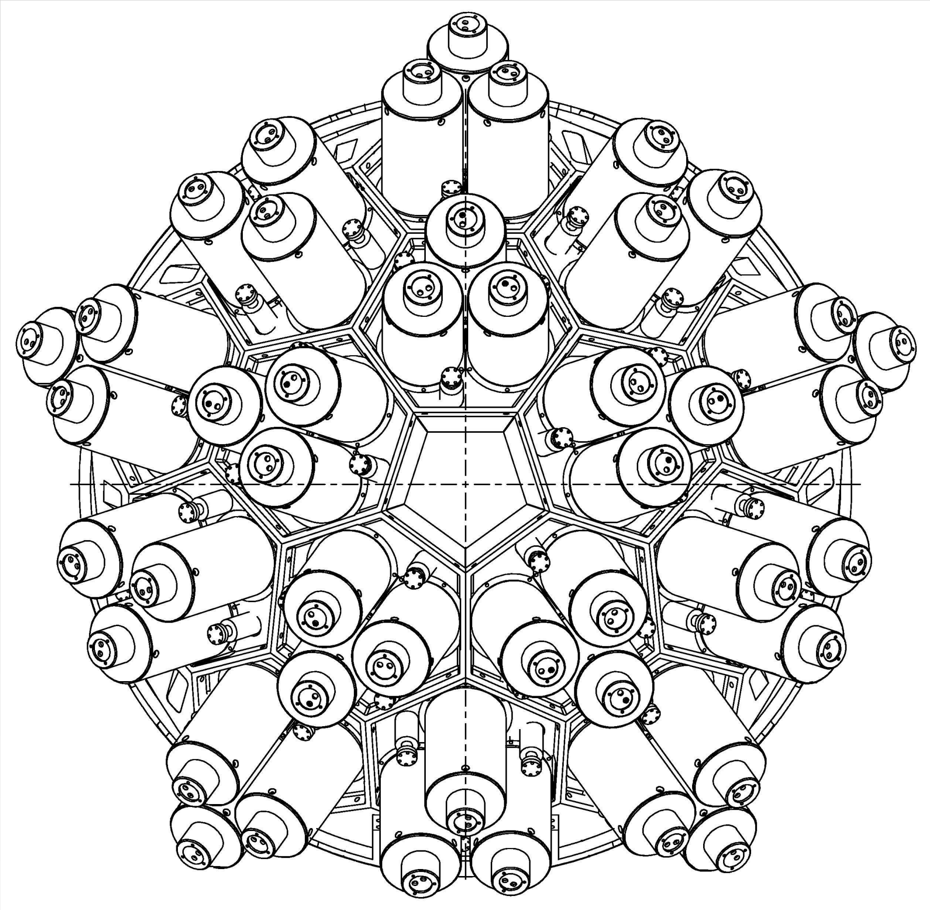
B.Nyako et al .ATOMKI, J.-N.Sheurer et al. CENBG, Bordaux, University of Napoli

Neutron Wall

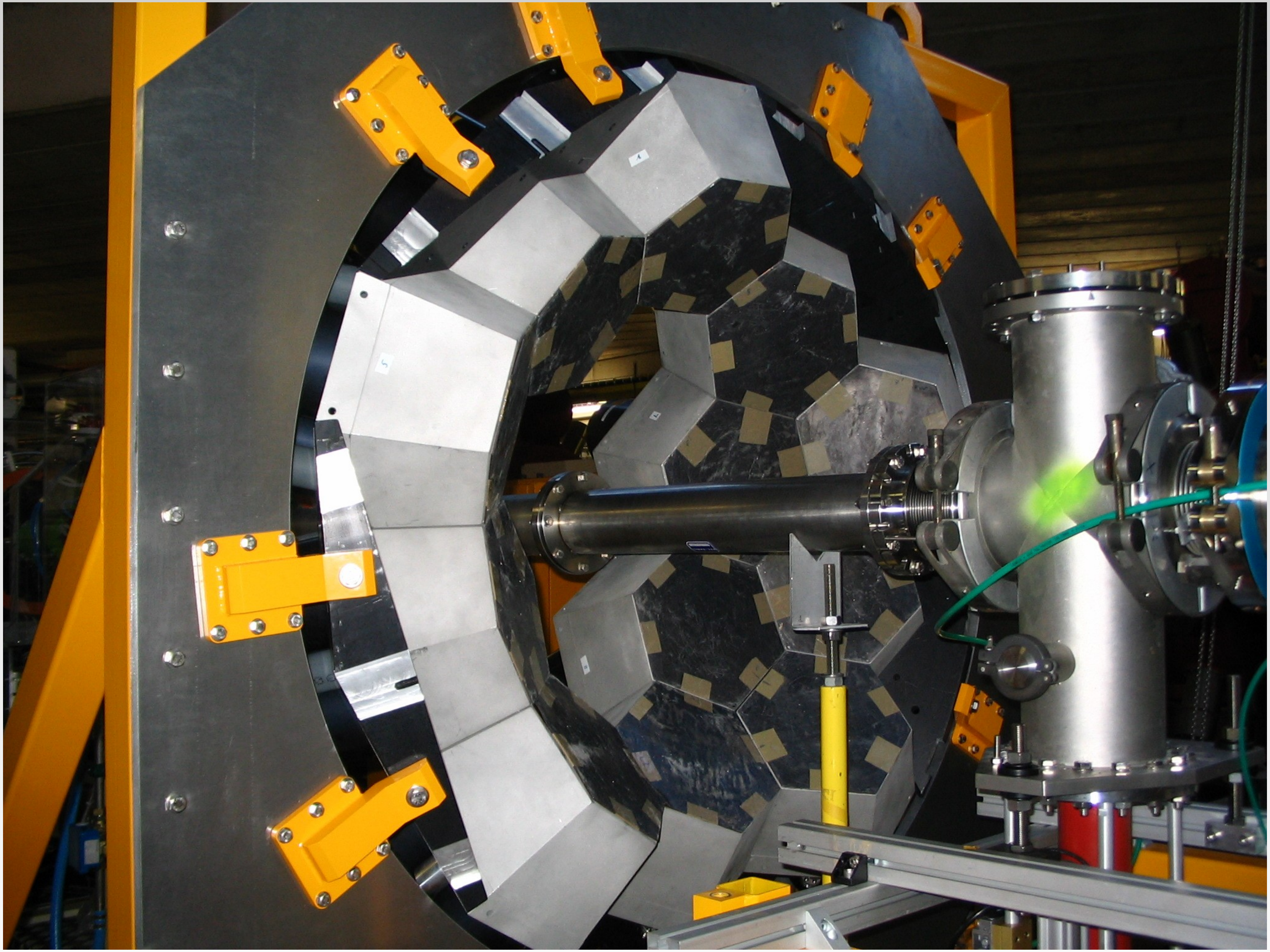
- Neutron detectors designed for selection of rare fusion-evaporation channels in γ-ray spectroscopy studies of proton-rich nuclei
- Owned (since 2003) by the European Gamma Ray Spectroscopy Pool,
  financed by the research councils from Sweden, UK, Germany and Poland,
  managed by the Uppsala University,
  run by collaboration: Uppsala, Stockholm, Lund, York, Daresbury, GSI, Warsaw, Świerk, GANIL
- Built for EUROBALL, moved to GANIL in 2004,
  usually coupled to EXOGAM and DIAMANT,
  9 experiments run in three campaings

Neutron Wall

- soild angle 1π, liquid scintillator BC501A - xylene, $C_6H_4(CH_3)_2$
- 50 detectors
- parameters: tof, zco, E
- ε_{abs} =0.15 (1.25 MeV)
- $\varepsilon_{fus\text{-}ev}$~0.20 - 0.25

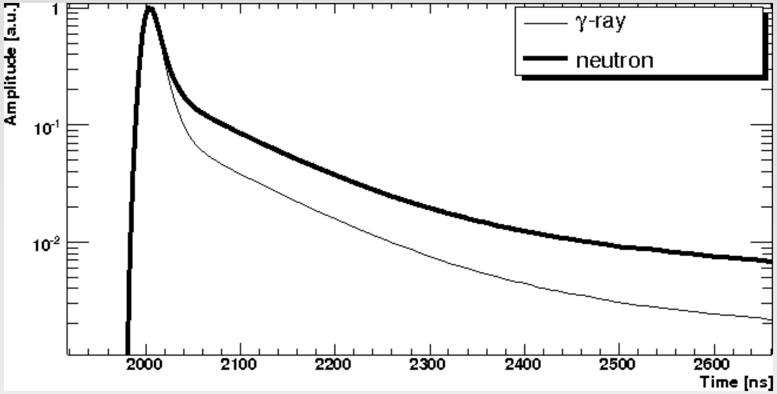


Neutron Wall

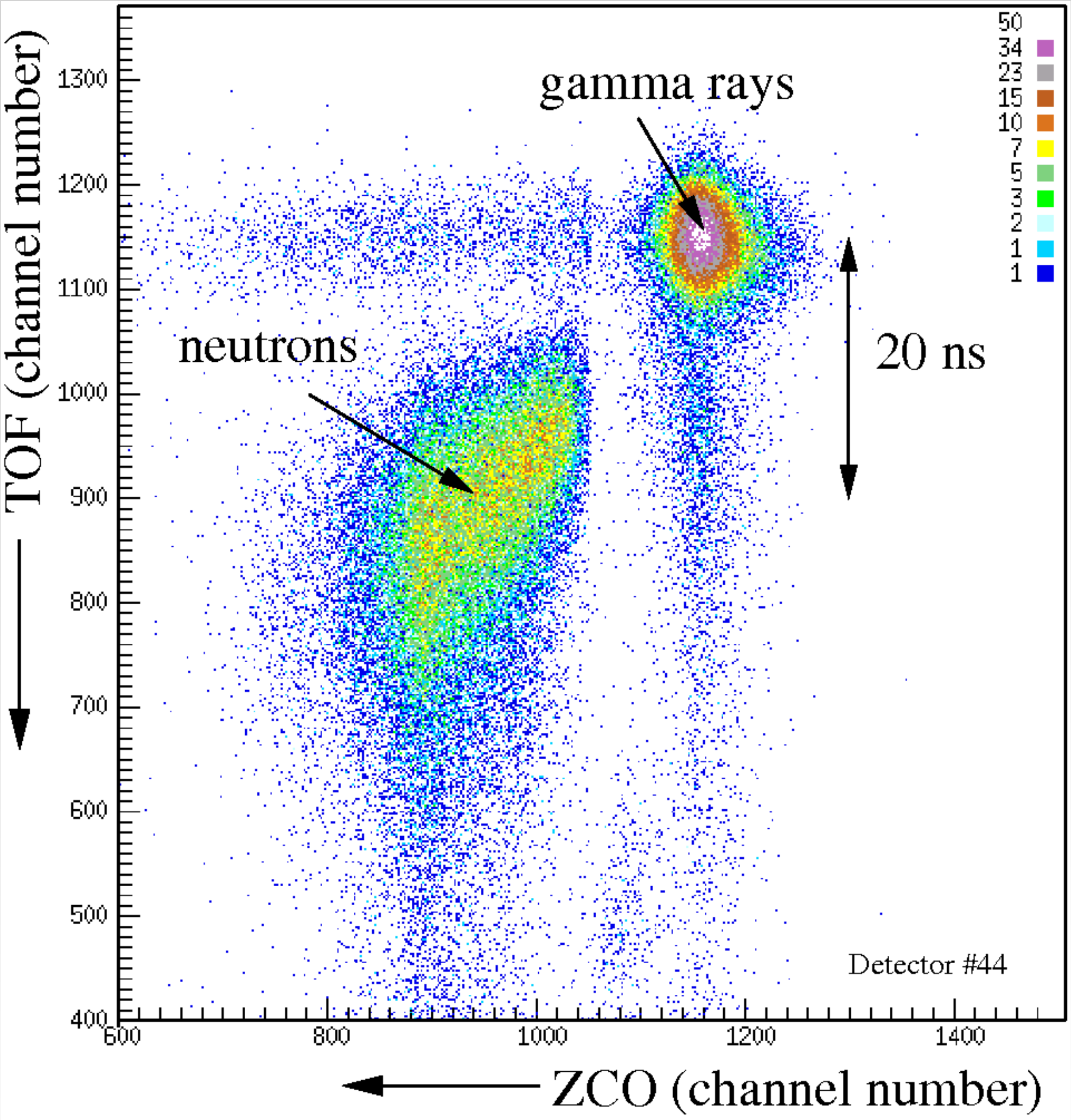


n-γ discrimination

Done by:
- time-fo-flight
- n-γ pulse shape difference (ZCO)

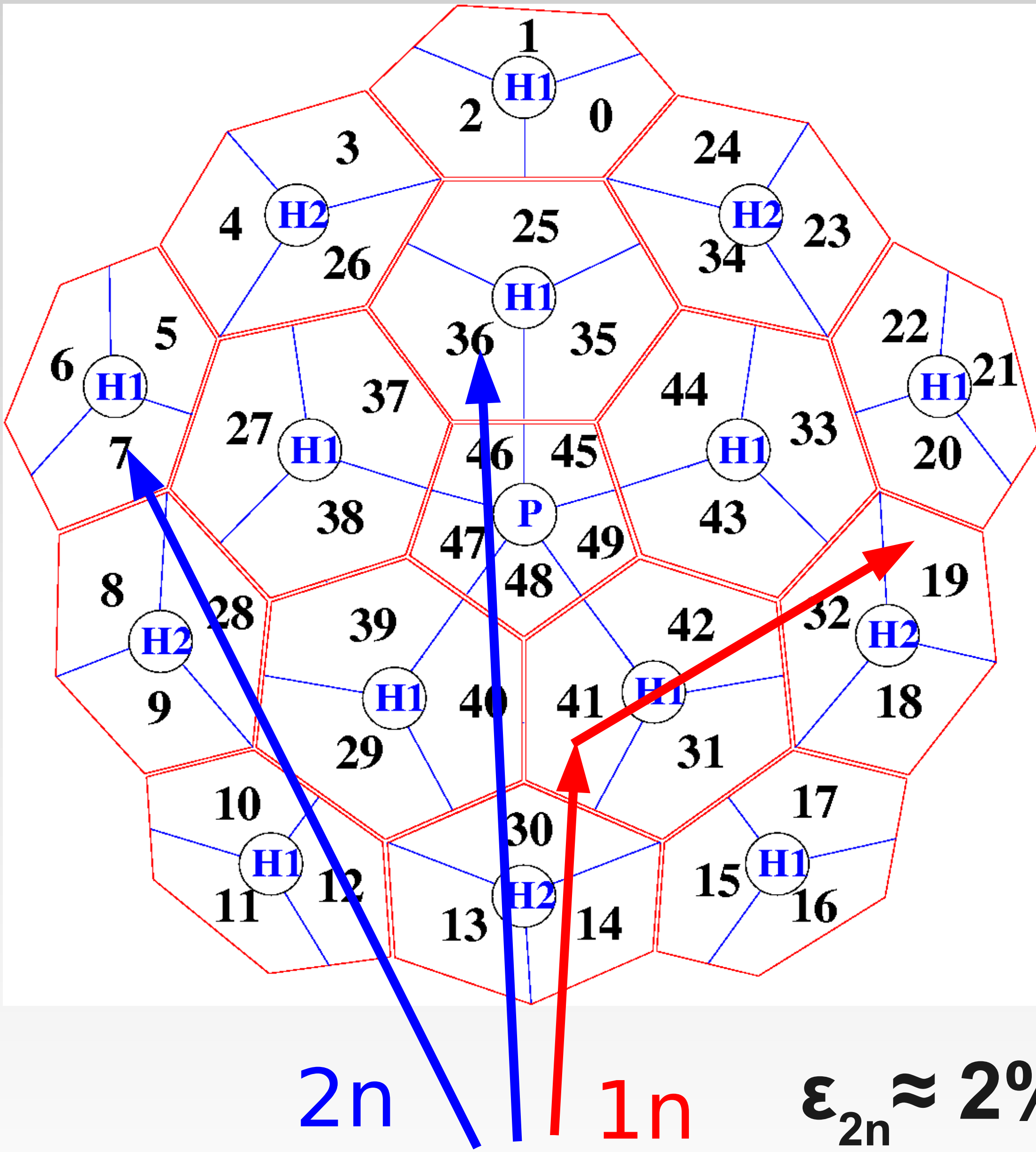


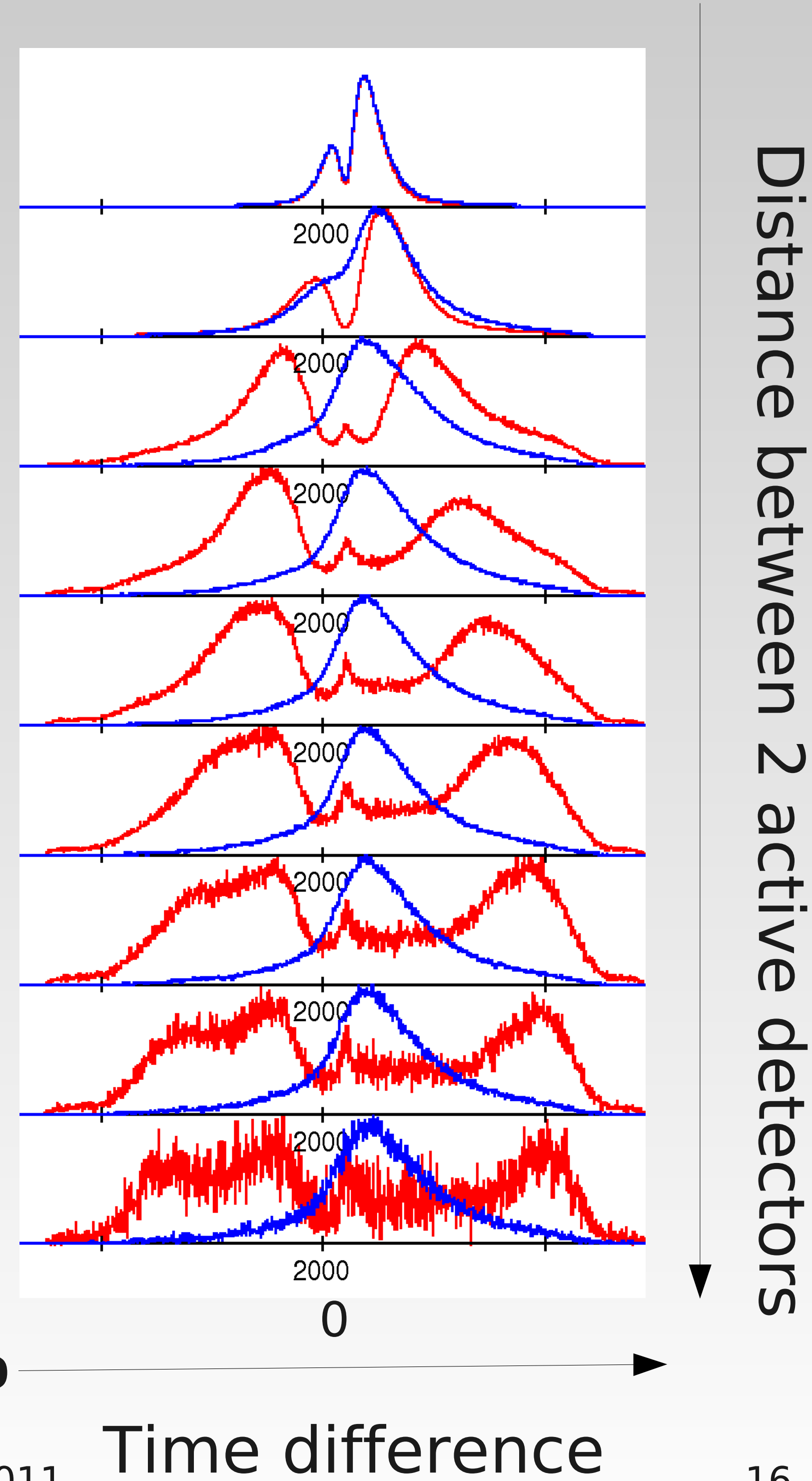
drawing from P-A Söderström, licentiate thesis 2009



n-γ misinterpretation probability: 0.3 %

2n discrimination





$\varepsilon_{2n} \approx 2\%$

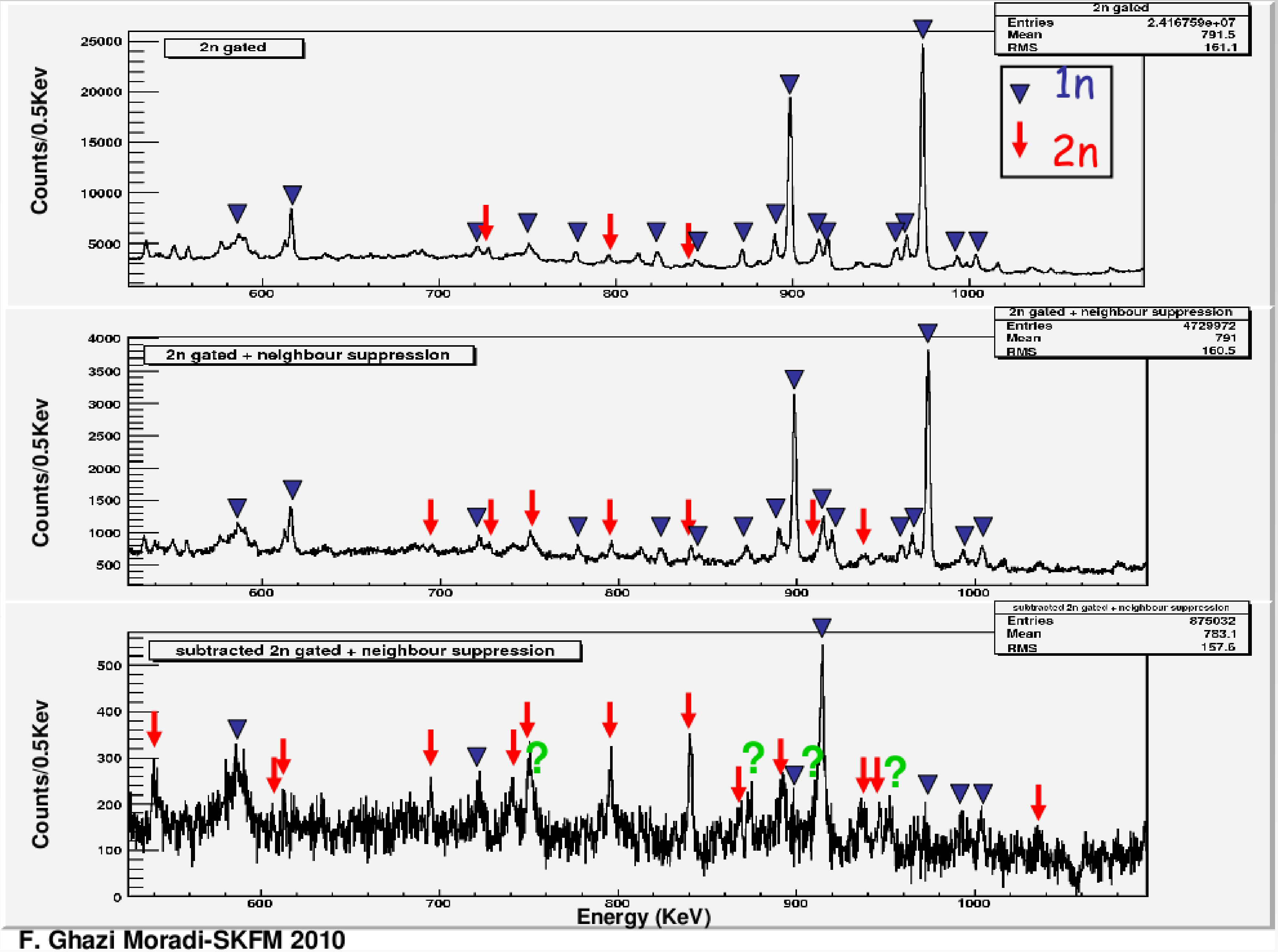
Identification of ^{92}Pd γ-ray lines

- Gamma rays from ^{92}Pd identified by: comparison of 1n and 2n gated spectra (with various additional dr-dt conditions)

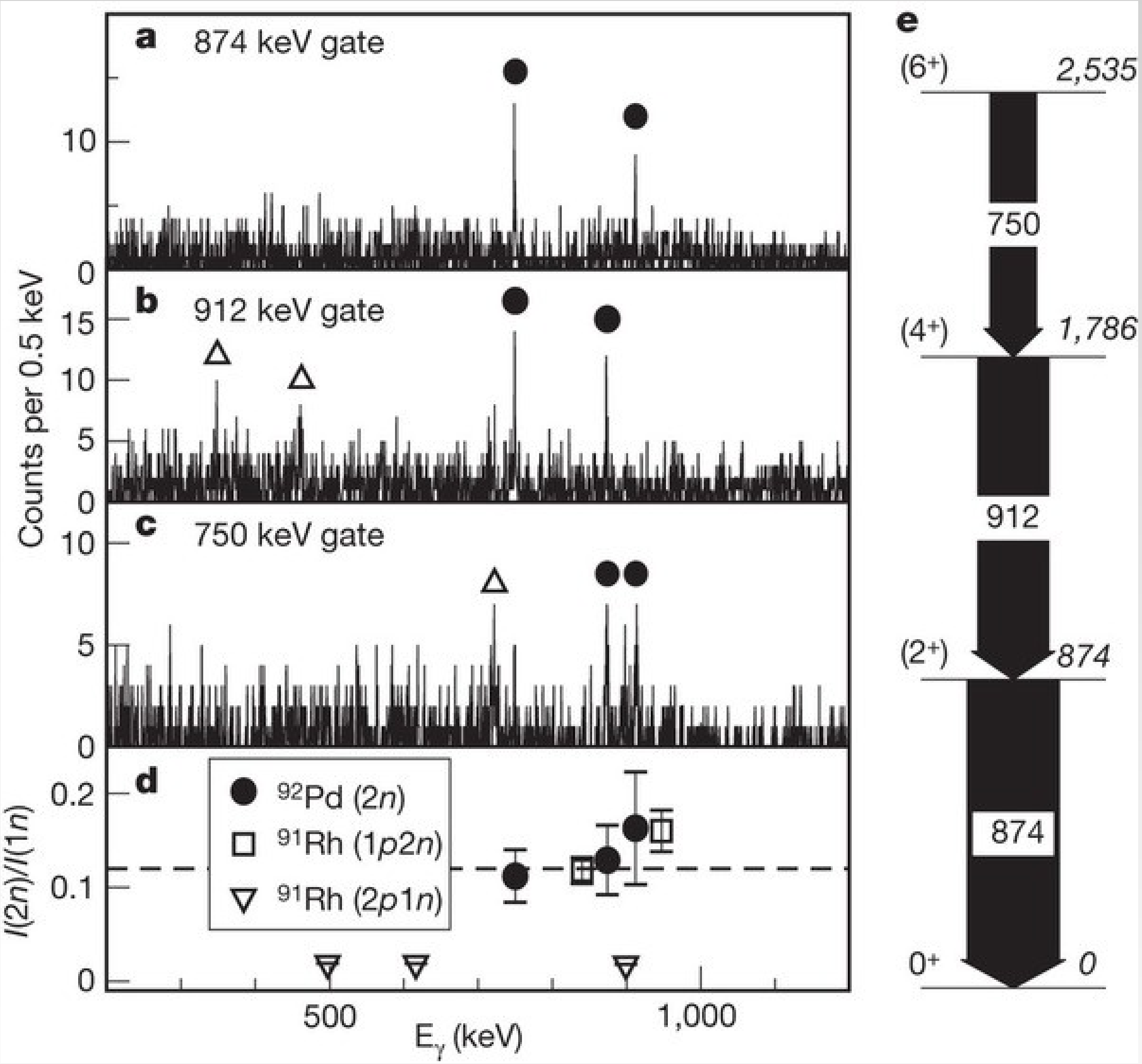
  Relatively enhanced with the charged particle veto condition.

- The possibility was excluded that these gamma rays are produced in reactions on possible target contaminants.

Identification of ^{92}Pd γ-ray lines



Identification of ^{92}Pd



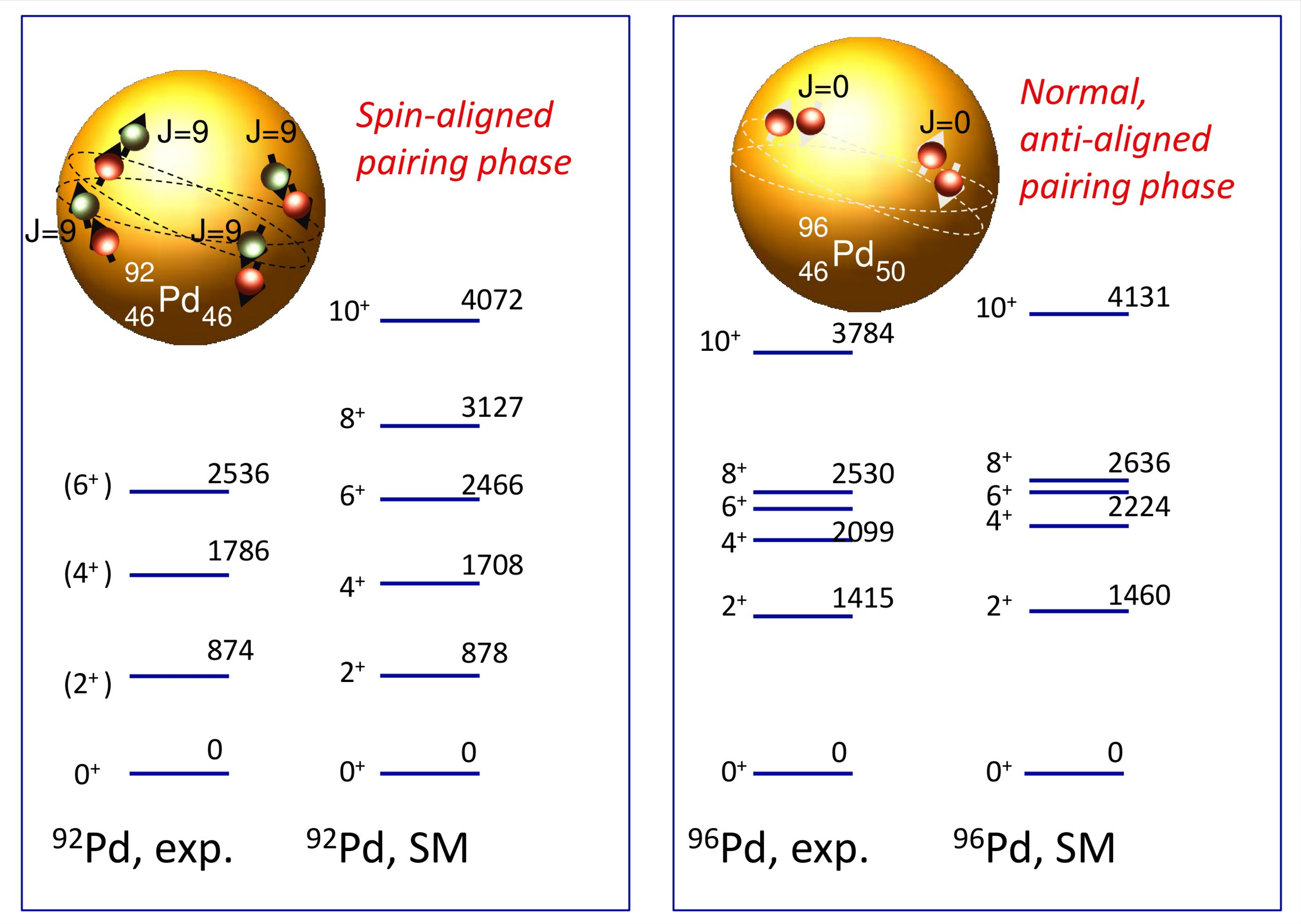
Shell Model calculations

By J.Blomqvist, C.Qui, R.Liotta

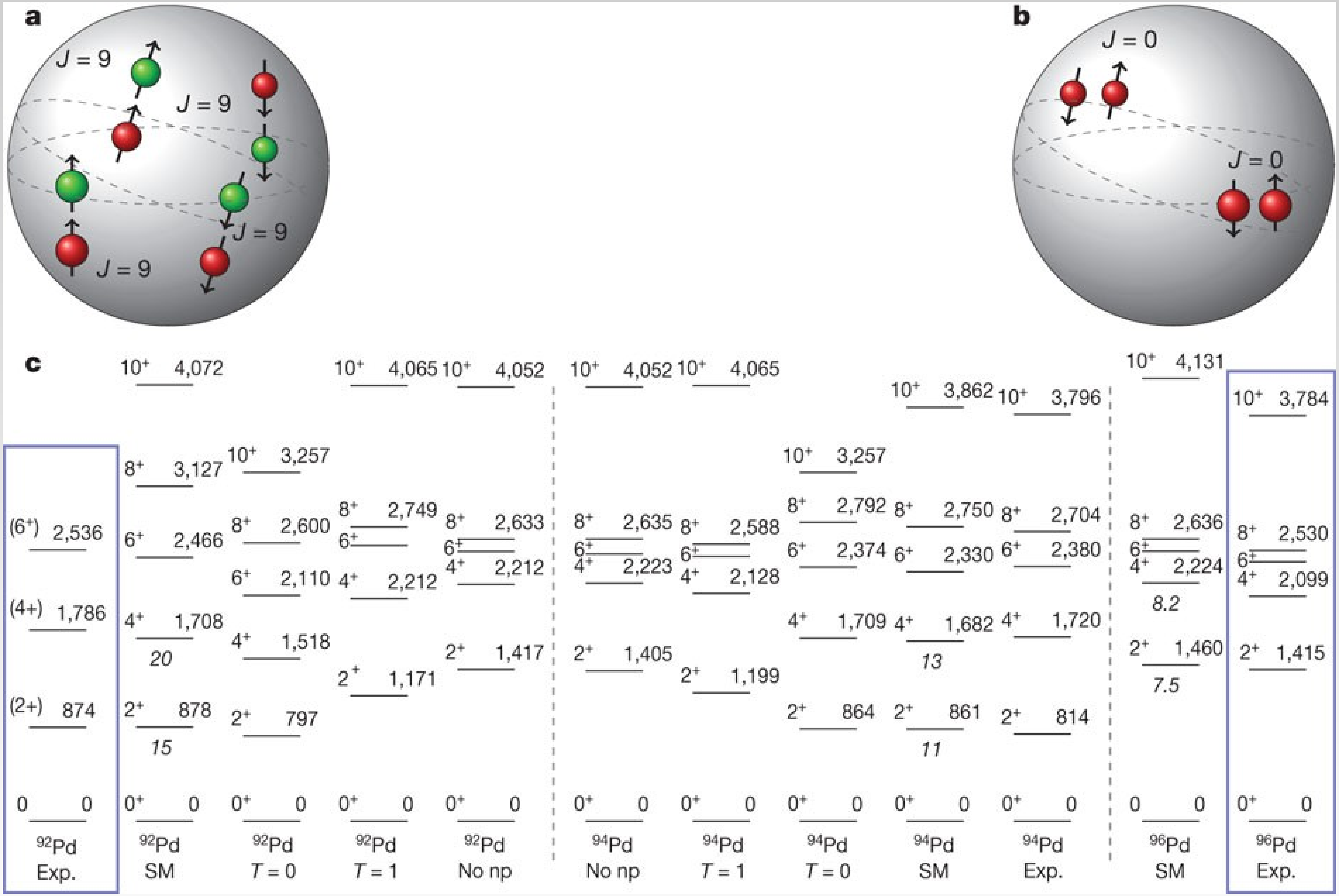
- $f_{5/2}$ $p_{3/2}$ $p_{1/2}$ $g_{9/2}$ model space
- matrix elements from a least-squares fit to experimental binding energies and excitation energies for A=63 to 96, starting from realistic interactions

A.F.Lisetskiy et al. Phys. Rev. C70 044314 (2004)

Structure of ^{92}Pd compared to ^{96}Pd

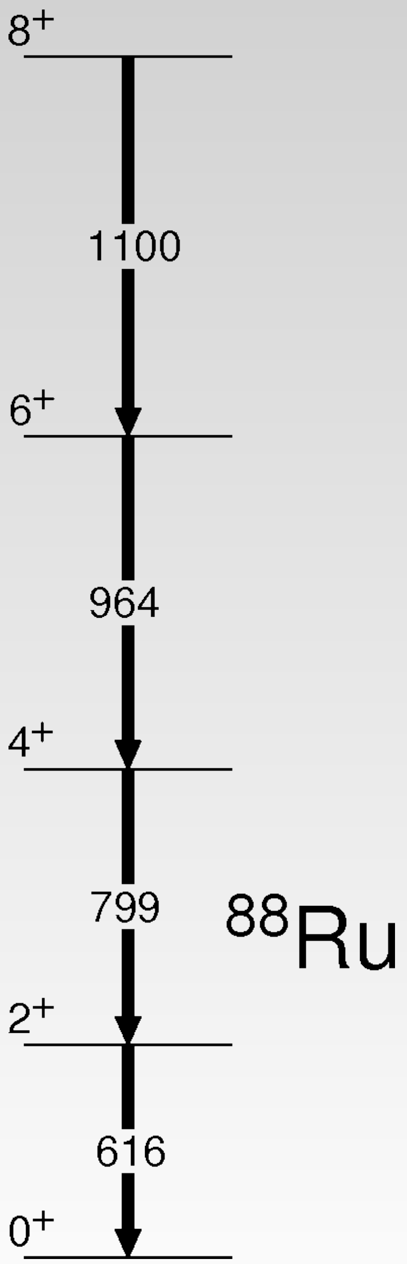


Shell Model tests of different pairing modes

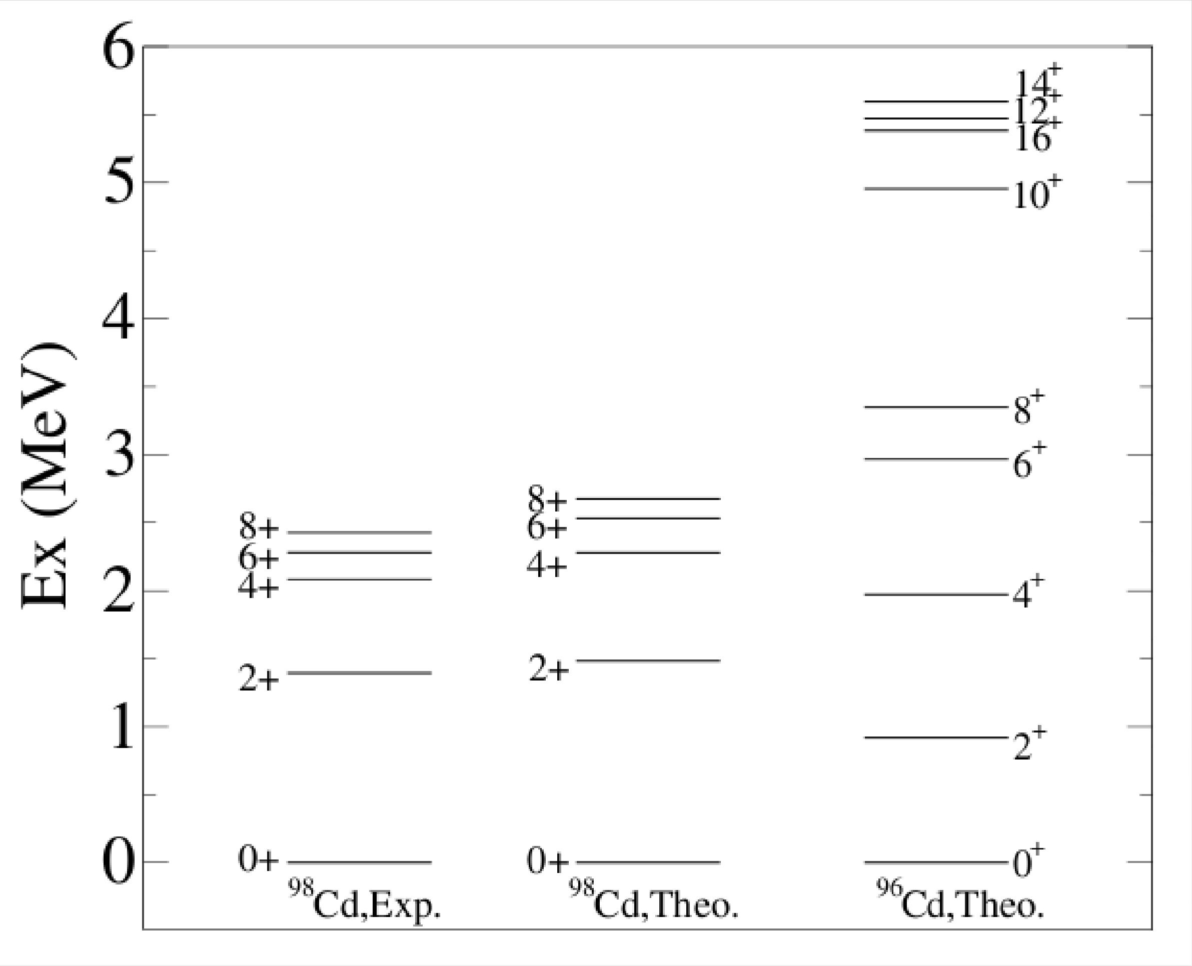


A comment on excited states in ^{88}Ru (N=Z=44)

- Significant contributions of $f_{5/2}$ and $p_{3/2}$ orbitals are necessary to reproduce energies of excited states of ^{88}Ru (rotational/vibrational collectivity)
- Such interpretation does not hold for ^{92}Pd, due to the purity of its wave functions ($g_{9/2}$ only)



Next: ^{96}Cd



An experiment to study ^{96}Cd accepted by the GANIL PAC

$^{40}Ca + ^{58}Ni \rightarrow ^{98}Cd\ (CN) \rightarrow ^{96}Cd^{*} + 2n$

Conclusions

- ^{92}Pd γ rays were identified, excitation energies of 2^+, 4^+, 6^+ proposed
- ^{92}Pd becomes the heaviest N=Z nucleus with excited states known
- Shell Model calculations indicate that states of ^{92}Pd are completely dominated by four isoscalar np pairs in the spin aligned $J^{\pi}=9^+$ coupling

The Collaboration

LETTER

doi:10.1038/nature09644

Evidence for a spin-aligned neutron–proton paired phase from the level structure of ^{92}Pd

B. Cederwall[1], F. Ghazi Moradi[1], T. Bäck[1], A. Johnson[1], J. Blomqvist[1], E. Clément[2], G. de France[2], R. Wadsworth[3], K. Andgren[1], K. Lagergren[1,4], A. Dijon[2], G. Jaworski[5,6], R. Liotta[1], C. Qi[1], B. M. Nyakó[7], J. Nyberg[8], M. Palacz[5], H. Al-Azri[3], A. Algora[9], G. de Angelis[10], A. Ataç[11], S. Bhattacharyya[2]†, T. Brock[3], J. R. Brown[3], P. Davies[3], A. Di Nitto[12], Zs. Dombrádi[7], A. Gadea[9], J. Gál[7], B. Hadinia[1], F. Johnston-Theasby[3], P. Joshi[3], K. Juhász[13], R. Julin[14], A. Jungclaus[15], G. Kalinka[7], S. O. Kara[11], A. Khaplanov[1], J. Kownacki[5], G. La Rana[12], S. M. Lenzi[16], J. Molnár[7], R. Moro[12], D. R. Napoli[10], B. S. Nara Singh[3], A. Persson[1], F. Recchia[16], M. Sandzelius[1]†, J.-N. Scheurer[17], G. Sletten[18], D. Sohler[7], P.-A. Söderström[8], M. J. Taylor[3], J. Timár[7], J. J. Valiente-Dobón[10], E. Vardaci[12] & S. Williams[19]

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