Isospin properties and pair correlations in ^{88}Ru

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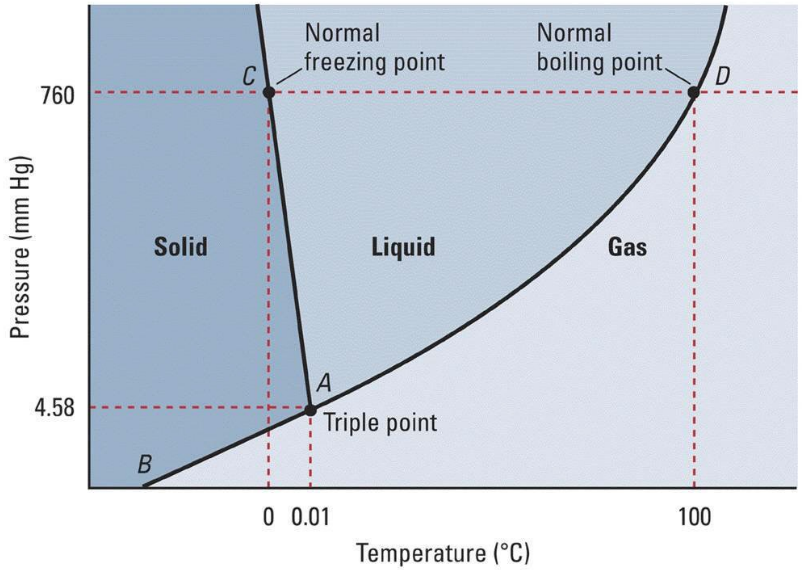
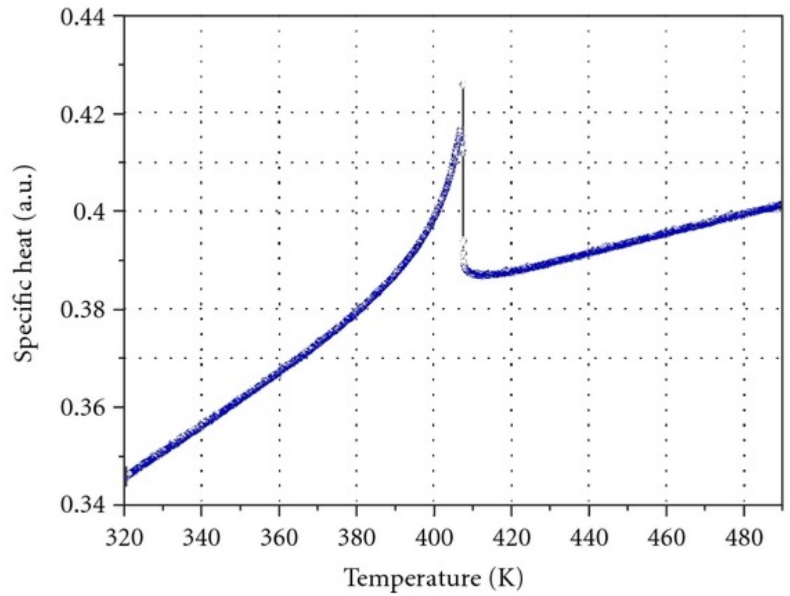
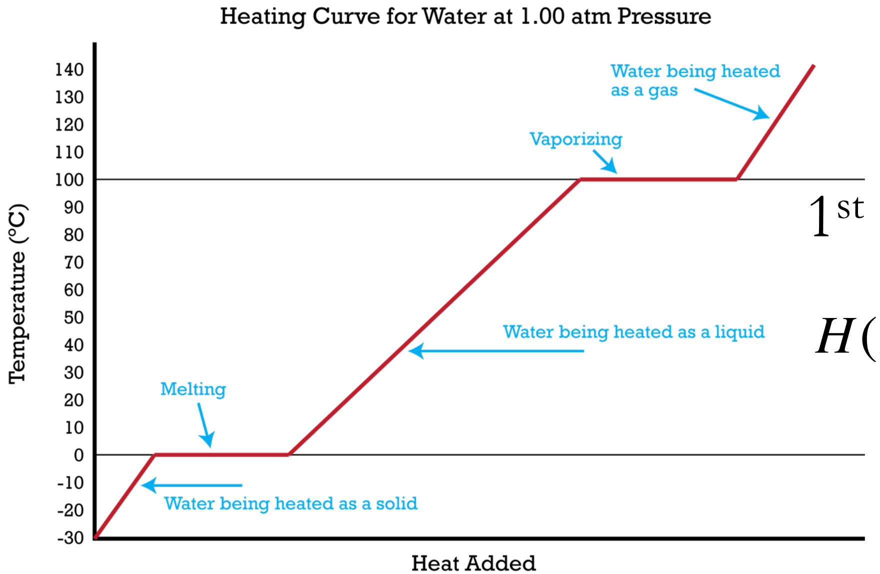
14th Nucleus-Nucleus Collisions Conference NN2024
August 18 - 23, 2024, Whistler, BC Canada

Phases of (macroscopic) matter - phase transitions





Temperature dependence of specific heat of $BaTiO_3$ single crystal around the paraelectric-ferroelectric phase transition point Tc
S. Grabovsky, M. Takesada, A. Onodera et al., Annual Meeting of Physical Society of Japan, March 2012



https://socratic.org

1^{st} order phase transition:

$$H(\lambda) = (1-\eta)H_0 + \eta H_1 \qquad \eta \text{ - "control" parameter}$$

$$\frac{d < H(\eta) >}{d\eta} \text{ discontinuity at } \eta = \eta_{cr}$$

Can we observe something similar in the nucleus?

Letters to the Editor

PUBLICATION of brief reports of important discoveries in physics may be secured by addressing them to this department. The closing date for this department is five weeks prior to the date of issue. No proof will be sent to the authors. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents. Communications should not exceed 600 words in length and should be submitted in duplicate.

Bound Electron Pairs in a Degenerate Fermi Gas*

LEON N. COOPER
Physics Department, University of Illinois, Urbana, Illinois
(Received September 21, 1956)

IT has been proposed that a metal would display superconducting properties at low temperatures if the one-electron energy spectrum had a volume-independent energy gap of order $\Delta \simeq kT_c$, between the ground state and the first excited state.[1,2] We should like to point out how, primarily as a result of the exclusion principle, such a situation could arise.

Consider a pair of electrons which interact above a quiescent Fermi sphere with an interaction of the kind that might be expected due to the phonon and the screened Coulomb fields. If there is a net attraction between the electrons, it turns out that they can form a bound state, though their total energy is larger than zero. The properties of a noninteracting system of such

$=(1/V)\exp[i(\mathbf{k}_1\cdot\mathbf{r}_1+\mathbf{k}_2\cdot\mathbf{r}_2)]$ which satisfy periodic boundary conditions in a box of volume V, and where $\mathbf{r}_1$ and $\mathbf{r}_2$ are the coordinates of electron one and electron two. (One can use antisymmetric functions and obtain essentially the same results, but alternatively we can choose the electrons of opposite spin.) Defining relative and center-of-mass coordinates, $\mathbf{R}=\frac{1}{2}(\mathbf{r}_1+\mathbf{r}_2)$, $\mathbf{r}=(\mathbf{r}_2-\mathbf{r}_1)$, $\mathbf{K}=(\mathbf{k}_1+\mathbf{k}_2)$ and $\mathbf{k}=\frac{1}{2}(\mathbf{k}_2-\mathbf{k}_1)$, and letting $\mathcal{E}_K+\epsilon_k=(\hbar^2/m)(\frac{1}{4}K^2+k^2)$, the Schrödinger equation can be written

$$(\mathcal{E}_K+\epsilon_k-E)a_{\mathbf{k}}+\sum_{\mathbf{k}'} a_{\mathbf{k}'}(\mathbf{k}|H_1|\mathbf{k}')\times\delta(\mathbf{K}-\mathbf{K}')/\delta(0)=0 \quad (1)$$

where

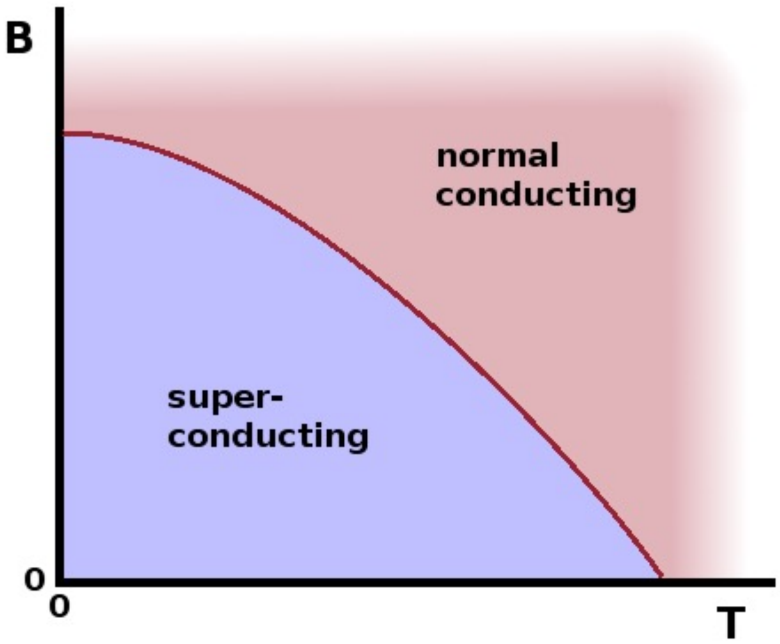
$$\Psi(\mathbf{R},\mathbf{r})=(1/\sqrt{V})e^{i\mathbf{K}\cdot\mathbf{R}}\chi(\mathbf{r},K), \quad \chi(\mathbf{r},K)=\sum_{\mathbf{k}}(a_{\mathbf{k}}/\sqrt{V})e^{i\mathbf{k}\cdot\mathbf{r}}, \quad (2)$$

and

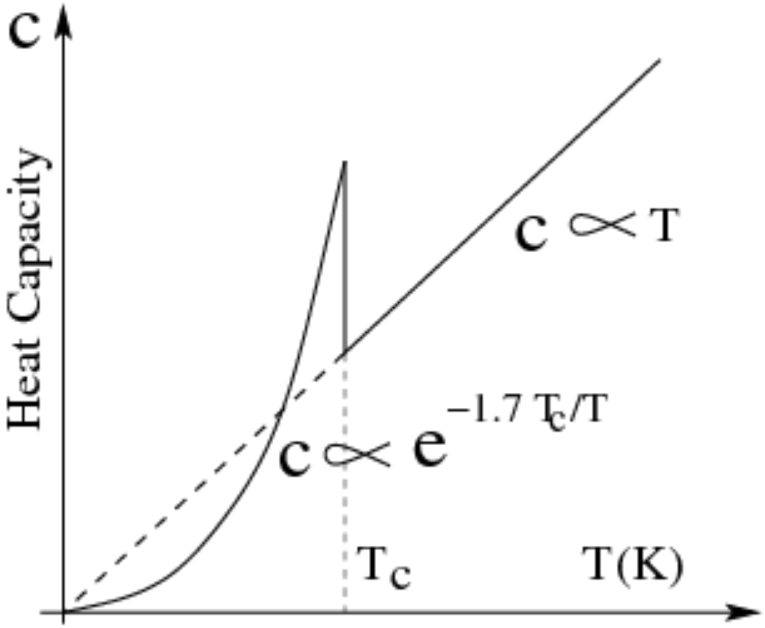
$$(\mathbf{k}|H_1|\mathbf{k}')=\left(\frac{1}{V}\int d\mathbf{r}e^{-i\mathbf{k}\cdot\mathbf{r}}H_1e^{i\mathbf{k}'\cdot\mathbf{r}}\right)_{0\text{ phonons}}.$$

We have assumed translational invariance in the metal. The summation over $\mathbf{k}'$ is limited by the exclusion principle to values of k_1 and k_2 larger than q_0, and by the delta function, which guarantees the conservation of the total momentum of the pair in a single scattering. The K dependence enters through the latter restriction.

Bardeen and Pines[3] and Fröhlich[4] have derived approximate formulas for the matrix element $(\mathbf{k}|H_1|\mathbf{k}')$; it is thought that the matrix elements for which the two electrons are confined to a thin energy shell near the Fermi surface, $\epsilon_1\simeq\epsilon_2\simeq\epsilon_F$, are the principal ones



http://users.aber.ac.uk



Can we observe something similar in atomic nuclei?

THE
PHYSICAL REVIEW
A journal of experimental and theoretical physics established by E. L. Nichols in 1893
SECOND SERIES, VOL. 114, No. 6 JUNE 15, 1959

Possible Superfluidity of a System of Strongly Interacting Fermions*†

L. N. COOPER,‡ R. L. MILLS, AND A. M. SESSLER
The Ohio State University, Columbus, Ohio
(Received January 30, 1959)

The possible superfluidity of a system of strongly interacting fermions is investigated on the assumption that an adequate description of the system in its "normal" state is given by independent fermions in a momentum-dependent potential. On the basis of this assumption we have investigated whether a correlated wave function of the form used by Bardeen, Cooper, and Schrieffer minimizes the ground-state energy. The nonzero terms in the expectation value of the Hamiltonian contain the modified kinetic energy and the full two-body potential between the fermion pairs. An integral equation is obtained in configuration space for the correlation function between pairs. This integral equation is meaningful even for potentials with hard cores, and a nonzero solution implies the existence of a superfluid state. A variational method is devised which provides a criterion for superfluidity and a lower bound for the transition temperature into the superfluid state. We find that a repulsive hard core does not in principle forbid the existence of a superfluid state, but whereas in the absence of a hard core an attractive two-body potential always leads to a superfluid state at sufficiently low temperatures, in the presence of a repulsive core there appears to be a critical strength of attraction needed to form a superfluid state. When the variational principle is applied to liquid He^3 or to nuclear matter, it is found for a wide class of trial functions that the system does not become a superfluid.

I. INTRODUCTION

THE fact that a system of fermions can become a superfluid is demonstrated by the observed behavior of the electron gas in many metals at low temperatures. It seems natural then to inquire whether or not other systems of fermions might display similar properties, and what the criterion for such behavior would be. This question is of particular interest because of recent conjectures[1] that nuclear matter might be superfluid in the sense that for an infinite medium there would be an energy gap between the ground state and the lowest single particle excitations. It has been further conjectured that this might show up for a finite nucleus as the explanation for the abnormally large single-particle excitation energy of even-even nuclei. Whether or not He^3, the other well-known Fermi fluid, has a superfluid phase at low temperatures has been a matter of concern since the discovery of the λ transition in He^4 and London's conjecture[2] that Bose statistics are crucial to the formation of the superfluid phase.

We have attempted to treat this question by taking over to an arbitrary system of fermions what appears to have worked very well for the electron gas. There the introduction of pair correlations into the wave function and the approximation that only pairs of given total spin and total momentum are strongly correlated was sufficient to account for the observed properties of the superconducting phase. In making this same assumption for an arbitrary system of fermions we have had to assume that in some sense the "normal" fluid could be described in an uncorrelated approximation. The situation in this regard, for a fermion system such as the nucleus, is much less clear than the corresponding situation in a metal where the lattice plays such a dominant rôle.

This basic conjecture of our procedure, the description of the normal fluid as a Fermi gas in a momentum-dependent potential, is discussed in Sec. II. In the third

* Supported in part by the National Science Foundation.
† A preliminary account of this work was presented at the *Kamerlingh-Onnes Conference on Low-Temperature Physics, Leiden, Netherlands, June, 1958* (Suppl. Physica **24**, September, 1958).
‡ Present address: Brown University, Providence, Rhode Island.
[1] Bohr, Mottelson, and Pines, Phys. Rev. **110**, 936 (1958); C. De Dominicis and P. C. Martin, Bull. Am. Phys. Soc. Ser. II, **3**, 224 (1958).
[2] F. London, Nature **163**, 694 (1949).

PHYSICAL REVIEW C, VOLUME 63, 044309

Thermal and electromagnetic properties of ^{166}Er and ^{167}Er

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Frank Laboratory of Neutron Physics, Joint Institute of Nuclear Research, RU-141980 Dubna, Moscow region, Russia

(Received 30 October 2000; published 6 March 2001)

The primary γ-ray spectra of ^{166}Er and ^{167}Er are deduced from the (^{3}He,$\alpha\gamma$) reaction and the (^{3}He,^{3}He$'\gamma$) reaction, respectively, enabling a simultaneous extraction of the level density and the γ-ray-strength function. Entropy, temperature, and heat capacity are deduced from the level density within the microcanonical and canonical ensembles, displaying signals of a phaselike transition from the pair-correlated ground state to an uncorrelated state at $T_c \sim 0.5$ MeV. The γ-ray-strength function displays a bump around $E_\gamma \sim 3$ MeV, interpreted as the pygmy resonance.

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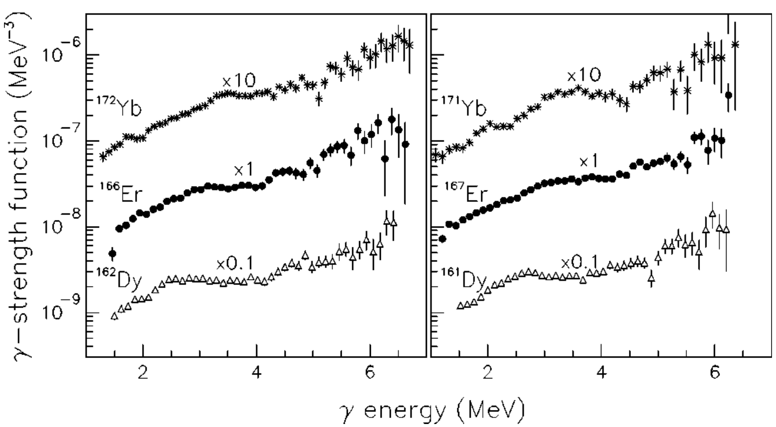

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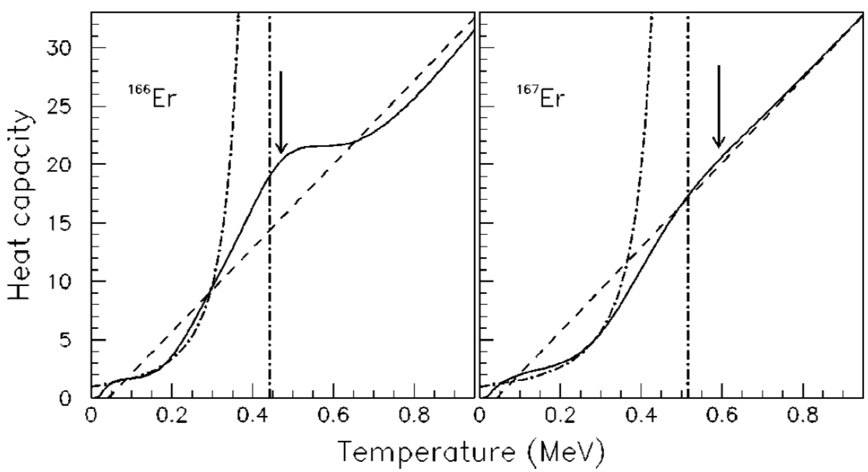
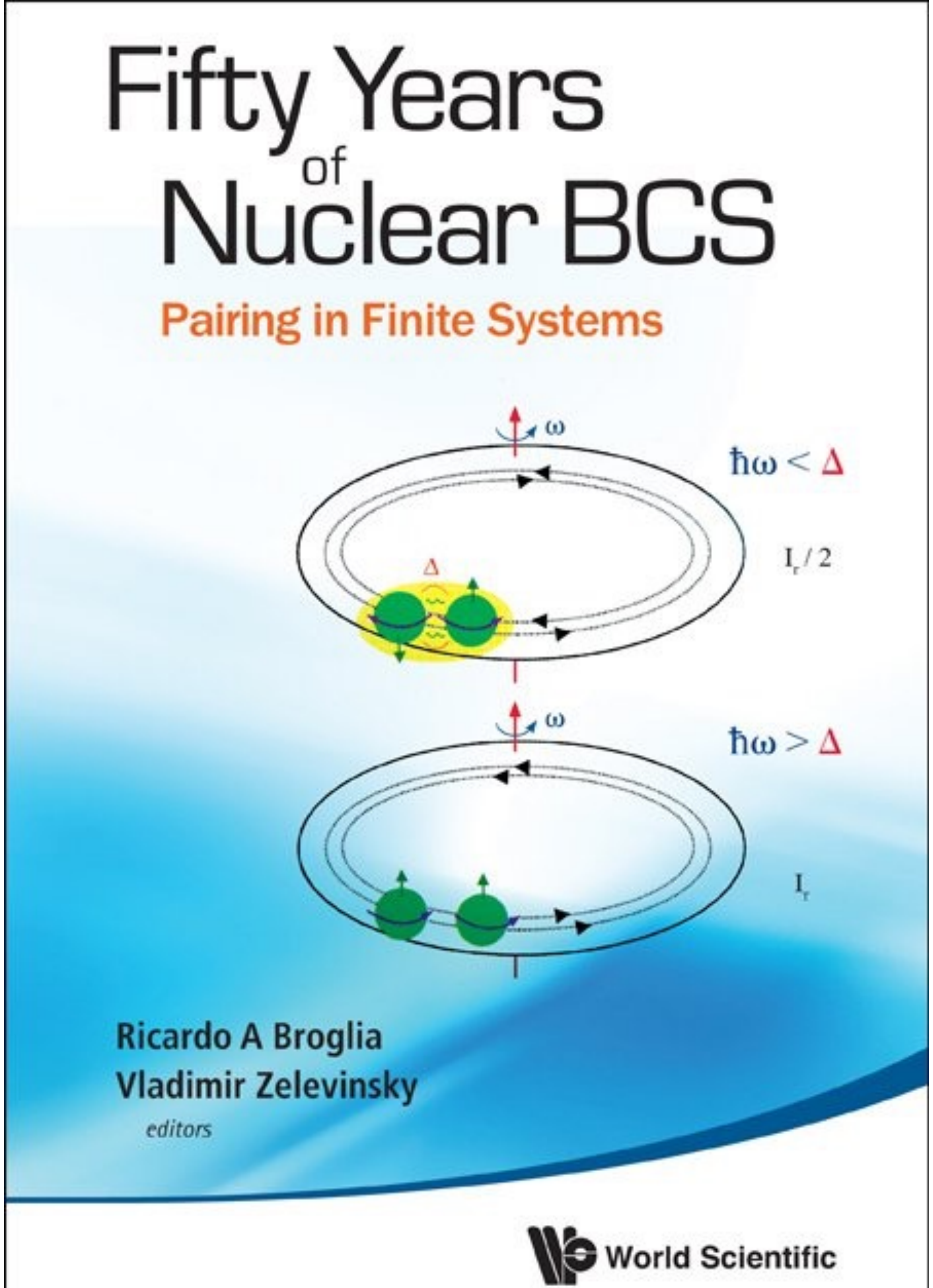
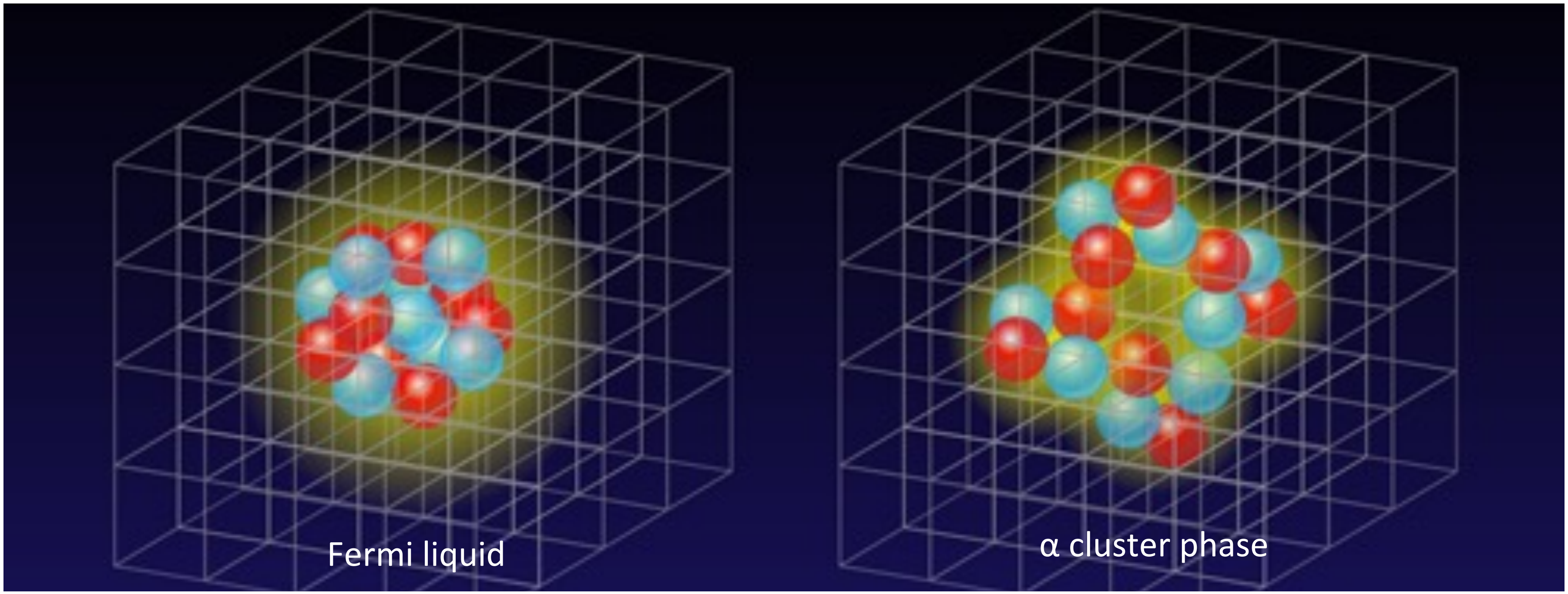




https://doi.org/10.1142/8526 (2013)

Exotic phases of nuclear matter
Quartetting and α-particle condensation

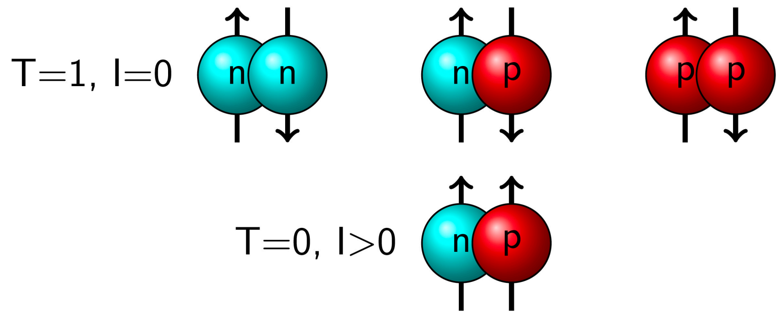


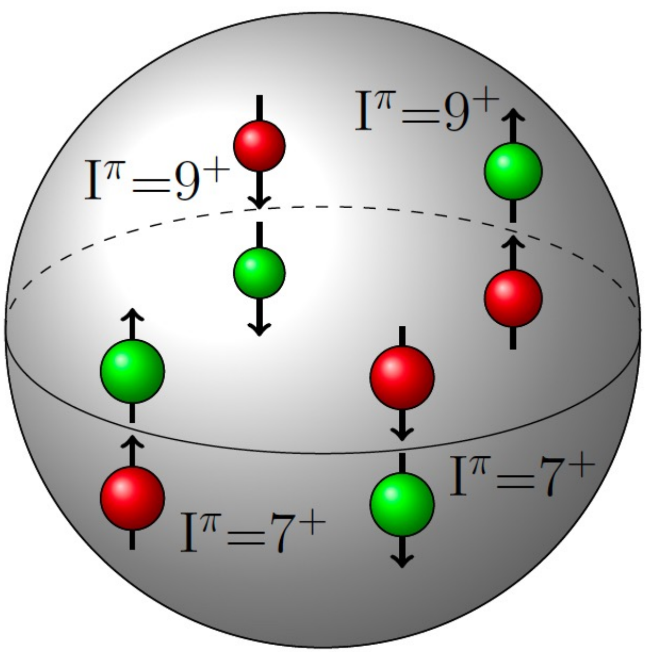
Selected for a Viewpoint in *Physics*
PRL **117,** 132501 (2016) PHYSICAL REVIEW LETTERS week ending 23 SEPTEMBER 2016

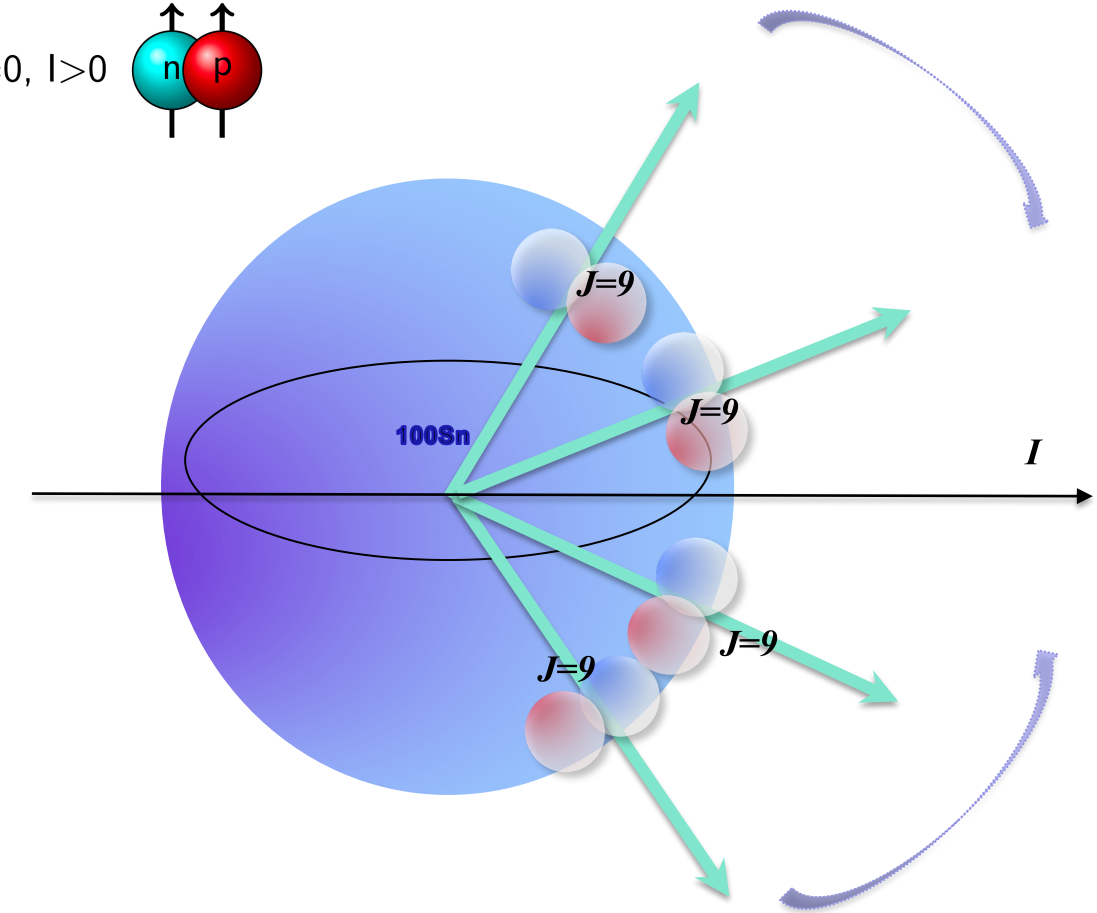
Nuclear Binding Near a Quantum Phase Transition

Serdar Elhatisari,[1] Ning Li,[2] Alexander Rokash,[3] Jose Manuel Alarcón,[1] Dechuan Du,[2] Nico Klein,[1] Bing-nan Lu,[2] Ulf-G. Meißner,[1,2,4] Evgeny Epelbaum,[3] Hermann Krebs,[3] Timo A. Lähde,[2] Dean Lee,[5] and Gautam Rupak[6]

Isospin NN pairing modes
(a unique possibility for nuclei due to the coupling of two Fermi liquids)



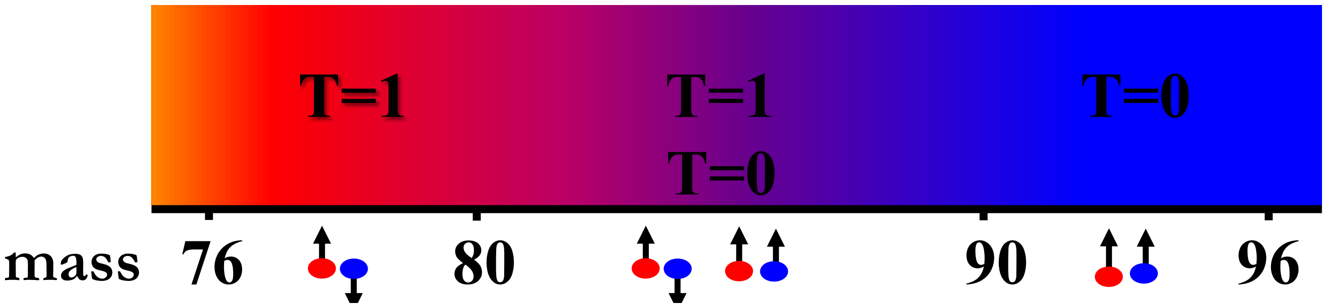


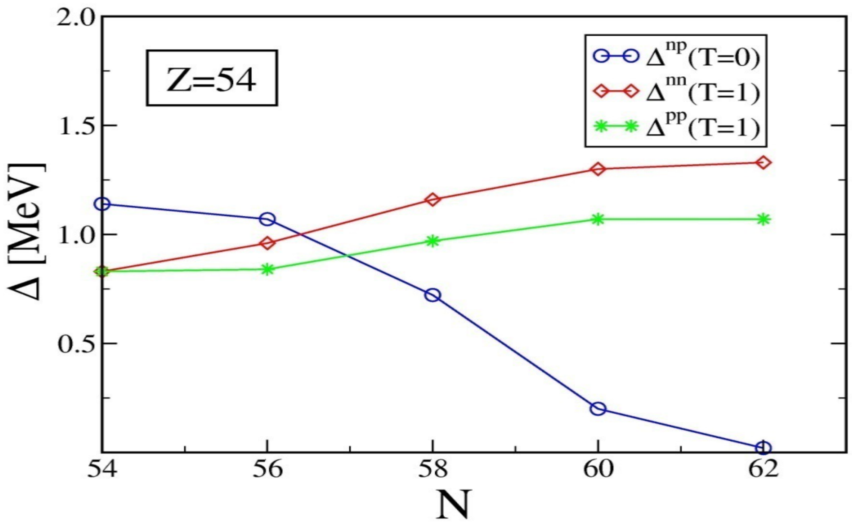


Isoscalar paired phase in ^{92}Pd?
B. Cederwall et al., Nature (London) 469, 68 (2011)

Theory predictions for neutron-proton pairing in the heaviest N ~ Z nuclei

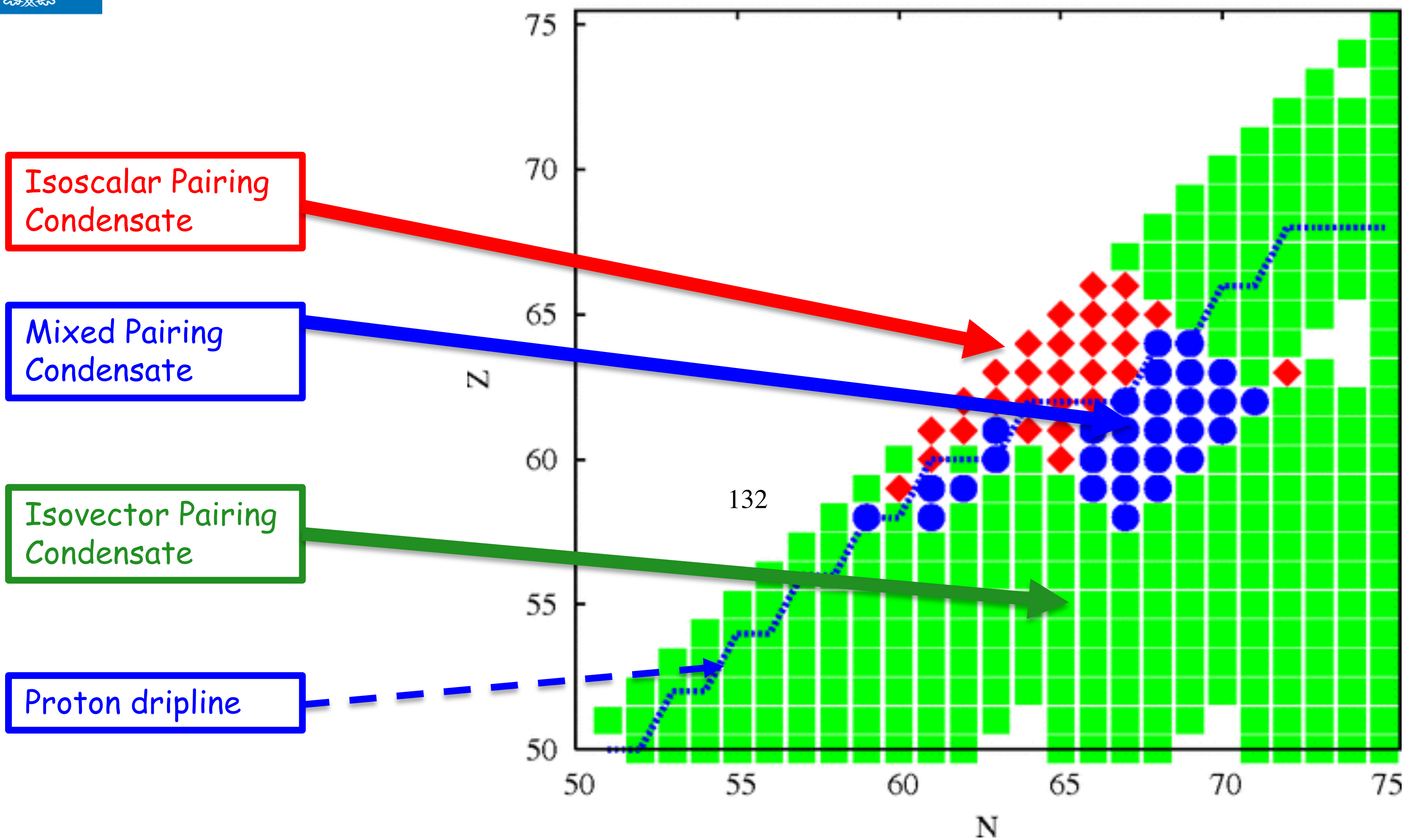
A. L. Goodman , PRC 60, 014311 (1999) –
HFB studies of ground states of e-e A = 76-96, N = Z nuclei





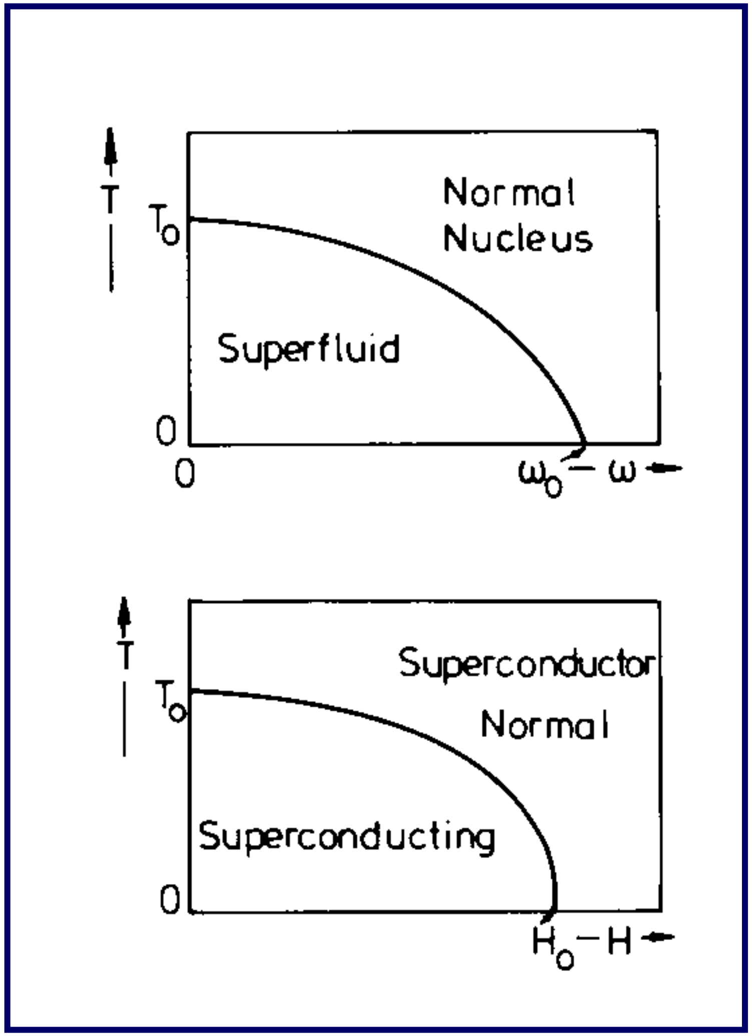
W. Satula,R.Wyss, Phys. Rev. Lett. Vol. 86, 4488 (2001)

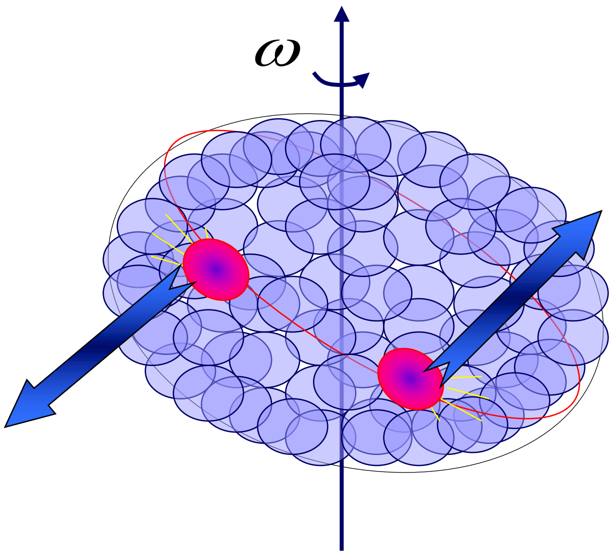
”Isocranking”: The isoscalar (np) pair gap is predicted to increase sharply as N → Z



"Mixed-Spin Pairing Condensates in Heavy Nuclei"
A. Gezerlis, G. F. Bertsch, and Y. L. Luo
Phys. Rev. Lett. 106, 252502 (2011)

Similarly to a magnetic field on a superconductor, the rotational motion of a deformed nucleus counteracts the isovector-coupled (J=0) superfluid phase by breaking time-reversed nn or pp pairs. (Coriolis anti-pairing effect)





Isospin-generalized HFB theory

"$T = 0$ and $T = 1$ pairing in rotational states of the $N = Z$ nucleus ^{80}Zr"
A. L. Goodman, PRC 63, 044325 (2001)

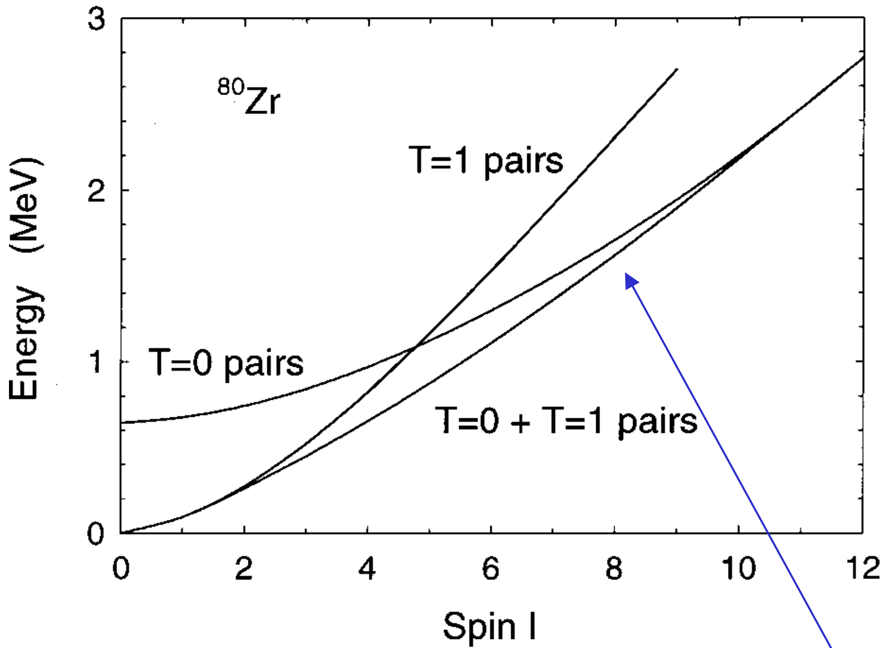


FIG. 1. Energies of the rotational bands versus the spin I.

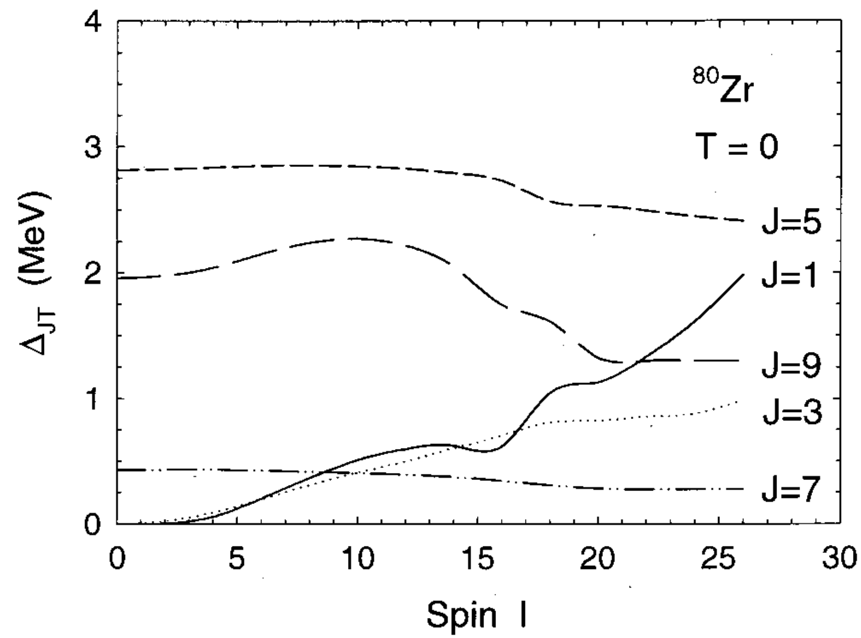
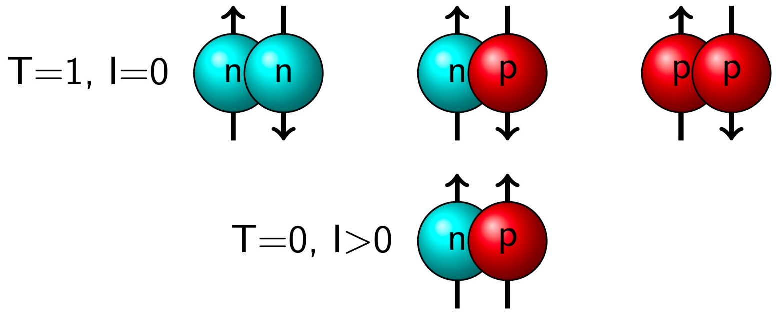


FIG. 9. Angular momentum components of the pair potential $\Delta_{J,T=0}$ for the $T=0$ pair band.

T=1 pairing is <u>suppressed</u> by the Coriolis effect in high-spin states
The T=0 coupling is less affected by the Coriolis anti-pairing effect and will still be active and could become dominant as I increases

Neutron-proton pairing in N ≈ Z nuclei - experimental probes



ISOVECTOR

ISOSCALAR

- Masses - binding energies in e-e and o-o nuclei indicate that **T=1 *np* pairing** is dominant, no evidence for a T=0 (deuteron-like) pair condensate **up to around A≈60. Need for accurate mass measurements in heavier N=Z systems**
- np (deuteron) pair transfer reactions
- GT Beta decay strengths
- Other radioactive decay modes: (alpha) proton???

Probe ground-state or low-spin correlations

?

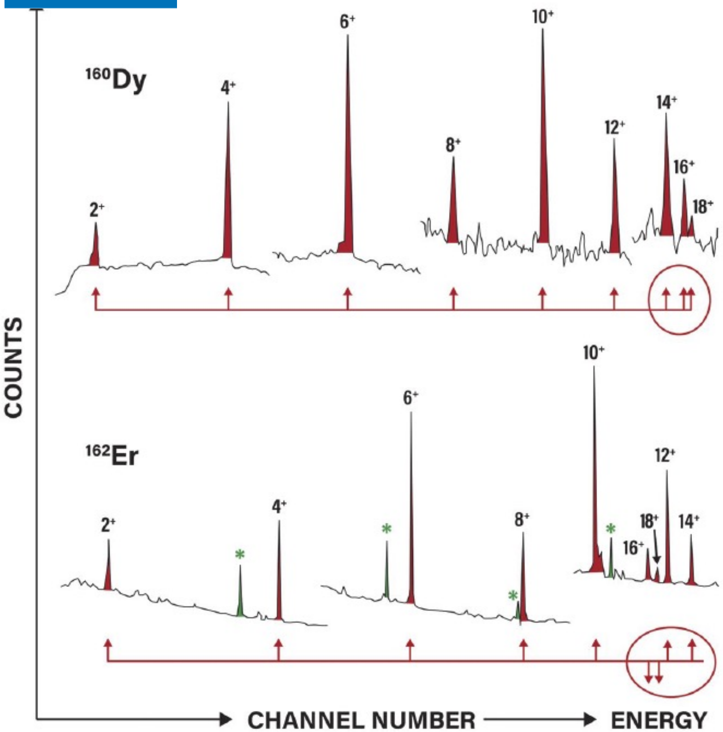
- Spectral properties of spherical N=Z nuclei near closed shells –deviations from classical s.p. behavior (e.g. ^{92}Pd – isoscalar spin-aligned coupling scheme*)

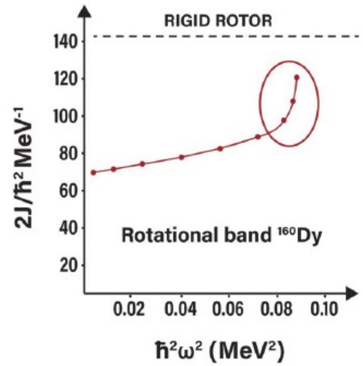
- **Rotational properties of deformed nuclei**

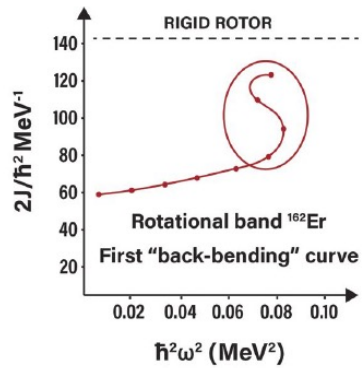
We know the isoscalar effective NN interaction is strongly attractive but can it produce a correlated np pairing condensate?

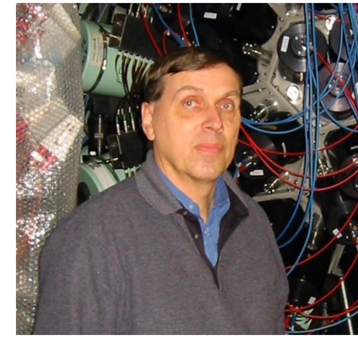
- B. Cederwall et al., Nature (London) 469, 68 (2011)
- S. Frauendorf and A. Macchiavelli, Prog. Part. Nucl. Phys. 78, 24 (2014)

Rotational alignments ("backbending") in deformed nuclei: a sensitive probe of pairing strength

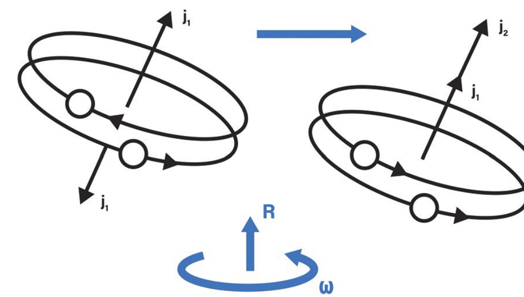








Arne Johnson 1944-2023



Note: The "Backbending" effect (A. Johnson et al., 1971) is not a complete phase transition. In the finite nuclear system the paired and unpaired phases are mixed after the first alignment ("Stockholm, S-band") (F.S. Stephens and R.S. Simon, 1972).

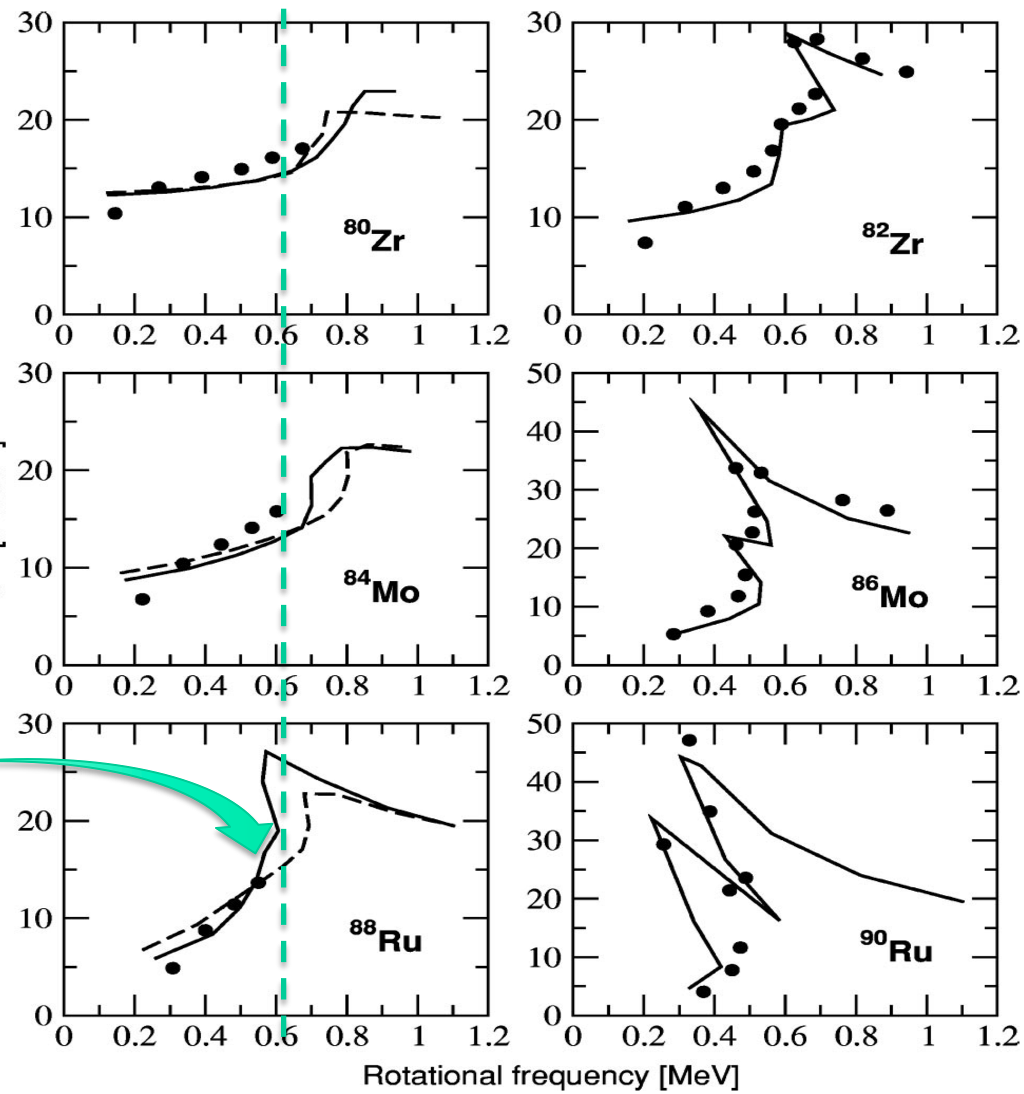
A. Johnson, H. Ryde, and J. Sztarkier, Phys. Lett. B34, 605 (1971)

A. Johnson, H. Ryde, S. A. Hjorth, Nuc. Phys. A179, 753 (1972)

F. S. Stephens and R. S. Simon. Nuc. Phys. A183, 257 (1972)

R. Wyss & M. A. Riley, Fifty Years of Backbending, Nuclear Physics News, 32:2, 16-20 (2022)

Delayed (or absent) paired (T=1) bandcrossings in deformed N=Z nuclei?



N. Marginenan *et al.*, Phys. Rev. C 65, 051303R (2002)

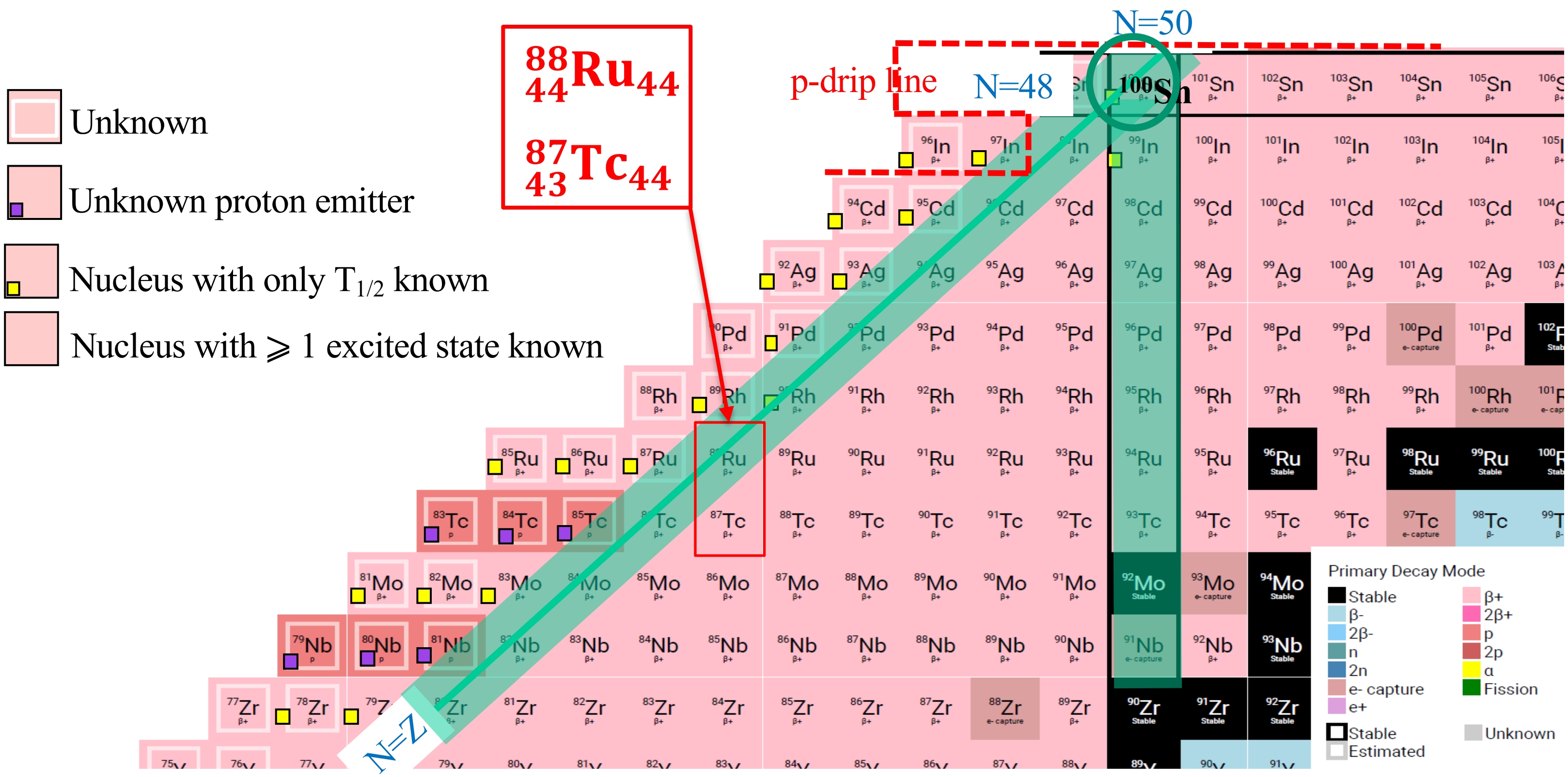
_____ PSM

_ _ _ PSM with enhanced np res. int

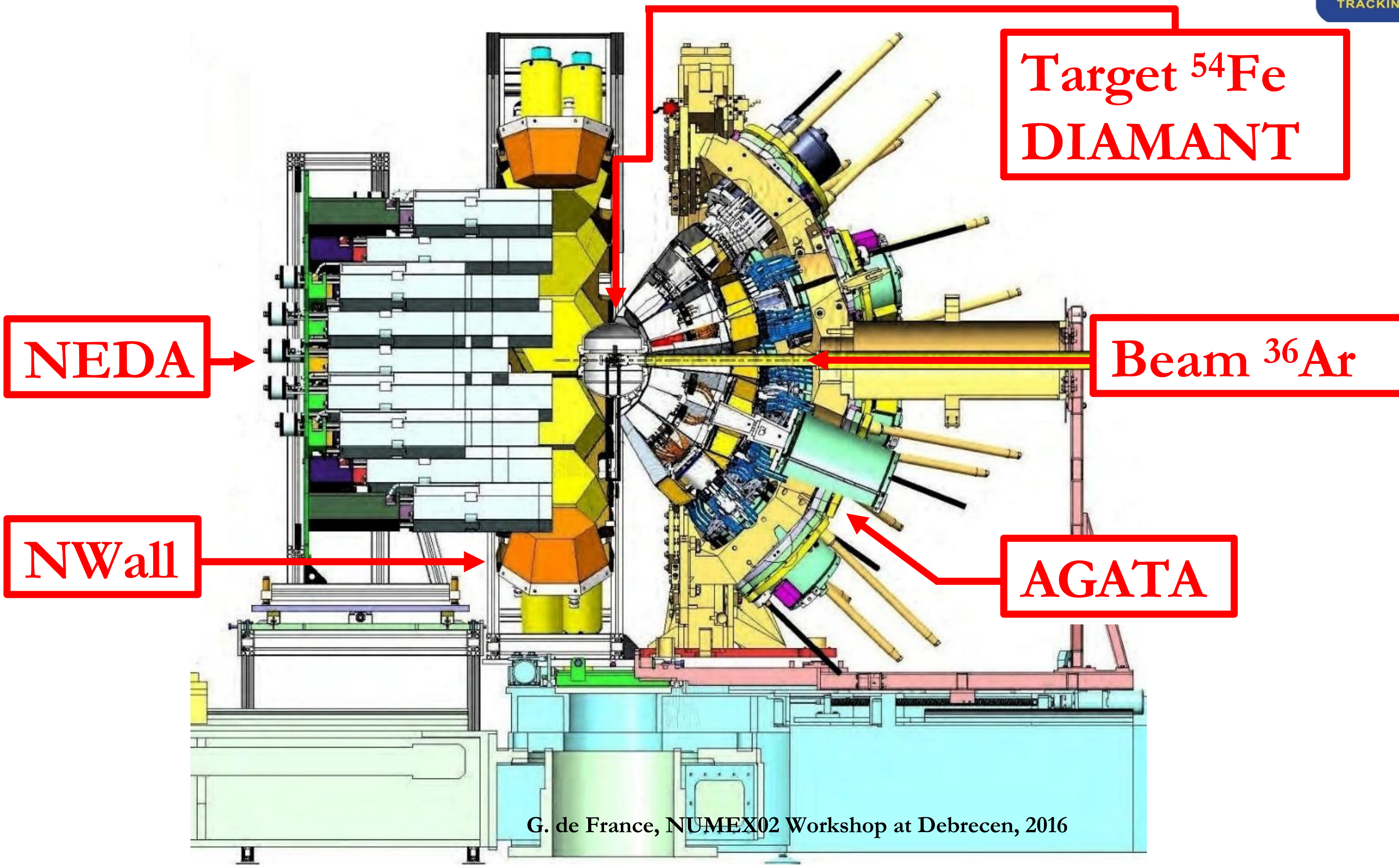
Situation prior to this work

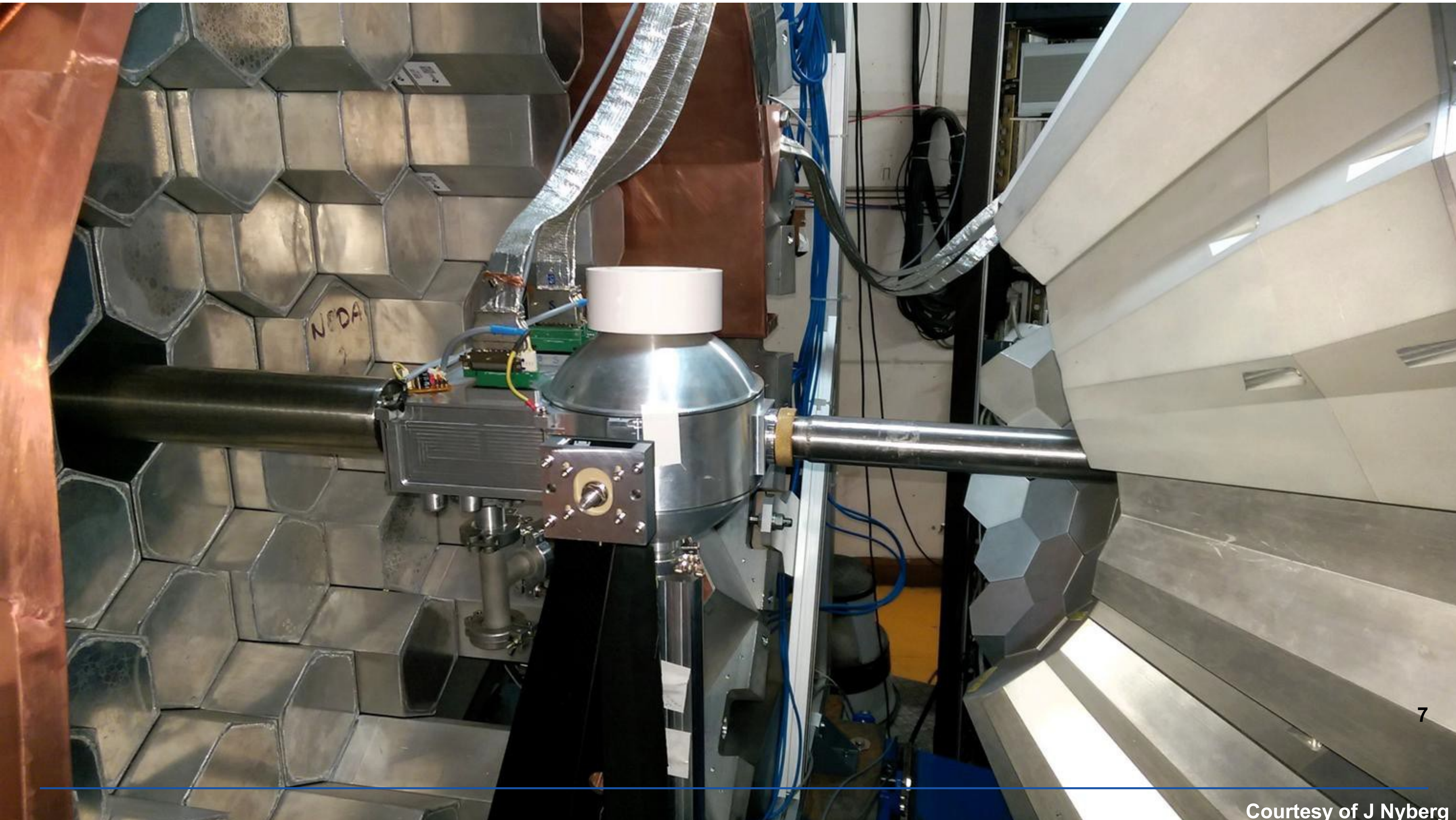
Experiment

Beam: ^{36}Ar (115 MeV, 5 ~ 10 pnA)
Target: ^{54}Fe (99.58%, 6 mg/cm^2)
Main contaminations: ^{16}O from oxidation, ^{56}Fe (0.40%)
Fusion-evaporation reactions of interest:
^{36}Ar(^{54}Fe, 2n)^{88}Ru
^{36}Ar(^{54}Fe, 2n1p)^{87}Tc



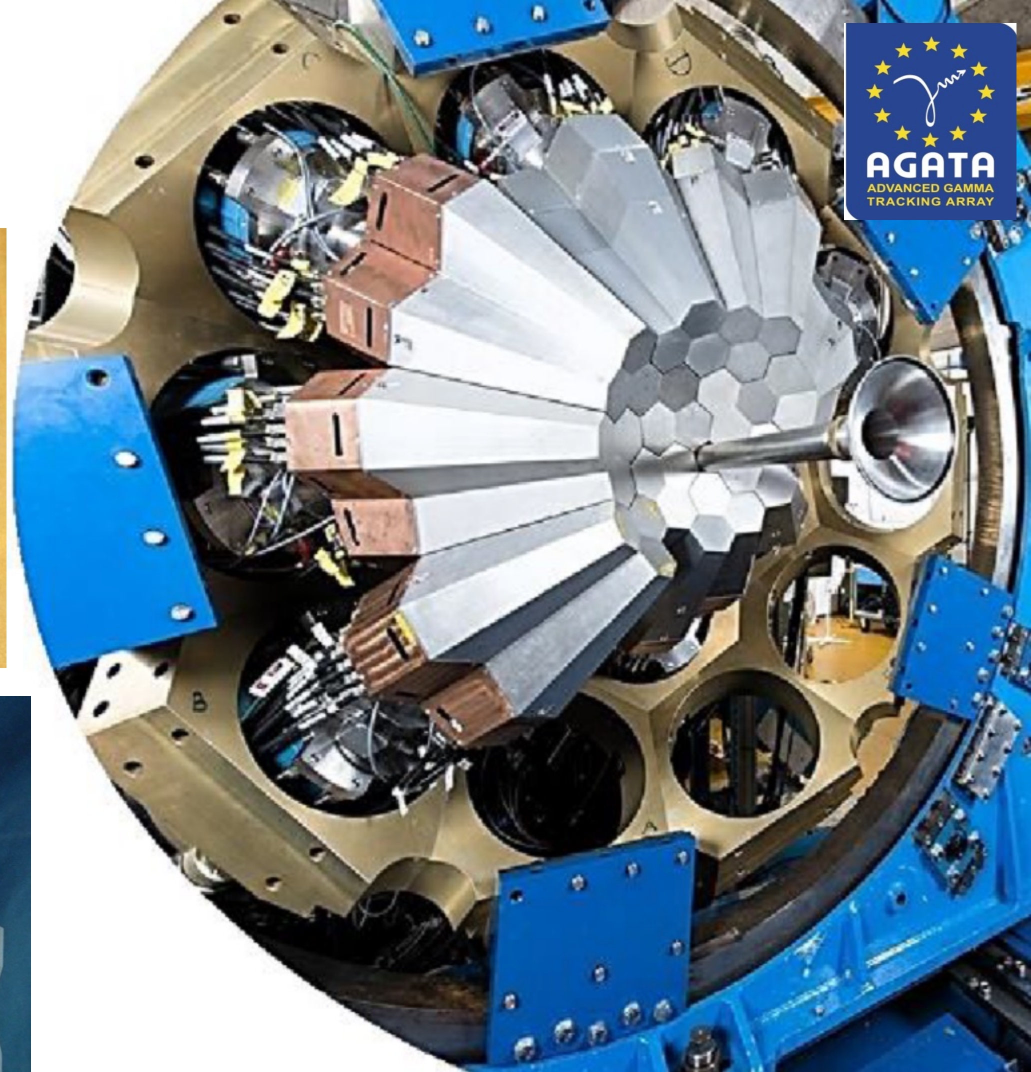
Experimental Setup

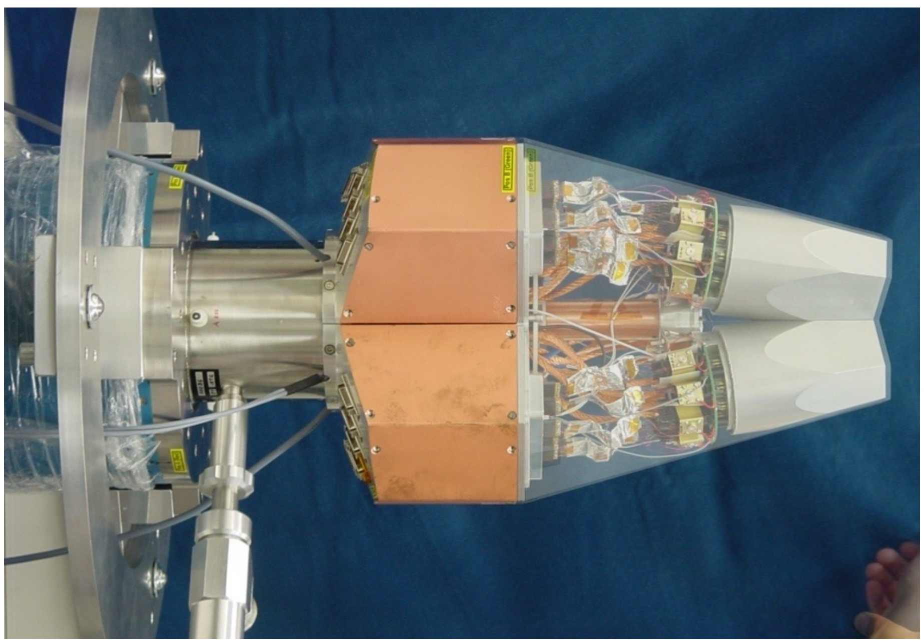




Courtesy of J Nyberg

AGATA



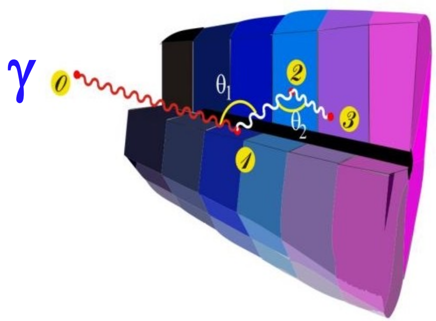


- 34 AGATA crystals (out of 180)
- ~ **0.8π** Coverage
- E, T, Position (*x*, *y*, *z*)
- Trigger: ***$\gamma\gamma$-n***

Basic ingredients of γ-ray tracking

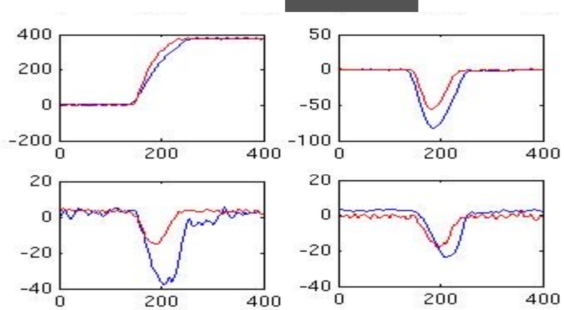
1

Highly segmented HPGe detectors



2

Digital electronics to record and process segment signals



3

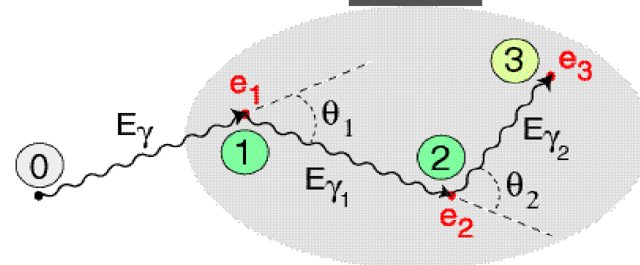
Pulse Shape Analysis to decompose recorded waves

Identified interaction

$(x,y,z,E,t)_i$

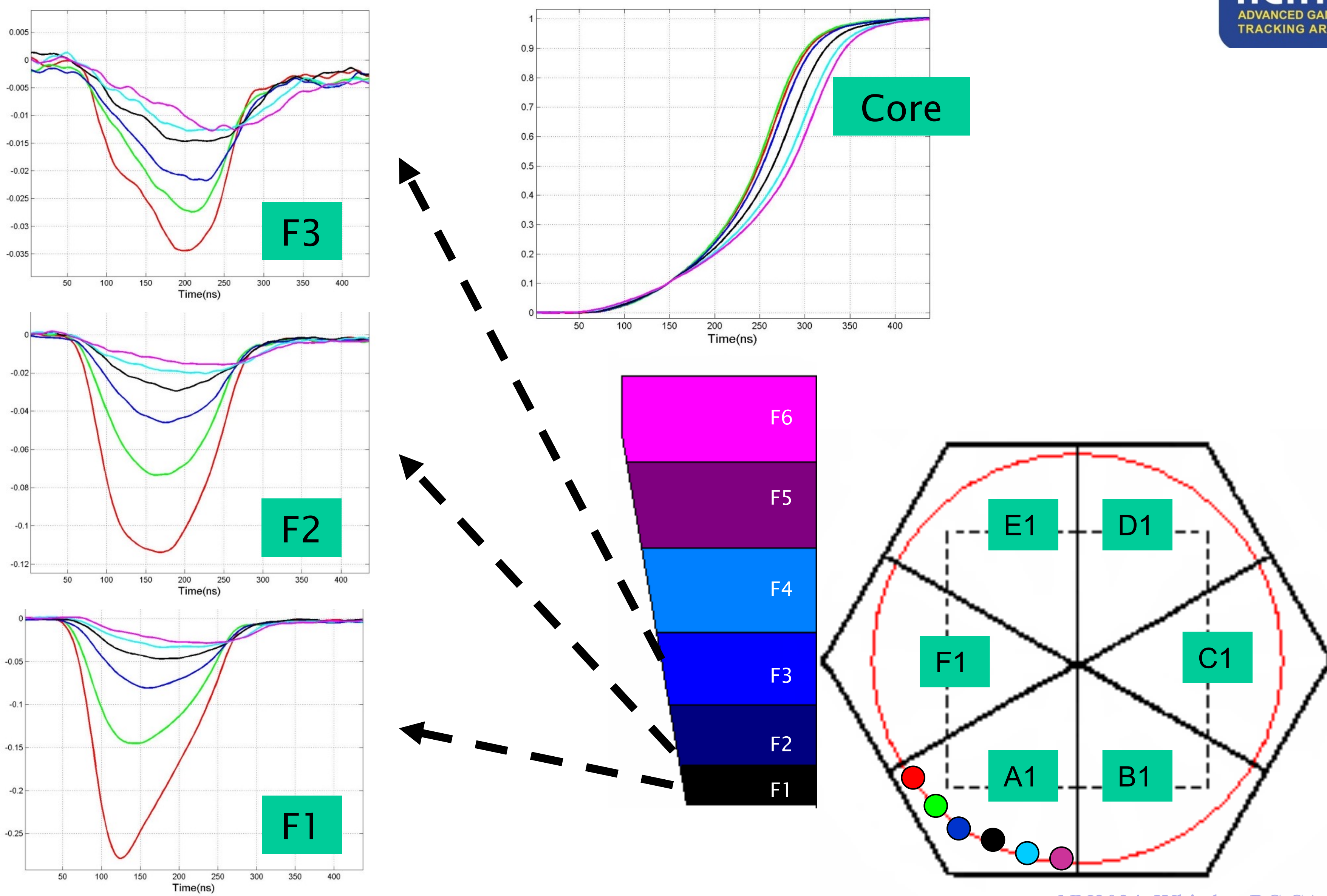
4

Reconstruction of tracks e.g. by evaluation of permutations of interaction points

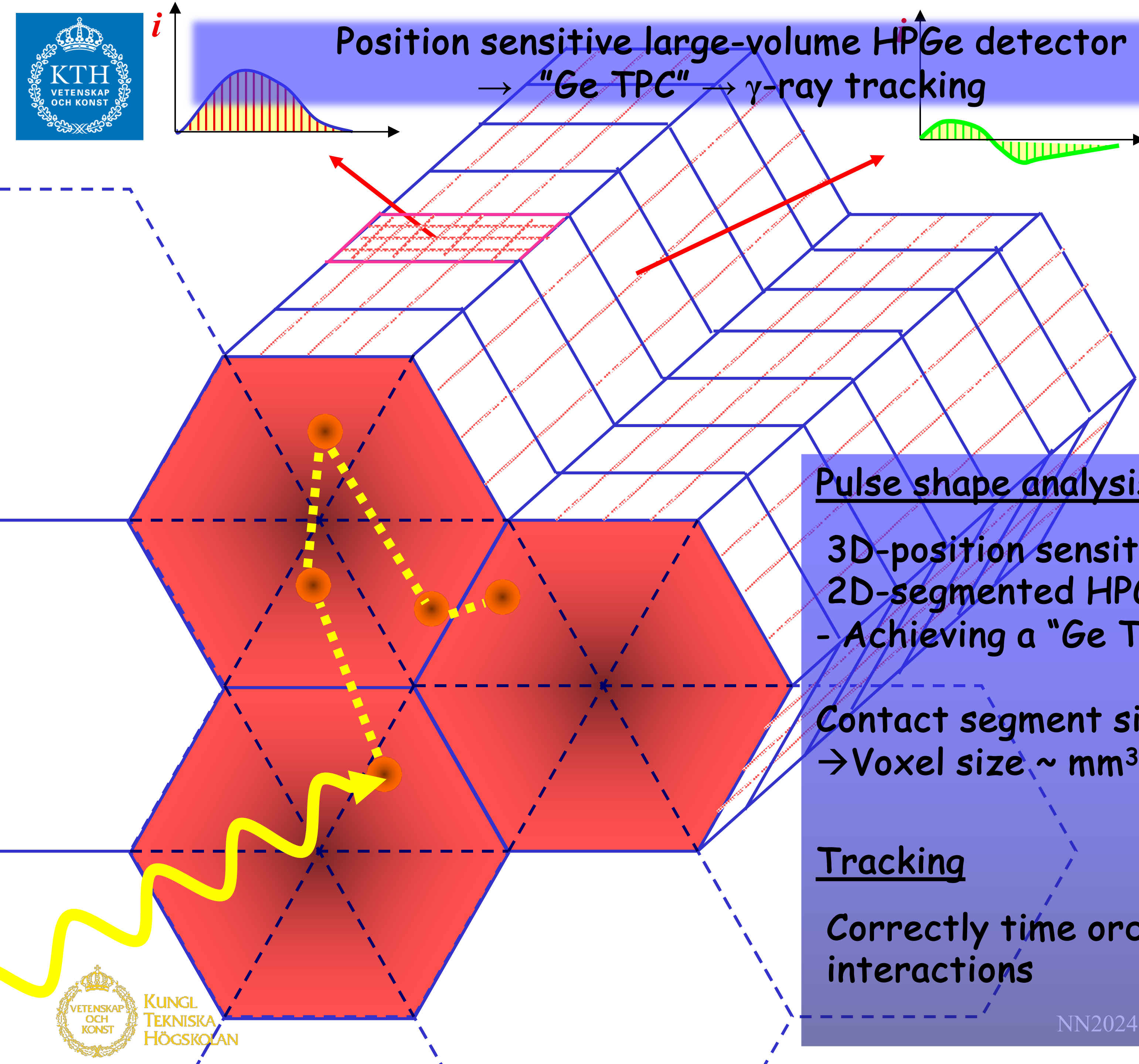


reconstructed γ rays

Pulse shape analysis – spatial resolution of 2-5 mm



Position sensitive large-volume HPGe detector
→ "Ge TPC" → γ-ray tracking



Pulse shape analysis

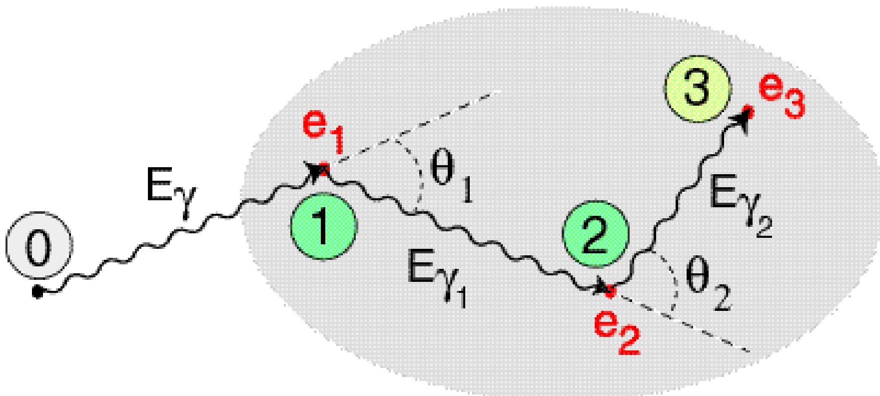
3D-position sensitivity from 2D-segmented HPGe detectors
- Achieving a "Ge TPC"

Contact segment size ~ cm^2
→Voxel size ~ mm^3

Tracking

Correctly time order all interactions

Forward Tracking of Compton Scattering Events



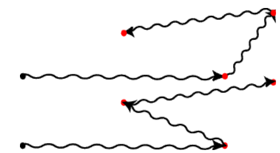
$$E_{\gamma'} = \frac{E_\gamma}{1 + \frac{E_\gamma}{m_0 c^2}(1 - \cos\theta)}$$

$$\cos\theta_{Pos} = \frac{\overrightarrow{01} \cdot \overrightarrow{12}}{|\overrightarrow{01}| \cdot |\overrightarrow{12}|} \Rightarrow E_{\gamma'}^{Pos}$$

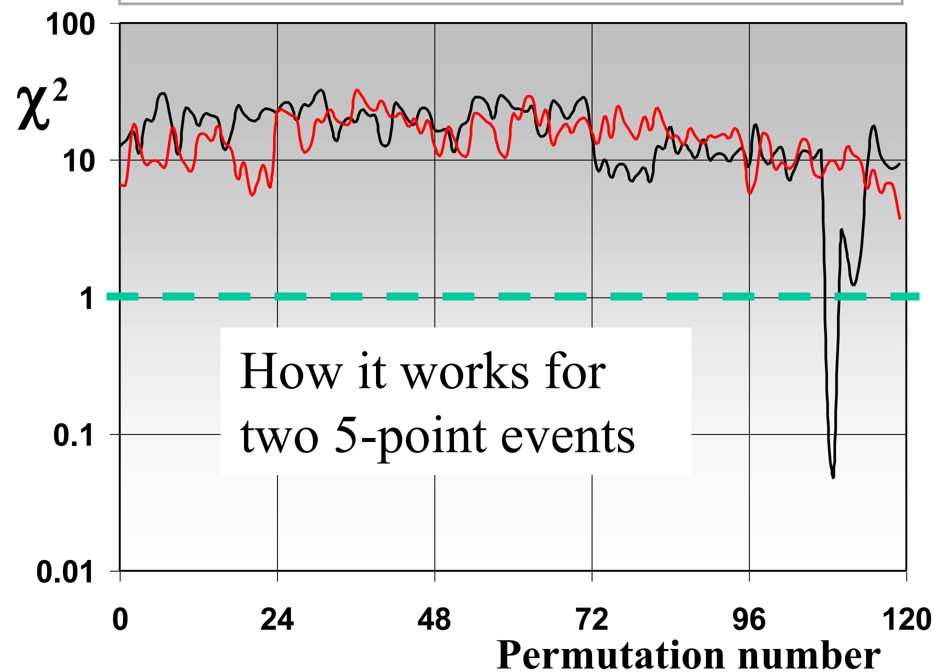
$$\chi^2 \approx \sum_{n=1}^{N-1} W_n \cdot \left(\frac{E_{\gamma'} - E_{\gamma'}^{Pos}}{E_\gamma} \right)_n^2$$

Find χ^2 for the N! permutations of the interaction points

0123 0132
0231 0213
0312 0321



Accept permutation with smallest χ^2 if this is below a predefined value

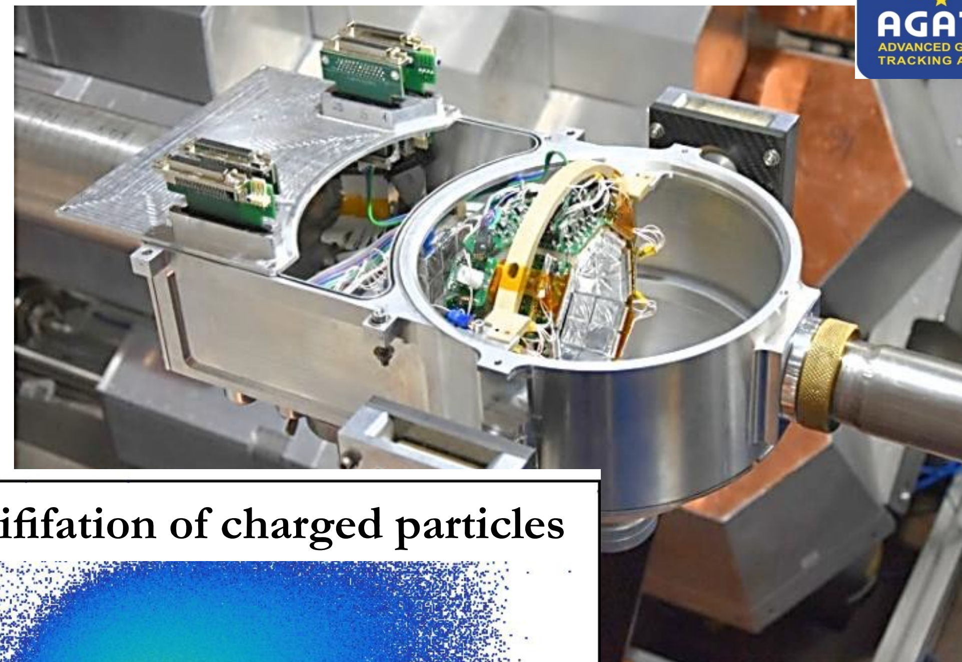


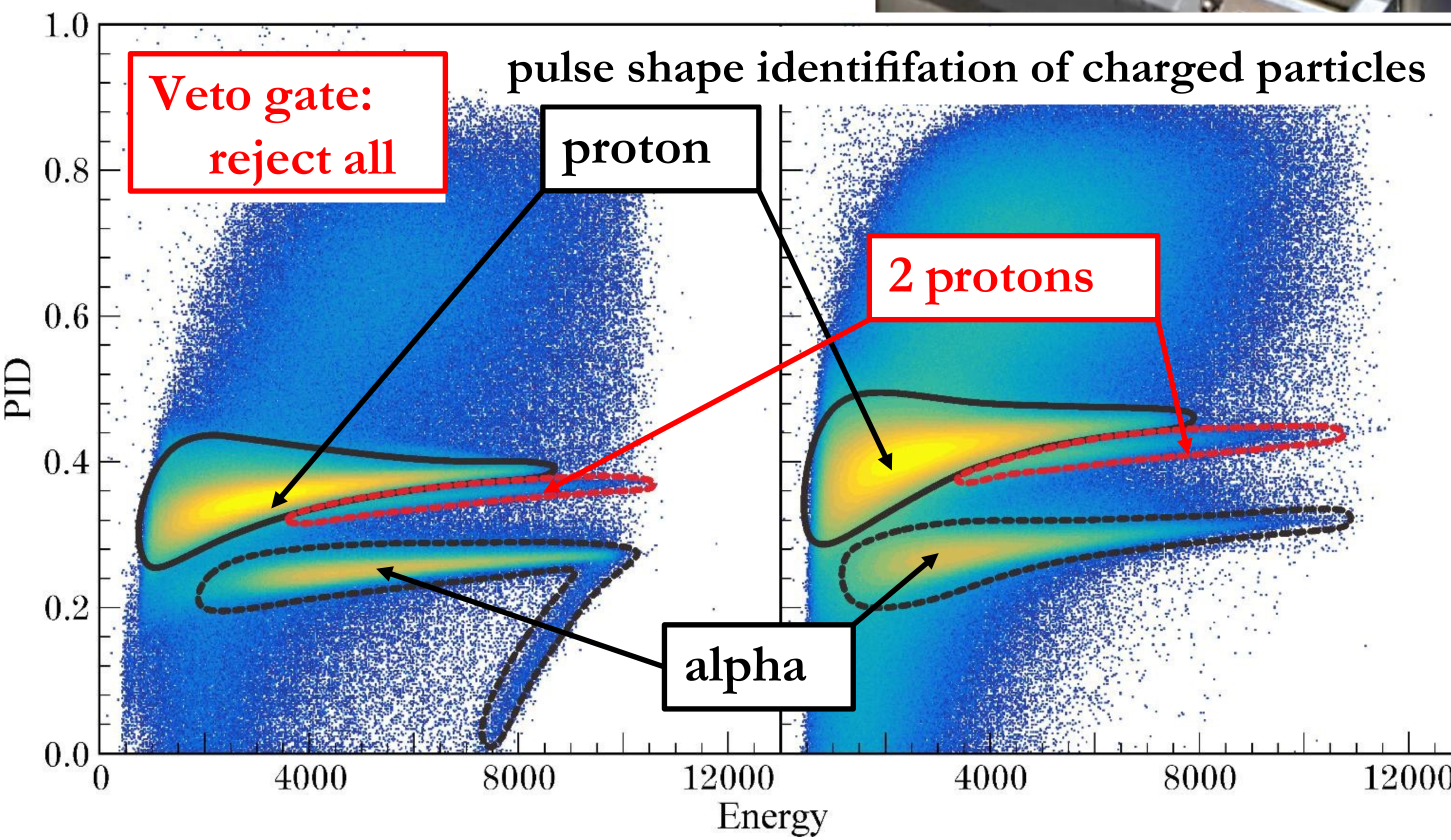
W_n contains physics of Compton scattering vertex and empiric factors

PROBLEMS : Position resolution, Short range scattering, Compton profile

DIAMANT charged particle array

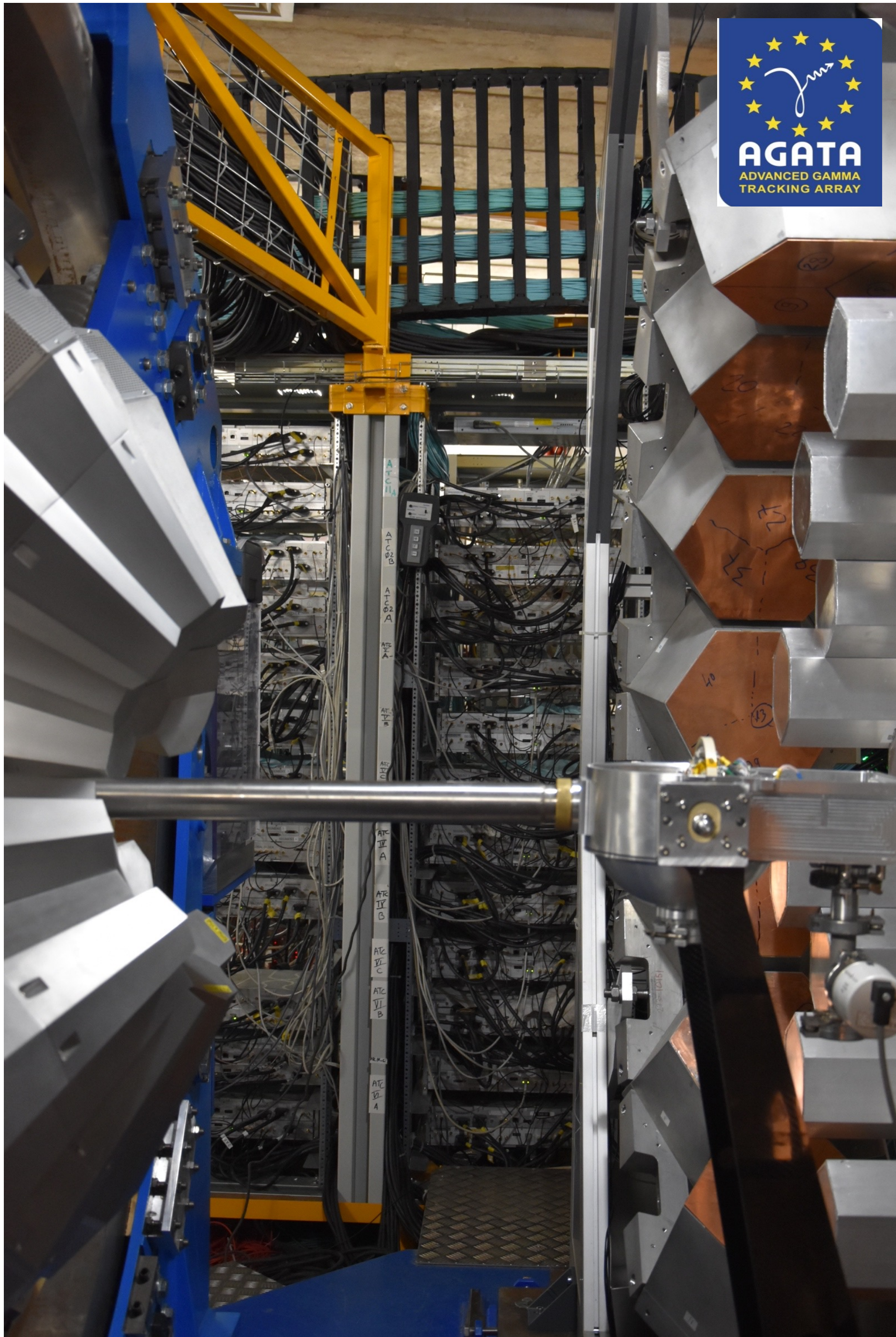
- 60 CsI(Tl) Detectors
- ~ 2π Coverage
- E, T, PID
- Slave Mode
- $\varepsilon_p \sim 40\%$, $\varepsilon_\alpha \sim 25\%$



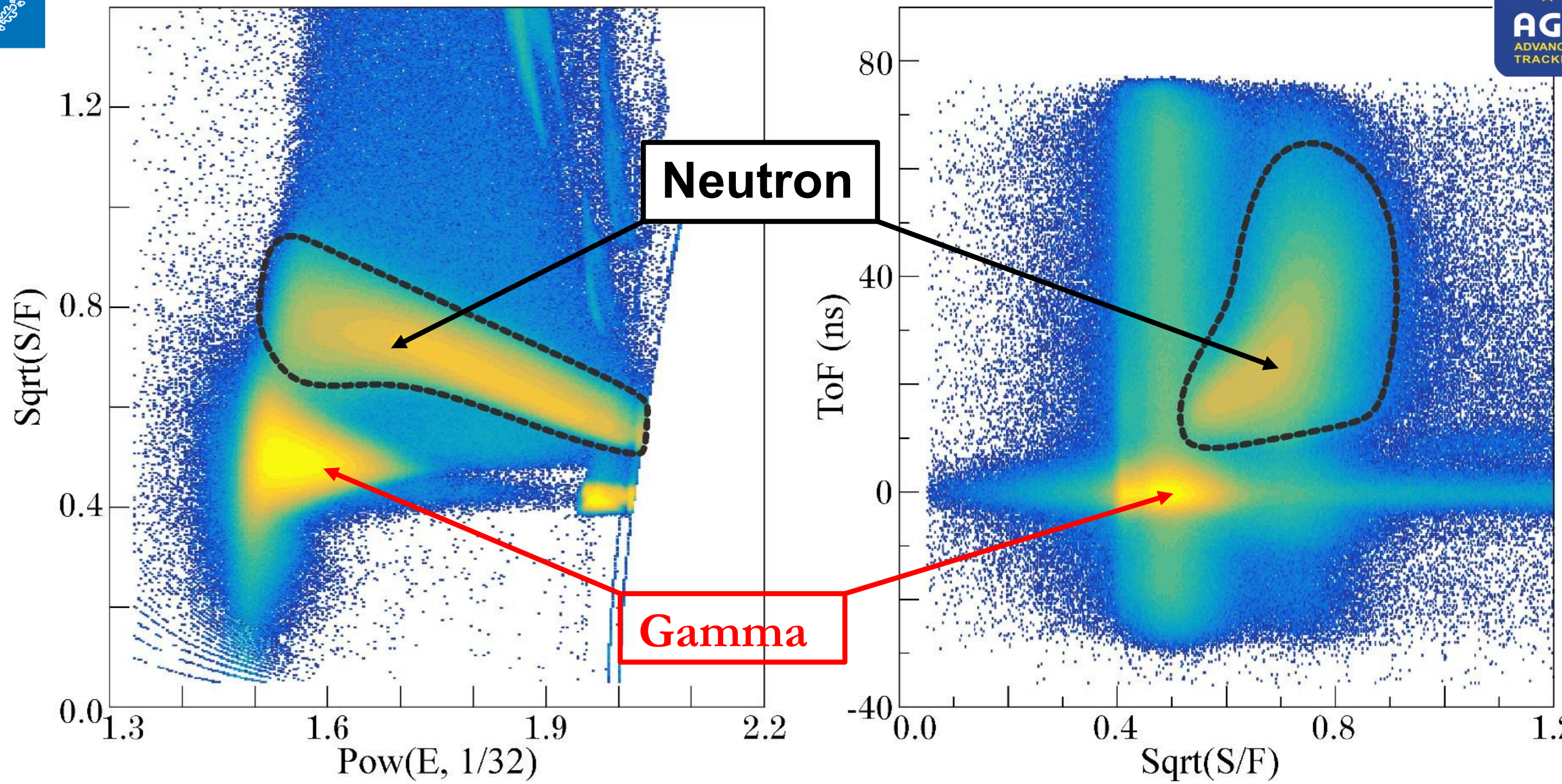


NEDA & NWall

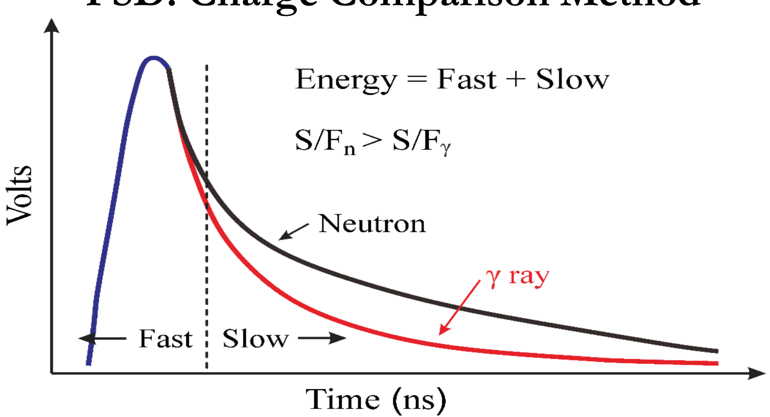
- Organic liquid scintillator cells
- 54 NEDA & 14 NWall
- ~ 1.6π Coverage
- Pulse Shape
- Trigger: $\gamma\gamma$-n *(neutron-like)*

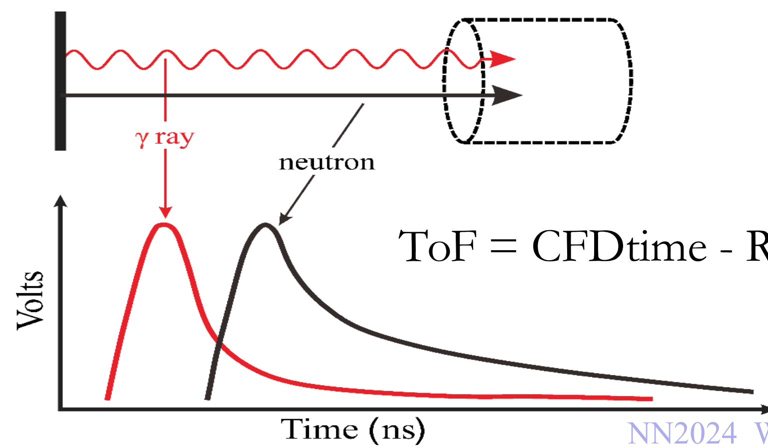


Neutron-γ Discrimination

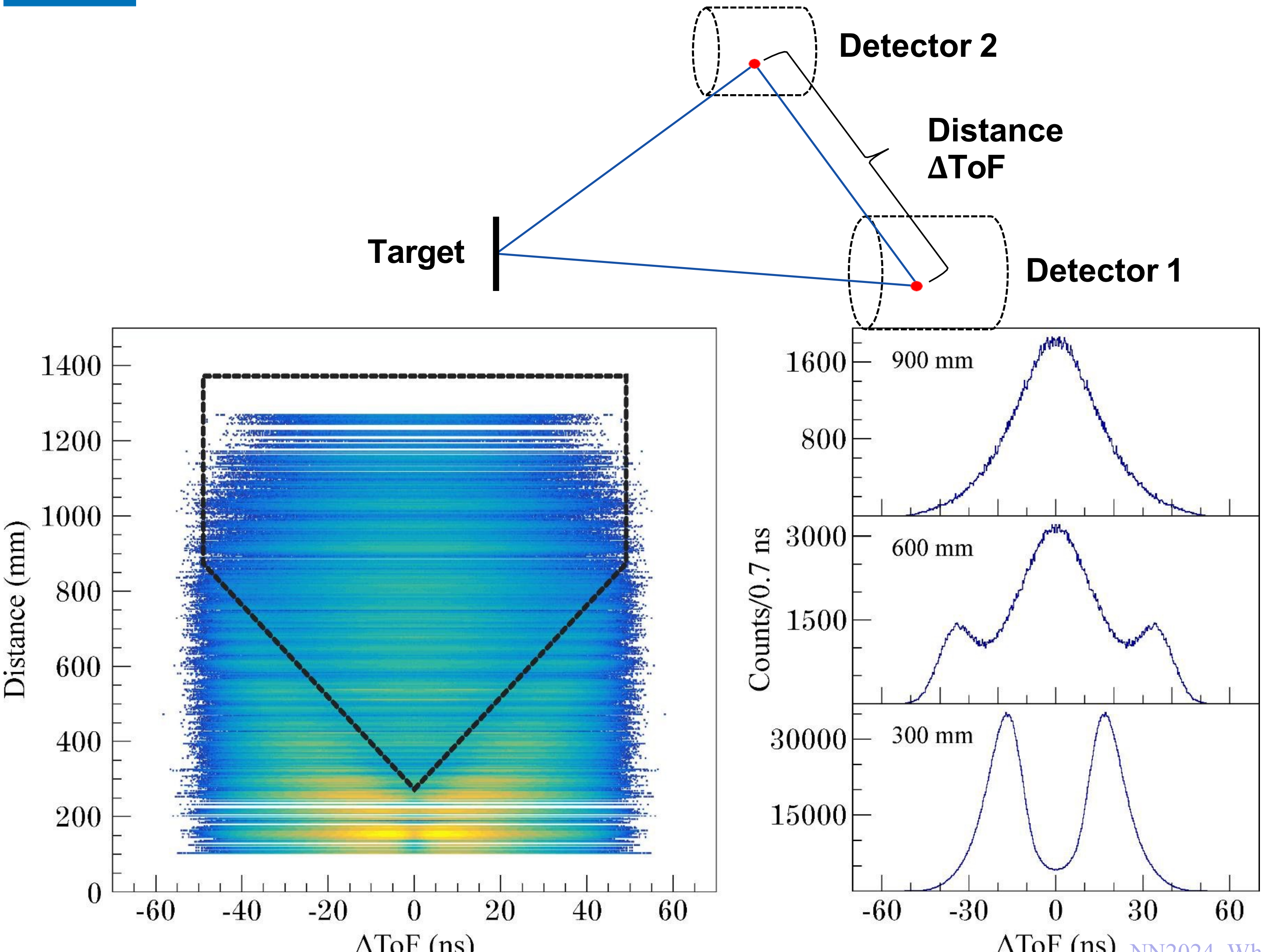


PSD: Charge Comparison Method

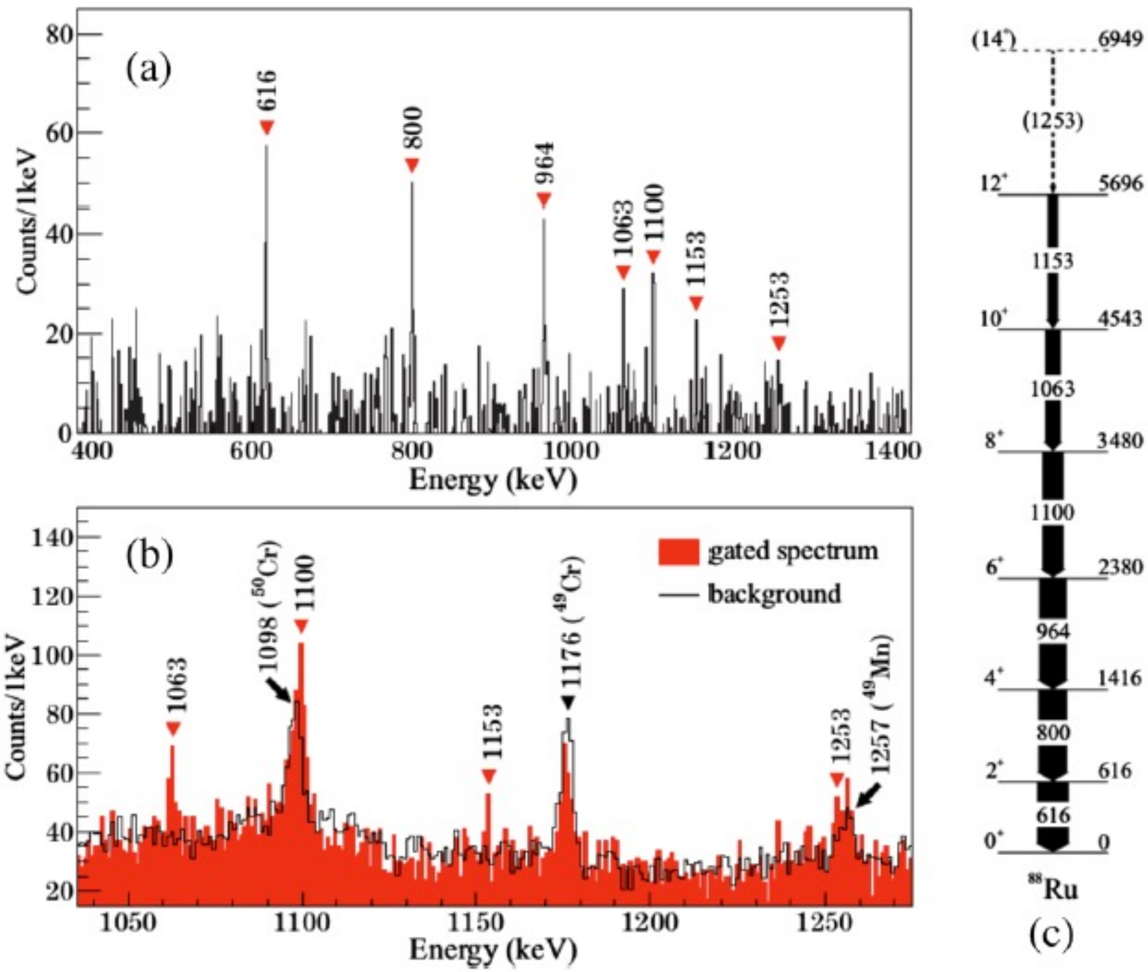




Neutron scatter rejection critical for identifying weak 2n- and 3n-emission reaction channels



Results: yrast band in ^{88}Ru

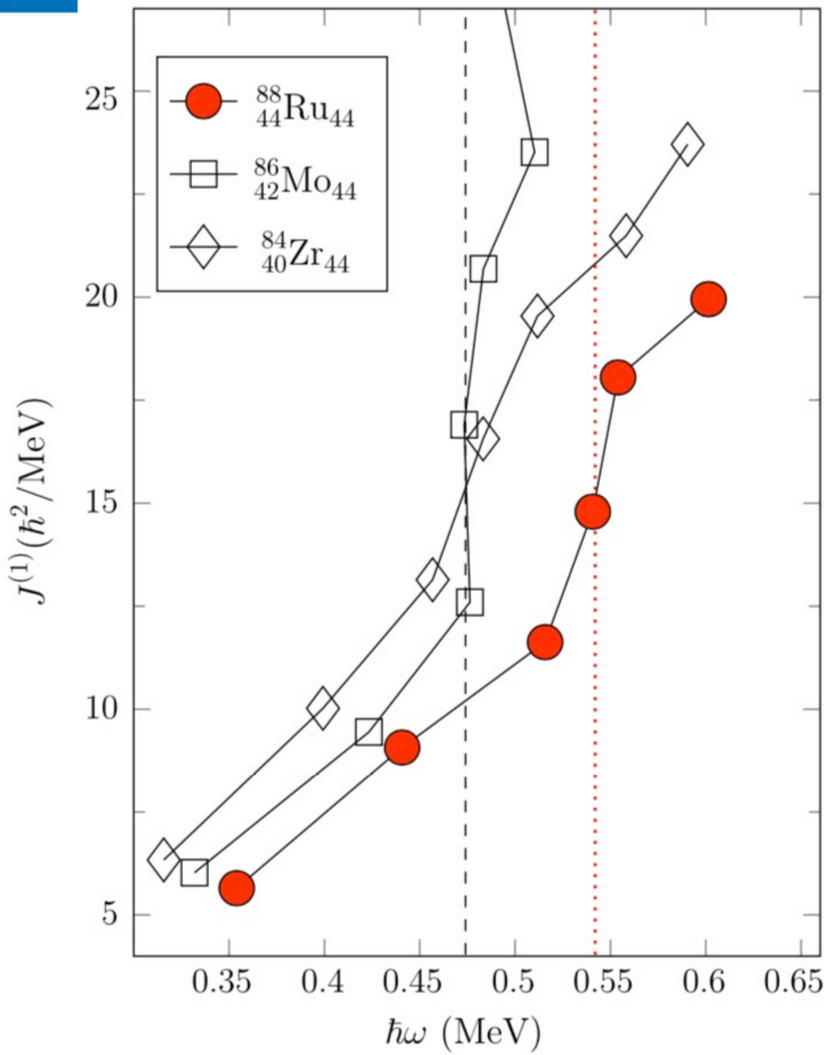


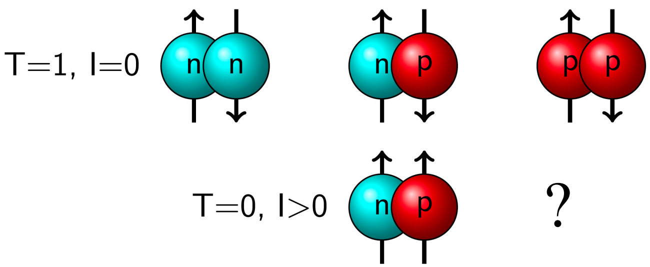
new

Marginean et al., Phys. Rev. C, 63, 031303(R), 2001.

Taken from B. Cederwall et al, PRL 124 062501 (2020)

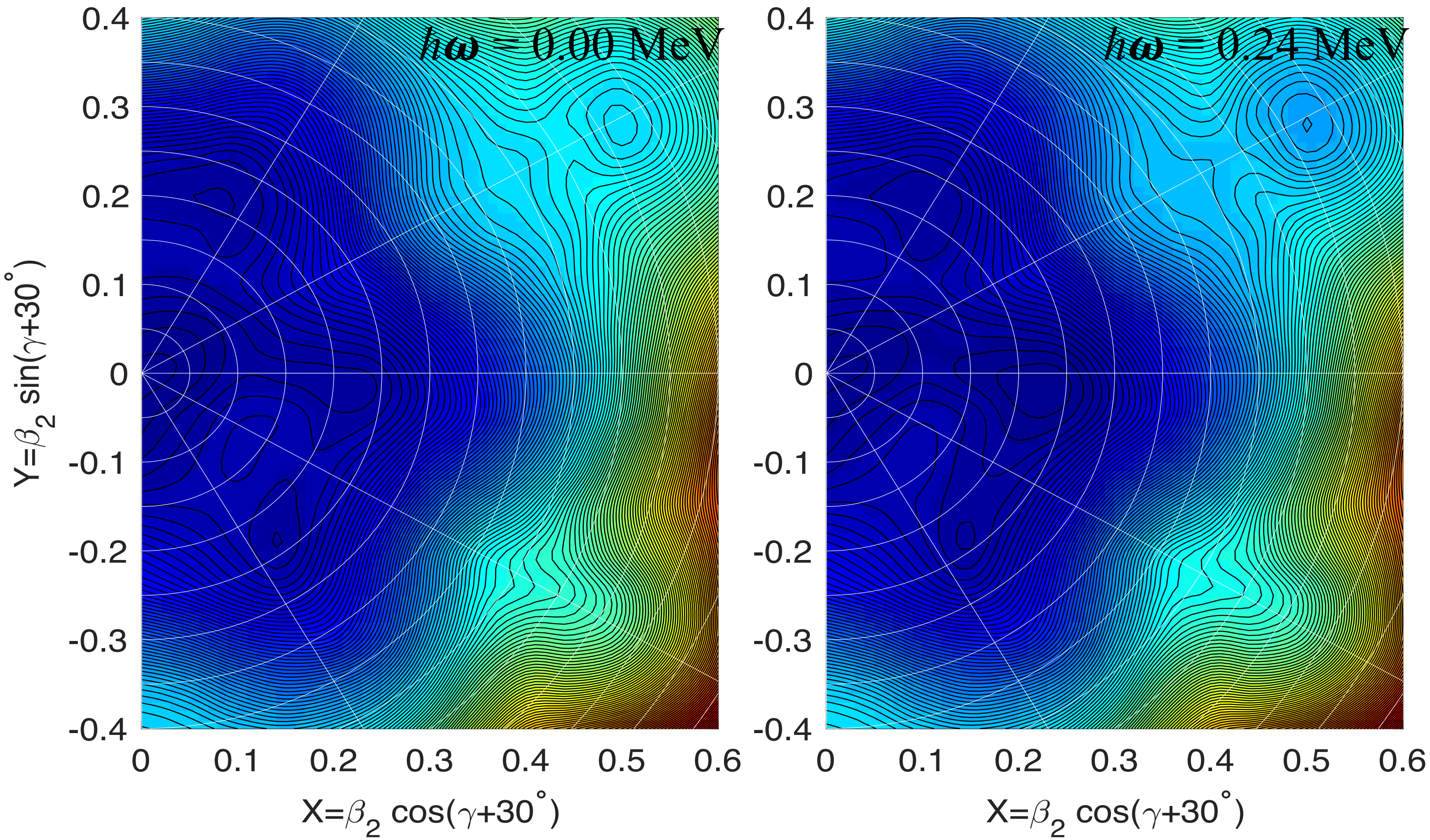
N=44 isotones





B. Cederwall et al, PRL 124 062501 (2020)

Strutinsky-type PES calculations * with standard isovector pairing
(total Routhian surface (TRS) approach)
Note: do not produce deformed ground-state shape
(but pronounced superdeformed minimum appears already at zero rot. frequency!)



* W. Nazarewicz, R. Wyss, A. Johnson, Nuclear Physics A 503(2), 285 (1989)

LSSM predictions for ^{88}Ru with interaction including an explicit pairing term (PMMU)

PMMU: $\mathbf{H = H_o + H_P + H_M + H_m}$:

H_o = s.p, H_P = pairing

H_M = multipole, contains QQ + OO components

H_m = monopole term

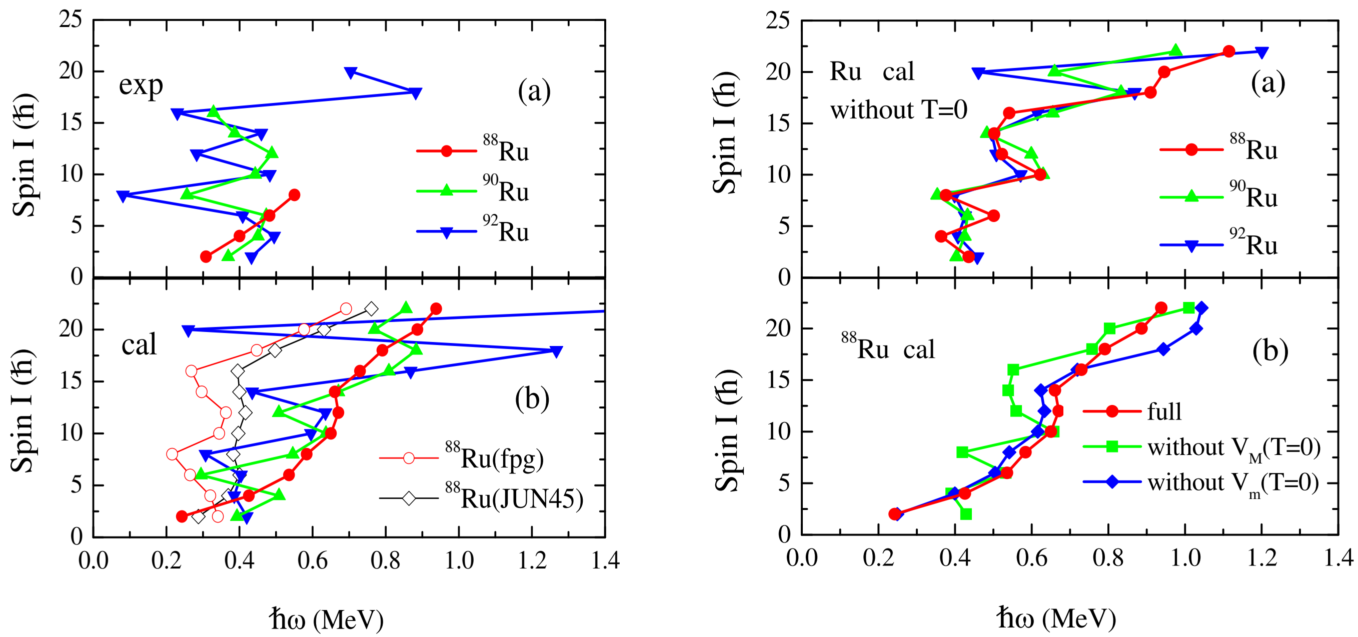
$$H = H_0 + H_P + H_M + H_m^{MU},$$

$$H_0 = \sum_{\alpha} \varepsilon_a c_\alpha^\dagger c_\alpha, \quad H_P = -\sum_{J=0,2} \frac{1}{2} g_J \sum_{M\kappa} P_{JM1\kappa}^\dagger P_{JM1\kappa}$$

$$H_M = -\frac{1}{2}\chi_2 \sum_M : Q_{2M}^\dagger Q_{2M} : -\frac{1}{2}\chi_3 \sum_M : O_{3M}^\dagger O_{3M} :$$

$$H_m^{MU} = \sum_{a \le b, T} V_m^{MU}(ab,T) \sum_{JMK} A_{JMTK}^\dagger(ab) A_{JMTK}(ab),$$

K. Kaneko, T. Mizusaki, Y. Sun, and S. Tazaki, Phys. Rev. C89, 011302(R) (2014)
Kaneko, Sun and de Angelis, Nuclear Physics A957, 144-153 (2017)

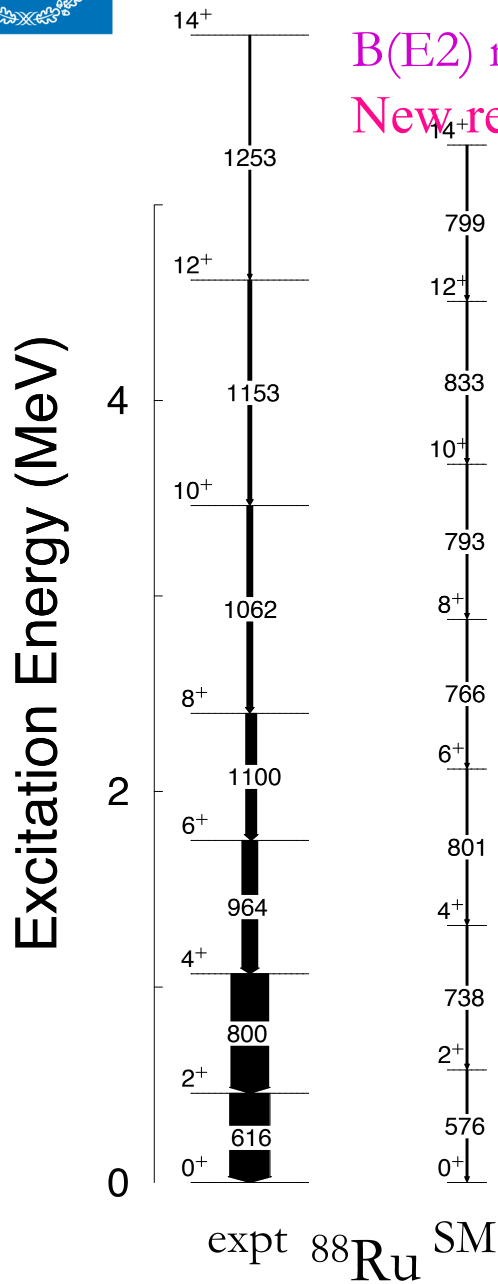


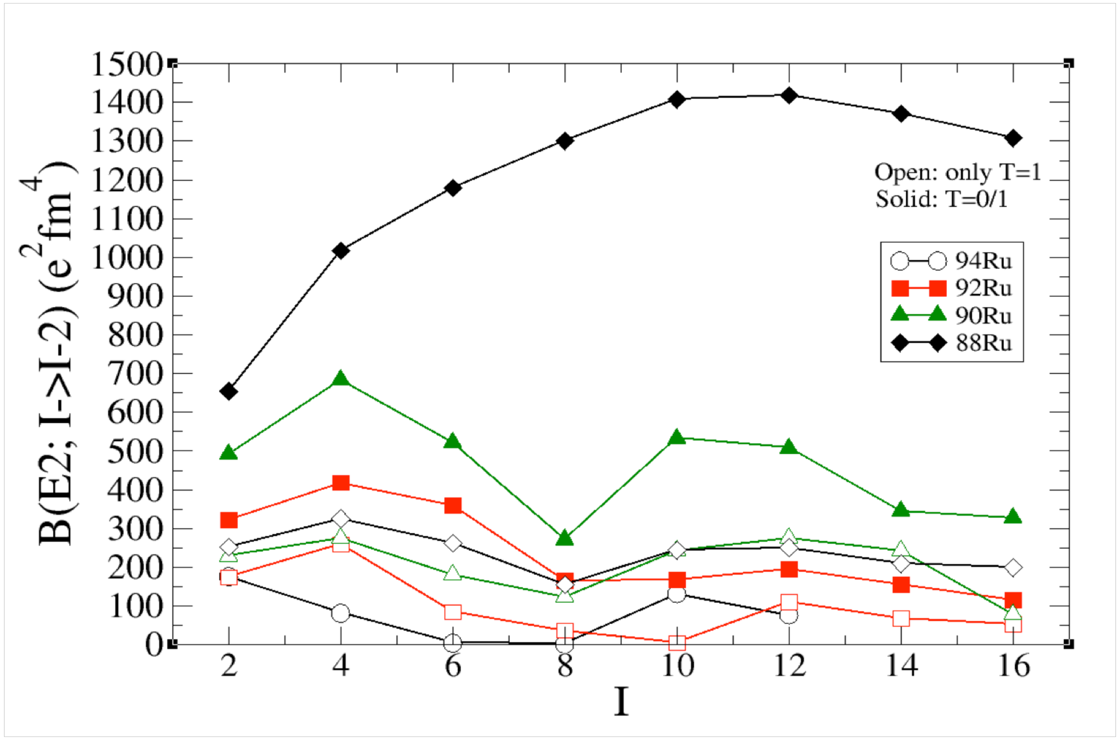
Note: Without the *T = 0 np* pairing, the smooth pattern in ^{88}Ru disappears and it lacks rotational behaviour as for ^{90,92}Ru. **QQ np T=0 is most important in ^{88}Ru.**

LSSM calculations: T=0 correlations drive collectivity

B(E2) measurements are critical

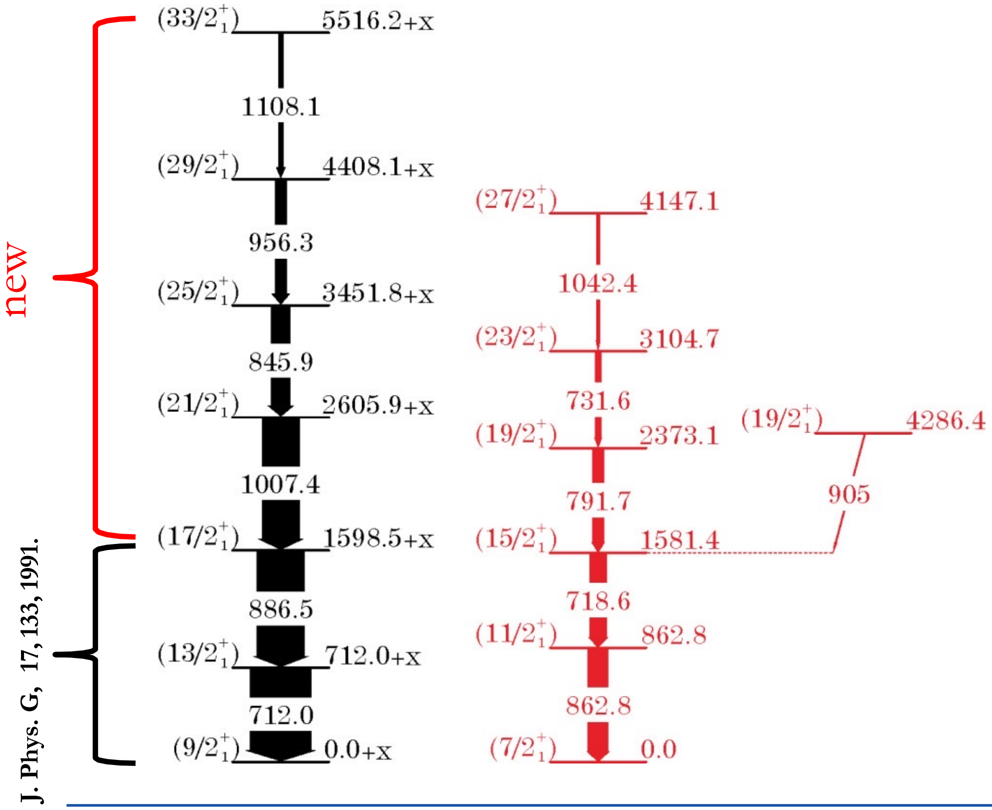
New results from GRETINA@FRIB (M. Bentley et al) , stay tuned!

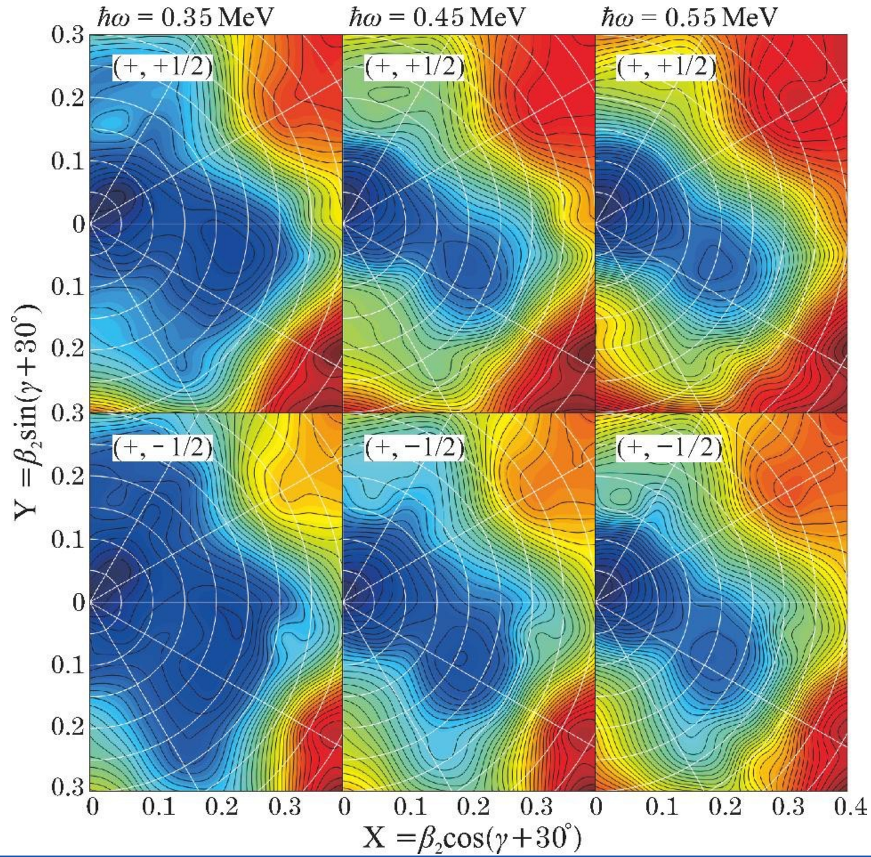




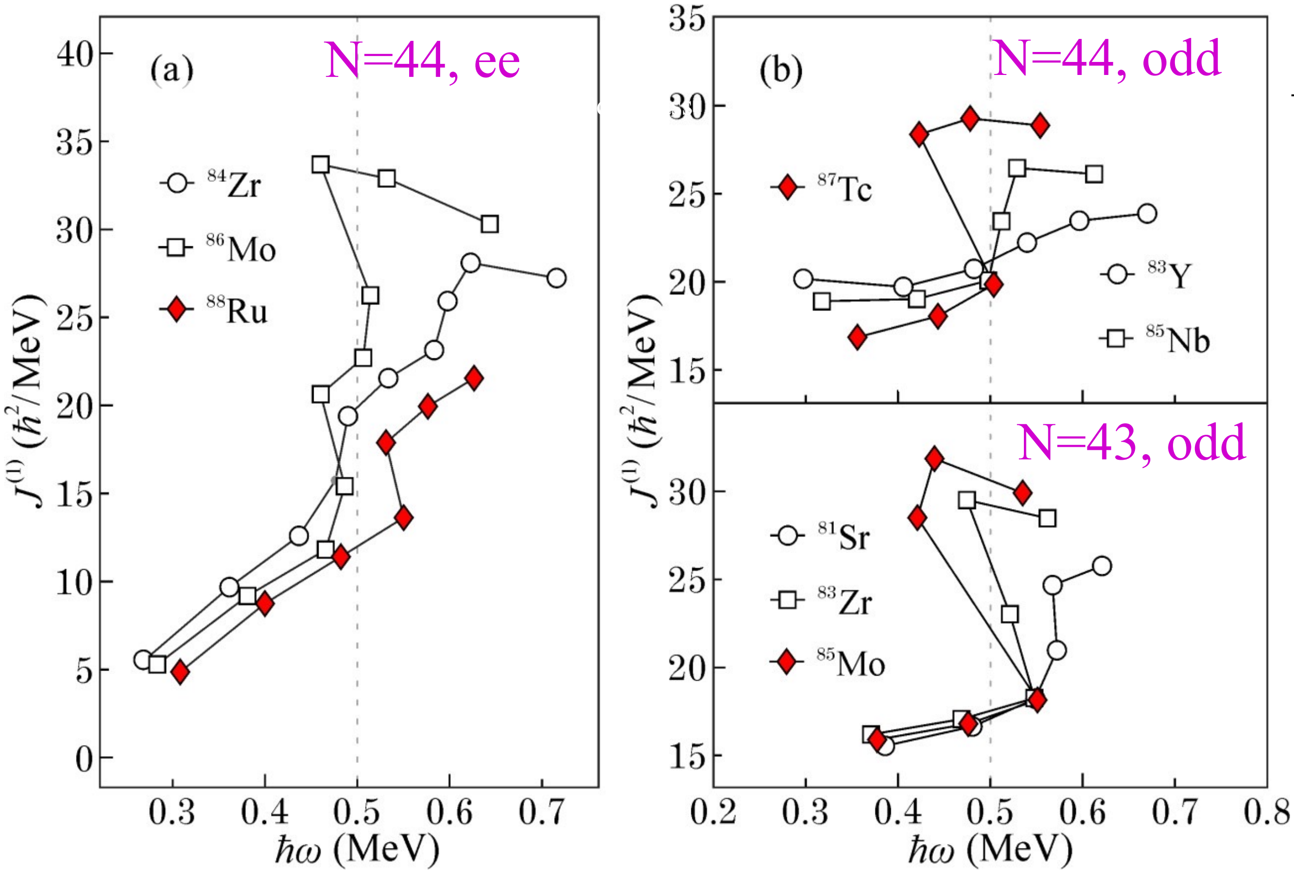
Calculated B(E2;I→I-2) values as a function of angular momentum in $^{88-94}$Ru. The calculations have been performed in the fpg space with the JUN45 interaction using standard effective charges. The theoretical calculations for the spectra of ^{88,90,92}Ru include, in addition to full neutron-proton interactions (solid symbols), also results for pure T=1 neutron-proton (open symbols) interactions. C. Qi et al.

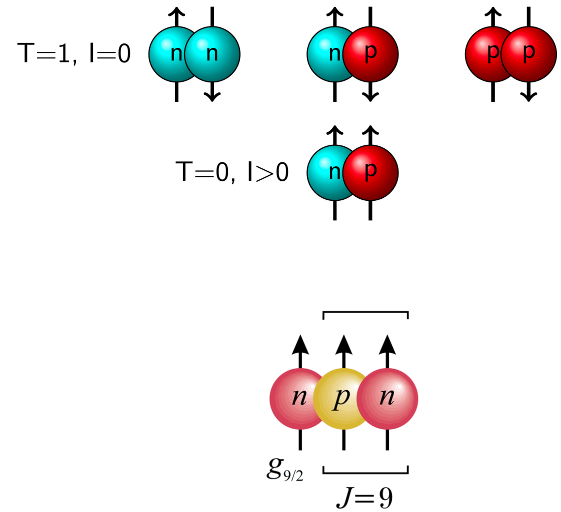
Extension of the ground state ($\pi g_{9/2}$) band and new oblate band in the T_Z=1/2 nucleus ^{87}Tc





Pairing isospin modes in deformed N~Z nuclei at intermediate angular momentum – odd-even vs even-even

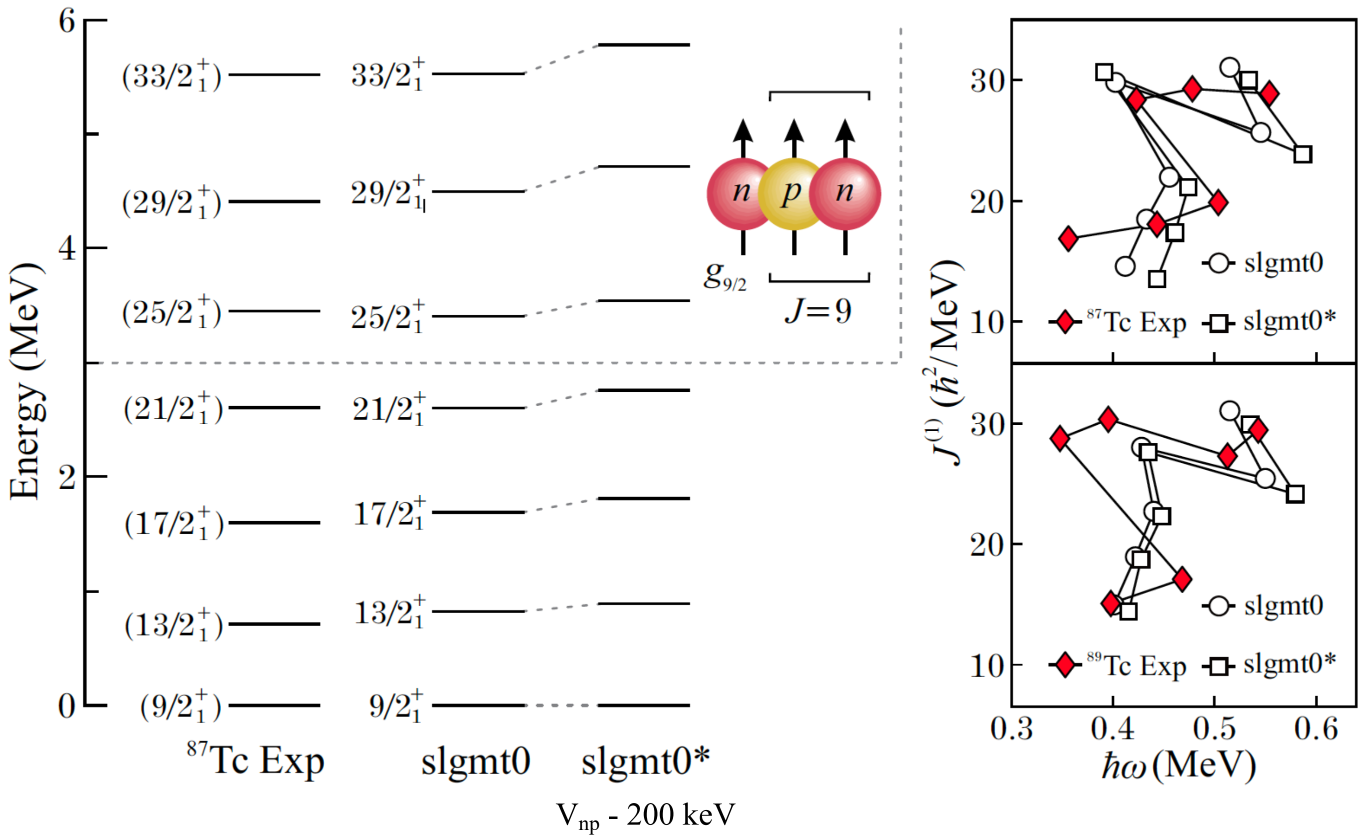




B. Cederwall et al, PRL 124 062501 (2020)

X. Liu et al, PRC 104 L021302 (2021)

Shell model calculation for ^{87}Tc (T_Z=1/2) – effect of spin-aligned np pairs (V_{np})



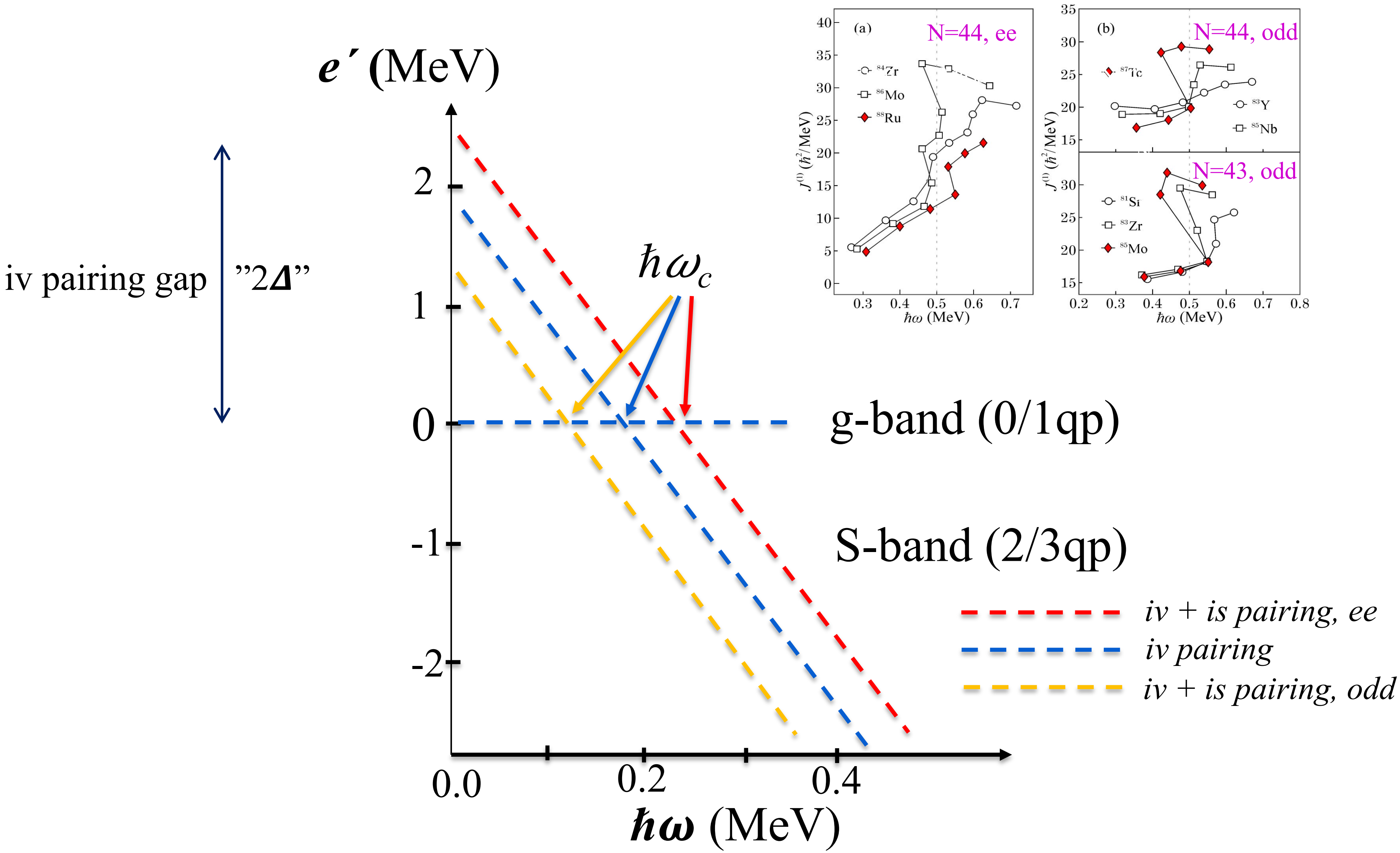
X. Liu et al, PRC 104 L021302 (2021)
F. J. D. Serduke, R. D. Lawson, and D. H. Gloeckner, Nucl. Phys. A 256, 45 (1976)

Odd-mass N~Z (T_Z=1/2) nuclei:

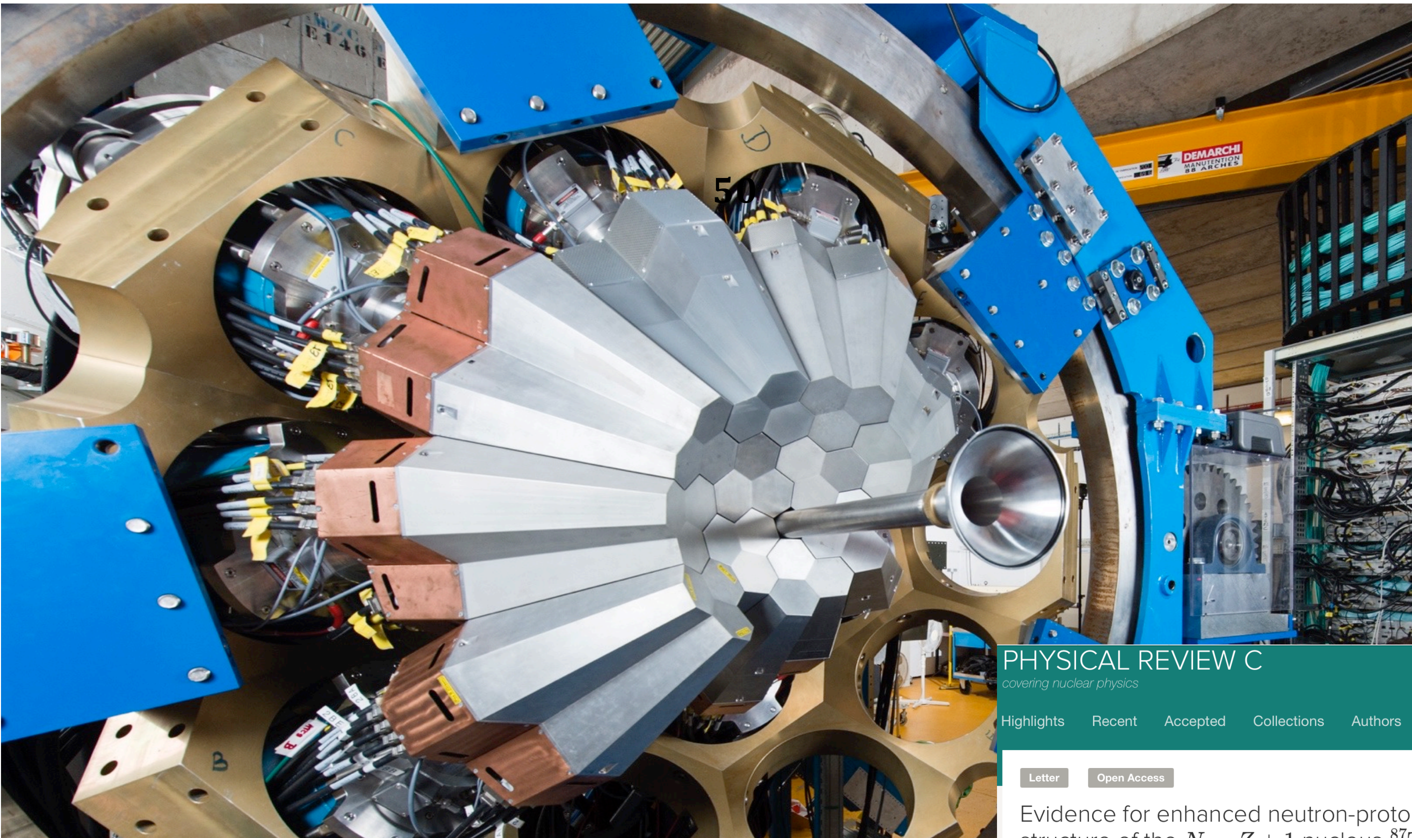
- Odd valence particle contributes constructively to isoscalr np pairing correlations ”spin-dependent effective 3-N” interaction as opposed to ”blocking” effect in pure isovector case?
- Increase of structural difference between 1qp and 3qp configuration reduces interaction strength in the band crossing?

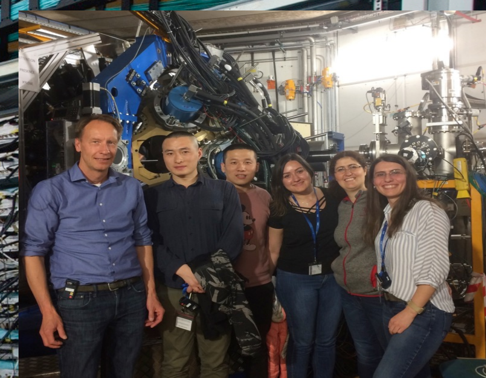
Influence of pairing isospin modes in deformed N~Z – odd-A vs even-even cases (naïve picture)

$$h' = h_0 + h_{pair} - \omega j_x$$



Experiment





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Evidence for enhanced neutron-proton correlations from the level structure of the $N = Z + 1$ nucleus $^{87}_{43}\mathrm{Tc}_{44}$

X. Liu *et al.*
Phys. Rev. C **104**, L021302 – Published 20 August 2021

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Accepted Paper

Isospin properties of nuclear pair correlations from the level structure of the self-conjugate nucleus ^{88}Ru

Phys. Rev. Lett.

B. Cederwall et al.

Accepted 18 December 2019

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Evidence for spherical-oblate shape coexistence in $^{87}\mathrm{Tc}$

X. Liu *et al.*
Phys. Rev. C **106**, 034304 – Published 9 September 2022

Summary

- Intermediate-angular momentum states in the heaviest deformed N~Z nuclei ^{88}Ru and ^{87}Tc have been observed with AGATA + ancillary detectors (NEDA/NWALL, DIAMANT)

- In ^{88}Ru, the rotational frequency for the configuration change between the ground-state and qp-aligned structures indicates a "delay" wrt standard calculations and expt data in neighboring Tz=1 isotones, in agreement with theoretical predictions for enhanced isoscalar np correlations.

- For, the $T_Z=1/2$ isotone, ^{87}Tc, we observe an earlier band crossing frequency compared with the neighboring N=44 and N=43 odd-mass nuclei for the yrast band built on the $\pi g_{9/2}$ ground state

- ∴ IV band crossing frequencies show opposite behavior as $T_Z \to 0$ for ee and oe systems
  - a new signature for enhanced IS pair correlations in these N~Z systems?

Thanks to AGATA collaboration, GANIL, NEDA, DIAMANT teams!

Thank You

Backup

PHYSICAL REVIEW C **69**, 034317 (2004)

Transition from the seniority regime to collective motion

J. J. Ressler,[1] R. F. Casten,[1] N. V. Zamfir,[1] C. W. Beausang,[1] R B. Cakirli,[1,2] H. Ai,[1] H. Amro,[1] M. A. Caprio,[1] A. A. Hecht,[1] A. Heinz,[1] S. D. Langdown,[1,3] E. A. McCutchan,[1] D. A. Meyer,[1] C. Plettner,[1] P. H. Regan,[1,3] M. J. S. Sciacchitano,[1] and A. D. Yamamoto[1,3]

[1]*Wright Nuclear Structure Laboratory, Yale University, New Haven, Connecticut 06520-8124, USA*

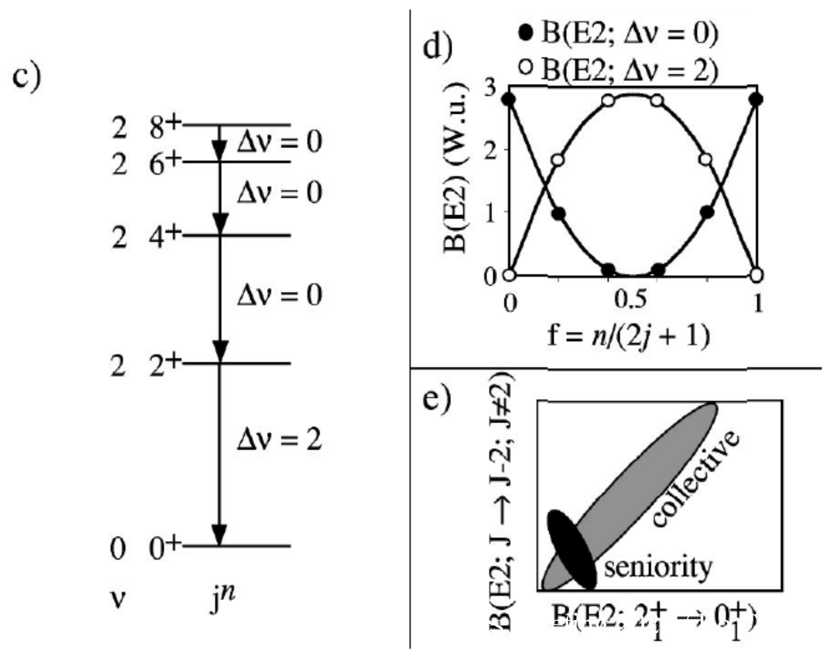
[2]*Istanbul University, 34459 Vezneciler-Istanbul, Turkey*

[3]*University of Surrey, Guilford, Surrey GU2 7XH, United Kingdom*

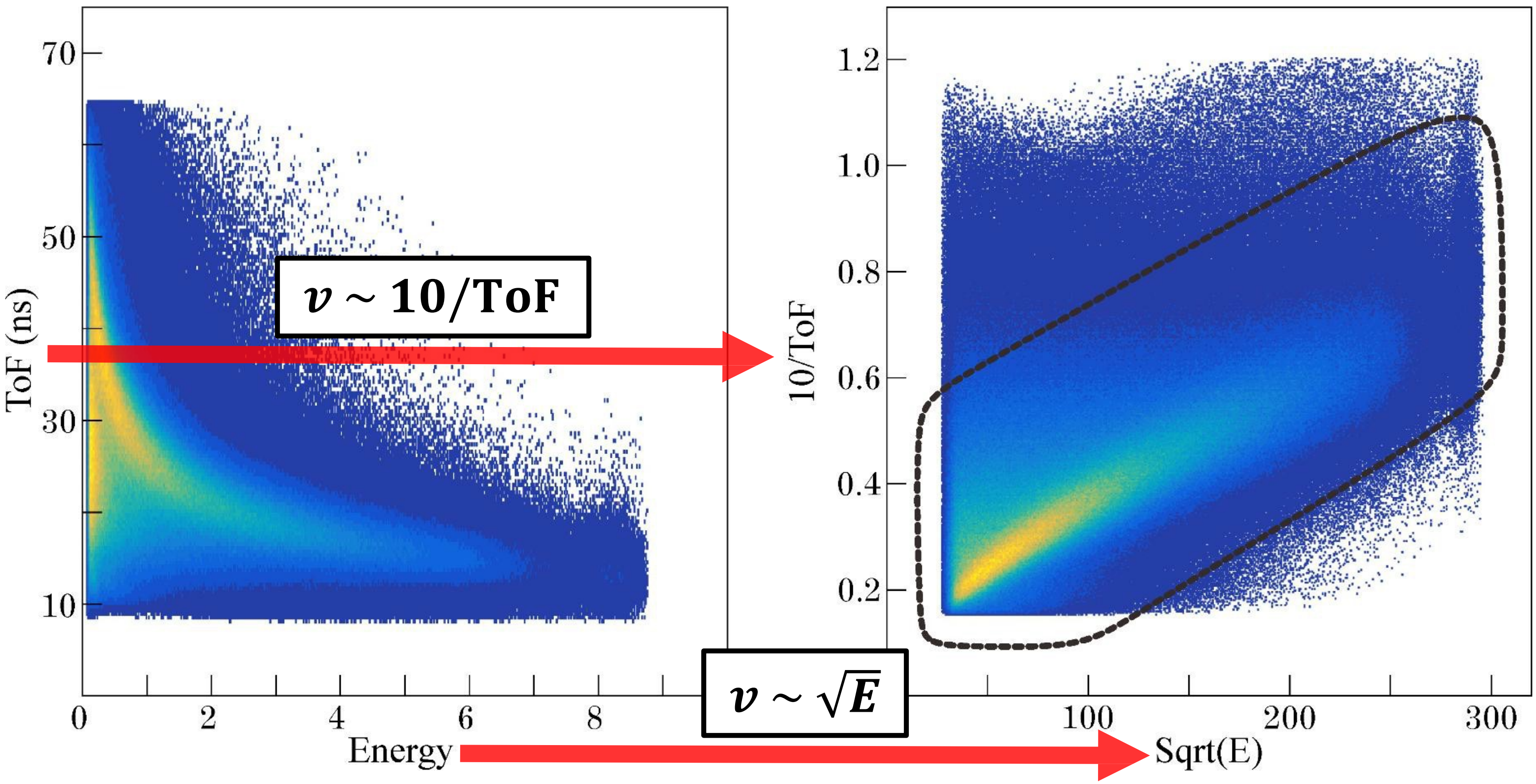
(Received 17 September 2003; published 15 March 2004)

$B(E2)$ values from isomeric states near closed shells are discussed in the context of the behavior of seniority conserving transitions induced by even tensor operators. This result provides a signature for the transition from the seniority regime to collective motion that can be of use in identifying shell structure in exotic nuclei.

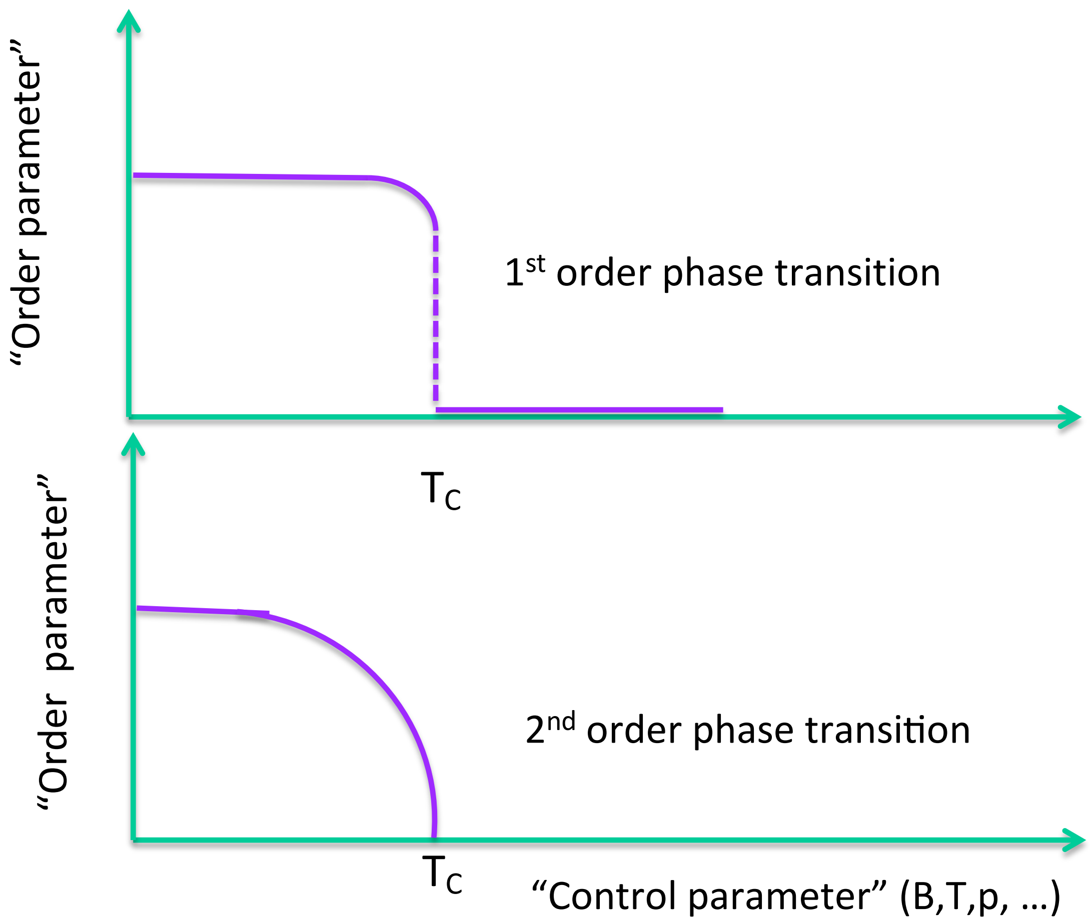
DOI: 10.1103/PhysRevC.69.034317 PACS number(s): 21.10.Pc, 21.60.Cs, 23.20.Lv, 27.80.+w

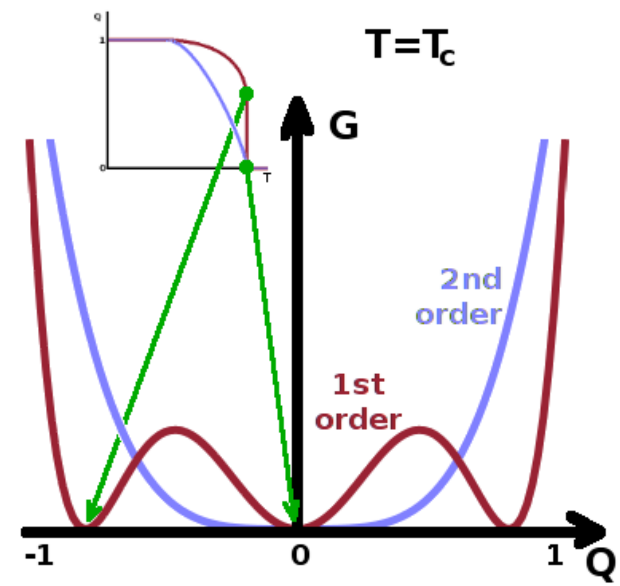


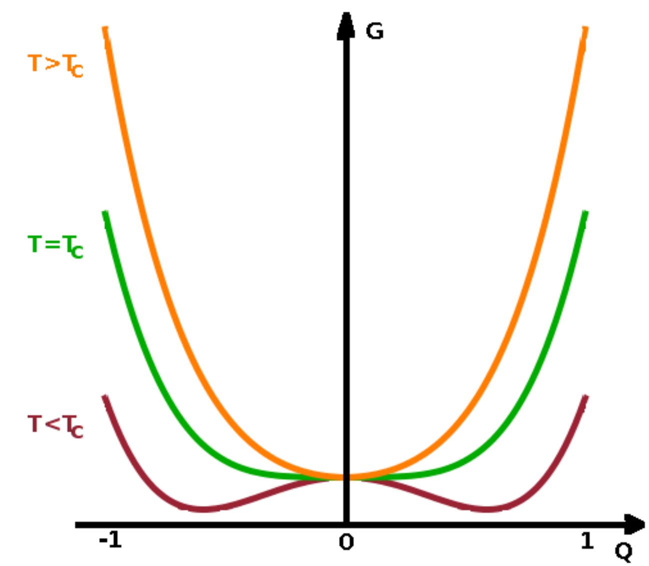
NEDA
energy vs TOF



Ginzburg-Landau theory

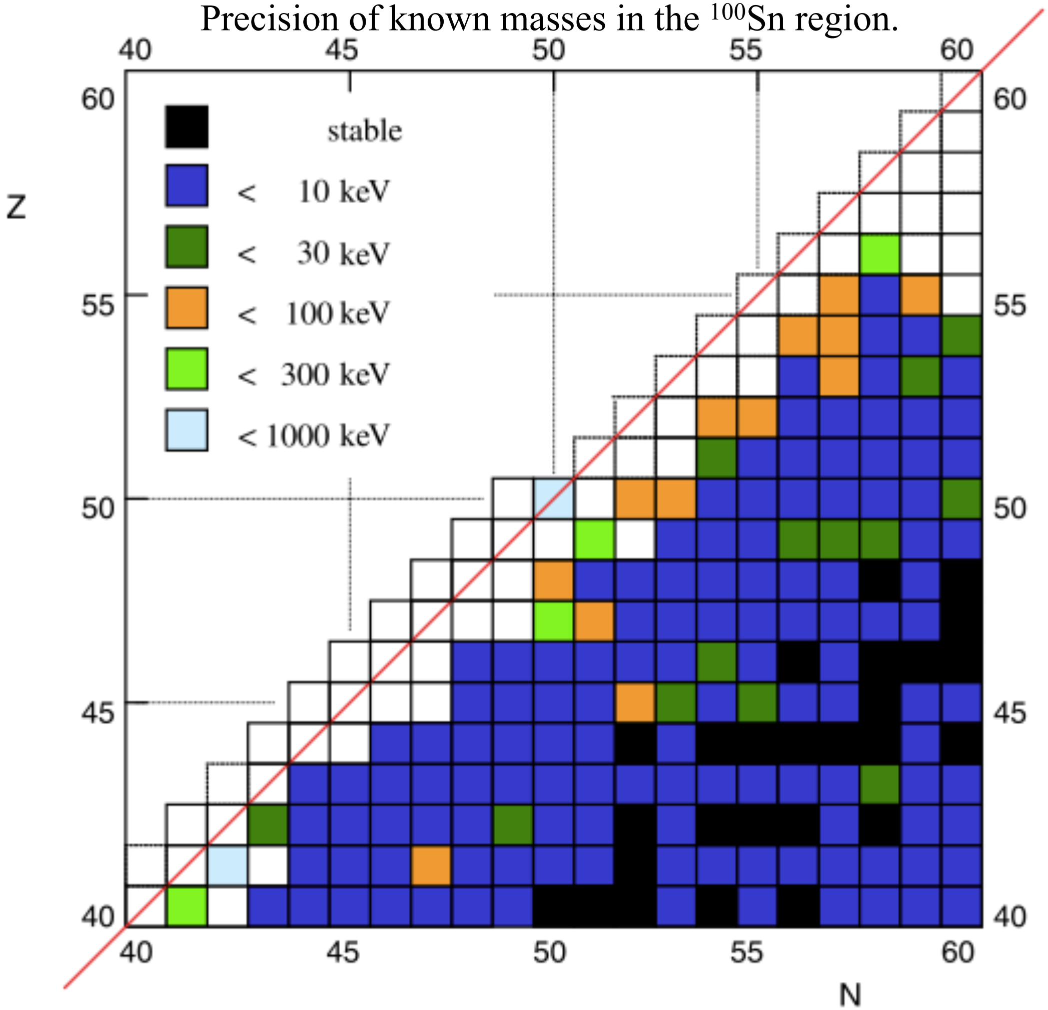






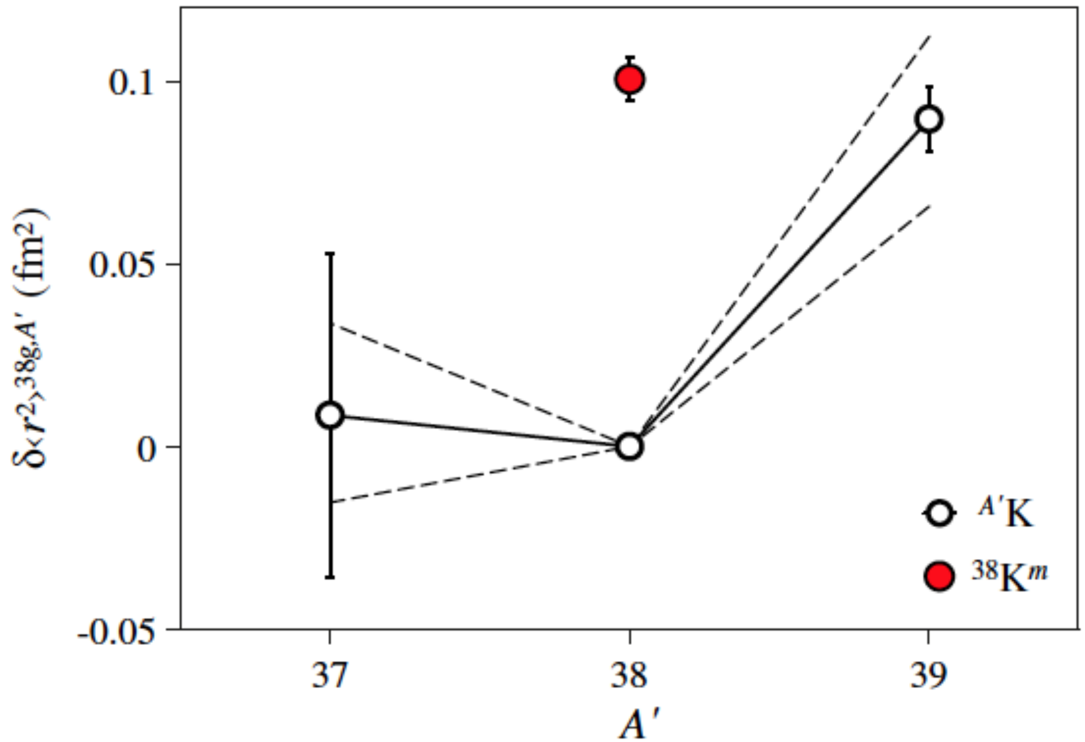
Note:
Atomic nuclei are finite systems!
Control parameter is discrete (particle number, excitation energy etc)
Two different coexisting fgermionic systems (neutrons and protons)

Precision of known masses in the ^{100}Sn region.



T. Faestermann, M. Górska, and H. Grawe, Prog. Part. Nucl.Phys. 69, 85 (2013)

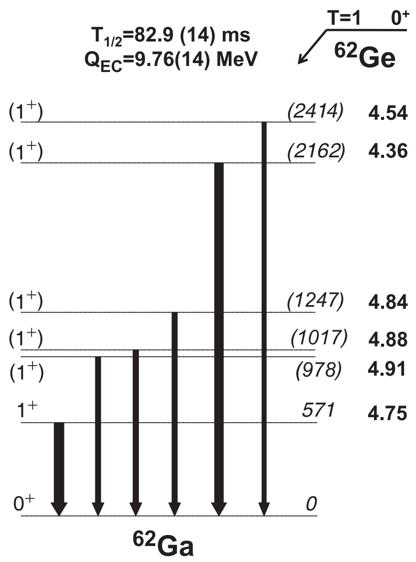
Evidence for *isovector* np pairing from nuclear charge radius



“Proton-Neutron Pairing Correlations in the Self-Conjugate Nucleus ^{38}K Probed via a Direct Measurement of the Isomer Shift”

M.L. Bissell et al., PRL 113, 052502 (2014)

GT (beta decay) strengths



"Hindered Gamow-Teller Decay to the Odd-Odd N = Z ^{62}Ga: Absence of Proton-Neutron T=0 Condensate in A = 62",
E. Grodner et al., PRL 113, 092501 (2014)

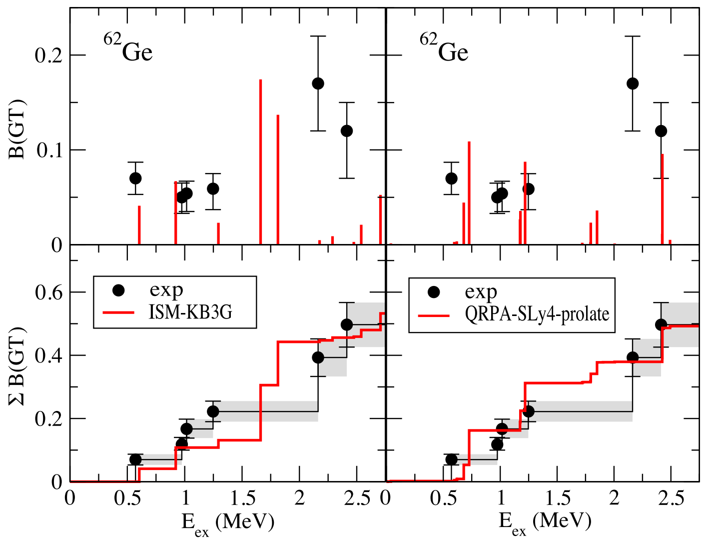
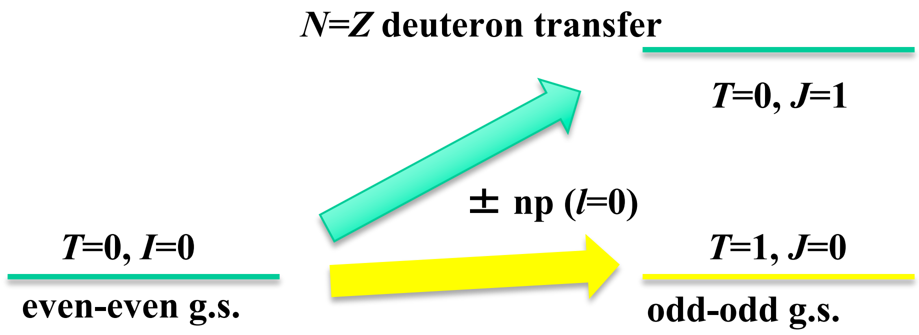


FIG. 4 (color online). Experimental (black) and calculated (red) single level $B(\mathrm{GT})$ and accumulated $B(\mathrm{GT})$ values for the ^{62}Ge to ^{62}Ga β decay. Left panels use the ISM approach using the KB3G interaction and right panels use the QRPA approach using the SLy4 interaction. Experimental uncertainty corridors are indicated in gray.

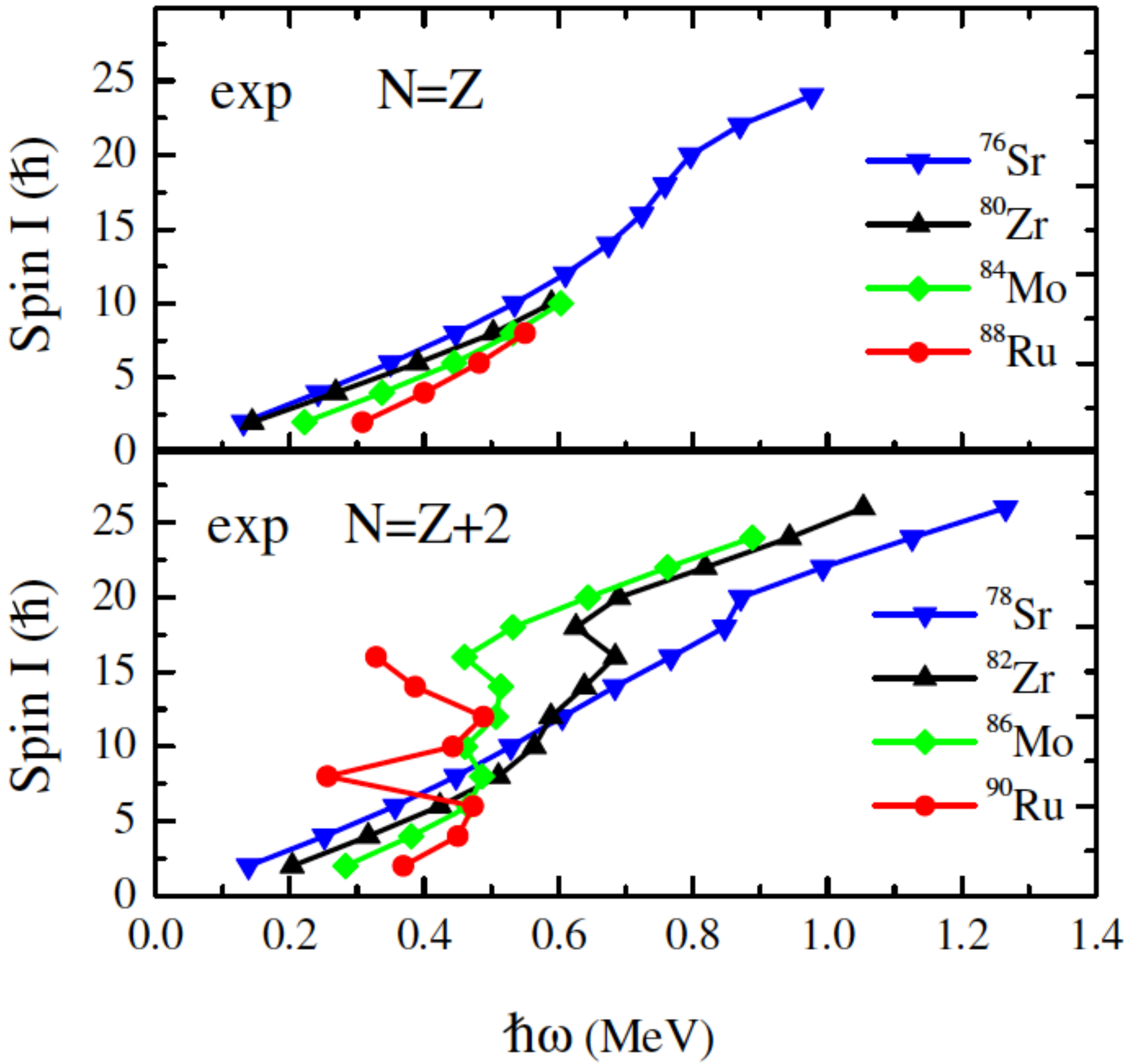
"Search for a new kind of superfluidity built on collective proton-neutron pairs with aligned spin is performed studying the Gamow-Teller decay of the T =1, $J^{\pi} = 0^{+}$ ground state of ^{62}Ge into excited states of the odd-odd N = Z nucleus 62 Ga. Individual Gamow-Teller transition strengths agree well with theoretical predictions of the interacting shell model and the quasiparticle random phase approximation. <u>The absence of any sizable low-lying Gamow-Teller strength in the reported beta-decay experiment supports the hypothesis of a negligible role of coherent T = 0 proton-neutron correlations in ^{62}Ga</u>. "

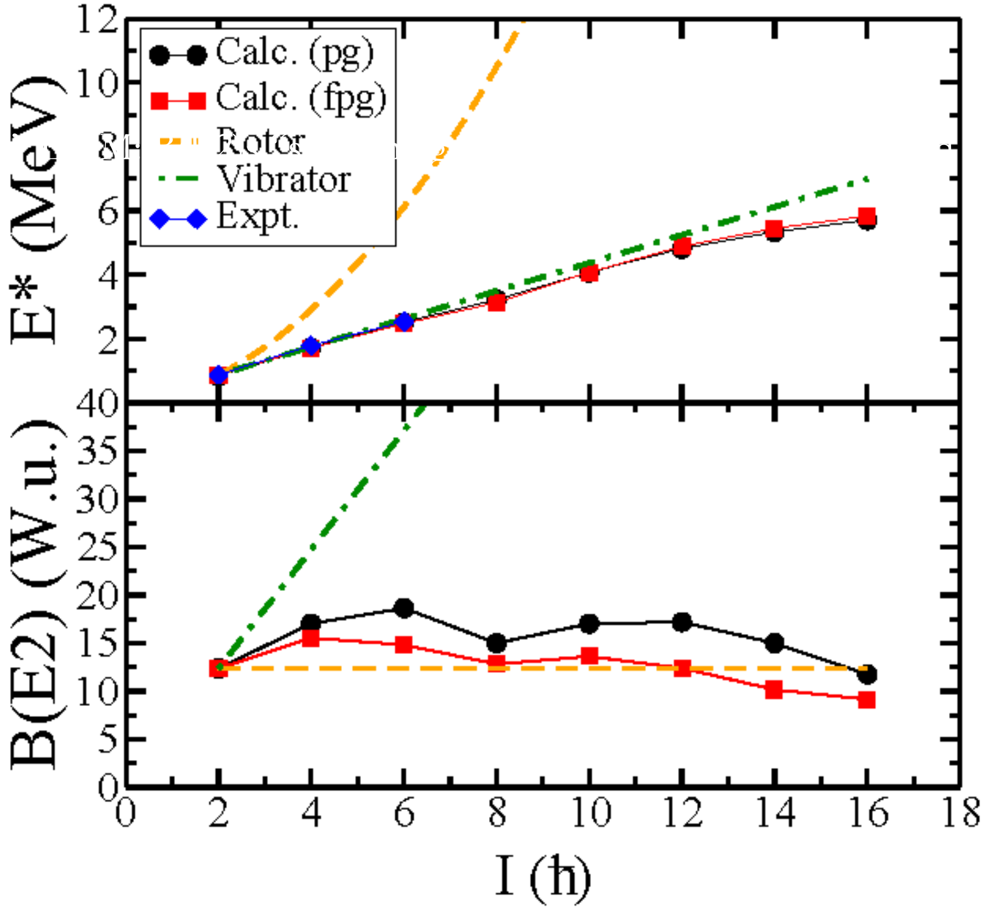


ISSUES:

1) Need for (reaction) theory to develop clear predictions
2) Will be many years before intense beams of ^{80}Zr, ^{84}Mo, ^{88}Ru, ^{92}Pd etc are available for such studies
3) Only probes ground-state or low-spin correlations

Experimental systematics I vs ω

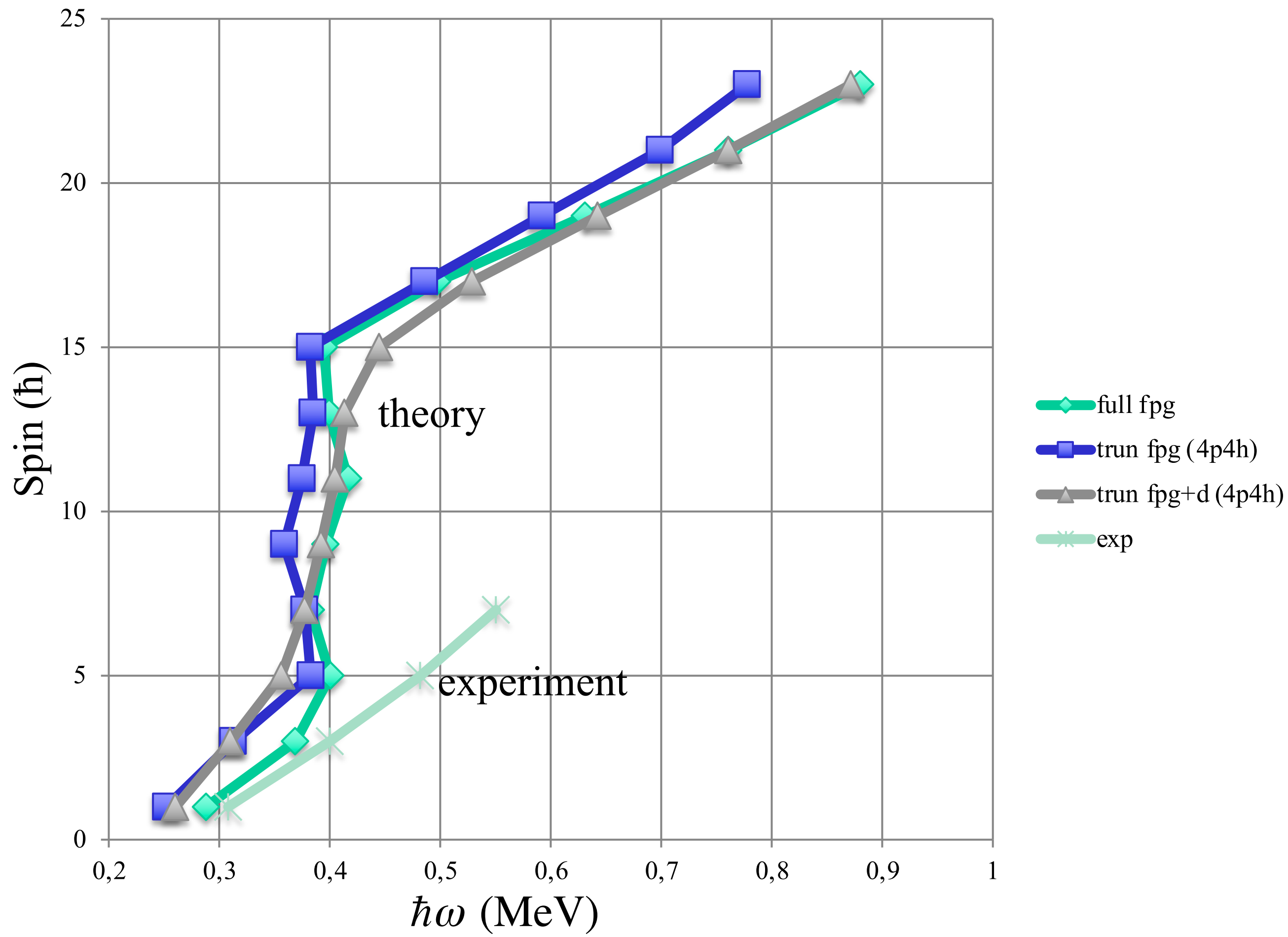




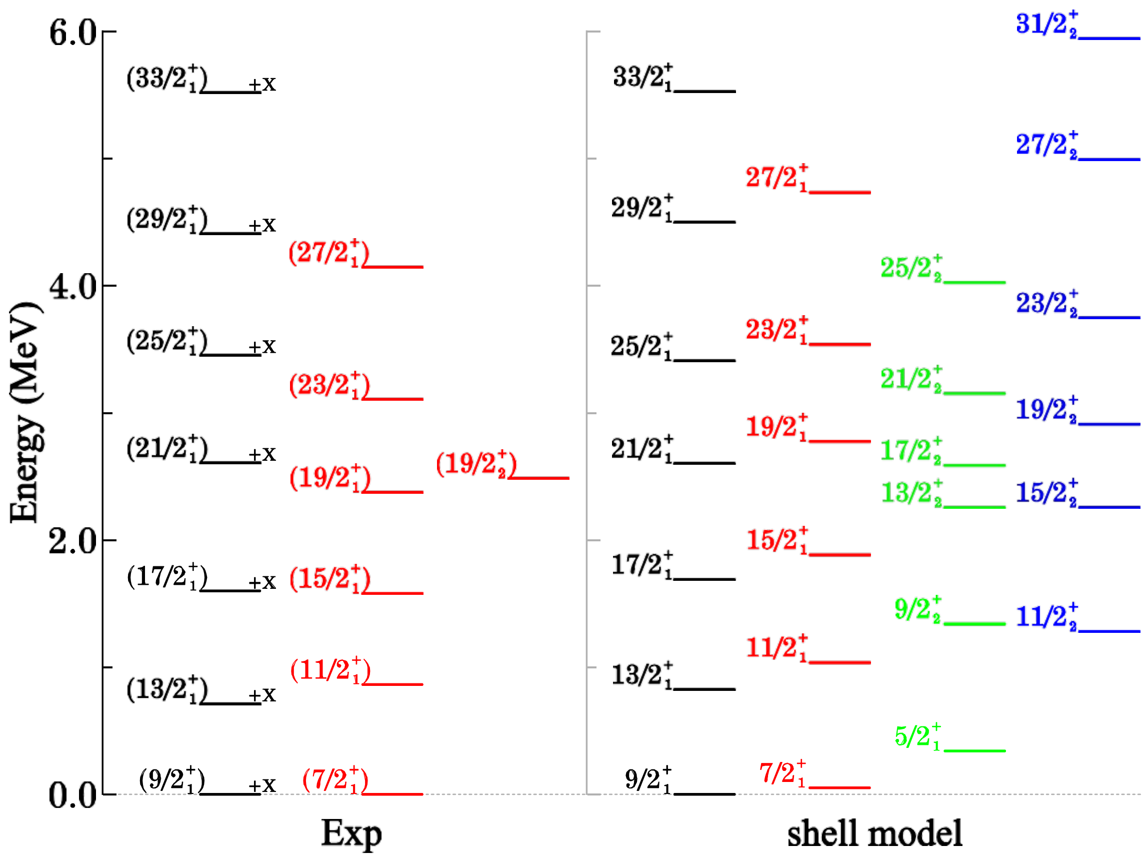
Upper: Shell model spectra of ^{92}Pd
calculated within the $1p_{3/2}0f_{5/2}1p_{1/2}0g_{9/2}$ space [10] (fpg) and the $1p_{1/2}0g_{9/2}$ space (pg).
Lower: B(E2; $I \rightarrow I-2$) values in ^{92}Pd calculated within the fpg and pg spaces. The two dashed lines show the predictions of the geometric collective model normalized to the 2^+_1 state
C.Qi, J.Blomqvist, T.Bäck, B. Cederwall, A. Johnson, R. J. Liotta, and R. Wyss,
PRC 84, 021301(R) (2011)

Predictions for ^{88}Ru

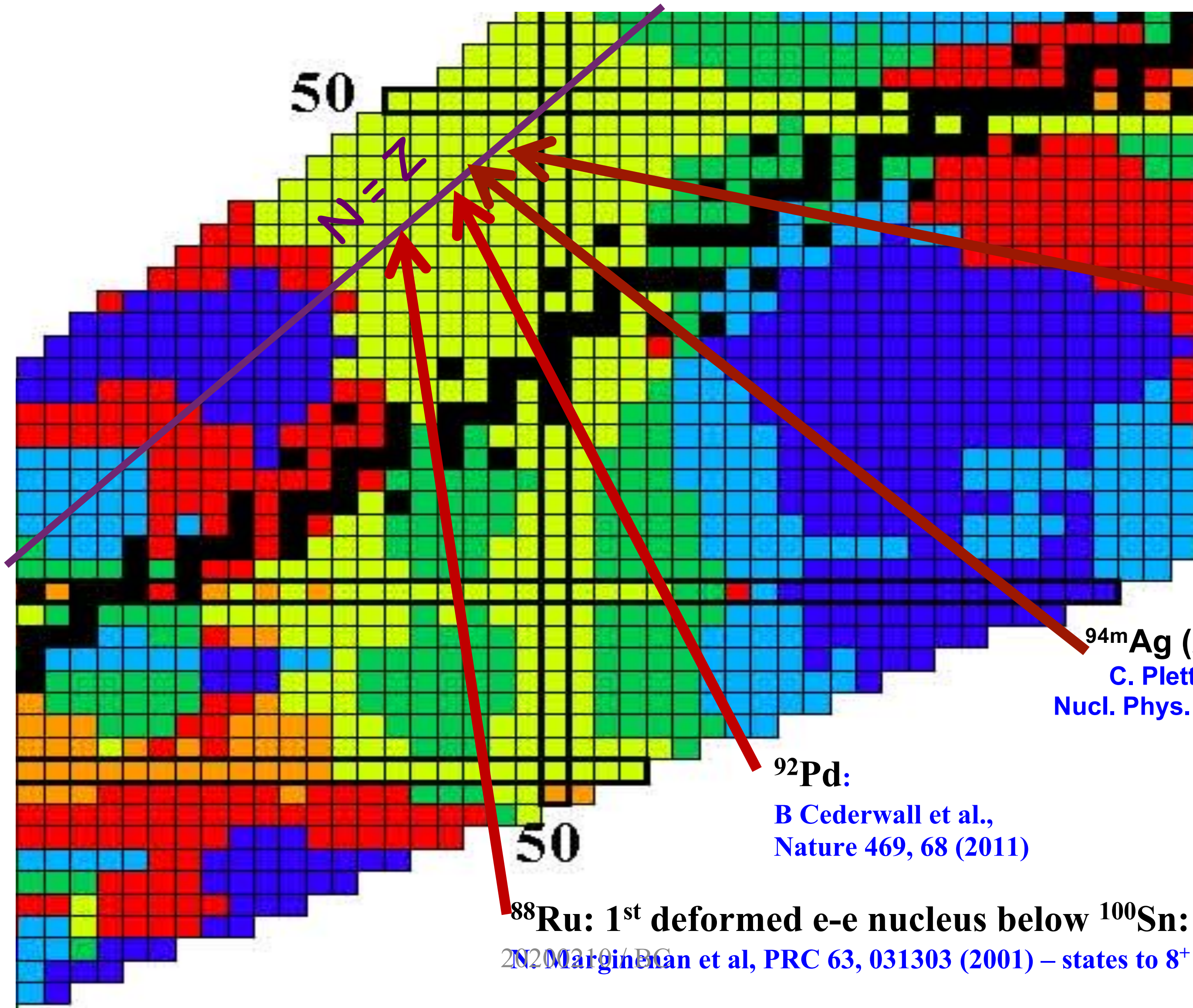
"Standard" SM calculations* for ^{88}Ru predict similar "alignment" of angular momentum



SM calculations for ^{87}Tc



As yet there is no data that definitively supports the presence of T=0 np BCS type pairing condensate, but clear evidence for influence of T=0 np interaction in spherical nuclei.



^{96m}Cd (16^{+})

B S Nara Singh et al., PRL 107, 172501 (2011)

P.J. Davies et al IoP talk + to be Published (2016)

^{94m}Ag (21^{+})

C. Plettner et al. Nucl. Phys. A733, 20 (2004)

^{92}Pd:

B Cederwall et al., Nature 469, 68 (2011)

^{88}Ru: 1st deformed e-e nucleus below ^{100}Sn:

N. Marginean et al, PRC 63, 031303 (2001) – states to 8^{+}