# *Signatures for proton-neutron pairs in $N \approx Z$ nuclei*

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Review

# Overview of neutron–proton pairing

CrossMark

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# Resume

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## Proton-neutron pairing and alpha-like quartet correlations in nuclei

From Monday, 19 September, 2016 - 09:00 to Friday, 23 September, 2016 - 13:00

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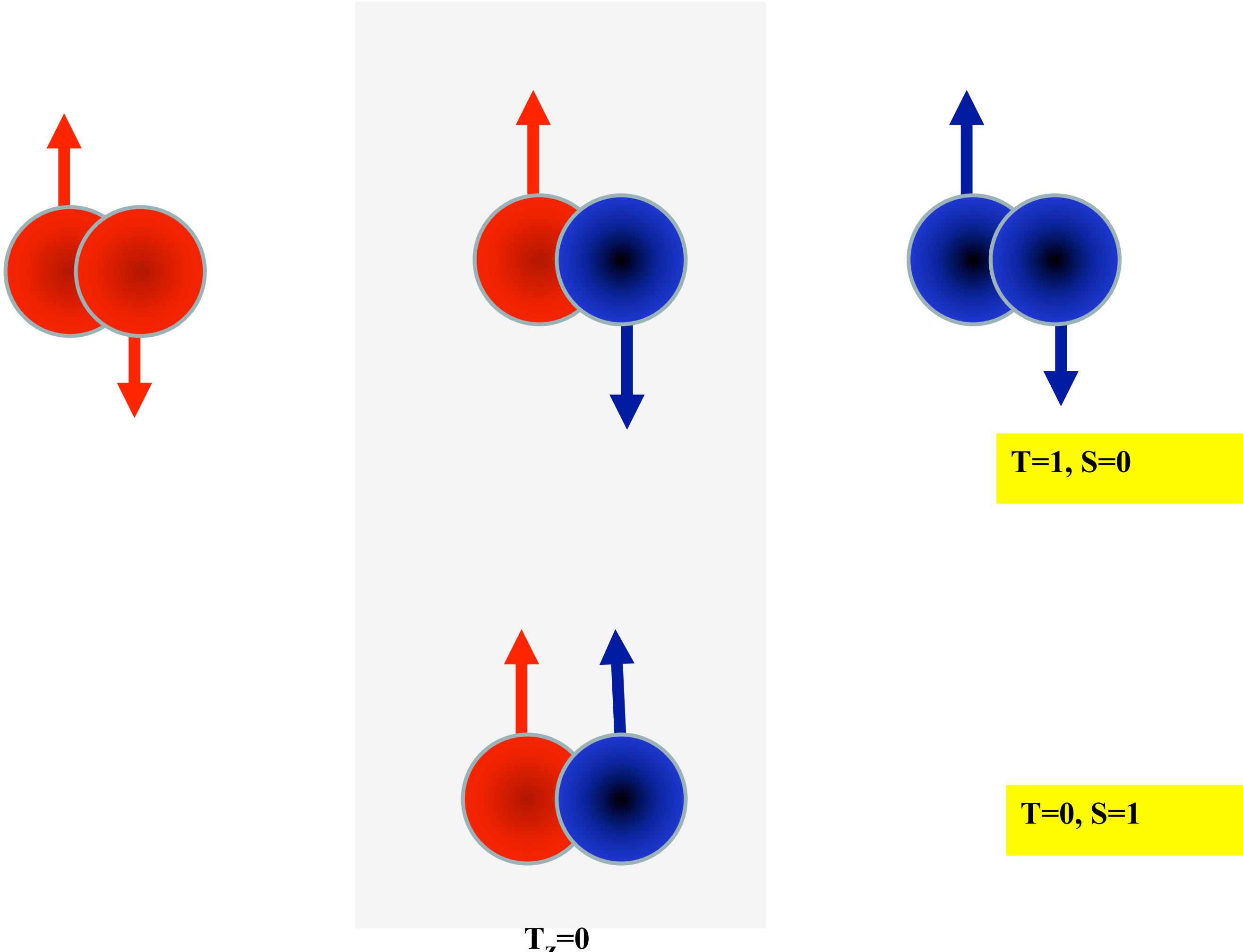



The interaction in both channels is about $v_{01}=1.5v_{10}$.

Proton-neutron pairing for N≈Z.

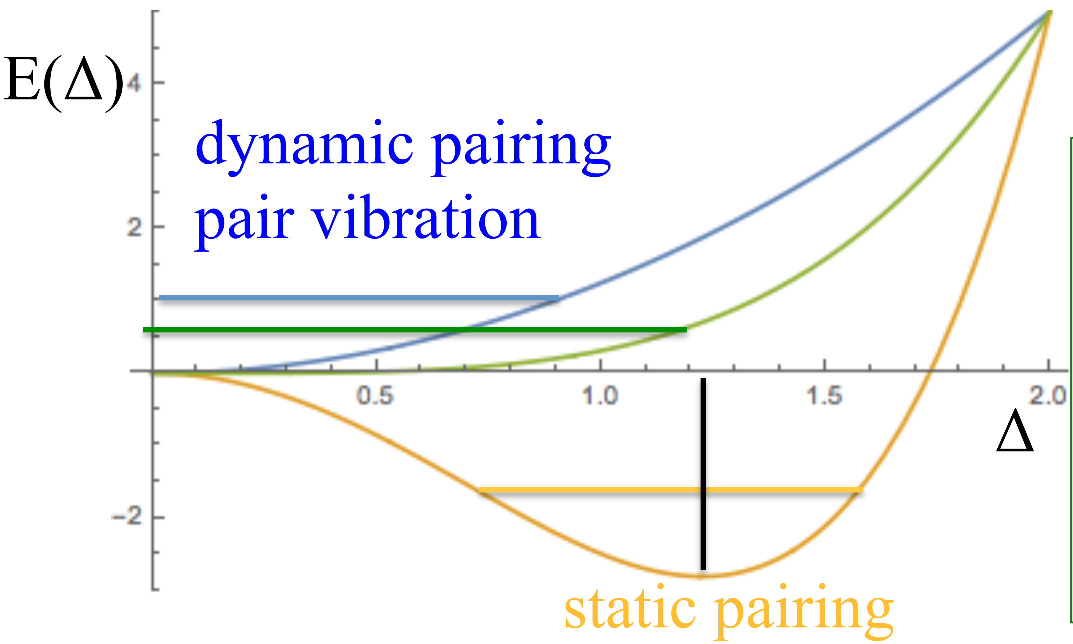
Which channel? $^2H$ has $^3S_1$ ground state

“Pairing” : presence of many correlated pairs of the same type

Analogy: pair condensate of infinite systems

Difference: strong fluctuations of the condensate parameter Δ.

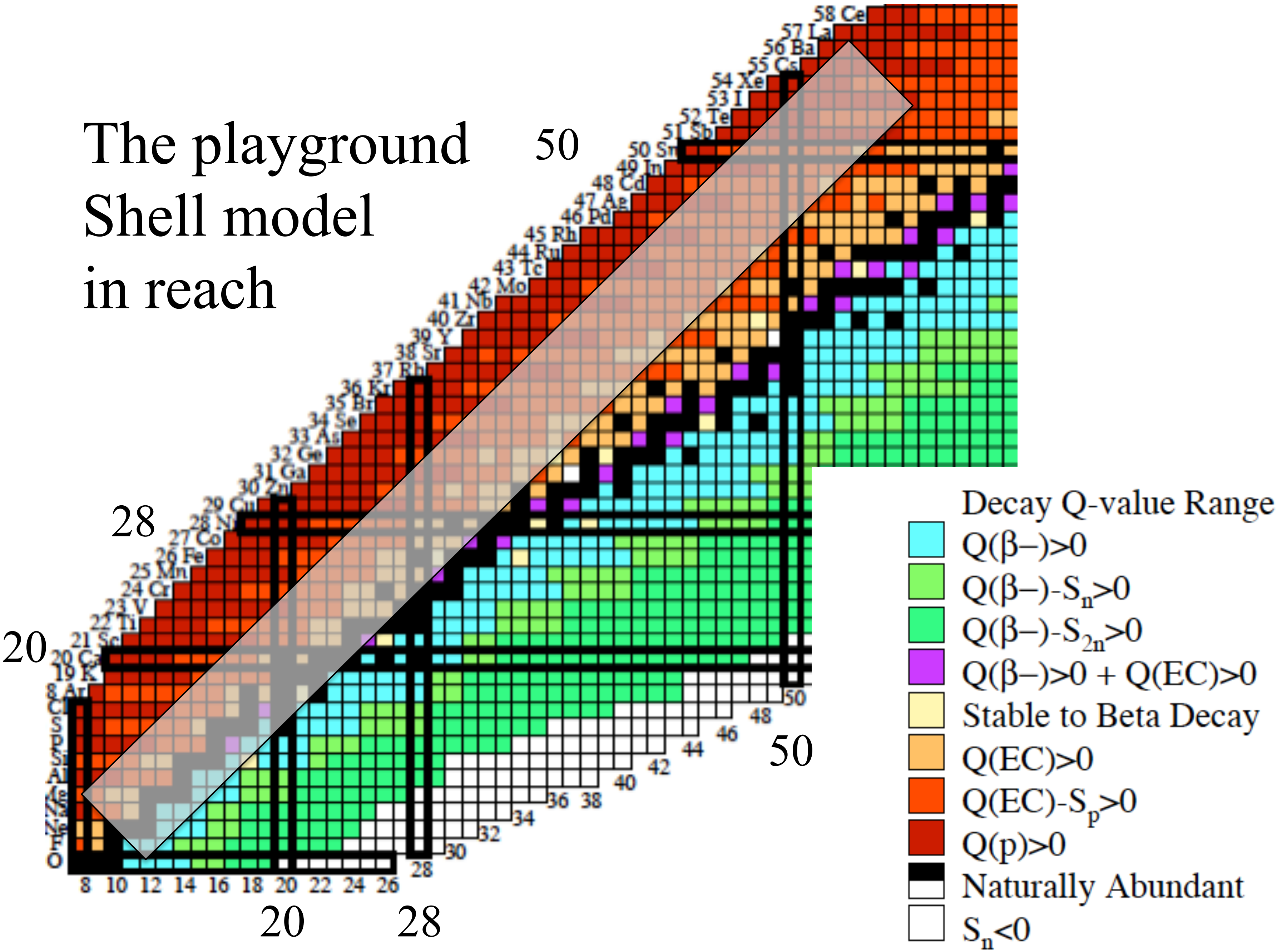
instead of phase transition smooth cross-over

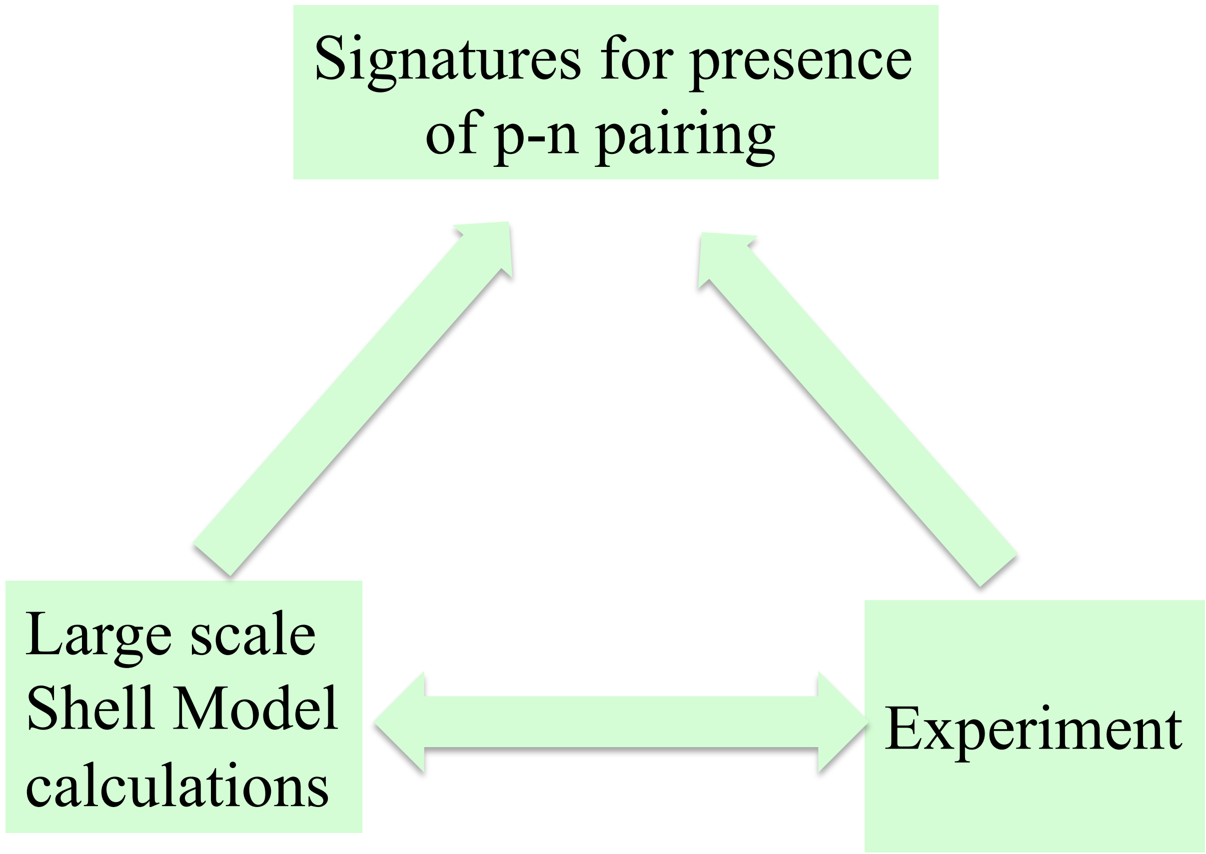



HFB->static equilibrium
QRPA->harmonic oscillations
Problem: critical regime
Shell model describes the crossover, ruler for correlation strength needed

mean field value “condensate”+pairing vibrations

The playground
Shell model
in reach





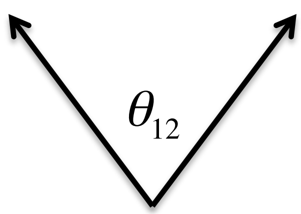

Which are suitable indicators of the correlations?

- Spin orbit vs. short range attraction: What can be qualitatively be expected?
- Mean field predictions
- Mean field signals:

  symmetry breaking and pair- and iso-rotational bands

  quasiparticle spectra
- Experimental binding energies and odd-odd spectra
- Rotation
- Shell model calculations: mean field signatures, pair correlation measures
- Pair transfer, β-decay, charge exchange reactions
- Quarteting vs. pairing

# Effective pn - interaction in j-j coupling.



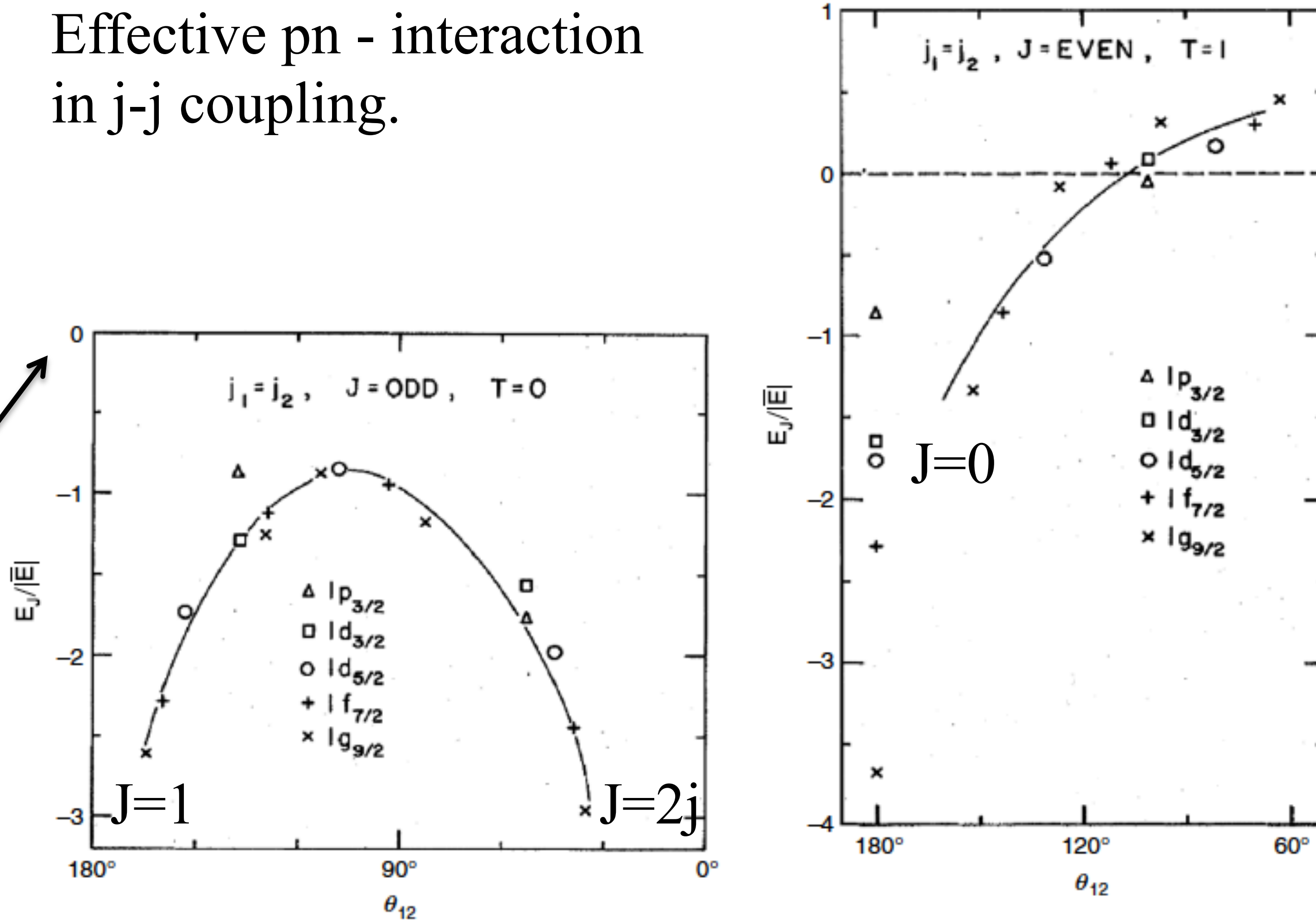
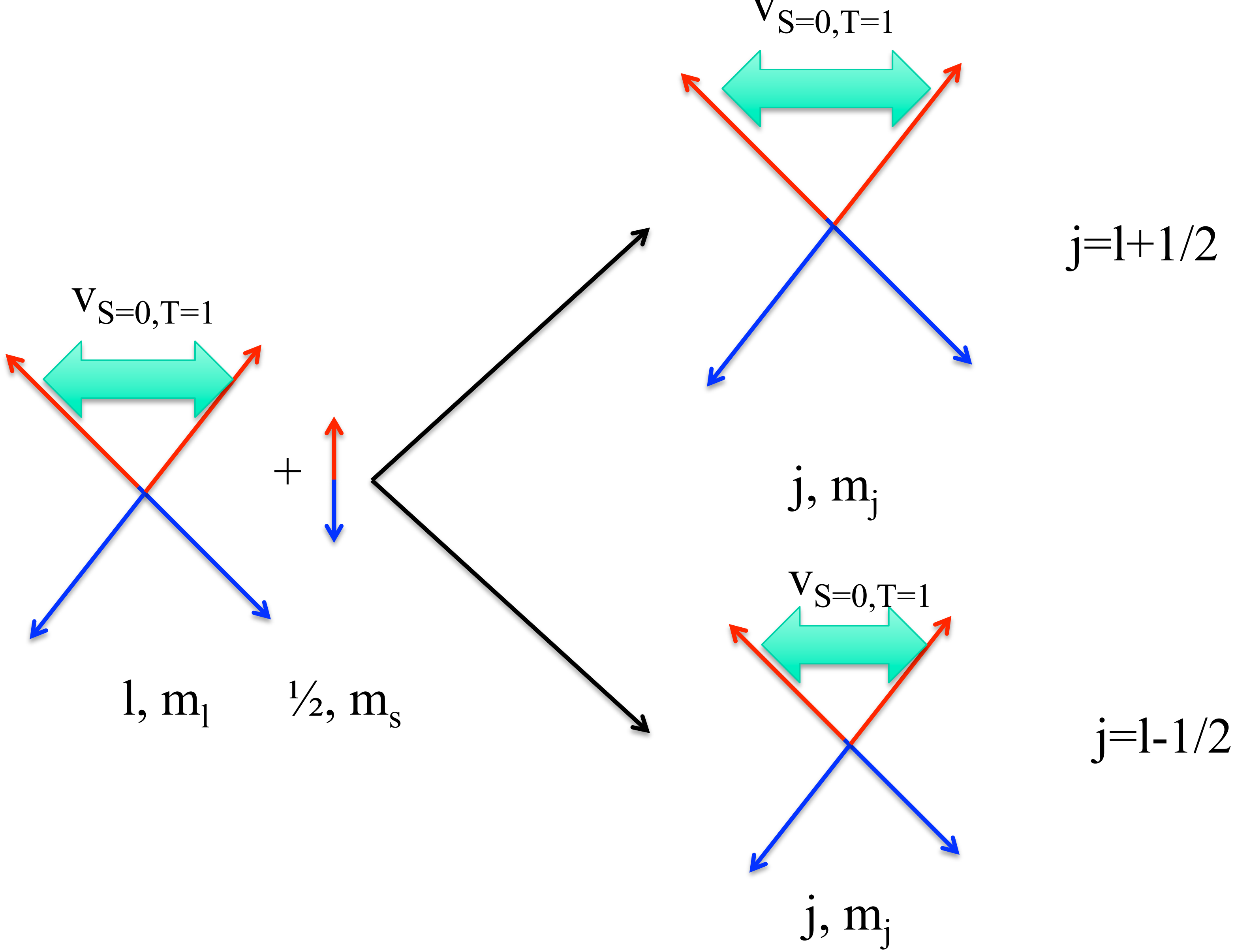
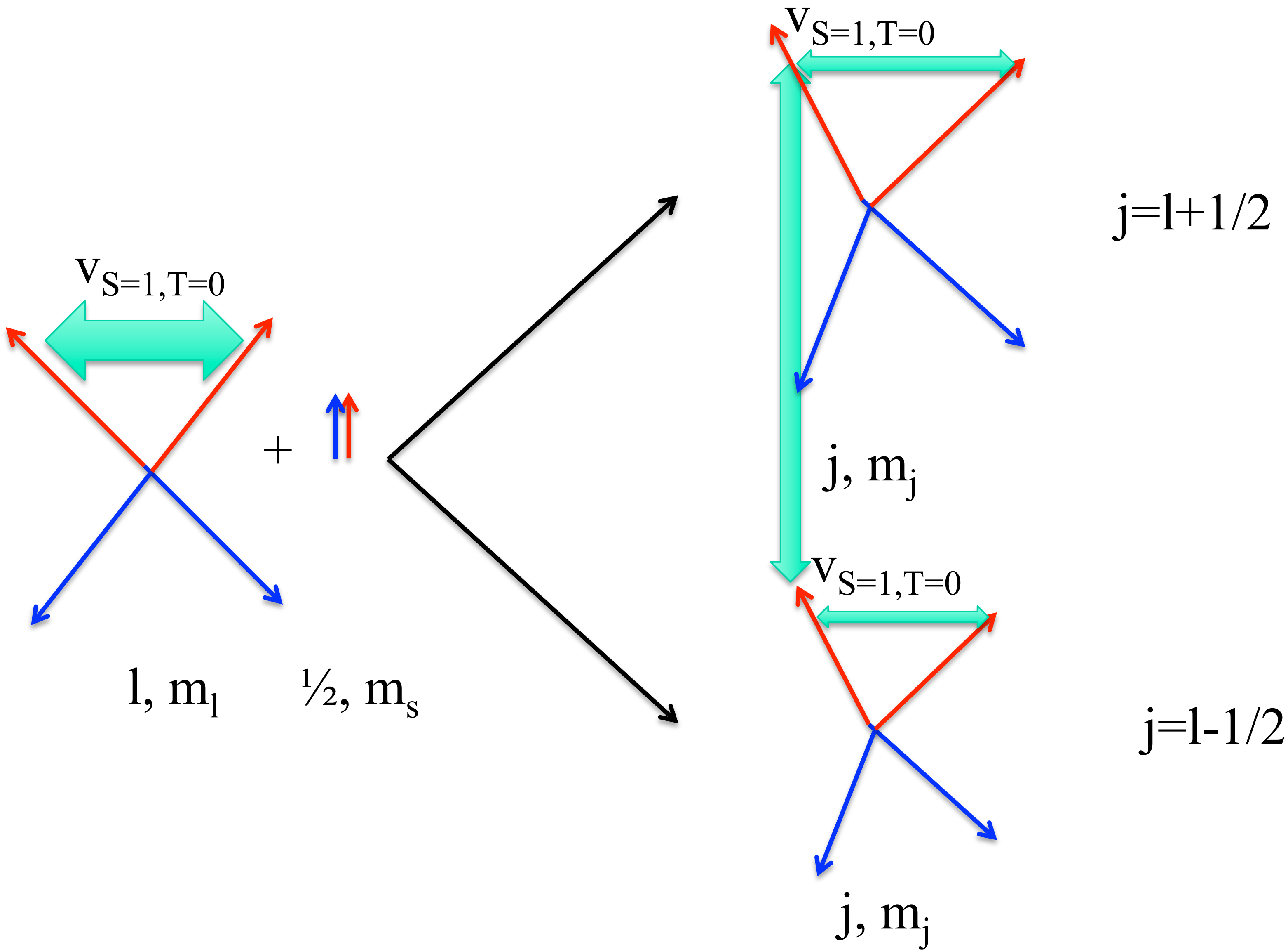




**Fig. 2.** The experimental interaction matrix elements $E_J$ between two nucleons in $j$-orbitals forming a $T = 0$ pair (left panel) and a $T = 1$ pair (right panel). The angle between the angular momenta $\vec{j}$ of the two nucleons is denoted by $\theta_{12}$. A scaling factor $E$ is applied such that different $j$-orbitals fall on the same curve. For each $j$-shell, the first point to the left corresponds to $J = 1$ and the last to the right to $J = 2j$ in the case $T = 0$, and the first point to the left corresponds to $J = 0$ in the case $T = 1$.
*Source:* From [6].

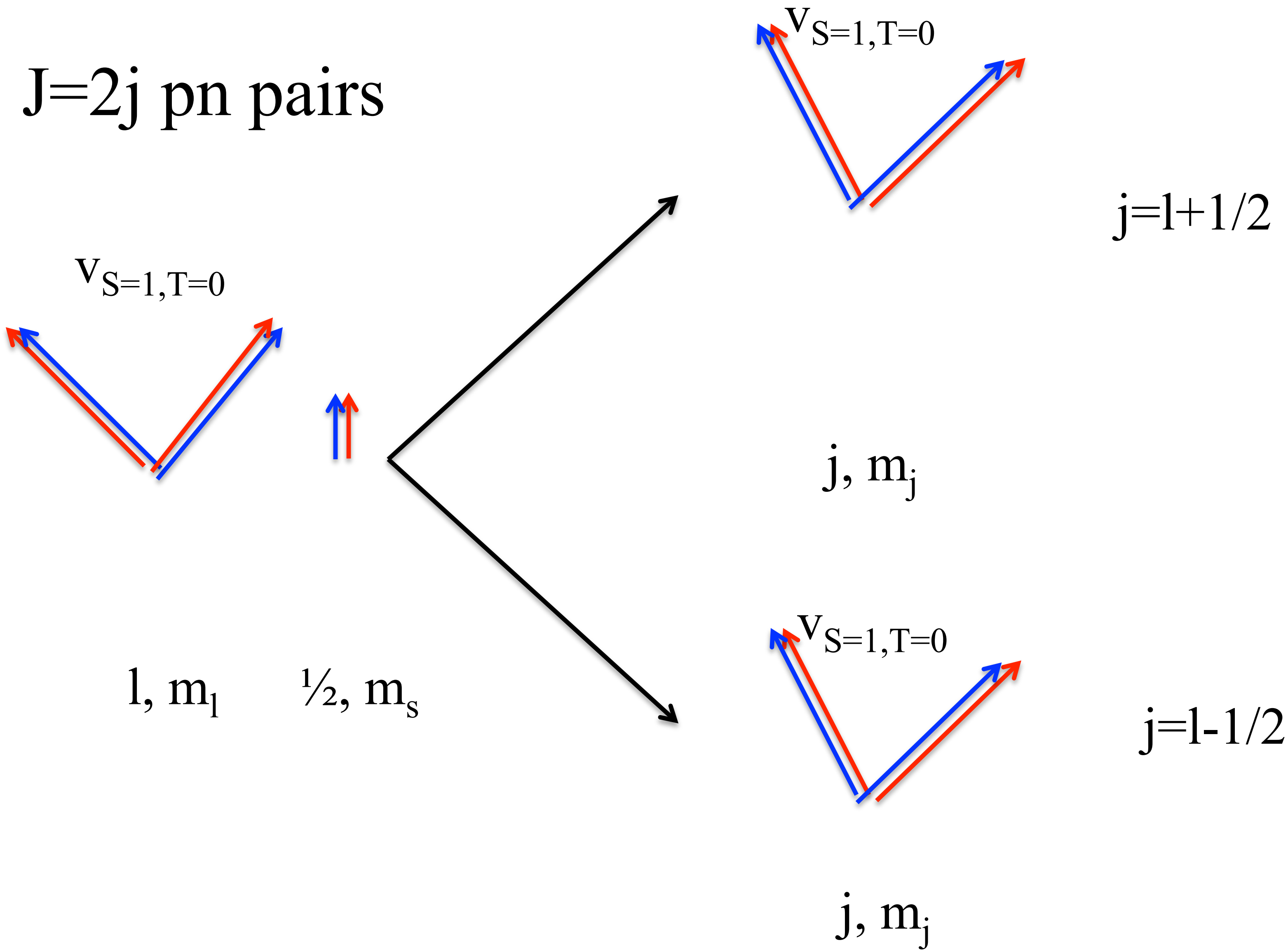



The spin-orbit splitting not important for the T=1 pairing.




The spin-orbit splitting attenuates the T=0 pairing.

# J=2j pn pairs




No pair scattering: angular momentum conserved.
They do not generate a condensate.

# Mean field calculations

# The HFB equations

$\beta^+ = Uc^+ + V\bar{c}$, pairs: $\left[c^+\bar{c}^+\right]_{TM_TJM}$

$$\begin{bmatrix} \varepsilon-\lambda+\Gamma & \Delta \\ \bar{\Delta} & -\left(\varepsilon-\lambda+\bar{\Gamma}\right) \end{bmatrix}\begin{bmatrix} U \\ V \end{bmatrix} = E\begin{bmatrix} U \\ V \end{bmatrix}$$

$\Gamma_1 = Tr_2(v_{12}\rho_2), \quad \Delta_1 = Tr_2(\tilde{v}_{12}\kappa_2)$

The T=0 and T=1 pairfields usually appear as separate solutions.

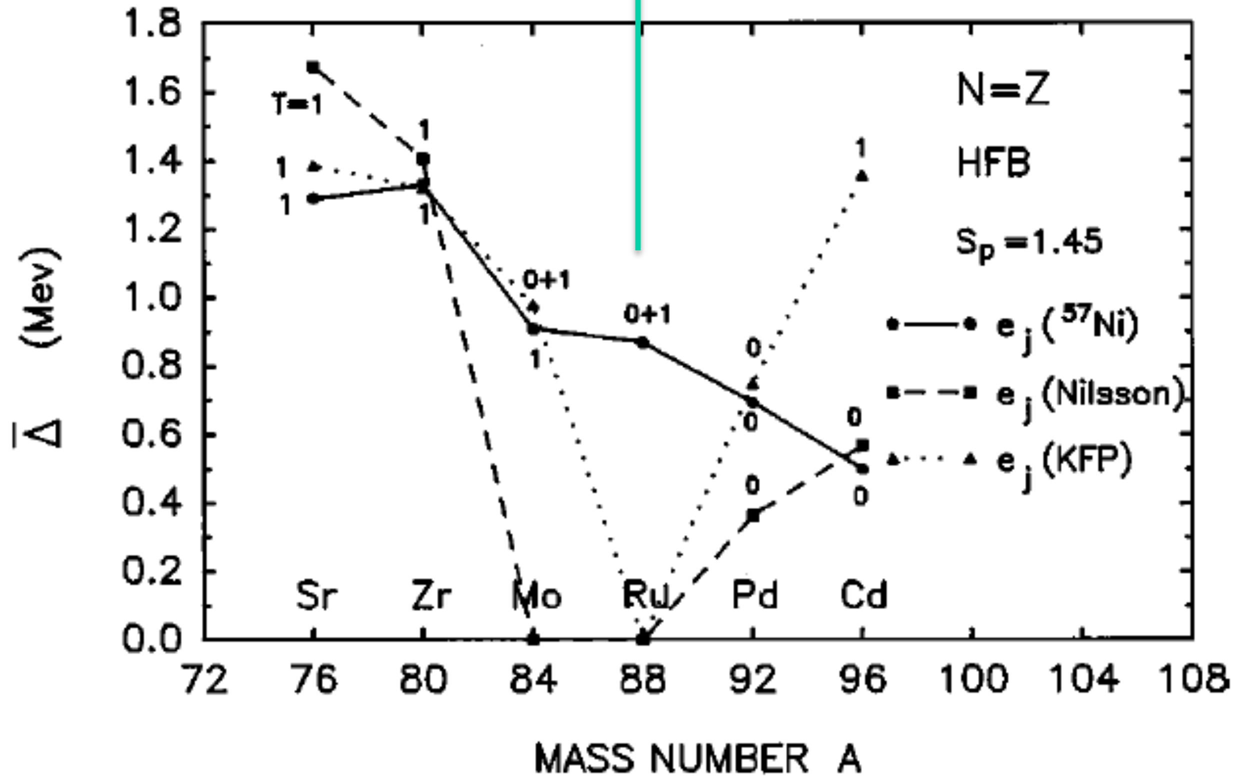
T=0 for

$^{20}Ne$
$^{24}Mg$
$^{28}Si$
$^{32}S$
$^{36}Ar$

HFB
Yale-Shakin
G-Matrix

A.L. Goodman, Adv. Nucl. Phys. 11 (1979) 263.

T=1 pairing　　T=0 (α,α) field

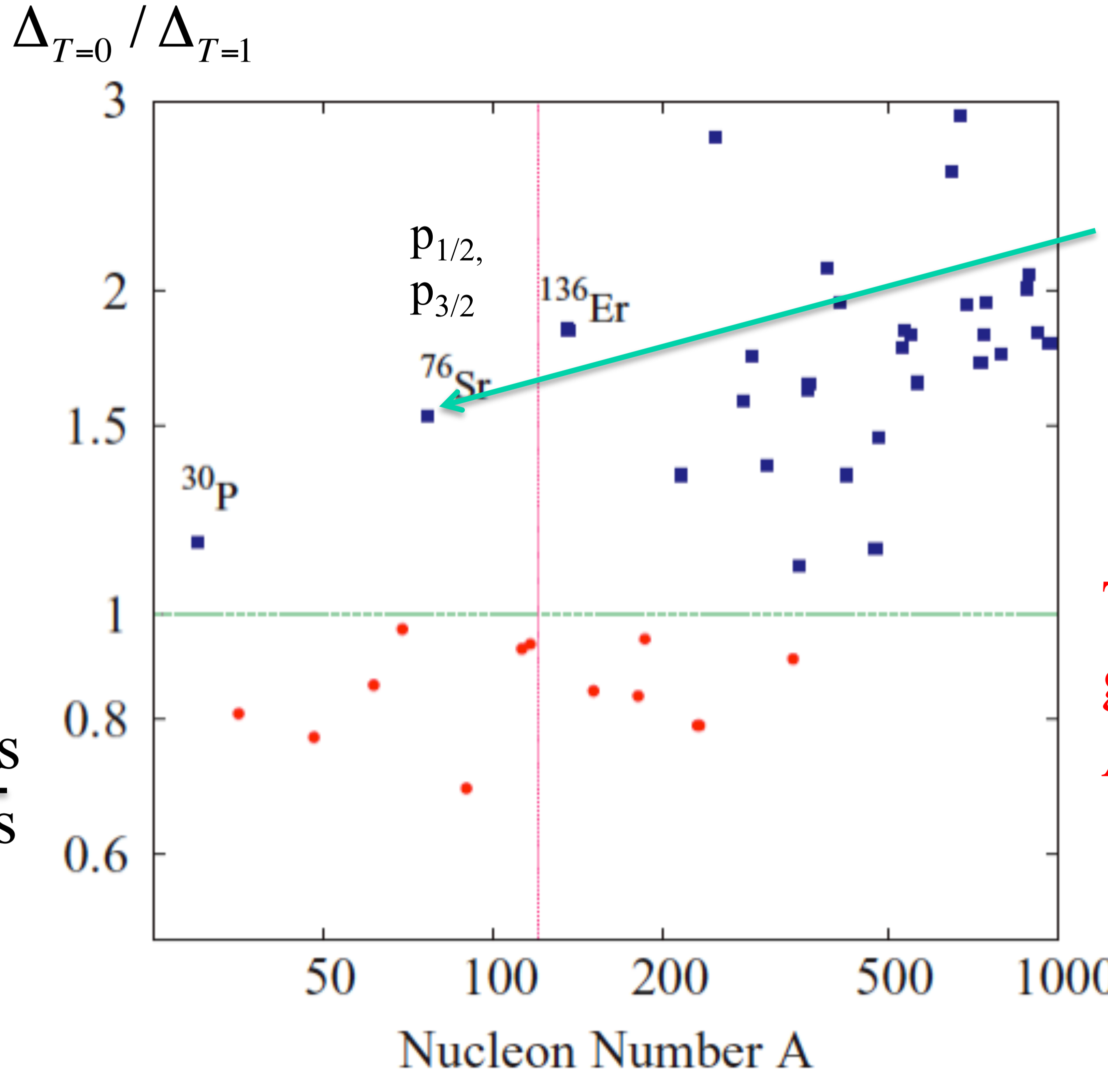



A. L. Goodman, PRC60, 014311 (1999)

T=0 (α,α) field: p and n in identical orbitals
???

Spin-orbit potential is located in surface -> ratio

$\frac{\sharp \text{ interior states}}{\sharp \text{ surface states}}$ increases with A.




Deformation may change the T=0 Preference.

T=1 ground states A<100

$\varepsilon$ spherical Woods Saxon, half filled j-shells

$v$ monopole term of $\delta$ interaction, $v_0 = 1.5 v_1$

G.F. Bertsch, Y. Luo, Phys. Rev. C 81 (2010) 064320

# Evidence for the presence of the pair fields in energies

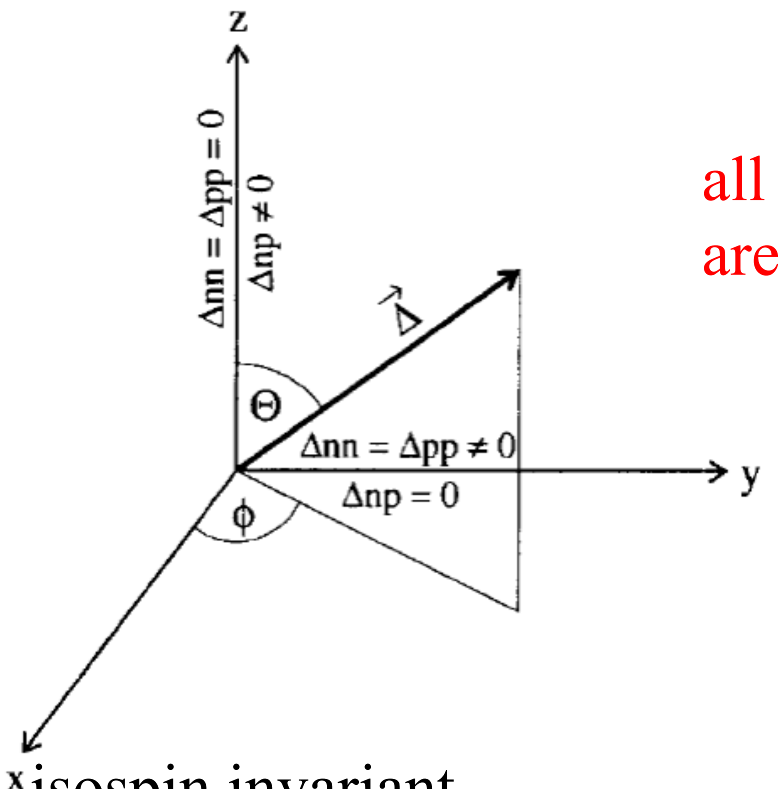
Spontaneous symmetry breaking -> pair rotational bands

T=1, J=0 and T=0, J=1 Cooper pairs

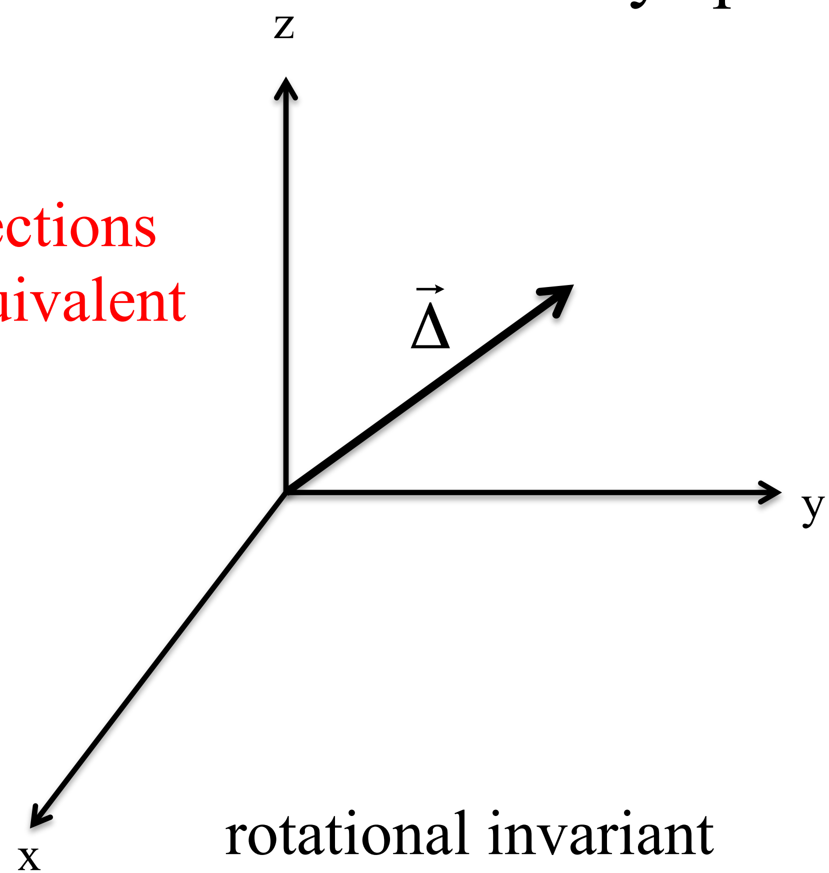
assume good isospin, subtract Coulomb energy $\langle v_C \rangle$

T=1, J=0 pair field
vector in isospace

T=0, J=1 pair field
vector in ordinary space




all directions
are equivalent




isospin invariant
Hamiltonian ->
iso-rotational excitations (SU2)
ΔA=4 quartet band

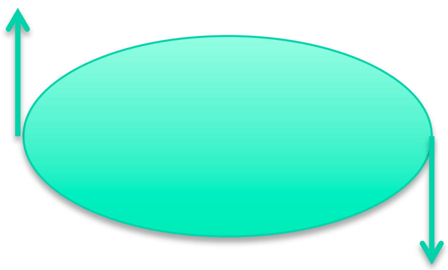
rotational invariant
Hamiltonian ->
rotational excitations (SU2)
ΔA=2 pair band

S.F. , J Sheikh NPA 645, 509 (1999)

S.F. , J Sheikh NPA 645, 509 (1999)

Deformed nucleus

Isovector pair field



rotation in ordinary space

rotational energy:

$$E(I) = <H> + \frac{I(I+1)}{2\theta}$$

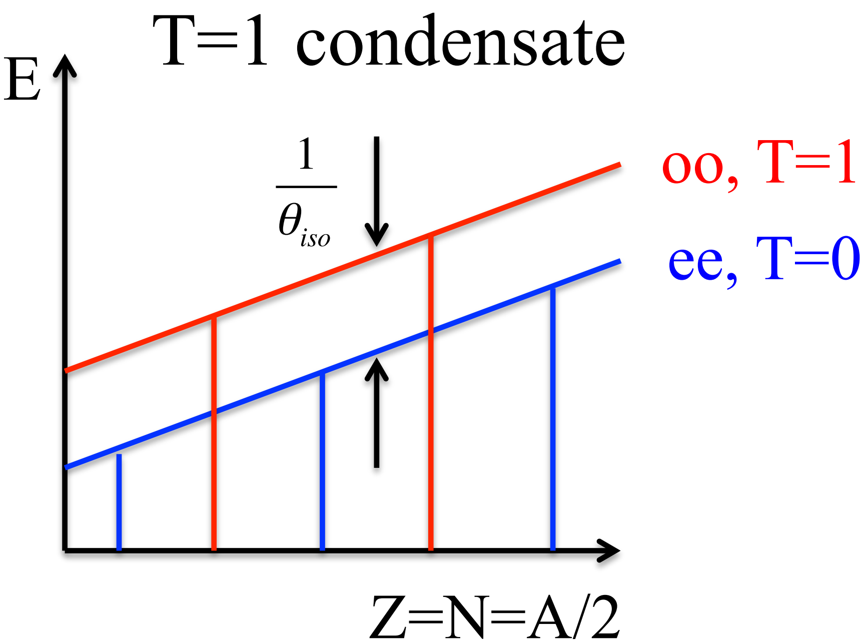
rotation in abstract isospace

isorotational energy:

$$E(I) = <H> + \frac{T(T+1)}{2\theta_{iso}}$$

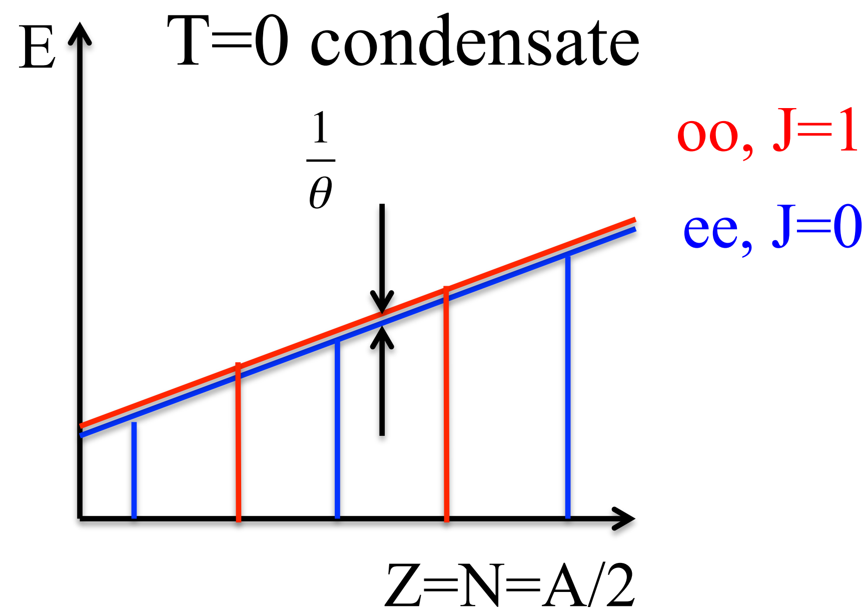
Limit of strong symmetry breaking: Wigner X=1
("large deformation" in isovector space)
The experimental X often close to 1, but not as close as for ordinary rotation. Weak deformation.

# p-n condensates generate pair-rotational bands: Regular sequence of ground states include the odd-odd nuclei




$$\frac{T(T+1)}{2\theta_{iso}} = \frac{75MeV}{A} T(T+1)$$

symmetry energy

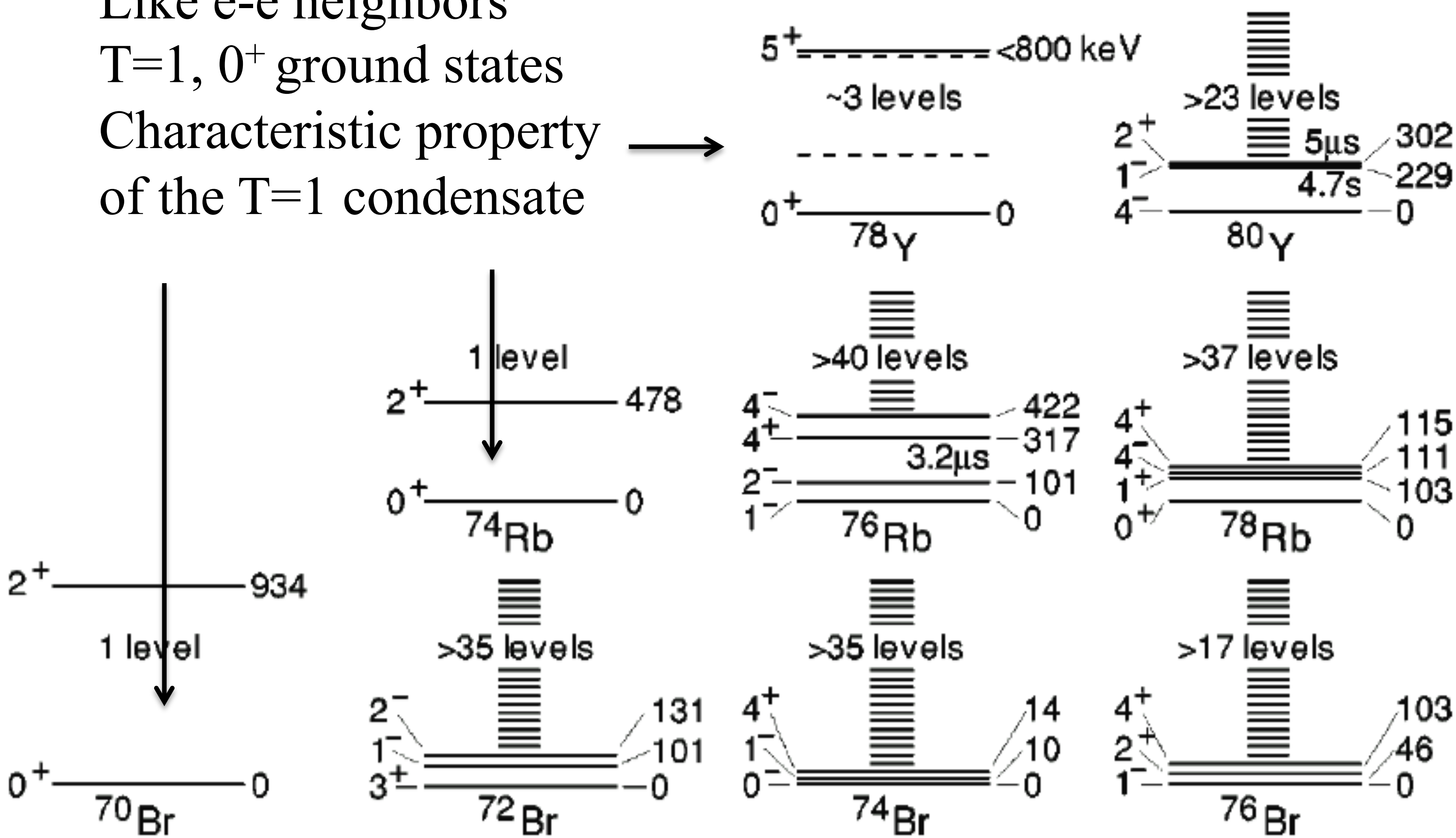



$$\frac{J(J+1)}{2\theta} \quad \theta \text{ large,}$$

cranking, Shell Model

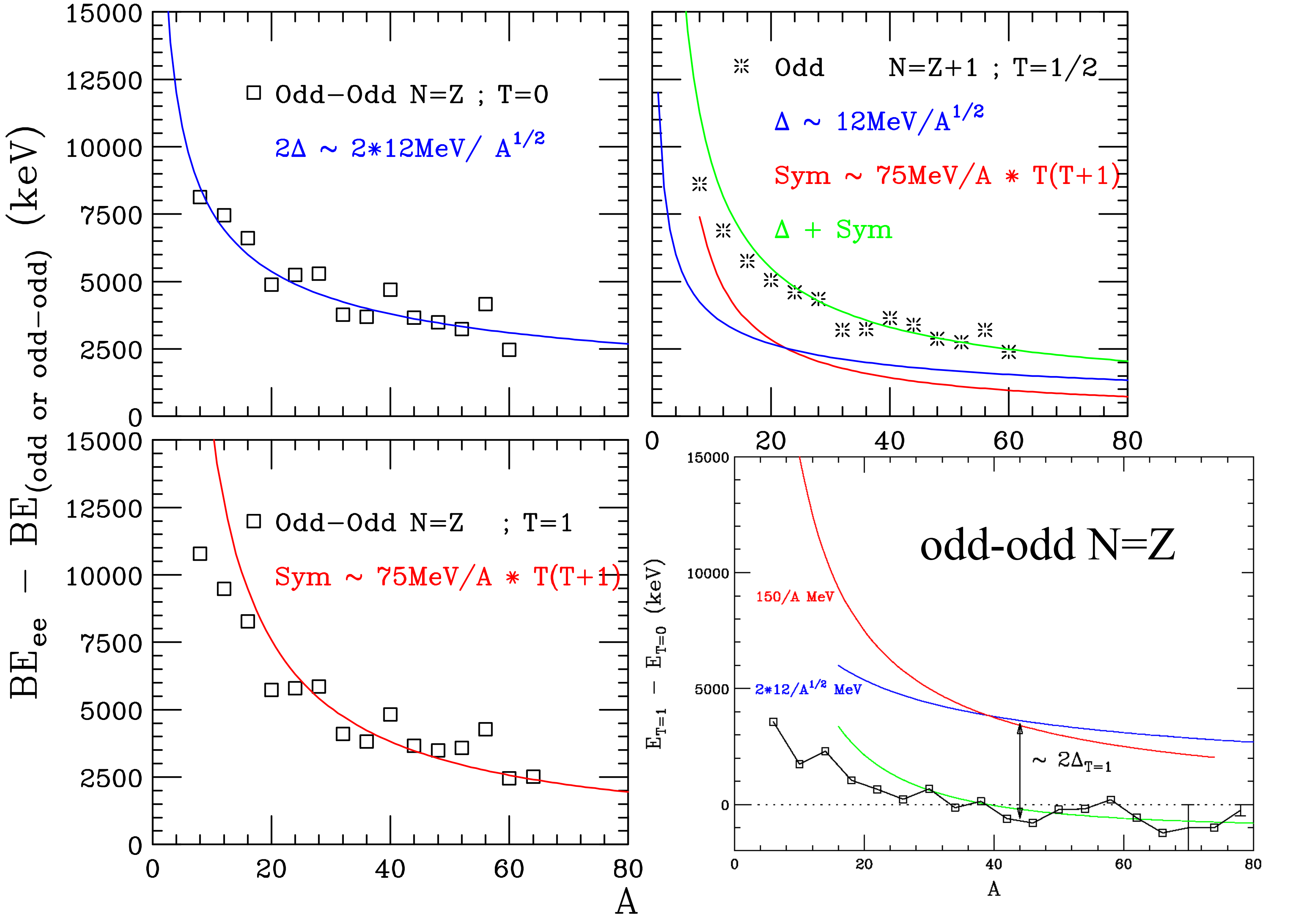
Isorotation generates a quartet sequence

Like e-e neighbors
T=1, $0^+$ ground states
Characteristic property
of the T=1 condensate

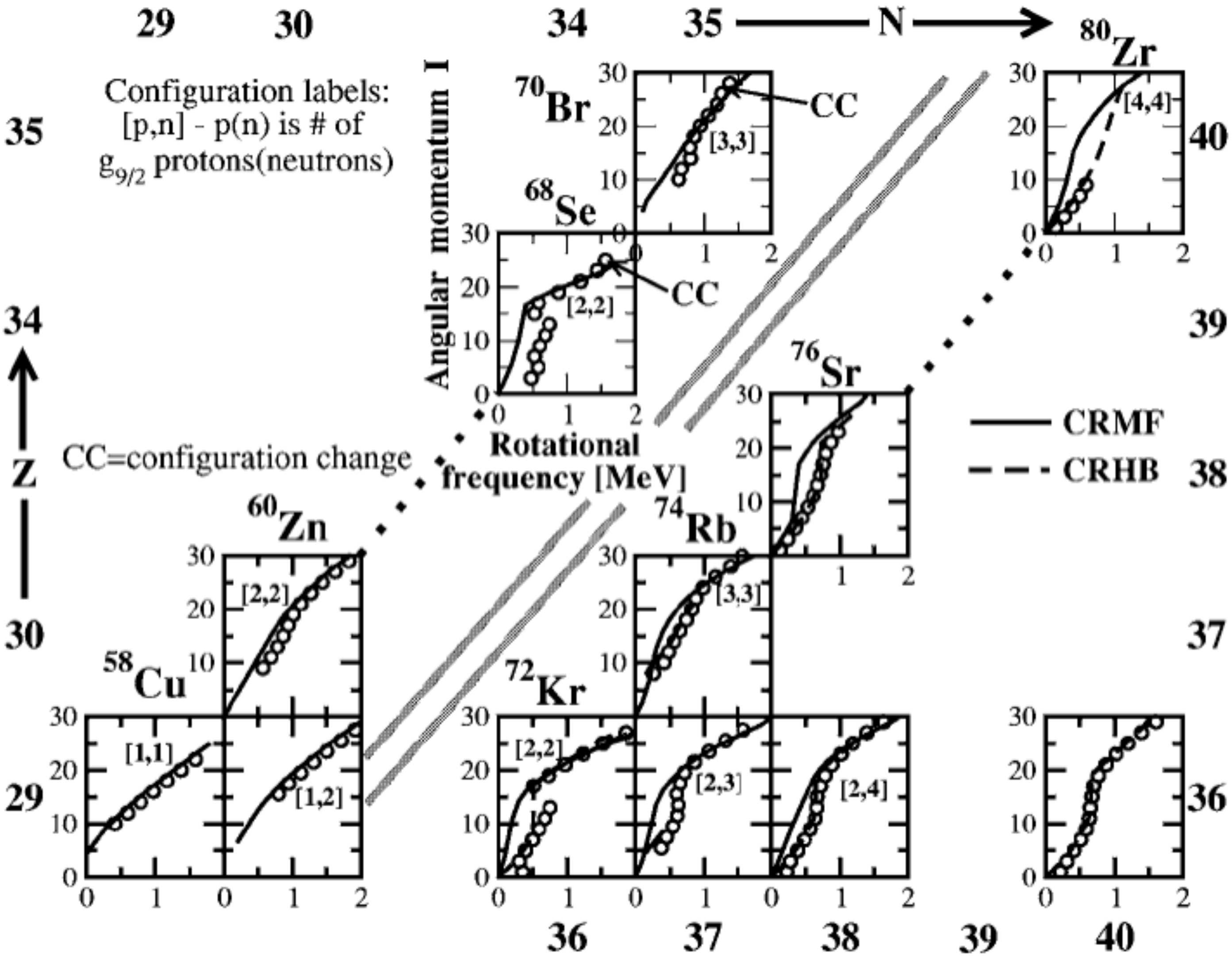



Lowest levels in odd-odd nuclei near N=Z

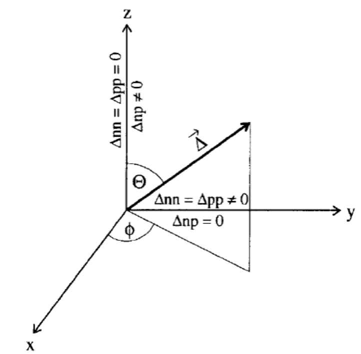
D. Jenkins et al., PRC65, 064307 (2002).




T=1 pair gap + isorotational energy account for the N≈Z binding energies



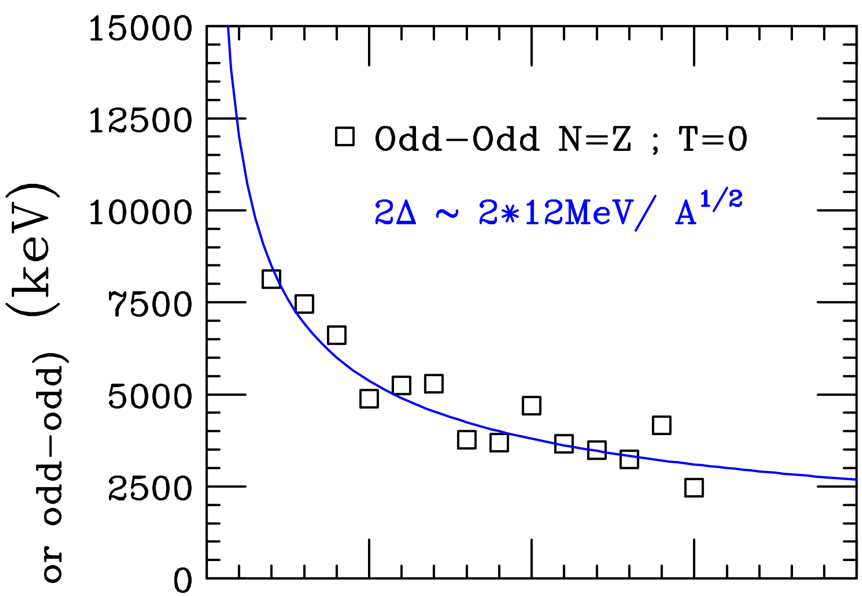

A. V. Afanasjev,
Int. J. Mod. Phys.
E 16, 275 (2007)

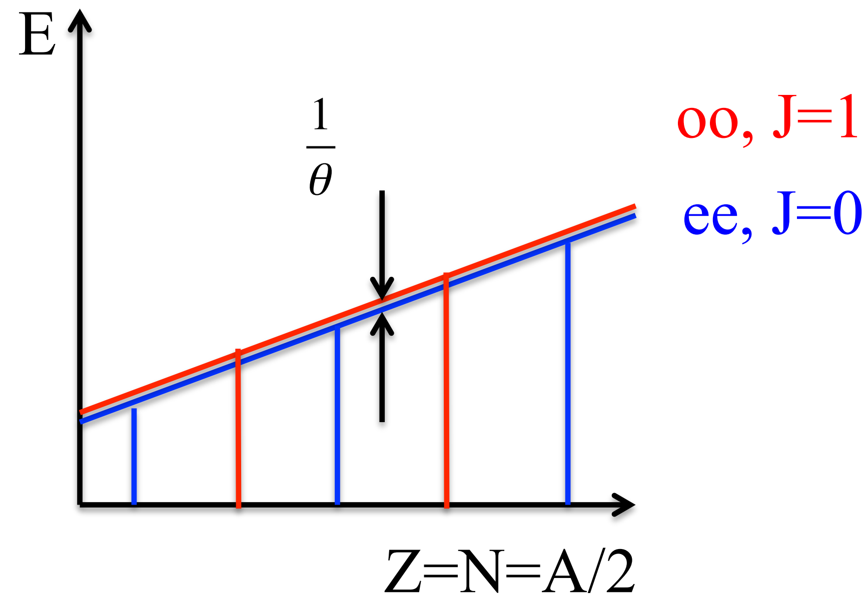



T=0 rotational states have the same structure for all directions of the IV pair field .

To calculate the rotational spectra one can use the y- direction of the condensate, which has no pn-component.

# T=0 condensate generates pair-rotational bands: Regular sequence of ground states include the odd-odd nuclei



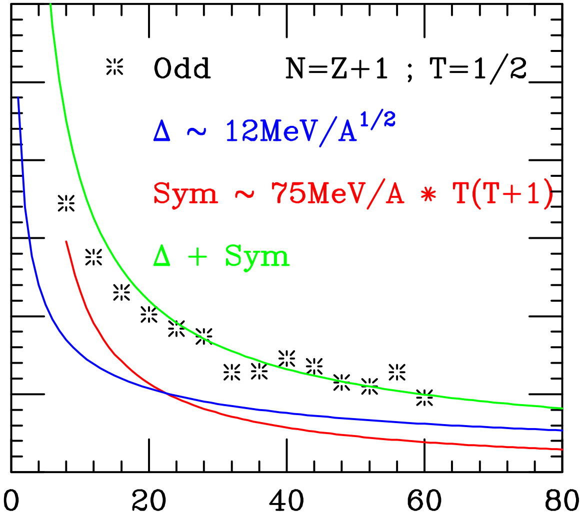



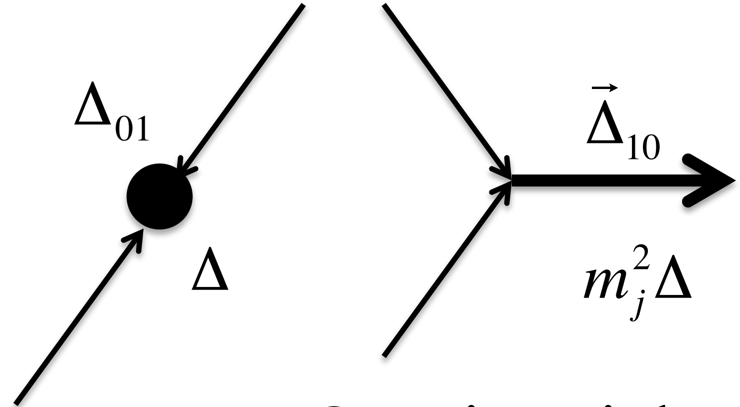

The experimental
T=0 odd-odd states do
not join a pair-rotational band

$\frac{J(J+1)}{2\theta}$ $\theta$ large,

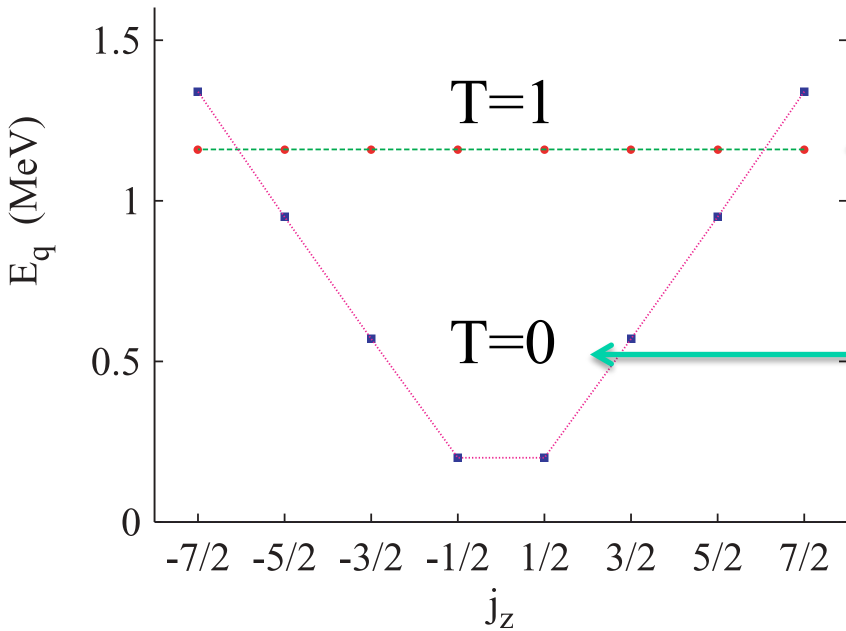
cranking, Shell Model

Gapless quasiparticle states are not observed




Quasiparticle spectra (j-shell)



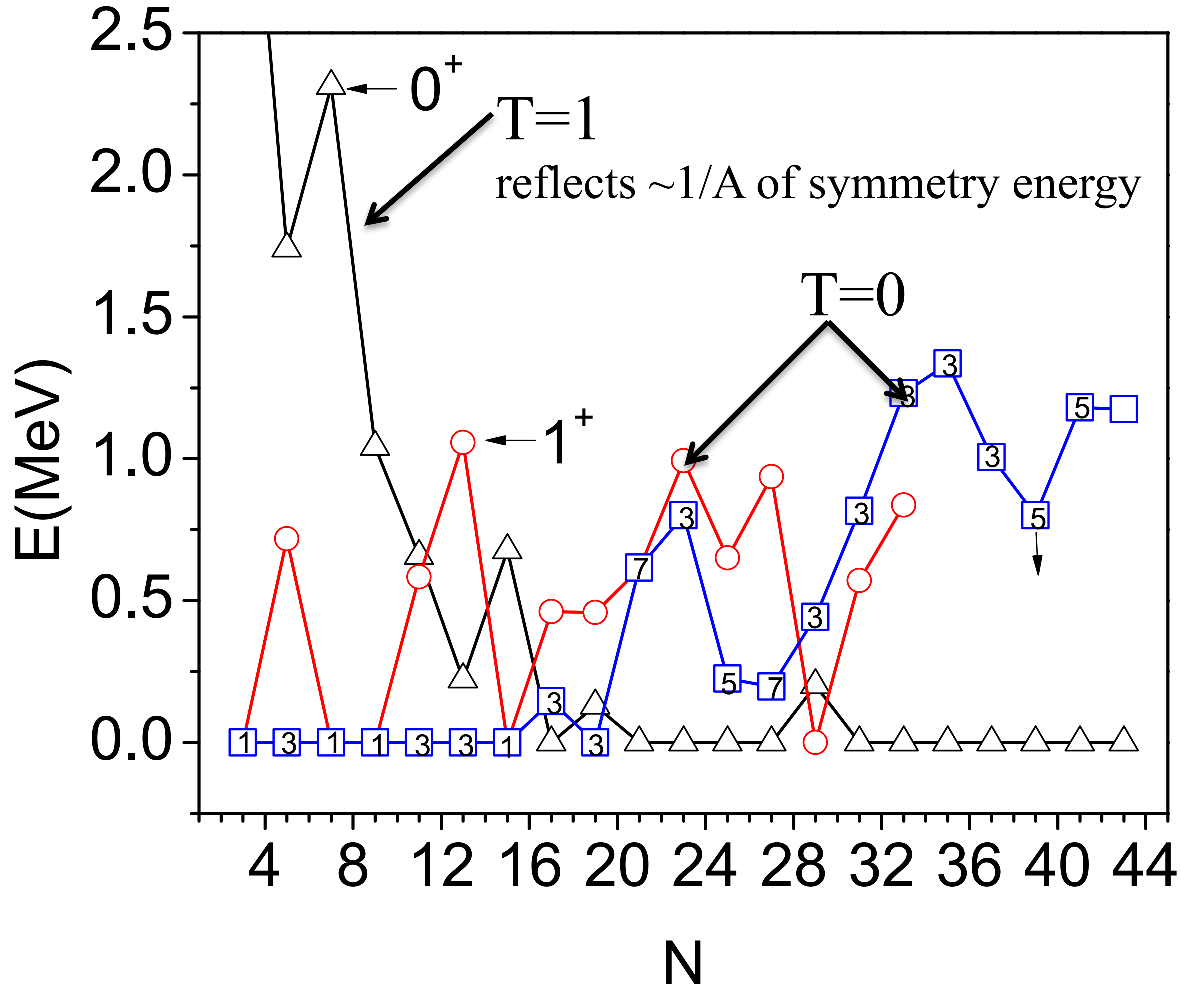

pair gap

between ee and odd-A

no pair gap

FIG. 1. (Color online) Quasiparticle energies in $^{48}$Cr for the $f$-shell space. Red circles, spin-singlet; blue squares, spin-triplet with condensate in the $S_z = 0$ channel. Lines are drawn to guide the eye.

A. Gezerlis,
G. F. Bertsch,
and Y. L. Luo,
PRL 106, 252502(2011)




J=2j or 2Ω (axial) the j of p and n are parallel "spin-alignment"

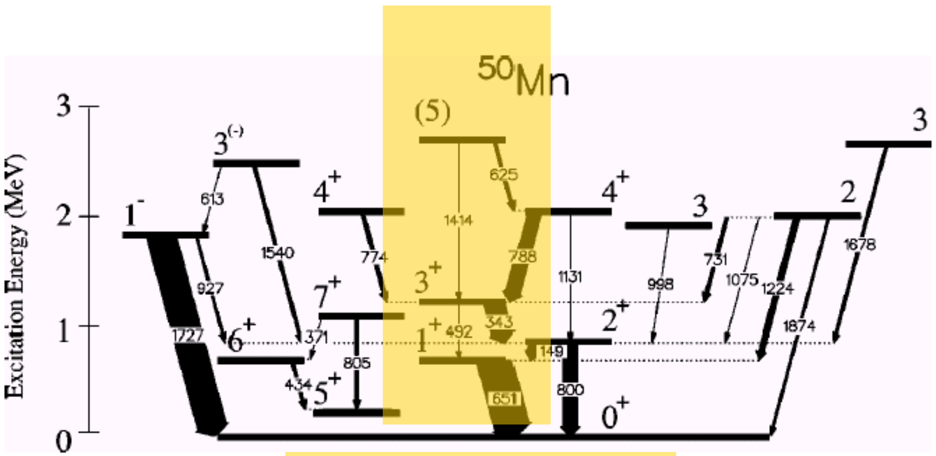
J=1 the j of p and n are almost antiparallel

Low-lying states in odd-odd N=Z nuclei

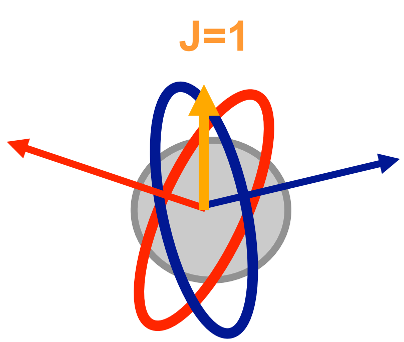
PHYSICAL REVIEW C, VOLUME 60, 064310

# Quasideuteron configurations in odd-odd $N=Z$ nuclei

A. F. Lisetskiy,[1] R. V. Jolos,[1,2] N. Pietralla,[1] and P. von Brentano[1]
[1]Institut für Kernphysik, Universität zu Köln, D-50937 Köln, Germany
[2]Bogoliubov Theoretical Laboratory, Joint Institute for Nuclear Research, 141980 Dubna, Russia




quasideuteron




| Odd-odd Nucleus | $B(M1;0_1^+\rightarrow 1_1^+)$ $(\mu_N^2)$ Expt. | Eq. (8) |
|---|---|---|
| ${}^{10}_{5}B_5$ | 7.5(32) | 5.32 |
| ${}^{14}_{7}N_7$ | 0.05(2) | 0.75 |
| ${}^{18}_{9}F_9$ | 20(4) | 14.65 |
| ${}^{22}_{11}Na_{11}$ | 5.0(3) | 3.70 |
| ${}^{26}_{13}Al_{13}$ | 8(2) | 6.78 |
| ${}^{30}_{15}P_{15}$ | 1.3(1) | 2.33 |
| ${}^{34}_{17}Cl_{17}$ | 0.23(2) | 0.005 |
| ${}^{38}_{19}K_{19}$ | 0.47(4) | 0.35 |
| ${}^{42}_{21}Sc_{21}$ | 11(4) | 15.62 |
| ${}^{46}_{23}V_{23}$ | | 6.40 |
| ${}^{50}_{25}Mn_{25}$ | | 6.34 |
| ${}^{54}_{27}Co_{27}$ | | 11.82 |
| ${}^{58}_{29}Cu_{29}$ | | 3.44 |
| ${}^{82}_{41}Nb_{41}$ | | 15.52 |

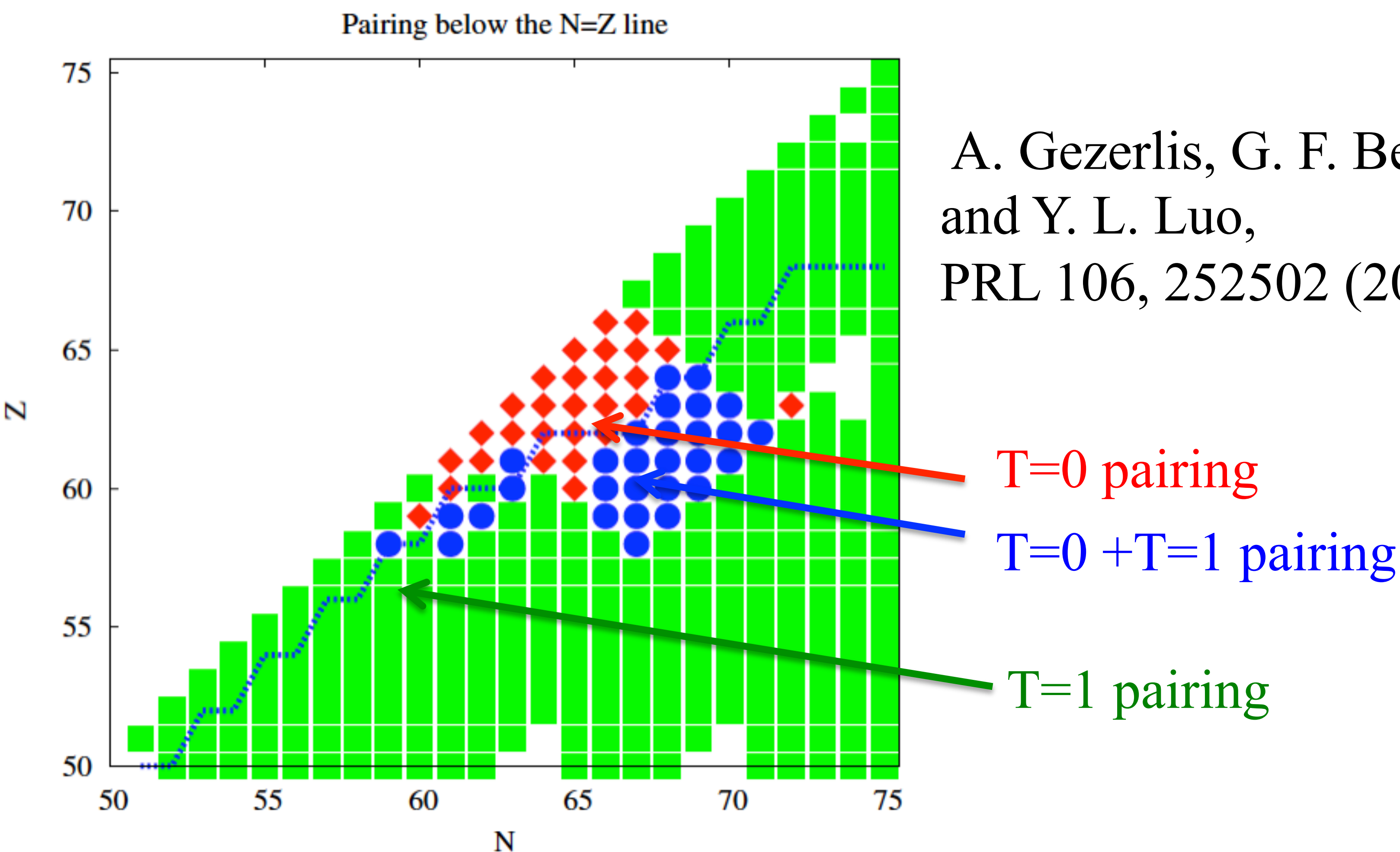
**$J_+$ large B(M1)**

**$J_-$ small B(M1)**

The B(M1) are reproduced by coupling the odd p and n to J=1
Rapid variations not expected for strong T=0 correlations

- The p-n isovector pairing has to be as strong as the pp and nn pairing for symmetry reasons. No additional parameter to adjust.
- Mean field calculations predict a T=1 pair field for $40 \leq A \leq 100$
- Binding energies and low energy spectra are consistent with absence of a T=0 field
- T=0 interaction aligns the spins of the lowest qp and qn in in the first T=0 states of oo nuclei. Not a pair field.
- There may be room for dynamical T=0 pair correlations.

# Going far proton-rich




A. Gezerlis, G. F. Bertsch, and Y. L. Luo, PRL 106, 252502 (2011)

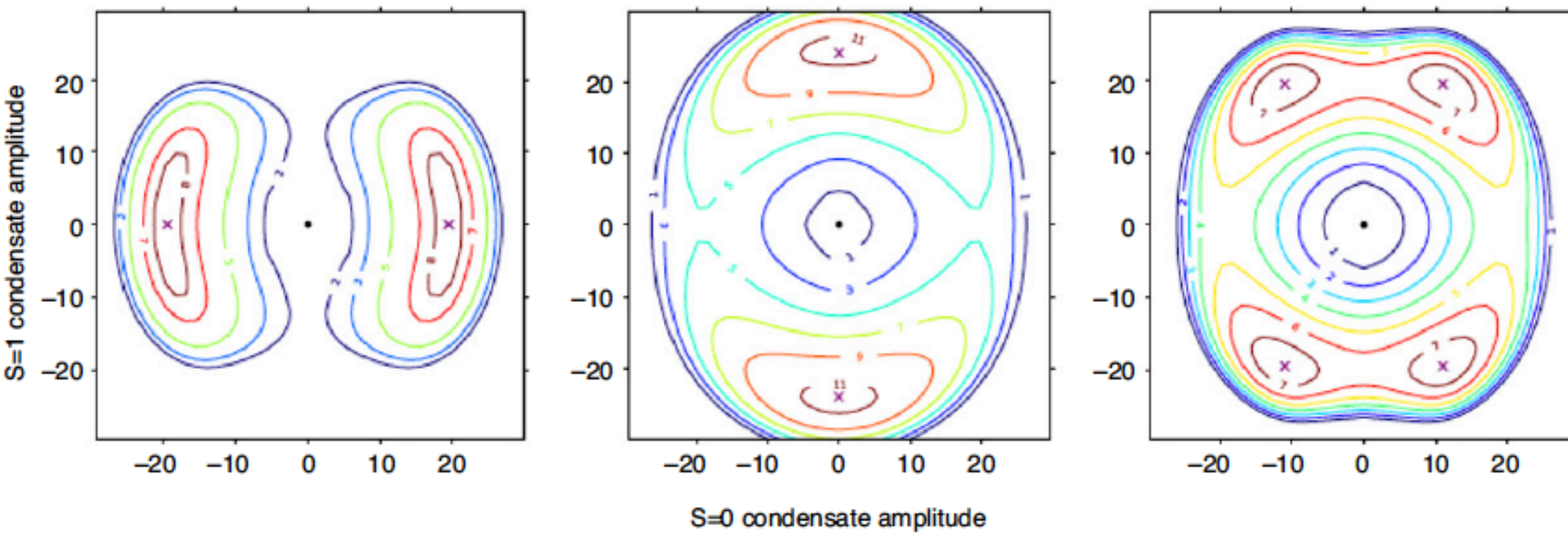



**Fig. 22.** Contour plots of the correlation energy in three different $A = 132$ nuclei as a function of the amplitudes of the isoscalar pair field $\kappa^0$ ($S = 1$ axis) and the isovector fields $\kappa_n = \kappa_p$ ($S = 0$ axis). Left panel: $^{132}_{60}Nd_{72}$ with dominating isovector pairing; middle panel: $^{132}_{66}Dy_{66}$ with dominating isoscalar pairing; right panel: $^{132}_{64}Gd_{68}$ with a mixture of both pairing types. The numbers show correlation energies in MeV. In all three cases, the maximum is marked by an X.

- More detailed calculations needed to specify for the region the signals for pn- pair correlations in the binding energies and excitation spectra
- Check them experimentally

# Shell model studies

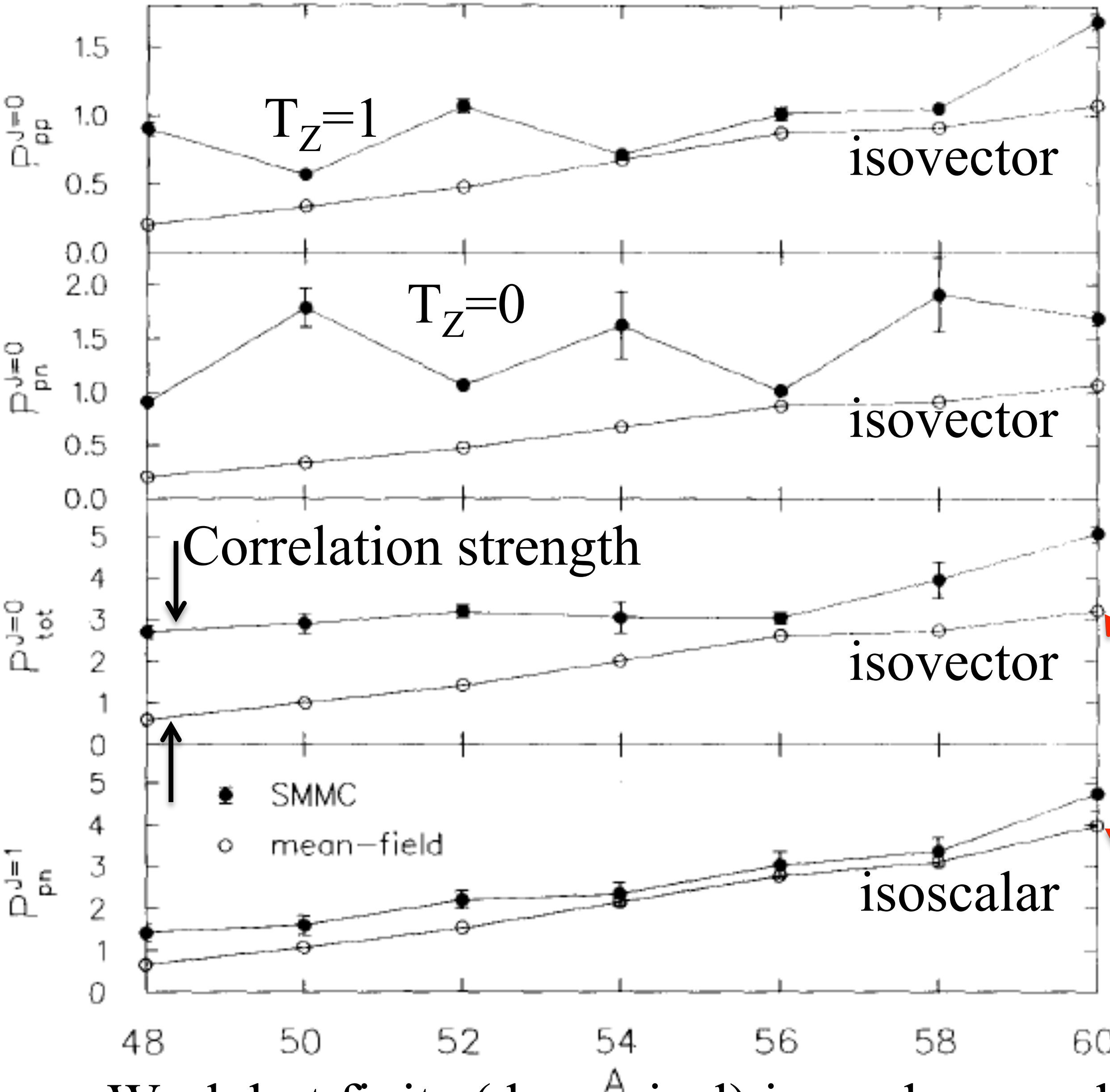
–Determine the strength of the pair correlations:

Pair counting operators $N(TM_T) = P^{+}_{TM_T} P_{TM_T}$

–Test simple model for pairing (quarteting)

–Control the strength of the pair correlations $G_{T=0} / G_{T=1}$ and study the consquences for observables.

Strong (staic) isovector correlations

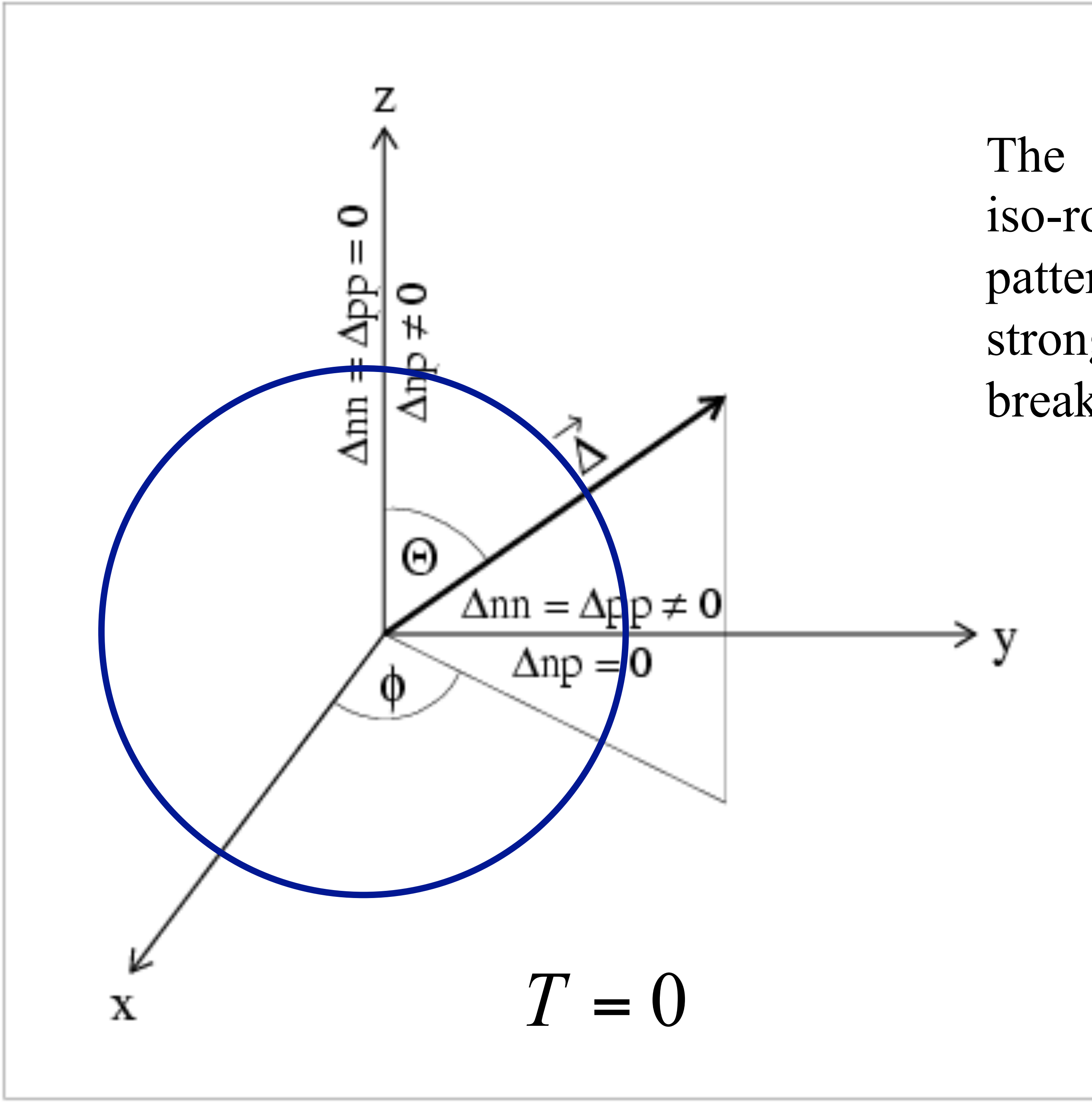



Shell Model Monte Carlo K. H.Langanke et al. NPA 613(97)253

expectation values of pair counting operators

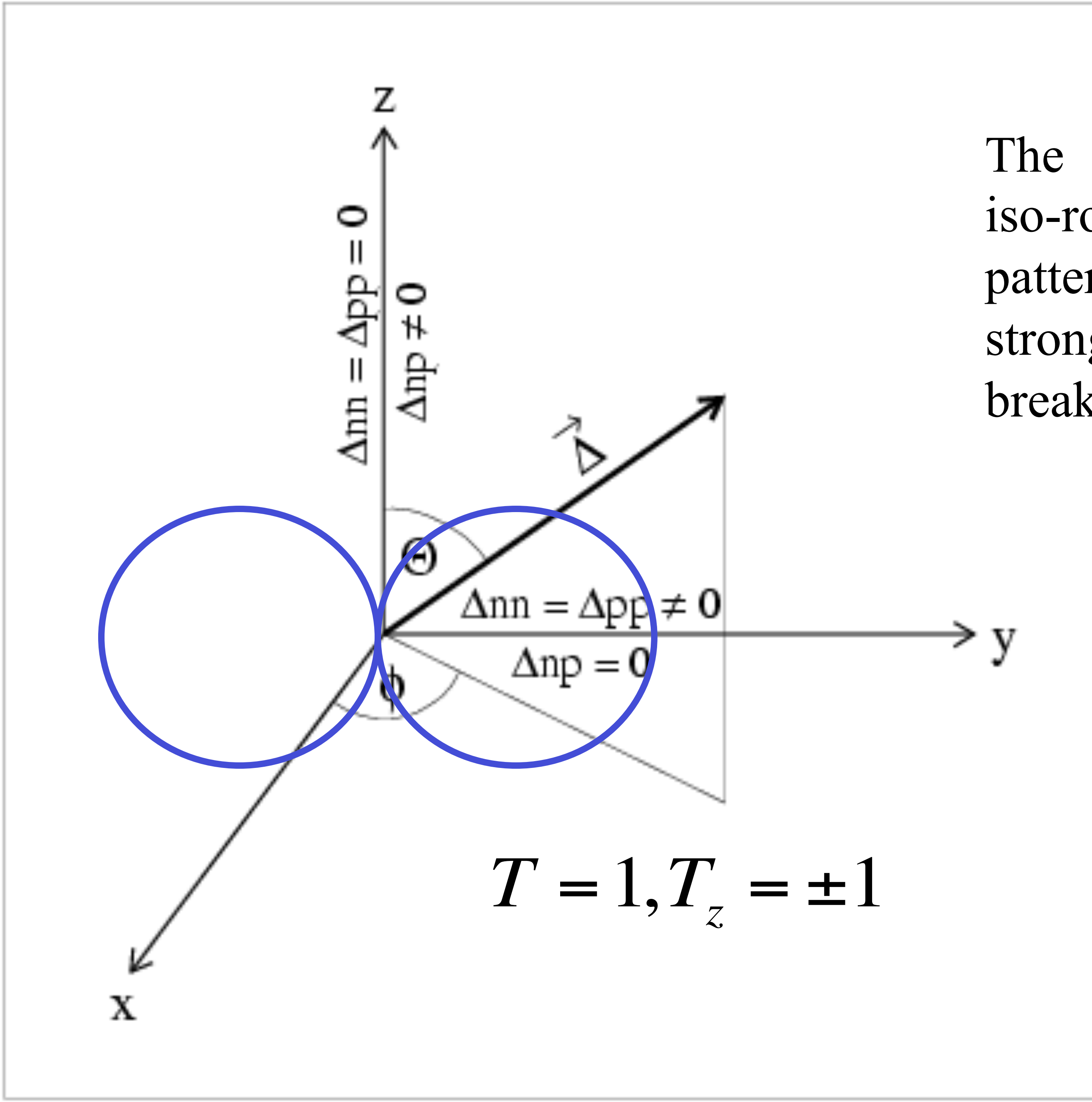
No pair correlations

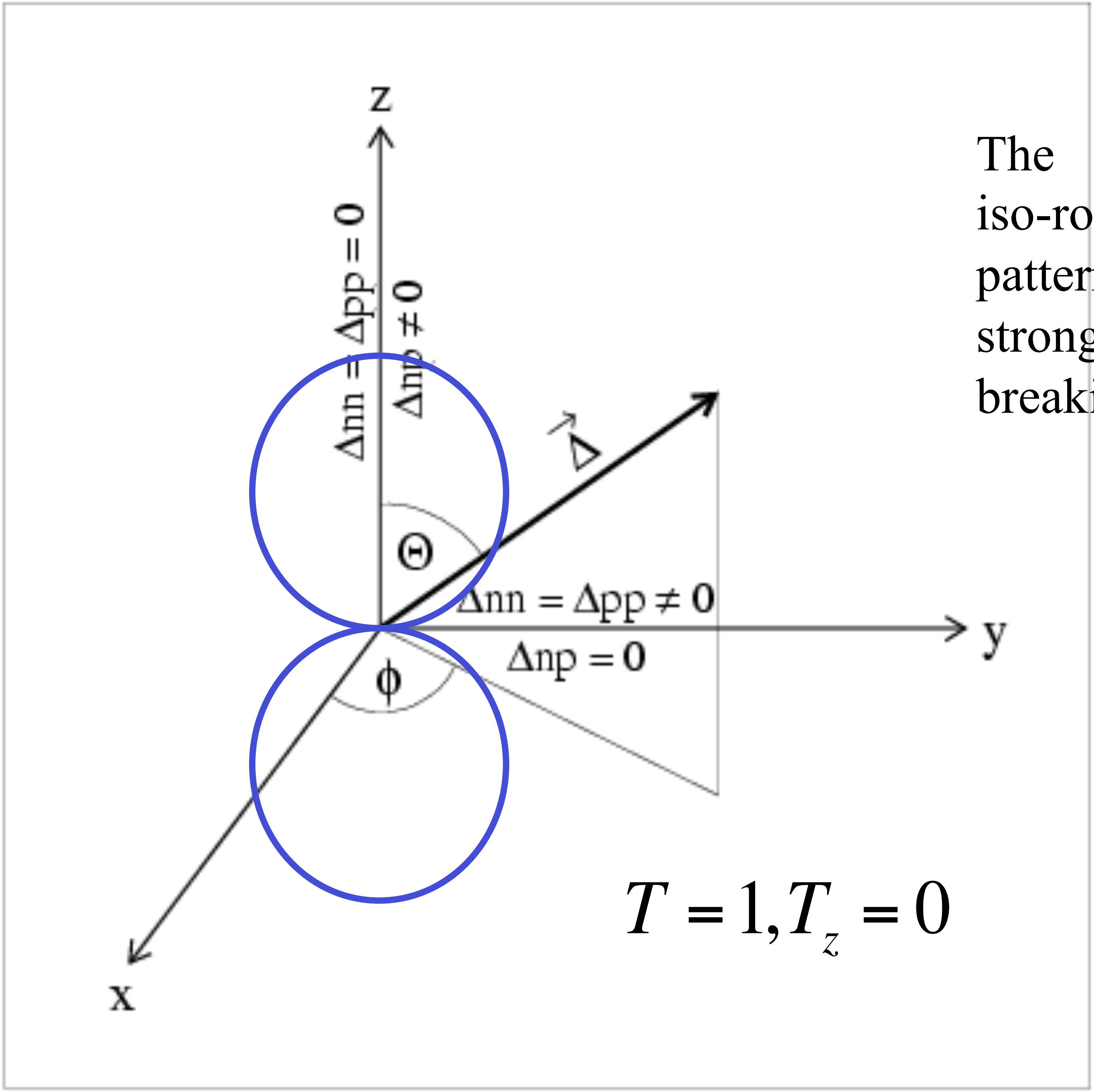
Weak but finite (dynamical) isoscalar correlations




The iso-rotational pattern of strong symmetry breaking

The iso-rotational pattern of strong symmetry breaking






The iso-rotational pattern of strong symmetry breaking

$$T = 1, T_z = 0$$

# T=1 and T=0 pairing in a simple model Hamiltonian

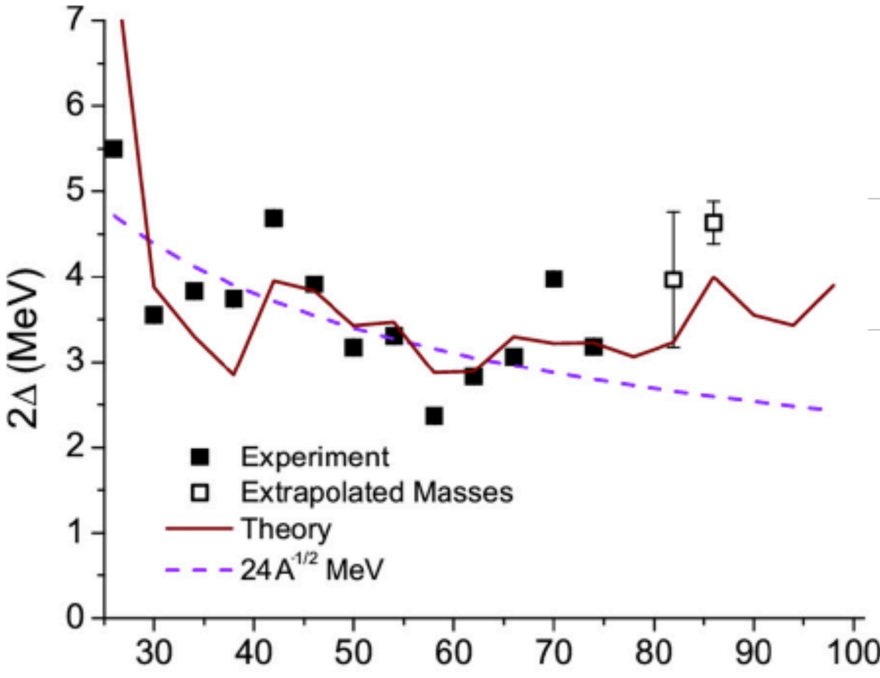
$$H = h_{nilsson} - G_v \sum_{M_T} P^+_{M_T} P_{M_T} - G_S D^+ D$$

$$P^+_{-1} = \sum_i c^+_{pi} c^+_{p\bar{i}} \qquad P^+_0 = \frac{1}{\sqrt{2}} \sum_i c^+_{pi} c^+_{n\bar{i}} - c^+_{p\bar{i}} c^+_{ni} \qquad P^+_1 = \sum_i c^+_{ni} c^+_{n\bar{i}}$$

$$D^+ = \frac{1}{\sqrt{2}} \sum_i c^+_{pi} c^+_{n\bar{i}} + c^+_{p\bar{i}} c^+_{ni}$$

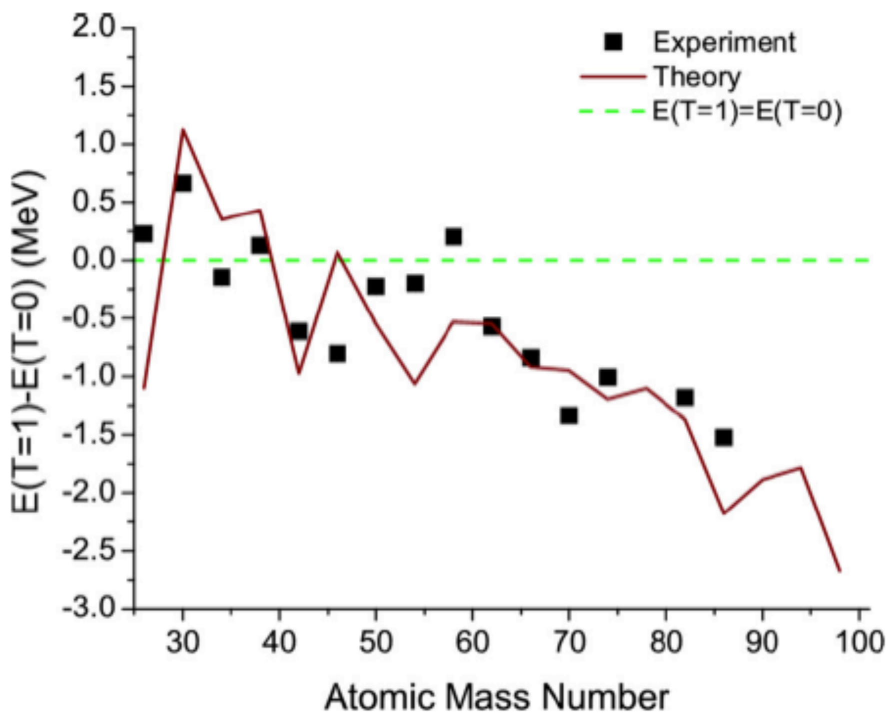
8 levels diagonalization
I. Bentley, S. F. PRC 88, 014322 (2013)

Micro-Macro for shell structure and deformation
interpolated QRPA
K. Neergard, I. Bentley, S. F., PRC 89, 034302 (2014)
K. Neergard, NUCLEAR THEORY, Vol. 36 (2017)
eds. M. Gaidarov, N. Minkov, Heron Press, Sofia, and private communication.




$$2\Delta = \frac{B(A-2,0,0) - 2B(A,0,0) + B(A+2,0,0)}{2}$$

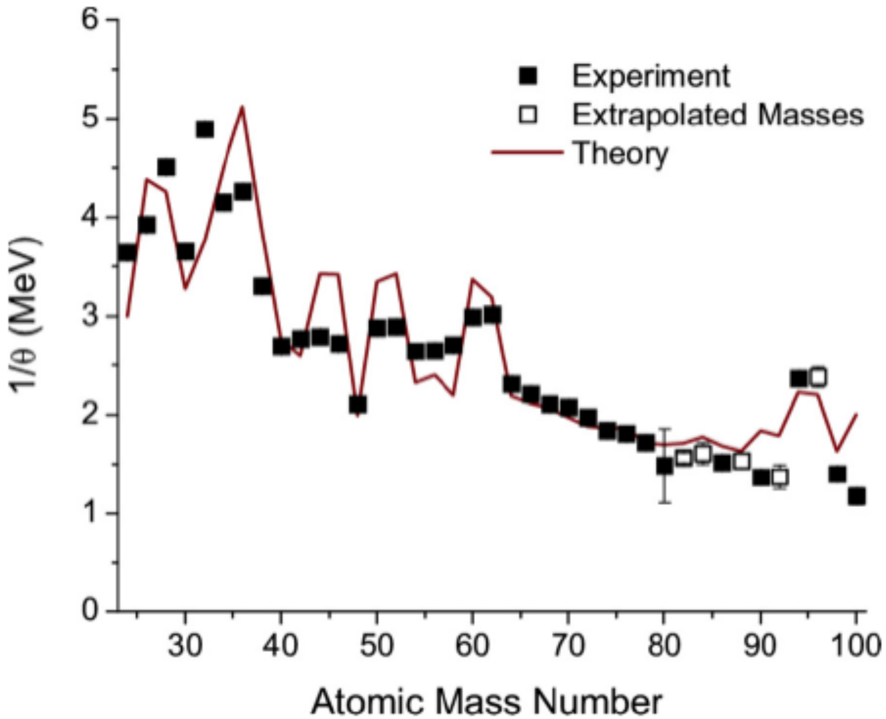
$$G = 8.6A^{-4/5}\ \text{MeV}.$$

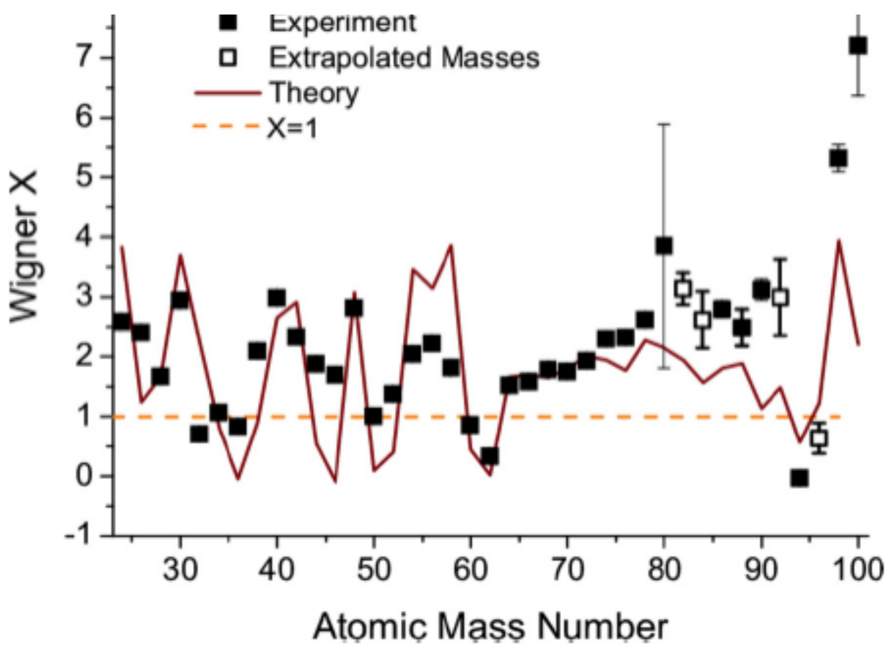



Pure isovector

$G_V=G$

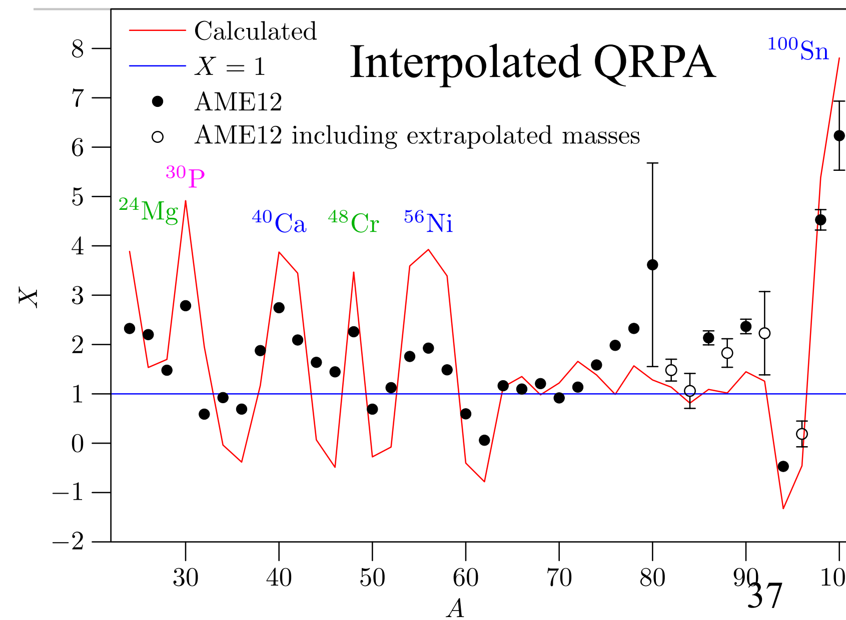
$G_S=0$

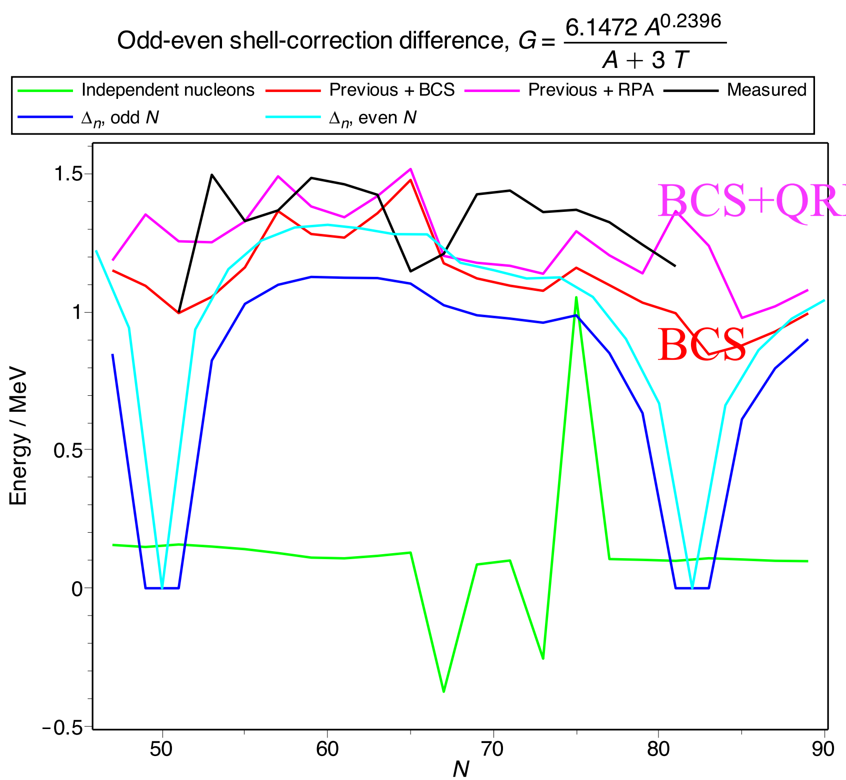


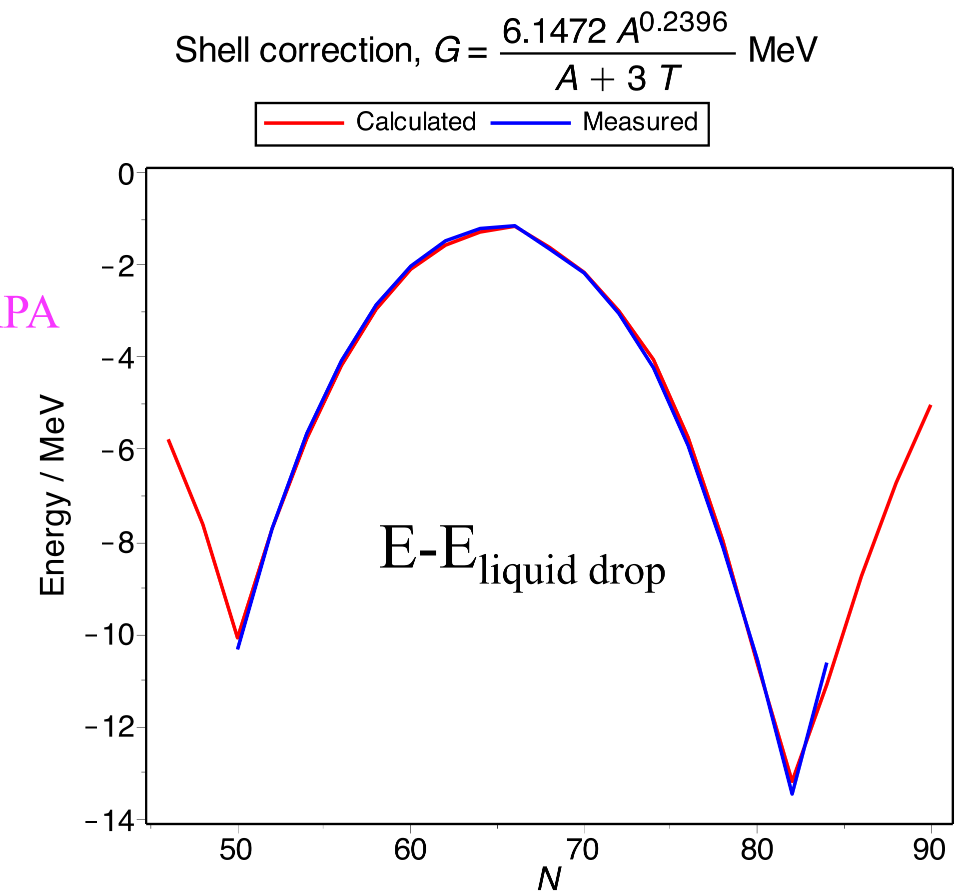




Pure isovector
$G_V = G$
$G_S = 0$

$$E_S(A,T) = \text{constant} + \frac{T(T+X)}{2\theta}$$






Perfect match from N=Z to N=32+Z

WS+shell correction +T=1 pair field+interpolated RPA

Sn isotopes

K. Neergard, to be published

# Pure isovector pairing approaches that exactly conserve isospin describe the binding and excitation energies in detail, including the Wigner X term and local fluctuations.

8 levels diagonalization I. Bentley, S. F. PRC 88, 014322 (2013)

Micro-Macro for shell structure and deformation interpolated QRPA
K. Neergard, I. Bentley, S. F., PRC 89, 034302 (2014)
K. Neergard, NUCLEAR THEORY, Vol. 36 (2017)
eds. M. Gaidarov, N. Minkov, Heron Press, Sofia and private communicatio

No new parameters compared to standard N>>Z approach.
Strength of T=1 interaction adjusted to
ee-oo mass differences or eo mass differences.

# T=1 and T=0 pairing in a simple model Hamiltonian

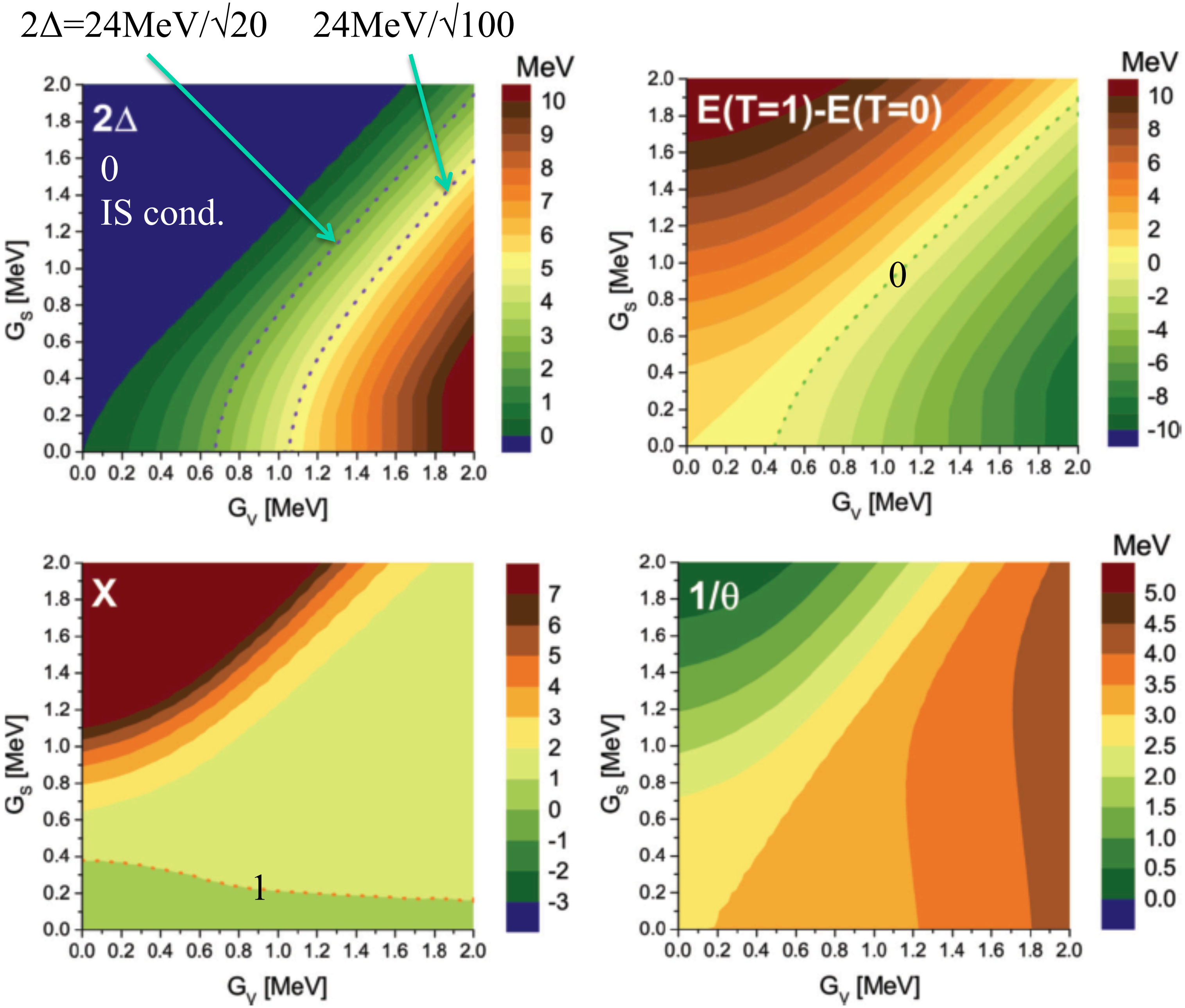
$$H = h_{nilsson} - G_v \sum_{M_T} P^+_{M_T} P_{M_T} - G_S D^+ D$$

$$P^+_{-1} = \sum_i c^+_{pi} c^+_{p\bar{i}} \quad P^+_0 = \frac{1}{\sqrt{2}} \sum_i c^+_{pi} c^+_{n\bar{i}} - c^+_{p\bar{i}} c^+_{ni} \quad P^+_1 = \sum_i c^+_{ni} c^+_{n\bar{i}}$$

$$D^+ = \frac{1}{\sqrt{2}} \sum_i c^+_{pi} c^+_{n\bar{i}} + c^+_{p\bar{i}} c^+_{ni}$$

8 levels diagonalization
I. Bentley, S. F. PRC 88, 014322 (2013)

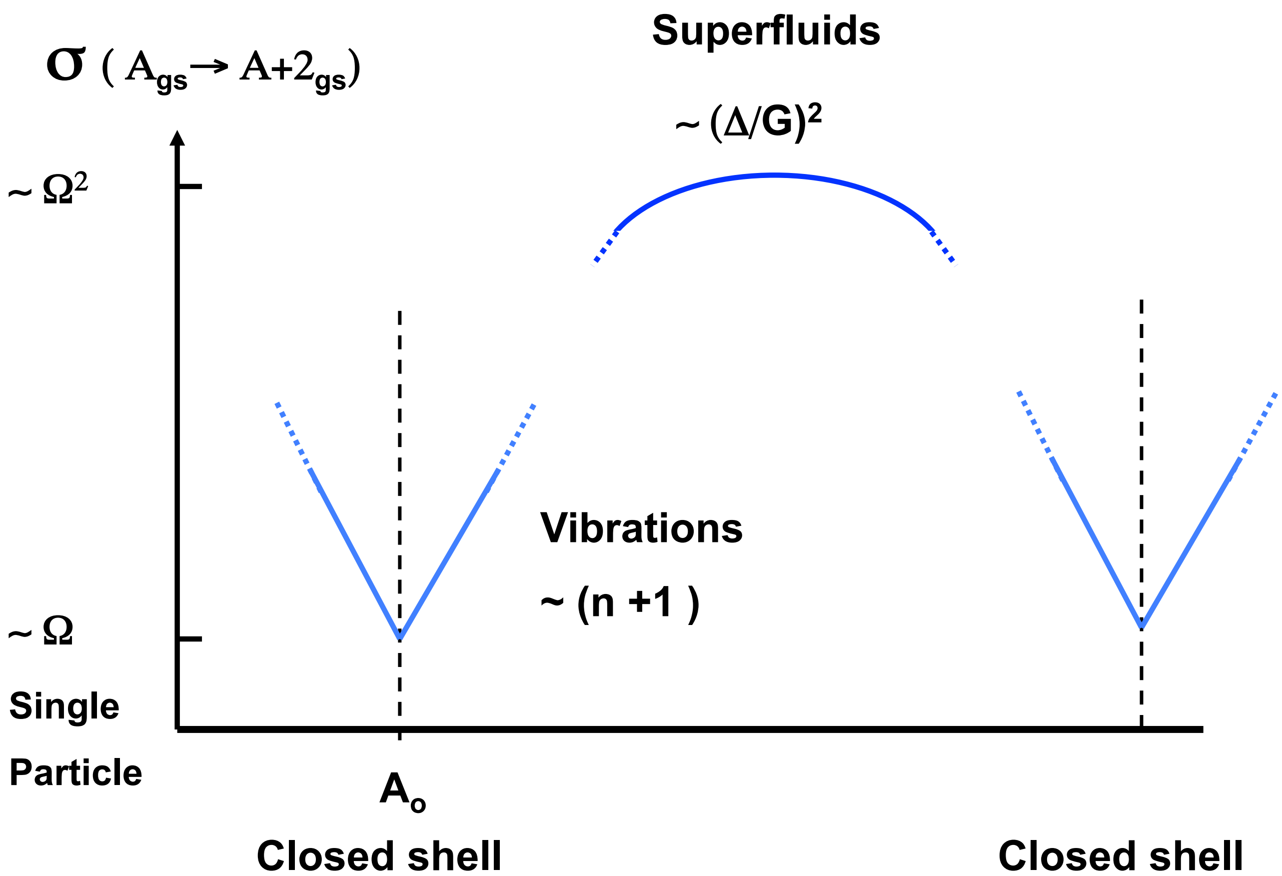
Switch on the the isoscalar interaction




There is room for dynamic isoscalar pair correlations.

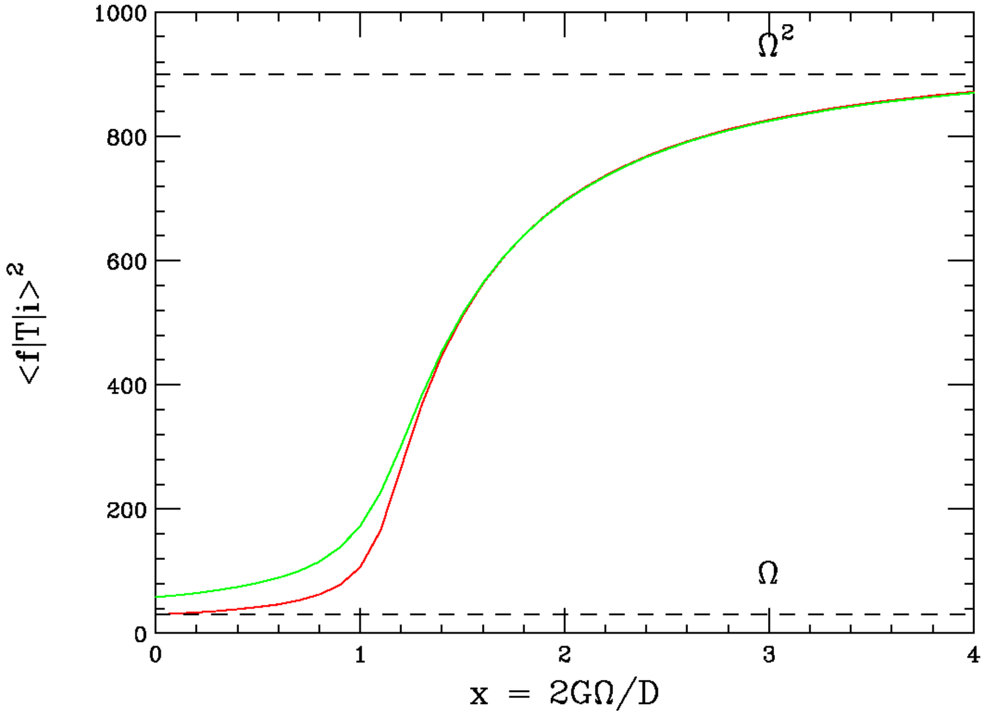
# Pair transfer strength

Collectively enhanced by the pair correlations
Enhancement is the most direct signature.




Systematic relative measurements and within a given nucleus.

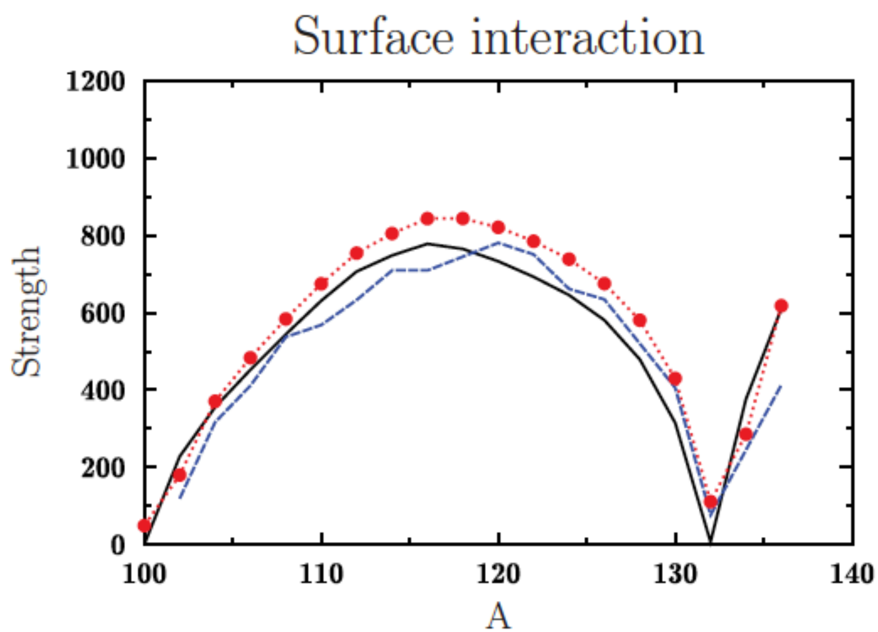
# The results from the Two j-shells model



PHYSICAL REVIEW C **85**, 034317 (2012)

## Pair-transfer probability in open- and closed-shell Sn isotopes

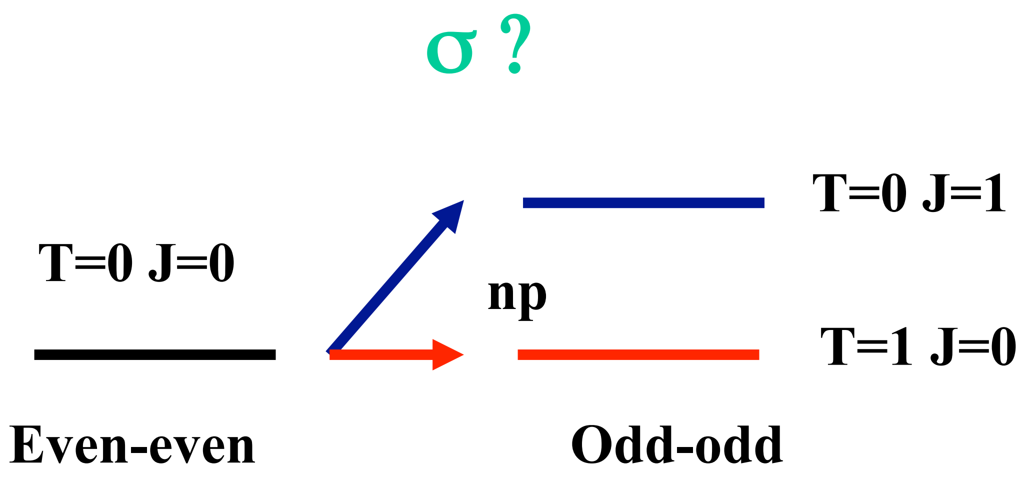
M. Grasso,[1] D. Lacroix,[2] and A. Vitturi[3,4]
[1]*Institut de Physique Nucléaire, IN2P3-CNRS, Université Paris-Sud, F-91406 Orsay Cedex, France*
[2]*Grand Accélérateur National d'Ions Lourds (GANIL), CEA/DSM-CNRS/IN2P3, Boulevard Henri Becquerel, F-14076 Caen, France*
[3]*Dipartimento di Fisica G. Galilei, via Marzolo 8, I-35131 Padova, Italy*
[4]*Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Padova, via Marzolo 8, I-35131 Padova, Italy*




Mean field approximation, surface delta interaction

- Only N-projected mean field or simple 1 or 2 shell model calculations on the market.
- Realistic Shell Model not yet applied to pair transfer.
- Measurement of absolute enhancement is difficult
- Ratio of IS/IV enhancement is easier and interesting because the IV strength is well established

# ($^3$He,p) Transfer Reactions

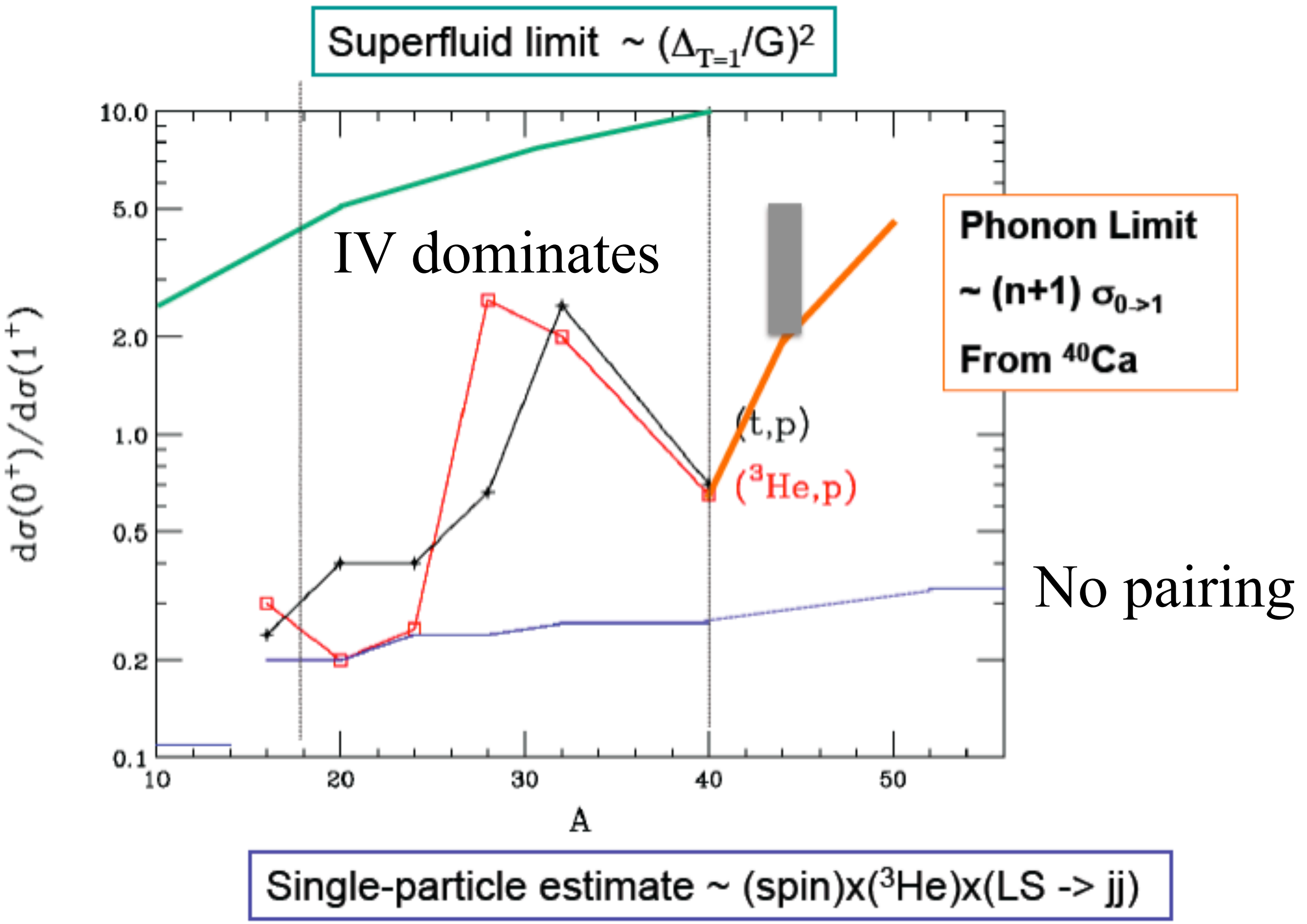



**($^3$He,p) -** L=0 transfer

**Measure the *np* transfer cross section to T=1 and T=0 states**

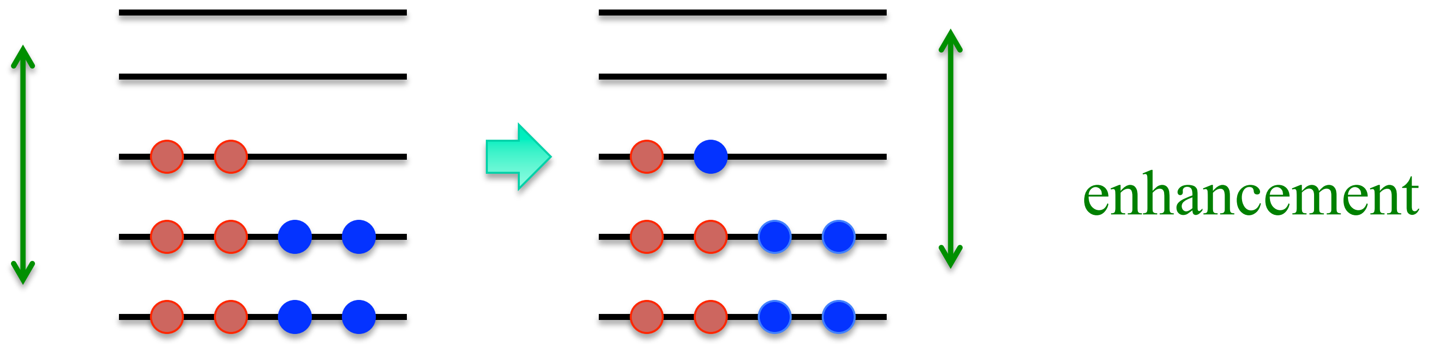
**Both absolute σ(T=0) and σ(T=1) and relative σ(T=0) / σ(T=1) tell us about the character and strength of the correlations**

# Does a beyond- m. f. IV scenario account for experiment?




Ratio between the cross sections for transfer of an IV pair and an IS pair from ee $0^+_1$ to the $0^+_1$ and the $1^+_1$ states in the oo.

# GT - transitions



$\beta^+$ decay

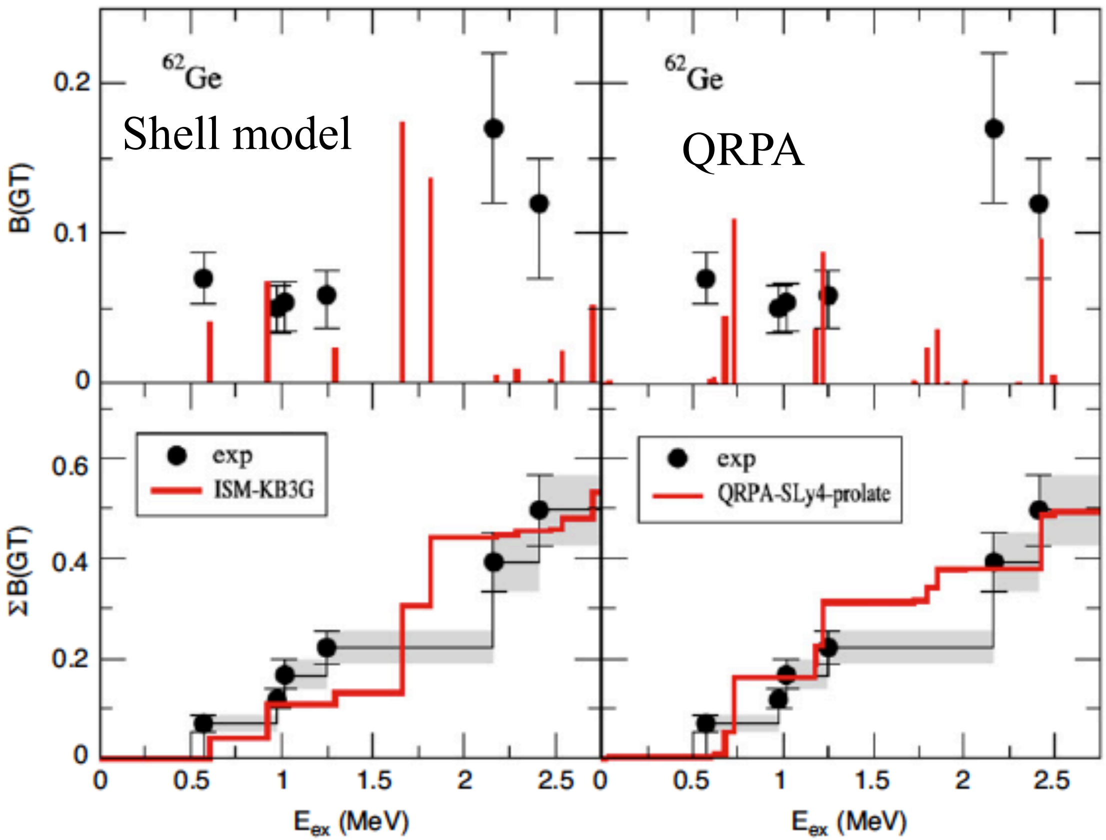



**Fig. 50.** Experimental (black color) and calculated (red color) single level $B(GT)$ and accumulated $B(GT)$ values for the $\beta^+$ decay $^{62}Ge \rightarrow {}^{62}Ga$: left panels with the Shell Model calculations using the KB3G interaction and right panels with the QRPA approach of Ref. [168]. Experimental uncertainty corridors are indicated in gray. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
*Source:* From Ref. [172].

QRPA with isoscalar paring interaction with coupling constant $G_S$=0.3 $G_{critical}$ for onset of isoscalar condensate.

Other QRPA studies of $\beta^+$ decay, $\beta^+\beta^+$ decay, and $\beta^-$ decay of neutron-rich nuclei require dynamical isoscalar pair correlation to reproduce data.

Charge exchange reactions A($^3$He,$^3$H)A test the influence of pairing correlations on the GT matrix element in a different energy range

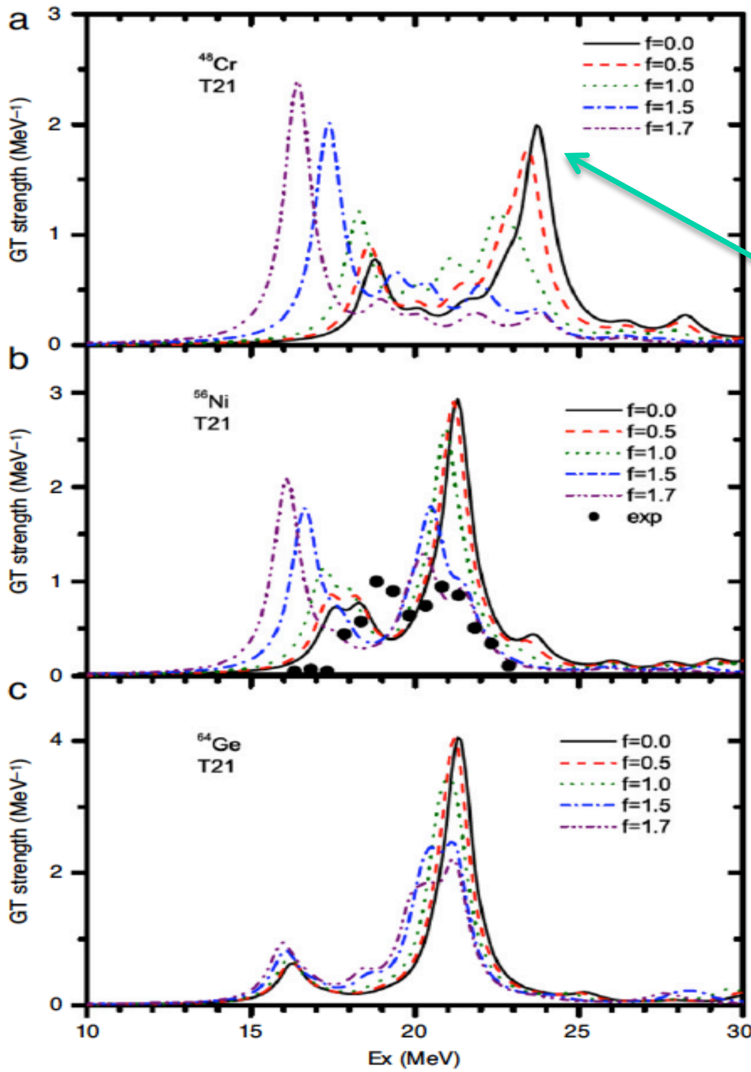



**Fig. 51.** GT strength in $^{48}$Cr, $^{56}$Ni and $^{64}$Ge by HFB + QRPA with the Skyrme interaction. *Source:* From Ref. [176].

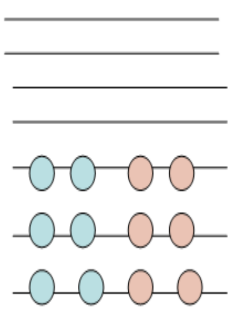
HFB+QRPA calculations
Uncertainty:
Competition of the
GT resonance in pp channel
with isoscalar pair
correlations

# Quarteting

# Isospin conservation and quarteting

$$H = \sum_i \varepsilon_i (N_i^{(\nu)} + N_i^{(\pi)}) + \sum_{ij,\tau} V(i,j) P^+_{i,\tau} P_{j,\tau}$$

$$P^+_{i1} \propto \nu^+_i \nu^+_{\bar{i}} \qquad P^+_{i-1} \propto \pi^+_i \pi^+_{\bar{i}} \qquad P^+_{i0} \propto \nu^+_i \pi^+_{\bar{i}} + \pi^+_i \nu^+_{\bar{i}}$$




***non-collective quartets***

$$Q^+_{ij} = [P^+_{i\tau} P^+_{j\tau'}]^{T=0} \propto P^+_{\nu\nu,i} P^+_{\pi\pi,j} + P^+_{\pi\pi,i} P^+_{\nu\nu,j} - P^+_{\nu\pi,i} P^+_{\nu\pi,j}$$

**collective quartet**

$$Q^+ = \sum_{ij} x_{ij} [P^+_{i\tau} P^+_{j\tau'}]^{T=0}$$

***quartet condensate***

$$|QCM> = Q^{+n_q} |->$$ (has T=0, J=0)

# Quartet condensation and Cooper pairs

$$|QCM\rangle = Q^{+n_q}|-\rangle \qquad Q^+ = \sum_{ij} x_{ij}[P^+_{i\tau}P^+_{j\tau'}]^{T=0}$$

$$Q^+ = 2\Gamma^+_{\nu\nu}\Gamma^+_{\pi\pi} - \Gamma^+_{\nu\pi}\Gamma^+_{\nu\pi} \qquad \Gamma^+_\tau = \sum_i x_i P^+_{i,\tau}$$

collective pairs

$$\boxed{|QCM\rangle = (2\Gamma^+_{\nu\nu}\Gamma^+_{\pi\pi} - \Gamma^+_{\nu\pi}\Gamma^+_{\nu\pi})^{n_q}|-\rangle}$$

'coherent' mixing of condensates formed by nn, pp and pn pairs

$$|PBCS0\rangle \propto (\Gamma^{+2}_{\nu\pi})^{n_q}|-\rangle \qquad |PBCS1\rangle \propto (\Gamma^+_{\nu\nu}\Gamma^+_{\pi\pi})^{n_q}|-\rangle$$

*calculations*

$$\delta_x \langle QCM|H|QCM\rangle = 0$$

method of recurence relations

# Quartet condensation versus pair condensation

$$H = \sum_i \varepsilon_i N_i + \sum_{ij} V_{J=0}^{T=1}(i,j) \sum_t P_{it}^+ P_{jt}$$

pairing forces extracted from SM interactions

$$|QCM> \equiv (Q^+)^{n_q} |->$$ $$|PBCS1> \propto (\Gamma_{\nu\nu}^+ \Gamma_{\pi\pi}^+)^{n_q} |->$$ $$|PBCS0> \propto (\Gamma_{\nu\pi}^{+2})^{n_q} |->$$

| | SM | QCM | PBCS1 | PBCS0 |
|---|---|---|---|---|
| $^{20}$Ne | 9.173 | 9.170 (0.033%) | 8.385 (8.590%) | 7.413 (19.187%) |
| $^{24}$Mg | 14.460 | 14.436 (0.166%) | 13.250 (8.368%) | 11.801 (18.389%) |
| $^{28}$Si | 15.787 | 15.728 (0.374%) | 14.531 (7.956%) | 13.102 (17.008%) |
| $^{32}$S | 15.844 | 15.795 (0.309%) | 14.908 (5.908%) | 13.881 (12.389%) |
| $^{44}$Ti | 5.973 | 5.964 (0.151%) | 5.487 (8.134%) | 4.912 (17.763%) |
| $^{48}$Cr | 9.593 | 9.569 (0.250%) | 8.799 (8.277%) | 7.885 (17.805%) |
| $^{52}$Fe | 10.768 | 10.710 (0.539%) | 9.815 (8.850%) | 8.585 (20.273%) |
| $^{104}$Te | 3.831 | 3.829 (0.052%) | 3.607 (5.847%) | 3.356 (12.399%) |
| $^{108}$Xe | 6.752 | 6.696 (0.829%) | 6.311 (6.531%) | 5.877 (12.959%) |
| $^{112}$Ba | 8.680 | 8.593 (1.002%) | 8.101 (6.670%) | 13.064 (13.064%) |

Conclusions

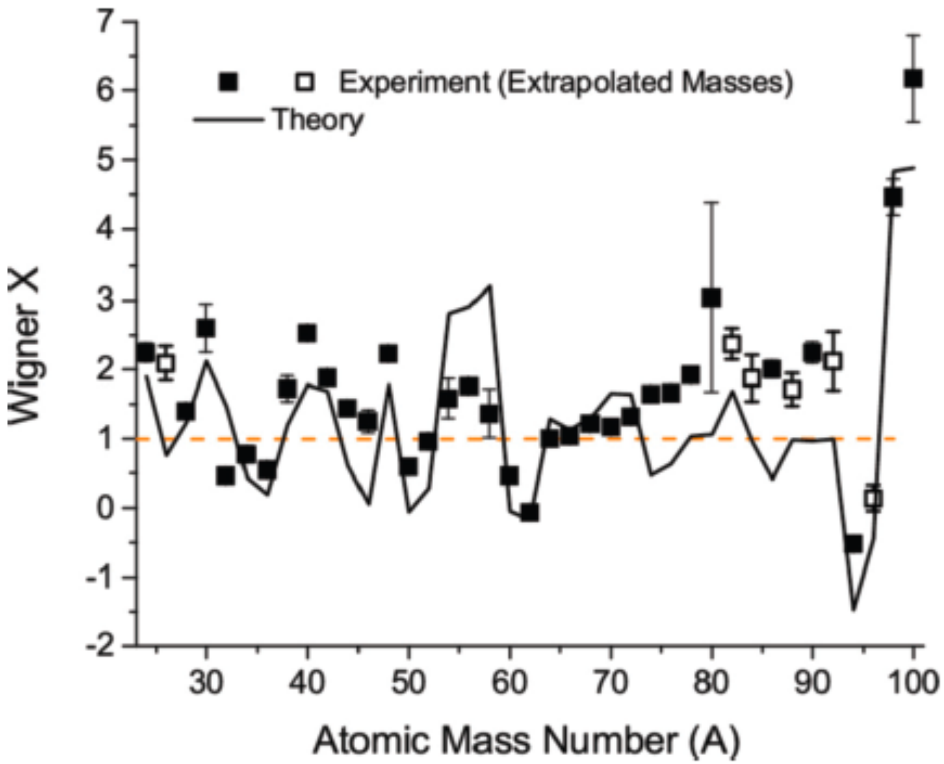
- *T=1 pairing is accurately described by quartets, not by pairs*
- *there is not a pure condensate of isovector pn pairs in N=Z nuclei*

States with good isospin always contain a mixture of Γππ, Γνν, Γπν.
How different are $P_{TM=0}P_A$|T=1 MF> and |QCM>?

N. S, D. Negrea, J. Dukelsky, C.W. Johnson, PRC85, 061303(R) (2012)

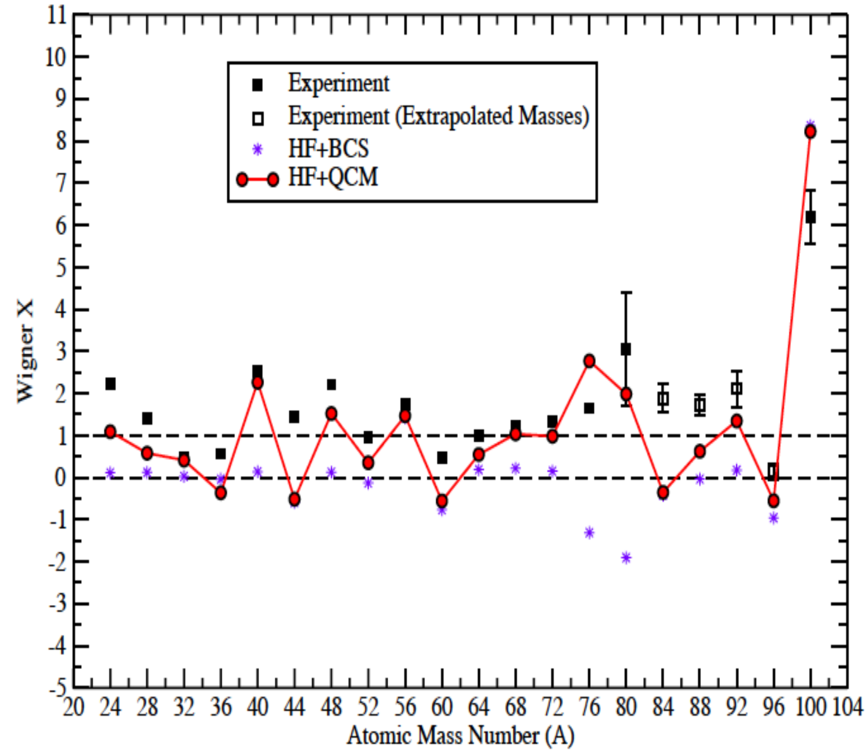
# Wigner energy: comparison with earlier calculations

$$H_V = \sum_k \epsilon_k \hat{N}_k - G_V \sum_{kk',\tau} \hat{P}^+_{k,\tau} \hat{P}_{k',\tau} + C\vec{T}\cdot\vec{T}$$




Bentley & Frauendorf PRC(2013)

$$H_V = \sum_k \epsilon_k \hat{N}_k - G_V \sum_{kk',\tau} \hat{P}^+_{k,\tau} \hat{P}_{k',\tau}$$




Negrea & Sandulescu PRC(2014)

# Isovector (J=0) pairing versus isoscalar (J=1) pairing

$$|QM\rangle = \prod_{\nu=1}^{N_Q} Q_\nu^\dagger |0\rangle. \qquad Q_\nu^+ = Q_\nu^{+(iv)} + Q_\nu^{+(is)}$$

$$|is\rangle = \prod_{\nu=1}^{N_Q} Q_\nu^{\dagger(is)} |0\rangle \qquad |iv\rangle = \prod_{\nu=1}^{N_Q} Q_\nu^{\dagger(iv)} |0\rangle$$

| | QM | iv | is | $< QM\|iv >$ | $< QM\|is >$ | $< iv\|is >$ |
|---|---|---|---|---|---|---|
| $^{20}$Ne | 15.985 | 14.402 (9.9%) | 15.130 (5.35%) | 0.884 | 0.953 | 0.843 |
| $^{24}$Mg | 28.625 | 23.269 (18.71%) | 26.925 (5.94%) | 0.650 | 0.910 | 0.336 |
| $^{28}$Si | 35.386 | 28.896 (18.34%) | 33.377 (5.68%) | 0.590 | 0.910 | 0.341 |
| $^{32}$S | 38.844 | 33.958 (12.58%) | 37.881 (2.48%) | 0.640 | 0.974 | 0.587 |
| $^{44}$Ti | 7.02 | 6.27 (10.6%) | 4.92 (30%) | 0.90 | 0.68 | 0.3 |
| $^{48}$Cr | 11.624 | 10.59 (8.9%) | 7.38 (36.5%) | 0.906 | 0.497 | 0.22 |
| $^{52}$Fe | 13.823 | 12.814 (7.3%) | 9.98 (27.83%) | 0.927 | 0.753 | 0.74 |
| $^{104}$Te | 3.147 | 3.041 (3.37%) | 1.549 (50.78%) | 0.978 | 0.489 | 0.314 |
| $^{108}$Xe | 5.495 | 5.240 (4.64%) | 2.627 (52.19%) | 0.958 | 0.354 | 0.234 |
| $^{112}$Ba | 7.035 | 6.614 (5.98%) | 4.466 (36.52%) | 0.939 | 0.375 | 0.376 |

T=1 and T=0 pairing correlations always coexist
&
difficult to disentangle

T=1 correlations dominate, some T=0 correlations ⟷ T=1 condensate+dynamical T=0

M. Sambataro, N.S. and C.W.Johnson, Phys. Lett. B740 (2015)137

# A<100: T=1 condensate combined with dynamical T=0 correlations

- The binding energies show iso-rotational pattern
- The N=Z odd-odd spectra have low density
- The rotational spectra can be quantitatively described by conventional mean-field without explicit pn-pairing, some indication for T=0 correlations
- Cross section for IV pair transfer larger than for IS pair transfer.
- Dynamical T=0 correlations->GT, M1