np Pairing Correlations in Single-l and Single-j Shell Models.*

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Introduction

Brief summary of data on binding energy differences and ground states of odd-odd N=Z nuclei

Discussion of the single l-shell model

Discussion of the single j-shell model

Role of the spin-orbit splitting

Conclusions and future work

The (^{3}He,p) transfer reaction

Discussion of systematics

Conference on "Nuclei at the Limits"
Argonne National Laboratory - July 26-30, 2004

Motivation

N=Z nuclei, unique systems to study *np* correlations.

☆ **Role of isoscalar (T=0) and isovector (T=1) pairing**

Large spatial overlap of *n* and *p*

Pairing vibrations (normal system)
Pairing rotations (superfluid system)

Does isoscalar pairing give rise to collective modes?

As you move out of N=Z *nn* and *pp* pairs are favored

☆ **What is (are) the "smoking-gun(s)"?**

Binding energy differences
Ground states of odd-odd self-conjugate nuclei

Rotational properties: moments of inertia, delayed alignments

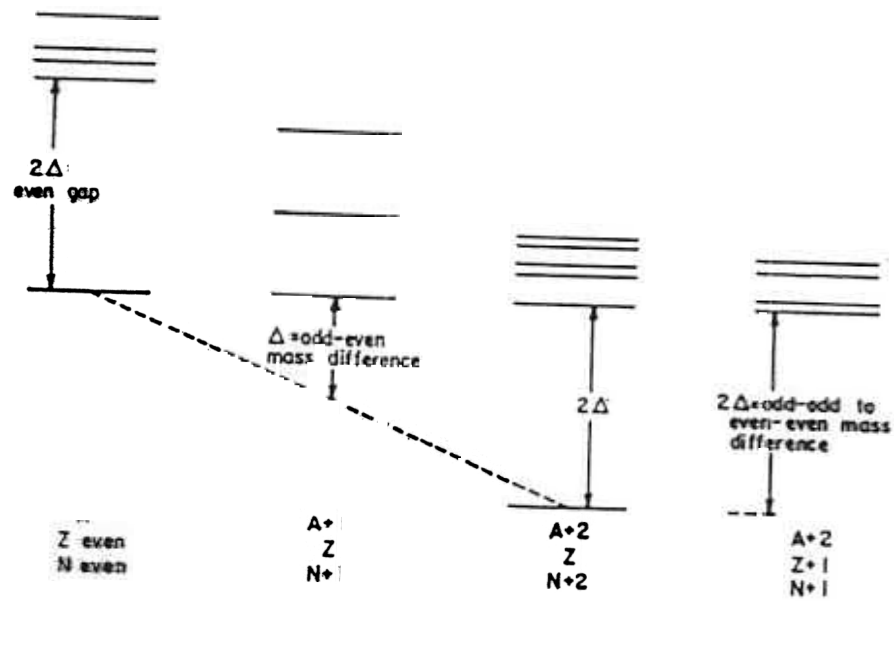
Two-particle transfer cross-sections

$$E \sim -G\left(N - \frac{v}{2}\right)\Omega = -\left(N - \frac{v}{2}\right)(2\Delta)$$

pairs

seniority

E_x



BE

$BE_{\text{even even}}$ $BE_{\text{odd odd}} \approx \Delta_p + \Delta_n$

$\langle BE \rangle_{ee}$ $BE_{oo}(N\ Z)$

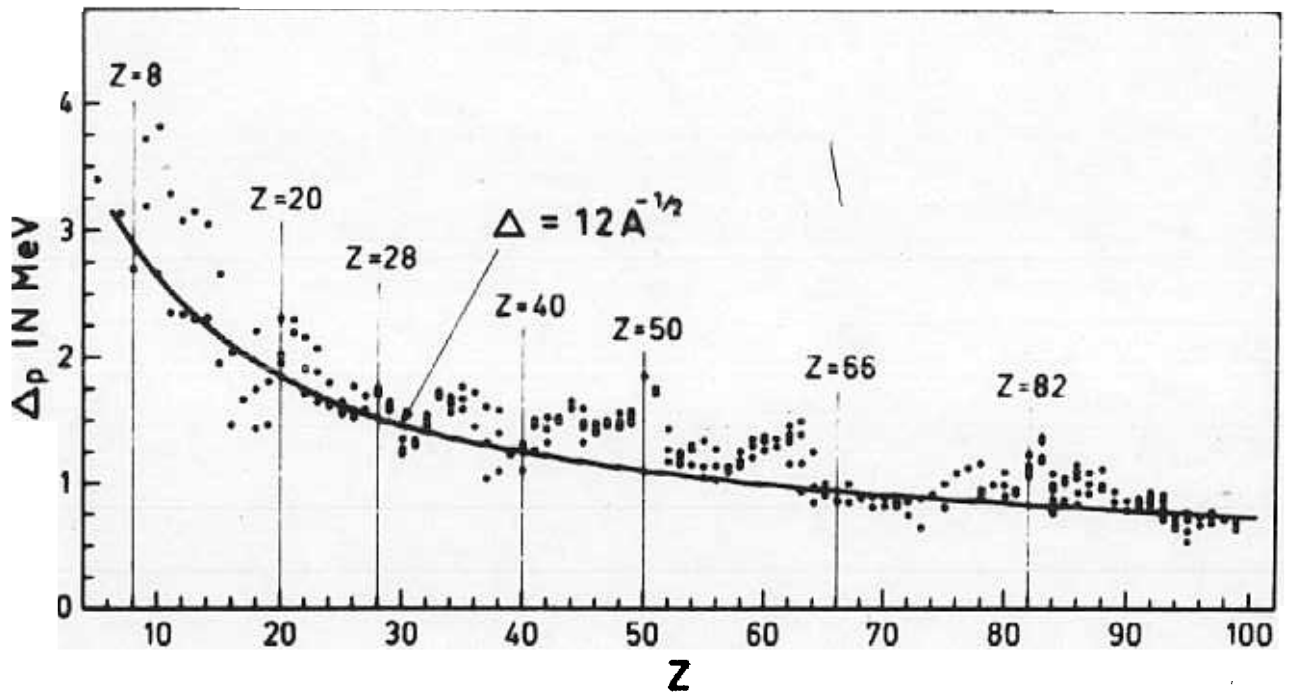
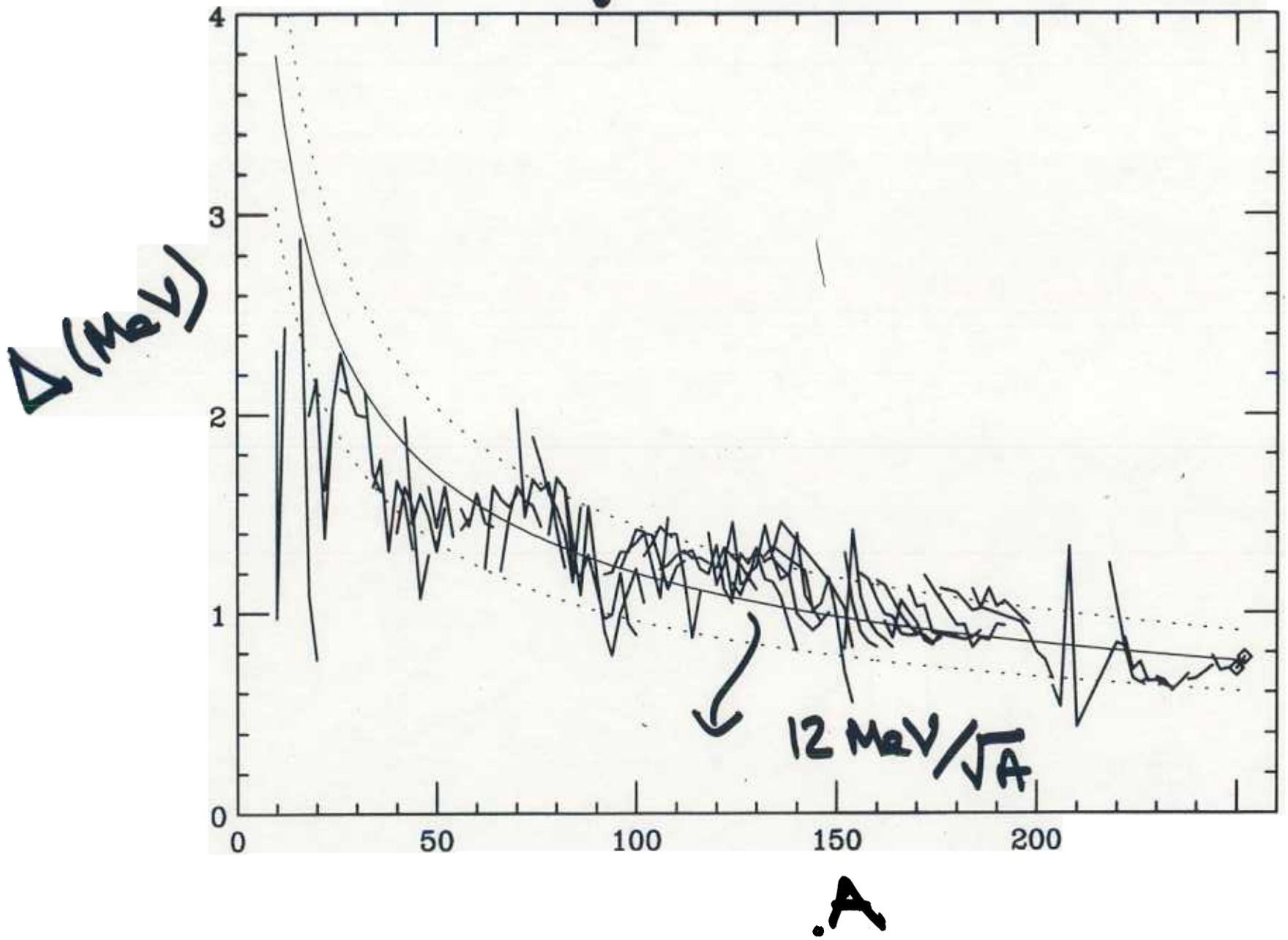
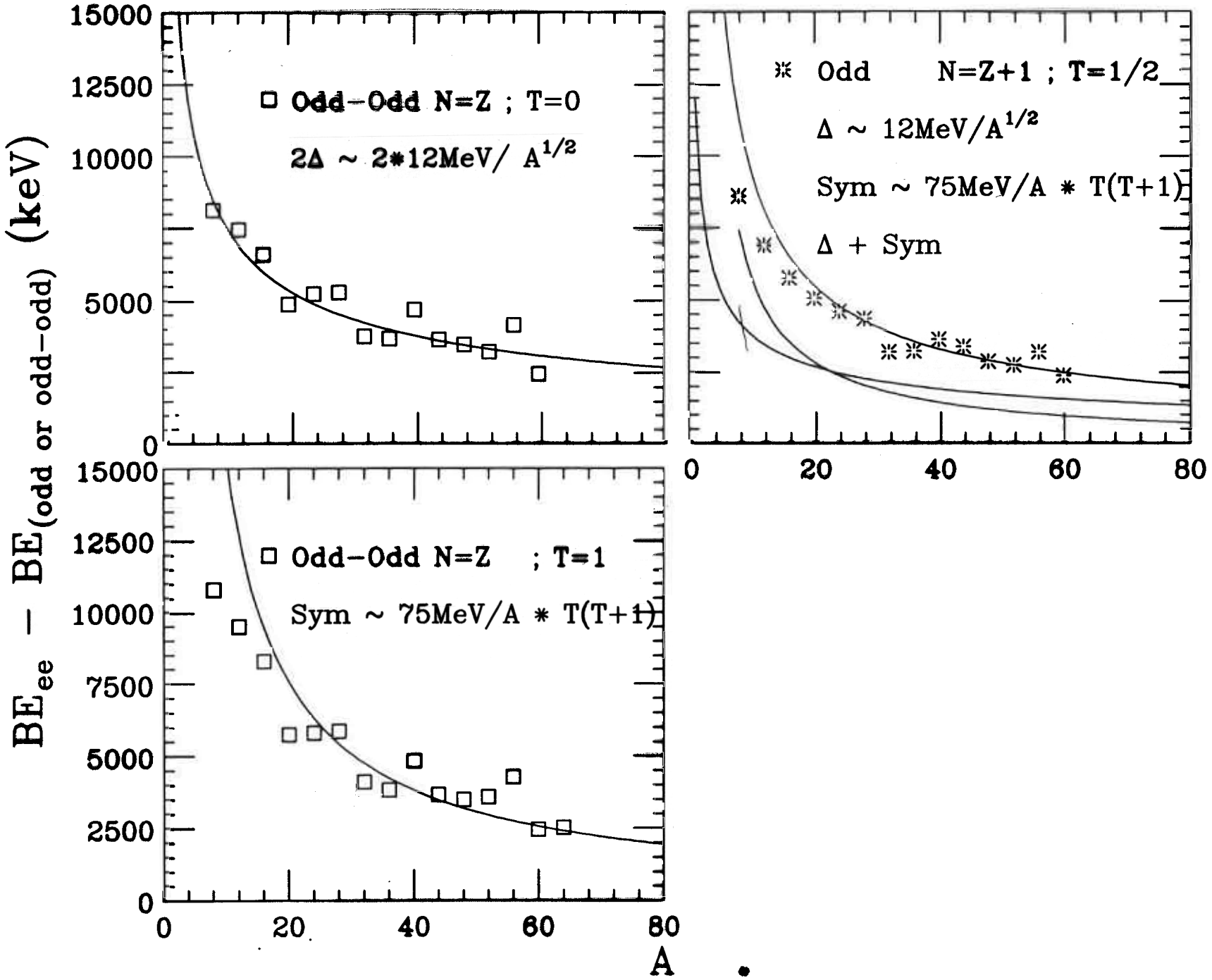


Figure 2-5 The odd-even mass differences for neutrons and protons are based on the analysis of N. Zeldes, A. Grill, and A. Simievic, *Mat. Fys. Skr. Dan. Vid. Selsk.* 3, No. 5 (1967).

$$\mathcal{F} = \mathcal{F}_{ng}(\varepsilon, A) * f(x) \qquad x = \varepsilon / 2\Delta$$




Odd-Odd N=Z ; T=0
2Δ ~ 2*12MeV/ A^1/2
Odd N=Z+1 ; T=1/2
Δ ~ 12MeV/A^1/2
Sym ~ 75MeV/A * T(T+1)
Δ + Sym
Odd-Odd N=Z ; T=1
Sym ~ 75MeV/A * T(T+1)
BE_ee − BE_(odd or odd-odd) (keV)
A
15000
12500
10000
7500
5000
2500
0
20
40
60
80

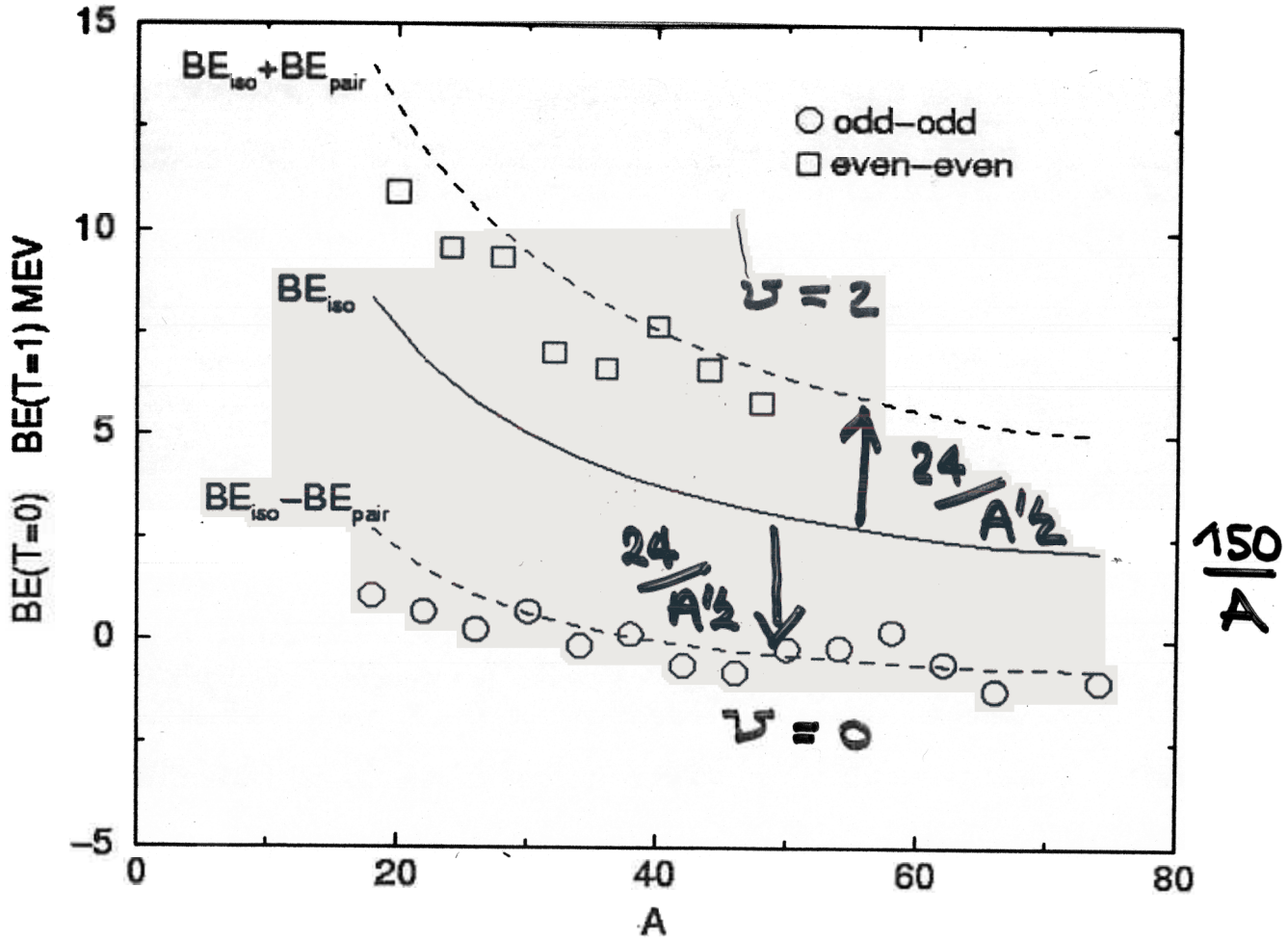
⇨ two ingredients

* isovector pairing gap $\Delta_{T=1}$
* Symmetry Energy $E_s(T)$

$N = Z$

ee		E_0
oo	$T=0$	$E_0 + 2\Delta_1 + E_s(0)$
	$T=$	$E_0 + 0 + E_s(1)$
[ee $T_z=$]		
ee	$T=1$	$E_0 + 2\Delta + E_s(1)$
oe	$T=1/2$	$E_0 + \Delta_1 + E_s(1/2)$

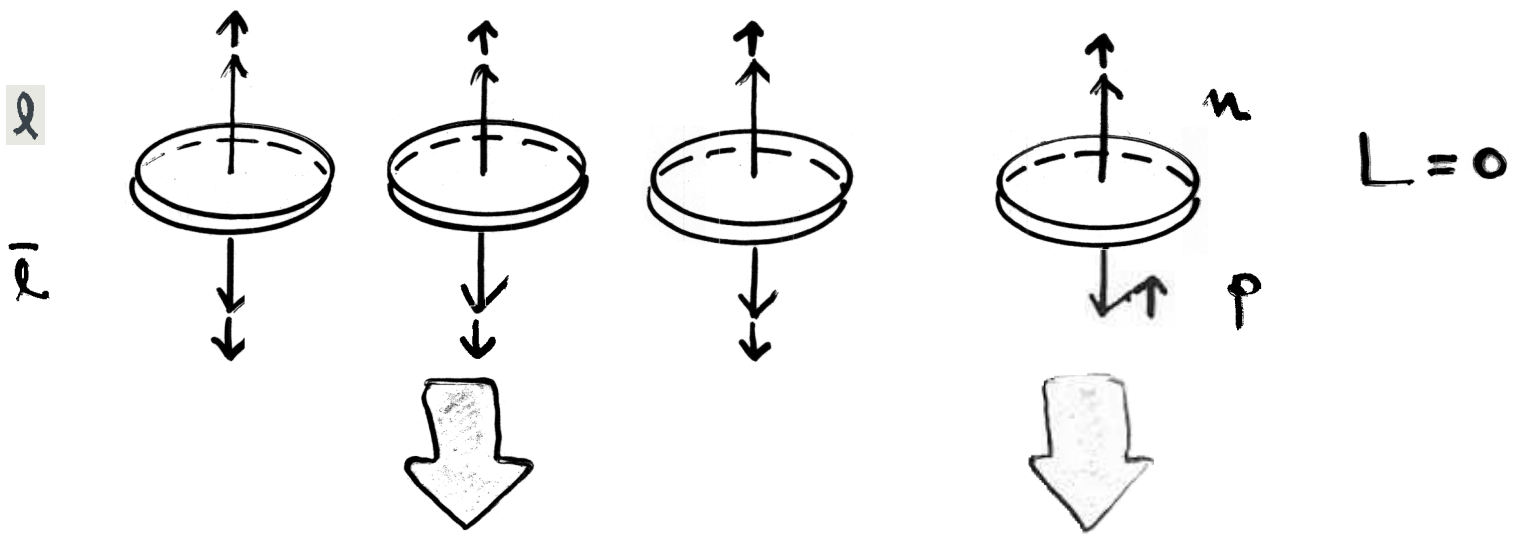
T=0 and T=1 states u N=Z nuclei



S.C. Pang NP A128 (69) 497
J.A. Evans et al. NP A367 (81) 77

Degenerate ℓ-shell

$$H = \underbrace{-G_1 \sum_{\mu} P^{+}_{\mu} P_{\mu}}_{\text{isovector}} \; \underbrace{- G_0 \sum_{m} D^{+}_{m} D_{m}}_{\text{isoscalar}}$$



$T=1 \quad S=0$

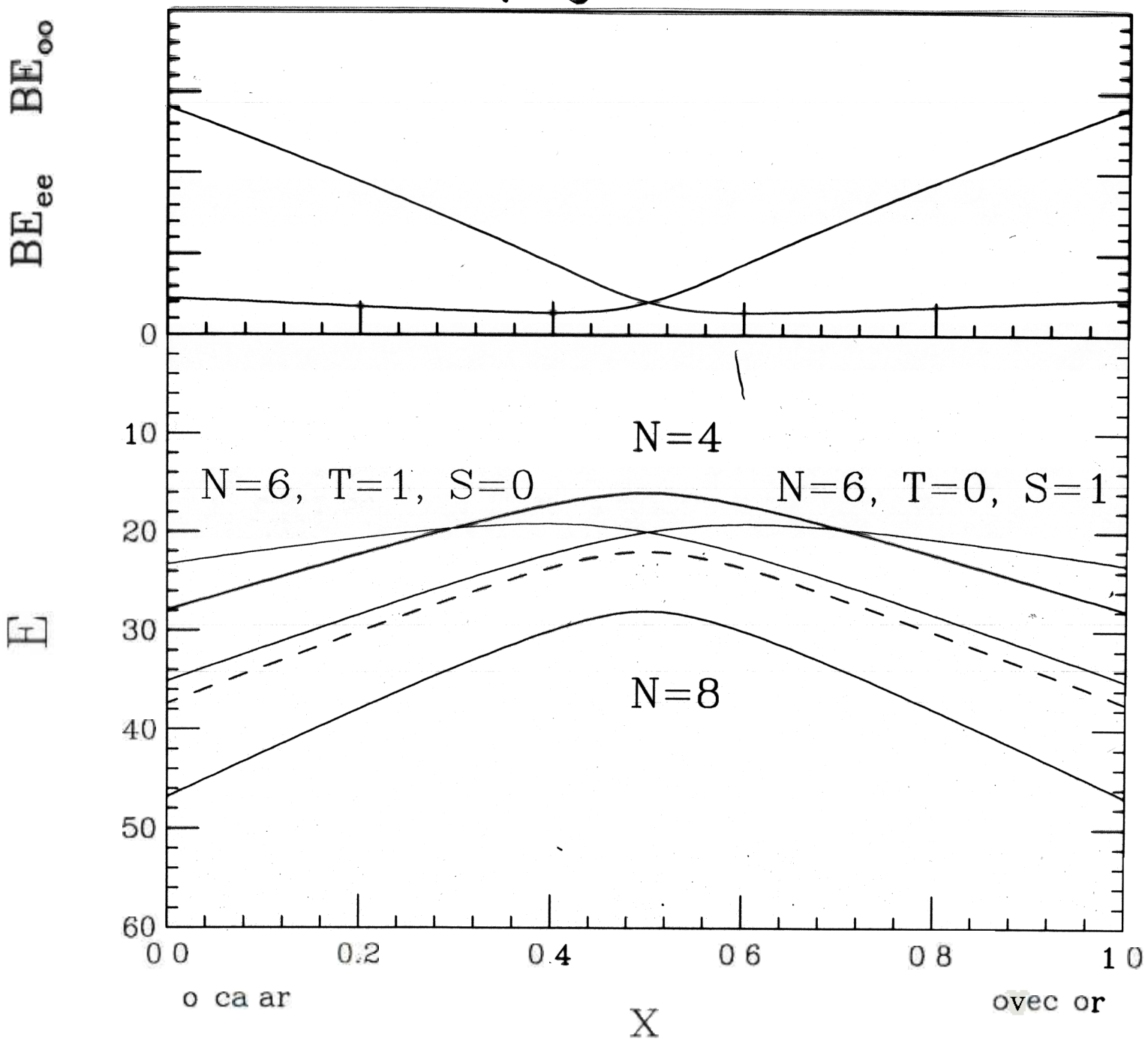
$T=0 \quad S=1$

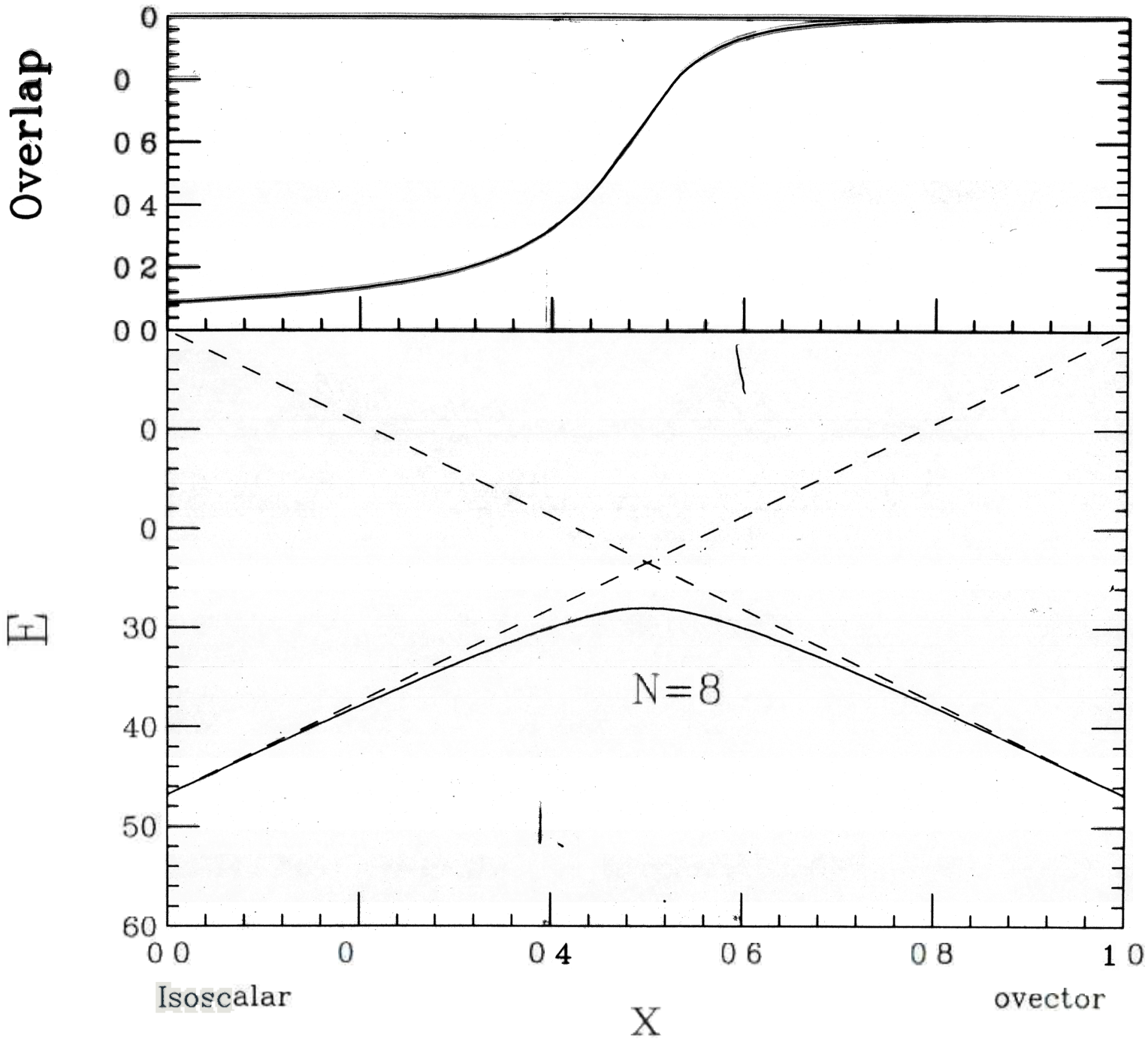
« deuteron-like pairs »

define $\quad \chi = \dfrac{G_1}{G_1 + G_0}$

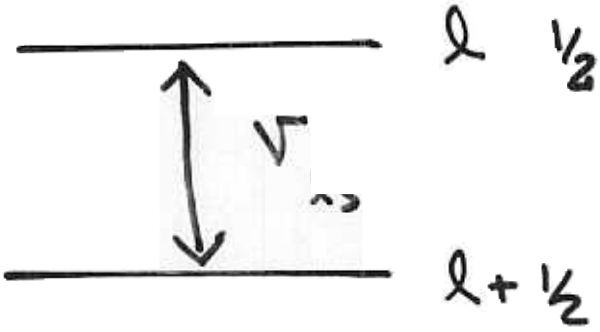
and look at $\quad \dfrac{H}{G} = \chi H_1 + (1-\chi) H_0$

X shell $\Omega = 6$




Overlap
0
0
0 6
0 4
0 2
0 0
E
0
0
30
40
50
60
N=8
0 0
0
0 4
0 6
0 8
1 0
Isoscalar
ovector
X

⇨ Now consider a j shell



L = 0 matrix elements

* $V_{ls} \to 0$ l-shell

* $V_{ls} \to \infty$ j shell

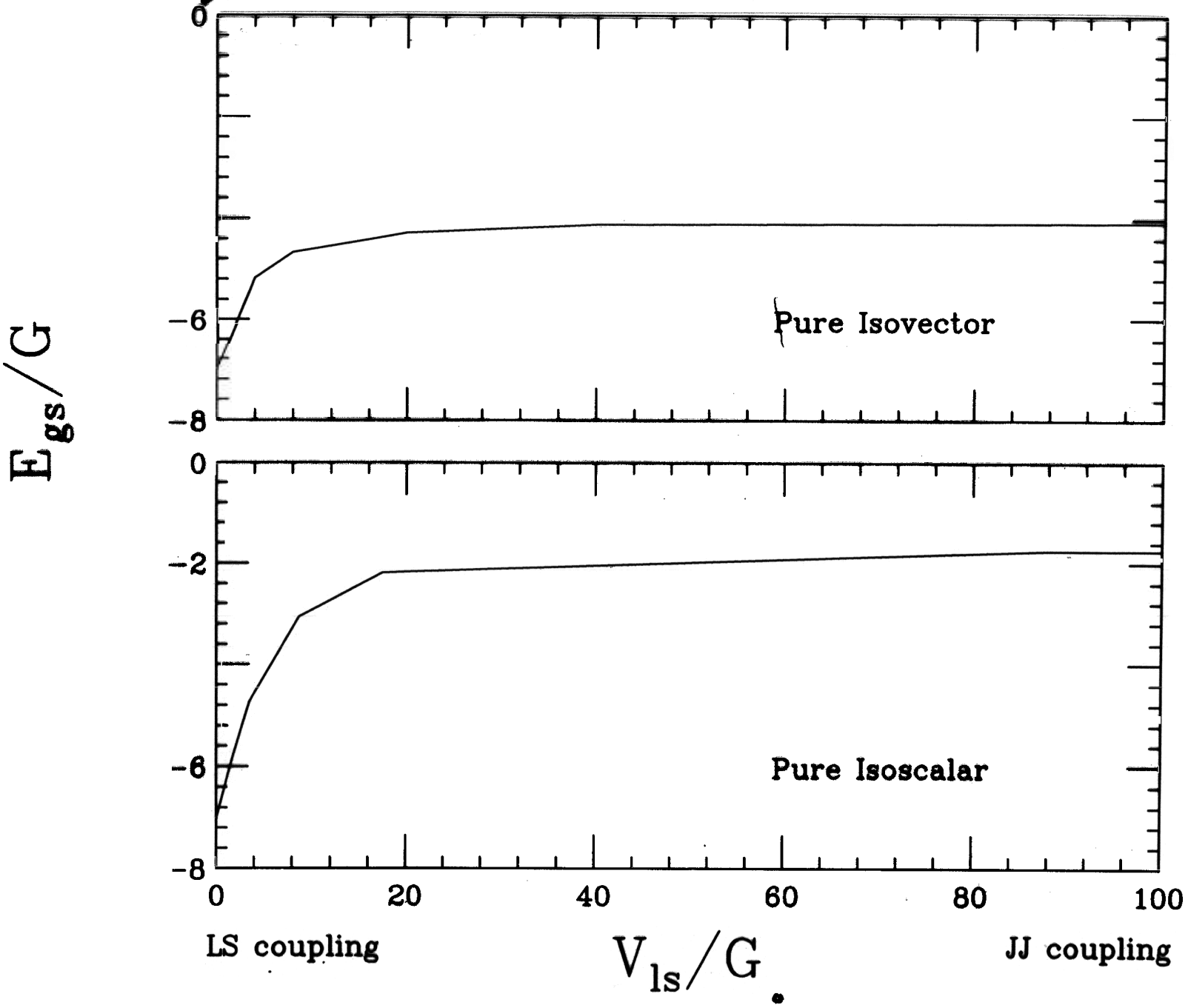
Use OXBASH

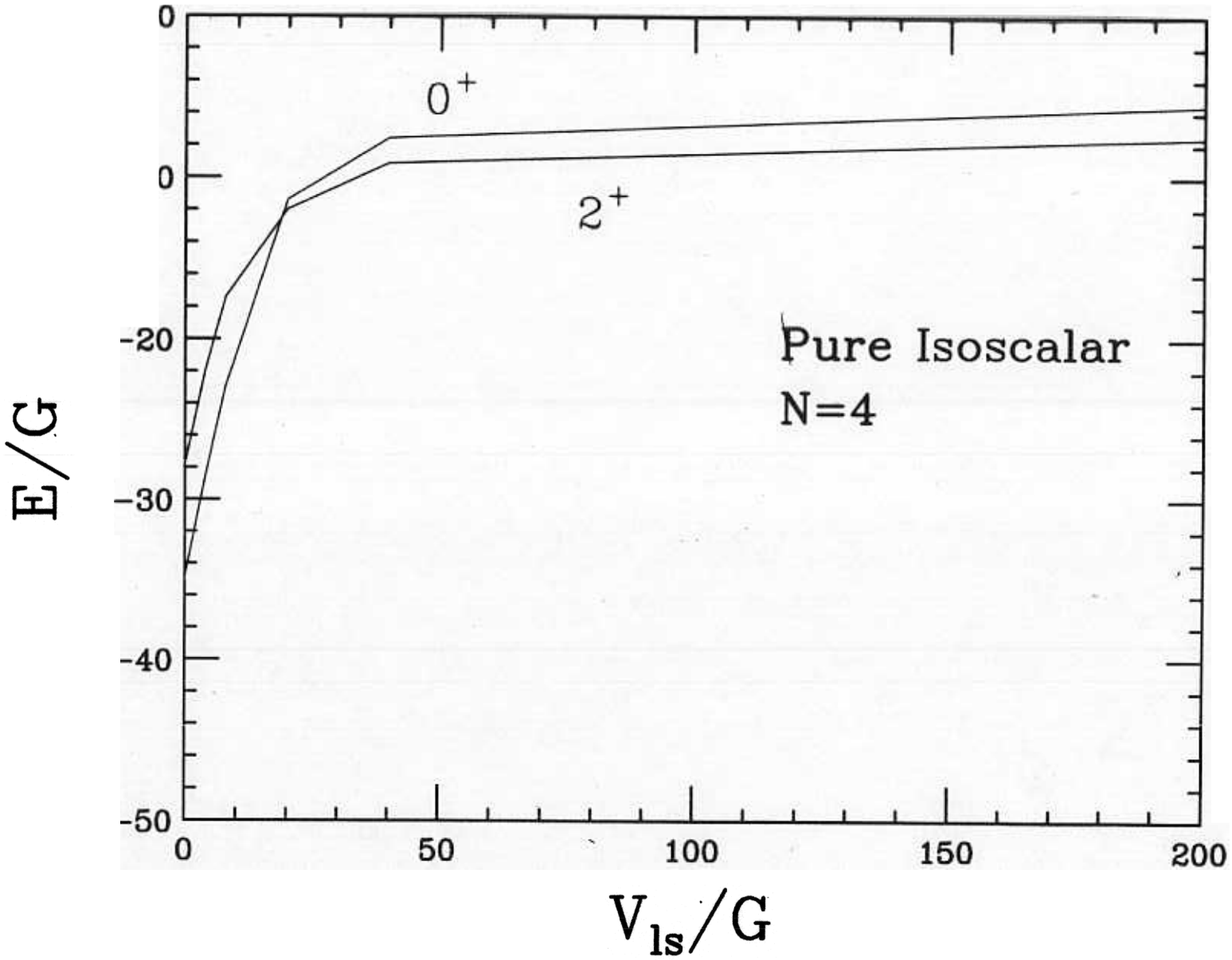
B.A. Brown et al
MSU Report 524 (1998)

$$V = x\, V^{T=}_{J=0} + (\quad x)\, V^{T=0}_{J=1}$$

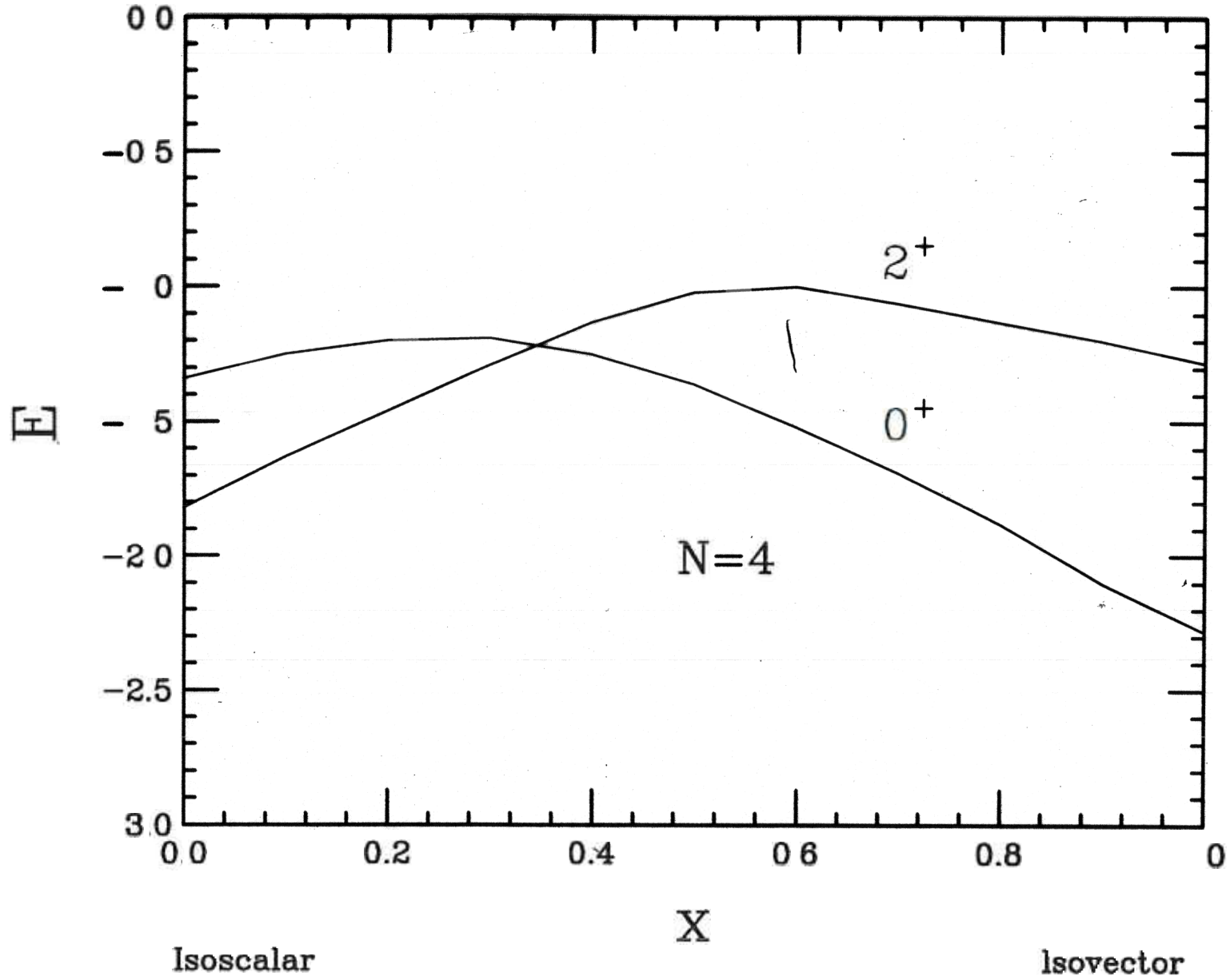
for j-shell

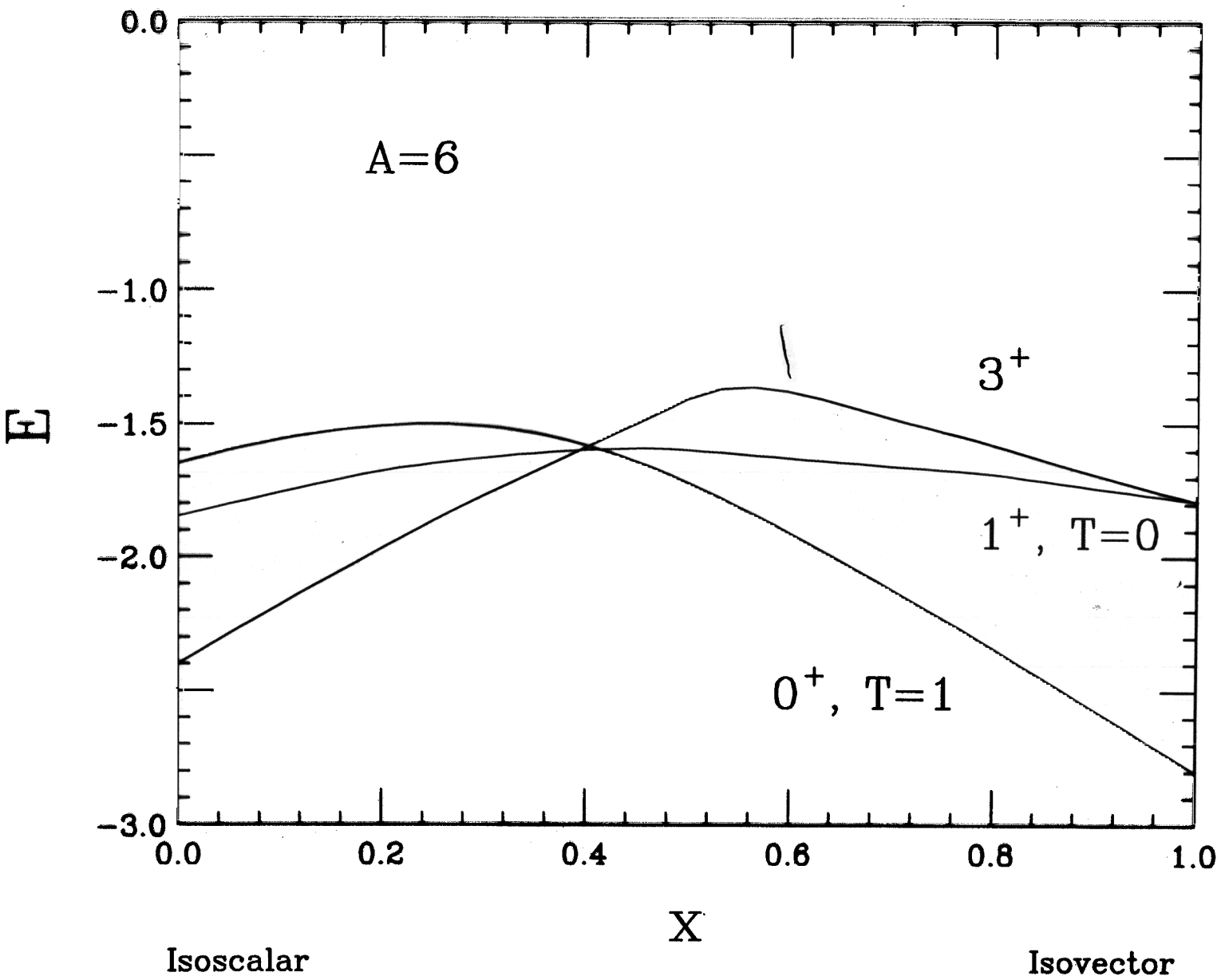
Two particles system



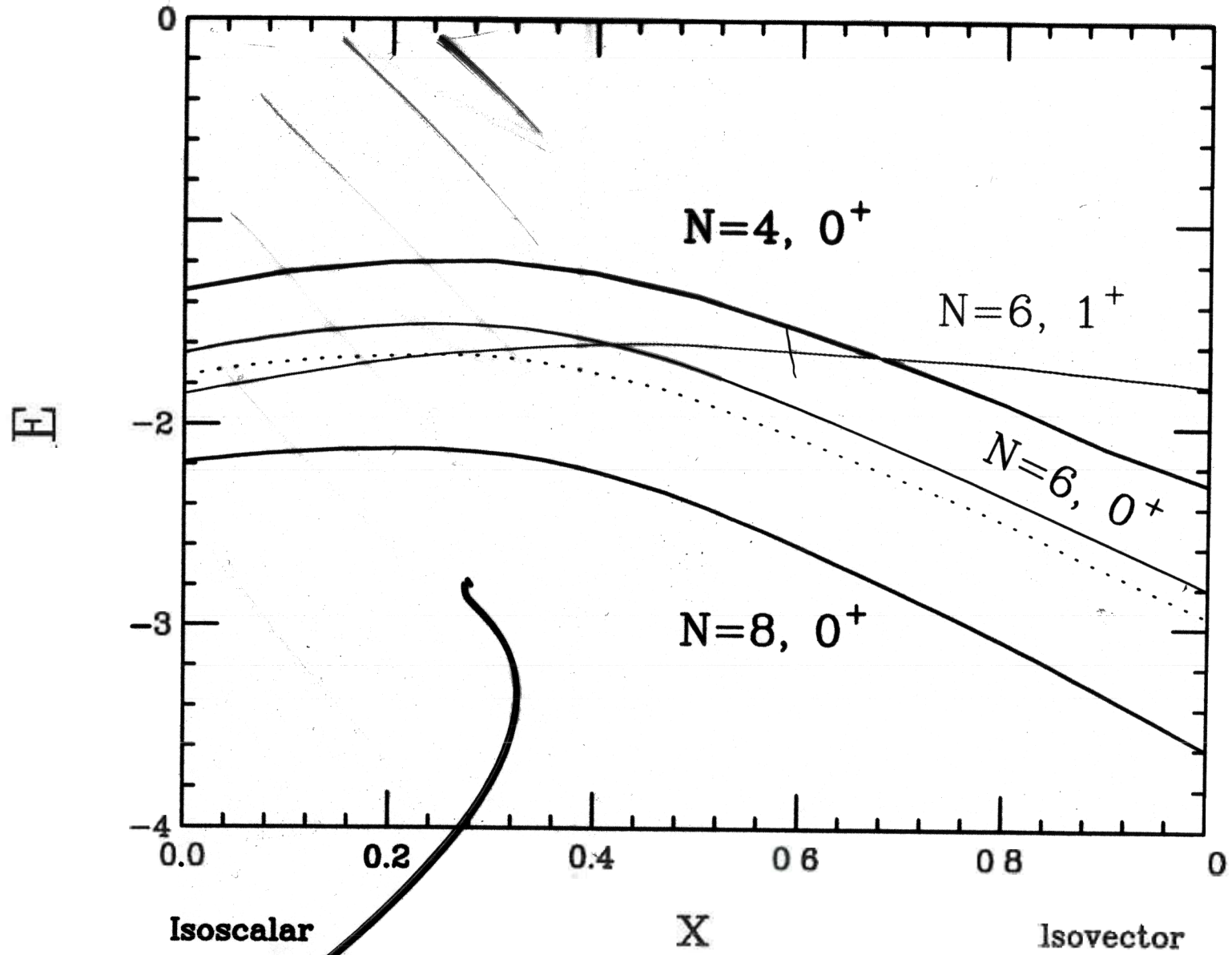


LS coupling **JJ coupling**


0 0
−0 5
− 0
− 5
−2 0
−2.5
3.0
E
0.0
0.2
0.4
0 6
0.8
0
X
2+
0+
N=4
Isoscalar
Isovector


A=6
3+
1+, T=0
0+, T=1
[T]
0.0
−1.0
−1.5
−2.0
−3.0
0.0
0.2
0.4
0.6
0.8
1.0
X
Isoscalar
Isovector

Single-j OXBASH



GS

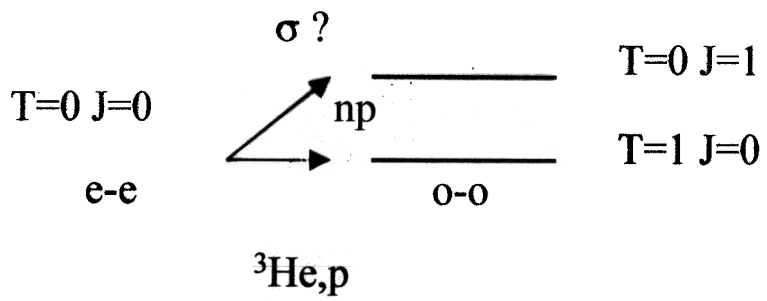
"FERROMAGNET"
i.e. skewed sp ms !!

$$V = V^{T=1}_{J=0} + (\quad x) \; {}^{T=0}_{J=1}$$

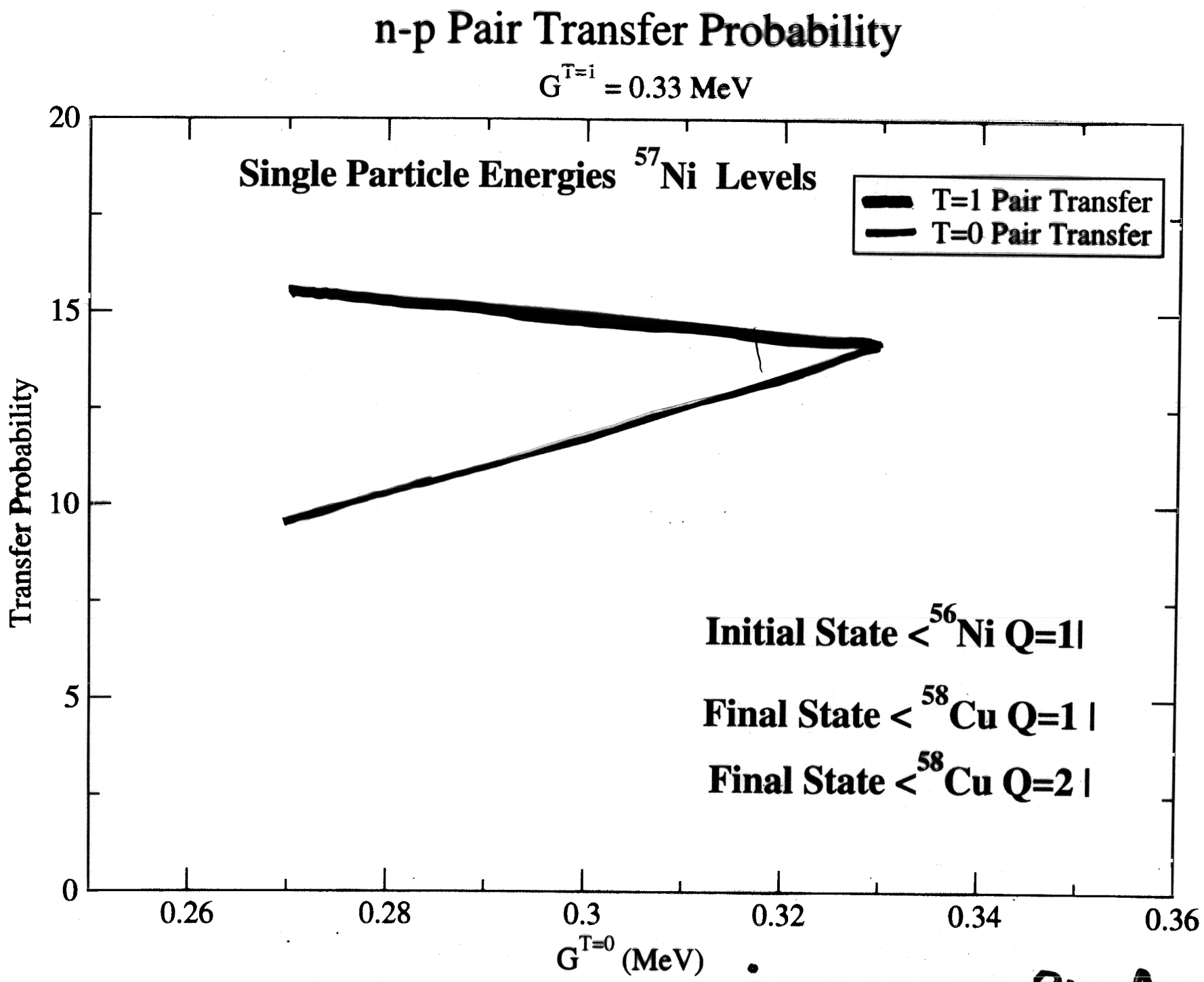
(^{3}He,p) Transfer Reactions

Two nucleon transfer reactions are an excellent tool to test correlations

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



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



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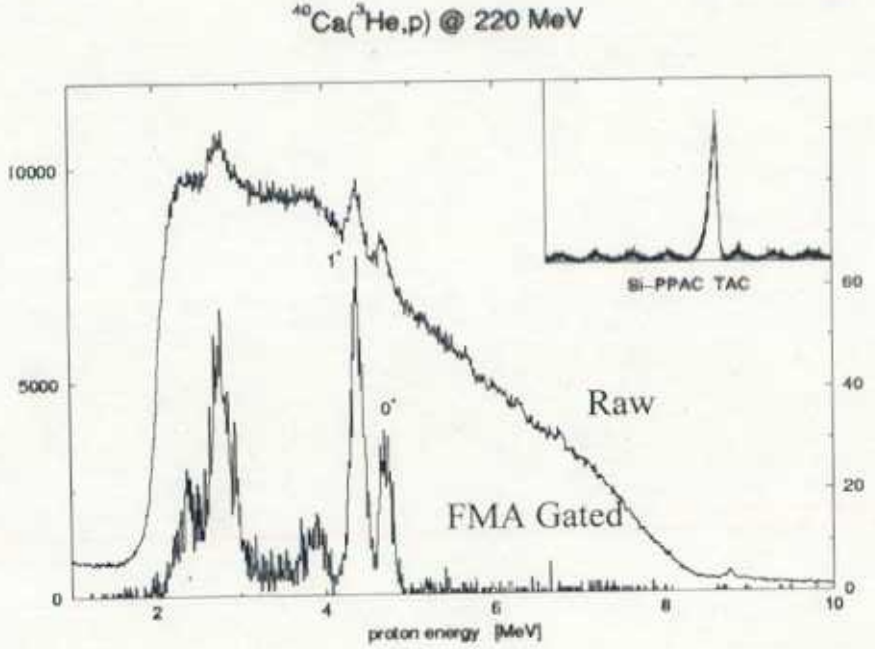
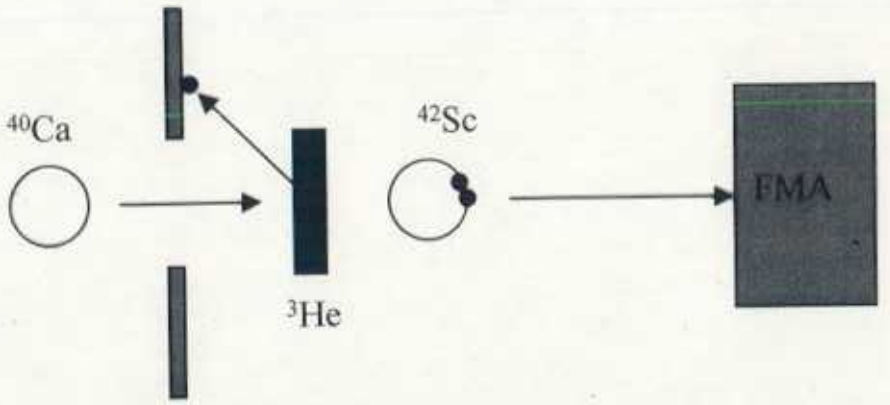


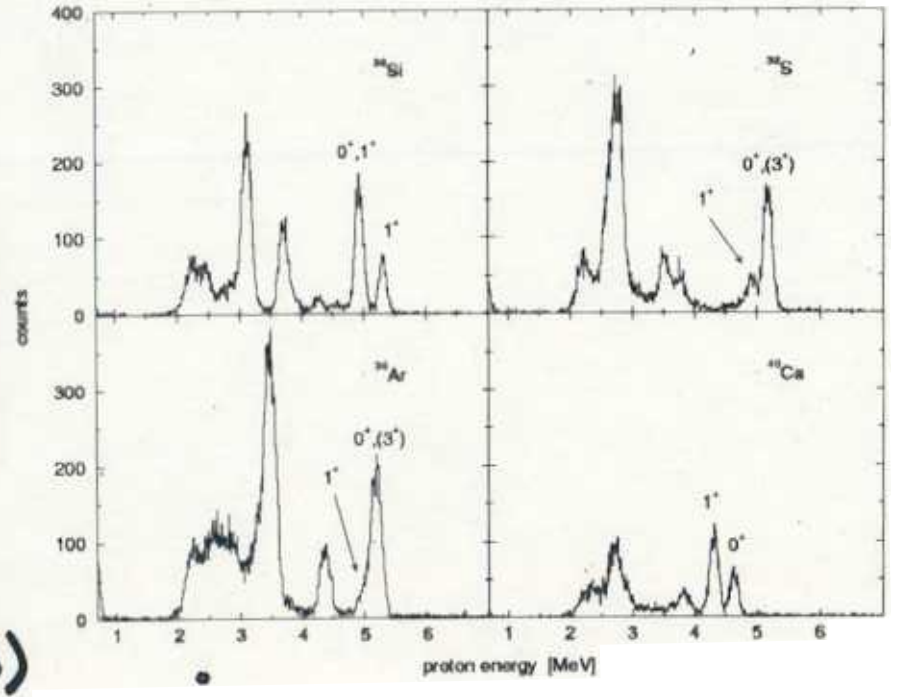
Inverse kinematics

Successful test experiment with stable beams

Approved ATLAS runs with ^{44}Ti and ^{56}Ni beams

Role of pairing phonons near ^{40}Ca and ^{56}Ni





K.E. Rehm et al. PRL 80 (1998)

Conclusions

- **T=0 states in odd-odd N=Z nuclei exhibit similar properties as any other odd-odd nuclei**

  Adding a np(T=0) pair blocks the T=1 correlations, giving a gap ~ 2*12MeV/$A^{1/2}$

- **Full isovector pairing reveals itself in the T=1 states**

  Direct consequence of isobaric analogues

- **Single-l and single-j shell models capture the most relevant ingredients of pairing correlations. They appear to support these findings.**

  Where is the elusive T=0 phase?

- **Future work**

  Two nucleon transfer reactions