Pairing functional of the surface di-neutron correlations

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Collaborators
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2_1^+ state in $^{>132}$Sn is a useful probe to the expected strong surface pairing in n-rich nuclei

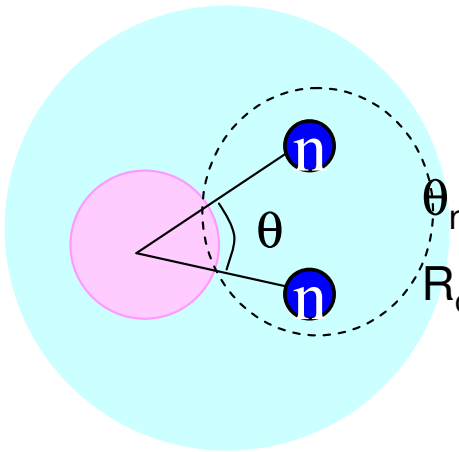
besides the soft dipole mode

di-neutron correlation: pairing with strong spatial correlation in n-rich nuclei

Spatially compact pair in nuclei

2n-halo nucleus ^{11}Li

Many discussions since ~late 1980'



$\theta_{nn}=48^{+14}_{-18}$ deg

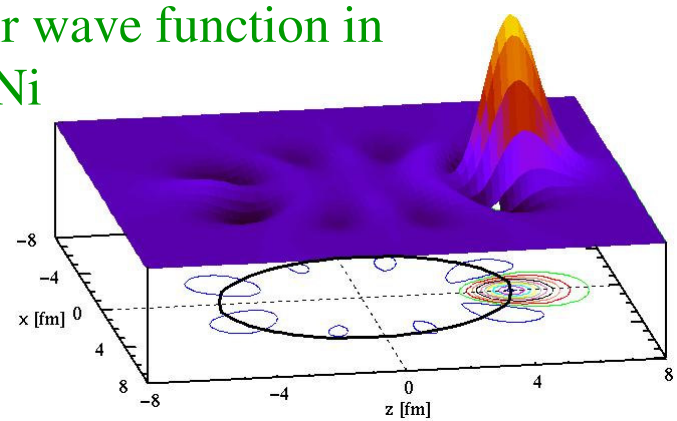
$R_{c,2n}$=5.01+-0.32 fm

New Coulomb break-up exp. on 11Li at RIKEN Nakamura et al. PRL30,252502 (2006)

neutron skin nuclei in medium mass region

Several weakly-bound neutrons

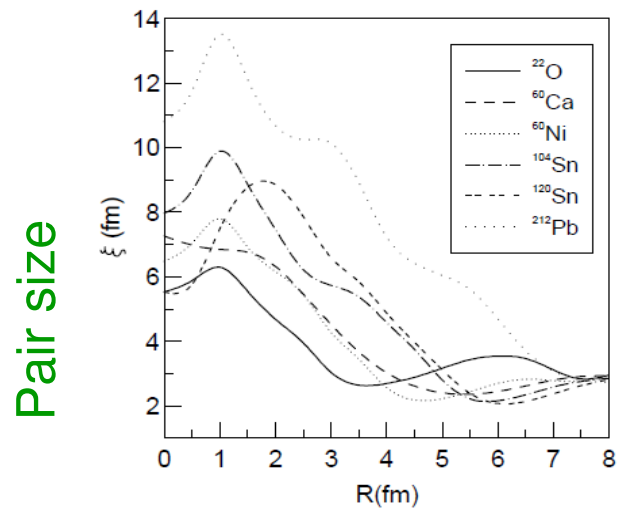
pair wave function in 84Ni



HFB calc. Using DDDI

Matsuo et al PRC71,064326(2005)

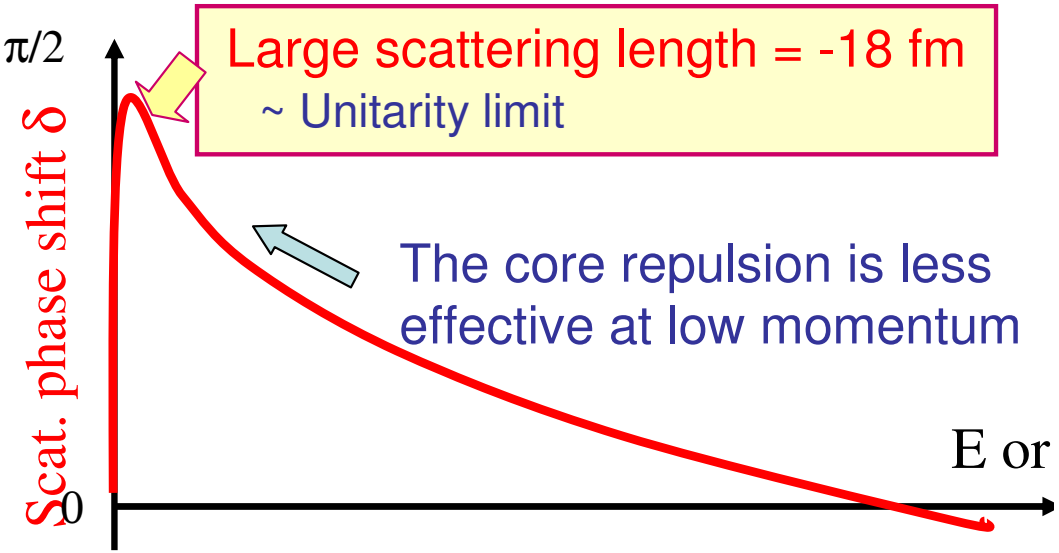
Pillet, Sandulescu, Schuck, PRC76, 024310 (2007)



Gogny HFB

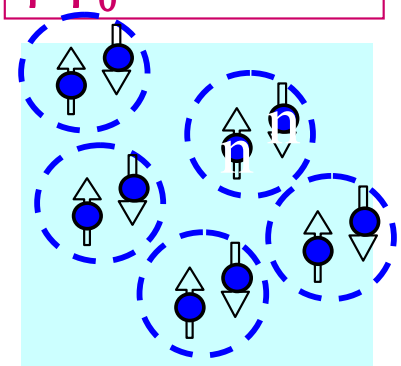
Di-neutron correlation: Strong coupling pairing in low-density matter (nuclear skin & halo)

^1S phase shift



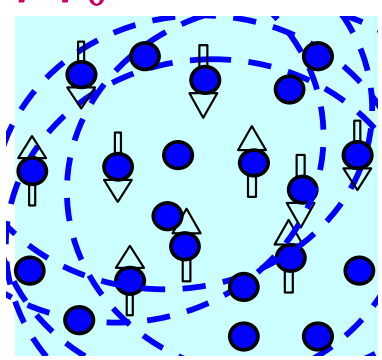
Low-density matter

$\rho/\rho_0 = 10^{-4}$-10^{-1}



Normal-density matter

$\rho/\rho_0 > 10^{-1}$

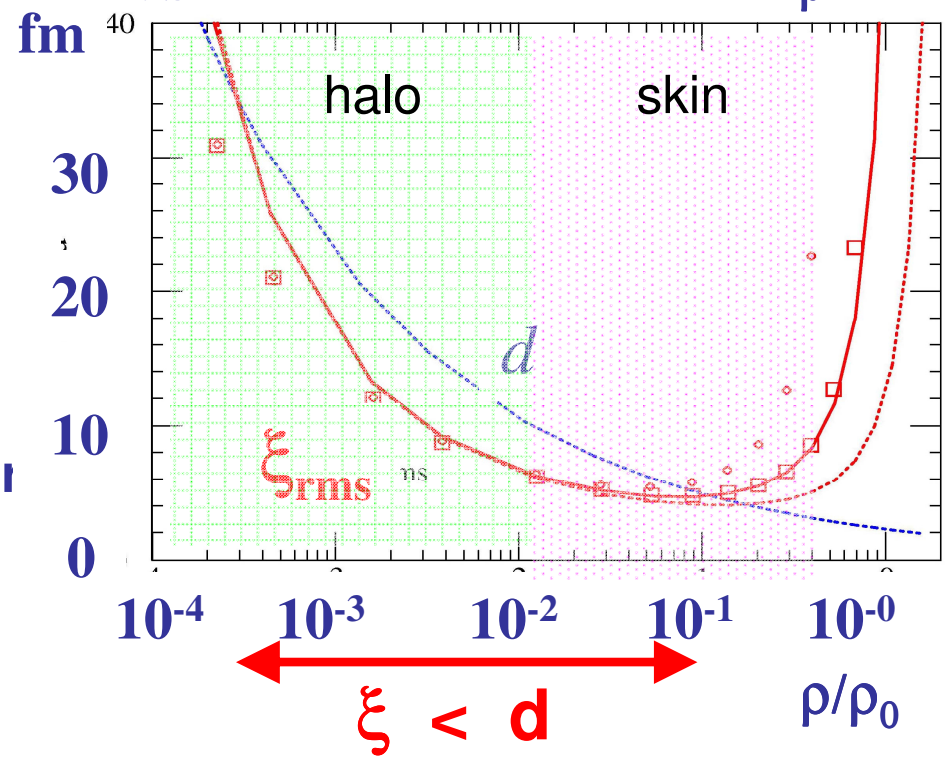


Size of Cooper pair in uniform matter

BCS using bare force

Matsuo PRC73, 044309 (2006)
Margueron et al. nucl-th/0710.4241

VS. inter-neutron distance $d=\rho^{-1/3}$



Coherence length < average inter-particle distance

BCS-BEC crossover/
Unitarity regime

We need a pairing functional (DDDI) suitable for the surface pairing & the low density matter

$$V_{pair,n}(\vec{r},\vec{r}') = \underbrace{V_n[\rho_n,\rho_p]}_{\text{Density dependent coupling}}\delta(\vec{r}-\vec{r}') \qquad E_{pair} = \sum_{q=n,p} V_q[\rho_n,\rho_p]\tilde{\rho}_q^*\tilde{\rho}_q$$

DDDI-bare (our proposal)

1. The large scattering length should be reproduced at low density

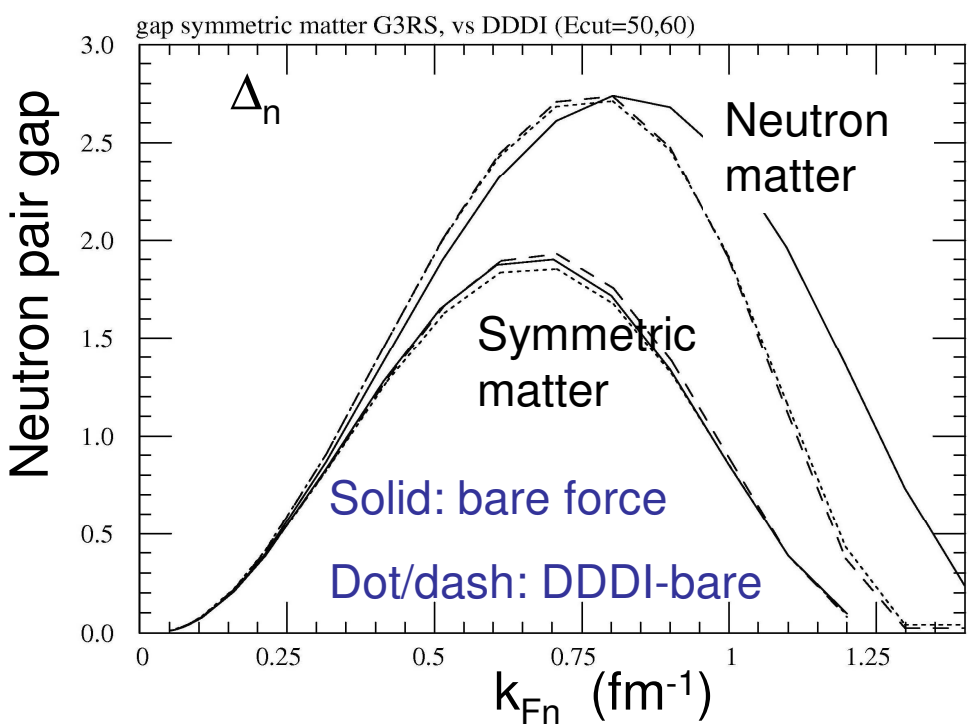
$$V_n[\rho_n=\rho_p=0] \rightarrow \quad v_0 = -\frac{2\pi^2\hbar^2 m^{-1}}{k_c-\pi/2a},$$

v_0= -458.4 for E_{cut}=60MeV

2. The density dependence of Δ_{matter}(BCS-bareNN) arises from the k-dependence of bare NN force

$$V_n[\rho_n,\cancel{\rho_p}] = V_n[k_{Fn}] = v_0 f(k_{Fn})$$

Fitting to the matter pairing gap



Parameterization

$$V=v_0+232.8\ k_{Fn}^{1.77}$$

reproduces fairly well the gap in symmetric matter and pure neutron matter (except for k_{Fn}>0.9, $\rho>1/4\rho_{0n}$)

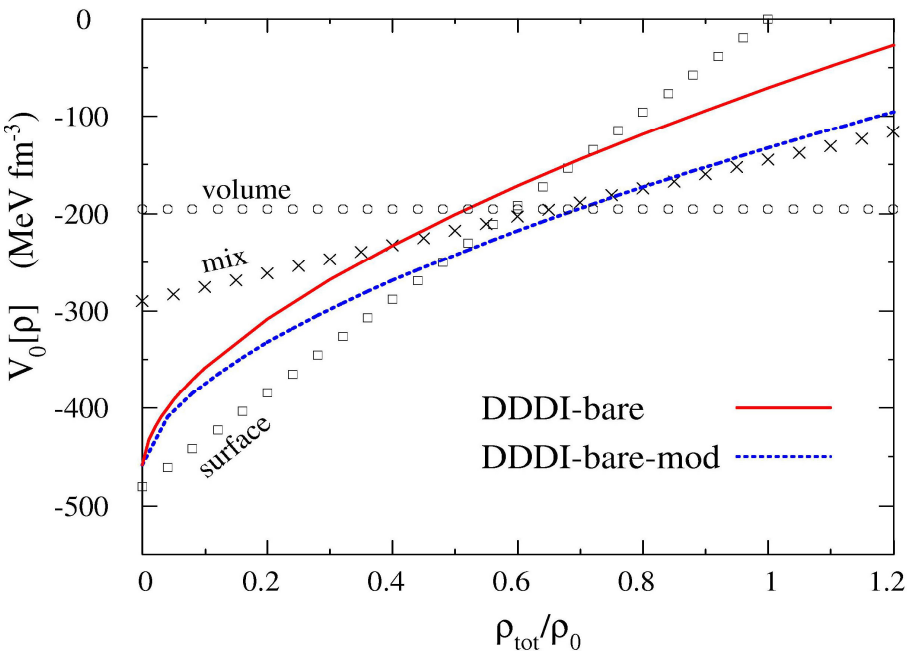
Matsuo PRC73, 044309 (2006)

DDDI-bare

$$V_n[\rho_n,\cancel{\rho_p}] = v_0\left(1-\underbrace{0.845}_{\eta}(\rho_n/0.08)^{\overbrace{0.59}^{\alpha}}\right)$$

Cf. Esbensen-Bertsch, Garrido et al.

Density dependent coupling of DDDI



DDDI-bare is insufficient → **DDDI-bare-mod**

V0=458, α=0.59, η=0.845 → η=0.71

Other popular DDDI's

volume (no r-dependence)

$$V_n[\rho_n,\rho_p]=v_0$$

surface

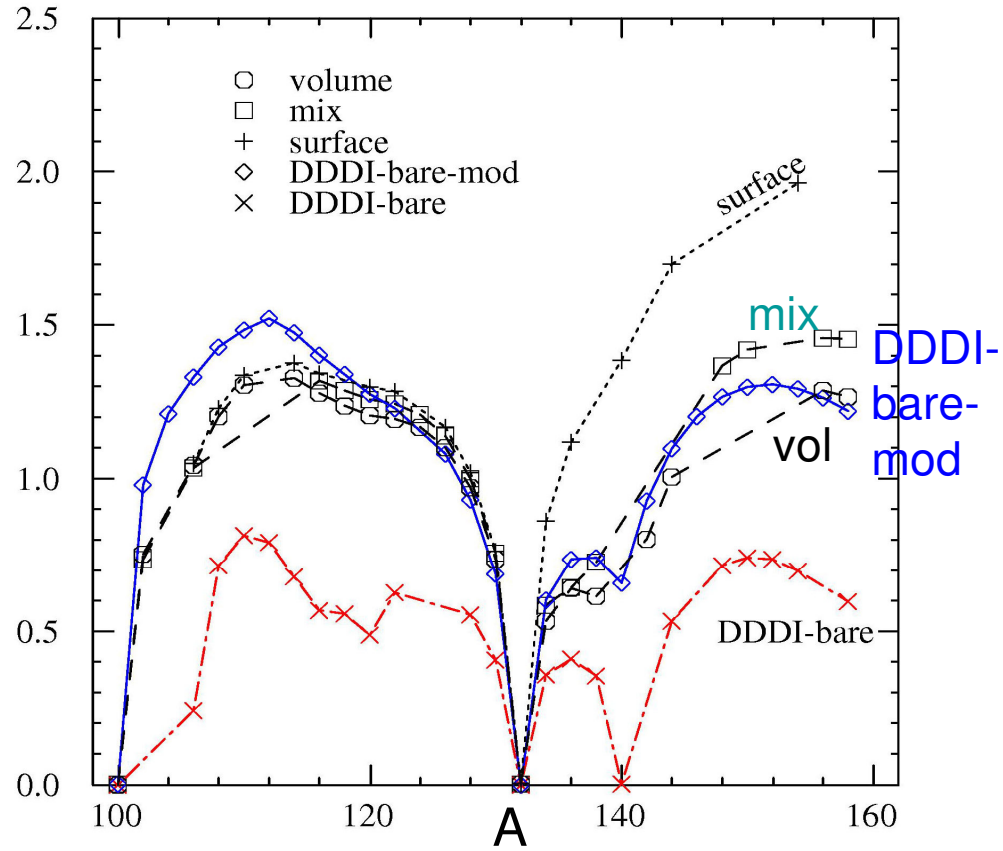
$$V_n[\rho_n,\rho_p]=v_0\left(1-\left(\rho_n+\rho_p/0.16\right)^1\right)$$

mix

$$V_n[\rho_n,\rho_p]=v_0\left(1-0.5\left(\rho_n+\rho_p/0.16\right)^1\right)$$

v_o is fixed to reproduce Δ in a nucleus (^{120}Sn)

Pairing gap in Sn isotopes



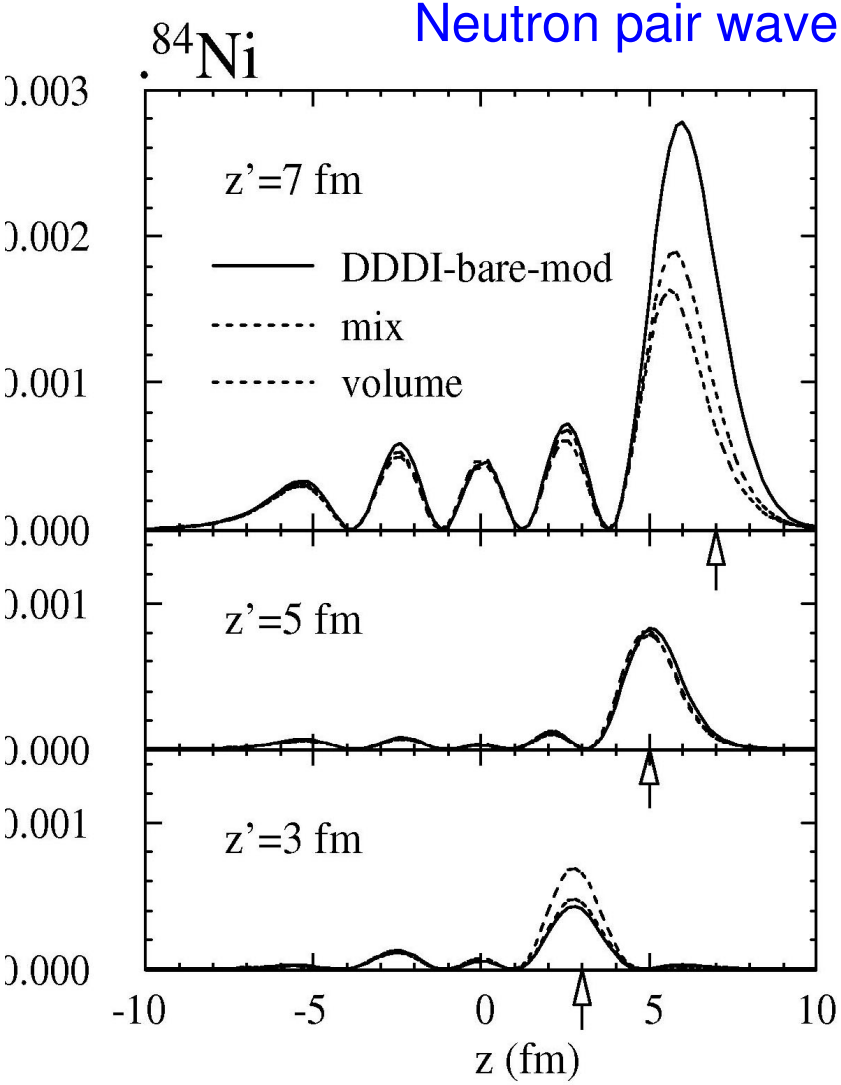
"DDDI-bare-mod", "mix", and "volume" give similar pairing gap, once fixed at ^{120}Sn

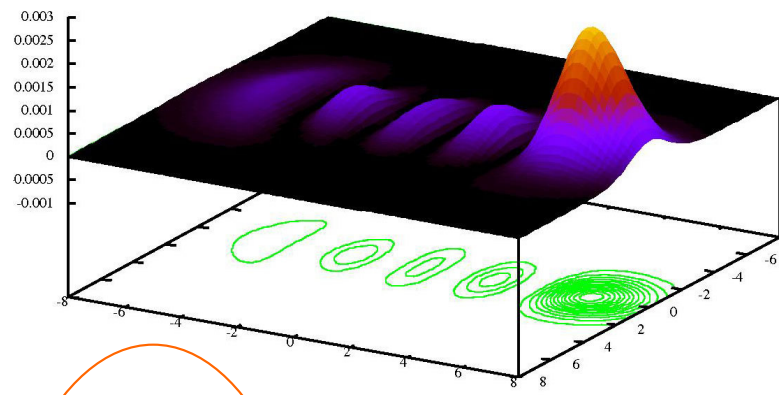
NB. But, these have rather large difference in their ρ-dependence !!

Cf. Dobaczewski et al. 2001, 2002

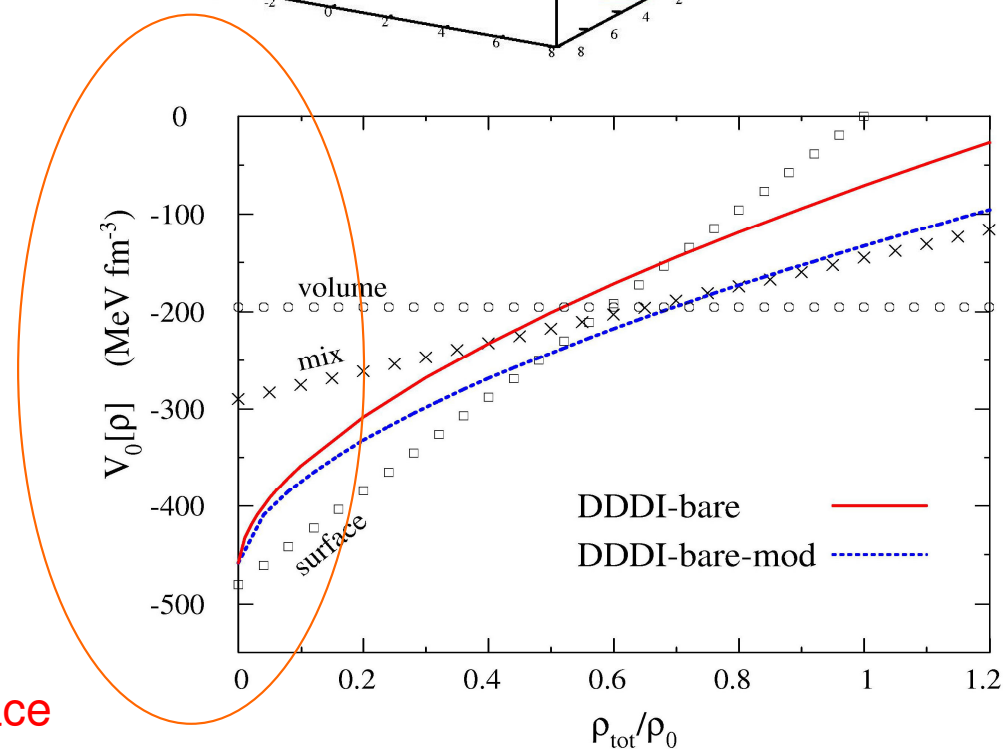
Di-neutron correlation is the surface phenomena. It is sensitive to the density dependence of coupling

Neutron pair wave unction $|\Psi_{pair}(\vec{r},\vec{r}')|^2 / \rho(r')$





^{84}Ni SLy4 DDDI-bare-mod



Di-neutron correlation outside the surface reflects the coupling V[ρ] at low densities

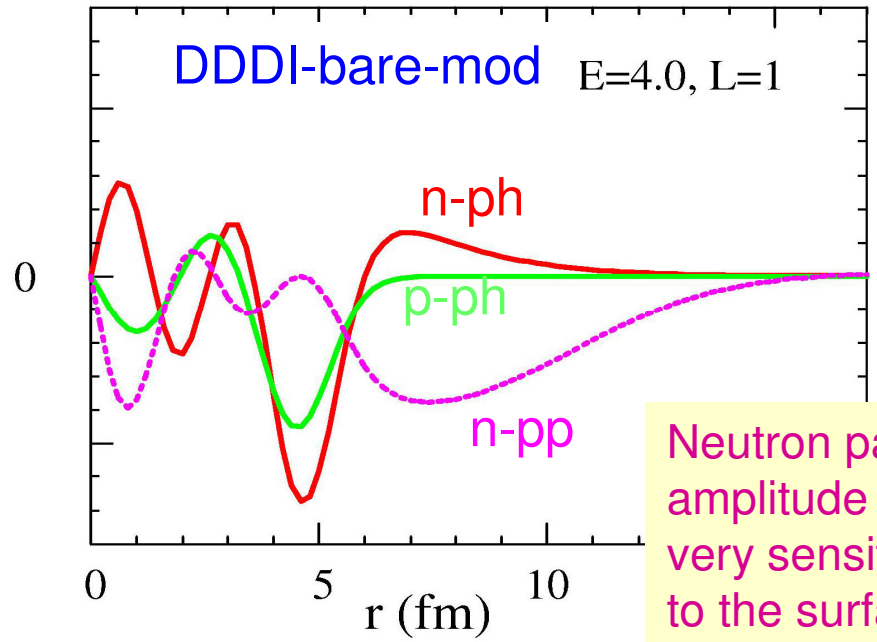
Soft dipole in ^{84}Ni

Transition densities of soft dipole mode

Skyrme-HFB + Continuum QRPA
SLy4 +Landau-Migdal approx

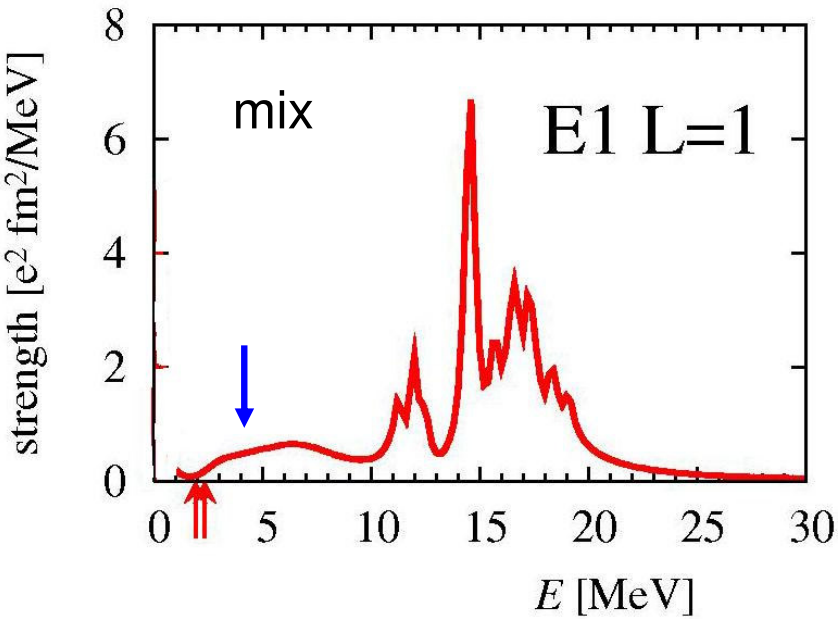
S_{1n}=1.98 MeV

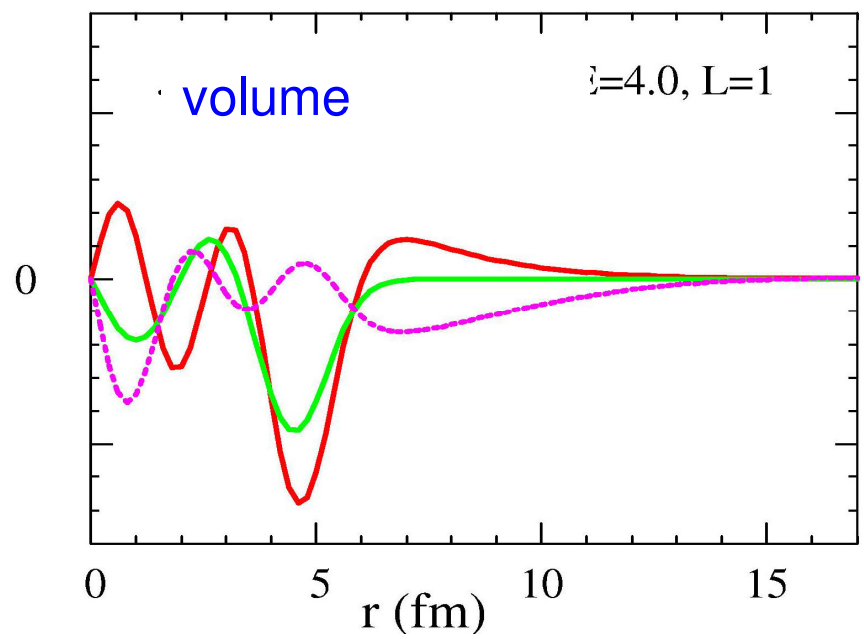
S_{2n}=2.47 MeV



Neutron pair amplitude is very sensitive to the surface pairing

B(E1) strength function



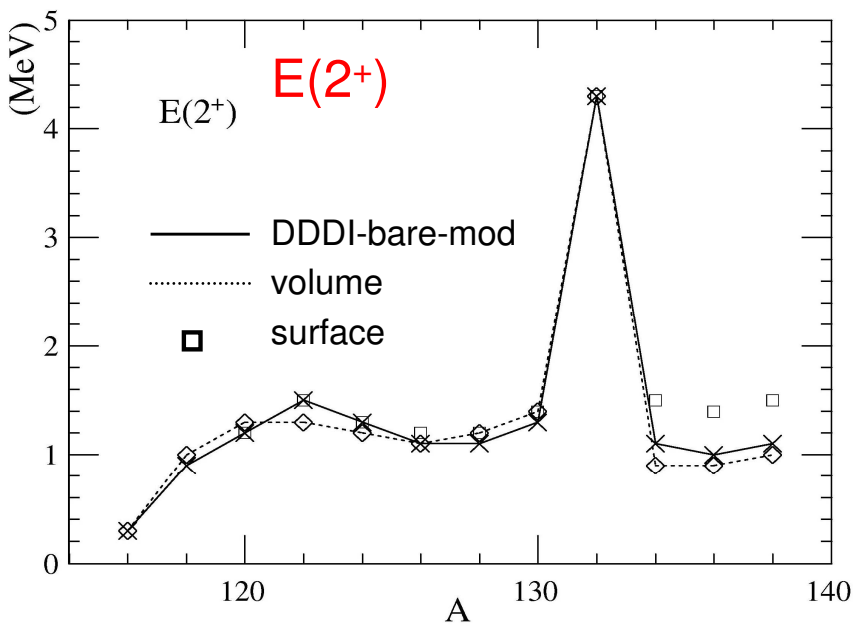


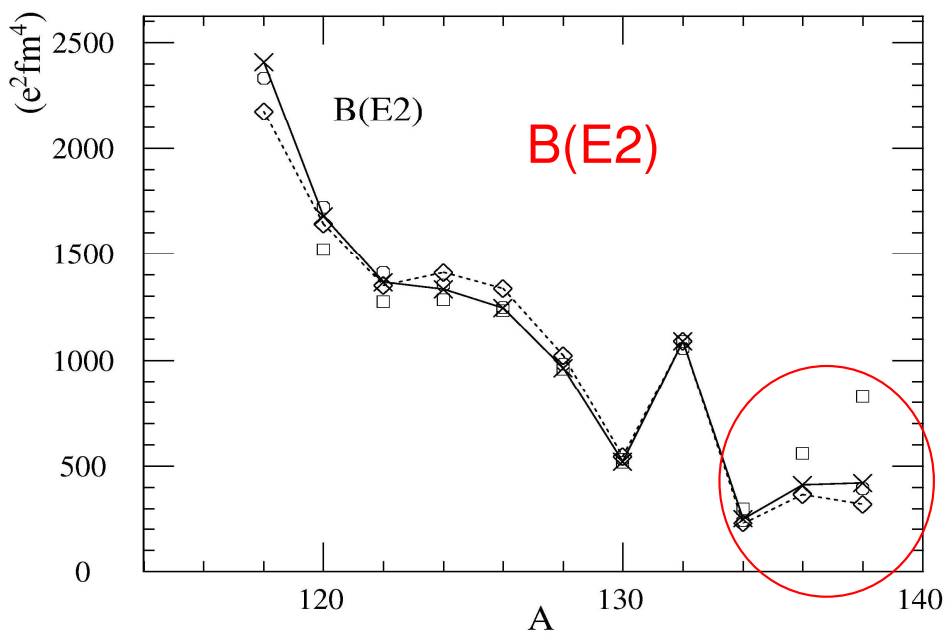
Quadrupole state in $>^{132}$Sn as a probe to the strong surface pairing

Skyrme HFB+QRPA, SLy4,

	^{134}Sn	^{132}Sn	
S_{1n}=	**3.31**	6.16	MeV
S_{2n}=	**5.13**	12.32	MeV

Volume pairing vs. DDDI-bare-mod pairing



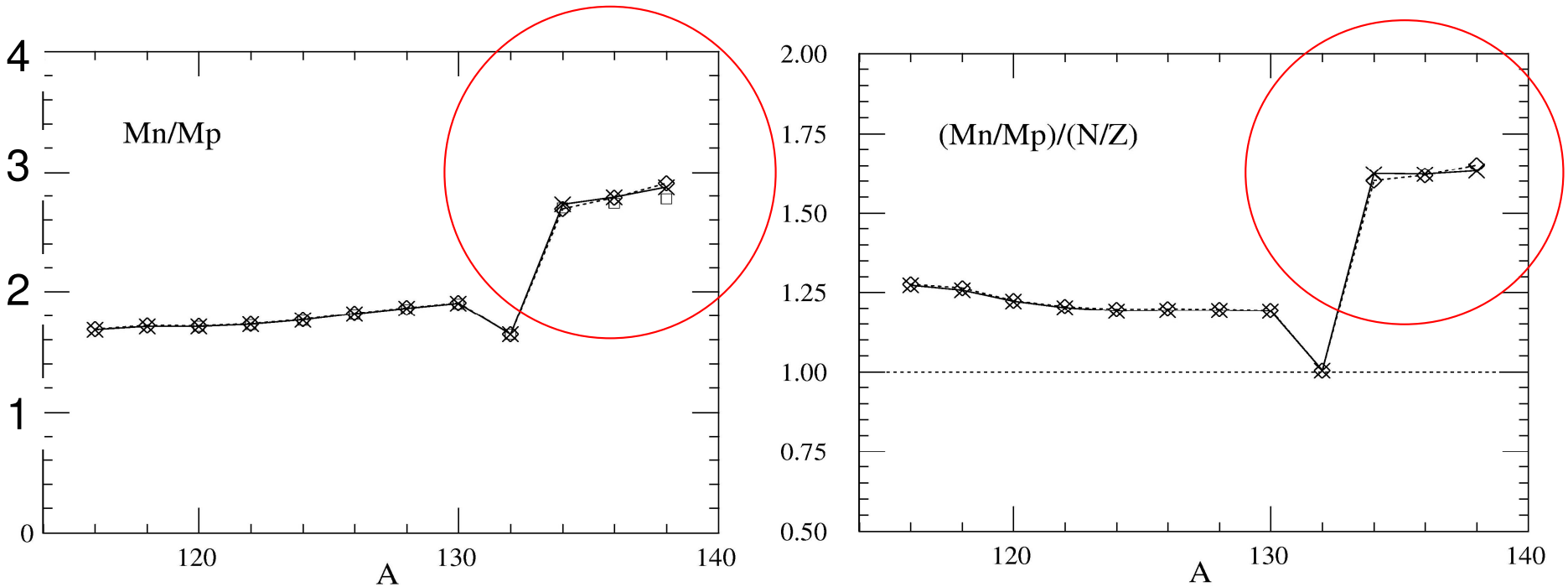


Small B(E2)

E(2+) and B(E2) is not very sensitive to the pairing as far as the average Δ is not different, but we may be able to distinguish the "surface" from the others.

M_n/M_p

Large M_n/M_p



Pair transfer strength to the 2^+ state: a sensitive probe

2n-transfer (addition) strength M_{add}^2

$$M_{add} = \left\langle 2^+ \left| \int Y_{2M} \psi^+(\vec{r}) \psi^+(\vec{r}) d\vec{r} \right| 0_{gs} \right\rangle$$

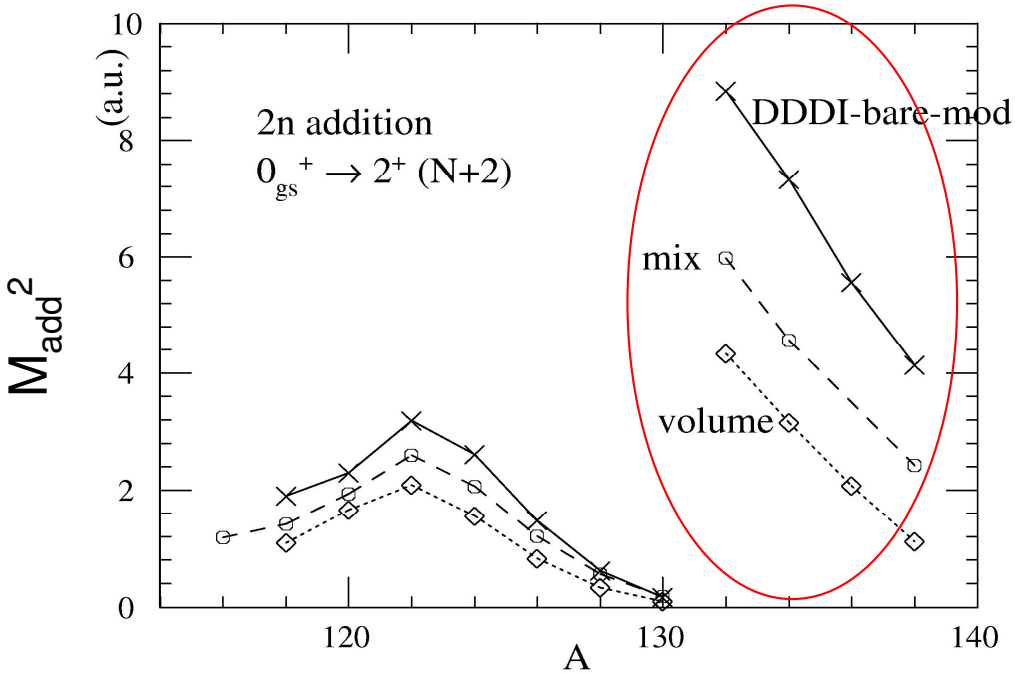
0_{gs}^+ (N) → 2_1^+ (N+2)

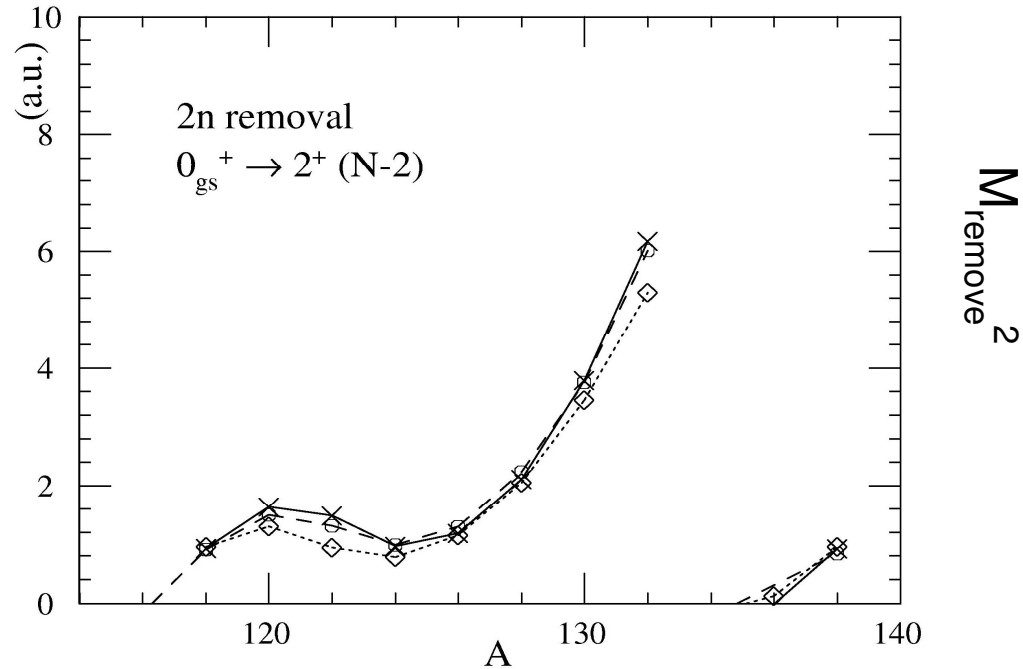
surface

2n-transfer (removal) strength M_{remove}^2

$$M_{remove} = \left\langle 2^+ \left| \int Y_{2M} \psi(\vec{r}) \psi(\vec{r}) d\vec{r} \right| 0_{gs} \right\rangle$$

0_{gs}^+ (N) → 2_1^+ (N-2)





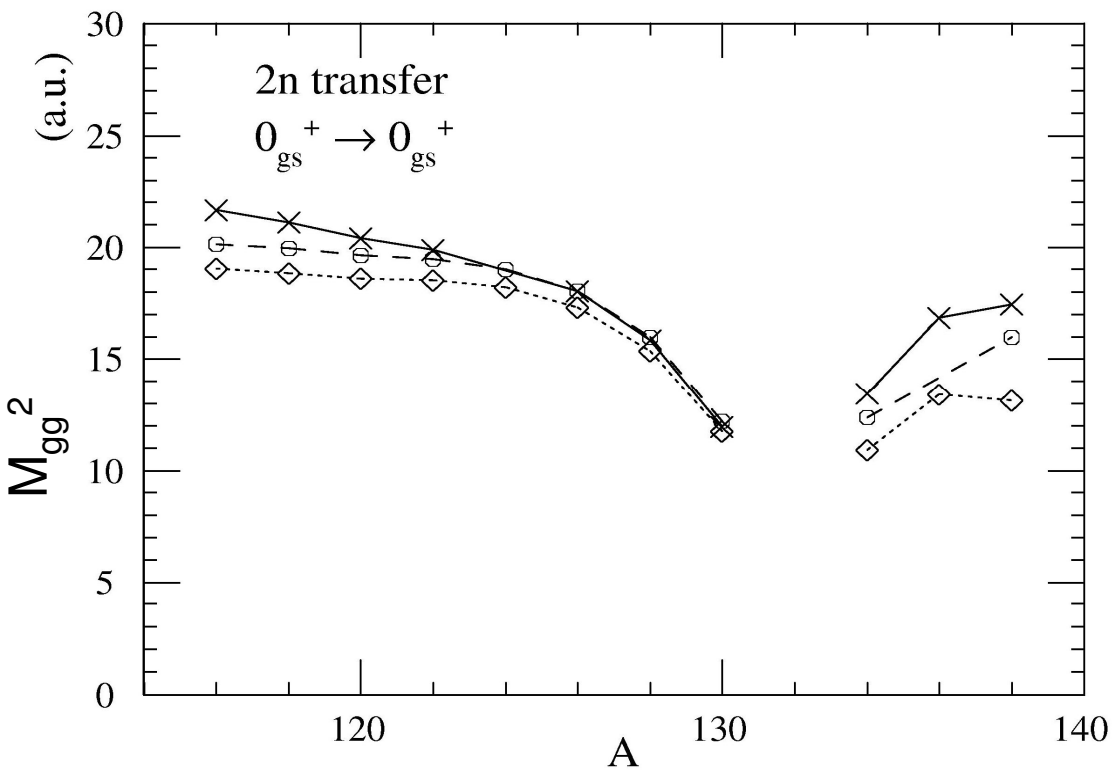
Pair-addition strength is quite sensitive to the pairing in the surface region !!

Pair-removal strength is NOT sensitive

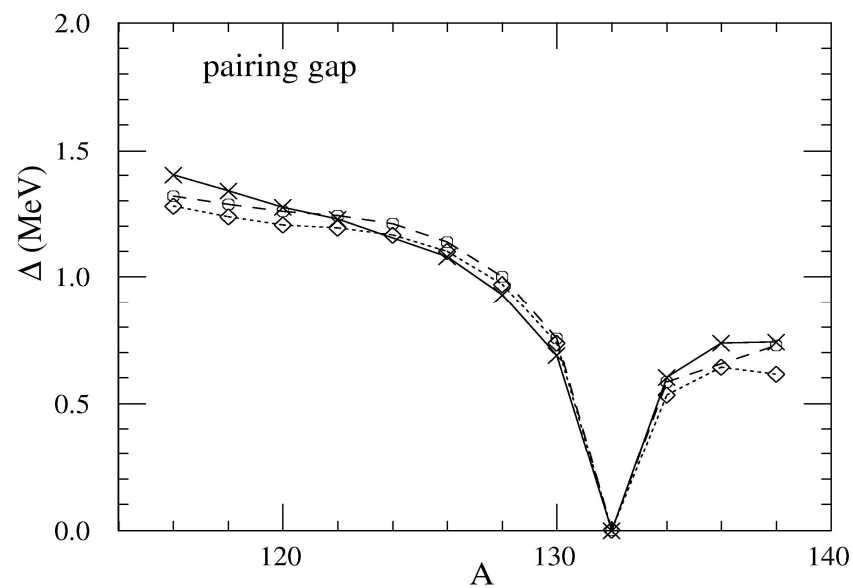
Pair transfer in $^{>132}$Sn (cont.)

ground –ground 2n transfer 0_{gs}^{+} (N) → 0_{gs}^{+} (N+2,N-2)

$$M_{gg} = \left\langle 0_{gs} \left| \int Y_{00} \psi^{+}(\vec{r}) \psi^{+}(\vec{r}) d\vec{r} \right| 0_{gs} \right\rangle = \int \tilde{\rho}(\vec{r}) d\vec{r}$$



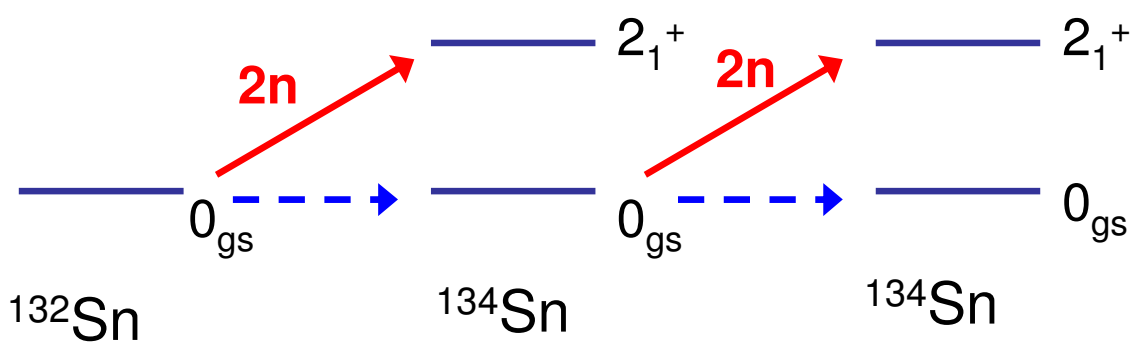
Pairing gap



Ground-ground transition MAY NOT be sensitive to the pairing in the surface region

NB. The form factor may change the situation

Conclusion

- **The low-density part of the pair coupling is essential for the di-neutron correlation.**

- **2_1^+ state in $^{>132}$Sn, especially the pair transfer strength, is a sensitive probe to the expected strong surface pairing in n-rich nuclei.**