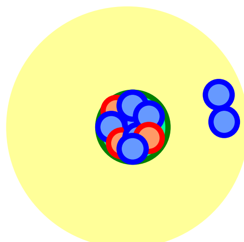
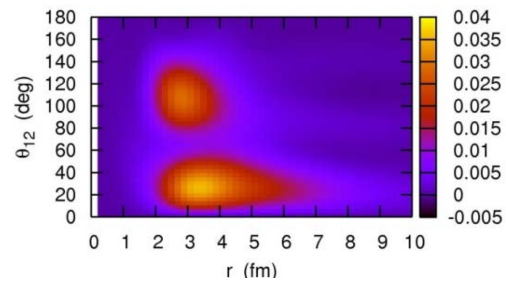
Two-nucleon correlations in the decays of unbound nuclei beyond the drip lines

Kouichi Hagino (Tohoku Univ.)
Hiroyuki Sagawa (Univ. of Aizu)



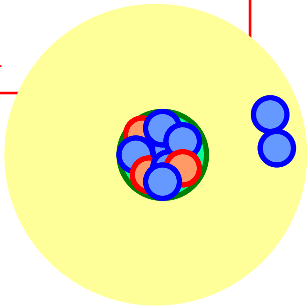


TOHOKU
UNIVERSITY

1. Di-neutron correlations in neutron-rich nuclei
2. Two-neutron decays of ^{26}O: three-body model
   - decay energy spectrum
   - angular distribution of two neutrons
   - decay width
3. Summary

Di-neutron correlations in neutron-rich nuclei

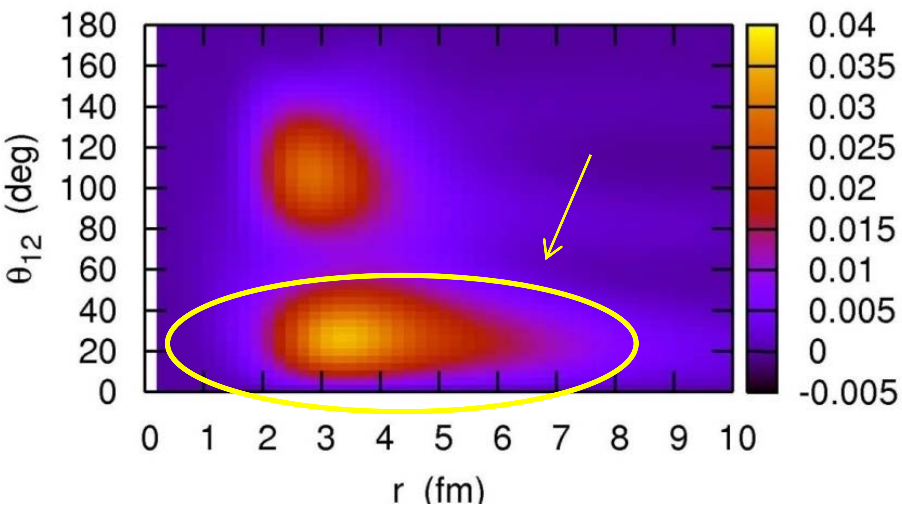
Strong di-neutron correlations
in neutron-rich nuclei



- ✓ Borromean nuclei (3body calc.)
  - Bertsch-Esbensen (‘91)
  - Zhukov et al. (‘93)
  - Hagino-Sagawa (‘05)
  - Kikuchi-Kato-Myo (‘10)

- ✓ Heavier nuclei (HFB calc.)
  - Matsuo et al. (‘05)
  - Pillet-Sandulescu-Schuck (‘07)

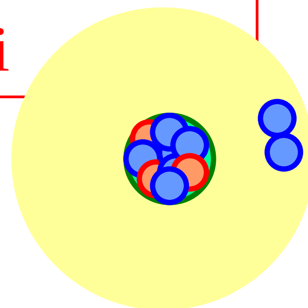
^{11}Li



K.H. and H. Sagawa,
PRC72(’05)044321

Di-neutron correlations in neutron-rich nuclei

Strong di-neutron correlations
in neutron-rich nuclei



✓ Borromean nuclei (3body calc.)
- Bertsch-Esbensen (‘91)
- Zhukov et al. (‘93)
- Hagino-Sagawa (‘05)
- Kikuchi-Kato-Myo (‘10)

✓ Heavier nuclei (HFB calc.)
- Matsuo et al. (‘05)
- Pillet-Sandulescu-Schuck (‘07)

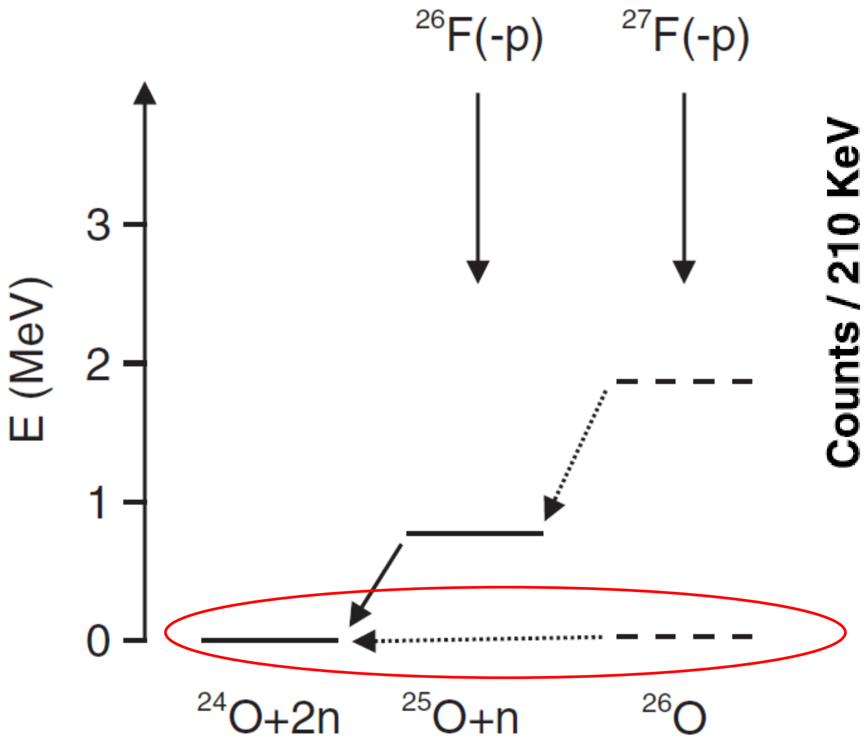
How to probe it?

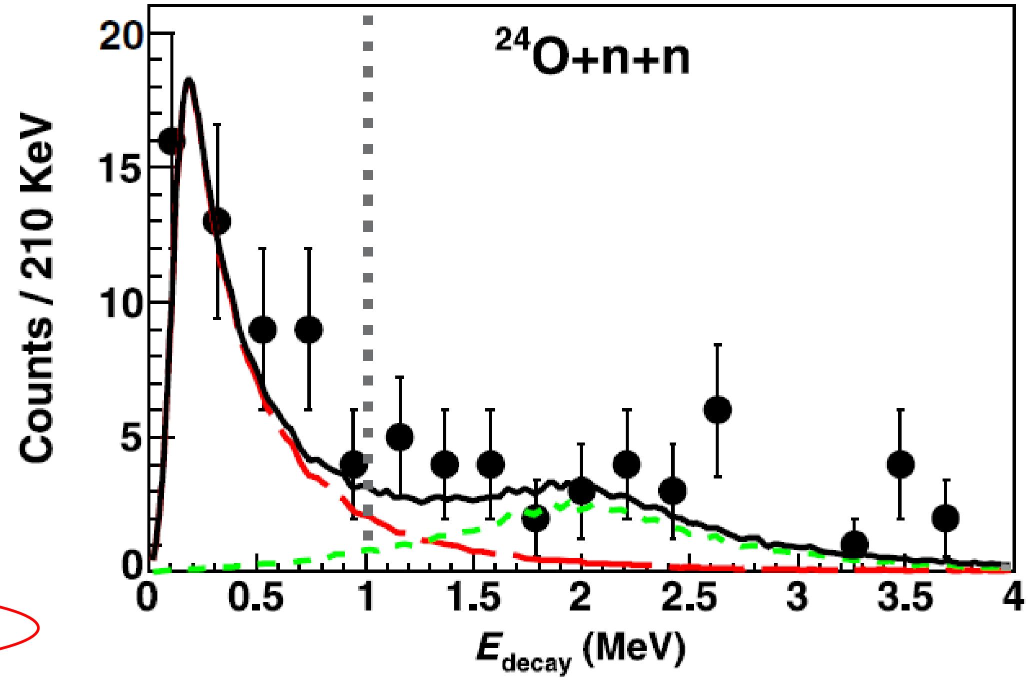
- Coulomb breakup
  - T. Nakamura et al.
  - cluster sum rule
  - (mean value of θ_{nn})
- pair transfer reactions
- two-proton decays
  - Coulomb 3-body problem
- two-neutron decays
  - 3-body resonance due to a centrifugal barrier
  - MoNA (^{16}Be, ^{13}Li, ^{26}O)
  - **SAMURAI (^{26}O)**
  - GSI (^{26}O)

Two-neutron emission decays of ^{26}O (MoNA@MSU)

E. Lunderberg et al., PRL108 (‘12) 142503
Z. Kohley et al., PRL 110 (‘13)152501

^{27}F (82 MeV/u) + ^{9}Be → ^{26}O → ^{24}O + n + n





$E_{decay} = 150\ ^{+50}_{-150}$ keV

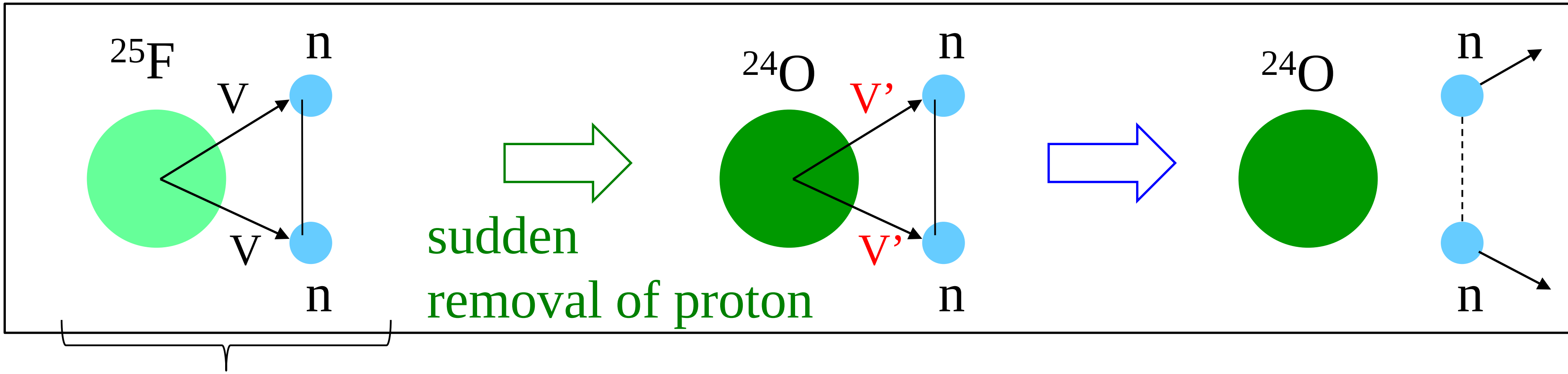
$\Gamma_{exp} = 1.0^{+0.34}_{-0.25}$ +/- 0.68 x 10^{-10} MeV

cf. Y. Kondo et al., (SAMURAI)
C. Caesar et al., PRC88 (‘13) 034313 (GSI exp.)

3-body model analysis

K.H. and H. Sagawa, PRC89 ('14) 014331

cf. Expt. : ^{27}F (82 MeV/u) + ^{9}Be → ^{26}O → ^{24}O + n + n



g.s. of ^{27}F (bound)

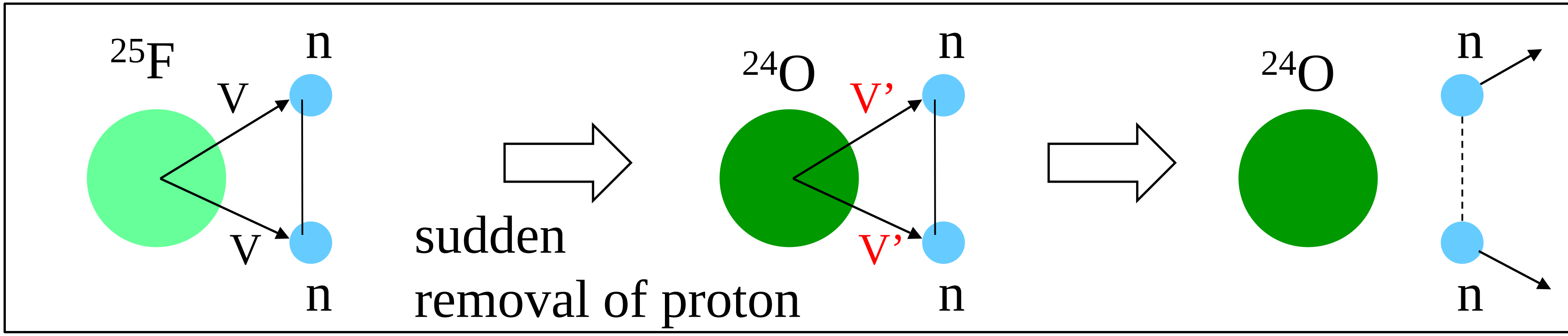
spontaneous decay

$$\Psi_{nn} \otimes |^{25}\mathrm{F}\rangle \qquad \Psi_{nn} \otimes |^{24}\mathrm{O}\rangle$$

→ the same config. (non-eigenstate of ^{24}O+n+n)

FSI ⟶ Green's function method

$$\begin{aligned} M_{fi} &= \langle (j_1 j_2)^{J=0} | (1 - vG_0 + vG_0 vG_0 - \cdots) | \Psi_i \rangle \\ &= \langle (j_1 j_2)^{J=0} | (1 + vG_0)^{-1} | \Psi_i \rangle \end{aligned}$$



➢ ^{24}O + n potential

Woods-Saxon potential

C.R. Hoffman et al., PRL100('08)152502

$e_{2s1/2}$ = -4.09 (13) MeV,

$e_{1d3/2} = +\ 770^{+20}_{-10}$ keV, $\Gamma_{1d3/2}$ = 172(30) keV

➢ ^{25}F + n potential

(^{24}O + n) potential + δV_{ls} ← pn tensor interaction

T. Otsuka et al., PRL95('05)232502

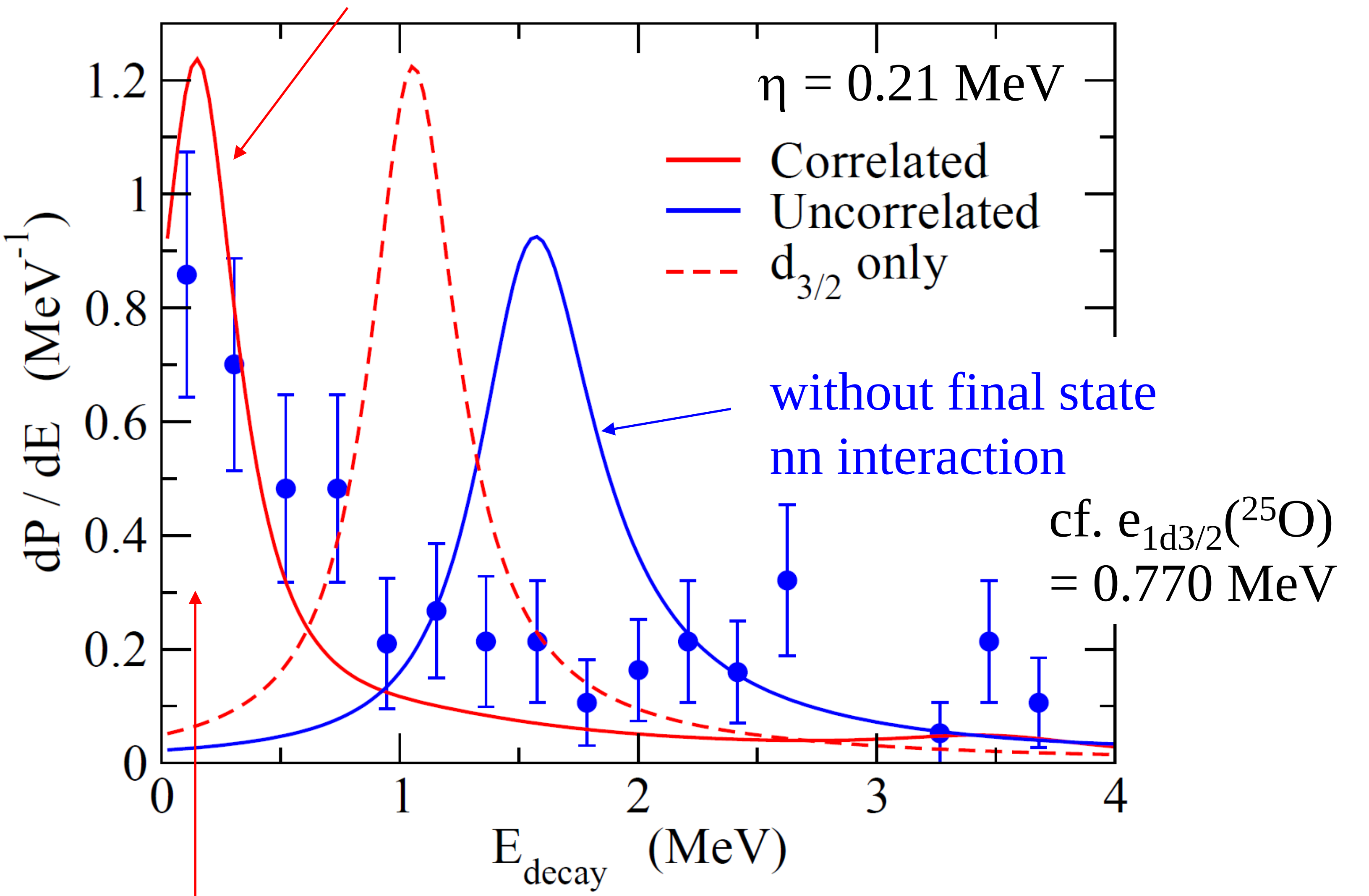
$e_{1d3/2}$ (^{26}F) = - 0.811 MeV

➢ nn interaction (density-dependent zero-range interaction)

← E_{exp} (^{27}F) = -2.80(18) MeV

Decay energy spectrum

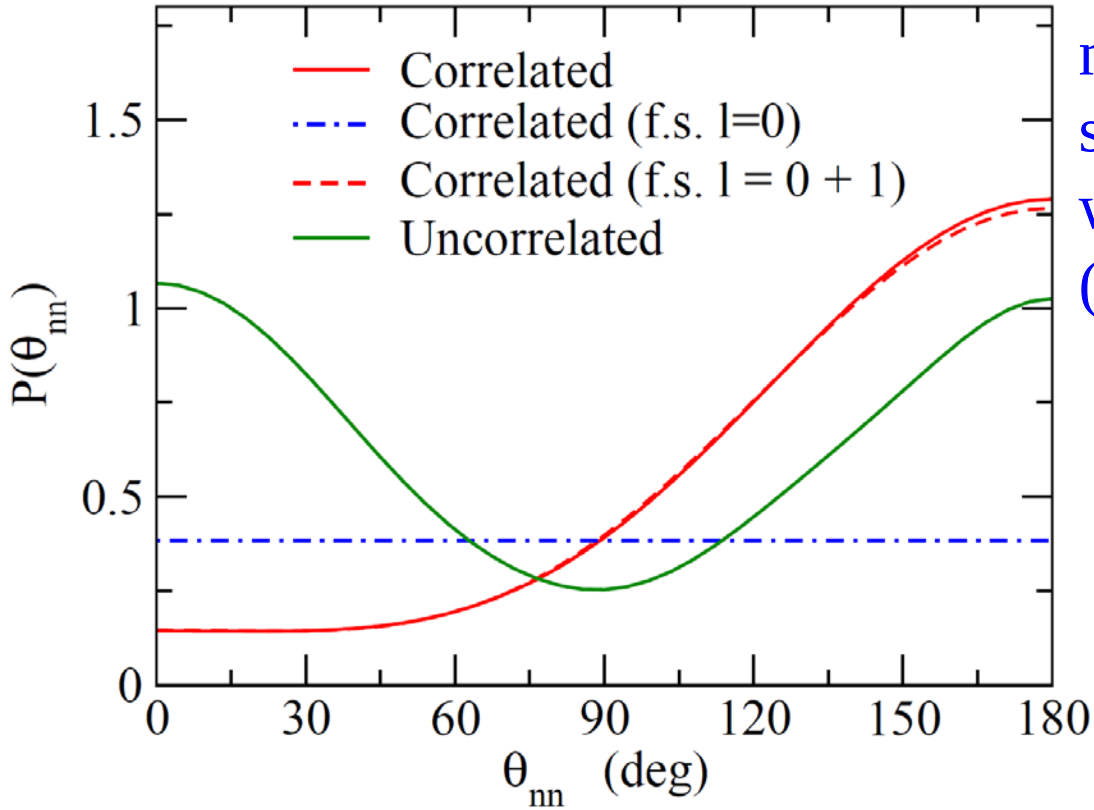
K.H. and H. Sagawa, PRC89 ('14) 014331



very narrow three-body resonance state ($\Gamma_{exp} \sim 10^{-10}$ MeV)

E_{peak} = 0.14 MeV with this setup

Angular correlation of the two emitted neutrons



main contributions:
s- and p-waves in three-body wave function
(no or low centrifugal barrier)

2n correlations
→ enhancement of back-to-back emission

$$\langle \theta_{\rm nn} \rangle = 115.3^\circ$$

⟷ dineutron correlation

$$\Psi(\boldsymbol{r},\boldsymbol{r}') = \alpha\,\Psi_{s^2}(\boldsymbol{r},\boldsymbol{r}') + \beta\,\Psi_{p^2}(\boldsymbol{r},\boldsymbol{r}')$$ → $\theta_r = 0$: enhanced

→ Fourier transform $e^{i\boldsymbol{k}\cdot\boldsymbol{r}} = \sum_l (2l+1) i^l \ldots.$ → $i^l \cdot i^l = i^{2l} = (-)^l$

↑ r ↑ r'

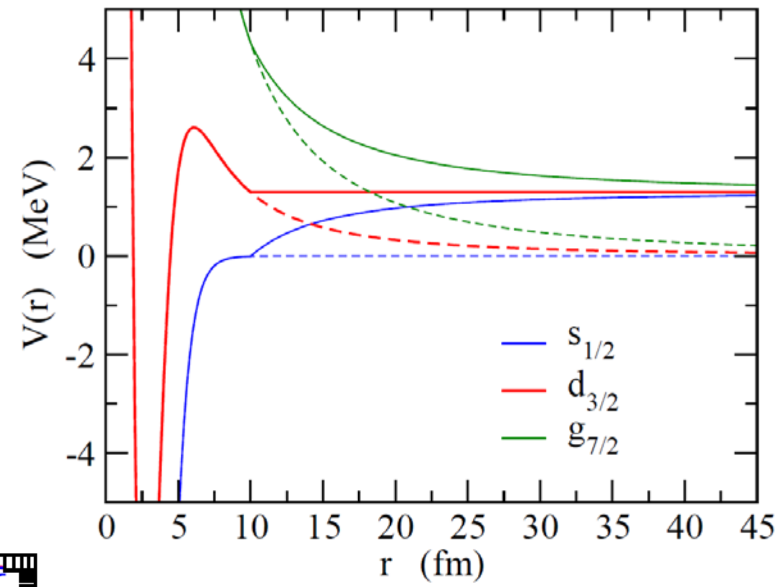
$$\tilde{\Psi}(\boldsymbol{k},\boldsymbol{k}') = \alpha\,\tilde{\Psi}_{s^2}(\boldsymbol{k},\boldsymbol{k}') - \beta\,\tilde{\Psi}_{p^2}(\boldsymbol{k},\boldsymbol{k}')$$ → $\theta_k = \pi$: enhanced

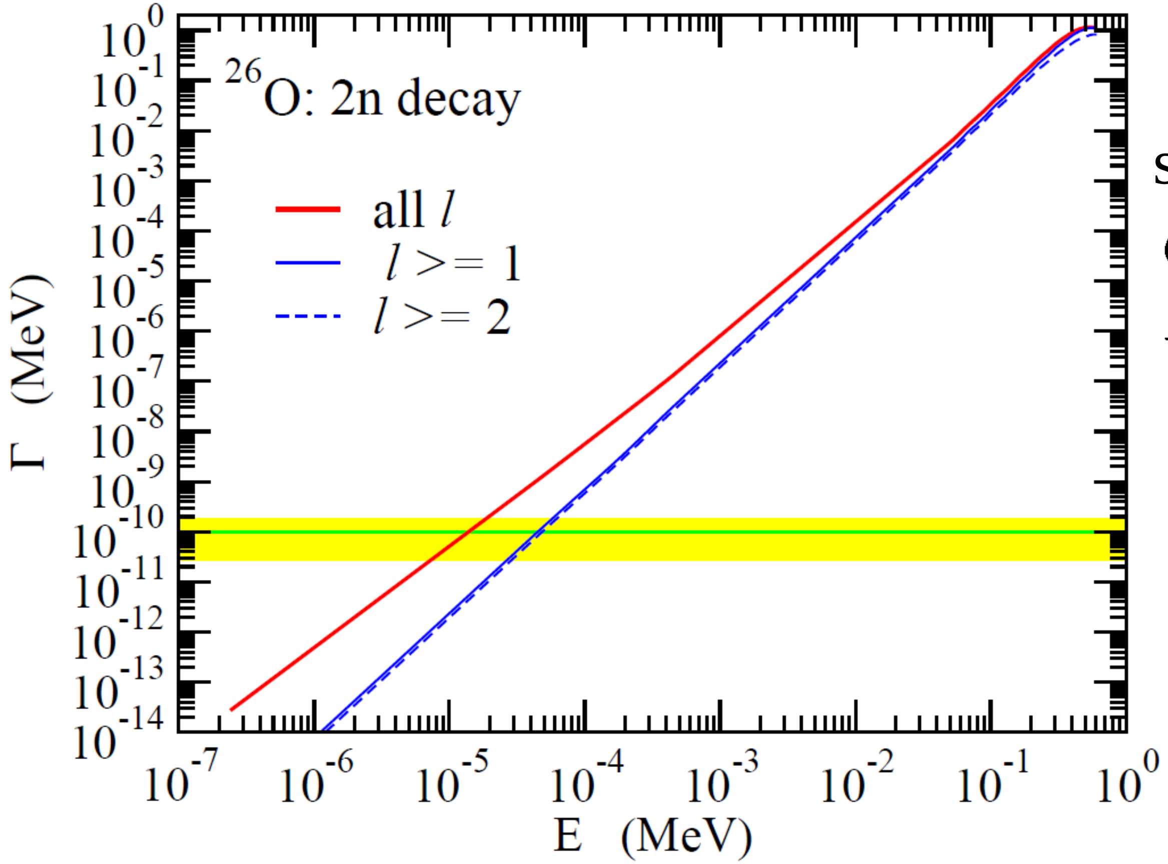
Decay width

two-potential method:

S.A. Gurvitz, PRL59 ('87) 262

$$\Gamma = 2\Im\langle\Phi_0|\delta V Q \frac{1}{QH_fQ - E_R - i\eta} Q\delta V|\Phi_0\rangle$$





simple prescription:

$$QH_fQ$$

$$\to Q_0(h_1 + h_2)Q_0 + v_{12}$$

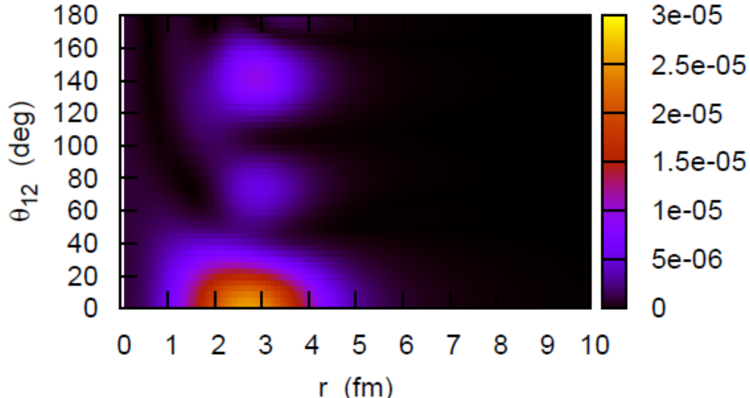
K.H., G.F. Bertsch, H. Sagawa, preliminary

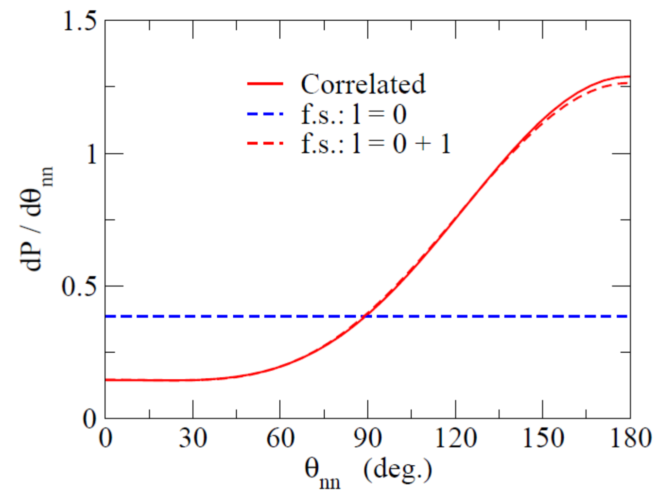
Summary

2n emission decay of ^{26}O ⟵ three-body model with
density-dependent zero-range interaction:
continuum calculations: relatively easy

- ✓ Decay energy spectrum: strong low-energy peak
- ✓ Energy distribution of 2 neutrons: three-body resonance
- ✓ Angular distributions: enhanced back-to-back emission

⟷ dineutron emission





☐ open problems

- ✓ Analyses for ^{16}Be, ^{13}Li (especially angular distributions)
- ✓ Decay width?