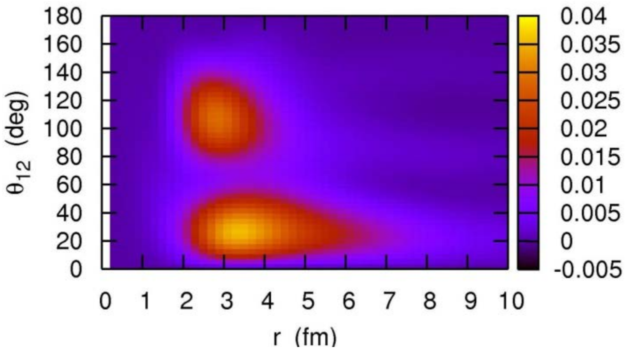
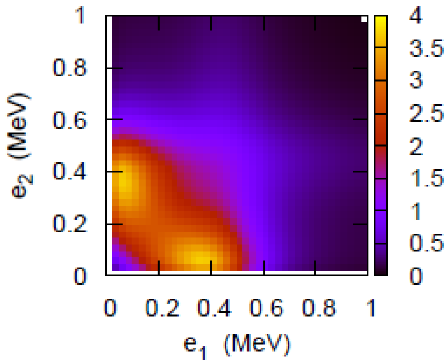
Two-particle correlations in continuum dipole transitions in Borromean nuclei

K. Hagino (Tohoku University)



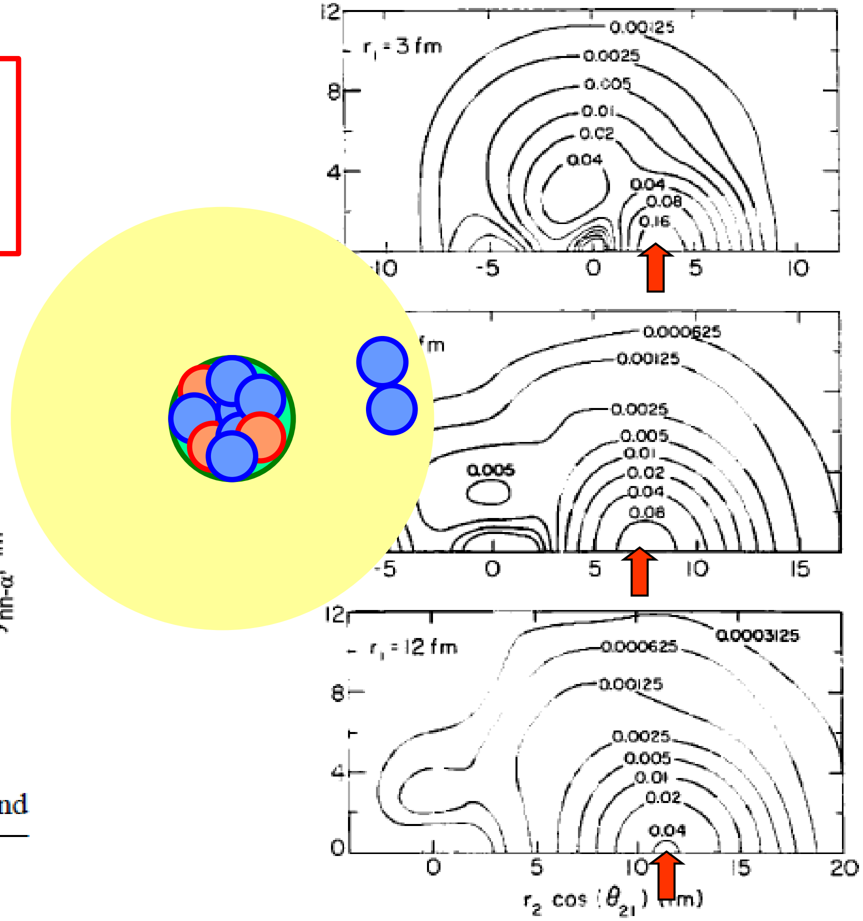


1. *Three-body model for Borommean nuclei:*
   Borromean nuclei and Di-neutron correlation
2. *Dipole excitations:*
   Energy distribution
3. *Summary*

Borromean nuclei and Di-neutron correlation

Borromean nuclei: unique three-body systems

$\rho_2(r_1, r_2, \theta_{12})$ for ^{11}Li



Three-body model calculations:

strong di-neutron correlation in ^{11}Li and ^{6}He

$x^2 y^2 \rho_2(x, y)$ for ^{6}He

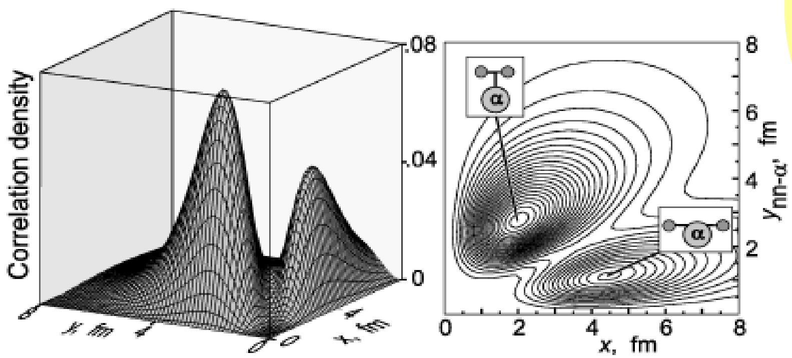


FIG. 1. Spatial correlation density plot for the 0^+ ground state of ^{6}He. Two components—di-neutron and cigarlike—are shown schematically.

Yu.Ts. Oganessian, V.I. Zagrebaev, and J.S. Vaagen, *PRL82('99)4996*

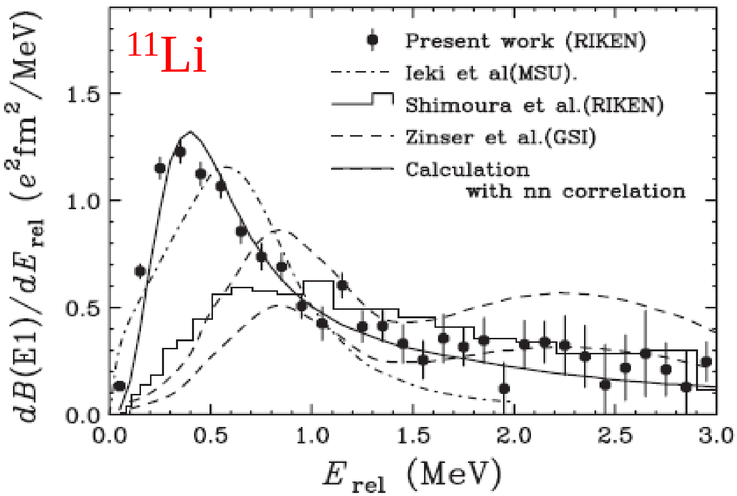
M.V. Zhukov et al., *Phys. Rep. 231('93)151*

G.F. Bertsch, H. Esbensen, *Ann. of Phys., 209('91)327*

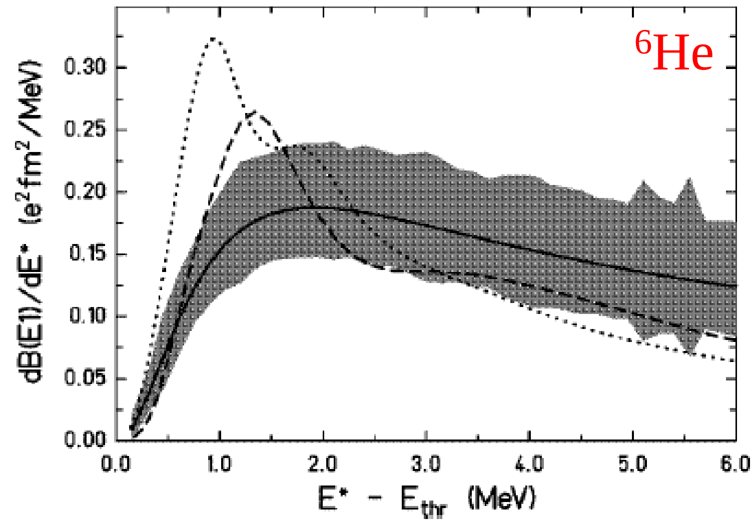
Remaining problem:

How to probe the strong dineutron correlation?

•Coulomb excitations?



T. Nakamura et al., PRL96('06)252502



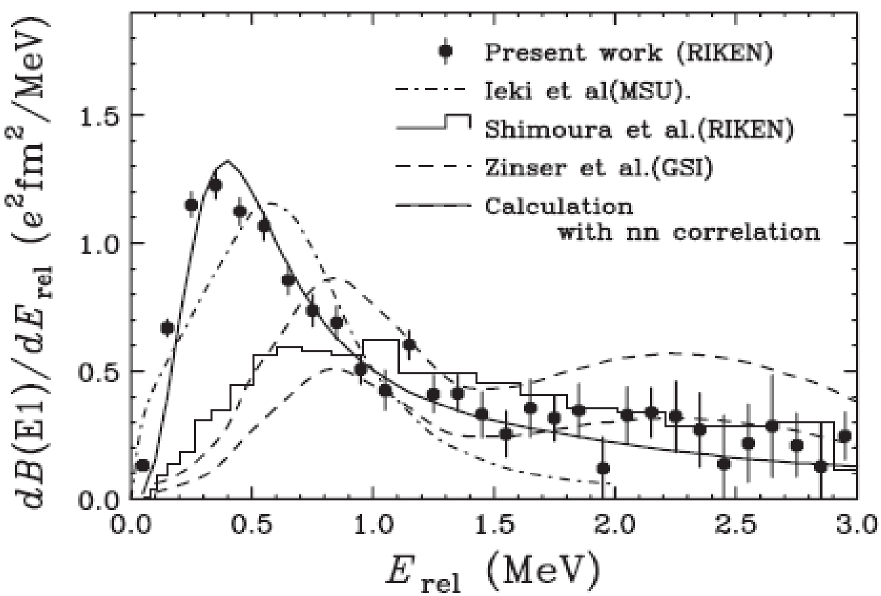
T. Aumann et al., PRC59('99)1252

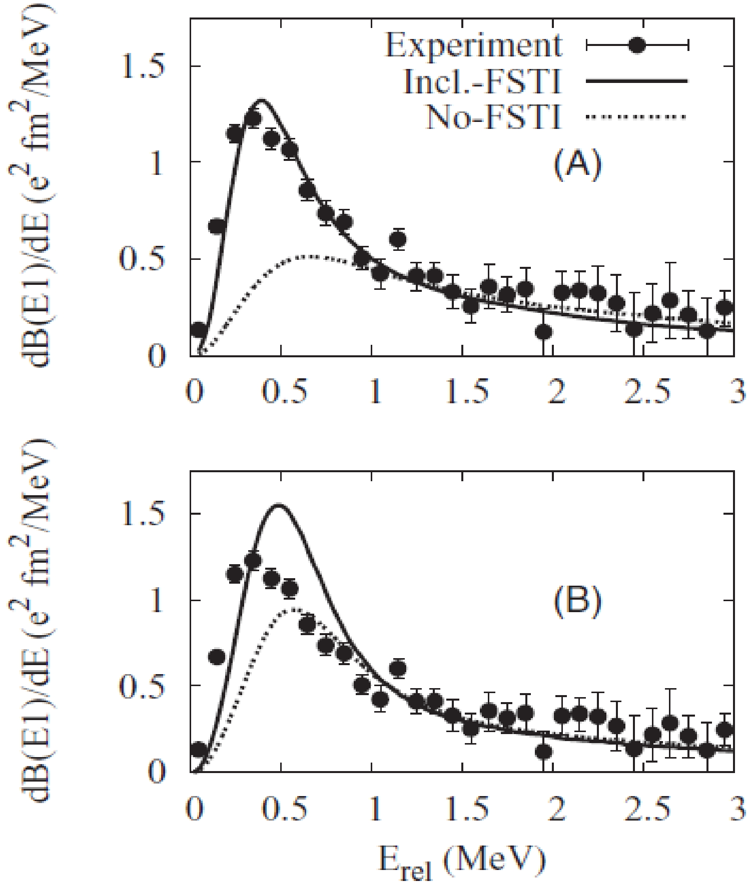
* (indirect) evidence for dineutron correlation

dineutron correlation in the ground state?

Experimental evidence: T. Nakamura et al., PRL96('06)252502

Recent Coulomb dissociation data of ^{11}Li





renewed interests in dineutron correlations in weakly bound nuclei

H. Esbensen, K. Hagino, P. Mueller, and H. Sagawa, PRC76('07)024302

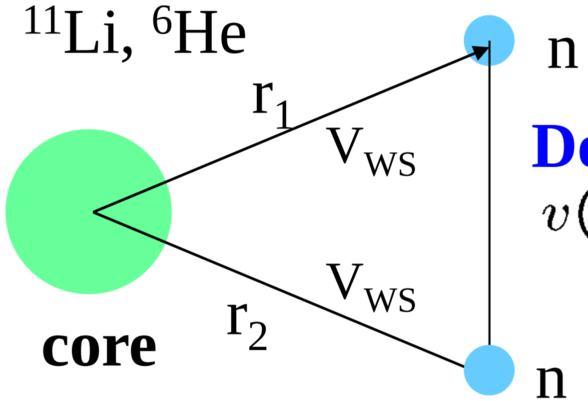
c.f. M. Matsuo et al., PRC71('05)064326
PRC73('06)044309

Remaining problems

- spatial structure of dineutron (cf. a large pair coherence length?)
- dineutron correlation in heavy nuclei?
- E1 excitations?
- Pair transfer?

⇩

Three-body model with density-dependent contact interaction



G.F. Bertsch and H. Esbensen,
Ann. of Phys. 209('91)327; PRC56('99)3054

↑
application
to ^{11}Li and ^{6}He

Density-dependent delta-force

$$v(\boldsymbol{r}_1,\boldsymbol{r}_2) = v_0(1+\alpha\rho(r)) \times\delta(\boldsymbol{r}_1-\boldsymbol{r}_2)$$

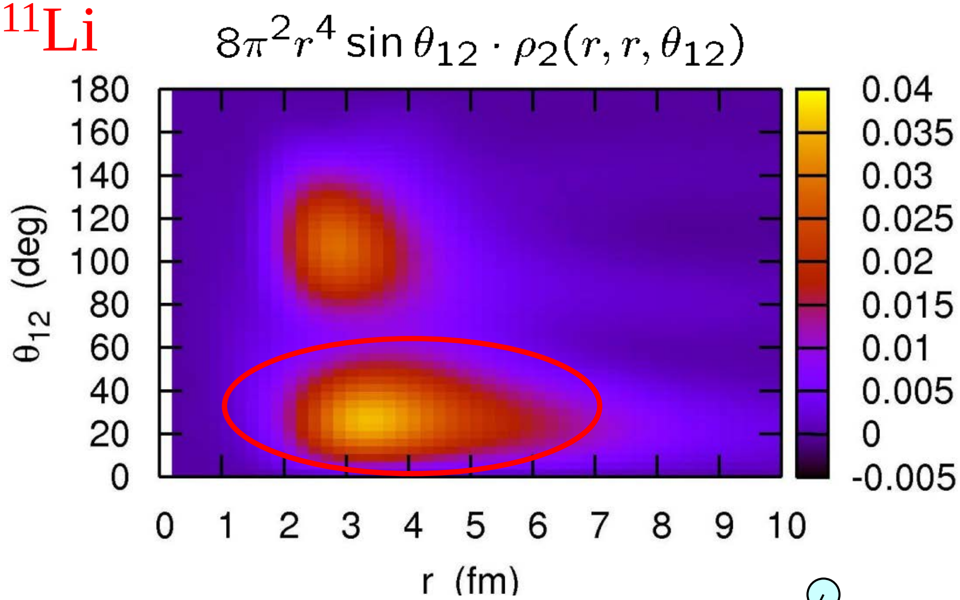
v_0 ⟵ nn scattering length
d.d. part ⟵ S_{2n}

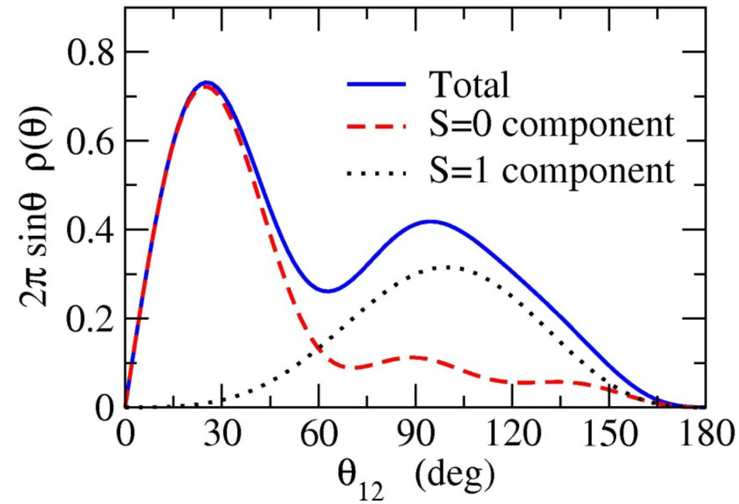
$$H=\frac{\boldsymbol{p}_1^2}{2m}+\frac{\boldsymbol{p}_2^2}{2m}+V_{nC}(r_1)+V_{nC}(r_2)+V_{nn}+\frac{(\boldsymbol{p}_1+\boldsymbol{p}_2)^2}{2A_cm}$$

Two-particle density for the ground state

→ strong di-neutron correlation

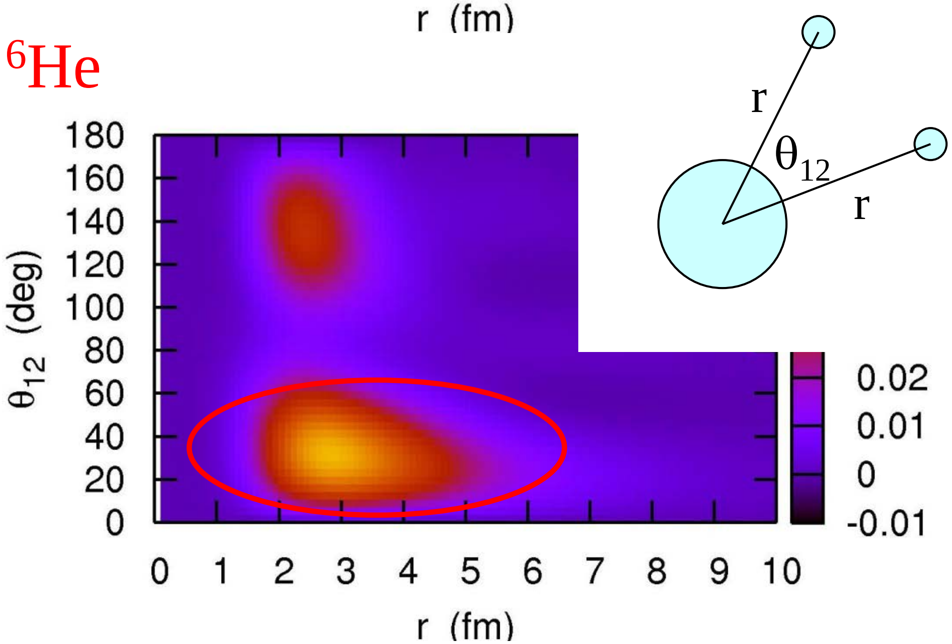
^{11}Li

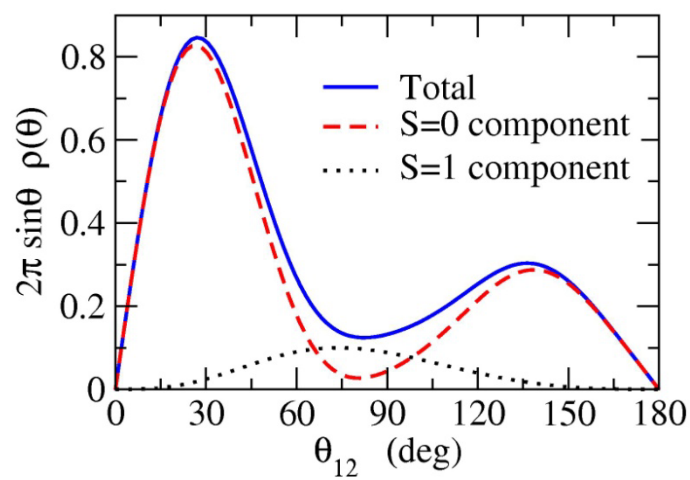




$$\langle \theta_{12} \rangle = 65.29 \;\; \text{deg.}$$

^{6}He



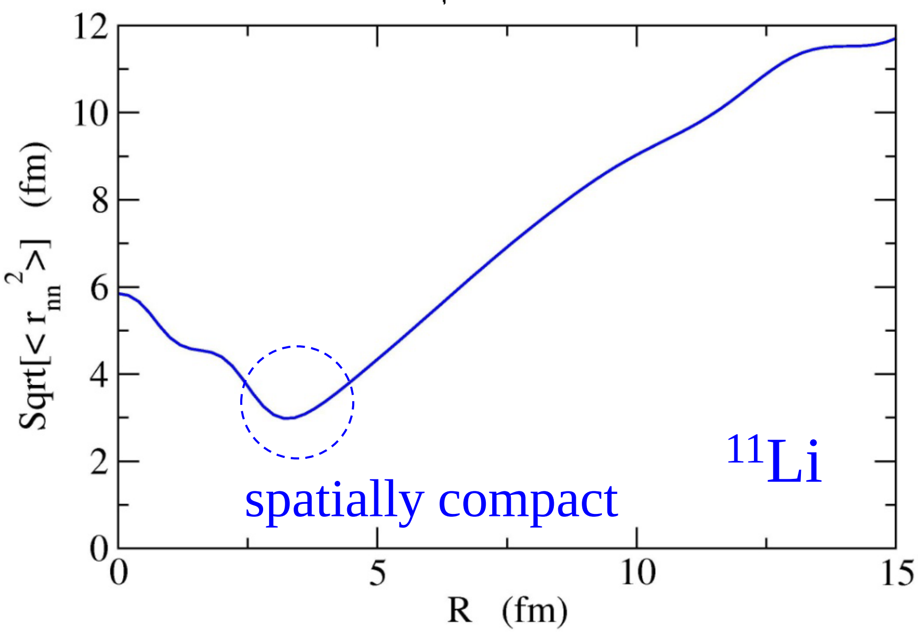


$$\langle \theta_{12} \rangle = 66.33 \;\; \text{deg.}$$

K.H. and H. Sagawa, PRC72('05)044321

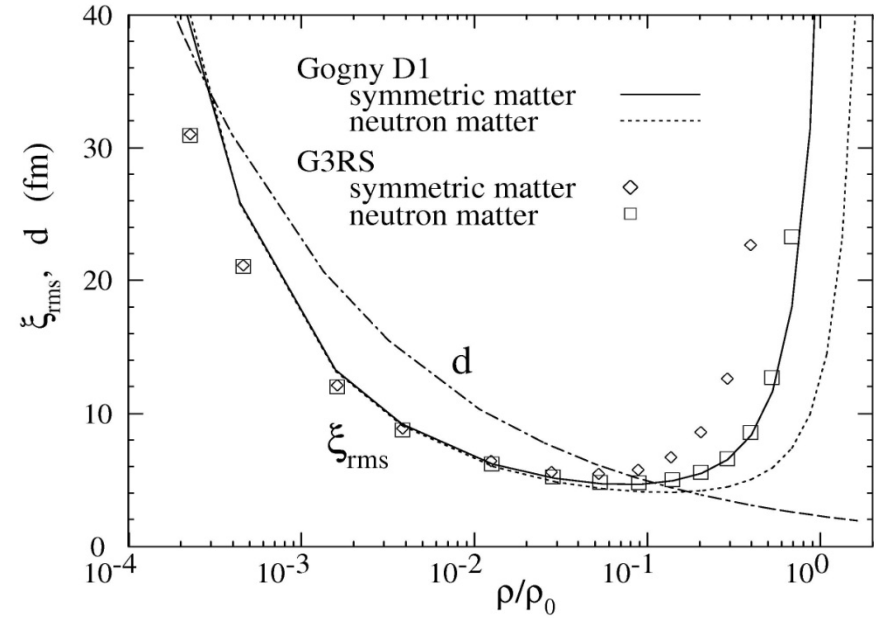
2n-rms distance

$$\sqrt{\langle r_{nn}^2\rangle}(R) = \sqrt{\frac{\int r^4 dr\,|f_{L=0}(r,R)|^2}{\int r^2 dr\,|f_{L=0}(r,R)|^2}}$$

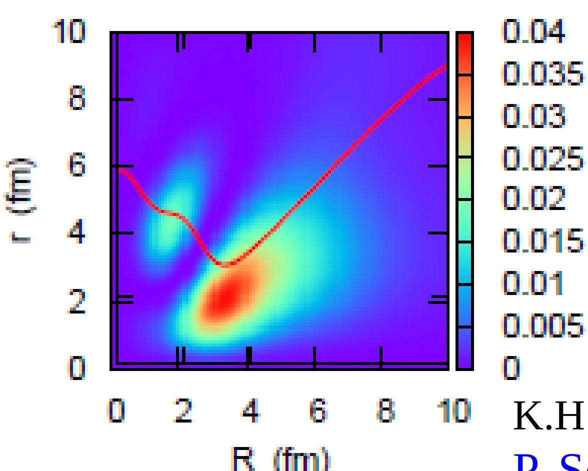


K.Hagino, H. Sagawa, J. Carbonell, and P. Schuck, PRL99('07)022506

Matter Calc.

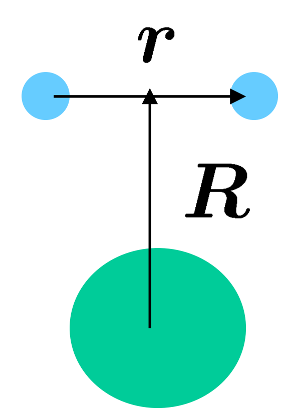


M. Matsuo, PRC73('06)044309



dineutron on the surface

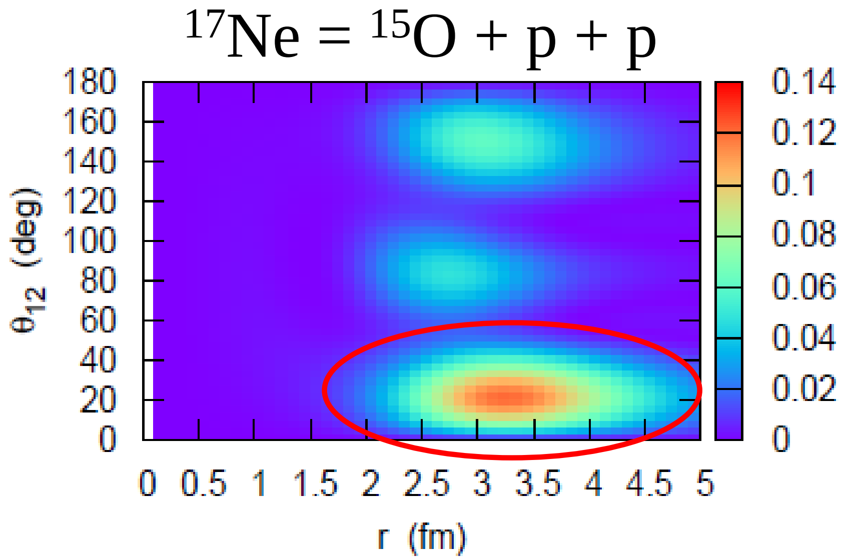
K.H., H. Sagawa, and P. Schuck, J. of Phys. G37('10)064040



cf. "di-proton" correlation

^{17}Ne = ^{15}O + p + p   (S_{2p} = 0.944 MeV)

v_{pp} = density-dep. contact interaction + Coulomb

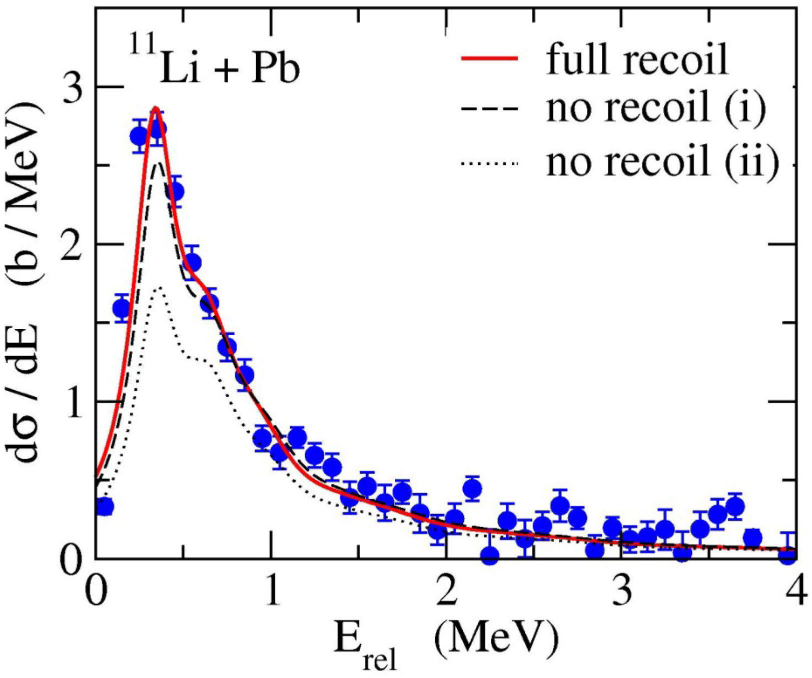


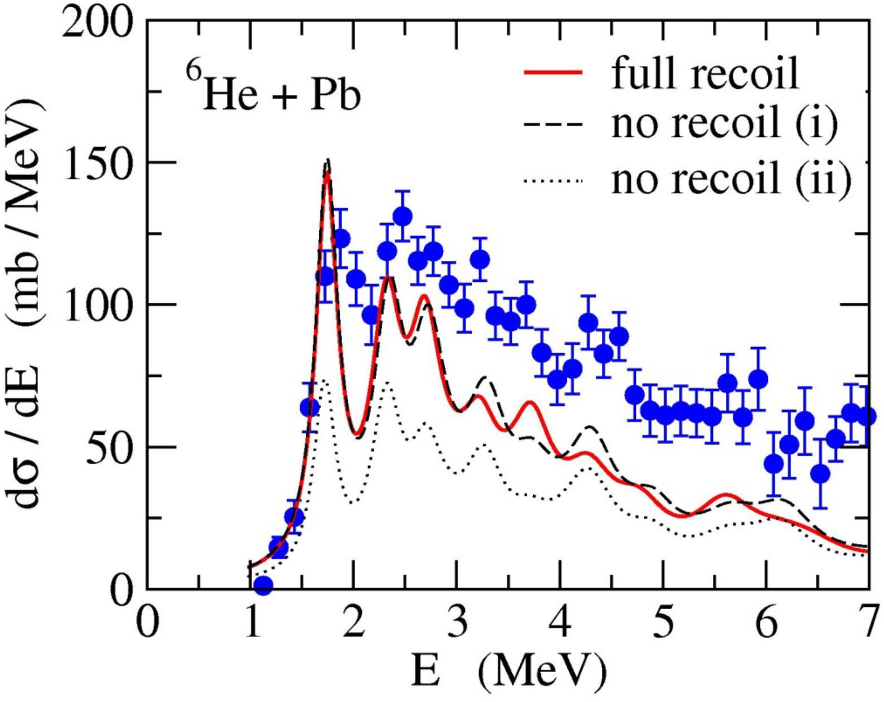
$$\langle v_{pp}^{(\mathrm{nucl})} \rangle = -3.26 \quad \mathrm{MeV}$$
$$\langle v_{pp}^{(\mathrm{Coul})} \rangle = 0.448 \quad \mathrm{MeV} \longleftarrow$$

about 15% contribution

T. Oishi, K. H., and H. Sagawa, PRC82('10)024315

Dipole excitation

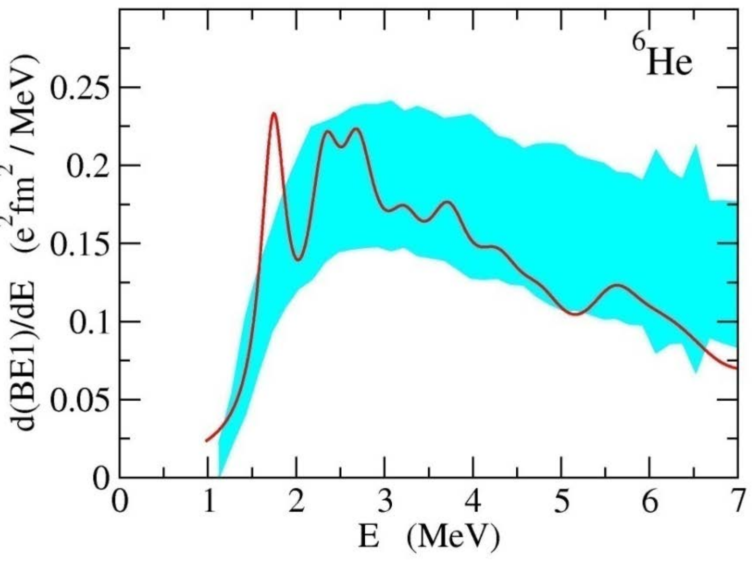




Response to the dipole field:

$$B_k(E1) = 3\,|\langle \Psi^k_{1^-}|\hat{D}_0|\Psi_{gs}\rangle|^2$$

$$\hat{\boldsymbol{D}} = -\frac{Ze}{A}(\boldsymbol{r}_1+\boldsymbol{r}_2)$$

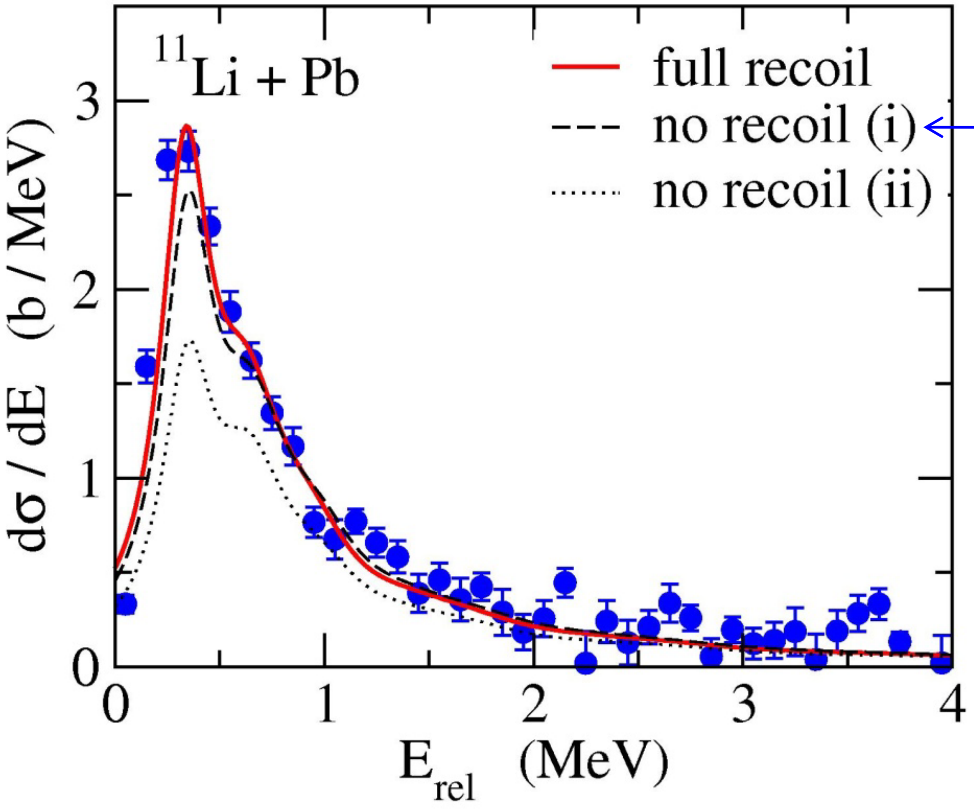


K.Hagino and H. Sagawa,PRC76('07)047302

recoil term

$$H = \frac{\boldsymbol{p}_1^2}{2m} + \frac{\boldsymbol{p}_2^2}{2m} + V_{nC}(r_1) + V_{nC}(r_2) + V_{nn}(\boldsymbol{r}_1, \boldsymbol{r}_2) + \frac{(\boldsymbol{p}_1 + \boldsymbol{p}_2)^2}{2A_c m}$$

$$= \frac{\boldsymbol{p}_1^2}{2\mu} + \frac{\boldsymbol{p}_2^2}{2\mu} + V_{nC}(r_1) + V_{nC}(r_2) + V_{nn}(\boldsymbol{r}_1, \boldsymbol{r}_2) + \frac{\boldsymbol{p}_1 \cdot \boldsymbol{p}_2}{A_c m}$$



with recoil for the g.s. but without for 1$^-$

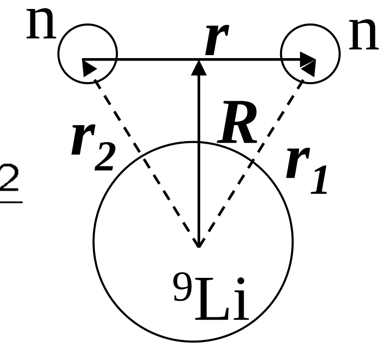
continuum calculations

K.Hagino and H. Sagawa,PRC76('07)047302

More direct information on the correlation?

$$|\Psi_{1^-}\rangle = \hat{D}|\Psi_{gs}\rangle$$

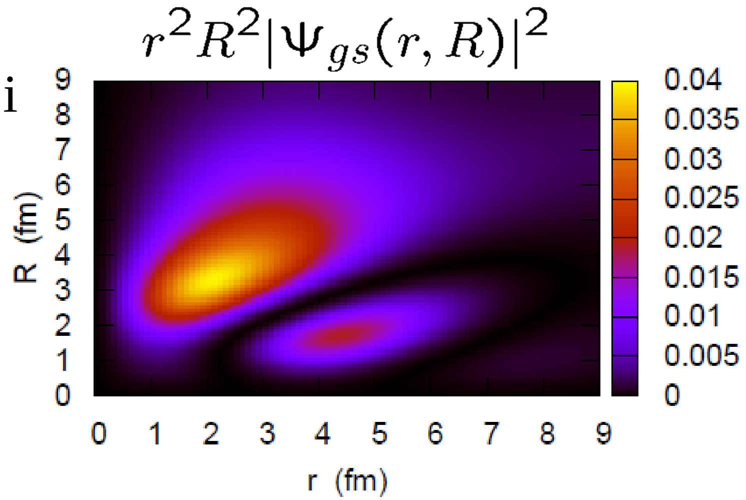
$$\boldsymbol{R} = \frac{\boldsymbol{r}_1 + \boldsymbol{r}_2}{2}$$



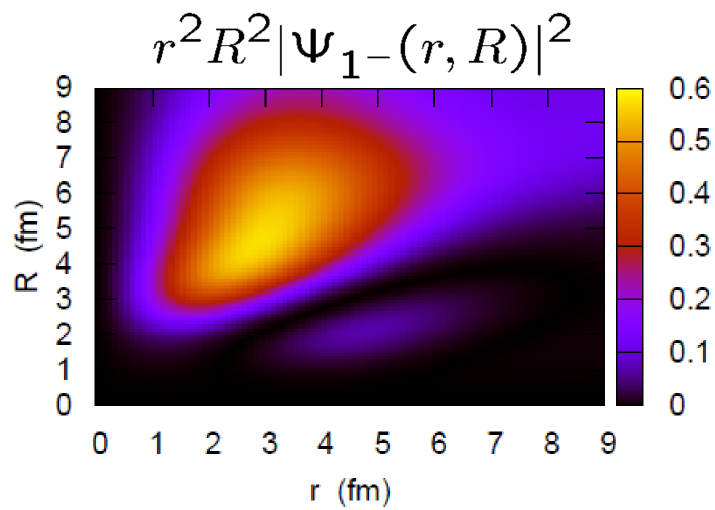
dipole operator

$$\hat{D} = -\frac{Ze}{A}(\boldsymbol{r}_1 + \boldsymbol{r}_2) = -\frac{2Ze}{A}\boldsymbol{R}$$

^{11}Li



dipole →

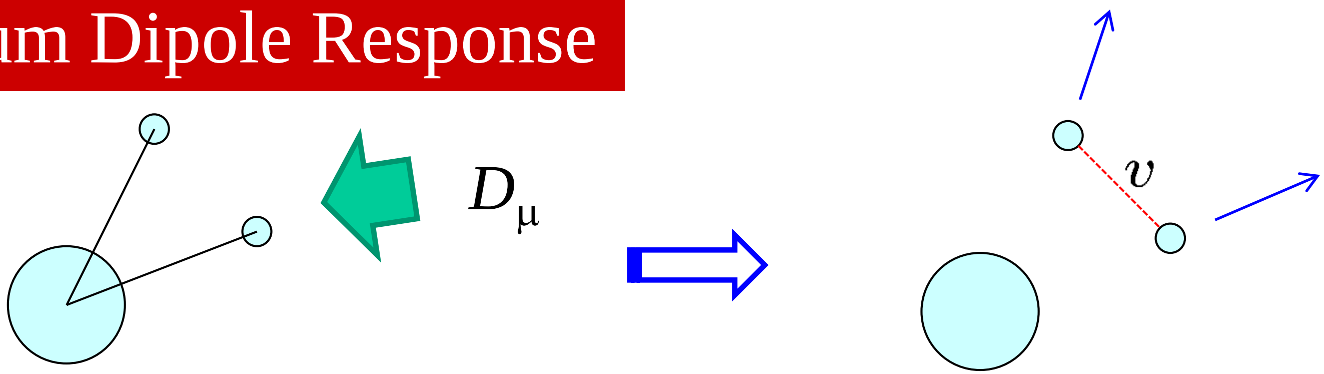


The relative motion $r = r_1 - r_2$ is not affected by the dipole operator.

Probing dineutron correlation with E1 excitation?

especially with energy (and angular) distribution(s)?

Continuum Dipole Response



$$M(E1) = \langle (j_1 j_2)^1_\mu | (1 - vG_0 + vG_0 vG_0 - \cdots) D_\mu | \Psi_{gs} \rangle$$
$$= \langle (j_1 j_2)^1_\mu | (1 + vG_0)^{-1} D_\mu | \Psi_{gs} \rangle$$

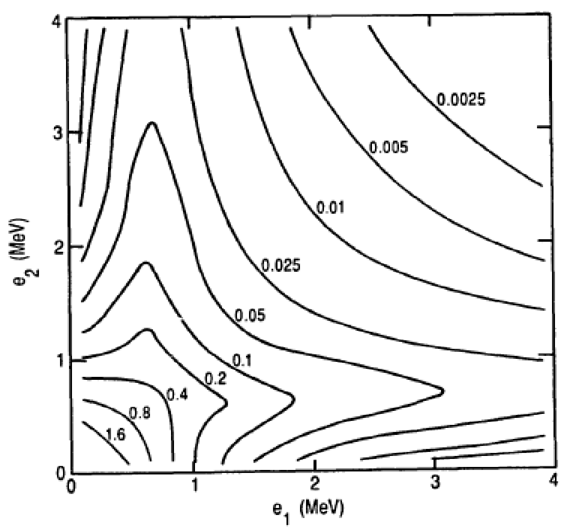
FSI

dipole operator

unperturbed continuum wf

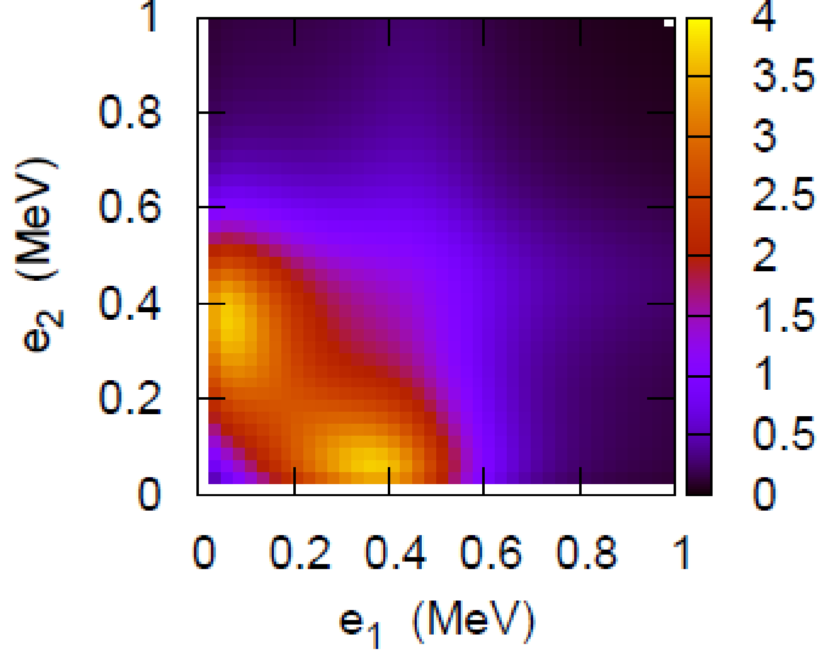
$$G_0(E) = \sum_{\mu, f.st.} \frac{\left| (j_1 j_2)^1_\mu \right\rangle \left\langle (j_1 j_2)^1_\mu \right|}{e_1 + e_2 - E - i\eta}$$

$$\boxed{\frac{d^2 B(E1)}{de_1 de_2} = 3 \sum_{l_1 j_2 l_2 j_2} |M(E1)|^2 \frac{dk_1}{de_1} \frac{dk_2}{de_2}}$$

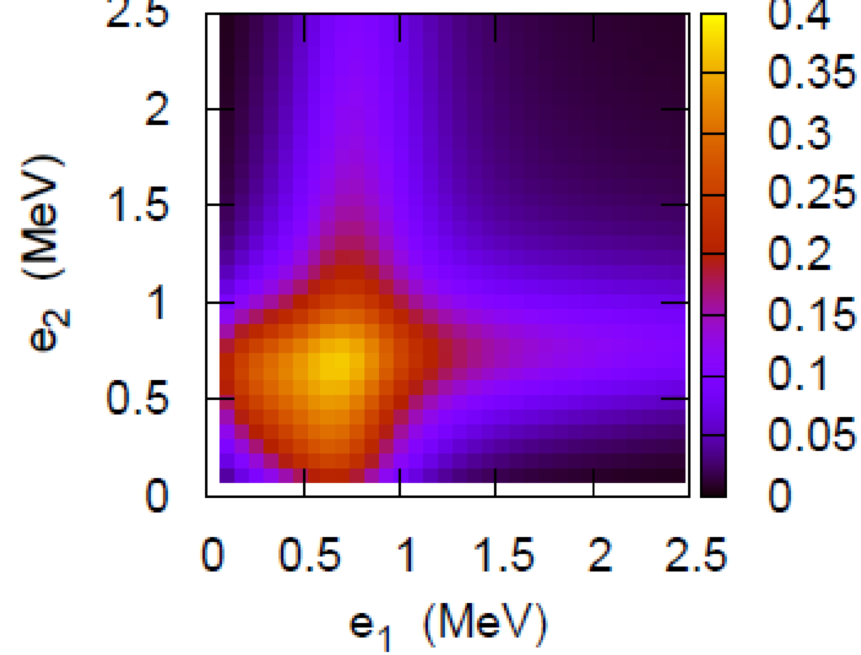


H. Esbensen and G.F. Bertsch, NPA542('92)310

^{11}Li

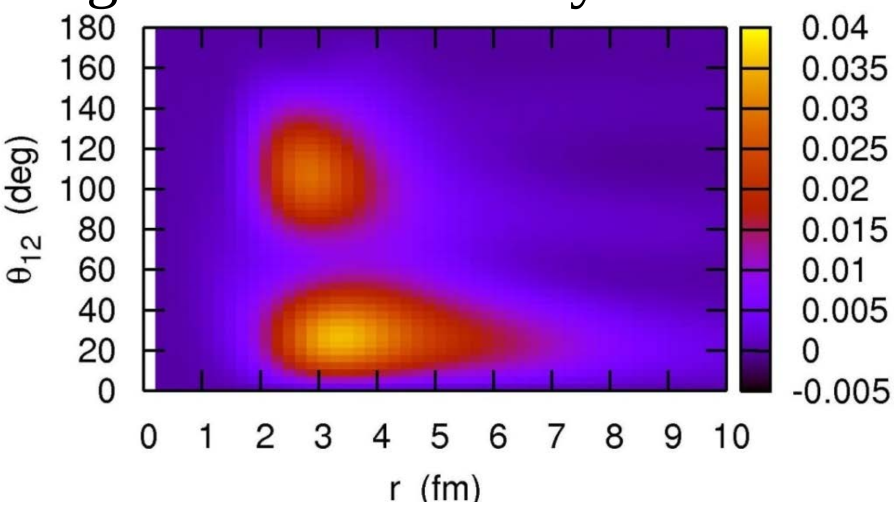


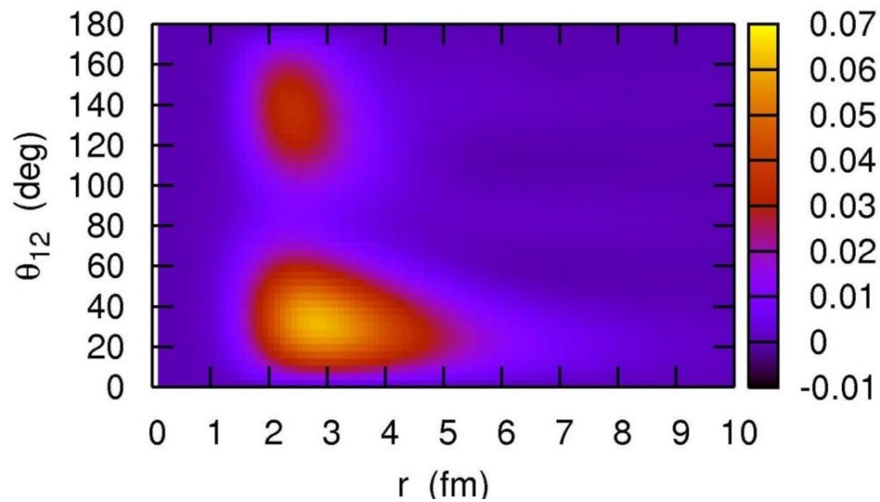
^{6}He

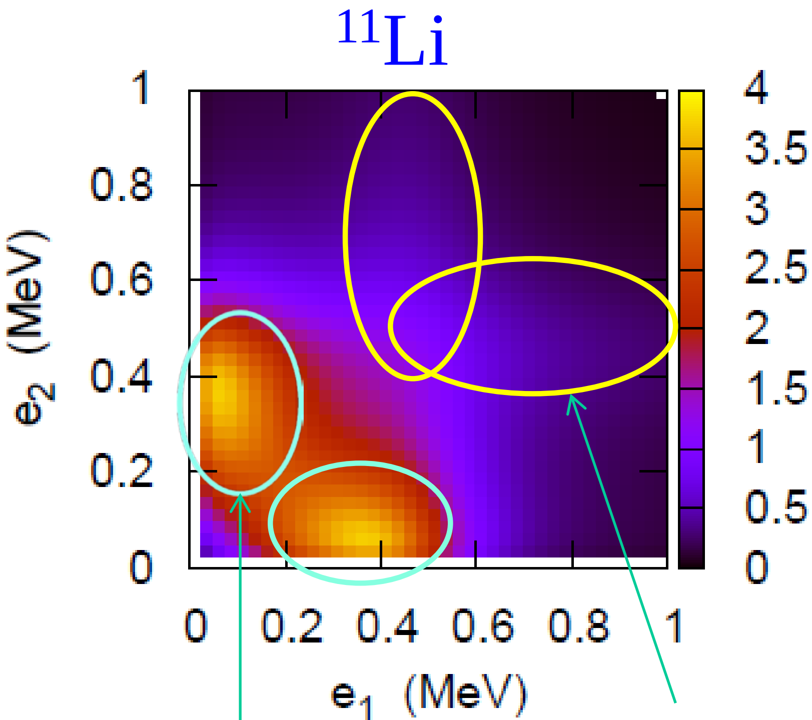


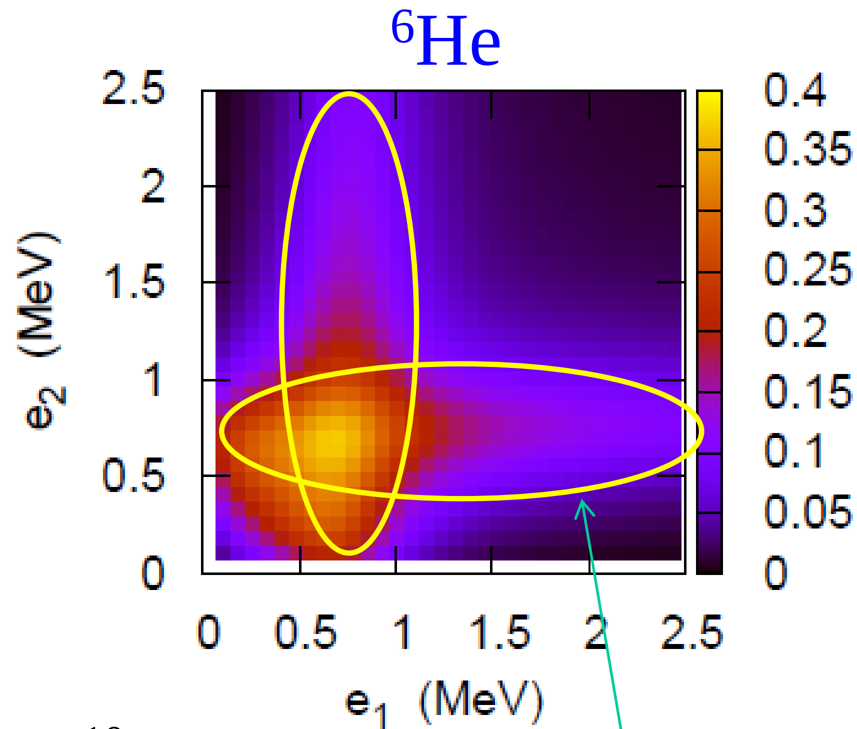
K.H., H. Sagawa, T. Nakamura, S. Shimoura, PRC80('09)031301(R)

cf. ground state density









s-wave virtual state in ^{10}Li

(scattering length:
a =-30 $^{+12}_{-31}$ fm)

$p_{1/2}$ resonance for ^{10}Li
at 0.54 MeV

$p_{3/2}$ resonance for ^{5}He
at 0.91 MeV

(cf. s-wave scattering length:
a = +4.97 +/- 0.12 fm)

◆distribution for ^{11}Li: consistent with preliminary expt. data (T. Nakamura et al.)

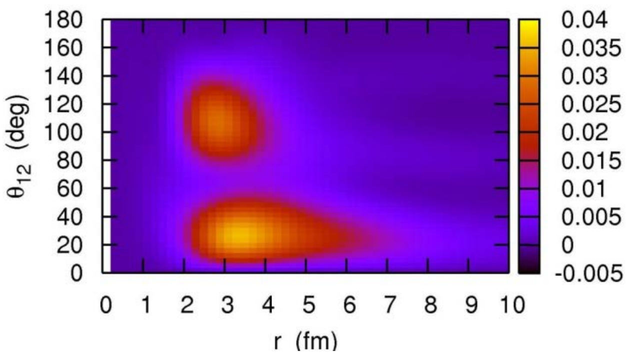
K.H., H. Sagawa, T. Nakamura, S. Shimoura, PRC80('09)031301(R)

Summary

Three-body model with density-dependent contact interaction

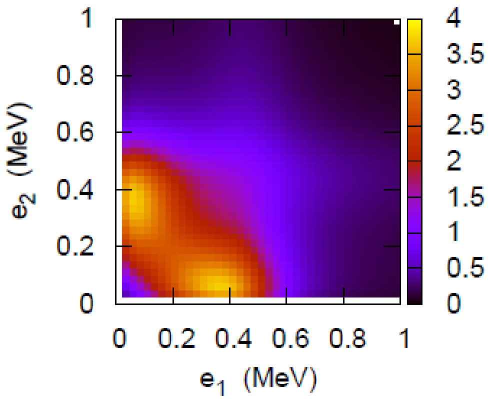
◆**Ground state of ^{11}Li and ^{6}He**

- similar di-neutron correlation



◆**Energy distribution**
of neutrons from the E1 excitations in ^{11}Li and ^{6}He

- the shape of distributions: primarily determined by n-core dynamics rather than n-n



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need another way to probe the dineutron correlation

- nuclear breakup
- pair transfer

cf. simple one-dimensional model

K.H., A. Vitturi, F. Perez-Bernal, and H. Sagawa, J. of Phys. G38('11) 015105