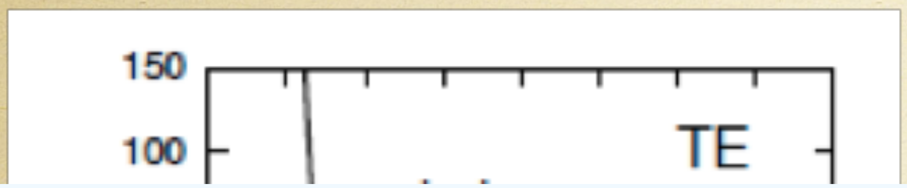
Importance of tensor forces in ground state of nuclei through high-momentum nucleons

= Overview =

Isao Tanihata, H. J. Ong, S. Terashima, T. Myo, and H. Toki

[1]IRCNPC and SPNEE, Beihang University, Beijing, China
[2]RCNP, Osaka University, Osaka, Japan
[3]Osaka Institute of Technology, Osaka, Japan

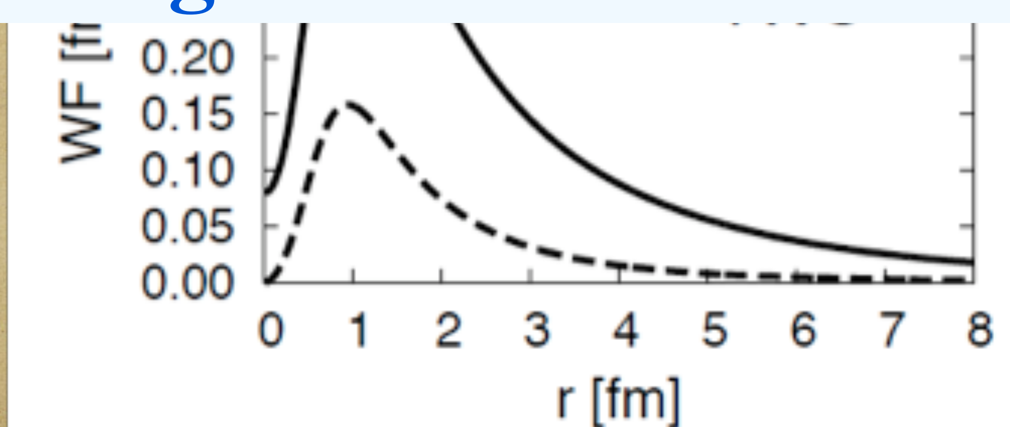
The importance of tensor is clear in deuteron



S=1 and L=0 or 2

Binding of deuteron (1^+)

1. **Tensor interactions provides most of the biding energy.**
2. **It is due to the D-wave mixing through the tensor interactions**
3. **The binding energy by tensor interactions are not from D^2 term but from SD cross term.**
4. **D wave has shorter range and thus has high-momentum.**
5. **High momentum nucleon are necessary to make binding.**

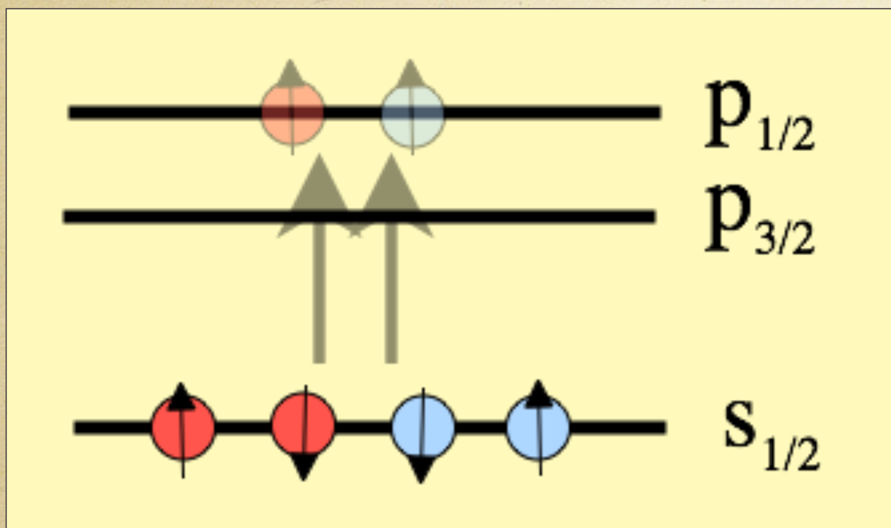


P(*D*)	5.78 [%]
Radius	1.96 [fm]
(SS)	2.00 [fm]
(DD)	1.22 [fm]

K.Ikeda, T.Myo, K.Kato,and H.Toki
Lecture Notes in Phys.818(2010) 165.

A simple view of the effect of tensor forces

- **Example in ^{4}He**



The selection rules

$\Delta L=2$, $\Delta S=2$
p-n pair: yes
n-n, p-p pair: no

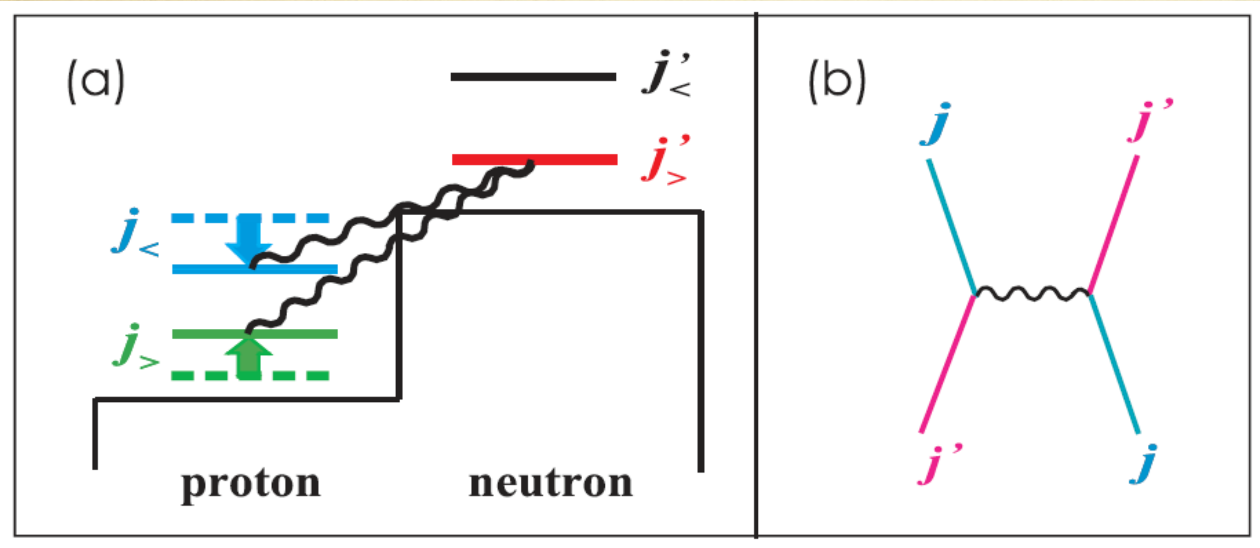
and
this mixed state includes
high-momentum nucleons

		H-J
Energy		-20.6
Kin. E		$\boxed{131.1}$
Pot. E		-151.7
C	^1E	-51.3
	^3E	-26.2
	$^1O+^3O$	-0.4
T	^3E	$\boxed{-69.7}$
	^3O	-0.5
LS+QLS		-3.6
P(D)%		12.8

M. Sakai, I. Shimodaya, Y. Akaishi, J. Hiura, and H. Tanaka, Prog. Theor. Phys. 56(1974)32.

Importance of tensor forces in nuclear structure

- **Change of single particle orbitals**
  - *Change of magic numbers in nuclear far from the stability line*



T. Otsuka, T . Suzuki, R. Fujimoto, H. Grawe and Y. Akashi, Phys. Rev. Lett. **95** (2005) 232502.

Other known effects related to 2p-2h configuration by tensor forces

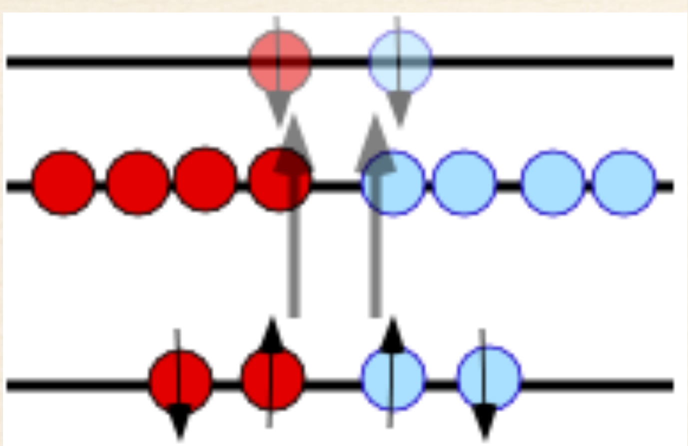
- **Deviation of scaler magnetic moments (or $<\sigma_Z>$) of doubly closed shell±1 from Schmidt values.**
  - ***H. Hyuga, A. Arima, and K. Shimizu, Null. Phys. A 336 (1980) 363.***

- **Mixing of $(s_{1/2})^2$ and $(p_{1/2})^2$ in ^{11}Li halo**
  - ***T. Myo, K. Kato, H. Toki, K. Ikeda, Phys. Rev. 76 (2007) 024305.***

Isoscalar moments need other explanations

Arima 1985.

- **If a nucleon-nucleon interaction is central, the total spin is a constant of motion.**
- **The expectation value of spin in nuclei with and LS-closed shell ±one nucleon are then the same as their Schmidt values, irrespective of the degree of configuration mixing.**
- **In order to modify the values, one has to have non-central interaction.**
- **Pion exchange potential include a strong tensor force.**



$\Delta L=2$, $\Delta S=2$
p-n pair: yes
n-n, p-p pair: no

Second order calculation up to $12\hbar\omega$

- H. Hyuga, A, Arima, and K. Shimizu (Nucl. Phys. **A 336** (1980) 363.

Table 2

Isoscalar spin operator

A	Orbit	Schmidt value	$\delta\langle S\rangle(\exp)/\langle S\rangle$ (%)
15	$p_{1/2}$	−0.1667	−49.4
17	$d_{5/2}$	0.5	−13.6
39	$d_{3/2}$	−0.3	−61.9
41	$f_{7/2}$	0.5	−11.9

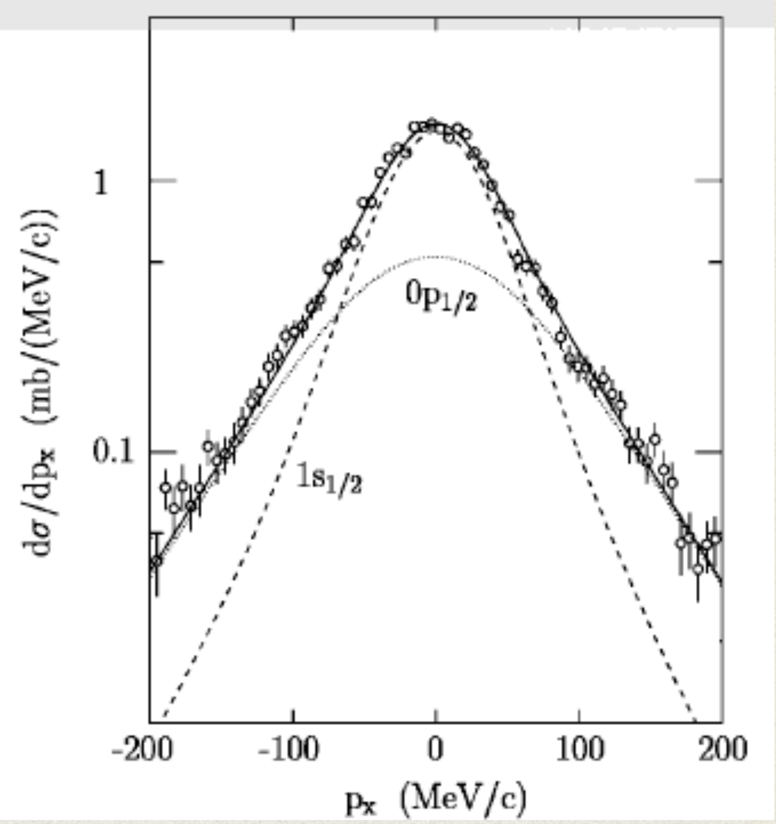
Table 4

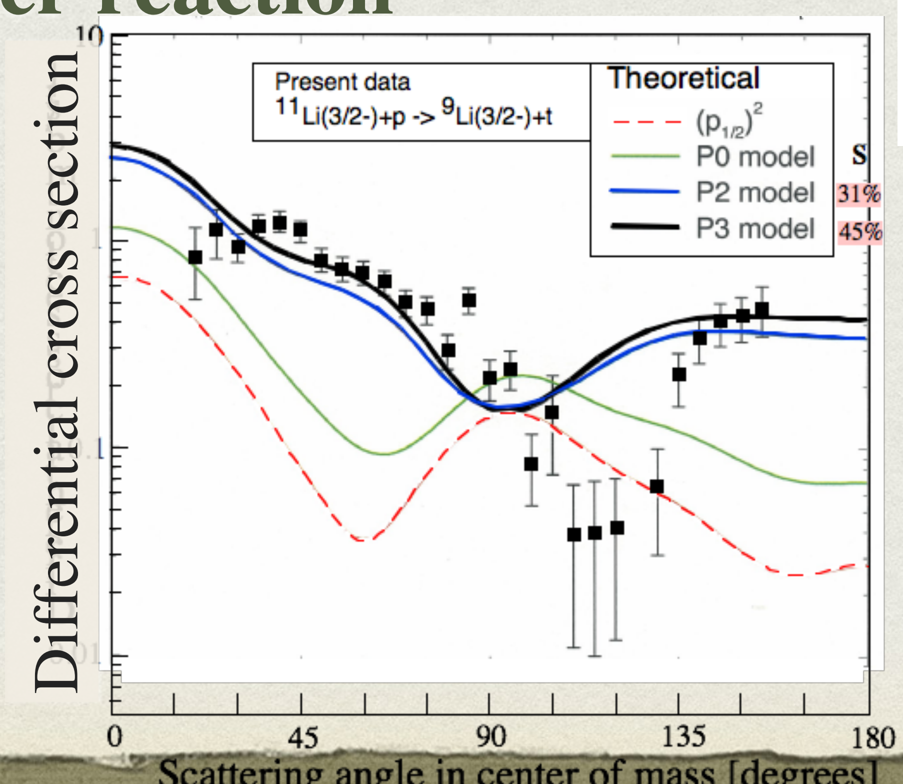
Contribution coming from the second-order configuration mixing

A	Orbit	$\delta\langle S\rangle/\langle S\rangle$ (H.J.)[6] (%)	$\delta\langle S\rangle/\langle S\rangle$ (Paris) (%)
15	$p_{1/2}$	−63	−57
17	$d_{5/2}$	−18	−17
39	$d_{3/2}$	−55	−56
41	$f_{7/2}$	−19	−23

s- and p- waves mixing in ^{11}Li

- **Momentum distribution of fragments ^{10}Li**
  - *Equal amount of $p_{1/2}$ and $s_{1/2}$. (Simon 1999)*
- **Beta-decay**
  - *30-40% $s_{1/2}$ wave and small amount of $p_{1/2}$ (Borge 1997)*
- **two-neutron transfer reaction**
  - *(^{11}Li+p --> ^{9}Li+t)*
  - *31-45% $s_{1/2}$ and $p_{1/2}$*
  - *(2008)*



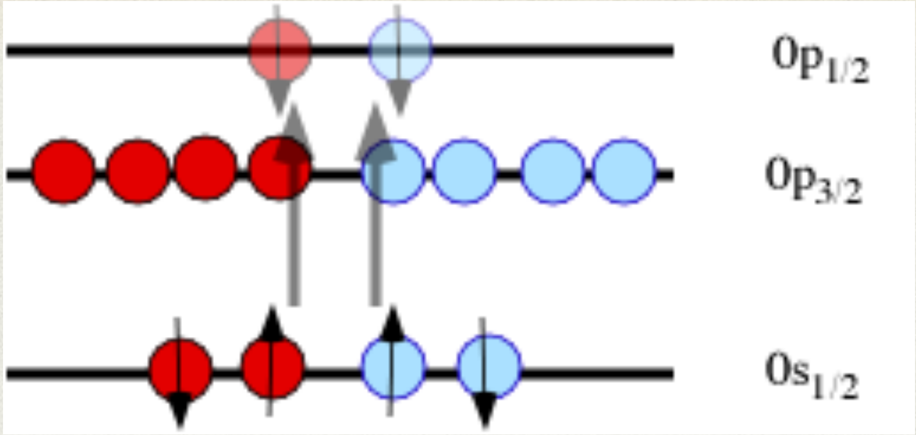


41% s
35% s

I. Tanihata et al., Phys. Rev. Lett 100 (2008) 192502..

Tensor Optimized Shell Model (TOSM)

Myo, Toki, Ikeda, Kato, Sugimoto, PTP 117 (2006)



$\Delta L=2$, $\Delta S=2$
p-n pair: yes
n-n, p-p pair: no

0p-0h + 2p-2h

$$\Phi(^4\mathrm{He}) = \Sigma_i C_i \psi_i(\{b_\alpha\}) = C_1 (0s)^4 + \underline{C_2 (0s)^2(\overline{0p}_{1/2})^2} + \cdots$$

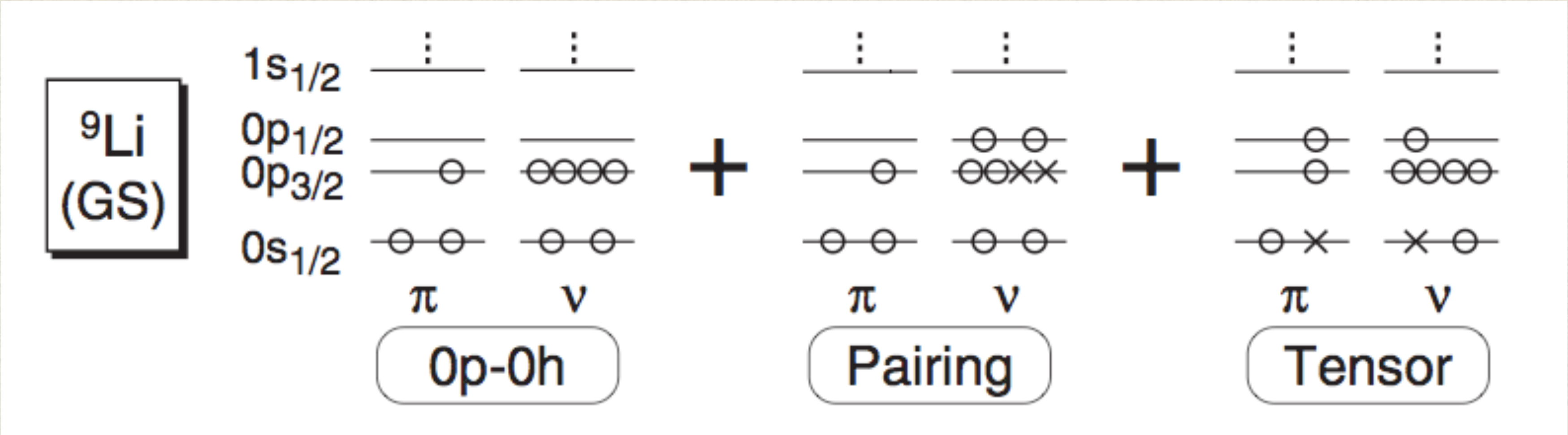
size parameter: $b_{0s} \neq b_{\overline{0p}}$

Energy variation

$$H = \sum_{i=1}^{A} t_i - T_G + \sum_{i<j}^{A} v_{ij}, \qquad v_{ij} = v_{ij}^{C} + v_{ij}^{T} + v_{ij}^{LS} + v_{ij}^{Clmb},$$

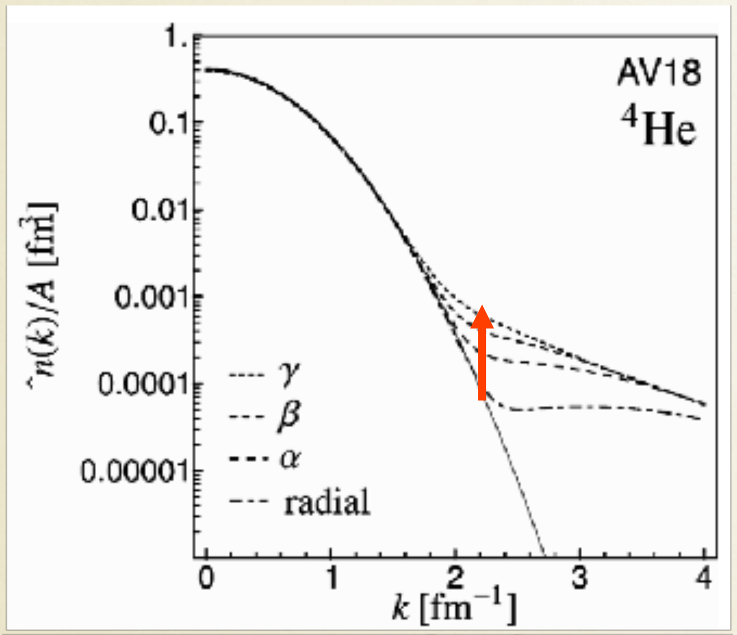
$$\delta \frac{\langle\Phi|\, H\, |\Phi\rangle}{\langle\Phi|\Phi\rangle} = 0 \quad \Rightarrow \quad \frac{\partial\langle H - E\rangle}{\partial b_\alpha} = 0\,, \quad \frac{\partial\langle H - E\rangle}{\partial C_i} = 0.$$

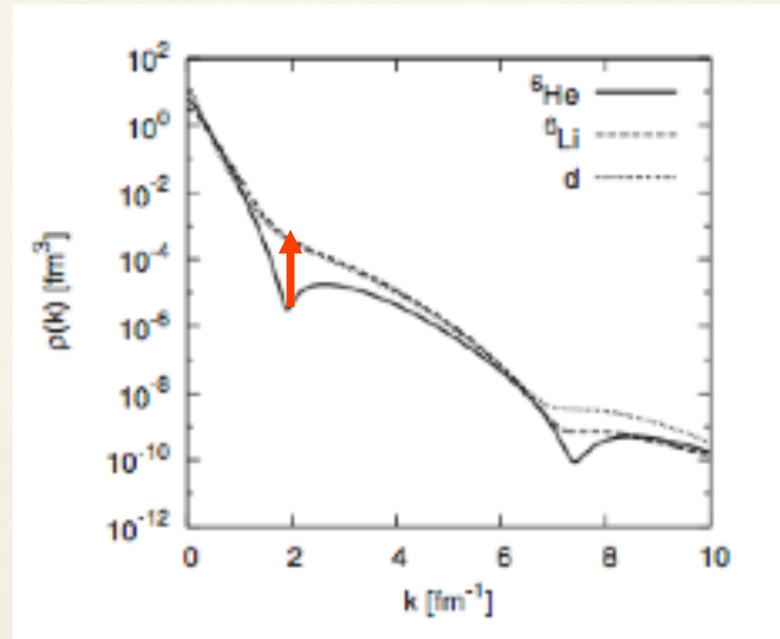
Mixing of $s_{1/2}$ and $p_{1/2}$ in ^{11}Li



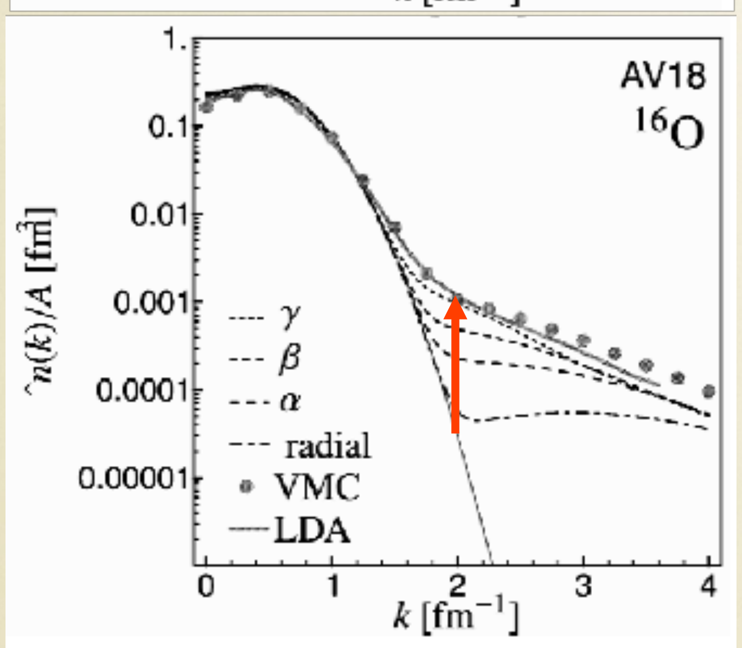
T. Myo, K. Kato, H. Toki, K. Ikeda, Phys. Rev. 76 (2007) 024305.

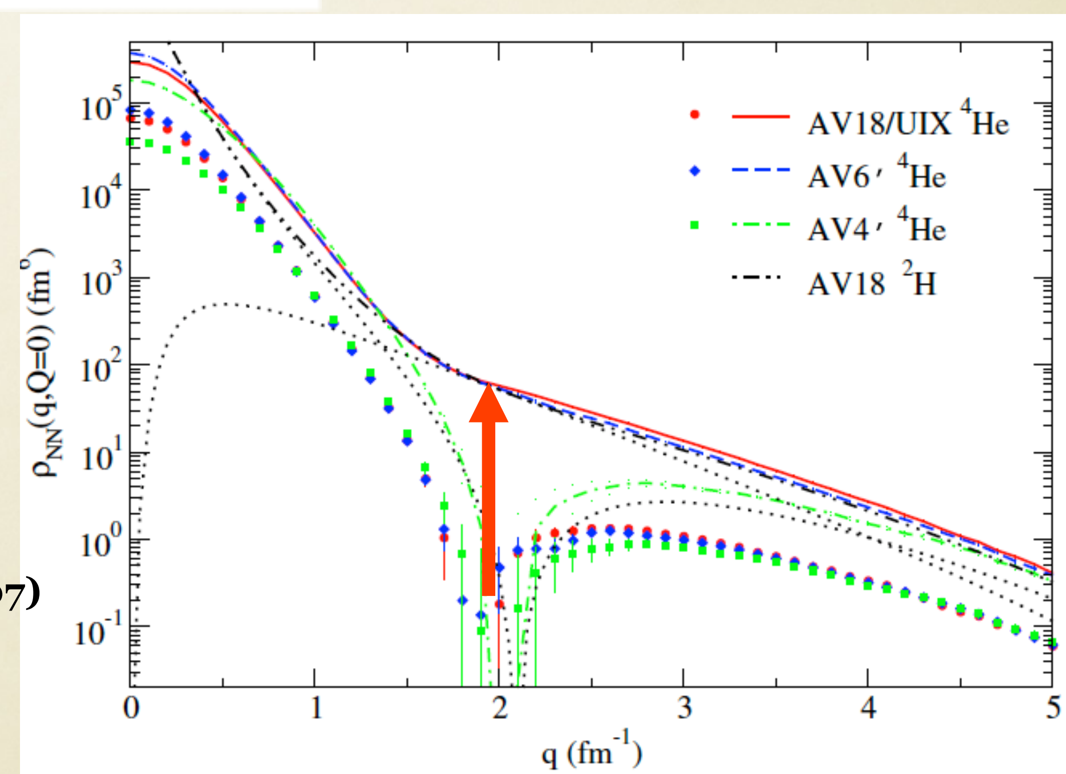
High-momentum components (Theoretical Predictions)





W. Horiuchi and Y. Suzuki,
PRC76, 024311(2007)





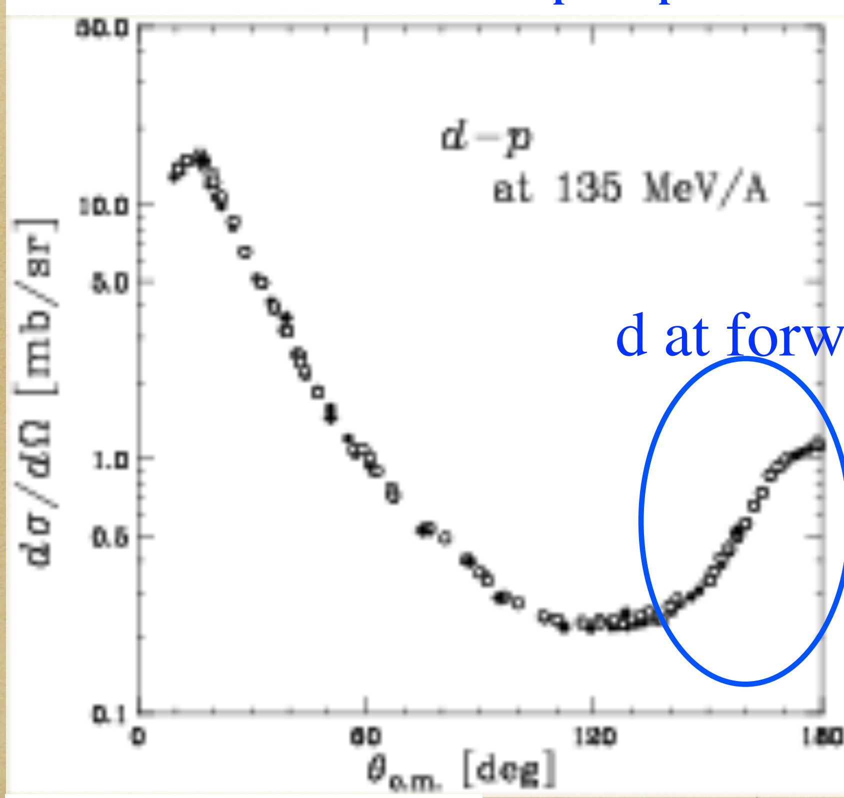
R. Schiavilla et al.,
PRL 98 132501 (2007)

T. Neff and H. Feldmeier,
NPA713, 311(2003)

Look for the high-momentum components by (p,d) reaction

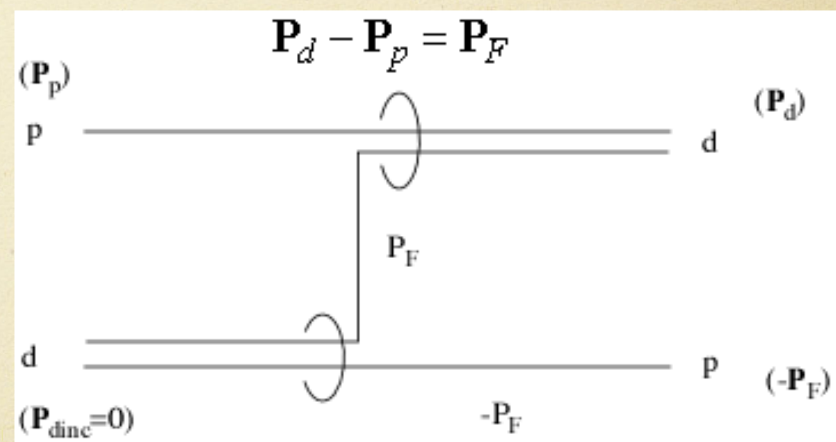
- $^{16}O(p,d)^{15}O$ at high-momentum transfer (high energy)
  - Use the neutron pick up reaction at large momentum transfer.

Forward neutron in (p,d) reaction is equivalent with back ward elastic scattering of p+d collision and both are neutron pick up domain.



d at forward angles

K. Sekiguchi et al.,
PRL 95 (2004) 162301

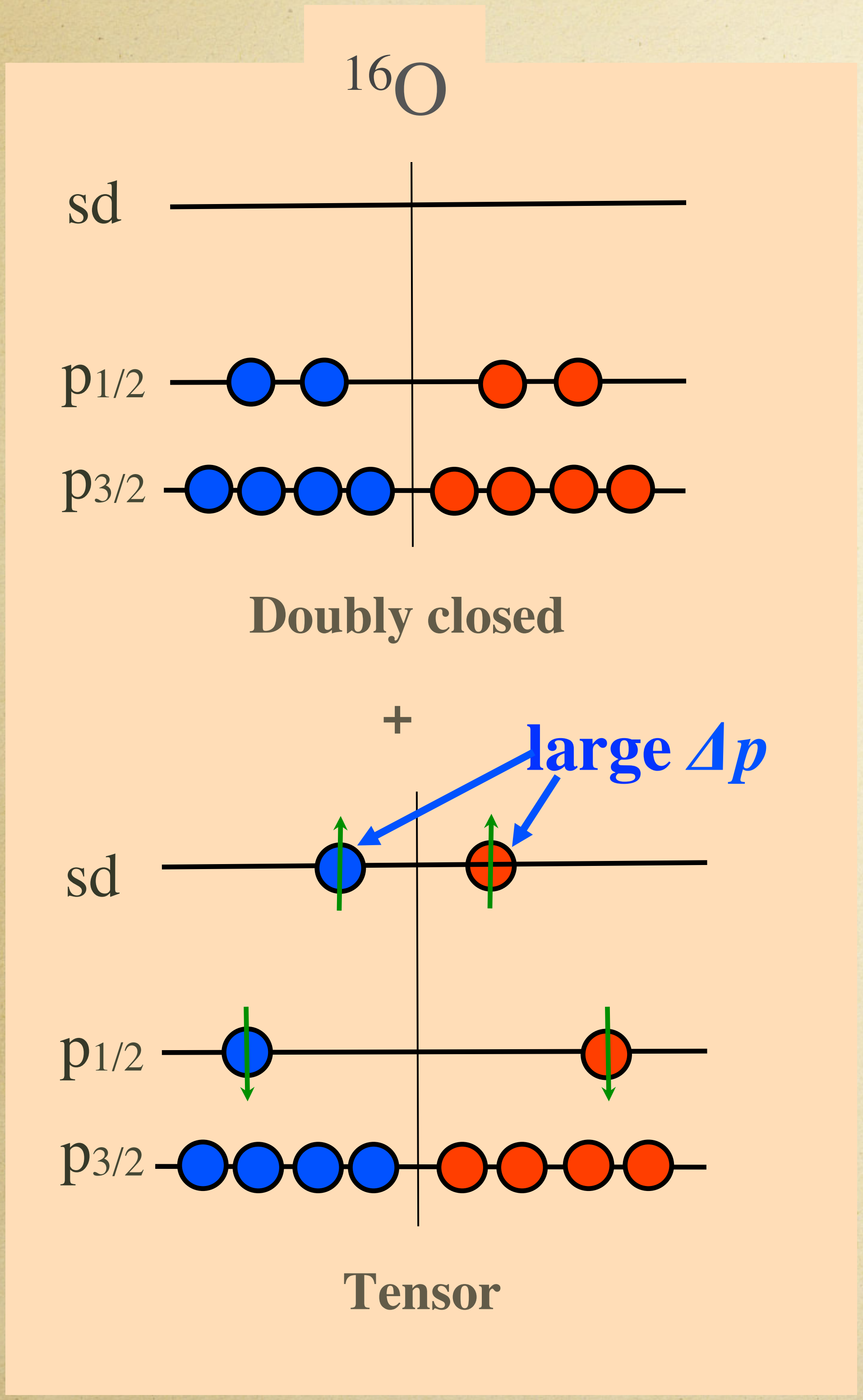


$$\sigma_F = K\frac{P_d}{p}N(P_F)\left[B_D + \frac{\hbar^2}{M}(\mathbf{p}-\mathbf{P}_d/2)^2\right]^2 \left|\langle\varphi(r), e^{i(\mathbf{p}-\mathbf{P}_d\cdot\mathbf{r}/2)}\rangle\right|^2$$

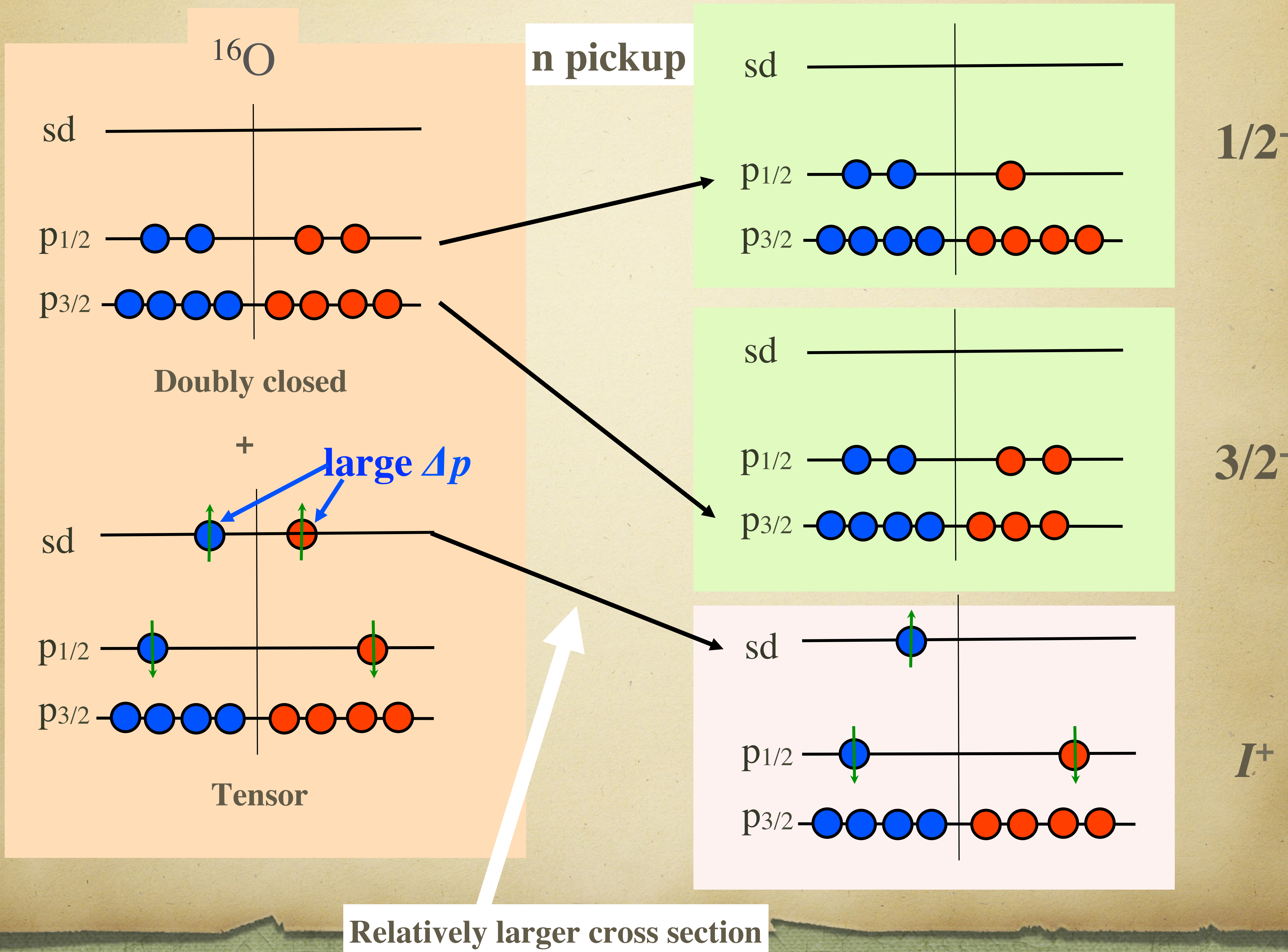
K: phase space constant, B_D: deutron binding nergy, M: nucleon mass by G. F Chew and M.L. Goldberger Phys. Rev. **77** (1950) 470.

Reaction at "backward" occurs by the high-momentum component in deuteron.

16O and (p,d) reaction



16O and (p,d) reaction

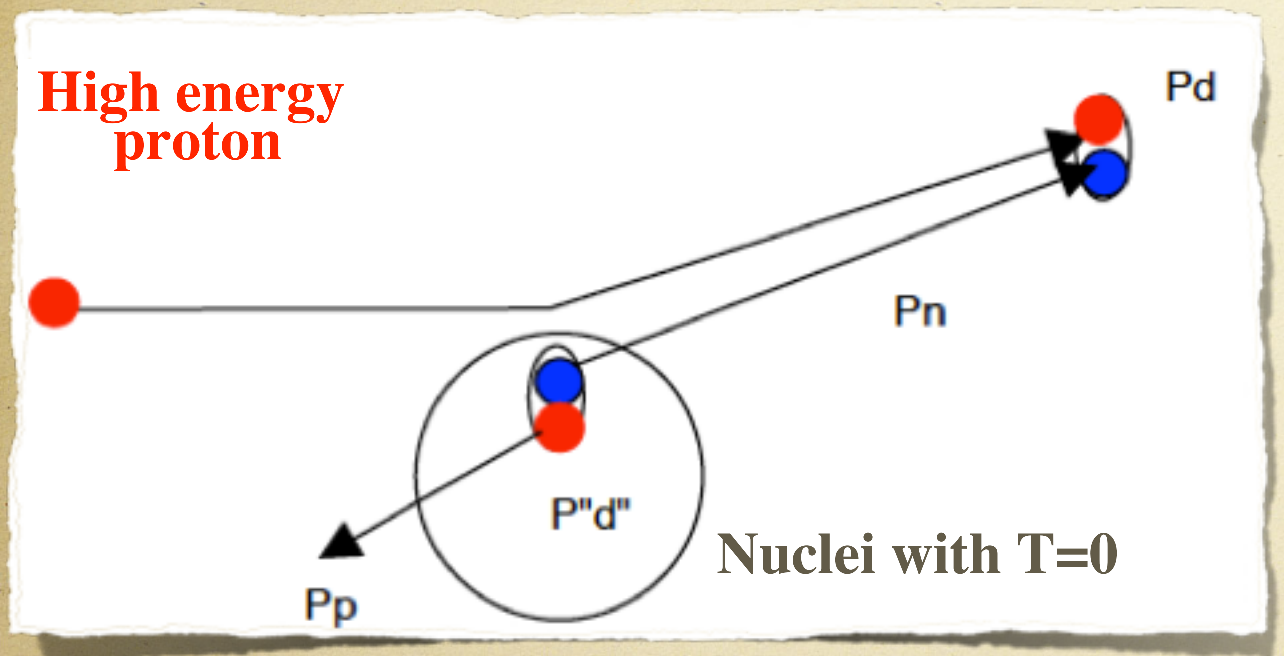


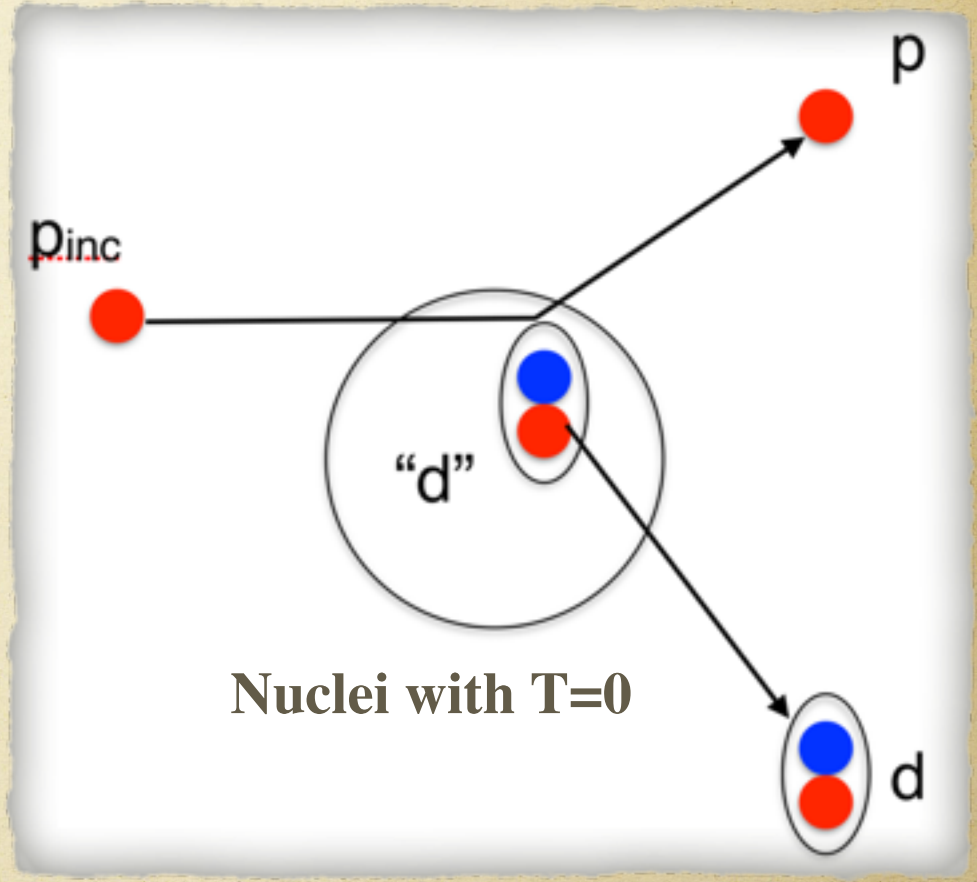
Recent studies of an observation of high-momentum components in ^{16}O will be presented in the following talk

by H. J. Ong

$^{16}O(p,pd)^{14}N$

- A measurement of correlated pn pairs in nuclei with large relative momenta.





T of residual nuclei = *T* of "d"

T of residual nuclei = 0 or 1
: independent from *T* of "d"

The first result of an isospin character of high-momentum pn pair will be presented in the talk by S. Terashima

So effect of tensor forces..

Present aims are;

1. **To observe the high momentum component in the ground state of a nucleus in specific states,**
2. **To see whether this high-momentum component is associated with the tensor forces, (selection rules)**
3. **To study the details of nucleon correlations that produce high-momentum component,**
4. **To search for other effects of tensor interactions in nuclei.**

Do not forget that the tensor force is an important origin of *l•s* force!

Summary

Necessities of tensor forces are presented in structure of nuclear ground states.

Recent studies show the effects of high-momentum neutrons in the ground state of ^{16}O by (p,d) and (p,pd) reactions.

- Tensor effects are strongly state dependent. It affects not only in the way just reduce the shell model components by 10~20% everywhere but the effect would be strongly state dependent. Also the binding energy may change suddenly due to the availability of orbitals.

Thank you for your attention
and
continuing attention to the
following talks.