RAON-8: Theory

천명기

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- Peking Univ.: Jie Meng

RAON-8 (THEORY)

1. 연구목표 대비 달성도

년도	세부연구목표	평가의 착안점 및 기준	목표 달성도
4차년도 (2021)	특이 핵구조연구	핵모델 연구 성과 및 신진인력의 참여도. 질량모델을 의한 국제 공동연구 참여.	90 %
	특이 우주 열 핵반응 연구	연구의 성과 및 대학원생 파견 가능한 해외연구소, 연구 그룹, 공동연구주제 발굴	90 %
	천체 핵합성 연구	연구의 독창성 및 연구 성과	90 %
	인력 양성 및 국제 연구 협력	국내 연구 인력의 양성 및 국제 협력 연구 유도 성과.	90%

RAON-8 (THEORY)

2. 연구 수행 방법

연구참여자 하은자, 천명기(숭실대), H. Sagawa(RIKEN),김성현 외 대학원생 3인

연구목표 (3차년도)
- N=Z nuclei 의 Pairing 상관과 왜곡도를 주는 tensor force 연구
- Skyrme 및 상대론적 핵 질량 모델 연구

▪ Two nucleon knock out reaction off 12C 에서의 Tensor force 효과 연구

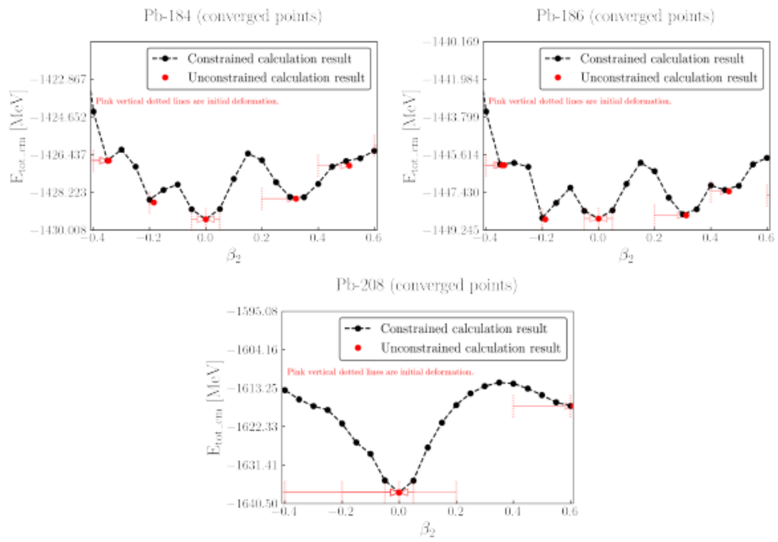
- sd-shell N=Z 핵에서의 isovector 및 isoscalar pairing 을 주는 tensor force 연구
- Pairing 에서의 deformed mean field 내의 isoscalar condensation 연구

TABLE III: Ratios of the np knockout to nn and pp knockout cross sections for ^{12}C+^{12}C reactions. Calculated results are given in the last four columns in different deformations with/without the TF by using the number of pairs in Fig. 1 (b) calculated by Eq. (11). Experimental data are taken from Ref. [47].

Ratio	Energy	Exp. Data	w/o TF $\beta_2 = 0.3$	w TF $\beta_2 = 0.3$	w/o TF $\beta_2 = 0.5$	w TF $\beta_2 = 0.5$
$\sigma_{-np}/\sigma_{-nn}$	250 MeV	47.50 / 5.33 =8.91				
	1.05 GeV	27.90 / 4.44 =6.28	7.8	4.5	4.0	9.7
	2.1 GeV	35.10 / 4.11 =8.54				
$\sigma_{-np}/\sigma_{-pp}$	250MeV	47.50 / 5.88=8.09				
	1.05 GeV	27.90 / 5.30 =5.26	7.8	4.5	4.0	9.7
	2.10 GeV	35.10 / 5.81=6.04				

▪ 핵모델연구

- 상대론적 핵구조 모델을 이용한 중핵 질량 모델연구
- 핵질량에서의 strutinsky 방법을 이용한 평균장이론의 수정 연구
- Skyrme 및 Quark Meson Coupling 모델에서의 유효 질량연구 및 nuclear shape coexistence 연구

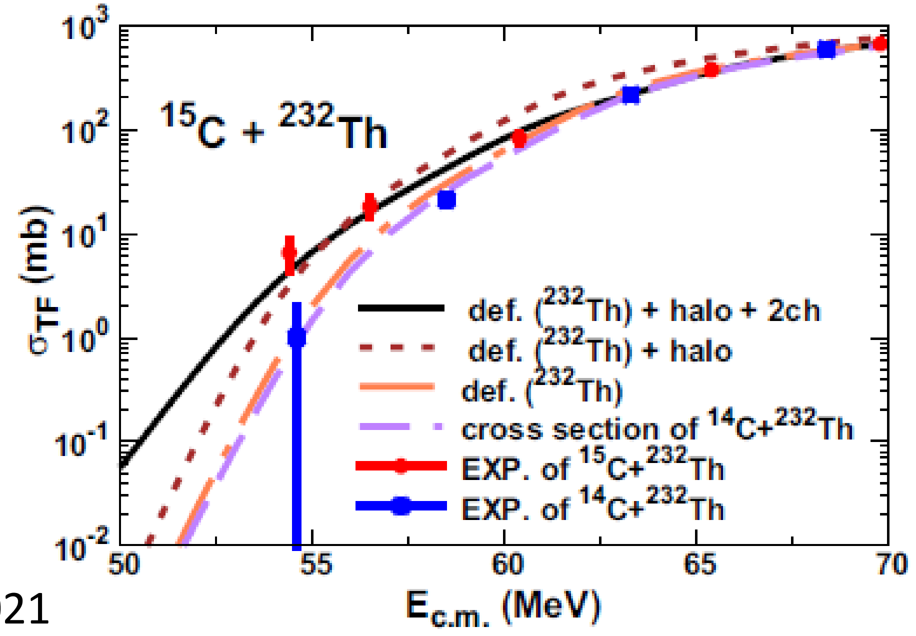


RAON-8 (THEORY) 2. 연구 수행 결과

연구참여자 **소운영(강원대), 김경식,최기석(항공대), 허경수,고혜민, 천명기(숭실대) M. Kusakabe (Beihang) 외 박사후연구원 1명 대학원생 2 명**

연구목표 (2차년도)
- 특이 Halo 핵관련 저에너지 핵반응연구
- 연구인력 양성프로그램 추진
- 국제공동연구 과제 발굴 및 수립
- 천체 핵합성연구

▪ 특이 핵반응 연구
- Halo nuclei Fusion Reaction 연구
- Heavy Nuclei Fusion 연구



PRC 2021

▪ 천체 핵합성연구
- Neutrino-process 등의 핵합성에서의 특이 핵반응연구 (베이항대, 동경대, 일본 국립천문대, Wisconsin, Nortre Dam..)
- p-nuclei (Mo and Ru isotopes) 의 우주물리적 기원 연구

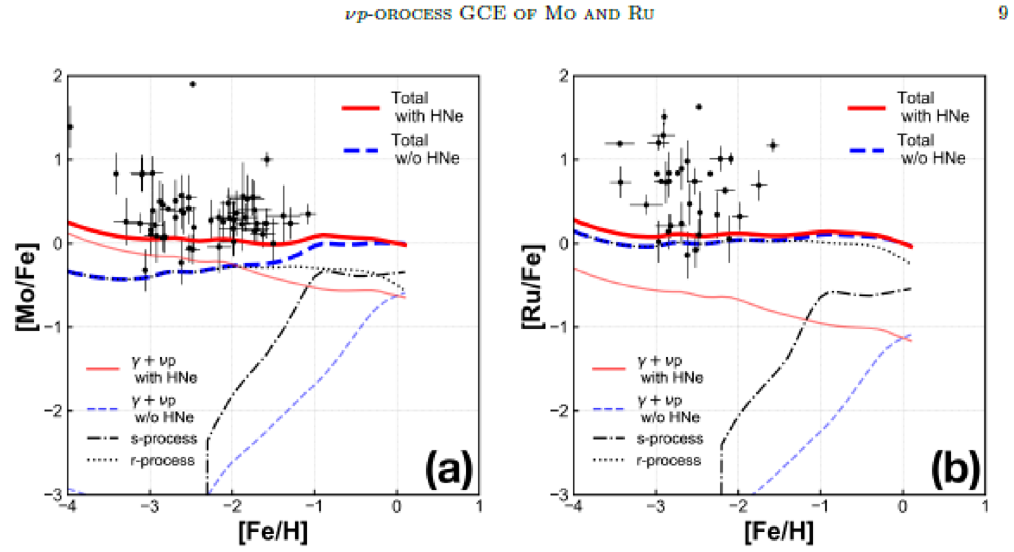


Figure 3. Elemental abundance evolution of (a)Mo and (b)Ru. Thin lines show each process contribution. Thick lines are the

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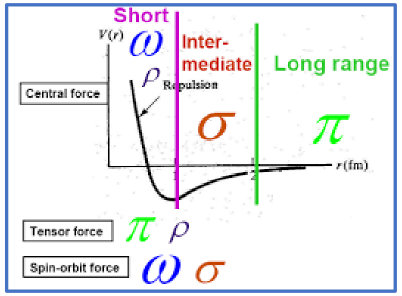
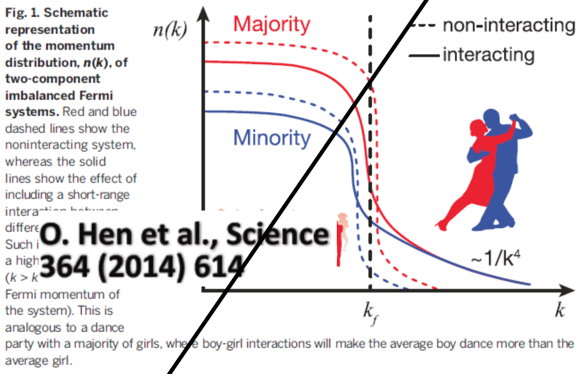
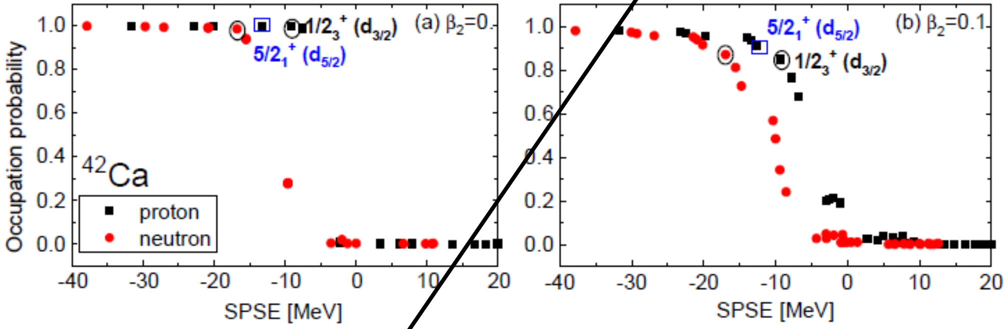
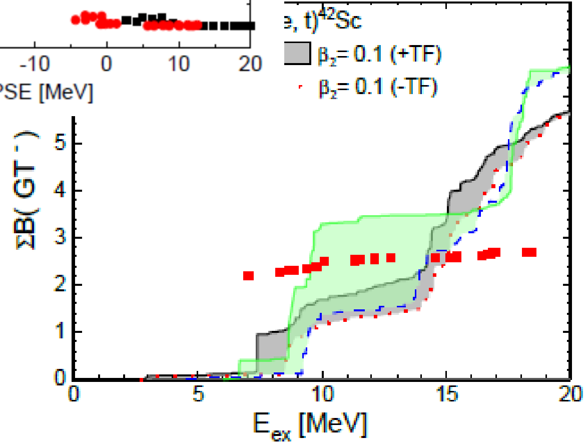
6. 최근 연구 I

1. Tensor force effects in Nuclear Structure : Ground states and GT excited states

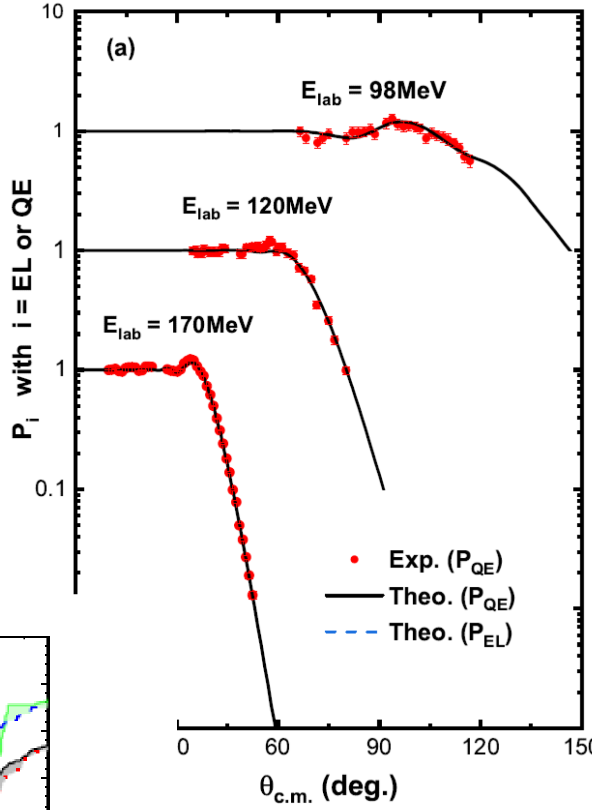


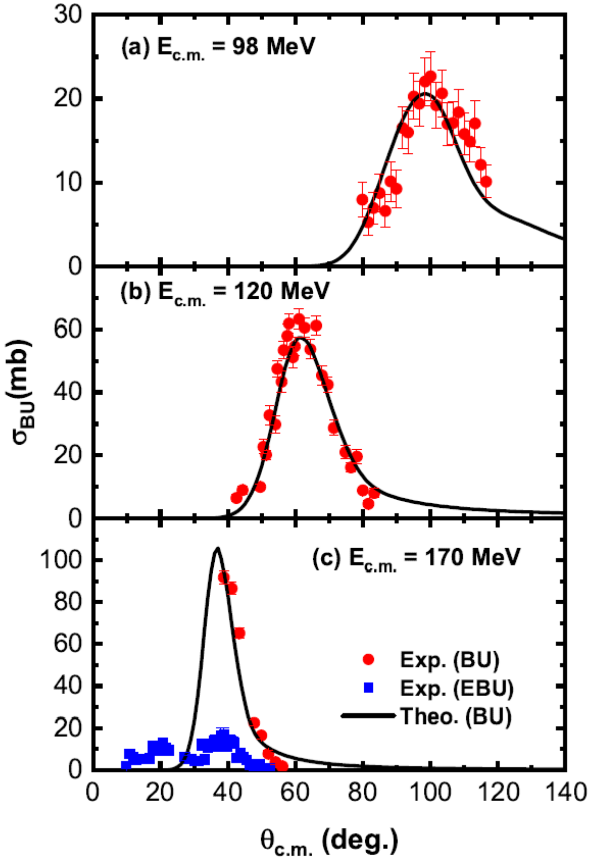






2. Coulomb Breakup reactions for 17F and 17O





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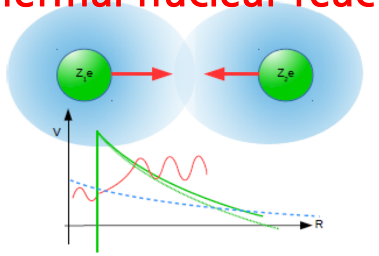
6. 최근 연구 II

3. Dynamical Screening and Strong Magnetic Field in thermal nuclear reactions in cosmos plasma enviorenment

JCAP 2021



- Nuclear Potential Perturbation
- Electrons in Boltzmann Distribution
- Poisson-Boltzmann Equation

Classical Thermal Nuclear Potential: Electron Background

$$\nabla^2\phi(r) = -4\pi Ze\delta(r^3) - 4\pi Zn_z e \exp\left[\frac{Ze\phi}{kT}\right]$$

$$+ 4\pi Zen_z \exp\left[\frac{-e\phi}{kT}\right]$$

$e\phi \ll kT \rightarrow$ First Order in Potential

$$\phi(r) = \frac{Ze^2}{r}e^{-r/\lambda_D}$$ Smaller $\lambda_D \rightarrow$ lower barrier.

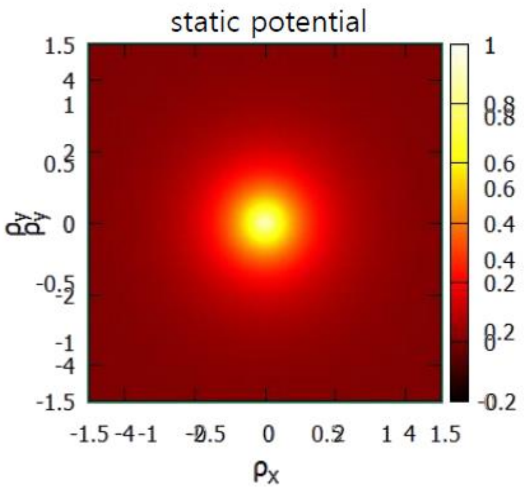
$$\lambda_D \equiv \left(\frac{T}{4\pi e^2 \sum_i (Z_i + Z_i^2) Y_i}\right)^{1/2}$$

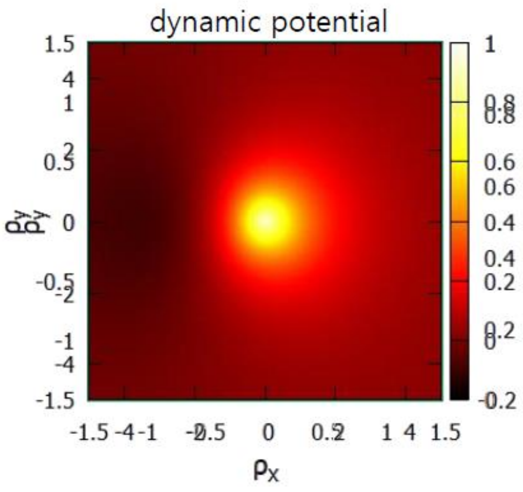
- **Background type**

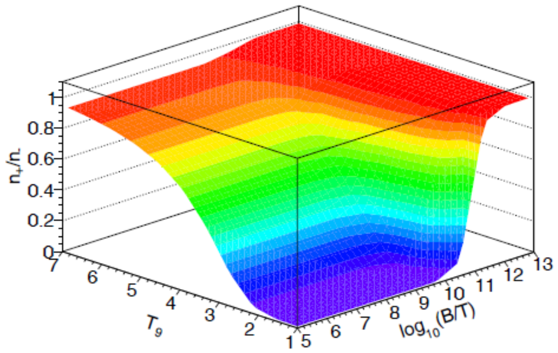
$$\varepsilon_l = 1 + \frac{1}{k^2\lambda_d^2}\left[1 + F\left(\frac{\omega}{\sqrt{2}kv}\right)\right]$$

- Free space
- Static plasma — $\delta(\vec{r})$
- Dynamic plasma — $\delta(\vec{r} - \vec{u}t)$

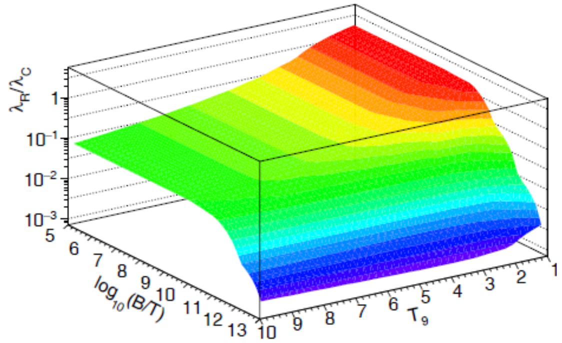
Extend to transverse permittivity & Check the distortion of photon spectra in plasma with SMAF







Positron/electron ratio vs. T_9 and B. $\rho = 10^6$ g cm^3, $Y_e = 0.5$.
Effects from chemical potential and low T.



λ_R/λ_C vs. T_9 and B
Shorter screening length →Stronger Screening

Direct Evidences of Tensor Force in Nuclear Structure and Nuclear Reactions in RAON and …

❖ How does the tensor force work ?

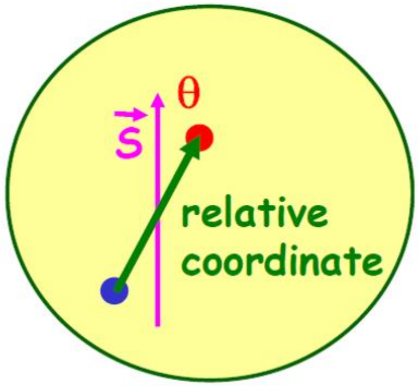
$$\hat{S}_{12} = 3\frac{(\boldsymbol{\sigma}_1 \cdot \boldsymbol{r})(\boldsymbol{\sigma}_2 \cdot \boldsymbol{r})}{r^2} - (\boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2) = -2S^2(1 - 3cos^2\theta) \sim Y_{2,0}$$

$\hat{S}_{12} = 0$ for $S = 0$

contribute only to S=1 states.

Spin of each nucleon ↑ is parallel, because the total spin must be S=1

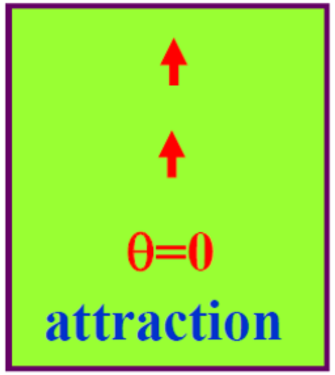
The potential has the following dependence on the angle θ with respect to the total spin $\vec{S}$.

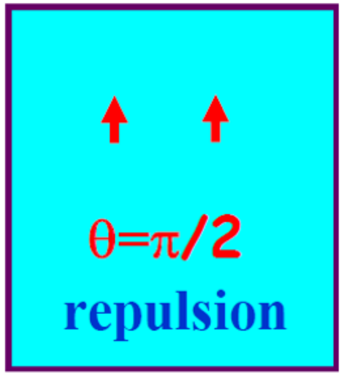


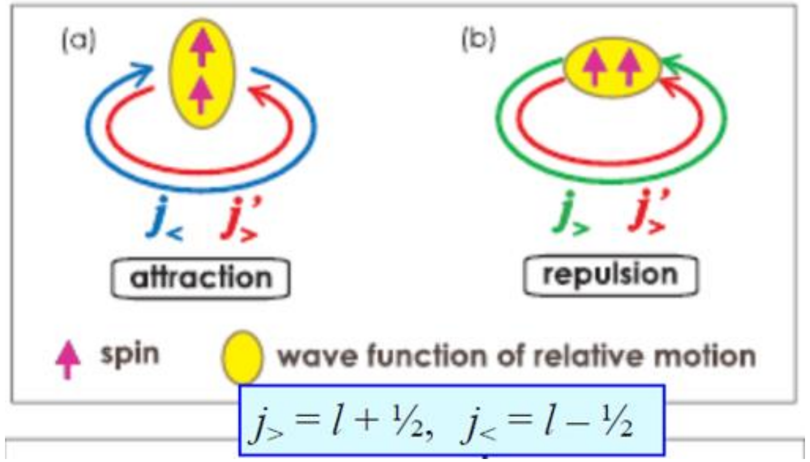
$\hat{V}_T = VT(r)\hat{S}_{12}$ $V_T(r) < 0$: Tensor force

$\hat{V}_T \sim \hat{S}_{12} \sim 1 - 3cos^2\theta$

nucleons

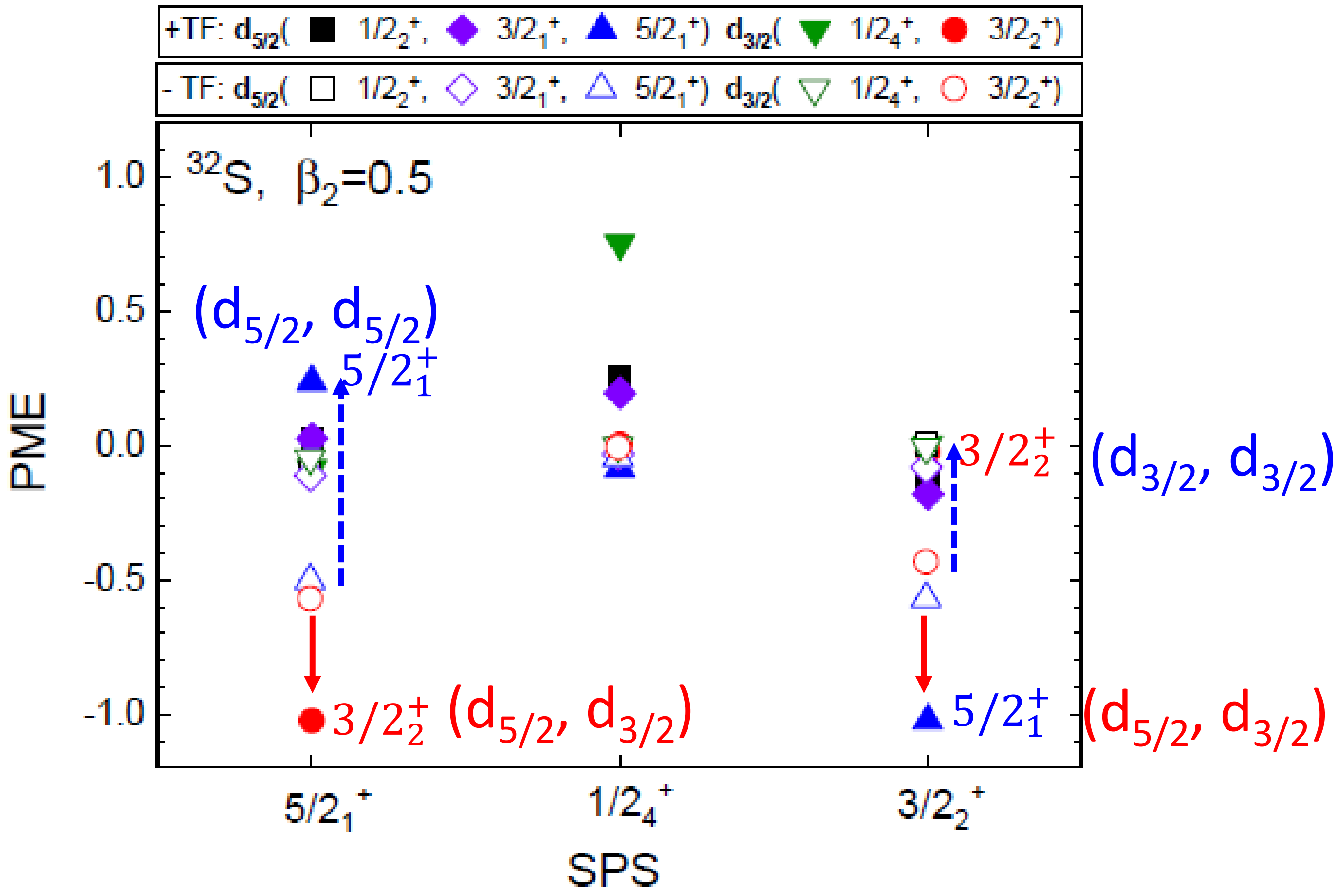






From Otsuka's talk

❖ Pairing matrix elements(PMEs) by *G*-matrix



$$\Delta_{p\bar{n}_\alpha} = \Delta_{\alpha p \bar{\alpha} n} = -\sum_{\gamma}\Bigg[\Big[\sum_{J,a,c} g_{\rm np}^{T=1} F^{J0}_{\alpha a\bar{\alpha}a} F^{J0}_{\gamma c\bar{\gamma}c} G(aacc,J,T=1)\Big] Re(u^*_{1n_\gamma} v_{1p_\gamma} + u^*_{2n_\gamma} v_{2p_\gamma})$$

$$+\Big[\sum_{J,a,c} g_{\rm np}^{T=0} F^{J0}_{\alpha a\bar{\alpha}a} F^{J0}_{\gamma c\bar{\gamma}c} i\underline{G(aacc,J,T=0)}\Big] Im(u^*_{1n_\gamma} v_{1p_\gamma} + u^*_{2n_\gamma} v_{2p_\gamma})\Bigg],$$

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❖ ^{12}C

Types	T	S	L	J (K = 0)
Like	T = 1	$(\alpha\bar{\alpha})$ S = 0	L = 0,2,4... (E)	J = 0,2,4... (E)
		$(\alpha\bar{\alpha})(\alpha\alpha)(\bar{\alpha}\bar{\alpha})$ S = 1	L = 1,3,5... (O)	J = E
Unlike	T = 1	$(\alpha\bar{\alpha})$ S = 0	L = 0,2,4... (E)	J = 0,2,4 ... (E)
		TF $(\alpha\bar{\alpha})(\alpha\alpha)(\bar{\alpha}\bar{\alpha})$ S = 1	L = 1,3,5... (O)	J = E
	T = 0	$(\alpha\bar{\alpha})$ S = 0	L = 1,3,5... (O)	J = 1,3,5 ... (O)
		TF $(\alpha\bar{\alpha})(\alpha\alpha)(\bar{\alpha}\bar{\alpha})$ S = 1	L = 0,2,4... (E)	J = O

$^3P_1$

$^3S_1, {}^3D_2, {}^3D_3$

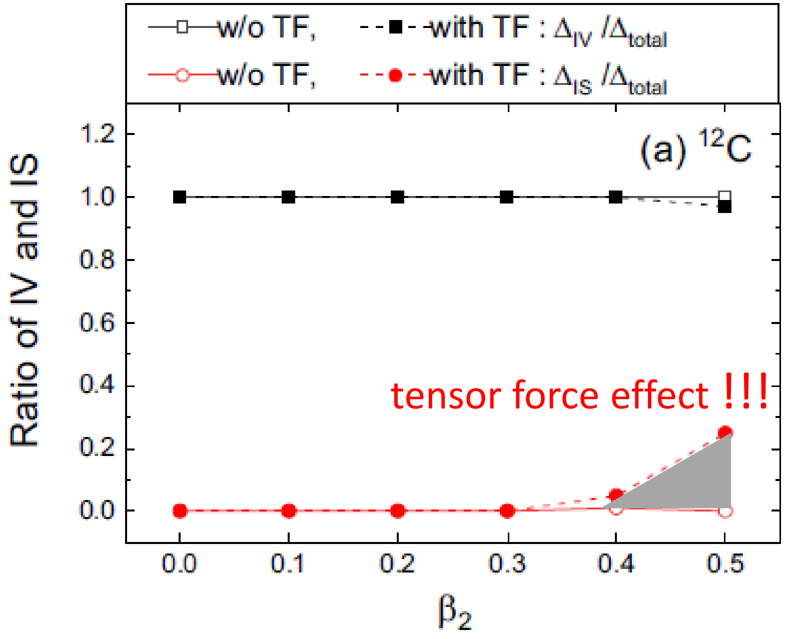
$$< N >_{pp} \sim \frac{\Delta_{pp}^2}{(G_{pp}^{T=1})^2}, < N >_{nn} \sim \frac{\Delta_{nn}^2}{(G_{nn}^{T=1})^2},$$

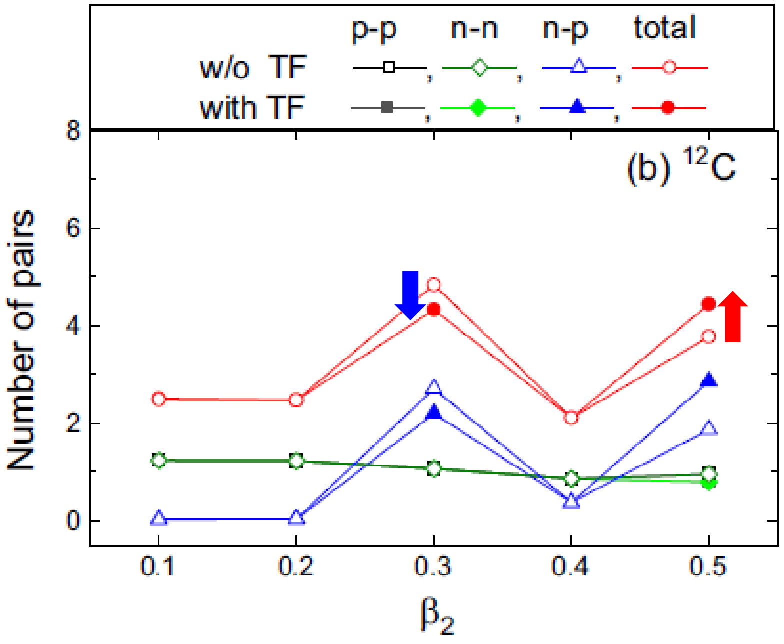
$$< N >_{np}^{T=0} \sim \frac{(\Delta_{np}^{T=0})^2}{(G_{np}^{T=0})^2}, < N >_{np}^{T=1} \sim \frac{(\Delta_{np}^{T=1})^2}{(G_{np}^{T=1})^2}$$

$^{2S+1}L_J$

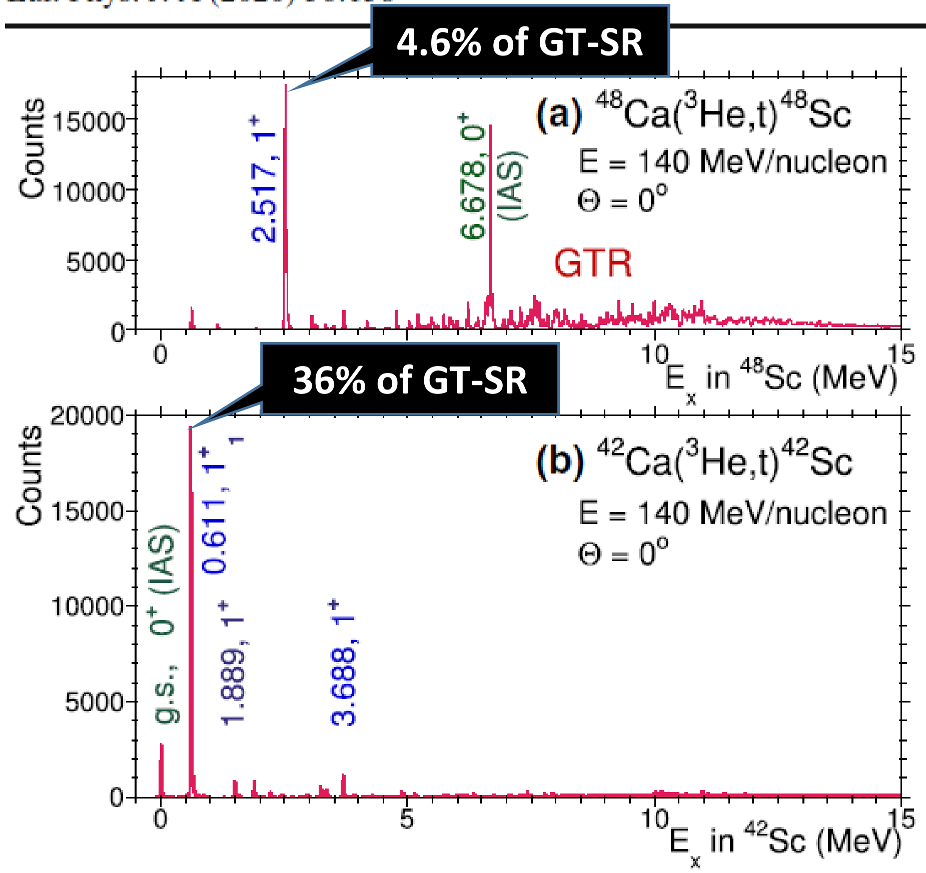
blue: repulsive,

red: attractive



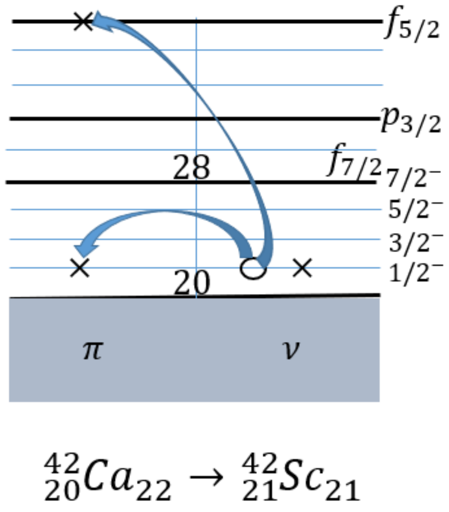


- # of *nn* & *pp* pairs are rarely by the **TF**, while that of *np* pairs changes at certain deformation.
- **TF** increases (decreases) the **PME**s of the T=0 *np* channel by its attractive (repulsive) property around β_2~0.5 (0.3)
- **TF is sensitive on the deformation** and may break the IV dominance of the *np* pairing.



❖ **particle-particle interaction**

IS-pairing: attractive



❖ **particle-hole interaction**

IV-pairing : repulsive

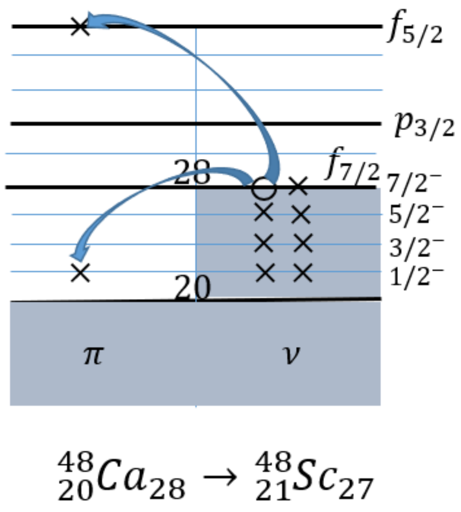
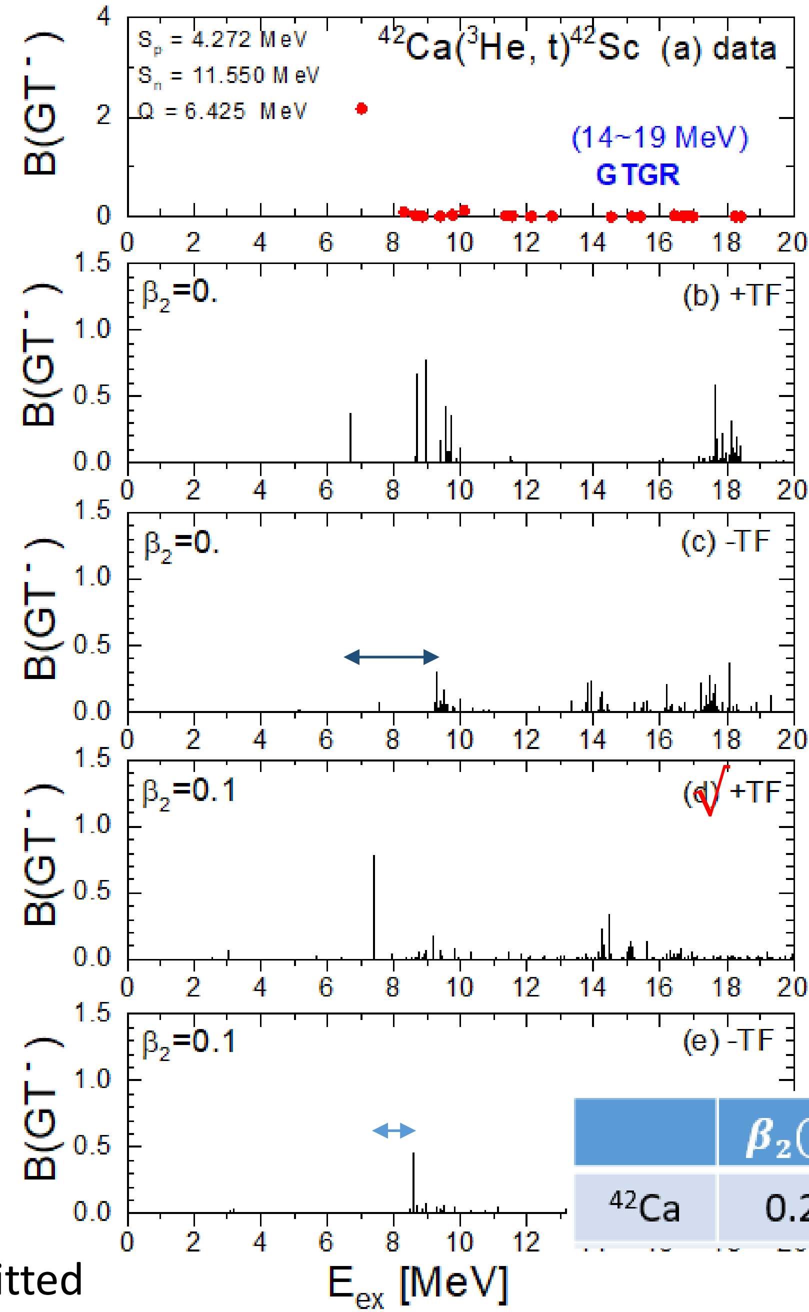


Fig. 1 **a** ^{48}Ca(^{3}He, t)^{48}Sc [32] and **b** ^{42}Ca(^{3}He, t)^{42}Sc [16] spectra taken at an intermediate incident energy of 140 MeV/nucleon and 0°. The vertical scales of **a** and **b** are so normalized that the heights of GT peaks (and IAS peaks) are proportional to their B(GT) [B(F)] values.

The GT sum-rule (GT-SR) suggests that the total GT strength is four times larger in ^{48}Sc than in ^{42}Sc. In ^{48}Sc, the broad GT-resonance (GTR) structure spreading in the $E_x \approx 5 - 14$ MeV region carries the main part of the GT-SR strength, while the $B(\mathrm{GT}) = 1.1$ of the sharp 2.517 MeV state is only 4.6% of the GT-SR. In ^{42}Sc, however, 0.611 MeV, $J^{\pi} = 1^{+}_{1}$ LeSGT state carries 36% of the GT-SR and ≈ 80% of the observed GT strength [16]

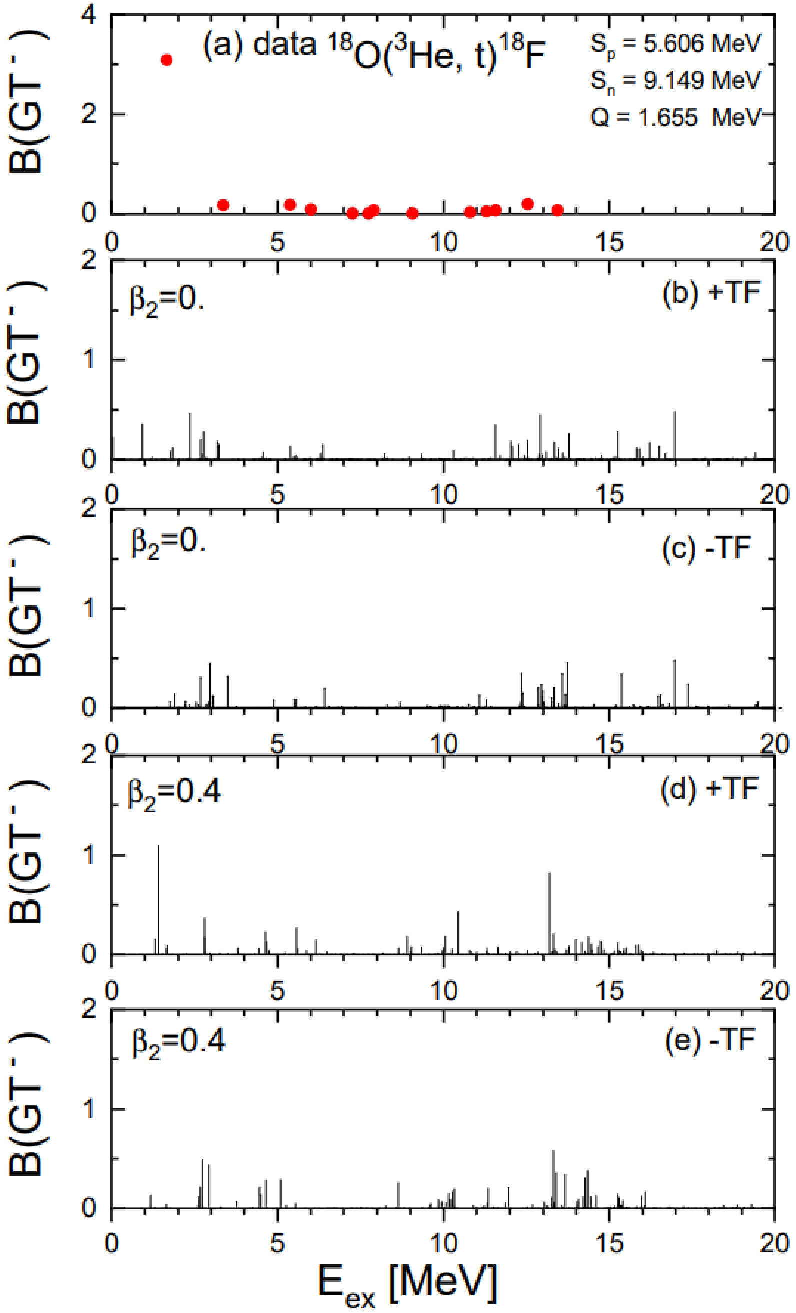
❖ Role of TF in GT states

Tensor force & Defor



$$\frac{g_{pp}}{g_{ph}} = 1.7 \;:\; {}^{42}\text{Ca}$$

	$\beta_2(E2)$	$\beta_2(FRDM)$	$\beta_2(RM$
^{42}Ca	0.245	0.	0.



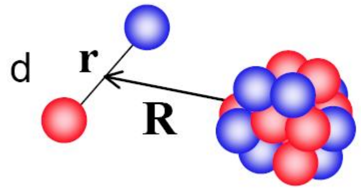
EPJA Submitted

Probing Neutron-Proton Correlations

longer-range

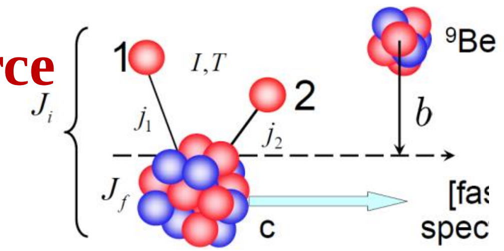
RCNP E365 (completed in Jan 2012):

Systematic studies of neutron-proton pairing in *sd*-shell nuclei using (p,^3He) and (^3He,p) transfer reactions



RIKEN NP1206-SAMURAI10 (April 18, 2013):

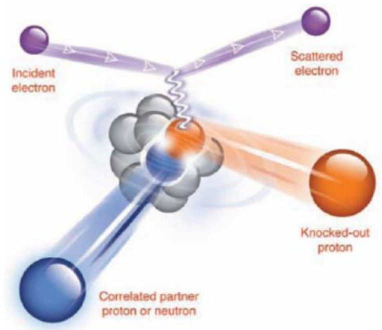
Study of Neutron-Proton Correlation & 3N-Force in N=Z nuclei



Proposal:

short-range

Study of Short-range Correlation in nuclei with high energy proton beam



PHYSICAL REVIEW C VOLUME 37, NUMBER 6 JUNE 1988

Fragmentation of carbon ions at 250 MeV/nucleon

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(Received 8 May 1987)

The single particle inclusive reactions $^{12}C + ^{12}C \rightarrow x +$ anything $(3 \le Z \le 6)$ have been studied at 250 MeV/nucleon at nine production angles from 0° to 4°. Production cross sections for most isotopes $(Z > 2)$ were determined. The longitudinal and transverse momentum distributions were constructed. The results at this energy are compared to the data at other energies and to the model of Friedman. It appears that, after the Coulomb effects are separated, there is very little energy dependence in the fragmentation process.

TABLE VI. Carbon-data cross sections.

	(mb) 250 MeV/nucleon	1.05 GeV/nucleon[a]	2.1 GeV/nucleon[a]	Friedman[b]
^{6}Li	26.35±2.1	27.10±2.20	30.00±2.40	19.6
^{7}Li	>17.19±1.3	21.50±1.10	21.50±1.10	14.2
^{8}Li	>1.33±0.34	2.40±0.18	2.19±0.15	2.5
^{7}Be	22.64±1.49	18.60±0.90	18.40±0.90	13.3
^{9}Be	10.44±0.85	10.70±0.50	10.60±0.50	13.8
^{10}Be	5.88±9.70	5.30±0.30	5.81±0.29	7.1
^{11}Be	0.36±0.26			
^{8}B	<3.21±0.59	1.43±0.10	1.72±0.13	2.1
^{10}B	47.50±2.42	27.90±2.20	35.10±3.40	22.1
^{11}B	65.61±2.55	48.60±2.40	53.80±2.70	42.2
^{12}B	<0.49±0.67	0.10±0.01	0.10±0.01	
^{10}C	5.33±0.81	4.44±0.24	4.11±0.22	6.1
^{11}C	55.97±4.06	44.70±2.80	46.50±2.30	41.3

[a]Reference 4.
[b]Reference 10.

TABLE III. Ratios of the np knockout to nn and pp knockout cross sections for $^{12}C + {}^{12}C$ reactions. Calculated results are given in the last four columns in different deformations with and without the TF (denoted as with TF and without TF) by using the number of pairs in Fig. 1(b) calculated by Eq. (11). Experimental data are taken from Ref. [47].

Ratio	Energy	Exp. data	Without TF $\beta_2 = 0.3$	With TF $\beta_2 = 0.3$	Without TF $\beta_2 = 0.5$	With TF $\beta_2 = 0.5$
$\sigma_{-np}/\sigma_{-nn}$	250 MeV	$47.50/5.33 = 8.91$				
	1.05 GeV	$27.90/4.44 = 6.28$	7.8	4.5	4.0	9.7
	2.1 GeV	$35.10/4.11 = 8.54$				
$\sigma_{-np}/\sigma_{-pp}$	250 MeV	$47.50/5.88 = 8.09$				
	1.05 GeV	$27.90/5.30 = 5.26$	7.8	4.5	4.0	9.7
	2.10 GeV	$35.10/5.81 = 6.04$				

RAON-8 (THEORY) 5. 연구개발 수행노력

- 논문 발표 성과

• **Chiral quark-meson coupling models for finite nuclei and their (e,e'p) reactions**
Soonchul Choi, Tsuyoshi Miyatsu, Youngshin Kwon, Kyungsik Kim, Myung-Ki Cheoun, Koichi Saito
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•**Analyses of quasielastic scattering data for the ^{11}Be + ^{197}Au system**
Kyoungsu Heo, Myung-Ki Cheoun, W. Y. So, Ki-Seok Choi, K. S. Kim
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•**Shell evolution of kinetic, potential and binding energies of N=Z nuclei in s-d shell in a deformed Woods-Saxon potential with the pairing correlation energies**
Eunja Ha, Seonghyun Kim, Myung-Ki Cheoun
J.Korean Phys.Soc. 78 (2021) 761-769

•**Fusion reaction of a weakly bound nucleus with a deformed target**
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•**Constraints on Nuclear Saturation Properties from Terrestrial Experiments and Astrophysical Observations of Neutron Stars**
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•**Electromagnetic transitions of the singly charmed baryons with spin 3/2**
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•**Big Bang nucleosynthesis in a weakly non-ideal plasma**
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- 글로벌 네트워크 협력

- RIKEN (일본), Kyushu University, Kyoto University, Tohoku University (일본), Moscow State University (러시아), PEKING UNIVERSITY (중국), BEIHANG UNIVERSITY (중국) : 핵구조 계산 방법 및 핵합성 이론 연구 수행

- 주제 발굴 성과

- NAOJ (일본), 베이항 대학 (중국), Wisconshin U.(미국): p-nuclei 의 우주물리적 기원 연구를 위한 공동연구

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