2010年10月14日

International Symposium on Nuclear Physics in Asia

Search for An Evidence of the Tensor Force at High Momentum

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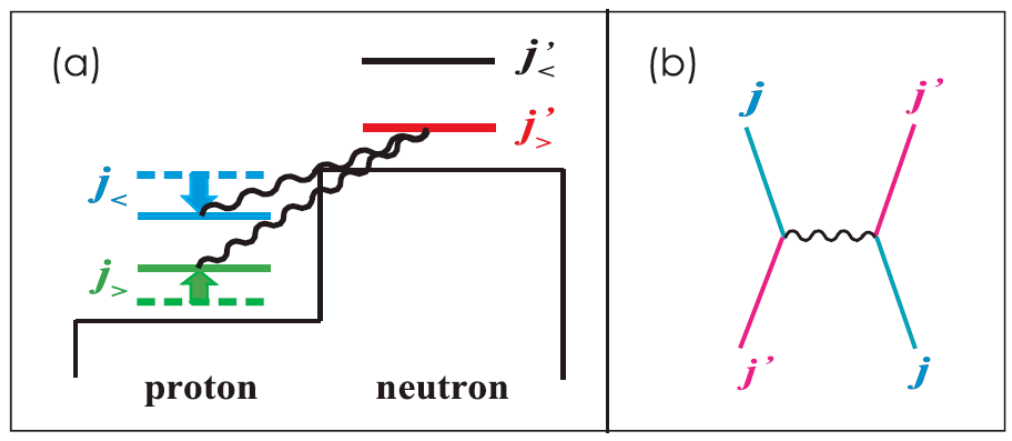
RCNP, Osaka University

(**RCNP-E314 Collaboration)**

- **Varying magic numbers in neutron-rich nuclei:**

  one of the hot topics in nuclear physics

- Possible role of tensor interactions in changing the spin-orbit splitting...



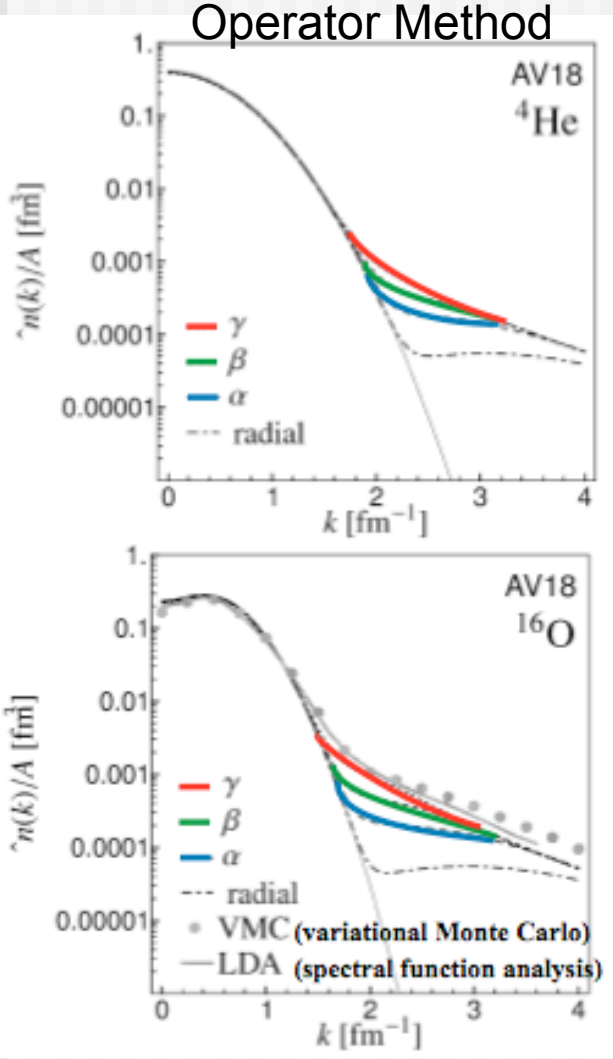
T. Otsuka *et al*, PRL95, 232502(2005)

But thus far the “evidences” from nuclei heavier than *d* and α are indirect…

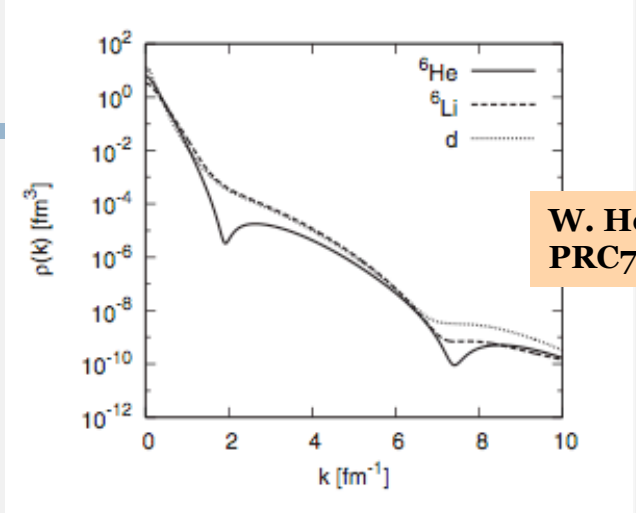
Is “direct” evidence on the tensor interactions possible, experimentally?

Theoretical Momentum Distribution

Unitary Correlation Operator Method

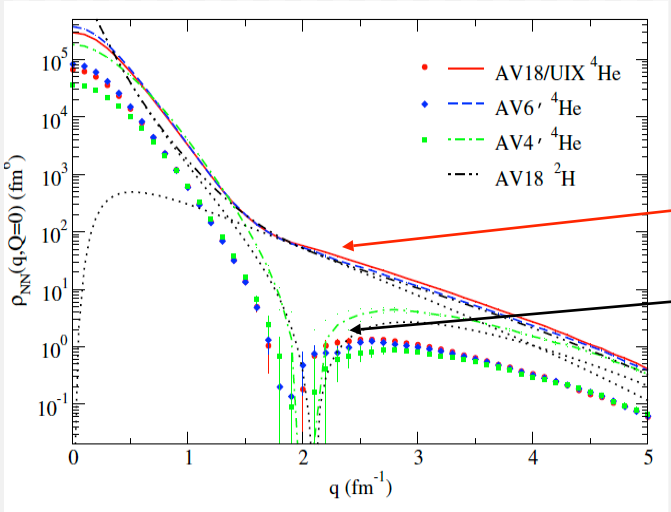


T. Neff and H. Feldmeier, NPA713, 311(2003)



α+*N*+*N* model

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



pn pair (lines)

pp pair (symbols)

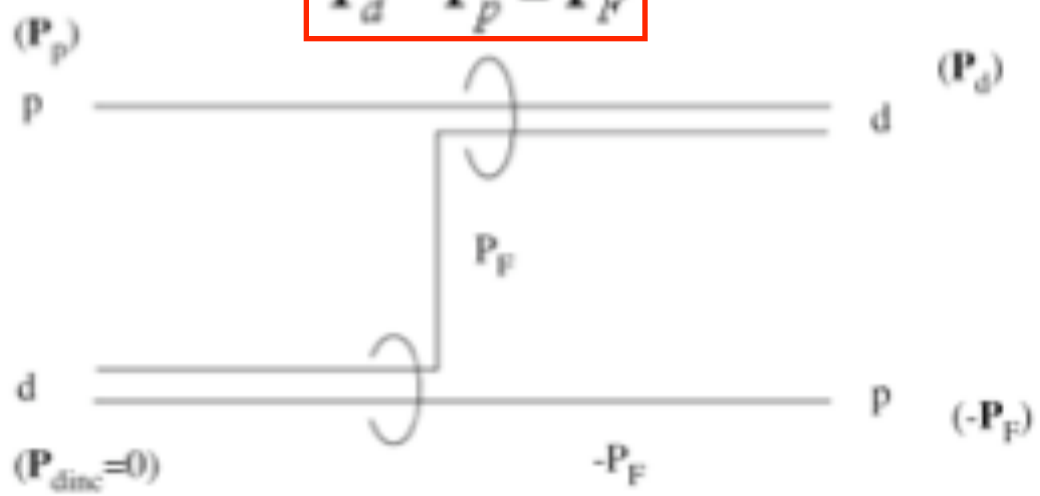
R. Schiavilla et al., PRL 98, 132501 (2007)

How to measure high momentum components?

- (e,$e'p$), (e,$e'pp$), (e,$e'pn$), etc.
- (p,$2p$), etc.

(*p*,*d*): Selective measurement of high momentum components

$$\mathbf{P}_d - \mathbf{P}_p = \mathbf{P}_F$$

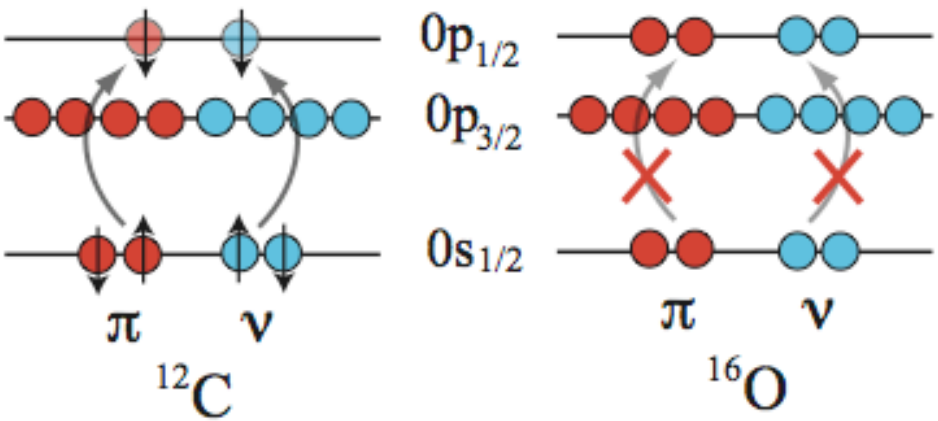


$$\sigma_F = K\frac{P_d}{p}N(P_F)\left[B_D + \frac{\hbar^2}{M}(\mathbf{p} - \mathbf{P}_d/2)^2\right]^2 \left|\left(\varphi(r), e^{i(\mathbf{p}-\mathbf{P}_d\bullet\mathbf{r}/2)}\right)\right|^2$$

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.

Subjects of Study: ^{12}C and ^{16}O

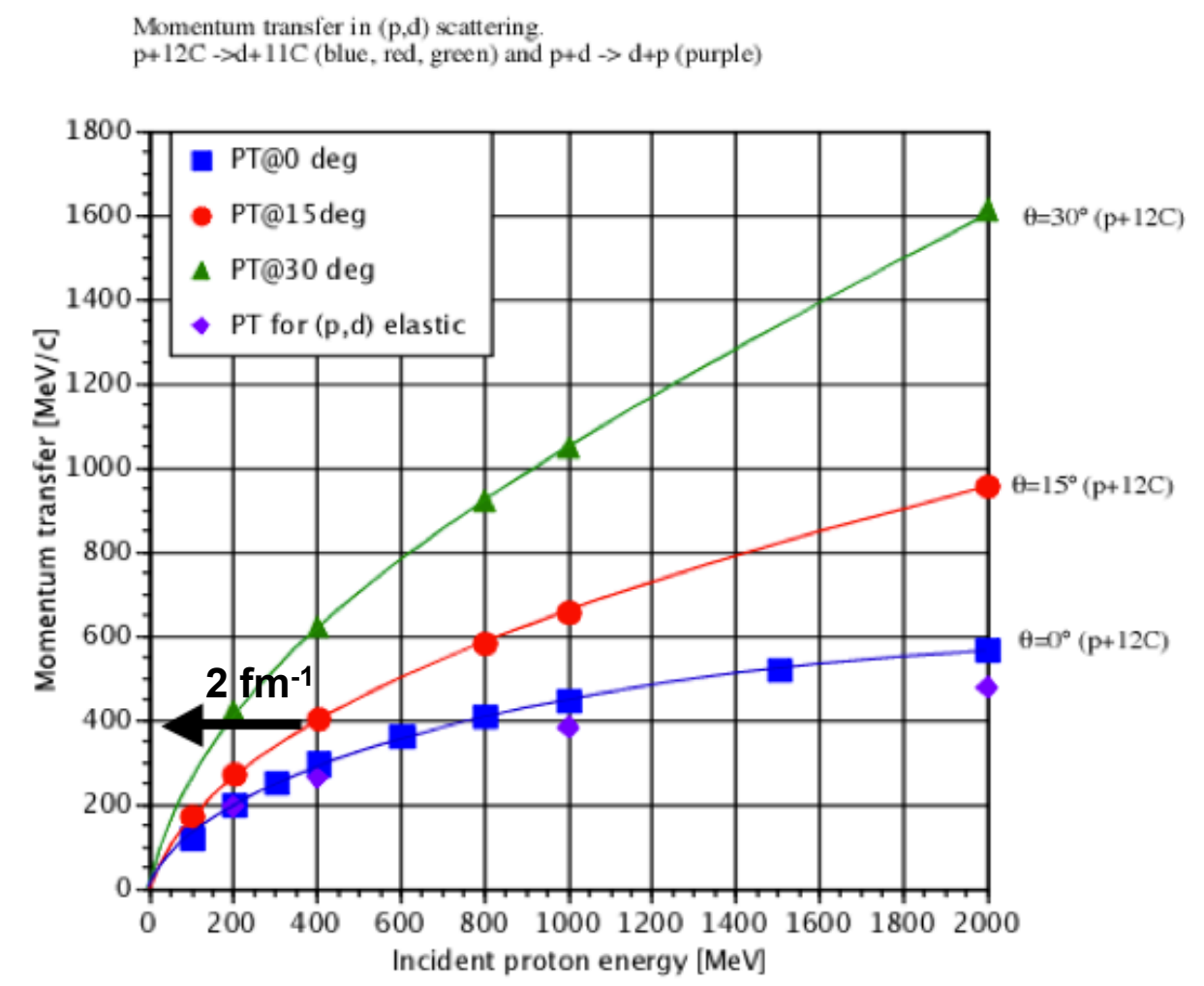
Excitation/Non-excitation of nucleons by the tensor interactions
as proposed by RCNP theory group
(Ikeda, Toki, Ogawa, Myo)



Selection Rule: $\Delta J=0$, $\Delta L=\Delta S=2$

- **Measure High Momentum Component**
- **Cover momentum transfer at around 2 fm^{-1} (~ 400 MeV/c)**

Momentum Transfer

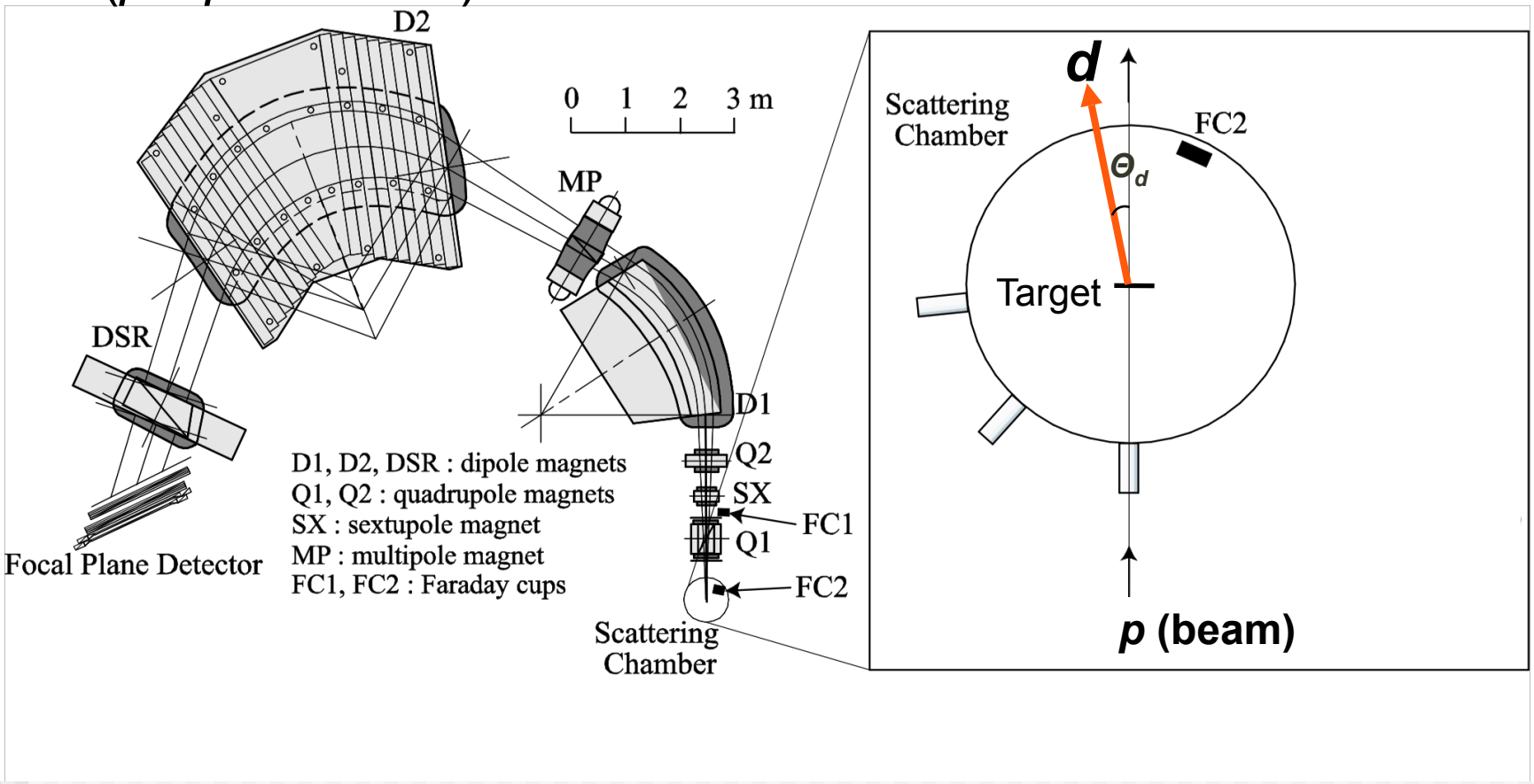


Experiment Setup

RCNP Grand RAIDEN

($p/\Delta p$ ~ 37000)

M. Fujiwara et al., NIMA422, 484(1999)



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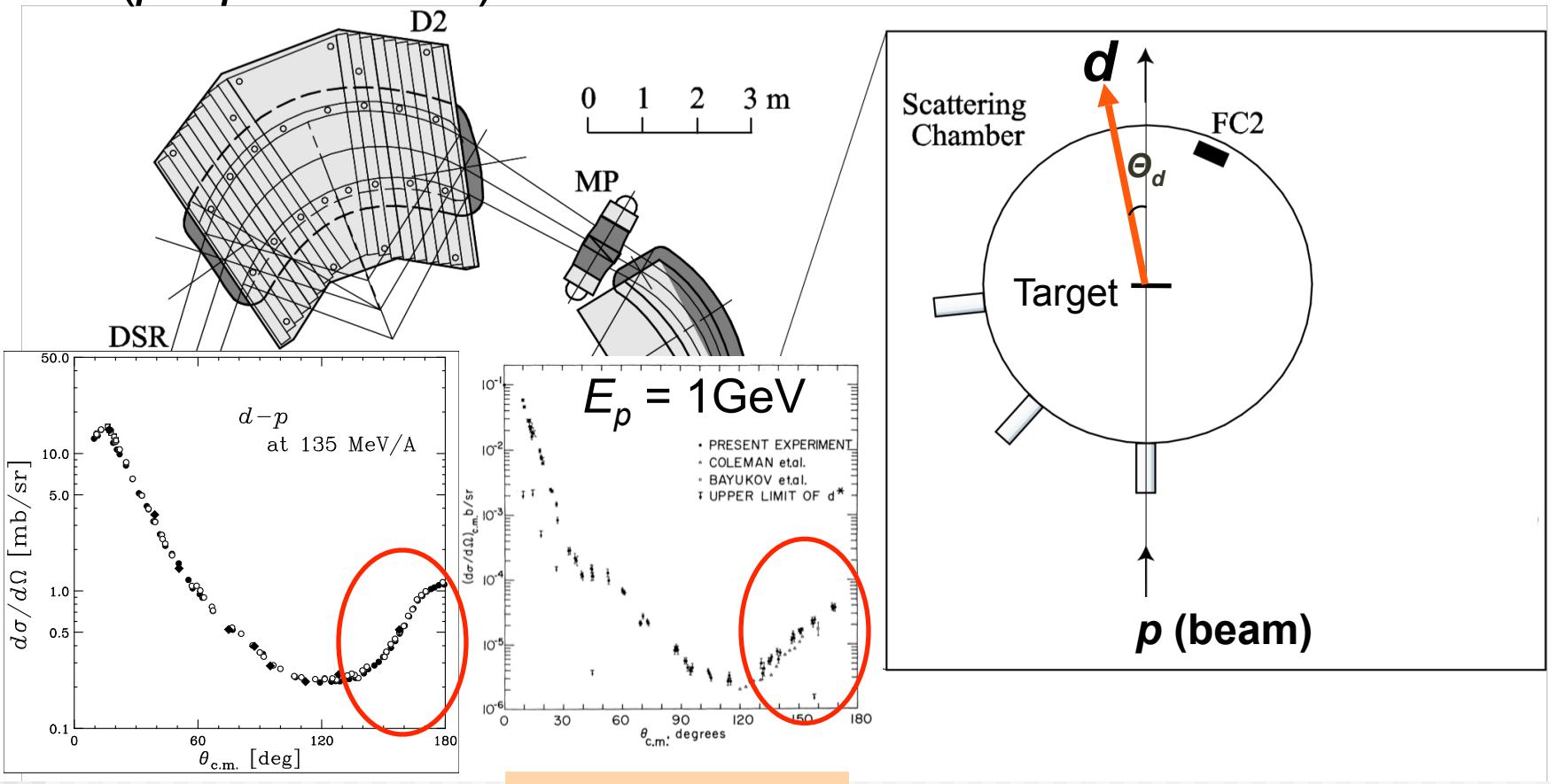
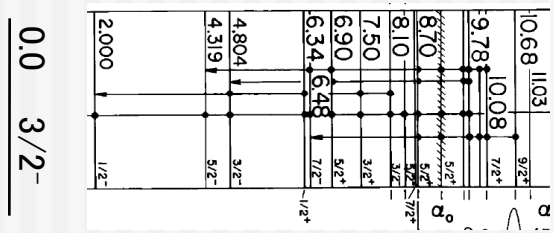


K. Sekiguchi *et al.*, PRL95, 162301(2004)

G. W. Bennett *et al.*, PRL19, 387(1967)

^{11}C
Level scheme



^{12}C (p,d)
$E_p = 198$ MeV
$\Theta_d = 10°$

^{12}C (p,d)
$E_p = 295$ MeV
$\Theta_d = 10°$

^{12}C (p,d)
$E_p = 392$ MeV
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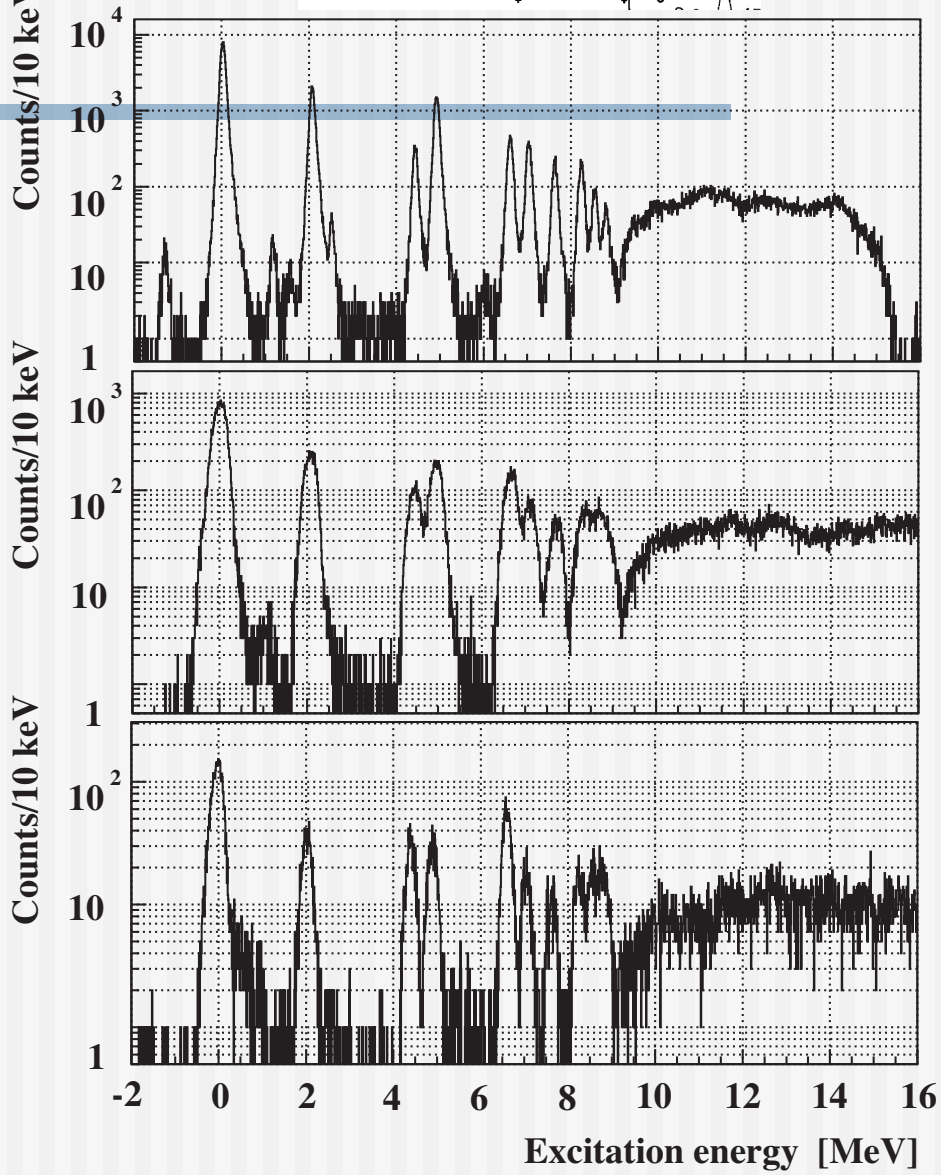

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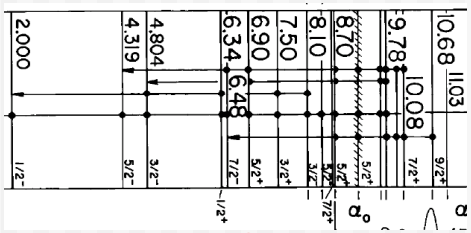

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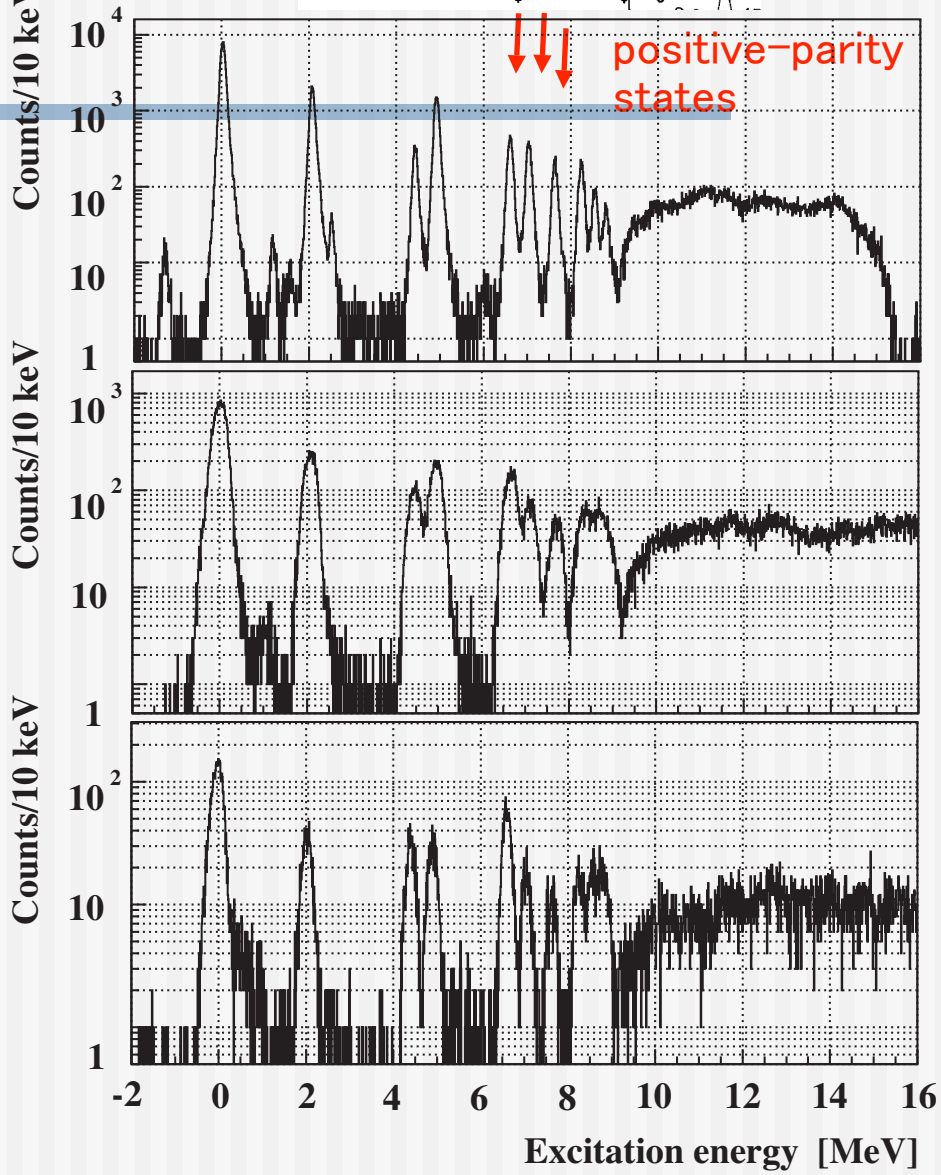
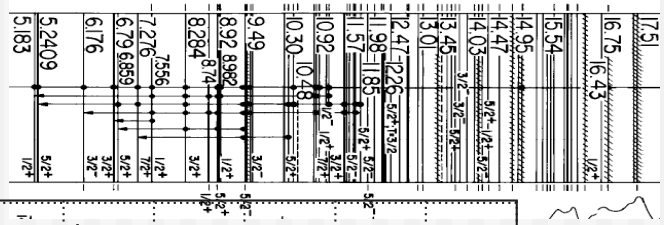


^{15}O
Level scheme



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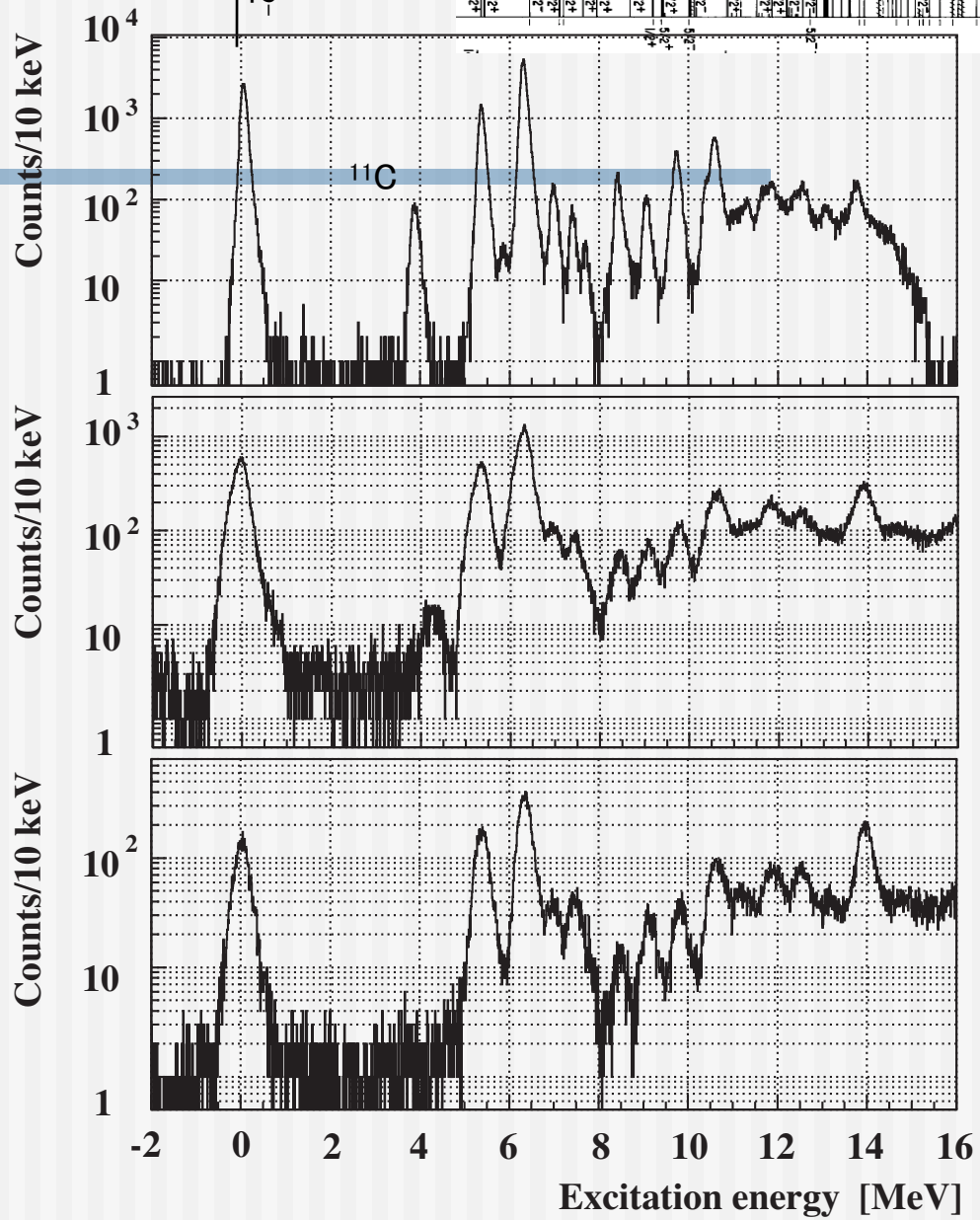
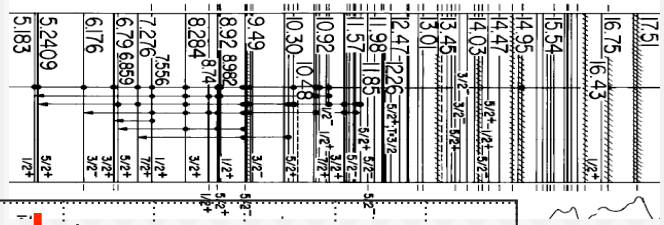


^{15}O
Level scheme



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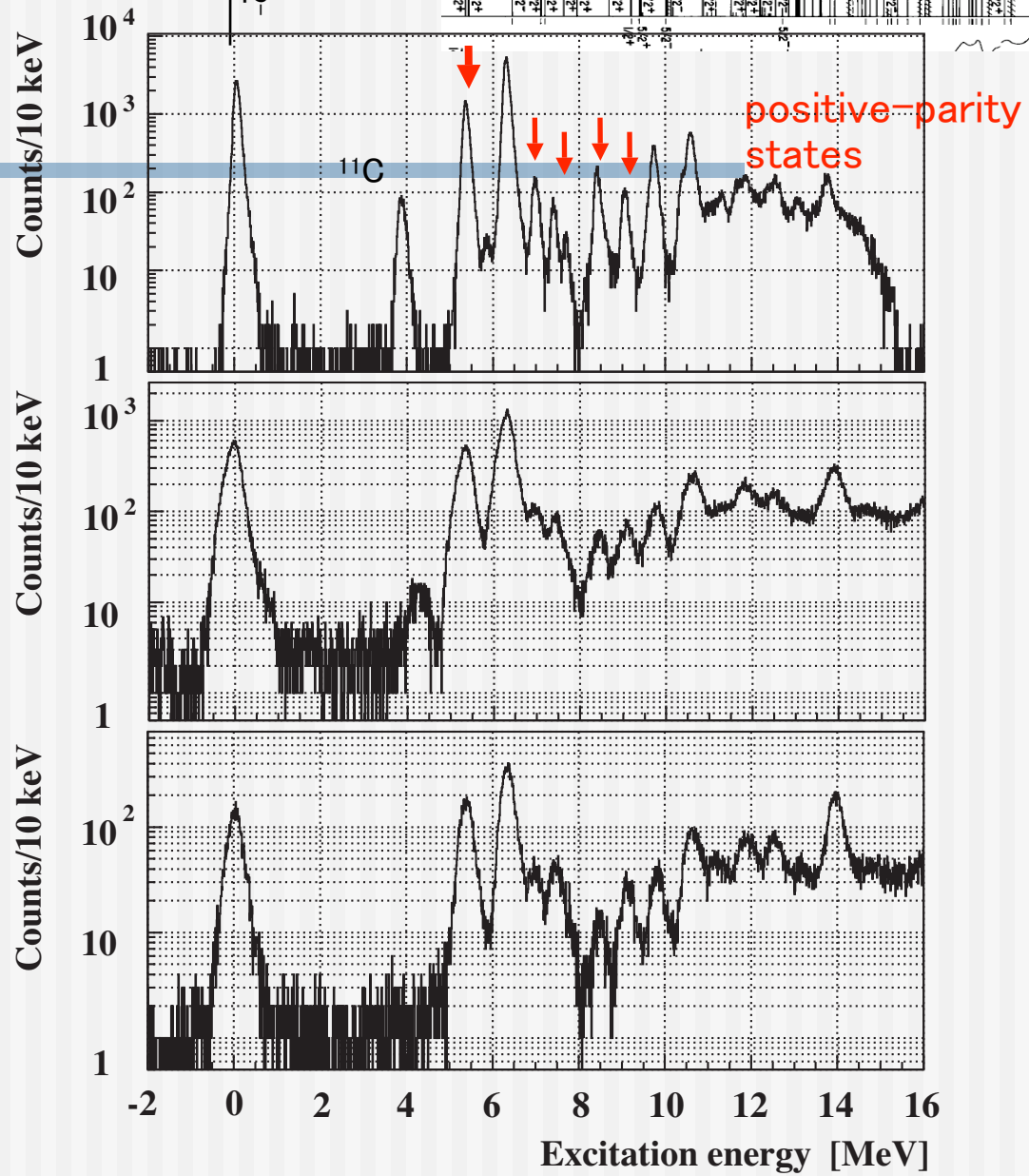
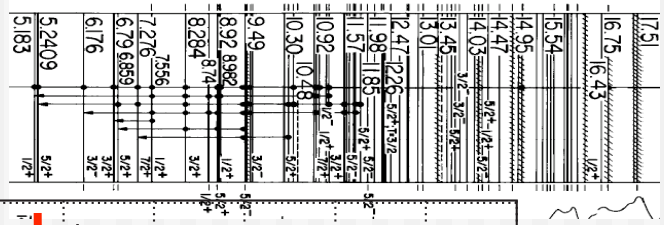


^{15}O
Level scheme



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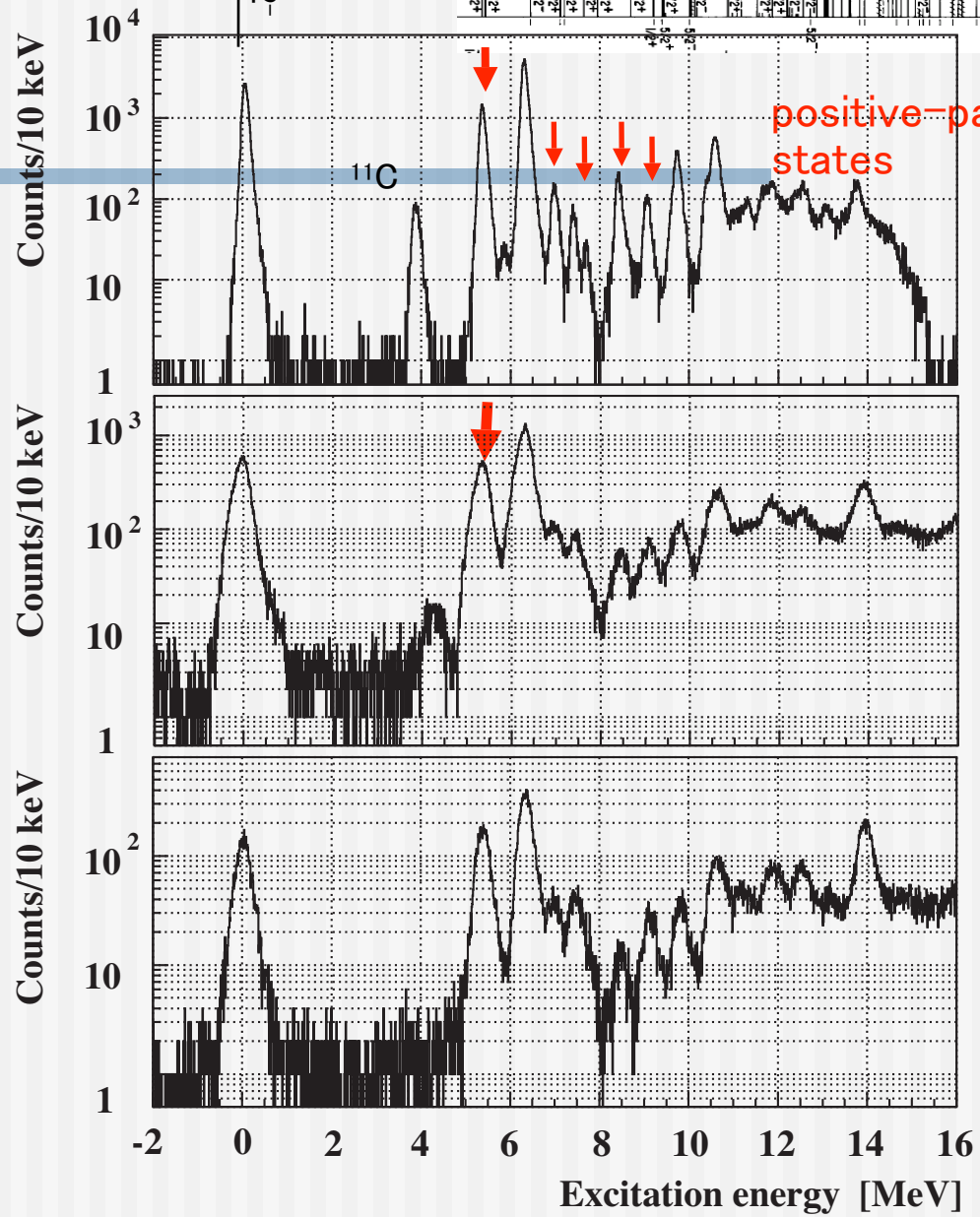

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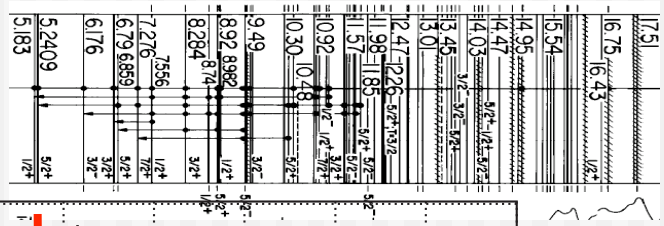

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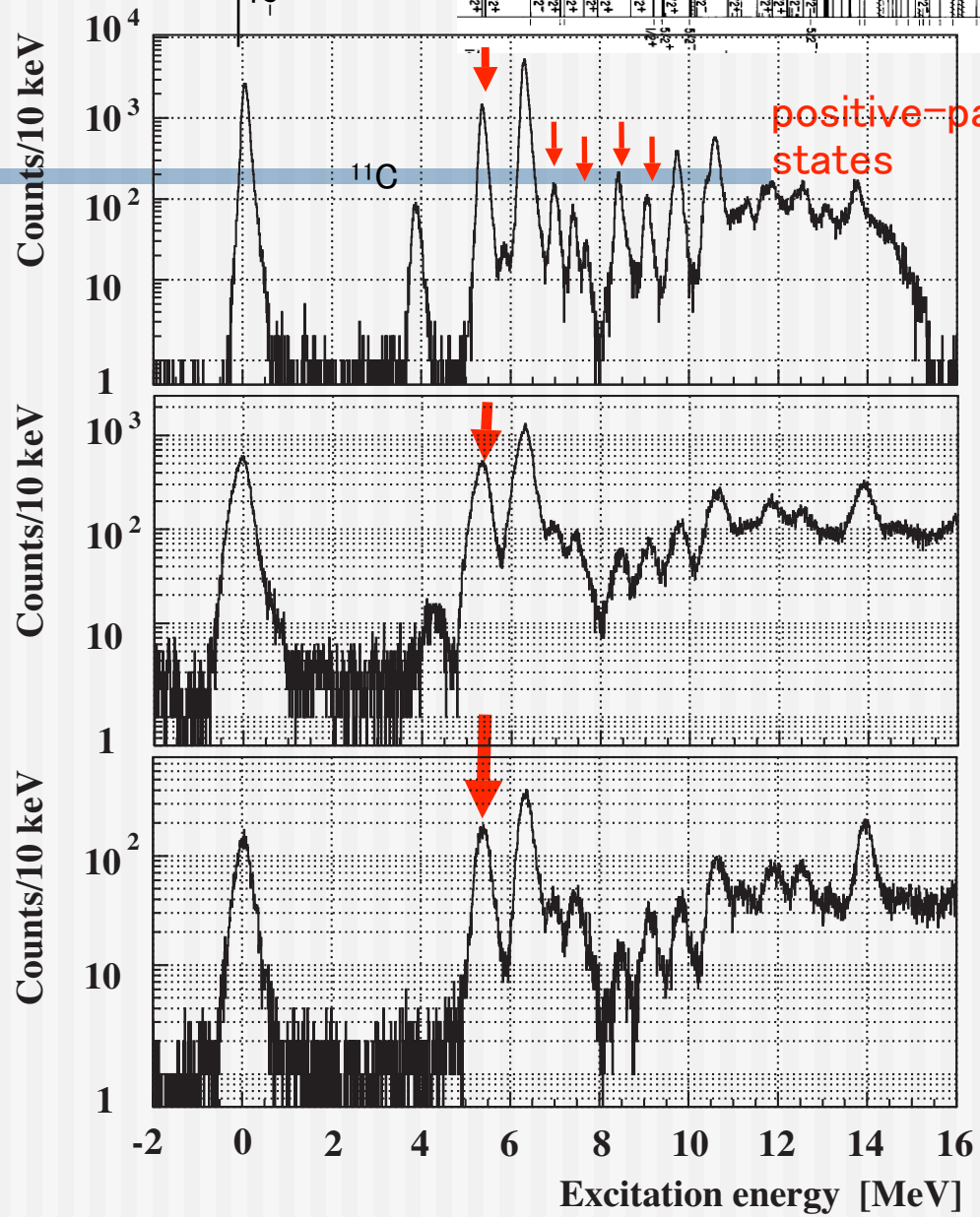
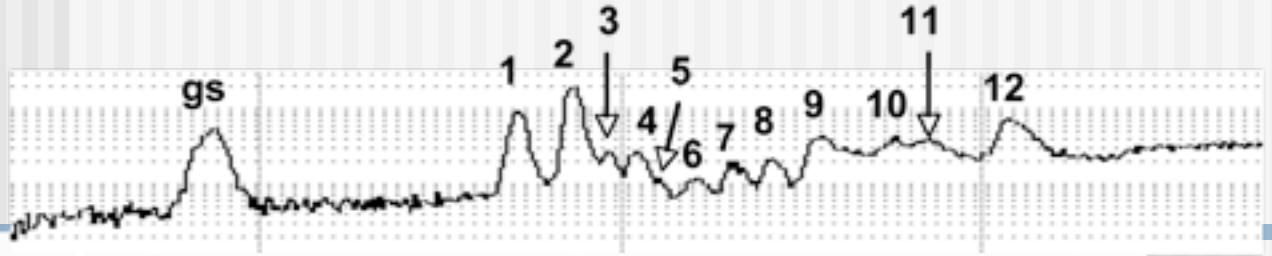
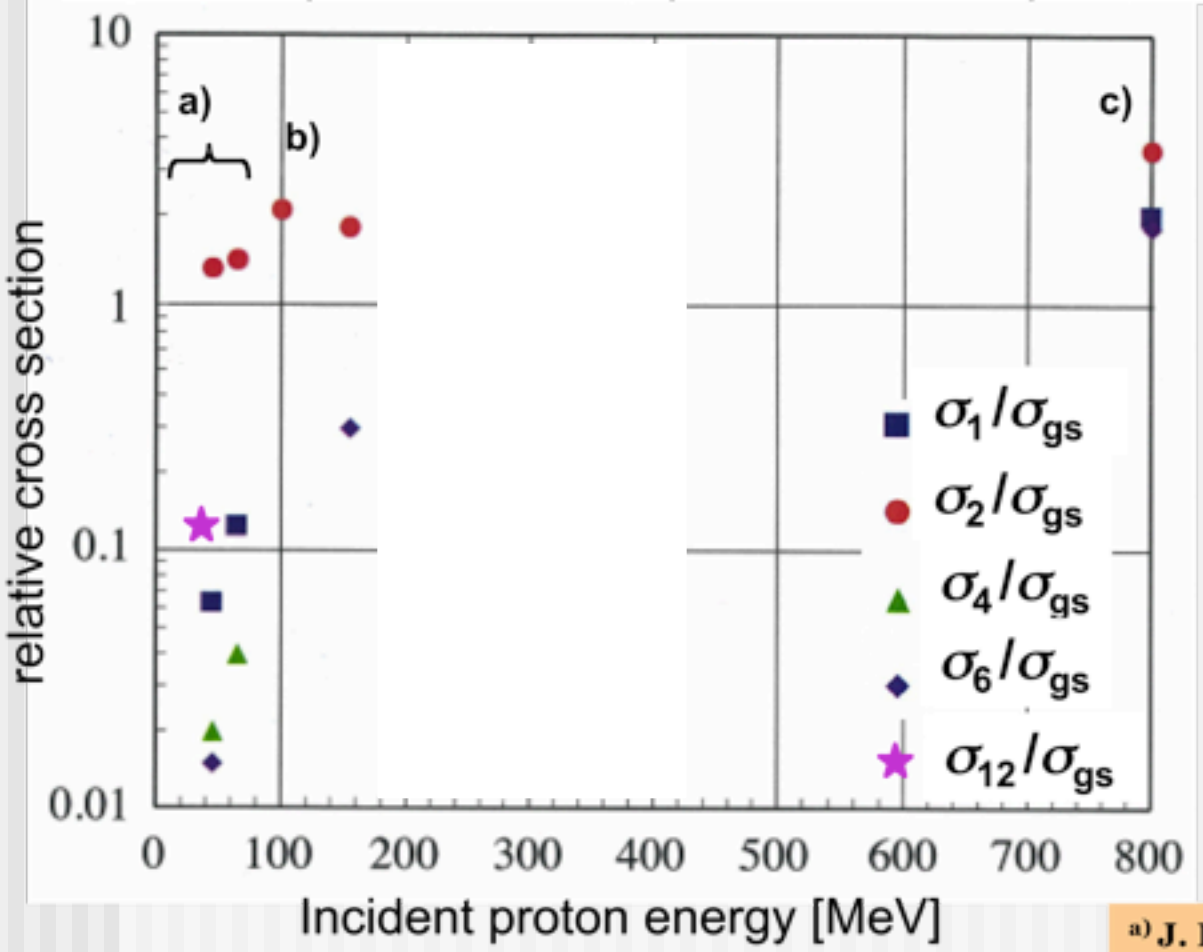


Relative Cross Section





	Ex[MeV]	J^π
gs	0.0	$1/2^-$
1	**5.2**	**$1/2^+$, $5/2^+$**
2	6.2	$3/2^-$
3	**6.8**	**$3/2^+$, $5/2^+$**
4	**7.3**	**$7/2^+$**
5	**7.6**	**$1/2^+$**
6	**8.3**	**$3/2^+$**
7	**8.9**	**$5/2^+$,$1/2^+$**,$(1/2)^-$
8	9.5	$(3/2)^+$,$5/2^-$
9	10.5	$(9/2^+)$,$(3/2^-)$,$(3/2)^+$
10	11.6	$5/2^-$
11	11.9	$5/2^-$, $5/2^-$
12	**13.6**	**$5/2^+$**
	13.7	$3/2^-$

[a] J. L. Snelgrove *et al.*, PR187, 1246(1969)
[b] J.K.P. Lee *et al.*, NPA106, 357(1968)
[c] G.R. Smith *et al.*, PRC30, 593(1984)

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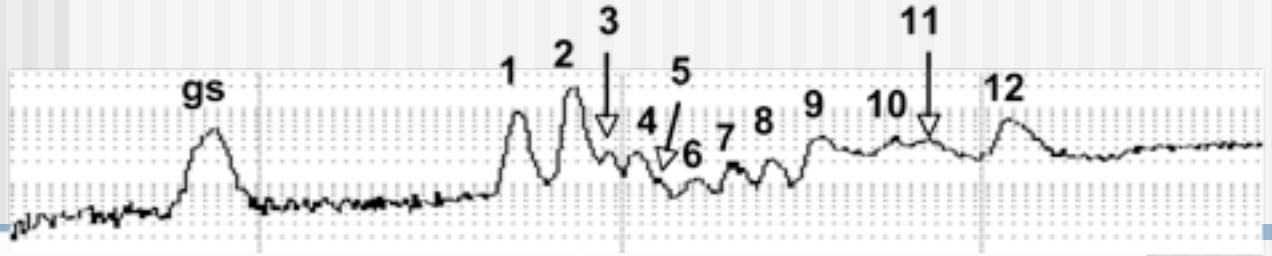

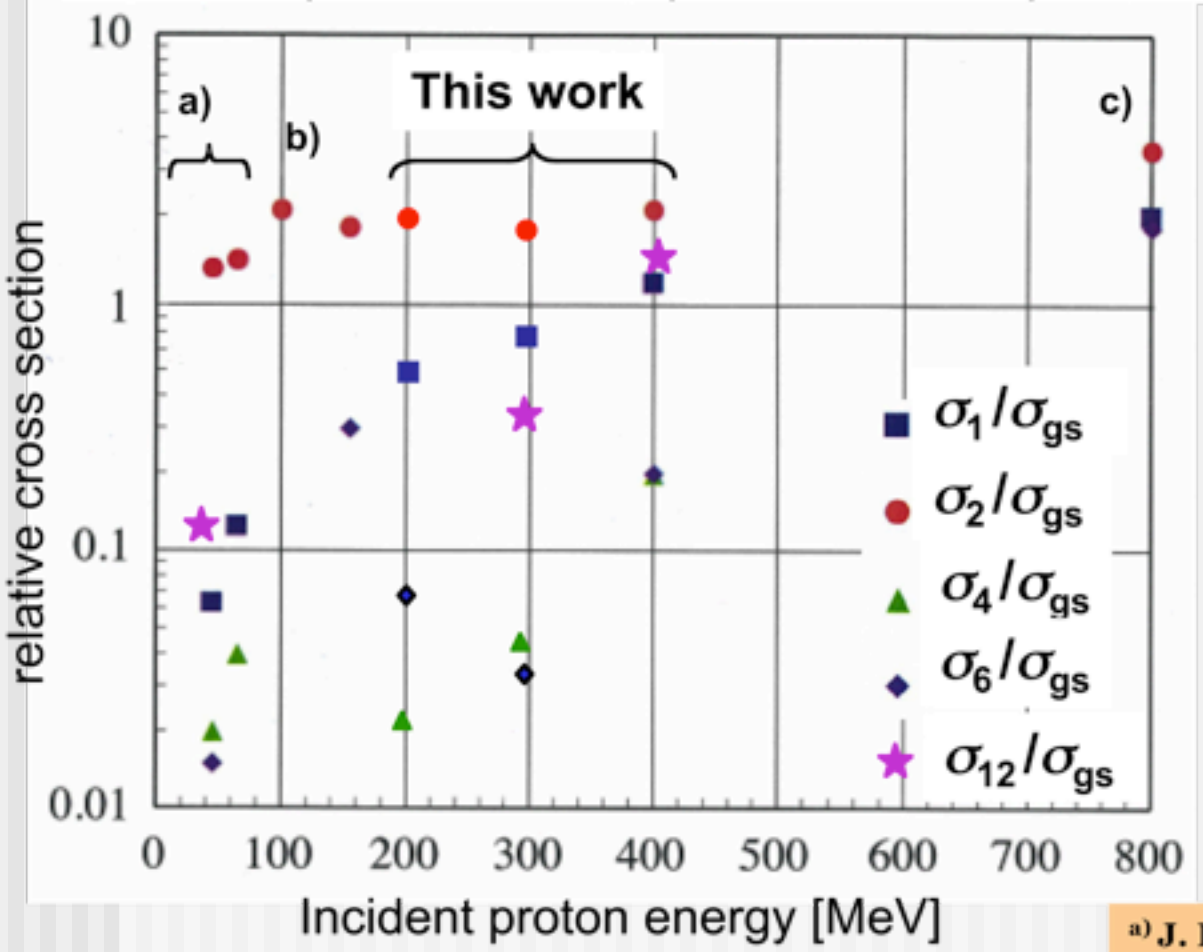

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11	11.9	$5/2^-$, $5/2^-$
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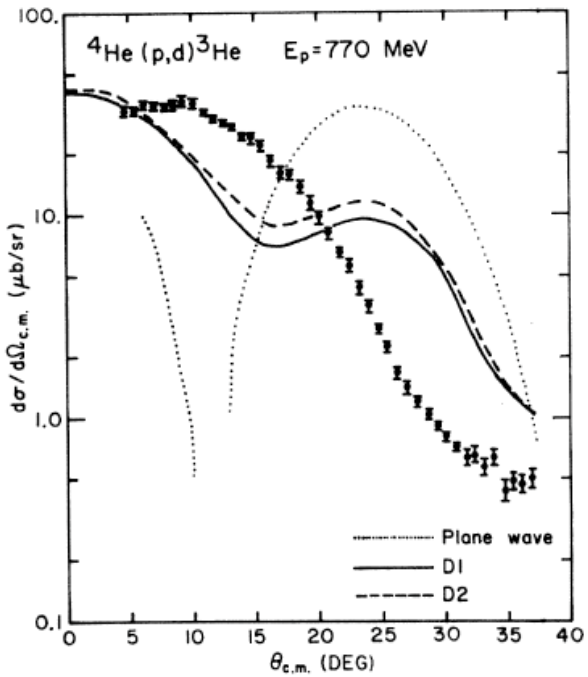

FIG. 1. The Saclay data are compared with PWBA and DWBA calculations employing an uncorrelated neutron + ^{3}He wave function obtained as described in the text. Optical potentials used in the DWBA are described in the text.

T. Bauer et al., PLB 67, 265 (1977)
E. Rost et al., PRC 17, 1513 (1978)

- pion exchange current
- finite-range DWBA

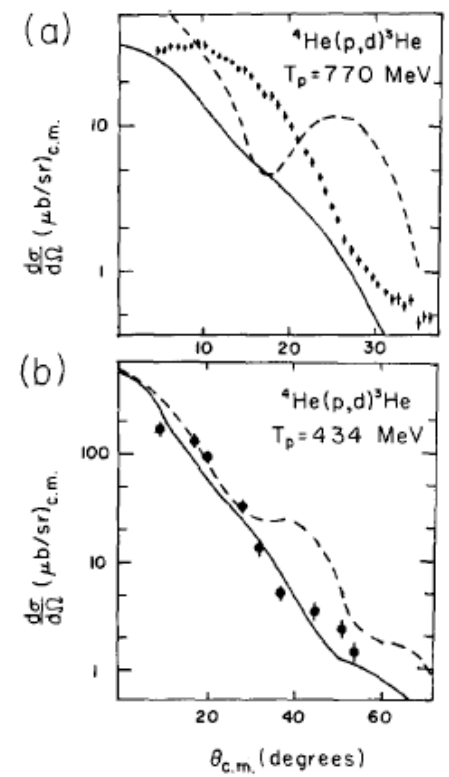

Fig. 2. (a) The T_p = 770 MeV ^{4}He (p, d) ^{3}He data is compared to exact finite-range DWBA predictions with (solid line) and without (dashed line) the corrections due to meson exchange; (b) the same comparison is made to the T_p = 434 MeV ^{4}He (p, d) ^{3}He data.

J. R. Shepard et al., PLB 89, 13 (1979)

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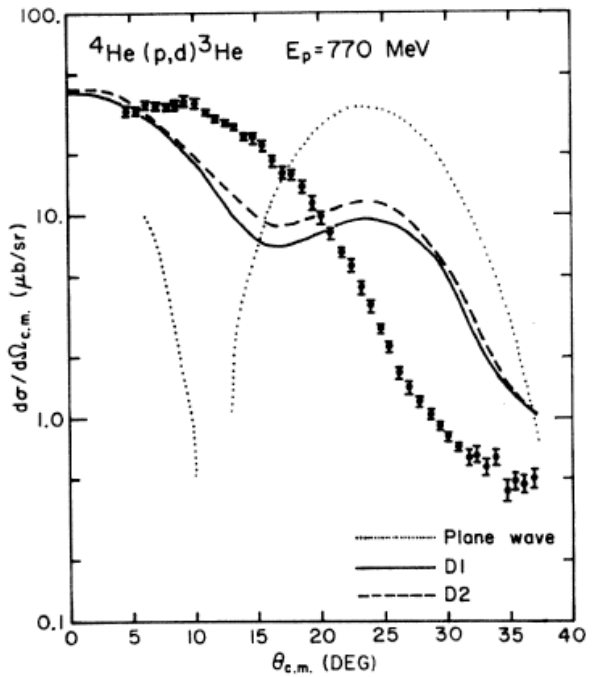

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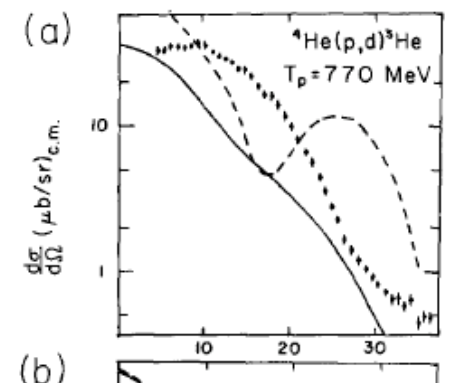
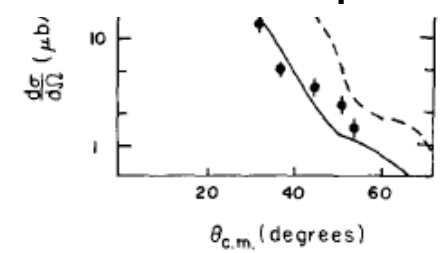


pion emission and reabsorption?



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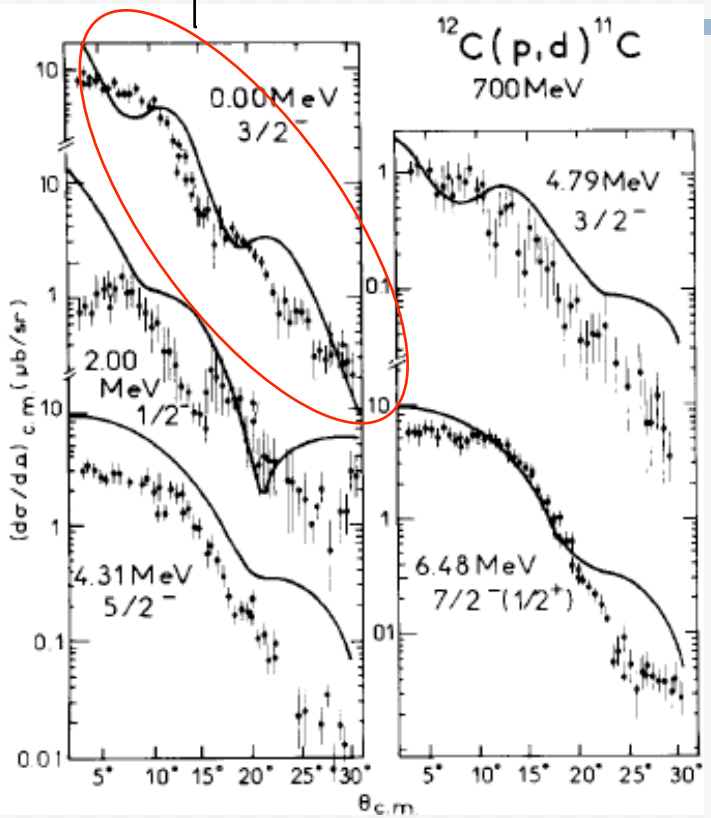
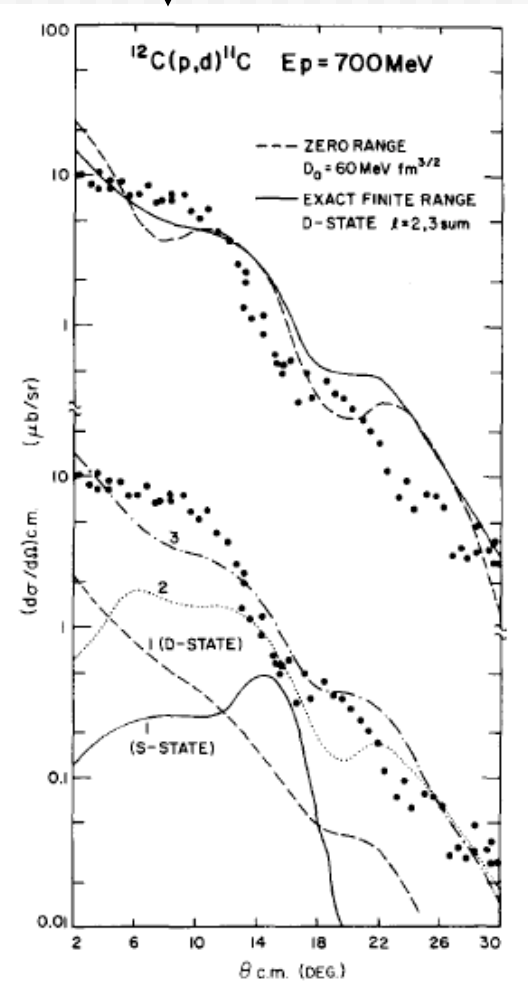
Flash back to earlier data (2)

deuteron D-state



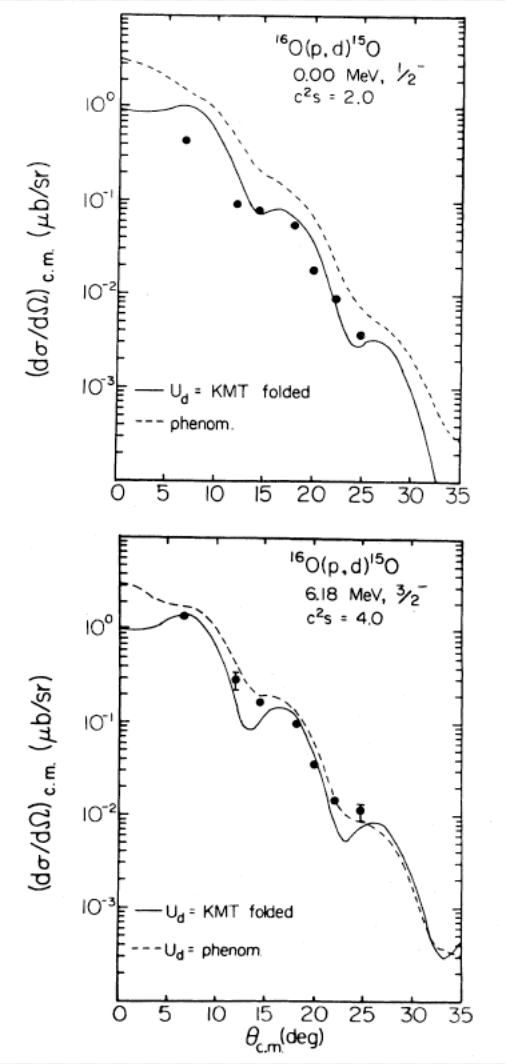
S. D. Baker et al., PLB 52, 57 (1974)



E. Rost et al., PLB 59, 413 (1975)

Flash back to earlier data (3)

- finite-range DWBA



- zero-range CCBA
- only S-state

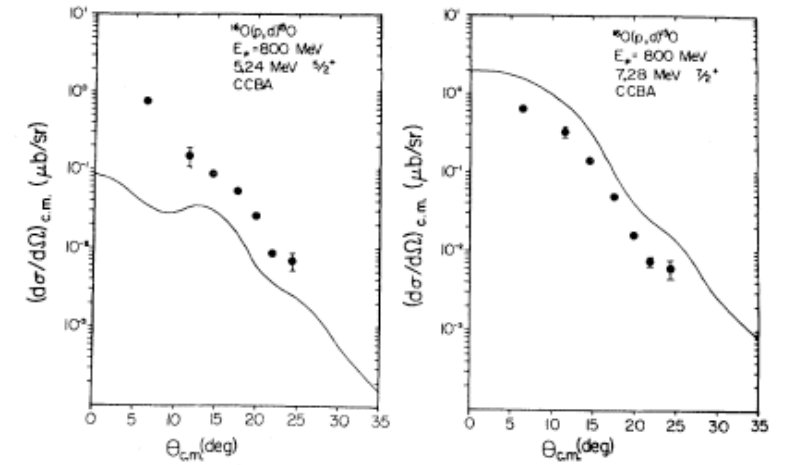


FIG. 21. Pickup data to $\frac{5}{2}^+$ and $\frac{7}{2}^+$ states in ^{15}O are compared to zero range CCBA calculations, proceeding through the strong 3^- state of the ^{16}O target, with $D_0 = -80$ MeV fm$^{3/2}$.

G. R. Smith et al., PRC 30, 593 (1984)

The deviations were blamed on the lack of understanding of the reaction mechanism..

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BUT, are those solely due to reaction mechanism?

PHYSICAL REVIEW C VOLUME 15, NUMBER 2 FEBRUARY 1977

One- and two-step processes in single-nucleon pickup*

Jan Källne
Los Alamos Scientific Laboratory, Los Alamos, New Mexico 87545

Andrew W. Obst
Northwestern University, Evanston, Illinois 60091

(Received 13 September 1976)

The reaction $^{12}C(p,d)^{11}C$ at high momentum transfers ($q \gtrsim 200$ MeV/c) has been examined with respect to single- and two-step processes. Our coupled-channel Born-approximation analysis of the reaction at 185 MeV shows that peculiarities observed in experimental angular distributions can be explained with the two-step process or the interference between the single-step and two-step processes. The analysis requires the presence of small $1d$ and $1f_{7/2}$ admixtures in the ^{12}C ground state along with the basic $1s^4 1p^8$ configuration. The different energy dependence in the single-step and two-step processes is discussed and illustrated by data at 185 and 700 MeV.

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- need more adequate nuclear structure info

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- need more adequate nuclear structure info
- tensor interaction?
- helps from both nuclear structure and reaction theorists are called for

Acknowledgment

RCNP-E314 collaborators:

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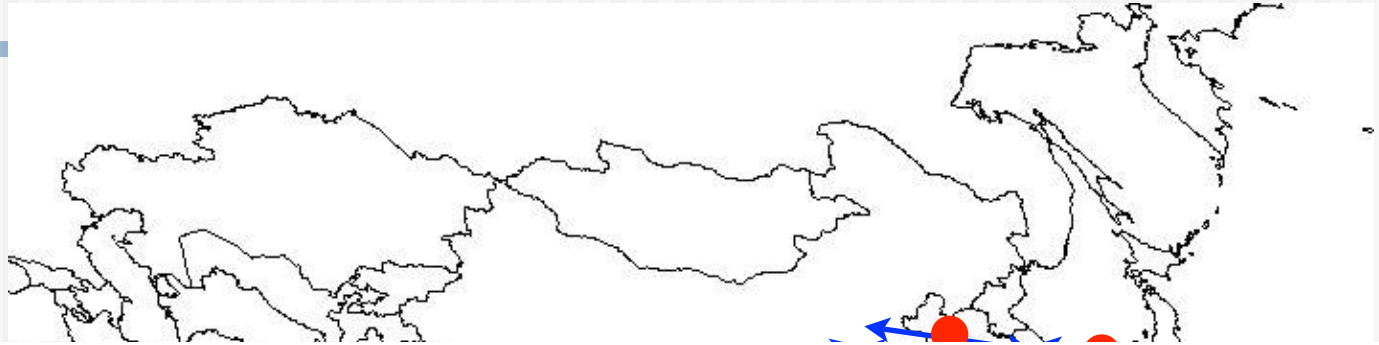
Summary

- $^{12}C(p,d)$, $^{16}O(p,d)$ reaction was performed using the RCNP Grand Raiden with proton beams at 200, 300 and 400 MeV.
- $^{16}O(p,d)^{15}O$: Ratios of the cross sections for positive-parity excited states to that of the ground state increased by a few orders of magnitude with increased momentum transfer.
- The enhanced cross sections at higher momentum transfer may indicate a direct evidence of the tensor force.

Pion exchange on different scale

Pion exchange on different scale

Pion exchange on different scale



Thank you very much for your attention!

谢谢!

ご清聴ありがとうございました!