Possible signature of tensor interactions observed via (*p*,*d*N) reaction

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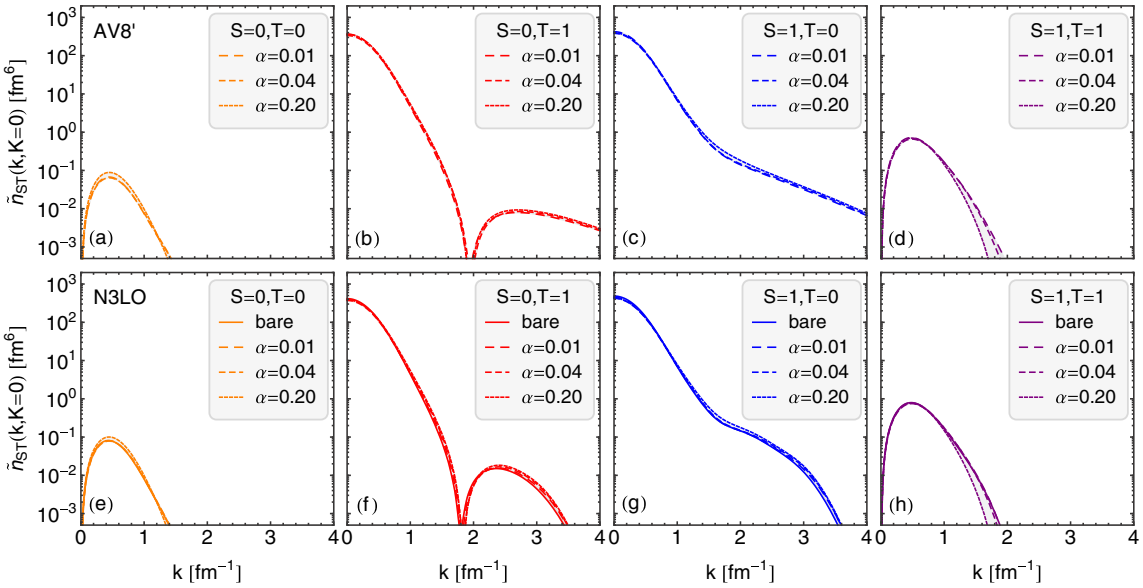
Beihang University, RCNP, Osaka University,
Kyoto University, Tsukuba University, RIKEN , GSI

INPC2016 Adelaide

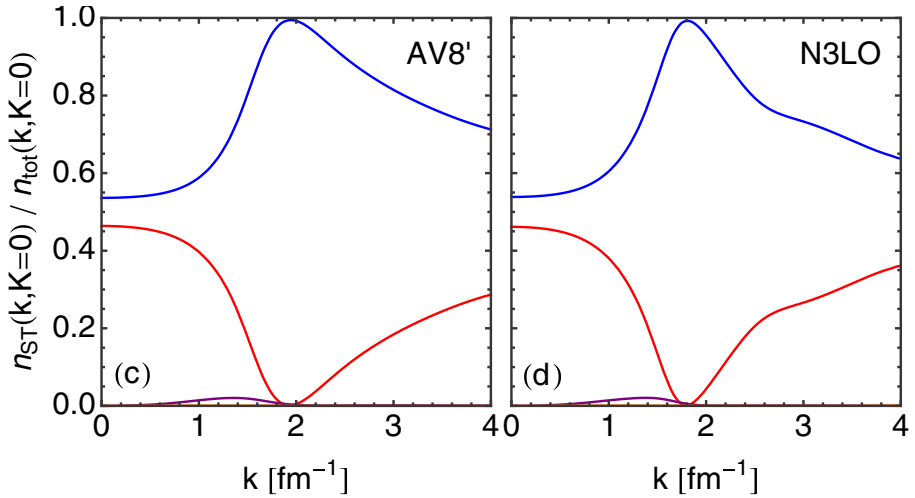
Isospin at high momentum transfer

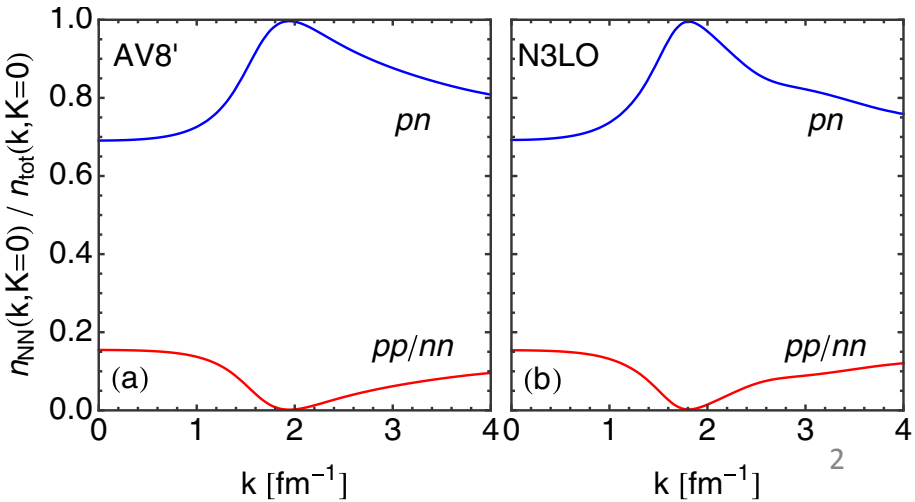


Reduced effect of tensor interaction predicted at around 1.8 fm^{-1} for T=1 state

This region is really important to pin down the effect of tensor interactions

T.Neff et al, PhysRevC92(2015)024003





Previous experiment with triple coincidence using electron probe

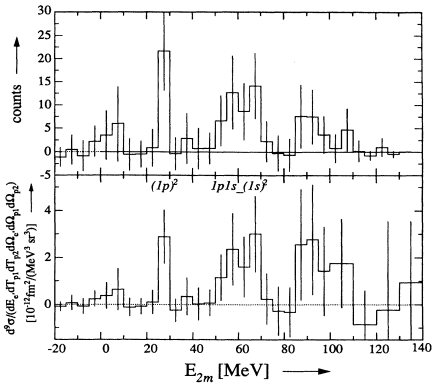


FIG. 1. In the upper panel the total number of triple coincidences, measured for $\theta_{p_1} = 53°$ ($\gamma^{\text{c.m.}}_{p_1q} = 35°$) and $\theta_{p_2} = -90°$, $-104°$, and $-118°$, is displayed as a function of the double missing energy E_{2m}. The data have been corrected for inefficiencies and accidental coincidences. In the lower panel the cross sections obtained from these data are presented. They are corrected for radiative effects.

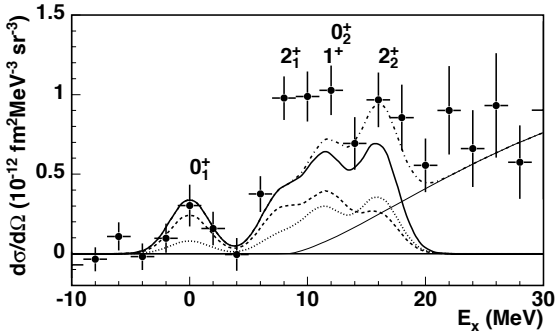
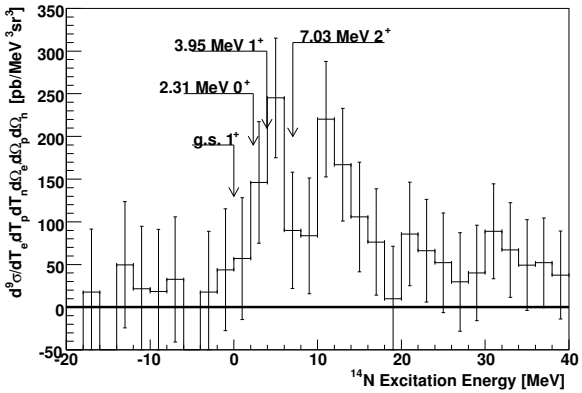


FIG. 1. The ninefold-differential cross section as a function of the excitation energy, averaged over missing momenta between 50 and 350 MeV/c and over γ_1 between 10° and 40° ($d\sigma/d\Omega = d^9\sigma/dE_{e'}d\Omega_{e'}dE_1d\Omega_1dE_2d\Omega_2$). The measured cross sections are indicated with the solid circles. The error bars represent the statistical uncertainty. The curves correspond to results of a microscopic calculation (see text).

^{16}O(e,e'pn) at MAINZ EPJA29(2006)261



^{12}C,^{16}O(e,e'pp) at NIKEFF PRL74(95), 1712, PRL81(98), 2213

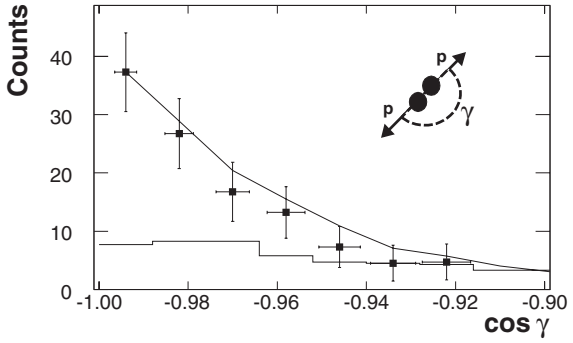


FIG. 3. The distribution of the cosine of the opening angle between the $\vec{p}_{\text{miss}}$ and $\vec{p}_{\text{rec}}$ for the $p_{\text{miss}} = 0.55$ GeV/c kinematics. The histogram shows the distribution of random events. The curve is a simulation of the scattering of a moving pair with a width of 0.136 GeV/c for the pair c.m. momentum.

^{12}C(p,ppn) at BNL PRL90(03),042301

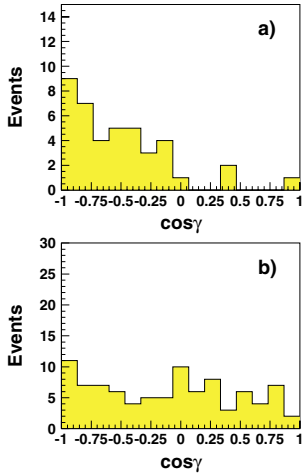
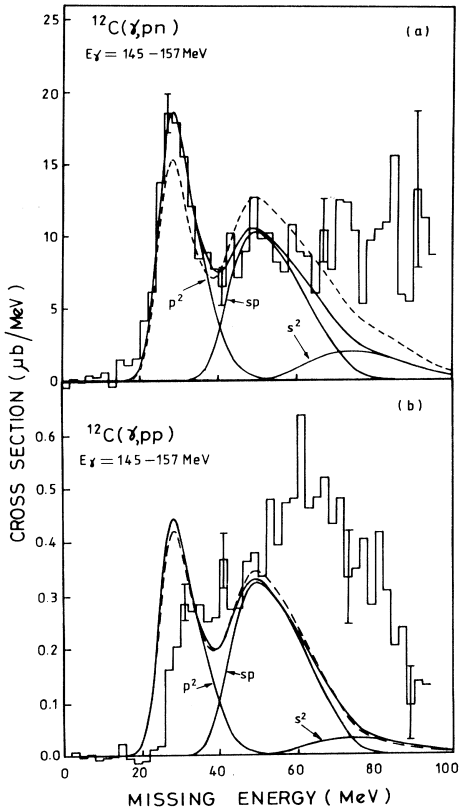


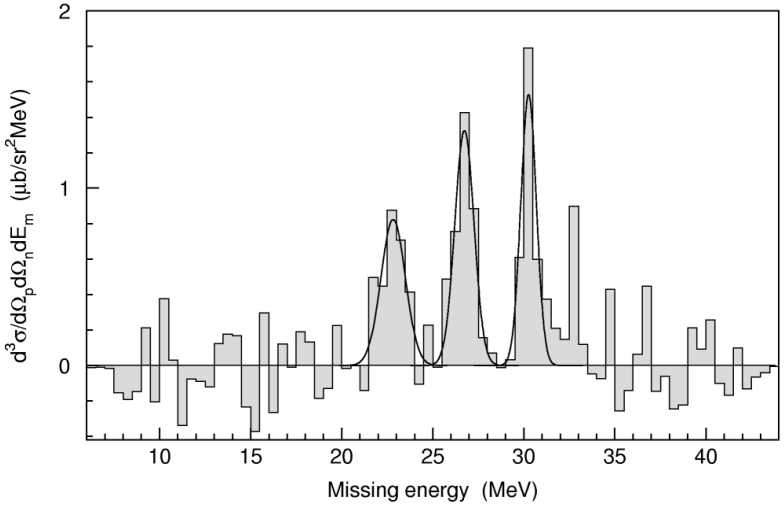
FIG. 2 (color online). Plots of cosγ, where γ is the angle between $\mathbf{p}_n$ and $\mathbf{p}_f$, for ^{12}C$(p, 2p + n)$ events. Panel (a) is for events with $p_n > 0.22$ GeV/c, and panel (b) is for events with $p_n < 0.22$ GeV/c; 0.22 GeV/$c = k_F$, the Fermi momentum for ^{12}C.

^{12}C(e,e'pp[or n]) at TJlab PRL99(07)072501

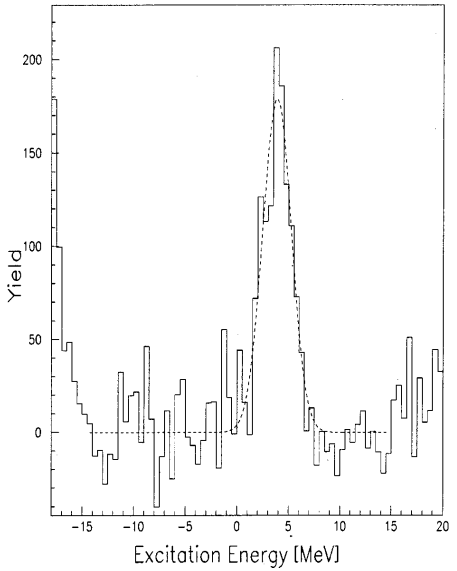
Previous experiment with real photon



^{16}O(γ,pp[n]) at MAINZ
PRC51(1995)1967



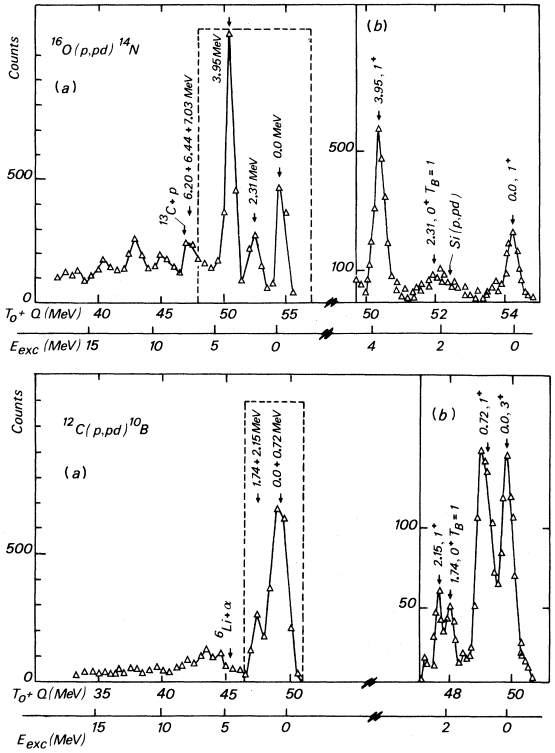
^{16}O(γ,pn) at MAX-lab
PRL83(1999)3146



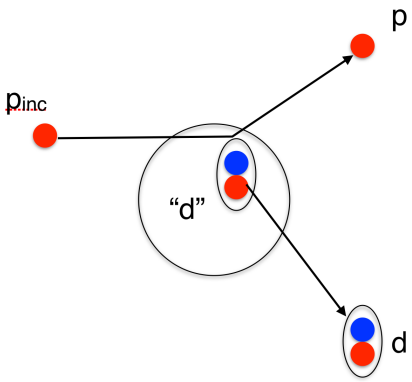
^{16}O(γ,pn) at SAL
PRC64(2001)064602

High-statistic measurement is needed
=> (p,dN) reaction

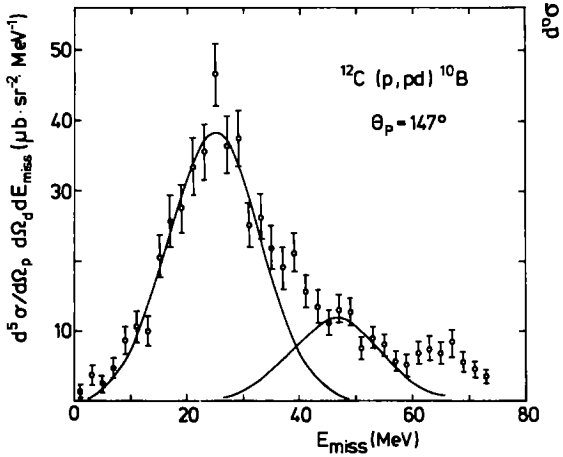
Similar channel with deuteron knockout

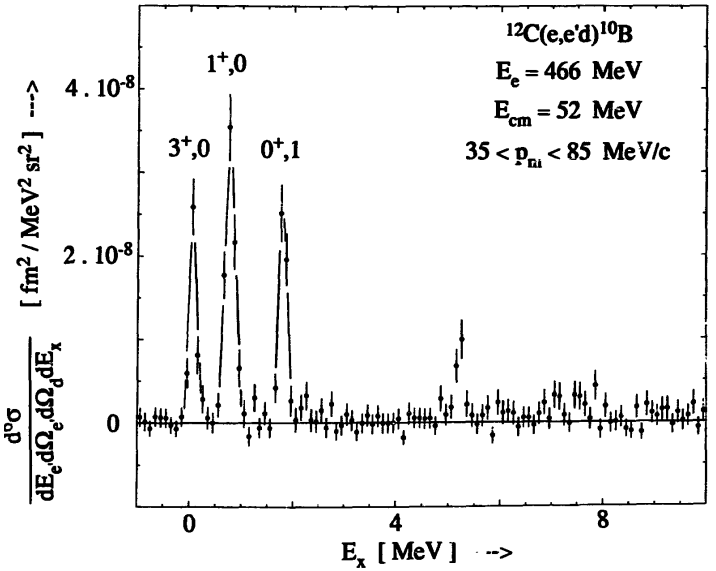


^{12}C,^{16}O(p,pd) PRC15(77) 843
75 MeV@Louvain



^{12}C(p,pd) NPA372(81) 317
670 MeV@Dubna





^{12}C(e,e'd) NPA578 (94) 93
ω=52 MeV@NIKHEF

Many bound states
=> moderate resolution is necessary

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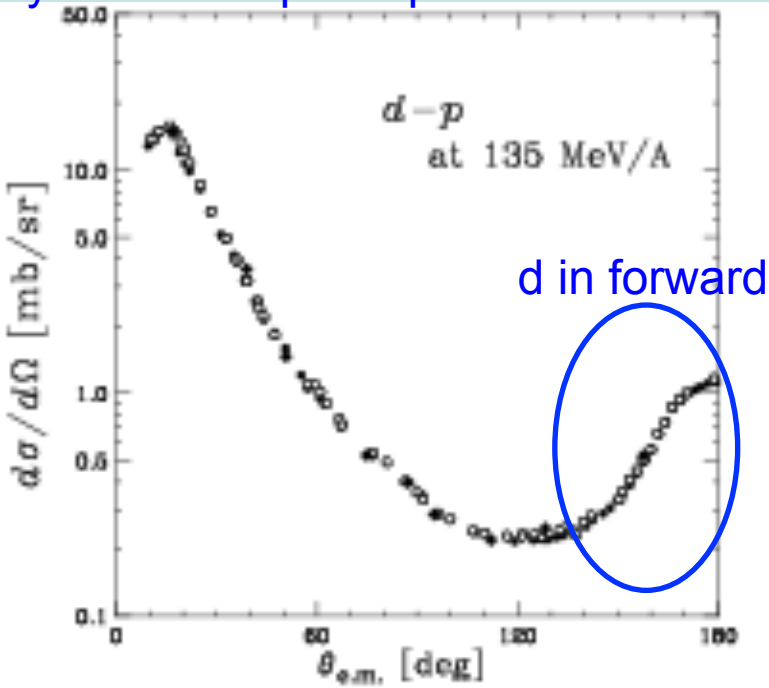
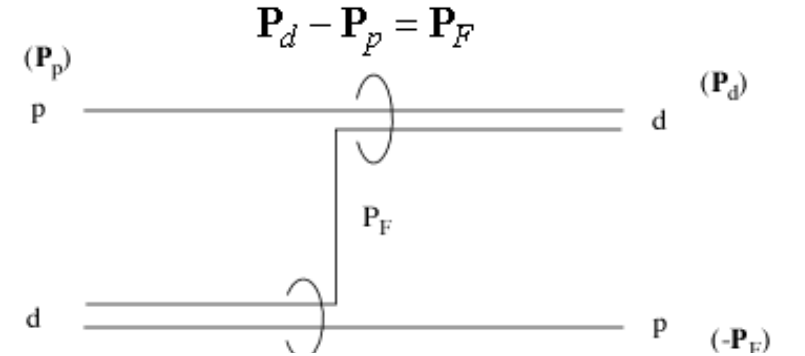
(p,d) reaction at high-momentum transfer

- Use the neutron pick up reaction at large momentum transfer.

Forward neutron in (p,d) reaction is equivalent to backward elastic scattering of p+d, which is dominated by a neutron pick-up.



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

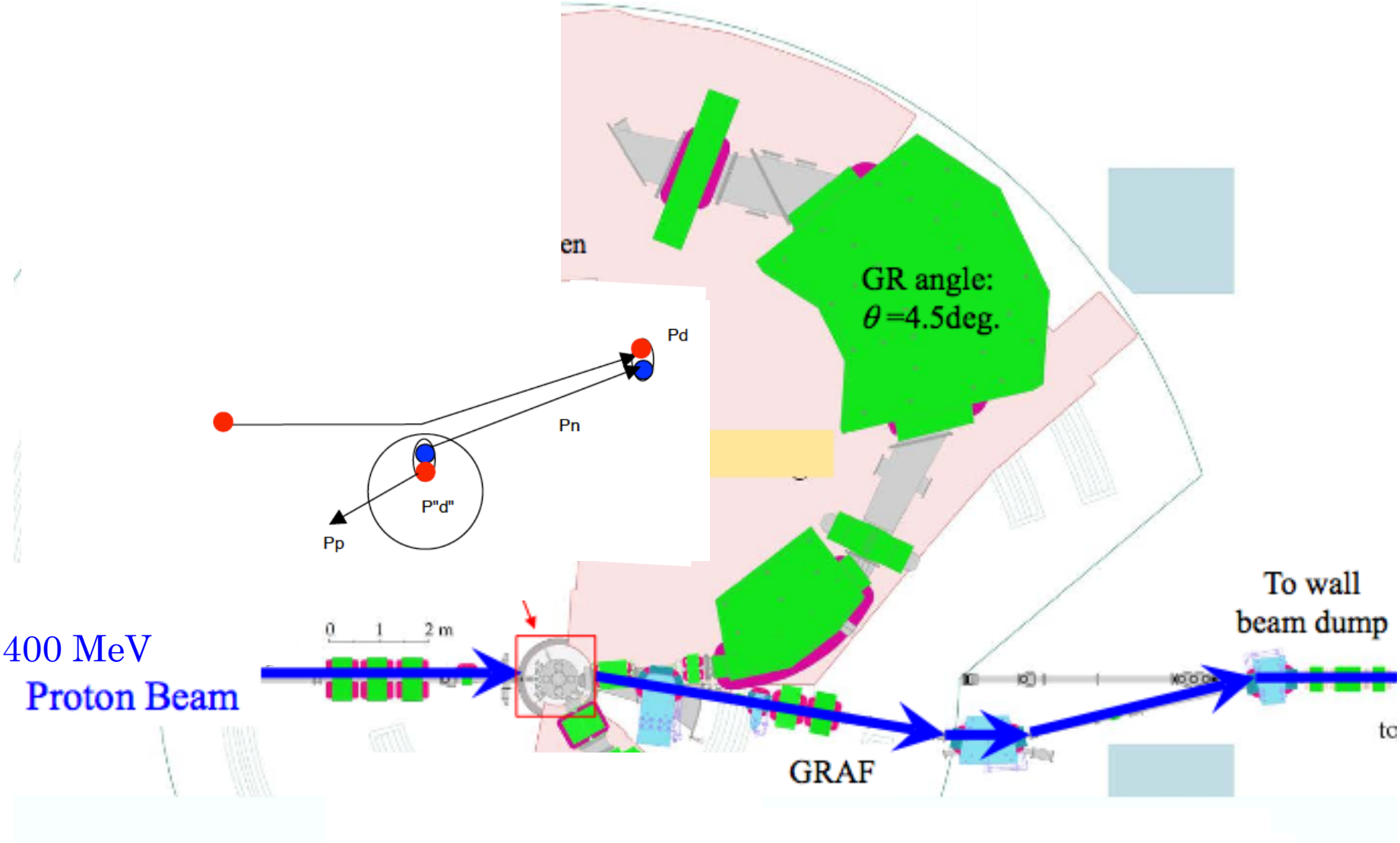


$$\sigma_F = K\frac{P_d}{p}N(P_F)\left[B_D + \frac{\hbar^2}{M}(\mathbf{p} - \mathbf{P}_d/2)^2\right]^{-2}\left|(\varphi(r), e^{i(\mathbf{p}-\mathbf{P}_d\bullet\mathbf{r}/2)})\right|^2$$

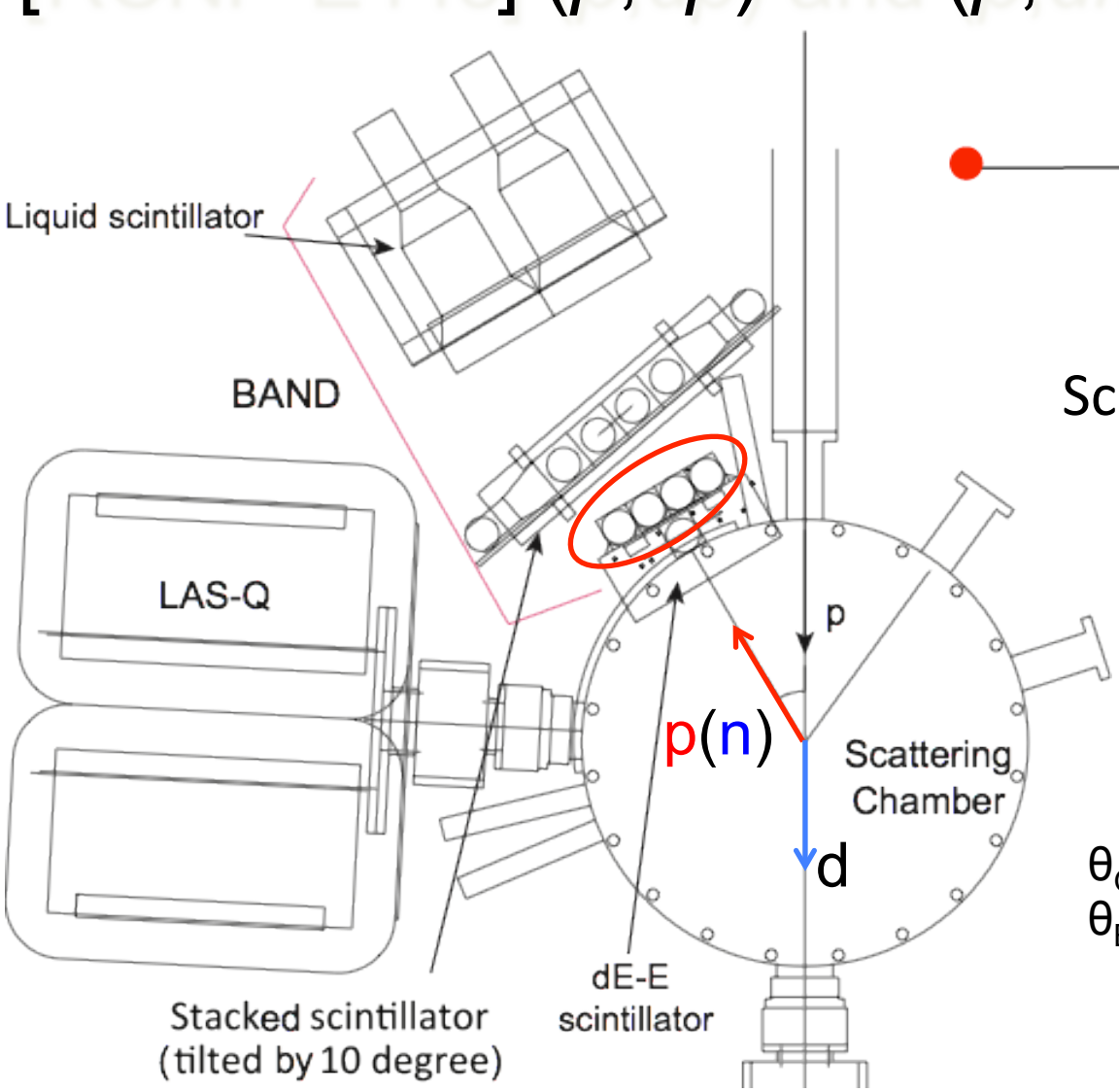
K: phase space constant, B_D: deutron binding nergy, M: nucleon mass
by G. F Chew and M.L. Goldberger Phys. Rev. **77** (1950) 470.

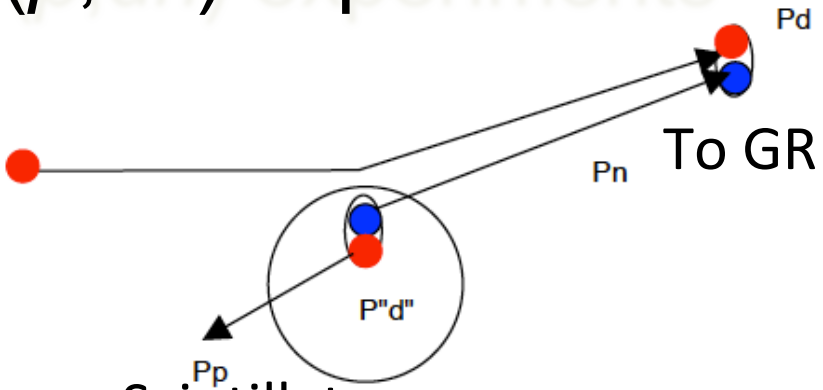
Reaction at "backward" occurs via the pickup of high-momentum neutron.

GRAF(Grand-RAiden Forward mode):
New beam line for low-background coincidence measurement



[RCNP-E443] (*p*,*dp*) and (*p*,*dn*) experiments





Scintillator array

400 MeV proton
20 pnA
60 mg/cm^2
Ice(H_2O) and CD_2

θ_{GR}=8.7^o, 15.0^o
θ_{BAND}=112^o ,135^o

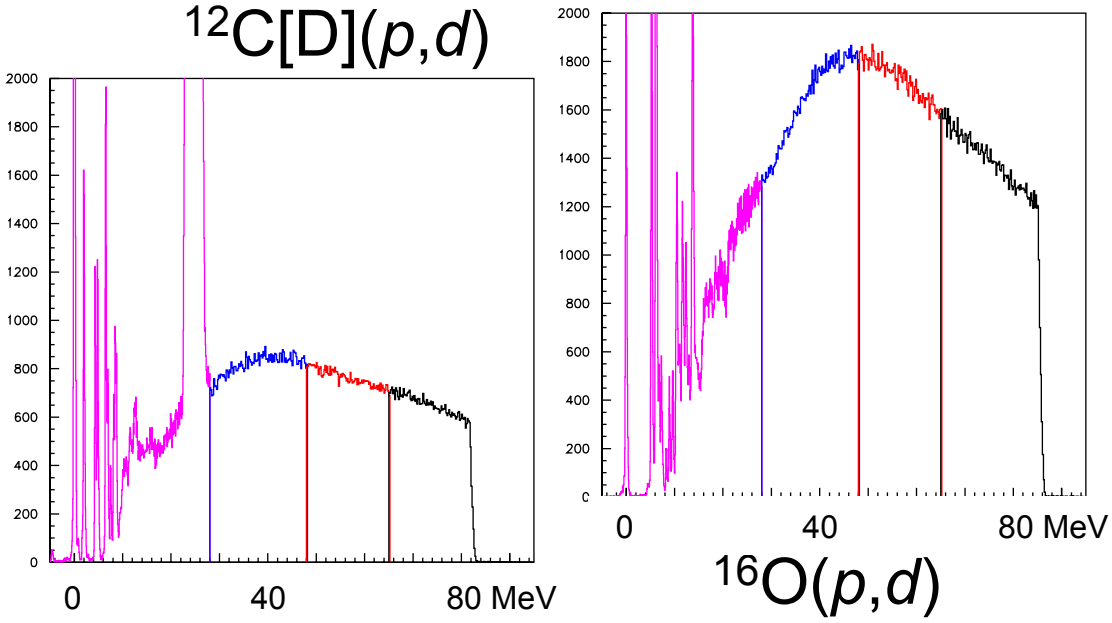
=>1.6 fm^{-1}(15.0^o)
1.4 fm^{-1}(8.7^o)

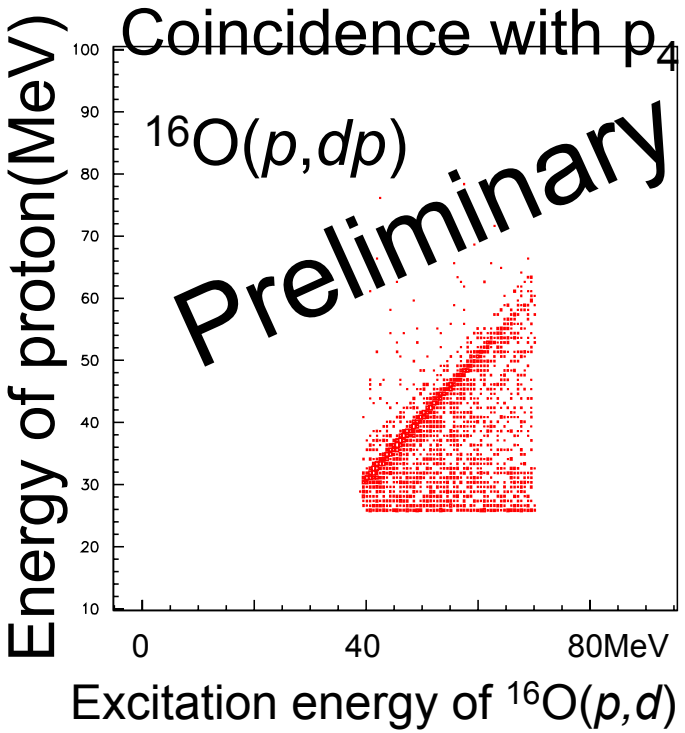
Spectrometer 5 ~ 19 deg

Correlation of p_{rec} and Ex

'HighBρ'-'0 MeV'-'20 MeV'-'40 MeV'

Inclusive spectra in CD_2&H_2O(*p*,*d*)





$$p_{rec} = p_5 = p_1^{(Beam)} - p_3^{(GR)} - p_4^{(BAND)}$$

$$e_5 = e_1^{(Beam)} + e_2^{(Target)} - e_3^{(GR)} - e_4^{(BAND)}$$

$$E_x = \sqrt{(e_5^2 - p_5^2)} - m_5$$

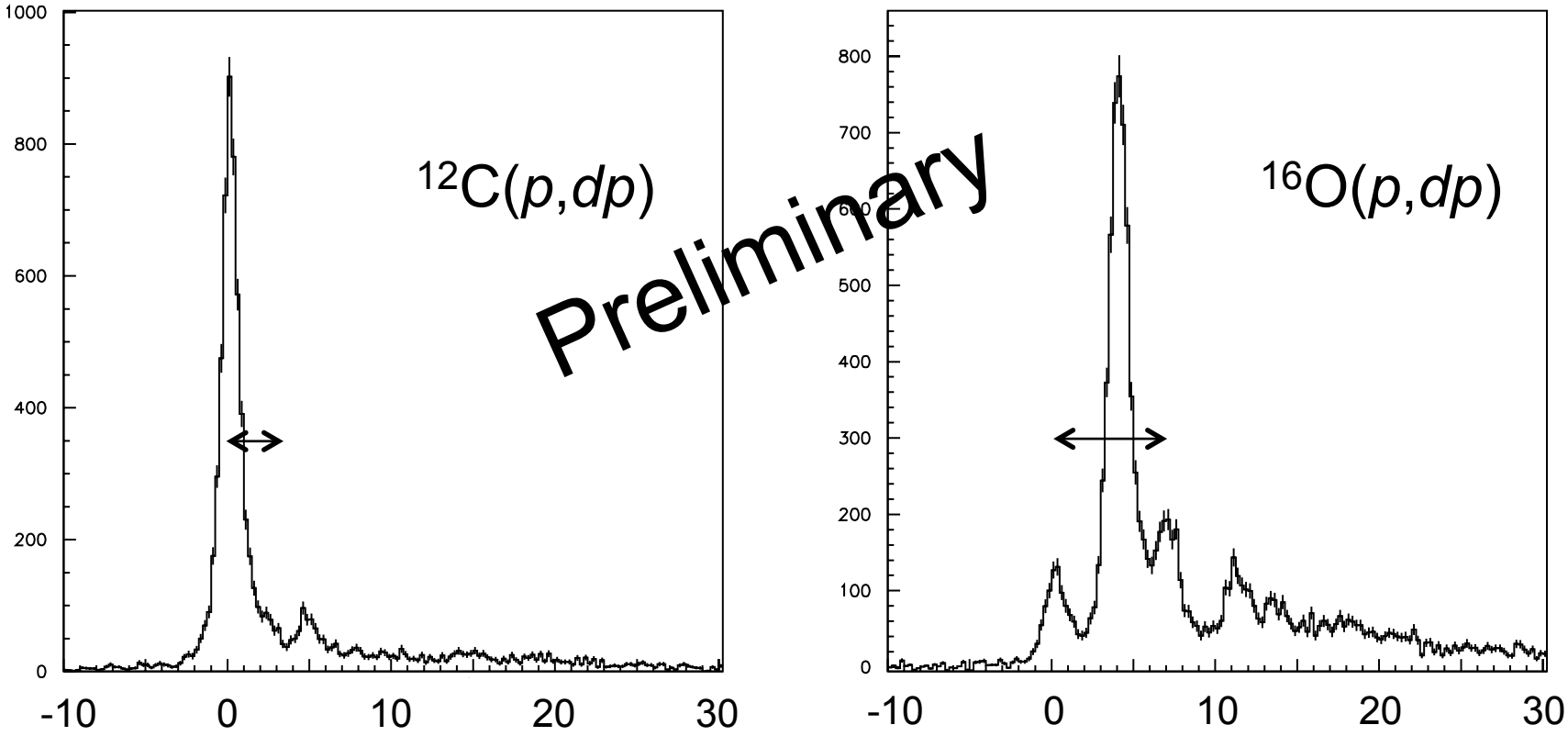
Notations:

"2"("1", "3" "4") "5":

^{12}C(*p*,*dp*)^{10}B

^{16}O(*p*,*dp*)^{14}N

Excitation energy spectra of (*p*,*dp*)

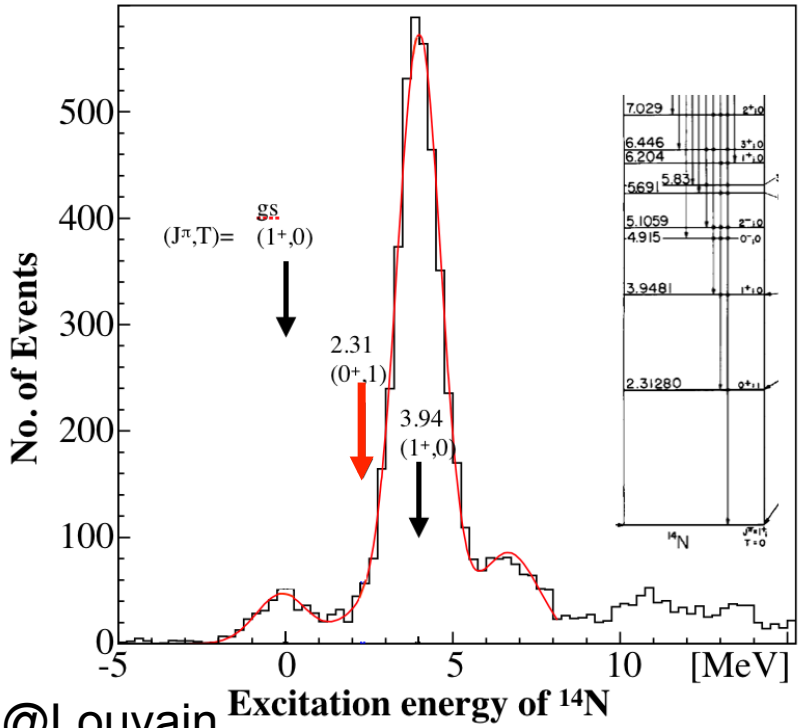


Clear peaks can be seen with
moderate energy resolution of 1.6 MeV [FWHM]

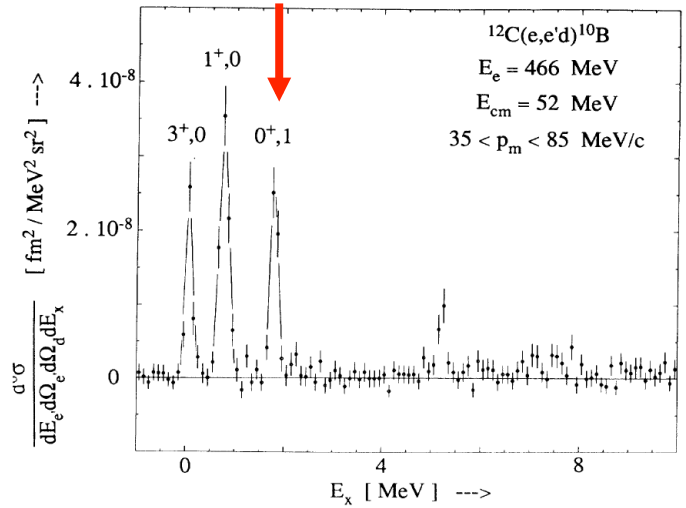
Strong suppression of *T*=1

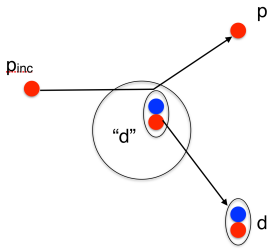
The low energy excited states are well separated.

Two main peaks are both (J^π, T)=(1^+, 0)

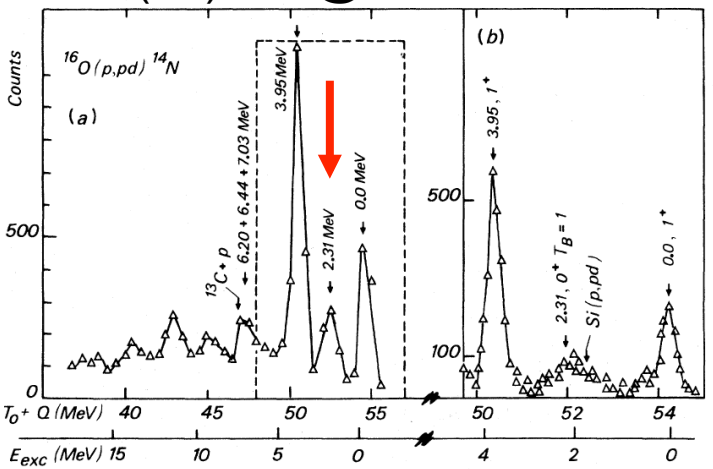


PRL62 (1989) 24 @NIKEFF



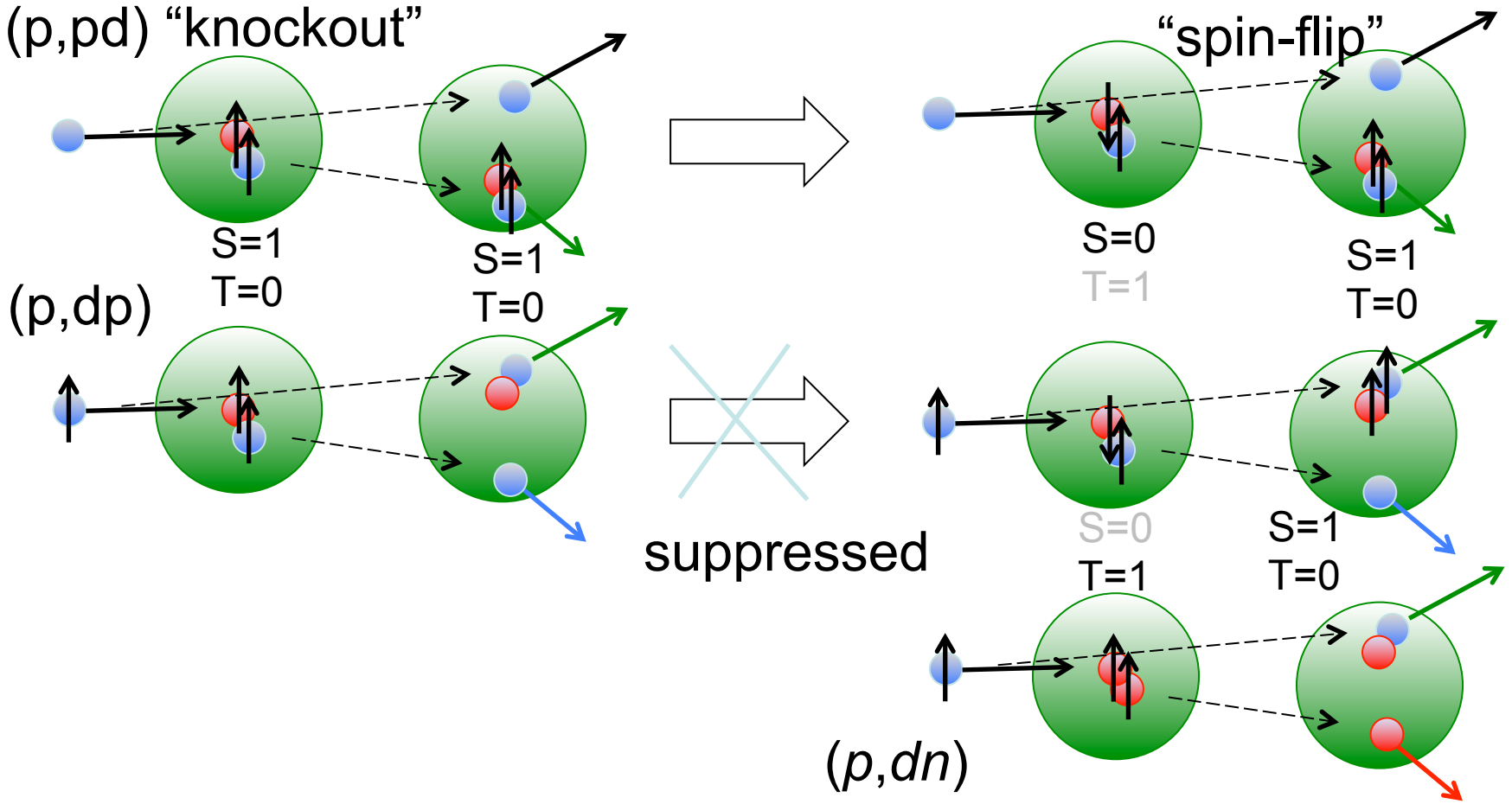


PRC15(77) 843@Louvain



T=1 state is observed in deuteron knockout experiment via (e,e'd) and (p,pd)

How we can understand *T*=1 suppression

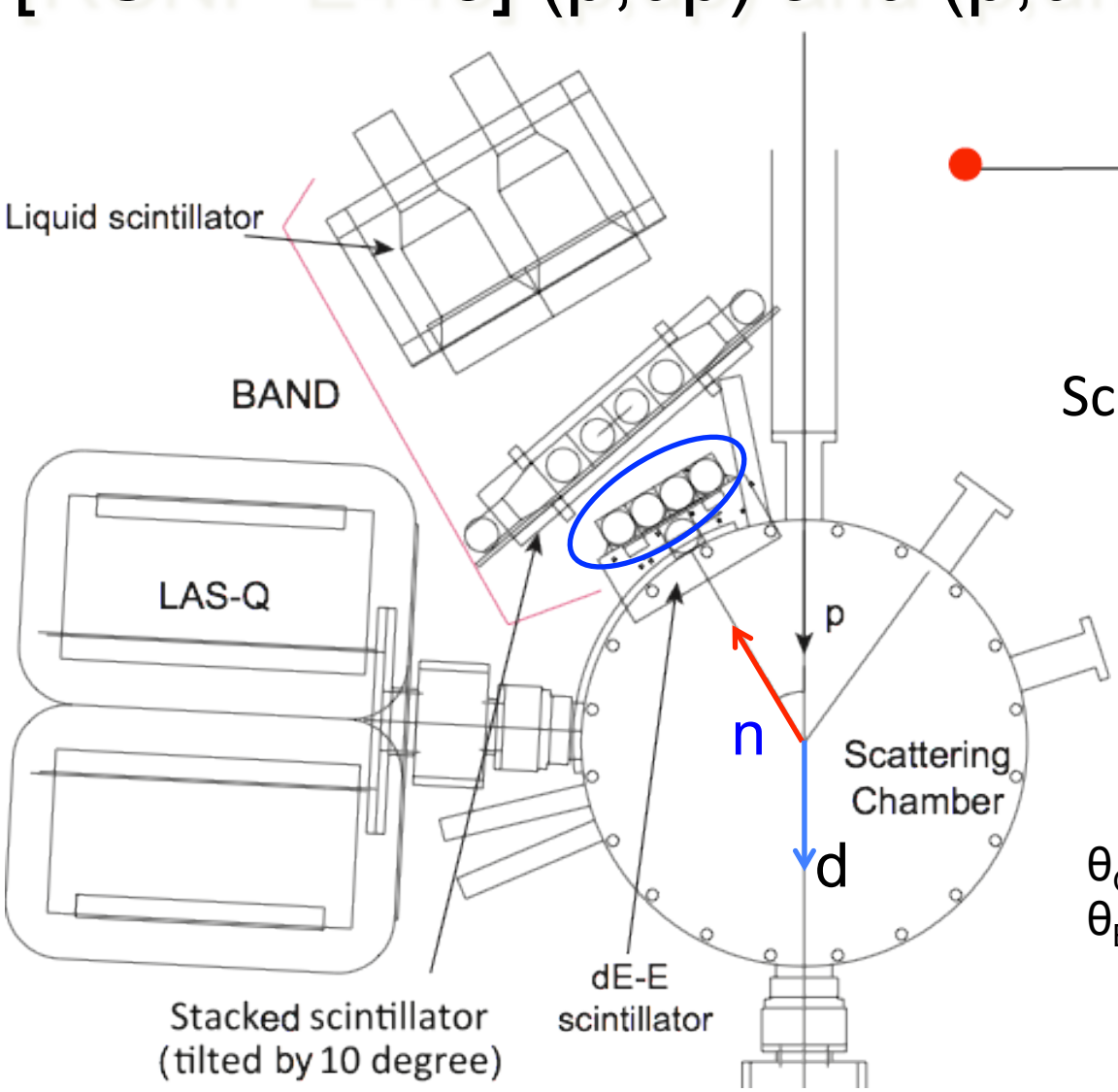


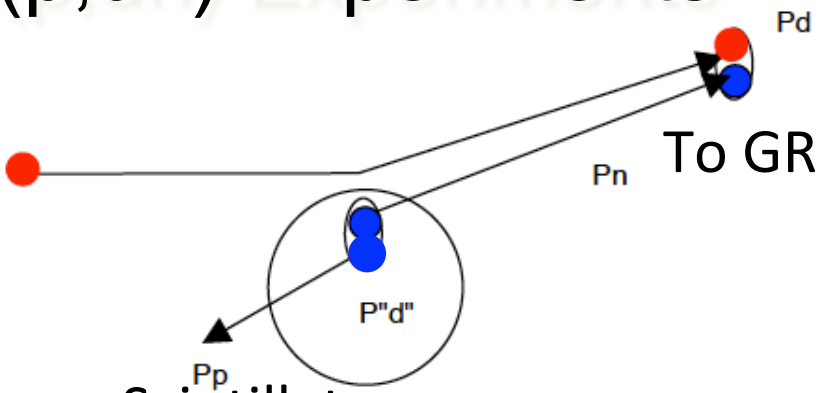
Possible signature of tensor-force effect.
Can also be examined via reduction in n-n pair

$^{16}O(p,dn)$

First observation of neutron-neutron pair at high momentum near 2 fm^{-1}.

[RCNP-E443] (p,dp) and (p,dn) Experiments





Scintillator array

400 MeV proton
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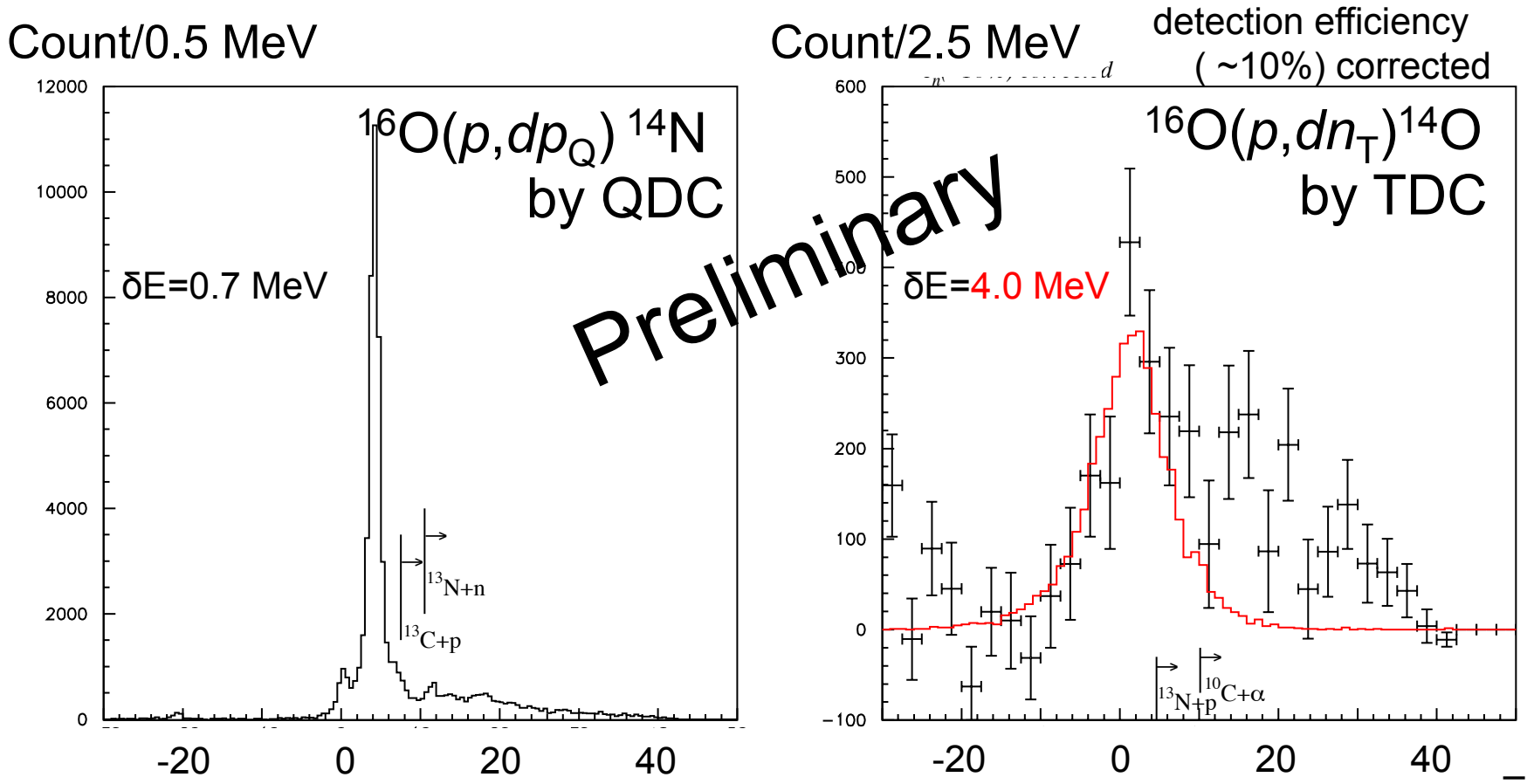
60 mg/cm^2
Ice(H_2O) and CD_2

θ_{GR}=8.7^o, 15.0^o
θ_{BAND}=112^o ,135^o

=>1.6 fm^{-1}(15.0^o)
1.4 fm^{-1} (8.7^o)

Spectrometer 5 ~ 19 deg

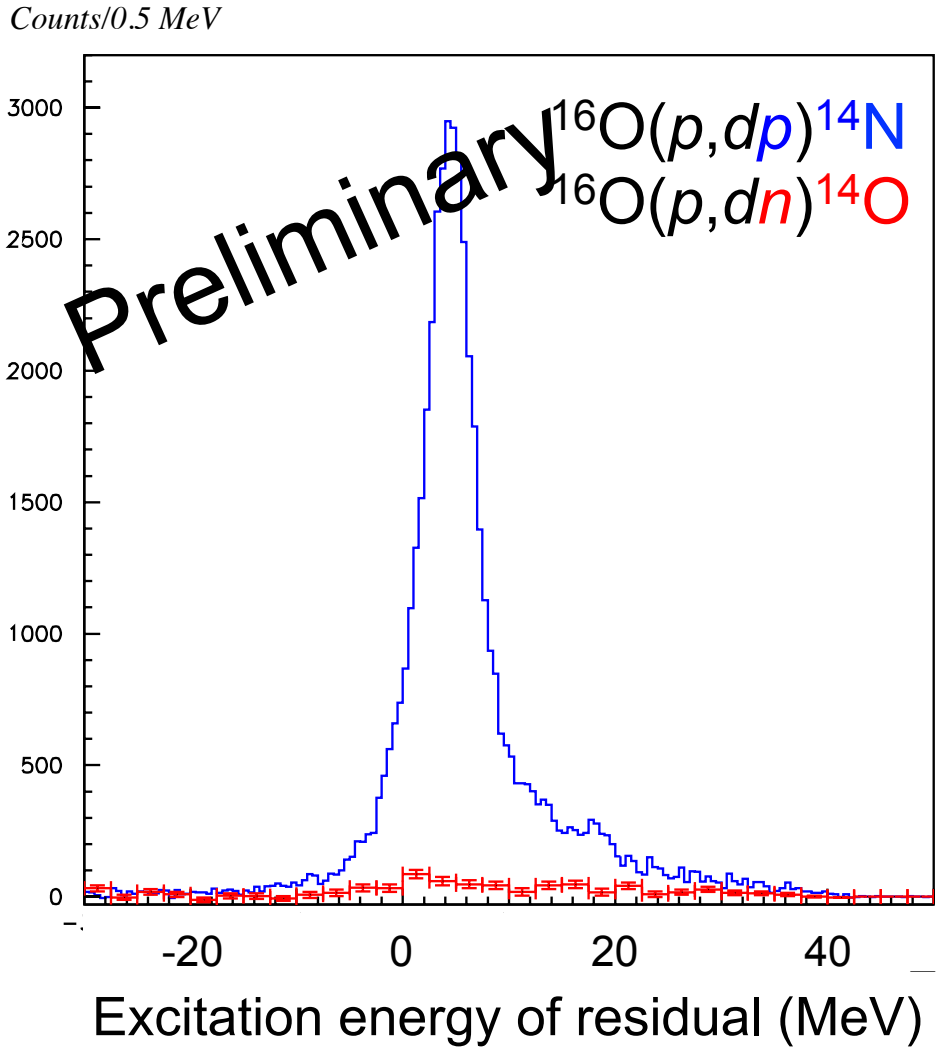
Comparison of ^{16}O(p,dN)@15°



First n-n removal spectra in ^{16}O with recoil-less condition

-80 MeV/c < p_{rec} < +80 MeV/c

Spectra difference in ^{16}O(*p*,*d*N) @15°

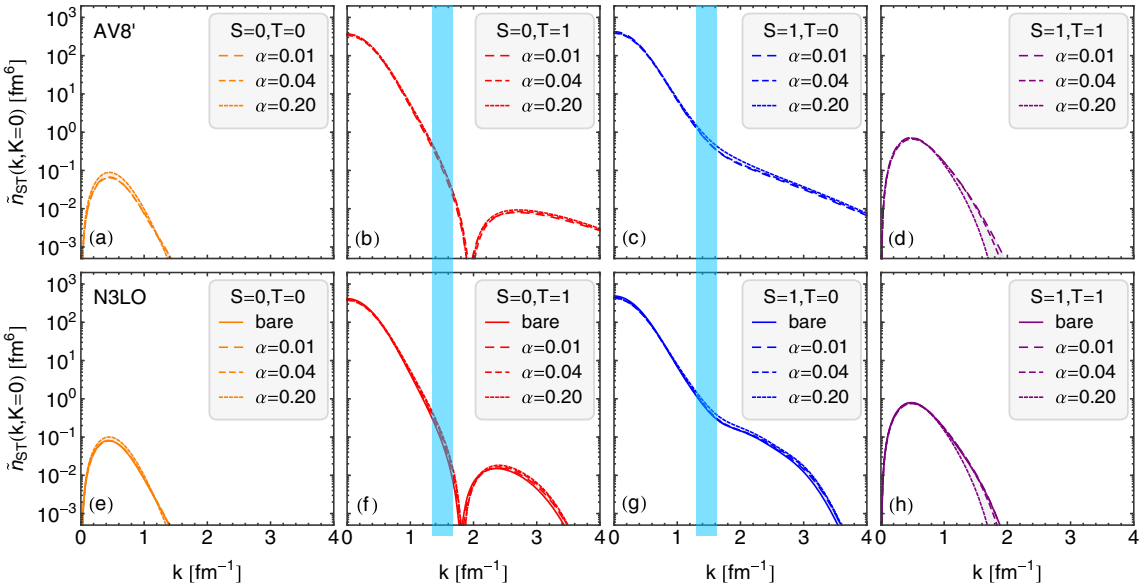


Direct comparison with ToF method for both proton and neutron

With Similar Resolution
2.5 MeV[σ]
&
4.0 MeV[σ incl F.P. uncertainly]

Strong suppression is observed

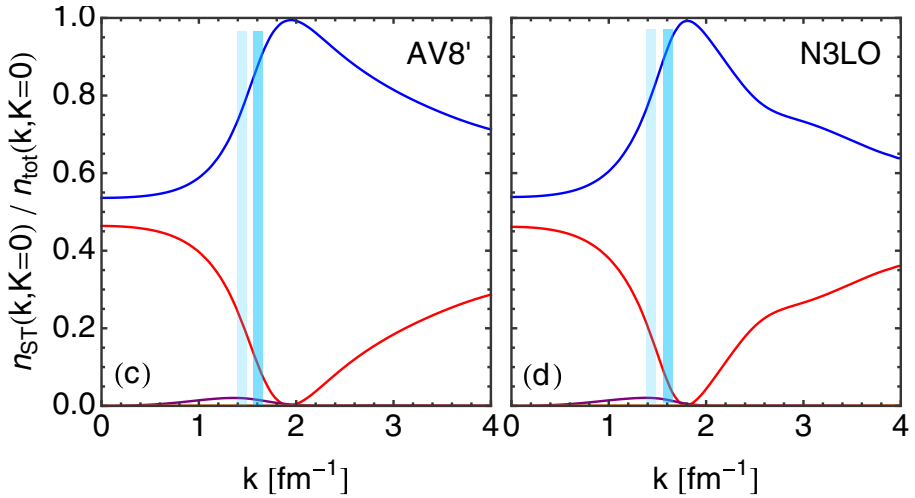
High momentum component

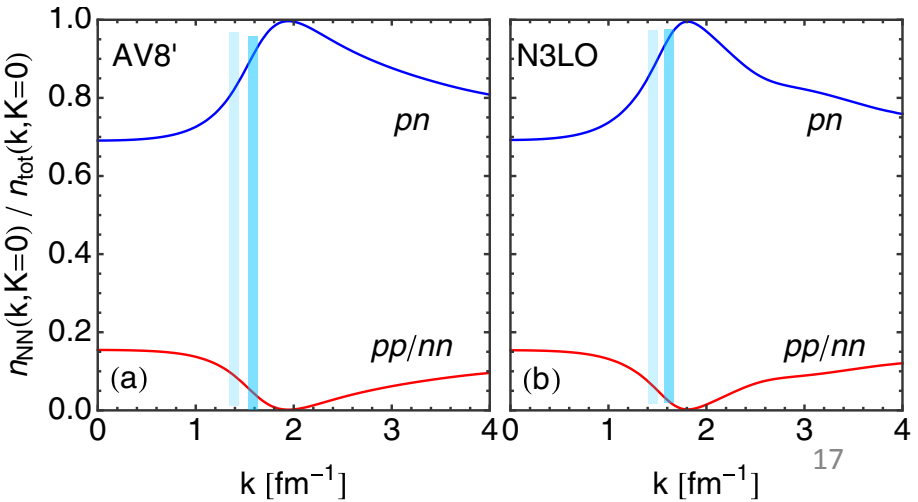


Reduced effect of tensor interaction predicted at around 1.8 fm^{-1} for T=1 state

Both T=1 and n-n suppressions can be consistently understood

T.Neff et al, PhysRevC92(2015)024003





Summary and Perspective

Coincidence measurements with high-momentum one-neutron (*p*,*d*) reaction at forward angle have been performed to study effect of tensor interactions in ^{12}C and ^{16}O.

In (*p*,*dp*) channel, several peaks corresponding to bound states can be resolved and their relative amplitudes are different from low energy experiment by deuteron knockout reaction.

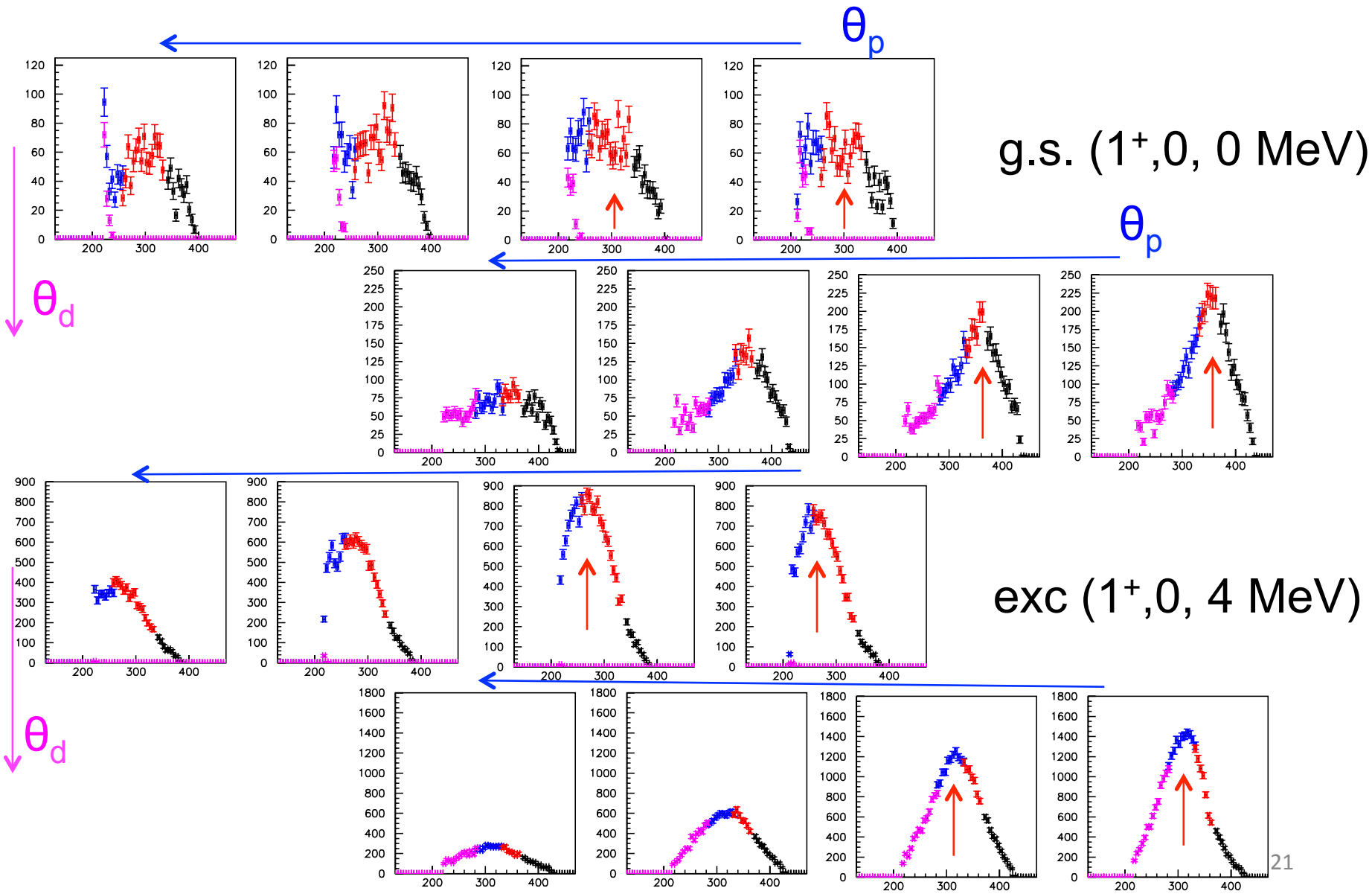
High-momentum neutron associated with pn pair with S=1 and T=0, which is a signature of the effect of tensor interactions, is strongly favored compared to the one with pn pair with S=0, T=1.

High-momentum neutron associated with nn pair has observed for the first time in ^{16}O via (*p*,*dn*), clear difference from (*p*,*dp*) is seen.

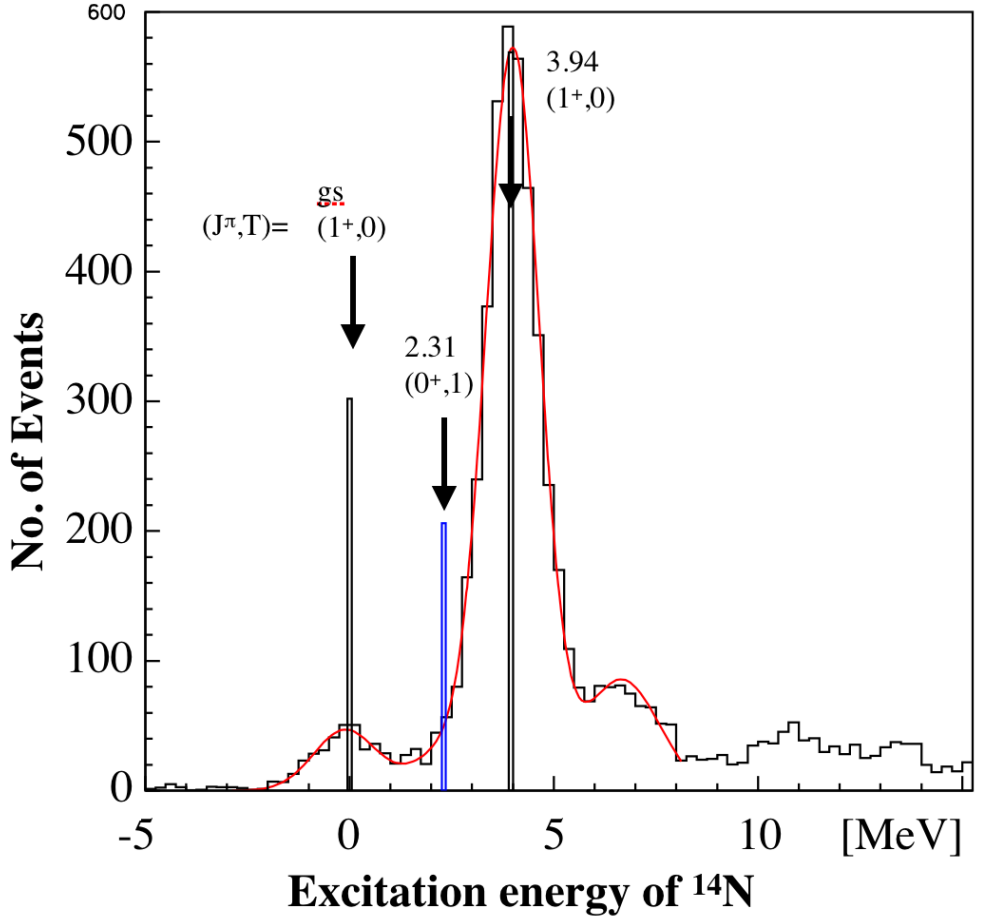
The results indicate possible signature of tensor-force effect.

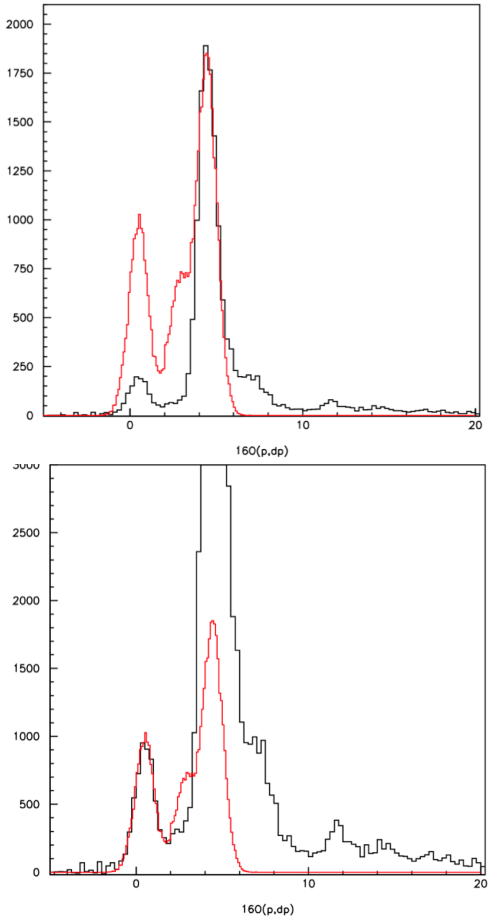
Thank you for your attention

Sharing energy spectra ^{16}O(*p*,*dp*)



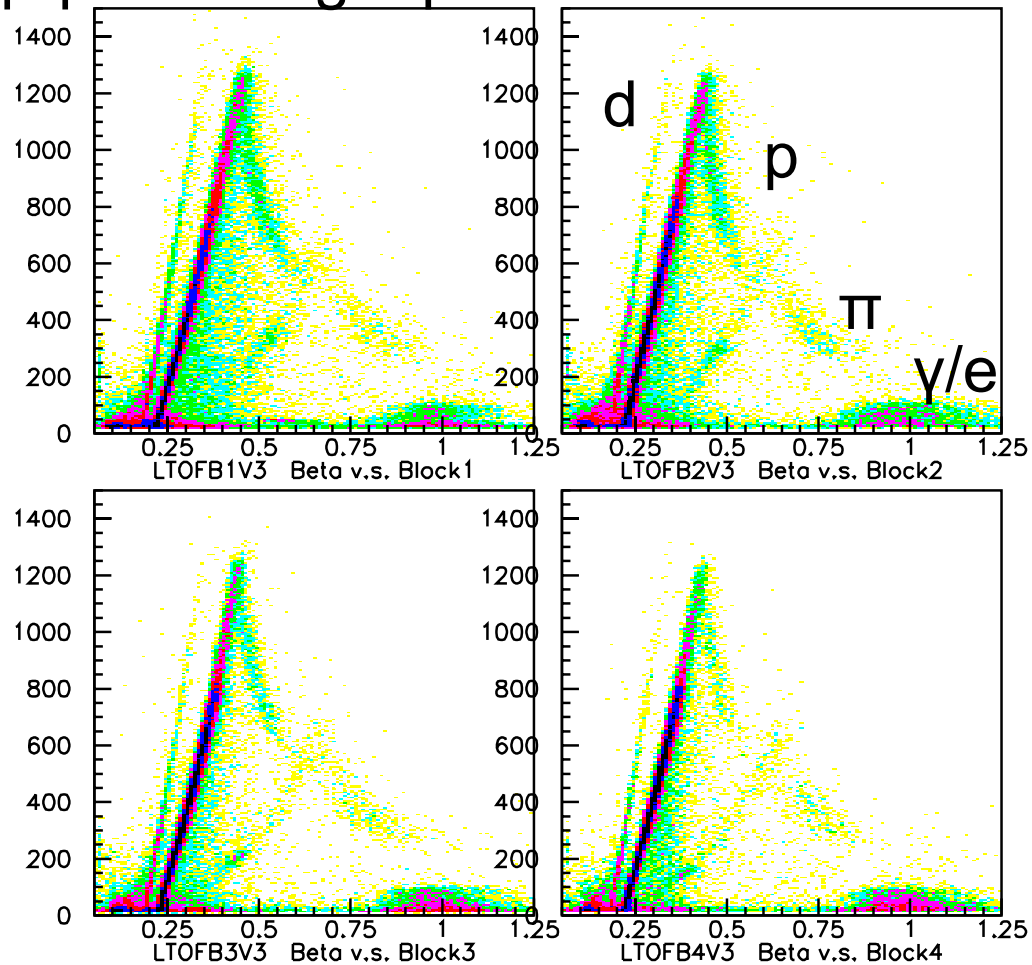
The *T*=1 excited state is not excited at high-momentum transfer.





energy and timing response

β-pulse height plot of all four-blocks



L assumed 50 cm from target
Slew correction by γ.
time offset adjusted by β=1

Clear particle identification and
expected performance

BAND-Block

6x6x9 cm^3 Plastic scintillator block behind thin plastic veto

Gamma insensitivity

Higher rate tolerance

[> 100 kHz/det@20 nA, actual condition]

Moderate resolution

[<3 % for higher energy proton around 50 MeV]

Good timing resolution

and neutron detection capability
[(p,dn) channel]

proton/neutron
(ADC-TDC/TDC)