Vector and tensor analyzing powers in $^{12}C(\vec{d},p)^{13}C^*$ reaction at energy $T_d = 270$ MeV.

A.S.Kiselev[1†], V.P.Ladygin, T.Uesaka, M.Janek, T.A.Vasiliev, M.Hatano, A.Yu.Isupova, H.Kato, N.B.Ladygina, Y.Maeda, A.I.Malakhov, S.Nedev, T.Saito, J.Nishikawa, H.Okamura, T.Ohnishi, S.G.Reznikov, H.Sakai, S.Sakoda, N.Sakomoto, Y.Satou, K.Sekiguchi, K.Suda, A.Tamii, N.Uchigashima, K.Yako

1) LHE JINR, Dubna, Moscow region, 141980 Russia
2) Department of Physics, University of Tokyo, Tokyo 113-0033, Japan
3) The Institute of Physical and Chemical Research (RIKEN), Wako 351-0198, Japan
4) Department of Physics, Saitama University, Saitama 338-8570, Japan
5) University of P.J.Safarik, 041-54 Kosice, Slovakia
6) University of Chemical Technology and Metallurgy, Sofia, Bulgaria
7) Center for Nuclear Study, University of Tokyo, Tokyo 113-0033, Japan
8) Cyclotron and Radioisotope Center, Tohoku University, Sendai, Miyagi 980-8578, Japan
9) Research Center for Nuclear Physics, Osaka University, Ibaraki, Osaka 567-0047, Japan

Abstract

In this work we present the experimental results on the tensor A_{yy} and vector A_y analyzing powers at $T_d = 270\ MeV$ for the $^{12}C(\vec{d},p)^{13}C^*$ reaction in the angular range from 4^o to 18^o in lab.

The data on the tensor analyzing power T_{20} for the $d(\vec{d},p)X$ and $^{12}C(\vec{d},p)^{13}C^*$ reaction at energy *140, 200* and *270 MeV* and at emission angle $\Theta_{cm} = 0^\circ$ are also obtained.

The experiment was performed at RIKEN Accelerator Research Facility (RARF), Japan.

Introduction

- The interest in the experimental and theoretical study of few nucleon transfer reactions has been renewed in the past years mainly due to the possibility to obtain information of astrophysical relevance from these reactions. Alternative indirect methods, such as the asymptotic normalization coefficient (ANC) method, based on the analysis of breakup or transfer reactions, have been used as a tool to obtain astrophysical *S*-factors.

- Single-nucleon transfer reactions that probe the degrees of freedom of single particles have been extensively used to study the structure of stable nuclei. The analysis of such reactions provides the angular momentum transfer, which gives information on the spin (j) and parity (π) of the final state.

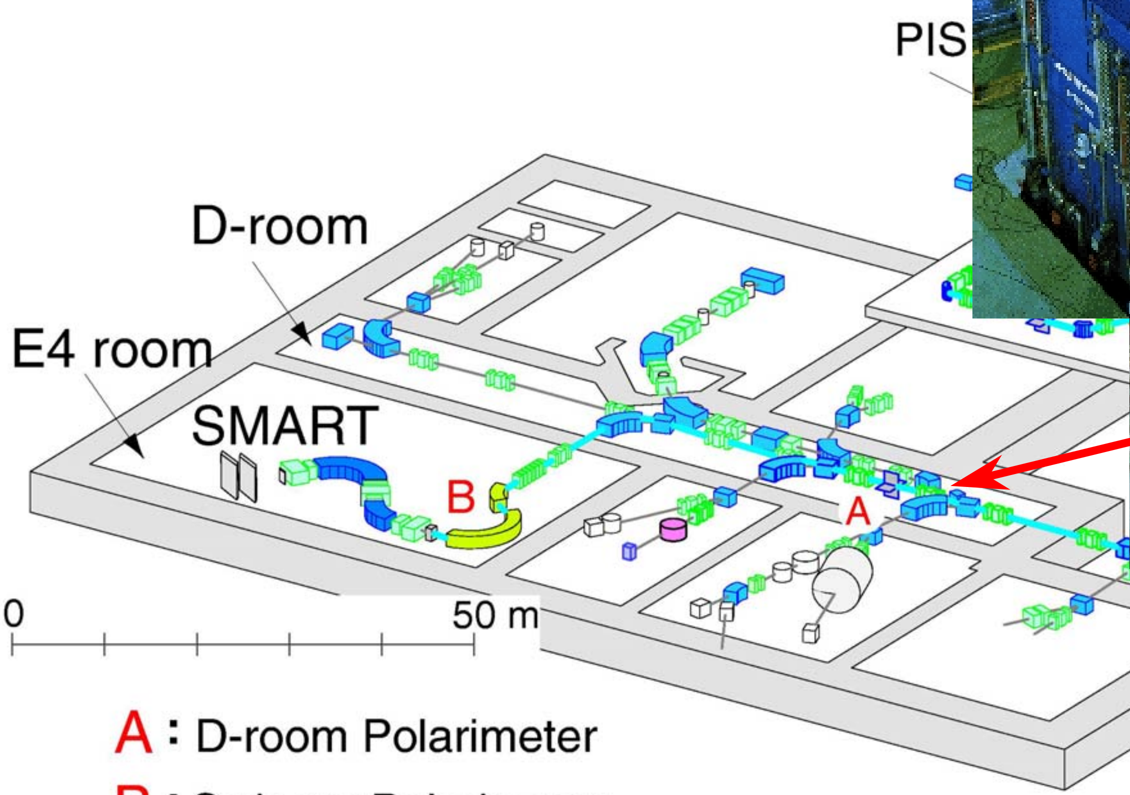
- Thanks to recent developments in radioactive beam production and in the detection of light charged particles, transfer reactions can now be used to investigate the single-particle structure of exotic nuclei.

- The ($\vec{d}, p$) stripping reaction has long been use as a means of probing the single particle structure of nuclei. In particular, through distorted wave Born approximation (DWBA) analyses it has been used to determine the orbital angular momentum and spectroscopic factors of specific states in the recoil nucleus.

- The $d(\vec{d}, p)^3H$ and $d(\vec{d}, p)X$ processes concern to ONE (One Nucleon Exchange) reactions. These reactions are the simplest processes with a large momentum transfer, so they could be used as a tool to study the deuteron structure at short distances. The polarization observables of these reactions are sensitive to the *D/S* wave ratio in the deuteron.

Experim

RIKEN Accelerator Research



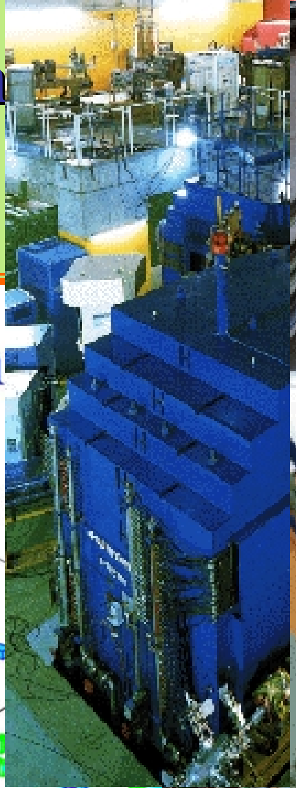
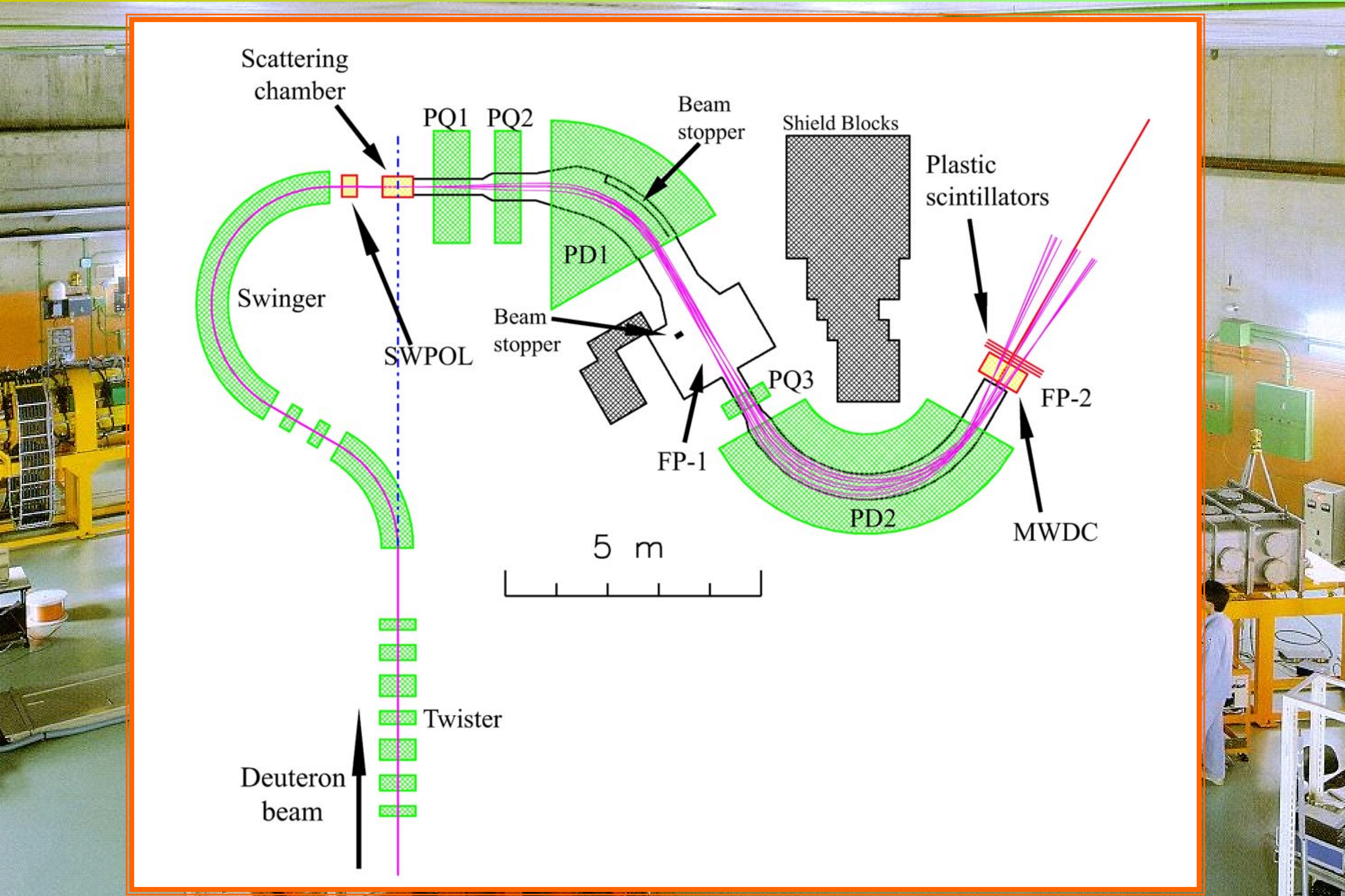


Figure 2.1: RIKEN Accelerator Reserch Facility (RARF)

Magnetic Spectrometer SMART



Vector (p_z) and tensor polarization (p_{zz}) of deuteron beam

The direction of symmetric axis of the beam polarization was controlled with a Wien filter located at the exit of polarized ion source (PIS).

The deuteron vector (p_z) and tensor (p_{zz}) beam polarizations with respect to their cylindrically symmetric axis Z are defined by

$$p_z = N_+ - N_-$$

$$p_{zz} = N_+ + N_- - 2N_0$$

where N_+, N_- and N_0 denotes the fractions of deuteron beam in magnetic substates $+1$, -1 and 0, respectively. In this experiment, four spin modes were used, whose ideal magnitudes of polarizations are

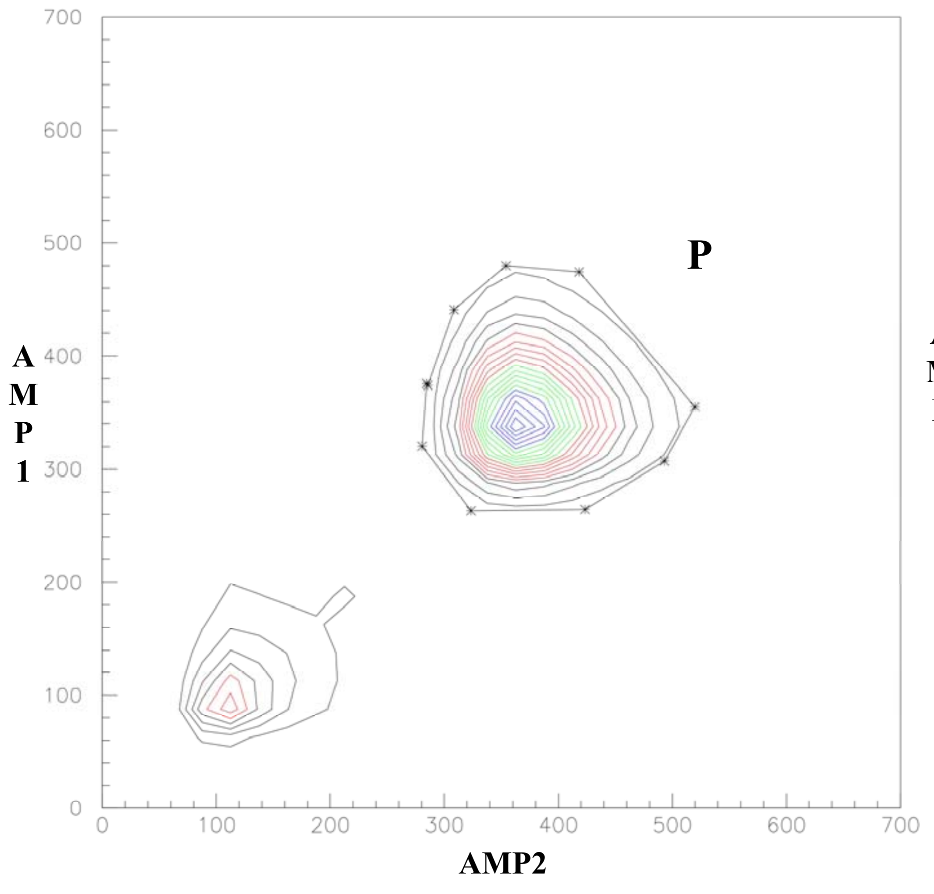
Mode 0 $(p_z, p_{zz}) = (0,0)$
Mode 1 $(p_z, p_{zz}) = (0,-2)$
Mode 2 $(p_z, p_{zz}) = (-2/3,0)$
Mode 3 $(p_z, p_{zz}) = (1/3,1)$

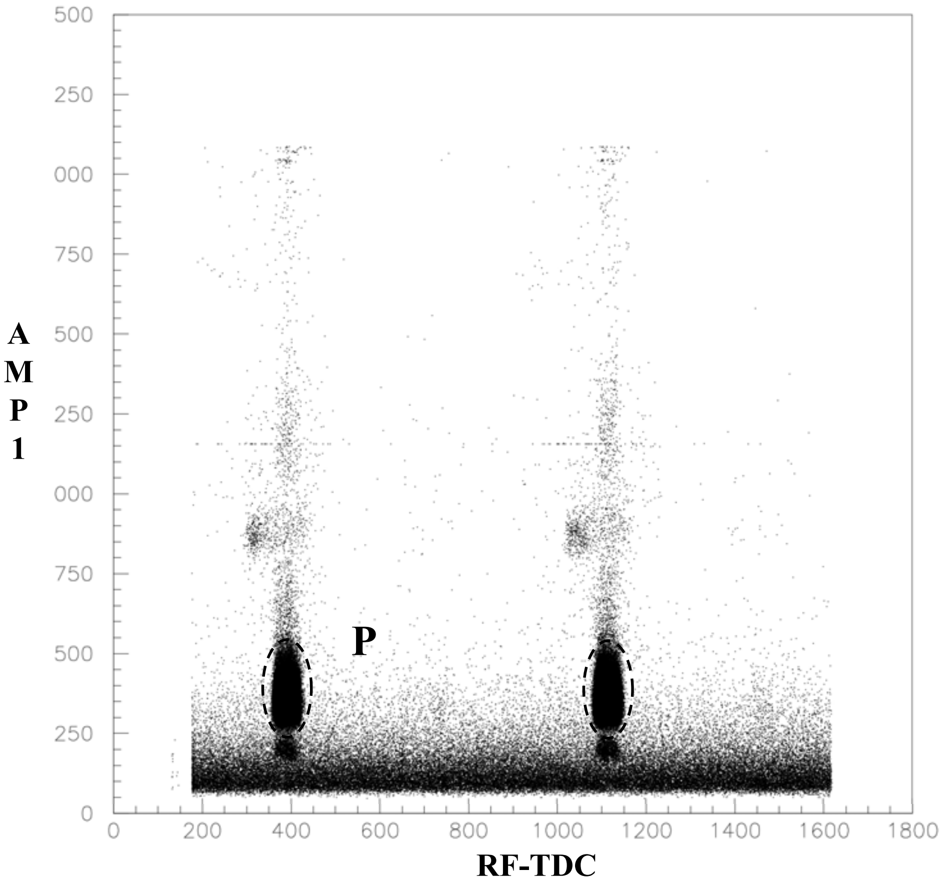
The *mode 0* **- unpolarized mode,** *mode 1* **- pure tensor mode,** *mode 2* **- pure vector mode and** *mode 3* **is mixed mode.**

Results of measurements of polarization for three modes

	$p_y \pm \Delta$	$p_{yy} \pm \Delta$
Mode 1	0.01852 ± 0.00723	-1.25646 ± 0.02271
Mode 2	0.55883 ± 0.1868	0.09322 ± 0.01185
Mode 3	-0.24581 ± 0.01429	0.76632 ± 0.01608

Detection and analysis

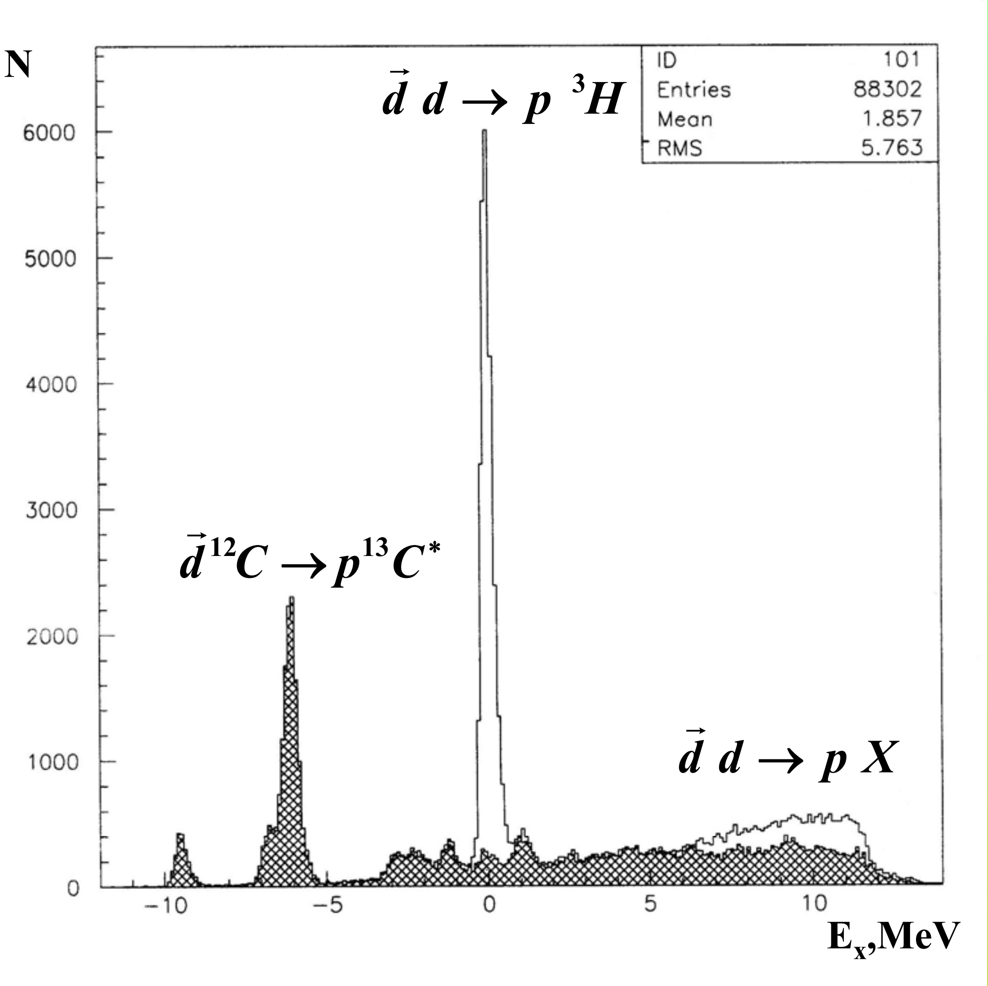




Correlation of the energy losses in the 1st and the 2nd scintillation detectors and radio frequency signal of the cyclotron

$$E_x = \sqrt{(E_0 - E_{3N})^2 - (P_0 - P_{3N})^2} - M_N$$

where
P_0 - the incident momentum,
$E_0 = 2M_d + T_d$ the total initial energy,
E_{3N} - energy of the three-nucleon system,
P_{3N} - momentum of the three-nucleon system,
M_N - the nucleon mass.



$CD_2 - C$ subtraction for the at 270 MeV. The open histogram corresponds to the yield from CD_2 target, the shadowed histogram – from carbon target, respectively.

The reactions with excitation of levels of a nucleus ^{13}C

$$\vec{d} + {}^{12}C \to p + X$$

$$p_3 = p_f \cdot ff \cdot p_0$$

$$p_0 = \sqrt{T\left(T + 2M_d\right)}$$

where

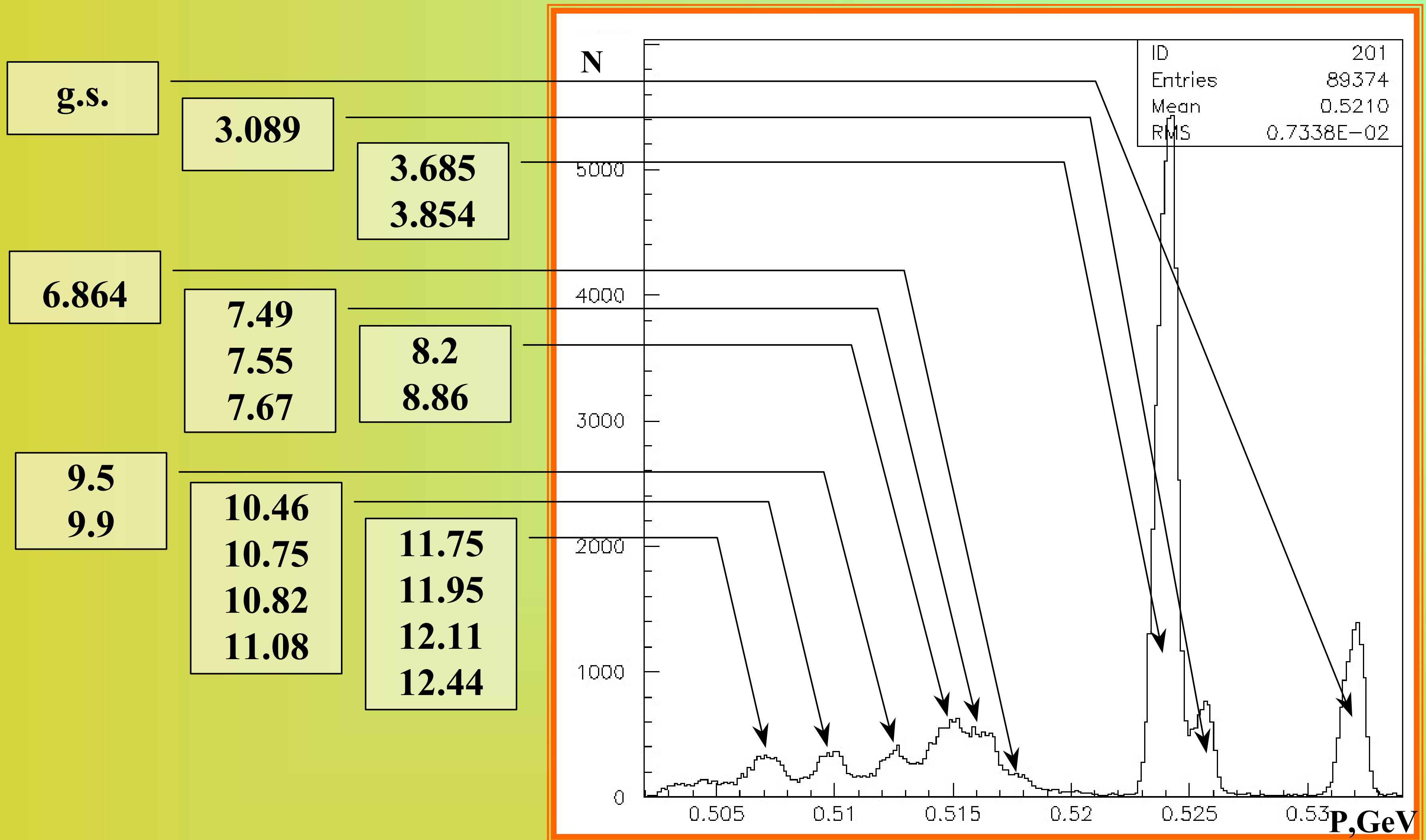
p_f – **the final momentum,**

ff – **field factor,**

T – **the kinetic energy of incident particle,**

M_d - **the nucleon mass.**

Momentum spectrum for $^{12}C(\vec{d},p)^{13}C^{*}$ *reaction at* $\Theta_{cm}=0^{\circ}$ *(140 MeV)*



Peaks corresponding to the ^{13}C **states are labeled by their excitation energies in** ***MeV***

Derivation of Analyzing Powers

The cross section asymmetries:

$$S^M = \frac{Y^M}{I^M e^M}$$

Y^M – yield of the true events

I^M – integrated beam charge/deuteron charge

e^M – (MWDC detection eciency)*(live-time ratio of the data aquisition)

To obtain the values of the analyzing powers it is necessary to determine the normalized cross section for the spin mode M (M=1,2,3). It is expressed as

$$N^M_{\exp} = \frac{S^M}{S^{M=0}} = \frac{Q^0 e^0 Y^M}{Q^M e^M Y^0}$$

Equations for analyzing powers

A_y A_{yy} **mode:**

$$\begin{cases} N^1_{\exp}(\Theta_{cm}) = 1 + \frac{1}{2} p^1_{yy} A_{yy}(\Theta_{cm}) \\ N^2_{\exp}(\Theta_{cm}) = 1 + \frac{3}{2} p^2_{y} A_{y}(\Theta_{cm}) \\ N^3_{\exp}(\Theta_{cm}) = 1 + \frac{3}{2} p^3_{y} A_{y}(\Theta_{cm}) + \frac{1}{2} p^3_{yy} A_{yy}(\Theta_{cm}) \end{cases}$$

A_{xx} **mode:**

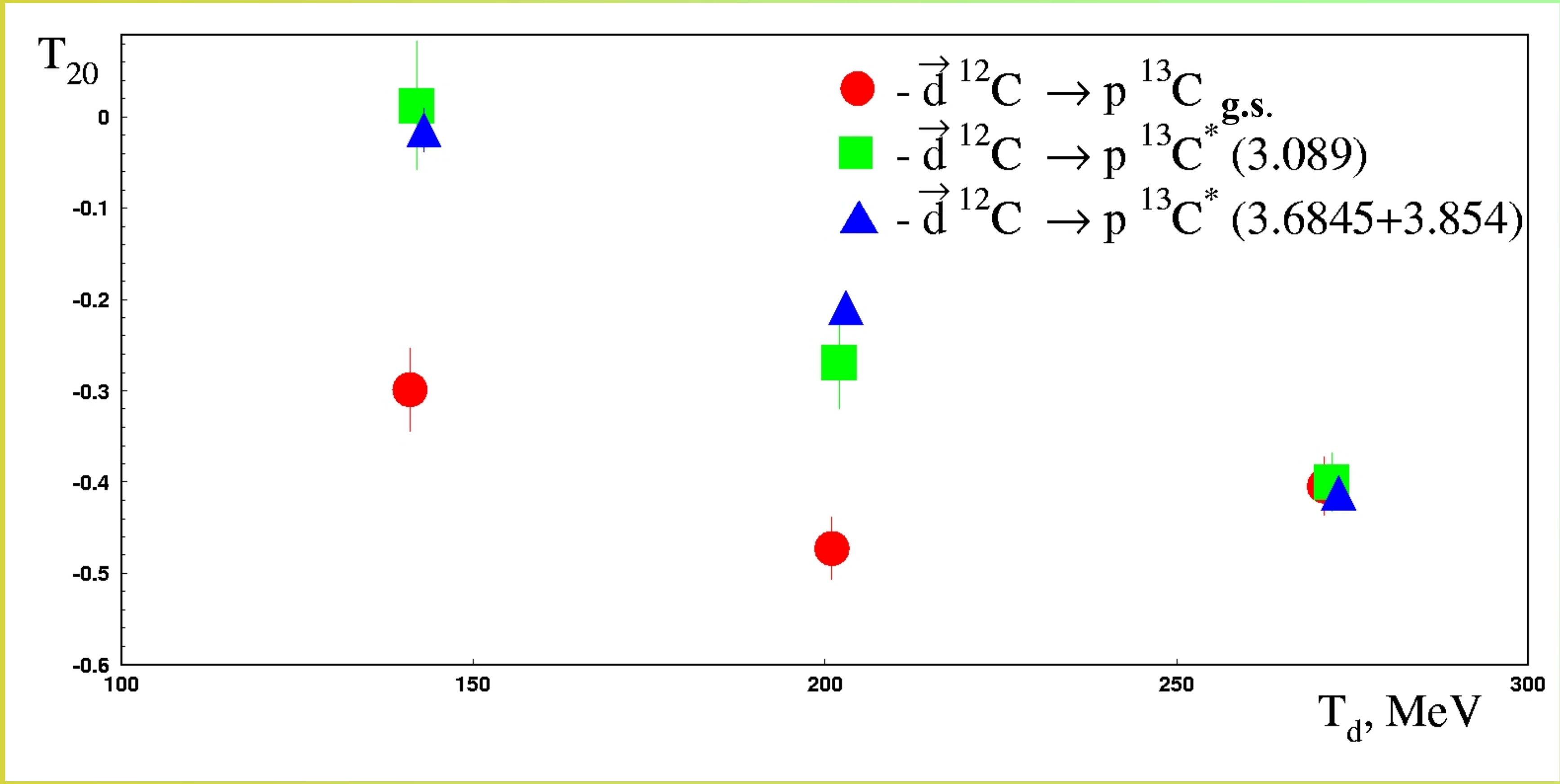
$$\begin{cases} N^1_{\exp}(\Theta_{cm}) = 1 + \frac{1}{2} p^1_{xx} A_{xx}(\Theta_{cm}) \\ N^3_{\exp}(\Theta_{cm}) = 1 + \frac{1}{2} p^3_{xx} A_{xx}(\Theta_{cm}) \end{cases}$$

at emission angle $\Theta_{cm} = 0^\circ$**:**

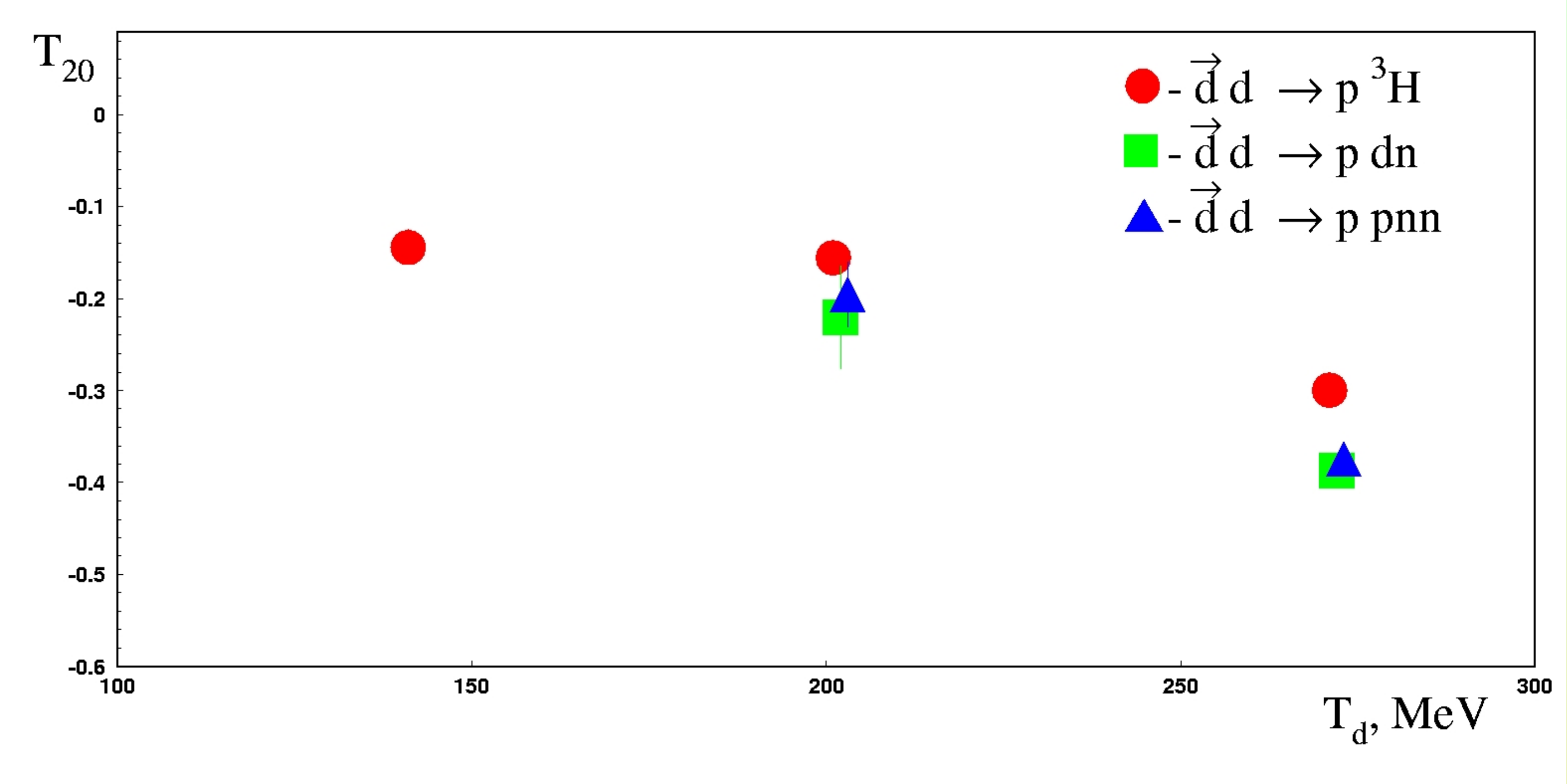
$$T_{20} = -\sqrt{2} \cdot \left(A_{xx} + A_{yy}\right)$$ **(for *200* и *270 MeV*)**

$$T_{20} = -\sqrt{2} \cdot A_{xx}$$ **(for *140 MeV*)**

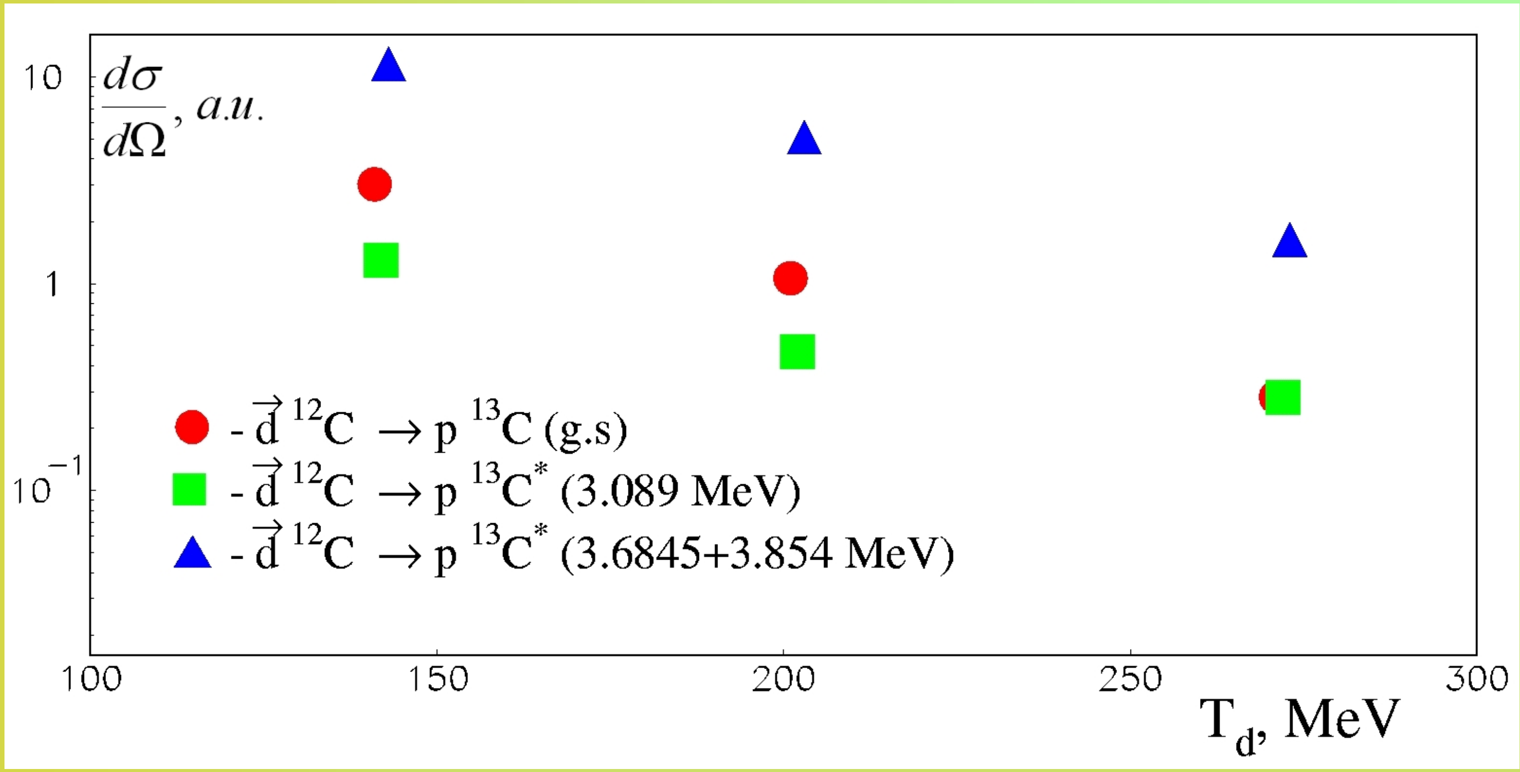
Results



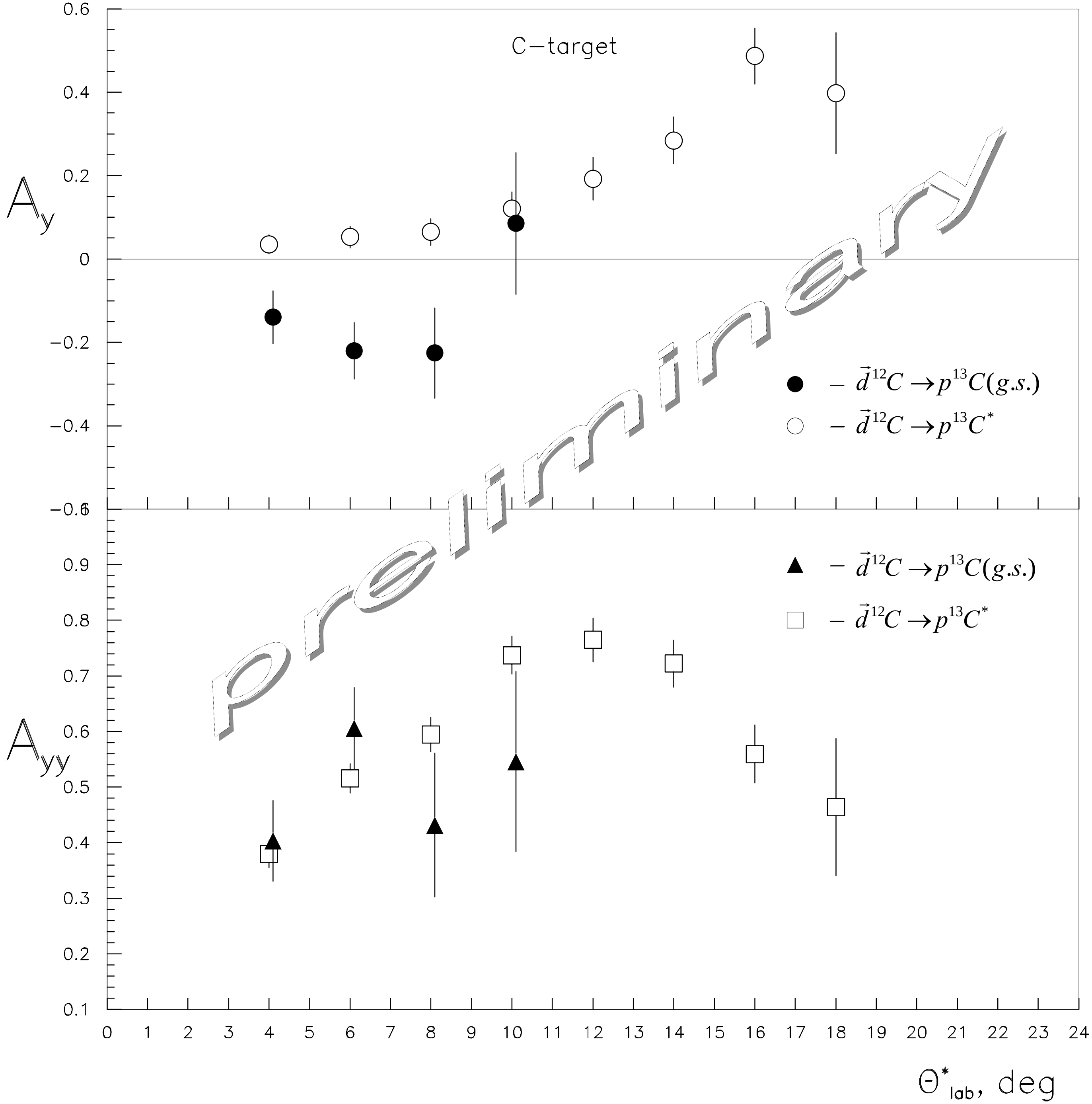
The experimental results of T_{20} analyzing powers for ${}^{12}C(\vec{d},p){}^{13}C^*$ reaction at energy T_d = 140, 200 and 270 *MeV* at emission angle $\Theta_{cm} = 0^\circ$.



The experimental results of T_{20} analyzing powers for $d(\vec{d},p)X$ reactions at energy T_d = 140, 200 and 270 *MeV* at emission angle $\Theta_{cm} = 0^\circ$.



The experimental results of cross section for $^{12}C(\vec{d},p)^{13}C^{*}$ reaction at energy T_d = 140, 200 and 270 *MeV* at emission angle $\Theta_{cm} = 0^{\circ}$.



The experimental results on the tensor A_{yy} and vector A_y analyzing

powers for the

$$^{12}C(\vec{d},p)^{13}C^*$$

reaction at energy $T_d = 270\ MeV$

in the angular range from 4° to 18° in lab.

Summary

- The experimental results on the tensor A_{yy} and vector A_y analyzing powers at T_d = *270 MeV* for the $^{12}C(\vec{d},p)^{13}C^*$ reaction in the angular range from 4° to 18° in lab. are obtained.

- The data on the tensor analyzing power T_{20} for the $^{12}C(\vec{d},p)^{13}C^*$ and $d(\vec{d},p)X$ reactions at energy *140, 200* and *270 MeV* and at emission angle $\Theta_{cm} = 0^\circ$ are obtained also.

- The experimental data on T_{20} for these reactions shows sensitivity to the spin structure of deuteron.

- The negative sign of analyzing power T_{20} for $^{12}C(\vec{d},p)^{13}C^*$ and $d(\vec{d},p)X$ reactions and positive sing of A_{yy} for $^{12}C(\vec{d},p)^{13}C^*$ reflect D/S ratio a components of wave function of deuteron.

- The tensor analyzing power T_{20} has negative value as for binary reaction as breakup reaction of deuteron. The reactions with excitation of levels of a nucleus ^{13}C have negative value also.

Thank You

for the attention!