24th European Conference on Few-Body Problems in Physics

Measurement of spin correlation coefficients in p–^{3}He scattering at 65 MeV

Minami Inoue

Department of Physics, Tohoku University, Japan

TOHOKU UNIVERSITY

東北大学

TOHOKU UNIVERSITY

Collaborators

- **Tohoku univ., Japan**
  M.Inoue , K.Sekiguchi , K.Miki , A.Watanabe , S.Nakai ,
  S.Shibuya , D.Sakai , Y.Utsuki
- **RCNP Osaka univ., Japan**
  K.Hatanaka, H.Kanda, H.J.Ong
- **Kyusyu univ., Japan**
  T.Wakasa, S.Goto, S.Mitsumoto, D.Inomoto, H.Kasahara
- **KEK, Japan**
  T.Ino
- **RIKEN, Japan**
  H.Sakai
- **Miyazaki univ., Japan**
  Y.Maeda, K.Nonaka
- **NIRS, Japan**
  T.Wakui
- **CYRIC Tohoku univ., Japan**
  M.Itoh

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Introduction

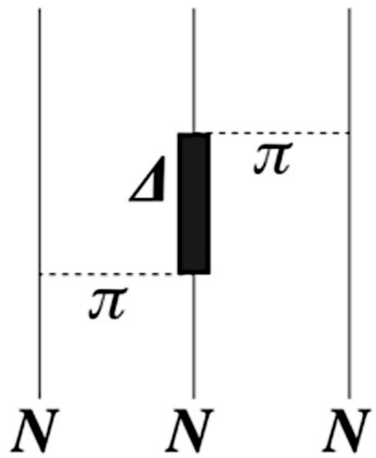
Nucleon-Nucleon force

In 1935, the first theoretical insight was given as meson exchange theory by Yukawa.
In 1990's, the Nucleon-Nucleon potentials have achieved to realistic ones.
(e.g. CD Bonn, AV18, Nijmegen)

- But in $A \geq 3$ system, some aspects are not explained by the NN potential only.
  (e.g. few nucleon system, nucleon binding energies, equation of state of nucleon matter)

Three-nucleon force

The force acting between three-nucleons is considered to be essential for fully understanding nucleon phenomena.
(e.g. Fujita-Miyazawa, Urbana IX, Tucson-Melbourne)



Introduction

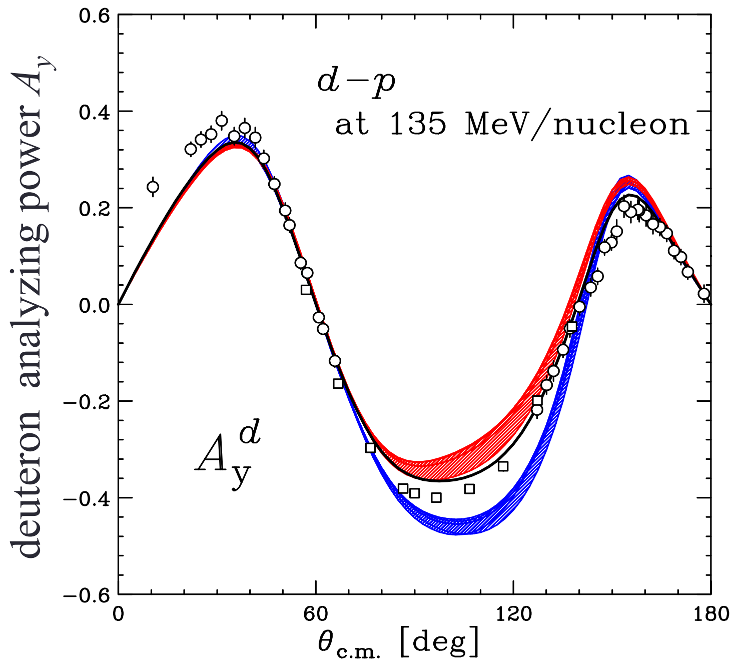
Few nucleon scattering
It is a good probe to study the dynamical aspects of nuclear forces.

- momentum dependence
- spin dependence
- isospin dependence

Nucleon-deuteron scattering …

□,○ exp. data
— NN(AV18)+3NF(UrbanaIX)
— NN(CD Bonn,AV18,Nijmegen I,II)+3NF(TM' 99)
— NN(CD Bonn,AV18,Nijmegen I,II)

K. Sekiguchi et al., PRC 65 034003 (2002).

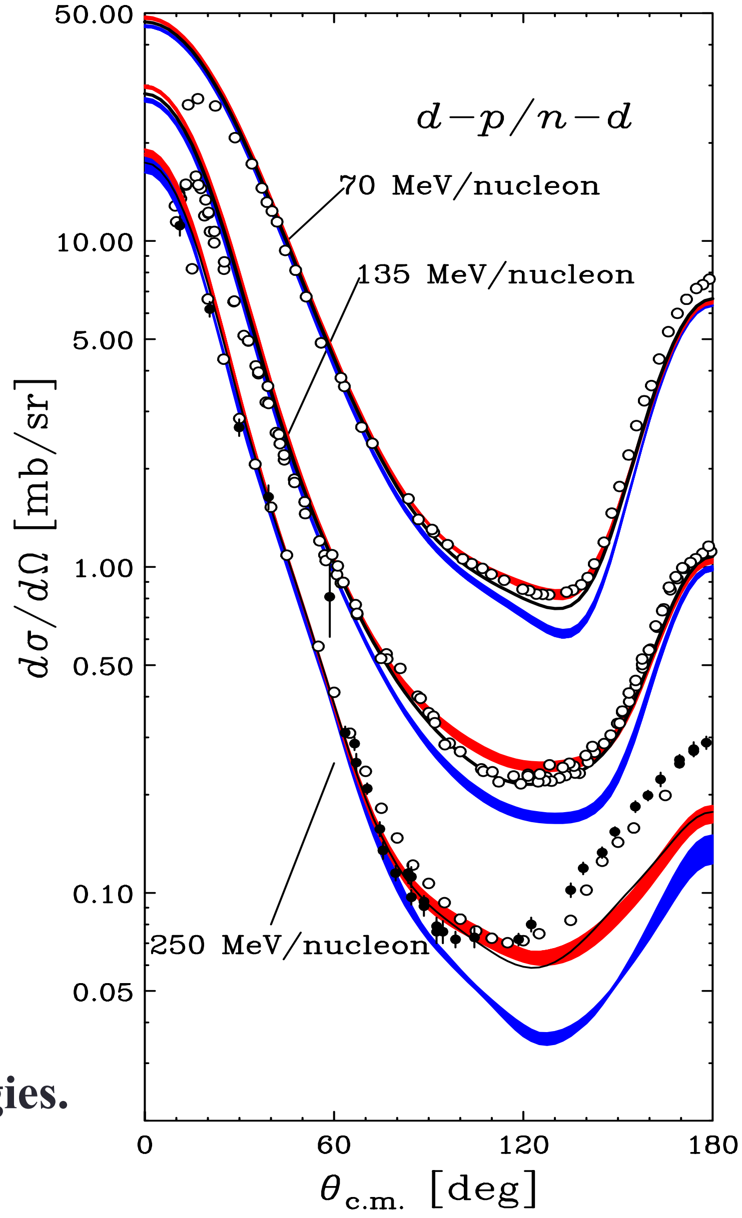


3NFs are necessary to explain the data for *N-d* elastic scattering.

Introduction

Energy dependence of *N-d* elastic scattering

3NFs effects are clearly seen in the cross section minimum at intermediate energies (E > 60 MeV).



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K. Sekiguchi et al., PRC 65 034003 (2002).

It is interesting to study 3NFs at intermediate energies.

In *d-p* scattering system, the total isospin is limited to $T = 1/2$.

Introduction

We have a strong interest in the isospin dependence of 3NFs.
(e.g. neutron-rich nuclei and neutron matter)

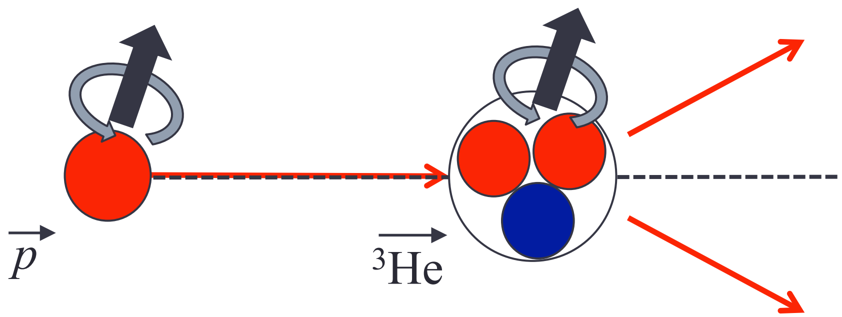
p-^{3}He scattering system

- Approaching the effects of 3NFs in 4N scattering system
- The simplest system to approach the $T = 3/2$ channel

We performed p-^{3}He scattering at intermediate energies and measured spin observables.

This work

- By using the 65 MeV polarized proton beam and the polarized ^3He target, the experiment of p-^3He elastic scattering was performed.
- The measured angles were $\theta_{Lab.} = 35°, 70°, 115°$. ($\theta_{C.M.} = 47°, 89°, 133°$)
- The observables were A_y, A_y^T, C_{yy}.



Spin correlation coefficient C_{yy} is obtained by bombarding the polarized proton beam on the polarized ^3He target and measuring the asymmetry of the scattered particles.

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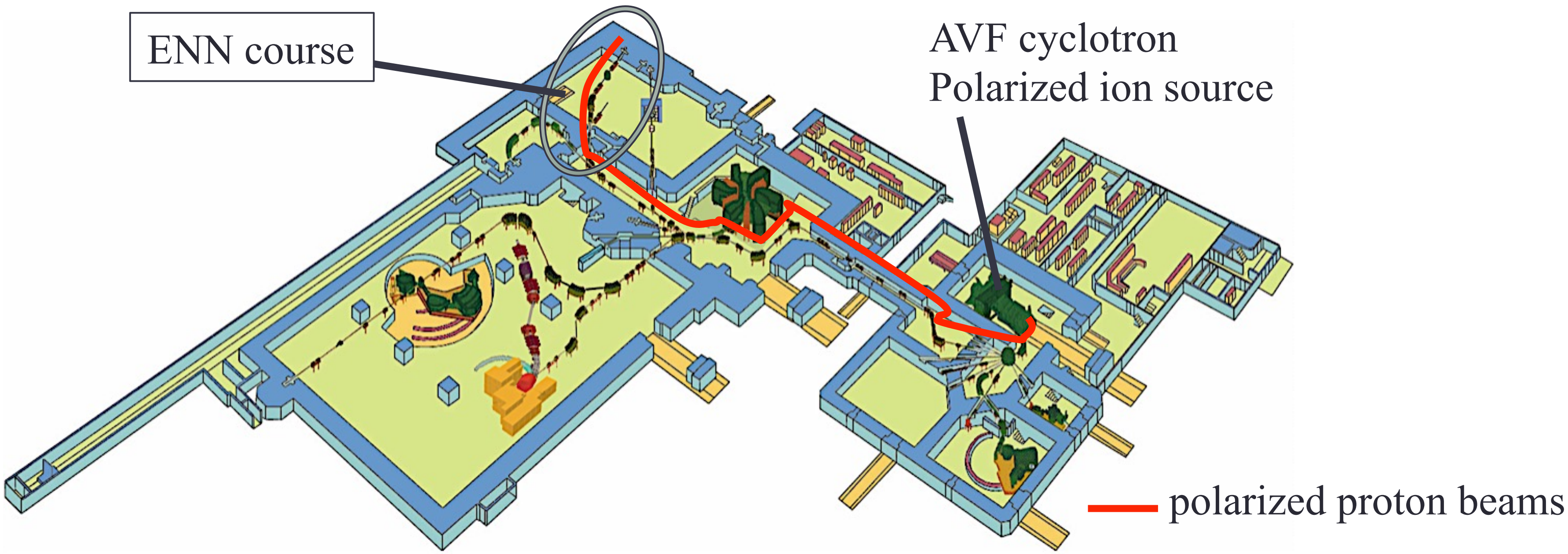
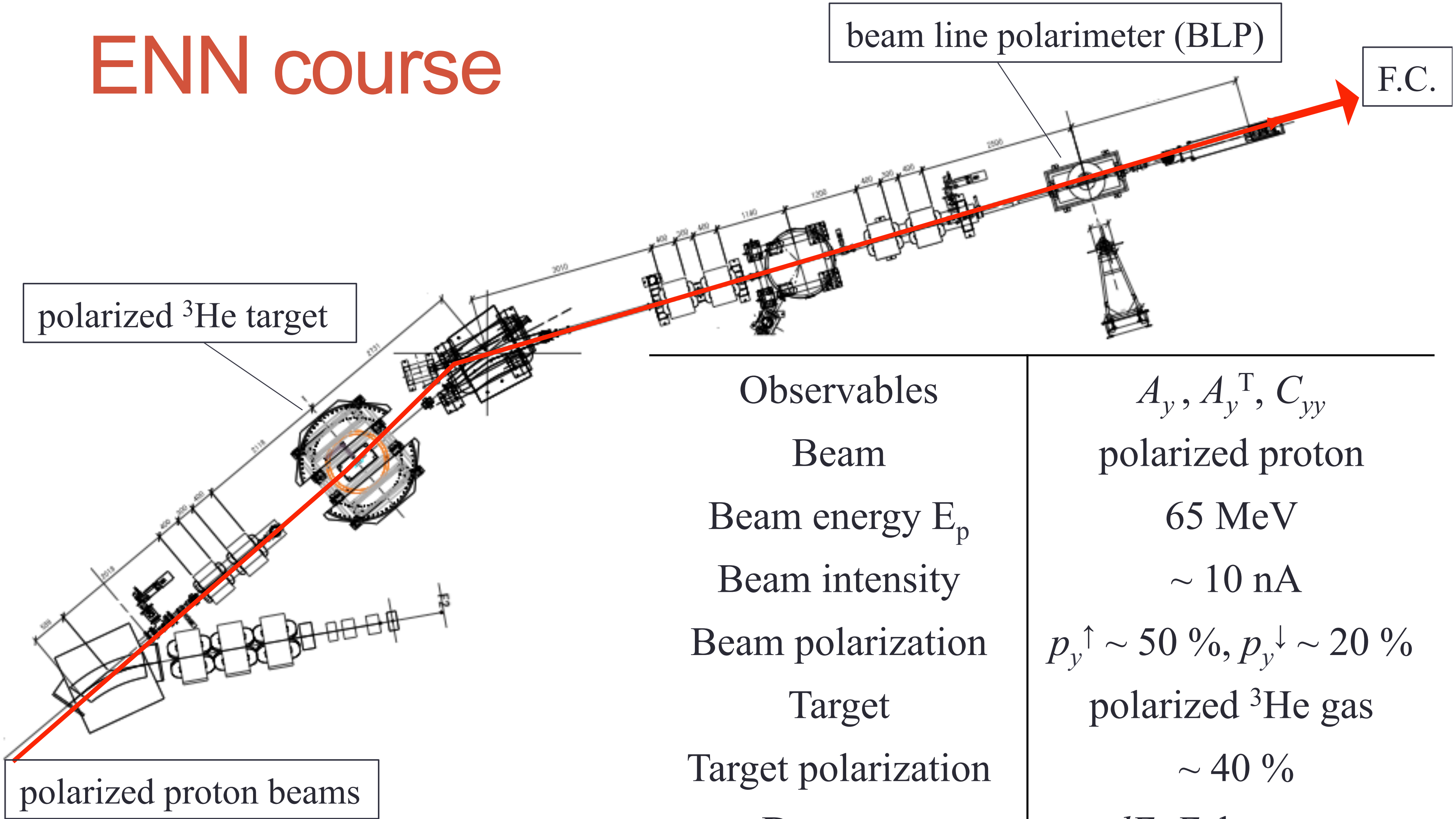
p–^{3}He scattering at 65 MeV

RCNP (Research Center for Nuclear Physics), Osaka University, Japan

- Polarized proton beams were provided by the polarized ion source.
- The beam was accelerated by the AVF cyclotron up to 65 MeV.
- The beam bombarded the polarized ^{3}He target.
- Scattered protons were detected by the *dE–E* scintillators.
- The beam polarization was measured by using *p-d* elastic scattering.

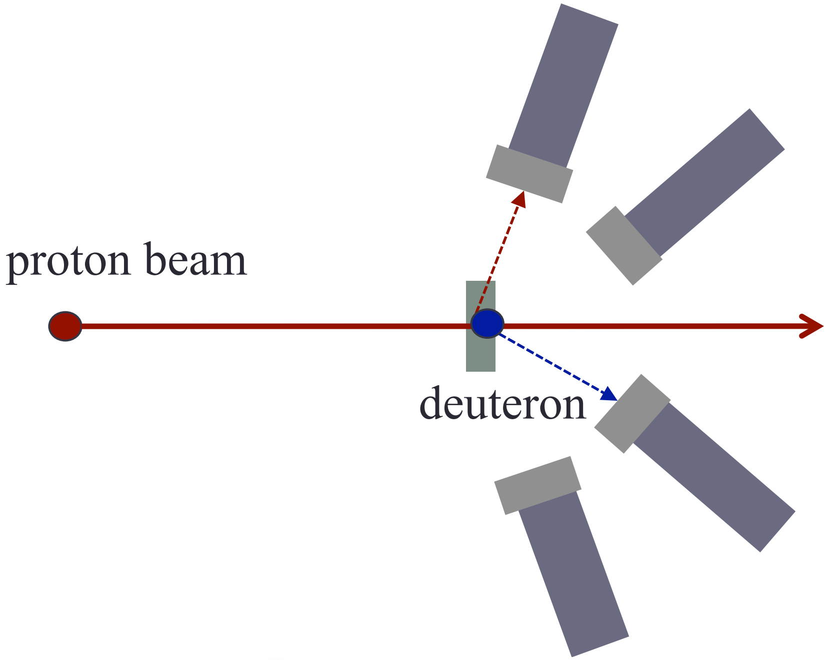


ENN course



Observables	A_y, A_y^{T}, C_{yy}
Beam	polarized proton
Beam energy E_p	65 MeV
Beam intensity	~ 10 nA
Beam polarization	$p_y^{\uparrow}$ ~ 50 %, $p_y^{\downarrow}$ ~ 20 %
Target	polarized ^{3}He gas
Target polarization	~ 40 %
Detectors	*dE–E* detectors
Measured angles	$\theta_{\mathrm{Lab.}}$ = 35°, 70°,115° ($\theta_{\mathrm{C.M.}}$ = 47°, 89°, 133°)

Beam Line Polarimeter



- The beam polarization was measured by using the reaction of *p-d* elastic scattering.
- Scattered protons and recoiled deuterons were detected in a kinematical coincidence condition.

$A_y = -0.539,\ dA_y = 0.025$
H.Shimizu et al., Nuclear Physics A382 (1982) 242-254.

Target	Thin film of CD_2(14.8 mg/cm^2)
Detector	plastic (20 mm^t×35 mm^H×20 mm^w) ＋ PMT(H7415)
Measured angles	θ_p= 70°, θ_d= 40°

$$Y_L^u = \frac{d\sigma}{d\Omega} n I^u (1 + A_y p_N^u) \Delta\Omega_L$$
$$Y_L^d = \frac{d\sigma}{d\Omega} n I^d (1 + A_y p_N^d) \Delta\Omega_L$$
$$Y_R^u = \frac{d\sigma}{d\Omega} n I^u (1 - A_y p_N^u) \Delta\Omega_R$$
$$Y_R^d = \frac{d\sigma}{d\Omega} n I^d (1 - A_y p_N^d) \Delta\Omega_R$$

n : the number of targets
I : the beam current

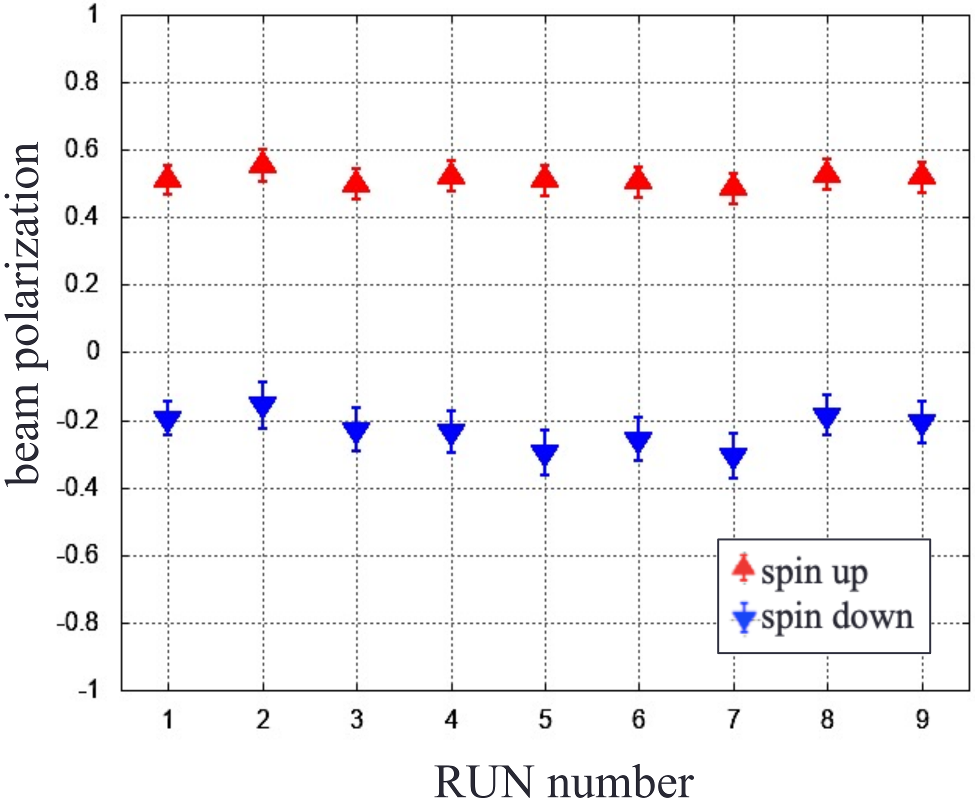
The beam polarization

Detector's solid angle is
time independently constant.

$$\frac{\Delta\Omega_L}{\Delta\Omega_R} = \frac{I^d Y_L^u - I^u Y_L^d}{I^u Y_R^d - I^d Y_R^u} = \text{const.}$$

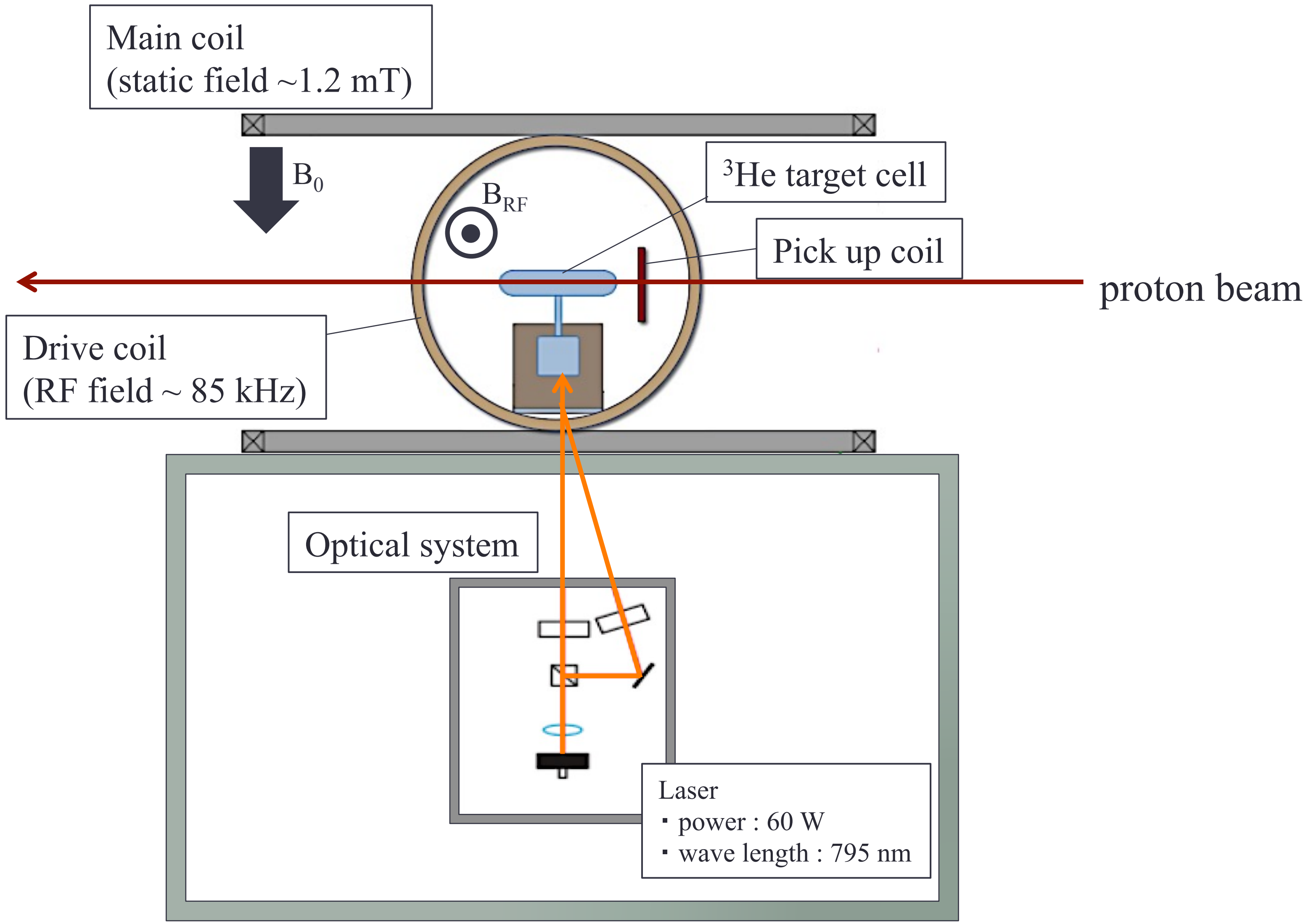
Using this constant, we extract
spin observables without using
the information of beam intensity.

$$p_N^u = \frac{1}{A_y} \frac{Y_L^u / Y_R^u - \Delta\Omega_L/\Delta\Omega_R}{Y_L^u / Y_R^u + \Delta\Omega_L/\Delta\Omega_R},$$
$$p_N^d = \frac{1}{A_y} \frac{Y_L^d / Y_R^d - \Delta\Omega_L/\Delta\Omega_R}{Y_L^d / Y_R^d + \Delta\Omega_L/\Delta\Omega_R}.$$

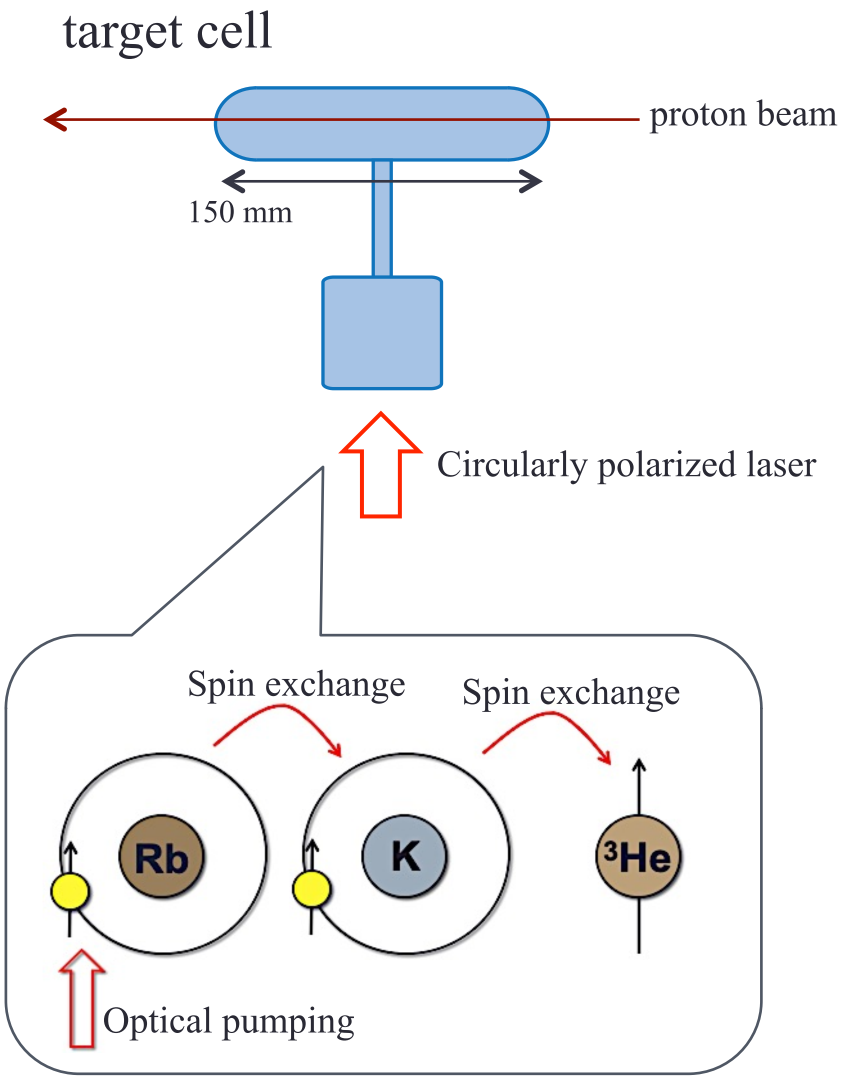


- Typical polarizations are $p_y^{\uparrow} \sim 50\%$, $p_y^{\downarrow} \sim 20\%$.
- Statistical uncertainties of each run are ~ 0.07 at most.

Polarized ^{3}He target



Polarized ^{3}He target

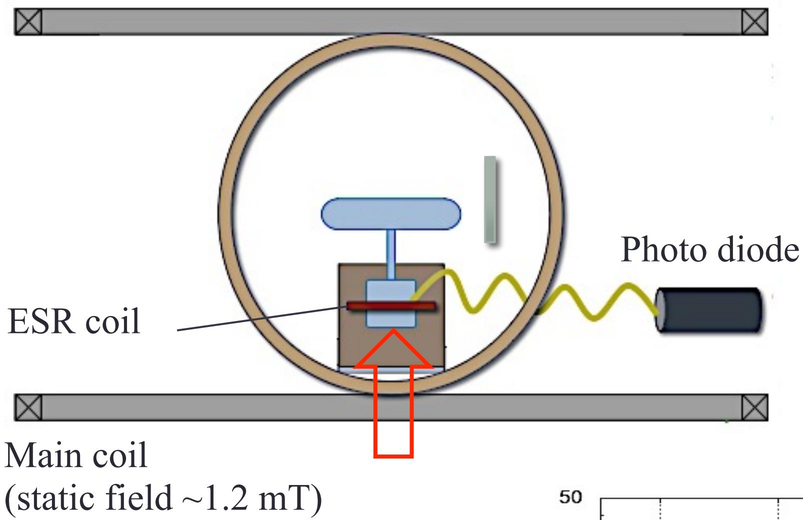


glass thickness	sides 1 mm^t, windows 0.5 mm^t
material	GE180 glass
contents	^{3}He (3atm, ~2 mg/cm^2), N_2 (~0.1 atm), A small amount of Rb, K

AH-SEOP method : to polarize ^{3}He

i. Circularly polarized laser polarizes Rb atoms by optical pumping under the static magnetic field.
ii. K atoms are polarized by spin exchange collision with Rb atoms.
iii. ^{3}He nucleus are polarized by hyper-fine interactions with K atoms.

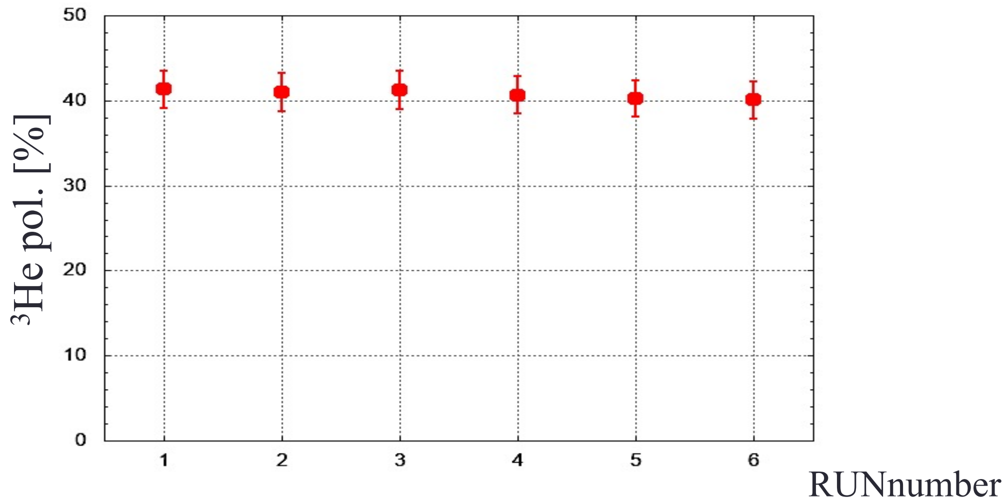
Polarized ^{3}He target



AFP-NMR method : to measure ^{3}He polarization

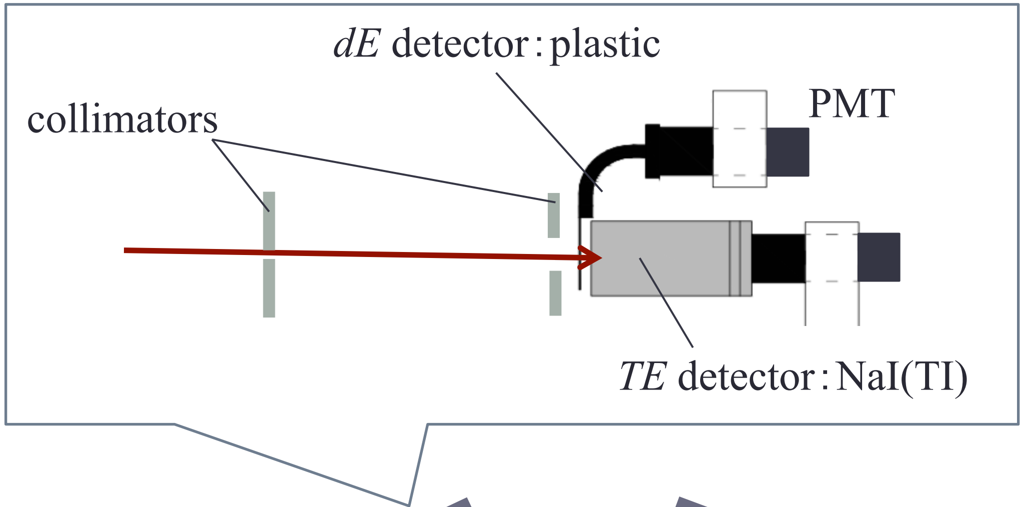
Rb-EPR method : to calibrate ^{3}He polarization

For more details, see talk by A.Watanabe



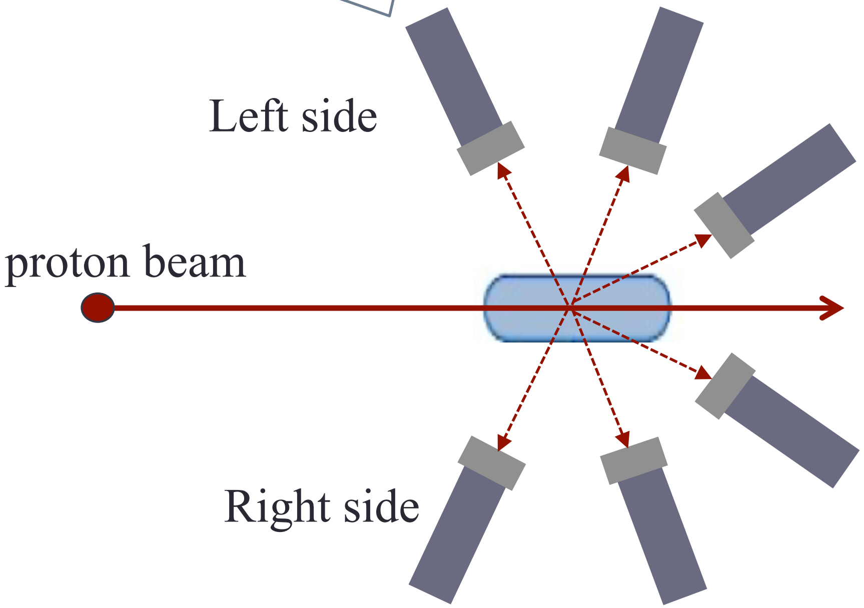
- Typical polarization is $p_y^{^3\mathrm{He}} \sim 40$ %.

Detector system for p-^{3}He scattering



Specification of detector

θ_{Lab} [deg.]	dE [mm^t]	TE [mm^t]	$\Delta\Omega$ [msr]
35	1.0	50	0.11
70	0.5	50	0.20
115	0.2	50	0.43



- Scattered protons were detected by dE−TE detectors which are consisted of NaI(Tl) and plastic scintillators.
- Double slit collimators were adopted.

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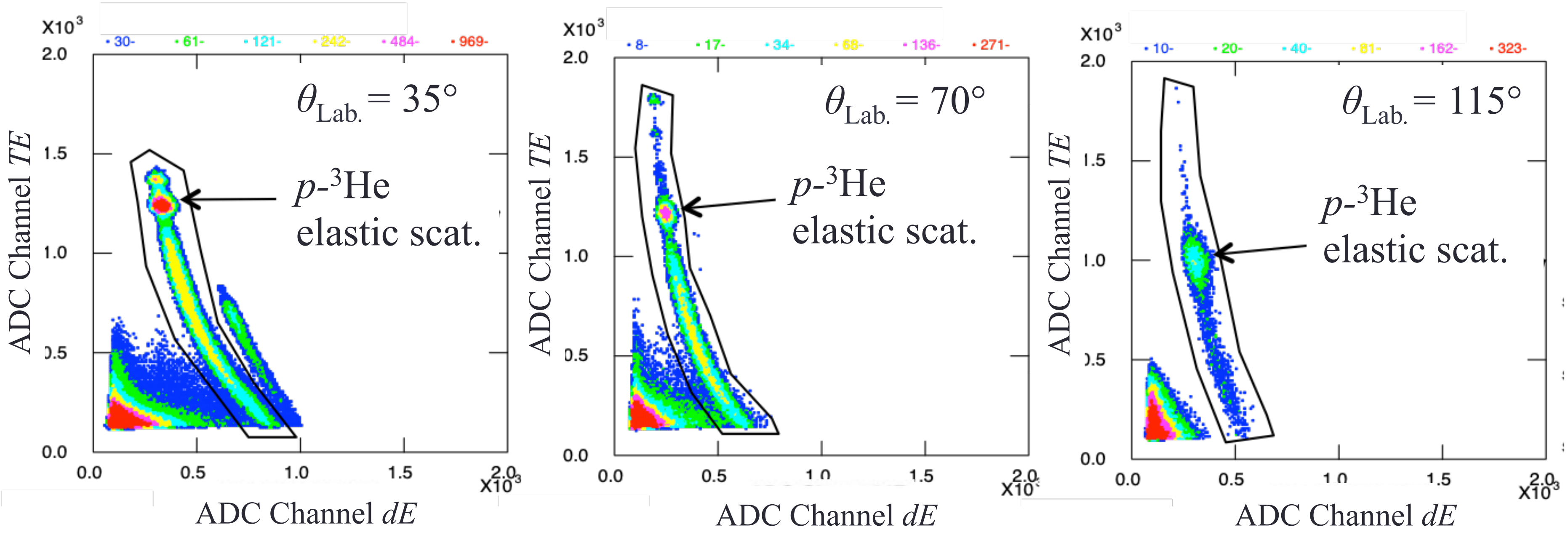
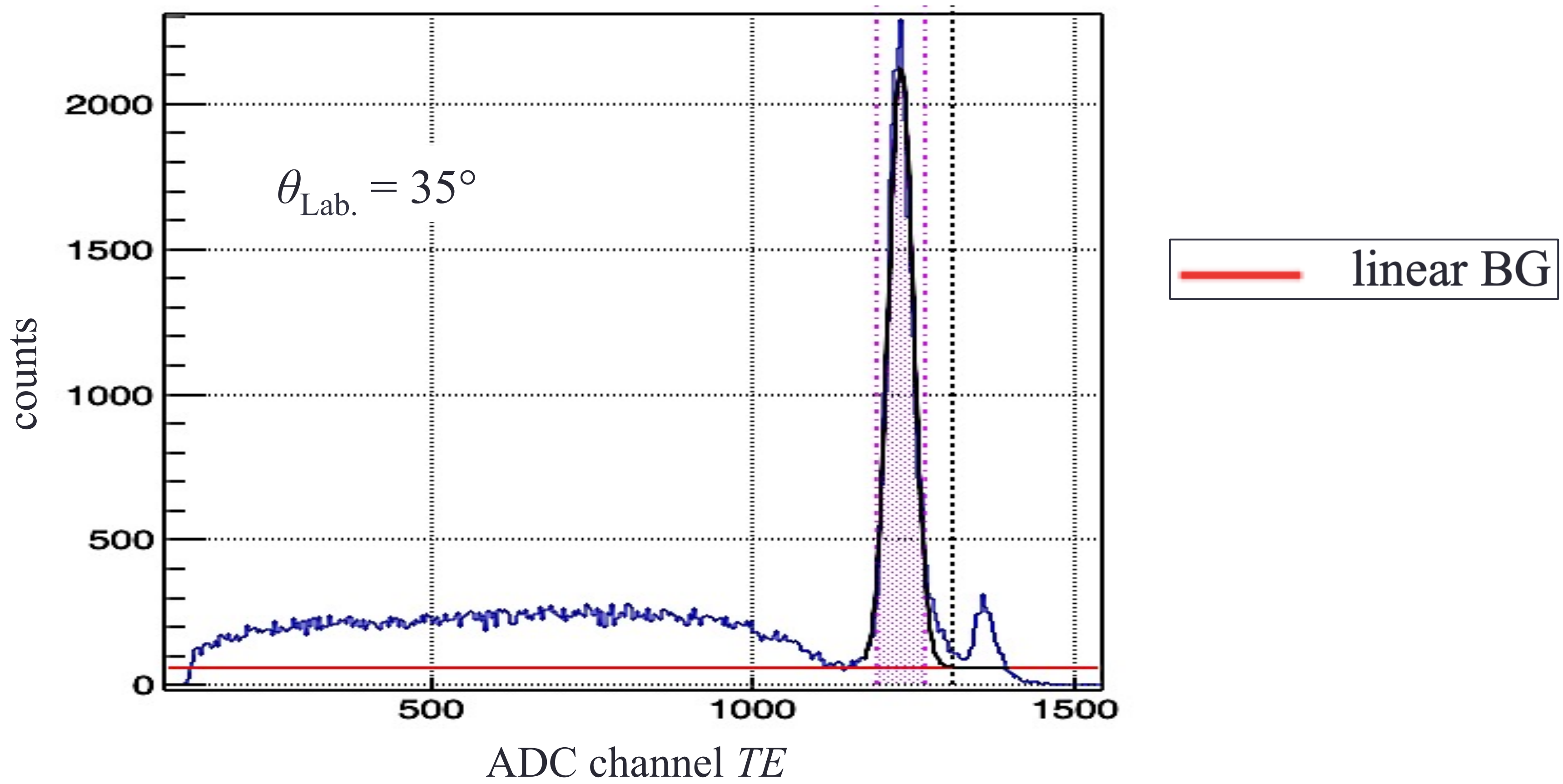
Energy spectra



Events for p-^{3}He elastic scattering are clearly seen.

Background Subtraction



- To estimate the ambiguity of background subtraction, the integrating range of a elastic scattering peak was changed from ±1σ to ±3σ.
- Values of spin observables were changed less than 0.02 .

Extraction of spin observables

Polarized cross sections for the left side are expressed as,

$$L_{\uparrow\uparrow} = L_0(1 + p_y^{\uparrow} A_y + p_y^T A_y^T + p_y^{\uparrow} p_y^T C_{yy})$$

$$L_{\uparrow\downarrow} = L_0(1 + p_y^{\uparrow} A_y - p_y^T A_y^T - p_y^{\uparrow} p_y^T C_{yy})$$

$$L_{\downarrow\uparrow} = L_0(1 - p_y^{\downarrow} A_y + p_y^T A_y^T - p_y^{\downarrow} p_y^T C_{yy})$$

$$L_{\downarrow\downarrow} = L_0(1 - p_y^{\downarrow} A_y - p_y^T A_y^T + p_y^{\downarrow} p_y^T C_{yy})$$

$L_{\uparrow\uparrow}$

beam pol. target pol.

$$A_y = \frac{L_{\uparrow\uparrow} + L_{\uparrow\downarrow} - (L_{\downarrow\uparrow} + L_{\downarrow\downarrow})}{p_y^{\downarrow}(L_{\uparrow\uparrow} + L_{\uparrow\downarrow}) + p_y^{\uparrow}(L_{\downarrow\uparrow} + L_{\downarrow\downarrow})}$$

$$A_y^T = \frac{1}{p_y^T} \frac{p_y^{\downarrow}(L_{\uparrow\uparrow} - L_{\uparrow\downarrow}) + p_y^{\uparrow}(L_{\downarrow\uparrow} - L_{\downarrow\downarrow})}{p_y^{\downarrow}(L_{\uparrow\uparrow} + L_{\uparrow\downarrow}) + p_y^{\uparrow}(L_{\downarrow\uparrow} + L_{\downarrow\downarrow})}$$

$$C_{yy} = \frac{1}{p_y^T} \frac{L_{\uparrow\uparrow} - L_{\uparrow\downarrow} + L_{\downarrow\uparrow} - L_{\downarrow\downarrow}}{p_y^{\downarrow}(L_{\uparrow\uparrow} + L_{\uparrow\downarrow}) + p_y^{\uparrow}(L_{\downarrow\uparrow} + L_{\downarrow\downarrow})}$$

The way of extraction for right side is same.

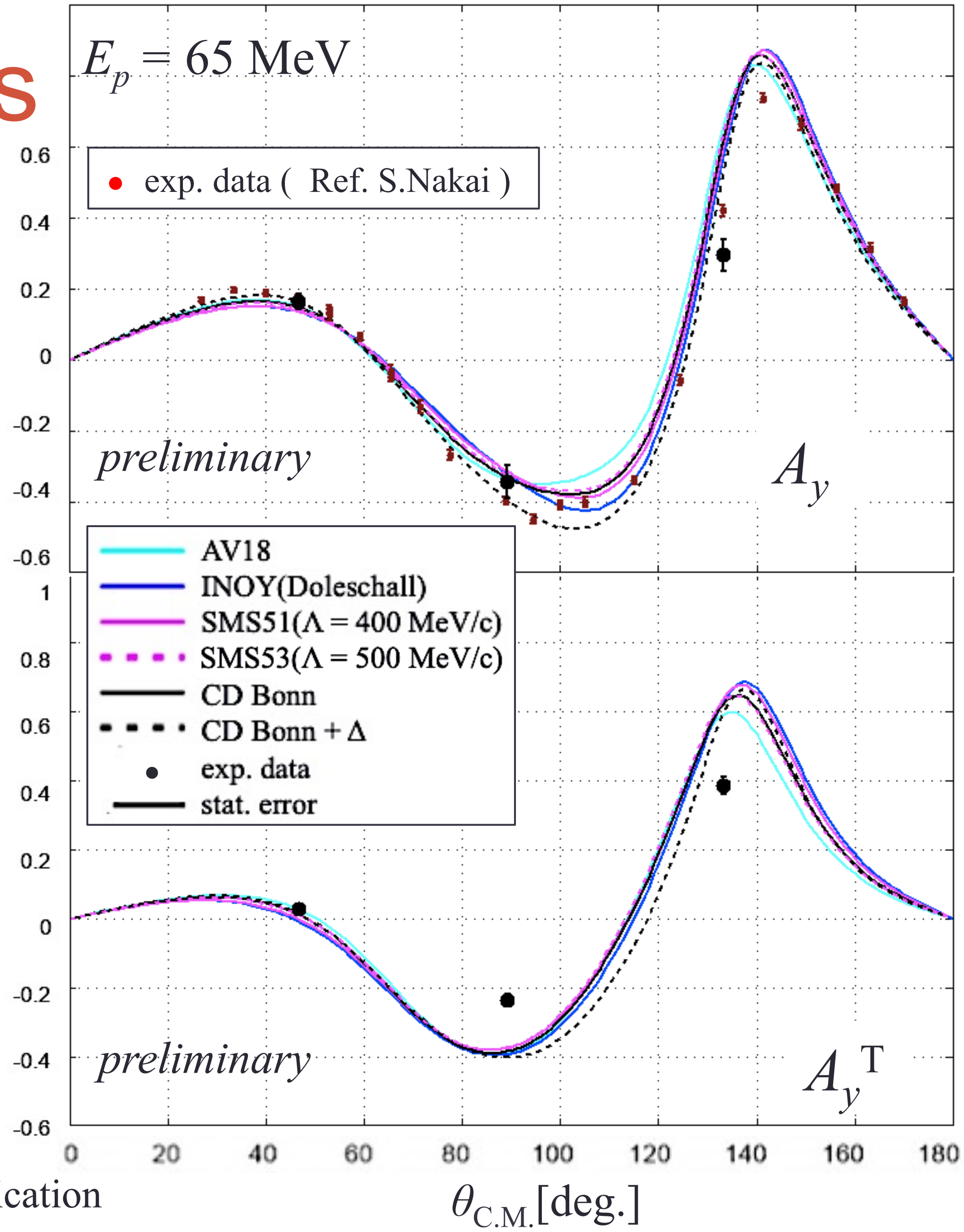
Spin observables

$A_y(p)$

- Statistical errors are only shown.
- Overall agreements are good.

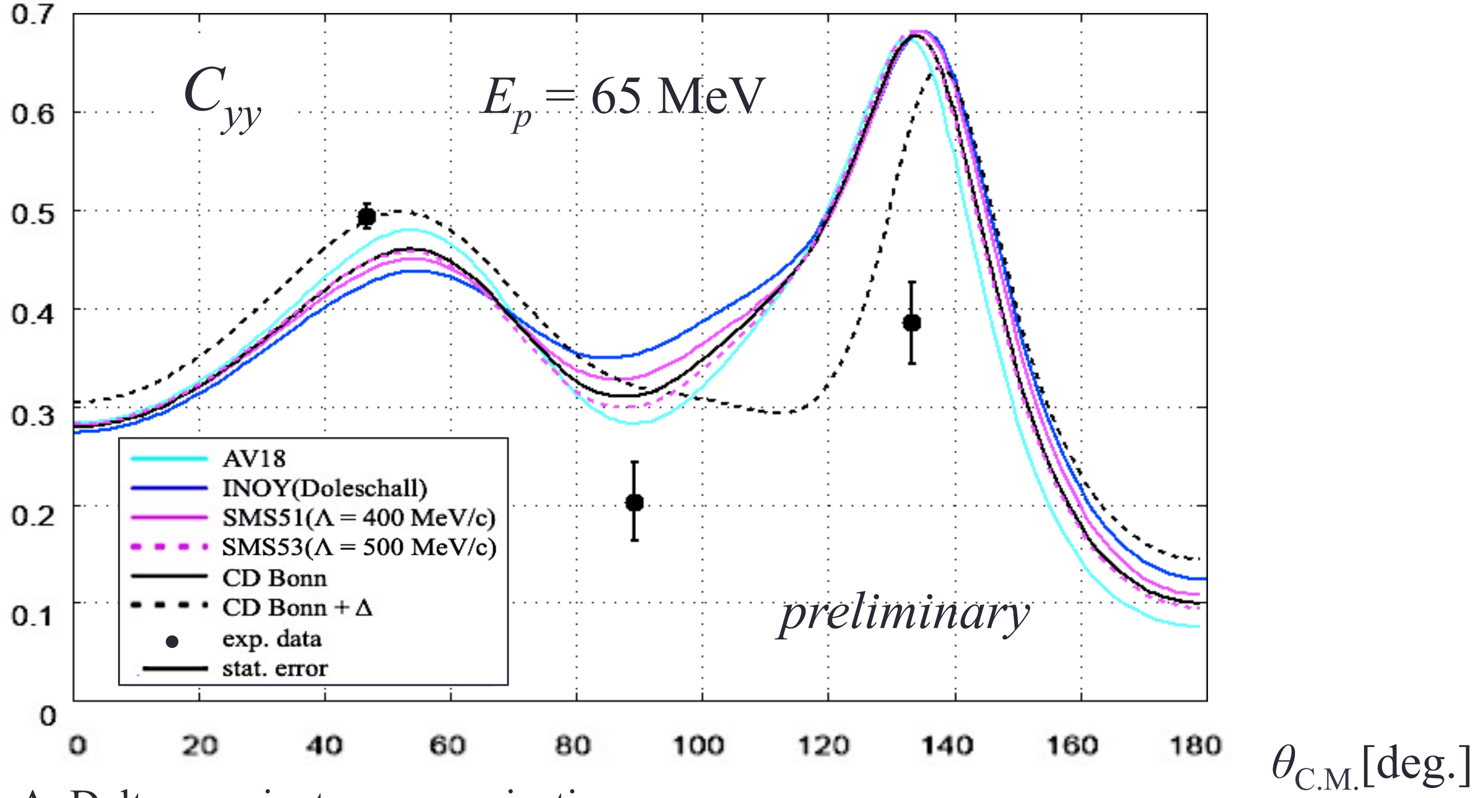
$A_y(^3\mathrm{He})$

- Statistical errors are only shown.
- Large difference is found at backward two angles.



*Calculations by A. Deltuva, private communication

Spin observables



*Calculations by A. Deltuva, private communication

- Statistical errors are only shown.
- Large difference is found at backward two angles.
- Sizable effects of Δ-isobar (3NFs) are predicted.

Contents

Summary

- 3NF plays important roles to understand various nuclear phenomena.
- For study of 3NF properties, we have measured p - ^{3}He scattering at 65 MeV by using the polarized proton beam and the polarized ^{3}He target. (@RCNP, Osaka Univ., Japan)
- Measured angles were $\theta_{\mathrm{Lab}} = 35°, 70°, 115°$.($\theta_{\mathrm{C.M.}} = 47°, 89°, 133°$)
- By comparing the data with the theoretical calculations, large discrepancies are found at the backward angles for A_y^{T} and C_{yy}.
- As the next step, we are planning to measure a complete set of spin correlation coefficients in a wide angular range.