Present Status of the Nucleon-Deuteron Elastic Scattering at Intermediate Energy

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RIKEN
Are there three-nucleon forces (3NF)?

\(3NF\) is much weaker than 2NF.

\[\text{→3NF effects are easily masked by 2NF effects.}\]

Equations of motion must be solved exactly.

\[\text{→Faddeev eq.}\]

\[\text{→2NF must be reliable.}\]

However, numerical calc. are extremely difficult.
L.D. Faddeev, Sov. Phys. JETP 12(1961)1014

Faddeev Equation

\[ H = H_0 + V_{12}^{NN} + V_{23}^{NN} + V_{31}^{NN} + V_{123} \]

→ can be solved exactly!
Independent of reaction models

2. Direct comparison possible between data and inputs

- Nuclear force (2NF, 3NF) input
  - Faddeev equation
  - Numerical results
  - Experimental results of 3NS

Characteristics
Two nucleon force (NF)

One $\pi$ Exchange (OPE) model by Hideki Yukawa


$m_\pi c^2 = 140$ MeV $\quad (J^\pi, T) = (0^-, 1)$

$$V^{\text{OPE}}_{1,2} = \frac{1}{3} \frac{f}{\hbar c} m c^2 \left( \frac{1}{1} \frac{1}{2} \right) \left( \frac{1}{1} \frac{1}{2} \right) + \left( 1 + \frac{3}{x} + \frac{3}{x^2} \right) S_{12} \exp \frac{-x}{x}$$

$$S_{12} = \frac{3}{r^2} \left( \frac{1}{1} \frac{1}{r} \right) \left( \frac{1}{2} \frac{r}{2} \right) - \left( \frac{1}{1} \frac{1}{2} \right)$$

$$x \equiv \frac{m}{\hbar c} r$$

Realistic modern 2 nucleon forces available now.

reproduces more than 3,500 exp. NN data with $x^2 \simeq 1$.

- CD Bonn pot. : strong non-locality
- AV18 pot. : OPE + phenom.
- Nijmegen I/II/93 pot. : one boson exch.

Main differences are of-shell properties
Three nucleon force (NF)

2. Fujita • Miyazawa type 3NF

\[ \text{(Prog. Theor. Phys. 17(1957)360.)} \]

- **N**: proton / neutron
  \[ m_N c^2 = 940 \text{MeV} \]
  \[ (J, T) = \left( \frac{1}{2}^+, \frac{1}{2} \right) \]

- **Δ**: excited state of nucleon
  \[ m_\Delta c^2 = 1232 \text{MeV} \]
  \[ (J, T) = \left( \frac{3}{2}^+, \frac{3}{2} \right) \]
other type of 3NF
3NF based on $2\pi$ exchange model

- **TM-3NF**
  current algebra

- **4. UR-3NF**
  FM+phenomenological SR term

- **7. BR-3NF**
  chiral Lagrangian + current algebra

- **10. Texas-3NF**
  chiral perturbation theory
Three-Nucleon Force

\[ V^{(3)} = \frac{1}{(2\pi)^6} \frac{g_{\pi NN}^2}{4m^2} \frac{F_{\pi NN}(q^2)}{(q^2 + m^2) \left( q'^2 + m^2 \right)} \bar{\sigma}_1 \cdot \vec{q} \bar{\sigma}_2 \cdot \vec{q}' \left[ \sigma^{\alpha \beta} \tau_\alpha \tau_\beta \right] \]

\[ \sigma^{\alpha \beta} = \delta^{\alpha \beta} \left[ a + b \vec{q} \vec{q}' + c(q^2 + q'^2) \right] - d(\vec{\tau}_3 \varepsilon^{\alpha \beta \gamma} \vec{\sigma}_3 \cdot \vec{q} \times \vec{q}') \]

\[ F_{\pi NN}^2(q^2) = \frac{2 - m^2}{2 + q^2} \quad \text{NN form factor} \]

- cut-off parameter

<table>
<thead>
<tr>
<th>3NF model</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>FM</td>
<td>0.0</td>
<td>-1.15</td>
<td>0.0</td>
<td>-0.29</td>
</tr>
<tr>
<td>TM</td>
<td>1.13</td>
<td>-2.62</td>
<td>1.05</td>
<td>-0.60</td>
</tr>
<tr>
<td>Urbana IX</td>
<td>0.0</td>
<td>-1.20</td>
<td>0.0</td>
<td>-0.30</td>
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<tr>
<td>Brazil</td>
<td>1.05</td>
<td>-2.29</td>
<td>1.05</td>
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</tr>
<tr>
<td>Texas</td>
<td>1.87</td>
<td>-3.82</td>
<td>0.0</td>
<td>-1.12</td>
</tr>
<tr>
<td>Ruhr</td>
<td>0.51</td>
<td>-1.82</td>
<td>0.0</td>
<td>-0.48</td>
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<tr>
<td>TM’</td>
<td>-0.87</td>
<td>-2.62</td>
<td>0.0</td>
<td>-0.60</td>
</tr>
</tbody>
</table>
### Faddeev type calculations

1. **Bochum-Cracow-KIT group calculation**
   - H. Witała, H. Kamada, W. Glöckle, E. Epelbaum

   **Input data**
   - **NN**
     - CD Bonn
     - AV18
   - **3NF**
     - Tucson-Melbourne
     - Urbana IX

2. **Hannover group calculation**
   - P.U. Sauer, D. Deltuva

   **Input data**
   - **NN**
     - CD Bonn
   - **3NF**
     - $\Delta$ – isobar

Both calc., \textit{nd} scattering assumed.

→ No Coulomb force effects included.
### First Evidence of 3NF Effects

**B.E. of $^3$H: 8.48 MeV**

**Faddeev calculations**

<table>
<thead>
<tr>
<th>NN pot.</th>
<th>NN only</th>
<th>NN+3NF(TM)</th>
<th>$\Lambda$</th>
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<tr>
<td>CD Bonn</td>
<td>8.00</td>
<td>8.483</td>
<td>4.86</td>
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<td>AV18</td>
<td>7.65</td>
<td>8.479</td>
<td>5.22</td>
</tr>
<tr>
<td>Nijm93</td>
<td>7.66</td>
<td>8.480</td>
<td>5.10</td>
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<tr>
<td>Ruhr</td>
<td>7.64</td>
<td>8.459</td>
<td>5.31</td>
</tr>
</tbody>
</table>

**NN force only calc. is underboud by 0.5-1.0 MeV.**

3NF fills this gap. (but with $\Lambda$)

→ put constraint on overall strength of 3NF.

### Hannover group C.C.

<table>
<thead>
<tr>
<th>calc.</th>
<th></th>
<th>8.29 (CDBonn + $\Lambda$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDBonn</td>
<td>8.00</td>
<td></td>
</tr>
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</table>

To study dynamical properties of 3NF

→ scattering

→ No adjustable parameter in Faddeev calc.
FIG. 1. (Color) Energies of ground or low-lying excited states of light nuclei computed with the AV18 and AV18/UIX interactions, compared to experiment. The light shading shows the Monte Carlo statistical errors. The dashed lines indicate the thresholds against breakup for each model or experiment.
To where should we look for 3NF effects?

Nd elastic scattering is very attractive since it is simple and offers a rich set of spin observables.
Low energy $pd$ scattering

Faddeev calc.

No parameter!

No need of 3NF!

$A_y (iT_{11})$ discrepancy

$\rightarrow$ 3NF?

Probably due to deficiency in $^3P_J$ phase shifts of NN.
To where should we look for 3NF effects?

Prediction by H. Witała. PRL 81 (’98) 1183.

→ go to $nd$ scatt. at intermediate energy.

Look at $d\sigma/d\Omega$ minimum region.
Let’s start with

135 MeV/u \ (E_d=270 MeV) data

at RIKEN by K. Sekiguchi
### pd and nd scattering at 70–400 MeV/A

<table>
<thead>
<tr>
<th>Observable</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>400</th>
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<tr>
<td>$\frac{d\sigma}{d\Omega}$</td>
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<tr>
<td>$\bar{p}$</td>
<td>$A_y$</td>
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<td>$\bar{d}$</td>
<td>$iT_{11}$</td>
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<td>$\bar{p} \rightarrow \bar{p}'$</td>
<td>$K_{y}^{y'}$</td>
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<td>$\bar{p}d$</td>
<td>$C_{nn}$</td>
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<td><img src="image.png" alt="Graph" /></td>
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<tr>
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<td>$C_{i,j,k}$</td>
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Other data: limited angular range $\frac{d\sigma}{d\Omega}$ and $A_y$.

$T_{20}$: 0.15–1.15 GeV/A

$\sigma_{tot}$ (nd)
$d + p$ at 270 MeV (RIKEN)

d: various spin(polarization) obs.

$\frac{d\sigma}{d\Omega}, P^y (= - A^y_p), iT_{11}, T_{20}, T_{22}, T_{21}$


Spin( polarization) transfer exp. by Sekiguchi

$d + p \rightarrow p + d$ at 270 MeV (135 MeV/u)

$K^y_{xx}, K^y_{yy}, K^y_{xz}, K^y_y$

K. Sekiguchi: to be published soon.
Vector and tensor polarized deuteron beams are provided by the polarized ion source (PIS).

The Spin axis is controlled by a Wien Filter prior to acceleration.

Single-turn extraction is available both for the AVF and Ring cyclotrons.

**Beam polarizations**: 60-80% of the theoretical maximum values

at D-room polarimeter (A) and the Swinger polarimeter (B)
magnetic moment $\mu = s \frac{e \hbar}{mc} (1 + a)$

cyclotron frequency in magnetic field $B$
$\omega_c = \frac{eB}{m}$

angular rotation frequency in $B$
$\omega_s = \frac{eB}{m} (a + 1)$

**Larmor freq. + Thomas precession (rel. effects)**

Dirac particle ($a = 0$) $\Rightarrow \omega_s = \omega_c$

Proton
$\mu_p = \frac{1}{2} \frac{e \hbar}{m_p c} \times 2.793$

Deuteron
$\mu_d = \frac{e \hbar}{m_d c} \times 0.857$

500 MeV proton

270 MeV deuteron

550°!
Method of spin rotation

Spin rotation before injection into cyclotron at low energy spin precession during accel.

Familiar at Tandem VdG accel...

- single turn extraction needed at cyclotron
  Thanks to RIKEN Accelerator Staff
- spin direction monitor needed after accel. With high efficiency.
SMART: Swinger and Magnetic Analyzer with Rotator and Twister
RIKEN data 270 MeV (135 MeV/u)
Coulomb

$d-p$

at 135 MeV/u

$\frac{d\sigma}{d\Omega}$ [mb/sr]

$\theta_{c.m.}$ [deg]

$iT_{11}$

$\theta_{c.m.}$ [deg]
Tensor behaviour chaotic
Measurement Conditions

Parameter

- Beam energy: \( E_d = 270 \text{ MeV} \)
- Target: Liq. H (19.8 mg/cm\(^2\)) , CH\(_2\) (93.4 mg/cm\(^2\))
- Beam intensity: 10 - 60 nA
- Vector and tensor beam polarizations: 60 - 80% of the theoretical maximum values

Measured Observables

- \( K_{xz}^{y'}, K_{xx}^{y'} - K_{yy}^{y'} (K_{xx}^{y'}, K_{yy}^{y'}), K_{y}^{y'} \)
- \( P^{y'} \) — Induced Polarization

Angular Range: \( \theta \text{ c.m.} = 90^\circ - 180^\circ \)

DPOL calibration:

induced polarization of \(^{12}\text{C}(\text{p},p_0)^{12}\text{C}\)

\[ |\delta \phi| \leq 60^\circ \]
\[ 5^\circ \leq \theta \leq 15^\circ \]
How to extract $d$ to $p$ polarization transfer coefficients?

- Control of Polarized Deuteron Beam Direction
- Measurement of Polarization of Scattered Protons ($p_y$)
  - Calibration of effective analyzing power for DPOL

**Polarized Cross Section**

$$p_y' \frac{\sigma}{\sigma_0} = p_y' + \frac{3}{2} p_y K_{yy}' + \frac{2}{3} p_{xz} K_{xx}' + \frac{1}{3} \left( p_{xx} K_{xx}' + p_{yy} K_{yy}' + p_{zz} K_{zz}' \right)$$

**Polarized $d$ beam ($p_y p_{yy} p_{xx} p_{xz}$) by PIS & Wien Filter**

- $K_{yy}'$ & $K_{yy'}$: $p_y' \frac{\sigma}{\sigma_0} = p_y' + \frac{3}{2} p_y K_{yy}' + \frac{1}{2} p_{yy} K_{yy}'$
- $K_{xx}$: $p_y' \frac{\sigma}{\sigma_0} = p_y' + \frac{1}{2} p_{xx} K_{xx}'$
- $K_{xz}$: $p_y' \frac{\sigma}{\sigma_0} = p_y' + \frac{2}{3} p_{xz} K_{xz}' + \frac{1}{3} \left( p_{xx} K_{xx}' + p_{yy} K_{yy}' + p_{zz} K_{zz}' \right)$

**$d$ beam spin mode**

<table>
<thead>
<tr>
<th>$P_z$</th>
<th>$P_{zz}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>#0</td>
<td>0</td>
</tr>
<tr>
<td>#1</td>
<td>0</td>
</tr>
<tr>
<td>#2</td>
<td>-2/3</td>
</tr>
<tr>
<td>#3</td>
<td>1/3</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**Induced Polarization**
Statistical Uncertainty

<table>
<thead>
<tr>
<th>$\delta P^y$</th>
<th>$\delta K^y_y$</th>
<th>$\delta K^y_{yy}$</th>
<th>$\delta K^y_{xx}$</th>
<th>$\delta K^y_{xz}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
<td>0.02</td>
</tr>
</tbody>
</table>

- **Systematic Uncertainty**

  Effective Analyzing Power $A_y^C$ 2%
  Beam Polarization 2%
  Bending Angle of the Spectrometer 1%

  Total 3%

- $A_y^p$ (= $P_y'$) data provide almost the same results.
3NF is definitely needed.

but $K_y y' K_{xz} y'$ ?
135 MeV/u

\( d-p \) at 135 MeV/u

\( p-d \) at 135 MeV/u

\( i T_{11} \)

Hannover calc.

- **NN**
- **NN+Δ**
$p-d$

at 135 MeV/u

$A_y^p$

$T_{20}$

$T_{21}$

$T_{22}$
How they look like if the energy is halved?

140 MeV (70 MeV/u) data at RIKEN
$d-p$ at 70 MeV/u

$T_{20}$ at 70 MeV/u

$T_{21}$

$T_{22}$

140 MeV
Chiral Effective Field Theory

- Relation with QCD
  Lagrangian $L= \ldots$

- Scale parameter $\Lambda$
  expand in power of $Q/\Lambda$ ($Q=$nucl. mom.)

- Chiral symmetry

- Effective theory

Chiral perturbation theory

$\pi+N+"garbage"$

"garbage"=heavy meson, $\Delta$

2N+3N on the same footing!

<table>
<thead>
<tr>
<th></th>
<th>2N forces</th>
<th>3N forces</th>
<th>4N forces</th>
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</thead>
<tbody>
<tr>
<td>LO</td>
<td>$X\bar{H}$</td>
<td>$\cdots$</td>
<td>$\cdots$</td>
</tr>
<tr>
<td>NLO</td>
<td>$X\bar{H}$</td>
<td>$\cdots$</td>
<td>$\cdots$</td>
</tr>
<tr>
<td>$N^2$LO</td>
<td>$X\bar{H}$</td>
<td>$\cdots$</td>
<td>$\cdots$</td>
</tr>
<tr>
<td>$N^3$LO</td>
<td>$X\bar{H}$</td>
<td>$\cdots$</td>
<td>$\cdots$</td>
</tr>
</tbody>
</table>
Chiral Eff. Field
Theory Calc. NNLO

E. Epelbaum et al.

64001.

$\Lambda = 500$-$600$ MeV/c
Results of 270 and 140 MeV

$d\sigma/d\Omega, \ iT_{11}$: Excellent fits!

→ clear 3NF effects in Nd scatt.
→ magnitudes of 3NF seem to be O.K.

4. $A_y(= - p^{y'})$, $T_{20}, T_{22}, T_{21}$: Poor fits!
   → defects in spin dependent part of 3NF.

6. $K_{xx}^{y'}, K_{yy}^{y'}$: reasonable fits! $K_{y}^{y'}, K_{xz}^{y'}$: poor.
   → spin-spin interaction of 3NF is reasonable?

9. 3NF: TM’/ Urbana IX does better job.
   → chiral symmetry requires: The $c$ term should be zero.

12. Chiral Eff. Field Theory calc. does reasonable job for $d\sigma/d\Omega$ but not much analyzing powers.
How they look like if the energy is doubled from 135 MeV/u ($E_d=270$ MeV)?

250 MeV/u data at RCNP
\[ n + d \text{ at 250 MeV (RCNP)} \]

Coulomb free

direct comparison is possible:

- between \( nd \) data vs. Faddeev calc.

\( \sim n \) : secondary beam exp. \( \rightarrow \) very difficult.

\( ^7\text{Li}(p,n)^7\text{Be} \) reaction

**Forward angle** : \( d(n,n)d \) \( \text{NTOF+NPOL} \)

- D liq. Scintillator (active target)

**Backward angle** : \( d(n,d)n \) \( (n,p) \) facility

recoiled \( d \) detected

All data points are normalized by np scatt.
$d(n,n)d$ NTOF+NPOL

Beam Swinger System

$\text{RCNP}$

$\text{Osaka University}$

LAS Spectrometer
\rightarrow n + d \text{ at 250 MeV}

by Yukie Maeda

\begin{align*}
\text{(n,p) facility} \\

n-d \text{ at 250 MeV/u}
\end{align*}
$p + d$ at 250 MeV (RCNP) by K. Hatanaka

$\frac{d\sigma}{d\Omega}, A_y$

Complete pol. transfer meas.: $K_x^{x'}, K_y^{y'}, K_z^{z'}, K_z^{x'}, K_x^{z'}$

proton to proton

3. direct comparison possible: between $nd$ vs. $pd$
$^n + d$ and $^p + d$ at 250 MeV

$n-d$ at 250 MeV/u

$p-d$
\textbf{NN}

\textbf{NN+3NF}

\textbf{NN+TM'}

\textbf{AV18+UR9}
$p-d$ at 250 MeV/u

$\theta_{c.m.}$ [deg]

$K_x$, $K_y$

**Legend**
- **NN**
- **NN+3NF**
- **NN+TM’**
- **AV18+UR9**
pd elastic scattering at 250 MeV

Hannover calc.
by Arnas Deltuva

3 baryon total $J = 35/2$

- CD Bonn $(I=7)$
- CDB $+$ $(I=5)$
- CDB $+$ $(I=6)$
- CDB $+$ $(I=7)$
PT for $pd$ elastic scattering at 250 MeV

Bochum-Cracow-KIT calc.  Hannover calc.

FM type( ) 3NF does not play a role in these spin obs.

Mostly due to c-term effects
Let’s look at

• Coulomb effects.
Data-to-data comparison between $nd$ vs. $pd$

\[
\frac{d}{d\Omega} \bigg|_{pd} \quad \frac{d}{d\Omega} \bigg|_{nd}
\]

Coulomb effect!?

Calculation by Y. Koike.

$Nd$ at $135/u$ MeV

Coulomb force is approx. included.
Results at 250 MeV

First and measurements at 250 MeV. Data-to-data comparison was made: \( \vec{n}d \) vs. \( \vec{p}d \)

→ 10-20% variation in \( d\sigma/d\Omega \)

→ Coulomb effect!? 

Direct comparison was made: \( nd \). data vs. calc.

\( d\sigma/d\Omega \): 50% disagreement in backward.

→ irrespective of 3NF

3. \( A_y \): large deviation in backward.

→ irrespective of 3NF

5. \( K_{x', y', z'}, K_{x', z'}, K_{z'} \) (pd vs. calc.)

→ TM 3NF does poor job.

→ almost no FM 3NF(\( \Delta \)) effects!
These results indicate:

→ defects of 3NF or relativistic effects or both? OR
→ defects of nucleon exchange process? OR
→ defects of NN interactions?
Results from TSL

(n,d) elastic angular distribution at 95 MeV

- August 2002
- October 2002
- Feb 2003 1st week
- Feb 2003 2nd week

CD Bonn without 3N
CD Bonn with 3N

Medley preliminary
How they look like if the energy is doubled?

400 MeV/u data
at RCNP
$\vec{p} + d$ at 400 MeV (RCNP)

A. Tamii: $\vec{p} + d \rightarrow d + p$ at 400 MeV

\[ \frac{d\sigma}{d\Omega}, A_y^p, A_y^d (=- P^y), K_y^y \]

Limited angular range

Very preliminary calc. by Kamada

- 2NF: CD Bonn
- 3NF: TM
Results at 400 MeV

Calc. by H. Kamada are very preliminary!

\( \frac{d\sigma}{d\Omega} \) : agreement?

\( A_y^p, \left( = - P_y' \right), i T_{11} \) : large deviation.

\( K_{y'} \) : large disagreement (opposite sign!)

\[ p + d \rightarrow d + p \]
Precise data on $p + d$ elastic scattering at $E_p = 70 - 400$ MeV become available now, not only $d\sigma/d\Omega$, $A_y^p$, ($= - P_{y'}$), $iT_{11}$, $T_{20}$, $T_{22}$, $T_{21}$ but also various Polarization Transfer Observables.

A lot of data expected at 135 MeV/u.
* Spin-correl. data from IUCF.
* Breakup data from KVI and may be from RIKEN → 135 MeV/u will be the most extensive data set.
Present status of 3NF study

3NF established firmly?

→ Yes and No.
→ Magnitudes seem to be O.K.
Spin dependence? Chaotic.

6. Defects of 3NF?

→ Yes, definitely in TM.
The $c$ term violates chiral symmetry.
→ Need to include, $\pi\rho$ and $\rho\rho$ exch. 3NF and more.

11. New development of Chiral Eff. Field Theory calc.
is extremely interesting.

13. Relativistic effects must be studied.
Are 2NFs reliable?

→ Questionable in terms of off-shell properties.

No need of 3NF in BE\(^{(3H)}\) by Y. Fujiwara!
Triton binding energy calculated from the SU$_6$ quark-model nucleon-nucleon interaction

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Properties of the three-nucleon bound state are examined in the Faddeev formalism, in which the quark-model nucleon-nucleon interaction is explicitly incorporated to calculate the off-shell $T$ matrix. The most recent version, fss2, of the Kyoto-Niigata quark-model potential yields the ground-state energy $E(^3\text{H}) = -8.514$ MeV in the 34 channel calculation, when the $np$ interaction is used for the nucleon-nucleon interaction. The charge root mean square radii of the $^3\text{H}$ and $^3\text{He}$ are 1.72 fm and 1.90 fm, respectively, including the finite size correction of the nucleons. These values are the closest to the experiments among many results obtained by detailed Faddeev calculations employing modern realistic nucleon-nucleon interaction models.
Are 2NFs reliable?

→ Questionable in terms of off-shell properties.

No need of 3NF in BE(³H) by Y. Fujiwara!
→ Should be tested by scatt. data.

→ Exchange term might be problematic.

Finally,

Recent 3NF studies have reached a new era of ‘the Renaissance’.

This is due to recent harmonious development of both experiments and theories.

But I think more theory inputs are needed.
Some experimental concern.
Results from KVI
Systematic Error of $d\sigma/d\Omega$ 

$d + p \quad 270 \text{ MeV}$

$\downarrow \quad \text{beam } d \rightarrow H_2^+$

3. measure $p + p \quad 135 \text{ MeV}$

$\uparrow \quad \text{compare}$

6. $NN$ phase-shift solution (SAID)

$$\frac{\left(\frac{d}{d\Omega}\right)_{\text{exp}}}{\left(\frac{d}{d\Omega}\right)_{\text{SAID}}} = 1.01 \pm 0.015$$

$Averaged \ Value \quad = 1.010 \pm 0.013$

$$\Delta \left(\frac{d}{d\Omega}\right)_{\text{exp}} \leq 2$$
\( p + d \)

- Sakamoto et al.,
  \( d+p \) : counter meas.

- Sakai et al.,

- Sekiguchi et al.,
  \( d+p \) : SMART spectr.

- Sekiguchi et al.,
  to be published.
  \( d+p \) & \( p+d \) :
  SMART spectr.
Sakamoto et al.,
d+p : counter meas.

Sakai et al.,

Sekiguchi et al.,
d+p : SMART spectr.

Sekiguchi et al.,
to be published.
d+p & p+d :
SMART spectr.

KVI data
to be published.
p+d : counter meas.
\[ \frac{\sigma_{\text{kvi}}}{\sigma_{\text{riken}}} \]

\[ \theta_{\text{c.m.}} \text{ [deg]} \]
$n+p$ at 293 MeV

$\theta_{LAS} = 0^\circ$
$\theta_{LAS} = 5^\circ$
$\theta_{LAS} = 10^\circ$

SAID

$\theta_{lab}^{proton}$ (deg)

$(\omega s/\mu m)$ $\omega p/\omega p_{lab}$
Experiments were carried out under the collaboration of researchers from University of Tokyo, RIKEN, CNS, RCNP, Saitama University, CYRIC and TIT.

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