Double polarized DD-fusion
Status of PolFusion experiment

(PNPI, Gatchina, Russia)

Polina Kravchenko
on behalf of collaboration

Motivation
Experimental setup
MC simulations and Mathematical model
Motivation

Increase the gain of nuclear fusion reaction


Cross section ↑ with factor 1.5 at 430keV
Motivation

Increase the gain of nuclear fusion reaction

\[ ^3\text{He} + \vec{d} \rightarrow ^4\text{He} + p \]
\[ \vec{t} + \vec{d} \rightarrow ^4\text{He} + n \]

What about

\[ \vec{d} + \vec{d} \rightarrow ^3\text{He} + n \]
\[ \vec{d} + \vec{d} \rightarrow t + p \]

No data in the low energy range 10-100keV
Theoretical predictions are complicated
not S-dominated
P-, D-waves can not be neglected
Motivation

\[ \vec{d} + \vec{d} \to ^3He + n \]
\[ \vec{d} + \vec{d} \to t + p \]

Sum of the independent channel-spin cross sections

\[ \sigma_0 = \frac{1}{9} \left( 2\sigma_{1,1} + 4\sigma_{1,0} + \sigma_{0,0} + 2\sigma_{1,-1} \right) \]

Quintet suppression Factor

\[ QSF = \frac{\sigma_{1,1}}{\sigma_0} \]
Motivation

$$\vec{d} + \vec{d} \rightarrow ^3He + n$$

$$\vec{d} + \vec{d} \rightarrow t + p$$

Sum of the independent channel-spin cross sections

$$\sigma_0 = \frac{1}{9}(2\sigma_{1,1} + 4\sigma_{1,0} + \sigma_{0,0} + 2\sigma_{1,-1})$$

Quintet suppression Factor

$$QSF = \frac{\sigma_{1,1}}{\sigma_0}$$

PolFusion experiment

➢ Cross section at low energy

➢ Angular distributions (n reduce the lifetime of reactor ➔ better control)

➢ QSF direct measurements
Experimental setup

Substantial part of the equipment from:

\[ {^3He}^{2+} (^{3}H^{+}) \]

\[ \vec{d}^0 \ (0.1\text{keV}) \]

\[ \vec{d}^+ \ (30 - 100\text{keV}) \]

\[ \sigma_0 = \frac{1}{9}(2\sigma_{1,1} + 4\sigma_{1,0} + \sigma_{0,0} + 2\sigma_{1,-1}) \]

Quintet  Triplet  Singlet

\[ n(p) \]
Experimental setup

Substantial part of the equipment from:

- $^3\text{He}^2+ (^3\text{H}^+)$
- \(\vec{d}^0 (0.1\text{keV})\)
- $n(p)$
- Quintet
- Triplet
- Singlet

\[
\sigma_0 = \frac{1}{9} \left( 2\sigma_{1,1} + 4\sigma_{1,0} + \sigma_{0,0} + 2\sigma_{1,-1} \right)
\]
Ion current at the source up to 20μA
Stable beam
Ionizer for energy up to 100keV

Current working conditions:
Dissociator power 160-300W
Nozzle T 43-55K
D flow 13-22ccm
Pressure: Dissociator 8mbar
HEX1 HEX2 8e-4mbar/1e-5mbar
Ionizer 7e-7mbar
Current HEX1/HEX2 170/150A
Ionizer Power ~150W
Dissociator upgrade
Reflected power decreased from 150W to 3W (@250W)
Nozzle cooling
Stable temperature down to 55K
Control system
Vacuum system
RF transition units.
4-π detector with 51% filling
576 Hamamatsu PIN-diodes (S3590-09)
PIN-diode active area: 1 cm²
depleted layer: 300 um
energy resolution: <50keV
low reverse voltage (<=50V)
Target: deuterated polymethylmethacrylate
Deuteron beam 15keV ~5μA

Central detector
Target: deuterated polymethylmethacrylate
Deuteron beam 15keV ~5uA

Central detector

Solid target measurements
- Signal quality
- Form and sources of electronic background

Integral amplitude spectra

<table>
<thead>
<tr>
<th>IntAmp</th>
<th>Entries</th>
<th>Mean</th>
<th>RMS</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>2825</td>
<td>1147</td>
<td>894.2</td>
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</tbody>
</table>
Central detector

Solid target measurements
- Signal quality
- Form and sources of electronic background
- Energy resolution better than 25keV

Target: deuterated polymethylmethacrylate
Deuteron beam 15keV ~5μA

ADC calibration
Interaction point
Profiles of ion and atomic beams
Detector geometry
Kinematics of reaction
Event distributions in space $\theta$ and $\phi$

Acceptance function

Efficiency
Observables

\[
\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} + \sum_{i=1}^{8} A_i^{(b)} b_i + \sum_{i=1}^{8} A_i^{(t)} t_i + \sum_{i,k=1}^{8} C_{ik}^{(bt)} b_i t_k
\]
Observables

Expressed in Cartesian coordinates

\[
\sigma(\theta, \phi) = \sigma_0(\theta) \left\{ 1 + \frac{3}{2} \left[ A_y^{(b)}(\theta)p_y + A_y^{(t)}q_y \right] + \frac{1}{2} \left[ A_z^{(b)}(\theta)p_z + A_z^{(t)}q_z \right] \right. \\
+ \frac{1}{6} \left[ A_{xy}^{(b)}(\theta)p_{xy} + A_{xy}^{(t)}q_{xy} \right] \\
+ \frac{2}{3} \left[ A_{xz}^{(b)}(\theta)p_{xz} + A_{xz}^{(t)}q_{xz} \right] \\
+ \frac{1}{4} \left[ C_{y,xy}(\theta)p_y q_y + C_{y,xy}(\theta)p_{xy} q_{xy} + C_{y,xy}(\theta)p_z q_z \\
+ C_{y,xy}(\theta)p_z q_z \right] \\
+ \frac{3}{4} \left[ C_{y,xz}(\theta)p_{xz} q_{xz} + C_{y,xz}(\theta)p_{xz} q_{xz} \right] \\
+ C_{y,zz}(\theta)p_{yz} q_{yz} + C_{y,zz}(\theta)p_{yz} q_{yz} \\
+ C_{y,zz}(\theta)p_{yz} q_{yz} + C_{y,zz}(\theta)p_{yz} q_{yz} \\
+ \frac{1}{4} \left[ C_{y,xx}(\theta)p_{xy} q_{xy} + C_{y,xx}(\theta)p_{xy} q_{xy} \right] \\
+ C_{zz,zz}(\theta)p_{zz} q_{zz} \right. \\
+ \frac{1}{3} \left[ C_{z,zz}(\theta)p_{zz} q_{zz} + C_{zz,zz}(\theta)p_{zz} q_{zz} \right] \\
+ \frac{1}{12} \left[ C_{z,zz}(\theta)p_{zz} q_{zz} + C_{zz,zz}(\theta)p_{zz} q_{zz} \right] \\
+ \frac{4}{9} \left[ C_{z,xx}(\theta)p_{xx} q_{xx} + C_{zz,yy}(\theta)p_{xx} q_{xx} \right] \\
+ \frac{8}{9} \left[ C_{z,xx}(\theta)p_{xx} q_{xx} + C_{zz,yy}(\theta)p_{xx} q_{xx} \right] \\
+ \frac{3}{9} \left[ C_{y,xx}(\theta)p_{xx} q_{xx} \right] \\
+ \frac{1}{9} \left[ C_{z,xx}(\theta)p_{xx} q_{xx} + C_{zz,yy}(\theta)p_{xx} q_{xx} \right] \\
+ \frac{1}{36} \left[ C_{z,xx}(\theta)p_{xx} q_{xx} \right] \\
+ \frac{1}{2} \left[ C_{z,xy}(\theta)p_{xy} q_{xy} + C_{z,xy}(\theta)p_{xy} q_{xy} + C_{z,xy}(\theta)p_{xy} q_{xy} \right] \} \\
\]

Observables

\[ \sigma(\Theta, \Phi) = \sigma_0(\Theta) \left( 1 + \frac{3}{2} \left[ A_y^{(b)}(\Theta) p_y + A_y^{(t)}(\Theta) q_y \right] + \frac{1}{2} \left[ A_z^{(b)}(\Theta) p_z + A_z^{(t)}(\Theta) q_z \right] \right) + \frac{1}{6} \left[ A_{xy}^{(b)}(\Theta) p_{xy} + A_{xy}^{(t)}(\Theta) q_{xy} \right] + \frac{2}{3} \left[ A_{xz}^{(b)}(\Theta) p_{xz} + A_{xz}^{(t)}(\Theta) q_{xz} \right] + \frac{9}{4} \left[ C_{y,z}^{(b)}(\Theta) p_y q_z + C_{x,z}^{(b)}(\Theta) p_x q_z + C_{x,y}^{(b)}(\Theta) p_x q_y + C_{y,x}^{(b)}(\Theta) p_y q_x \right] \]

Spins of both deuterons are aligned:
Only \( p_z, q_z \neq 0 \) and \( p_{zz}, q_{zz} \neq 0 \)

\[ \sum_{i=1}^{8} A_{i}^{(t)} t_i + \sum_{i,k=1}^{8} (t_i b_i \cdot k) \]

QSF direct measurements possible
\[
\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} + \sum_{i=1}^{8} A_i^{(b)} b_i + \sum_{i=1}^{8} A_i^{(t)} t_i + \sum_{i,k=1}^{8} C_{ik}^{(bt)} b_i t_k
\]

### Observables

#### Experiments

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Symbols</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^2\text{H}(d,p)^3\text{H}$</td>
<td>$\sigma_0$</td>
<td>2015</td>
</tr>
<tr>
<td>$^2\text{H}(d,n)^3\text{He}$</td>
<td>$A_y$</td>
<td>2010</td>
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<tr>
<td></td>
<td>$A_{zz}$</td>
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<td>$A_{xz}$</td>
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<td>1990</td>
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<tr>
<td></td>
<td>$C_{yy}$</td>
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<tr>
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<td>$C_{zz,xz}$</td>
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<td>$^2\text{H}(d,n)^3\text{He}$</td>
<td>$P_{y'}$</td>
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<td>$^2\text{H}(d,p)^3\text{H}$</td>
<td>$K_{x'}^x$</td>
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<tr>
<td></td>
<td>$K_{y'}^y$</td>
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</tbody>
</table>

### Deuterium Fusion experiments

- Unpolarized beam, unpolarized solid target
- Unpolarized beam, unpolarised gas target
- Polarized beam, unpolarized solid target
- Polarized beam, unpolarized gas

References:

- Theus et al. Nucl.Phys. 80 (1966)
- Wenzel et al. Phys.Rev.88 (1952)
Observables

\[
\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} + \sum_{i=1}^{8} A^{(b)}_i b_i + \sum_{i=1}^{8} A^{(t)}_i t_i + \sum_{i,k=1}^{8} C^{(bt)}_{ik} b_i t_k
\]

Deuterium Fusion experiments

<table>
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<tr>
<th>Experiments</th>
<th>Observables</th>
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<tbody>
<tr>
<td>$^2\text{H}(d,p)^3\text{H}$</td>
<td>$\sigma_0$</td>
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<tr>
<td>$^2\text{H}(d,n)^3\text{He}$</td>
<td>$A_y$, $A_{zz}$, $A_{xz}$</td>
</tr>
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<td>$^2\text{H}(d,p)^3\text{H}$</td>
<td>$C_{zz}$, $C_{yy}$, $C_{zz,zz}$, $C_{y,zz}$, $C_{y,xz}$, $C_{zz,xz}$</td>
</tr>
<tr>
<td>$^2\text{H}(d,n)^3\text{He}$</td>
<td>$P_{y'}$</td>
</tr>
<tr>
<td>$^2\text{H}(d,p)^3\text{H}$</td>
<td>$K_{x,x}^{'}, K_{y,y}^{'}$</td>
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</table>

Unpolarized beam, unpolarized solid target
Unpolarized beam, unpolarised gas target
Polarized beam, unpolarized solid target
Polarized beam, unpolarized gas

Double Polarized DD Fusion (PNPI)

Franz et al. Nucl.Phys. A 122 (1968)
Theus et al. Nucl.Phys. 80 (1966)
Wenzel et al. Phys.Rev.88 (1952)
Partial-wave expansion of the reaction amplitude processes
$d\,d \to ^3\text{He}\,n$ and $d\,d \to ^3\text{H}\,p$

E. N. Komarov, S. G. Sherman

Abstract

The partial-wave expansion of the amplitude of the nuclear reaction for particles with spins $1 + 1 \to 1/2 + 1/2$ is performed with the identical particles in the initial state (for example, $d\,d \to ^3\text{He}\,n$ and $d\,d \to ^3\text{H}\,p$).

The reaction amplitude for the low energy range is written taking into account the $s-, p-$ and $d$-waves only. The work has been done in the frame of POLFUSION experiment.

The work has been performed at the High Energy Physics Department (HEPD).

Annotation

Obtained partial-wave decomposition of the amplitude of the reaction for particles with spins $1 + 1 \to 1/2 + 1/2$ for identical particles in initial state (for example, $d\,d \to ^3\text{He}\,n$ and $d\,d \to ^3\text{H}\,p$).

For the low energy range the amplitude is written in the form taking into account $s-, p-$ and $d$-waves. The work was performed in the frame of the POLFUSION experiment.

The work was performed in the Department of High Energy Physics (HEPD).

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Theory. Partial wave expansion for scattering amplitude two-body reaction with spin $1+1 \rightarrow 1/2+1/2$

Differential cross section of the reaction with polarized particles:

$$\frac{d\sigma}{d\Omega} = Spur[\hat{A} \cdot \rho \cdot \hat{A}^+]$$

Amplitude: matrix $4 \times 9$

$$A = \begin{pmatrix}
B_{12}^{12} & B_{11}^{12} & B_{10}^{12} & B_{10}^{11} & B_{10}^{11} & B_{10}^{11} & B_{10}^{11} & B_{10}^{11} & B_{10}^{11}
B_{02}^{12} & B_{01}^{12} & B_{00}^{12} & B_{00}^{11} & B_{00}^{11} & B_{00}^{11} & B_{00}^{11} & B_{00}^{11} & B_{00}^{11}
B_{02}^{11} & B_{01}^{11} & B_{00}^{11} & B_{00}^{10} & B_{00}^{10} & B_{00}^{10} & B_{00}^{10} & B_{00}^{10} & B_{00}^{10}
B_{12}^{11} & B_{11}^{11} & B_{10}^{11} & B_{10}^{10} & B_{10}^{10} & B_{10}^{10} & B_{10}^{10} & B_{10}^{10} & B_{10}^{10}
\end{pmatrix}$$

$$B_{\sigma'}^{s'}_{\sigma} = \frac{1}{2i \sqrt{k_i k_f}} \sum_{J=0}^{\infty} \sum_{l=|J-s|}^{J+s} \sum_{l'=|J-\sigma|}^{J+\sigma} i^{l-l'} \sqrt{4\pi(2l+1)} C_{l0\sigma}^{JM} C_{l'\sigma-\sigma'}^{l'\sigma-\sigma'} R_{l'l'}^{s}s Y_{l'm}(\cos \theta, \phi) = \sqrt{\frac{2l+1}{4\pi}} P_{lm}(\cos \theta e^{im\phi})$$
Theory. Partial wave expansion for scattering amplitude two-body reaction with spin $1+1 \rightarrow 1/2+1/2$

Differential cross section of the reaction with polarized particles:

$$\frac{d\sigma}{d\Omega} = Spur[\hat{A} \cdot \rho \cdot \hat{A}^+]$$

Amplitude: matrix $4 \times 9$

$$A = \begin{pmatrix} B_{12}^{12} & B_{11}^{12} & B_{10}^{12} & B_{10}^{11} & B_{10}^{10} & B_{10}^{11} & B_{10}^{12} & B_{10}^{11} & B_{10}^{10} \\ B_{02}^{12} & B_{02}^{11} & B_{02}^{10} & B_{02}^{11} & B_{02}^{10} & B_{02}^{11} & B_{02}^{10} & B_{02}^{11} & B_{02}^{10} \\ B_{02}^{12} & B_{02}^{11} & B_{02}^{10} & B_{02}^{11} & B_{02}^{10} & B_{02}^{11} & B_{02}^{10} & B_{02}^{11} & B_{02}^{10} \\ B_{12}^{-1} & B_{12}^{-1} & B_{12}^{-1} & B_{12}^{-1} & B_{12}^{-1} & B_{12}^{-1} & B_{12}^{-1} & B_{12}^{-1} & B_{12}^{-1} \end{pmatrix}$$

$$B_{s's'}^{s'} = \frac{1}{2i \sqrt{k_i k_f}} \sum_{J=0}^{\infty} \sum_{l=|J-s|}^{J+s} \sum_{l'=|J-s'|}^{J+s'} \sqrt{4\pi (2l + 1)} C_{l0s}^{JM} C_{l's'}^{J\sigma} \hat{R}_{l'l'}^{J's'} (E)$$

Factorization using penetrability assumption for energy dependence:

$$Y_{lm}(\cos \theta, \phi) = \sqrt{\frac{2l + 1}{4\pi}} P_{lm}(\cos \theta e^{im\phi})$$

Penetrability function

Energy-independent matrix element

Penetrability function

Energy-independent matrix element

Complex partial wave

$R_{\ell' \ell}^{J's'} (E) = C(E) \hat{R}_{\ell' \ell}^{J's'}$
Theory. Partial wave expansion for scattering amplitude two-body reaction with spin $\frac{1}{2}+\frac{1}{2}$

Differential cross section of the reaction with polarized particles:

$$\frac{d\sigma}{d\Omega} = Spur[\hat{A} \cdot \rho \cdot \hat{A}^+]$$

$$B^s_{\sigma'\sigma} = \frac{1}{2i \sqrt{k_i k_f}} \sum_{J=0}^{\infty} \sum_{l=|J-s|}^{J+s} \sum_{J'}^{J+\sigma} i^{l-l'} \sqrt{4\pi (2l+1)} C_{l0s}^{JM} C_{l's'\sigma'\sigma} R_{l'l'} s' Y_{l'} \sigma' - \sigma'$$

6 transitions due to the total spin and orbital angular momenta

All states with partial waves up to $\ell=4$ taken into account

<table>
<thead>
<tr>
<th></th>
<th>$S \rightarrow S'$</th>
</tr>
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<tbody>
<tr>
<td>a</td>
<td>$0 \rightarrow 0$ Singlet-singlet $a^J_{l1}$</td>
</tr>
<tr>
<td>b</td>
<td>$0 \rightarrow 1$ Singlet-triplet $b^J_{l1}$</td>
</tr>
<tr>
<td>c</td>
<td>$1 \rightarrow 0$ Triplet-singlet $c^J_{l1}$</td>
</tr>
<tr>
<td>d</td>
<td>$1 \rightarrow 1$ Triplet-triplet $d^J_{l1}$</td>
</tr>
<tr>
<td>e</td>
<td>$2 \rightarrow 0$ Quintet-singlet $e^J_{l1}$</td>
</tr>
<tr>
<td>f</td>
<td>$2 \rightarrow 1$ Quintet-triplet $f^J_{l1}$</td>
</tr>
</tbody>
</table>

Amplitude: matrix $4 \times 9$

$$A = \begin{pmatrix}
B_{12}^{12} & B_{12}^{11} & B_{12}^{10} & B_{12}^{11} & B_{12}^{10} & B_{12}^{11} & B_{12}^{10} & B_{12}^{11} & B_{12}^{10} \\
B_{02}^{12} & B_{02}^{11} & B_{02}^{10} & B_{02}^{11} & B_{02}^{10} & B_{02}^{11} & B_{02}^{10} & B_{02}^{11} & B_{02}^{10} \\
B_{02}^{12} & B_{02}^{11} & B_{02}^{10} & B_{02}^{11} & B_{02}^{10} & B_{02}^{11} & B_{02}^{10} & B_{02}^{11} & B_{02}^{10} \\
B_{12}^{12} & B_{12}^{11} & B_{12}^{10} & B_{12}^{11} & B_{12}^{10} & B_{12}^{11} & B_{12}^{10} & B_{12}^{11} & B_{12}^{10} \\
B_{10}^{12} & B_{10}^{11} & B_{10}^{10} & B_{10}^{11} & B_{10}^{10} & B_{10}^{11} & B_{10}^{10} & B_{10}^{11} & B_{10}^{10} \\
B_{01}^{12} & B_{01}^{11} & B_{01}^{10} & B_{01}^{11} & B_{01}^{10} & B_{01}^{11} & B_{01}^{10} & B_{01}^{11} & B_{01}^{10} \\
B_{00}^{12} & B_{00}^{11} & B_{00}^{10} & B_{00}^{11} & B_{00}^{10} & B_{00}^{11} & B_{00}^{10} & B_{00}^{11} & B_{00}^{10} \\
B_{00}^{12} & B_{00}^{11} & B_{00}^{10} & B_{00}^{11} & B_{00}^{10} & B_{00}^{11} & B_{00}^{10} & B_{00}^{11} & B_{00}^{10} \\
B_{00}^{12} & B_{00}^{11} & B_{00}^{10} & B_{00}^{11} & B_{00}^{10} & B_{00}^{11} & B_{00}^{10} & B_{00}^{11} & B_{00}^{10} \\
\end{pmatrix}$$

$$B_{00}^{00} = \frac{1}{i k_f k_i} [a_{00}^0 P_0 + 5a_{22}^2 + 9a_{44}^4 P_4]$$

$$B_{10}^{10} = \frac{1}{2i k_f k_i} \left[ \frac{5}{\sqrt{3}} b_{22}^2 P_{21} + \frac{9}{\sqrt{10}} b_{44}^4 P_{41} \right]$$

$$B_{12}^{12} = \frac{1}{2i k_f k_i} \left[ \left( -\frac{10}{3} \sqrt{\frac{1}{7} f_{22}^2 + \frac{2}{3} \sqrt{\frac{5}{2} f_{20}^2 - \frac{5}{3} \sqrt{2} f_{22}^3 + \frac{1}{3} \sqrt{\frac{5}{7} f_{24}^2 + \frac{2}{3} \sqrt{5} f_{24}^3}} \right) P_{21} + \ldots \right]$$
Theory. Partial wave expansion for scattering amplitude two-body reaction with spin 1+1 → 1/2+1/2

Differential cross section of the reaction with polarized particles:

\[
\frac{d\sigma}{d\Omega} = Spur[\hat{A} \cdot \rho \cdot \hat{A}^+] 
\]

Amplitude: matrix 4×9

\[
A = \begin{pmatrix}
B^{12}_{1/2} & B^{12}_{11} & B^{12}_{11} & B^{12}_{10} & B^{12}_{10} & B^{12}_{10} & B^{12}_{10} & B^{12}_{10} & B^{12}_{10} \\
B^{02}_{1/2} & B^{02}_{11} & B^{02}_{11} & B^{02}_{10} & B^{02}_{10} & B^{02}_{10} & B^{02}_{10} & B^{02}_{10} & B^{02}_{10} \\
B^{02}_{1/2} & B^{02}_{11} & B^{02}_{11} & B^{02}_{10} & B^{02}_{10} & B^{02}_{10} & B^{02}_{10} & B^{02}_{10} & B^{02}_{10} \\
B^{12}_{12} & B^{12}_{11} & B^{12}_{11} & B^{12}_{10} & B^{12}_{10} & B^{12}_{10} & B^{12}_{10} & B^{12}_{10} & B^{12}_{10} \\
\end{pmatrix}
\]

\[
B^{s's'}_{\sigma'\sigma} = \frac{1}{2i \sqrt{k_i k_f}} \sum_{J=0}^{\infty} \sum_{l=-J}^{J} \sum_{l'=-J}^{J} i^{l-l'} \sqrt{4\pi(2l+1)} C_{l0\sigma}^{JM} C_{l'\sigma'-\sigma}^{J\sigma} R_{l' l}^{s's'} Y_{l' \sigma'-\sigma'}
\]

6 transitions due to the total spin and orbital angular momenta

All states with partial waves up to \(\ell=4\) taken into account

\[
B^{00}_{00} = \frac{1}{i \sqrt{k_i k_f}} \left[ a^{0}_{00} P_0 + 5a^{2}_{22} + 9a^{4}_{44} P_4 \right]
\]

\[
B^{10}_{10} = \frac{1}{2i \sqrt{k_i k_f}} \left[ \frac{5}{\sqrt{3}} b^{2}_{22} P_{21} + \frac{9}{\sqrt{10}} b^{4}_{44} P_{41} \right]
\]

\[
\frac{d\sigma_0}{d\Omega} = \frac{1}{9} (|A_{11}|^2 + |A_{12}|^2 + |A_{13}|^2 + |A_{14}|^2 + |A_{15}|^2 + |A_{16}|^2 + |A_{17}|^2 + \ldots + |A_{49}|^2)
\]

\[
B^{12}_{12} = \frac{1}{2i \sqrt{k_i k_f}} \left[ \left( -\frac{10}{3} \sqrt{\frac{1}{7} f_{22}^2 + \frac{2}{3} \sqrt{\frac{5}{2} f_{20}^2 - \frac{5}{3} \sqrt{2} f_{22}^3 + \frac{1}{3} \sqrt{\frac{5}{7} f_{24}^2 + \frac{2}{3} \sqrt{5} f_{24}^3} } \right) P_{21} + \ldots \right]
\]

25
Minimization procedure

\[
\chi^2 = (\mathbf{O} - [M] \cdot \mathbf{A})^T V_o^{-1} (\mathbf{O} - [M] \cdot \mathbf{A})
\]
We can take into account all states with partial waves up to $\ell=4$. 
We can take into account all states with partial waves up to $\ell = 4$. Here $\ell = 2$ for comparison with H.Paetz gen Schieck’s group result.
Conclusions

Data on polarized d-d cross sections will provide useful and expected information in nuclear fusion with polarized fuel and astrophysics.

The experimental setup is under construction.
Data on polarized d-d cross sections will provide expected information in nuclear fusion with polarized fuel and astrophysics

The experimental setup is under construction

Agreement for collaboration PREFER is signed (Polarization Research for Fusion Experiments and Reactors)
Conclusions

Data on polarized d-d cross sections will provide expected information in nuclear fusion with polarized fuel and astrophysics.

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We are looking forward for financial supports for hardware and manpower.

2 new Phd students started in Summer 2018.

Thank you!