THE DOUBLE-POLARIZED DD-FUSION EXPERIMENT + DETECTOR SYSTEM

P. Kravtsov

for the PolFusion collaboration
The experiment goal

Investigation of 4-nucleons reaction with polarization of the both initial particles at 10-100 keV energy (center of mass).
dd-fusion experiments

Deuterium Fusion experiments

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


Franz et al. Nucl.Phys. A 122 (1968)
Theus et al. Nucl.Phys. 80 (1966)
Wenzel et al. Phys.Rev.88 (1952)
The Quintet suppression factor

Direct experiment required!

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

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

Petersburg Nuclear Physics Institute, Russia
Forschungszentrum Jülich, Germany
Cologne University, Germany

University ITMO, St. Petersburg, Russia
KVI, Gronningen, Netherlands

Ferrara University, Italy

Financial support: RSF (2014-2016)
The layout of the experiment

$^3\text{He}^{2+}$ (0.8 MeV),
$^3\text{H}^+$ (1.0 MeV)

Luminosity: $3.3 \times 10^{25}$ 1/cm$^2$ s
Count rate: $\sim 120$/h (30 keV)
3 week beam time

Polarized Ion Source
Ion beam: $I = 20 \, \mu$A
$(1.3 \times 10^{14} \, \text{d/s})$
$E_{\text{beam}} = 32$ keV
Vector polarization: $\pm 0.7$

Ferrara (IUCF) ABS
$I \sim 4 \times 10^{16}$ at/s
Target density $\sim 2.7 \times 10^{11}$ at/cm$^2$
Vector polarization: $\pm 0.7$

dd-polarimeter
or LSP

$\vec{d}^0$ (0.1 eV)

$\vec{d}^+ + \vec{d}^- \rightarrow \begin{cases} ^3\text{He}^{2+} + n + e \\ ^3\text{H}^+ + p + e \end{cases}$

Ion source

$\vec{d}^+$ (1-32 keV)

Lamb-Shift Polarimeter

$n$ (2.4 MeV),
p (3.0 MeV)

(60000 events)
Polarized ion source (POLIS)

POLIS

✓ Ion current at the source up to 20uA
✓ Magnets power supplies
✓ Vacuum system problems
☐ Unstable beam
☐ New ionizer for energy up to 100keV
• High voltage (100kV)
• Microwave 2.45GHz ~200W
• Uniform magnetic field (875G)
• Gradient magnetic field
• Helium for plasma ignition
Polarized atomic beam source (ABS)

**Ferrara ABS**
- Dissociator upgrade
- Nozzle cooling
- Control system
- Vacuum system
- RF transition units
ABS nozzle cooling

Stable temperature down to 55K
• New schematic for better matching with generator
• Geometry optimization of RF circuit
• Reflected power decreased from 150W to 3W (@250W)
• Two-channel RF matchbox with splitter to feed both dissociators from single generator
Normal operation

POLIS
Detector
Deflector
Ioniser
LSP

Abs

POLIS Tuning

POLIS
Detector
Deflector
NRP
LSP

ABS
Polarimetry. LSP ionizer

Magnets (1000G)
Extractor and focusing
Ionizer cell
Cathode
Polarimetry. LSP Na cell

[Image of a 3D diagram of a system labeled with numbers and a photograph of a related setup]
Polarimetry. Deflector for NRP
The observables in the $d+d \rightarrow ^3\text{He}+n$ and $d+d\rightarrow ^3\text{H}+p$ reactions with polarized deuterons
Detector system design

Detector chamber

Helmholtz coils

Readout electronics connectors

NdFeB permanent magnets

Detector system

Detector chamber
Magnet system

B = 300 G = 2.5 Bc

Magnet field is generated by 24 permanent magnets with dimensions 80 x 40 x 10 mm³ with pole tip field of 1.25 T at the surface (NdFeB N40)
Detector system. PIN diodes version.

- 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)

Square detector elements (4x4 diodes)
Standard PCB assembly with spring through-hole mounting (no solder!)
Simulation of the detector system

P. Kravtsov

03.02.2017
PIN-diodes test bench

- Preamplifier
- Oscilloscope
- Vacuum chamber
- Detector
- Bleeding valve
- Turbopump
- Forepump
- $\text{H}_2$
- Alpha-source:
  - $^{239}\text{Pu} + ^{240}\text{Pu} = 80.4\%$
  - $^{238}\text{Pu} + ^{241}\text{Am} = 19.6\%$
  - $^{234}\text{U} + ^{235}\text{U} + ^{238}\text{U}$
  - $^{241}\text{Am}$
PIN diode test measurements

- Dead layer thickness measurement \((D \leq 1\mu m)\)
  

- Active area uniformity tests
  
  Inhomogeneity <0.5% for the whole active area

- Hydrogen vacuum performance
  
  Better 0.16% stability at hydrogen pressure of \(10^{-4}\) mbar.

  Expected vacuum in the experiment \(10^{-5} \div 10^{-6}\) mbar.
Detector system assembly
Readout electronics

Readout requirements:
- 600 channels
- Total count rate \( \leq 1 \text{kHz} \)
- Standard interface (Ethernet?)
- Event synchronization for coincidence trigger

CSP from ATLAS CSC [BNL]

ASF48 readout board
Readout signal processing

Benefits
- Precise analytical fit
- No baseline dependence
- Best resolution (<=5LSB)
Energy resolution

Test pulse

**E = 1000 keV**

**RMS = 0.49% = 4.9 keV**

(15 keV with cable and $C_{det} = 40 \text{pF}$)
Signal quality checks:
- ADC range clipping
- Signal shape (derivatives)
- Peaks position
Solid target experiment

Target: deuterated polymethylmethacrylate
Deuteron beam 15keV ~5uA
Solid target results

$^3\text{He}^{2+}$

$^3\text{He}^{2+}$

$t$

$p$
Full scale readout electronics (ASF-48)

Concentrator CROS3

Power distributor (5V 40A)

ASF48 (12+1)
Data acquisition software

- ASF48 test software
- Full scale DAQ software based on MIDAS (Maximum Integrated Data Acquisition System)
  http://midas.psi.ch
  - Flexible distributed DAQ system
  - Web interface for run control and monitoring
  - Data transfer / logging capability
  - Online data monitoring
  - Online database
  - Message logging
  - Alarms
Data acquisition software

Run Status
Running time: 0h04m00s
Alarms: On
Restart: Yes
Data dir: /home/lkst/online/

Experiment Name: polfu

12:59:51 [ASF48,INFO] FIFO is almost full: c40003e2

Equipment

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Status</th>
<th>Events</th>
<th>Events/s</th>
<th>Data[MB/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASF48</td>
<td>ASF48@localhost</td>
<td>71771</td>
<td>303.8</td>
<td>1.725</td>
</tr>
</tbody>
</table>

Logging Channels

<table>
<thead>
<tr>
<th>Channel</th>
<th>Events</th>
<th>MiB written</th>
<th>Compr.</th>
<th>Disk level</th>
</tr>
</thead>
<tbody>
<tr>
<td>#0: run00030.mld</td>
<td>71880</td>
<td>408.750</td>
<td>N/A</td>
<td>11.4 %</td>
</tr>
</tbody>
</table>

Clients

- mhttpd [localhost]
- ASF48 [localhost]
- Logger [localhost]
- Analyzer [localhost]
Thank you!
BACKUP
# Hyperfine states

<table>
<thead>
<tr>
<th></th>
<th>ABS</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>85% value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFS after Sextupole 1</td>
<td>MFT</td>
<td>HFS after Sextupole 2</td>
<td>SFT</td>
<td>WFT</td>
<td>HFS after ABS</td>
<td>Pz</td>
<td>Pzz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1, 2, 3</td>
<td>---</td>
<td>1, 2, 3</td>
<td>---</td>
<td>---</td>
<td>1, 2, 3</td>
<td>+1/3</td>
<td>-1/3</td>
<td>0.272</td>
<td>-0.332</td>
</tr>
<tr>
<td>1, 2, 3</td>
<td>1-4</td>
<td>2, 3</td>
<td>---</td>
<td>---</td>
<td>2, 3</td>
<td>0</td>
<td>-1</td>
<td>-0.02</td>
<td>-0.85</td>
</tr>
<tr>
<td>1, 2, 3</td>
<td>3-4</td>
<td>1, 2</td>
<td>---</td>
<td>---</td>
<td>1, 2</td>
<td>+2/3</td>
<td>0</td>
<td>+0.561</td>
<td>-0.02</td>
</tr>
<tr>
<td>1, 2, 3</td>
<td>3-4</td>
<td>1, 2</td>
<td>---</td>
<td>on</td>
<td>3, 4</td>
<td>-2/3</td>
<td>0</td>
<td>-0.561</td>
<td>+0.02</td>
</tr>
<tr>
<td>1, 2, 3</td>
<td>3-4</td>
<td>1, 2</td>
<td>2-6</td>
<td>---</td>
<td>1, 6</td>
<td>+5/6</td>
<td>+0.5</td>
<td>+0.714</td>
<td>+0.434</td>
</tr>
<tr>
<td>1, 2, 3</td>
<td>1-4</td>
<td>2, 3</td>
<td>2-6</td>
<td>---</td>
<td>3, 6</td>
<td>+1/6</td>
<td>-0.5</td>
<td>+0.145</td>
<td>-0.391</td>
</tr>
<tr>
<td>1, 2, 3</td>
<td>1-4</td>
<td>2, 3</td>
<td>3-5</td>
<td>---</td>
<td>2, 5</td>
<td>-1/6</td>
<td>-0.5</td>
<td>-0.145</td>
<td>-0.459</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>POLIS</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>75% value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFS after Sextupole 1</td>
<td>MFT</td>
<td>HFS after Sextupole 2</td>
<td>SFT</td>
<td>WFT</td>
<td>HFS after ABS</td>
<td>Pz</td>
<td>Pzz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1, 2, 3</td>
<td>---</td>
<td>1, 2, 3</td>
<td>---</td>
<td>---</td>
<td>1, 2, 3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1, 2, 3</td>
<td>1-4</td>
<td>2, 3</td>
<td>---</td>
<td>---</td>
<td>2, 3</td>
<td>-0.5</td>
<td>-0.5</td>
<td>-0.375</td>
<td>-0.375</td>
</tr>
<tr>
<td>1, 2, 3</td>
<td>3-4</td>
<td>1, 2</td>
<td>---</td>
<td>---</td>
<td>1, 2</td>
<td>+0.5</td>
<td>-0.5</td>
<td>+0.375</td>
<td>-0.375</td>
</tr>
<tr>
<td>1, 2, 3</td>
<td>3-4</td>
<td>1, 2</td>
<td>---</td>
<td>on</td>
<td>3, 4</td>
<td>-1</td>
<td>+1</td>
<td>-0.75</td>
<td>+0.75</td>
</tr>
<tr>
<td>1, 2, 3</td>
<td>3-4</td>
<td>1, 2</td>
<td>2-6</td>
<td>---</td>
<td>1, 6</td>
<td>+1</td>
<td>+1</td>
<td>+0.75</td>
<td>+0.75</td>
</tr>
<tr>
<td>1, 2, 3</td>
<td>1-4</td>
<td>2, 3</td>
<td>2-6</td>
<td>---</td>
<td>3, 6</td>
<td>0</td>
<td>+1</td>
<td>+0.02</td>
<td>+0.75</td>
</tr>
<tr>
<td>1, 2, 3</td>
<td>1-4</td>
<td>2, 3</td>
<td>3-5</td>
<td>---</td>
<td>2, 5</td>
<td>0</td>
<td>-2</td>
<td>-0.02</td>
<td>-1.5</td>
</tr>
</tbody>
</table>
Unpolarized cross sections

\[ \sigma(^{2}H(d,n)^{3}He) \]

\[ \sigma(^{2}H(d,p)^{3}H) \]