G9A-FROST
Experiments

New generation of CLAS photoproduction experiments with FROzen Spin Polarized Target (FROST)

- E02-112: $\gamma p \rightarrow KY$ (K$^+$, K$^+$, K$^0$, K$^0$)
- E03-105/E04-102: $\gamma p \rightarrow \pi^0 p, \pi^+ n$
- E05-012: $\gamma p \rightarrow \eta p$
- E06-013: $\gamma p \rightarrow \pi^+ \pi^- p$

Goal: study of exited baryons.

Next step (after g1 and g8) towards “complete experiment”
Running configurations

Four possible combinations of beam-target polarization:

**g9a this fall:**
- circularly polarized beam, longitudinally polarized target
- linearly polarized beam, longitudinally polarized target

**g9b in 2009:**
- circularly polarized beam, transversely polarized target
- linearly polarized beam, transversely polarized target
Target material: butanol (C₄H₉OH) 50 mm long, 15 mm diameter

Dynamical polarization using microwaves outside of CLAS in high magnetic field (5T) at a temperature of about 1K.

Switch to “Frozen” mode: temperature < 50 mK, holding magnetic field ~0.5T.

Relaxation time of the order of a few hundreds hours.
FROST running configuration
FROST polarizing configuration
\[
\frac{1}{\sigma_0} \cdot \frac{d\sigma}{d\Omega} = 1
\]

\[-P_{\Omega} P_{Z}^{\text{lab}} \cdot E
\]

\[+ P_{XY}^{\text{lab}} \cdot \sin(\beta - \phi) \cdot T
\]

\[+ P_{\Omega} P_{XY}^{\text{lab}} \cdot \cos(\beta - \phi) \cdot F
\]

\[-P_{T} \cdot \cos 2(\alpha - \phi) \cdot \Sigma
\]

\[+ P_{T} P_{Z}^{\text{lab}} \cdot \sin 2(\alpha - \phi) \cdot G
\]

\[-P_{T} P_{XY}^{\text{lab}} \cdot \cos(\beta - \phi) \sin 2(\alpha - \phi) \cdot H
\]

\[-P_{T} P_{XY}^{\text{lab}} \cdot \sin(\beta - \phi) \cos 2(\alpha - \phi) \cdot P
\]

<table>
<thead>
<tr>
<th>Photon</th>
<th>Target</th>
<th>Recoil</th>
<th>Target + Recoil</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
<td>x'</td>
<td>x'</td>
</tr>
<tr>
<td>-</td>
<td>x</td>
<td>y'</td>
<td>y'</td>
</tr>
<tr>
<td>-</td>
<td>z</td>
<td>-</td>
<td>z'</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

| unpolarized | \begin{array}{cccccccc}
\sigma_0 & 0 & T & 0 & 0 & P & 0 & T_{z'} & -L_{z'} \\
\end{array} |
| linear pol. | \begin{array}{cccccccc}
-\Sigma & H & (-P) & -G & O_{z'} & (-T) & O_{z'} & (-L_{z'}) & (T_{z'}) \\
\end{array} |
| circular pol. | \begin{array}{cccccccc}
0 & F & 0 & -E & -C_{x'} & 0 & -C_{z'} & 0 & 0 & 0 & 0
\end{array} |
Circularly Polarized photon beam on longitudinally polarized target

\[
\frac{1}{\sigma_0} \cdot \frac{d\sigma}{d\hat{\Omega}} = 1
\]

\[-P_\perp P_Z^{\text{lab}} \cdot E
\]

\[+P_{XY}^{\text{lab}} \cdot \sin(\beta - \phi) \cdot T
\]

\[+P_{XY}^{\text{lab}} \cdot \cos(\beta - \phi) \cdot F
\]

\[-P_T \cdot \cos 2(\alpha - \phi) \cdot \Sigma
\]

\[+P_T P_Z^{\text{lab}} \cdot \sin 2(\alpha - \phi) \cdot G
\]

\[-P_T P_{XY}^{\text{lab}} \cdot \cos(\beta - \phi) \sin 2(\alpha - \phi) \cdot H
\]

\[-P_T P_{XY}^{\text{lab}} \cdot \sin(\beta - \phi) \cos 2(\alpha - \phi) \cdot P
\]

<table>
<thead>
<tr>
<th>Photon</th>
<th>Target</th>
<th>Recoil</th>
<th>Target + Recoil</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
<td>x'</td>
<td>x'</td>
</tr>
<tr>
<td>-</td>
<td>x</td>
<td>y</td>
<td>z</td>
</tr>
<tr>
<td>-</td>
<td>z</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>x'</td>
<td>x'</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>z'</td>
<td>z'</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>z'</td>
<td>z'</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>z'</td>
<td>z'</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unpolarized</td>
<td>\sigma_0</td>
<td>0</td>
<td>T</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>linear pol.</td>
<td>-\Sigma</td>
<td>H</td>
<td>(-P)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>circular pol.</td>
<td>0</td>
<td>F</td>
<td>0</td>
</tr>
</tbody>
</table>
Linearly Polarized photon beam on longitudinal polarized target

\[
\frac{1}{\sigma_0} \cdot \frac{d\sigma}{d\Omega} = 1
\]

\[-P_\odot P_Z^{\text{lab}} \cdot E + P_{XY}^{\text{lab}} \cdot \sin(\beta - \phi) \cdot T + P_\odot P_{XY}^{\text{lab}} \cdot \cos(\beta - \phi) \cdot F - P_T \cdot \cos 2(\alpha - \phi) \cdot \Sigma + P_T P_Z^{\text{lab}} \cdot \sin 2(\alpha - \phi) \cdot G - P_T P_{XY}^{\text{lab}} \cdot \cos(\beta - \phi) \sin 2(\alpha - \phi) \cdot H - P_T P_{XY}^{\text{lab}} \cdot \sin(\beta - \phi) \cos 2(\alpha - \phi) \cdot P\]

<table>
<thead>
<tr>
<th>Photon</th>
<th>Target</th>
<th>Recoil</th>
<th>Target + Recoil</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-</td>
<td>x</td>
<td>y</td>
<td>z</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>x'</td>
<td>y'</td>
<td>z'</td>
<td>x</td>
</tr>
<tr>
<td>x'</td>
<td>y'</td>
<td>z'</td>
<td>z</td>
</tr>
</tbody>
</table>

| unpolarized | \(\sigma_0\) | 0 | T | 0 | 0 | \(P\) | 0 | \(T_{z'}\) | \(-L_{x'}\) | \(T_{z'}\) | \(L_{z'}\) |
| linear pol. | -\(\Sigma\) | H | (-P) | -G | \(O_{z'}\) | (-T) | \(O_{z'}\) | (-L_{z'}\) | (T_{z'}) | (-L_{x'}\) | (-T_{x'}) |
| circular pol. | 0 | F | 0 | -E | \(-C_{x'}\) | 0 | \(-C_{z'}\) | 0 | 0 | 0 | 0 |
\[ \frac{d\sigma}{d\chi_i} = \sigma_0 \left\{ \left( 1 + \Lambda_z \cdot P_z \right) + \delta_\odot \left( I^\odot + \Lambda_z \cdot P_z^\odot \right) \right\} \]

\[ (\Rightarrow \Rightarrow - \Leftarrow \Leftarrow) := \frac{d\sigma(\Rightarrow \Rightarrow)}{d\chi_i} - \frac{d\sigma(\Leftarrow \Leftarrow)}{d\chi_i} = 2 \cdot \sigma_0 \left\{ \delta_\odot \left( I^\odot + \Lambda_z \cdot P_z^\odot \right) \right\} \]

\[ (\Leftarrow \Leftarrow - \Rightarrow \Rightarrow) := \frac{d\sigma(\Leftarrow \Leftarrow)}{d\chi_i} - \frac{d\sigma(\Rightarrow \Rightarrow)}{d\chi_i} = 2 \cdot \sigma_0 \left\{ \delta_\odot \left( -I^\odot + \Lambda_z \cdot P_z^\odot \right) \right\} \]

1) \( (\Rightarrow \Rightarrow - \Leftarrow \Leftarrow) + (\Leftarrow \Leftarrow - \Rightarrow \Rightarrow) := \frac{d\sigma_{3/2}}{d\chi_i} - \frac{d\sigma_{1/2}}{d\chi_i} = 4 \cdot \sigma_0 \cdot \delta_\odot \cdot (\Lambda_z \cdot P_z^\odot) \)

2) \( (\Leftarrow \Leftarrow - \Leftarrow \Leftarrow) - (\Rightarrow \Rightarrow - \Rightarrow \Rightarrow) := -4 \cdot \sigma_0 \cdot (\Lambda_z \cdot P_z) \)
Experiment configuration

- Torus current 1920 A. Out bending positive particles.
- Three targets:
  - 5 cm long polarized butanol at nominal CLAS center
  - 1.5 mm thick $^{12}$C disk, 6 cm downstream of CLAS center
  - 3.5 mm thick CH2 disk, 16 cm downstream of CLAS center
- Trigger: at least one charged particle in CLAS
  - L1: ST.AND.TOF.AND.L2 sector based
  - 2.6 mm collimator for circularly polarized beam
  - 2 mm collimator for linearly polarized beam
**Startup plan**

- Take everything out of the beam line: radiator, collimator, converter, TAC, photon profiler.
- Verify with MCC that they have set up machine fast shutdown interlock from the tagger magnet.
- Let MCC establish beam in the Hall and tune it on the tagger dump.
- Ask MCC to set up digitizer on the tagger dump viewer to monitor electron beam position on the dump. Have strip-chart running for that.
- Set the beam current to 5 nA.
- Harp scans. Have width better than 150 μm and shoulder-to-peak ratio better than 10-4 on the tagger harp.
- Put the 10-4 r.l. radiator in.
- Ramp up pair spectrometer magnet and put converter in.
- Do photon harp scan with no collimation and 6.4 mm collimator.
- Center beam on the collimator using rates in the start counter and rates in the pair spectrometer with and without collimation. Use the larger collimator (6.4 mm) for alignment. Do a horizontal scan of the collimator position. After it is centered horizontally, do a vertical scan with MCC steering the beam vertically. If it turns out that when beam is centered on the collimator but off-center on the target, we would need to adjust the height of the collimator box using its supporting screws.
- Insert 2.6 mm collimator and recheck its alignment.
- Plateau tagger HV if necessary.
- Calibrate the SLM.
- Make sure MCC gives us control of the attenuator and adjust the beam charge asymmetry to 0.
- Perform a Moller run.
Startup plan

- Have all CLAS detectors ON and ready.
- Check that the L2 segment collectors are working.
- Start DAQ and make sure that we have data coming from all detectors.
- Check all on-line histograms. Pay special attention to the TOF decoupled paddles (at back angles). Establish a reference histogram set for monitoring.
- Check trigger rates.
- In fast reconstruction, check that we see three targets: the main one (5-cm long butanol) located at the nominal CLAS center, $^{12}\text{C}$ about 6 cm downstream of the CLAS center, and $\text{CH}_2$ about 16 cm downstream of the CLAS center.
- Choose beam intensity. Some factors to consider include:
  - Trigger rate. Live time >80%
  - Tagger rate. Singles rate of T-counters <4 MHz.
  - DC occupancy <2%.
- As soon as we have some data taken, cook the files and perform a TOF calibration to see if all software modifications work as expected.
Schedule

Commissioning
October 23 - October 26 at 2.705 GeV/p 5 pass
October 27 Linac Energy change to 0.5 GeV
October 27- October 29 at 2.528 GeV/p 5 pass

Production
October 30 - November 5 at 2.528 GeV/p 5 pass
November 6 Linac Energy change to 0.8 GeV
November 6 at 2.445 GeV/p 3 pass
November 7 pass change to 2 pass
November 7 - November 19 at 1.645 GeV/p
November 20 - November 26 Holiday. Down.
November 27 Linac Energy change to 0.611 GeV
November 27 - December 6 at 2.478 GeV/p 4 pass
December 7 Linac Energy change to 0.7 GeV
December 7 - December 20 at 3.539 GeV 5 pass linearly polarized beam
December 21 - January 3 Holidays. Down.
January 4 Linac Energy change to 0.9 GeV
January 4 - January 10 at 1.851 GeV/p 2 pass
January 11 Linac Energy change to 0.379 GeV
January 15 Linac Energy change to 0.908 GeV
January 15 - January 30 at 4.591 GeV 5 pass linearly polarized beam
January 31 Shutdown
Running pattern

- Polarize target
- Do polarization measurement with NMR in high field
- Switch to frozen mode
- Take data for 4 days
- Monitor polarization with NMR in low field
- Do special runs (Moller, normalization)
- Measure residual polarization in high field
- Repolarize target, flip polarization (~ 1 shift)
- .....  

Coordinate repolarization with energy changes and beam studies
General beam parameters

- Instability of the electron beam energy $<10^{-4}$
- Beam spot size at 2C21A and 2C24A
  $\sigma_x < 150 \, \mu m$, $\sigma_y < 150 \, \mu m$
- Beam position instabilities at 2C21A and 2C24A $<100 \, \mu m$
- Beam halo at the tagger harp (shoulder/peak) $\sim 10^{-4}$
- Beam current $\sim 20 \, nA$
- Instability of beam current $<5\%$
- In no circumstances beam spot position on the tagger dump should be adjusted by changing tagger magnet current!
- **Machine fast shutdown interlocked with the tagger magnet.**
Circularly polarized beam

- $10^{-4}$ radiation length radiator at 2C24A
- 2.6 mm collimator.
- Maximum polarization of the electron beam.
- Beam charge asymmetry $<5 \times 10^{-4}$
- Bleedthrough from other halls $<10^{-3}$
- Beam halo at the tagger harp (shoulder/peak) $\sim 10^{-4}$
- Half-wave plate IN-OUT periodically
- Møller runs every few days
- Normalization runs with Total Absorption Counter in the beam at very low intensity ($<50$ pA) every few days.
Linearly polarized beam

- 50 μm Diamond radiator on the goniometer at 2C21A
- 2 mm collimator
- All magnets between 2C21A and tagger degaussed and OFF!
- Equal spot size at 2C21A and 2C24A
- Position stability is very important.
Holding magnets
FROST in EEL
Installation in Hall B