Vertically pointing transversely polarized target system for the Drell-Yan experiment E1039

M. Yurov, D. Keller, D. Crabb, D. Day

Solid Polarized Target Group

Spin 2016 09/16, Urbana-Champaign, IL
1. Motivation
2. Subsystems status
3. Full system test
4. Future improvements
Access the sea quark Sivers function by measuring TSSAs in Drell-Yan production

- unpolarized 120 GeV proton beam from Main Injector at Fermilab
- existing E906/SeaQuest spectrometer to detect muon pair
- fixed polarized target
  - high luminosity
  - transversely polarized
  - high polarization proton/deuteron target
Access the sea quark Sivers function by measuring TSSAs in Drell-Yan production

- unpolarized 120 GeV proton beam from Main Injector at Fermilab
- existing E906/SeaQuest spectrometer to detect muon pair
- fixed polarized target
  - solid NH3(ND3) 8 cm long target cell: $1.42 \times 10^{42} (2.11 \times 10^{42}) \text{cm}^{-2}$
  - vertically pointing 5T magnetic field
  - polarization: 80% (32%), dilution: 0.176 (0.3), packing frac.: 0.6
POLARIZED TARGET DY E1039

- NMR
- Insert
- Microwave
- Pumps
- Target material
- Fridge
- Magnet

LN2
LHe
MagnetFridge
Insert
NMR
Microwave
Pumps
Target material
Fridge
Magnet

M. Yurov, UVA
Polarized Target Subsystems

Original design by S. Penttila, Oxford Instr.
kept at LANL storage since ~2000

Feasibility study
shipped to UVA in 2013
1st cooldown 06/2013
Magnet  Fridge  Insert  NMR  Microwave  Pumps  Target material

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Feasibility study
shipped to UVA in 2013
1st cooldown 06/2013

Rotation of the coils
shipped to Oxford Instruments
new configuration, 2nd cooldown
$dB/B < 10^{-4}$ on 3d grid, 5T over 8cm
Back to UVA
3rd cooldown, rotated coils test
magnet is in a very good shape
POLARIZED TARGET SUBSYSTEMS

Fridge modifications
- replaced separator can
- cleaned heat exchangers oxide/corrosion
- leak checked
- refitted run and bypass valves
- installed new LHe channel
- installed 8 temperature sensors
- manufactured new nose, 10mil window
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Fridge alignment
- made laser setup
- shell, fridge, turret and piston rotation
- target insert length

Fridge tests
- 4th and 5th cooldowns
- reached 1K 07/2015
New insert

four 2.7x2x80mm long target cups
NH3, C disk, empty
six NMR channels (3 per cup)
microwave horn for full cup volume
temperature sensors
He3 bulb line
copper thermal barrier
carbon fiber enclosure
New insert

- four 2.7x2x80mm long target cups
- NH$_3$, C disk, empty
- six NMR channels (3 per cup)
- microwave horn for full cup volume
- temperature sensors
- He3 bulb line
- copper thermal barrier
- carbon fiber enclosure

Insert test

- Warm test is complete
- Load and polarization test
New NMR system developed by LANL
followed general Liverpool design
Q-meter as double wide VME module
1 analog / 1 digital boards, crate controller
16 bit ADCs/DACs, modern RF electronics
USB/Ethernet interface, LabView based DAQ

LANL NMR system tests at UVA
1st NMR cooldown 2014 (total 3 cold tests)
04/2016 full comparison to Liverpool Q-meter
signal/noise ratio - waiting for results
New NMR system developed by LANL followed general Liverpool design
Q-meter as double wide VME module
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1st NMR cooldown 2014 (total 3 cold tests)
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New microwave source
- purchased by LANL
- new EIO tube from CPI, 20W output
- controlled by stepper motor
- new PS with software control UI

Microwave source test
- built setup at UVA in 2015
- checked freq adjustments
- checked cathod HV adjustment
Pumping system

designed and built by Oerlikon

target heat load $\sim 1.4$W

$\mu$-wave: $\sim 1$W, beam: $\sim 0.37$W

3 roots (7000), 1 rotary vane (840)

requires 100L LHe per day

14000 m$^3$/hr pumping capacity

Construction and tests

first assembly at LANL spring 2015

tested and shipped to FNAL

assembled and tested 10/2015
Production
dedicated setup to produce NH3 beads
NH3 gas slowly frozen above LN2 bath
~1000 g is needed for 2 yr run
~450 g currently produced
purchased three LN2 dewars for storage

Pre-Irradiation
creates paramagnetic centers for DNP
14 MeV electron beam under LAr bath
routinely done at NIST (Gaithersburg)
time consuming, trained manpower
~100 g irradiated and ready for experiment
FULL SYSTEM TEST

Final preparations and run

put vacuum chamber back together

leak checked fridge shell + nose

M. Yurov, UVA
FULL SYSTEM TEST

Final preparations and run

installed fridge

fitted turret to UVA pumping system

pipe fitting

back of the turret

front of the turret

fridge
FULL SYSTEM TEST

Final preparations and run
made test target insert, practiced installation

getting cold
FULL SYSTEM TEST

Test results

Fridge performance

magnet fill
~2.5 hrs to bring resistors to 4K
~1 hr to fill magnet can
Test results

Fridge performance

separator and nose fill

~1hr to fill the nose after a night on standby
very stable, very little attention required
Test results

**Polarization**

polarized fresh NH₃ both positively and negatively

took extensive TE measurements

alternated UVA and new LANL NMR systems

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**Graphs and Images**

- **Polarization Increase**
- **UVA NMR Signal**
- **Enhanced Signal**
- **LANL NMR Signal**
FUTURE IMPROVEMENTS

Fast target helicity flips through Adiabatic Fast Passage (AFP)

- Frequent change of target polarization is required
- Crucial to minimize false asymmetry systematic effects
- Traditionally achieved by microwave frequency change
- Takes ~1hr (3-4hrs) for proton (deuteron) targets

**AFP**

- Irradiate with RF field $\perp B_0$
- Pass through resonance by varying RF field frequency
- Under certain RF sweep parameters - reversal of spin direction
Fast target helicity flips through Adiabatic Fast Passage (AFP)

AFP at UVA

performed AFP on different materials (5T, 1K)
15NH3, D-butanol, butanol+tempo
preliminary results on flip efficiency

15NH3

<table>
<thead>
<tr>
<th>Nuclei</th>
<th>Substance dopant</th>
<th>$e^-$ conc. (spins/g)</th>
<th>$\delta \rho_{\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^1\text{H}$</td>
<td>1-butanol EHBA-C(\V)</td>
<td>$2.0 \times 10^{19}$</td>
<td>-0.76</td>
</tr>
<tr>
<td>$^7\text{Li}$</td>
<td>$^7\text{LiH}$</td>
<td>low</td>
<td>-0.90</td>
</tr>
<tr>
<td>$^1\text{H}$</td>
<td>(irradiated)</td>
<td></td>
<td>-0.90</td>
</tr>
<tr>
<td>$^{19}\text{F}$</td>
<td>8-fluoro-1-pentanol</td>
<td>$1 \times 10^{-20}$</td>
<td>-0.37</td>
</tr>
<tr>
<td>$^1\text{H}$</td>
<td>TEMPO</td>
<td></td>
<td>-0.40</td>
</tr>
<tr>
<td>$^2\text{H}$</td>
<td>1-butanol-d$<em>{16}$ EHBA-C(V)-d$</em>{22}$</td>
<td>$2.36 \times 10^{19}$</td>
<td>-0.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$6.35 \times 10^{19}$</td>
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before

flip efficiency 0.55

after
Fast target helicity flips through Adiabatic Fast Passage (AFP)

**AFP at UVA**

performed AFP on different materials (5T, 1K)

15NH3, D-butanol, butanol+tempo

preliminary results on flip efficiency

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<td>1-butanol</td>
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<tr>
<td></td>
<td>EHBA-Cr(V)</td>
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<td></td>
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<tr>
<td>³Li</td>
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<tr>
<td>²H</td>
<td>1-butanol-d₁₆</td>
<td>2.36 × 10¹⁹</td>
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<tr>
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**D-Butanol**

![Graphs showing flip efficiency before and after](image)

flip efficiency >0.8
Fast target helicity flips through Adiabatic Fast Passage (AFP)

AFP at UVA

performed AFP on different materials (5T, 1K)
15NH3, D-butanol, butanol+tempo
preliminary results on flip efficiency

D-Butanol pedestal flip

Table 1
Results from AFP experiments with various nuclei in different target materials

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Automated Microwave Frequency Control of DNP Targets

See Darshana-Perera talk later

- $\mu$-wave optimal frequency for maximum polarization changes over time
- function of radiation dose, number of anneals, environment
- has to be adjusted manually by Target Operator during the run

**UVA recent developments**

- frequency seeking algorithm
- standalone plug & play controller for DC motor driven EIO tubes
- rates and run environment MC simulation
- new LabView package to control stepper motor driven EIO tubes
Rebuilt vertically polarized target system

- 6 dedicated cooldowns at UVA and at Oxford Instr. during ~3yrs
- 2 parasitic cooldowns at UVA for new LANL NMR system
- over $1M investment in equipment, LHe, and manpower
- LANL LRDR funds and UVA DOE grant

Successfully tested 04/2016

- Very stable performance of the magnet and cryogenics
- Polarized NH3 with test target insert
- Designed and manufactured new target insert
- Comparison of UVA and new LANL NMR systems

New studies

- Successfull NH3 AFP, preliminary flip efficiency results
- Automated Microwave Frequency Control of DNP Targets