Overview of SpinQuest Polarized Target System

New Perspectives 2024

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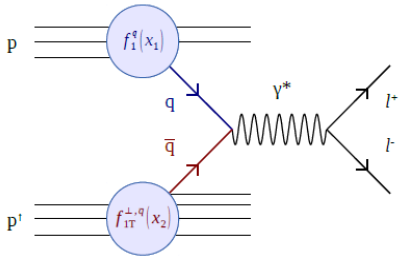
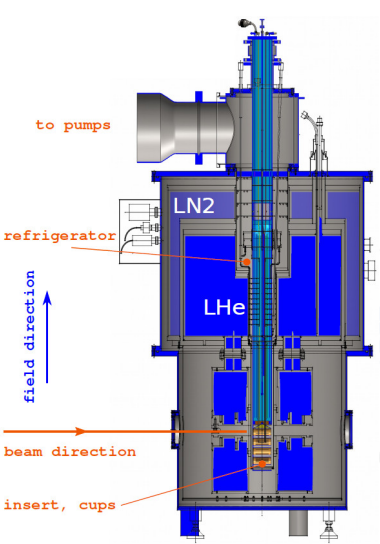
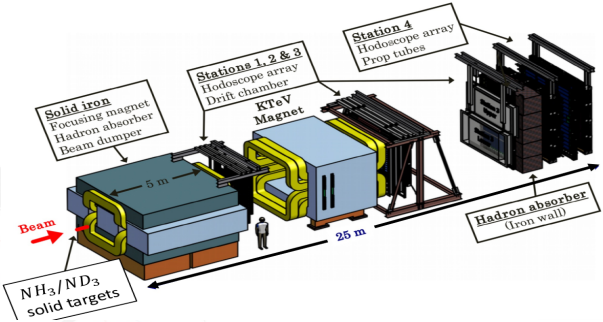
SpinQuest: Motivation and Goals

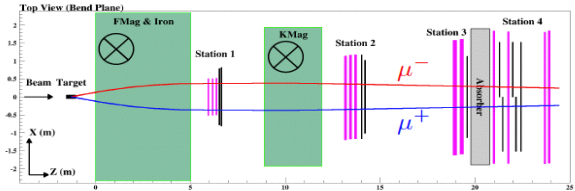
- SpinQuest/E1039 experiment uses a 120 GeV proton beam and transversely polarized targets;
  - Ammonia (NH_3) as a proton target
  - Deuterated ammonia (ND_3) as a neutron target
- SpinQuest aims to help resolving the proton spin puzzle by measuring the Sivers function of sea quarks in Drell-Yan scattering:
  - A non-vanishing Sivers function is an evidence of sea quark's Orbital Angular Momentum
  - OAM of sea quarks could contribute up to $\sim$ 50% of the proton spin
- SpinQuest will also measure the Transverse Single Spin Asymmetry in J/ψ production to access the gluons Sivers function



SpinQuest: Experimental Setup



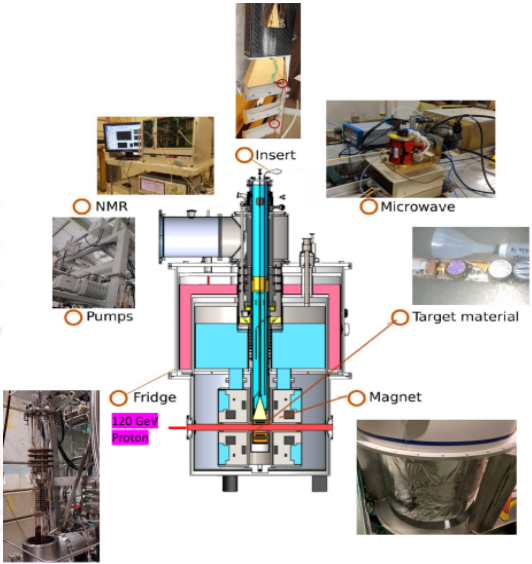




Detailed experimental overview by **Md. Forhad Hossain**

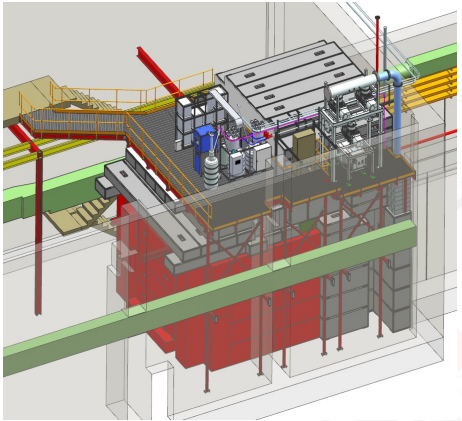
SpinQuest: Polarized Target System

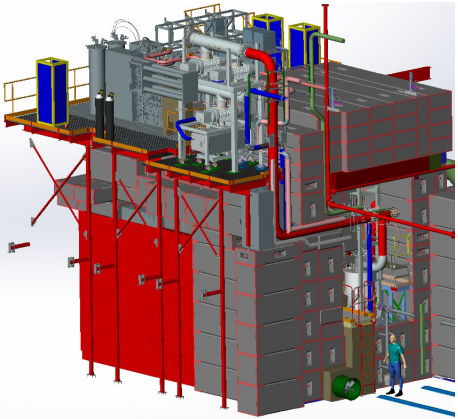
- 5 T superconducting magnet
- 140 GHz microwave source
- Carbon fiber insert with 3 cups
- 3 NMR coils per cup
- Exploit Dynamic Nuclear Polarization technique with maximum polarization of about 80% (35%) for NH_3 (ND_3)
- ^{4}He evaporation refrigerator consisting of 3 W of cooling power to keep the target at 1.1 K with 17,000 m^3/h pumps



Cryogenic System

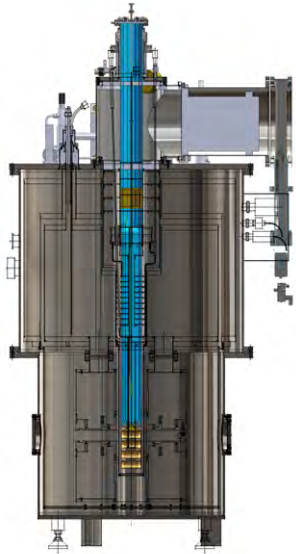
- The SpinQuest cryogenic system has been built from scratch
- The helium liquefaction system has two Dewars each of about 250 L capacity





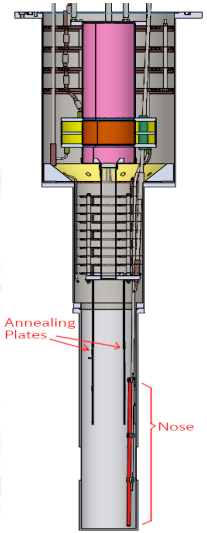
Superconducting Magnet

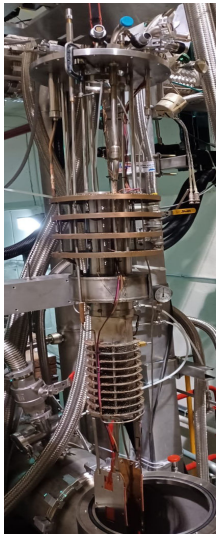
- The magnet consists of NbTi coils impregnated in epoxy to prevent them from moving
- The superconducting magnet coils provide a 5 T uniform transverse magnetic field with $\frac{dB}{B} < 10^{-4}$ over 8 cm



Evaporation Refrigerator

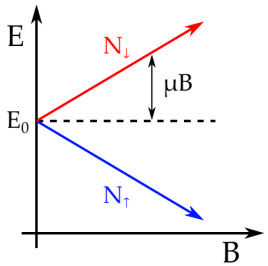
- Critical components of the high cooling system are:
  - High power root pumps with a capacity of 17,000 m^3/h
  - Liquid ^{4}He supply
  - Heat exchanger to lower ^{4}He temperature to 1 K
  - Thermal shielding
- Evaporated ^{4}He is pumped out by high power root pumps to keep the temperature at 1 K and pressure at 0.12 Torr

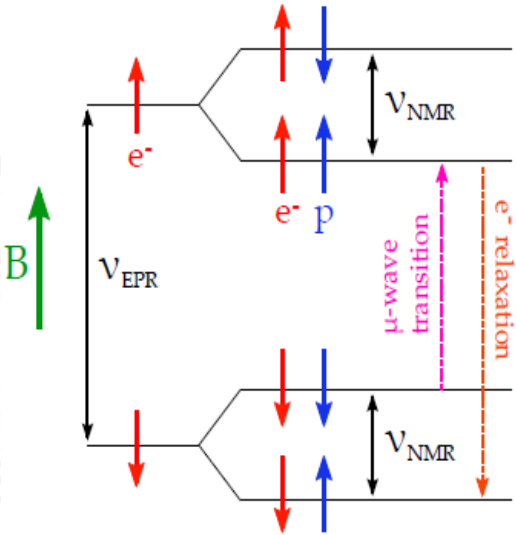




Dynamic Nuclear Polarization

- Degree of polarization at thermal equilibrium: $P_{TE}^{NH_3} = \tanh \frac{\mu B}{kT}$
- Spin polarization is transferred from electrons to nuclei via Radio Frequency irradiation and an external magnetic field
- At temperature of 1 K and 5 T magnetic field, the electron polarization is about 98% compared to 0.3% for protons

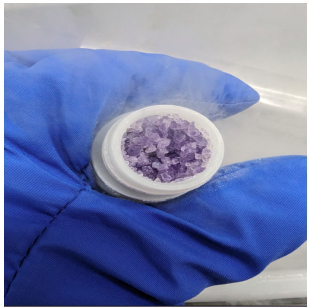




Target Materials

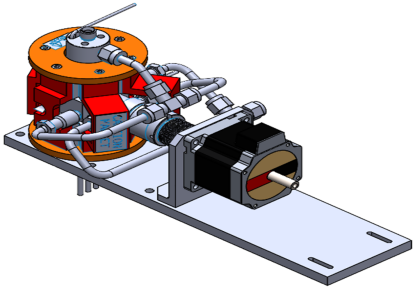
- A good DNP target material candidate is characterized by the maximum achievable polarization, dilution factor, and resistance to the radiation damage
- 8 cm long solid NH_3/ND_3 target material doped with paramagnetic free radical get irradiated at National Institute of Standard and Technology then shipped to Fermilab
- The polarization decays over time due to the radiation damage but it can be restored by the annealing process

Material	NH_3	ND_3
Dilution Factor	0.176	0.3
Packing Fraction	0.60	0.60
Average Polarization	80%	32%



Microwave Setup

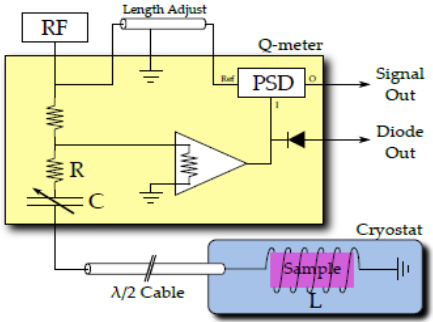
- 140 GHz RF signal is generated by Extended Interaction Oscillator
- The optimal frequency can fluctuate within limits as the spin direction is flipped and the target accumulate radiation damage from the beam
- The EIO is coupled to the target cups via a wave guide



See **Vibodha Bandara's** talk for more details

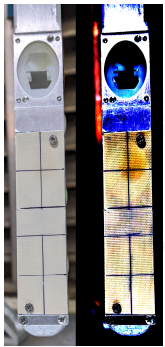
Nuclear Magnetic Resonances Setup

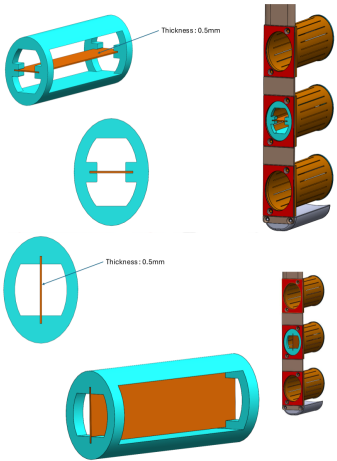
- Polarization is measured using Q-meter based NMR
- A series of conductive (C) Q-meters are connected to NMR coils of inductance (L) and resistance (R)
- The RF field is produced by three NMR coils embedded inside each target cup
- The LCR circuit is tuned to the Larmor frequency of the target material
- Three different NMR measurement techniques are used for systematic checks

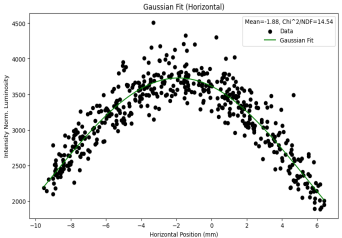


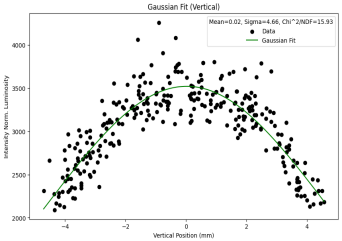
Beam Commissioning Studies

- Performed a beam scan with horizontal and vertical tungsten plates
- Deployed G10 sheets on the beamline window and target cups for beam-target centering



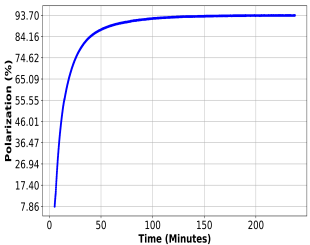


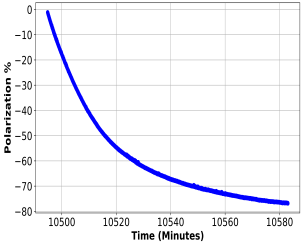




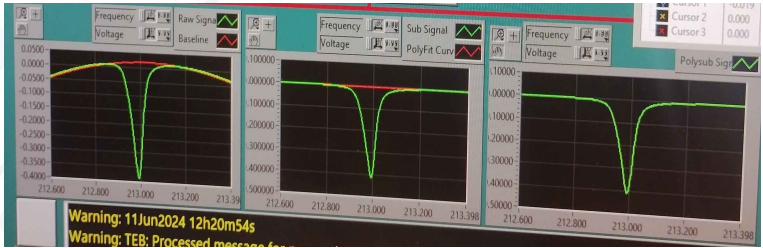
Beam center: horizontal at -1.88 mm
vertical at 0.02 mm

NH_3 Production Data-taking





- Production data were collected for both positive (spin up) and negative (spin down) polarizations with
  - average protons/spill of $\sim 1.3 \times 10^{12}$
  - total protons on target of $\sim 2.2 \times 10^{15}$, where $\sim 7.2 \times 10^{14}$ (1.5×10^{15}) achieved with positive (negative) polarization
  - average positive polarization $\sim 87.7\%$
  - average negative polarization $\sim$ -70.5%



See the talk by **Mohammad Farooq** for the heat load study on polarization

Summary and Outlook

- The experiment has been able to run with a maximum beam intensity of 3×10^{12} protons/spill
- So far, the collaboration was able to achieve 90% of the beam commissioning goals and to collect two weeks of production data
- Currently, studies are dedicated to fulfil the remained 10% of the beam commissioning goals before the accelerator shutdown
  - Perform the quench commissioning study to determine the highest possible beam intensity the superconducting magnet can handle without a quench
  - Determine the highest possible beam intensity the system can tolerate under the maximum liquid ^{4}He pumping
- In the 2024 fall run, the experiment plans to also use the transversely polarized ND_3 target

Thank You!

This work is supported by U.S. DOE # : DE-FG02-96ER40950 and DE-FG02-07ER41528

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