The Polarized Target for the SpinQuest Experiment at Fermilab

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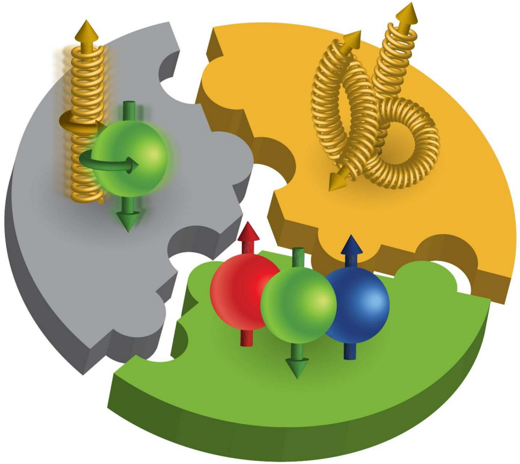
SOLID POLARIZED TARGET GROUP *at the*
UNIVERSITY *of* VIRGINIA

Outline

- Background
    - Motivation
    - Parton Distributions
- Experiment
    - Beam
    - Detectors
    - Target
    - Machine Learning Online Reconstruction
- Expected Results
- Collaboration information

The Spin Crisis/Puzzle

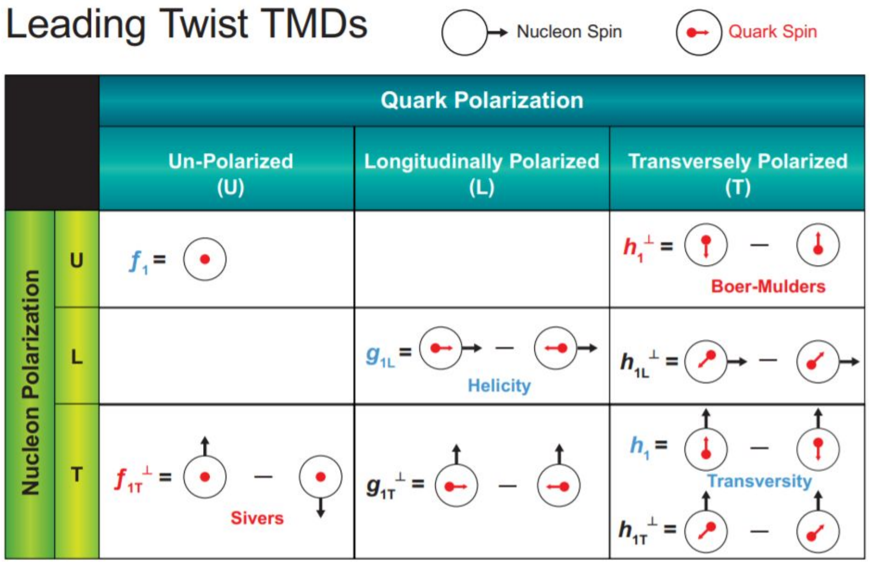


- Intrinsic spin of quarks is not enough to explain spin of proton (~30%)
- Intrinsic spin of gluons also contributes (~25%)
- Orbital Angular Momentum of partons also believed to contribute (~45%)
  - Valence Quarks
  - Sea Quarks
  - Gluons

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_{\bar{q}} + L_g$$

TMDs and the Sivers Asymmetry

- Describe correlation between transverse momenta of partons and the transverse spin of the nucleon.
- Sivers asymmetry: unpolarized parton within polarized nucleon.
- A non-vanishing Sivers asymmetry for the sea quarks is evidence of non-zero Orbital Angular Momentum.
- Polarized Drell-Yan scattering allows us to access sea quark Sivers function via angular asymmetry of resultant muons.

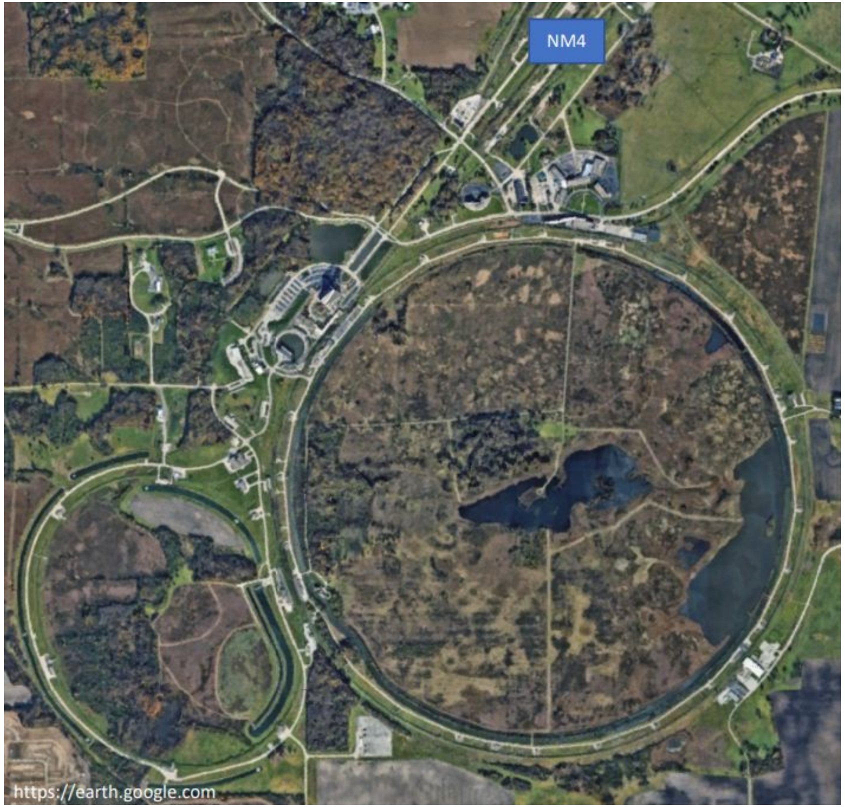


Leading Twist TMDs

		Quark Polarization		
		Un-Polarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
Nucleon Polarization	U	f_1 =		$h_1^{\perp}$ = − Boer-Mulders
	L		g_{1L} = − Helicity	$h_{1L}^{\perp}$ = −
	T	$f_{1T}^{\perp}$ = − Sivers	$g_{1T}^{\perp}$ = −	h_1 = − Transversity $h_{1T}^{\perp}$ = −

Experimental Layout

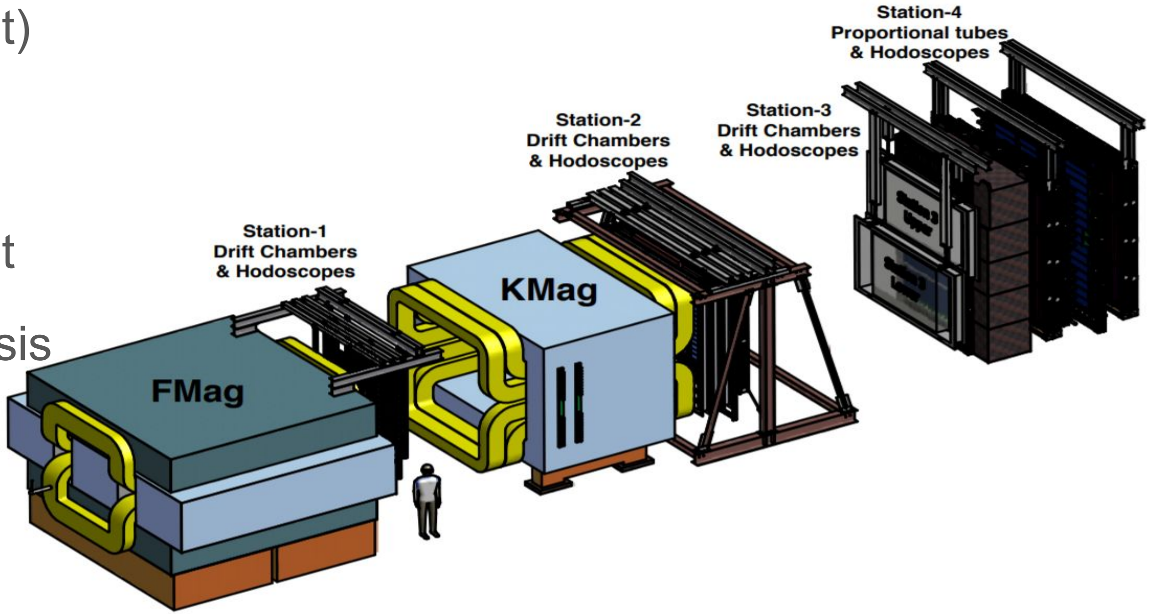
- Detector is the existing E906 spectrometer.
- Fermilab main injector beam
  - 120 GeV
  - ~5x10^{12} protons per 4 second spill, ~10^{17} per year
- Target of polarized solid Ammonia
  - Either NH_3 or ND_3
  - Maximum polarization level of 95% or 45%, respectively.



https://earth.google.com

The Detector

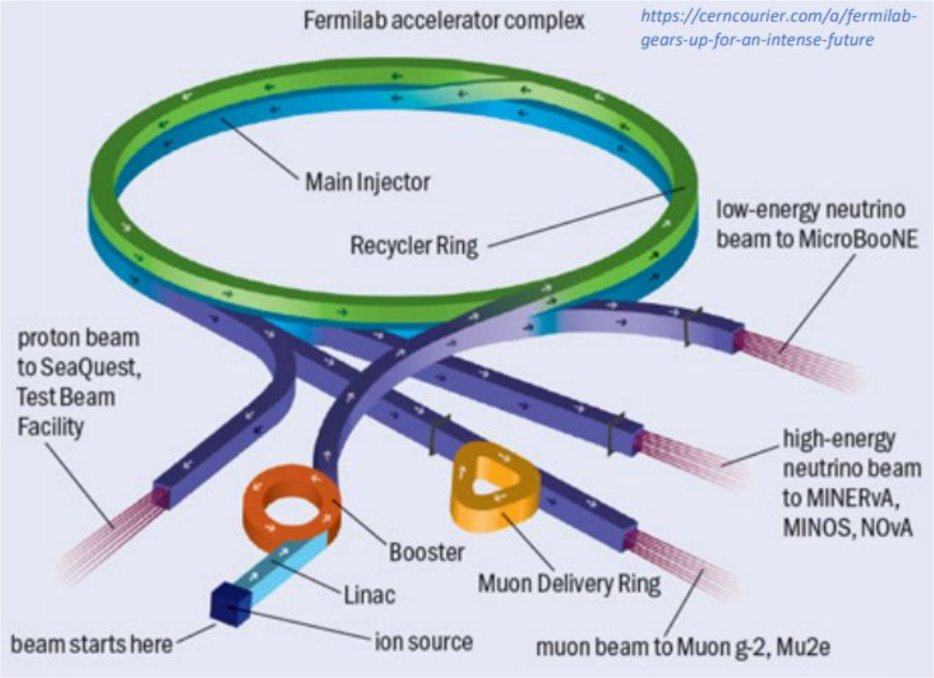
- Existing E906 (SeaQuest) Spectrometer.
- 2 Magnets
  - Beam Dump Magnet
  - Spectrometer Analysis Magnet
- 4 Tracking Stations
  - Drift Chambers
  - Hodoscopes
  - Proportional Tubes



The SpinQuest spectrometer
(Kei Nagai, image)

The Beam

- COM energy $\sqrt{s}$ =15.5 GeV
- 4.4 second spill ~5x10^{12} protons
  - Buckets of 1 ns length with interval 19 ns (54 MHz)
  - Each bucket contains ~5,000 protons.
- ~10^{17} protons delivered per year
- We're shooting for the highest instantaneous proton intensity ever attempted on this type of target.

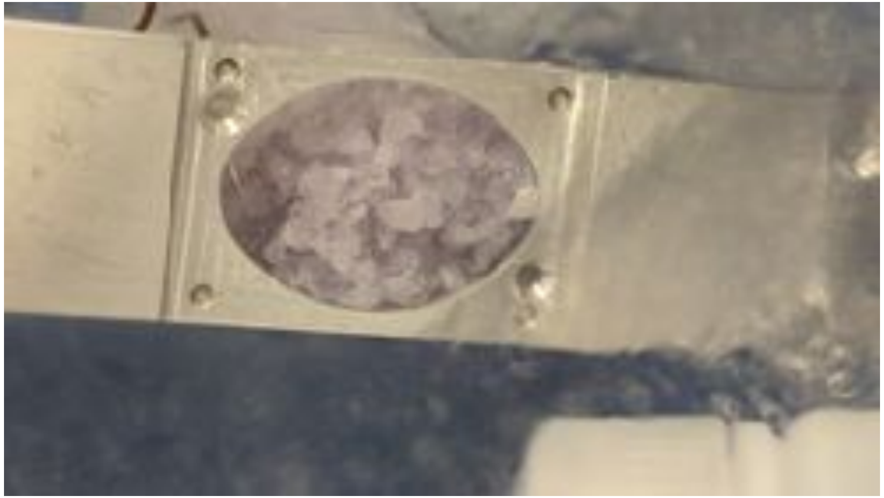


Challenges for this Experiment

- Low cross-section of Drell-Yan process and small asymmetry to be measured
  - Need to maximize events while minimizing false asymmetries
- Preventing magnet quenching
  - Large amount of heat from each spill
- Keeping the target polarized
  - Evaporated helium needs to be quickly pumped out
- Radiation damage to target
  - Requires frequent change-outs
- High radiation in target cave
  - Electronics need to either be radiation-hard or further away.

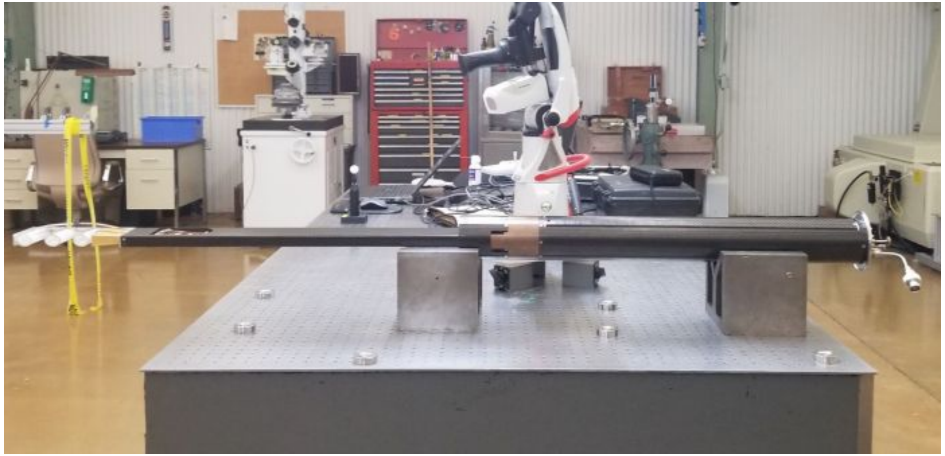
Target Material

- Frozen NH_3 or ND_3 beads.
  - High dilution factor
  - High radiation resistance
- Irradiated using electron beam
- Polarized using dynamic nuclear polarization
  - Average NH_3 polarization: 86%
  - Average ND_3 polarization: 32%
- Because of irradiation during experiment, will need to be replaced every 8-10 days.



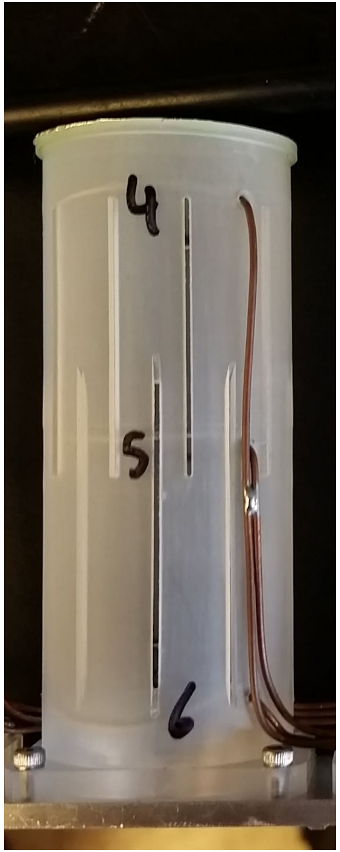
Target Insert

- Target insert made of carbon fiber
- Insert holds three 8cm cups for target material, only one of which will be in the beam at any one time.
- To increase total N of interactions, using a very long target.
- Gold microwave horn at end of insert spreads microwave evenly over target for DNP.



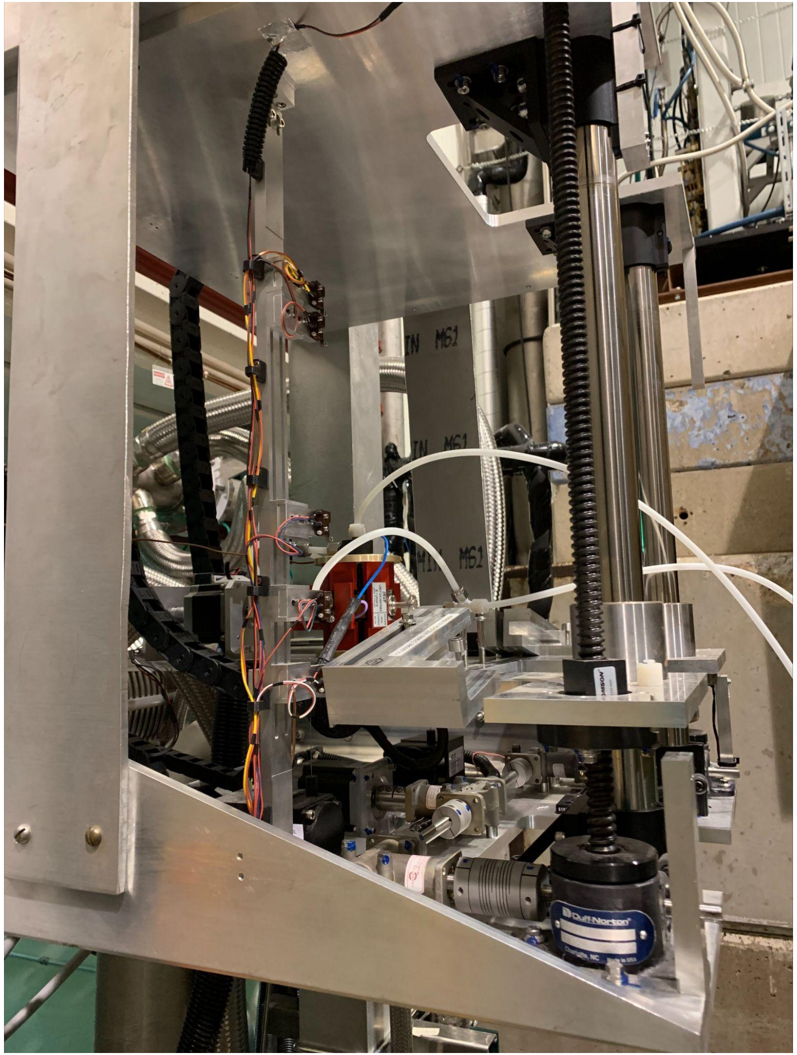
Nuclear Magnetic Resonance Coils

- 3 NMR coils on each cup
- Coils spaced evenly over the length of the cup.
- Because of length of target, need more than one point of measurement.
- NMR cable is longer than normal (14 λ/2 vs 7 λ/2), so Devin Seay’s work is important, especially for Deuterium measurement.



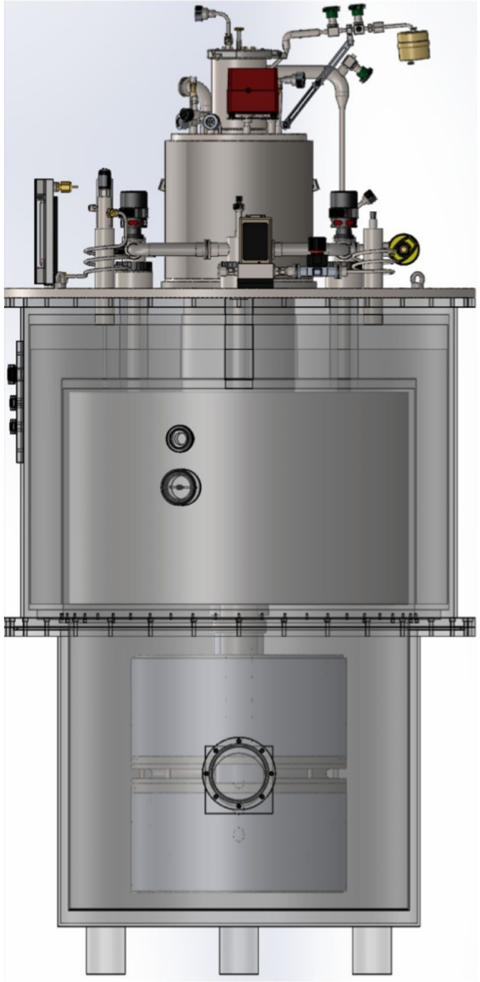
Microwave Source

- 140 GHz microwave source
- Generated by Extended Interaction Oscillator (EIO)
- Interaction between electron beam and resonant cavities
- Optimal frequency changes based on polarization direction and radiation damage, so frequency is tunable



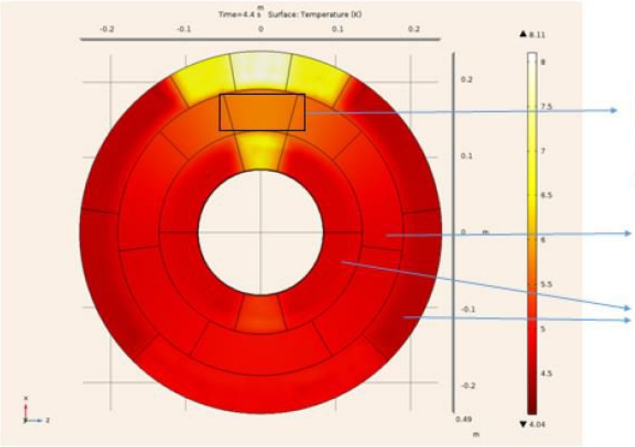
Target Magnet

- Superconducting 5T Magnet made by Oxford Instruments
- Homogeneity level of 10^{-4} over target area
- Target coils made of Niobium-titanium in an epoxy to prevent movement when energized.



Magnet Quenching Studies

- Simulations to determine maximum intensity without the magnet quenching
- Heat deposit simulated using GEANT, heat flow using COMSOL.
- Study found maximum intensity ~1.2×10^{13} protons/spill, 2x higher than we plan to do.



The hot spot spread uniformly due to the thermal conductivity of the copper matrix

Magnet coil

Stainless-steel former

$$c\frac{\partial T}{\partial t} = \nabla(\kappa \nabla T) + P_{ext} + P_{He}$$

Credit: Zulkaida Akbar

Evaporation Refrigerator and Pumps

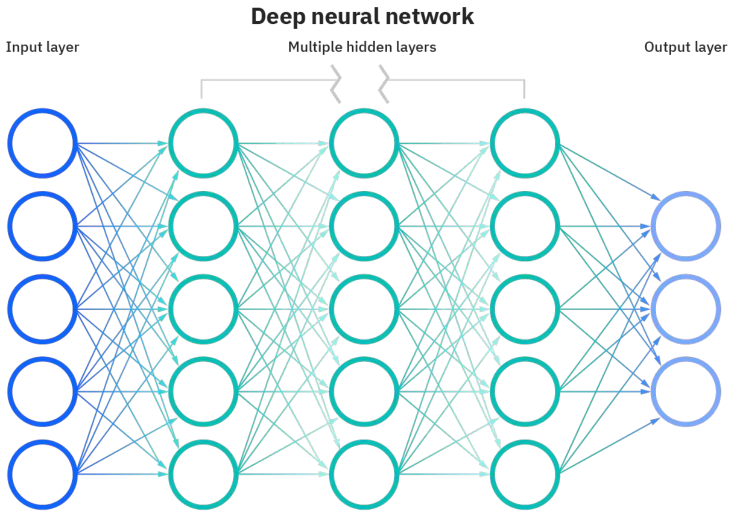
- To achieve maximum polarization, need to cool to lower than 4K.
- ^{4}He evaporation refrigerator
  - 1.4 W at 1 K (20 slpm)
  - 3 W at 1.1 K (40 slpm)
- 17,000 m^3/h pumps to remove evaporated helium.

Helium Liquifier

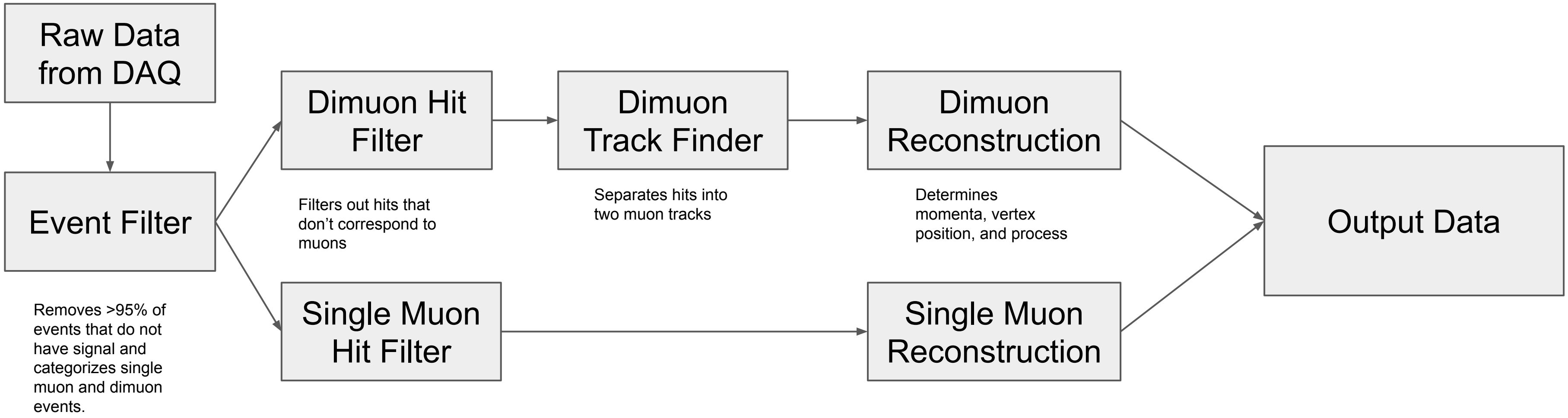
- We will go through a lot of Helium, and it's expensive
- We will recapture evaporated Helium and reliquify it.
- Liquifier can produce 200 liquid liters per day of LHe.
    - 70% delivered to target magnet due to transfer efficiency
    - Expect to run through ~110 liters per day.
- 500 liters of storage

Machine Learning Online Monitoring

- Because of high radiation in cave, hard to monitor target.
- Machine learning allows for faster analysis, allowing us to monitor high-level processes in real time.
- Look at accumulated data for J/psi and Drell-Yan and make sure incoming data match expected patterns
- Monitor single muon tracks for L/R or U/D asymmetries



Data flow for Online Reconstruction



Raw Data from DAQ

Event Filter

Removes >95% of events that do not have signal and categorizes single muon and dimuon events.

Dimuon Hit Filter

Filters out hits that don't correspond to muons

Dimuon Track Finder

Separates hits into two muon tracks

Dimuon Reconstruction

Determines momenta, vertex position, and process

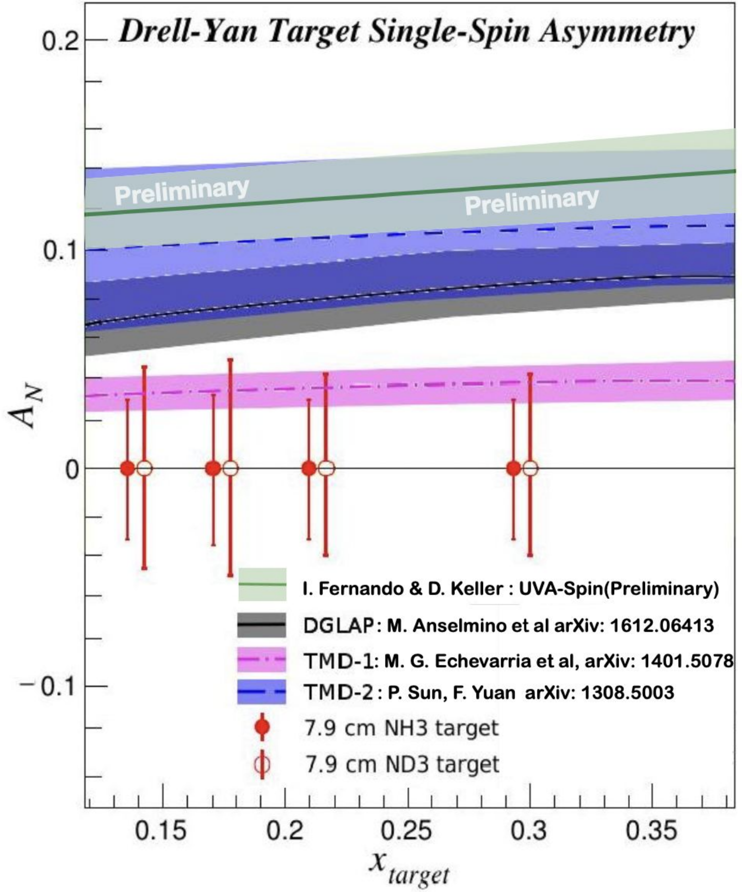
Single Muon Hit Filter

Single Muon Reconstruction

Output Data

Expected Sensitivity

- Experiment will run for two years in order to collect enough Drell-Yan events.
- J/ψ process has much higher cross-section, so we will reach good statistics within weeks.
- Anticipated error should allow for sign determination.



Timeline and Status

- 2021: detector and readout electronics commissioning using cosmic rays
- Spring 2022: QT and Polarized target installed
- July 2022: QT Commissioning started
- September 2022: Target Magnet first cooldown
- November 2022: Polarized Target Commissioning
- February 2023: Operational Readiness Review
- Early 2023: Begin production runs for 2+ years

SpinQuest Collaboration

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More information:

https://spinquest.fnal.gov/

http://twist.phys.virginia.edu/E1039/