SpinQuest in 10 Minutes

New Perspectives 2024

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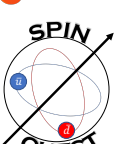
(For the SpinQuest Collaboration)

July 9, 2024

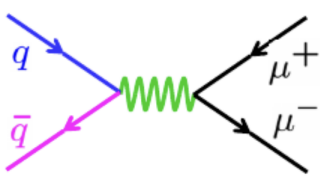


Why Polarized Drell-Yan in SpinQuest?

- Spin Crisis!
- Plan to measure an asymmetry (called Sivers asymmetry)that allows us to tell if sea quarks have non-zero OAM.
- Compared to the SIDIS (Semi-inclusive Deep Inelastic Scattering) process, Drell-Yan (DY) is a cleaner process.

beam: valence quarks at high x

target: sea quarks at low/intermediate x



$$\frac{d^2\sigma}{dx_b dx_t} = \frac{4\pi\alpha^2}{x_b x_t s} \sum_{q\in\{u,d,s,\ldots\}} e_q^2 \left[\bar{q}_t(x_t) q_b(x_b) + q_t(x_t)\bar{q}_b(x_b)\right]$$

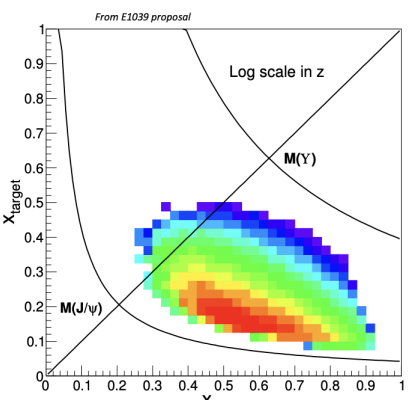
Sea-quarks dominance

u-quark dominance

$(2/3)^2$ vs. $(1/3)^2$

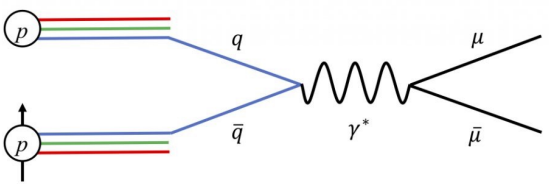
acceptance limited

(Fixed Target, Hadron Beam)



Valence-quarks dominance

Physics at SpinQuest



$$A_N = \frac{\sigma_{\uparrow}^{DY} - \sigma_{\downarrow}^{DY}}{\sigma_{\uparrow}^{DY} + \sigma_{\downarrow}^{DY}}$$

Accessing Sea Quark Sivers function
from from Drell-Yan Process

Kinematically Suppressed!

$$A_N \propto \frac{\sum_q e_q^2 \left[f_1^q(x_b) \cdot f_{1T}^{\perp,\bar{q}}(x_t) + 1 \longleftrightarrow 2 \right]}{\sum_q e_q^2 \left[f_1^q(x_b) \cdot f_1^{\bar{q}}(x_t) + 1 \longleftrightarrow 2 \right]}$$

See Harsha Srilal's talk for some details.

Measurement: The amplitude of the azimuthal angular modulation of the outgoing particles' (di-muons) scattering cross section with respect to the transverse spin direction of the polarized proton.

Bonus Physics: Transverse Single Spin Asymmetry in J/ψ Production
See Chatura Kuruppu's Talk

Timeline and Status

- March 2018: DOE approval.
- May 2018: Fermilab stage-2 approval.
- June 2018: E906 decommissioned.
- Fall 2018: Transferred the polarized target from UVA to Fermilab.
- 2021: Commissioned all components using cosmic rays.
- May 2024: Beam commissioning.
- Nov 2024- Jan 2027: Expected production data taking time.

Collaboration Members

https://spinquest.fnal.gov

INSTITUTIONS 21	FULL MEMBERS 47 Postdocs 7 Grad. Students 11	AFFILIATE MEMBERS
1) Abilene Christian University	Donald Isenhower (PI), Michael Daugherity, Shon Watson	Roy Salinas, Rusty Towell, Shannon McNease, Yves Ngenzi, Thomas Fitch
2) Argonne National Laboratory	Paul Reimer (PI), Donald Geesaman	Kevin Bailey, Thomas O'Connor
3) Aligarh Muslim University	Huma Haider (PI), Mohit Singh	
4) Boston University	David Sperka (PI), Zijie Wan	
5) Fermi National Accelerator Laboratory	Nhan Tran (PI), Evan Niner, Erik Voirin, Cristina Mantilla	Carol Johnstone, Charles Brown, Nhan Tran, Richard Tesarek
6) KEK	Shin'ya Sawada (PI)	Shigeru Ishimoto
7) Los Alamos National Laboratory	Kun Liu (SP), Liliet Diaz	Jan Boissevain, Patrick McGaughey, Andi Klein
8) Mississippi State University	Lamiaa El Fassi (PI), Vaniya Ansari , Muhammad Asif Zubair	Dipangkar Dutta
9) New Mexico State University	Stephen Pate (PI), Vassili Papavassiliou, Chatura Kuruppu, Dinupa Nawarathne, Harhsa Sirilal	
10) RIKEN	Yuji Goto (PI)	
11) Shandong University	Qinghua Xu (PI)	
12) Tokyo Institute of Technology	Toshi-Aki Shibata (PI)	
13) University of Colombo	Hansika Atapattu (PI), Vibodha Bandara	
14) University of Illinois, Urbana-Champaign	Jen-Chieh Peng (PI), Ching Him Leung	Naomi Makins, Daniel Jumper, Jason Dove, Mingyan Tian, Bryan Dannowitz, Randall McClellan, Shivangi Prasad
15) University of Michigan	Wolfgang Lorenzon (PI), Levgen Lavrukhin	Daniel Morton, Richard Raymond, Marshall Scott
16) University of New Hampshire	Karl Slifer (PI)	Maurik Holtrop
17) Tsinghua University	Zhihong Ye (PI)	
18) University of Virginia	Dustin Keller (SP), Kenichi Nakano, Ishara Fernando, Forhad Hossain, Ernesto Diaz, Arthur Conover, Jay Roberts, Devin Seay, Nuwan Chaminda, Dima Watkins, Amal Pattividana, Sibte Asghar Abidi	Donal Day, Donald Crabb, Oscar Rondon, Zulkaida
19) Yamagata University	Yoshiyuki Miyachi (PI), Norihito Doshita	Takahiro Iwata, Norihiro Doshita
20) Yerevan Physics Institute	Hrachya Marukyan (PI)	
21) National Center for Physics	Waqar Ahmed (PI), Muhammad Farooq	

Spectrometer

- 120 GeV proton beam from Fermilab MI in a 4.4-sec spill.

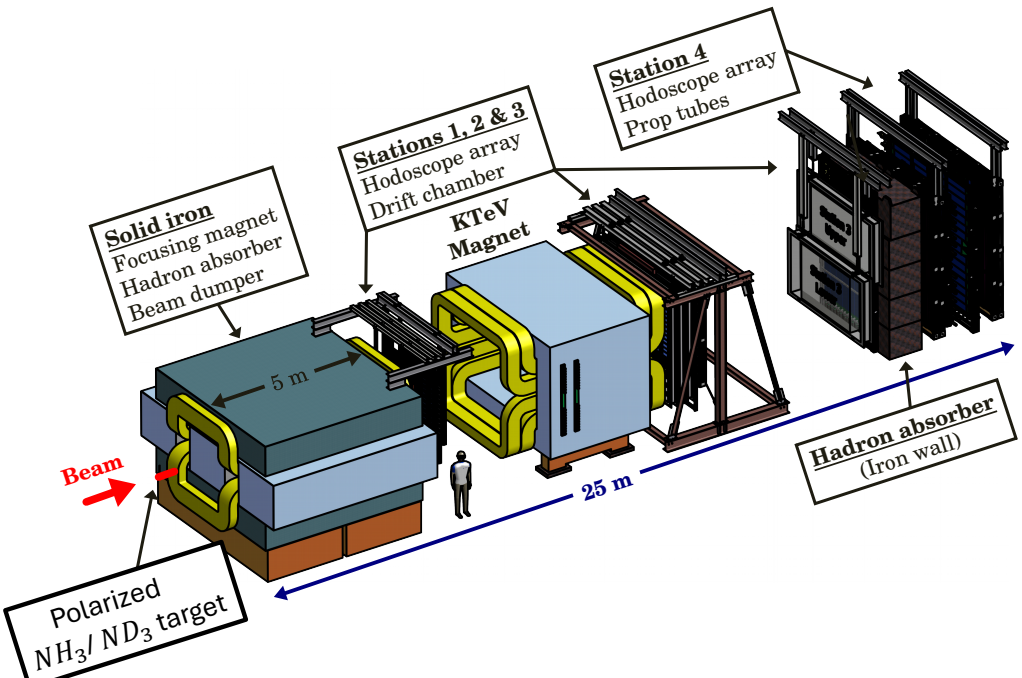
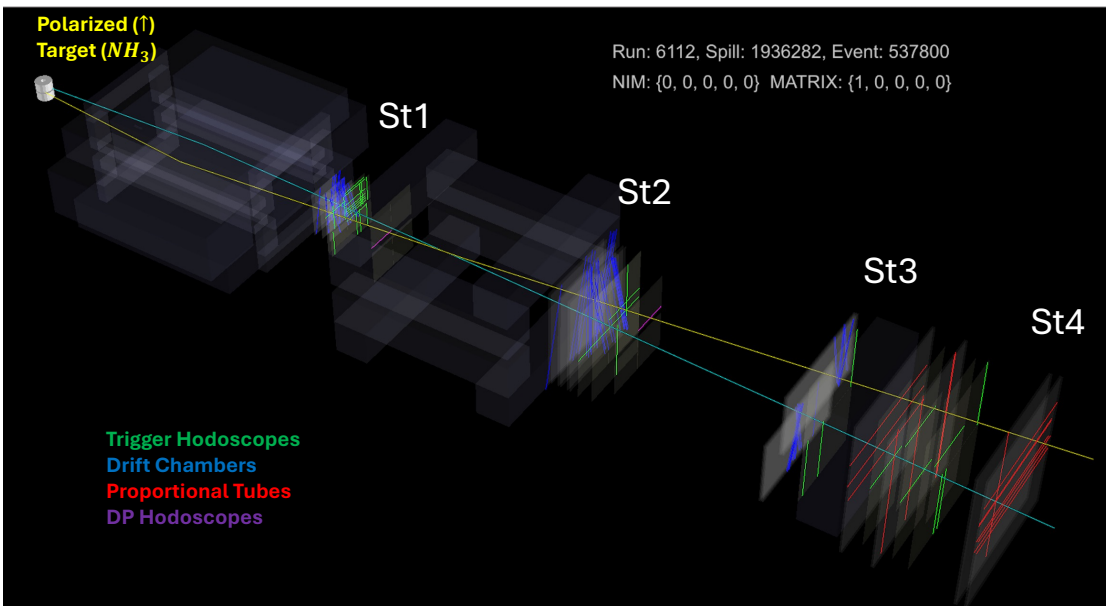
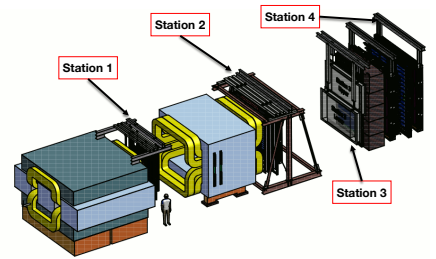


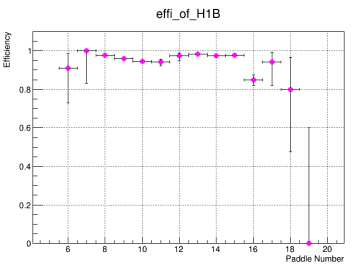
Figure. SeaQuest Spectrometer

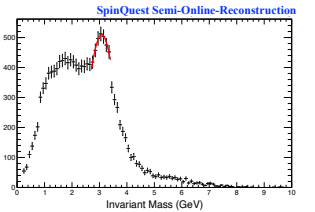
SpinQuest Event Display



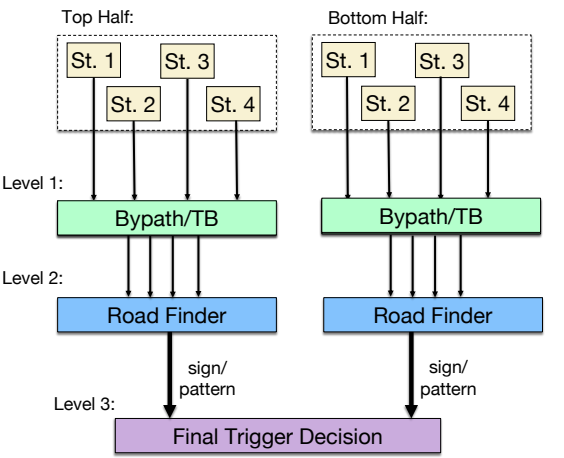
SpinQuest's Dimuon Trigger





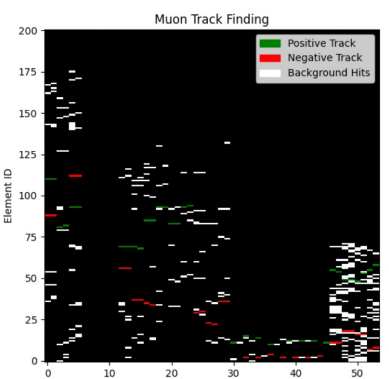


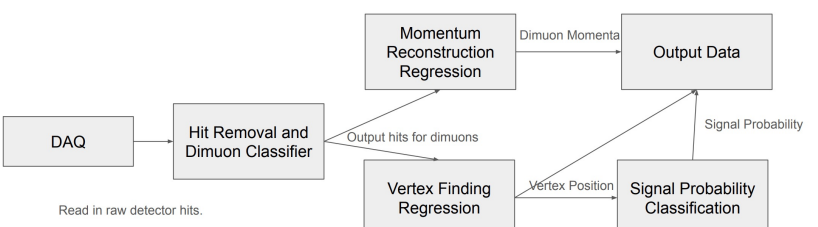
Three Level Trigger System:

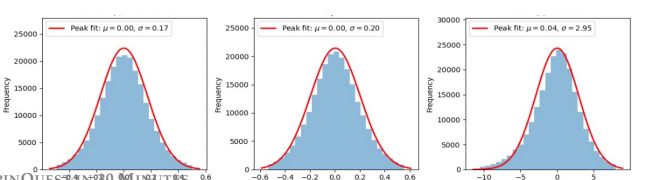


Machine Learning Effort in Dimuon Reconstruction

- The program reads raw event files from the decoder and performs fast reconstruction.
- Key components of the AI model include:
  - An event filter using a CNN classifier to analyze each event.
  - A track finder implemented as a CNN classifier.
  - Momentum reconstruction via DNN regression.
  - Vertex reconstruction using DNN regression.
  - A target dump separator designed as a basic DNN classifier.
- Each classifier outputs a Softmax probability, which can be used to sort the results efficiently.

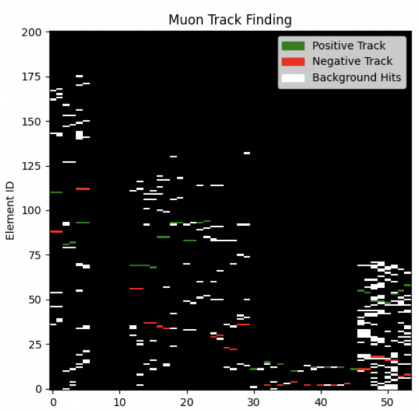


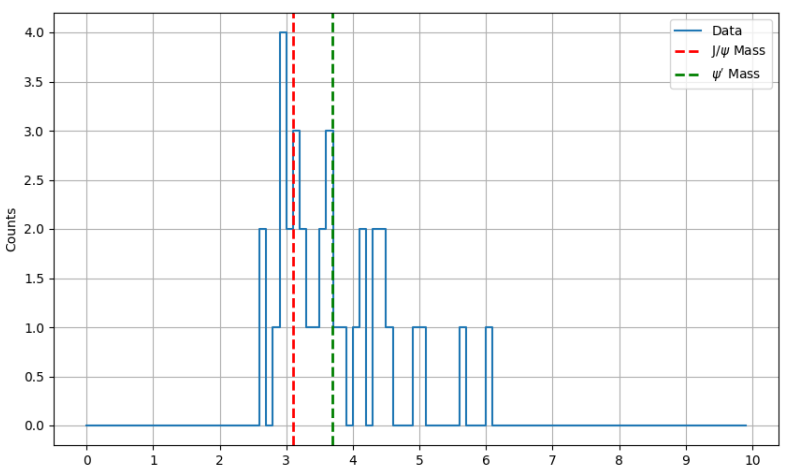




AI ONLINE MONITORING SYSTEM USING QTRACKER

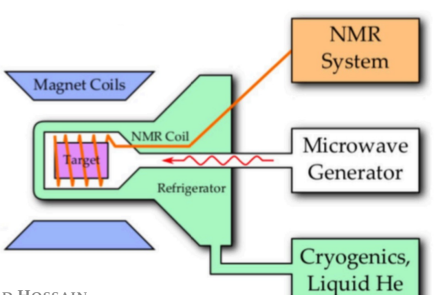
- This invariant mass uses QTracker to reconstruct the spill just a few seconds after it occurs, enabling the observation of the dimuon spectrum change in real-time.
- The reconstruction with QTracker is exceptionally fast, allowing for near real-time evaluation of the data as it comes in.

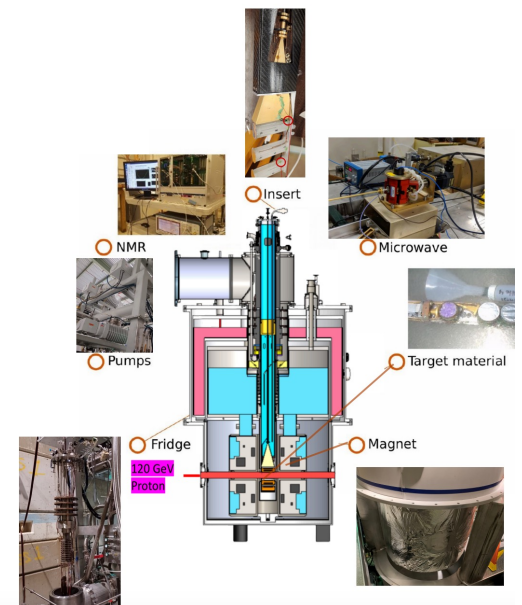




Polarized Target System

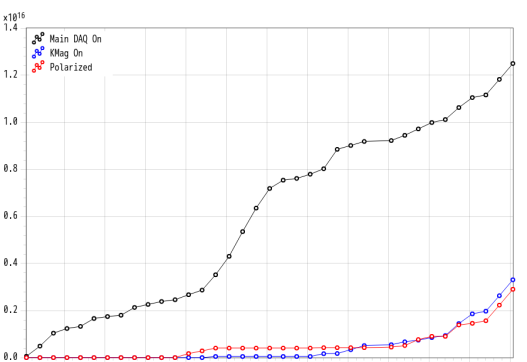
- Carbon fiber insert with 3 cells.
- 140 GHz microwave source (Details in **Vibodha Bandara's Talk**).
- Ammonia beads (NH3 or ND3).
- Target uses Dynamic Nuclear Polarization to enhance the polarization (Details in **Vaniya Ansari's Talk.**).
- 5T Magnet Applied vertically to the target field.

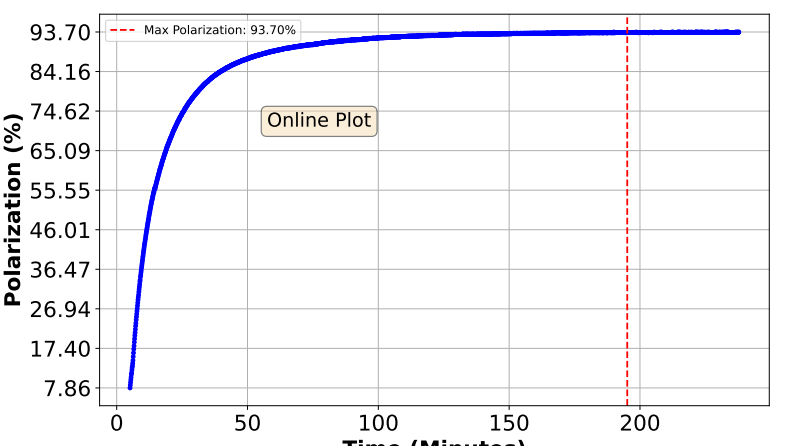




Polarization Data Taking Results

- Dynamic nuclear polarization (DNP) is used to enhance the polarization. More details in **Muhammad Farooq's** talk.
- The average beam intensity for the right polarization monitoring plot is approximately is about 1.5×10^{12} protons/spill.

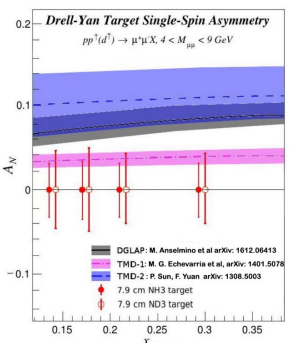


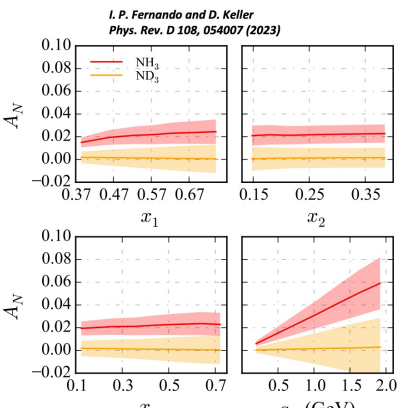


Expected Results

- Experiment will run for two years in order to collect enough Drell-Yan events.
- Projected uncertainties:
  - Statistical uncertainties: $3-5\%$.
  - Efficiency and Acceptance: 3%.
  - We have been working to minimize the systematic uncertainties arising from the target materials and polarization.

If $A_N \neq 0$, major discovery: "Smoking Gun" evidence for $L_{\bar{u},\bar{d}\neq 0}$





$$A = \frac{2}{f|S_T|} \frac{\int d\phi_S d\phi \frac{dN(x_b,x_t,\phi_S,\phi)}{d\phi_S d\phi} sin(\phi_S)}{N(x_b,x_t)}$$

Material	Density	Dilution factor	Packing fraction	Polarization	Interaction length
NH_3	0.867 g/cm^3	0.176	0.60	80%	5.3%
ND_3	1.007 g/cm^3	0.300	0.60	32%	5.7%

Conclusion

- SpinQuest is poised to provide critical insight:
  - For the sea-quark Sivers function and sea-quark Orbital Angular Momentum (OAM).
  - For $\bar{u}, \bar{d}$ flavor asymmetry sensitivity to spin.
- Measurement of Sivers function for gluons (J/ψ Transverse Single Spin Asymmetry [TSSA]).
- Perform the first measurement of the sea-quarks Sivers asymmetry in Drell-Yan proton-proton scattering.
- Pushes the 120 GeV-proton-beam intensity frontier on a solid polarized target.