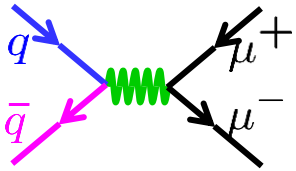
Polarized Drell-Yan at Fermilab MI (P-1027)



Fermilab PAC Meeting

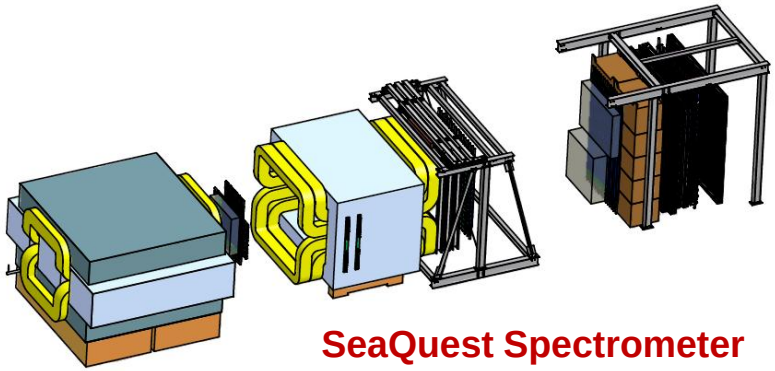
(15-Oct-2012)

Wolfgang Lorenzon (U Michigan), Paul Reimer (Argonne)

- Sivers Function in Polarized Drell-Yan
  - ➡ fundamental QCD prediction:

$$f_{1T}^{\perp q}\Big|_{DIS} = -\, f_{1T}^{\perp q}\Big|_{D-Y}$$

  - ➡ address major milestone in hadronic physics (HP13)



SeaQuest Spectrometer

- MI polarization scheme: from 2 Siberian snakes to 1
- Answers to June PAC concerns

Polarized Drell-Yan Experiment

NOT YET DONE!

- Access to transverse-momentum dependent distribution (TMD) functions
  - $\longrightarrow$ Sivers, Boer-Mulders, etc
- Transversely Polarized Beam or Target
  - $\longrightarrow$ Sivers function in single-transverse spin asymmetries (SSA) (sea quarks or valence quarks)
    - – valence quarks constrain SIDIS data much more than sea quarks
  - $\longrightarrow$ transversity $\otimes$ Boer-Mulders function
  - $\longrightarrow$ baryon production, incl. pseudoscalar and vector meson production, elastic scattering, two-particle correlations, J/ψ and charm production
- Beam and Target Transversely Polarized
  - $\longrightarrow$ flavor asymmetry of sea-quark polarization
  - $\longrightarrow$ transversity (quark $\otimes$ anti-quark for pp collisions)
    - – anti-quark transversity might be very small

Transverse Momentum Distributions (Introduction)

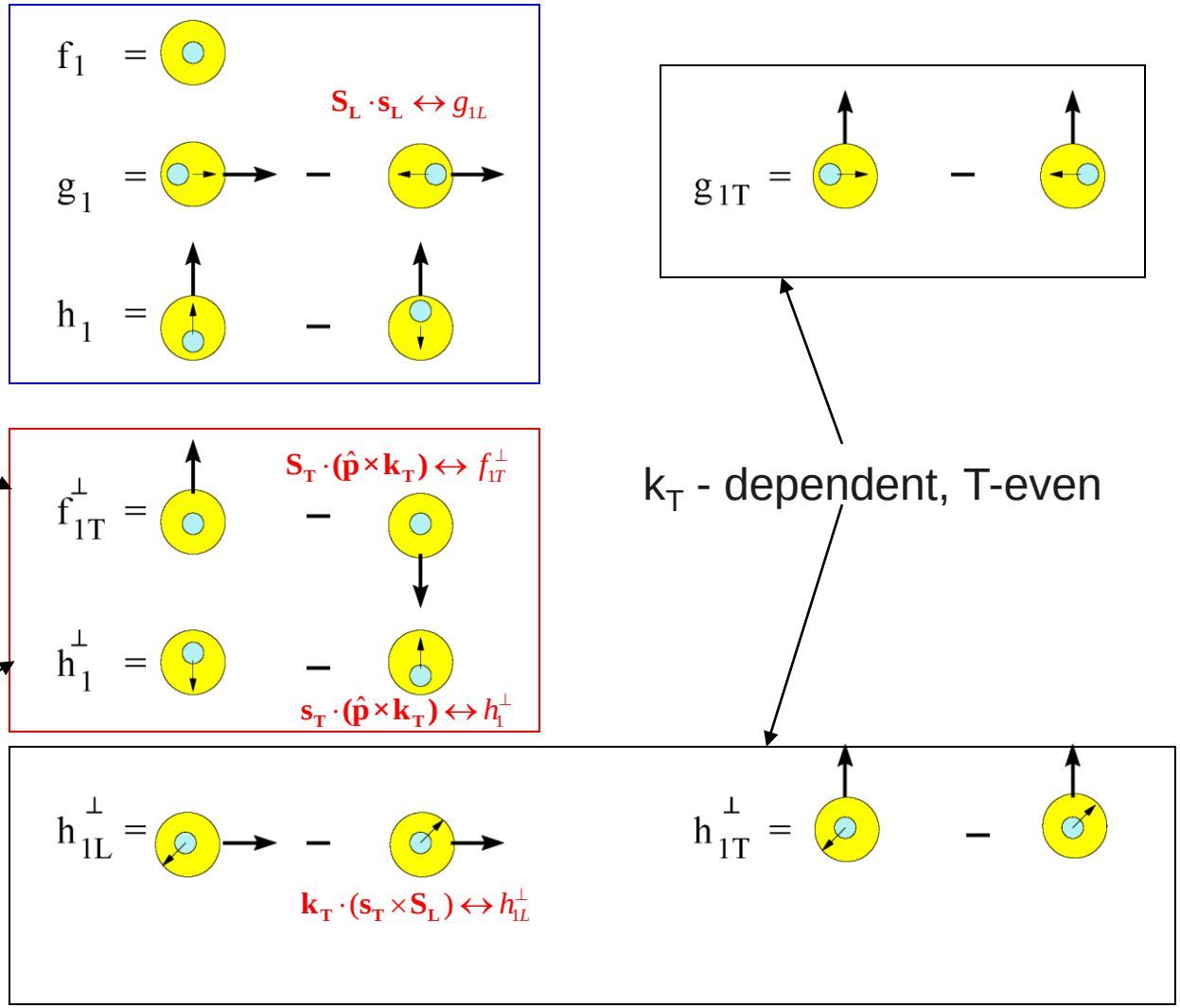
survive k_T integration

Sivers Function

k_T - dependent,

Naïve T-odd

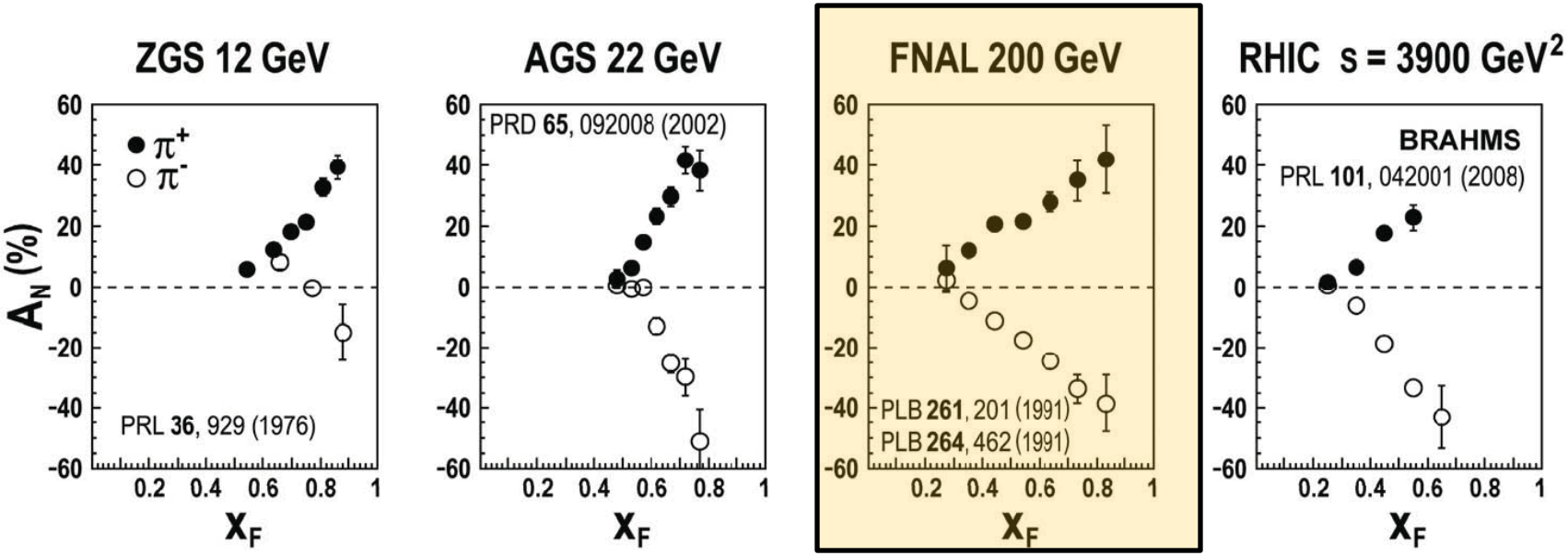
Boer-Mulders Function



k_T - dependent, T-even

Inclusive Pion Asymmetry in p-p Collisions

- "E704 effect":
  - ➡ polarized beam at Fermilab (tertiary beam from production & decay of hyperons)
  - ➡ beam intensity too low for DY
- Sivers function:
  - ➡ possible explanation for large inclusive asymmetries



C. Aidala SPIN 2008 Proceeding and CERN Courier June 2009

Sivers Function

- describes transverse-momentum distribution of unpolarized quarks inside transversely polarized proton
- captures non-perturbative spin-orbit coupling effects inside a polarized proton
- leads to a $\sin(\phi - \phi_S)$ asymmetry in SIDIS and a $\sin\phi_b$ asymmetry Drell-Yan
- done in SIDIS (HERMES, COMPASS)
- Sivers function is time-reversal odd

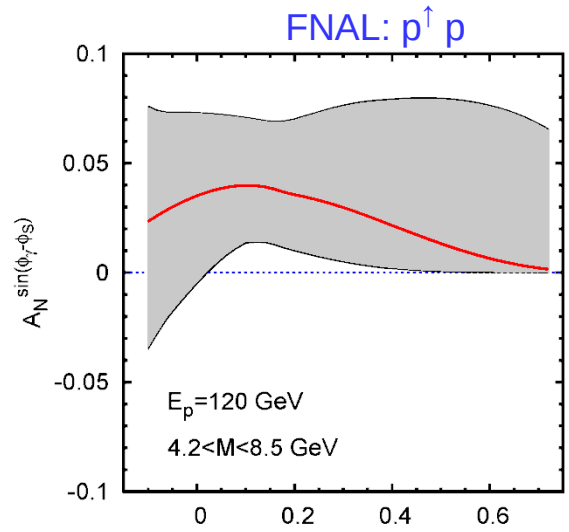
➡ leads to sign change

$$f_{1T}^{\perp q}\Big|_{DIS} = -\, f_{1T}^{\perp q}\Big|_{D-Y}$$

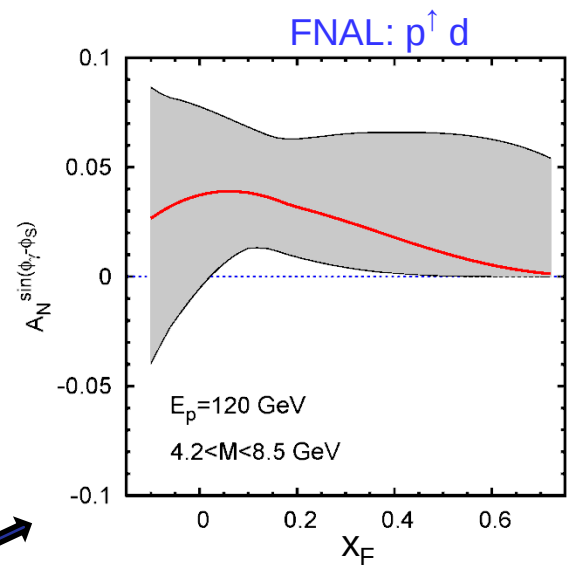
➡ fundamental prediction of QCD (goes to heart of gauge formulation of field theory)

Predictions based on fit to SIDIS data

(gray error bands correspond to $\Delta\chi^2 = 20$)



120 GeV polarized beam
√s ~ 15 GeV
(on hydrogen)

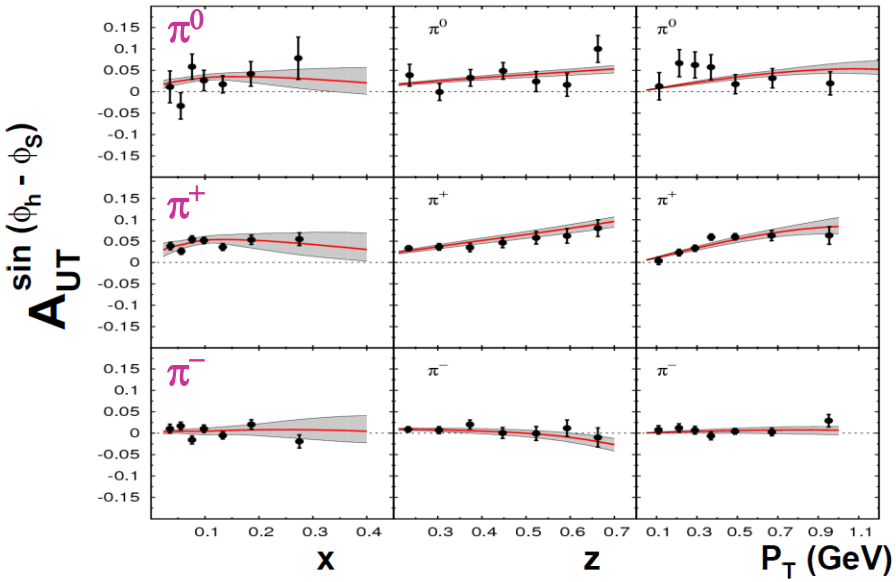


120 GeV polarized beam
√s ~ 15 GeV
(on deuterium)

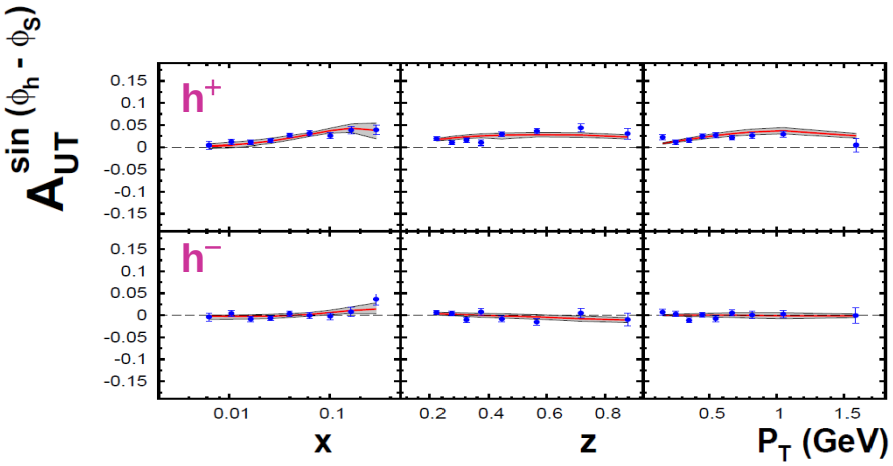
Anselmino et al. priv. comm. 2010

Sivers Asymmetry Measurements

HERMES (p)



COMPASS (p)



- Global fit to sin $(\phi_h - \phi_S)$ asymmetry in SIDIS (HERMES, COMPASS)
  - ➡ u- and d- Sivers functions have opposite signs
- Future measurements at Jlab (12 GeV) planned

Comparable measurements needed in Drell-Yan process

Hadronic Physics Milestone #13

- Report to NSAC, 11-Aug-2008 (by subcommittee on performance measures)
  - ➡ Table 11: New, Updated and Continuing Milestones for Hadronic Physics SeaQuest spectrometer
    - → 2015 | HP13 (new) | Test unique QCD predictions for relations between single-transverse spin phenomena in p-p scattering and those observed in deep-inelastic lepton scattering
  - ➡ New Milestone HP13 reflects the intense activity and theoretical breakthroughs of recent years in understanding the parton distribution functions accessed in spin asymmetries for hard-scattering reactions involving a transversely polarized proton. This leads to new experimental opportunities to test all our concepts for analyzing hard scattering with perturbative QCD.

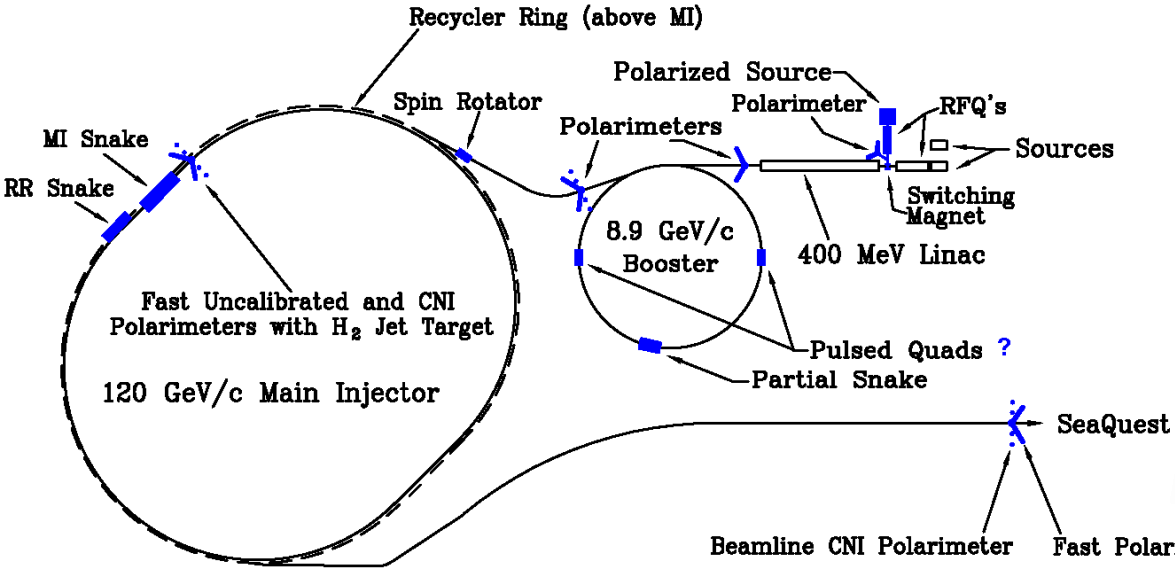
Planned Polarized Drell-Yan Experiments

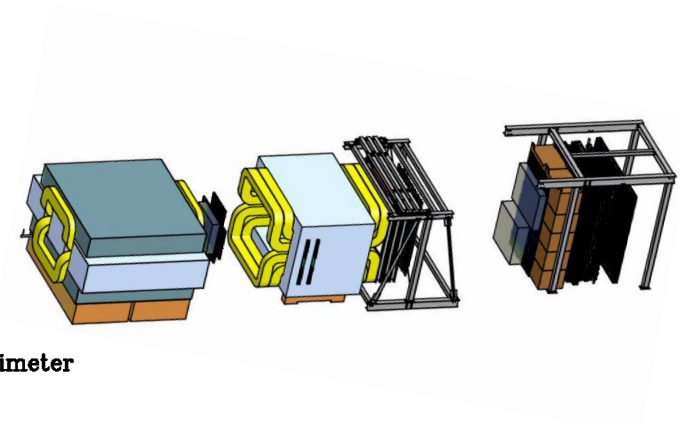
experiment	particles	energy	x_b or x_t	Luminosity	timeline
COMPASS (CERN)	$\pi^{\pm} + p^{\uparrow}$	160 GeV $\sqrt{s}$ = 17.4 GeV	$x_t = 0.2 – 0.3$	2×10^{33} cm^{-2} s^{-1}	2014
PAX (GSI)	$p^{\uparrow} + p_{bar}$	collider $\sqrt{s}$ = 14 GeV	$x_b = 0.1 – 0.9$	2×10^{30} cm^{-2} s^{-1}	>2017
PANDA (GSI)	$p_{bar} + p^{\uparrow}$	15 GeV $\sqrt{s}$ = 5.5 GeV	$x_t = 0.2 – 0.4$	2×10^{32} cm^{-2} s^{-1}	>2016
NICA (JINR)	$p^{\uparrow} + p$	collider $\sqrt{s}$ = 20 GeV	$x_b = 0.1 – 0.8$	1×10^{30} cm^{-2} s^{-1}	>2014
PHENIX (RHIC)	$p^{\uparrow} + p$	collider $\sqrt{s}$ = 500 GeV	$x_b = 0.05 – 0.1$	2×10^{32} cm^{-2} s^{-1}	>2018
RHIC internal target phase-1	$p^{\uparrow} + p$	250 GeV $\sqrt{s}$ = 22 GeV	$x_b = 0.25 – 0.4$	2×10^{33} cm^{-2} s^{-1}	>2018
RHIC internal target phase-1	$p^{\uparrow} + p$	250 GeV $\sqrt{s}$ = 22 GeV	$x_b = 0.25 – 0.4$	6×10^{34} cm^{-2} s^{-1}	>2018
SeaQuest (unpol.) (FNAL)	$p + p$	120 GeV $\sqrt{s}$ = 15 GeV	$x_b = 0.35 – 0.85$ $x_t = 0.1 – 0.45$	3.4×10^{35} cm^{-2} s^{-1}	2012
pol. SeaQuest[§] (FNAL)	$p^{\uparrow} + p$	120 GeV $\sqrt{s}$ = 15 GeV	$x_b = 0.35 – 0.85$	1×10^{36} cm^{-2} s^{-1}	>2015

[§] *$L = 1 \times 10^{36}$ cm^{-2} s^{-1} (LH_2 tgt limited) / $L = 2 \times 10^{35}$ cm^{-2} s^{-1} (10% of MI beam limited)*

Polarized Drell-Yan at Fermilab Main Injector

- Polarize Beam in Main Injector





- Use SeaQuest dimuon Spectrometer
  - ➡ fixed target experiment, optimized for Drell-Yan
  - ➡ luminosity: $L_{av} = 3.4 \times 10^{35}$ /cm^2/s
    - → $I_{av} = 1.6 \times 10^{11}$ p/s (=26 nA)
    - → $N_p = 2.1 \times 10^{24}$ /cm^2
  - ➡ approved for 2-3 years of running: 3.4×10^{18} pot
  - ➡ by 2015: fully understood, ready to take pol. beam

P-1027 Collaboration (October 2012)

Abilene Christian University
Donald Isenhower, Tyler Hague, Rusty Towell, Shon Watson

Academia Sinica
Wen-Chen Chang, Yen-Chu Chen, Shiu Shiuan-Hal, Da-Shung Su

Argonne
John Arrington, Don Geesaman Kawtar Hafidi, Roy Holt, Harold Jackson, Paul E. Reimer*, Josh Rubin

University of Colorado
Ed Kinney

Fermilab
Chuck Brown, David Christian

University of Illinois
Bryan Dannowitz, Markus Diefenthaler, Bryan Kerns, Naomi C.R Makins, R. Evan McClellan

KEK
Shinya Sawada

Los Alamos National Laboratory
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University of Michigan
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Tokyo Institute of Technology
Shou Miyasaka, Ken-ichi Nakano, Florian Saftl, Toshi-Aki Shibata

Yamagata University
Yoshiyuki Miyachi

University of Basque Country†
Gunar Schnell

*Co-Spokespersons
†new group (Aug'12)

Collaboration contains most of the E-906/SeaQuest groups and one new group (total 16 groups as of October 2012)

P-1027 collaboration working closely with SPIN@FERMI collaboration

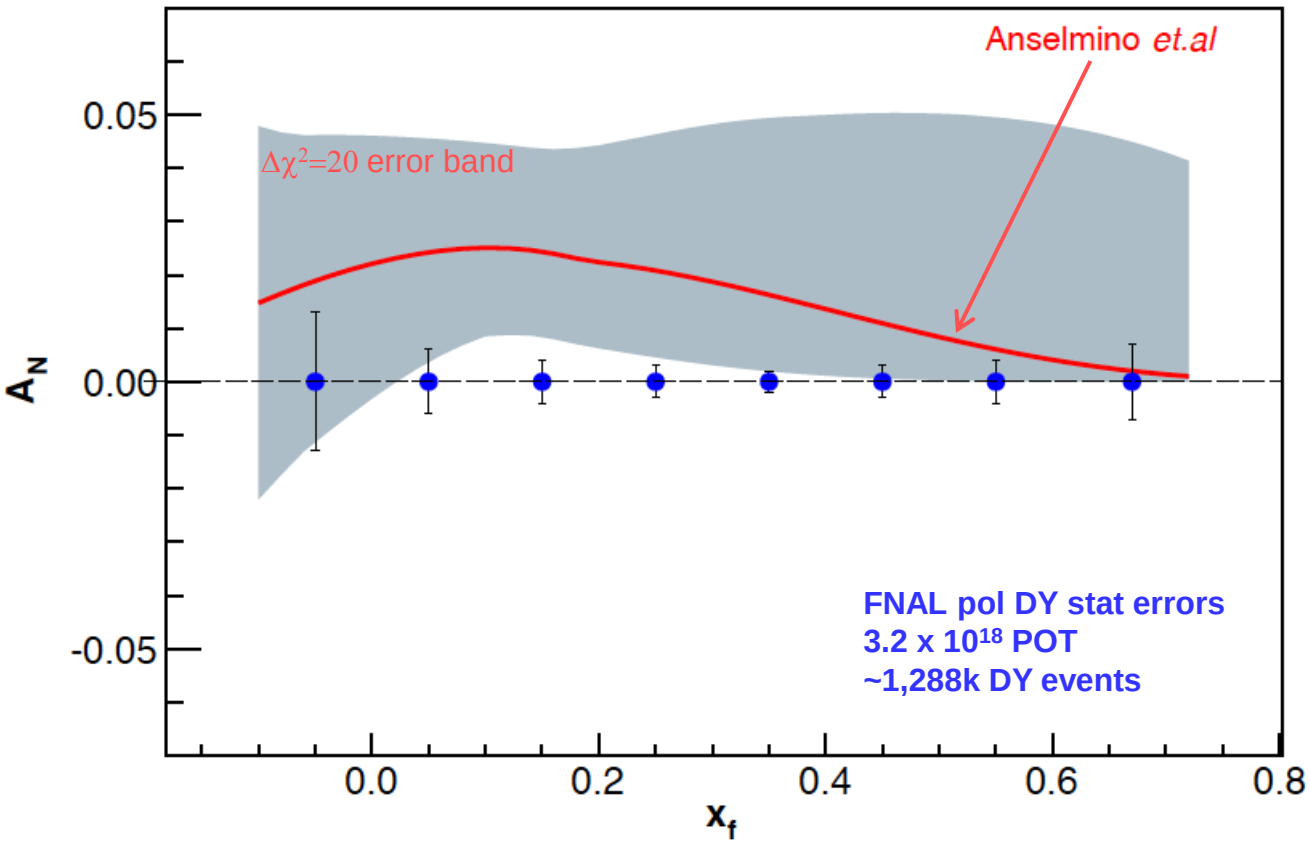
Sivers Asymmetry at Fermilab Main Injector

- Experimental Sensitivity

75% FMag focusing !

➡ luminosity: $L_{av} = 2 \times 10^{35}$ (10% of available beam time: $I_{av} = 15$ nA)

➡ 3.2×10^{18} total protons for 5×10^5 min: (= 2 yrs at 50% efficiency) with $P_b = 70\%$



Note:

$$A_N = \frac{2}{p} A_{TU}^{\sin f_b}$$

➡ Can measure not only sign, but also the size & maybe shape of the Sivers function !

Requests to Fermilab (at June PAC)

- SeaQuest spectrometer and experimental hall
  - ➡ continue to use NM3/4; counting house plus infrastructure
- Provide polarized beam in slow extraction mode (assumed 70% in stat. analysis)
  - ➡ continue to study issues with space limitations and work-arounds

Funding Model

- Investment of funds from NP and HEP
  - ➡ most groups funded through NP DOE or NSF
  - ➡ also funding from Japan and Taiwan
- Indications that both NP and HEP need to provide funding (similar to SeaQuest)
  - ➡ Phase I approval needed to pursue cooperative funding between agencies

Conclusions (at June PAC)

- Extraordinary opportunity at Fermilab
  - ➡ set up best polarized DY experiment to measure sign change in Sivers function
    - → high luminosity, large x-coverage, high-intensity polarized beam
    - → spectrometer already setup and running
  - ➡ with (potentially) minimal impact on neutrino program
    - → 10% of available beam time at MI
- Cost to polarize Main Injector $20M - $30M
  - ➡ includes 50% contingency
- Several hurdles to take
  - ➡ investigating using 1 snake in MI
    - → never been done at high energy
    - → but successfully at low energies (IUCF, Bates, AMPS)
  - ➡ investigating no partial snake in Booster
    - → polarization loss might be small (<10%)

Overview

The proposal for a Polarized-Proton-Beam Drell-Yan Experiment was considered for the first time at this meeting. It involves development of new polarized beam capabilities at Fermilab and use of the existing SeaQuest apparatus. The Committee discussed this proposal and suggested several areas for further investigation.

Polarized Drell-Yan Measurements with the Main Injector (P-1027)

Members of the SeaQuest Collaboration presented their proposal (P-1027), an experiment to expose their E-906 detector to a transversely-polarized proton beam. The goal of the experiment is to measure the "Sivers Function" by comparing polarization asymmetries in the Drell-Yan process, a high priority measurement in QCD. The polarized Drell-Yan process is thought to be the cleanest of many competing determinations of this quantity. The proponents emphasized that Fermilab is the best place to make this measurement. The P-1027 Collaboration proposes a fabrication and installation schedule to begin in 2013, with data taking to commence in 2015. The requested exposure is likely to be two years.

Although the SeaQuest detector would be reused in P-1027, numerous modifications to the Main Injector, Booster, and Linac will be required in order to produce a 70% transversely polarized beam directed to an unpolarized hydrogen target. Nevertheless, P-1027 is a natural way to capitalize on the investment made in SeaQuest, and cooperation between the DOE Offices of Nuclear Physics and High Energy Physics is valuable.

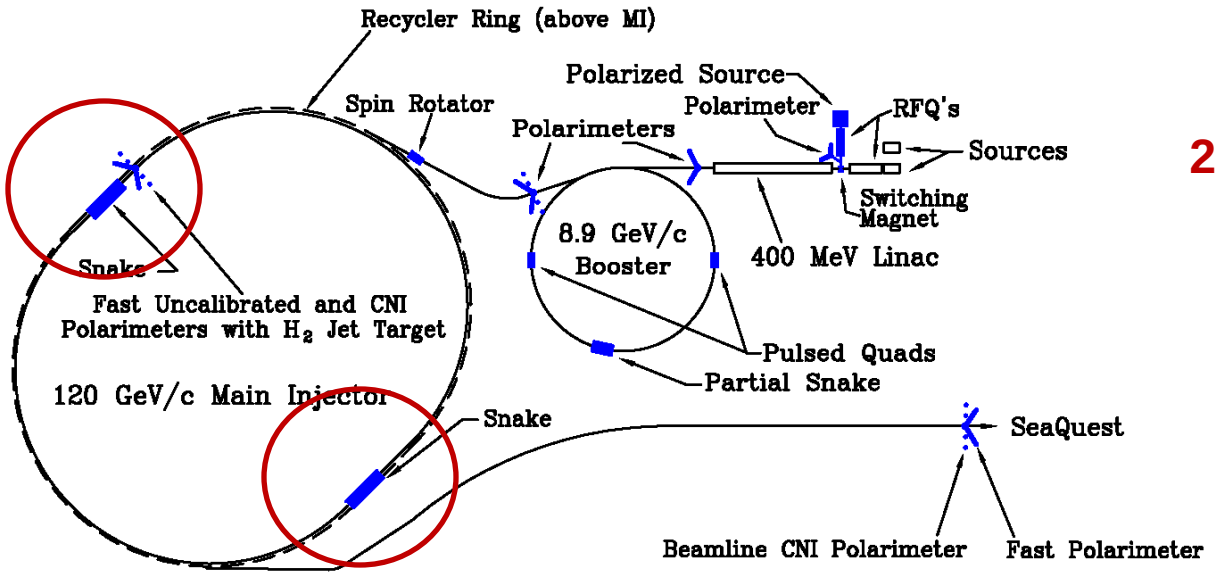
As proposed, P-1027 could significantly impact the core programs at the Laboratory. Even with this concern in mind, the PAC can imagine a scenario in which impacts on the core program might be minimized.

The PAC has concerns, and would like answers to some questions before being able to consider making a recommendation on the request for Stage I approval.

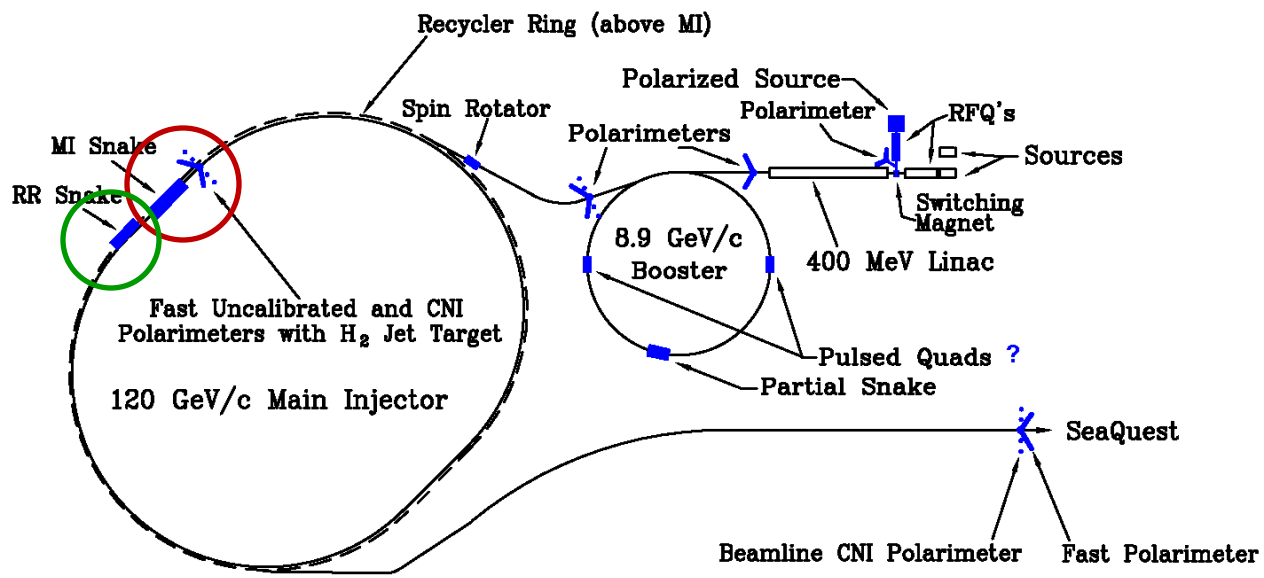
Questions for P-1027

1. Running with two Siberian Snakes in the Main Injector would impact the core Fermilab program as one of them would require removal of the NOvA extraction kickers. What would the reduction in polarization be with one MI snake and what would be the quantitative effect on the goals of the experiment?
2. In-kind and M&O contributions from outside of Fermilab sufficient to mount and sustain the experiment would be necessary in order to recommend approval, and the budget model needs to be fleshed out in greater detail with the DOE ONP, OHEP, and NSF. What arrangements can be made to secure outside funding?
3. There are two estimates for Snake fabrication and they vary widely. What are the anticipated costs for snake fabrication?
4. What are the likely impacts on the Fermilab infrastructure and expert personnel in the installation and commissioning of the components of the proposed polarized-proton beam in this system?
5. What are the likely resource and infrastructure implications for operating such a beam?

From 2 Siberian Snakes to 1 – I



2 Siberian Snakes in MI

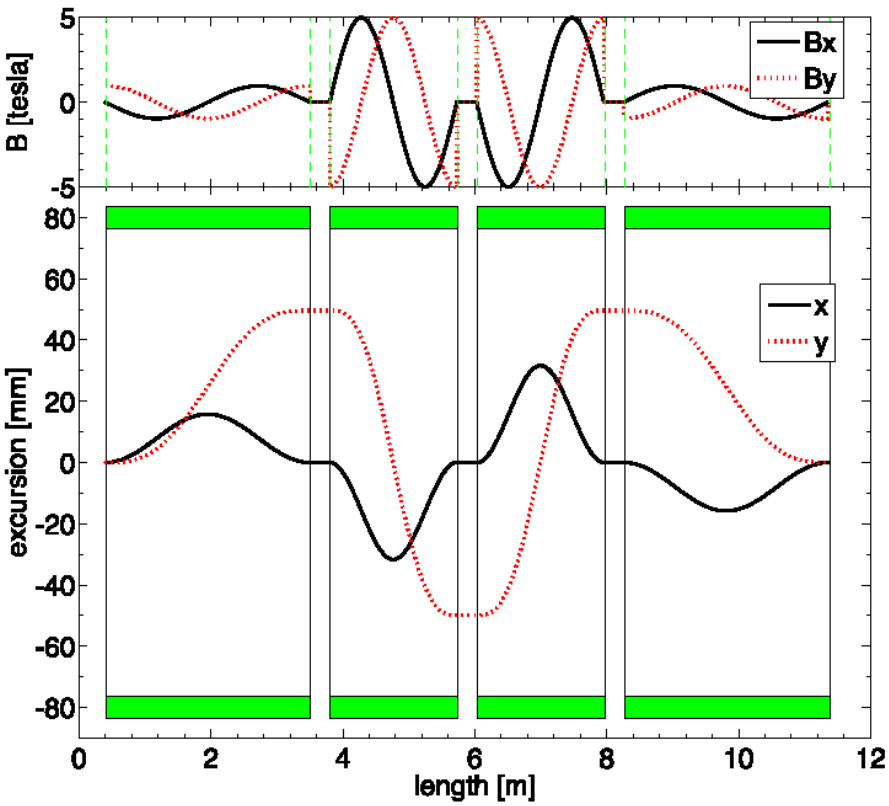


1 Siberian Snake in MI

plus 1 warm snake in RR

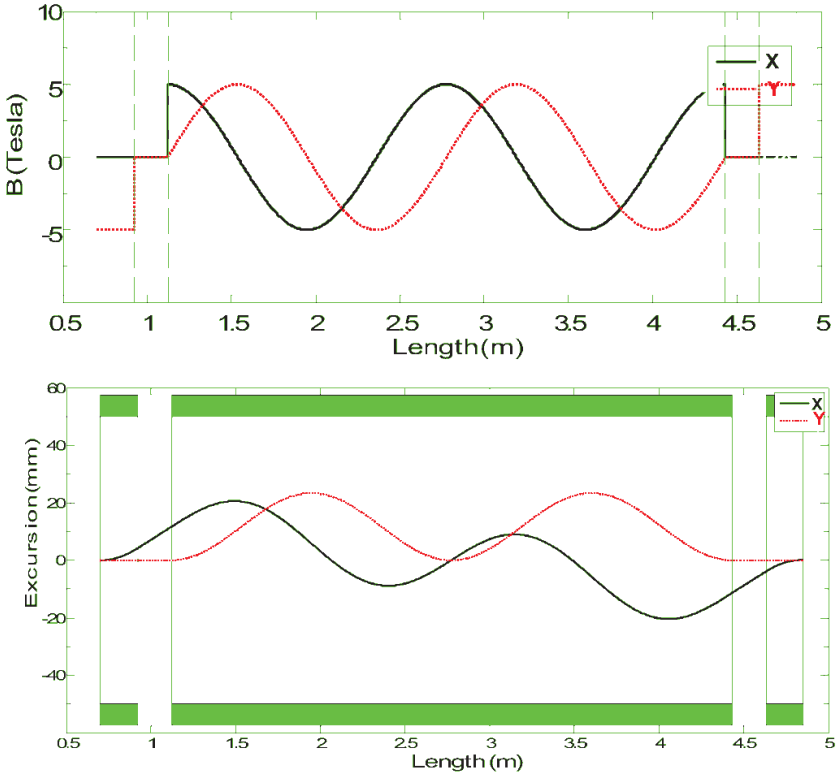
From 2 Siberian Snakes to 1 – II

Original 2-snake design:
- 4 helical dipoles / snake
- 5T / 11m long / 6” ID



- Cost: $4M
- does not fit

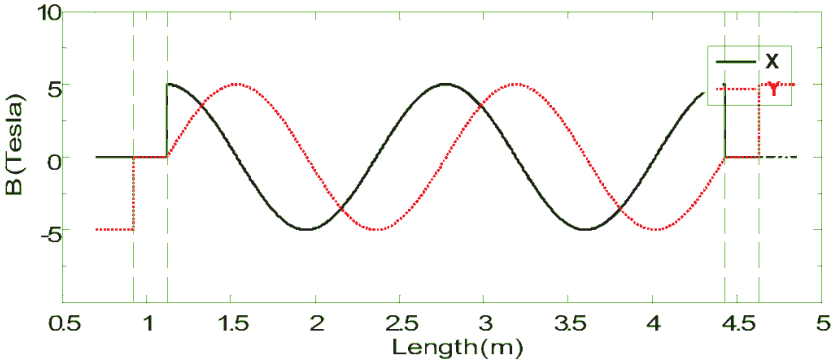
New 1-snake design:
- 1 helical dipole + 2 conv. dipoles
- 5T / 3.3m long / 4” ID

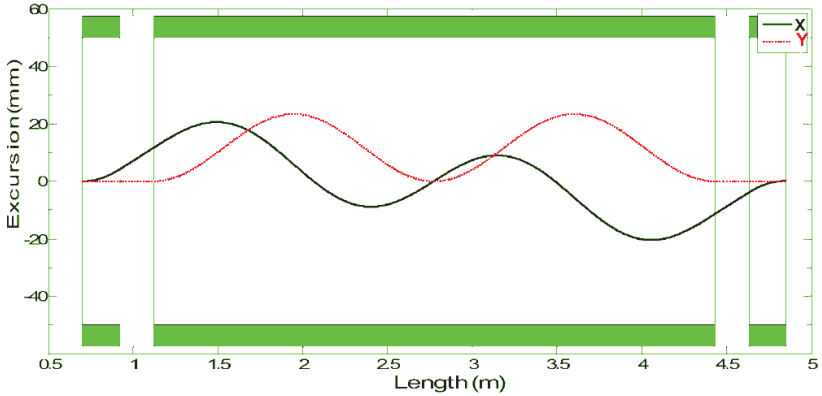


- Cost: $500k
- less space

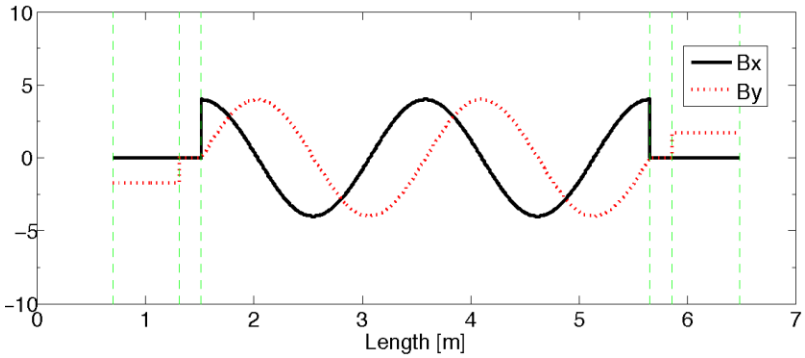
1-Snake Design – Further Improvements

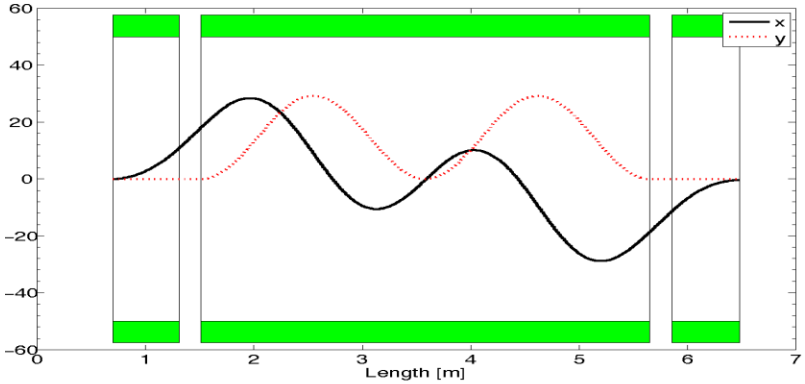
1-snake design (4.2m long):
-helix: 5T / 3.3m / 4” ID
-dipoles: 5T / 0.22m / 4” ID (**cold**)





Improved design (5.8m long):
-helix: 4T / 4.2m / 4” ID
-dipoles: 4T / 0.62m / 4” ID (**warm**)





T. Roser (BNL): - test snakes/rotators up to 5.4T
- operation not above 4T

PAC Q&A 1

Q *Running with two Siberian Snakes in the Main Injector would impact the core Fermilab program as one of them would require removal of the NOvA extraction kickers. What would the reduction in polarization be with one MI snake and what would be the quantitative effect on the goals of the experiment?*

A: Single snake solution found

- 3 month of world expert time:
  - → less space: fits fine into MI30
  - → much lower cost: see Q&A 3 found
- No additional loss in polarization
- No change to physics goals!

PAC Q&A 2

Q *In-kind and M&O contributions from outside of Fermilab sufficient to mount and sustain the experiment would be necessary in order to recommend approval, and the budget model needs to be fleshed out in greater detail with DOE ONP, OHEP, and NSF. What arrangements can be made to secure outside funding?*

A: Need participation and cooperation of several funding agencies for it to succeed:

- Roughly equal contributions from DOE/ONP and DOE/OHEP. In SeaQuest, was accomplished with a split between Fermilab effort and ONP support for M&S
- Several discussions with
  - → DOE/ONP: Ted Barnes, MEP Program Officer
  - → NSF: Brad Keister and Gail Dodge, Nuclear Physics (CAREER, MRI)
  - → Foreign Collaborators in Europe and Asia
- JINR (Dubna) joined SPIN@FERMI collaboration (Sept 2012)
  - → S. Belov help reassemble and upgrade original ZGS/AGS pol. proton source
- **Before more can be worked out with DOE/ONP, past experience (SeaQuest) shows that Phase I approval from Fermilab is needed** — it demonstrates that Fermilab is interested in project

PAC Q&A 3 – I

Q *There are two estimates for Snake fabrication and they vary widely. What are the anticipated costs for snake fabrication?*

A:

	June '12	Oct '12
Preaccelerator	$2.0 M	$1.9 M
Polarized H- ion source	$0.6 M	$0.6 M
35 keV polarimeter	$0.2 M	$0.2 M
RFQ and power supply (35 keV to 750 keV)	$0.3 M	$0.3 M
Beam lines, switching magnets & vacuum system	$0.5 M	$0.5 M
Building Modification	$0.1 M	$0.1 M
Installation (~4wks)	$0.2 M	$0.2 M
400 MeV LINAC	$0.3 M	$0.3 M
400 MeV polarimeter	$0.1 M	$0.1 M
Installation (~4wks)	$0.2 M	$0.2 M
8.9 GeV/c Booster	$3.4 M	$1.1 M
Solenoid and Partial Siberian snake (ramped warm)	$2.0 M	**$0.4 M**
Two 3 μsec pulsed quadrupoles with power supplies	$0.1 M	$0.1 M
8.9 GeV/c polarimeter	$0.9 M	$0.2 M
8.9 GeV/c transfer line spin rotator	$0.1 M	$0.1 M
Installation (~6wks)	$0.3 M	$0.3 M

PAC Q&A 3 – II

	June '12		Oct '12	
Recycler Ring		$0.0 M		$0.4 M
one superconducting solenoidal Siberian Snake			$0.1 M	
8.9 GeV/c polarimeter			$0.2 M	
Installation (~2wks)			$0.1 M	
Main Injector		$8.57 M		$1.3 M
Two/**One** superconducting helical Siberian Snake(s)	$4.27 M		**$0.5 M**	
Power supply for snake	$0.7 M		**$0.1 M**	
120 GeV/c polarimeters (CNI & Inclusive)	$0.6 M		$0.4 M	
Cryogenics (2 Buildings@1.06M, Equip: 0.3 M)	$2.7 M		-------	
Installation (~6wks)	$0.3 M		$0.3 M	
120-150 GeV/c Transfer Line		$2.8 M		$0.5 M
120-150 GeV/c polarimeters (CNI & Inclusive)	$0.4 M		$0.4 M	
120-150 GeV/c transfer line spin rotator	$2.0 M		-------	
Installation (~4/**2**wks)	$0.2 M		$0.1 M	
Miscellaneous		$0.6 M		$0.6 M
Computers, control modules, cables, and interface	$0.3 M		$0.3 M	
Transport, reconfiguration, technical (guess estimate)	$0.3 M		$0.3 M	
Subtotals		$17.67 M		$6.1 M
Project Management estimate (15% of subtotal)	$2.65 M		$0.9 M	
Contingency (~50%)	$10.16 M		$3.5 M	
PROJECT TOTAL		**~$30.485 M**		**~$10.5 M**

PAC Q&A 4

Q *What are the likely impacts on the Fermilab infrastructure and expert personnel in the installation and commissioning of the proposed polarized-proton beam in this system?*

A:

➡ **Infrastructure**:

→ Polarized source must be added in parallel to the current RFQ source.

→ Electricity and Cryogenics is needed for the snake at MI30. This may require additional building, but there is room for the snake and the building, (may increase costs by 10%).

➡ **Fermilab's Expert Personnel**:

→ All within the existing skill set at Fermilab required to operate the Main Injector.

- possible exception of polarimetry

→ These personnel are in demand during shutdowns when installation will take place, so availability of these personnel will affect duration of installation.

PAC Q&A 5

Q *What are the likely resources and infrastructure implications for operating such a beam?*

A: Single snake solution greatly minimizes conflicts between operation of polarized beam and NuMI beam line. Nevertheless, there will always be some impact:

- **NuMI Luminosity**:
  - → Time during slow extraction will be limited to 10% of the MI time, as with SeaQuest. Since we run in parallel with test beam (FTBF), of the 10%, only time when the FTBF would not be operating would be lost.
- **MCR Operations**:
  - → Once beam is tuned, should have similar impact to running test beam or SeaQuest. Establishing initial tune may require more “expert” personnel.
- **Polarimeter Operations**:
  - → Collaboration willing to accept responsibility for these devices; will work with AD to incorporate them into AD’s diagnostic and feedback systems.
- **Maintenance**:
  - → Additional cryogenic facility, and magnets and snakes in accelerator complex will require maintenance, but nothing out of the range of the normal periodic maintenance done at Fermilab.

Requests to Fermilab

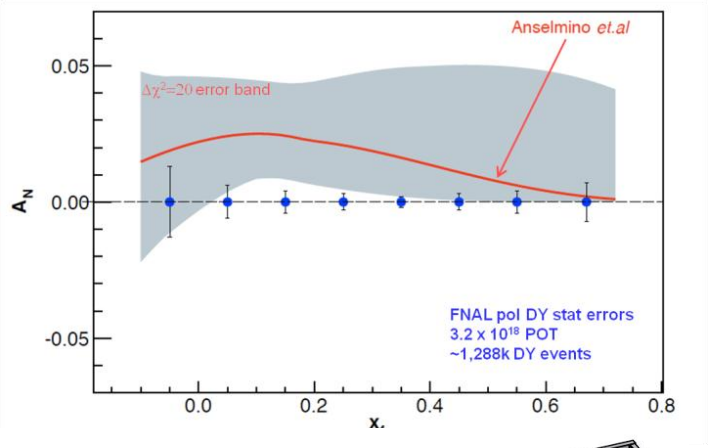
- Continue availability of NM3/4 for SeaQuest spectrometer
- Provide polarized beam in slow extraction mode

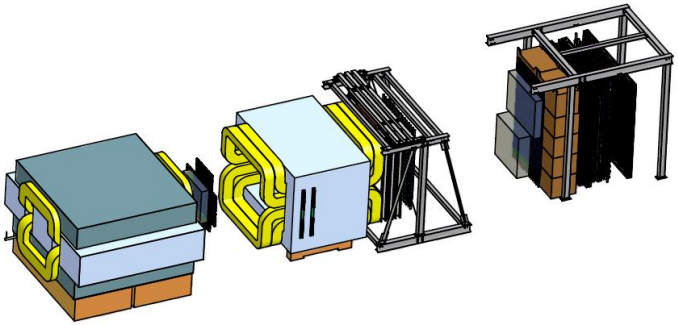
Request to PAC

- Recommend Phase I approval
  - ➡ Before more can be worked out with DOE/ONP, past experience (SeaQuest) shows that Phase I approval from Fermilab is needed

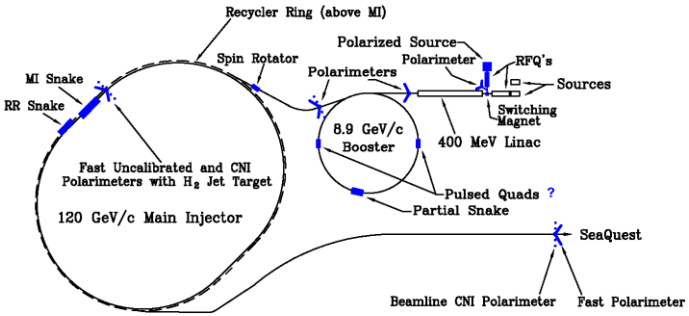
Conclusions

- Extraordinary opportunity at Fermilab
  - ➡ set up best polarized DY experiment to measure sign change in Sivers function
    - → major milestone in hadronic physics (HP13)
    - → high luminosity, large x-coverage, high-intensity polarized beam
    - → spectrometer already setup and running
  - ➡ with minimal impact on neutrino program
    - → 10% of available beam time at MI





- Simpler design: 2-snakes → 1-snake
  - ➡ less real estate, no additional loss in polarization

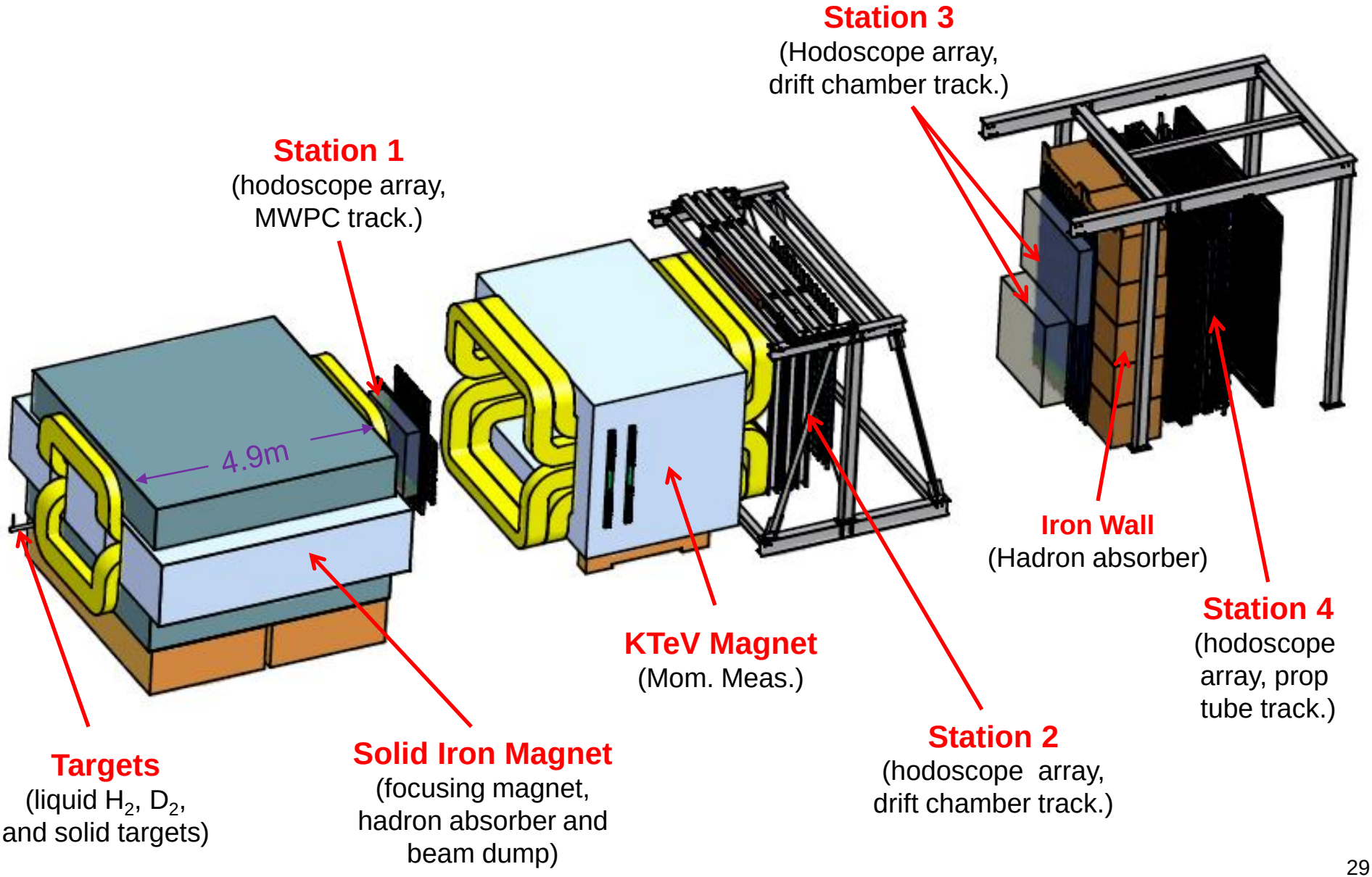


- Cost to polarize Main Injector is ~$10M (including 50% contingency)

The END

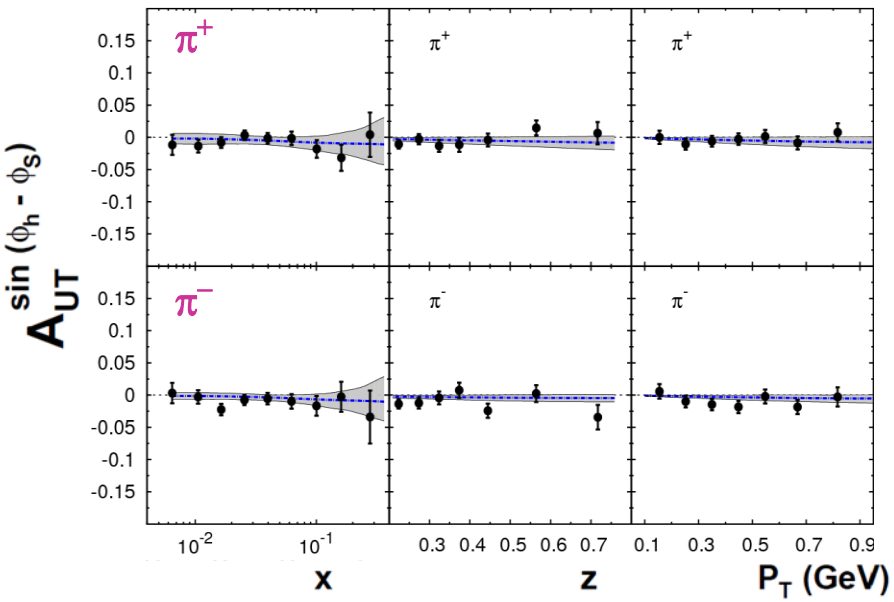
Backup Slides

Drell-Yan Spectrometer for SeaQuest
(25m long)

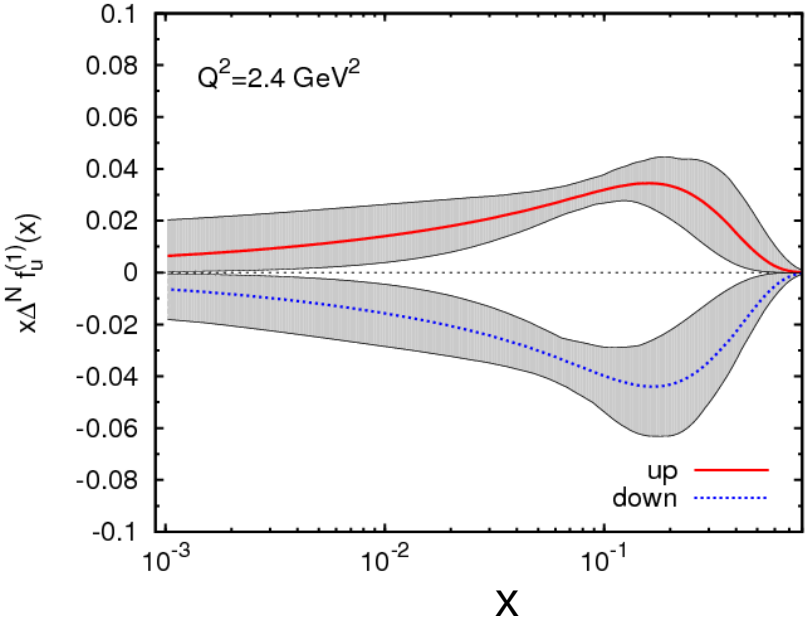


Sivers Asymmetry Measurements and Fits

COMPASS (d)



Anselmino et al. (arXiv:1107.4446 [hep-ph])



- Global fit to sin ($\phi_h - \phi_S$) asymmetry in SIDIS (HERMES (p), COMPASS (p), COMPASS (d))

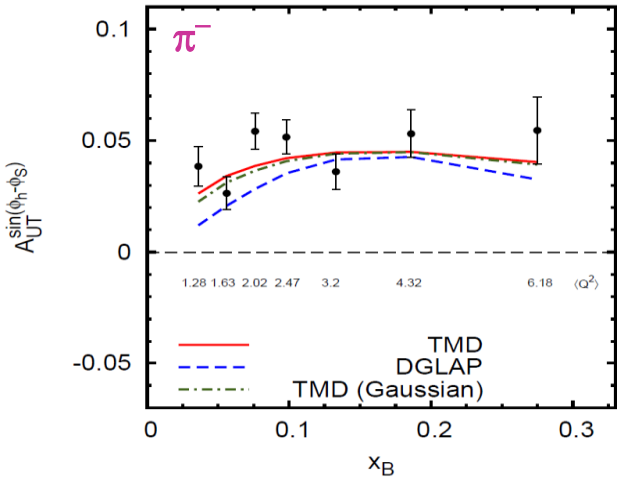
First moment of Sivers functions:

➡ u- and d- Sivers have opposite signs, of roughly equal magnitude

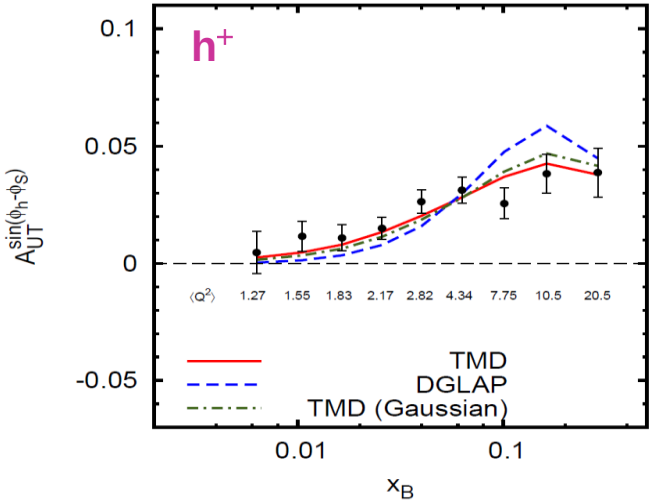
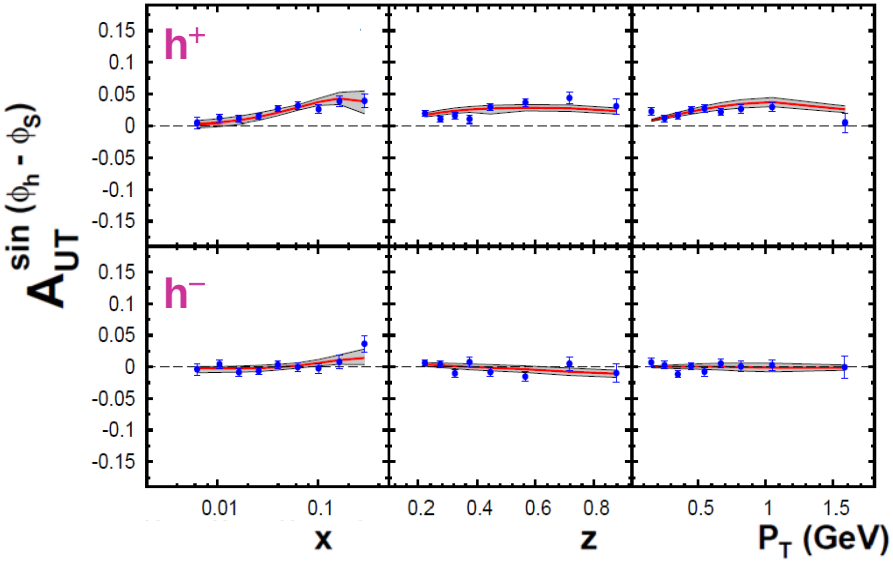
QCD Evolution of Sivers Function

Anselmino et al. (arXiv:1209.1541 [hep-ph])

HERMES (p)



COMPASS (p)



- Initial global fits by Anselmino group included DGLAP evolution only in collinear part of TMDs (not entirely correct for TMD-factorization)
- Using TMD Q^2 evolution:
  $\longrightarrow$ agreement with data improves