Drell-Yan Experiments at Fermilab: SeaQuest and Beyond

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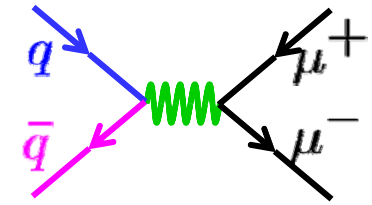
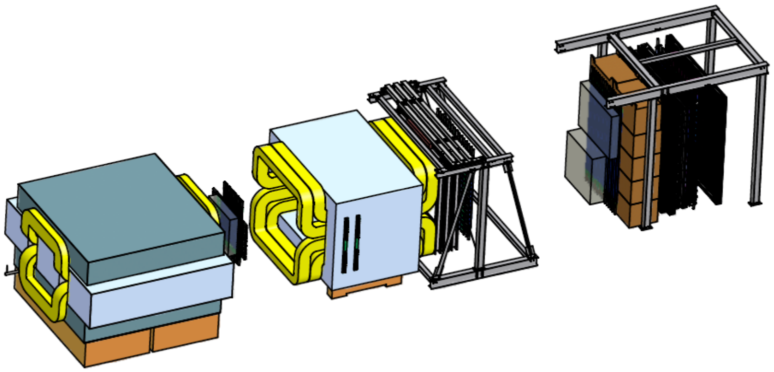
(30-October-2013)
PacSPIN2013



- **SeaQuest: Fermilab Experiment E906**
  - ➡ Status and Plans



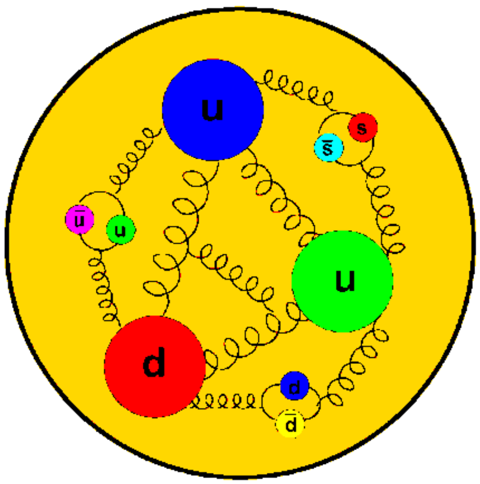
- **Beyond SeaQuest**
  - ➡ **Polarized** Drell-Yan at Fermilab (**E1027**)

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

This work is supported by

What is the Structure of the Nucleon?

Flavor Structure of the Proton

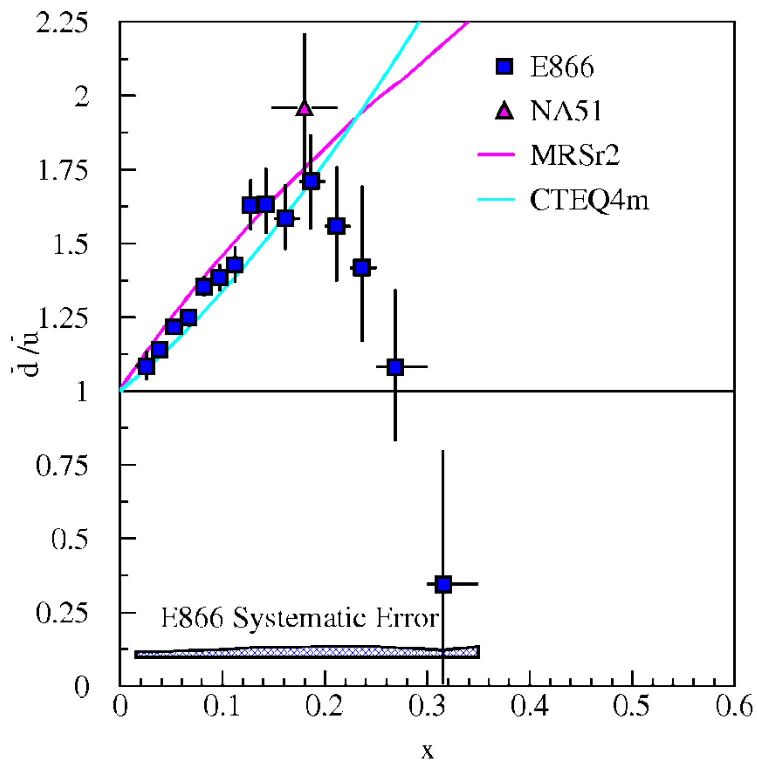


➡ Constituent Quark Model
Pure valence description: proton = 2u + d

➡ Perturbative Sea
sea quark pairs from g → $q\bar{q}$
should be flavor symmetric: $\boxed{\bar{d} = \bar{u}}$

➡ What does the data tell us?

E866: $\boxed{\bar{d} > \bar{u}}$

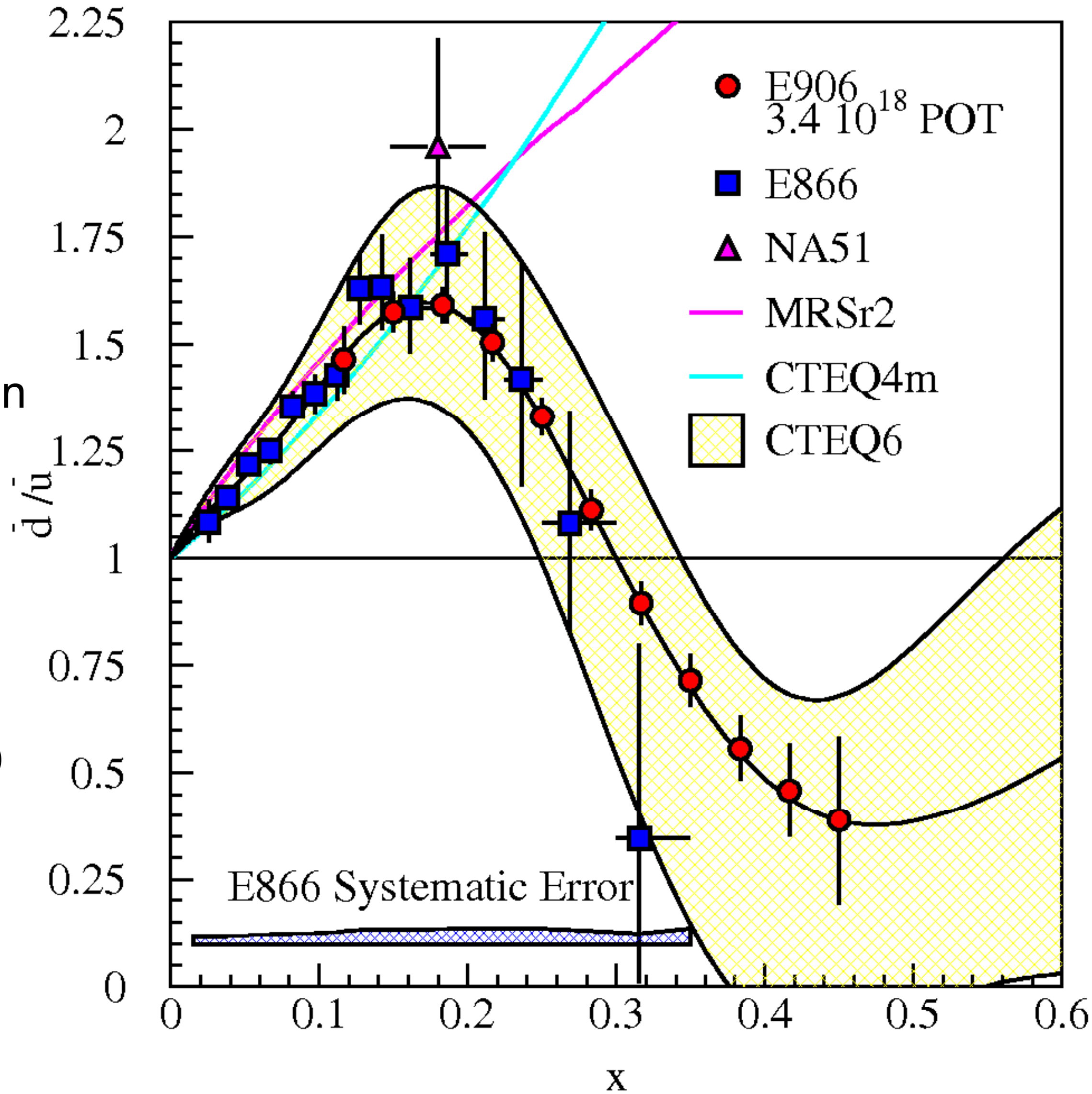


➡ Are there more gluons and thus symmetric anti-quarks at higher x?

➡ Unknown other mechanisms with unexpected x-dependence?

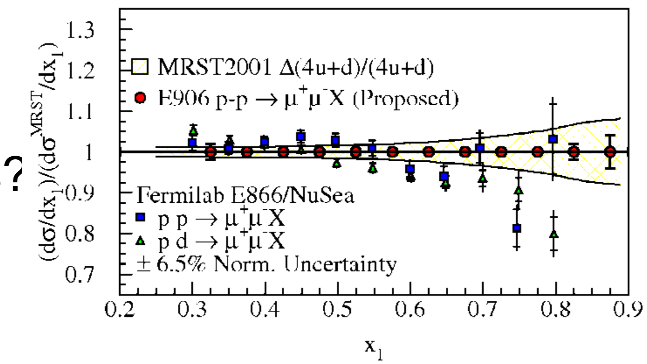
SeaQuest Projections for d-bar/u-bar Ratio

- SeaQuest will extend E866 measurements and reduce statistical uncertainty
- SeaQuest expects systematic uncertainty to remain at ≈1% in cross section ratio
- 5 s slow extraction spill each minute
- Intensity:
  - 2 x 10^{12} protons/s (I_{inst} =320 nA)
  - 1 x 10^{13} protons/spill

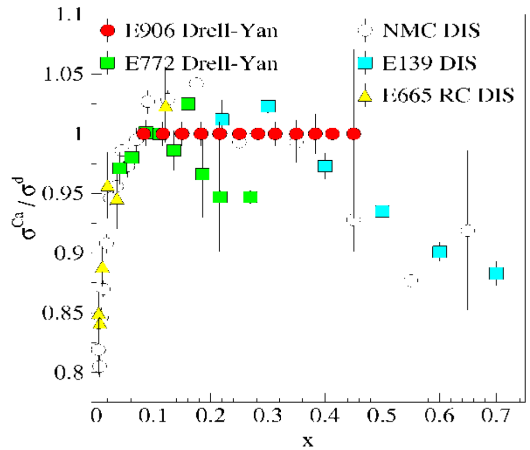


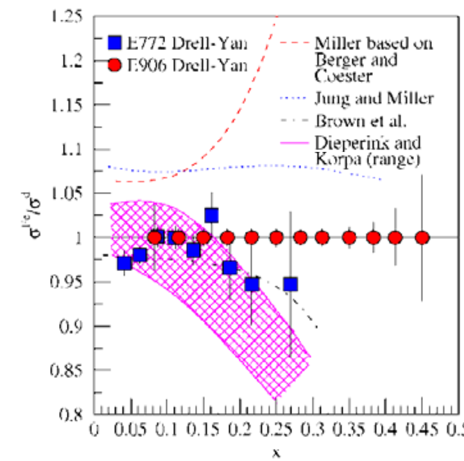
SeaQuest: what else …

- **What is the structure of the nucleon?**
  - ➡ What is $\bar{d}\,/\,\bar{u}$? What is the origin of the sea quarks?
  - ➡ What is the high x structure of the proton?

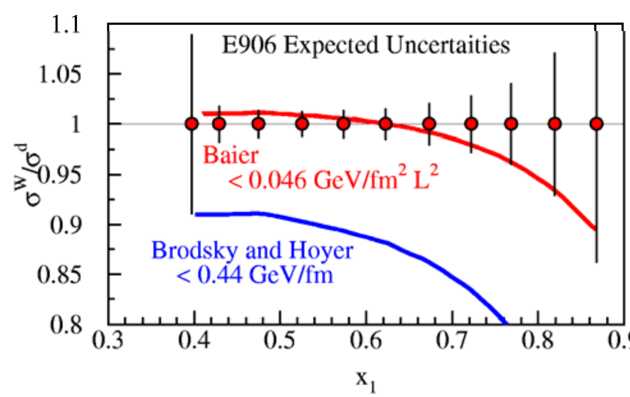


- **What is the structure of nucleonic matter?**
  - ➡ Is anti-shadowing a valence effect?
  - ➡ Where are the nuclear pions?



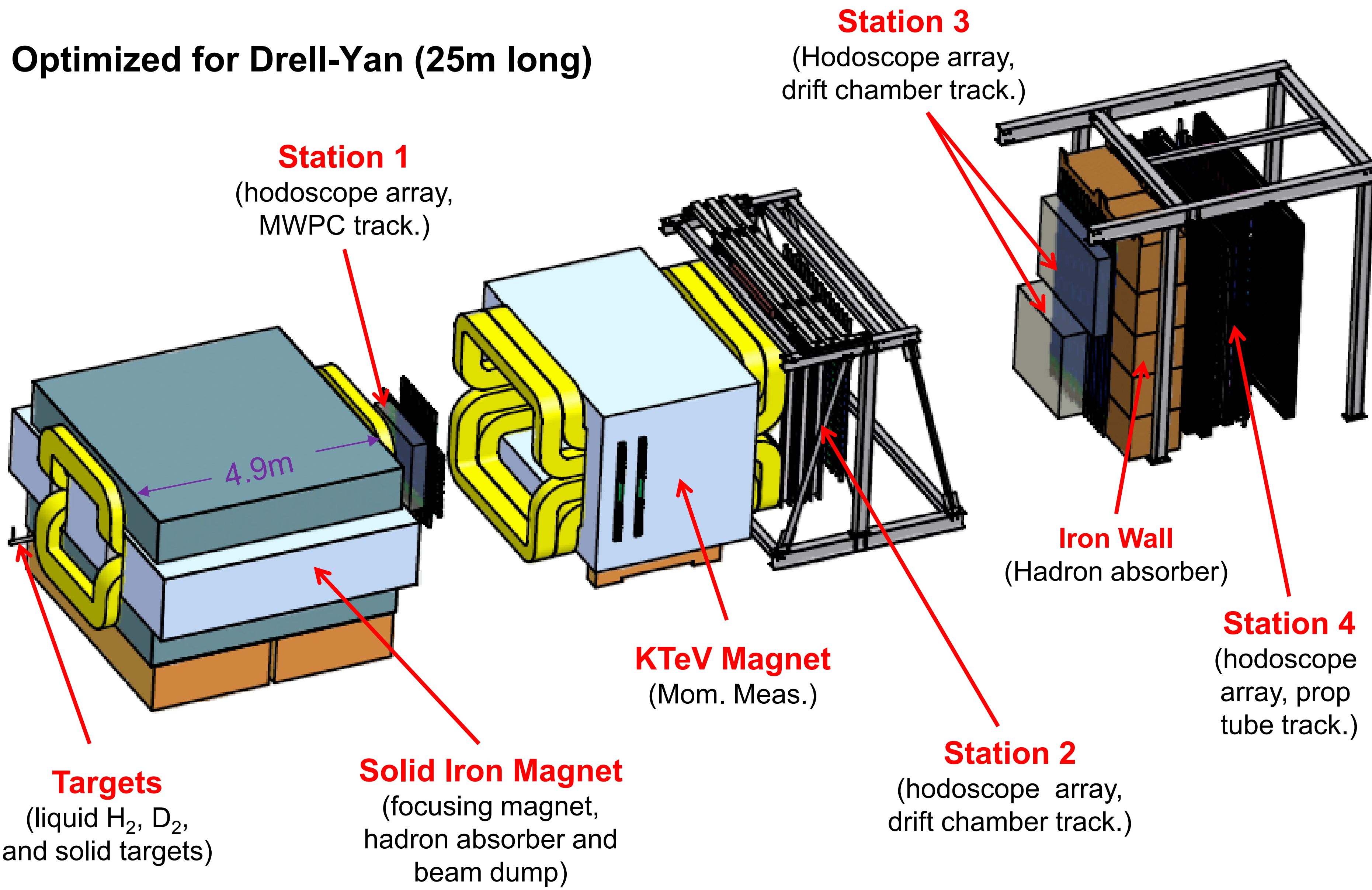


- ***Do colored partons lose energy in cold nuclear matter ?***
  - ➡ How large is energy loss of fast quarks in cold nuclear matter?



A simple Spectrometer for SeaQuest

Optimized for Drell-Yan (25m long)



The SeaQuest Collaboration

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*Co-Spokespersons

Oct, 2013
(70 collaborators)

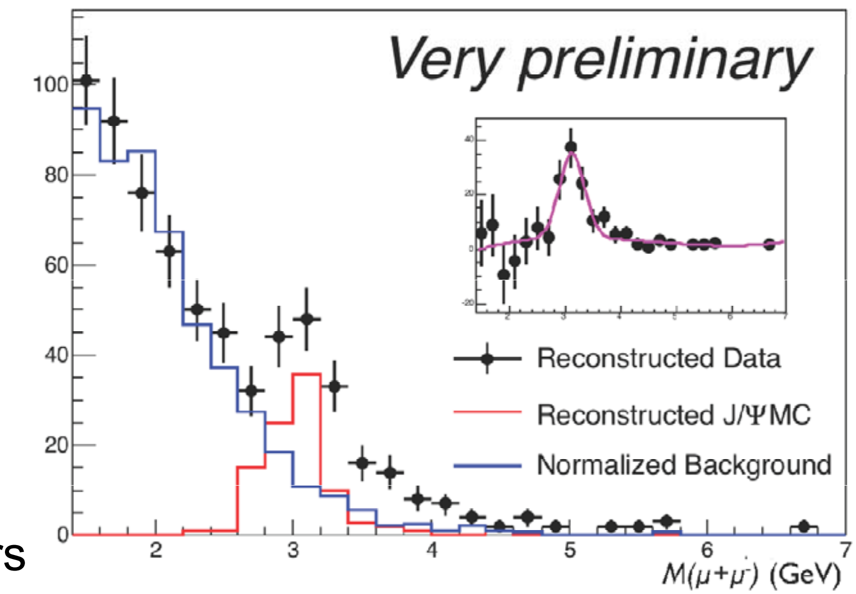
From Commissioning Run to Science Run

- Commissioning Run (late Feb. 2012 – April 30th, 2012)
- First beam in E906 on March 8th, 2012
- Extensive beam tuning by the Fermilab accelerator group
  - ➡ 1 x10^{12} protons/s (5 s spill/min)
  - ➡ 120 GeV/c
- All the detector subsystems worked
  - ➡ improvements for the production run completed
- Main Injector shut down began on May 1st , 2012
- Reconstructable dimuon events seen:

  $M_{J/\Psi}$ = 3.12 ± 0.05 GeV

  σ = 0.23 ± 0.07 GeV

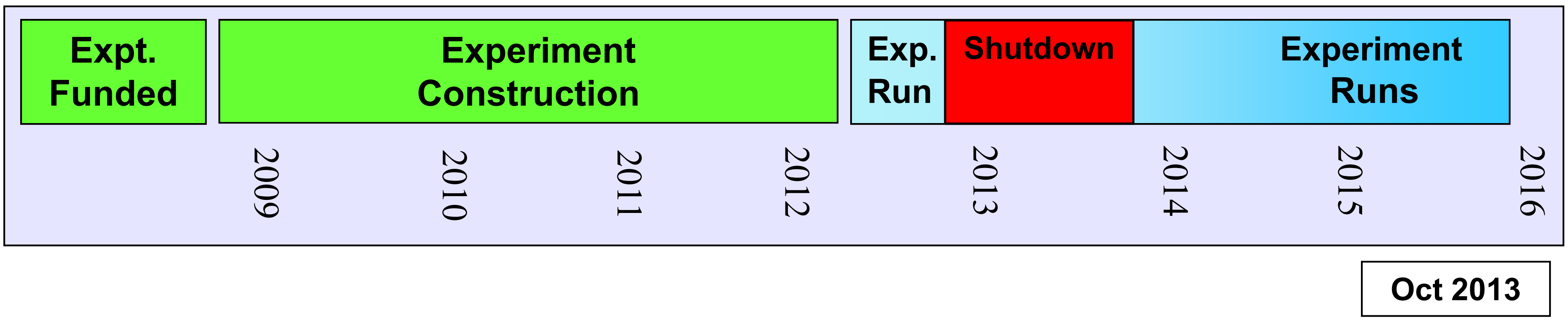
A successful commissioning run



- Science Run start in Nov. 2013 for 2 years

The long Path towards the Science Run

- Stage I approval in 2001
- Stage II approval in December 2008
- Commissioning Run (March - April 2012)
- Expect beam again in November 2013 (for 2 years of data collection)



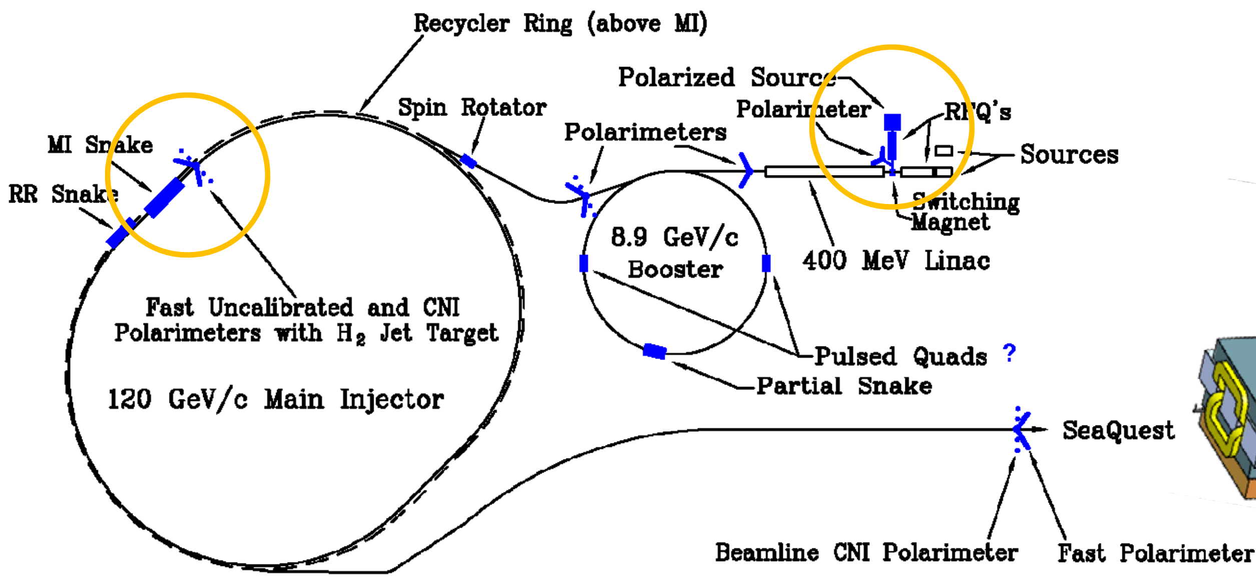
Apparatus available for future programs at, *e.g.* Fermilab, (*J-PARC or RHIC*)

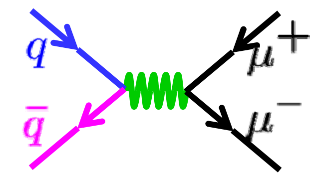
➡ significant interest from collaboration for continued program:

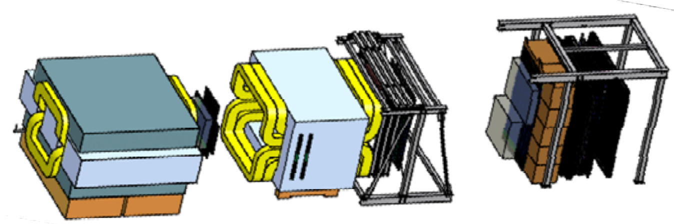
- Polarized beam in Main Injector
- Polarized Target at NM4

Let's Add Polarization

- **Polarize Beam** in Main Injector & use SeaQuest dimuon Spectrometer
  ➡ measure Sivers asymmetry





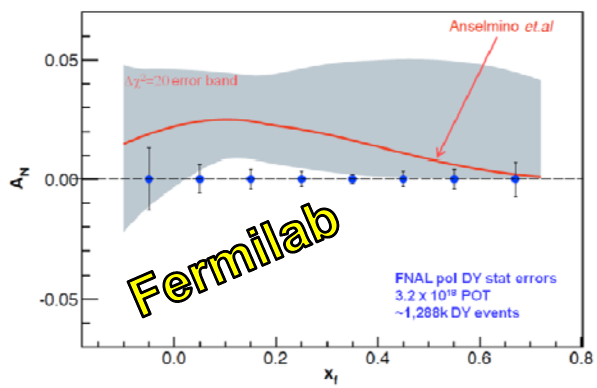


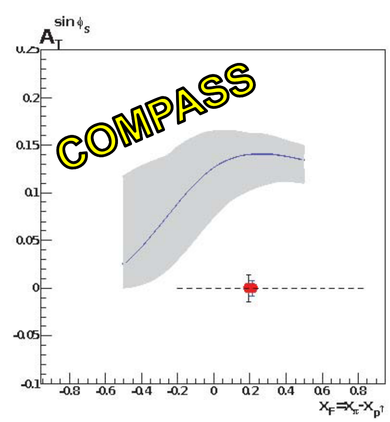
- **Sivers function**
  ➡ captures non-perturbative spin-orbit coupling effects inside a polarized proton
  ➡ is naïve time-reversal odd:
    ✓ leads to sign change:
    Sivers function in SIDIS = - Sivers function in Drell-Yan: $f_{1T}^{\perp}\big|_{SIDIS} = -f_{1T}^{\perp}\big|_{DY}$
    ✓ fundamental prediction of QCD (in non-perturbative regime)

Polarized Drell-Yan at Fermilab Main Injector - II

- **Polarized Drell-Yan:** NOT YET DONE!
  - ➡ major milestone in hadronic physics (HP13)

- **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
    - ⟶ (SeaQuest) spectrometer already setup and running
  - ➡ with (potentially) minimal impact on neutrino program
    - ⟶ run alongside neutrino program (10% of beam needed)
  - ➡ experimental sensitivity:
    - ⟶ 2 yrs at 50% eff, P_b = 70%
    - ⟶ luminosity: L_{av} = 2 x 10^{35} /cm^2/s





- **Cost** estimate to **polarize** Main Injector $10M (total)
  - ➡ includes 15% project management & 50% contingency

Planned Polarized Drell-Yan Experiments

experiment	particles	energy	x_b or x_t	Luminosity	timeline
COMPASS (CERN)	$p^{\pm}$ + $p^{\uparrow}$	160 GeV $\sqrt{s}$ = 17.4 GeV	x_t = 0.2 – 0.3	2 x 10^{33} cm^{-2} s^{-1}	2014, 2018
PAX (GSI)	$p^{\uparrow}$ + p_{bar}	collider $\sqrt{s}$ = 14 GeV	x_b = 0.1 – 0.9	2 x 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 x 10^{32} cm^{-2} s^{-1}	>2016
NICA (JINR)	$p^{\uparrow}$ + p	collider $\sqrt{s}$ = 20 GeV	x_b = 0.1 – 0.8	1 x 10^{30} cm^{-2} s^{-1}	>2014
PHENIX (RHIC)	$p^{\uparrow}$ + p	collider $\sqrt{s}$ = 500 GeV	x_b = 0.05 – 0.1	2 x 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 x 10^{33} cm^{-2} s^{-1}	
RHIC internal target phase-1	$p^{\uparrow}$ + p	250 GeV $\sqrt{s}$ = 22 GeV	x_b = 0.25 – 0.4	6 x 10^{34} cm^{-2} s^{-1}	
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 x 10^{35} cm^{-2} s^{-1}	2012 - 2015
polDY§ (FNAL)	$p^{\uparrow}$ + p	120 GeV $\sqrt{s}$ = 15 GeV	x_b = 0.35 – 0.85	2 x 10^{35} cm^{-2} s^{-1}	>2016
	§ L= 1 x 10^{36} cm^{-2} s^{-1} (LH_2 tgt limited) / L= 2 x 10^{35} cm^{-2} s^{-1} (10% of MI beam limited)				

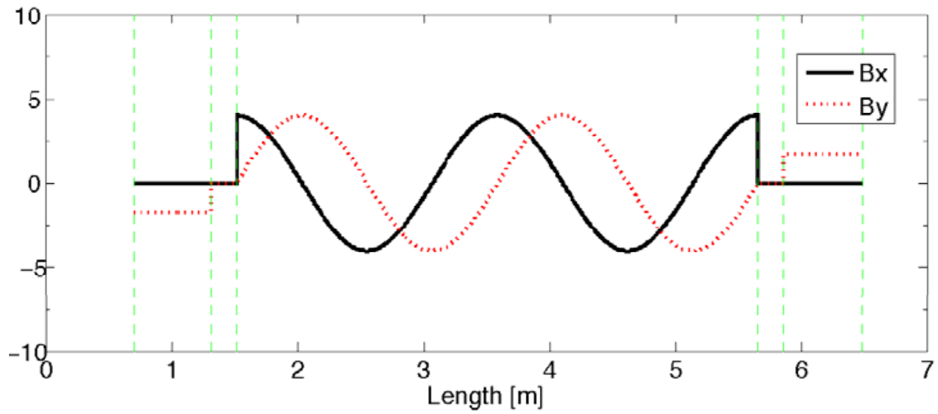
A Novel Siberian Snake for the Main Injector

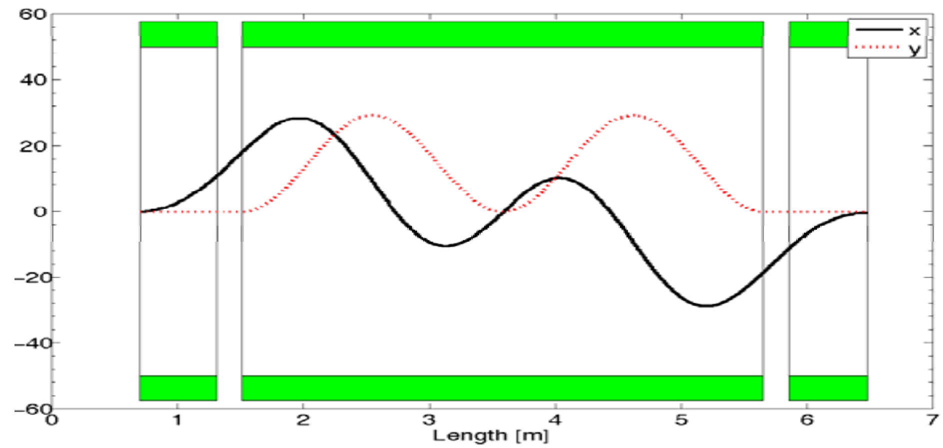
Single snake design (5.8m long):

- 1 helical dipole + 2 conv. dipoles
  - helix: 4T / 4.2 m / 4” ID
  - dipoles: 4T / 0.62 m / 4” ID

- use 2-twist magnets
  - 4π rotation of B field

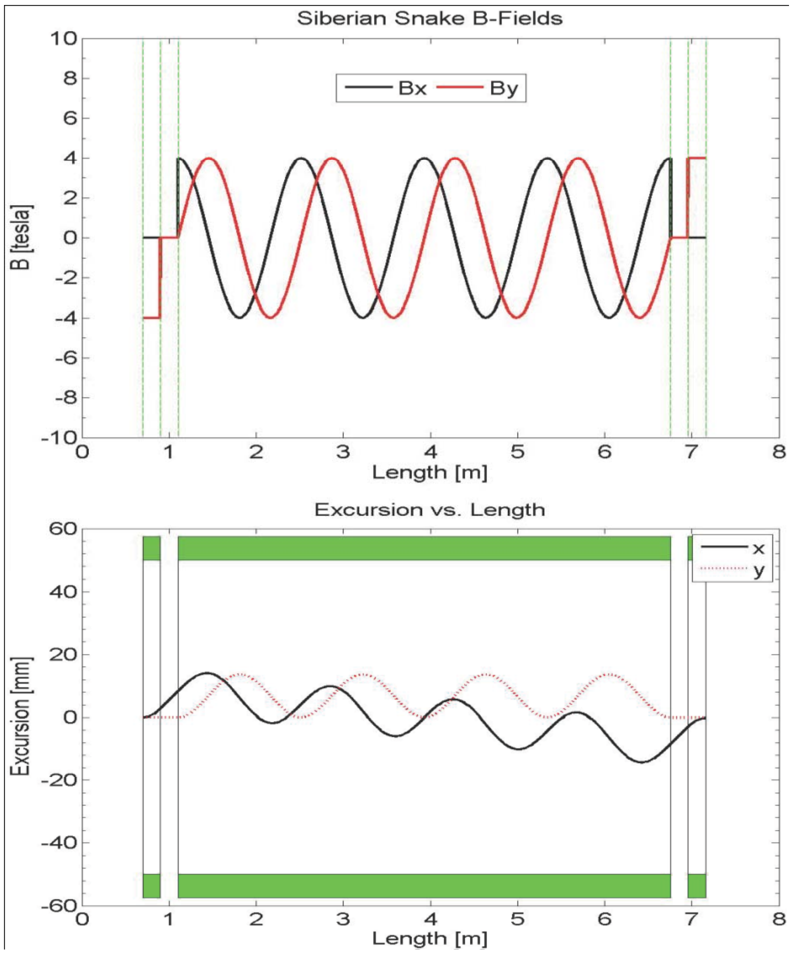
- never done before in a high energy ring
  - RHIC uses snake pairs
  - single-twist magnets (2π rotation)



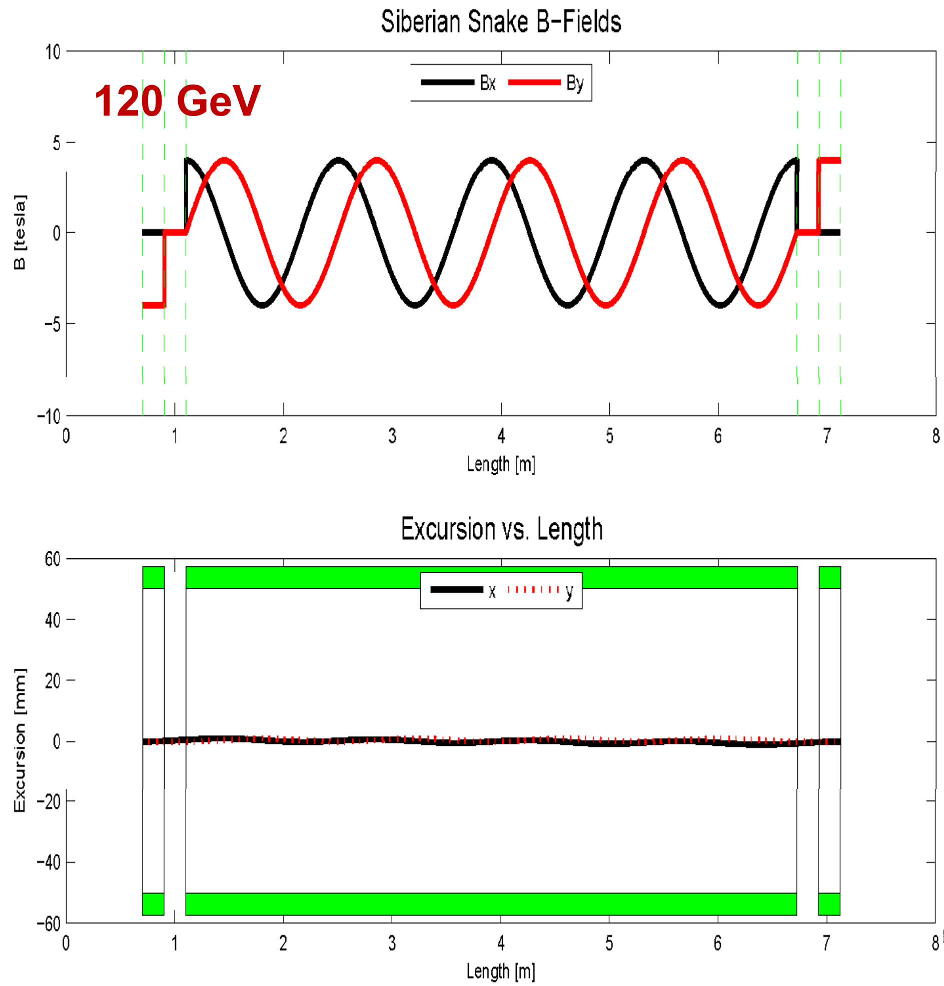


Siberian Snake Studies

8.9 GeV 4T



4-twist 4T

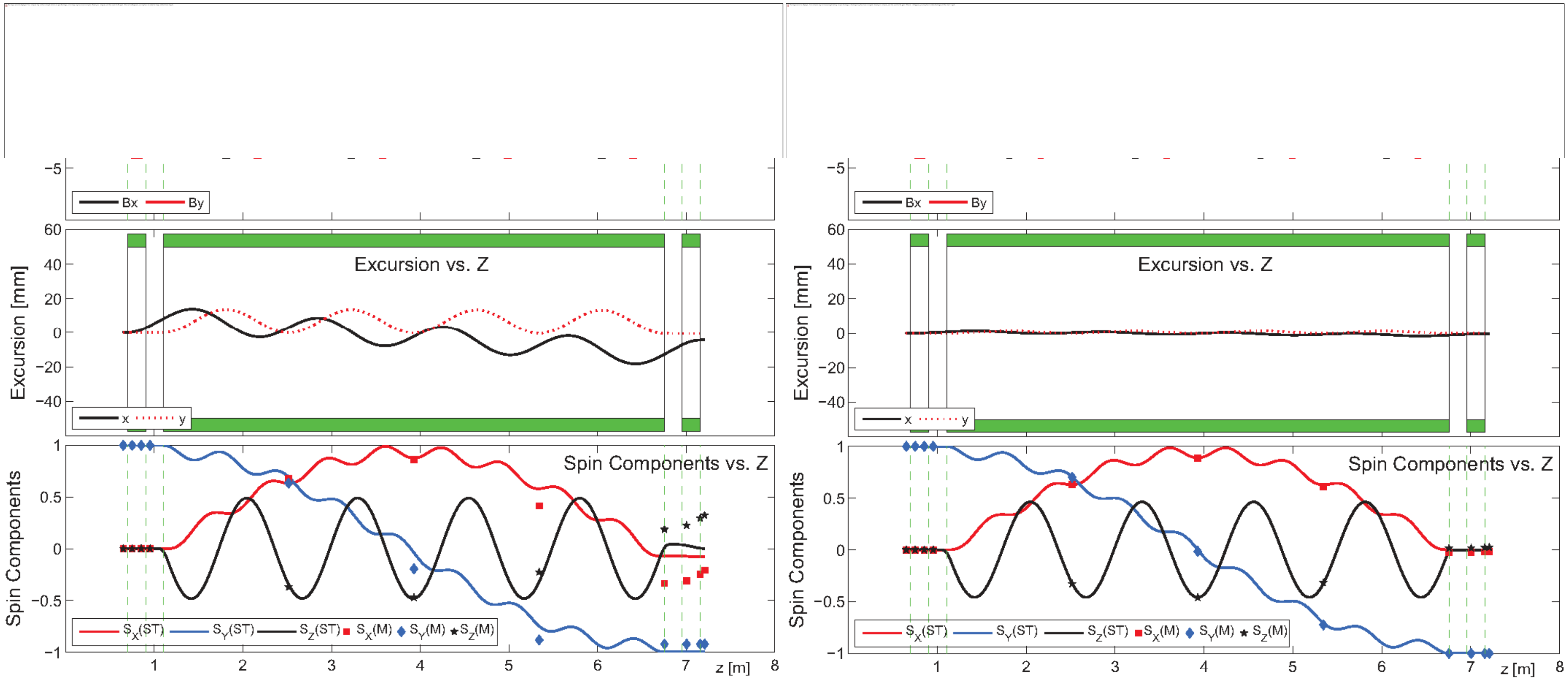


beam excursions shrink w/ number of twists

beam excursions shrink w/ beam energy

Siberian Snake Studies- II

Including fringe fields



x, y, z spin components vs distance

♦ transport matrix formalism (E.D. Courant): fringe field not included, β = 1 (fixed)

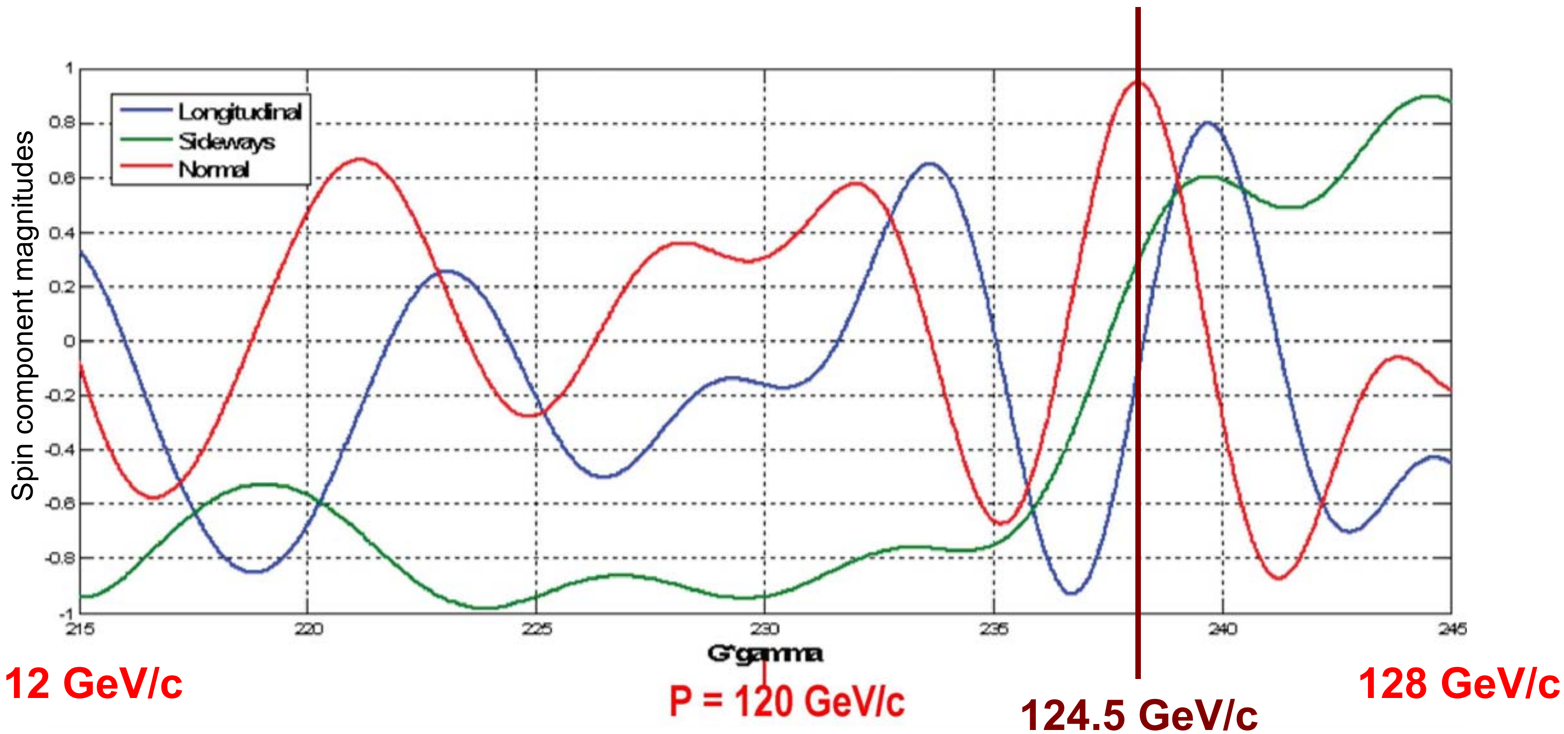
– spin tracking formalism (Thomas-BMT): fringe field included, β varibale

fringe fields have <0.5% effect at 8.9 GeV and <<0.1% effect at 100 GeV [arXiv: 1309.1063]

Spin direction control for extracted beam

- Spin rotators used to control spin direction at BNL
- Spin@Fermi collaboration recent studies (to save $$)
  - ➡ rotate beam at experiment by changing proton beam energy around nominal 120 GeV

radial (“sideways”) / vertical (“normal”)



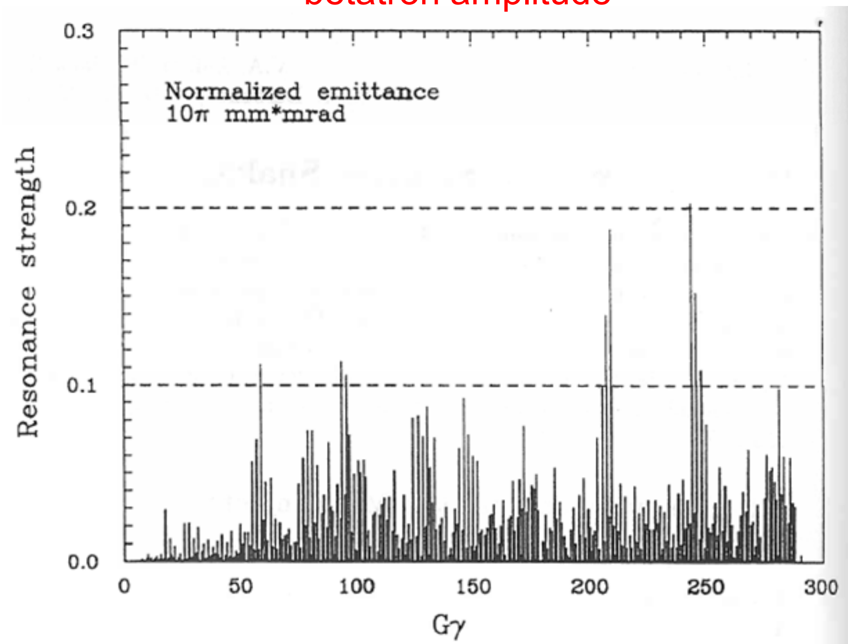
The Path to a polarized Main Injector

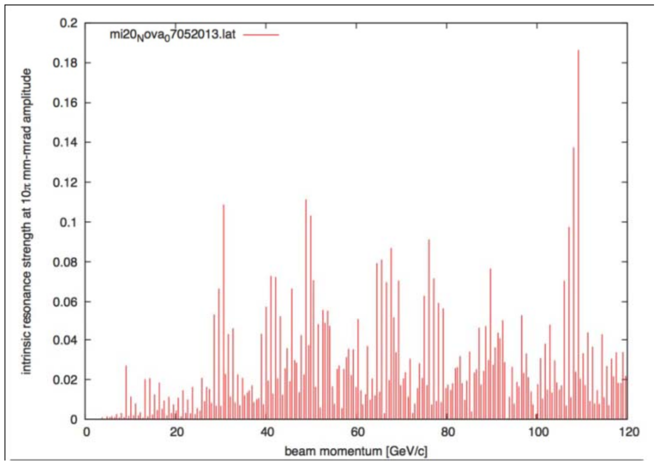
Stage 1 approval from Fermilab: 14-November-2012

- Collaboration with A.S. Belov at INR and Dubna to develop polarized source
- Detailed machine design and costing using 1 snake in MI
  - ➡ Spin@Fermi collaboration provide design
    - ⟶ get latest lattice for NOVA:
      - › translate "mad8" optics file to spin tracking code ("zgoubi")
    - ⟶ determine intrinsic resonance strength from depolarization calculations
    - ⟶ do single particle tracking with "zgoubi" with novel single-snake
    - ⟶ set up mechanism for adding errors into the lattice:
      - › orbit errors, quadrupole mis-alignments/rolls, etc.
    - ⟶ perform systematic spin tracking
      - › explore tolerances on beam emittance
      - › explore tolerances on various imperfections: orbit / snake / etc
  - ➡ Fermilab (AD) does verification & costing

Intrinsic Resonance Strength in Main Injector

Depol calculations: single particle at 10π mm-mrad betatron amplitude





- 1995 Spin@Fermi report
  - ➡ before MI was built

- using NOVA lattice (July 2013)

- very similar: largest resonance strength just below 0.2

  → one snake sufficient (E. Courant rule of thumb)

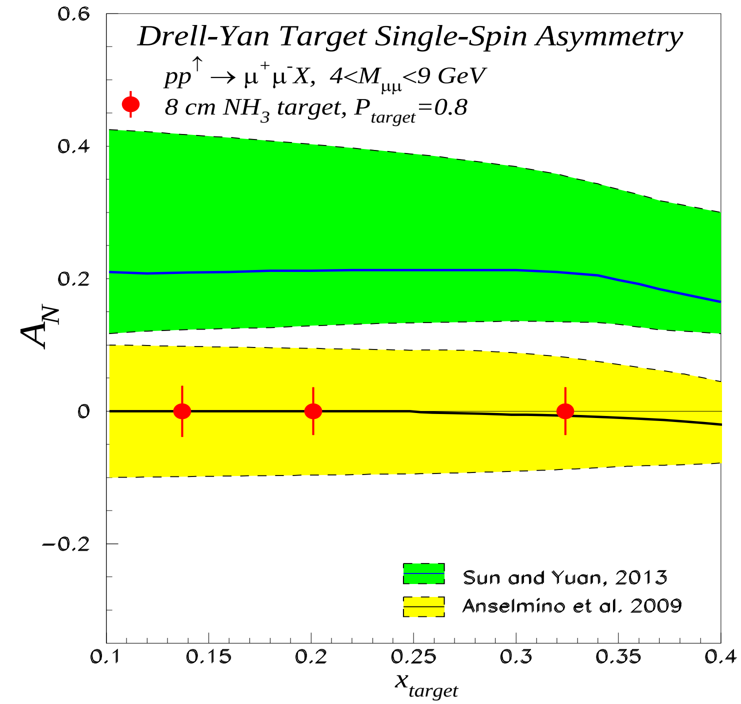
Another Way to Add Polarization: E1039

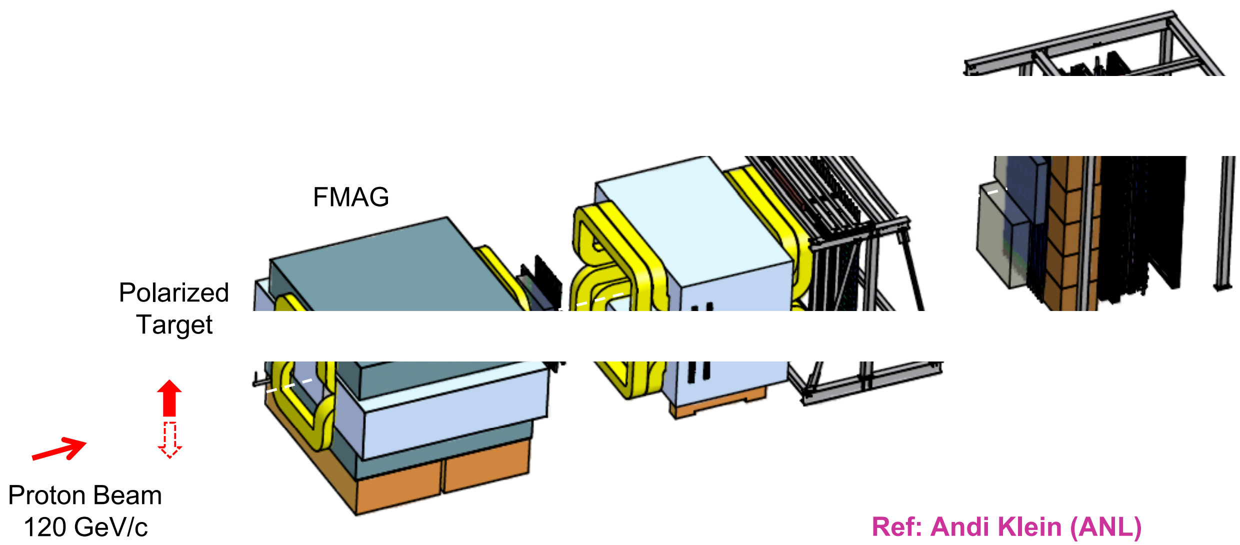
Polarized Target at Fermilab

- Probe Sea-quark Sivers Asymmetry with a polarized proton target at SeaQuest

  – sea-quark Sivers function poorly known

  – significant Sivers asymmetry expected from meson-cloud model





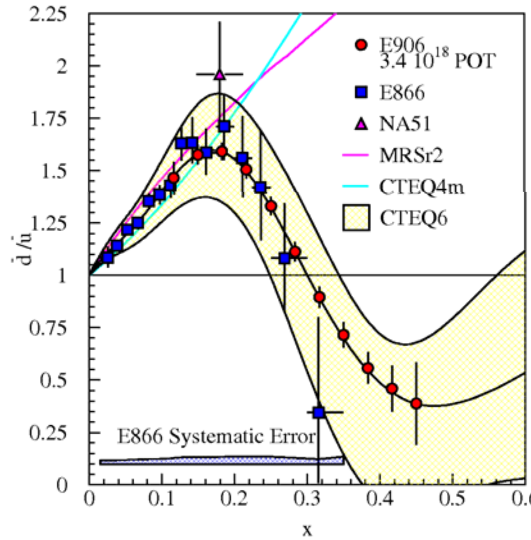
– use current SeaQuest setup

– a polarized proton target, unpolarized beam

Ref: Andi Klein (ANL)

Summary

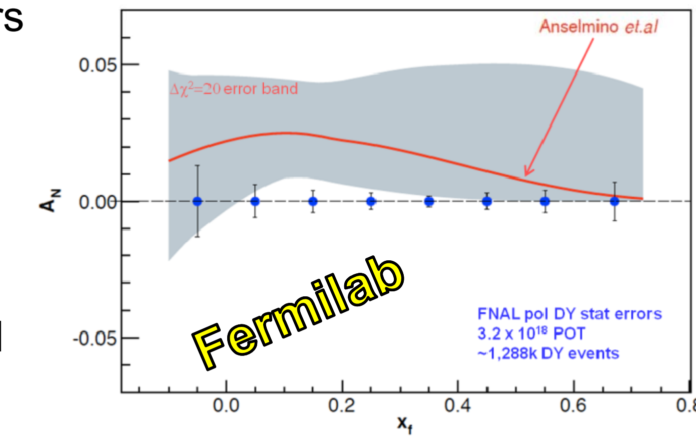
- **SeaQuest (E906):**
  - ➡ What is the structure of the nucleon? $\bar{d}\,/\,\bar{u}$?
  - ➡ How does it change in the nucleus?
    - ⟶ provide better understanding on the physical mechanism which generates the proton sea



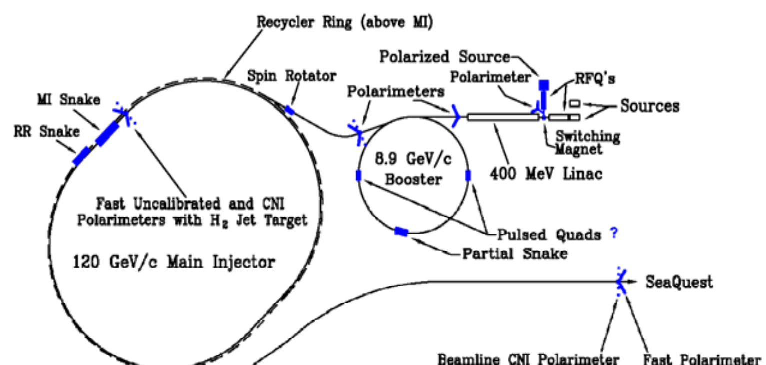
- **Polarized Drell-Yan (E1027):**
  - ➡ QCD (and factorization) require sign change in Sivers asymmetry:

$$f_{1T}^{\perp}\Big|_{SIDIS} = - f_{1T}^{\perp}\Big|_{DY}$$

  - ⟶ test fundamental prediction of QCD (in non-perturbative regime)
  - ➡ Measure DY with both Beam or/and Target polarized
    - ⟶ broad spin physics program possible



  - ➡ Path to polarized proton beam at Main Injector
    - ⟶ perform detailed machine design and costing studies
      - › proof that single-snake concept works
      - › applications for JPARC, NICA, ….
    - ⟶ Secure funding



Thank You