

The SeaQuest Drell-Yan Experiments: At a transitional cross road

30 June 2017

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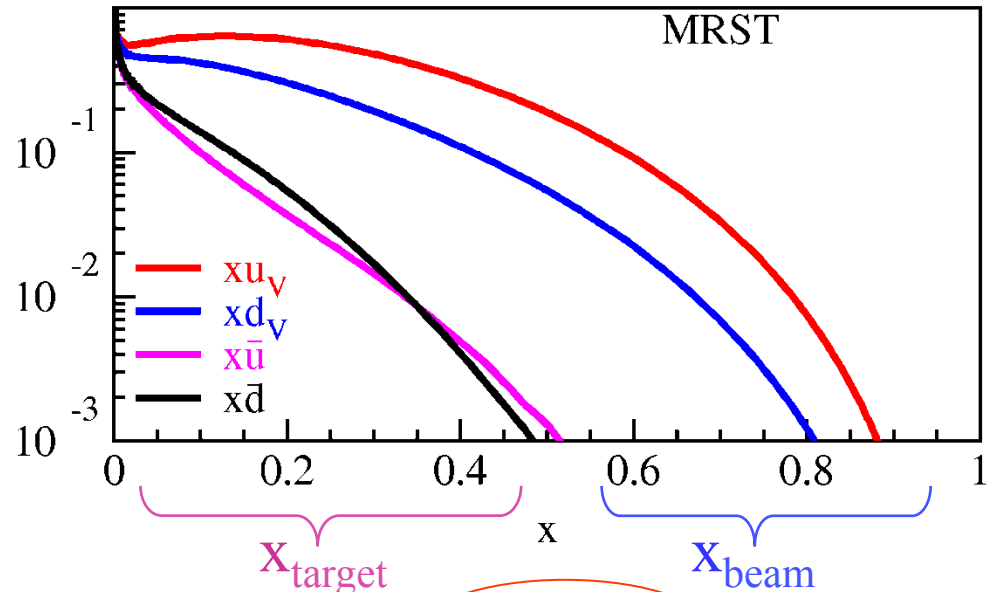
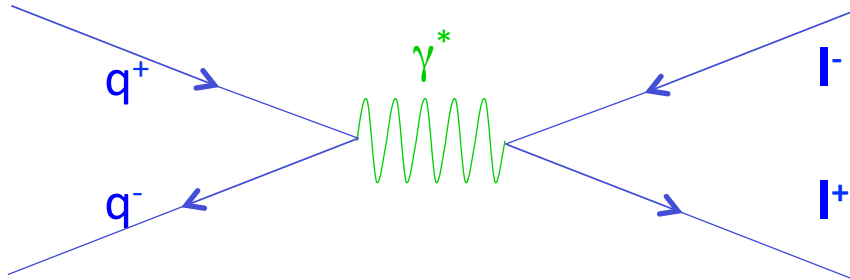
- I. Introduction to Physics
(Two slides on each of 906 and 1039)
- II. Status of experiments
- III. Moving forward

Physics



Guggenheim, Bilbao, Spain

Drell-Yan Cross Section



- Cross section is a convolution of beam and target parton distributions

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

Acceptance limited

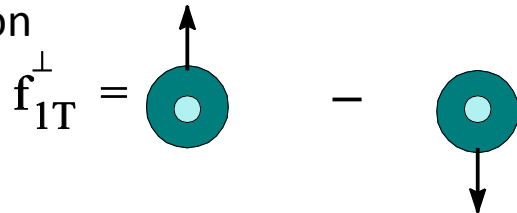
(Fixed Target, Hadron Beam)

- u-quark dominance
(2/3)² vs. (1/3)²

Beam	Sensitivity	Experiment
Hadron	Beam quarks target antiquarks	Fermilab, J-PARC RHIC (forward acpt.)
Anti-Hadron	Beam antiquarks Target quarks	J-PARC, GSI-FAIR Fermilab Collider
Meson	Beam antiquarks Target quarks	COMPASS, J-PARC

Goals of E1039: Spin of the proton

- Sivers Function: Correlation between unpolarized quarks and a nucleon's transverse polarization



- Non-zero Sivers distribution \Rightarrow non-zero quark orbital momentum

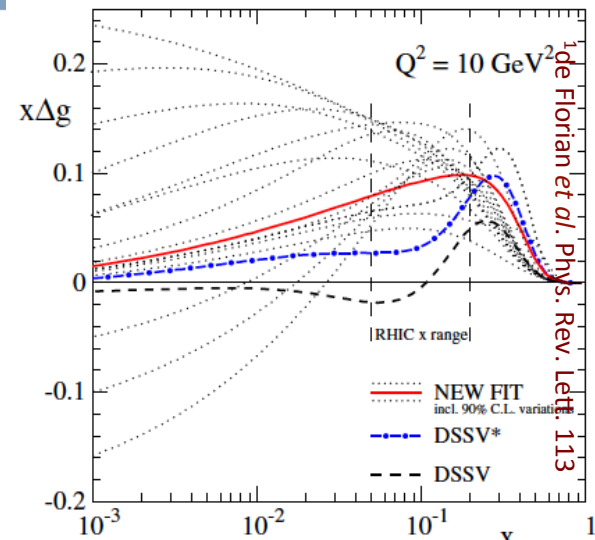
$$\frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + L$$

$$\Delta \Sigma = \Delta u + \Delta d + \Delta s$$

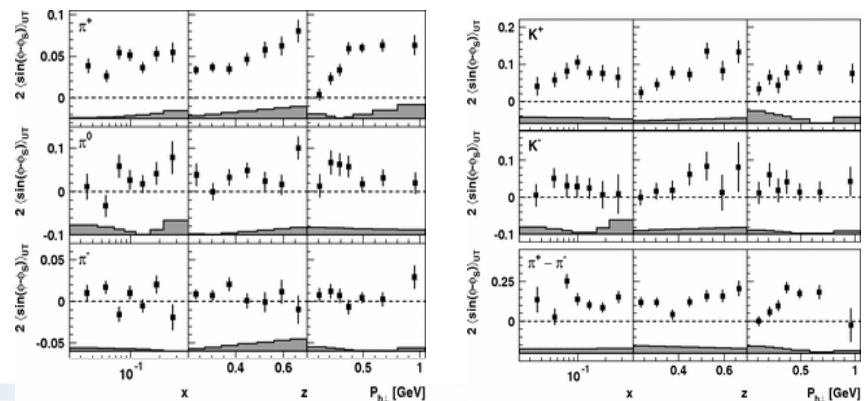
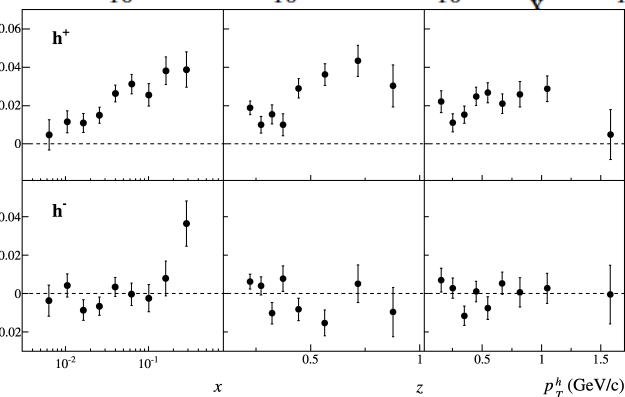
$$\frac{1}{2} \Delta \Sigma \approx 25\% \quad \Delta G \approx 0-15\%$$

$$L \approx \text{unmeasured}$$

HERMES, Airapetian *et al.* Phys. Rev. Lett. 103, 152002



COMPASS, Adhikari *et al.* Phys. Lett. B, 717, 383



29 June 2017



E1039 Physics: Orbital angular momentum of sea quarks

- Consider a nucleonic pion cloud
 $|p\rangle = |p_0\rangle + |N\pi\rangle + |\Delta\pi\rangle + \dots$

Pions $J^P=0^-$ Negative Parity

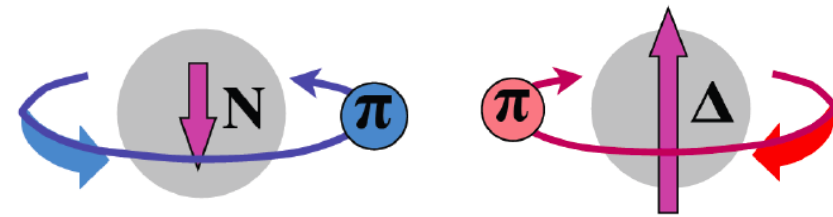
Need $L=1$ to get proton's $J^P=\frac{1}{2}^+$

Sea quarks should carry orbital angular momentum.

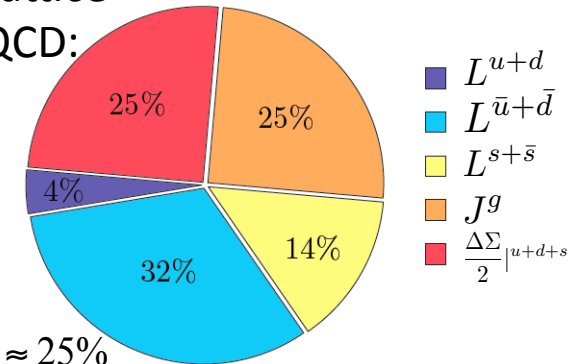
E1039 Physics: QCD gauge invariance

- Interference between spin-flip and non-flip amplitudes w/different phases
- Soft gluons
 - “gauge links” required for color gauge invariance
 - Re-interactions are **final (or initial) state ... and may be process dependent!**

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



Lattice
QCD:



$$\Delta\Sigma_q \approx 25\%$$

$$2 L_q \approx 46\% \text{ (0\% (valence) + 46\% (sea))}$$

$$2 J_g \approx 25\% \quad \text{K.-F. Liu et al arXiv:1203.6388}$$

Physics of E906: Light Antiquark Flavor Asymmetry

- Naïve Assumption:

$$\bar{d}(x) = \bar{u}(x)$$

- NMC (Gottfried Sum Rule)

$$\int_0^1 [\bar{d}(x) - \bar{u}(x)] dx \neq 0$$

- NA51 (Drell-Yan)

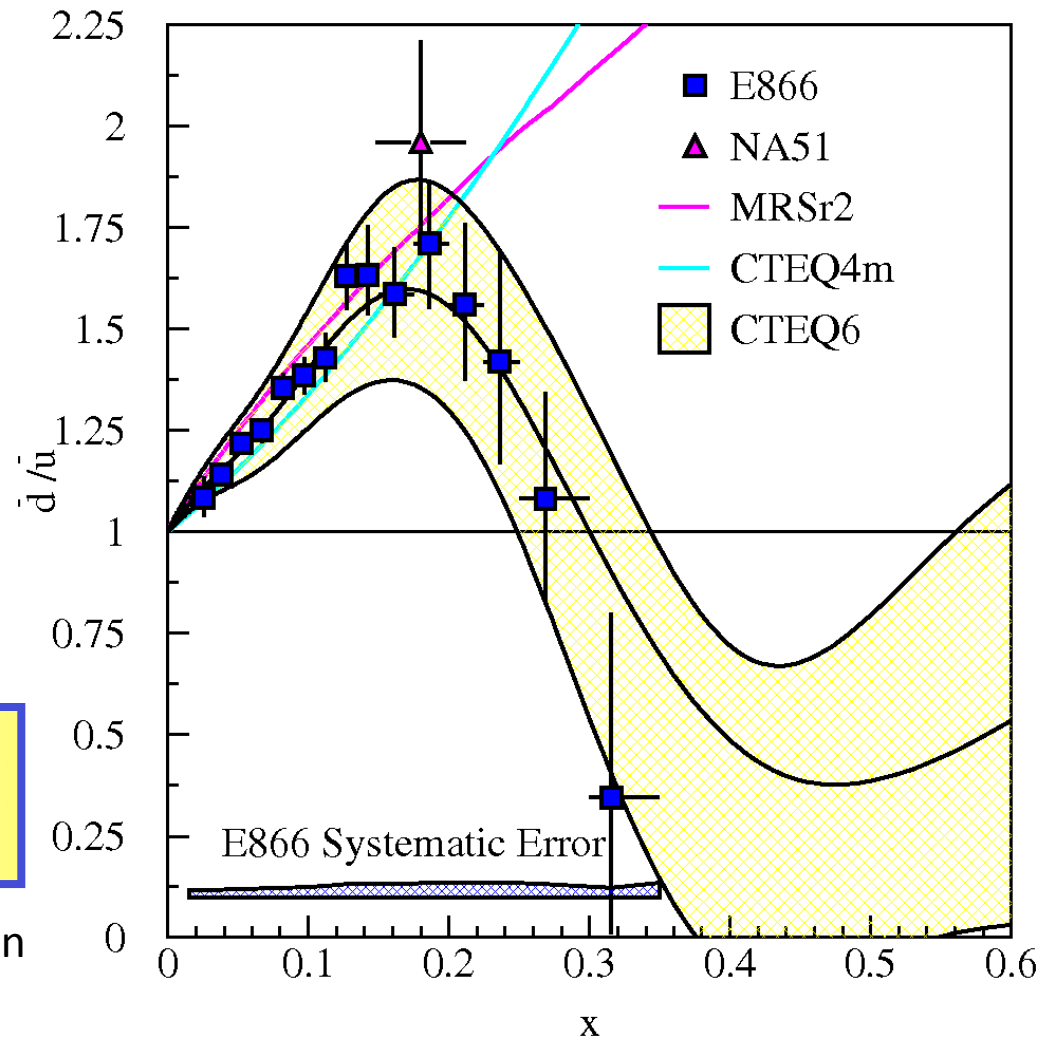
$$\bar{d} > \bar{u} \text{ at } x = 0.18$$

- E866/NuSea (Drell-Yan)

$$\bar{d}(x)/\bar{u}(x) \text{ for } 0.015 \leq x \leq 0.35$$

- Knowledge of sea dist. are data driven
- Sea quark distributions are difficult for Lattice QCD but the Lattice is making progress

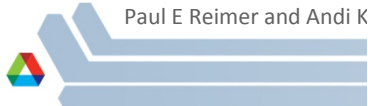
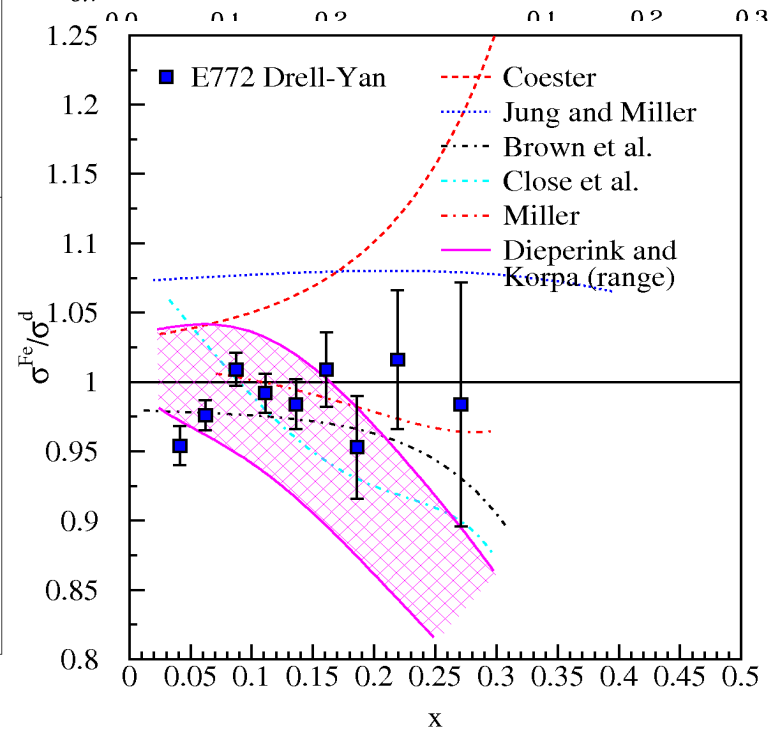
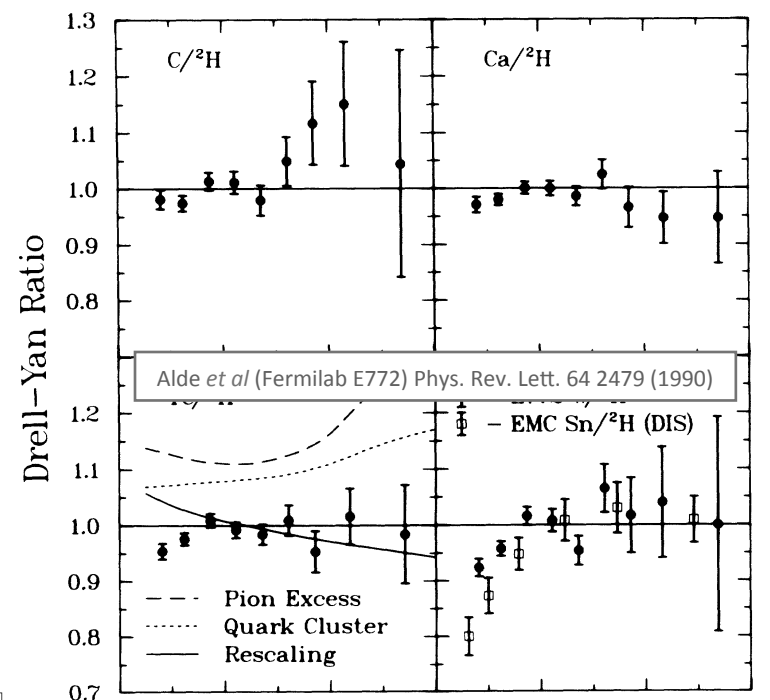
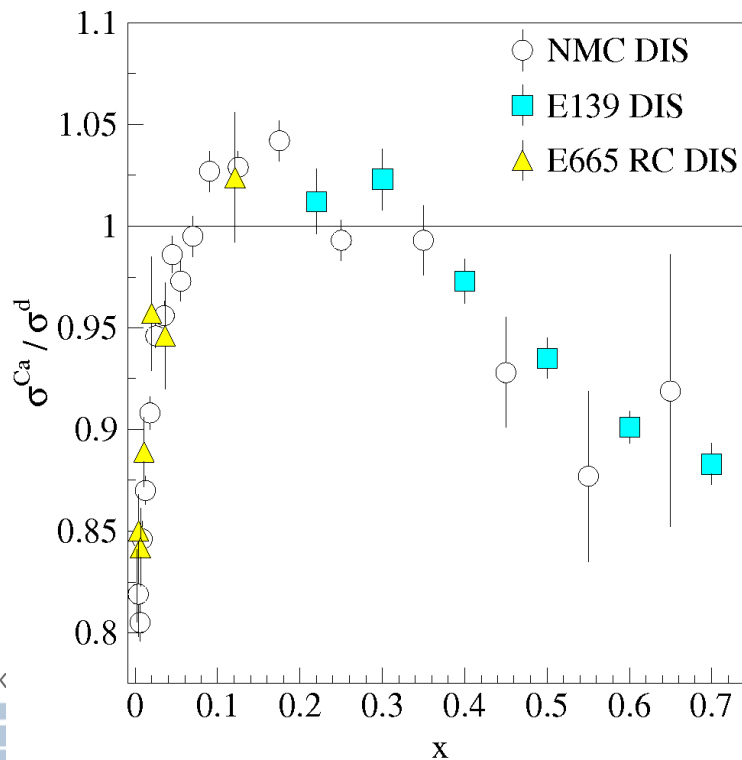
- Non perturbative QCD models can explain excess d-bar quarks, but not return to symmetry or deficit of d-bar quarks



Physics of E906: EMC effect

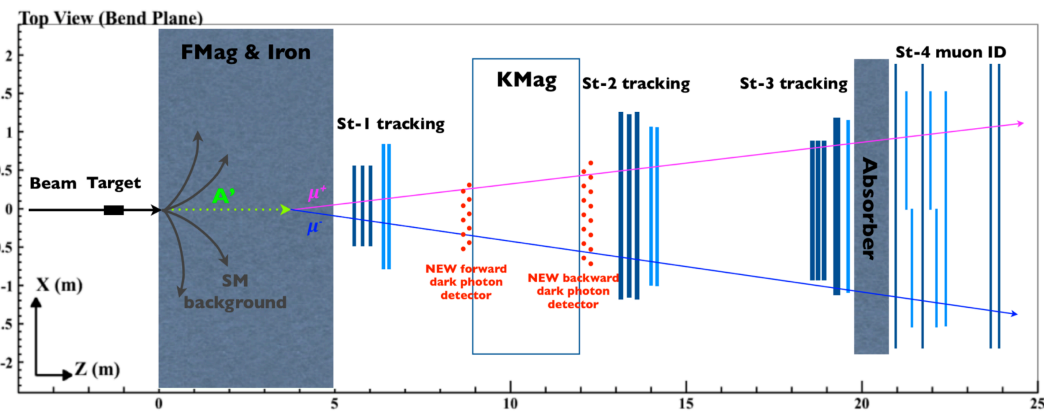
- Shadowing present in Drell-Yan
- Anti-shadowing not seen in Drell-Yan—Valence only?
- The binding of nucleons in a nucleus is expected to be governed by the exchange of virtual “Nuclear” mesons.
- No antiquark enhancement seen in Drell-Yan (Fermilab E772) data.
- Contemporary models predict large effects to antiquark distributions as x increases.

- Models must explain both DIS-EMC effect and Drell-Yan



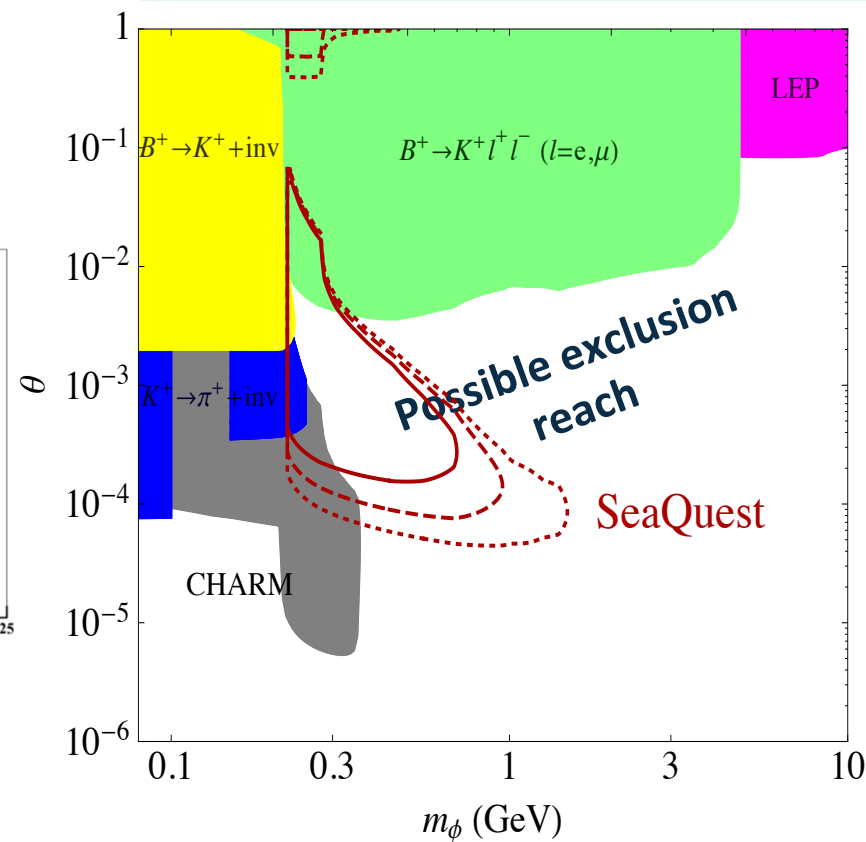
P1067 Physics: Dark Photons

- Classic Beam Dump Experiment



- Minimal impact on Drell-Yan program

$$\mathcal{L} \propto -\frac{1}{4} \mathcal{F}_{\mu\nu}^{\text{SM}} \mathcal{F}_{\text{SM}}^{\mu\nu} - \frac{1}{4} \mathcal{F}_{\mu\nu}^{\text{hidden}} \mathcal{F}_{\text{hidden}}^{\mu\nu} + \frac{1}{2} \epsilon \mathcal{F}_{\mu\nu}^{\text{SM}} \mathcal{F}_{\text{hidden}}^{\mu\nu} + m_{A'}^2 A_{\mu}^{\text{hidden}} A_{\text{hidden}}^{\mu}$$



Status: Experiments moving forward



E1039 DOE/Nuclear Physics

Office of Nuclear Physics requested a full proposal in Fall, 2016

- Reviews back beginning of April
- Quantitative ratings (5 reviewers):
 - 2 Reviewers: Extraordinary/High Impact Application - Must Support (7) 7.0**
 - 3 Reviewers: Excellent/Outstanding Application - Strongly Encourage Funding (5-6) 6.0**
 - one stated that he would have rated it a 7.0 except for budget questions

E1039: Selected excerpts from reviews

- The proposed research is **an essential component** of the overall program on the proton structure and the properties of QCD
- Generally speaking this PT scheme looks more favorable compared to what is used now by the COMPASS experiment at CERN.
- It is to my mind **very rare case in the modern hadron physics** when with **a very limited investment** one can start really competitive and **highly scientifically attractive program**. Integration of the Polarised Target to the running Drell-Yan experiment will provide unique or complementary information on 3D structure of the nucleon and **will help to resolve long standing proton spin crisis**.
- The scientific innovation of the proposed experiment is therefore extremely high.
- Even the slightest hint on a flavor asymmetry in the Sivvers seaquark distributions would be **sensational ..**
- The current experiment E1039 thus stands out by its ability to elucidate the sea (anti-)quark contributions

(note that the emphasis is ours)

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Gulshan Rai (DOE Office of Nuclear Physics, Medium Energy Physics Program Manager)

- Extremely supportive based on these reviews
- **Wants to see this happening** (his words)
- From his email to the collaboration:

The experiment E1039 is deemed to have high merit and impact provided the stipulated measurement precision can be achieved

- Requests:
 1. Provide DOE NP with a detailed cost breakdown and schedule for accomplishing the work inclusive of experiment installation, re-work shielding and beamline modifications.
 2. Address the technical comments from the reviews and mitigation of risks from lessons learned in operating E906. Submit a report to DOE NP.

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The experiment E1039 is deemed to have high merit and impact provided the stipulated measurement precision can be achieved

- Requests:

1. Provide DOE NP with a detailed plan for accomplishing the work inclusive of experimental and online modifications.
2. Address the technical challenges and mitigation of risks from lessons learned in operating E9 and submit a report to DOE NP.

Completed

E1039 Status: Target



- Reached 94% polarization
- World's highest luminosity target
- 3 coil design, proven to work
- New NMR system

- Reviewer:

What is of particular importance for the polarized DY experiment it is ability of the PT material to hold high intensity strong interacting hadron beam with out significant degradation of the system performance.

- Polarized ND_3 as well
- Only experiment in the world to measure flavor dependence of Sivers sea quark

E1039 Status: Cryo plant



New, modern liquefier system

- Turn-key/low maintenance vs $\frac{1}{4}$ FTE
- Warranty for most of run
- 140 l/day capacity (100 l/day needed) => **2 spare cold heads**
- LANL purchased a 60lt/day system
 - spend 230K\$ “unearned fee” on new liquefier.
 - \$100k carry over, (with DOE permission)

Paul E Reimer and Andi Klein: Presentation to the Fermilab Pre-PAC Meeting



E1039 Status: Budget estimates

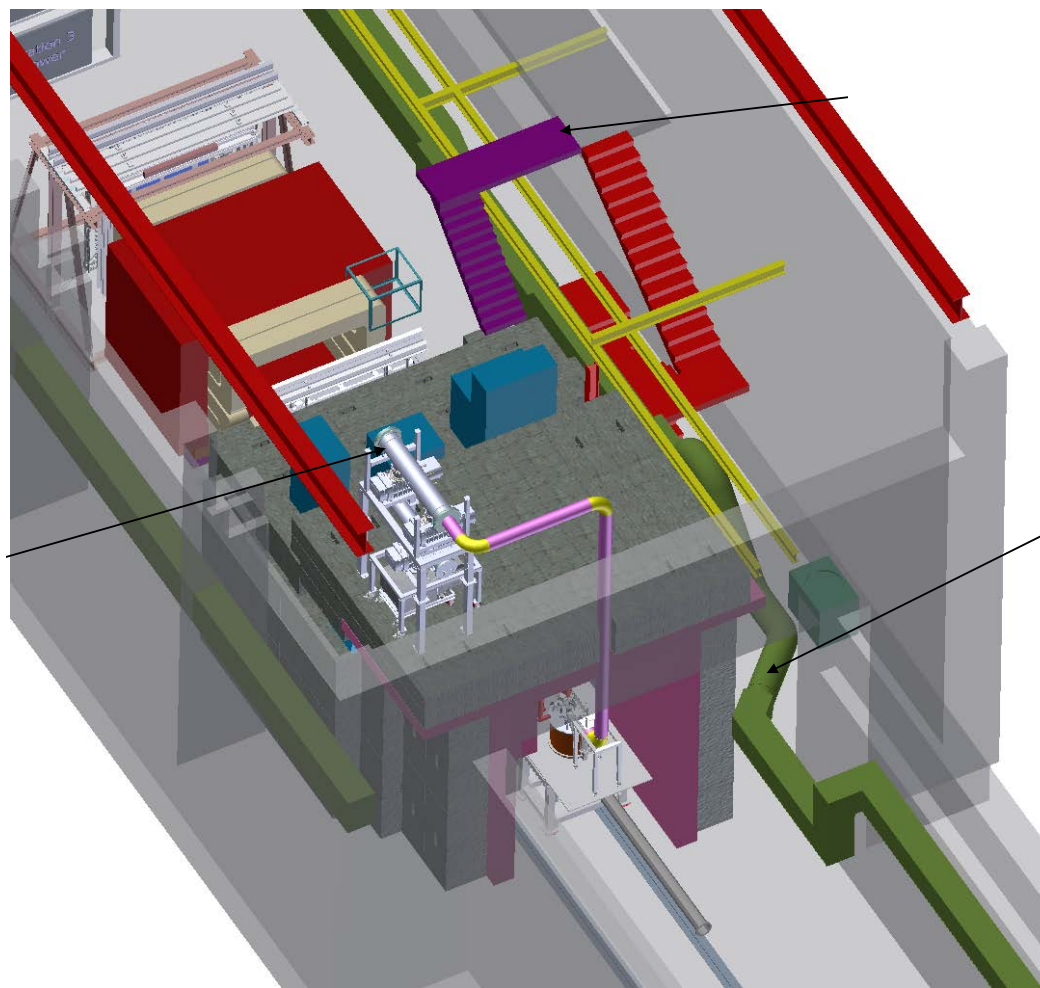
Shielding:

- *Collaboration between Igor Rankho (FNAL) and Jan Boissevain*
- Target moves slightly up steam
- Penetrations for L/R monitor
- pump lines
- identify shielding material

Target Cave and Top of Magnet

- *Jim Kilmer (FNAL) and Jan Boissevain*
- Target stand
- Tracks
- cryogenics lay out and design
- magnet top: platform and access
- additional electrical service
- cooling supply
- installation costs for services

Beam Line *Carol Johnson and Adam Watts (FNAL)*



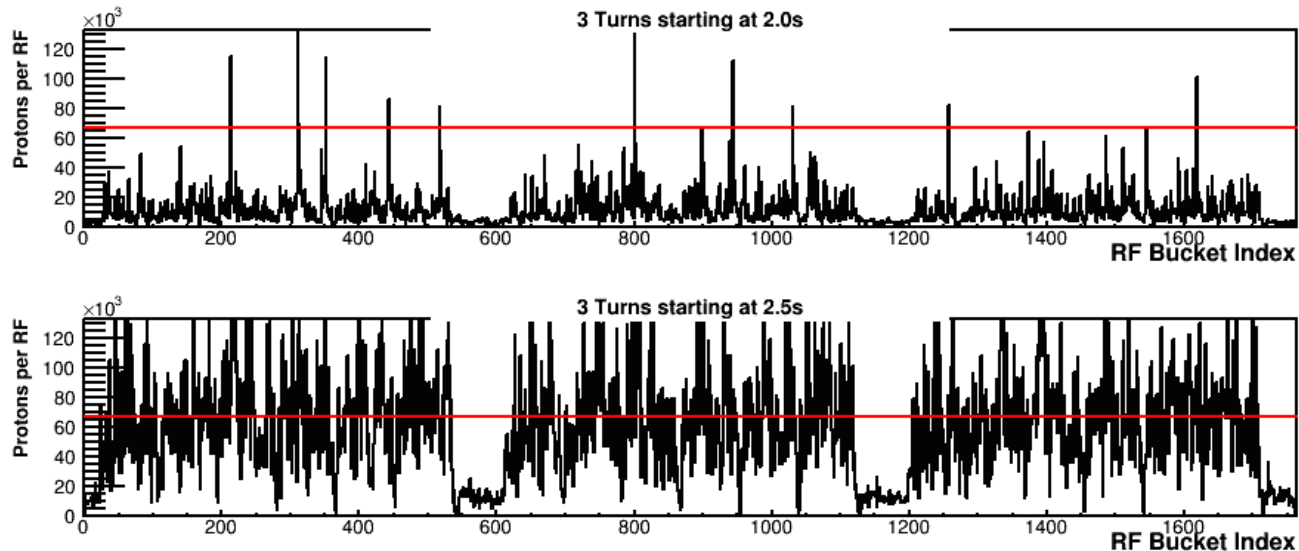
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Summary of E1039

- E1039 ready to start installation
- Technical challenges overcome
- Excellent reviews of the science as well as the technical project
- DOE NP excited , wants to see this experiment happening
- LANL continues to generously support this effort (see liquefier)

E906 Status

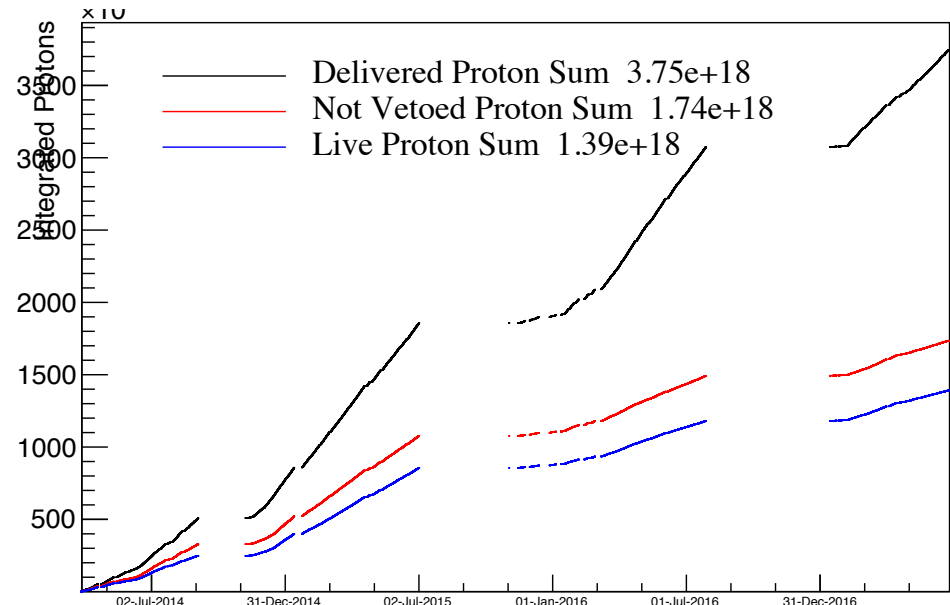


New DAQ system:

- readout between spills
- Eliminates most dead time

Main Injector beam in a slow spill—
difficult to obtain good duty factor

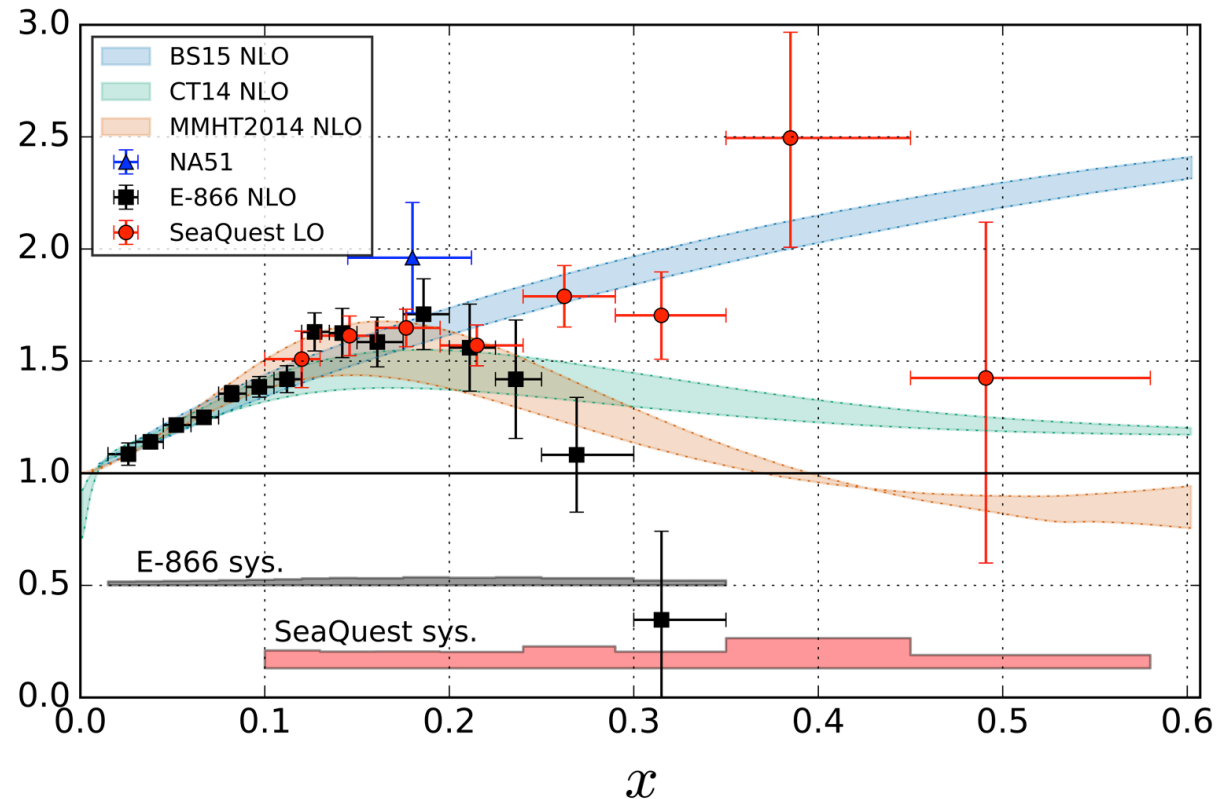
- 1.4×10^{18} of the 5.3×10^{18} approved "live protons"
- 1.7×10^{18} of the 7×10^{18} protons with good duty factor



E906 Status

3.5×10^{17} live protons
 $\frac{1}{4}$ of recorded protons

$$\frac{\bar{d}(x)}{\bar{u}(x)}$$



- Caveats:
- Rate dependence correction has a kinematic dependence
 - Leading order extraction
 - NLO code tested
 - Correct method -> global fit
 - Large x_{beam} dbar/ubar
 - ...

Really desire an additional year, with some effort being put into the duty factor

P1067 Dark Photon Status

- New trigger scintillators installed in SeaQuest
- Commissioning progressing carefully
- **Can and will run concurrently with either E906 or E1039**



SeaQuest Experiment

Where does this road lead?

Fixed Target Beam lines

Main Injector 120 GeV

Tevatron 800 GeV

Dilemma

FY 2018: Running E906 vs installing E1039

- Presently no funding for E1039 is assured from DOE Office of Nuclear Physics.
 - Clearly the President's proposed budget will not allow E1039 or E906.
- **E906 recognizes the scientifically compelling and exciting case for E1039, and feels that given the circumstances, E906 should step aside to allow E1039 to run if possible.**
- If not, then E906 would like to increase its statistical precision by recording one additional year of data.
- Delivery of beam to E906 in FY2018, will reactivate the beam dump making any installation of E1039 significantly more complicated.

Plan

Therefore, SeaQuest E906 and E1039 jointly propose

- E906 suspends operation for FY2018 or until a funding decision is made by DOE.
- To reach a decision, communication and cooperation between **SeaQuest, Office of Nuclear Physics, Fermilab and Office of High Energy Physics** is of the utmost importance.
- When a decision is made, either E1039 or E906 will present a proposal to the Fermilab directorate.
- If the directorate requests a PAC review, we request that the PAC move expeditiously.

Presenting a proposal at this time would not be an efficient use of the PAC's time

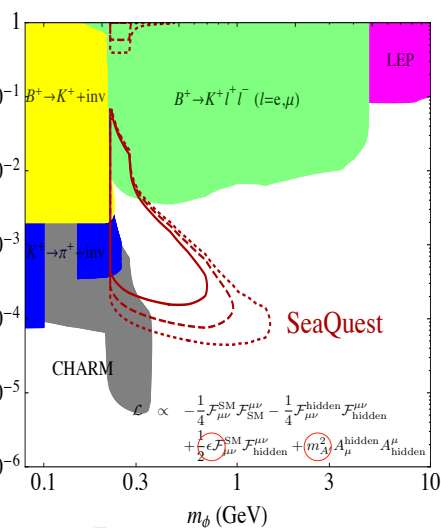
Conclusion

E1039

- Received excellent reviews on our DOE/ONP proposal
- Made significant progress on the target, cryo plant design and shielding design
- Awaiting decision from DOE.
 - It might be helpful is Fermilab and Office of Nuclear Physics discuss this.

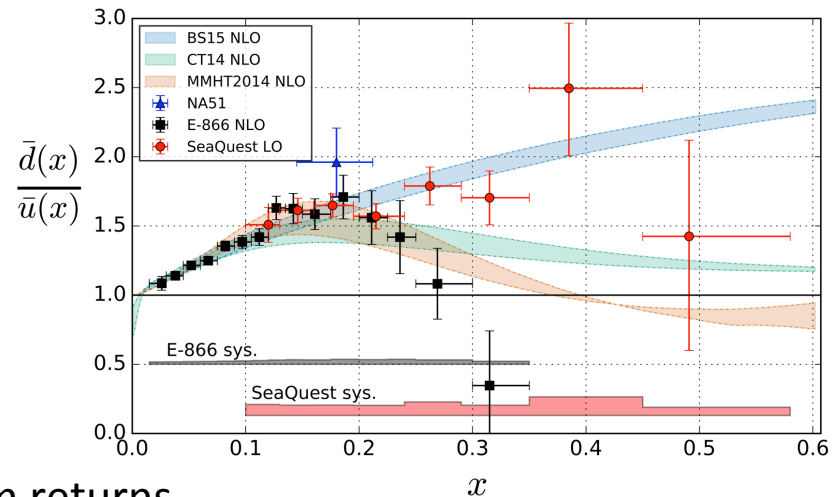
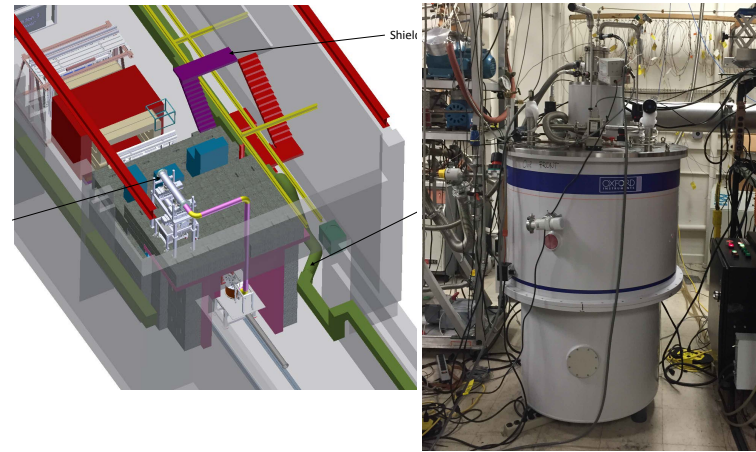
E906

- Is recording important, analyzable data
- Is receiving less “effective” beam than requested
- Has interesting preliminary results



P1067

- Trigger commissioning
- Production data when beam returns



Budget uncertainties preclude us from submitting a meaningful proposal