Los Alamos
NATIONAL LABORATORY
EST.1943

Overview of E1039/SpinQuest

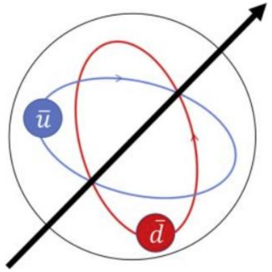
Kun Liu

SpinQuest Review, 12/1/2020

Overview

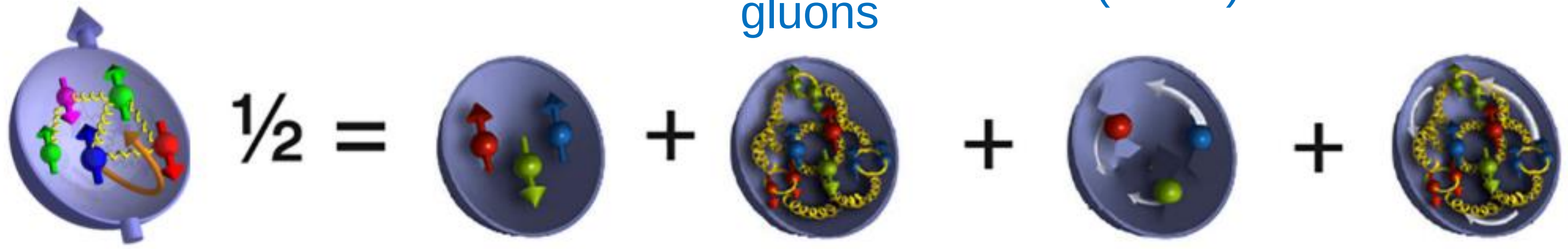
- Introduction
- Transition from SeaQuest to SpinQuest
- Collaboration
- Past, current and future funding support
- Charge and schedule of this review

Introduction – physics



Spin puzzle: 70% of the nucleon spin is missing!

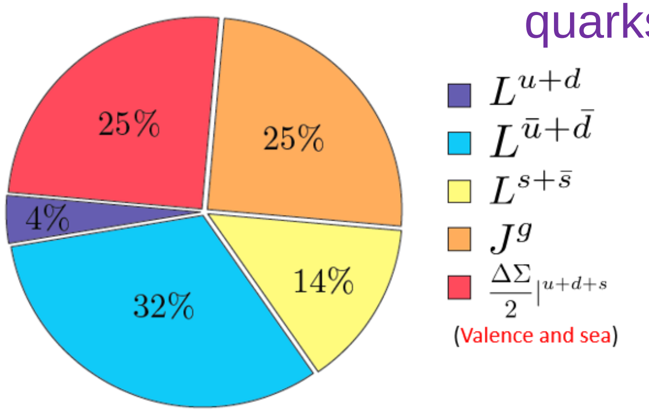
Spin of gluons 0 - 40% (RHIC)

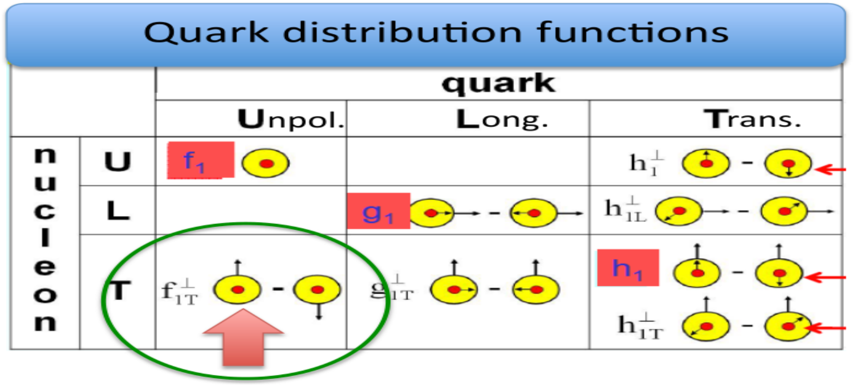


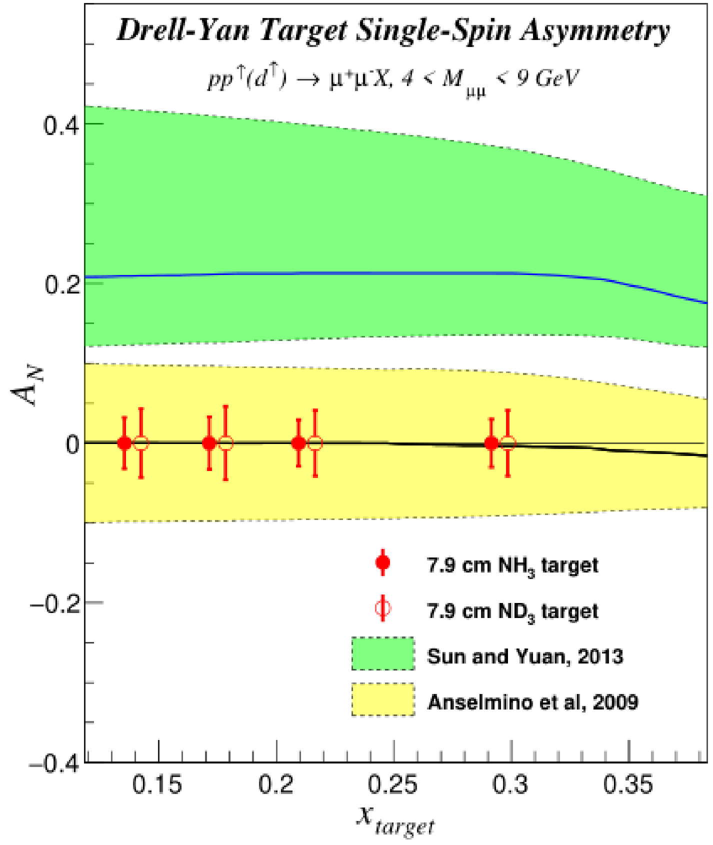
Spin of valance quarks ~25% (CERN, SLAC)

Orbital angular momentum?

K.-F. Liu *et al* arXiv:1203.6388



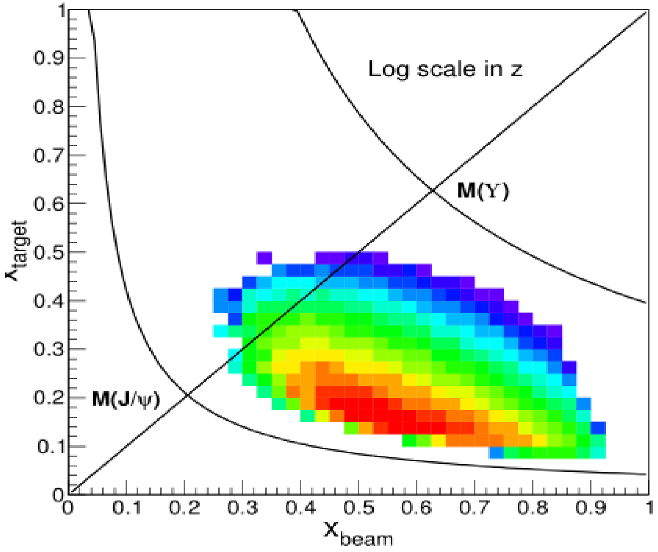


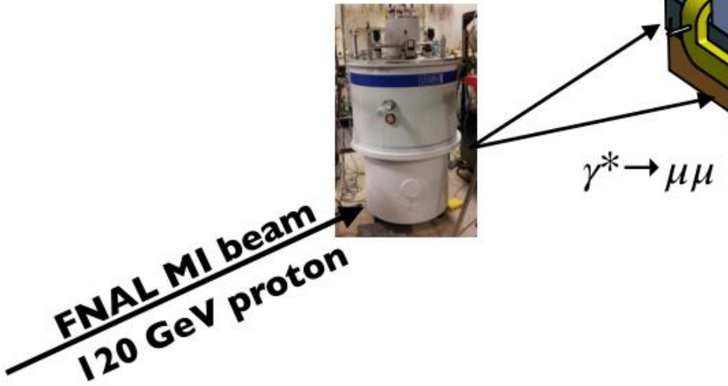


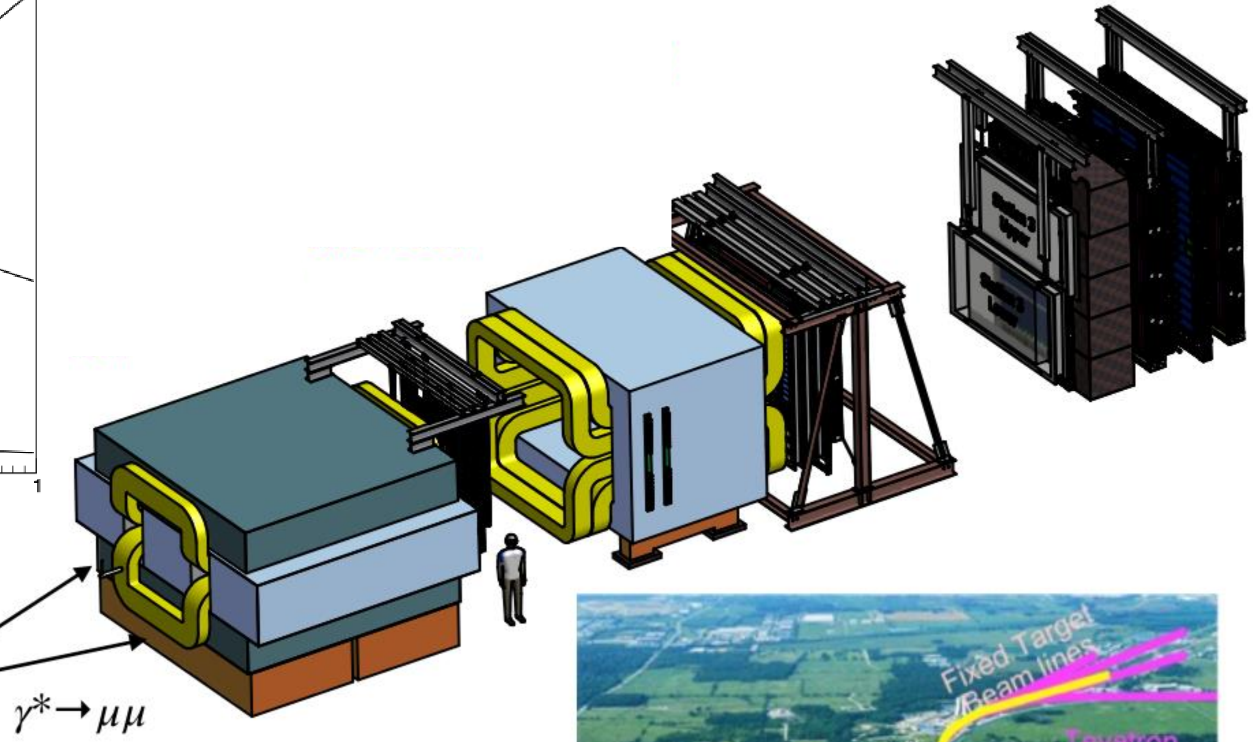
OAM from sea quarks could contribute up to half of the proton's spin

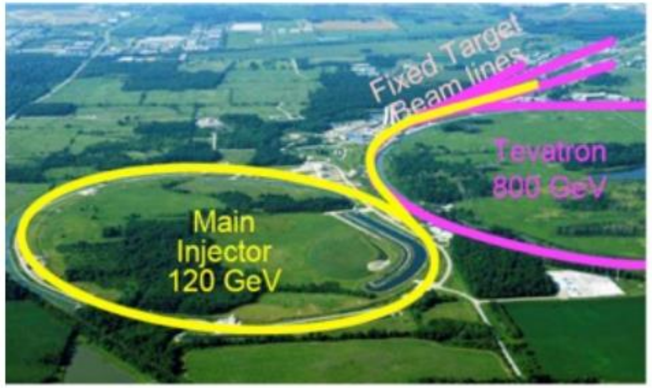
The Sivers function vanishes if the quarks have no ***orbital motion***

Introduction – experimental setup



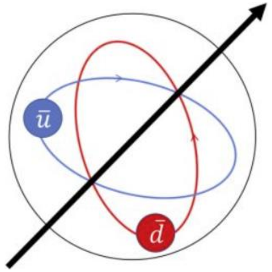






- **120GeV proton beam from FNAL Main Injector**
- **Polarized proton/deuteron (NH_3/ND_3) target**
- **Existing dimuon spectrometer**

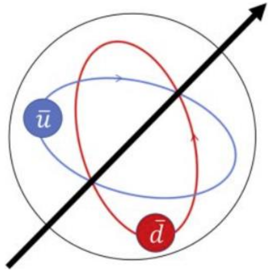
Introduction – future programs

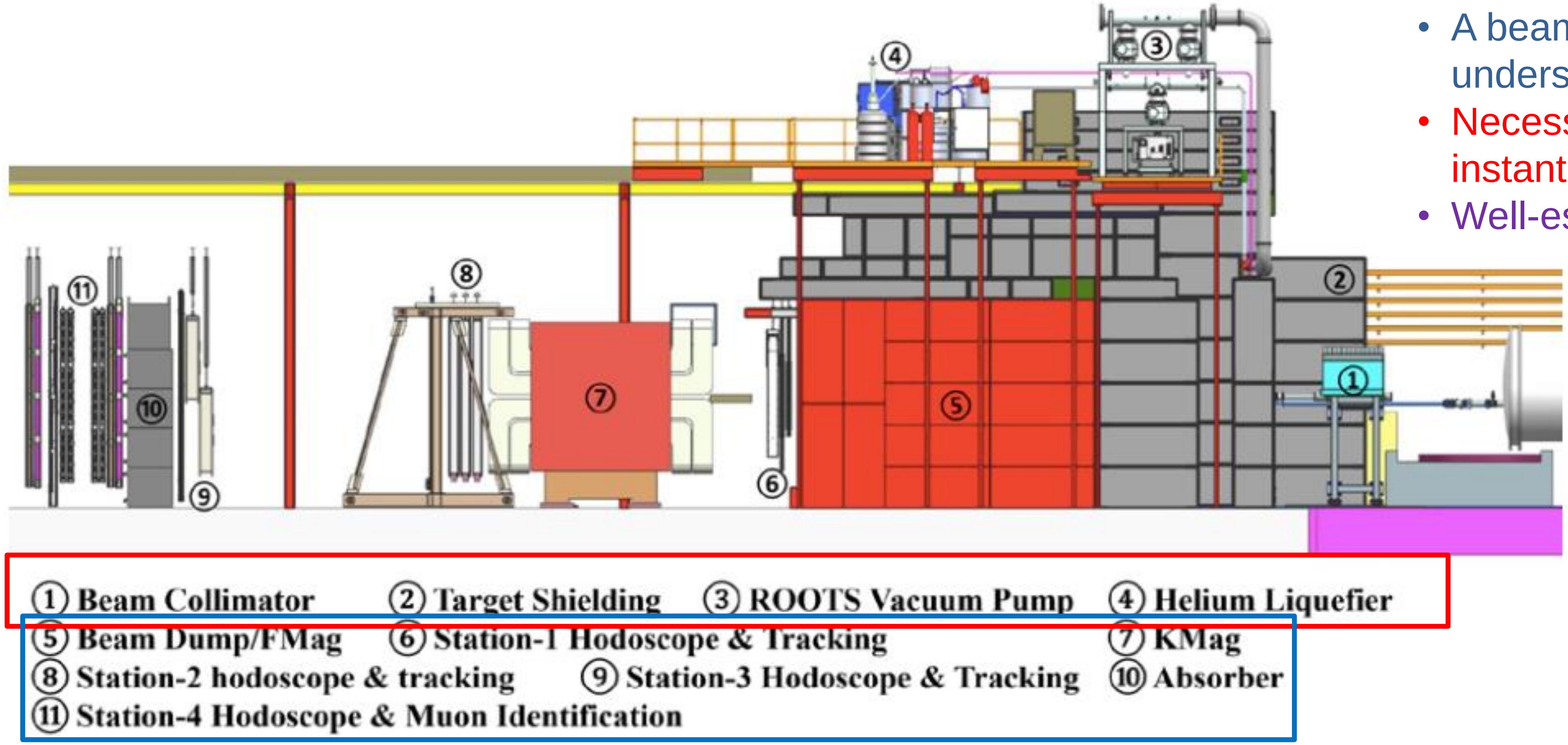


Two follow-up programs are currently being pursued after the successful completion of the E1039

- DarkQuest. Dark photon search using displaced vertex approach and additional EMCal detector
- Transverse structure of the Deuteron (gluon transversity)

Transition from SeaQuest to SpinQuest





Inherited from SeaQuest (5 – 11)

- A beam/spectrometer combination with well-understood capabilities and limitations
- Necessary instrumentation to cope with high instantaneous intensity environment
- Well-established analysis procedure

New polarized target system (1 – 4) – more details in the next talk

- Tighter beam requirements (better shielding and new collimator)
- Cryogenic infrastructure (liquefier, pump, service platforms, etc.)
- Larger operation and maintenance overhead
- Additional systematic uncertainties

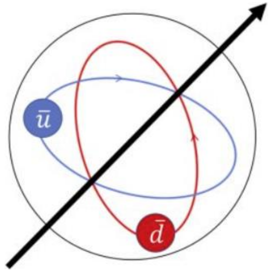
SpinQuest Collaboration

- 17 institutions from 5 countries (Armenia, China, Sri Lanka, Japan, USA)
- 51 collaborators
  - 12 grad students
  - 10 postdocs
  - 29 faculties
- 22 collaborators reside in or relocated to FNAL since the beginning of the installation

ACU: Donald Isenhower (PI), Michael Daugherity, Shon Watson
ANL: Paul Reimer (PI), Donald Geesaman
FNAL: Rick Tesarek (PI), Carol Johnstone, Charles Brown, Cristina Suarez
KEK: Shin'ya Sawada (PI)
LANL: Kun Liu (PI, SP), Ming Liu, Astrid Morreale, Mikhail Yurov, Kei Nagai, Zongwei Zhang
MSU: Lamiaa El Fassi (PI), Dipangkar Dutta, Catherine Ayuso, Nuwan Chaminda
NMSU: Stephen Pate (PI), Vassili Papavassiliou, Abinash Pun, Forhad Hossain, Dinupa Nowarathne
RIKEN: Yuji Goto (PI)
Shandong U: Qinghua Xu (PI), Zhaohuizi Ji
TokyoTech: Kenichi Nakano (PI), Toshi-Aki Shibata
U. Colo: Darshana Perera(PI), Harsha Sirilal, Vibodha Bandara
UIUC: Jen-Chieh Peng (PI), Jason Dove, Ching-Him Leung
U. Mich: Wolfgang Lorenzon (PI), Ievgen Lavrukhin, Minjung Kim, Noah Wuerfel
UNH: Karl Slifer (PI), David Ruth
UVA: Dustin Keller (PI, SP), Ishara Fermando, Zulkaida Akbar, Liliet Diaz, Anchit Arora, Arthur Conover
Yamagata U: Yoshiyuki Miyachi (PI), Norihito Doshita
YerPhI: Hrachya Marukyan (PI)

- Postdocs *- Grad students*

Past and current funding



- LANL LDRD-DR, $5.2M, FY13 – FY16
  - ❑ Theory development ($1.5M)
  - ❑ Polarized target refurbishment (with UVA)
  - ❑ Equipment purchases

- DOE-NP, $2.36M, FY18 – FY20
  - ❑ Intended for design, installation, and purchase of a helium liquefier
  - ❑ Depleted in early FY20

- DOE-HEP, $2.5M, FY18 – present
  - ❑ Intended for E906 decommissioning, E1039 beamline and spectrometer operation
  - ❑ Started to support installation in early FY20
  - ❑ So far received about $1.89M

Future funding model proposal (non-final)

- Remaining installation, cryo-safety review preparation, and initial commissioning – **$877k** provided by DOE-HEP through FNAL
- Consumables during the initial commissioning – **$150k** provided by DOE-NP (already arrived at FNAL)

Pass FNAL Operation Readiness Review

- Operation and maintenance of the beamline, target and spectrometer during the two-year production – provided by DOE-NP

*** This page is merely our understanding and/or suggestion**

Charge of this review

Q1: Does the collaboration have an achievable, sufficiently detailed, resource-loaded schedule for the remaining target construction and experimental installation work, which will lead to completion by mid-2021, in time for initial commissioning with beam before the Summer 2021 accelerator shutdown?

Q2: Are the requirements on Fermilab staff and resources and on collaboration personnel for completion of the remaining experimental installation work well understood? Have the required personnel been identified and allocated for the installation in FY21? Is the remaining cost to complete installation well-understood, and is there an adequate estimate of the contingency on the remaining work?

Q3: Has the experiment developed a sufficiently detailed plan for commissioning the detector in preparation for physics data-taking? Are the roles and responsibilities of collaboration members and Fermilab staff well-defined for this commissioning period?

Q4: Has the collaboration prepared an initial run plan for experimental operations to record the data required to achieve the desired sensitivity? Is there sufficient margin in this plan to reach the desired sensitivity with an achievable operational efficiency? Are the roles and responsibilities of collaboration members and Fermilab staff well-defined for the run period?

Q5: The new polarized target is critical to the success of the experiment. Have sufficient resources been allocated to install, commission, and maintain the target throughout SpinQuest running? Have the technical risks been identified and mitigation plans developed?

Q6: Are the ES&H (Environment, Safety, and Health) aspects of all anticipated work during the completion of installation, initial commissioning, and initial running being properly assessed and managed, with clear roles and responsibilities? Did the polarized target get the required special attention?

Schedule of this review – Day One

8:30 – 9:00	Executive Session	
9:00 – 9:40	Overview of the SpinQuest Experiment	
9:40 – 10:30	Overview of the target system	Q5, Q6
10:30 – 10:45	Break	
10:45 – 11:35	Infrastructure Installation	Q2, Q6
11:35 – 12:25	Target System Installation	Q1, Q6
13:00 – 14:00	Executive Session	
14:00 – 14:30	Questions to the SpinQuest Collaboration	

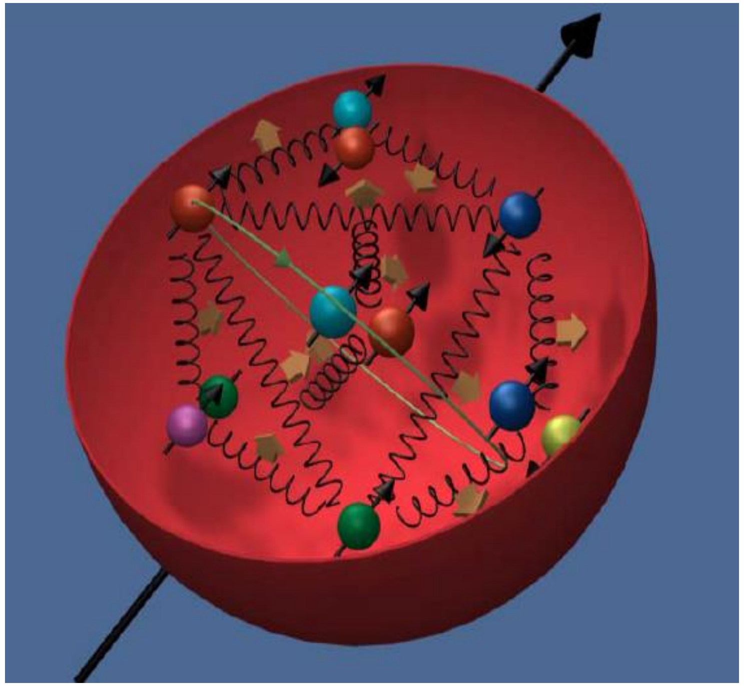
Schedule of this review – Day Two

8:30 – 9:00	Executive Session	
9:00 – 10:00	Answers to Questions from Day 1	
10:00 – 10:15	Break	
10:15 – 10:55	Operational Roles and Responsibilities	Q3, Q4, Q6
10:55 – 11:35	Commissioning Plan	Q3
11:35 – 12:15	Experiment Operation Plan	Q4
12:45 – 14:00	Executive Session	
14:00 – 14:30	Closeout	

Backup

The Spin Crisis

The need for a major breakthrough in understanding the origin of the nucleon spin and the related 3D nucleon structure



Naïve quark model: ↑ ↓ ↑ **= ½**

Spin crisis : 70% of nucleon spin is missing!

SLAC, CERN: quark (1/2)ΔΣ ~ 25%

$$\frac{1}{2}=\frac{1}{2}\Delta\Sigma_q+L_q+\Delta G+L_g$$

14

$$x_B=\frac{parton\ longitudinal\ momentum}{proton\ longitudinal\ momentum}$$

Interested in momenta transverse to the proton's direction of motion

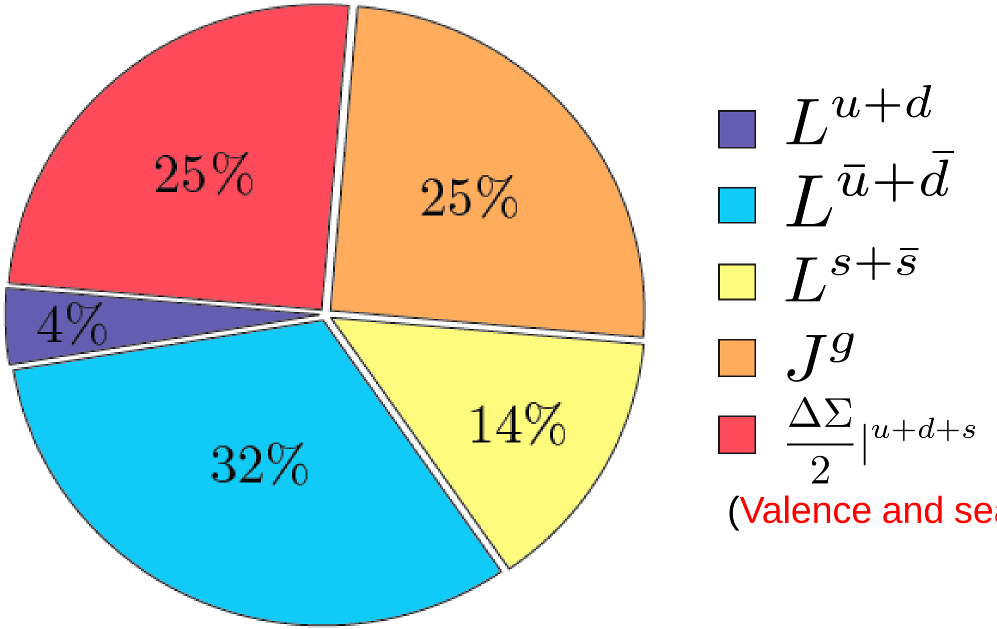
RHIC: gluon ΔG ~ 0 - 20%

Orbital angular momentum ?

Importance of Sea Quarks

Recent lattice QCD results

K.-F. Liu *et al* arXiv:1203.6388



(Valence and sea)

DS_q » 25% $L_u \approx - L_d$

$2\ L_q$ » 46% (0%(valence)+46%(sea))

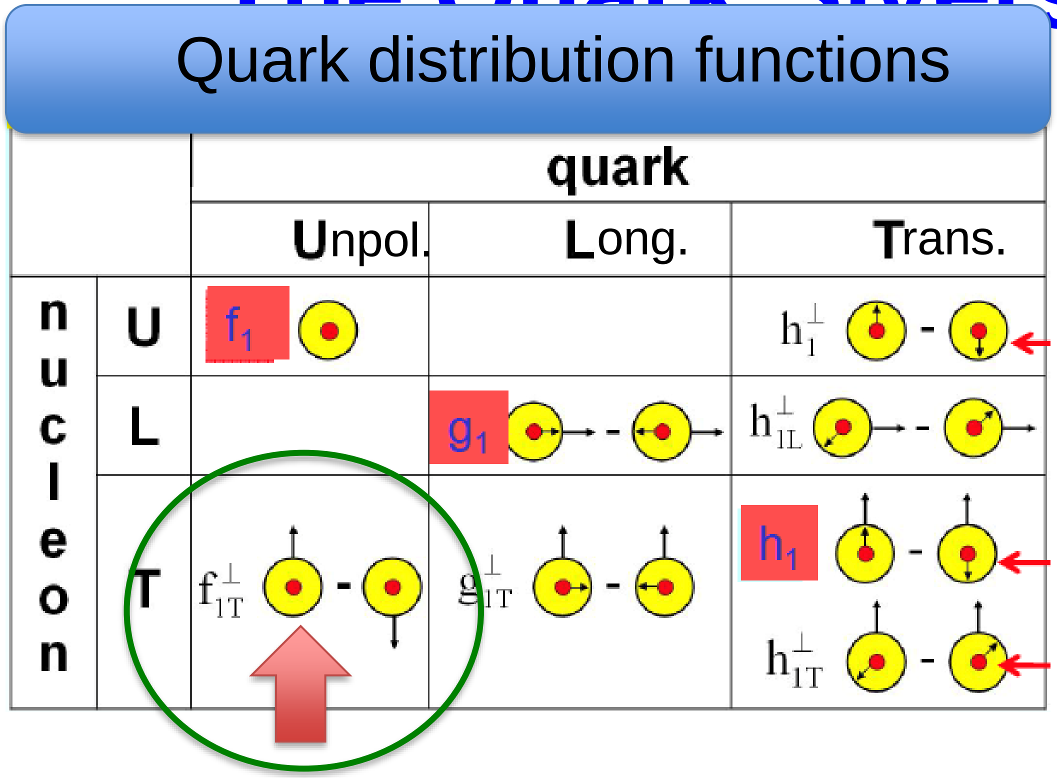
$2\ J_g$ » 25% $J_g = DG + L_g$

Orbital angular momentum ? Sea quarks' angular momentum could be a major part of the "missing spin".

- All of the quark orbital momentum comes from the sea quark contribution
- Important to understand it experimentally ad theoretically

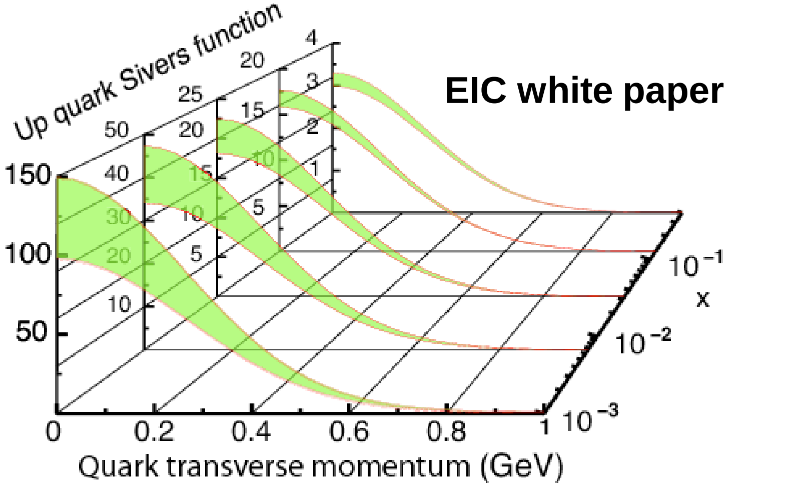
Transverse Momentum Distributions

The Quark Sivers Function



The quark Sivers distribution (function)

Expected dramatic increase at lower x

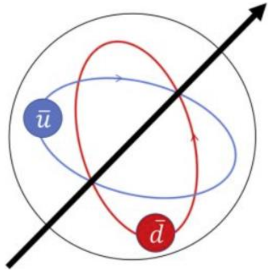


- Focus on transverse momentum – 3D structure of the nucleon

$$f_{1T}^{\perp[\mathcal{C}]}(x,k_T^2)\,(\vec{S}_T \times \vec{k}_T) = \frac{M}{2}\,\mathrm{F.T.}\,\langle P,S_T|\,\overline{\psi}(0)\,\mathcal{L}_{\mathcal{C}}(0,\xi)\,\not{n}_-\,\psi(\xi)\,|P,S_T\rangle\big|_{\xi^+=0}$$

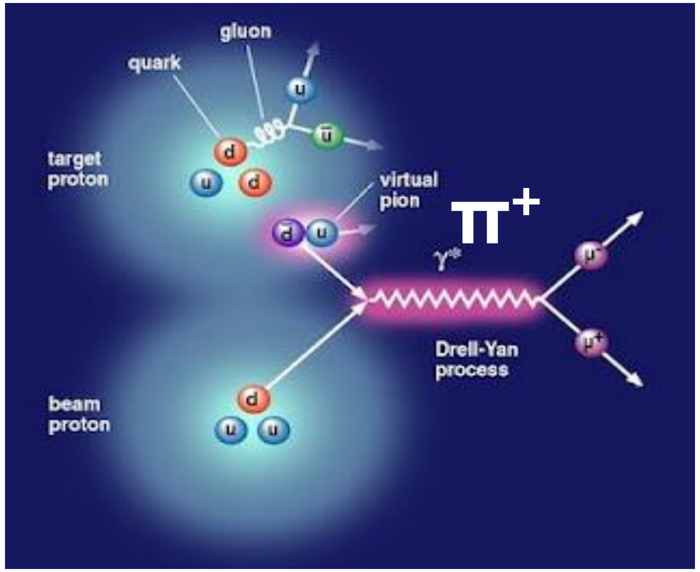
The Sivers function vanishes if the quarks have no orbital motion

Other Indications of Large Sivers Asymmetry



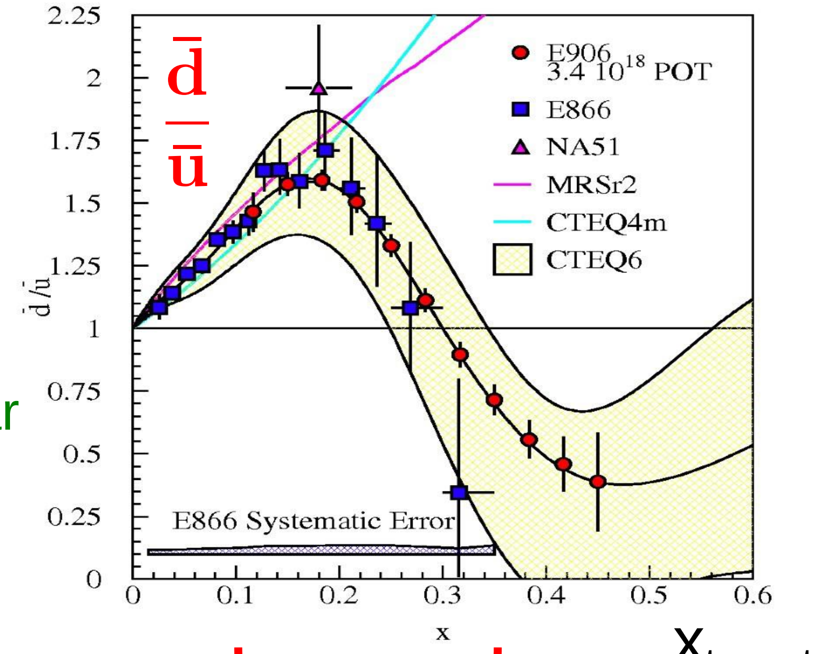
The meson cloud model

$|p\rangle = p + N\pi^+ + \Delta\pi + \ldots$



Consequence 1: enhanced $\frac{\bar{d}}{\bar{u}}$

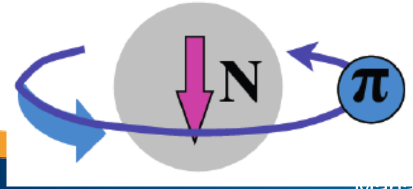
Observed in the sea quark region

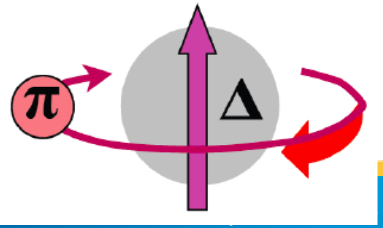


Consequence 2: Large orbital angular momentum and Sivers asymmetry

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

Need **L=1** to get proton's $J^p=½^+$

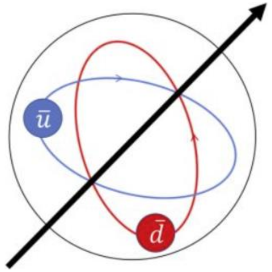




Our experiments E866, E906

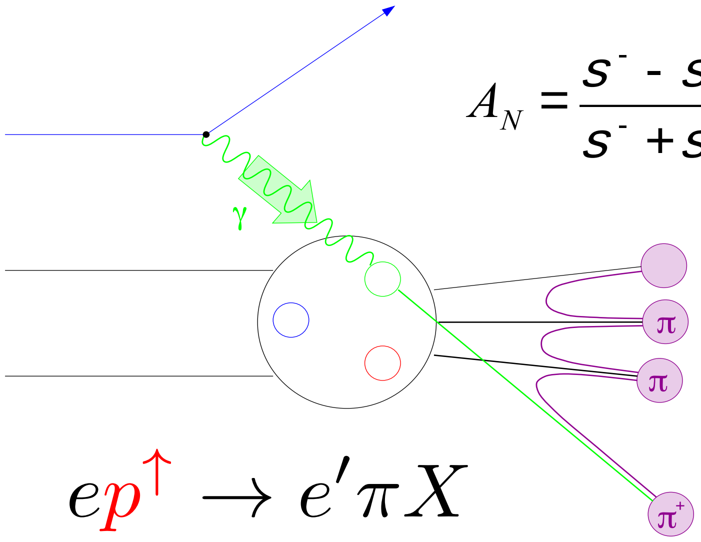
Future E1039

Accessing the Quark Sivers Distribution



Polarized target experiment

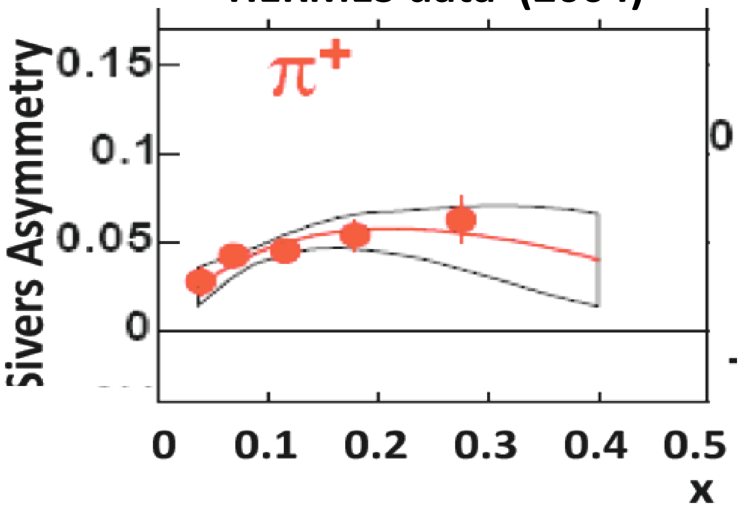
Left-right asymmetry in Semi-Inclusive Deep Inelastic Scattering (SIDIS) on a polarized nucleon

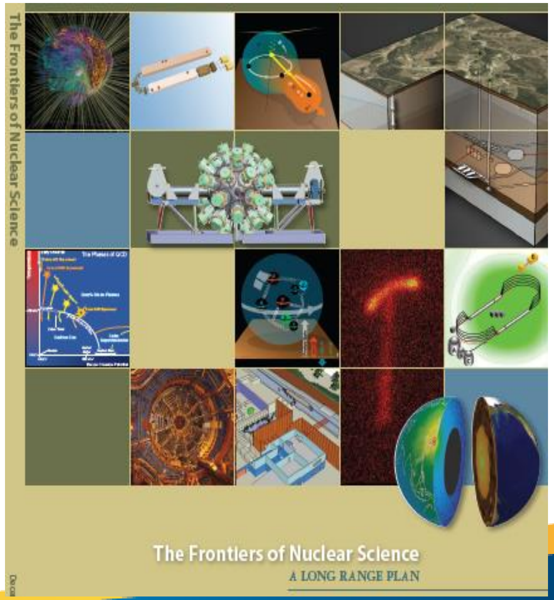


$$A_N = \frac{s^{\uparrow} - s^{\downarrow}}{s^{\uparrow} + s^{\downarrow}}$$

$$e p^{\uparrow} \rightarrow e' \pi X$$

HERMES data (2004)

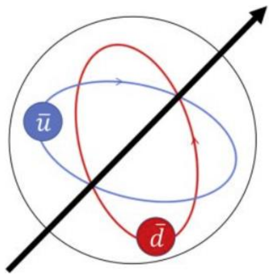




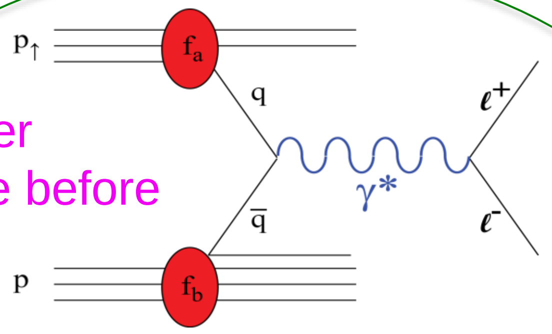
Sivers distribution was believed to vanish until very recently!

New opportunities

Sivers Asymmetry in Polarized Drell-Yan



Never done before

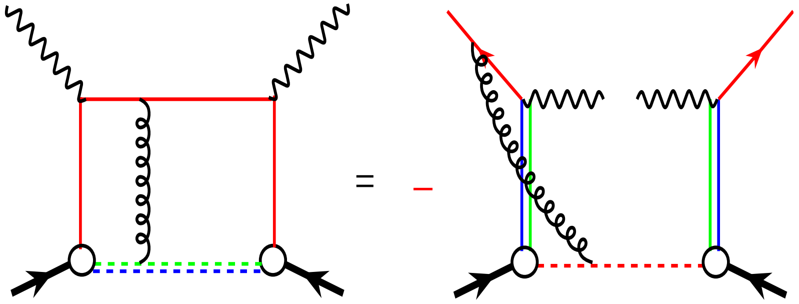


$$pp^{\uparrow} \rightarrow \mu^+\mu^- X$$

Left-right asymmetry in Drell-Yan di-muon production on a polarized nucleon

Cornerstone prediction of QCD factorization

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



SIDIS = – DY

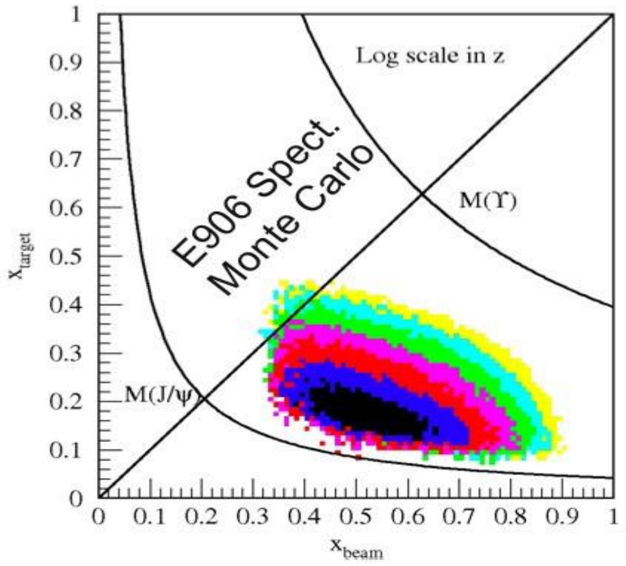
- The same quark Sivers distribution in both processes, but with an opposite sign

Deeply rooted in the gauge invariance in QCD

DOE Milestone: “Test unique QCD predictions for relations between single-spin phenomena in p-p scattering and those observed in deep-inelastic scattering”

Making Use of a Unique Opportunity

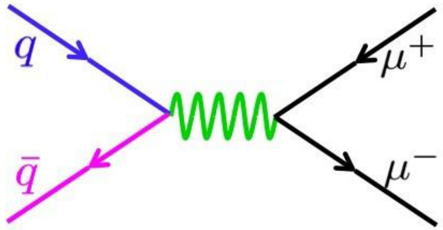
We take advantage of the E906 DY Exp. @ Fermilab. (SeaQuest)
E_{lab} = 120 GeV, $s^{1/2}$ = 15 GeV



$$\frac{d^2\sigma}{dx_b\,dx_t} = \frac{4\pi\alpha^2}{9x_b\,x_t}\frac{1}{s}\sum_q e_q^2\left[\bar{q}_t(x_t)q_b(x_b) + q_t(x_t)\bar{q}_b(x_b)\right]$$

small

Antiquark from the target



A New Polarized Target

P beam