Probing the Sivers Asymmetry from light-sea quarks with the SpinQuest (E1039) experiment

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For the SpinQuest Collaboration

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Durham Convention Center
Durham, NC, USA

UVA - Spin
PHYSICS GROUP

UNIVERSITY of VIRGINIA

SPIN QUEST

Fermilab

U.S. DEPARTMENT OF ENERGY | Office of Science

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Outline


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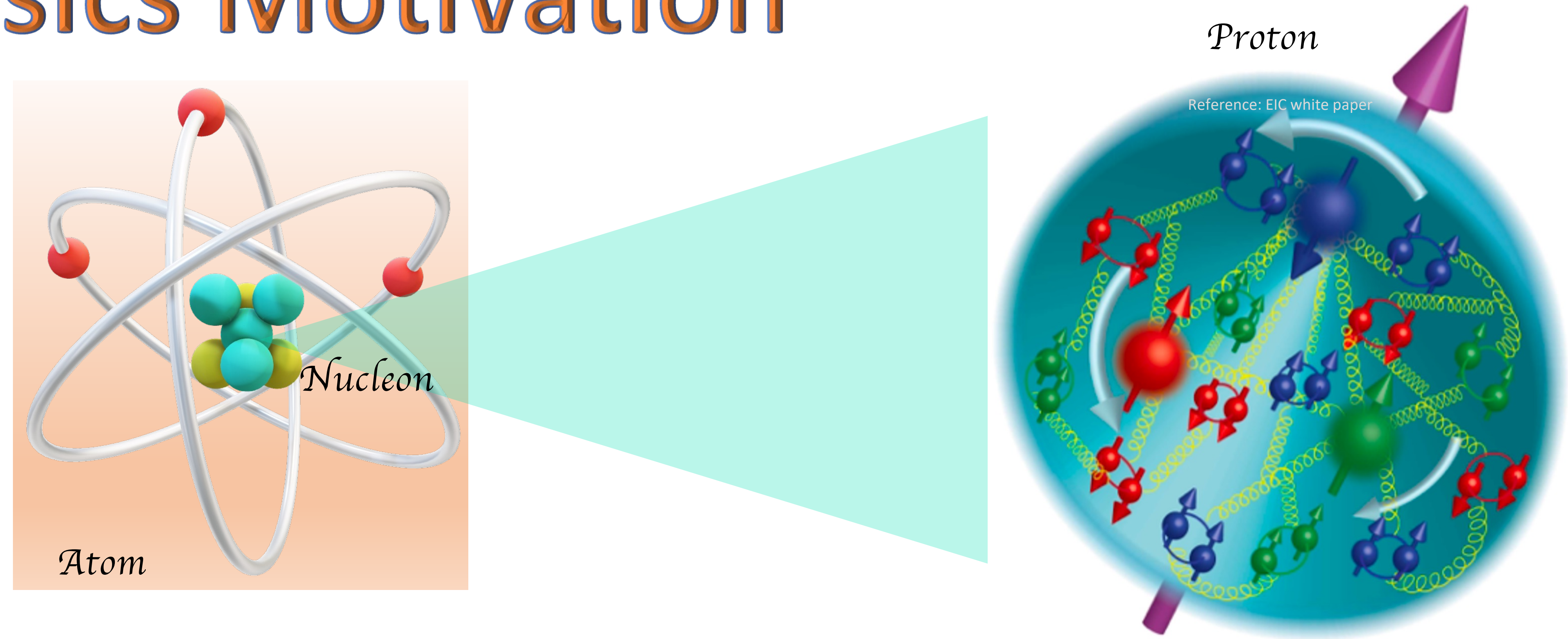
July 2022 @ Fermilab

- ➢ Physics motivation
- ➢ Possible missing spin contributions
- ➢ TMD PDFs, Sivers Function & Sign
- ➢ Global analyses, global context & sea-quark Sivers functions
- ➢ Polarized fixed target Drell-Yan / SpinQuest / E1039 experiment at Fermilab
- ➢ Projected Uncertainties & goodness of event-reconstruction
- ➢ SpinQuest / E1039 timeline

Physics Motivation



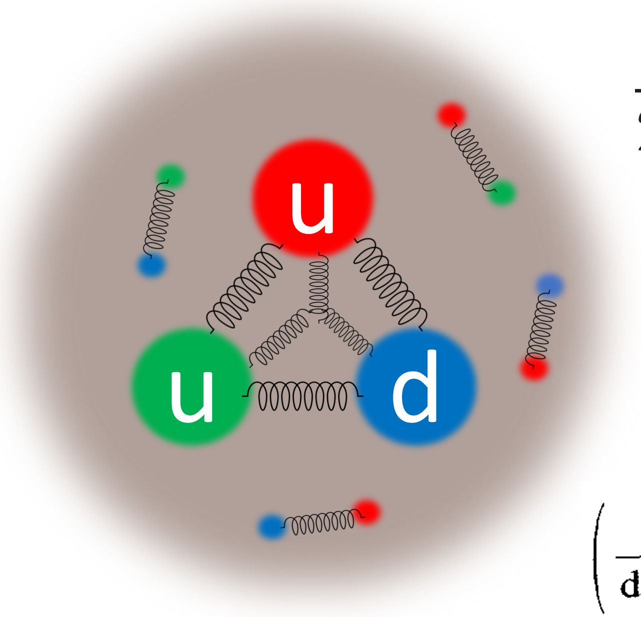
Proton Spin (1/2) = Valence quarks' (intrinsic) Spin + Sea quarks' (intrinsic) Spin + Valence quarks' OAM + Sea quarks' OAM + Gluons (intrinsic) Spin + Gluons OAM

Valence quarks' (intrinsic) Spin + Sea quarks' (intrinsic) Spin: quarks' total intrinsic spin

Valence quarks' OAM + Sea quarks' OAM: quarks' total OAM

OAM : Orbital Angular Momentum

Physics Motivation



Ji's decomposition

$$\frac{1}{2} = \boxed{\frac{1}{2}\sum_q \Delta q} + \sum_q L_q^z + J_g^z$$

Jaffe-Manohar decomposition

$$\frac{1}{2} = \boxed{\frac{1}{2}\sum_q \Delta q} + \sum_q \mathcal{L}^q + \Delta G + \mathcal{L}^g$$

Intrinsic spin contribution by valence & sea quarks $\sim (12 \pm 9 \pm 14)\%$

$$\left(\frac{d^2\sigma}{dQ^2\, d\nu}\right)^{\uparrow\downarrow} - \left(\frac{d^2\sigma}{dQ^2\, d\nu}\right)^{\uparrow\uparrow} = \frac{4\pi\alpha^2}{E^2Q^2}\left[M(E + E'\cos\theta)G_1(Q^2,\nu) - Q^2G_2(Q^2,\nu)\right]$$

QCD Corrected
Quark Parton Model
(Ellis-Jaffe Sum rule)
0.189 ± 0.005

$$A = \frac{d\sigma^{\uparrow\downarrow} - d\sigma^{\uparrow\uparrow}}{d\sigma^{\uparrow\downarrow} + d\sigma^{\uparrow\uparrow}}$$

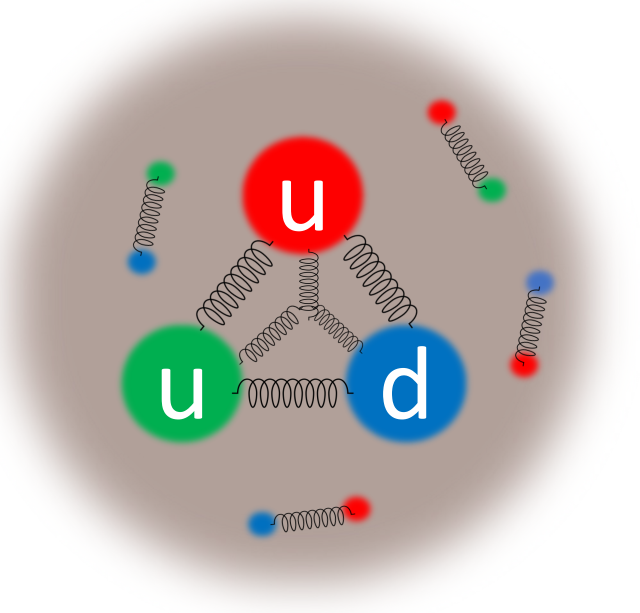
$$\int_0^1 g_1^p\, dx = \boxed{0.126} \pm 0.010 \pm 0.015$$

$$g_1(x) = \tfrac{1}{2}\sum e_i^2\left(q_i^+(x) - q_i^-(x)\right)$$

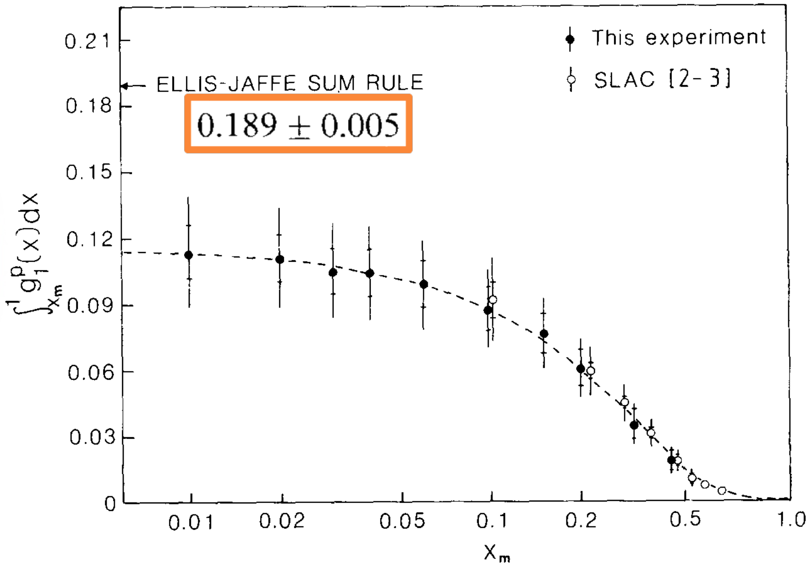
Nuclear Physics B328 (1989) 1–35

EMC Collaboration (1989)
Asymmetry measurements from Deep inelastic scattering of longitudinally polarized muons on longitudinally polarized proton

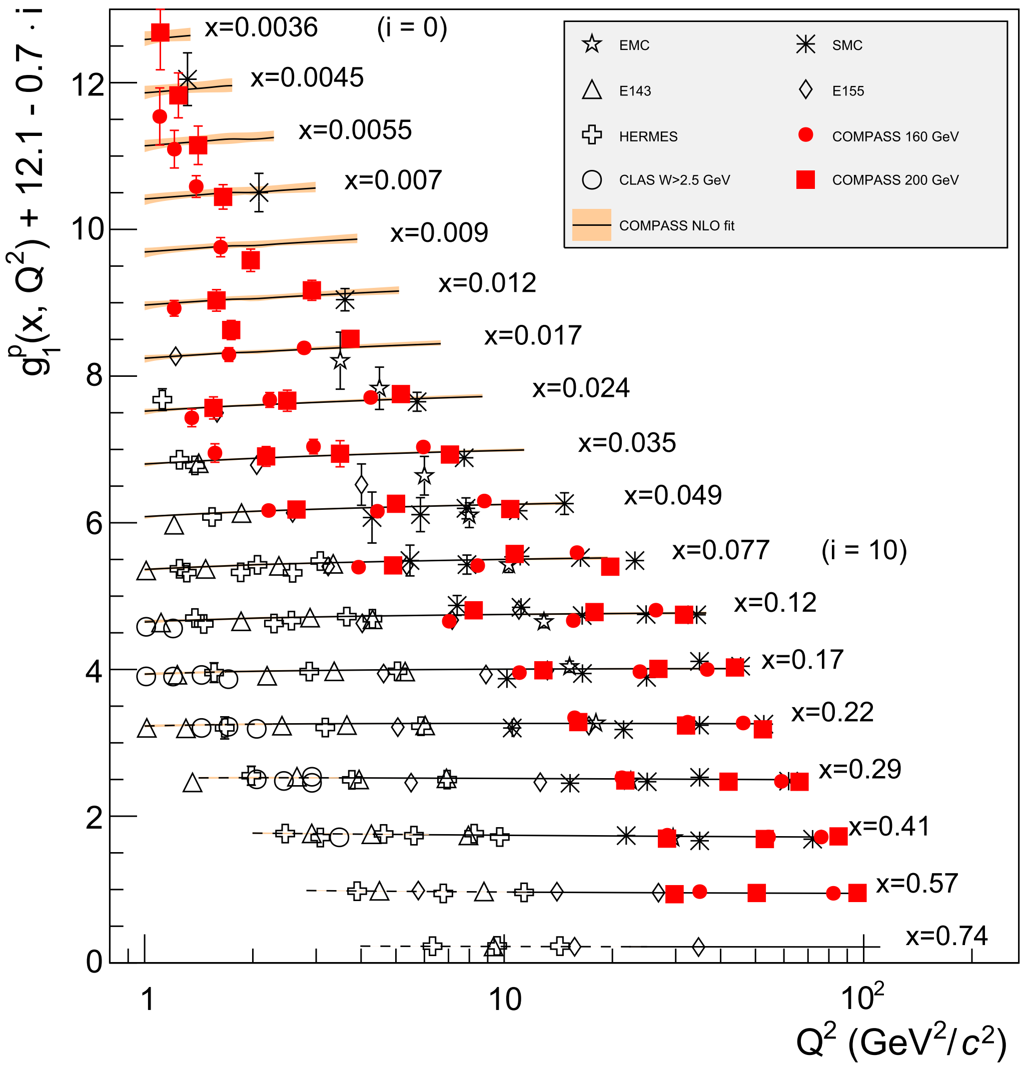
Physics Motivation



Nuclear Physics B328 (1989) 1–35



COMPASS Collaboration: Physics Letters B 753 (2016) 18–28



$$\int_0^1 g_1^p \, dx = \boxed{0.126} \pm 0.010 \pm 0.015$$

$$\langle S_z \rangle_{\text{valence}} = +0.535 \pm 0.032 \pm 0.046$$

$$\langle S_z \rangle_{\text{sea}} = -0.475 \pm 0.080 \pm 0.115$$

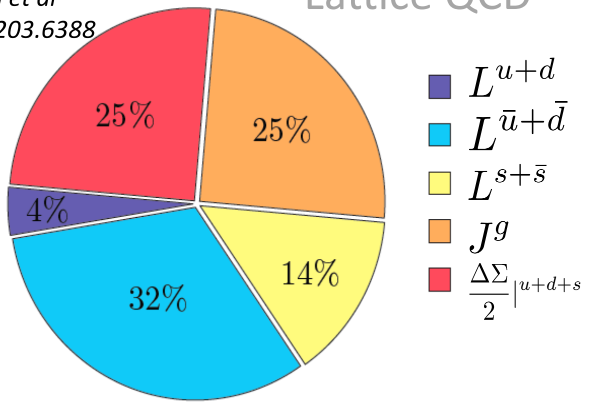
Intrinsic spin contribution
(total) by valence & sea quarks

$$\sim (12 \pm 9 \pm 14)\%$$

Possible missing spin contributions

K.-F. Liu et al
arXiv:1203.6388

Lattice QCD



$\Delta\Sigma_q \approx 25\%$

2 $L_q \approx 50\%$ (4% (valence)+46% (sea))

2 $J_g \approx 25\%$

Jaffe-Manohar decomposition

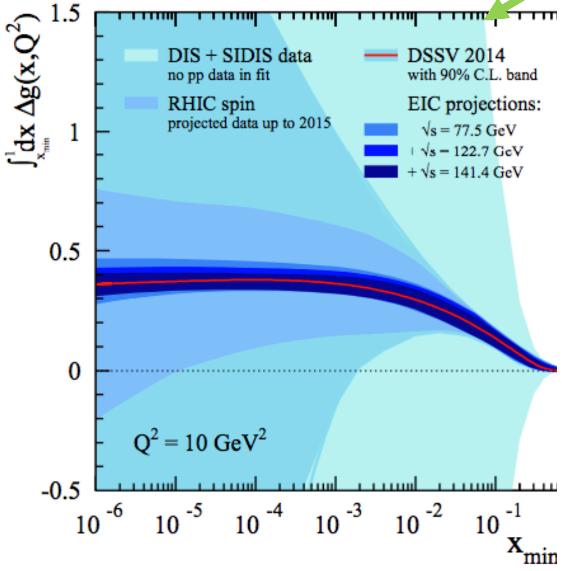
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \boxed{\Delta G + L_g} + \boxed{L_q} + \boxed{L_{\bar{q}}}$$

Gluon total angular momentum

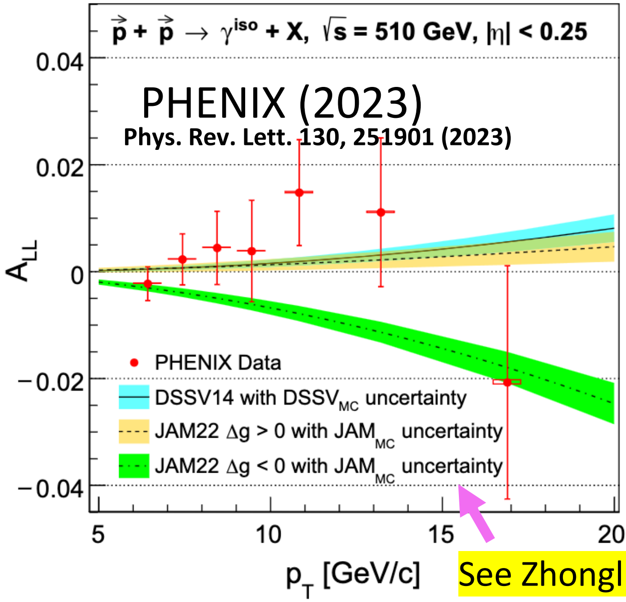
Valence quarks' OAM

Sea-quarks' OAM

- ➢ Sea quark OAM could be a major contribution
  (J. Ellis and M. Karliner, Phys. I,ett. B213 (1988) 73)
- ➢ Separation of gluon intrinsic spin and OAM is constrained by gauge invariance

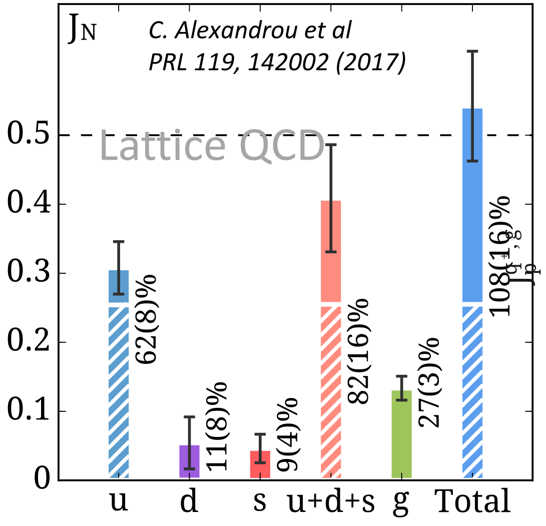


E. C. Aschenauer, et al PRD 92, 094030 (2015)

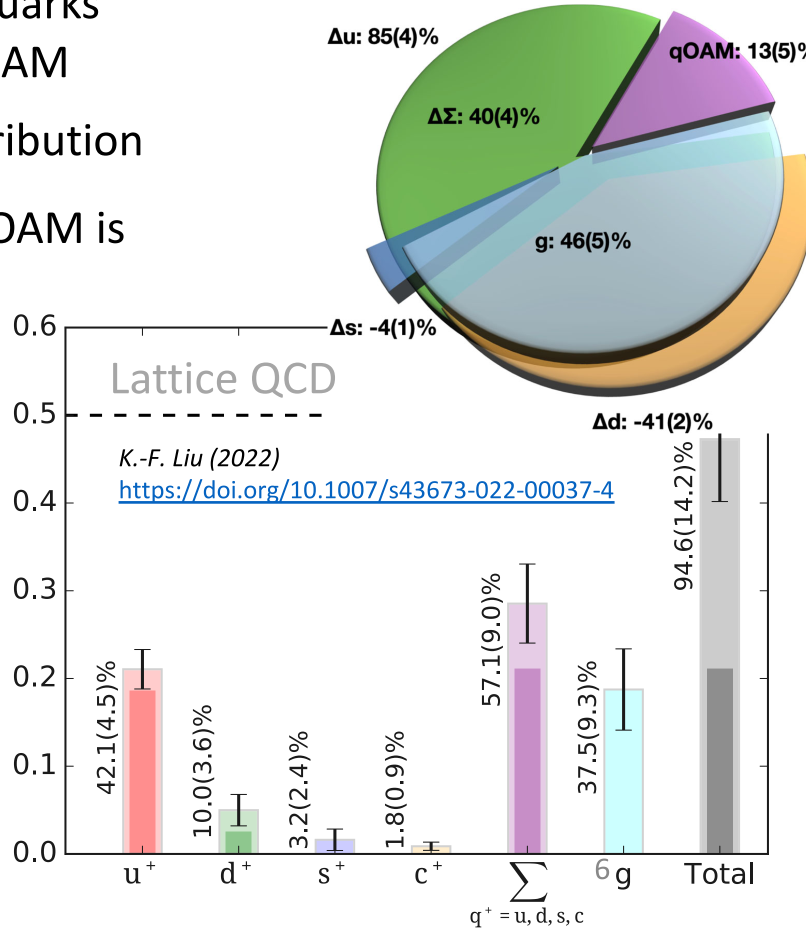


PHENIX (2023)
Phys. Rev. Lett. 130, 251901 (2023)

See Zhongling Ji 's talk

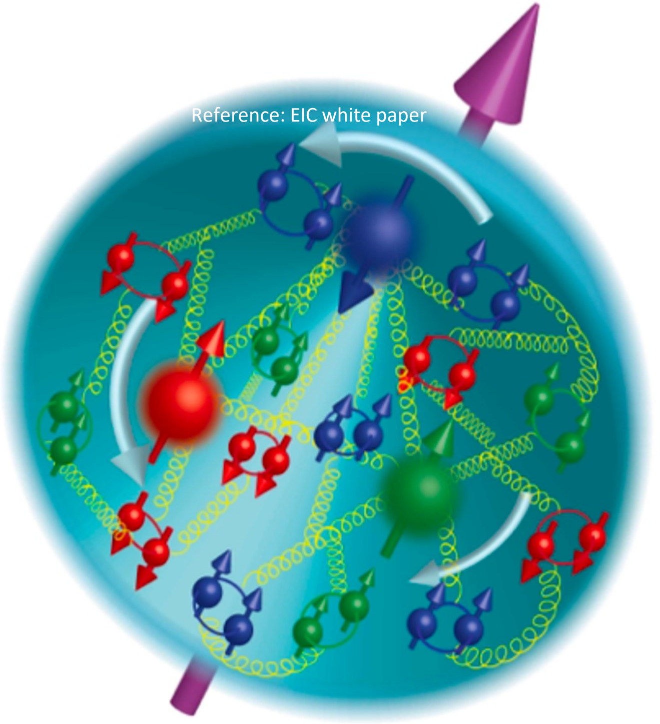


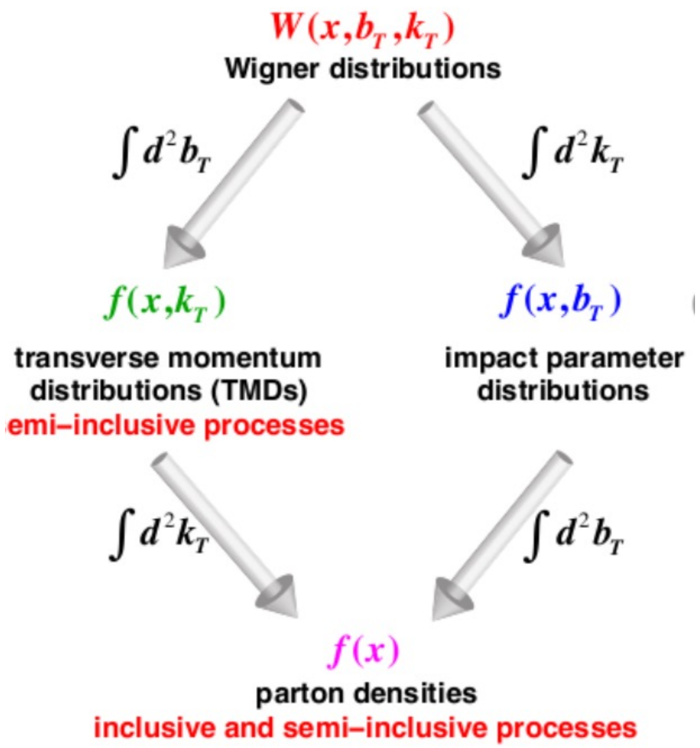
C. Alexandrou et al
PRL 119, 142002 (2017)



K.-F. Liu (2022)
https://doi.org/10.1007/s43673-022-00037-4

TMD PDFs





Orbital angular momentum of quarks being closely connected with their transverse position and transverse momenta since,

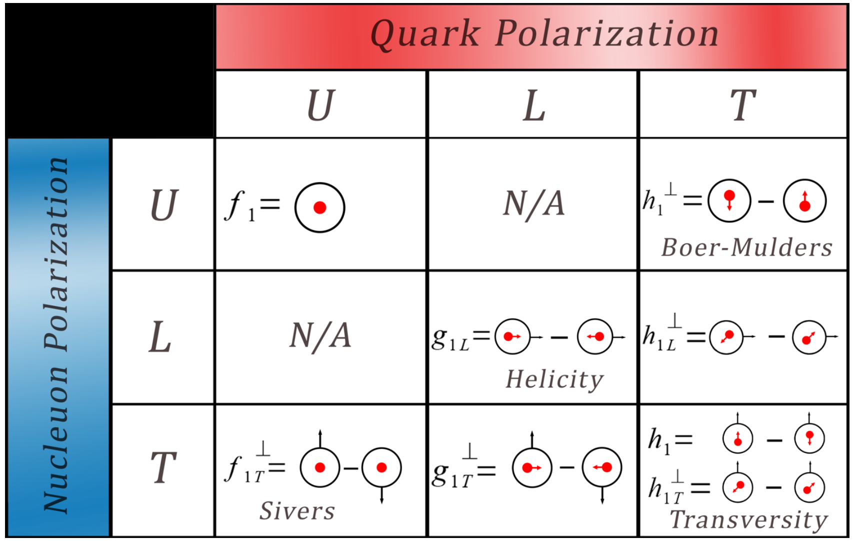
$$\vec{L} = \vec{r} \times \vec{p}$$

Orbital motion of quarks → 3D momentum structure of the nucleon

Distribution functions:

- Parton Distribution Functions (PDFs) $f(x)$: The number density of partons with longitudinal momentum fraction
- Transverse Momentum Dependent Parton Distribution Functions (TMD PDFs) : $f(x, k_T)$
  The joint distribution of partons in their longitudinal momentum fraction x, and their momentum transverse to the proton's momentum direction.

TMD PDFs



		Quark Polarization		
		U	L	T
Nucleon Polarization	U	$f_1 =$ ⊙	N/A	$h_1^\perp =$ ⊙ − ⊙ Boer-Mulders
	L	N/A	$g_{1L} =$ ⊙ − ⊙ Helicity	$h_{1L}^\perp =$ ⊙ − ⊙
	T	$f_{1T}^\perp =$ ⊙ − ⊙ Sivers	$g_{1T}^\perp =$ ⊙ − ⊙	$h_1 =$ ⊙ − ⊙ $h_{1T}^\perp =$ ⊙ − ⊙ Transversity

$$\Phi(x, k_T; S) = \int \frac{d\xi^- d\xi_T}{(2\pi)^3} e^{ik.\xi} \langle P, S|\bar{\psi}(0)\ \mathcal{U}_{[0,\xi]}\ \psi(\xi)|P, S\rangle|_{\xi^+=0}$$

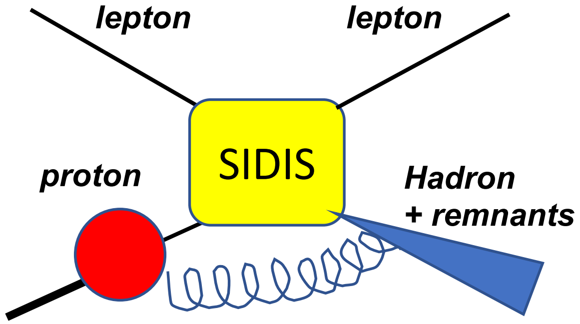
Quark correlator can be decomposed into 8 components
(6 T -even and 2 T -odd terms) at leading-twist

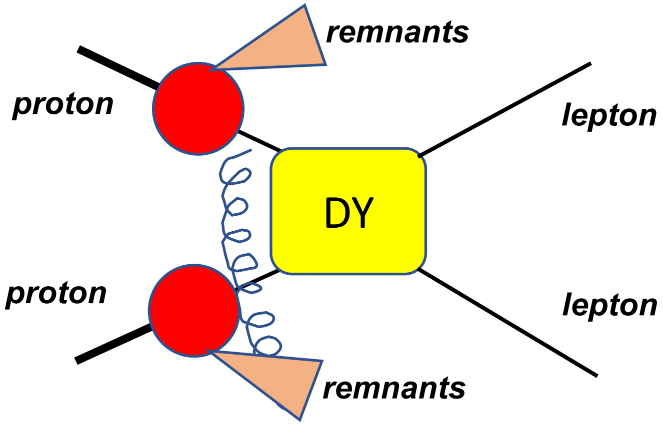
$$\Phi(x, k_T, P, S) = \boxed{f_1(x, k_T^2)\frac{\not{P}}{2} + \frac{h_{1T}(x, k_T^2)}{4}\gamma_5[\not{S}_T, \not{P}] + \frac{S_L}{2} g_{1L}(x, k_T^2)\gamma_5\not{P} + \frac{k_T.S_T}{2M} g_{1T}(x, k_T^2)\gamma_5\not{P} + S_L h_{1L}^\perp(x, k_T^2)\gamma_5\frac{[\not{k}_T, \not{P}]}{4M} + \frac{k_T.S_T}{2M} h_{1T}^\perp(x, k_T^2)\gamma_5\frac{[\not{k}_T, \not{P}]}{4M}}$$

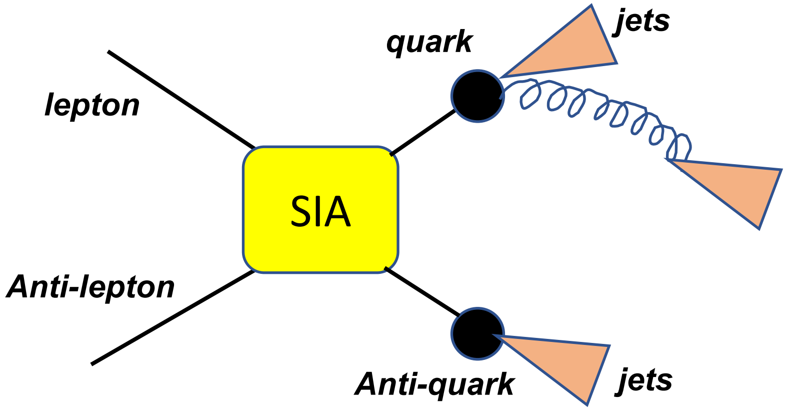
T-even

$$+\boxed{ih_1^\perp(x, k_T^2)\frac{[\not{k}_T, \not{P}]}{4M} - \frac{\epsilon_T^{k_T S_T}}{4M} f_{1T}^\perp(x, k_T^2)\not{P}}$$

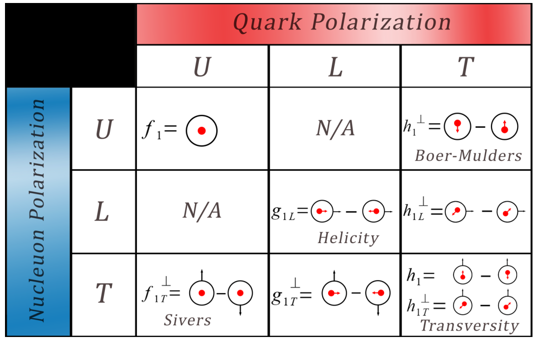
T-odd





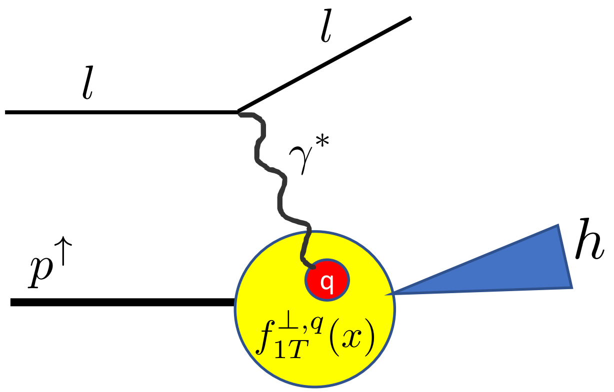


TMD PDFs



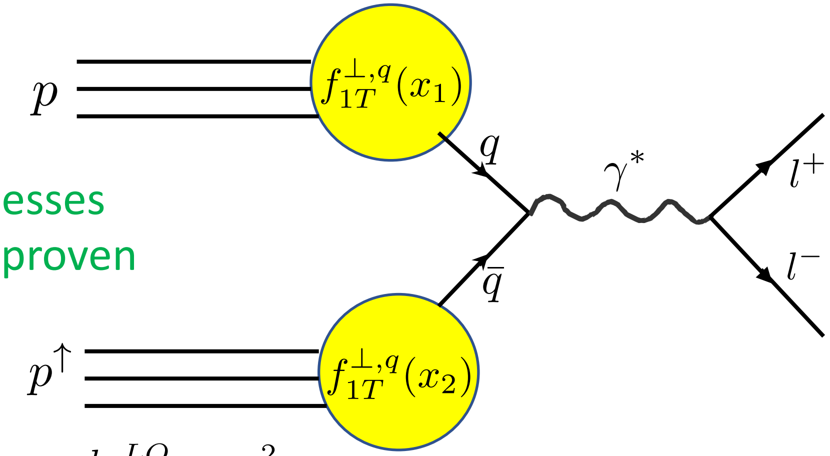
		Quark Polarization		
		U	*L*	*T*
Nucleuon Polarization	*U*	$f_1=$ ⊙	*N/A*	$h_1^{\perp}=$ ⊙ − ⊙ *Boer-Mulders*
	L	*N/A*	$g_{1L}=$ ⊙ − ⊙ *Helicity*	$h_{1L}^{\perp}=$ ⊙ − ⊙
	T	$f_{1T}^{\perp}=$ ⊙ − ⊙ *Sivers*	$g_{1T}^{\perp}=$ ⊙ − ⊙	$h_1=$ ⊙ − ⊙ $h_{1T}^{\perp}=$ ⊙ − ⊙ *Transversity*

Polarized Semi Inclusive DIS



* For these two processes TMD factorization is proven

Polarized DY



$$\frac{d\sigma^{LO}_{SIDIS}}{dxdydzdp_T^2d\phi_h d\psi} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{y^2}{2x}\right)\right]$$
$$\times\left(F_{UU,T}+\epsilon F_{UU,L}\right)\left\{1+\cos 2\phi_h\left(\epsilon A_{UU}^{\cos 2\phi_h}\right)\right.$$
$$+S_T\left[\sin(\phi_h-\phi_s)\left(A_{UT}^{\sin(\phi_h-\phi_s)}\right)+\sin(\phi_h+\phi_s)\left(\epsilon A_{UT}^{\sin(\phi_h+\phi_s)}\right)\right.$$
$$\left.+\sin(3\phi_h-\phi_s)\left(\epsilon A_{UT}^{\sin(3\phi_h-\phi_s)}\right)\right]$$

$$A_{UU}^{\cos 2\phi_h} \propto h_1^{\perp q}\otimes H_{1q}^{\perp h} \quad \mathrm{BM}\otimes\mathrm{CF}$$
$$A_{UT}^{\sin(\phi_h-\phi_s)} \propto f_{1T}^{\perp q}\otimes D_{1q}^{h} \quad \mathrm{Sivers}\otimes\mathrm{FF}$$
$$A_{UT}^{\sin(\phi_h+\phi_s)} \propto h_1^{q}\otimes H_{1q}^{\perp h} \quad \mathrm{Transv}\otimes\mathrm{CF}$$
$$A_{UT}^{\sin(3\phi_h-\phi_s)} \propto h_{1T}^{\perp q}\otimes H_{1q}^{\perp h} \quad \mathrm{Pretz}\otimes\mathrm{CF}$$

$$\frac{d\sigma^{LO}}{d\Omega} = \frac{\alpha_{em}^2}{Fq}F_v^1\left\{1+\cos^2\theta+sin^2\theta cos2\phi_{CS}A_U^{cos2\phi_{CS}}\right.$$
$$+S_T\left[\left(1+\cos^2\theta\right)\sin\phi_s A_T^{\sin\phi_s}+\sin^2\theta\left(\sin(2\phi_{CS}+\phi_s)A_T^{\sin(2\phi_{CS}+\phi_s)}\right.\right.$$
$$\left.\left.+\sin(2\phi_{CS}-\phi_s)A_T^{\sin(2\phi_{CS}-\phi_s)}\right)\right]$$

$$A_T^{\cos 2\phi_{CS}} \propto h_1^{\perp q}\otimes h_1^{\perp q} \quad \mathrm{BM}\otimes\mathrm{BM}$$
$$A_T^{\sin\phi_s} \propto f_1^{q}\otimes f_{1T}^{\perp q} \quad \mathrm{PDF}\otimes\mathrm{Sivers}$$
$$A_T^{\sin(2\phi_{CS}-\phi_s)} \propto h_1^{\perp q}\otimes h_1^{q} \quad \mathrm{BM}\otimes\mathrm{Transv}$$
$$A_T^{\sin(2\phi_{CS}+\phi_s)} \propto h_1^{\perp q}\otimes h_{1T}^{\perp q} \quad \mathrm{BM}\otimes\mathrm{Pretz}$$

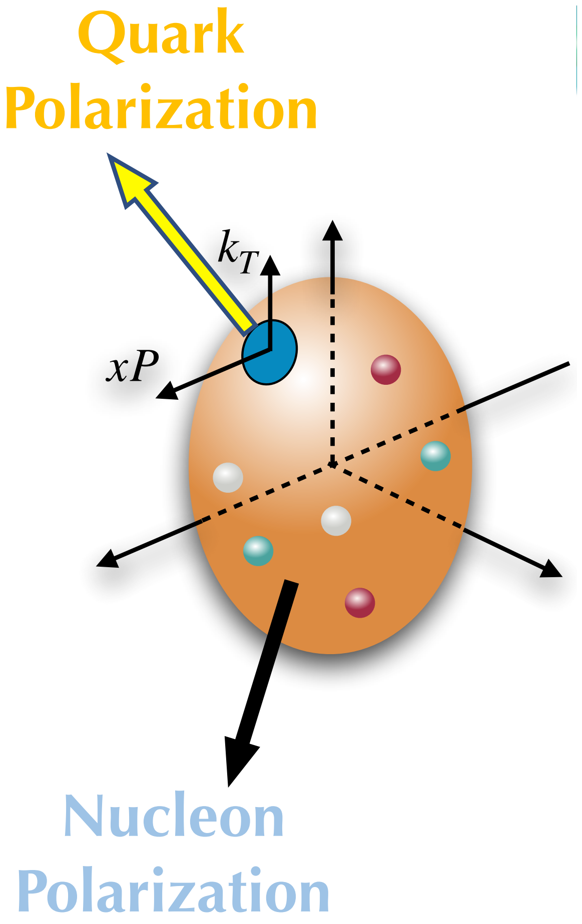
$$h_1^{\perp q}\Big|_{SIDIS} = -h_1^{\perp q}\Big|_{DY}$$
$$f_{1T}^{\perp q}\Big|_{SIDIS} = -f_{1T}^{\perp q}\Big|_{DY}$$

$$h_1^{q}\Big|_{SIDIS} = h_1^{q}\Big|_{DY}$$
$$h_{1T}^{\perp q}\Big|_{SIDIS} = h_{1T}^{\perp q}\Big|_{DY}$$

Sivers Function

$$f_{q/p^{\uparrow}}(x,\mathbf{k_T}) = f_{q/p}(x,\mathbf{k_T}) + f_{1T}^{\perp}(x,\mathbf{k_T})\mathbf{S}.(\hat{\mathbf{P}} \times \hat{\mathbf{k_T}})$$

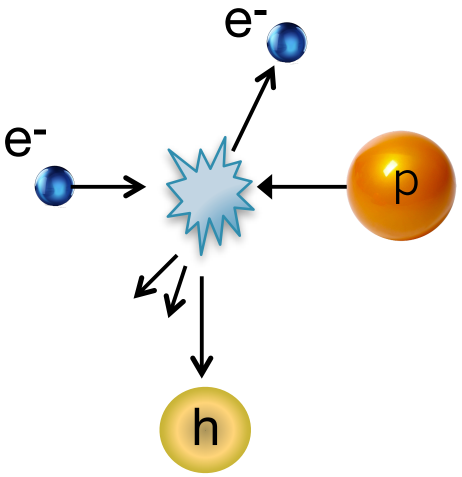
The Sivers function describes the correlation between the momentum direction of the struck quark and the spin of its parent nucleon.



Pic.. Courtesy: Alexei Prokudin

Semi-Inclusive DIS

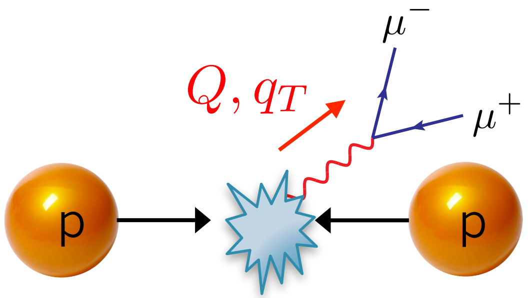
$$\sigma \sim f_{q/P}(x,k_T)D_{h/q}(z,k_T)$$



Meng, Olness, Soper (1992)
Ji, Ma, Yuan (2005)
Idilbi, Ji, Ma, Yuan (2004)
Collins (2011)

Drell-Yan

$$\sigma \sim f_{q/P}(x_1,k_T)f_{\bar{q}/P}(x_2,k_T)$$



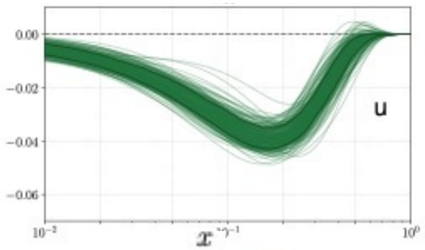
E1039

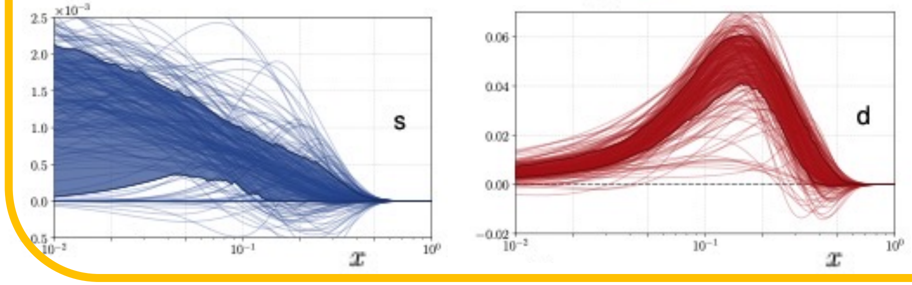
Collins, Soper, Sterman (1985)
Ji, Ma, Yuan (2004)
Collins (2011)

Pic.. Courtesy: Alexei Prokudin

Global analyses: Sivers functions

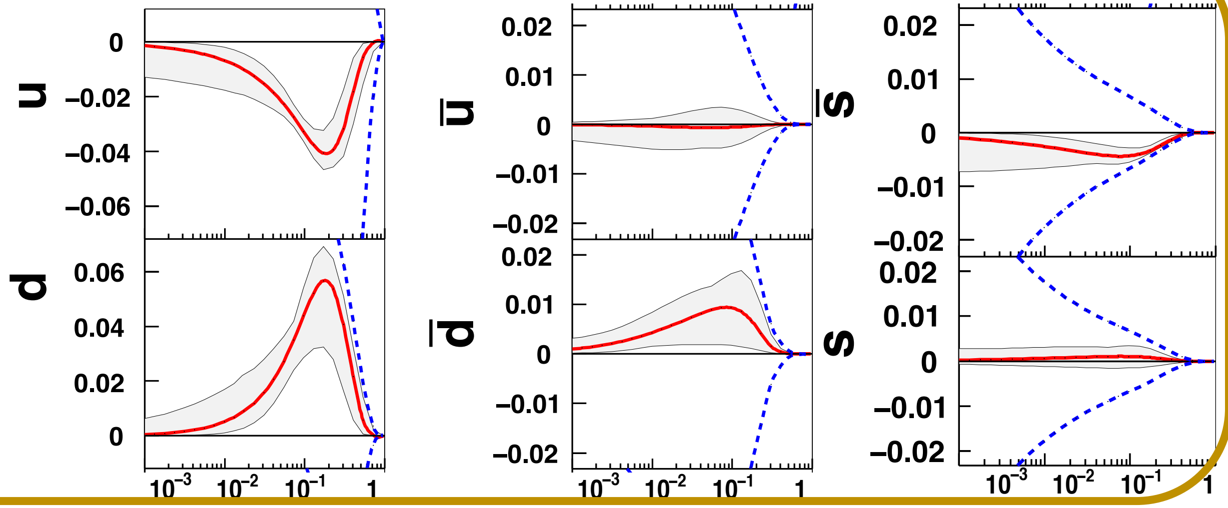
A. Bacchetta, F. Delcarro,
C. Pasiano, M. Radici
arXiv 2004.14278 (2020)



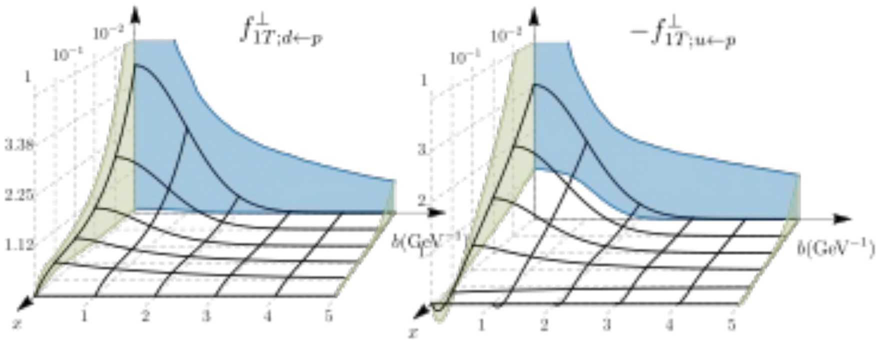


HERMES (2020)
COMPASS (2009)
COMPASS (2015)
JLab (2011)

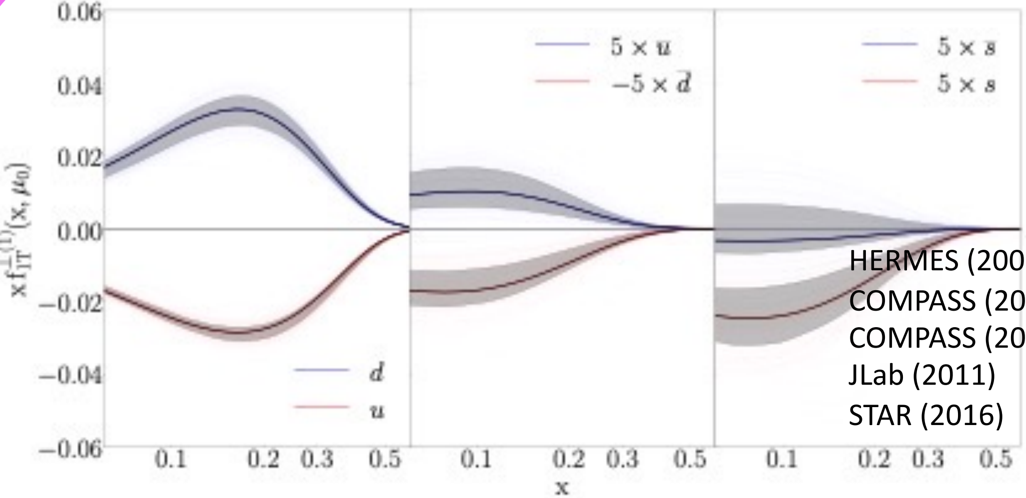
M. Anselmino, M. Boglion, U. D'Alesio, S. Melis, F. Murgia, A. Prokudin_PRD_79_54010_(2009)



HERMES (2020), COMPASS (2009),COMPASS (2015)
JLab (2011), STAR (2016),COMPASS DY (2017)

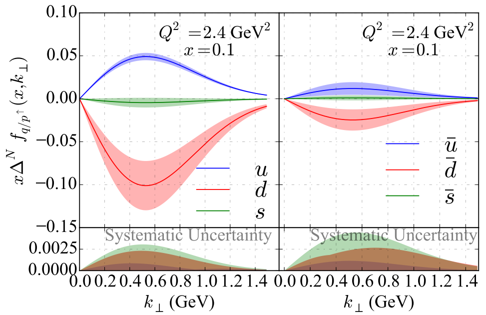


M. Bury, A. Prokudin , A. Vladimirov,, JHEP_05_151 (2021)



HERMES (2009)
COMPASS (2009)
COMPASS (2015)
JLab (2011)
STAR (2016)

M. Echevarria, Z. Kang, J. Terry_JHEP_01_126_(2021)

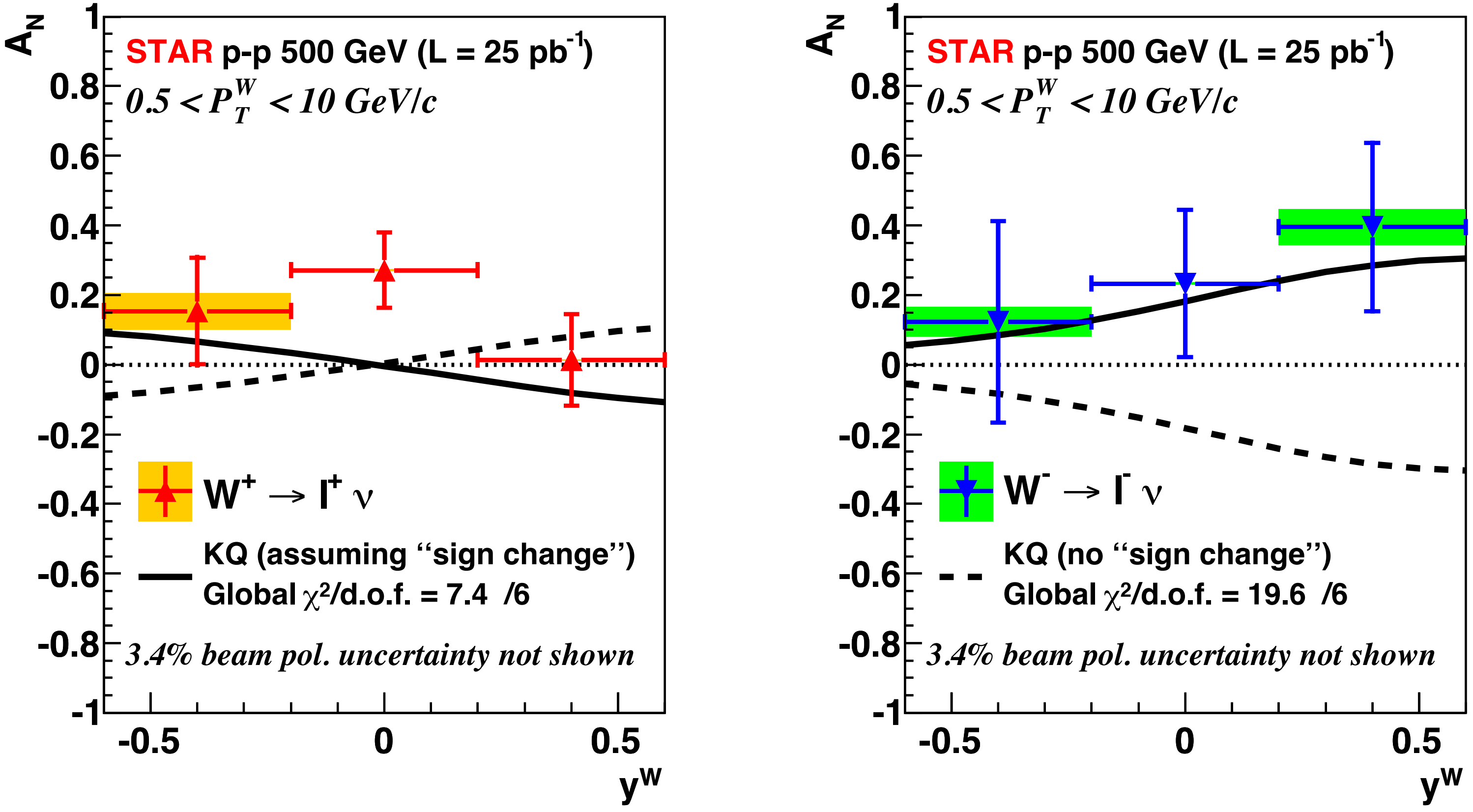


I. P. Fernando and D. Keller
Phys. Rev. D.108.054007 (2023)

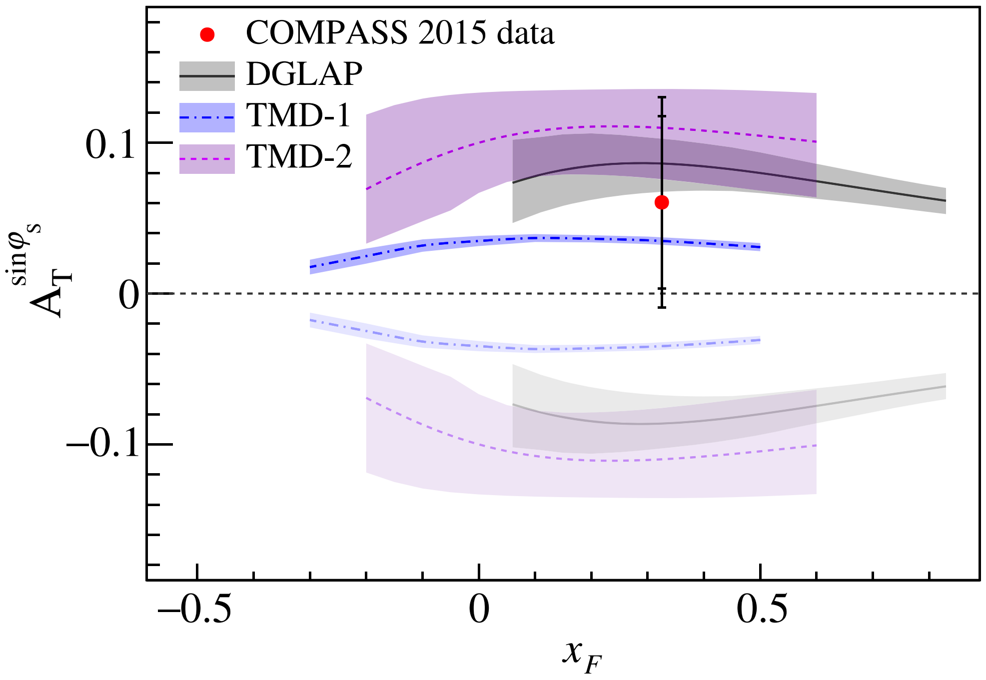
Using Deep Neural Networks

Sign of Sivers Functions

STAR Collaboration (PRL 116 132301 (2016))



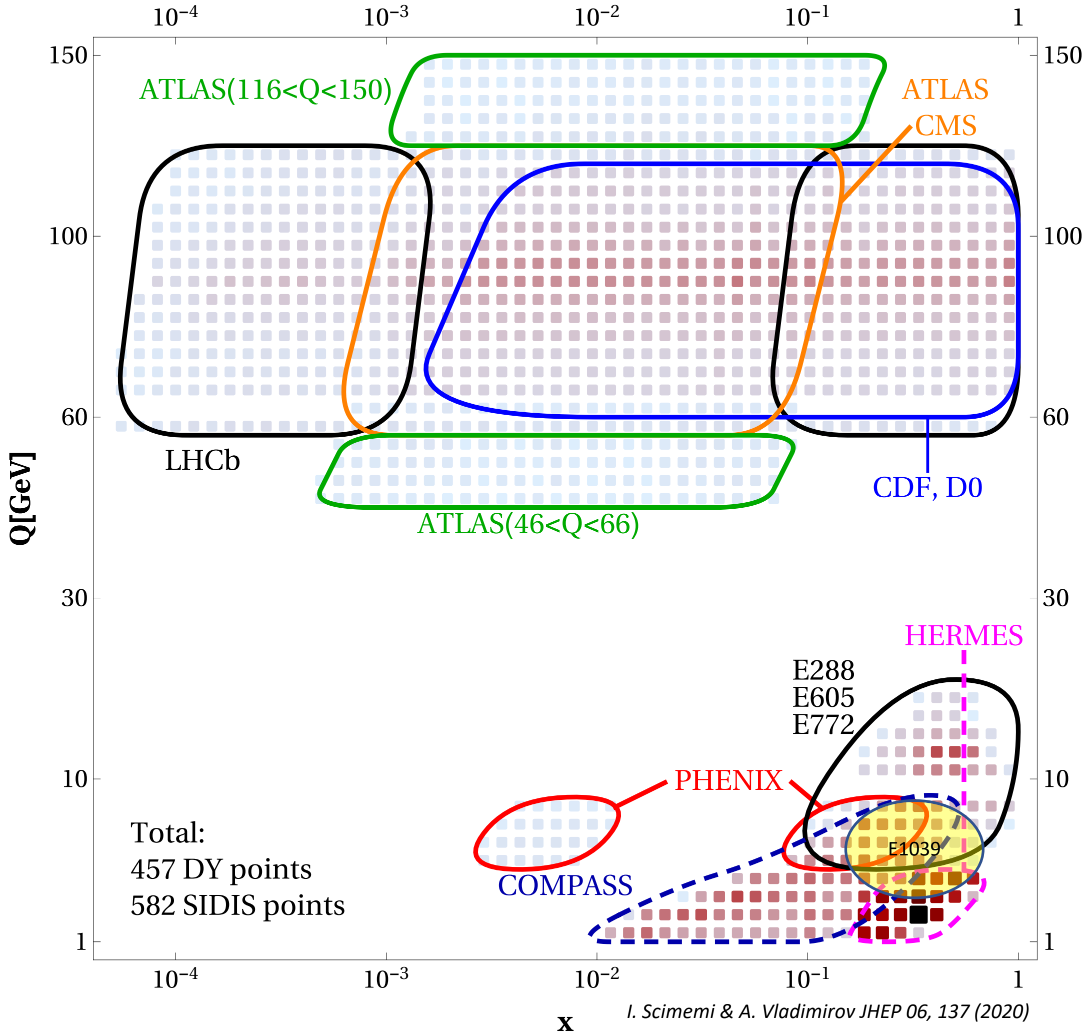
COMPASS Collaboration (PRL 119 112002 (2017))



TSSA amplitude for W+/W- from STAR data is favors the "sign-change"
In DY relative to SIDIS (model based without TMD evolution)

Dark Shaded (Light-shaded): with(without) "sign-change"

SpinQuest in the Global Context

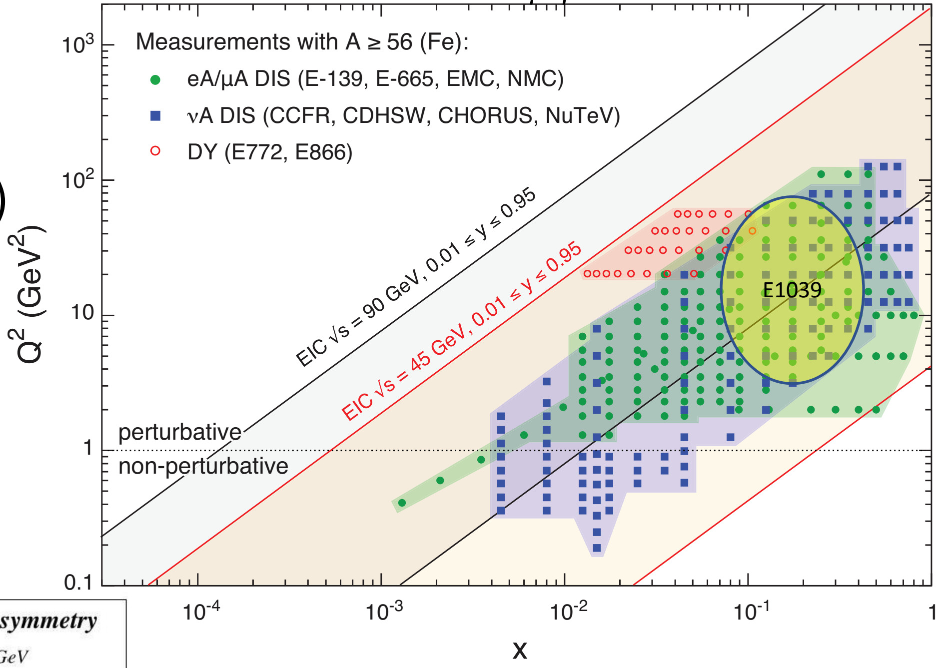


I. Scimemi & A. Vladimirov JHEP 06, 137 (2020)

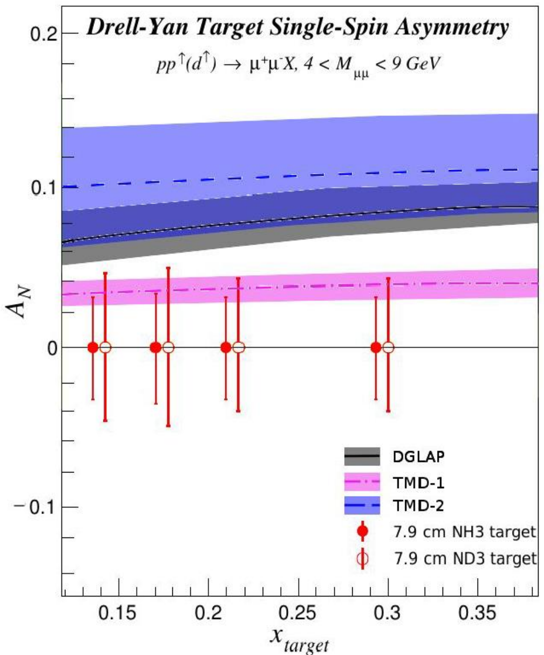
Drell-Yan measurements above the J/ψ peak fall in a unique region with Q^2 in the range of $16 < M^2 < 81$ GeV^2 and Q_T < few GeV

In terms of
Q^2, P_T, x_{target}
and the process (DY)
E1039 has a unique kinematics setting for the sea quarks

EIC white paper



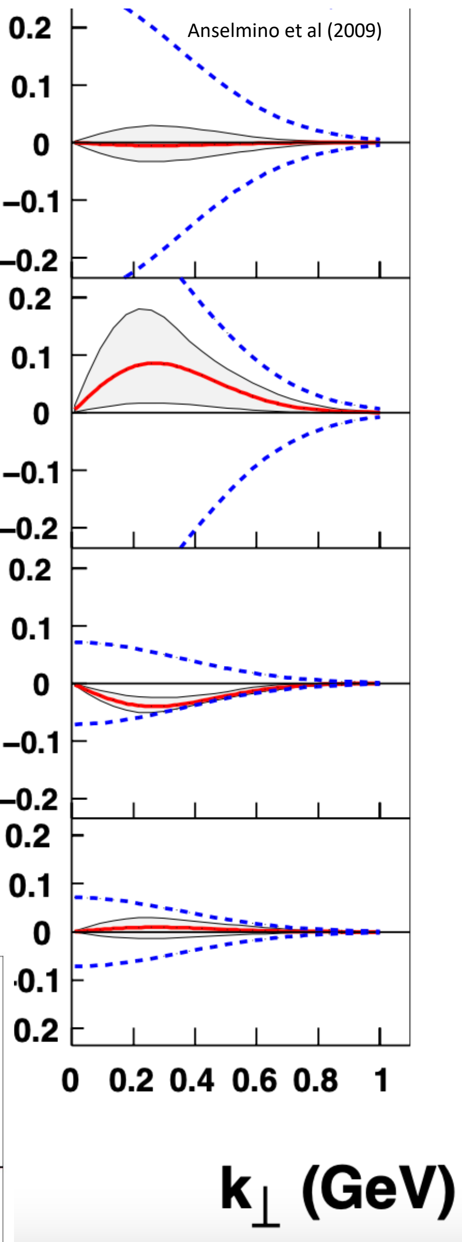
From E1039 proposal



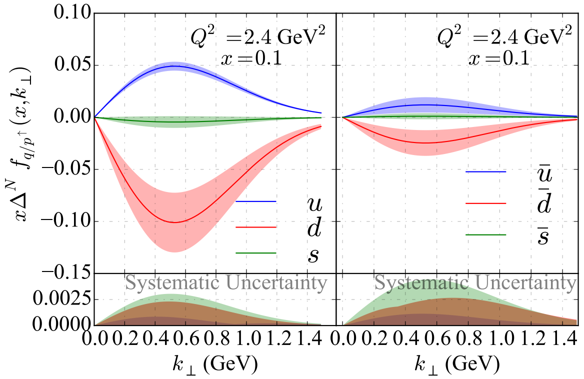
- The E1039 experiment focuses unique kinematics to extract **sea** quark Sivers function in DY
- ←Plot: Uncertainties in the predicted Sivers asymmetry in polarized Drell-Yan process from SpinQuest.

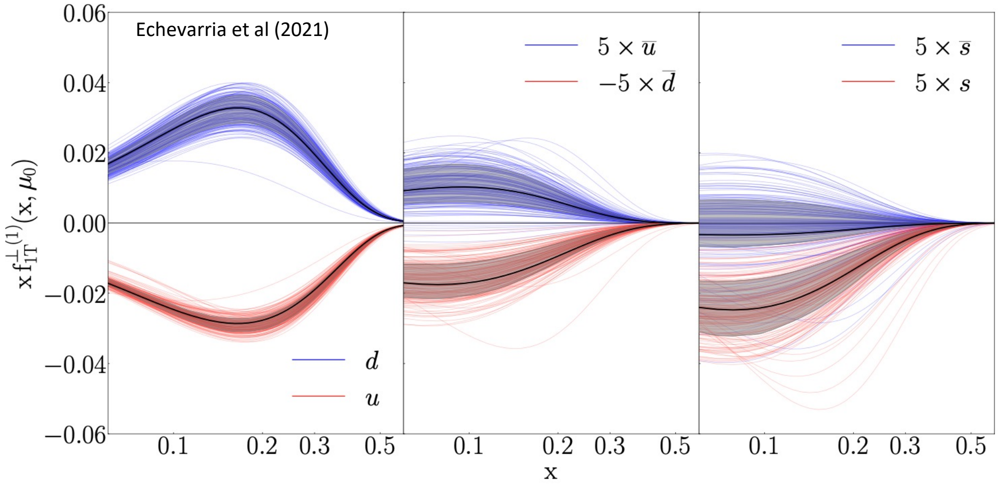
DGLAP: M. Anselmino et al arXiv:1612.06413
TMD-1: M. G. Echevarria et al arXiv:1401.5078
TMD-2: P. Sun and F. Yuan arXiv:1308.5003

Sea-quarks Sivers functions



- Initial attempts to measure the Sivers asymmetry for sea quark Sivers have been reported by the STAR collaboration at RHIC using W/Z boson production. Their data is statistically limited and favor a sign-change only if TMD evolutions effects are significantly smaller than expected.
- Lack of experimental data for smaller x to extract the sea quarks' Sivers functions.
  * Various types of assumptions/treatment (flavor-independent and flavor-dependent)
  * Uncertainties through global fitting became large relative to the 'valence' quarks.
- As DY data facilitate a clean probe compared to the SIDIS process because there is no fragmentation associated with the process; the SpinQuest will contribute to the Sivers asymmetry data in Drell-Yan proton-proton scattering from the sea quarks.





SpinQuest / E1039 Goals

- SpinQuest will perform the first measurement of the Sivers asymmetry in Drell-Yan proton-proton scattering from the sea quarks ($\bar{u}$ & $\bar{d}$) with sign.

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

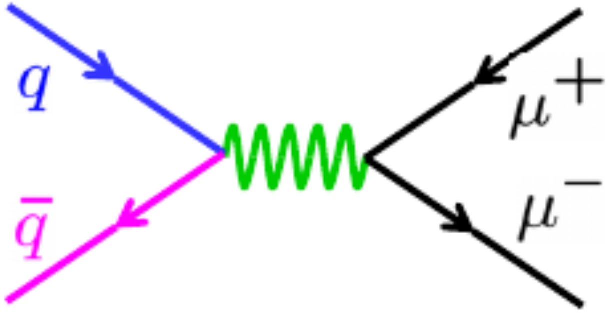
A direct QCD prediction is a Sivers effect in the Drell-Yan process
that has the opposite sign compared to the one in semi-inclusive DIS.

- Measurement of Sivers function for gluons (J/psi TSSA)
- Explore a unique range of virtualities and transverse momenta not accessible through Z^0 /$W^{\pm}$ measurements
- Extensions: transversity, tensor charge, tensor polarized observables, dark sector, polarized proton beam,...

Polarized fixed target Drell-Yan : Sensitivity to sea-quarks

beam: valence quarks at high x

target: sea quarks at low/intermediate x



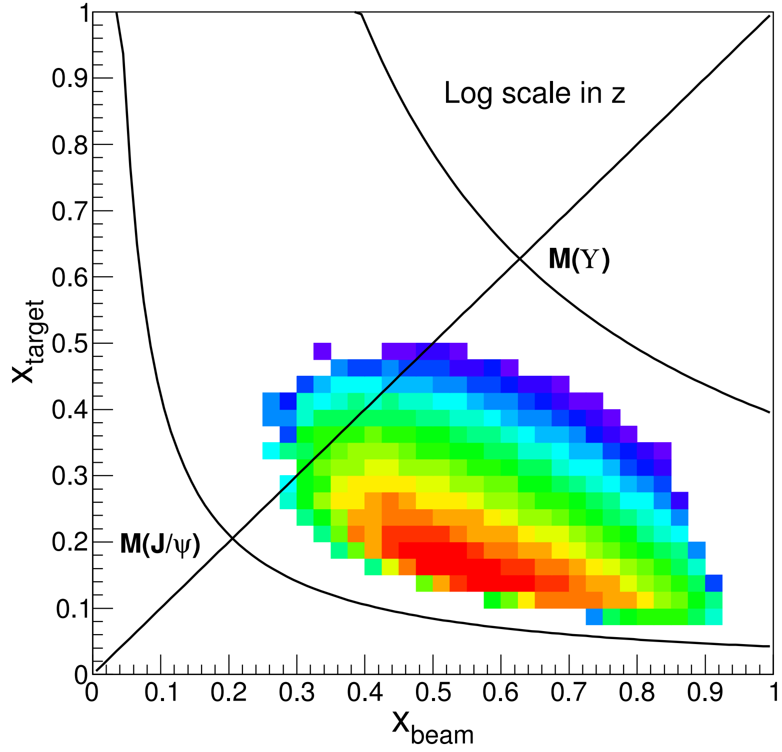
$$\frac{d^2\sigma}{dx_b dx_t} = \frac{4\pi\alpha^2}{x_b x_t s} \sum_{q\in\{u,d,s,...\}} \boxed{e_q^2} \left[\bar{q}_t(x_t) q_b(x_b) + \cancel{q_t(x_t)\bar{q}_b(x_b)}\right]$$

u-quark dominance
$(2/3)^2$ vs. $(1/3)^2$

acceptance limited
(Fixed Target, Hadron Beam)

Sea-quarks dominance

From E1039 proposal

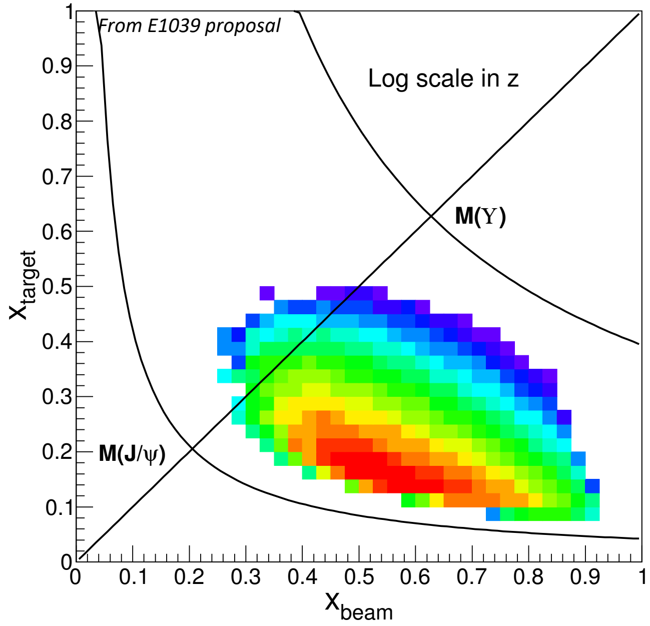


Valence-quarks dominance

Polarized fixed target DY & J/ψ @ SpinQuest / E1039 experiment

$$A = \frac{\sigma(p_b^{un} p_t^{\uparrow}) - \sigma(p_b^{un} p_t^{\downarrow})}{\sigma(p_b^{un} p_t^{\uparrow}) + \sigma(p_b^{un} p_t^{\downarrow})}$$

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.



Drell-Yan $\sigma(p + p^{\uparrow(\downarrow)} \rightarrow \gamma + X)$

$$f_{q/p^{\uparrow}}(x, \mathbf{k_T}, \mathbf{S_T}; Q) = f_{q/p}(x, \mathbf{k_T}; Q) + \frac{1}{2}\Delta^N f_{q/p^{\uparrow}}(x, \mathbf{k_T}, \mathbf{S_T}; Q)$$

J/ψ $\sigma(p + p^{\uparrow(\downarrow)} \rightarrow J/\psi + X)$

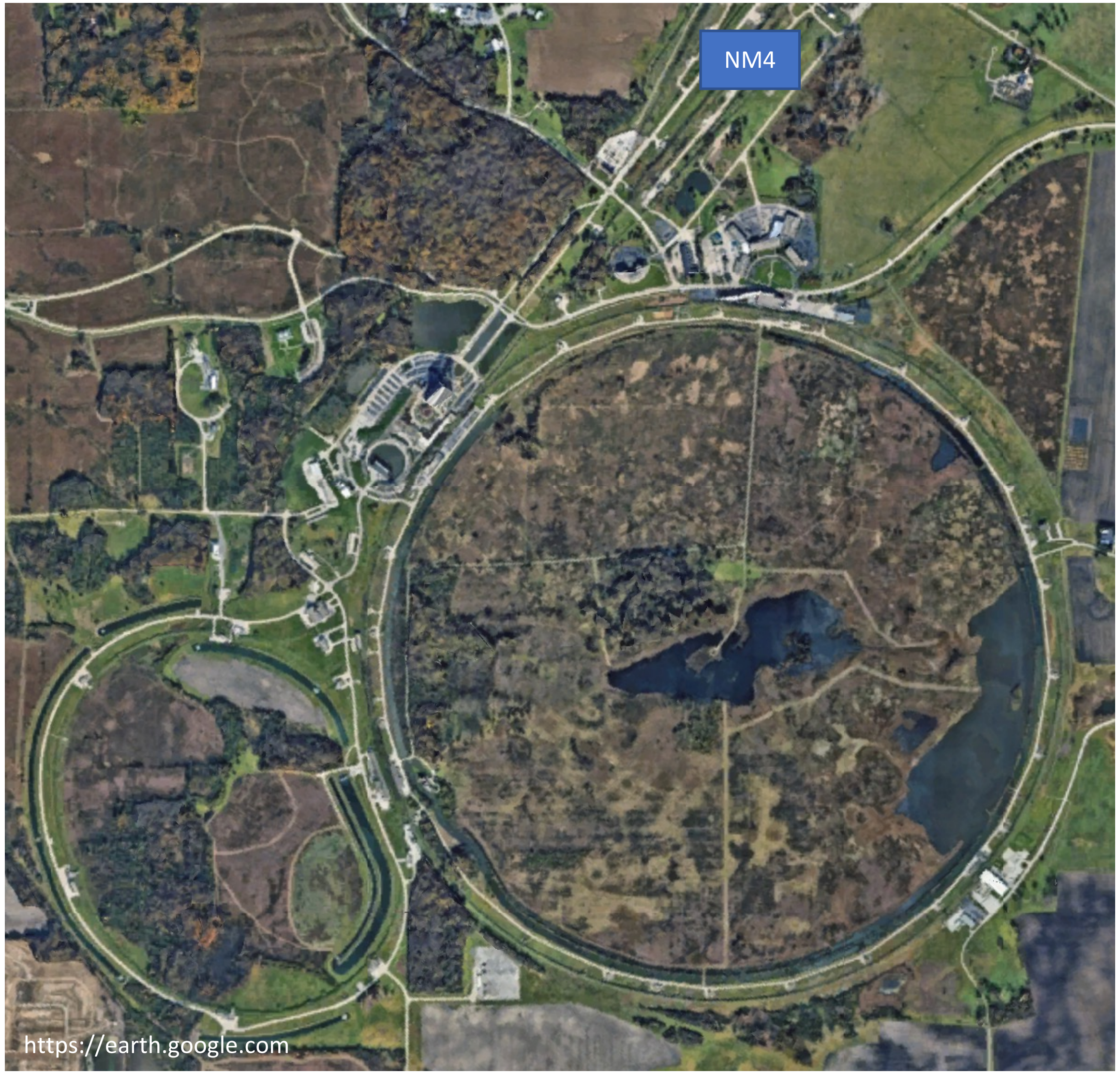
$$f_{g/p^{\uparrow}}(x, \mathbf{k_T}, \mathbf{S_T}; Q) = f_{g/p}(x, \mathbf{k_T}; Q) + \frac{1}{2}\Delta^N f_{g/p^{\uparrow}}(x, \mathbf{k_T}, \mathbf{S_T}; Q)$$

- SpinQuest will be able to explore a new region of kinematics for J/ψ compare to the PHENIX measurements
- J/ψ production:
  - PHENIX → gg fusion at $\sqrt{s}$ =200 GeV
  - SpinQuest → $q\bar{q}$ annihilation at $\sqrt{s} = 15.5$ GeV

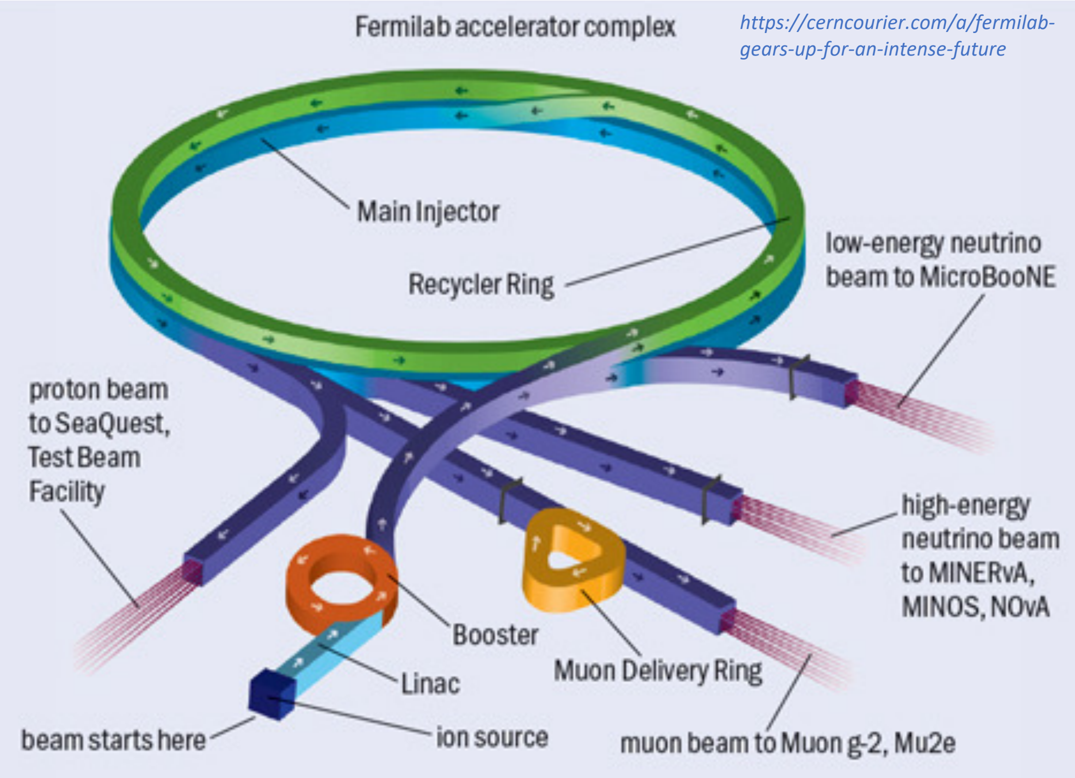
https://spinquest.fnal.gov

INSTITUTIONS 22	**FULL MEMBERS 42 Postdocs 7 Grad. Students 14**	**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	Richard Tesarek (PI)	Carol Johnstone, Charles Brown, Nhan Tran
6) KEK	Shin'ya Sawada (PI)	Shigeru Ishimoto
7) Los Alamos National Laboratory	Kun Liu (SP) , Mikhail Yurov , Kei Nagai	Jan Boissevain, Patrick McGaughey, Andi Klein
8) Mississippi State University	Lamiaa El Fassi (PI), Eric Fuchey, Catherine Ayuso	
9) New Mexico State University	Stephen Pate (PI), Vassili Papavassiliou, Forhad Hossain, 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	Darshana Perera
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), Anchit Arora	Maurik Holtrop
17) Tsinghua University	Zhihong Ye (PI)	
18) University of Virginia	Dustin Keller (SP), Kenichi Nakano, Ishara Fernando, Zulkaida Akbar, Ernesto Diaz, Liliet Diaz, Arthur Conover, Jay Roberts Devin Seay, Amal Pattividana	Donal Day, Donald Crabb, Oscar Rondon
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	Shahryar Khan, Maham Ibrar
22) MIT	Phil Harris (PI), Noah Paladino	William(Patrick) McCormack, Duc Hoang

Fermilab proton beam main injector



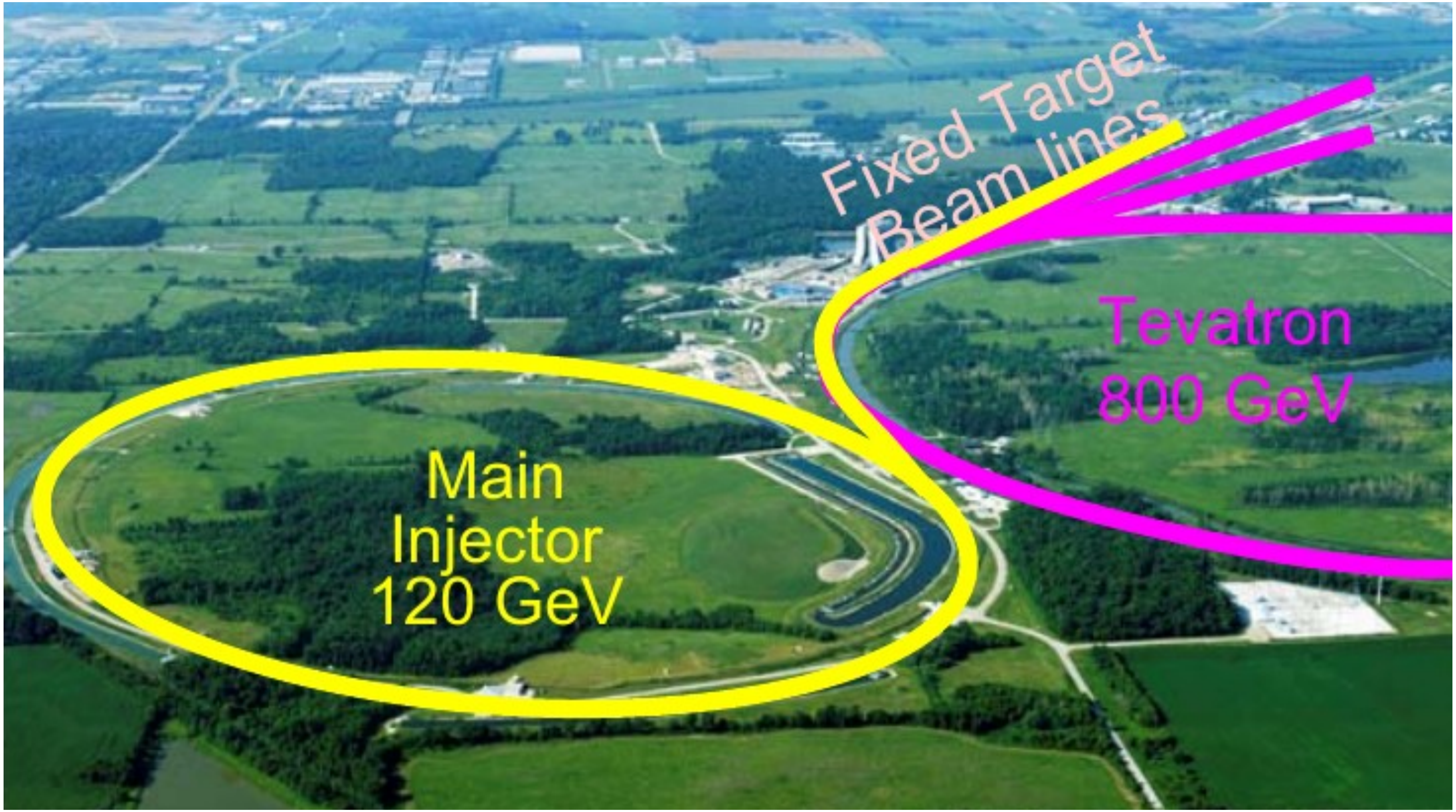
https://earth.google.com



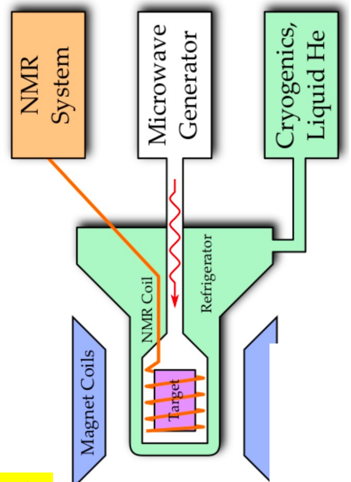
https://cerncourier.com/a/fermilab-gears-up-for-an-intense-future

- 120 GeV/c proton beam
- $\sqrt{s} = 15.5$ GeV
- Projected beam
  - $5 \times 10^{12} protons/spill$ Where $spill \approx 4.4\ s/min$
  - Bunches of $1ns$ with $19ns$ intervals ~ 53 MHz
  - $7 \times 10^{17} protons/year$ on target!

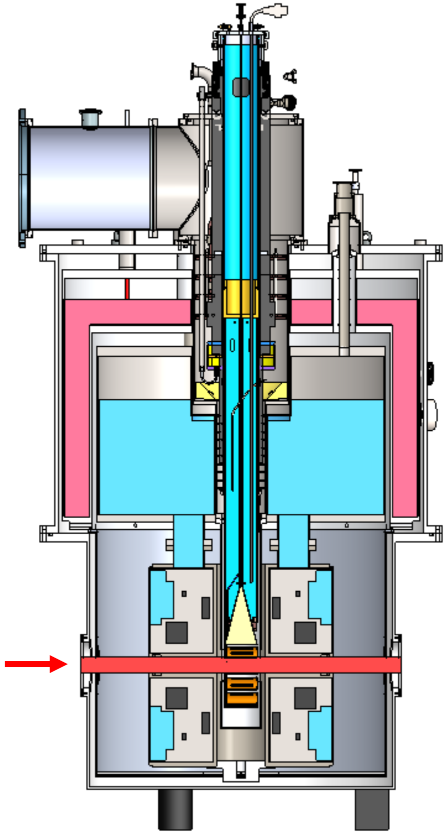
Fermilab proton beam main injector



SpinQuest / E1039 Experiment Setup

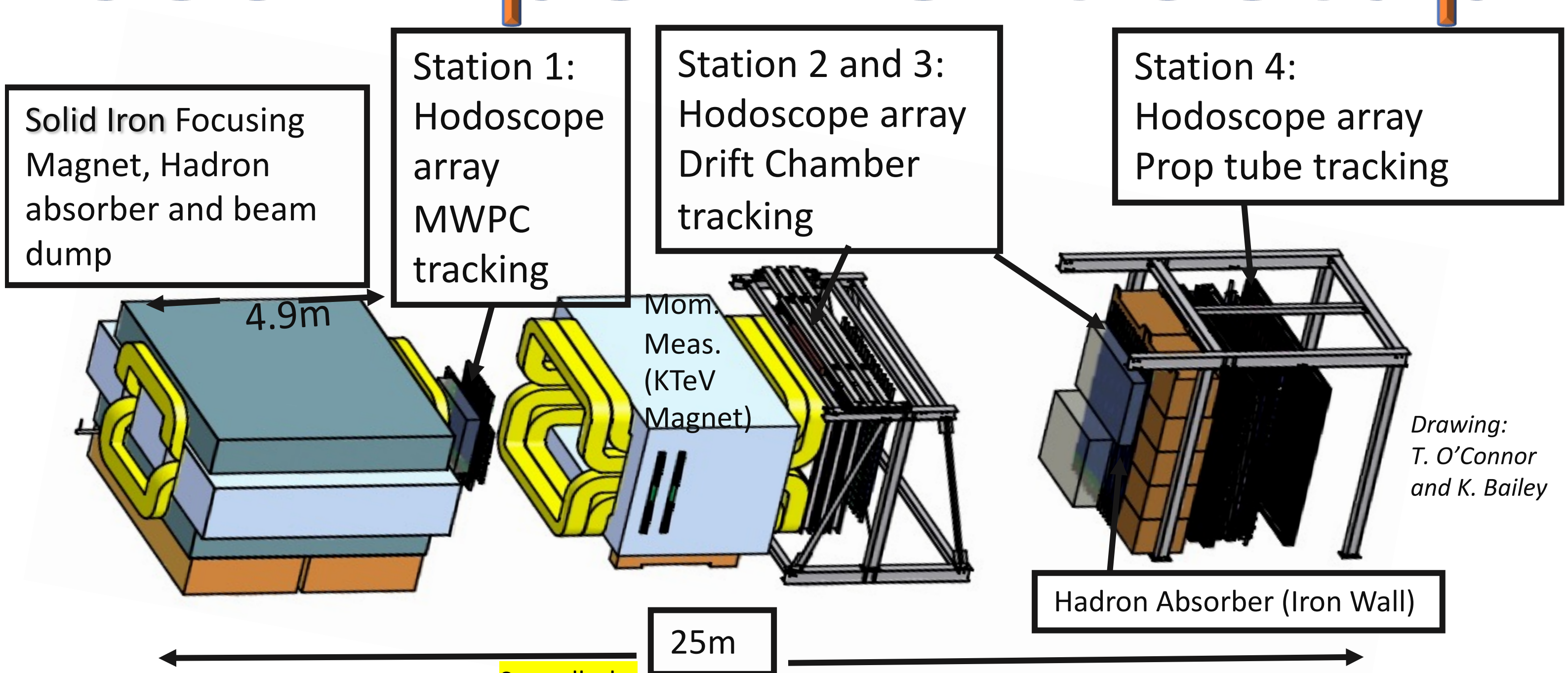


See talks by
Muhammad Farooq (SpinQuest Target)
Vibodha Bandara (Target Refrigerator)



120 GeV Proton

Polarized solid NH3 & ND3 target setup (by LANL & UVA)



Solid Iron Focusing Magnet, Hadron absorber and beam dump

Station 1: Hodoscope array MWPC tracking

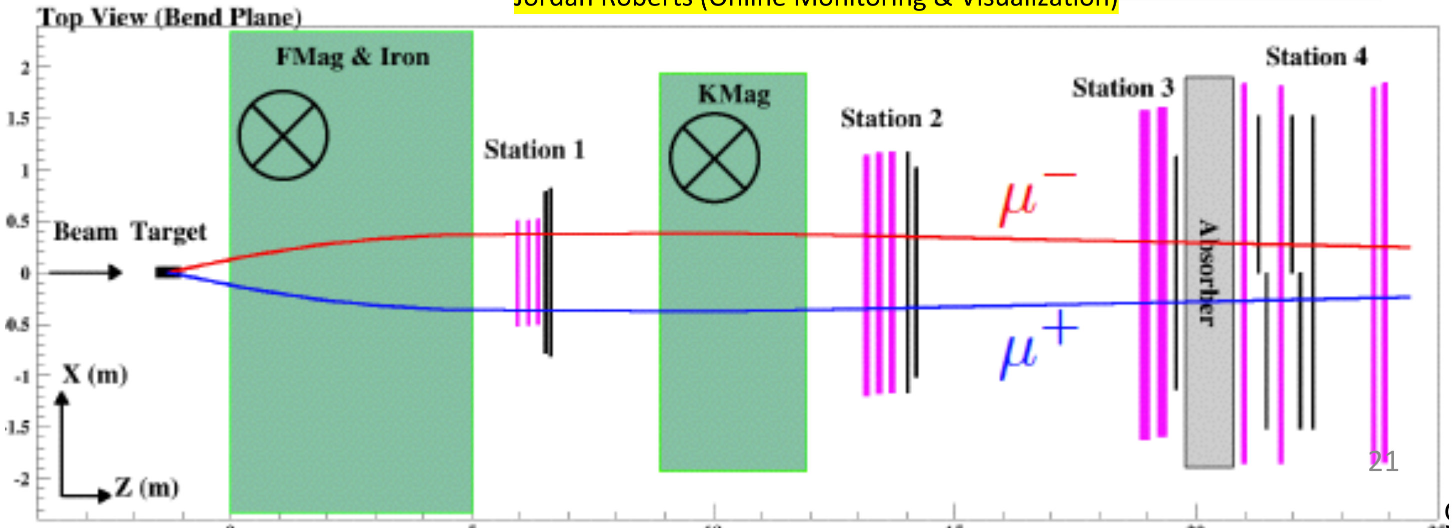
Station 2 and 3: Hodoscope array Drift Chamber tracking

Station 4: Hodoscope array Prop tube tracking

Hadron Absorber (Iron Wall)

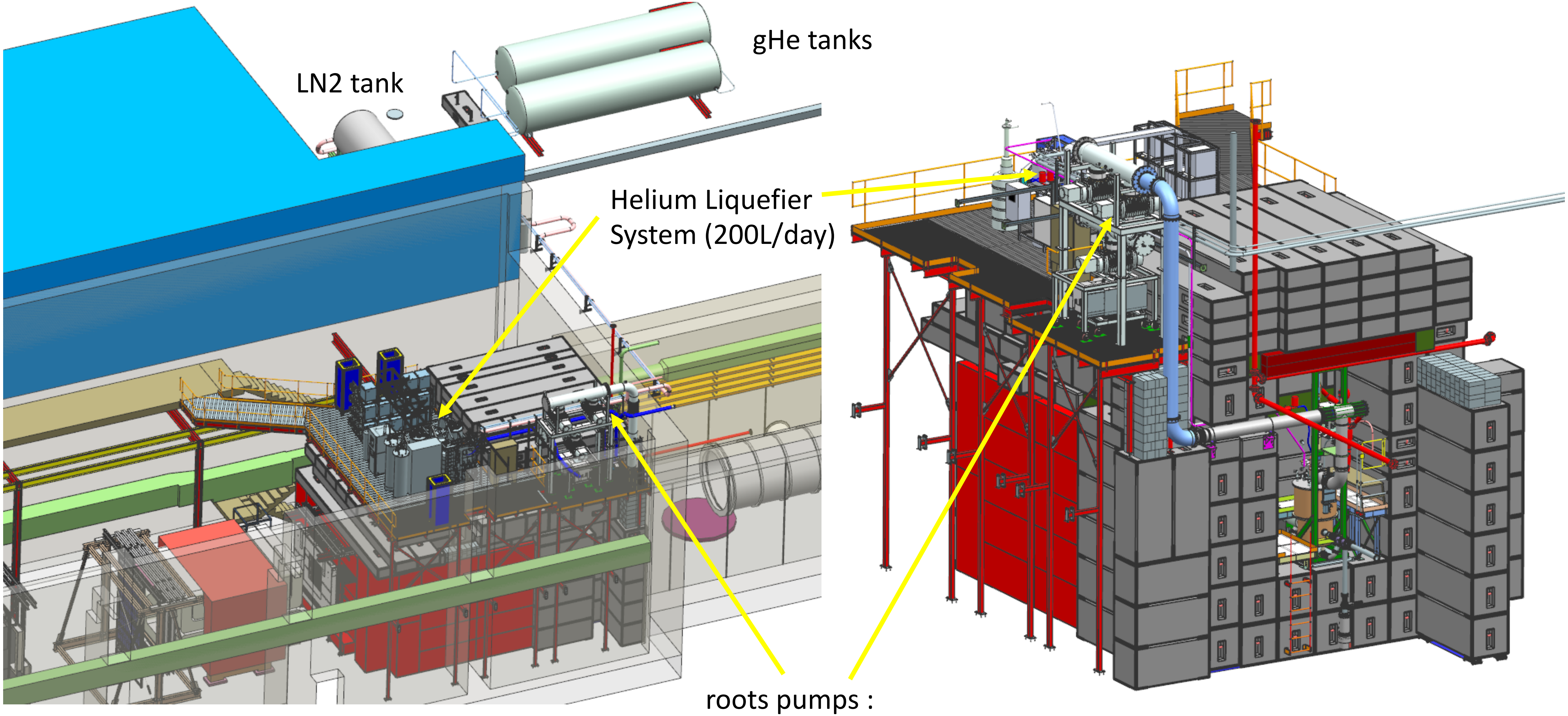
Drawing: T. O'Connor and K. Bailey

See talks by
Eric Fuchey (GPU based OR)
Jordan Roberts (Online Monitoring & Visualization)



- Designed for high intensity proton beam ($5\times10^{12} protons/spill$ with 4.4s spill)
- 8 cm long solid NH_3 and ND_3 target cells
- Magnetic Field: B = 5 T with uniformity $dB/B < 10^{-4}$ over 8 cm
- ^{4}He evaporation refrigerator (3 W of maximum cooling power) keeping the target at 1.1 K.
- 140 GHz microwave source (with DNP technique)
- Helium Liquefier System (200 L/day) for sustainable cooling

SpinQuest / E1039 Experiment Setup



gHe tanks

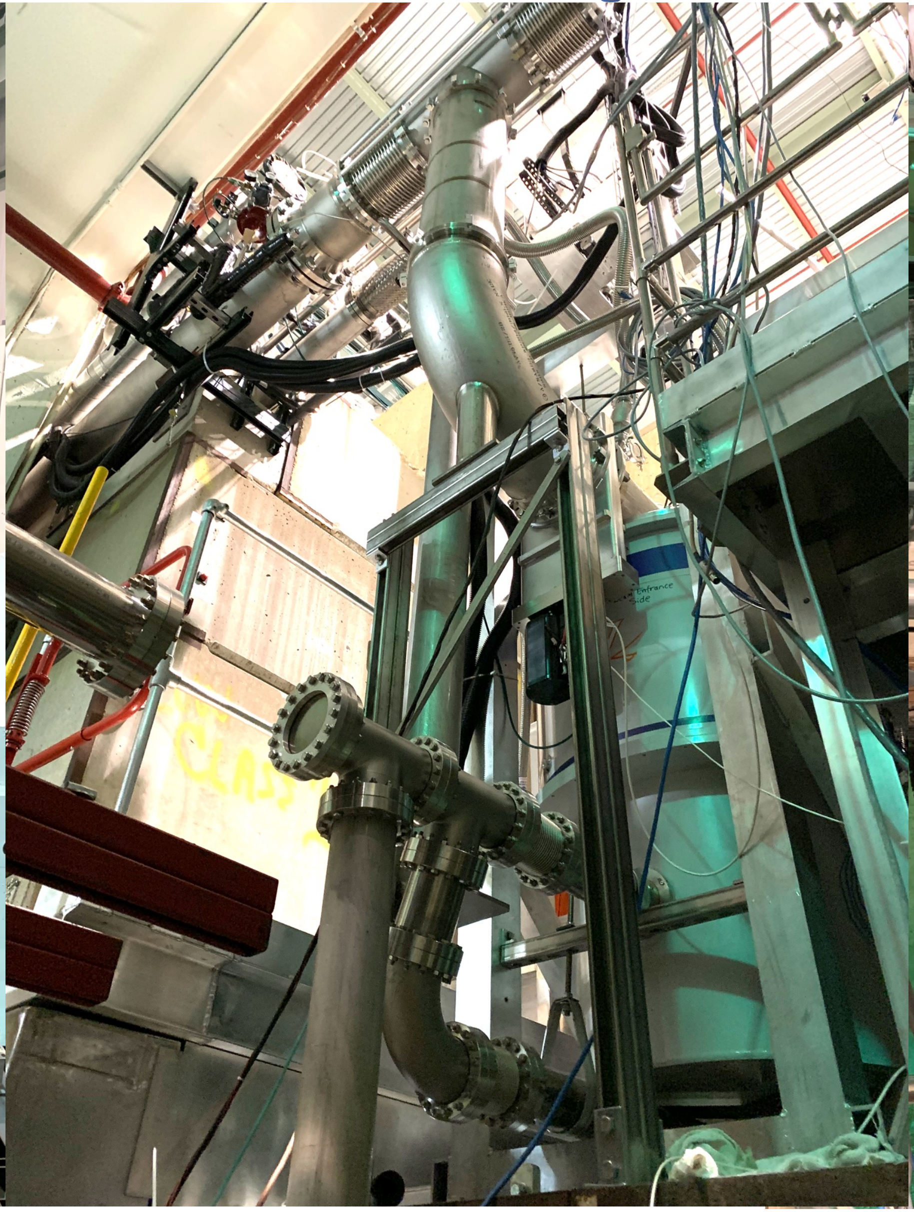
LN2 tank

Helium Liquefier
System (200L/day)

roots pumps :
pumping power 17K m^3 per hour

SpinQuest / E1039 Experiment Setup

From beam down-stream

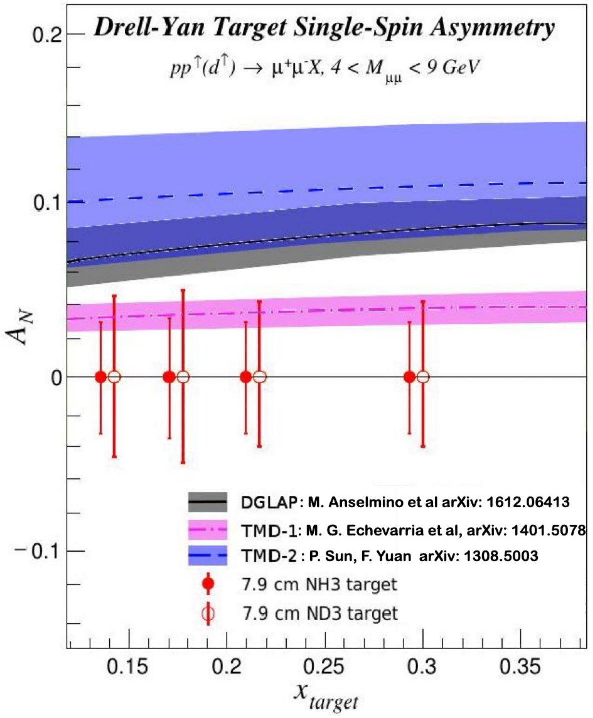


Beam-window and superconducting magnet

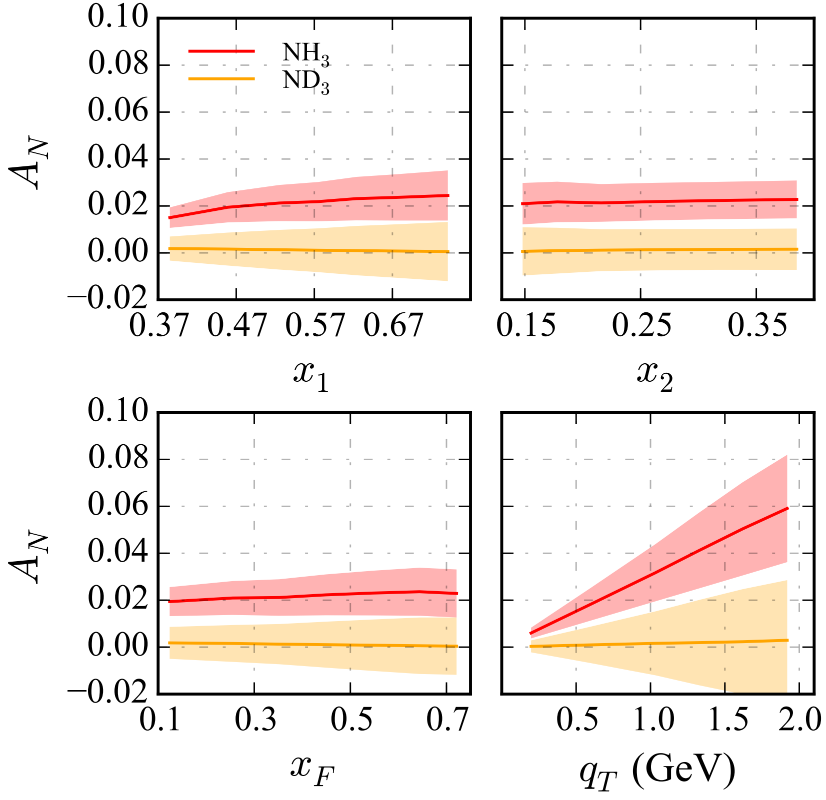
From target cave to beam-upstream

Predicted Uncertainties

- Beam (∽ 2.5%)
  - Relative luminosity
  - Drifts
  - Scraping
- Analysis sources (< 3.5%)
  - Tracking efficiency
  - Trigger & geometrical acceptance
  - Mixed background
  - Shape of DY
- Target (< 6 %)
  - TE calibration
  - Polarization inhomogeneity
  - Density of target ($NH_{3(s)}$)
  - Uneven radiation damage
  - Beam-Target misalignment
  - Packing fraction
  - Dilution factor



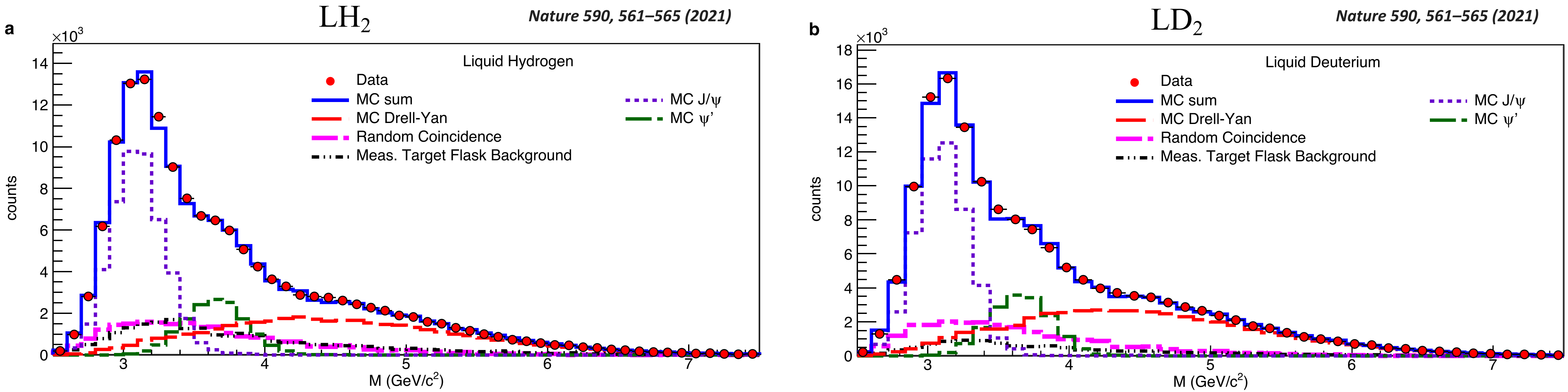
I. P. Fernando and D. Keller
Phys. Rev. D 108, 054007 (2023)



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

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%

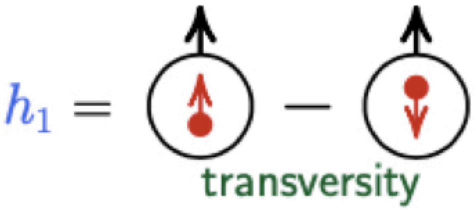
Goodness of event-reconstruction from E906



- Monte-Carlo describe data well
- Better resolution than expected
  - $\delta\sigma_M(J/\psi)$ ~ 220 MeV
  - $\delta\sigma_M(DY)$ ~ truth-reconstructed from event-by-event MC
  - J/ψ and ψ' separation

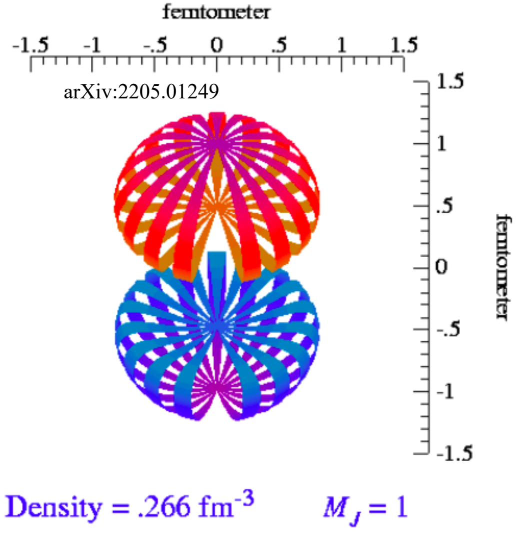
The projected event selection/reconstruction is expected to be the same for E1039

Future: Transversity distributions

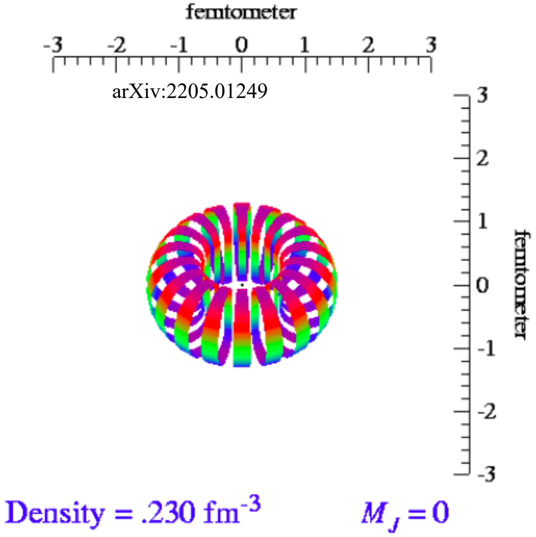


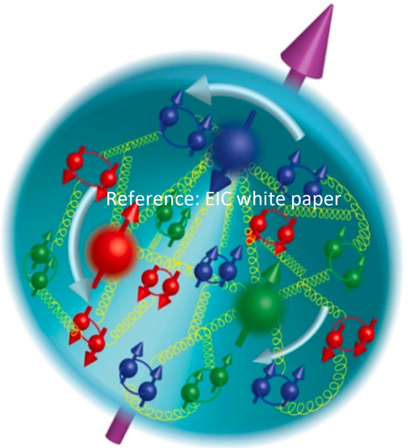
Distribution of transversely polarized quarks (or gluons) in a transversely polarized nucleon.

Sea-quark Transversity in the Deuteron



Gluon Transversity in the Deuteron





https://arxiv.org/abs/2205.01249

https://doi.org/10.1016/j.nima.2020.164504

- ➢ The deuteron is the simplest spin-1 system and offers a vast array of observables to explore as we begin to build the composite spin picture of nuclei.
- ➢ We proposed the first ever Spin-1 TMD measurements using a polarized deuteron target, including a direct measurement of gluon transversity, while also for the first time measuring the sea-quark transversity distribution of the deuteron/neutron.
- ➢ In combination with our Dark Sector program, we are awaiting Fermilab PAC's Stage-1 approval.

SpinQuest Status / E1039 Timeline

- 2018, March: DOE approval
- 2018, May: Fermilab stage-2 approval
- 2018, June: E906 decommissioned
- 2019, May: Transferred the polarized target from UVA to Fermilab
- 2023 All components of the detector and the target system are fully commissioned without the polarized target material…
  * Polarized target material (NH_3/ND_3) is presently under FNAL ES&H as well as Rad Safety Review.
- SpinQuest will be the first 1 K and high intensity polarized target experiment at Fermilab.
- FNAL ES&H is in contact with JLab regarding the rad safety aspects of NH_3/ND_3 in the material handling procedures.

SpinQuest / E1039 Timeline

- Polarized target commissioning with NH3/ND3 target material will be expected to complete by the beginning of November 2023
- E1039 first beam commissioning starts in mid-November 2023 [Run for 2+ years, 2023-2025+]
- 2026: Data taking with Transversely polarized Spin 1 targets.

A summarized form of DY Experiments

Experiment	Particles	Energy (GeV)	x_b or x_t	Luminosity $(cm^{-2}s^{-1})$	$A_T^{sin\emptyset_s}$	P_b or P_t (f)	$rFOM^\#$	Timeline
COMPASS (CERN)	$\pi^- + p^\uparrow$	190 $\sqrt{s} = 17.4$	$x_t = 0.1 - 0.3$	2×10^{33}	0.14	$P_t = 90\%$ f=0.22	1.1×10^{-3}	2015-2016, 2018
PANDA (GSI)	$\bar{p} + p^\uparrow$	15 $\sqrt{s} = 5.5$	$x_t = 0.2 - 0.4$	2×10^{32}	0.07	$P_t = 90\%$ f=0.22	1.1×10^{-4}	>2020
PAX (GSI)	$p^\uparrow + \bar{p}$	Collider $\sqrt{s} = 14$	$x_b = 0.1 - 0.9$	2×10^{30}	0.06	$P_b = 90\%$	2.3×10^{-5}	>2022
NICA (JINR)	$p^\uparrow + p$	Collider $\sqrt{s} = 20$	$x_b = 0.1 - 0.8$	1×10^{31}	0.04	$P_b = 70\%$	6.8×10^{-5}	>2020
PHENIX/STAR (RHIC)	$p^\uparrow + p^\uparrow$	Collider $\sqrt{s} = 510$	$x_b = 0.05 - 0.1$	2×10^{32}	0.08	$P_b = 60\%$	1.0×10^{-3}	>2018
sPHENIX (RHIC)	$p^\uparrow + p^\uparrow$	$\sqrt{s} = 200$ $\sqrt{s} = 510$	$x_b = 0.1 - 0.5$ $x_b = 0.05 - 0.6$	8×10^{31} 6×10^{32}	0.08	$P_b = 60\%$ $P_b = 50\%$	4.0×10^{-4} 2.1×10^{-3}	>2021
SeaQuest (FNAL: E-906)	$p + p$	120 $\sqrt{s} = 15$	$x_t = 0.1 - 0.45$ $x_b = 0.35 - 0.85$	3.4×10^{35}	…..	…..	……	2012-2017
SpinQuest ‡ (FNAL: E-1039)	$p + p^\uparrow$	120 $\sqrt{s} = 15$	$x_t = 0.1 - 0.5$	4.4×10^{35}	0-0.2*	$P_t = 85\%$ f=0.176	0.15 or 0.09	2024-2025
SpinQuest #(Transversity)	$p^\uparrow + p$	120 $\sqrt{s} = 15$	$x_b = 0.1 - 0.5$	4.4×10^{35}	0-0.2*	$P_b = 85\%$ f=0.176	0.15 or 0.09	2026-2029

‡ 8 cm NH_3 target / $L = 1 \times 10^{36} cm^{-2}s^{-1}$, #(Tensor Polarized Spin-1 target) / $L = 1 \times 10^{36} cm^{-2}s^{-1}$

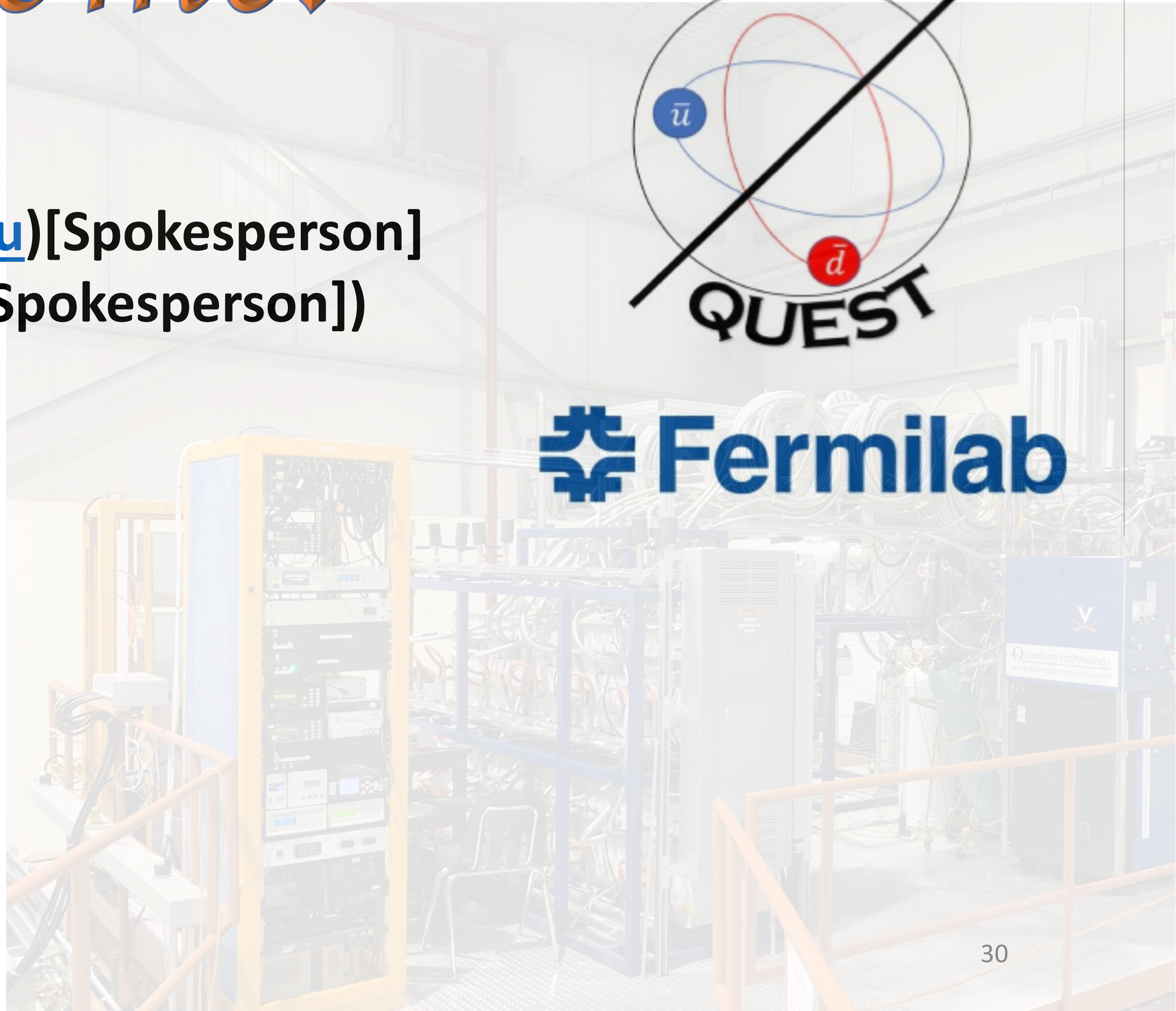
*Not constrained by SIDIS data / #rFOM = relative lumi * P^2 * f^2 w.r.t E-1027 (f=1 for pol. P beams, f=0.02 for π^- beam on NH_3)

Welcome!

Please Join The Effort
Dustin Keller [UVA] (dustin@virginia.edu)[Spokesperson]
Kun Liu [LANL] (liuk.pku@gmail.com) ([Spokesperson])

https://spinquest.fnal.gov/

http://twist.phys.virginia.edu/E1039/



Thank you

SPIN QUEST

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