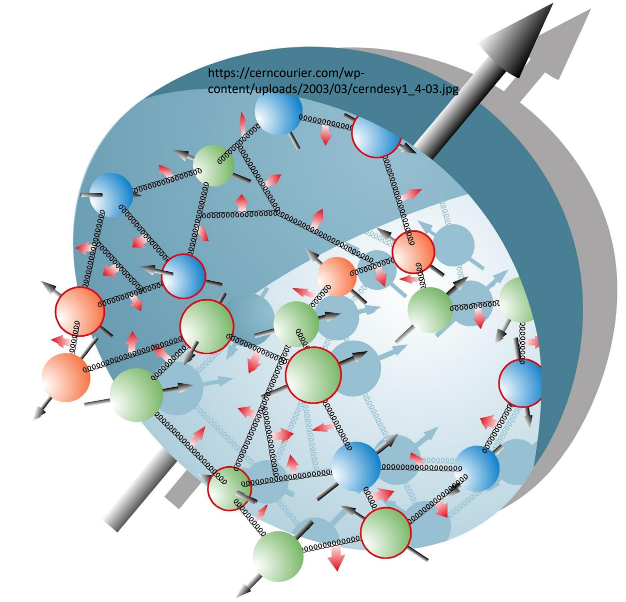
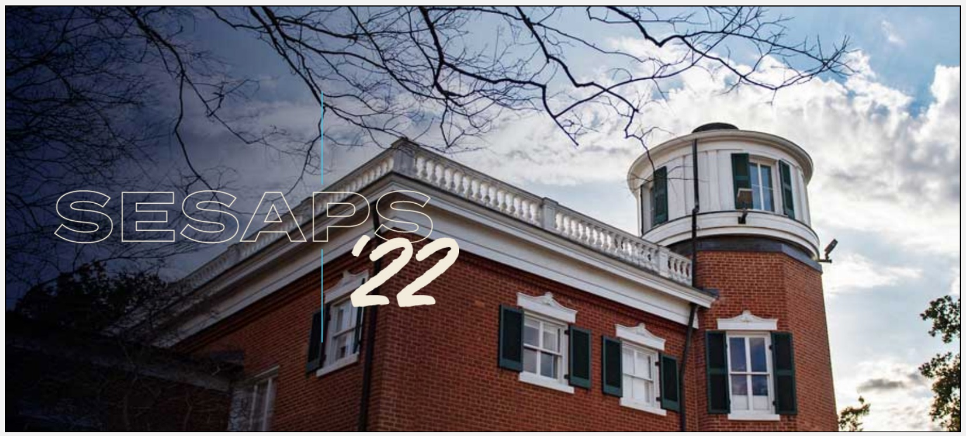
The SpinQuest (E1039) Experiment: Probing the sea-quarks' Sivers asymmetry





Ishara Fernando

For the SpinQuest Collaboration

SPIN QUEST

Fermilab

UNIVERSITY of VIRGINIA

UVA - Spin
PHYSICS GROUP

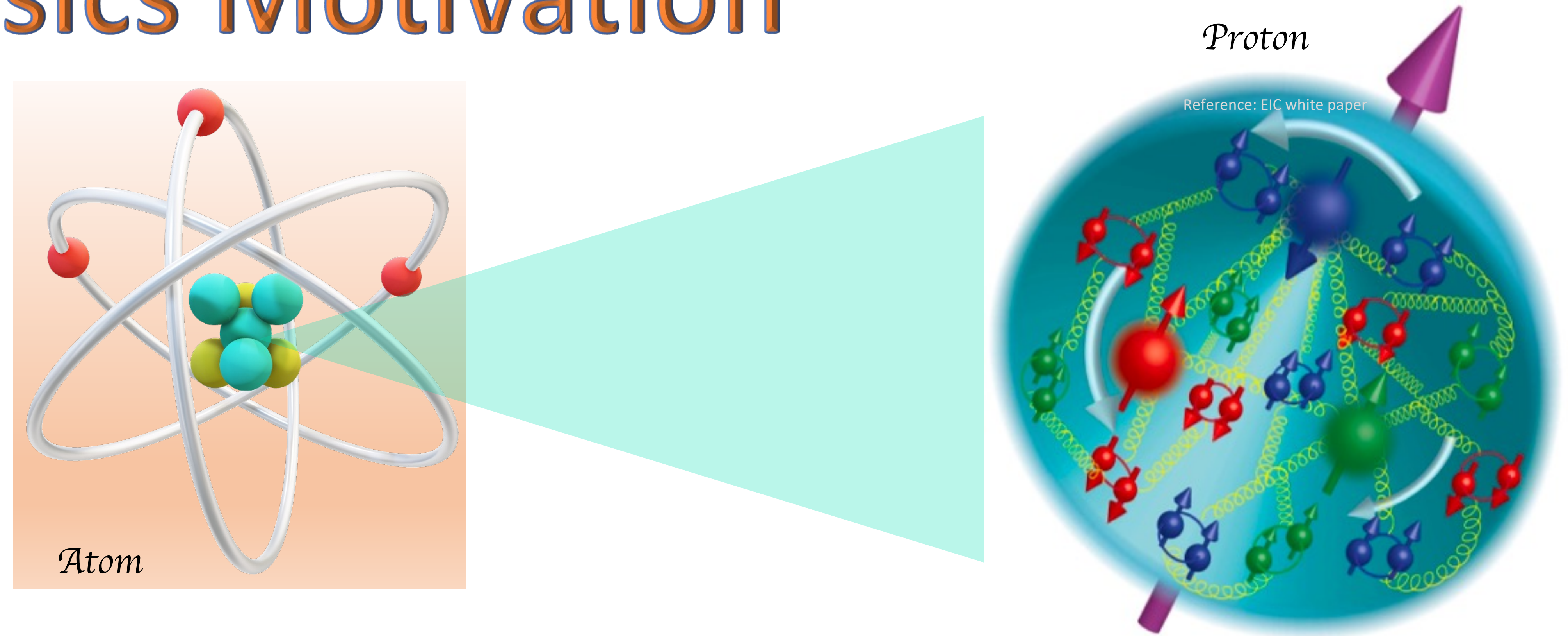
U.S. DEPARTMENT OF ENERGY | Office of Science

This work is supported by DOE contract DE-FG02-96ER40950

Outline

- 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
- SpinQuest / E1039 Goals

Physics Motivation



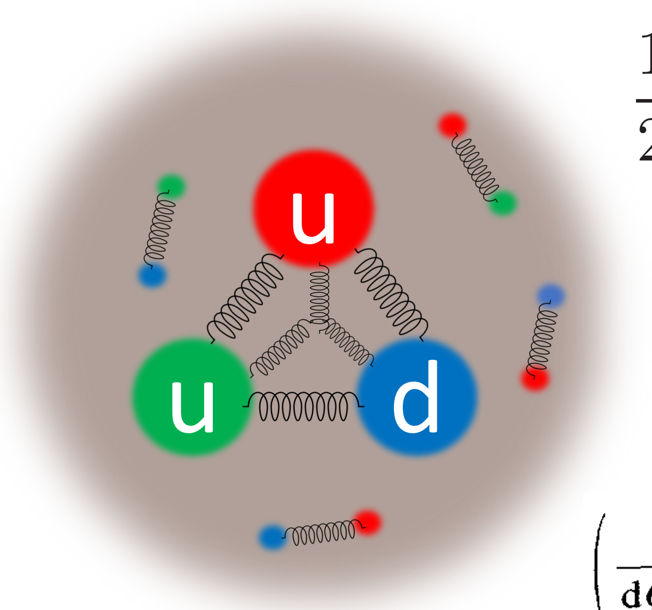
Proton Spin (1/2) = Valence quarks' (intrinsic) Spin + Sea quarks' (intrinsic) Spin + Valence quarks' OAM + Sea quarks' OAM + Gluons (intrinsic) Spin + Gluons OAM

(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

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

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

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

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

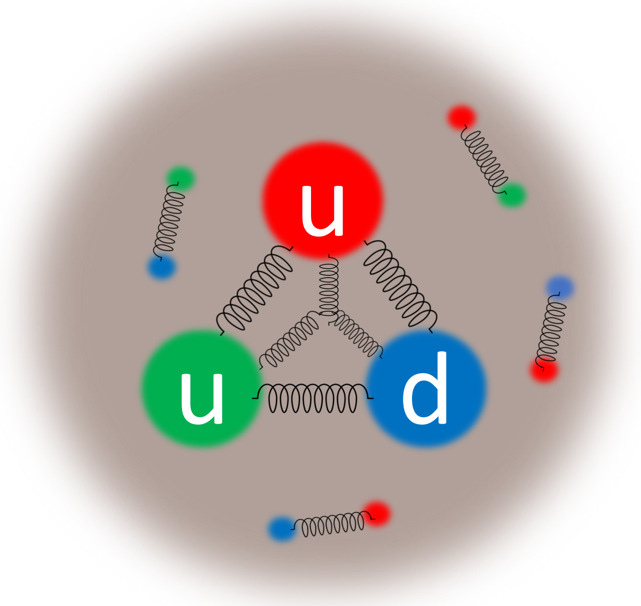
$$\int_0^1 g_1^p\,dx = \boxed{0.126} \pm 0.010 \pm 0.015$$

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

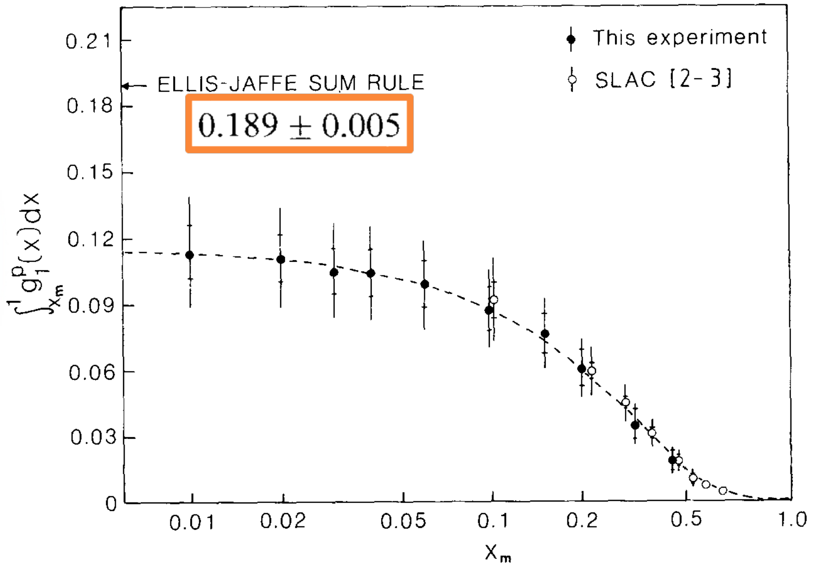
Nuclear Physics B328 (1989) 1–35

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

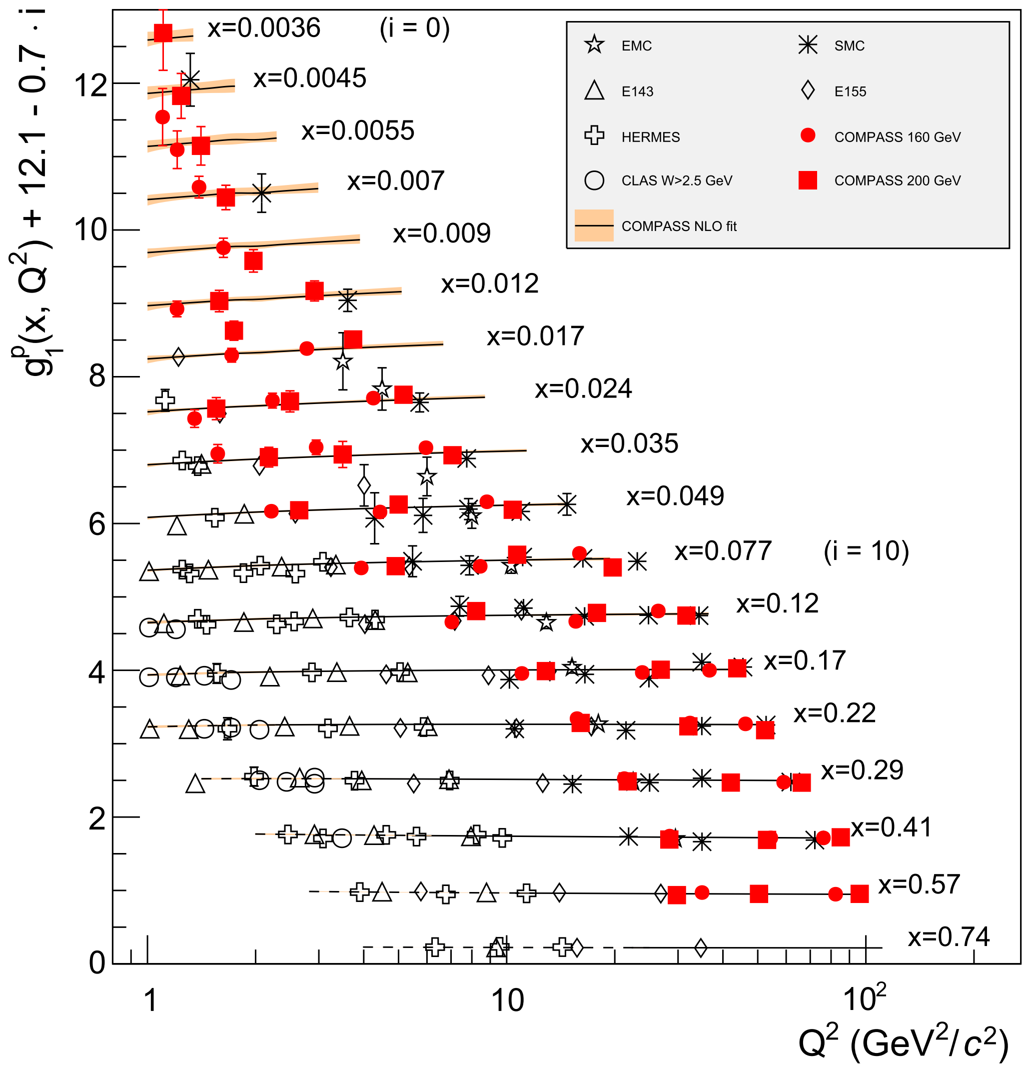
Physics Motivation



Nuclear Physics B328 (1989) 1–35



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



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

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

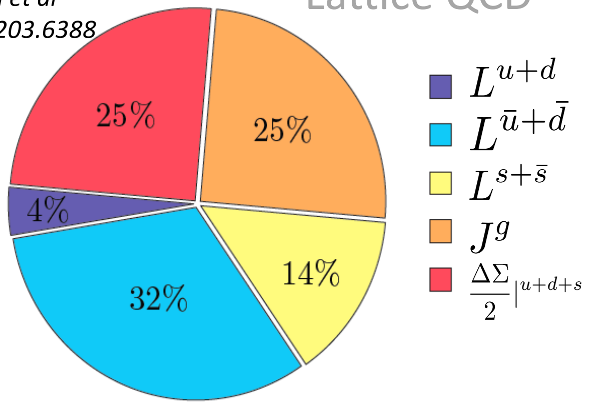
$$\langle S_z \rangle_{\text{sea}} = -0.475 \pm 0.080 \pm 0.115$$

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

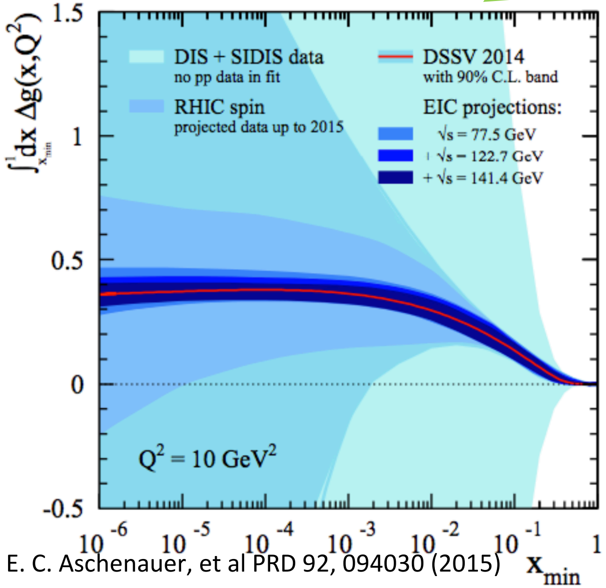
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_g + L_q + L_{\bar{q}}$$

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

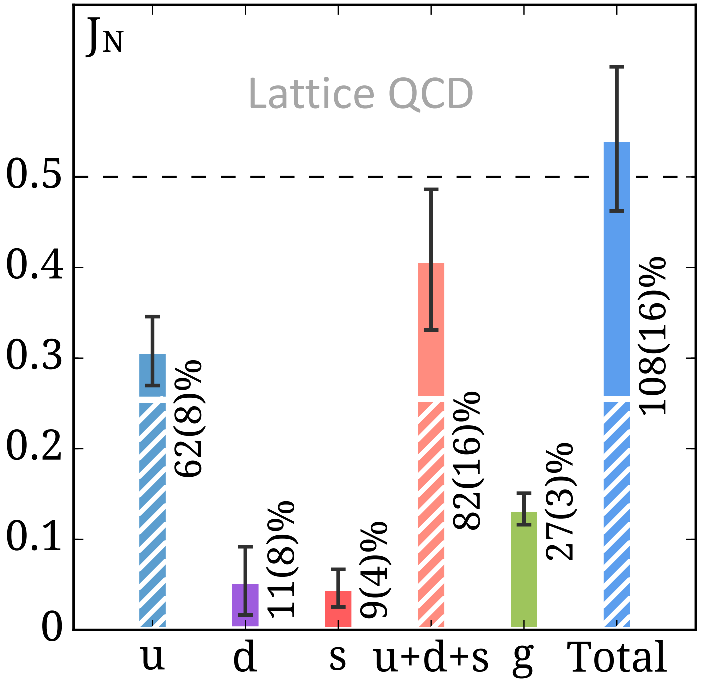


E. C. Aschenauer, et al PRD 92, 094030 (2015)

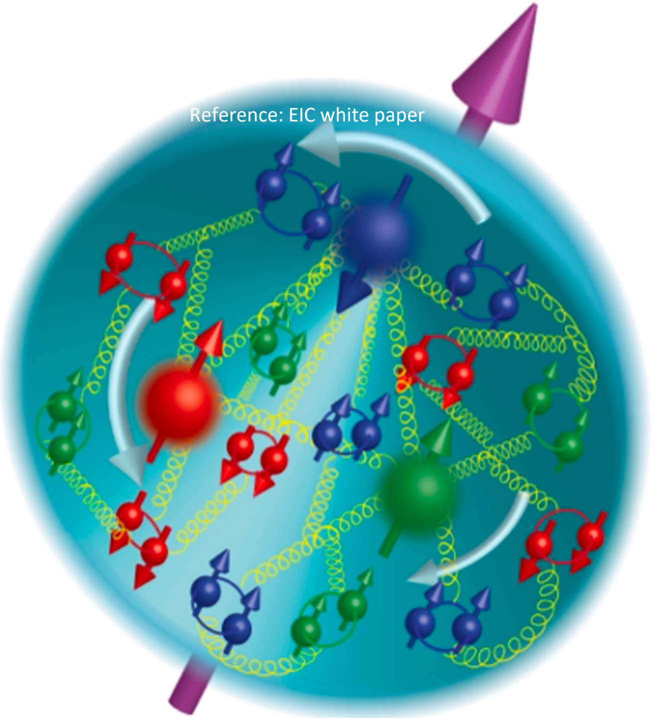
	$\frac{1}{2}\Delta\Sigma$	J	L	$\langle x \rangle$
u	0.415(13)(2)	0.308(30)(24)	-0.107(32)(24)	0.453(57)(48)
d	-0.193(8)(3)	0.054(29)(24)	0.247(30)(24)	0.259(57)(47)
s	-0.021(5)(1)	0.046(21)(0)	0.067(21)(1)	0.092(41)(0)
g	-	0.133(11)(14)	-	0.267(22)(27)
tot.	0.201(17)(5)	0.541(62)(49)	0.207(64)(45)	1.07(12)(10)

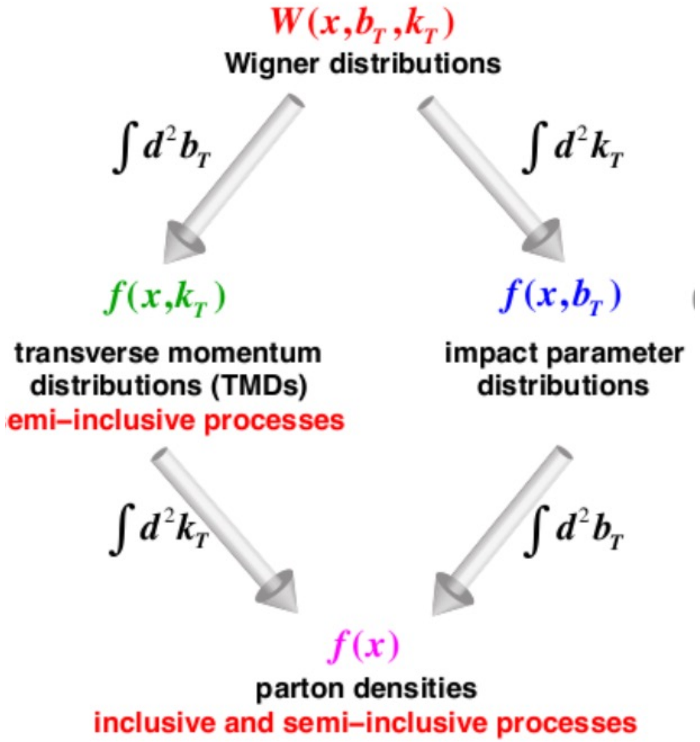
C. Alexandrou et al PRL 119, 142002 (2017)

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



TMD PDFs





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

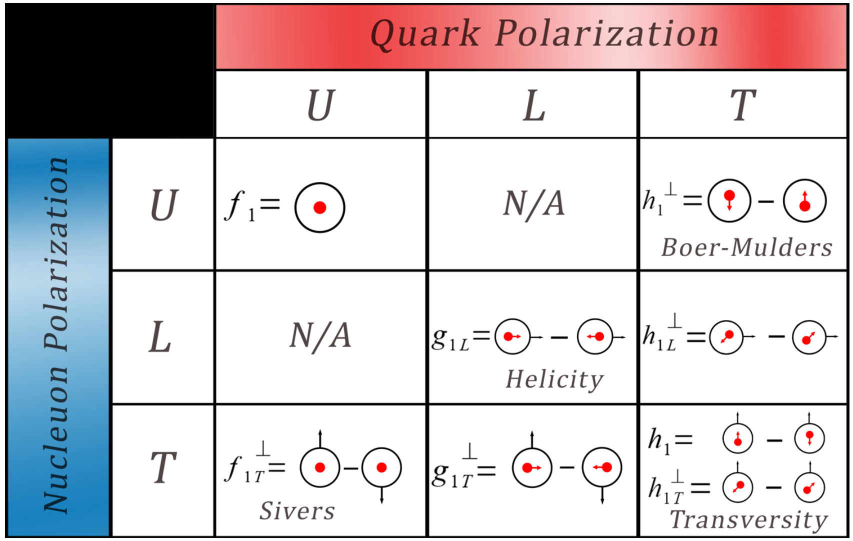
$$\vec{L} = \vec{r} \times \vec{p}$$

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



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

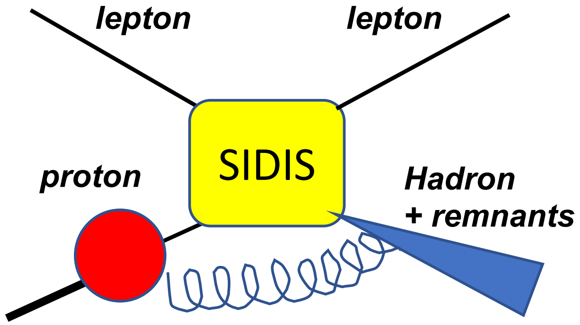
Quark correlator can be decomposed into 8 components
(6 T -even and 2 T -odd terms) at leading-twist

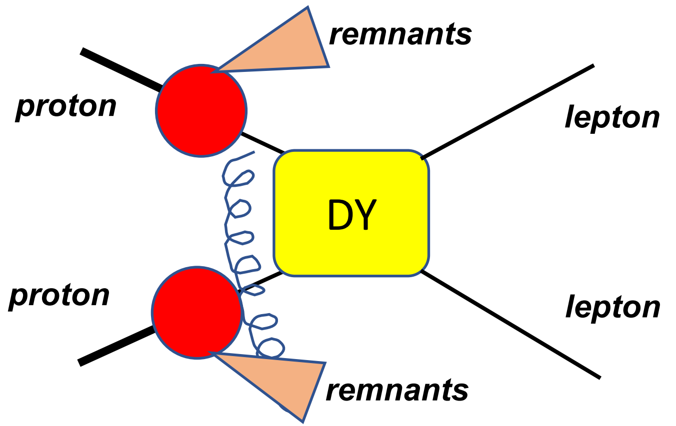
$$\Phi(x, k_T, P, S) = f_1(x, k_T^2)\frac{\not{P}}{2} + \frac{h_{1T}(x, k_T^2)}{4}\gamma_5[\not{S}_T, \not{P}] + \frac{S_L}{2} g_{1L}(x, k_T^2)\gamma_5 \not{P} + \frac{k_T.S_T}{2M} g_{1T}(x, k_T^2)\gamma_5 \not{P}$$
$$+ S_L h_{1L}^\perp(x, k_T^2)\gamma_5 \frac{[\not{k}_T, \not{P}]}{4M} + \frac{k_T.S_T}{2M}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

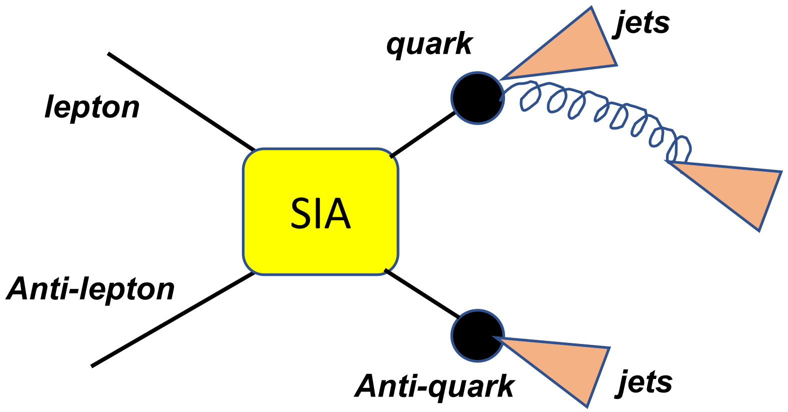
T-even

$$+ i h_1^\perp(x, k_T^2)\frac{[\not{k}_T, \not{P}]}{4M} - \frac{\epsilon_T^{k_T S_T}}{4M} f_{1T}^\perp(x, k_T^2)\not{P}$$

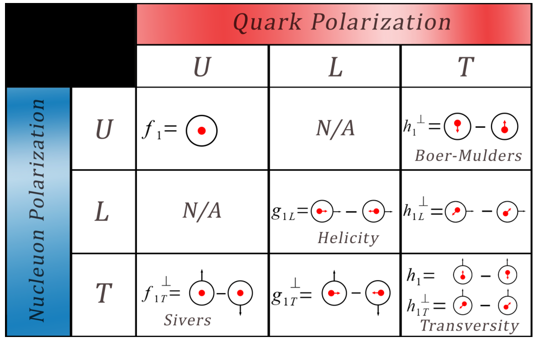
T-odd



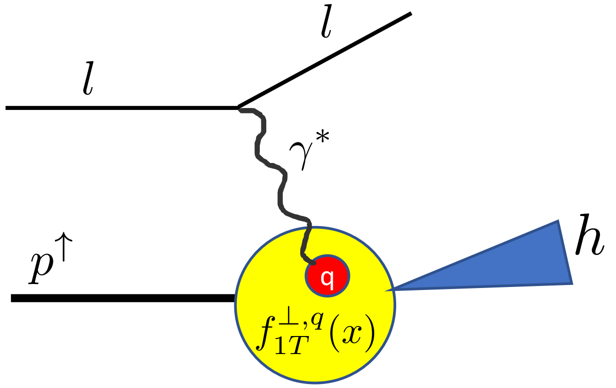




TMD PDFs

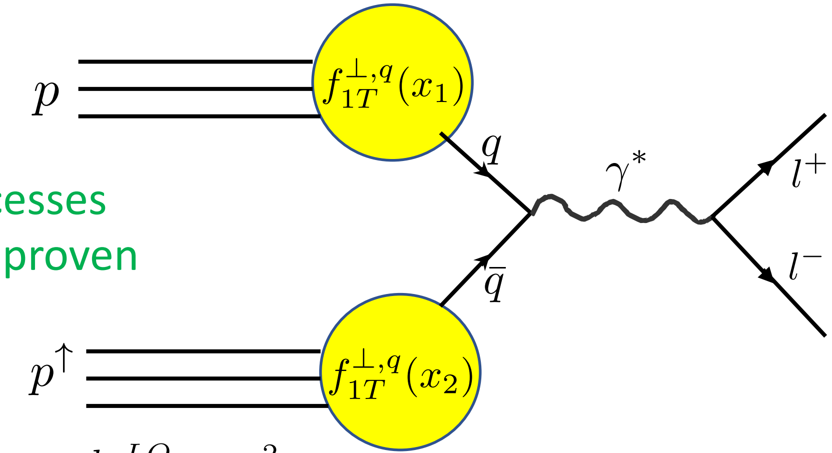


Polarized Semi Inclusive DIS



* For these two processes TMD factorization is proven

Polarized DY



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

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

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

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

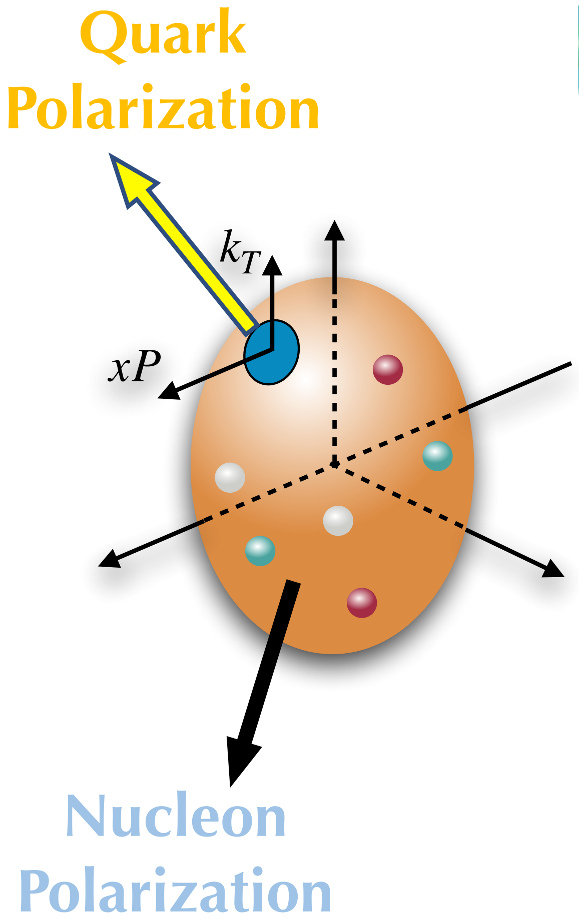
$$h_1^{\perp q}\Big|_{SIDIS} = -h_1^{\perp q}\Big|_{DY}$$
$$f_{1T}^{\perp q}\Big|_{SIDIS} = -f_{1T}^{\perp q}\Big|_{DY}$$

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

Sivers Function

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

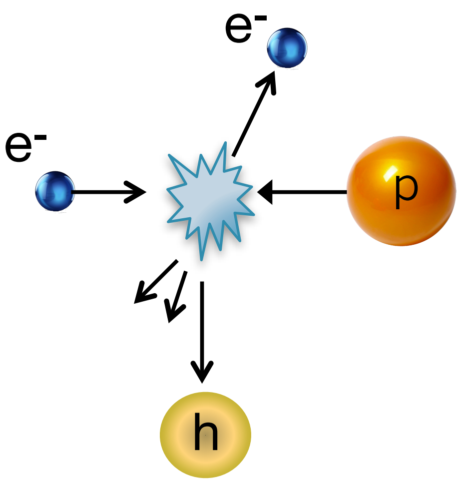
The Sivers function describes the correlation between the momentum direction of the struck quark and the spin of its parent nucleon.



Pic.. Courtesy: Alexei Prokudin

Semi-Inclusive DIS

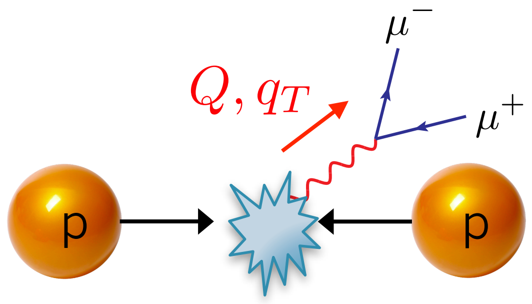
$$\sigma \sim f_{q/P}(x,k_T)D_{h/q}(z,k_T)$$



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

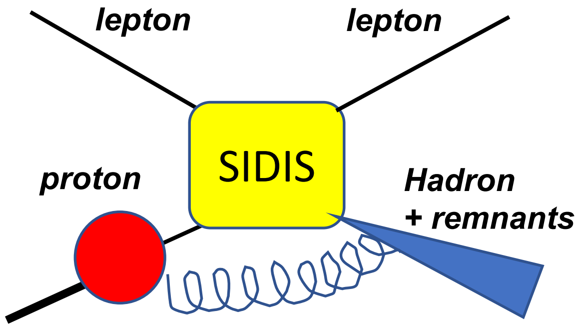
Collins, Soper, Sterman (1985)
Ji, Ma, Yuan (2004)
Collins (2011)

Pic.. Courtesy: Alexei Prokudin

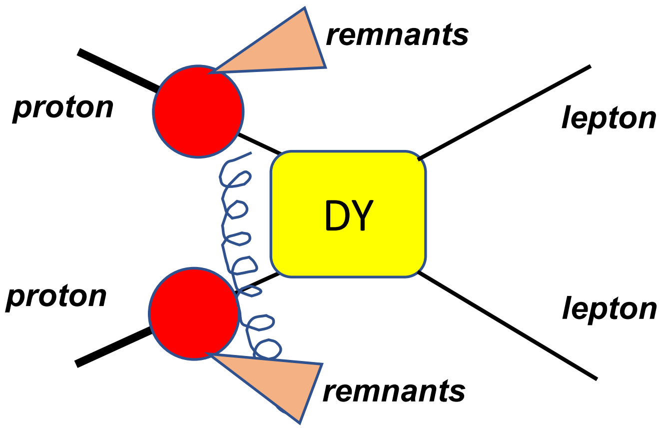
Sivers Function

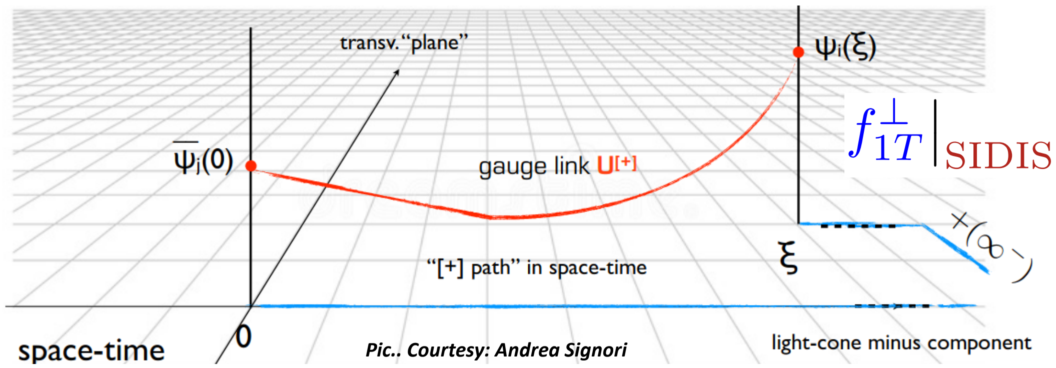
$$f_{q/p^{\uparrow}}(x,\mathbf{k_T}) = f_{q/p}(x,\mathbf{k_T}) + f_{1T}^{\perp}(x,\mathbf{k_T})\mathbf{S}.(\hat{\mathbf{P}} \times \hat{\mathbf{k_T}})$$

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

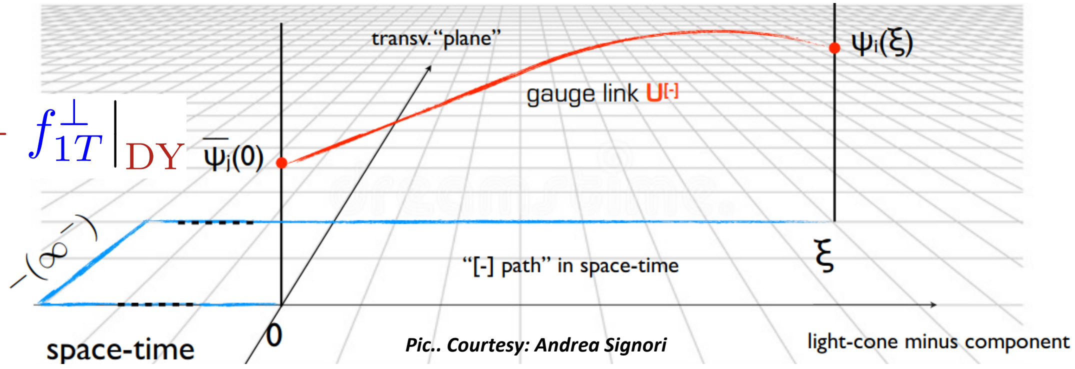


- The gauge-invariant definition of the Sivers function predicts the opposite sign for the Sivers function in SIDIS compared to processes with color charges in the initial state and a colorless final state in Drell-Yan, $J/\psi, W^{\pm}, Z$
- This inclusion of the gauge link has profound consequences on factorization proofs and on the concept of universality, which are of fundamental relevance for high-energy hadronic physics



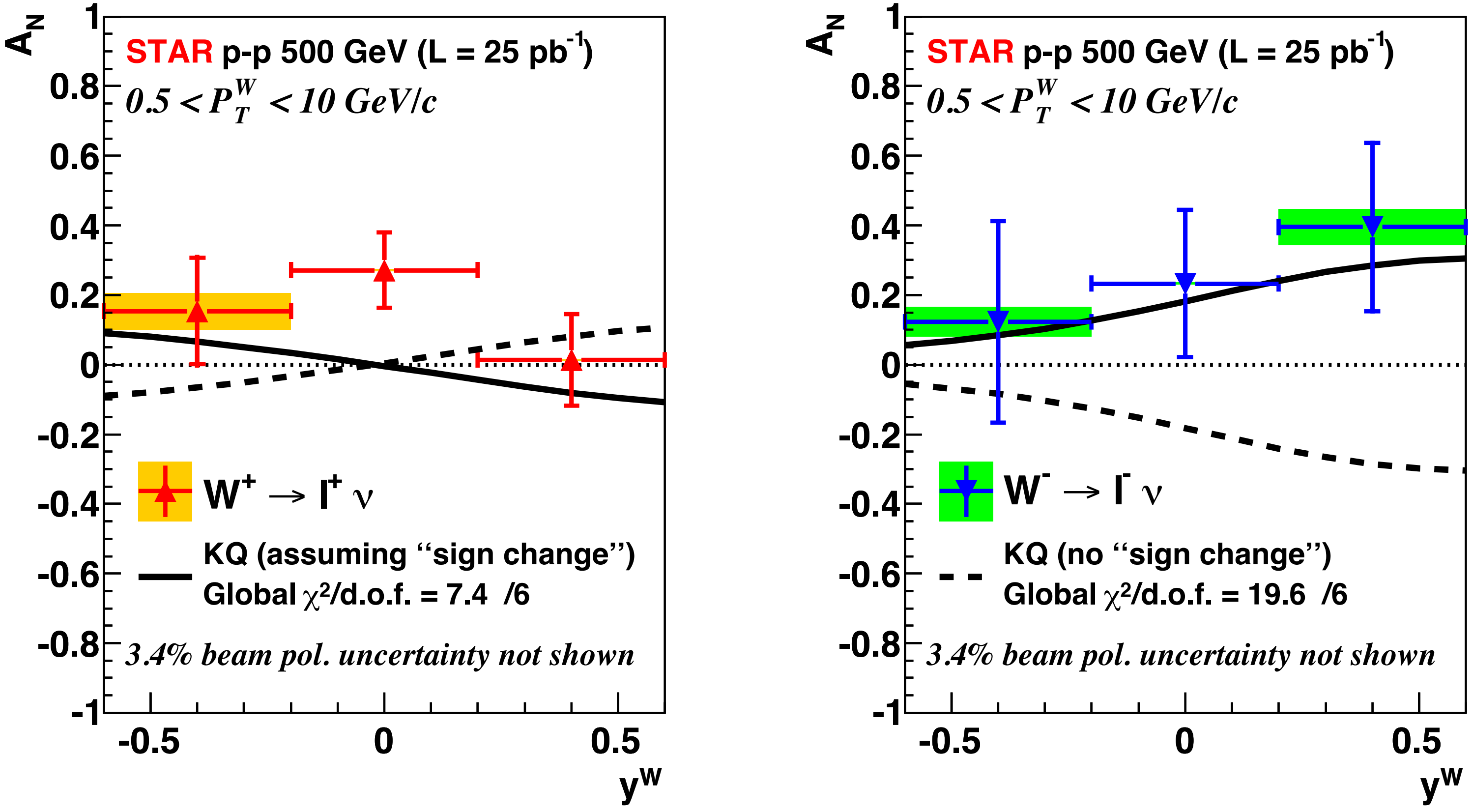


$$f_{1T}^{\perp}\big|_{\mathrm{SIDIS}} = - f_{1T}^{\perp}\big|_{\mathrm{DY}}$$

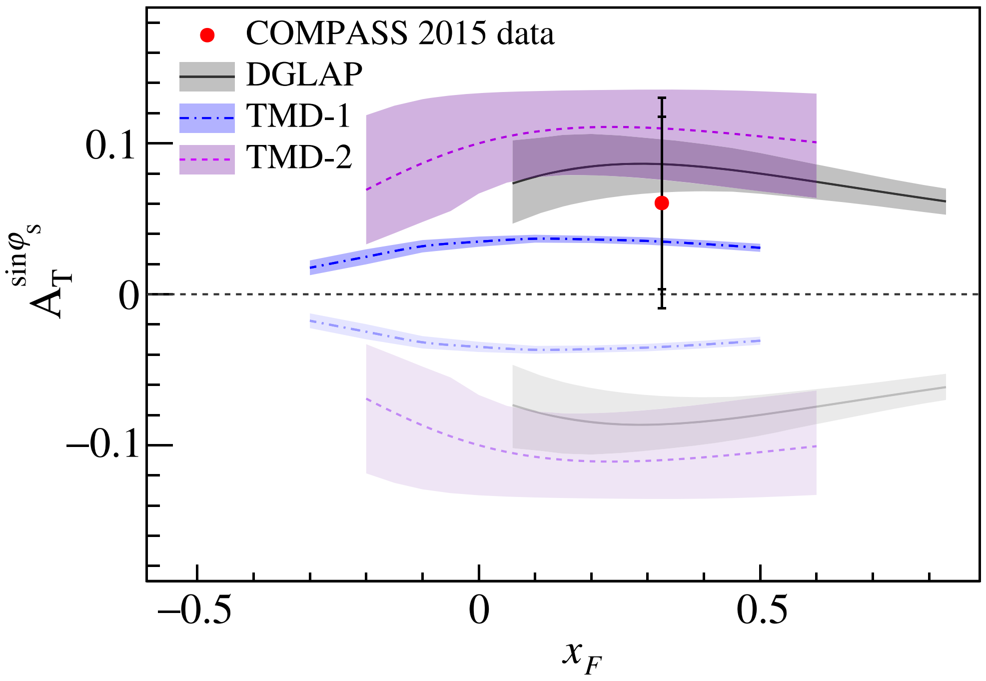


Sign of Sivers Functions

STAR Collaboration (PRL 116 132301 (2016))



COMPASS Collaboration (PRL 119 112002 (2017))

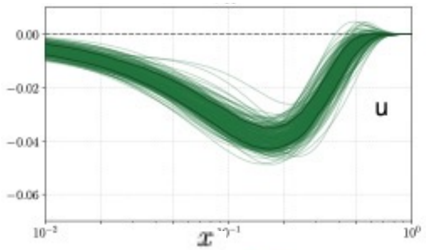


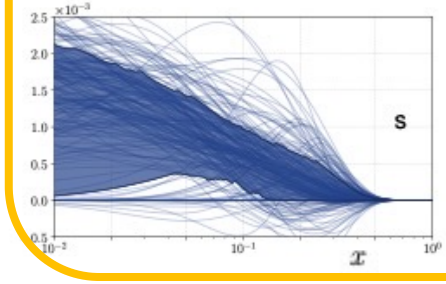
Dark Shaded (Light-shaded): with(without) "sign-change"

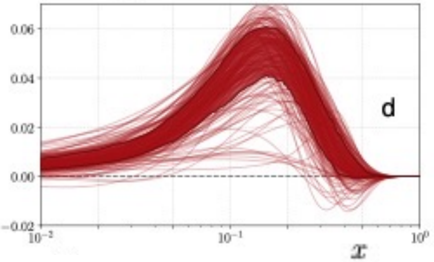
TSSA amplitude for W+/W- from STAR data is favors the "sign-change"
In DY relative to SIDIS (model based without TMD evolution)

Global analyses: Sivers functions

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

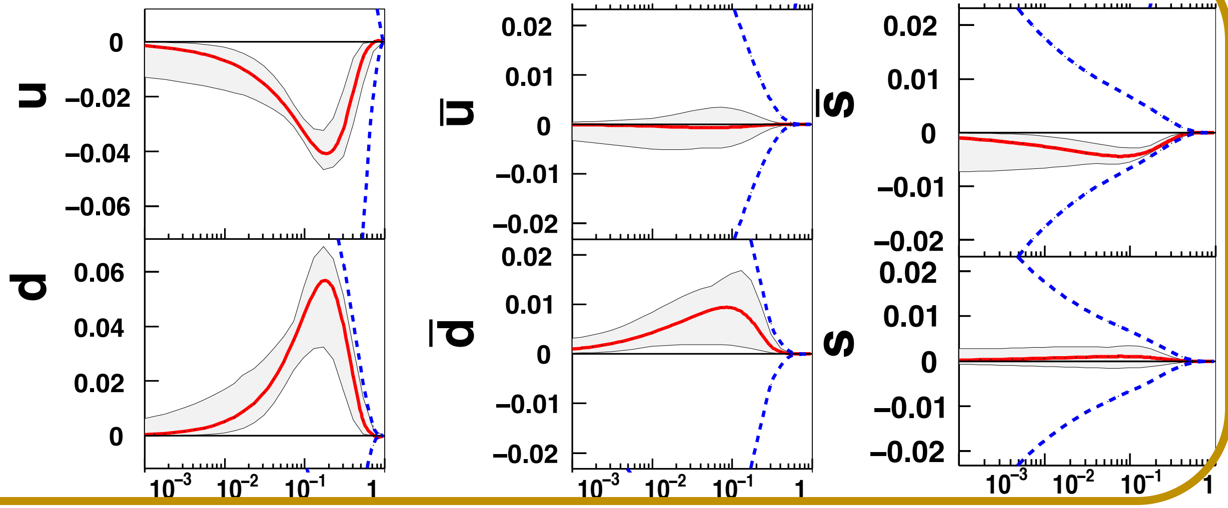




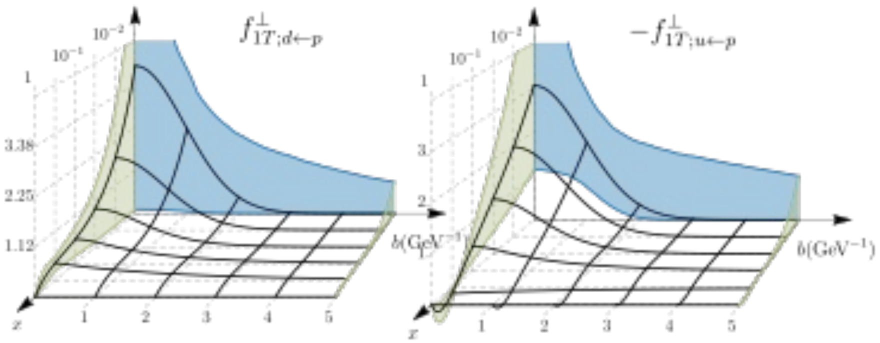


HERMES (2020)
COMPASS (2009)
COMPASS (2015)
JLab (2011)

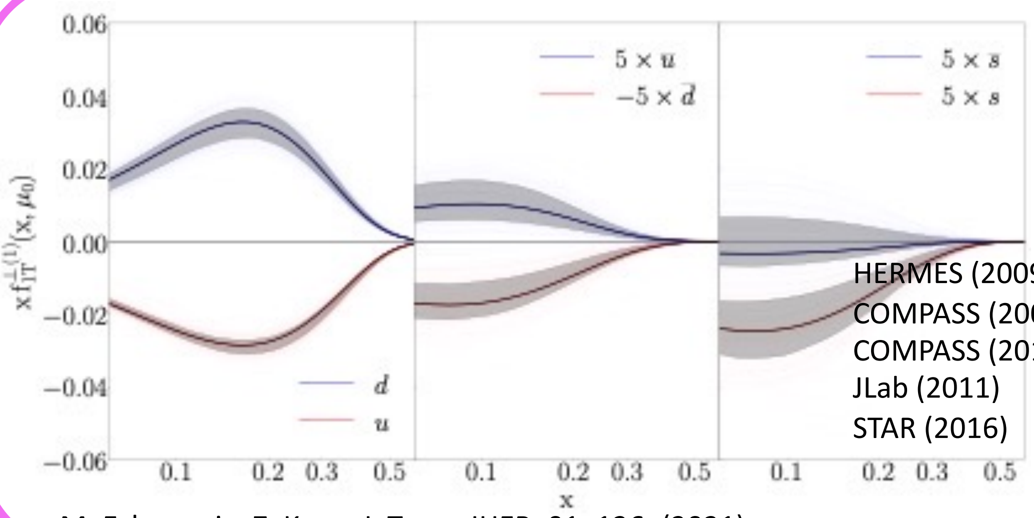
M. Anselmino, M. Boglion, U. D'Alesio, S. Melis, F. Murgia, A. Prokudin_PRD_79_54010_(2009)



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

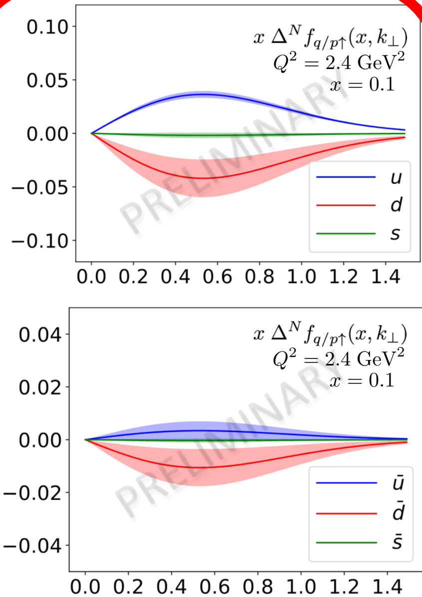


M. Bury, A. Prokudin , A. Vladimirov,, JHEP_05_151 (2021)



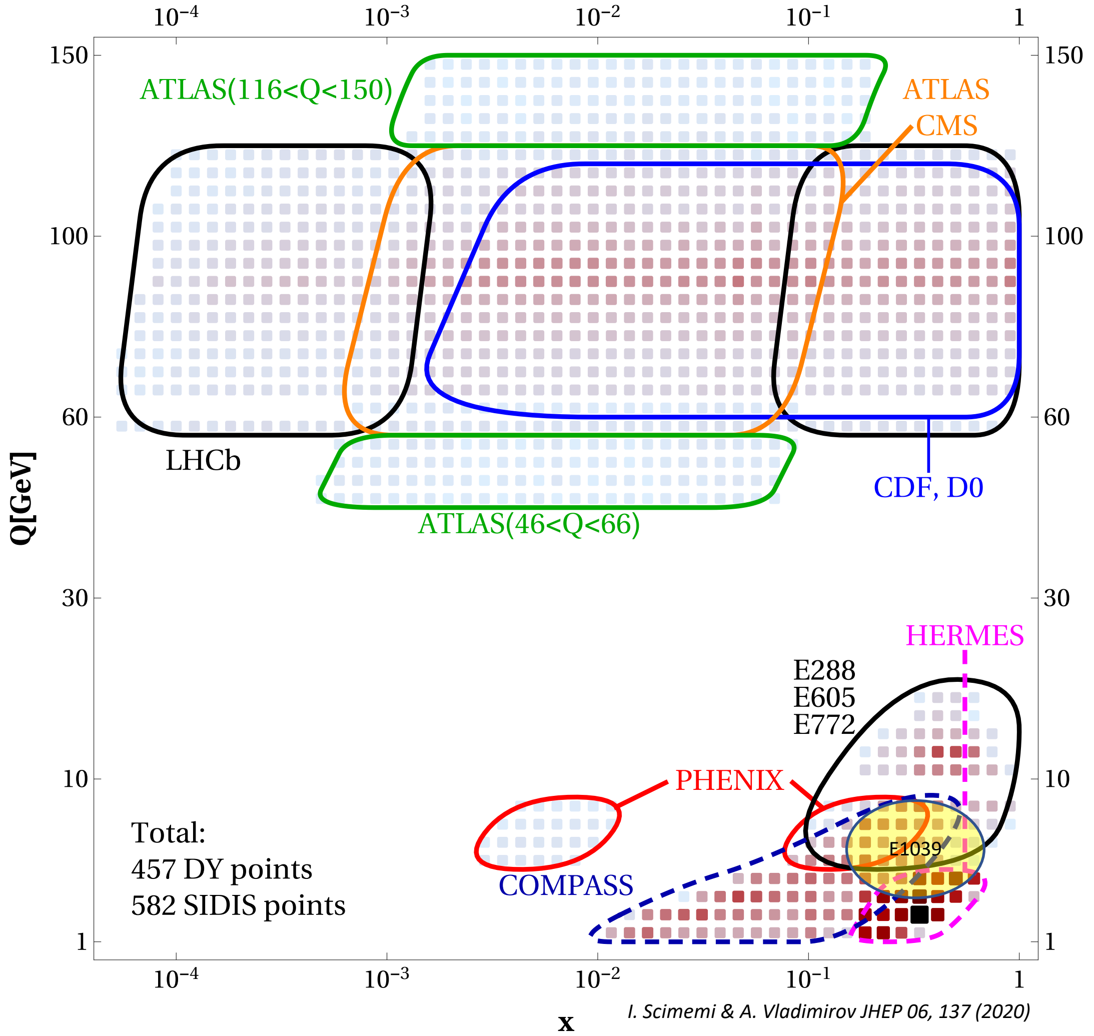
HERMES (2009)
COMPASS (2009)
COMPASS (2015)
JLab (2011)
STAR (2016)

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



I.P. Fernando & D. Keller (PRELIMINARY)
Using a Deep Neural Network

SpinQuest in the Global Context

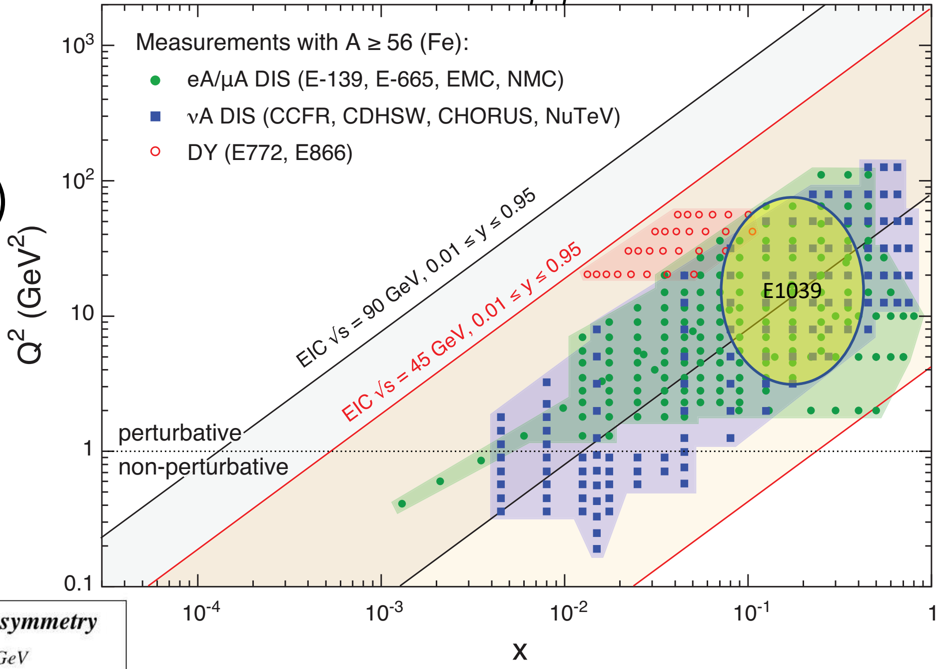


I. Scimemi & A. Vladimirov JHEP 06, 137 (2020)

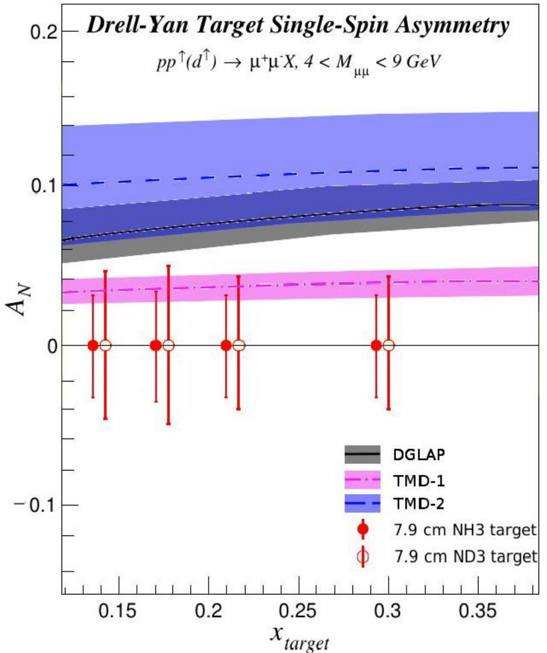
Drell-Yan measurements above the J/ψ peak fall in a unique region with Q^2 in the range of $16 < M^2 < 81$ GeV^2 and Q_T < few GeV

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.

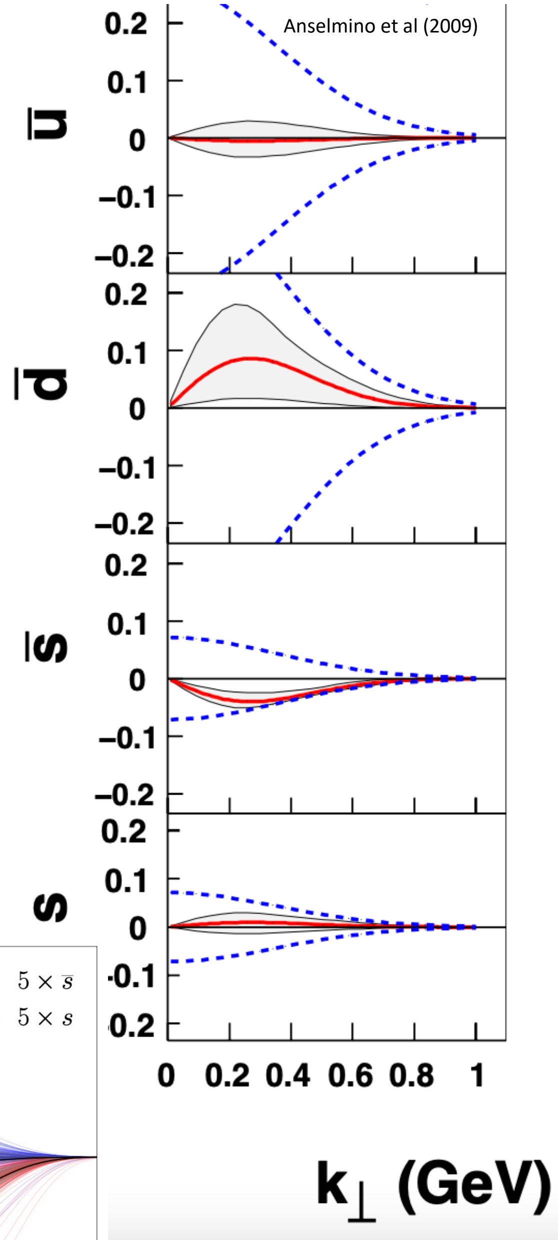
DGLAP: M. Anselmino et al arXiv:1612.06413
TMD-1: M. G. Echevarria et al arXiv:1401.5078
TMD-2: P. Sun and F. Yuan arXiv:1308.5003

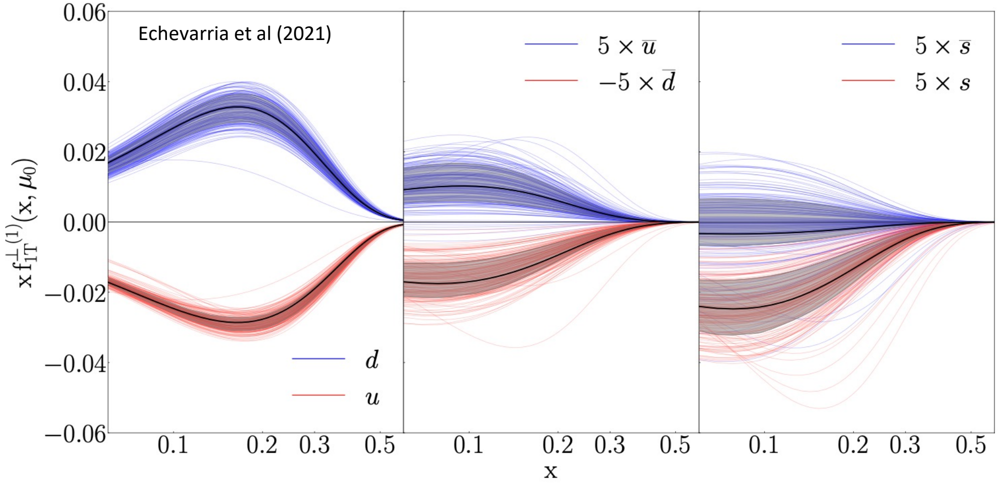
Sea-quarks Sivers functions

- 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.

- SpinQuest will perform the first measurement of the Sivers asymmetry in Drell-Yan proton-proton scattering (clean probe compared to the SIDIS process because there is no fragmentation associated with the process) from the sea quarks.

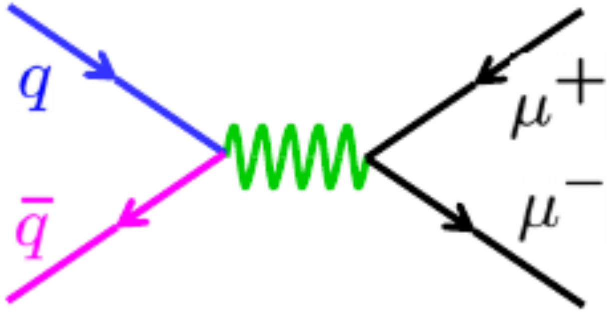




Polarized fixed target Drell-Yan : Sensitivity to sea-quarks

beam: valence quarks at high x

target: sea quarks at low/intermediate x

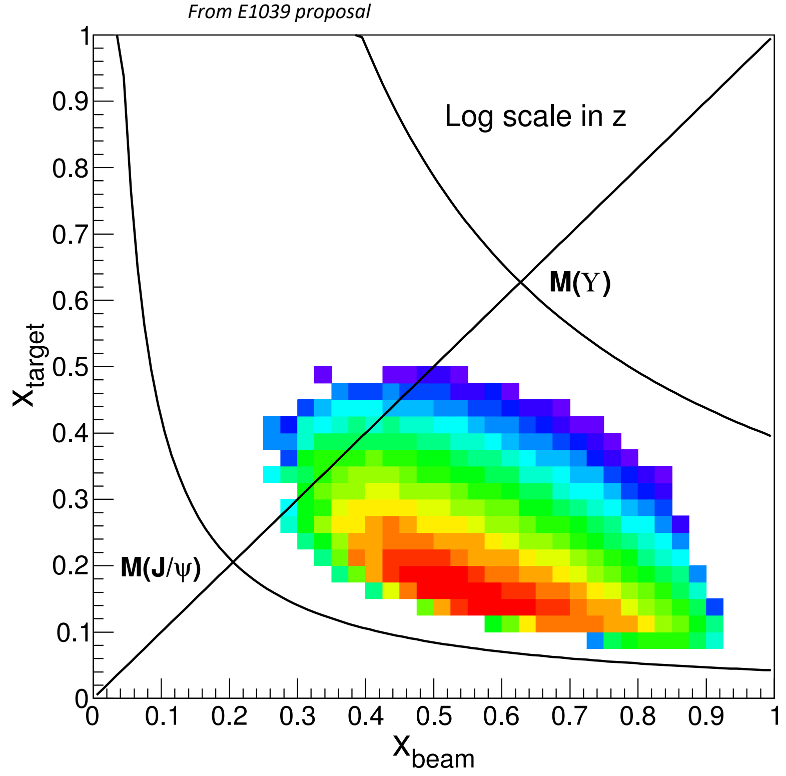


$$\frac{d^2\sigma}{dx_b dx_t} = \frac{4\pi\alpha^2}{x_b x_t s} \sum_{q\in\{u,d,s,\dots\}} e_q^2 [\bar{q}_t(x_t) q_b(x_b) + q_t(x_t)\bar{q}_b(x_b)]$$

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

acceptance limited
(Fixed Target, Hadron Beam)

Sea-quarks dominance

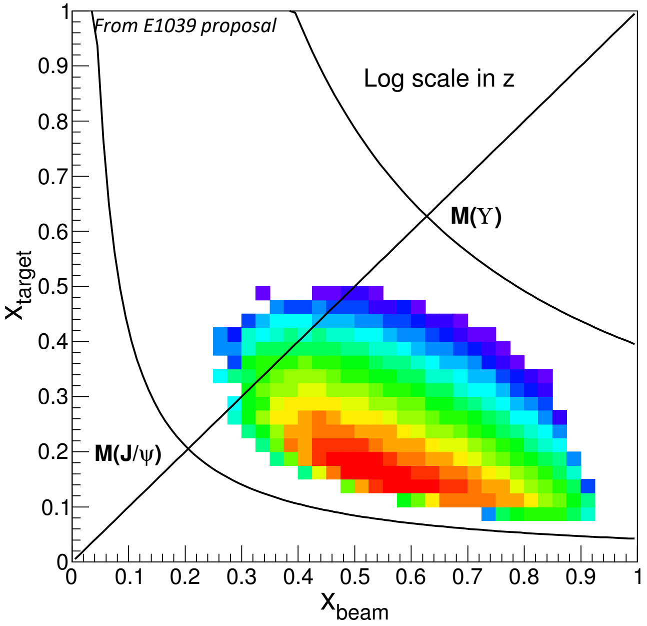


Valence-quarks dominance

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

About SpinQuest/E1039 Collaboration

https://spinquest.fnal.gov

INSTITUTIONS 20	FULL MEMBERS 48 Postdocs 6 Grad. Students 12	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)	
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), Ming Liu, Kei Nagai	Jan Boissevain, Patrick McGaughey, Andi Klein
8) Mississippi State University	Lamiaa El Fassi (PI), Eric Fuchey	Dipangkar Dutta
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10) RIKEN	Yuji Goto (PI)	
11) Shandong University	Qinghua Xu (PI), Zhaohuizi Ji	
12) Tokyo Institute of Technology	Toshi-Aki Shibata (PI)	
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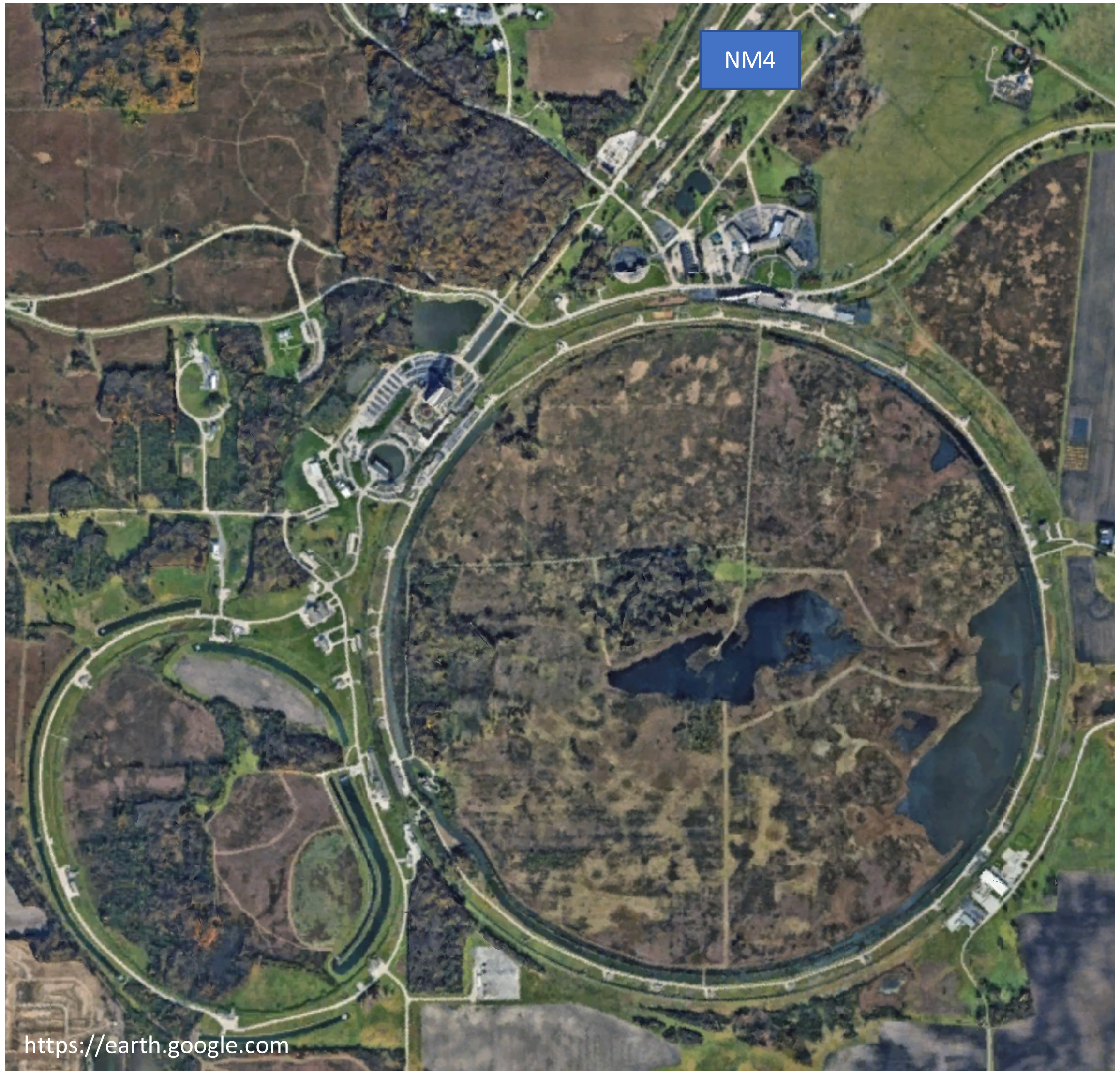
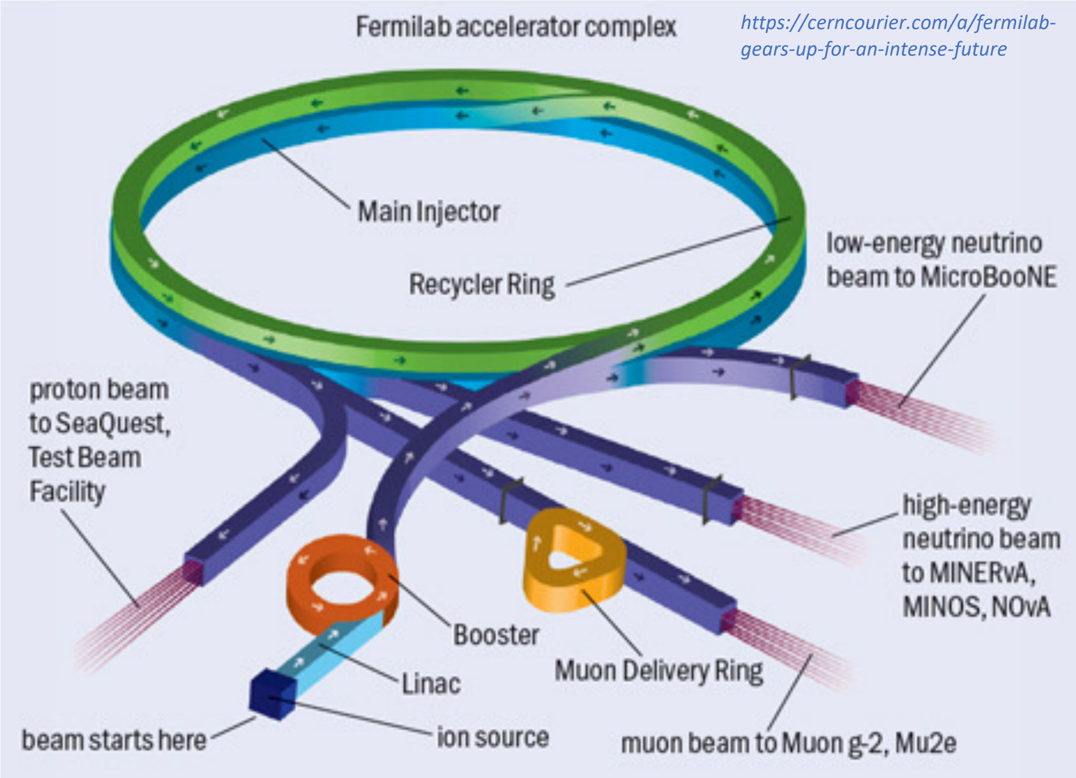
15) University of Michigan	Wolfgang Lorenzon (PI), Levgen Lavrukhin, Noah Wuerfel	Daniel Morton, Richard Raymond, Marshall Scott
16) University of New Hampshire	Karl Slifer (PI)	Maurik Holtrop
17) Tsinghua University	Zhihong Ye (PI)	
18) University of Virginia	Dustin Keller (SP), Kenichi Nakano, Ishara Fernando, Zulkaida Akbar, Waqar Ahmed, Liliet Diaz, Anchit Arora, Arthur Conover, Jay Roberts	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)	

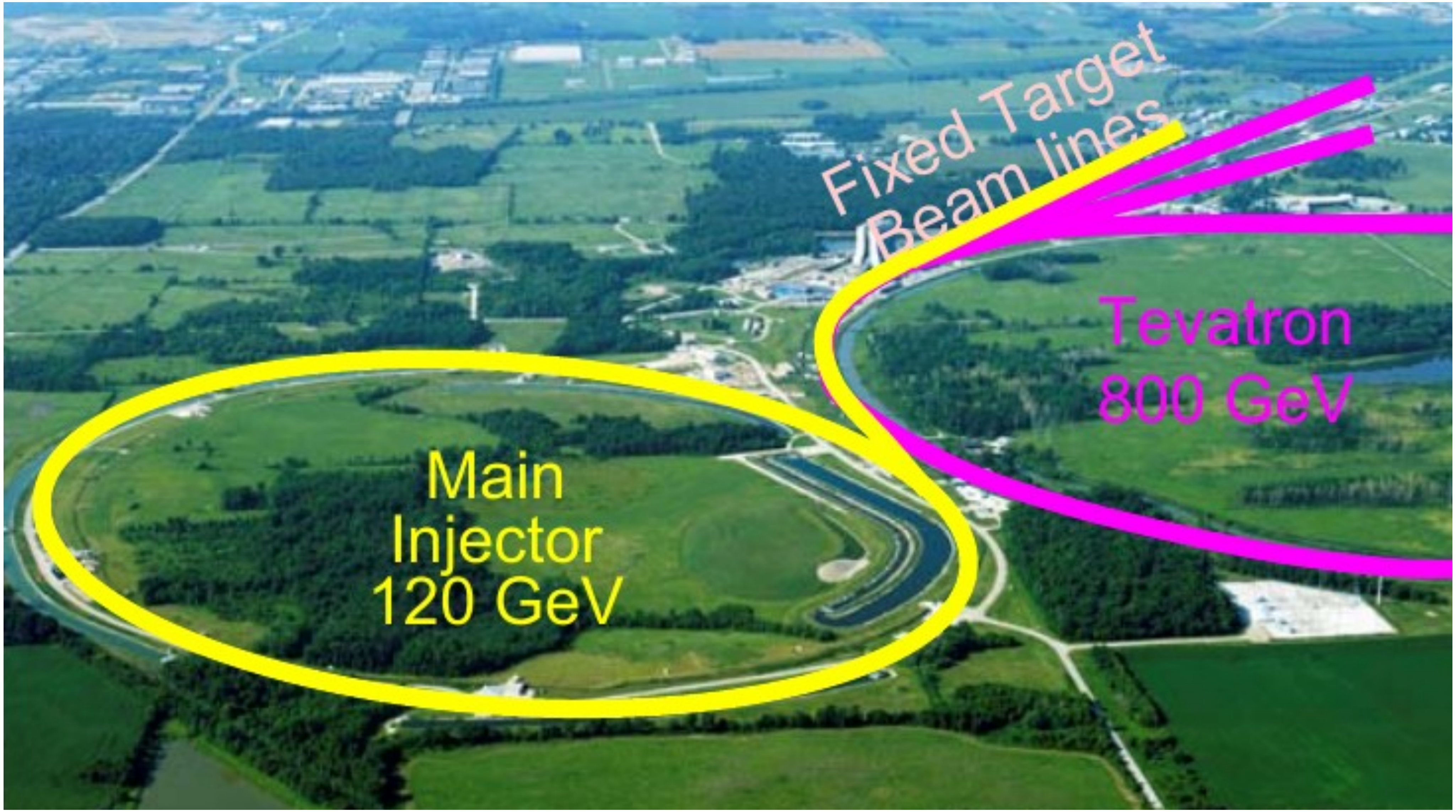
Fermilab proton beam main injector



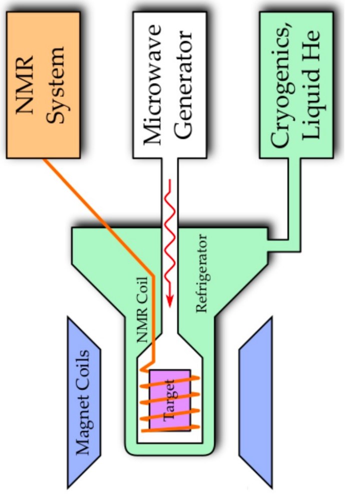


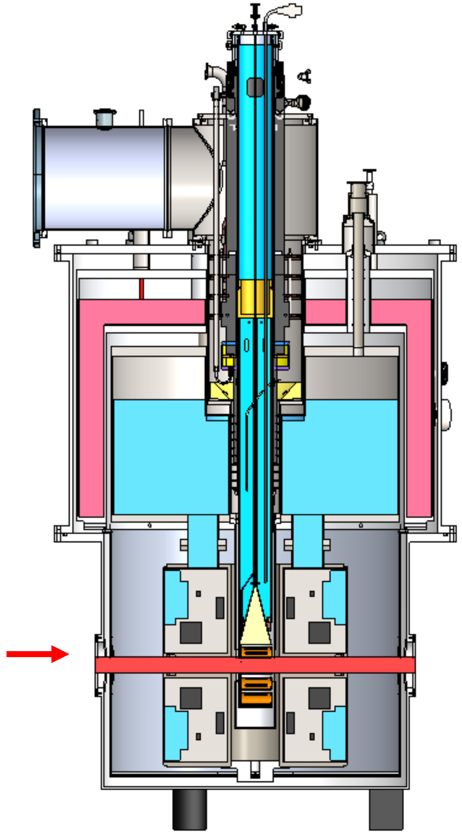
- 120 GeV/c proton beam
- $\sqrt{s} = 15.5$ GeV
- Projected beam
  - $5\times10^{12} protons/spill$ Where $spill \approx 4.4\ s/min$
  - Bunches of $1ns$ with $19ns$ intervals ~ $53\ MHz$
  - $7\times10^{17} protons/year$ on target!

Fermilab proton beam main injector

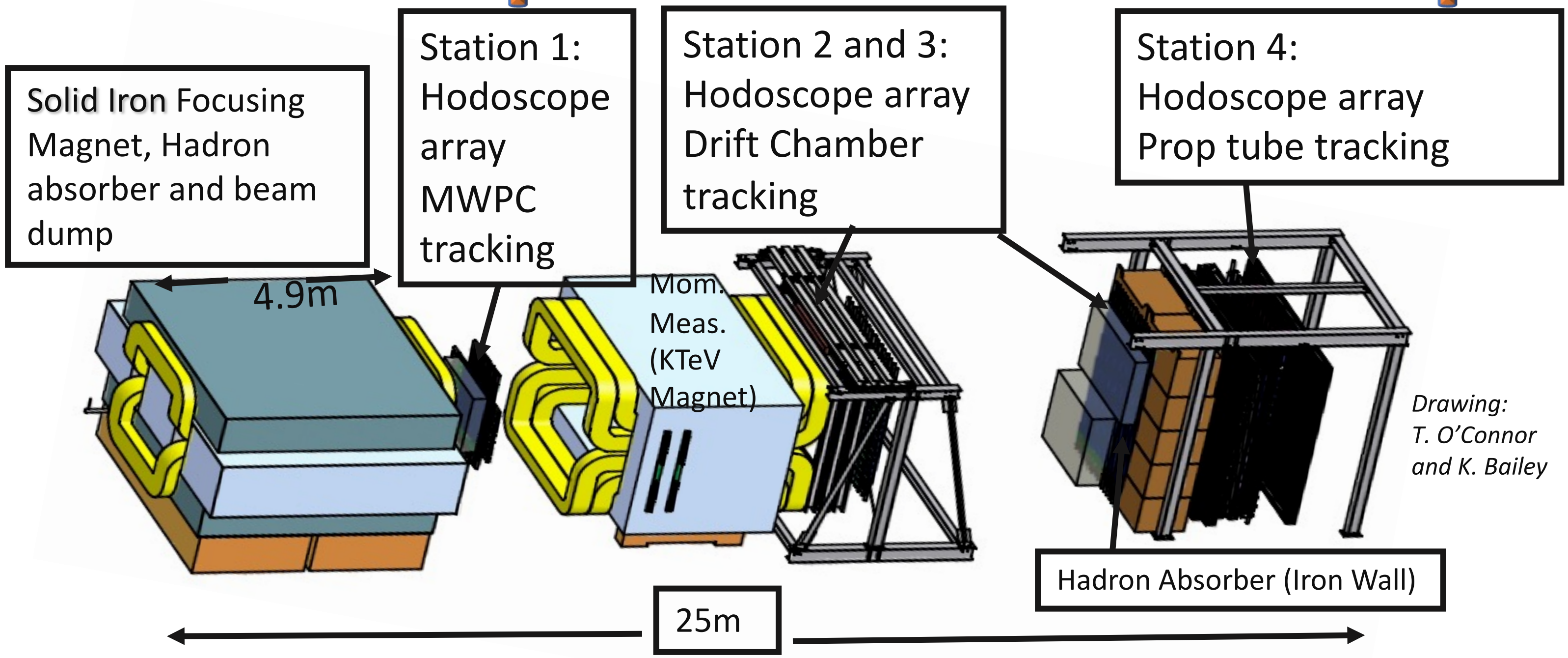


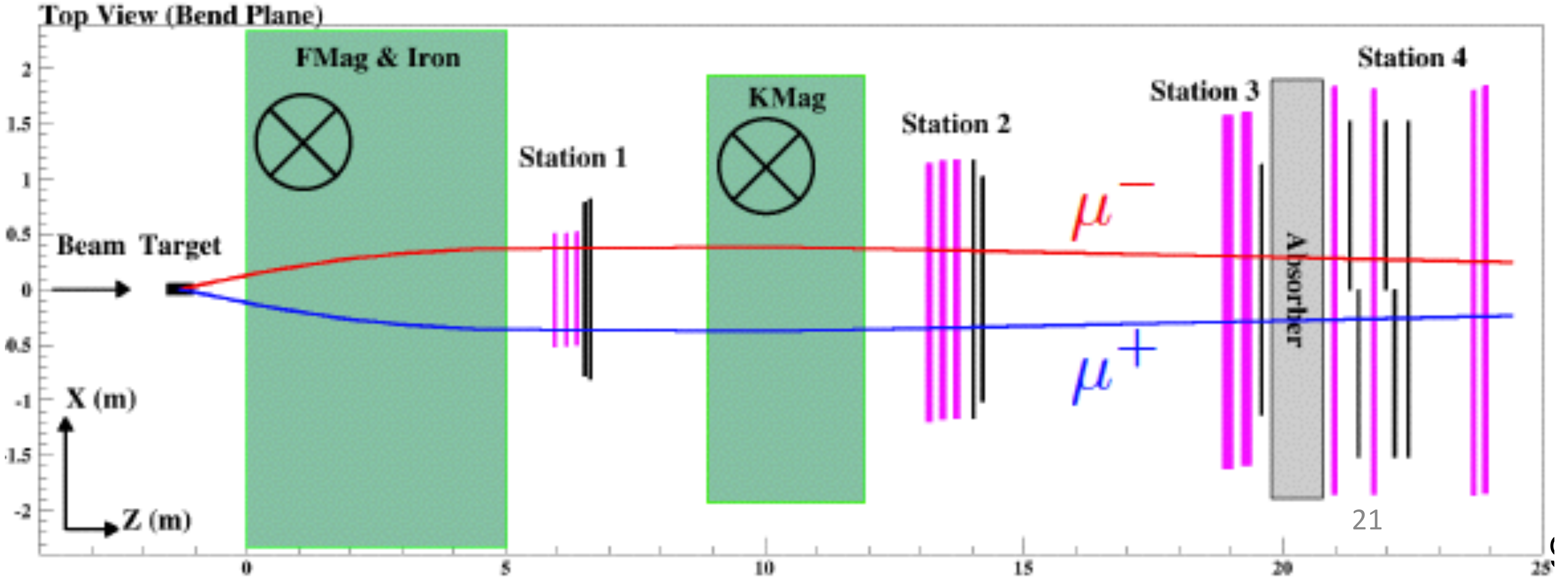
SpinQuest / E1039 Experiment Setup





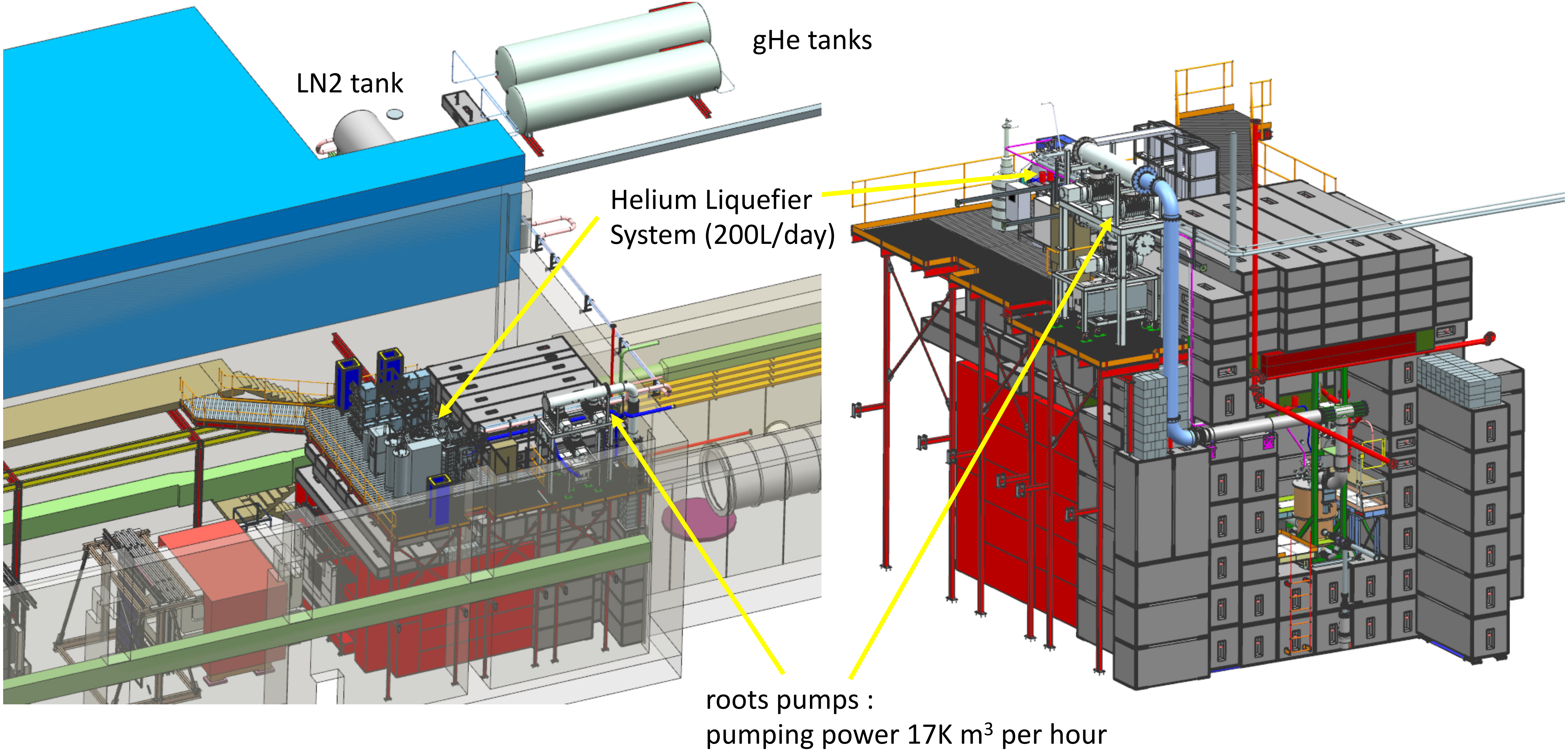
Polarized solid NH3 & ND3 target setup





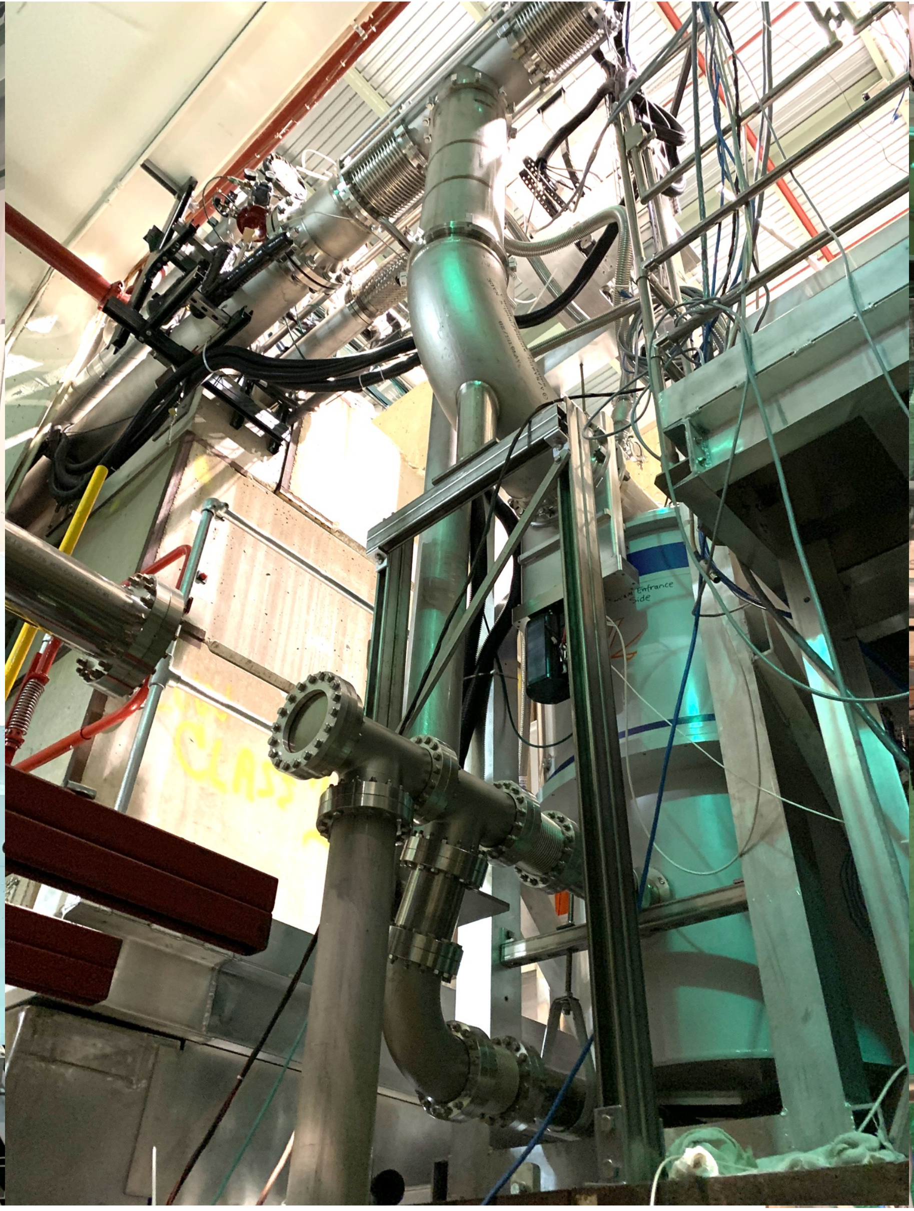
- Designed for high intensity proton beam (5×10^{12} $protons/spill$ with 4.4s spill)
- 8 cm long solid NH_3 and ND_3 target cells
- Magnetic Field: B = 5 T with uniformity $dB/B < 10^{-4}$ over 8 cm
- ^{4}He evaporation refrigerator (3 W of maximum cooling power) keeping the target at 1.1 K.
- 140 GHz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

SpinQuest / E1039 Experiment Setup



SpinQuest / E1039 Experiment Setup

From beam down-stream

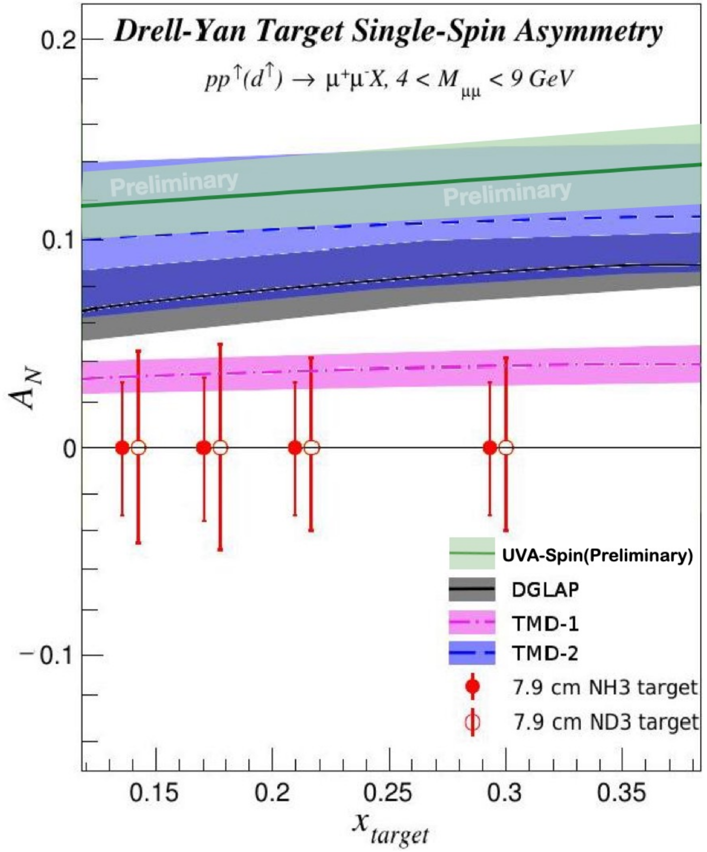


Beam-window and superconducting magnet

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



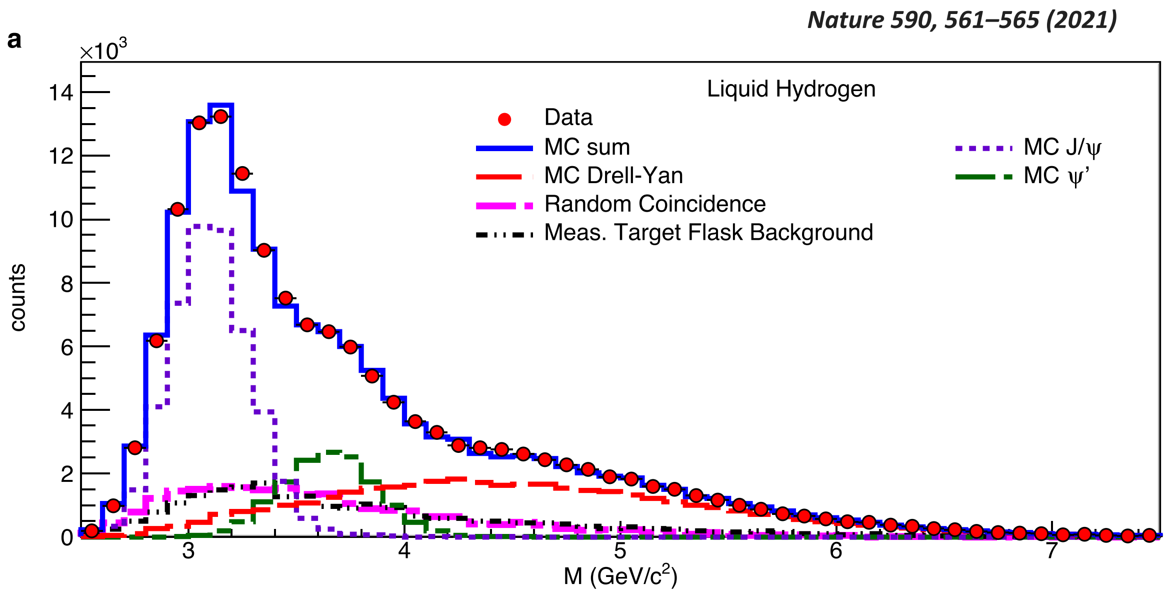
DGLAP: M. Anselmino et al arXiv:1612.06413
TMD-1: M. G. Echevarria et al arXiv:1401.5078
TMD-2: P. Sun and F. Yuan arXiv:1308.5003
A. Prokudin et al (in progress)
I. Fernando, D. Keller (Preliminary)

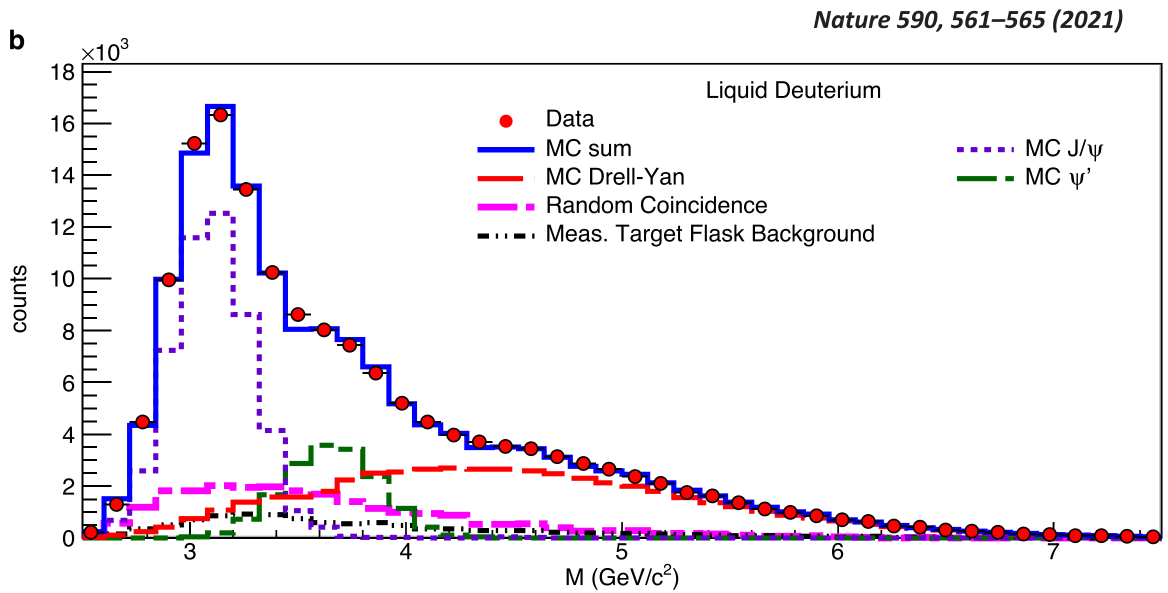
$$A = \frac{2}{f|S_T|}\frac{\int d\phi_S d\phi \frac{dN(x_b,x_t,\phi_S,\phi)}{d\phi_S d\phi} sin(\phi_S)}{N(x_b,x_t)}$$

x_2 bin	$< x_2 >$	NH_3 ($p^{\uparrow}$)		ND_3 ($d^{\uparrow}$)	
		N	ΔA (%)	N	ΔA (%)
0.10 - 0.16	0.139	5.0×10^4	3.2	5.8×10^4	4.3
0.16 - 0.19	0.175	4.5×10^4	3.3	5.2×10^4	4.6
0.19 - 0.24	0.213	5.7×10^4	2.9	6.6×10^4	4.1
0.24 - 0.60	0.295	5.5×10^4	3.0	6.4×10^4	4.1

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

SpinQuest / 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
- Now: commission all components using cosmic rays,
  Target Cooldown Commissioning
- Polarized target commissioning will be completed by January 2023
- E1039 first beam commissioning starts in January 2023
  [Run for 2+ years, 2023-2025+]

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.

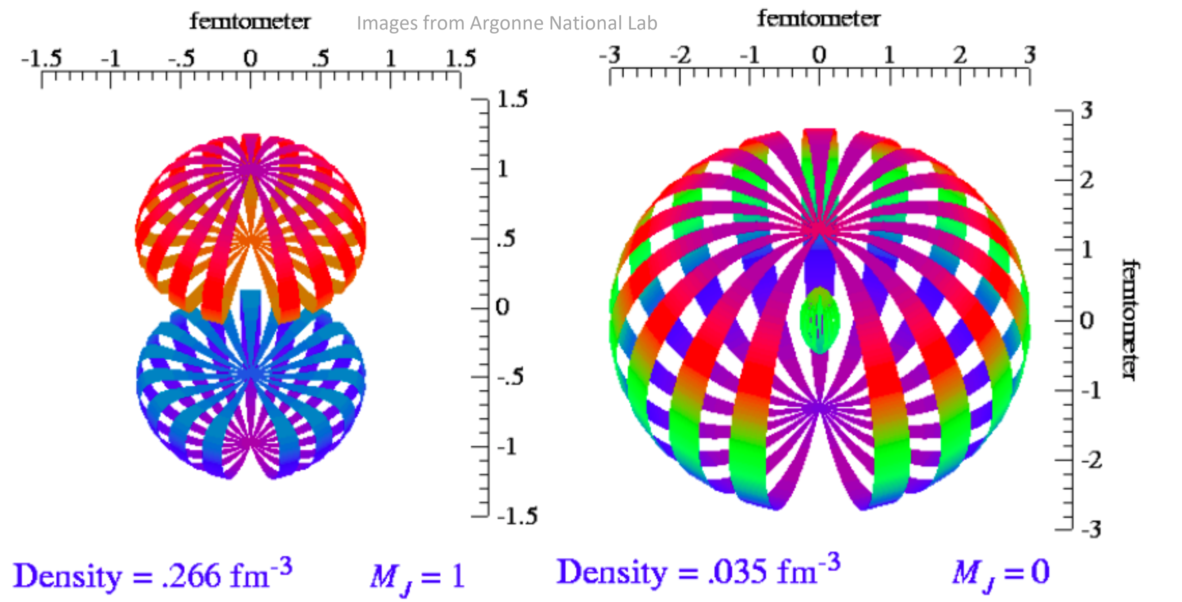
$$f_{1T}^{\perp}\Big|_{\mathrm{SIDIS}} = -\, f_{1T}^{\perp}\Big|_{\mathrm{DY}}$$

  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,...

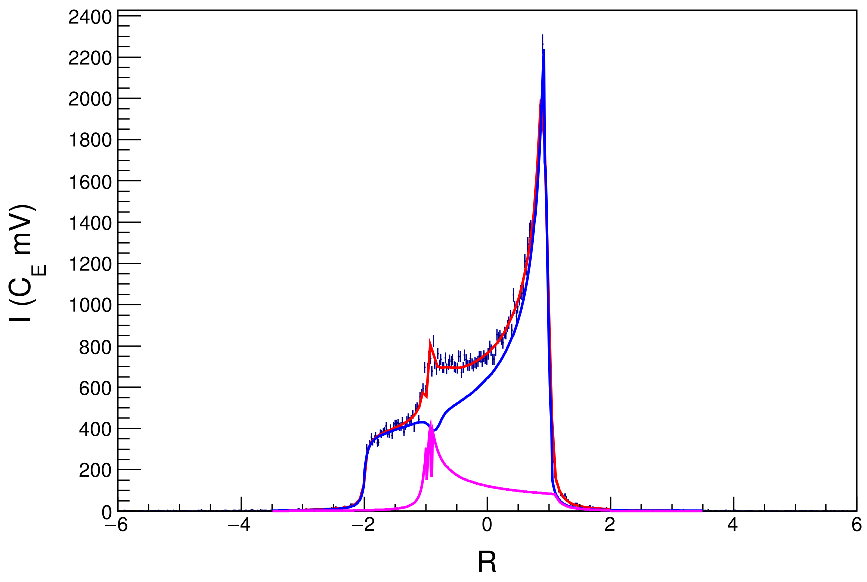
Future: Transverse Structure of Spin-1 target with DY

https://arxiv.org/abs/2205.01249

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



Graphical representation of the shape of the deuteron for two specified equidensity surfaces



- Deuteron is a Spin-1 has two polarization profiles: Vector Polarization and Tensor Polarization
- Transvesly vector polarized Deuteron target at SpinQuest, facilitate access to the sea-quark transversity

BM from unpolarized-DY (E906)

$$A_{UT}^{\sin(\varphi_{cs}+\varphi_s)\frac{q_T}{M_N}}\Big|_{pD^{\uparrow}\to l^+l^-X} \simeq -\frac{\left[4h_{1u}^{\perp(1)}(x_p)+h_{1d}^{\perp(1)}(x_p)\right]\left[\bar{h}_{1u}(x_{D^{\uparrow}})+\bar{h}_{1d}(x_{D^{\uparrow}})\right]}{\left[4f_{1u}(x_p)+f_{1d}(x_p)\right]\left[\bar{f}_{1u}(x_{D^{\uparrow}})+\bar{f}_{1d}(x_{D^{\uparrow}})\right]}$$

- Transverly Tensor polarized Deuteron → Tensor structure of the Deuteron, gluon transversity and clean $\bar{d}$ transversity from $m = \pm 1$ states

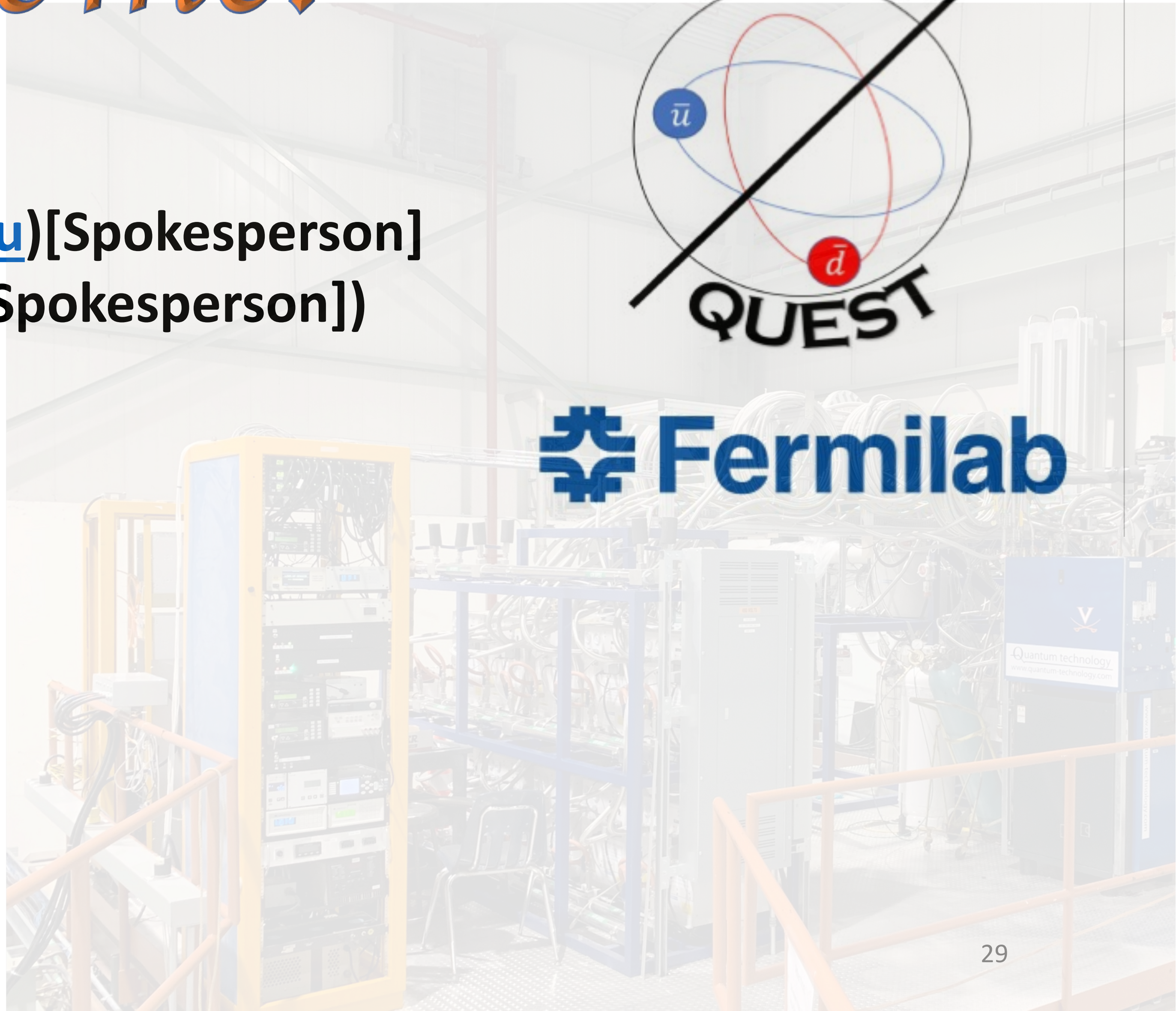
Welcome!

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

This work is supported by DOE contract DE-FG02-96ER40950