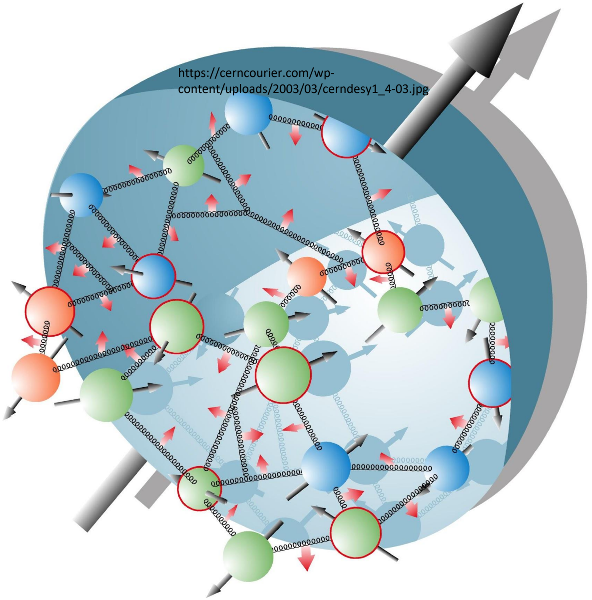
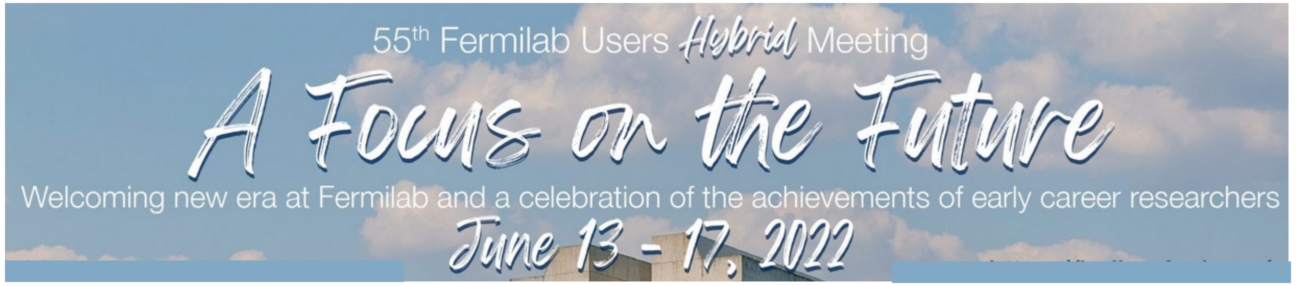
The SpinQuest Experiment (E1039) at Fermilab

Ishara Fernando

For the SpinQuest Collaboration





SPIN QUEST

Fermilab

UNIVERSITY of VIRGINIA

UVA - Spin
PHYSICS GROUP

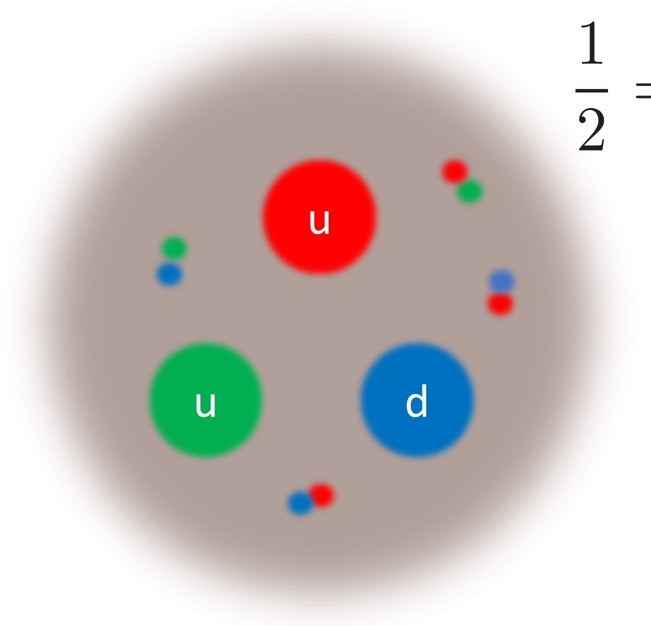
U.S. DEPARTMENT OF ENERGY | Office of Science

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



Ji's decomposition

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

Jaffe-Manohar decomposition

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

Intrinsic spin contribution
by valence & sea quarks

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

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

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

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

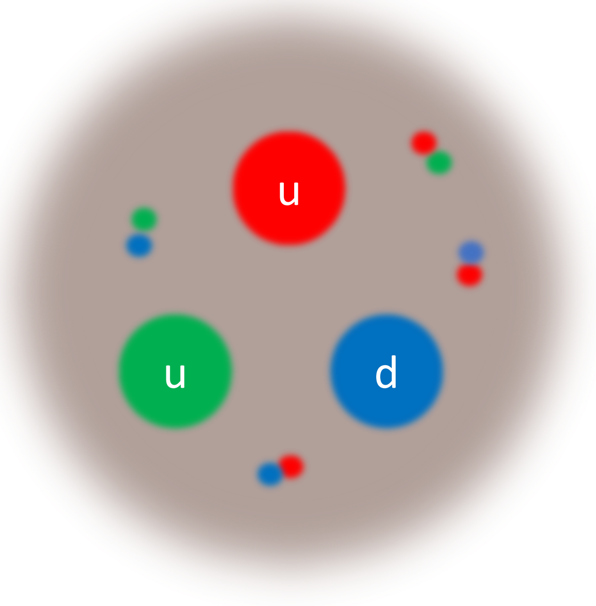
$$g_1(x) = \tfrac{1}{2}\sum e_i^2 (q_i^+(x) - q_i^-(x))$$

Nuclear Physics B328 (1989) 1–35

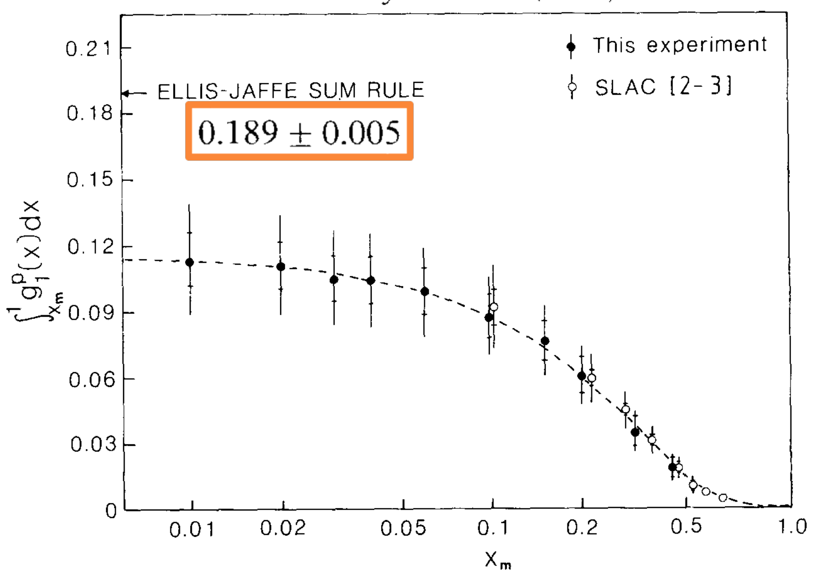
EMC Collaboration (1989)

Asymmetry measurements from Deep inelastic scattering of longitudinally polarized muons on longitudinally polarized proton

Physics Motivation



Nuclear Physics B328 (1989) 1–35

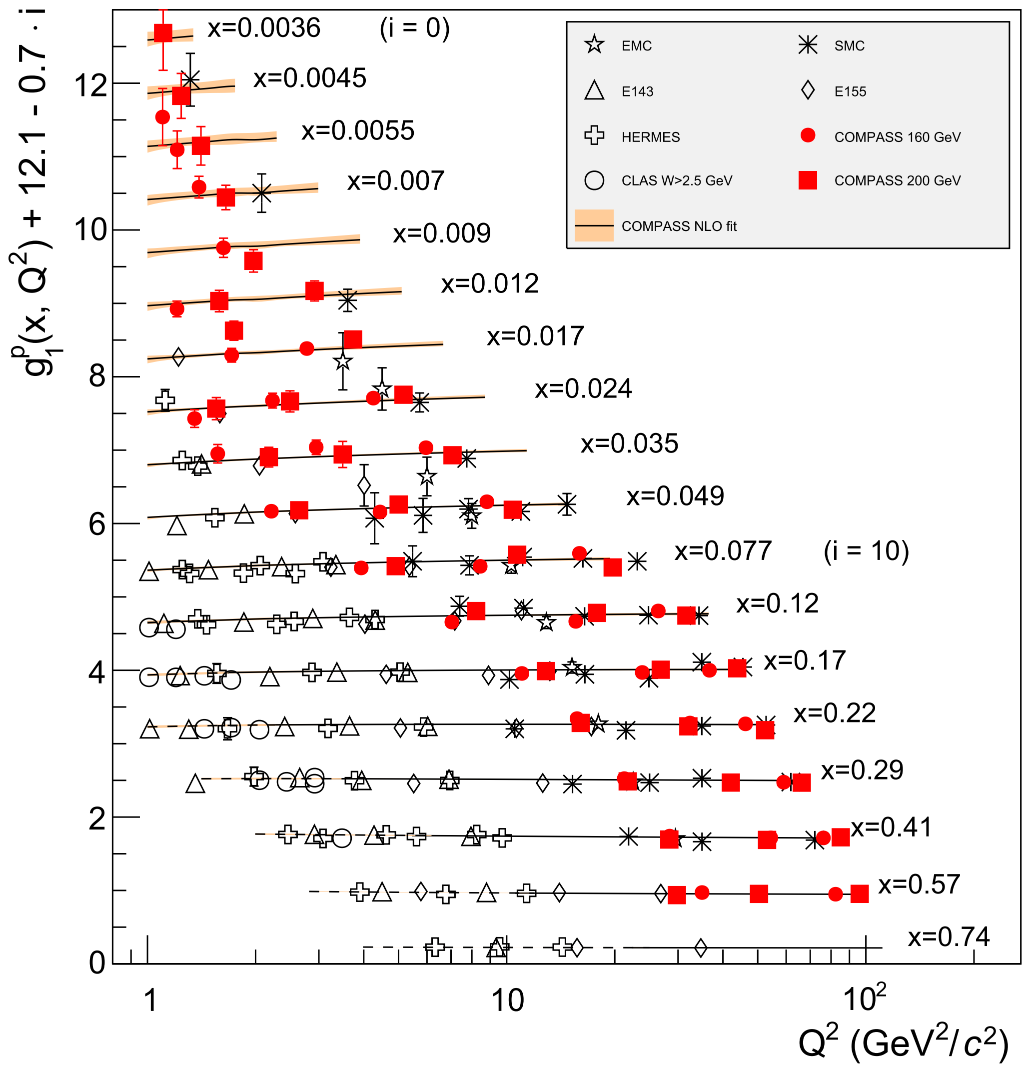


$$\int_0^1 g_1^p \, dx = 0.126 \pm 0.010 \pm 0.015$$

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

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

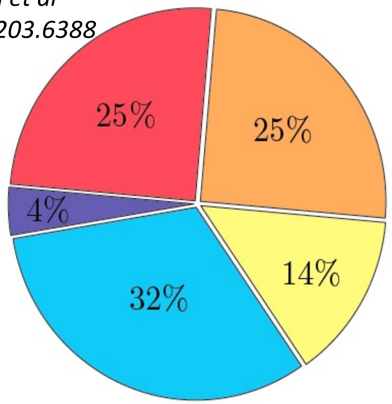
COMPASS Collaboration: Physics Letters B 753 (2016) 18–28



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

Possible missing spin contributions

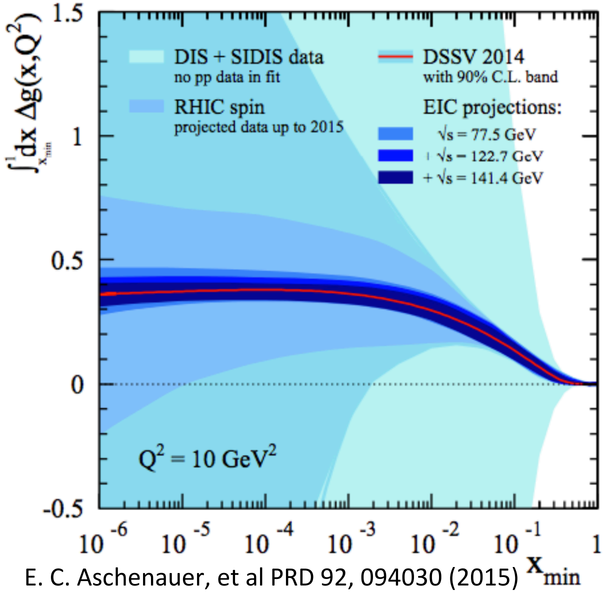
K.-F. Liu et al
arXiv:1203.6388



$\Delta\Sigma_q \approx 25\%$

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

$2\ J_g \approx 25\%$



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

Jaffe-Manohar decomposition

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

Gluon total angular momentum

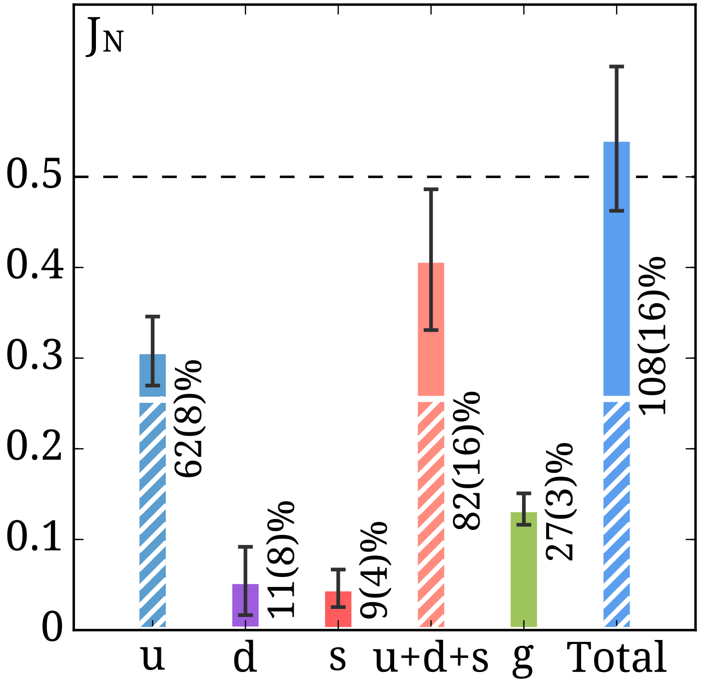
Valence quarks' OAM

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

	$\frac{1}{2}\Delta\Sigma$	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)



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

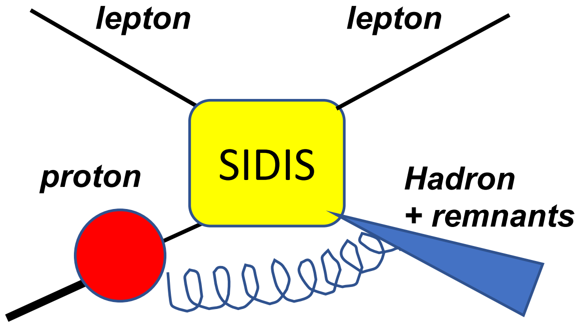
$$\Phi(x, k_T, P, S) = f_1(x, k_T^2)\frac{\not{P}}{2} + \frac{h_{1T}(x, k_T^2)}{4}\gamma_5[\not{S}_T, \not{P}] + \frac{S_L}{2} g_{1L}(x, k_T^2)\gamma_5 \not{P} + \frac{k_T.S_T}{2M} g_{1T}(x, k_T^2)\gamma_5 \not{P}$$

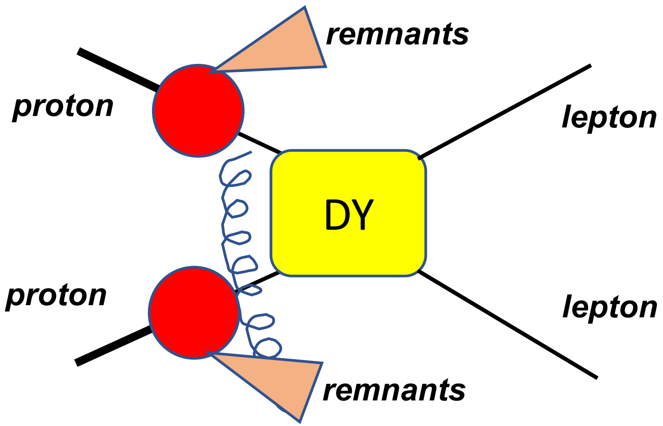
$$+ S_L h_{1L}^\perp(x, k_T^2)\gamma_5 \frac{[\not{k}_T, \not{P}]}{4M} + \frac{k_T.S_T}{2M} h_{1T}^\perp(x, k_T^2)\gamma_5 \frac{[\not{k}_T, \not{P}]}{4M}$$

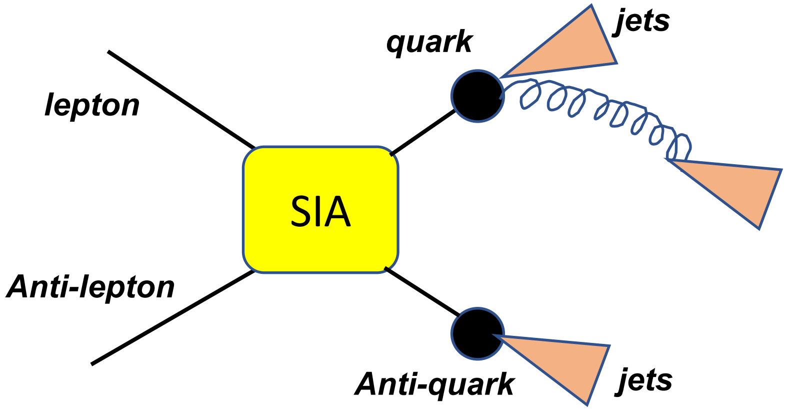
T-even

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

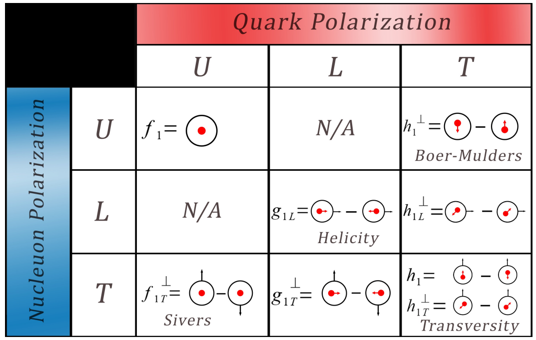
T-odd



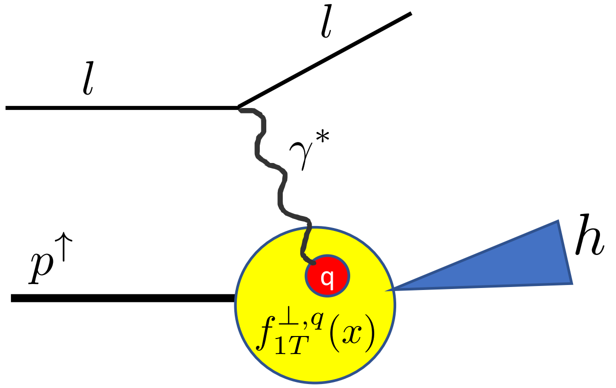




TMD PDFs

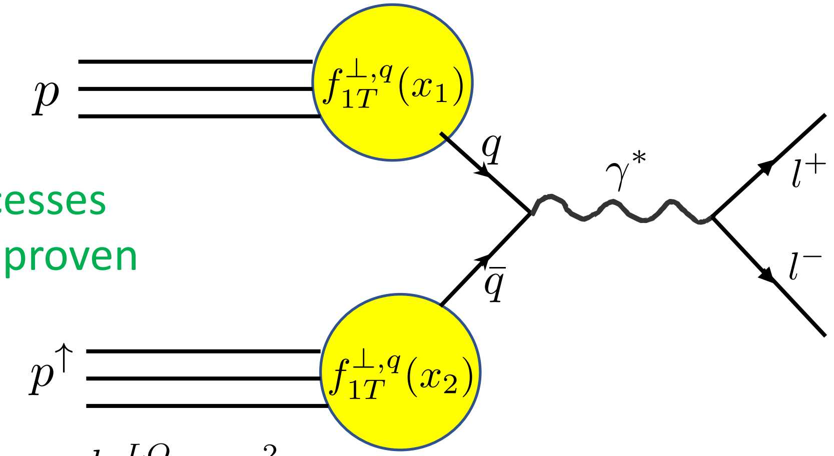


Polarized Semi Inclusive DIS



* For these two processes TMD factorization is proven

Polarized DY



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

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

$A_{UU}^{\cos 2\phi_h} \propto h_1^{\perp q} \circledast H_{1q}^{\perp h}$ BM ⊛ CF

$A_{UT}^{\sin(\phi_h-\phi_s)} \propto f_{1T}^{\perp q} \circledast D_{1q}^{h}$ Sivers ⊛ FF

$A_{UT}^{\sin(\phi_h+\phi_s)} \propto h_1^{q} \circledast H_{1q}^{\perp h}$ Transv ⊛ CF

$A_{UT}^{\sin(3\phi_h-\phi_s)} \propto h_{1T}^{\perp q} \circledast H_{1q}^{\perp h}$ Pretz ⊛ CF

$A_T^{\cos 2\phi_{CS}} \propto h_1^{\perp q} \circledast h_1^{\perp q}$ BM ⊛ BM

$A_T^{\sin\phi_s} \propto f_1^{q} \circledast f_{1T}^{\perp q}$ PDF ⊛ Sivers

$A_T^{\sin(2\phi_{CS}-\phi_s)} \propto h_1^{\perp q} \circledast h_{1T}^{\perp q}$ BM ⊛ Transv

$A_T^{\sin(2\phi_{CS}+\phi_s)} \propto h_1^{\perp q} \circledast h_1^{q}$ BM ⊛ Pretz

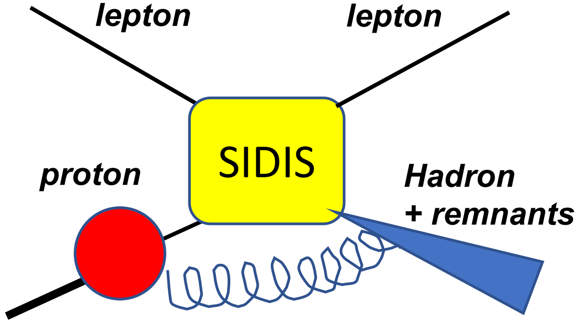
$$h_1^{\perp q}\Big|_{SIDIS} = -h_1^{\perp q}\Big|_{DY}$$
$$f_{1T}^{\perp q}\Big|_{SIDIS} = -f_{1T}^{\perp q}\Big|_{DY}$$

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

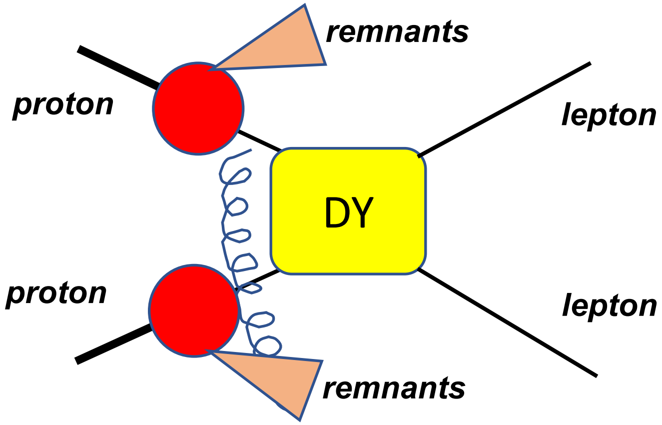
Sivers Function

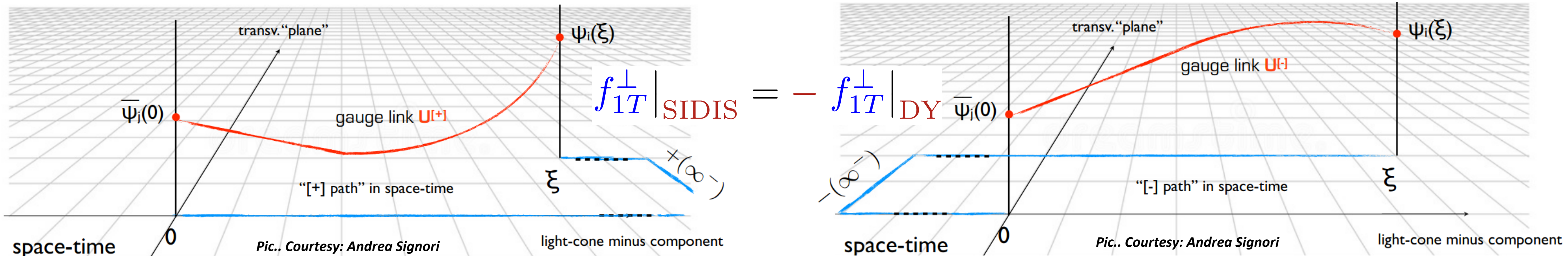
$$f_{q/p^{\uparrow}}(x,\mathbf{k_T}) = f_{q/p}(x,\mathbf{k_T}) + f_{1T}^{\perp}(x,\mathbf{k_T})\mathbf{S}.(\hat{\mathbf{P}} \times \hat{\mathbf{k_T}})$$

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



- 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/ψ, $W^{\pm}$, 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

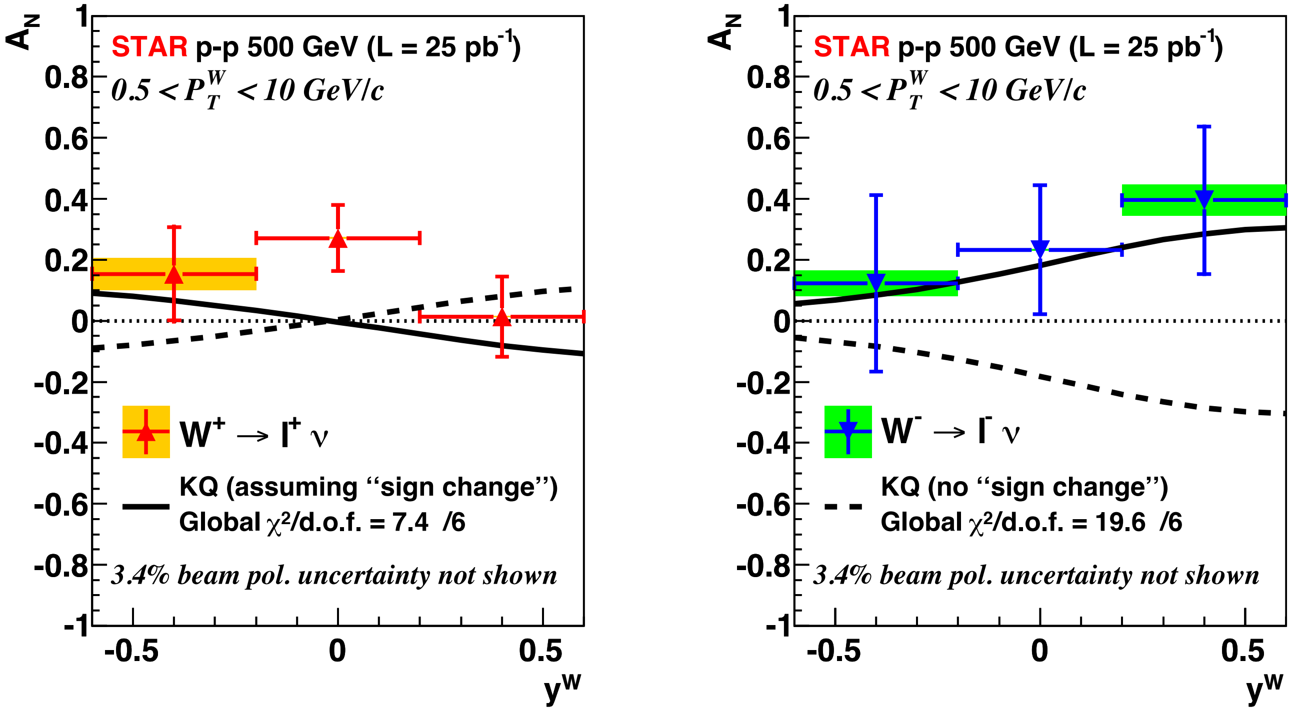




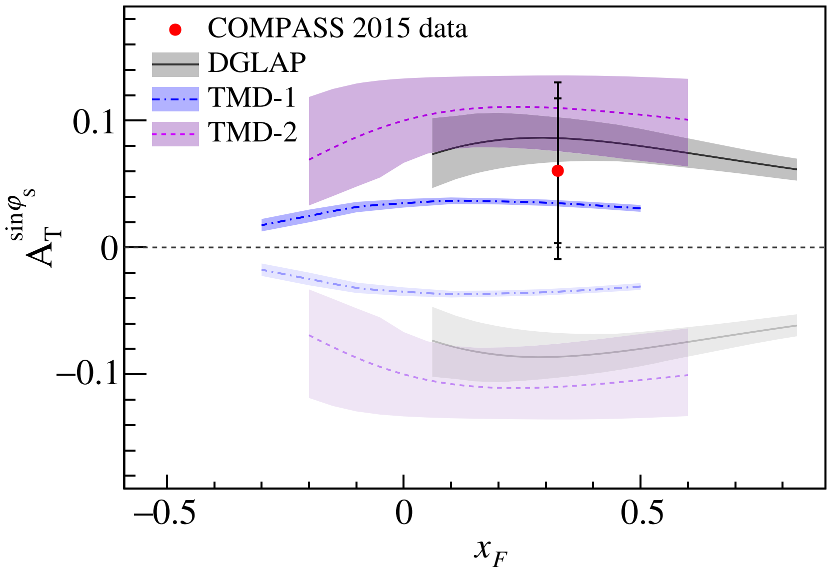
$$f_{1T}^{\perp}\big|_{\mathrm{SIDIS}} = - f_{1T}^{\perp}\big|_{\mathrm{DY}}$$

Sign of Sivers Functions

STAR Collaboration (PRL 116 132301 (2016))



COMPASS Collaboration (PRL 119 112002 (2017))

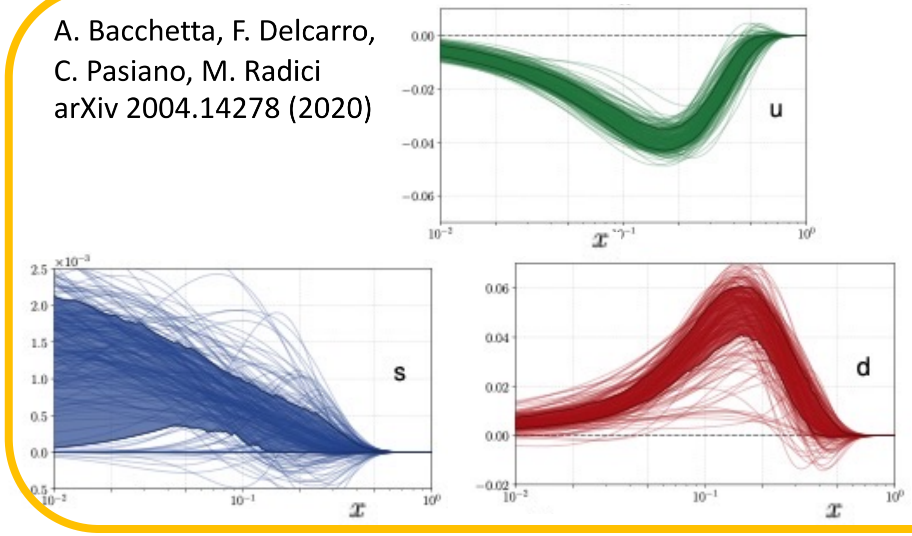


TSSA amplitude for W+/W- from STAR data is favors the "sign-change"
In DY relative to SIDIS (model based without TMD evolution)

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

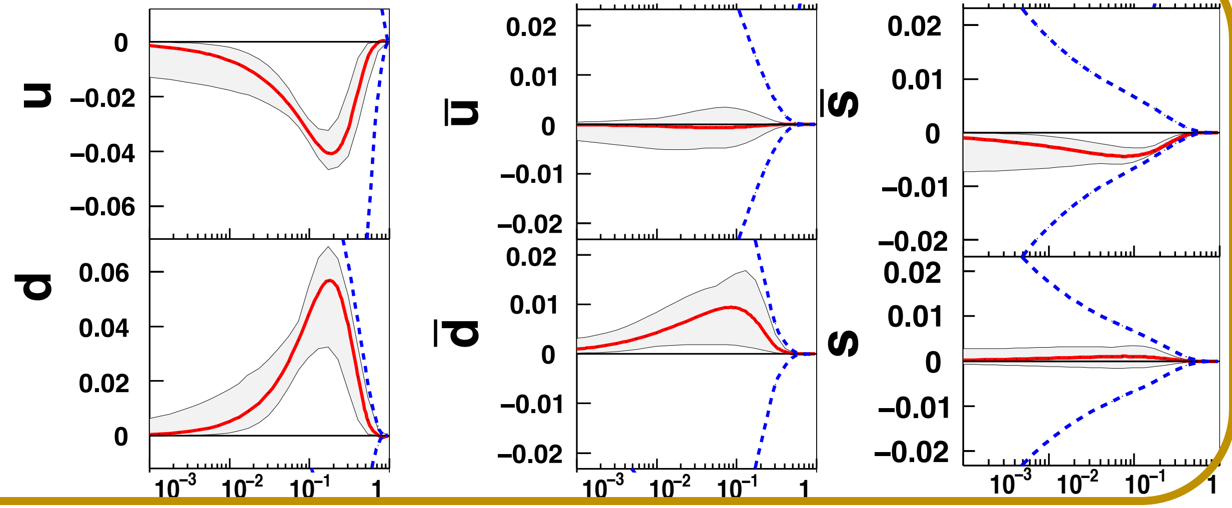
Global analyses: Sivers functions

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

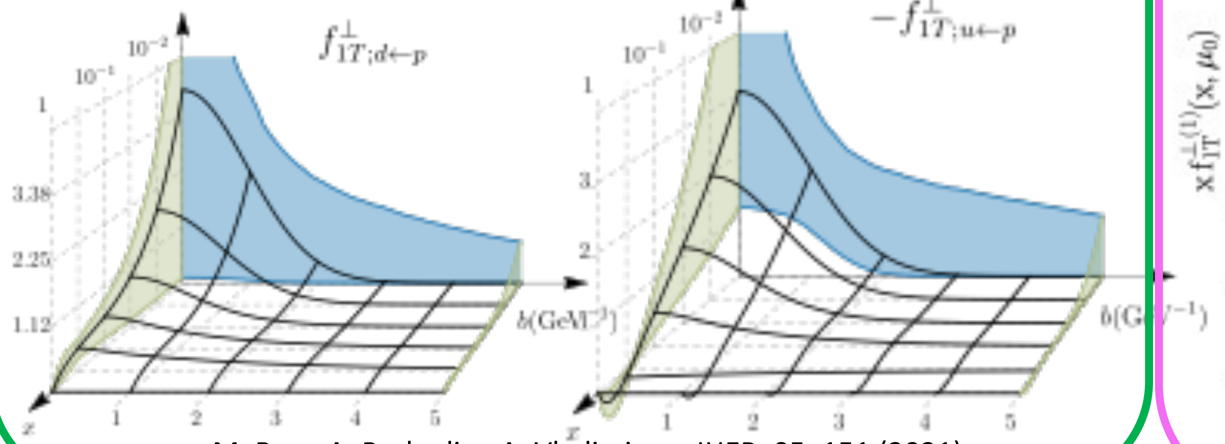


HERMES (2020)
COMPASS (2009)
COMPASS (2015)
JLab (2011)

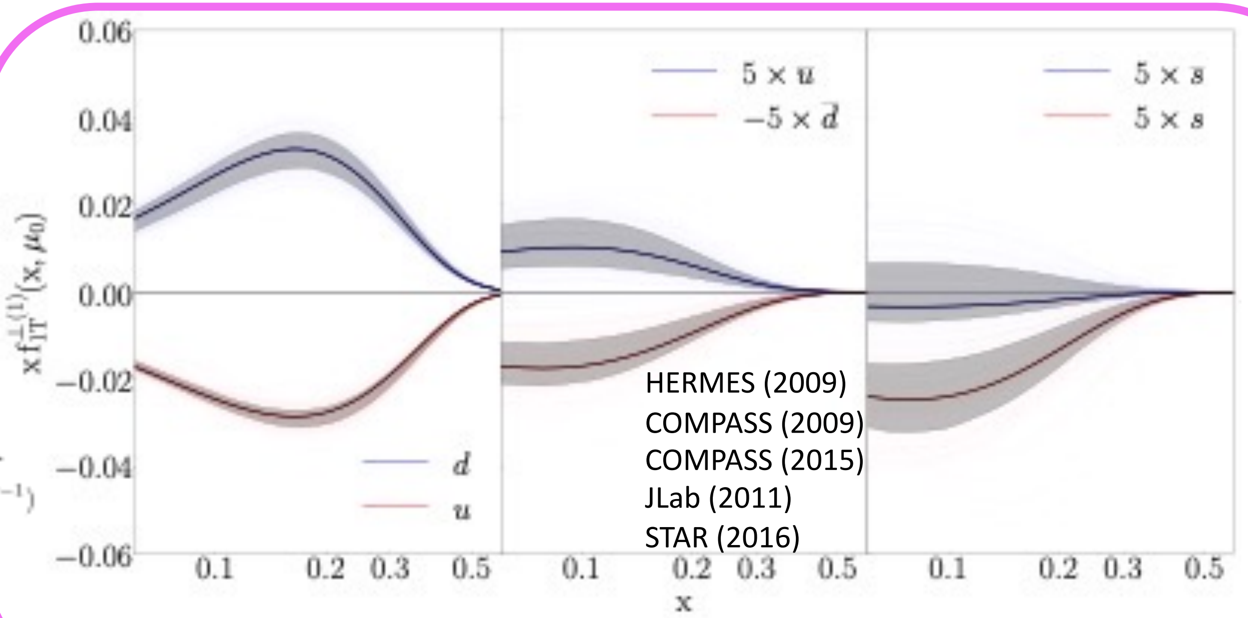
M. Anselmino, M. Boglion, U. D'Alesio, S. Melis, F. Murgia, A. Prokudin_PRD_79_54010_(2009)



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



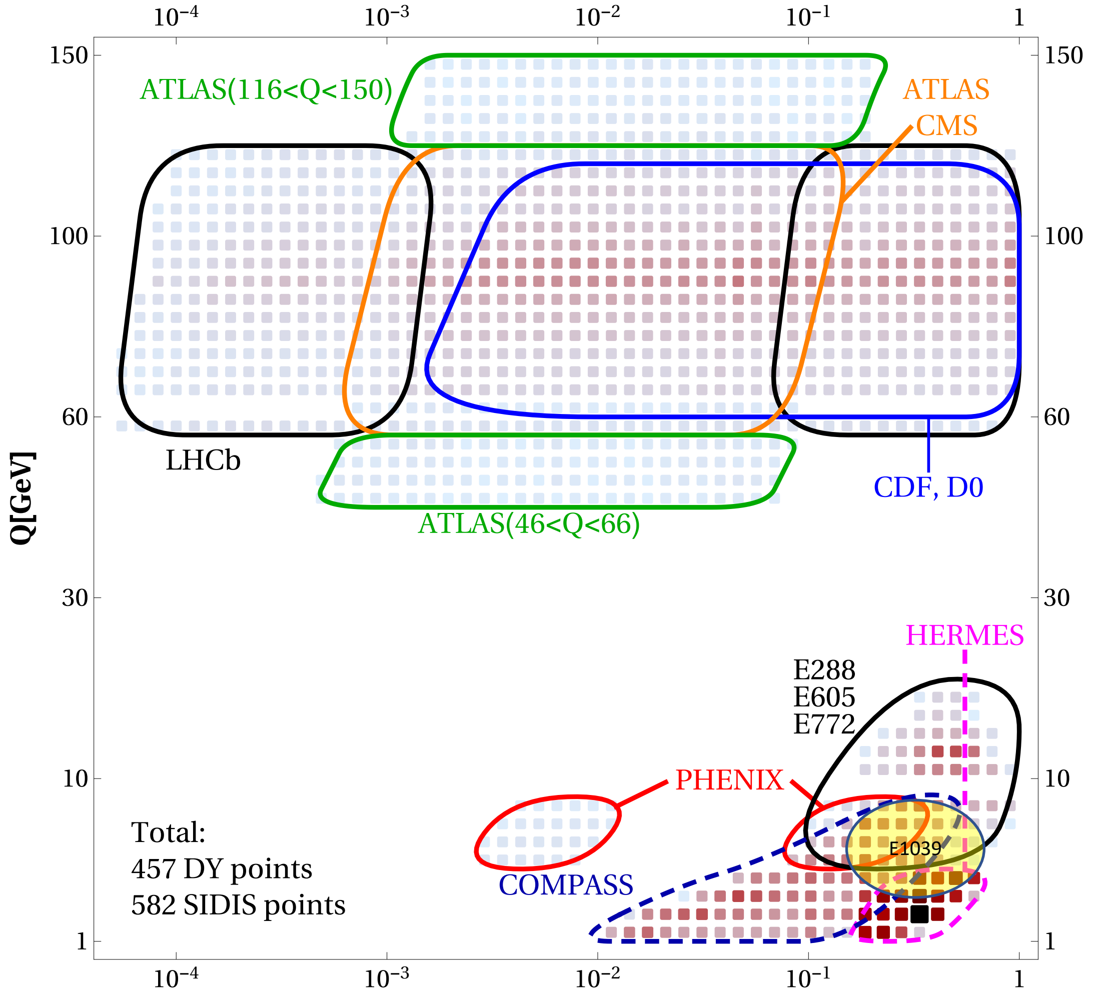
M. Bury, A. Prokudin , A. Vladimirov,, JHEP_05_151 (2021)



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

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

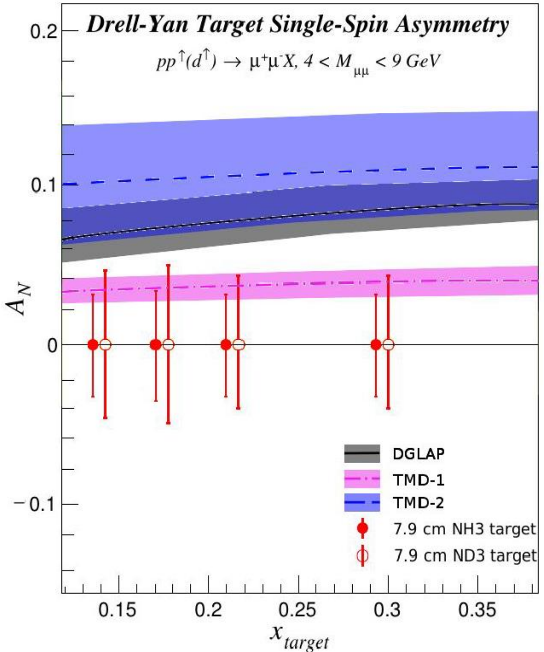
SpinQuest in the Global Context



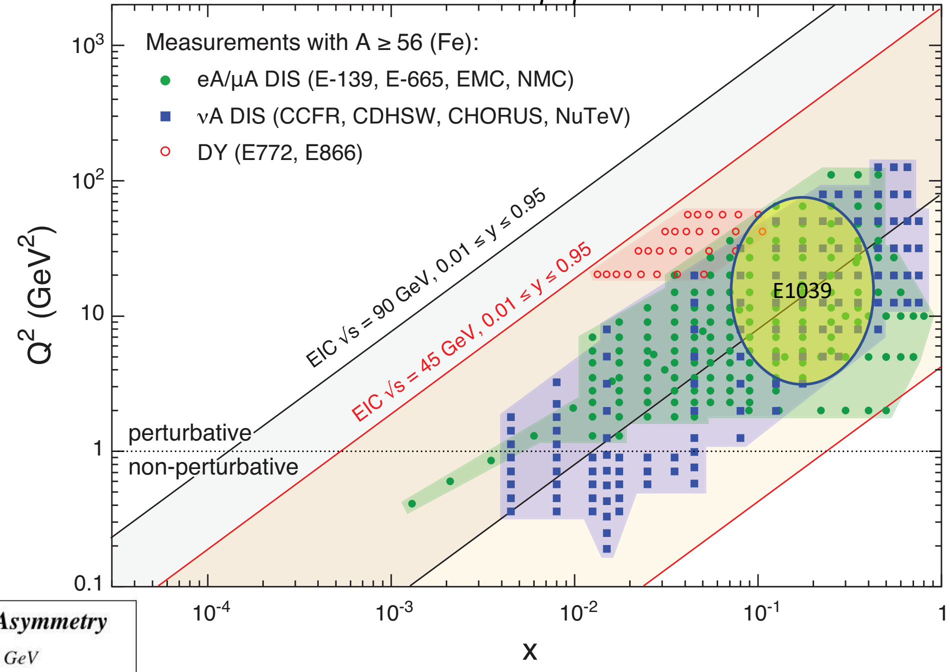
I. Scimemi & A. Vladimirov JHEP 06, 137 (2020)

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

From E1039 proposal



EIC white paper

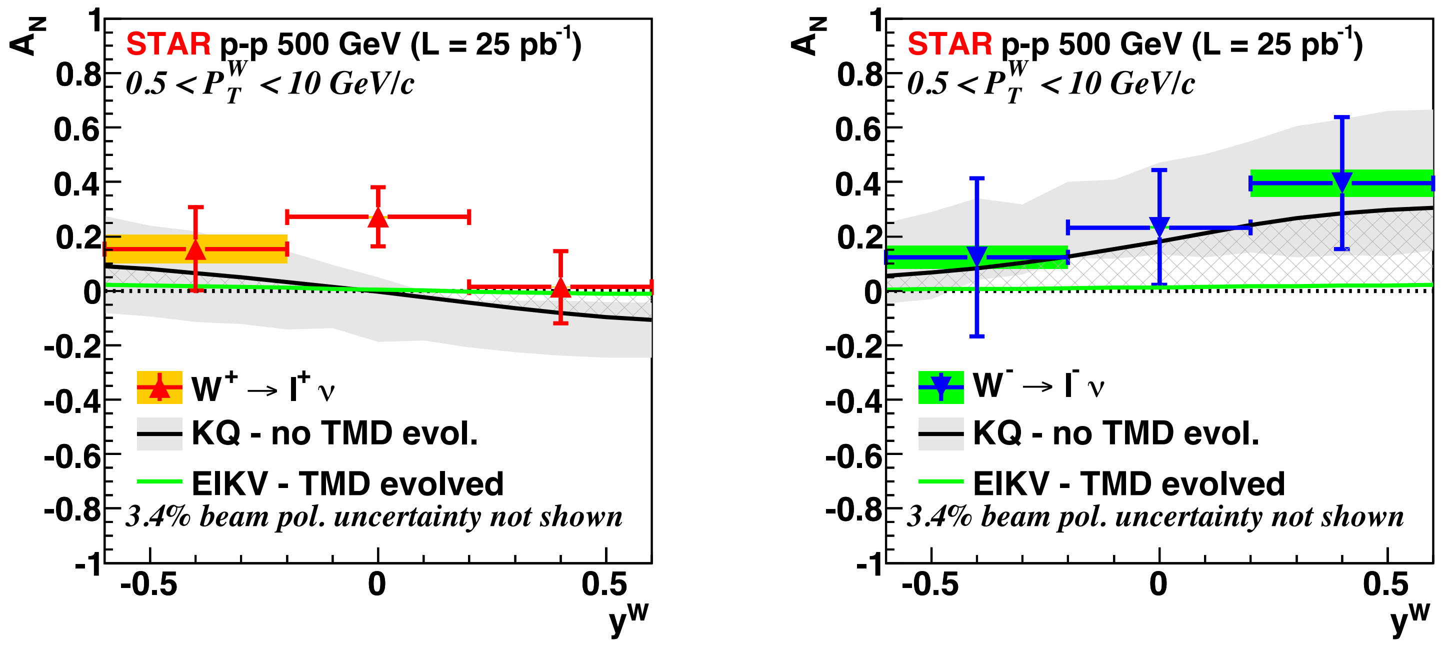


- ➢ The E1039 experiment will provide unique information for the sea quark Sivers function in DY
- ➢ ←Plot: Uncertainties in the predicted Sivers asymmetry in polarized Drell-Yan process from SpinQuest.

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

STAR Collaboration (PRL 116 132301 (2016))



The solid gray bands represent the uncertainty due to the unknown sea quark Sivers functions estimated by saturating the sea quark Sivers function to their positivity limit in the KQ (**Z.-B. Kang and J. -W. Qiu PRL 103,172001 (2009)**)calculation

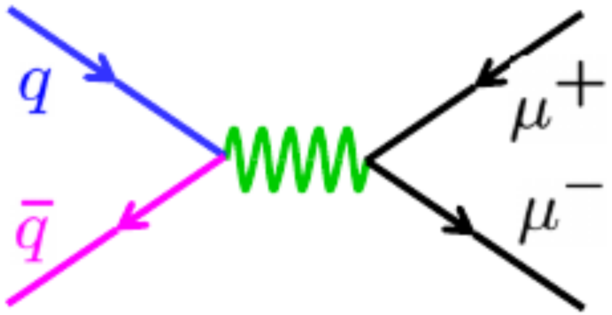
- Initial attempts to measure the Sivers asymmetry for sea quark Sivers have been reported by the STAR collaboration at RHIC using W/Z boson production. Their data is statistically limited and favor a sign-change only if TMD evolutions effects are significantly smaller than expected.

- SpinQuest will perform the first measurement of the Sivers asymmetry in Drell-Yan proton-proton scattering 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

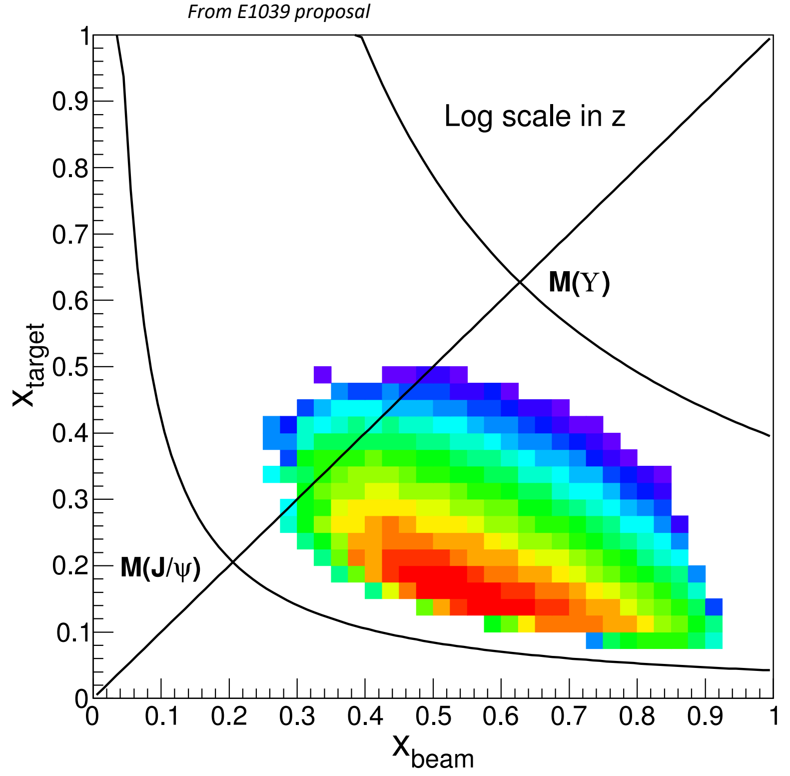


$$\frac{d^2\sigma}{dx_b dx_t} = \frac{4\pi\alpha^2}{x_b x_t s} \sum_{q\in\{u,d,s,...\}} e_q^2 \left[\bar{q}_t(x_t) q_b(x_b) + q_t(x_t)\bar{q}_b(x_b)\right]$$

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

acceptance limited
(Fixed Target, Hadron Beam)

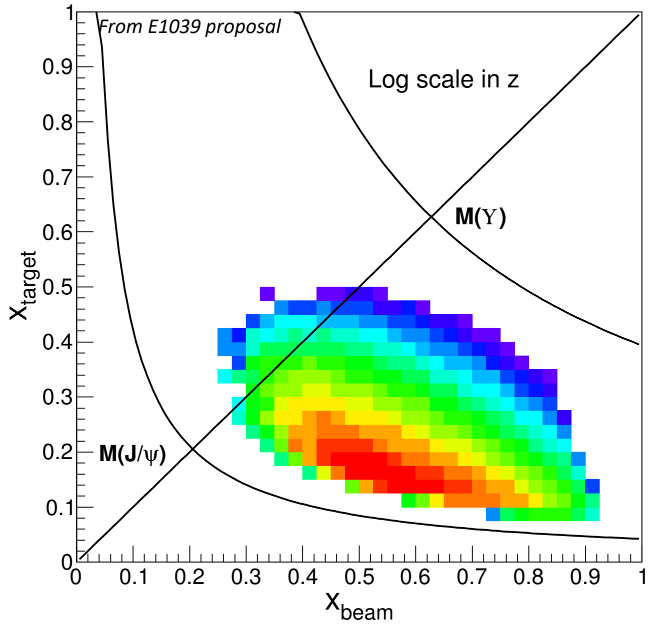
Sea-quarks dominance



Valence-quarks dominance

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

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



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

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

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

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

- 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 53 Postdocs 6 Grad. Students 15	AFFILIATE MEMBERS
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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	
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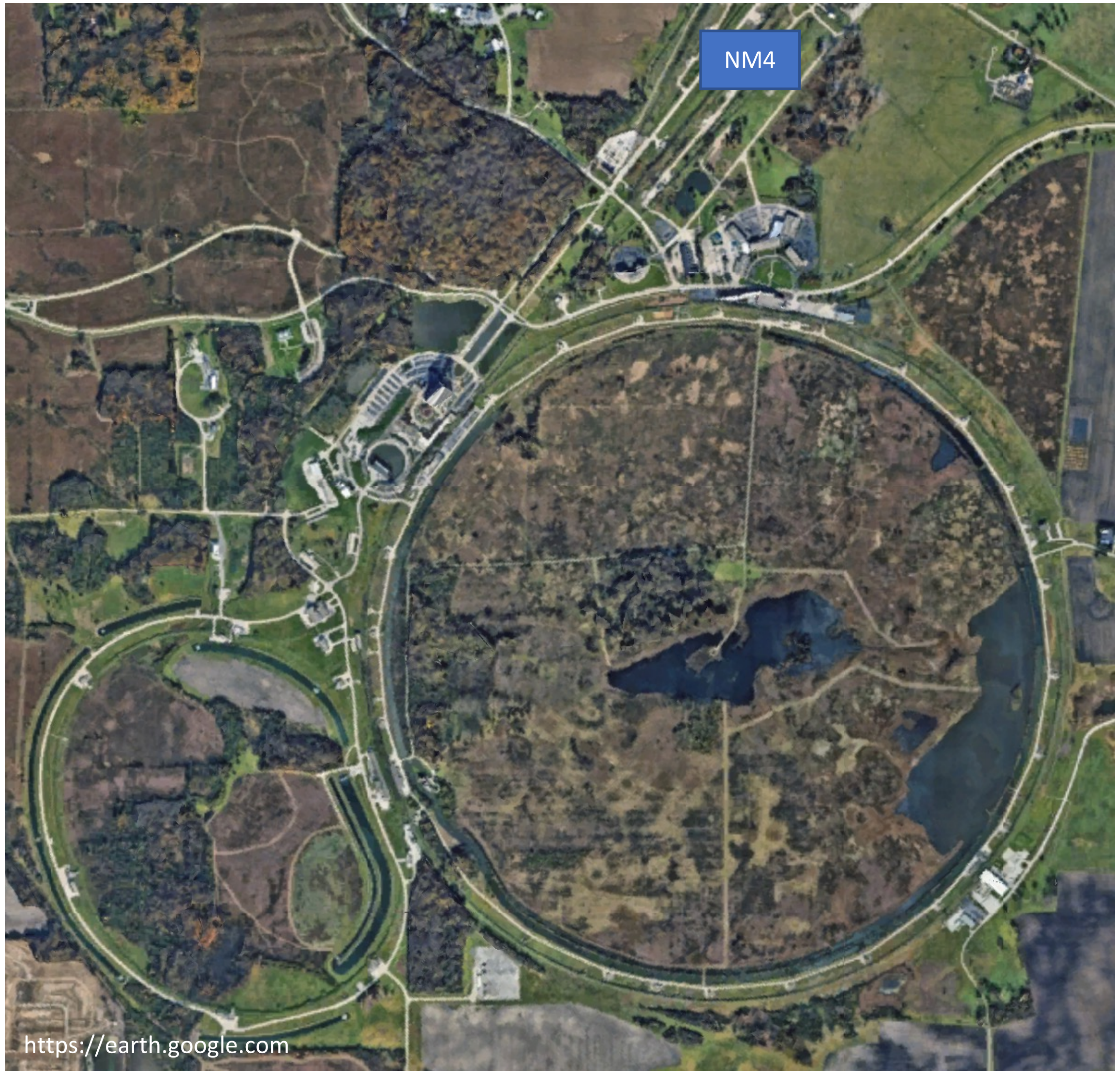
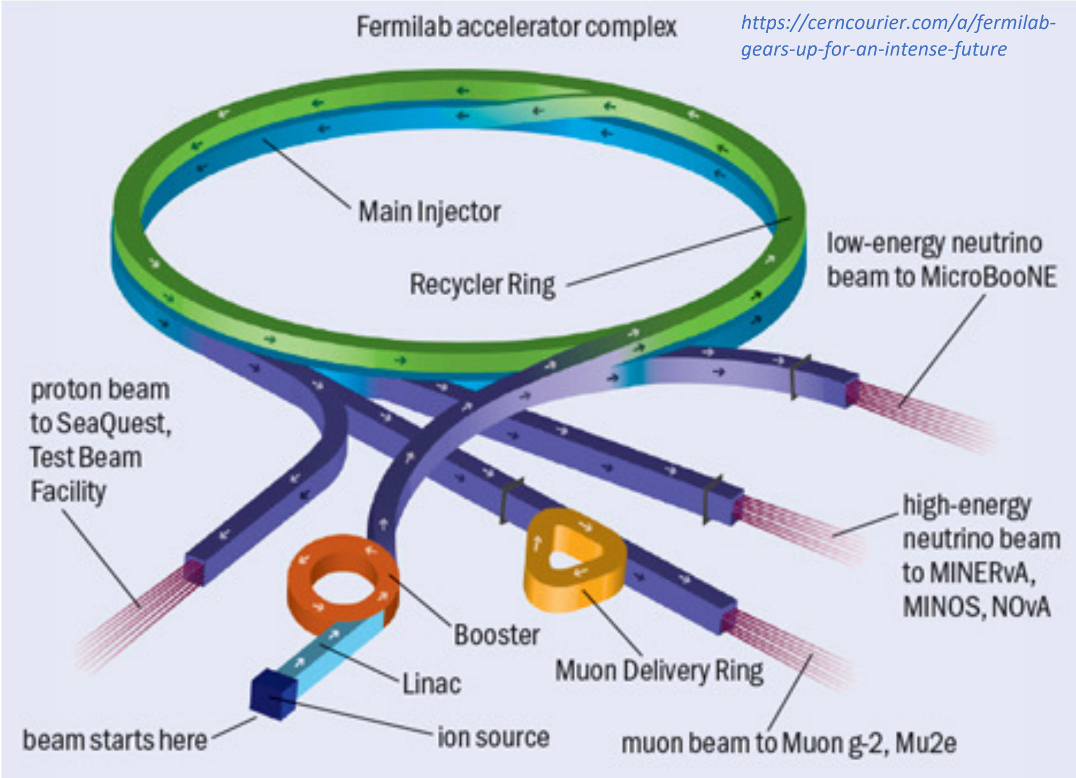
17) Tsinghua University	Zhihong Ye (PI)	
18) University of Virginia	Dustin Keller (SP), Kenichi Nakano, Ishara Fernando, Zulkaida Akbar, Waqar Ahmed, Liliet Diaz, Anchit Arora, Arthur Conover, Jay Roberts	Donal Day, Donald Crabb, Jixie Zhang, Oscar Rondon, Ellen Brown, Blaine Norum, Matthew Roberts
19) 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

$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9x_1x_2}\frac{1}{s} \times \sum_i e_i^2[q_{ti}(x_t)\bar{q}_{bi}(x_b) + \bar{q}_{ti}(x_t)q_{bi}(x_b)]$$

Fermilab E866/NuSea

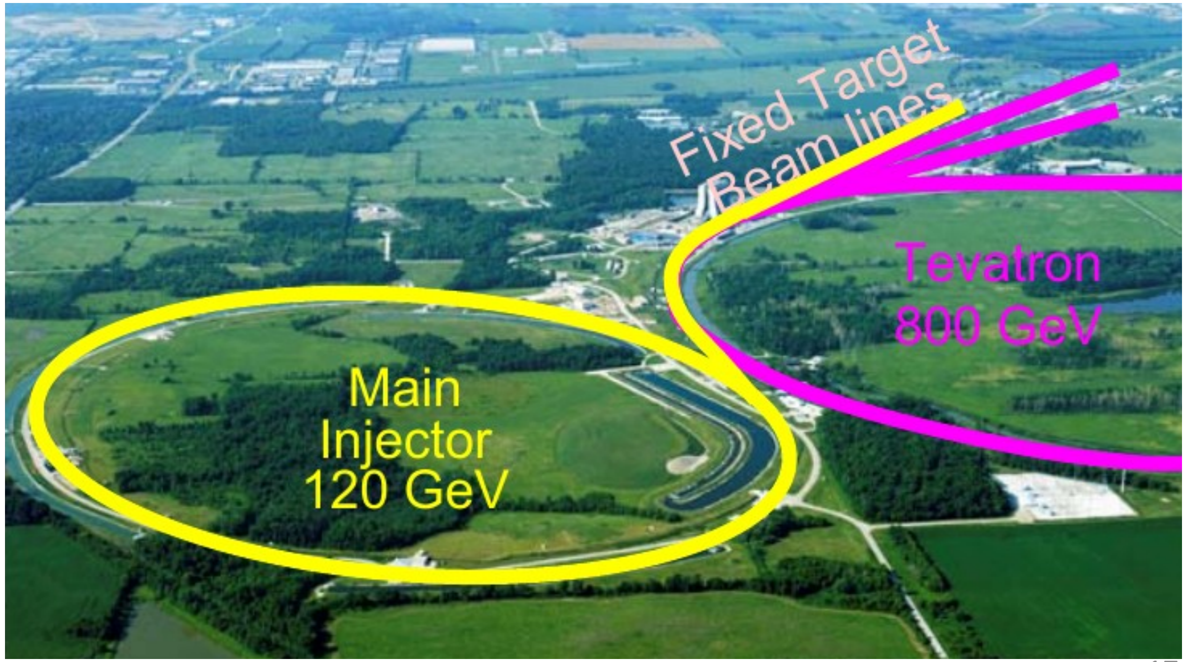
Data in 1996-1997
^{1}H, ^{2}H and nuclear targets
800 GeV proton beam

Fermilab E906/E1039

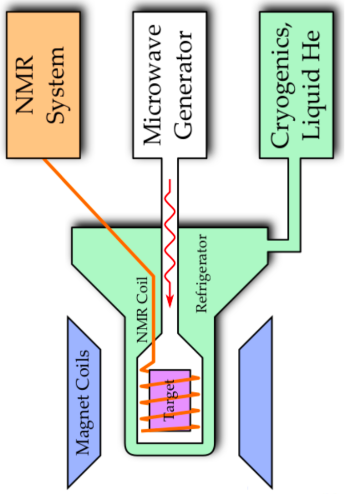
Data in > 2010
^{1}H, ^{2}H and nuclear targets
120 GeV proton beam

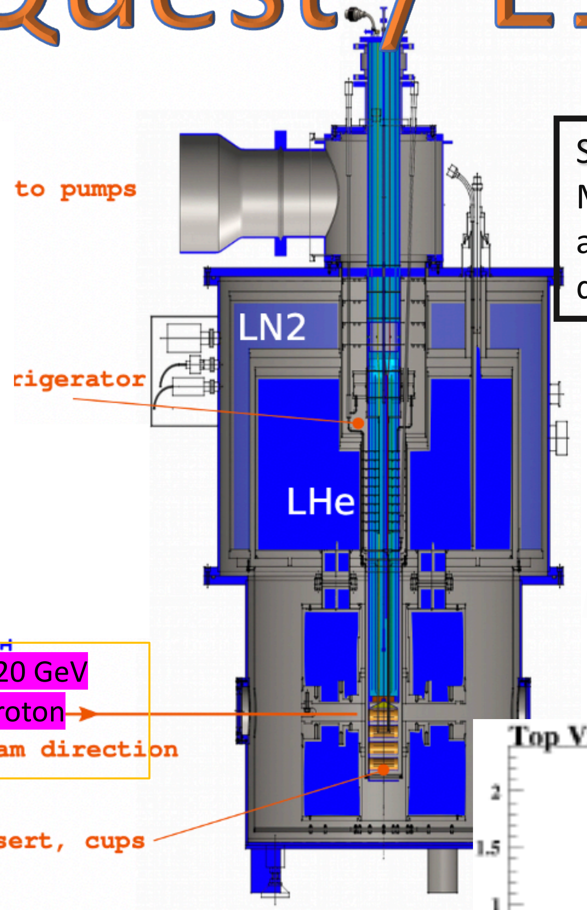
Therefore, the SpinQuest/E1039 experiment will get,

- Cross-Section scales as ~7 times compare to that with 800 GeV beam
- Luminosity is ~7 times compare to that with 800 GeV beam
- ~49 x Statistics with 800 GeV beam

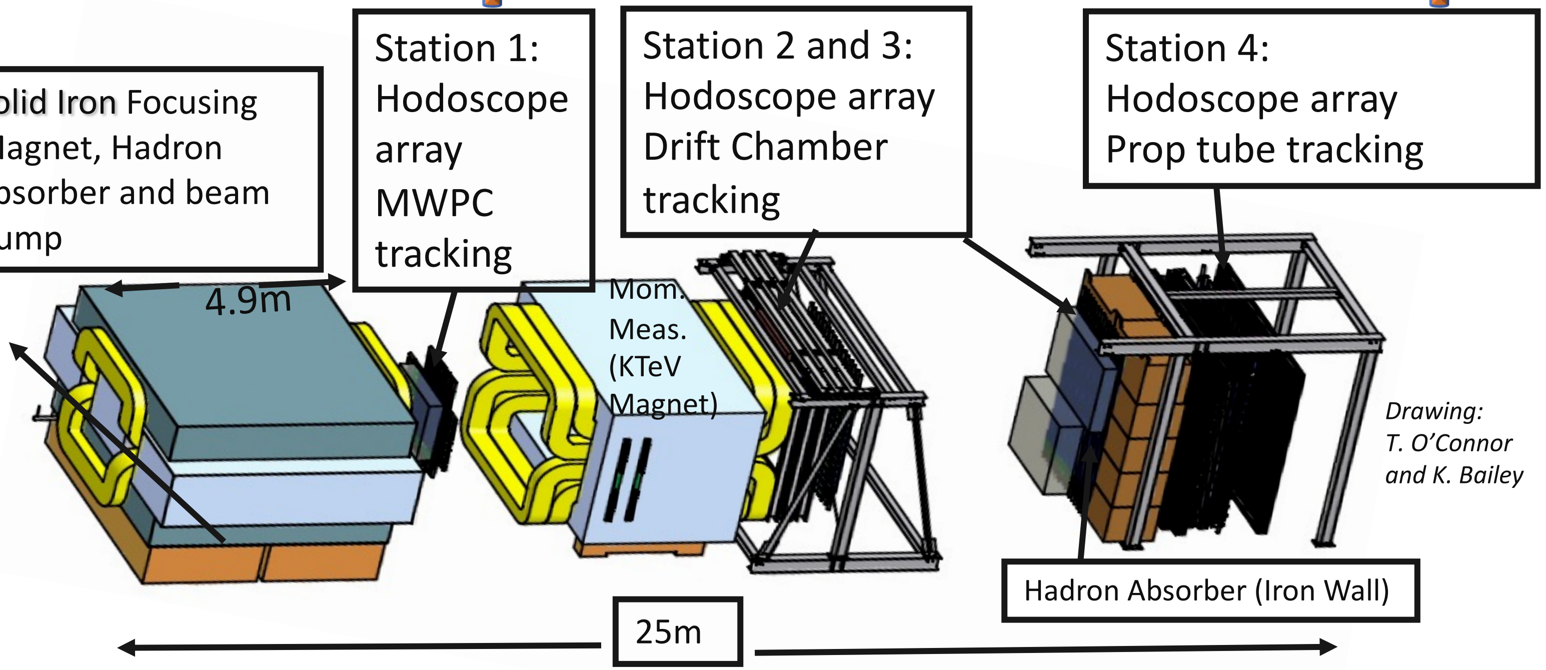


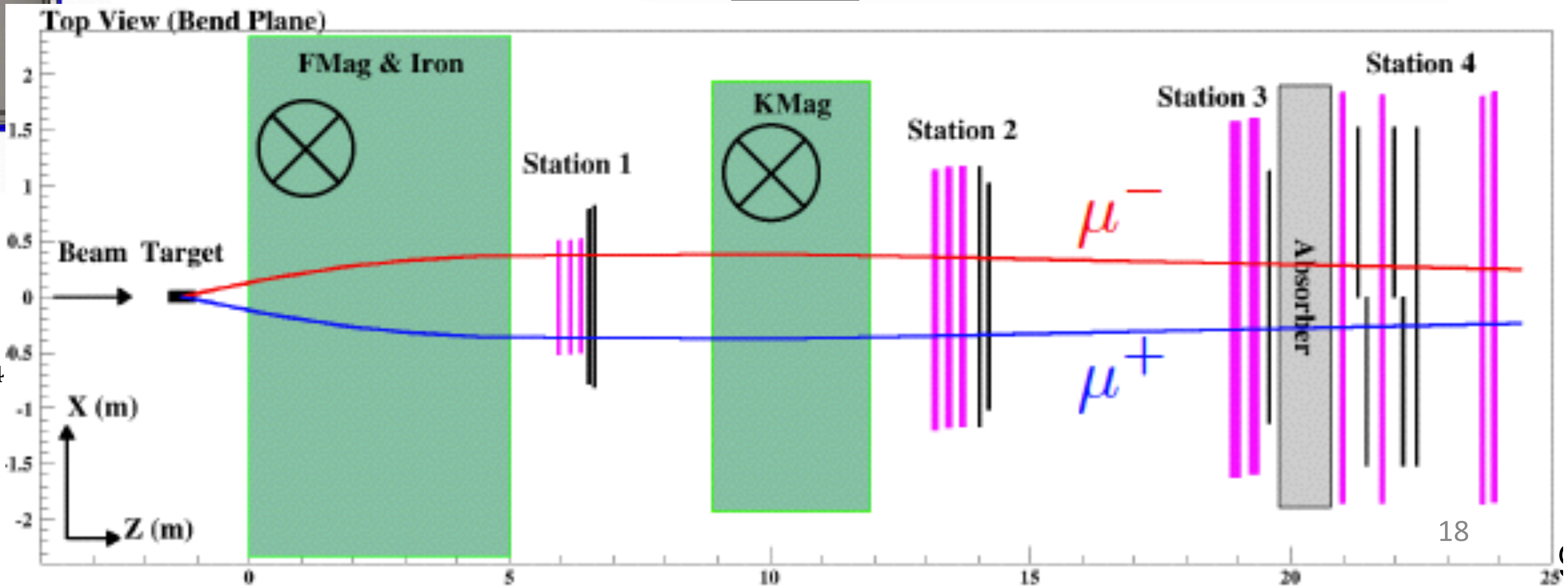
SpinQuest / E1039 Experiment Setup





Polarized solid NH3 & ND3 target setup

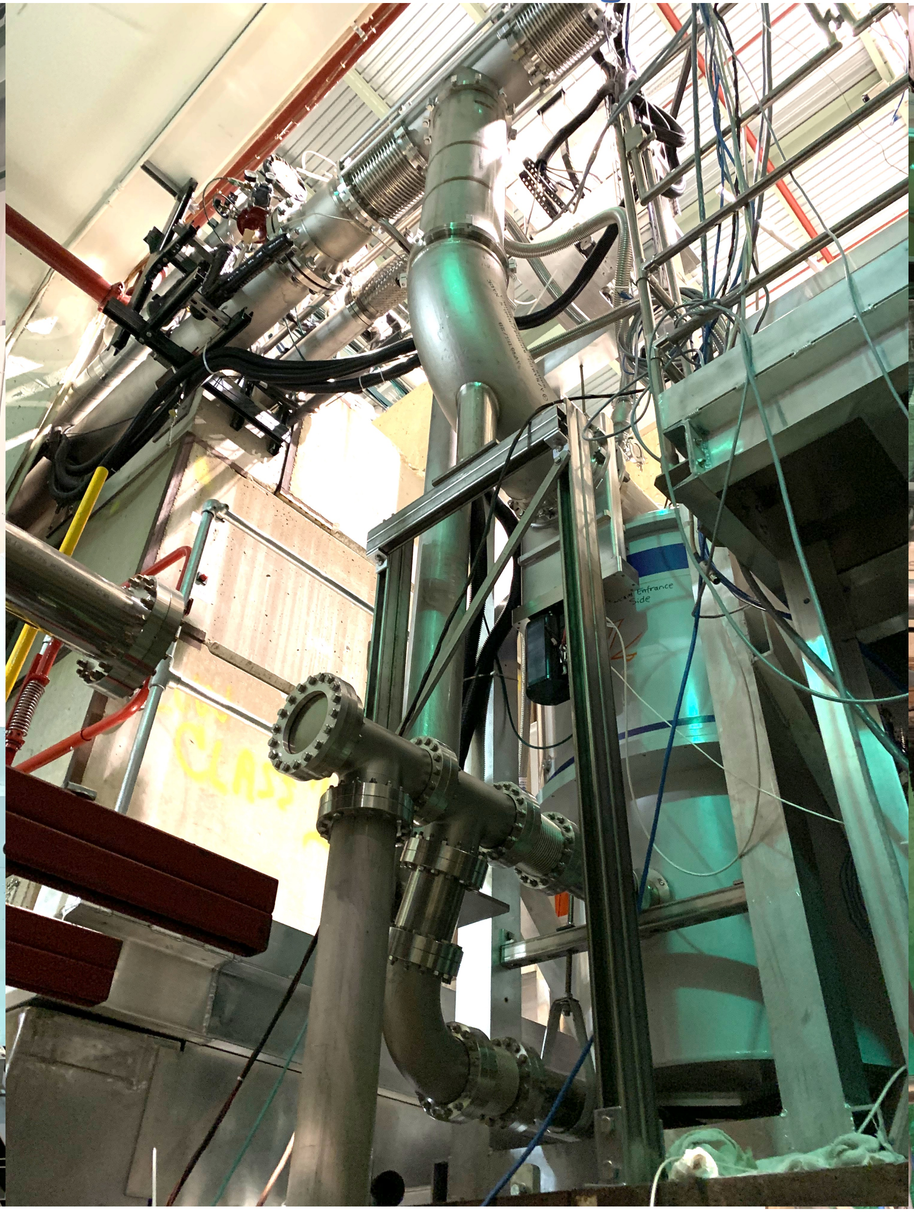




- Designed for high intensity proton beam (5×10^{12} $protons/spill$ with 4.4s spill) by **LANL-UVA group**
- 8 cm long solid NH_3 and ND_3 target cells
- Magnetic Field: B = 5 T with uniformity $dB/B < 10^{-4}$ over 8 cm
- ^{4}He evaporation refrigerator (3 W of maximum cooling power) keeping the target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

SpinQuest / E1039 Experiment Setup

From beam down-stream

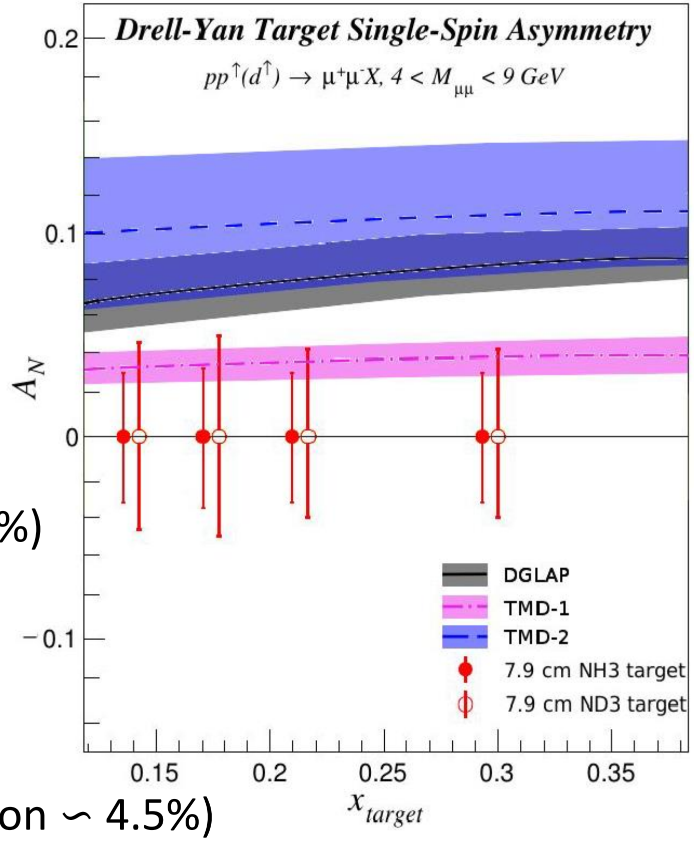


Beam-window and superconducting magnet

From target cave to beam-upstream

Predicted Uncertainties

- Beam (∽ 2.5%)
  - Relative luminosity (∽ 1%)
  - Drifts (< 2%)
  - Scraping (∽ 1%)
- Analysis sources (∽ 3.5%)
  - Tracking efficiency (∽ 1.5%)
  - Trigger & geometrical acceptance (<2%)
  - Mixed background (∽ 3%)
  - Shape of DY (∽ 1%)
- Target (∽ 6-7 %)
  - TE calibration (proton ∽ 2.5%; deuteron ∽ 4.5%)
  - Polarization inhomogeneity (∽ 2%)
  - Density of target ($NH_{3(s)}$) (∽ 1%)
  - Uneven radiation damage (∽ 3%)
  - Beam-Target misalignment (∽ 0.5%)
  - Packing fraction (∽ 2%)
  - Dilution factor (∽ 3%)



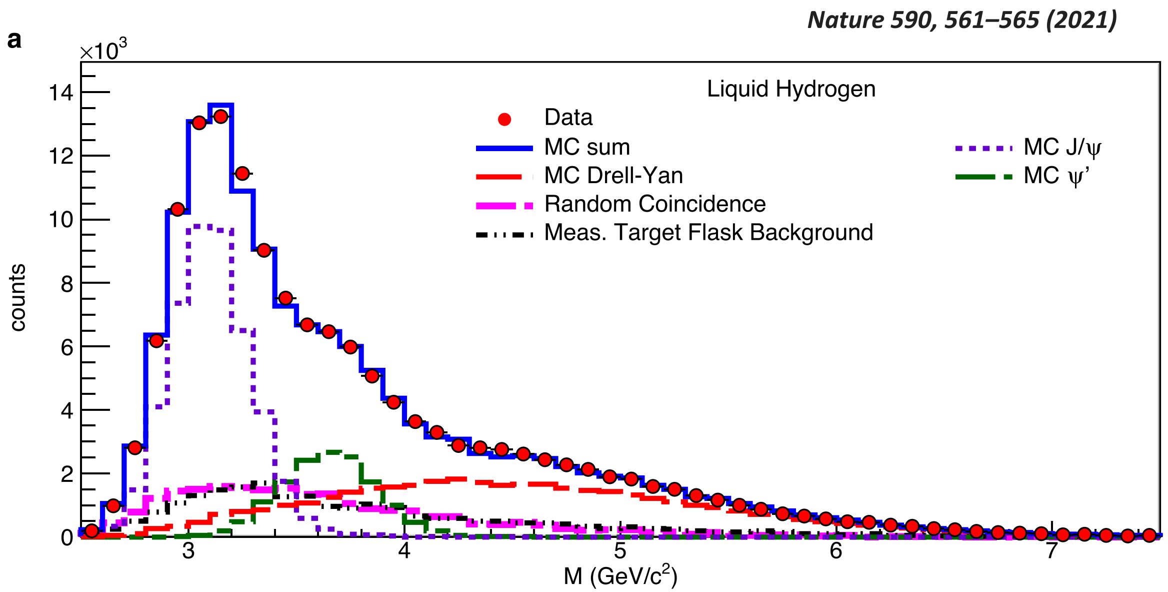
DGLAP: M. Anselmino et al arXiv:1612.06413
TMD-1: M. G. Echevarria et al arXiv:1401.5078
TMD-2: P. Sun and F. Yuan arXiv:1308.5003
A. Prokudin et al (in progress)
I. Fernando, D. Keller (in progress)

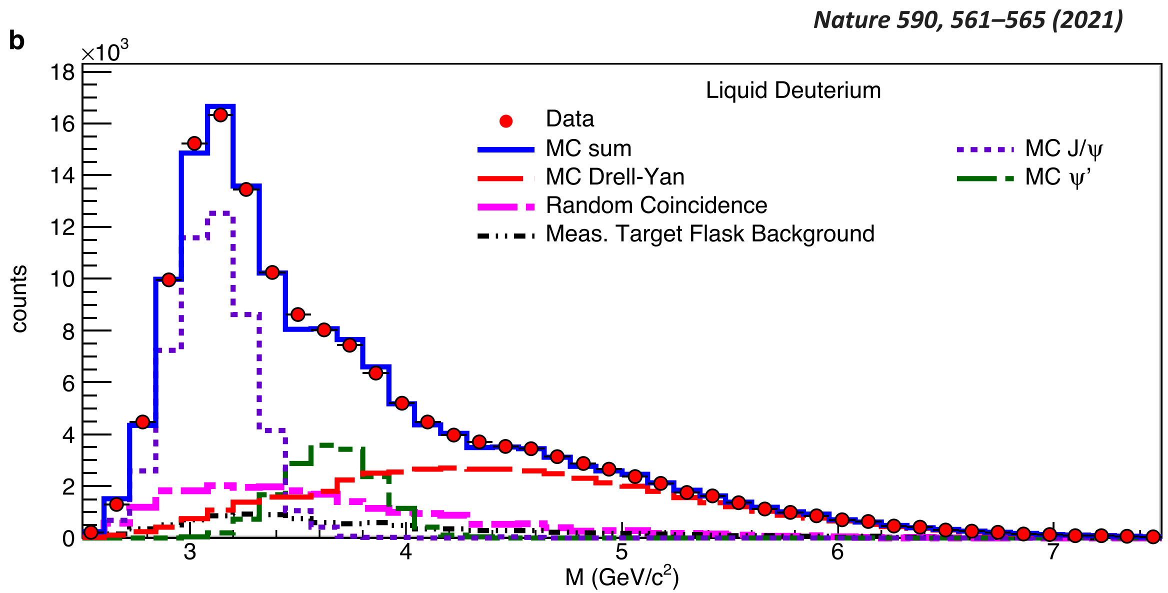
$$A = \frac{2}{f|S_T|}\frac{\int d\phi_S d\phi \frac{dN(x_b,x_t,\phi_S,\phi)}{d\phi_S d\phi} sin(\phi_S)}{N(x_b,x_t)}$$

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
- Polarized target commissioning will be completed by Fall of 2022
- E1039 commissioning starts in this Fall 2022
  [Run for 2+ years, 2022-2024+]

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,...

Welcome!

Please Join The Effort
Dustin Keller (dustin@virginia.edu)[Spokesperson]
Kun Liu ([Spokesperson])

https://spinquest.fnal.gov/

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

SPIN QUEST

Fermilab

Thank you

SPIN QUEST

Fermilab

UNIVERSITY of VIRGINIA

UVA - Spin PHYSICS GROUP

U.S. DEPARTMENT OF ENERGY | Office of Science

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Back-up Slides

(Un)Polarized DY

Experiment	Particles	Energy (GeV)	x_b or x_t	Luminosity (cm^{-2} s^{-1})		P_b or P_t (f)	rFOM#	Timeline
COMPASS (CERN)	$\pi^- + p^\uparrow$	160 GeV $\sqrt{s} = 17$	$x_t = 0.1 – 0.3$	2×10^{33}		$P_t = 90\%$ f = 0.22	1.1×10^{-3}	2015-2016, 2018
J-PARC (high-p beam line)	$\pi^- + p$	10-20 GeV $\sqrt{s} = 4.4\text{-}6.2$	$x_b = 0.2 – 0.97$ $x_t = 0.06 – 0.6$	2×10^{31}		---	---	>2020? under discussion
fsPHENIX (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}		$P_b = 60\%$ $P_b = 50\%$	4.0×10^{-4} 2.1×10^{-3}	>2021?
SeaQuest (FNAL: E-906)	$p + p$	120 GeV $\sqrt{s} = 15$	$x_b = 0.35 – 0.9$ $x_t = 0.1 – 0.45$	3.4×10^{35}		---	---	2012 – 2017
Pol tgt DY‡ (FNAL: E-1039)	$p + p^\uparrow$ $p + d^\uparrow$	120 GeV $\sqrt{s} = 15$	$x_t = 0.1 – 0.45$	3.0×10^{35} 3.5×10^{35}		$P_t = 85\%$ f = 0.176	0.15	2021-2023+
Pol beam DY§ (FNAL: E-1027)	$p^\uparrow + p$	120 GeV $\sqrt{s} = 15$	$x_b = 0.35 – 0.9$	2×10^{35}		$P_b = 60\%$	1	>2021?

Source: Wolfgang Lorenzon

‡ *8 cm NH_3 target* / § *L= 1×10^{36} cm^{-2} s^{-1} (LH_2 tgt limited) / L= 2×10^{35} cm^{-2} s^{-1} (10% of MI beam limited)*

**not constrained by SIDIS data* / # rFOM = relative lumi * P^2 * f^2 wrt E-1027 (f=1 for pol p beams, f=0.22 for π^- beam on NH_3)