Measurement of the Sivers asymmetry at SpinQuest experiment

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New Perspectives 2021

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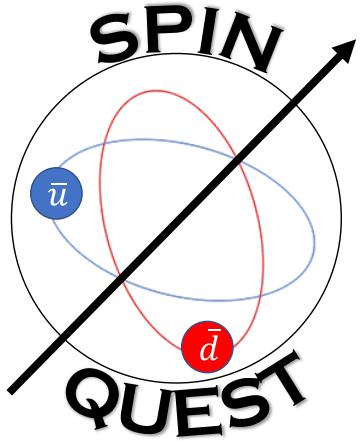

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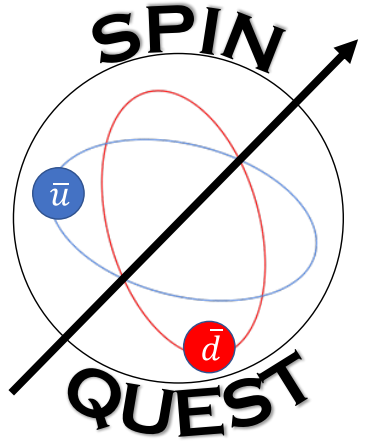
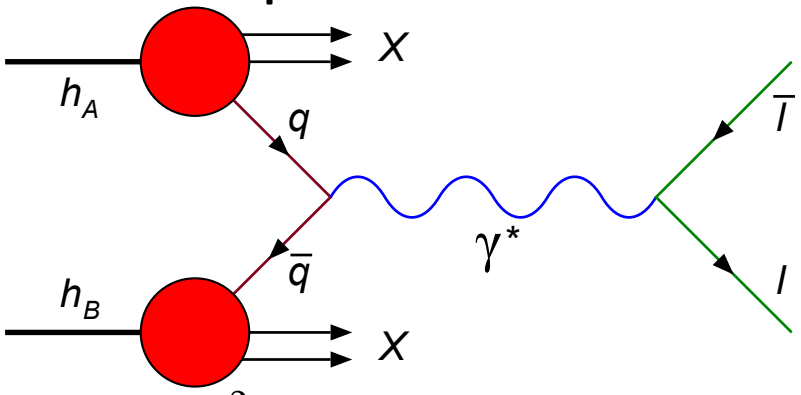
E1039/SpinQuest

- A fixed target experiment with a transversely polarized NH_3 and ND_3 targets
- Measure the azimuthal asymmetry in Drell-Yan process
- Provide information on the Sivers function of the light sea quarks

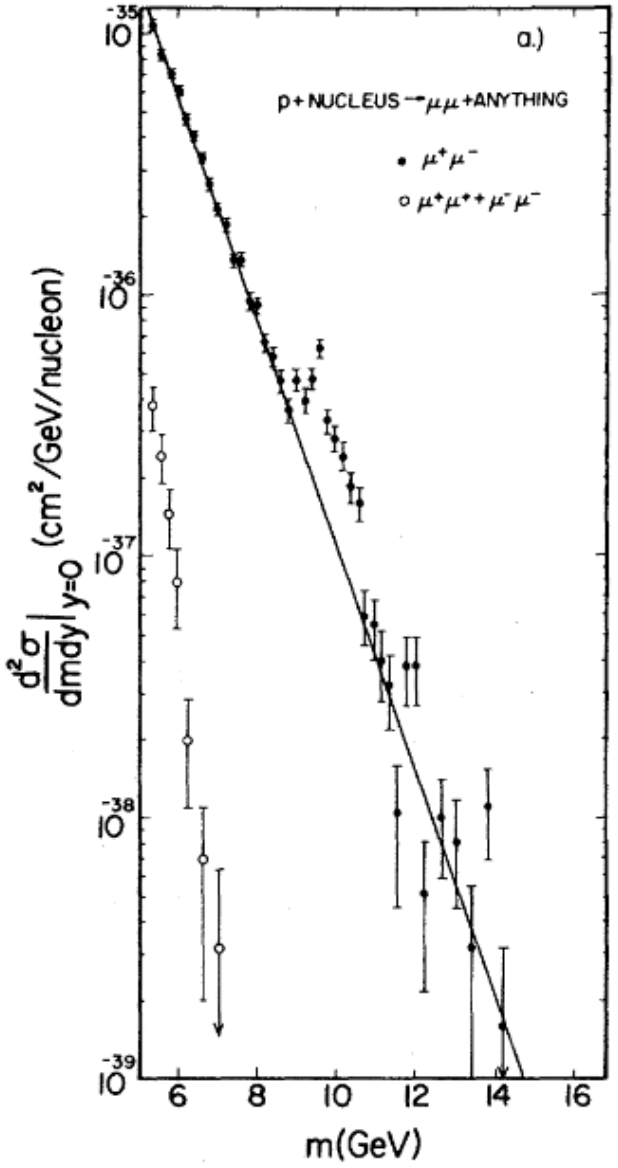


Drell-Yan process

- A long history of dimuon experiment here in Fermilab
- Previous experiments were addressing the longitudinal motion of quarks



$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9M^2} \sum_i e_i^2 [q_i(x_1)\bar{q}_i(x_2) + \bar{q}_i(x_1)q_i(x_2)]$$



Discovery of Upsilon

Phys. Rev. Lett. 39, 252

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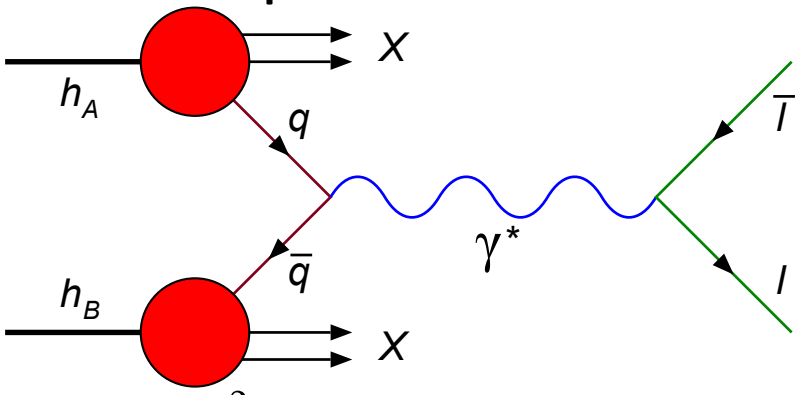

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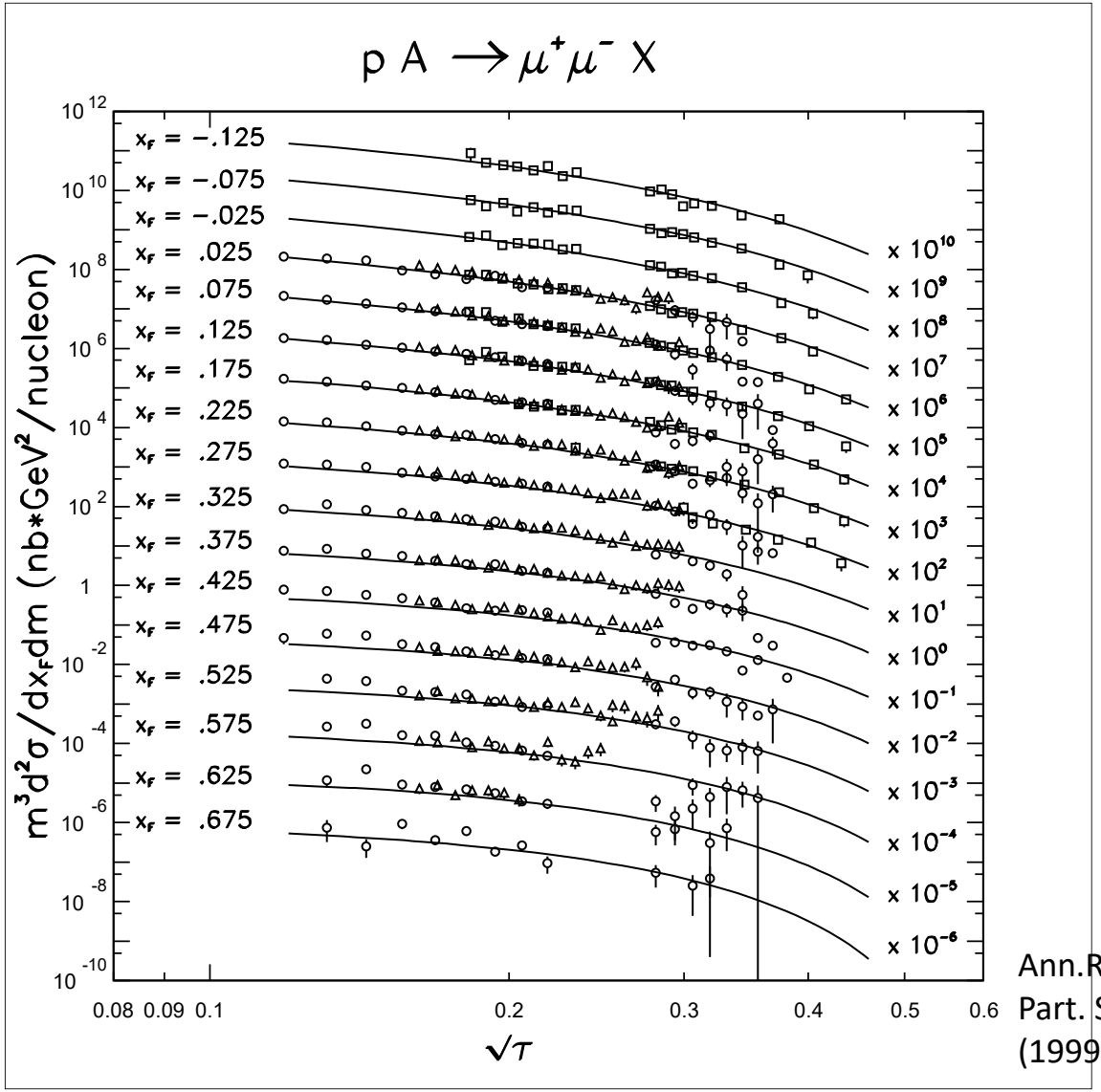
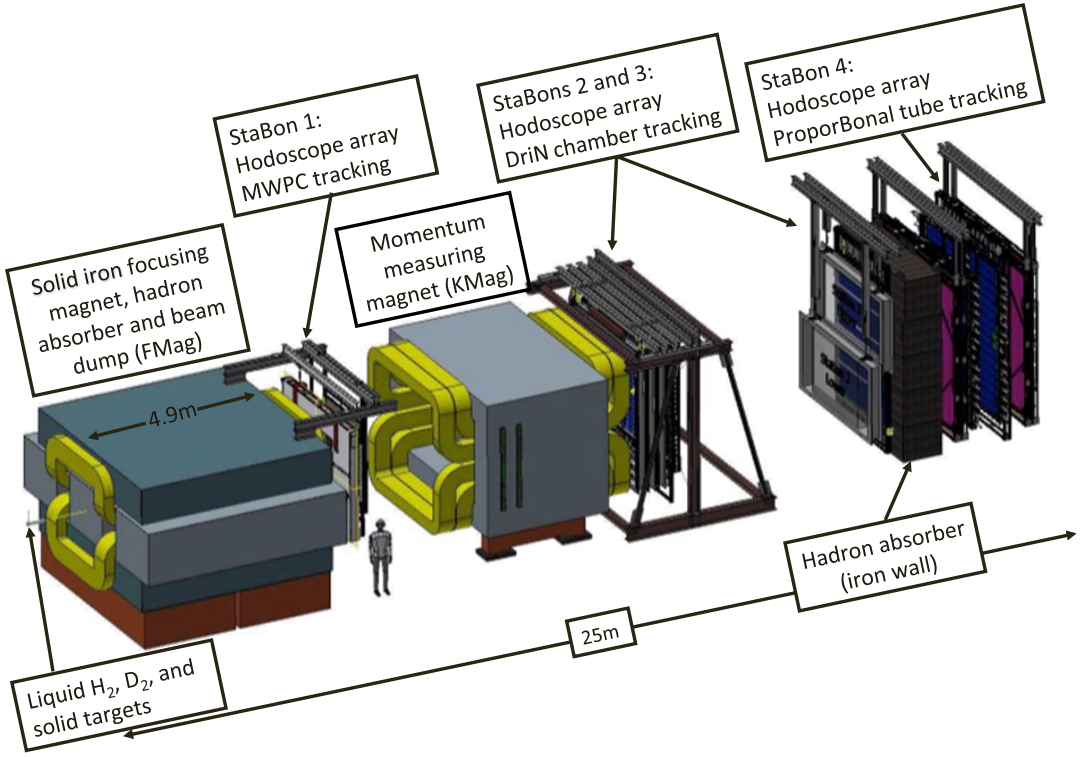


Ann.Rev.Nucl. Part. Sci. 49 (1999) 217

A compilation of Drell-Yan data from CERN(NA3) and Fermilab(E605 and E772)

SeaQuest Experiment

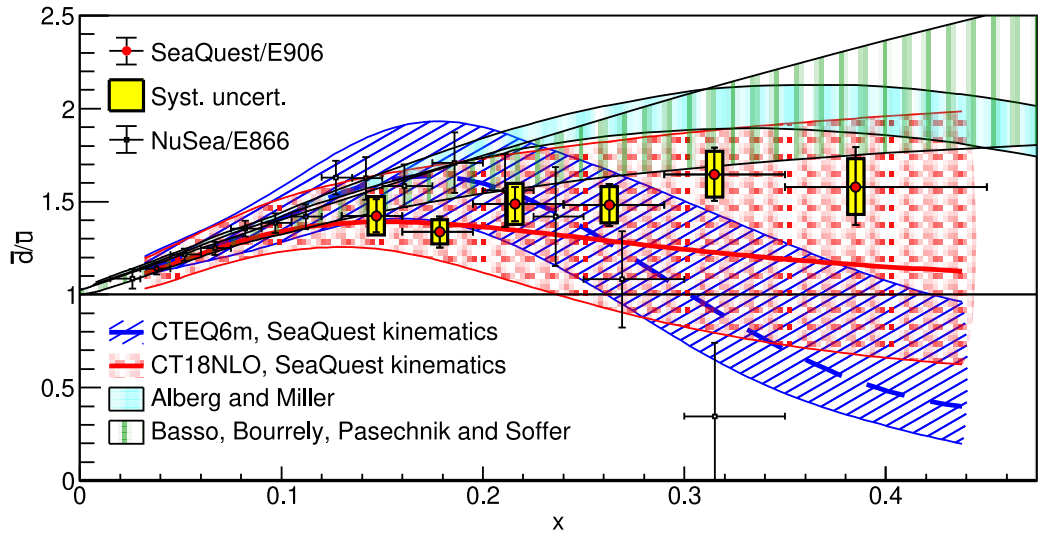
- Most recent Drell-Yan Experiment at Fermilab
- 120 GeV proton beam from Main Injector
- A forward spectrometer
- The antiquarks are more likely to come from the target
- Design to measure the sea quark structure at higher x

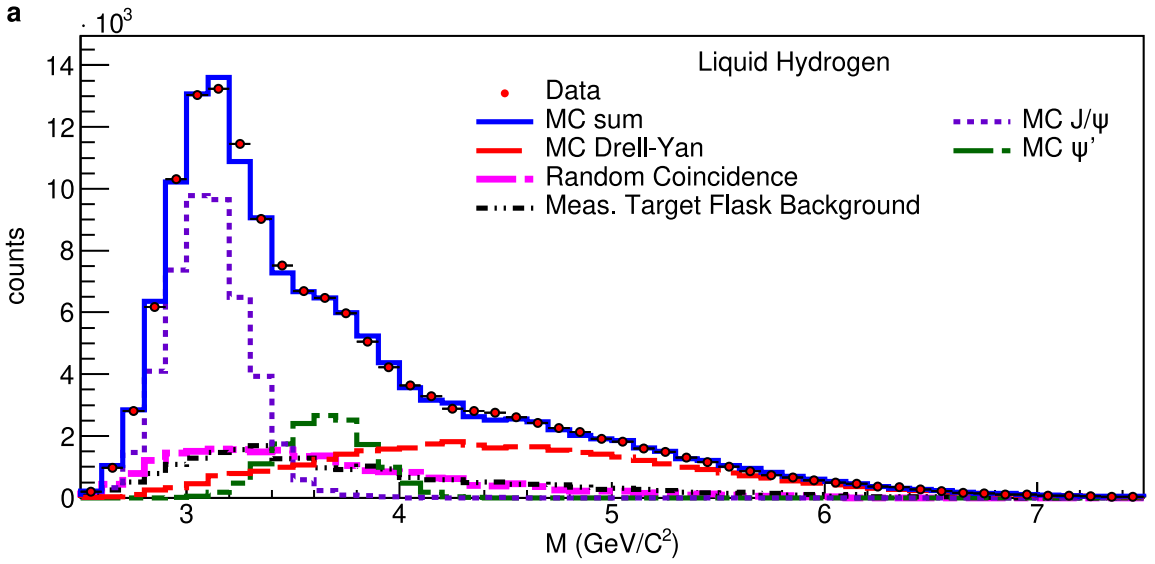


Nucl. Instrum. Methods
Phys. Res., Sect. A 930, 49 (2019)

Result from SeaQuest

- The mass spectrum contain the J/ψ peak and well as the Drell-Yan continuum at high mass
- The antiquark structure can be probed using the Drell-Yan process

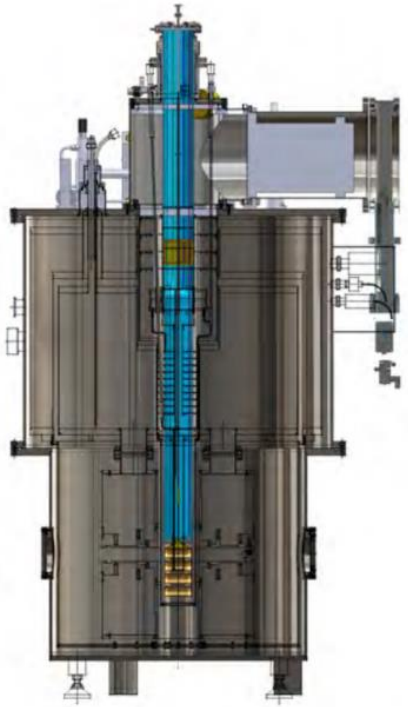


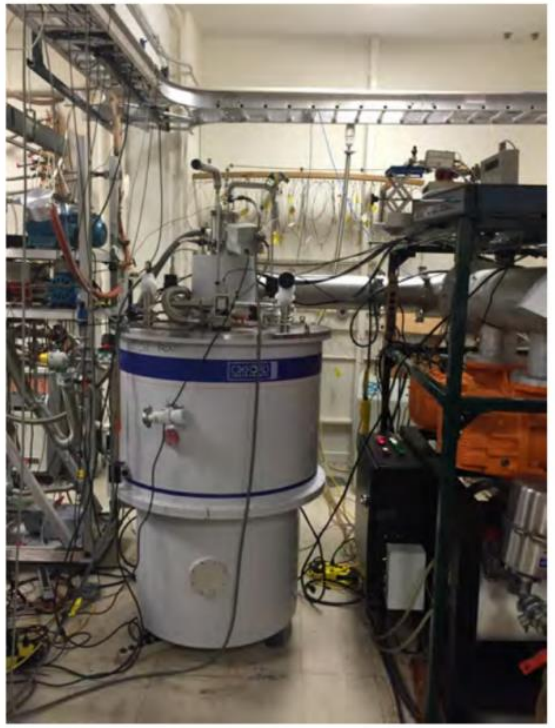


Nature volume 590, pages 561–565 (2021)

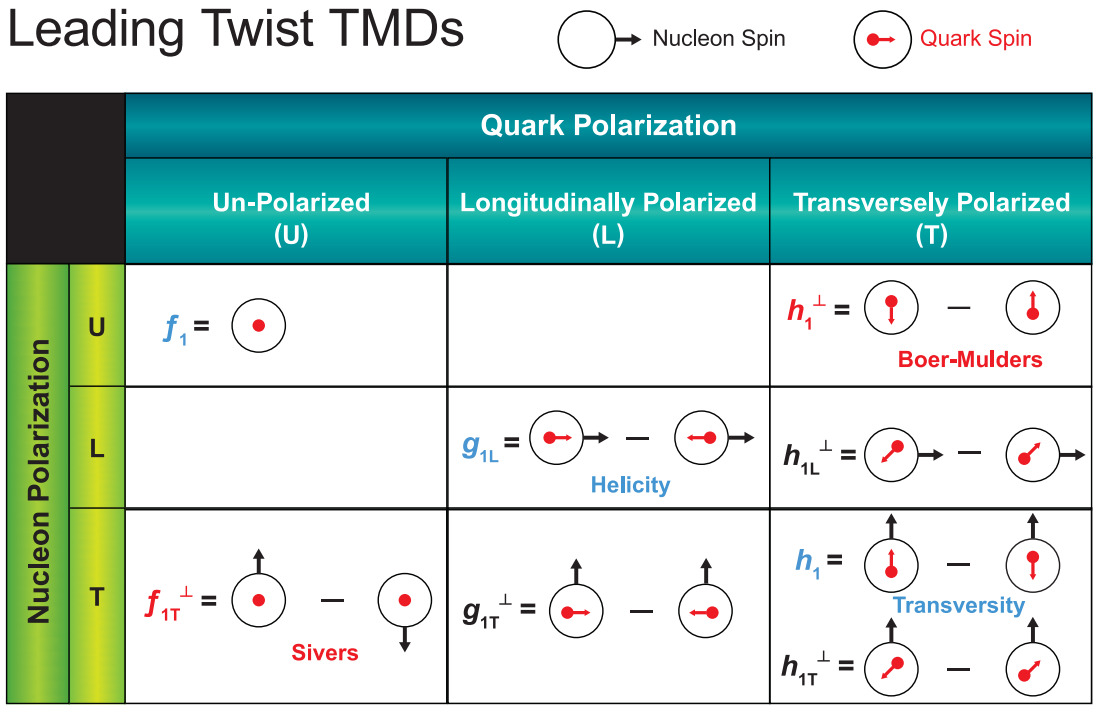
SpinQuest Experiment

- First Drell-Yan experiment at Fermilab with a polarized target
- The same spectrometer from SeaQuest will be used
- The transversely polarized target allows us to probe the transverse degree of freedom of partons in nucleon





Transverse momentum dependent parton distributions (TMDs)



- Eight quark TMDs
- Classified by the polarization of the nucleon and quarks
- Similar TMDs for gluon

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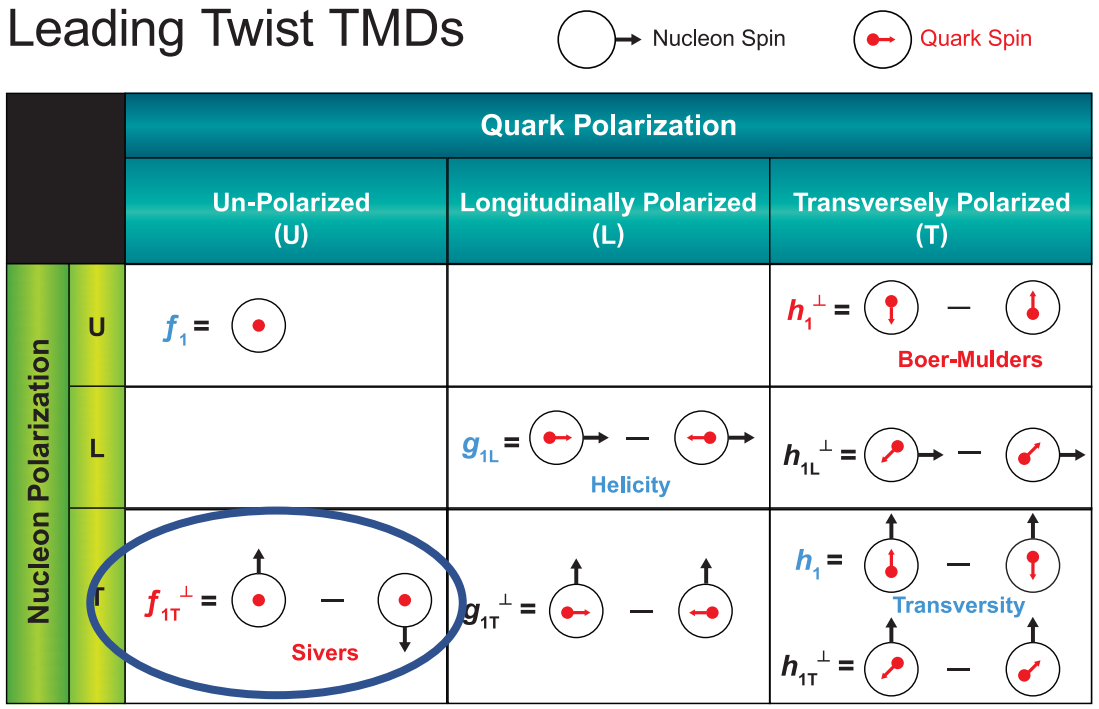

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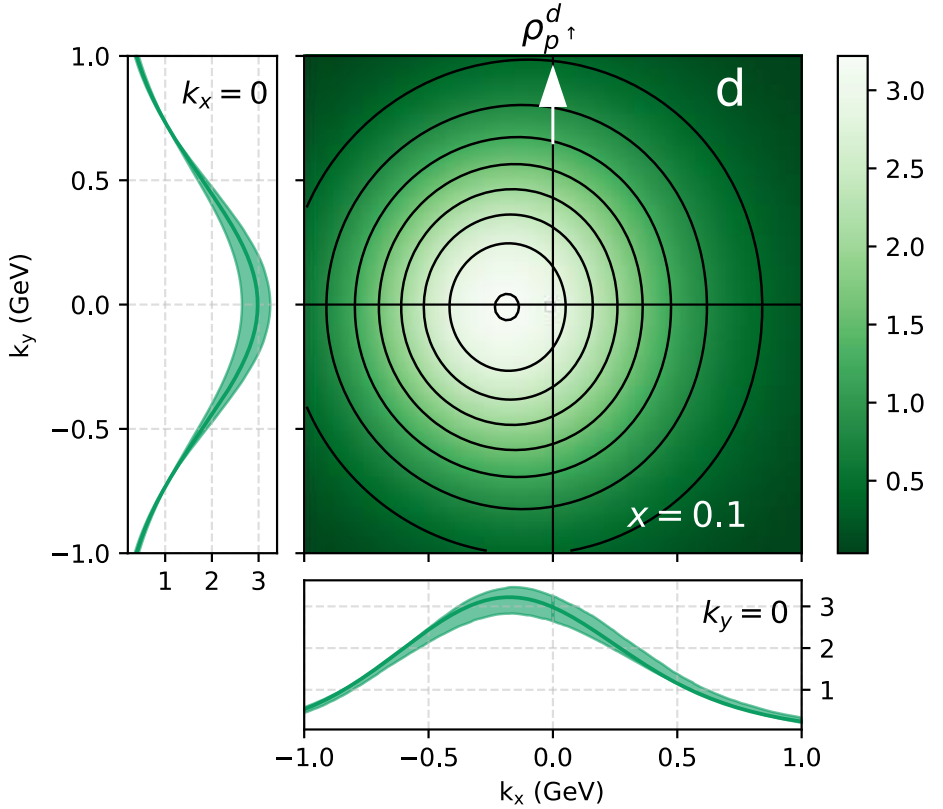
Sivers function

- Correlation between the quark transverse momentum and the nucleon transverse spin vector
- Causes a left-right asymmetry in measured dimuon distribution relative to nucleon transverse spin direction
- The current models are fitted to DIS data
  - Mostly sensitive to the valence quarks

$$\hat{f}_{q/p^{\uparrow}}\left(x,\vec{k}_{\perp}\right) = f_{q/p}(x,k_{\perp}) + \frac{2k_{\perp}}{m_p} \underbrace{f_{1T}^{\perp q}(x,k_{\perp})}_{\text{Sivers function}} \vec{S}\cdot\left(\hat{P}\times\hat{k}_{\perp}\right)$$



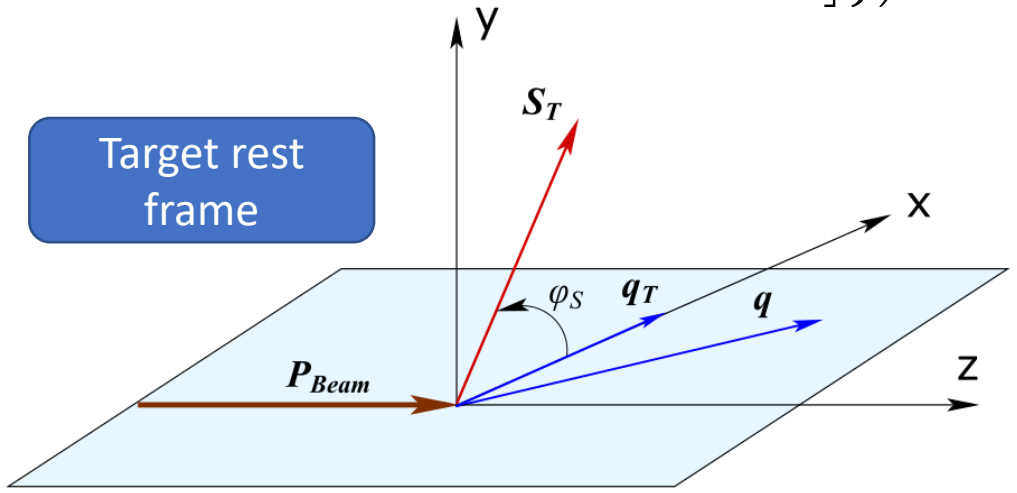
The number density of quarks in a proton polarized along $\hat{y}$, for $x = 0.1$

arXiv:2004.14278v1

Measuring Sivers functions in the Drell-Yan process

- The angular distribution can be expressed as

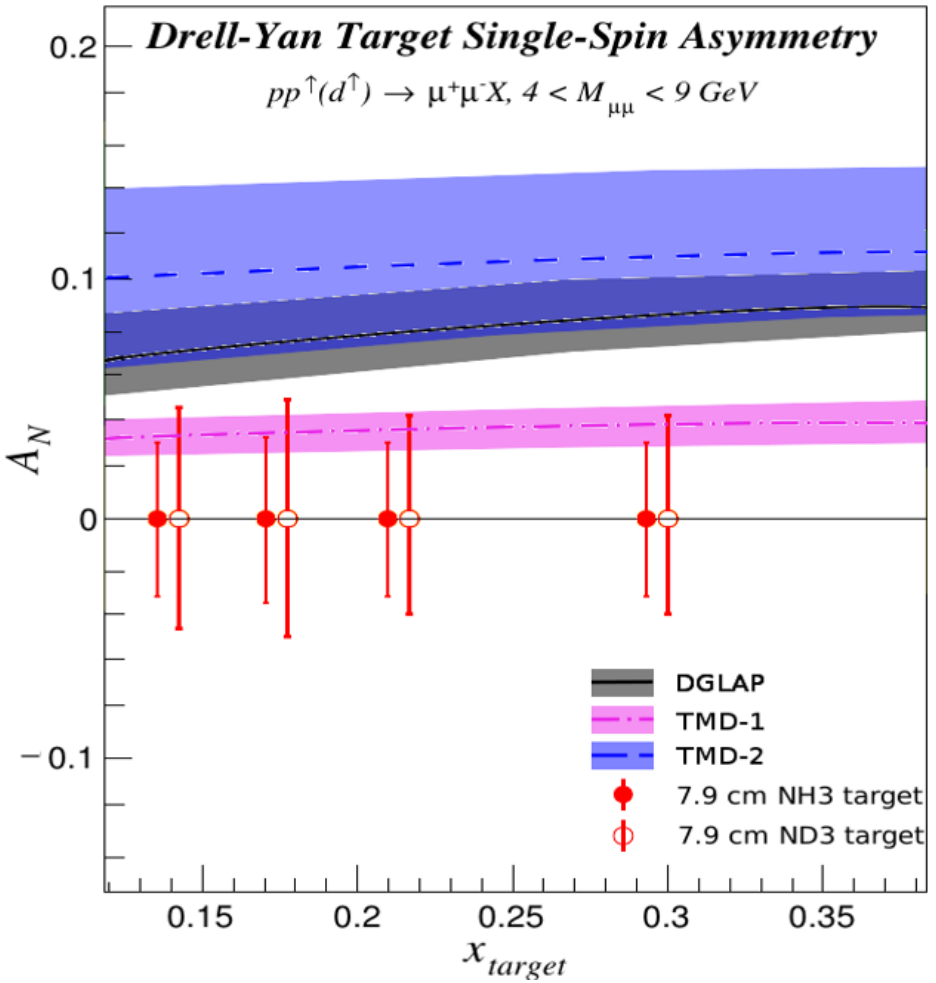
$$\frac{d\sigma}{dq^4 d\Omega} \propto \hat{\sigma}_U \Big(1 + S_T \Big\{ D_1 A_T^{\sin\varphi_s} \sin\varphi_s + D_2 \Big[A_T^{\sin(2\varphi_{CS}-\varphi_S)} \sin(2\varphi_{CS}-\varphi_S) + A_T^{\sin(2\varphi_{CS}+\varphi_S)} \sin(2\varphi_{CS}+\varphi_S) \Big] \Big\} \Big)$$



- $A_T^{\sin\varphi_S}$ is related to the convolution of the Sivers function $f_{1T}^{\perp}$ and unpolarized TMD f_1
- The other modulations are related to other TMDs

Expected Sensitivity

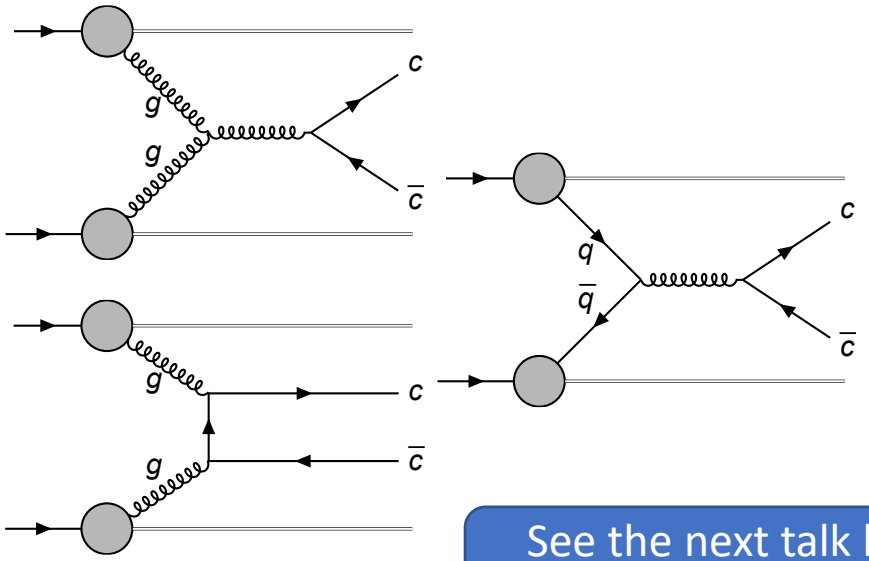
- Expected results after two years of combined running on NH3 and ND3 targets.
- The three bands are from different theoretical predictions
  - Fitted to DIS data, insensitive to the sea quark contribution

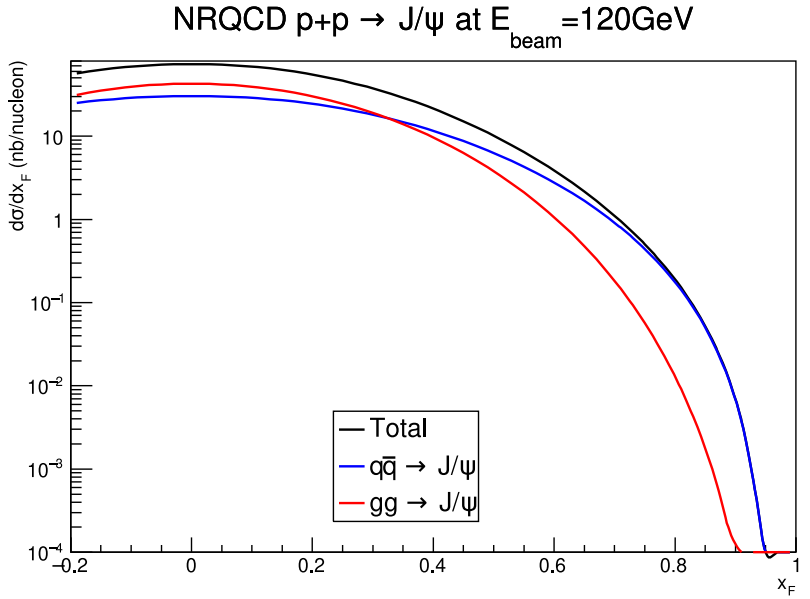


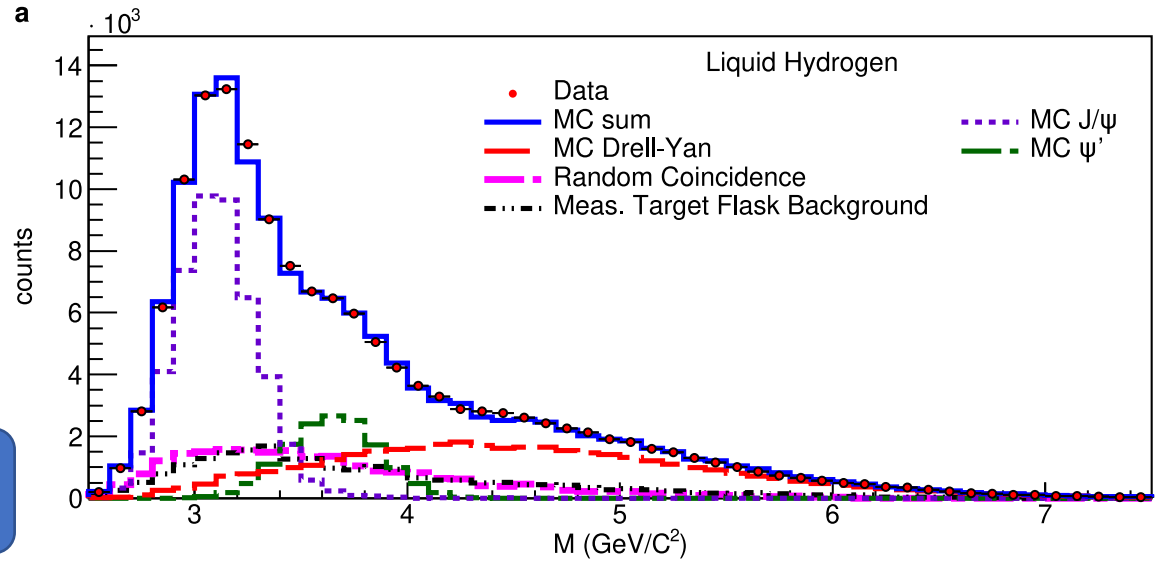
DGLAP: M. Anselmino et al arXiv:1612.06413
TMD-1: M. G. Echevarria et al arXiv:1401.5078
TMD-2: P. Sun and F. Yuan arXiv:1308.5003

J/ψ production

- The J/ψ production is sensitive to the gluon Sivers function as well as the quark Sivers function







See the next talk by Forhad Hossain

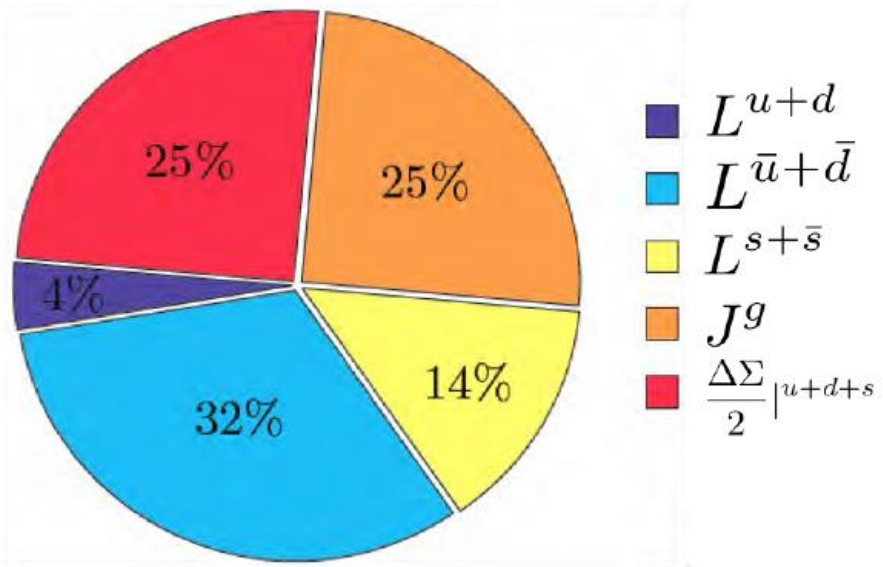
Conclusion

- SpinQuest can measure the transverse single spin asymmetry in Drell-Yan process and charmonium production
- This can provide information to the Sivers function for the quarks and gluons
- Expect to start beam commissioning in December 2021 and physics run in spring 2022

Orbital angular momentum

- The spin of the quark alone cannot fully account for the spin of the proton
- Orbital angular momentum of the sea quarks can be significant contribution

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



$\Delta\Sigma_q \approx 25\%$ $\quad L_u \approx - L_d$

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

$2\ J_\sigma \approx 25\%$