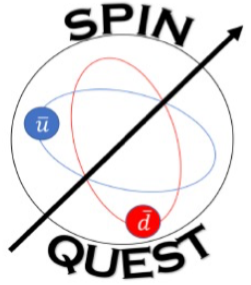
Extracting Sivers Asymmetry in Drell-Yan at SpinQuest Experiment using a likelihood method

Harsha Sirilal Kalu Arachchige, S. Pate, Dinupa Nawarathne, V. Papavassiliou



Outline

- The Proton
- SpinQuest
  - Physics
  - Experimental Setup
- Asymmetry Extraction (Simulation Study)
  - Simulating the dataset
  - Likelihood Estimate
  - Un-binned Unfolding
  - Results

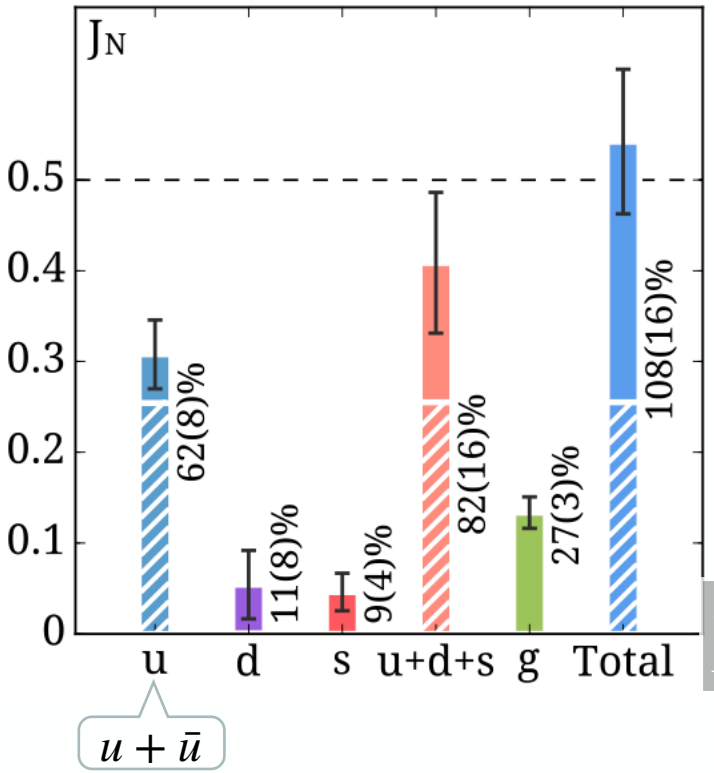
The Proton

Orbital Angular Momentum

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

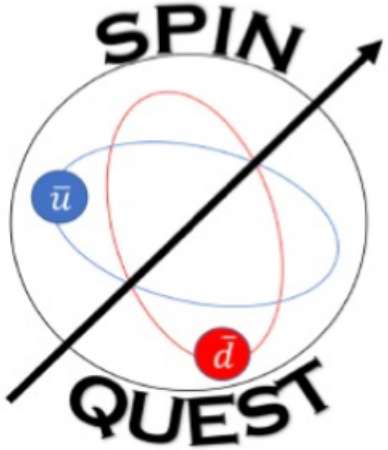
Intrinsic Spin

Sea Quarks



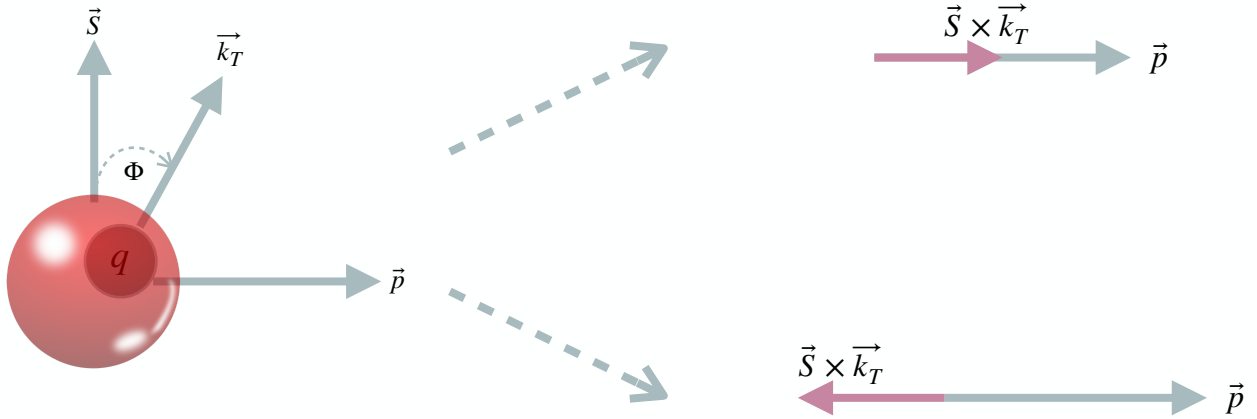
	$\frac{1}{2}\Delta\Sigma$	J	L	$\langle x \rangle$
u	0.415(13)(2)	0.308(30)(24)	−0.107(32)(24)	0.453(57)(48)
d	−0.193(8)(3)	0.054(29)(24)	0.247(30)(24)	0.259(57)(47)
s	−0.021(5)(1)	0.046(21)(0)	0.067(21)(1)	0.092(41)(0)
g	···	0.133(11)(14)	···	0.267(22)(27)
Tot.	0.201(17)(5)	0.541(62)(49)	0.207(64)(45)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

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



SpinQuest

Sivers Function ($f_{1T}^{\perp}(x, k_T)$)



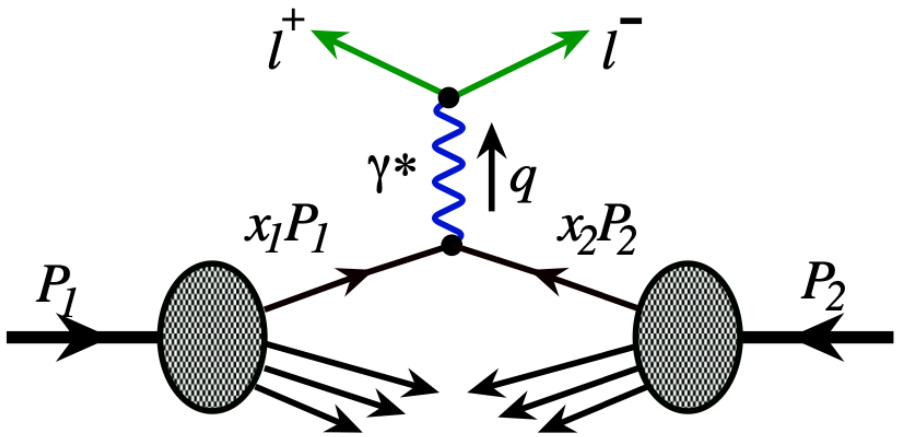
- Describe a correlation between the nucleon Spin ($\vec{S}$) and the Parton's transverse momentum ($\vec{k_T}$).
- Average correlation over many polarized nucleons is non-zero.

$$\left\langle \vec{p} \cdot \left(\vec{S} \times \vec{k_T} \right) \right\rangle \neq 0$$

$$p * S * k_T * \sin(\Phi)$$

Sine modulation in Φ_{lab}

Drell-Yan Process



Jen-Chieh Peng and Jian-Wei Qiu
The Universe 4 (2016) 3, 34-44

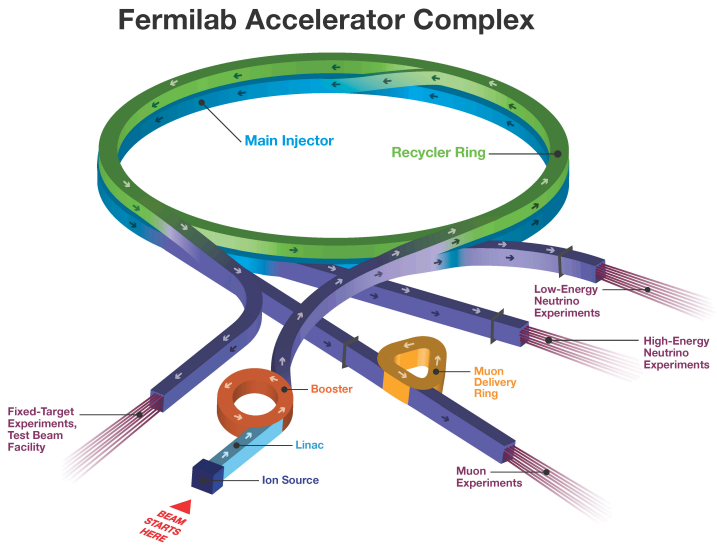
Beam is unpolarized $\rightarrow f_{1T}^{\perp}(x, k_T)$ of the beam will wash out

- Quark from the beam will struck on an anti-quark in the polarized target producing a virtual photon which will decay into a lepton pair.

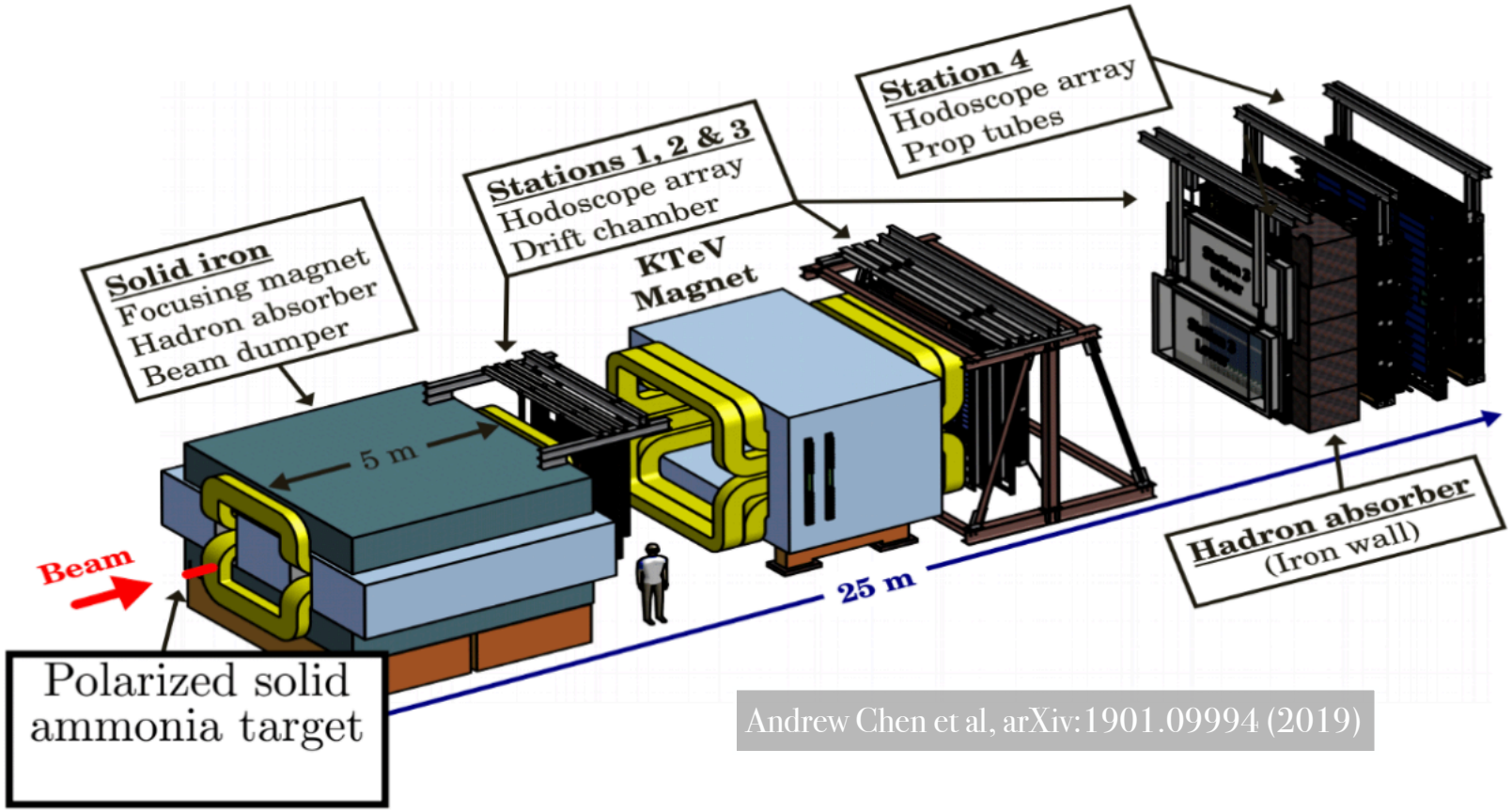
$$\frac{d\sigma^{LO}}{d\Omega} = \frac{\alpha_{em}^2}{Fq} F_v^1 \left\{ 1 + \cos^2\theta + sin^2\theta cos2\phi_{CS} A_U^{cos2\phi_{CS}} \right.$$
$$+ S_T \left[(1 + \cos^2\theta) \sin\phi_s A_T^{\sin\phi_s} + \sin^2\theta \left(\sin(2\phi_{CS} + \phi_s) A_T^{\sin(2\phi_{CS}+\phi_s)} \right.\right.$$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

$$A_T^{\sin\phi_s} \propto f_1^q \otimes f_{1T}^{q\perp}$$

Target is polarized and we are looking for a non-zero sinusoidal modulation in the azimuthal distribution of leptons (di-muons) in the lab frame



https://www.fnal.gov/pub/science/particle-accelerators/accelerator-complex.html



Andrew Chen et al, arXiv:1901.09994 (2019)

- 4×10^{12} protons per spill (4 seconds)
- Fixed Targets : NH_3/ND_3
- Polarization : Transverse to the beam

Asymmetry Extraction Using a Likelihood Technique (Simulation Study)

Likelihood of an event in E1039

- Azimuthal distribution of di-muons in lab frame,

$$\frac{d\sigma}{d\Omega} \sim 1 + P_i * A_N * \sin(\Phi_{pol,i} - \Phi_i)$$

- Therefore the likelihood of a measured event i,

$$L_i(A_N) \propto (1 + P_i * A_N * \sin(\phi_s - \phi_i))$$

- $\therefore$ Negative log likelihood of the data set,

$$ln\ L(A_N) = -\sum_i \ln\left(1 + P_i * A_N * \sin(\phi_s - \phi_i)\right)$$

GOAL :
Find A_N that minimize the $L(A_N)$

- In SpinQuest:
  - $P_i, A_N \in [0,1], \quad \sin(\Phi_s - \Phi_i) \in [-1,1]$ and $A_N << 1.$

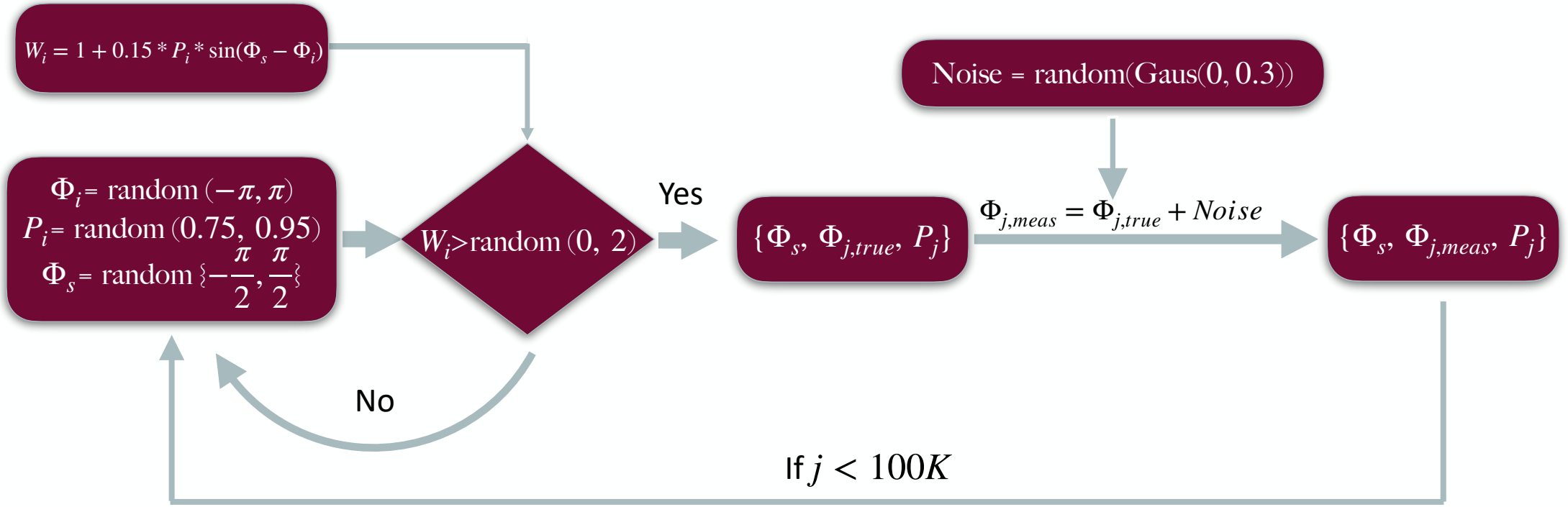
- $\therefore$ using a power series expansion of $ln\ L(A_N)$,

$$A_N = \frac{\sum_i \sin(\phi_s - \phi_i)}{\sum_i P_i^2 * \sin^2(\phi_s - \phi_i)} \qquad (1)$$

- Error will be :

$$\sigma_{A_N} = \sqrt{\sigma^2(A_N)} = \frac{1}{\sqrt{\frac{d^2L(A_N)}{dA_N^2}}} = \pm\sqrt{\frac{1}{\sum_i P_i^2 * \sin^2(\phi_s - \phi_i)}} \qquad (2)$$

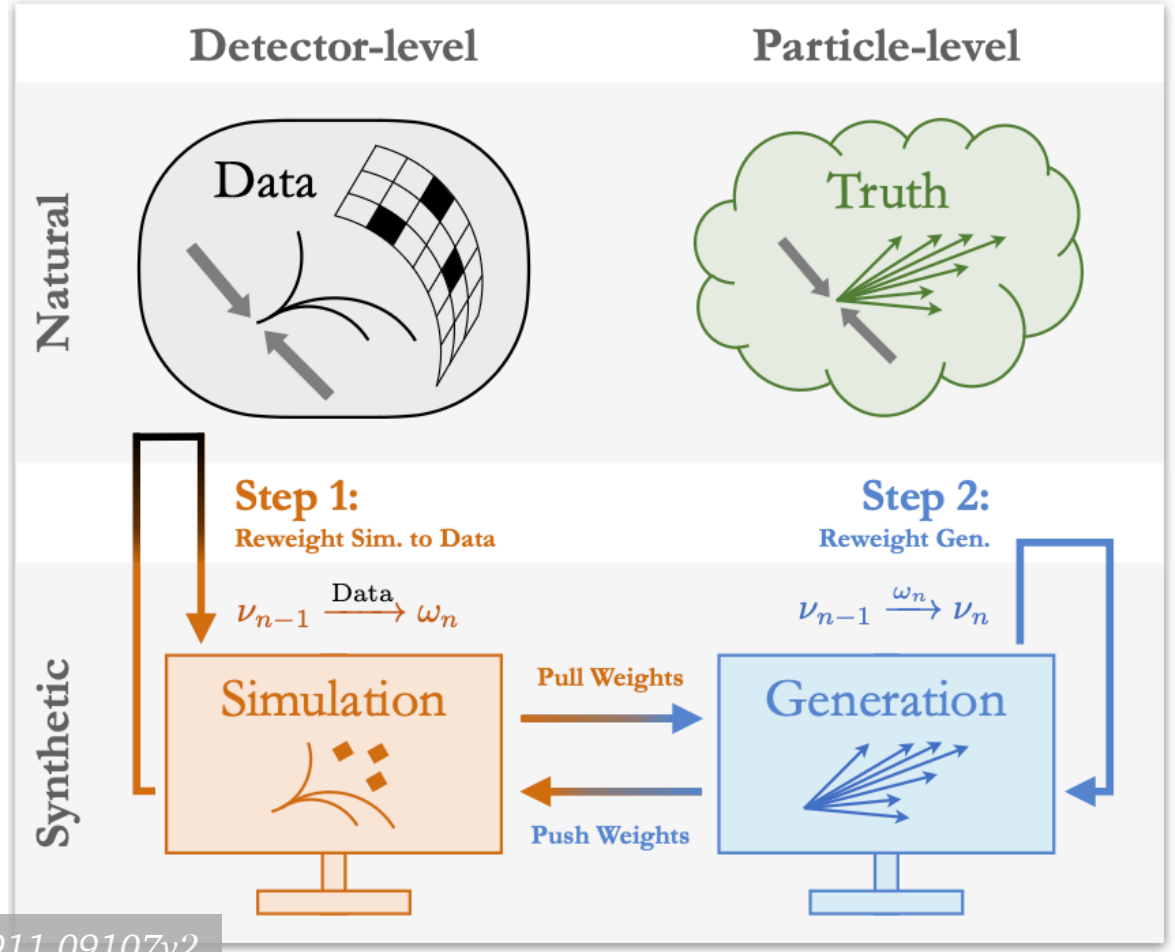
Simulating SpinQuest's dataset ($\{\Phi_S, \Phi_i, P_i\}$)



Unfolding

- An un-binned unfolding technique : Omnifold
- Un-binned version of Bayesian unfolding.
- Its job is to remove the smearing introduced by the detector.

Refer to the talk by Dinupa Nawarathne in SeaQuest session



arXiv:1911.09107v2

Results

Injected $A_N = 0.15$

	A_N	σ_{A_N}
Measured	0.1768	0.0055
Unfolded	0.1463	0.0055

Conclusion

- SpinQuest is focused on extracting the $\bar{u}$ and $\bar{d}$ contributions to the Sivers Asymmetry in Drell-Yan.
- Fixed targets used are polarized with DNP technique.
- Temporal changes in the magnitude of polarization suggest to use an un-binned analysis framework.
- Expected dataset is $\sim 200\ 000$ DY events.
- Likelihood estimation along with Omnifold returned the injected value at the $1 - \sigma$ level.

Thank You !!!