Unveiling Sea Quark Dynamics: Measuring Sivers Asymmetry with Polarized Target at SpinQuest

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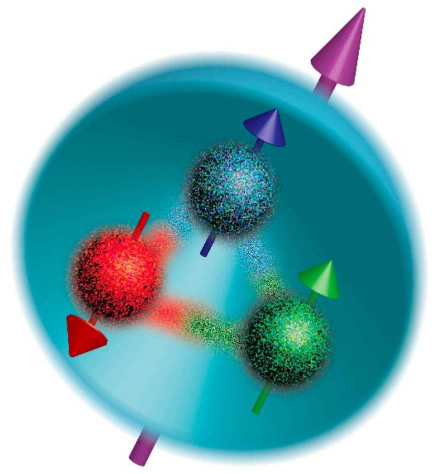
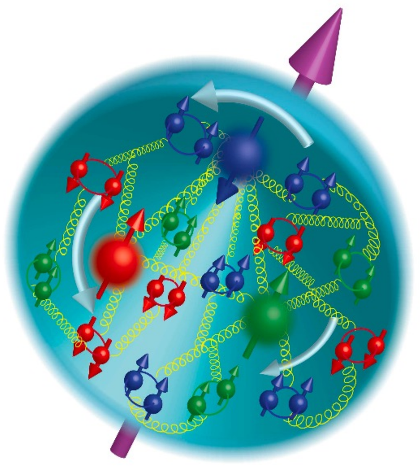
01. Proton Spin Puzzle.!

- In the 1980s, a proton's spin was naively explained by the alignment of the spins of its constituent quarks. EMC experiment measured only ~30% of proton spin comes from valence quarks and 70% of the proton spin is missing (unexpected!)

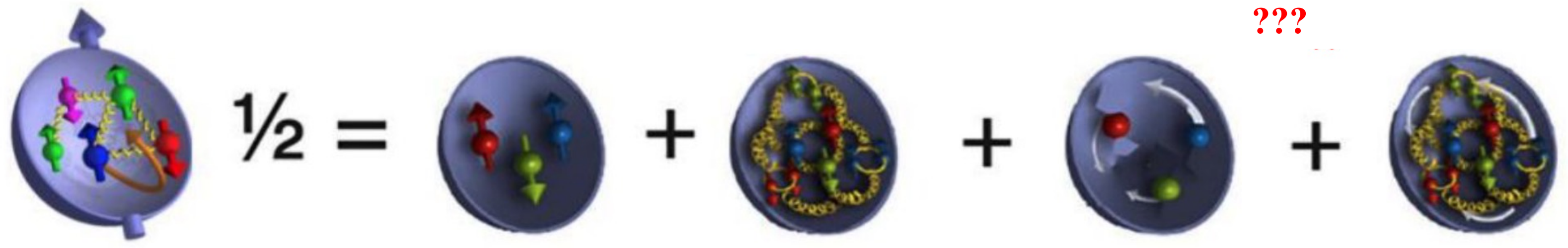


EIC white paper

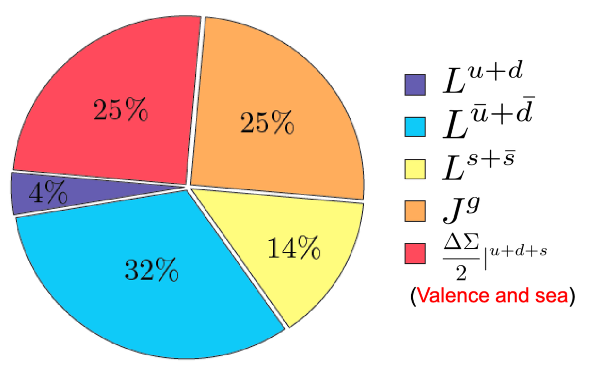


EIC white paper

- valence quarks, sea quarks, gluons, and their possible orbital motion are expected to contribute to overall nucleon spin
- Lattice QCD predicts non-zero quark Orbital Angular Momentum
- The need for a breakthrough to understand the origin of the nucleon spin and the related 3D nucleon structure



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



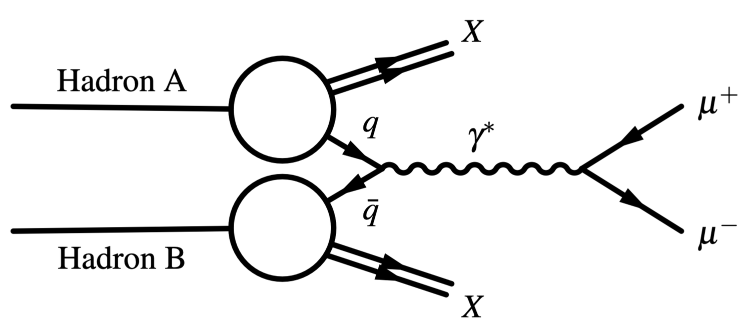
- $\Delta\Sigma_q \approx 25\%$
- $L_u \approx -L_d$
- $2L_q \approx 46\%$ [0% (Valance) + 46% (Sea)]
- $2J_g \approx 25\%$
- $J_g = \Delta G + L_g$

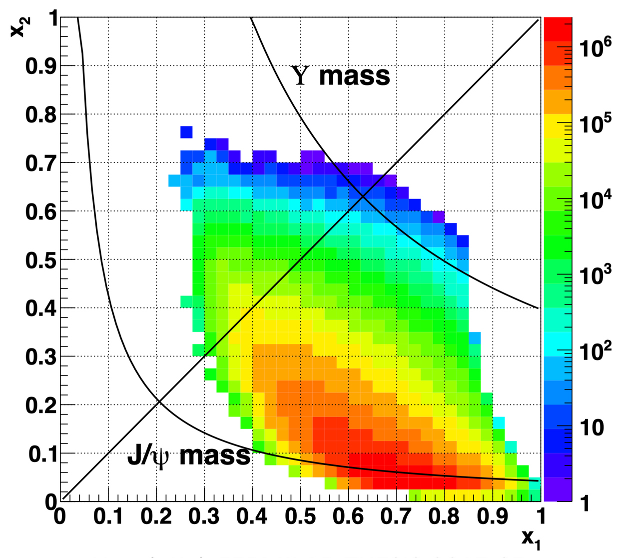
- In this model, all the quark orbital momentum comes from the sea quark contribution
- Sea quarks' angular momentum could be a major part of the "missing spin"

02. Drell-Yan Process

- Drell-Yan is an essential complement to semi-inclusive deep inelastic scattering (SIDIS)
- Critical for probing proton spin and testing QCD
- It is the cleanest method, free from fragmentation functions, involves two Parton transverse momentum distributions (TMDs), and provides direct access to sea-quark distributions
- The antiquark PDF is always involved in the reaction
- The kinematics is simple and can be determined experimentally
- Most events arise from beam-quarks and target anti-quarks kinematic acceptance is $x_1 \gg x_2$ (valance quarks dominance)

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

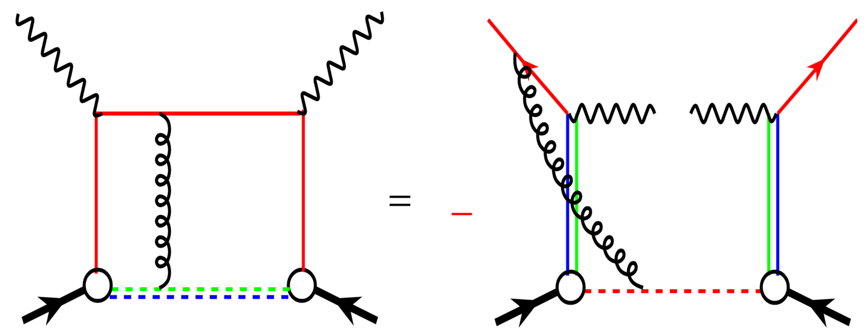




Nagai, Kei. FERMILAB-THESIS-2017-05

03. SpinQuest Objectives

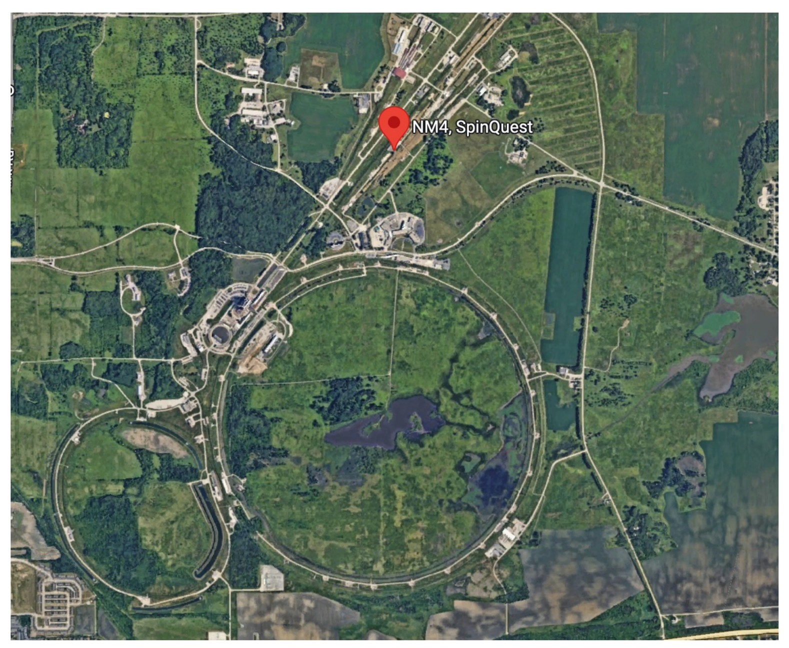
- SpinQuest will conduct the first measurement of the Sivers asymmetry in Drell-Yan proton-proton scattering involving sea quarks ($\bar{u}$ and $\bar{d}$) with sign. $f_{1T}^{\perp q}|_{SIDIS} = -f_{1T}^{\perp q}|_{DY}$

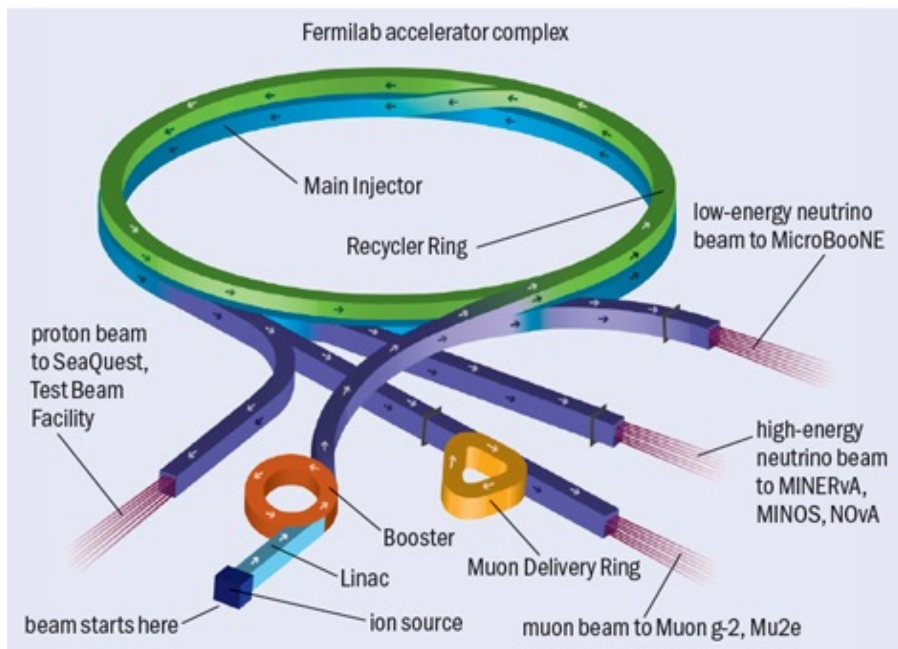


- Measurement of the Sivers function for gluons (J/psi transverse single-spin asymmetry)
- Investigate a distinct range of virtualities and transverse momenta that cannot be accessed through Z^0 or $W^{\pm}$ measurements

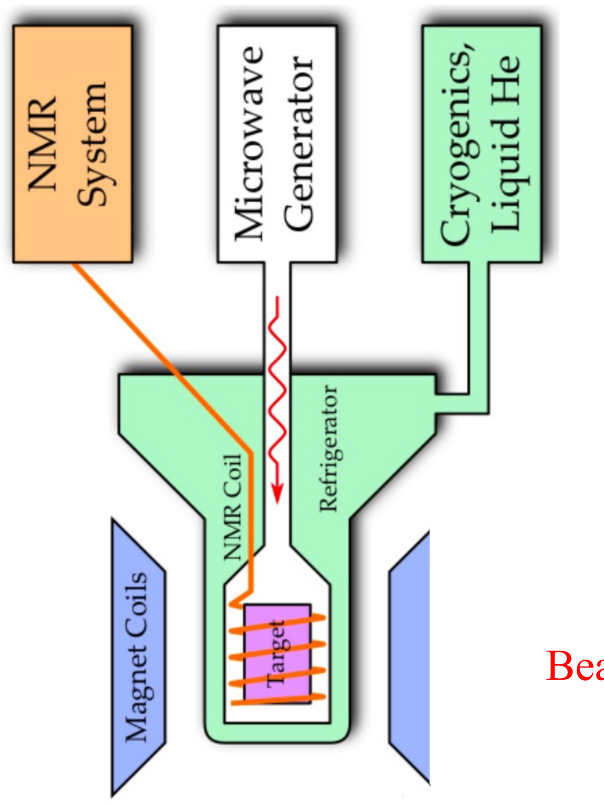
04. Beamline and the Target System

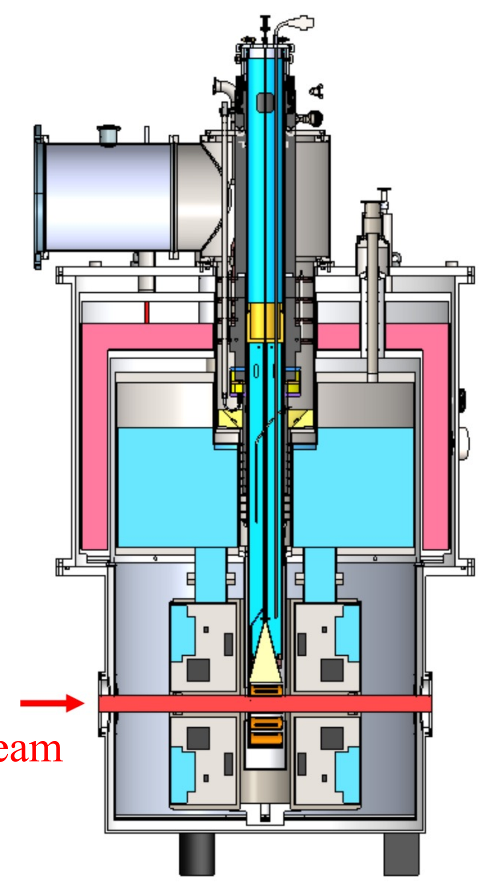
- Beam:
  - proton beam energy 120 GeV
  - $\sqrt{s} = 15.5 GeV$
  - Consisting of $5\times10^{12} protons/spill$
  - Beam spill $\approx 4.4 s/min$
  - Expect 7×10^{17} $POT/Year$





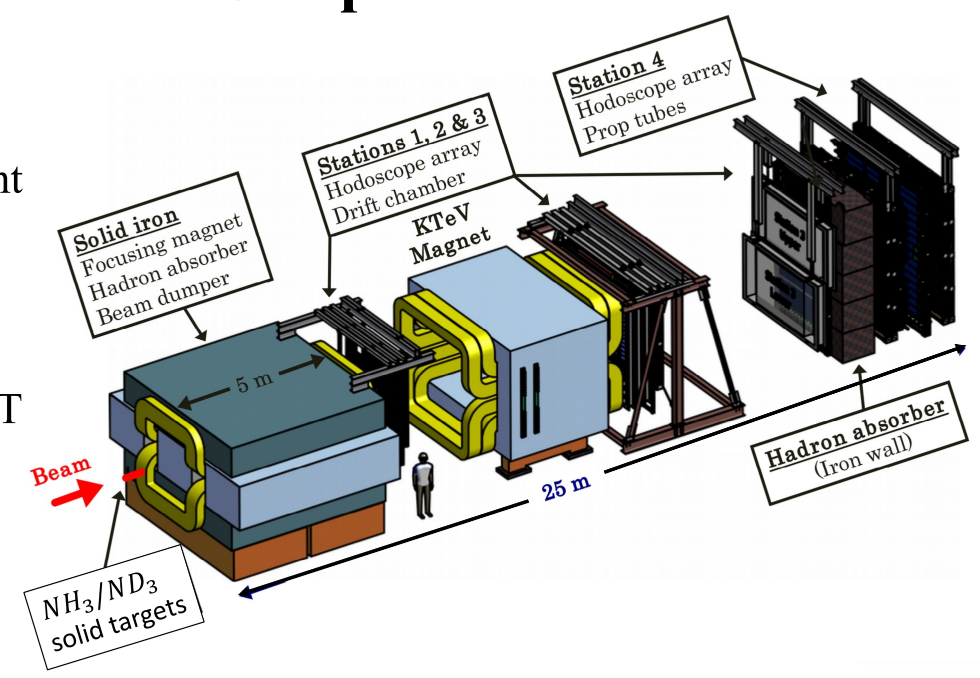
- Target System:
  - 8 cm long solid NH_3 and ND_3 target cells
  - Magnetic Field: B = 5 T with uniformity $dB/B < 10^{-4}$ T over 8 cm
  - Maintaining the target at 1.1K using He^4evaporation refrigerator
  - Expected polarizations:
    - NH_3: 80%
    - ND_3: 32%

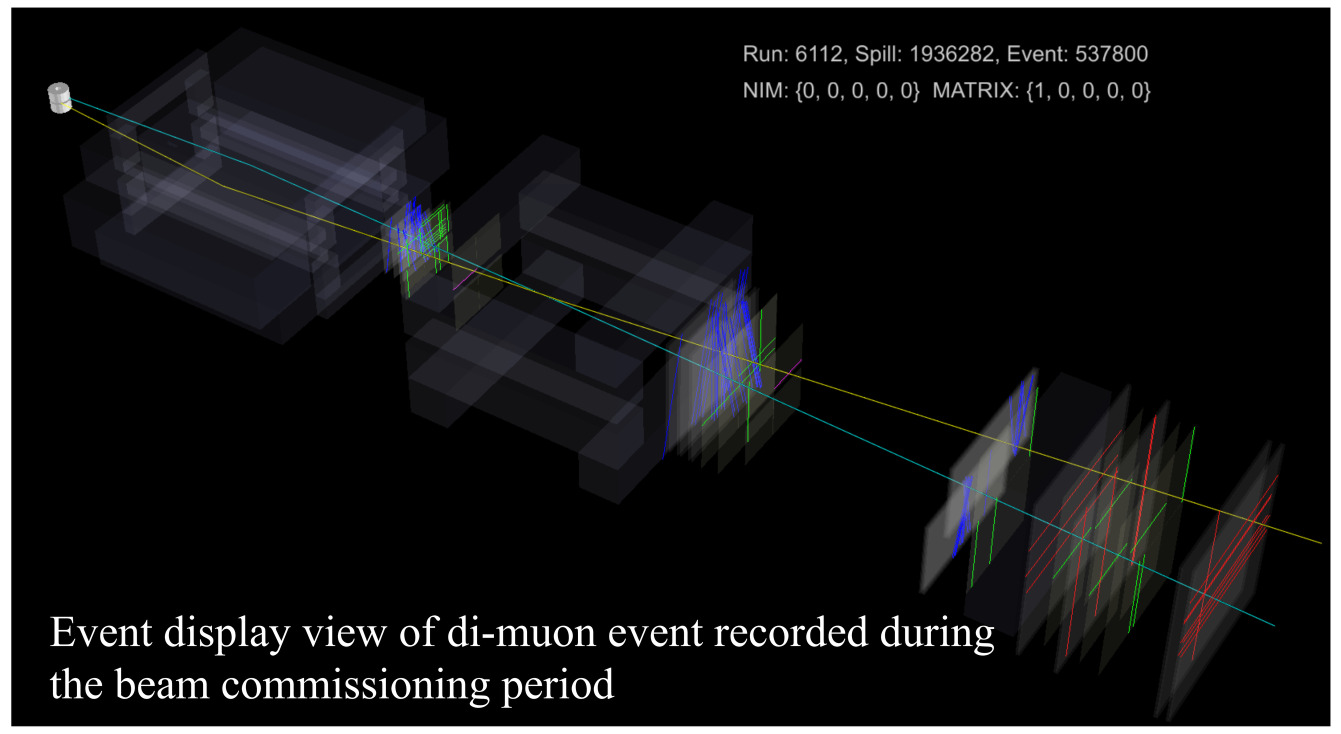




05. Spectrometer Setup

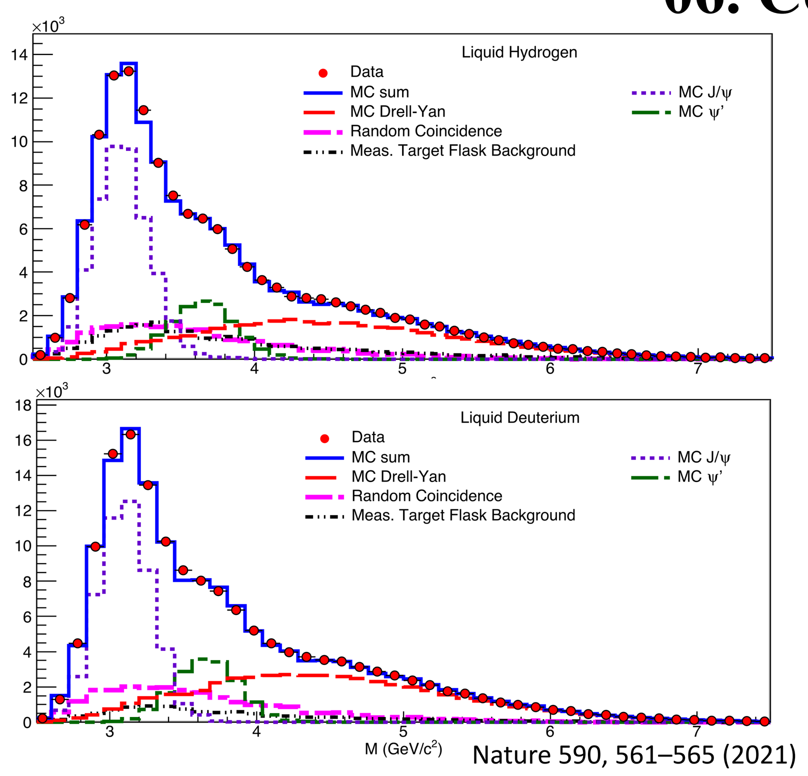
- Taking the advantage of the spectrometer used by E906 experiment
- Made by 24 wire chamber planes, 16 hodoscope planes and 8 planes with proportional tubes
- FMag generates magnetic field of 1.8T to select muons in appropriate momentum region
- KMag generates magnetic field of 0.4T and useful to evaluate momenta of muon candidates



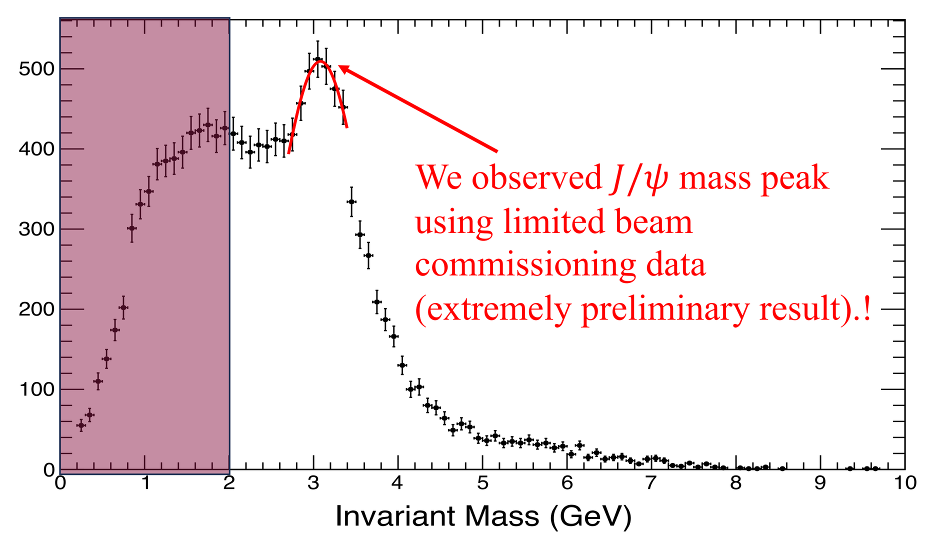


Event display view of di-muon event recorded during the beam commissioning period

06. Conclusions



Nature 590, 561–565 (2021)



- SpinQuest can measure the transverse single spin asymmetry (TSSA) in Drell-Yan (DY) process and charmonium production
- This can provide information to the Sivers function for the quarks and gluons
- Projected event selection/reconstruction is expected to be the same for E1039 from E906
- $\delta\sigma_M(J/\psi) \sim 220$ MeV

- Already collected data during the beam commissioning and analyzed invariant mass spectrum with the limited data collected by online reconstruction (not full reconstruction)
- We expect better efficiency and resolution from offline analysis
- Further investigations are ongoing to study:
  - transversity, tensor charge, tensor polarized observables, dark sector, polarized proton beam and many more.....

Stay tuned for more updates!

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