

The Overlap of SpinQuest and STAR Spin

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E1039 Collaboration Meeting

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OUTLINE

- Ancient history
- Brief intro to STAR
- Recent global analyses
- Complementary SpinQuest and STAR



The Things We Tell Our Students!

From my talk to ACU undergrads:

Lots of money spread over lots of labs!

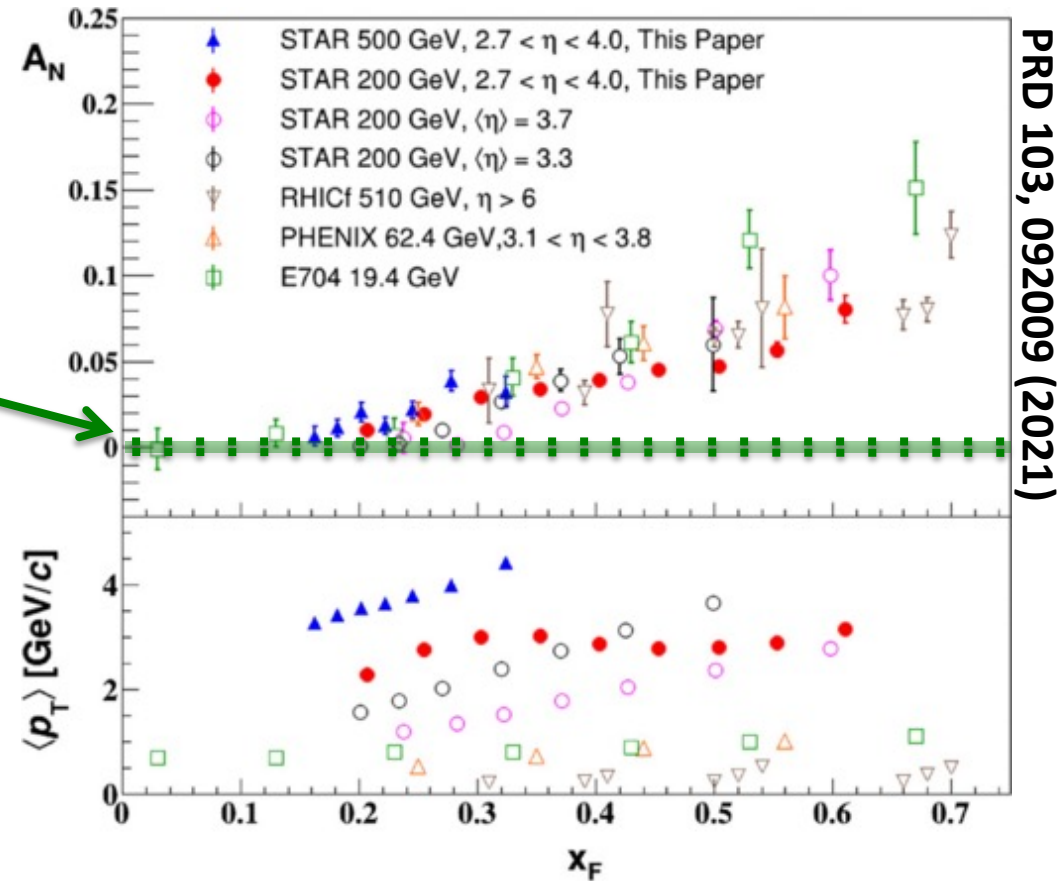
Why not pool everything together into one grand experiment?

- ***Independent verification is critical to the scientific method!***
 - We all bring biases to the table. Period.
 - *Why do we not allow you to copy each other's homework?*
- **We want as complete a picture as we can get**
 - Different experiments can compliment each other
 - Compare overlapping results for consistency
 - Shine light on still-dark areas of the room

Ancient History

Transverse single spin asymmetries should be *small*

A_N for forward scattering
MUCH LARGER than naïve
expectation

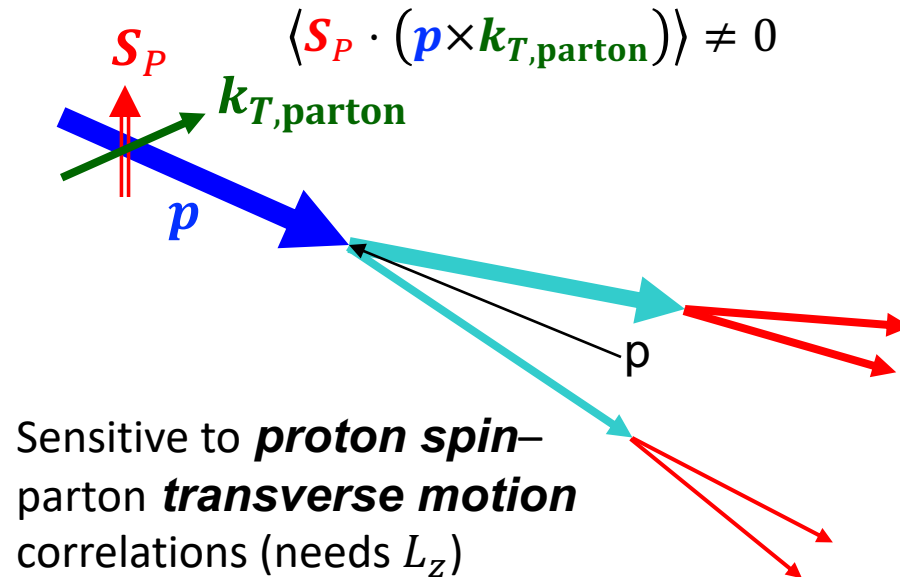


Shown results from
PLB 261, 201 (1991)
PRL 101, 222001 (2008)
PRD 89, 012001 (2014)
PRD 90, 012006 (2014)

Mechanisms for Transverse Single-spin Asymmetries

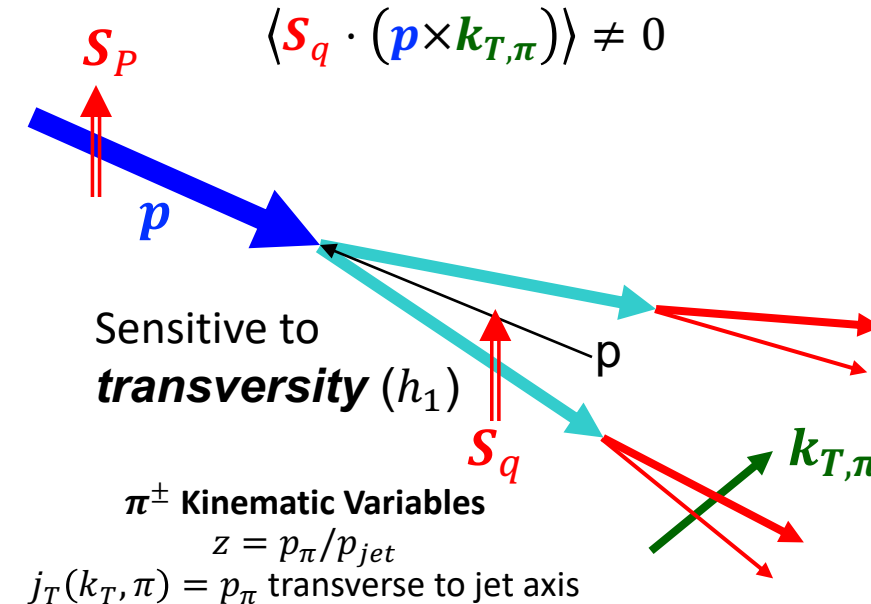
Sivers mechanism: asymmetry in the forward jet or γ *production*

D. Sivers, PRD 41, 83 (1990); 43, 261 (1991)



Collins mechanism: asymmetry in the forward jet *fragmentation*

J. Collins, NP B396, 161 (1993)



Separate Sivers and Collins:

Go beyond inclusive production - *e.g. DY, W, Jets, correlations, direct photons*

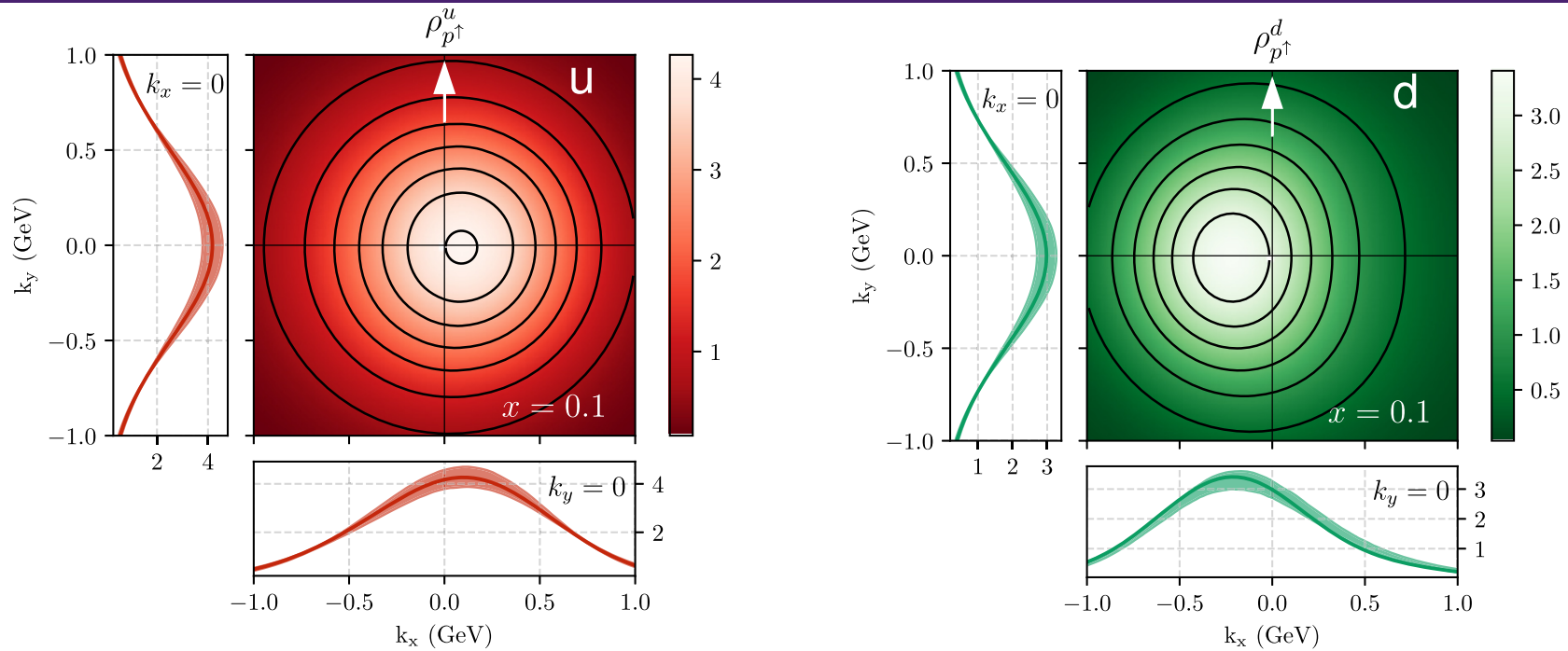
Sivers $\sim \sin(\phi_S)$

ϕ_S —angle between spin and event plane

Collins $\sim \sin(\phi_S - \phi_H)$

ϕ_H —angle of hadron around jet axis

What Else Do We Get Out of This?



Pavia, PLB 827, 136961 (2022)

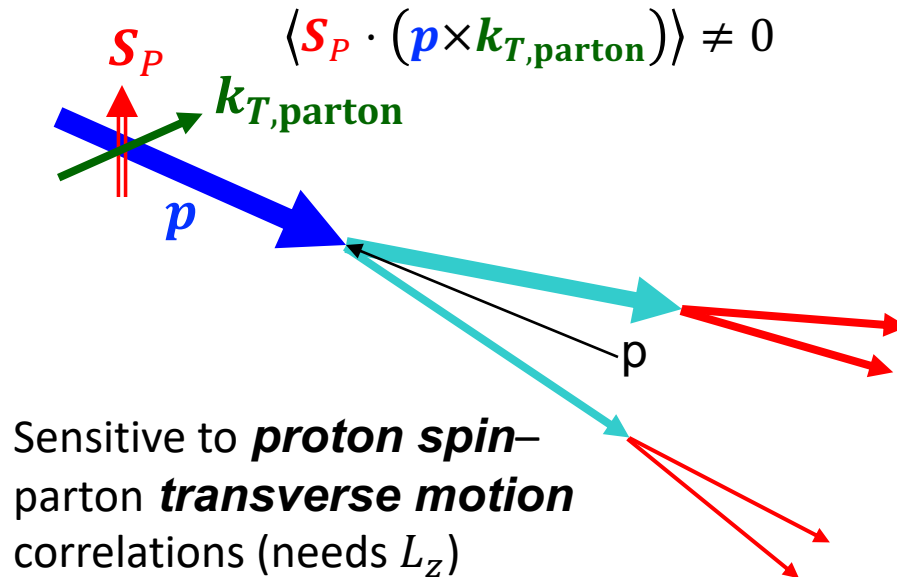
Use Sivers asymmetries to map distribution of unpolarized quarks in 3D momentum space

- Distortions require two ingredients:
 - Wavefunctions have component w/ non-zero angular momentum
 - Final-state interaction effects present
- Important constraints on nucleon models

Mechanisms for Transverse Single-spin Asymmetries

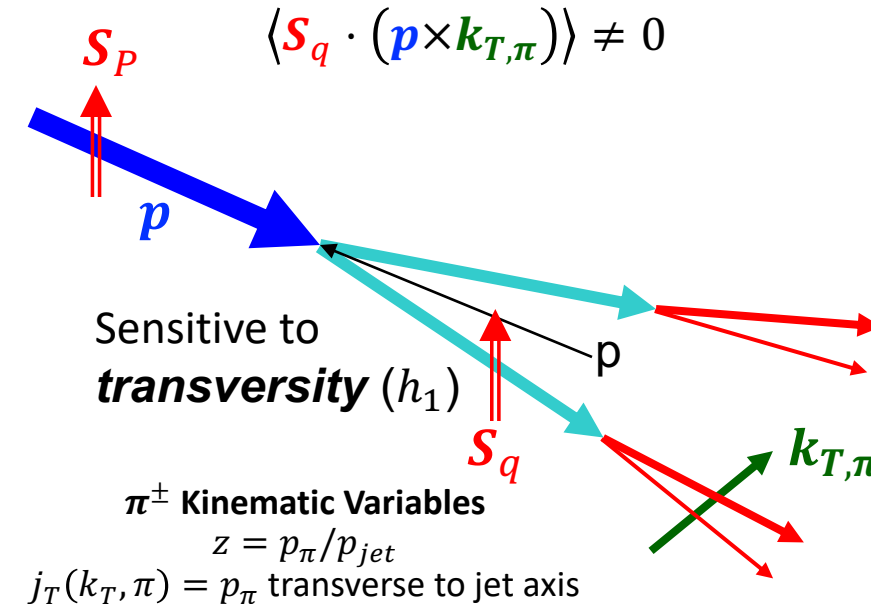
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Key Ingredient: Transverse-momentum Dependent (TMD)

Parton Distributions and Fragmentation Functions

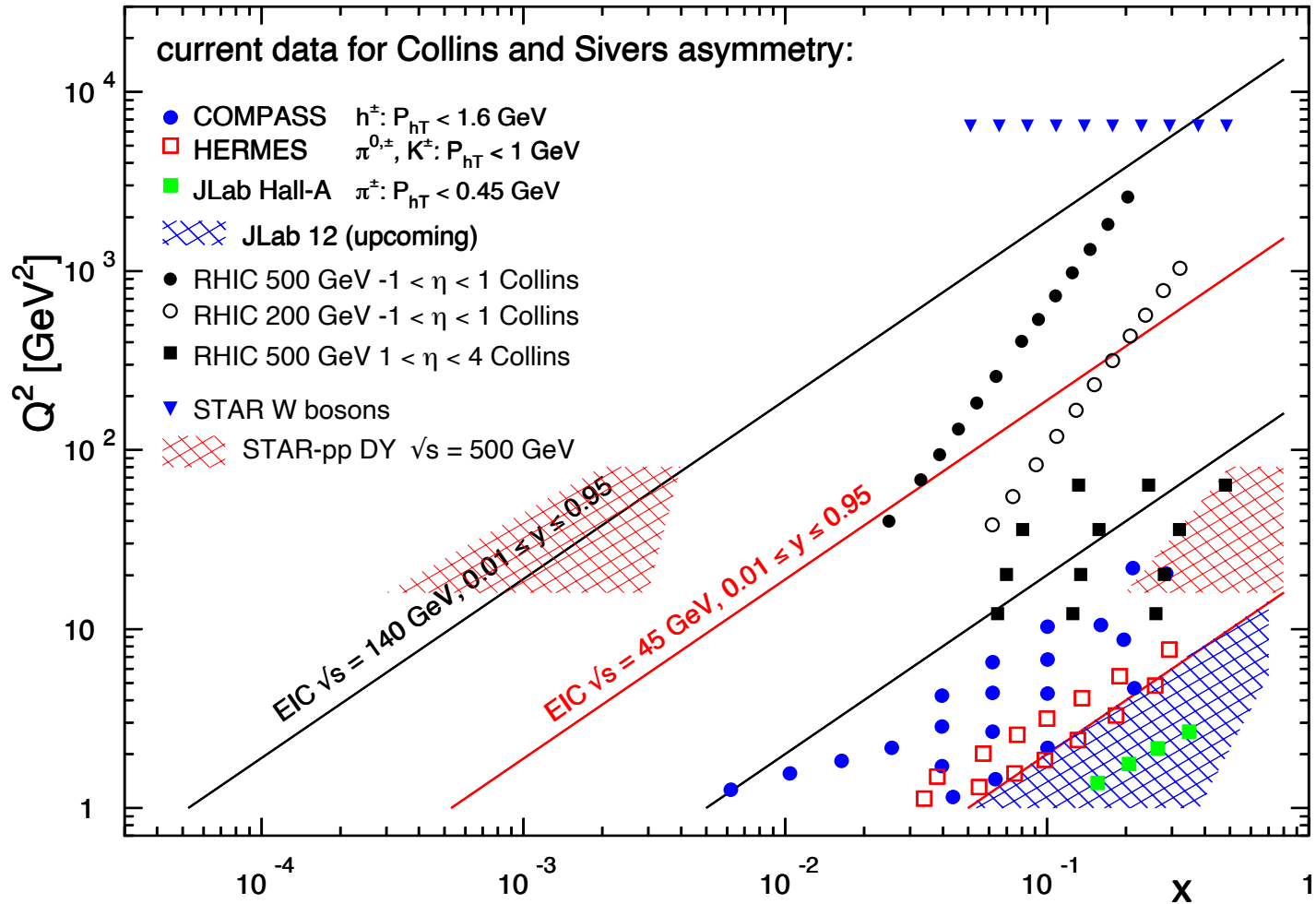
→ But are they universal?! Do TMD equations factorize?!

It's Complicated

→ ***But are they universal?! Do TMD equations factorize?!***

- **Generally, no!**
- **Very useful exceptions!**
 - SIDIS
 - e^+e^-
 - $p + p$: W-bosons, Drell-Yan
- ***Experimental tool to inform theoretical questions***
 - Do TMDs depend on the observable (e.g. SIDIS vs. p+p)?
 - Is our factorized formulation of pQCD valid with TMDs?
 - How do TMDs evolve as the kinematics change?

Landscape of TMDs



TMDs from fixed target data

→ high x at low Q^2

Important to span the *full kinematic space*, e.g., at STAR

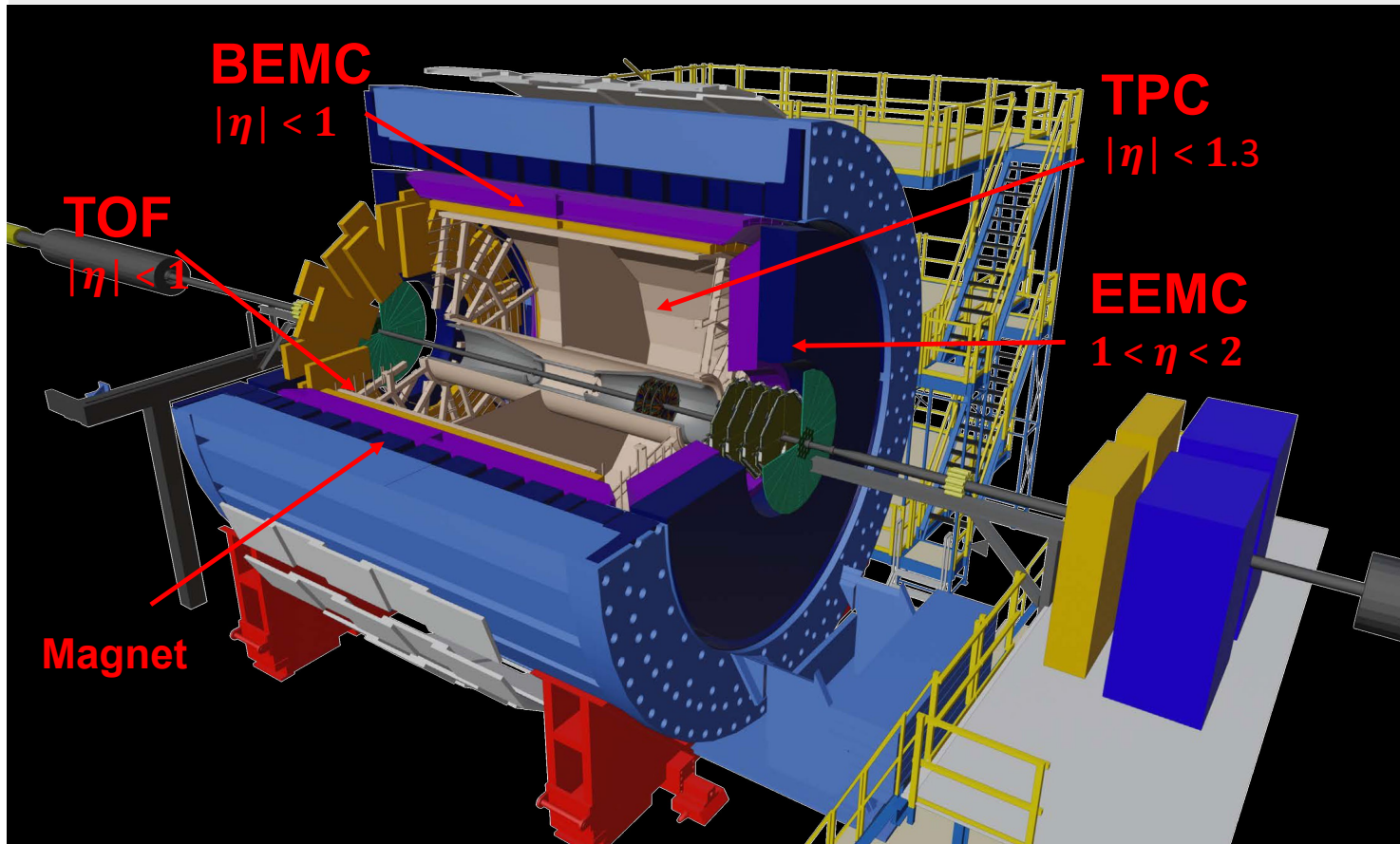
The Solenoidal Tracker at RHIC



RHIC as Polarized-proton Collider

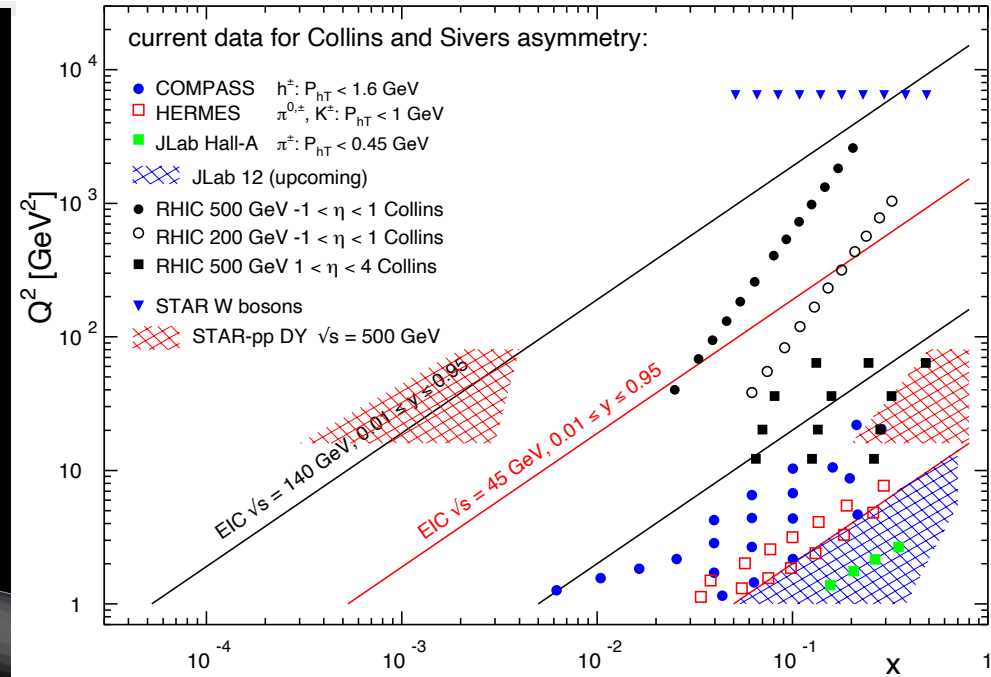
- “Siberian Snakes” → mitigate depolarization resonances
- Choice of spin orientation → *independent of experiment*
- Spin direction varies bucket-to-bucket (9.4 MHz)
- Spin pattern varies fill-to-fill

The Solenoidal Tracker at RHIC



Central Detectors: $|\eta| < 1$

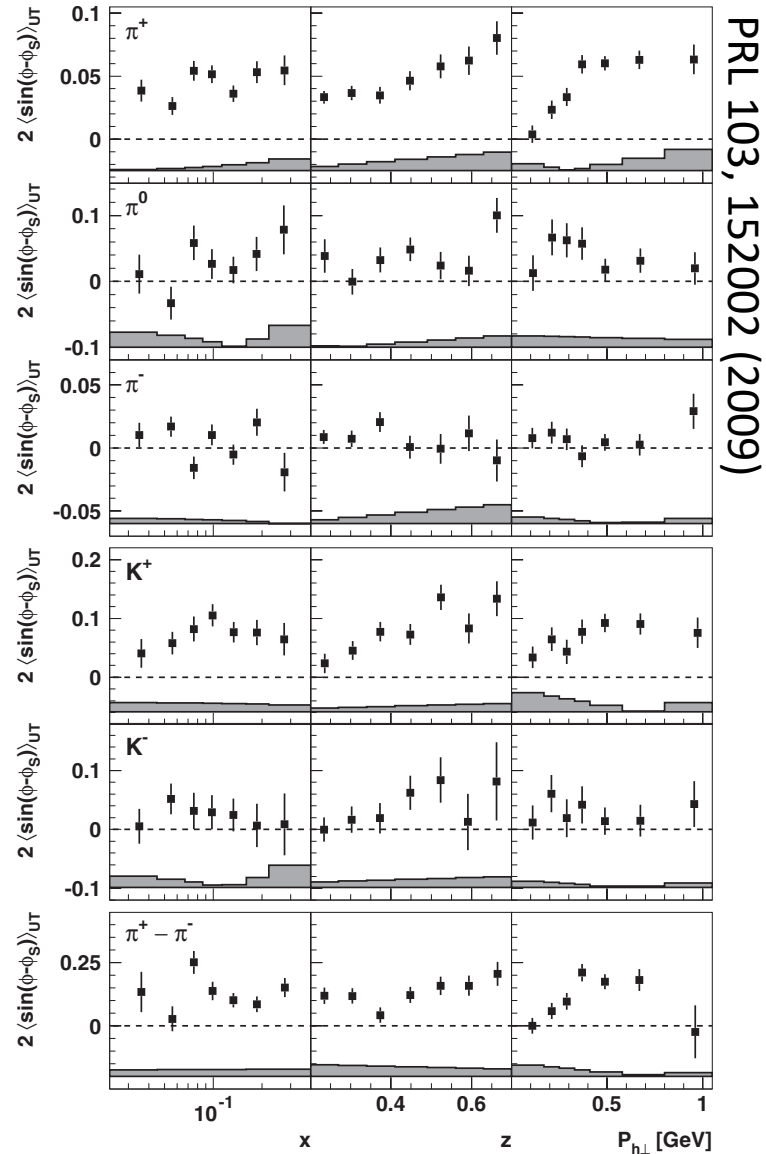
- Tracking + PID + E/M Cal.
- Jets, π^\pm , K , p , e^\pm , π^0 , γ



Forward Detectors: $1 < \eta < 4$

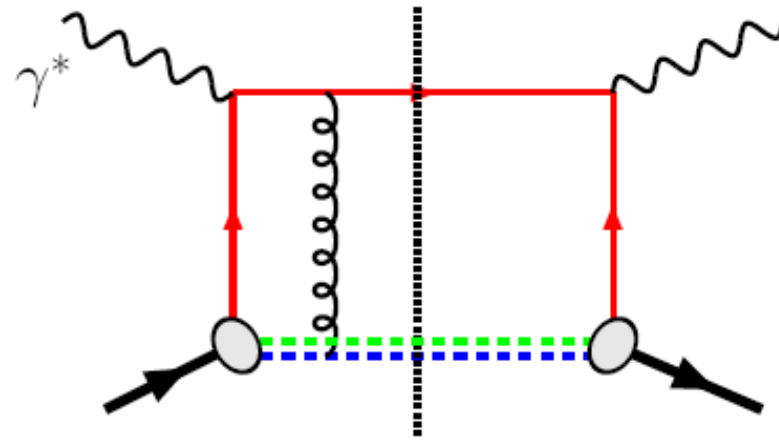
- Tracking + HCAL + E/M Cal.
- Jets, h^\pm , π^0 , γ , e^\pm

Sivers Effect in SIDIS



QCD:

DIS:
Final-state interaction



Sivers effect exists in SIDIS!

- Positive for π^+ and K^\pm
 - Consistent with zero for π^-
- Cool! Does it exist in $p + p$?*

Sivers Effect

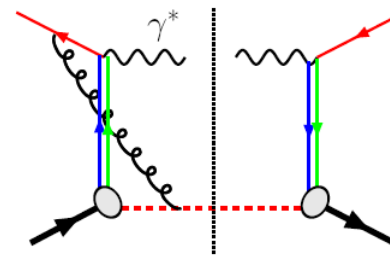
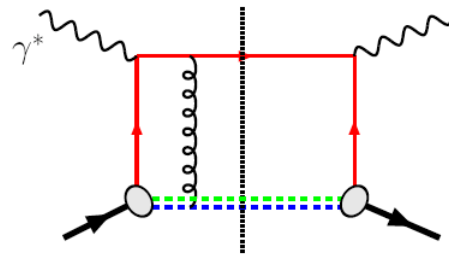
Color interactions in QCD

“Modified-universality” of the “Sivers” function

QCD:

DIS:
Final-state interaction

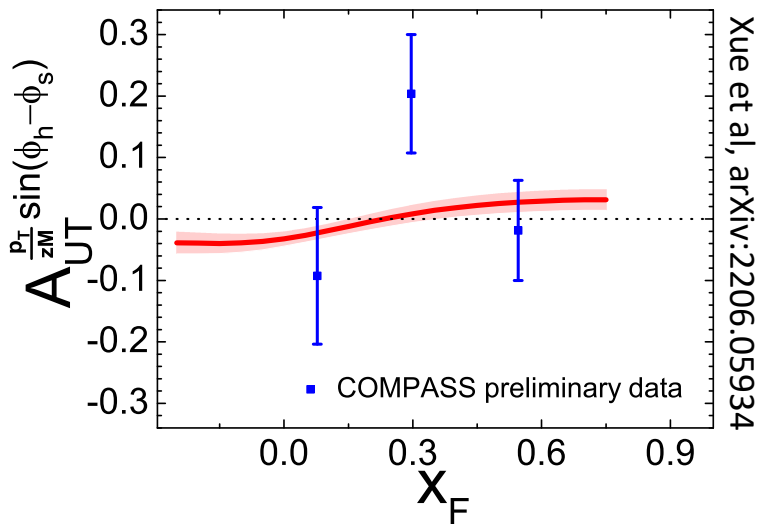
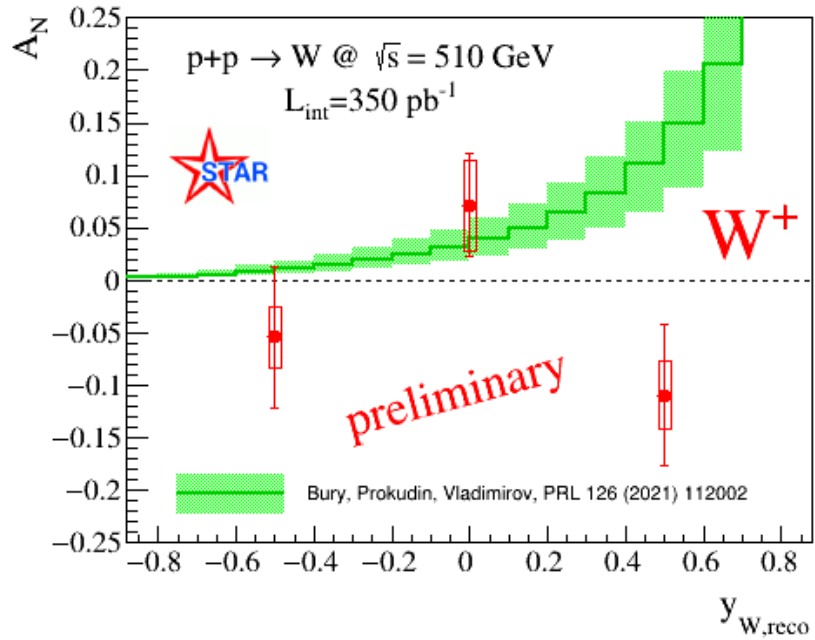
Drell-Yan or W:
Initial-state interaction



$$\text{Sivers}_{\text{DIS}} = -\text{Sivers}_{\text{Drell-Yan or Sivers}_W}$$

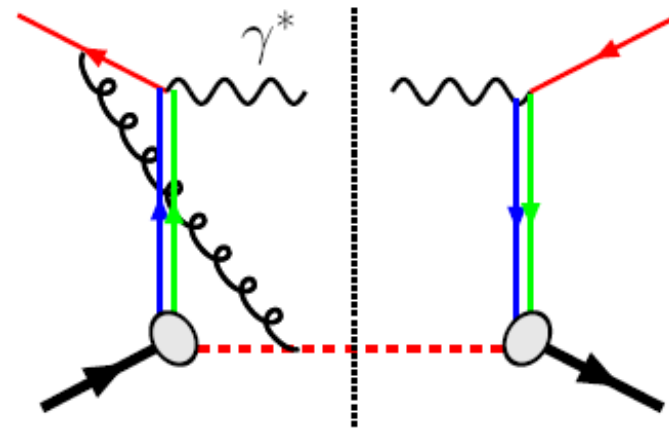
One interpretation: *Repulsive interaction between like color charges!*

Sivers Effect in Hadroproduction



QCD:

Drell-Yan or W:
Initial-state interaction

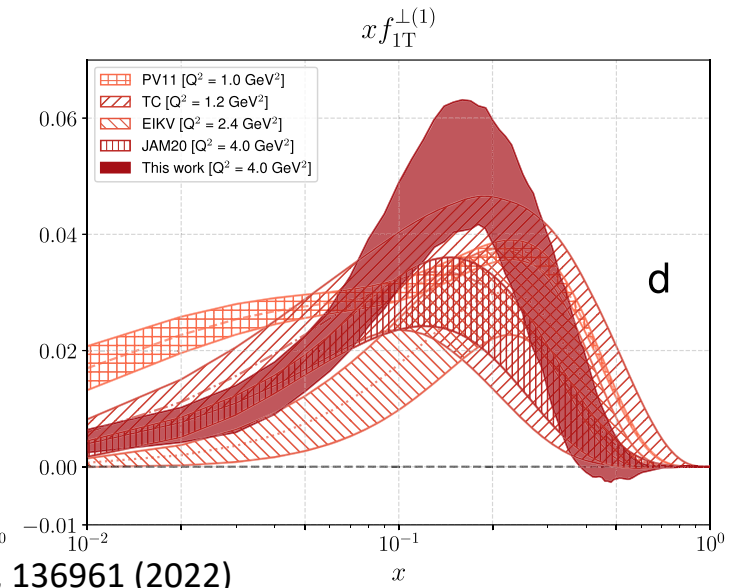
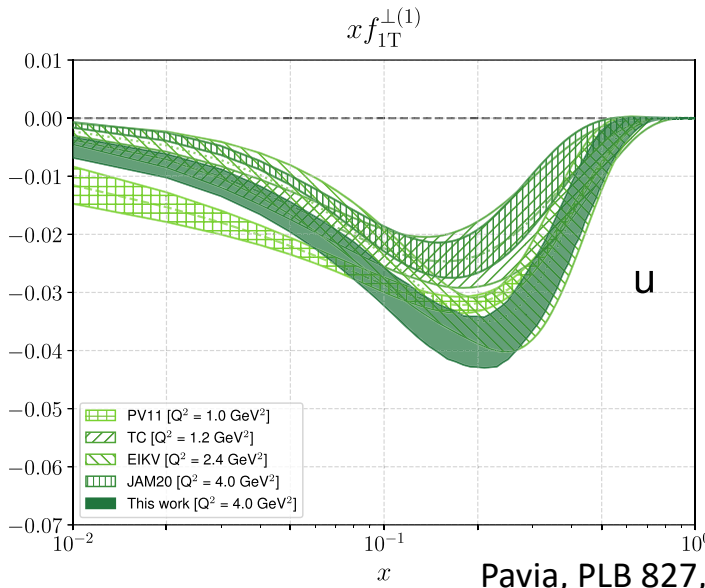
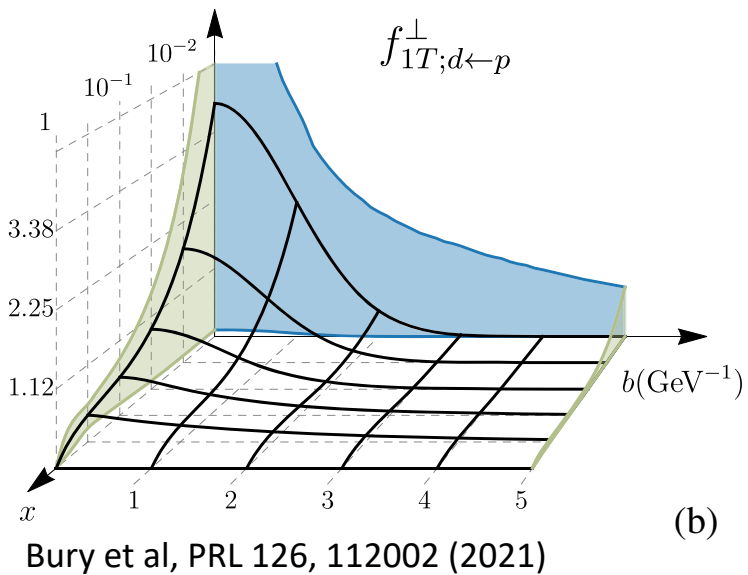
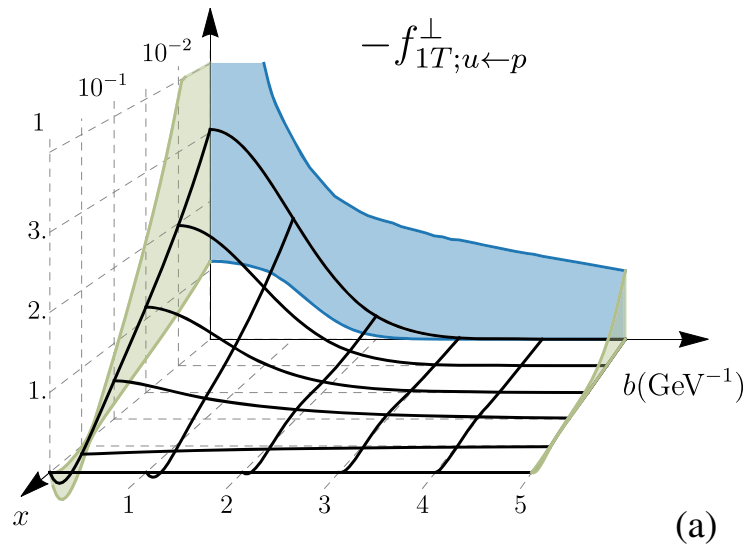


Sivers effect in $p/\pi + p$?

- Not enough statistics, yet
- So far, consistent with either option

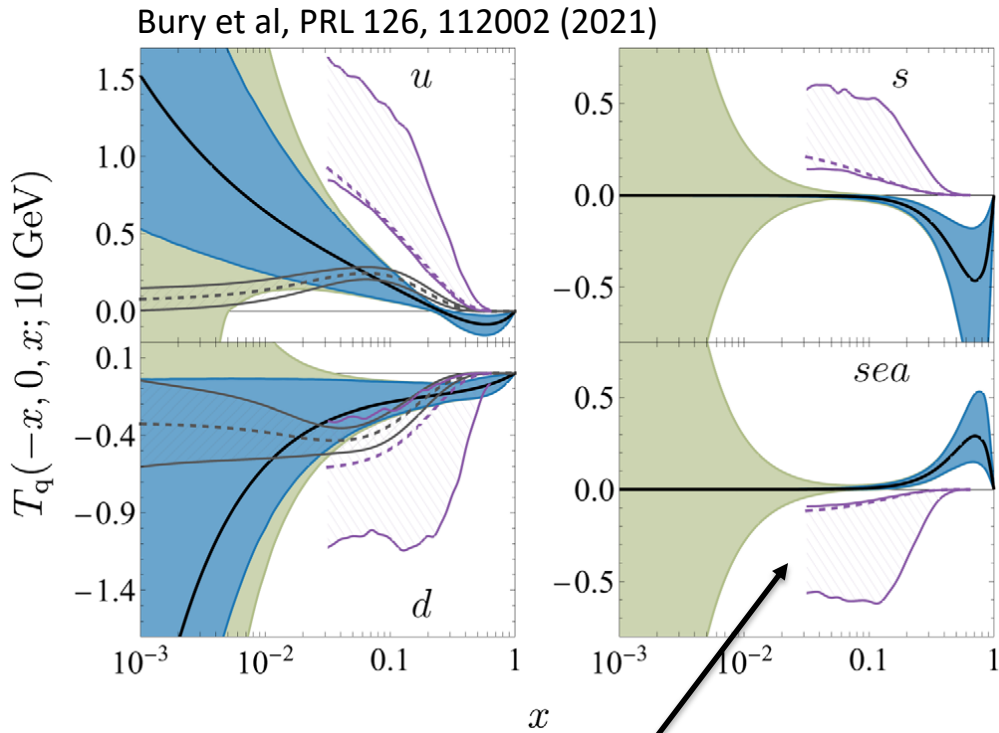
Some Recent Global Analyses

- Recent global analyses utilize SIDIS+pp/ π p Data
- Sign-change is *preferred* but not nearly *confirmed*
- Still statistics (and kinematics) limited
- **BIG** questions about the sea!



Pavia, PLB 827, 136961 (2022)

Sea Questions



Significant difference in sea-quark Sivers functions between different groups

From the Bury et al paper:

“The resulting fit (without the sign change) does exhibit tensions between DY and SIDIS data sets, however, the fit...cannot exclude the same sign of Sivers functions in DY and SIDIS kinematics. The sign of the sea-quark Sivers function plays the central role here...Therefore, with the current data precision, the flip of the sign for the N_{sea} parameter alone is sufficient to describe the data and almost compensates the effect of the overall sign-flip at the level of the cross section.”

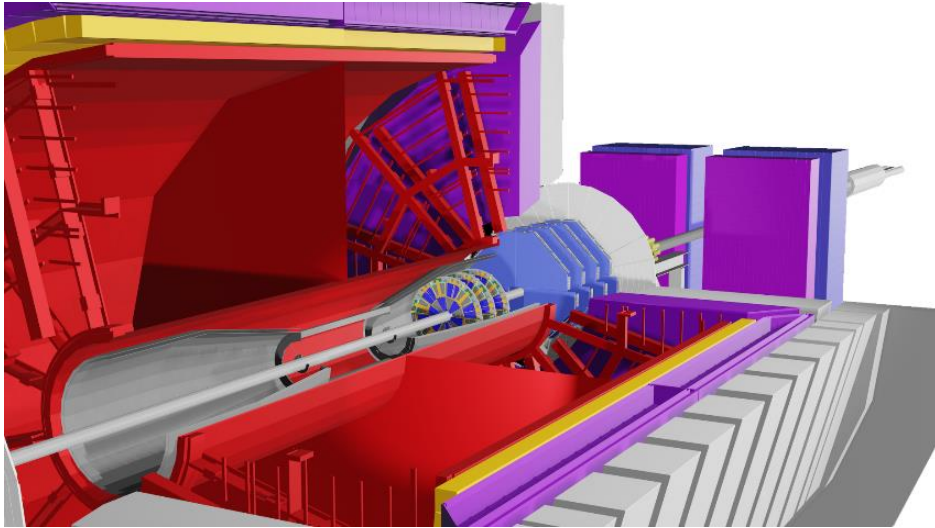
Taking Stock

- Sivers effect exists and is promising!
- The sign-change is a pretty important benchmark
- So far, results are inconclusive
 - Not enough statistics
 - Small asymmetries?
- TMD evolution is still a tough question
- Sea quark seems to be wide open
 - Got to be picky to get at it
- Need more data—hadroproduction especially!

SpinQuest and STAR to the Rescue!

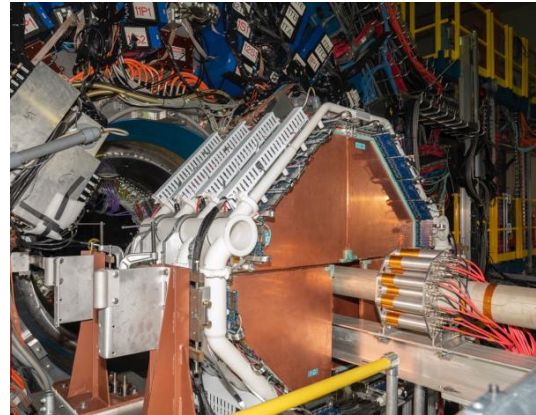
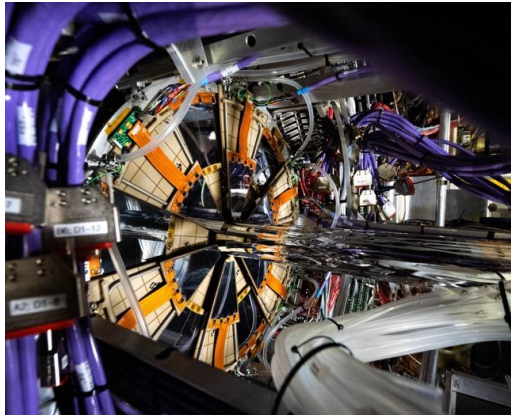
- Quoting, again, from Bury et al
“Indeed, the sign of the DY cross section is mostly determined by the sea contribution due to the favored $q + \bar{q} \rightarrow W/Z/\gamma$ subprocess, whereas the sea contribution in SIDIS is suppressed.”
- Most experimental data are focused on the valence region
 - Sign-change is the headline
 - Expect largest asymmetries?
- Critical to have experiments like SpinQuest that tackle the sea!
- In this respect, there is important complementarity between E1039 and experiments like STAR...

SpinQuest and STAR to the Rescue!

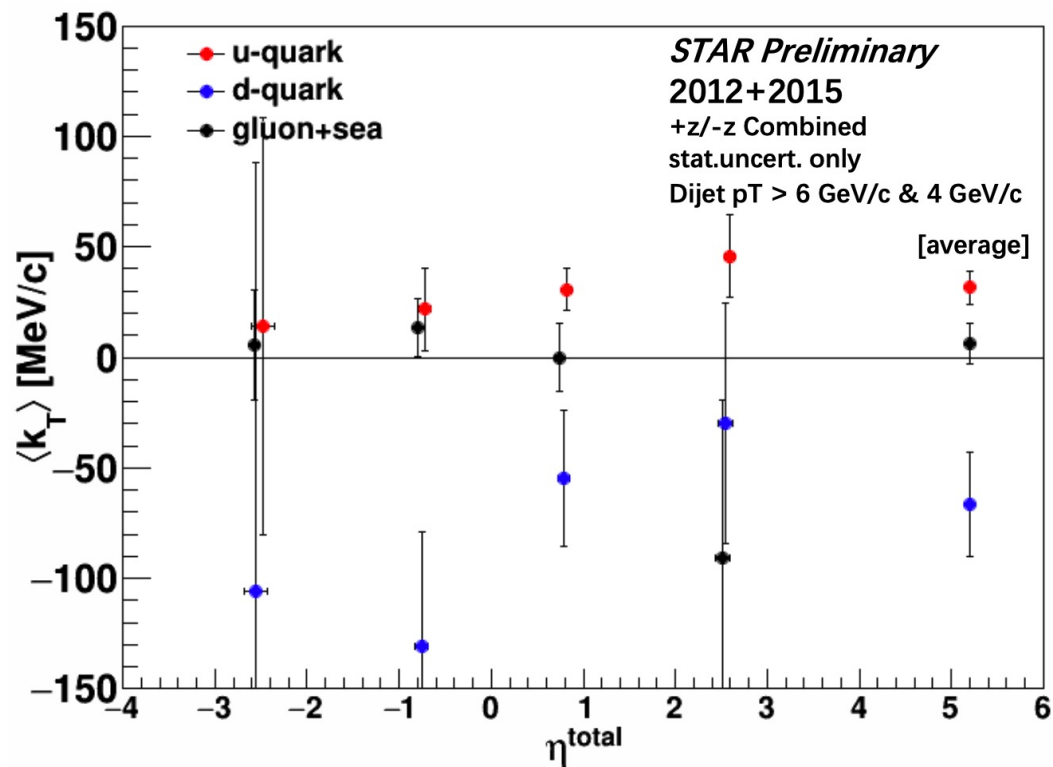


STAR Forward Upgrade in for 2022

- HCAL+ECAL+Tracking
- Dedicated Drell-Yan trigger
- Full jet reconstruction
- Dedicated dijet trigger



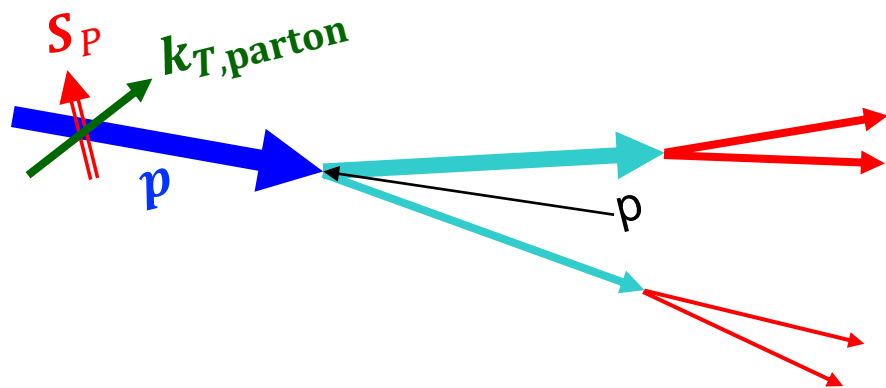
SpinQuest and STAR to the Rescue!



In principle, access Sivers through “dijets”
Use the dijet to measure an imbalance in the
initial-state intrinsic transverse momentum

Still lots of theoretical questions!

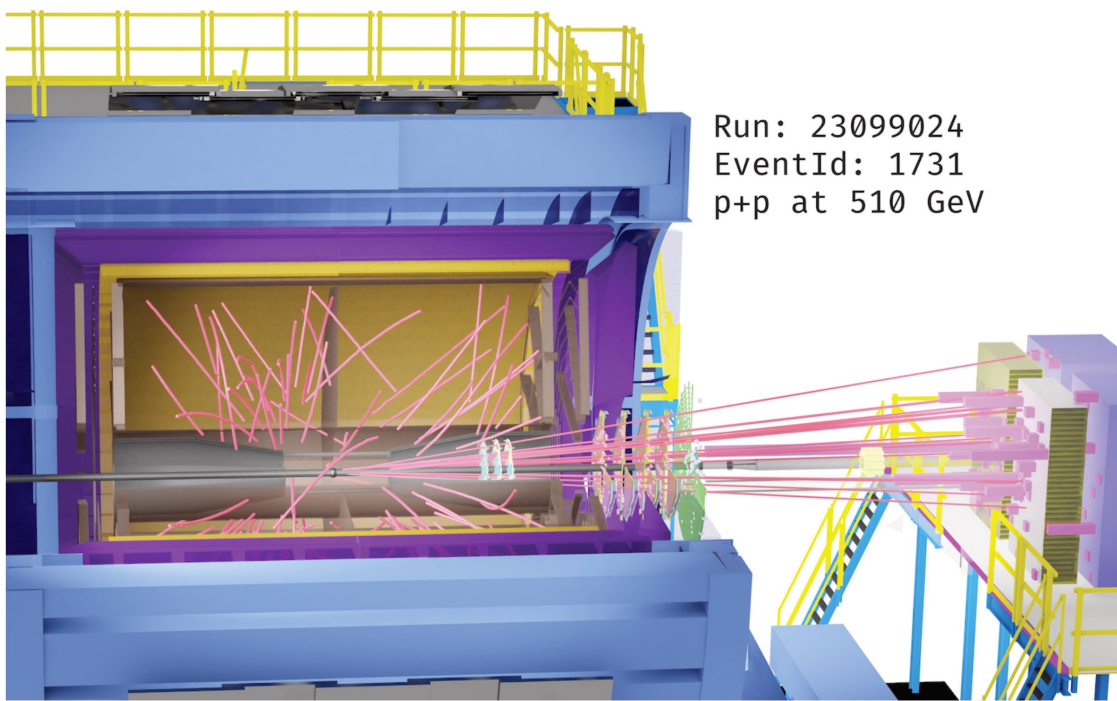
...But, hey, we're experimentalists, right?



SpinQuest and STAR to the Rescue!

One specific (simple) example of SpinQuest – STAR synergy:

- Imagine a STAR DY event sampling a high-x valence quark from the leftward beam scattering off of a low-x sea quark from the rightward
- Controlling the spin of the leftward beam samples valence-quark Sivers



SpinQuest completes the picture

- Optimized to sample the sea quark from the *polarized target*
- Can STAR complement SpinQuest? Yes!
 - Controlling the spin of the *rightward* beam samples low-x sea quark Sivers
- Overlapping, complementary experiments are critical for the full picture

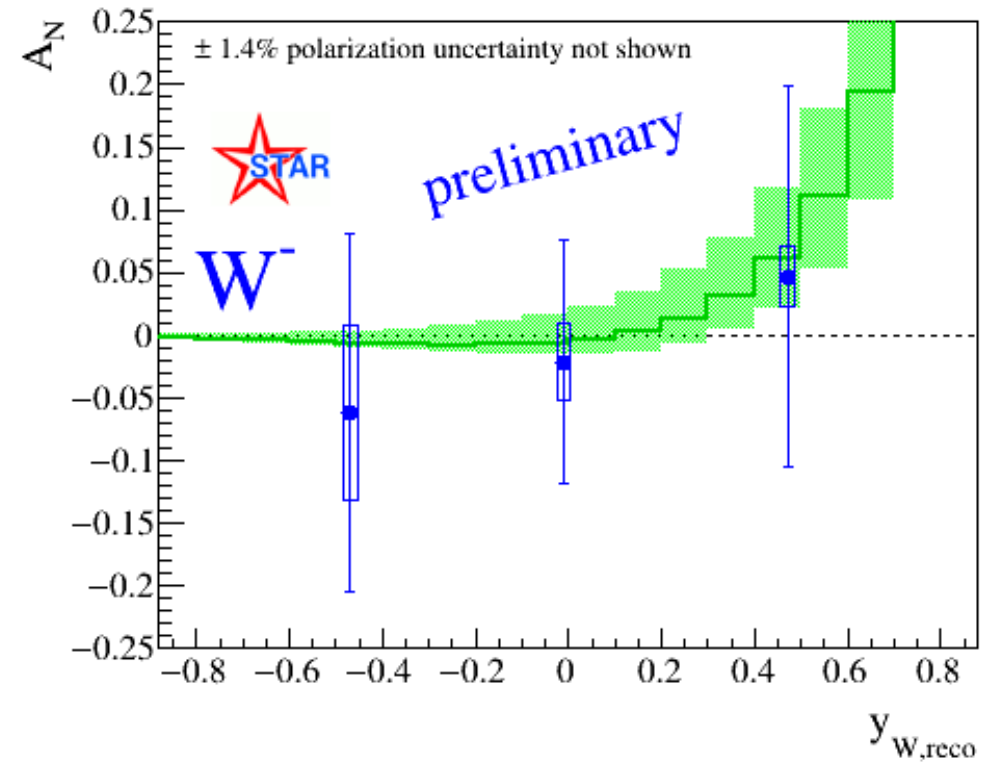
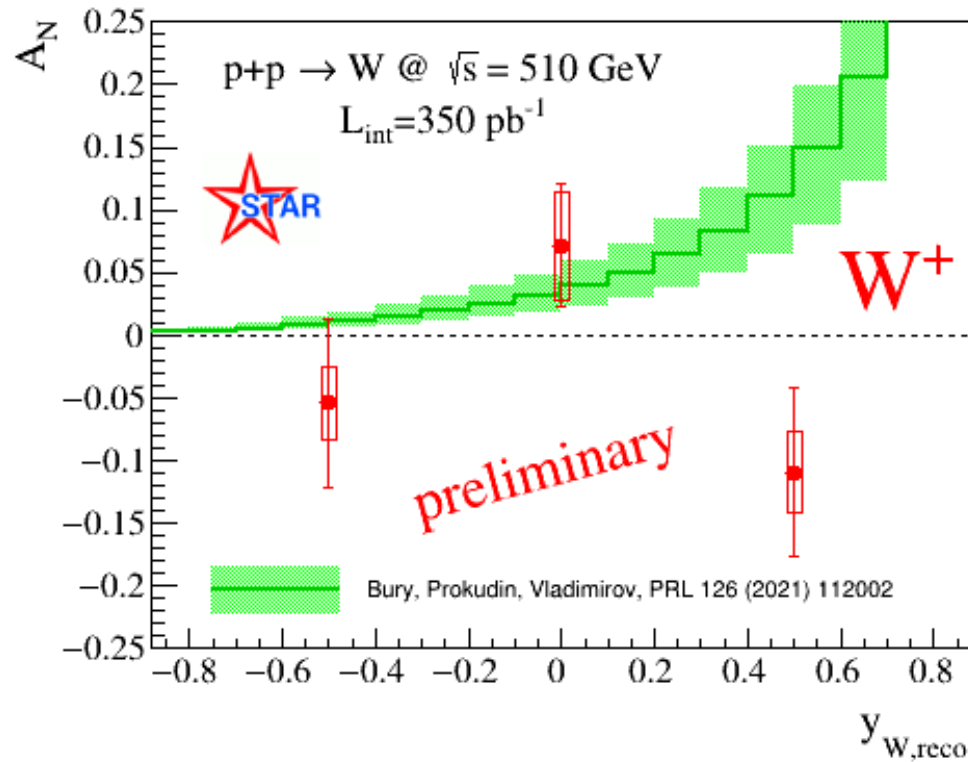
Final Thoughts

- SpinQuest and STAR Spin both focus on critical and beautiful physics
- Independent experiments that overlap and complement are critical for robust science and reliable discovery
- Current Sivers extractions demonstrate vividly the need for more data
 - Particularly from hadroproduction
 - Over a broad kinematic coverage
 - With a variety of observables
 - With sensitivity to the sea quark
- SpinQuest and STAR are poised to provide critical insight
 - For the sign change
 - For the sea quark
 - For the comprehensive mapping of the Sivers function to come

Back up

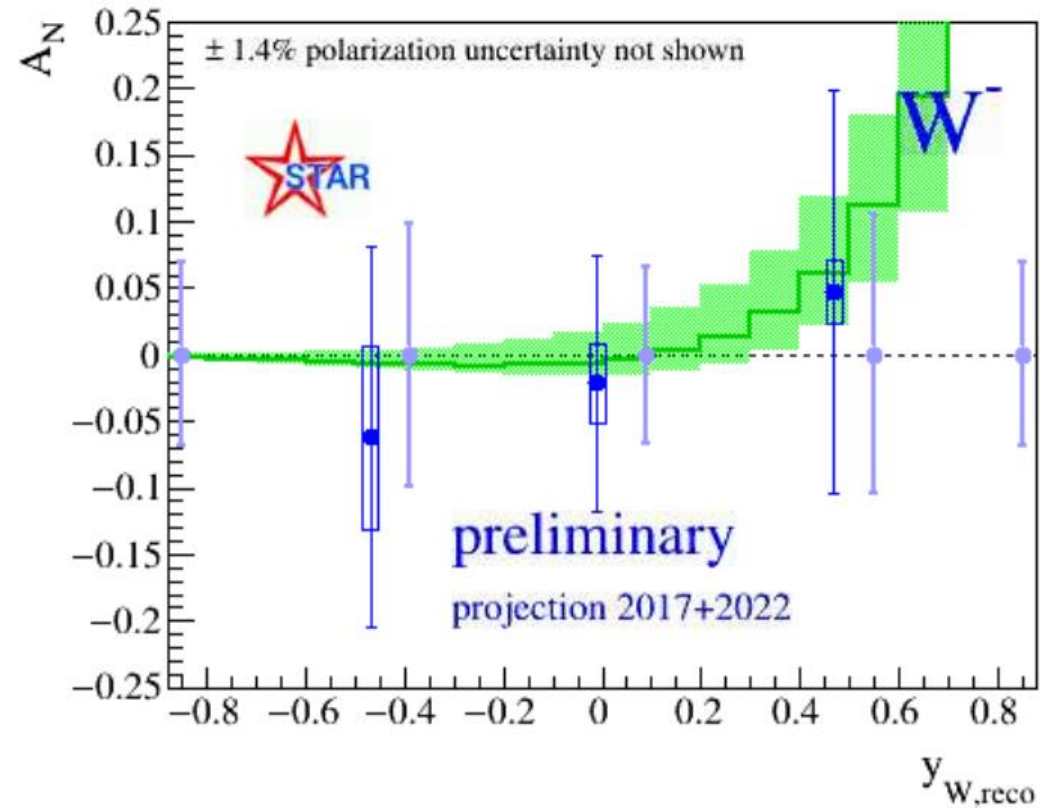
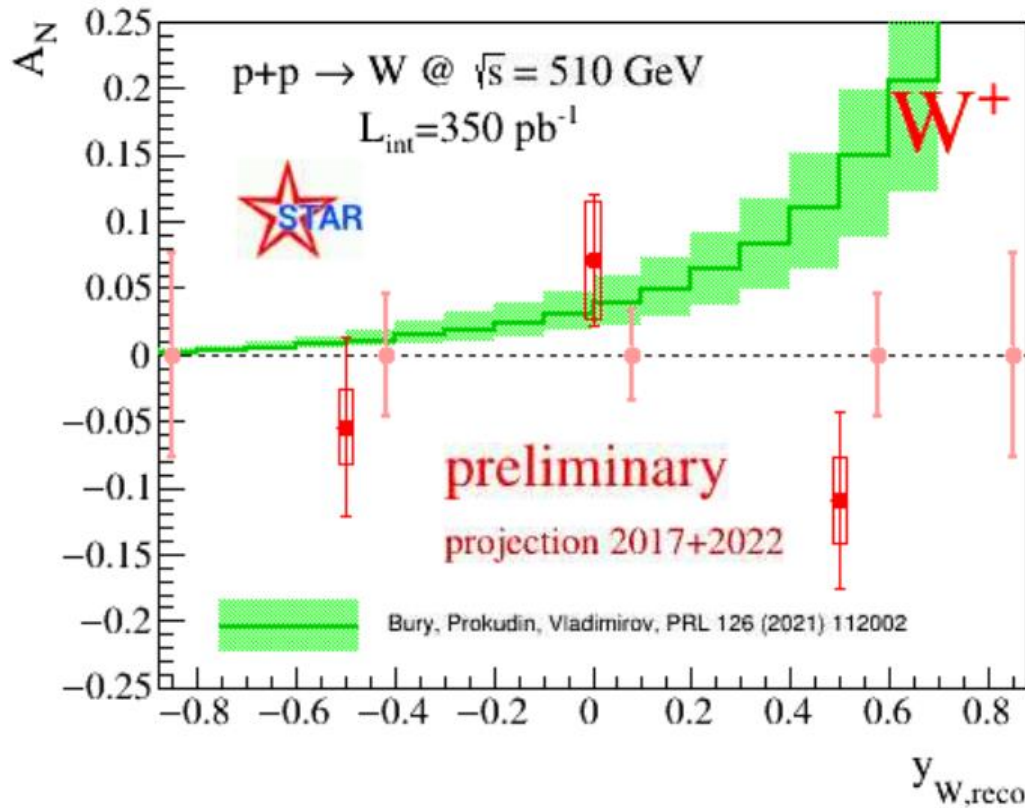
Sivers Effect at STAR

Preliminary Results from the 2017 dataset



Sivers Effect at STAR

Projections from the 2022 dataset



Reference: O. Eyser, RHIC-AGS Users' Meeting 2022