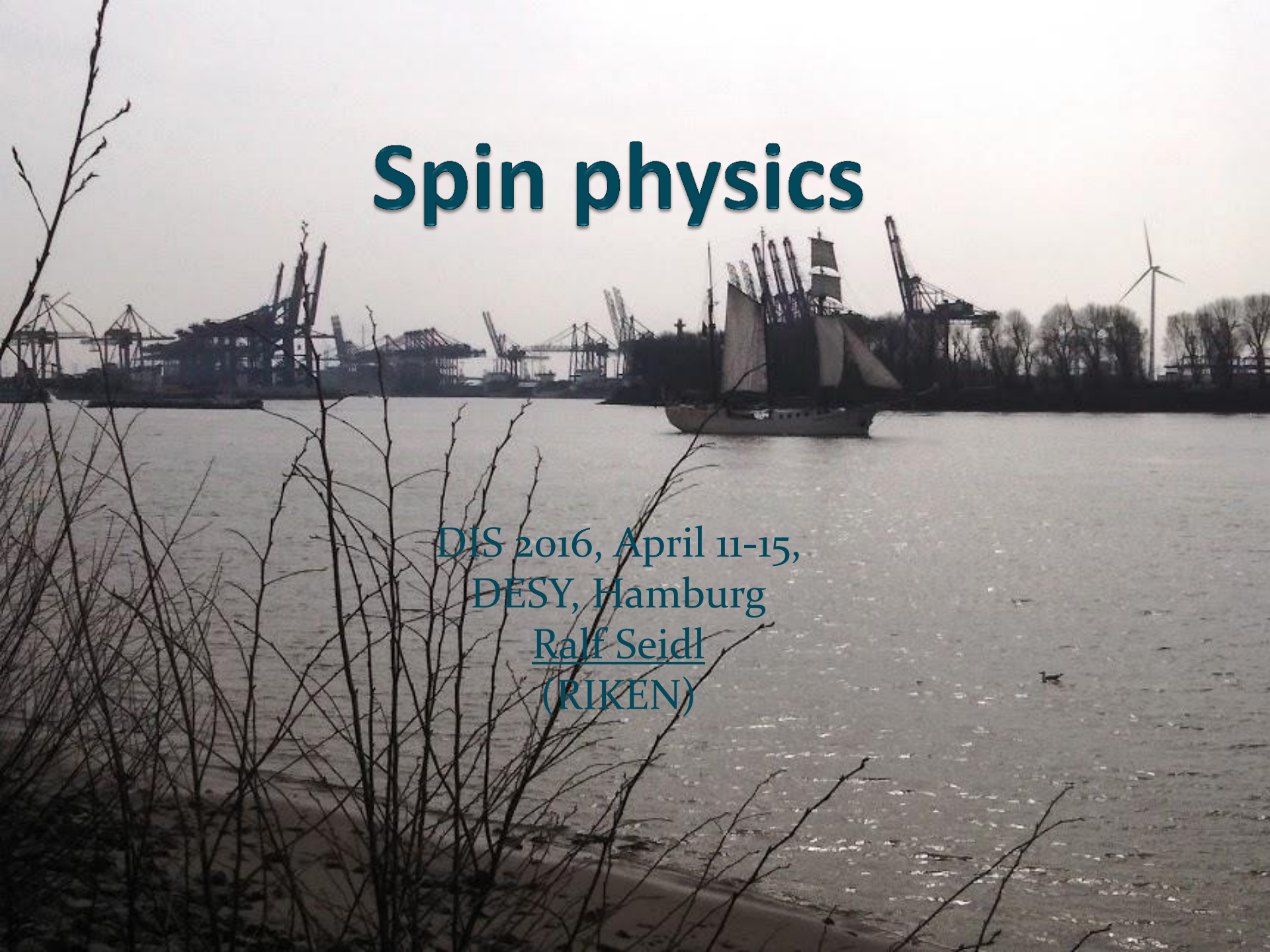


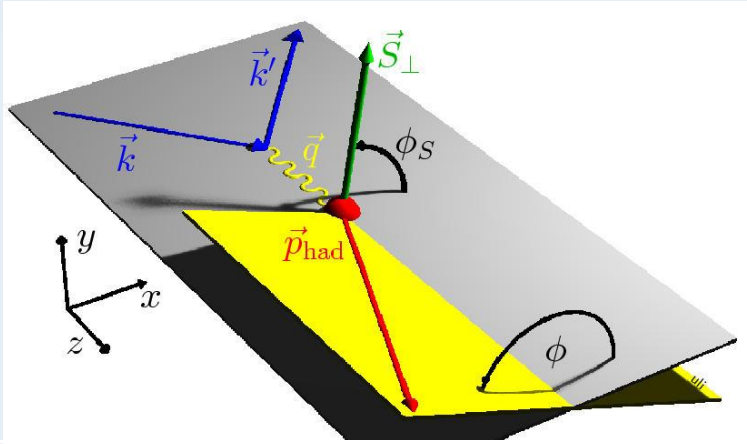
# Spin physics

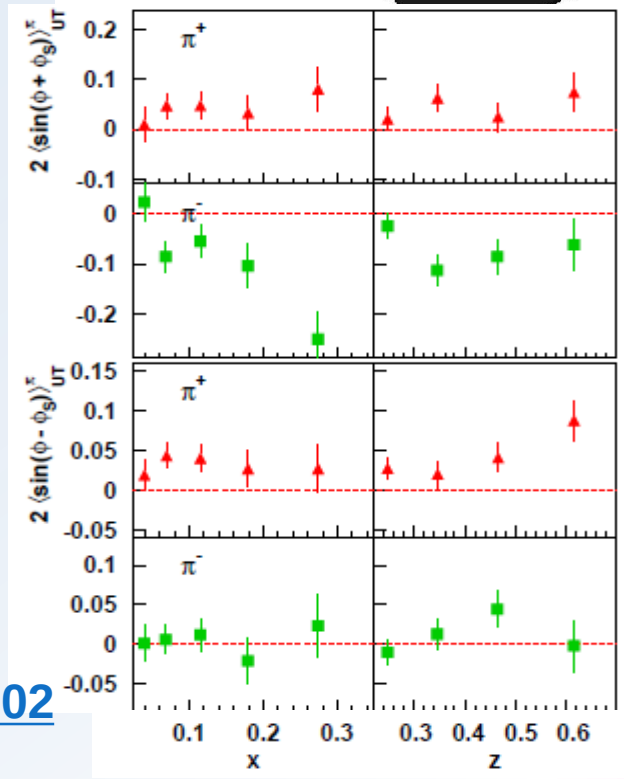
DIS 2016, April 11-15,
DESY, Hamburg

Ralf Seidl
(RIKEN)

# Early HERMES findings (ca 2002)

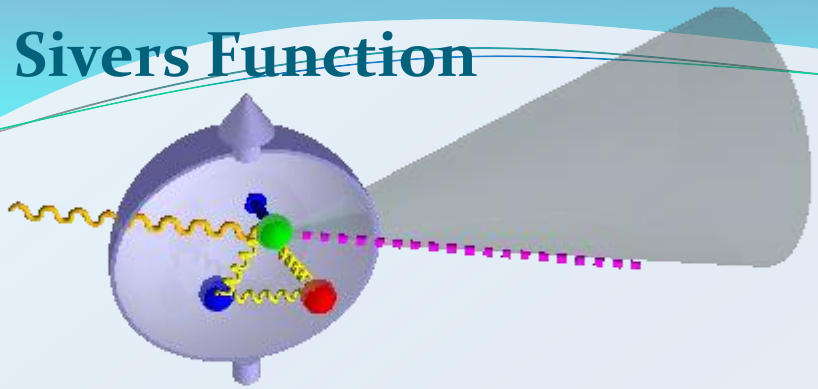
- ep↑ → e'hX
- Both azimuthal modulations related to Sivers effect ($\sin(\phi-\phi_s)$) and Collins effect ($\sin(\phi+\phi_s)$) nonzero
- Large, negative Collins effect for negative pions hard to explain in u quark dominance



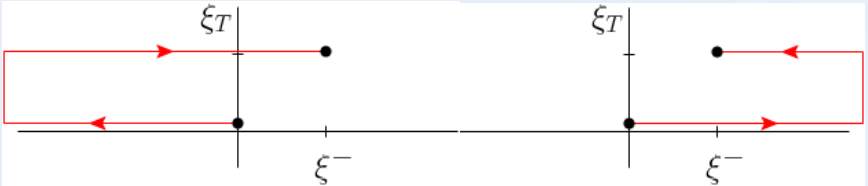




**HERMES:**
PRL 94 (2005) 012002

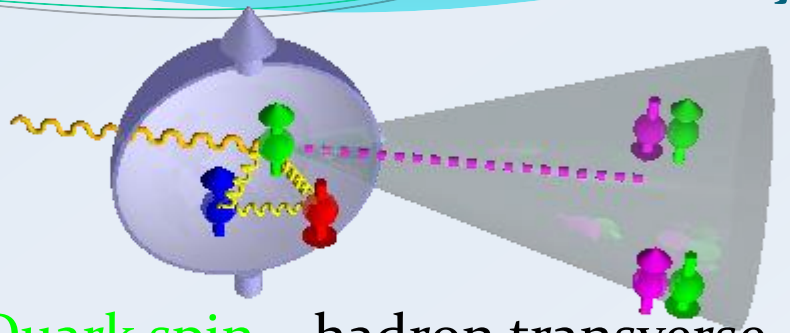
# Sivers Function



- Proton–spin – quark orbit ($k_T$) correlation
- Suggested in ’93 – dead due to time reversal
- Brodsky-Hwang-Schmid ‘02 model example of Sivers function using gauge links
- Belitsky-Yuan ‘02 → gauge links generally needed
- Collins → function can exist, but modified universality (the SIGN change)




# Collins Function (x Transversity)



- Quark spin – hadron transverse momentum correlation (in fragmentation)
- Analyzer for quark transversity → access to tensor charge (Lattice, BSM?)
- A polarized (ie signed) fragmentation function
- Transverse momentum conservation requires some compensation ( Terayev-Schaefer)

**Figs from Buffing et al.** :
PRD 86 (2012) 074030



RIKEN

# SIDIS TMDs at present

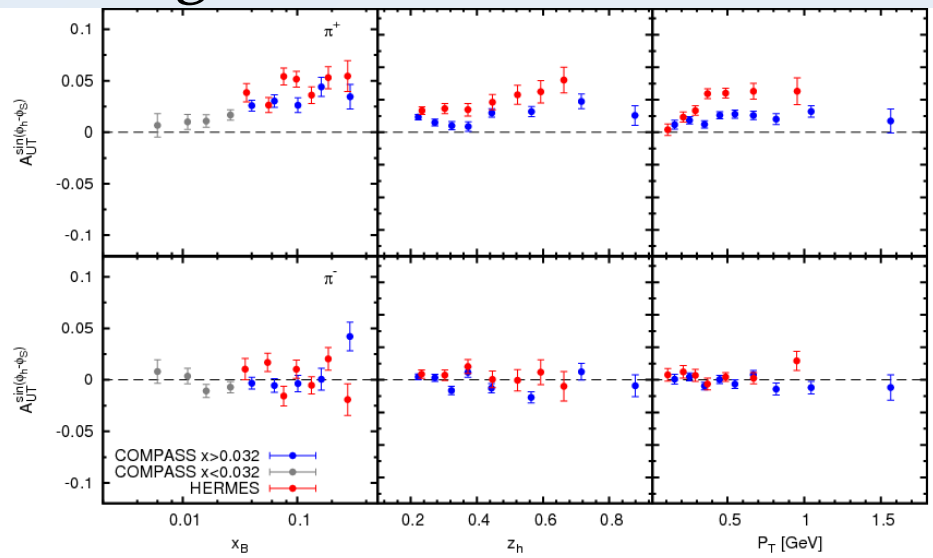
→Bressan
→vanHulse
→Boglione
→Avakyan

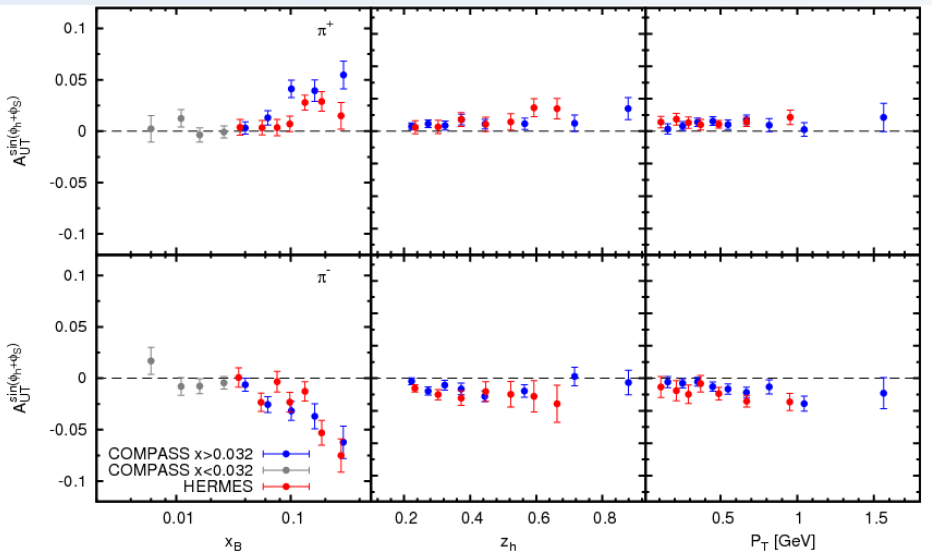
## Sivers Function:

- measured by HERMES and COMPASS in valence region
- Slight differences as initial suggestion for TMD evolution
- up and down functions comparable and of opposite sign

## Collins Function:

- Collins FF and Transversity measured by HERMES and COMPASS in valence region; FFs by Belle, BaBar and BesIII
- Disfavored fragmentation with opposite sign to fav. FF



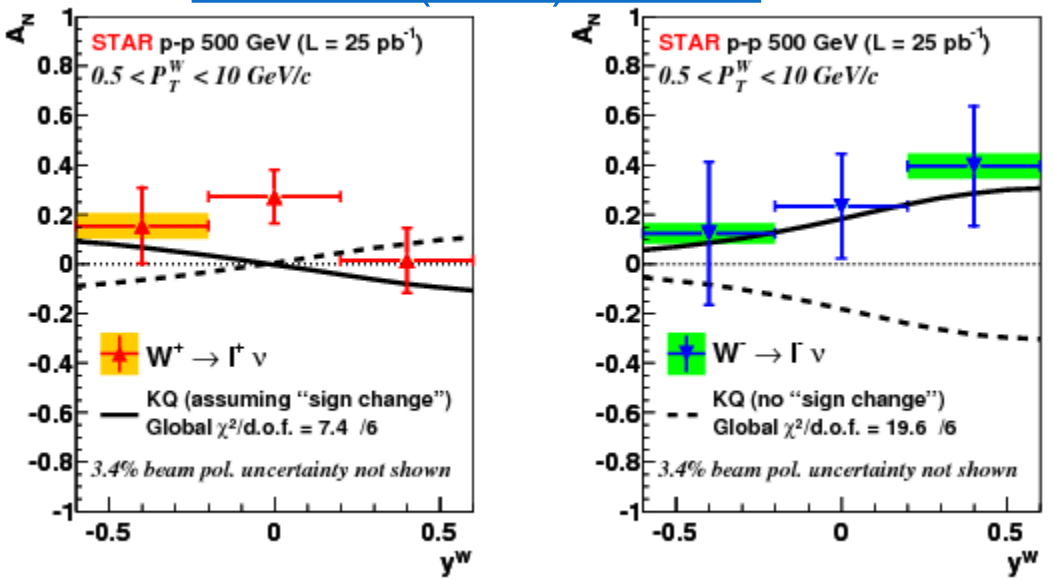



# Towards the sign change

- Using recoil method reconstruct W transverse momentum and azimuthal asymmetry
- First indication of expected sign change!
- Evolution effects could reduce size of asymmetries
- 2017 data taking will substantially improve statistics; also DY and Z asymmetries

→Fazio

STAR: PRL 116 (2016) 132301

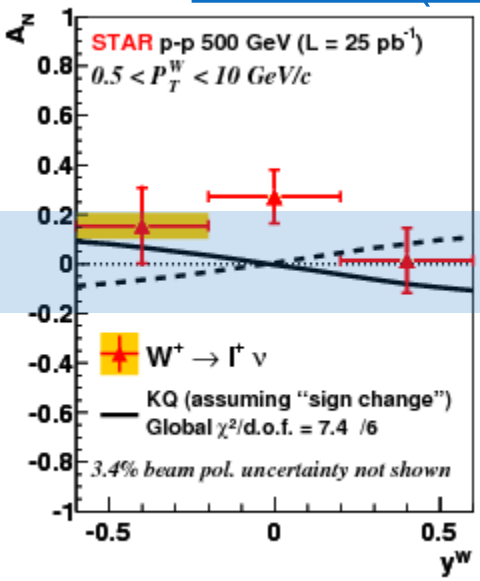


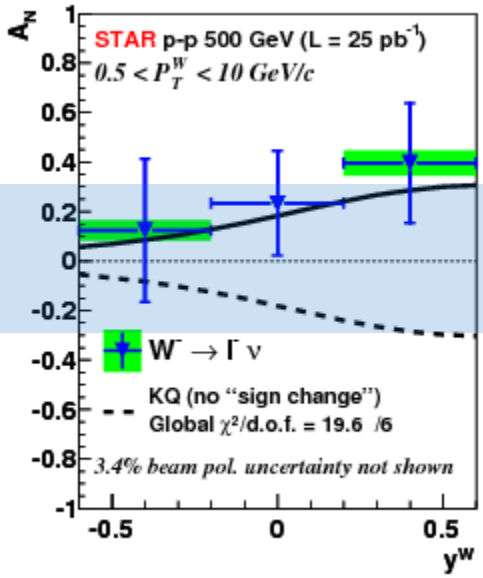
# Towards the sign change

- Using recoil method reconstruct W transverse momentum and azimuthal asymmetry
- First indication of expected sign change!
- Evolution effects could reduce size of asymmetries
- 2017 data taking will substantially improve statistics; also DY and Z asymmetries

→Fazio

STAR: PRL 116 (2016) 132301



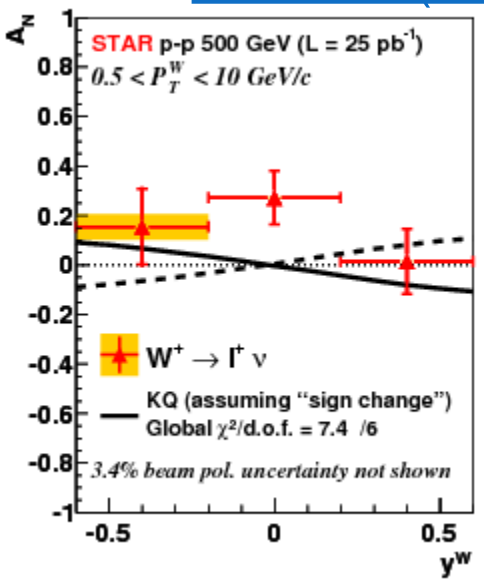



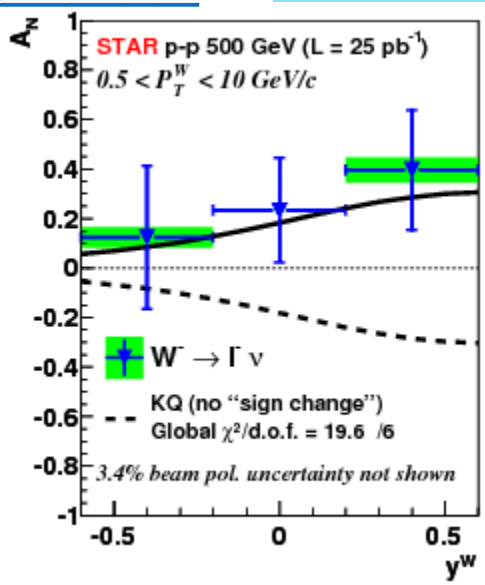
# Towards the sign change

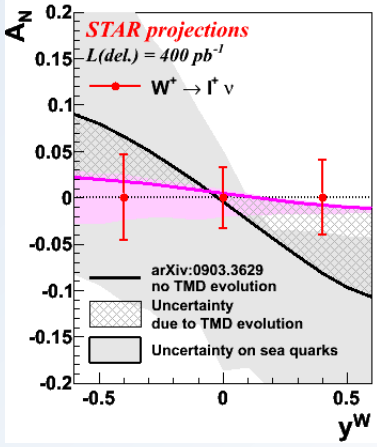
- Using recoil method reconstruct W transverse momentum and azimuthal asymmetry
- First indication of expected sign change!
- Evolution effects could reduce size of asymmetries
- 2017 data taking will substantially improve statistics; also DY and Z asymmetries

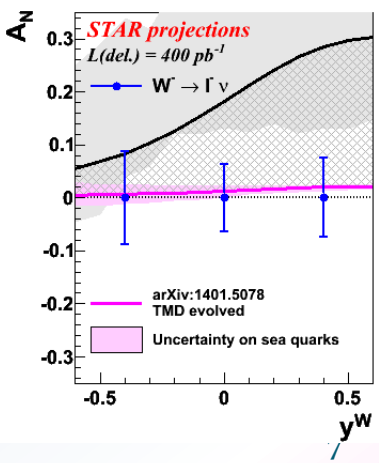
→Fazio

STAR: PRL 116 (2016) 132301



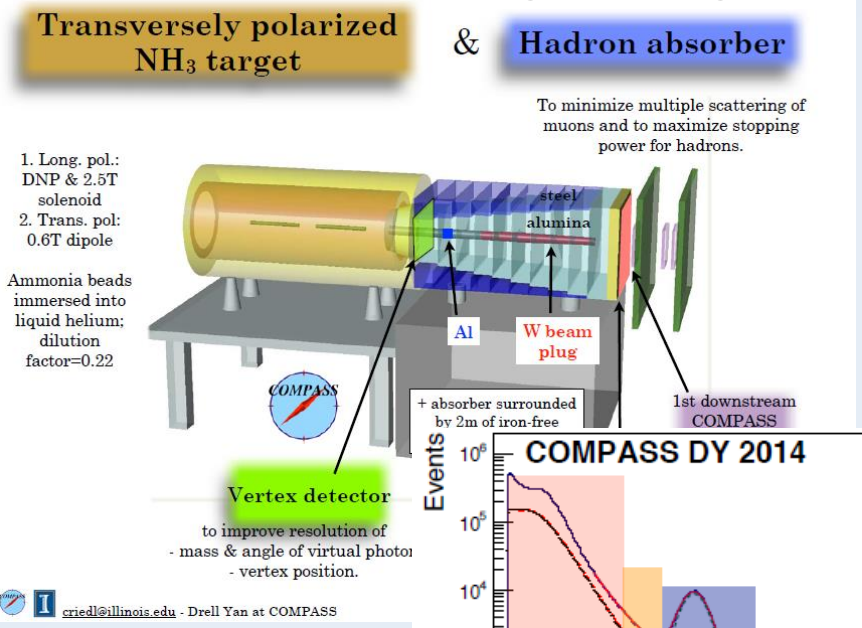



# Sivers Sign change, evolution and sea

→Quaresma

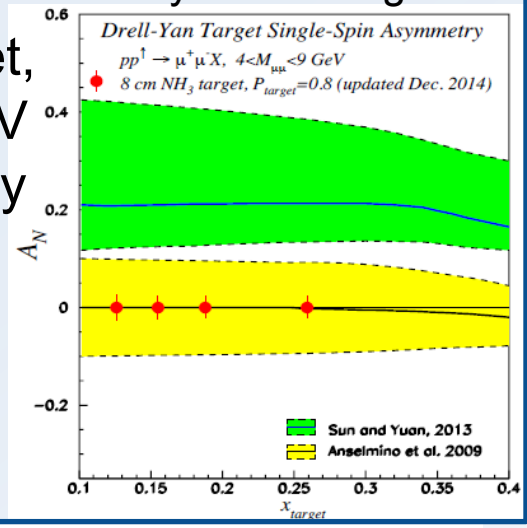
COMPASS: polarized $NH_3$ target + 160 GeV $\pi^-$ beam → Sensitivity to u quark Sivers and sign change

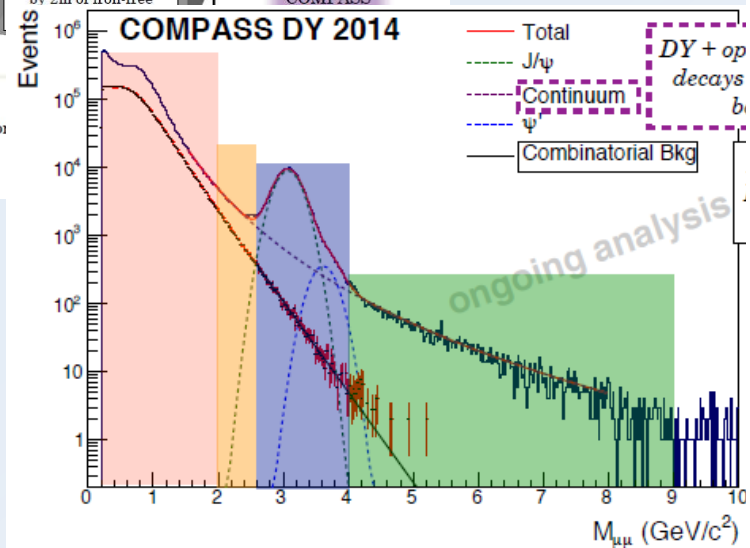


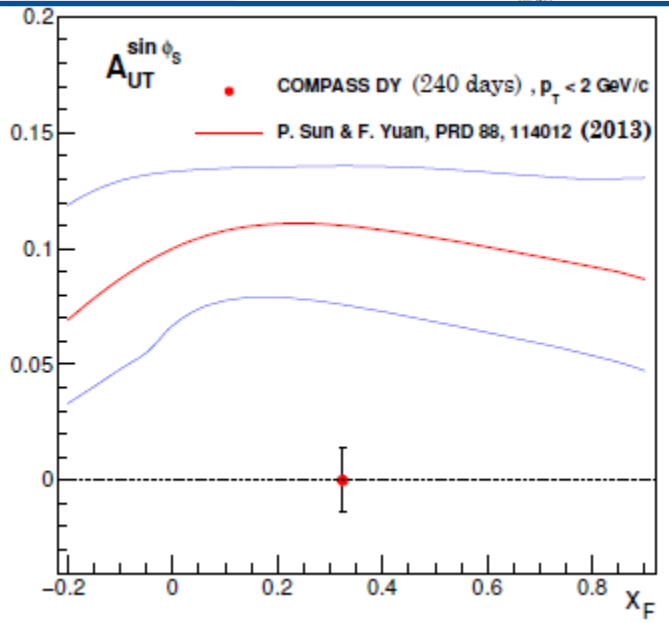

Presentation by C.Riedl

FNAL E1039: polarized $NH_3$ target, unpolarized 125GeV p beam →Sensitivity to $\bar{u}$ Sivers

projection for 1year running



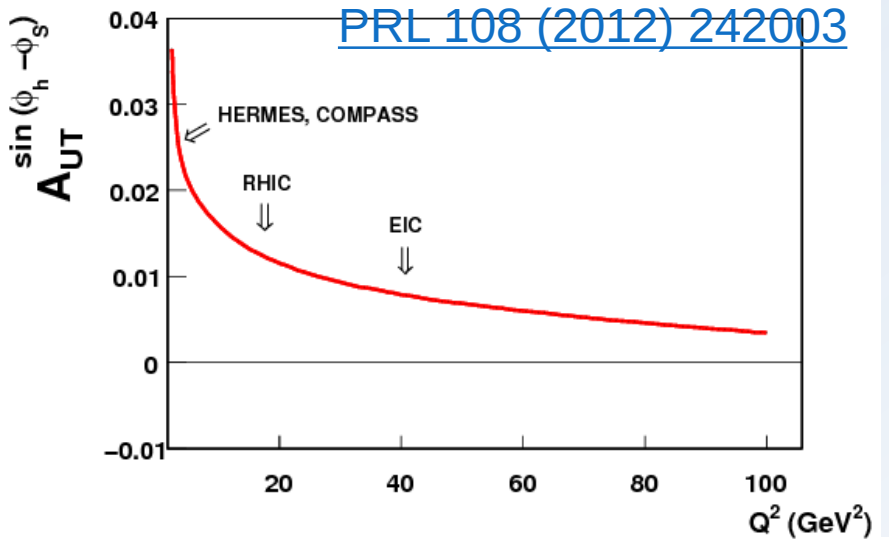



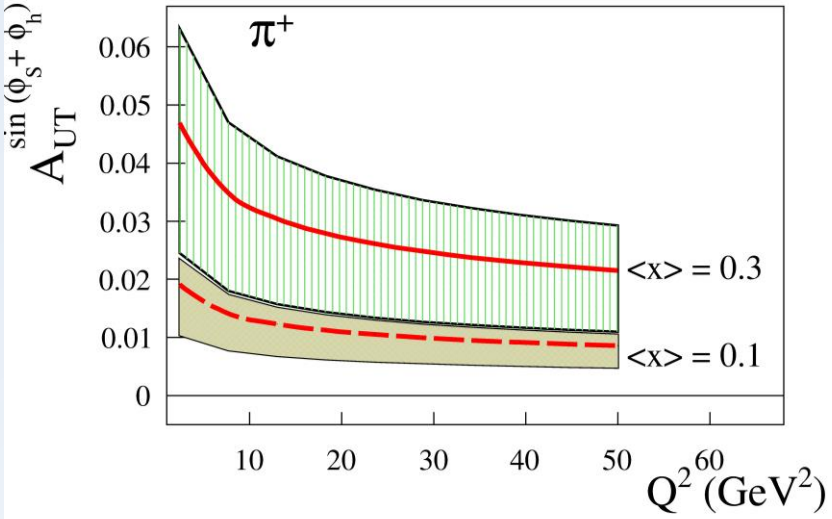



# About TMD evolution

- Large theoretical effort to understand TMD evolution (see for example Evolution and REF workshop series)
- Large overlap with low-x community
- Despite predominantly using CSS formalism large differences due to treatment of non-perturbative terms in evolution → relevant for many spin related TMDs
- Data needed

**Aybat, Prokudin, Rogers**
PRL 108 (2012) 242003



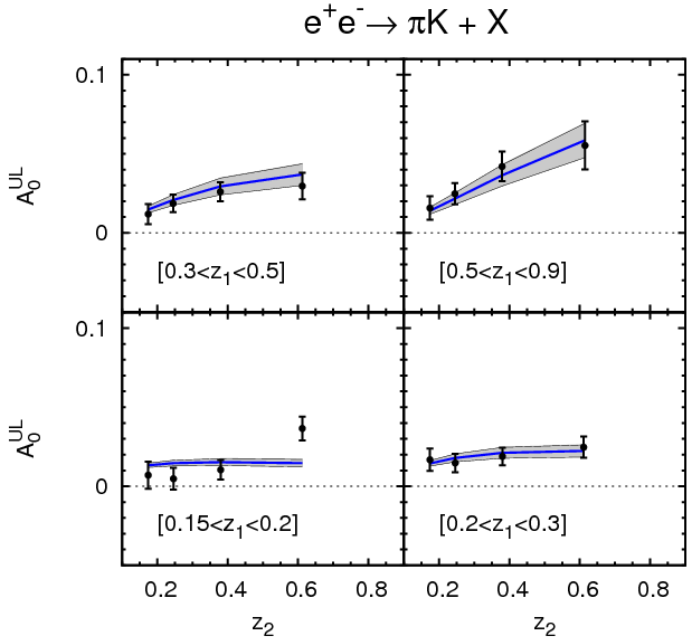




**Kang, Prokudin, Sun, Yuan**
PRD 93 (2016) 014009

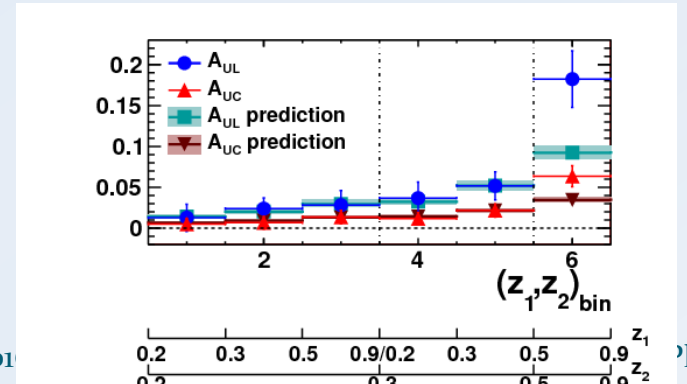
# Quark transversity via Collins: Kaons

**BABAR:** PRD 92 (2015) 111101

**Anselmino et al:** PRD 93 (2016) 034025




**BESIII:** PRL 116 (2016) 042001



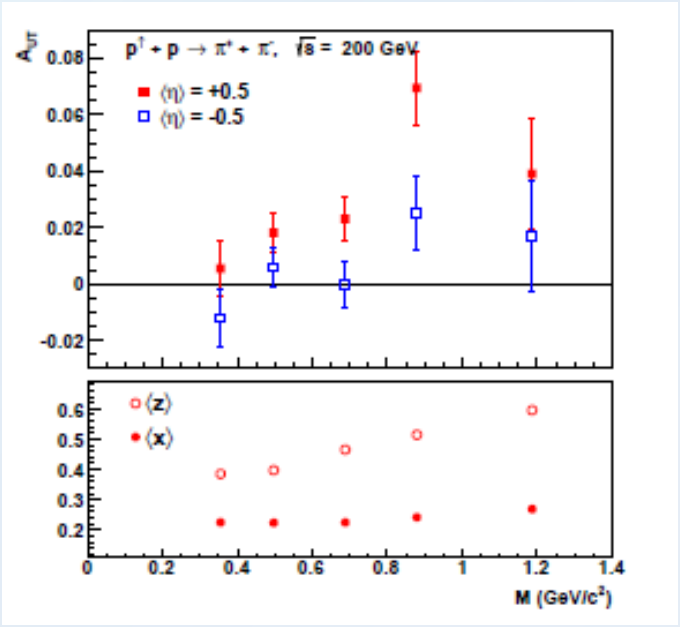

- Addition of kaon Collins fragmentation strongly needed for flavor decomposition of quark transversity
- Large amount of potentially participating FFs well described by light and "heavy" favored and disfavored FFs
- Allows inclusion of HERMES and COMPASS kaon asymmetries (+eventually EIC) in fits
- Also: pion Collins at lower scale(BESIII) consistent with TMD evolution
- Also: unpolarized kaon multiplicities from COMPASS

→vanHulse
→Bressan
→Gonzalez Hernandez

→Kunne
→Hahne

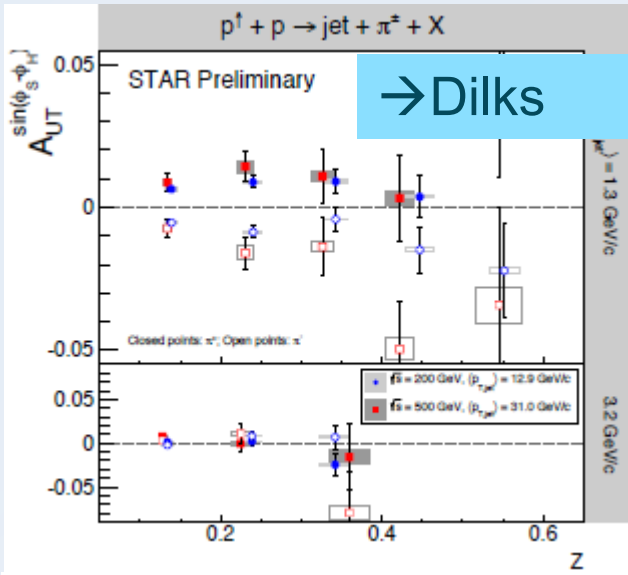
# Transversity in proton collisions

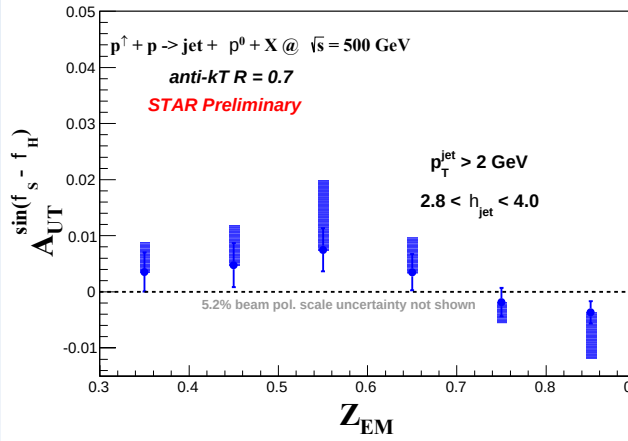
**STAR:** PRL 115 (2015) 242501




- Published Interference FF asymmetries from STAR + preliminary 500GeV data
- Pavia group with first global fits to SIDIS+RHIC+Belle data

- Nonzero Collins asymmetries (hadron in jets) at central rapidities
- Substantial theoretical progress for hadron in jet measurements
  - unpolarized: Kaufmann et al.
  - polarized Kang et al.
- For roughly same x and kt similar size → evolution effects moderate?
- Using forward EmCal first hint of nonzero Collins asymmetries for $\pi^0$ in EM jets



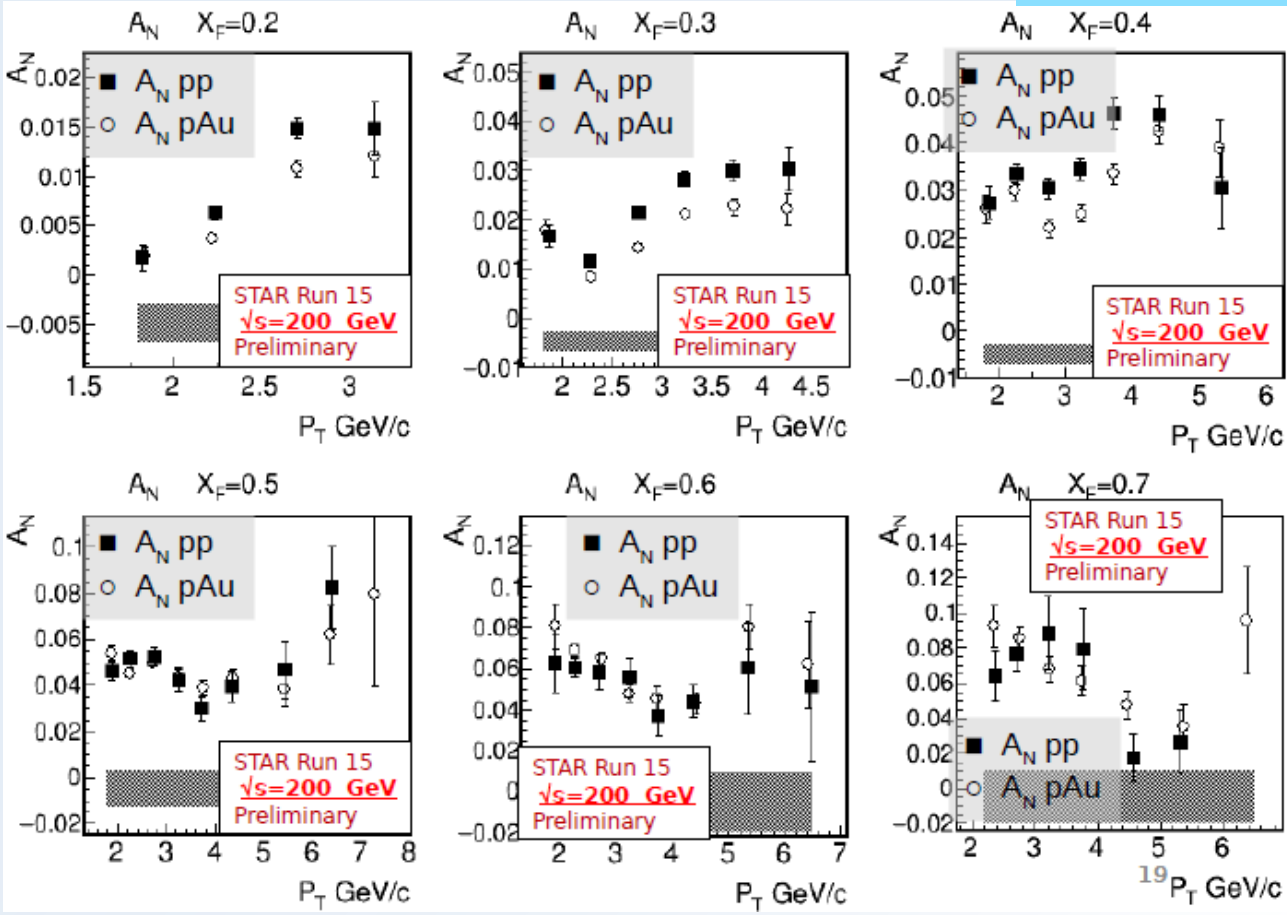



# Transverse spin asymmetries in pA

2015: $p^{\uparrow}$+A collision at $\sqrt{s_{NN}} = 200$ GeV

→Dilks

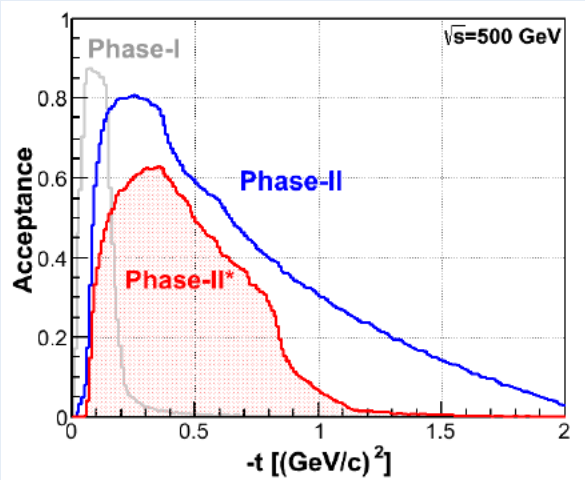
- Several theory predictions of diminished pA asymmetries due to nonlinear low-x behavior (either final or initial state effects)
- No substantial reduction seen in 2015 STAR data
- However, origin of $A_N$ asymmetries still unclear

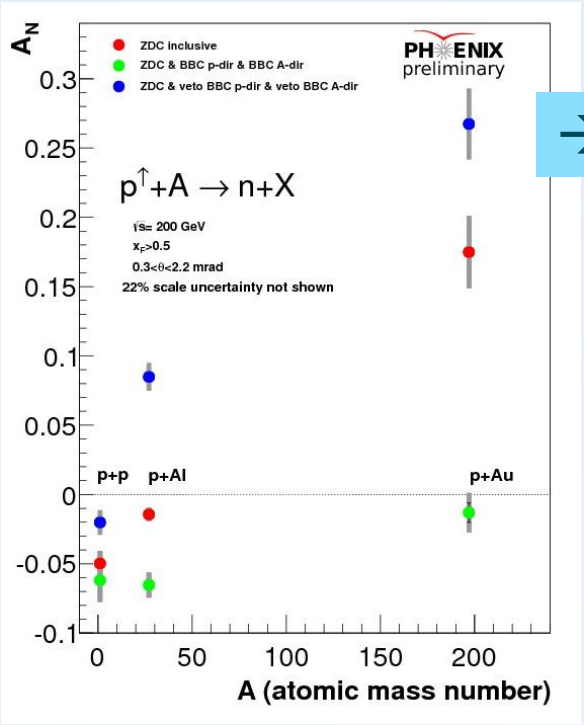



→Koike
→Yoshida
→Yabe

# …and other surprises

- Some indications of forward pion asymmetries in pp not due to initial state (higher twist related to Sivers) or final state (related to Collins or other FF) hard effects but diffractive
- 2015 STAR data included roman pots to answer this question




→Tanida

- Unexpected forward neutron asymmetry A behavior
- Potentially different contributions from Ultraperiphal collisions (EM) and hadronic (Reggeon) interactions
- More studies ongoing, including $P_t$ dependence

# Quark and gluon Helicities

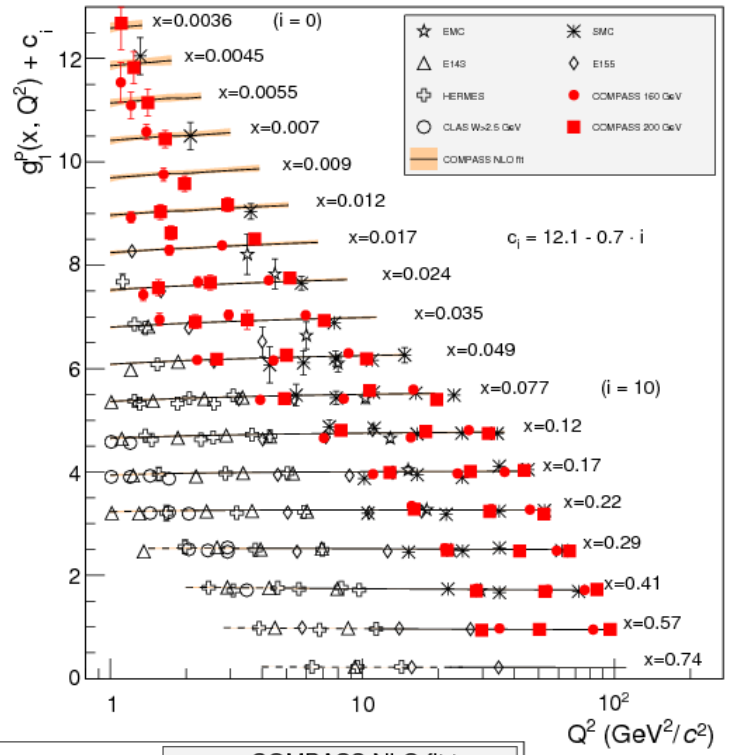
$$\Delta q(x) \;\; \Delta \bar{q}(x) \;\; \Delta g(x)$$

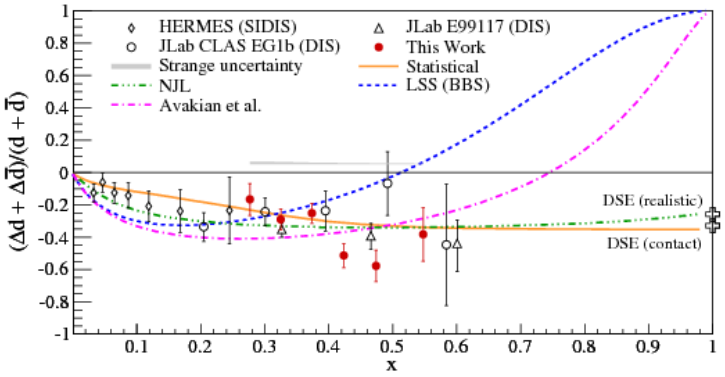
# DIS updates

→Wilfert
→Nunes

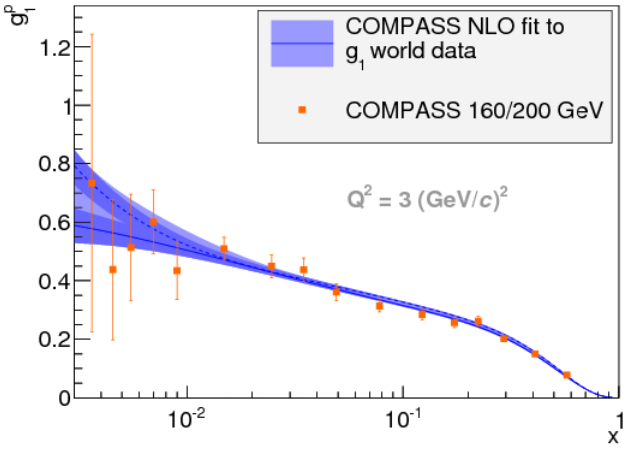
- Final COMPASS data at 200GeV now available
- Also new updates from JLAB6 on longitudinally polarized $He^3$, p and d targets → no indication of high-x sign change of $\Delta d(x)$

COMPASS: PLB 753 (2016) 18-28




**HallA:** PLB744 (2015) 309

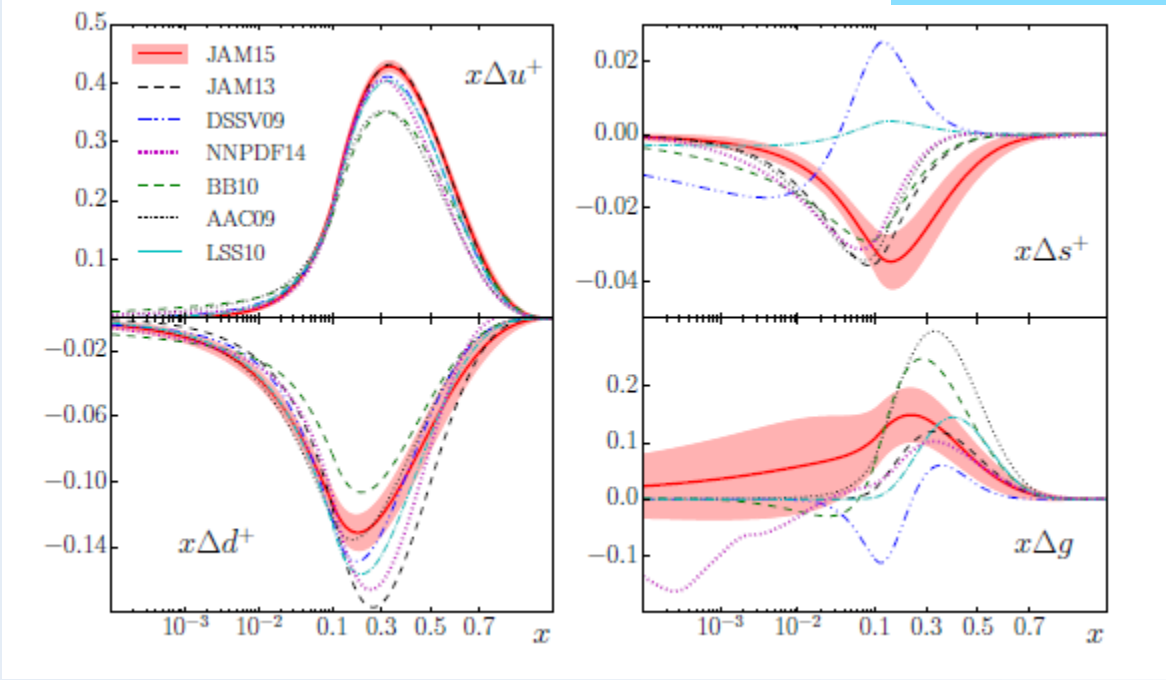


# Helicity fits

- New JAM fit of inclusive $g_1$ data taking into account lower $Q^2$ JLAB data via Higher twist and mass effect treatment
- NNPDF includes some RHIC data using DSS FFs (pol1.1), working on own FFs for fully global fit
- DSS FF update on pion FFs, ready for Kaon FFs when COMPASS multiplicities published

Sato et al.: [arXiv:1601.07782](arXiv:1601.07782)

→Sato

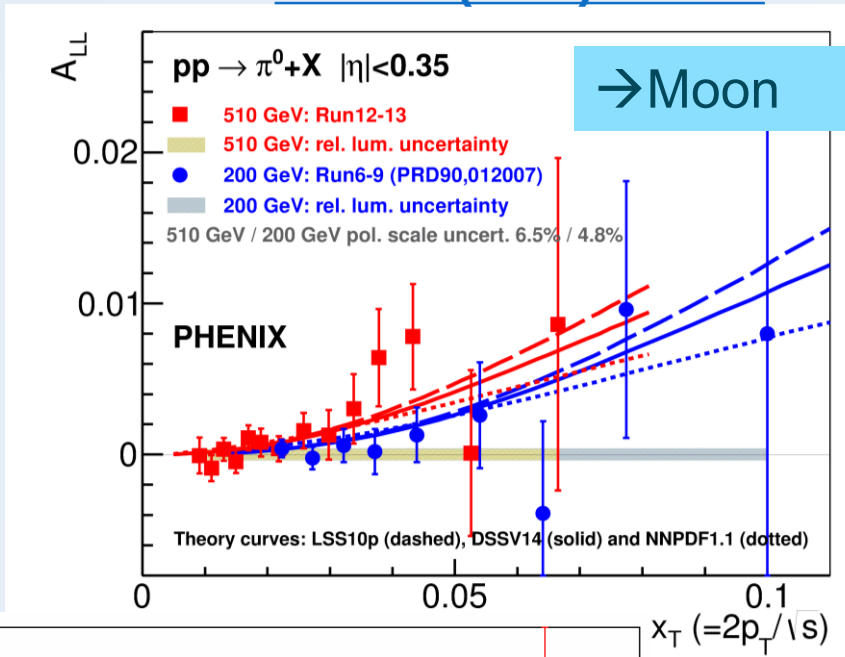



- Usual caveat about inclusive polarized DIS Fits: flavor sensitivity mostly via $g_A$ and hyperon decay constants with $SU(3)_F$ assumption

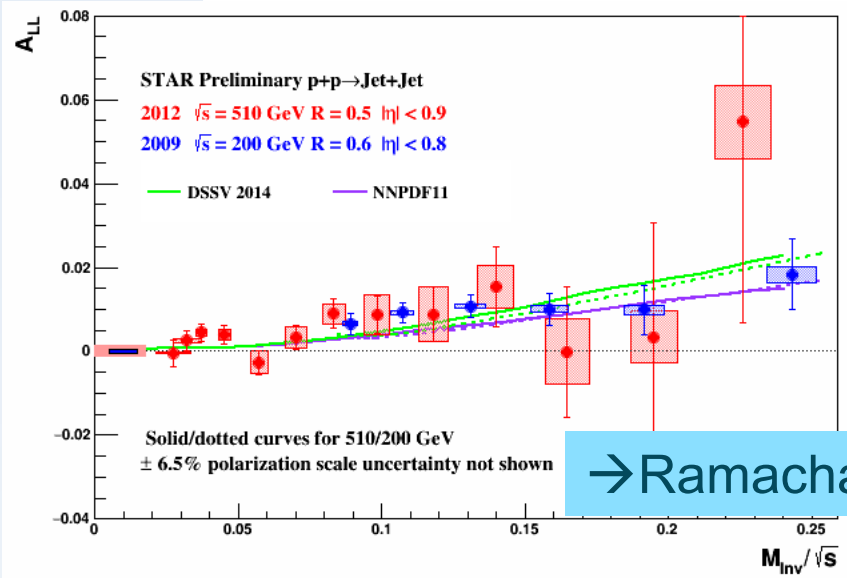
# Gluons: To higher energies

- Nonzero gluon polarization established with RHIC $\sqrt{s}$ = 200 GeV data
- RHIC 510 GeV data (>2011) now confirms it in workhorse (jet, pion) measurements
- Extend access to lower x by higher energy (now~ $10^{-2}$)

**PHENIX** PRD 93 (2016) 011501

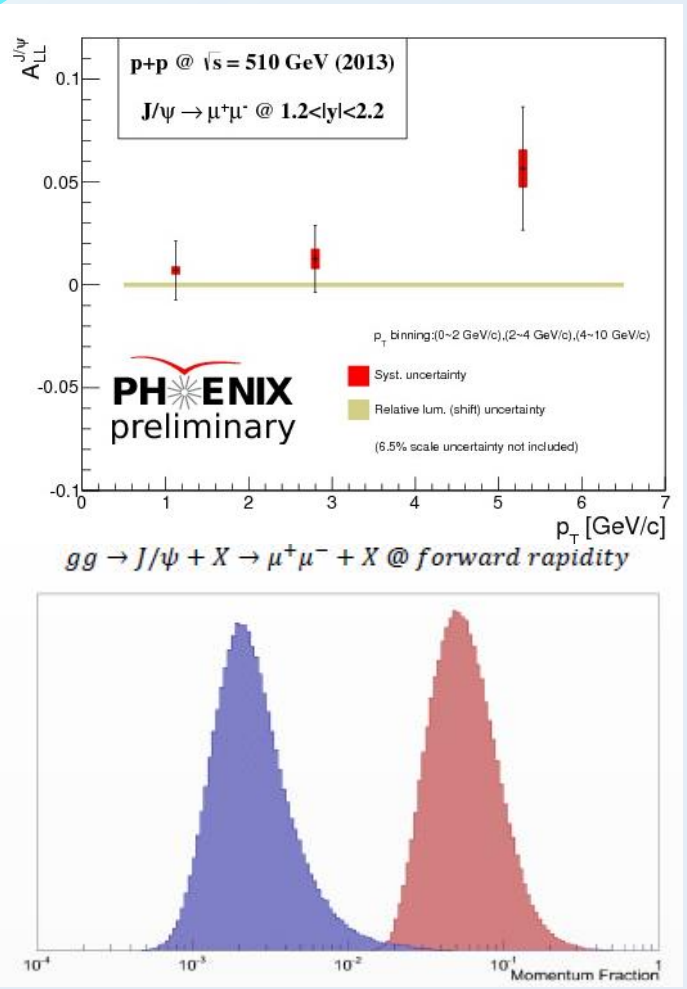



→Moon



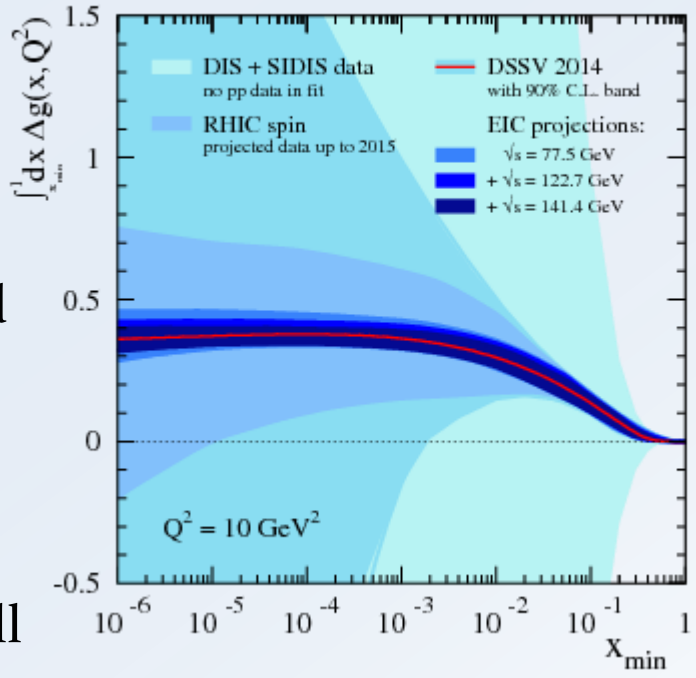

→Ramachandran

# …and lower x




- PHENIX forward J/ψ measurements reach close to $x\sim10^{-3}$
- Including feed-down almost entirely produced from gg
- Due lack of knowing production mechanism interpretation still difficult

RPD 92 (2015) 094030

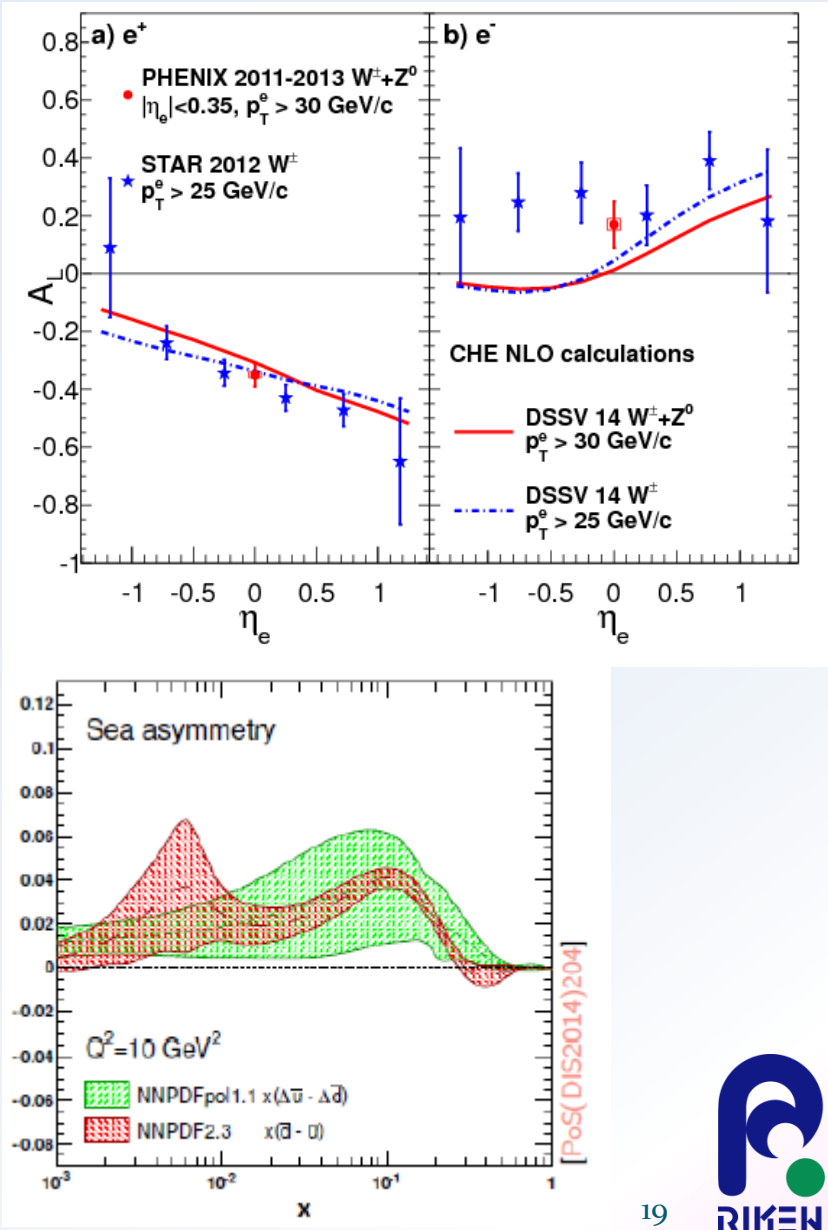



- Other forward $\pi^0$ measurements ongoing to get better precision down to $x\sim10^{-3}$
- Eventually EIC to pin down integrals, strangeness and need for OAM

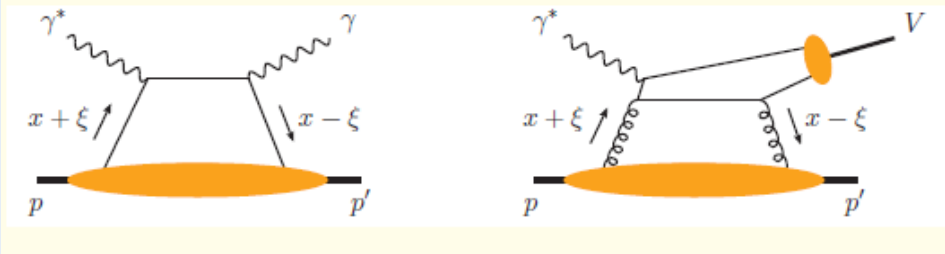
# Sea quark helicites

STAR: PRL 113 (2014) 072301
PHENIX: PRD 93 (2016) 051103

- STAR 2012 data at boundary of DSSV uncertainty bands
- Reweighted NNPDFpol1.1 shows substantial polarized light sea asymmetry
- opposite sign to most cloud models
- All central PHENIX data published,
- 2013 STAR data and forward PHENIX data pending



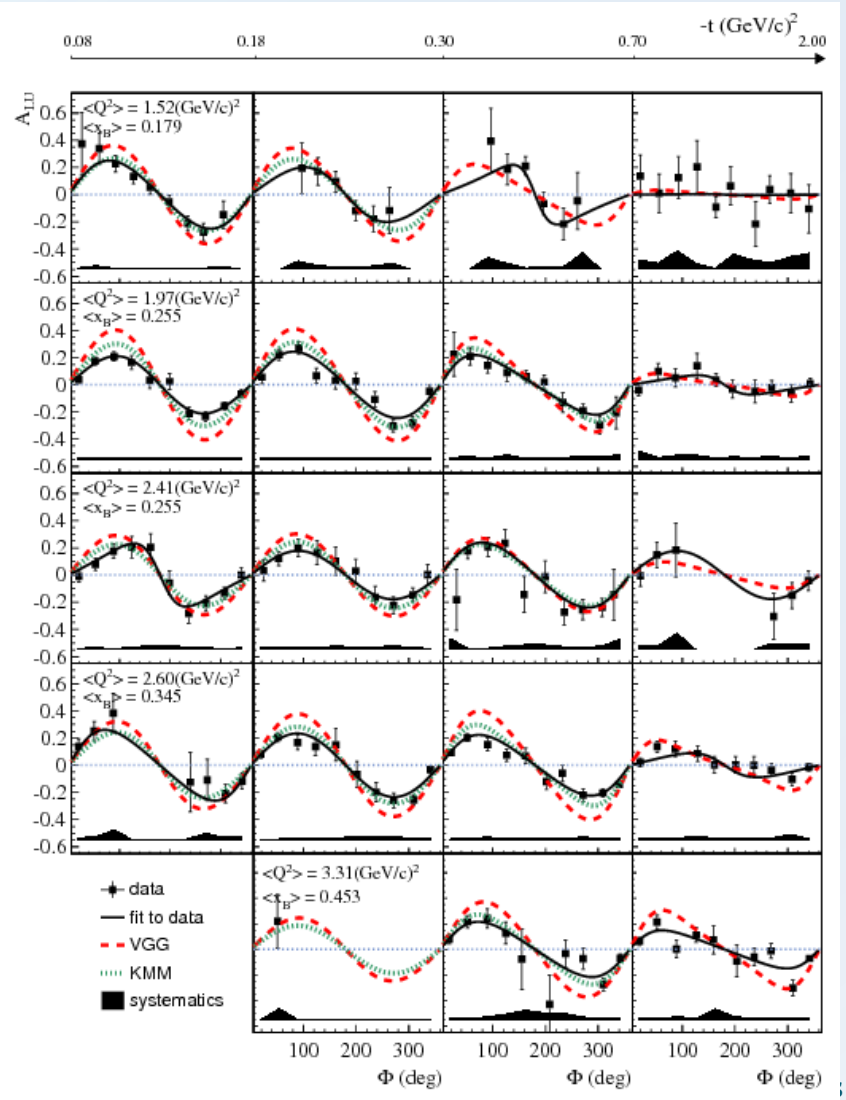
# GPDs and spatial imaging



# New DVCS measurements

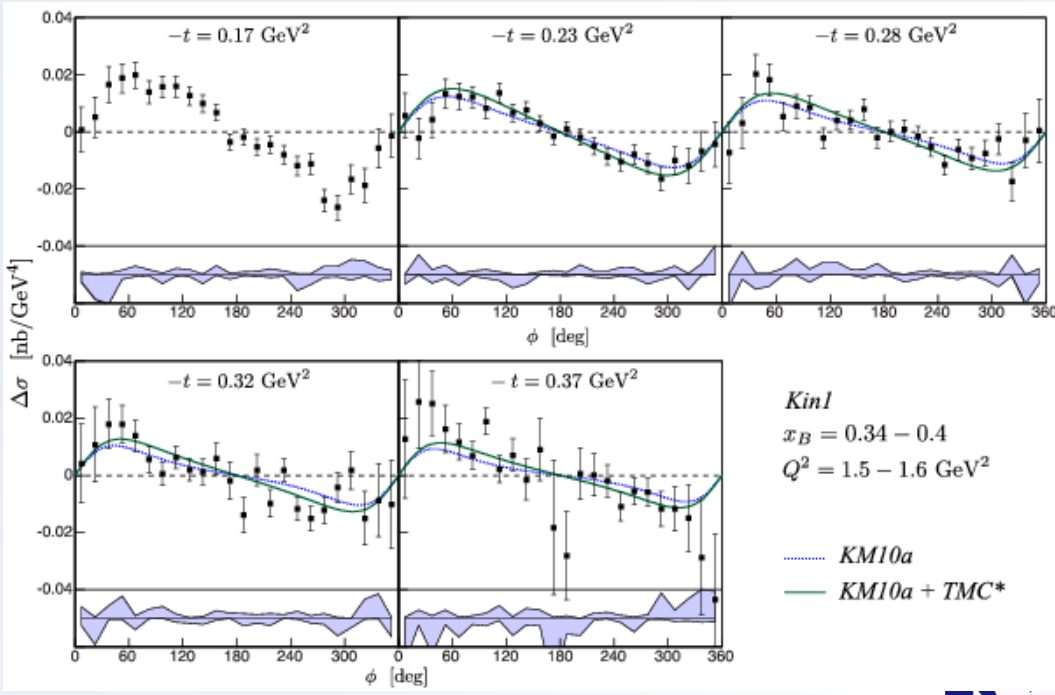
→Joo
→Sabatie
→Niccolai
→Joerg

**CLAS:** [PRD 91 (2015) 052014]




- Various DVCS asymmetries to access different combinations and parts of contributing GPDs

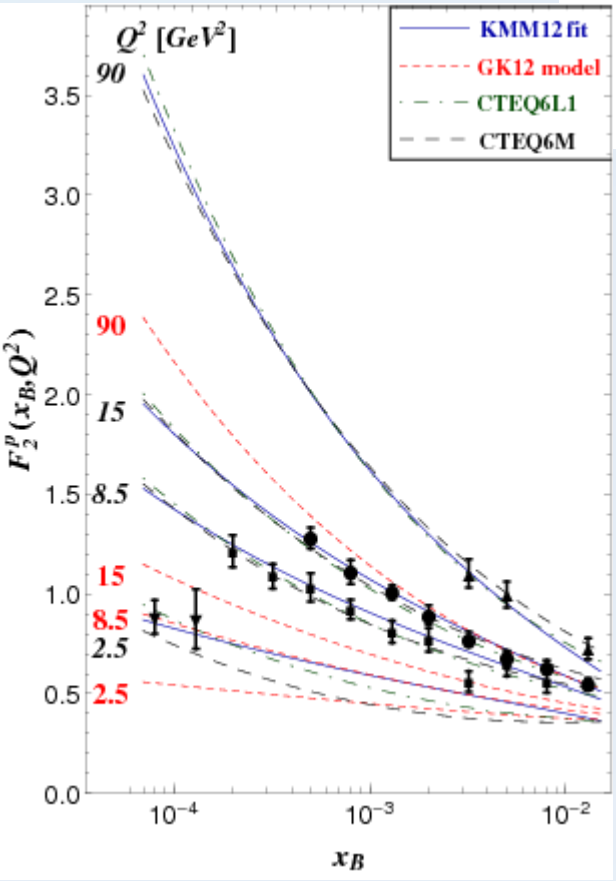
**Hall A:** [PRC92 (2015) 055202]

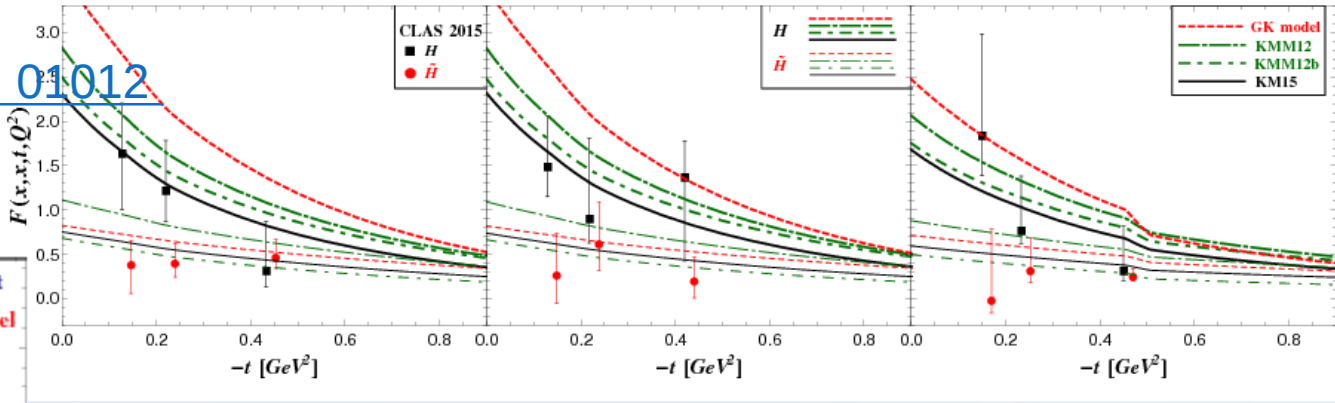


# …and GPD fits

→Mueller

**Kumericki, Mueller:**
EPJ Web Conf. 112 (2016) 01012



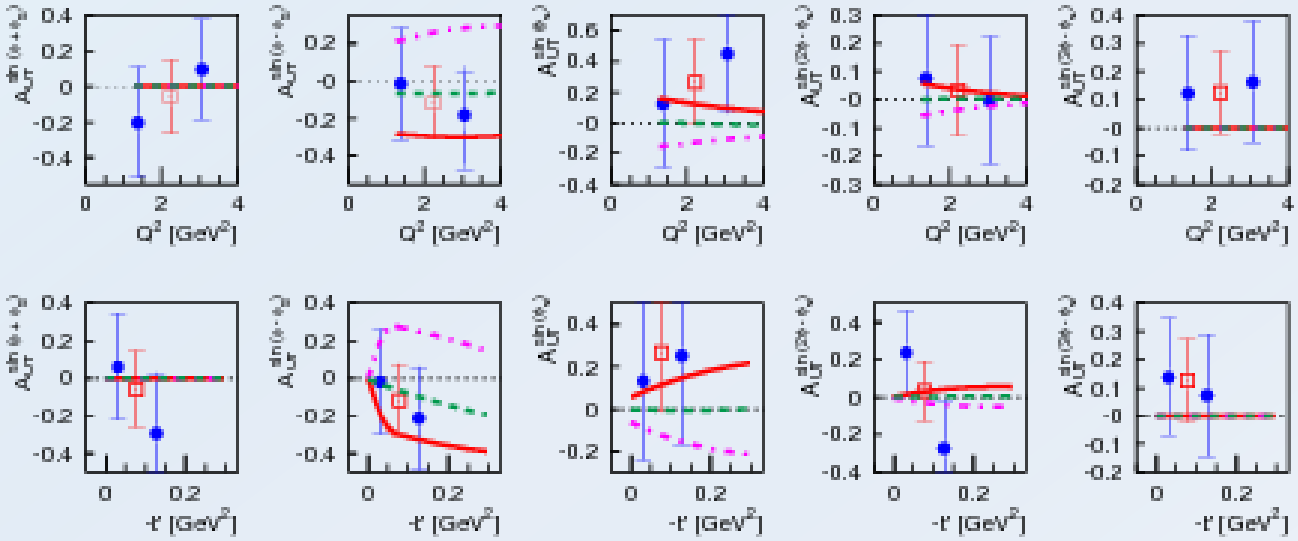

- Towards global fits of DVCS data
- GPDs related to regular pdfs and form factors:

  $H \rightarrow$ q, $\tilde{H} \rightarrow \Delta$q for $\xi \rightarrow$ o
- Recent fits consistent with pdfs but earlier models not

# Transverse GPDs and exclusive meson production

→Manaenkov

**HERMES:** EPJC 75 (2015) 600



- HERMES data prefer positive πω form factor in GK model

- Exclusive pion, rho, omega production on a transversely polarized target → Access to poorly known transverse GPDs ($H_T$, $E_T$, $\widetilde{H}_T$, $\widetilde{E}_T$)

→Boussarie
→Goldstein

# Summary

- First indication of Sivers sign change, expect answer with STAR run17 and COMPASS results
- data to pin down effects of TMD evolution
- Transversity now also accessible at RHIC
- New information towards understanding transverse asymmetries in hadron collisions, but also new puzzles (such as A dependence)
- Gluon spin contribution confirmed at higher collision energies, started accessing lower x
- Polarized light sea seems to be asymmetric and disfavors pion cloud models
- GPDs via DVCS and DVMP
- More to come in the future:
  - COMPASS GPD
  - JLAB11
  - RHIC (CNM 2017-23 plan)
  - EIC