SBS Physics: From Form Factors to Tagged DIS and Semi-inclusive DIS

- The motivation for the SBS program
- A quick snapshot of the experiments
- The discovery potential

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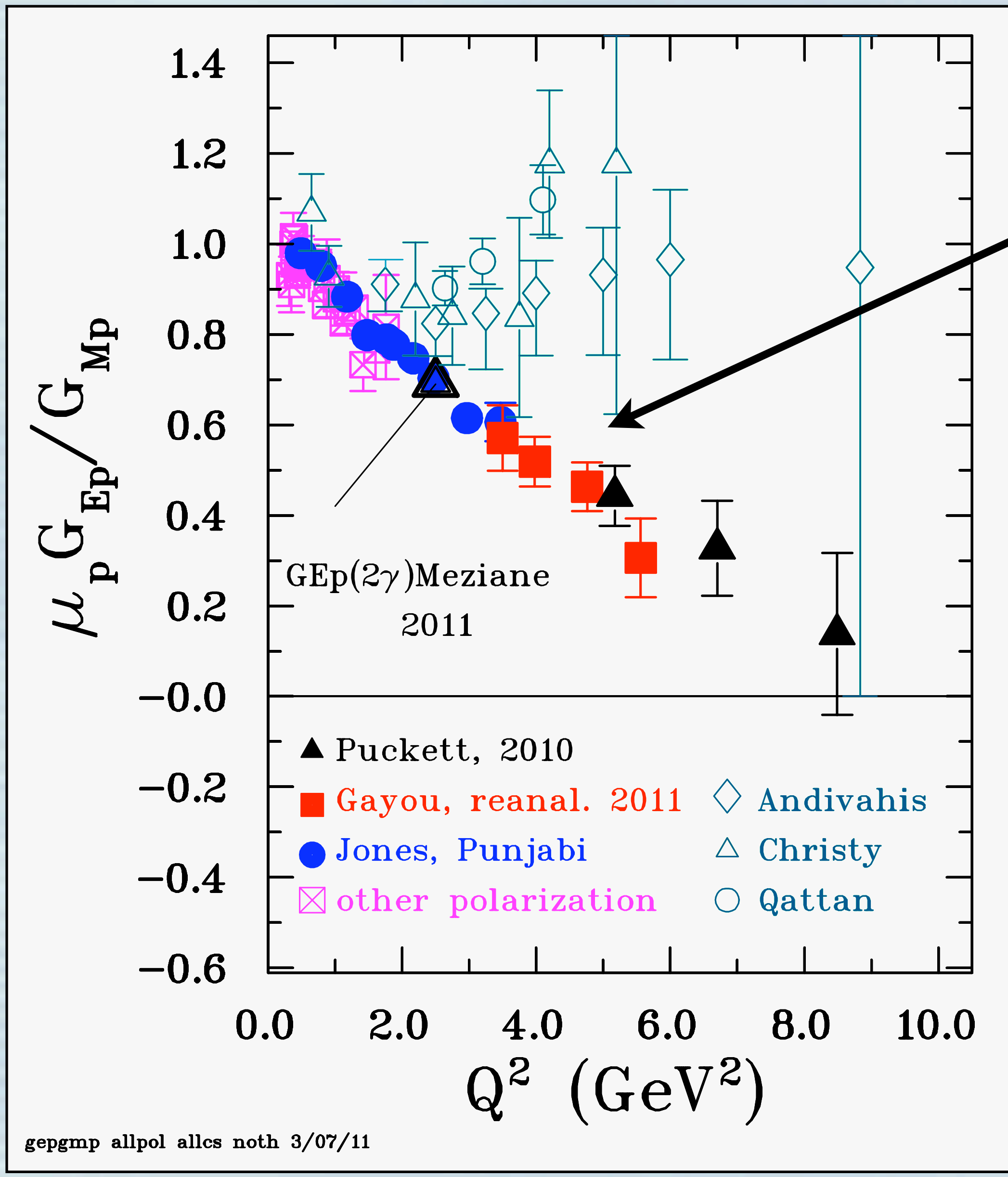
August 5, 2019

At JLab, it was discovered that the ratio of the elastic electric and magnetic form factors of the proton decrease nearly linearly with Q^2



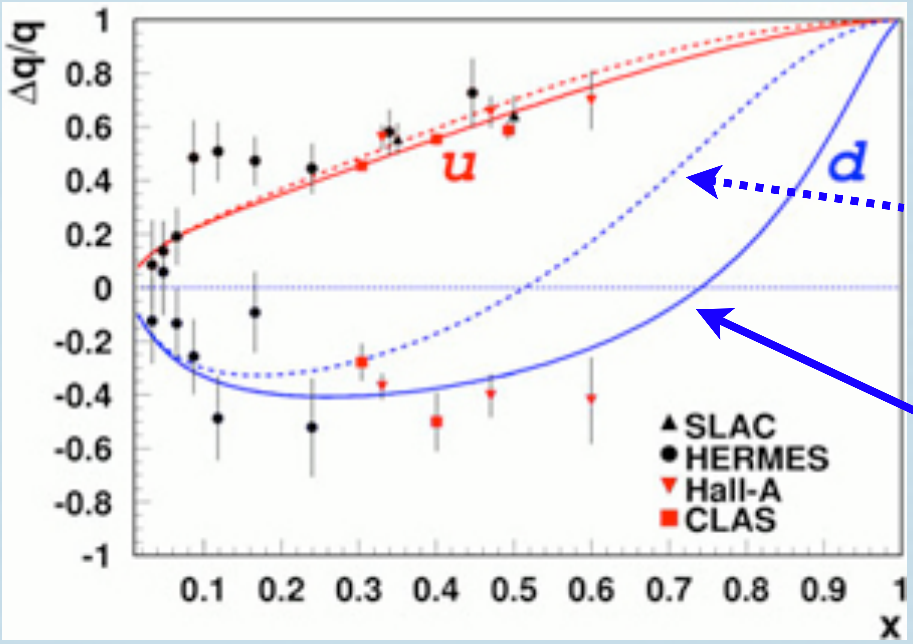
Data from both Rosenbluth separations and the double-polarization technique.

Resulted in the 2017 Bonner Prize in Nuclear Physics being awarded to to Charles Perdrisat of William and Mary

- Explanations for the Q^2 behavior of G_E^p/G_M^p have emphasized the role of quark orbital angular momentum.
- Again, there was a pressing need to obtain corresponding data on the neutron at high Q^2.
- But the elastic cross sections at high Q^2 are very small!

Evidence for quark orbital angular momentum has subsequently been seen in a variety of other experiments

Deep-inelastic scattering with polarized beam and targets

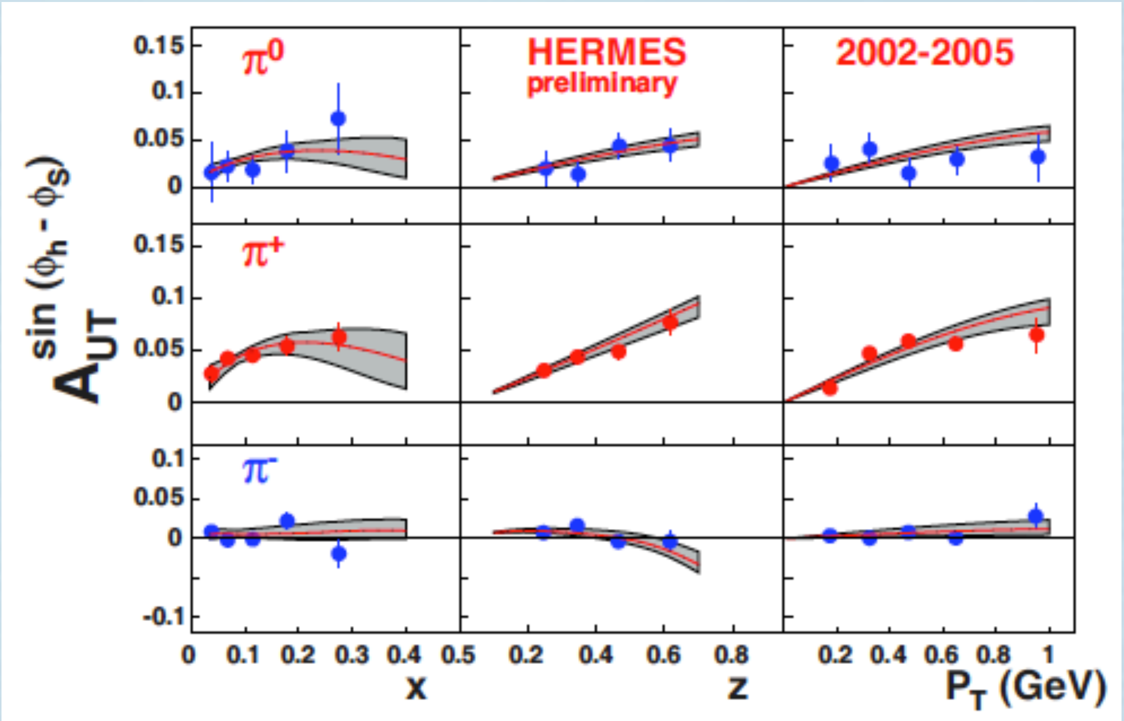


Model without quark orbital angular momentum.

Model with quark orbital angular momentum.

Flavor-separated spin contributions from up and down quarks

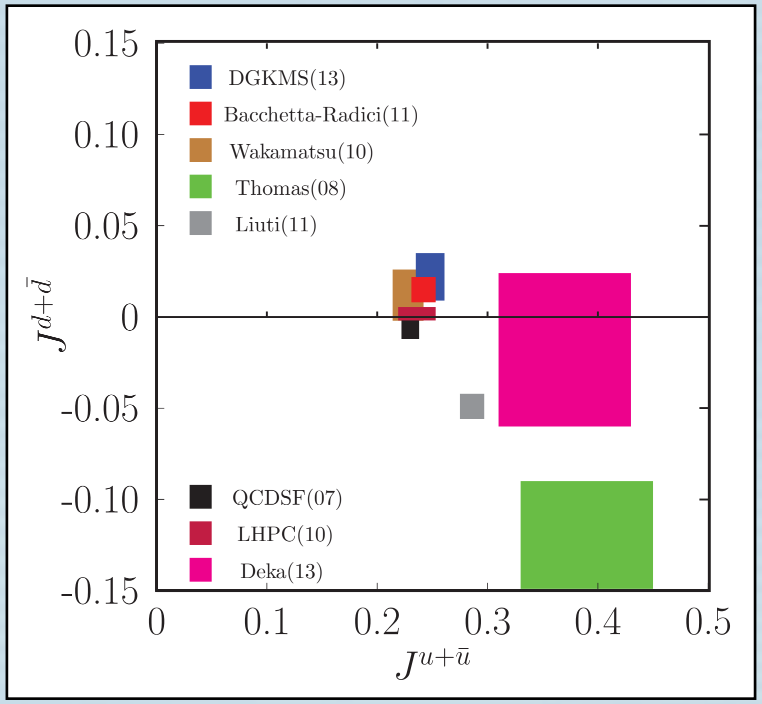
Non-zero Sivers effect in semi-inclusive DIS



GPD models constrained by data from DVCS, DVMP, FF's and more used with the Ji Sum Rule.

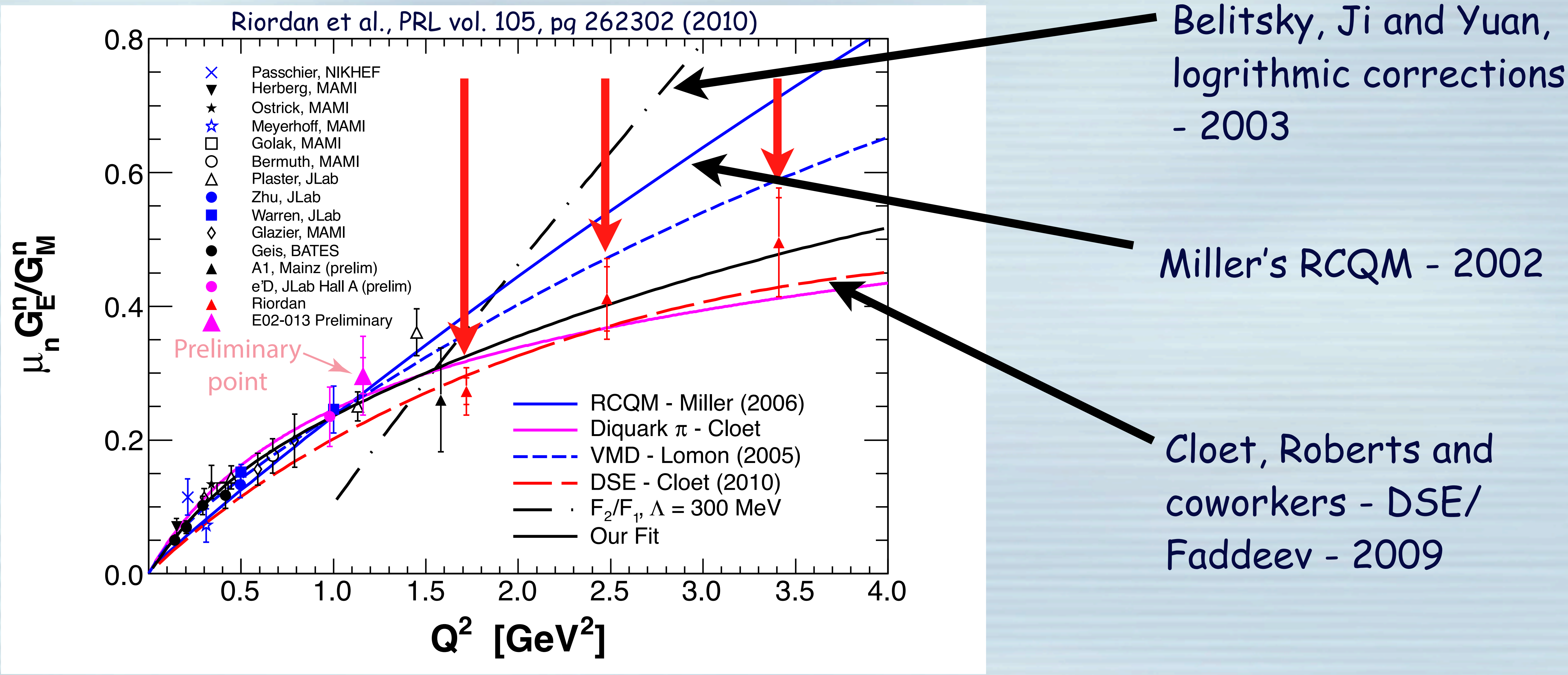
$$L^{u+\bar{u}} = -0.146\ldots-0.172$$

$$L^{d+\bar{d}} = 0.263\ldots0.237$$



P. Kroll, EPJ Web of Conferences **85**, 01005 (2015)

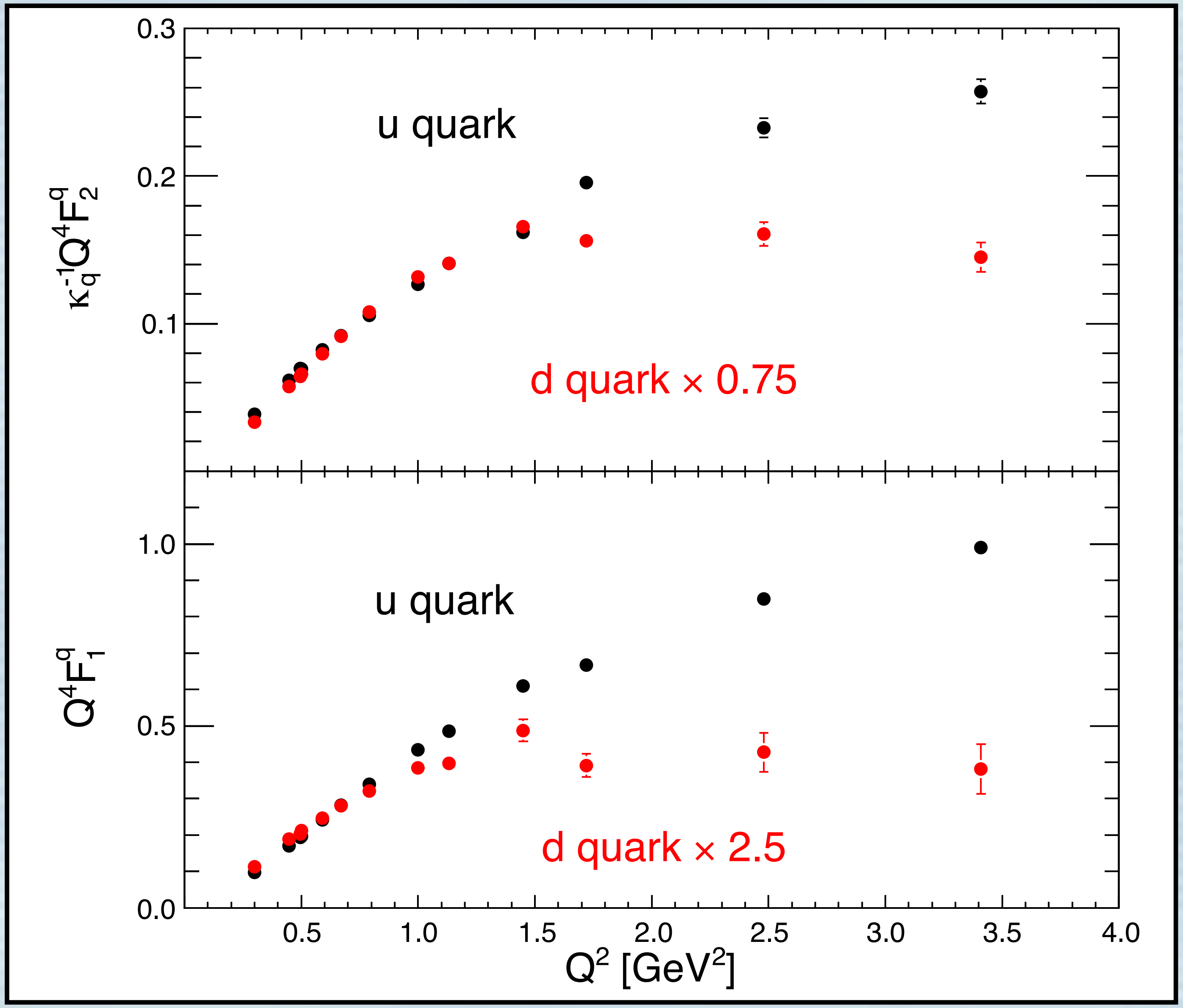
Data from the Hall A polarized ^{3}He experiment (E02-013) extended knowledge of G_E^n to high Q^2



The BigBite G_E^n experiment provided the first test of theories developed to explain the surprising proton results, although clearly, higher Q^2 would be desirable

Proton and neutron FF data can be combined to extract the individual quark contributions

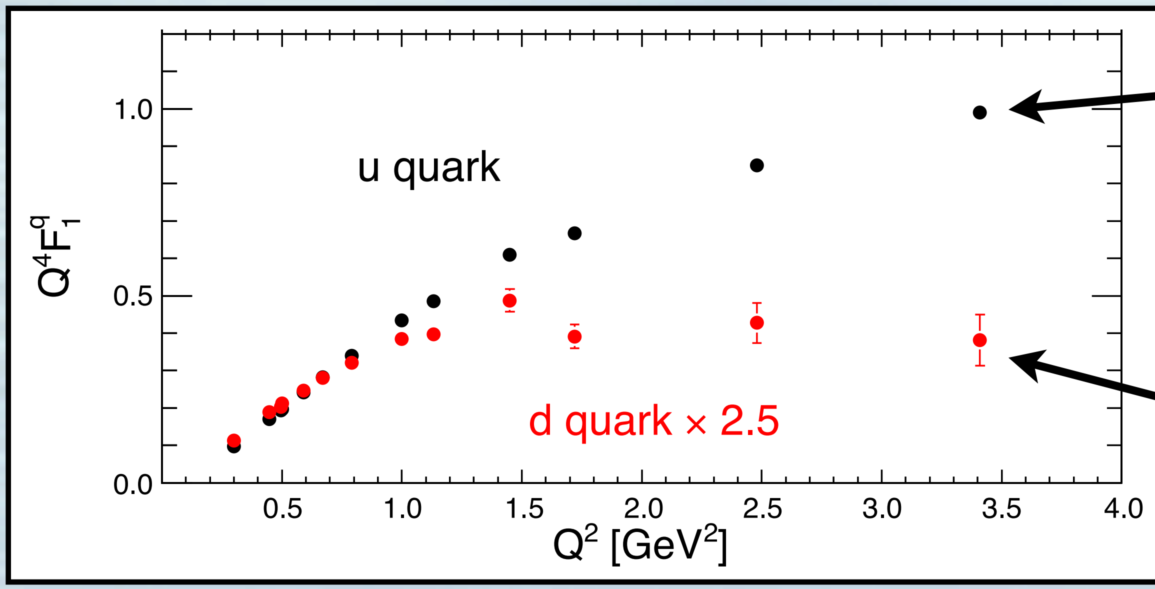
Cates, de Jager, Riordan and Wojtsekhowski, PRL vol. 106, pg 252003 (2010)

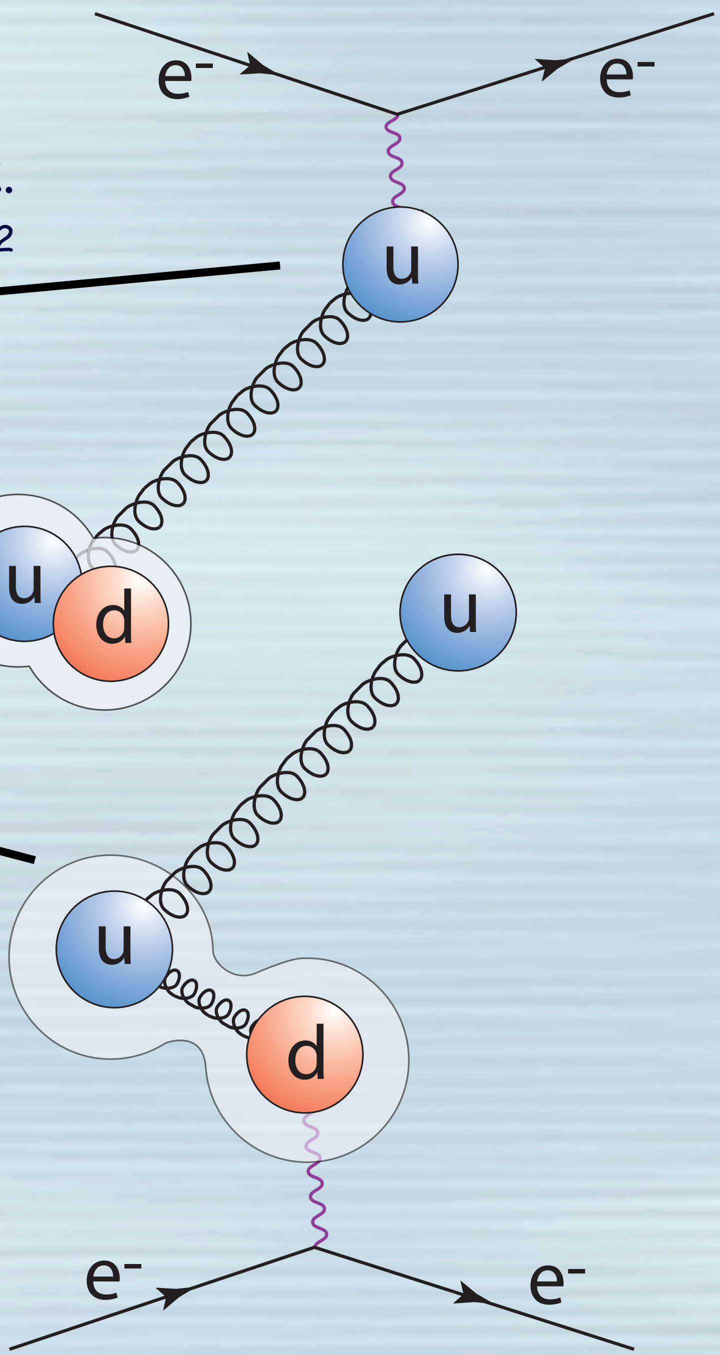


$$F^u_{1(2)} = 2F^p_{1(2)} + F^n_{1(2)} \quad \text{and} \quad F^d_{1(2)} = 2F^n_{1(2)} + F^p_{1(2)}$$

A naive scaling argument suggested by Jerry Miller invokes diquarks

u-quark scattering amplitude is dominated by scattering from the lone "outside" quark. Two constituents implies $1/Q^2$





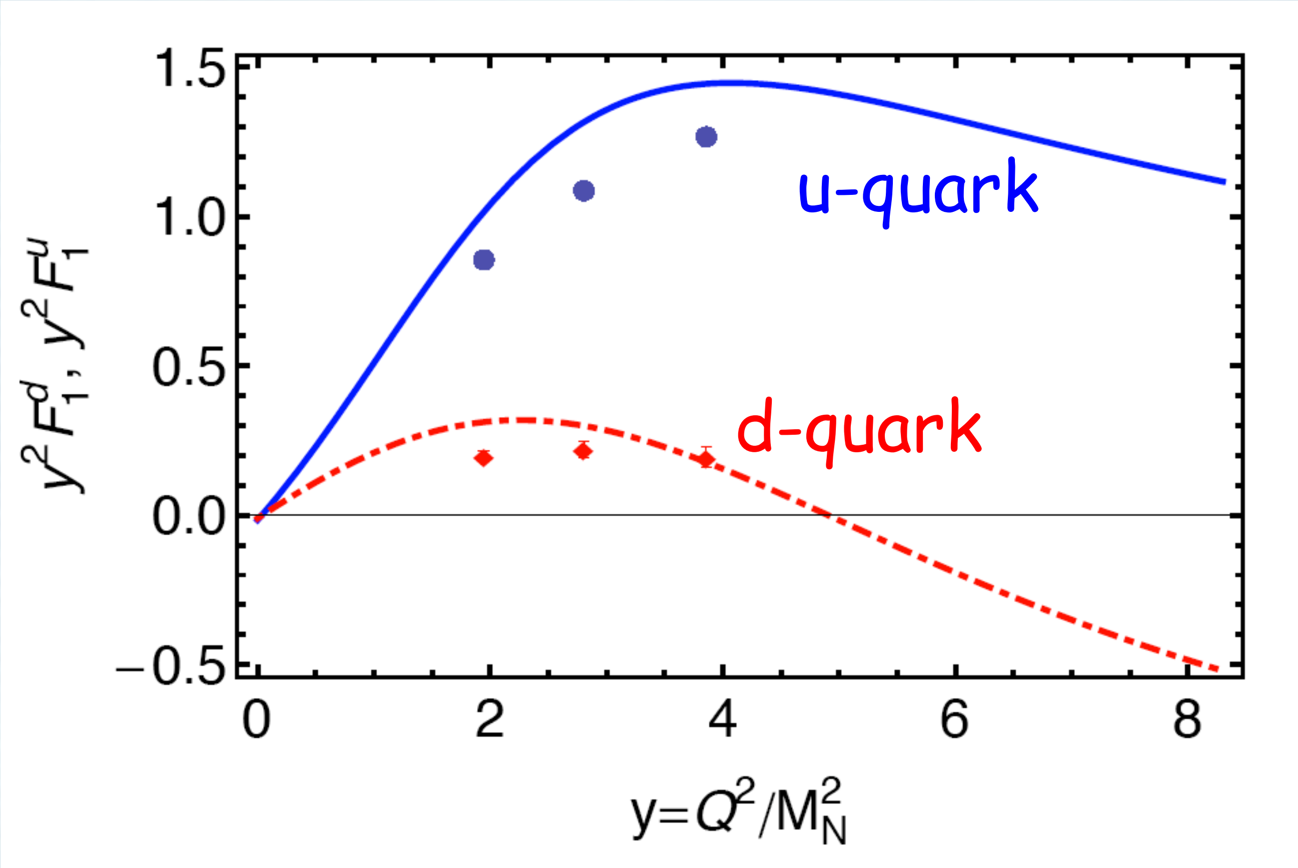
d-quark scattering amplitude is necessarily probing inside the diquark. Two gluons need to be exchanged (or the diquark would fall apart), so scaling goes like $1/Q^4$

While at present this idea is at the conceptual stage, it is an intriguingly simple interpretation for the very different behaviors, and dovetails nicely into the outstanding question of missing states in the N* spectrum.

DSE/Faddeev model from Argonne

Cloët, Roberts and Wilson, using the QCD DSE approach, have made:

" ... a prediction for the Q^2-dependence of u- and d-quark Dirac and Pauli form factors in the proton, which exposes the critical role played by diquark correlations within the nucleon."



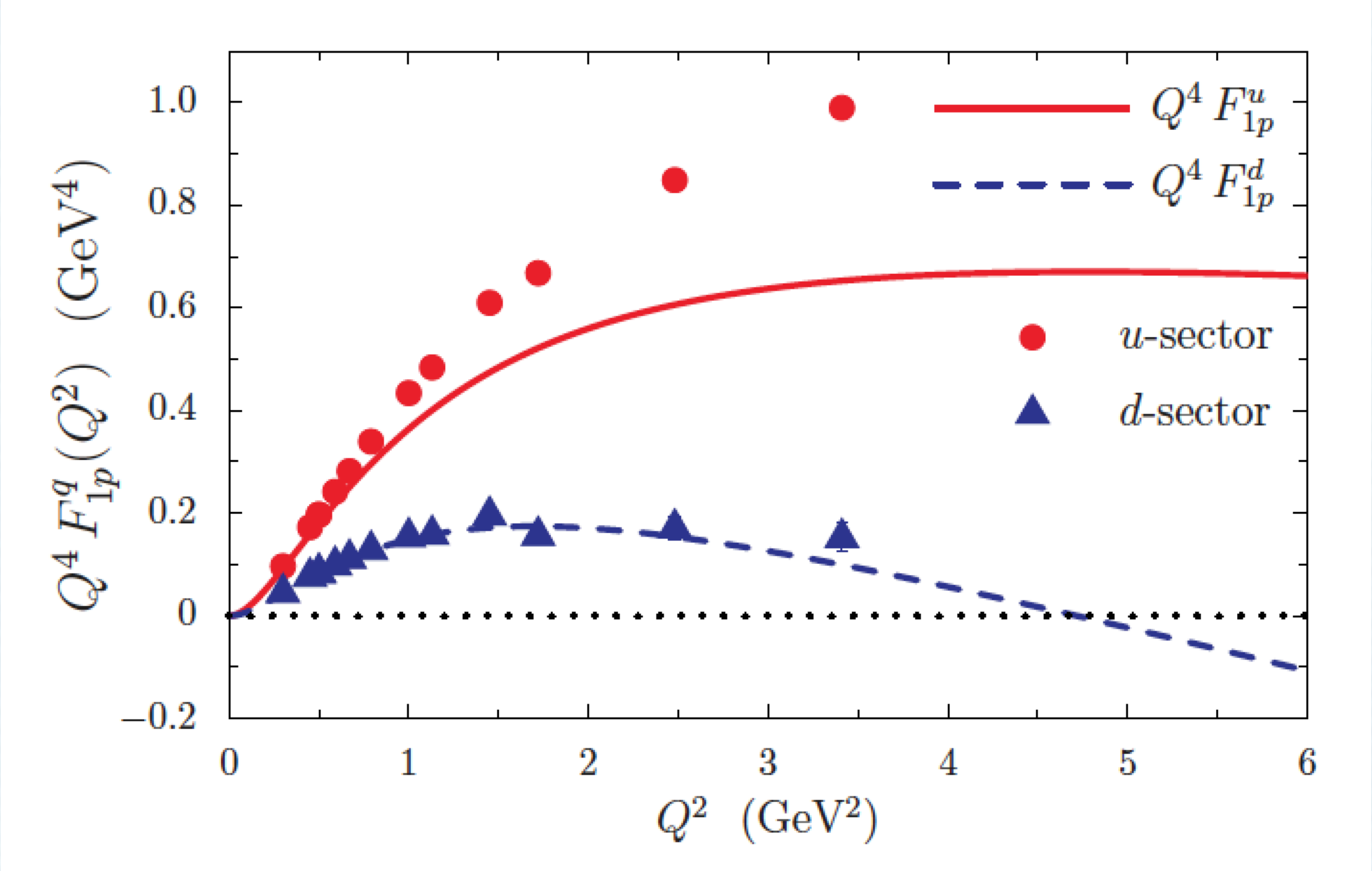
arXiv:1103.2432v1

Within their model, the different behaviors of the u- and d-quark FFs are a direct consequence of diquark degrees of freedom.

Nambu-Jona-Lasinio model

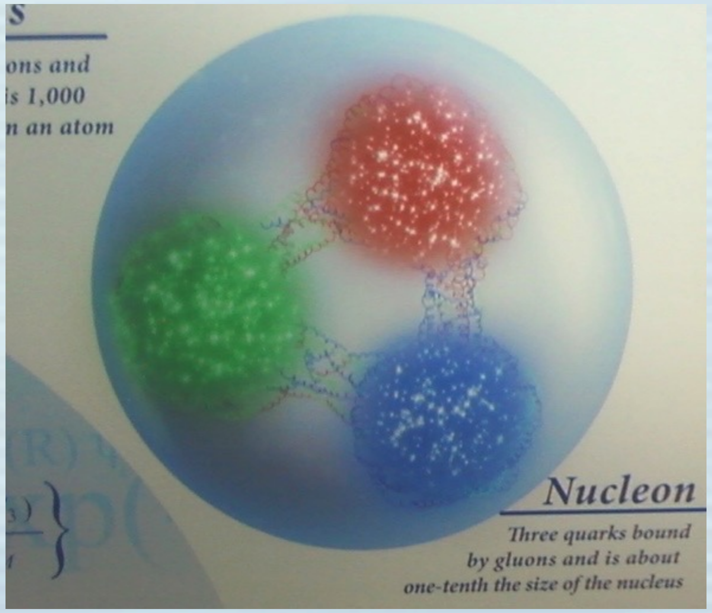
Cloet, Bentz and Thomas

PHYSICAL REVIEW C **90**, 045202 (2014)

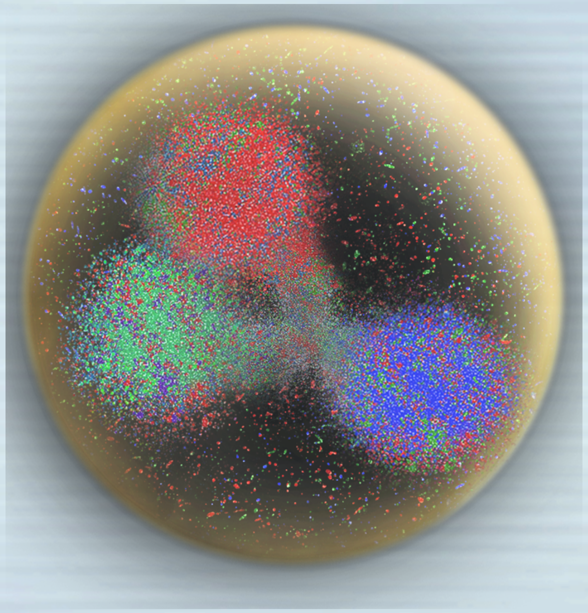


Again, the importance of scalar diquark correlations causes distinctly different behavior for the u- and d-quark sectors

Could flavor-decomposed form factors change our basic notions of nucleon struture?



A cartoon of the nucleon
from the lobby of JLab



From the DOE Pulse Newsletter:
A not-very-scientifically guided
depiction of a nucleon with a
diquark-like structure

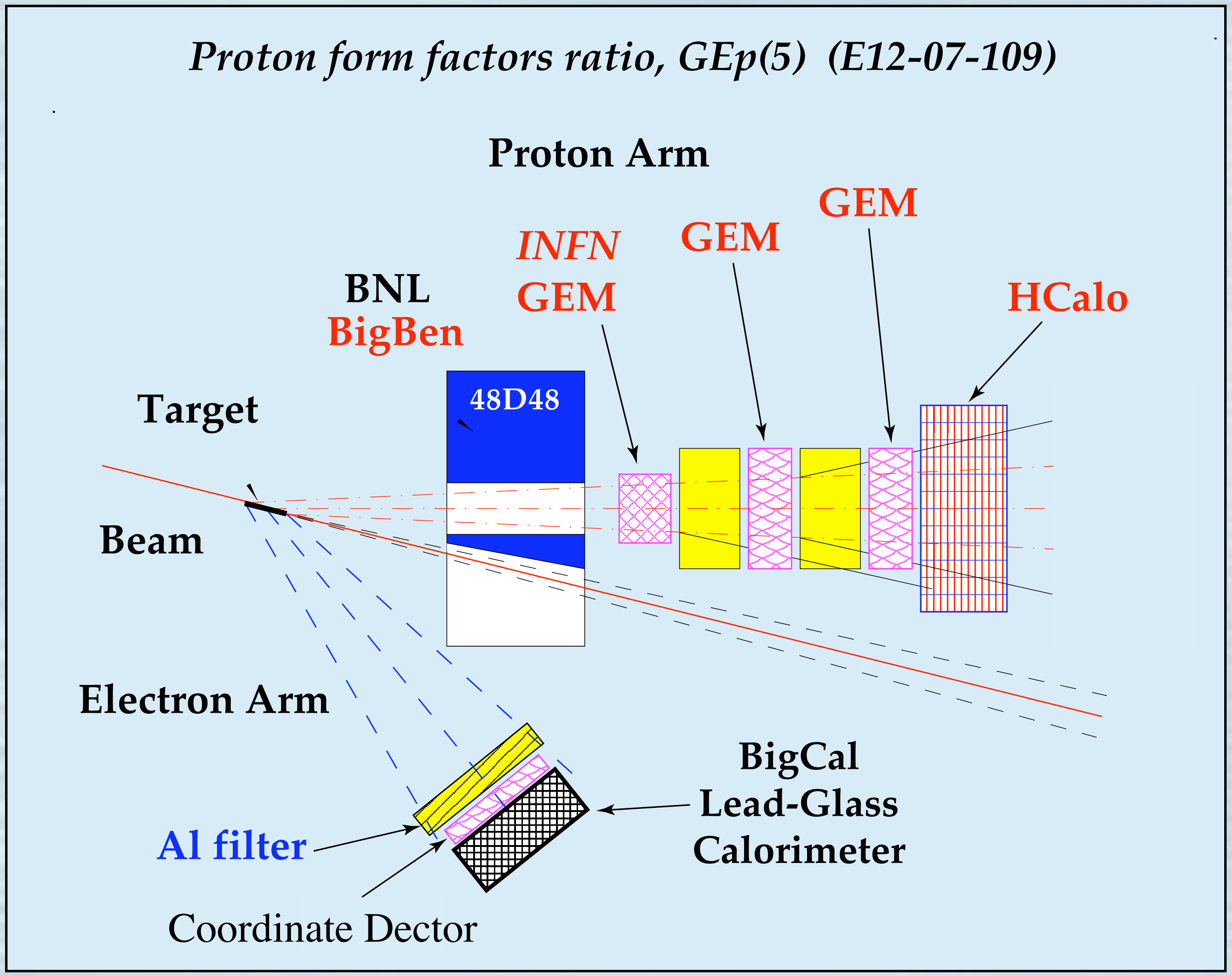
Maybe .... but the answers to questions like these will become much clearer at higher values of Q^2 !!!

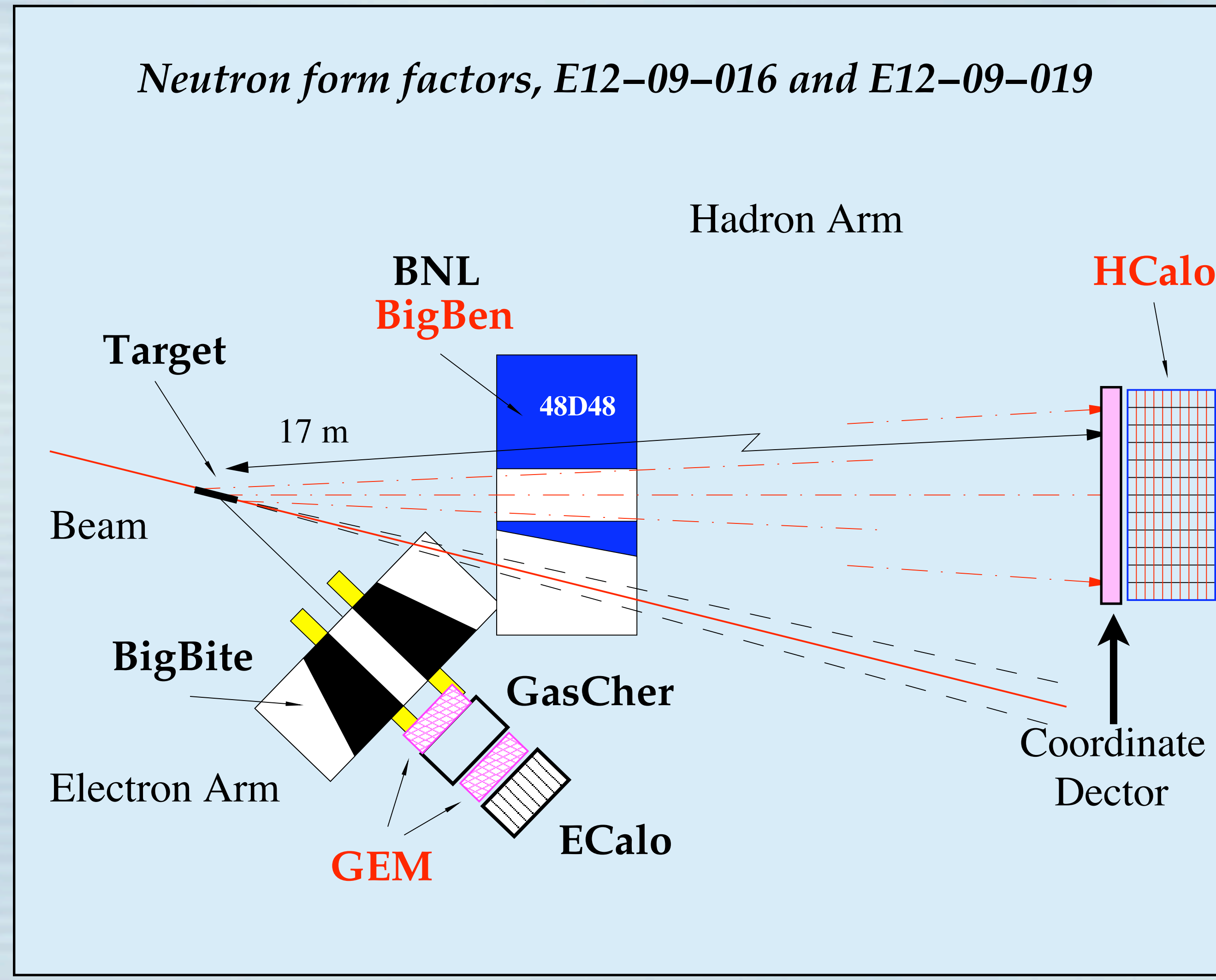
The first SBS experiments and their likely order:

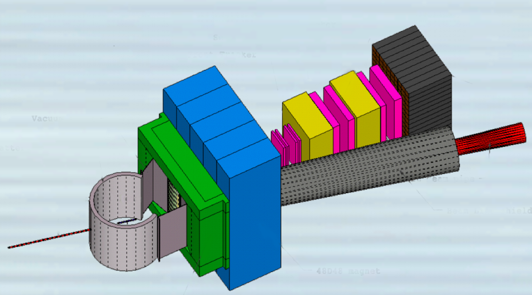
- E12-09-019: measurement of G_M^n/G_M^p to Q^2=13.5 GeV^2.
  Installation will probably begin in May of 2020
- E12-17-004 measurement of G_E^n/G_M^n at Q^2=4.5 GeV
- E12-09-016: measurement of G_E^n/G_M^n to Q^2=10 GeV^2.
- E12-07-109: measurement of G_E^p/G_M^p to Q^2=12 GeV^2.

Super Bigbite will provide game-changing capability to study the elastic nucleon form factors at very high momentum transfer.

The SBS equipment will be configured differently depending on the experiment



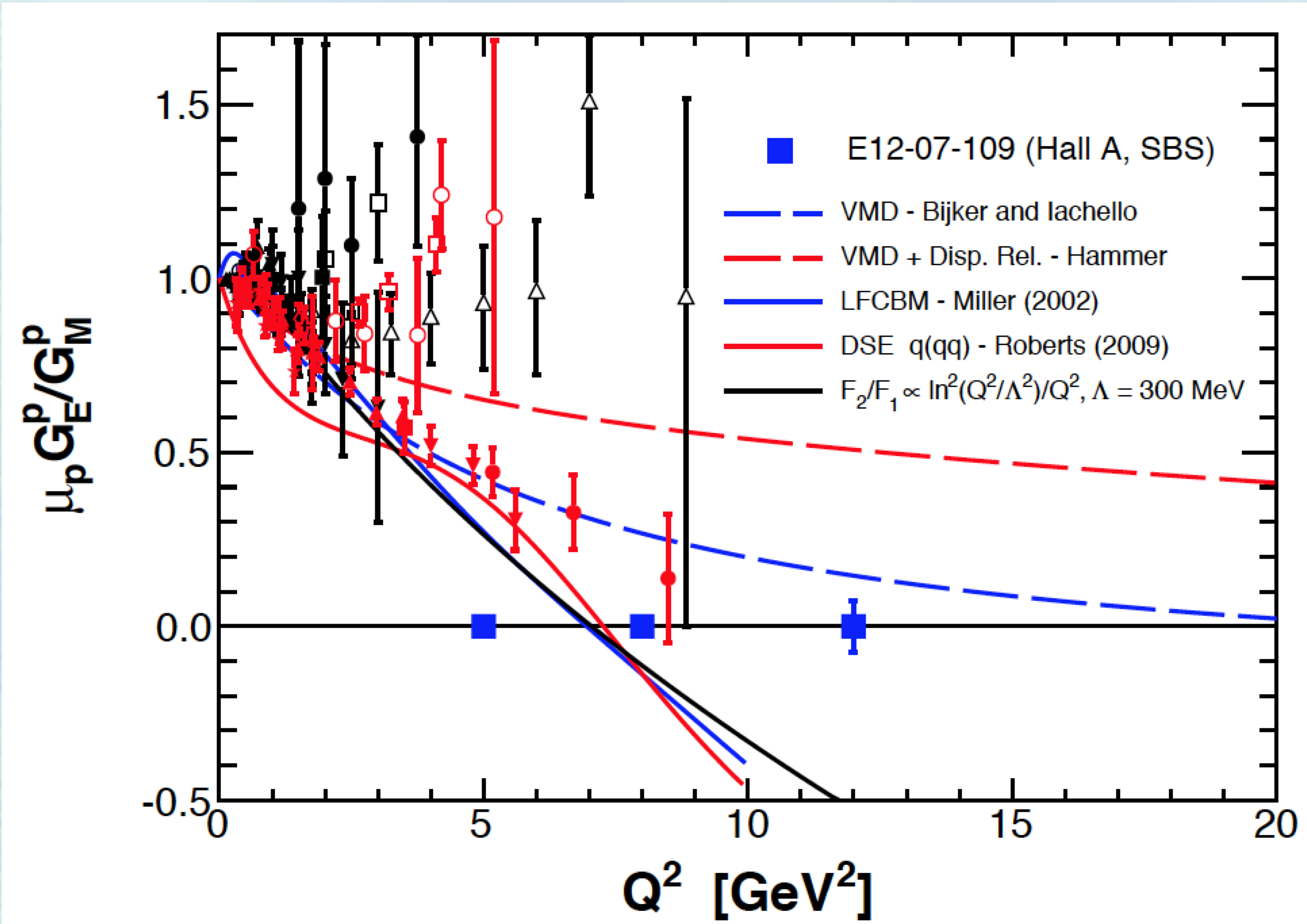




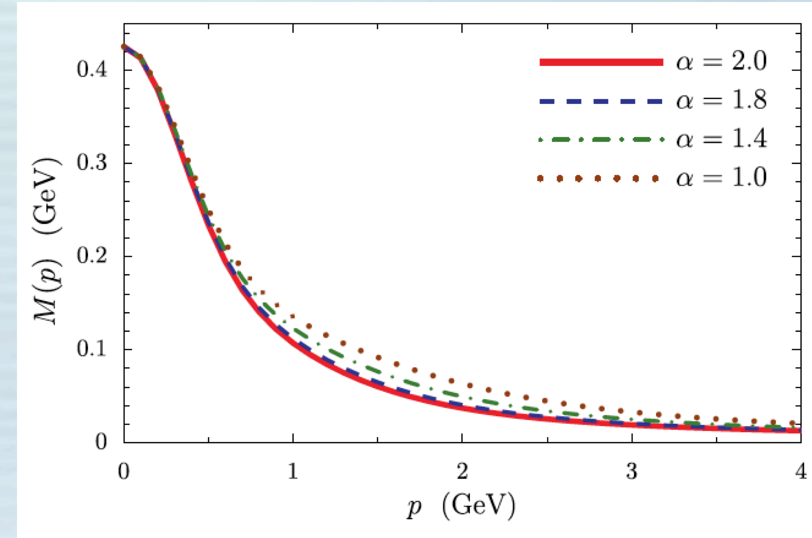
G_E^p/G_M^p

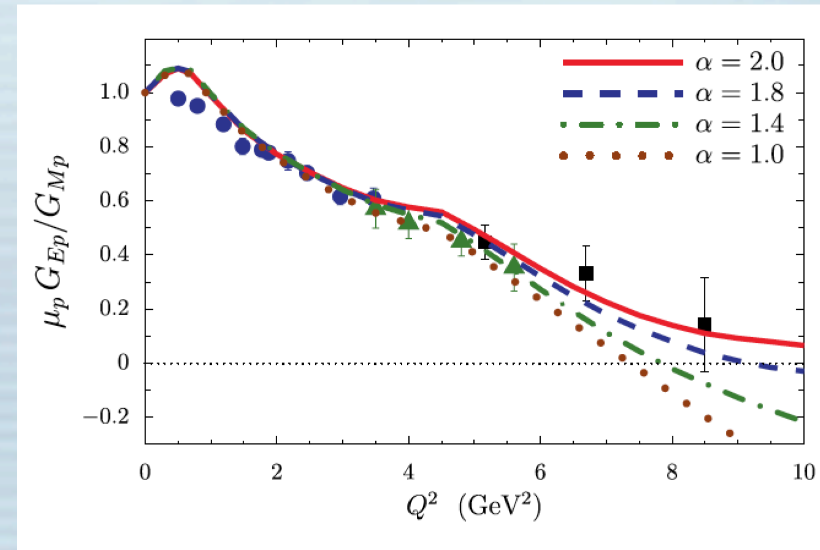
G_E^n/G_M^n and G_M^n/G_M^p

The SBS measurement of G_E^p/G_M^p: E12-09-019



G_E^p/G_M^p projected data

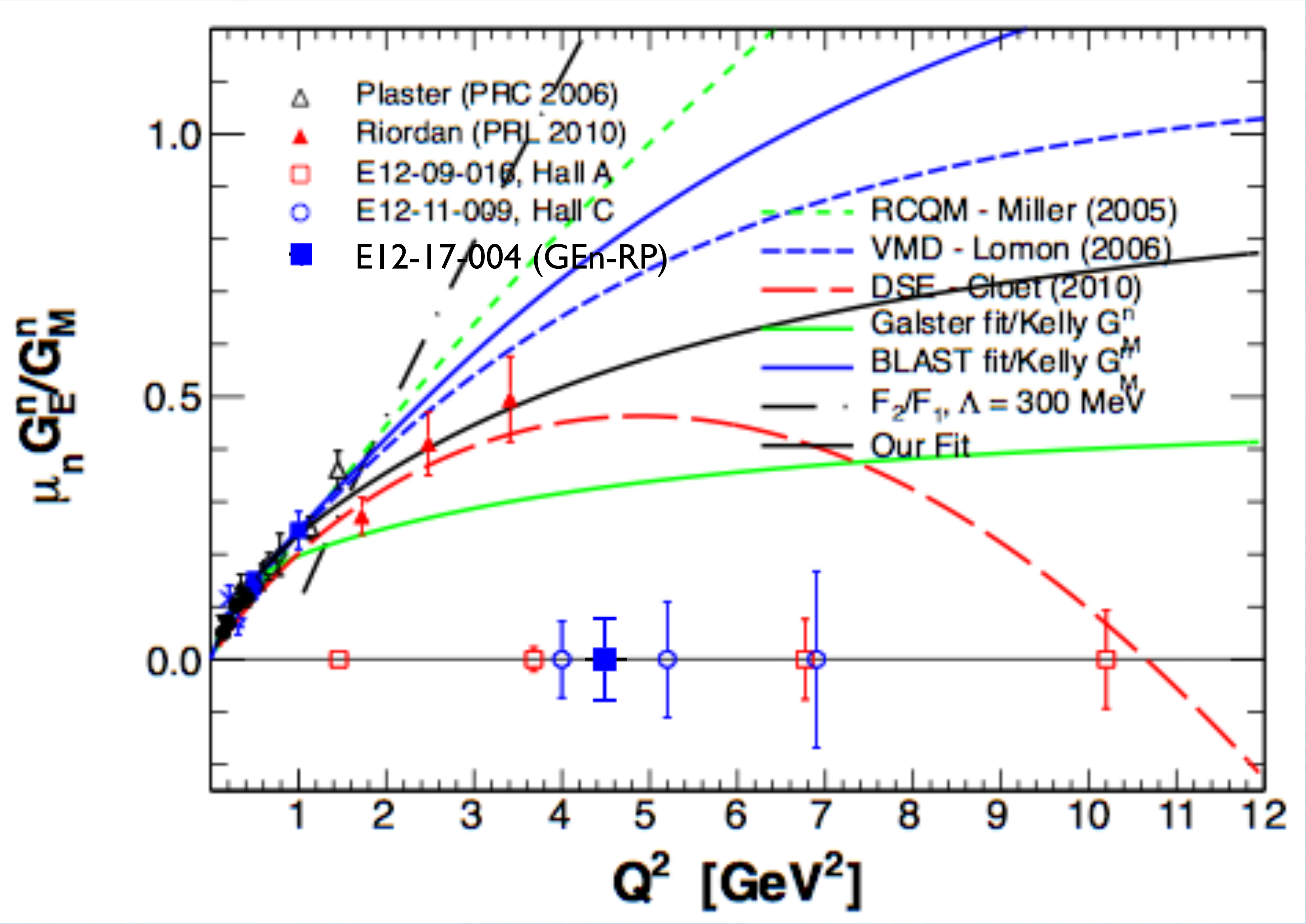




Cloet, Roberts, Thomas, PRL 111, 101803 (2013)

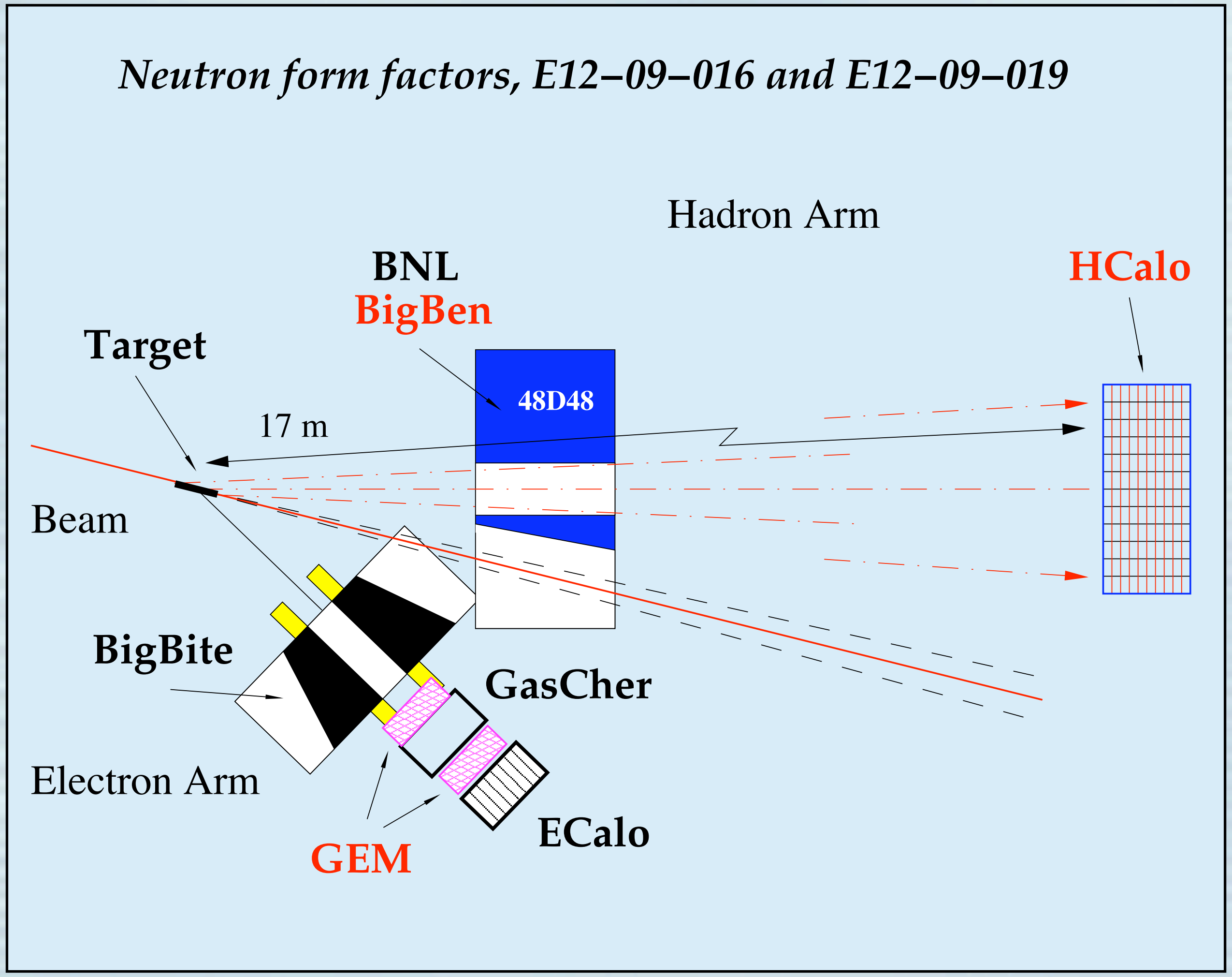
The zero crossing of G_E^p/G_M^p provides sensitivity to the mass function $M(p^2)$

SBS measurements of G_E^n/G_M^n will provide powerful discrimination between different models



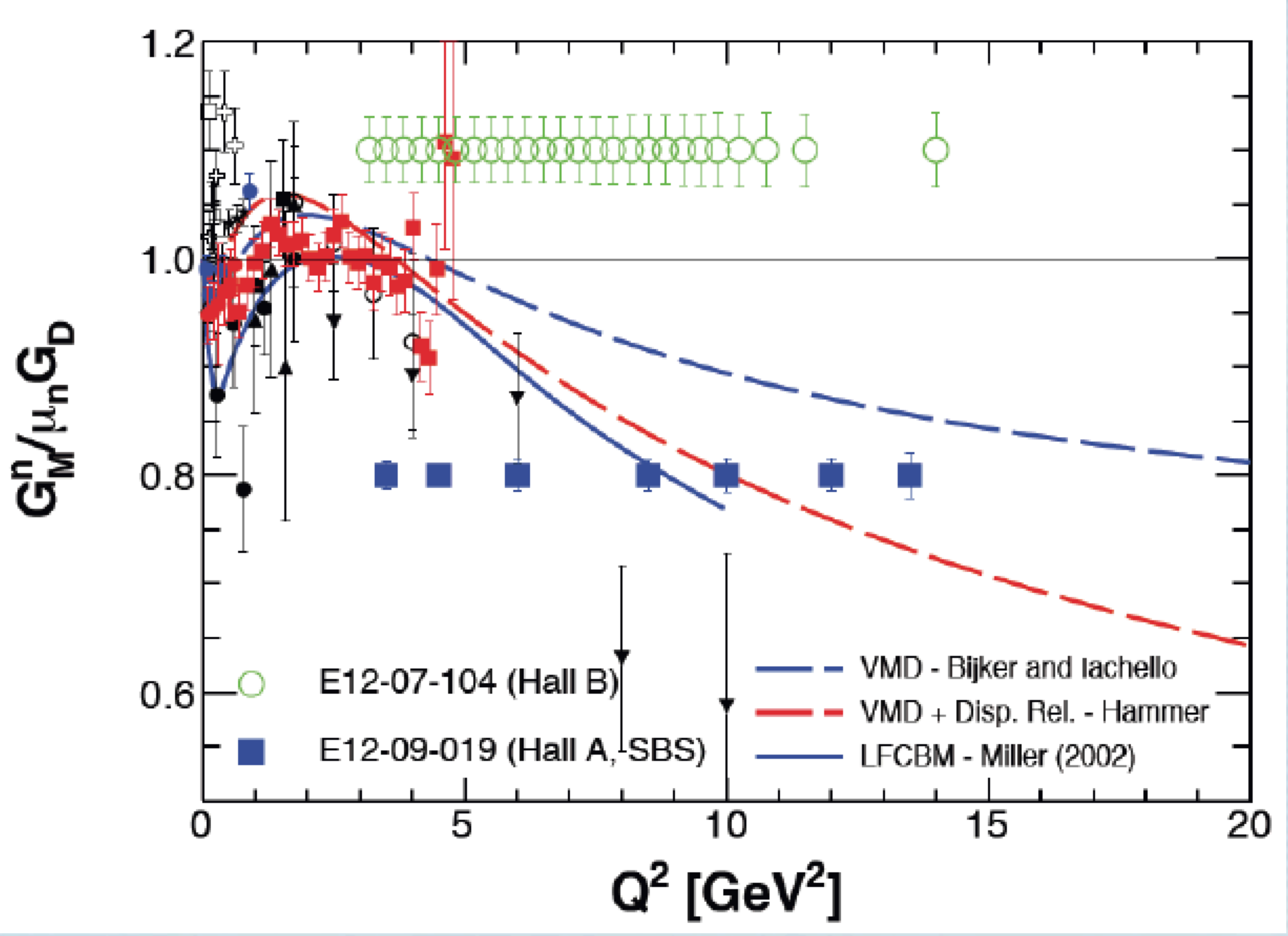
If the turnover and zero crossing is seen somewhere around 10 GeV², it will provide powerful support for the DSE description of the nucleon.

The first SBS experiment: measurement of the ratio G_M^n/G_M^p: E12-09-019

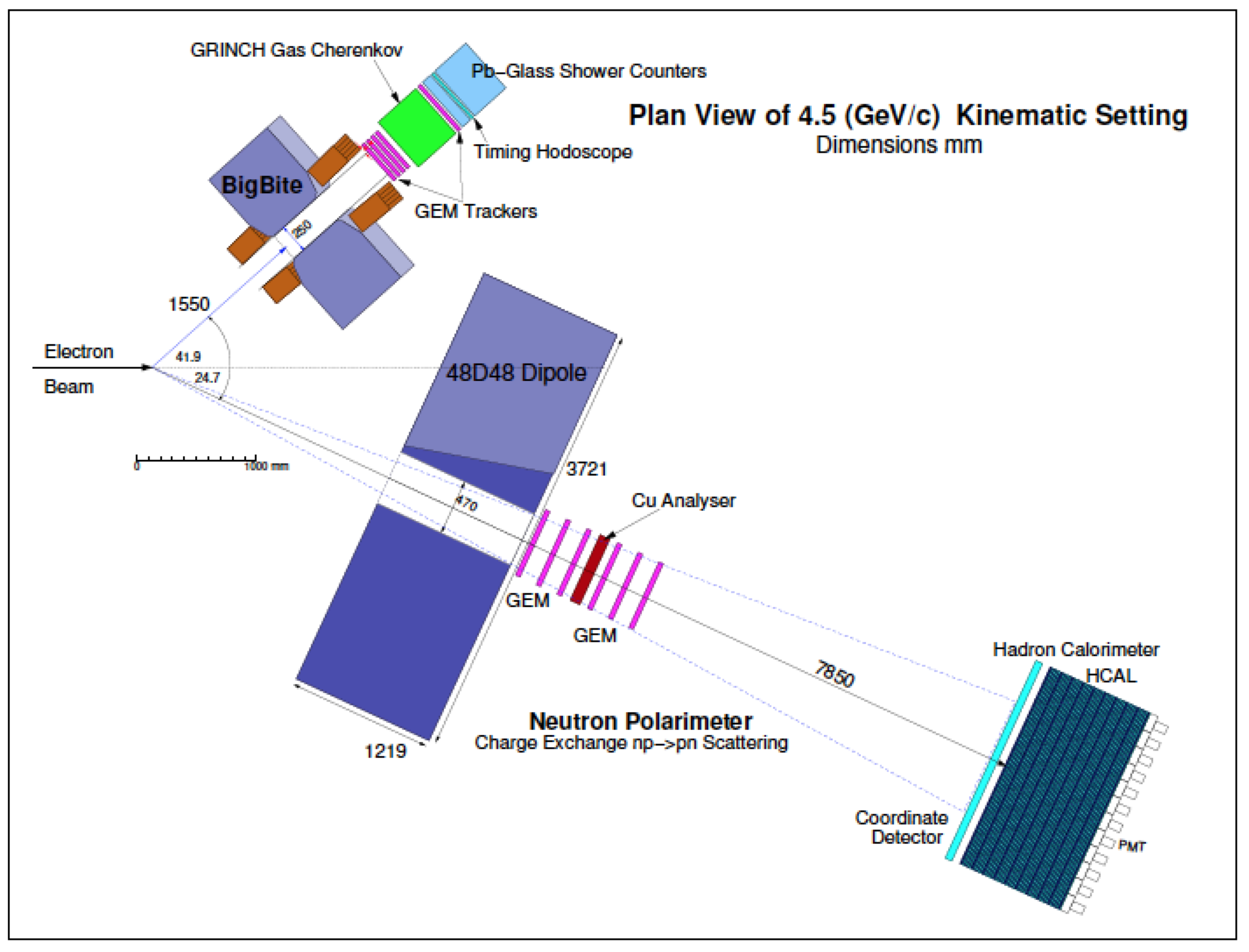


- Basically the same setup as the polarized ^{3}He G_E^n experiment but with a standard LH_2/LD_2 target
- SBS as neutron arm w/48D48 + HCAL
- Magnet deflects protons to separate them from neutrons.
- BigBite as electro arm w/upgraded 12 GeV detector package (including re-use of GEMs built for G_E^p, not otherwise in use during BigBite exit's.
- Complementary to CLAS12 G_M^n measurement with different and smaller systematics

The first SBS experiment: measurement of the ratio G_M^n/G_M^p: E12-09-019

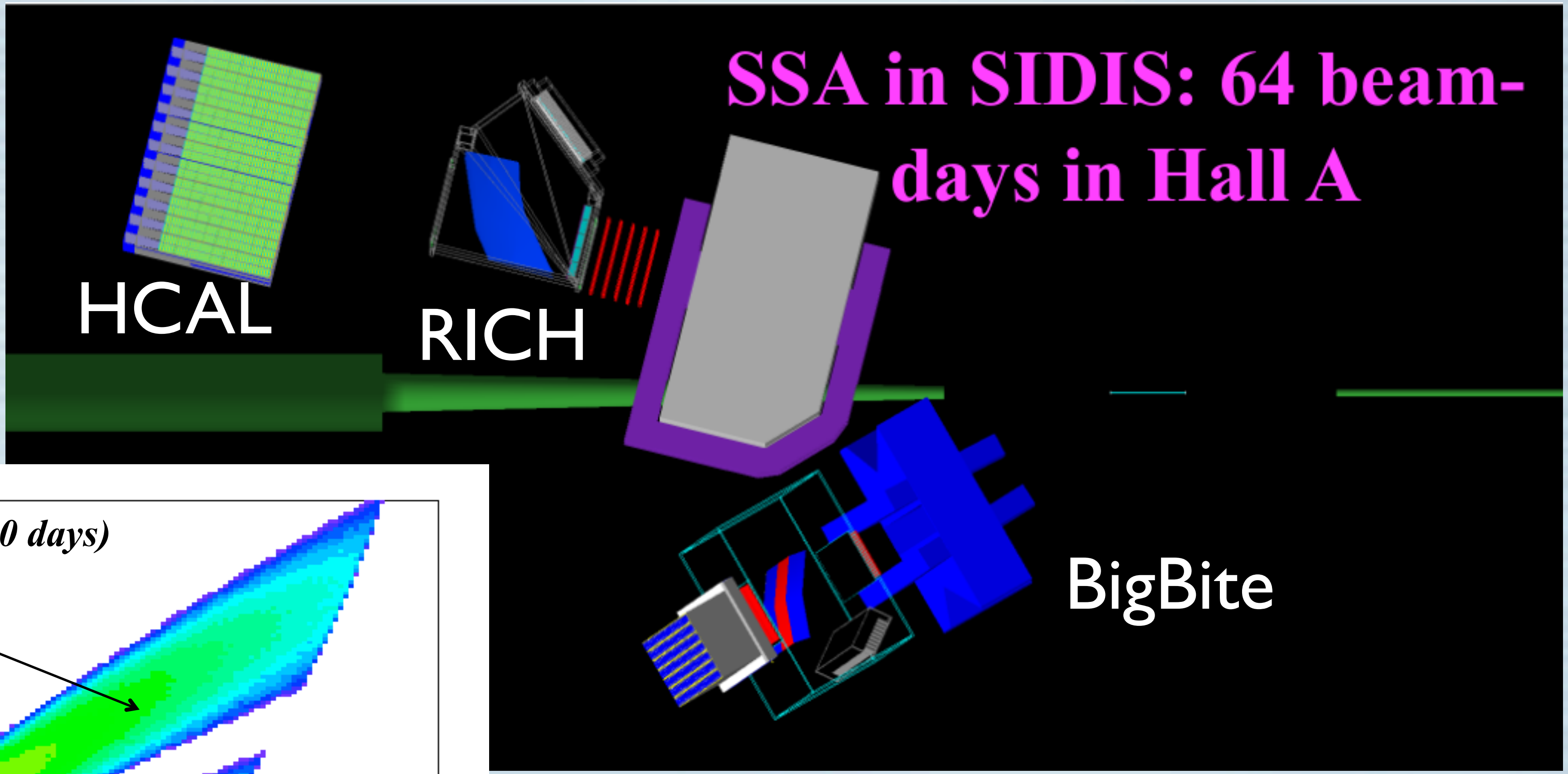


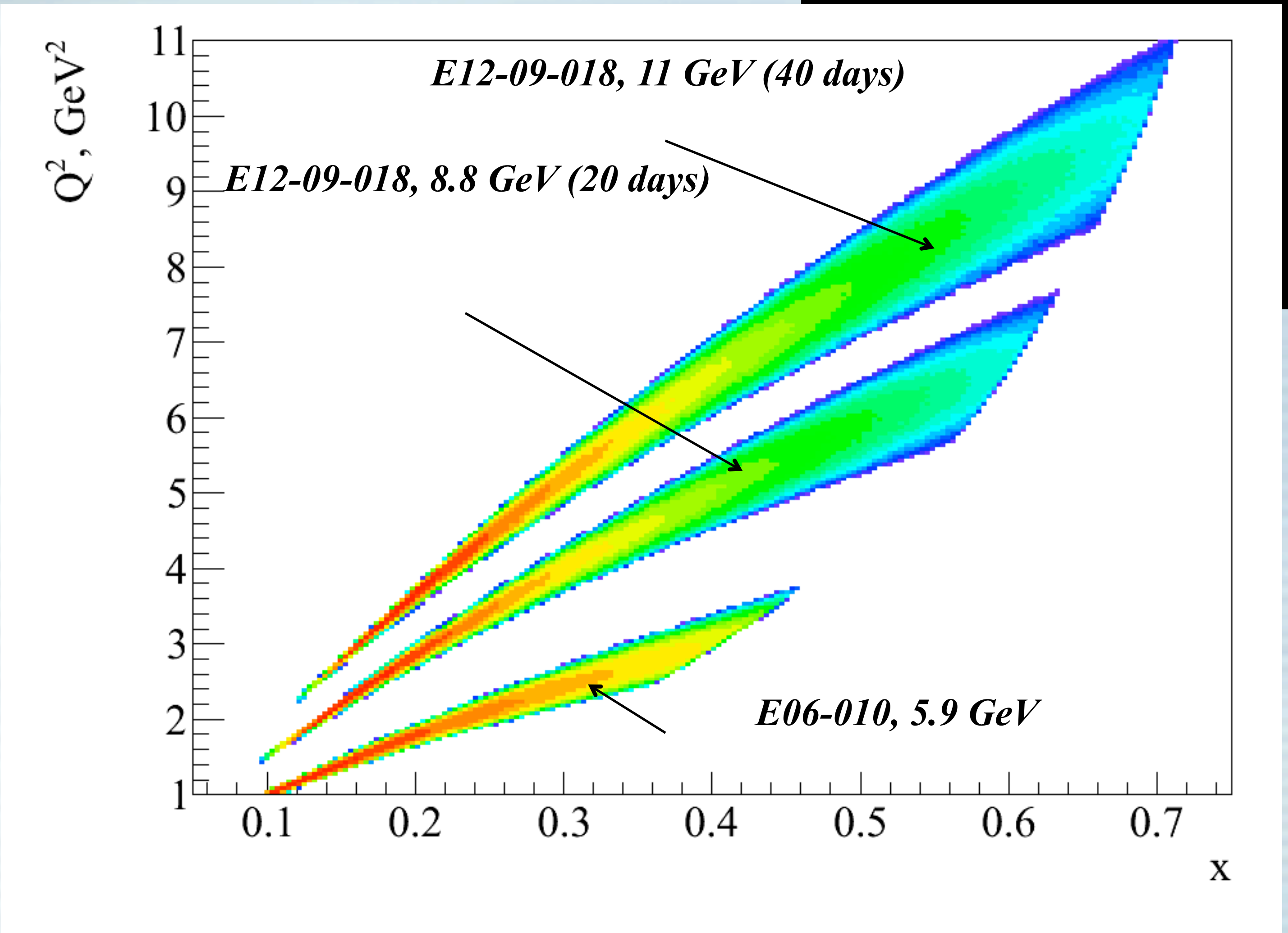
The SBS G_E^n-Recoil Polarimeter experiment: E12-17-004

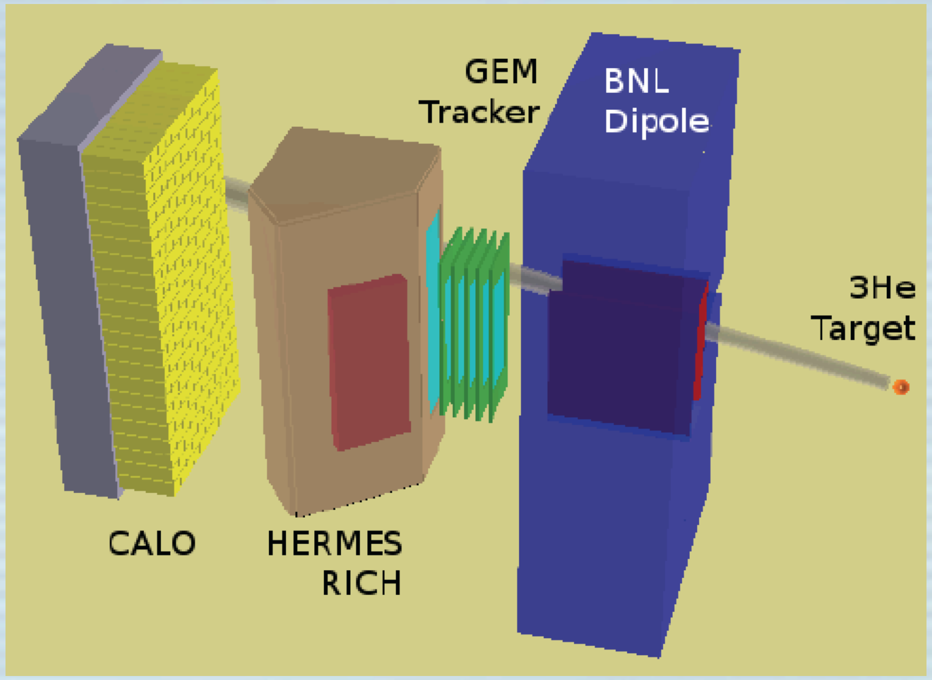


- Will run (almost) parasitically with the G_M^n/G_M^p experiment.
- Will use a copper analyzer just after the 48D48 Dipole, taking advantage of new data from Dubna.
- Will require only ~100 additional hours running
- Will provide highest existing Q^2 point for G_E^n/G_M^p!
- Will also provide additional data on analyzing power which will guide potential future experiments.

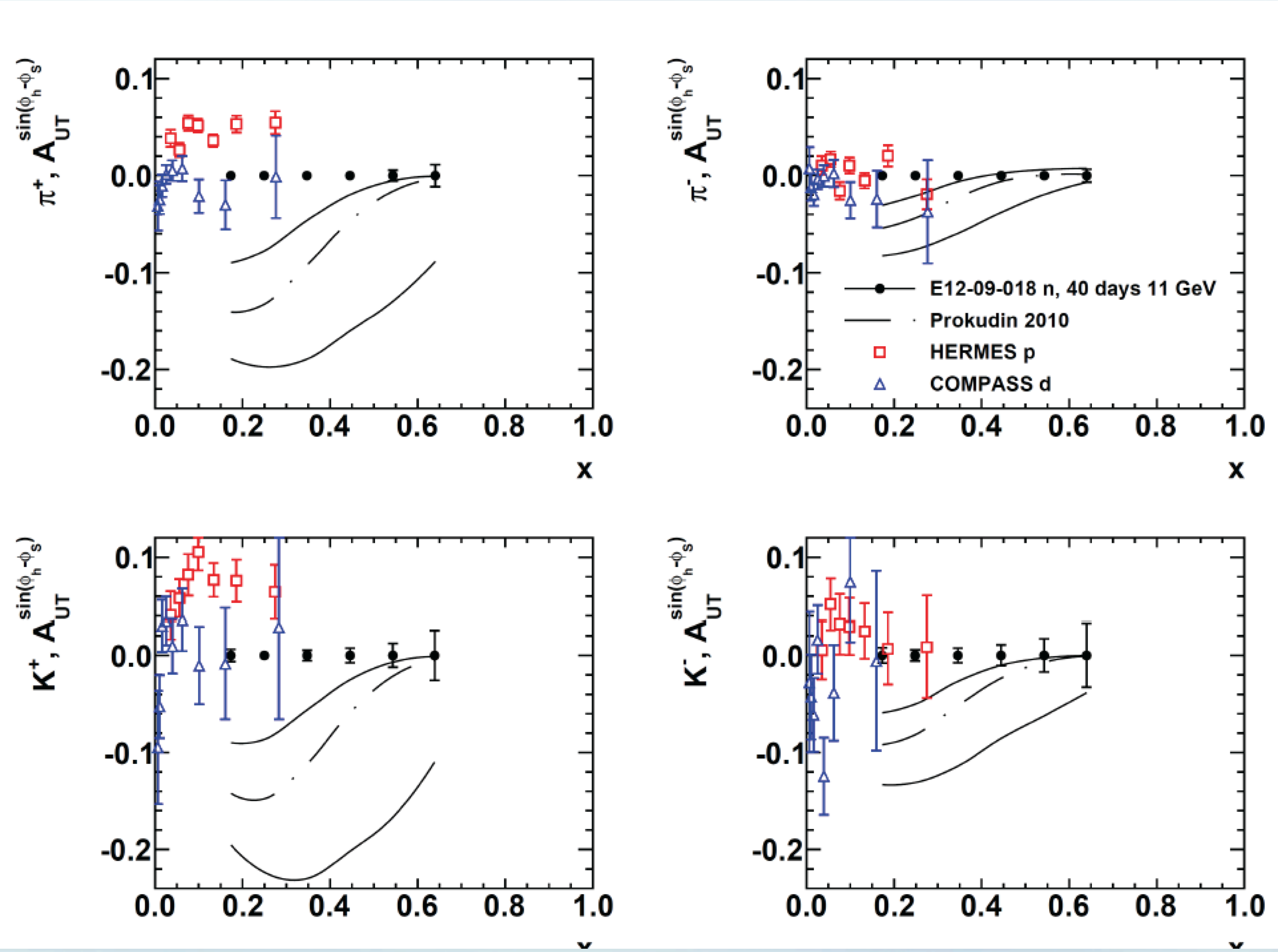
Neutron Transversity with SBS+BB
Semi-inclusive DIS: E12-09-018







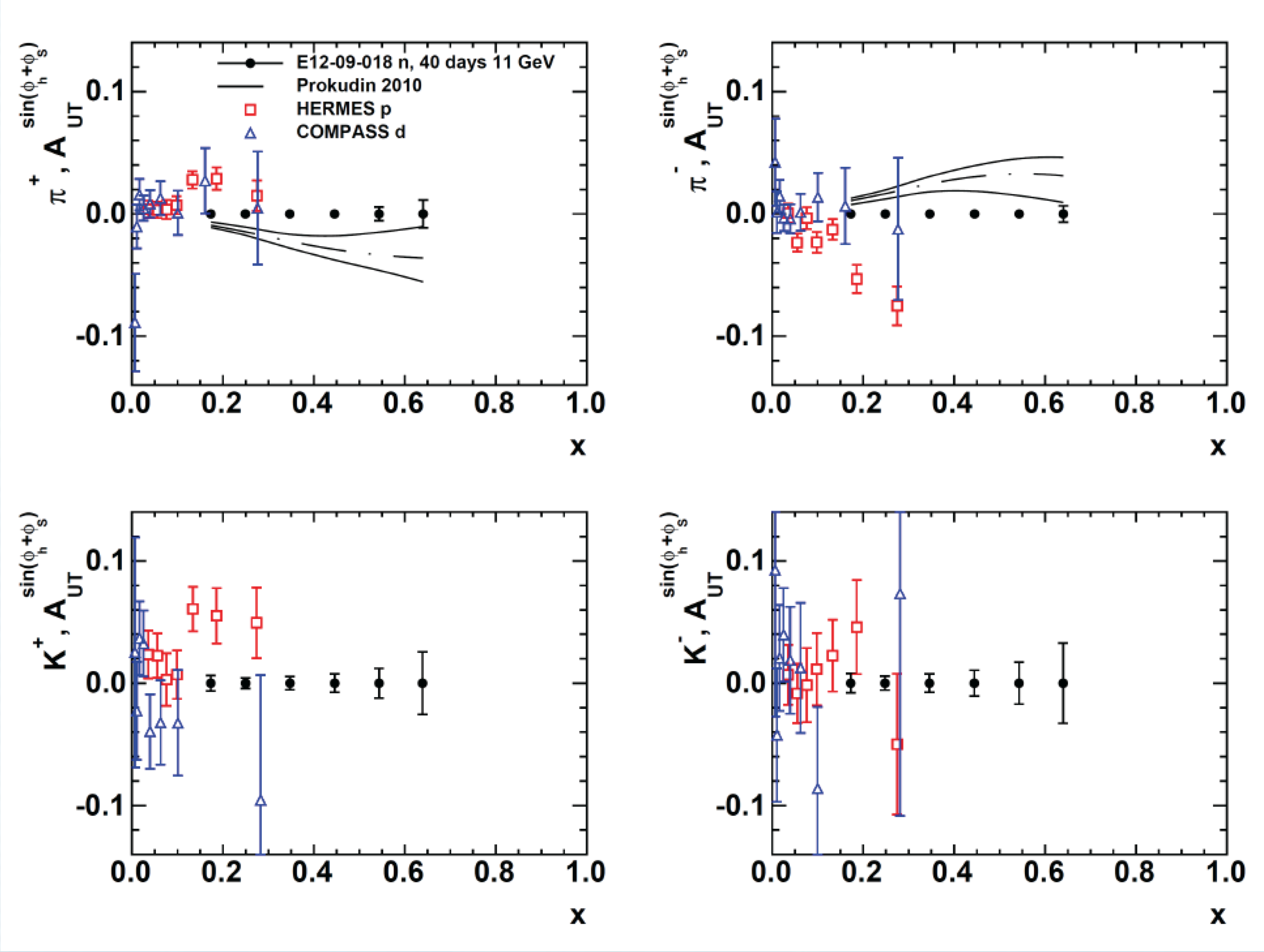
SBS+BB projected results for neutron Sivers single-spin asymmetries



- JLab E12-09-018—approved for 64 beam-days by JLab PAC38, A- scientific rating
- Transverse target single-spin asymmetries in ^{3}**He**(e,e'h)X ($h=\pi^{\pm,0}$, $K^{\pm}$)
- ~100X higher statistical figure-of-merit for neutron than HERMES proton data
- First precision measurements in a multi-dimensional kinematic binning

Projected $\pi^{\pm}$, $K^{\pm}$ neutron A_{UT}^{sivers} asymmetries vs. x for compared to HERMES, COMPASS, phenomenological fit

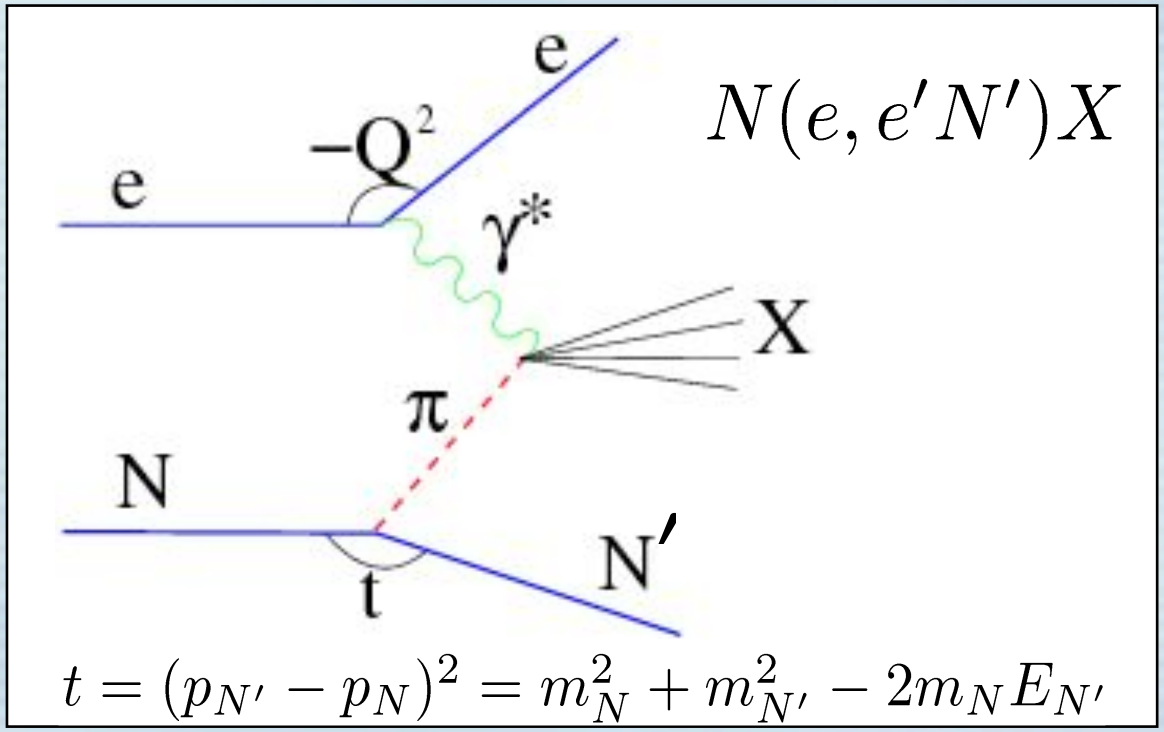
SBS+BB projected results for neutron Collins single-spin asymmetries

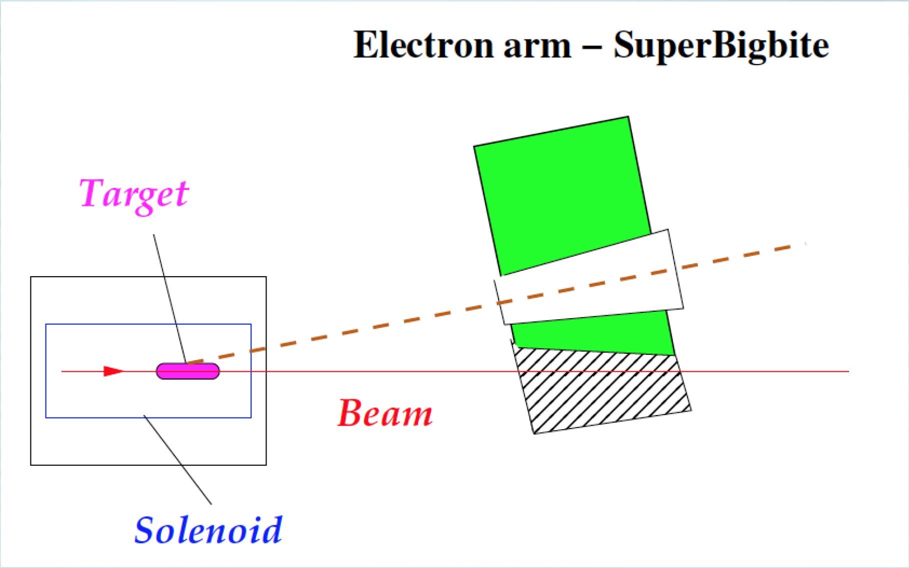


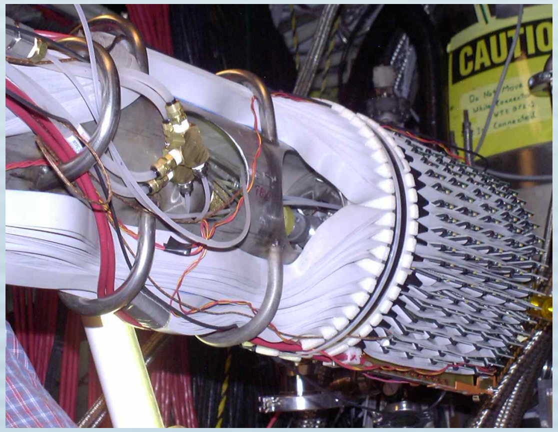
$\pi^{\pm}$, $K^{\pm}$ neutron Collins asymmetries compared to HERMES, COMPASS, phenomenological fit

The SBS Tagged DIS experiment: PR12-15-006

Pion Exchange (Sullivan) Process -DIS from the pion cloud of the nucleon







- |t| has to be small to enhance contribution from Sullivan process -> use rTPC detection technique pioneered by JLab BONUS experiment with CLAS6
- BUT, small cross section means need luminosity – solution: use an optimized rTPC with Super BigBite, L ~ 10^{37}

Summary

- The large solid angles of the SBS detector systems result in excellent statistics.
- Some of the most sophisticated models, some based on what Ji called "approximate QCD" will be put to stringent tests.
- The way we think about the nucleon is likely to be profoundly influenced.