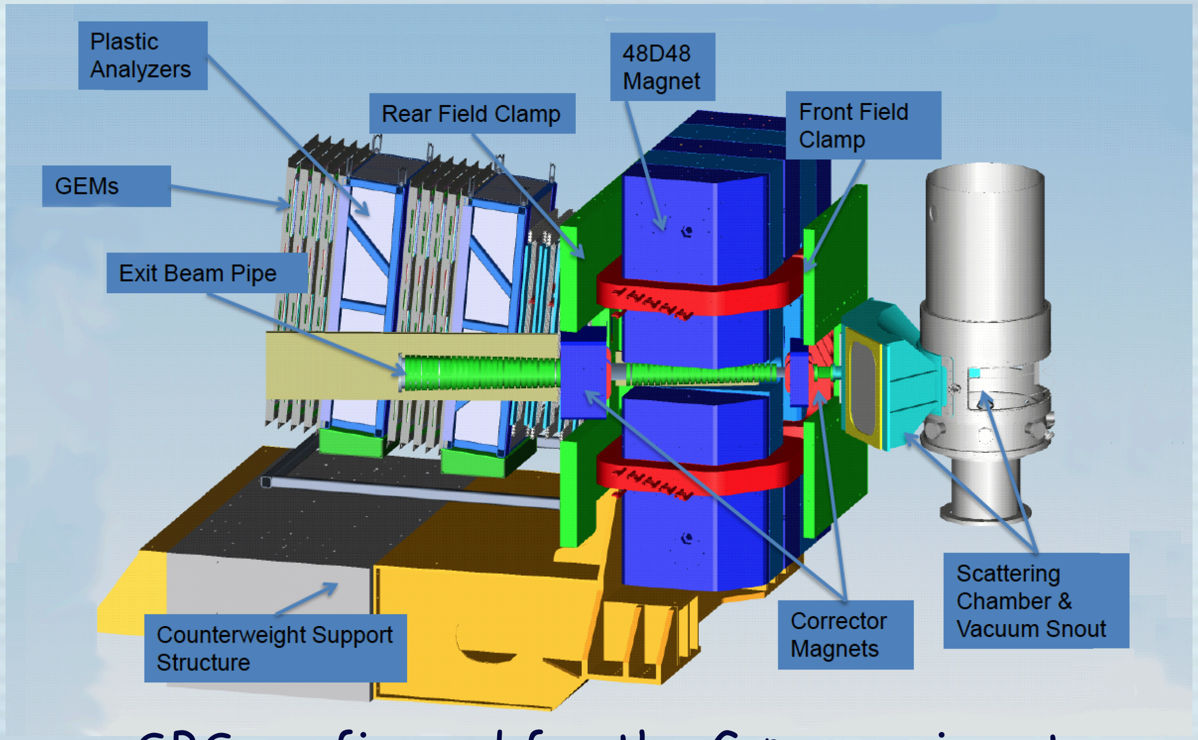
SBS Update:
Overview of Physics and Status

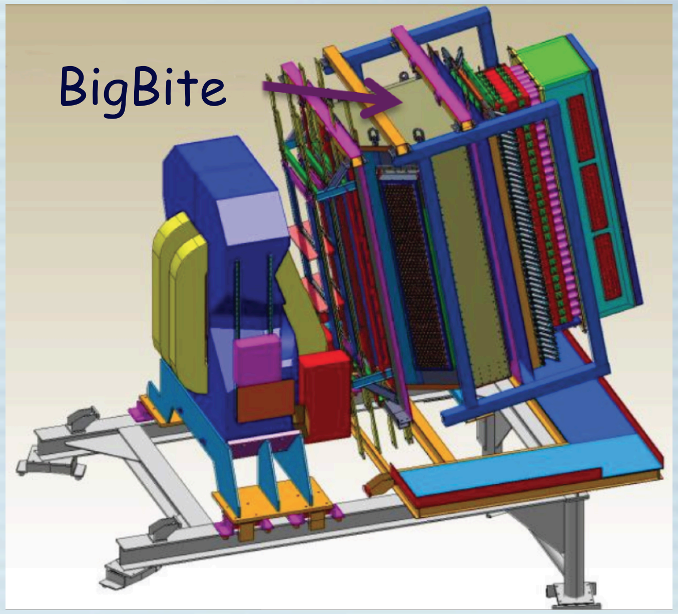
Gordon Cates for the SBS Collaboration

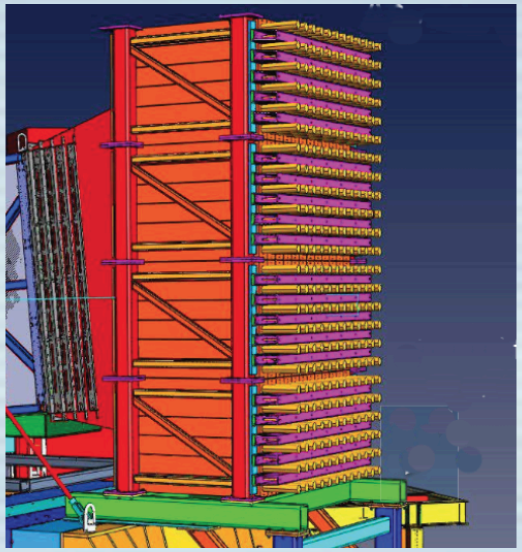
July 9, 2021

What is SBS ?

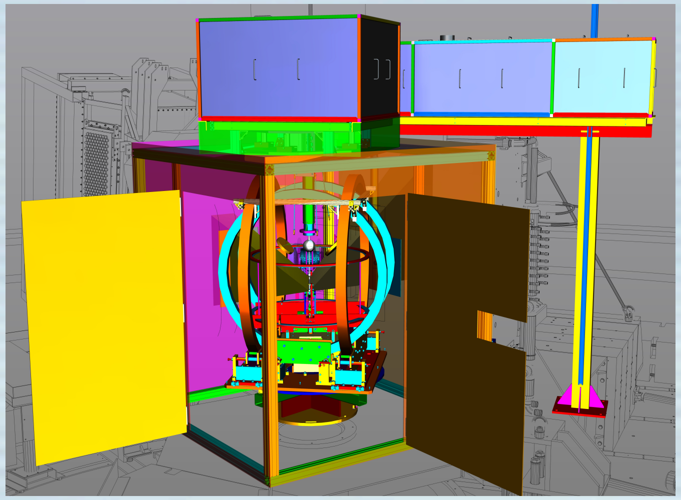


SBS configured for the G_E^p experiment

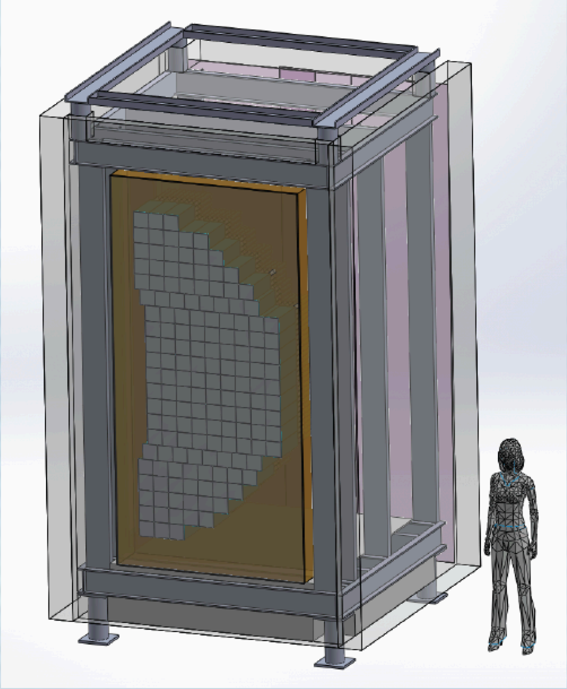




HCal - hadron calorimeter



Polarized ^{3}He target



ECal - electron calorimeter

Well .... with the primary construction and all its dependencies, it has lots of pieces.

What physics will SBS access ?

- Greatly extend our knowledge of the elastic nucleon form factors at high Q^2.
  - I'll spend most of my time discussing this physics
- Single-spin asymmetries (SSAs) in semi-inclusive deep inelastic scattering (SIDIS); Sivers and Collins asymmetries, etc.
  - Evaristo Cisbani will discuss this expt. later in this session.
- Polarization transfer in Wide-Angle Charged-Pion Photoproduction
- Tagged Deep Inelastic Scattering (TDIS)
- Spin Asymmetry A_1^n (although we are not <u>yet</u> seeking re-approval after reaching jeopardy).

The SBS elastic nucleon form factor experiments

- E12-09-019: measurement of G_M^n/G_M^p to Q^2=13.5 GeV^2.

  1st SBS Run Group: installation underway right now in Hall A

- E12-17-004: measurement of G_E^n/G_M^n at Q^2=4.5 GeV^2

  1st SBS Run Group: installation underway right now in Hall A

- E12-09-016: measurement of G_E^n/G_M^n to Q^2=10 GeV^2.

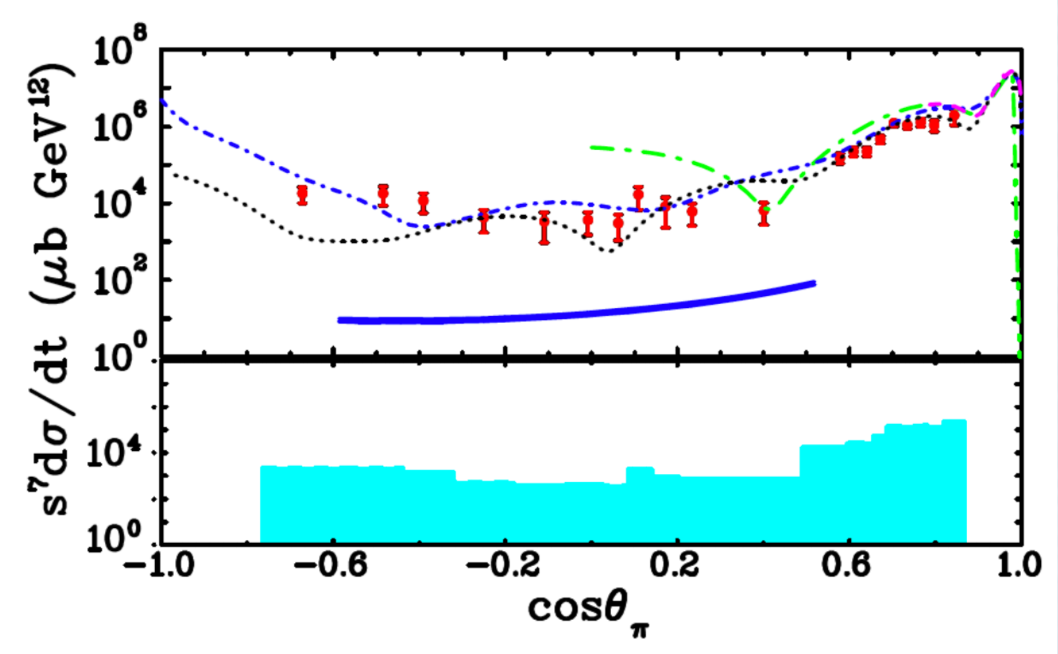
- E12-07-109: measurement of G_E^p/G_M^p to Q^2=12 GeV^2.

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

Polarization transfer in wide-angle charged-pion photo production

E12-20-008

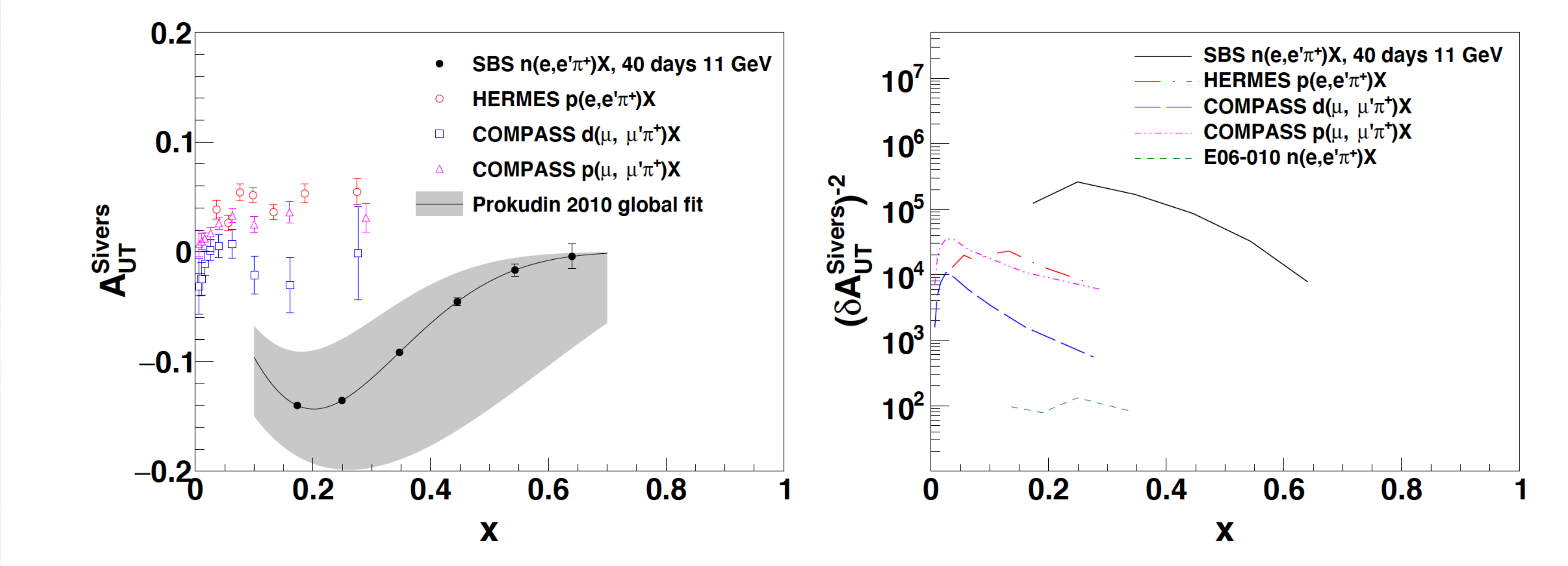
- γ N → N′ $\pi^{\pm}$, single pion photo-production, is arguably the simplest inelastic hadronic process.
- For decades, however, theoretical estimates of the cross sections were two orders of magnitude smaller than observed.
- Twist-2 handbag mechanisms were similarly too small.
- Recent calculations by Kroll and coworkers including twist-3 contributions reproduce the data nicely.
- *A* signature of the twist-3 process is that two double polarization observables will have opposite signs.



- Study $\vec{\gamma}\, n \rightarrow \pi^- \vec{p}$
- Will use identical experimental setup to GEn-RP.
- Only about four days of data needed for striking "smoking-gun" result confirming the dominance of the twist-3 contribution.

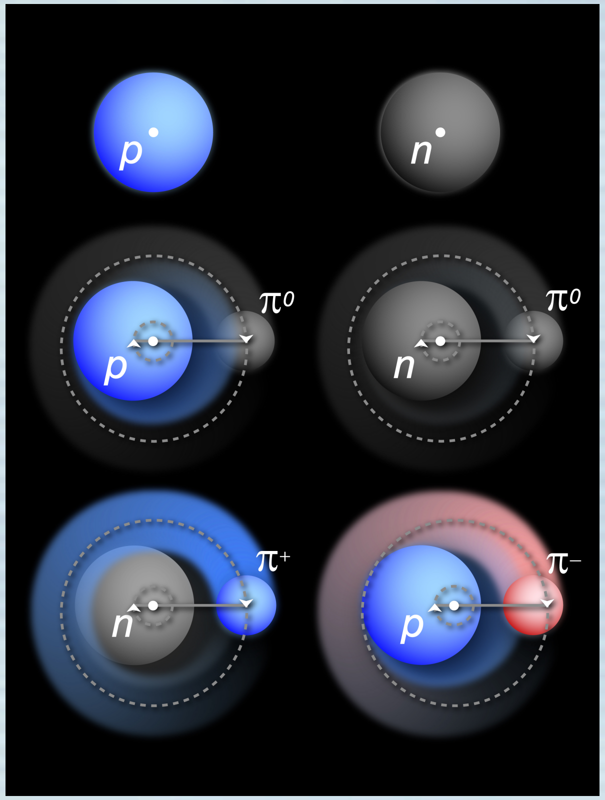
Single-spin asymmetries in semi-inclusive deep inelastic scattering
E12-09-018

- Will study the SIDIS process $\vec{n}(e, e'\pi^{\pm}(K^{\pm}))$
- Will use a very-high-luminosity transversely polarized ^{3}He target,
- BigBite for the electron arm, and
- SBS, the HERMES RICH and HCAL for the hadronic arm.
- Will achieve statistics on the neutron roughly ~100x that of any previous study of SSAs in SIDIS for x > 0.1.

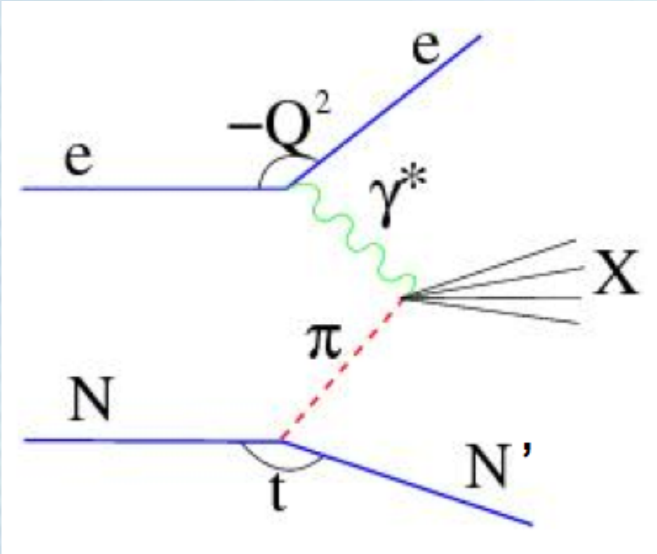


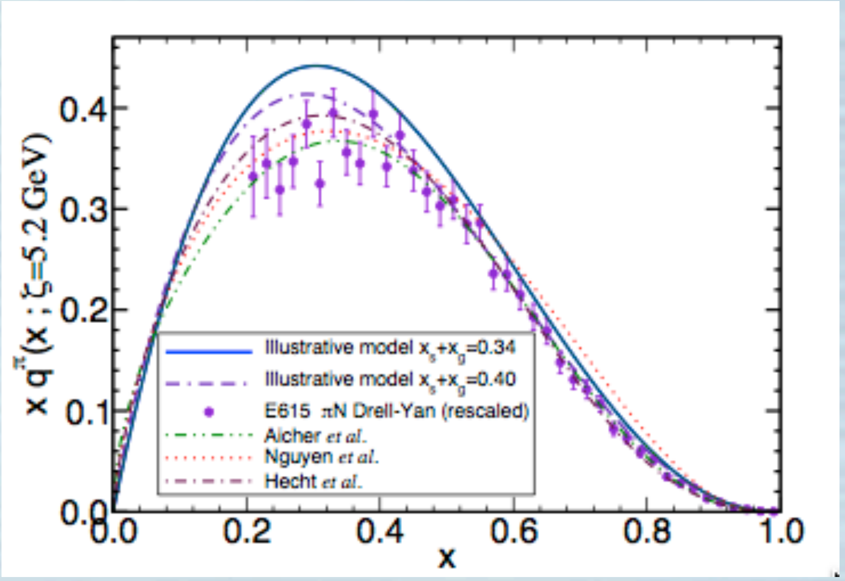
See Evaristo Cisbani's talk at 11:15

SBS Tagged Deep Inelastic Scattering (TDIS) experiment: E12-15-006



- Detect the electron and the (very low energy) recoil proton.
- You are essentially scattering off the meson cloud



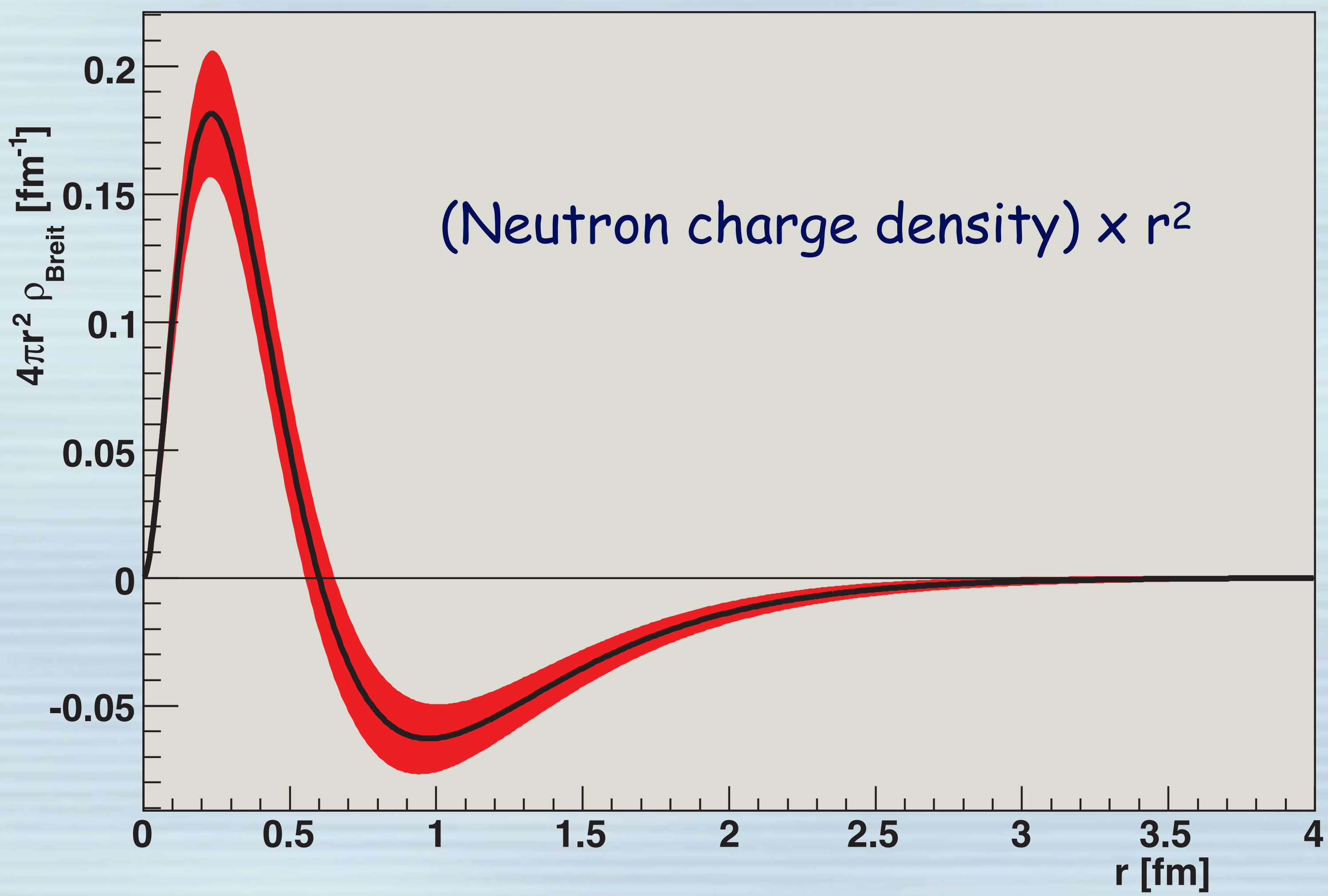


Existing data for the pion structure function from E615 using the Drell-Yan process

- Understanding the meson cloud.
- Measuring the pion structure function via the Sullivan process.

The physics of ground-state nucleon form factors (FFs) at high Q^2

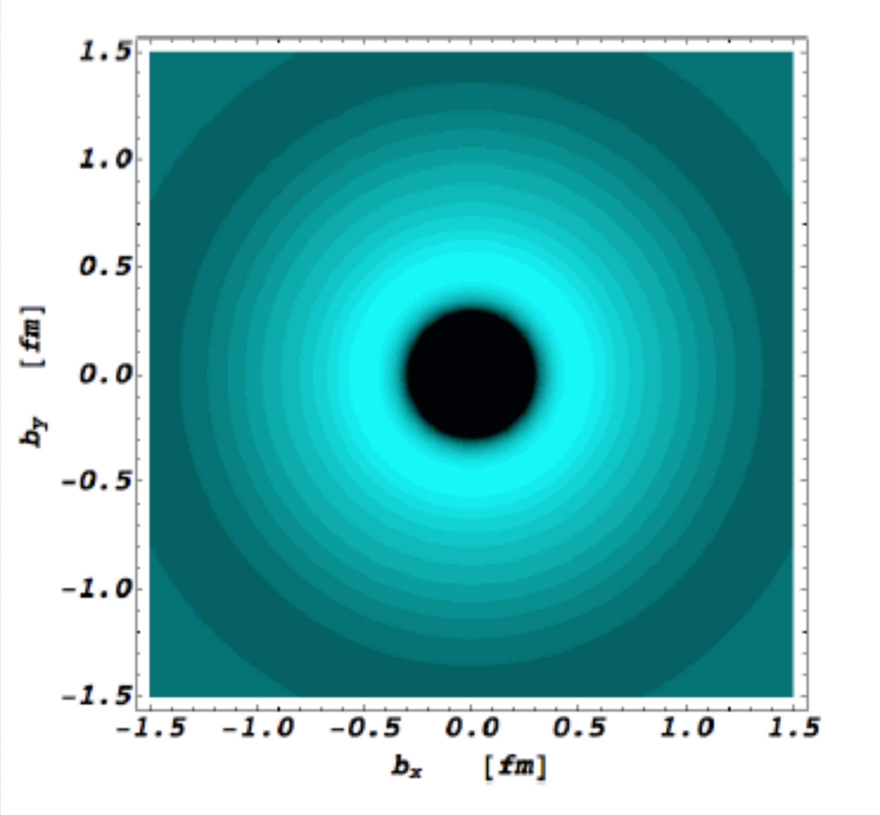
FFs can provide high-resolution "snapshots" of the nucleon: non-relativistic picture



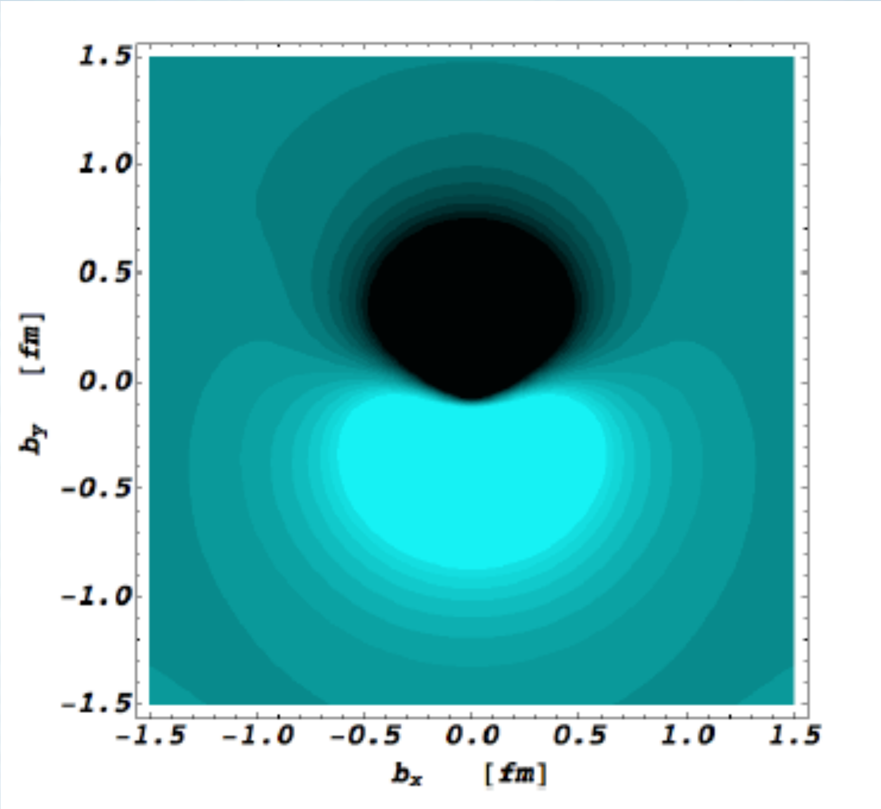
From the 2007 Long Range Plan

Here the density is essentially the Fourier transform of G_E^n . The negative pion cloud surrounding a positive core is clearly visible.

FFs can provide high-resolution "snapshots" of the nucleon - relativistic picture



Longitudinally polarized neutron



Transversely polarized neutron

Carlson and Vanderhaeghen, PRL v.100, pg.032004 (2008)

- Above, the light-front "charge" densities of both longitudinally and transversely polarized neutrons.
- Note the electric dipole moment of the transversely polarized neutron, which is due to the magnetic dipole moment when viewed from a boosted reference frame.

The FFs currently provide one of the strongest constraints on GPDs

$$\int_{-1}^{+1} dx H^q(x,\xi,Q^2) = F_1^q(Q^2) \quad \text{and} \quad \int_{-1}^{+1} dx E^q(x,\xi,Q^2) = F_2^q(Q^2)$$

Among other things, FFs thus play a role in determining the angular momentum of the quarks using Ji's Sum Rule:

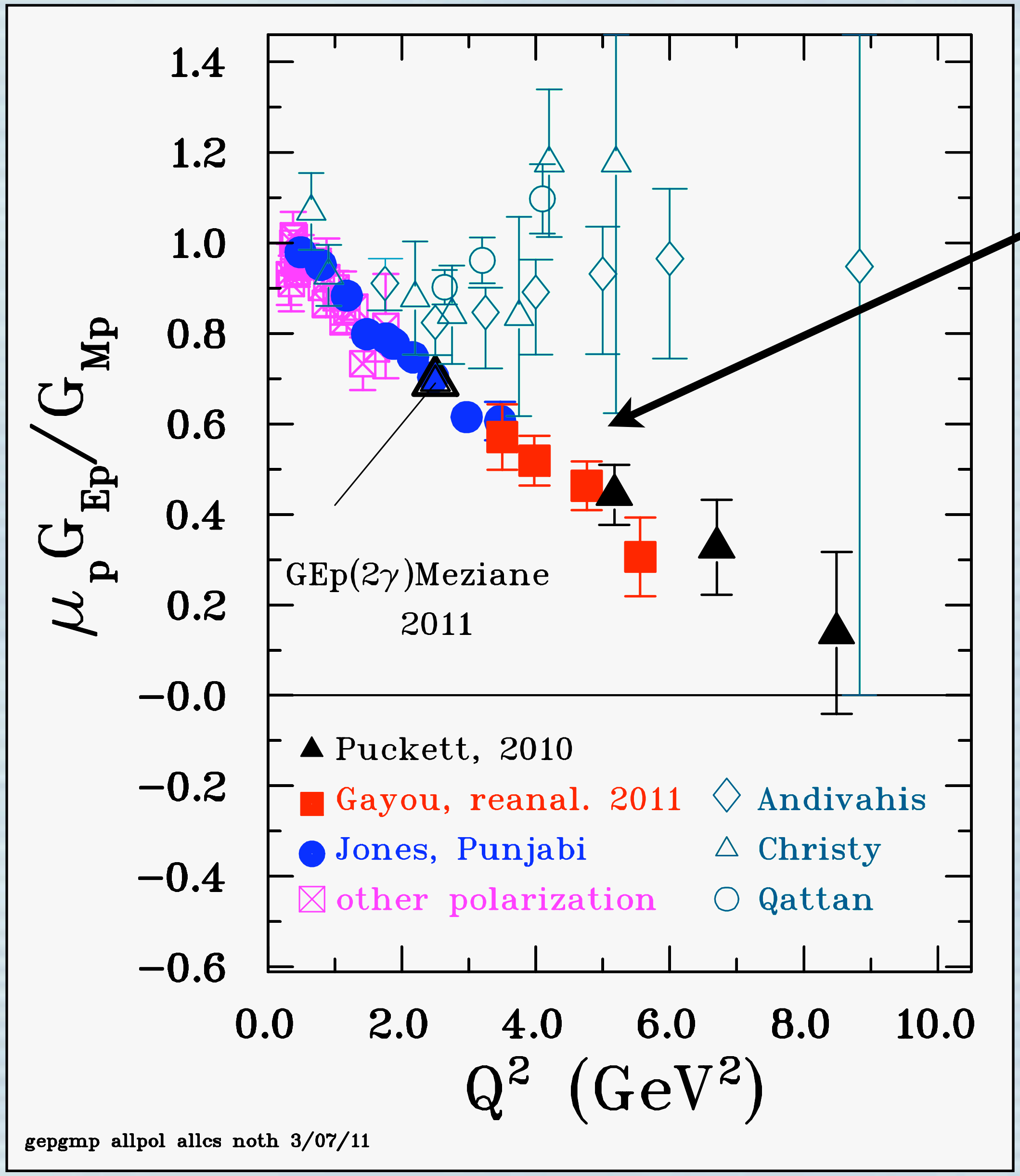
$$J^q = \frac{1}{2}\int_{-1}^{1} x\,dx\;[\,H^q(x,\xi,0) + E^q(x,\xi,0)]$$

FFs thus play a an important role in the entire GPD program, one of the signature goals of the 12 GeV upgrade

More generally, the nucleon FFs at high Q^2 provide unique insight into the QCD structure of the nucleon

Some examples ....

The ratio of the electric and magnetic FFs of the proton, $\mu_p G_E^p/G_M^p$, using the recoil polarization technique

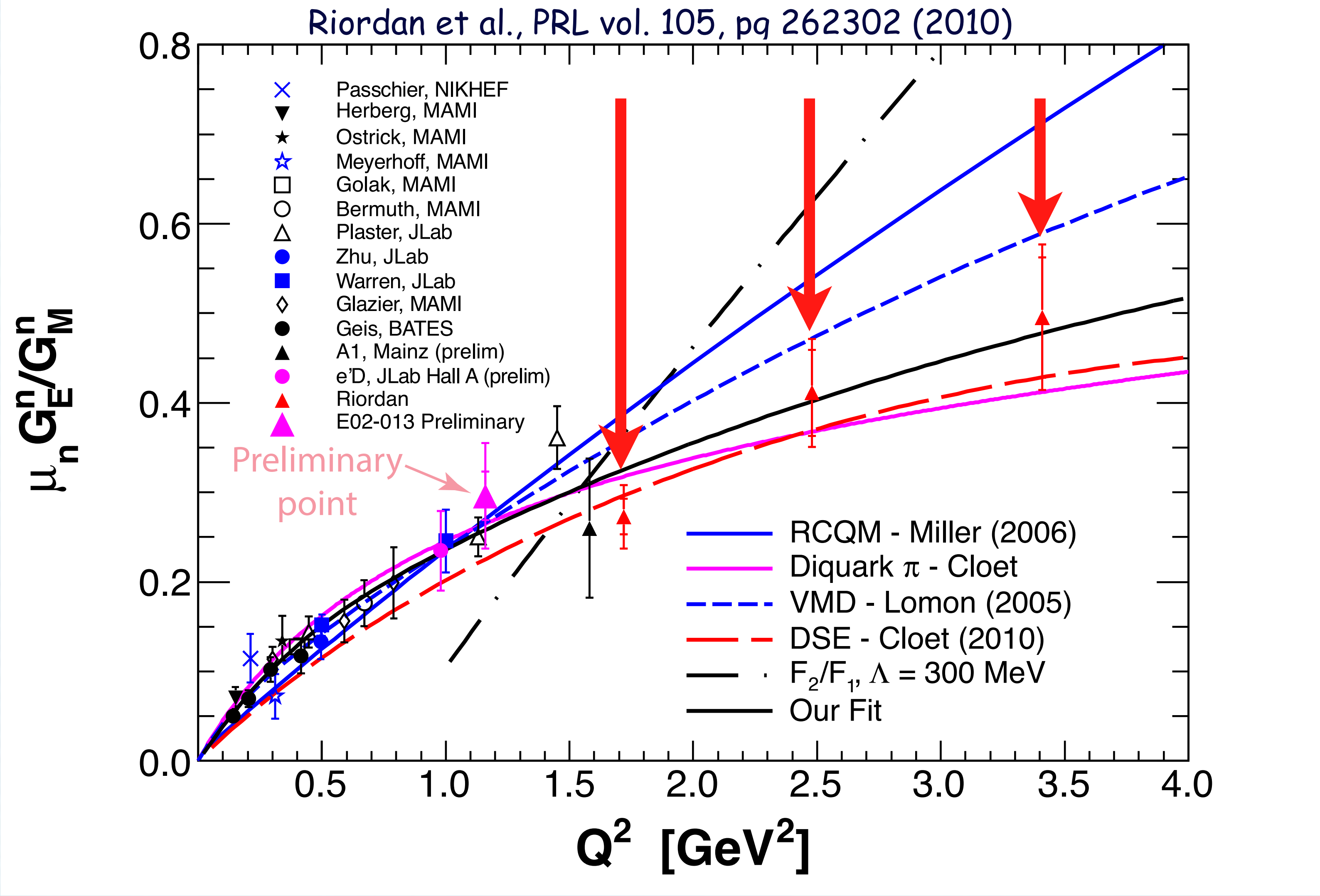


Data from both Rosenbluth separations and the double-polarization technique.

Resulted in the 2017 Bonner Prize for Charles Perdrisat of William and Mary

- Explanations for the Q^2 behavior of G_E^p/G_M^p often emphasize the role of <u>quark orbital angular momentum</u>.
- It should be noted, however, that diquark correlations could also be responsible (not necessarily to the exclusion quark OAM).

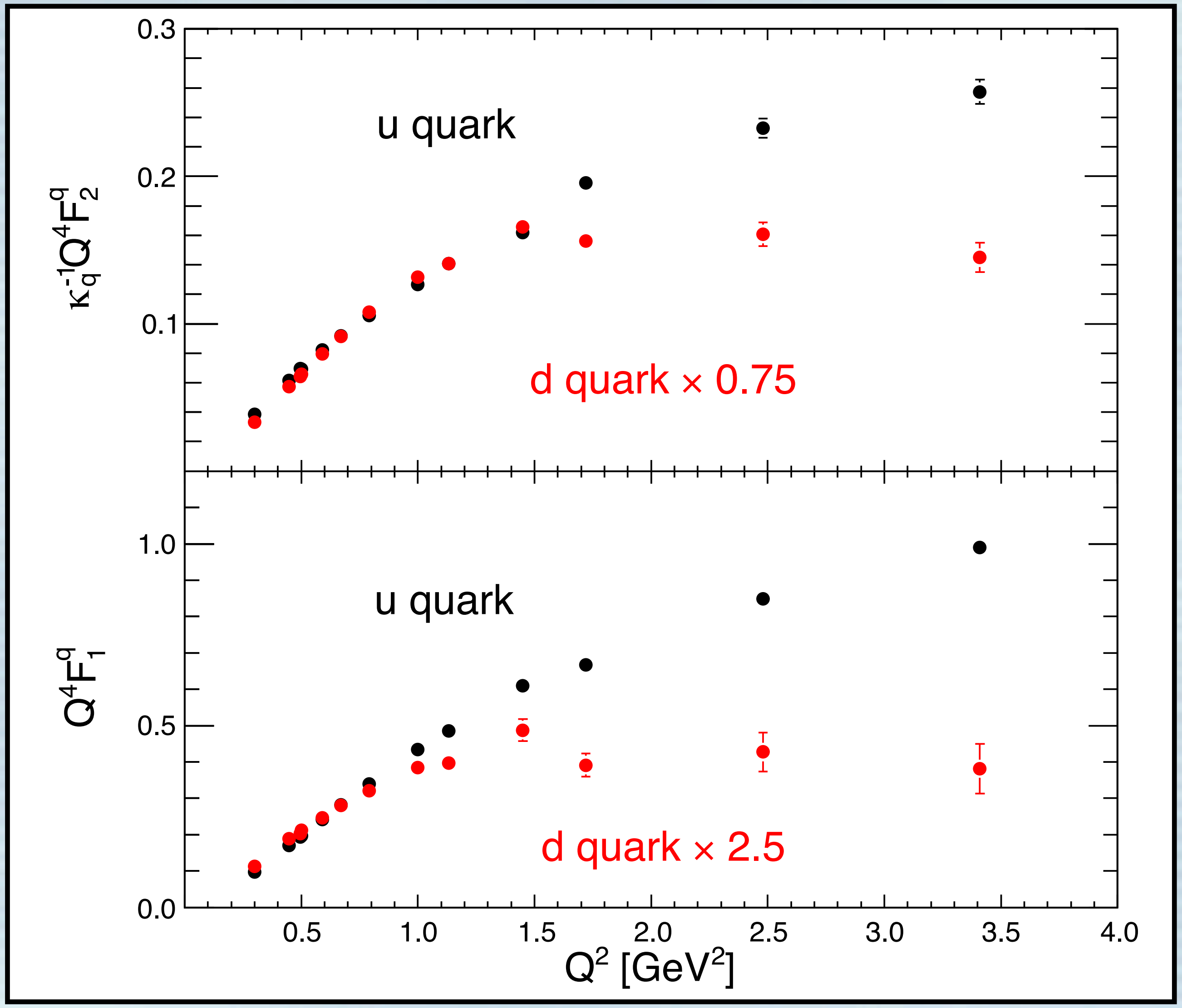
The corresponding ratio, $\mu_n G_E^n/G_M^n$, for the neutron was extended to high Q^2 from the Hall A polarized ^{3}He experiment (E02-013)



The data made it possible to extract the individual FF contributions from the different quark flavors.

The FFs of the up- and down-quarks have distinctly different Q^2 behavior

Cates, de Jager, Riordan and Wojtsekhowski, PRL vol. 106, pg 252003 (2011)

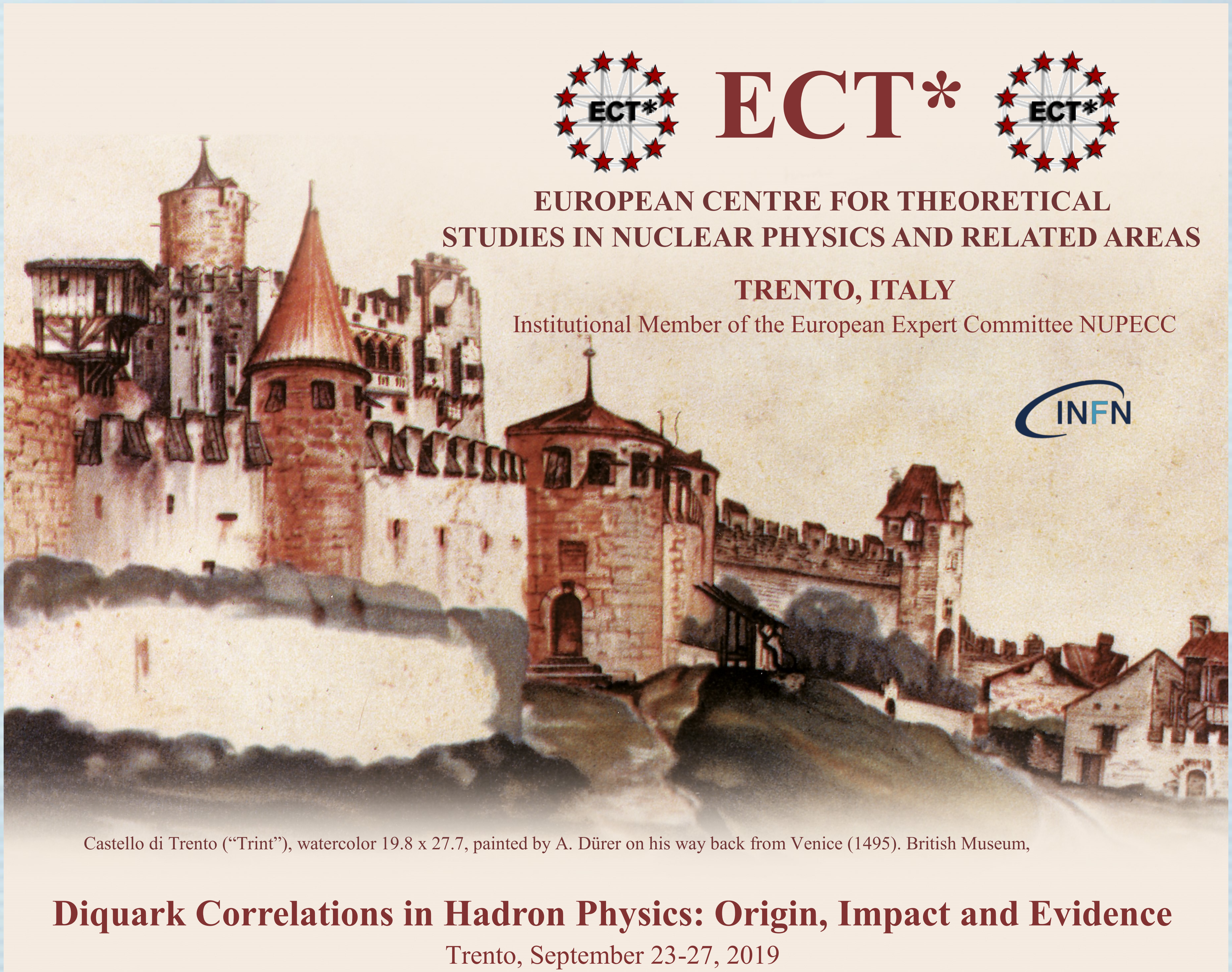


More details on this from Bogdan Wojtsekhowski tomorrow.

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

Many of the theoretical models that reproduce the above trends indicate the importance of <u>diquark correlations</u>.

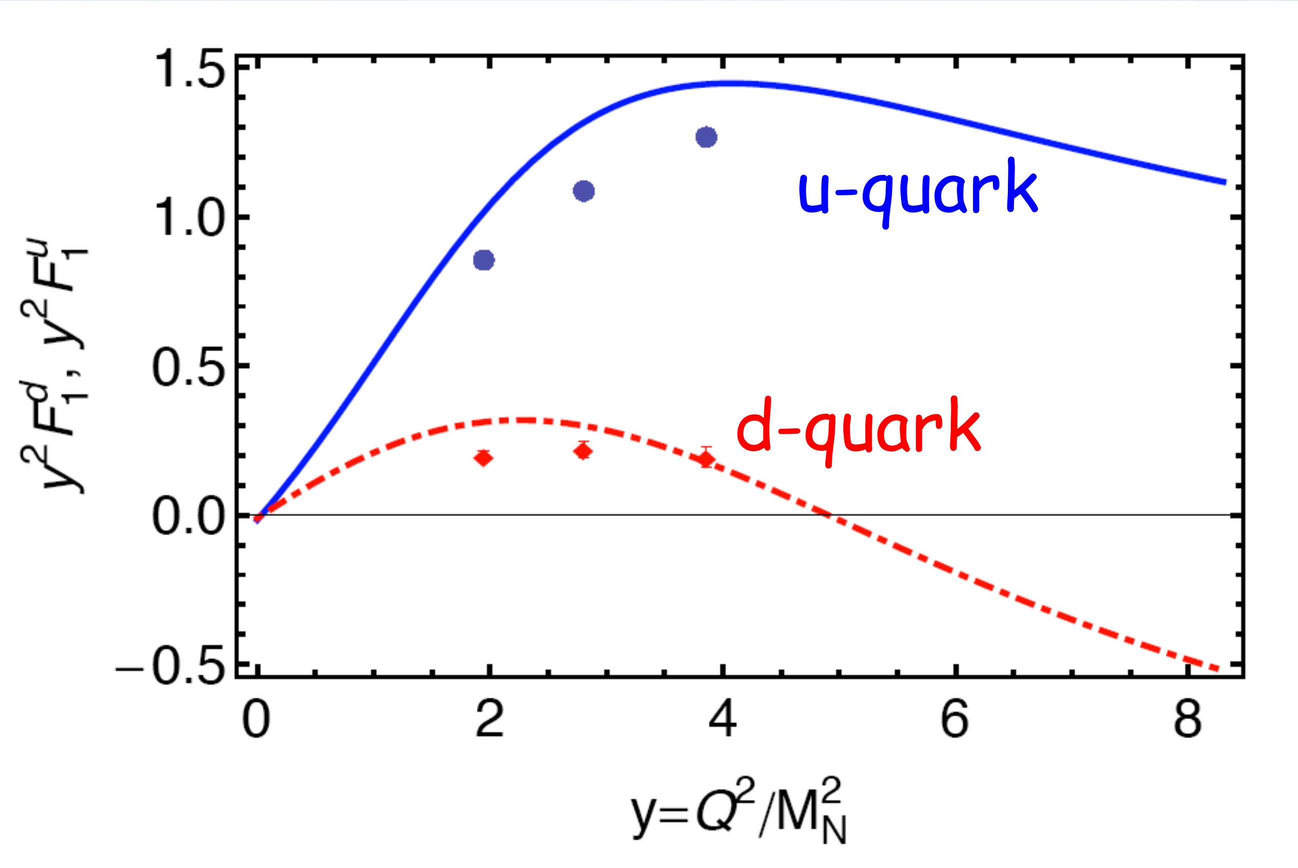
Workshop on diquarks at ECT* in Trento
(September 2019)



DSE/Faddeev calculation of $Q^4F_1^u$ and $Q^4F_1^d$

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.

A relativistic constituent quark model including quark-diquark configurations immersed in a pion cloud

PHYSICAL REVIEW C **86**, 015208 (2012)

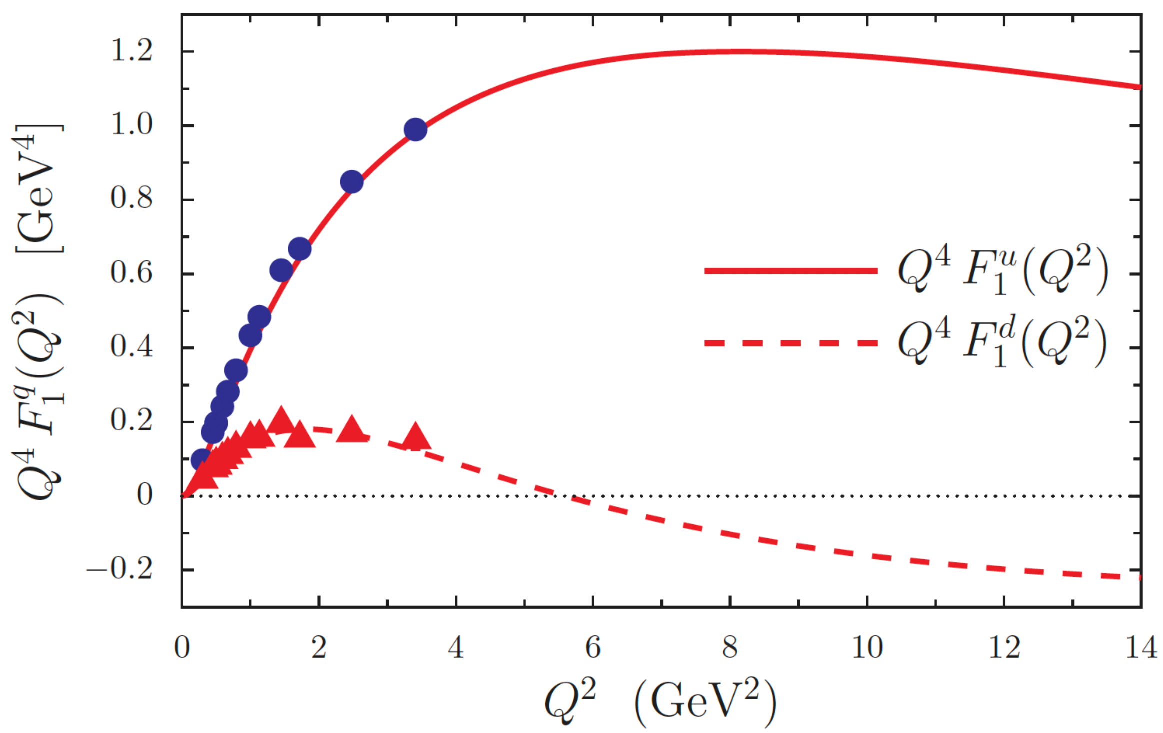


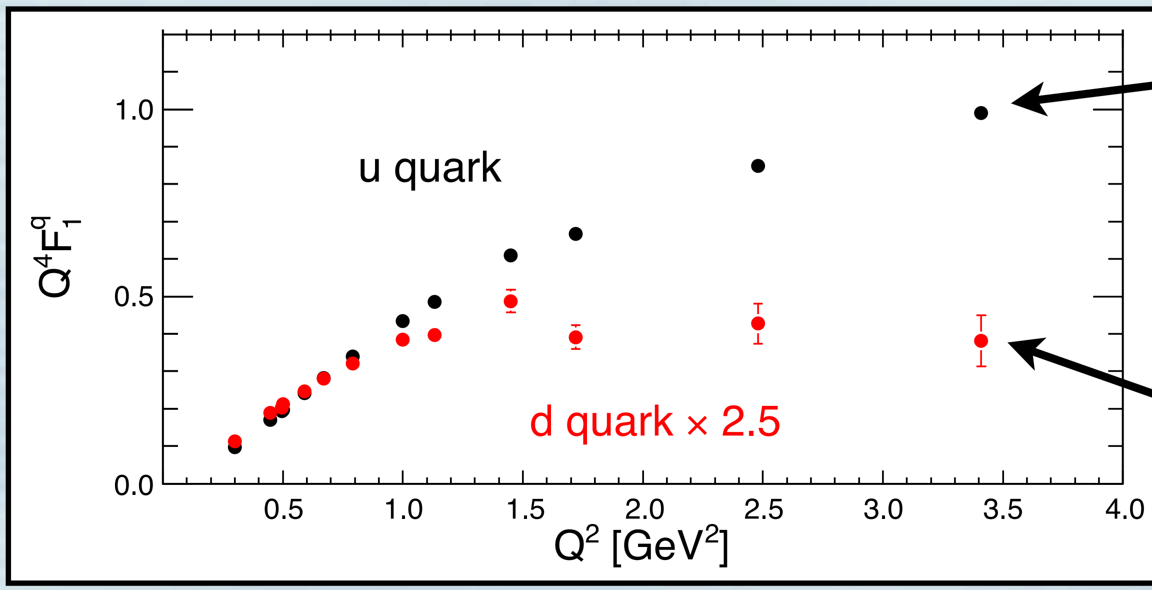
FIG. 10. (Color online) Model results for Dirac quark sector form factors F_1^u and F_1^d multiplied by Q^4. The data are from Refs. [8,17–22,28–32].

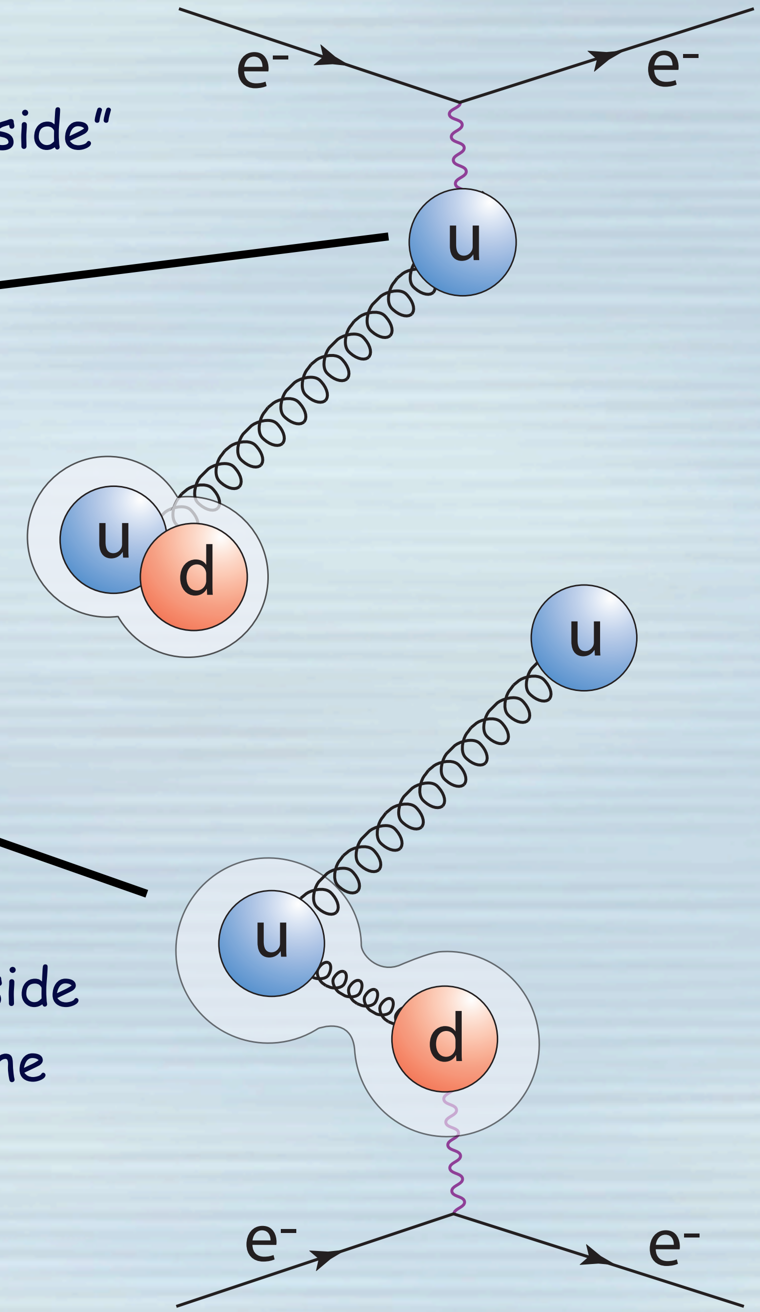
Jerry Miller
and Ian Cloët

Constituent quark models without quark-diquark configurations have a much tougher time reproducing the flavor separated FFs.

A (very) simplified constituent counting argument provides some intuitive understanding

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



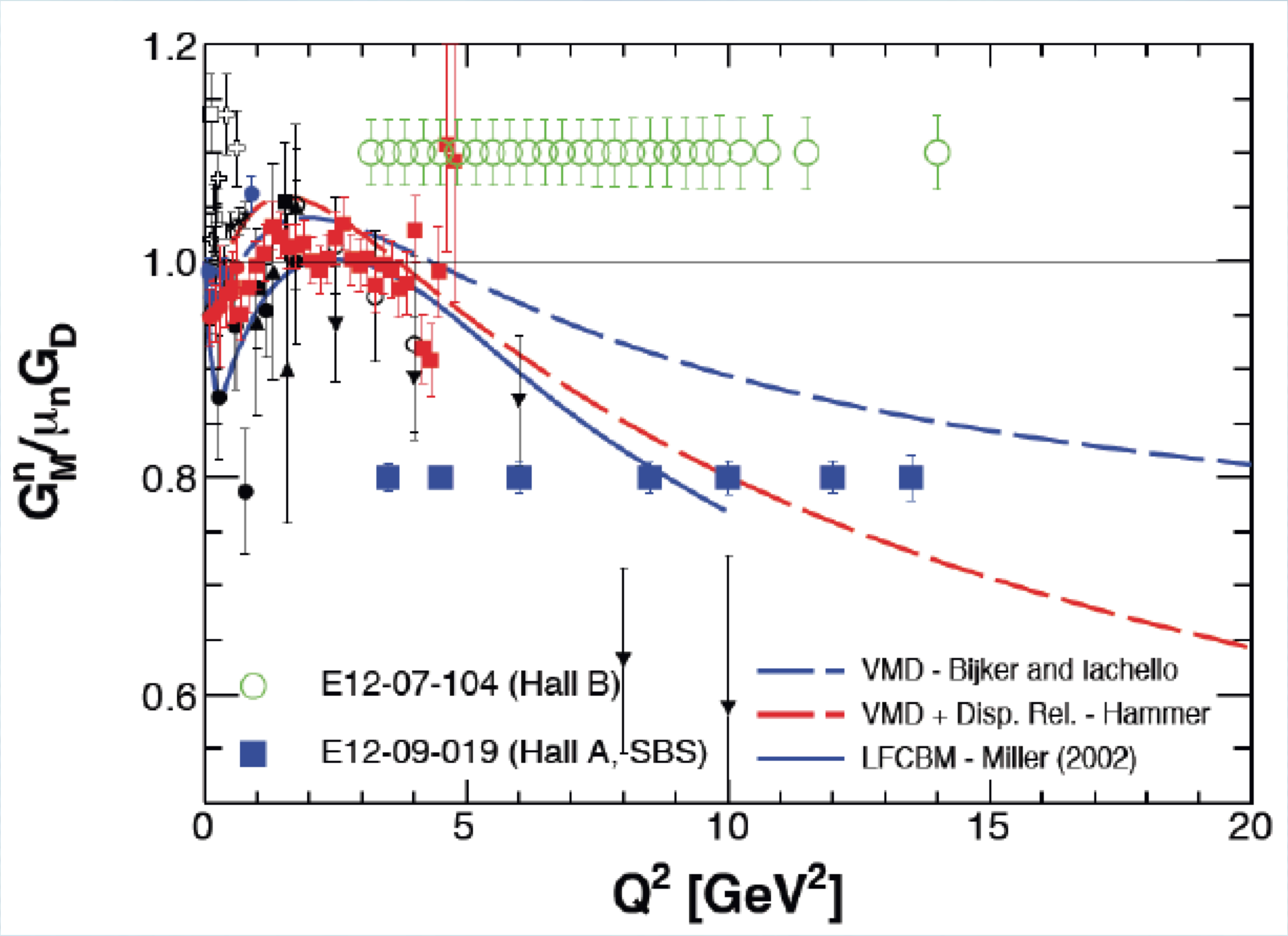


d-quark scattering amplitude is necessarily probing inside the diquark. Two gluons need to be exchanged (or the diquark would fall apart), so scaling goes like $1/Q^4$

This simple view was suggested to us early on by Jerry Miller

The SBS program will be a game changer in our understanding of the nucleon FFs at high Q^2

In the first SBS run group: measurement of the ratio G_M^n/G_M^p: E12-09-019



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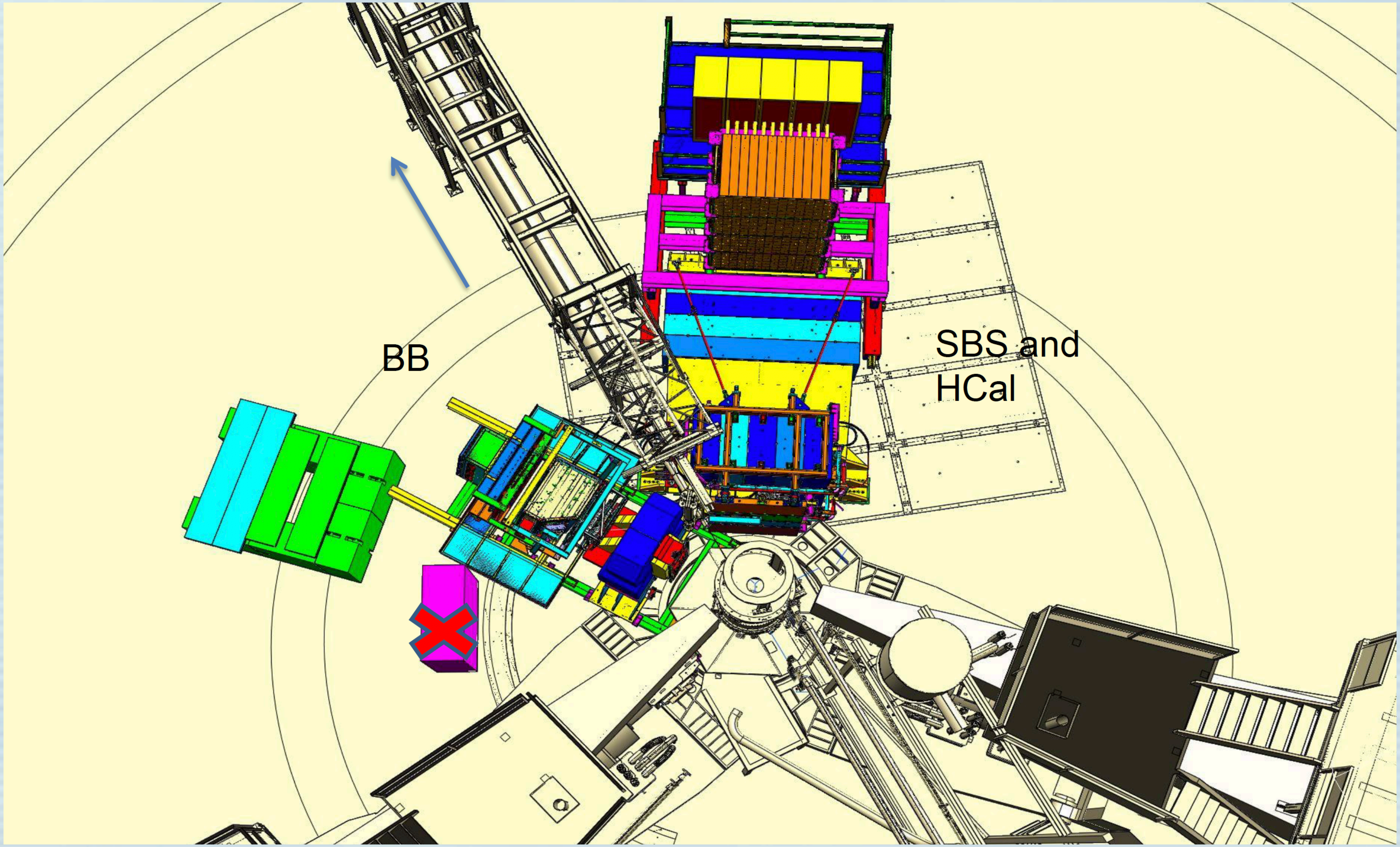
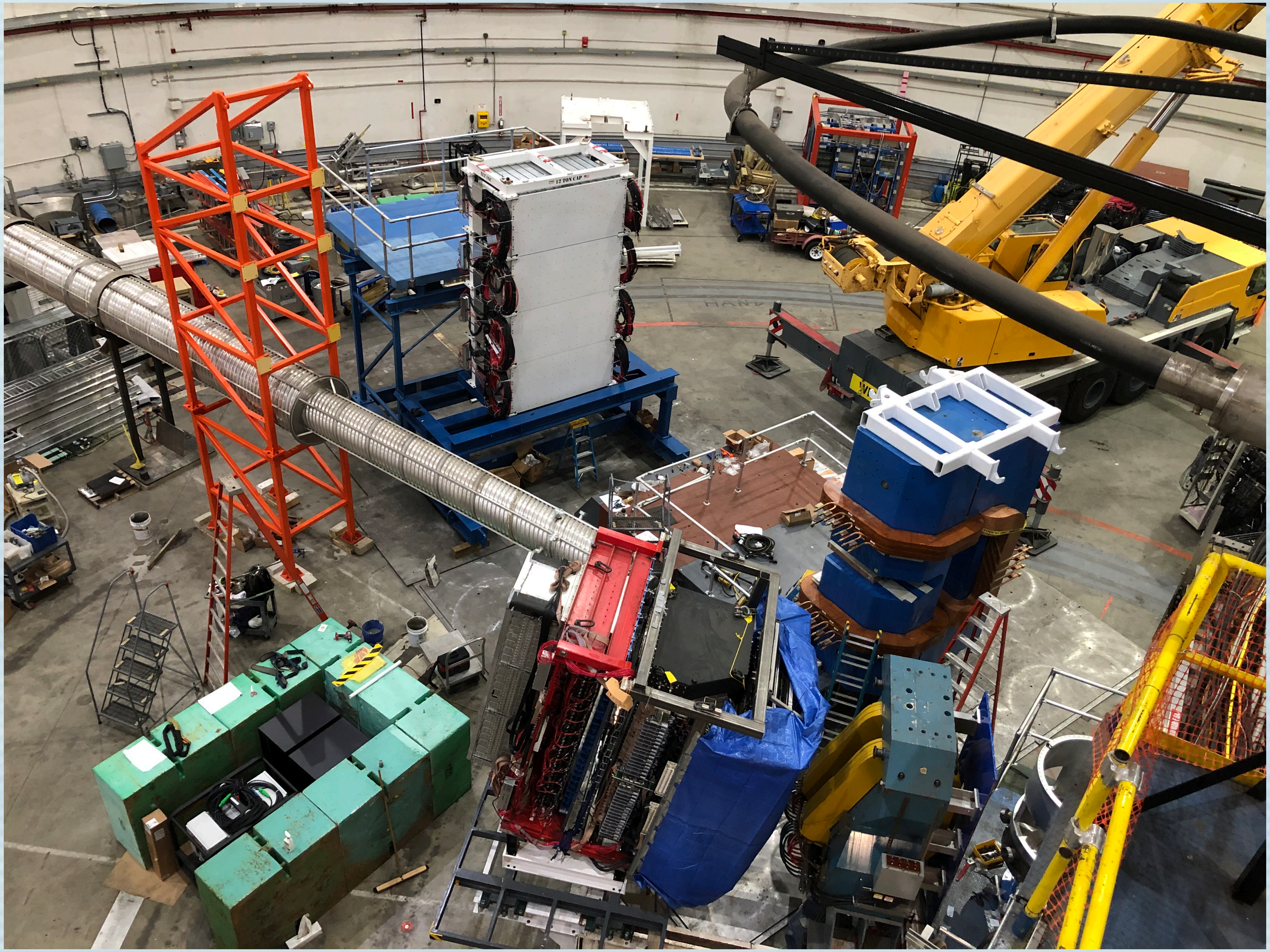
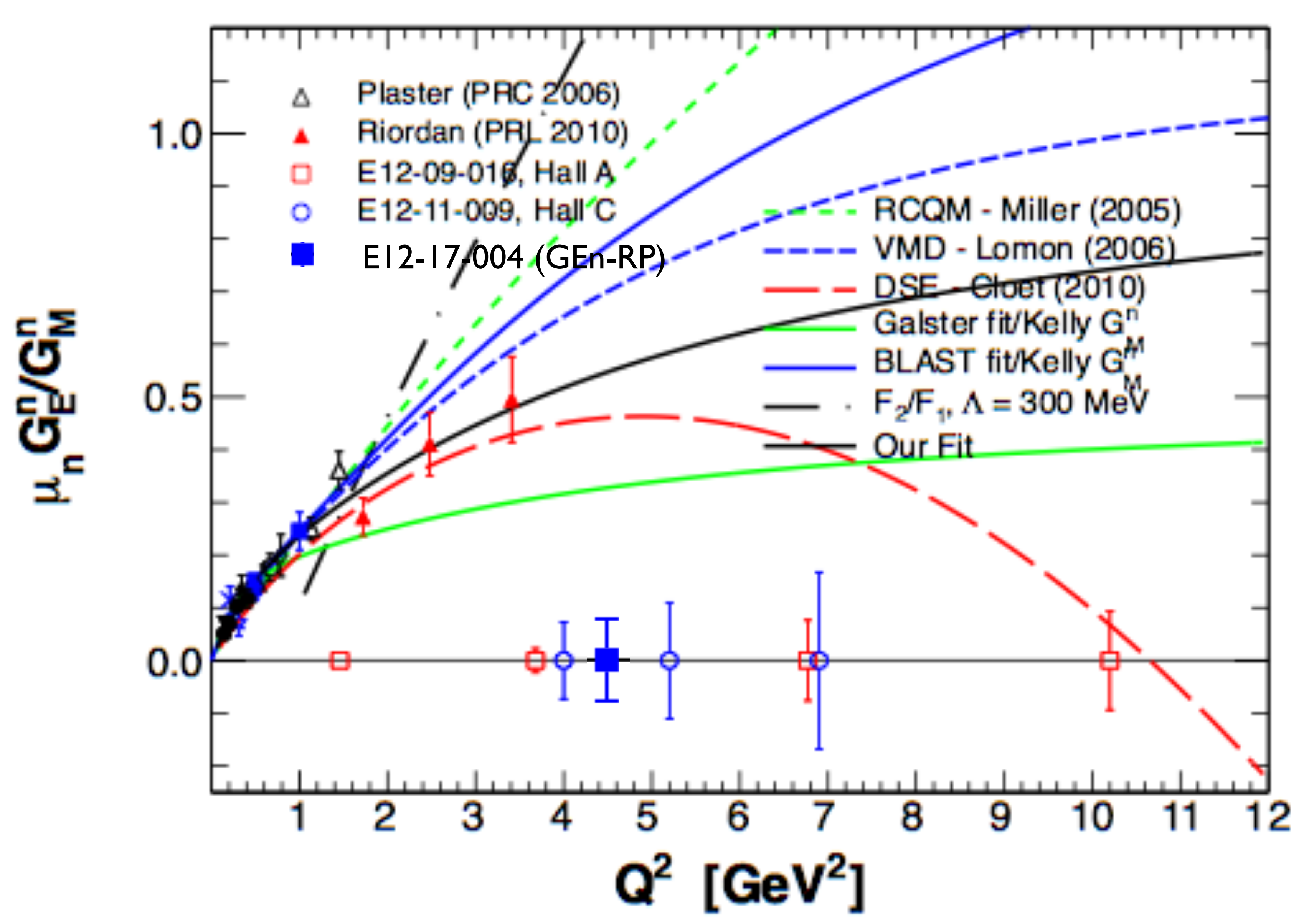


In the **first** SBS run group: measurement of the ratio G_M^n/G_M^p:

E12-09-019

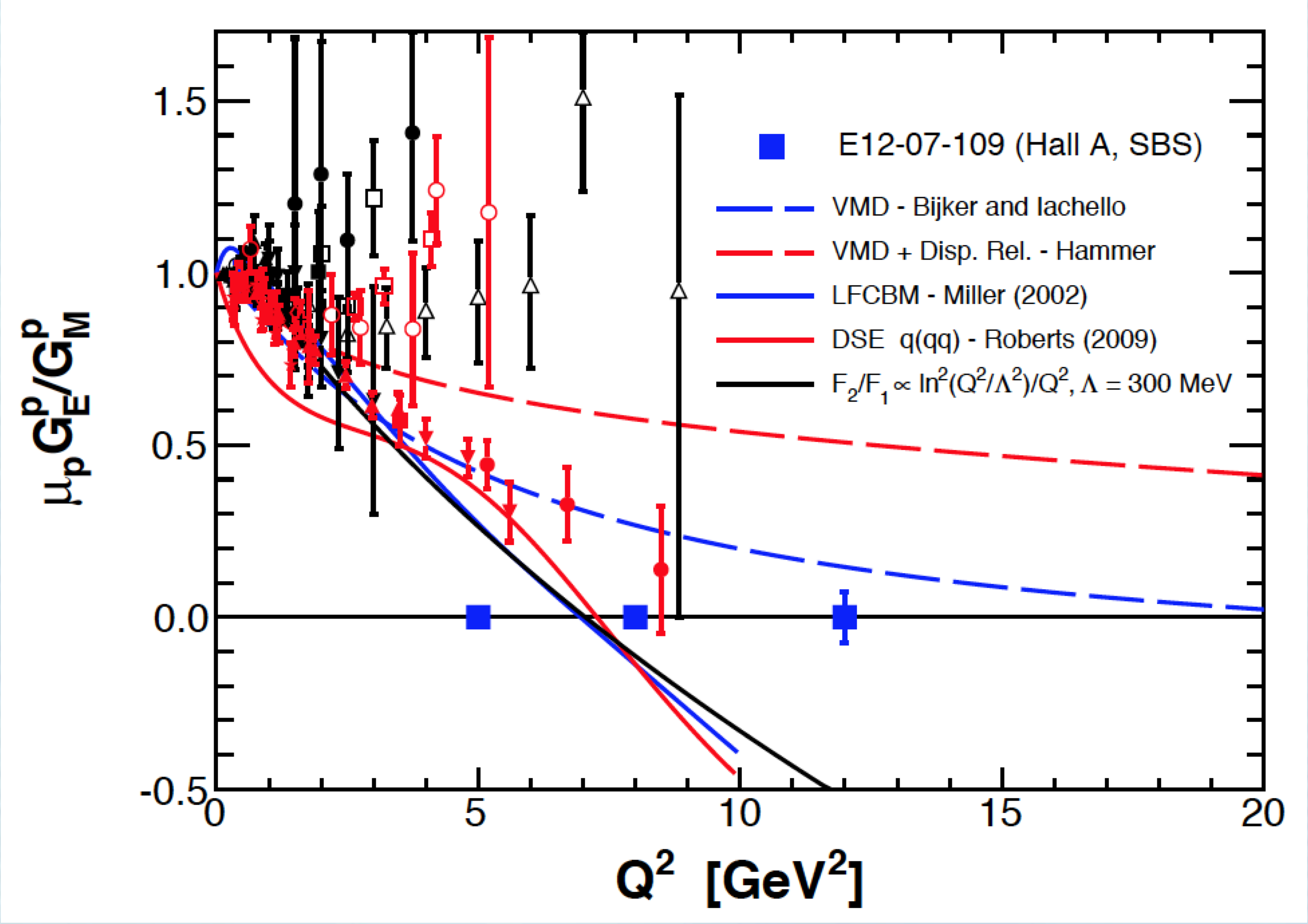


The SBS polarized-^{3}He G_E^n experiment: projected results

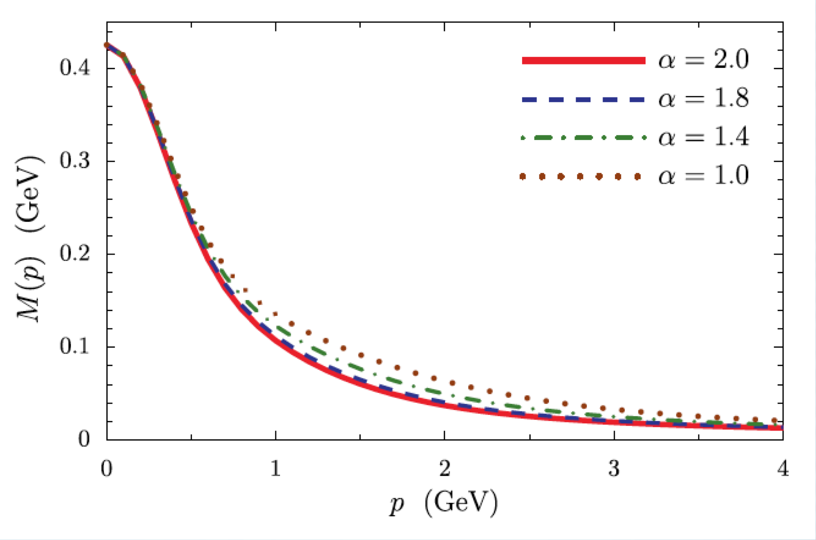


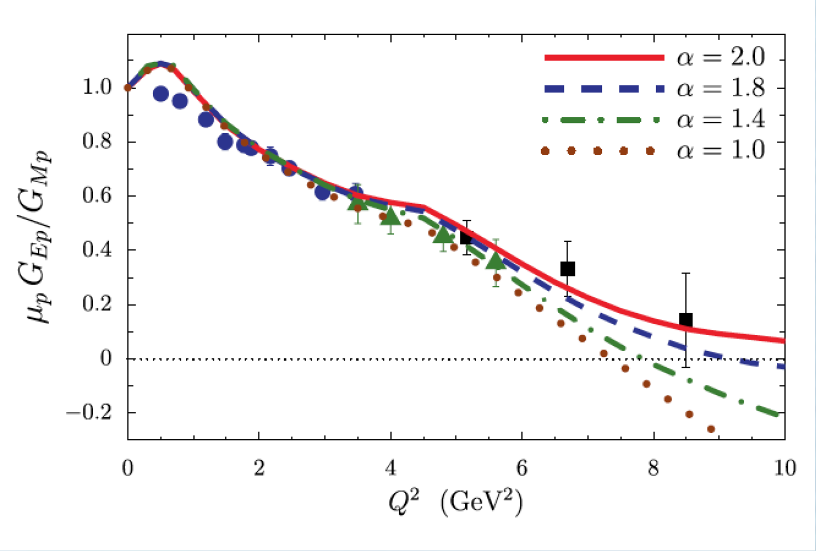
Installation will begin late winter/spring of 2022

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



G_E^p/G_M^p projected data





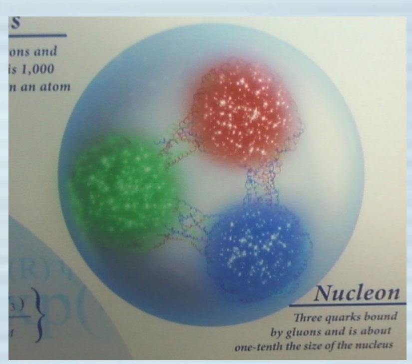
Cloet, Roberts, Thomas, PRL 111, 101803 (2013)

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

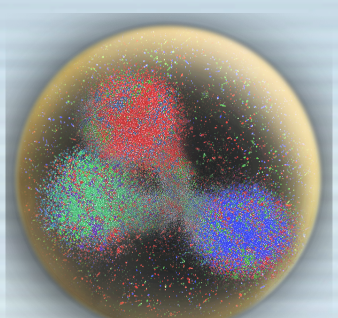
Summary

- The nucleon form factors have a long history of providing surprises going all the way back to the early days at SLAC.
- SBS has the potential to have a dramatic impact on our understanding of the nucleon.
- SBS will start running in the fall of <u>this year</u> !

We need more collaborators! Talk to us!



A cartoon of the nucleon from the lobby of JLab



From the DOE Pulse Newsletter: Artist's conception of a nucleon with quark-diquark structure