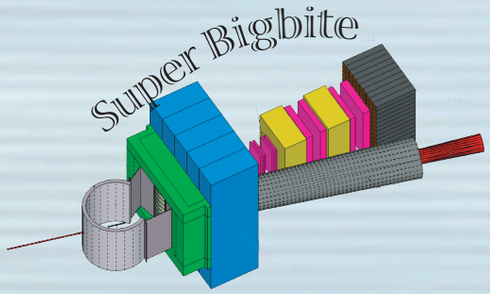
The SBS G_E^n polarized ^{3}He experiment

- Some history illustrating the important physics being addressed.
- Some detail on the SBS GEn experiment.
- A few comments on the impact of the experiment.

Gordon D. Cates

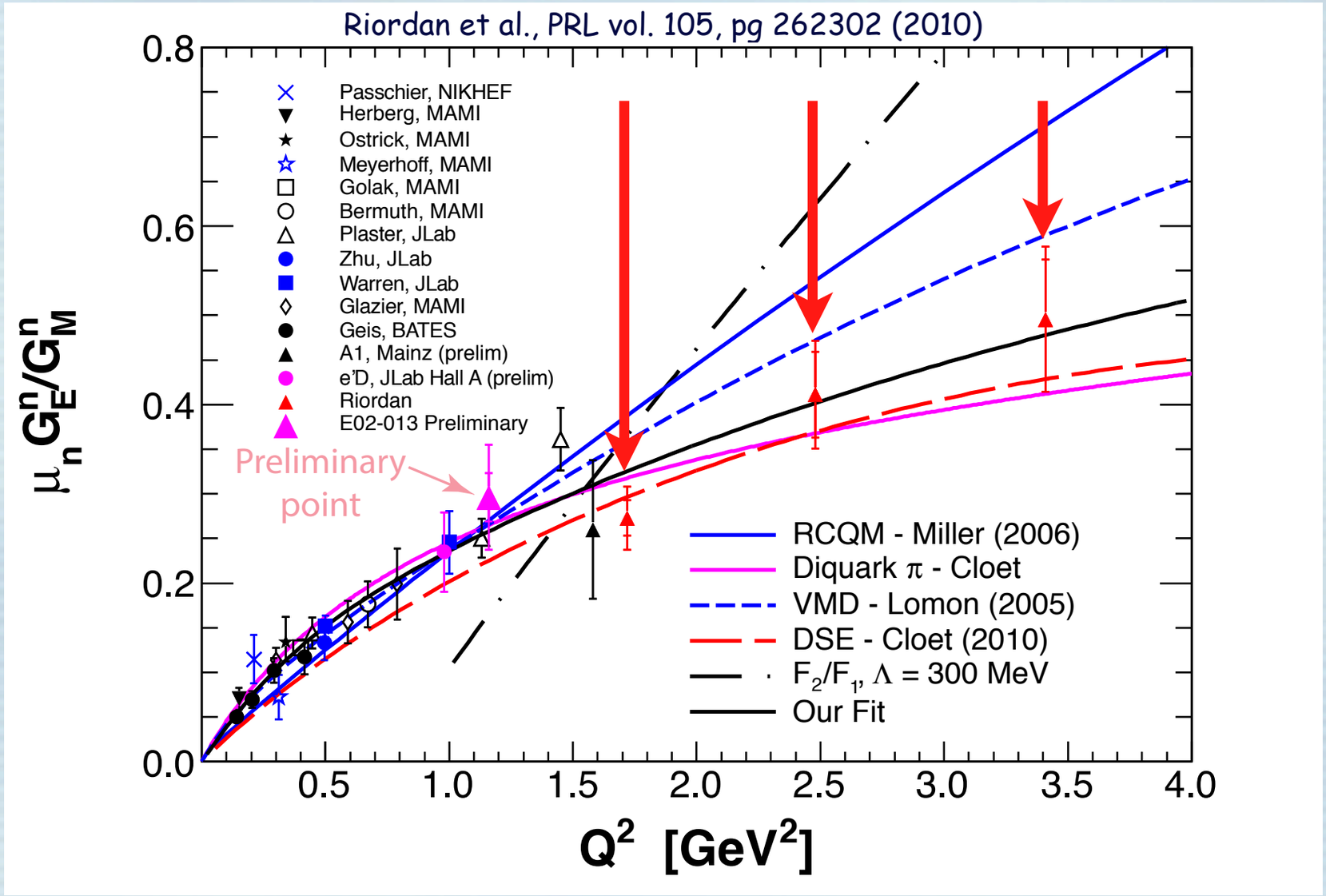
January 31, 2020



Why is SBS (and G_E^n) so important?

It's useful to look at the history .....

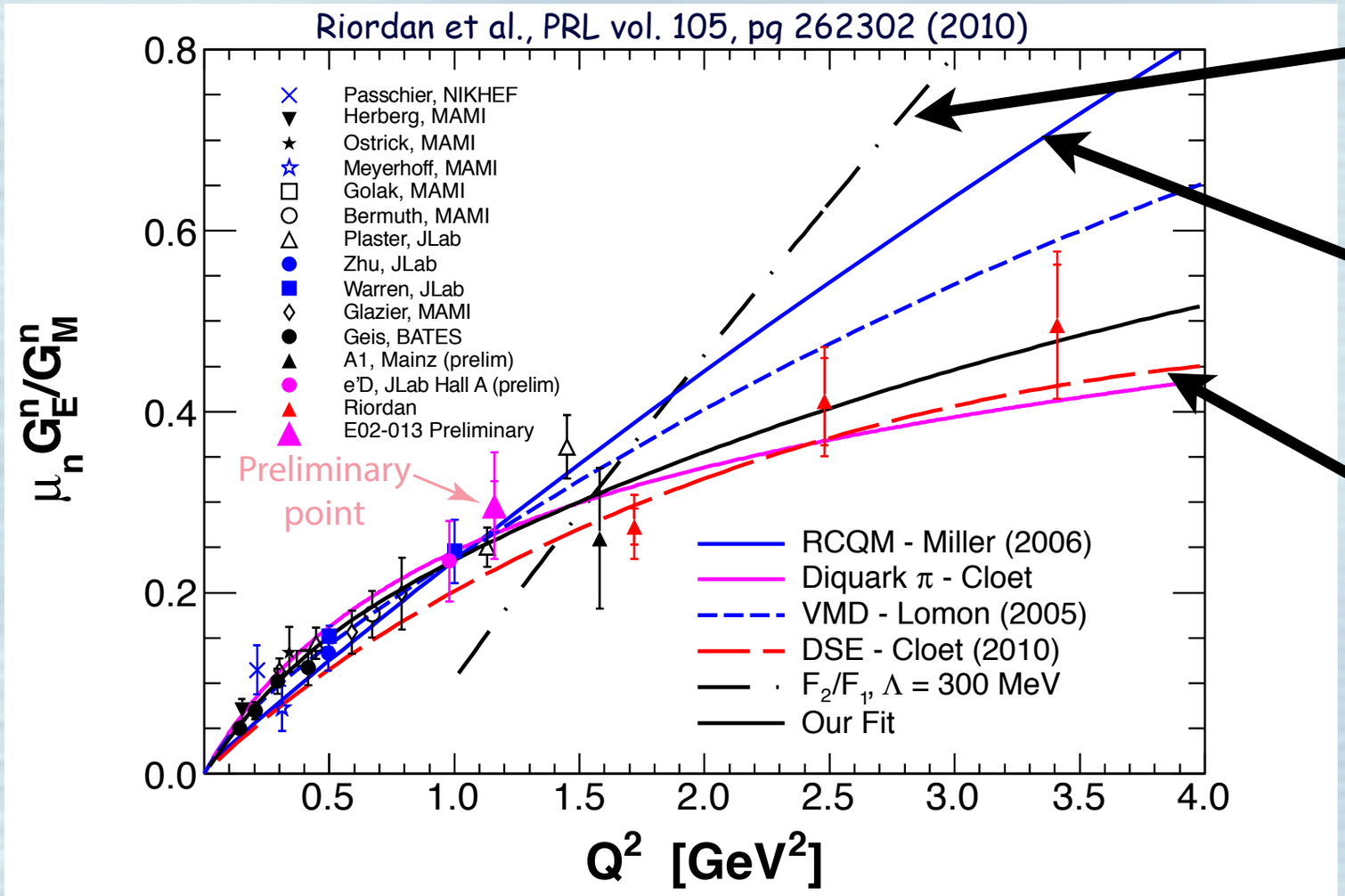
The first Hall A polarized ^{3}He experiment (E02-013)



Published in 2010

Extended our knowledge of G_E^n into the Q^2 range where the dramatic Q^2 behavior was discovered in G_E^p

The first Hall A polarized ^{3}He experiment (E02-013)



Belitsky, Ji and Yuan, logrithmic corrections - 2003

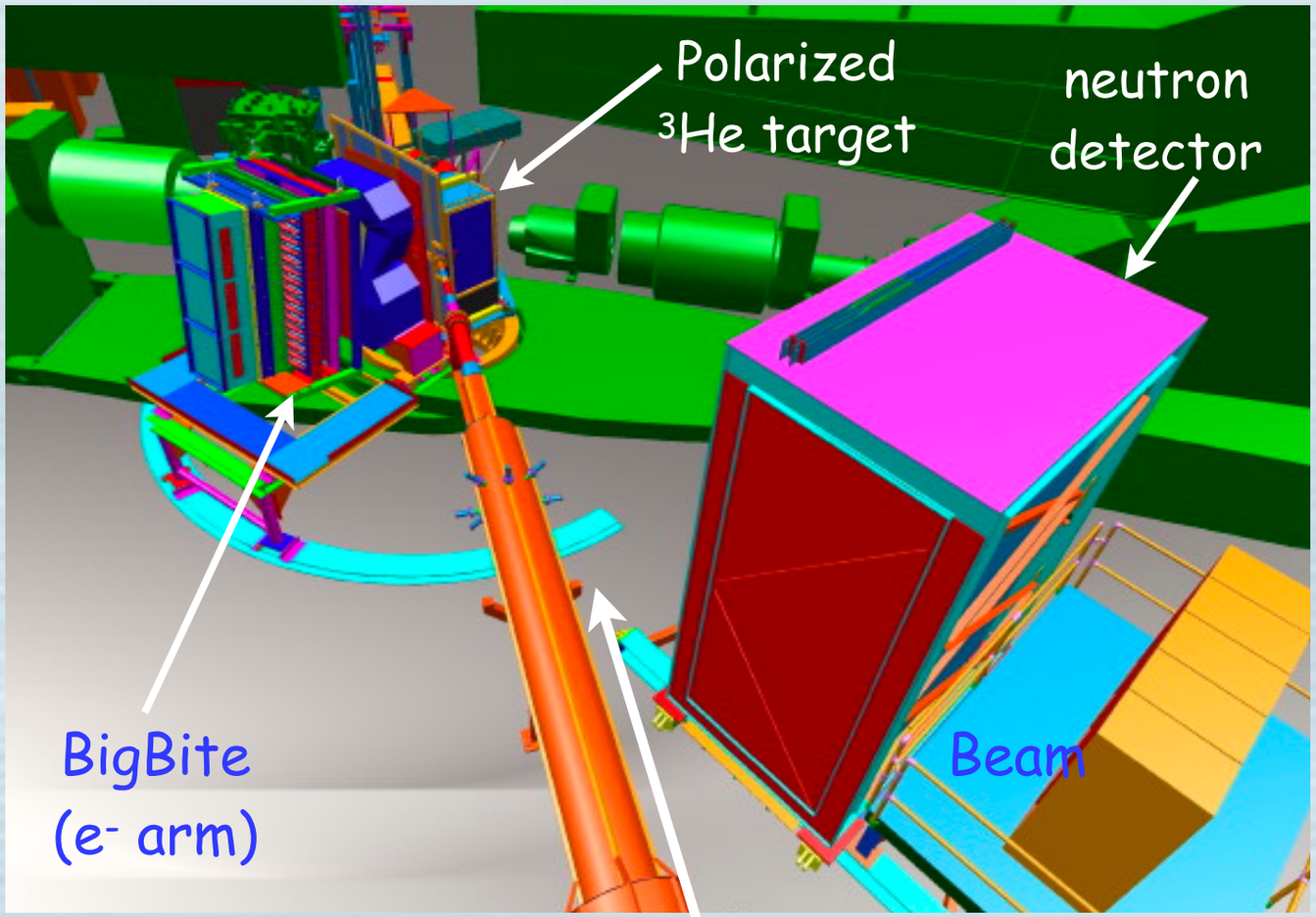
Miller's RCQM - 2002

Cloet, Eichmann, El-Bennich, Kahn and Roberts - DSE/Faddeev - 2009

Extended our knowledge of G_E^n into the Q^2 range where the dramatic Q^2 behavior was discovered in G_E^p

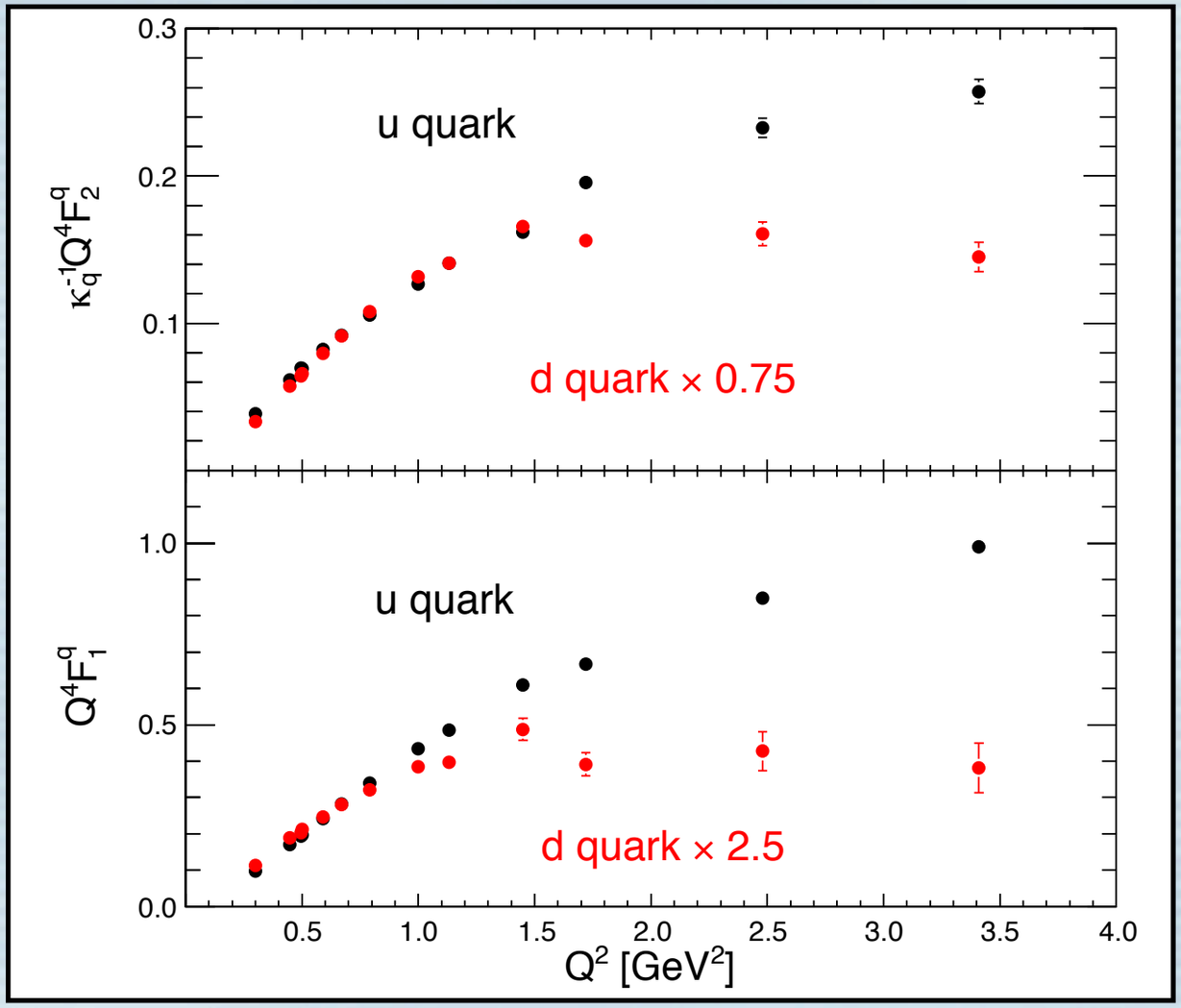
Multiple innovations were needed to measure G_E^n to high Q^2

$^3\vec{He}(\vec{e},e'n)pp$



- Open geometry spectrometer: the first use of Big Bite with full tracking.
- High luminosity polarized ^{3}He target, with a figure of merit more than 10x higher than E142 that measured the neutron spin structure.
- The neutron detector was, I believe the world's largest at that time.

With <u>both</u> proton and neutron FF data, it becomes possible to extract the individual quark contributions



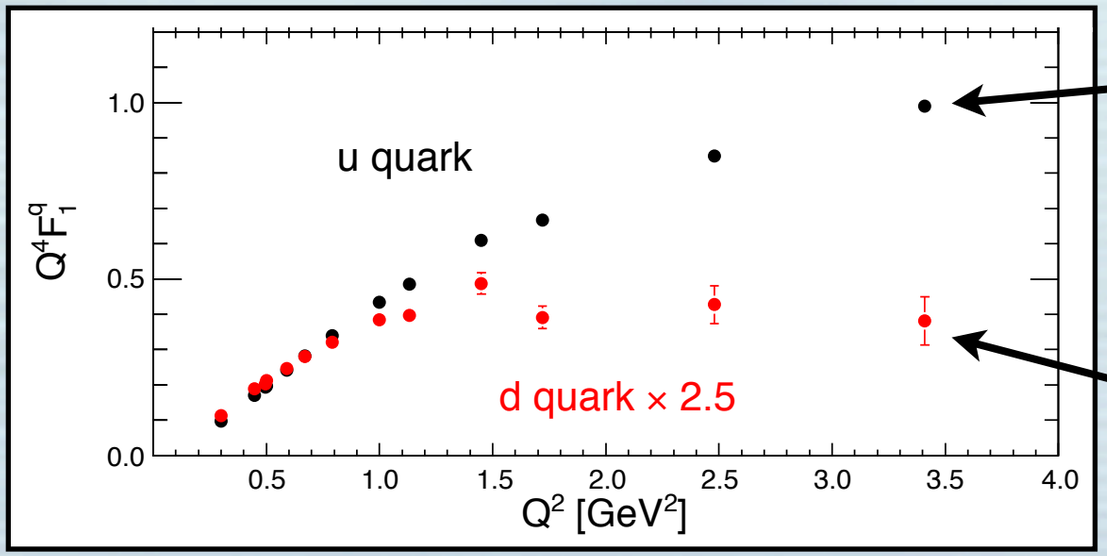
Cates, de Jager, Riordan and Wojtsekhowski, PRL vol. 106, pg 252003 (2011)

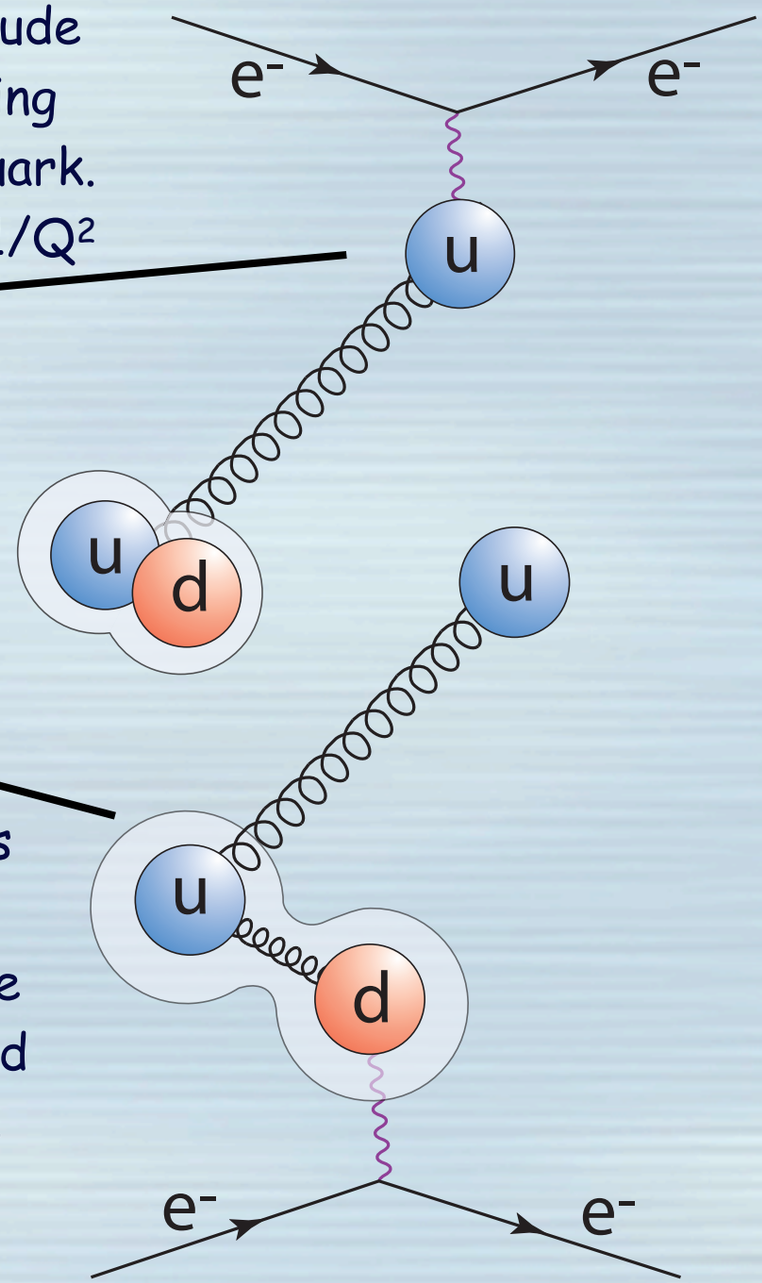
$$F^u_{1(2)} = 2F^p_{1(2)} + F^n_{1(2)} \quad \text{and} \quad F^d_{1(2)} = 2F^n_{1(2)} + F^p_{1(2)}$$

Distinctly different behavior was seen for the u- and d-quark contributions to the form factors

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 $1/Q^2$

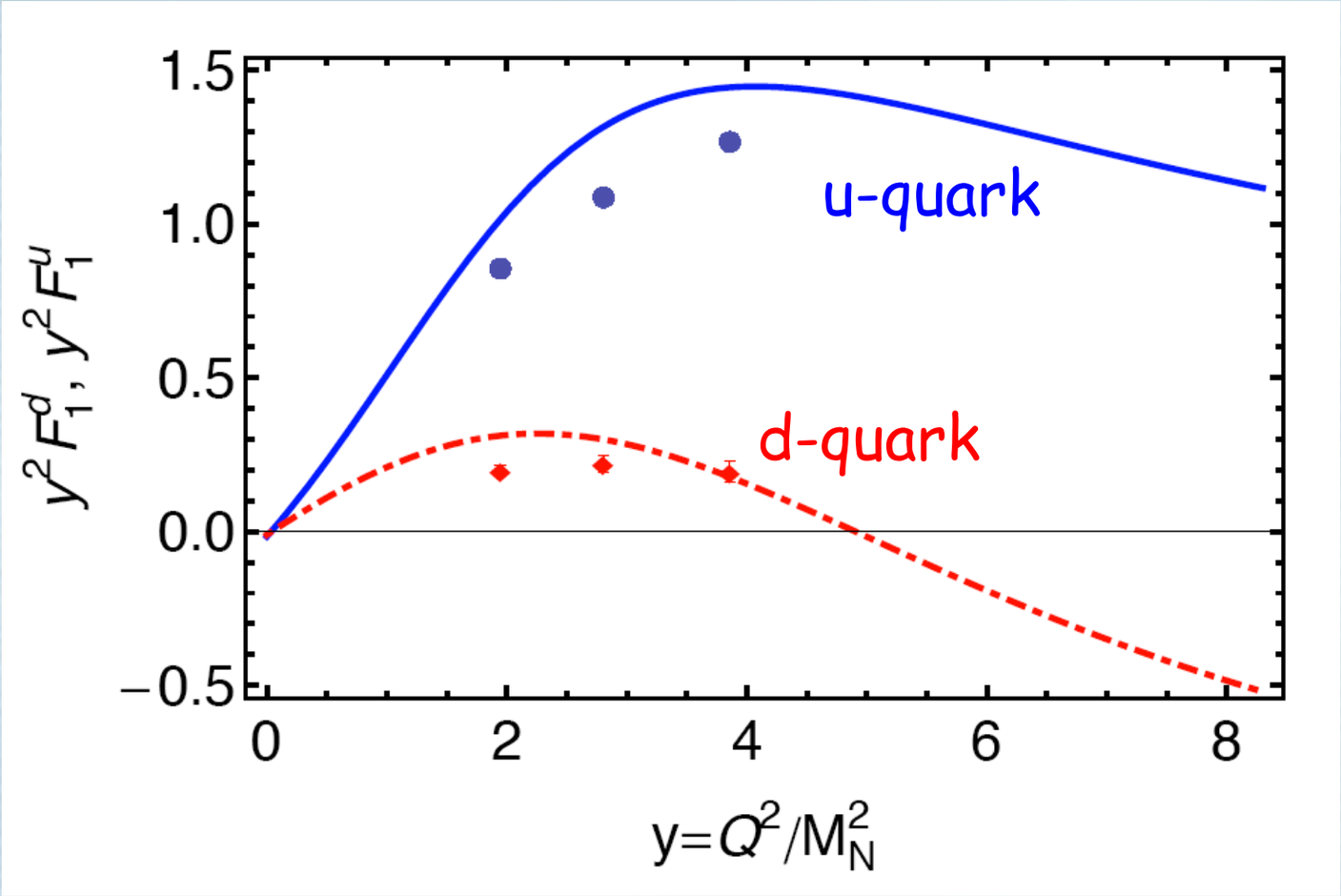




d-quark scattering amplitude is necessarily probing inside the diquark. Two gluons need to be exchanged (or the diquark would fall apart), so scaling goes like $1/Q^4$

While the above picture is over simplified, there is increasing theoretical support for the general idea being illustrated.

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

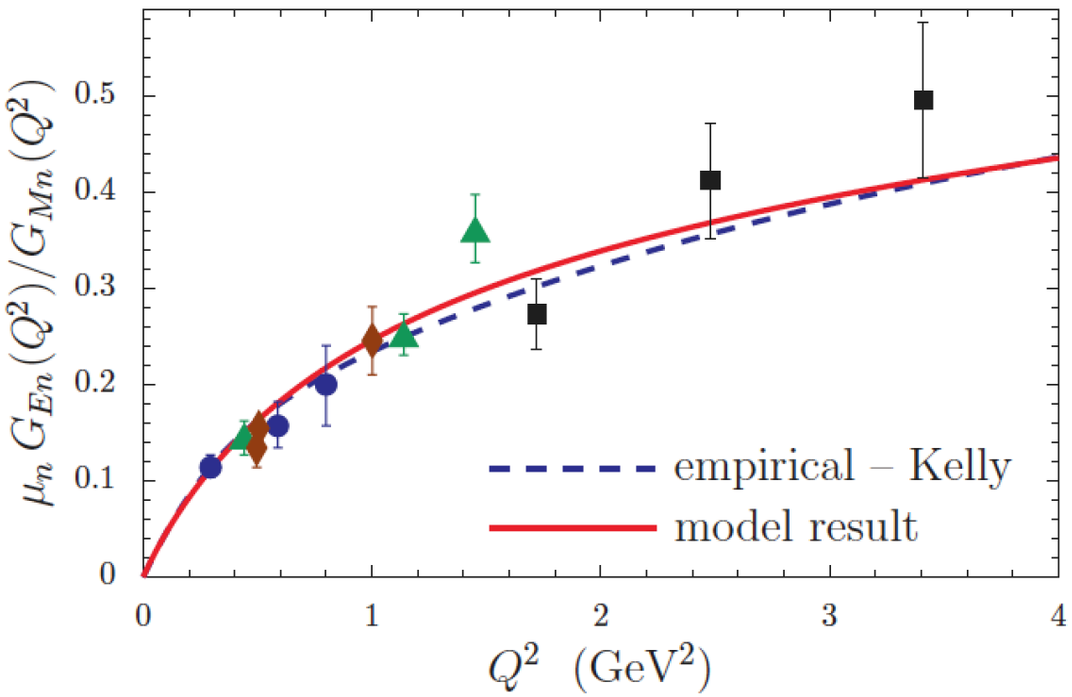


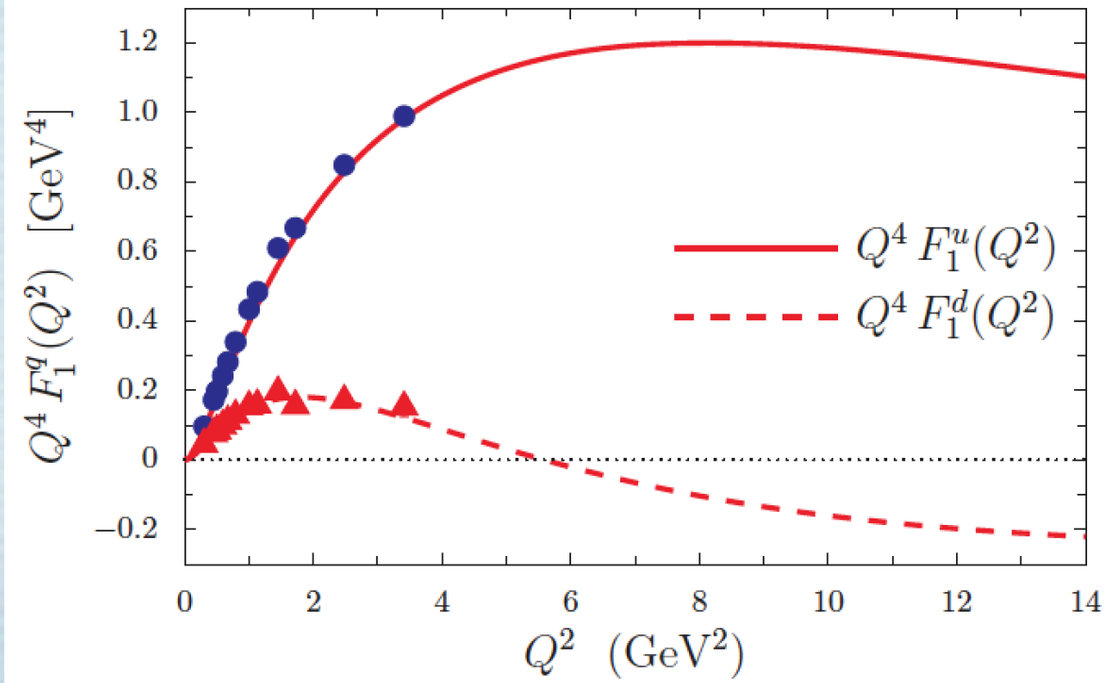
arXiv:1103.2432v1

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."

Miller/Cloet relativistic constituent quark-diquark model with pion cloud





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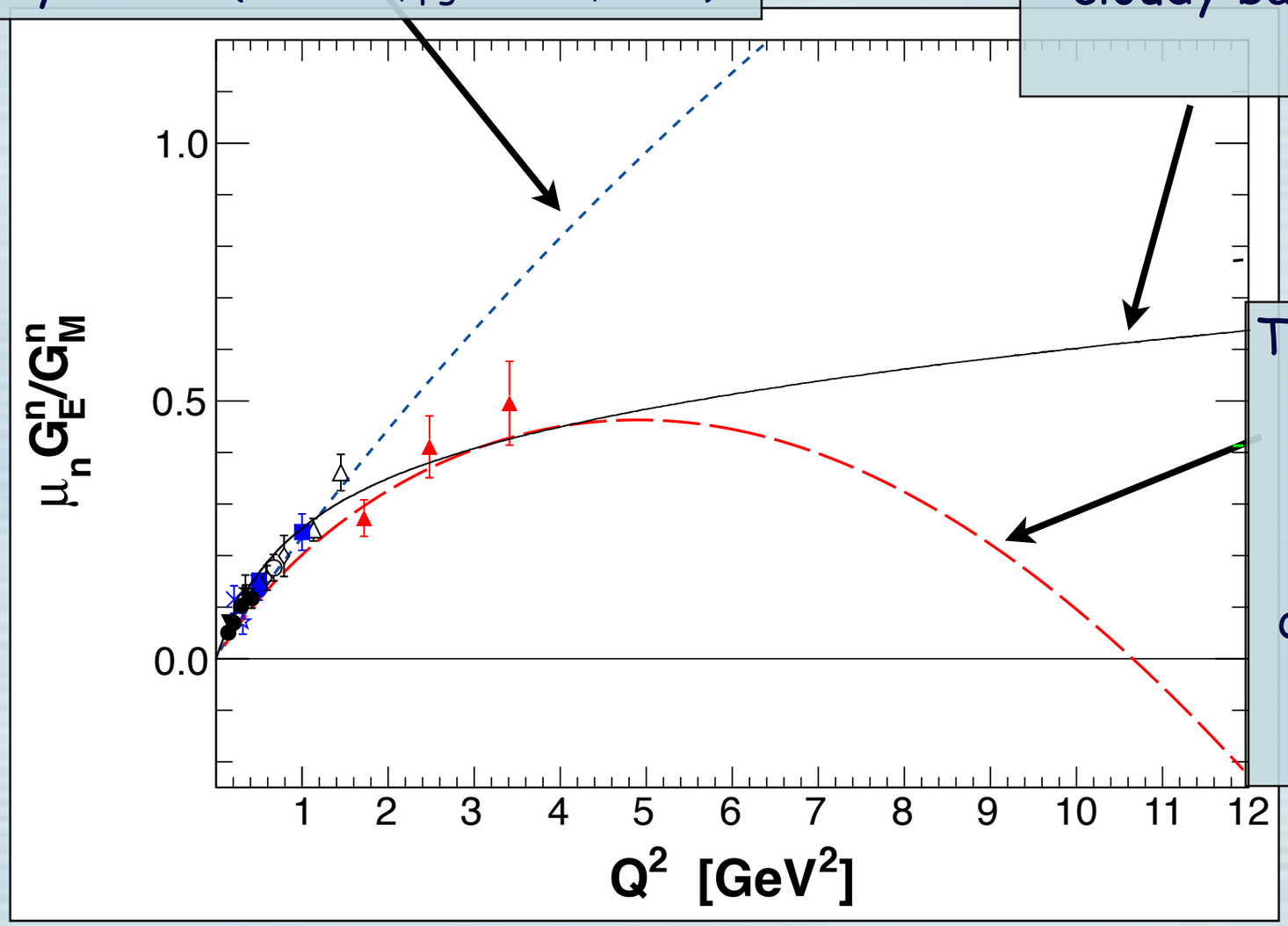
So what will the SBS polarized ^{3}He G_E^n experiment bring to this discussion

A measurement of G_E^n/G_M^n at high Q^2 provides excellent discrimination between different theoretical descriptions

Light-front cloudy bag model
Jerry Miller (PRC v66, pg032201, 2002).

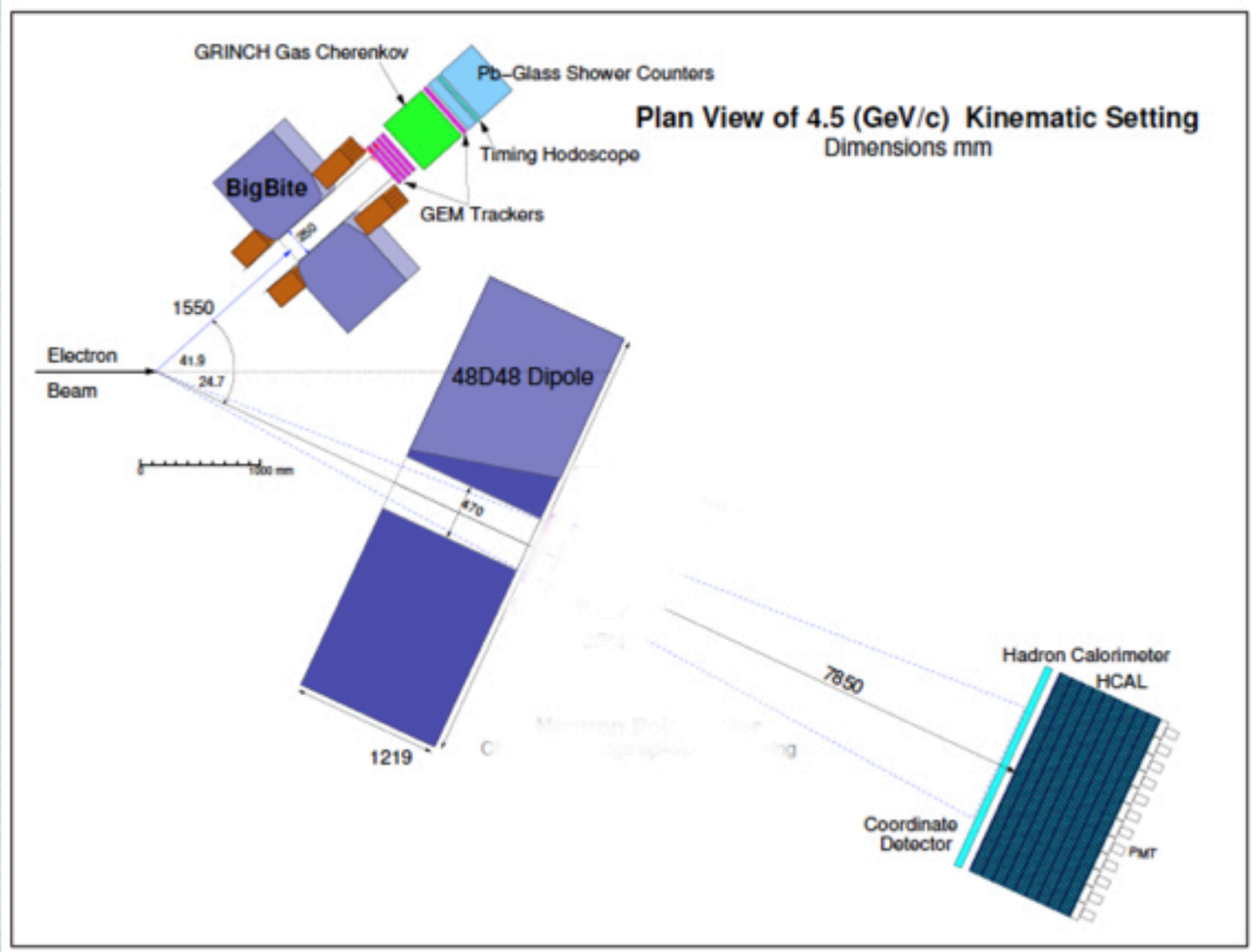
An updated quark-diquark light-front cloudy bag model by Ian Cloët and Jerry Miller.



The QCD DSE model of Cloët, Roberts et al. in which the constituent quark mass is dynamically generated and diquark degrees of freedom are incorporated.
(Few Body Systems v46, pg1 2009)

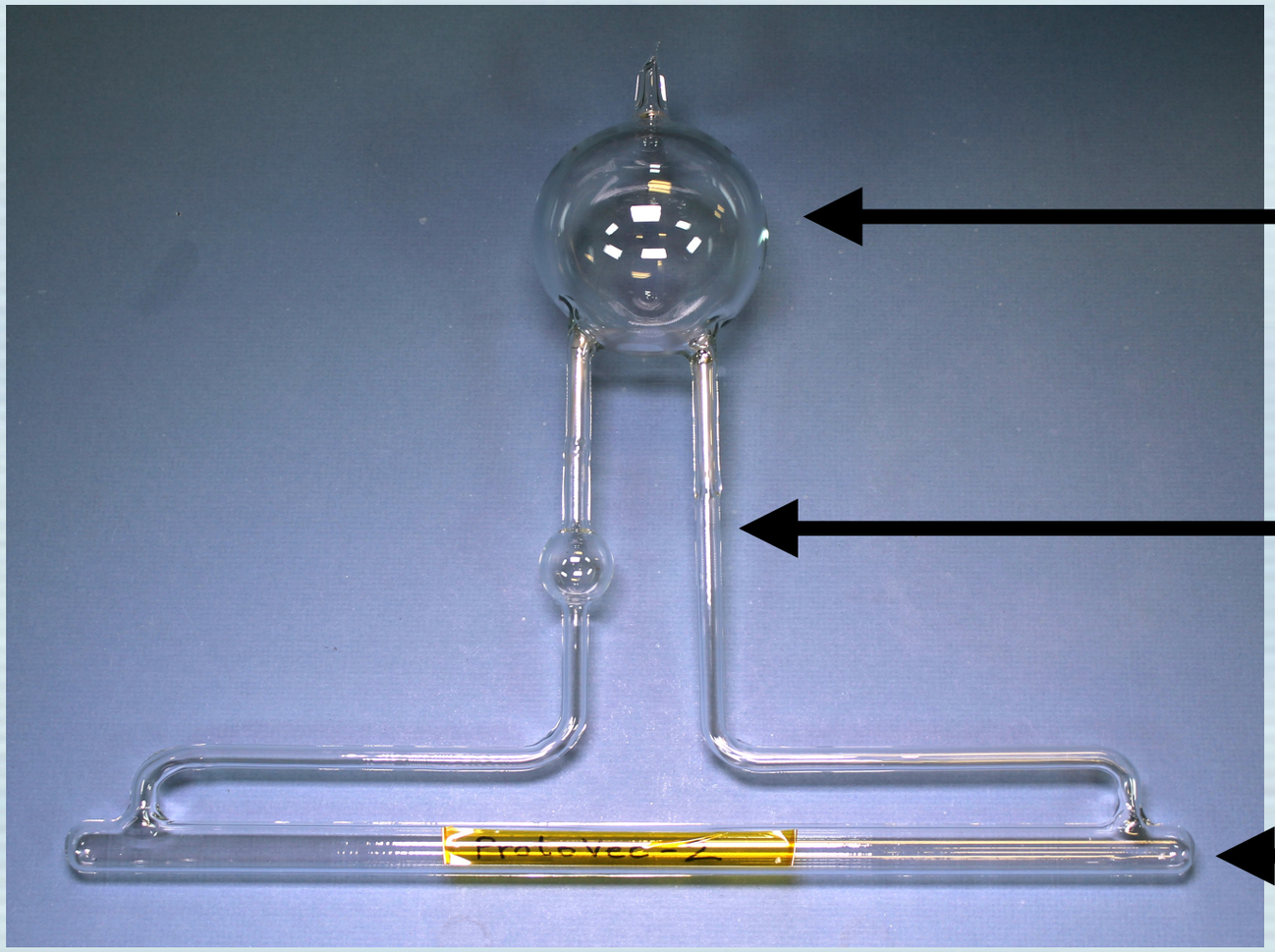
Behavior becomes unambiguously different at high Q^2. Interestingly only models incorporating diquarks agree well with the high-Q^2 data.

Experimental setup for the SBS polarized ^3He G_E^n experiment: E12-09-016



- The electron arm: Bigbite upgraded with GEMs
- The neutron arm: the SBS magnet and the hadron calorimeter
- Very-high luminosity polarized ^3He target.

On the polarized ^{3}He targets



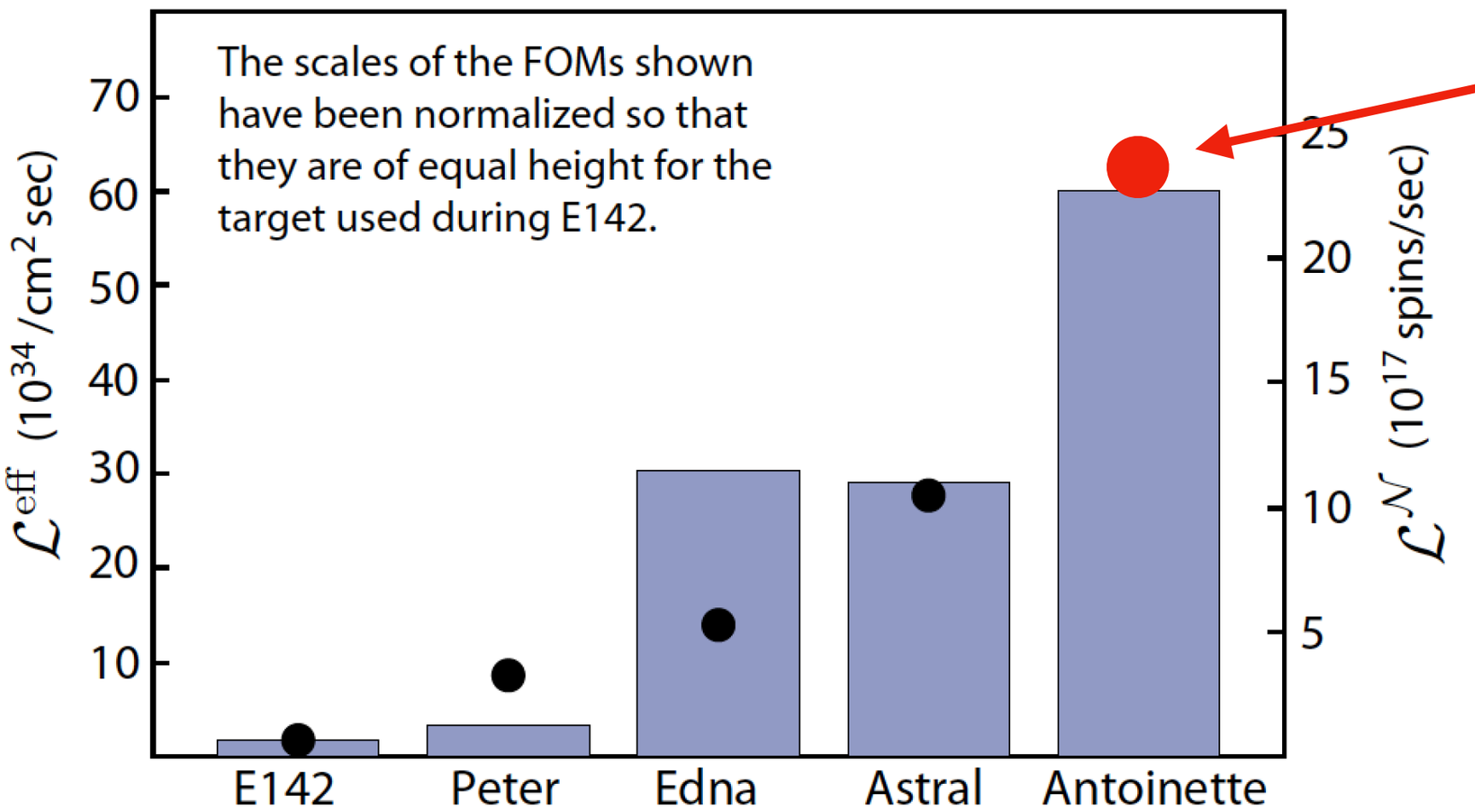
^{3}He is polarized by spin-exchange optical pumping

Gas is circulated by driving convection, easily done by preferentially heating one "transfer tube"

Beam goes through the bottom "target chamber"

Increasing capability of polarized ^{3}He targets

PHYSICAL REVIEW C **91**, 055205 (2015)

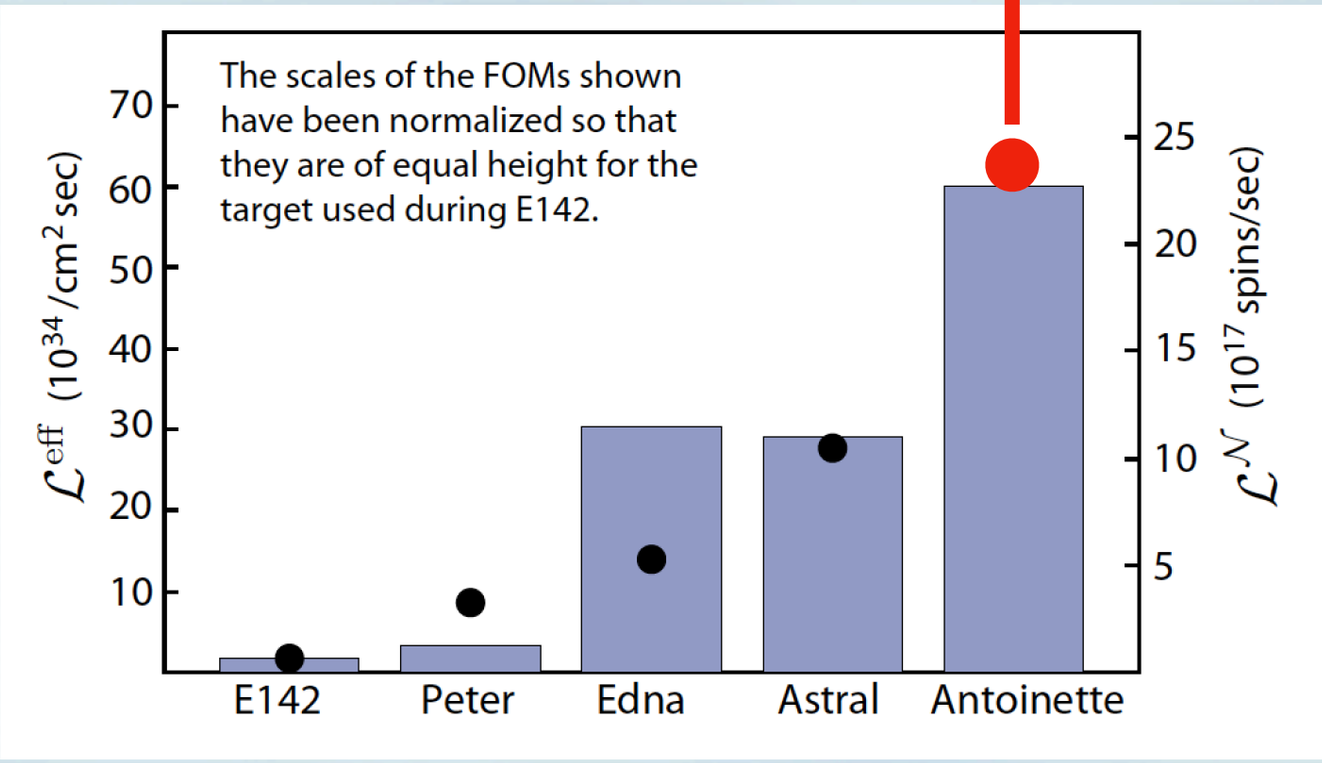


Hall C A_1^n running right now

- The blue bar labeled "Antoinette" shows the results of a bench test that served as an early proof-of-principle for the Hall C A_1^n target cells.
- The red dot, added to the figure from our paper, shows the actual in-beam performance in Hall C right now (at least on a good day!).

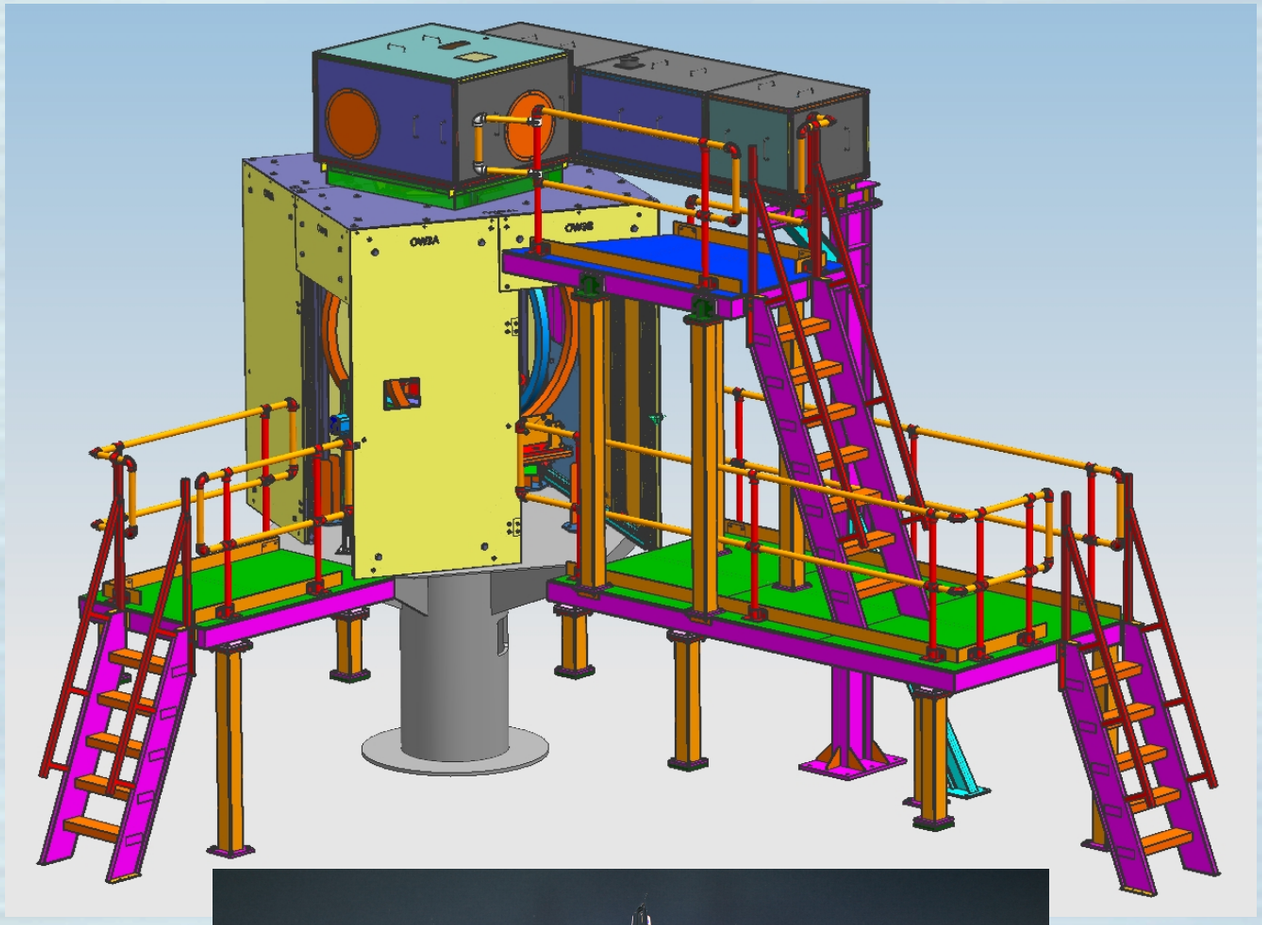
Projected performance of the SBS G_E^n polarized ^{3}He target

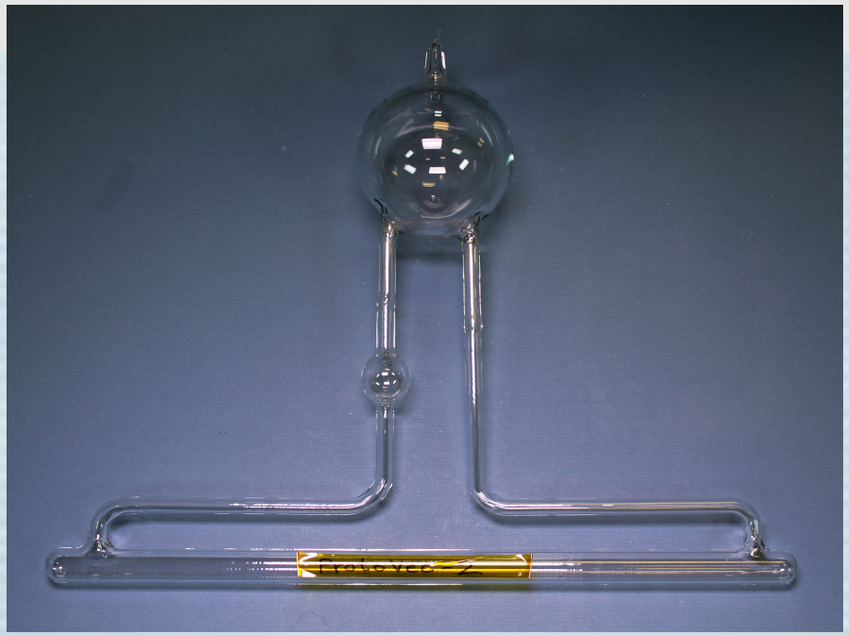
The SBS G_E^n target will have a figure of merit 2-3 times higher than the current A1n target.



- The SBS target will be twice the size with a 50% longer target length.
- The "pumping chamber" will be illuminated from two directions, which substantially improves performance

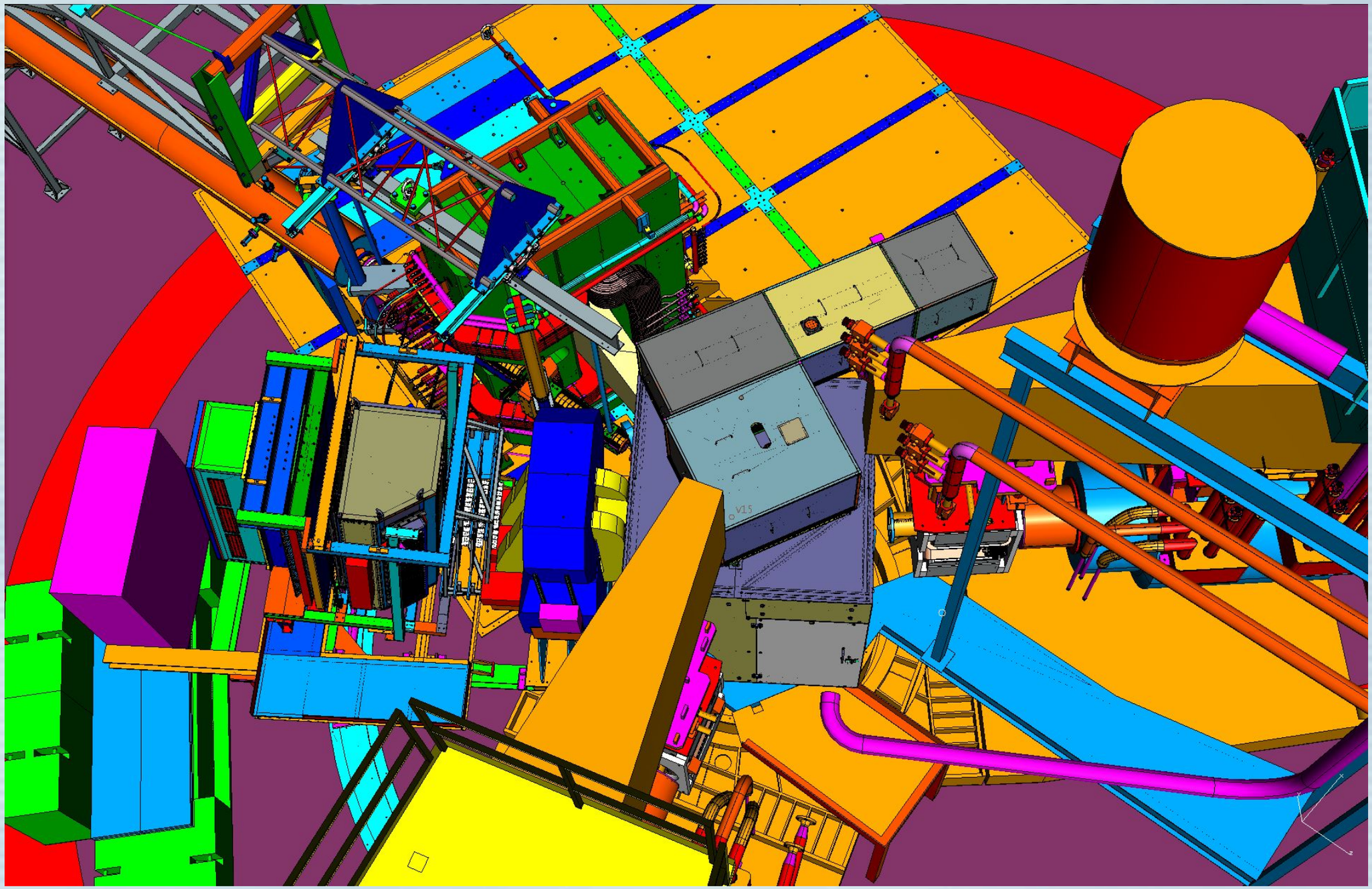
The SBS polarized ^{3}He target





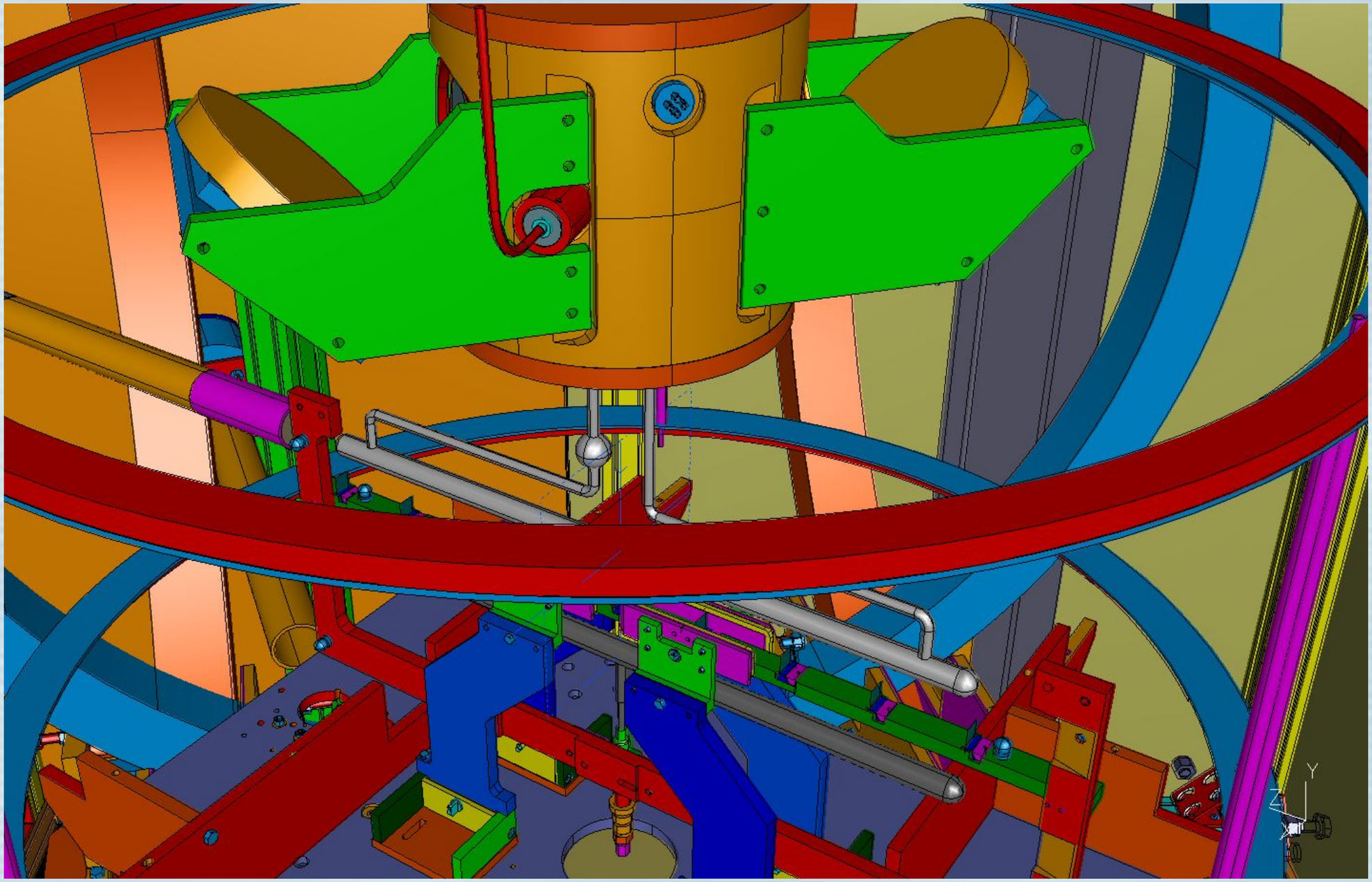
- Will have a FoM nearly 100 times higher than used at SLAC for E-142.
- Spectrally-narrowed high-power diode-laser arrays provide advantage over previous high-Q^2 polarized ^{3}He G_E^n experiment.
- Convection-driven target cells circulate polarized ^{3}He more quickly, allowing higher beam current (8uA -> 60uA) while maintaining high polarization of 60%.

Engineering model for the G_E^n setup



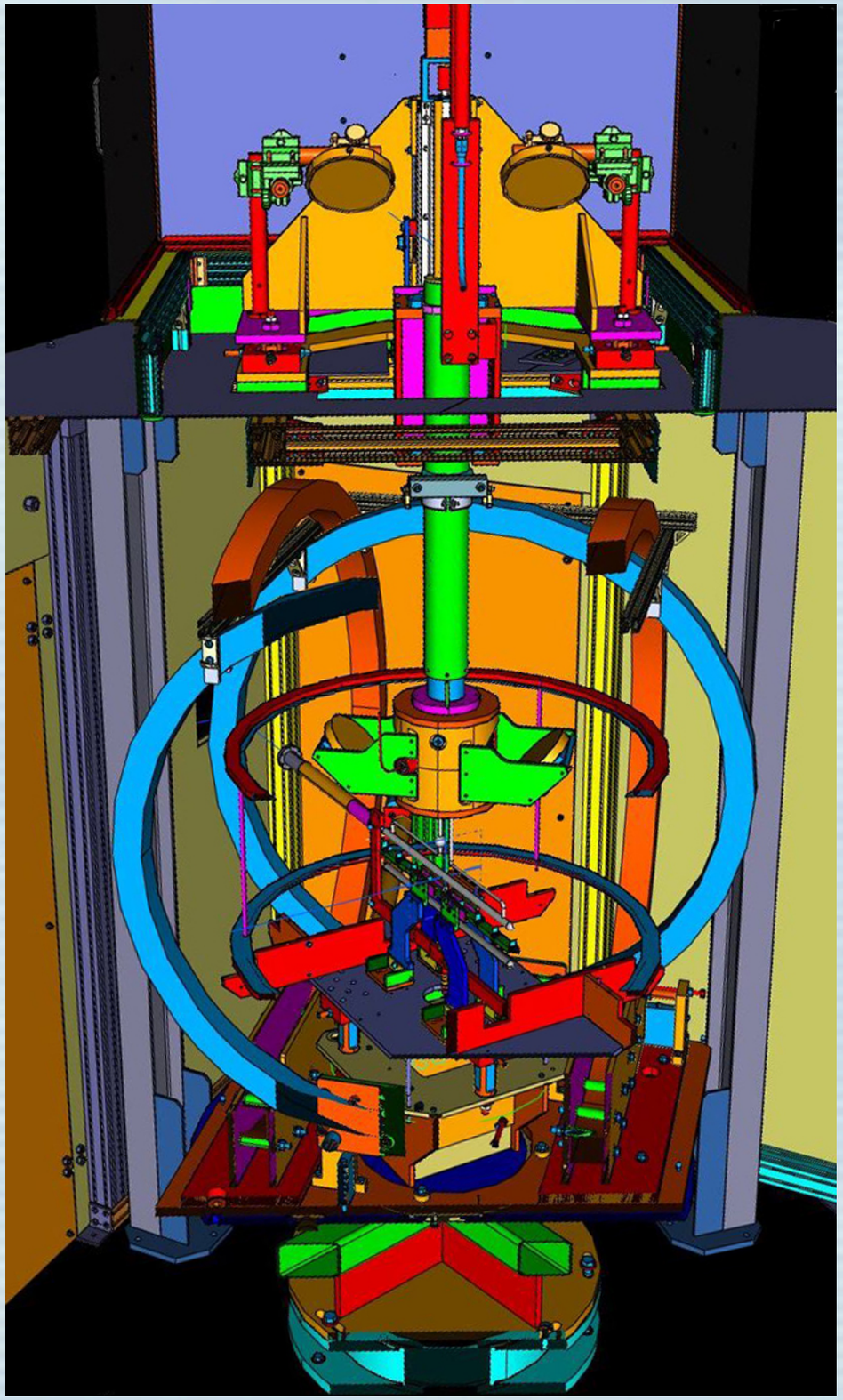
Overview of G_E^n target on the pivot.

Closeup of the the target ladder



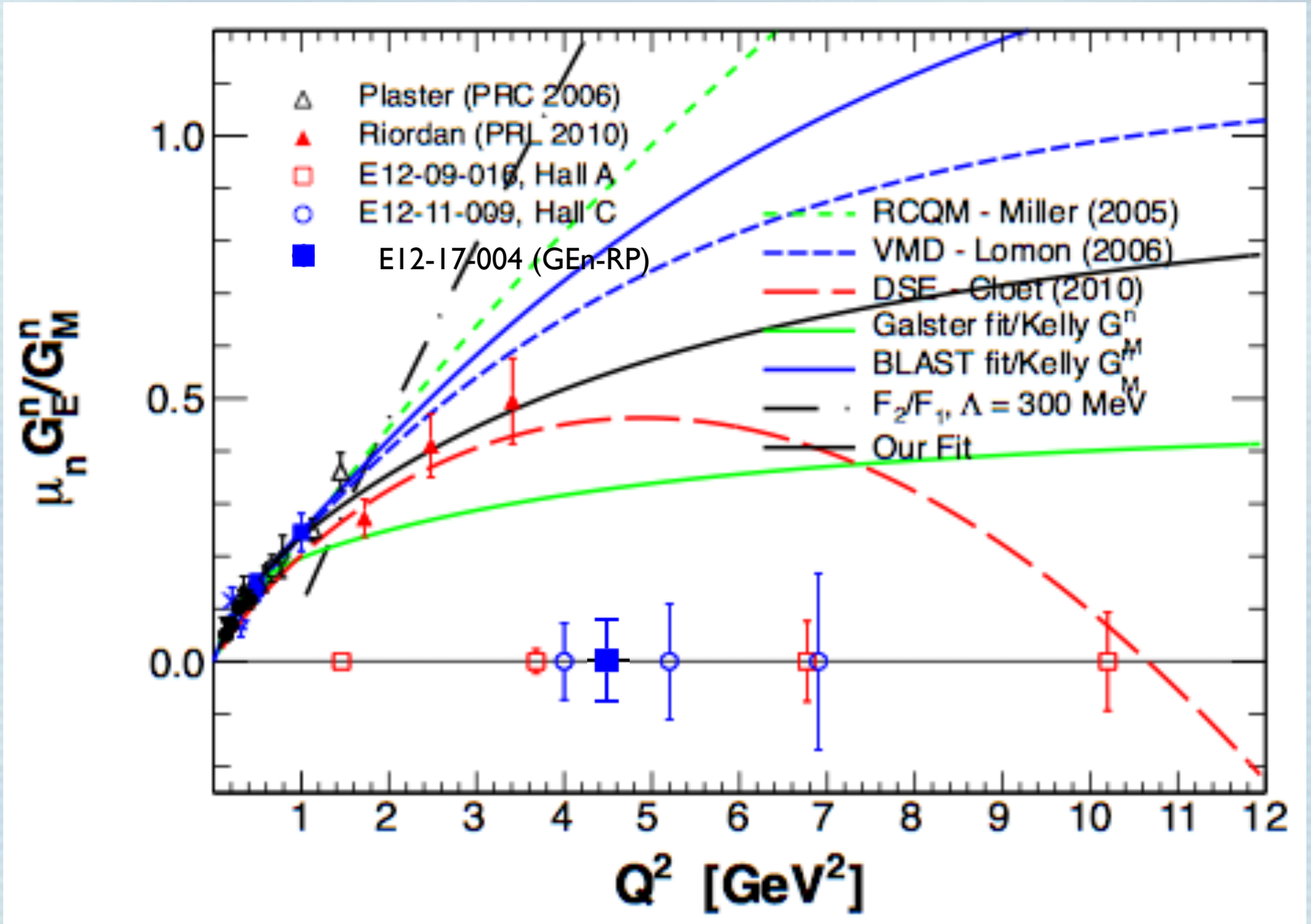
Note ability to illuminate the target from two directions

Internal view of the target

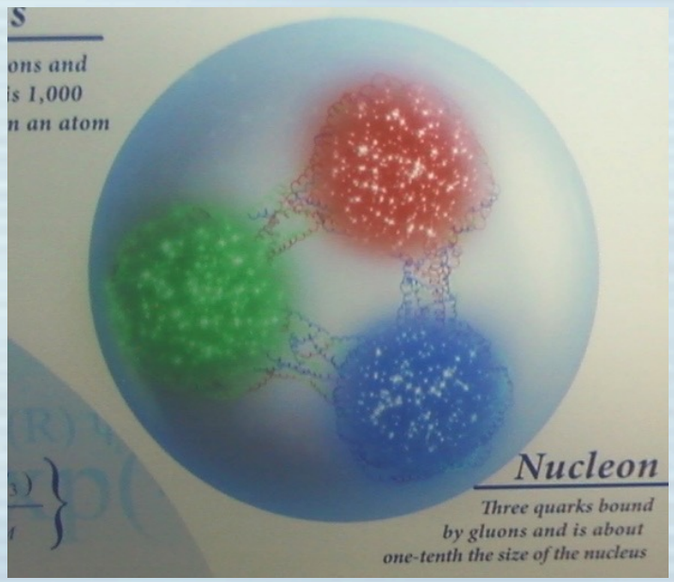


Closeup emphasizing target ladder.

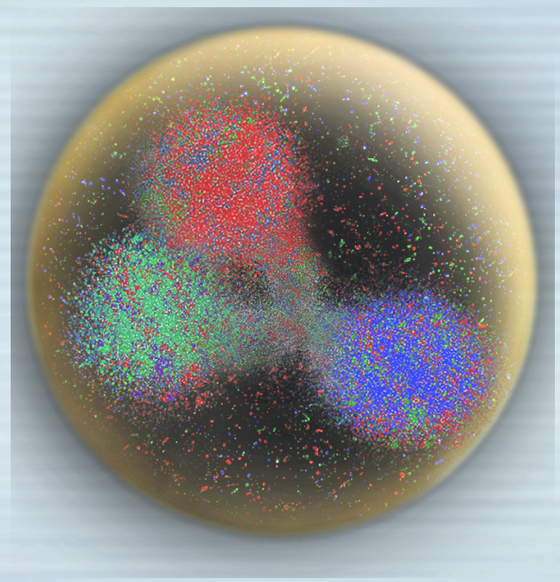
The SBS polarized-^{3}He G_E^n experiment: projected results



SBS could help shape a qualitatively different picture of nucleon structure



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

While this cartoon is WAY too simple, it illustrates how SBS might influence fundamental concepts of hadronic structure

Summary

- The SBS polarized ^{3}He G_E^n experiment will dramatically increase the Q^2 range over which G_E^n is known.
- If the dramatic predictions of certain models are verified, it could profoundly affect our view of the nucleon.
- There are great opportunities here for students and physicists at all levels, with much work to be done. Join us if you haven't already!