JLab in the 6 GeV Era

L. Cardman

JLab in (what's left of) the 6 GeV Era

L. Cardman

Outline

I. Budgets

A. The Tradeoff between Operations and the Upgrade
(and how it helped during the Long Range Plan exercise)

B. Equipment Plans

II. Getting from 5 GeV to 6.0 GeV

(and strengthening the base for the Upgrade)

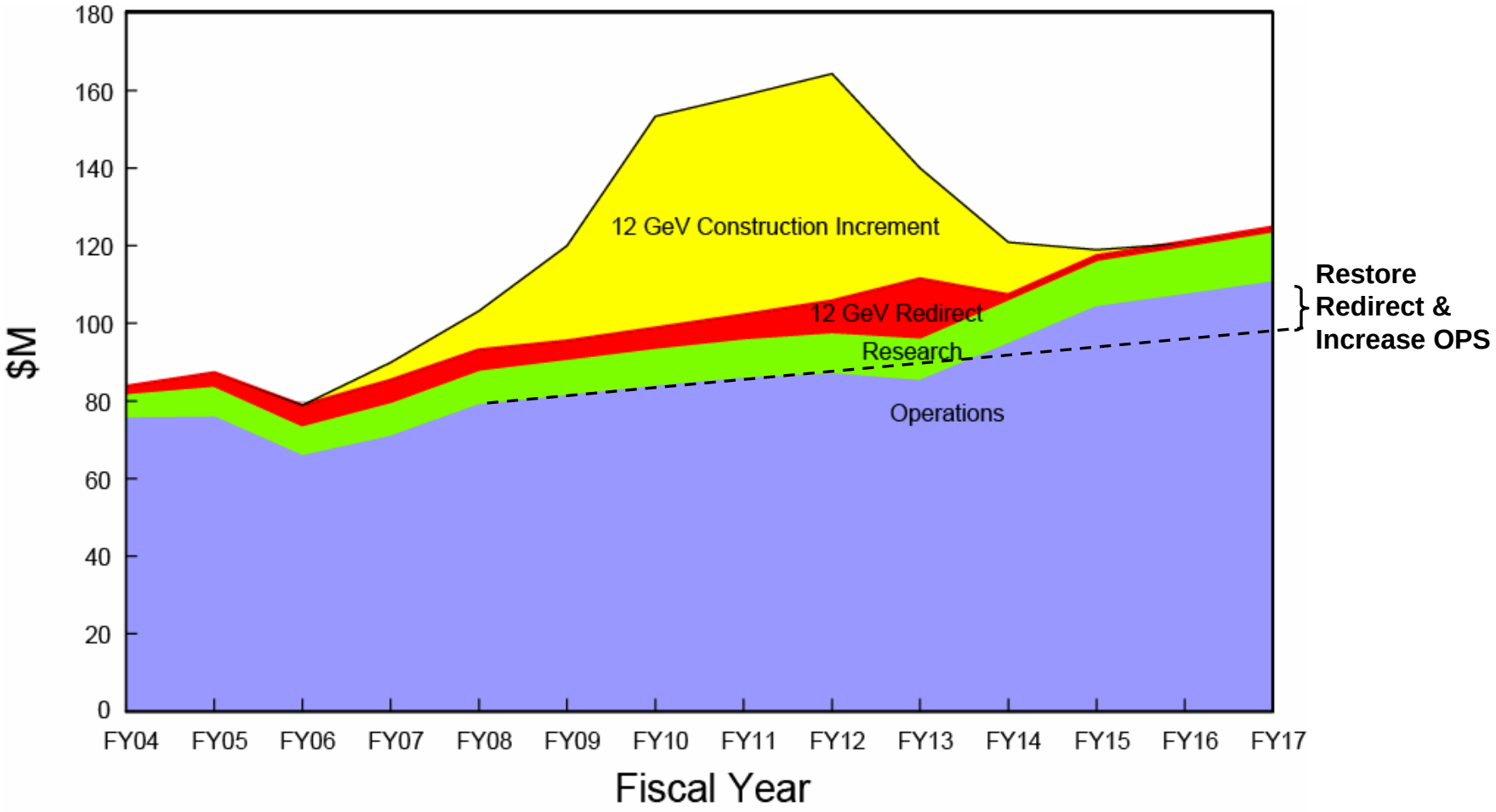
III. The PAC, Jeopardy, and Running

Now until the Upgrade Shutdown

IV. JLab Science Highlights to Come

As told at the NSAC Long Range Plan

I. JLab Budget



- Operations at ~80% of Optimum (assuming FY09 PB)
- Redirect sums to $49M of the $306M TPC of the 12 GeV Upgrade
- Working to obtain ~10% more of the TPC from non-DOE sources

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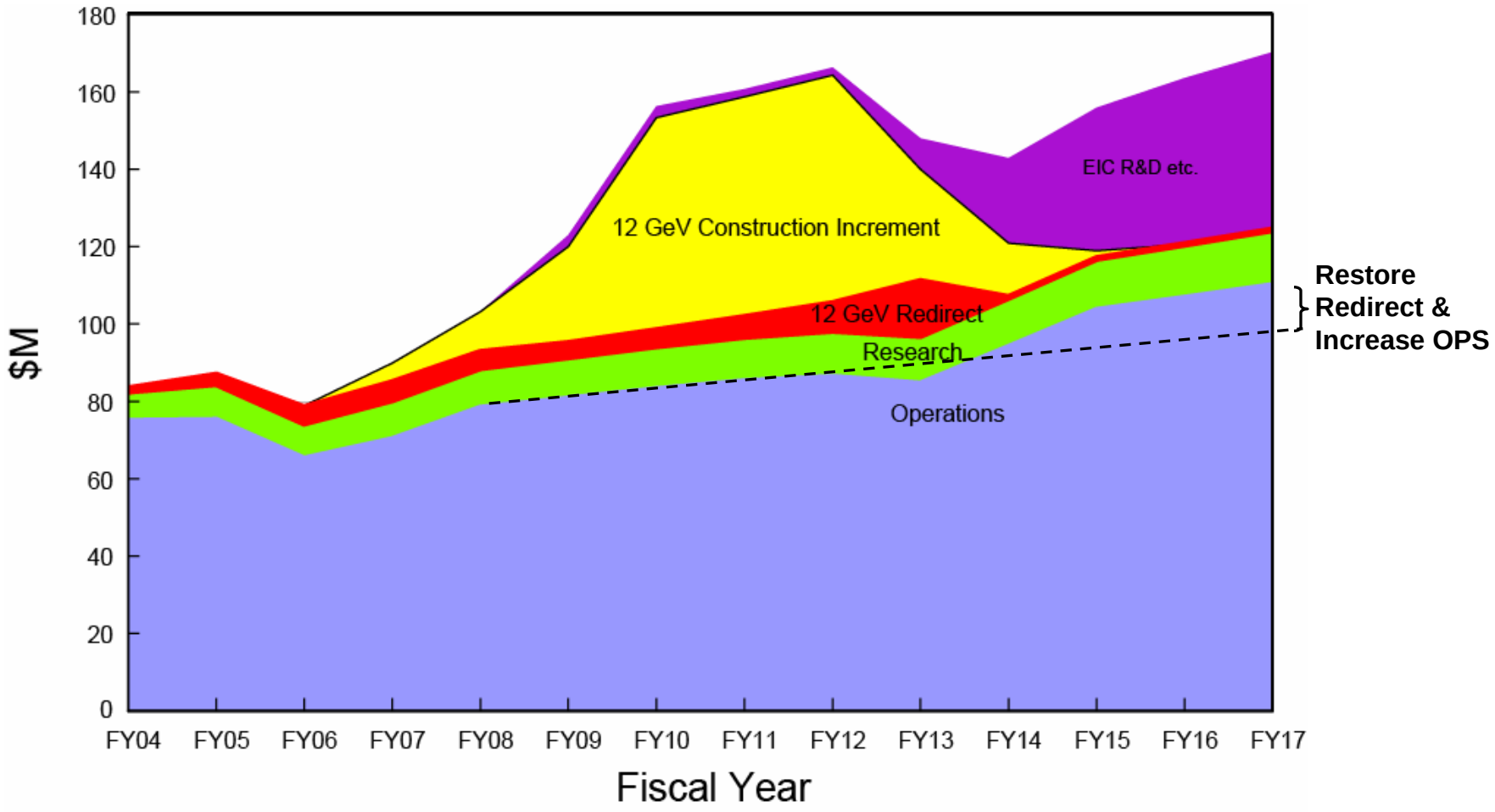

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Budget Tradeoffs

6 GeV Operations:

- Budget Profile shows tradeoff between current OPS and the Upgrade
  - FY07: 33 weeks (w/ substantial low energy, low impact running)
  - FY08 PB: 34 weeks
  - Optimum: 41 weeks
- Restoring Optimum Ops would cost ~$7M/year (and we're not likely to get it)

Major Equipment Efforts for 6 GeV Running

Operation of CEBAF and the nature of typical experiments using its beams require routine "upgrades" and new apparatus construction (funded from base budget and collaborators' resources)

- ***Most*** experiments run using CEBAF require some unique apparatus; examples underway include:
  - Q_{weak}, FROST, BNL HDIce Target, HES/HKS, G_E^p-III, ….
  - Planning includes construction of this apparatus
- Accelerator enhancement/improvement projects include:
  - "C50" Cryomodule Program
  - RF source efficiency upgrade
  - Load-lock polarized electron source, …..
- Current planning has experimental equipment construction "winding down" in the last three years of the 12 GeV project and the funds being redirected to apparatus for the Upgrade

II. Getting from 5 GeV to 6.0 GeV (The 6 GeV Energy Recovery Plan)

The 6 GeV Energy Recovery Plan Includes:

- Cryomodule refurbishment program “C50”
  - Rebuild weakest CEBAF cryomodules with state of the art processes, boost RF power in reworked zones
- Add Renascence
  - 12 GeV style module, third in the sequence.
  - Intended to contribute to 6 GeV running, demonstrate 12 GeV specifications
- 6 GeV operational support
  - Window upgrades, module maintenance
  - Performance Integration Team.

Cryomodule Refurbishment Program

What is it?

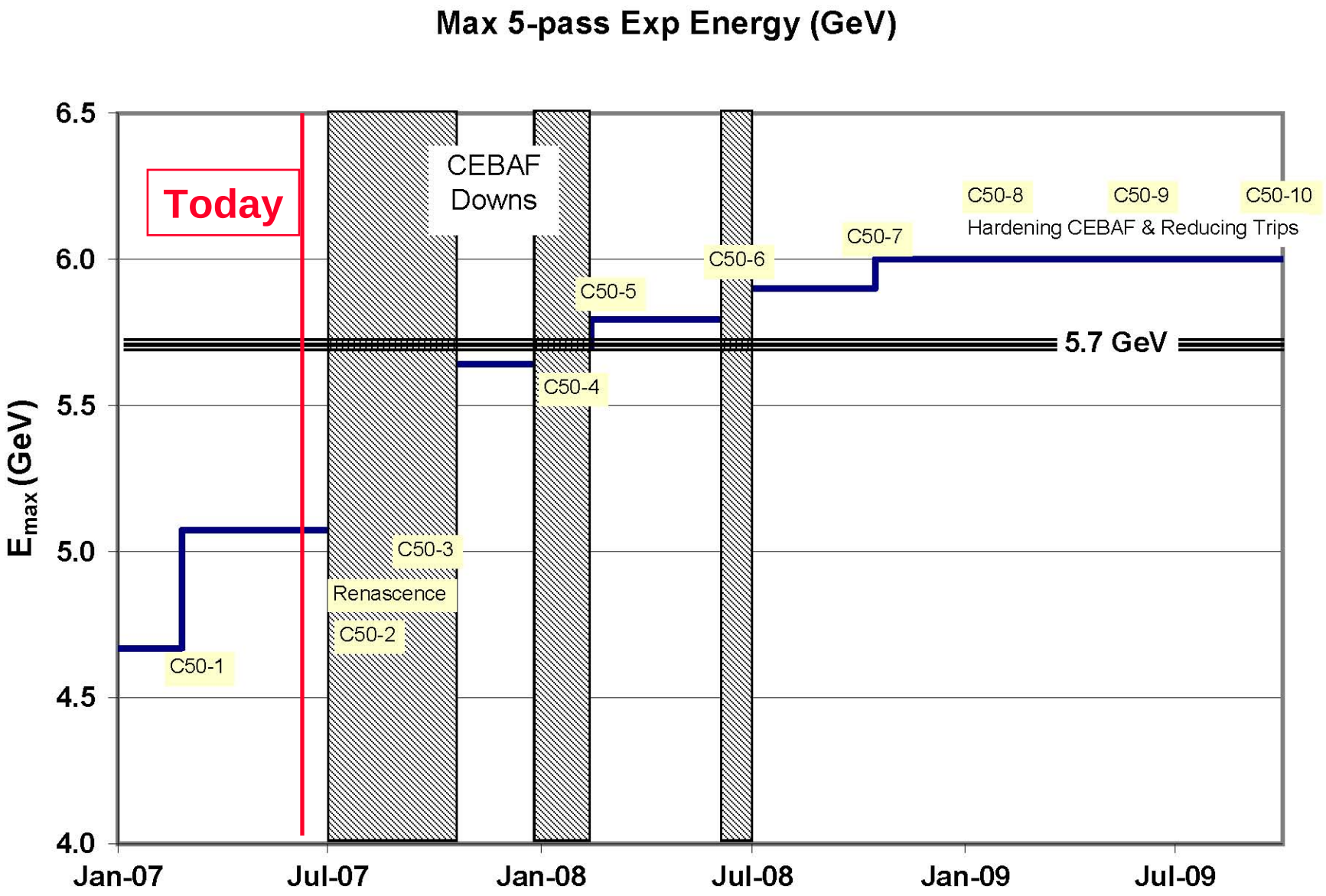
- Full rebuild of existing modules to 50 MV (12.5 MV/m).
- Goal is to achieve high energy (5.75 GeV) running beginning March 2008.
- Rework will continue until 12 GeV project starts to provide a solid 6 GeV base.
- Minimal changes only:
  process cavity, rf doglegs to eliminate trips, worn parts replaced.

Cryomodule

Cryounit

Cavity pair (with doglegs)

6 GeV Energy Recovery Plan



6 GeV Energy Recovery Plan

- **How are we doing?**
  - C50-1 is operational, shows full expected performance - *without trips*
  - Renascence and C50-2 are on track for July installation, C50-3 in October
  - The pipeline is loaded and moving
- **Planning for 5.75 GeV operation after the Jan-Feb 2008 down**
- **We are taking all possible care to protect existing modules,**
  - Minimizing thermal cycles
  - Cold gas purge allows module swaps without thermal cycling.
- **CASA investigated running with unbalanced linac energies**
  - ***Studies indicate it should work***, giving us more “breathing room” for meeting our energy goals

III. The PAC, Jeopardy, and Running

Broad Goals:

- Identify the best physics possible to be completed in what's left of the 6 GeV era while:
  - Keeping faith on major commitments to the User Community
  - Maintaining as much flexibility as possible to accommodate the best new ideas
- Prepare to launch 12 GeV running with the best physics possible by:
  - Identifying the best experiment proposals to be done
  - Securing user commitments to the construction project
  - Maintaining flexibility to identify and respond to new developments between now and the start of 12 GeV running

6 GeV to 12 GeV Transition

Planned Approach:

- **Alternate 6 and 12 GeV PACs (until ~3 years before Upgrade shutdown, then just 12 GeV)**
- **Focus of 6 GeV PACs will include:**
  - Review of new proposals
  - Jeopardy review of approved experiments (until ~3 years before 12 GeV Upgrade Shutdown)
  - Annual Review of multi-year plan for completion of the 6 GeV program
- **After CD-2 and the release of FY08/09 budget information:**
  - We will develop a multi-year plan for the remainder of 6 GeV running and present it to the PAC for comment
  - We will review this plan annually until ~3 years before Shutdown, when it will become final

6 GeV PAC Allocations

- **A key goal is to avoid over-commitment for the remainder of the 6 GeV era**
- **For the first such 6 GeV PAC (PAC31):**
  - Each hall was given its nominal allocation based on “routine” running levels, backlog, and jeopardy review cases
  - However, since there is only one “6 GeV PAC/year, this corresponds to half the annual allocation of the past
- **For future 6 GeV PACs (PAC33, 35, …), we will review situation and adjust allocations:**
  - Next Spring, after the FY08 budget allocation is known and the FY09 President’s budget has been presented
  - Annually thereafter

6 GeV to 12 GeV Transition (cont.)

Planned Approach:

- **12 GeV PACs for the next few years will:**
  - Identify physics "appropriate for the first 5 years of 12 GeV Operations"
  - Initially consider only proposals associated with User commitments to the Upgrade Construction (PAC30 and PAC32)
  - Consider proposals that include non-base equipment at later PACs
- **~4 years before the start of 12 GeV running the PAC will assign Scientific Ratings to all approved proposals**
- **~3 years before the start of 12 GeV operation hall-by-hall:**
  - Each hall will provide for PAC review and comment (and potential improvement) a "commissioning and early running" plan
  - It will represent the collaboration's tradeoff between the best possible science and the realities of commissioning equipment
  - 3 years after the start of physics in each hall, jeopardy will begin

IV: JLab Science Highlights to Come (as told at the NSAC Long Range Plan)

Plans for the 6 GeV Program Over the Next 5 Years

- **Completion of data-taking for milestone-related physics**
  - Baryon spectroscopy (frozen spin target data)
  - DVCS (CLAS Phase II and Hall A separation of BH×DVCS and $DVCS^2$)
  - Structure function moments (σ_L/σ_T on D, SANE, d_2^n)
  - …..
- **Important new data on:**
  - Nucleon EM form factors (G_E^p to higher Q^2; G_E^n just completed)
  - Strange quark distributions (HAPPEx III and G0)
  - Hypernuclear spectroscopy (HKS)
  - Correlations (Coulomb Sum Rule)
  - Dispersive effects in electron scattering [(e^+,e^+), Rosenbluth tests , pol. Transfer tests]
  - …..
- **Unique new experimental directions:**
  - PREx (rms radius of neutron dist. for nuclear structure, astrophysics, and atomic PV Standard Model tests)
  - Q_{Weak} (Weak charge of the proton for a Standard Model Test)
- **Measurements in new areas of research that will be a focus of science with the 12 GeV Upgrade, such as:**
  - Single spin asymmetries
  - DVCS w/ Longitudinally polarized target
  - Hadronization

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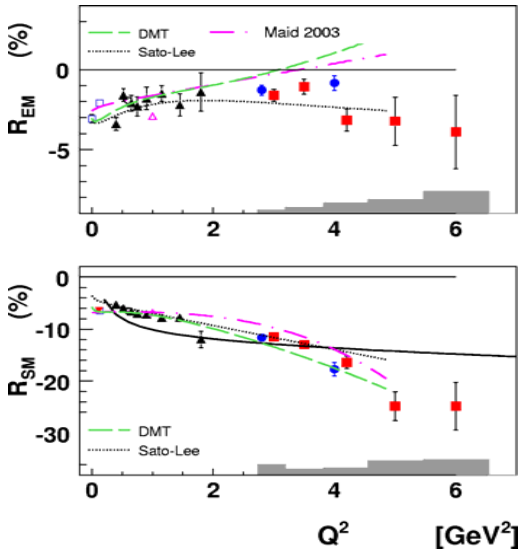
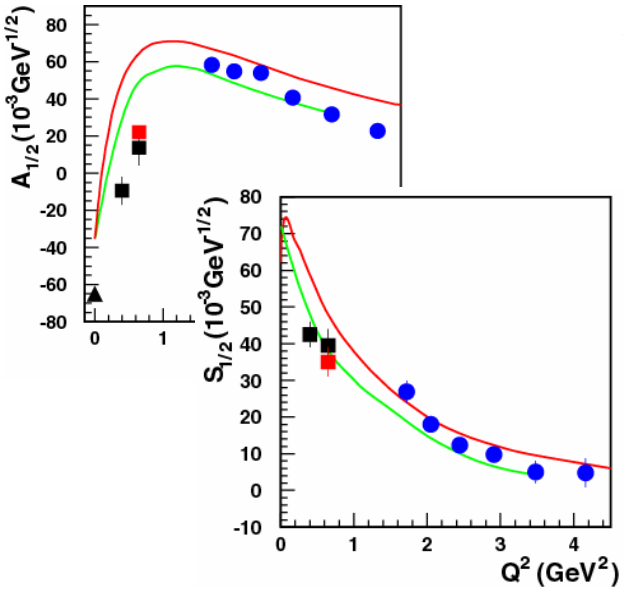
Substantial Progress on the Extraction of the Nucleon's Transition Form Factors

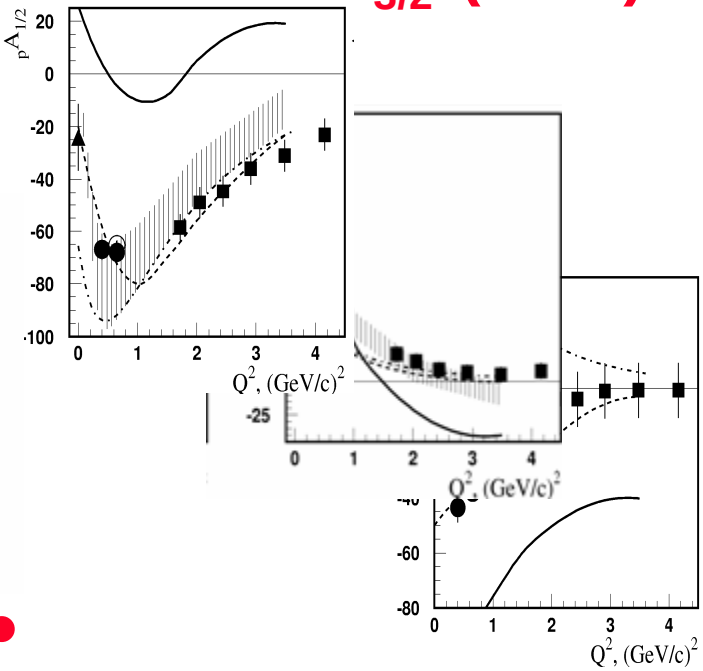
NΔ



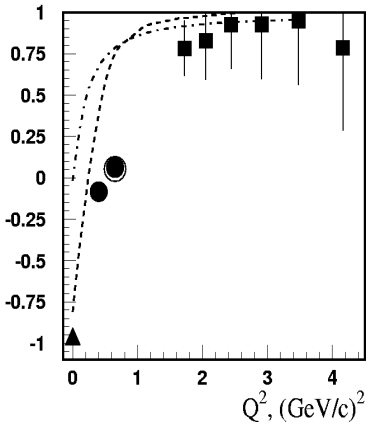
Roper $P_{11}(1440)$



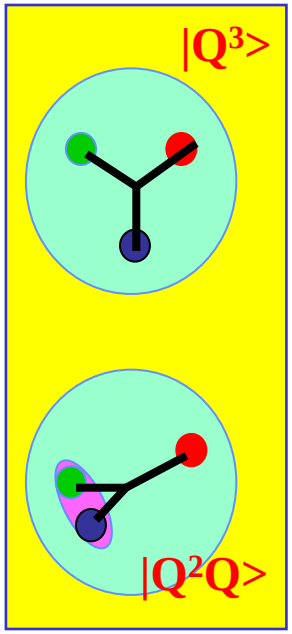
$N_{3/2^-}(1520)$



$D_{13}(1520)$, and more to come ● ● ● ● ●



These data are revealing the importance of the pion cloud and the character of the transitions while providing a formidable testing ground for theories of the nucleon



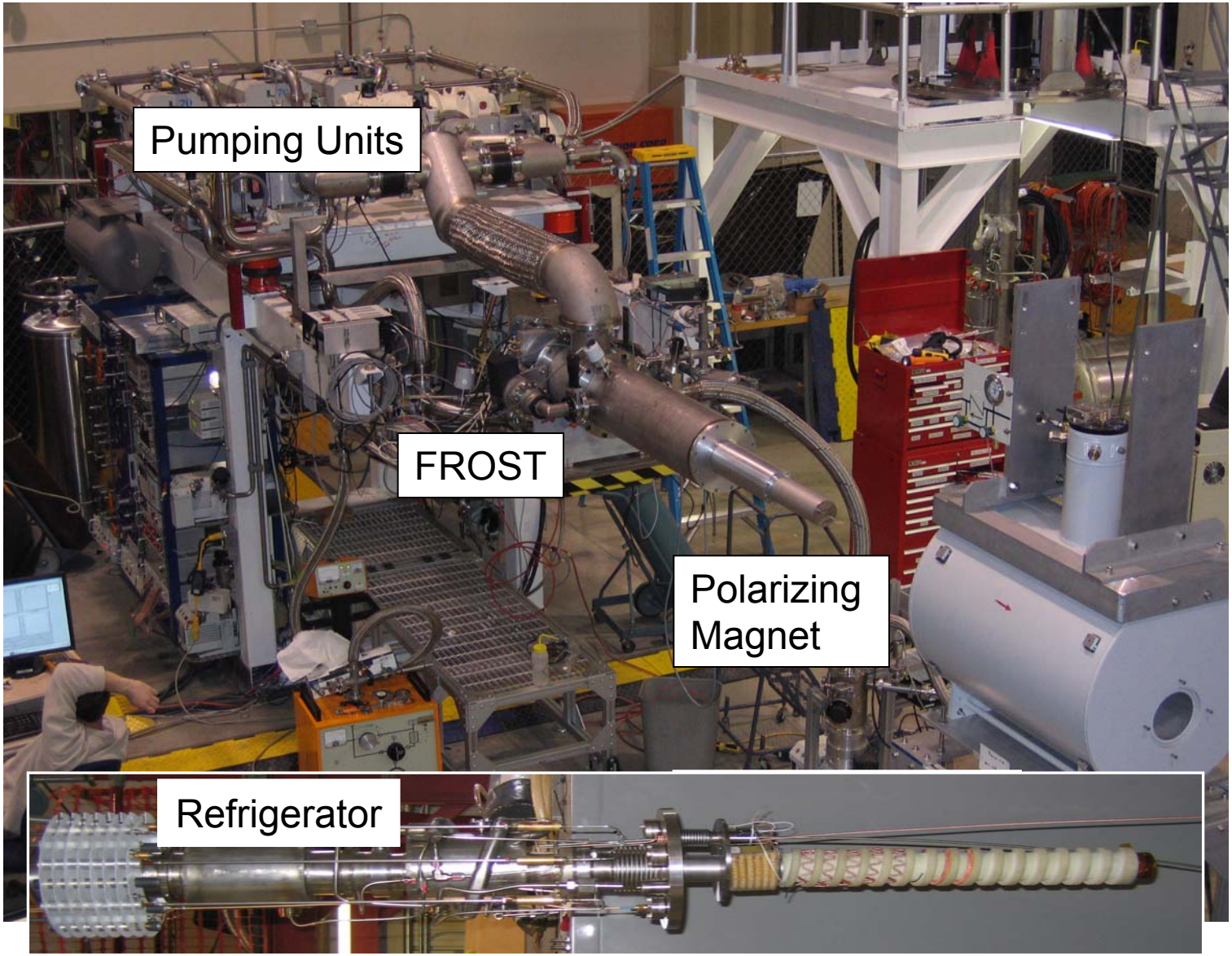
Substantial Progress on N* Analysis

Nucleon Excited States Identified Tentatively
By the CLAS N* analysis effort

- Analyses so far used unpolarized cross section data and hyperon recoil polarization.
- FROST program will have much more sensitivity to new states via polarized photons and a polarized target; it will run in FY07/08

State N/Δ J^P	Mass (MeV)	Channel	VB Rating (Max *****)	Quark Model state?
$N/\Delta 3/2^+$	1720 ± 20	$p\pi^+\pi^-$	***	Not in $\|Q^3\rangle$, but in Large N_c spectroscopy
$N3/2^-$	1840-1900 1900-1950	$K\Lambda$, $K\Sigma$ $K\Lambda$, $K\Sigma$	** **	In $\|Q^3\rangle$ model, not in $\|Q^2Q\rangle$ In $\|Q^3\rangle$ at higher mass
$N1/2^-$, $N1/2^+$, $N3/2^-$	~2100	$p\eta$	*, *, **	In $\|Q^3\rangle$ at similar mass

FROST Has Reached Its Design Temperature and Will Be Ready For Installation This Summer



HD ICE at JLab

E06–101 (A rated, 85 d): $\vec{\gamma} + H\vec{D} \rightarrow K^0\vec{\Lambda}, K^0\vec{\Sigma} \Rightarrow \gamma n \rightarrow K^0\Lambda, K^0\Sigma$

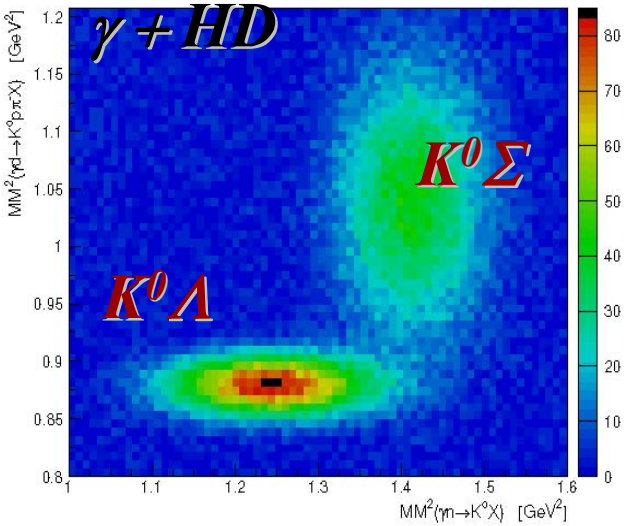
$\Rightarrow \sigma, \Sigma, E, G, P, T, C_x, C_z, O_x, O_z, L_x, L_z, T_x, T_z$

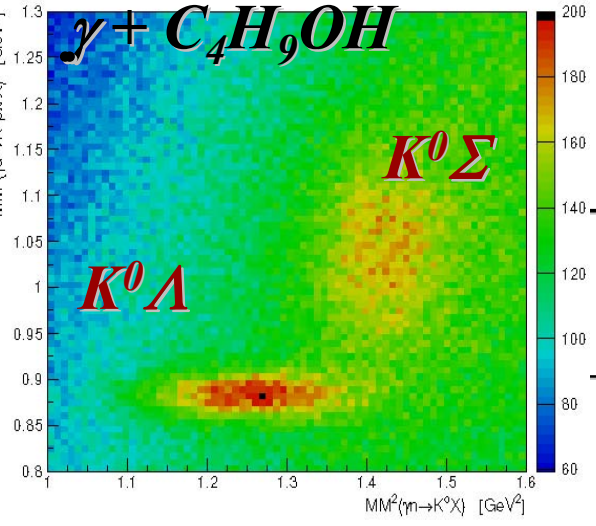
$(\sigma + 13$ spin-asymmetries$)$

an (over-) complete, model-independent set $\Leftrightarrow$ *a 1st in 50 years*

$\rightarrow K^0\Lambda,\ K^0\Sigma$

75 days





$\rightarrow K^0\Lambda,\ K^0\Sigma$

3130 days

$\rightarrow K^0\Lambda$ *only*

1150 days

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Nucleon and Pion Form Factors

- The spatial distribution of charge and magnetization provide a key testing ground for theories constructing nucleons from quarks and gluons.
- Experimental insights into nucleon structure from the flavor decomposition of the nucleon form factors

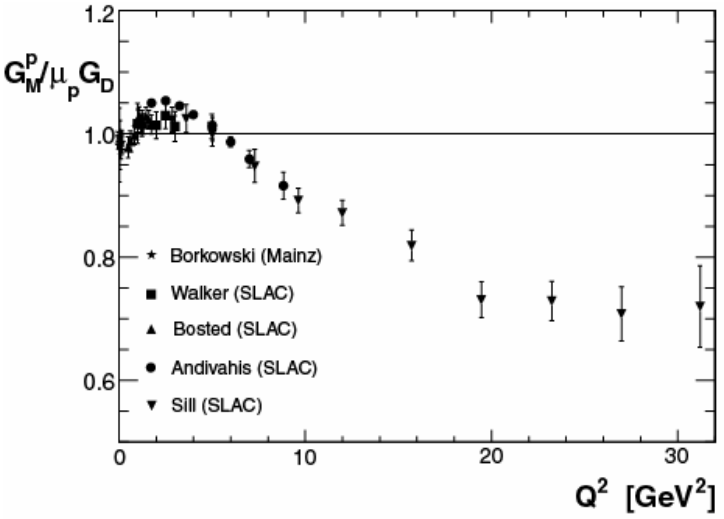
PRECISION

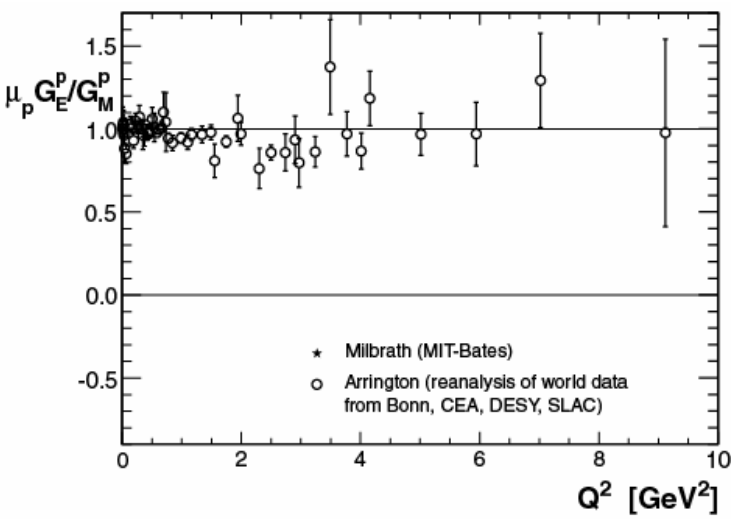
$$\left.\begin{matrix} G_E^p & G_E^n & G_E^{p,Z} \\ G_M^p & G_M^n & G_M^{p,Z} \end{matrix}\right\} \Rightarrow \begin{matrix} G_E^u & G_E^d & G_E^s \\ G_M^u & G_M^d & G_M^s \end{matrix}$$

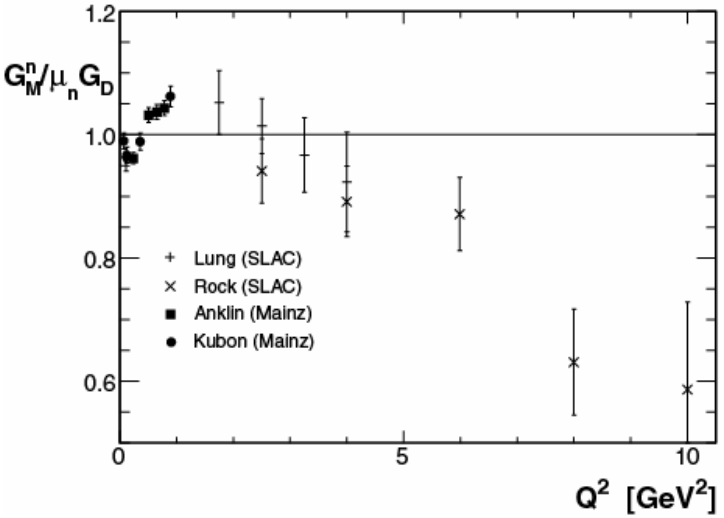
- Fundamental ingredients in “Classical” nuclear theory
- Additional insights from the measurement of the form factors of nucleons embedded in the nuclear medium
  - implications for binding, equation of state, EMC…
  - precursor to QGP

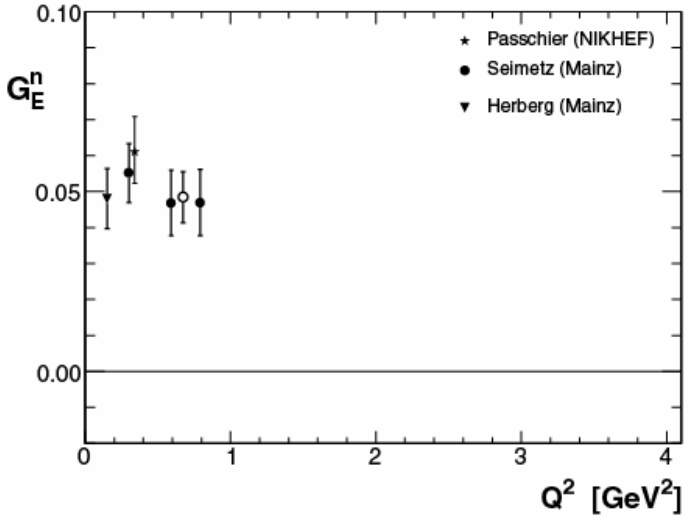
JLab data on the EM form factors provide a testing ground for theories constructing nucleons from quarks and glue

Before JLab and Recent non-JLab Data



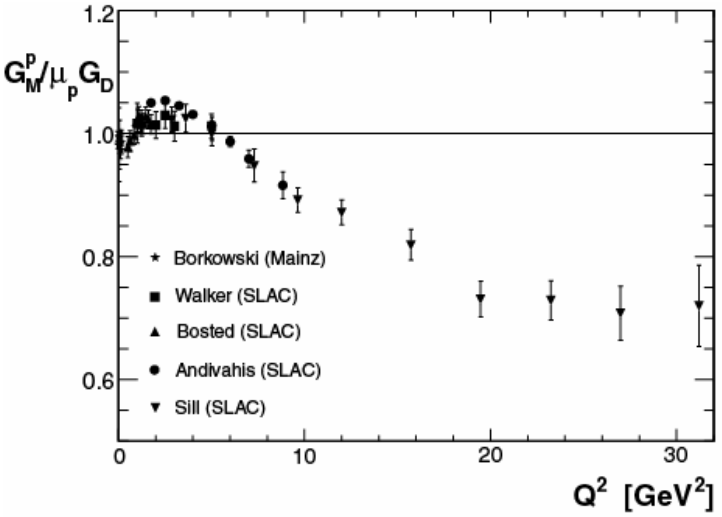


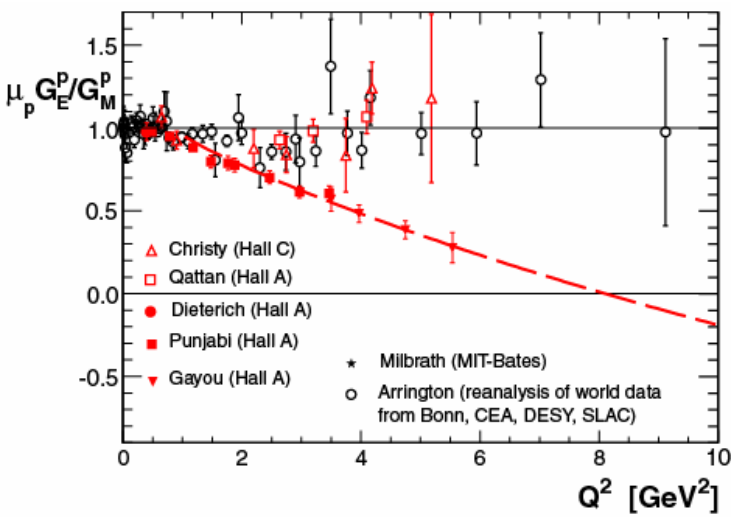


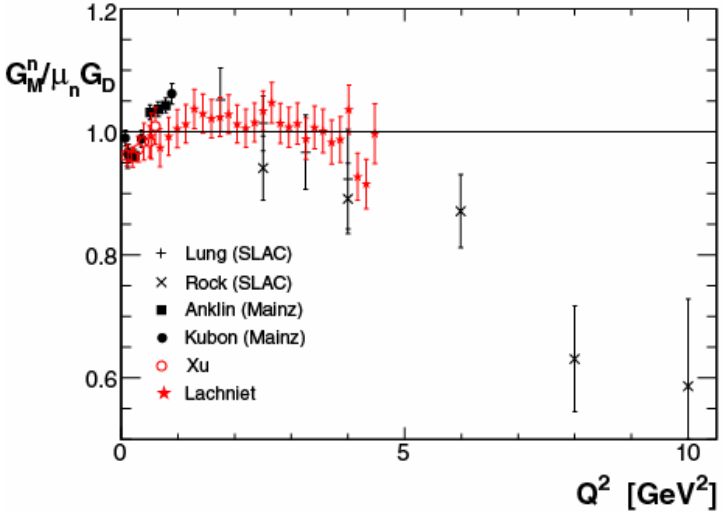


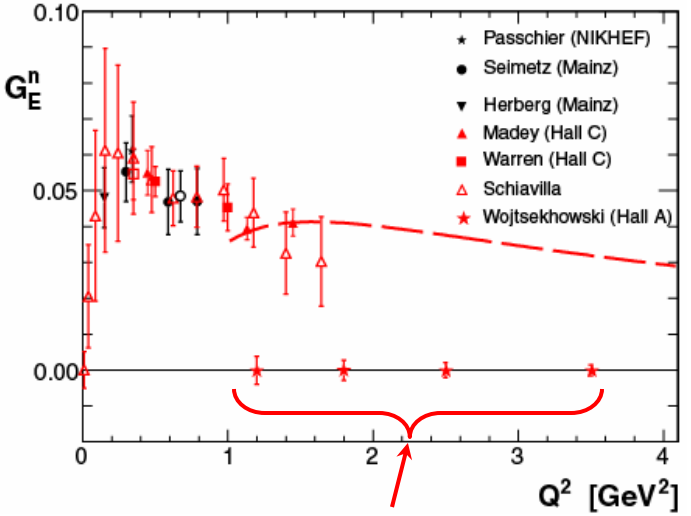
JLab data on the EM form factors provide a testing ground for theories constructing nucleons from quarks and glue

Today, with Available JLab Data





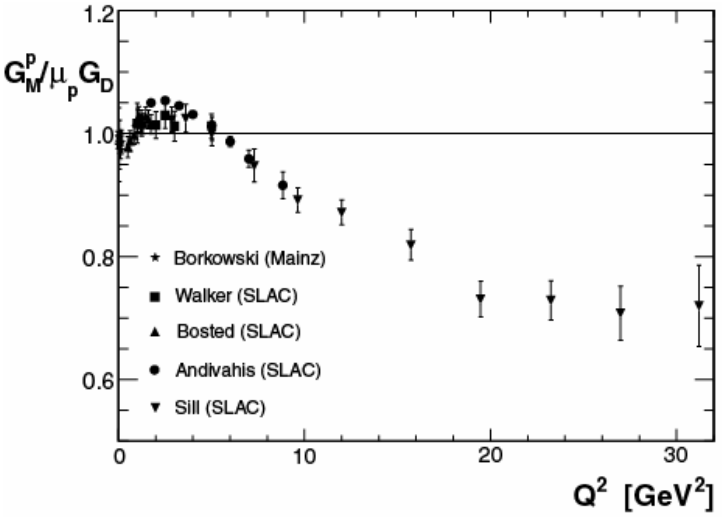


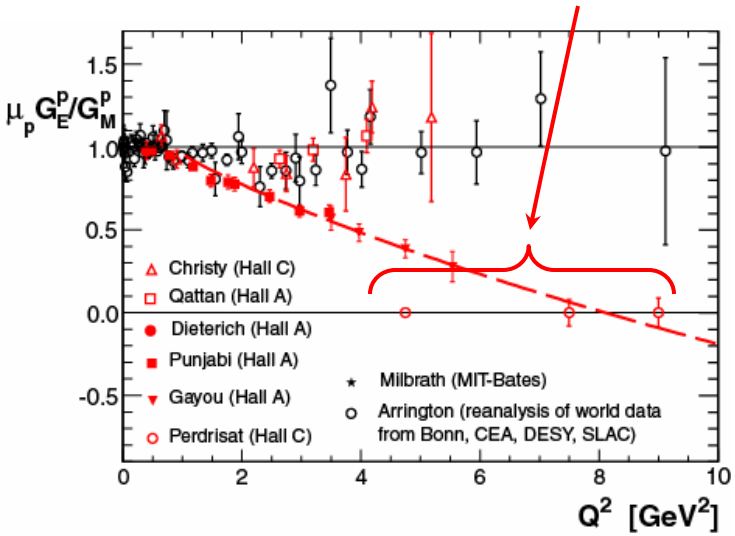


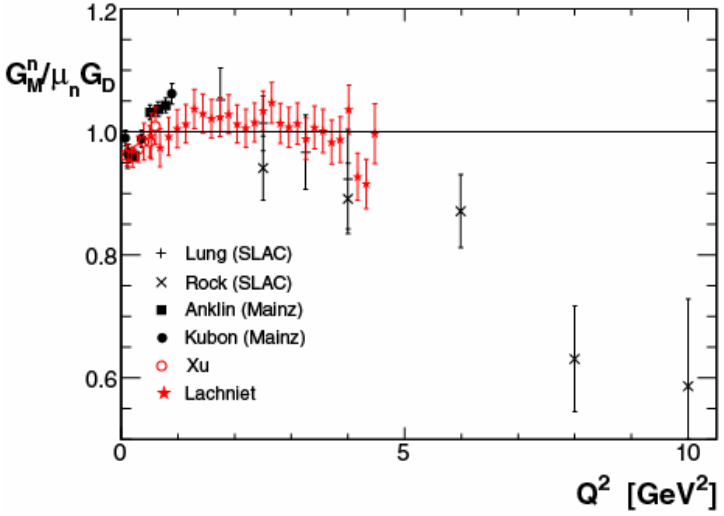
Data taken; analysis underway

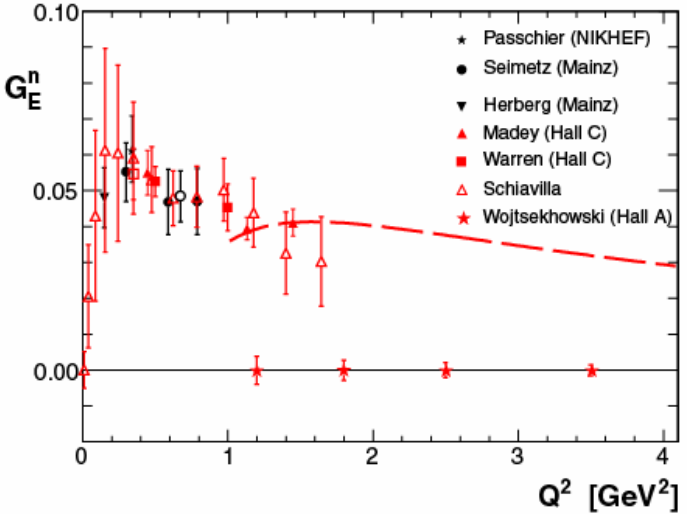
JLab data on the EM form factors provide a testing ground for theories constructing nucleons from quarks and glue

Today, with Available JLab Data and Planned G_E^p Extension

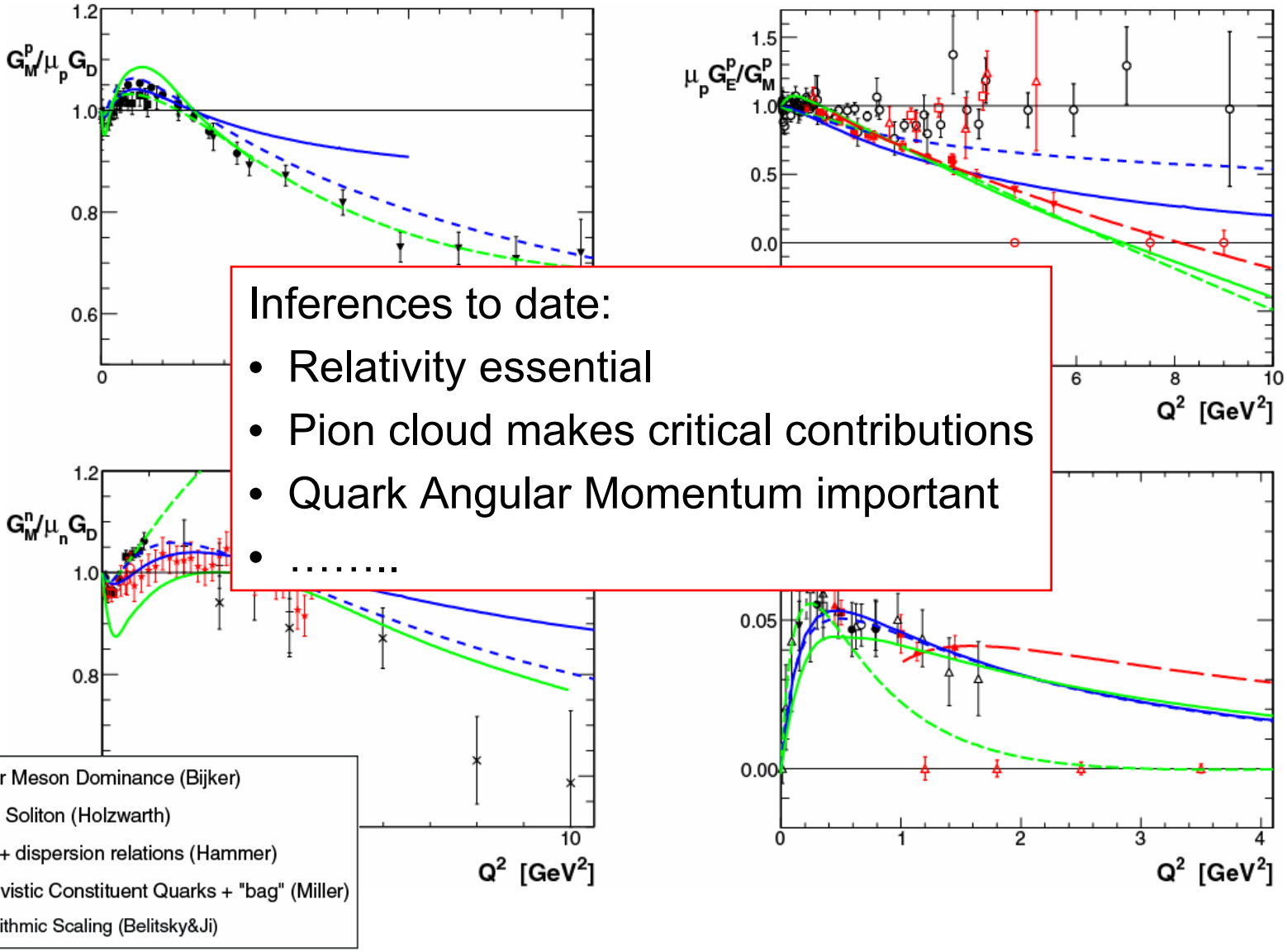








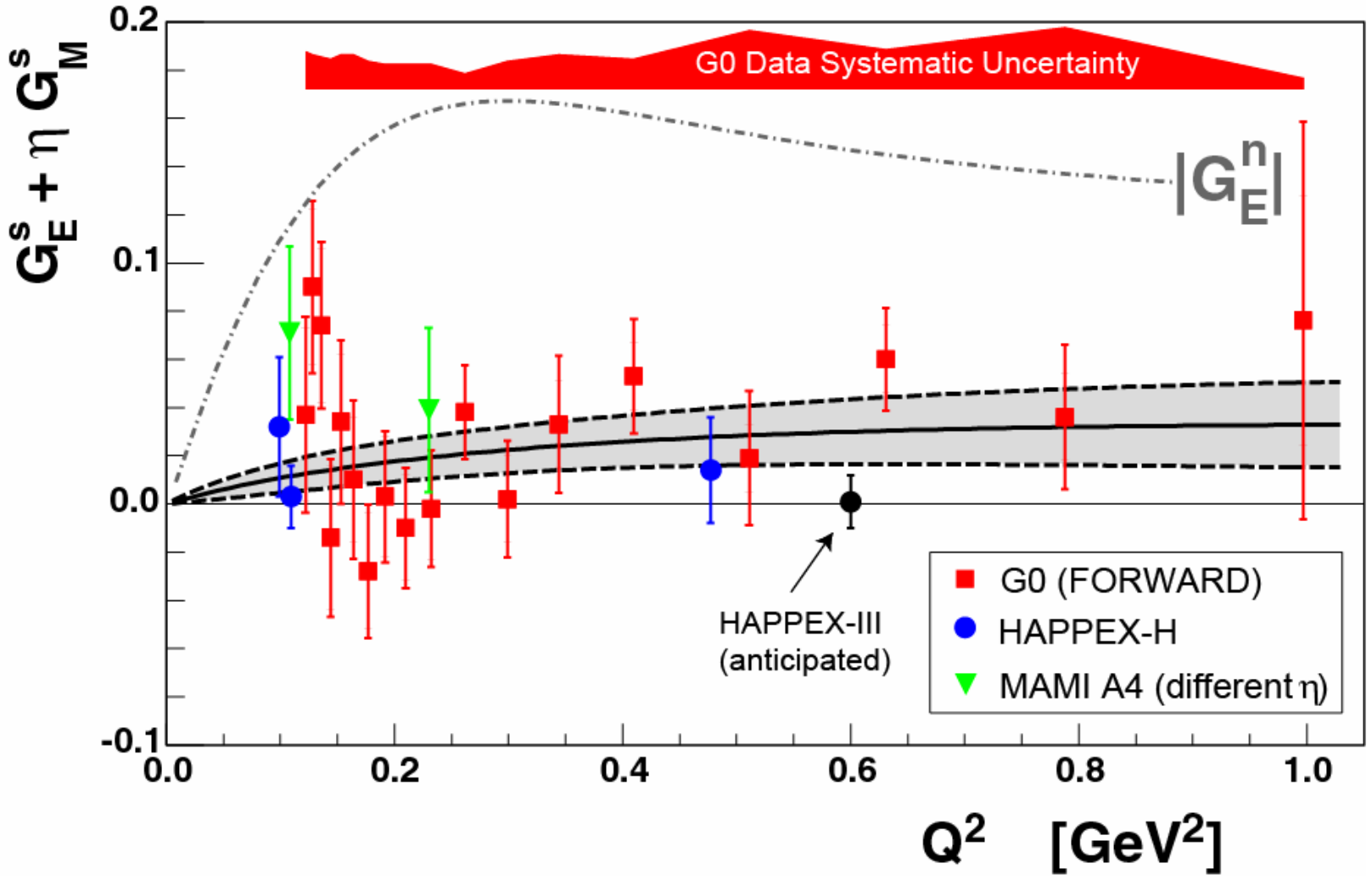
JLab data on the EM form factors provide a testing ground for theories constructing nucleons from quarks and glue



Inferences to date:

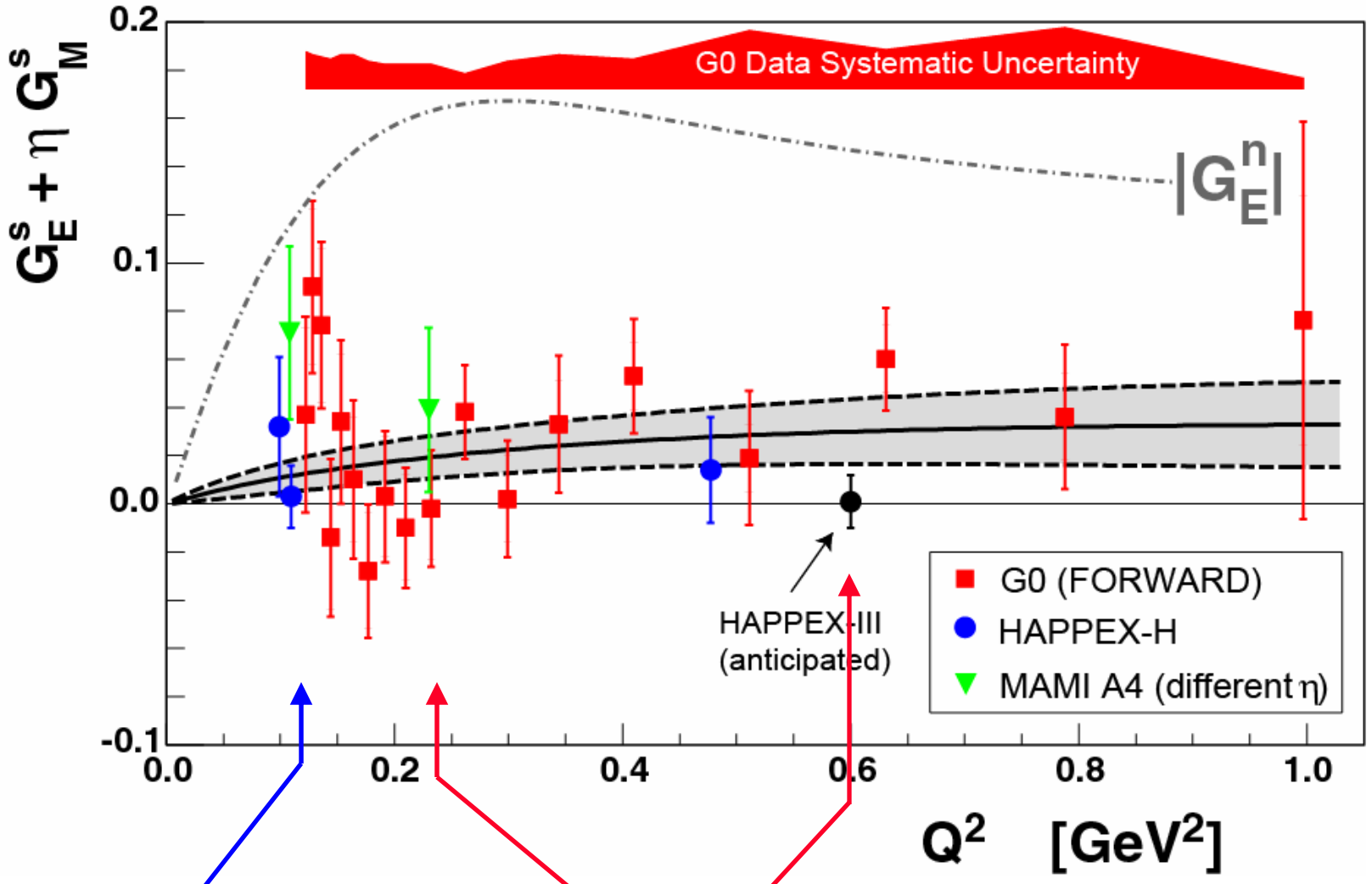
- Relativity essential
- Pion cloud makes critical contributions
- Quark Angular Momentum important
- ……..

The Strange Quark Form Factors of the Nucleon



The Strange Quark Form Factors of the Nucleon

Backward Angle and Helium Data Permit Electric/Magnetic Separations



Data Available from SAMPLE and HAPPEx He

Q^2 Values for G0 Backward Angle runs just completed

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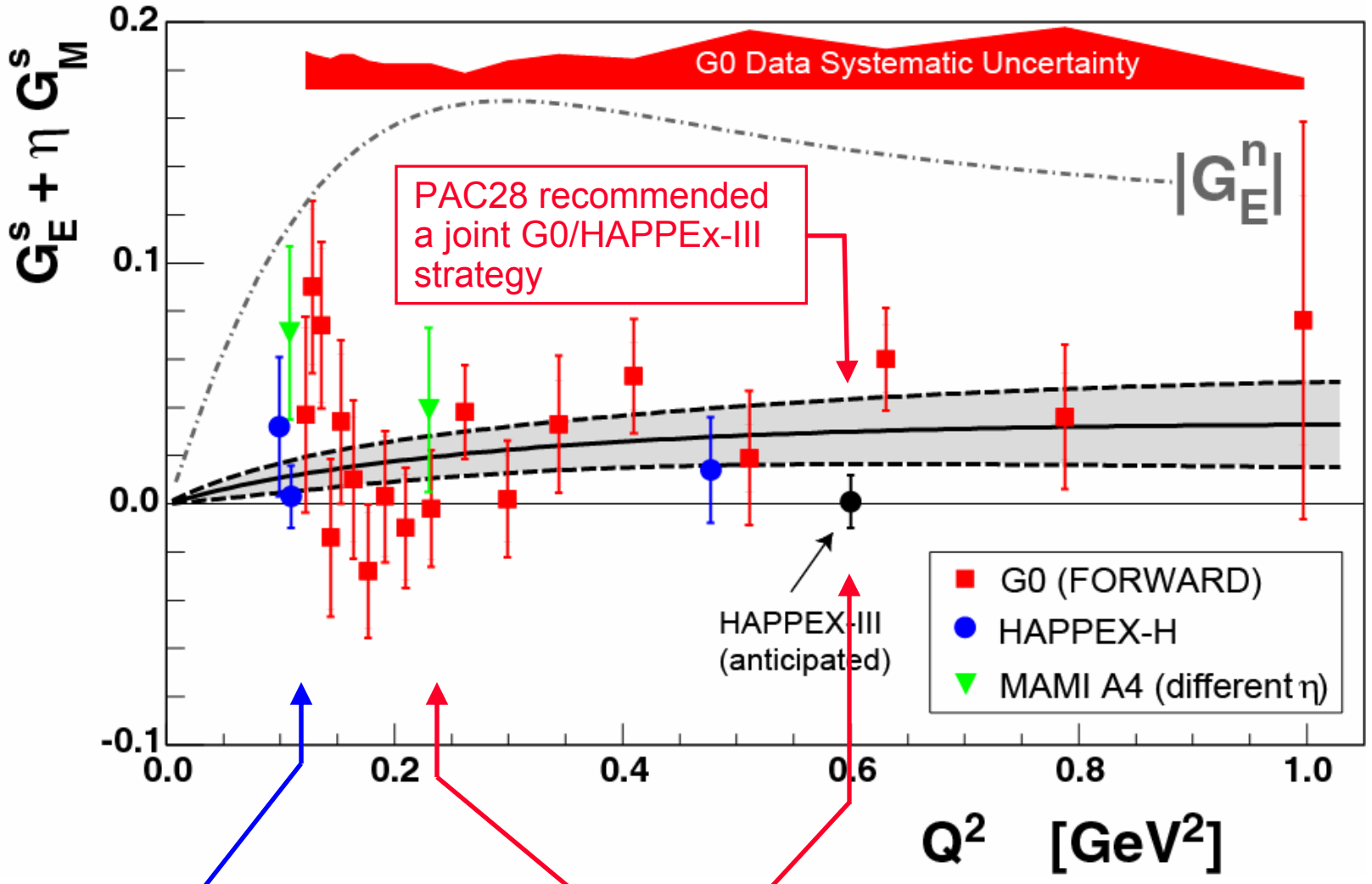

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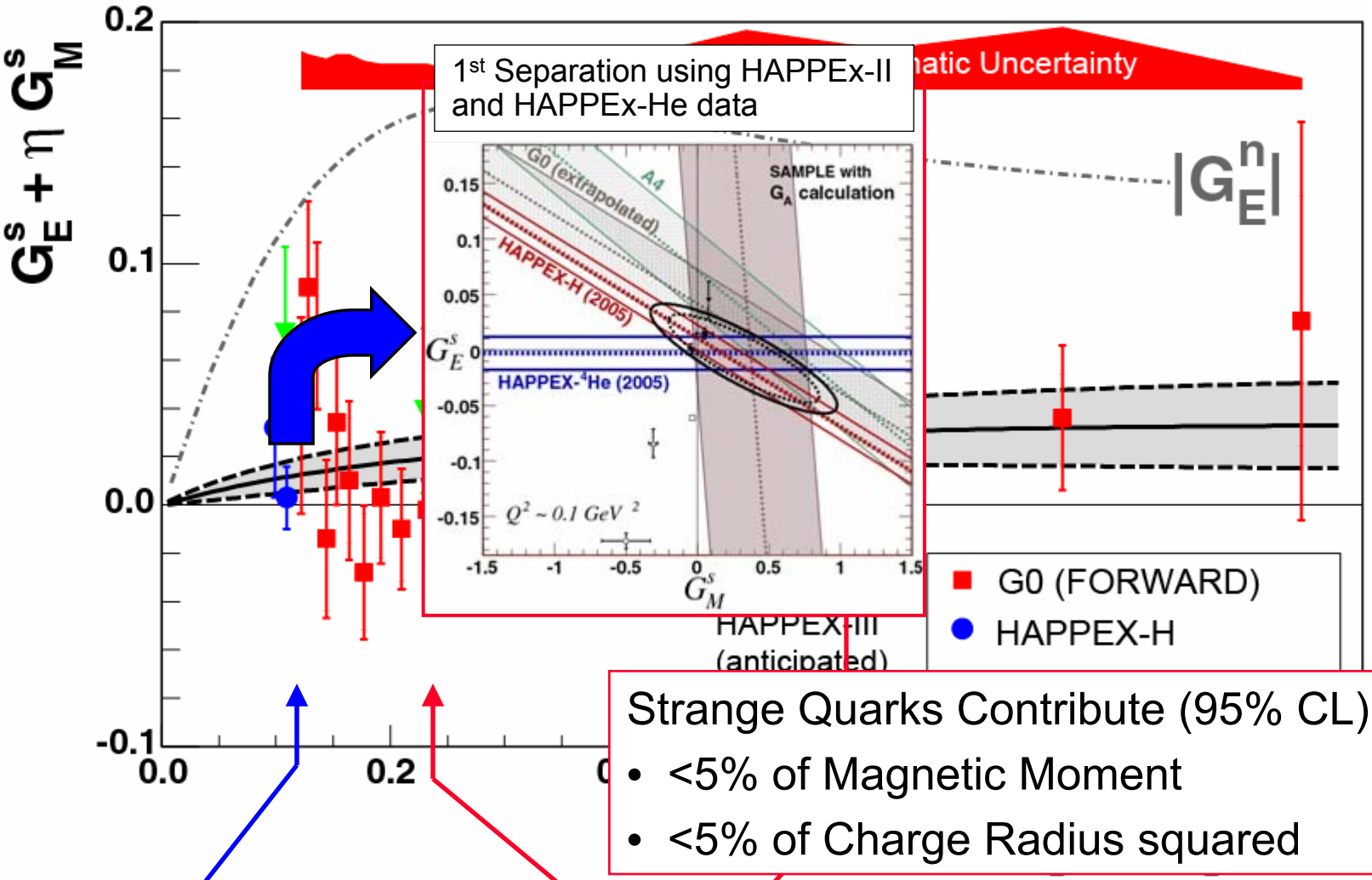


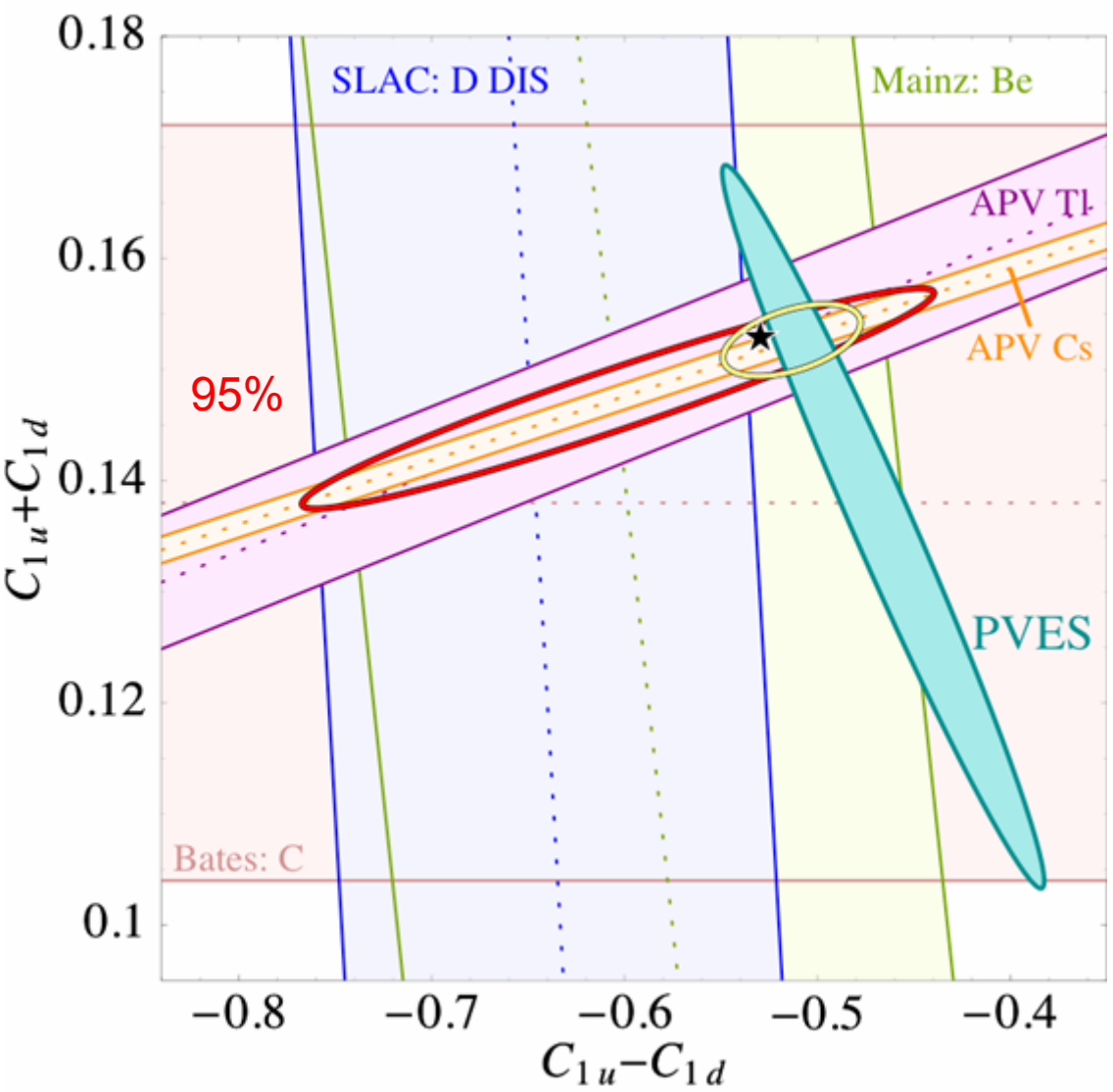
Strange Quarks Contribute (95% CL):

- <5% of Magnetic Moment
- <5% of Charge Radius squared

Data Now Available from SAMPLE and HAPPEx II

Q^2 Values for G0 Backward Angle runs

These Experiments Have Impact Well Beyond Our Understanding of Nucleon Structure: e.g. for C_{1q} couplings in the Standard Model



(Young et al.)

Dramatic improvement in knowledge of weak couplings!

Factor of 5 increase in precision of Standard Model test

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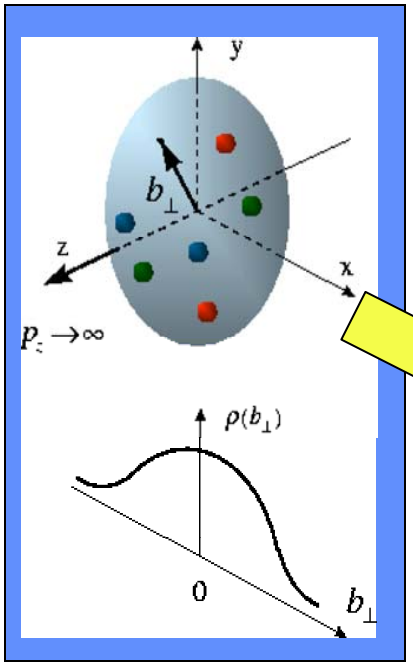
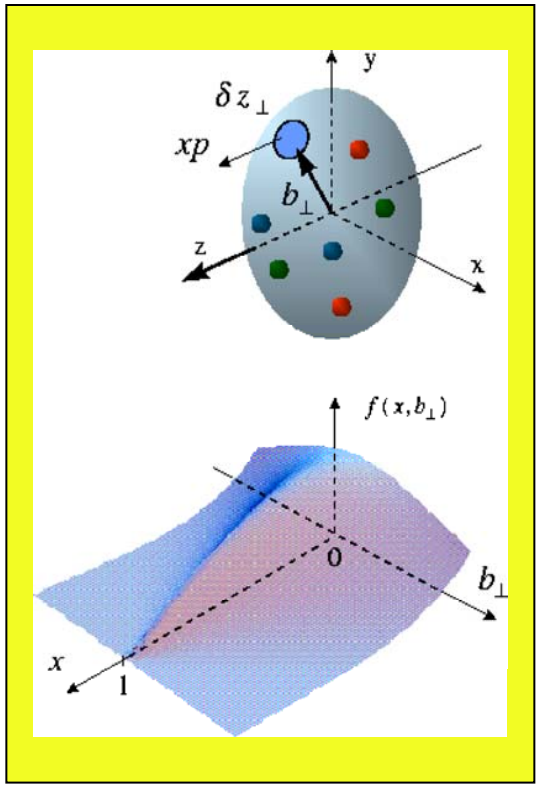
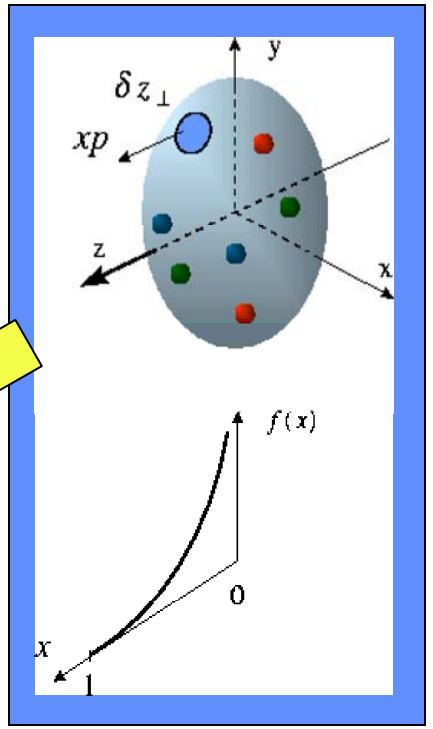
Beyond form factors and quark distributions – Generalized Parton Distributions (GPDs)

X. Ji, D. Mueller, A. Radyushkin (1994-1997)





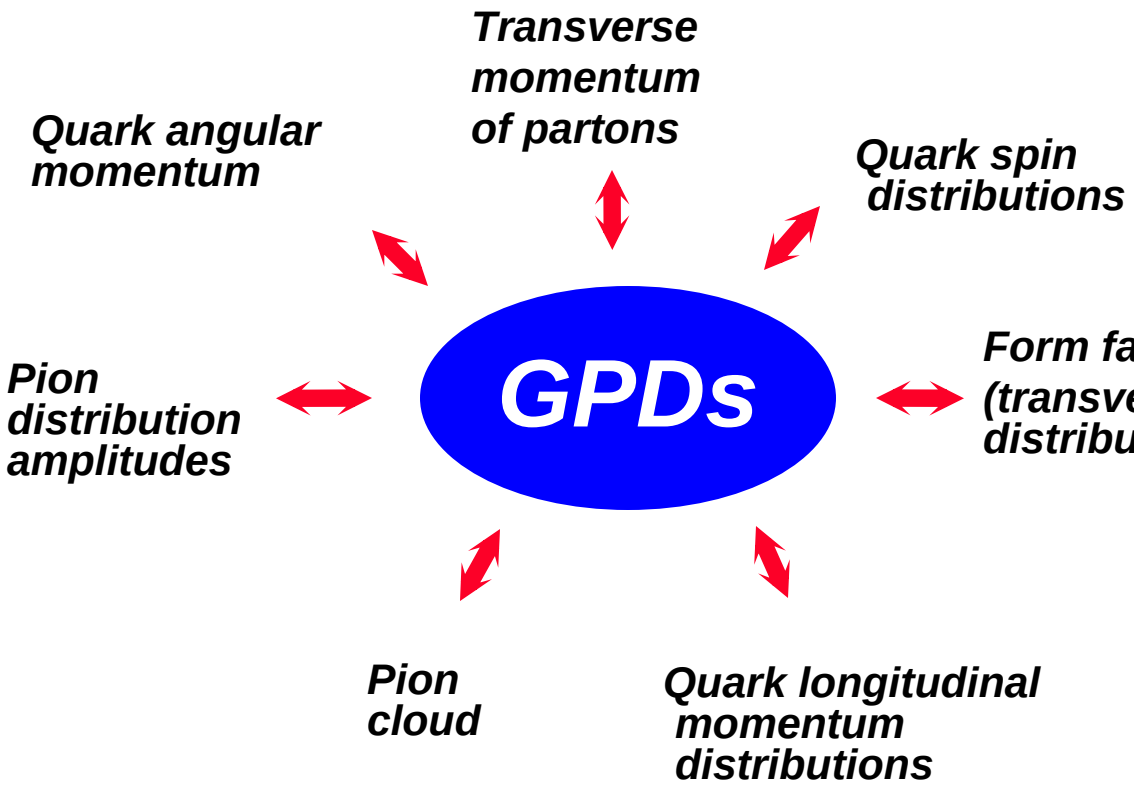


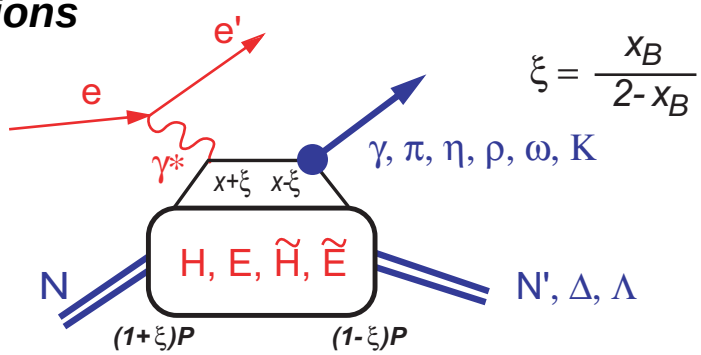
Elastic Scattering & Form Factors:
Transverse charge & current densities in coordinate space

DES & GPDs:
Correlated quark distributions In transverse coordinate and longitudinal momentum space

DIS & Structure Functions:
Quark longitudinal & helicity distributions in momentum space

Developing a Unified Description of Hadron Structure via the Recently Devised Generalized Parton Distributions

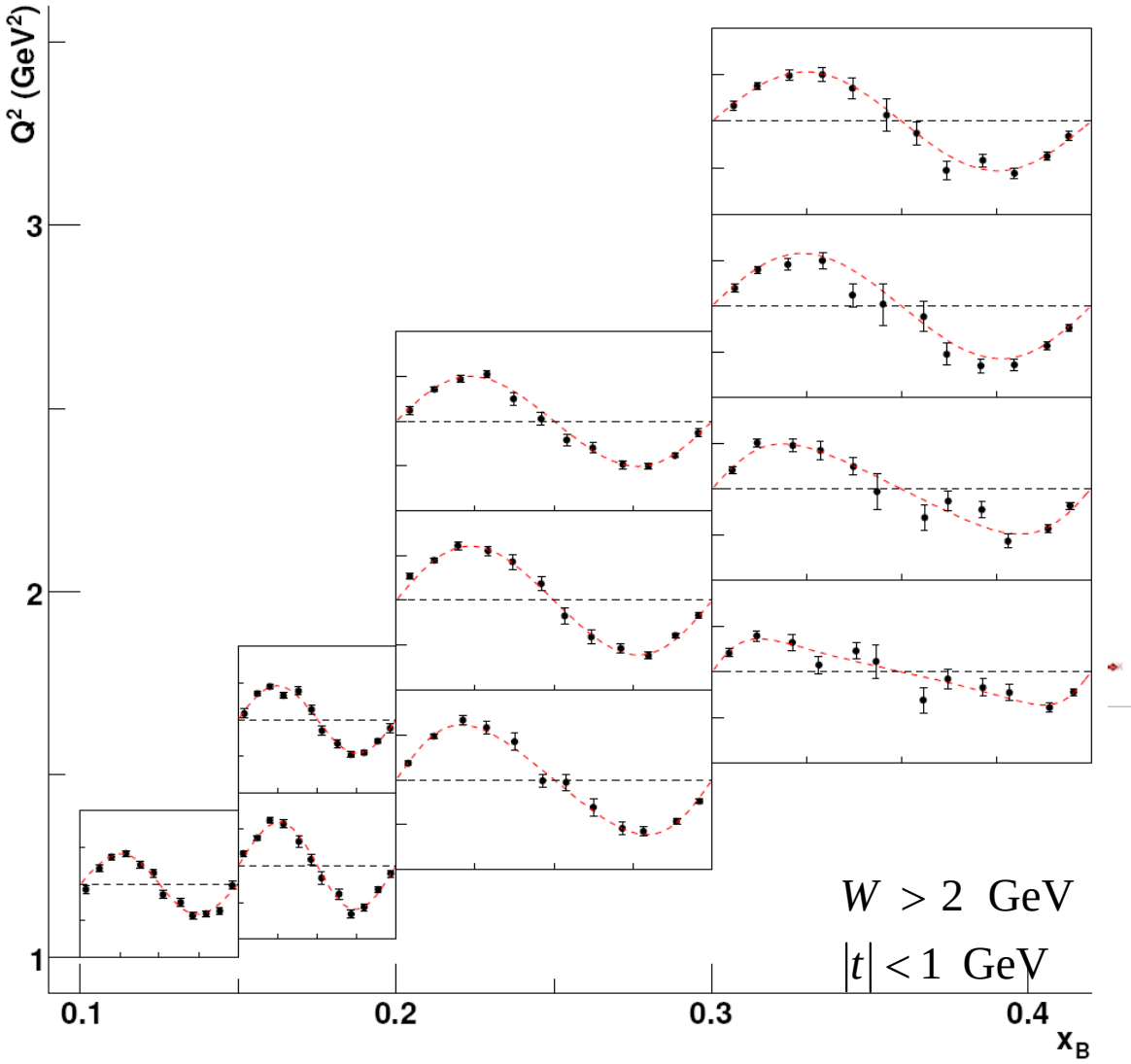


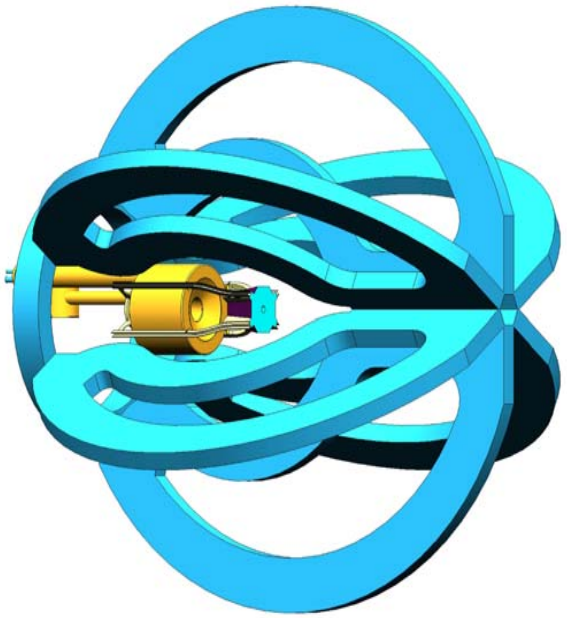


H, E - unpolarized, $\widetilde{H}$, $\widetilde{E}$ - polarized GPD

The GPDs Define Nucleon Structure

CLAS e1DVCS Demonstrated Experimental Feasibility over a broad range of x and Q^2





Achieved 2x10^{34} luminosity with SC solenoid and dedicated calorimeter w/ 424 $PbWO_4$ crystals

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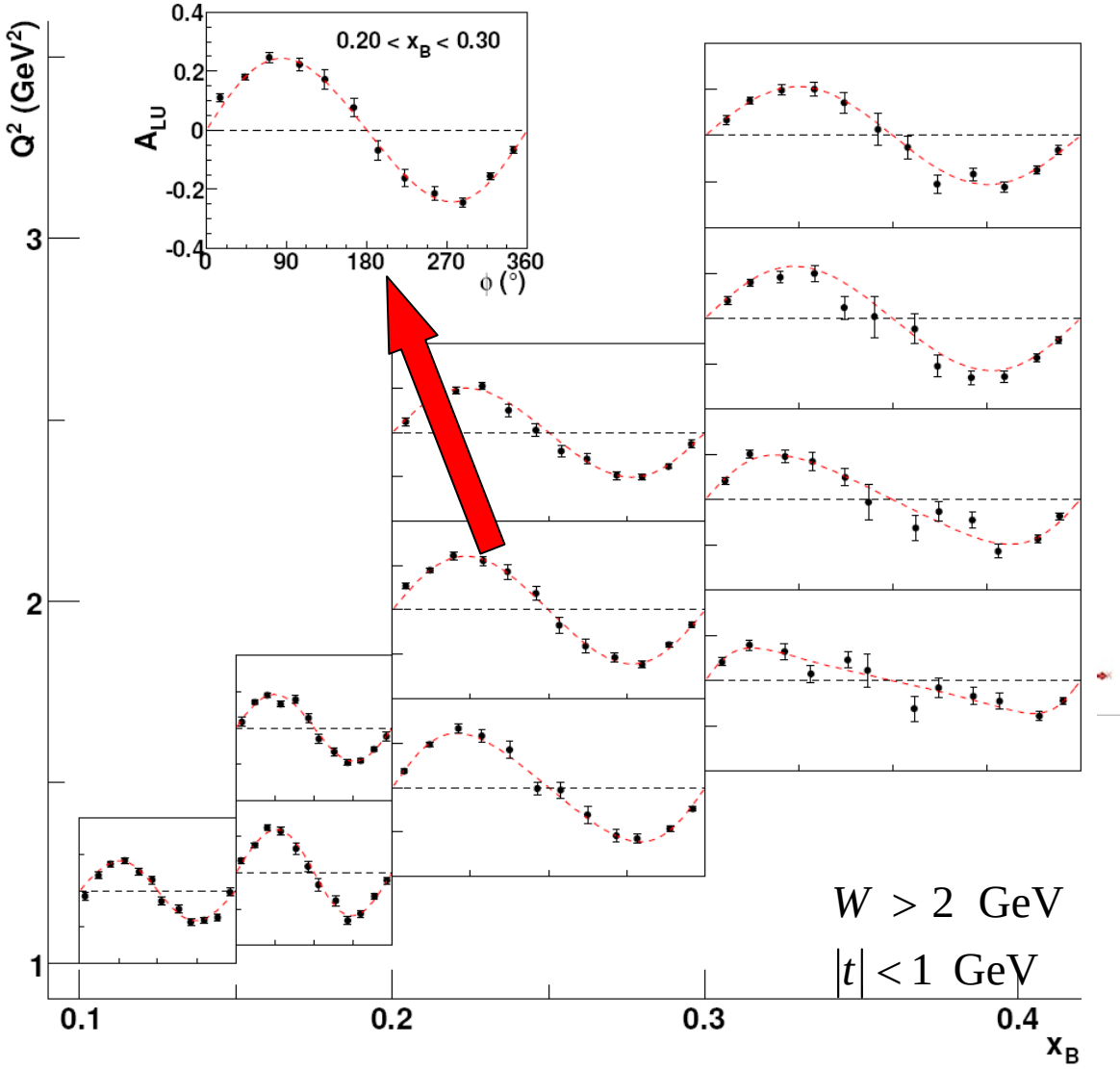

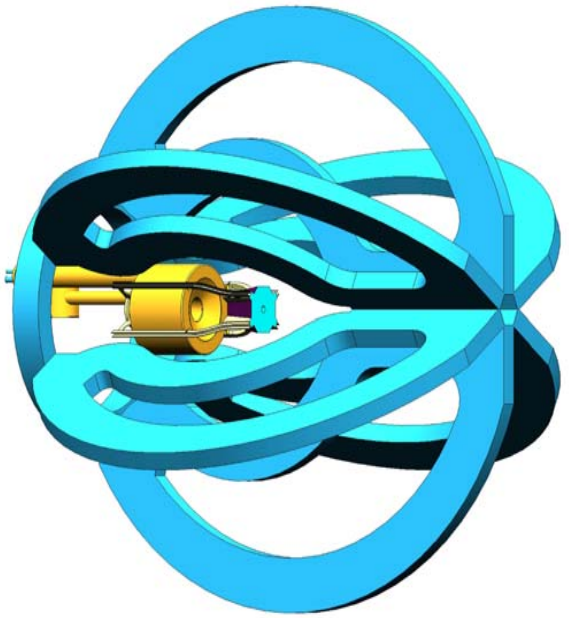

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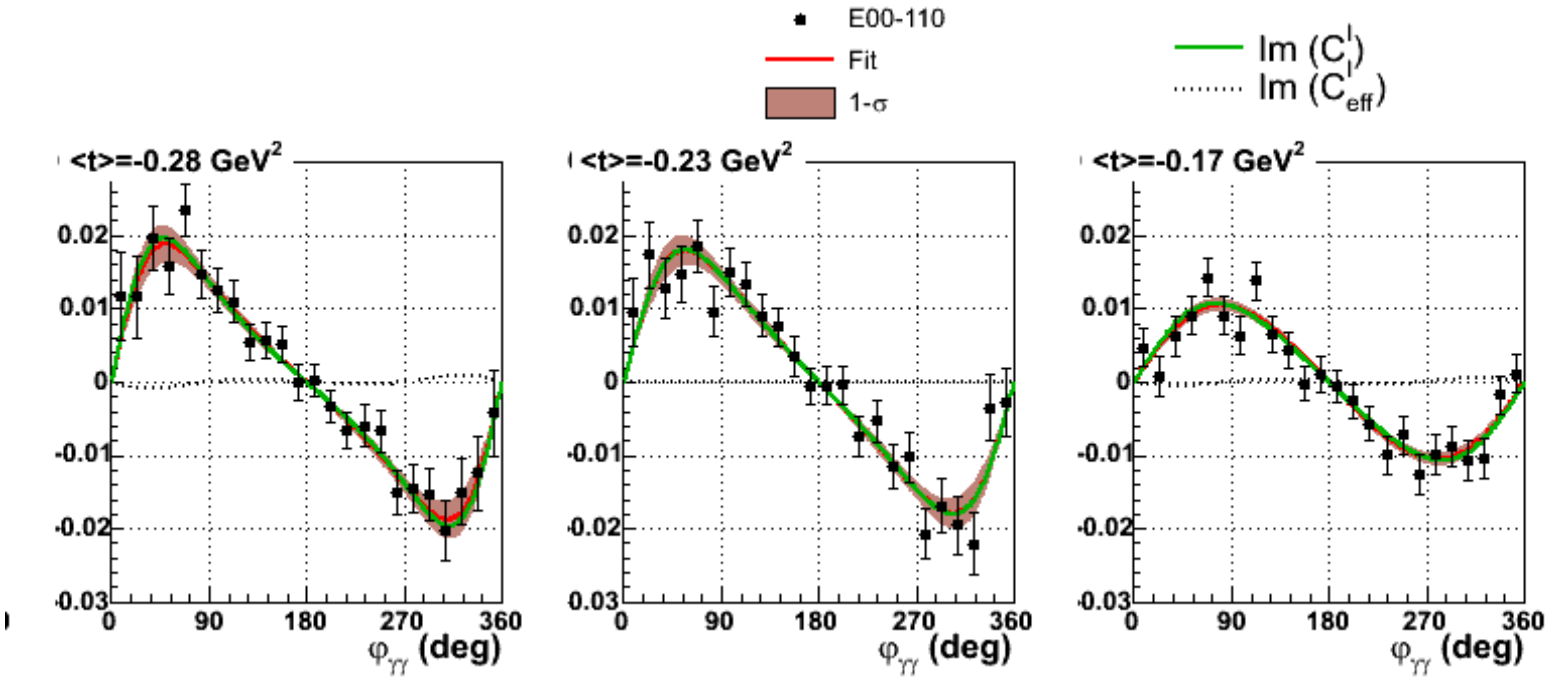
Hall A E00-110 Demonstrated Handbag Dominance at Modest Q^2

$$\frac{d^4\sigma^+}{dx_B dQ^2 d\varphi\, dt} - \frac{d^4\sigma^-}{dx_B dQ^2 d\varphi\, dt} \quad [\mathrm{nb/GeV^4}]$$

Corrected for real and virtual radiation



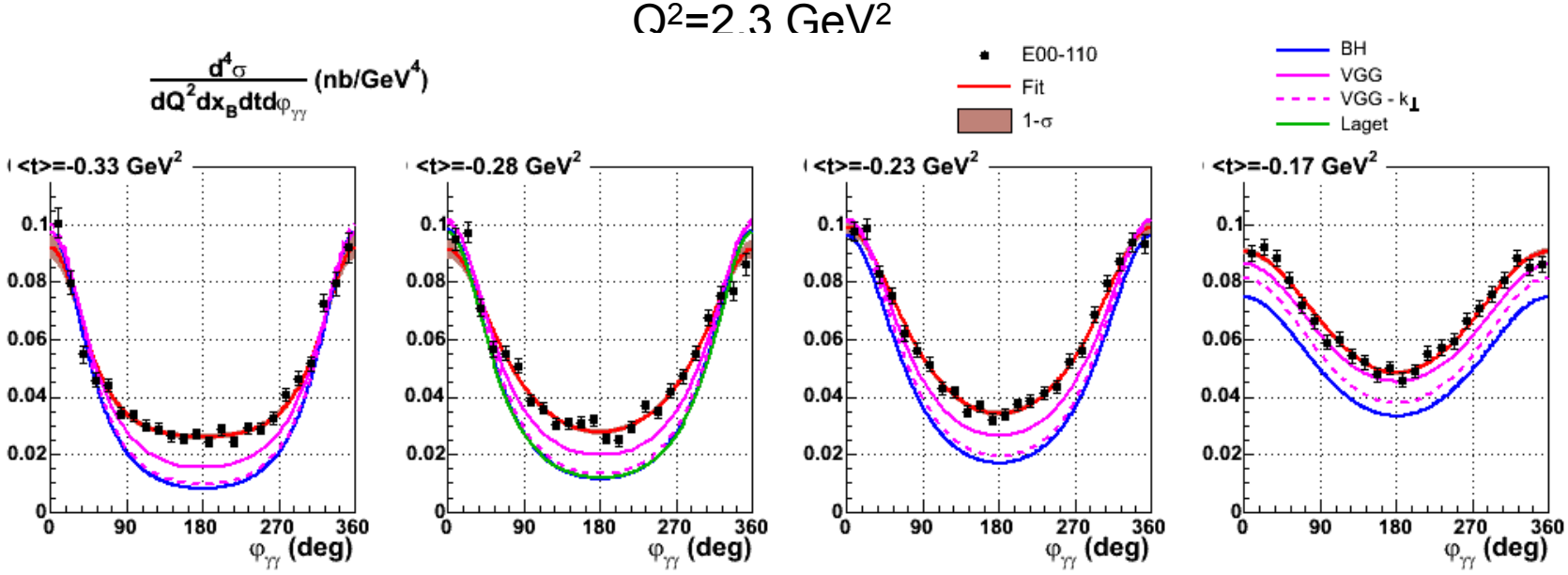
Twist 2 contribution

Twist 3 contribution strongly suppressed

The Twist-2 term can be extracted accurately from the cross-section difference

Dominance of twist-2 ⇒ handbag dominance ⇒ DVCS interpretation straightforward

.....and the Limited Understanding We Have Today of the GPDs

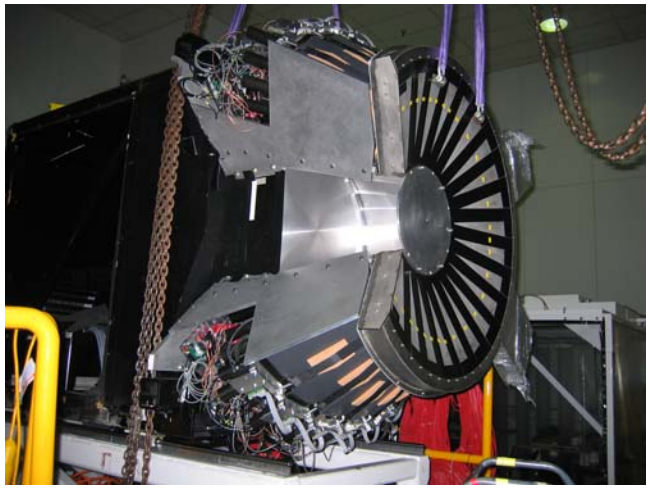


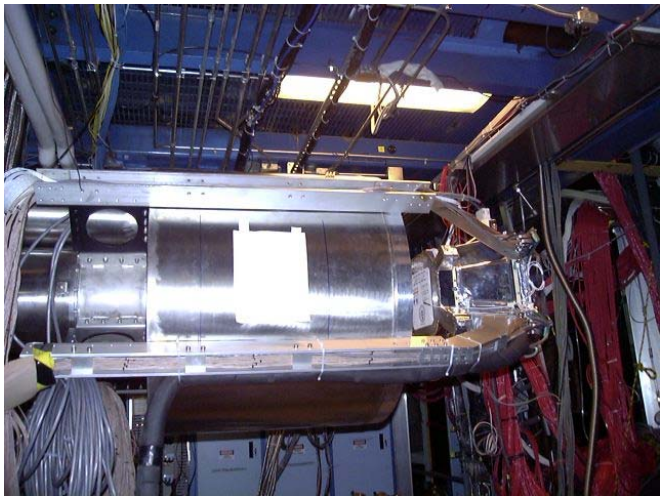
a priori modeling of the GPDs substantially underestimated the cross sections

We are only beginning to understand what the GPDs will teach us about the structure of the nucleon

DVCS @ 6 GeV

- **Newly-approved hall A experiment will:**
  - Separate the BH×DVCS and $DVCS^2$ contributions to the measured cross sections, and
  - explore our quantitative understanding of the process
- **Two CLAS experiments will:**
  - Complete e1DVCS data set surveying the modest x and Q^2 region
  - Explore DVCS with a longitudinally polarized target, accessing new GPDs sensitive to spin structure of the nucleon





Plans for the 6 GeV Program Over the Next 5 Years

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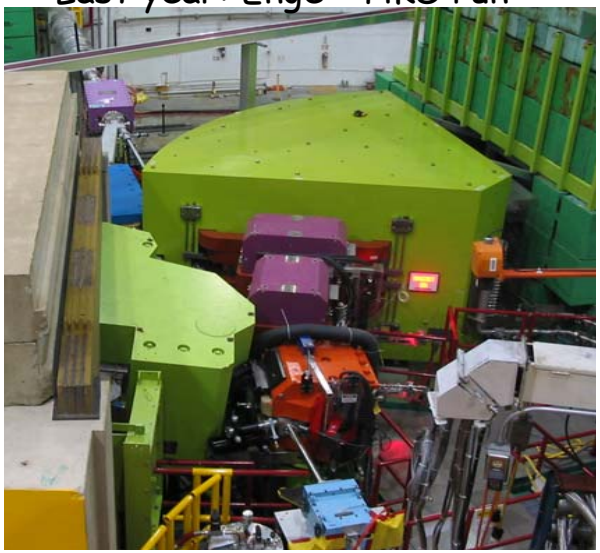
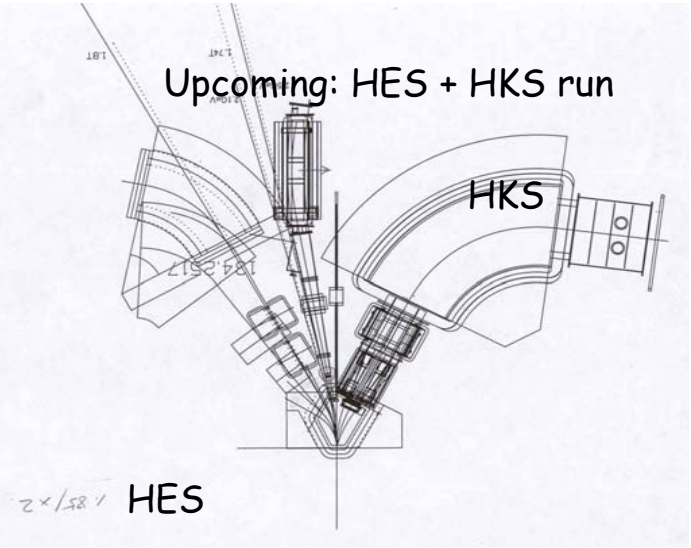
    …..

Hypernuclear Spectroscopy (HKS/HES) Program

Last year: Enge + HKS run





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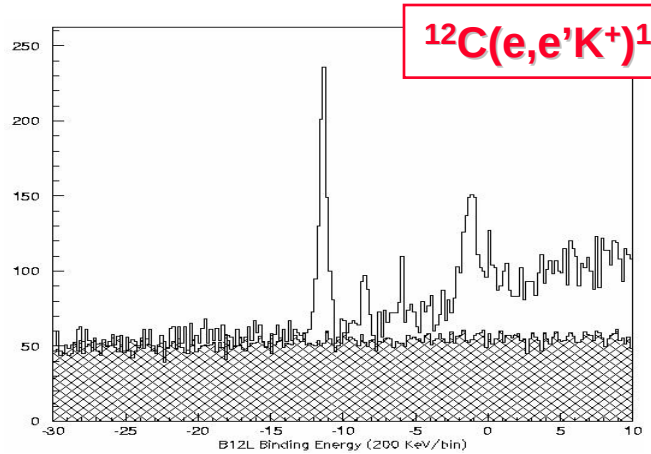
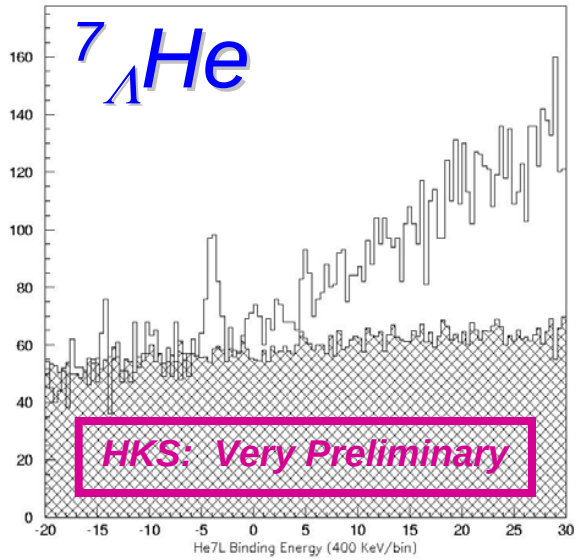


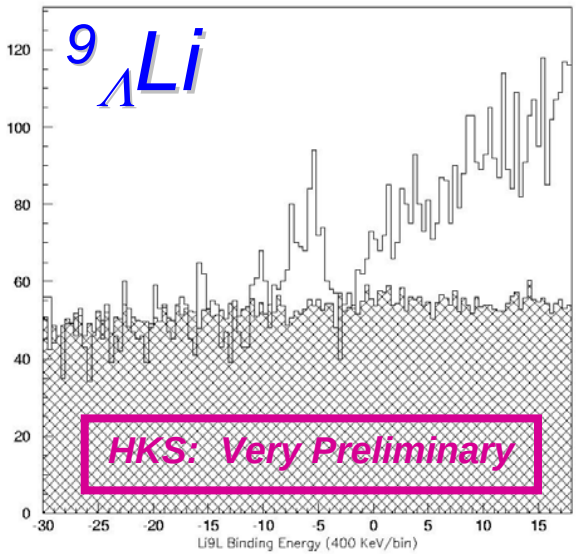
• A new experimental setup (with the Japanese-built HKS and HES spectrometers) will allow for both **high-resolution (~400 keV) and high-statistics access to hypernuclear excitations**

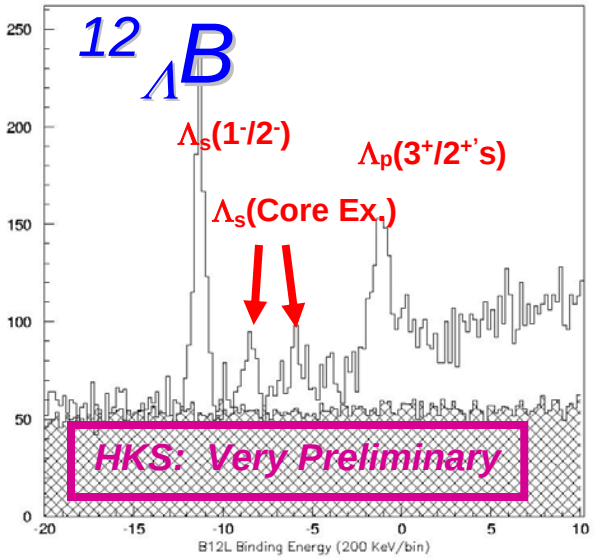
•This will allow for a **breakthrough program** accessing weakly-excited hypernuclear states, with the **potential to greatly improve our understanding of matter with strange quarks embedded.**

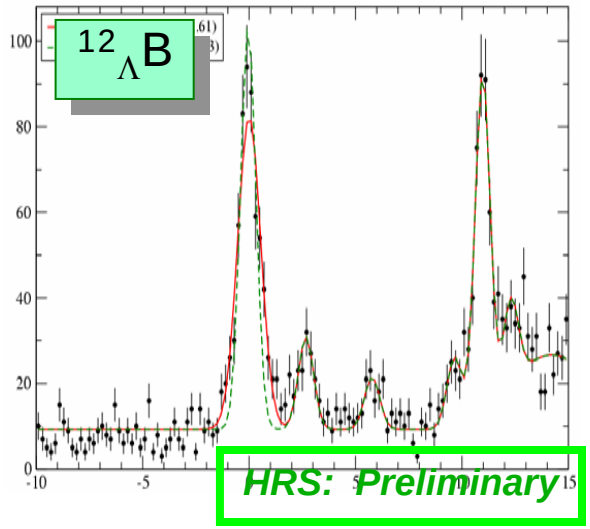
• The situation is analogous to the dramatic progress in validating the Independent-Particle Shell Model and the quantitative findings on N-N correlations and the bound-nucleon properties with the A(e,e'p) reaction in the '80's and '90's

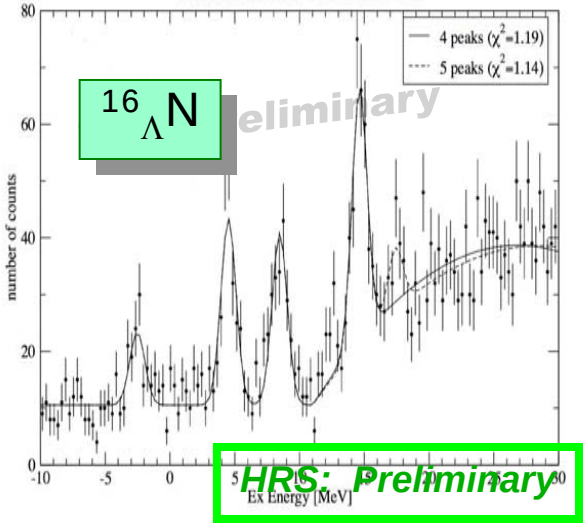
Preliminary Hypernuclear Spectra Emerging from JLab Experiments

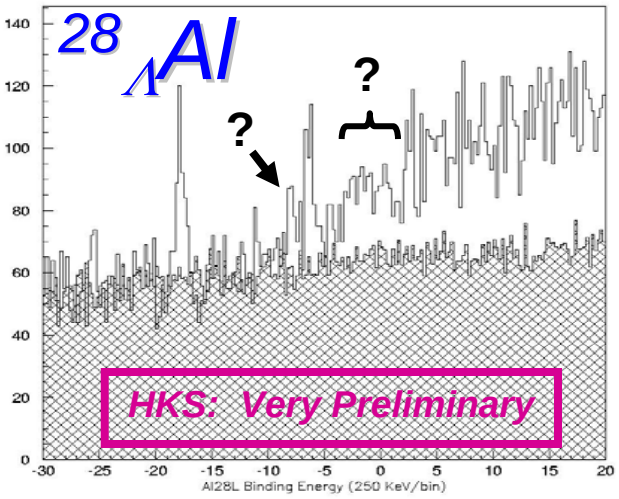












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Lead (^{208}Pb) Radius Experiment : PREX

E = 850 MeV, $\theta = 6^0$
electrons on lead

Elastic Scattering Parity Violating Asymmetry

Z^0 of Weak Interaction :

Clean Probe Couples Mainly to Neutrons

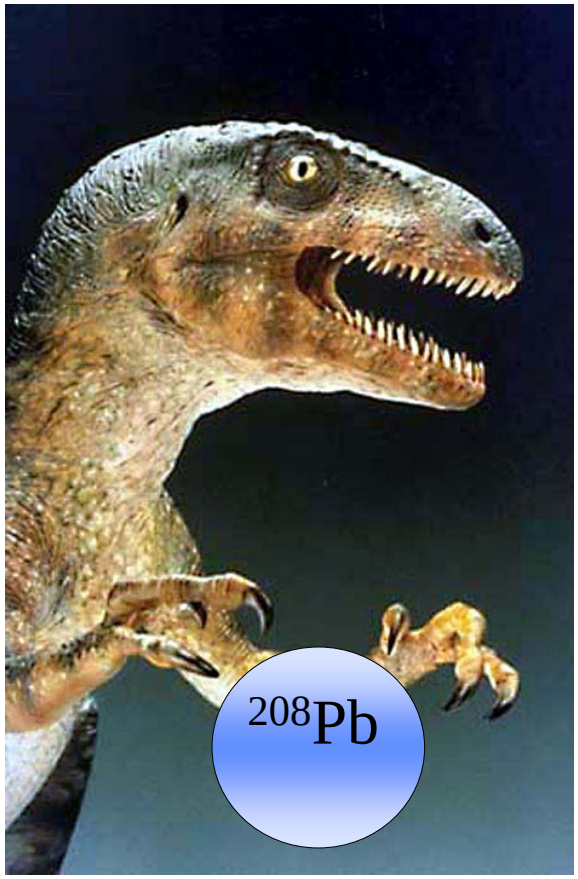
(T.W. Donnelly, J. Dubach, I Sick)

In PWIA (to illustrate) :

$$A = \frac{\left(\frac{d\sigma}{d\Omega}\right)_R - \left(\frac{d\sigma}{d\Omega}\right)_L}{\left(\frac{d\sigma}{d\Omega}\right)_R + \left(\frac{d\sigma}{d\Omega}\right)_L} = \frac{G_F Q^2}{2\pi\alpha\sqrt{2}}\left[\underbrace{1-4\sin^2\theta_W}_{\approx 0} - \frac{F_n(Q^2)}{F_P(Q^2)}\right]$$

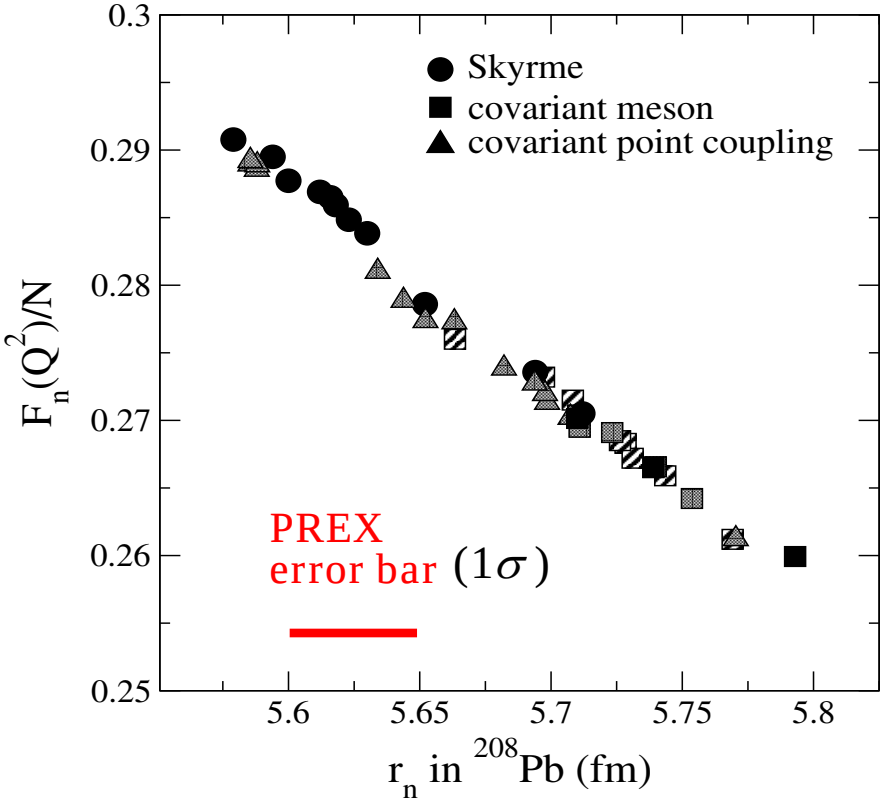
w/ Coulomb distortions (C. J. Horowitz) :

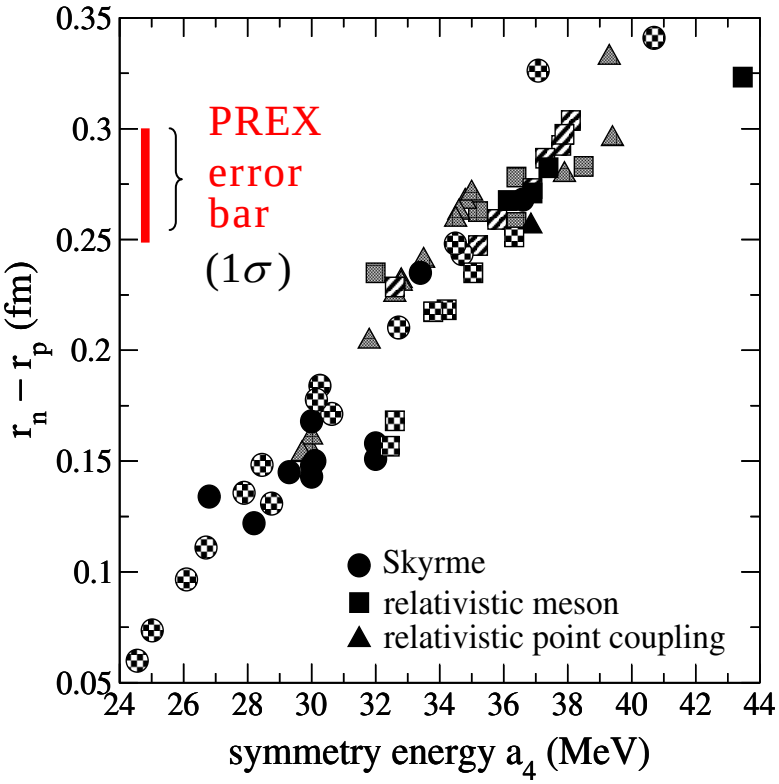
$$\frac{dA}{A} = 3\% \quad \rightarrow \quad \frac{dR_n}{R_n} = 1\%$$



One Q^2 is Sufficient to Pin Down the RMS Radius And Determine the Symmetry Energy for the EOS

^{208}Pb





(R.J. Furnstahl)

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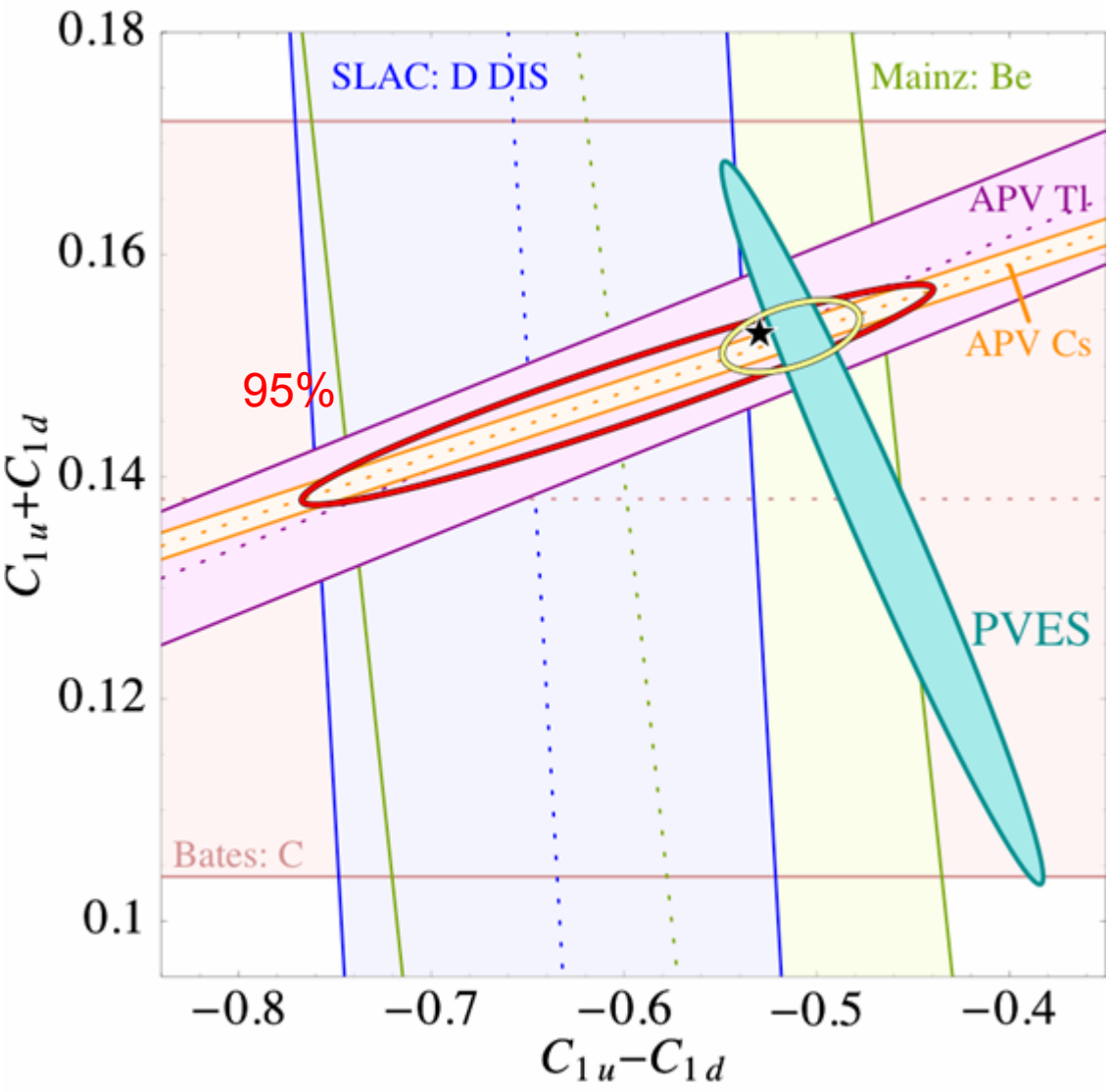
New update on C_{1q} couplings – Dec 2006



(Young et al.)

Dramatic improvement in knowledge of weak couplings!

Factor of 5 increase in precision of Standard Model test

Future: Q_{weak} Experiment (2010: 6 GeV)

- Precise measurement of the proton's weak charge in PVES

$$Q^p_{\text{weak}} = -2(2C_{1u} + C_{1d}) \qquad Q^2 = 0.03\,\text{GeV}^2,\ \theta = 8^\circ$$

- At low energy and small scattering angle:

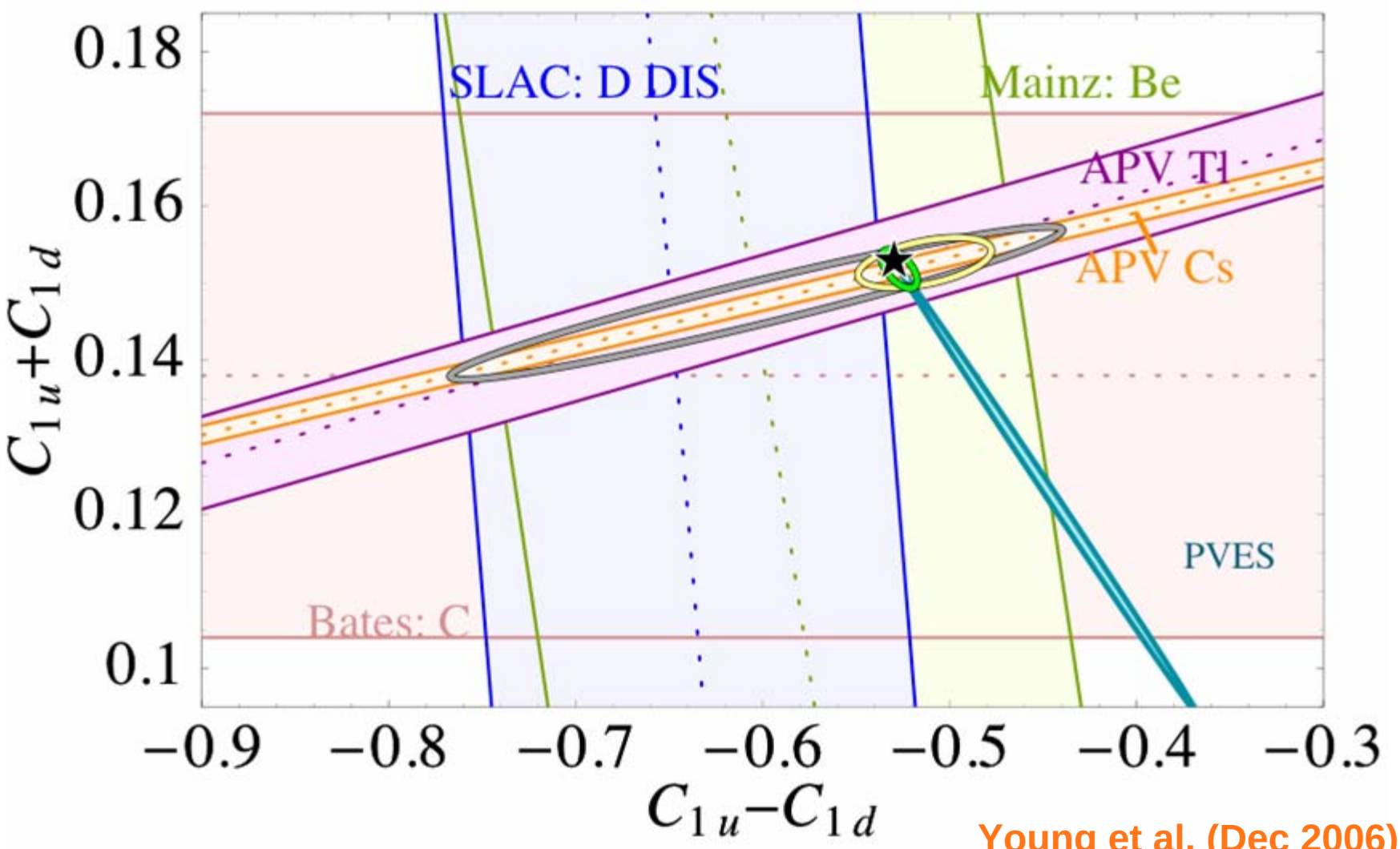
$$A_{LR} = -\frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\left[Q_{\text{weak}} + \beta_A \tilde{G}_A^p \sqrt{Q^2} + \beta_V Q^2 + \ldots\right]$$

$$\beta_A \propto \theta + O(\theta^3)$$

Anapole uncertainty

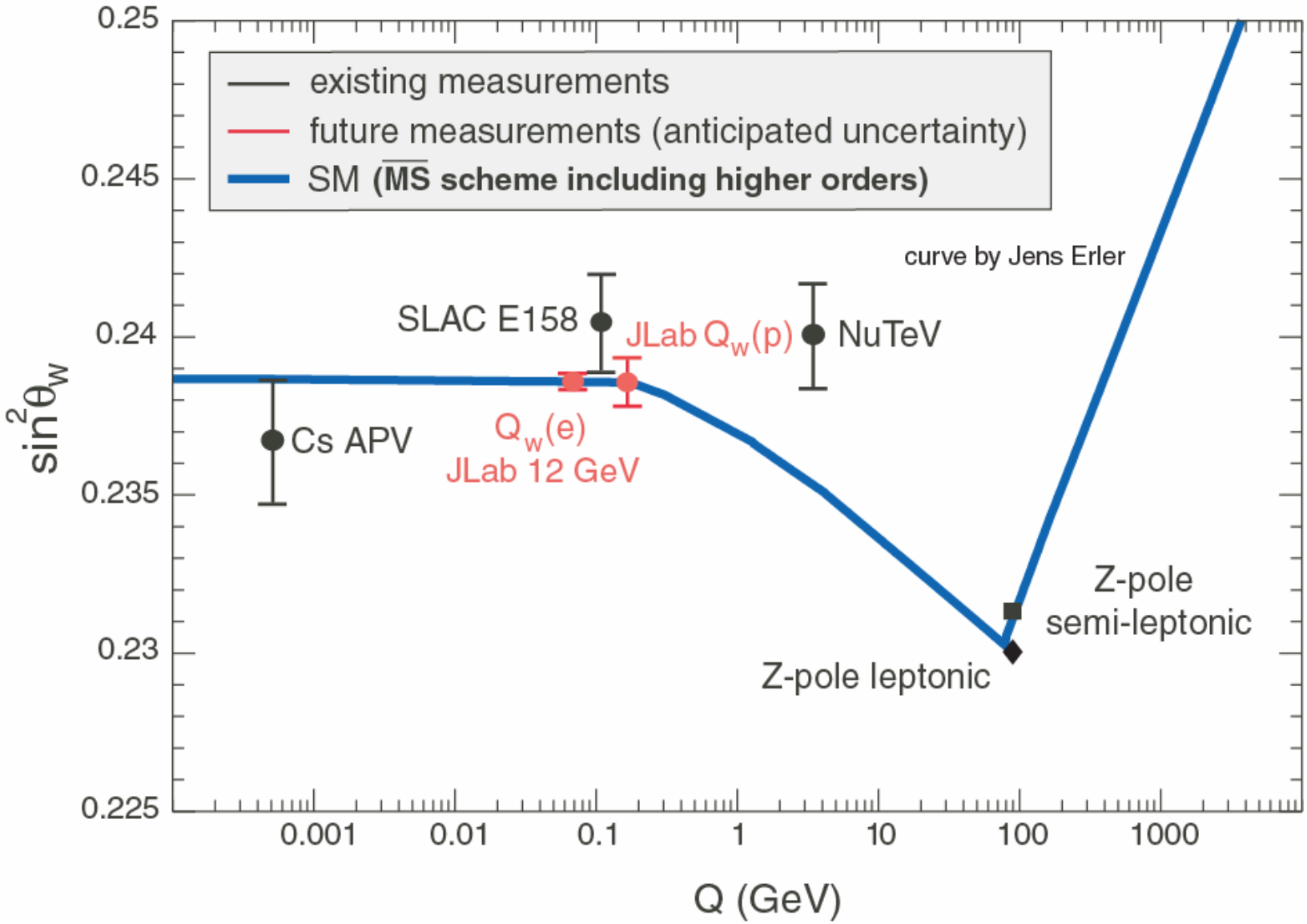
Strangeness uncertainty

Possible Impact of Qweak



Young et al. (Dec 2006)

Q_{Weak} also Tests the Running of $Sin^2\theta_W$



Summary

- **FY07 and projected FY08 budgets will support running at ~80% of optimum and needed equipment construction**
- **Cryomodule refurbishment is progressing well; we anticipate 5.75 GeV beams next Spring**
- **The PAC will be alternating between 6 and 12 GeV physics over the next few years as we seek to optimize our science**
- **The outstanding physics already on the 6 GeV “books” was an essential ingredient in our success at the NSAC Long Range Plan,**
- **A key aspect of that program is its breadth, with substantial programs relevant to the nuclear structure and fundamental symmetries communities as well as the hadronic physics community**