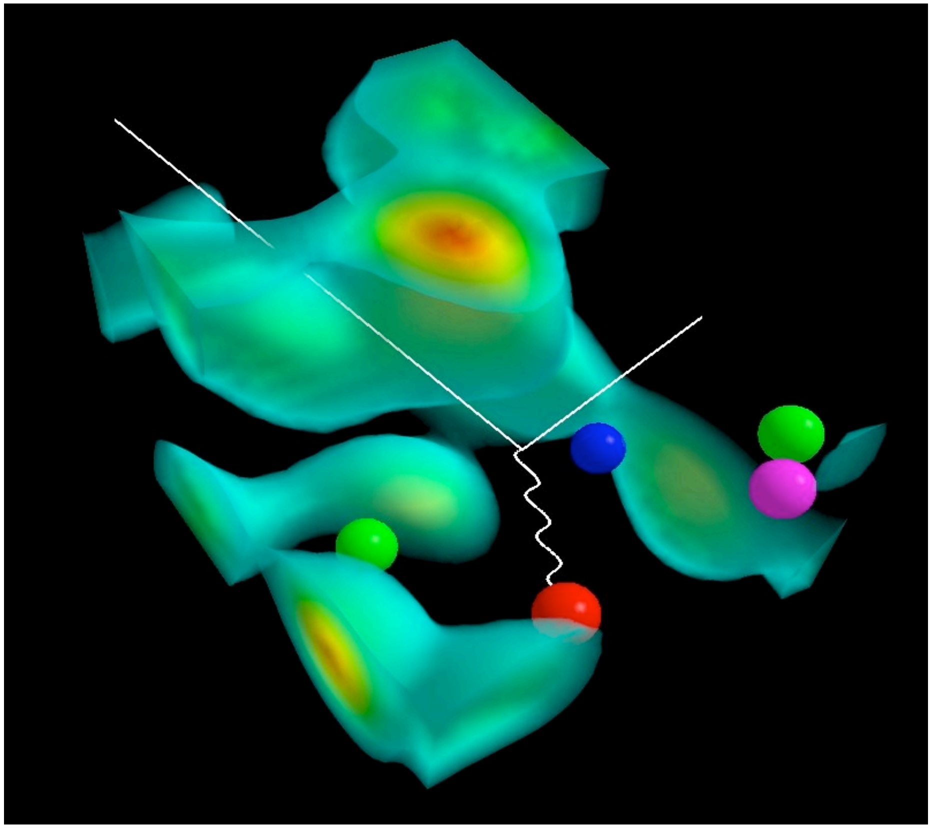
Science Vision: Present Status, Future Opportunities



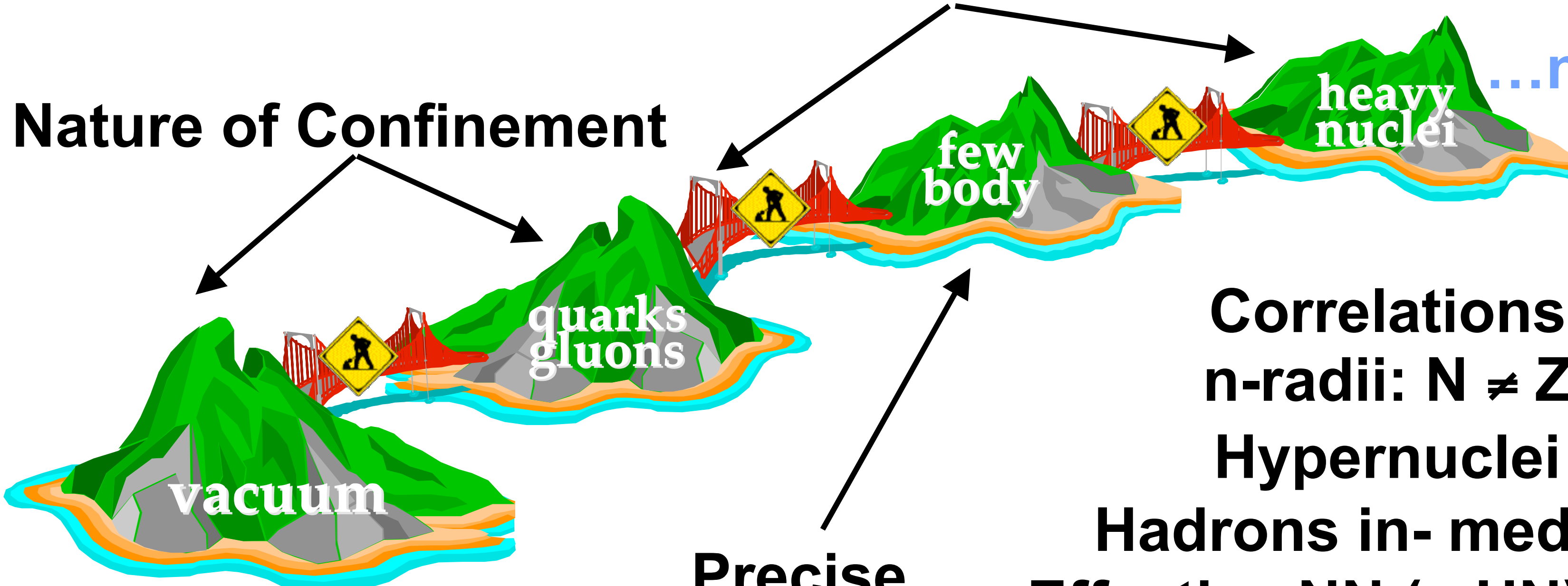
Anthony W Thomas - Chief Scientist

Science & Technology Review: July 12-14, 2006

JLab Central to Nuclear Science

Quark-Gluon Structure
Of Nucleons and Nuclei

Nature of Confinement



…n-stars

Correlations
n-radii: N ≠ Z
Hypernuclei
Hadrons in- medium
Effective NN (+ HN) force

Precise
few-nucleon
calculations

Exotic mesons
and baryons

Nuclear Physics Research Goals

Year	OMB Milestones in Hadronic Physics — TJNAF Responsible for 8 of 10
2008	Make measurements of spin carried by the glue in the proton with polarized proton-proton collisions at center of mass energy, $\sqrt{s_{NN}}$ = 200 GeV.
2008	Extract accurate information on generalized parton distributions for parton momentum fractions, x, of 0.1 - 0.4 , and squared momentum change, –t, less than 0.5 GeV^2 in measurements of deeply virtual Compton scattering.
2009	Complete the combined analysis of available data on single π, η, and K photo-production of nucleon resonances and incorporate the analysis of two-pion final states into the coupled-channel analysis of resonances.
2010	Determine the four electromagnetic form factors of the nucleons to a momentum-transfer squared, Q^2, of 3.5 GeV^2 and separate the electroweak form factors into contributions from the u, d and s-quarks for $Q^2 < 1$ GeV^2 .
2010	Characterize high-momentum components induced by correlations in the few-body nuclear wave functions via (e,e'N) and (e,e'NN) knock-out processes in nuclei and compare free proton and bound proton properties via measurement of polarization transfer in the reaction.
2011	Measure the lowest moments of the unpolarized nucleon structure functions (both longitudinal and transverse) to 4 GeV^2 for the proton, and the neutron, and the deep inelastic scattering polarized structure functions $g_1(x, Q^2)$ and $g_2(x,Q^2)$ for x=0.2-0.6, and $1 < Q^2 < 5$ GeV^2 for both protons and neutrons.
2012	Measure the electromagnetic excitations of low-lying baryon states (<2 GeV) and their transition form factors over the range Q^2 = 0.1 – 7 GeV^2 and measure the electro- and photo-production of final states with one and two pseudoscalar mesons.
2013	Measure flavor-identified q and $\bar{q}$ contributions to the spin of the proton via the longitudinal-spin asymmetry of W production.
2014	Perform lattice calculations in full QCD of nucleon form factors, low moments of nucleon structure functions and low moments of generalized parton distributions including flavor and spin dependence.
2014	Carry out ab initio microscopic studies of the structure and dynamics of light nuclei based on two-nucleon and many-nucleon forces and lattice QCD calculations of hadron interaction mechanisms relevant to the origin of the nucleon-nucleon interaction.

Summary of Approved Experiments CY 2007+

- **HALL A: 20 experiments, 12 rated A or A^-**
  - **4.5 years normal operation**
- **HALL B: 12 experiments, 10 rated A or A^-**
  - **2.4 years normal operation**
- **HALL C: 14 experiments, 12 rated A or A^-**
  - **4.3 years with Q_{weak} II**

Highest Scientific Priorities

Hall A:

- ^{4}He (pol e, e' pol p) and Coulomb SR : HP 2010 (03-104,05-110)
- HAPPEx III and G0 (Hall C) : HP 2010 (05-019)
- PRex : neutron radius in Pb (06-002)
- High momentum shell structure in ^{208}Pb (06-007)
- d2 : higher twist spin structure : HP 2011 (06-014)

Hall B:

- e^{+}-e^{-} comparison (test two-γ exchange) : HP 2010 (04-116)
- DVCS at 6 GeV: HP 2008 (05-013)
- Baryon Resonance Program: HP 2009 (02-112, 04-102, 06-013)
- Exotics & Pentaquarks (04-015, 04-017)

Highest Scientific Priorities (cont.)

Hall C:

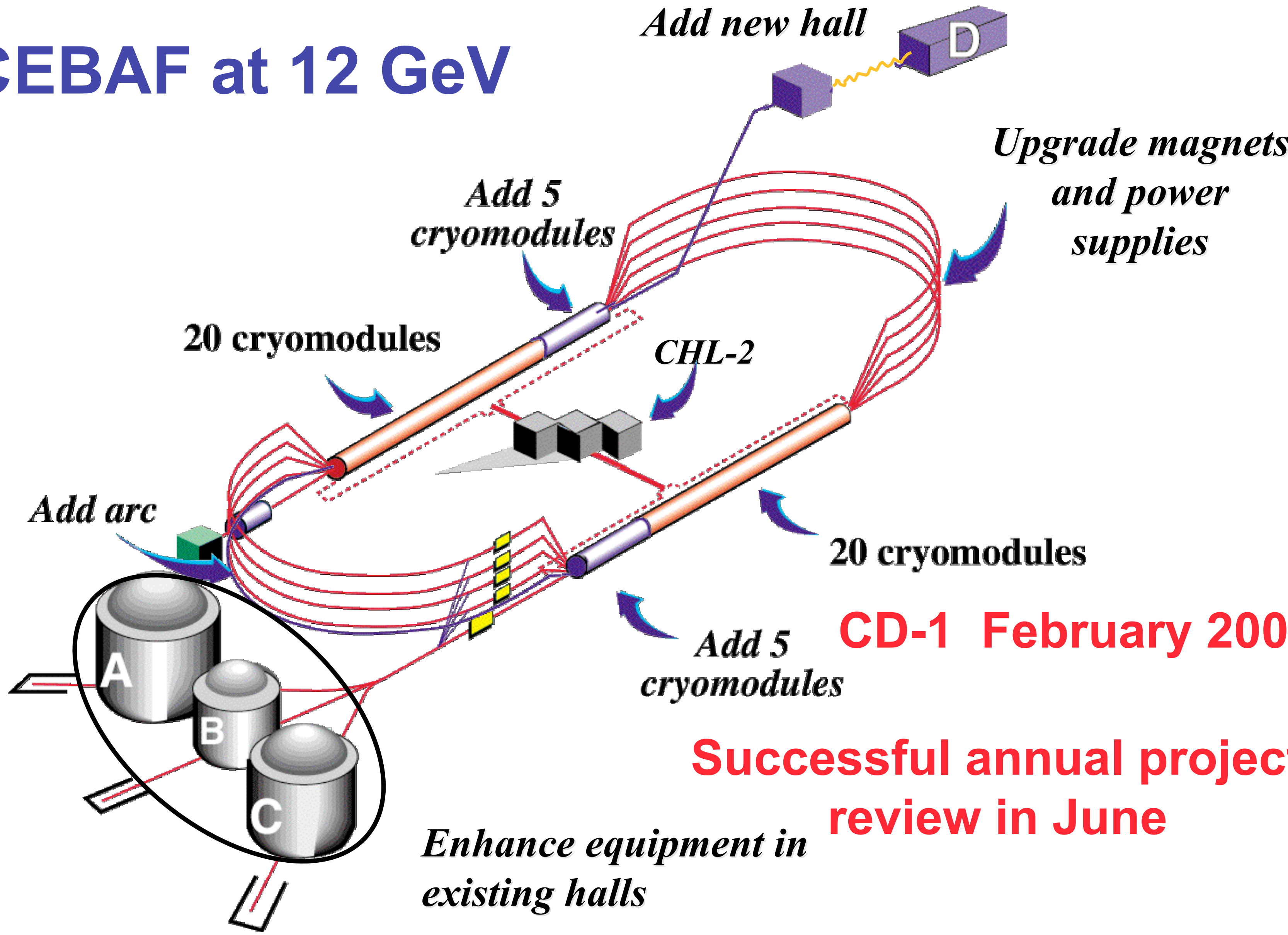
- **G0** (04-115, 06-008) **: HP 2010**
- **G_{Ep} to Q^2=9 GeV^2 : HP 2010** (04-018)
- **Q_{weak}** (05-008)
- **Hypernuclear Spectroscopy (HKS)** (05-115)
- **SANE and semi-SANE : HP 2011 and 2013** (03-109, 04-113)

These experiments must be done!

Under President's FY07 and current 12 GeV schedule expect to complete essentially all approved experiments.

Consultation with PAC, Users (and JSA Science Council) will guide management decisions if scenario changes.

CEBAF at 12 GeV



CD-1 February 2006

Successful annual project review in June

Highlights of the 12 GeV Program

- Revolutionize Our Knowledge of Spin and Flavor Dependence of Valence PDFs

- Revolutionize Our Knowledge of Distribution of Charge and Current in the Nucleon

- Totally New View of Hadron (and Nuclear) Structure: GPDs
  - Determination of the quark angular momentum

Highlights of the 12 GeV Program….2

- Exploration of QCD in the Nonperturbative Regime:
  - ➢ Existence and properties of exotic mesons
- New Paradigm for Nuclear Physics:
  Nuclear Structure in Terms of QCD
  - ➢ Spin and flavor dependent EMC Effect
  - ➢ Study quark propagation through nuclear matter
- Precision Tests of the Standard Model
  - ➢ Factor 20 improvement in $(2C_{2u}-C_{2d})$

Planning for 12 GeV Science and Construction – Formal Start with PAC30 : August 21-24, 2006

Basic process similar to that for original CEBAF construction:

User proposals combining science to be done in the 12 GeV era with commitments to equipment construction

PAC review of the science proposals

Construction commitments will be included in the project plan

A major review of the science program 2-3 years prior to the start of 12 GeV physics to define scientific priorities

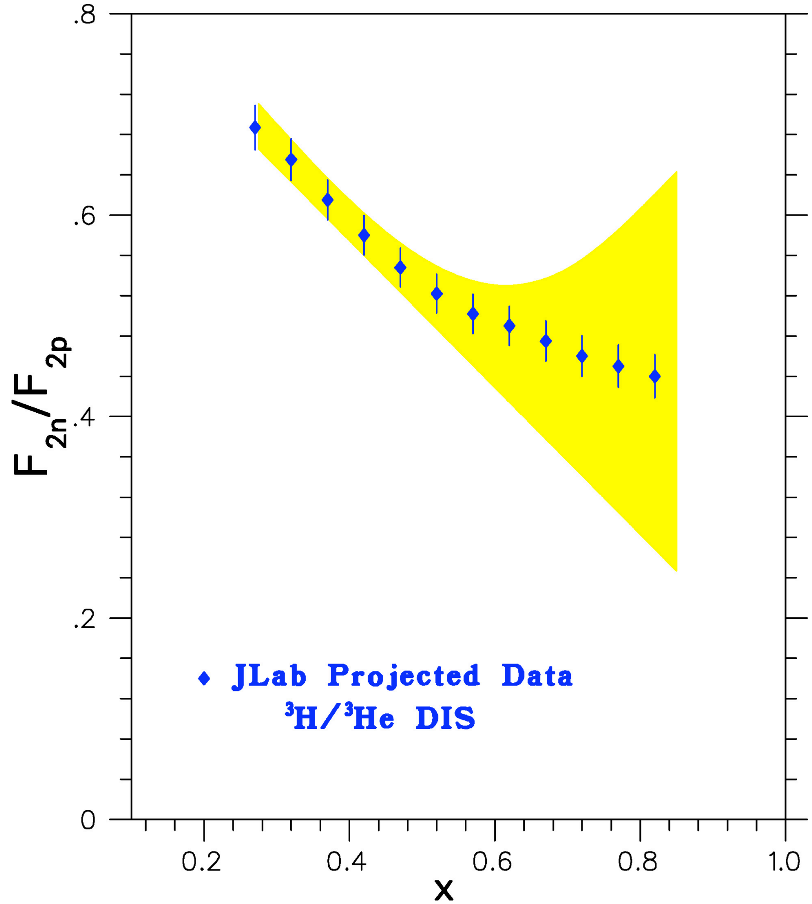
Startup of Physics driven hall-by-hall by a combination of commissioning requirements and scientific priorities (with PAC review and comment on the plans, hall-by-hall)

6 GeV Highlights Leading to the 12 GeV Upgrade

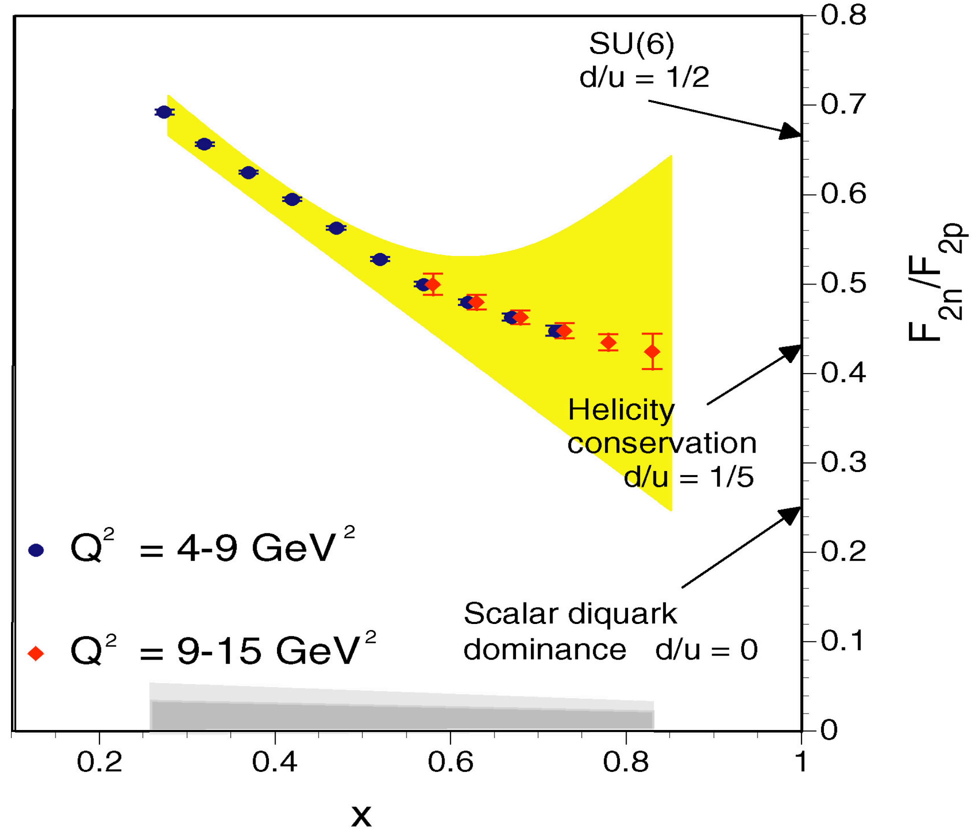
- **Parton Distribution Functions**
- **Form Factors**
- **Generalized Parton Distributions**
- **Exotic Meson Spectroscopy: Confinement and the QCD vacuum**
- **Nuclei at the level of quarks and gluons**
- **Tests of Physics Beyond the Standard Model**

12 GeV : Unambiguous Flavor Structure x! 1

Hall C 11 GeV with HMS

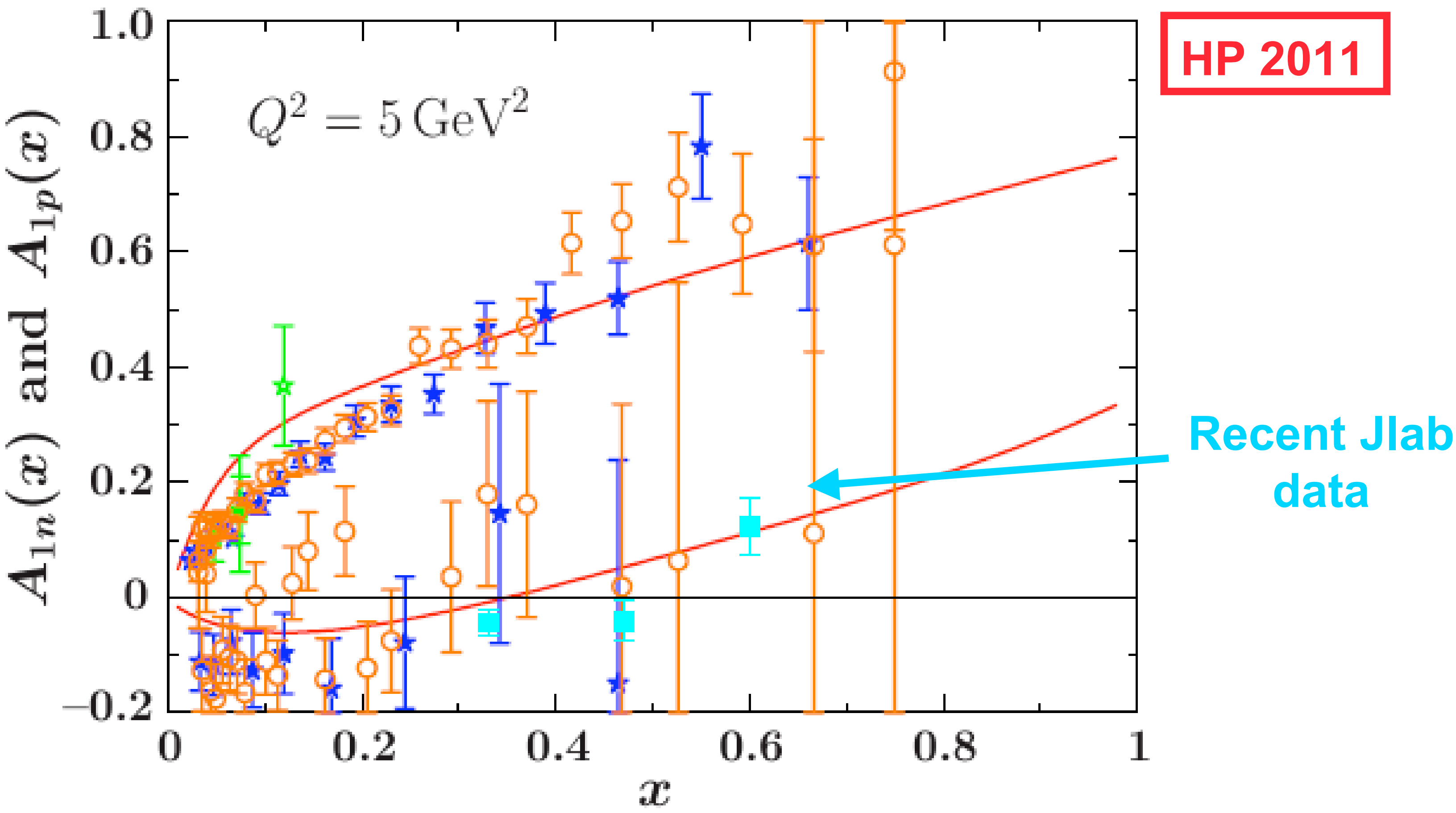


HallB 11 GeV with CLAS12



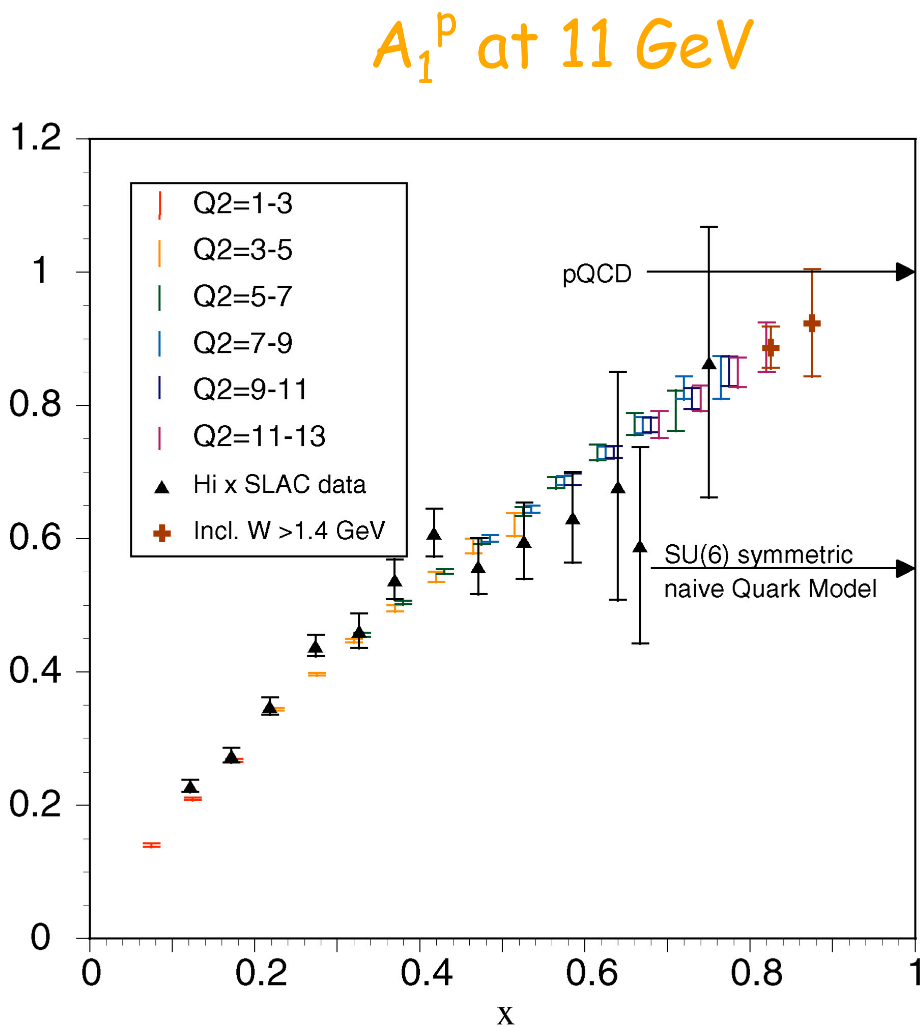
Initial investigation with BONUS early 06
- talks of L. Cardman and D. Skopik

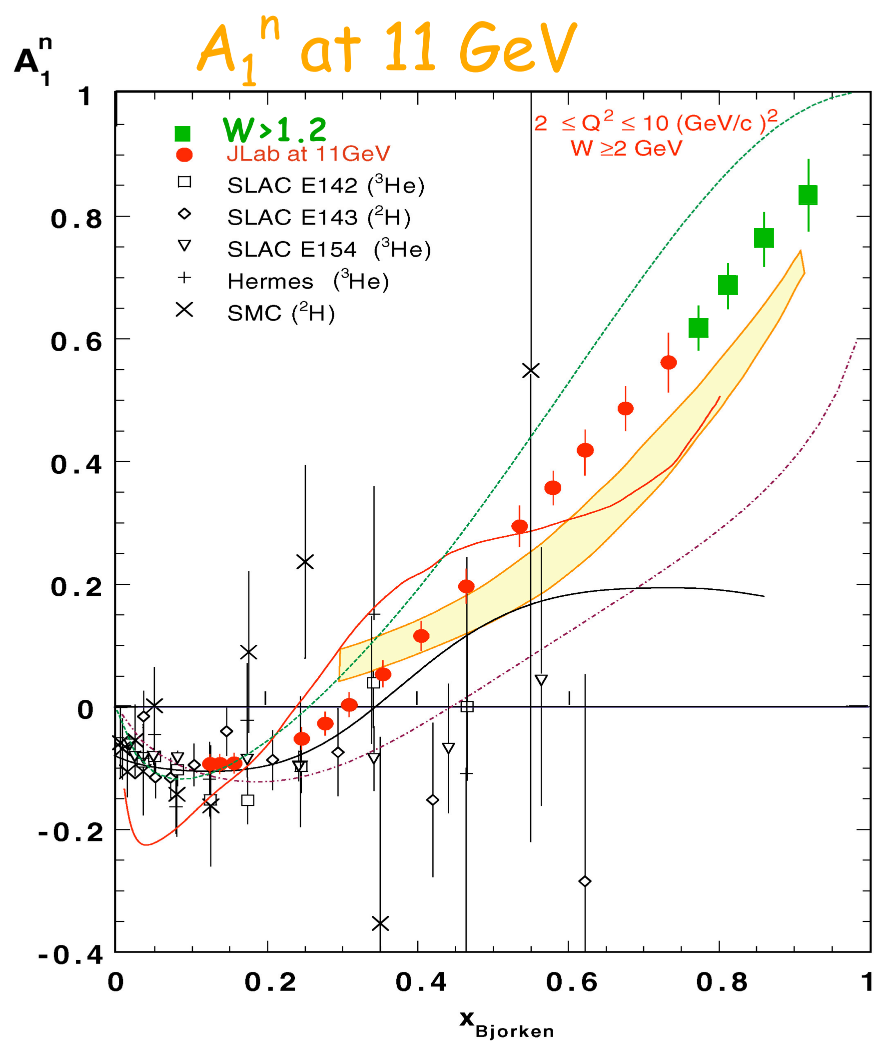
Proton and Neutron Asymmetry



Cloet, Bentz, AWT, (Phys. Lett. B621 (2005) 246)

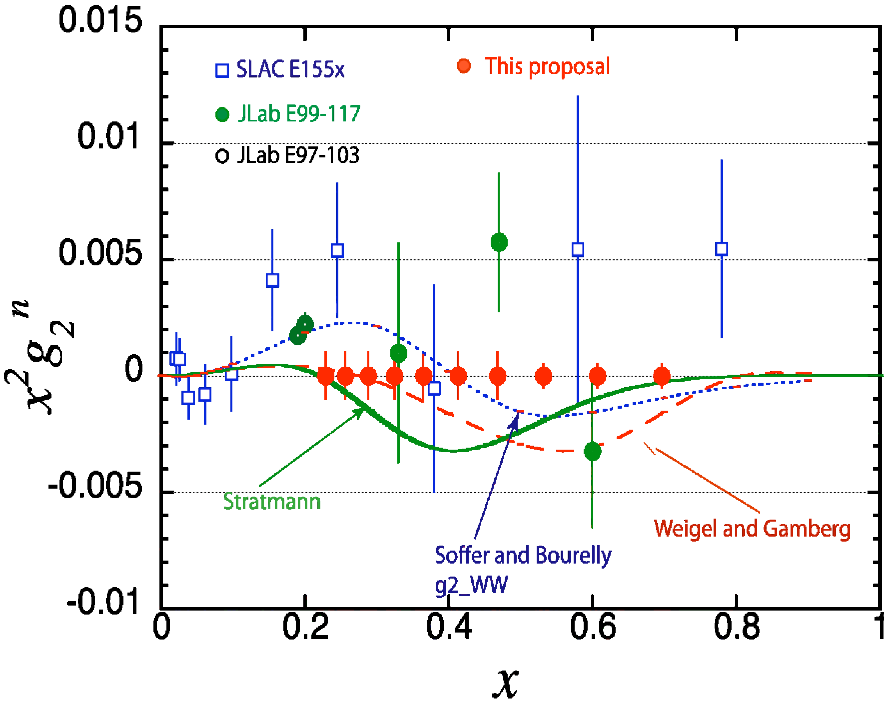
12 GeV : Unambiguous Resolution of Valence Spin

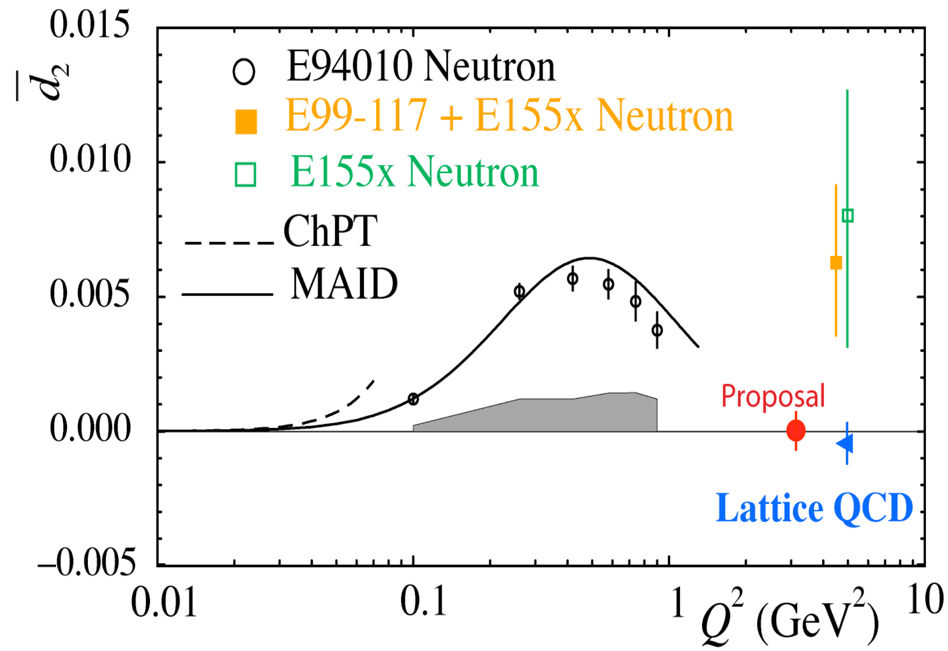




Precision Measurement of d_2^n (late 2007)

E06-014 : Seonho Choi, Xiaodong Jiang, Zein-Eddine Meziani, Brad Sawatzky (Jian-ping Chen)





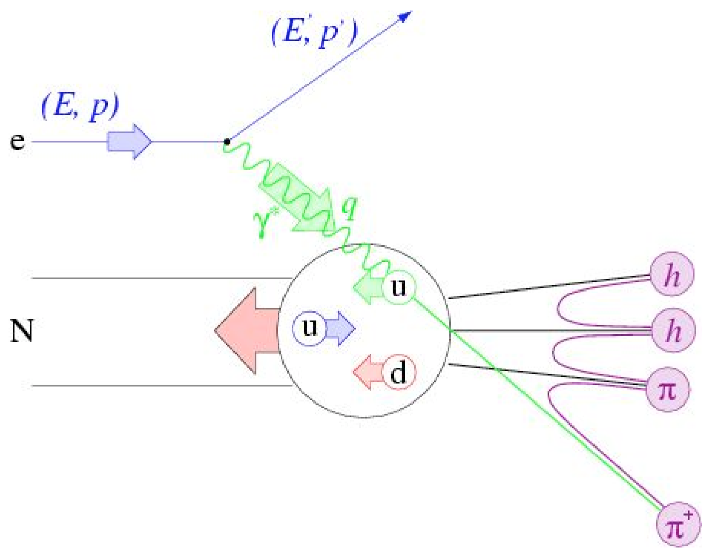
- Use of BigBite significantly shortens required beam time
- Information on quark-gluon correlations in the neutron
- Access color polarizabilities through d_2 and f_2
- Benchmark test of Lattice QCD

HP2011

Flavor Decomposition: semi-inclusive DIS

DIS probes only the sum of quarks and anti-quarks → requires assumptions on the role of sea quarks

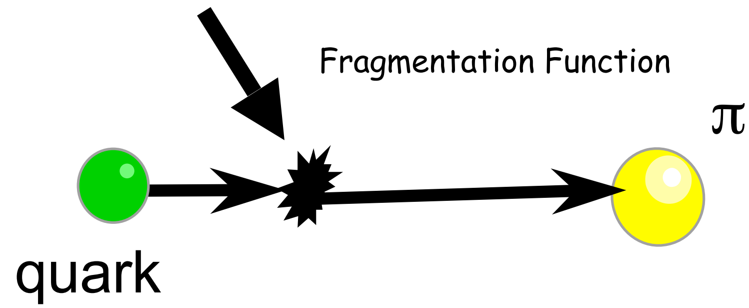
$$\sum e_q^2 (q + \bar{q})$$



Solution: Detect a final state hadron in addition to scattered electron

→ Can 'tag' the flavor of the struck quark by measuring the hadrons produced: 'flavor tagging'

$$\sum e_q^2 \, q(x) \, D_{q \to M}(z)$$



(e,e') $W^2 = M^2 + Q^2 (1/x - 1)$

For M_m small, $\vec{p}_m$ collinear with $\vec{\gamma}$, and $Q^2/\nu^2 \ll 1$

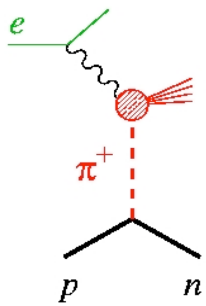
(e,e'm) $W'^2 = M^2 + Q^2 (1/x - 1)(1 - z)$

$z = E_m/\nu$

Flavor asymmetry of proton sea: Quarks or mesons?

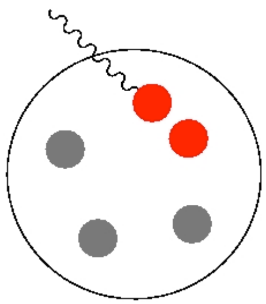
HP 2013

...New: Polarization!



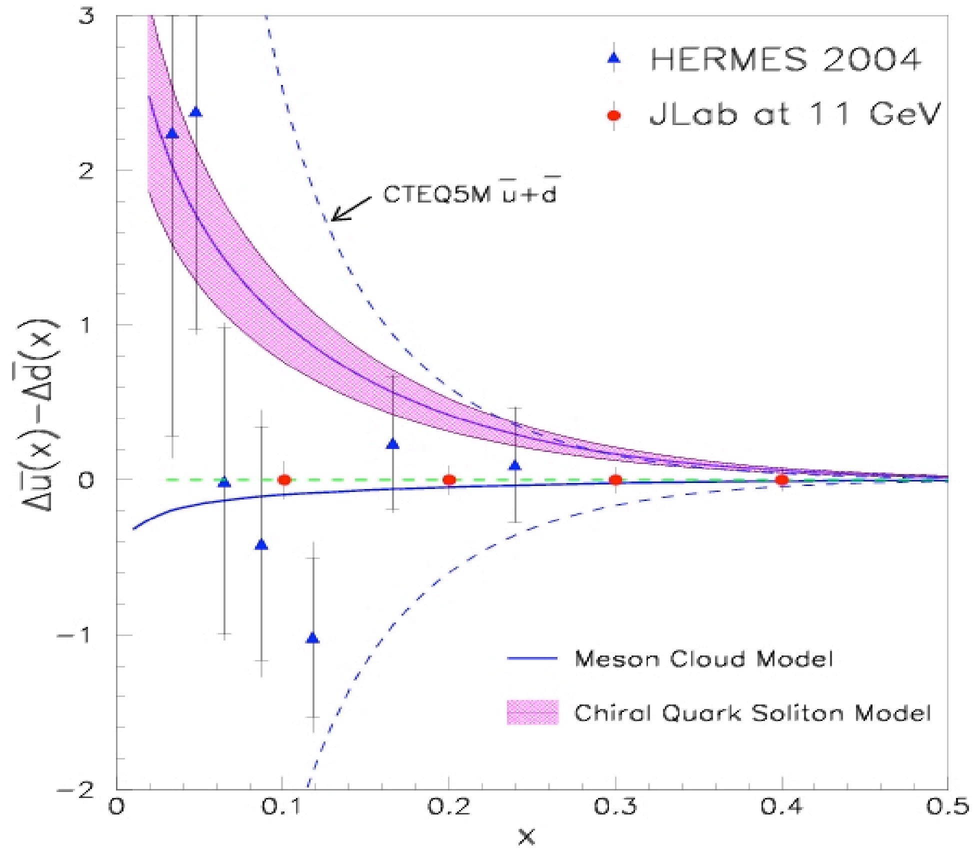
pion cloud

$\Delta\bar{u} - \Delta\bar{d} = 0$



$q\bar{q}$ pair
(Pauli blocking)

$\Delta\bar{u} - \Delta\bar{d} > 0$



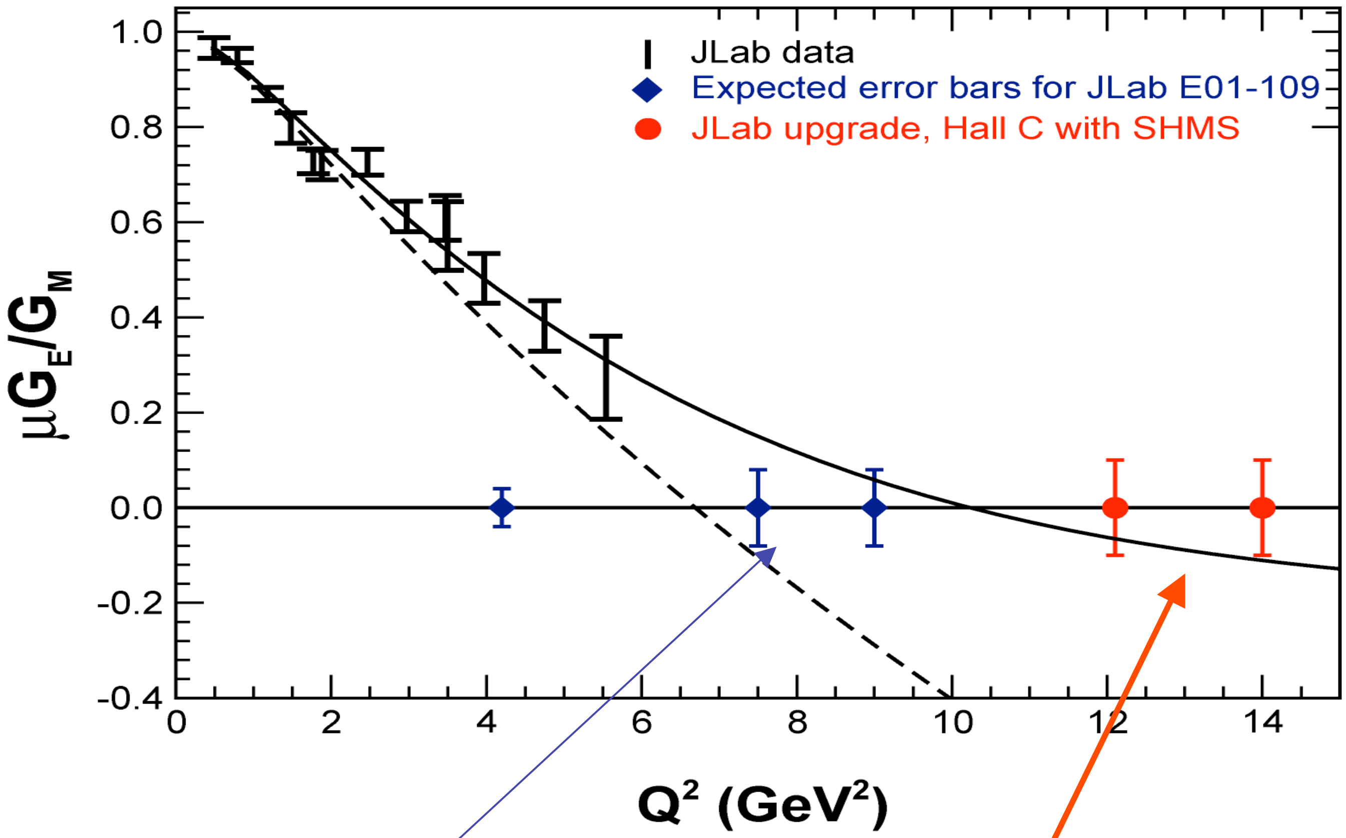
[Thomas 83; Schreiber *et al.*, 90; Diakonov *et al.* 96; Fries, Schaefer, Weiss 03]

...Can be answered by initial SIDIS measurements in 2009 and fully with 12 GeV

6 GeV Highlights Leading to the 12 GeV Upgrade

- Parton Distribution Functions
- Form Factors
- Generalized Parton Distributions
- Exotic Meson Spectroscopy:
  Confinement and the QCD vacuum
- Nuclei at the level of quarks and gluons
- Tests of Physics Beyond the Standard Model

Revolutionize Our Knowledge of Distribution of Charge and Current in the Nucleon



HP 2010

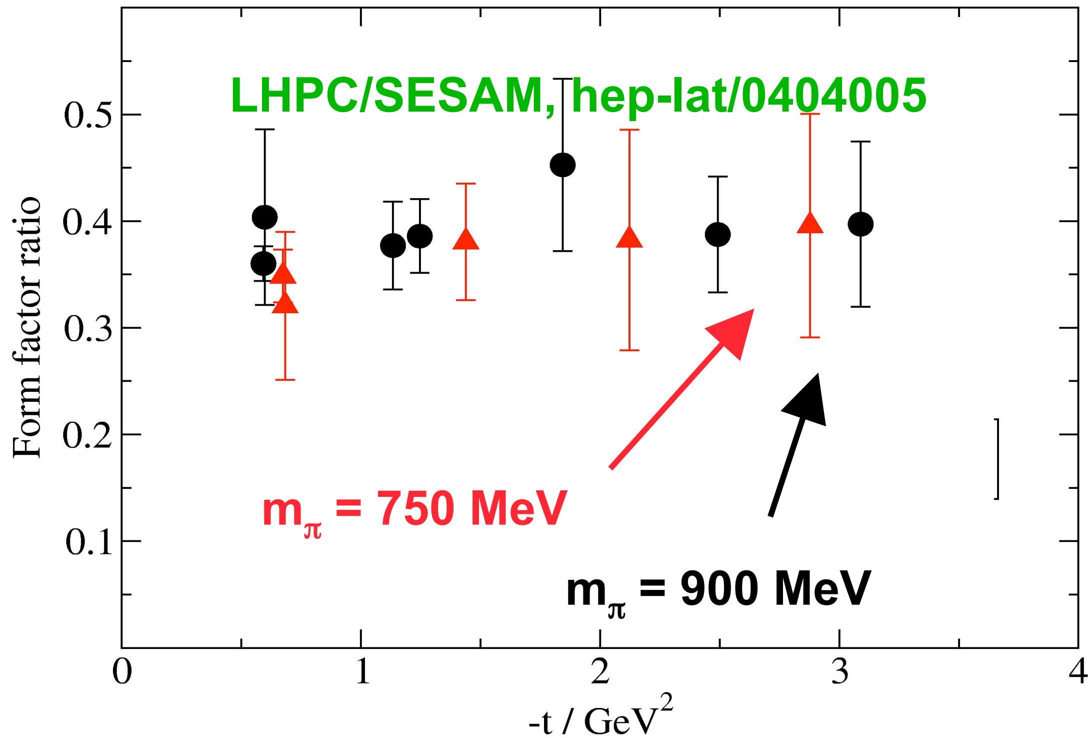
- Perdrisat *et al*. E01-109 _ will increase range of Q^2 by 50% in 2007 (range of Q^2 for n will double over next 3-4 years)
- With 12 GeV and SHMS in Hall C

Elastic Nucleon Form Factors $G^{p(n)}_{E,M}(Q^2)$

Magnetic Moments ($Q^2 = 0$) known experimentally to high precision

Large Q^2 behavior controlled by lattice spacing *a*

Need to work on fine lattice

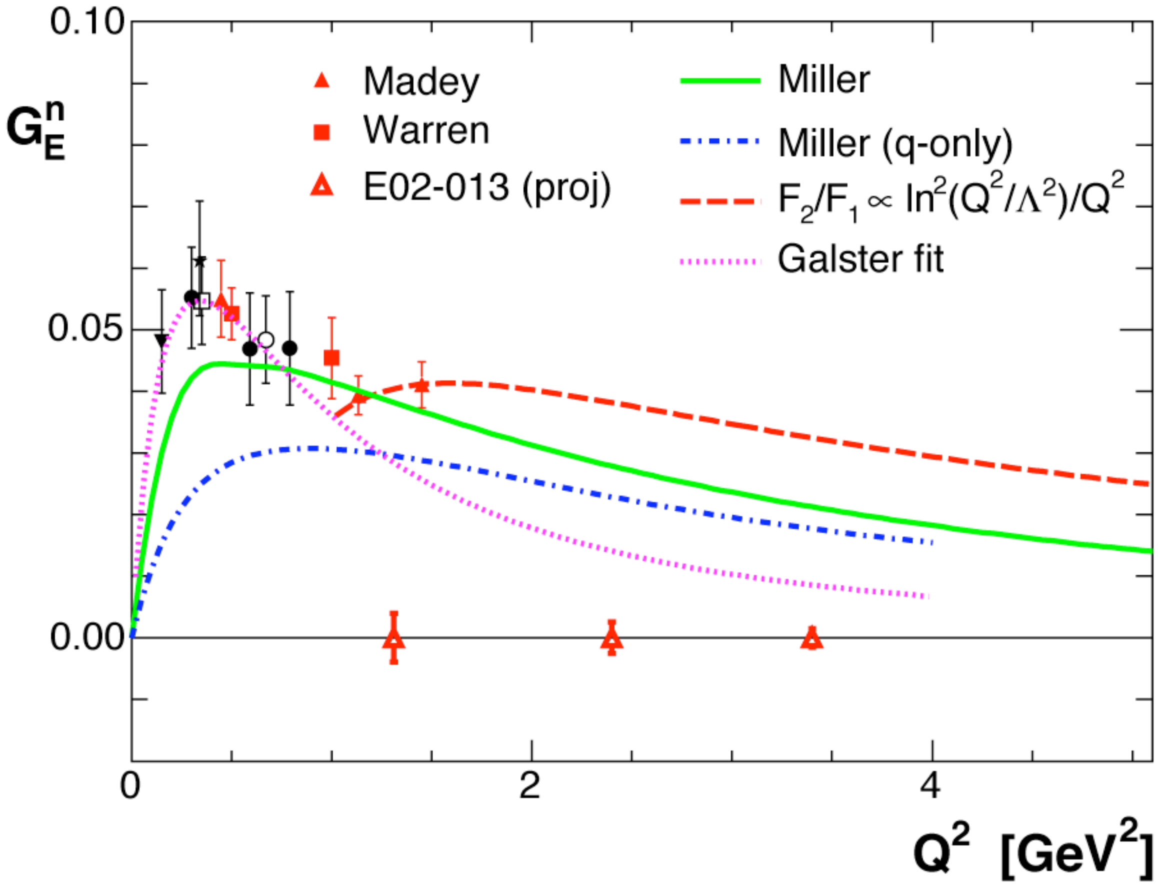


- **Importance of pQCD corrections**
  Brodsky
- **pQCD computation**
  Belitsky, Ji, Yuan

$$\frac{Q^2 F_2(Q^2)}{\log^2(Q^2/\Lambda^2) F_1(Q^2)} \simeq \text{const}$$

- **Q^2 ' 6 GeV^2 : R. Edwards talk**

Neutron Electric Form Factor G_E^n



HP 2010

- **Will extend Q^2-range to double that presently available, essential for tests of GPD models**
- **Role of pion cloud**
- **Relativistic effects important ingredient**
- **Data test if "log scaling" is applicable at similar low Q^2-values as observed for G_E^p**

Experiment completed on May 10 this year.

E02-013: Gordon Cates, Kathy McCormick, Nilanga Liyanage, Bogdan Wojtsekhowski, Bodo Reitz

Strangeness Widely Believed to Play a Major Role – Does It?

- As much as 100 to 300 MeV of proton mass??

$$M_N = \langle N(P)| -\frac{9\alpha_s}{4\pi}\mathrm{Tr}(G_{\mu\nu}G^{\mu\nu}) + m_u\bar{\psi}_u\psi_u + m_d\bar{\psi}_d\psi_d + m_s\bar{\psi}_s\psi_s|N(P)\rangle$$

$$\Delta M_N^{s-\mathrm{quarks}} = \frac{y m_s}{m_u + m_d}\sigma_N$$

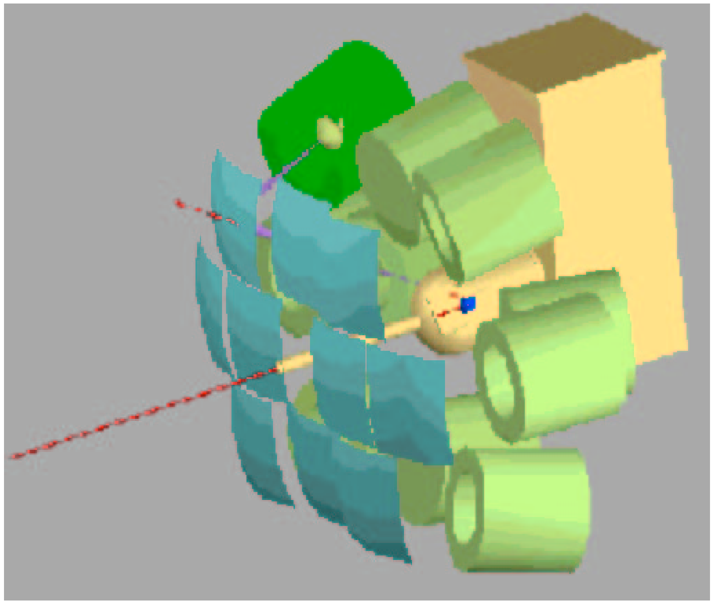
Through proton spin crisis:

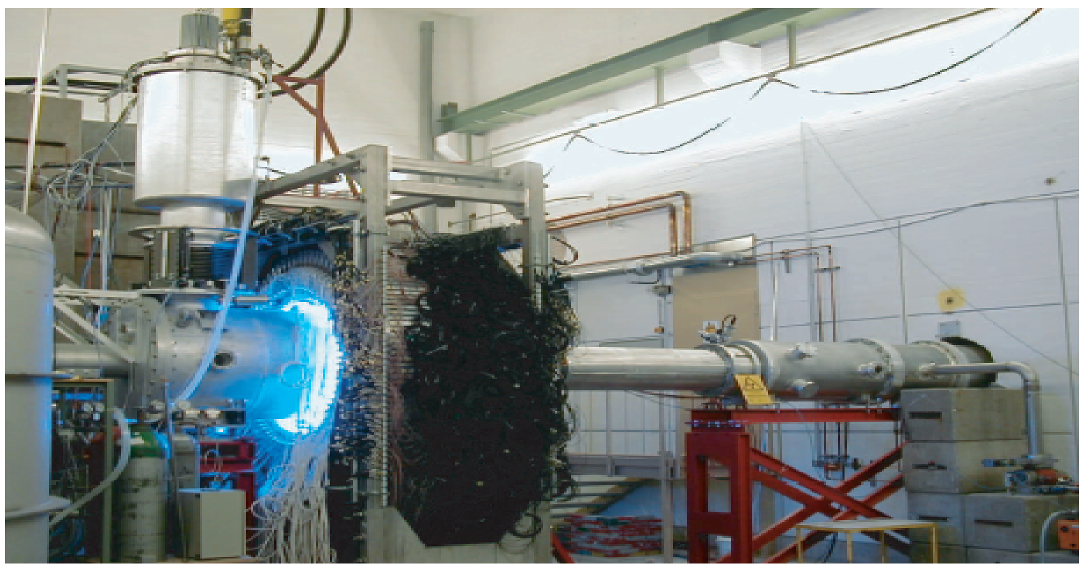
- as much as 10% of the spin of the proton??

HOW MUCH OF THE ELECTRIC & MAGNETIC FORM FACTORS ?

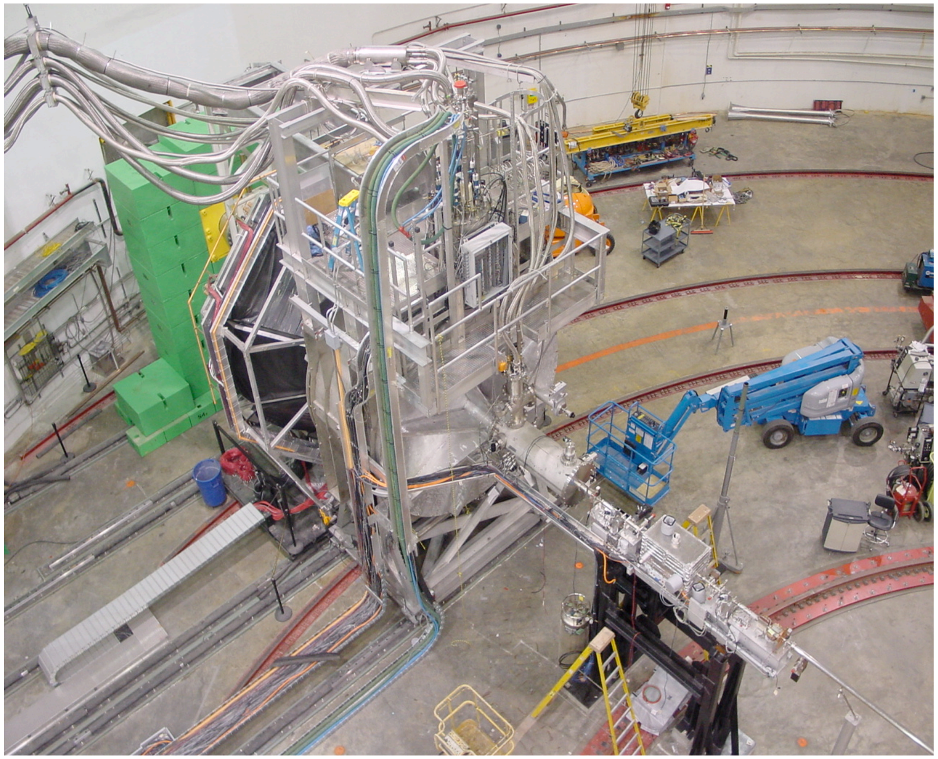
HP 2010

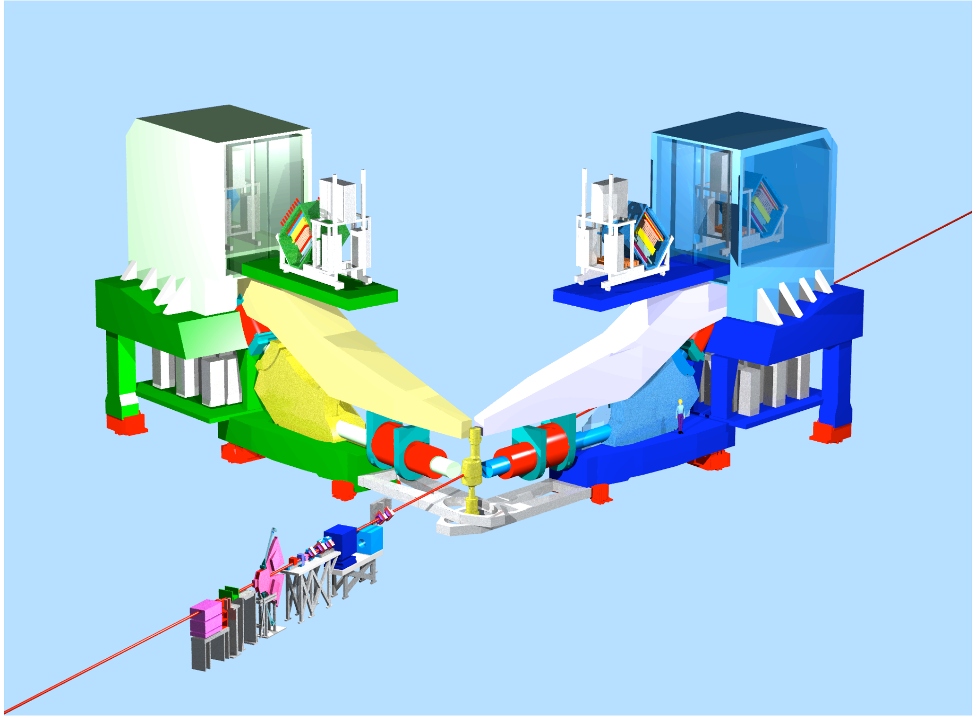
Major International Effort Past 10 Years



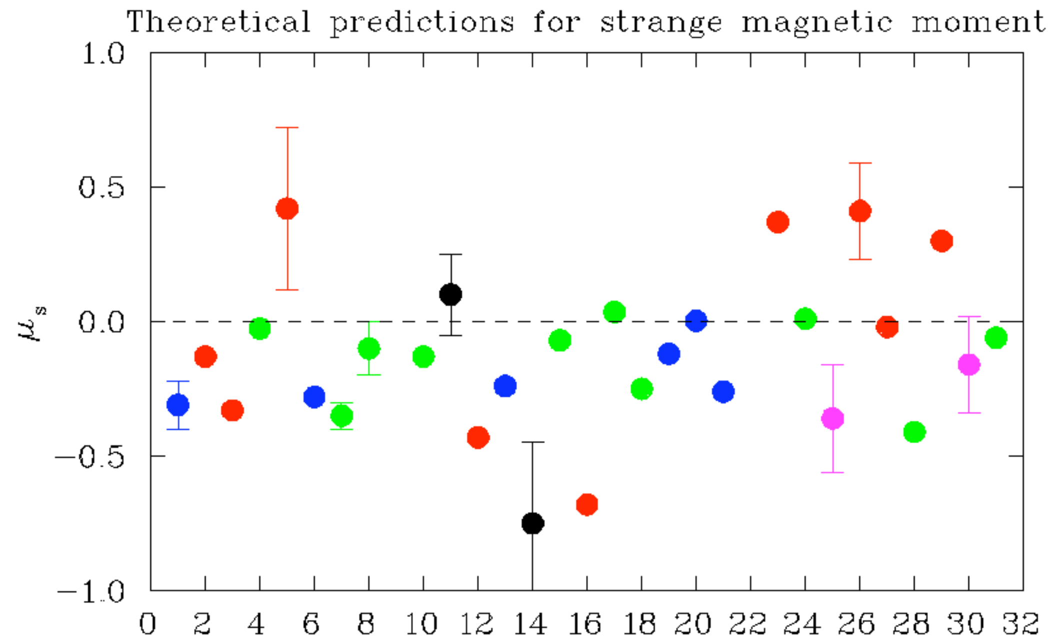


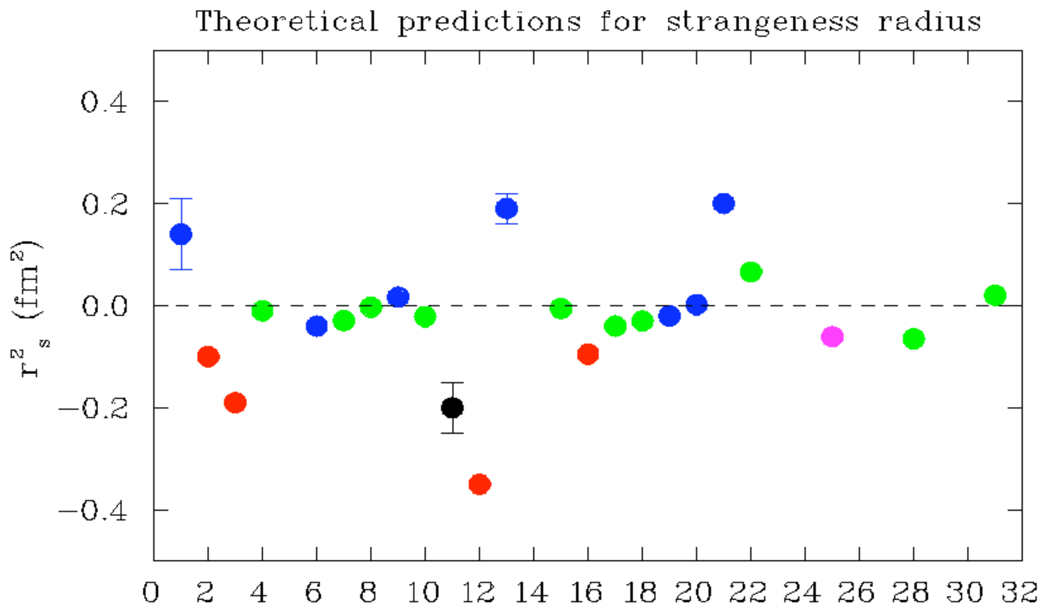
G0 and HAPPEx at Jlab





Early Theoretical predictions at $Q^2 = 0$





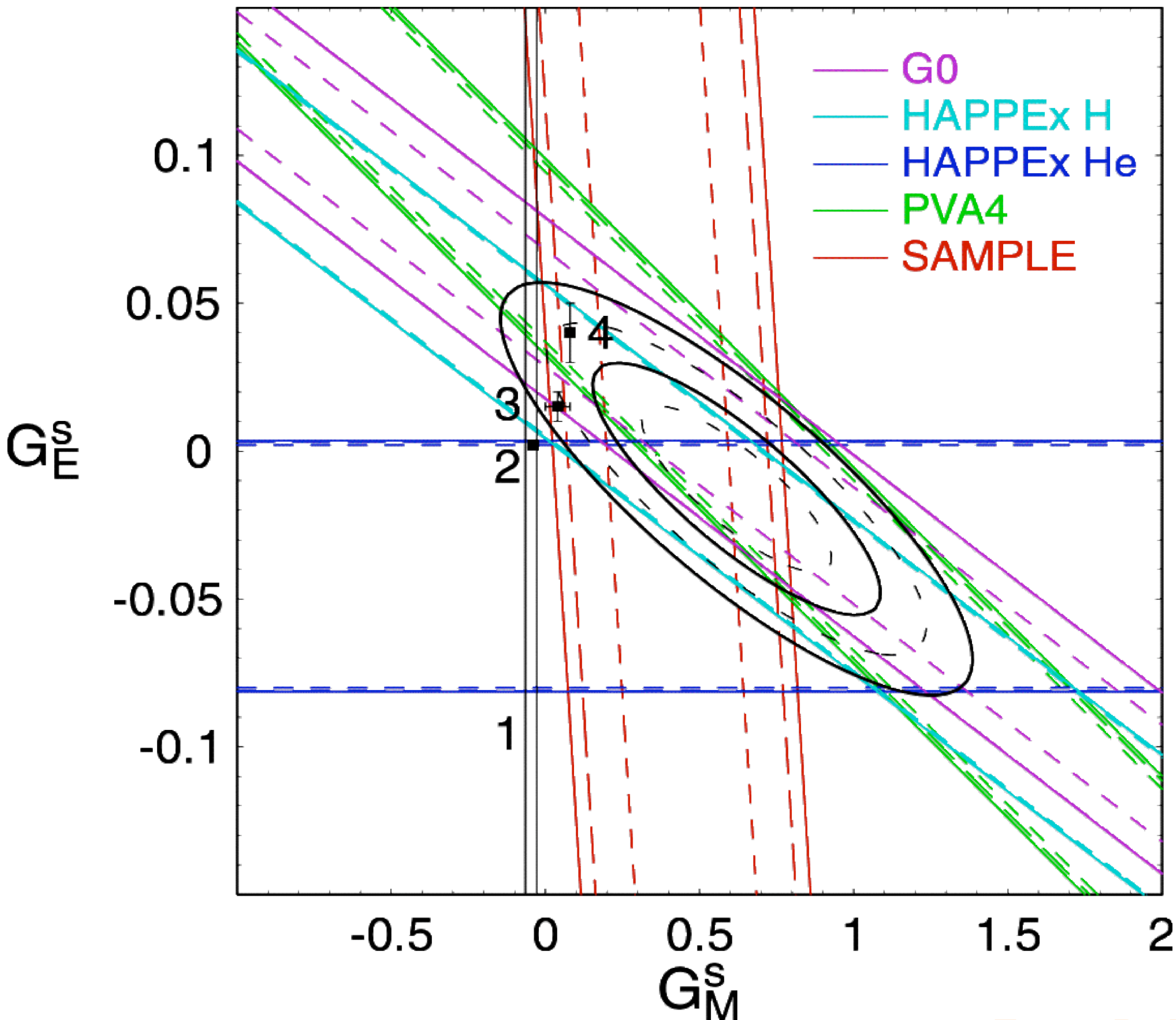
$$\mu_s \equiv G^s_M(Q^2 = 0)$$

Non-zero value of $G^s{}_E$ or $G^s{}_M$ requires spatial separation of s and s

$$r_s^2 \equiv -6\left[\frac{dG^s_E}{dQ^2}\right]_{Q^2=0}$$

from Mark Pitt

Strange Quark Form Factors at $Q^2 = 0.1\ GeV^2$



July 2005

$G_E^s = -0.013 \pm 0.028$

$G_M^s = +0.62 \pm 0.31\ \mu_N$

Theories

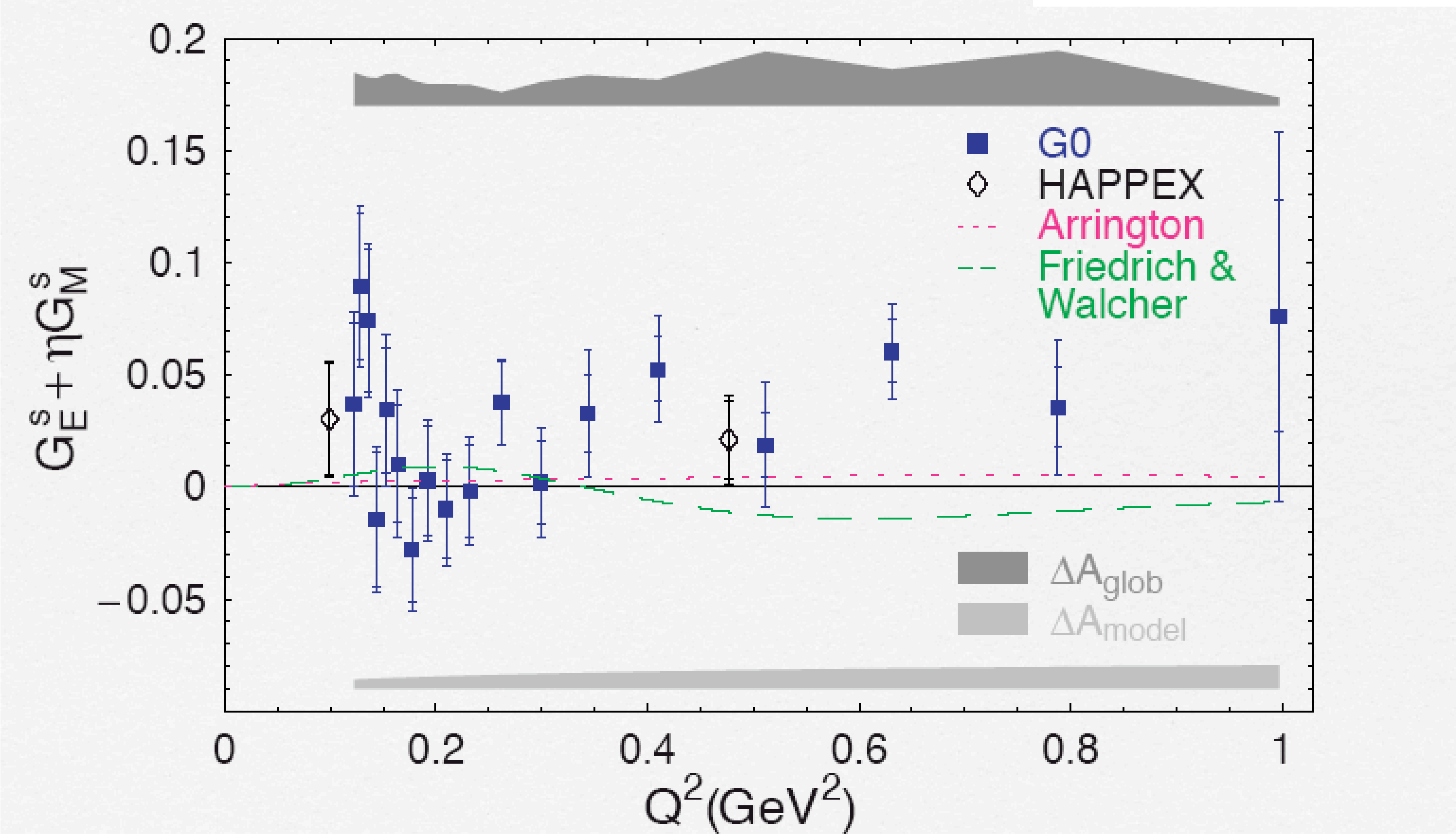
1. Leinweber, et al.
   PRL **94** (05) 212001
2. Lyubovitskij, et al.
   PRC **66** (02) 055204
3. Lewis, et al.
   PRD **67** (03) 013003
4. Silva, et al.
   PRD **65** (01) 014016

From D. Beck

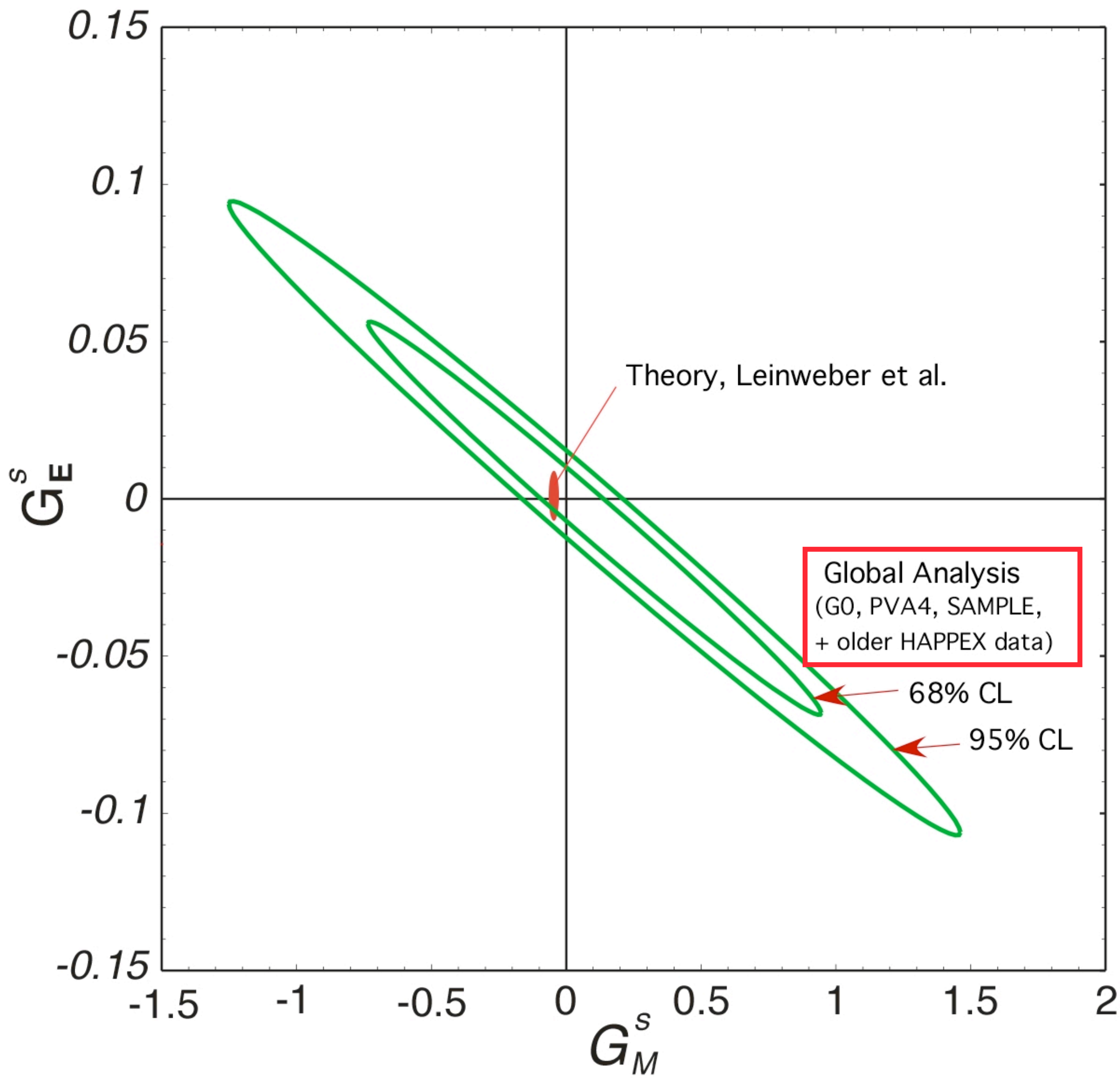
http://www.npl.uiuc.edu/exp/G0/Forward

Ross Young (Theory) & Colleagues: Why not use ALL the data?

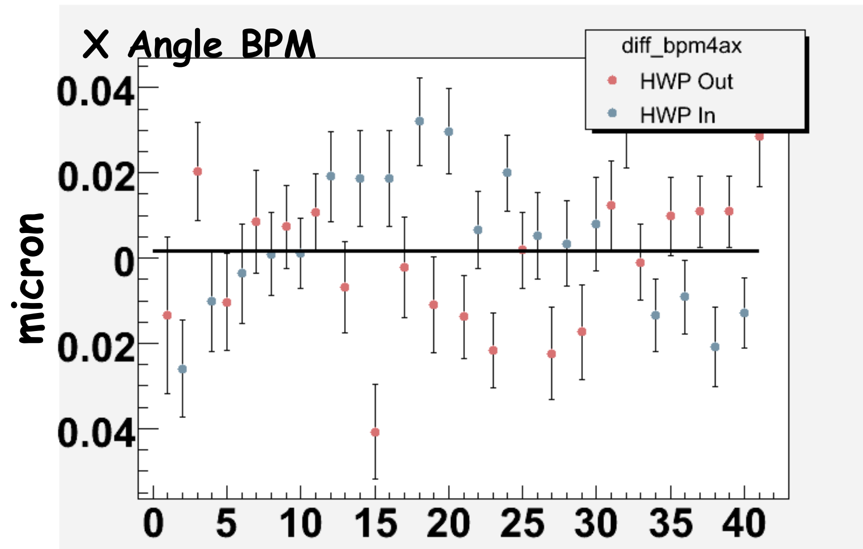
No theoretical constraint (other than charge symmetry) ; use systematic Taylor expansion of $G_{E,M}{}^{s}$ in of powers Q^2

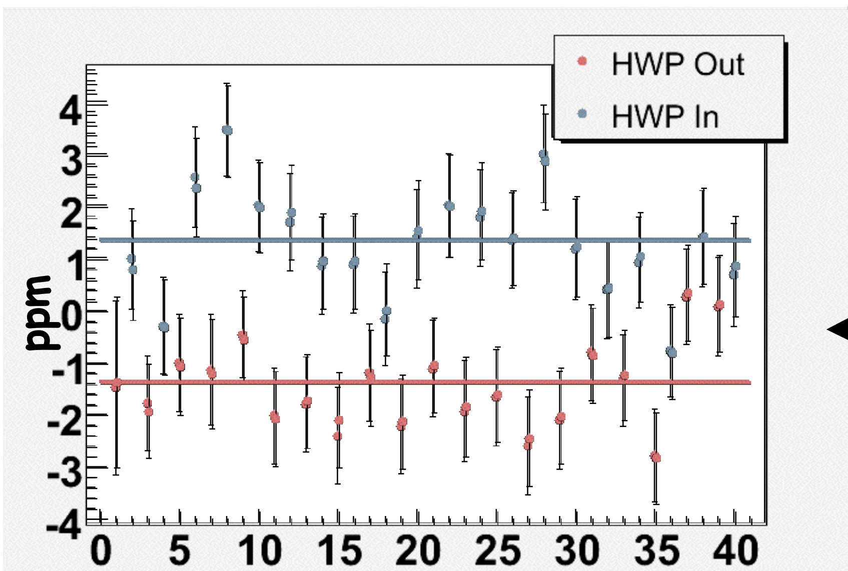


Young, Roche, Carlini, Thomas – nucl-ex/0604010 (pre- latest HAPPEx)



Latest HAPPEx Run : Outstanding Achievement !





Surpassed Beam Asymmetry Goals for Hydrogen Run

Energy: -0.25 ppb

X Target: 1 nm

X Angle: 2 nm

Y Target : 1 nm

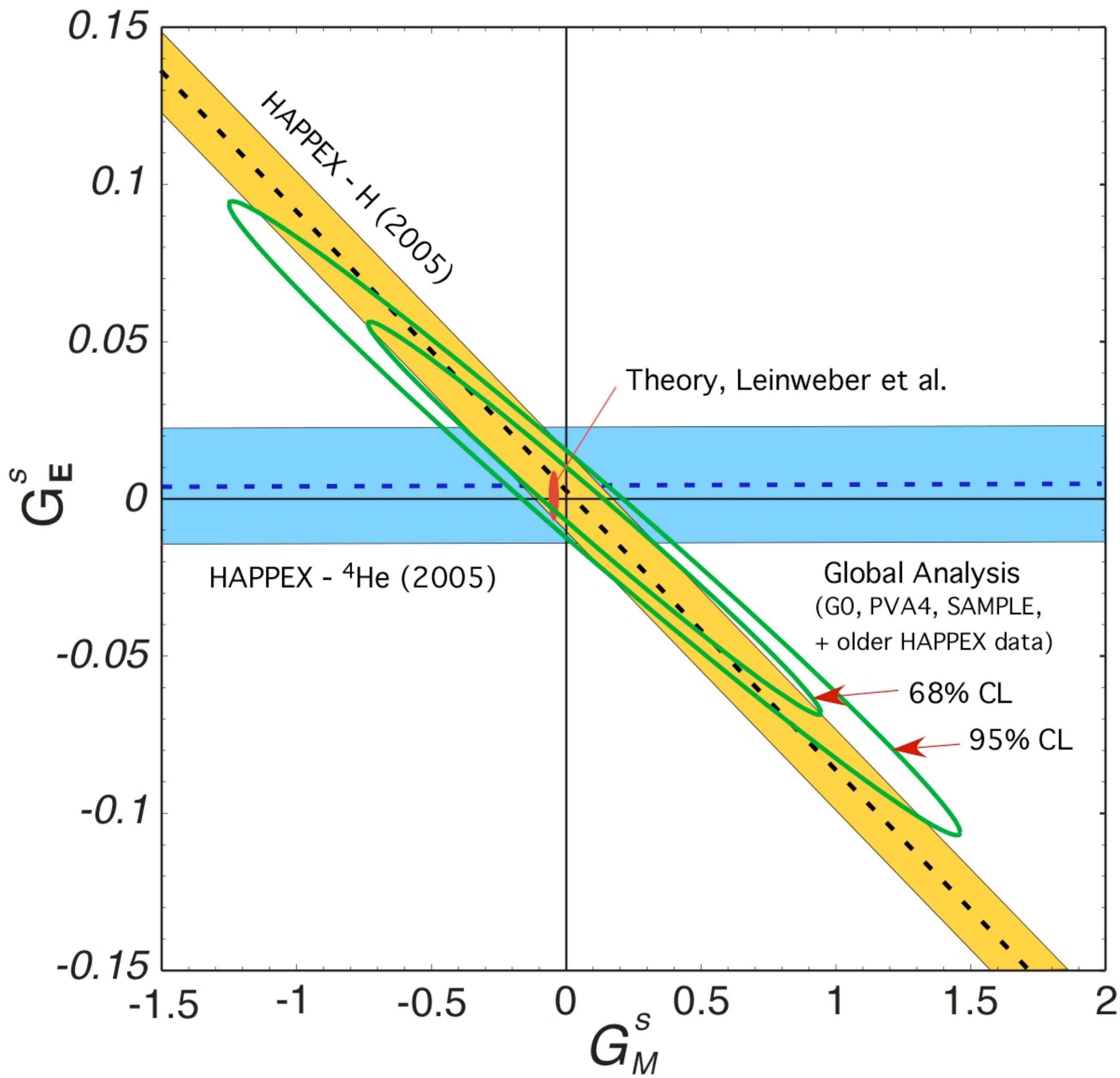
Y Angle: <1 nm

← **Corrected and Raw**

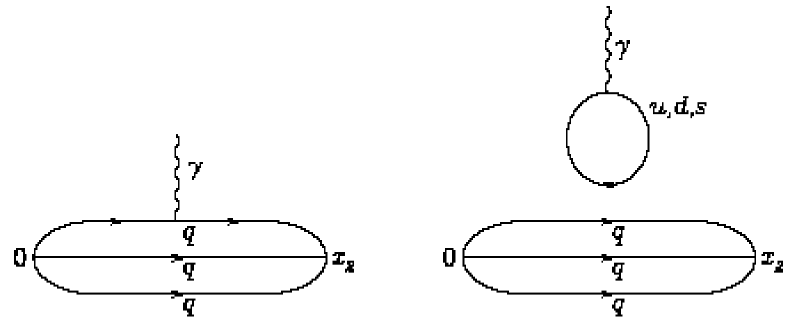
Total correction for beam position asymmetry on Left, Right, or ALL detector: 10 ppb

from Kent Paschke

Superimpose NEW HAPPEx Measurement (April APS Meeting)



Magnetic Moments within QCD



CS

$p = 2/3\, u^p - 1/3\, d^p + O_N$

$n = -1/3\, u^p + 2/3\, d^p + O_N$

$\Rightarrow$ $2p + n = u^p + 3\, O_N$

(and $p + 2n = d^p + 3\, O_N$)

$\Sigma^+ = 2/3\, u^\Sigma - 1/3\, s^\Sigma + O_\Sigma$

$\Sigma^- = -1/3\, u^\Sigma - 1/3\, s^\Sigma + O_\Sigma$

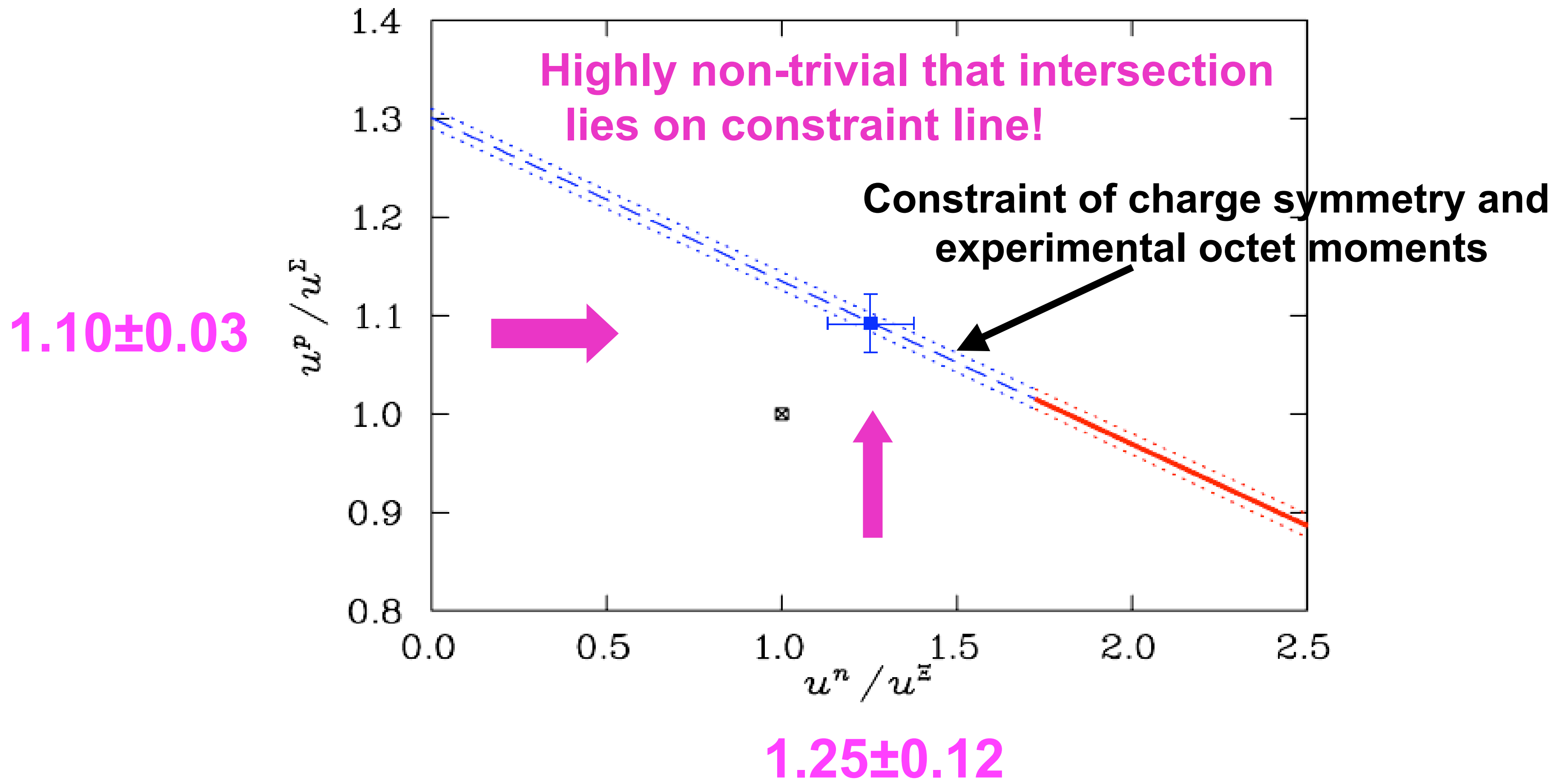
$\Rightarrow$ $\Sigma^+ - \Sigma^- = u^\Sigma$

HENCE: $O_N = 1/3\, [\, 2p + n - (\, u^p / u^\Sigma\,)\, (\Sigma^+ - \Sigma^-)\,]$

Just these ratios from Lattice QCD

OR $O_N = 1/3\, [\, n + 2p - (\, u^n / u^\Xi\,)\, (\Xi^0 - \Xi^-)\,]$

Modern Lattice QCD Result for G_M^s



Yields :$G_M^s = -0.046 \pm 0.019\ \mu_N$

Leinweber et al., (PRL June '05) hep-lat/0406002

January 2006: G_E^s by same technique

In this case only know Σ^- radius (and p and n)

) $<r^2>_s$ = - 0.007 § 0.004 § 0.007 § 0.021 fm^2

More accurate, use absolute theoretical values of valence u and d charge radii:

2p +n = u ^{p} +3 O_N **p + 2n = d ^{p} + 3 O_N**

) $<r^2>_s$ = 0.000 § 0.006 § 0.007 fm^2 ; 0.002 § 0.004 § 0.004 fm^2

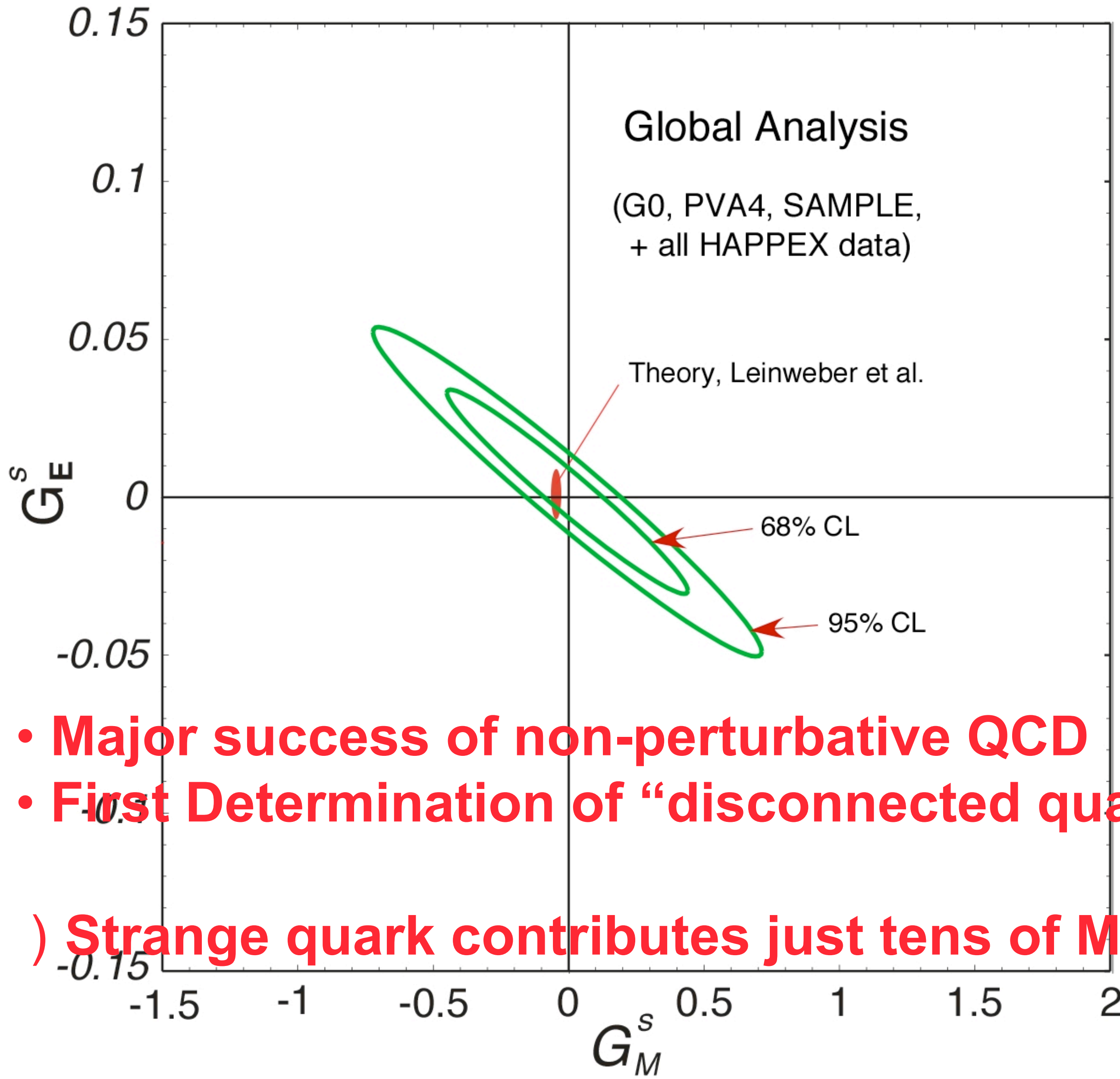
$$G_E^s(0.1\,\mathrm{GeV}^2) = +0.001 \pm 0.004 \pm 0.004$$

(up to order Q^4)

Note consistency and level of precision!

Leinweber, Young et al., hep-lat/0601025: Jan 2006

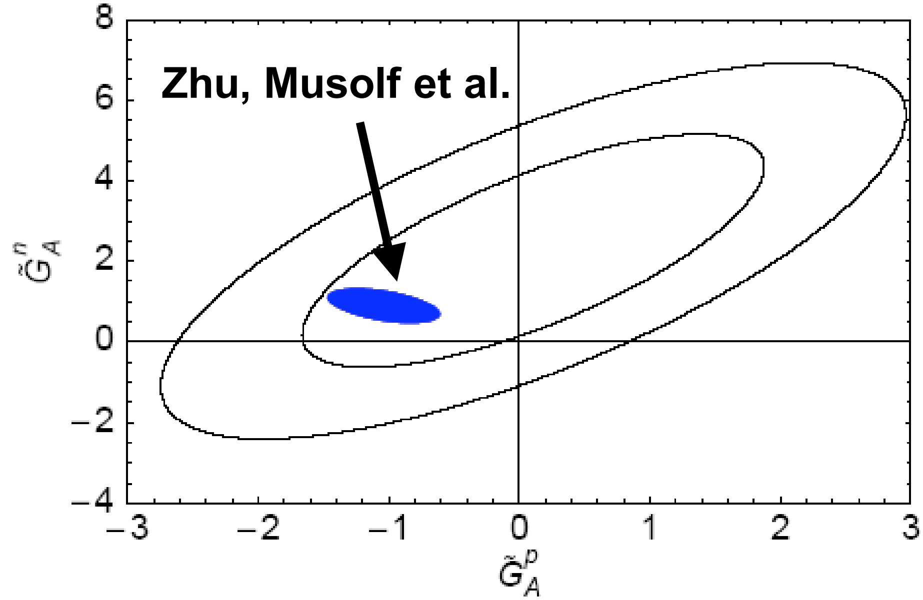
Include new HAPPEx data : halves errors of previous world data !



- **Major success of non-perturbative QCD**
- **First Determination of "disconnected quark loop"**

) Strange quark contributes just tens of MeV to M_N

Axial Form Factors: including anapole moment

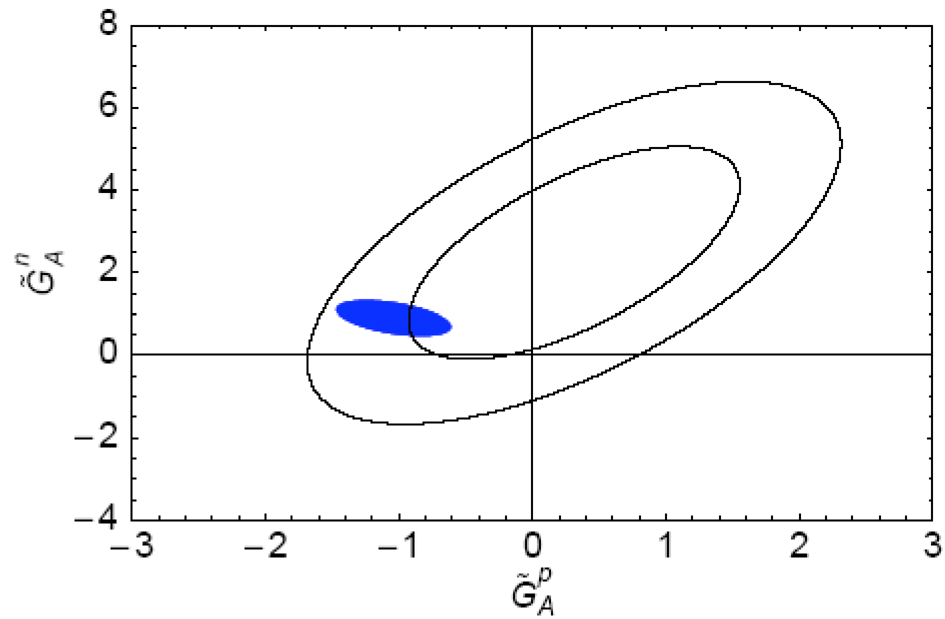


World Data pre-latest HAPPEx

(Young et al., nucl-ex/0604010)

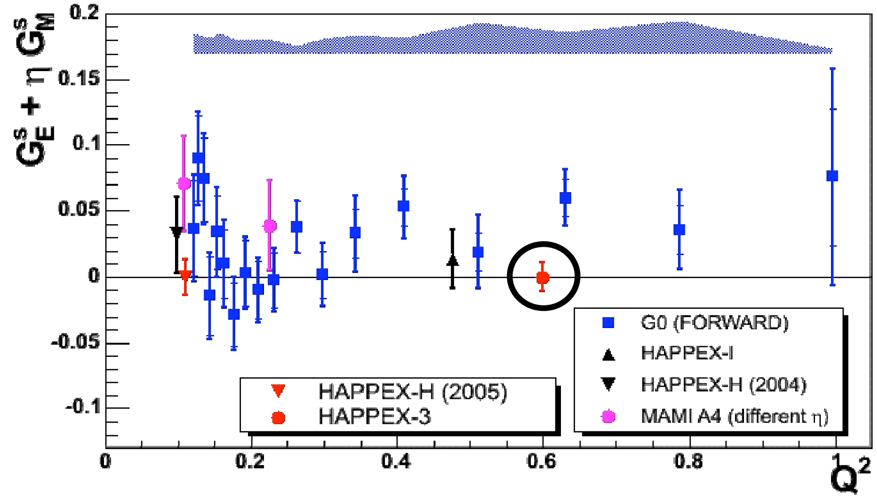
World Data with new HAPPEx

(Young, Roche, Carlini and Thomas, extended analysis)



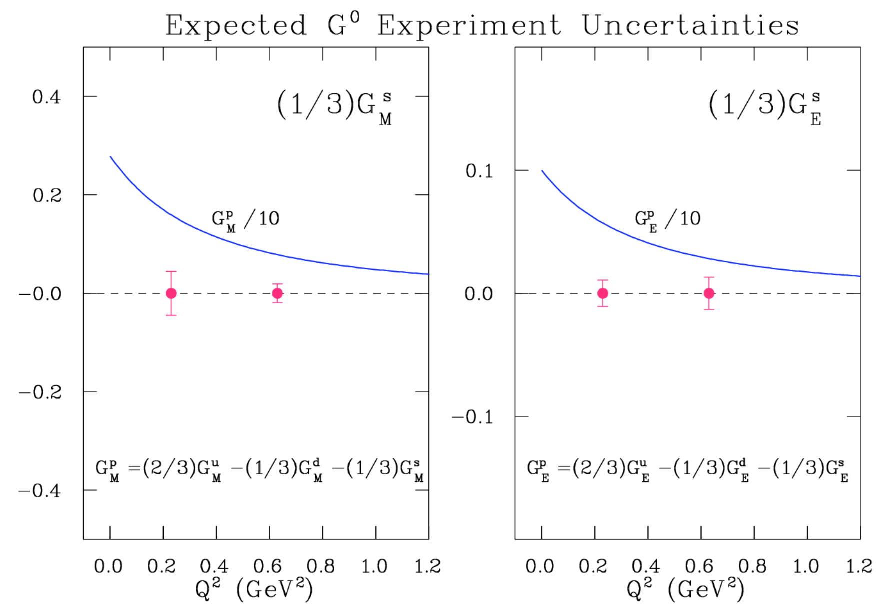
Strange Form Factor Measurements – Future Plans

HAPPEx: "HAPPEx3"
measure $G^s_E + 0.48G^s_M$ with high precision at Q^2~0.6 GeV^2



G^0: Turn experiment around

- detect electrons at θ = 108°
- add Cerenkov for pion rejection
- measure at Q^2 = .23 and .63 GeV^2
- LH_2 and LD_2 targets



Mainz A4: Turn experiment around

- detect electrons at θ = 145°
- Measure at Q^2 = .23 and .47 GeV^2
- LH_2 and LD_2 targets

from Mark Pitt

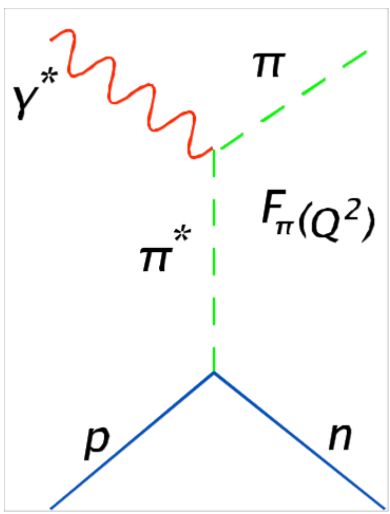
E01-004: New Pion Form Factor Data

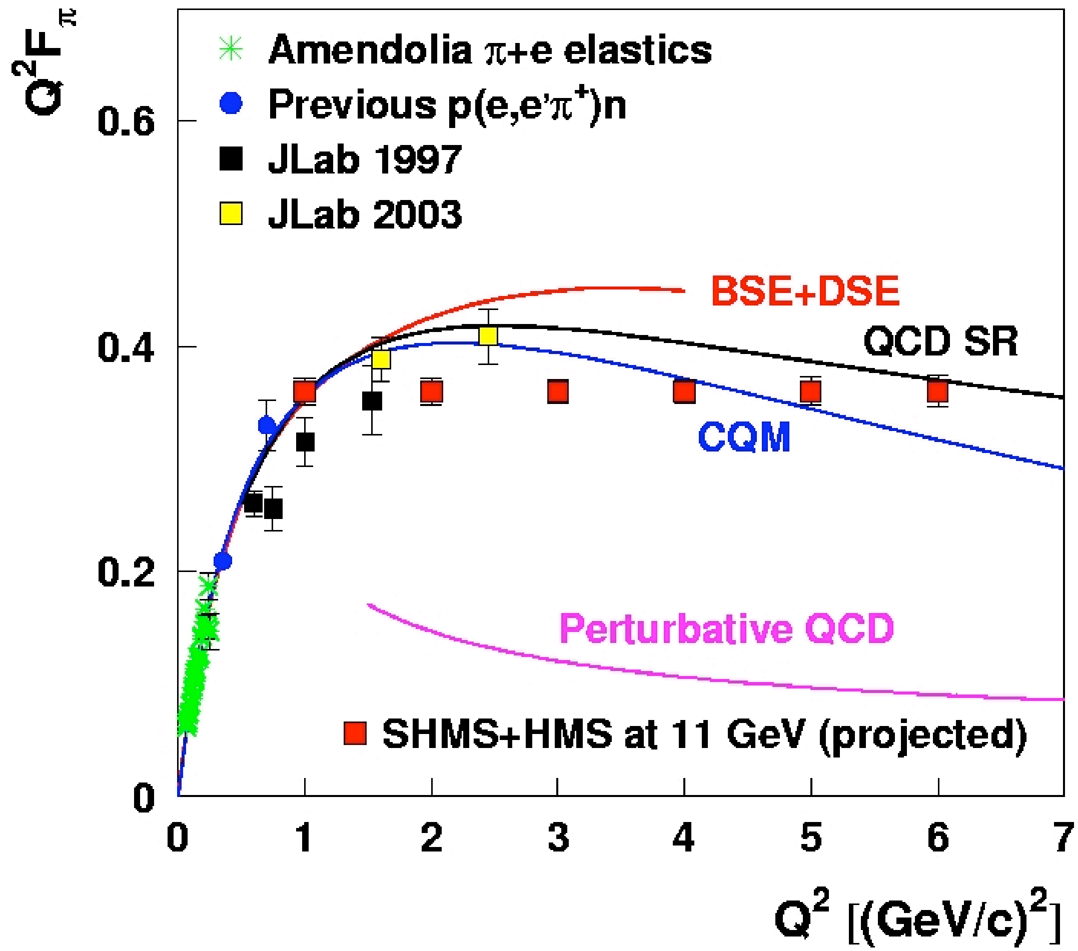
More details: T. Horn

Increase in coverage in Q^2

Data point at Q^2=1.60 GeV^2 to check model dependence of mass pole extrapolation

Possibility to rule out phenomenological calculations.

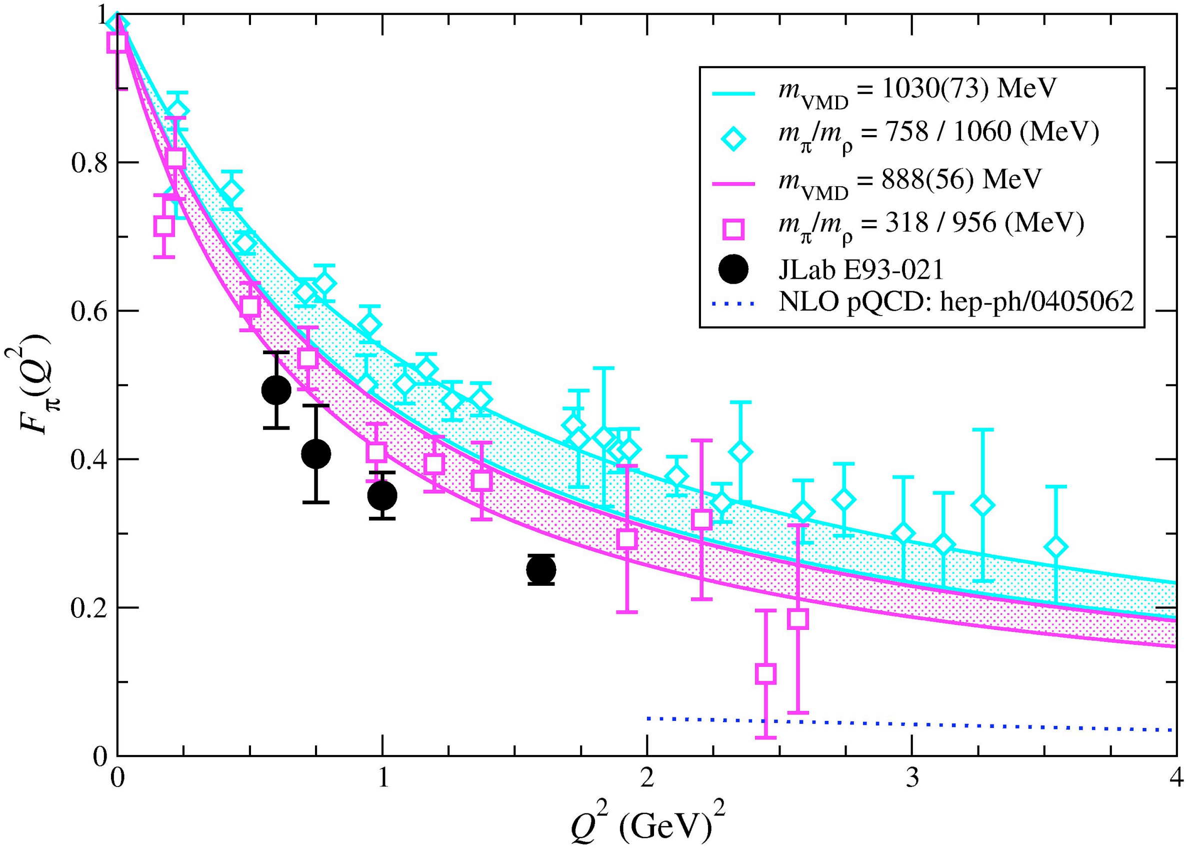




To reach regime of pQCD expectation

need higher energy of the 12 GeV Upgrade

Pion Form Factor – Lattice QCD



LHPC: Bonnet *et al*
hep-lat/0411028

- Pion Form factor vs Q^2 commensurate with experiment
- Future: pion GPDs and transition form factors

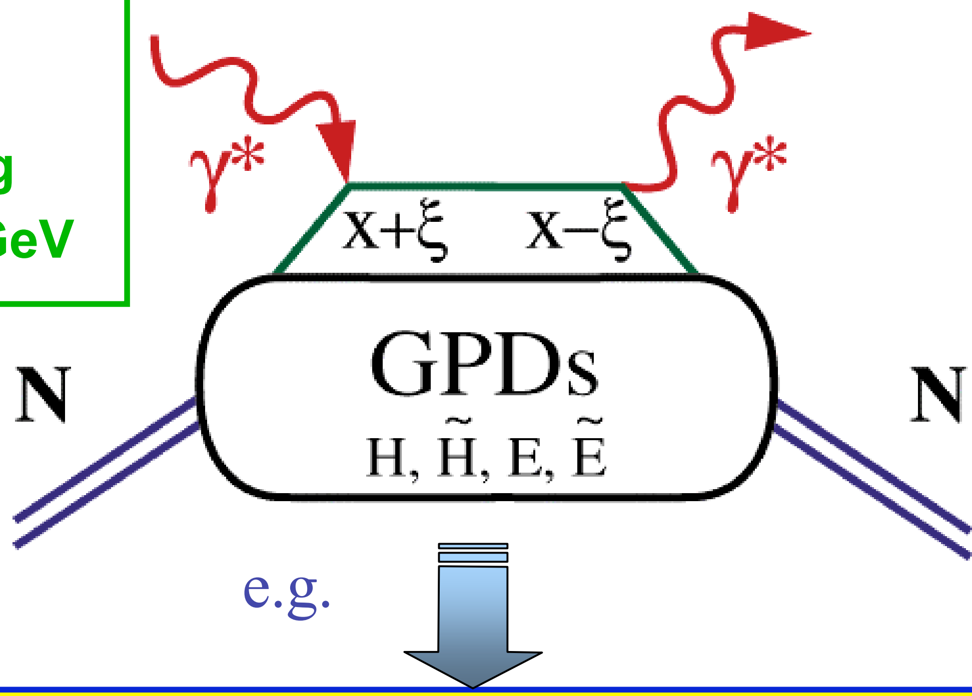
6 GeV Highlights Leading to the 12 GeV Upgrade

- Parton Distribution Functions
- Form Factors
- **Generalized Parton Distributions**
- Exotic Meson Spectroscopy:
  Confinement and the QCD vacuum
- Nuclei at the level of quarks and gluons
- Tests of Physics Beyond the Standard Model

Studies of the Generalized Parton Distributions (GPDs): New Insight into Hadron Structure

See talk of L. Cardman for promising results at 6 GeV

HP 2008



X. Ji & A. Radyushkin (1996)

Quark angular momentum (Ji's sum rule)

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

X. Ji, Phy.Rev.Lett.78,610(1997)

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QCD: Unsolved in Nonperturbative Regime

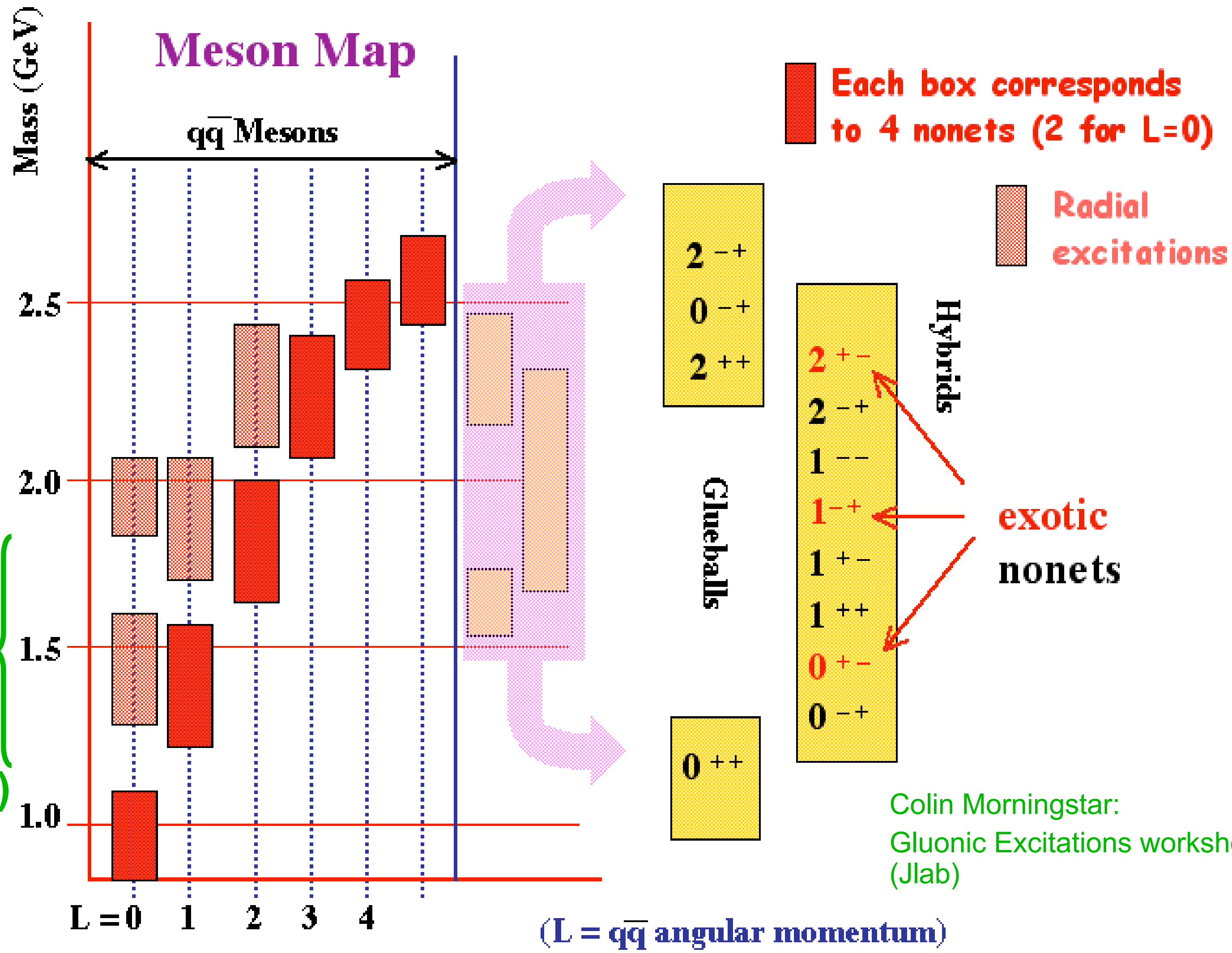
The Nobel Prize in Physics 2004

Gross, Politzer, Wilczek

- **2004 Nobel Prize awarded for "asymptotic freedom"**
- **BUT in nonperturbative regime QCD is still unsolved**
- **One of the top 10 challenges for physics!**
- **Is it right/complete?**
- **Do glueballs, exotics and other apparent predictions of QCD in this regime agree with experiment?**

JLab at 12 GeV is uniquely positioned to answer!

Glueballs and hybrid mesons



Initial search FY07 – G12 (CLAS)

Colin Morningstar:
Gluonic Excitations workshop, 2003 (Jlab)

Photo-couplings and Transition FF: $H \to \gamma M$

Photo-couplings between hybrid and conventional mesons need to be calculated!

GlueX proposal to produce hybrid mesons using real photons supported by flux-tube model calculations

$$\Gamma(\pi^{+}_{1H} \to a_2^{+} \gamma) \sim O(100\,\text{keV})$$

$$\Gamma(b^{+}_{JH} \to \pi^{+} \gamma) \sim O(1000\,\text{keV})$$

Close and Dudek, PRL91, 142001 (2003); PRD 69 034010 (2004)

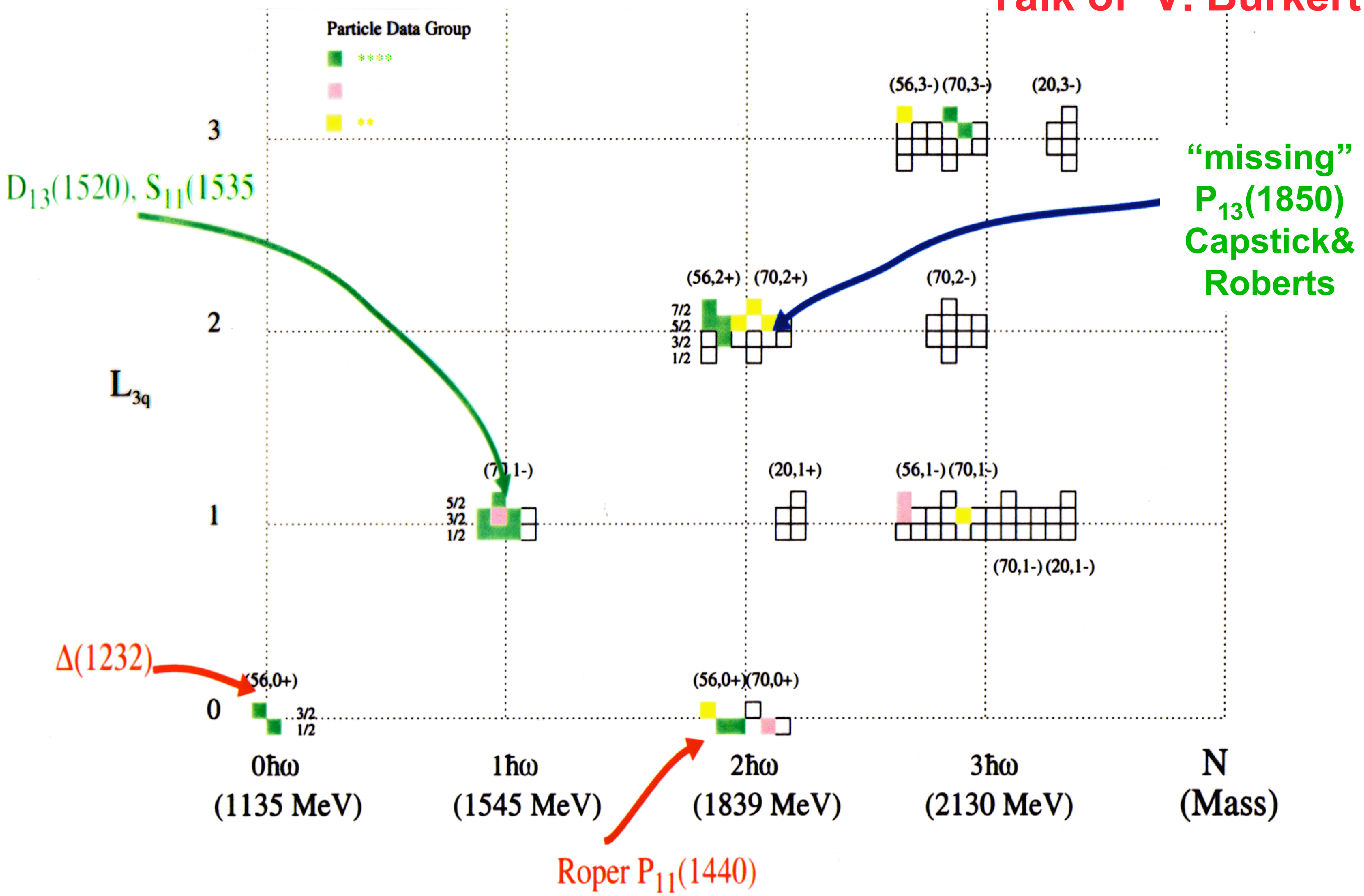
$$(\text{cf: } \Gamma(b_1^{+} \to \pi^{+} \gamma) = 230 \pm 60\,\text{keV})$$

JLab lattice QCD group investigating photo-couplings

Report on PWA collaboration with Gluex and Lattice work: Jo Dudek

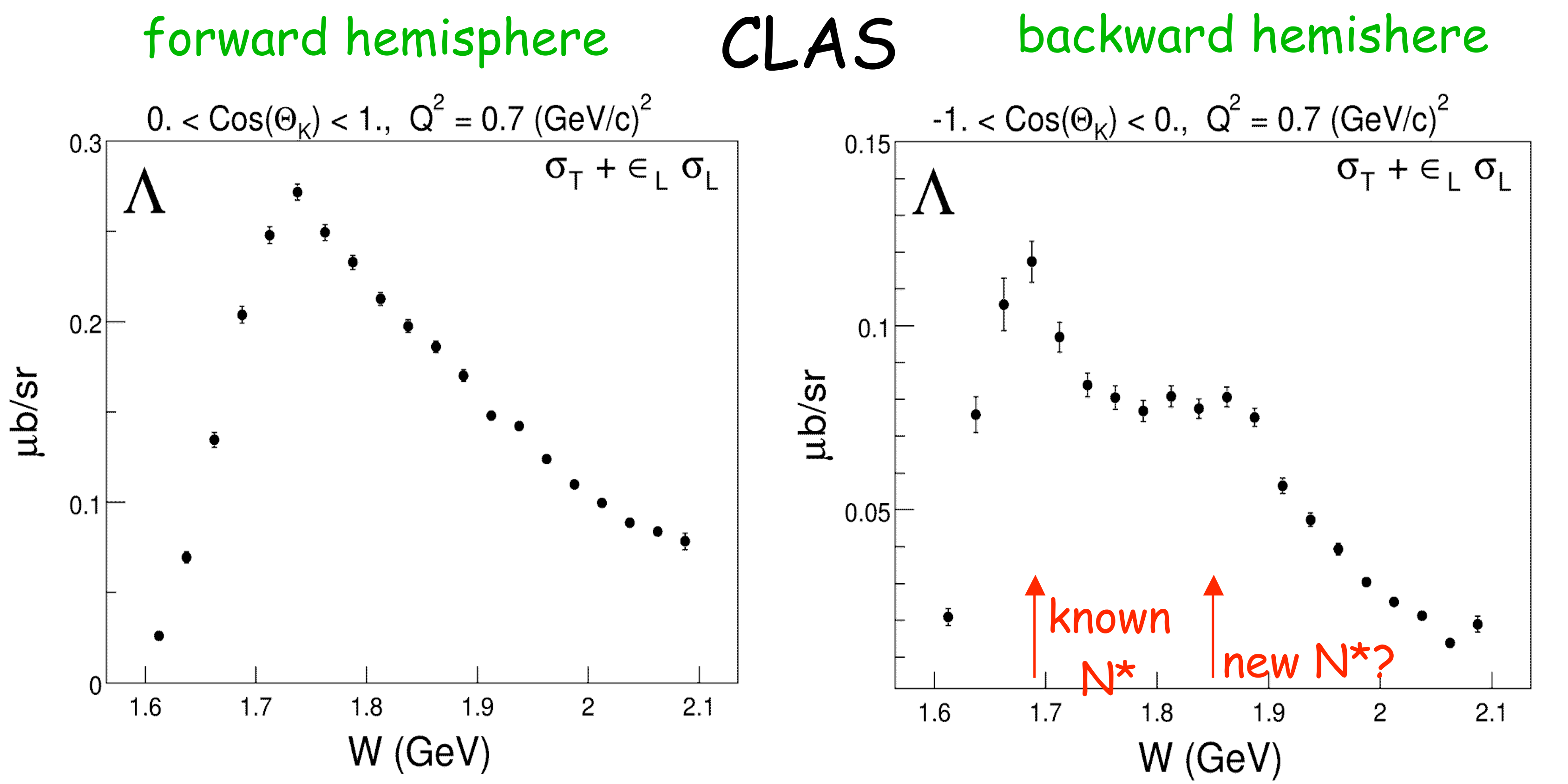
Baryon Spectroscopy: e.g. "Missing States"

Talk of V. Burkert



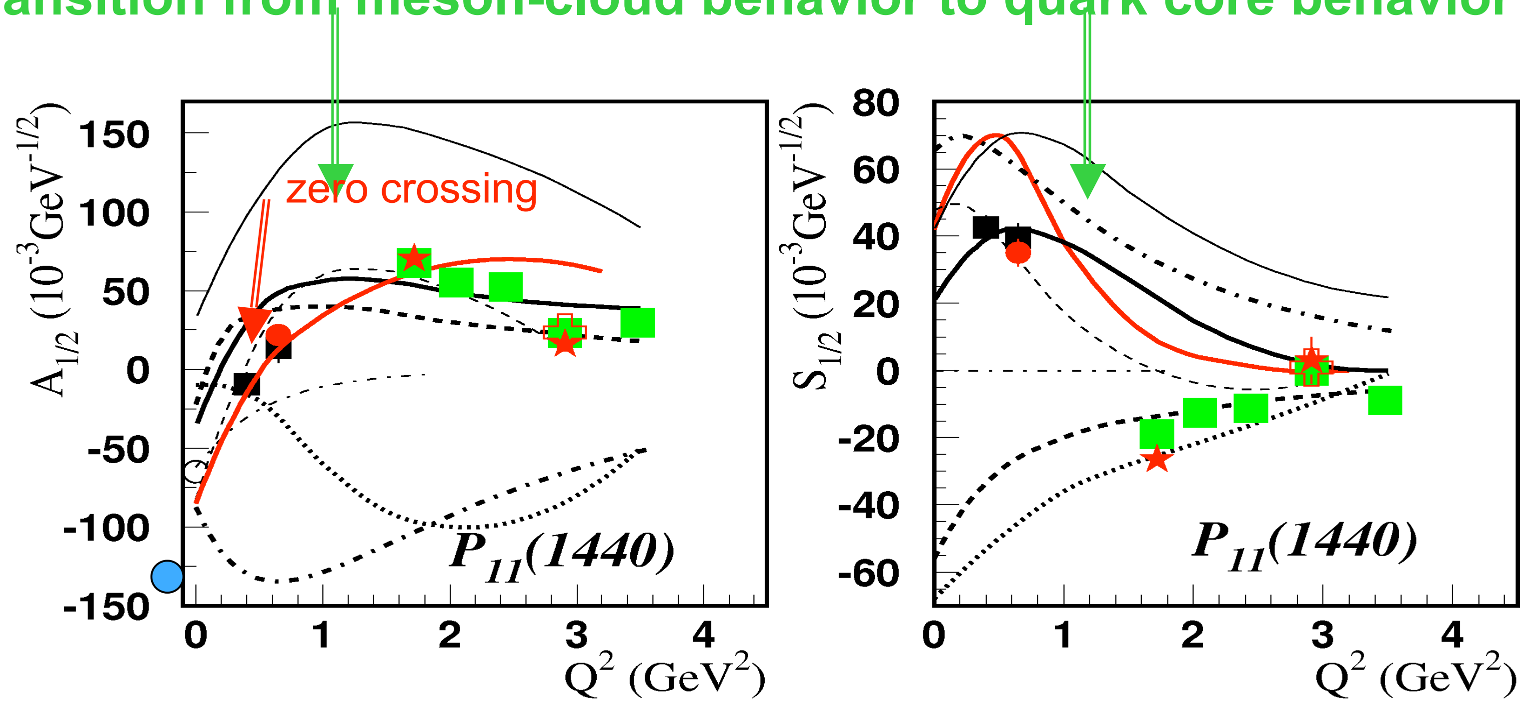
New N* state in KΛ/KΣ production ?

Possible new nucleon state near 1840 MeV visible in photo- and electroproduction total cross section data.



Transition form factor γp $P_{11}(1440)$

Transition from meson-cloud behavior to quark core behavior ?



■ ■ ● Analysis of CLAS $p\pi^0$, $n\pi^+$, data

Low Q^2 behavior consistent with meson-cloud model

High Q^2 behavior consistent with small quark core

Development of the Excited-Baryon Analysis Center (EBAC) at JLAB

Objective :

Reach DOE milestone by 2009

"Complete the combined analysis of available single pion, eta and kaon photo-production data for nucleon resonances and incorporate analysis of two-pion final states into the coupled channel analysis of resonances."

Progress in 2006

January: EBAC was established

Leading Investigator: T.-S. Harry Lee

January - May : Developing research programs

- Invited theorists to visit EBAC to discuss their participations
- Hired a research associate: Mark Paris
- Developed a collaboration with CLAS collaboration (including Aznuryan and Mokeev)

June: A team was formed to analyze π, _, $\pi\pi$ production data

B. Julia-Diaz (University of Barcelona)

T.-S. H. Lee (EBAC and Argonne National Laboratory)

A. Matsuyama (Shizuoka University)

M. Paris (EBAC)

T. Sato (Osaka University)

On-going

– Developing Collaborations with Julich Group

K. Nakayama (Jülich and University of Georgia)

A. Sibirtsev (EBAC and Jülich)

– Forming a team to analyze, _, _, and _ production data

B. Julia-Diaz (University of Barcelona)

T.-S. H. Lee (EBAC and Argonne National Laboratory)

B. Saghai (Saclay); K. Tsushima (University of Salamanca)

– Developing approaches to analyze, π π, and π _ production data

S. Capstick (Florida State University)

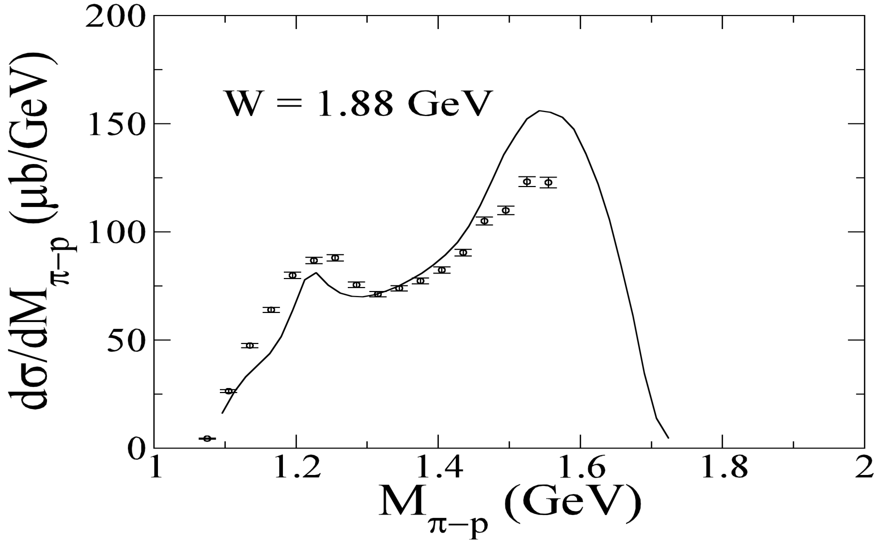
A. Kiswandhi (student, Florida State University)

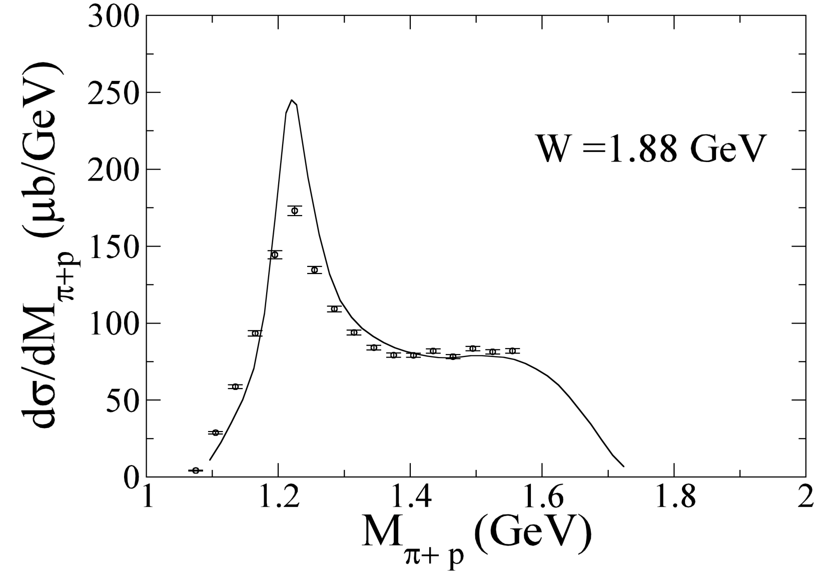
T.-S. H. Lee (EBAC and Argonne National Laboratory)

W. Roberts (Florida State University)

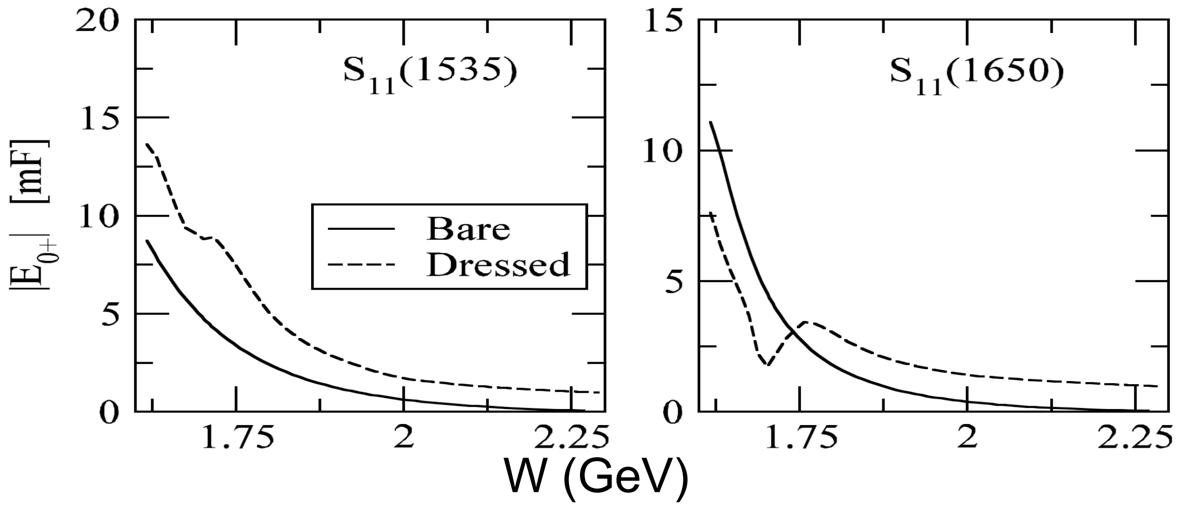
Preliminary Results from EBAC

JLAB data of _p → π+π- p





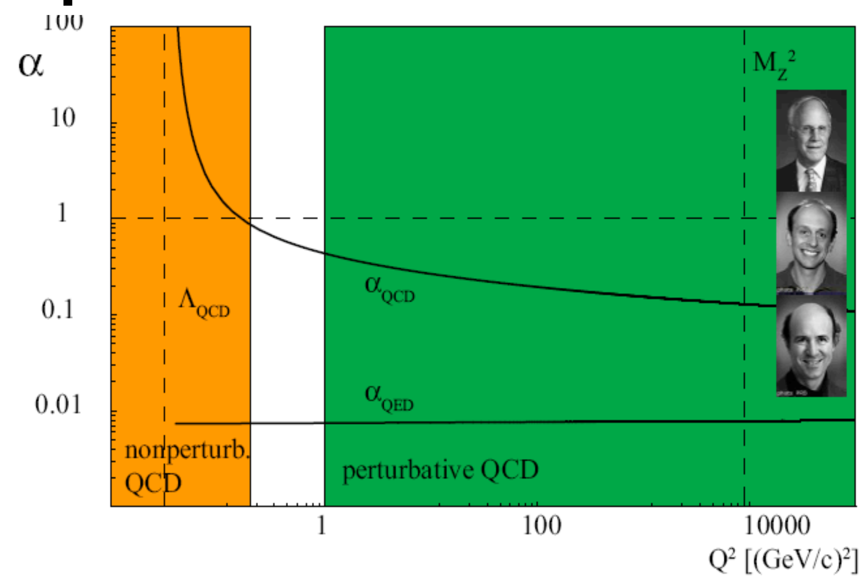
Meson Cloud effects on _N → N*



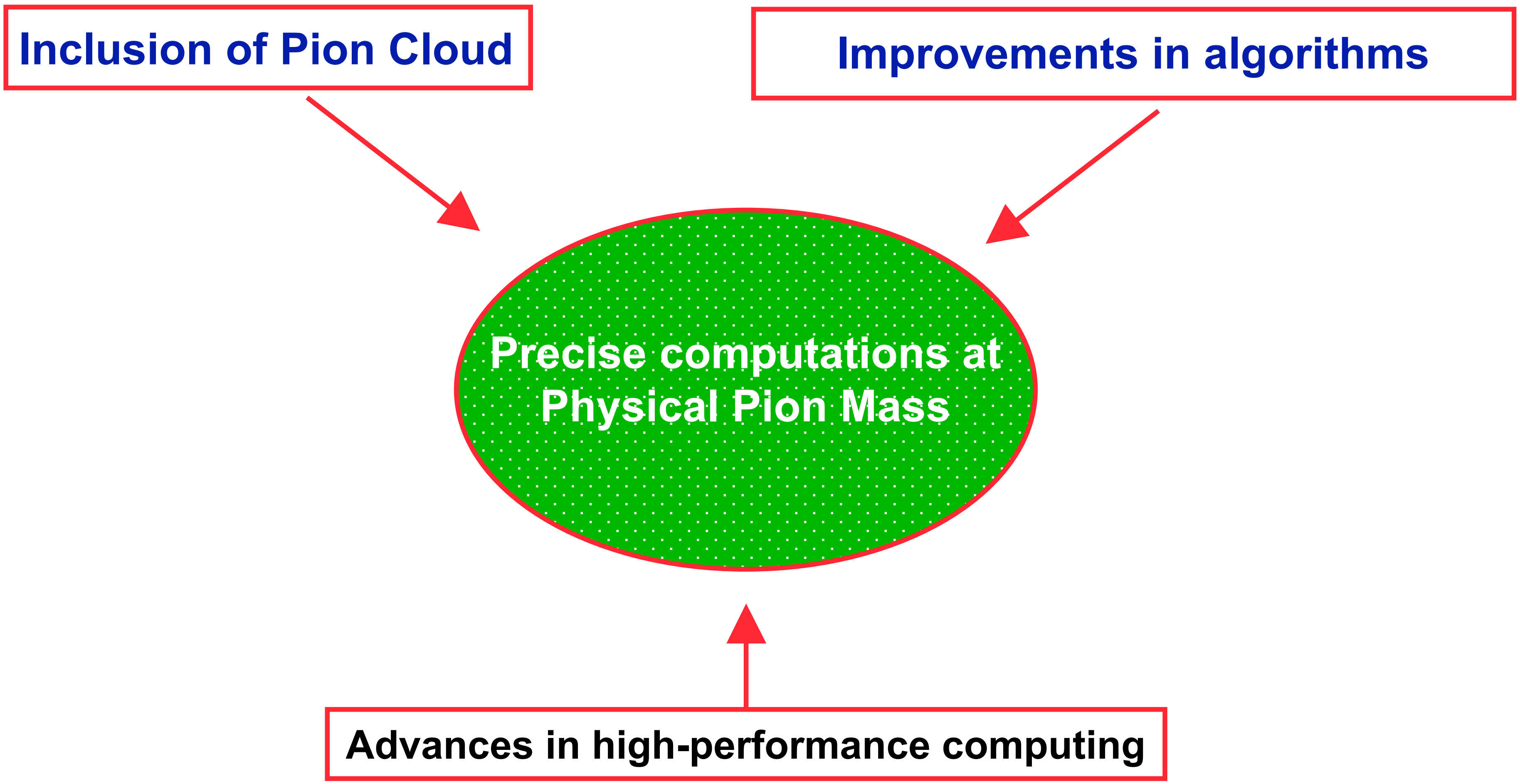
Time Frame for 12 GeV & Advances in Lattice QCD) Wonderful synergy!

That is: Our growing ability to use lattice QCD to calculate the unambiguous consequences of nonperturbative QCD is beautifully matched to the capacity of Jlab at 12 GeV to measure the corresponding observables with precision!

….and hence really test if QCD is the complete theory of the strong interaction



Advances in Lattice QCD



Dedicated Break-out session plus plenary talk of D. Richards

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Nuclear Physics: The Core of Matter, The Fuel of Stars

(NAS/NRC Report, 1999)

Science Chapter Headings:

The Structure of the Nuclear Building Blocks

The Structure of Nuclei

Matter at Extreme Densities

The Nuclear Physics of the Universe

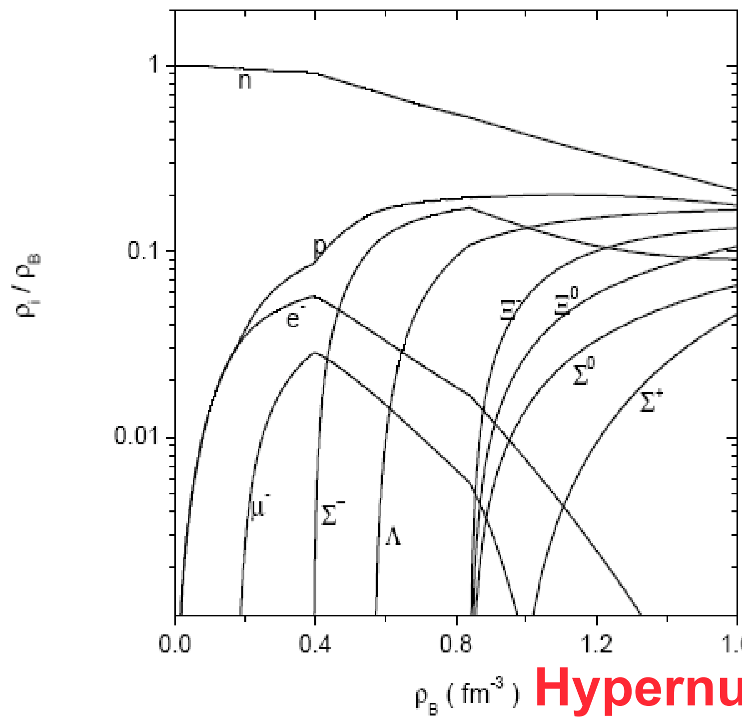
Symmetry Tests in Nuclear Physics

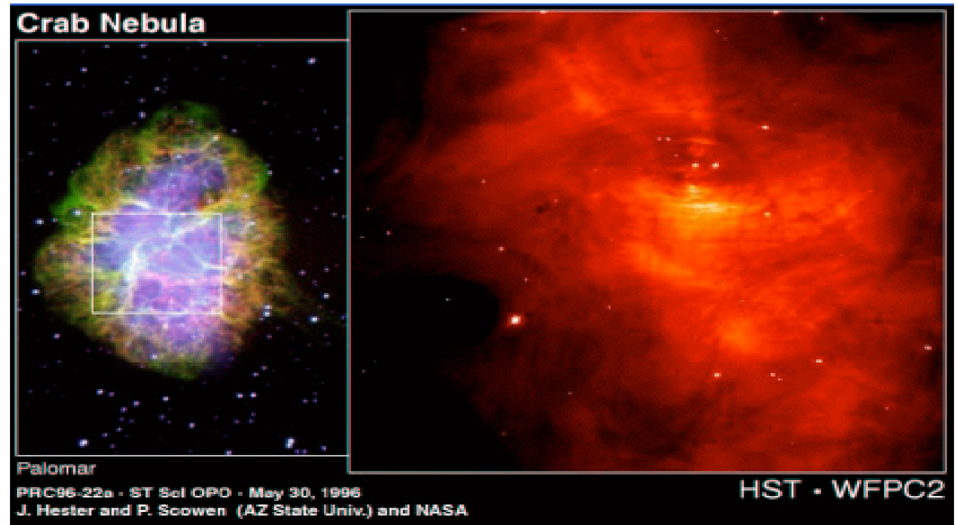
Neutron Star Composition

Hyperons enter at just 2-3 ρ_0

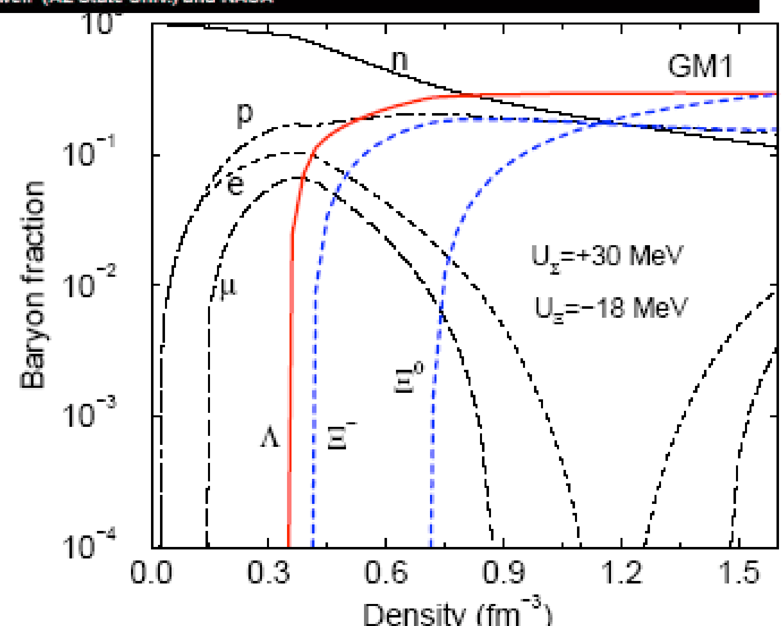
Hence need effective Σ-N and Λ-N forces in this density region!

Hypernuclear data is important input





?



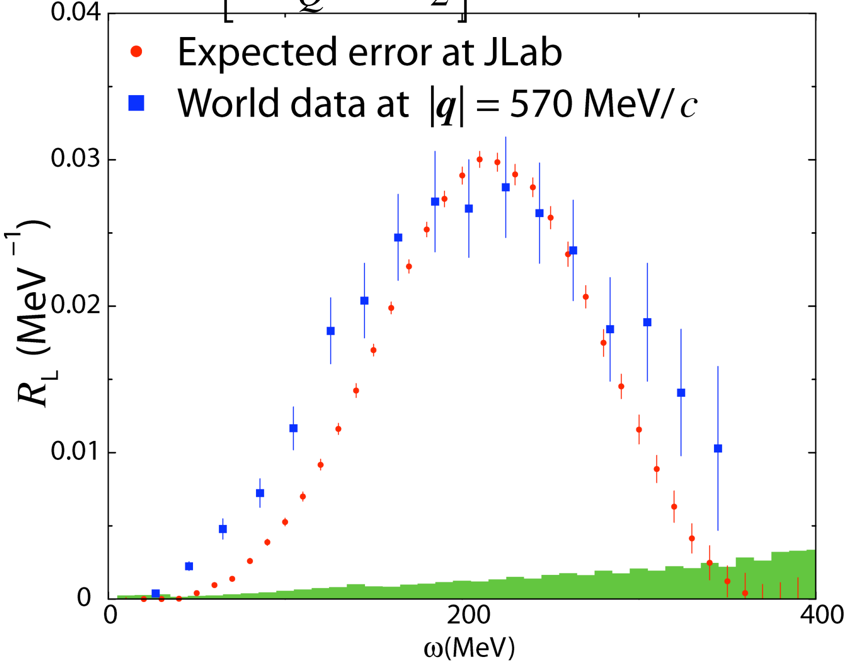
Hypernuclei at JLab: L. Cardman

Coulomb Sum Rule (Summer 2007)

Response Functions in Quasi-Elastic Scattering

$$\frac{d^2\sigma}{d\Omega d\omega} = \sigma_{Mott}\left[\frac{Q^4}{q^4}R_L(q,\omega) + \frac{Q^2}{2q^2}\frac{1}{\varepsilon}R_T(q,\omega)\right]$$

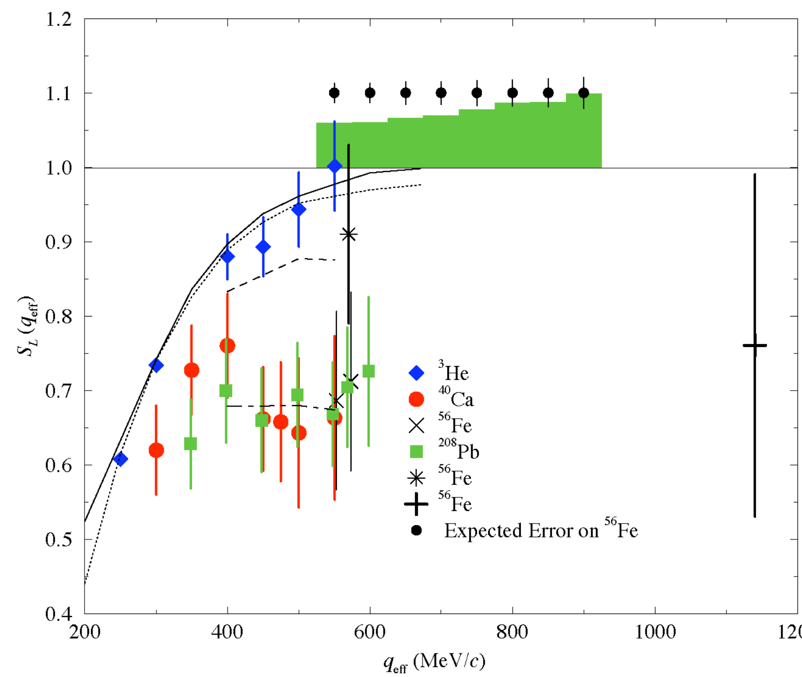
$$\varepsilon = \left[1 + \frac{2q^2}{Q^2}\tan^2\frac{\theta}{2}\right]^{-1}$$



Coulomb Sum

$$S_L(q) = \int_{\omega_{el}^+}^{\infty} d\omega \frac{R_L(q,\omega)}{Z\bar{G}_E^2(Q^2)}$$

$$\bar{G}_E^2(Q^2) = \left(\left|G_E^p(Q^2)\right|^2 + (N/Z)\left|G_E^n(Q^2)\right|^2\right)\frac{1+Q^2/4M^2}{1+Q^2/2M^2}$$



E05-110: Jian-ping Chen, Seonho Choi, Zein-Eddine Meziani

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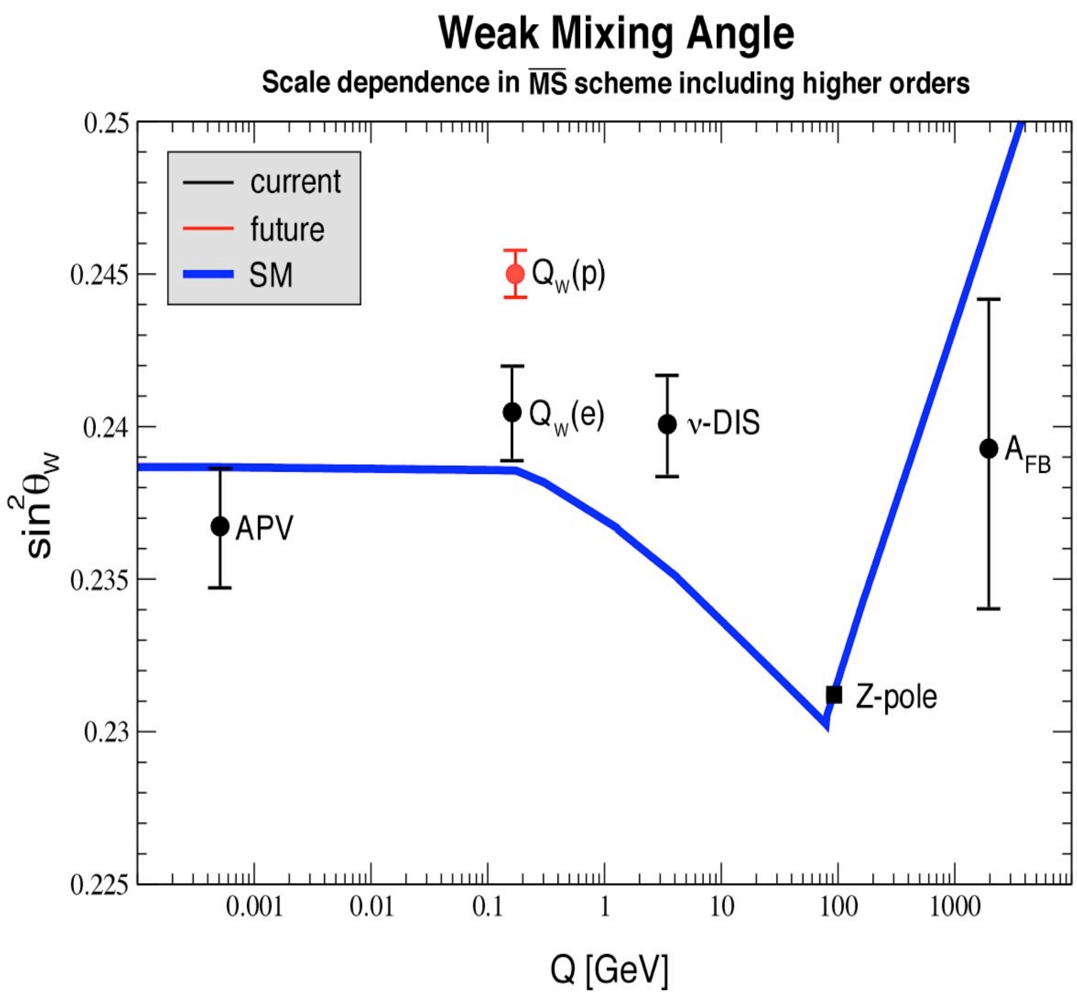
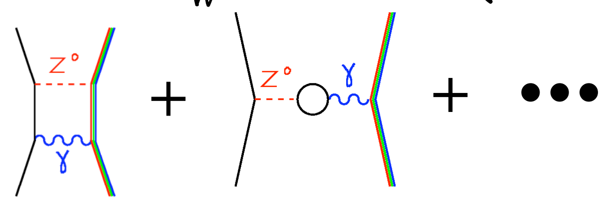
The Q^p_{weak} Experiment

Precision test of the Standard Model and a search for New Physics Beyond the Standard Model – at the TeV scale



- Electroweak radiative corrections
  → $\sin^2\theta_W$ varies with Q



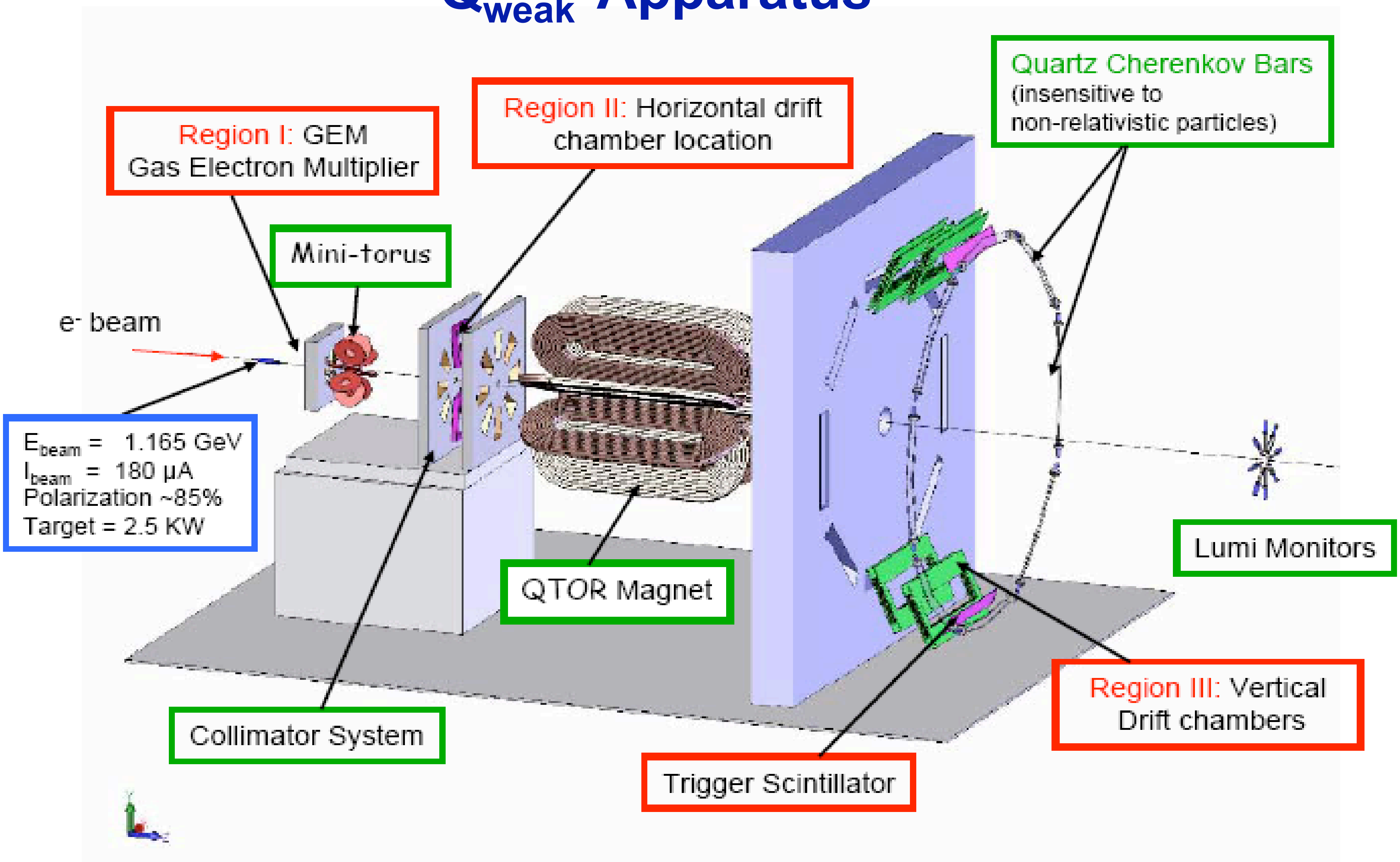
- Extracted values of $\sin^2\theta_W$ must agree with Standard Model or new physics is indicated.

$$Q^p_{weak} = 1 - 4\sin^2\theta_W \sim 0.072$$

- A 4% Q^p_{Weak} measurement probes for new $\frac{\Lambda}{g} \sim \frac{1}{\sqrt{\sqrt{2}G_F|\Delta Q^p_W|}} \approx 4.6\ \text{TeV}$ to:

- Q^p_{weak} (semi-leptonic) and E158 (pure leptonic) make a powerful program to search for and identify new physics.

Q_{weak} Apparatus



Axion Search : Recent Observation by PVLAS

Polarization experiments

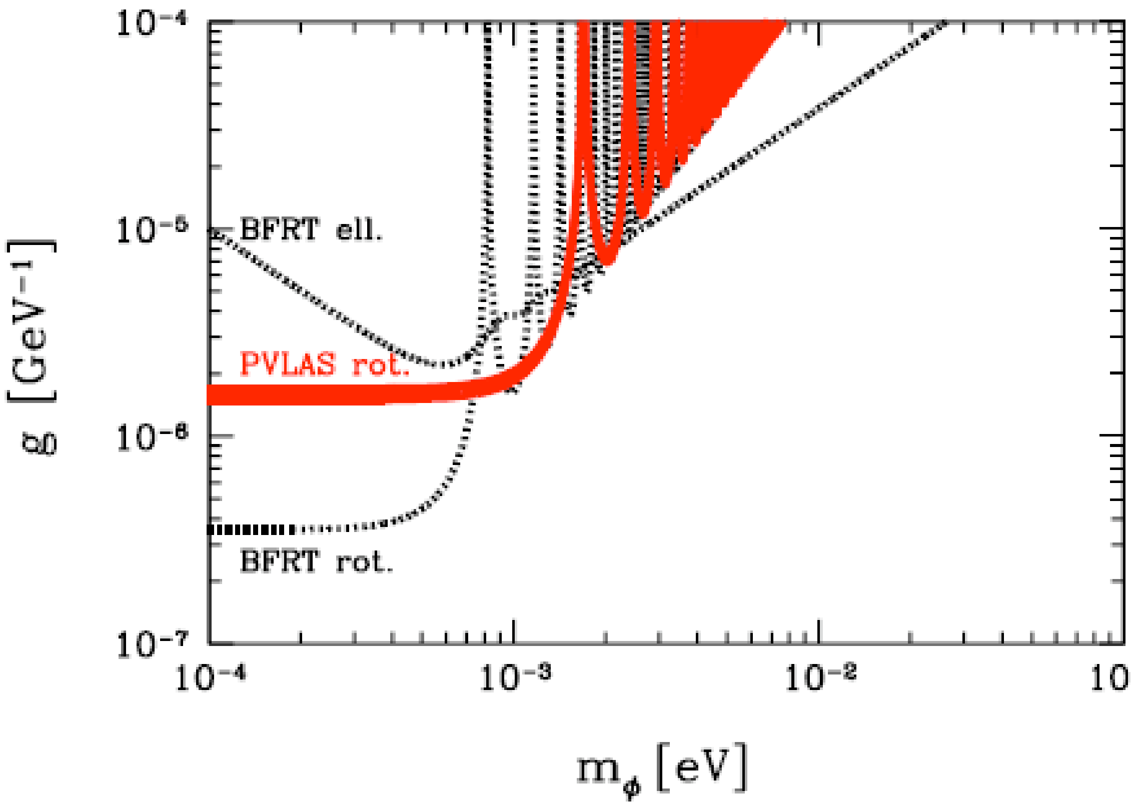
- Send linearly polarized laser beam through transverse magnetic field ⇒ measure changes in polarization state
- Real and virtual production induce
  - **rotation:** photons polarized || $\boldsymbol{B}$ will disappear leading to apparent rotation of polarization plane by

$$\varepsilon_\phi = -N_r \left(\frac{gB\ell}{4}\right)^2 F(q\ell)\,\sin 2\theta$$

  - **ellipticity:** virtual production causes retardation between $\boldsymbol{E}_{||}$ and $\boldsymbol{E}_\perp$ ⇒ elliptic polarization

$$\psi_\phi \approx \frac{N_r}{6}\left(\frac{g\,B\,\ell}{4}\right)^2 \frac{m_\phi^2\,\ell}{\omega}\,\sin 2\,\theta$$

for small masses, $m_\phi^2 \ell/4\omega \ll 1$.

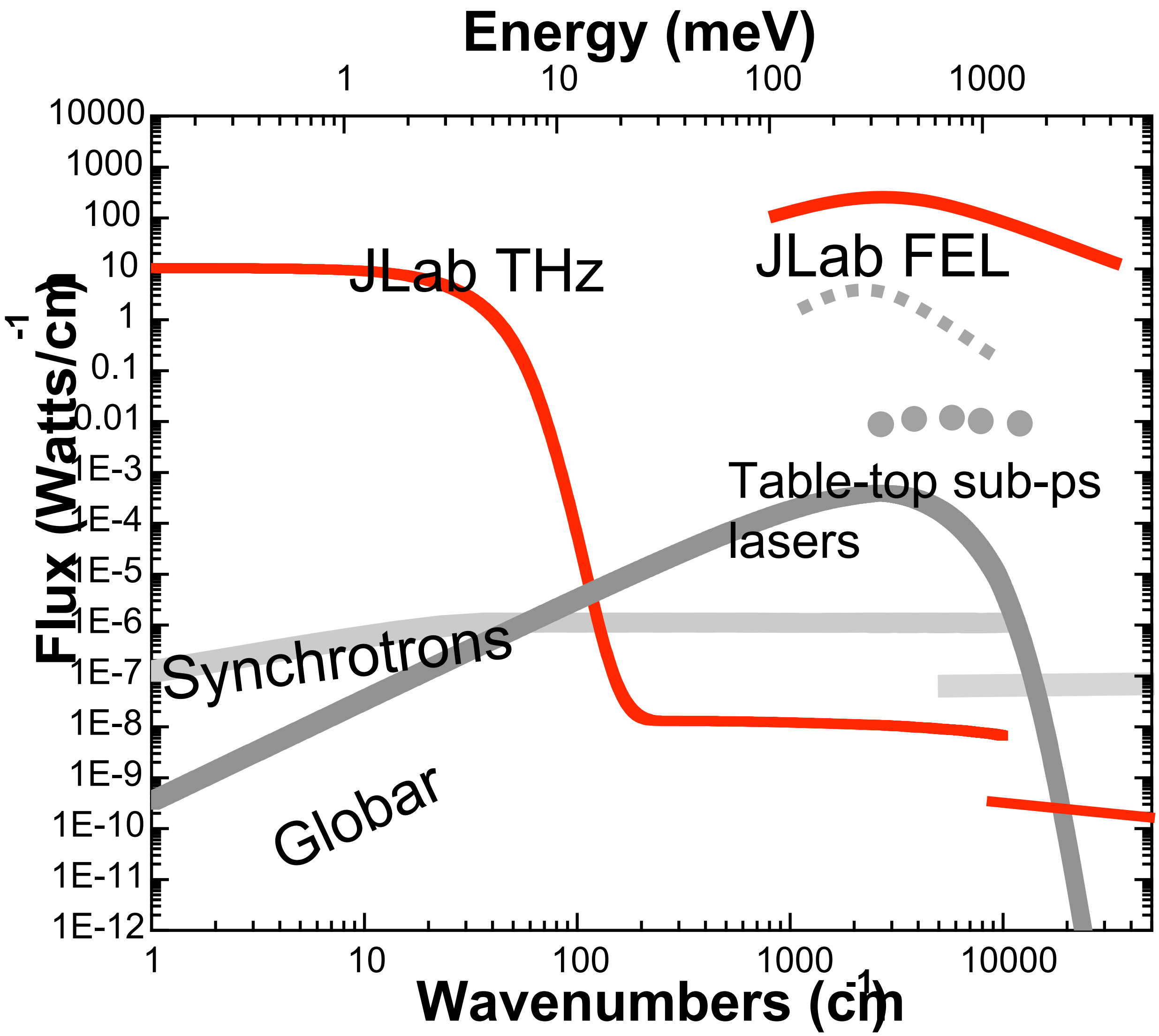


Publication: [Zavattini *et al.* '05]

$$1.7\times10^{-6}\ \mathrm{GeV}^{-1} \lesssim g \lesssim 1.0\times10^{-5}\ \mathrm{GeV}^{-1}$$
$$0.7\ \mathrm{meV} \lesssim m_\phi \lesssim 2.0\ \mathrm{meV}$$

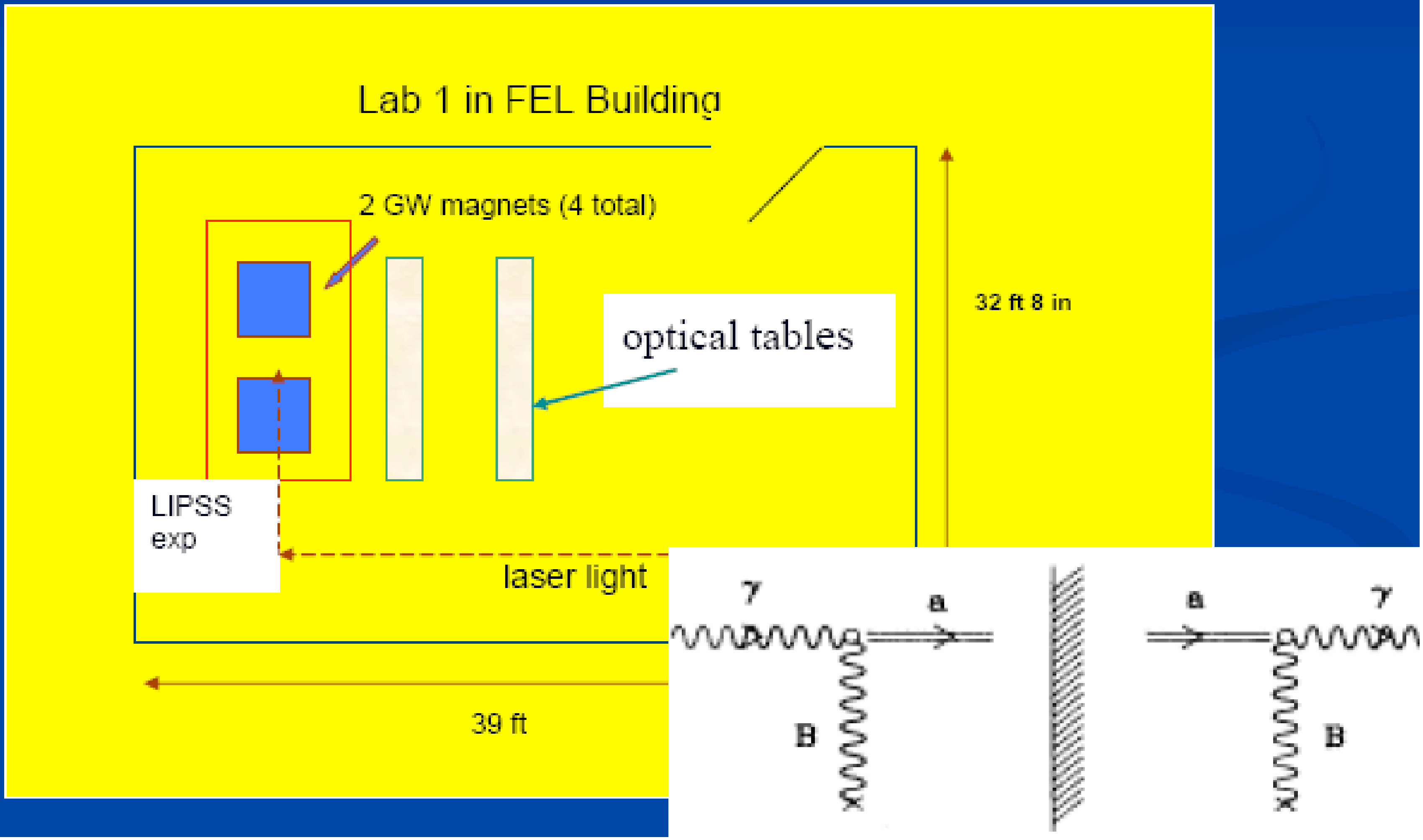
From K. Baker

JLab FEL Power from THz to UV



For information: www.jlab.org/FEL

The experiment will be mounted in Laboratory 1 in the FEL Building. There will be two GW magnets used for PS generation, and two for photon regeneration.

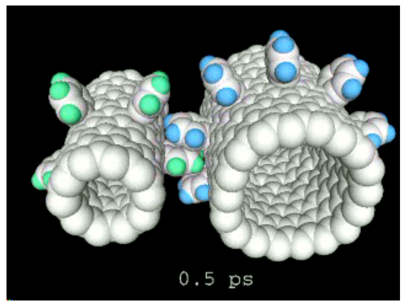


Forefront Condensed Matter and Life Sciences

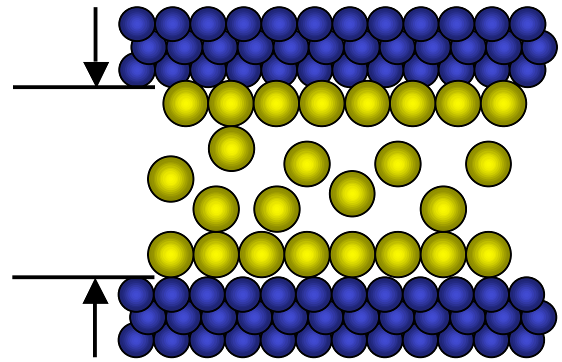
Nano-Fluids (talk by G. Williams)

in New Technologies, in Chemistry, Bio Medicine, Geology

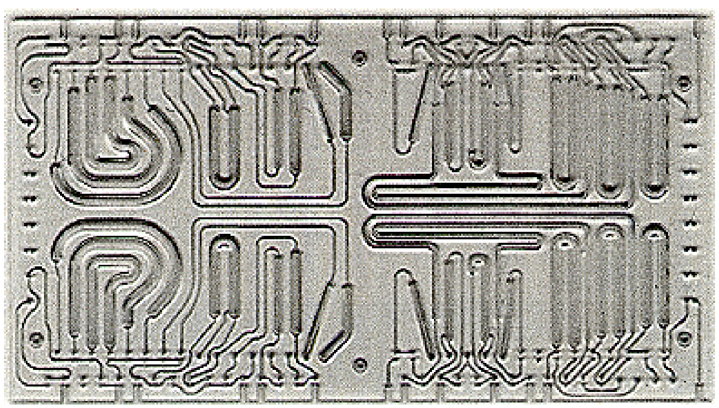
From Micro- to Nano-Gears



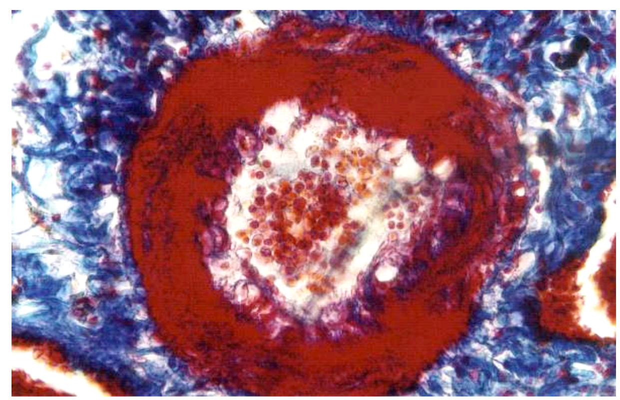
Nano Tubes



Lubrication in Nano Slits



Chemistry Lab of Tomorrow: On a Chip



Blood/Fat Flow in Capillaries