

Science Vision: Present Status, Future Opportunities

Anthony W Thomas
Chief Scientist

Science & Technology Review:
Aug 30 – Sept 1, 2005



Thomas Jefferson National Accelerator Facility



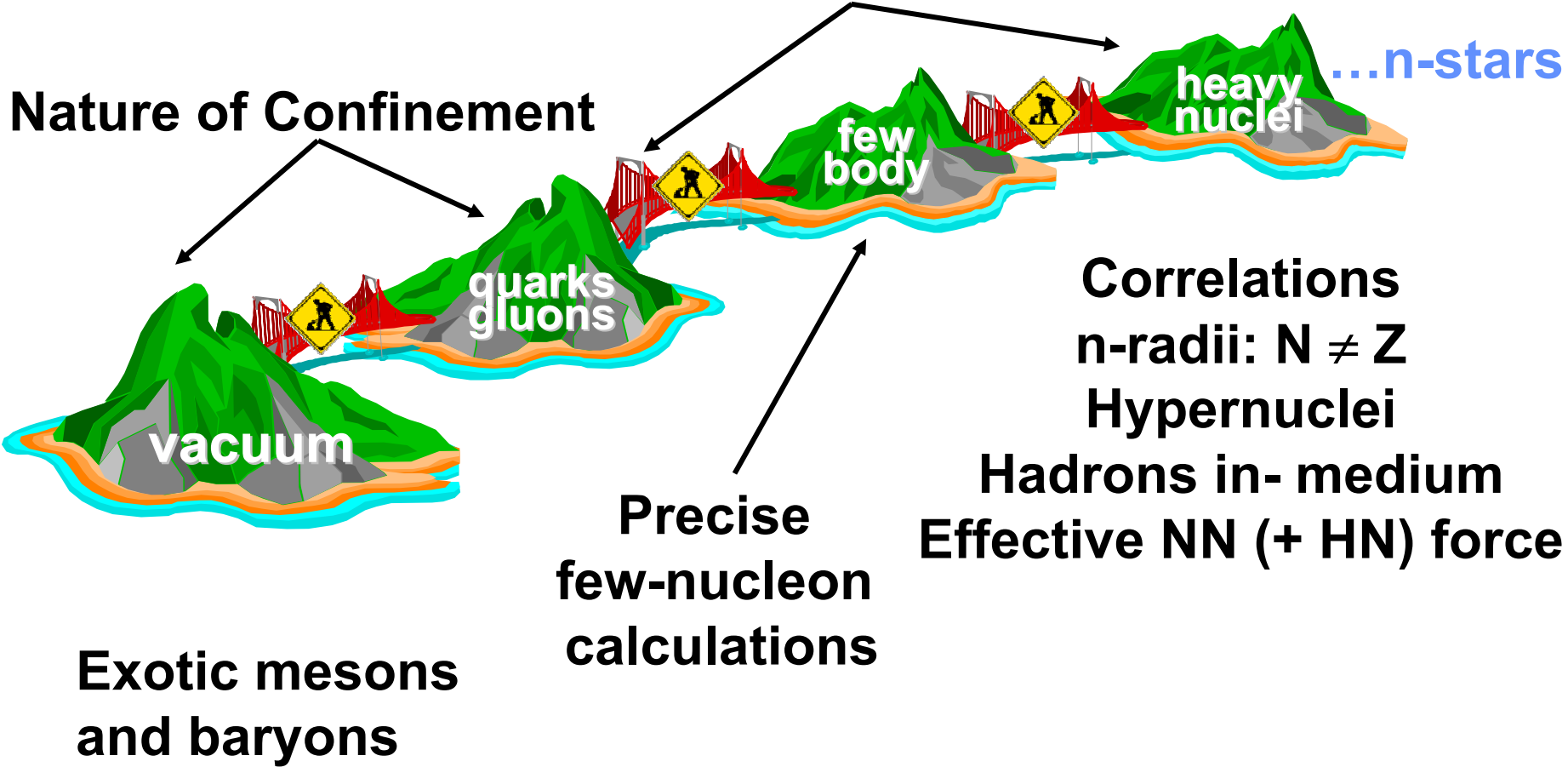
Outline

- Jefferson Lab in Context of Nuclear Physics World-wide
- 6 GeV: Exciting Science and a Natural Transition to the 12 GeV Upgrade
- Highlights of Current program
 - Pentaquarks?
 - SIDIS; duality
 - Form factors
 - Strangeness content of nucleon
 - Transition Form Factors; baryon spectroscopy
 - Λ Hypernuclei
- Synergy with theory
 - notably Lattice QCD



JLab Central to *all* of Nuclear Science

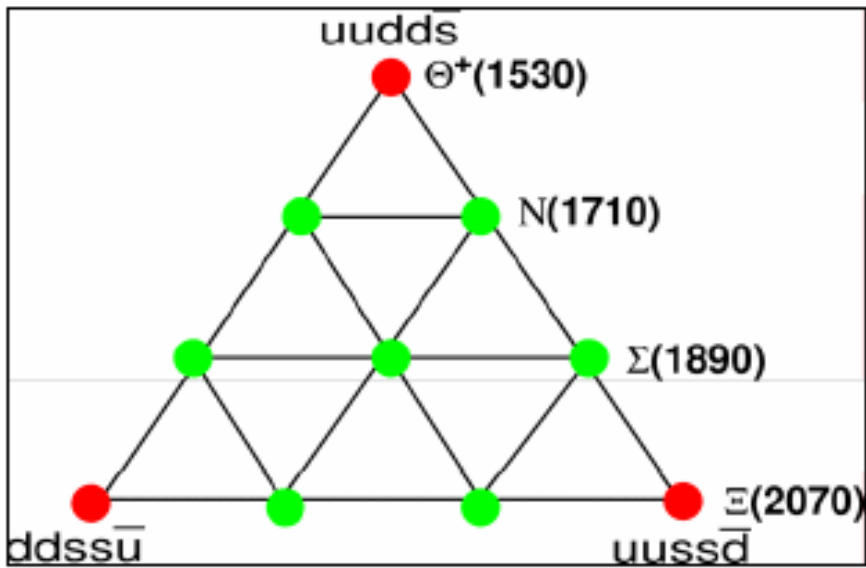
Quark-Gluon Structure Of Nucleons and Nuclei



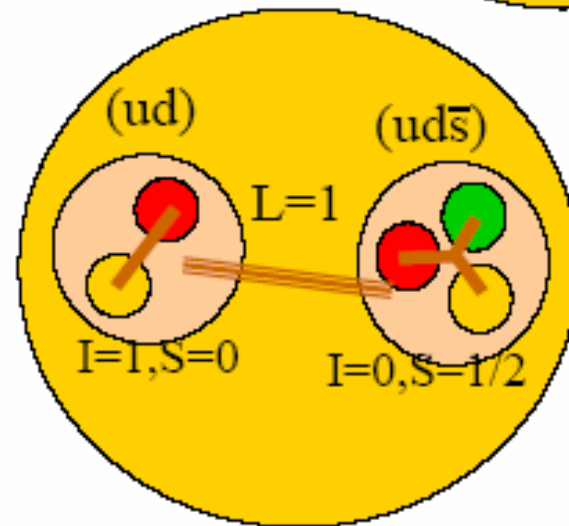
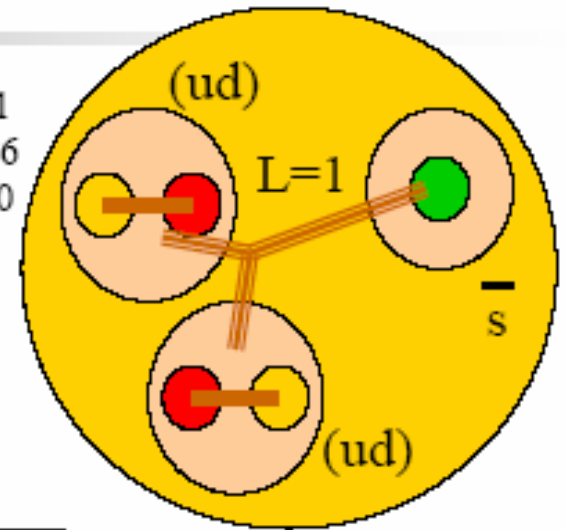
Pentaquark Structure

Pentaquarks:
 rotational excitations of the soliton
 [rigid core surrounded by chiral
 (meson) fields]

Diakonov *et al.*, *Z. Phys A* **359**, 305 (1997).

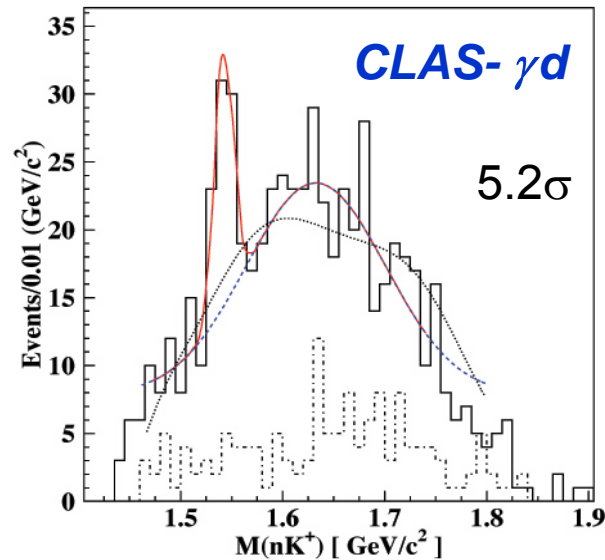
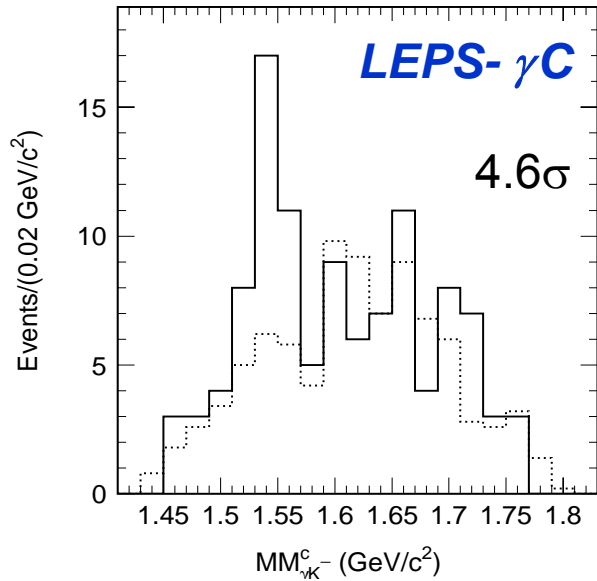


JW hep-ph/0307341
 JM hep-ph/0308286
 SZ hep-ph/0310270

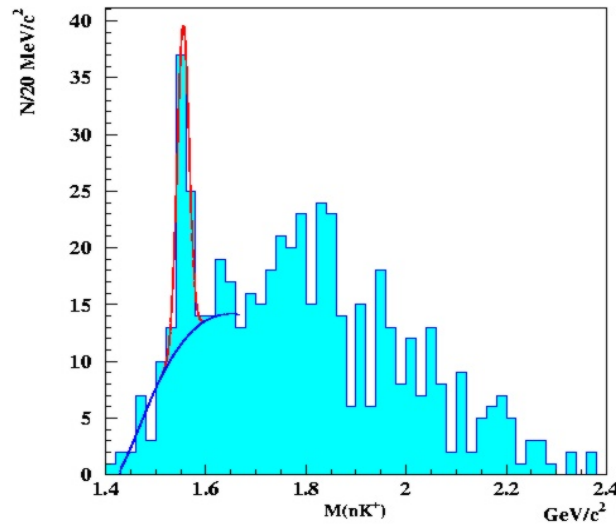
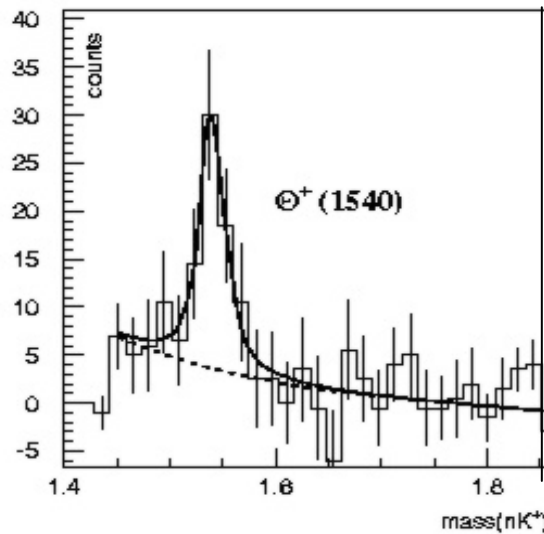


Karliner, Lipkin, hep-ph/0307243

Positive Results for Θ^+ in "1st Round"



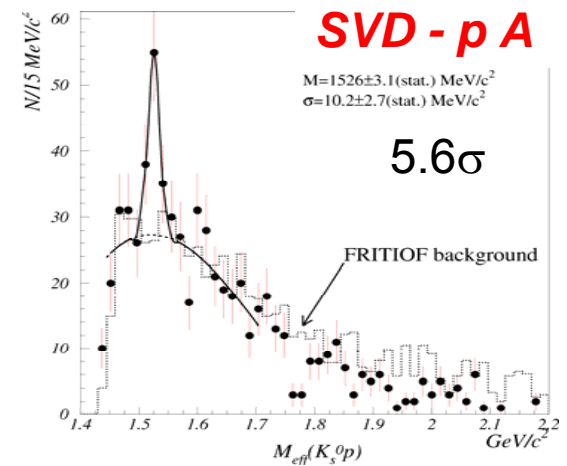
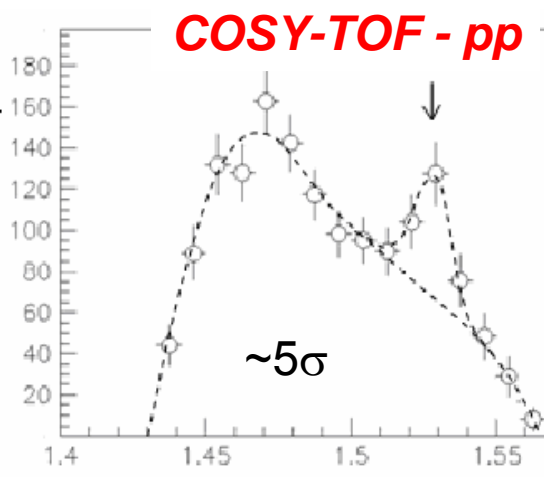
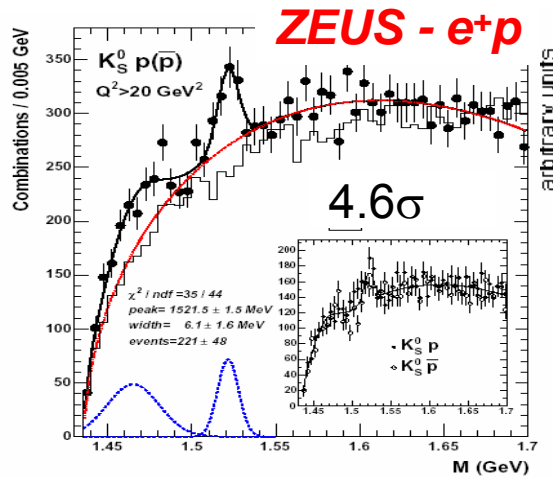
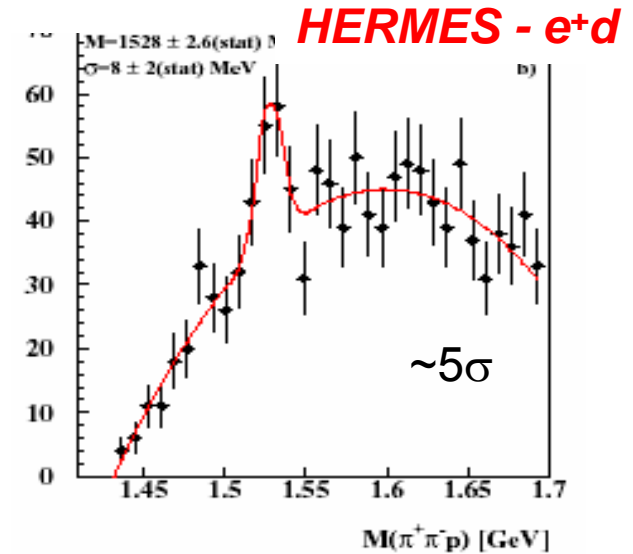
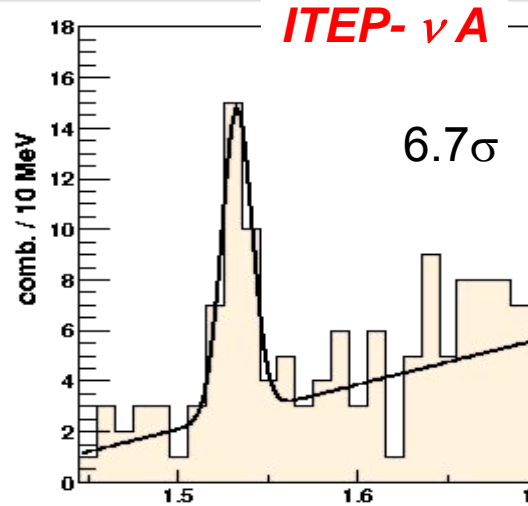
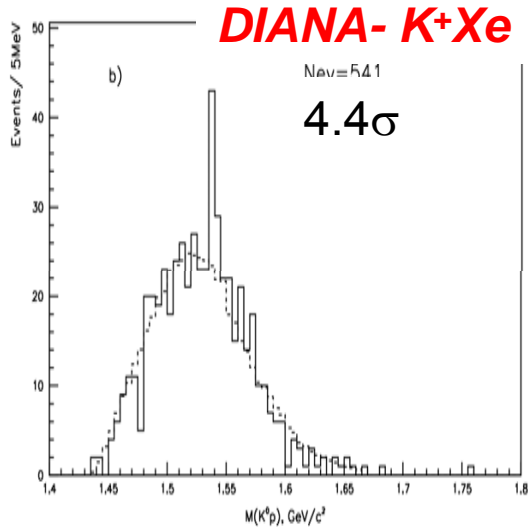
In $K^+ n$ mode



Further Evidence in "1st Round"

$K^0 p$

Evidence (published) from 6 experiments



Pentaquark Publicity 2003

USA TODAY, TUESDAY, JULY 1, 2003 '03

NEW YORK TIMES INTERNATIONAL TUESDAY, JULY 1, 2003

A Subatomic Discovery Emerges From Experiments in Japan

By KENNETH CHANG

Slamming high-energy particles of light into carbon atoms, physicists have unexpectedly produced a new type of subatomic particle.

Protons and neutrons, the building blocks of atoms, are made of smaller particles known as quarks, which come in six varieties. A proton, for example, consists of three quarks — two so-called up quarks and one down quark. Physicists know of slews of particles containing two or three quarks.

Now they believe they know of a particle containing five quarks that perhaps could have been common in the very early universe. (No one

the experiments, Dr. Takashi Nakano, of the Research Center for Nuclear Physics at Osaka University, said Dr. Nakano said that he should look through the data for signs of five-quark particles.

"Dimitri Diakonov was very confident of that," Dr. Nakano said. Dr. Nakano and his collaborators looked, and they found a peak in their graphs corresponding to the mass of the five-quark particle that Dr. Diakonov had predicted. "He was right," Dr. Nakano said. "Actually, I was very surprised."

Dr. Kenneth H. Hicks, a professor of physics at Ohio University and another member of the Spring-

would consist of two up quarks, two down quarks and one known as an anti-strange quark.

The findings will be reported Friday in the journal *Physical Review Letters*.

prohibit five-quark one had seen any hint of searching, pondered if their particle.

ity to people who do not believe that colliding protons that gives have plays an important part that makes sense, because it is because, the less likely in the amount of collision changes in the theory at least from what made. Hence his observations, they are positive replication in a larger formation. But if they are cracked, the basis for the plot for consequences were, and the device do

Five alive!

As noted, new subatomic "pentaquark" has been found. Quarks, one of the building blocks of matter, come in six varieties. A proton, for example, consists of three quarks — two so-called up quarks and one down quark. Physicists know of slews of particles containing two or three quarks.

Now they believe they know of a particle containing five quarks that perhaps could have been common in the very early universe. (No one

Scientists find fleeting form of basic matter

By JAMES JOYCE

Scientists have confirmed the existence of a previously unknown kind of matter, a strange, fleeting subatomic particle that has been the subject of a 36-year search.

One of the scientists who discovered it said he was not sure if it was a new particle or just a new way of looking at an old one. He said he was not sure if it was a new particle or just a new way of looking at an old one.

The newly identified particle, dubbed a "pentaquark" because of its five ingredients, is five times as heavy as a proton and is made of five quarks.

Physicists also probably first in and out of being today, the most lived product of high-energy collisions between cosmic rays and atoms in deep space or Earth's upper atmosphere.

PARTICLE

Scientists find unknown form of basic matter

Scientists had to duplicate these conditions in the lab by finding powerful energy beams that target carbon or hydrogen atoms. Then, they hit them with a laser to analyze the data, to see what they had done, and whether themselves it wasn't a false conclusion. Their findings will be published in *Physical Review Letters*, a peer-reviewed physics journal, later this month.

"When he first saw the computer results that was the signature of the new category of particle," he thought it was quite strange," said Ohio University physics Professor Ken Hicks, who was a collaborator in the Japanese experiment and headed similar work at the U.S. Department of Energy's Thomas Jefferson National Accelerator Facility in Virginia.

The Japanese colleague had a similar reaction. "It must be

PHYSICS

Evidence for 'Pentaquark' Particle Sets Theorists Rejoicing

Three quarks (two up and one down) and two quarks (one up and one down) and one anti-strange quark. The findings will be reported Friday in the journal *Physical Review Letters*.

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Researchers later in addition quark look data must regarding the subatomic particle that appears to be a new form of matter.

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Physics team goes where no quark has gone before

By Ken Gribben

Physicists have discovered a new type of subatomic particle, one made of five quarks. The discovery was made by a team of physicists from the University of Tokyo and other institutions in Japan.

New five-quark states found at CERN

Only a few months after the first burst of excitement over the appearance of several laboratories of what seems to be a new kind of particle, evidence has been found for a new five-quark state that appears to be closely related.

The consistent sign of the new particles that were invented in the 1960s has been very successful in describing the known baryons as composites of three valence quarks. Quantum chromodynamics (QCD), the theory of strong interactions, does not forbid baryons containing more than three quarks. In fact, such states were proposed a long time ago, but no good candidates were found by experimenters until recently. The search was revived by the theoretical physicists Victor Petrov and Maxim Polyakov. They predicted that the masses of the lightest pentaquark baryons would be very narrow. Diakonov et al. (2002) had proposed that the masses of the lightest pentaquark baryons would be very narrow. Diakonov et al. (2002) had proposed that the masses of the lightest pentaquark baryons would be very narrow.

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News

New five-quark states found at CERN

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

Figure 15

Figure 16

Figure 17

Figure 18

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Figure 95

Figure 96

Figure 97

Figure 98

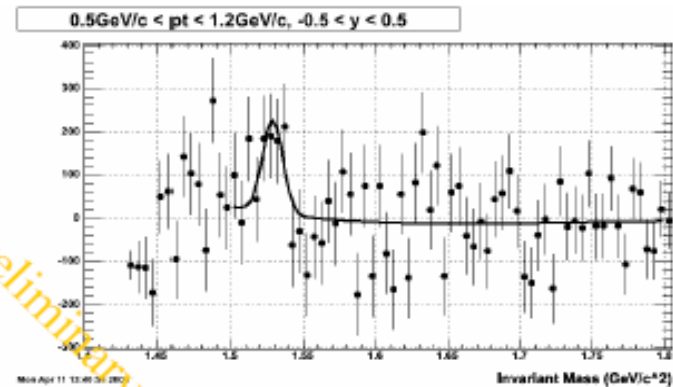
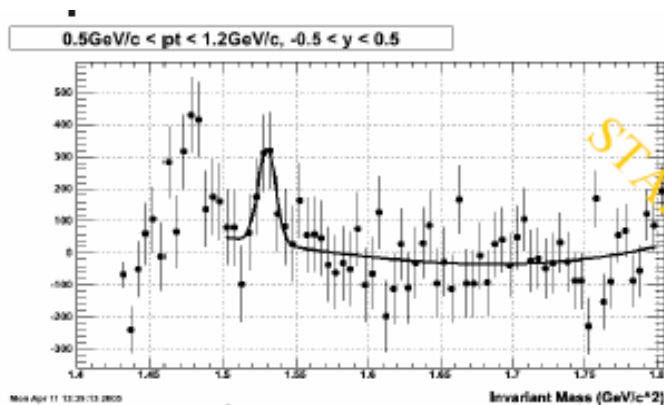
Figure 99

Figure 100

New Claims Since April 2005

- STAR Collaboration (Θ^{++})

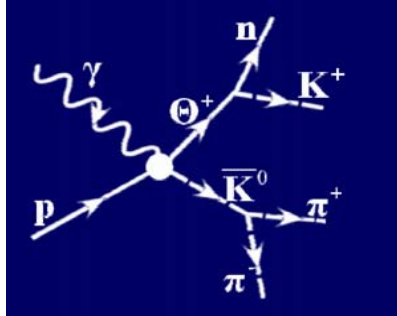
- Ma, APS Meeting, Tampa, FL April 2005.
- Huang, International Conference on QCD and Hadronic Physics, Beijing, June 20, 2005.



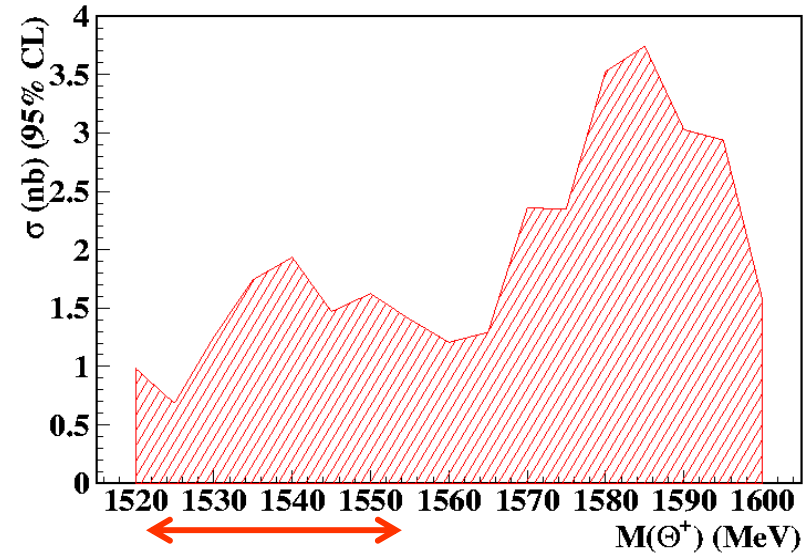
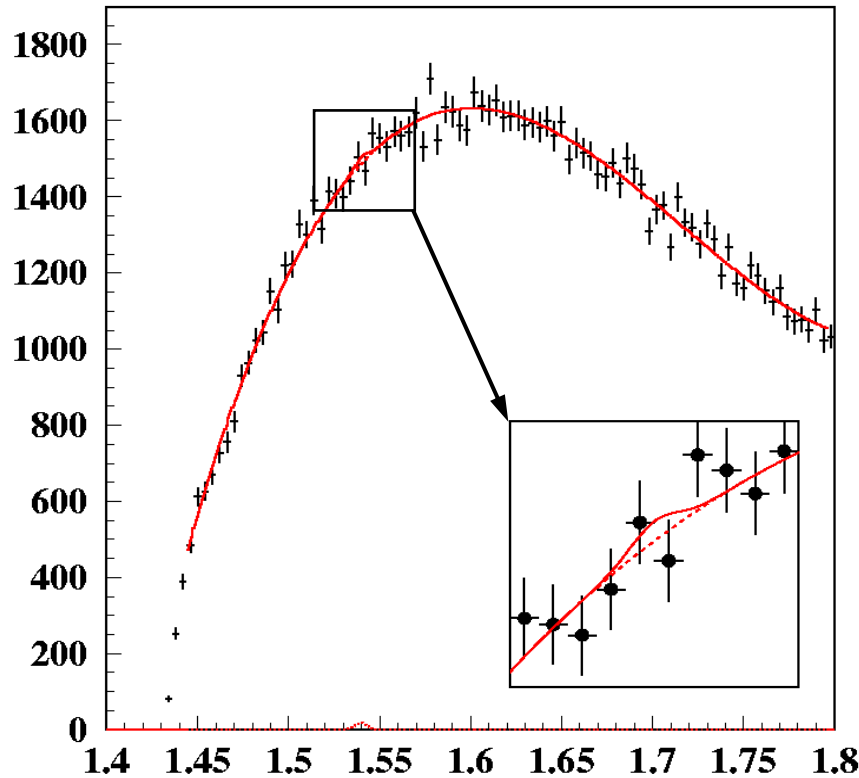
- SPring-8 $\gamma d \rightarrow \Theta^+ \Lambda(1520)$

- Nakano, International Conference on QCD and Hadronic Physics, Beijing, June 20, 2005.

2005 JLab Search on p



► The new data show no signal



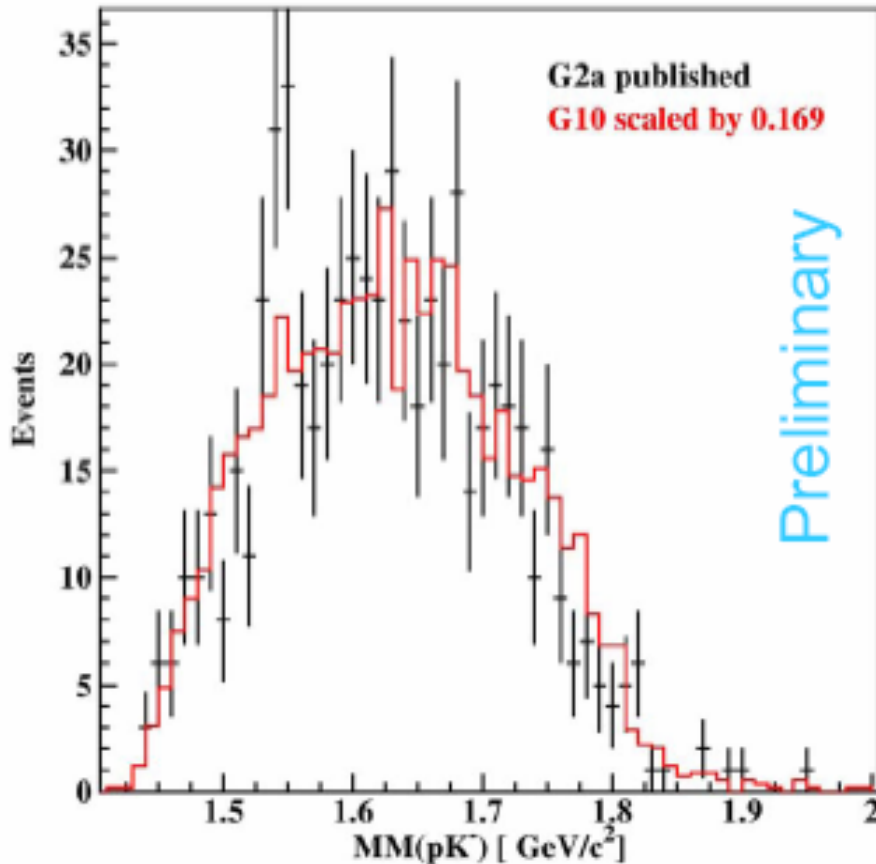
Upper limits (95% CL) :

$$\sigma_{\gamma p \rightarrow \Theta^+ K^0} < 2 \text{ nb @ } 1520 - 1555 \text{ MeV}$$

$$< 4 \text{ nb @ } 1560 - 1600 \text{ MeV}$$

g11: Tampa

High Statistics CLAS result - g10



- Two distributions statistically consistent with each other:
 - 26% c.i. for null hypothesis from the Kolmogorov test (two histograms are compatible).
 - Reduced $\chi^2=1.15$ for the fit in the mass range from 1.47 to 1.8 GeV/c²
- G10 mass distribution can be used as a background for refitting the published spectrum.

Comparison of g11 with SAPHIR

Observed Yields

SAPHIR

$$N(\Theta^+)/N(\Lambda^*) \sim 9\%$$

CLAS

$$N(\Theta^+)/N(\Lambda^*) < 0.5\% \text{ (95\% CL)}$$

Cross Sections

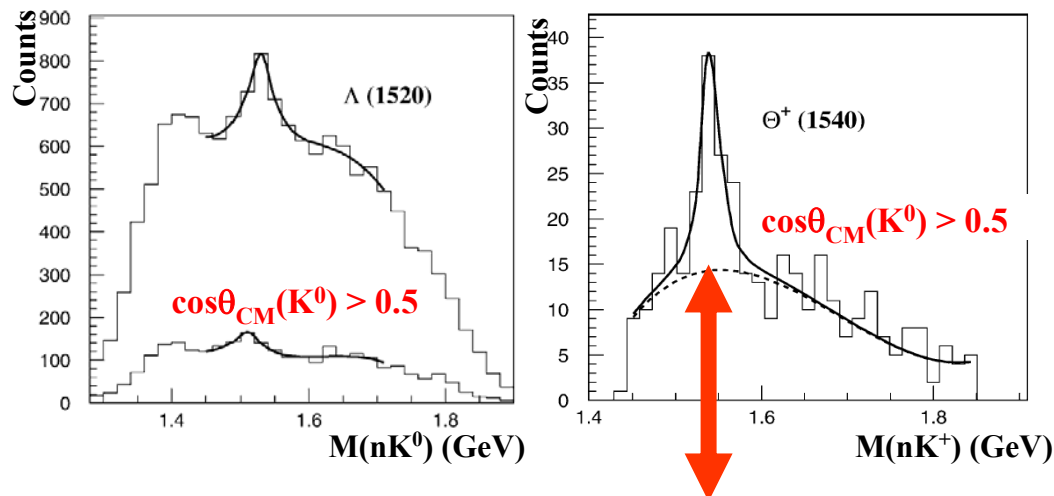
SAPHIR

$$\sigma_{\gamma p \rightarrow \Theta^+ K^0} \sim 200 \text{ (50) nb}$$

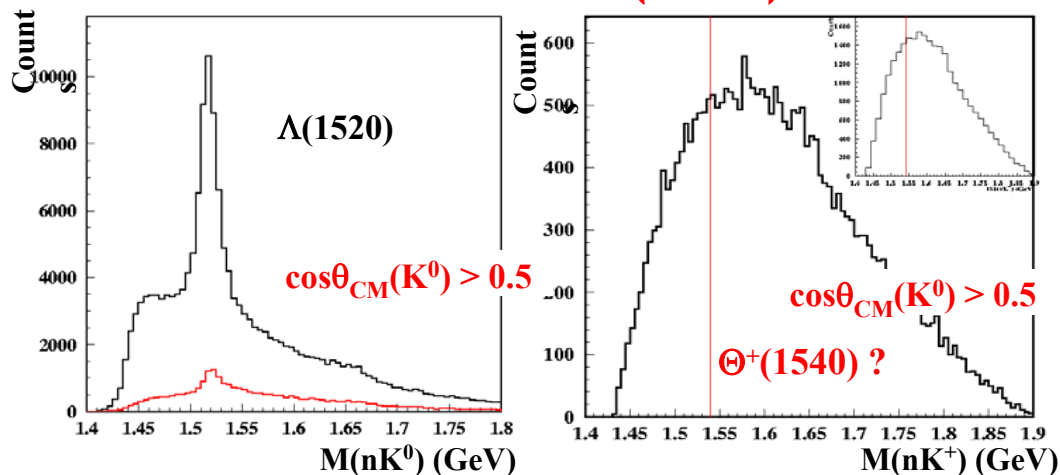
CLAS

$$\sigma_{\gamma p \rightarrow \Theta^+ K^0} < 2 \text{ nb (95\% CL)}$$

SAPHIR (2003)



CLAS (2005)



Pentaquark Publicity 2005

APS NEWS Nov 2005
Volume 28, No. 4
A Publication of The American Physical Society | <http://www.aps.org/apsnews>

New Experiment Casts Doubt on Quasie Pentaquark

By Eric Riedel

It is not all bad for the pentaquark. The first finding that the pentaquark is a new particle is a surprise. It is a surprise to the CERN Large Hadron Collider (LHC) because the particle was discovered in the first place. The LHC is the world's largest particle accelerator. It is a surprise because the pentaquark was discovered in the first place. The LHC is the world's largest particle accelerator. It is a surprise because the pentaquark was discovered in the first place.

news@nature.com
The best in science journalism

Doubt is cast on pentaquarks

Mark Kaplan

Scientists' suspicion that pentaquarks may be an experimental phantom.

Physicists have come home empty-handed from a thorough hunting expedition for pentaquarks. The lack of evidence is not too surprising, but it is a surprise because the pentaquark was discovered in the first place. The LHC is the world's largest particle accelerator. It is a surprise because the pentaquark was discovered in the first place.

Jefferson Lab
Exploring the Nature of Matter

Hydrogen nucleus diagram showing quarks and gluons.

Pentaquark Debate Heat Up
New data from Jefferson Lab shows that the pentaquark is not what it was expected to be.

SCIENCE NEWS
A TOBY'S ARMOR
A TOBY'S ARMOR
A TOBY'S ARMOR
A TOBY'S ARMOR

listen up
THE EVOLUTION OF ECHolocation

Science NOW
Do You Believe in Pentaquarks?

PENTAQUARK

Diagram showing the structure of a pentaquark with quarks and gluons.

CERN COURIER
Mystery deepens as pentaquarks refuse to make an appearance

Physicists are still looking for the pentaquark. The LHC is the world's largest particle accelerator. It is a surprise because the pentaquark was discovered in the first place.

NewScientist.com
BREAKING NEWS
Pentaquark hunt shows a blank

The hunt for the pentaquark has been a long and difficult one. The LHC is the world's largest particle accelerator. It is a surprise because the pentaquark was discovered in the first place.

LE SCIENZE
Dalla scoperta del pentaquark
La scoperta del pentaquark ha aperto una nuova frontiera nella fisica delle particelle.

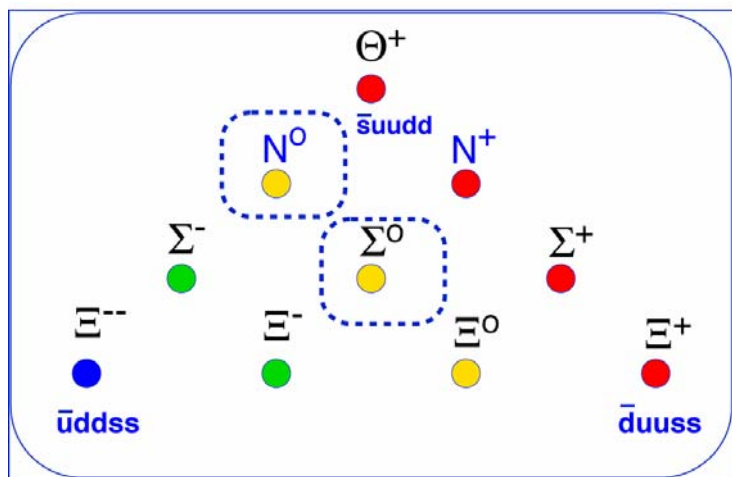
PHYSICS TODAY
The hunt for the pentaquark

The hunt for the pentaquark has been a long and difficult one. The LHC is the world's largest particle accelerator. It is a surprise because the pentaquark was discovered in the first place.

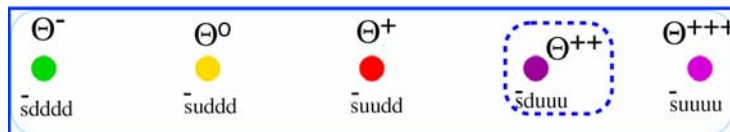
High Resolution Search for $Q^+(1540)$ Partners in JLab/Hall A

Search for narrow resonances in the mass range 1.5-1.8 GeV/c², motivated by popular pentaquark models:

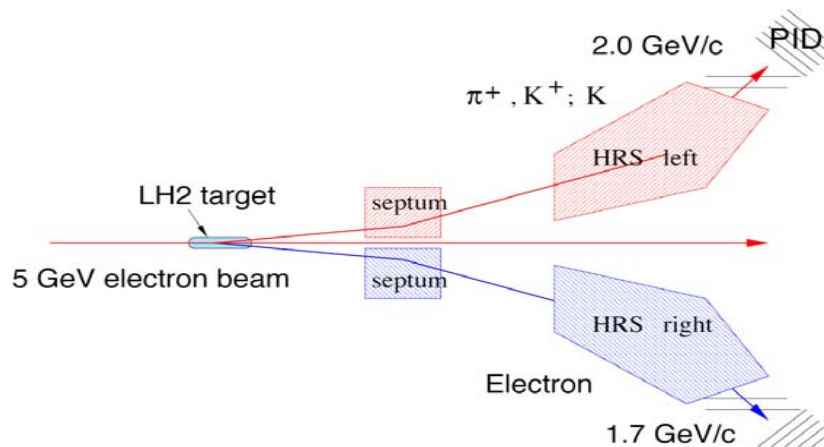
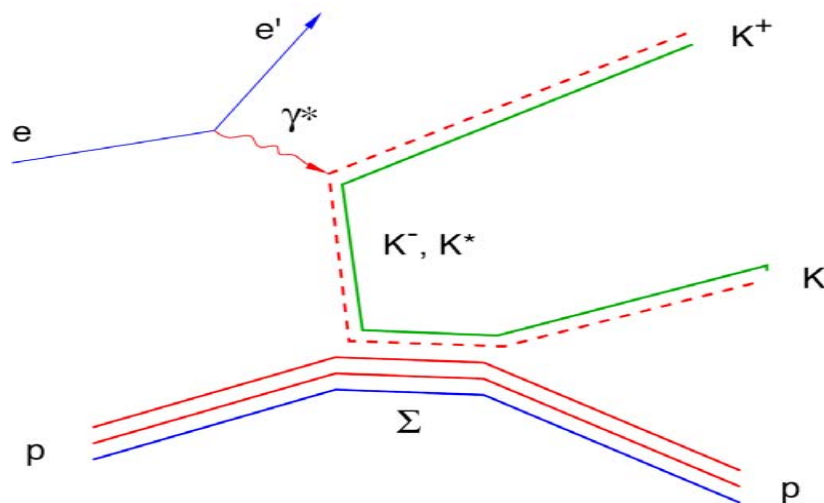
Anti-decuplet (Diakonov 1997)



Isotensor multiplet (Capstick 2003)



Missing mass technique

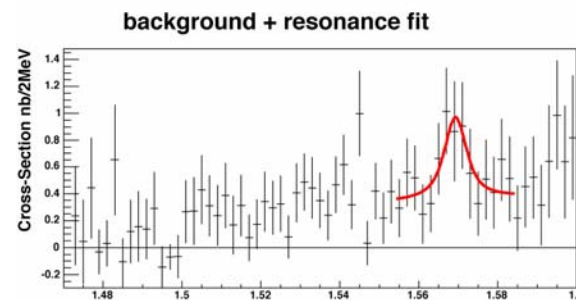
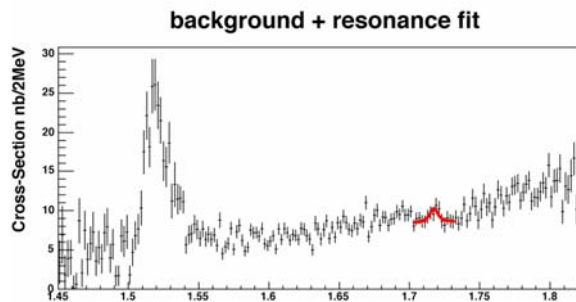
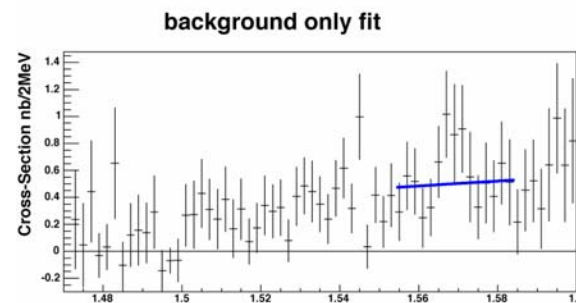
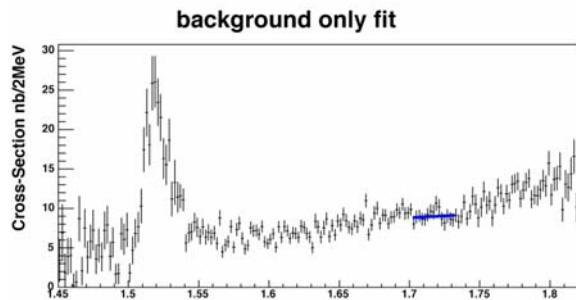


Σ^0 Search

Θ^{++} Search

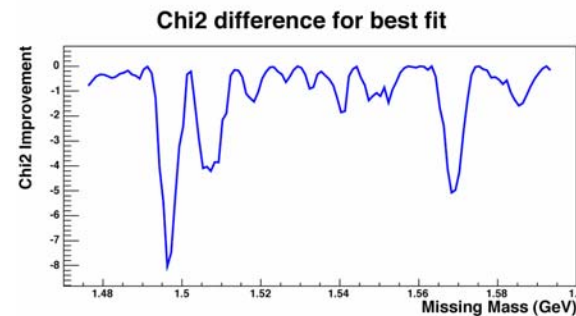
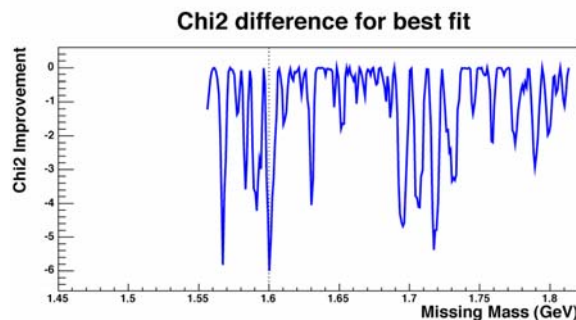
Σ^0

Θ^{++}



$\Gamma_{res}=0.005$
 $\sigma_{instr}=0.0015$

$\Gamma_{res}=0.005$
 $\sigma_{instr}=0.0015$



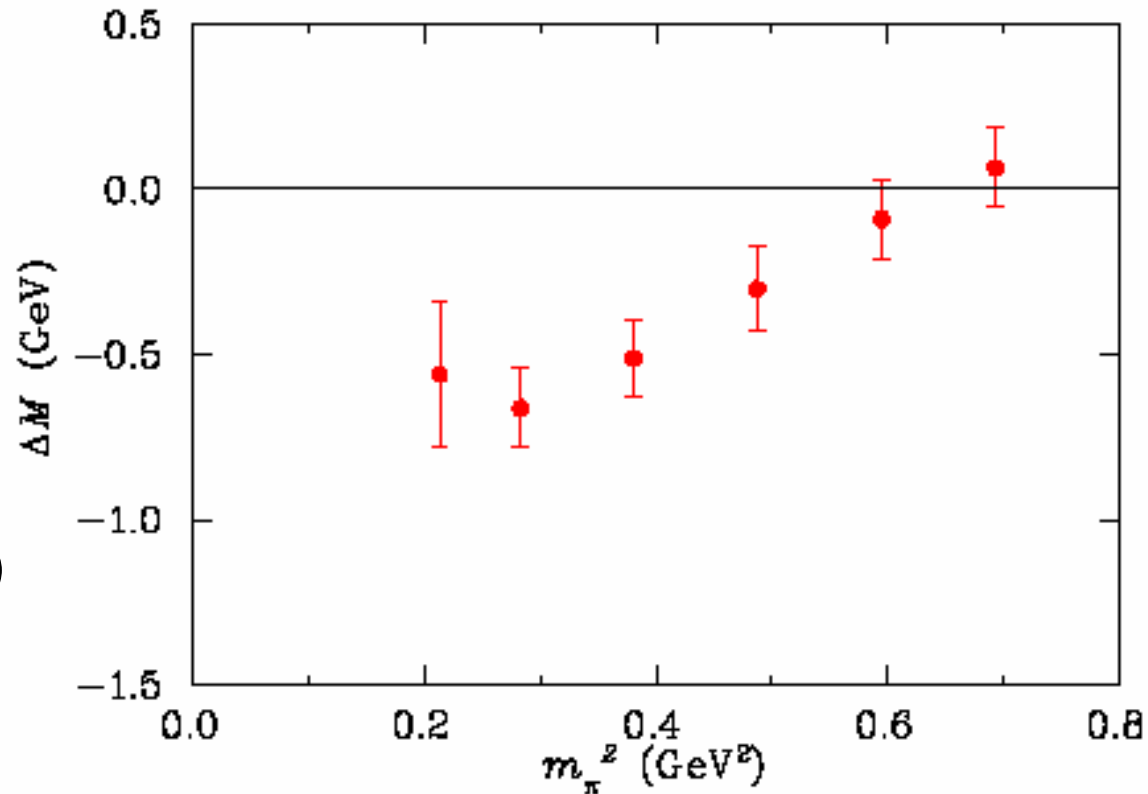
Upper limit on production xsect

$$\sigma_{\gamma^* p \rightarrow K^+ \Sigma^0} < 8 \text{ nb}$$

$$\sigma_{\gamma^* p \rightarrow K^- \Theta^{++}} < 3 \text{ nb}$$

And just in case you think you understand...

Lattice QCD study* of spin-3/2 pentaquark —
show mass compared with p-wave NK system



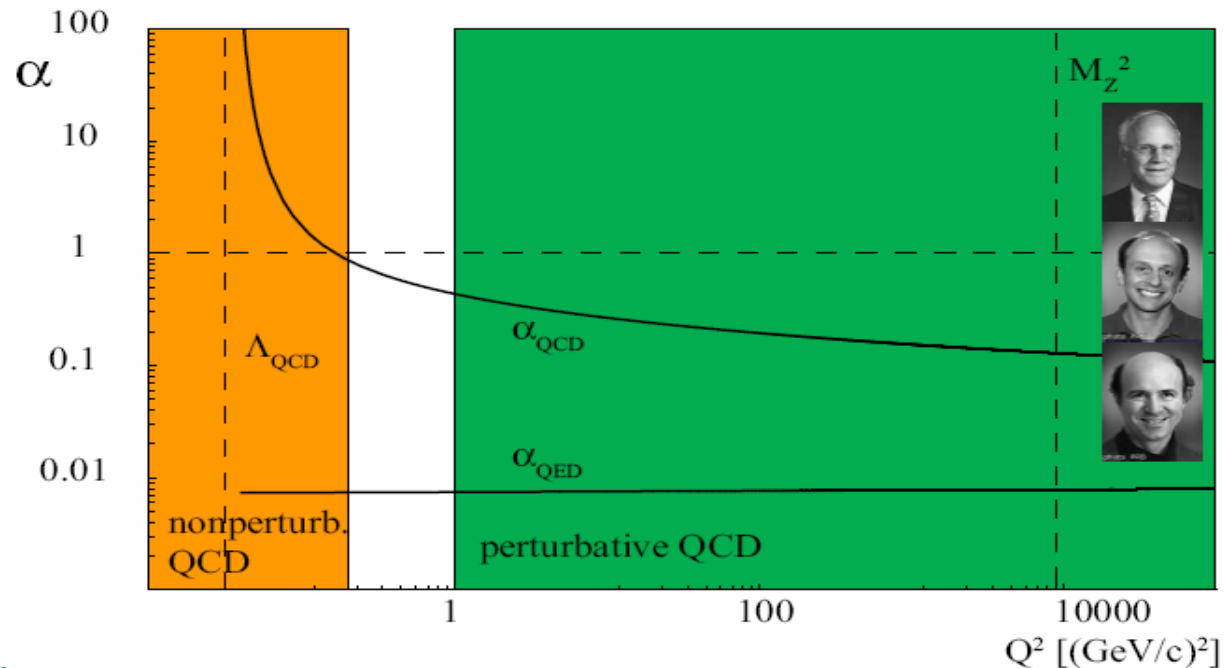
Clear indication
of attraction
(and possibly
interesting
chiral behavior)

* [hep-lat/0405015](https://arxiv.org/abs/hep-lat/0405015): Lasscock et al. [CSSM- Jlab Collaboration]

Pentaquark Summary

- Existence or otherwise is a CRUCIAL question in strong interaction physics
- Wilczek, Jaffe: That we cannot say whether such such exotica exist or not shows HOW LITTLE WE UNDERSTAND NON-PERTURBATIVE QCD

- Jefferson Lab is the ideal facility to definitively answer this question!





Marciana Marina, Isola d'Elba, Italy.

Electron-
Nucleus
Scattering
VIII
Workshop,
June 21-25,
2004



Thomas Jefferson National Accelerator Facility



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 Spin and Flavor Dependence of Valence PDFs

- In over 35 years of study of DIS no-one has had the facilities to map out the crucial valence region
- Region is fundamental to our understanding of hadron structure: i.e. how nonperturbative QCD works!

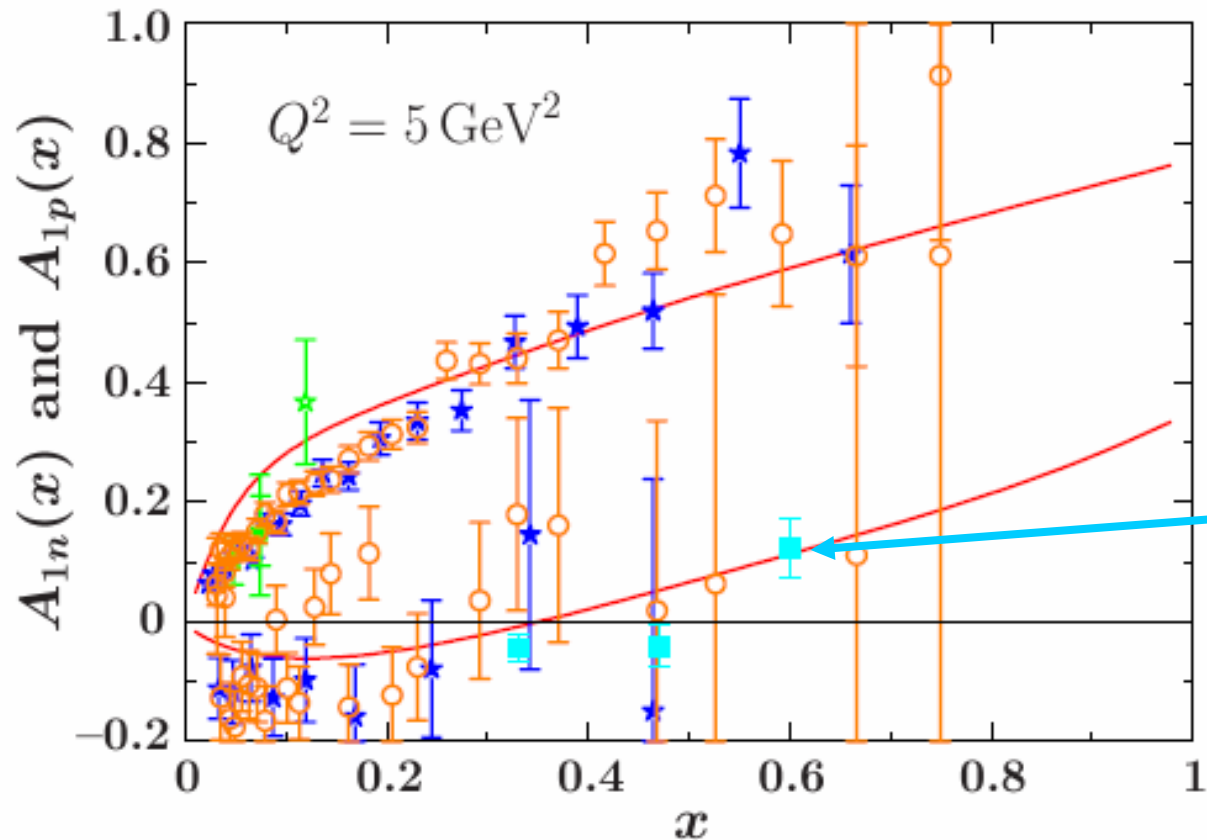
Role of di-quark correlations?

Role of hard scattering: pQCD / LCQCD guidance?

Breaking of $SU(6)$ symmetry?

Moments of PDFs (and GPDs) from Lattice QCD....

Proton and Neutron Asymmetry



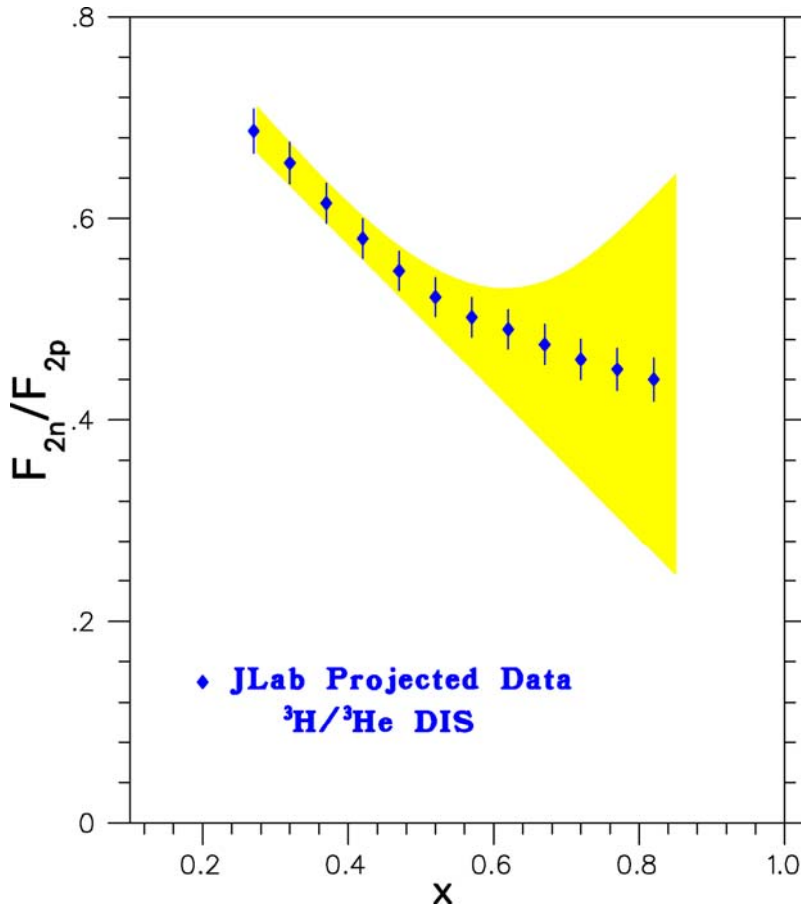
Recent Jlab data

c.f. covariant NJL model, with confinement

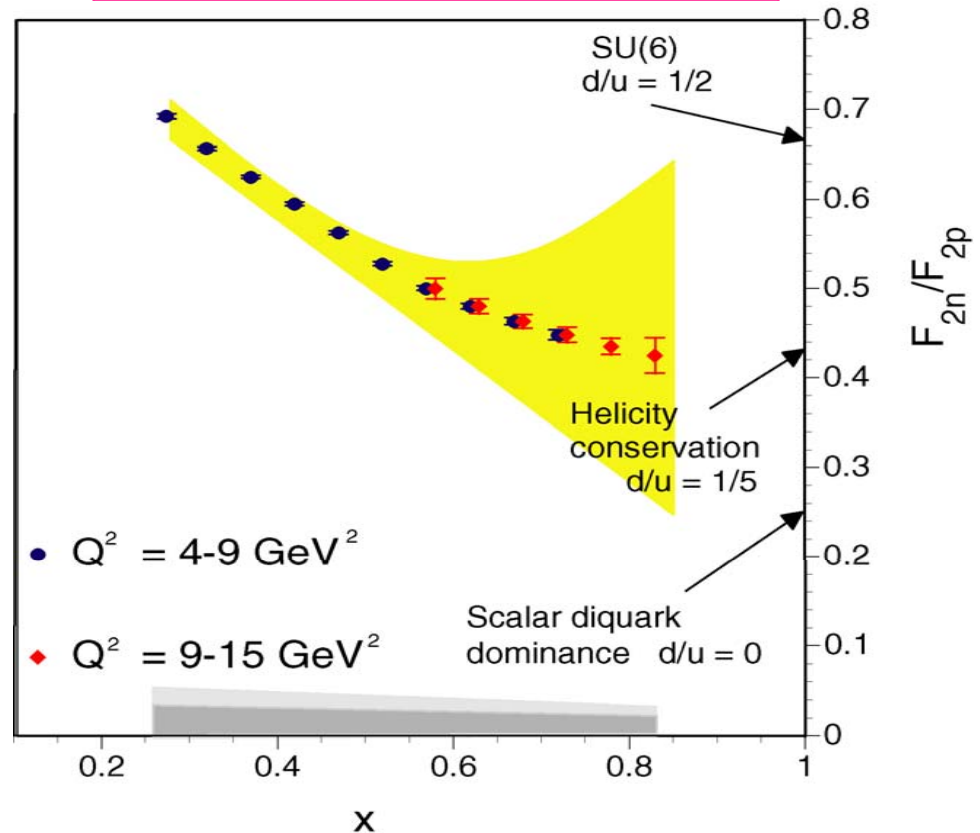
Cloet, Bentz, AWT, (Phys. Lett. B621 (2005) 246)

12 GeV : Unambiguous Flavor Structure x! 1

Hall C 11 GeV with HMS



HallB 11 GeV with CLAS12

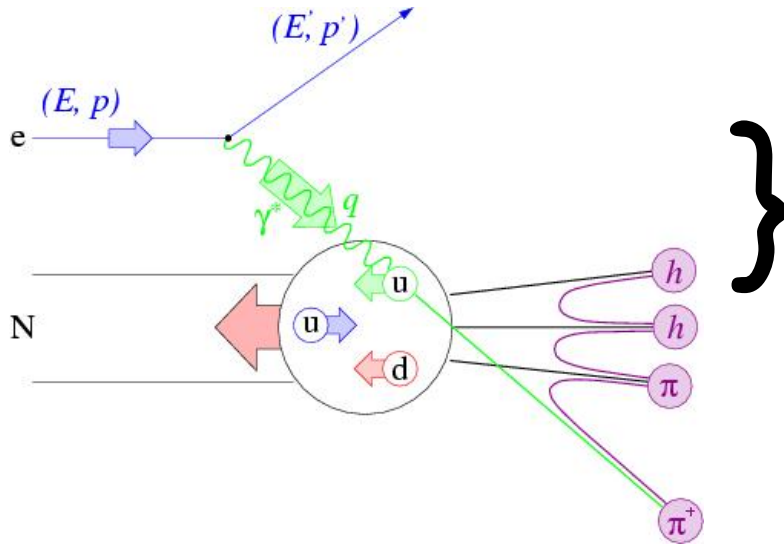


Initial investigation with BONUS early 06

Flavor Decomposition: semi-inclusive DIS

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

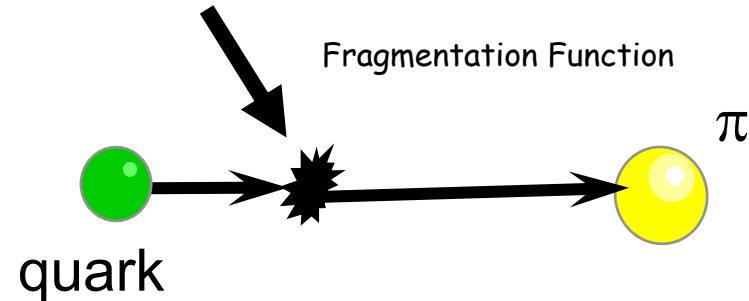
$$\sum e_q^2 (q + \bar{q})$$



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

\rightarrow Can 'tag' the flavor of the struck quark by measuring the hadrons produced: **'flavor tagging'**

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



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

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

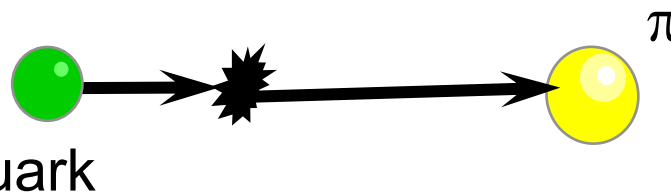
(e,e'm) $W'^2 = M^2 + Q^2 (1/x - 1)(1 - z)$

$z = E_m/v$

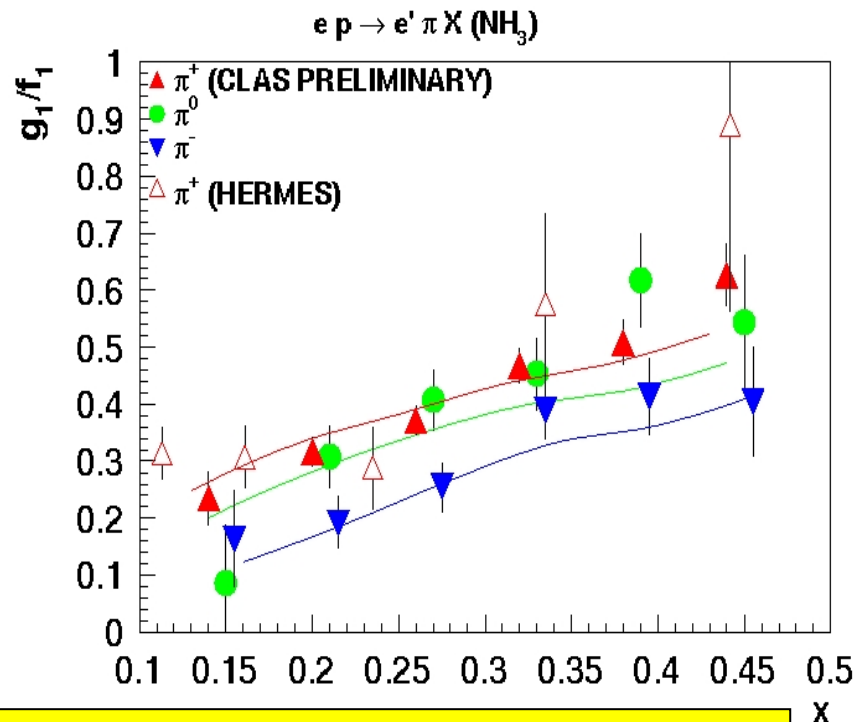
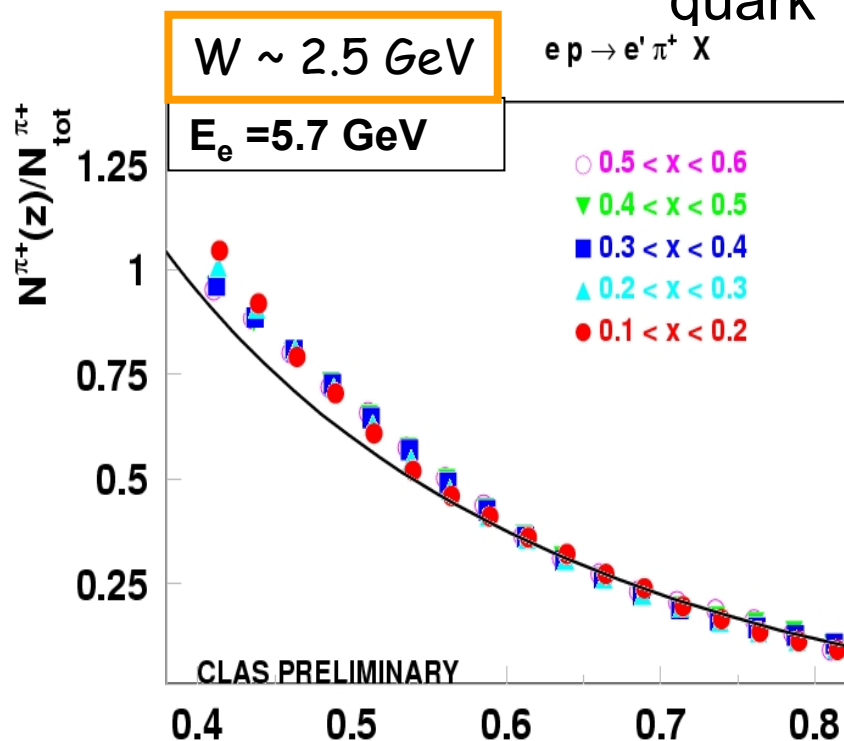
Low-Energy Factorization?

CLAS Collaboration,
H. Avakian et al.

$$\sum_q e_q^2 q(x) D_{q \rightarrow M}(z)$$



Collinear
Fragmentation

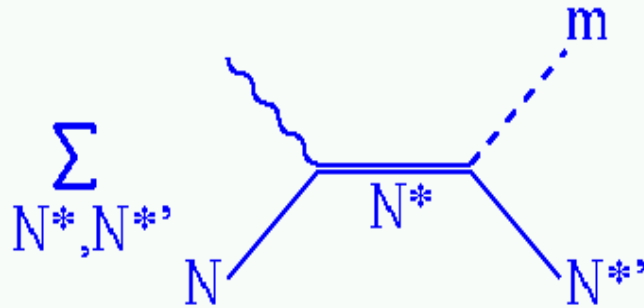


No significant variation observed in z distributions of π^+ for different x ranges ($0.4 < z < 0.7$, $M_X > 1.5 \text{ GeV}$)

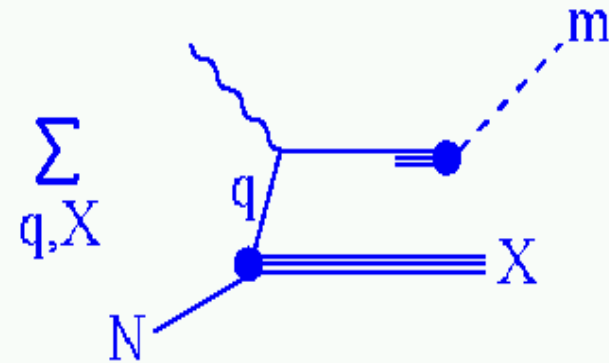
x dependence of CLAS A_1^P ($A_2=0$) consistent with HERMES data (at $x3$ higher Q^2) and with PEPSI (LUND)MC.

Duality in Meson Electroproduction

hadronic description



quark-gluon description



$$\sum_{N'^*} \left| \sum_{N^*} F_{\gamma^* N \rightarrow N^*}(Q^2, W^2) \mathcal{D}_{N^* \rightarrow N'^* M}(W^2, W'^2) \right|^2$$

Transition
Form Factor

Decay
Amplitude

$$\sum_q e_q^2 q(x) D_{q \rightarrow M}(z)$$

Fragmentation
Function

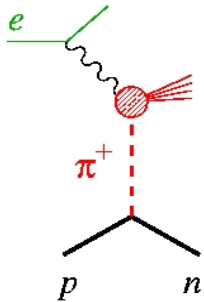
Requires non-trivial cancellations of decay angular distributions
If duality is not observed, factorization is questionable

Duality and factorization possible for $Q^2, W^2 \leq 3 \text{ GeV}^2$ (Close and Isgur, Phys. Lett. B509, 81 (2001); Close and Melnitchouk, Phys.Rev.C68:035210,2003)

Flavor asymmetry of proton sea: Quarks or mesons?

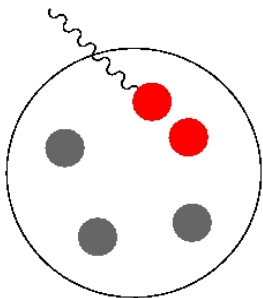
HP 2013

...New: Polarization!



pion cloud

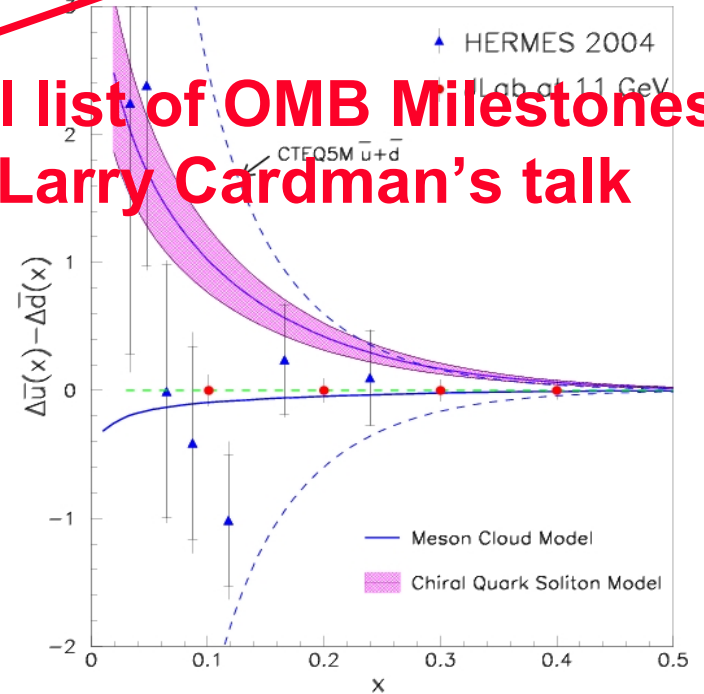
$$\Delta\bar{u} - \Delta\bar{d} = 0$$



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

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

Full list of OMB Milestones
in Larry Cardman's talk



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

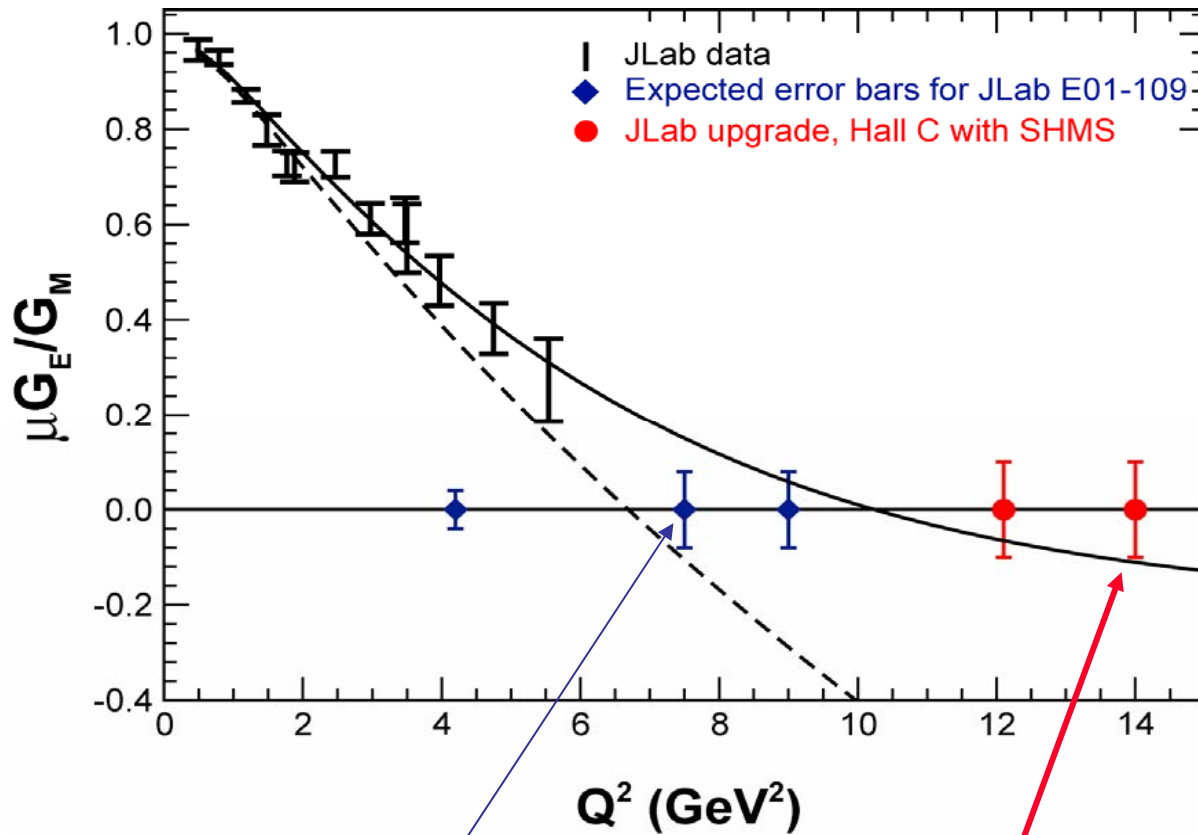
[Thomas 83; Schreiber *et al.*, 90;
Diakonov *et al.* 96; Fries, Schaefer, Weiss 03]

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



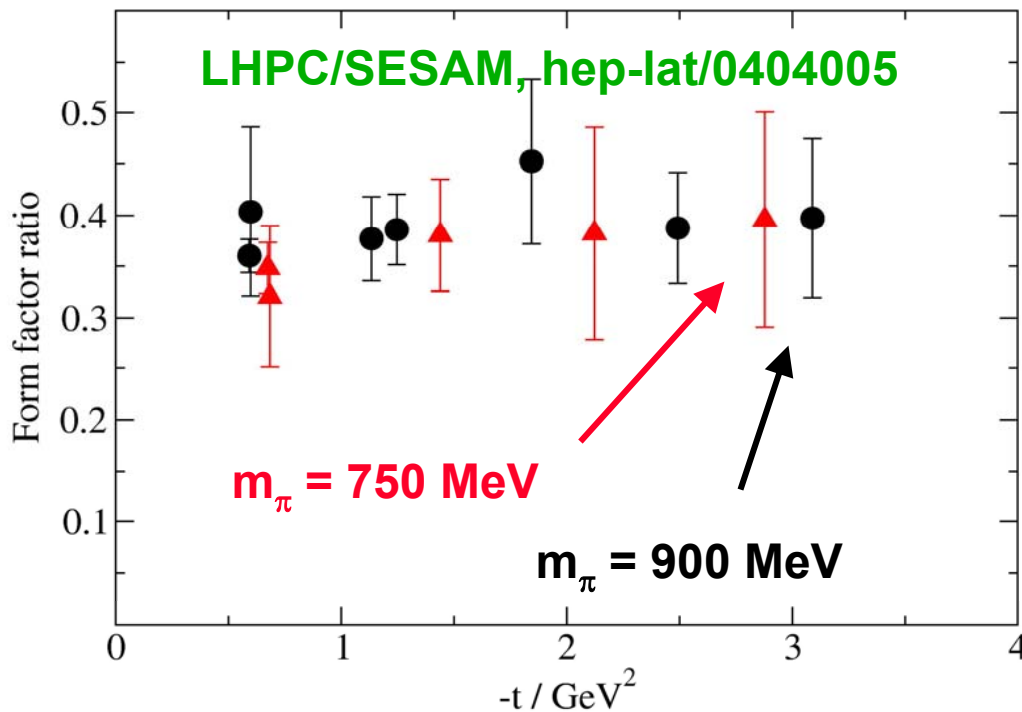
HP 2010

David Richards
to discuss 2γ
corrections

- 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
 - Lattice computation to physical quark masses and large volumes
- **Large Q^2 behavior** controlled by lattice spacing a
 - Need to work on fine lattice



- Importance of pQCD corrections

Brodsky

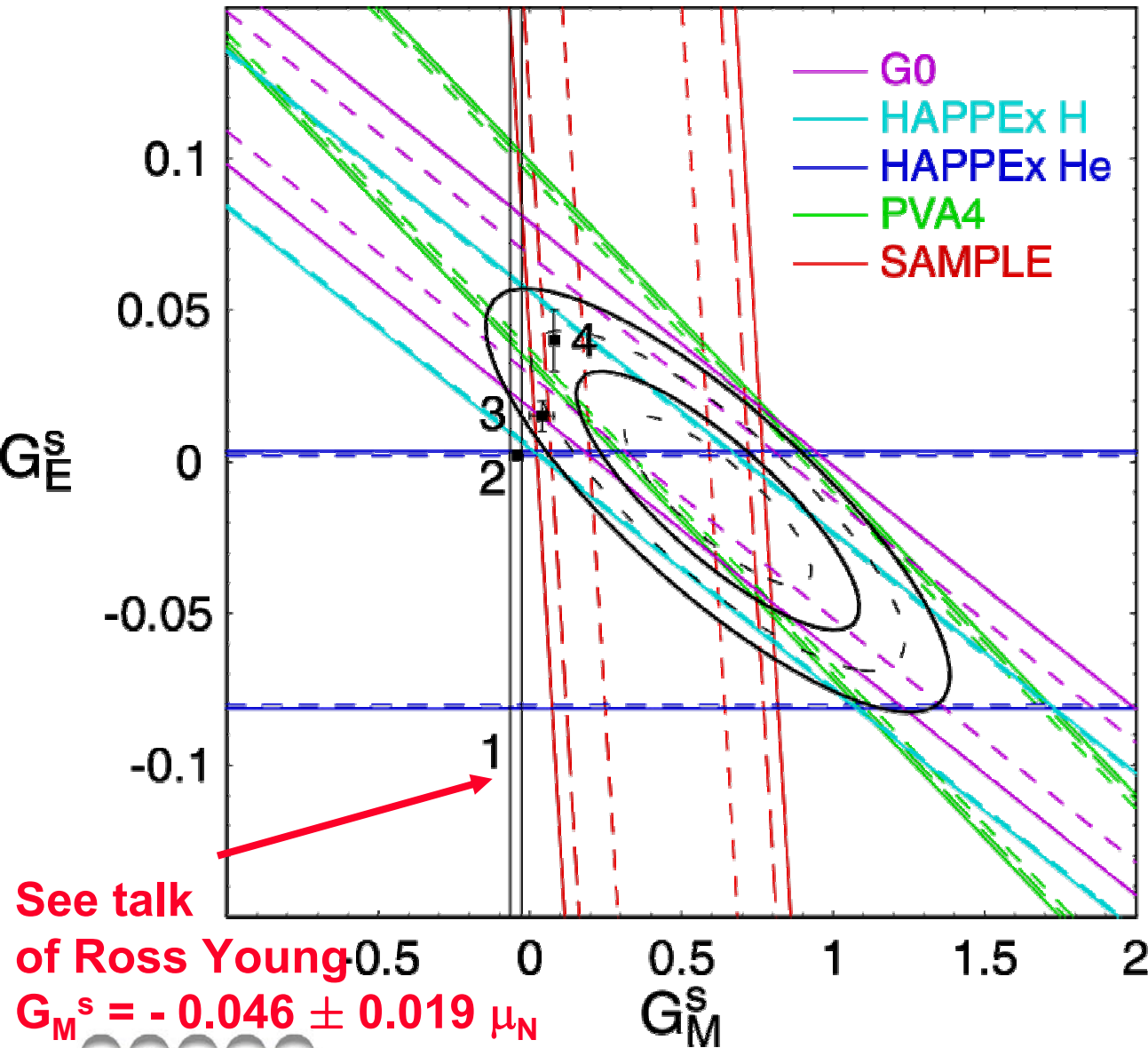
- pQCD computation

Belitsky, Ji, Yuan

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

- $Q^2 \simeq 6 \text{ GeV}^2$ by **2010**
- $Q^2 \simeq 10 \text{ GeV}^2$ by **2012**

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



$$G_E^S = -0.013 \pm 0.028$$

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

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

See talk
of Ross Young
 $G_M^S = -0.046 \pm 0.019 \mu_N$

Significance & Comparison with Lattice QCD

Size and sign of the strange magnetic moment
is astounding!

- Experimental isoscalar nucleon moment is $0.88 \mu_N$
c.f. this result which is (G0) $- 0.54 \mu_N$: i.e. - 60% !!
- Also remarkable versus lattice QCD which gives
 $+0.03 \pm 0.01 \mu_N$ (Leinweber et al., PRL 94 (2005) 212001)
- Sign would require violation of universality of
valence quark moments by $\sim 70%$!

MORE DETAIL: TALK OF Ross Young...



Parity Violating Studies on ^1H and ^4He

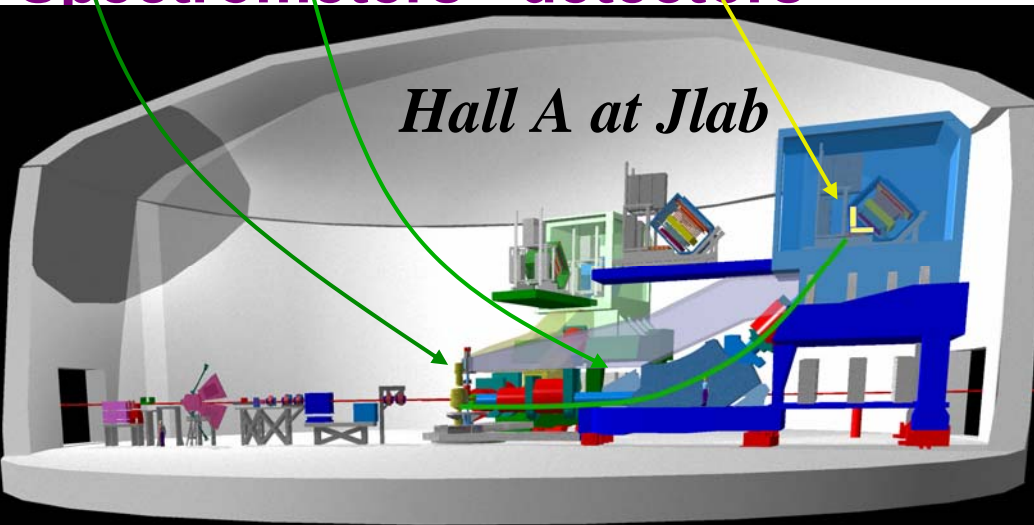
3 GeV beam in Hall A

$\theta_{lab} \sim 6^\circ$

$Q^2 \sim 0.1 \text{ (GeV/c)}^2$

target	A_{PV} $G^S = 0$ (ppm)	Stat. Error (ppm)	Syst. Error (ppm)	sensitivity
^1H	-1.6	0.08	0.04	$\delta(G^S_E + 0.08G^S_M) = 0.010$
^4He	+7.8	0.18	0.18	$\delta(G^S_E) = 0.015$

Septum magnets (not shown)
High Resolution
Spectrometers detectors



Brass-Quartz integrating detector

PMT

Cherenkov cones

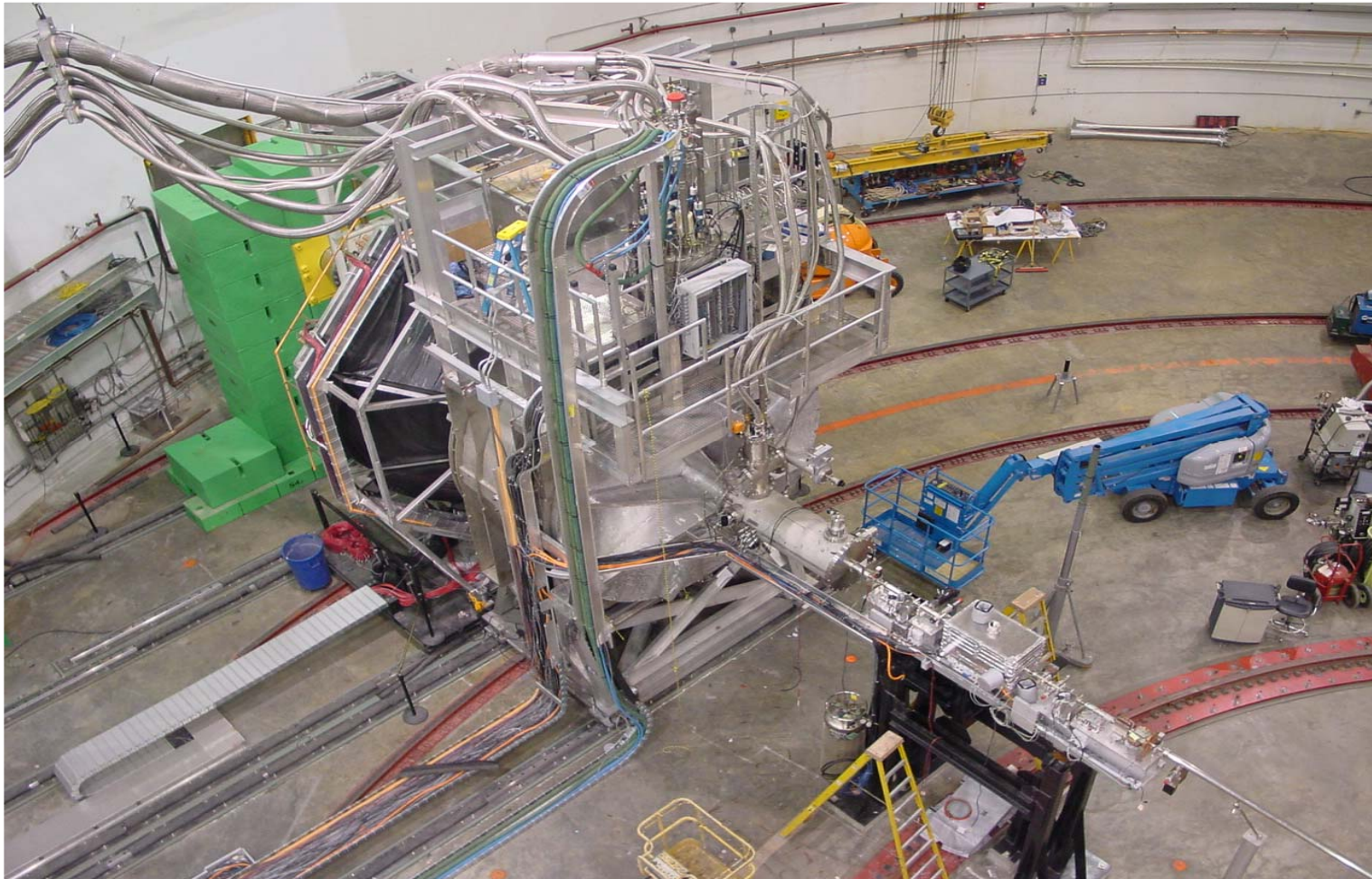
PMT

Elastic Rate:
 $^1\text{H}: 120 \text{ MHz}$
 $^4\text{He}: 12 \text{ MHz}$

Background $\leq 3\%$

Science
U.S. DEPARTMENT OF ENERGY

G0 Experiment in Hall C

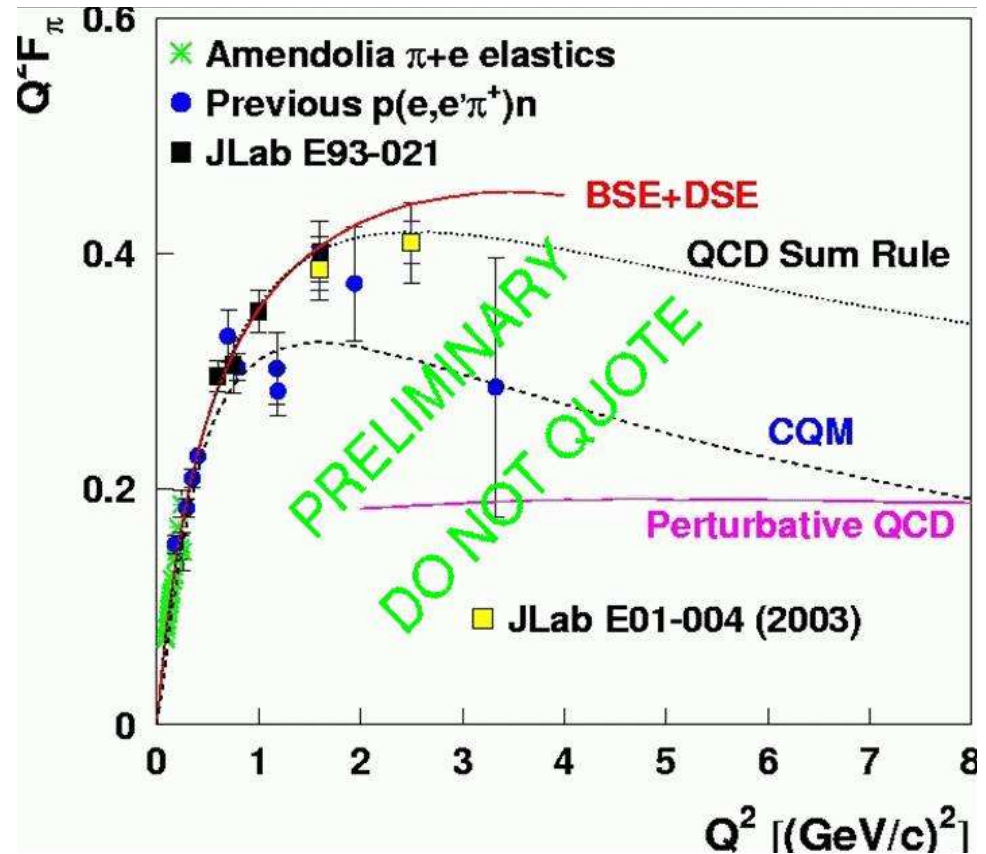
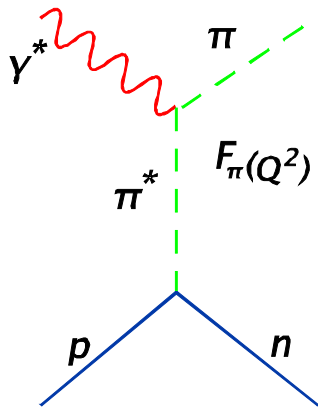


G0 and HAPPEX will define these form factors up to 1 GeV² over the next 2 years

2010

E01-004: New Pion Form Factor Data

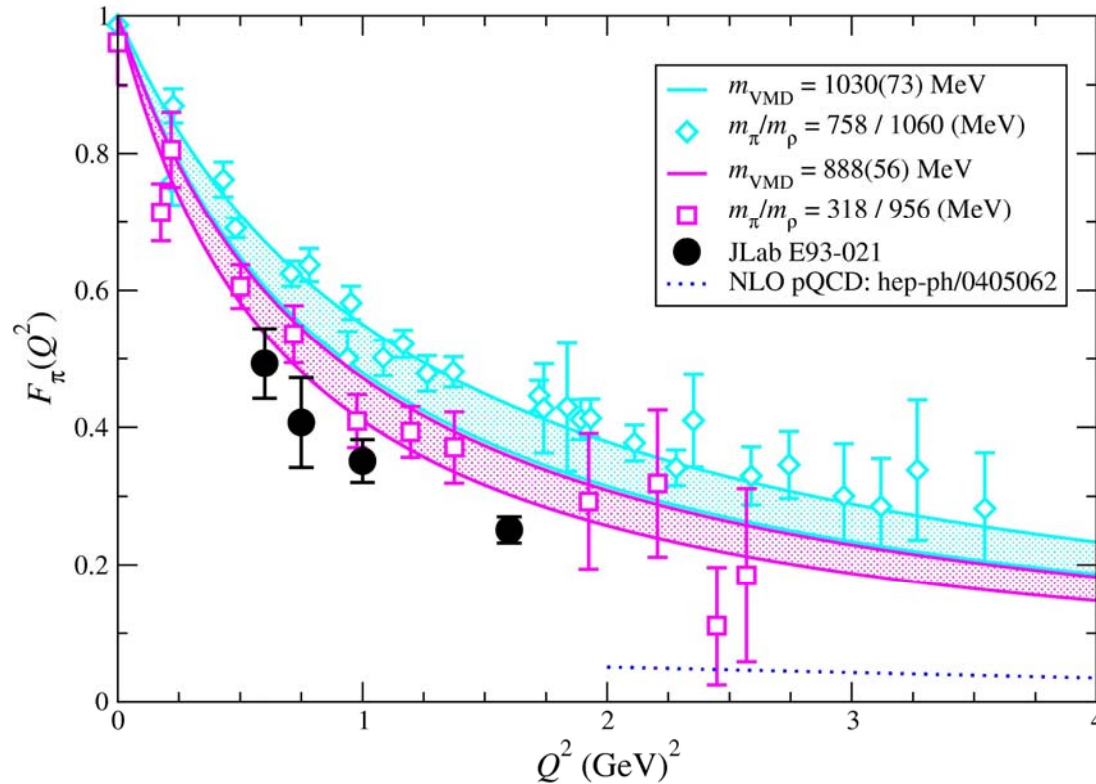
- Increase in dynamic coverage in Q^2
- Data point at $Q^2=1.60 \text{ GeV}^2$ to check model dependence of mass pole extrapolation
- Possibility to rule out phenomenological calculations.



Outer uncertainties reflect present status of analysis, the inner bars reflect anticipated final uncertainties.

To reach regime of pQCD expectation require higher energy electron of the 12 GeV Upgrade

Pion Form Factor – Lattice QCD



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

- Pion Form factor over Q^2 commensurate with experiment
- Pion GPD's and transition form factors

6 GeV Highlights Leading to the 12 GeV Upgrade

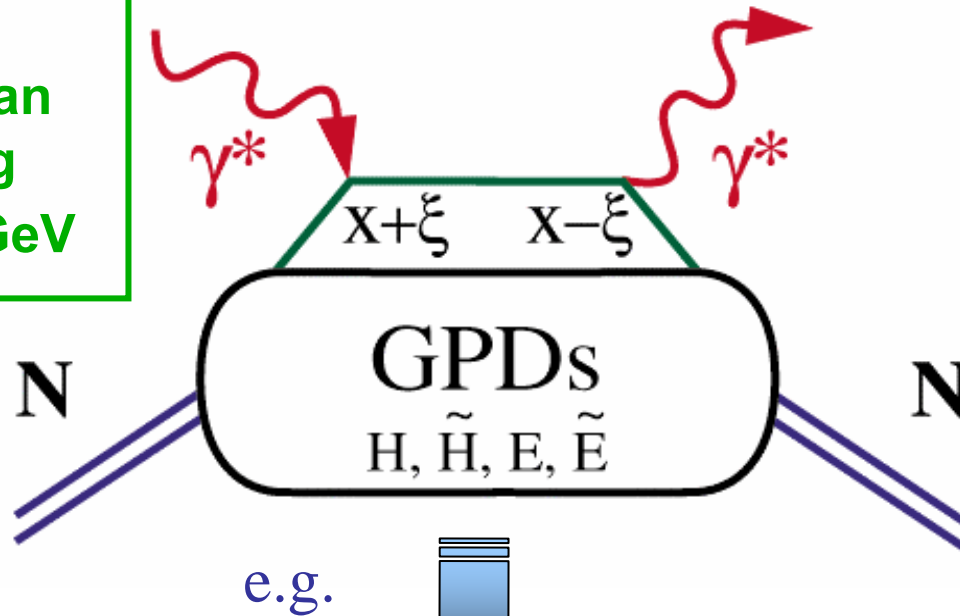
- Parton Distribution Functions
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Studies of the Generalized Parton Distributions (GPDs): New Insight into Hadron Structure

See talk of
Larry Cardman
for promising
results at 6 GeV

HP 2008



X. Ji &
A. Radyushkin
(1996)

Quark angular momentum (Ji's sum rule)

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

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

6 GeV Highlights Leading to the 12 GeV Upgrade

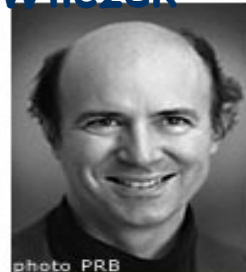
- Parton Distribution Functions
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QCD: Unsolved in Nonperturbative Regime



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!



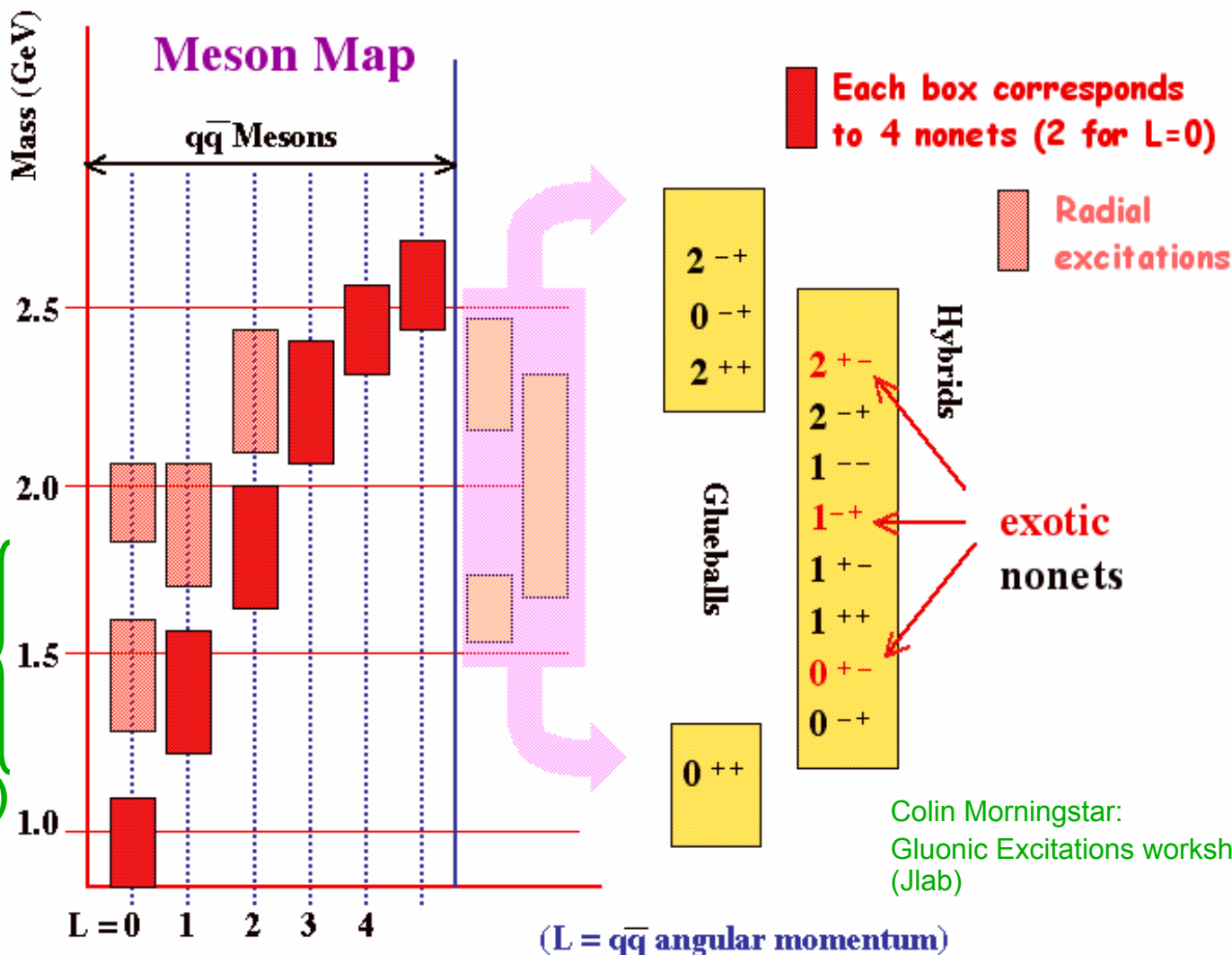
Thomas Jefferson National Accelerator Facility

Page 37



U.S. DEPARTMENT OF ENERGY

Glueballs and hybrid mesons



Initial search
FY07 –
G12 (CLAS)

Colin Morningstar:
Gluonic Excitations workshop, 2003
(Jlab)

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

- 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
 - No suppression of conventional-hybrid photo-couplings for hybrids near 2 GeV

$$\Gamma(\pi_{1H}^+ \rightarrow a_2^+ \gamma) \sim \mathcal{O}(100)\text{keV}$$

$$\Gamma(b_{JH}^+ \rightarrow \rho^+ \gamma) \sim \mathcal{O}(1000)\text{keV}$$

$$(\text{c.f. } \Gamma(b_1^+ \rightarrow \rho^+ \gamma) = 230 \pm 60\text{keV})$$

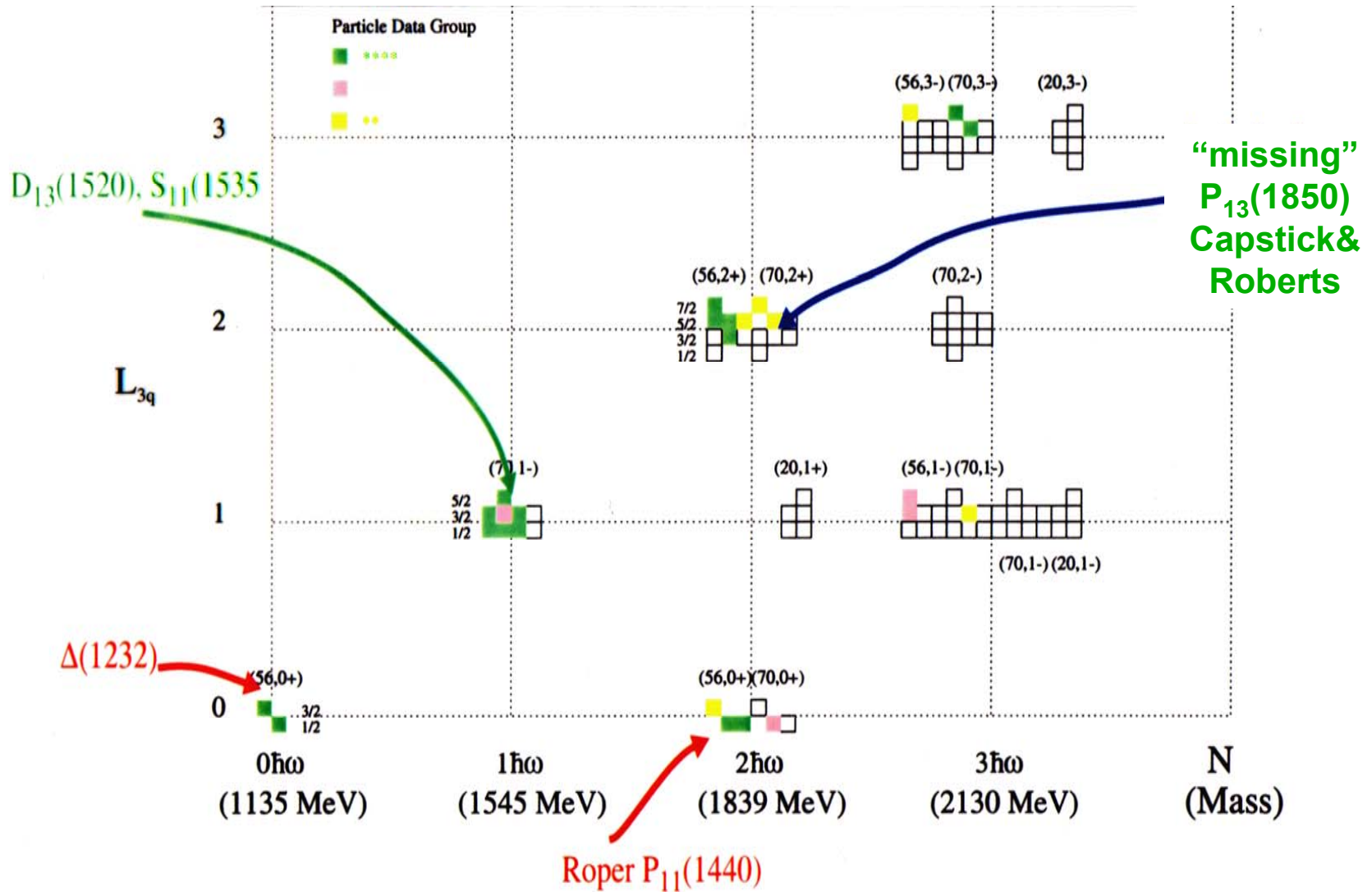
Close and Dudek,
PRL91, 142001 (2003);
PRD 69 034010 (2004)

Investigate and attempt to verify prediction using
lattice QCD

Report on PWA collaboration with
GlueX and Lattice work: David Richards



Baryon Spectroscopy: e.g. "Missing States"



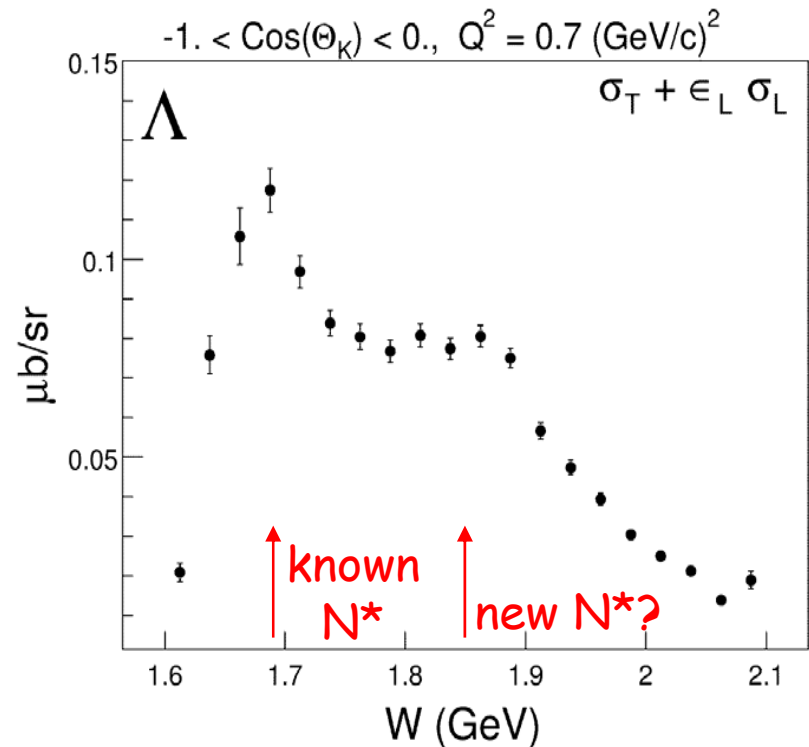
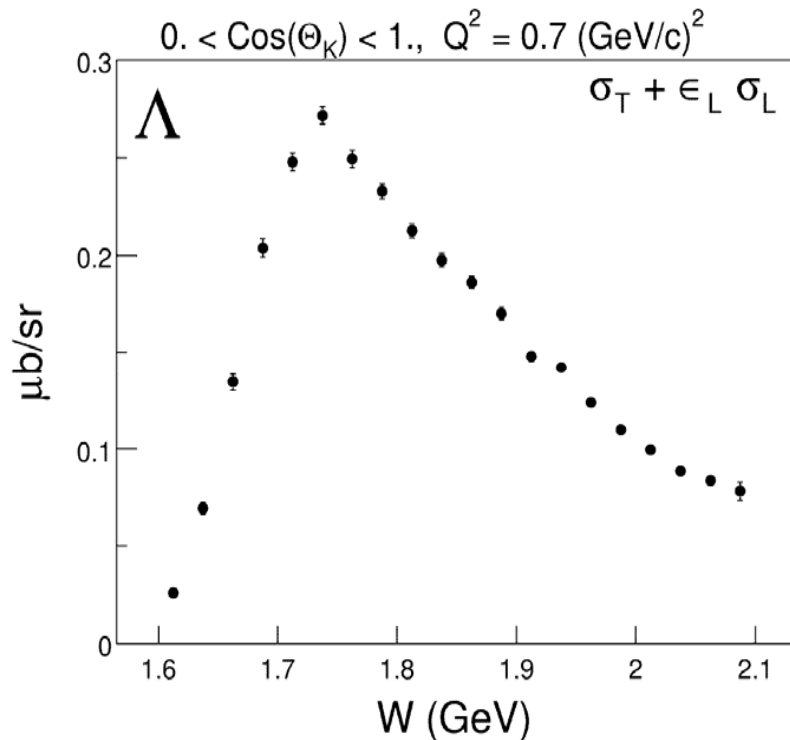
New N^* state in $K\Lambda/K\Sigma$ production ?

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

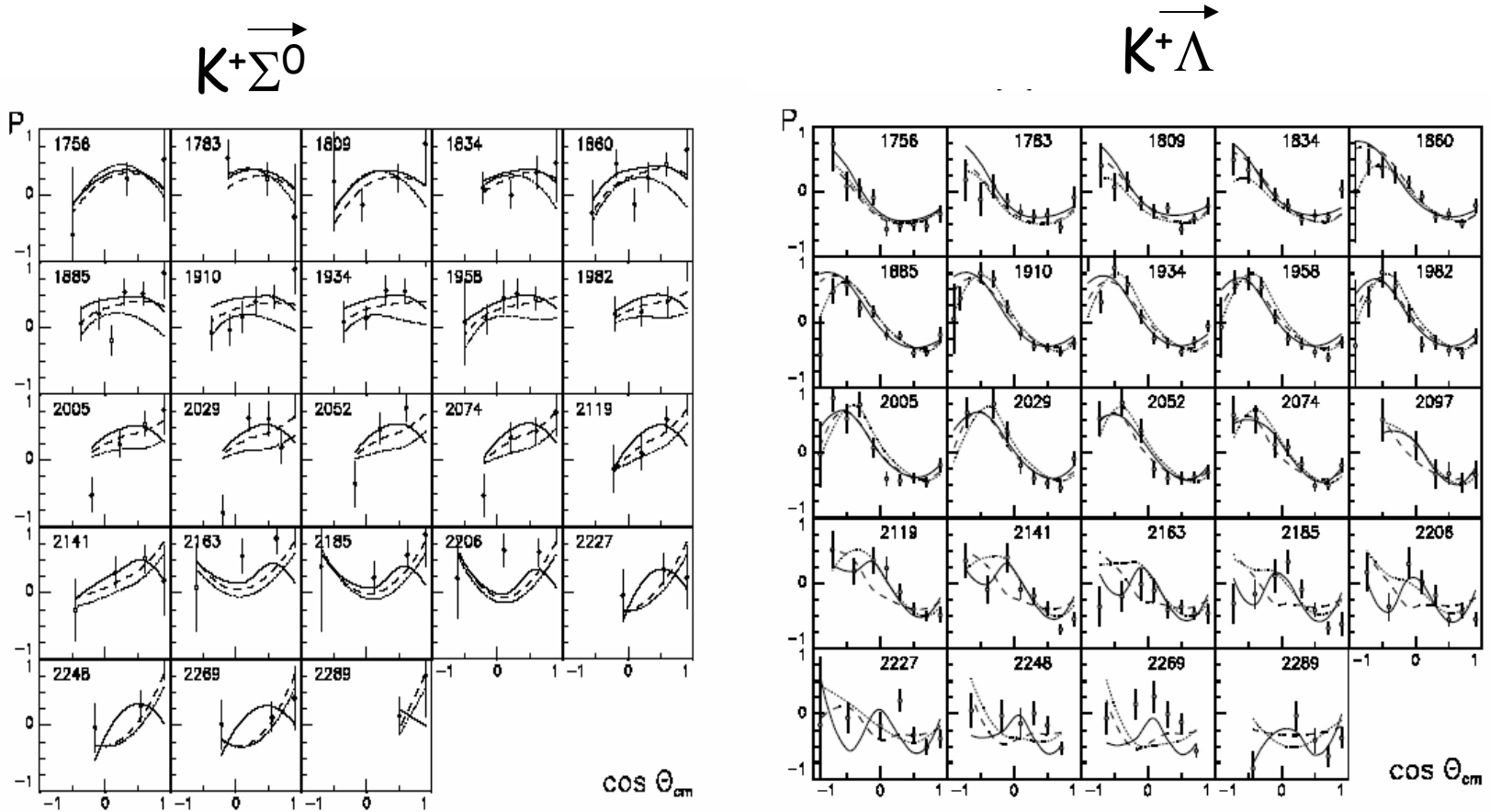
forward hemisphere

CLAS

backward hemisphere



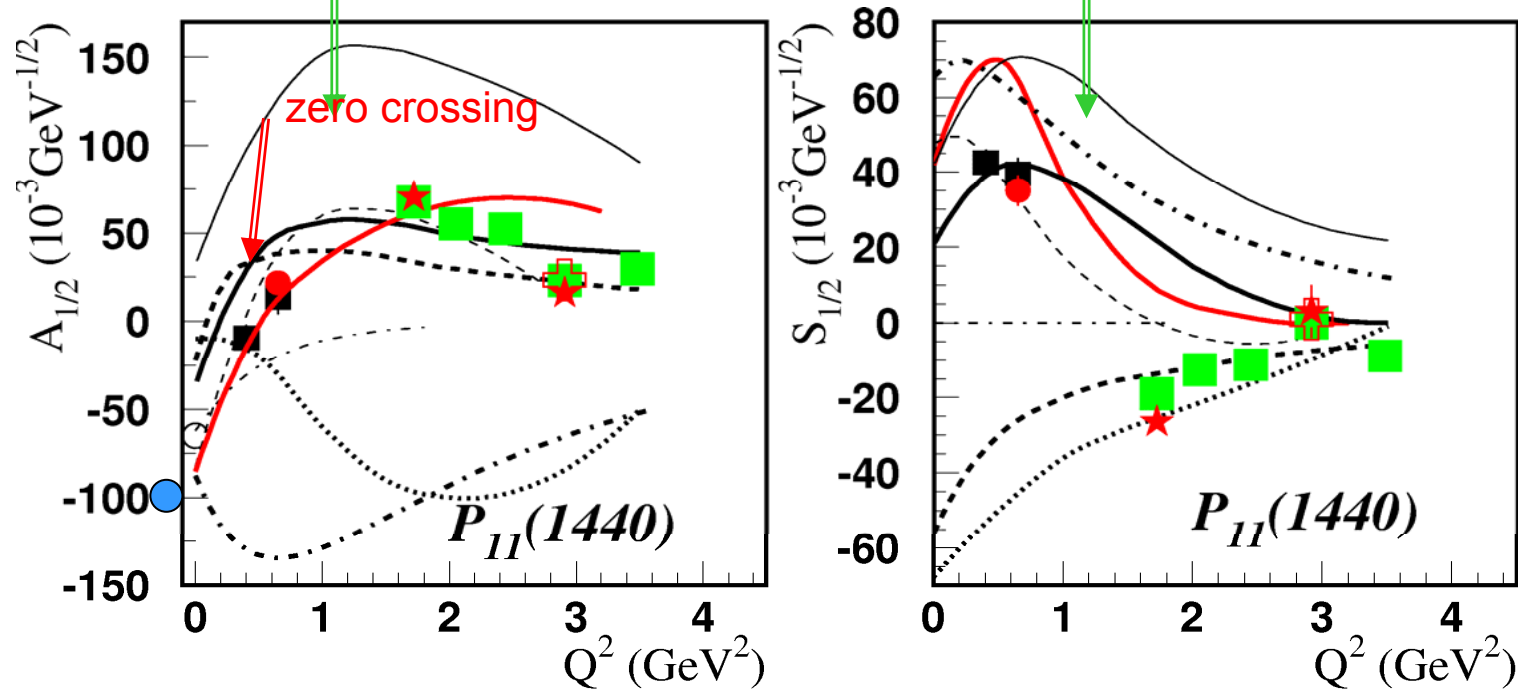
New states in $K^+\Lambda$ and $K^+\Sigma$ photoproduction



- Analysis finds new P_{11} state at 1840 MeV, and $G = 140$ MeV
- A P_{11} state @ 1840 MeV is consistent with symmetric quark model
- It is inconsistent with diquark-quark symmetry

Transition form factor $\gamma p P_{11}(1440)$

- Transition from meson-cloud behavior to quark core behavior ?



- ■ ● UIM 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
- Roper amplitudes not consistent with gluonic excitation

Excited-Baryon Analysis Center

A proposal for the establishment of an excited-baryon analysis center at JLab

HP 2009

- **Role:** To develop theoretical tools (e.g. coupled channel; EFT) to analyze existing & future CLAS (and other) data
- **Scientific relevance:**
 - i)** identify new baryon resonances
 - ii)** measure couplings & transition form factors
 - iii)** comparison with LQCD
 - iv)** deepen understanding of how QCD is realized
- **Critical theoretical issues:**
 - i)** background-resonance separation
 - ii)** incorporation of multi-particle final states
 - iii)** importance of unitarity, analyticity...



Proposed Structure of EBAC

S&T Review 2003: “A critical need in the overall JLab program is to have a systematic effort dedicated to analysis of photo- and electro-production of baryons and mesons. The theory group, in concert with the needs of the experimental collaborations, has begun to formulate a plan to establish an N* Analysis Center. We applaud this long-needed initiative.”

After 2004 S&T Review: proposal to DOE

- **Senior theorist with a broad knowledge of hadronic and electromagnetic interactions, reaction theory, and the methods used in phenomenological analysis**
- **Mid- and junior-level staff positions and term/visiting positions for theorists and experimentalists to advance the program and to interface with relevant groups. Strong workshop/visitor program.**
- **Independent, expert Scientific Advisory Board**



Collaboration with ANL Theory Group

Proposed Time Table

- Pose the results from **homework** problems on website by the end of June
 - Invite other groups to send in their results by August 15
 - Present a summary of the comparisons at the second workshop (Aug.29 -sept 2) of Argonne Theory Institute
-
- Develop a plan for future collaborations and/or communications between different groups.
- Inform the organizers of 2005 N^* meeting at Florida State University (Oct. 12-15, 2005)

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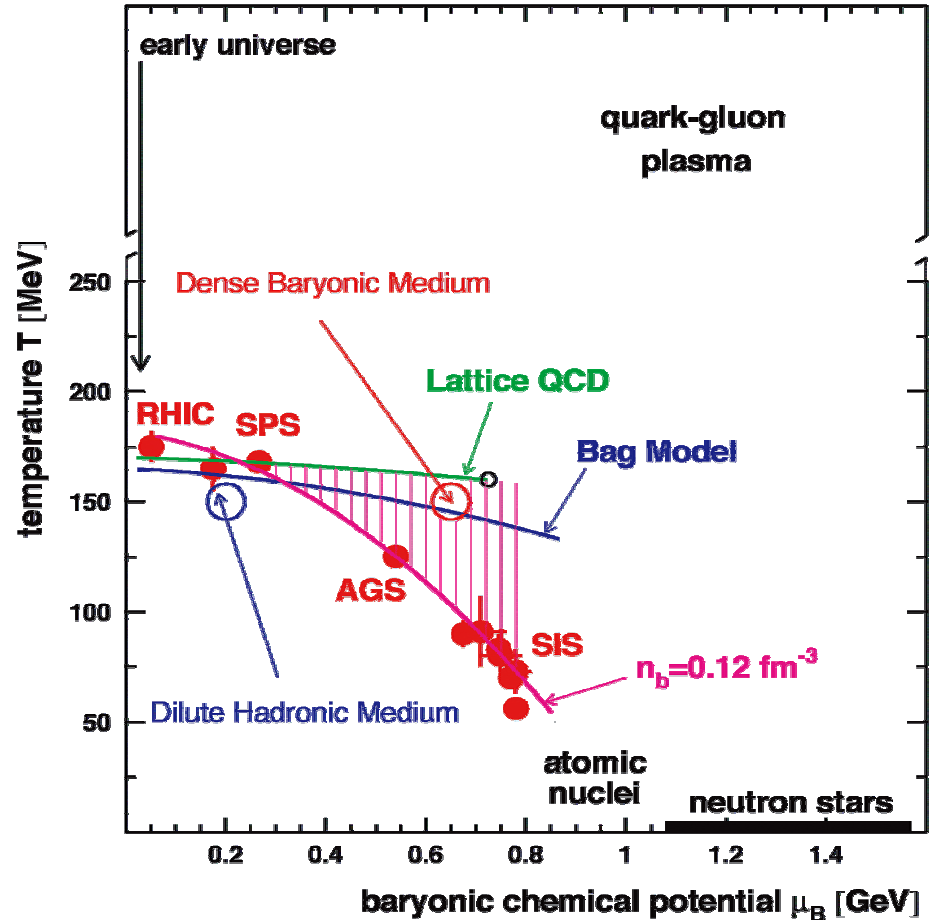
Major Challenges for Nuclear Physics

- Origin of Nuclear Saturation

- EOS ... as $\rho \uparrow$; as $T \uparrow$
as $S \uparrow$; as $N-Z \uparrow$

- Phase Transition to:

- quark matter (QM),
superconducting QM, strange condensate
- related to nuclear astrophysics; n-stars....

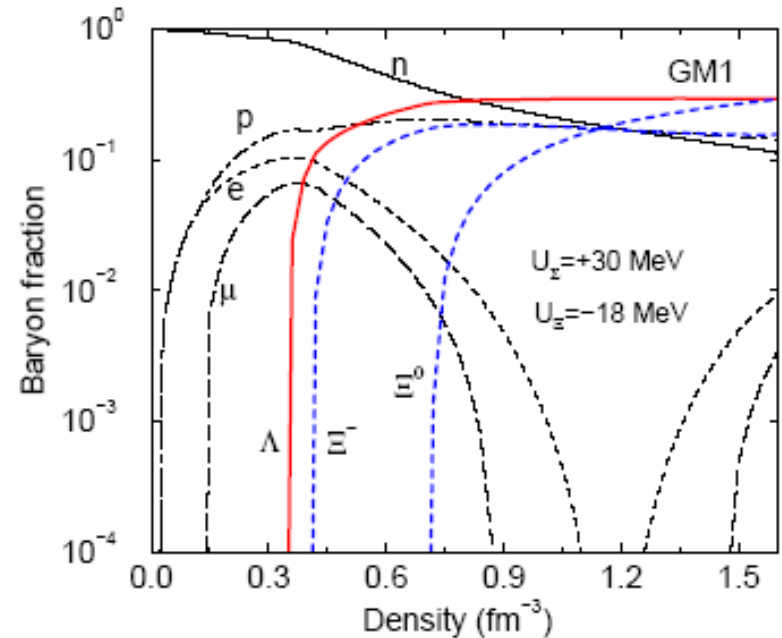
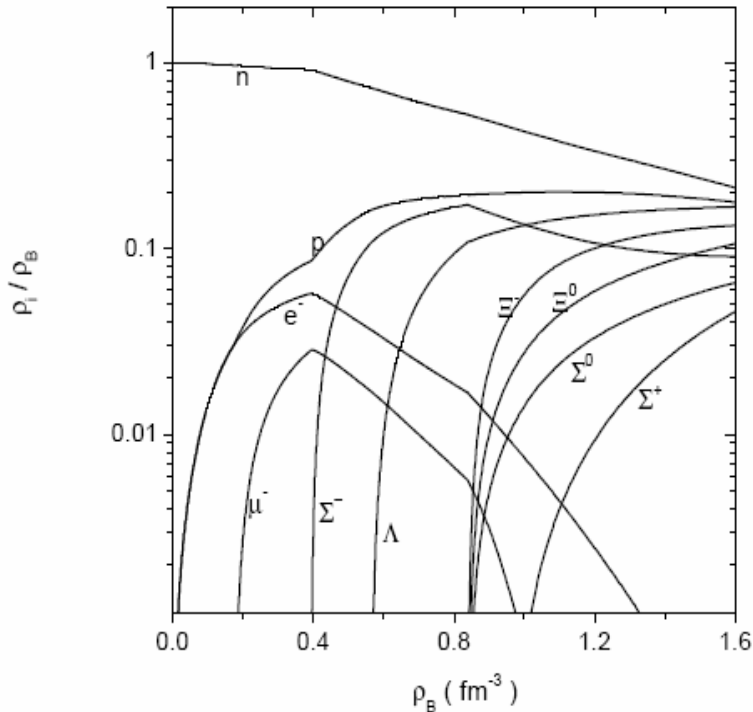
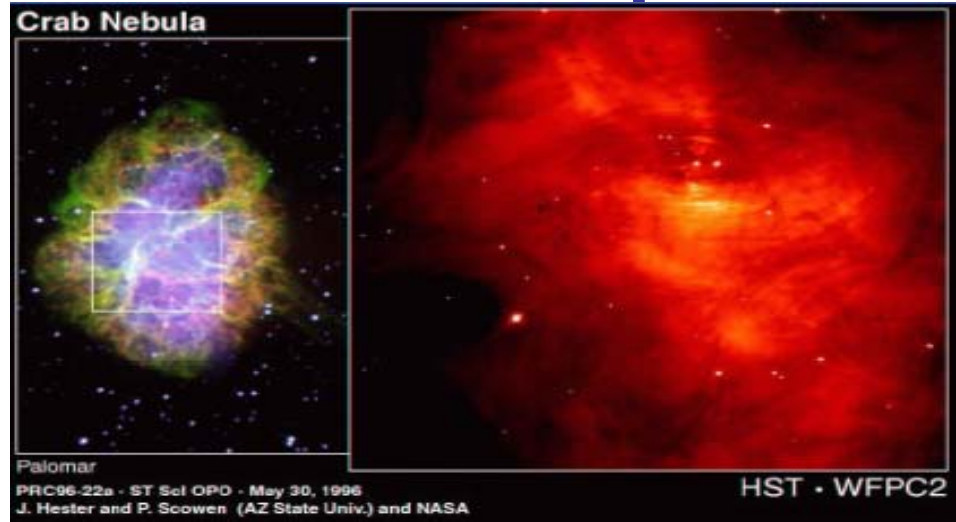


Neutron Star Composition

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



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

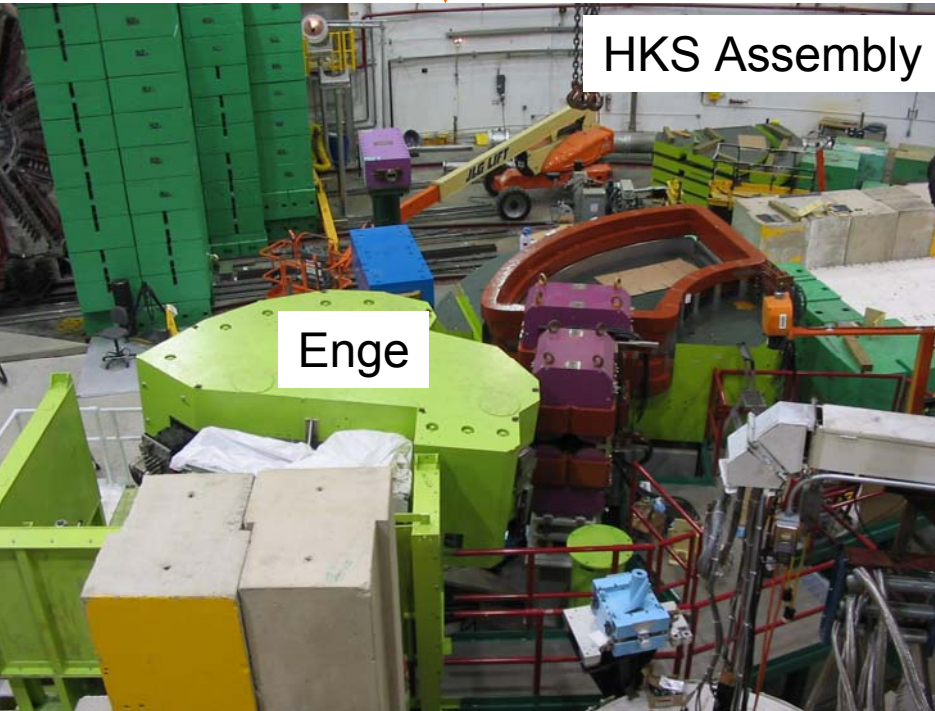


Present Installation: HKS



Present Hypernuclear Spectroscopy equipment combination is beam splitter, Enge (e^-), HKS (K^+)

Installation ongoing in Hall C (April 13)

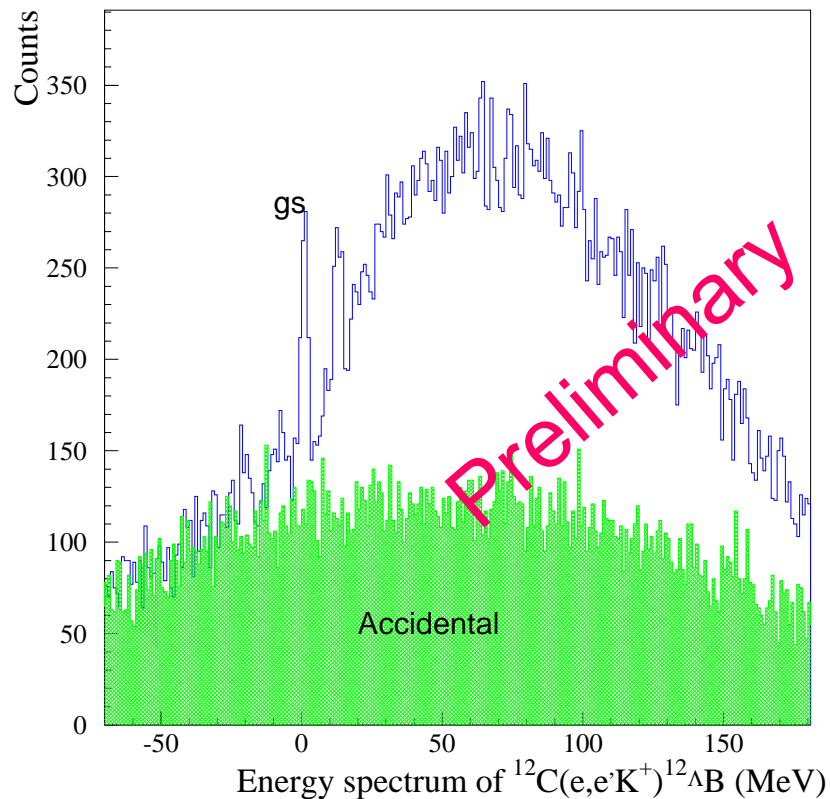
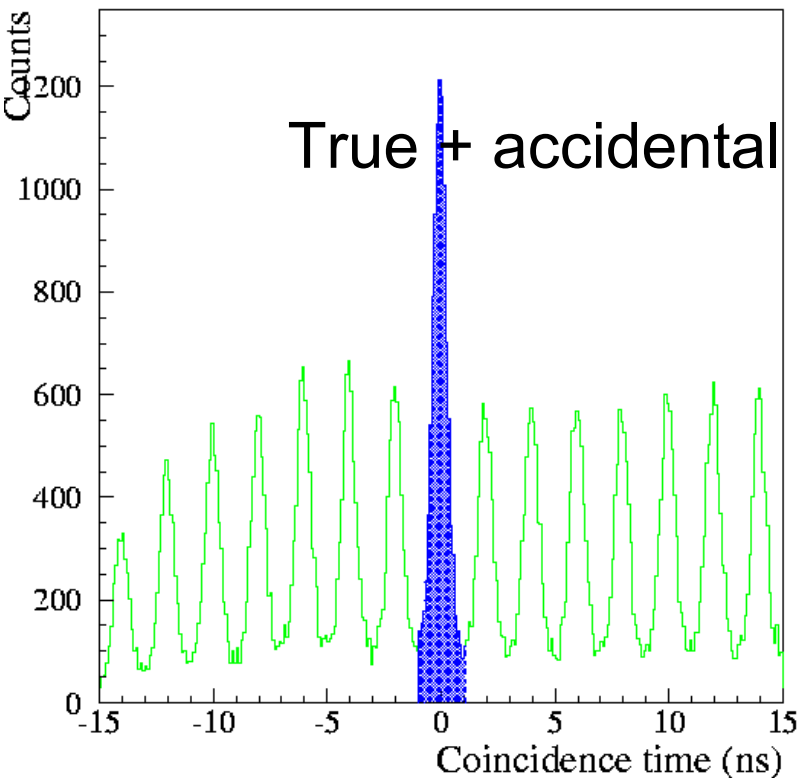


Installation completed (early June) →



Thomas Jefferson Na

Carbon ($^{12}_{\Lambda}B$) data



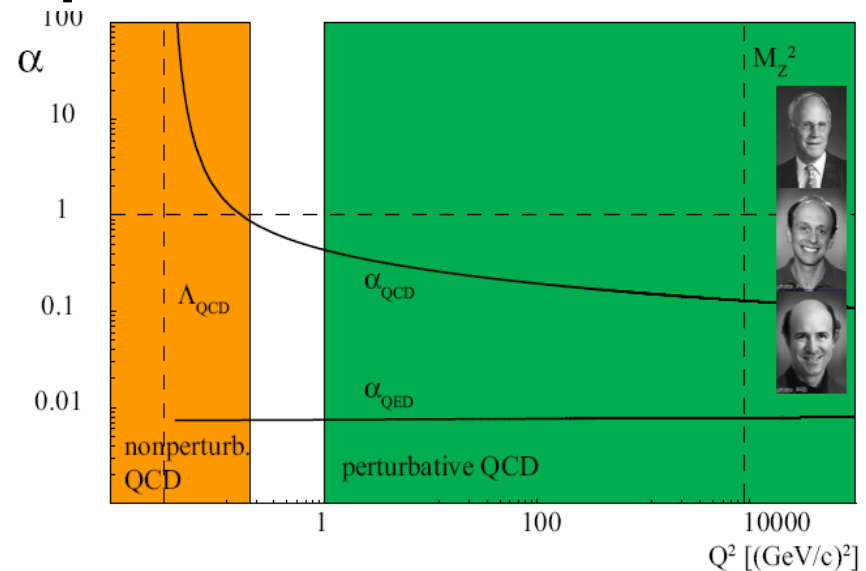
$^{12}_{\Lambda}B$ g.s

~ 600 counts (~20/hr) ~1 MeV -> 400 keV
 (Previous exp. (E89-009) 165 counts with 900 keV.
 HallA 300 counts with 700 keV.)

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

Inclusion of Pion Cloud

Actions with exact chiral symmetry

Precise computations at
Physical Pion Mass

Advances in high-performance computing

Computational Advances

- **Cluster Trends**

- 1 Tflop-scale clusters currently offering \$1/Mflops price-performance
- Cluster hardware price-performance increasing at least as fast as Moore's Law (performance/price doubling every 18 months)

- **Ramped funding model tuned to physics goals**



	'05	'06	'07	'08	'09	'10	'11
\$M/yr (new)		1.0	1.5	2.0	2.5	3.0	3.0
Tflops-year	0.5	2.5	5	10	18	34	55

(In addition to \$1.2m of base JLab and SciDAC funding)

Optimal Lattice Hadron Program

- Program of lattice studies with milestones linked to 12 GeV – *White Paper to DOE, Feb '05.*

“Coarse”
 $a = 0.11 \text{ fm}$

Tflop-year
 $\sim m_\pi^{-7} a^{-6}$

m_π (MeV)	$L^3 \times L_t$	$m_\pi L$	Tflops-yrs
> 350	$24^3 \times 64$	4.6	1.0
	$32^3 \times 64$	6.2	2.8
300	$32^3 \times 64$	5.3	4.4
	$36^3 \times 64$	6	6.9
250	$36^3 \times 64$	5	12
	$40^3 \times 64$	5.5	18
210	$48^3 \times 64$	5.5	60
<hr/> <hr/>			
350	$30^3 \times 64$	4.7	7.3
300	$36^3 \times 64$	4.9	23
250	$48^3 \times 64$	5.4	117

“fine”
 $a = 0.09 \text{ fm}$

more detail: David Richards



FEL Program Development

- THz User Working Group 9/2004
- DOE-BES/NIH/NSF report on THz opportunities 12/2004
- User meeting 3/2005
- Laser Biosciences Workshop 6/2005
- IRMMW meeting 9/2005
- Laser Precision Micro-fabrication Workshop 4/2005
- 150 users at User meeting March 2005 from > 30 groups

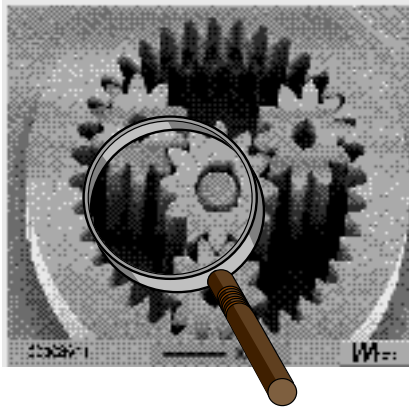


Forefront Condensed Matter and Life Sciences

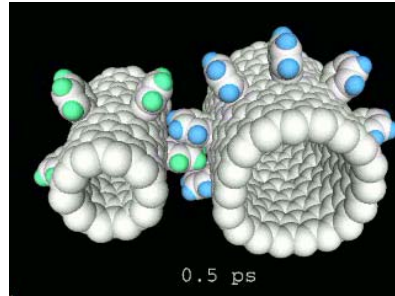
Nano-Fluids

(talk by G. Williams)

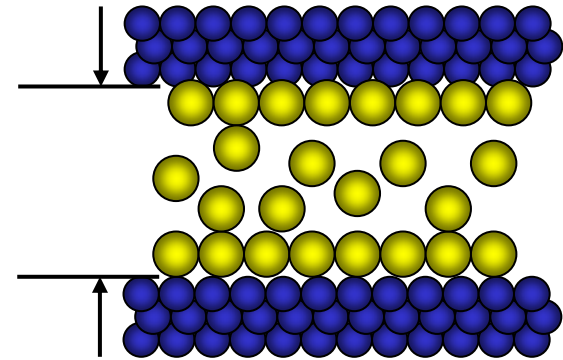
in New Technologies, in Chemistry, Bio Medicine, Geology



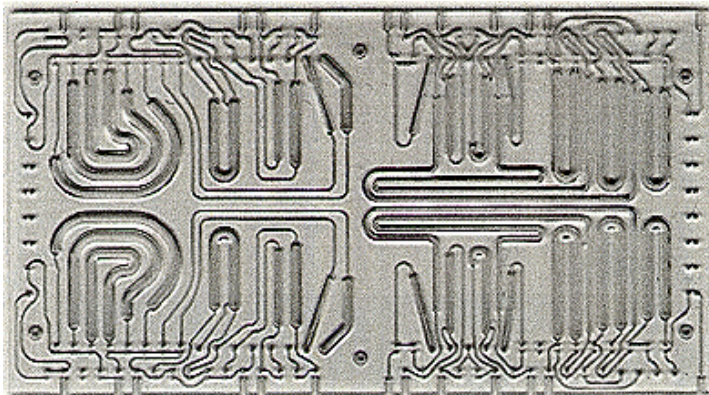
*From Micro- to
Nano-Gears*



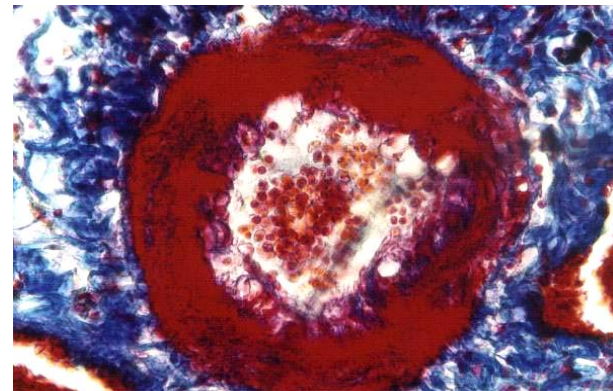
Nano Tubes



Lubrication in Nano Slits



*Chemistry Lab of Tomorrow:
On a Chip*

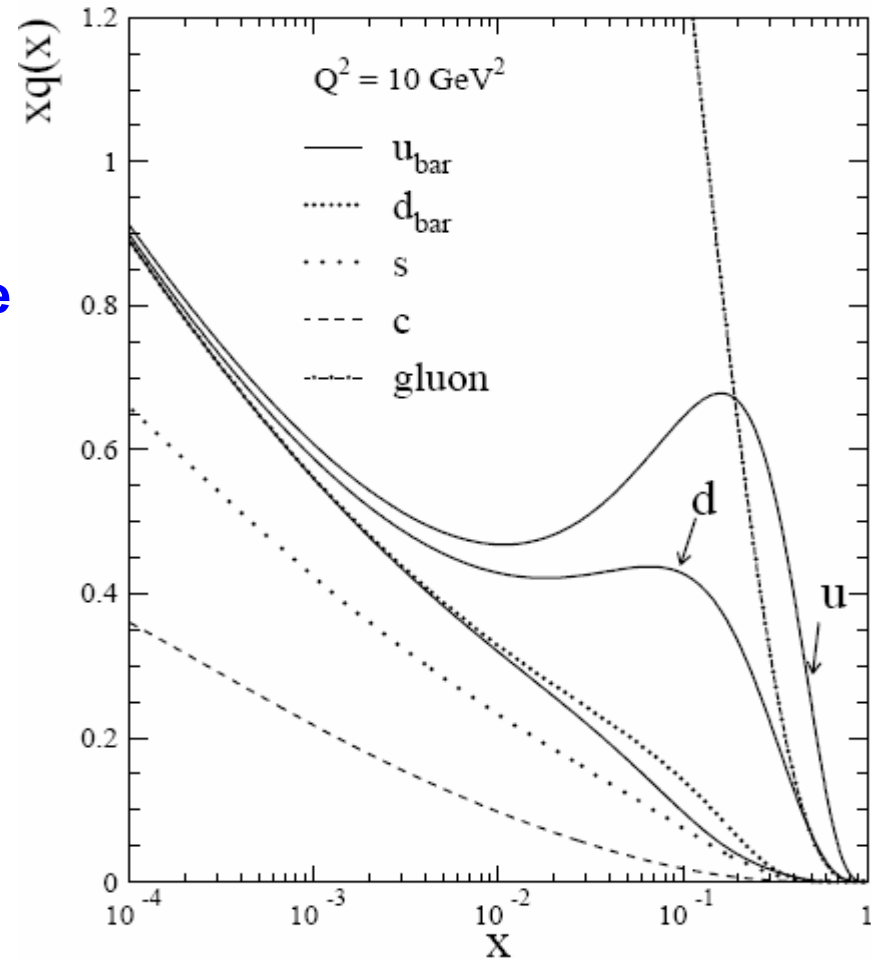


Blood/Fat Flow in Capillaries

CEBAF II/ELIC

Science addressed:

- What is the gluonic structure of atomic nuclei?
- How is the structure of the quark-anti-quark sea (spin & flavor) modified in nuclei?
- Modification of the QCD vacuum in-medium?



← ELIC → 12 GeV →

DOE Reviews in 2005

- **Science Review:**

The overall proposed program represents an impressive coherent framework of research directed towards one of the top frontiers of contemporary science

- **DOE Independent Project (Lehman) Review:**

No impediment to CD-1 !