Physics Potential of the Jefferson Lab 12 GeV Upgrade

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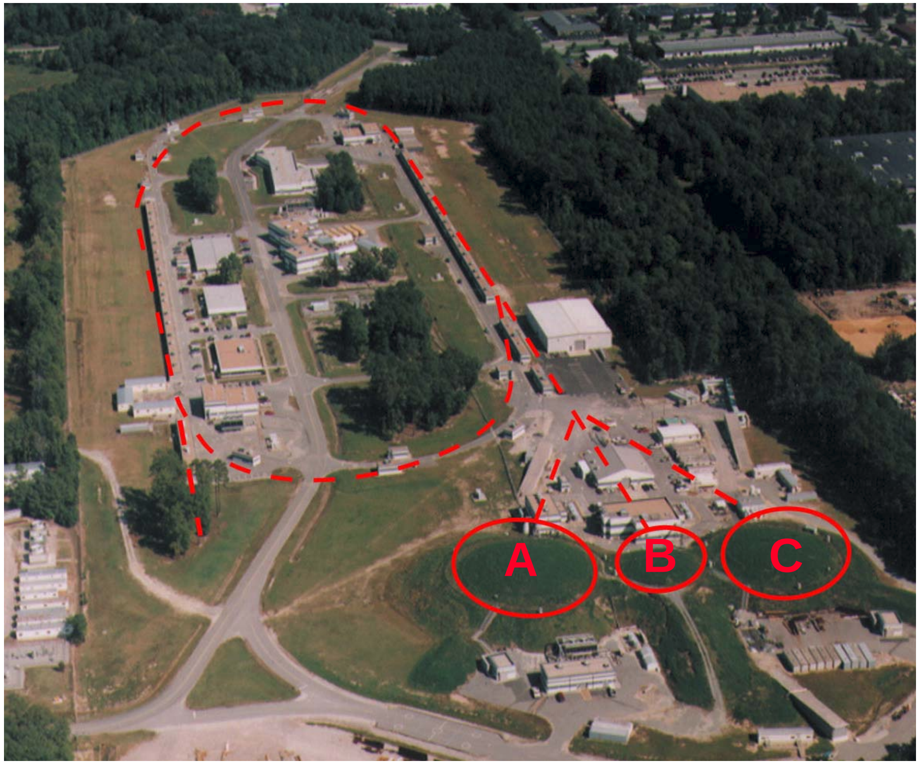
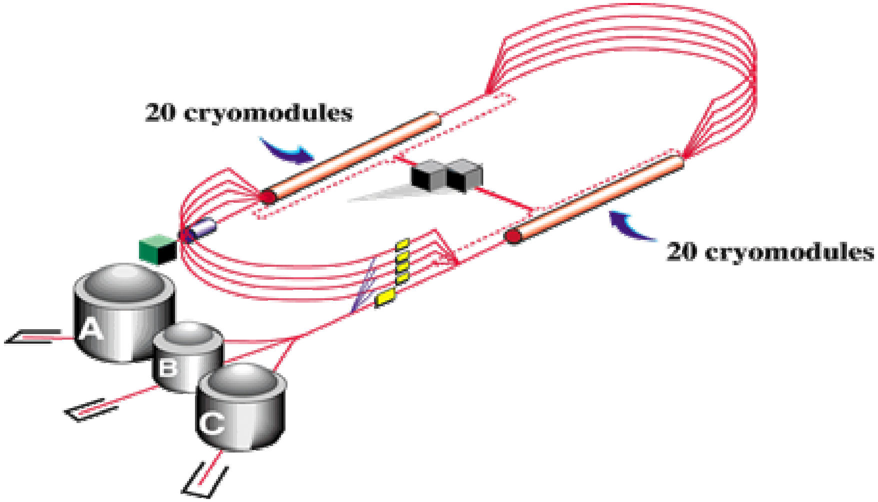
UNIVERSITY OF REGINA

CAP Congress, Laval University, Quebec City, June 11, 2008.





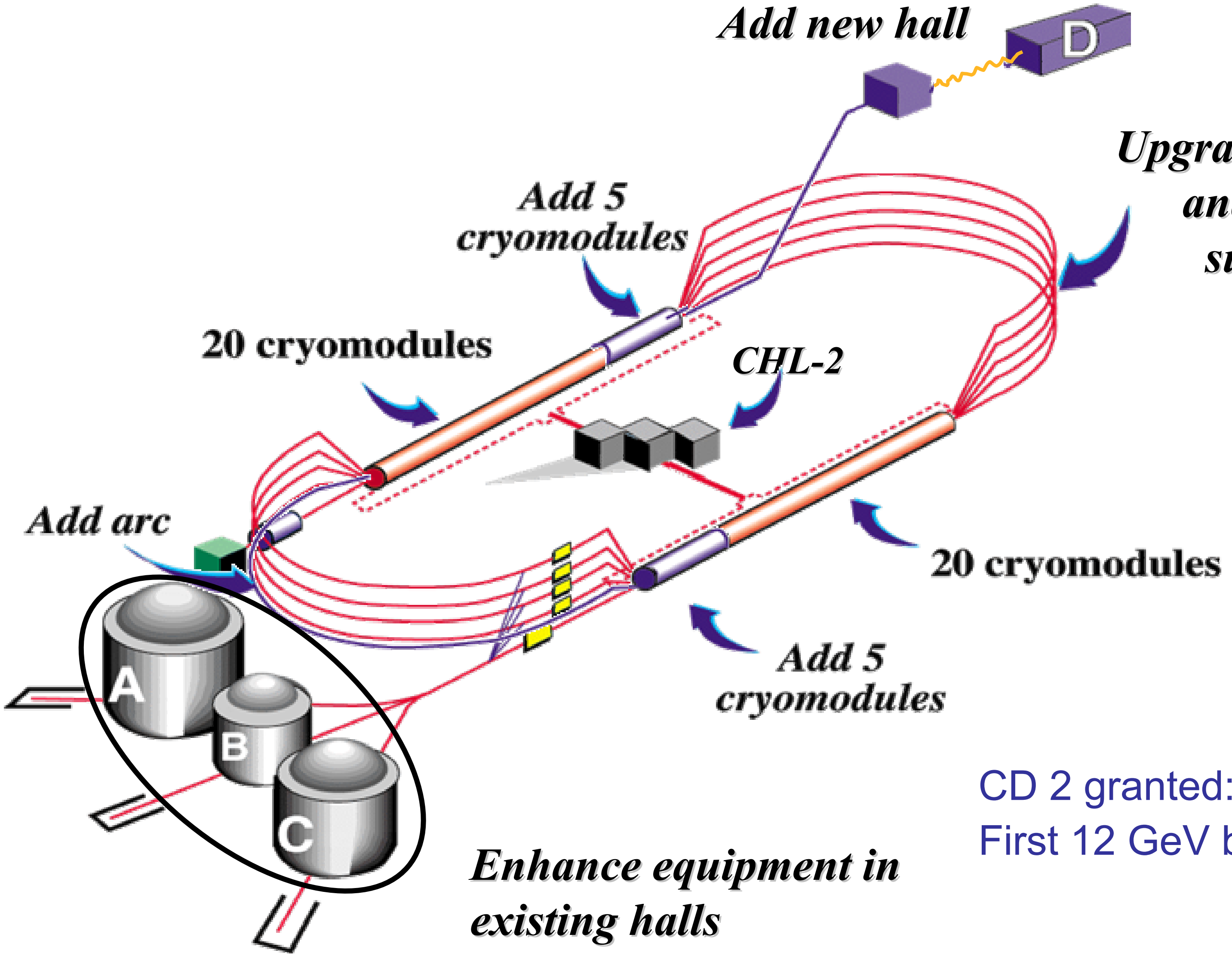
Two Cold Superconducting Linacs

Continuous Polarized Electron Beam

- E → 6 GeV
- > 100 μA
- up to 80% polarization
- concurrent to 3 Halls

First beam delivered in 1994

JLab 12 GeV Upgrade



Add new hall

Upgrade magnets and power supplies

Add 5 cryomodules

20 cryomodules

CHL-2

Add arc

20 cryomodules

Add 5 cryomodules

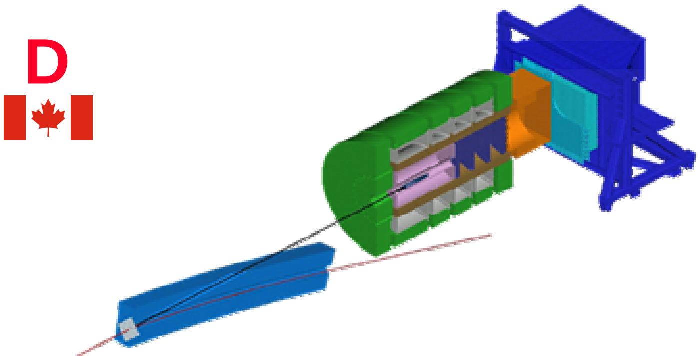
Enhance equipment in existing halls

CD 2 granted: Nov/07

First 12 GeV beam: mid-2013

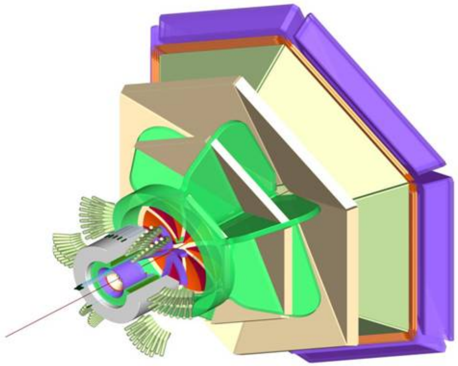
Upgrade Capabilities in Halls A, B, & C, and a New Hall D

D



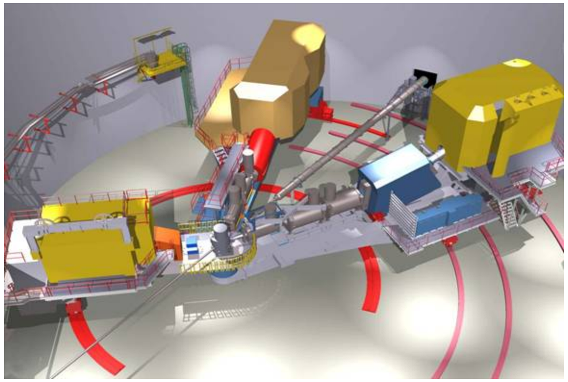
GlueX: 9 GeV tagged polarized photons and a 4π hermetic detector.

B



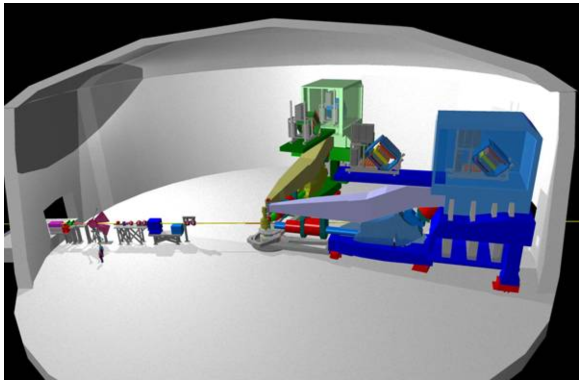
CLAS-12: upgraded to higher (10^{35}) luminosity and coverage.

C



Super High Momentum Spectrometer (SHMS) at high luminosity and forward angles.

A



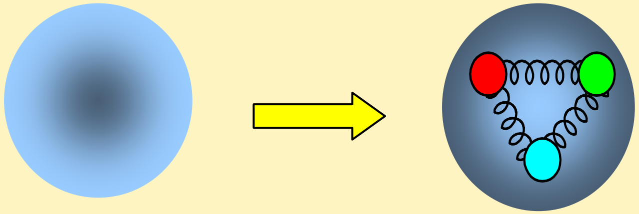
Existing HRS spectrometers, and specialized large installation experiments (e.g. 12 GeV Möller).

The Physics Issue in Brief

	u	+	u	+	d	=	proton
mass:	0.003	+	0.003	+	0.006	≠	0.938

98% of the proton’s mass is not due to the “rest mass” of its valence constituents, and hence does not arise from the Higgs mechanism.

⇒ The proton’s mass arises dynamically through the quark and gluon interactions of Quantum Chromo-Dynamics (QCD).



Our ability to answer the question:

How do the nucleon’s properties

(mass, spin, charge radius, etc.)

arise from its quark and gluon constitutents?

requires that we develop a quantitative (as opposed to qualitative) understanding of non-perturbative QCD.

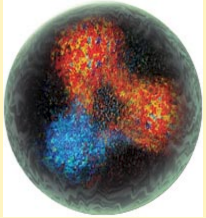
Why electron scattering experiments?

Transition from pQCD to Strong QCD needs data with high precision for a quantitative understanding of confinement.

1990's advancements:
Intense CW electron beams.
Polarized targets/polarimetry.
Improvement in polarized e sources.

Luminosity:
(SLAC, 1978) ~ 8 x 10^{31} cm^{-2}-s^{-1}
(JLab, 2000) ~ 4 x 10^{38} cm^{-2}-s^{-1}

$$d = 1 \rightarrow 0.1\,\mathrm{fm} \quad \Leftrightarrow \quad Q^2 = 0.1 - 10\,\mathrm{GeV}^2$$



- JLab 12 GeV Upgrade will play a crucial role towards our better understanding of hadron structure.
- On world scene, JLab program complements the work at J-PARC and GSI as well as radioactive beam facilities.

12 GeV Approved Experiments to Date

EXOTIC MESONS	**NUCLEAR EFFECTS DUE TO QCD**
Mapping the Spectrum of Light Quark Mesons and Gluonic Excitations with Linearly Polarized Photons (E12-06-102, Hall D)	Inclusive Scattering from Nuclei at *x*>1 in the Quasi-elastic and Deeply-Inelastic Regimes (E12-06-105, Hall C)
NUCLEON AND MESON ELECTROMAGNETIC STRUCTURE	Color Transparency in Exclusive Vector Meson Electroproduction (E12-06-106, Hall B)
Charged Pion Form Factor to High Q^2 (E12-06-101, Hall C)	Color Transparency in $A(e,e'p)$ and $A(e,e'\pi)$ (E12-06-107, Hall C)
σ_L/σ_T Ratio in Semi-Inclusive Deep Inelastic Scattering (E12-06-104, Hall C)	Quark Propagation and Hadron Formation (E12-06-117, Hall B)
Probing the Proton's Quark Dynamics in Semi-Inclusive Pion Production (E12-06-112, Hall B)	F_2^n/F_2^p, d/u and A=3 EMC Effect in Deep Inelastic Scattering off ^{3}H and ^{3}He Mirror Nuclei (E12-06-118, Hall A)
F_2^n/F_2^p at Large x_{Bj} via $^2H(e,e'p)X$ (E12-06-113, Hall B)	Hadronization in Nuclei by Deep Inelastic Scattering (E12-07-101, Hall B)
Neutron Magnetic Form-Factor at High Q^2 Using the Ratio Method on ^{2}H (E12-07-104, Hall B)	*A*-dependence of J/Ψ Production Near Threshold (E12-07-106, Hall C)
Proton Magnetic Form Factor from Q^2=7-17.5 GeV^2 (E12-07-108, Hall A)	**GENERALIZED PARTON DISTRIBUTIONS**
Proton Form Factor Ratio Measurements at Q^2=13,15 GeV^2 (E12-07-109, Hall A)	Hard Exclusive Electroproduction of π^0 and η (E12-06-108, Hall B)
NUCLEON SPIN STRUCTURE	Electron-Helicity Dependent Deeply Virtual Compton Scattering (E12-06-114, Hall B)
Longitudinal Spin Structure g_1 of p,d (E12-06-109, Hall B)	Deeply Virtual Compton Scattering (E12-06-119, Hall B)
Neutron Spin Asymmetry A_1^n in the Valence Quark Region using Polarized ^{3}He Target (E12-06-110, Hall C)	$1/Q^n$ Scaling Test of the L-T Separated Pion Electroproduction Cross Section (E12-07-105, Hall C)
"Color Polarizabilities" in the Neutron: Measurement of g_2^n, d_2^n at High Q^2 (E12-06-121, Hall C)	**PHYSICS BEYOND THE STANDARD MODEL**
Neutron Asymmetry A_1^n in the Valence Quark Region (E12-06-122, Hall A)	Parity-Violating Asymmetry in Deep Inelastic Scattering off Deuterium (E12-07-102, Hall C)
Spin-Orbit Correlations with Longitudinally Polarized Target (E12-07-107, Hall B)	

NUCLEON AND MESON ELECTROMAGNETIC STRUCTURE

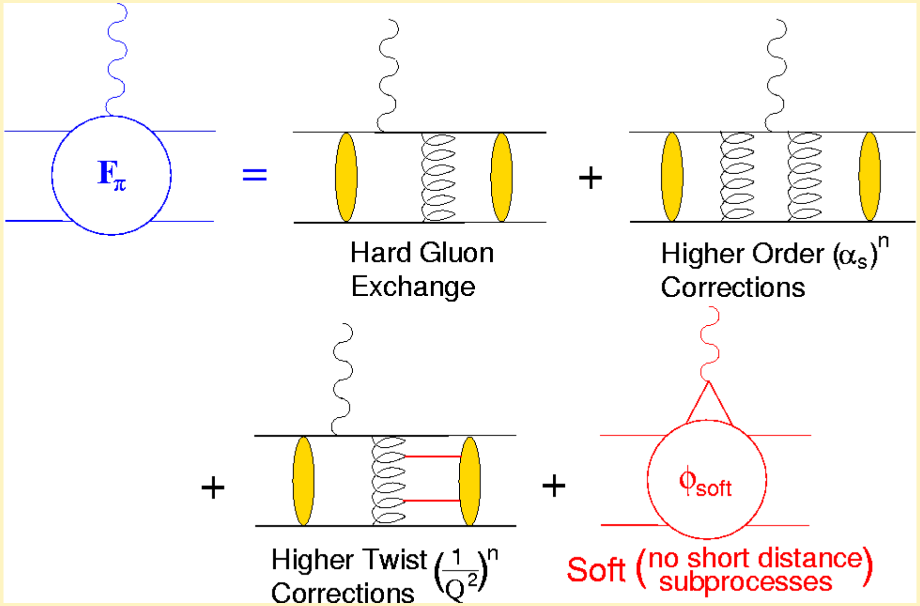
e.g. Charged Pion Form Factor to High Q^2
(E12-06-101, Hall C)

π^+ Electric Form Factor and QCD

- The simple $q\bar{q}$ valence quark structure of mesons presents the ideal laboratory for testing our understanding of bound quark systems.

→ all hadronic structure models use the π^+ as a test case.

“The positronium atom of QCD”



Excellent opportunity for studying the **QCD transition** from effective $q\bar{q}$ degrees of freedom to quarks and gluons.

i.e. from the **strong QCD** regime to the **hard QCD** regime.

Jefferson Lab is the only facility capable of these measurements.

Determination of F_π via Pion Electroproduction

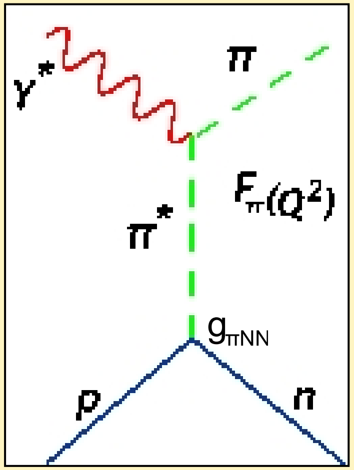
At low Q^2<0.3 GeV^2, the π^+ form factor can be measured exactly using high energy π^+ scattering from atomic electrons.

$\Rightarrow F_\pi$ determined by the pion charge radius 0.657±0.012 fm.

To access higher Q^2, one must employ the $p(e,e'\pi^+)n$ reaction.

- the t-channel process dominates σ_L at small $-t$<0.02 GeV^2.

$$\frac{d\sigma_L}{dt} \propto \frac{-tQ^2}{(t-m_\pi^2)}\, g_{\pi NN}^2(t)\, F_\pi^2(Q^2,t)$$



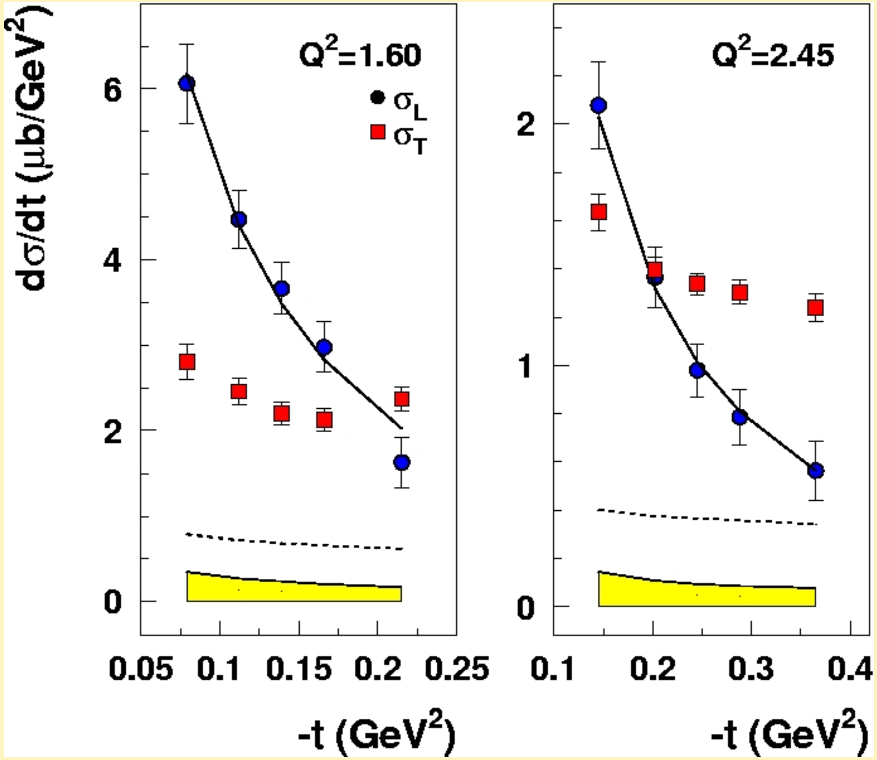
In the actual analysis, a model incorporating the π^+ production mechanism and the `spectator' nucleon is used to extract F_π from σ_L.

Extraction of F_π from JLab *6 GeV* Data

Technique: $$\frac{d\sigma}{dt}=\varepsilon\frac{d\sigma_L}{dt}+\frac{d\sigma_T}{dt}+\ldots$$

- Rosenbluth separation required to isolate σ_L.
  - •Measure cross section at fixed (W,Q^2,-t) at 2 beam energies.
  - •Simultaneous fit at 2 ε values to determine σ_L, σ_T, and interference terms.

- **Control of point-to-point systematic uncertainties crucial due to 1/Δε error amplification in L/T separation.**
- Careful attention must be paid to spectrometer acceptance, kinematics, efficiencies, …



$$F_\pi=\frac{1}{1+Q^2/\Lambda_\pi^2}$$

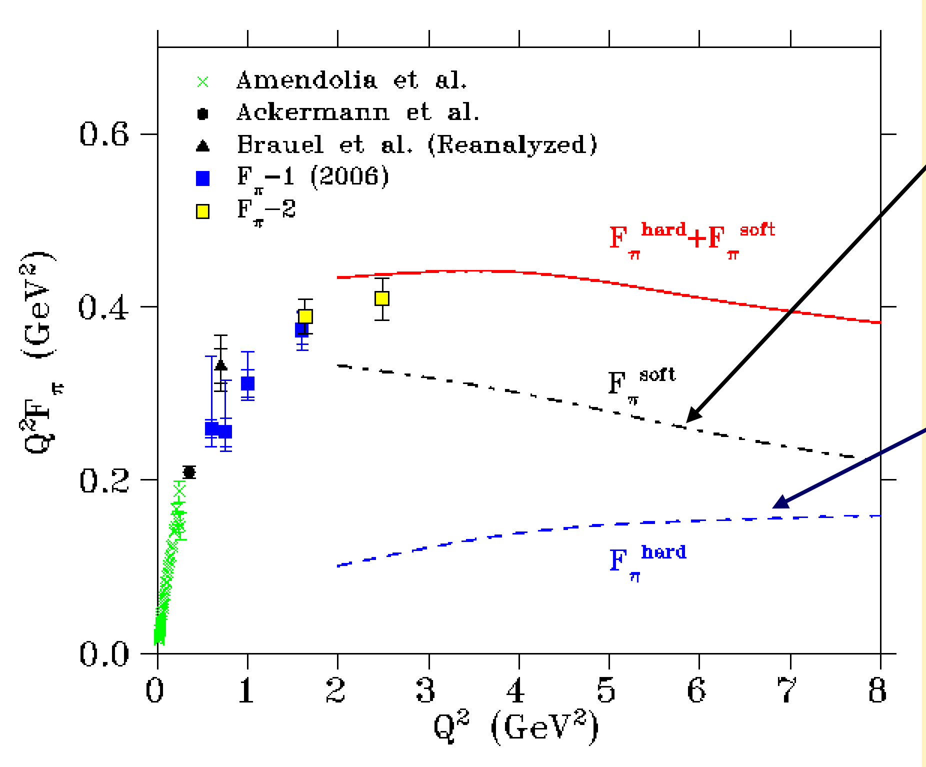
Fit of VGL Regge model to σ_L gives F_π at each Q^2.

The role of Soft and Hard QCD in F_π

pQCD LO+NLO Calculation:

Analytic perturbation theory at the parton amplitude level.

*A.P. Bakulev, K. Passek-Kumericki, W. Schroers, & N.G. Stefanis, PRD **70** (2004) 033014.*



SOFT QCD:

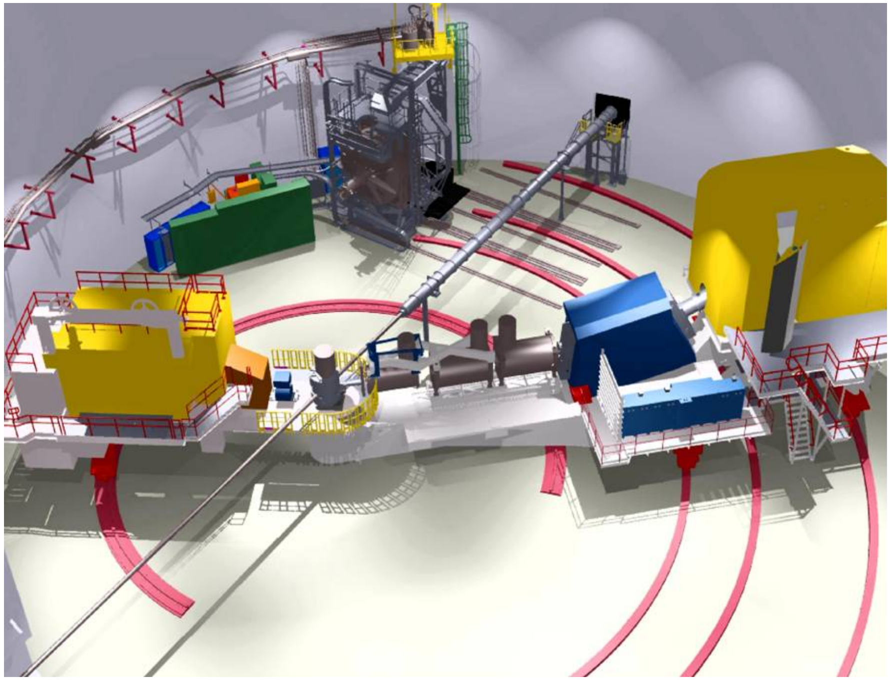
- Extra piece needed to describe data.
- Model-dependent.
- Estimated from local quark-hadron duality model.

HARD QCD: pQCD LO+NLO

- JLab 6 GeV F_π results are far from the values predicted by pQCD.
- At the distance scales probed by the experiment (0.15<r<0.30 fm), the π^+ structure is not governed by the two valence quarks.
- Virtual quarks and gluons dominate.

Experimental Hall C

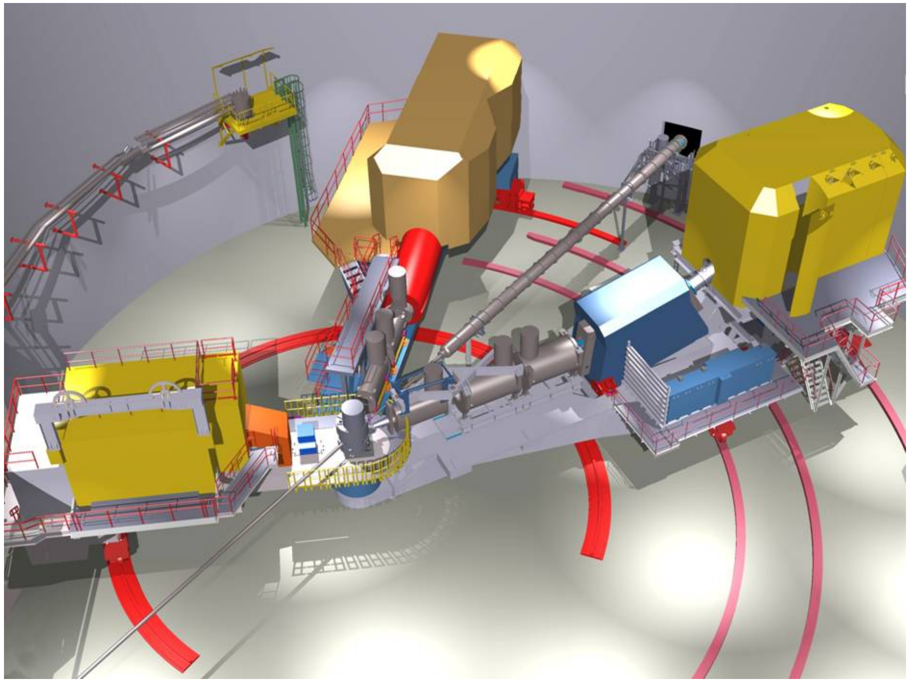
At the present 6 GeV Beam Energy



Hall C’s High Momentum Spectrometer, Short Orbit Spectrometer and specialized equipment for studying:

- The strange quark content of the proton.
- Form factors of simple quark systems.
- The transition from hadrons to quarks.
- Nuclei with a strange quark embedded.

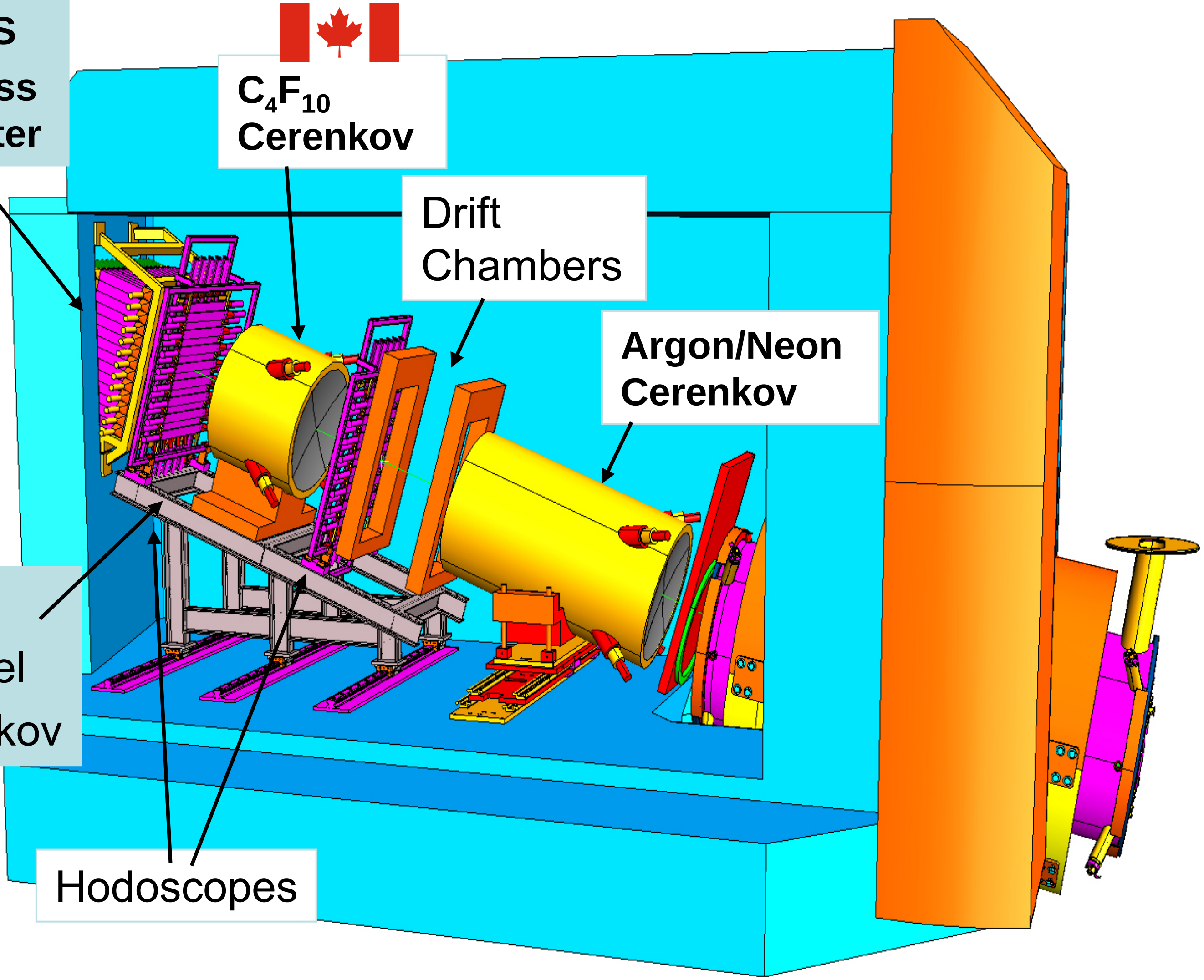
After the 12 GeV Upgrade



Add a Super- High Momentum (12 GeV) Spectrometer for studying:

- Super-fast (high x_B) quarks.
- Form factors of simple quark systems.
- The transformation of quarks into hadrons.
- Quark-quark correlations.

Super-High Momentum Spectrometer (SHMS) Focal Plane Detectors



HERMES Lead Glass Calorimeter

C_4F_{10} Cerenkov

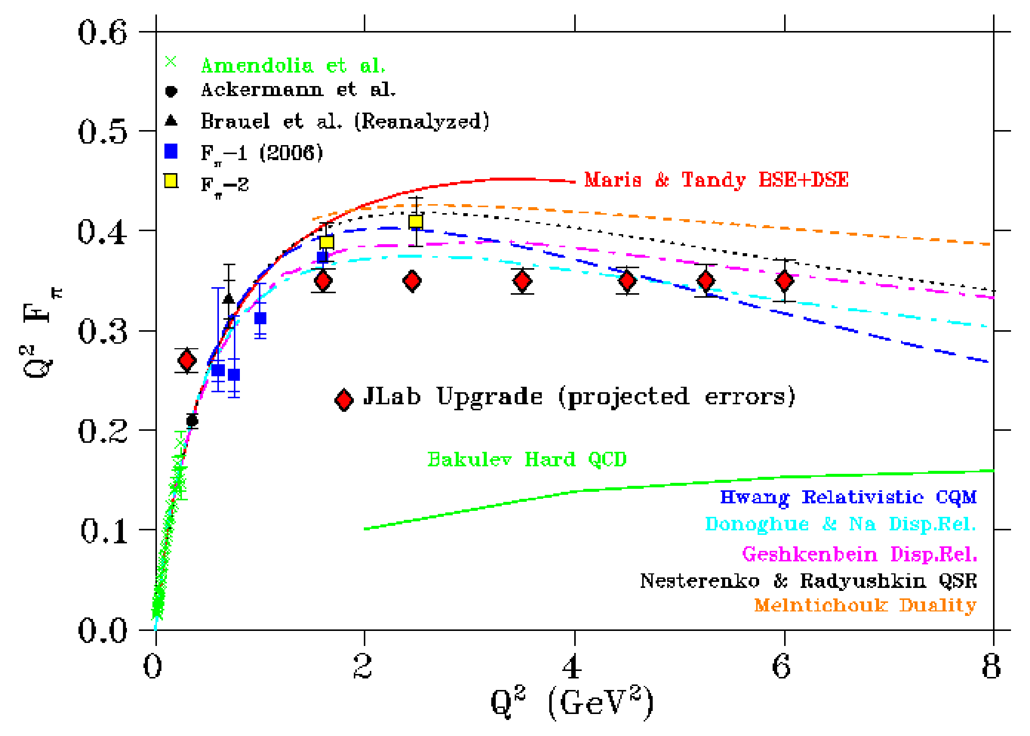
Drift Chambers

Argon/Neon Cerenkov

Future Aerogel Cerenkov

Hodoscopes

$F_{\pi^+}(Q^2)$ after JLab 12 GeV Upgrade



E12-06-101:
G. Huber and
D. Gaskell
spokespersons

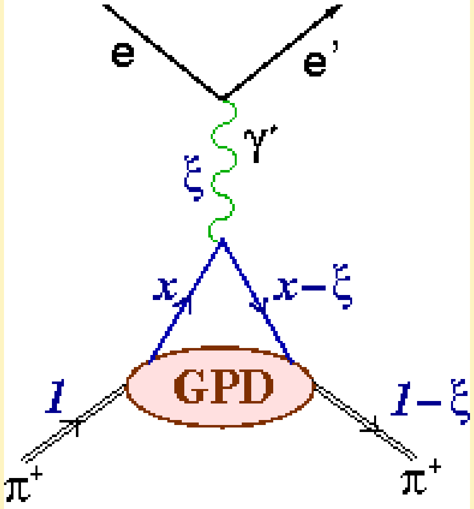
JLab Upgrade will allow our measurements to be extended shorter distance scales to discover the scale where valence quarks dominate pion's structure.

→ **Different theoretical viewpoints on whether higher-twist mechanisms dominate until very large momentum transfer or not.**

GENERALIZED PARTON DISTRIBUTIONS

e.g. $1/Q^n$ Scaling Test of the
L-T Separated Pion Electroproduction
Cross Section
(E12-07-105, Hall C)

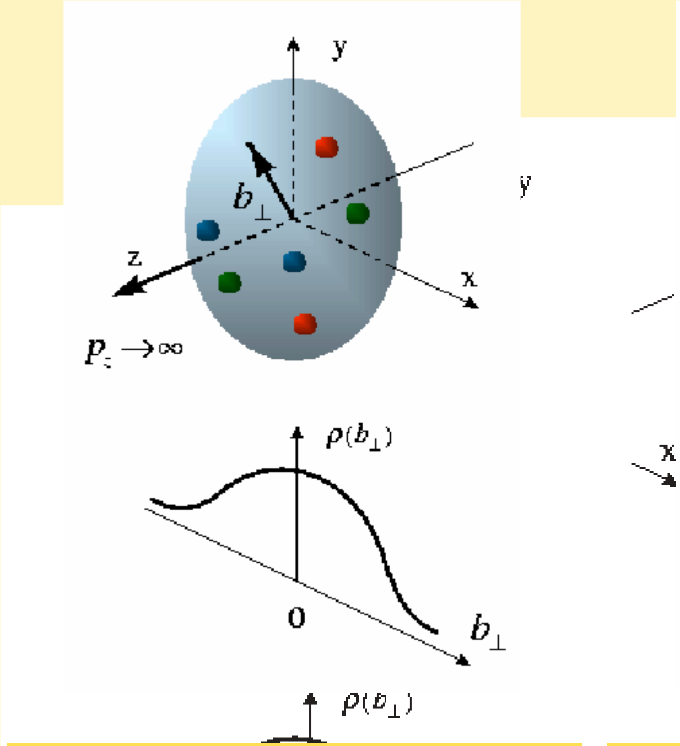
Generalized Parton Distributions (GPDs)



- GPDs offer a unified framework for parton distributions and hadronic form factors.
- GPDs are universal quantities and reflect the structure of the hadron independently of the probing reaction.
- GPD picture applies strictly to the hard-scattering regime, where the interaction can be clearly separated into perturbative (pQCD) and non-perturbative factors.
  - GPD contains the non-perturbative part of the interaction and represents the interference of quark wave functions, differing by momentum fraction ξ.

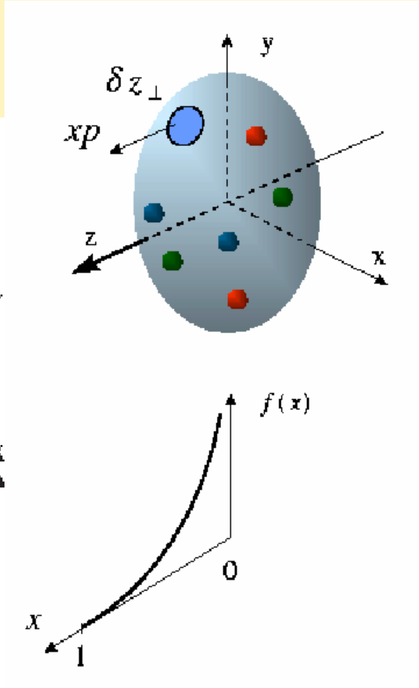
$$F_\pi(Q^2) = \int_0^1 \sum_q H_\pi^q(\xi, x, Q^2)\,dx$$

GPDs Yield 3-Dimensional Quark Structure



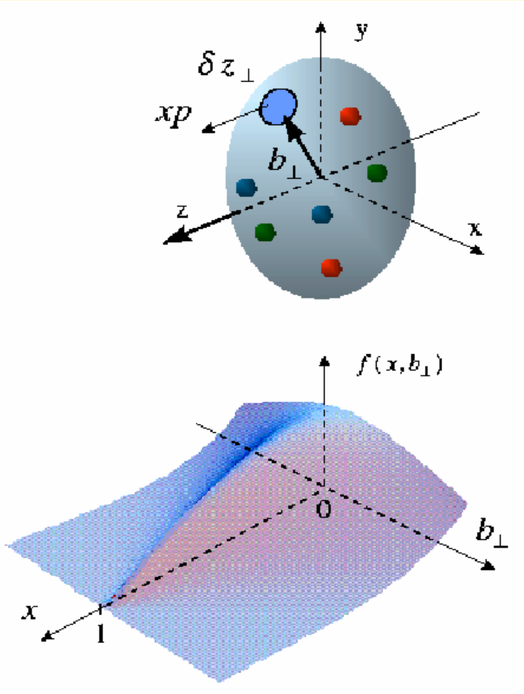
Elastic Scattering

transverse quark distribution in Coordinate space



DIS

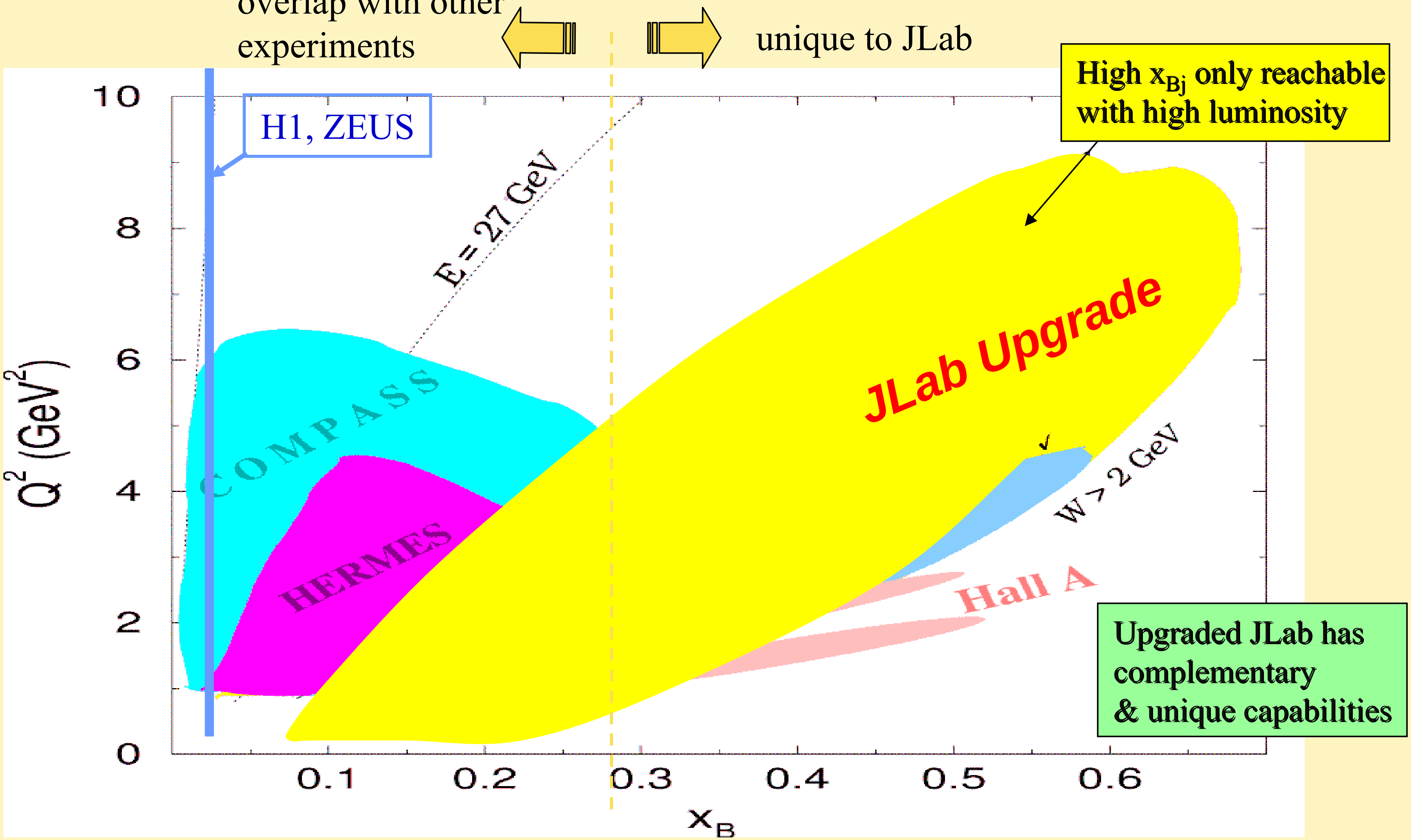
longitudinal quark distribution in momentum space



DES (GPDs)

Fully-correlated quark distribution in both coordinate and momentum space

Deeply Virtual Exclusive Processes - Kinematics Coverage of the 12 GeV Upgrade



overlap with other experiments

unique to JLab

High x_{Bj} only reachable with high luminosity

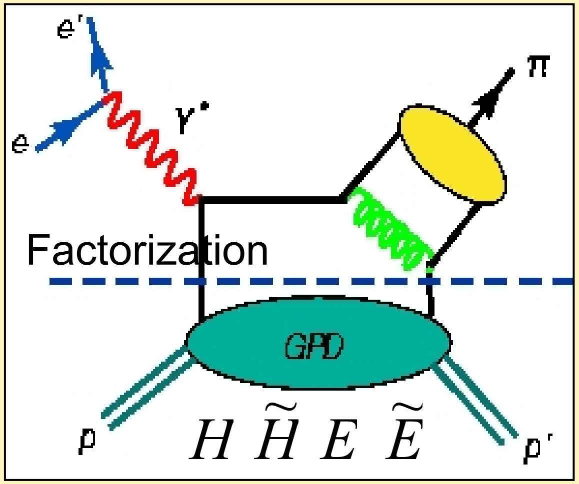
Upgraded JLab has complementary & unique capabilities

Hard-Soft Factorization

- **To access physics contained in GPDs, one is limited to the kinematic regime where hard-soft factorization applies.**
  - Determining the applicability of the GPD mechanism is a high priority for the JLab 12 GeV program.
  - Only if hard-soft factorization applies can GPDs be extracted.

One of the most stringent tests of factorization is the Q^2 dependence of the π^+ electroproduction cross section.

- **σ_L scales to leading order as Q^{-6}.**
- **σ_T scales as Q^{-8}.**
- **As Q^2 becomes large: $\sigma_L >> \sigma_T$.**

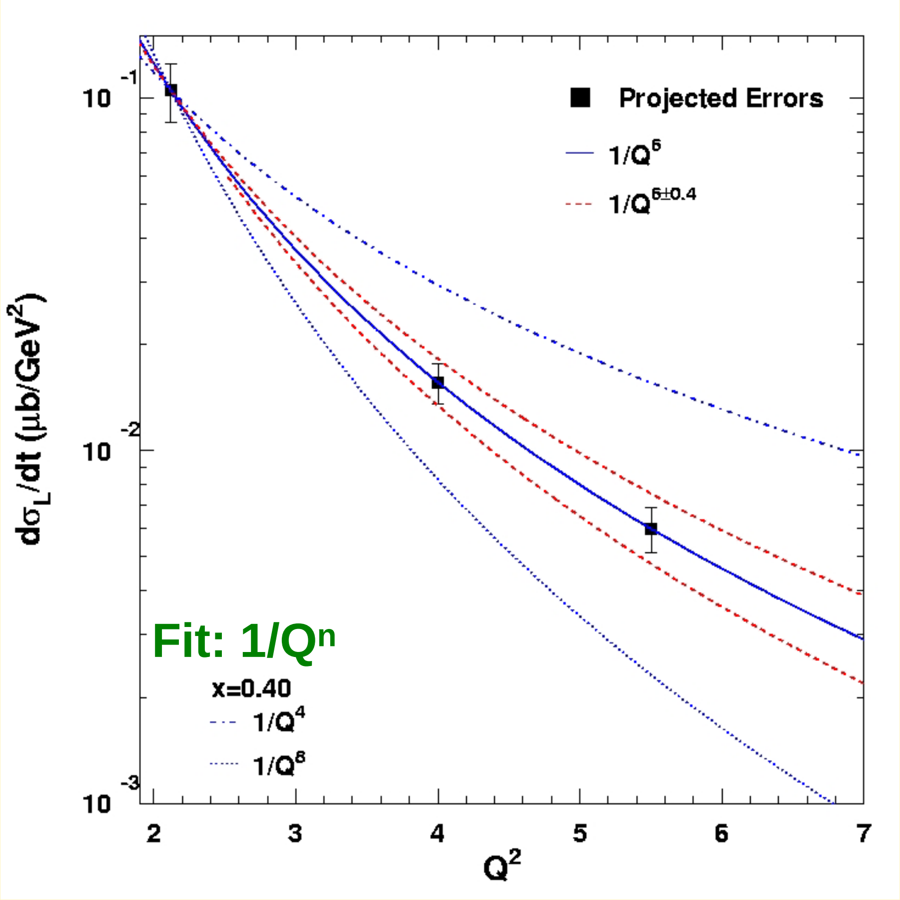


1/Q^n Scaling Test after JLab 12 GeV Upgrade

- Measure separated cross sections for the p(e,e'π^+)n reaction at three values of x_{Bj}.
- QCD scaling predicts σ_L~Q^{-6} and σ_T~Q^{-8}.
- The Q^2 coverage is a factor of 3-4 larger compared to 6 GeV.

"A detailed study to determine whether or not meson electroproduction can provide information on GPDs is important."

-- JLab PAC32



E12-07-105:
T. Horn and G. Huber and spokespersons

EXOTIC MESONS

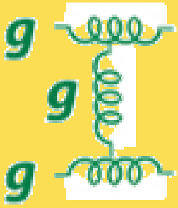
Mapping the Spectrum of Light Quark Mesons and Gluonic Excitations with Linearly Polarized Photons

(E12-06-102, Hall D)

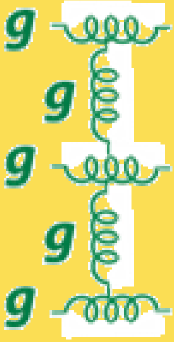
Mesons in QCD

Conventional Meson

$$3 \otimes \bar{3} = 1 \oplus 8$$



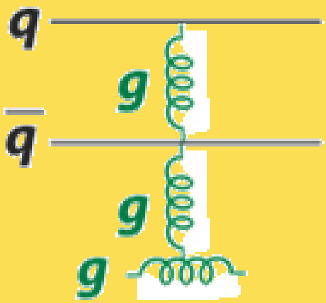
Glueball Meson



$$8 \otimes 8 = 1 \oplus 8 \oplus \cdots$$

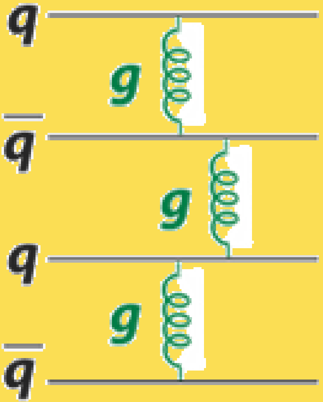
$$(8 \otimes 8)_8 \otimes 8 = 1 \oplus \cdots$$

Hybrid Meson



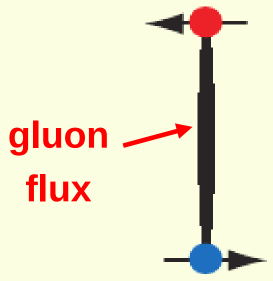
$$(3 \otimes \bar{3})_8 \otimes 8 = 1 \oplus \cdots$$

4-quark Meson or Molecule



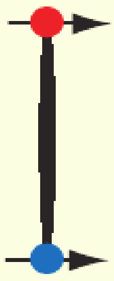
Conventional Mesons vs. Hybrid Mesons

Conventional mesons correspond to the flux tube in its ground state - gluonic degrees of freedom do not contribute.



$\vec{L}=0,\ \vec{S}=0$

$\pi,\ K$

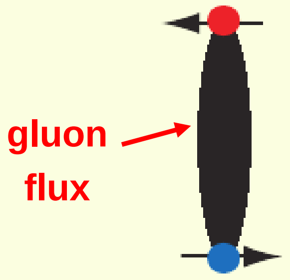


$\vec{L}=0,\ \vec{S}=1$

$\rho,\ K^*,\ \gamma$

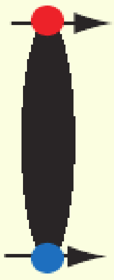
In its first excited state the flux tube has: $J^{PC}=1^{+-}\ or\ 1^{-+}$

Now include the quantum numbers of the excited flux tube:



$\vec{L}=0,\ \vec{S}=0$

$J^{PC}=1^{--}\ or\ 1^{++}$



$\vec{L}=0,\ \vec{S}=1$

Exotic $\boxed{J^{PC}=0^{+-},1^{-+},2^{+-}}$

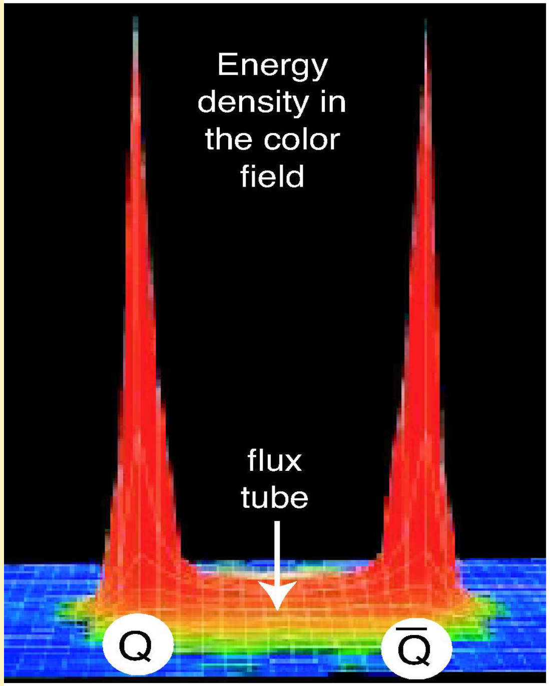
$J^{PC}=0^{-+},1^{+-},2^{-+}$

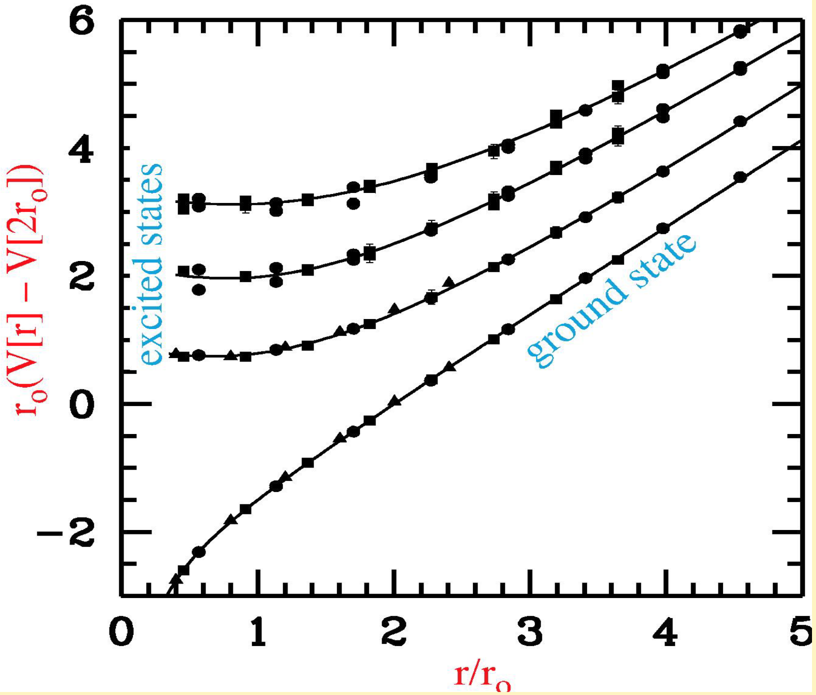
Exotic Hybrid Meson Mass Range

Lattice QCD computations in heavy-quark sector:

- Insight into excitations of gluon string binding the $q\overline{q}$
- For heavy quarks, energy associated with "excited string" of around 1 GeV.
  - Lowest 1^{-+} state around 1.8-2.0 GeV:

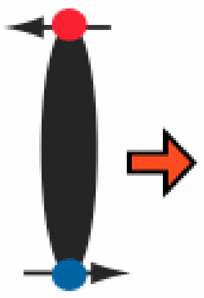
    plus chiral correction ~ -0.1 to -0.2 GeV.





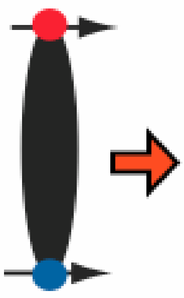
Production of Hybrid Mesons

Combine excited glue QN $J^{PC} = 1^{+-}$ *or* 1^{-+} with those of the quarks:



$J^{PC} = 1^{--}$ *or* 1^{++}

$\vec{L} = 0, \ \vec{S} = 0$



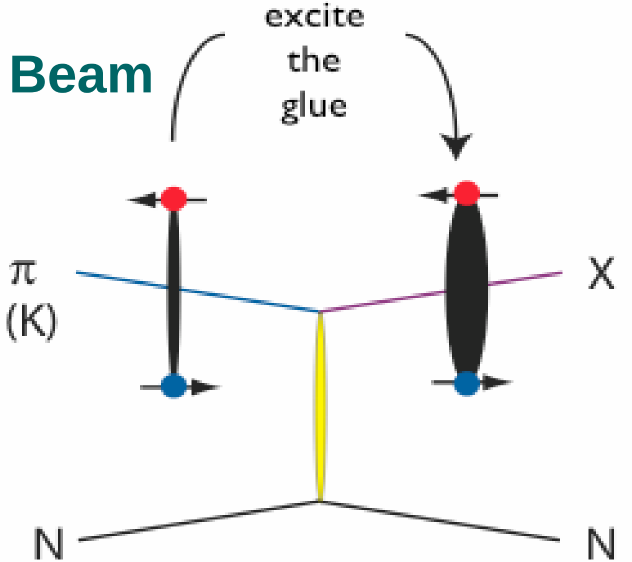
$J^{PC} = 0^{-+}, 1^{+-}, 2^{-+}$

$J^{PC} = 0^{+-}, 1^{-+}, 2^{+-}$

exotic

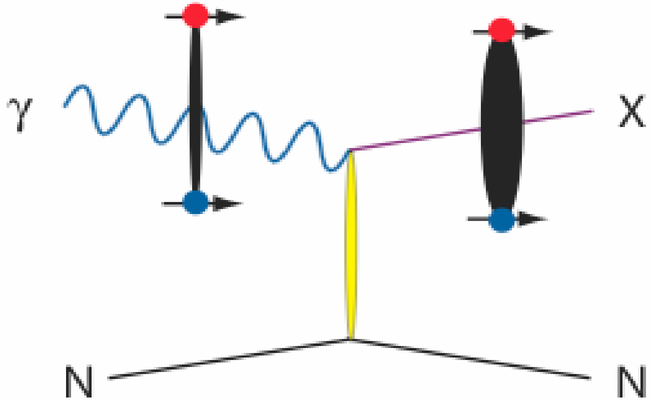
$\vec{L} = 0, \ \vec{S} = 1$

π/*K* Beam



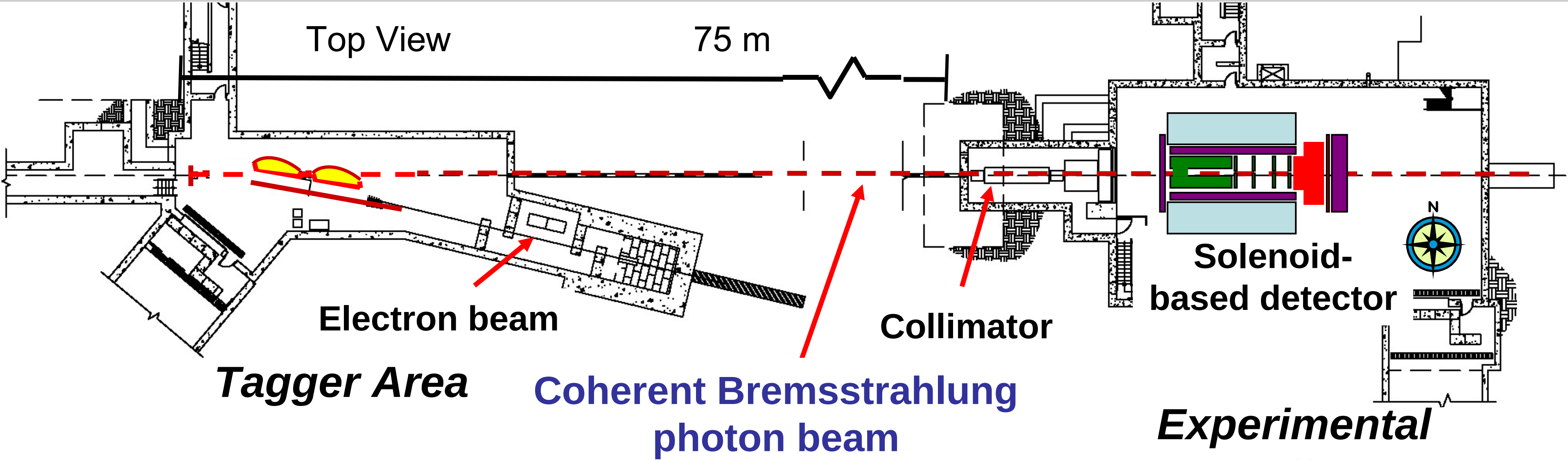
produced hybrids
are not expected to be exotic

Photon Beam



produced hybrids
can be exotic

Coherent Photon beam and Experimental Hall D



Top View

75 m

Electron beam

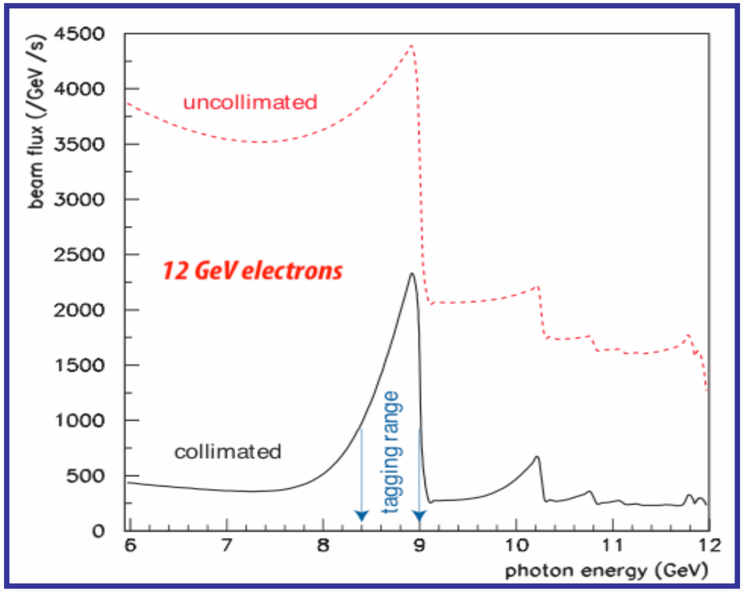
Tagger Area

Coherent Bremsstrahlung photon beam

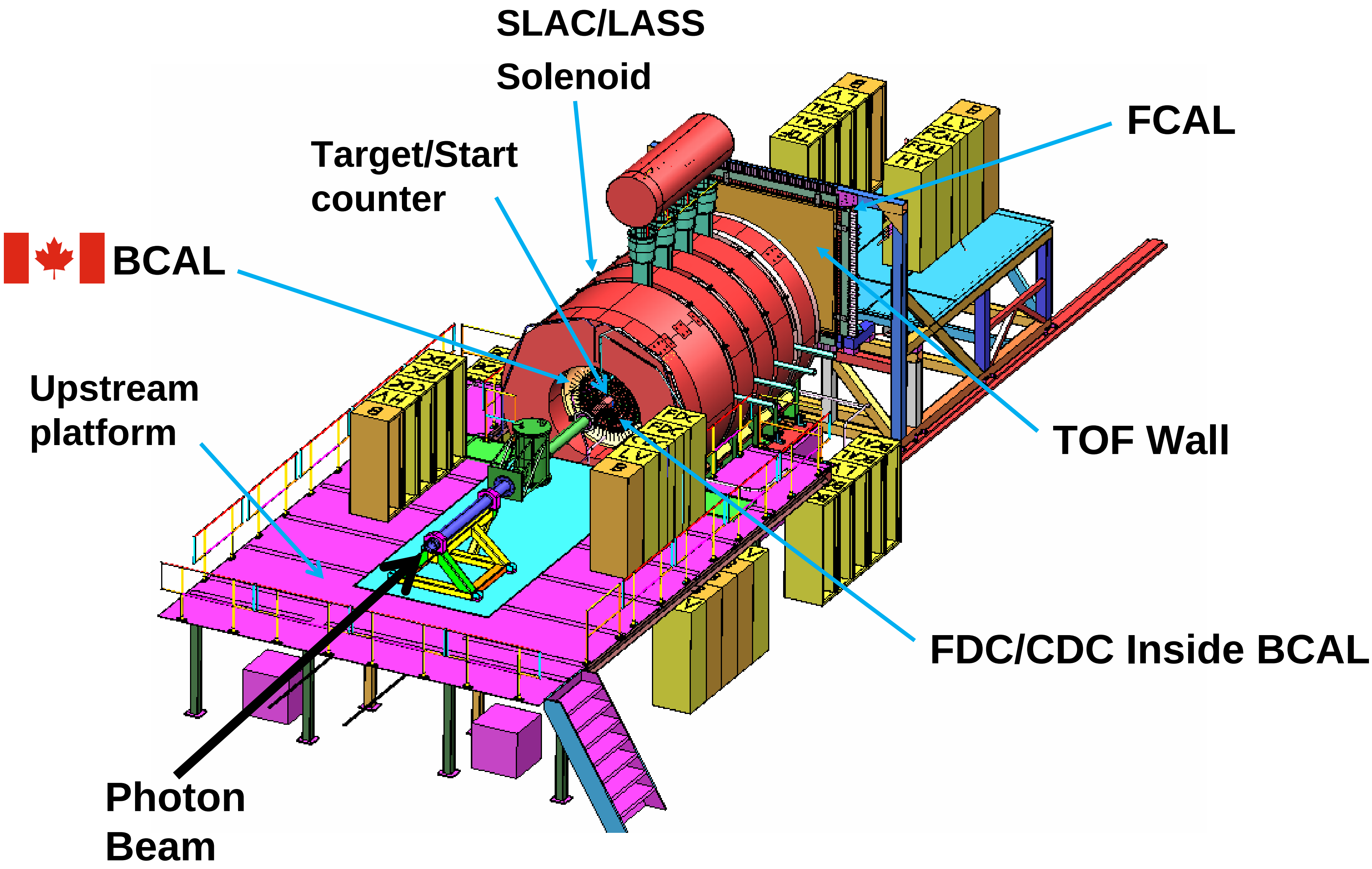
Collimator

Solenoid-based detector

Experimental Hall D



Hall D: *GlueX* Detector



SLAC/LASS Solenoid

Target/Start counter

BCAL

Upstream platform

Photon Beam

FCAL

TOF Wall

FDC/CDC Inside BCAL

GlueX Experiment Goals

FIRST 5 YEARS:

- Establish the existence of a $J^{PC}=1^{-+}$ or 2^{+-} exotic meson in several decay channels if it is present at a level of a few % of conventional mesons.
  - If exotics are not present, the few % level exclusion limit would present problems for QCD-based predictions made to date.
- Measure branching modes for established exotic states to validate QCD predictions.
- Add to the knowledge of conventional meson spectroscopy that straddles the light and heavy quark sectors.

12 GeV Upgrade: Phases and Schedule

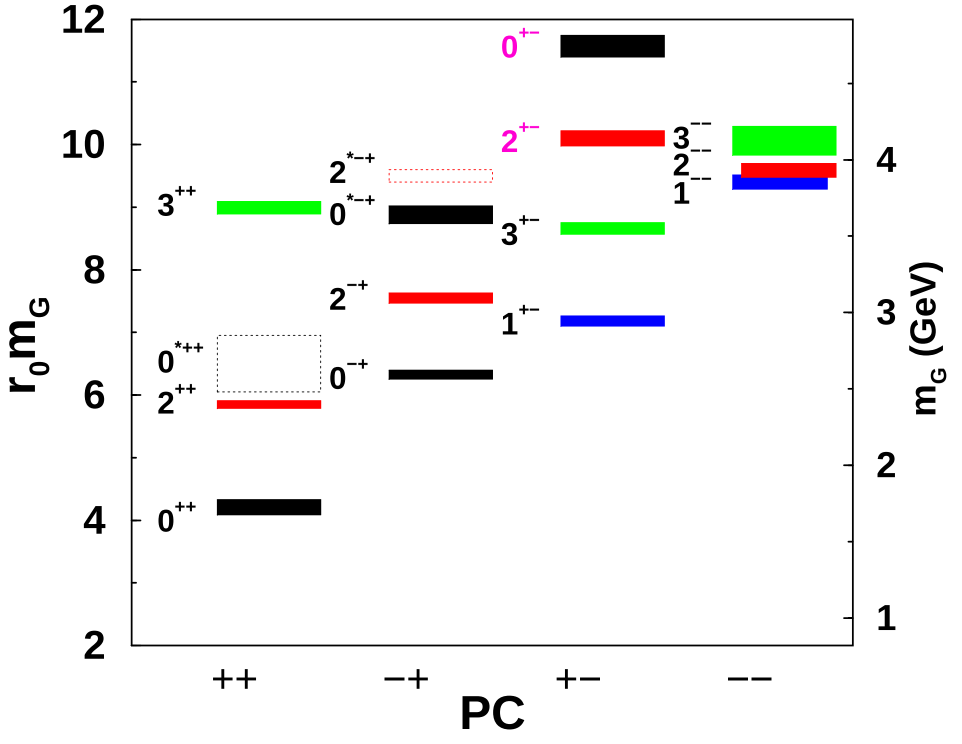
(based on funding guidance provided by DOE-NP in June-2007)

- **2009-2013 Construction** – *starts in ~6 months!*
  - *Parasitic machine shutdown – May 2011 through Oct 2011 (6 months)*
  - *Accelerator shutdown start mid-May 2012*
  - *Accelerator commissioning mid-May 2013*

- **2013-2015 Pre-Operations** (beam commissioning)
  - *Hall A commissioning start ~October 2013*
  - *Hall D commissioning start ~April 2014*
  - *Halls B and C commissioning start ~October 2014*

Glueballs

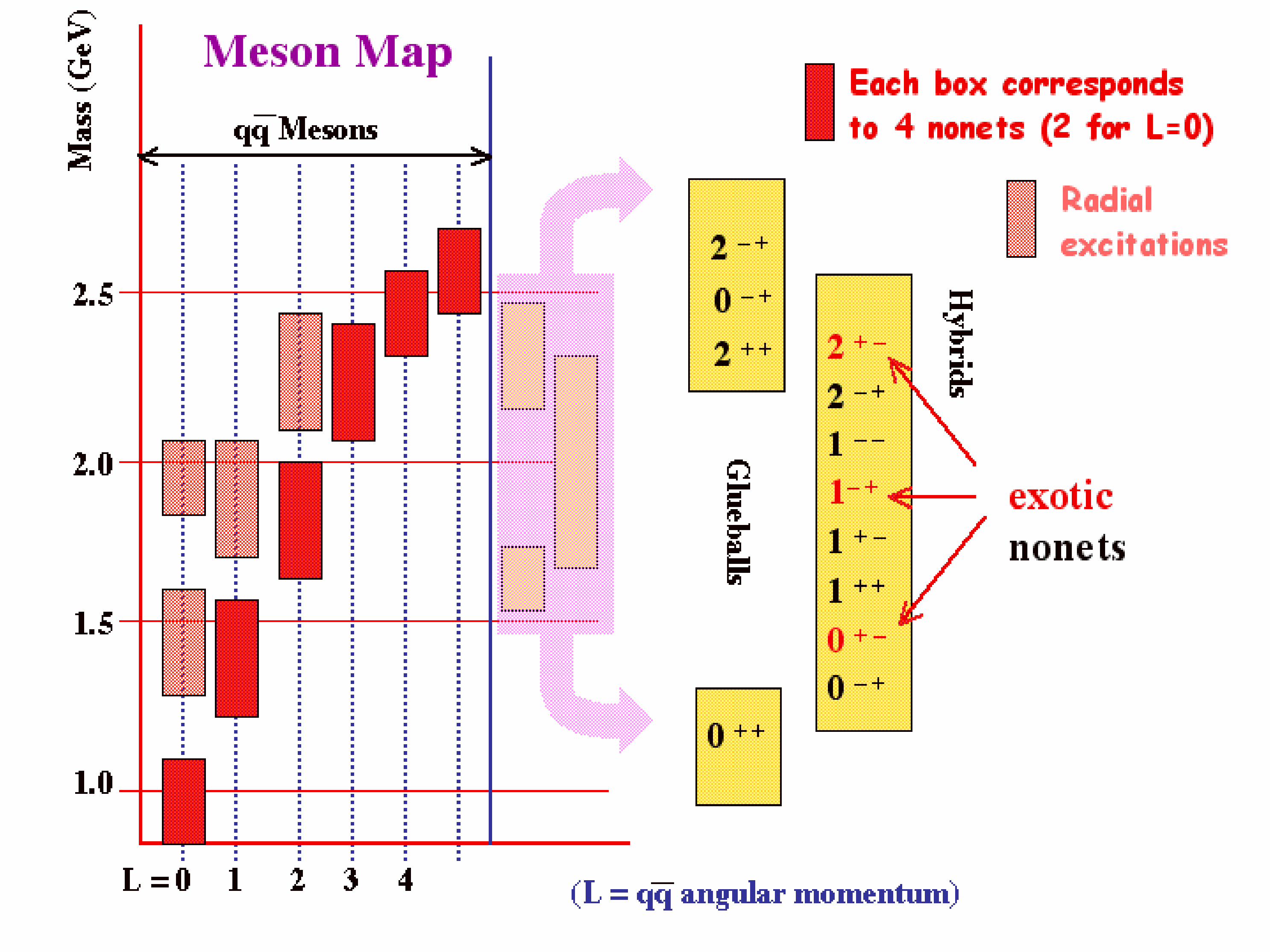
Glueballs are “pure gluon” states emblematic of non-Abelian nature of QCD.



Quenched Lattice QCD calculation provides a road-map for experimental searches.

Morningstar and Peardon, PRD **60**(1999) 034509.

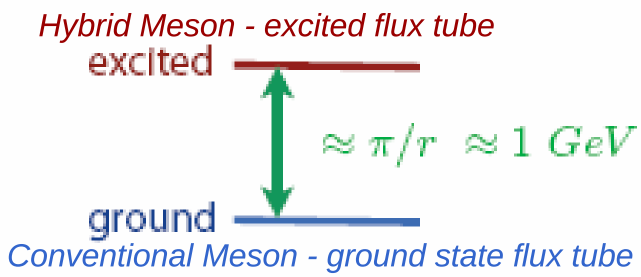
Glueballs and hybrid mesons



Masses and Widths of Hybrid Mesons

Masses and Widths

widths are expected to be of order 150-200 MeV



LQCD Mass Predictions for: $J^{PC} = 1^{-+}$

Author		1^{-+} Mass (GeV/c^2)	
Collab.	Year	$u\bar{u}/d\bar{d}$	$s\bar{s}$
UKQCD	(1997)	1.87 ± 0.20	2.0 ± 0.2
MILC	(1997)	$1.97 \pm 0.09 \pm 0.30$	$2.170 \pm 0.080 \pm 0.30$
MILC	(1999)	$2.11 \pm 0.10 \pm (sys)$	
SESAM	(1998)	1.9 ± 0.20	
Mei& Luo	(2003)	$2.013 \pm 0.026 \pm 0.071$	
Bernard *et al.*	(2004)	1.792 ± 0.139	2.100 ± 0.120

LQCD Mass Predictions for other exotic J^{PC}

Multiplet	J^{PC}	Mass (GeV/c^2)
π_1	1^{-+}	1.9 ± 0.2
b_2	2^{+-}	2.0 ± 0.11
b_0	0^{+-}	2.3 ± 0.6

above for $u\bar{u}/d\bar{d}$ for $s\bar{s}$ add ≈ 0.3 GeV

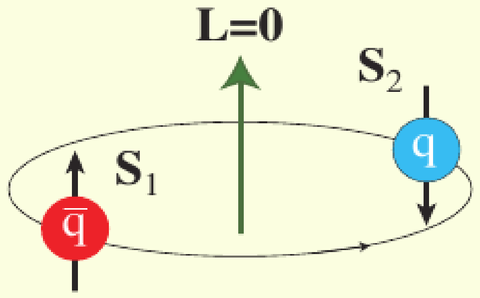
LQCD predicts lightest exotic mass of ~2 GeV

Conventional Light Mesons

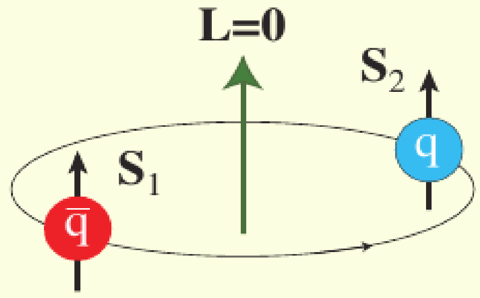
$\vec{J} = \vec{L} + \vec{S}$

$P = (-1)^{L+1}$

$C = (-1)^{L+S}$



$J^{PC} = 0^{-+}: \ \pi, \ K$

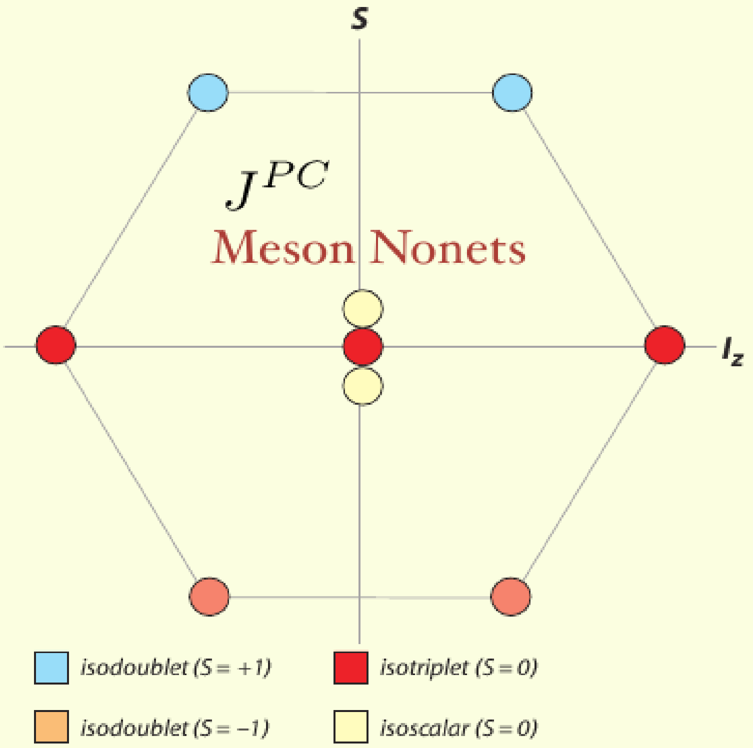


$J^{PC} = 1^{--}: \ \rho, \ K^*, \ \gamma$

Certain spin-parity combinations are not allowed - exotic:

$J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}$

For light quarks (u, d, s) and fixed J, P and C we expect nonets of mesons:



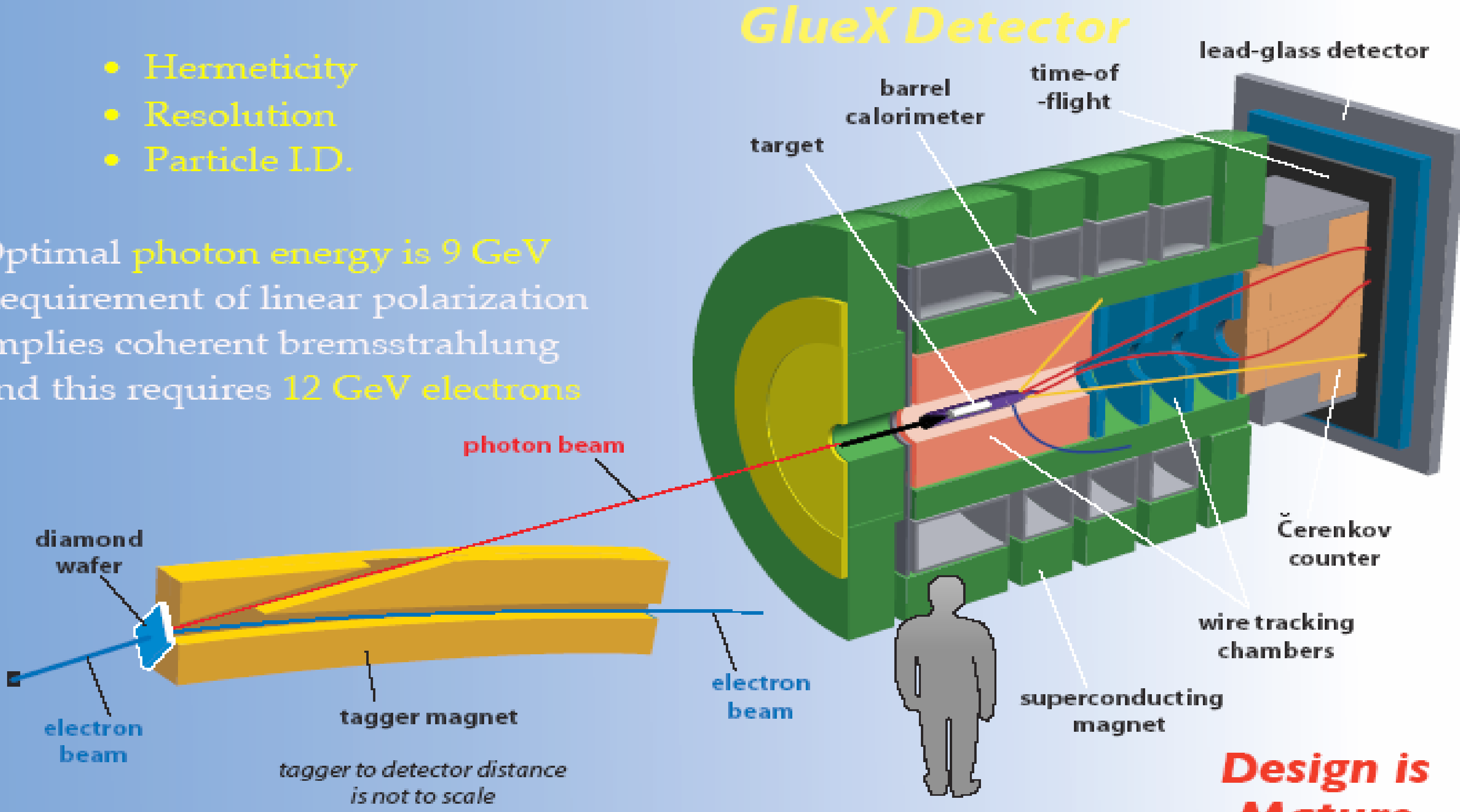
- 🟦 isodoublet ($S = +1$)
- 🟧 isodoublet ($S = -1$)
- 🟥 isotriplet ($S = 0$)
- 🟨 isoscalar ($S = 0$)

GlueX

Optimized for doing amplitude analyses

- Hermeticity
- Resolution
- Particle I.D.

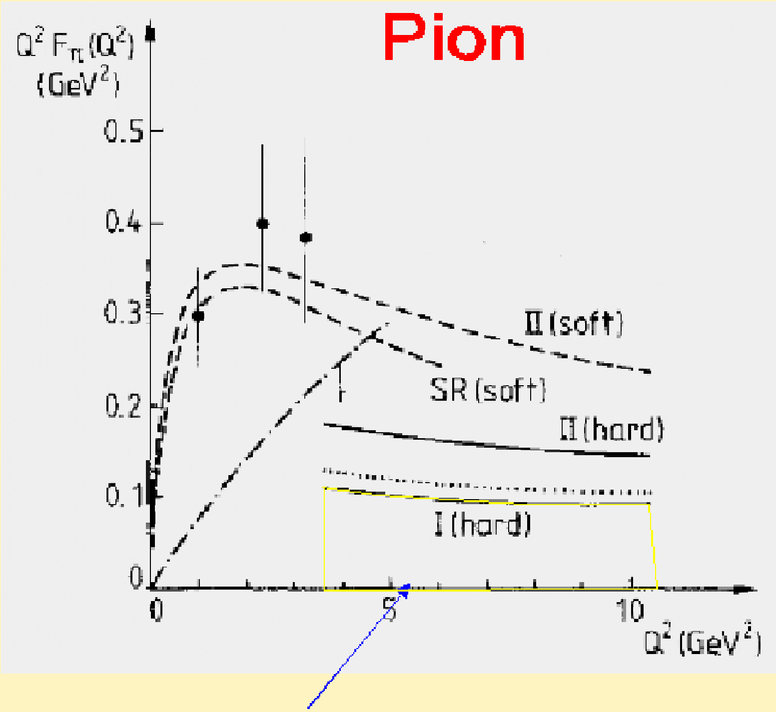
Optimal photon energy is 9 GeV
Requirement of linear polarization
implies coherent bremsstrahlung
and this requires 12 GeV electrons



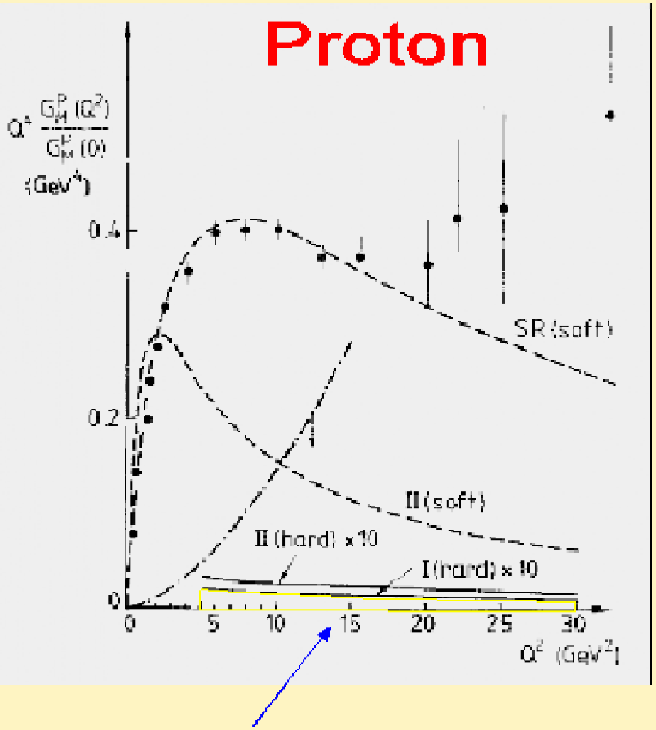
Design is Mature

Collaboration has been carrying out R&D for last 5 years

The pion as a QCD Laboratory



Hard contributions
~30-50% at Q^2=5 GeV^2



Hard contributions
≤1% at Q^2=5 GeV^2

Isgur & Llewellyn-Smith, PRL 52(84)1080

Excellent opportunity for studying the **QCD transition** from $q\bar{q}$ effective degrees of freedom to quarks and gluons.

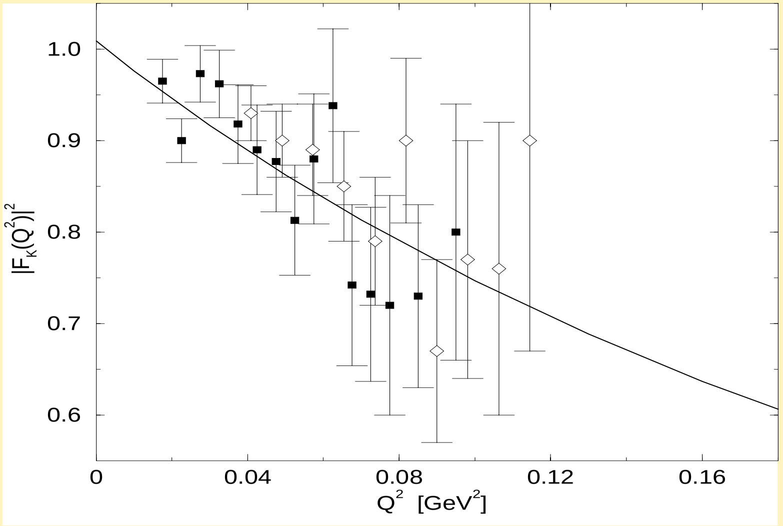
i.e. from the strong QCD regime to the hard QCD regime.

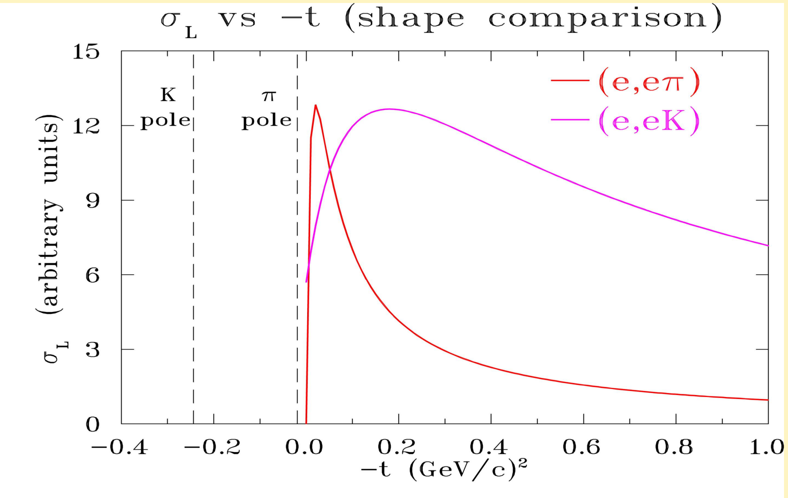
Jefferson Lab is the facility capable of these measurements.

Measurement of K^+ Form Factor

- Can “kaon cloud” of the proton be used in the same way as the pion to extract kaon form factor via ***p(e,e’K⁺)**Λ* ?
- Kaon pole further from kinematically allowed region.
- Can we demonstrate that the “pole” term dominates the reaction mechanism?

A proposal to the next JLab 12 GeV PAC is under investigation.





Nucleon Spin Structure Functions (SSF's)

- **g_1**: electron spin and target nucleon spin are parallel, antiparallel.

$$g_1(x,Q^2)=\frac{1}{2}\sum_i e_i^{\,2}[q_i^{\uparrow}(x,Q^2)-q_i^{\downarrow}(x,Q^2)],\quad i=u,\bar{u},d,\bar{d},s,\bar{s}\ldots$$

- **g_2**: electron spin and target nucleon spin are perpendicular.
  - Probes a combination of transverse and longitudinal parton polarization distributions within the nucleon.

- Focus of the SSF program in Deep Inelastic Scattering measurements has been to determe the moments of the SSF's.
  - Related to quark matrix elements that can be calculated from QCD.

- Difference of the first moments of the proton and neutron g_1^p, g_1^n is the fundamental Bjorken sum rule:

$$S_{Bj}=\left[g_1^{\,p}(x,Q^2)-g_1^{\,n}(x,Q^2)\right]dx=\frac{1}{6}\frac{g_A}{g_V}C_{NS}(\alpha_s)$$

where g_A is the nucleon's isovector, axial charge, from neutron β decay.

Structure Function Measurements:
Spin and Flavor Dependence of Valence Parton Distribution Functions

- In over 35 years of study of Deep Inelastic Scattering, no one has had the facilities to map out the crucial valence region.
  - **Large x:** sea quarks are effectively “stripped away”.
- 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) $[u,\bar{u},d,\bar{d},s,\bar{s}]$ symmetry?
  - Moments of PDFs (and GPDs) from Lattice QCD.
    - Lattice only computes lowest moments of polarized and unpolarized parton distribution functions, not spin structure functions.

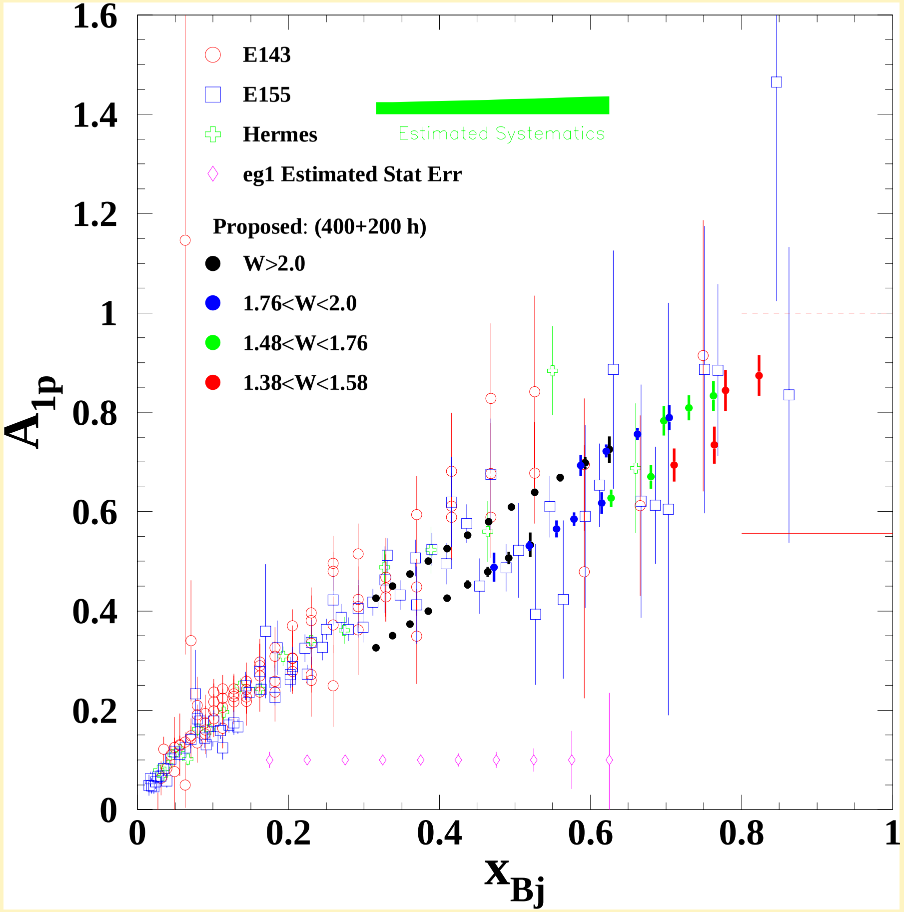
Spin Dependence at Large x Poorly Known

- x = momentum fraction of struck parton.
- Upcoming (2008) experiment to determine proton spin structure functions A_1^p, g_2^p.

$$A_1(x,Q^2)=\frac{1}{F_1(x,Q^2)}\left[g_1(x,Q^2)-\gamma^2 g_2(x,Q^2)\right]$$

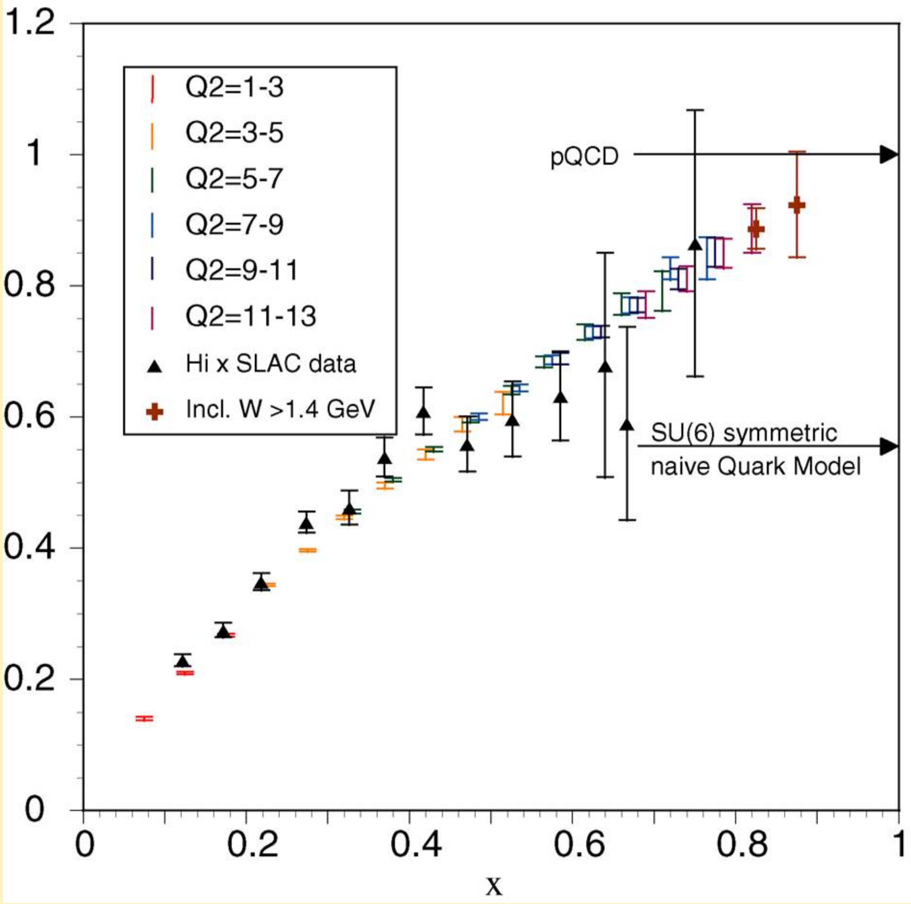
where $\gamma^2 = Q^2/\nu_2$

- Natural connection to Lattice QCD:
  - x→1 data inadequate for estimating beyond the first moment.
  - Will allow up to 3rd moment to be studied.

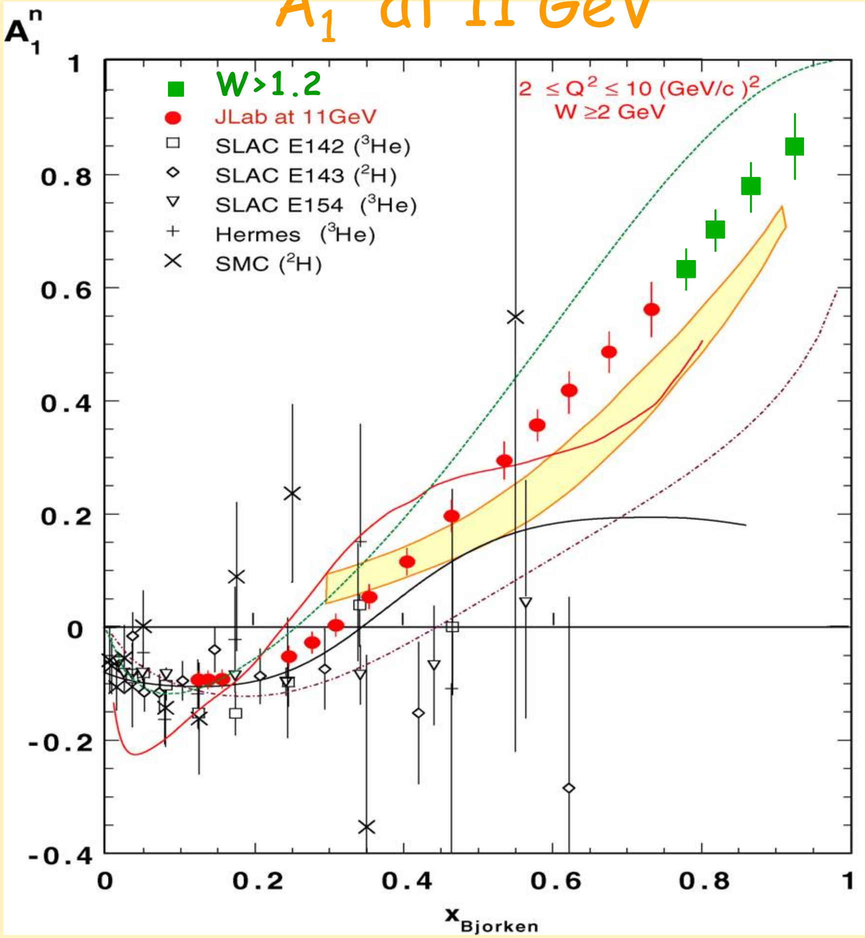


12 GeV: Unambiguous Extraction of Parton Distribution Higher Moments

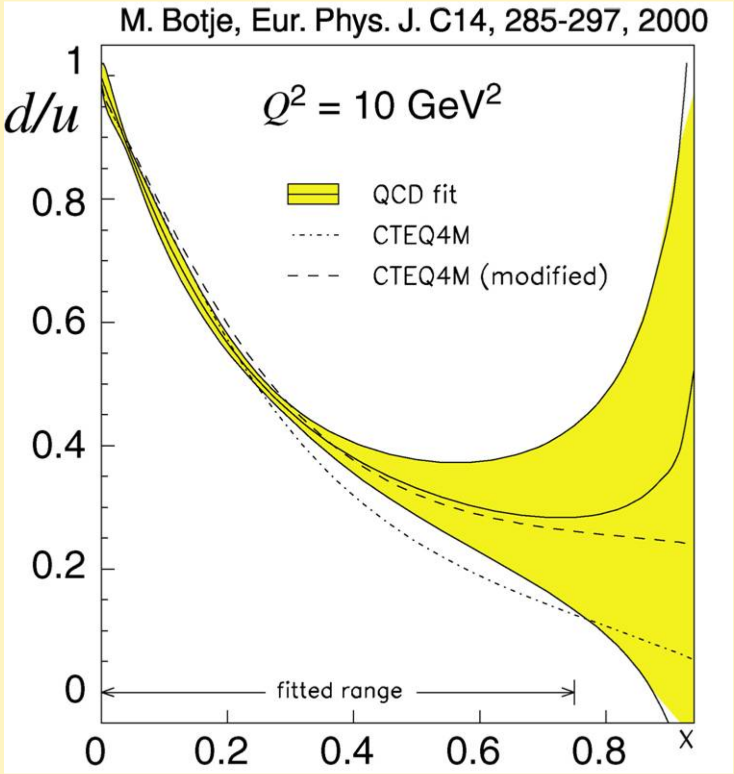
A_1^p at 11 GeV



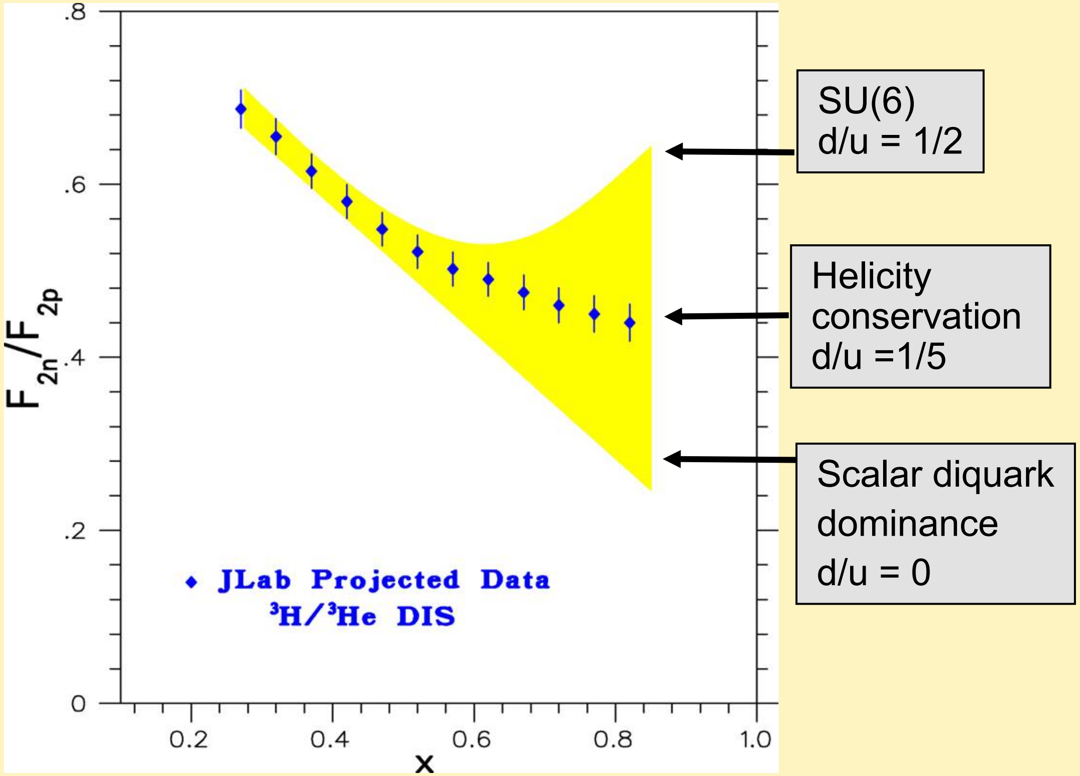
A_1^n at 11 GeV



Large x F_{2n}/F_{2p} measurements to greatly improve our knowledge of Valence d-Quark Momentum Distributions


M. Botje, Eur. Phys. J. C14, 285-297, 2000

Hall C 11 GeV with HMS



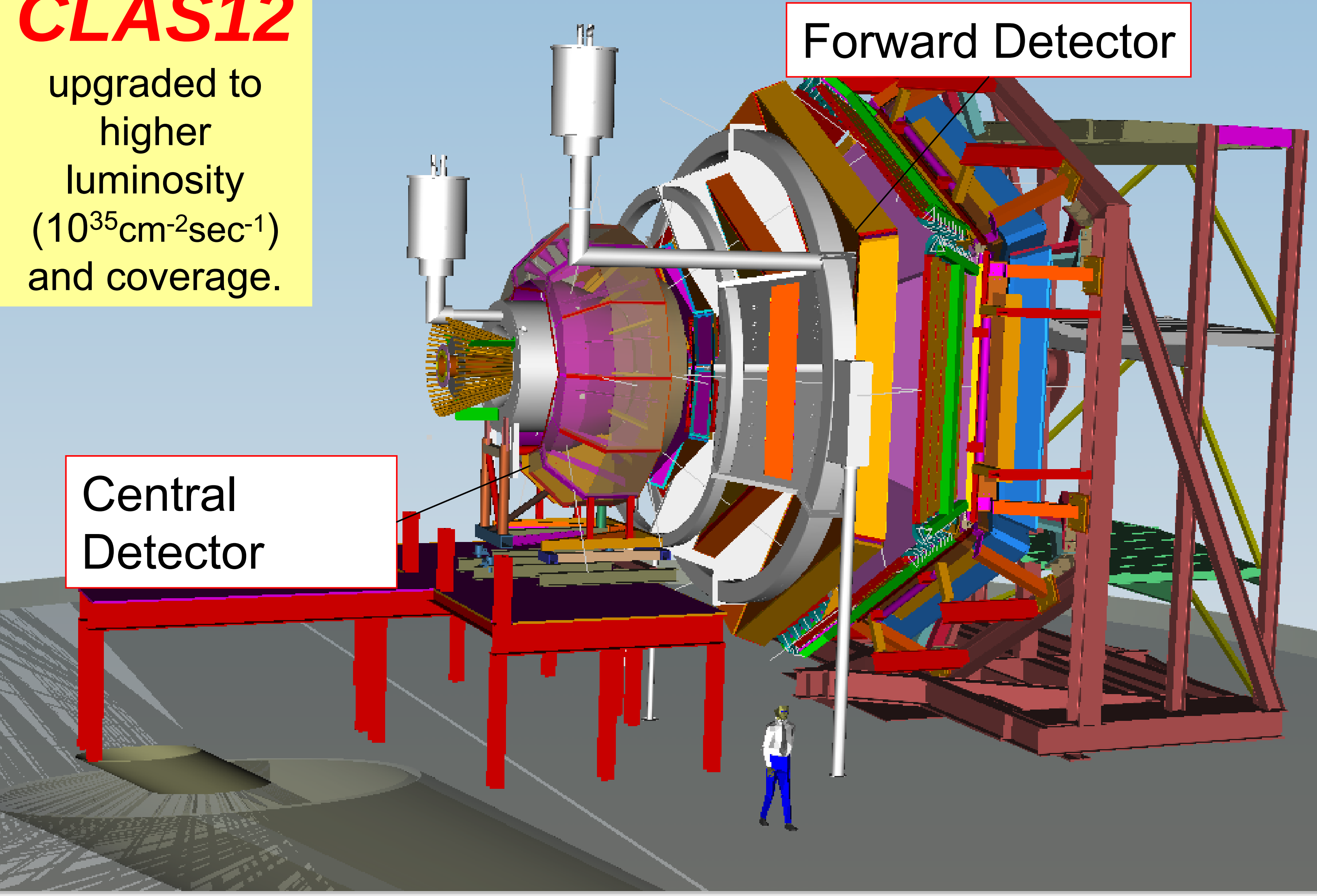
SU(6)
d/u = 1/2

Helicity
conservation
d/u =1/5

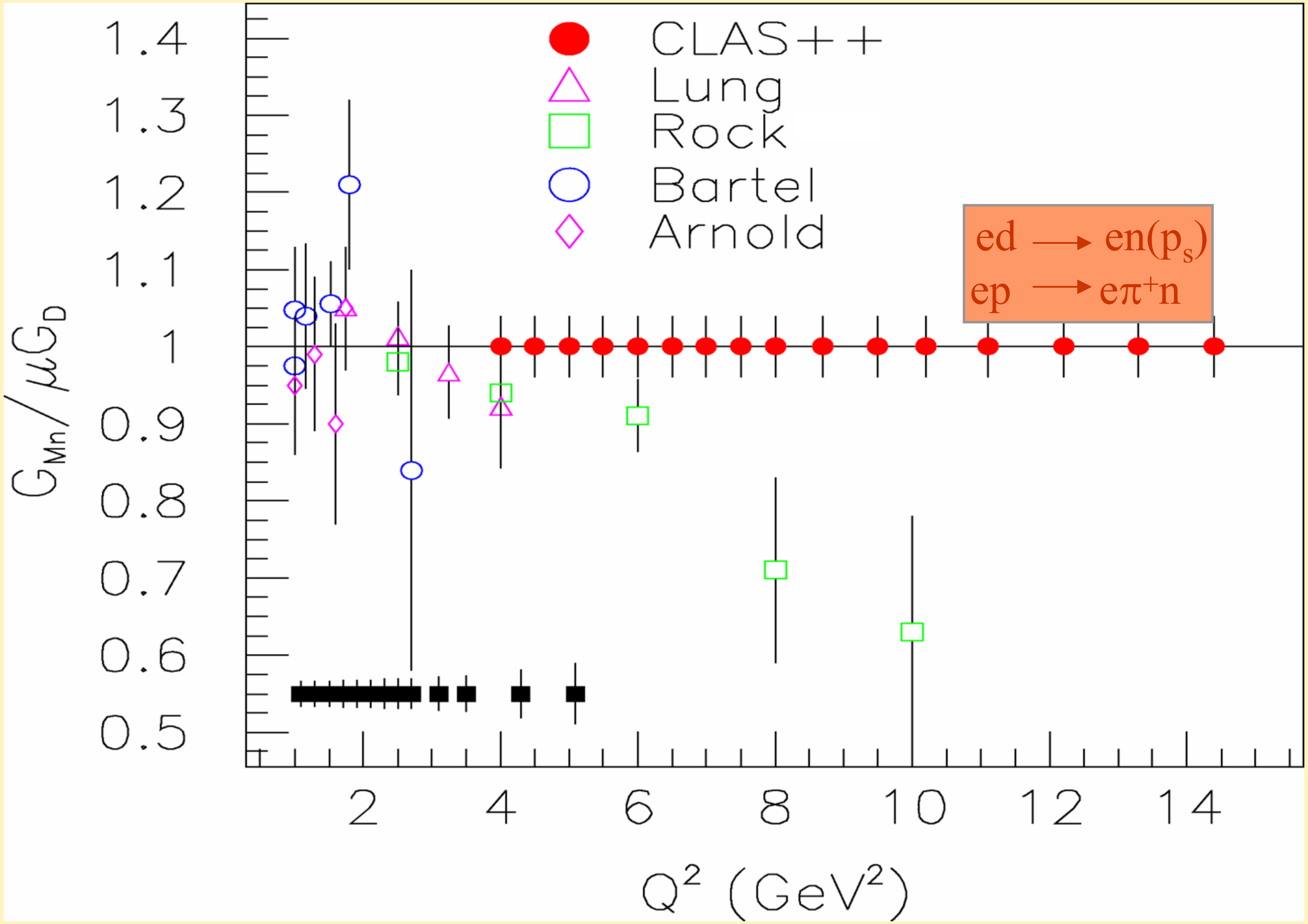
Scalar diquark
dominance
d/u = 0

Hall B: *CLAS12*

upgraded to higher luminosity (10^{35}cm^{-2}sec^{-1}) and coverage.



CLAS 12 : Neutron G_M^n



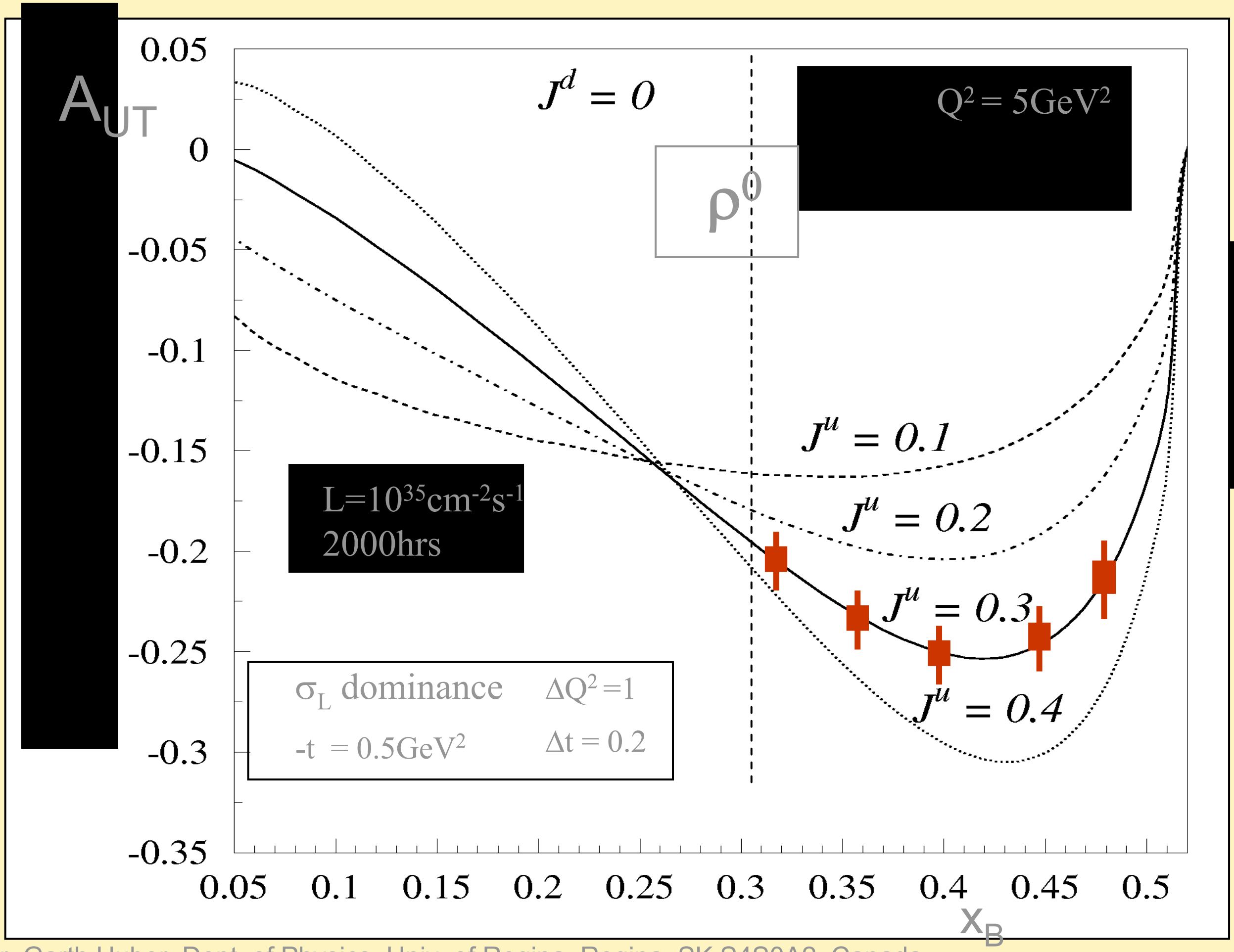
Exclusive ρ^0 with transverse target

$$A_{UT} = -\frac{2\Delta_\perp (\mathrm{Im}(AB^*))/\pi}{|A|^2(1-\xi^2) - |B|^2(\xi^2+t/4m^2) - \mathrm{Re}(AB^*)2\xi^2}$$

ρ^0

$A \sim (2H^u + H^d)$

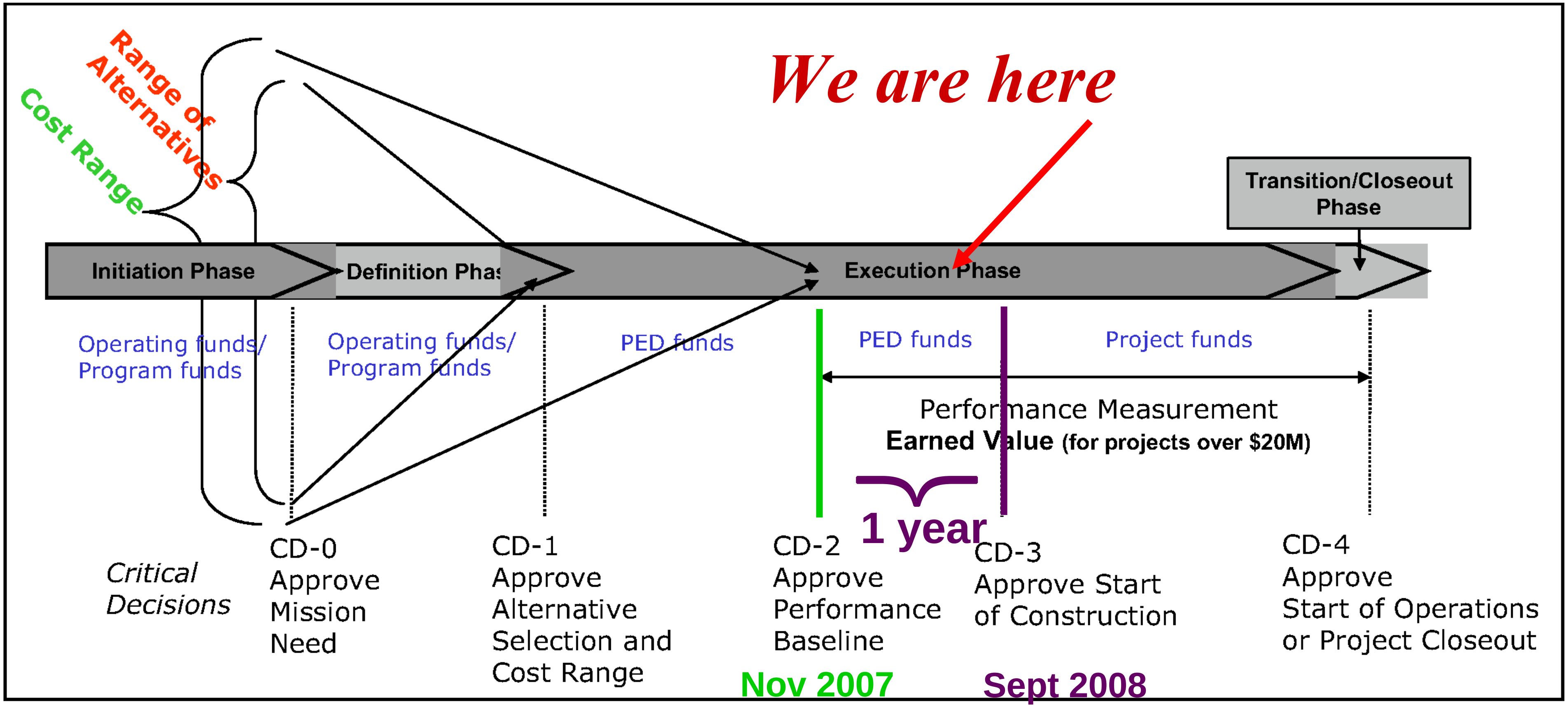
$B \sim (2E^u + E^d)$



Asymmetry depends linearly on the GPD E, which enters Ji's sum rule.

K. Goeke, M.V. Polyakov,
M. Vanderhaeghen, 2001

USDOE Generic Project Timeline



Critical Decisions

CD-0
Approve
Mission
Need

CD-1
Approve
Alternative
Selection and
Cost Range

CD-2
Approve
Performance
Baseline
Nov 2007

CD-3
Approve Start
of Construction
Sept 2008

CD-4
Approve
Start of Operations
or Project Closeout

12 GeV Upgrade: Phases and Schedule

(based on funding guidance provided by DOE-NP in June-2007)

- ☐2004-2005 Conceptual Design (CDR) - ***finished***
- ☐2004-2008 Research and Development (R&D) - ***ongoing***
- ☐2006 Advanced Conceptual Design (ACD) - ***finished***
- ☐2006-2008 Project Engineering & Design (PED) - ***ongoing***
- ☐2009-2014 Construction – ***starts in ~6 months!***
  - ➢**Accelerator shutdown start ~May 2012**
  - ➢**Accelerator commissioning ~May 2013**
- ☐2013-2015 Pre-Ops (beam commissioning)
  - ➢**Hall commissioning start October 2013**

12 GeV UPGRADE SCHEDULE