Physics Potential of JLab Upgrade

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CEBAF @ JLab Today

- Main physics programs
  - nucleon electromagnetic form factors (incl. strange)
  - N $\rightarrow$ N* electromagnetic transition form factors
  - spin structure functions of the nucleon
  - form factors and structure of light nuclei

- Superconducting recirculating electron accelerator
  - max. energy 6 GeV
  - max current 200 μA
  - e polarization 80%

- Experimental equipment in 3 halls (simultaneous operation) $L[cm^{-2}s^{-1}]$
  - 2 High Resolution Spectrometers (p_{max}=4 GeV/c) 10^{39}
  - 2 spectrometers (p_{max}=7 and 1.8 GeV/c) + special equipment 10^{39}
  - Large Acceptance Spectrometer for e and γ induced reactions 10^{34}

Physics Drivers for JLab Upgrade

- New capabilities
  - search for origin of confinement (J^{PC} exotic mesons)
  - determine parton distributions (high Q^2 and W) via
    - polarized and unpolarized inclusive scattering
    - semi-inclusive (tagged) structure functions
    - exclusive processes (DVCS, meson production)

- Push present program to higher Q^2
  - form factors of mesons, nucleons, and light nuclei

Gluonic Excitations

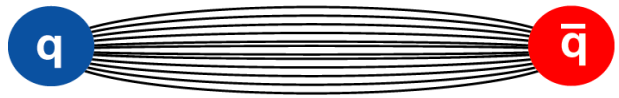
Dynamical role of Glue

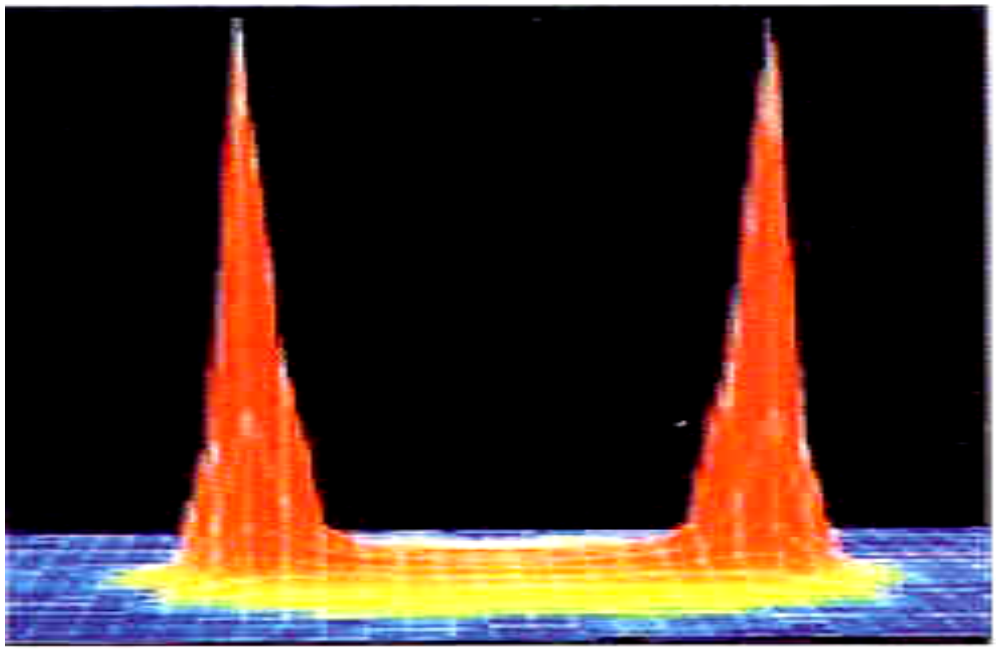
Confinement

Search for Exotic Mesons: Basic idea

Color field:

due to self interaction, confining flux tubes form between static color charges





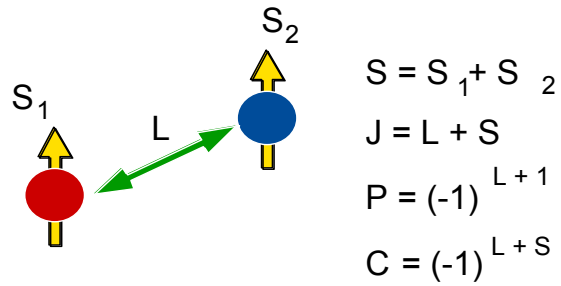
Original idea by Nambu,

now verified by Lattice QCD calculations

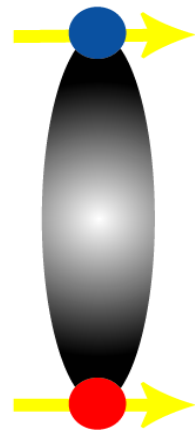
Excitation of the flux tube can lead to exotic quantum numbers

Excited Flux Tube Quantum Numbers

Normal mesons: $J^{PC} = 0^{-+}$ 1^{+-} 2^{-+}



First excited state of flux tube has J=1
combined with S=1 for quarks



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

exotic
(mass ~ 1.7 – 2.3 GeV)

Photons couple to exotic mesons via $\gamma \rightarrow$VM transition (same spin configuration)

Strategy for Exotic Meson Search

- Use photons to produce meson final states
  - tagged photon beam with 8 – 9 GeV
  - linear polarization to constrain production mechanism

- Use large acceptance detector
  - hermetic coverage for charged and neutral particles
  - typical hadronic final states:

$$f_1\eta \longrightarrow K\bar{K}\eta \longrightarrow K\bar{K}\pi\pi\pi$$
$$b_1\pi \longrightarrow \omega\pi \longrightarrow \pi\pi\pi\pi$$
$$\rho\pi \longrightarrow \pi\pi\pi$$

  - high data acquisition rate

- Perform partial-wave analysis
  - identify quantum numbers as a function of mass
  - check consistency of results in different decay modes

Finding an Exotic Wave

An exotic wave ($J^{PC} = 1^{-+}$) was generated at level of 2.5 % with 7 other waves. Events were smeared, accepted, passed to PWA fitter.

$$X(\text{exotic}) \rightarrow \rho\pi \rightarrow 3\pi$$

Mass

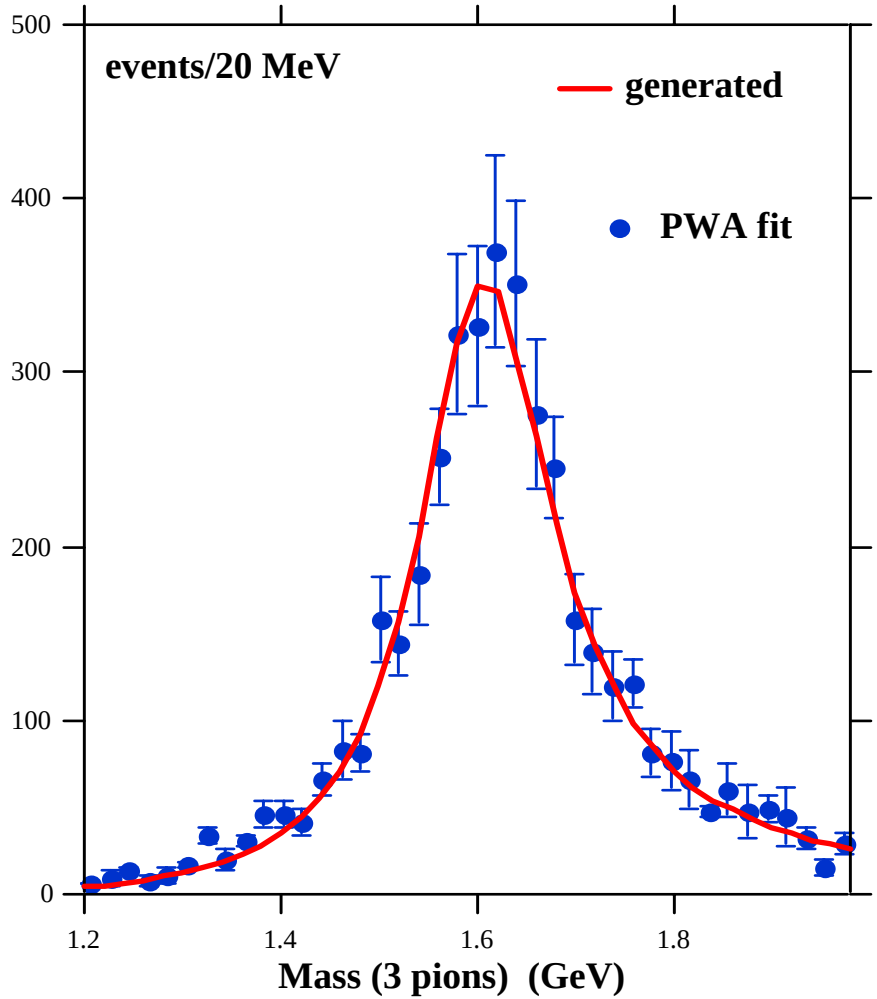
Input: 1600 MeV
Output: 1598 +/- 3 MeV

Width

Input: 170 MeV
Output: 173 +/- 11 MeV

Statistics shown here correspond to a few days of running.

Double-blind M. C. exercise

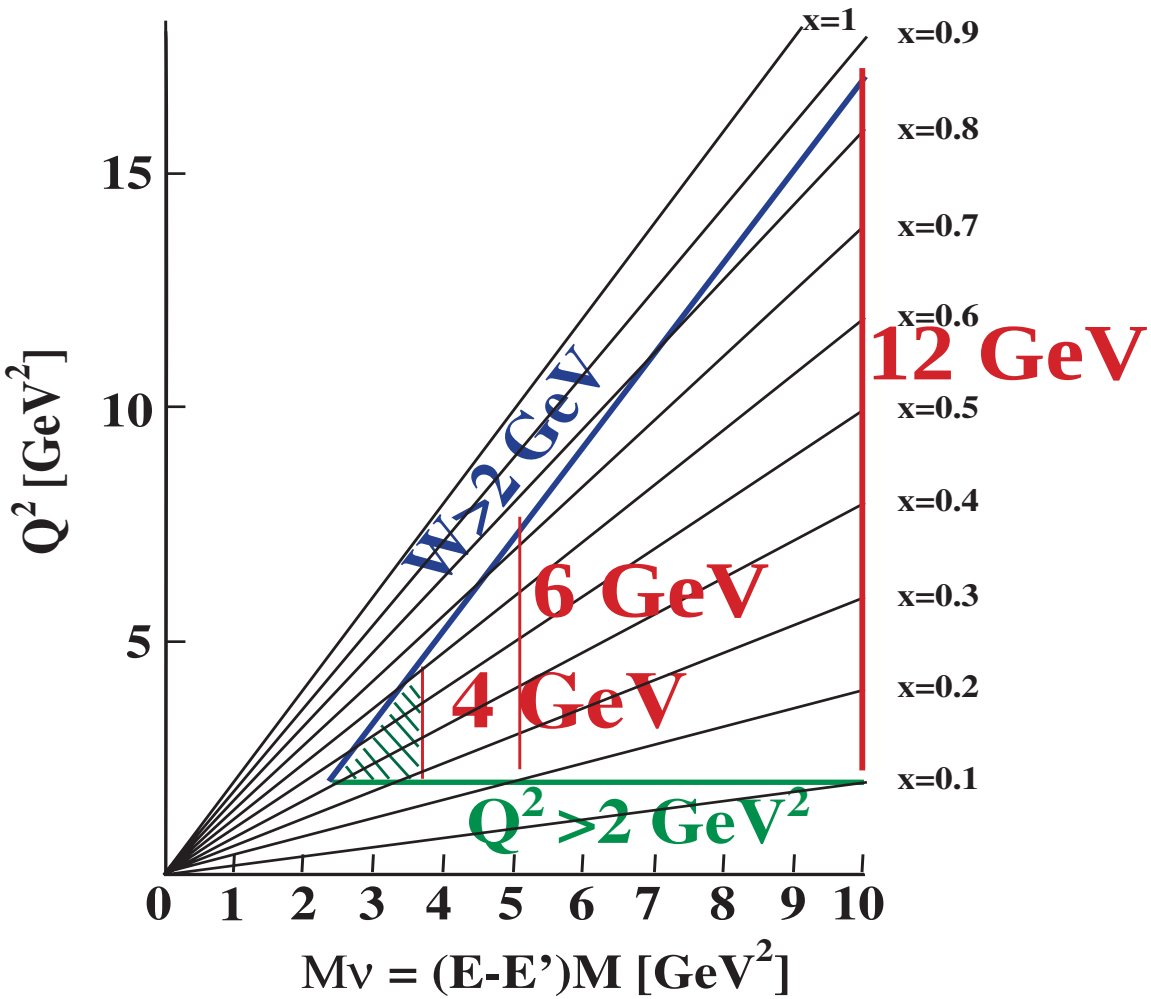


Valence Quark Structure of the Nucleon

Parton Distributions at large x

Enhanced Access to the DIS Regime

- **12 GeV will access the valence quark regime for x > 0.3**
- **where constituent quark properties are not masked by the sea quarks**



Predictions for large x_{Bj}

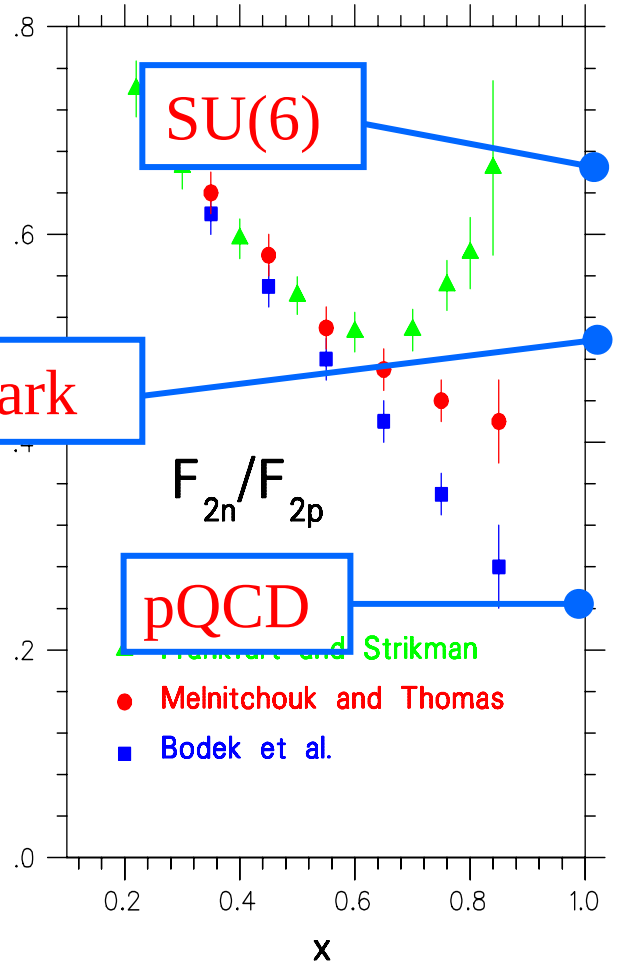
Proton Wavefunction (Spin and Flavor Symmetric)

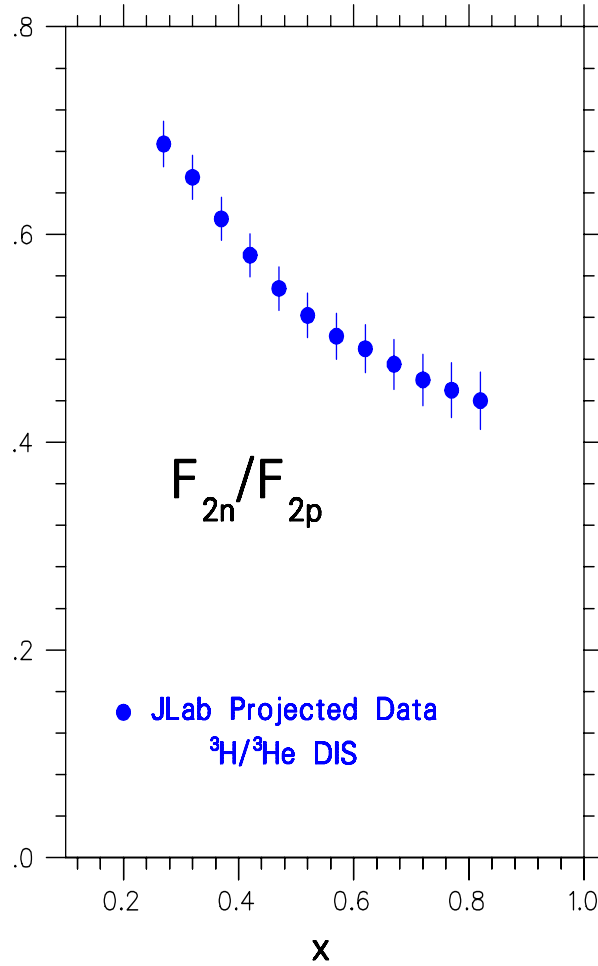
$$|p\uparrow\rangle = \frac{1}{\sqrt{2}}|u\uparrow(ud)_{S=0}\rangle + \frac{1}{\sqrt{18}}|u\uparrow(ud)_{S=1}\rangle - \frac{1}{3}|u\downarrow(ud)_{S=1}\rangle - \frac{1}{3}|d\uparrow(uu)_{S=1}\rangle - \frac{\sqrt{2}}{3}|d\downarrow(uu)_{S=1}\rangle$$

Nucleon Model	F_2^n/F_2^p	d/u	$\Delta u/u$	$\Delta d/d$	A_1^n	A_1^p
SU(6)	2/3	1/2	2/3	-1/3	0	5/9
Valence Quark	1/4	0	1	-1/3	1	1
pQCD	3/7	1/5	1	1	1	1

Valence Quark Distribution

- Physics issue:
  - u and d quarks as $x_{Bj} \rightarrow 1$
- Experimental problem:
  - extract information from H and D
  -
  - need to correct for nuclear effects in D
- Solution for JLab upgrade
  - compare ^{3}He and ^{3}H (nuclear effects ~ same)





Neutron Spin Structure Function A_1^n

Physics issue:

determine n spin structure

Experimental problem:

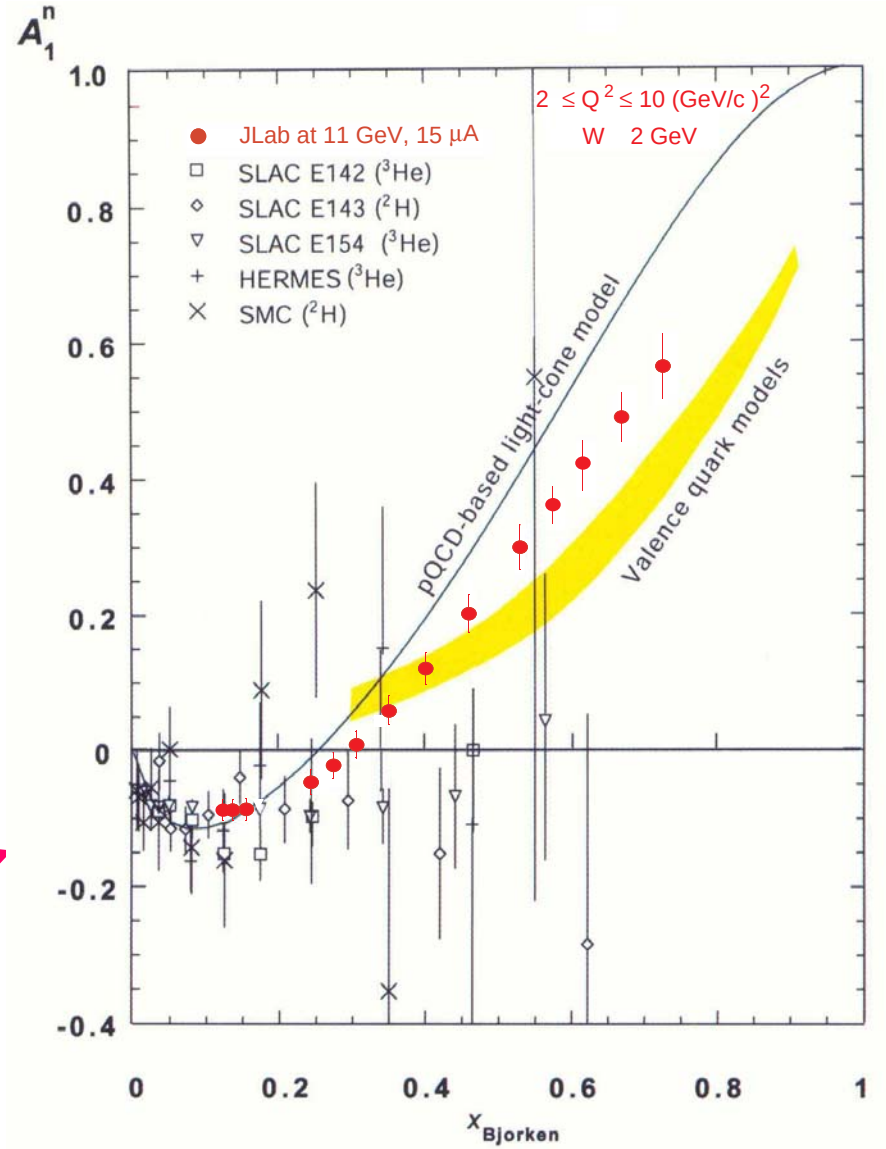
no free neutron target

choices: D – p or $^3\vec{He}$

Solution for JLab upgrade:

use $^3\vec{He}$ target and 15μA beam

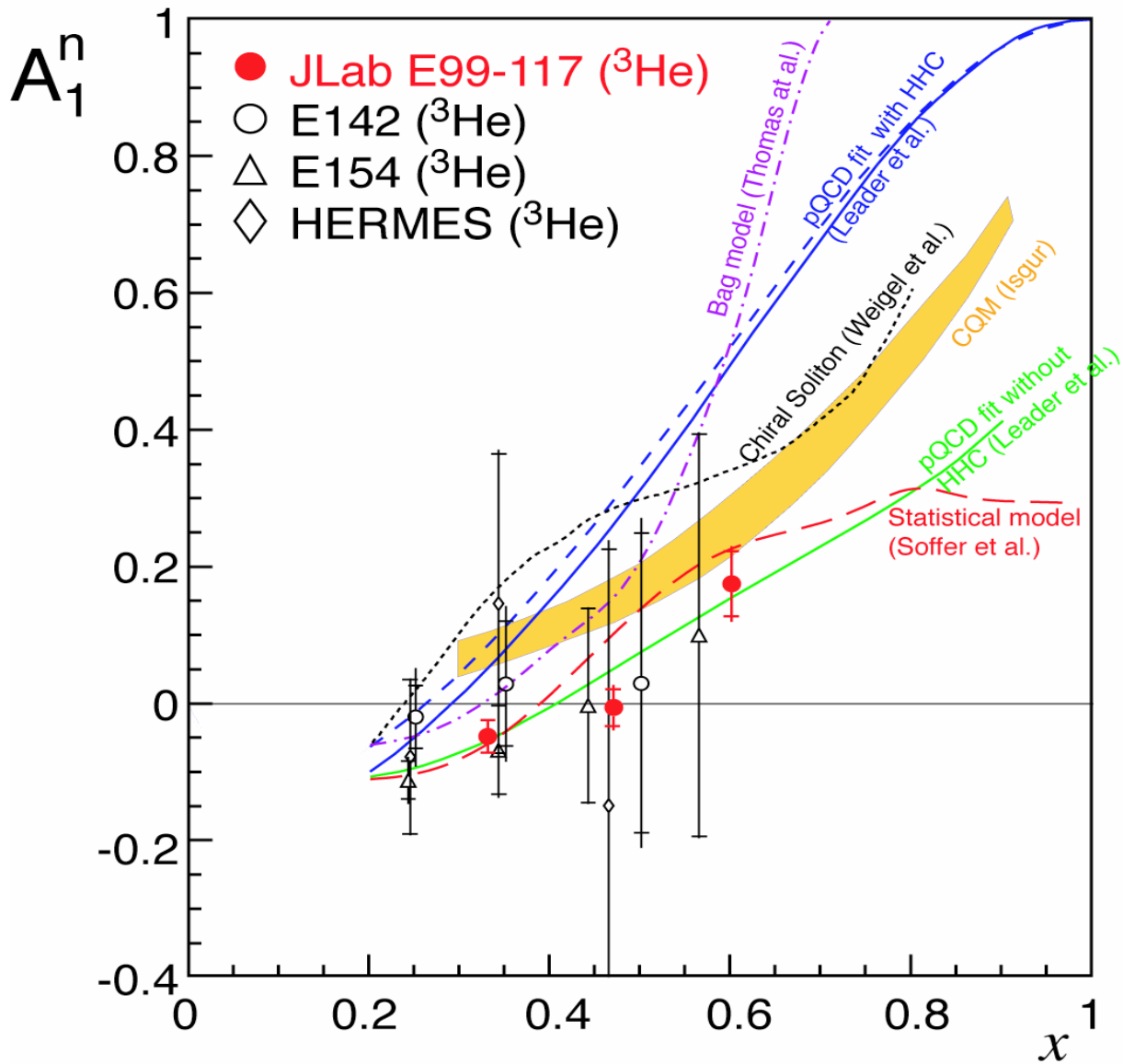
use broad acceptance spectrometer for e detection



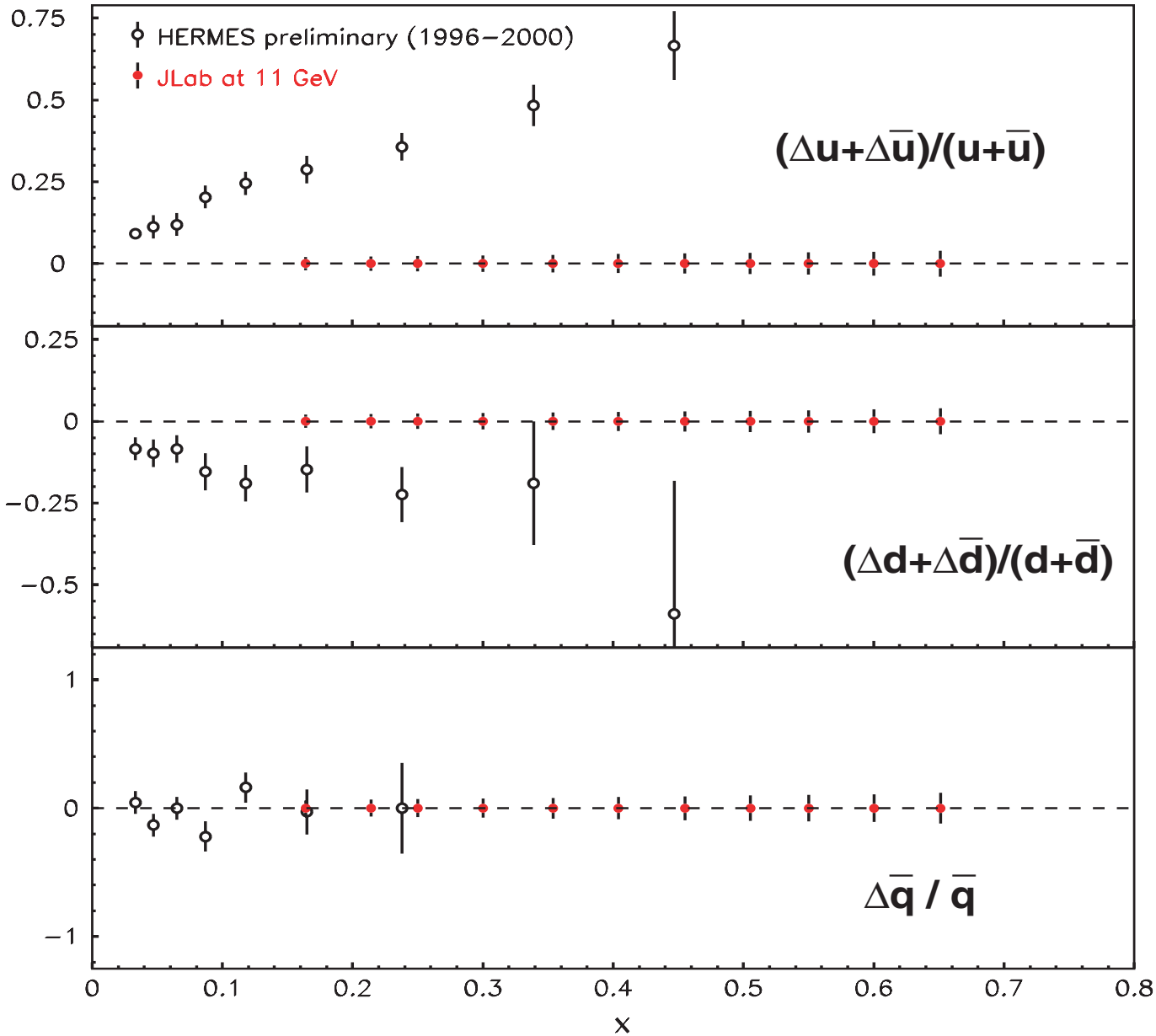
He^3 Data Demonstrate the Feasibility of These Experiments

New E99-117 data

provide first indication that A_1^n deviates from 0 at large x, but are clearly at variance with pQCD prediction assuming Hadron Helicity Conservation



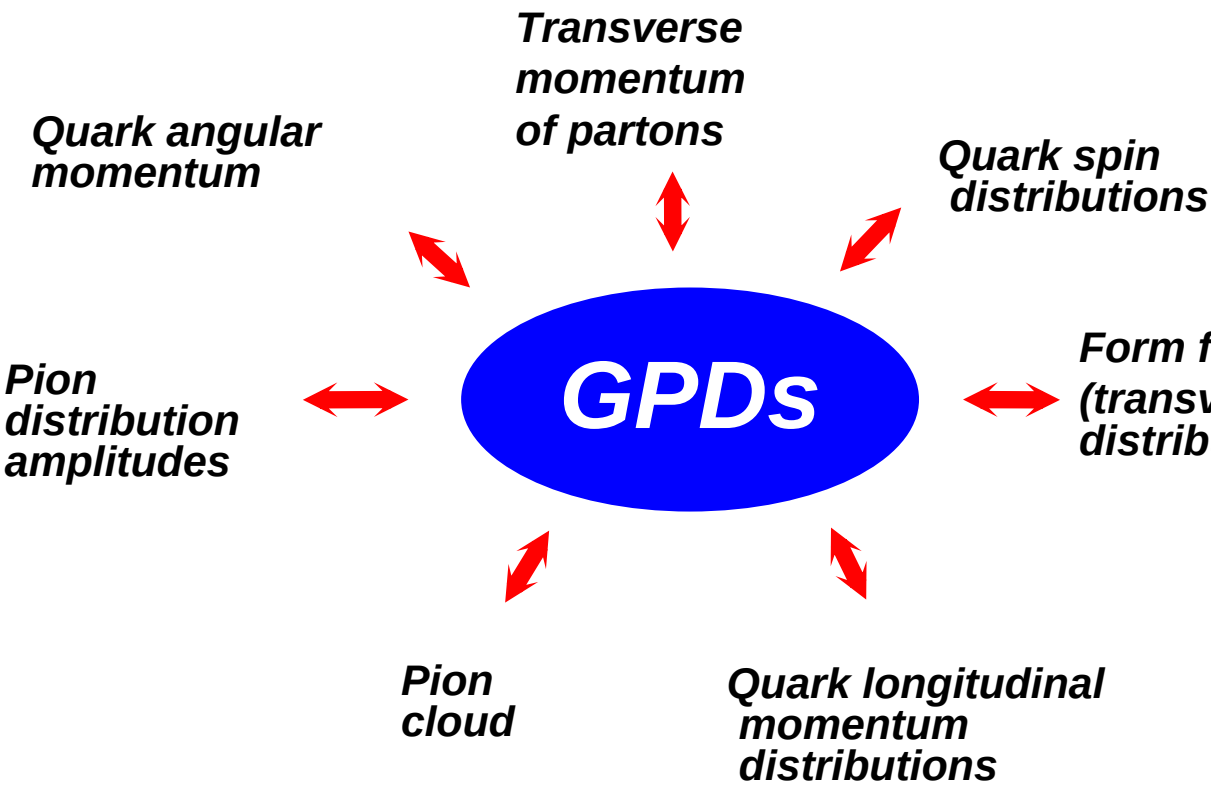
Flavor Decomposition: (e,e'π^+)/(e,e'π^-)

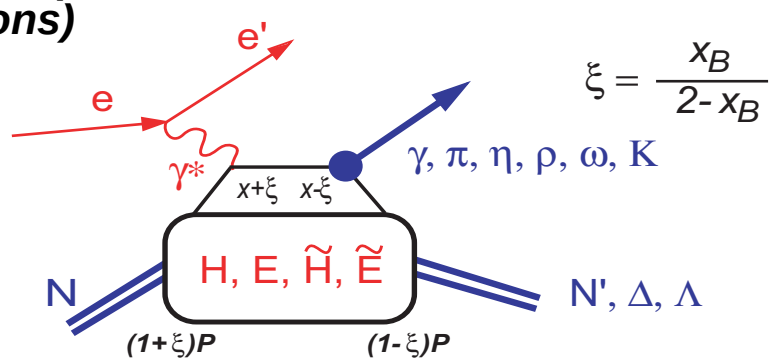


3-dimensional view of the Nucleon

Deep Exclusive Scattering

Generalized Parton Distributions

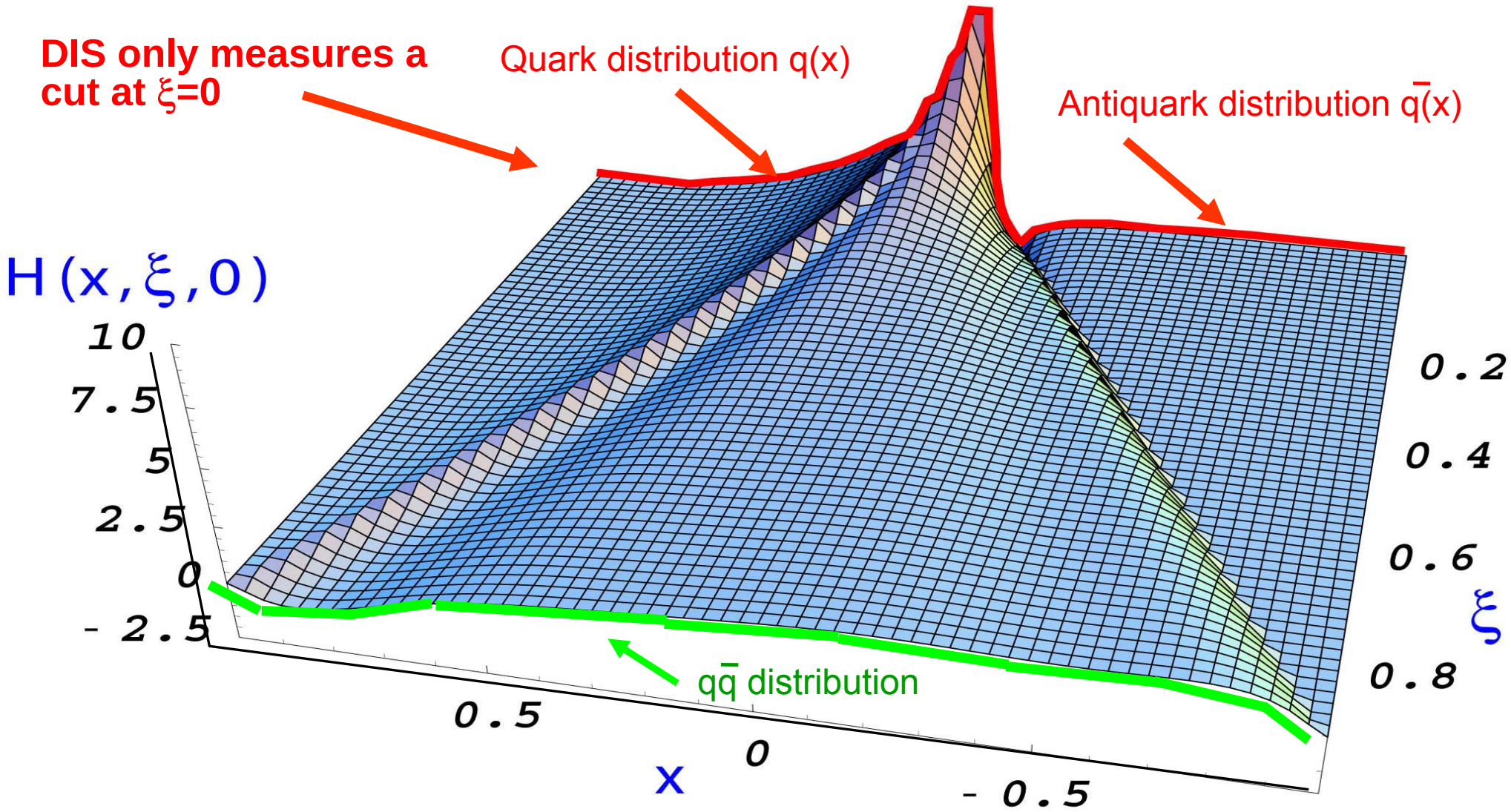




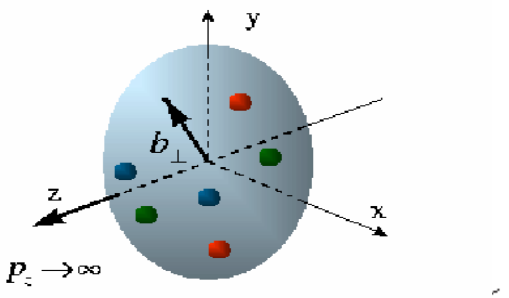
H, E - unpolarized, $\widetilde{H}, \widetilde{E}$ - polarized GPD

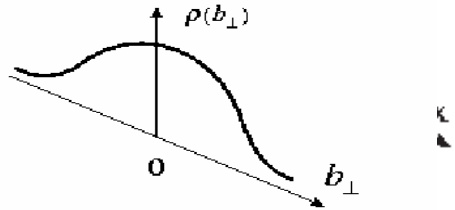
The GPDs Define Nucleon Structure

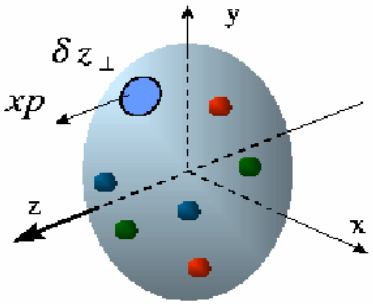
GPDs Contain Much More Information than DIS

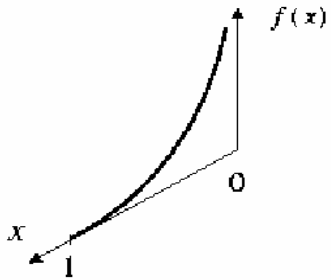


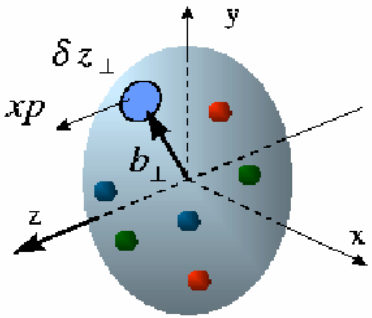
Proton Properties Measured in Different Experiments

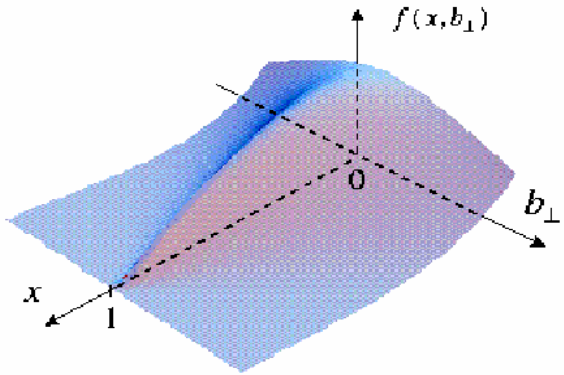












Elastic Scattering
transverse quark distribution in Coordinate space

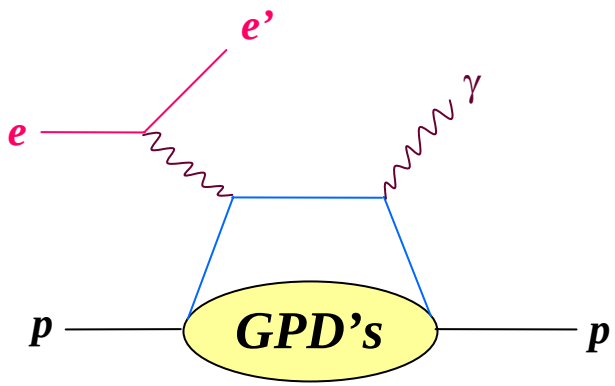
DIS
longitudinal quark distribution in momentum space

DES (GPDs)
The fully-correlated Quark distribution in both coordinate and momentum space

DVCS

Physics issue:

constrain GPD's from DVCS measurement

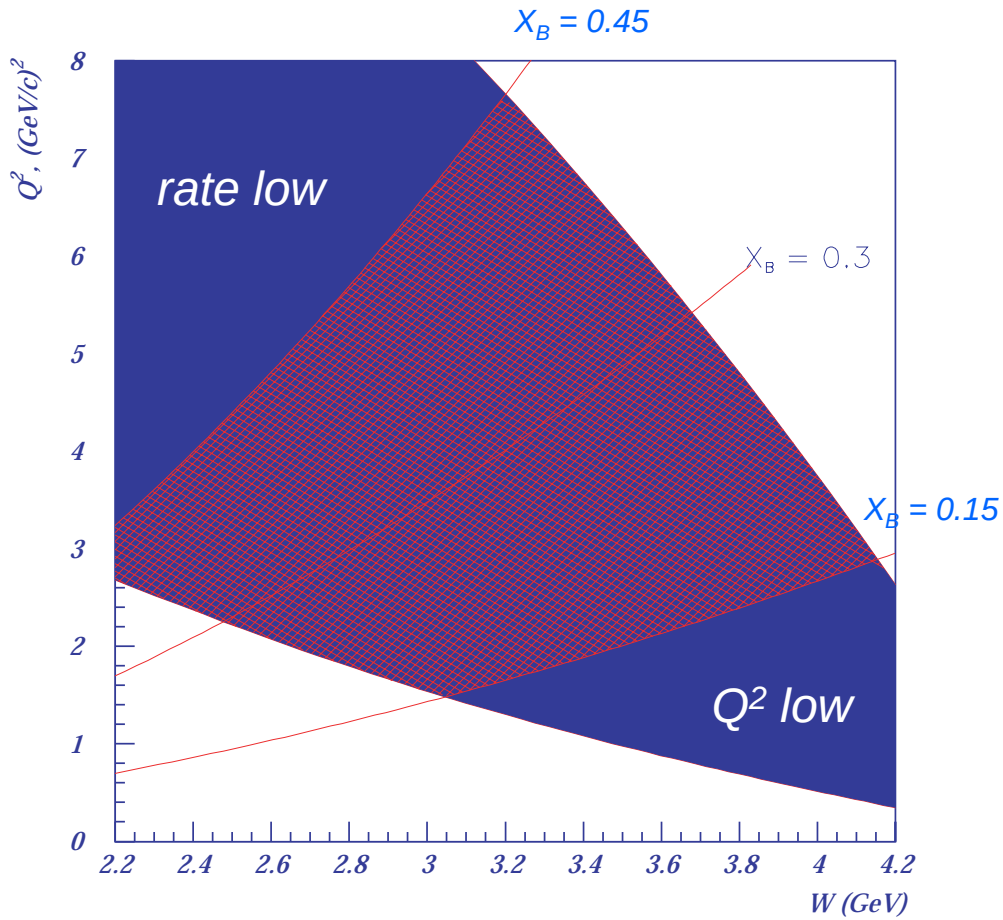


Experimental issue:

isolate small DVCS cross section

Solution for CEBAF Upgrade:

- detect all final state particles
- observe interference term DVCS-BH



CLAS acceptance for DVCS

DVCS Single-Spin Asymmetry

$Q^2 = (2.9 – 3.1)\ GeV^2$

$W = (2.65 – 2.95)\ GeV$

$-t = (0.2 – 0.4)\ GeV^2$

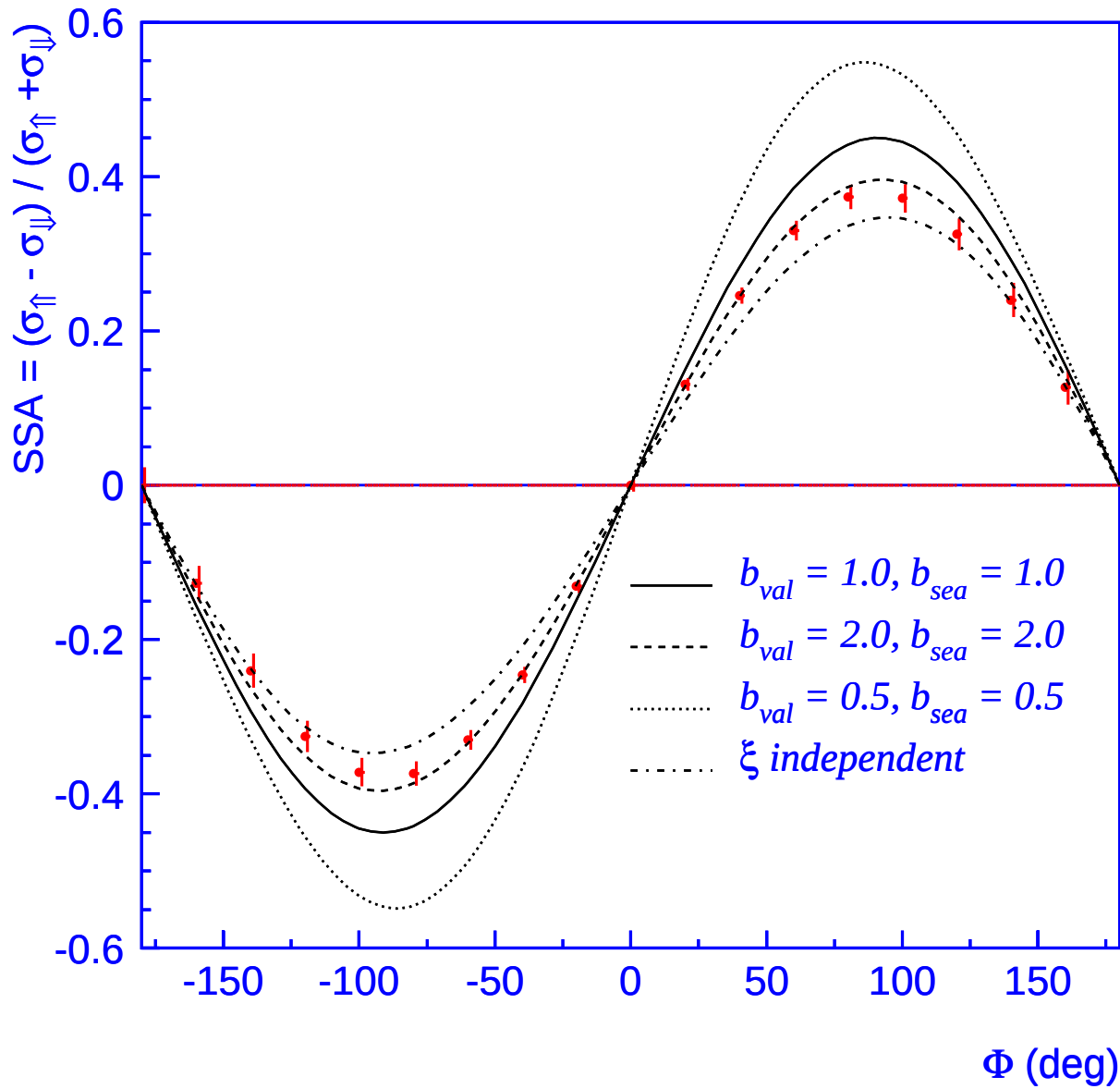
CLAS experiment

$E_0 = 11\ GeV$

$P_e = 80\%$

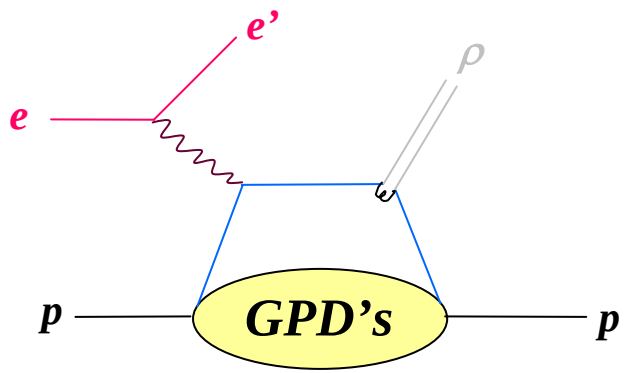
$L = 10^{35}\ cm^{-2}s^{-1}$

Run time: 500 hrs



Hard Meson Electroproduction (ρ^0)

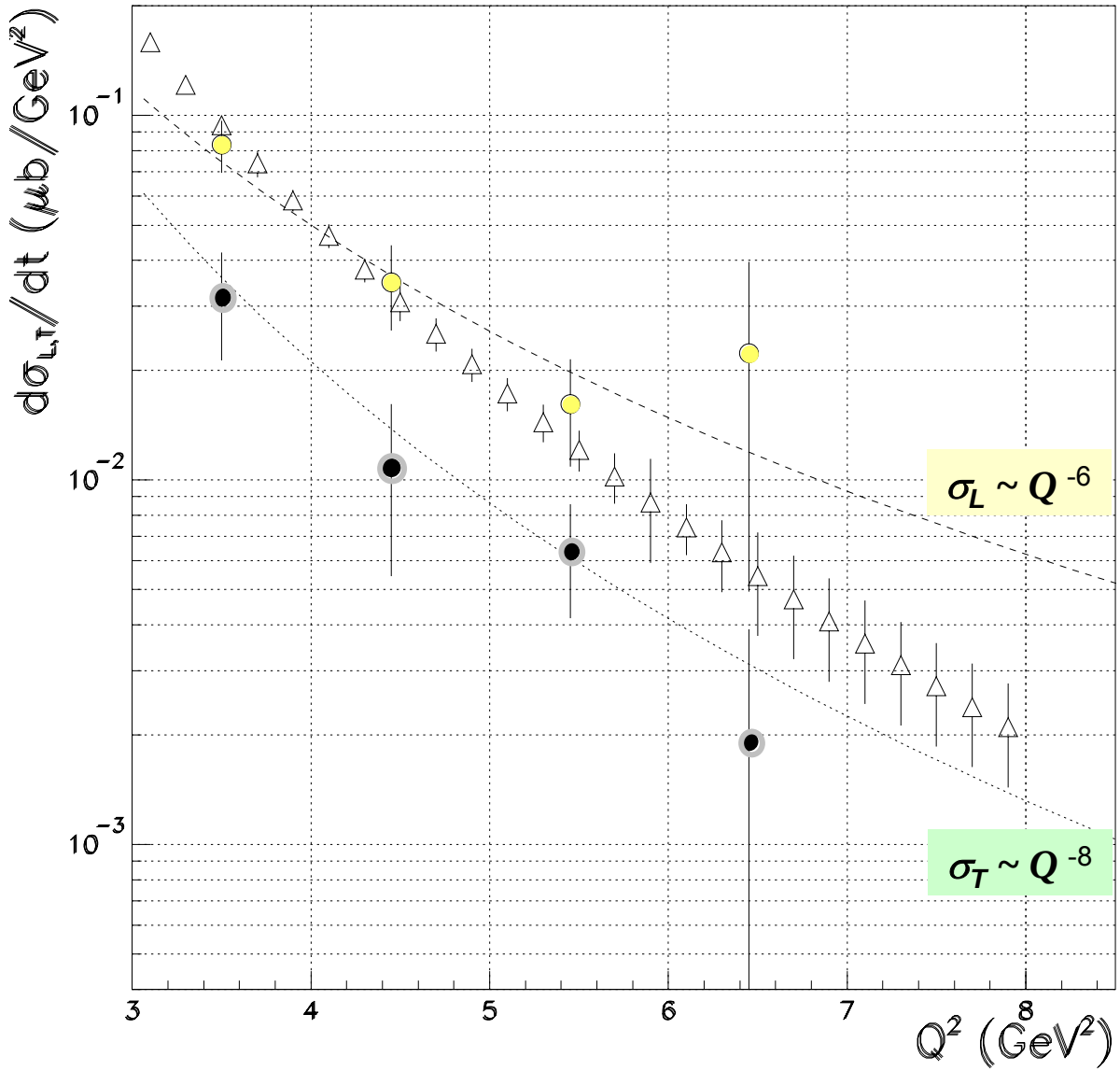
Physics issue: map out GPD's (need to isolate σ_L)



Technique: determine σ_L from $\rho \rightarrow \pi\pi$ decay angle distribution

CLAS at 11 GeV

400 hrs at L = 10^{35} $cm^{-2}s^{-1}$



Pushing Present Program To Higher Q^2

Form Factors and Other Rich Program

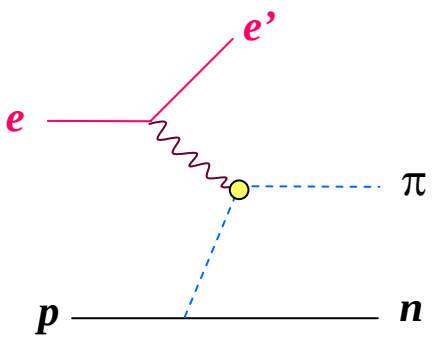
Pion Form Factor

Physics issue:

π electromagnetic structure, can be predicted in pQCD

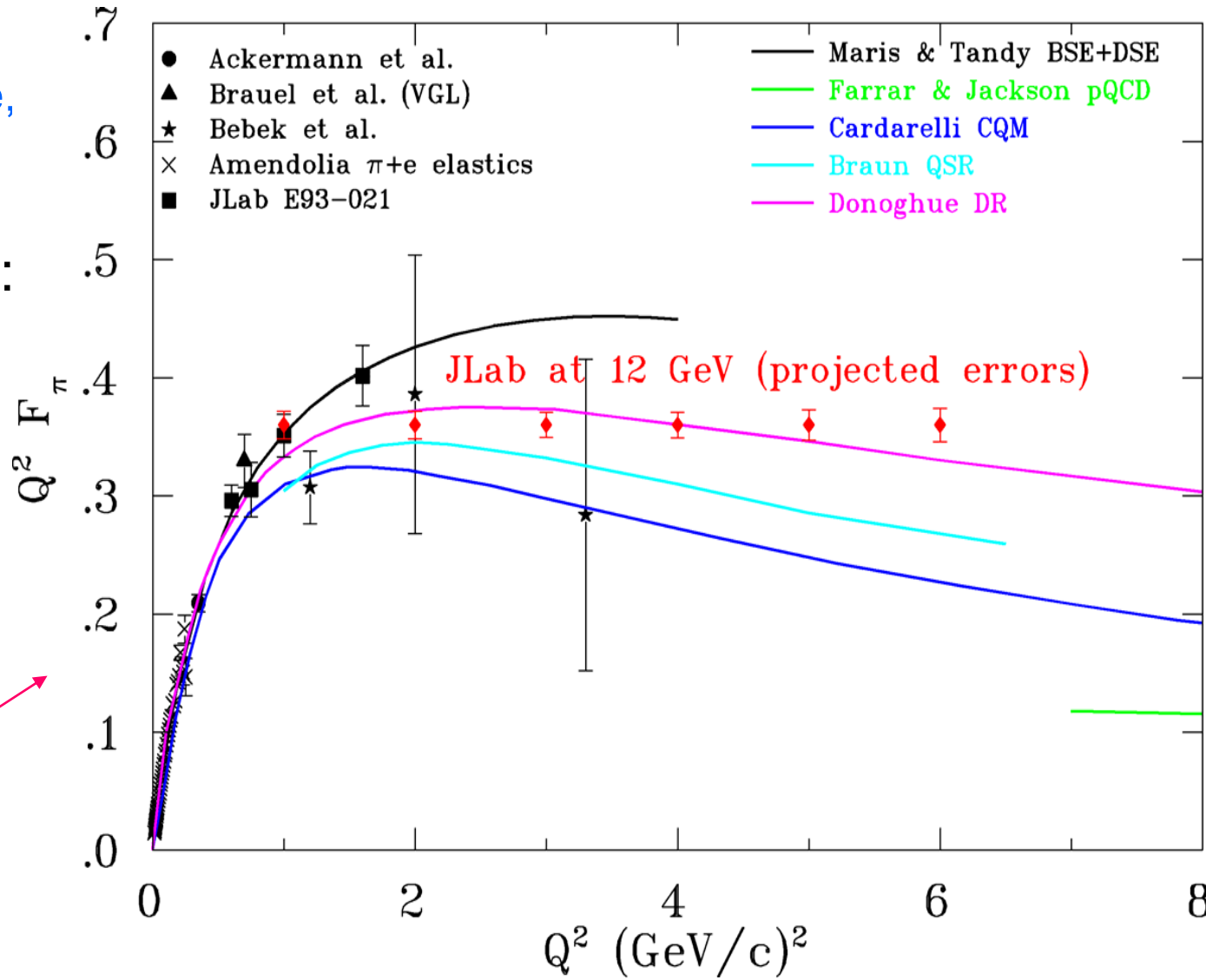
Experimental technique:

isolate $\gamma^* \pi \rightarrow \pi$ vertex



JLab Upgrade:

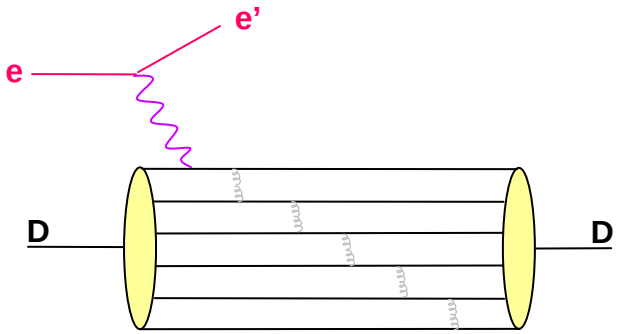
- use HMS to detect e'
- use SHMS to detect π



Deuteron Form Factor

Physics question:

at what Q^2 can the D be described as a 6q system

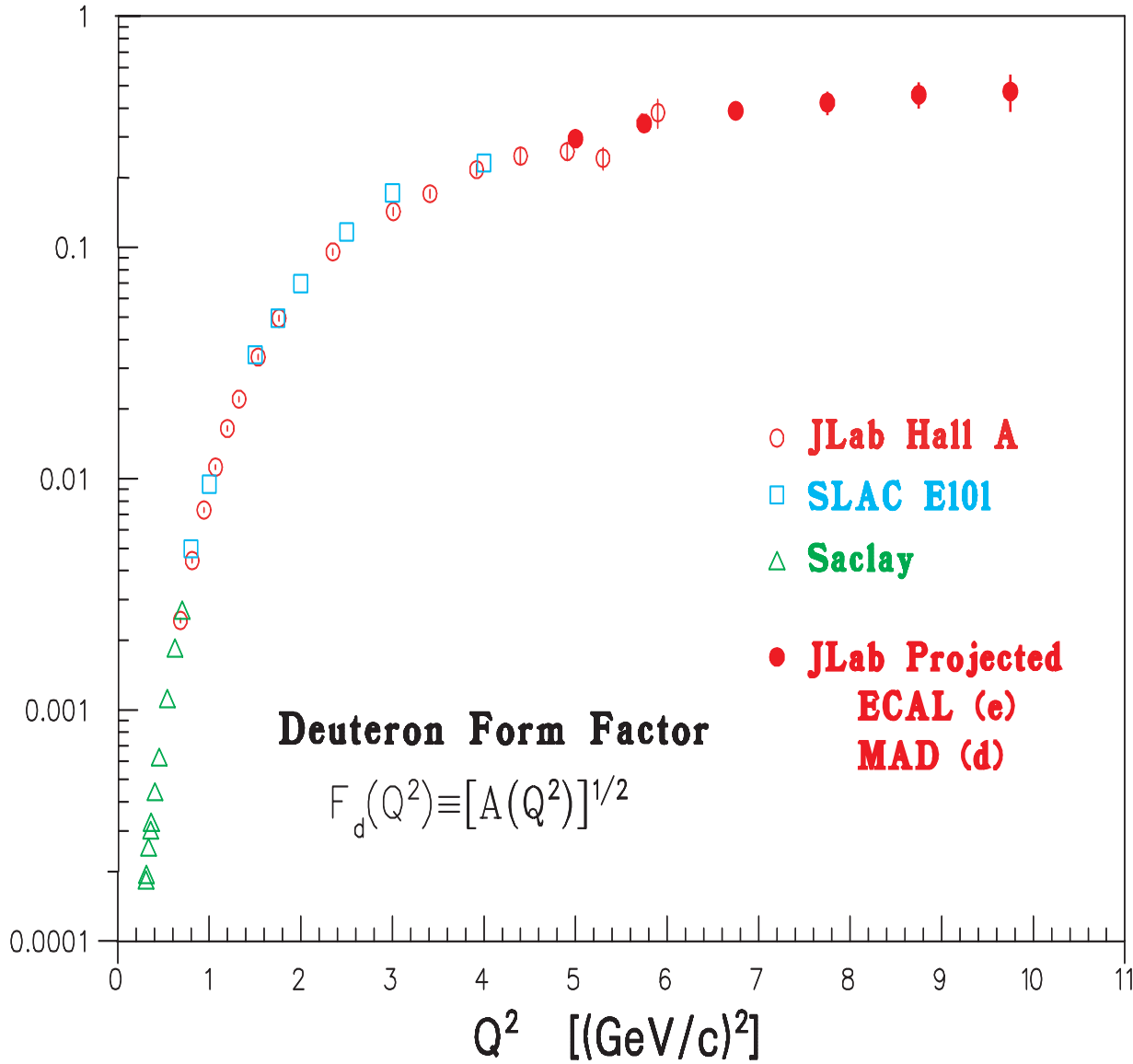


Experimental problem:

isolate small cross section eD→ eD elastic process

Solution for JLab Upgrade:

- use calorimeter for e' detection
- use MAD to detect recoil D



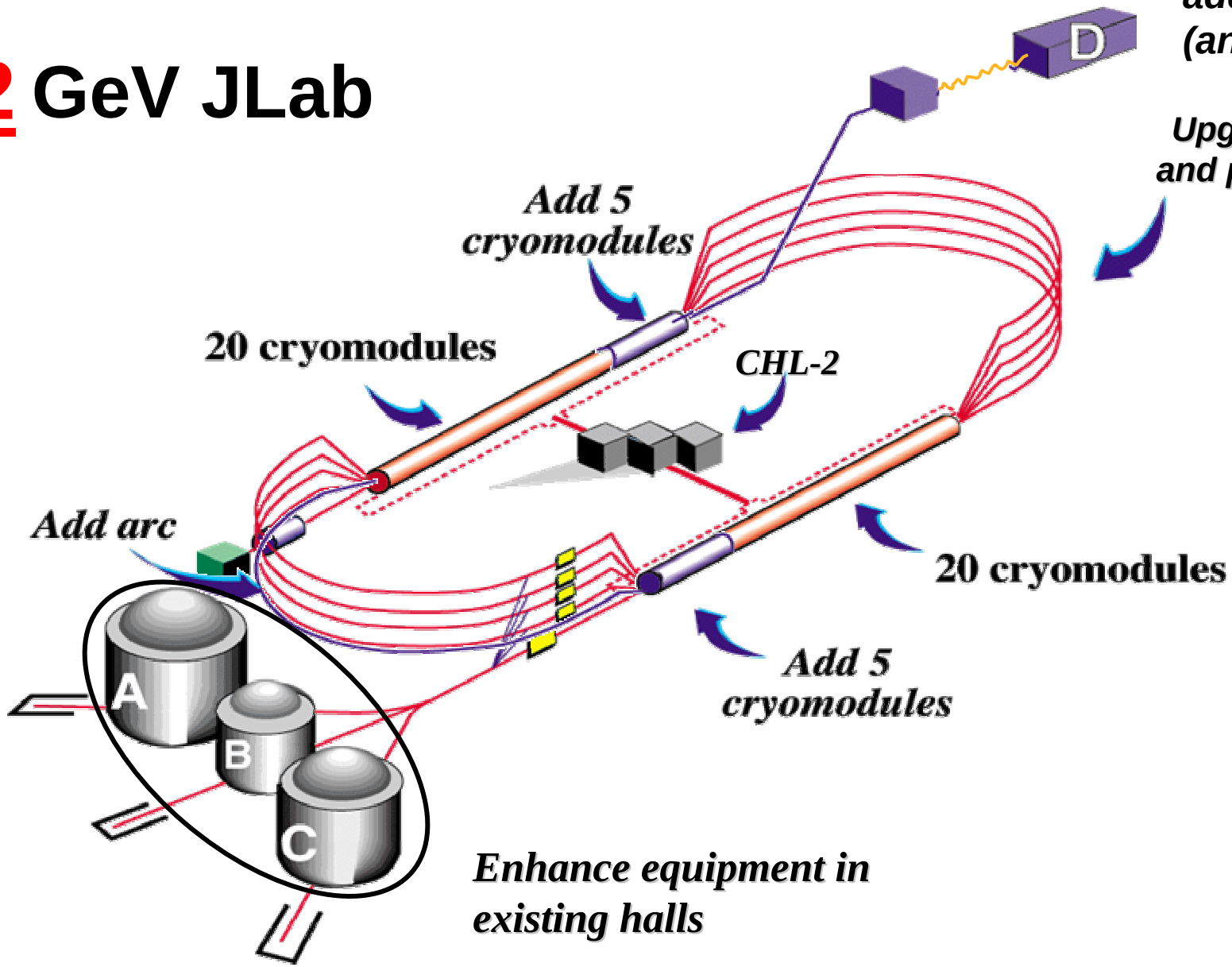
Other Physics Topics

- J/Ψ production at threshold
- semi-inclusive scattering
- color polarizabilities and higher twist effects
- quark-hadron duality, onset of scaling
- coupling constant for $\eta \to \gamma\gamma$ via Primakoff
- color transparency, short-range NN-correlations
- Standard Model test

JLab Upgrade Plan

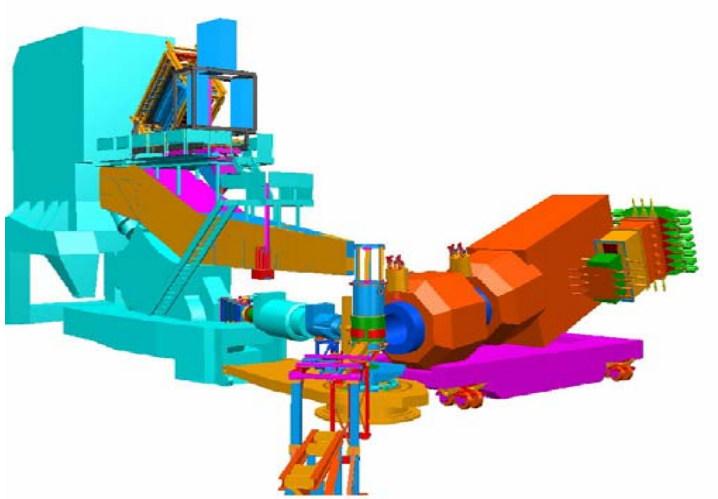
- Upgrade accelerator to 12 GeV max. energy
  - maintain 100% duty cycle
  - keep beam power constant (1MW) ⟶ max. current 80μA
- Build a new hall for meson spectroscopy (Hall D)
  - polarized tagged photon beam (coherent bremsstrahlung)
  - large acceptance detector for real photons only
- Upgrade existing 3 halls for higher beam energy

12 GeV JLab


add Hall D
(and beam line)
D
Upgrade magnets
and power supplies
Add 5
cryomodules
20 cryomodules
CHL-2
Add arc
20 cryomodules
Add 5
cryomodules
A
B
C
Enhance equipment in
existing halls

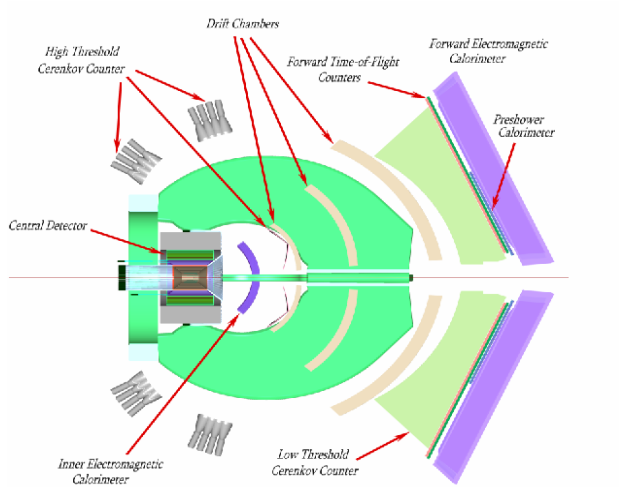
Combined With Enhanced and/or Complementary Equipment in Halls A, B, & C and a New Hall D

A



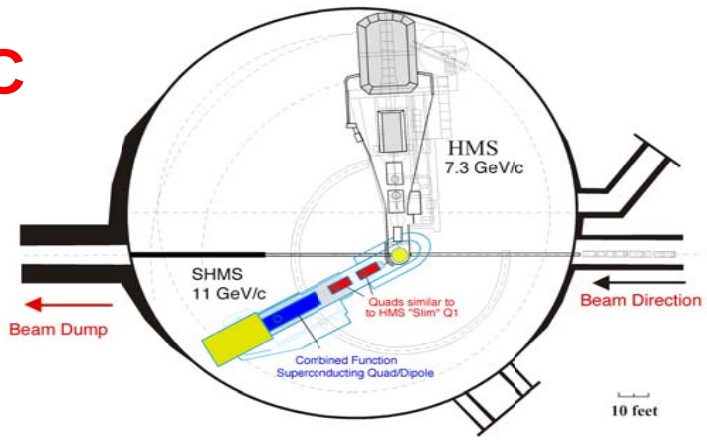
Medium Acceptance Detector (MAD) at high luminosity and intermediate angles

B



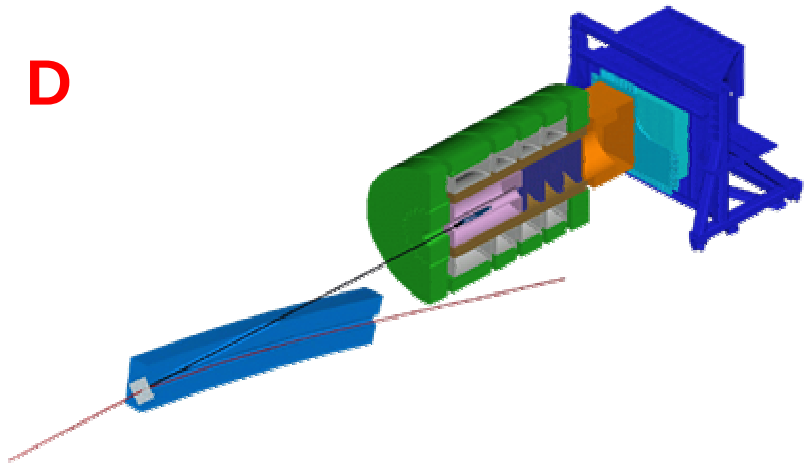
CLAS upgraded to higher (10^{35}) luminosity and coverage

C



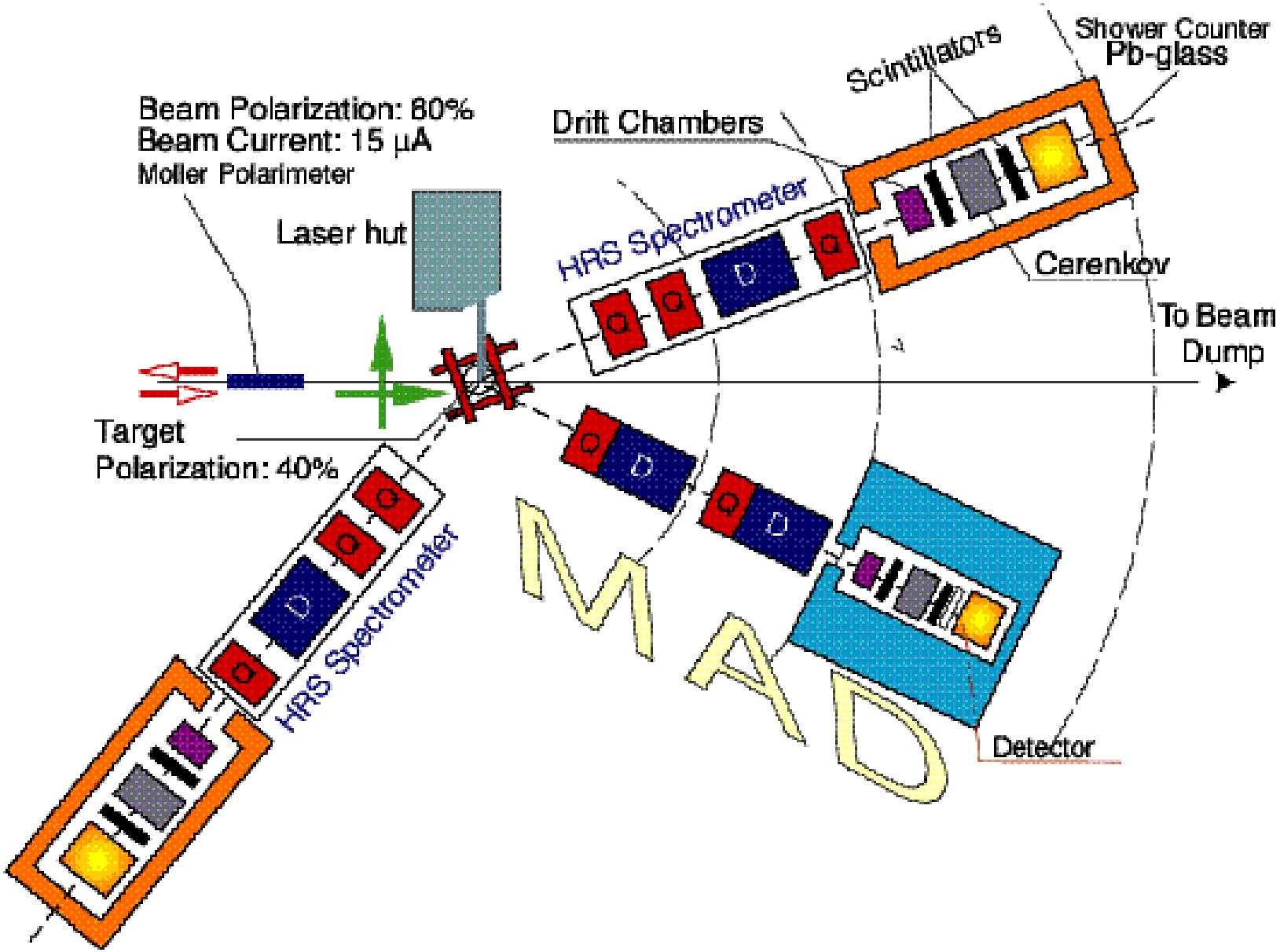
Super High Momentum Spectrometer (SHMS) at high luminosity and forward angles

D

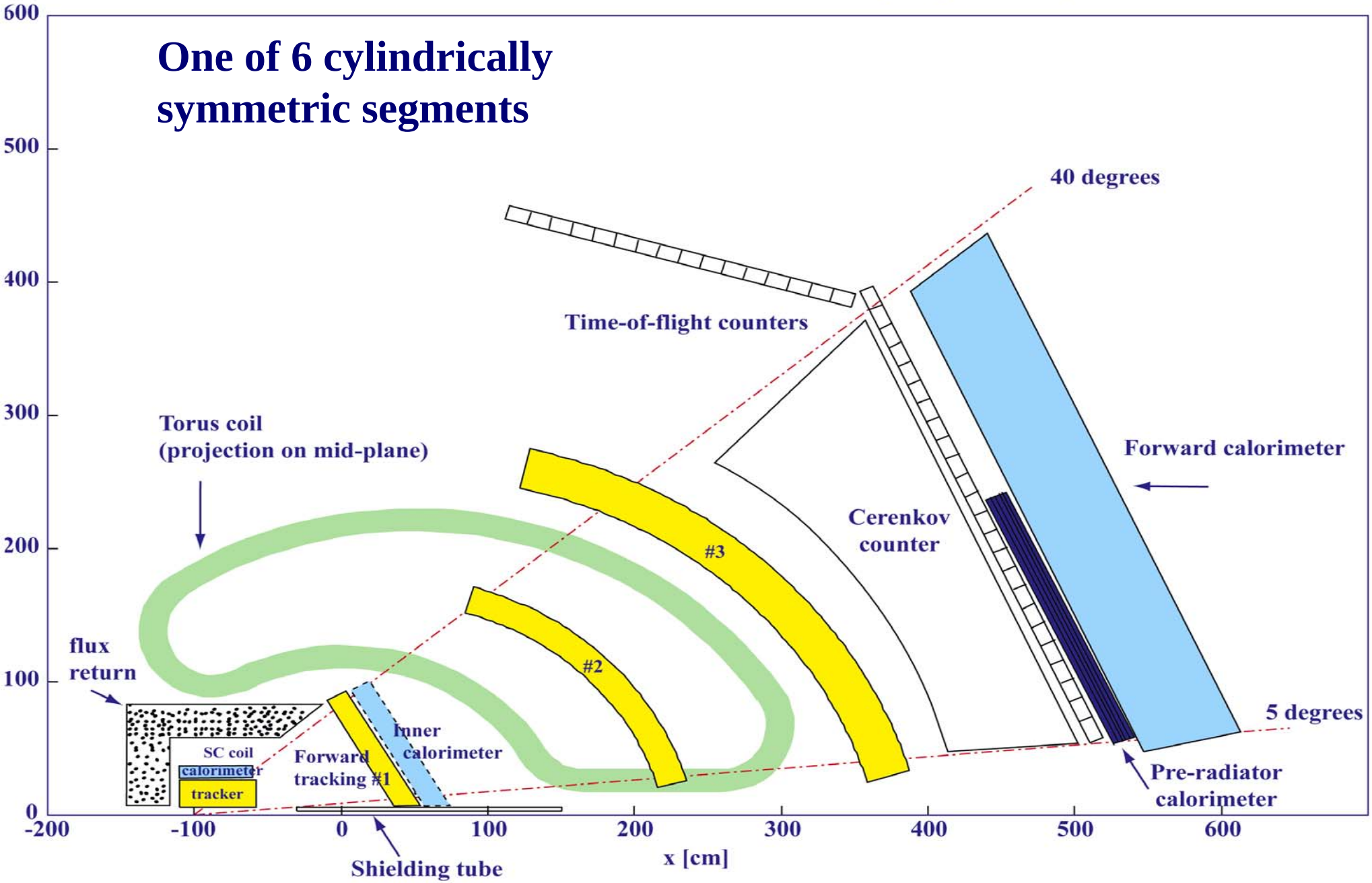


9 GeV tagged polarized photons and a 4π hermetic detector

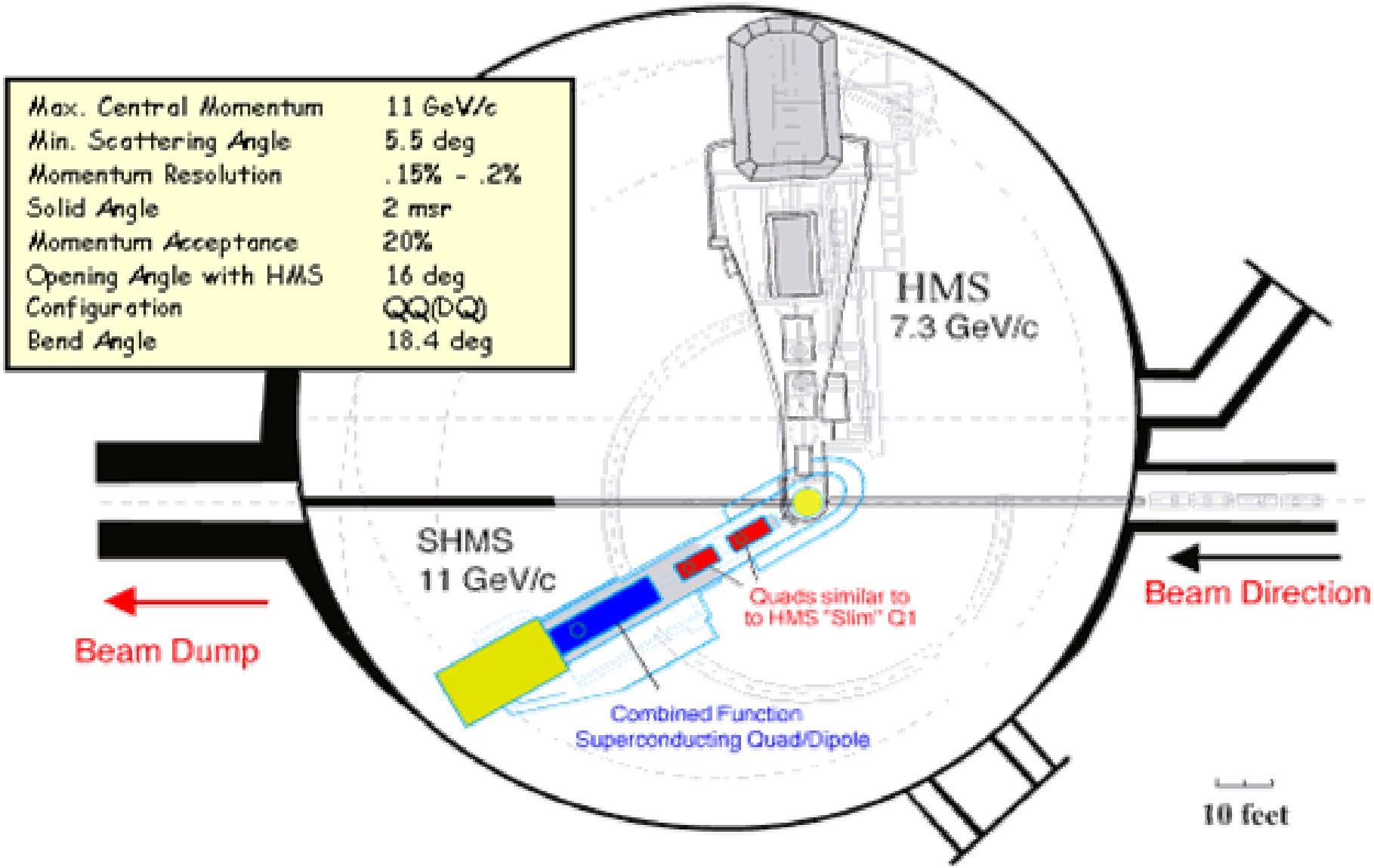
Hall A Floor Plan with MAD Spectrometer



CLAS UPGRADE CONCEPT (Top View)

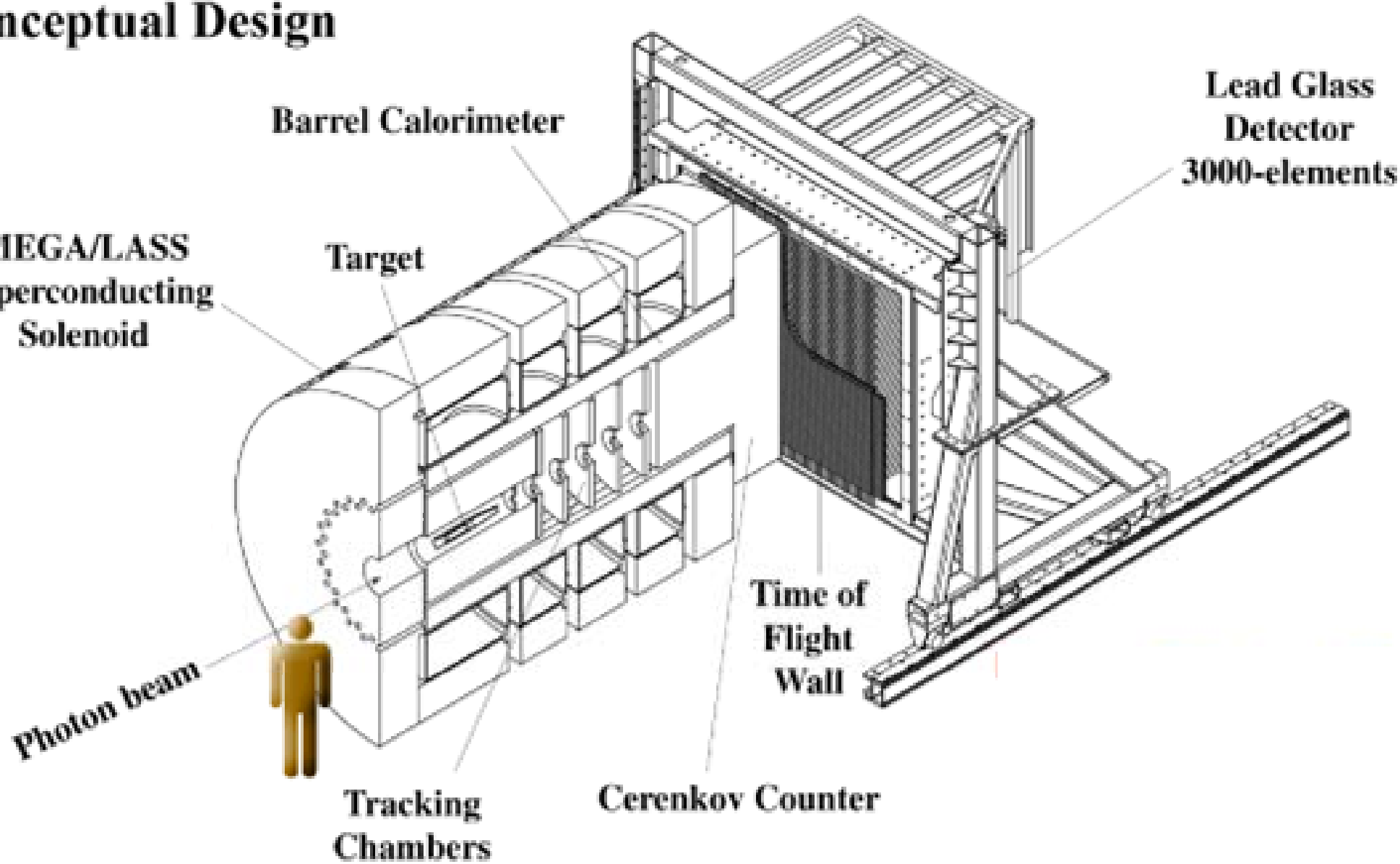


SHMS - HMS Spectrometers After Upgrade



The Hall D Detector

The Hall D Spectrometer Conceptual Design



12 GeV Upgrade Project Status

- Developed by JLab User Community in collaboration with JLab
  - pCDR ready with extensive physics experiment and equipment designs
  - http://www.jlab.org/gev.html
- Nuclear Science Advisory Committee (NSAC)
  - plan presented during last 5-year Long Range Plan
  - recommended by NSAC for new construction
- Department of Energy 20-year Facility Plan
  - JLab upgrade named near-term priority
- Construction
  - construction start expected in FY2007
  - 3 year construction project

Long-Term Future @ JLab

Study underway for an electron-light ion collider at JLab to investigate

- inclusive and semi-inclusive DIS
- deep exclusive reactions (GPD's)
- **fully categorize nucleon structure in terms of quarks and gluons**
- **how properties of quarks and gluons change when in a nucleus**
- **how nucleons were created in the early phases of the universe**

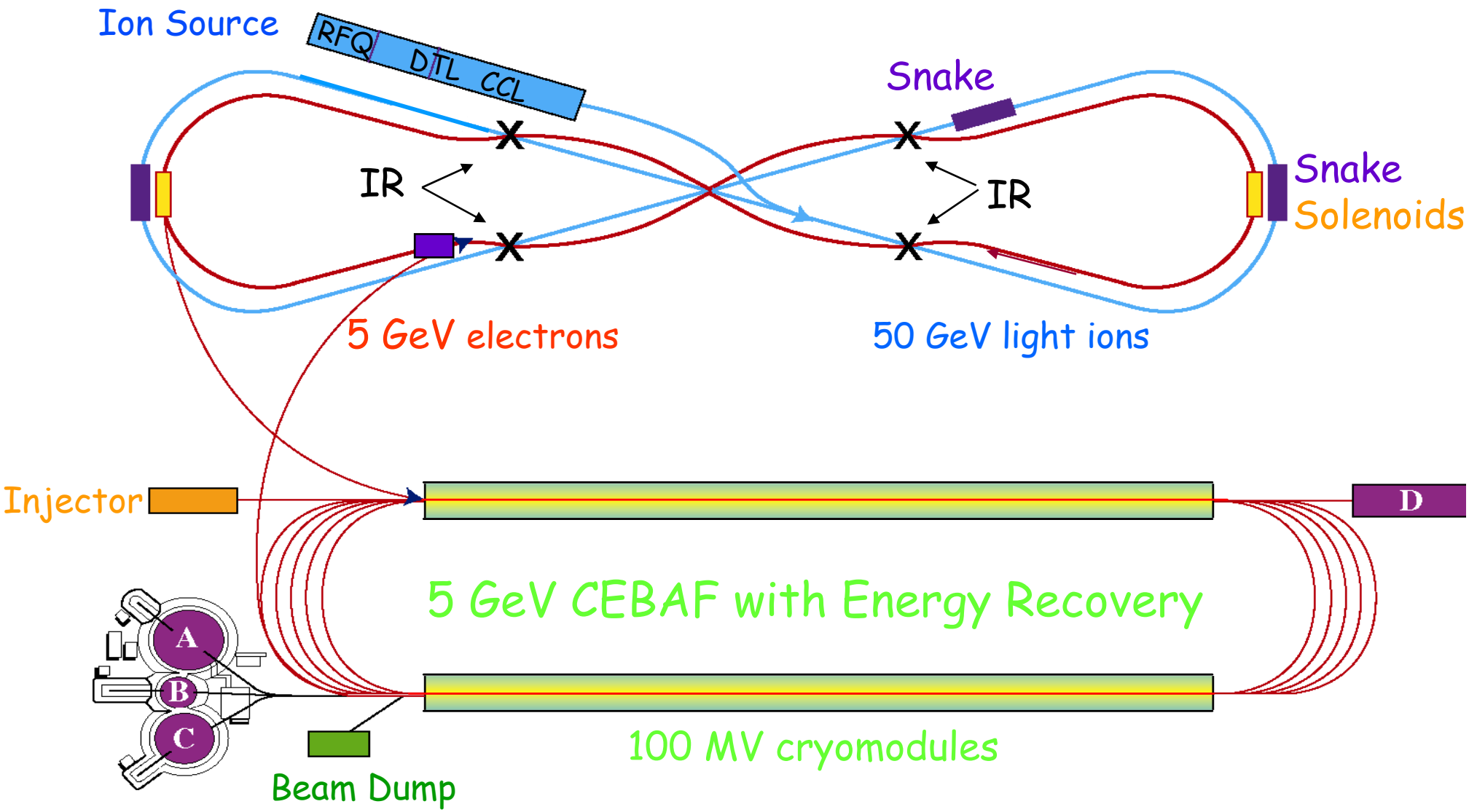
Parameters

electrons	3 - 7 GeV
ions (p, d, ^{3}He)	30-150 GeV
luminosity	$\leq 6 \times 10^{34}$ cm^{-2} s^{-1}

Design maintains fixed target capability with

- 25 GeV external beam
- luminosity ~10^{38} cm^{-2} s^{-1}

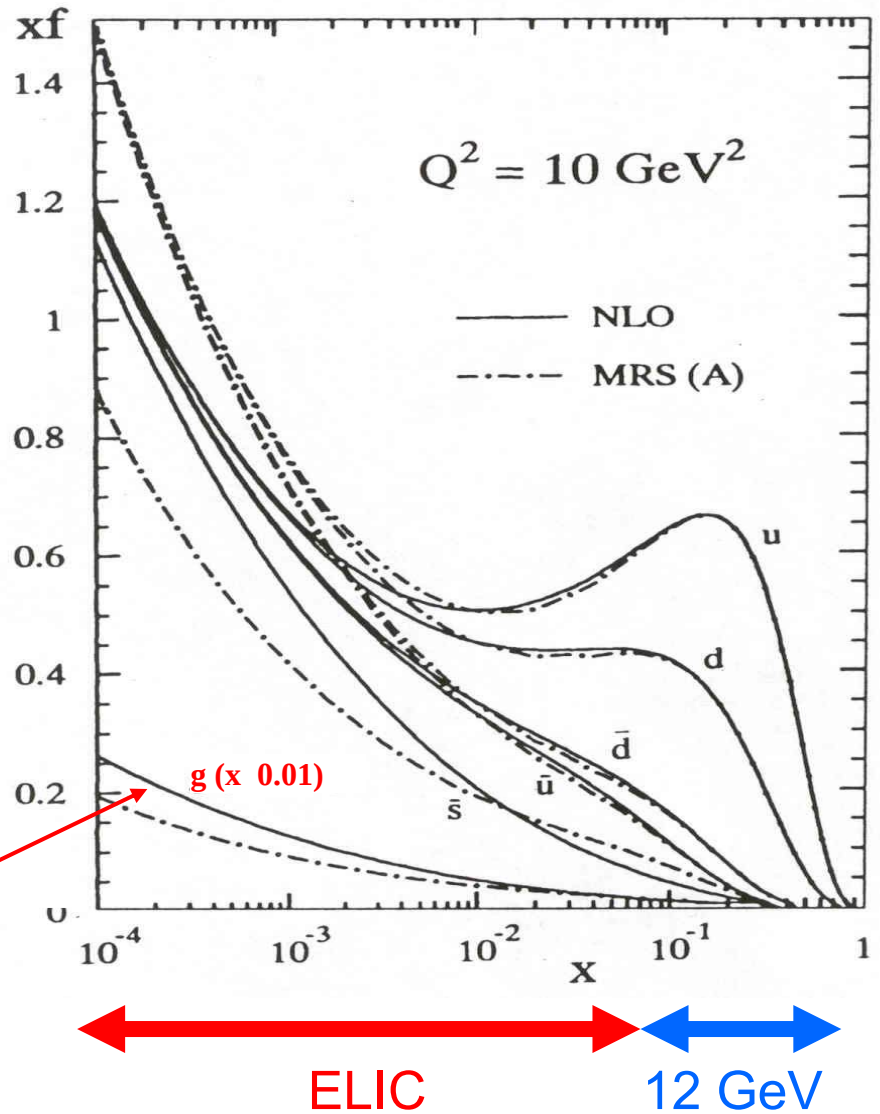
Electron-Light Ion Collider Layout



CEBAF II/ELIC Upgrade - Science

Science addressed by the second Upgrade:

- How do quarks and gluons provide the binding and spin of the nucleons?
- How do quarks and gluons evolve into hadrons?
- How does nuclear binding originate from quarks and gluons?



Summary

- JLab 12 GeV upgrade focused on understanding the quark substructure of mesons and nucleons
- experimental program requires
  - new and upgraded equipment
  - luminosities between 10^{35} and 10^{39} $cm^{-2}s^{-1}$
- upgrade is a cost-effective extension
- strong community support and endorsement
- construction start expected in 2007
- long term: collider + high $\mathbf{L}$ fixed target facility