The JLab 12 GeV Energy Upgrade of CEBAF for QCD and Hadronic Physics

Larry Cardman

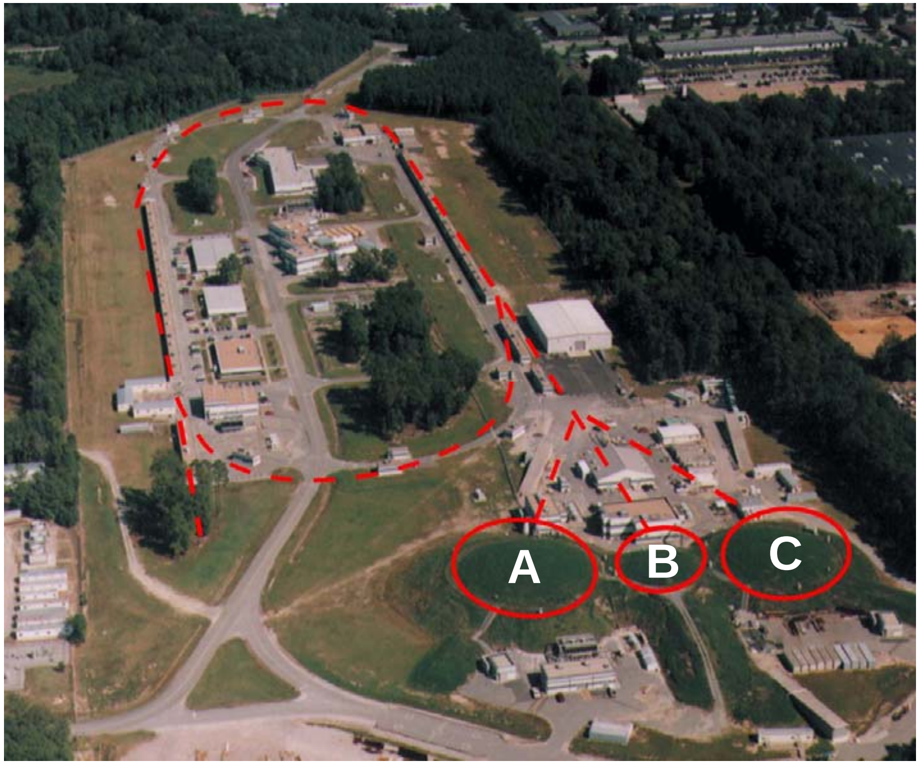
(for Leigh Harwood and the 12 GeV Project Team)

PAC07

June 25, 2007

Jefferson Lab Today

2000 member International User Community exploring the quark-gluon structure of matter



A recirculating superconducting linac provides 100% duty factor polarized beams of remarkable quality with energies up to 6 GeV

CEBAF's innovative design allows delivery of beam with independent currents and independent (but correlated) energies to three experimental halls simultaneously

Each of the three halls offers complementary experimental capabilities and allows for large equipment installations to extend scientific reach

JLab's Scientific Mission

How are the hadrons constructed from the quarks and gluons of QCD?

What is the QCD basis for the nucleon-nucleon force?

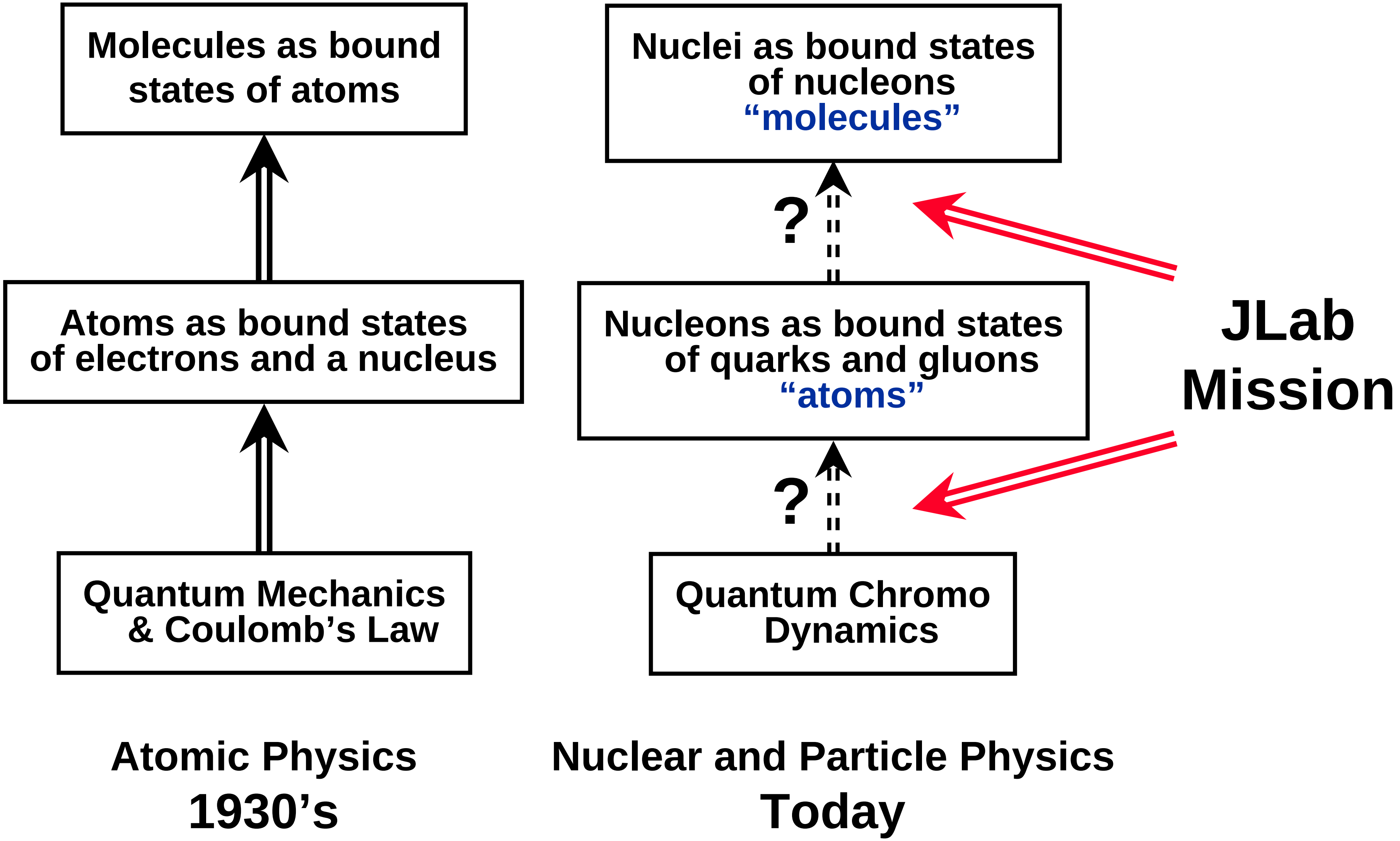
Where are the limits of our understanding of nuclear structure?

- To what precision can we describe nuclei?
- To what distance scale can we describe nuclei?
- Where does the transition from the nucleon-meson to the QCD description occur?

To make progress toward these research goals we must address critical issues in "strong QCD":

- What is the mechanism of confinement?
- Where does the dynamics of the q-q interaction make a transition from the strong (confinement) to the perturbative (QED-like) QCD regime?
- How does Chiral symmetry breaking occur?

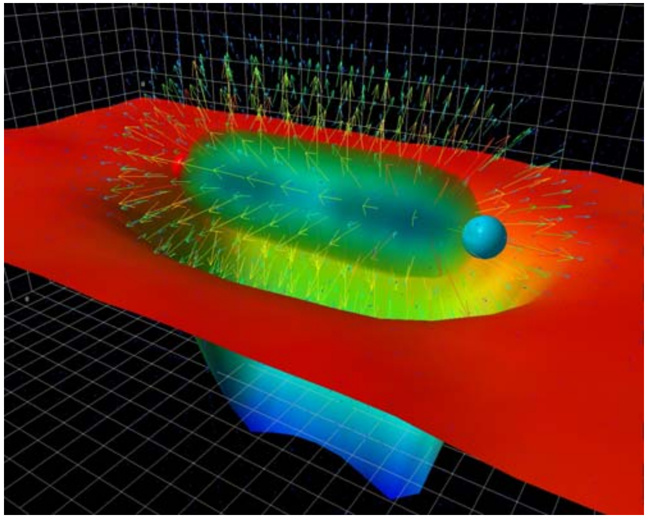
Atomic Physics versus Quark Physics

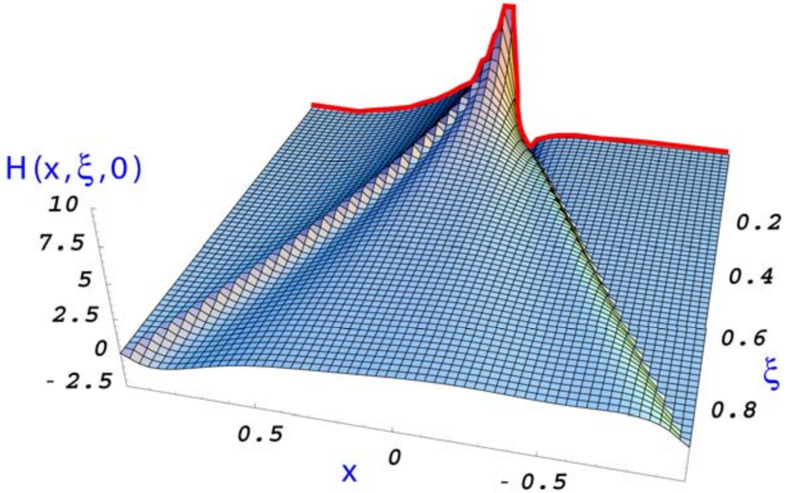


What is the Science Motivating the Upgrade?

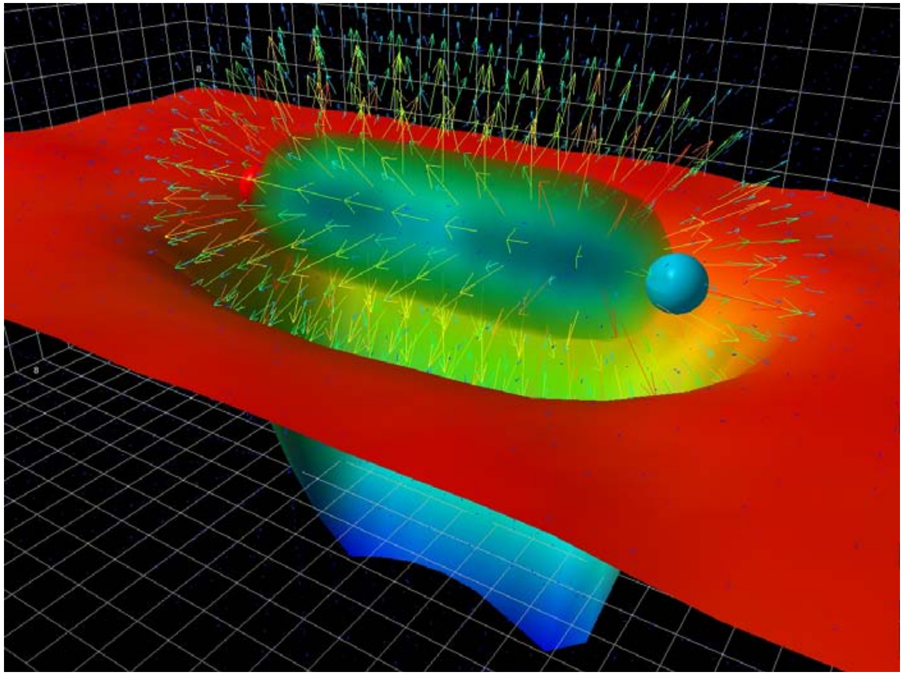
The 12 GeV Upgrade Will Support Breakthrough Programs in Four Areas:

- **The experimental study of the confinement of quarks – one of the outstanding questions of the 21st century physics (Hybrid Meson Program)**
- **Dramatic improvements in our knowledge of the fundamental quark-gluon structure of the nuclear building blocks (GPDs and Valence PDFs)**
- **Further exploration of the limits of our understanding of nuclei in terms of nucleons and the *N-N* force**
- **Precision experiments with sensitivity to TeV scale physics beyond the Standard Model**
- **And other science we can't foresee**





Gluonic Excitations and the Origin of Confinement



QCD predicts a rich spectrum of as yet to be discovered gluonic excitations - whose experimental verification is crucial for our understanding of QCD in the confinement regime.

With the upgraded CEBAF, a linearly polarized photon beam, and the GlueX detector, Jefferson Lab will be uniquely poised to:

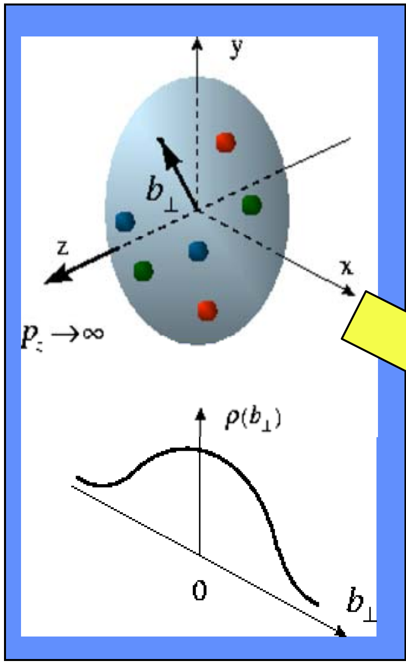
- **- discover these states (hybrid mesons),**
- **- map out their spectrum, and**
- **- measure their properties**

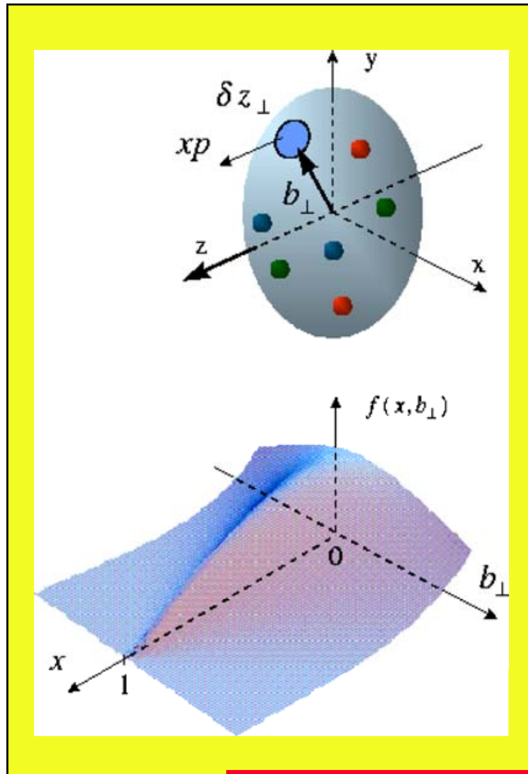
This program:

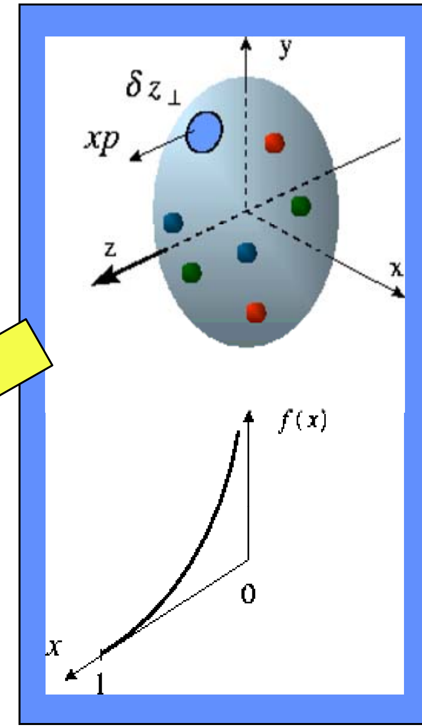
- **Set the maximum beam energy**
- **Drove the need for a 4th Hall**

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

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







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

DES
Correlated q
In transverse
and longitudi
space

This program:
- **Drove spectrometer requirements for CLAS12 & the SHMS**
- **Sets beam power goal**

NSAC Long Range Plan DOE (4/07)

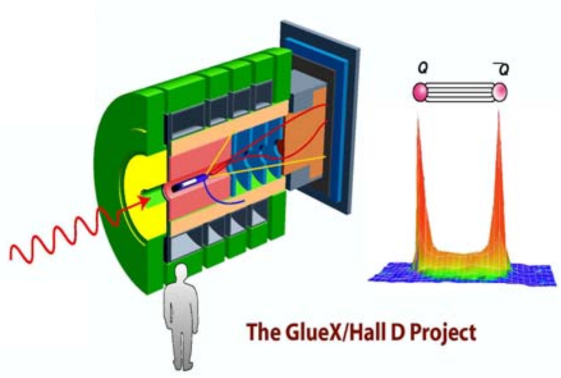
Recommendation #1: ***We recommend the completion of the 12 GeV Upgrade at Jefferson Lab. The Upgrade will enable new insights into the structure of the nucleon, the transition between the hadronic and quark/gluon descriptions of nuclei, and the nature of confinement.***

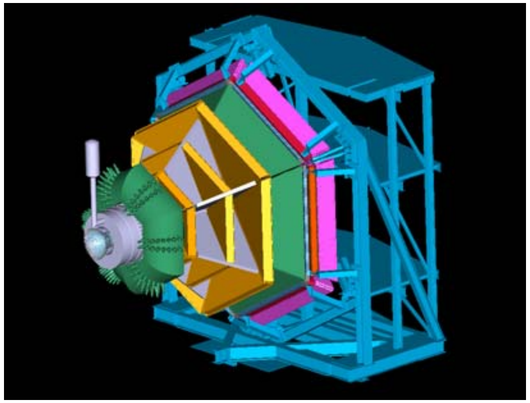
A fundamental challenge for modern nuclear physics is to understand the structure and interactions of nucleons and nuclei in terms of quantum chromodynamics. Jefferson Lab's unique electron microscope has given the US leadership in addressing this challenge. Its first decade of research has already provided key insights into the structure of nucleons and the dynamics of finite nuclei.

Doubling the energy of this microscope will enable three-dimensional imaging of the nucleon, revealing hidden aspects of its internal dynamics. It will complete our understanding of the transition between the hadronic and quark/gluon descriptions of nuclei, and test definitively the existence of exotic hadrons, long-predicted by QCD as arising from quark confinement. Through the use of parity violation, it will provide low-energy probes of physics beyond the Standard Model complementing anticipated measurements at the highest accessible energy scales.

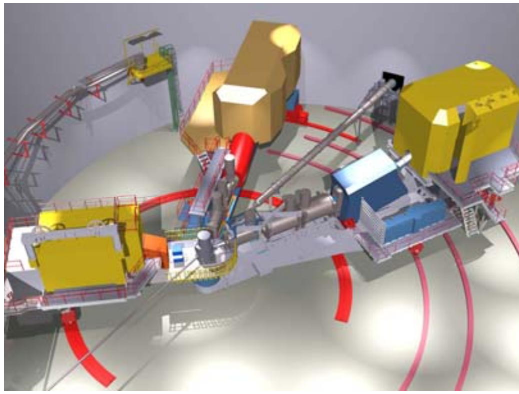
Overview of 12 GeV Physics Instrumentation

GLUEx (Hall D): **exploring origin of confinement by studying hybrid mesons**

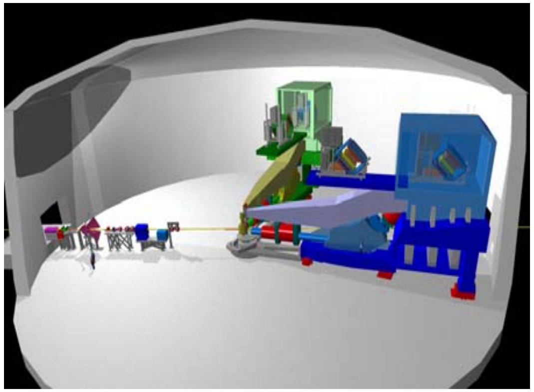




CLAS12 (Hall B): **understanding nucleon structure via generalized parton distributions**



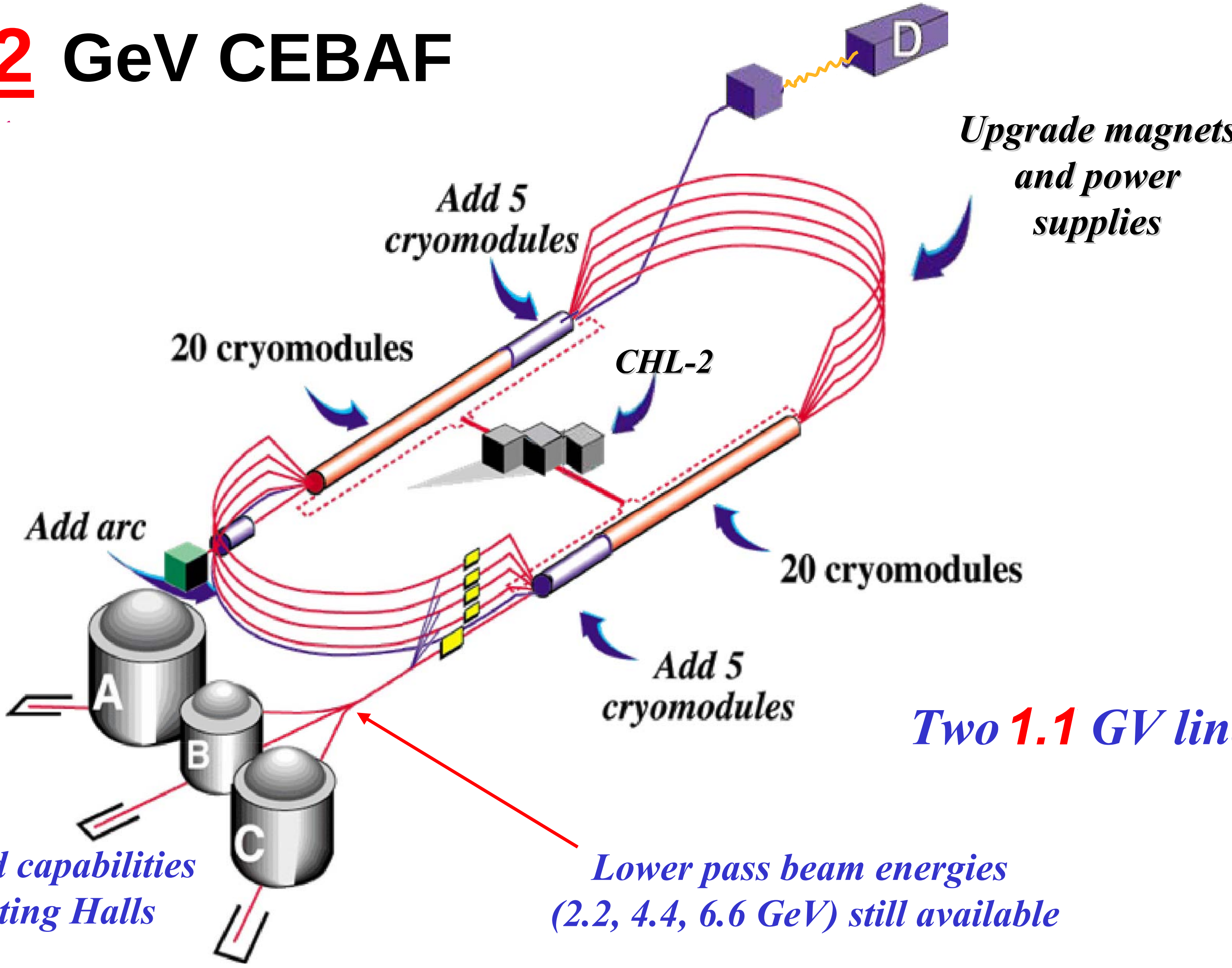
SHMS (Hall C): **precision determination of valence quark properties in nucleons and nuclei**



Hall A: **short range correlations, form factors, hypernuclear physics, & future new experiments**

How Will CEBAF Be Upgraded to Provide the Beams Needed ?

12 GeV CEBAF



Two 1.1 GV linacs

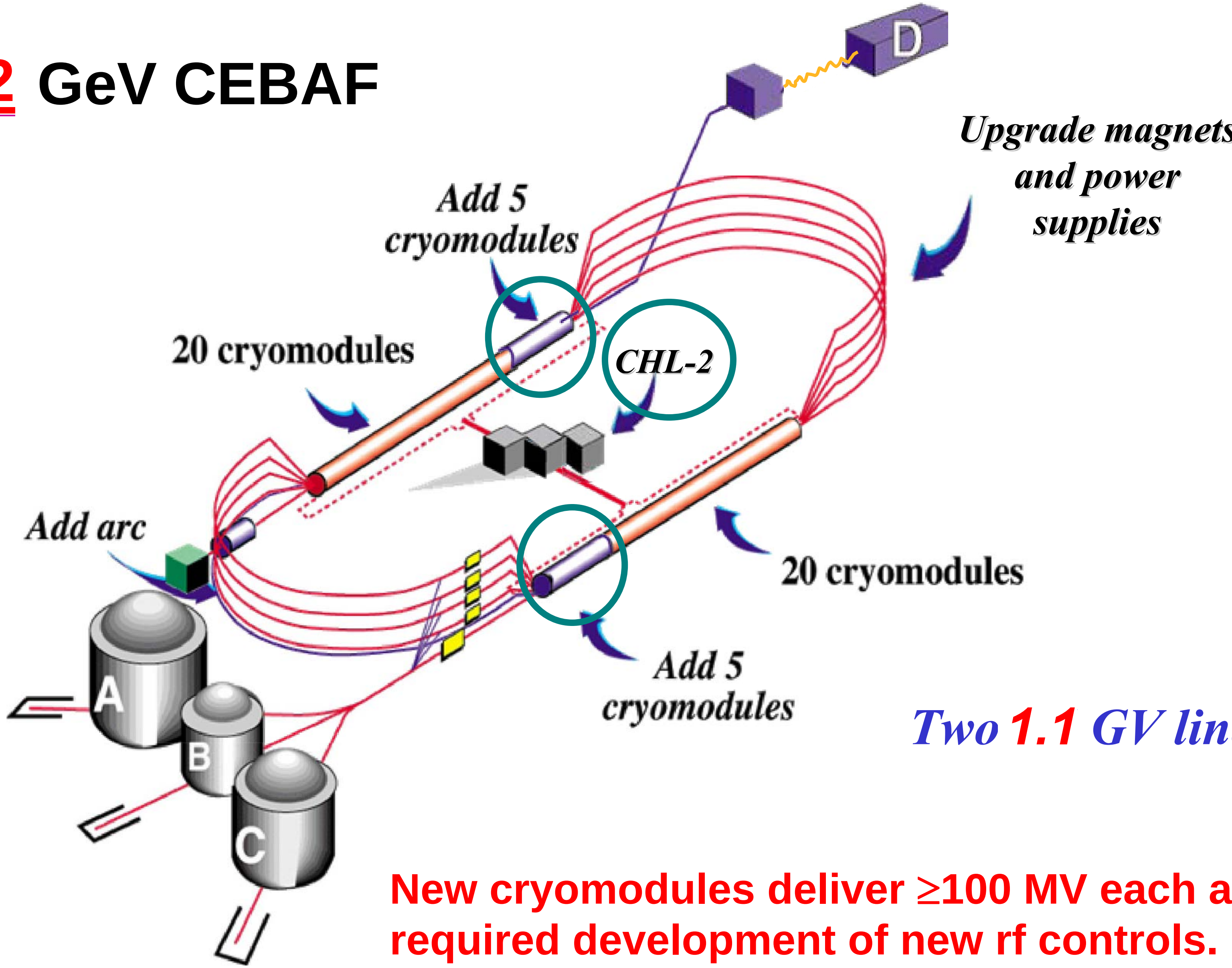
Enhanced capabilities in existing Halls

Lower pass beam energies (2.2, 4.4, 6.6 GeV) still available

High-level Parameters

	Now	Upgrade
ACCELERATOR:		
Beam energy	6 GeV	12 GeV
Voltage of each linac	0.6 GV	1.1 GV
Number of recirculations	5	5 ½
Beam power (total program)	1 MW	1 MW
Beam current (hybrid mesons)	-	5 μA
Emittance	1 nm-rad	7 nm-rad
Energy spread	0.01%	0.02%
CRYOPLANT	4.5 kW	9 kW
EXPERIMENTAL HALLS	3	4

12 GeV CEBAF



Two **1.1** *GV linacs*

New cryomodules deliver ≥100 MV each and required development of new rf controls.

Upgraded CHL delivers 2x cooling power

Cryogenics

Existing plant is at full capacity with 6 GeV configuration.

⇒ **We must build a new plant.**

We already have a critical component, a 2K cold-box that is a spare for the present refrigerator

⇒ **Adding a second 4K system will provide an additional 4.6 kW at 2K at relatively low cost**

This cost-effective solution, defines the boundary conditions for the cryogenic properties of the new cryomodules:

- **Each of the two plants must supply:**
  - **One existing, 20 cryomodule linac**
  - **Five New 100 MV cryomodules**
  - **Reasonable headroom**
- **Thus the capacity available**
  - **300 W @ 2K**
  - **300 W @ 50K**

“Ganni cycle” adopted for CHL

- **Reduced capital costs**
- **Reduces operating costs by 30%**

Cryomodule Voltage and Cavity Gradient

What is needed?

Present: 6 GeV / 5 passes = 1.2 GeV / pass = 0.6 GeV / linac

12 GeV: 12 GeV / 5.5 passes = 2.2 GeV / pass = 1.1 GeV / linac

$\Rightarrow$ Need to add 0.5 GV / linac

Adding 0.5 GV / linac

- There are 5 empty zones at the end of each linac
- One 100 MV cryomodule per zone is the obvious solution

"100" MV cryomodules

- Exact requirement is 98 MV (average for each linac)
- Add ~10% for operational contingency $\Rightarrow$ 108 MV / cryomodule
- 8 cavities/cryomodule } 5.6m, the current cryomodule length
- 7 $\lambda/2$ cells per cavity }
- 108 MV $\div$ 5.6 m = 19.2 MV / m (Original CEBAF Spec. was 5 MV/m We've progressed significantly)
- Cryo Capacity set requirement for Q_0

SRF Performance

<u>1st cryomodule intended to reach 100 MV (reported at PAC05):</u>

Thermal design of the cavity endgroups limited performance

Redesign needed (and now completed)

Integrated cryomodule performance with the new design was tested in January, 2007 with a “1/4 cryomodule”

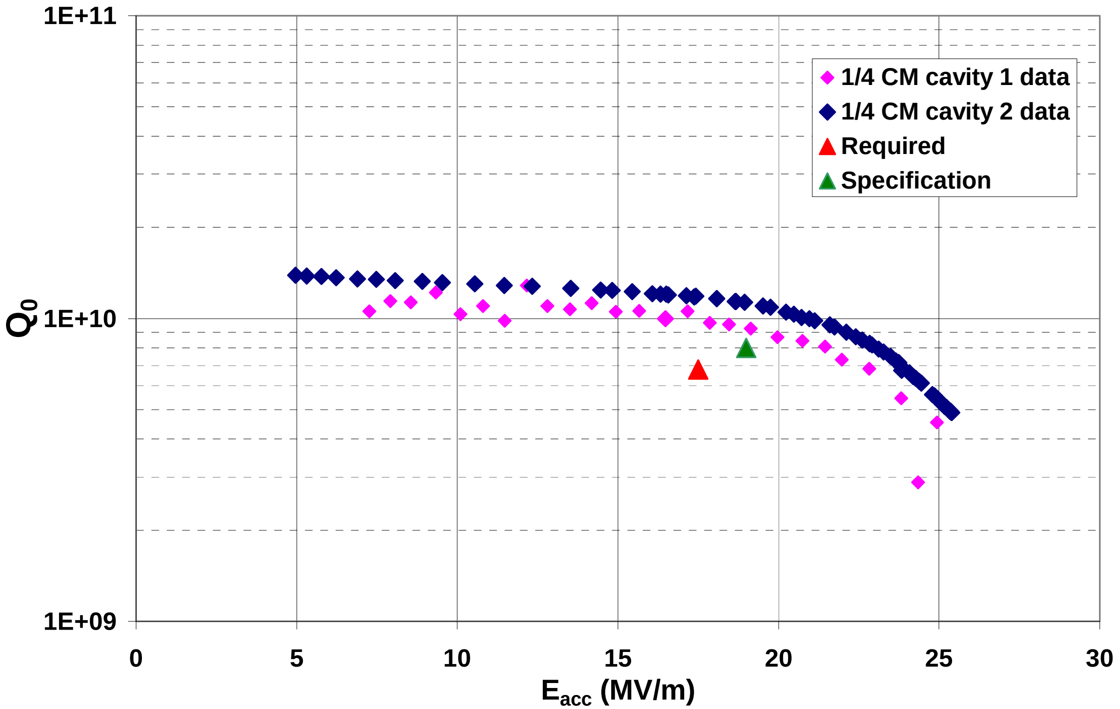
<u>Cavity performance</u>

Cavities achieved:

- **≥19.2 MV/m at $Q_0 \geq 8 \times 10^9$ in cw mode**
- **24 MV/m before quench**

Field emission was not an issue

Tuners, windows, etc met or surpassed design requirements



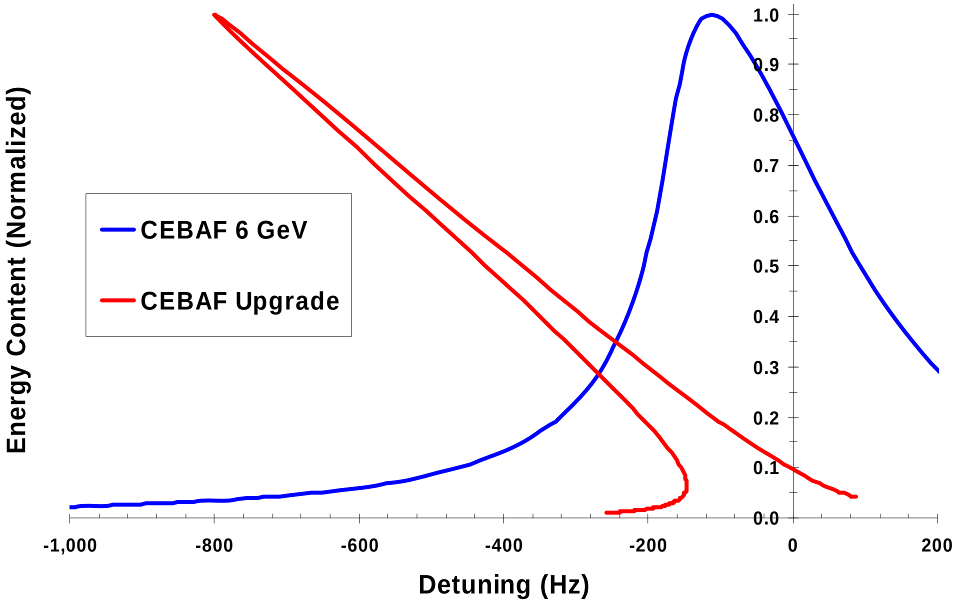
RF control

High-level performance requirements are the same as 6 GeV

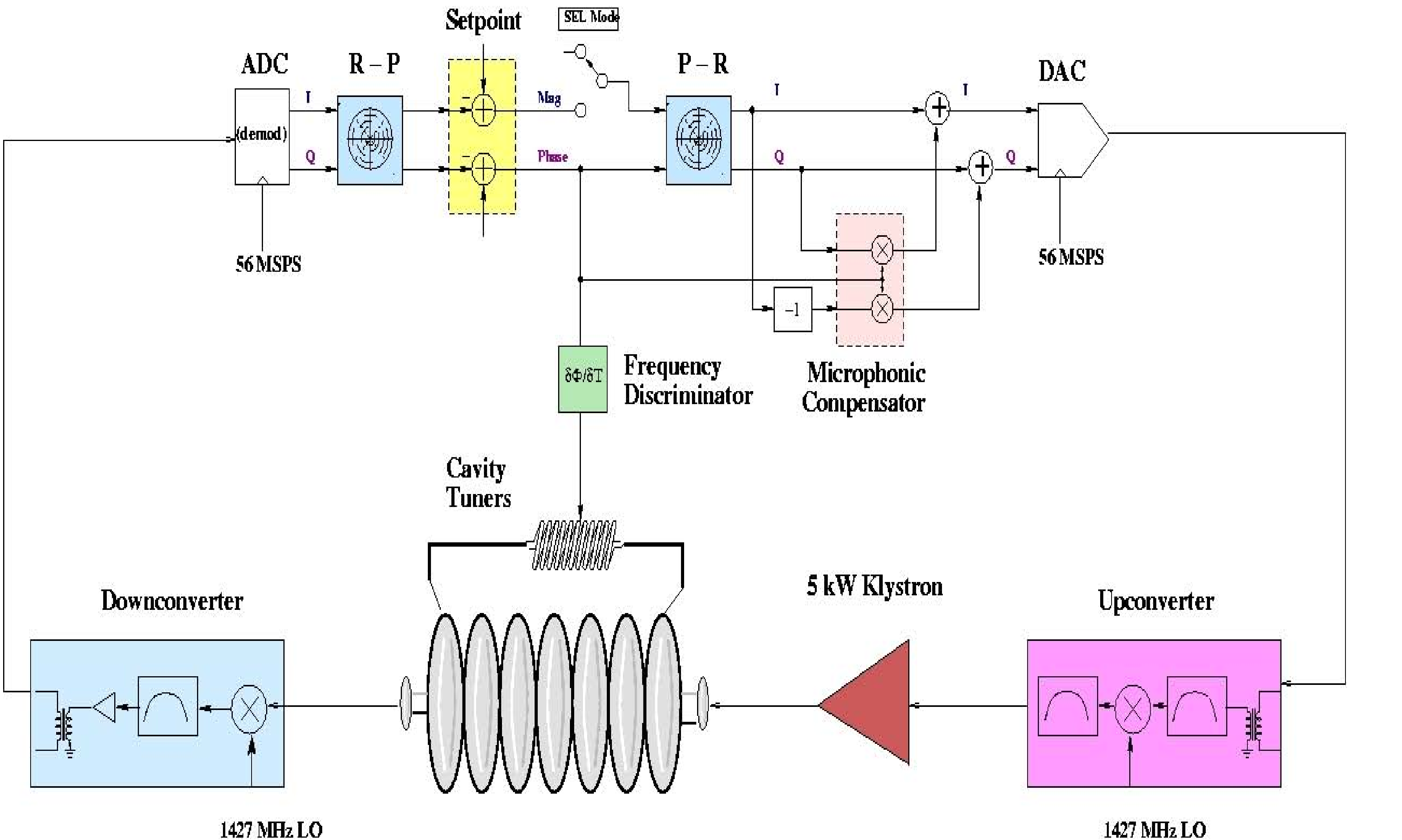
- **Amplitude noise: $<1 \times 10^{-4}$**
- **Phase noise: $<0.2^{o}$**

But: We must deal with narrow bandwidth and large Lorentz detuning

- **$Q_{external} \geq 2 \times 10^{7}$**
- **Stiffness $\approx$ 1.5 Hz/(MV/m)^2**
  - **$\Rightarrow$Very tilted (double-valued) detuning curve**



RF Power & Control: Digital Self-Excited Loop



Collaboration w/ Cornell

RF Power & Control: Digital Self-Excited Loop

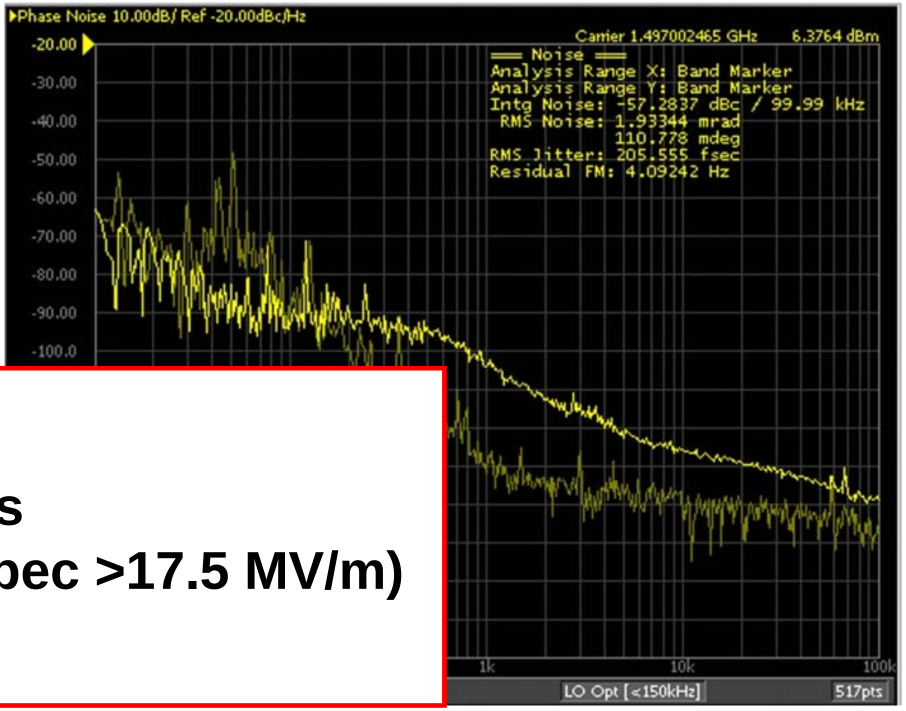
Benefits

- **Allows simple “cold” start when cavity is far from resonance**
- **Allows rapid recovery after a cavity trip**
- **Allows easy in situ cavity He processing**

Status

- **Tested in the FEL on a SC cavity with gradients to ~5MV/m.**
- **Frequency locked and phase control achieved.**

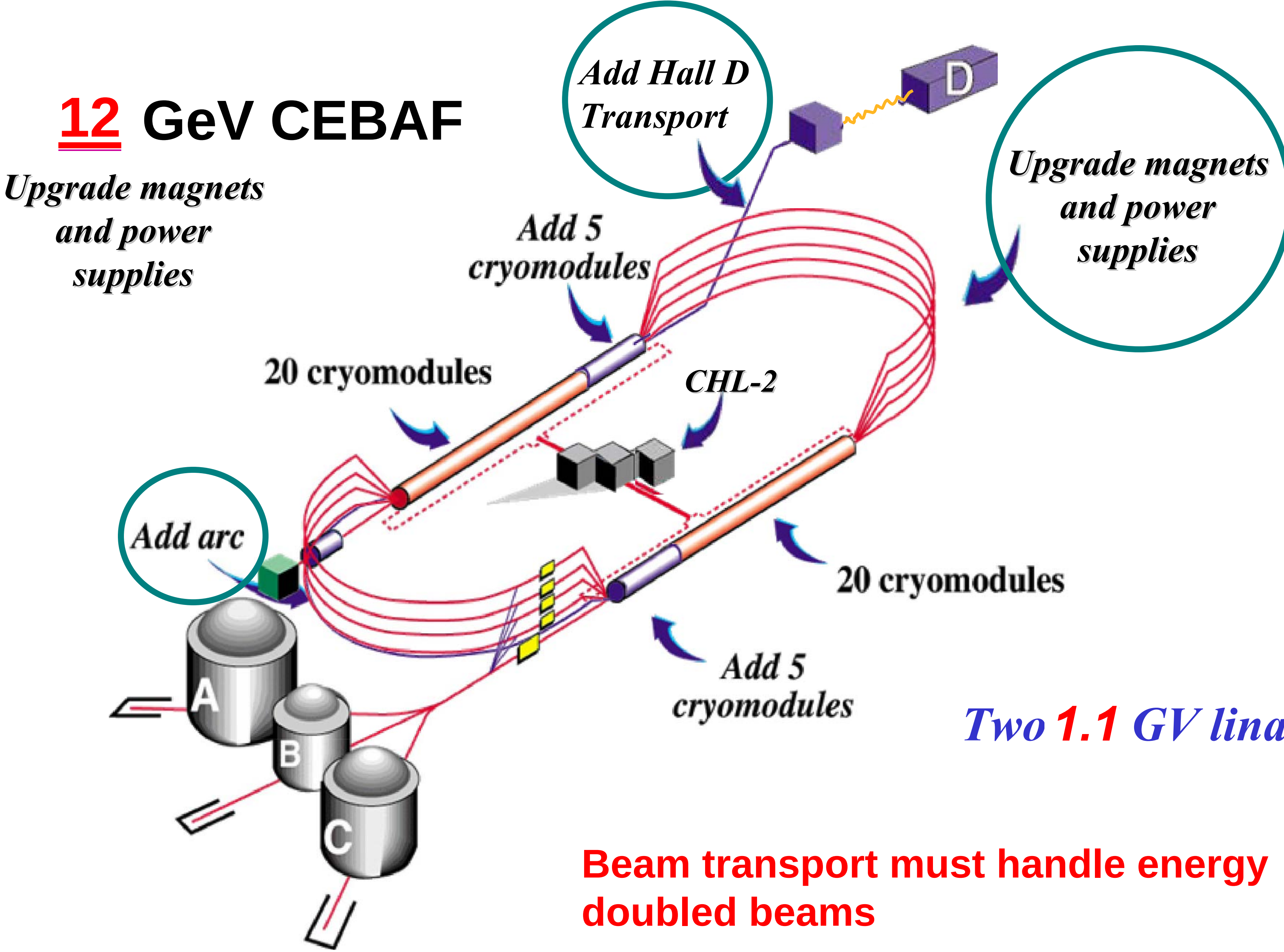
Cavity Phase Noise Spectrum:
Rms phase Error: 0.11°



Next steps

- **Further develop control algorithms**
- **Operate cavity at high gradient (Spec >17.5 MV/m)**
- **Run with vertical slice test**

12 GeV CEBAF



*Two **1.1** GV linacs*

Beam transport must handle energy doubled beams

Extra Arc and Hall D transport must be added

Beam Transport: Arc Dipoles

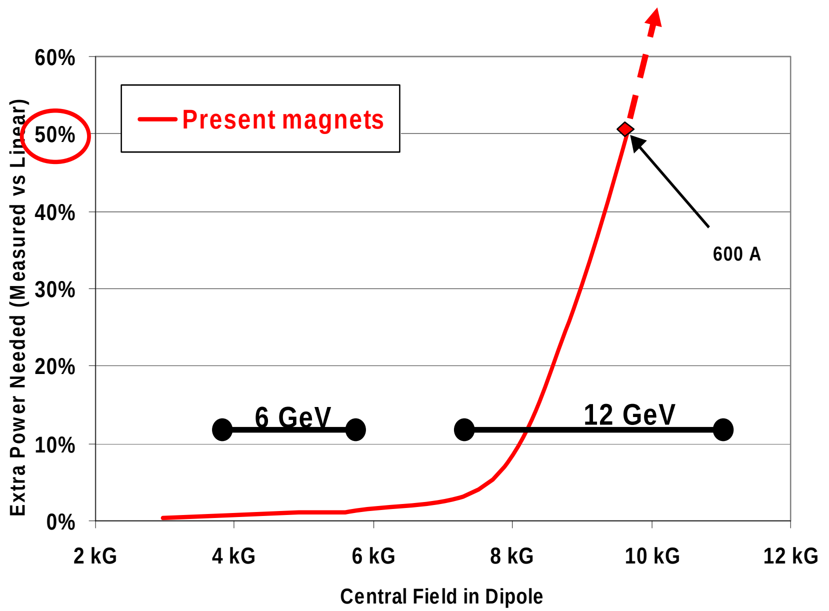
<u>Goals:</u>

Minimize cost without sacrificing beam quality.

Use as many of the existing magnets and power supplies as possible in a situation where the beam energy has doubled

<u>The principal challenge:</u> Saturation of the iron in the magnets

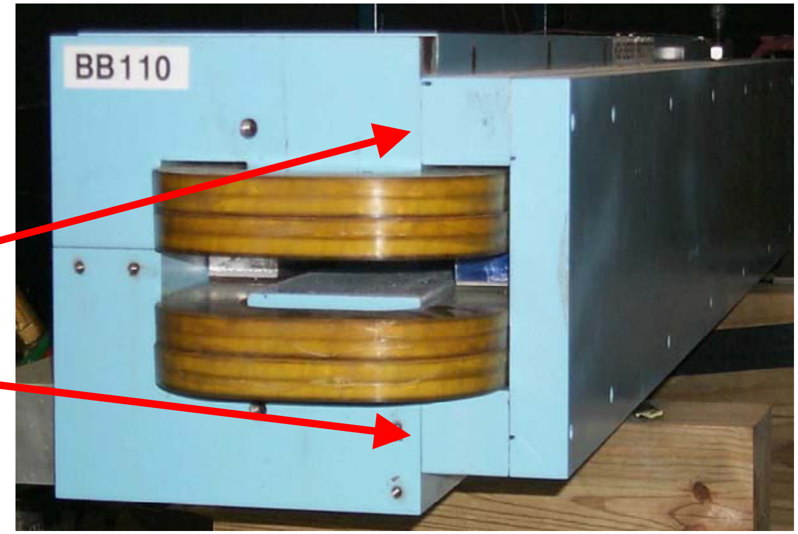
<u>Arc Dipoles:</u> Power increases well beyond linear B-I curve prediction when current Is increased to deliver field needed for 11 GeV Beam



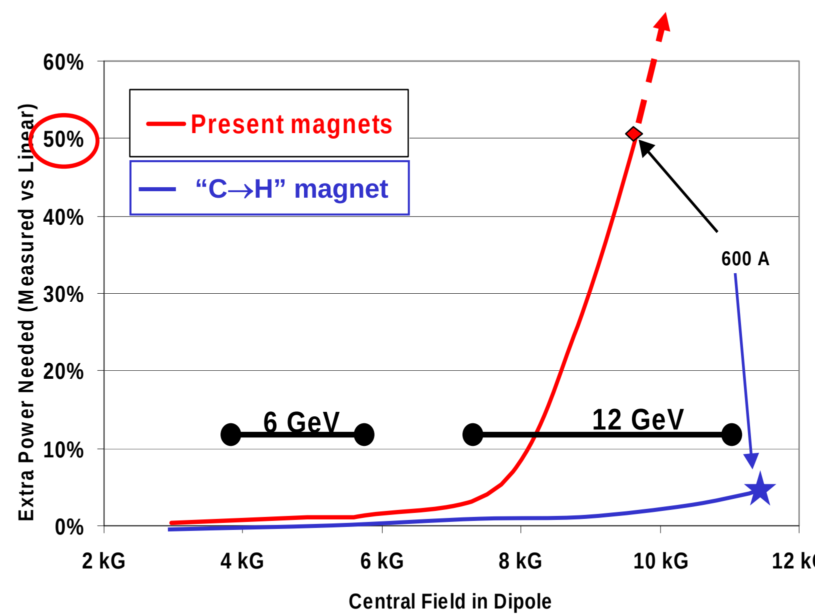
Beam Transport: Arc Dipoles

Simple Solution:

Add Return iron to convert original 'C' Magnet design to 'H' Magnet geometry



Arc Dipoles: Linearity of B/I Curve is restored



Beam Transport: Overall Impact

Magnets

- ~2100 magnets in present machine
- Changes needed:
  - Large Dipoles (340)

Arcs (250):	Reuse all (add iron to change from "C" to "H")
Spreaders/recombiners (90):	Reuse 60; Replace 30
– Quadrupoles (700):	90% unchanged; replace 10%
– Steering dipoles (700):	No change

Power supplies

- Replace 15 of the 36 large (>100kW) power supplies
- Replace power supplies on ~20% of the quadrupoles

What is the Formal Status of the Upgrade Project?

Project Status

CD-0: Approved March 2004

CD-1: Approved February 2006

Lehman review underway as I speak

OECM External Independent Review (EIR) scheduled for August

CD-2: Scheduled for September 2007

TPC Range: $225M - $306M

Costs split ~equally between accelerator upgrade and experimental equpment (including conventional construction w/ each)

Project Planning (w/ Current DOE Guidance)

Begin construction (CD-3)	Fall 2008
Accelerator down	Spring 2012 thru Spring 2013
Accelerator commissioning	Summer 2013
Re-start research program	Fall 2013
Start research at 12 GeV	Summer 2014

Summary

An exciting science program investigating the nature of quark confinement and other aspects of "strong" QCD motivates the Upgrade of CEBAF from 6 to 12 GeV and the addition of major experimental equipment

The 12 GeV Upgrade is the highest priority in the recent (4/07) NSAC Long Range Plan

Improvements in SRF Technology and thoughtful reuse and/or revision of many components of CEBAF make the Upgrade highly cost effective

Accelerator construction & commissioning would last ~3½ years, including ~1 year suspension of accelerator operations.

Next steps:

- **CD-2 approval in early Fall**
- **Construction starts a year later**