

STATUS AND PLANS OF JLAB12

Patrizia Rossi

Jefferson Lab



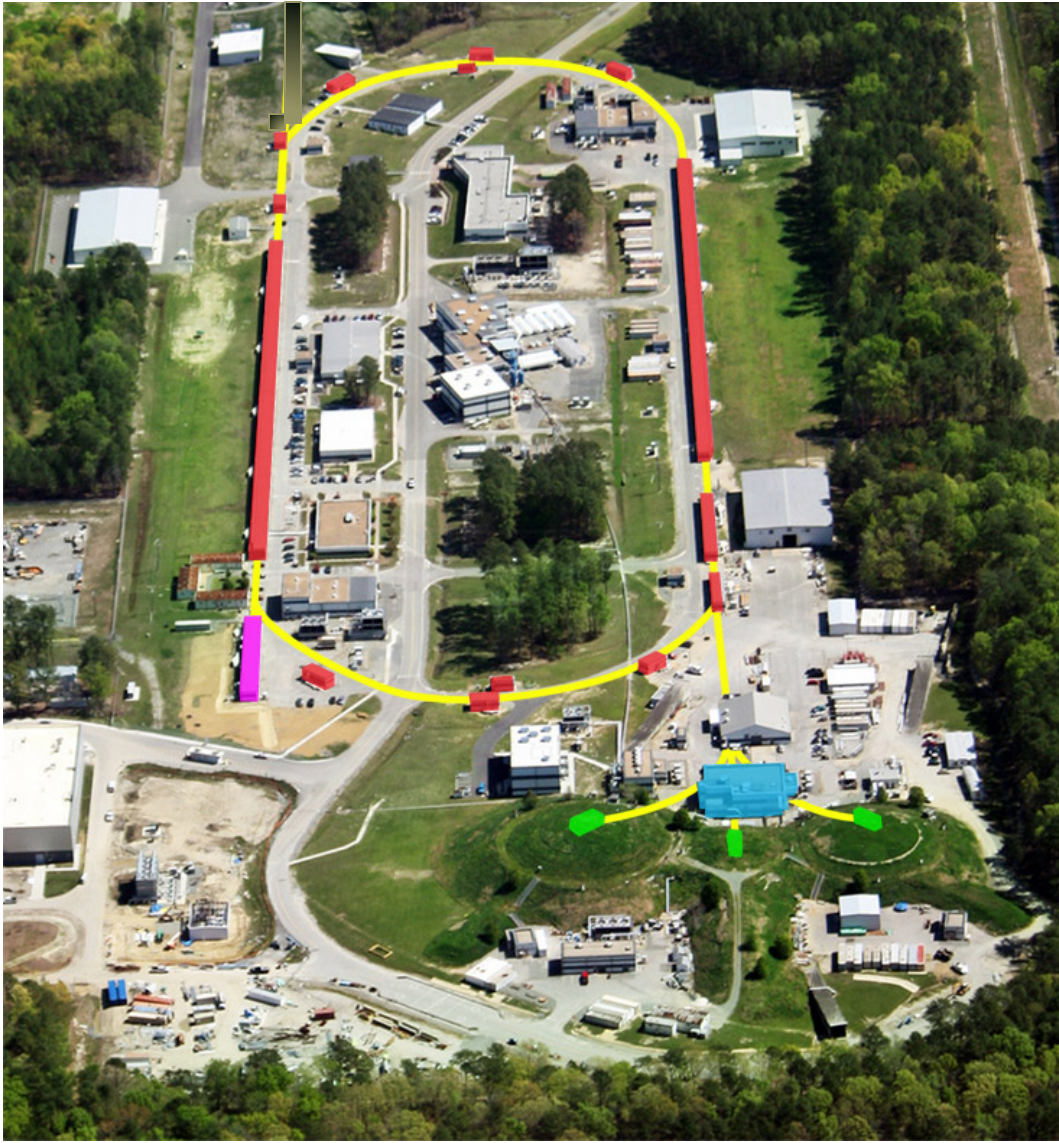
International Conference on Science and Technology for FAIR in Europe 2014
October 13–17, 2014 Worms, Germany

Jefferson Lab Mission



- Explore the fundamental nature of confined states of quarks and gluons → **Non-perturbative regime of QCD**
- Discover evidence for physics beyond the standard model

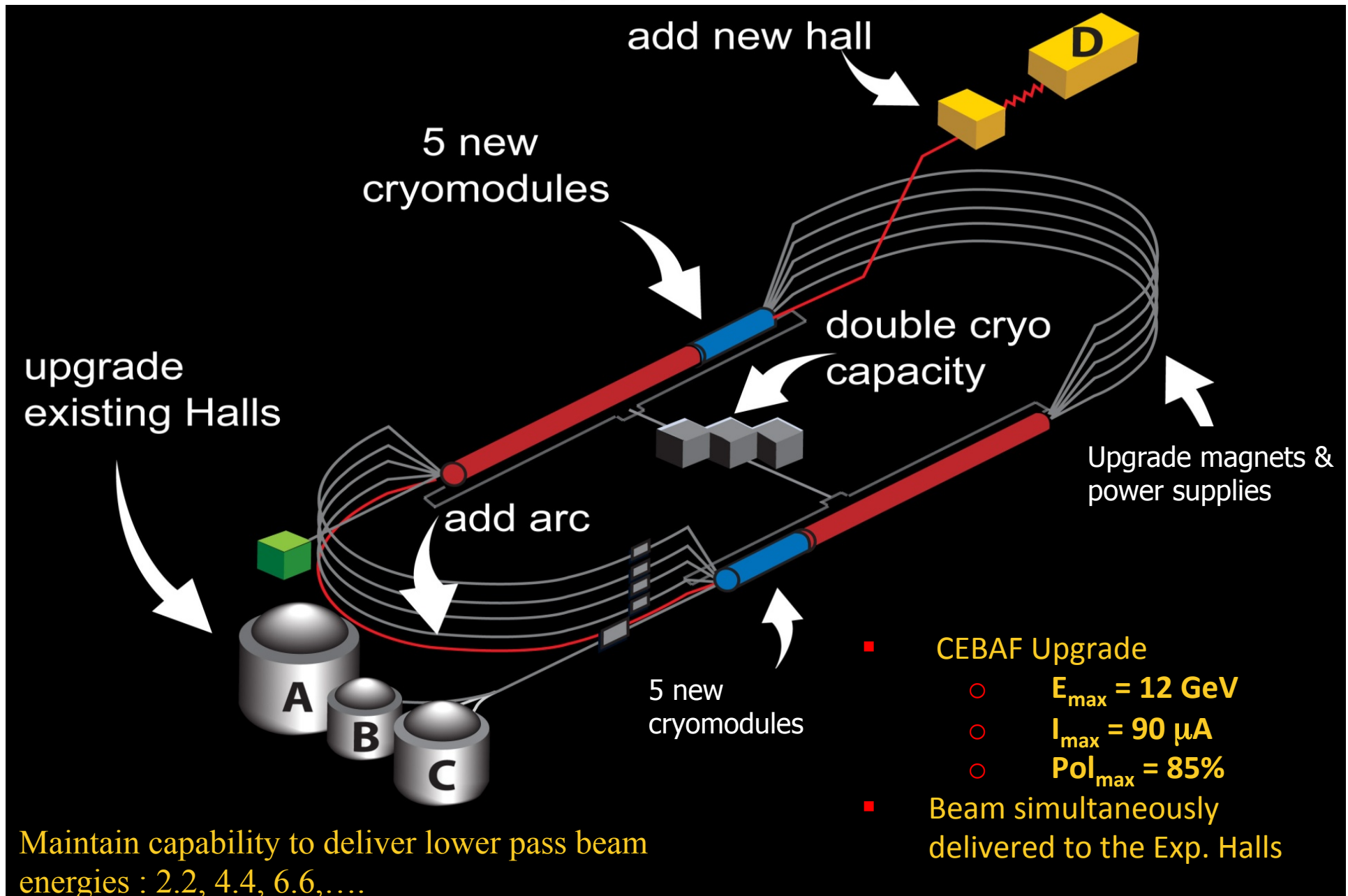
Jefferson Lab at a Glance



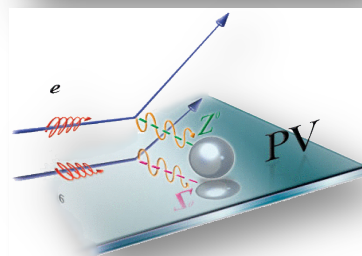
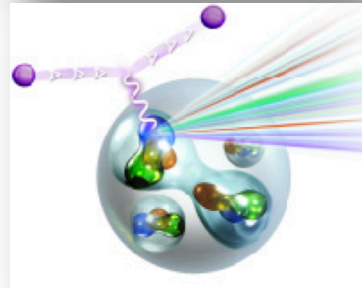
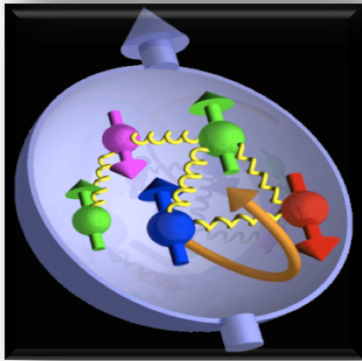
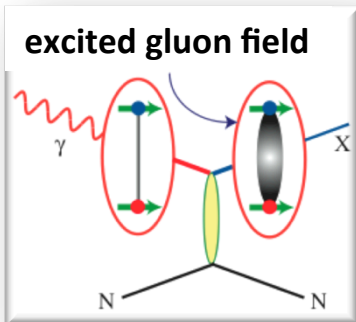
- First large **high-power CW recirculating e-linac** based on **SRF** technology
- $E_{\text{max}} = 6 \text{ GeV}$ (1995-2012)
- $I_{\text{max}} = 200 \mu\text{A}$
- $\text{Pol}_{\text{max}} = 85\%$

- ~ **1400** Active Users
- ~ **800** FTEs
- Produces ~**1/3** of US PhDs in Nuclear Physics

CEBAF Upgrade (2012-2014): 6→12 GeV

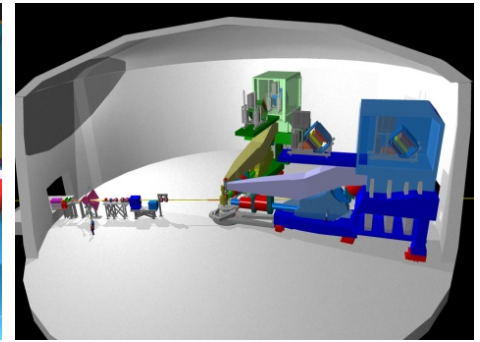
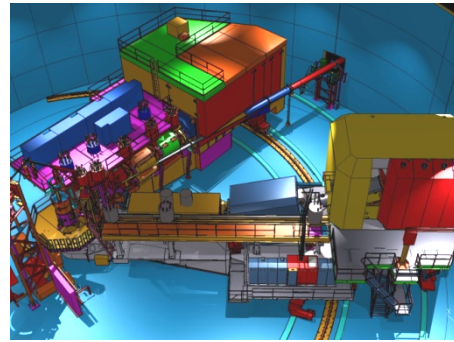
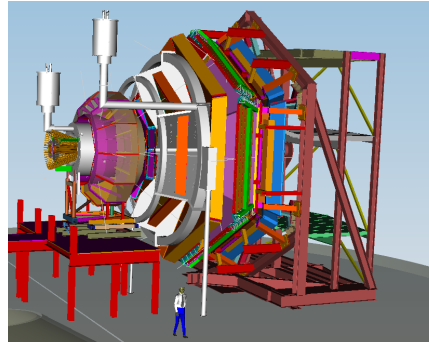
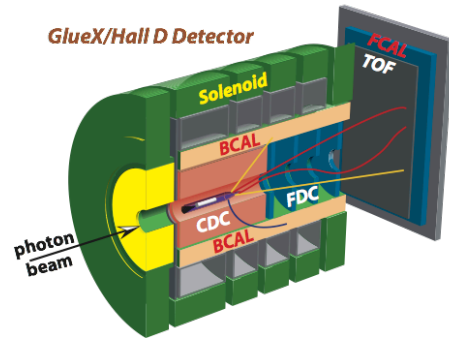


Physics Program



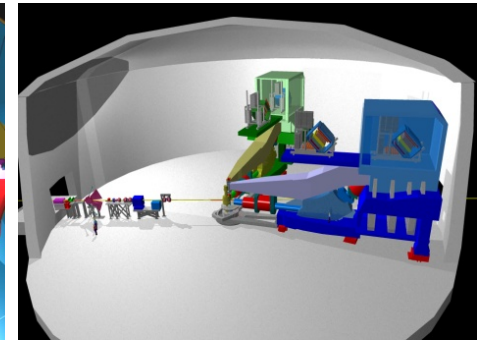
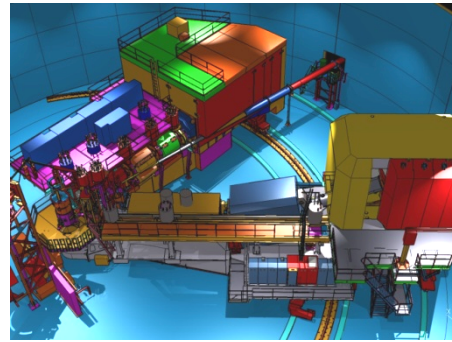
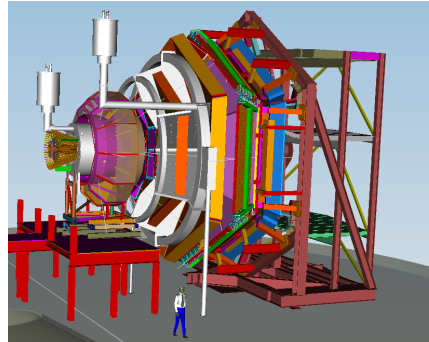
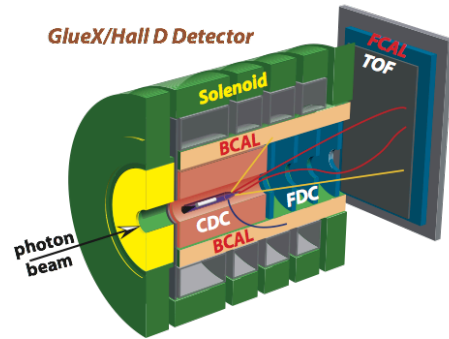
- **Study the role of gluonic excitations in the spectroscopy of light mesons**
- **Explore the inner structure of the nucleon:**
 - multi-dimensional parton distribution functions (TMD, GPD)
 - parton distribution functions at large- x
 - elastic and transition form factors
- **Study the relation between the short-range nuclear structure and the parton dynamics**
- **Discover evidence for physics beyond the standard model of particle physics**

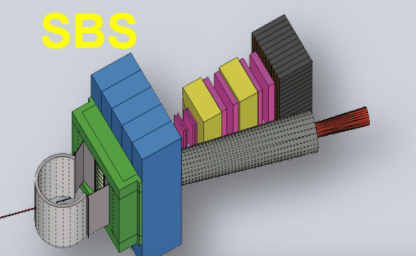
Detector Requirements: Complementarity



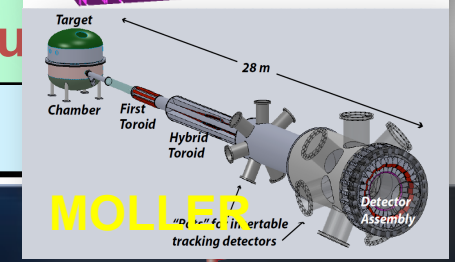
Hall D	Hall B	Hall C	Hall A
excellent hermeticity	luminosity 10^{35}	energy reach	custom installations
polarized photons	hermeticity	precision	
$E_\gamma \sim 8.5\text{-}9\text{ GeV}$	11 GeV beamline		
10^8 photons/s	target flexibility		
good momentum/angle resolution		excellent momentum resolution	
high multiplicity reconstruction		luminosity up to 10^{38}	
particle ID			

Detector Requirements: Complementarity



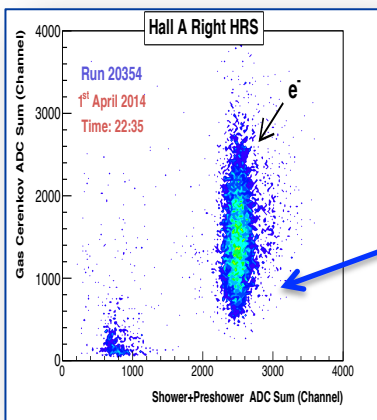
Hall D	Hall B	Hall C	Hall A
excellent hermeticity	luminosity 10^{35}	energy reach	
polarized photons	hermeticity	precision	
$E_\gamma \sim 8.5-9$ GeV	11 GeV beamline		
10^8 photons/s	target flexibility		
good momentum/angle resolution		excellent momentum	
high multiplicity reconstruction		luminosity up to 10^{35}	
particle ID			

Target	Chamber	First Toroid	Hybrid Toroid
28 m			

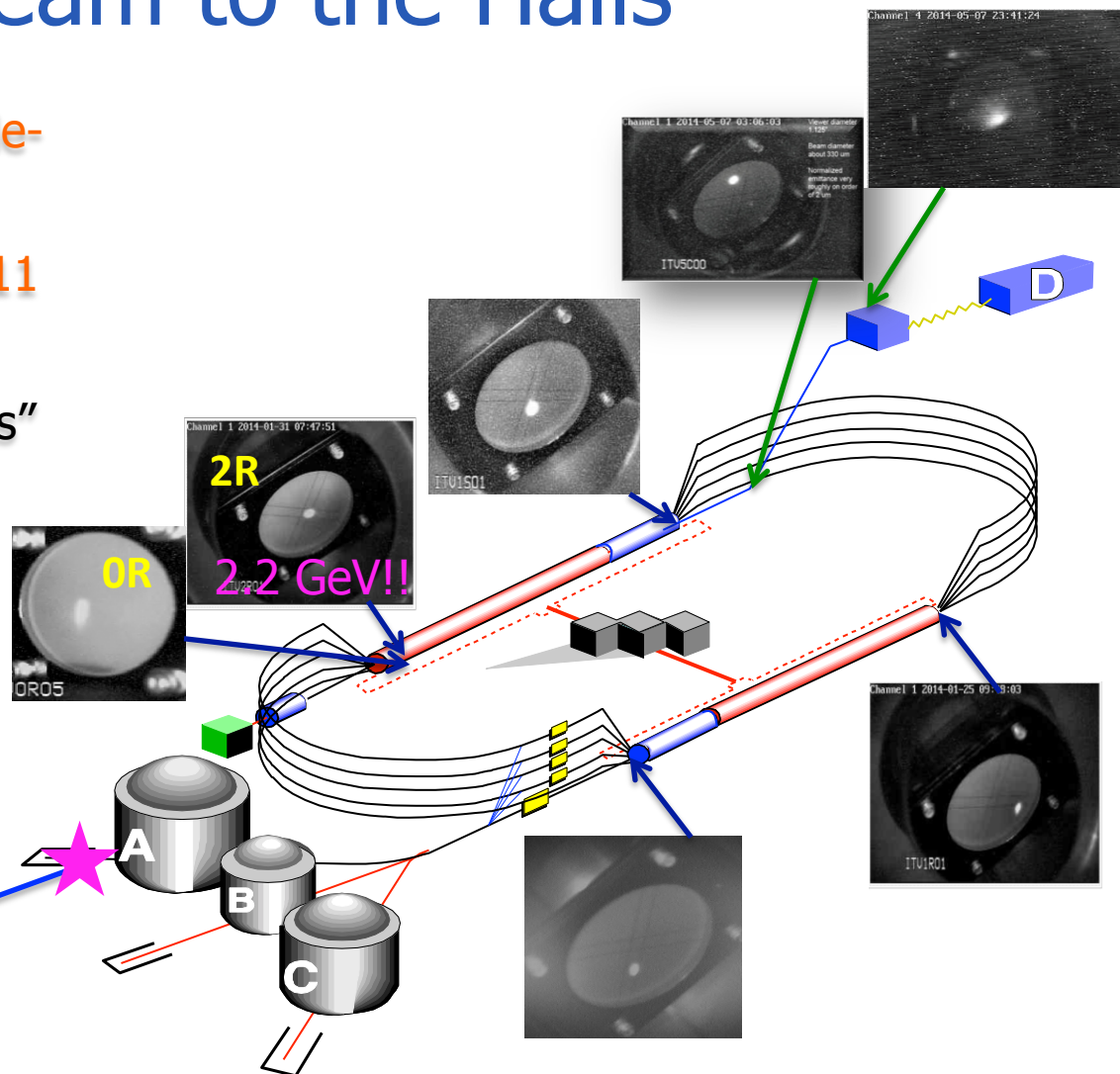


Accelerator Commissioning & First Beam to the Halls

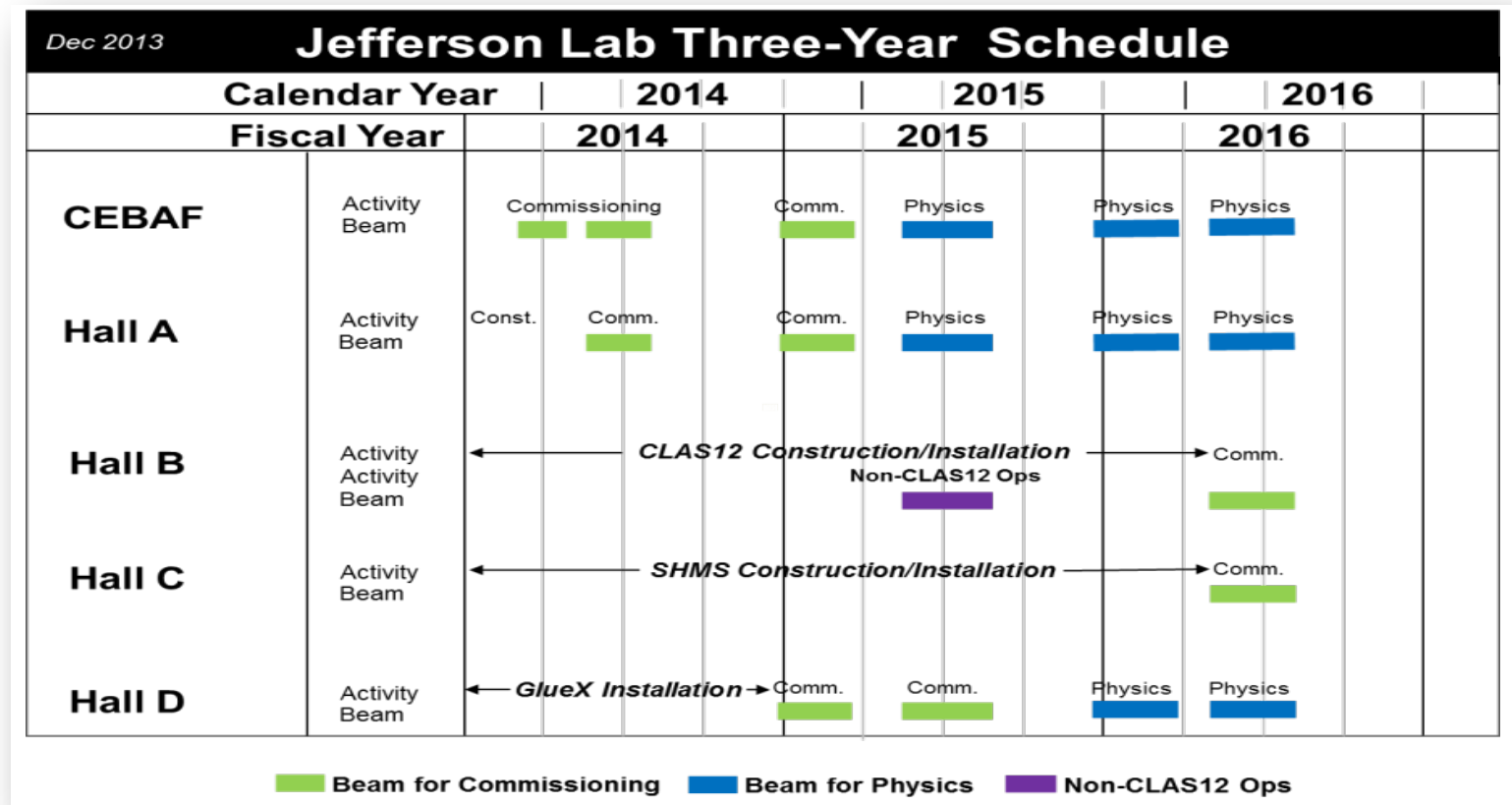
- ★ Feb 5, 2014 achieved full upgrade-energy of 2.2 GeV in one pass.
- ★ April 1, 2014 "3-pass" beam, 6.11 GeV electrons @ 2 nA in Hall A
- ★ May 7, 2014 10.5 GeV ("5.5 pass" beam) to Hall-D Tagger dump
- ★ October 2014 beam to Hall D, Hall A, Hall B simultaneously



Beam on Carbon Target



12 GeV CEBAF: Three Year Schedule



- 15-Months Schedule Released: Oct 2014 – Dec 2015
- It covers the first experiment run period of the “12 GeV Era” to be executed in parallel with the Accelerator Commissioning & Development necessary to bring the machine to its design performance.

12 GeV Approved Experiments

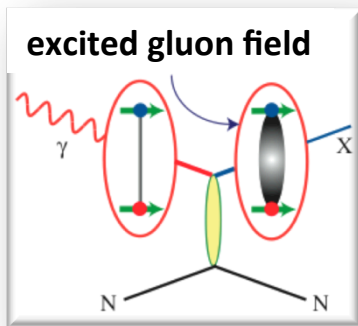
Topic	Hall A	Hall B	Hall C	Hall D	Other	Total
The Hadron spectra as probes of QCD (GluEx and heavy baryon and meson spectroscopy)		1		3		4
The transverse structure of the hadrons (Elastic and transition Form Factors)	5	3				11
The longitudinal structure of the hadrons (Unpolarized and polarized parton distribution functions)			6			11
The 3D structure of the hadrons (Generalized Parton Distributions and Transverse Momentum Distributions)	5	9	7			21
Hadrons and cold nuclear matter (Medium modification of hadrons, quark hadronization, nuclear parton distribution functions, hypernuclear spectroscopy, few body experiments)	6	3	7		1	17
Low-energy tests of the Standard Model and Fundamental Symmetries	3	1		1	1	6
TOTAL	21	20	22	5	2	70

More than 7 years of approved experiments

**PAC41 (May 2014): Select ~ 600 PAC days for “High Impact”
to provide a strategic core program**

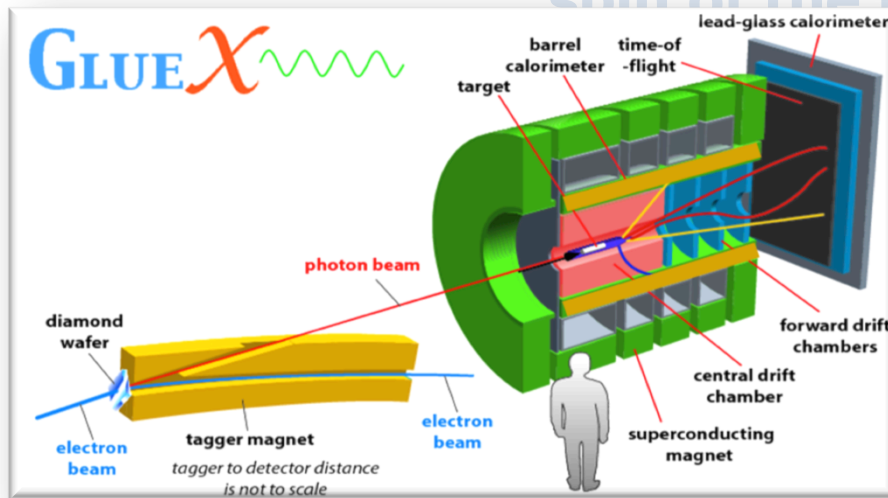
- Those experiments will receive priority for scheduling in the first 5 years of 12 GeV running
- They represent **less than half** of the anticipated running time

Physics Program

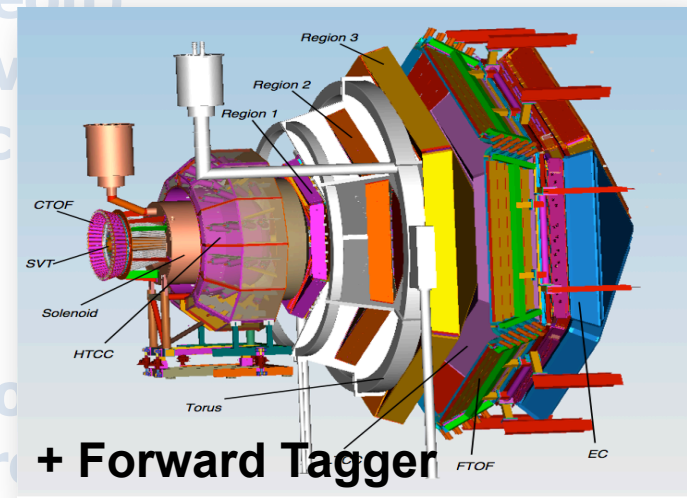


- **Study the role of gluonic excitations in the spectroscopy of light mesons**

- Measure the new multi-dimensional parton distribution functions (chase to the missing spin of the nucleon)



Hall D : real photons



Hall B: quasi-real photons

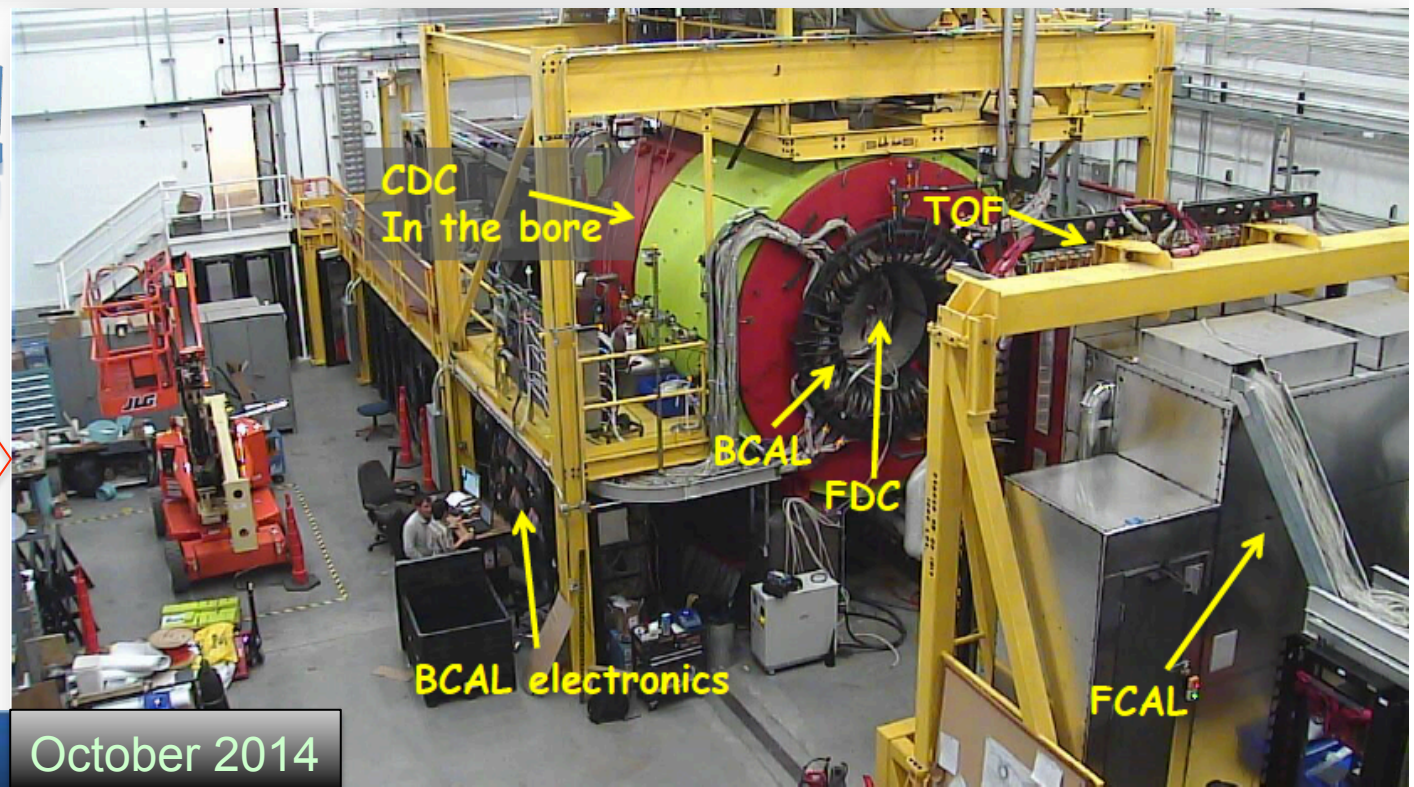
- Discover evidence for physics beyond the standard model of particle physics

Hall D & the GlueX detector



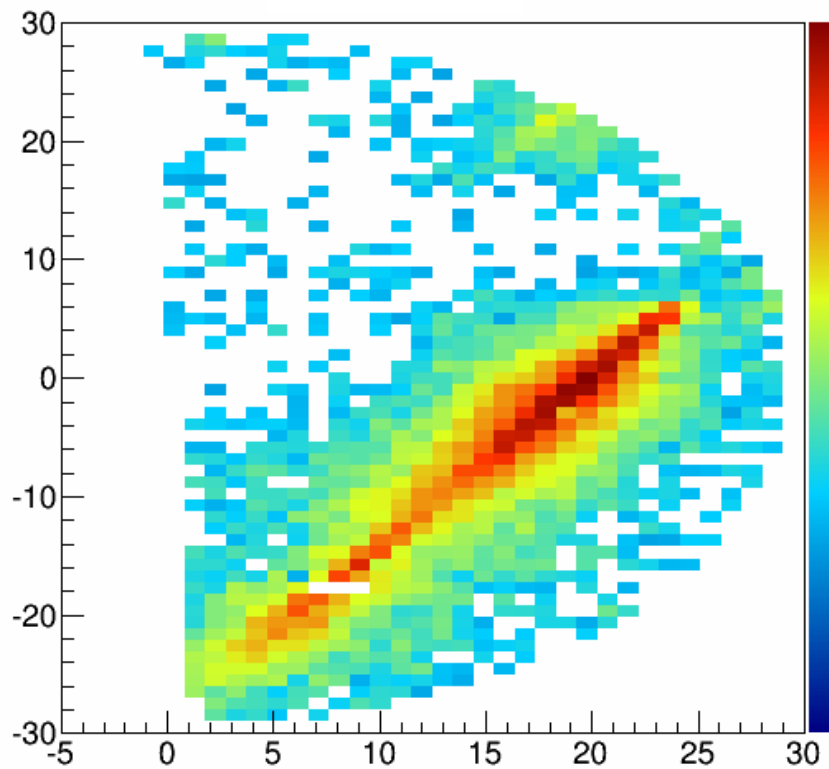
DONE !!

**Ready for
beam**

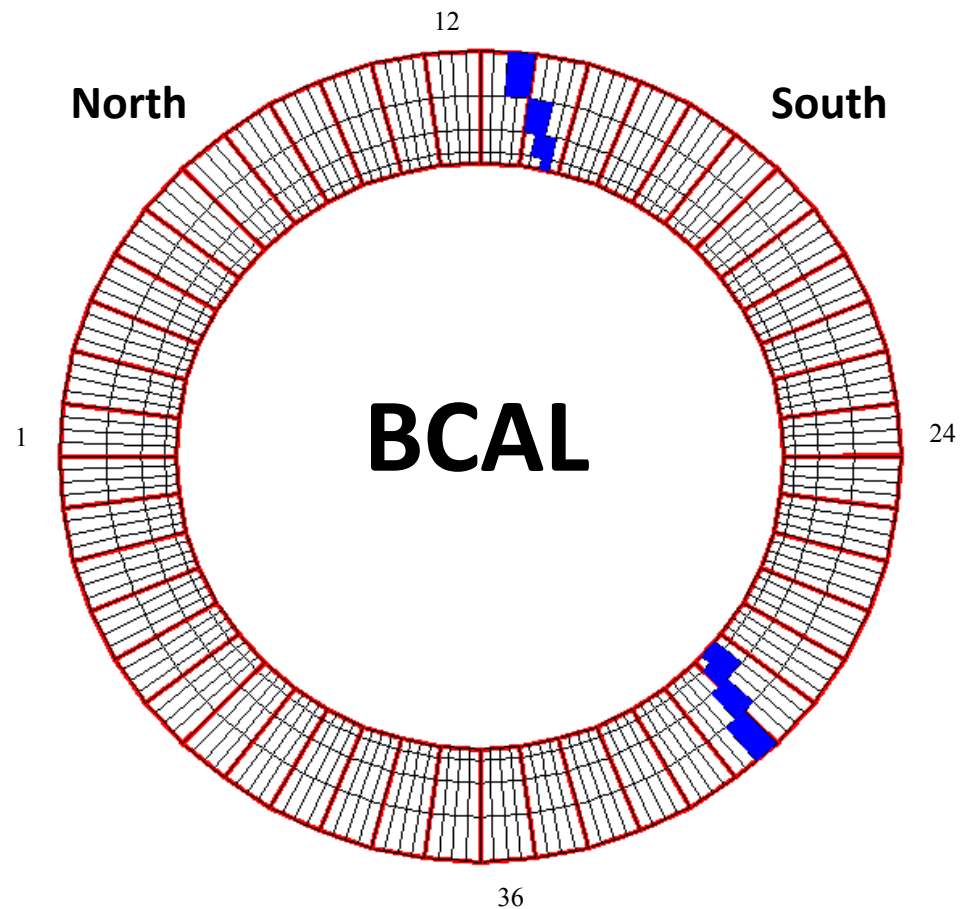


Cosmic Events in the Calorimeters

FCAL



BCAL upstream



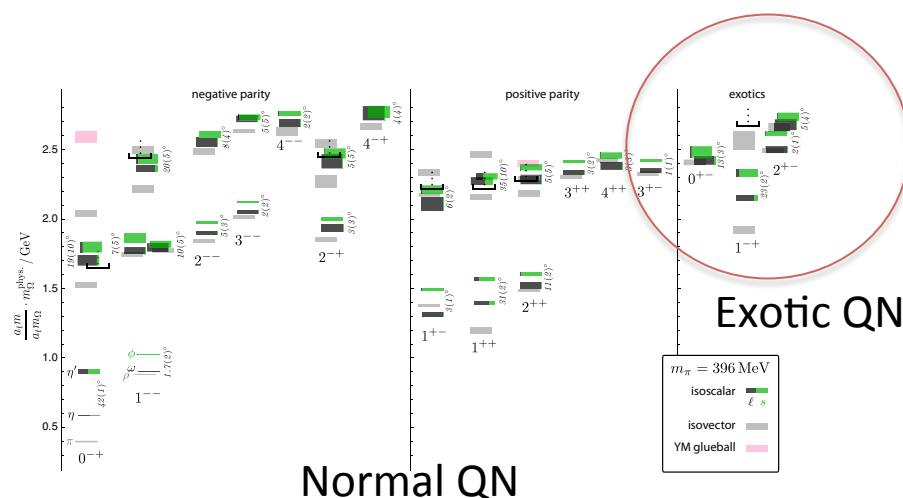
The GlueX Experiment



High Impact Exp. From PAC41

Search for mesons in which the gluonic field contributes directly to the J^{PC} quantum numbers of the states --- hybrid mesons. Some are expected to have "exotic" quantum numbers.

Lattice QCD calculation of the light-quark meson spectrum



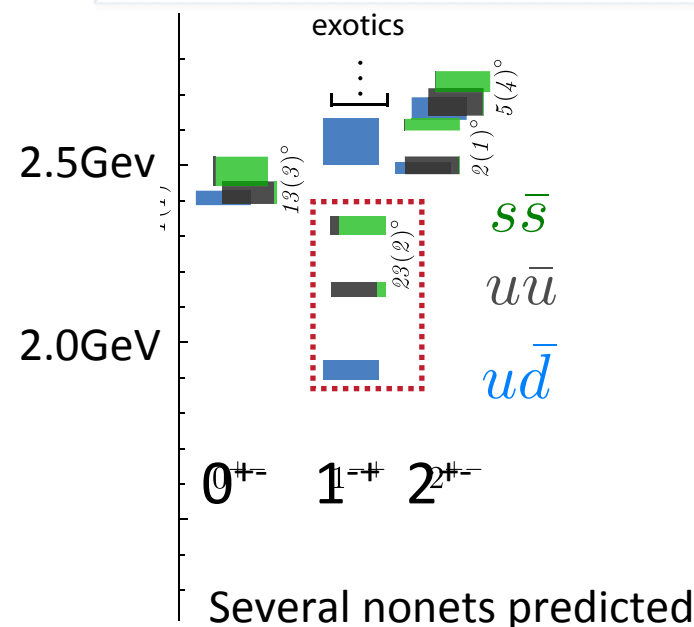
Quarks \oplus Excited Gluon Field

$$J^{PC} = \begin{cases} 1^{+-} \\ 1^{-+} \end{cases}$$

→ Hybrid Meson

Exotic

$$J^{PC} = \begin{cases} 0^{-+} & 1^{-+} & 2^{-+} \\ 0^{+-} & 1^{+-} & 2^{+-} \end{cases}$$



Physics in GlueX

$$\gamma p \rightarrow X(J^{PC})(p, n)$$

$$\pi_1(1^{-+}) \rightarrow \rho\pi \rightarrow \pi\pi\pi$$

$$h_0(0^{+-}), \pi_1(1^{-+}), h_2(2^{+-})$$

$$\rightarrow b_1\pi \rightarrow \omega\pi\pi \rightarrow 5\pi$$

$$\pi^+\pi^-\pi^0 p$$

$$\pi^+\pi^+\pi^-\pi^0 n$$

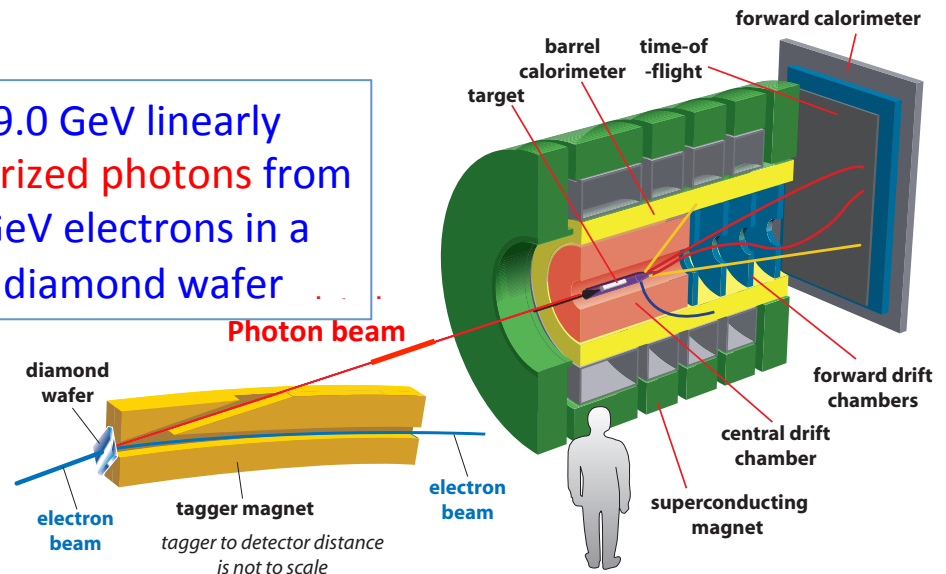
$$\pi^+\pi^-\pi^+\pi^-\pi^0 p$$

$$\pi^0\pi^0\pi^0\eta p$$

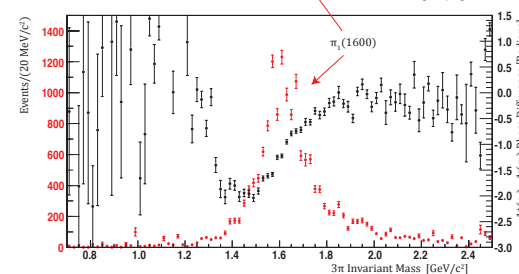
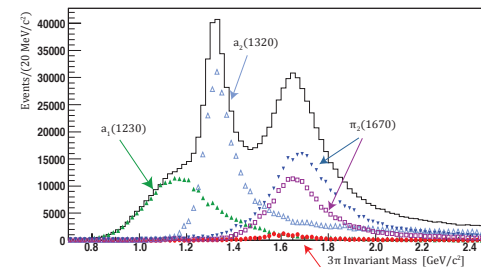
Fully
reconstruct
final states

- All of these channels have been studied in Monte Carlo to understand the acceptance.
- These studies have been used to “stress” the offline reconstruction software.

8.4-9.0 GeV linearly
polarized photons from
12 GeV electrons in a
thin diamond wafer



Charged particle tracking +
timing and photon detection
in a 2T magnetic field.



$$\sigma_{3\pi} = 10\mu b$$

$$\sigma_{tot} = 120\mu b$$

95% purity
~22% efficiency

Physics Analysis: Plan

Prove we understand the detector

$$\gamma p \rightarrow \pi^0 p$$

$$\gamma p \rightarrow \eta p$$

$$\gamma p \rightarrow \rho p$$

$$\gamma p \rightarrow \omega p$$

$$\gamma p \rightarrow \eta' p$$

$$\gamma p \rightarrow \phi p$$

Initial exotic hybrid searches

$$\gamma p \rightarrow \eta \pi(n, p)$$

$$\gamma p \rightarrow \eta' \pi(n, p)$$

$$\gamma p \rightarrow \rho \pi(n, p)$$

$$\gamma p \rightarrow \omega \pi(n, p)$$

$$\gamma p \rightarrow \omega \pi \pi(n, p)$$

$$\gamma p \rightarrow \eta \pi \pi(n, p)$$

Strange Baryons

$$\gamma p \rightarrow K^+ \Lambda$$

$$\gamma p \rightarrow K \Sigma$$

$$\gamma p \rightarrow K K \Xi$$

- High Luminosity run

Other Physics Interests

η Decays

η Primakov

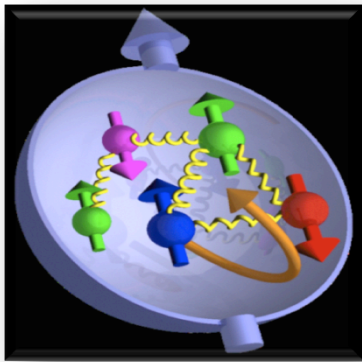
J/ ψ Production

...

- Oct 2014 - Jun 2015: Commissioning/engineering run **10 GeV**
- Nov – Dec 2015: **GlueX** physics commissioning run **12 GeV**
- Apr – May 2016: **GlueX** run **12 GeV**

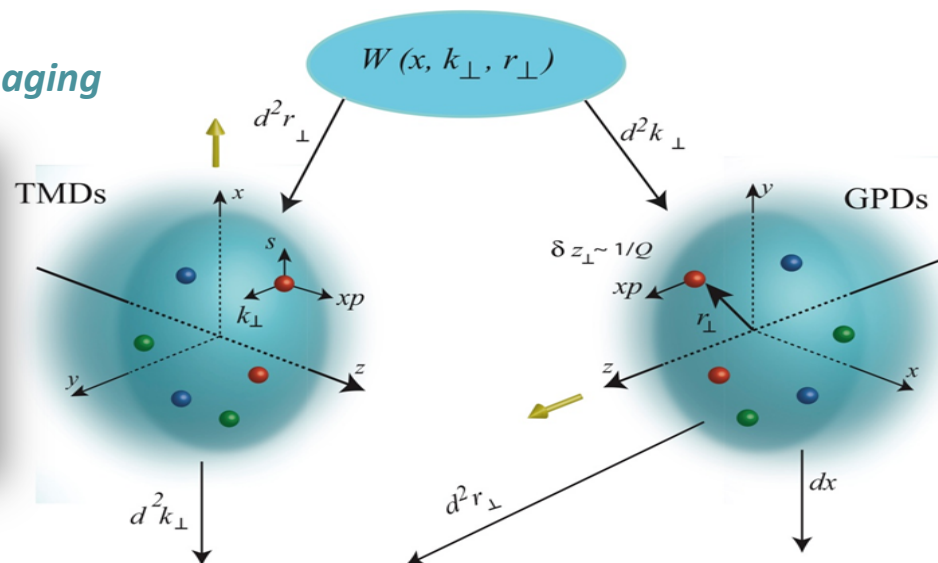
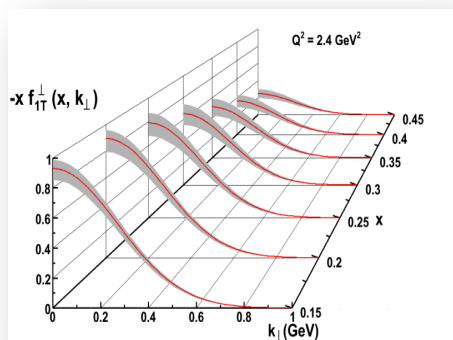
Physics Program

- Study the role of gluonic excitations in the spectroscopy of light mesons
- **Explore the inner structure of the nucleon:**
 - multi-dimensional parton distribution functions (TMD, GPD)
 - parton distribution functions at large- x
 - elastic and transition form factors
- Study the relation between the short-range nuclear structure and the parton dynamics
- Discover evidence for physics beyond the standard model of particle physics

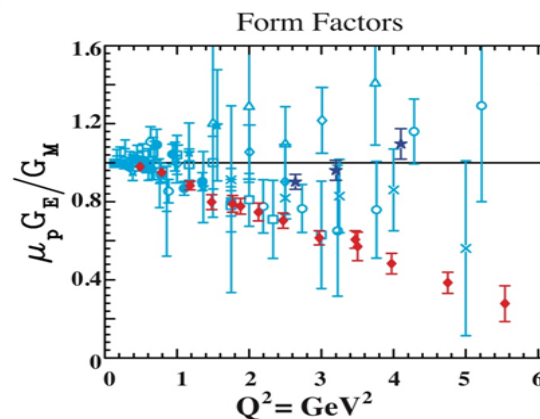
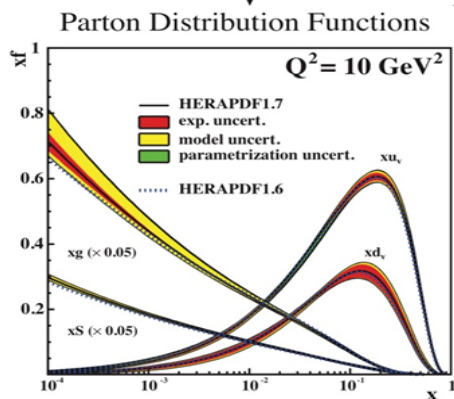
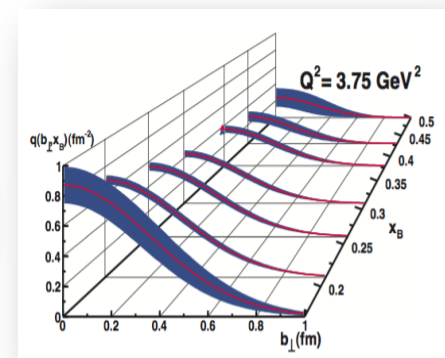


3D Mapping of the Nucleon

Transverse Momentum Imaging



Transverse Spatial Imaging



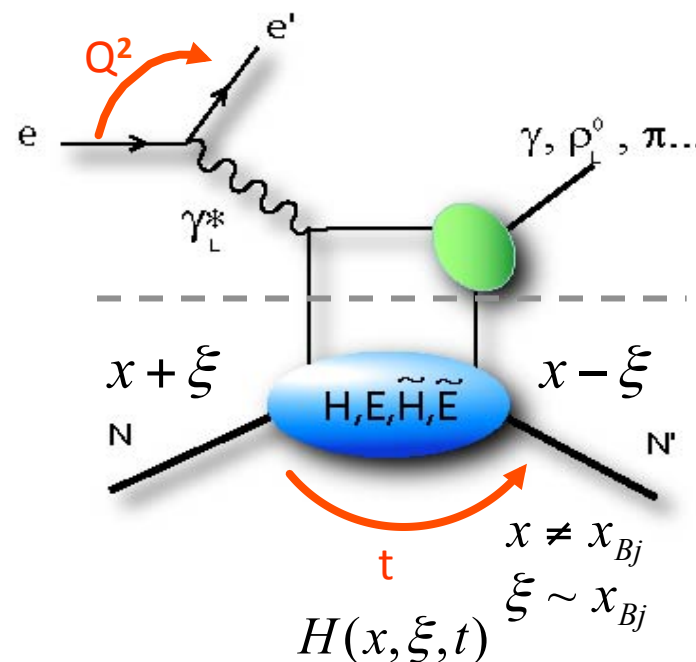
3D Parton Distributions: GPD

- At leading twist eight GPDs accessible in **EXCLUSIVE** processes
- NOT directly accessible but only through models/parameterizations** → their extractions require measurements of x-sections and asymmetries in a **large kinematic domain of x_B , t , Q^2** (GPD) and with different combinations of beam/target polarization

Polarized beam, unpolarized target: $\Rightarrow H(\xi, t)$

Unpolarized beam, longitudinal target: $\Rightarrow \tilde{H}(\xi, t)$

Unpolarized beam, transverse target: $\Rightarrow E(\xi, t)$



- Access to quark orbital angular momentum (Ji's Sum Rule)**

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

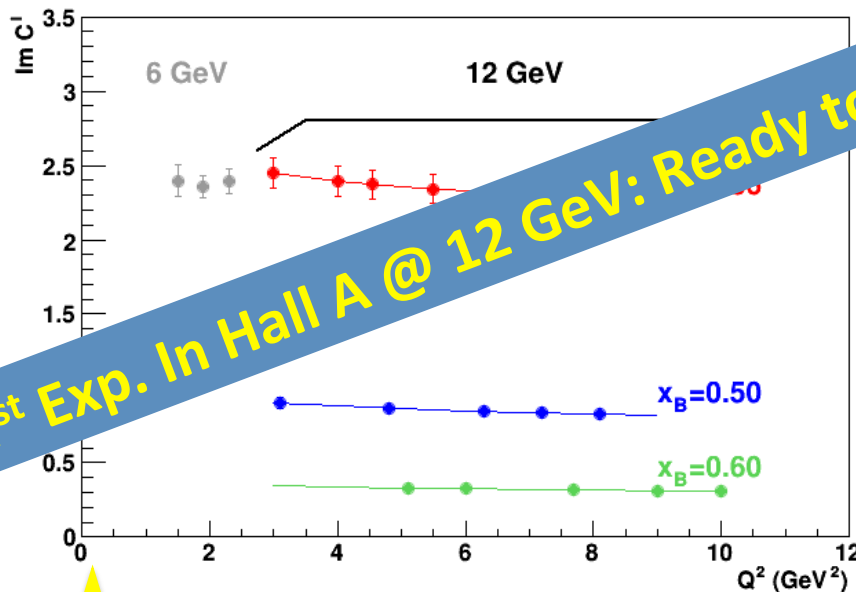
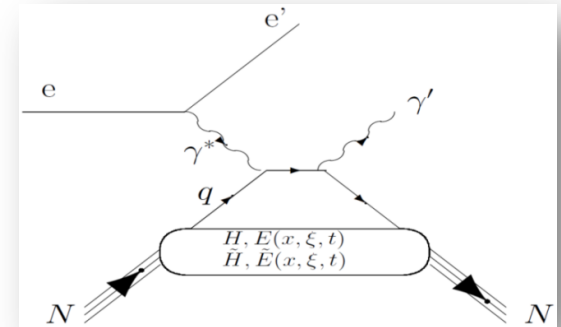
- Transversely polarized HD-Ice target
- Unpolarized neutron target



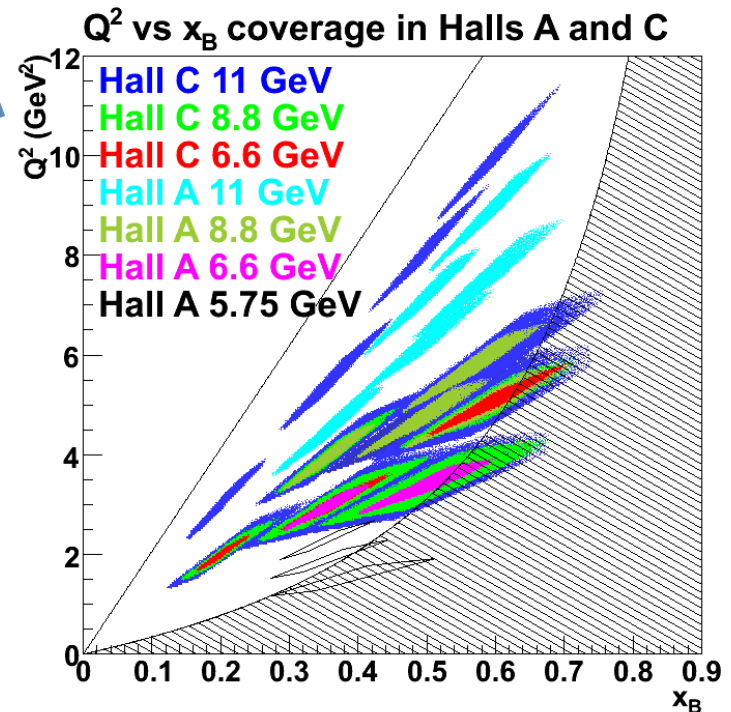
High Impact Exp. From PAC41

DVCS @ 12 GeV

- DVCS is the cleanest process to access GPDs and measurements are planned in all three Halls: A, B, C.
- The DVCS program in **Hall A** and **Hall C** will be to focus on some specific kinematics and make precision measurements → **test of the “handbag” formalism**. One signature is the **scaling behavior of the CFFs**

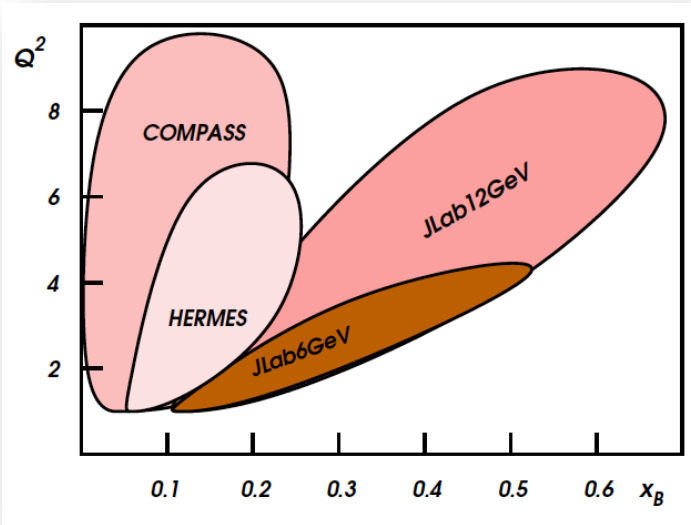


High Impact Exp. From PAC41

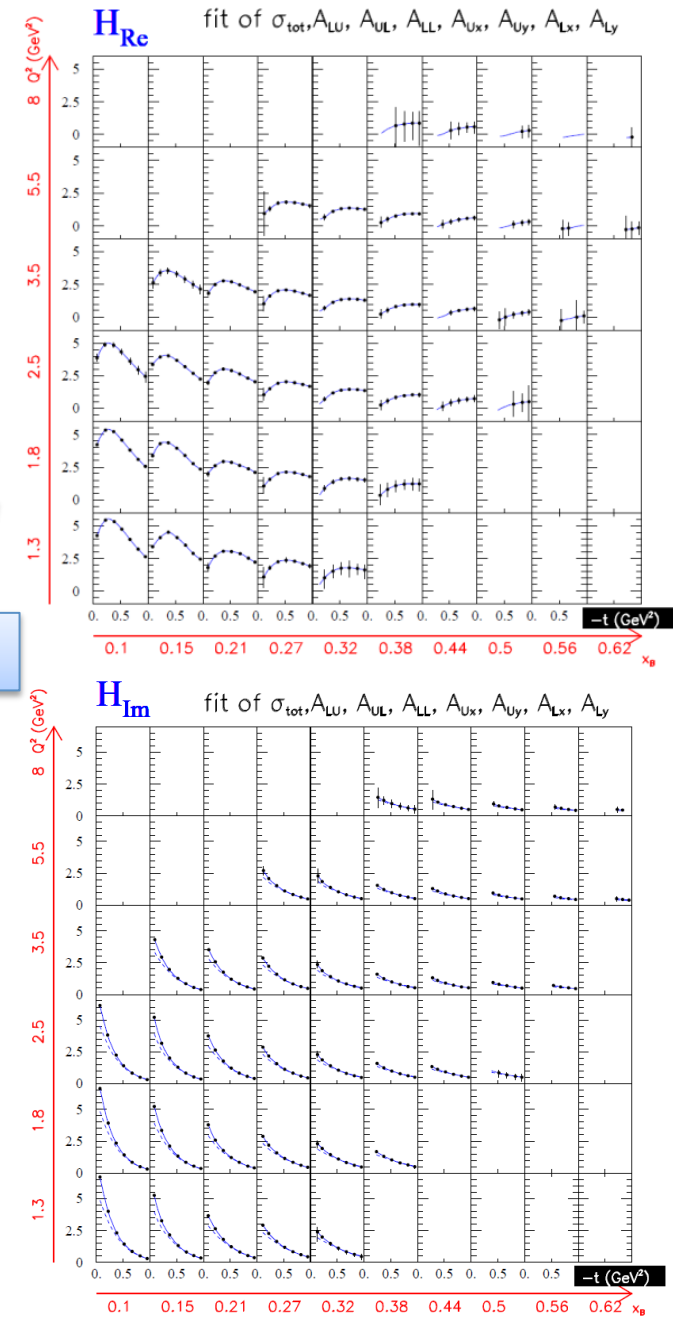


DVCS @ 12 GeV

- **CLAS12** is expected to measure all the DVCS observables accessible with a polarized beam, a longitudinally and a transversely polarized target.
- The JLAB12 program will explore the DVCS physics in the **valence region** and it will be complementary to other facilities

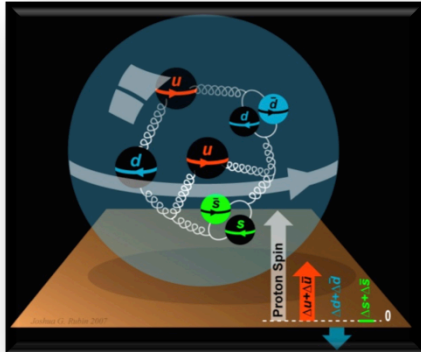


impact on \mathcal{H}



3D Parton Distributions: TMD

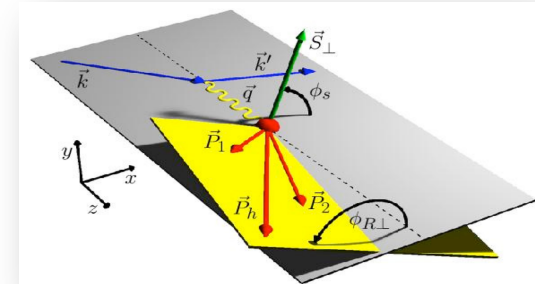
- Access orbital motion of quarks → contribution to the proton's spin



- DIS → $\Delta\Sigma \approx 0.25$
- RHIC + DIS → ΔG

$$\int_{0.05}^{0.2} \Delta g(x) dx = 0.1 \pm_{0.07}^{0.06}$$

- L_q



- TMDs accessible in semi-inclusive processes

		quark polarization		
		U	L	T
nucleon polarization	U	f_1		h_1^\perp Boer-Mulders
	L		g_{1L} helicity	h_{1L}^\perp worm-gear
	T	f_{1T}^\perp Sivers	g_{1T} worm-gear transversity	h_1, h_{1T}^\perp pretzelosity

- Observables: Azimuthal asymmetries due to correlations of spin q/n and transverse momentum of quarks

$$h_1^{\perp q}(x, k_T^2) \frac{(\mathbf{P} \times \mathbf{k}_T) \cdot \mathbf{S}_q}{M}$$

- Two major asymmetries:
 - Sivers: effect in distribution functions
 - Collins: effect in fragmentation functions

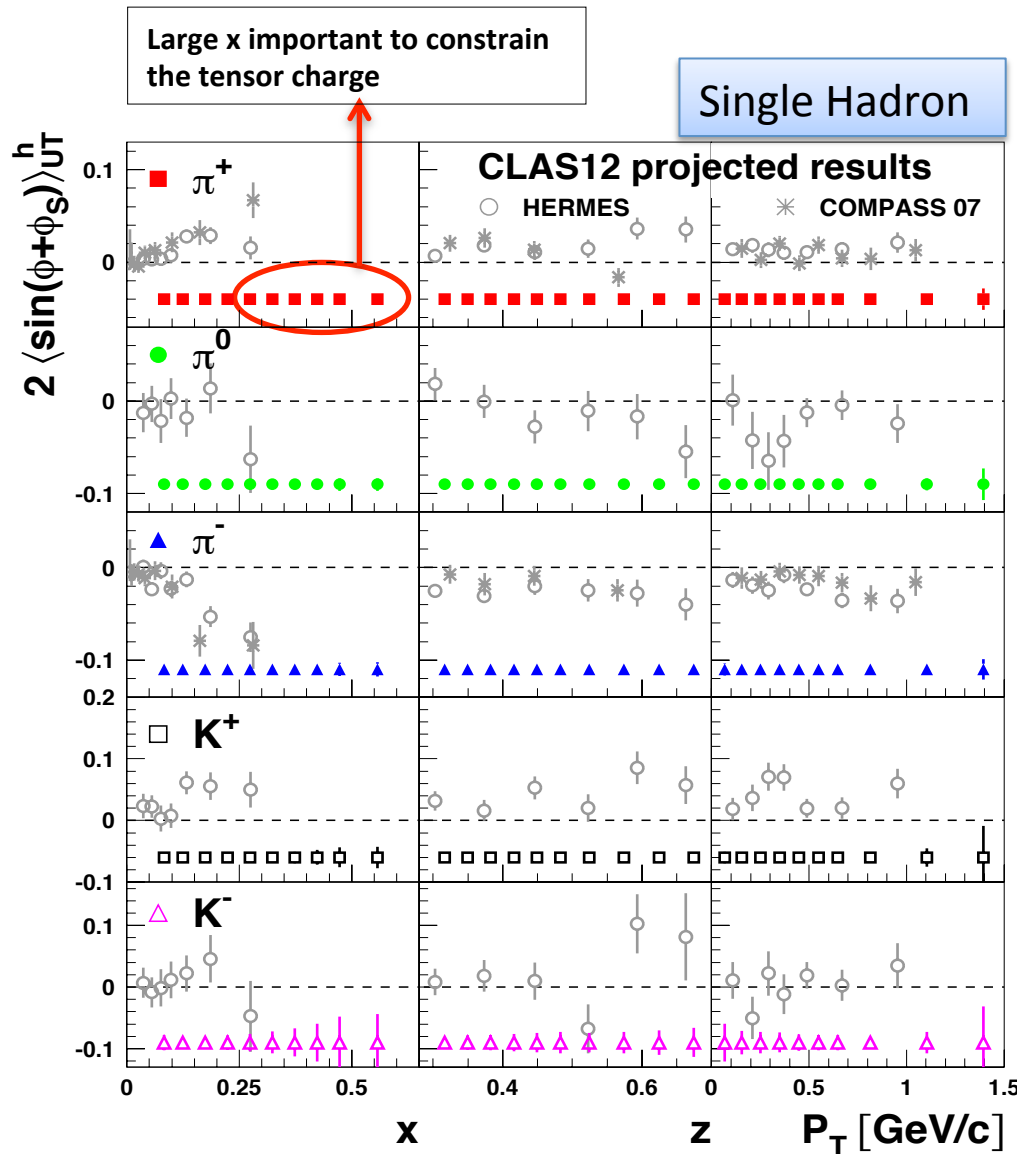
Transversity with CLAS12



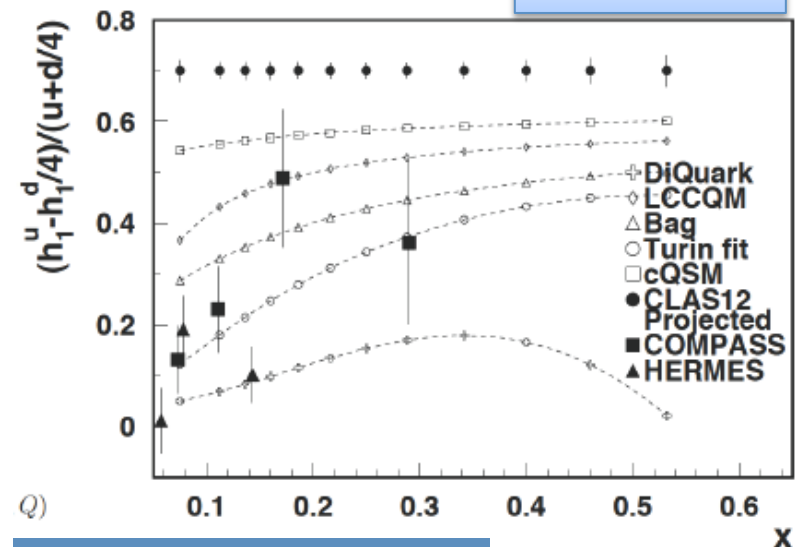
High Impact Exp. From PAC41
(C12-11-111 + C12-12-009)

N/q	U	L	T
U	f_1		h_1^\perp
L		g_1	h_{1L}^\perp
T	f_{1T}^\perp	g_{1T}^\perp	h_1^\perp h_{1T}^\perp

- HD-transversely polarized target and CLAS12



Di-hadron



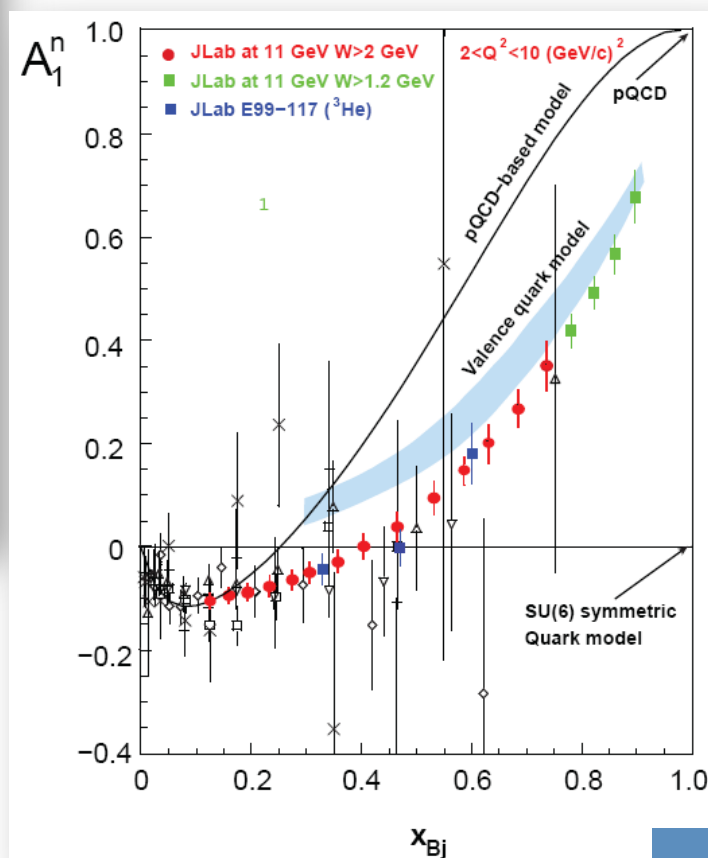
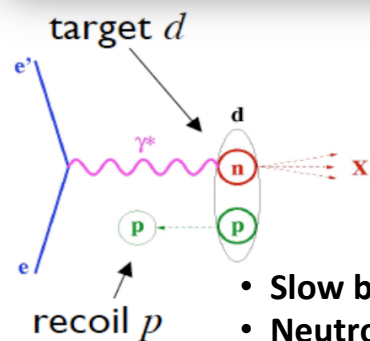
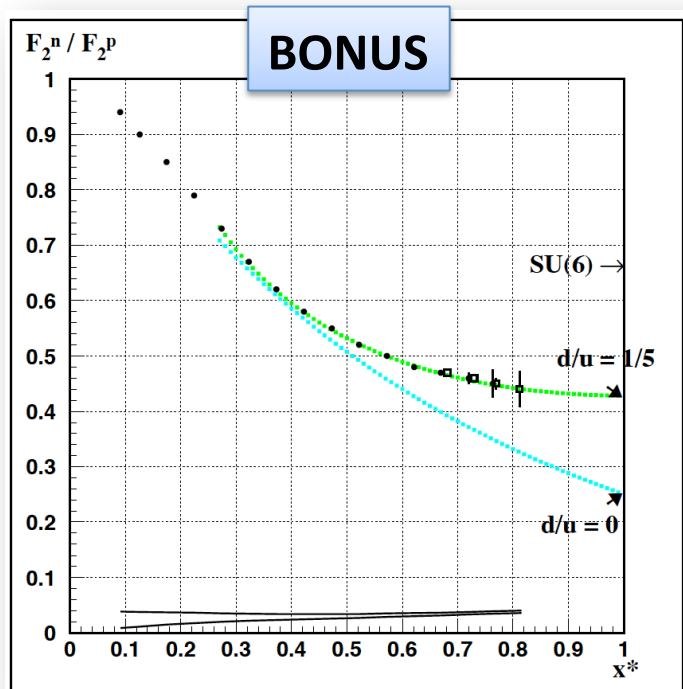
Not before 2017

PDFs in the limit $x \rightarrow 1$



High Impact Expts.

X $\rightarrow 1$ predictions	F_2^n/F_2^p	d/u	A_1^n	A_1^p
SU(6)	2/3	1/2	0	5/9
Diquark Model/Feynman	1/4	0	1	1
Quark Model/Isgur	1/4	0	1	1
Perturbative QCD	3/7	1/5	1	1
QCD Counting Rules	3/7	1/5	1	1



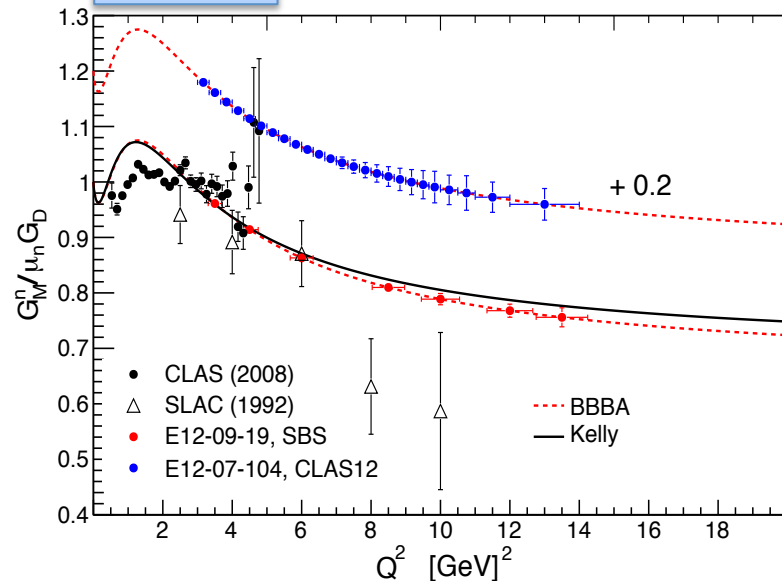
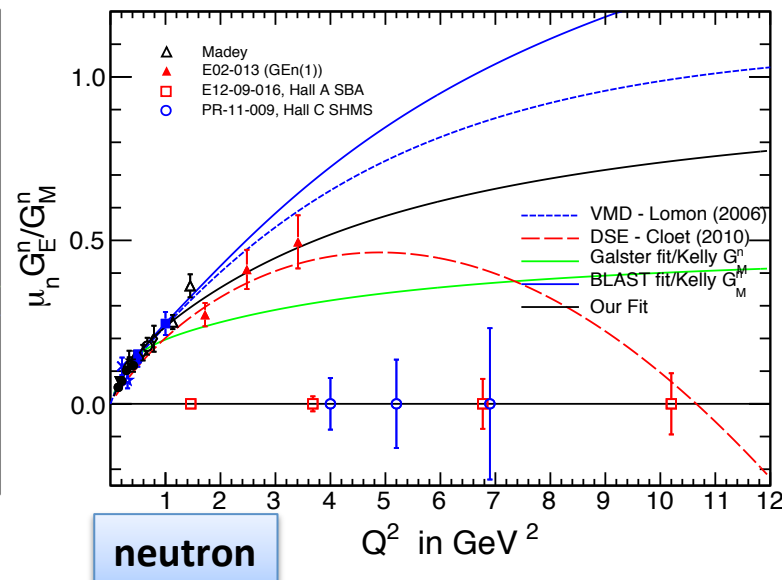
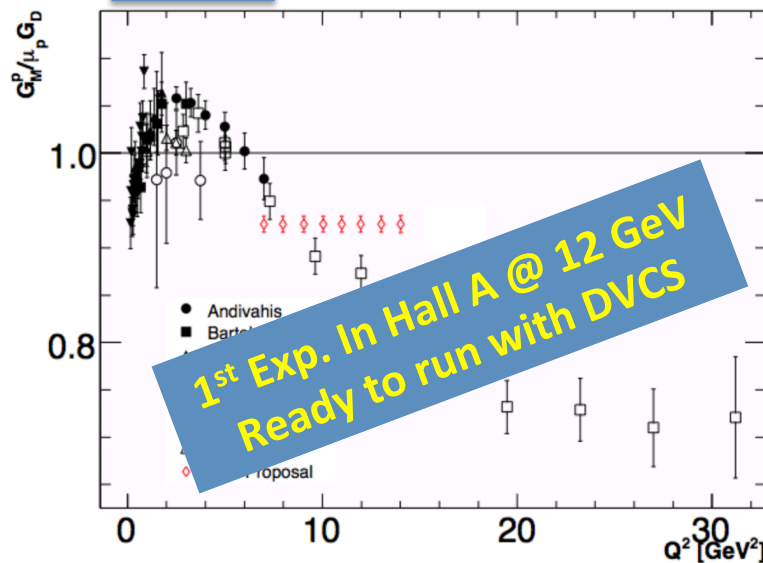
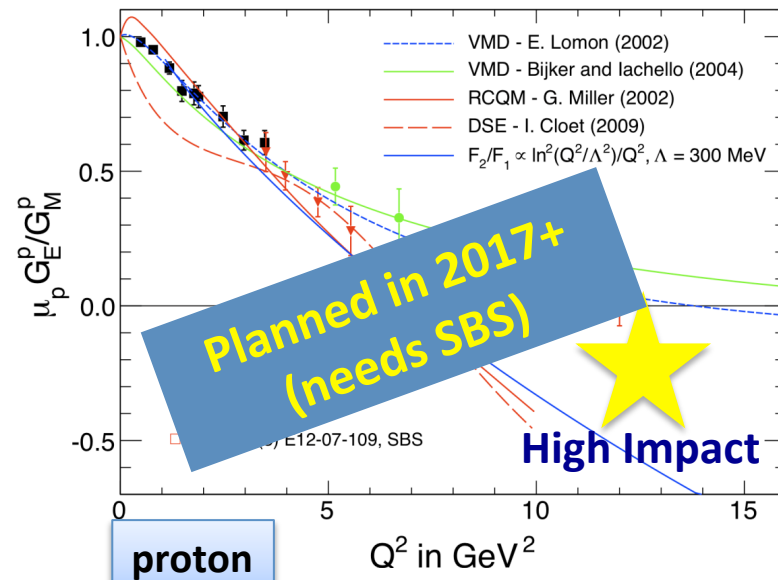
First precision data
above $x = 0.6$!

$0.3 < x < 0.77$
 $3 < Q^2 < 10 \text{ (GeV/c)}^2$

Wide Q^2 span
 \rightarrow explore possible
 Q^2 -dependence

One of the first
Experiment in Hall C

Nucleon e.m. Form Factors @ 12 GeV



3 expts

- G_E^p / G_M^p
- G_E^n / G_M^n

3 expts

- G_M^p
- G_M^n

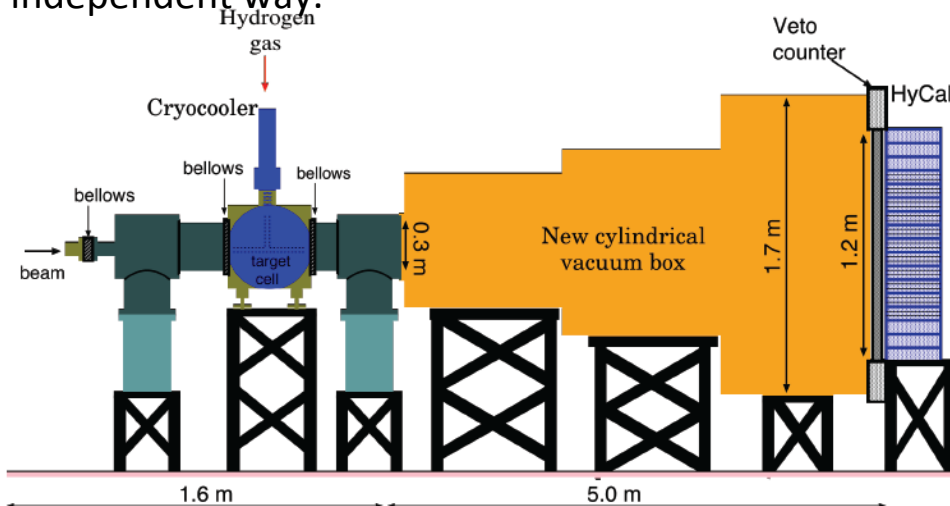
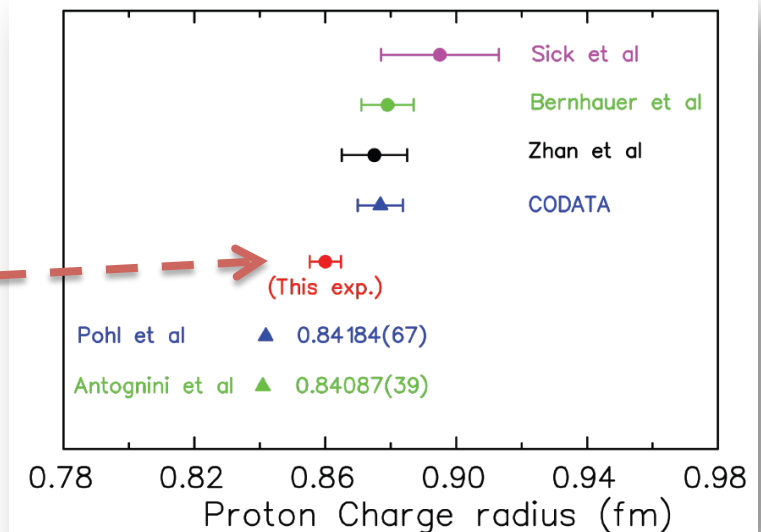
PRad Experiment : pre-CLAS12 Science

Proton Radius Puzzle



High Impact Exp. From PAC41

- Measurement of the proton charge radius from the Lamb shift in muonic hydrogen has given a value that is $\sim 7\sigma$ lower than the values obtained from energy level shifts in electronic hydrogen and from e-p scattering experiments
- The PRad experiment determines the e-p elastic cross section at very low Q^2 (10^{-4} to 10^{-2} GeV^2) by e.m. calorimetry only. The e-p cross sections will be normalized to the well known Møller cross sections measured simultaneously within the same detector acceptance \rightarrow reach a sub-percent precision of r_p in an essentially model independent way.



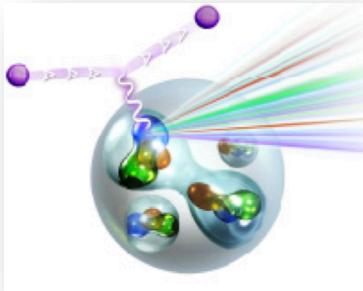
Experiment Preparation

- The HyCal is in Hall B and work on the crystals and readout is ongoing.
- Work on the vacuum box is underway.

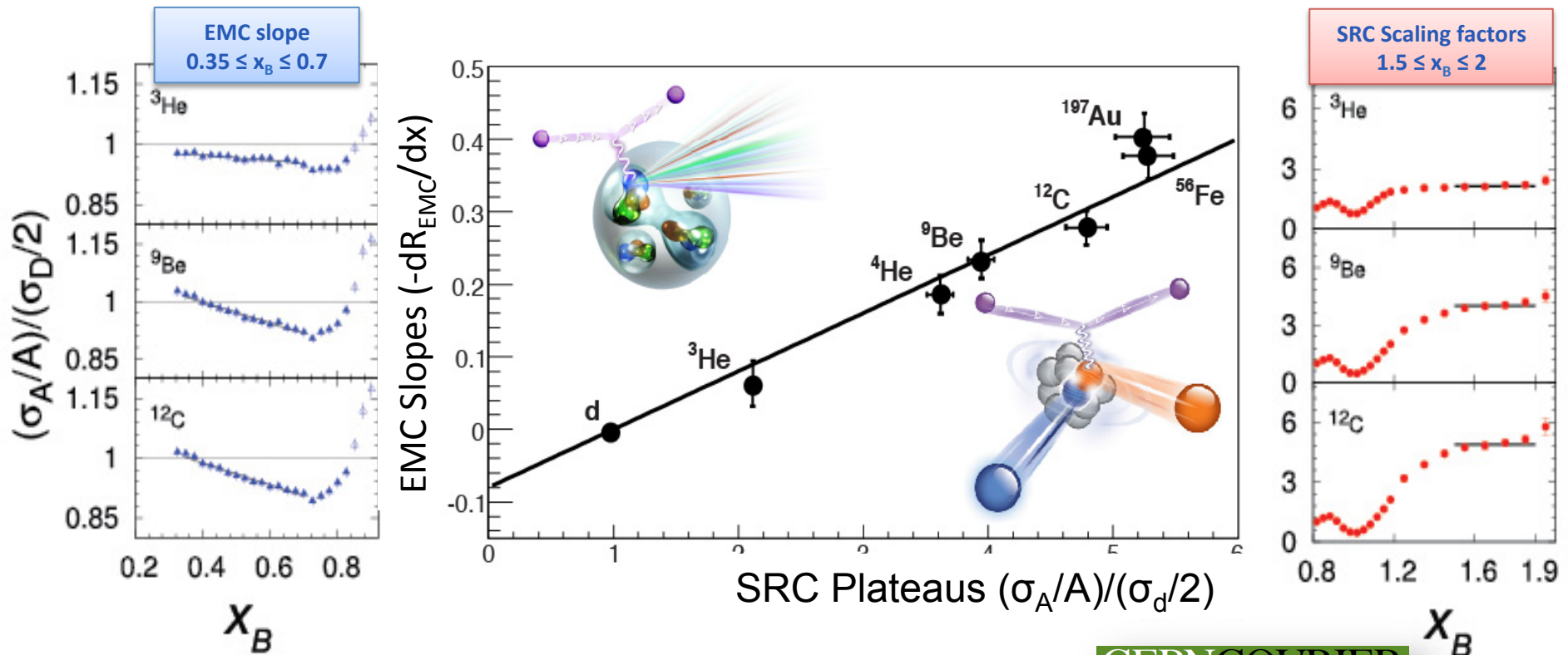
Not commit to having PRad ready for a run before Summer 2015

Physics Program

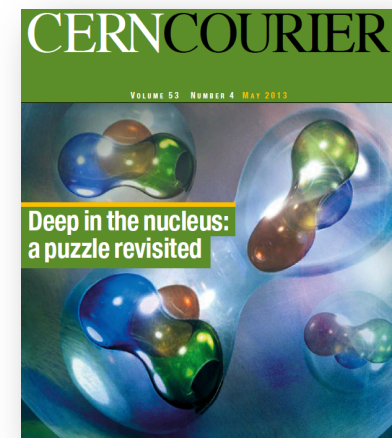
- Study the role of gluonic excitations in the spectroscopy of light mesons
- Measure the new multi-dimensional parton distribution functions (chase to the missing spin of the nucleon)
- Study the transverse structure of the hadrons (Elastic and transition Form Factors)
- **Study the relation between the short-range nuclear structure and the parton dynamics**
- Discover evidence for physics beyond the standard model of particle physics



Experimental SRC and EMC Correlation



- The data show that EMC effect slopes are proportional to the SRC plateaus.
- An intriguing possibility: the EMC effect and SRCs are both a consequence of the local QCD effects within the nucleus.

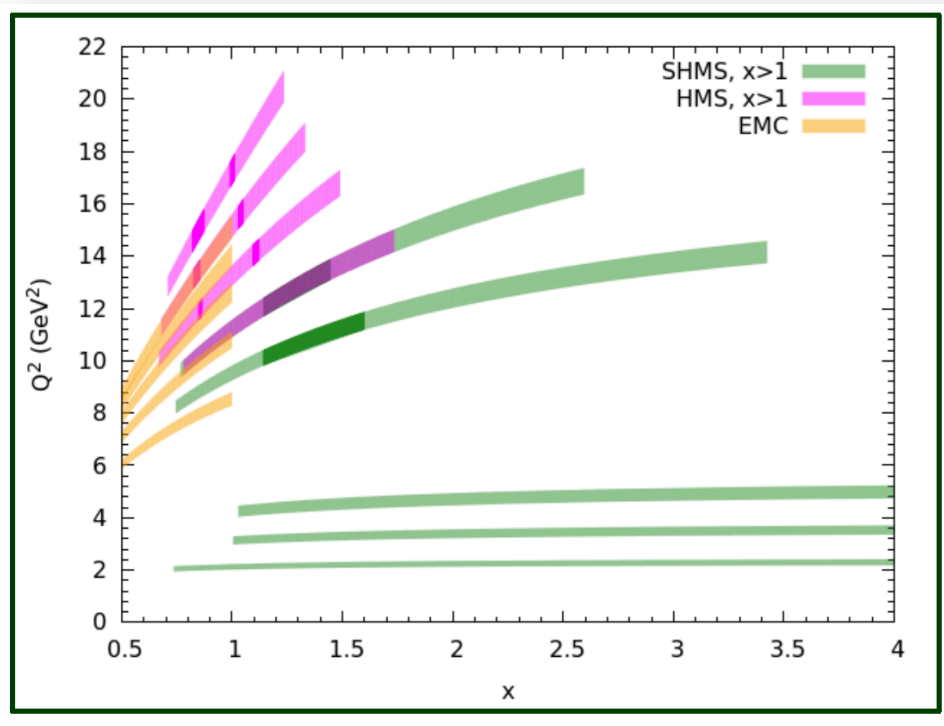


Systematic Studies of $x > 1$ Region



High Impact

E12-06-105: Inclusive Scattering from Nuclei at $x > 1$ in Quasi-Elastic and Deep Inelastic regime regimes
E12-11-112: Precision Measurement of the Isospin Dependence in 2N & 3N SRC regions.

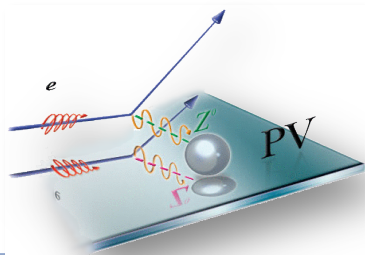


Kinematic reach of the **Hall C**
E12-06-105 measurements

- Measure wide range of kinematics
- Measure with many targets: D2, H3, He3, He4, Be, C, Cu, Au

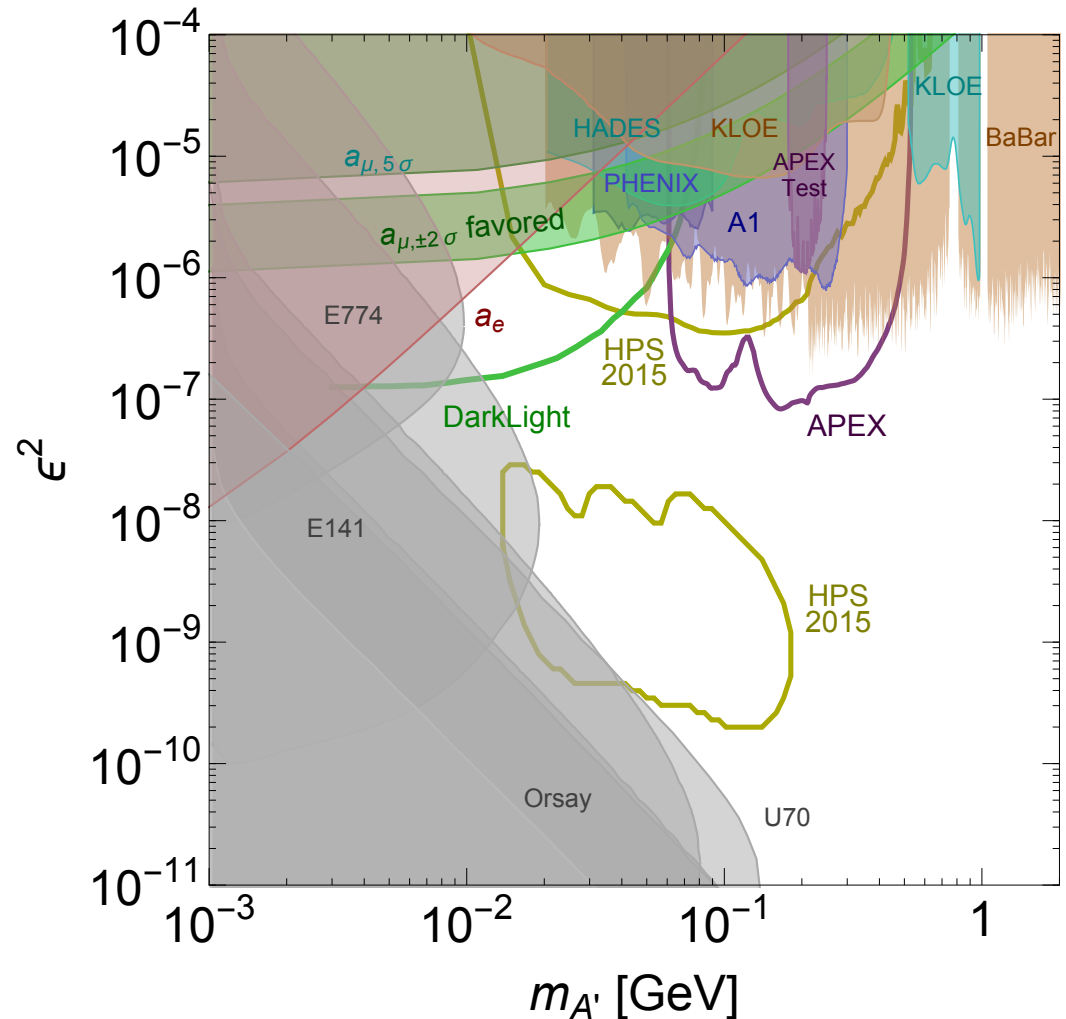
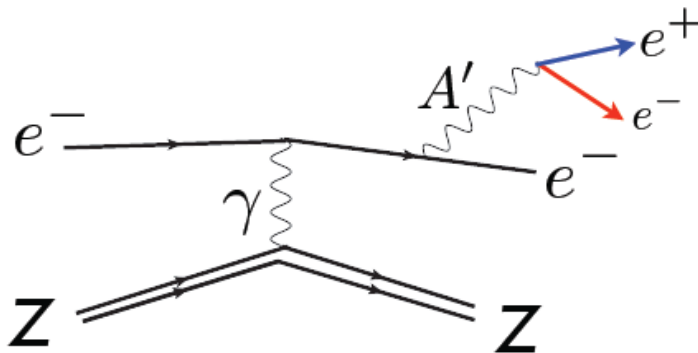
Physics Program

- Study the role of gluonic excitations in the spectroscopy of light mesons
- Measure the new multi-dimensional parton distribution functions (chase to the missing spin of the nucleon)
- Study the transverse structure of the hadrons (Elastic and transition Form Factors)
- Study the relation between the short-range nuclear structure and the parton dynamics
- **Discover evidence for physics beyond the standard model of particle physics**



Heavy Photon Search

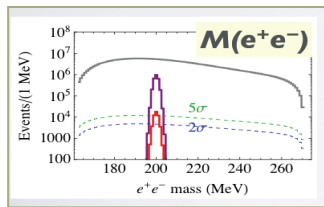
- **The astrophysical evidence for Dark Matter is compelling**, but so far, there's no proof that DM has been produced at colliders, or interacted with sensitive detectors
- **Heavy photons** can couple indirectly to regular electric charge by virtue of their mixing with *the* photon. Accordingly, they can be produced by, and decay into electrons and positrons.



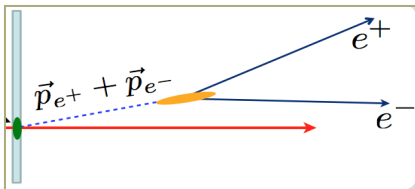
Heavy Photon Search: Hall A, Hall B & FEL

Heavy Photon Search (HPS) (Hall B)

Bump hunt region



Displaced decay vertex search



Ready for beam at the beginning of December

High Impact

High Impact

APEX (Hall A)

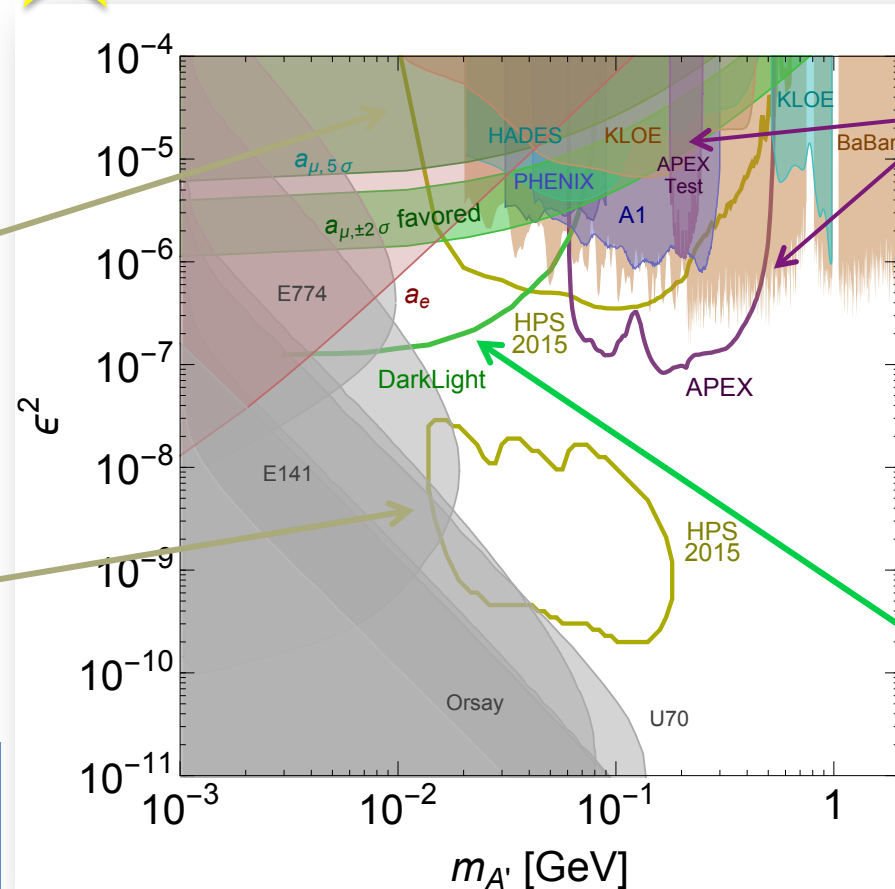
PRL107,191804 (2011)

e-N fixed-target, e^+e^- pair in **HRS focusing spectrometers**. Search for 50-500 MeV A' decaying promptly to e^+e^- pairs.

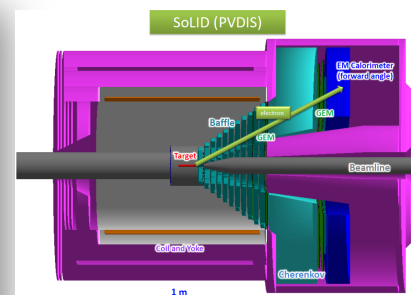
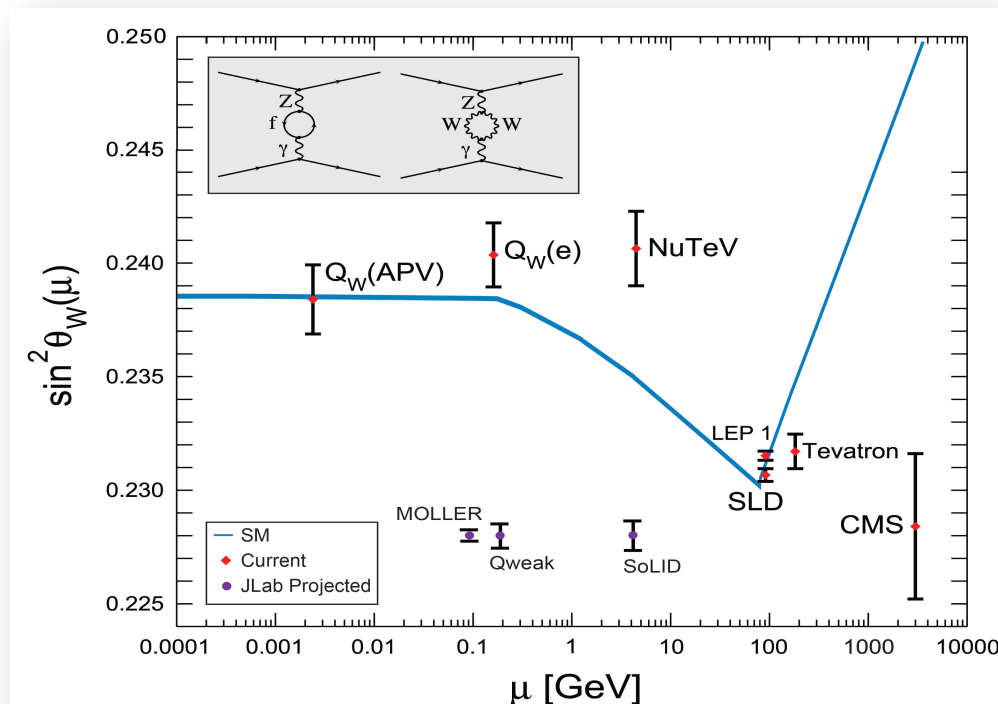
Planned in 2017+

DARKLIGHT (FEL)

Search for A' in “visible” $e^- p \rightarrow e^- p A', A' \rightarrow e^+e^-$
“invisible” decay modes $e^- p \rightarrow e^- p A', A' \rightarrow inv.$



Parity violating Experiments

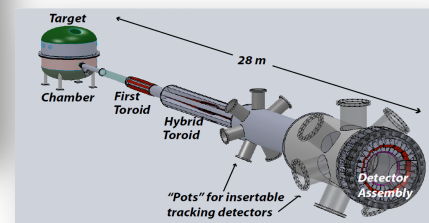


SoLID Parity-violating DIS (PVDIS)

$$A_{PV} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha} [a(x) + Y(y)b(x)]$$

weak coupling $\sim C_{2q}$

- pre-CDR submitted to JLab management
- CLEO solenoid committed



MOLLER

Purely leptonic
interaction at low
energy

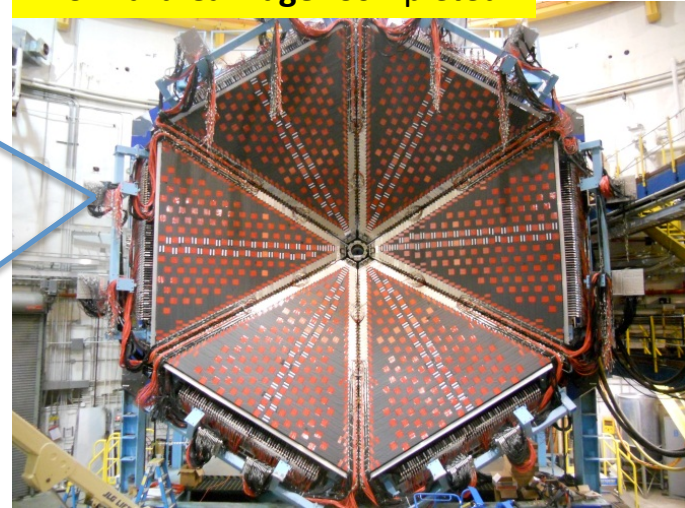
$$A_{PV} = mE \frac{G_F}{\sqrt{2}\pi\alpha} \frac{4 \sin^2 \theta}{(3 + \cos^2 \theta)^2} Q_W^e$$

$$\sim 1 - 4 \sin^2 \theta_W$$

- **MOLLER Science Review on September 2014**
- **Positive outcome**
 - the panel strongly supported making the proposed
 - collaboration looking forward to the final report and to moving forward to a technical cost and schedule review.

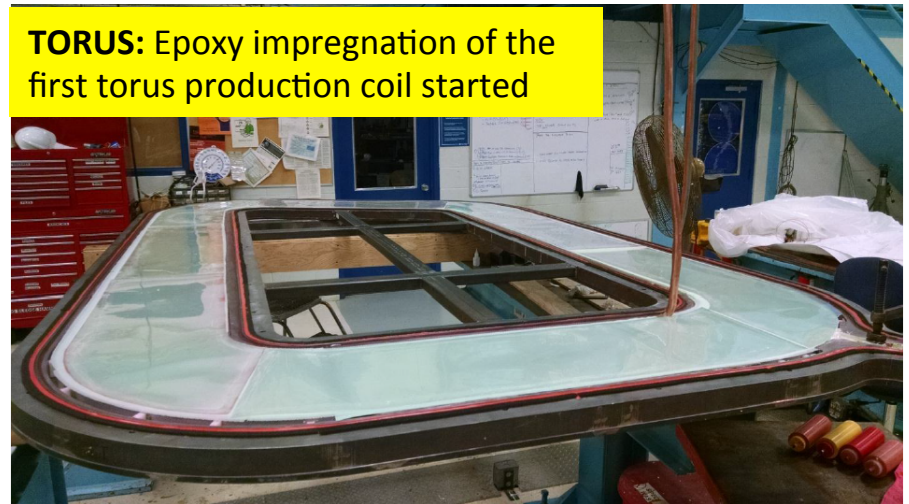
Hall B:CLAS12 Status

Forward Carriage: Completed



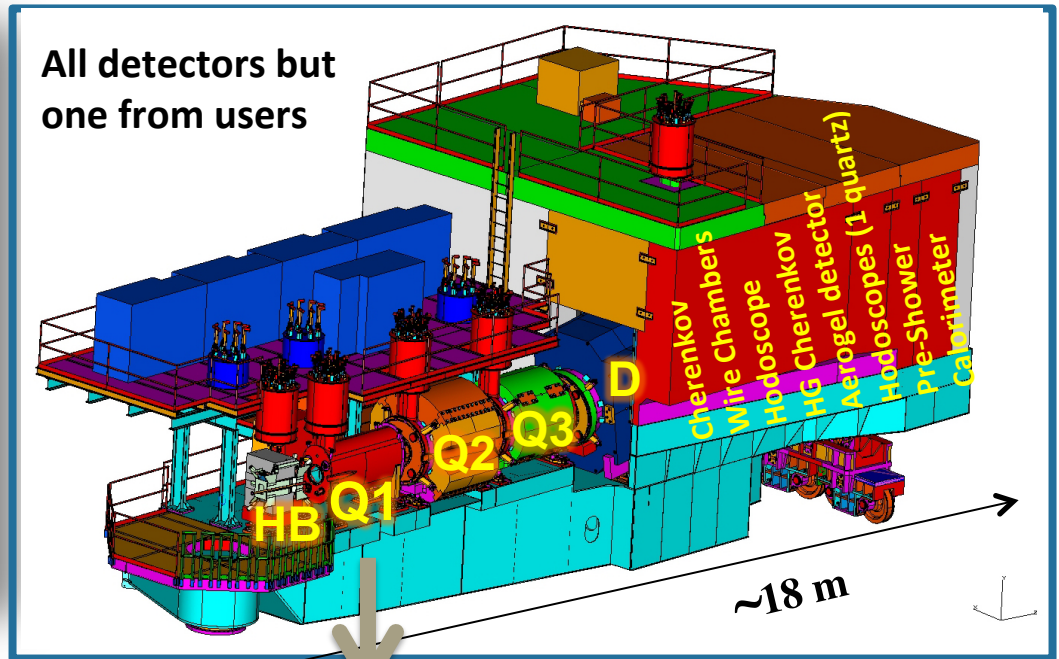
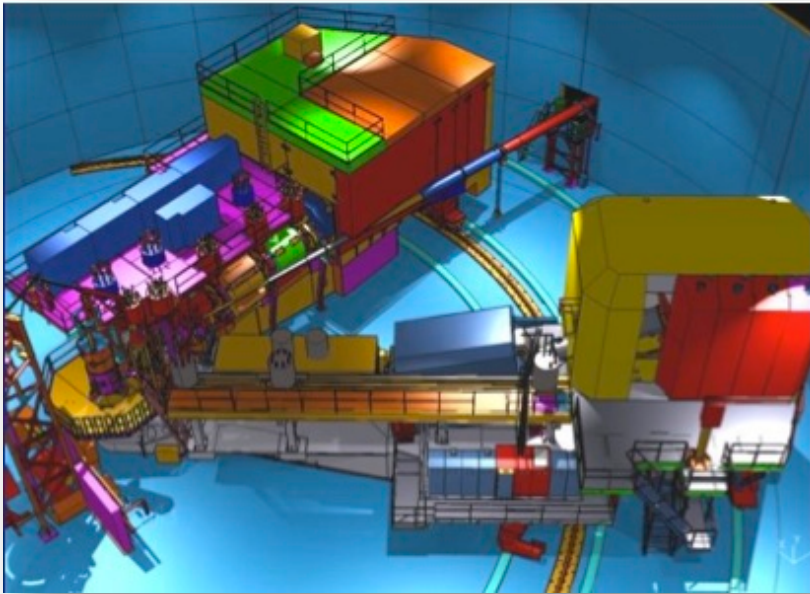
Hall B 74% complete

TORUS: Epoxy impregnation of the first torus production coil started



- Schedule driven by the two superconducting magnets (completion february/march 2016)
- Commissioning of the Hall planned for late spring 2016

Hall C: SHMS Status

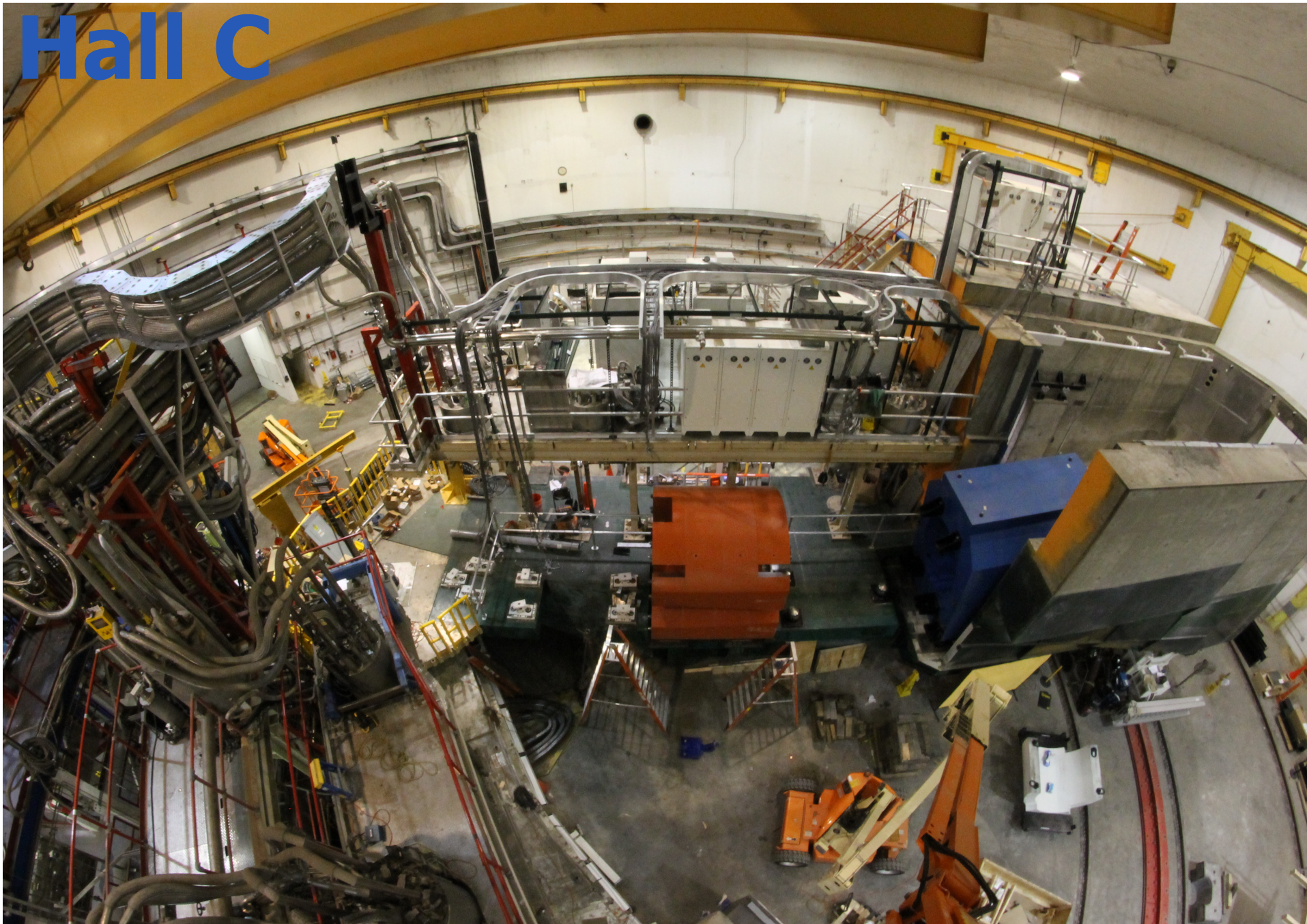


Hall C 74% complete

- All Detectors (but one) & Stands: Finished, Tested, Ready to Install
- Schedule driven by the superconducting magnets (last one will be delivered on Dec 2015)
- Commissioning of the Hall planned for spring 2016



Hall C



The Long Range Plan

- US Nuclear Physics Long Range Plan:
 - Charge assigned on April 2014
 - Report due by **October 2015**
- QCD Town Meetings Recommendations:

Recommendation 1:

Our highest priority recommendation is the **completion of construction and robust operation of the 12 GeV CEBAF** facility at Jefferson Lab, along with targeted instrumentation investments such as the **MOLLER and SoLID projects**, to fully realize its scientific potential

Recommendation 2:

A high luminosity, **high energy polarized Electron Ion Collider (EIC)** is the highest priority of the U.S. NP QCD community for future new construction (*voted jointly with Phases of QCD community*)

EIC Jefferson Lab Design

4



- 12 GeV CEBAF is electron injector
- e-p/A : A above 200 (Au, Pb) - p, d, ^3He pol.
- low x: $x \rightarrow 0.0001$
- high polarization: $> 70\%$
- high luminosity: $10^{34} \text{ cm}^{-2}\text{s}^{-1}$
- Initial configuration (MEIC):
 - 3-12 GeV on 20-100 GeV ep/eA collider
- Upgradable to higher energies (20x250)

Summary & Outlook

The 12 GeV science is about to start!

- 1) The CEBAF accelerator upgrade is now a reality: the first beam of the 12 GeV era has been delivering to Hall A, B, D.
- 2) The first experiment schedule has been released.
- 3) In Hall D, commissioning run is in place: very exciting after about 15 years of efforts!!!
The current focus: making sense of the data which come soon.
- 4) In Hall A, equipment is on the floor to execute together both a 3rd generation DVCS experiment, to validate the formalism towards 3D spatial imaging in the simplest process, and a precision measurement of elastic e-p cross section.
- 5) In Hall B, the Heavy Photon Search experiment is ready for taking beam beginning of December. Working is in progress to install the Proton Radius experiment.
- 6) The CLAS12 detector in Hall B and SHMS in Hall C are completed at 74%. Commissioning of the two detectors are foreseen in spring 2016.
- 7) Two major installations in Hall A, SoLID and MOLLER, are moving forward.
- 8) Jefferson Lab has been working for a next generation of Electron Ion Collider.