The CLAS12 Program at Jefferson Lab

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Outline

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  - Nucleon Structure
  - Meson Spectroscopy
  - Hybrids and Exotics
  - Photoproduction and the Forward Tagger
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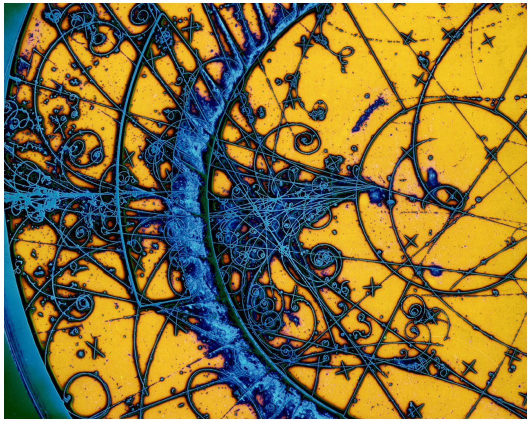
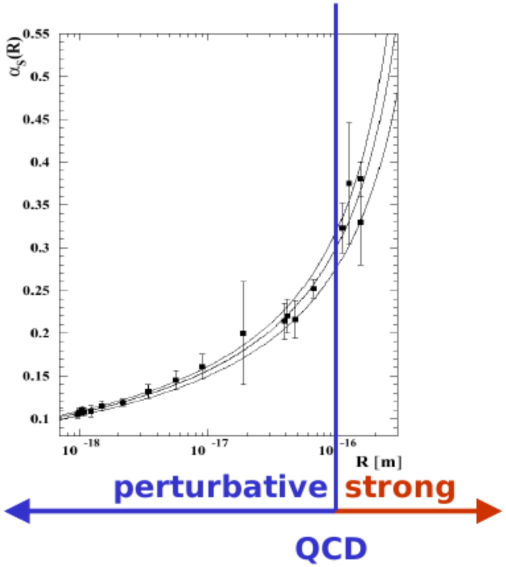
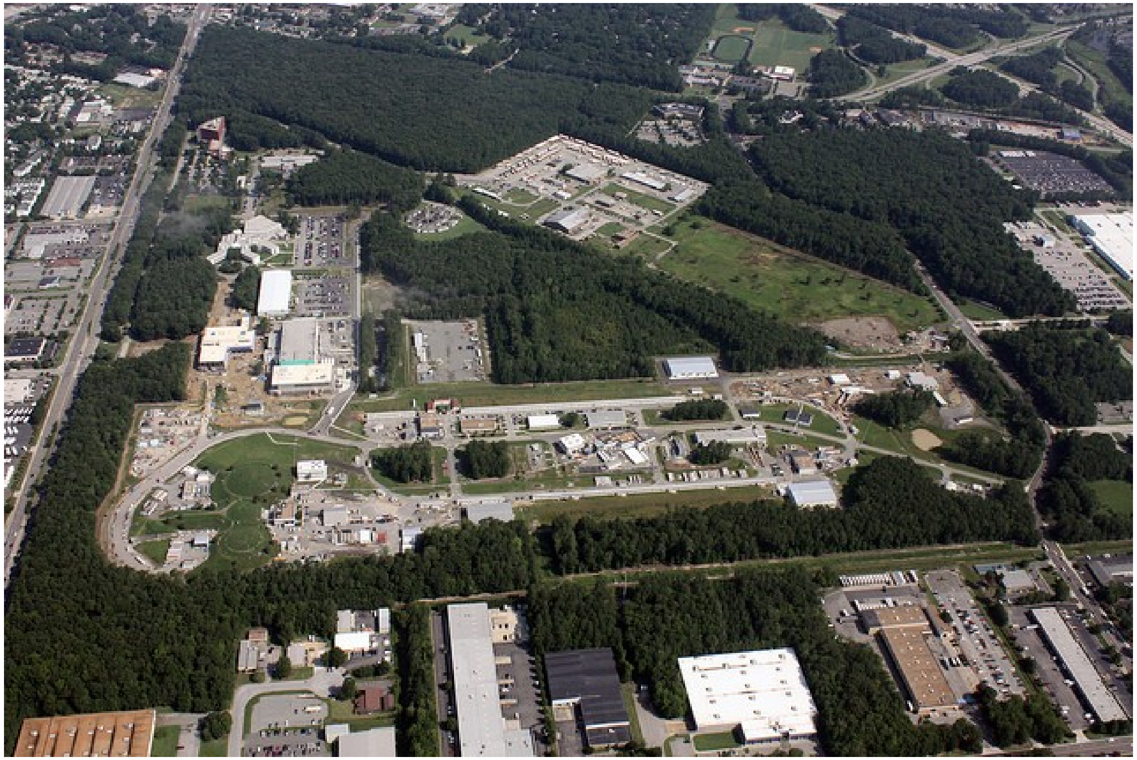
Introduction



- From its roots in the experimental particle physics of the 1950's and 60's, the development around 40 years ago of the theory of QCD has provided a powerful tool in our understanding of strong force interactions, confinement, and the structure of hadrons
- At high energies, this theory has had great success in describing interactions, as the small QCD coupling constant makes the interaction easier to calculate
- At lower energies, this constant approaches unity and perturbative methods, used in the high energy regime, no longer hold
- With the recent development of new theoretical and experimental tools, an opportunity to gain new insights into the spectrum and structure of hadrons is almost upon us
- The forthcoming 12 GeV upgrade at Jefferson Lab is one such facility that will enable further exploration of the Standard Model in this direction, but first a little history...



A Short History of Jefferson Lab



- Jefferson Lab is a US Department of Energy national facility, located in Newport News, Virginia
- It began life in 1984, taking the initial name CEBAF, after its centrepiece, the Continuous Electron Beam Accelerator Facility

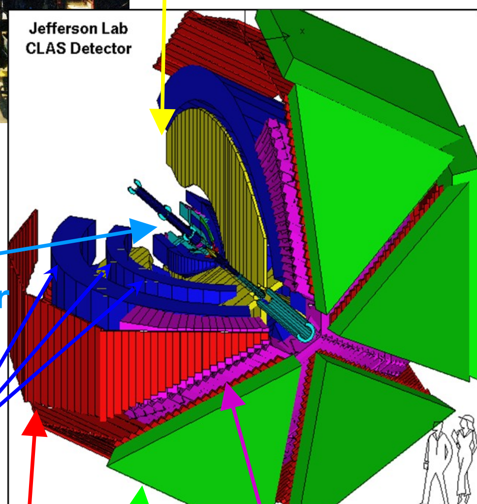
- CEBAF is a multi-pass (up to 5 passes) racetrack accelerator, 7/8 of a mile in circumference
- Utilises superconducting radio-frequency technology in an anti-parallel, double linac configuration to produce and deliver beam to three experimental halls

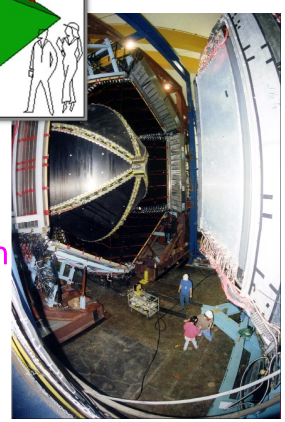
INFN Jefferson Lab

A Short History of Jefferson Lab

- These three halls, imaginatively designated A, B and C, house a variety of experimental equipment, optimised for studying different aspects of the atomic nucleus
- By the end of its initial phase of operation (1995 - 2012) CEBAF was capable of delivering highly polarised, high-quality electron beams of up to 6 GeV simultaneously to up to three experimental halls
- The halls need not receive the same energy, and with delivered beam currents ranging from a few tens of nA (Hall B), to order 100 μA (Halls A & C), CEBAF has proved to be a very capable and versatile machine

Hall B and CLAS

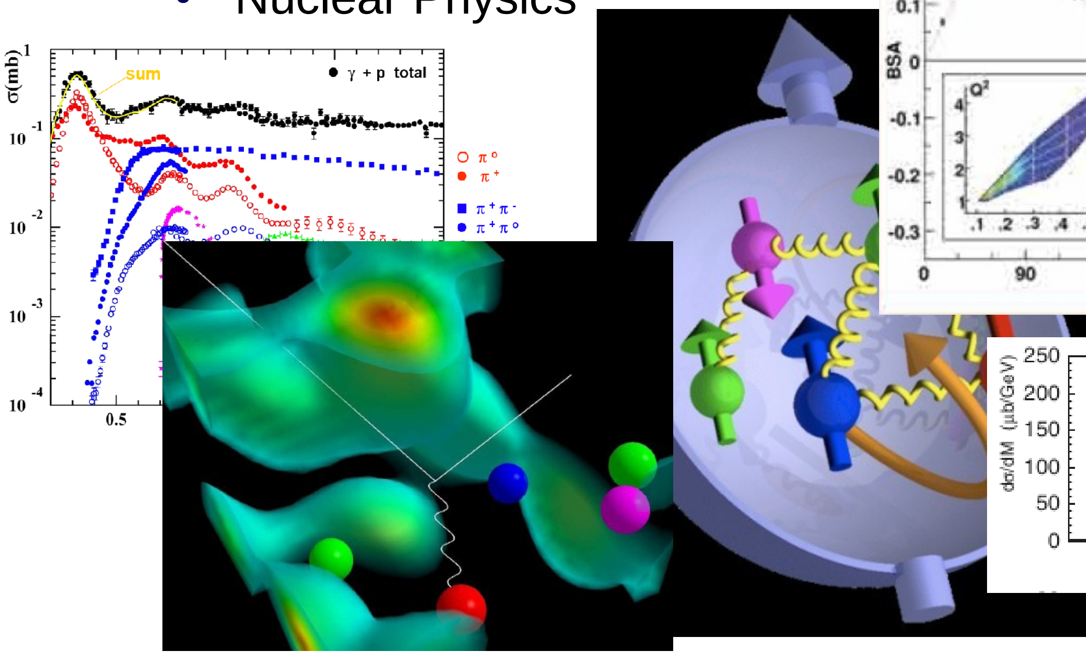


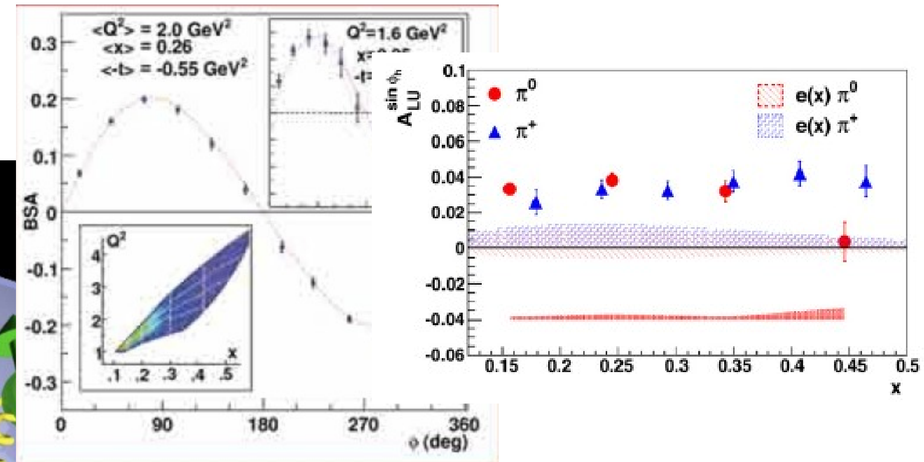


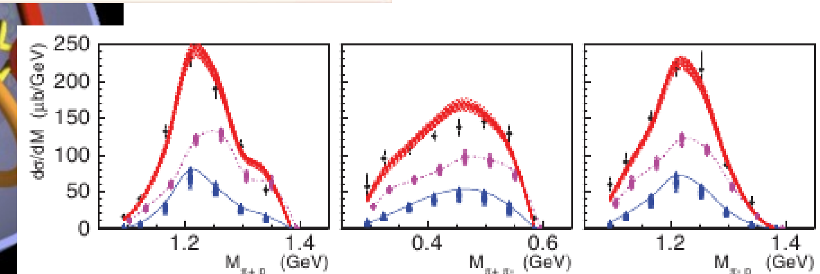
- Hall B is the smallest of the three halls, and in the 6 GeV era contained CLAS – the CEBAF Large Acceptance Spectrometer
  - CLAS combined a toroidal magnetic field with a multi-layered and segmented arrangement of various particle detection systems
  - The CLAS experimental program exploited the advantages this design offered, including;
    - Large acceptance coverage
    - Good momentum resolution
    - Operation with high luminosity beams (compared to other large acceptance facilities)
    - Polarised photon and electron beams
    - Operation with polarised targets

Physics at 6 GeV with CLAS

- In the 6 GeV era, CLAS was used in an extensive program of photo- and electroproduction experiments, investigating numerous topics, including;
  - Nucleon structure
  - Hadron spectroscopy
  - Nuclear Physics



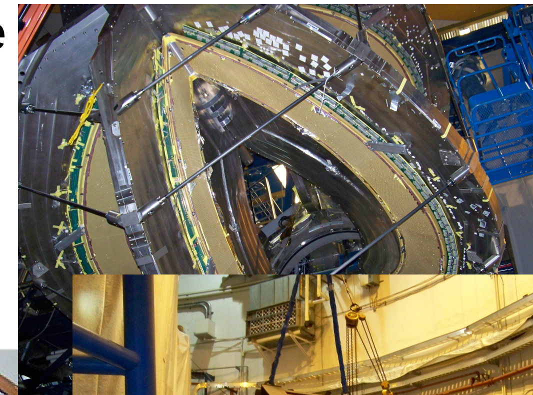


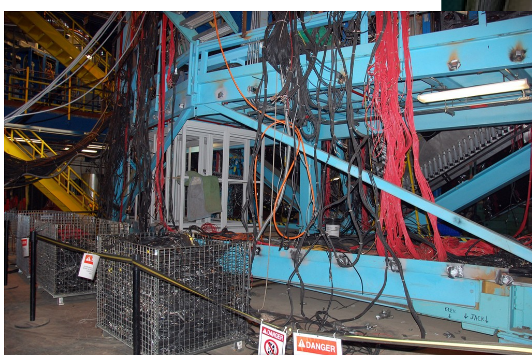


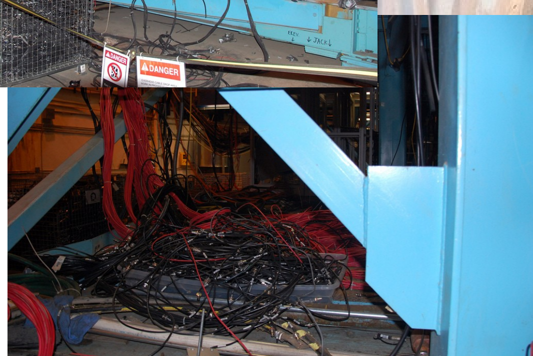
- Experimental running may be at an end with CLAS, but there is still data to be analysed and physics to extract

CLAS Today

- With the end of 6 GeV running, CLAS is now in the process of being dismantled
- A time-consuming process, involving the removal of kilometres of cabling, opening the CLAS clamshell, disconnecting detector subsystems and removal from hall, dismantling of support structures, etc.

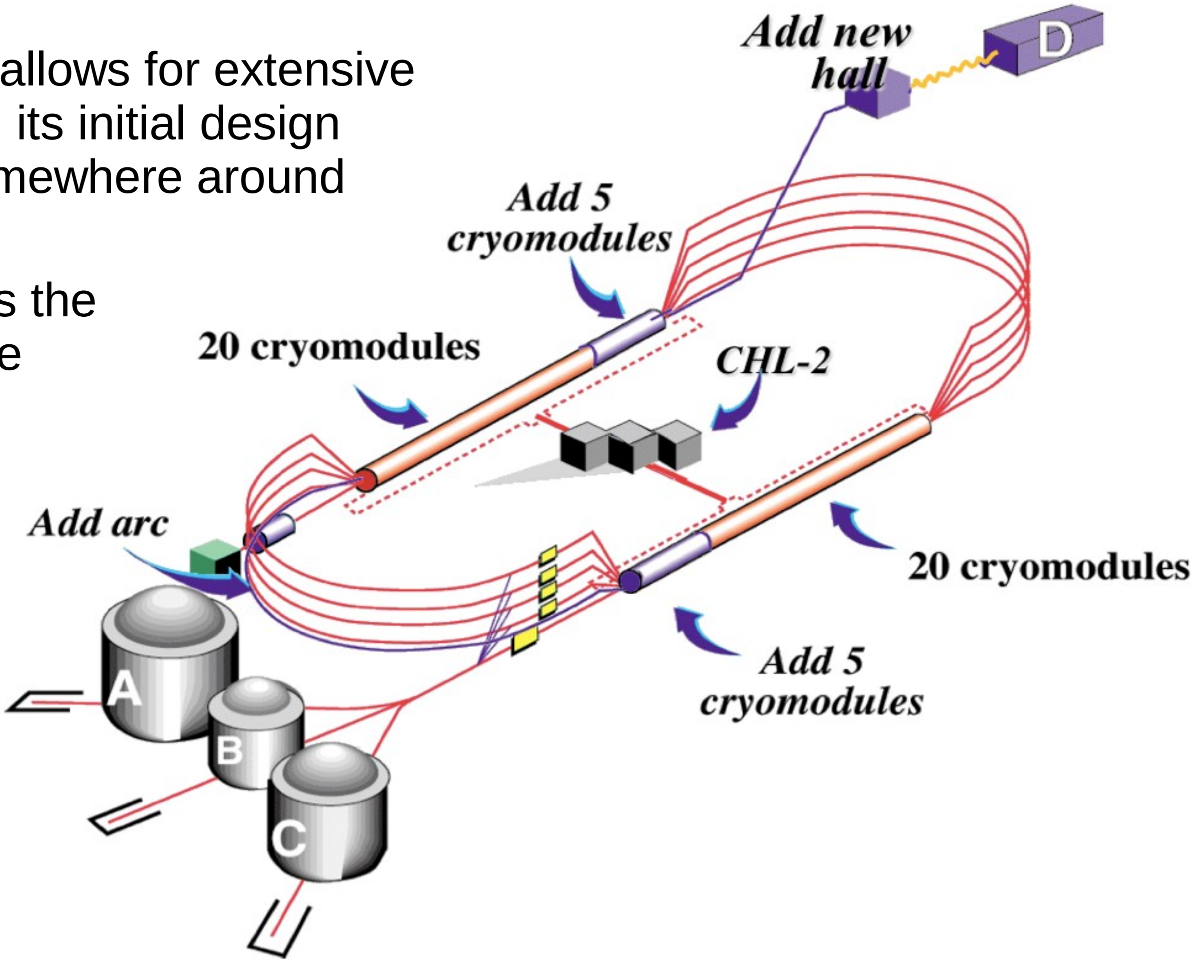




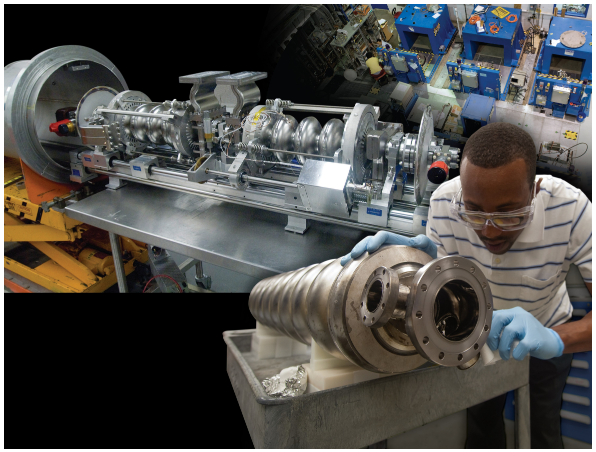


The 12 GeV Upgrade

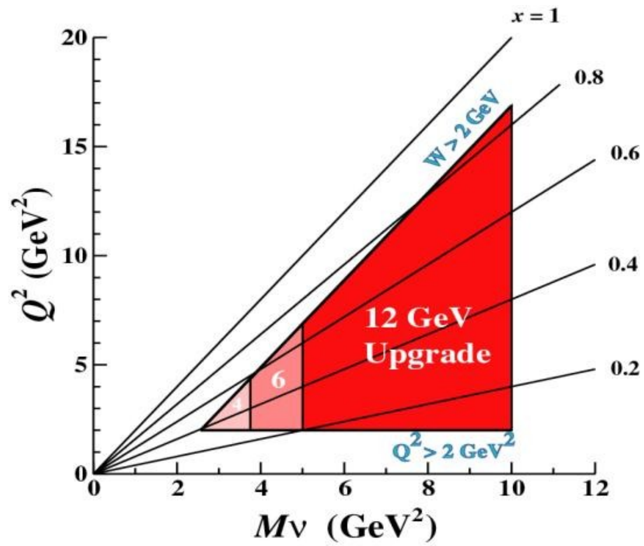
- The design of CEBAF allows for extensive energy upgrades, from its initial design energy of 4 GeV to somewhere around 25 GeV
- The 12 GeV upgrade is the first such upgrade to be performed at the lab (6 GeV beam was coaxed out of the original 4 GeV design energy by improvements in accelerator technology and cryogenic efficiency)

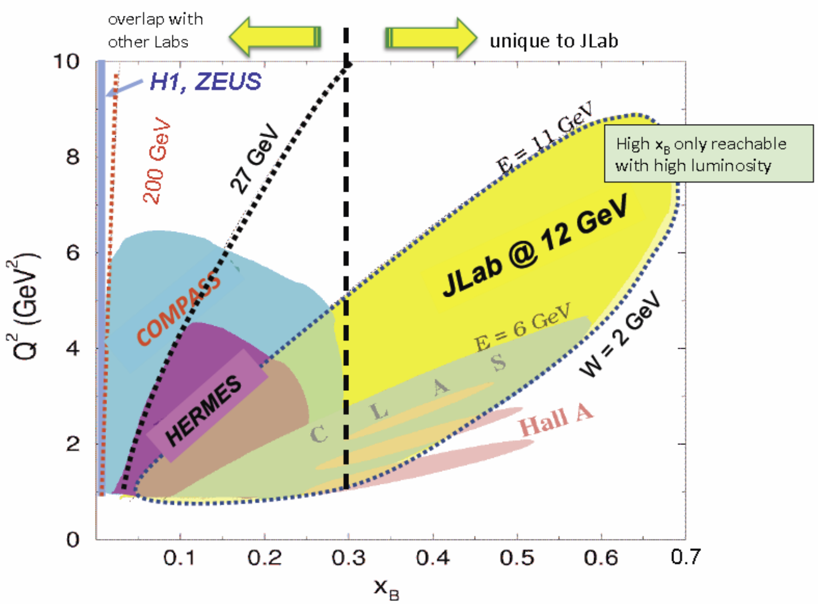


The 12 GeV Upgrade



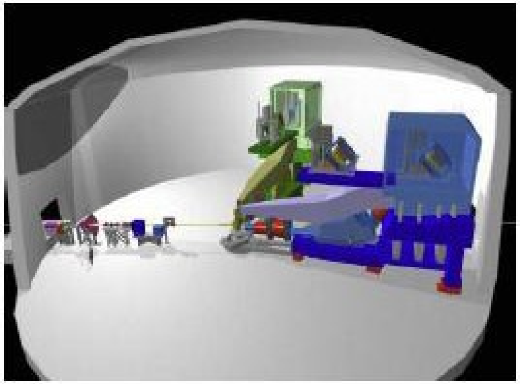
- The existing accelerator cavities will be reconditioned, and complemented by additional cavities in order to increase the energy gained in each pass through the accelerator
- The upgraded accelerator will deliver 12 GeV electron beam to Hall D, with Halls A, B and C receiving 11 GeV, greatly extending the kinematic range available for experiments

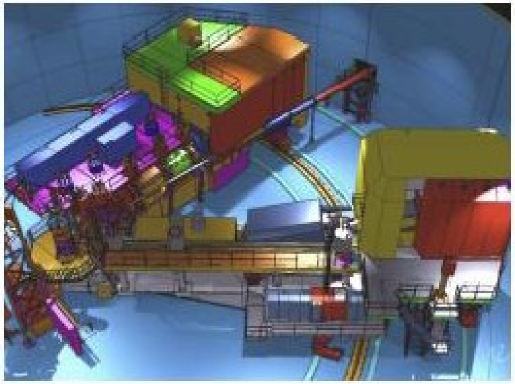




The 12 GeV Upgrade

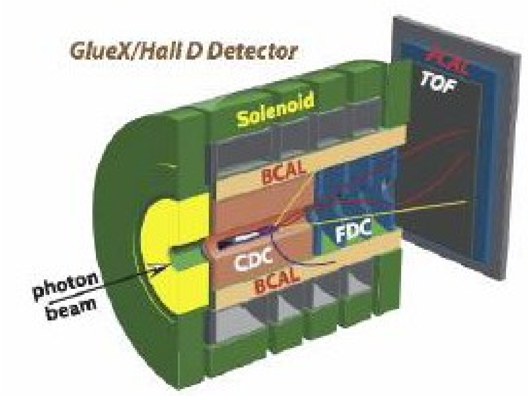
- CEBAF will retain the ability to deliver beam simultaneously to multiple halls, at varying energy and current





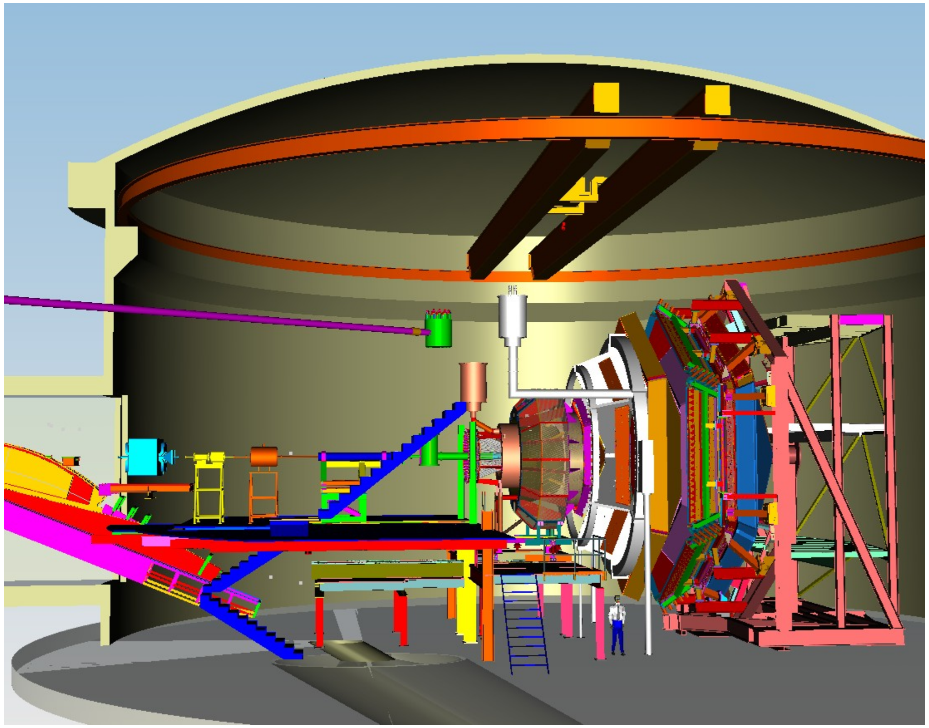
- Halls A and C will receive upgrades to their experimental equipment to exploit the higher beam energies available

- A new experimental hall, Hall D, has been constructed, where tagged photon beams will be created from the CEBAF electron beam for hybrid meson searches, and studies of meson and baryon spectroscopy
- And as for Hall B...

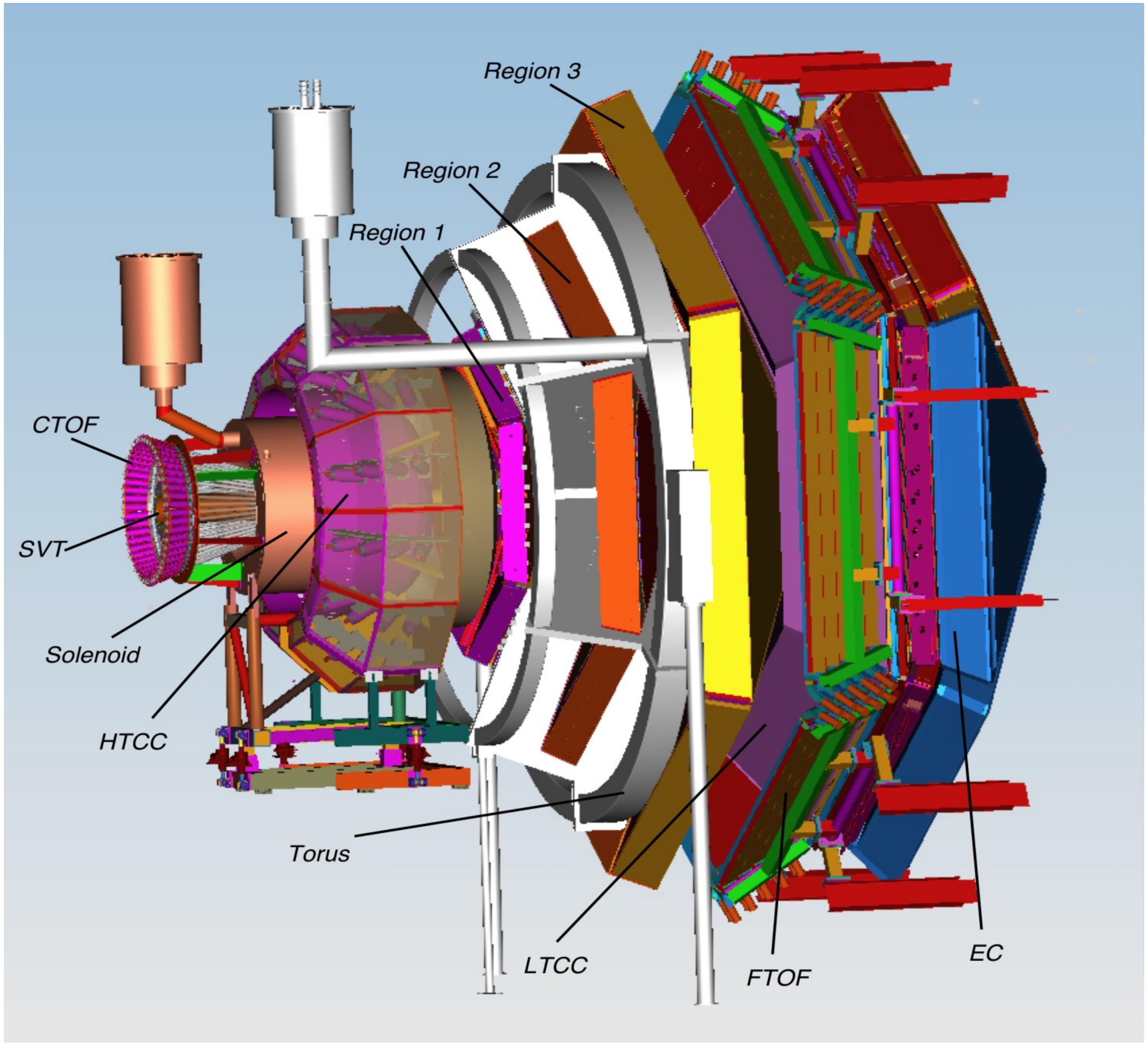


CLAS12

- In order to take full advantage of the 12 GeV post-upgrade beam from CEBAF, CLAS is in the process of being extensively upgraded and can be considered as an entirely new detector
- CLAS12 will comprise two new detector systems working together; a forward detector based upon a toroidal magnetic field (cf. CLAS), and a central detector based around a solenoid
- The forward detector will re-use some existing CLAS hardware, including the electromagnetic (EM) calorimeter, part of the forward time of flight (TOF) wall and the existing Cerenkov detector
- CLAS12 will be able to operate at ten times the luminosity of CLAS, with large acceptance for the kinematics of the upgraded CEBAF beam



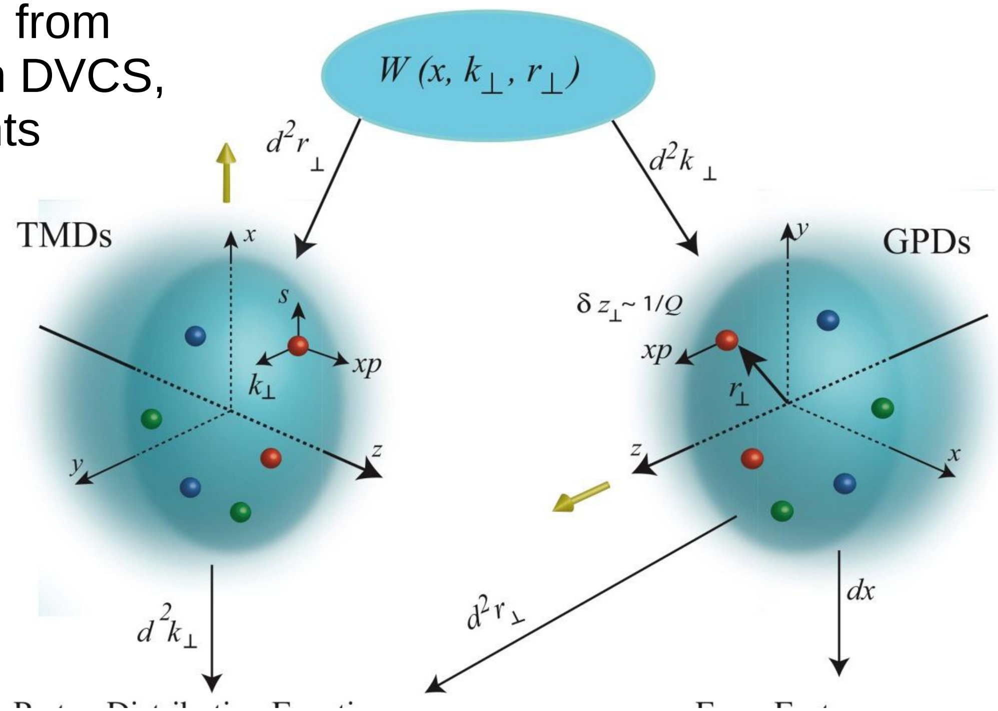
Physics with CLAS12



- An extensive program of experiments has been proposed for CLAS12, building on the successes at 6 GeV and exploiting the new capabilities of CEBAF and CLAS12
- CLAS12 has been built with a new generation of experiments in DVCS and DIS in mind, but its capabilities are also useful for experiments in spectroscopy and nuclear physics

Nucleon Structure

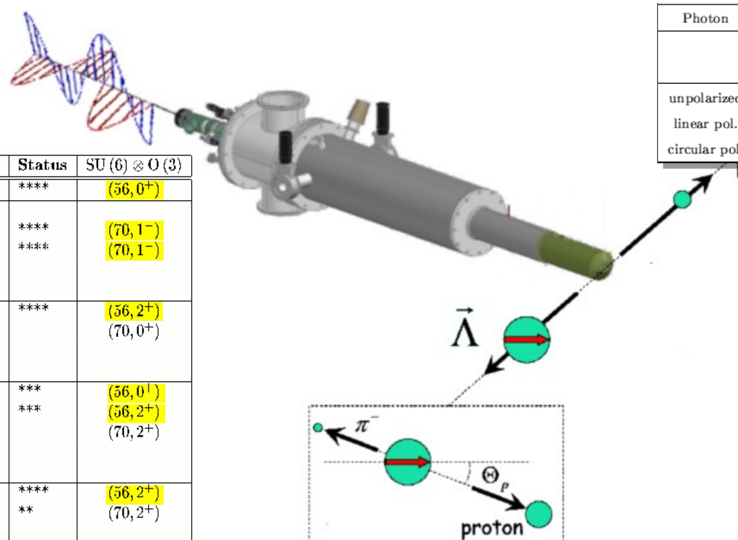
- In order to gain an understanding of nucleon structure at the level of quarks and gluons, two kinds of quantity have been identified for study
  - Generalised Parton Distributions (GPDs), providing spatial information
  - Transverse Momentum Distributions (TMDs), for momentum tomography
- These quantities are derived from experimental observations in DVCS, DVMP and SIDIS experiments
- By combining the information contained in these distributions, it should be possible to obtain a 3-dimensional picture of the nucleon in position and momentum space
- CLAS12 is ideally suited to studying these reactions, with its large acceptance and ability to detect multi-particle final states



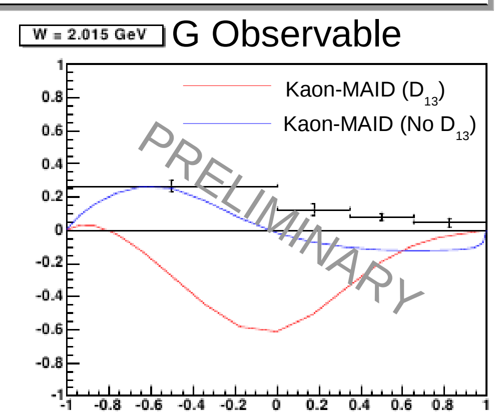
Photoproduction and Spectroscopy

- Spectroscopy was one of the cornerstones of the CLAS experimental program at 6 GeV, for the most part using the secondary photon beam available to the hall
- For example, the N* program performed at the lab studied the nucleon resonance spectrum using polarised photon beams and targets

Photon		Target				Recoil			Target + Recoil		
	–	–	–	–	x'	y'	z'	x'	x'	z'	z'
	–	x	y	z	–	–	–	x	z	x	z
unpolarized	σ_0	0	T	0	0	P	0	$T_{x'}$	$-L_{x'}$	$T_{z'}$	$L_{z'}$
linear pol.	$-\Sigma$	H	(-P)	$-G$	$O_{x'}$	(-T)	$O_{z'}$	$(-L_{z'})$	$(T_{z'})$	$(-L_{x'})$	$(-T_{x'})$
circular pol.	0	F	0	$-E$	$-C_{x'}$	0	$-C_{z'}$	0	0	0	0



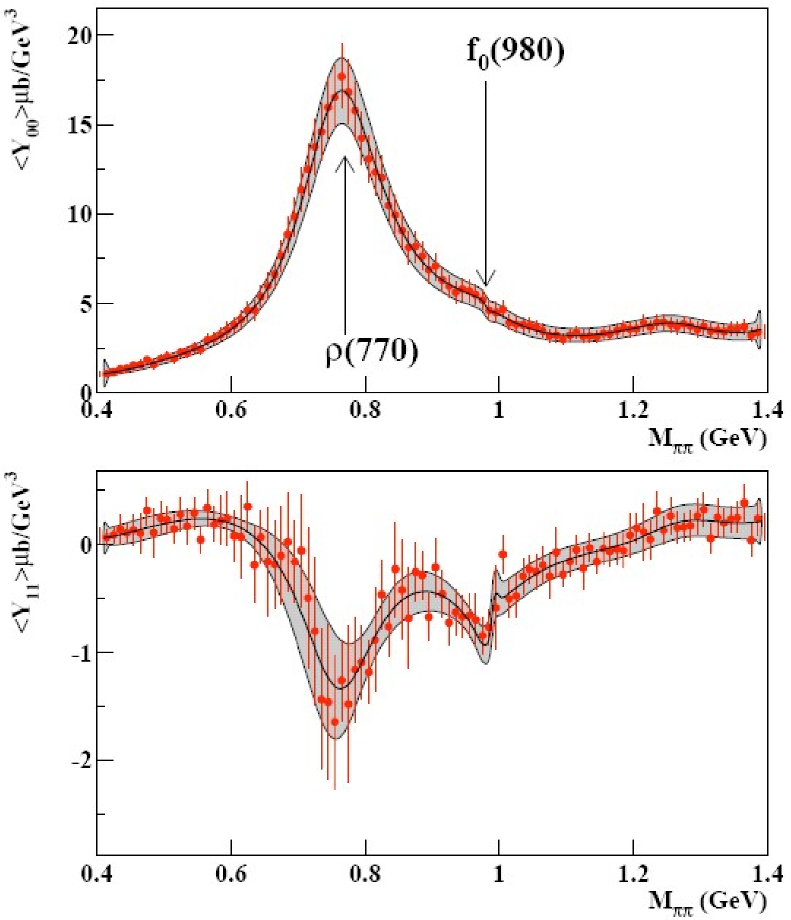
N*	Status	SU (6) ⊗ O (3)	Parity	Δ*	Status	SU (6) ⊗ O (3)
P_{11} (938)	****	$(56, 0^-)$	+	P_{33} (1232)	****	$(56, 0^+)$
S_{11} (1535)	****	$(70, 1^-)$				
S_{11} (1650)	****	$(70, 1^-)$		S_{31} (1620)	****	$(70, 1^-)$
D_{13} (1520)	****	$(70, 1^-)$	-	D_{33} (1700)	****	$(70, 1^-)$
D_{13} (1700)	***	$(70, 1^-)$				
D_{15} (1675)	****	$(70, 1^-)$				
P_{11} (1520)	****	$(56, 0^-)$		P_{31} (1875)	****	$(56, 2^+)$
P_{11} (1710)	***	$(70, 0^-)$	+	P_{31} (1835)		$(70, 0^+)$
P_{11} (1880)		$(70, 2\ )$				
P_{11} (1975)		$(20, 1^-)$				
P_{13} (1720)	****	$(56, 2\ )$		P_{33} (1600)	***	$(56, 0^+)$
P_{13} (1870)	*	$(70, 0^-)$		P_{33} (1920)	***	$(56, 2^+)$
P_{13} (1910)		$(70, 2^-)$	+	P_{33} (1985)		$(70, 2^+)$
P_{13} (1950)		$(70, 2^-)$				
P_{13} (2030)		$(20, 1^-)$				
F_{15} (1680)	****	$(56, 2^-)$		F_{35} (1905)	****	$(56, 2^+)$
F_{15} (2000)	**	$(70, 2^-)$	+	F_{35} (2000)	**	$(70, 2^+)$
F_{15} (1995)		$(70, 2^-)$				
F_{17} (1990)	**	$(70, 2^-)$	+	F_{37} (1950)	****	$(56, 2^+)$



- Continuing a photoproduction program with CLAS12 offers many opportunities for high-quality science, particularly in meson spectroscopy, searches for hybrids and exotics, and baryon spectroscopy

Meson Spectroscopy

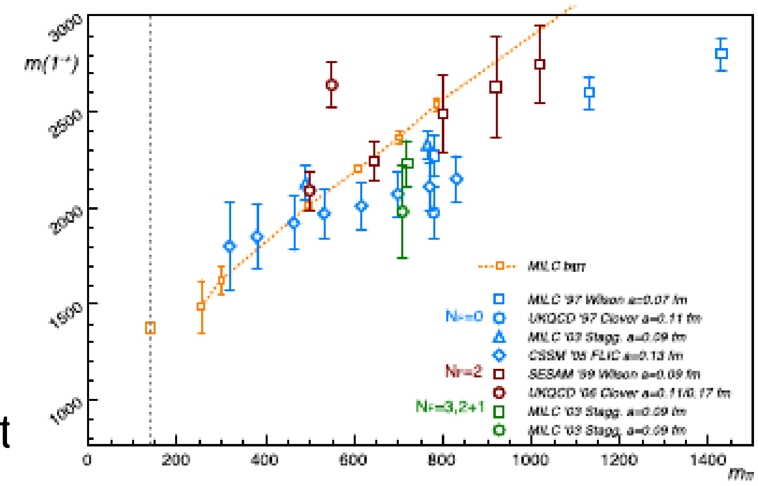
- Mesons, being composed of a quark and antiquark, are the simplest bound quark system, and at low masses, excited states are well established
- At higher masses, many states predicted by quark models have yet to be observed
- Even the interpretation of some observed states in quark models is uncertain
- Promising work has already been done measuring scalar mesons in photoproduction reactions, and the energy upgrade will enable detailed study of states at higher masses, which CLAS could not reach before



M. Battaglieri et al. (CLAS Collaboration), "Photoproduction of π+π- Meson Pairs on the Proton", Phys. Rev. D 80, 072005 (2009)

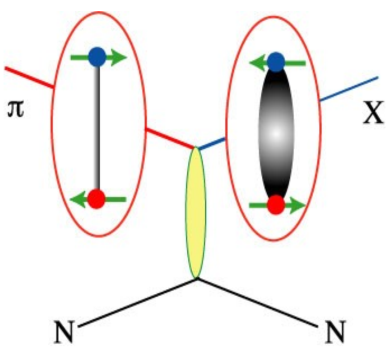
Hybrids and Exotics

- Recent results from lattice QCD calculations suggest the existence of unconventional states, and a spectrum far richer than the quark model predicts
- These unconventional states include hybrids (qqg), tetraquarks ($qq\bar{q}\bar{q}$) and glueballs
- A photon beam may be more effective at producing exotic states – it can fluctuate into a $q\bar{q}$ pair with aligned spins, and exotic quantum numbers



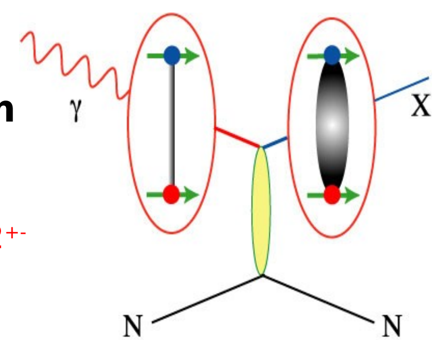
Pion Beam

Quark spins
anti-aligned
$J^{PC} = 1^{--}, 1^{++}$



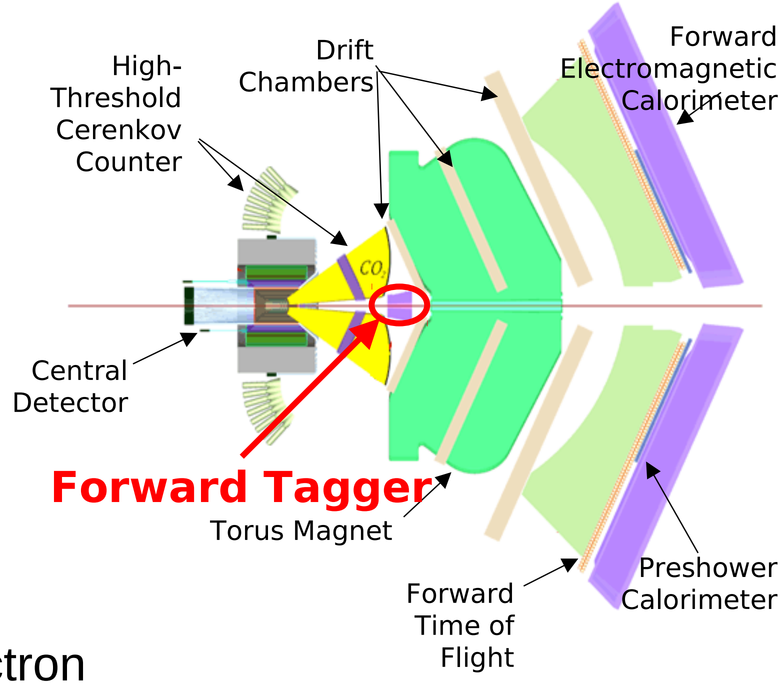
Photon Beam

Quark spins
already aligned
$J^{PC} = 0^{+-}, 1^{-+}, 2^{+-}$

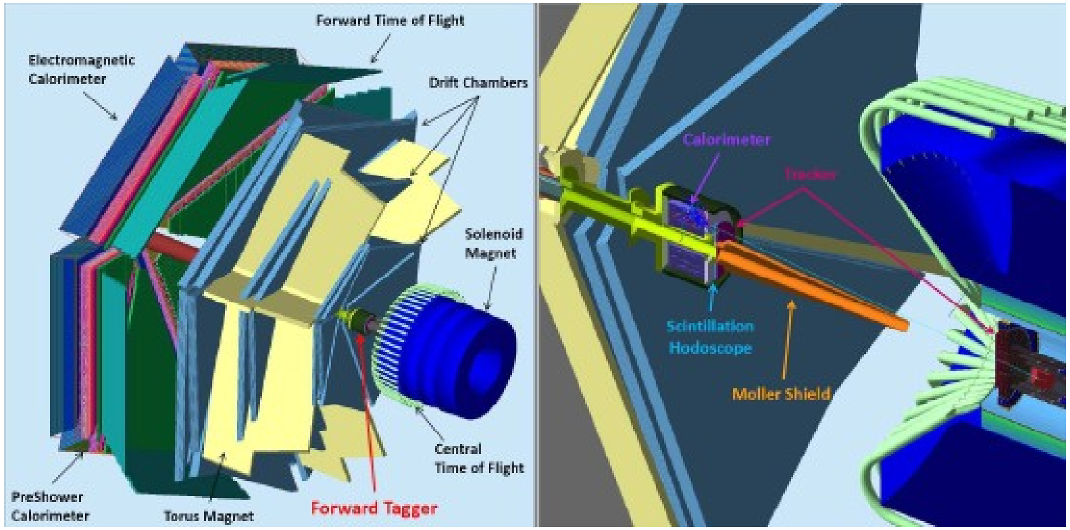


The Forward Tagger

- The Hall B photon tagger will not be upgraded for 12 GeV, with Hall D and its dedicated photon beam largely replacing the photoproduction and spectroscopy program of Hall B
- However, CLAS12 will maintain a distinct and relevant photoproduction program, which will complement that of Hall D, via the Forward Tagger
- The Forward Tagger will enable experiments using quasi-real photons up to 10 GeV, produced when an electron scatters with very low Q^2, i.e. at very small angles
- Low Q^2 electron detection has been identified as an attractive technique for meson spectroscopy
- Photons produced are linearly polarised, and the degree of polarisation can be determined on an event-by-event basis from the kinematics of the scattered electron

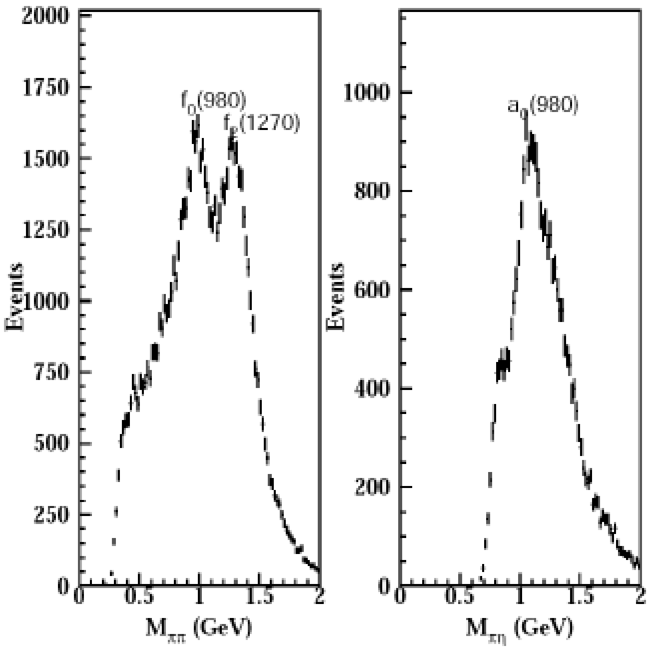


The Forward Tagger



- Maintaining a complimentary photoproduction program in Hall B will give JLab a unique photoproduction program with two facilities located on the same site

- Analyses have already been performed on CLAS data showing mesons produced by low Q2 electron scattering can be identified paving the way for using this technique with the Forward Tagger and CLAS12



Summary

- Jefferson Lab has a strong track record in many aspects of nuclear science, including spectroscopy of hadronic states
- The 12 GeV era at Jefferson Lab offers many opportunities to build on the lab's successes, and continue spectroscopy programs at higher energies
- Although the spectroscopy focus will shift to Hall D, CLAS12 still has useful capabilities in this area
- With the Forward Tagger, a relevant and distinct photoproduction program will be possible in Hall B, complimenting that of Hall D
- Stay tuned for the remaining talks in this session, outlining more of the physics opportunities for CLAS12