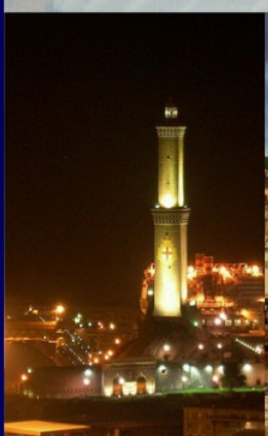
Meson Spectroscopy at JLab at 12 GeV

Stuart Fegan

INFN Genova

PHIPSI13 Workshop

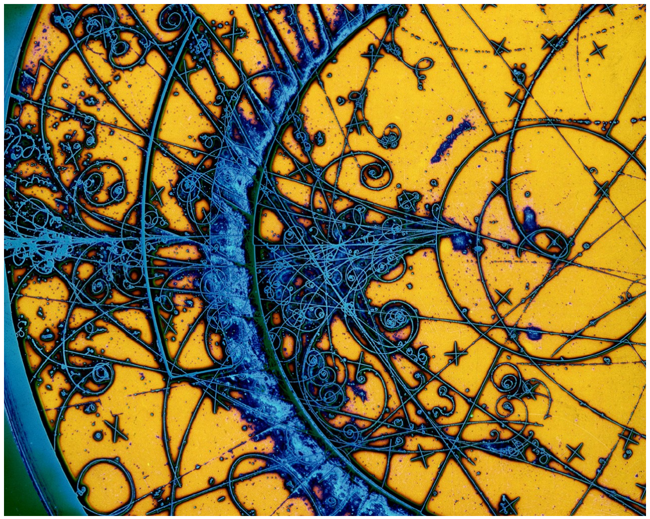
Sapienza, Universitá di Roma, September 10th, 2013



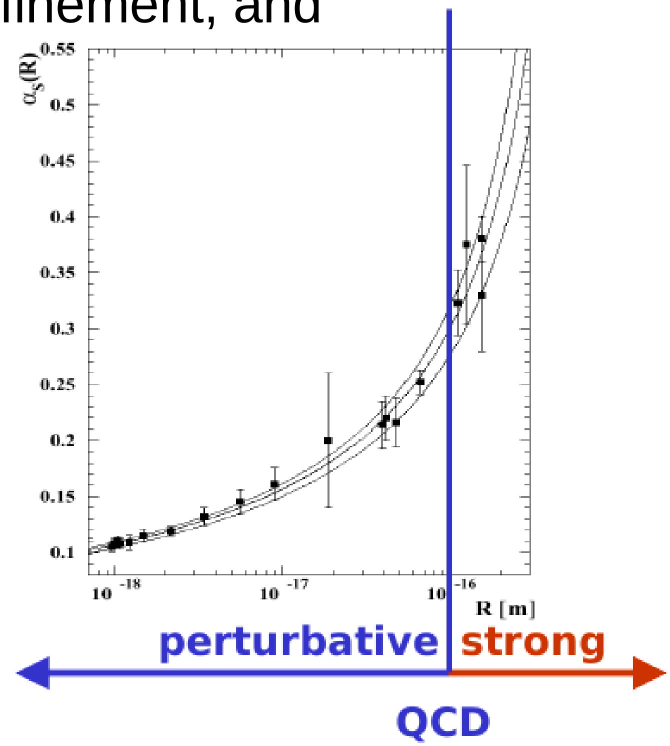

Outline

- Introduction
  - QCD and Quark models
- Meson Spectroscopy
  - Mesons, hybrids and exotics, and predictions from Lattice QCD
- JLab and the 12 GeV upgrade
- Meson Spectroscopy at 12 GeV
  - Real photoproduction in Hall D with GlueX
  - Quasi-real photoproduction in Hall B with the Forward Tagger and CLAS12
  - Data analysis and Partial Wave Analysis
- Summary

Introduction



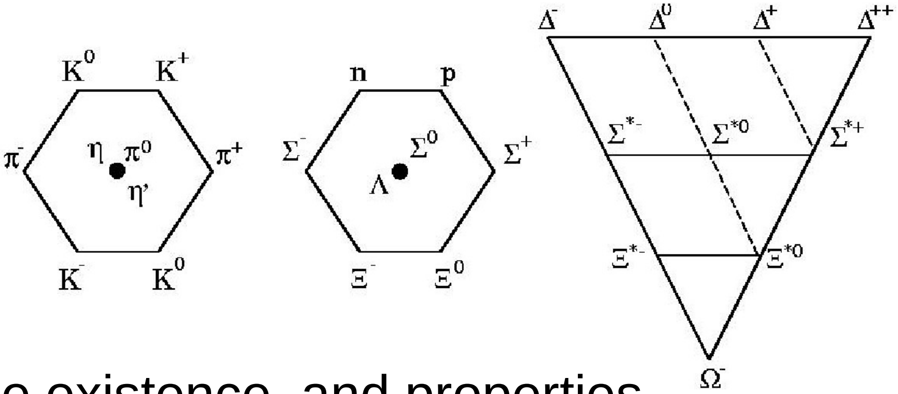
- From its roots in the experimental particle physics of the 1950's and 60's, the development around 40 years ago of the theory of QCD has served as a powerful tool in our understanding of strong force interactions, confinement, and the structure of hadrons



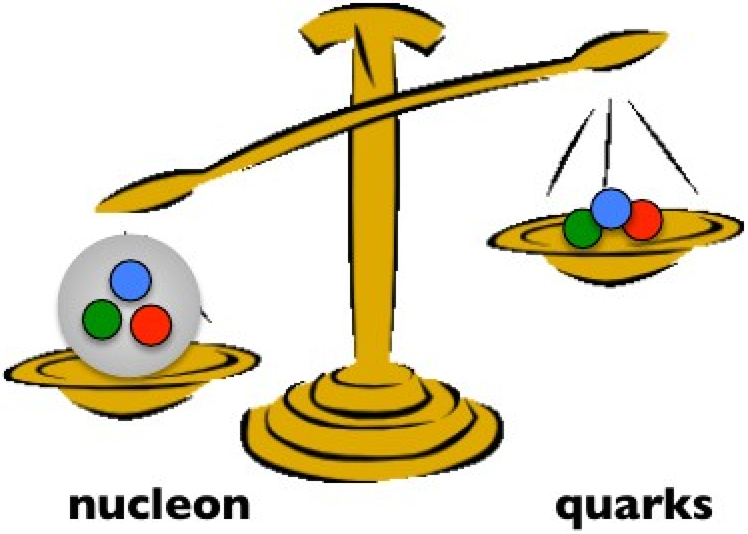
- At high energies, this theory has had great success in describing interactions, as the small QCD coupling constant makes the interaction easier to calculate
- At lower energies, this constant approaches unity and perturbative methods, used in the high energy regime, no longer hold

Introduction (cont.)

- Quark models play a vital role in the non-perturbative regime; predicting numerous hadronic states from the degrees of freedom associated with the coloured quarks of QCD



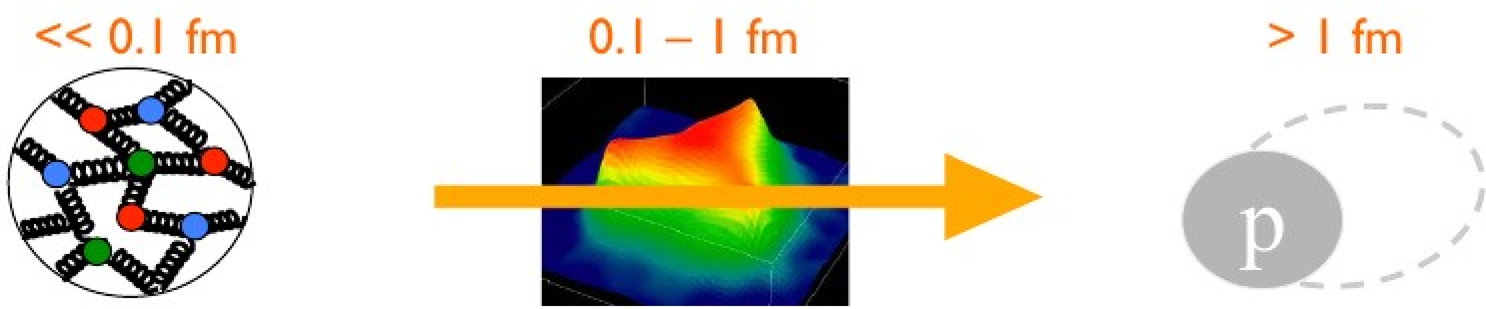
- Experimental data has verified the existence, and properties of, many of these states, however, these models are unable to tell the full story
- Quark mass accounts for only around 1% of the observed nucleon mass
- Our understanding of how quarks and gluons are confined in hadronic states, and the dynamics of the QCD interaction, still has gaps



Why Hadron Spectroscopy?

- To understand these issues, we must study the properties of hadrons and the rules of QCD
- Hadron spectroscopy is one such tool for observing QCD in action and attempts to answer some fundamental questions;
  - What is the internal structure and what are internal degrees of freedom of the hadrons?
  - What is the role of Gluons?
  - What is the origin of quark confinement?
  - Are 3-quark and quark-antiquark the only possible configurations?

Perturbative **Transition** **Non-Perturbative**

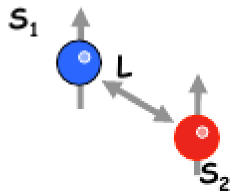


Quarks and Gluons Effective Degrees of Freedom Mesons and Baryons

INFN Jefferson Lab

Meson Spectroscopy

- Mesons, being composed of a quark and antiquark, are the simplest bound quark system, making them an obvious choice for studies of how quarks combine to form hadrons
- The Constituent Quark Model, has had success predicting meson spectrum at low mass
  - CQM describes mesons as quark-antiquark pairs, of spin S=0,1 and orbital angular momentum L
  - SU(3) flavour symmetry implies a nonet of states with the same quantum numbers, J^{PC}, for each value of L and S



$S=S_1+S_2 \quad J= L+S$

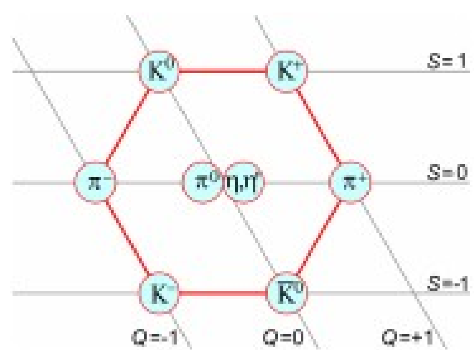
$P = (-1)^{L+1} \quad C= (-1)^{L+S}$

$J^{PC}= 0^{-+} \Rightarrow (\pi,K,\eta,\eta')$

$1^{--} \Rightarrow (\rho,K^*,\omega,\Phi)$

$1^{+-} \Rightarrow (b_1,K_1,h_1,h_1')$

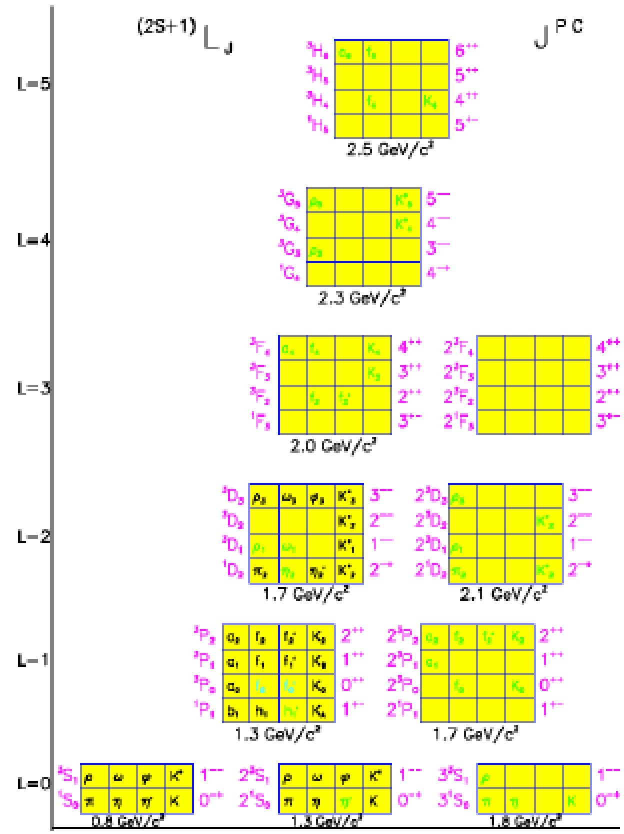
...



Meson Spectroscopy

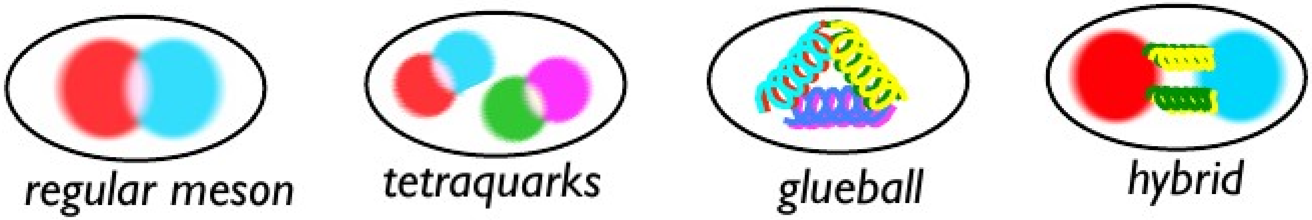
- However, despite this success at predicting low mass states, many of the states predicted by quark models at higher masses have yet to be observed
- Even the assignment of some observed states in terms of quark models is uncertain
- This could be down to problems with the model, limitations of experimental techniques, or perhaps something more... exotic?

Light Quark Mesons



Yellow: expected meson states
Black: established states
Green: tentative assignments

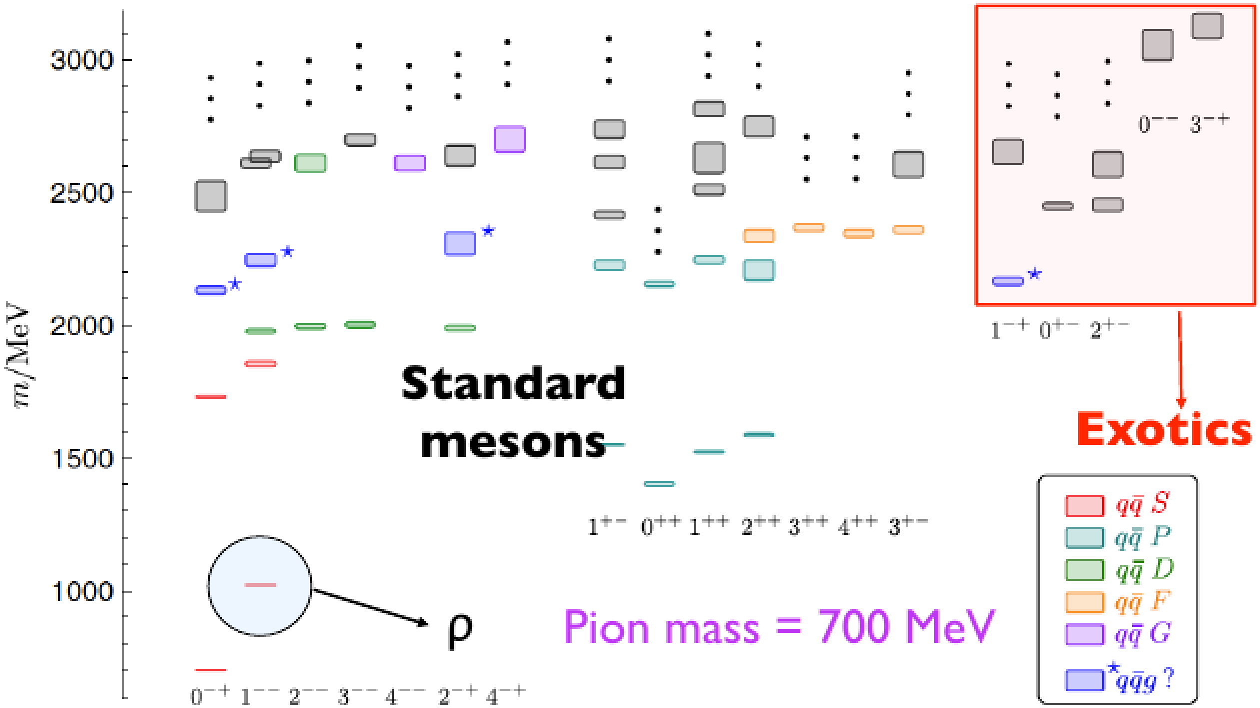
Hybrids and Exotics



- QCD requires that bound states are colour neutral
- This does not mean that unconventional quark-gluon configurations do not exist
- These potential states include tetraquarks ($qq\overline{qq}$), glueballs and hybrid mesons (qqg)
- Spectroscopy of these states, if unambiguously confirmed, would enable exploration of gluonic degrees of freedom
- Some phenomenological models predict such states, and make suggestions for masses and decay modes

On the Lattice

- Lattice QCD calculations are now starting to make predictions of the meson spectrum, including exotic states

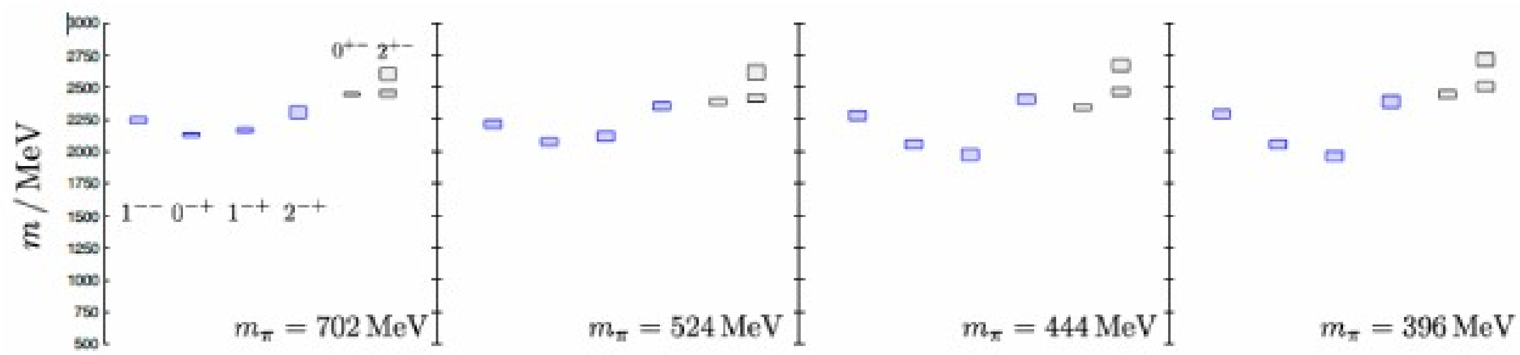


J. Dudek, et. al., Phys. Rev. D82 (2010) 034508

- Limitations remain due to unrealistic quark masses and computational limits on lattice size

On the Lattice (cont.)

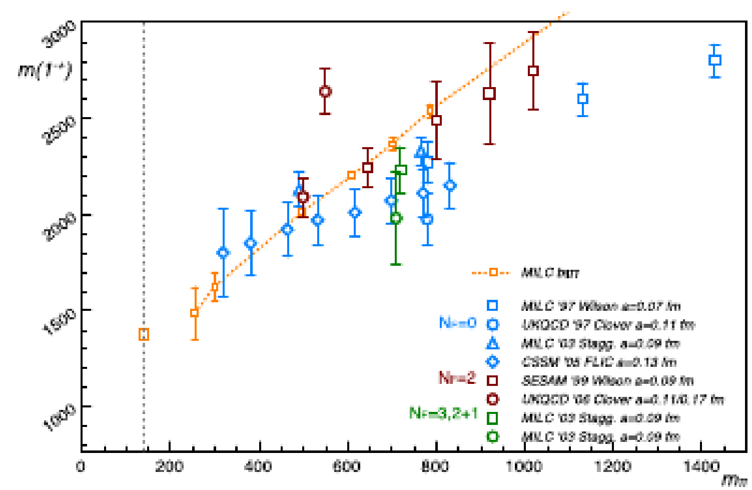
- Although unphysical (m_π = 700 MeV), the quark masses employed in the calculations are beginning to approach reality
- As the quark mass is decreased, the spectra produced continue to show qualitative agreement with each other, and with known states



J. Dudek, et. al., Phys. Rev. D84 (2011) 074023

Hybrids and Exotics

- Strong theoretical and phenomenological evidence for the existence of a rich spectrum of unconventional states
- Hybrids and exotics may be more effectively produced by photon beams
- A photon can fluctuate into a $q\bar{q}$ pair with aligned spins, accessing exotic quantum numbers that pion beams cannot

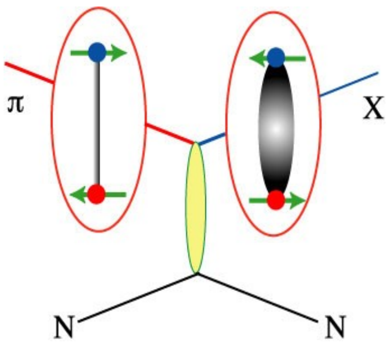


- It is here that the JLab meson spectroscopy program will contribute

Pion Beam

Quark spins anti-aligned

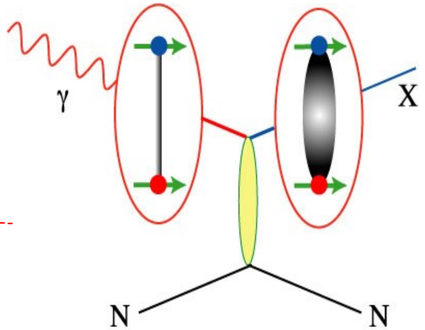
$J^{PC} = 1^{--}, 1^{++}$



Photon Beam

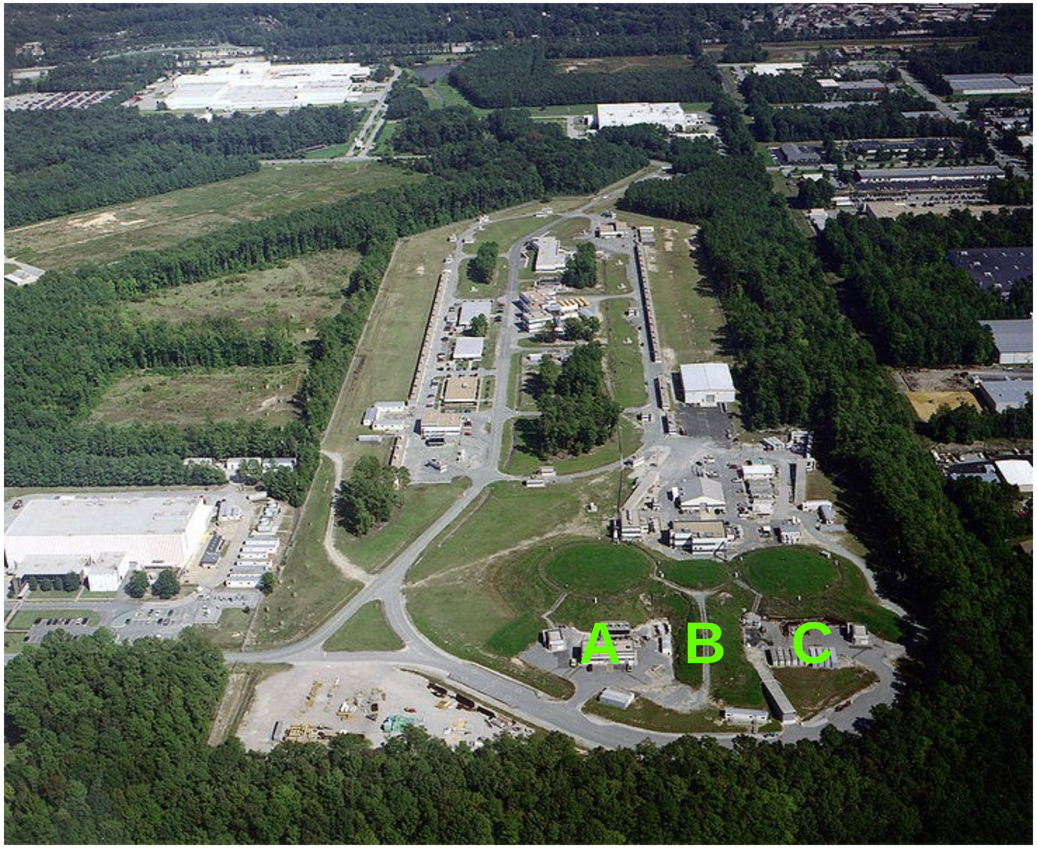
Quark spins already aligned

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



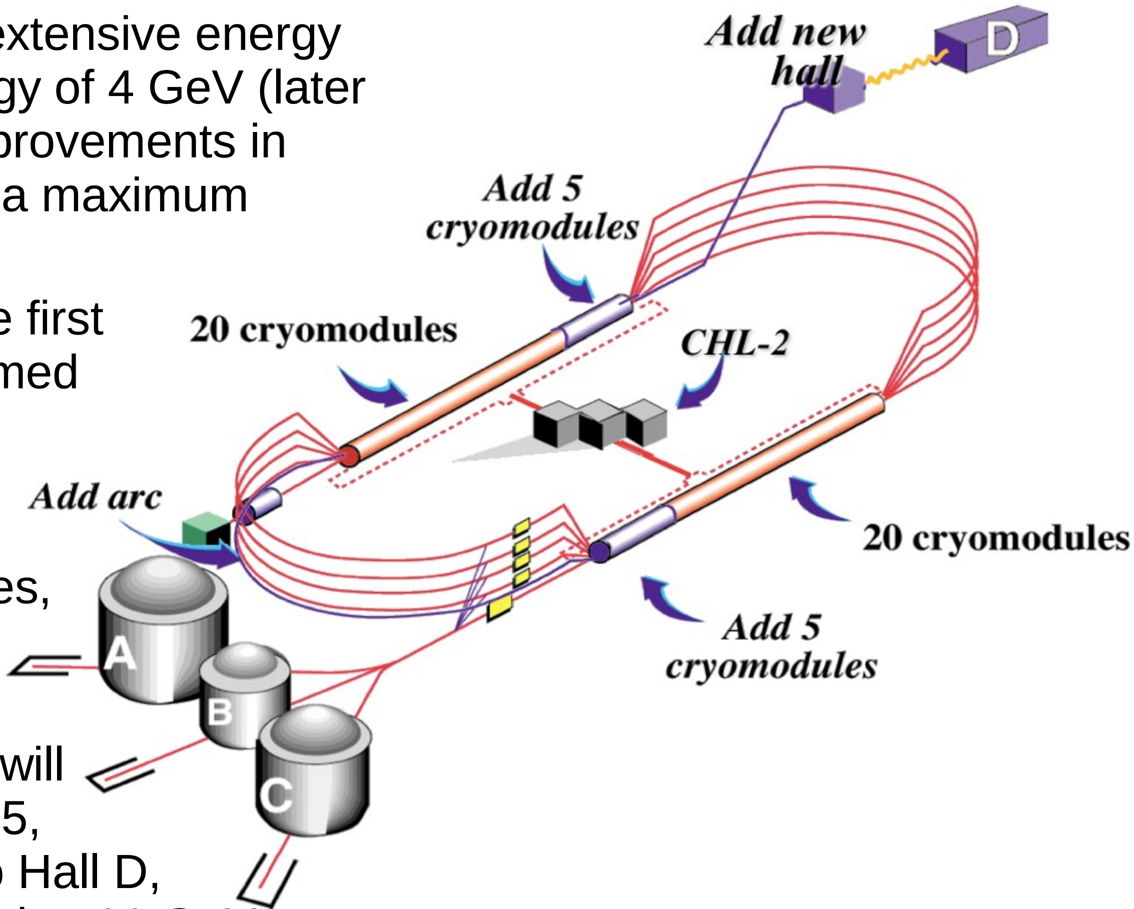
JLab and CEBAF

- Jefferson Lab is a US Department of Energy national facility, located in Newport News, Virginia
- CEBAF uses superconducting radio-frequency technology in an anti-parallel, double linac configuration
- From 1995-2012, performed a variety of experiments in three halls, with highly polarised, high-quality electron beams up to 6 GeV
- Although the halls received beam simultaneously, it need not be at 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 proven to be a very capable and versatile machine



The 12 GeV Upgrade

- CEBAF design allows for extensive energy upgrades, from initial energy of 4 GeV (later increased to 6 GeV via improvements in accelerator technology) to a maximum around 24 GeV
- The 12 GeV upgrade is the first such upgrade to be performed at the lab, involving the installation of new accelerator cavities, upgrades to existing cavities, and construction of a new experimental hall; Hall D
- The upgraded accelerator will begin operations in 2014/15, delivering 12 GeV beam to Hall D, with halls A, B and C receiving 11 GeV

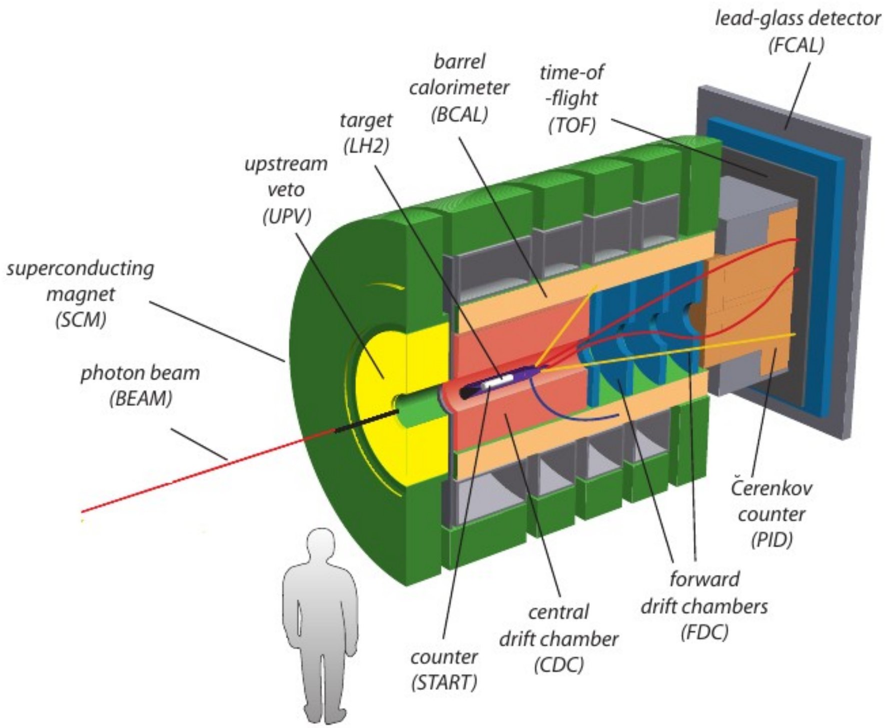


JLab Today

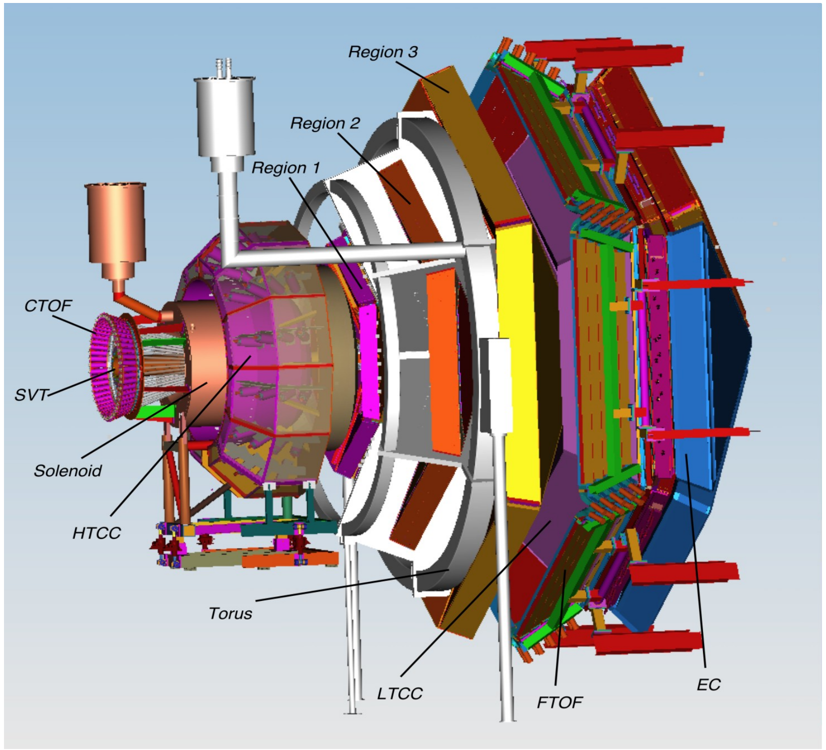
- The 12 GeV upgrade is well underway, and the lab remains a hive of activity despite the current lack of beam
- CEBAF will retain the ability to deliver simultaneous beams to multiple halls, with varying energy and current
- Halls A and C are receiving upgrades to their experimental equipment in order to take advantage of the higher beam energies available
- In the new Hall D, a brand new detector system is being constructed for the GlueX experiment
- In Hall B, CLAS (CEBAF Large Acceptance Spectrometer) is being extensively rebuilt, and is considered to be a new detector; CLAS12

CLAS12 and GlueX

GlueX in Hall D

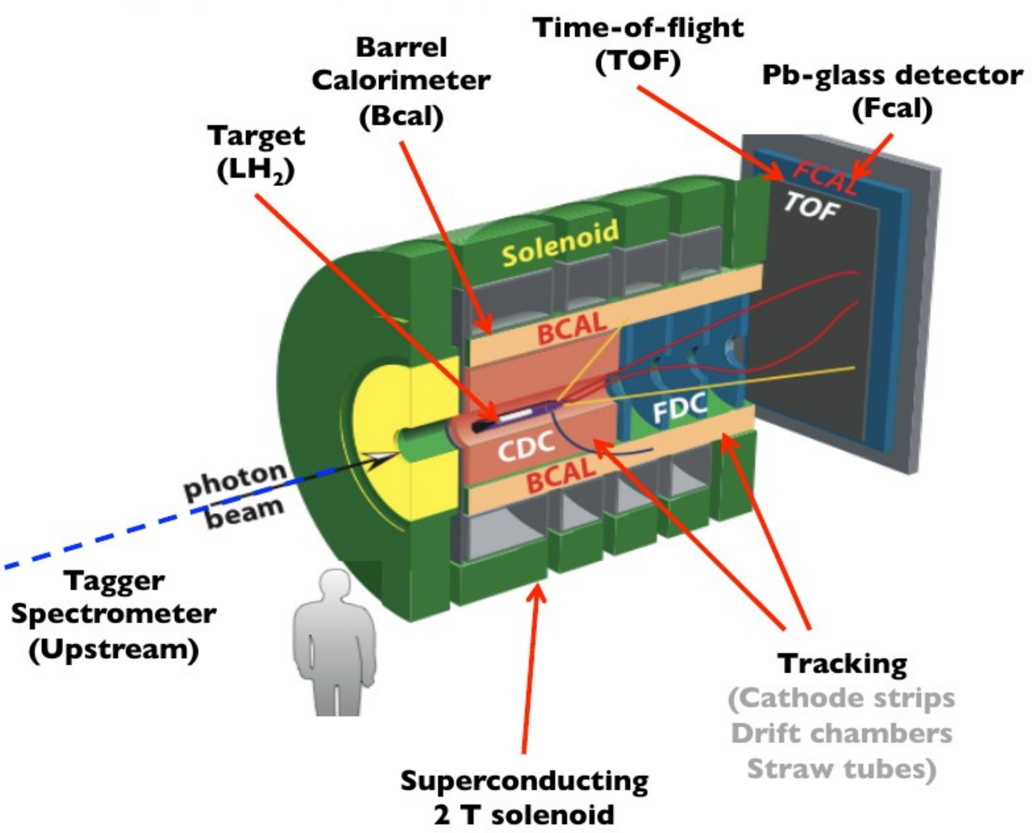


CLAS12 in Hall B



- The JLab Meson spectroscopy program will use both CLAS12 and GlueX, exploiting large acceptance for good particle identification
- Both will use high intensity tagged photon beams; real photons in GlueX, quasi-real in CLAS12

Hall-D

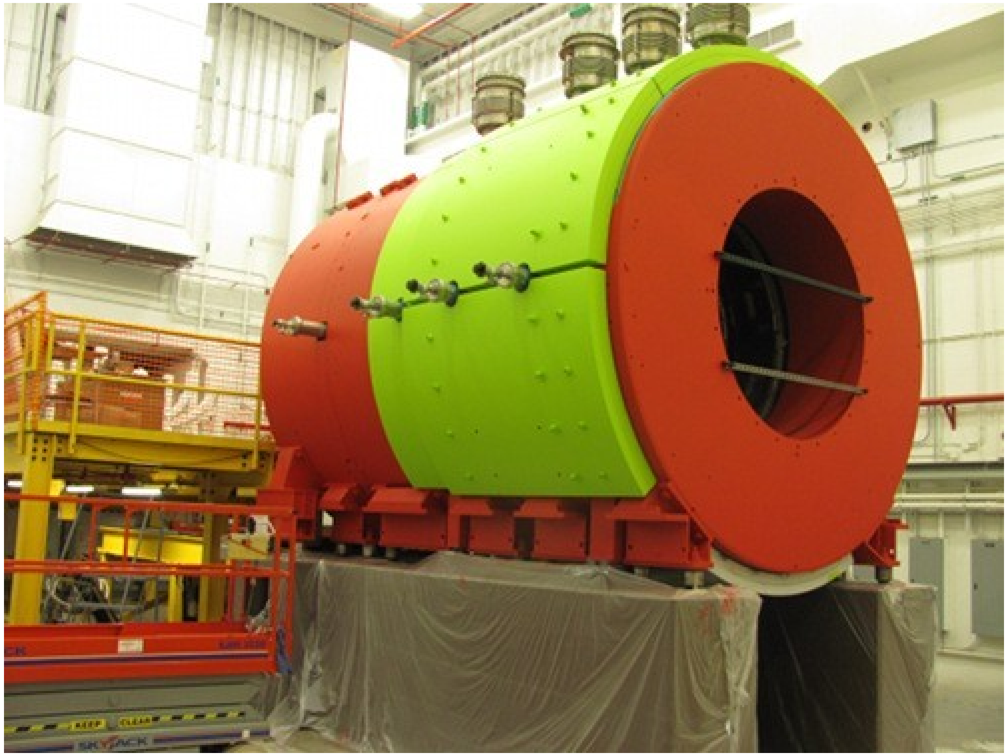


- Real photon beam, produced via coherent brensstrahlung, interacts with target
- Charged and neutral particle detection in hermetic solenoid-based detector
- Uniform acceptance makes data easier to analyse
- Photon beam is polarised, constraining amplitude analyses

INFN Jefferson Lab

GlueX

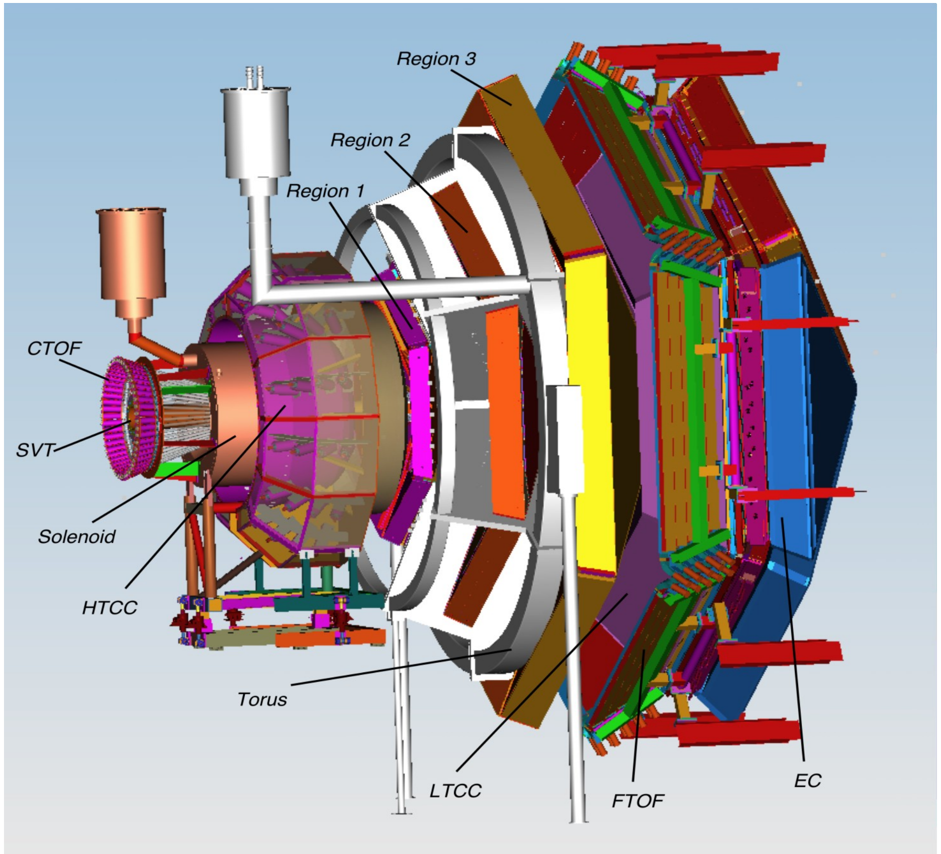
- 12 GeV electron beam can produce tagged photons up to 9 GeV; well-suited to hybrid and glueball searches



- GlueX will deliver photoproduction data several orders of magnitude greater than existing spectroscopy programs
- Initial flux of 10^7 photons/sec
- Partial Wave Analyses will be performed to determine the quantum numbers of meson states

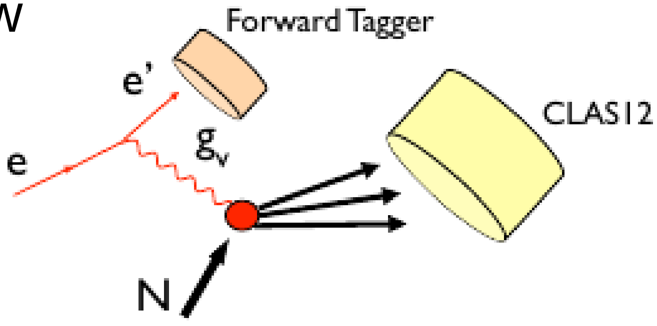
CLAS12

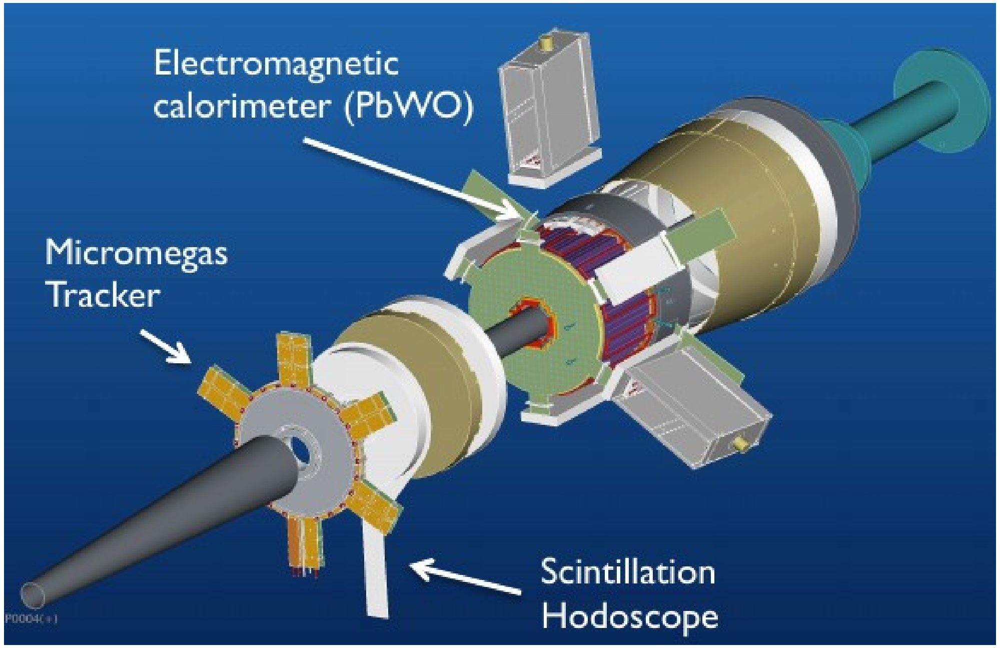
- Capabilities of CLAS12 also useful for meson spectroscopy
- Bremsstrahlung facility available in Hall B, but it is designed for the 6 GeV era
- Upgrade unnecessary as the GlueX experiment in Hall-D is specifically designed for real photons
- Instead a complimentary program is planned for CLAS12 using quasi-real photons



The Forward Tagger

- When an electron scatters with very low Q^2, i.e. at very small angles, quasi-real photons are produced
- Low Q^2 electron detection has been identified as an attractive technique for meson spectroscopy



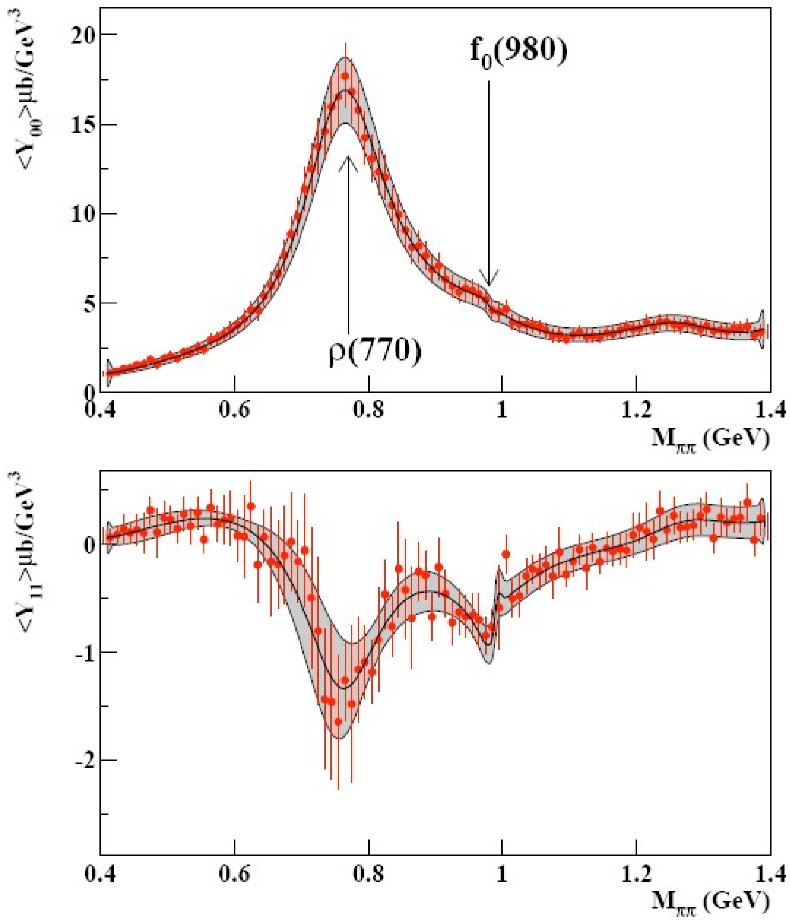


- Photons produced are linearly polarised, with polarisation determinable on an event-by-event basis from the kinematics of the scattered electron
- The Forward Tagger will enable spectroscopy experiments with CLAS12 using quasi-real photons up to 10 GeV

INFN Jefferson Lab

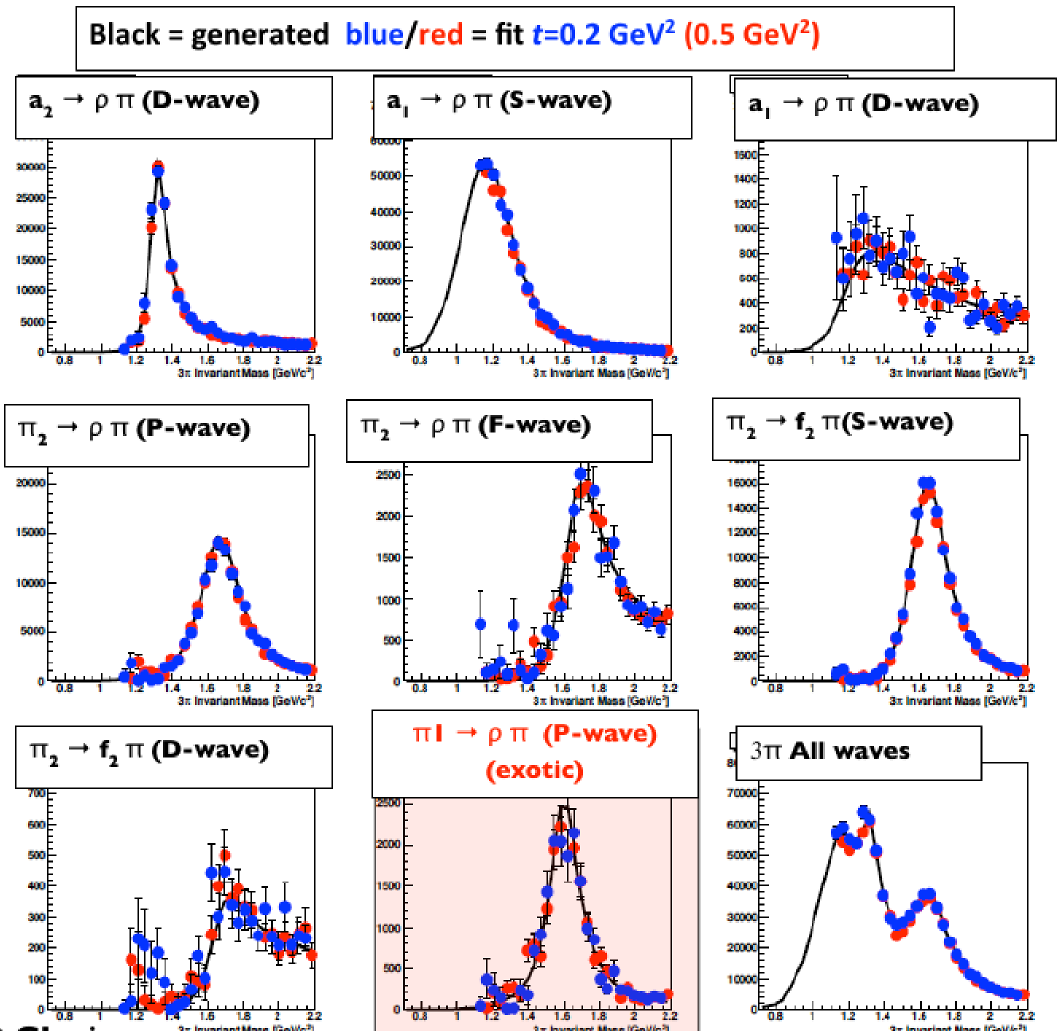
Partial Wave Analysis

- Promising work has already been done measuring scalar mesons in photoproduction reactions at 6 GeV with CLAS in Hall B
- Evidence for the observation of the f_0(980) state has been seen in partial wave analysis of the $\gamma p \rightarrow p\pi^+\pi^-$ reaction
- Distributions of measured particles in the final state are interpreted in terms contributing partial wave amplitudes
- At 12 GeV, detailed study of states at higher masses will be possible



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

Projections at 12 GeV

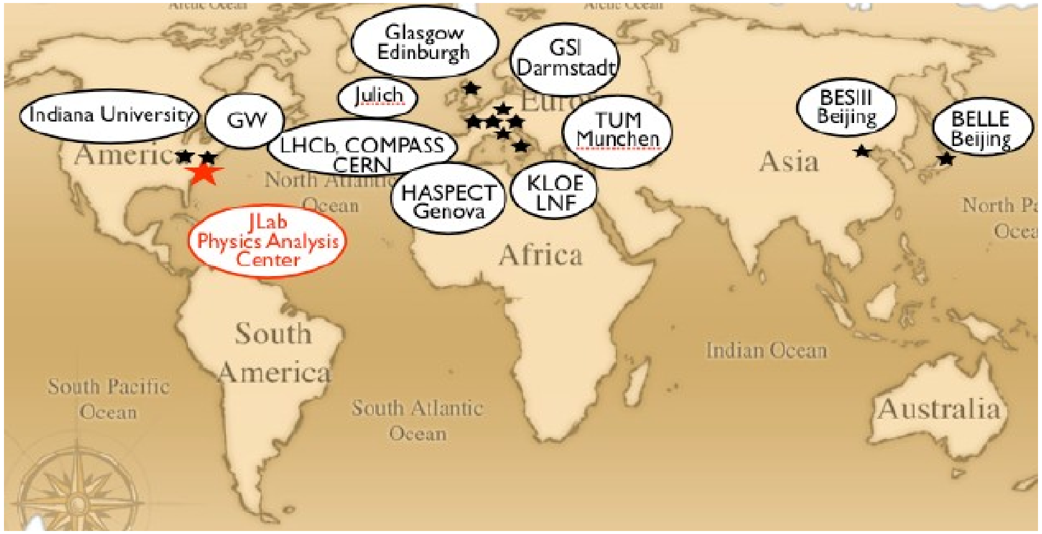


D.Glazier

- Feasibility study of PWA at 12 GeV with CLAS12
- Reference reaction $\gamma p \rightarrow (n)\pi^{+}\pi^{+}\pi^{-}$
- Existing data and its theoretical interpretation used to generate pseudo data in terms of 8 isobar channels (including an exotic P-wave state)
- Projected onto CLAS12 geometry and PWA fit performed
- Fit is stable over CLAS12 acceptance

HASPECT: A Proposal for Future Analysis

- The 12 GeV data at JLab will provide high-quality, high-statistics data, requiring a robust analysis framework
- Partial Wave Analysis lies on the boundary between theory and experiment, with scattering theory used to define contributing waves
- Resonant and non-resonant contributions included, and fits to data used to find states
- Feedback required to fine-tune waves in terms of the properties of contributing states



- HASPECT (Hadron SPEctroscopy CenTer) is one proposal for coordinating the efforts of theorists and experimentalists

Summary

- Meson spectroscopy poses a tantalising opportunity to address fundamental questions in our understanding of QCD
- The existence of exotic states, suggested by both quark models and Lattice QCD calculations, would enable exploration of the role of gluons in the QCD interaction at the scale of hadrons
- Independent, but complimentary, experimental programs in meson spectroscopy via photoproduction are planned in two of the halls at Jefferson Lab following the 12 GeV upgrade
- Each experiment is tailored to the unique capabilities and advantages offered by the detector systems in each hall
- This new chapter in Jefferson Lab's history offers many opportunities to build on previous JLab strengths in hadron spectroscopy, and continue this legacy into higher energies