Hadron Spectroscopy in the Light Quark Sector

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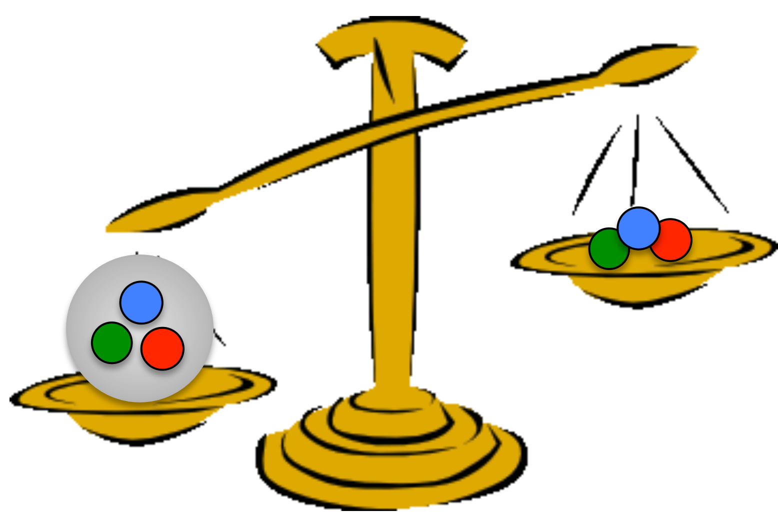
Marciana Marina, Italy, 27 June – 1 July 2016

QCD and Spectroscopy

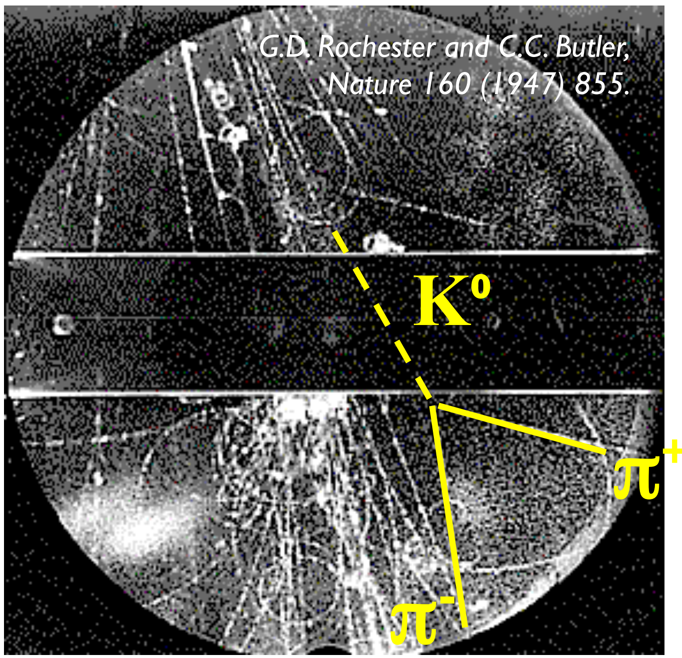
- Hadrons are one of the most relevant manifestations of the works of QCD
- Hadrons have an internal structure being made of quarks: known quark configurations are baryons, made of tree quarks and mesons, made of quark-antiquark pairs
- Quark masses account only for a small fraction of the nucleon mass: ~ 1%
  - m_q ~ 10 MeV
  - m_N ~ 1000 MeV

  while the remaining fraction is to to the force that binds the quarks: **QCD**
- Hadron spectroscopy is a "portal" to Quantum Chromo Dynamics



Hadron Spectroscopy

Historically, the study of hadron properties led to some of the most relevant discoveries in particles physics



C.F.Powell, Nobel Lecture, 11th December 1950

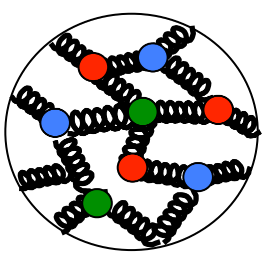
- in 1947 the discovery of the pion by Powell, Occhialini and Lattes
- in the same year, the discovery of strange particles by Rochester and Butler
- the interpretation of the ϕ decay to KK by Zweig and others in 1963
- the postulation of the existence quarks in 1964 to explain the richness of the baryon spectrum
- the discovery of the J/ψ in 1974
- …

After many years, hadron spectroscopy remains a very active field and a precious source of information for the understanding of quark-gluon interaction

Hadrons and QCD

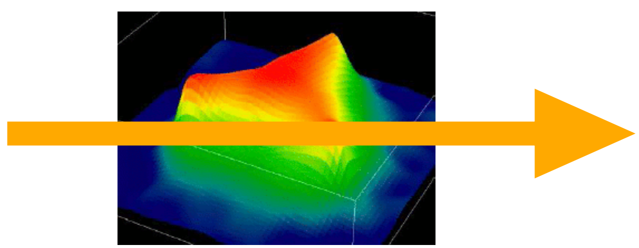
- Hadrons are color neutral systems made of quarks and gluons but…
  - What is the internal structure and what are the internal degrees of freedom of hadrons?
  - What is the role of gluons?
  - What is the origin of quark confinement?
  - Are 3-quarks and quark-antiquark the only possible configurations?
- <u>Spectroscopy is a key tool to investigate these issues</u>

<< 0.1 fm



Quarks and Gluons

0.1 – 1 fm



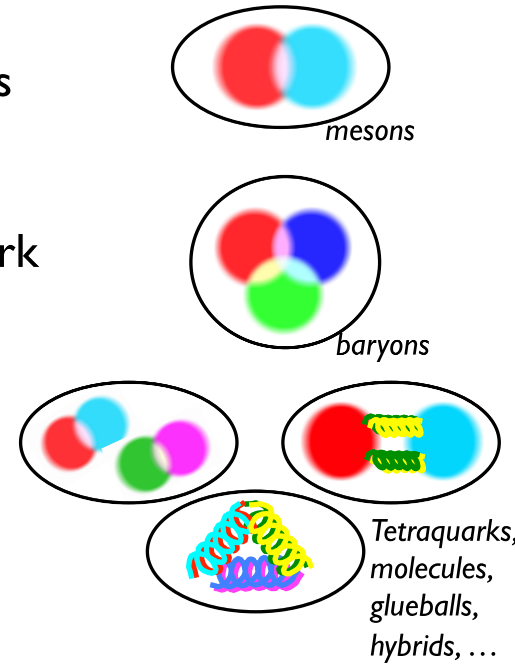
Effective Degrees of Freedom

> 1 fm

Mesons & Baryons

Spectroscopy and QCD

How can we exploit spectroscopy to probe QCD?



Baryons: building blocks of ordinary matter, baryon structure is most obviously related to color degrees of freedom

Mesons: the simplest quark bound states, i.e. the best benchmark to understand how quarks interact to form hadrons

Exotics: unconventional quark-gluon configuration can reveal hidden aspects of QCD

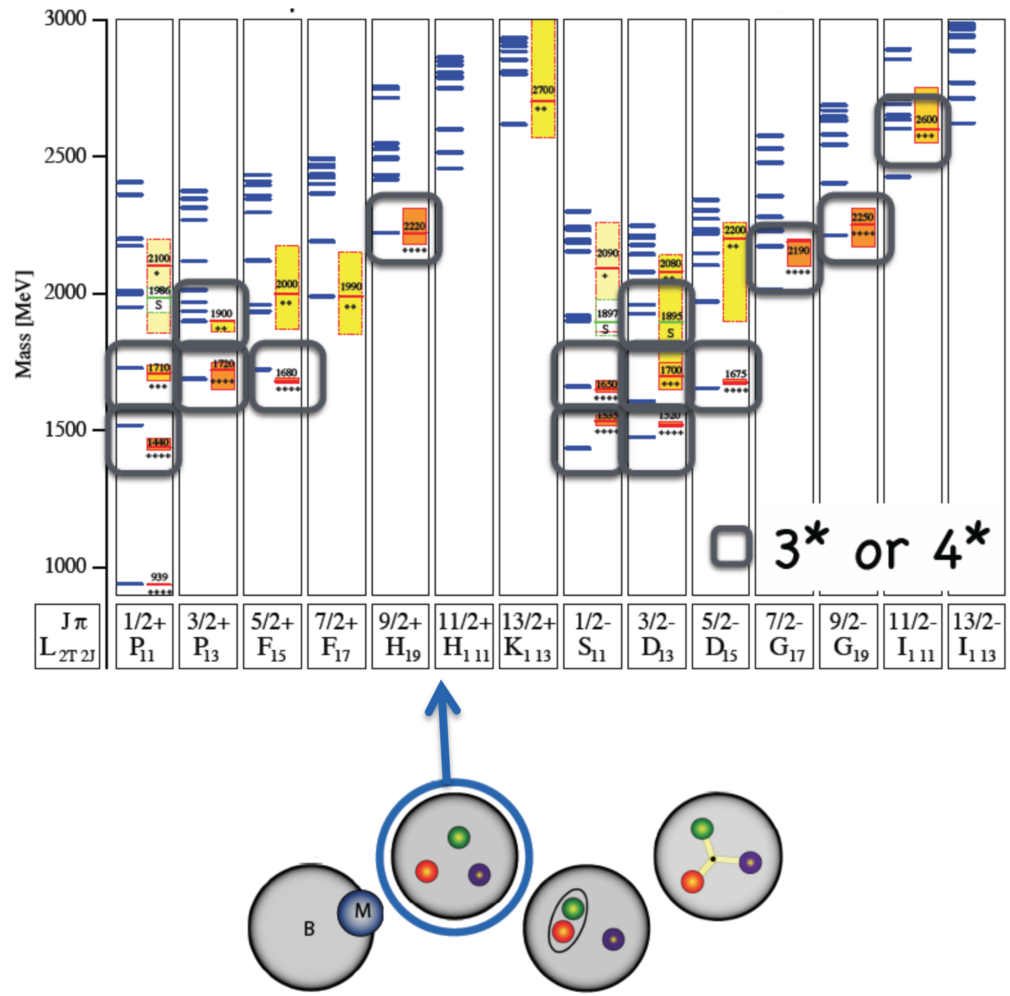
Global effort involving experimentalists and theorists from all over the world…

- different probes (hadron, lepton, photon beams)
- collider vs. fixed target experiments
- different reaction processes
- from low to high energy physics

Baryon Spectroscopy

The baryon spectrum has been crucial for the development of QCD:

- Multiplet structure led to the proposal of the quark model
- The discovery of the Ω^- confirmed the path was correct
- Inner structure connected to number of colors



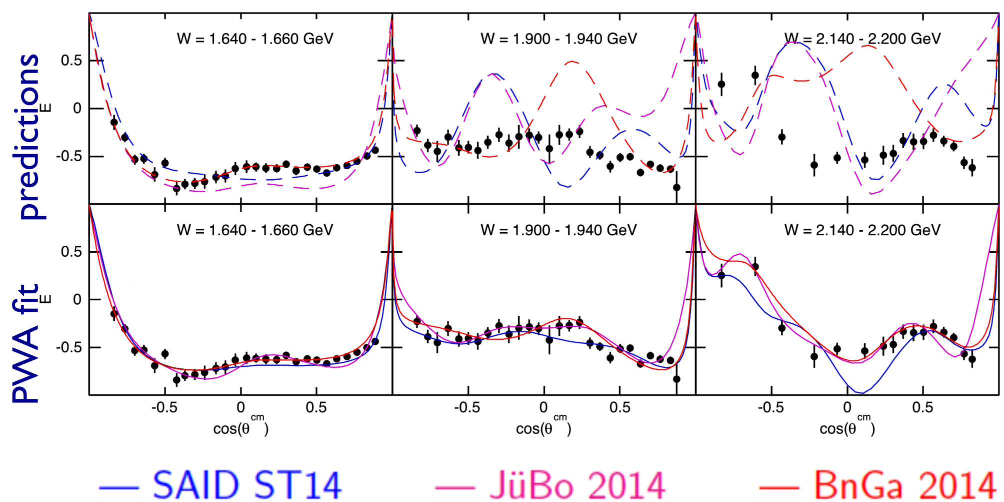
Many open questions (light quarks):

- Nucleon resonance spectrum and missing states
- Effective degrees of freedom and transition from partonic to hadronic description
- Strangeness rich states

Search for Missing Resonances

- High precision data from ELSA, JLab, GRAAL, MAMI
- Measurement of multiple polarization observables in photoproduction off nucleons ("complete" experiments)
- Evidence of new states found in coupled-channel analyses
- Large impact of new data expected!

$\gamma p \rightarrow \pi^+ n$: Helicity Asymmetry E



S. Strauch et al. (CLAS), PLB750 (2015) 53

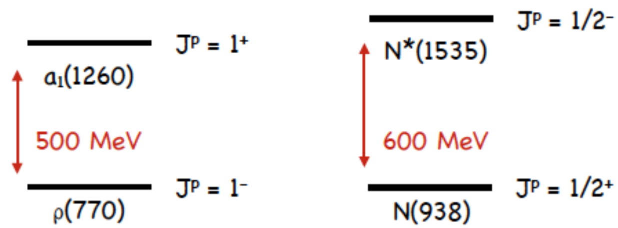
PDG baryon summary table for N* resonances

N^*	J^P $(L_{2I,2J})$	2010	2012	future
p	$1/2^+$ (P_{11})	****	****	
n	$1/2^+$ (P_{11})	****	****	
$N(1440)$	$1/2^+$ (P_{11})	****	****	
$N(1520)$	$3/2^-$ (D_{13})	****	****	
$N(1535)$	$1/2^-$ (S_{11})	****	****	
$N(1650)$	$1/2^-$ (S_{11})	****	****	
$N(1675)$	$5/2^-$ (D_{15})	****	****	
$N(1680)$	$5/2^+$ (F_{15})	****	****	
$N(1685)$			*	
$N(1700)$	$3/2^-$ (D_{13})	***	***	
$N(1710)$	$1/2^+$ (P_{11})	***	***	
$N(1720)$	$3/2^+$ (P_{13})	****	****	
$N(1860)$	$5/2^+$		**	
$N(1875)$	$3/2^-$		***	
$N(1880)$	$1/2^+$		**	
$N(1895)$	$1/2^-$		**	
$N(1900)$	$3/2^+$ (P_{13})	**	***	
$N(1990)$	$7/2^+$ (F_{17})	**	**	
$N(2000)$	$5/2^+$ (F_{15})	**	**	
~~$N(2080)$~~	D_{13}	**		
~~$N(2090)$~~	S_{11}	*		
$N(2040)$	$3/2^+$		*	
$N(2060)$	$5/2^-$		**	
$N(2100)$	$1/2^+$ (P_{11})	*	*	
$N(2120)$	$3/2^-$		**	
$N(2190)$	$7/2^-$ (G_{17})	****	****	
~~$N(2200)$~~	D_{15}	**		
$N(2220)$	$9/2^+$ (H_{19})	****	****	
$N(2250)$	$9/2^-$ (G_{19})	****	****	
$N(2600)$	$11/2^-$ $(I_{1,11})$	***	***	
$N(2700)$	$13/2^+$ $(K_{1,13})$	**	**	

... upcoming updates ...

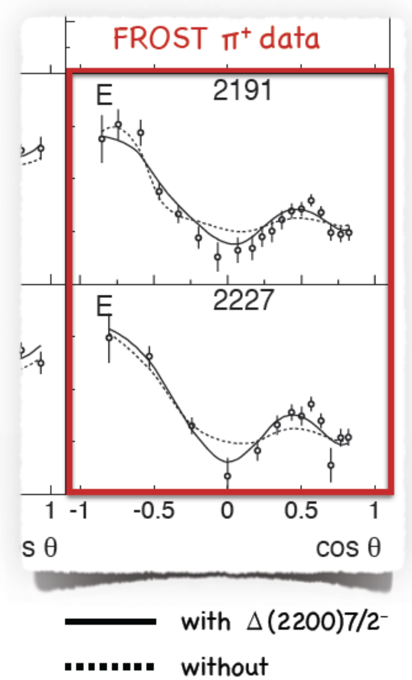
Search for Parity Doublets

Spontaneous breaking of the chiral symmetry leads to large mass gap between chiral partners:

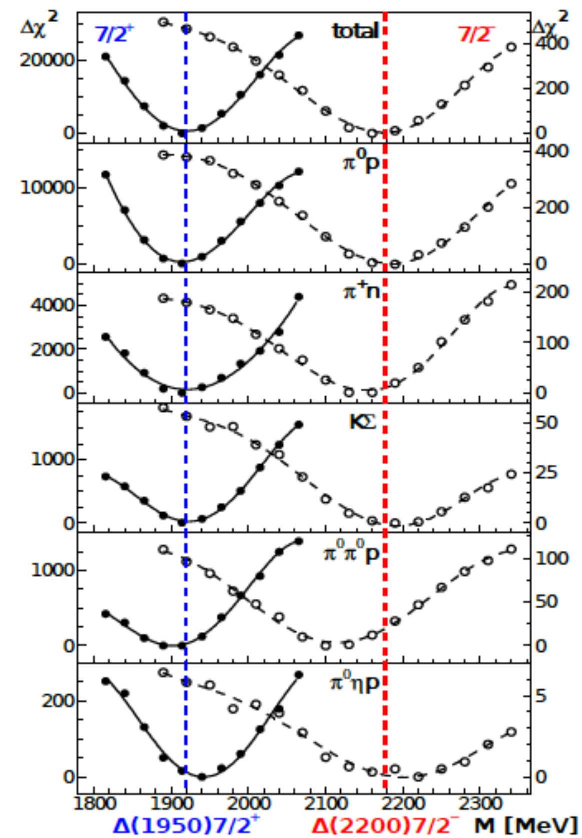


Mesons and baryons at higher masses are often observed in parity doublets

$\Delta(1910)1/2^+$	$\Delta(1920)3/2^+$
$\Delta(1900)1/2^-$	$\Delta(1940)3/2^-$
$\Delta(1905)5/2^+$	$\Delta(1950)7/2^+$ (****)
$\Delta(1930)5/2^-$	$\Delta(2200)7/2^-$ (*)



BnGa analysis of CLAS and CBELSA/TAPS data



A.V. Anisovich *et al.*, arXiv:1503.05774 (2015)

Evidence found for $\Delta(2200)7/2^-$ in a preliminary analysis of the Bonn/Gatchina group

$M(\Delta 7/2^-) \approx 2180$ MeV

… and not ≈ 1950 MeV

Chiral symmetry is not restored in high-mass hadrons

Evidence for new Baryons and Decays

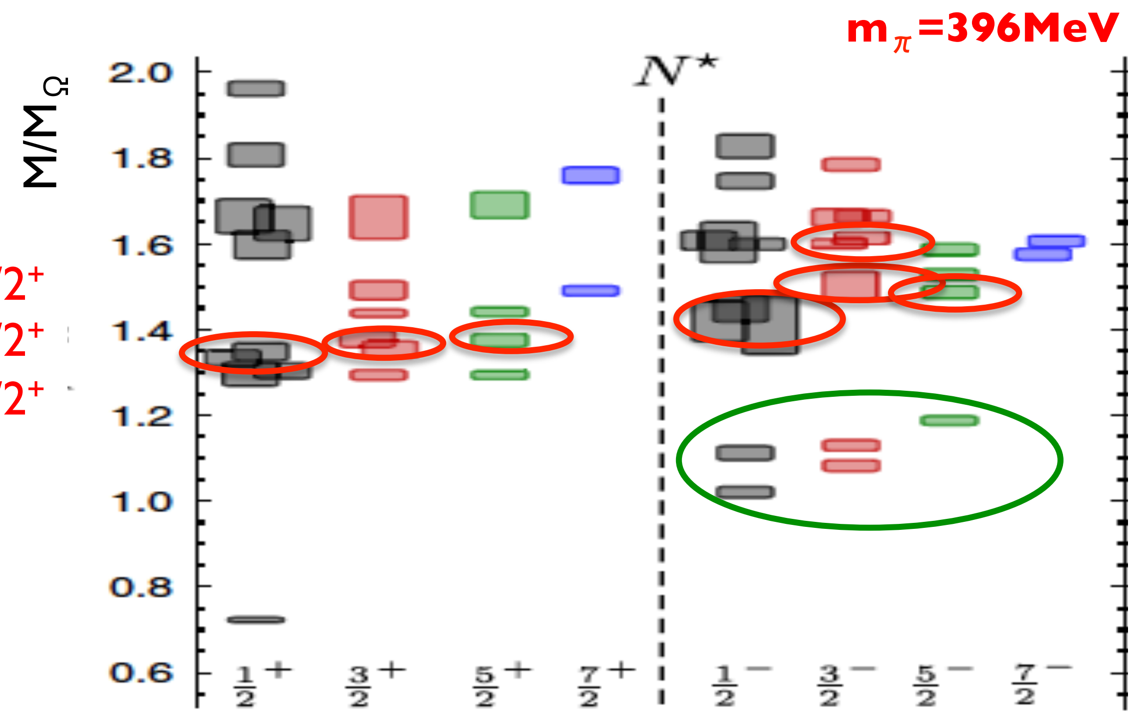
State N((mass)J^P	PDG pre 2010	PDG 2016	$K\Lambda$	$K\Sigma$	$N\gamma$
N(1710)$1/2^+$	***	****	****	**	****
N(1880)$1/2^+$		**	**		**
N(1895)$1/2^-$		**	**	*	**
N(1900)$3/2^+$	**	***	***	**	***
N(1875)$3/2^-$		***	***	**	***
N(2150)$3/2^-$		**	**		**
N(2000)$5/2^+$	*	**	**	*	**
N(2060)$5/2^-$		**		**	**

(Bonn/Gatchina: First coupled-channel analysis that includes nearly all new photoproduction data)

Do new states fits with LQCD predictions?

R. Edwards et al., Phys.Rev. D84 (2011) 074508

N(1860)5/2$^+$
N(1900)3/2$^+$
N(1880)1/2$^+$



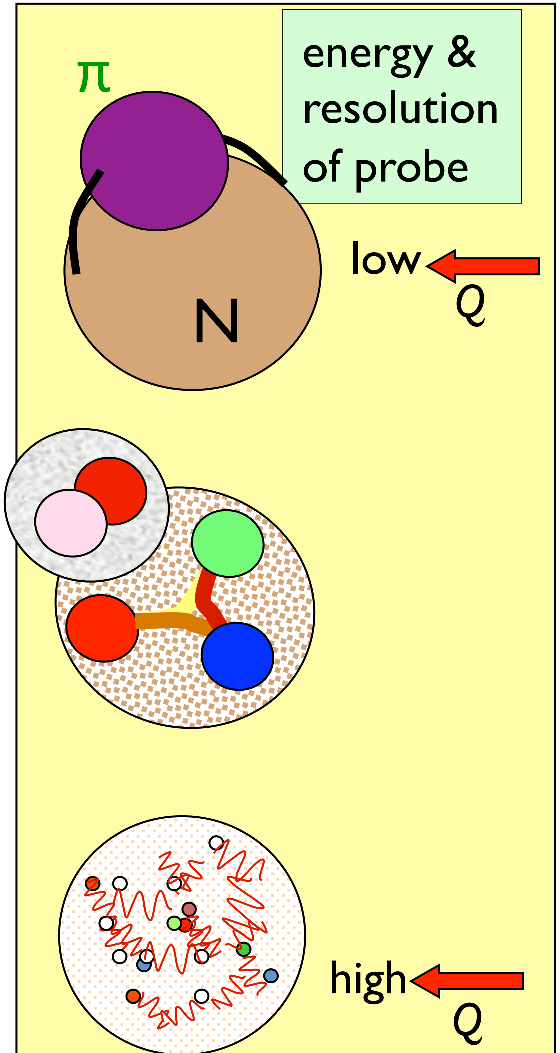
N(2060)5/2$^-$
N(2120)3/2$^-$
N(1875)3/2$^-$
N(1895)1/2$^-$

Known states:
N(1675)5/2$^-$
N(1700)3/2$^-$
N(1520)3/2$^-$
N(1650)1/2$^-$
N(1535)1/2$^-$

Lowest J$^+$ states 500 -700 MeV high **Lowest J$^-$** states 200-300 MeV high

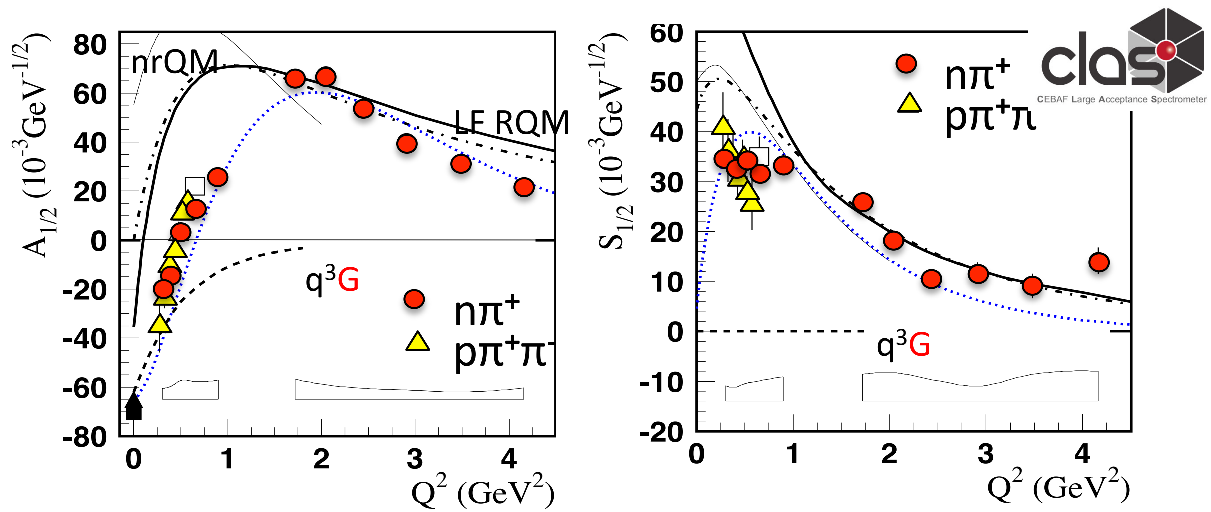
Ignoring the mass scale, new states fit with the J^P values predicted from LQCD

Transition Form Factors



Electro-production can be used to explore the hadron structure at different wavelengths (Q^2)

Electro-couplings of "Roper" N(1440)1/2$^+$

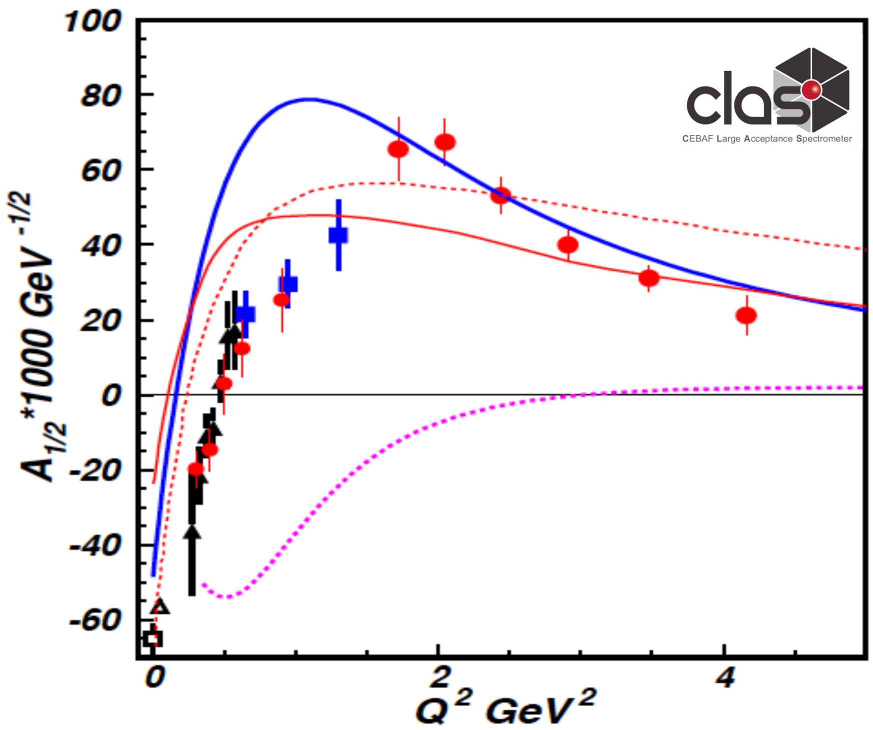


- Nπ and Nππ give consistent results
- $A_{1/2}$ changes sign and has large magnitude at high Q^2
- QM fails to reproduce low Q^2 behavior, LFQM better at large Q^2
- Both $A_{1/2}(Q^2)$ and $S_{1/2}(Q^2)$ inconsistent with hybrid model prediction

The "Roper" resonance

Description of the N(1440)1/2$^+$ $A_{1/2}$ electro-coupling in LF QM that incorporate the inner core of three dressed quarks in the first radial excitation and outer meson-baryon (MB) cloud:

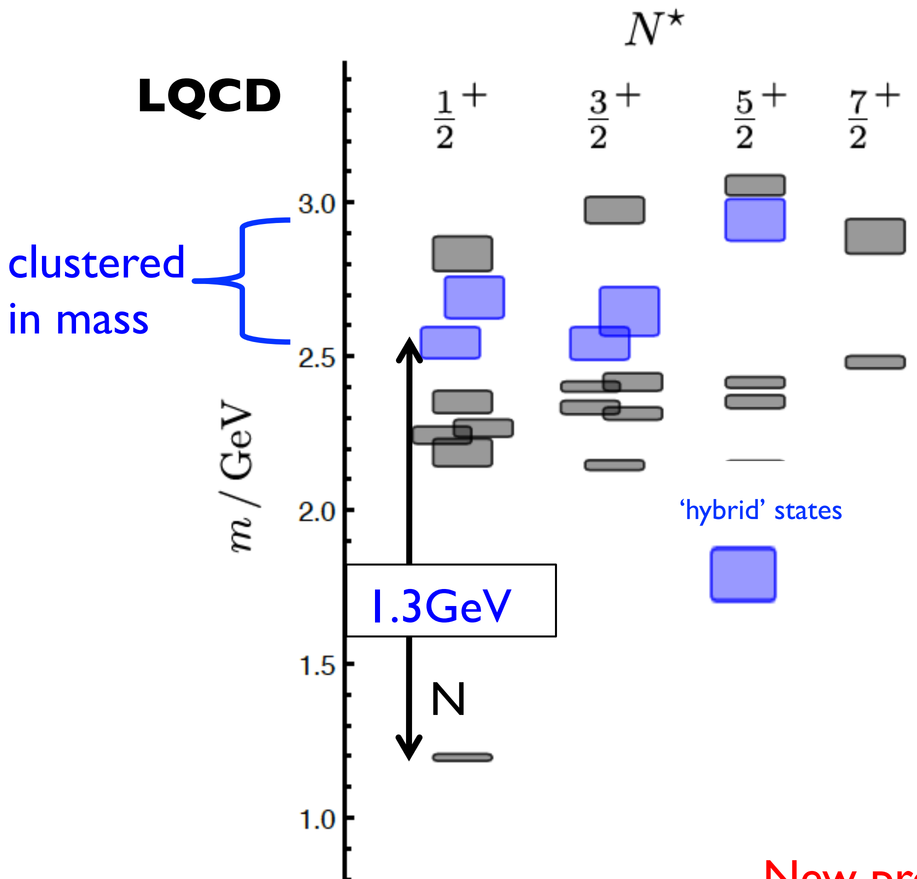
- Nπ loops to model MB cloud; **running quark mass**, in LF RQM. I.G. Aznauryan, V.B., Phys. Rev. C85, 055202 (2012)
- Nσ loops to model MB cloud**; frozen constituent quark mass**. I.T. Obukhovsky, et al., Phys. Rev. D89, 014032 (2014).
- **Quark core** contributions from DSE/QCD (2015), J. Segovia et al., arXiv:1504.04386
- MB cloud **inferred from the CLAS data** as the difference between the data and quark core evaluated in DSE/QCD



The structure of N(1440)1/2$^+$ resonance is determined by the interplay between a core of three dressed quarks in the 1st radial excitation and the external meson-baryon cloud

Hybrid Baryons

J.J. Dudek and R.G. Edwards, PRD 85 (2012) 054016



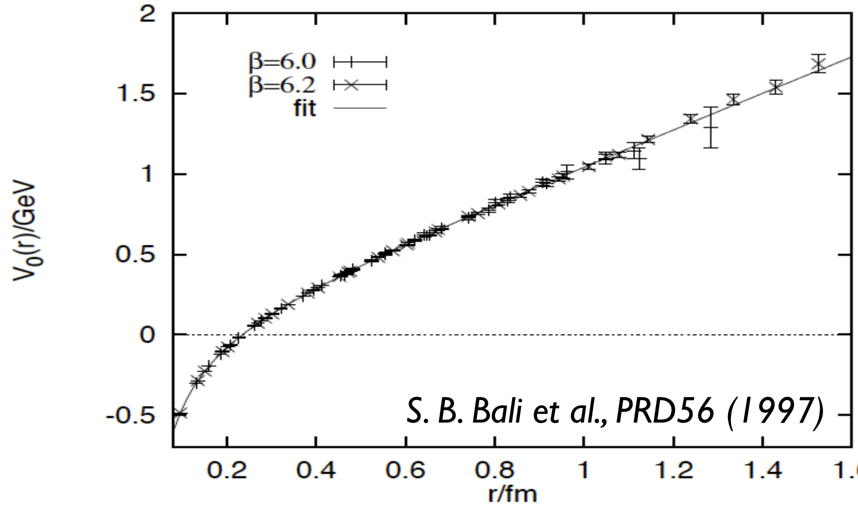
q^{3}G baryons have same J^P values as q^3 baryons, but are more extended objects

Measurement of the Q^2 dependence of transition form factors can allow us to distinguish between "ordinary" and "hybrid" states

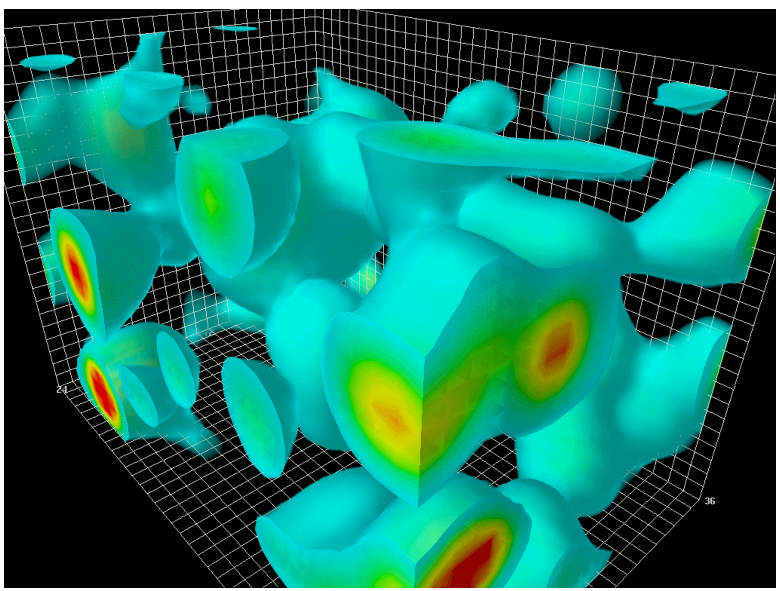
New proposal to search for hybrid baryons with CLAS12 submitted to JLab PAC

Meson Spectroscopy

Goals in meson spectroscopy are to investigate fundamental aspects of QCD, studying meson spectrum and decays and searching for exotic states



D. Leinweber: LQCD visualization of the QCD vacuum



Light quark mesons (uds):

- sensitive to chiral symmetry breaking and vacuum condensate effects
- probe the strong force at larger distances (confinement)

Heavy quark mesons (cbt):

- can be described with non-relativistic potential models
- probe the strong force at smaller distances where short-range color interaction dominates

Meson Spectroscopy

Many experiments in the world have studied and are studying the hadron spectrum in the light-quark sector using different production processes

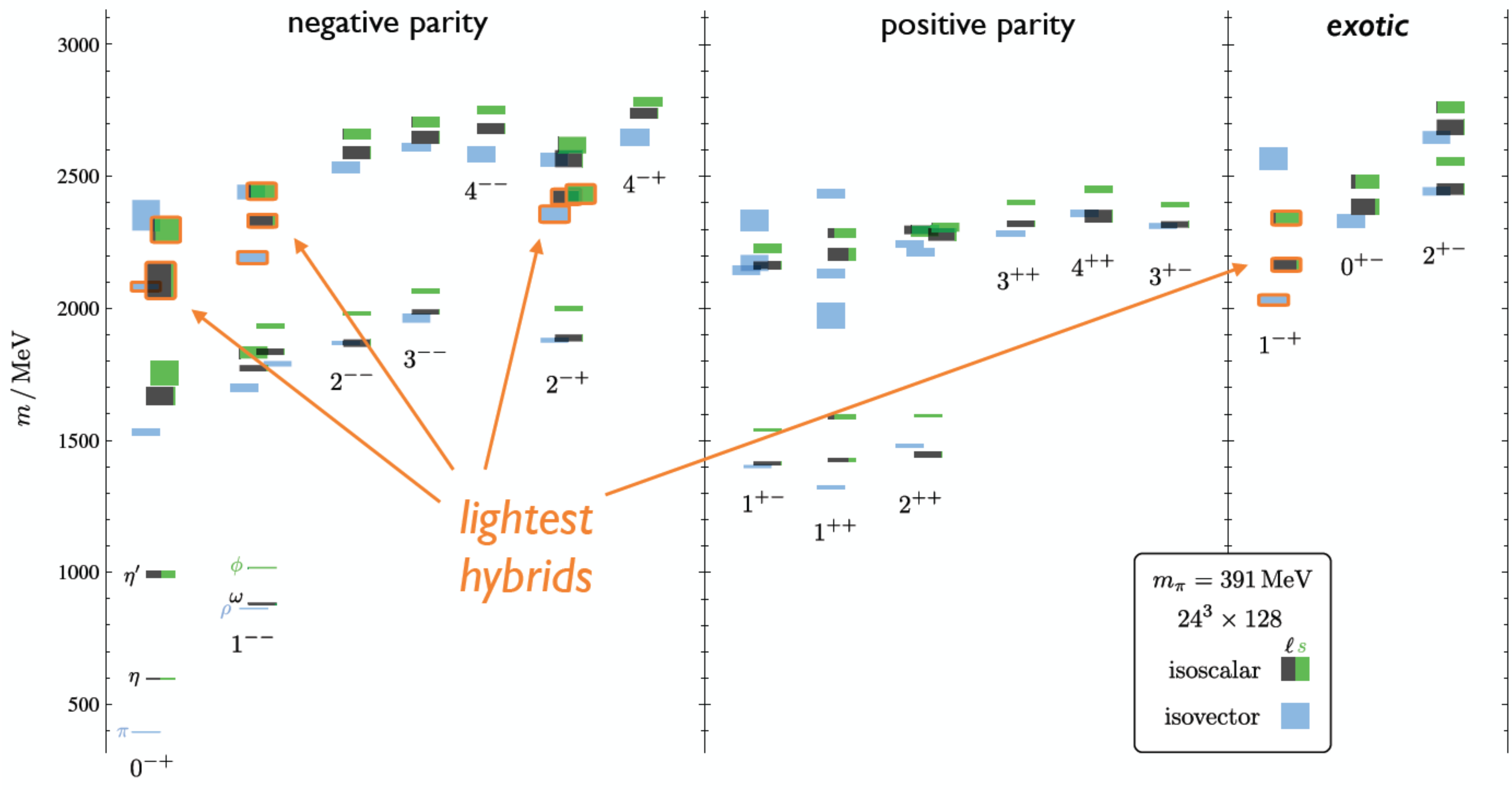
- proton-antiproton annihilation:
  Crystal Barrel at CERN, Panda at FAIR, ...
- $e^+ e^-$ annihilation:
  LEP, Babar at SLAC, Belle at KEK, KLOE at Frascati, CLEO at Cornell, BES at Beijing, KLOE-II, Belle II at SuperKEKB, …
- proton-proton scattering:
  WA experiments at CERN, GAMS at Protvino, LHC, …
- pion beams on fixed target:
  E852 at BNL, VES at Protvino, COMPASS at Cern, …
- photoproduction experiments:
  CLAS at Jefferson Lab, GlueX and CLAS12 at Jefferson Lab

Focus on:

- Determining the mass spectrum and properties: high precision data and PWA
- Investigate rare and poorly known states: high statistics and unexplored final states
- Search for exotics

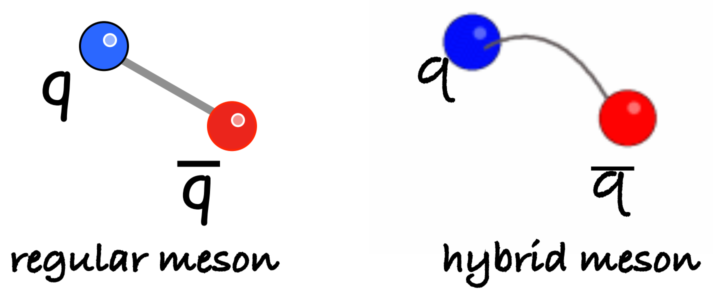
Mesons on the Lattice

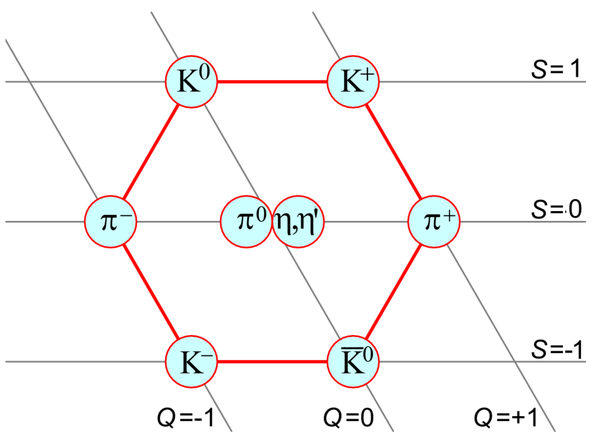
Dudek, Edwards, Guo, and Thomas, PRD 88, 094505 (2013)



Hybrids and Exotics

- Hybrids ($q\bar{q}g$) are the ideal system to study $q\bar{q}$ interaction and the role of gluons
- Existence is not prohibited by QCD but not yet firmly established.
- A possibility to identify unambiguously a meson as an hybrid state is to look for *exotic quantum numbers*





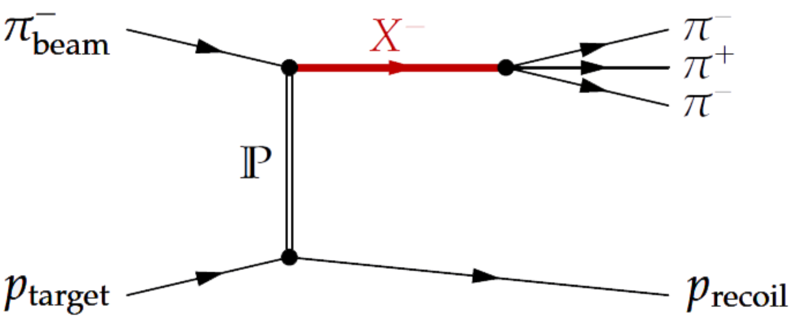
- Excitation of the glue leads to a new spectrum of hadrons that can have *exotic quantum numbers*

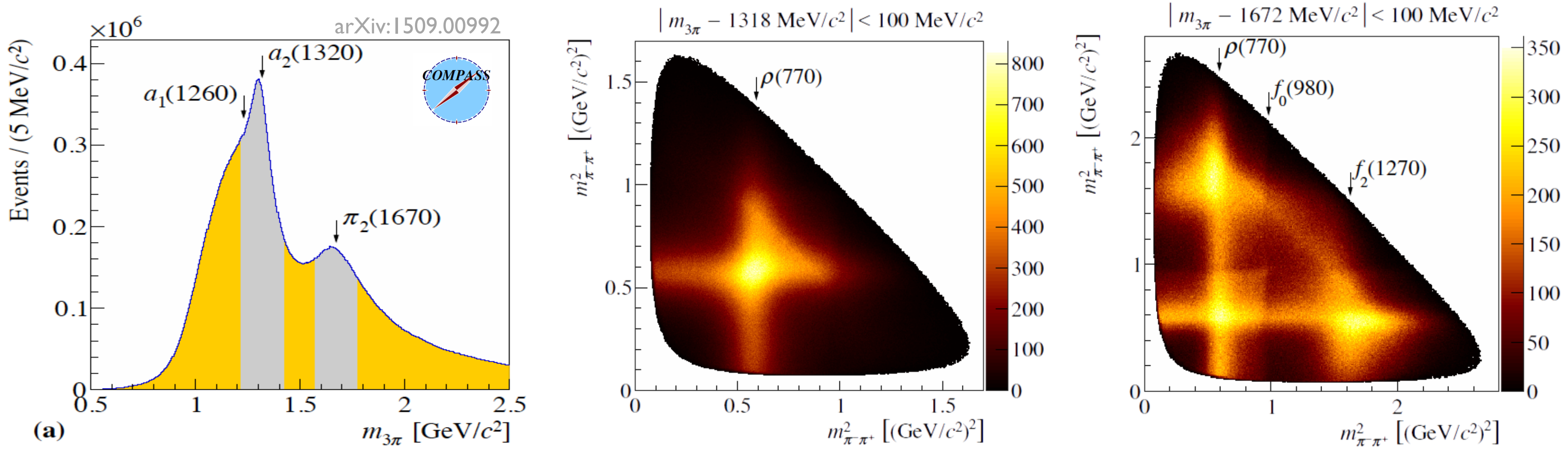
  $J^{PC} = 0^{+-}, 1^{-+}, 2^{+-} \ldots$
- For each exotic quantum number combination, a nonet of state should exist
- Lattice QCD predictions indicated the mass of the lowest state to be around 2 GeV, a range that can be explored by present experiments

Searching for new states

COMPASS:

- The largest data set of $\pi^+\pi^-\pi^-$ final state
- Diffractive pion (190 GeV/c) scattering on proton
- Investigation of the 3-pion mass spectrum up to 2.5 GeV
- PWA analysis focused on J^{PC} = 0^{-+}, 1^{++}, 2^{-+}, 2^{++}, 4^{++}





Searching for new states

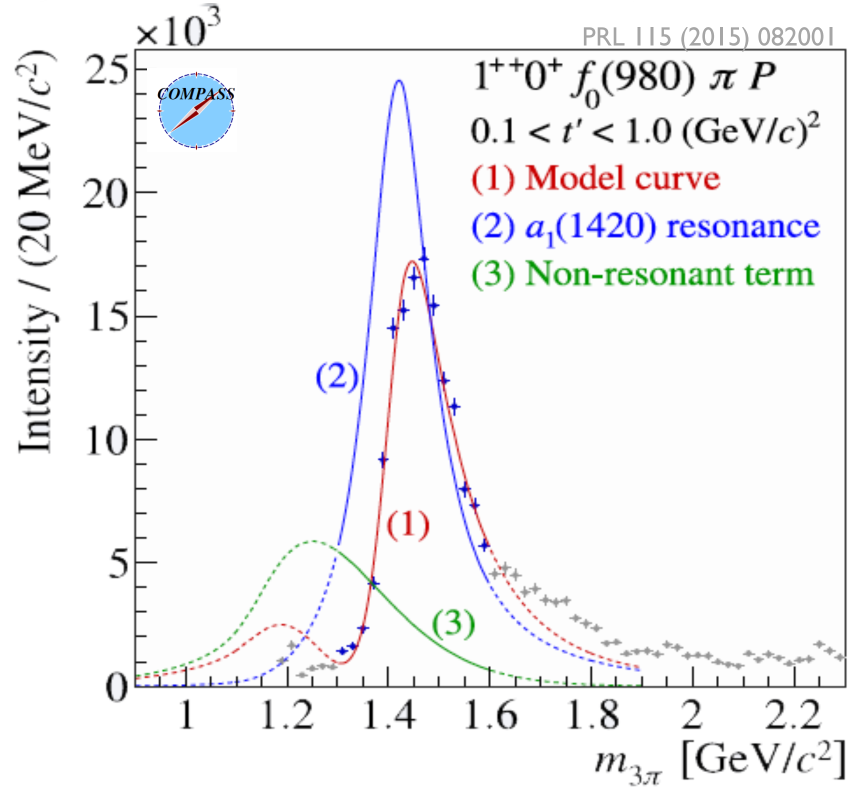
PWA analysis:

- Based on isobar model including $[\pi\pi]_S$, $\rho(770)$, $f_0(980)$, $f_2(1270)$, $f_0(1500)$, $\rho_3(1690)$
- Analysis as a function of t and mass
- Spin J and orbital angular momentum L up to 6

Results:

- Unexpected peak around 1.4 GeV/c^2 with small intensity (0.3%): **a_1(1420)**
- No quark-model states expected at 1.4 GeV/c^2:
  - First excited 1^{++} state expected to be heavier and wider
  - Isospin partner of narrow f_1(1420)?
- Peculiar decay mode:
  - Only seen in $f_0(980)\ \pi$
  - $f_0(980)$ has large ss content and is often interpreted as tetraquark
- a_1(1420) lies suspiciously close to KK* threshold

PRL 115 (2015) 082001

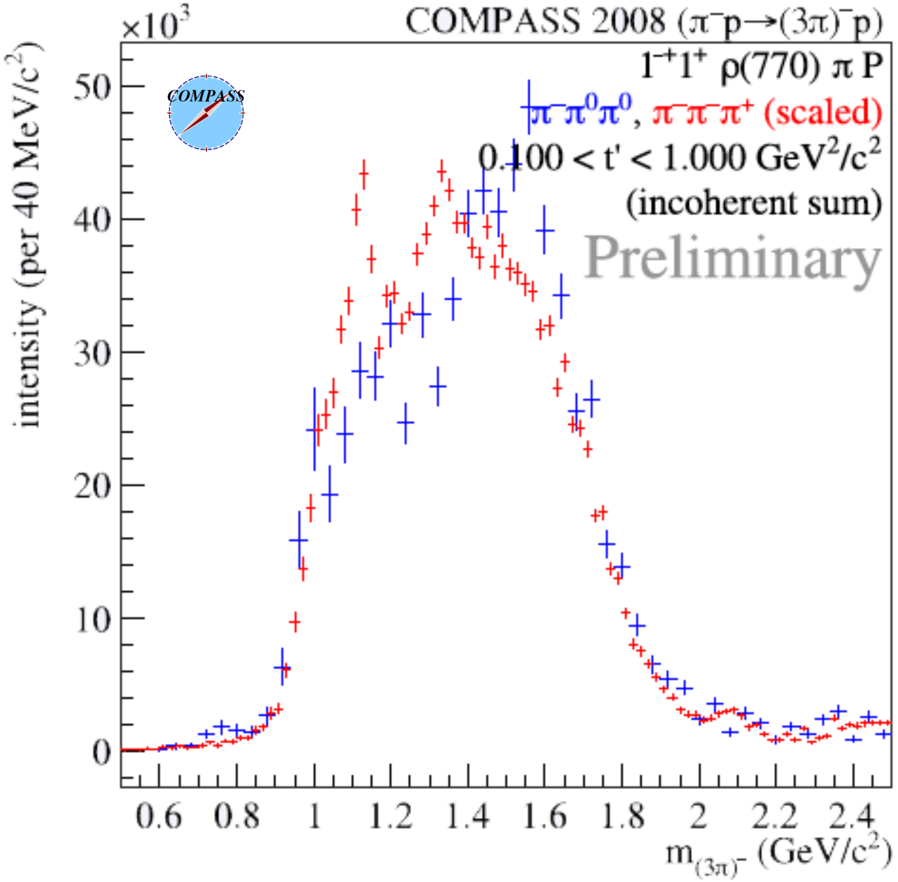


- 1^{++} peak consistent with Breit-Wigner resonance
- $a_1(1420)$:
  $M_0 = 1414^{+15}_{-13}\ \mathrm{MeV}/c^2$
  $\Gamma_0 = 153^{+8}_{-23}\ \mathrm{MeV}/c^2$

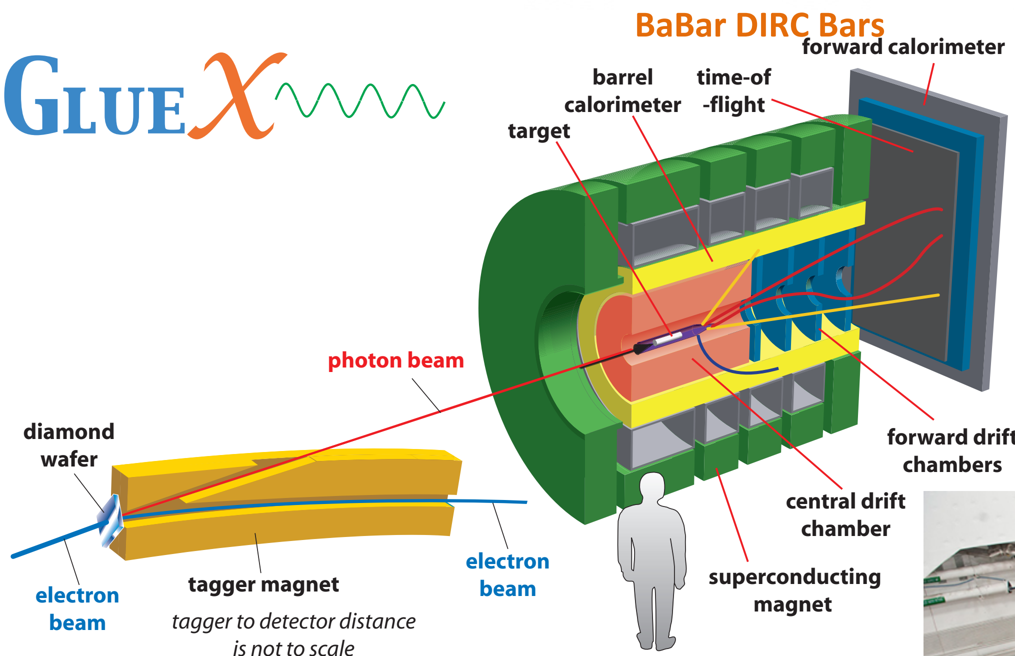
Exotics?

Significant intensity found in 1^{-+} exotic wave:

- Quantum number of lowest mass hybrid multiplet from LQCD calculation
- Previous experiments including low statistics Compass sample observed a peak interpreted as evidence of the hybrid $\pi_1(1600)$
- Broad structure observed in 3 pion charged and neutral final state
- Consistent with non-resonant contribution
- More investigation needed: different probes and kinematics



The GlueX Experiment

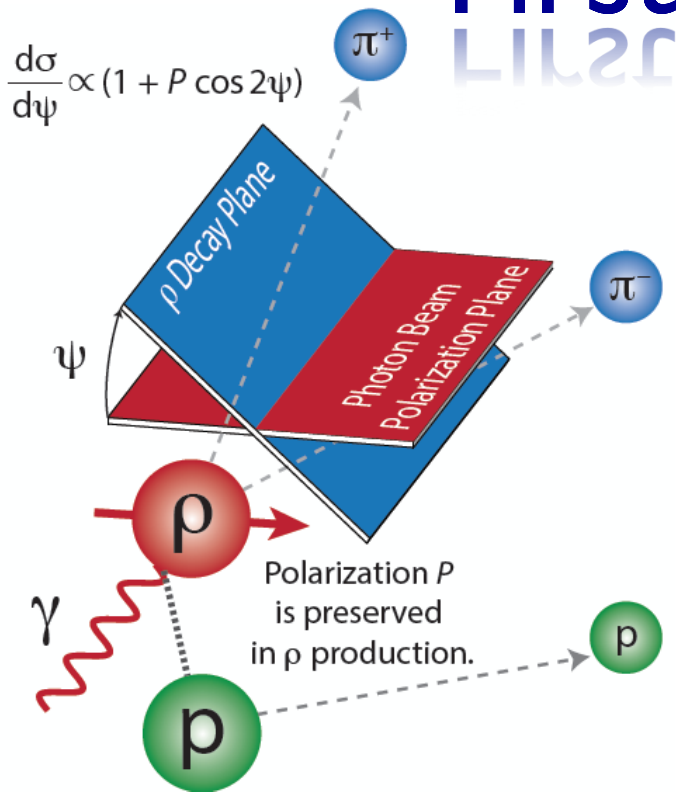


Physics in 2016:

Photo Production of Hybrids, Light-quark Mesons and Strangeonium States

- 12 GeV e^- beam up to 2.2 μA.
- Linearly polarized photons (P_γ≈40%) from coherent bremsstrahlung on diamond radiator
- Design intensity of 10^8 γ/s in coherent peak (E_γ = 8.4-9 GeV)

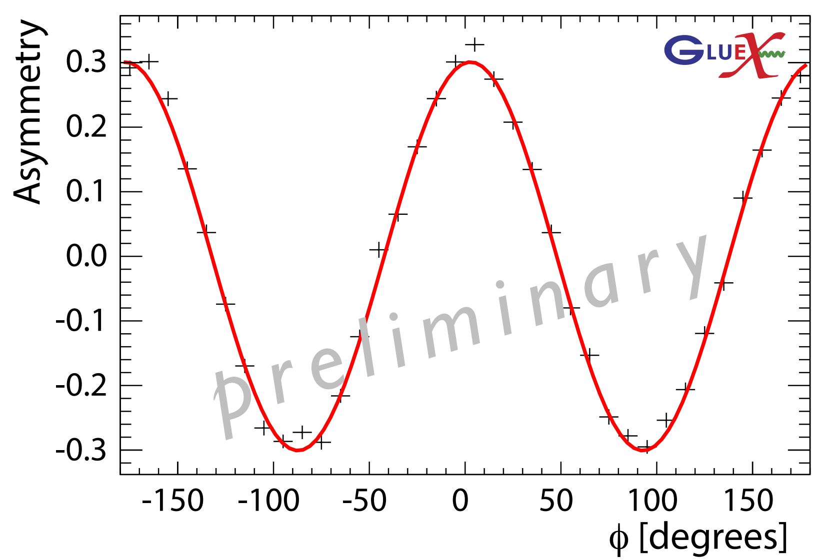
First Physics with GlueX



Beam asymmetry in ρ photoproduction

- Between 100 and 1000 times the 3000 existing events from SLAC
- Large polarization transfer to the ρ
- Acceptance errors not included

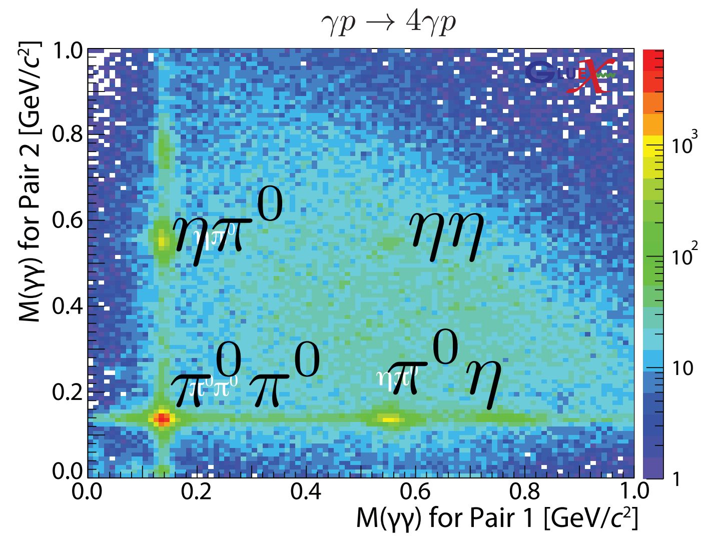
$$P\Sigma\cos 2\phi = \frac{N_{\parallel} - N_{\perp}}{N_{\parallel} + N_{\perp}}$$



Working with the Joint Physics Analysis Center (JPAC) on models for analysis

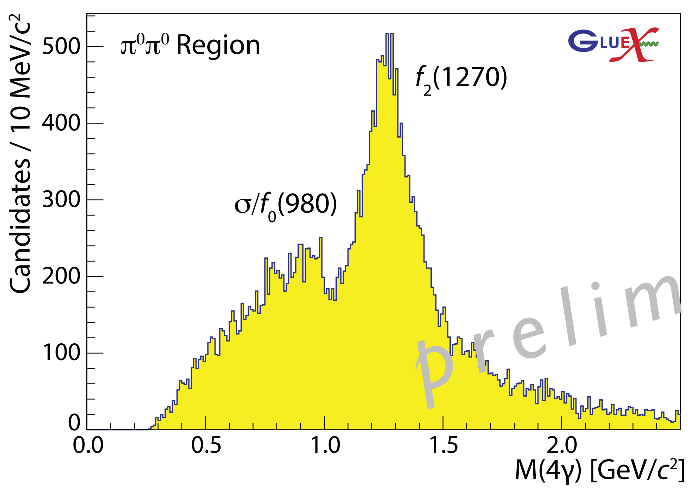
First Physics with GlueX

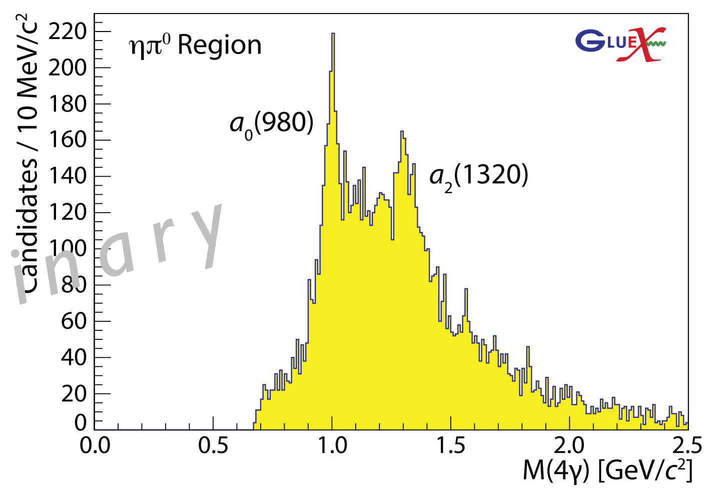
$\gamma p \rightarrow p\gamma\gamma\gamma\gamma$



- About 6% of the spring 2016 statistics from early in the run and using a very preliminary production run
- Clear signals for σ, $f_0(980)$, $f_2(1270)$, $a_0(980)$ and $a_2(1320)$

Physics run start in Fall 2016





CLAS12

Forward Detector:

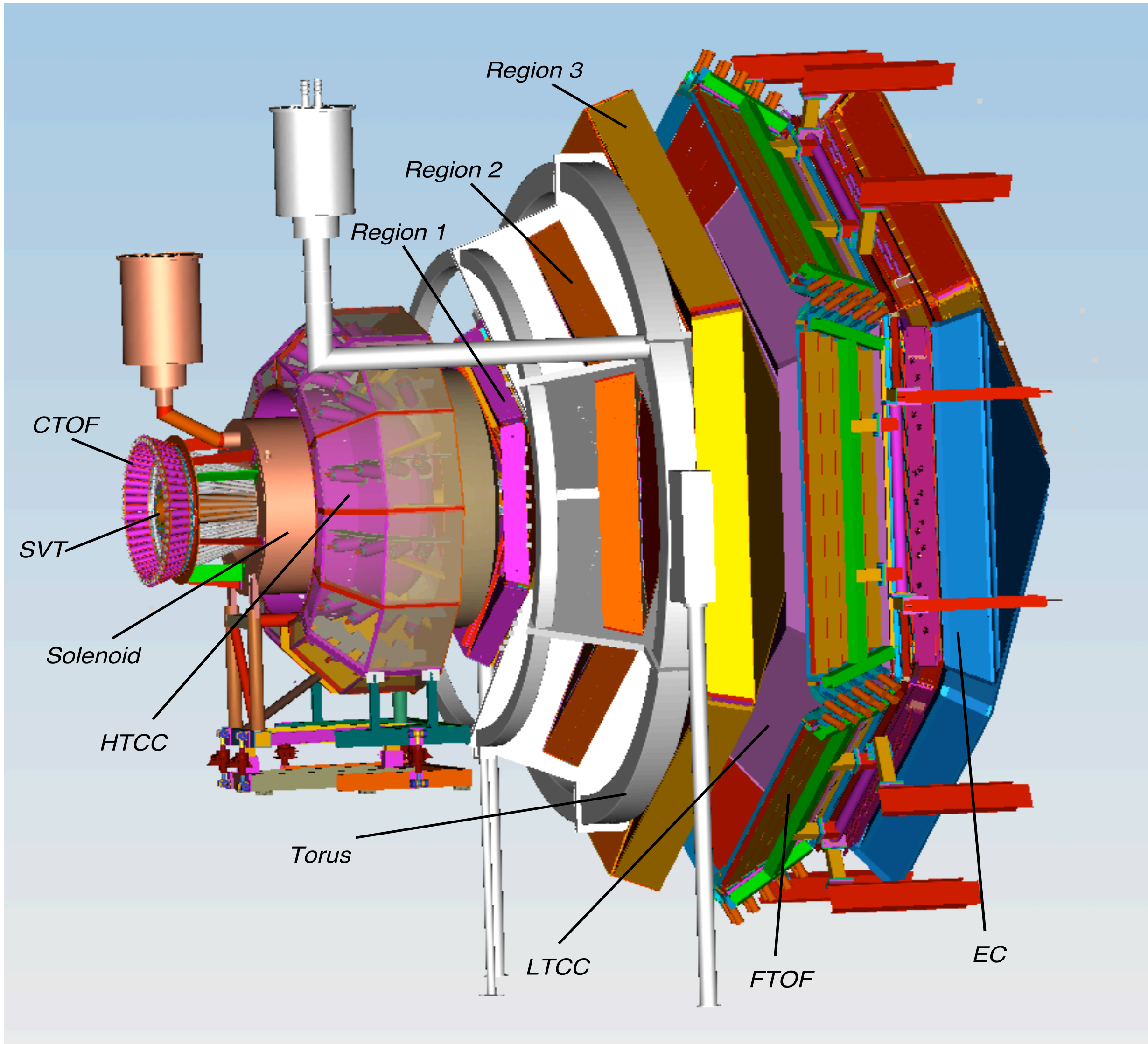
- *TORUS magnet*
- *Forward SVT tracker*
- *HT Cherenkov Counter*
- *Drift chamber system*
- *LT Cherenkov Counter*
- *Forward ToF System*
- *Preshower calorimeter*
- *E.M. calorimeter (EC)*

Central Detector:

- *SOLENOID magnet*
- *Barrel Silicon Tracker*
- *Central Time-of-Flight*

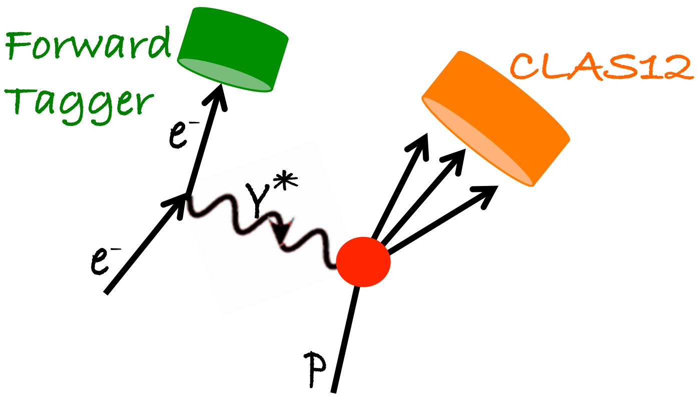
Proposed upgrades:

- *Micromegas (CD)*
- *Neutron detector (CD)*
- *RICH detector (FD)*
- *Forward Tagger (FD)*



Commissioning in 2017

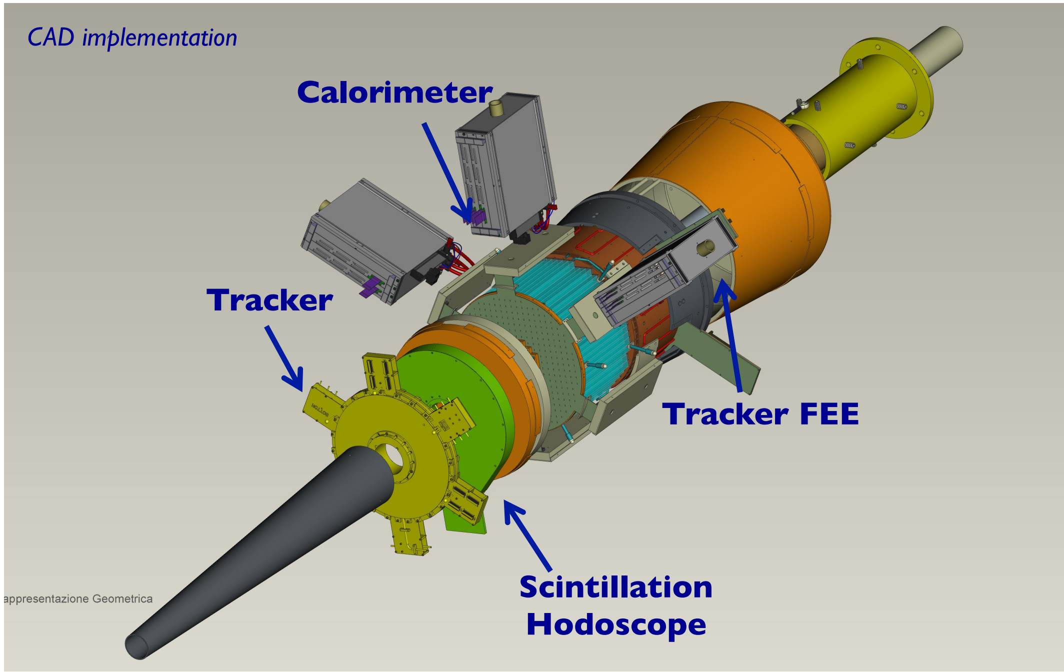
The CLAS12 Forward Tagger



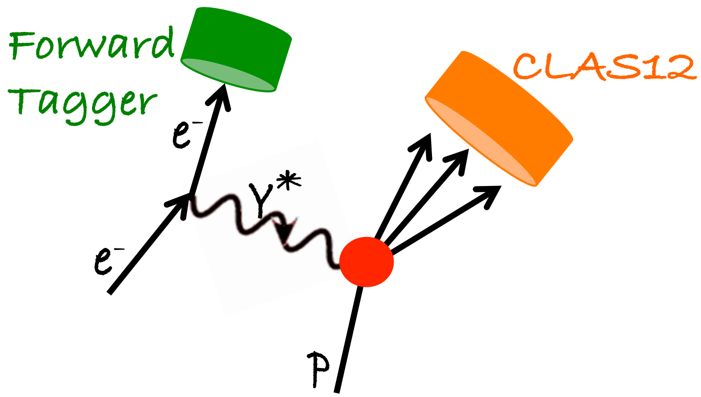
Quasi-real photoproduction on proton target:

- Detection of multiparticle final state from meson decay in the large acceptance spectrometer CLAS12
- Detection of the scattered electron for the tagging of the quasi-real photon in the novel Forward Tagger

Forward Tagger	
E’	0.5-4.5 GeV
ν	7-10.5 GeV
θ	2.5-4.5 deg
Q^2	0.007 – 0.3 GeV^2
W	3.6-4.5 GeV
Photon Flux	5 x 10^7 γ/s @ $L_e=10^{35}$



The CLAS12 Forward Tagger



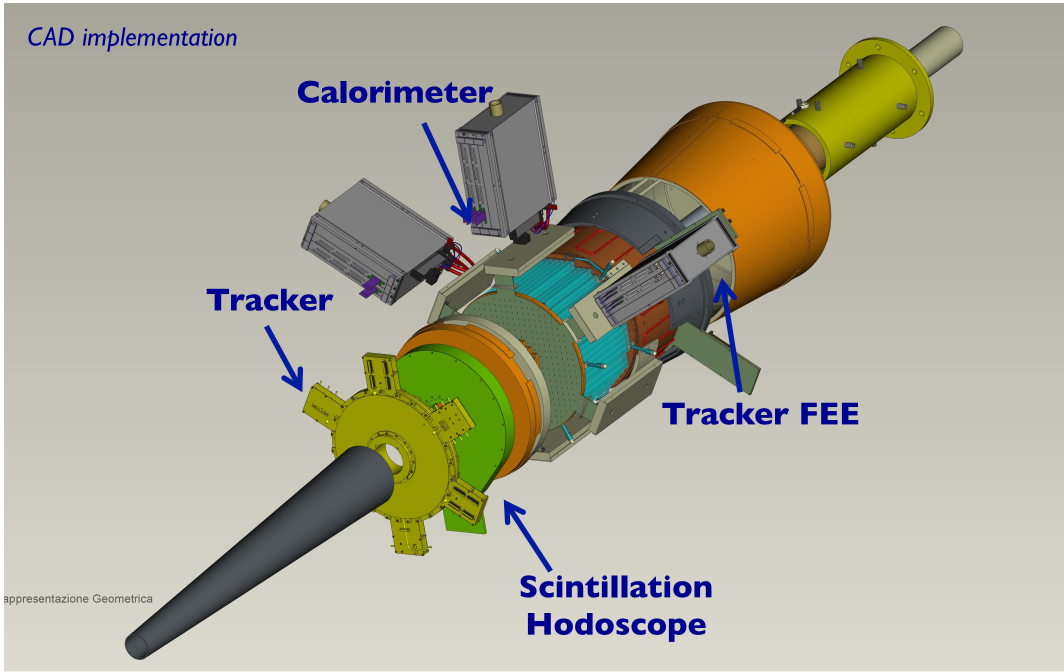
Physics goals

Meson spectroscopy:
- Detailed mapping of the meson spectrum up to 2.5 GeV
- Investigation of strangeonium and strangeness rich states
- Search for exotics

Baryon spectroscopy:
- Study of "very-strange" hyperons
- Search for hybrid baryons

Quasi-real photoproduction on proton target:

- Detection of multiparticle final state from meson decay in the large acceptance spectrometer CLAS12
- Detection of the scattered electron for the tagging of the quasi-real photon in the novel Forward Tagger



Summary and Perspectives

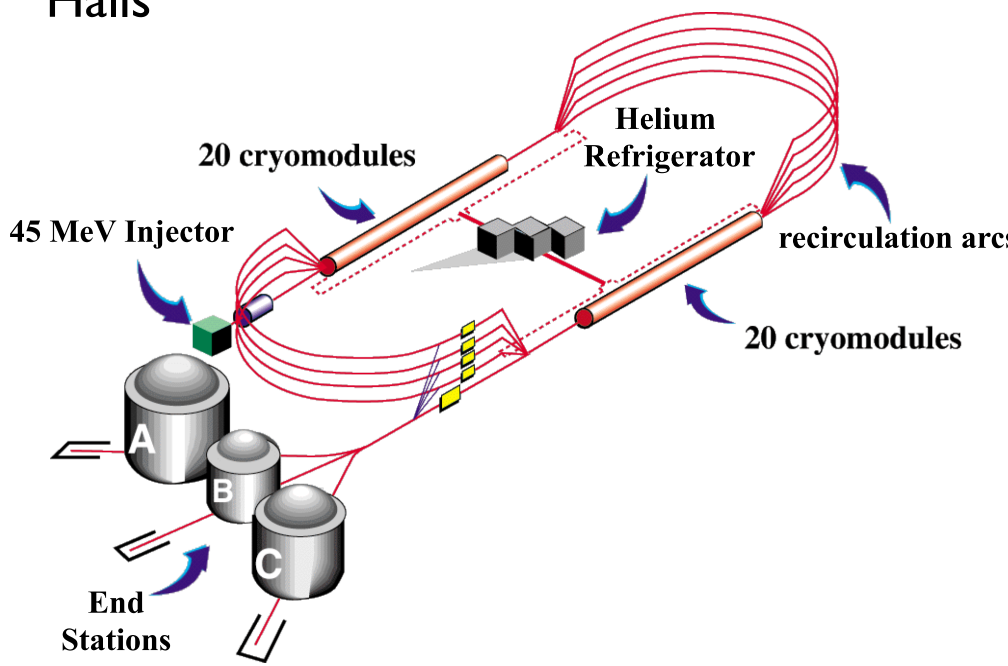
- The study of hadron spectroscopy can shed light on fundamental problems in the understanding of strong interaction and QCD
- Primary focus in the field is to establish the baryon and meson spectra, determine resonance state properties and search for exotic configurations
- Experiments all over the world are collecting high statistics high precision data, providing new insight in the hadron spectrum and structure
- The new experimental data with the support of recent theoretical developments can lead to solve some of the most intriguing puzzles in hadronic physics

Backup

Jefferson Laboratory

Continuous Electron Beam Accelerator Facility (CEBAF):

- a superconducting electron machine based on two Linacs in racetrack configuration
- Simultaneous distribution to 3 experimental Halls

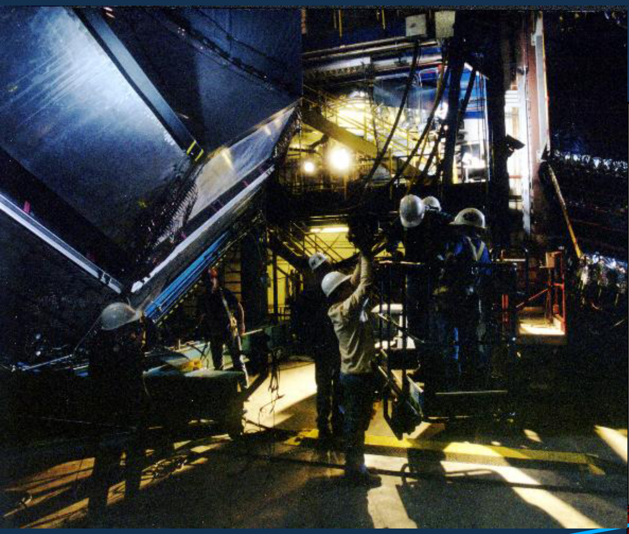


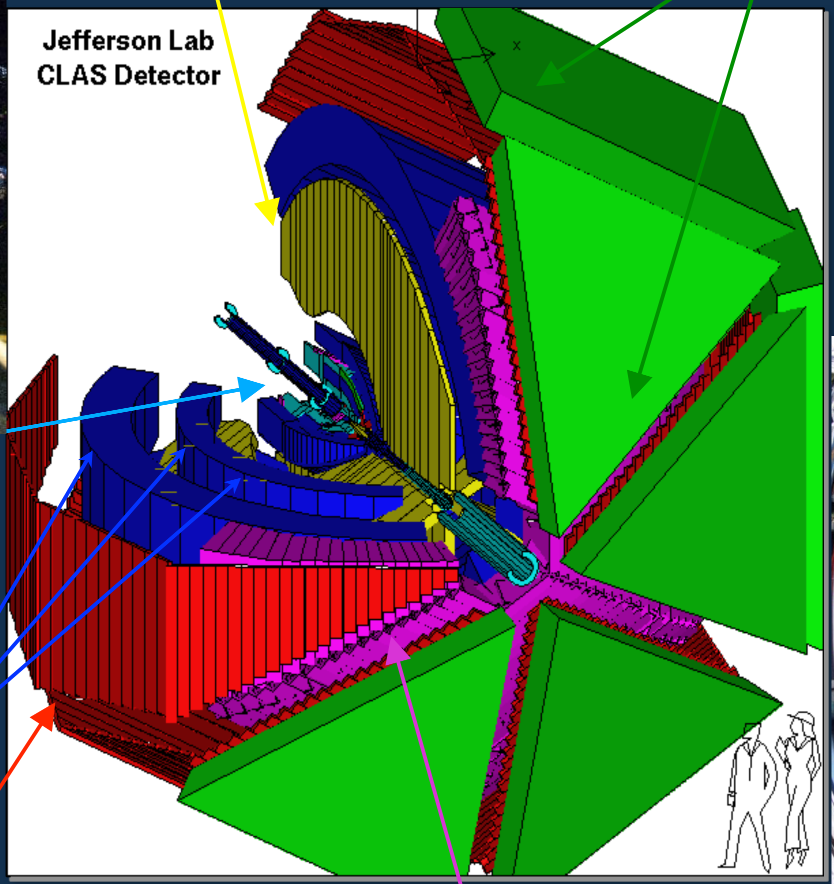
High electron polarization
Beam Power: 1MW
Beam Current: 200 μA
Max Energy: 6 GeV
RF: 1499 MHz

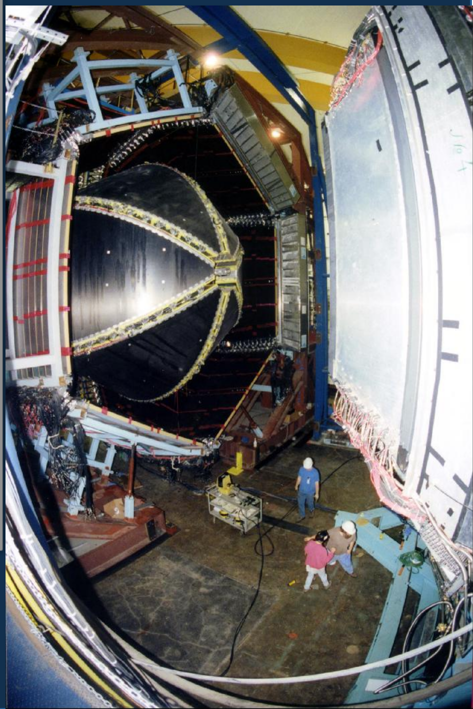
CEBAF Large Acceptance Spectrometer

Torus Magnet
6 Superconductive Coils

Electromagnetic Calorimeter
lead/plastic scintillator, 1296 PMTs







Target + γ
start counter
e mini-torus

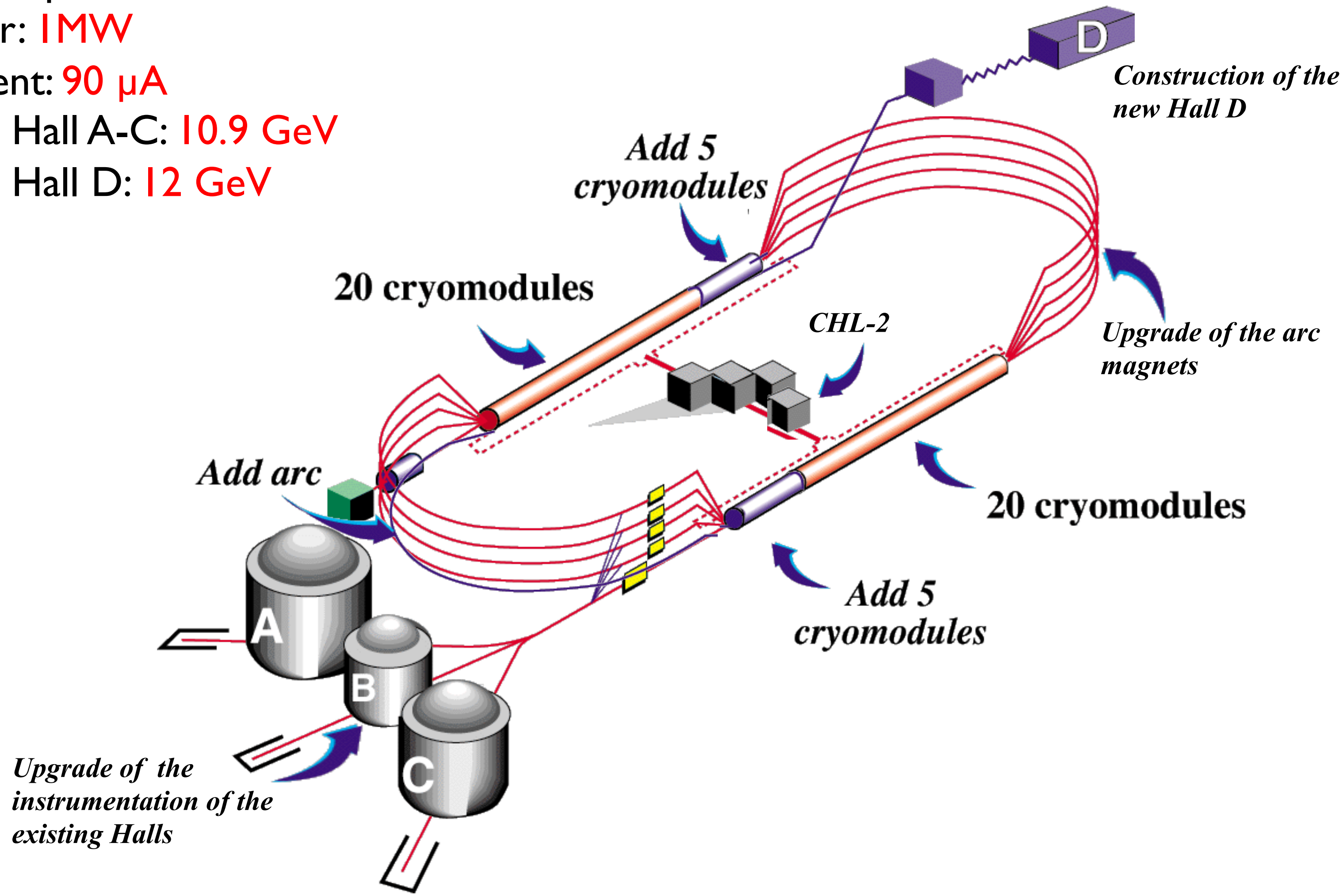
Drift Chamber
35,000 cells

Time of Flight
Plastic Scintillator,
684 PMTs

Cherenkov Counter
e/π separation, 256 PMTs

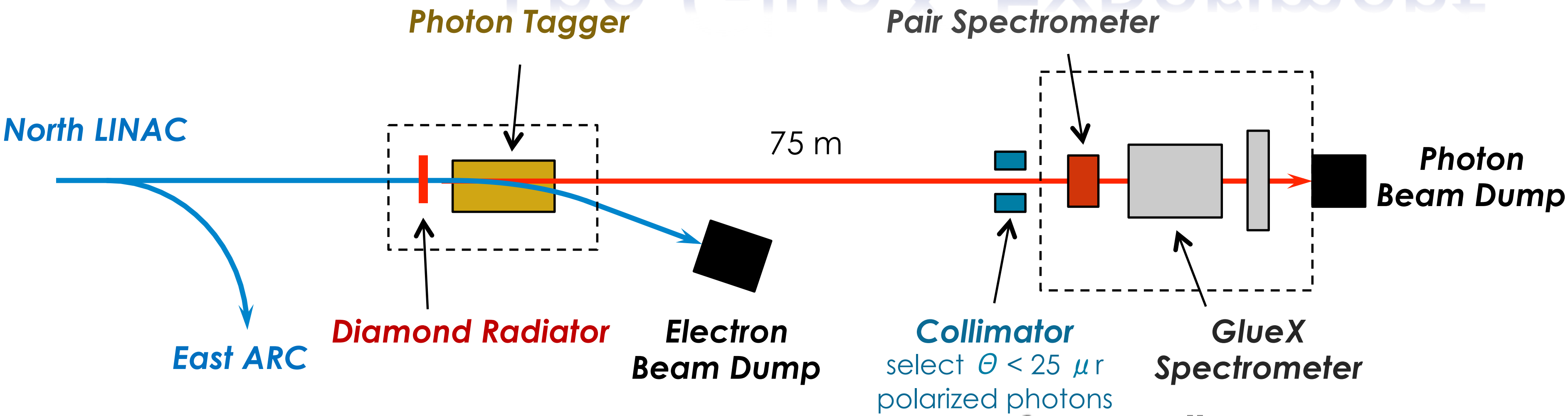
Jefferson Lab Upgrade

High electron polarization
Beam Power: 1MW
Beam Current: 90 μA
Max Energy Hall A-C: 10.9 GeV
Max Energy Hall D: 12 GeV

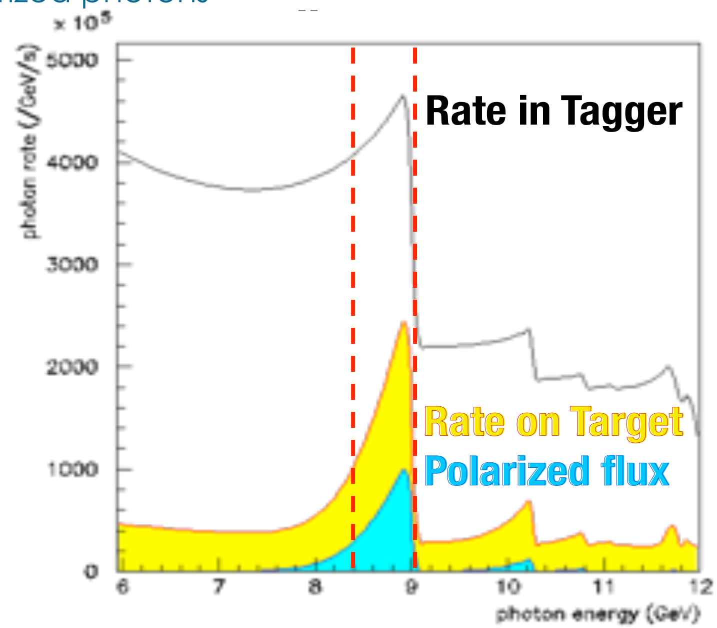


Jefferson Lab Upgrade

The GlueX Experiment

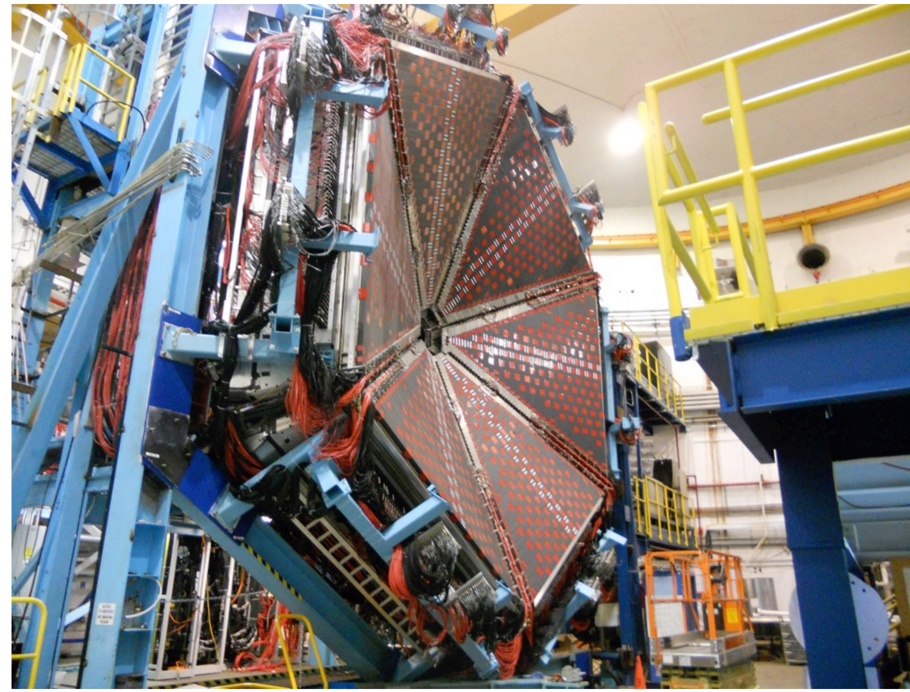


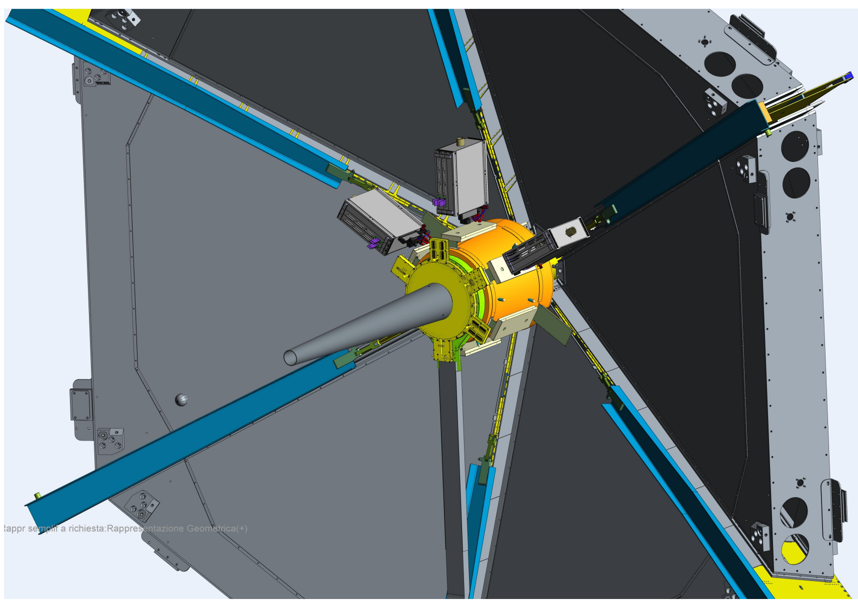
- 12 GeV e$^-$ beam up to 2.2 μA.
- Linearly polarized photons (P_γ≈40%) from coherent bremsstrahlung on diamond radiator
- Design intensity of 10^8 γ/s in coherent peak (E_γ = 8.4-9 GeV)



The CLAS12 Forward Tagger

- FT components in final assembly/test phase at different institutions
- Integration and installation plan defined
- First FT detector (calorimeter) to be transferred at Jefferson Lab in the Fall for full commissioning



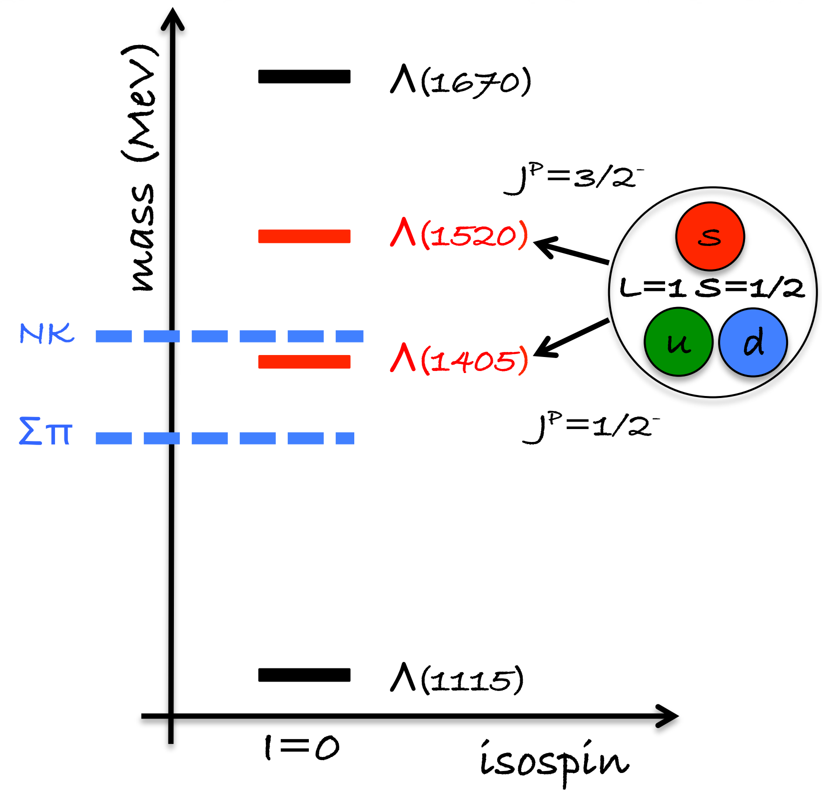


- Installation scheduled for late summer 2016
- Commissioning of the full CLAS12 detector in Fall 2016
- First physics run in spring 2017

The Puzzling Λ(1405)

First excited state of the Λ baryon:

- State known since 1950's
- PDG:
  - M=(1405±1) MeV
  - Γ=(50±2) MeV
  - $J^P=1/2^-$ based on CQM assignment
- Mass inconsistent with CQM expectations
- Complex line shape
- Mass is below NK threshold but state has a strong coupling to NK
- Different interpretations:
  - Standard 3 quark state
  - Molecule or hybrid
  - Dynamically generated state with two overlapping poles (χUT)



PDG: "The nature of the Λ(1405) has been a puzzle for decades: three-quark state or hybrid; two poles or one. We cannot here survey the rather extensive literature…"

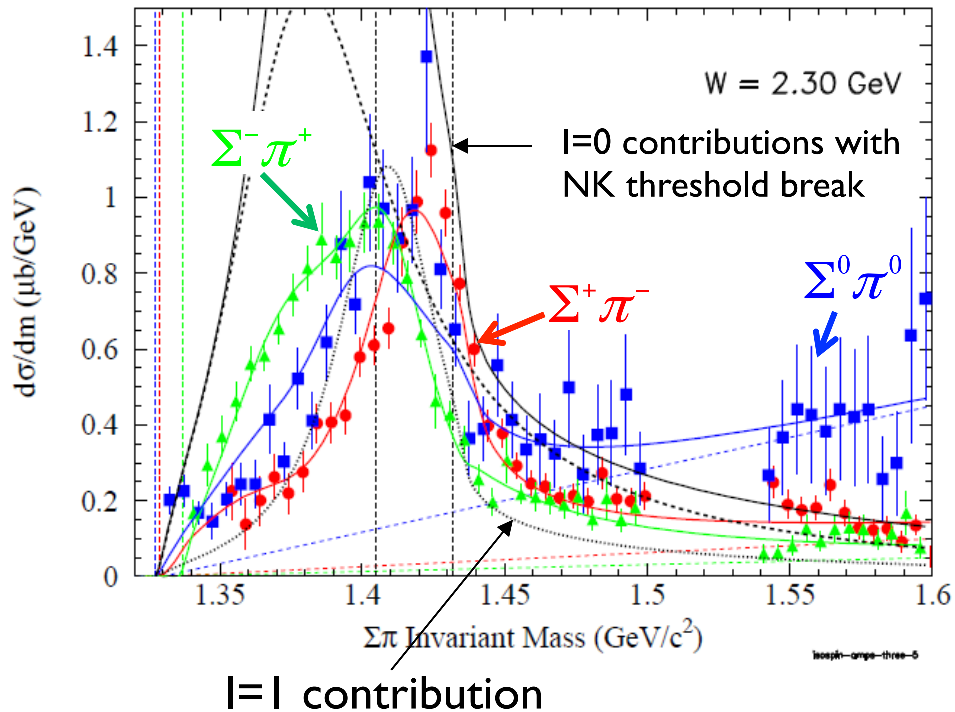
The Puzzling Λ(1405)

An issue since its prediction/discovery:

- CQM: SU(3) singlet 3q state, I=0, $J^P = ½^-$
- Unusual mass, line shape and couplings
- Proposed as dynamically generated state, molecule, …

CLAS at JLAB:

- Measured in photoproduction off proton
- Analysis of lines shape from Σπ decay consistent with I=1 contribution (resonance or continuum?)
- J^P=1/2$^-$ experimentally determined for the first time from decay angular distribution



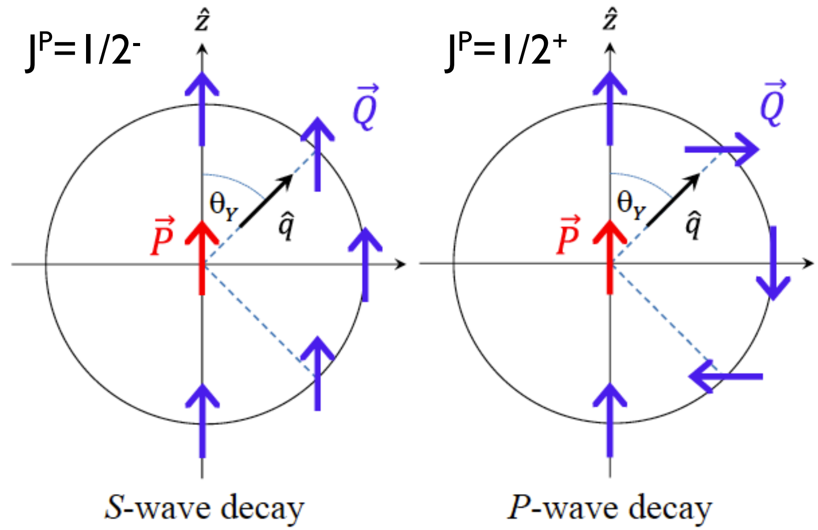
Phys. Rev. C 87, 035206 (2013)
Nucl. Phys A 914, 51 (2013)
Phys. Rev. Lett. 112, 082004 (2014)

Λ(1405) Spin and Parity

Parity and spin of the state were never measured before and PDG J^P assignment is based on the CQM expectation

- J and P can be inferred finding a reaction where Λ(1405) is created polarized and studying the decay:

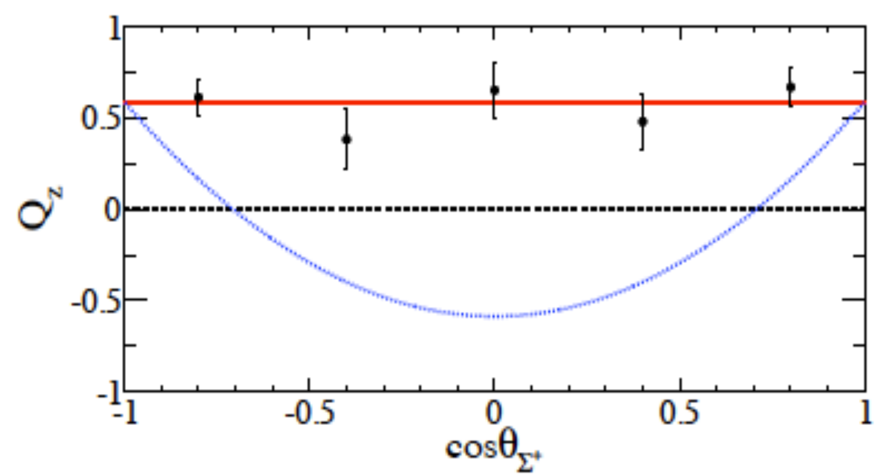
  $\Lambda(1405) \rightarrow \Sigma\,\pi$
- Decay angular distribution relates to J:
  - J=1/2: flat distribution
  - J=3/2: "smile" or "frown" distribution
- Parity is given by polarization transfer to daughter



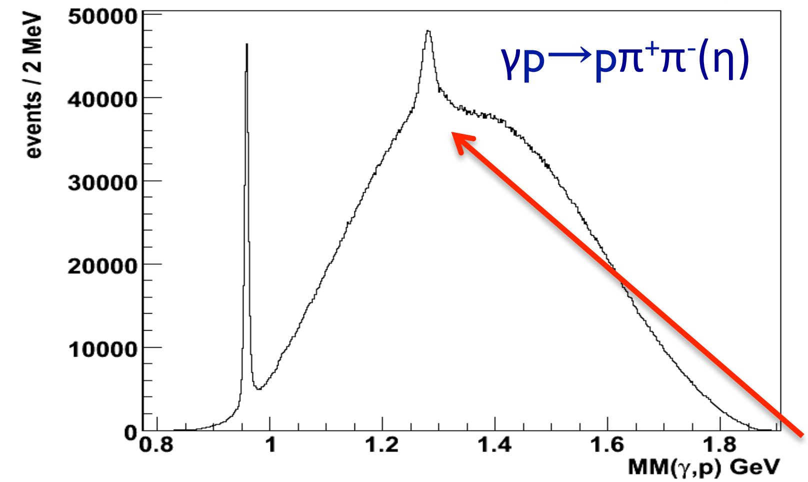
Analysis of decay angular distribution indicate an isotropic decay in S-wave

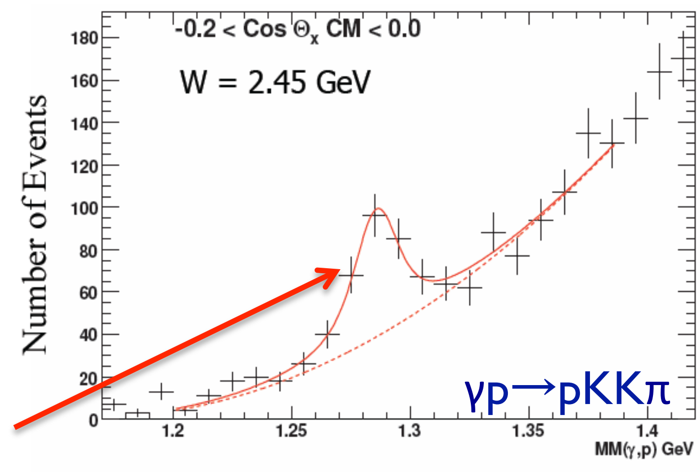
$J^P=1/2^-$

experimentally determined for the first time

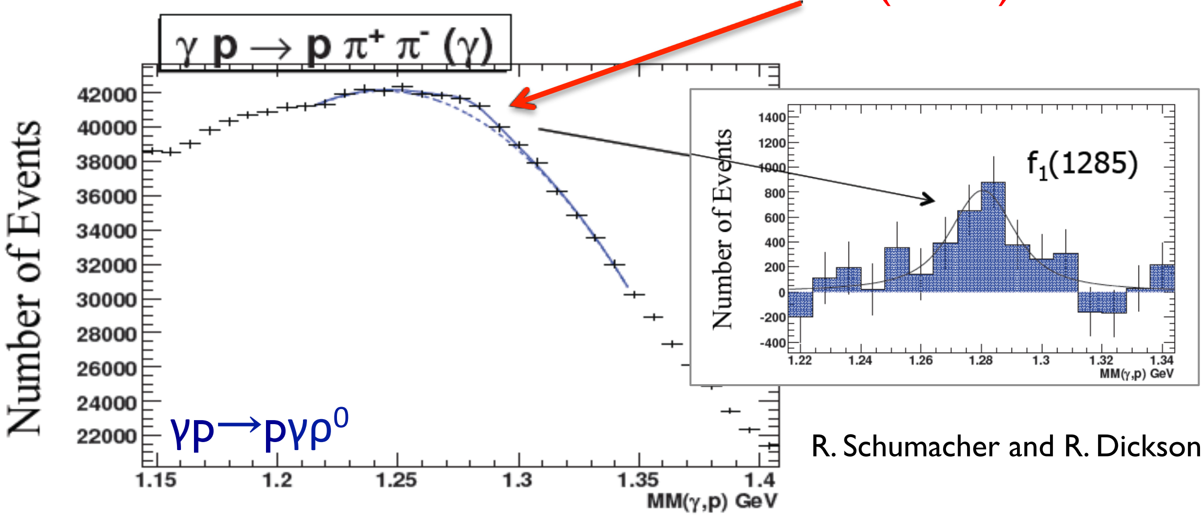


The f_1(1285) at CLAS





x(1280)



R. Schumacher and R. Dickson (CMU)

Study extended to different final states to determine branching ratios and disentangle possible contributions from overlapping states

R. De Vita

Light Meson Decays

The $\eta \rightarrow \pi^+\pi^-\pi^0$

- Isospin violating process → mainly proceeds via strong interaction
- Low energy description of strong interactions (ChPT)
- Provide constraint on light quark masses

$$Q^2 = \frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2} \quad with\ \hat{m} = \frac{1}{2}(m_d + m_u)$$

- Decay width at up to NLO ChPT proportional to Q^{-4}
- Dalitz density distribution in η-rest frame can be parameterized as a polynomial expansion around X = Y = 0

$$|A(X,Y)|^2 \approx 1 + aY + bY^2 + cX + dX^2 + eXY + fY^3 + gX^2Y + hXY^2 + lX^3 + \ldots$$

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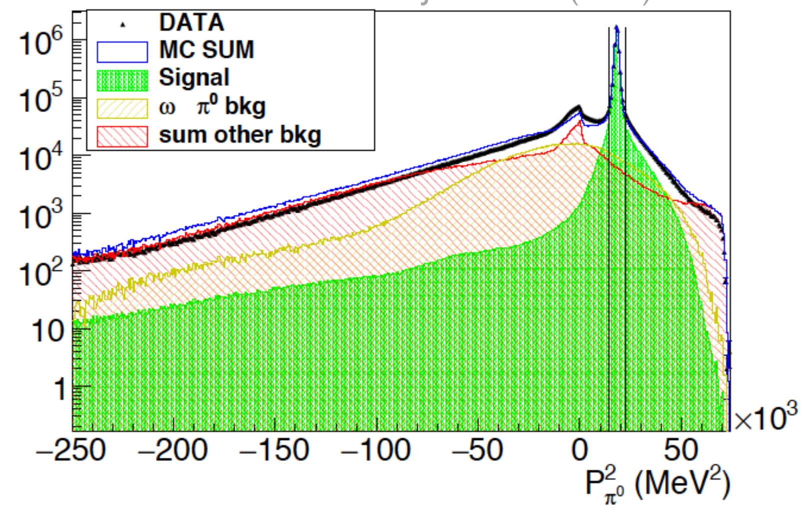

KLOE-2

- New independent measurement
- 1.7 fb^{-1} → 4.48 x 10^6 events
- New analysis scheme
- Overall efficiency 38%
- Reduction of systematic uncertainties respect to KLOE08 analysis
- Fit including also the g parameter

$\eta \to \pi^+\pi^-\pi^0$ at KLOE-2

Dalitz plot analysis:

- Charge conjugation violating parameters consistent with zero
- Fits without g parameter consistent with previous analyses
- f,g parameters needed to describe the data
- Most precise determination of ChPT expansion parameters

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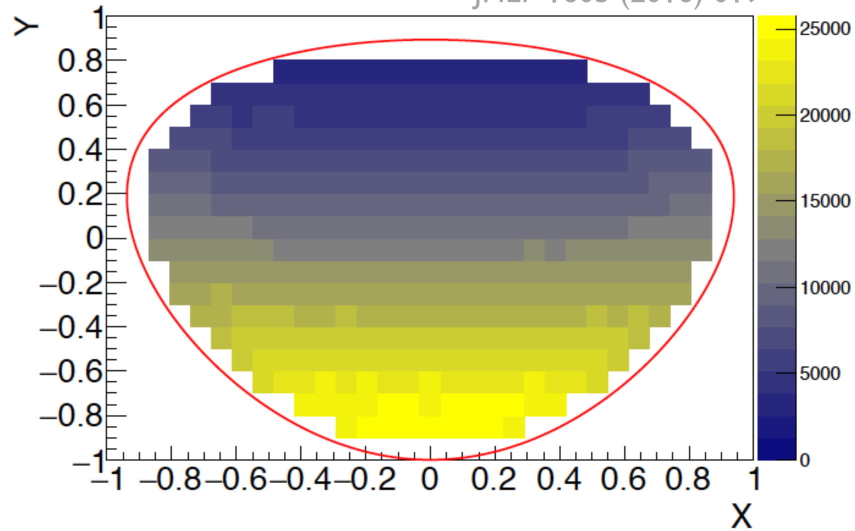


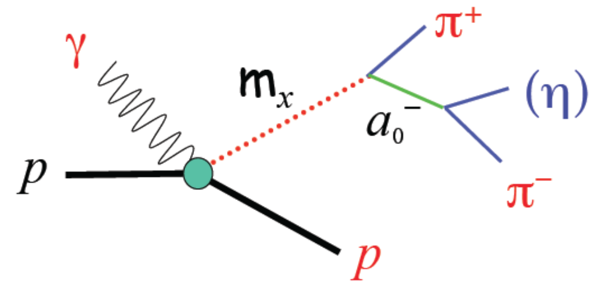
$$|A(X,Y)|^2 \approx 1 + aY + bY^2 + cX + dX^2 + eXY + fY^3 + gX^2Y$$

Fit/set#	a	$b \cdot 10$	$d \cdot 10^2$	$f \cdot 10$	$g \cdot 10^2$	c, e, h, l	χ^2/dof	Prob
(1)	-1.095 ± 0.003	1.454 ± 0.030	8.11 ± 0.32	1.41 ± 0.07	-4.4 ± 0.9	free	354/361	0.60
(2)	-1.104 ± 0.002	1.533 ± 0.028	6.75 ± 0.27	0	0	0	1007/367	0
(3)	-1.104 ± 0.003	1.420 ± 0.029	7.26 ± 0.27	1.54 ± 0.06	0	0	385/366	0.24
(4)	-1.095 ± 0.003	1.454 ± 0.030	8.11 ± 0.33	1.41 ± 0.07	-4.4 ± 0.9	0	360/365	0.56
(5)	-1.092 ± 0.003	1.45 ± 0.03	8.1 ± 0.3	1.37 ± 0.06	-4.4 ± 0.9	0	369/365	0.43
(6)	-1.101 ± 0.003	1.41 ± 0.03	7.2 ± 0.3	1.50 ± 0.06	0	0	397/366	0.13

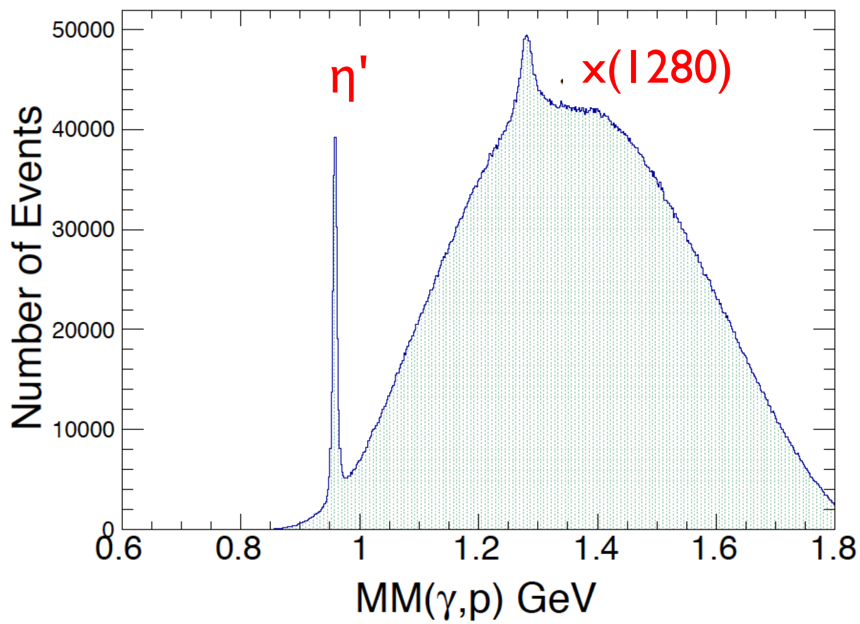
Investigating Rare Meson Properties

$f_1(1285)$: $I^G(J^{PC}) = 0^+(1^{++})$

- Well-established axial-vector meson seen in several hadronic reactions;
  - ~7000 events reported world-wide
  - seen in PWA analyses
- Possible "dynamically generated" KK* – c.c. state
- Extraction of resonance parameters complicated by potential overlap with other states, e.g. η(1295)



(possible reaction topology)



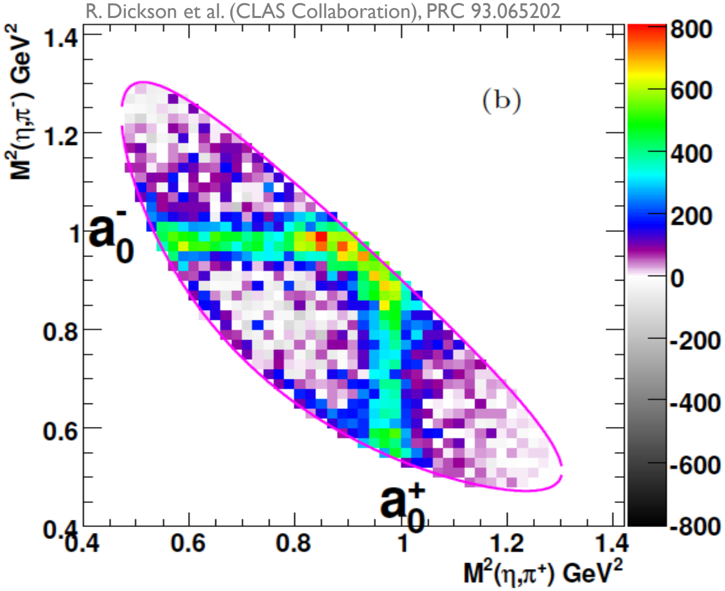
Study of the $f_1(1285)$ in $\gamma p \rightarrow p\pi^+\pi^-(\eta)$ at CLAS:

- Structure at m~1280 MeV observed in the γp missing mass spectrum
- great statistics: ~1.5 x 10^5 x(1280) events
- Which state is it? f1(1285), η(1295), or both?

R. Dickson et al. (CLAS Collaboration), PRC 93.065202

The $f_1(1285)$ at CLAS

R. Dickson et al. (CLAS Collaboration), PRC 93.065202



Dalitz analysis of $x \rightarrow \eta\pi^+\pi^-$:

- dominance of decay via $a_0^{\pm}\pi^{\mp}$ intermediate state
- strong interference of a_0 bands seen
- amplitude analysis consistent with p-wave decay and positive parity
- Observed structure is associated with the $f_1(1285)$

Results:

- $J^P=1^+$
- Mass (MeV) = 1281.0 ± 0.8
- Width, Γ (MeV) = 18.4 ± 1.4 narrower than PDG value (24.2 ± 1.1)
- $\Gamma(\gamma\rho^0)/\Gamma(\eta\pi\pi)$ = 0.047 ± 0.018, more than 3σ below PDG value

First observation of the $f_1(1285)$ in photoproduction