JLUO Annual Meeting, Jefferson Lab, June 10, 2024

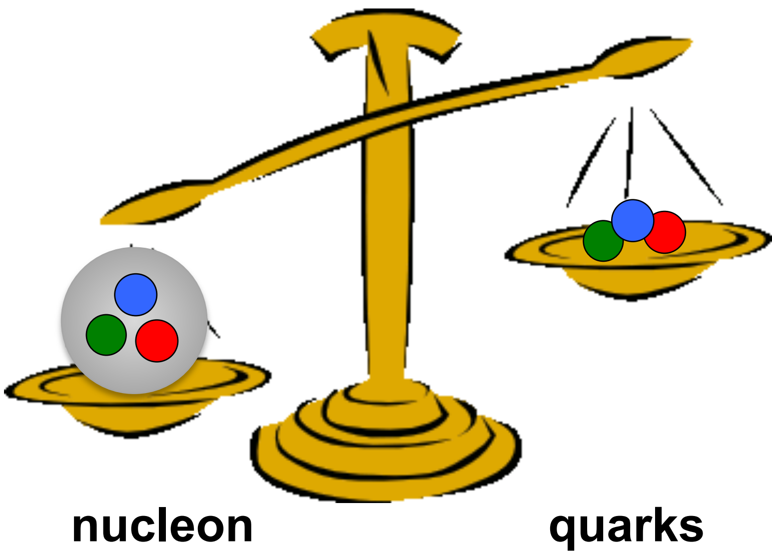
Meson spectroscopy at CLAS and CLAS12

Raffaella De Vita (Jefferson Lab)
for the CLAS Collaboration

QCD and Spectroscopy

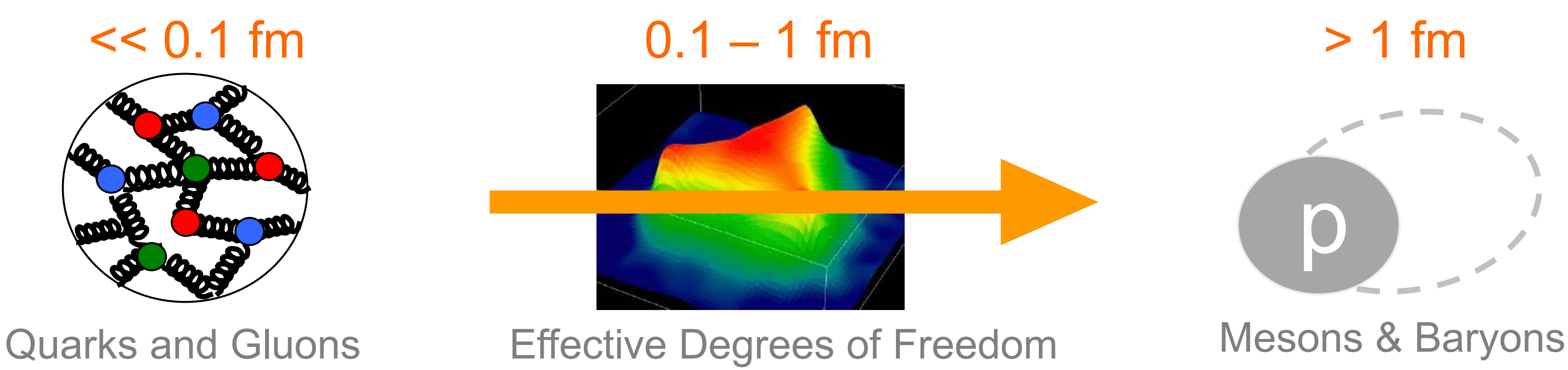
- Hadrons are one of the most relevant manifestations of the works of QCD
- Hadrons have an internal structure being made of quarks: known quark configurations are baryons, made of tree quarks and mesons, made of quark-antiquark pairs
- Quark masses account only for a small fraction of the nucleon mass: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

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



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>Meson spectroscopy is a key tool to investigate these issues</u>



Meson spectroscopy

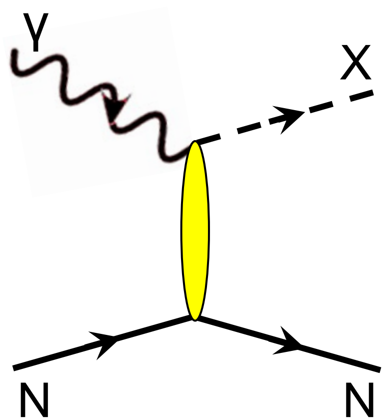
Objective:

Mesons are the simplest quark bound state, i.e. the best benchmark to understand how quarks interact to form hadrons and what the role of gluons is

- Precise determination of the meson spectrum
- Search for unusual states as hybrids (qqg), tetraquarks (qqqq) and glueballs

Technique:

Use (quasi) real tagged photon beams to produce the meson resonances and isolate the single states by detecting the decay products



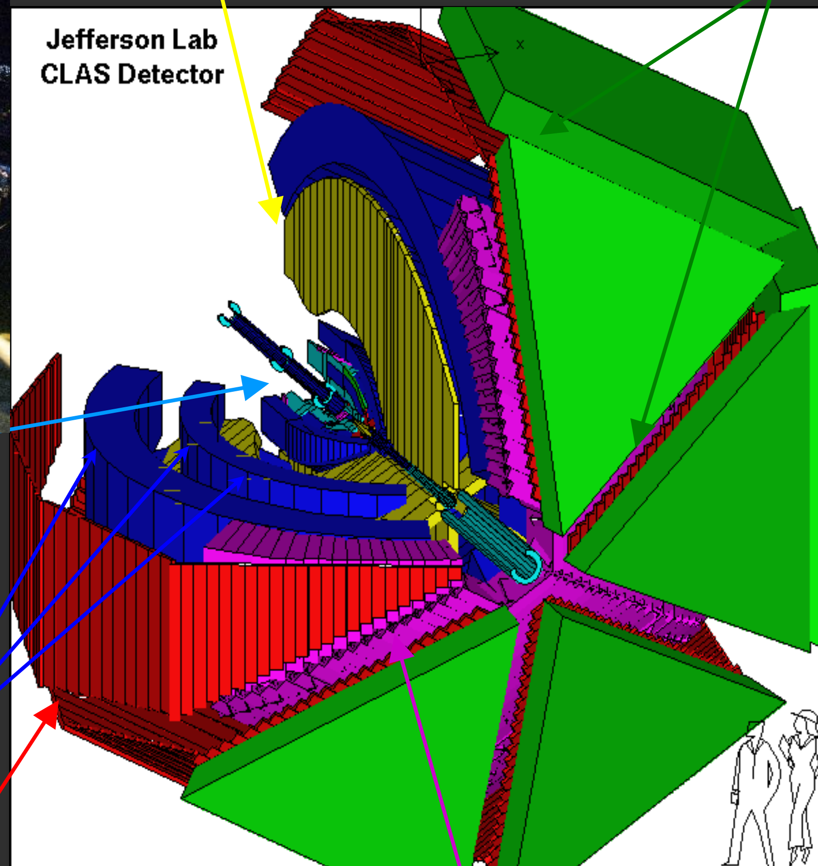
- Use of S=1 probe provides complementary information to S=0 (pion beams) probes
- Measurement of the decay products and PWA to isolate single resonances
- Full determination of initial state allows to study the production mechanism

- High intensity photon beams and large acceptance detector are needed!!

CEBAF Large Acceptance Spectrometer

Torus Magnet
6 Superconductive Coils

Electromagnetic Calorimeter
lead/plastic scintillator, 1296 PMTs

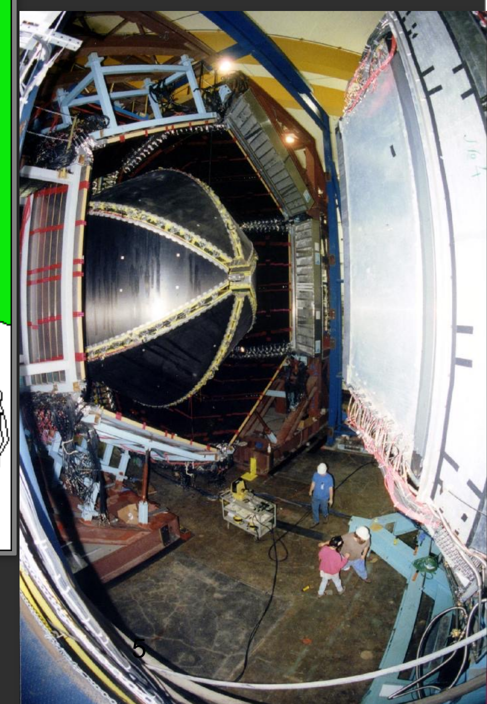


Target +
γ start counter
e mini-torus

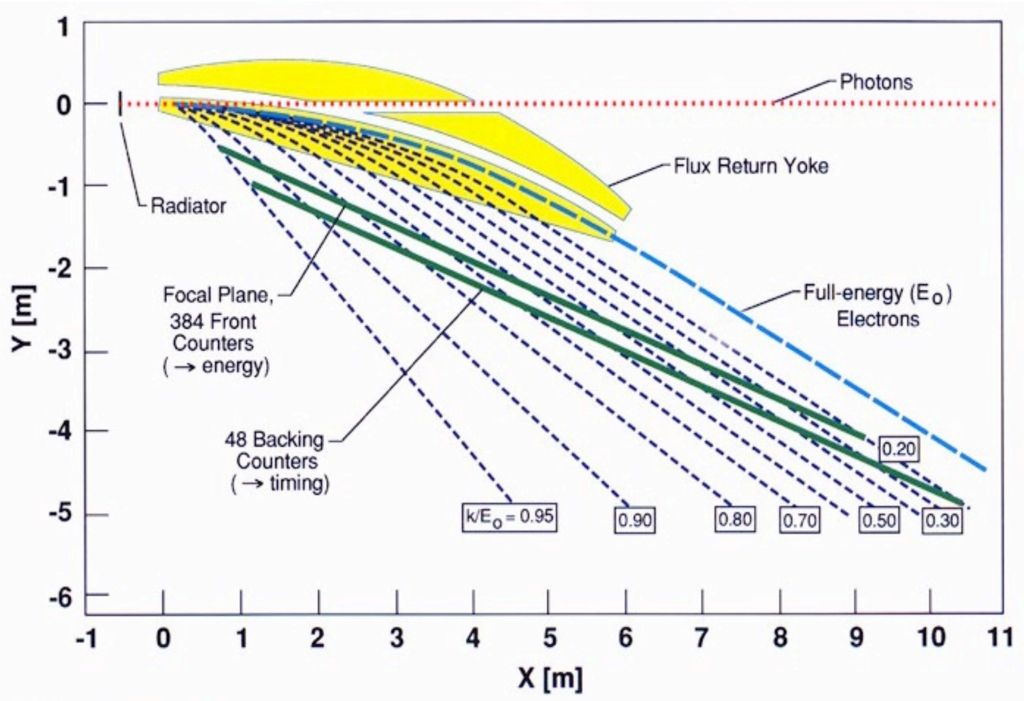
Drift Chamber
35,000 cells

Time of Flight
Plastic Scintillator,
684 PMTs

Cherenkov Counter
e/π separation, 256 PMTs



Hall B Photon Tagger



- Photon beam produced from the primary electron beam via Bremsstrahlung
- Gold and diamond radiator for In/Coherent Bremsstrahlung
- Energy coverage: 0.2-0.95 E_0
- Efficiency ~ 80%
- Energy Resolution ~ 10^{-3}
- Timing Resolution ~100 ps

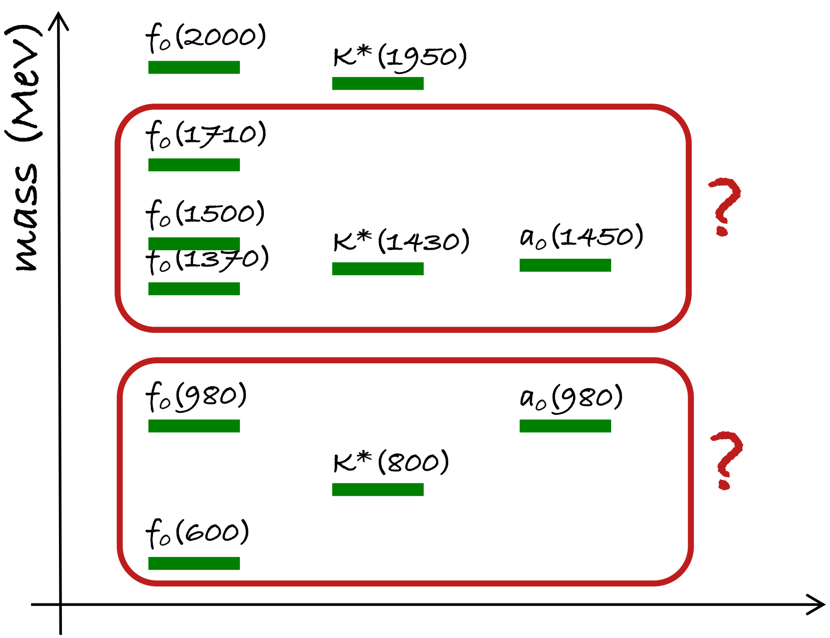
✱ Maximum photon energy of 5.7 GeV
- W_{max} ~ 3.4 GeV

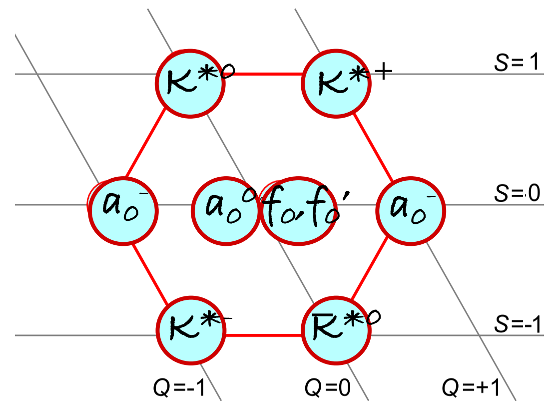
✱ Beam intensity 10^7 γ/s

Scalar mesons and the $f_0(980)$

Scalars are fundamental states because they represent the Higgs sector of strong interaction:

- same quantum numbers of the QCD vacuum
- responsible for chiral symmetry breaking





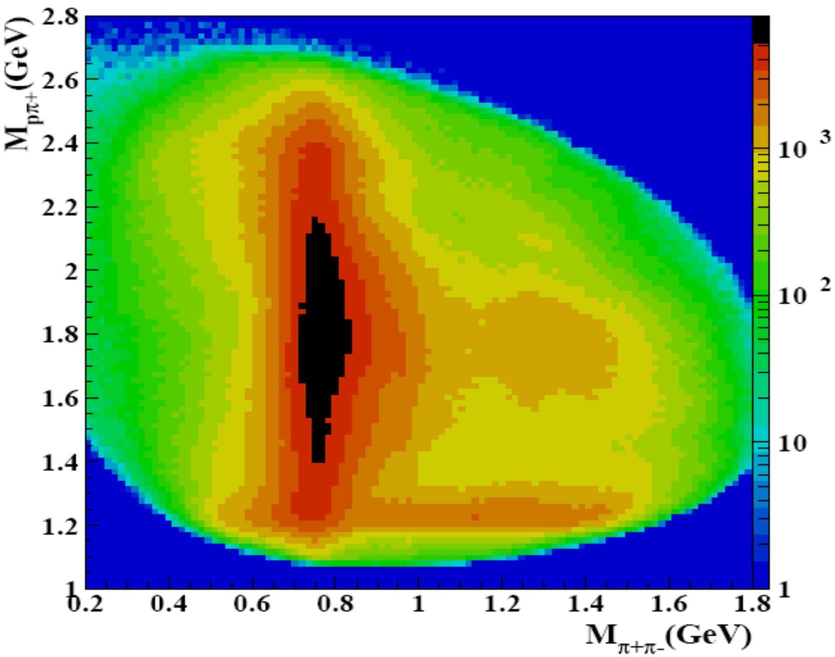
The $f_0(980)$ is one of the lowest mass scalar and isosinglet candidate of the first nonet:

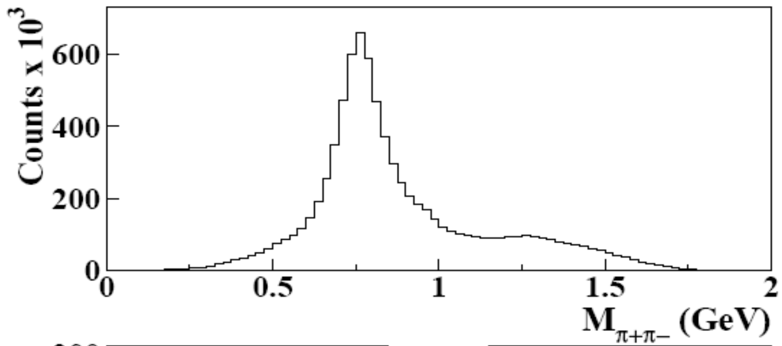
➔ Unusual mass hierarchy of the multiplet ($f_0(980)$ almost degenerate with $a_0(980)$) and decays led to propose these states as tetraquarks

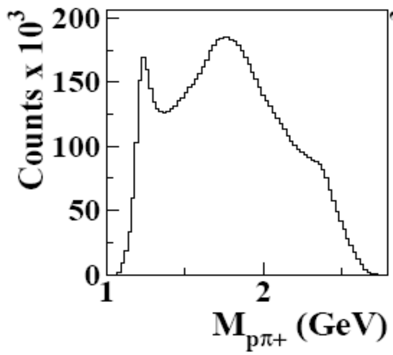
The $f_0(980)$ at CLAS

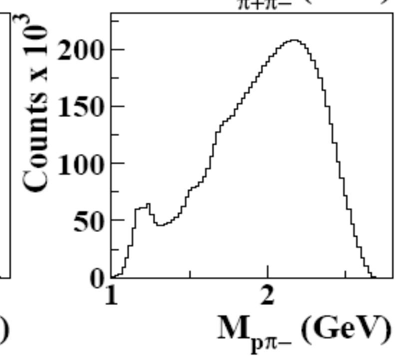
Study of $\pi^+\pi^-$ production on the proton and of scalar meson production

- Bremsstrahlung photon beam: 1.6-3.8 GeV
- 40 cm long liquid hydrogen target
- ~$7 \cdot 10^9$ triggers
- Integrated Luminosity ~ 80 pb^{-1}







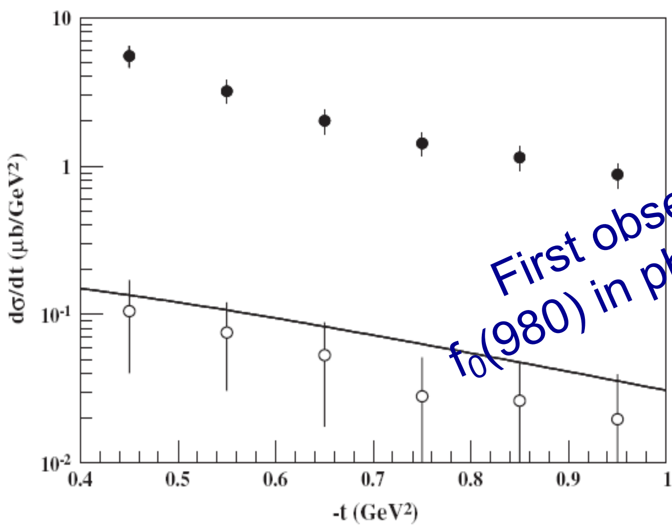


- Proton and π^+ detected in CLAS
- Reaction $\gamma p \rightarrow p\pi^+\pi^-$ isolated via missing mass
- Analysis focused on high energy (3.0-3.8 GeV) and low –t (0.4-1.0 GeV^2) region

The $f_0(980)$ at CLAS

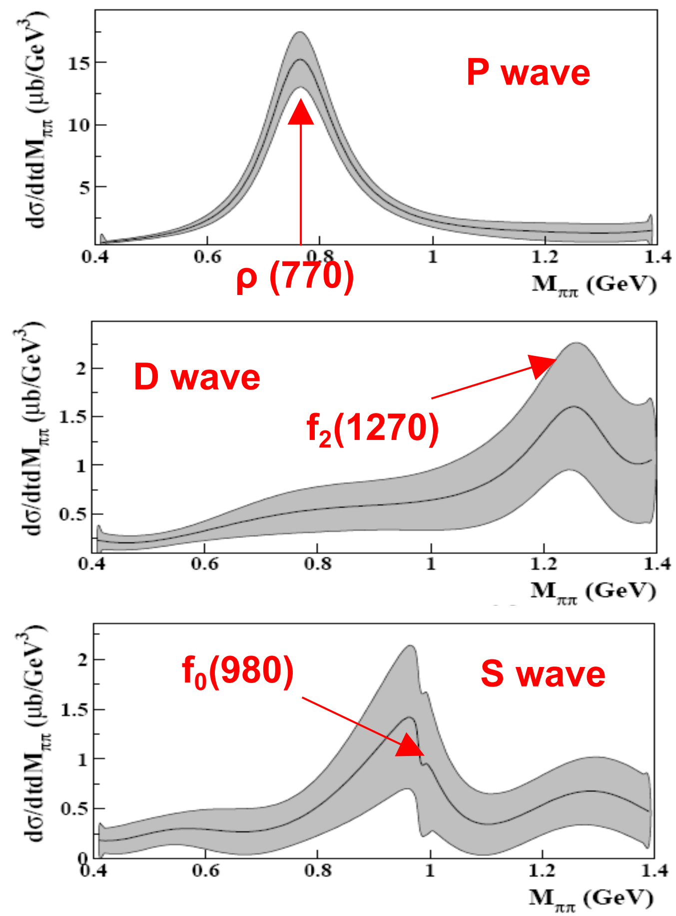
$\gamma p \to p\pi^+\pi^-$

- M($\pi^+\pi^-$) spectrum below 1.5 GeV:
  - P-wave: ρ meson
  - D-wave: $f_2(1270)$
  - S-wave: σ, $f_0(980)$ and $f_0(1370)$
- Moments of the 2-pion angular distribution extracted via likelihood fit of data
- Partial Wave fitted to experimental moments
- **Known states well reproduced, e.g. ρ(770)**



First observation of $f_0(980)$ in photoproduction

3.4 GeV < E_g < 3.6 GeV
0.5 GeV^2 < -t < 0.6 GeV^2



M. Battaglieri et al. (CLAS Collaboration), PRL 102, 102001

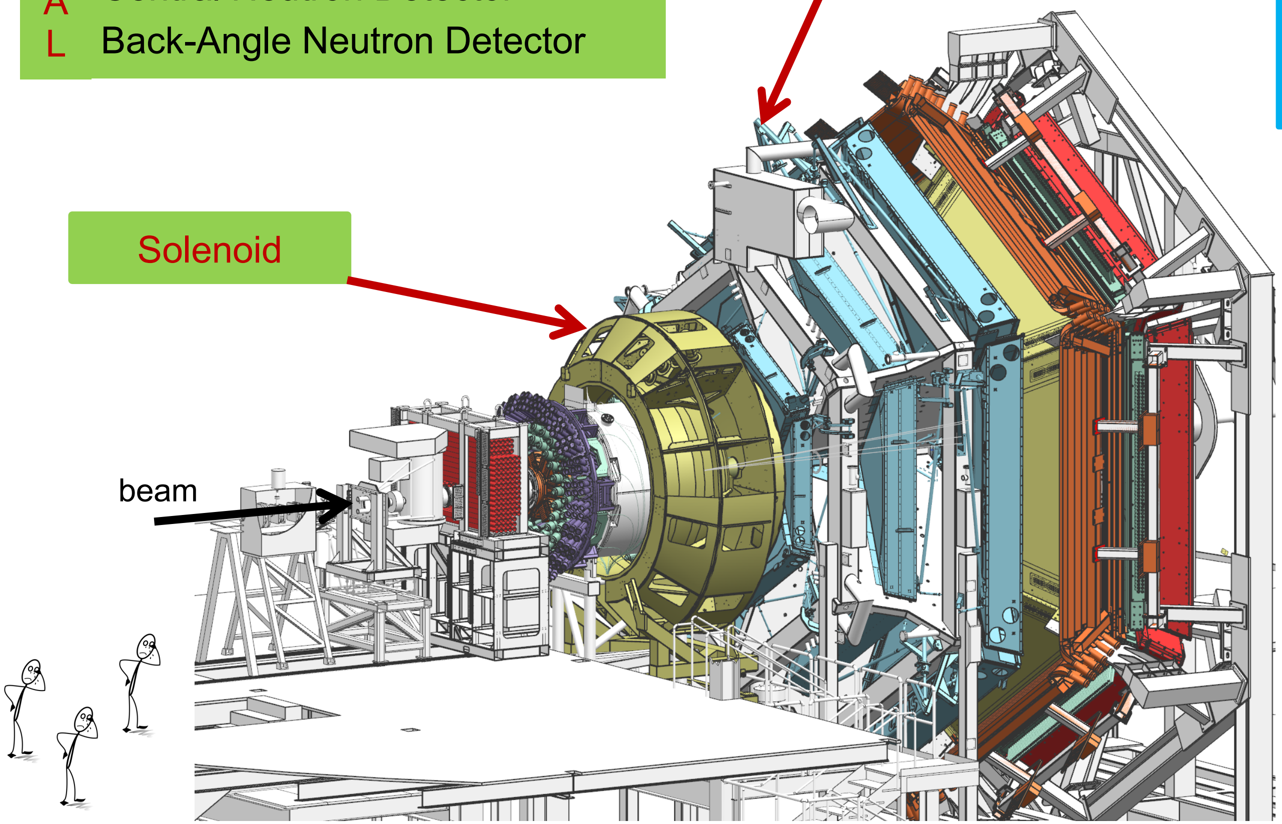
CLAS12

CENTRAL

- Beamline
- Target
- Central Vertex Tracker
- Central Time of Flight
- Central Neutron Detector
- Back-Angle Neutron Detector

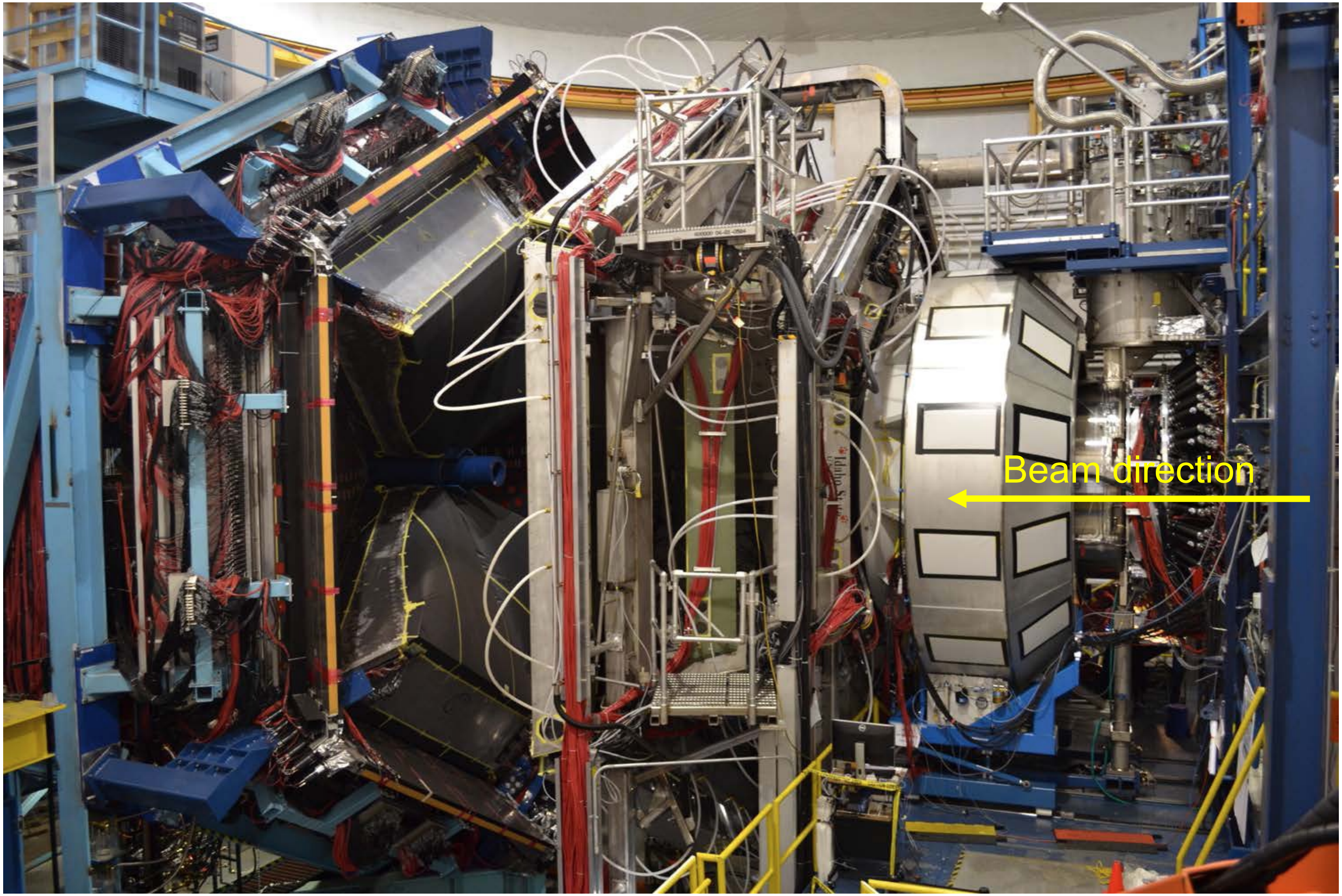
FORWARD

- High Threshold Cherenkov
- Forward Tagger
- Drift Chambers
- Low Threshold Cherenkov
- Ring Imaging Cherenkov
- Forward Time of Flight
- EM Calorimeter

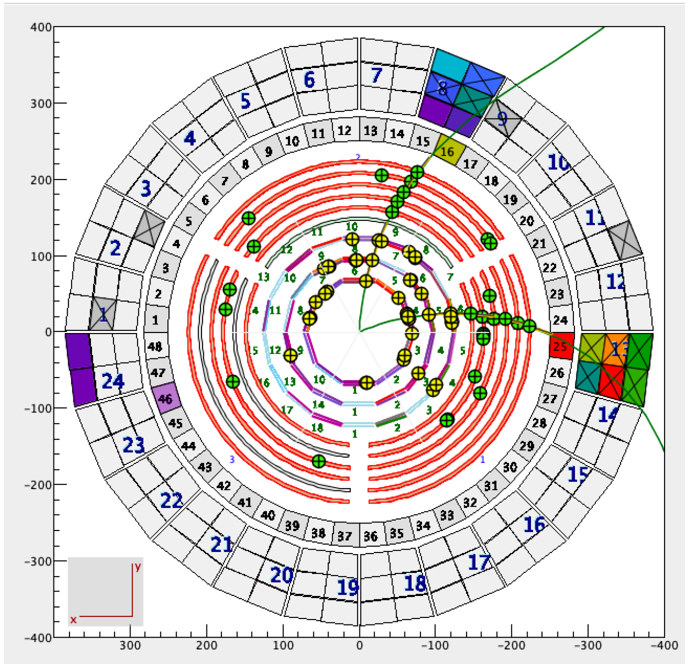


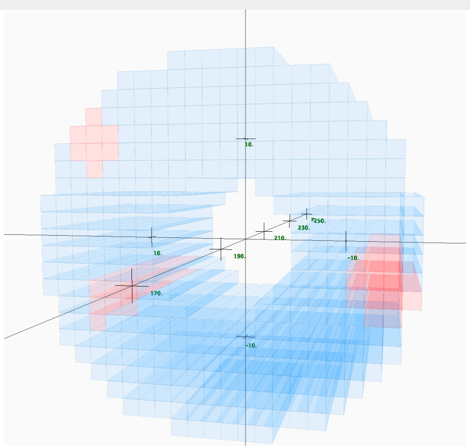
	Forward	Central
Angular coverage	$5^o – 35^o$	$35^o – 135^o$
Momentum resolution	dp/p < 1%	dp/p < 5%
θ resolution	1 mrad	5 – 10 mrad
ϕ resolution	1 mrad/sinθ	5 mrad/sinθ

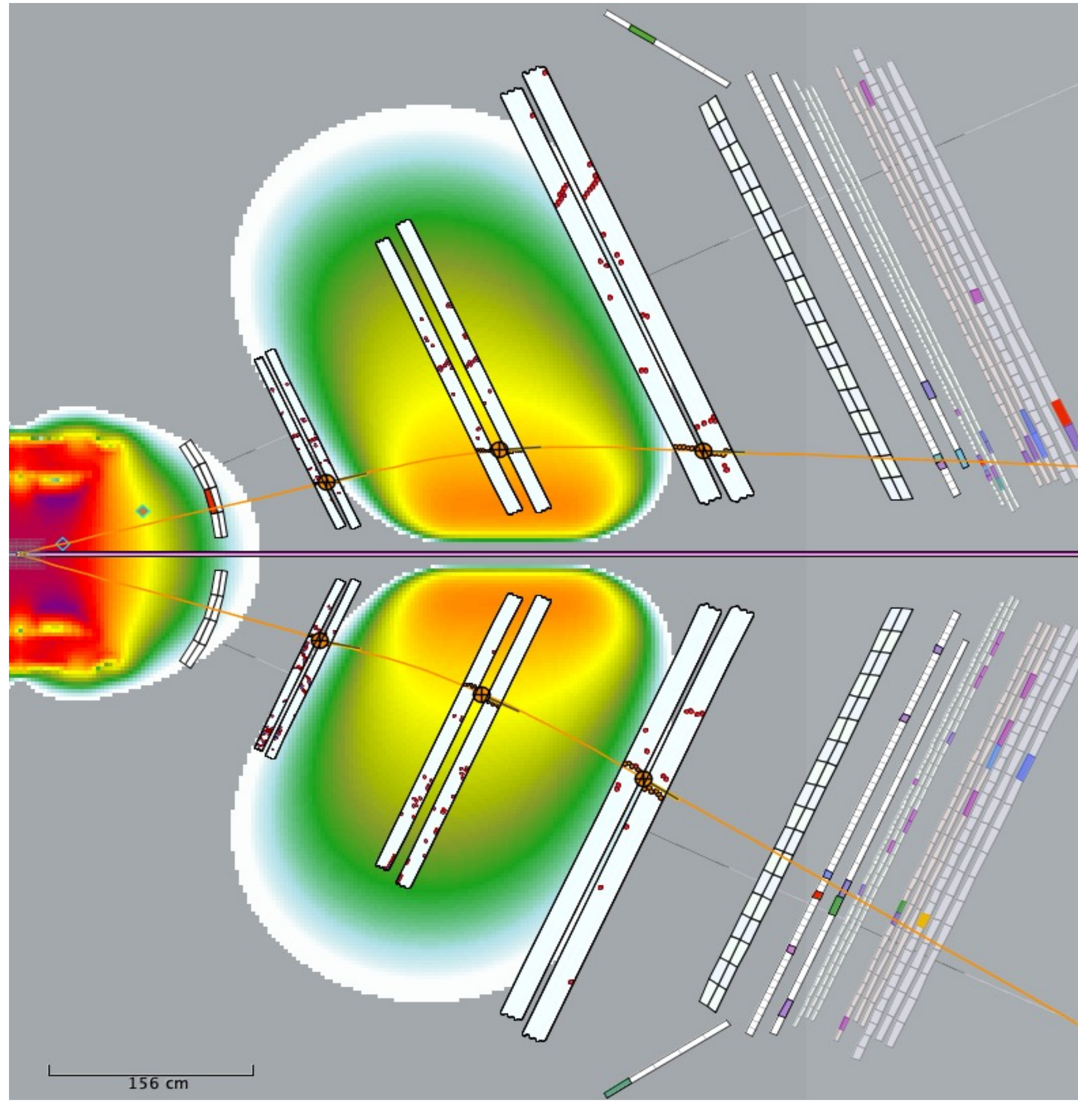
CLAS12 in Hall B



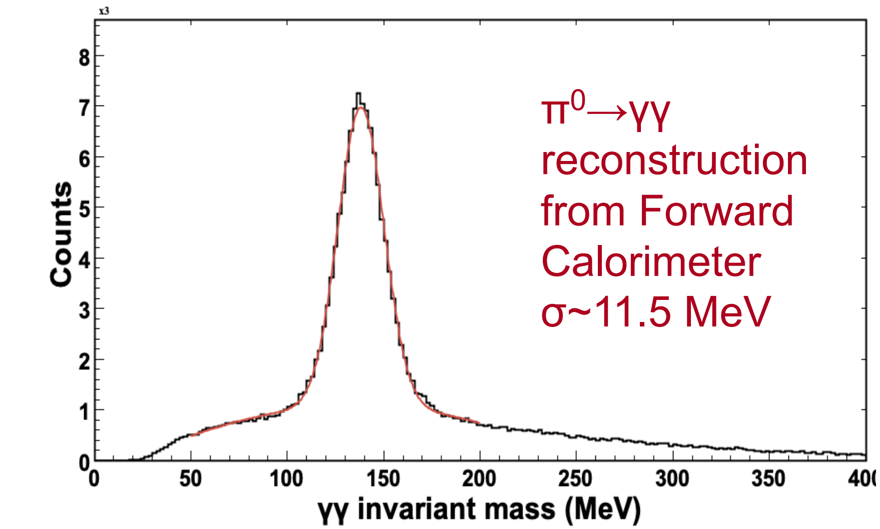
CLAS12 Event Display

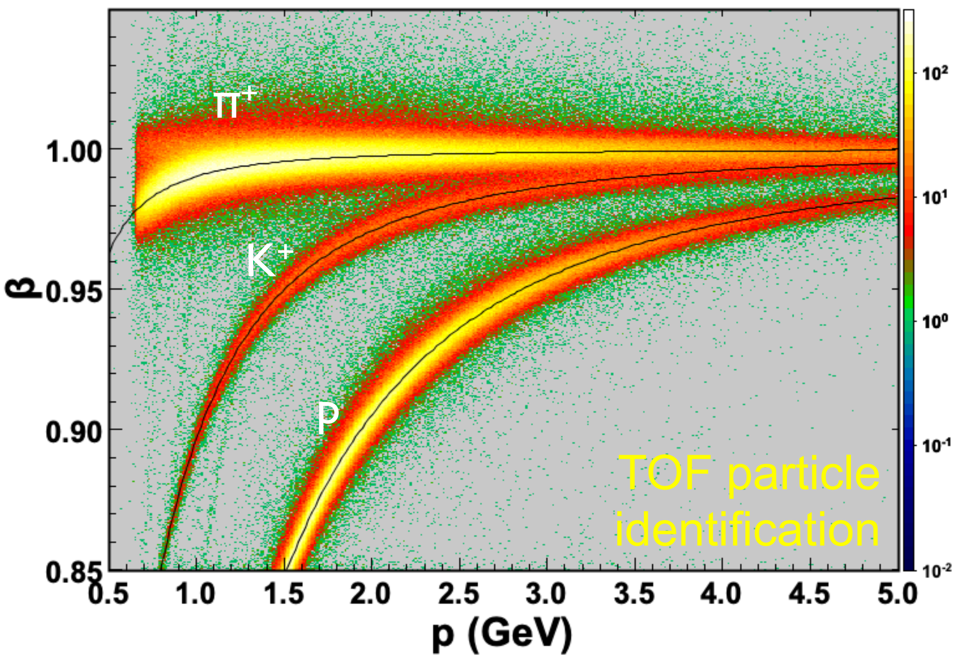


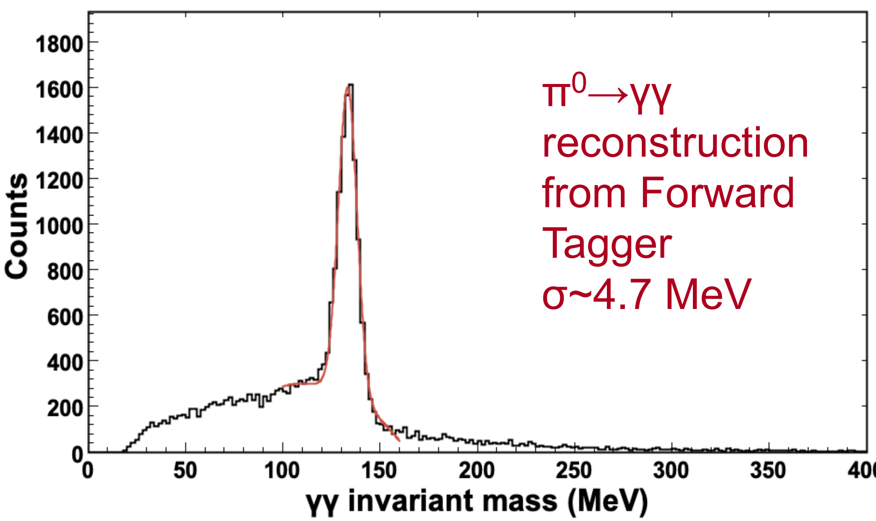


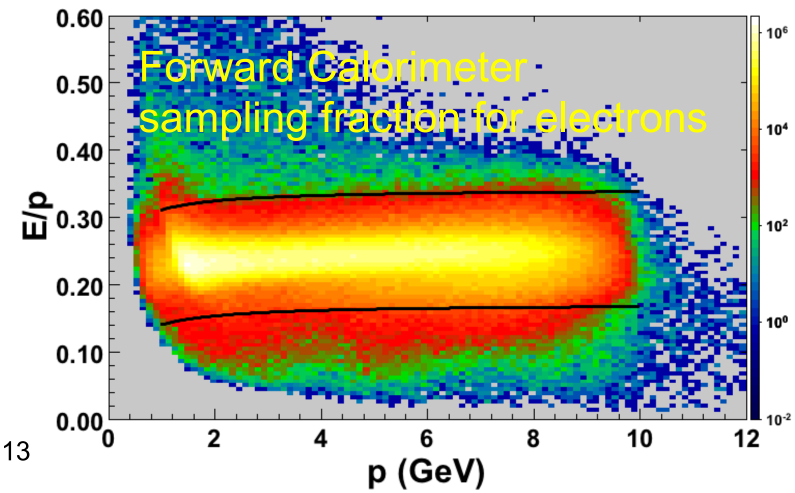


Event reconstruction









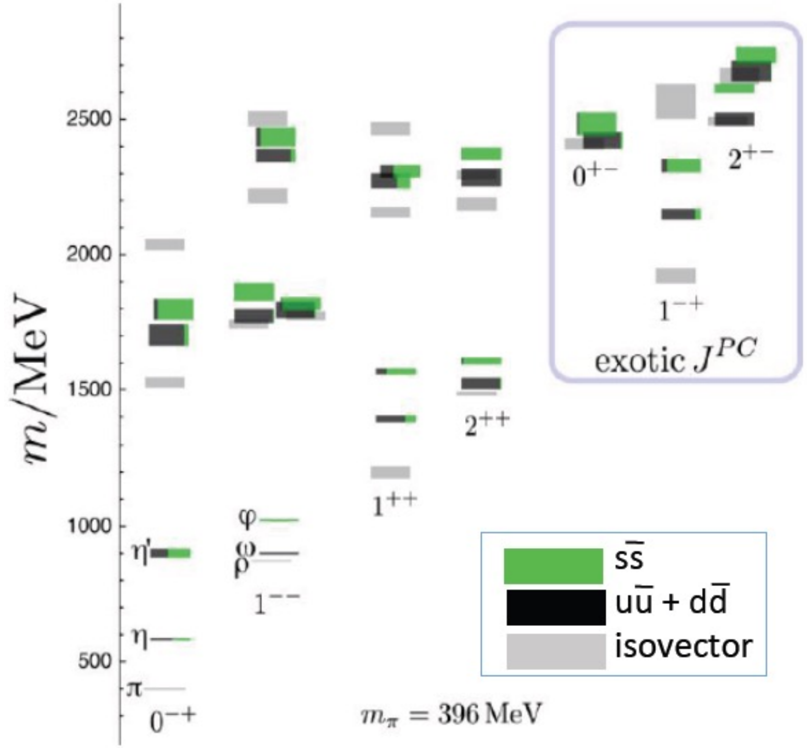
Meson spectroscopy at CLAS12

Predictions of the light quark meson spectrum now available from lattice QCD:

- Spectrum includes meson state with large gluonic content (hybrids) with both regular and exotic quantum numbers
- Experimental signature: a multiplet of gluonic mesons with exotic J^{PC}, i.e. non quark-antiquark
- Searches in progress at several facilities, world-wide

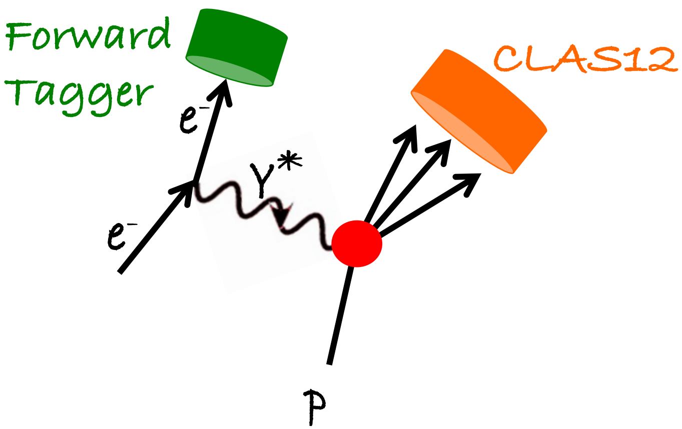
CLAS12 uses quasi-real photo-production to investigate the light quark meson spectrum and search for hybrid meson states

Meson Spectrum in LQCD

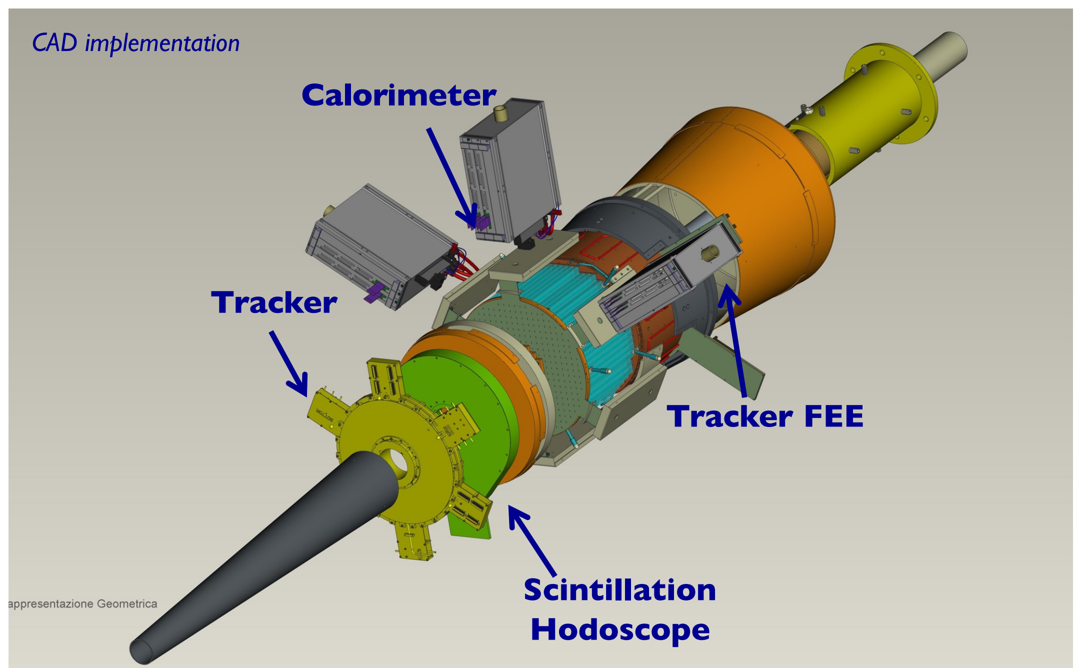


Dudek, Edwards, Guo and Thomas, PRD 88, 094505 (2013)

Quasi-real photoproduction



- 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 CLAS12 Forward Tagger
- High-intensity and high-polarization tagged “photon” beam; degree of polarization can be determined event-by-event from the electron kinematics

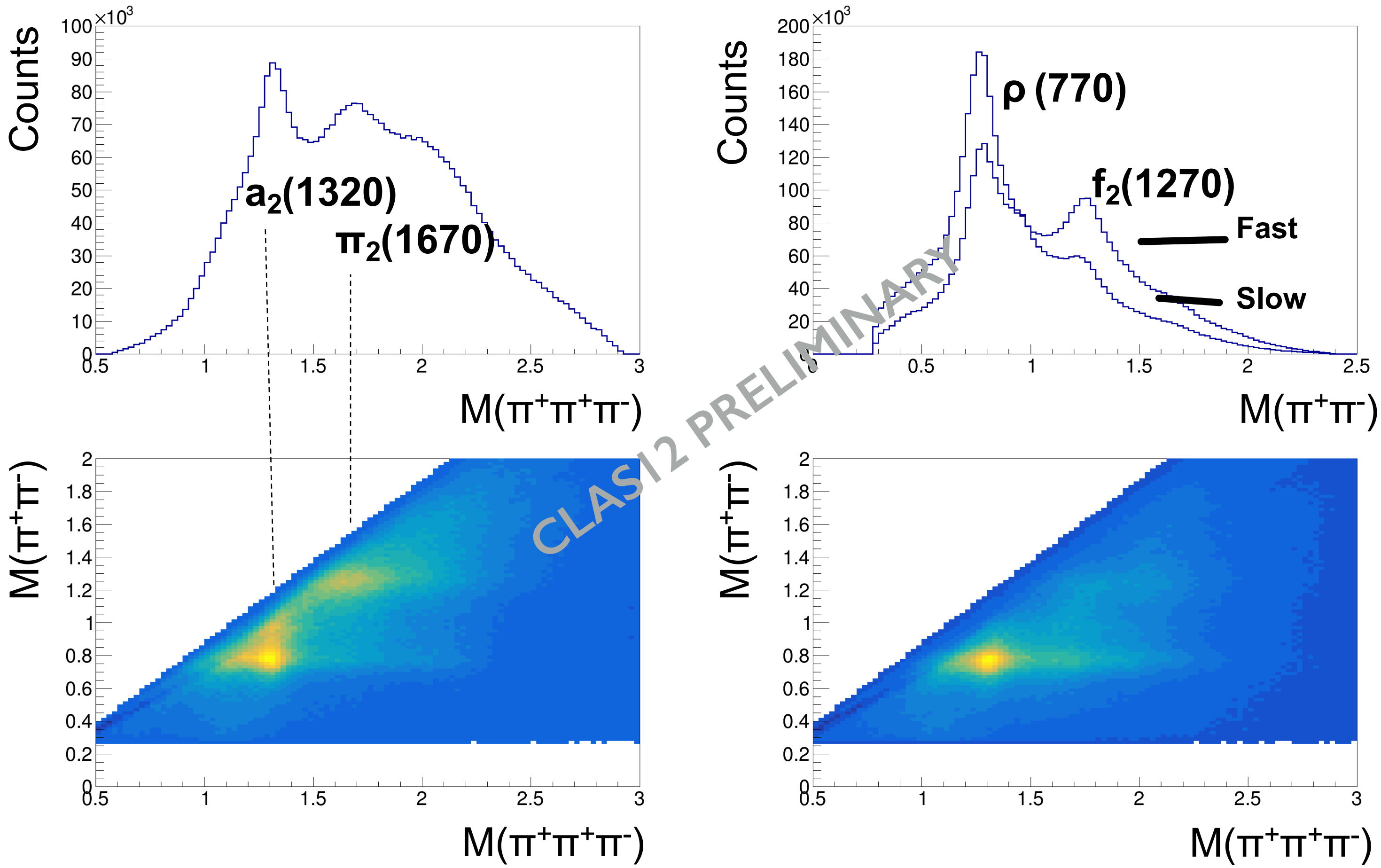


MesonEx:

- Detailed mapping of the meson spectrum up to masses of 2.5 GeV
- Search for rare or poorly known states (strangeness-rich, scalars, …)
- Search states with unconventional quark-gluon configurations

CLAS12 $\pi^+\pi^+\pi^-n$ preliminary data

- Preliminary analysis of 3 pion channel from the 10.6 GeV data
- Candidate for search of the exotic $\pi_1(1600)$
- Spectrum richness already accessible with a fraction of the expected data



MesonEx status

- Approximately 35% of expected data available for analysis after major improvements to event reconstruction
- Focus on charged decay products (better resolution)
- First extract two pseudoscalar ($\pi^+\pi^-$, K^+K^-)
- Fourier analysis of angular distributions, i.e. extract moments
  - more general expansion than just partial waves
  - check acceptance corrections
  - check distortions from backgrounds
  - model independent formalism
  - already applied to CLAS di-meson photoproduction data
- Extract partial waves from moments or directly fit partial waves
- Expand to vector-pseudoscalar final states

arXiv.org > hep-ph > arXiv:1906.04841

Search...

Help | Advanc

High Energy Physics - Phenomenology

Moments of angular distribution and beam asymmetries in $\eta\pi^0$ photoproduction at GlueX

V. Mathieu, M. Albaladejo, C. Fernández-Ramírez, A. W. Jackura, M. Mikhasenko, A. Pilloni, A. P. Szczepaniak (JPAC collaboration)

(Submitted on 11 Jun 2019)

$$\langle Y_{\lambda\mu}\rangle(E_\gamma,t,M) = \frac{1}{\sqrt{4\pi}}\int d\Omega_\pi \frac{d\sigma}{dt\,dM\,d\Omega_\pi} Y_{\lambda\mu}(\Omega_\pi)$$

Moments relate directly to partial wave amplitudes

$$H^0(11) = H^1(11) + 2\sqrt{\frac{2}{5}}\,\mathrm{Re}(P_1^{(+)}D_2^{(+)*}) ,$$

$$H^1(11) = \frac{2}{15}\left[3\sqrt{5}\,\mathrm{Re}(P_0^{(+)}D_1^{(+)*}) - \sqrt{15}\,\mathrm{Re}(P_1^{(+)}D_0^{(+)*}) + 5\sqrt{3}\,\mathrm{Re}(S_0^{(+)}P_1^{(+)*})\right] ,$$

$$H^0(20) = H^1(20) - \frac{2}{35}\left[7|P_1^{(+)}|^2 - 5|D_1^{(+)}|^2 + 10|D_2^{(+)}|^2\right] ,$$

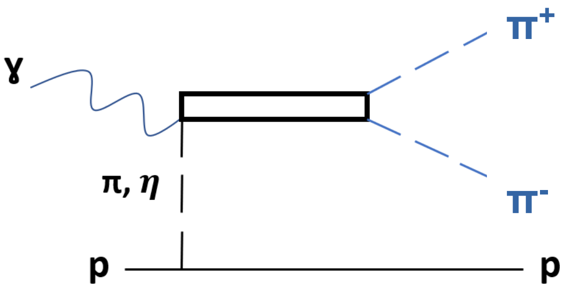
$$H^1(20) = \frac{4}{35}\left[7|P_0^{(+)}|^2 + 5|D_0^{(+)}|^2 + 7\sqrt{5}\,\mathrm{Re}(S_0^{(+)}D_0^{(+)*})\right] ,$$

$$H^0(21) = H^1(21) + \frac{2}{7}\sqrt{6}\,\mathrm{Re}(D_1^{(+)}D_2^{(+)*}) ,$$

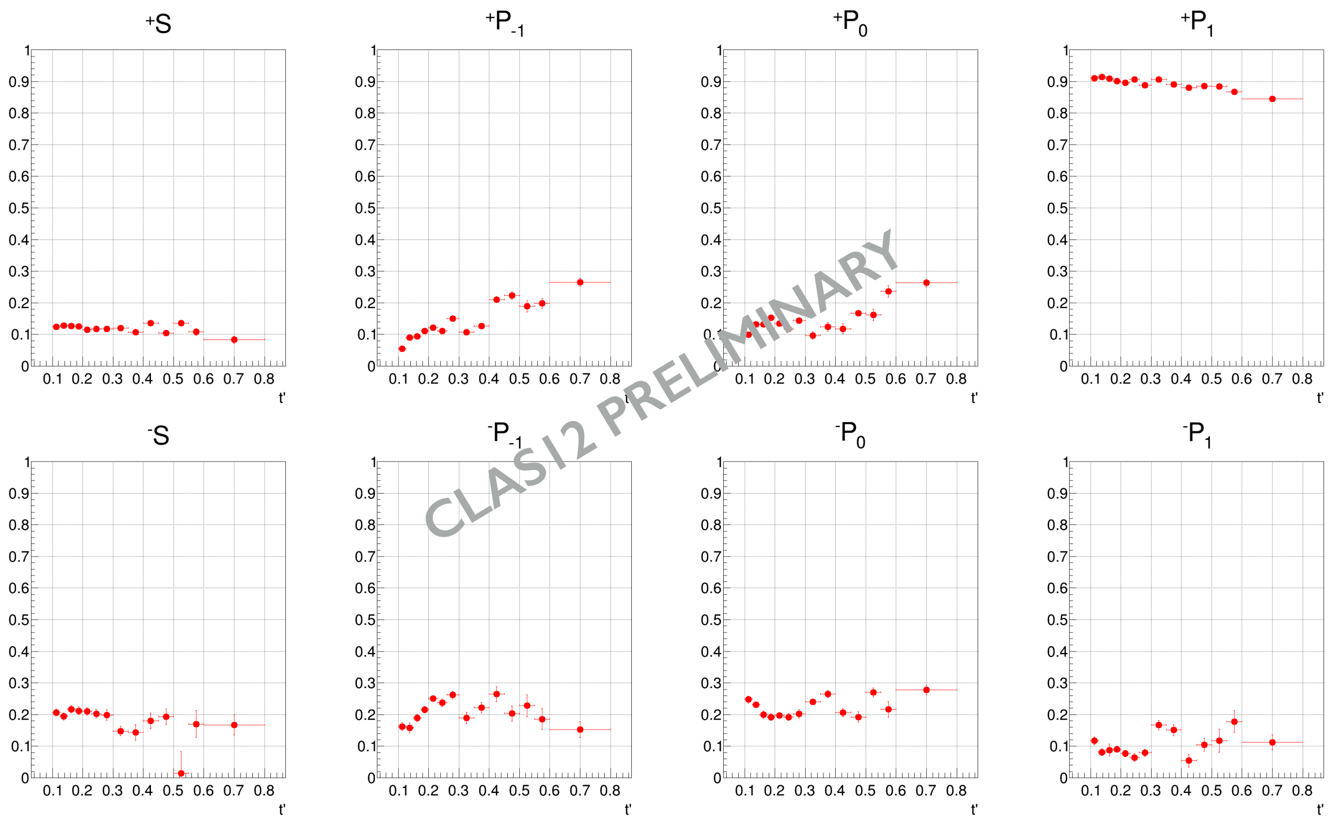
$$H^1(21) = \frac{2}{35}\left[7\sqrt{5}\,\mathrm{Re}(S_0^{(+)}D_1^{(+)*}) + 7\sqrt{3}\,\mathrm{Re}(P_0^{(+)}P_1^{(+)*}) + 5\,\mathrm{Re}(D_0^{(+)}D_1^{(+)*})\right] ,$$

Analysis carried out by a team involving several institutions and collaborators (Glasgow, INFN, Jlab, York, …)

MesonEx: $\pi^+\pi^-$ p preliminary data



- Analysis tools, including PWA, ready
- Preliminary results in good agreement with expectations from S-channel helicity conservation and pomeron exchange



Summary

- Meson spectroscopy has been one of the pillars of the CLAS Collaboration physics program since the beginning of operations
- Rich results portfolio with CLAS at 6 GeV, using tagged photons
- Program extended to 12 GeV with CLAS12 using quasi-real photons
- Preliminary results available for benchmark channels using data collected so far
- Key reaction channels (πππ or KKπ) already accessible but will require full statistics for extracting partial waves:
  - Proposal jeopardy defense at upcoming PAC to confirm the remaining beam time (50%)