Elba XII Workshop
Electron-Nucleus Scattering XII
Elba International Physics Center
June 25-29, 2012

Meson Spectroscopy at CLAS and CLAS12

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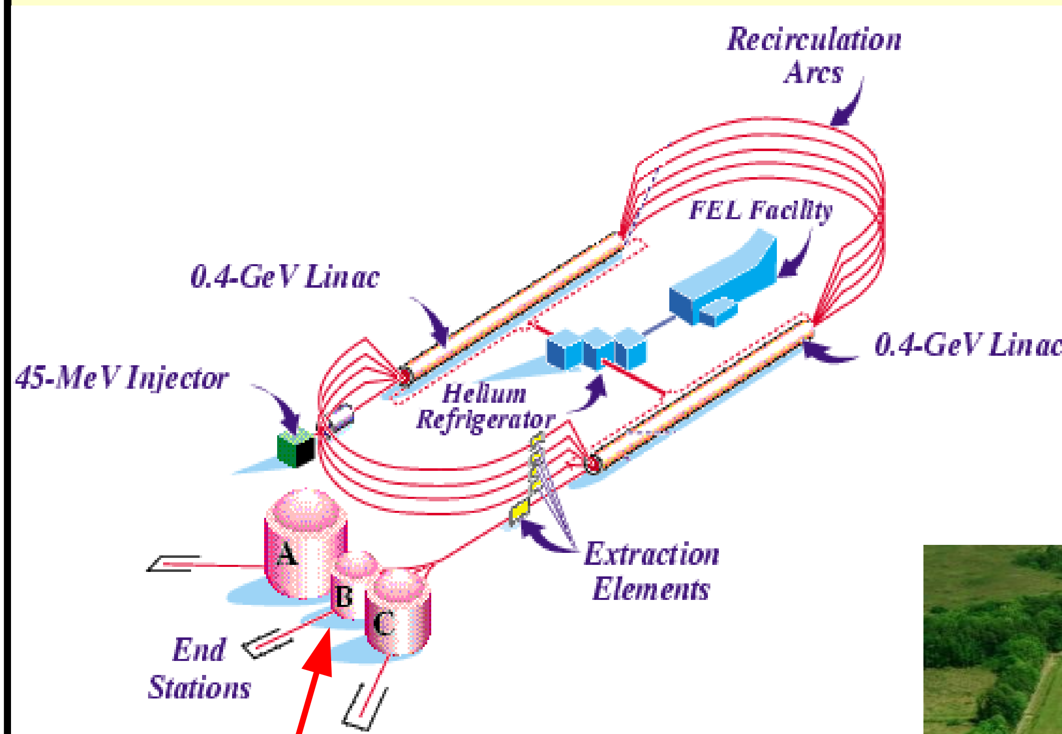
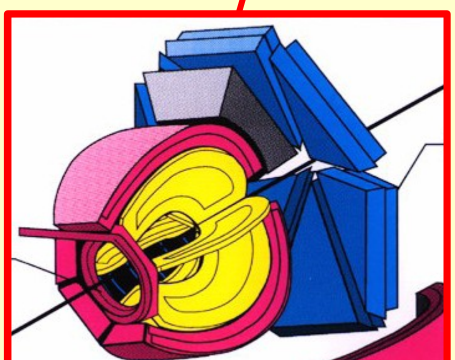
INFN-Ge Italy

Marciana Marina, Isola d'Elba, Italy.

Jefferson Lab (now)

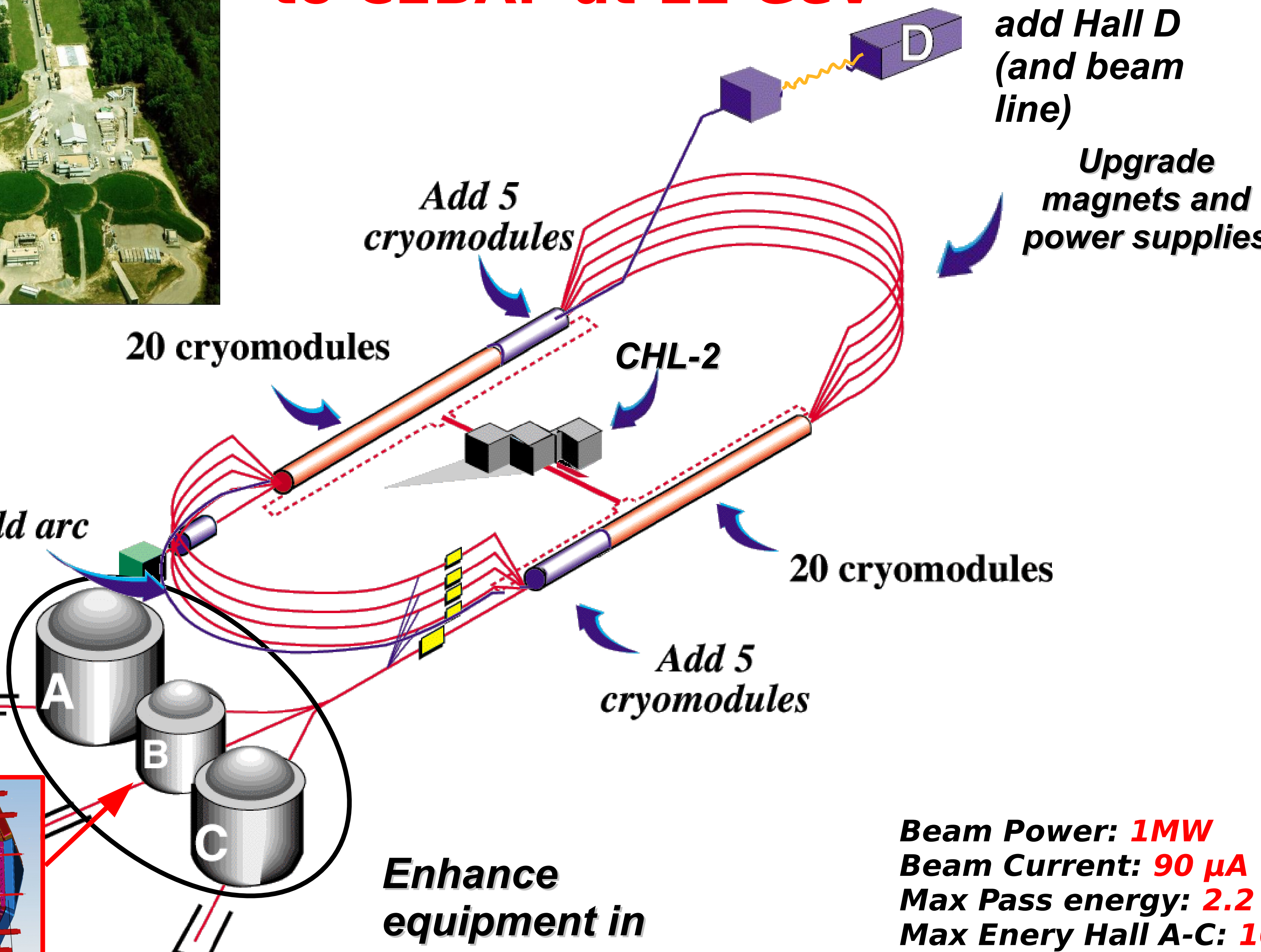


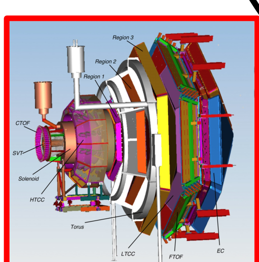
E_{max}	~ 6 GeV
I_{max}	~ 200 μA
Duty Factor	~ 100%
σ_E/E	~ 2.5 10^{-5}
Beam P	~ 80%
E_γ	~ 0.8-5.7 GeV



CLAS

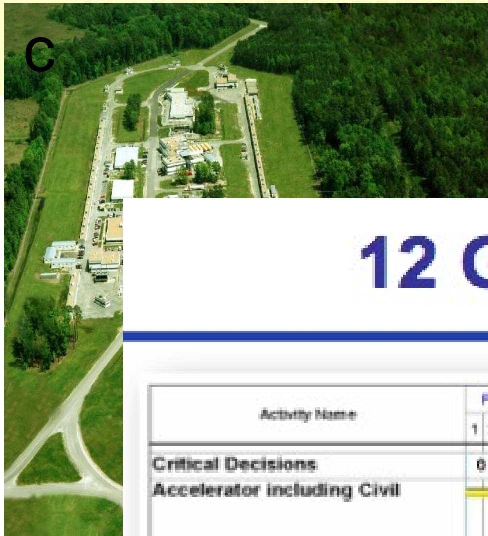
From CEBAF at 6 GeV to CEBAF at 12 GeV





CLAS12

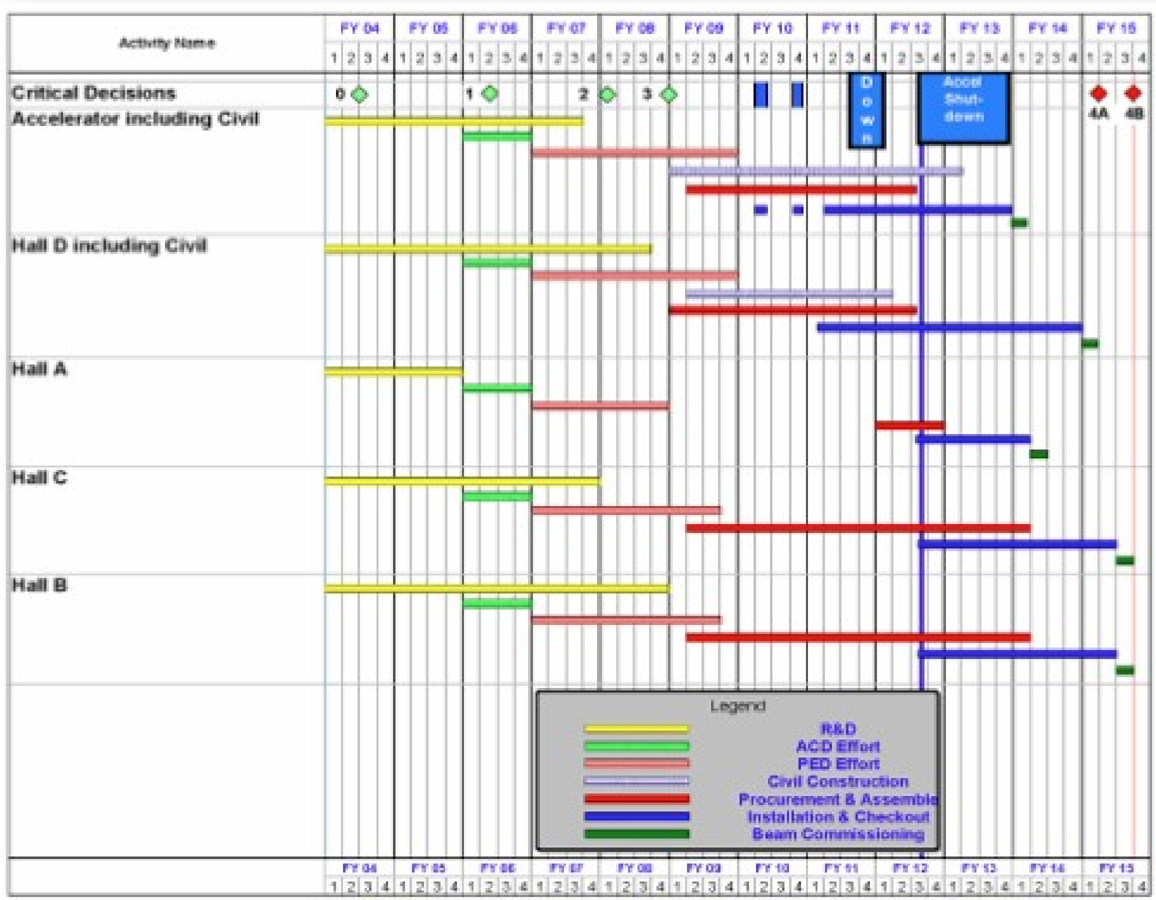
Beam Power: ***1MW***
Beam Current: ***90 μA***
Max Pass energy: ***2.2 GeV***
Max Enery Hall A-C: ***10.9 GeV***
Max Energy Hall D: ***12 GeV***



From CEBAF at 6 GeV to CEBAF at 12 GeV

add Hall D

12 GeV Upgrade Project Schedule



May 18: Completed 6 GeV program

FY12: reduction of $16M
→ extended 12 month shutdown

~~12~~ 16-month installation
May 2012 - ~~May~~ Sept 2013

Hall A commissioning start
~~Oct 2013~~ Feb 2014

Hall D commissioning start
~~April 2014~~ Oct 2014

Halls B & C commissioning
start ~~Oct 2014~~ Apr 2015

Project Completion June 2015

HallA Feb 14
HallD Oct 14
HallB Apr 15

s

GeV
10.9 GeV
Max Energy Hall D: 12 GeV

existing halls

The image

JSA

Thomas Jefferson National Accelerator Facility

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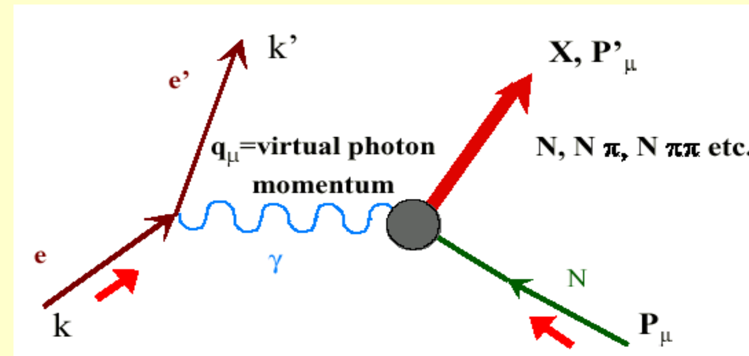
Office of Science
U.S. DEPARTMENT OF ENERGY

The tool: electromagnetic interaction

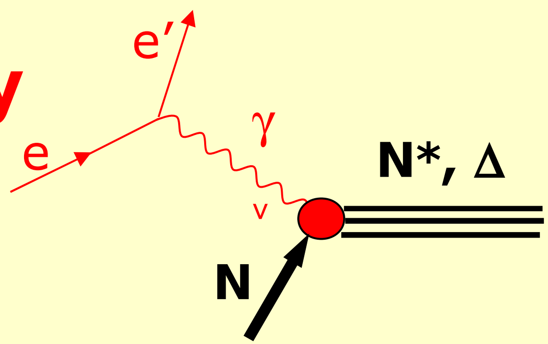
- **weaker than strong interactions**
- **therefore calculable perturbatively**
- **based on the well-known QED**

$-q^{m}q_{m} = Q^2$ = photon virtuality
***s* = CM total energy**
***t* = momentum transfer**

The scattering is normally analyzed in term of the One-Photon-Exchange approximation (OPE)



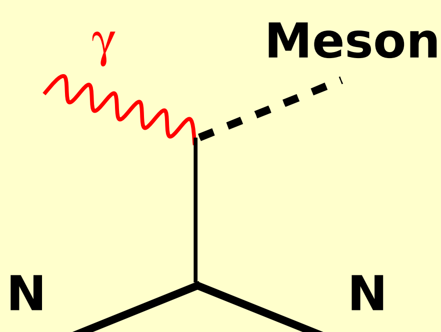
Baryon spectroscopy



- **Direct γ_v - *qqq* system coupling**
- **Establish the excitation spectrum**
- **Access to strong interaction dynamics (Q^2 evolution of resonance form factors)**

JLab today!

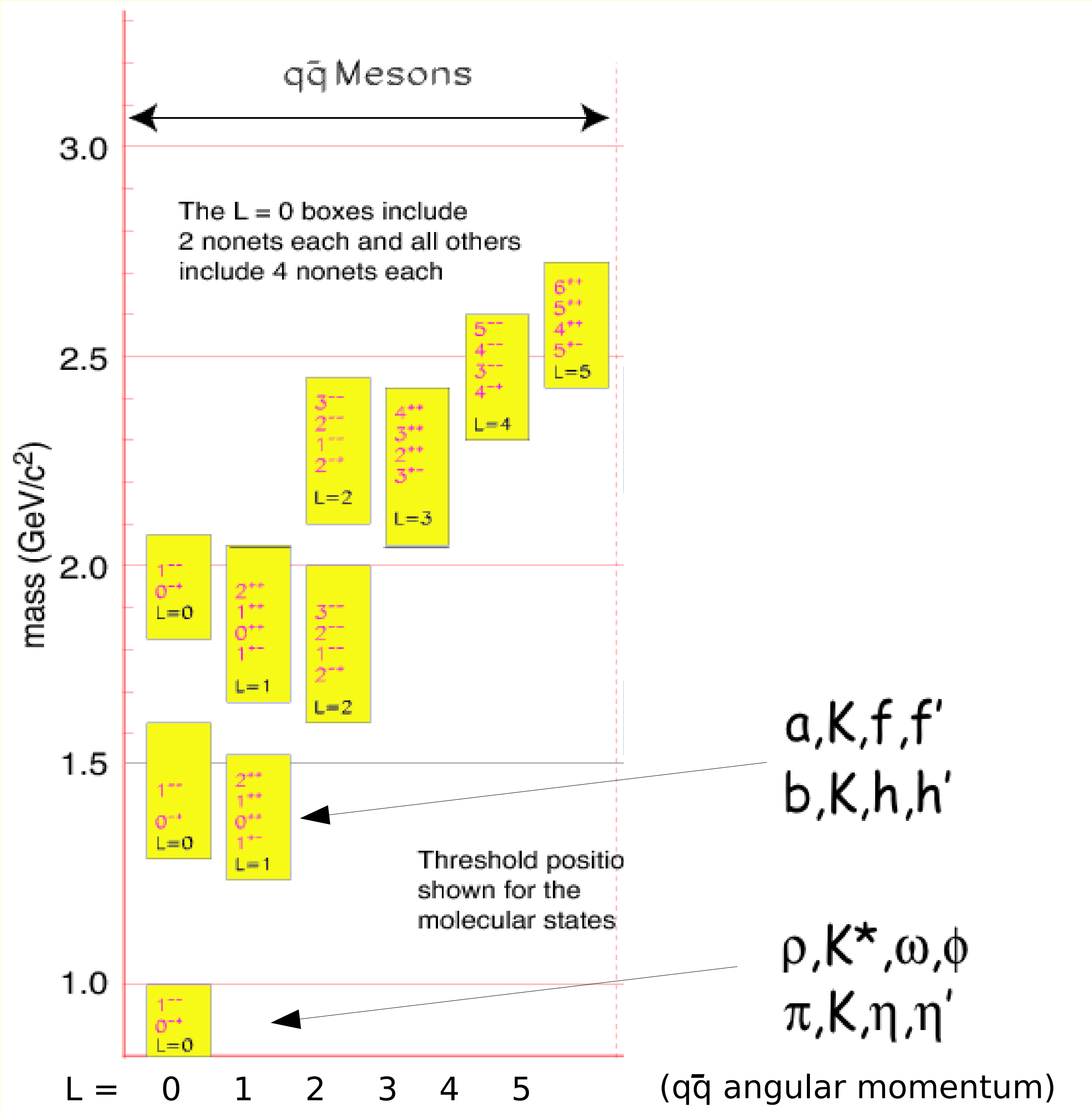
Meson spectroscopy



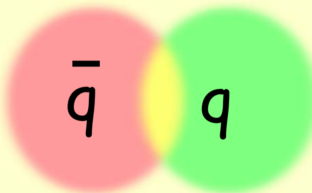
- **$q\bar{q}$ system → easier to study**
- **Access to gluonic degrees of freedom**
- **towards a quantitative understanding of quark and gluon confinement**

JLab tomorrow!

Meson spectrum



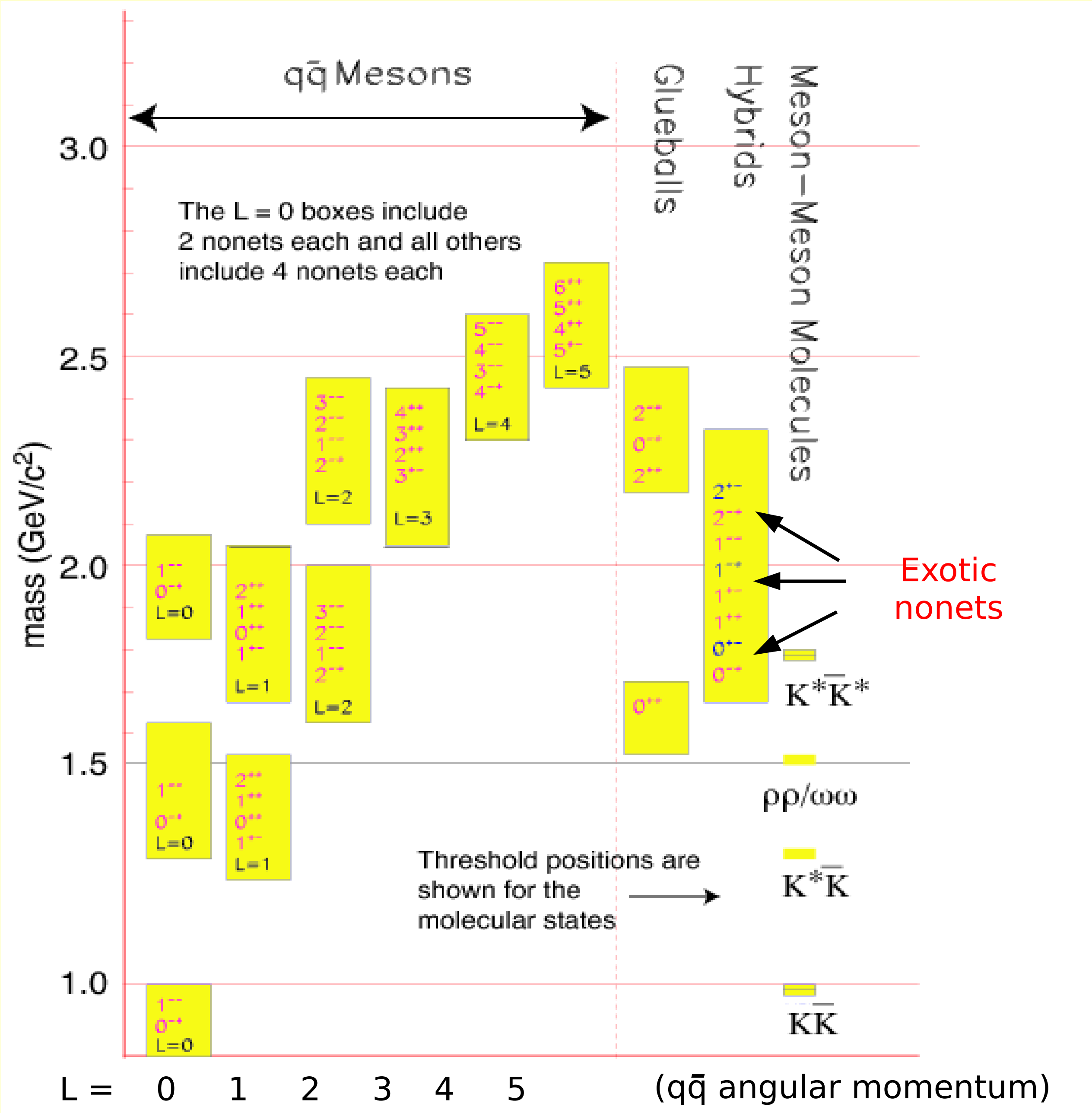
Quarks are confined inside colorless hadrons they combine to 'neutralize' color force



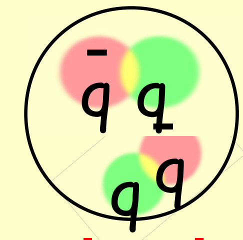
Meson come in nonets of the same quantum number (last two members mix)

Consider light quarks: u,d,s

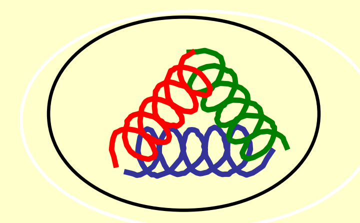
Meson spectrum



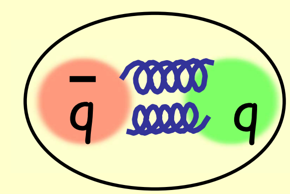
Other quark-gluon configuration can give colorless objects



molecules



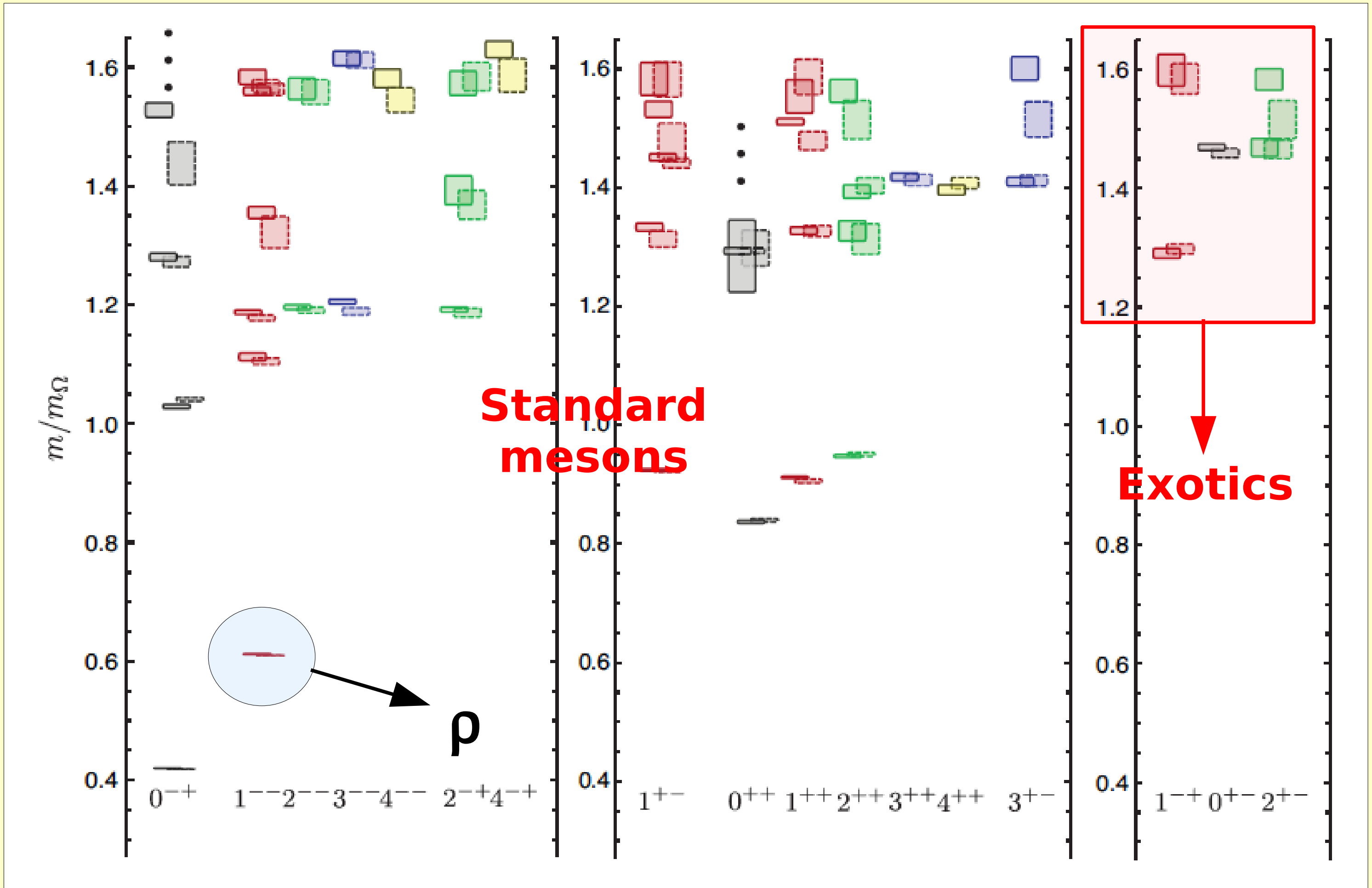
glueball



hybrid mesons

QCD does not prohibit such states but not yet unambiguously observed

QCD Lattice calculations



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

Lattice-QCD predictions for the lowest hybrid states

0^{+-} 1.9 GeV
1^{-+} 1.6 GeV

Hybrid mesons and glueballs mass range:

1.4 GeV - 3.0 GeV

This mass range is accessible in photoproduction experiments with a beam energy in the range 5 GeV < E_γ <12 GeV

Perfectly matched to JLab12 energy!

Meson spectroscopy program in CLAS12

Exp-11-005

M.Battaglieri, R.De Vita, D.Glazier, C.Salgado, S.Stepanyan, D.Weygand and the CLAS Collaboration

Study the meson spectrum in the 1-3 GeV mass range to identify gluonic excitation of mesons (hybrids) and other quark configuration beyond the CQM

Hybrid mesons and Exotics

- **Search for hybrids looking at many different final states**
- **Charged and neutral-rich decay modes**
- $\gamma p \rightarrow p\ 3\pi$, $\gamma p \rightarrow p\ \eta\ \pi$, ...

Hybrids with hidden strangeness and *strangeonia*

- **Intermediate mass of *s* quarks links long to short distance QCD potential**
- **Good resolution and kaon Id required**
- $\gamma p \rightarrow p\ \varphi\ \pi$, $\gamma p \rightarrow p\ \varphi\ \eta$, $\gamma p \rightarrow p\ 2K\ \pi$, ...

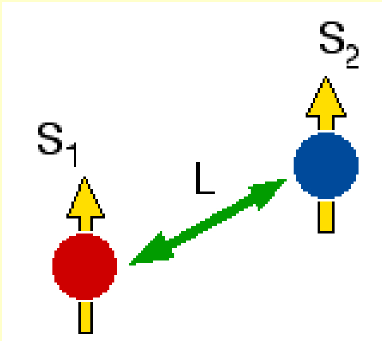
Scalar mesons

- **Poorly know f_0 and a_0 mesons in the mass range 1-2 GeV**
- **Theoretical indications of unconventional configurations ($q\bar{q}q\bar{q}$ or *gg*)**
- $\gamma p \rightarrow p\ 2\pi$, $\gamma p \rightarrow p\ 2K$, ...

One of the most important issue in hadron physics and main motivation for the JLab 12 GeV upgrade

Meson spectroscopy with photons at JLab

☆ **Search for mesons with 'exotic' quantum numbers (not compatible with quark-model)**

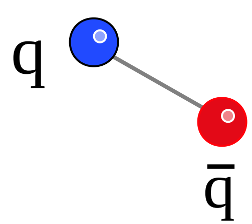


$S=S_1+S_2$ $J= L+S$ $P = (-1)^{L+1}$ $C= (-1)^{L+S}$

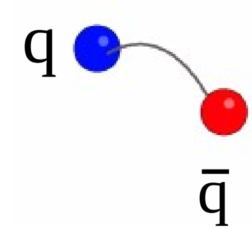
Not-allowed: $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-} \ldots$

Unambiguous experimental signature for the presence of gluonic degrees of freedom in the spectrum of mesonic states

Normal meson:
flux tube in ground state
m=0
$CP=(-1)^{S+1}$

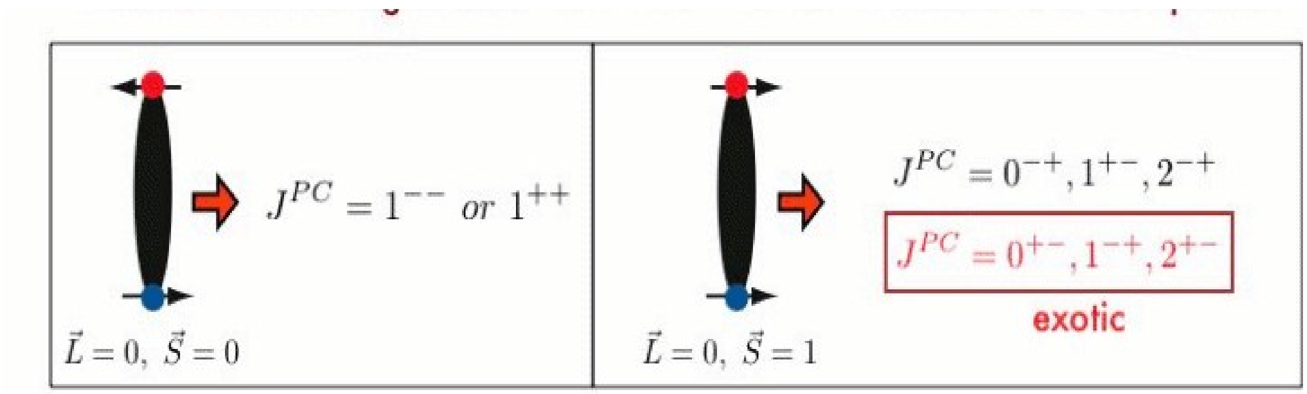


Hybrid meson:
flux tube in excited state
m=1
$CP=(-1)^{S}$

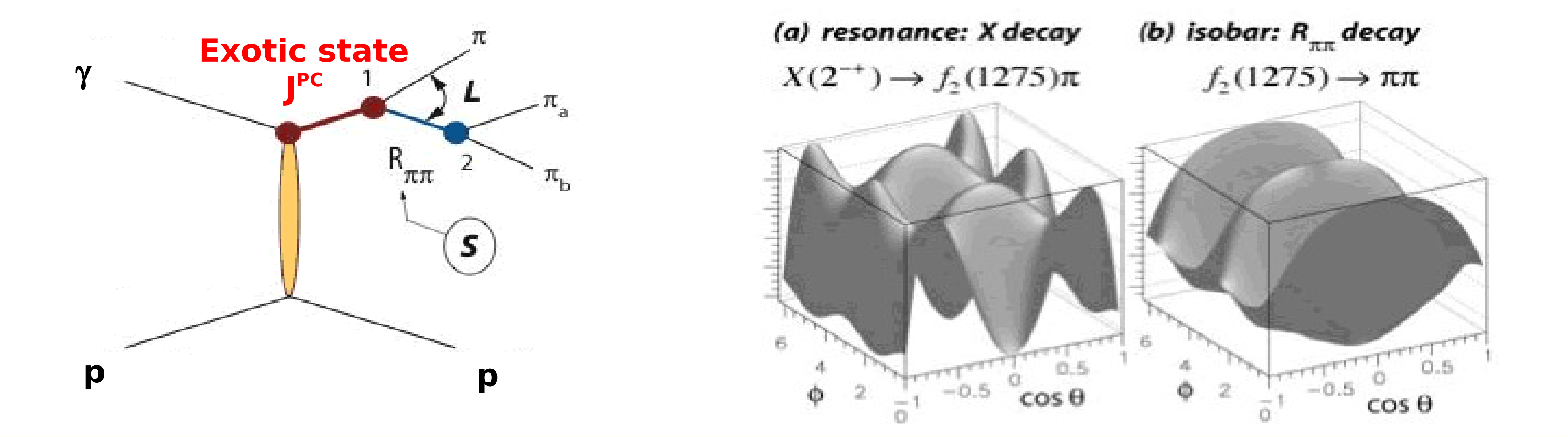


Flux tube J^{PC} 1^{-+}, 1^{+-}

Combine excited glue quantum number with those of the quarks



Partial Wave Analysis



- Parametrize the cross section in term of partial waves
- Fit to data to extract amplitudes
- A model is needed to parametrize amplitudes:
  Isobar Model, Dispersion Relations, …
- Strong interaction between theoreticians and experimentalists to develop the best analysis framework

PWA were successfully performed on CLAS data ($\gamma p \rightarrow p\, \pi^+\pi^-$, $\gamma p \rightarrow n\, \pi^+\pi^+\pi^-$, …) using different models

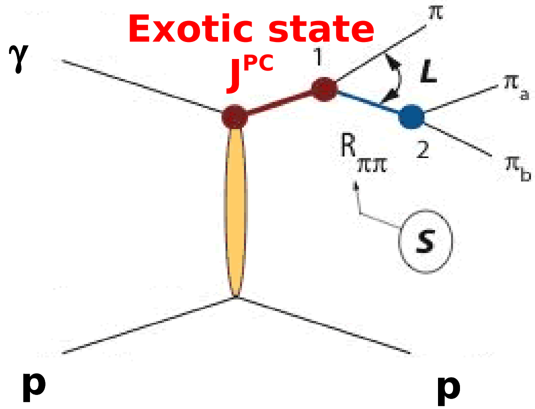
e.g. first observation of the $f_0(980)$ in a photoproduction experiment

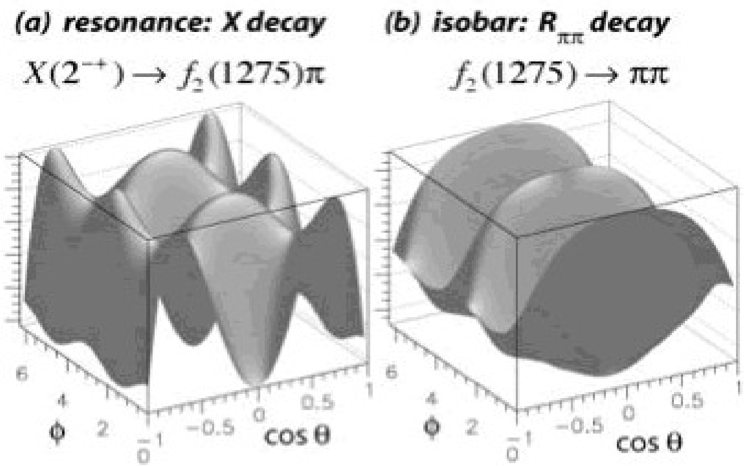
M.B. et al. PRL 102 2009 102001

Partial Wave Analysis

1) the isobar model

e.g. 3π system





Does the PWA work with photo-production data?

Use the PWA machinery on CLAS data

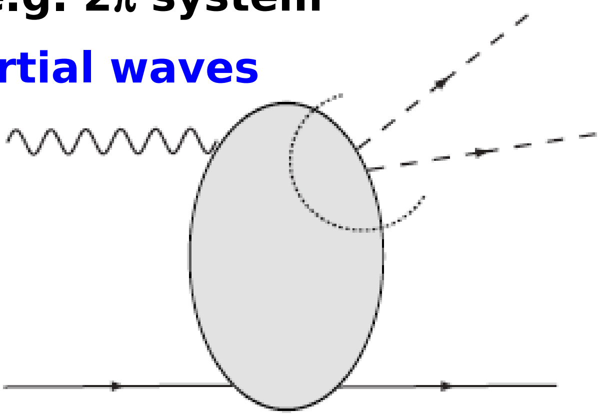
2) Moments+Dispersion relations

e.g. 2π system

1) Moments of the angular distribution in term of partial waves

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

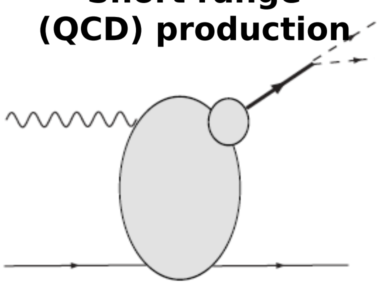
$$\langle Y_{00}\rangle = N\left[|S|^2 + |P_-|^2 + |P_0|^2 + |P_+|^2 + |D_-|^2 + |D_0|^2 + |D_+|^2 + |F_-|^2 + |F_0|^2 + |F_+|^2\right]$$



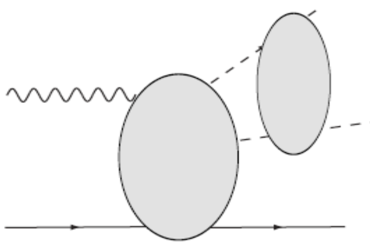
2) Parametrize partial waves in term of known ππ phase shift and unknown coefficients using Dispersion Relations

3) Derive partial wave cross sections to compare with models

Short range (QCD) production



Meson formation

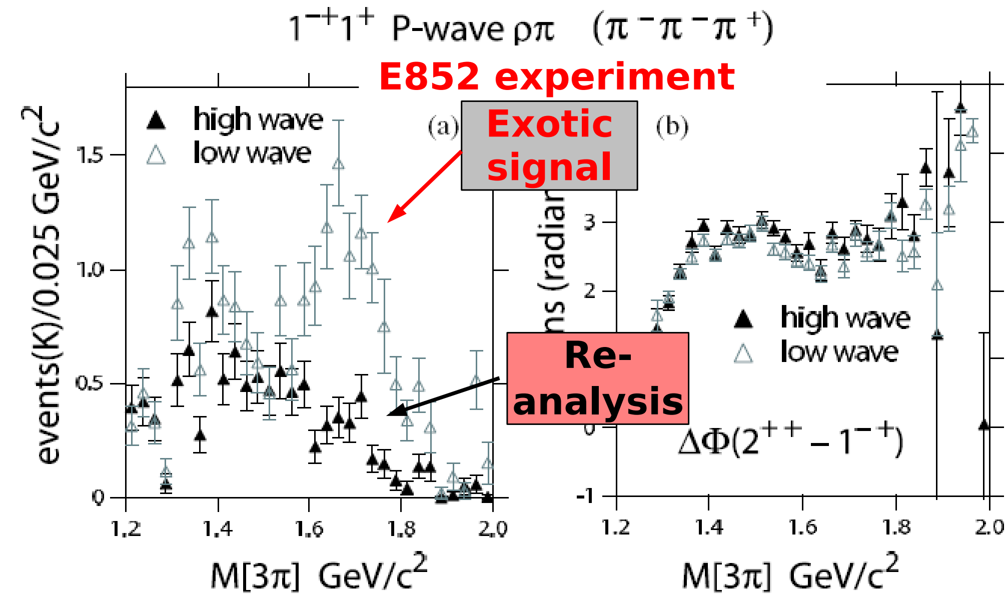


Partial Wave Analysis with CLAS

Isobar Model

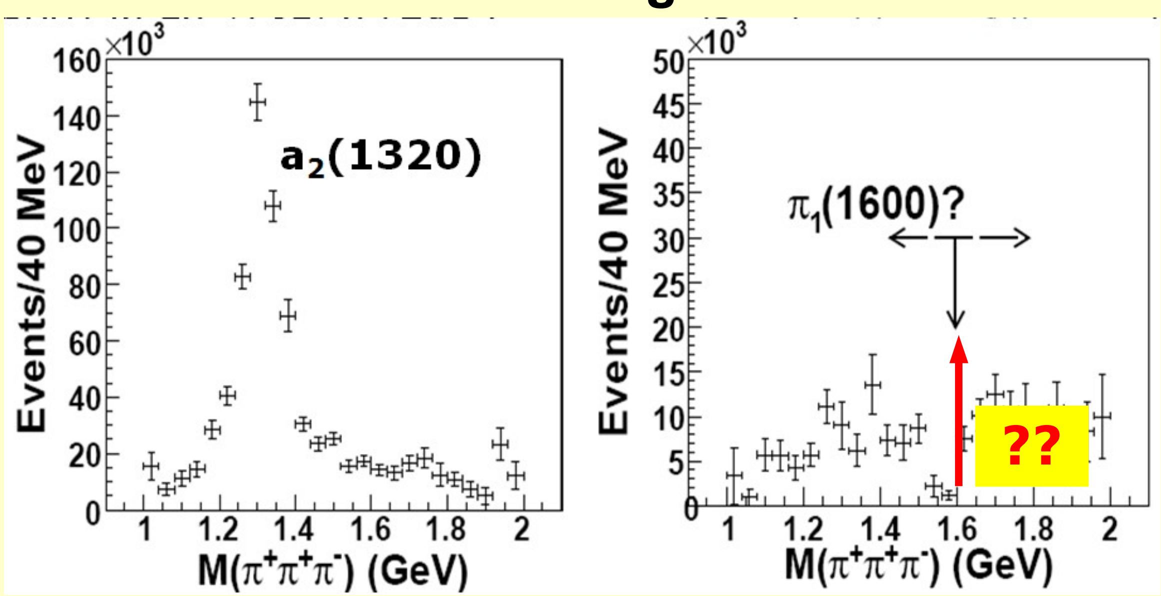
$\gamma\, p \rightarrow (n)\ \pi^+ \pi^+ \pi^-$

- Possible evidence of exotic meson $\pi_1(1600)$ in $\pi^- p \rightarrow p\ \pi^-\pi^-\pi^+$ (E852-Brookhaven)
- Not confirmed in a re-analysis of a higher statistic sample
- Now confirmed by Compass
- Simple final state with low bg



M.Nozar et al Phys.Rev.Lett.102:102002,2009

CLAS/g6c



- Clear evidence of non-exotic 2^{++} state $a_2(1320)$

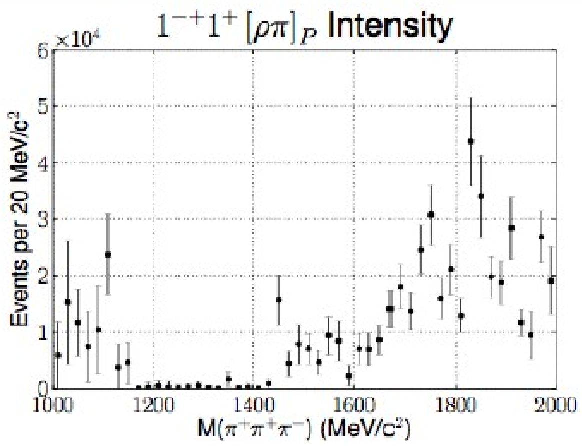
No-evidence of exotic 1^{-+} state $\pi_1(1600)$

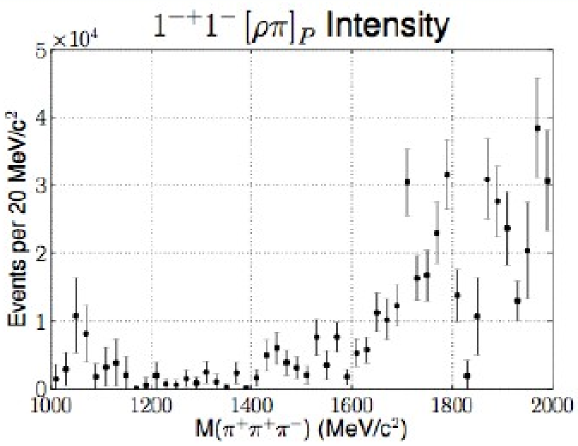
- Relevance of baryon resonance background

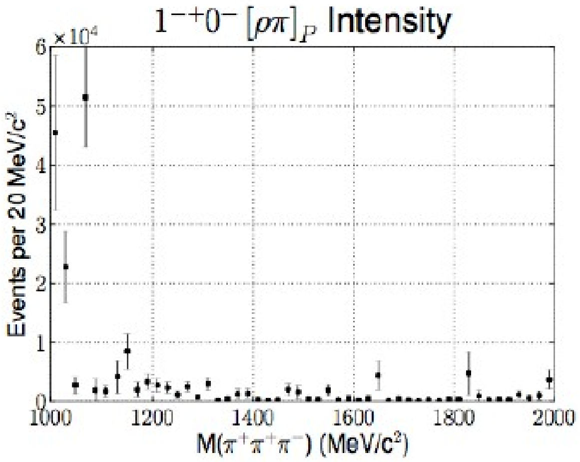
PWA in CLAS is feasible!

PWA 1−+ Exotic Wave

P.Eugenio
ATHOS2012







- No clear resonance signal
- High mass results fluctuate
- Accounts for at most 2% of total intensity

preliminary

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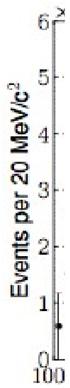
PWA 1−+ Exotic Wave

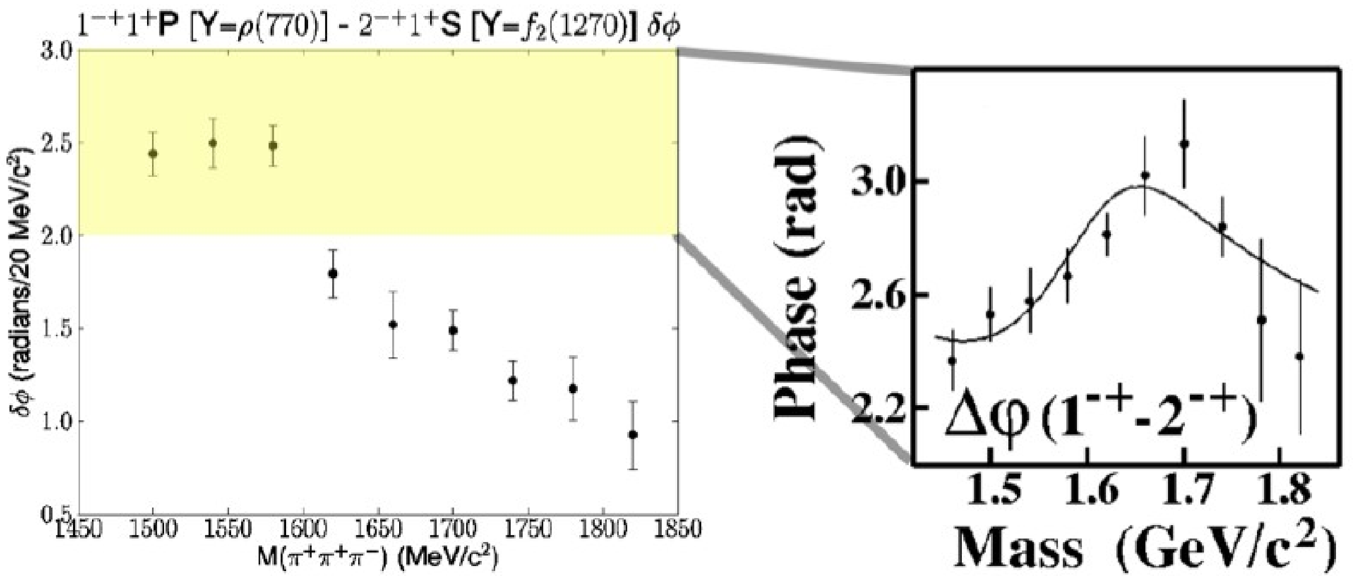
P.Eugenio
ATHOS2012



PWA 1−+ – 2−+ phase motion

CLAS g12

BNL-E852



prelimin

- No evidence for exotic 1^{-+} phase motion
- Phase motion consistent with resonating 2^{-+}

preliminary

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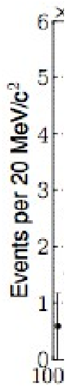
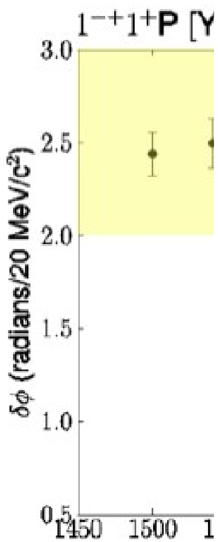
PWA 1−+ Exotic Wave

P.Eugenio
ATHOS2012

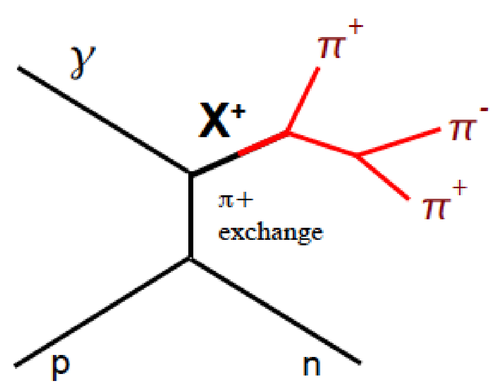
PWA 1−+ − 2−+ phase motion



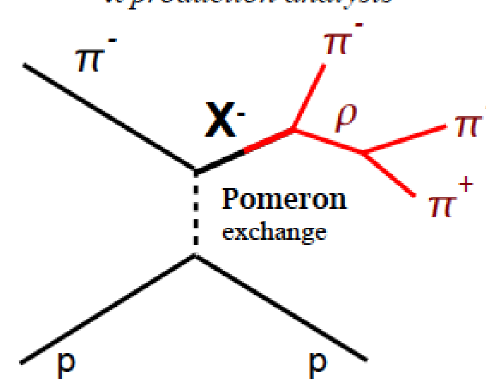


Where is the $\pi_1(1600)$ in photoproduction?

Current CLAS g12 analysis



π production analysis



Also observed via: $X^- \rightarrow \eta'\pi^-$, $f_1\pi^-$, $(b_1\pi)^-$

prelimin

preliminary

Non-observation of $\pi_1(1600)$ in charge exchange photoproduction is consistent with exotic production via Pomeron
however, $\pi_1(1600) \rightarrow \rho\pi$ but not $\rho\pi \rightarrow \pi_1(1600)$

If true then C-Parity forbids photoproduction of $\pi_1(1600)$

Allowed J^{PC}:
[S,P, D wave pomeron production]
1−−, 0+−, 1+−, 2+−, 1−−, 2−−, 3−−

exotic

Isovector G = +1 channels: 2π, 2πη, ..
Isoscaler G = -1 channels: πη, πηη, 3π, 3πη, ..

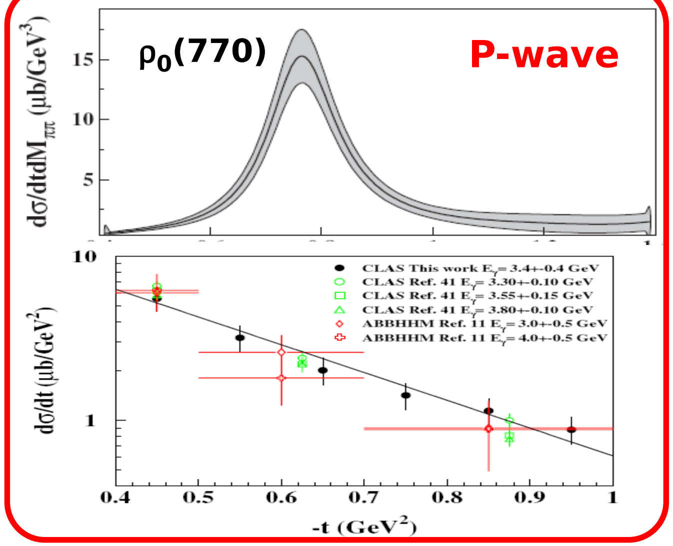
Partial Wave Analysis with CLAS

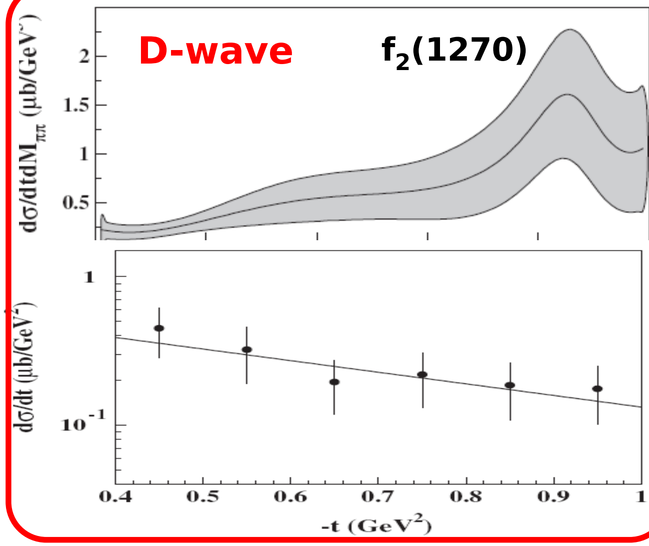
Moments + Dispersion relations

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

$M(\pi^+\pi^-)$ spectrum below 1.5 GeV:

P-wave: ρ meson
D-wave: $f_2(1270)$
S-wave: σ, $f_0(980)$ and $f_0(1320)$

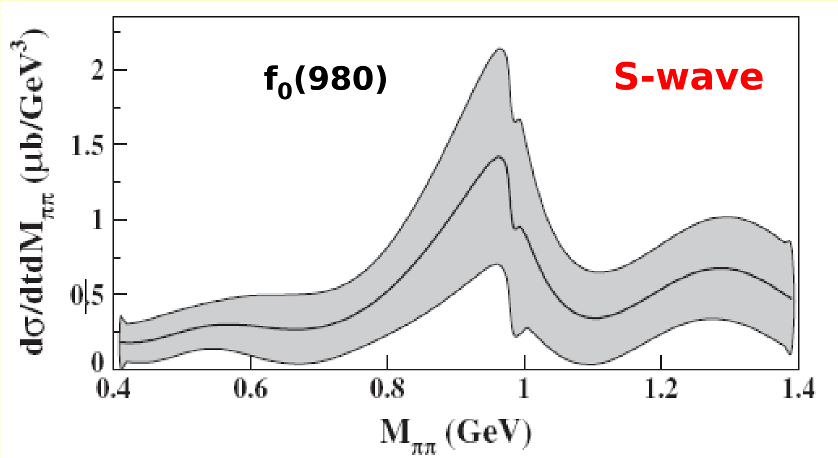




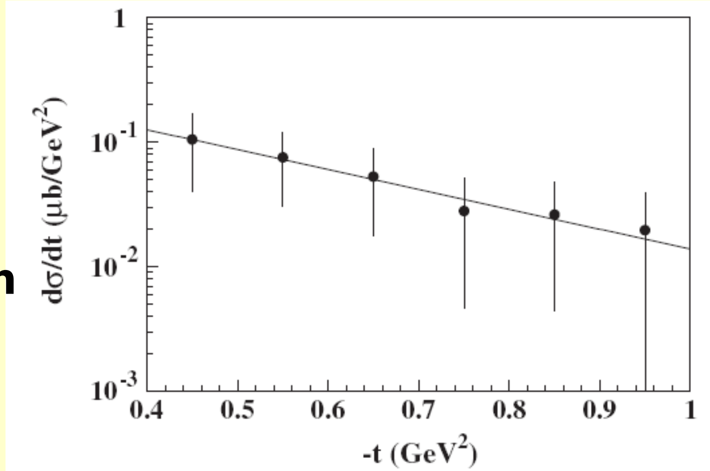
Known states are well reproduced, ρ(770)

PWA in CLAS is feasible!

MB ,De Vita A. Szczpaniak et al. Phys.Rev.Lett. 102:102001,2009
MB ,De Vita A. Szczpaniak et al Phys.Rev. D80:072005,2009



First observation of the $f_0(980)$ in a photoproduction experiment

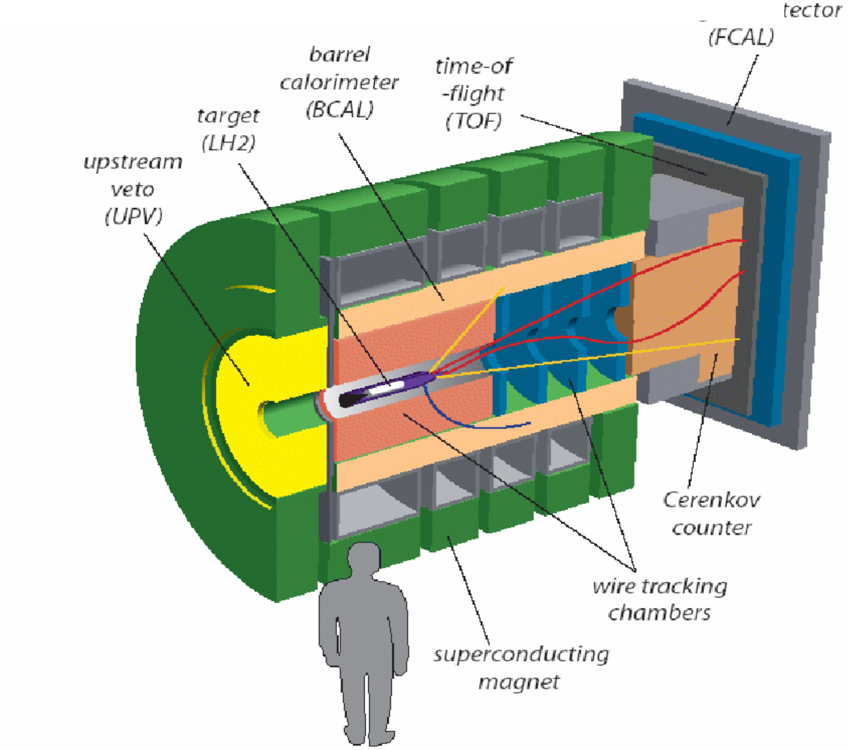


Meson spectroscopy with photons at JLab-12GeV

✯ The Detector

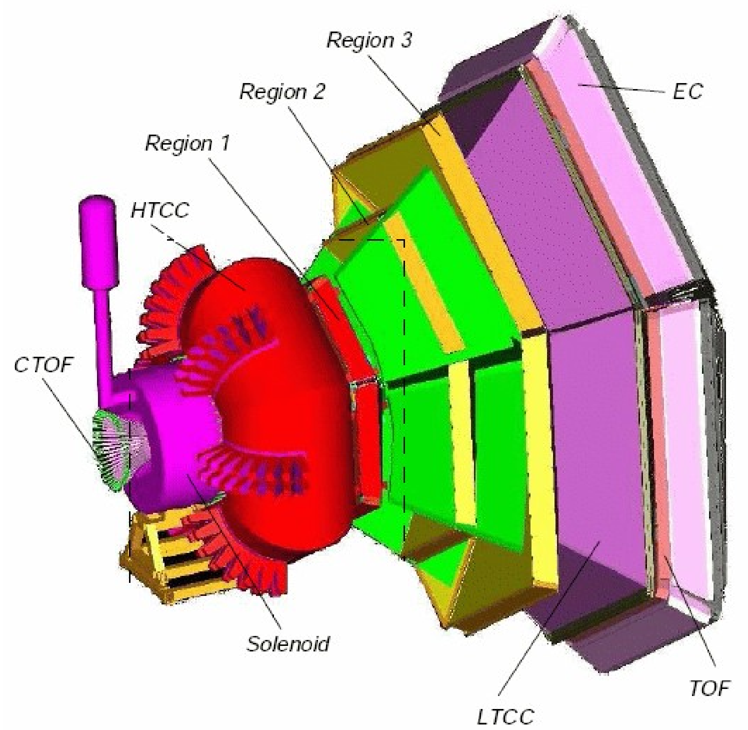
- Determination of J^{PC} of meson states requires Partial Wave Analysis
- Decay and Production of exclusive reactions
- Good acceptance, energy resolution, particle Id

Hall-D - GlueX Detector



- Good hermeticity
- Uniform acceptance
- Limited resolution
- Limited pID

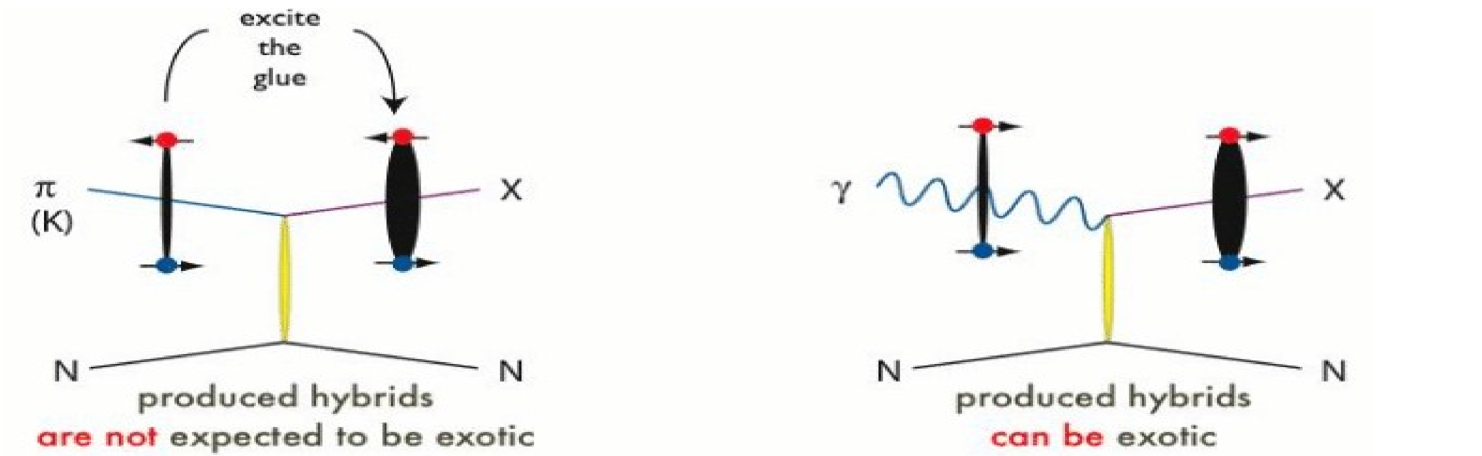
Hall-B - CLAS12 Detector



- Good resolution
- Good pID
- Reasonable hermeticity
- Un-uniform acceptance

Why photoproduction?

- Photoproduction: exotic J^{PC} are more likely produced by S=1 probe



Need spin-flip for exotic quantum number

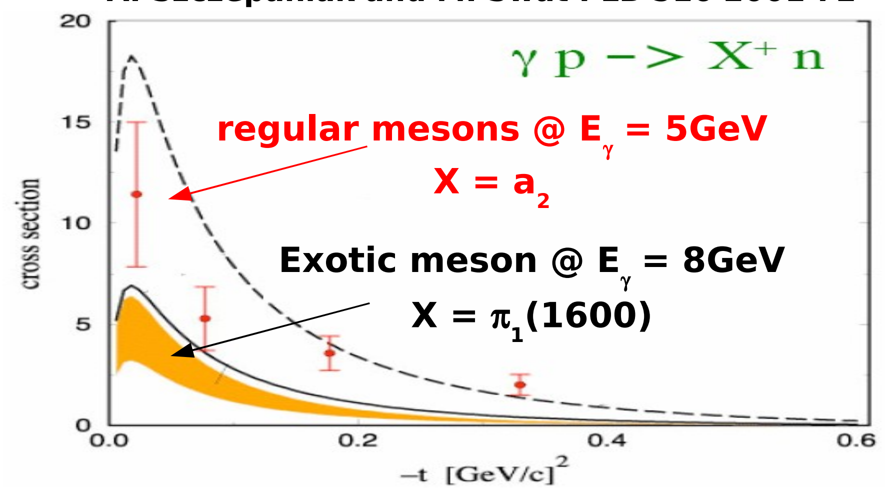
No spin-flip for exotic quantum number

- **Linear polarization acts like a filter to disentangle the production mechanisms and suppress backgrounds**

- **Production rate for exotics is expected comparable as for regular mesons**

Few data (so far) but expected similar production rate as regular mesons

A. Afanasev and P. Page et al. PR A57 1998 6771
A. Szczepaniak and M. Swat PLB 516 2001 72



Meson spectroscopy with photons at JLab-12GeV

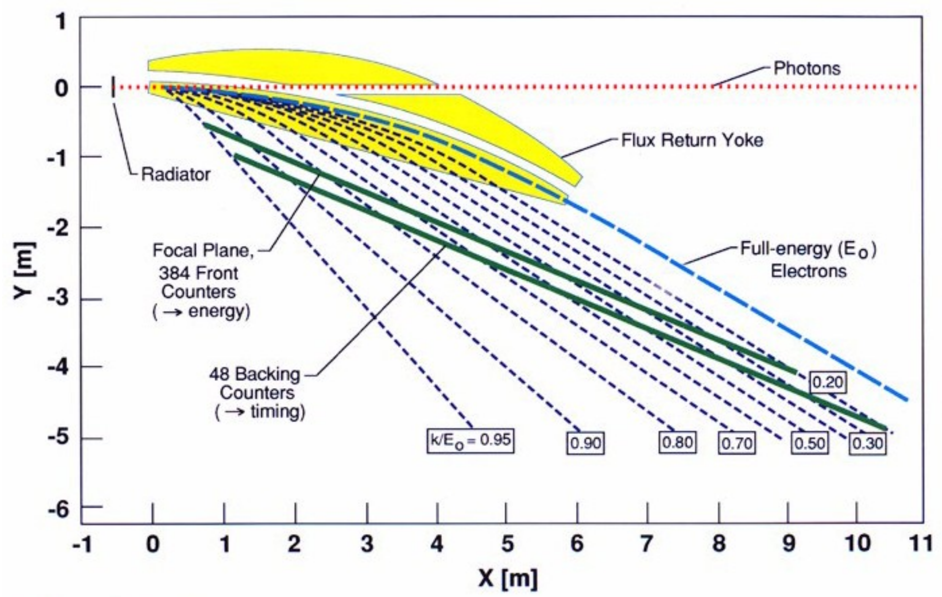
Photon beam requirement

- High luminosity
- Tagger
- Linear polarization

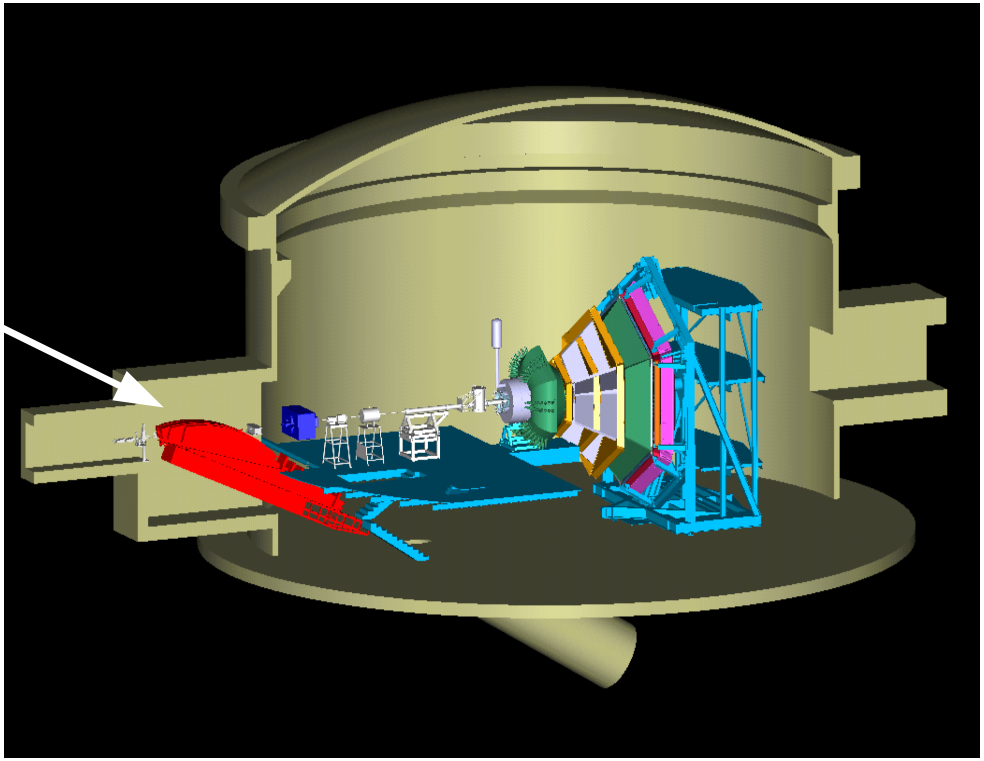
With a 12 GeV electron beam only few choices

1) Bremsstrahlung (Hall-D)
2) Low Q^2 electroprod (Hall-B)

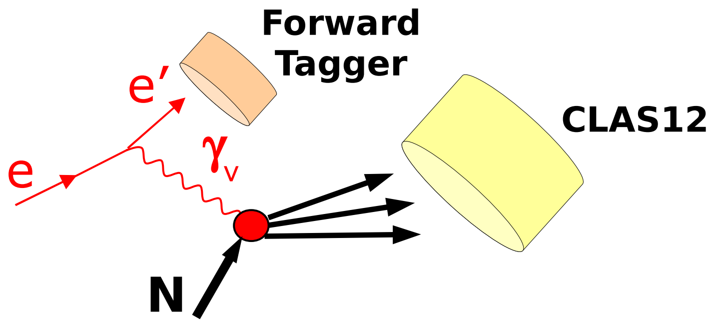
The Hall-B real photon tagger



The Hall-B existing dipole magnet is unable to deflect the 11 GeV primary beam on the existing beam-dump



Quasi-real photoproduction with CLAS12
(Low Q^2 electron scattering)



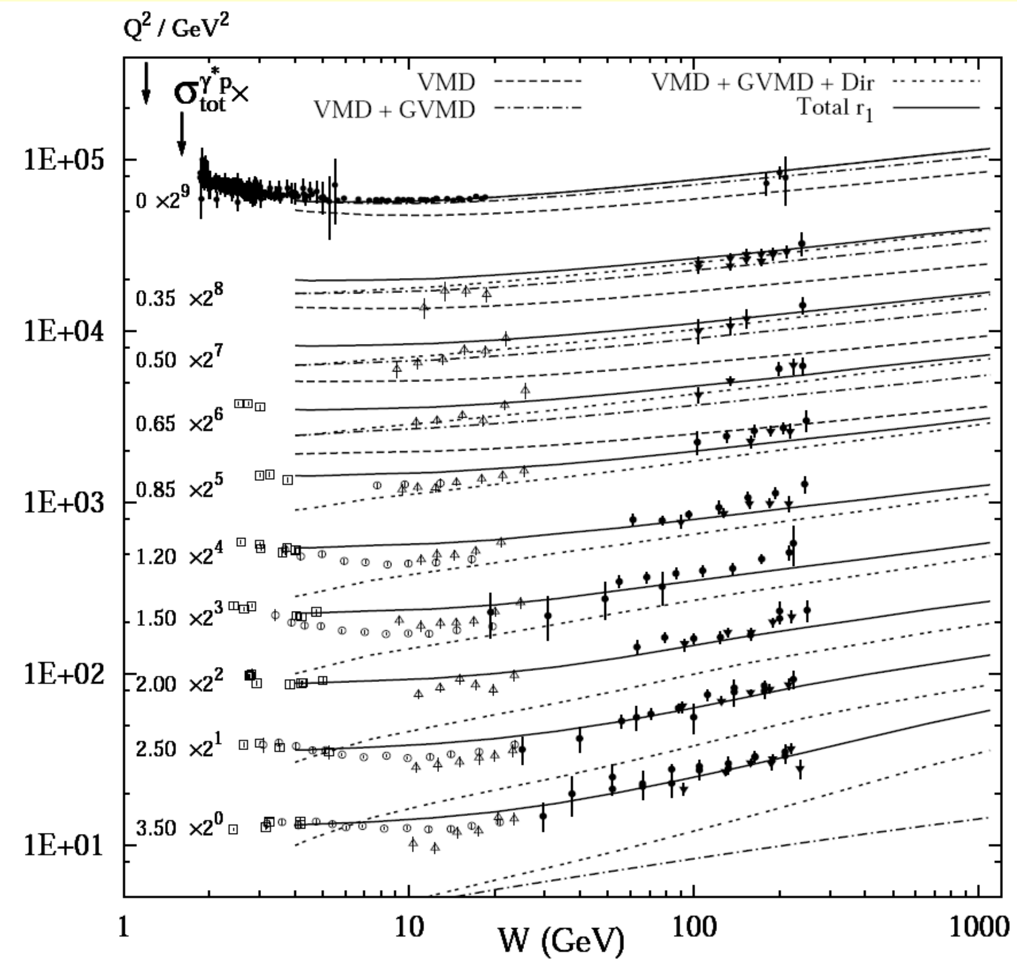
$E_{scattered}$	0.5 - 4.5 GeV
θ	2.5^o - 4.5^o
ϕ	0^o - 360^o
ν	6.5 - 10.5 GeV
Q^2	0.01 - 0.3 GeV^2 ($< Q^2 >$ 0.1 GeV^2)
W	3.6 - 4.5 GeV

- **Electron scattering at "0" degrees (2.5^o - 4.5^o)**
  low Q^2 virtual photon ⇔ real photon
- **Photon tagged by detecting the scattered electron at low angles**
  High energy photons 6.5 < E_γ < 10.5 GeV
- **Quasi-real photons are linearly polarized**
  Polarization ~ 70% - 10% (measured event-by-event)
- **High Luminosity (unique opportunity to run thin gas target!)**
  Equivalent photon flux N_γ ~ 5 10^8 on 5cm H_2 (L=10^{35} $cm^{-2}s^{-1}$)
- **Multiparticle hadronic states detected in CLAS12**
  High resolution and excellent PID (kaon identification)

Complementary to Hall-D (GLUEX)

Q^2 dependence of the Xsec

Studies at large W (~100GeV) show a smooth transition between Q^2=0 and $Q^2 \neq 0$



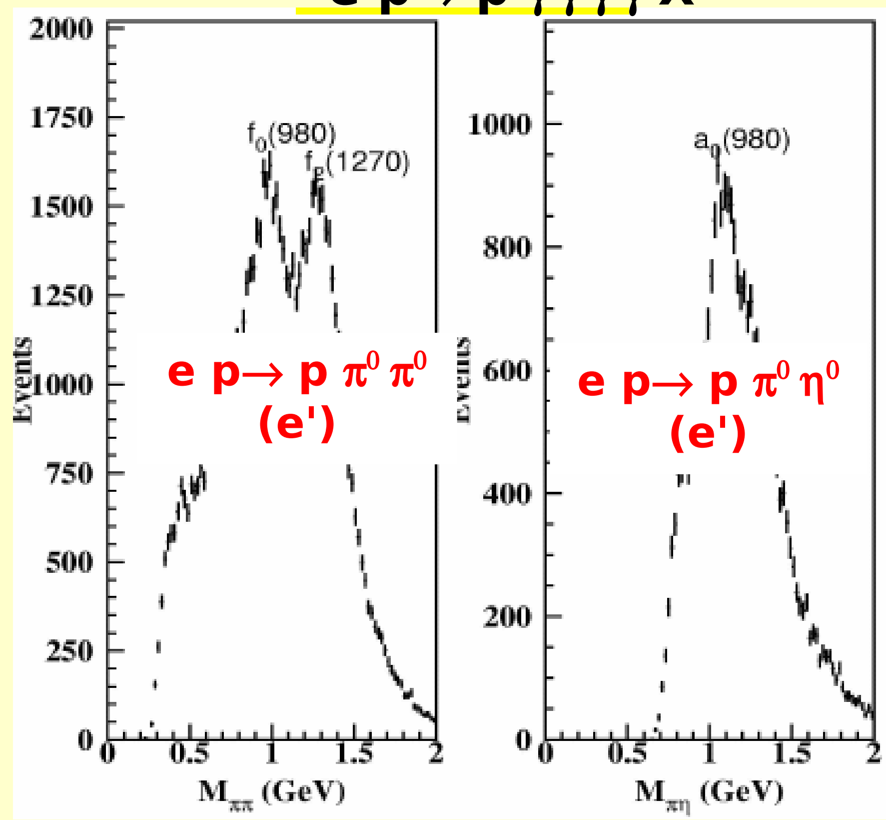
Well known technique used in hep

$Q^2 < W^2$

COMPASS	**<1 GeV^2**	**<Q^2> ~ 10^{-1} GeV^2**
ZEUS:	**~ 10^{-7} – 0.02 GeV^2**	**<Q^2> ~5 10^{-5} GeV^2**
H1:	**<2 GeV^2**	

Tested in CLAS

e p→ p γγγγ X



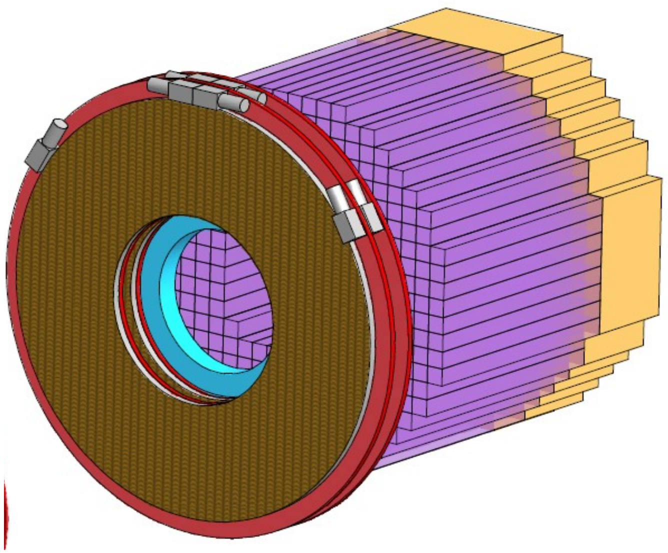
e p→ p $\pi^0 \pi^0$ (e')

e p→ p $\pi^0 \eta^0$ (e')

Bright meson peaks show up
The technique works!

Forward Tagger

Calorimeter + hodoscope + tracker



Electron energy/momentum

- Photon energy (ν=E-E')
- Polarization $\varepsilon^{-1} \sim 1 + \nu^2/2EE'$

Veto for photons

Electron angles

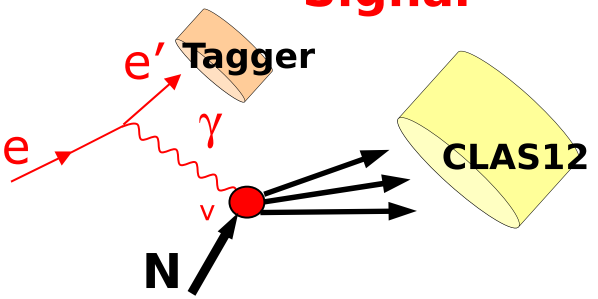
- $Q^2 = 4\ E\ E' \sin^2 \vartheta/2$
- Scattering plane

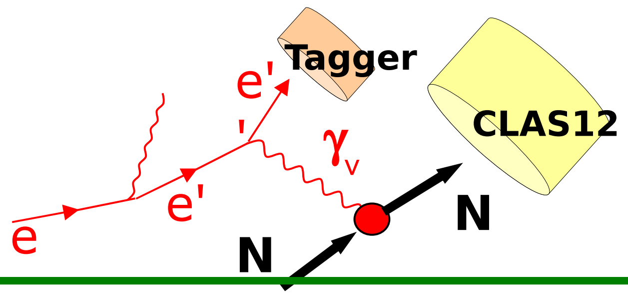
Rates in the forward tagger

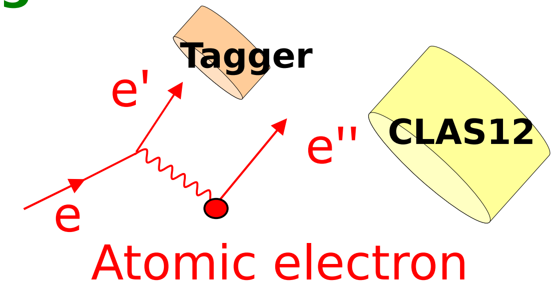
$L_e \sim 10^{35}$ cm^{-2} s^{-1} ($N_\gamma \sim 5\ 10^8\ \gamma$/s)

Inelastic electro-production — Elastic radiative tail — Moeller scattering

Signal — Background





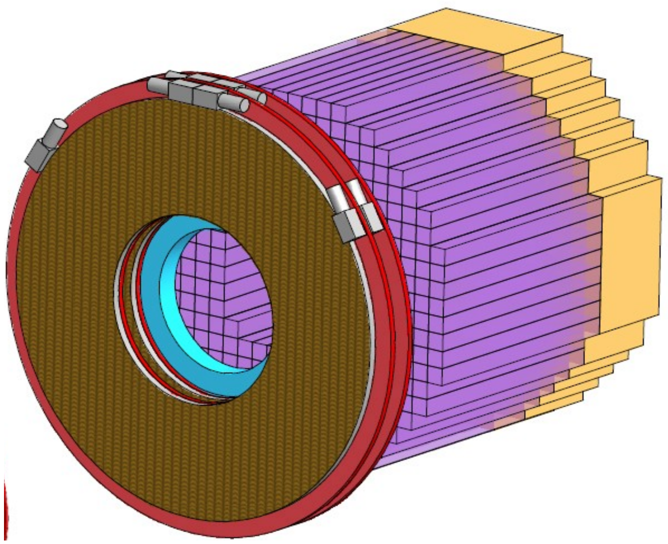


Single arm: R~7 kHz

Single arm: R~ 40kHz R~ 180kHz

Forward Tagger

Calorimeter + hodoscope + tracker



Electron energy/momentum

- Photon energy (ν=E-E')
- Polarization $\varepsilon^{-1} \sim 1 + \nu^2/2EE'$

Veto for photons

Electron angles

- $Q^2 = 4\ E\ E'\ \sin^2 \vartheta/2$
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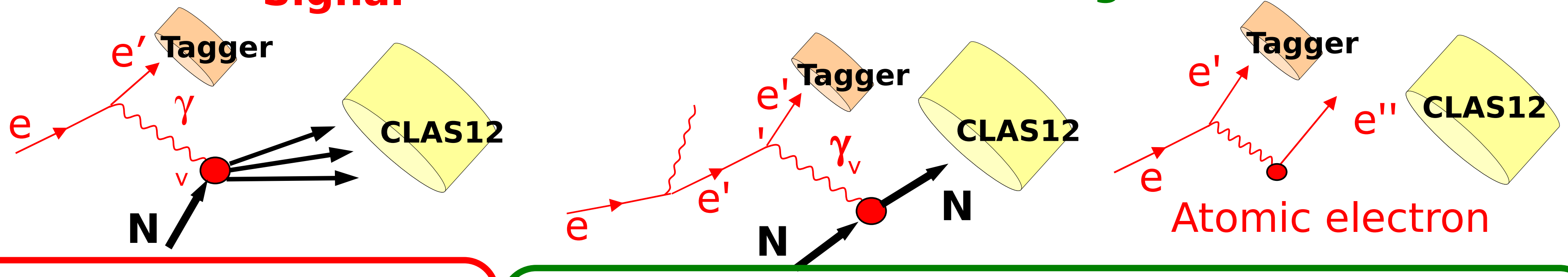
Rates in the forward tagger

$L_e \sim 10^{35}\ cm^{-2}\ s^{-1}$ ($N_\gamma \sim 5\ 10^8\ \gamma/s$)

Inelastic electro-production | Elastic radiative tail | Moeller scattering

Signal | Background

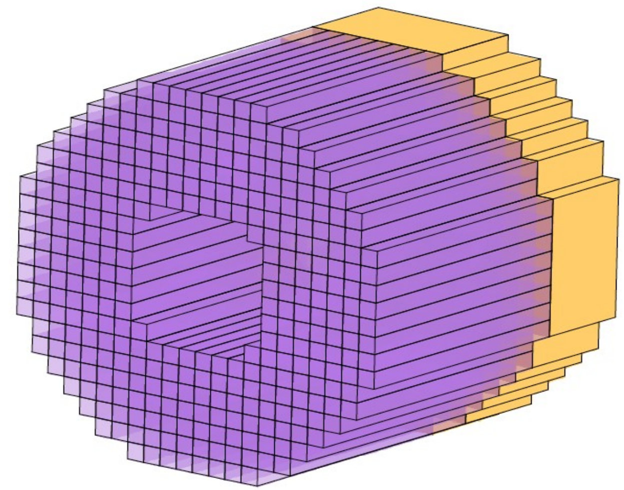


FT/CLAS12 coinc: R~1 kHz

FT/CLAS12 coinc: R=0 R=0 R_{RND}~1KHz

Forward Tagger

Calorimeter + hodoscope + tracker



Electron energy/momentum

Photon energy (ν=E-E')

Polarization $\varepsilon^{-1} \sim 1 + \nu^2/2EE'$

$\delta\nu / \nu = \delta E'/(E-E')$

Veto for photons

Electron angles

$Q^2 = 4\ E\ E'\ \sin^2 \vartheta/2$

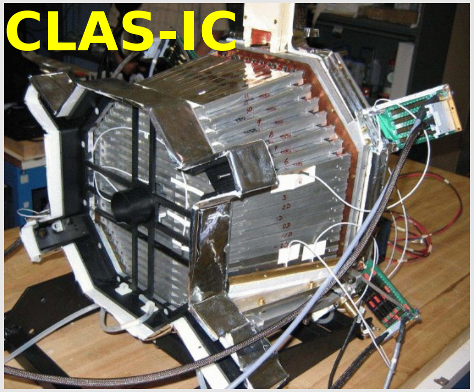
Scattering plane

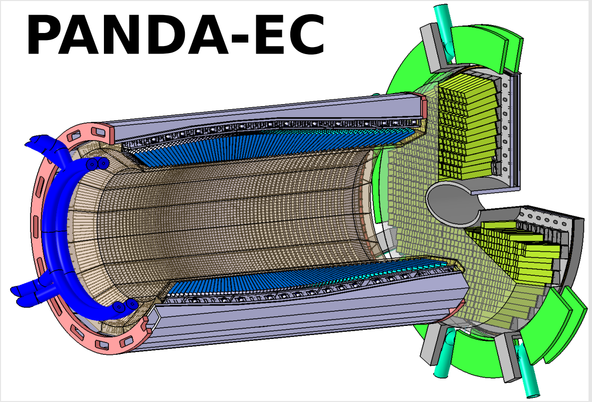
Calorimeter

Homogeneous, fast, dense, inorganic-crystals (PbWO4)

Specs

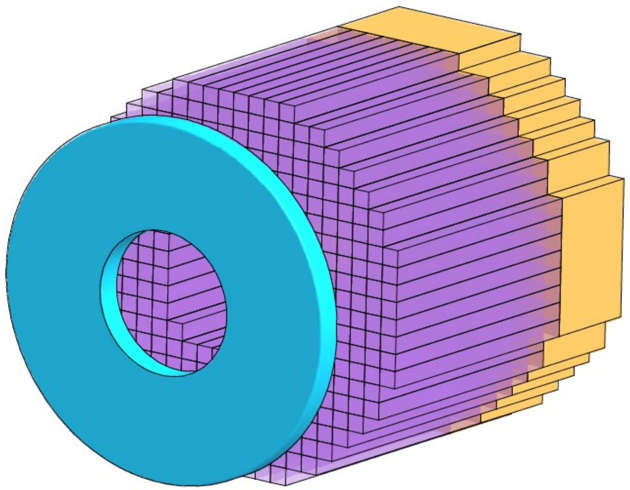
- Radiation hard
- Good light yield
- Energy resolution
- Time resolution
- Light read-out (APD/SiPM)





Forward Tagger

Calorimeter + hodoscope + tracker



Electron energy/momentum

- Photon energy (ν=E-E')
- Polarization $\varepsilon^{-1} \sim 1 + \nu^2/2EE'$

Veto for photons

Electron angles

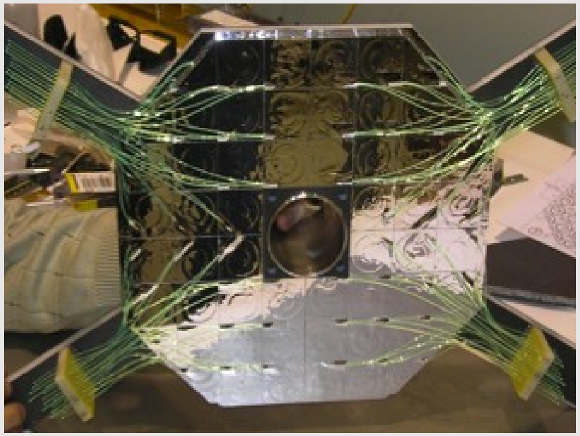
- Q^2= 4 E E' $\sin^2 \vartheta/2$
- Scattering plane

Hodoscope

Specs

- Good timing (<ns) for MIPs
- High segmentation (same as the cal or higher)
- 100% efficient to charged particles

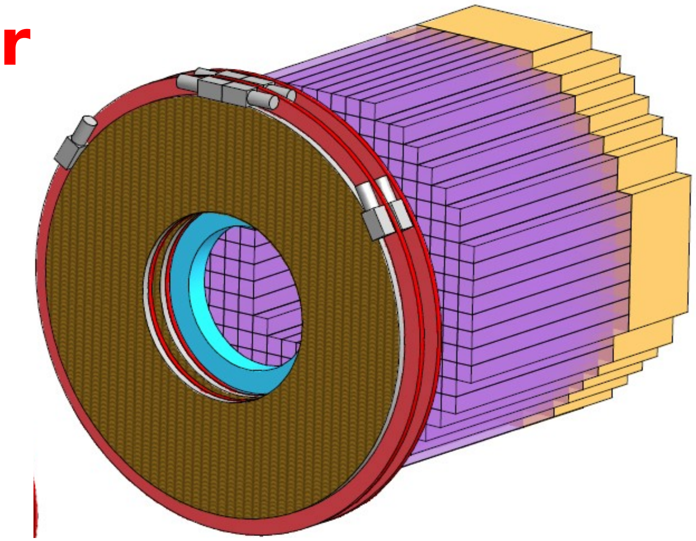
Plastic scintillator tiles with WLS fibres coupled to SiPM



CLAS-HODO

Forward Tagger

Calorimeter + hodoscope + tracker



Electron energy/momentum

Photon energy (ν=E-E')

Polarization $\varepsilon^{-1} \sim 1 + \nu^2/2EE'$

Veto for photons

Electron angles

$Q^2 = 4\,E\,E'\,\sin^2 \vartheta/2$

Scattering plane

Tracker

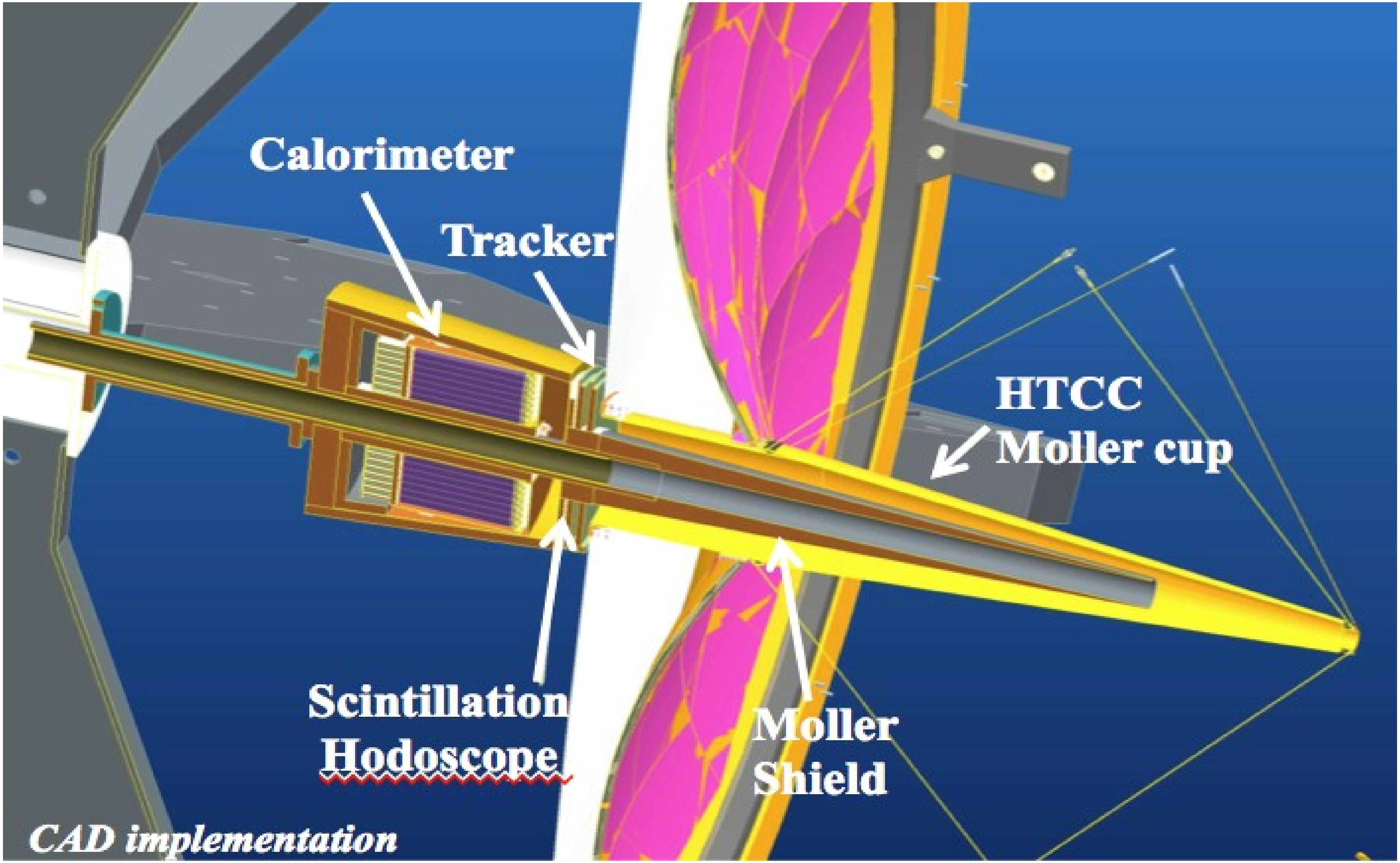
Sustain high rate, moderate resolution, low material budget (Micromegas)

Specs

- 5T solenoidal field
- High pixel density (FW)
- 100-300 μm resolution
- Integrated in the CLAS12 base equipment

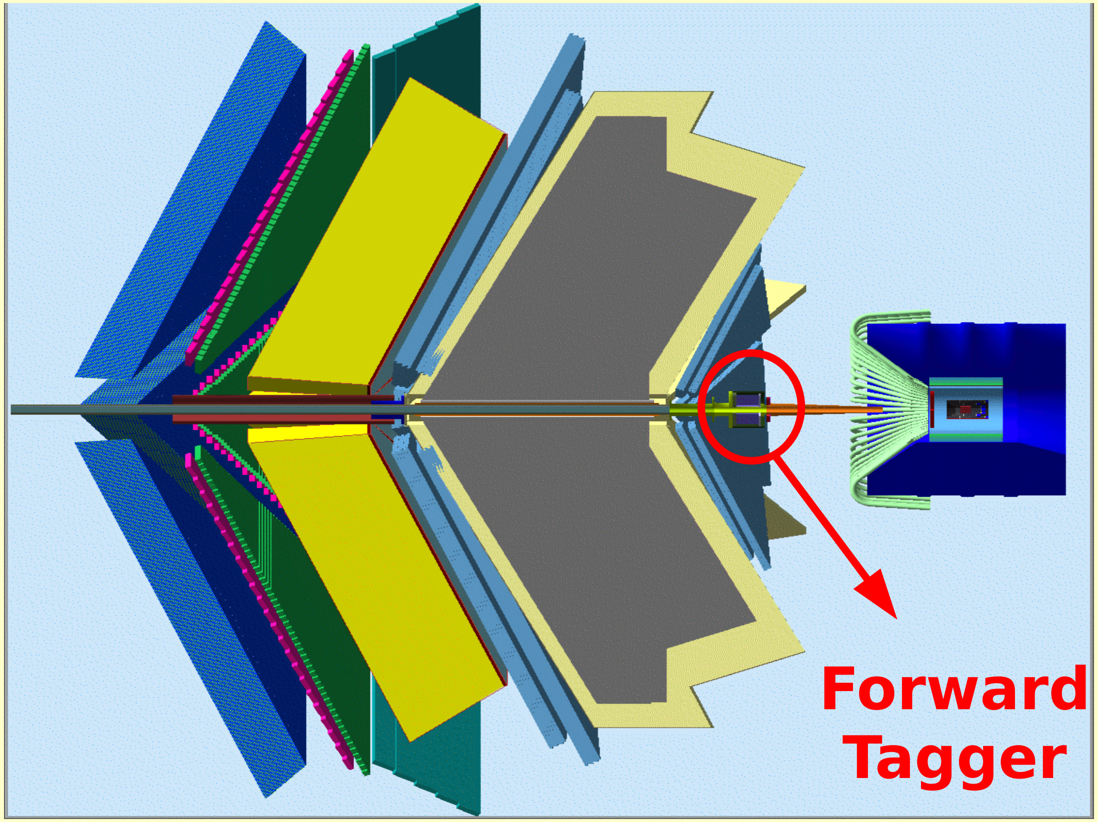
CLAS12-μM

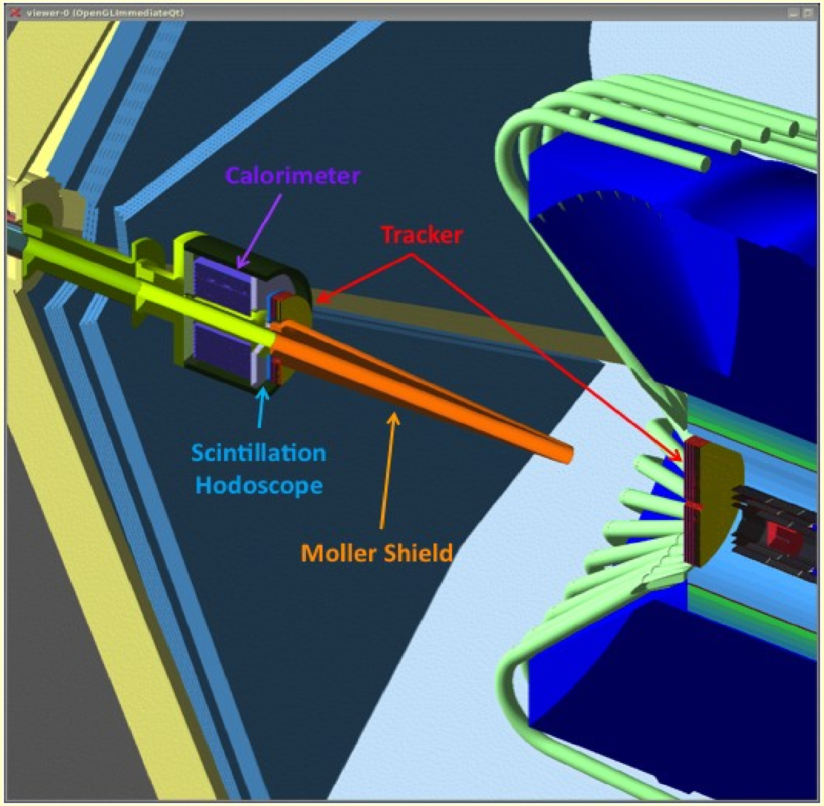
The Forward Tagger in CLAS12



The Forward Tagger in CLAS12

- Compatible with standard electron runs



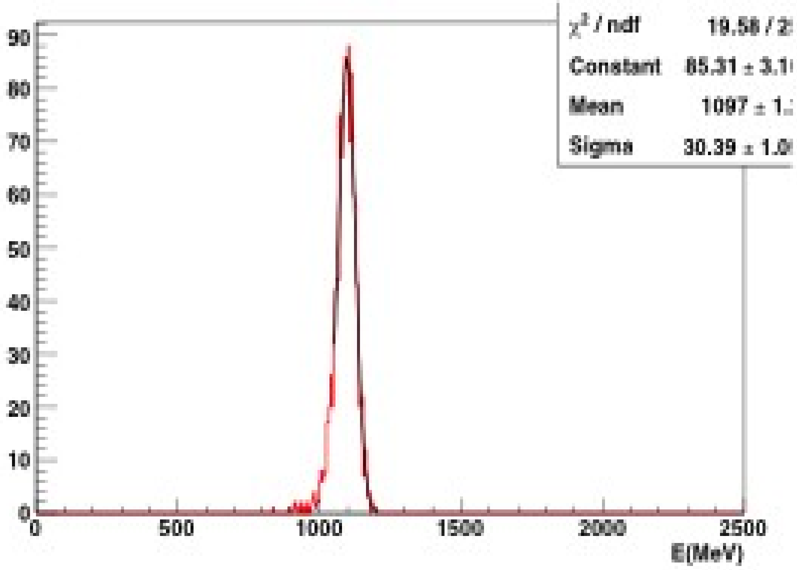


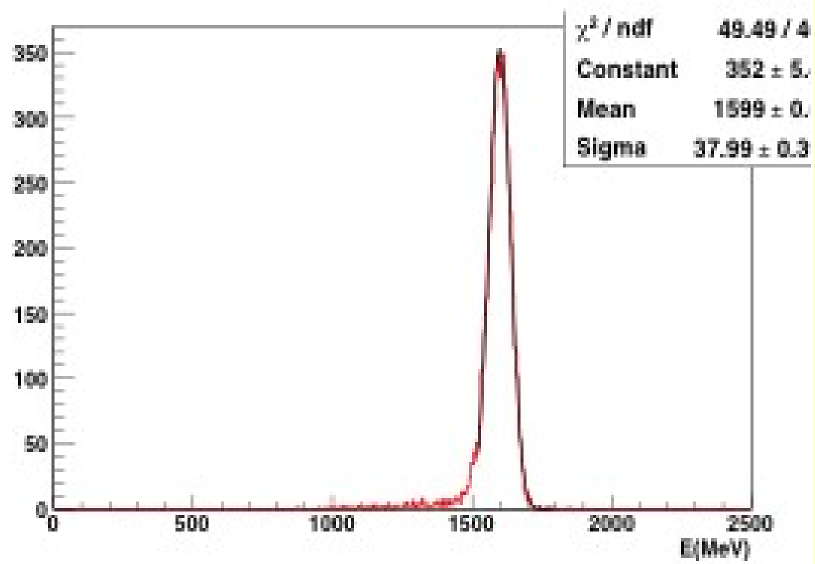
- Photon detector for leading DVCS experiments
- Extend the CLAS12 coverage for neutrals at small angles

Photons and electrons can run in parallel!

FT R&D and prototyping

- Tender for 370 PbWO-II crystals completed
- 9/16 ch FT-Cal and FT-Hodo proto tested at JLab and BTF@LNF





Final energy resolution:

- σ/E = 2.5 % at 1.31 GeV (MC: 2.2%)
- σ/E = 2.2 % at 1.92 GeV (MC: 1.9 %)

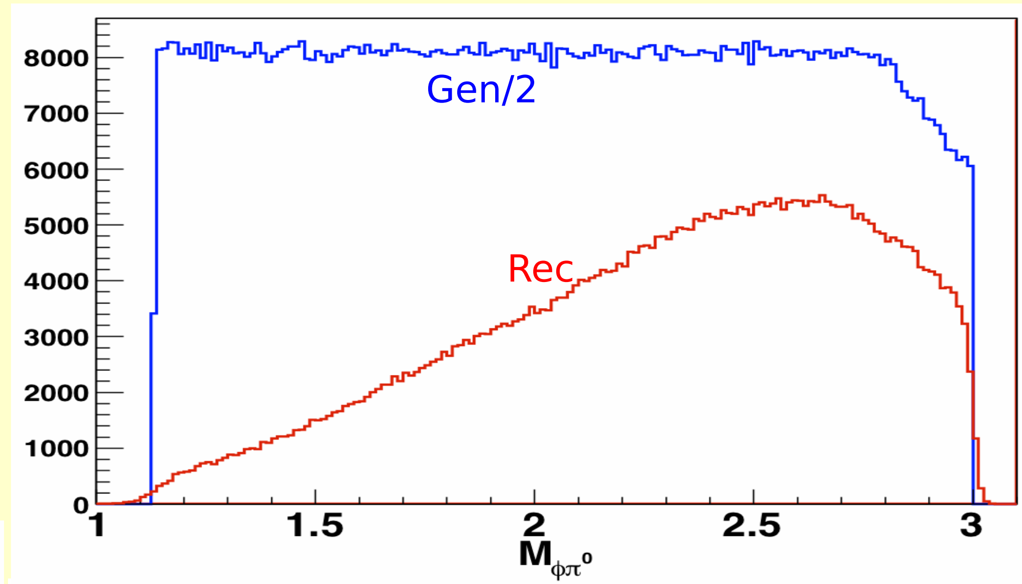
- APDs procurement in 2013 and full detector assembly in 2014

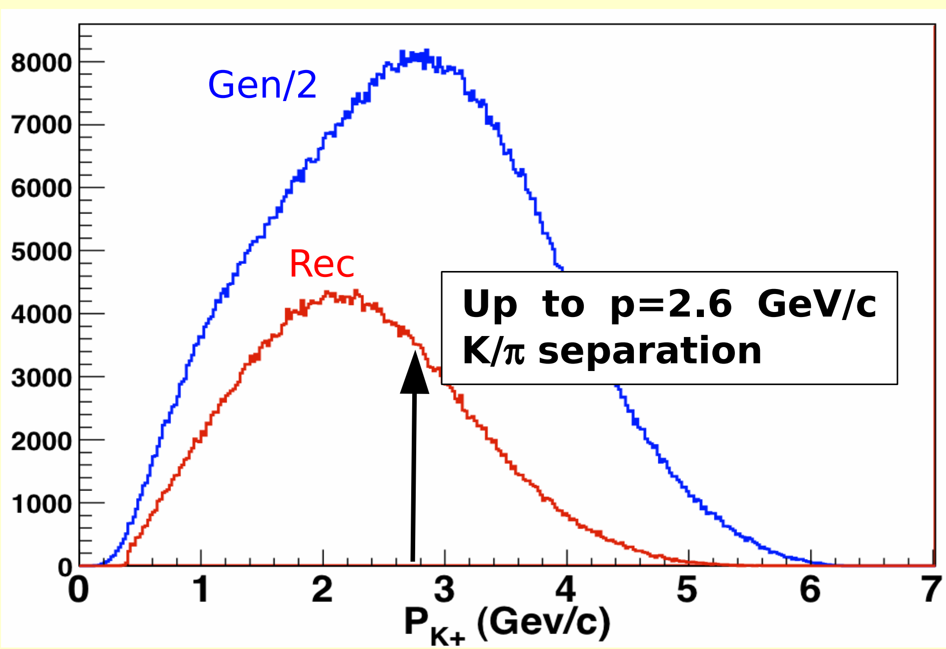
Search for strangeonia in CLAS12

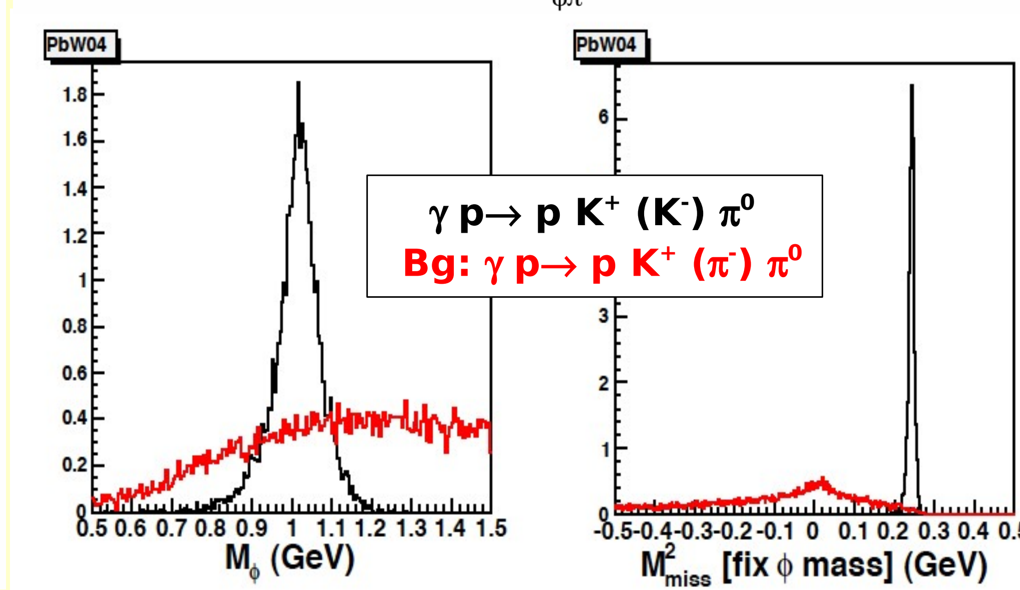
CLAS12 simulations

$\gamma\, p \rightarrow p\ C(M=1480,\ \Gamma=130\ MeV) \rightarrow p\ \varphi\, \pi^0 \rightarrow p\ K^+(K^-)\ \gamma\gamma$

- **Unusual BR in $\varphi\pi$ (OZI suppressed)**
- **$J^{PC}=1^{--}$ $\sigma \sim$ 10nb**
- **Tetra-quarks or hybrid**
- **CLAS12 acceptance ~ 10%**
- **High-p K id relies on kin-fit**
- **K/π separation for p<2.6 GeV/c**







Partial Wave Analysis in CLAS12

$\gamma\, p \rightarrow n\, \pi^+ \pi^+ \pi^-$

✯ **The process is described as sum of 8 isobar channels:**

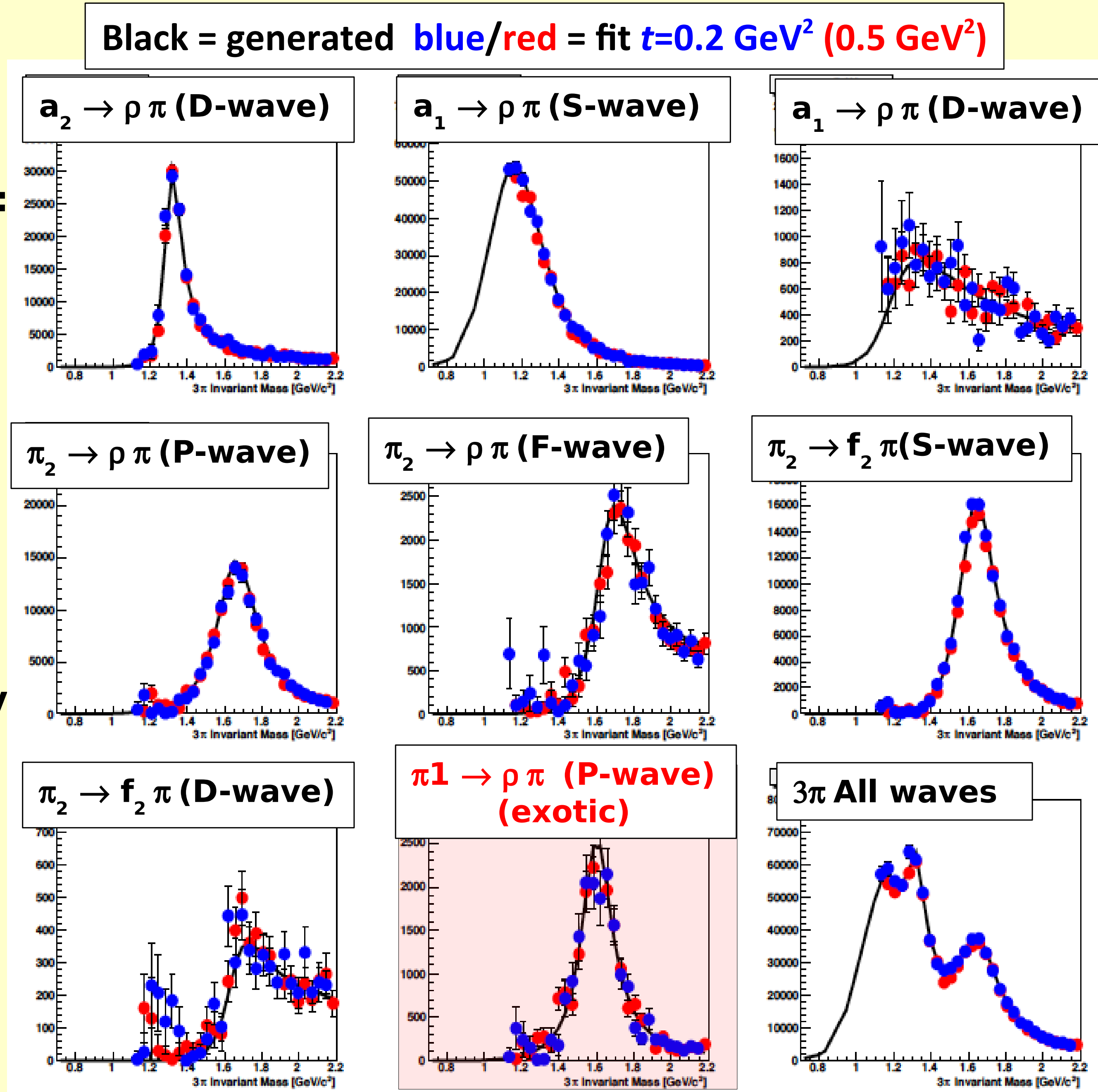
- $a_2 \rightarrow \rho\, \pi$ (D-wave)
- $a_1 \rightarrow \rho\, \pi$ (S-wave)
- $a_1 \rightarrow \rho\, \pi$ (D-wave)
- $\pi_2 \rightarrow \rho\, \pi$ (P-wave)
- $\pi_2 \rightarrow \rho\, \pi$ (F-wave)
- $\pi_2 \rightarrow f_2\, \pi$ (S-wave)
- $\pi_2 \rightarrow f_2\, \pi$ (D-wave)
- $\pi 1 \rightarrow \rho\, \pi$ (P-wave) (exotic)

✯ **Amplitudes calculated by A.Szczepaniak and P.Guo**

✯ **CLAS12 acceptance projected and fitted**

✯ **PWA is stable against CLAS12 acceptance/ resolution distortion**

PWA in CLAS12 is feasible !



Partial Wave Analysis in CLAS12

The photon linear polarization is necessary to extract production mechanisms and filter-out specific processes

$\pi 1 \rightarrow \rho\,\pi$
P-wave (exotic)

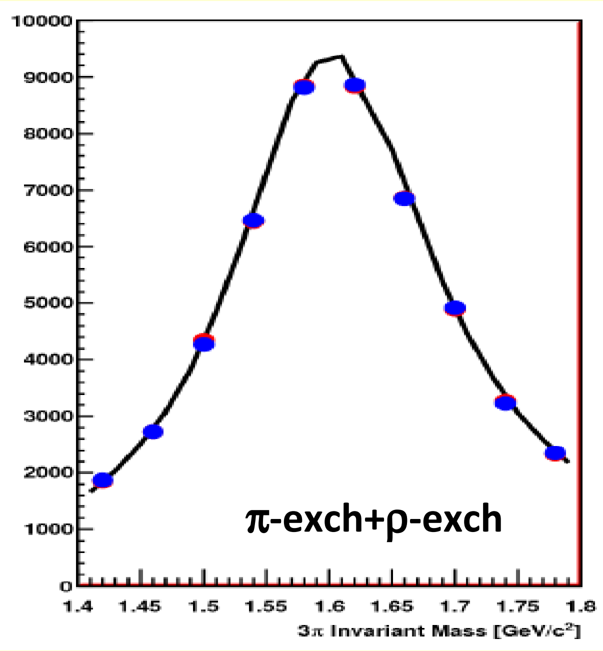
Two possible production mechanisms

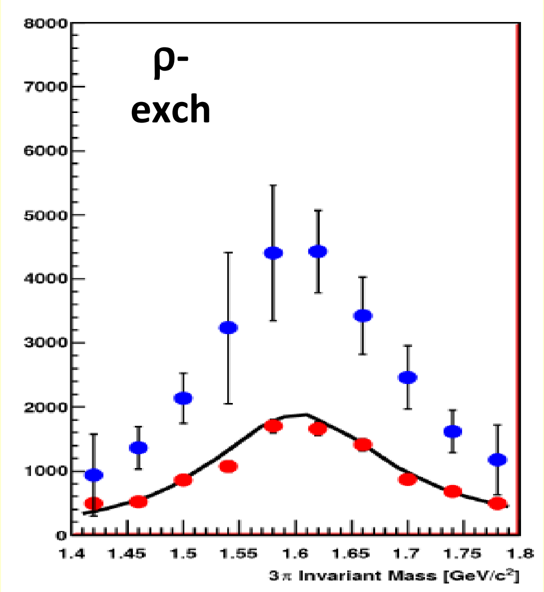
π-exchange (un-natural parity)
ρ-exchange (natural parity)

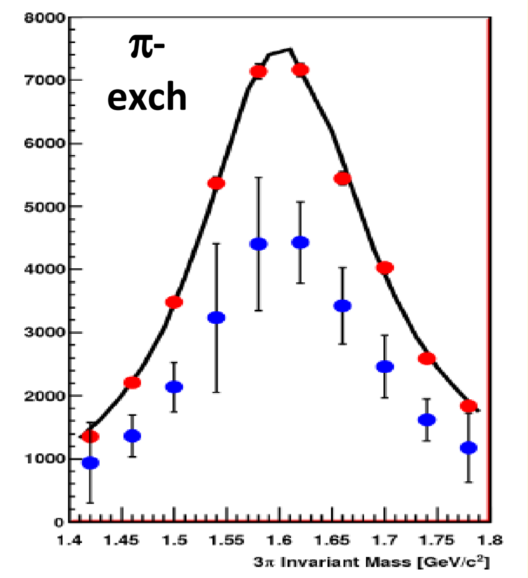
In red: fit result including the linear polarization
In blue: fit result ignoring the polarization

The sum of the two can be fit with or w/o polarization

Including linear polarization in the fit the two exchanges can be reliably separated







Expected results

Production

Cross sections

$\sigma(\gamma p \rightarrow p\ 3\pi)$	~	10 μb
$\sigma(\gamma p \rightarrow p\ \eta\ \pi)$	~	.2 μb
$\sigma(\gamma p \rightarrow p\ K\ K\ \pi)$	~	10 nb
$\sigma(\gamma p \rightarrow p\ \varphi\ \eta)$	~	10 nb

Assuming exotic meson production ~1%

Yield/Mass bin to run PWA ~5000 ev

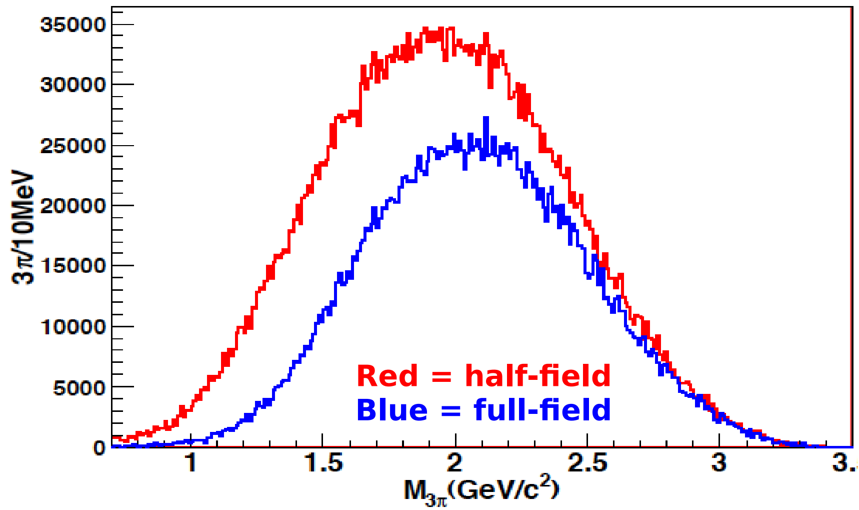
80 days of production beam time

Can be scheduled in parallel to already approved electron runs

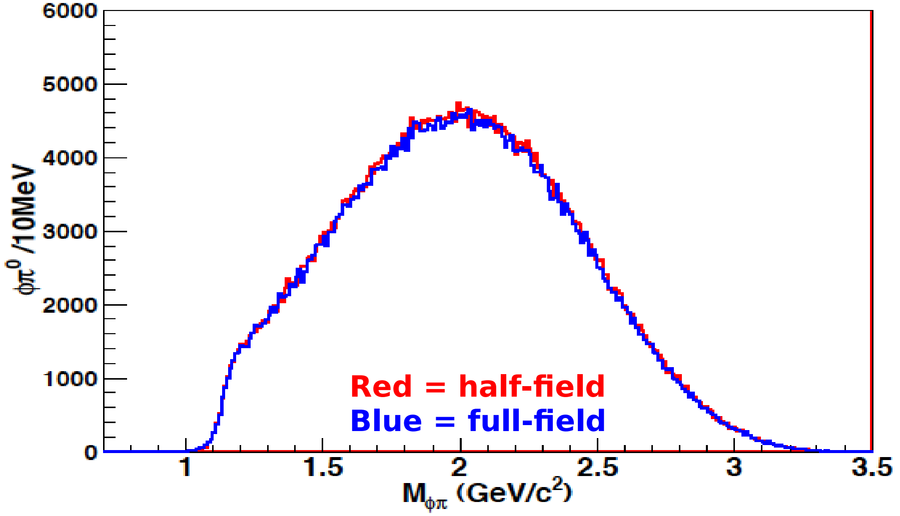
Commissioning and calibration

- **15d FT commissioning**
- **20d+4d low luminosity (L_e~5 10^{33} cm^{-2} s^{-1}) & minimum bias trigger (2-prongs)**

Expected yield 20d run
$\gamma\ p \rightarrow\ (n)\ \pi^+\ \pi^+\ \pi^-$



Expected yield 80d run
$\gamma\ p \rightarrow\ p\ (K^-)\ K^+\ \pi^0$



Meson spectroscopy at JLab with CLAS and CLAS12

- Comprehensive meson spectroscopy program using up-to-6-GeV photon-beam and the CLAS detector in Hall-B
- Exotics and strangeness-rich mesons search will be extended to CLAS12 in the JLab 12 GeV era
- Low Q^2 electron scattering is a complementary technique to the Hall-D coherent Bremsstrahlung
- New equipment: Forward Tagger (calorimeter + hodoscope + tracker) compatible with standard operation of CLAS12
- Excellent CLAS12 resolution and particle Id
- Complete PWA feasible in CLAS12

Dedicated detectors and high intensity photon beams at JLab-12 are under construction, ready to run in a near future!