Search for EXOTICA at CLAS12

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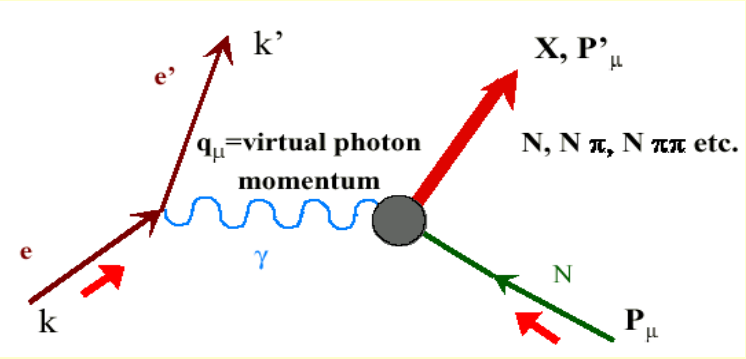
The tool: electromagnetic interaction

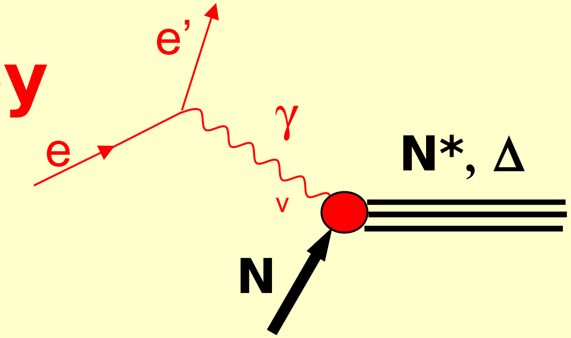
- weaker than strong interactions
- therefore calculable perturbatively
- based on the well-known QED

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



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

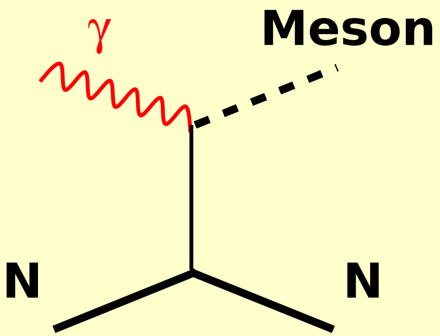
Baryon spectroscopy



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

JLab today!

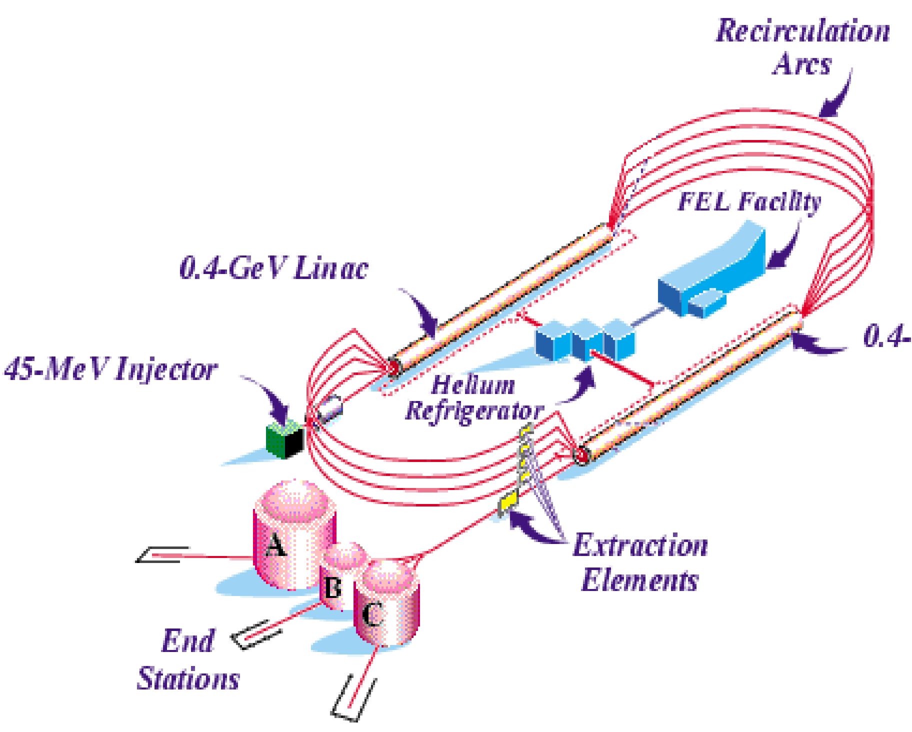
Meson spectroscopy



- **$q\bar{q}$ system → easier to study**
- **Indirect coupling to initial particle**
- **Access to gluonic degrees of freedom**

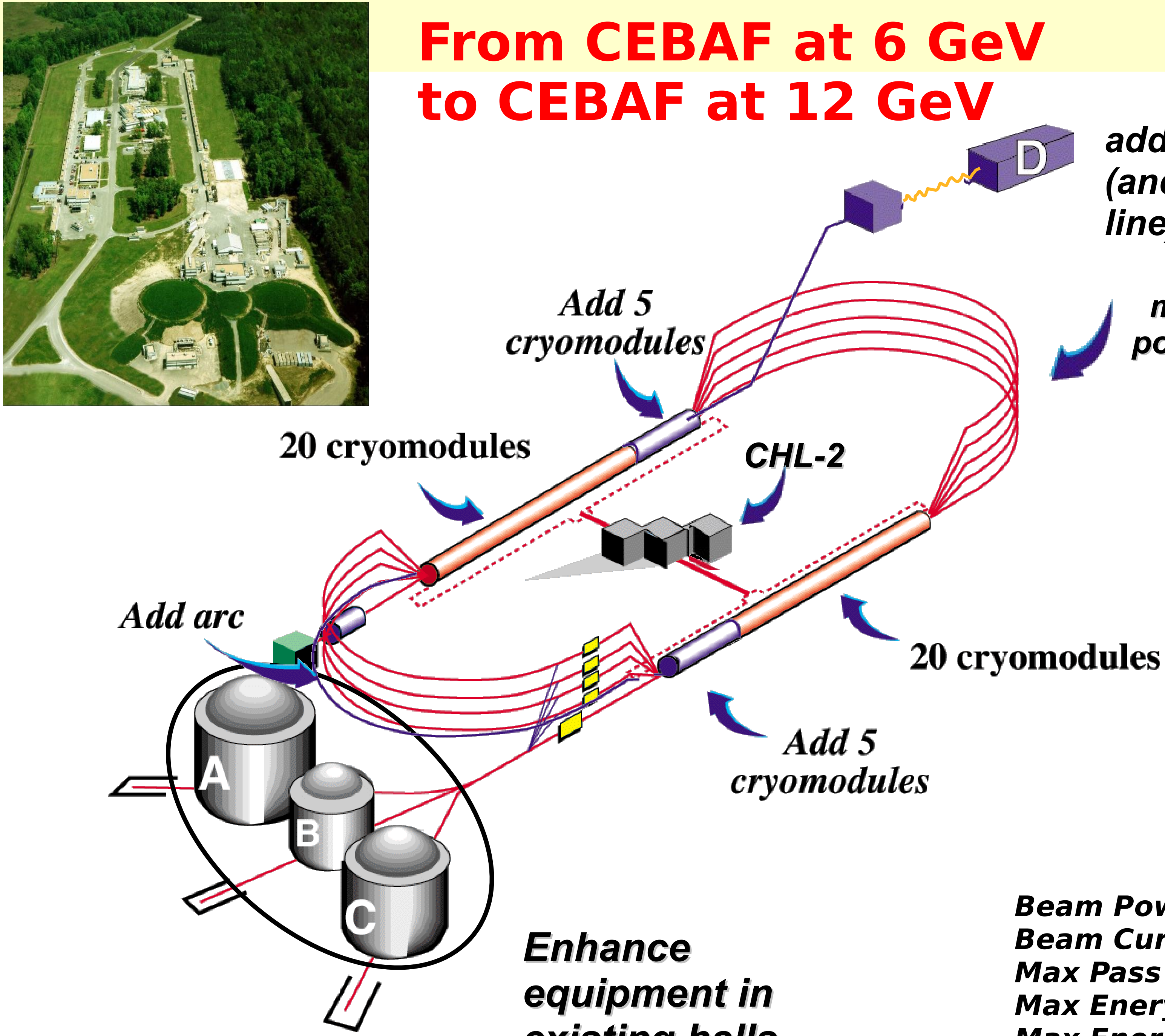
JLab tomorrow!

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**

From CEBAF at 6 GeV to CEBAF at 12 GeV



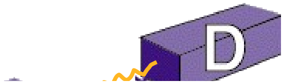
add Hall D (and beam line)

Upgrade magnets and power supplies

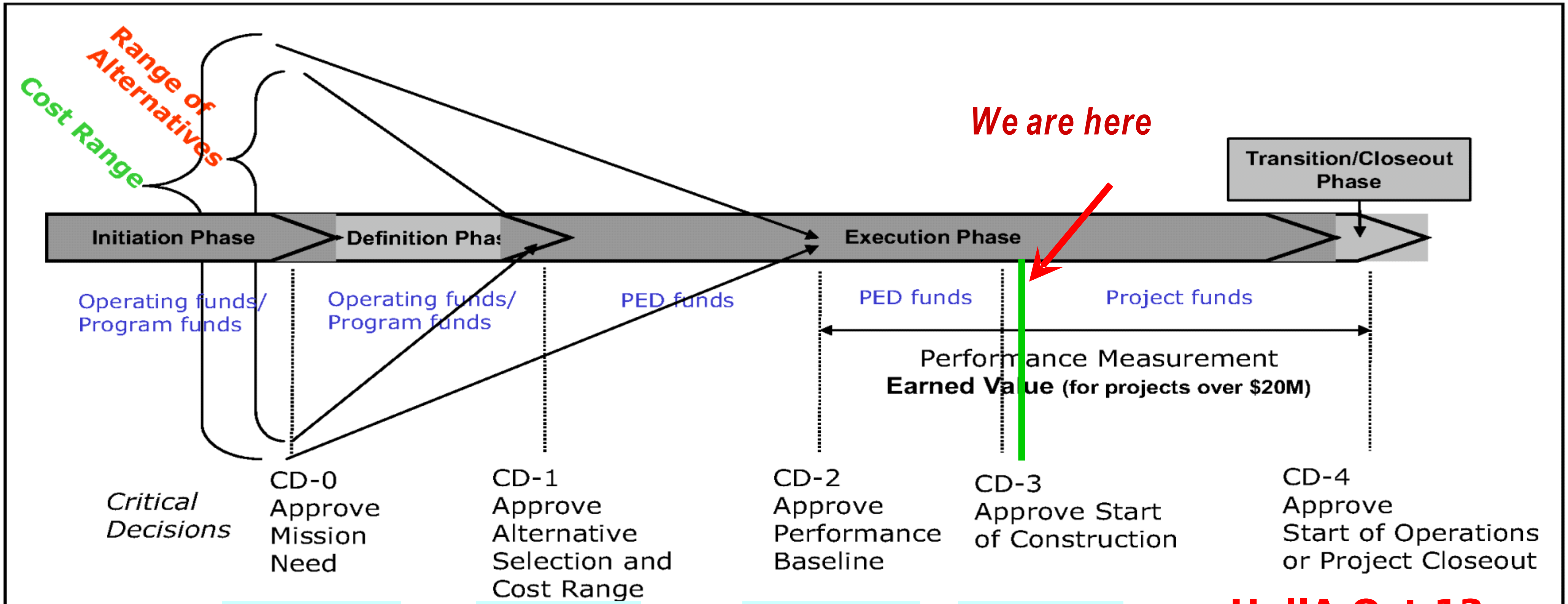
Enhance equipment in existing halls

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



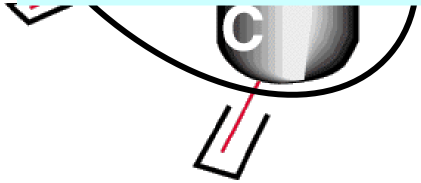
add Hall D
(and beam



MAR 2004	FEB 2006	NOV 2007	SEP 2009

12 GeV Upgrade– Approval dates

HallA Oct 13
HallD Apr 14
HallB Oct 14



Enhance equipment in existing halls

Beam Power: 1MW
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Max Enery Hall A-C: 10.9 GeV
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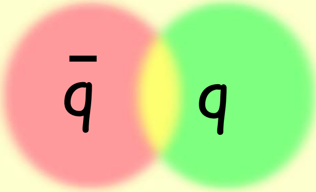
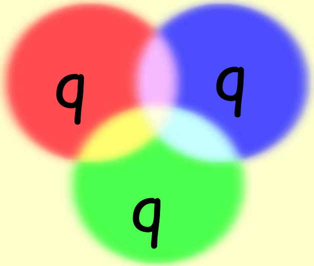
Beyond the quark model: hybrids and exotics

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

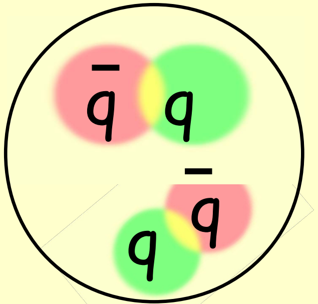


mesons

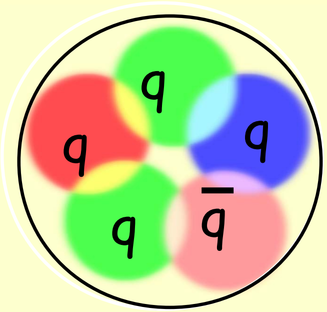


baryons

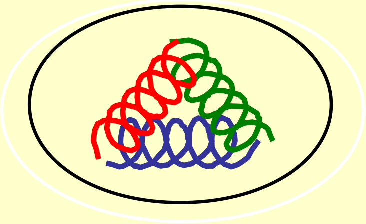
Other quark-gluon configuration can give colorless objects



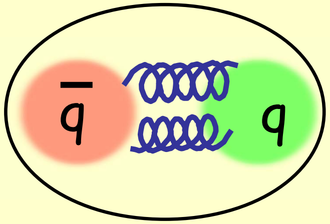
molecules



pentaquarks



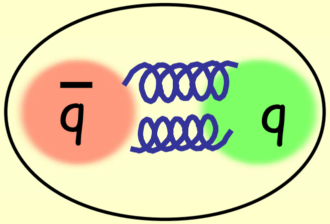
glueball mesons



hybrid mesons

QCD does not prohibit such states
but not yet unambiguously observed

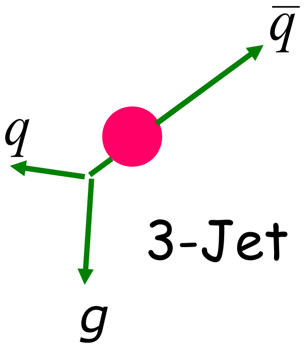
Meson spectroscopy with photons at JLab

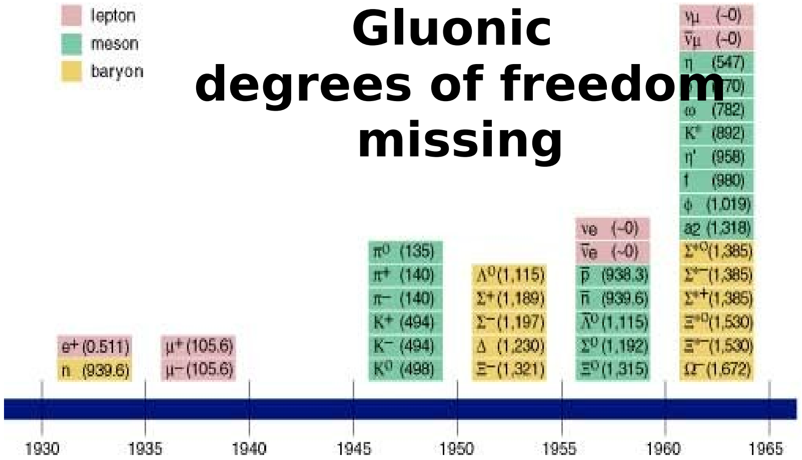


hybrid mesons

- ☆ **Understanding gluonic excitations of mesons and the origin of confinement**

Gluon jets observed at high energy





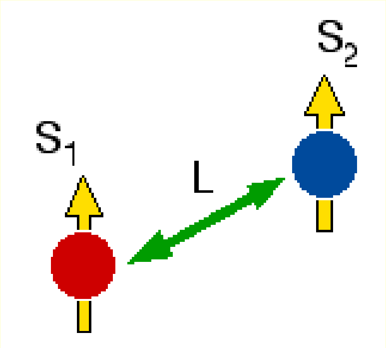
Gluonic degrees of freedom missing

Spectroscopy

one of the most important issue in hadron physics and main motivation for the JLab 12 GeV upgrade (GlueX program in Hall-D)

Meson spectroscopy with photons at JLab

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

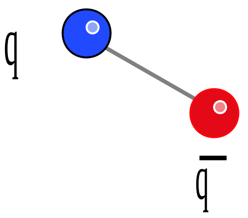


$S=S_1+S_2$ $J= L+S$ $P = (-1)^{L+1}$ $C= (-1)^{L+S}$

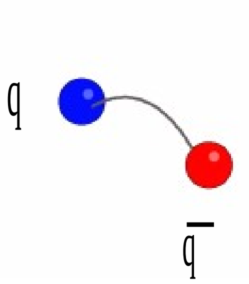
Not-allowed: $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-} \ldots$

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
$CP=(-1)^{S+1}$

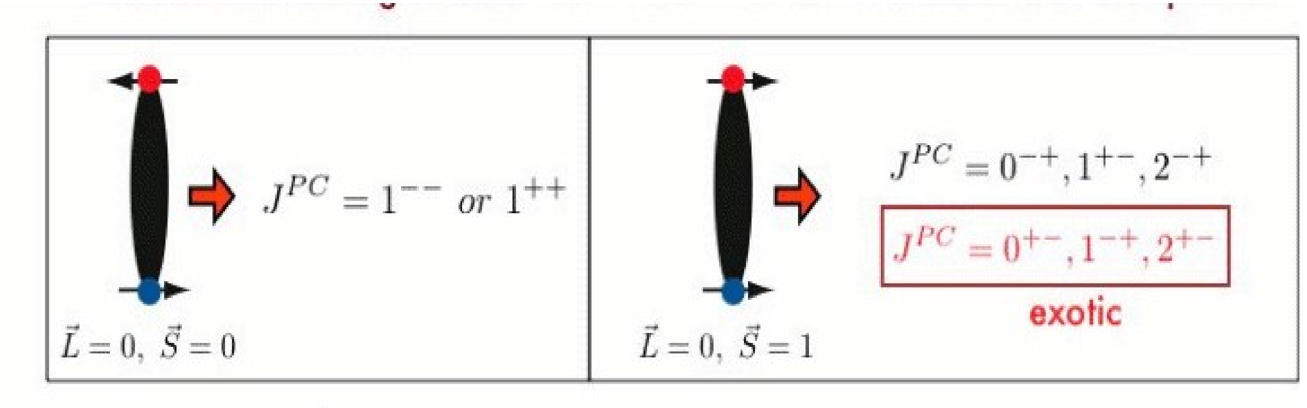


Hybrid meson:
flux tube in excited state
m=1
$CP=(-1)^{S}$



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

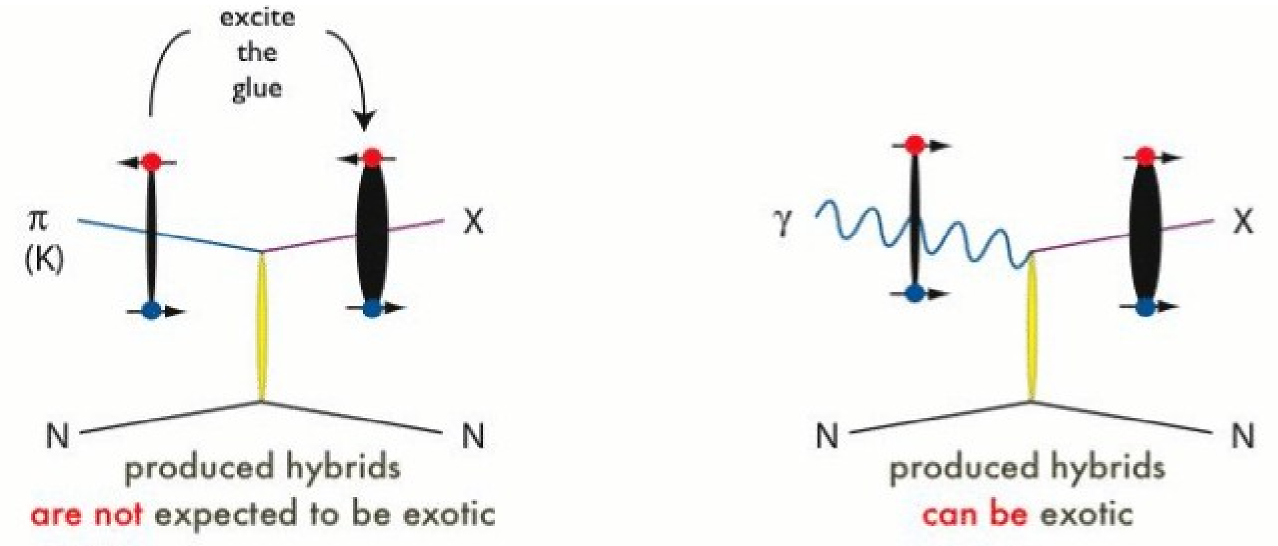
Combine excited glue quantum number with those of the quarks



Meson spectroscopy with photons at JLab

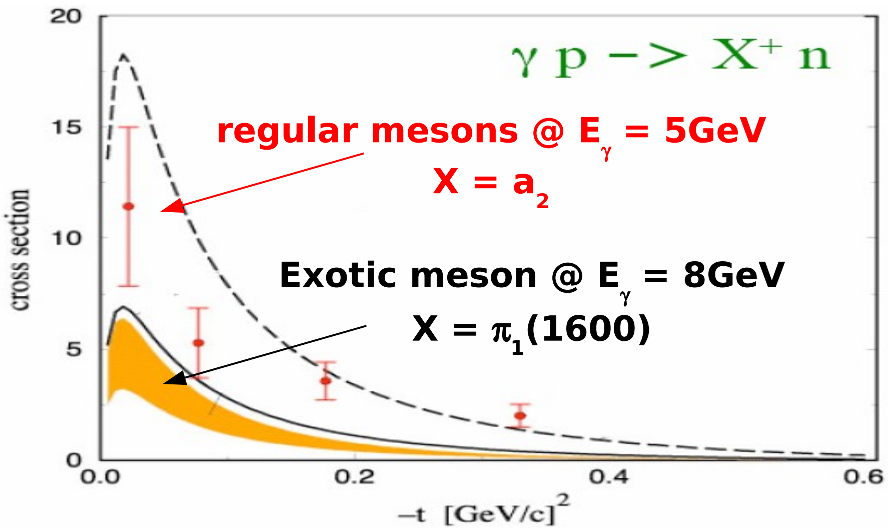
Why photoproduction?

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



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

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



regular mesons @ E_γ = 5GeV

$X = a_2$

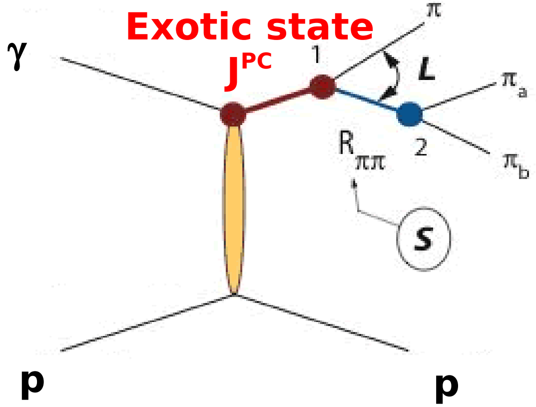
Exotic meson @ E_γ = 8GeV

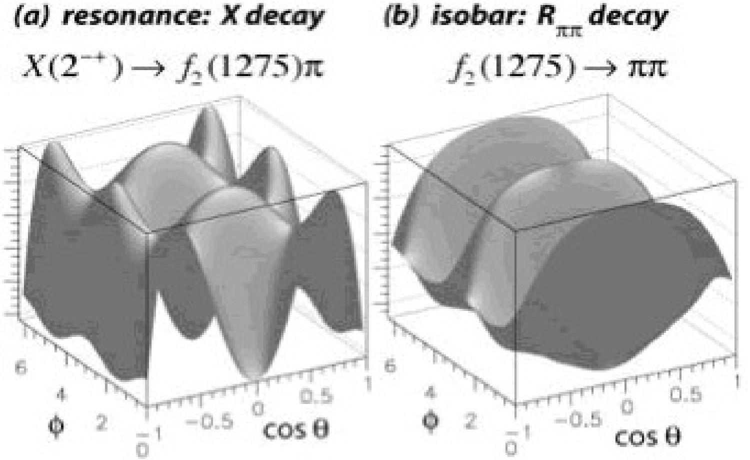
$X = \pi_1(1600)$

Partial Wave Analysis

1) the isobar model

e.g. 3π system




(a) resonance: X decay

$X(2^{-+}) \rightarrow f_2(1275)\pi$

(b) isobar: $R_{\pi\pi}$ decay

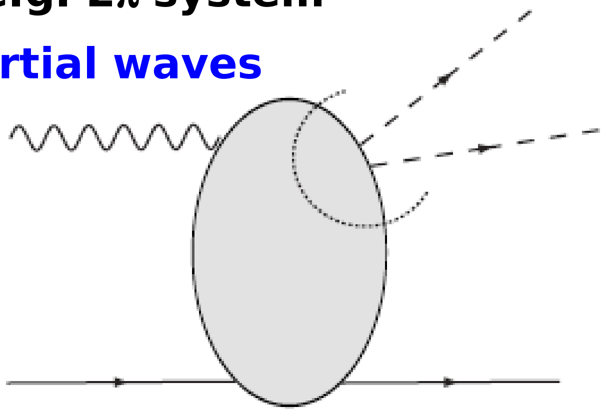
$f_2(1275) \rightarrow \pi\pi$

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

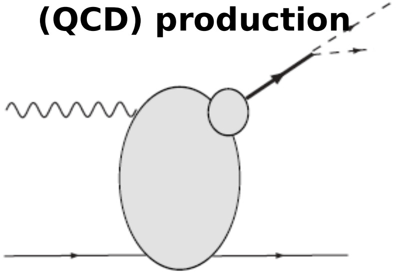
$$\langle Y_{\lambda\mu}\rangle(E_\gamma,t,M) = \frac{1}{\sqrt{4\pi}}\int d\Omega_\pi \frac{d\sigma}{dtdMd\Omega_\pi} Y_{\lambda\mu}(\Omega_\pi)$$

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

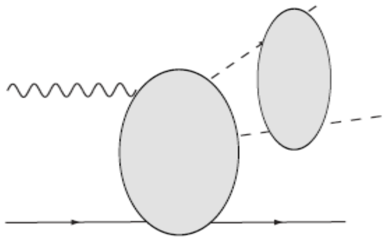
2) Parametrize partial waves in term of known ππ phase shift and unknown coefficients using Dispersion Relations

3) Derive partial wave cross sections to compare with models

Short range (QCD) production



Meson formation



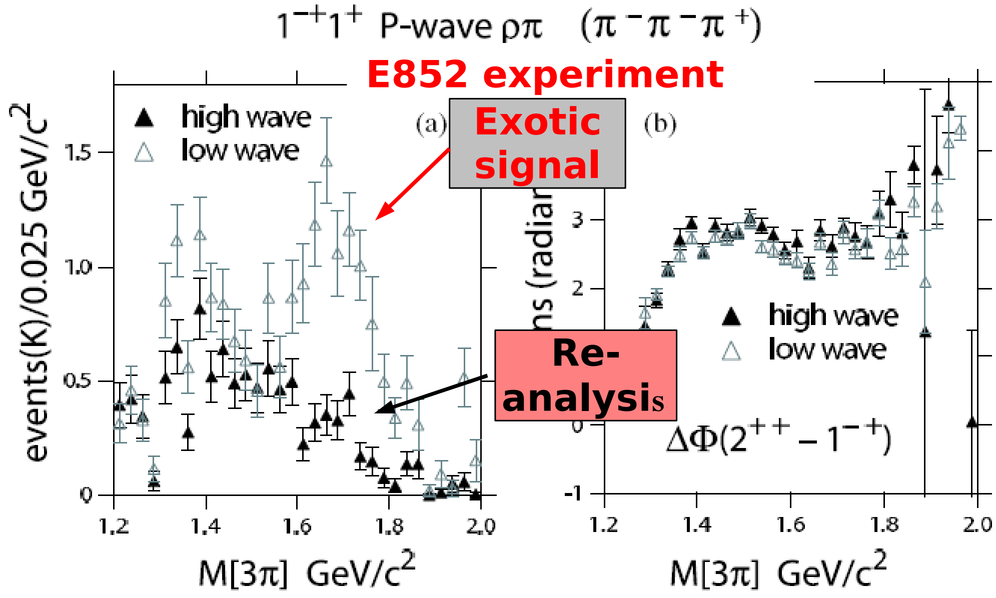
Partial Wave Analysis with CLAS

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**

Simple final state with low background



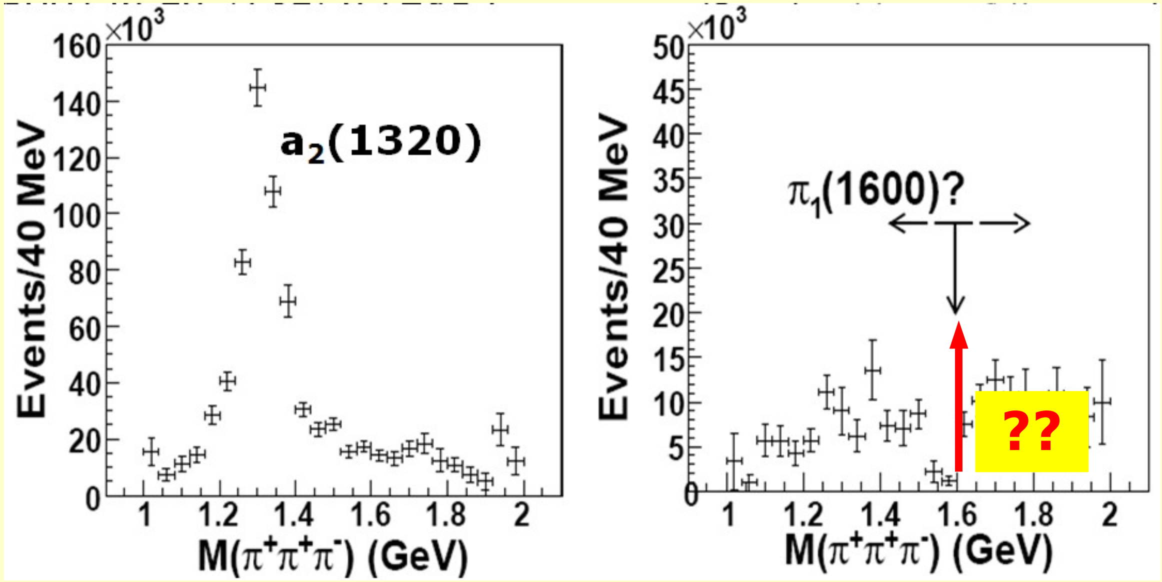
E852 experiment

Exotic signal

Re-analysis

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!

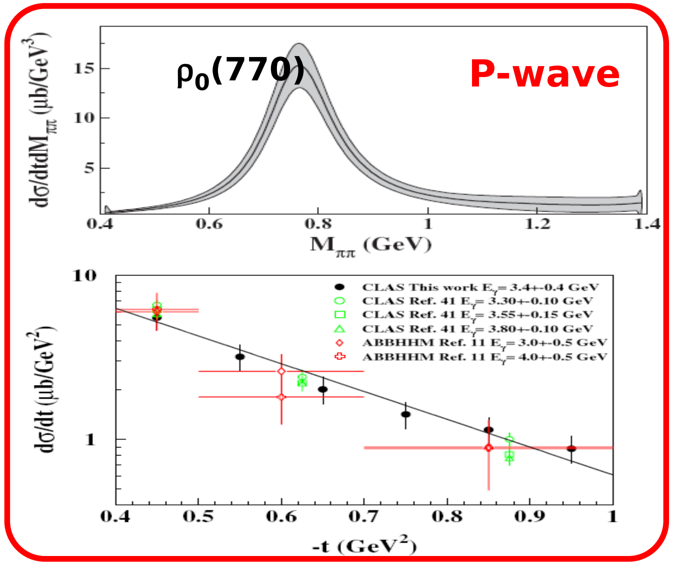
Partial Wave Analysis with CLAS

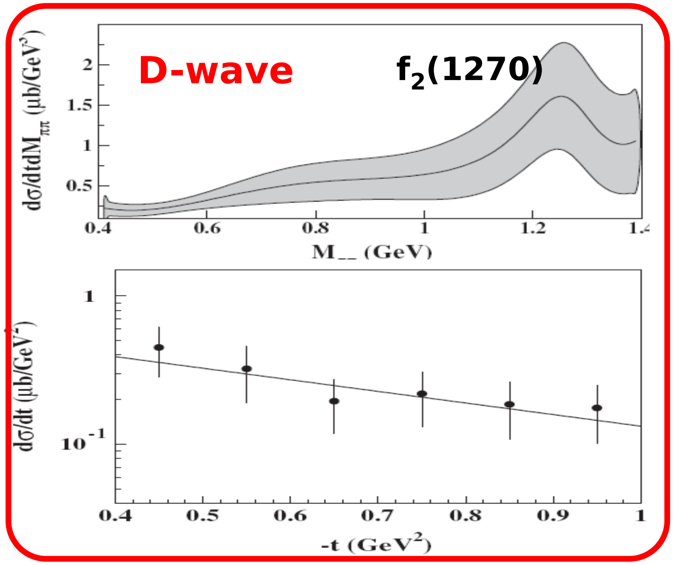
Moments + Dispersion relations

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

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

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

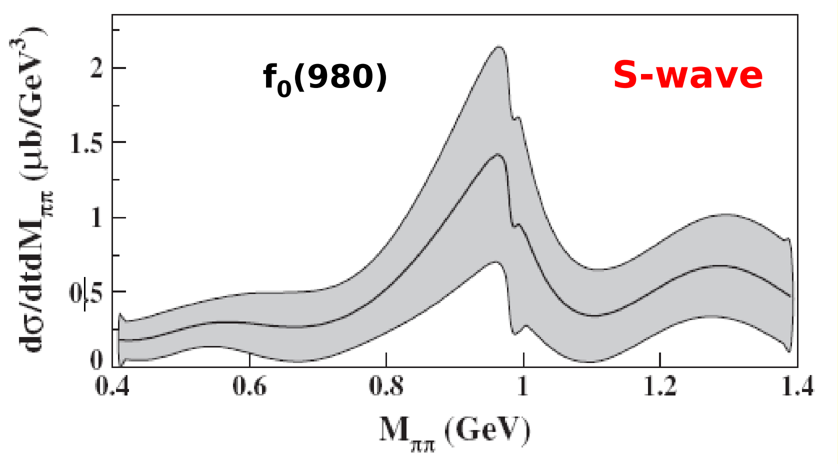




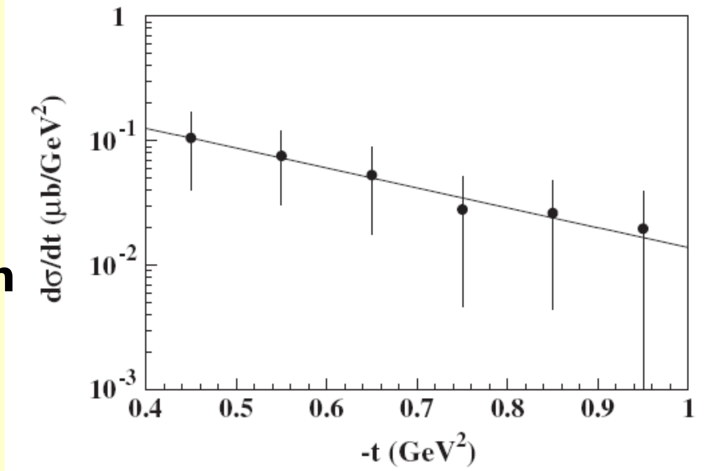
Known states are well reproduced, ρ(770)

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

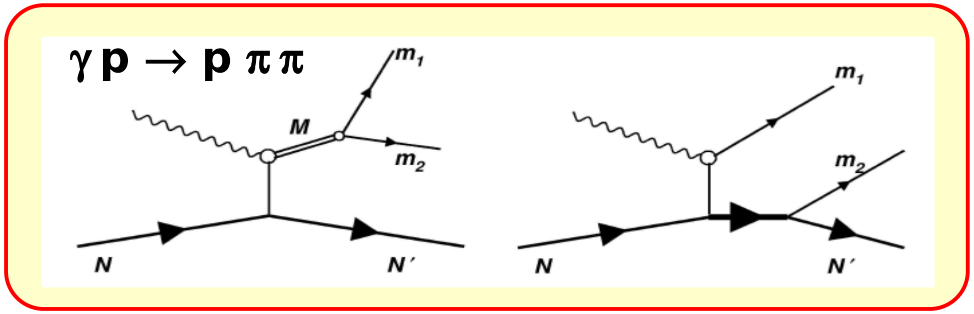


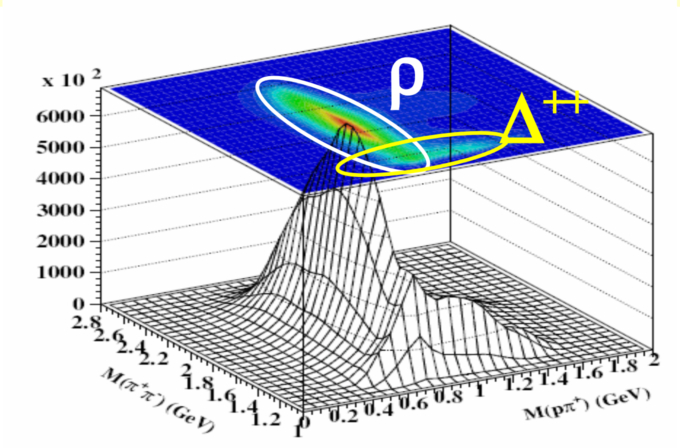
First observation of the $f_0(980)$ in a photoproduction experiment



Coherent meson production on nuclei

- **Eliminate *s-channel* resonance background**





- **Simplify PWA: S=I=0 target acts as spin and parity filter for final state mesons**
- **Production cross section expected ~ $e^{-bt}|A\,F_A(t)|^2 \rightarrow$ low -*t* kinematic**

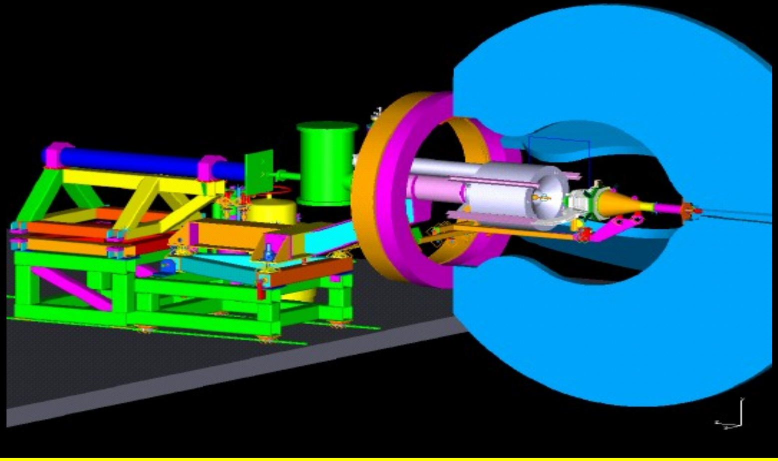
Detection of recoiling nucleus:
- low -*t* (p~0.2-0.5 GeV)
- thin (gas) target (~10^{-3} g/cm^2)

Photon beam:
- small size
- high flux

quasi-real photoproduction Hall-B

- Radial TPC with 7atm. He4 Target
- Solenoid for forward -focusing of Moeller electrons and bending of recoil nucleus in the TPC
- PbWO4 calorimeter for improved photon acceptance at forward angles

EG6: Meson spectroscopy in coherent ^{4}He photoproduction



The detector: CLAS12

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

Hermetic charged/neutral particles detector

Forward Detector

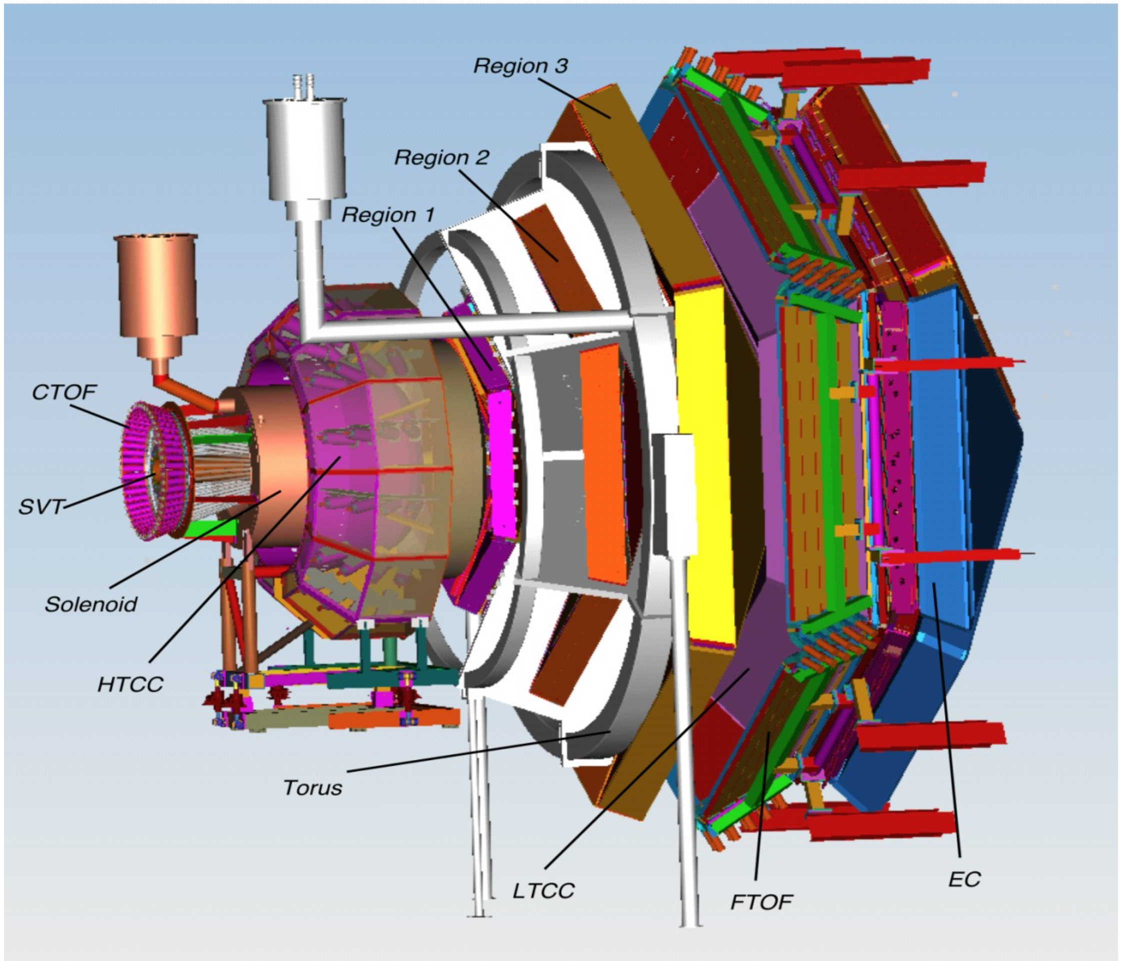
- ✭ TORUS Magnet
- ✭ Forward SVT tracker
- ✭ HT Cerenkov Counter
- ✭ LT Cerenkov Counter
- ✭ Forward TOF System
- ✭ Preshower calorimeter
- ✭ E.M. Calorimeter

Central Detector

- ✭ SOLENOID magnet
- ✭ Barrel silicon tracker
- ✭ Central TOF

Proposed updates

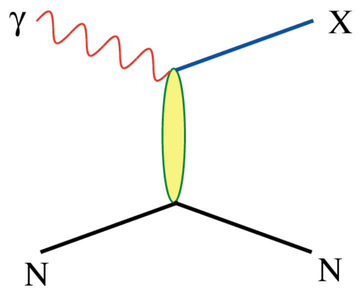
- ✭ Micromegas (CD)
- ✭ Neutron detector (CD)
- ✭ Forward Tagger



Meson spectroscopy with photons at JLab-12GeV

✮ The photon beam requirements

- **High luminosity**
- **Tagger (initial photon energy) is required to add 'production' information to decay**
- **Linear polarization is useful to simplify the PWA and essential to isolate the nature of the t-channel exchange**



✮ **Essential to isolate production mechanisms (M)**

✮ **Polarization acts as a J^{PC} filter if M is known**

✮ **Linear polarization separates natural and unnatural parity exchange**

- **With a 12 GeV electron beam only few choices:**

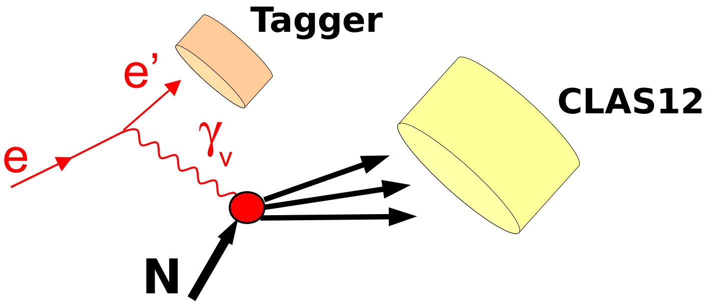
1) Bremsstrahlung

2) Quasi-real electro-production

Hall-D and Hall-B will host real photon beams!

Photoproduction in CLAS12

Quasi-real electroproduction at Low Q^2



- ✭ **Electron scattering at "0" degrees (2° - 5°)**
  low Q2 virtual photon ⇔ real photon
- ✭ **Photon tagged by detecting the scattered electron at low angles**
  High energy photons $7 < E_\gamma < 10.5$ GeV
- ✭ **Quasi-real photons are linearly polarized**
  Polarization ~ 65% - 20% (individual)
- ✭ **High Luminosity (unique opportunity to run thin gas target!)**
  Equivalent photon flux $N_\gamma \sim 5\ 10^7$ on 40cm H_2 ($L=10^{35}$ $cm^{-2}s^{-1}$)

Complementary to Hall-D (GLUEX)
Exploits the unique PID&resolution of CLAS12

Photoproduction in CLAS12

Photon beam requirement

- High Luminosity
- Tagger (initial photon energy) is required to add 'production' information to decay
- Linear polarization simplifies the PWA

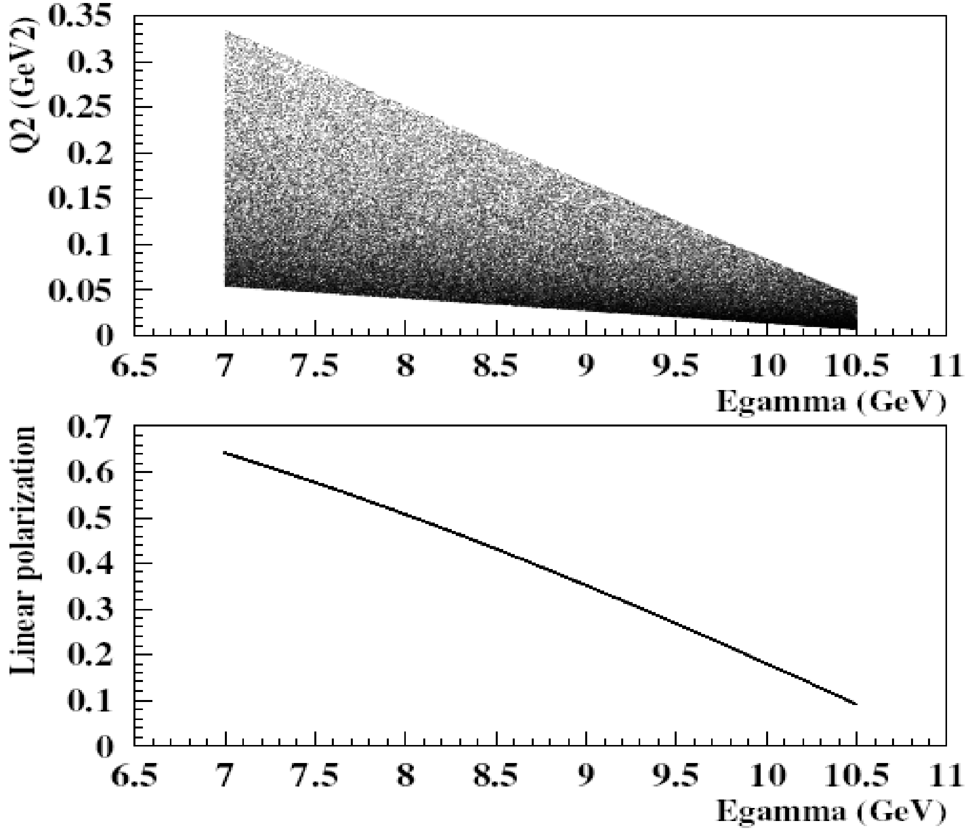
Quasi-real electroproduction at Low Q^2

Electron kinematics:

- E=0.5-4 GeV
- θ=2-5 deg

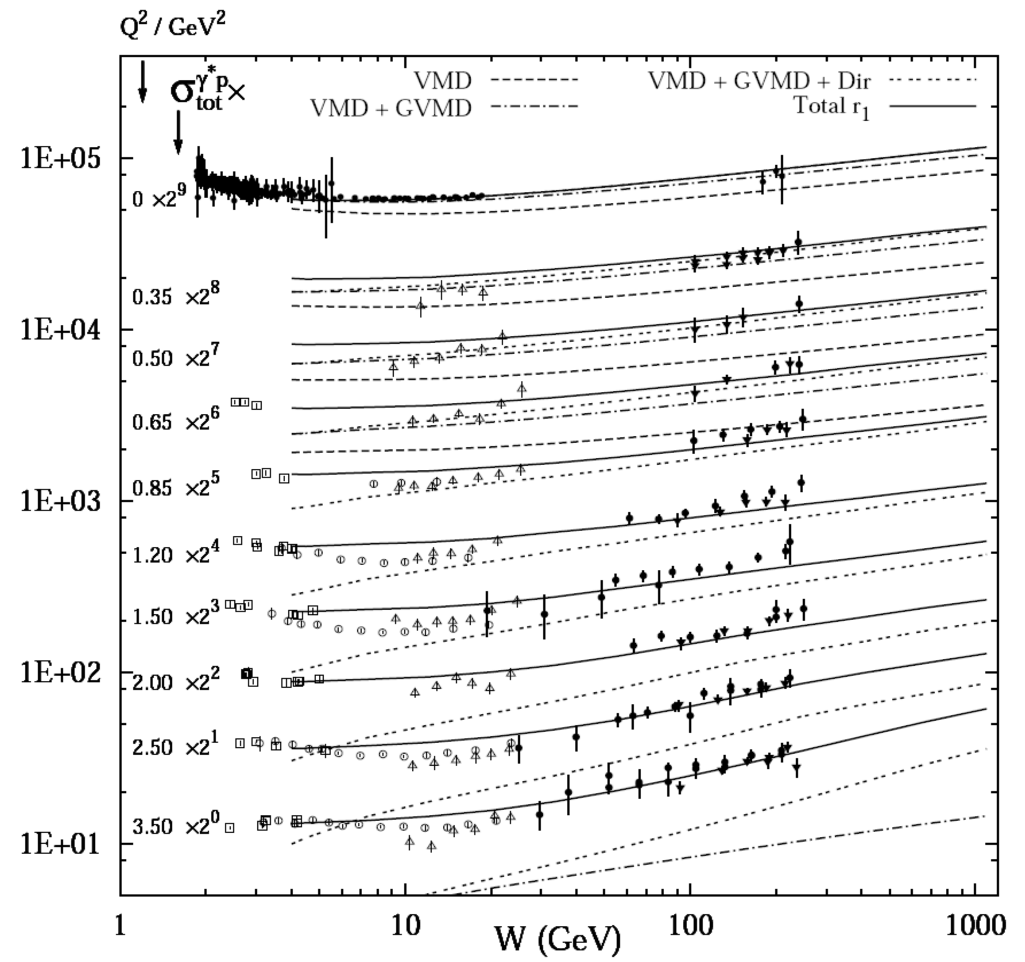
⇓

- Q_2=0.007-0.33 GeV$_2$
- E_g=7-10.5 GeV
- Photon Polarization: 10-65%



Q^2 dependence of the Xsec

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



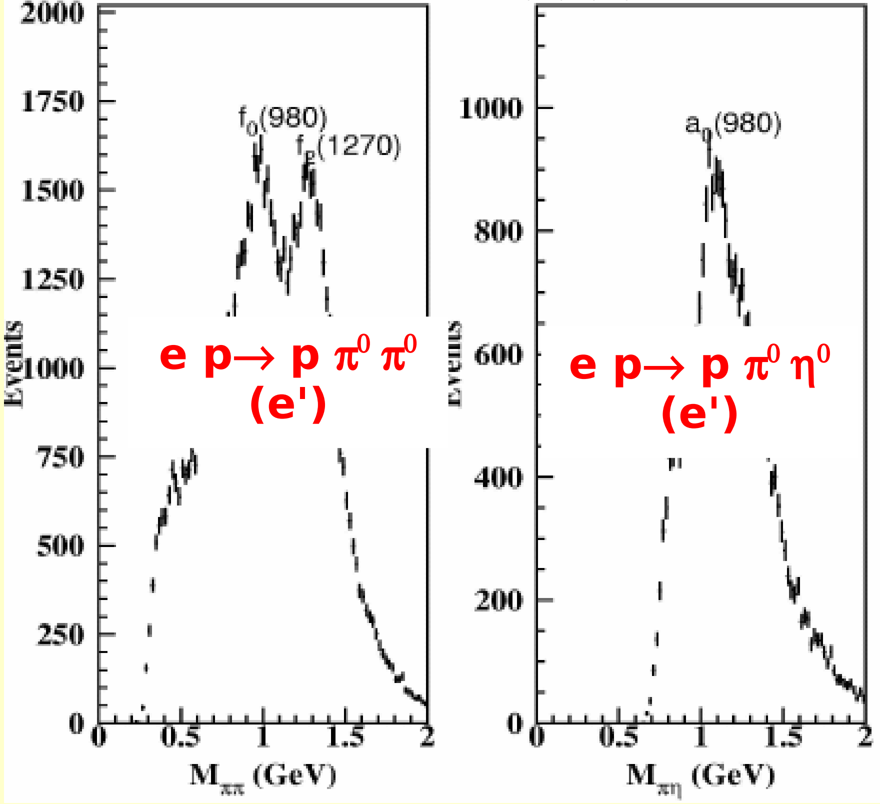
Well known technique used in hep

$Q^2 < W^2$

COMPASS:	**<1 GeV^2**	**$\langle Q^2 \rangle \sim 10^{-1}$ GeV^2**
ZEUS:	**10^{-7} – 0.02 GeV^2**	**$\langle Q^2 \rangle \sim 5\ 10^{-5}$ 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 + tracking device + veto

Electron energy/momentum

Photon energy (ν=E-E')

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

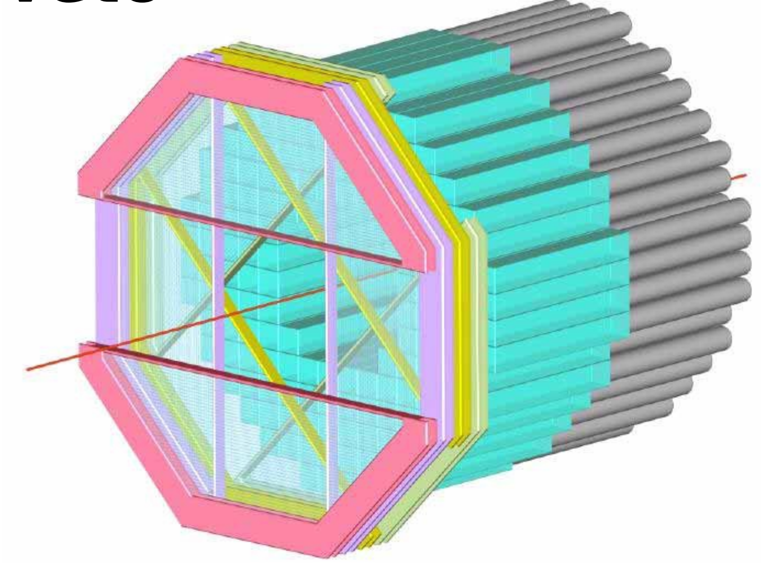
$\delta\nu/\nu = \delta E'/(E-E')$

Electron angles

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

φ polarization plane

Veto for photons

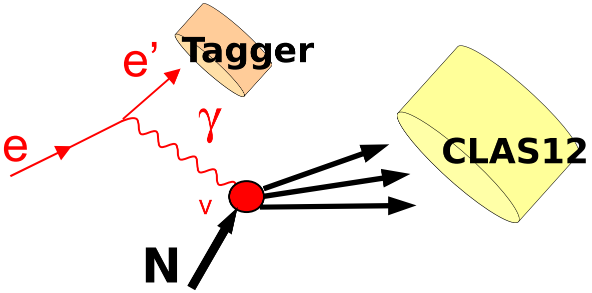


Rates in the forward tagger

$L_e \sim 10^{35}$ cm^{-2} s^{-1} ($N_\gamma \sim 0.5\ 10^8\ \gamma$/s)

Inelastic electro-production

Signal

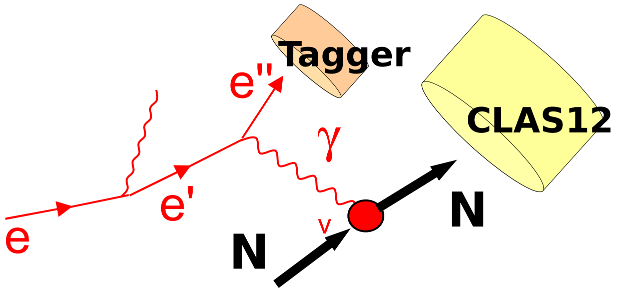


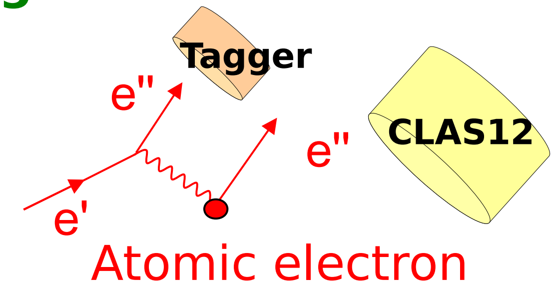
R ~10kHz

Elastic radiative tail

Moeller scattering

Background



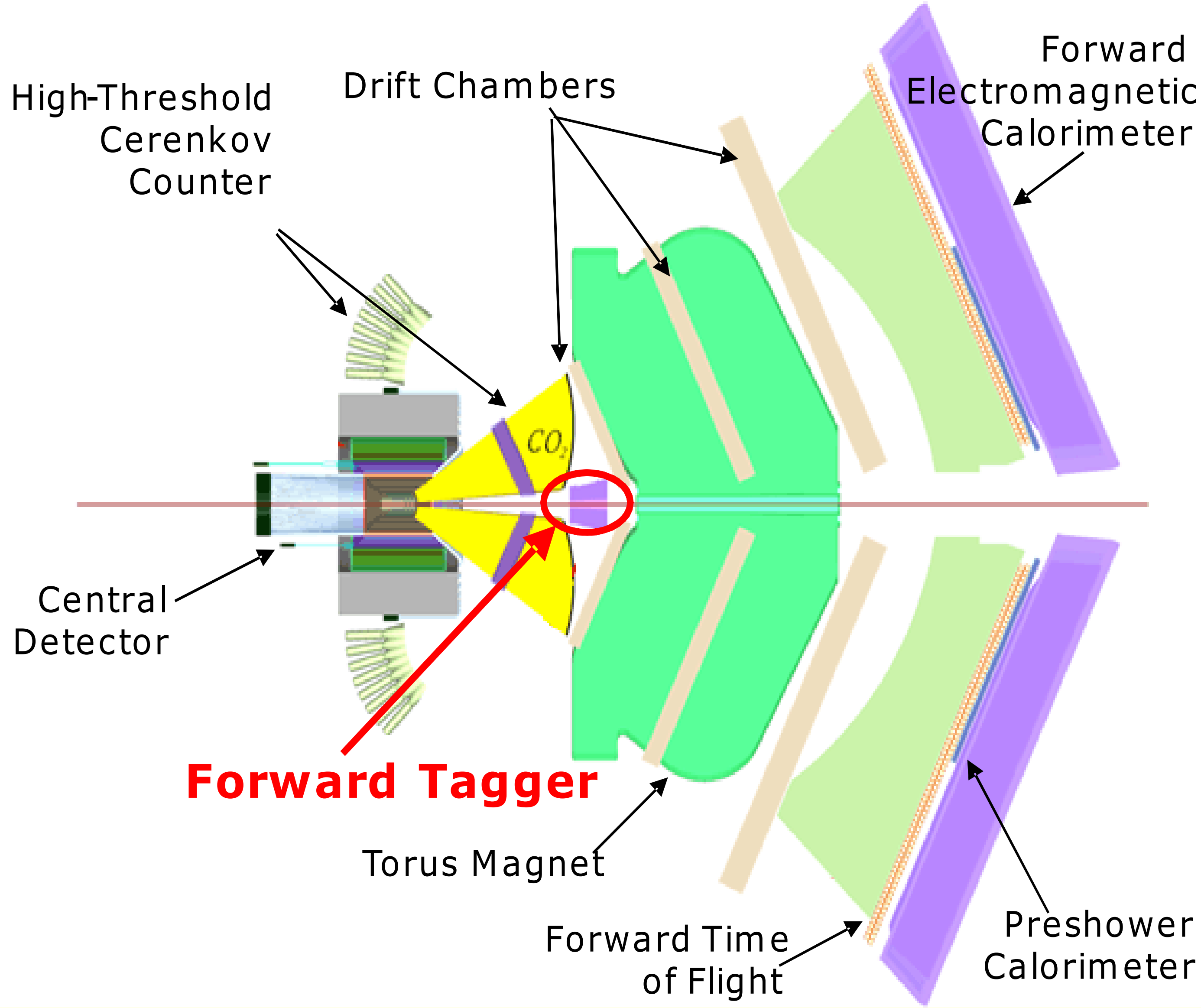


R ~100kHz

R ~10MHz

The Forward Tagger in CLAS12

- ✯ **Compatible with standard electron runs (HTCC)**
- ✯ **Photon detector for leading DVCS experiments**
- ✯ **Extend the CLAS12 coverage for neutral from 5^o to 2^o**



photons and electrons can run in parallel!

Calorimeter options

- Radiation hardness
- light yield (cooling?)
- timing

- temperature dependence
- Magnetic field effect
- light read-out (APD/SiPM)

- **Homogeneous (crystals)**

EM shower: ionization energy of charged particles (electrons)

Longitudinal size:

Radiation lenght X_0 (e loses 1-1/e E)

~ 180 A/Z^2 (gr/cm^2)

Transverse size:

Moliere Radius R_M (90% of shower)

~ 7 A/Z (gr/cm^2)

- **PbWO**
  Fast, rad hard, few light, well known

- **LSO/LYSO**
  Quite fast (8x), more light (100x)
  poorly known

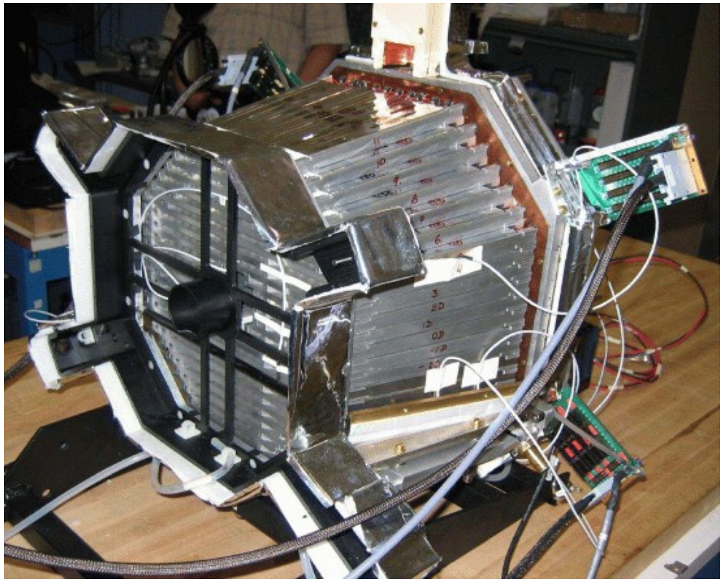
- **LaBr**
  Fast, a lot of light (600x), expensive

PbWO4

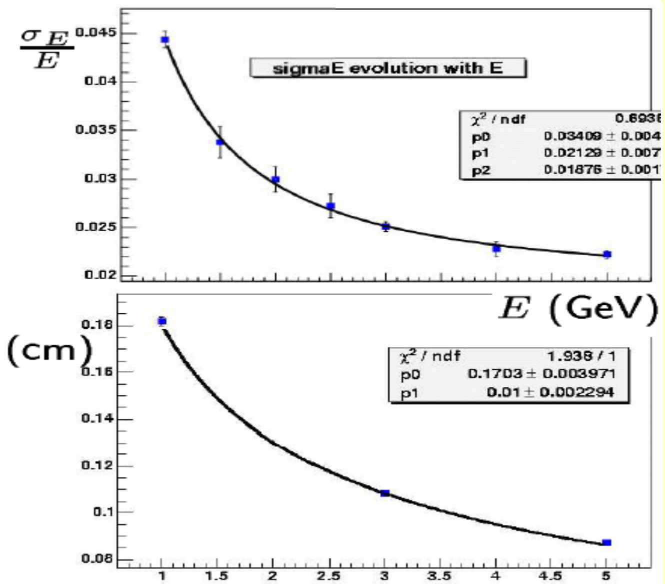
τ_{Decay} ~ 6.5 ns
R_M ~ 2.1 cm
ρ ~ 8.3 g/cm^3
X_0 ~ 0.9 cm
light yield 0.3% (LY NaI(Tl))

CMS(LHC)	ECAL
ALICE (LHC)	PHOS
CLAS (JLab)	IC
PANDA (GSI)	EMC

CLAS Inner Calorimeter



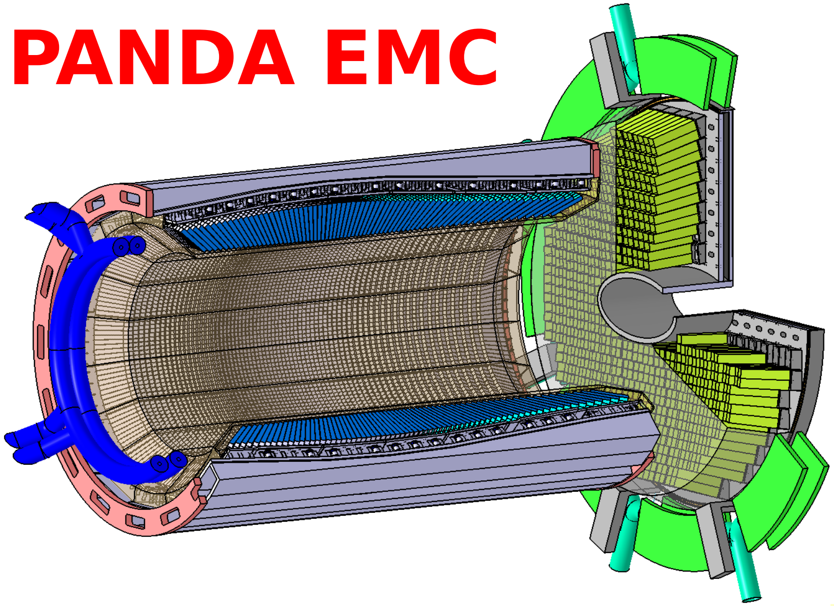
- 424 PbWO4 crystals
- L = 16 cm = 17 X_0
- Front size 1.3x1.3 cm^2
- Back size 1.6x1.6 cm^2
- Controlled Temperature (0.1 ^{0}C)
- APD readout



$$\frac{\sigma_E}{E} = \frac{0.02}{E} \oplus \frac{0.03}{\sqrt{E}} \oplus 0.024$$

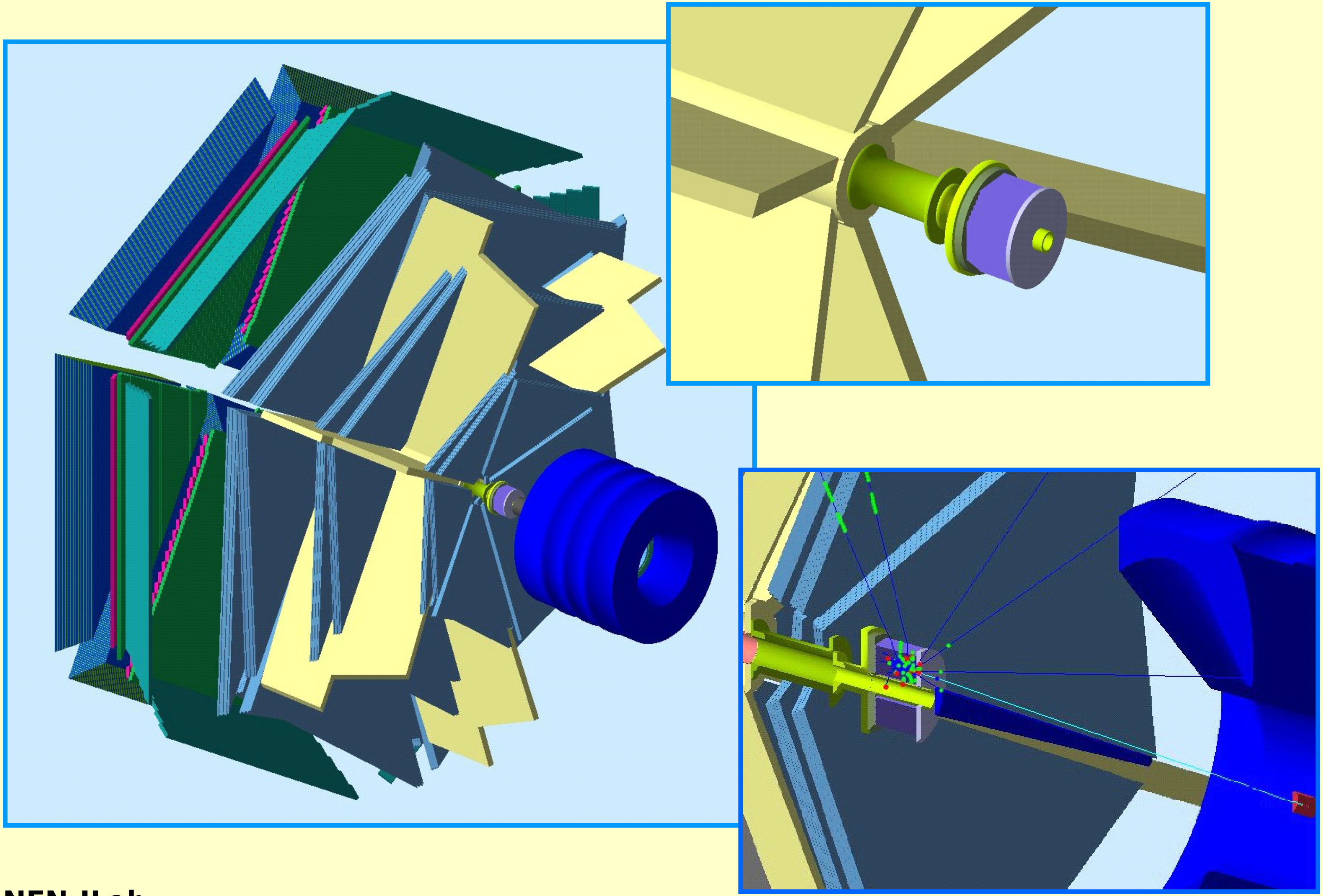
$$\sigma_x = \frac{0.2}{\sqrt{E}} \ (\mathrm{cm})$$

PANDA EMC



- 16k PbWO-II crystals
- Size = 2 x 2 x 20 cm3 (23 X_0)
- LY = 20 phe/MeV
  (80 phe/MeV @ -25^{0}C)
- APD readout
- Resolution (2/√E ⊕ 1)%

GEANT4 Simulations



INFN-JLab

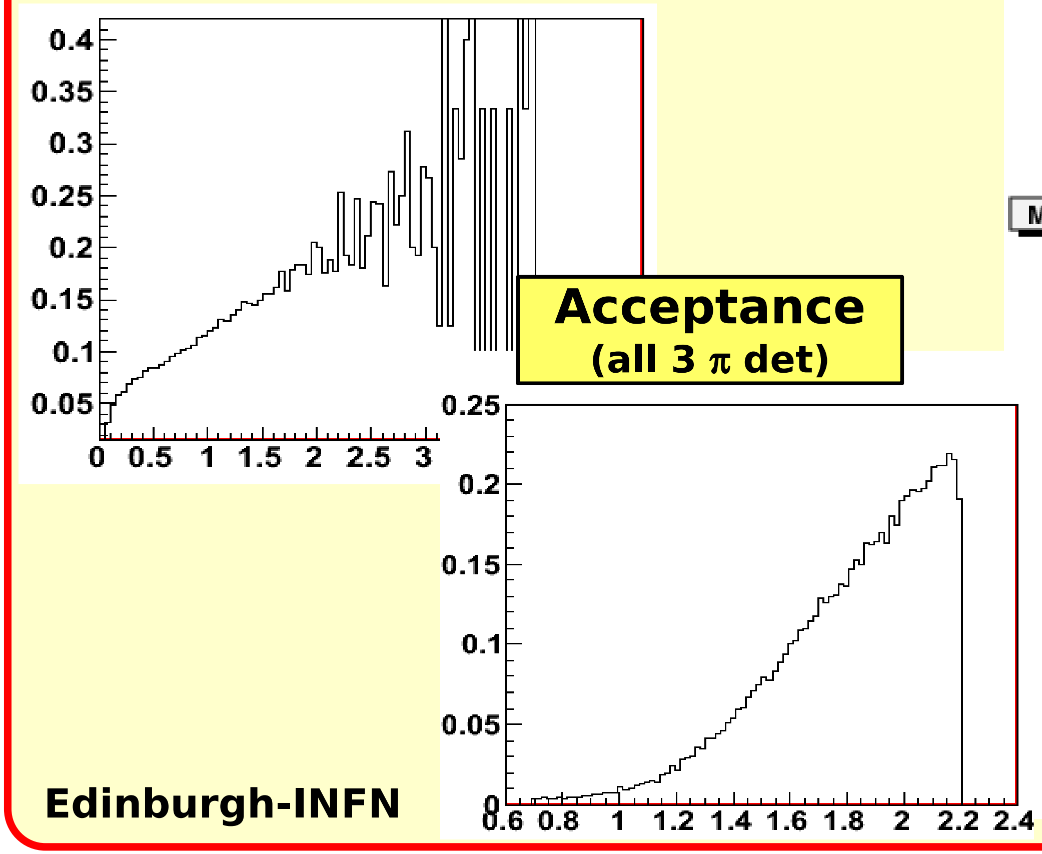
Physics channels simulation

Acceptance and resolution studies

- Determine CLAS12 acceptance
- Determine resolution for exclusive channel selection and mass reconstruction

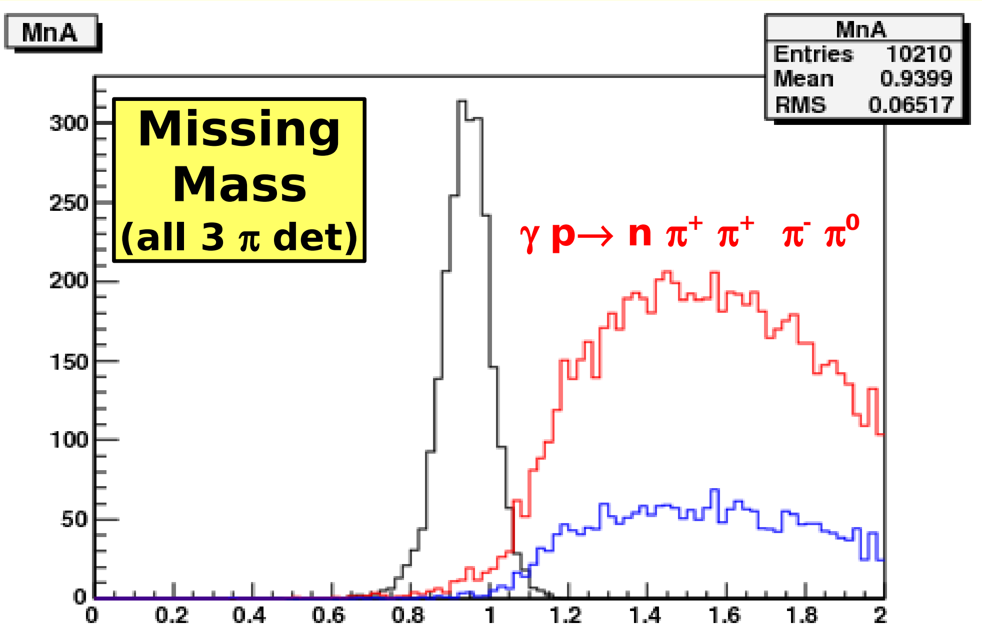
$\gamma\, p \rightarrow n$ Res (M=1.6 GeV, Γ=150 MeV)

$\rightarrow n\, \pi^{+}\, \pi^{+}\, \pi^{-}$



Acceptance
(all 3 π det)

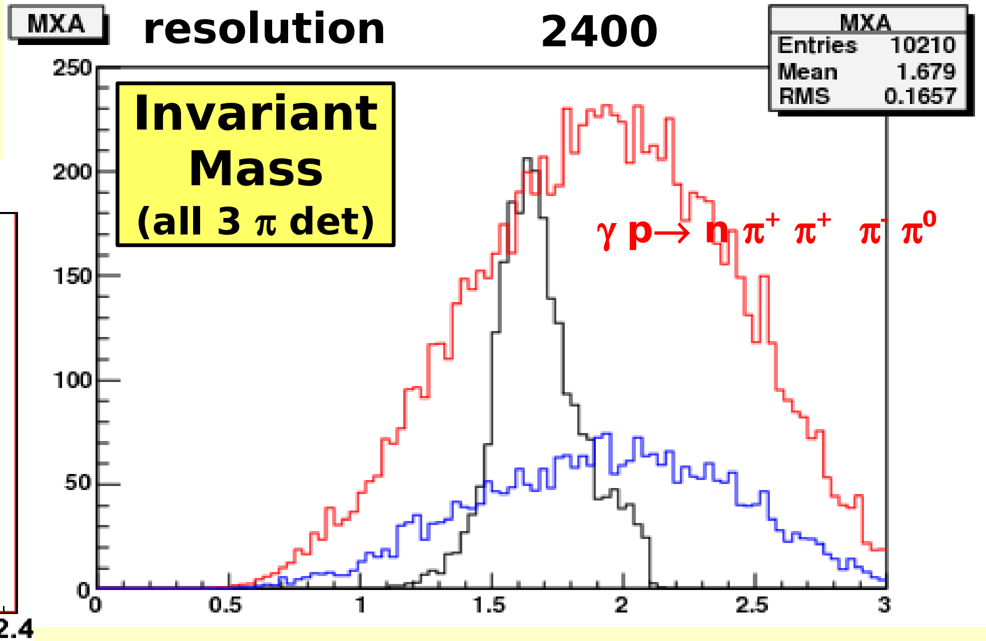
Edinburgh-INFN



Missing Mass
(all 3 π det)

CLAS IC resolution

Torus field 2400



Invariant Mass
(all 3 π det)

Partial Wave Analysis

IU-Edinburgh-INFN-JLab

Benchmark channel:

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

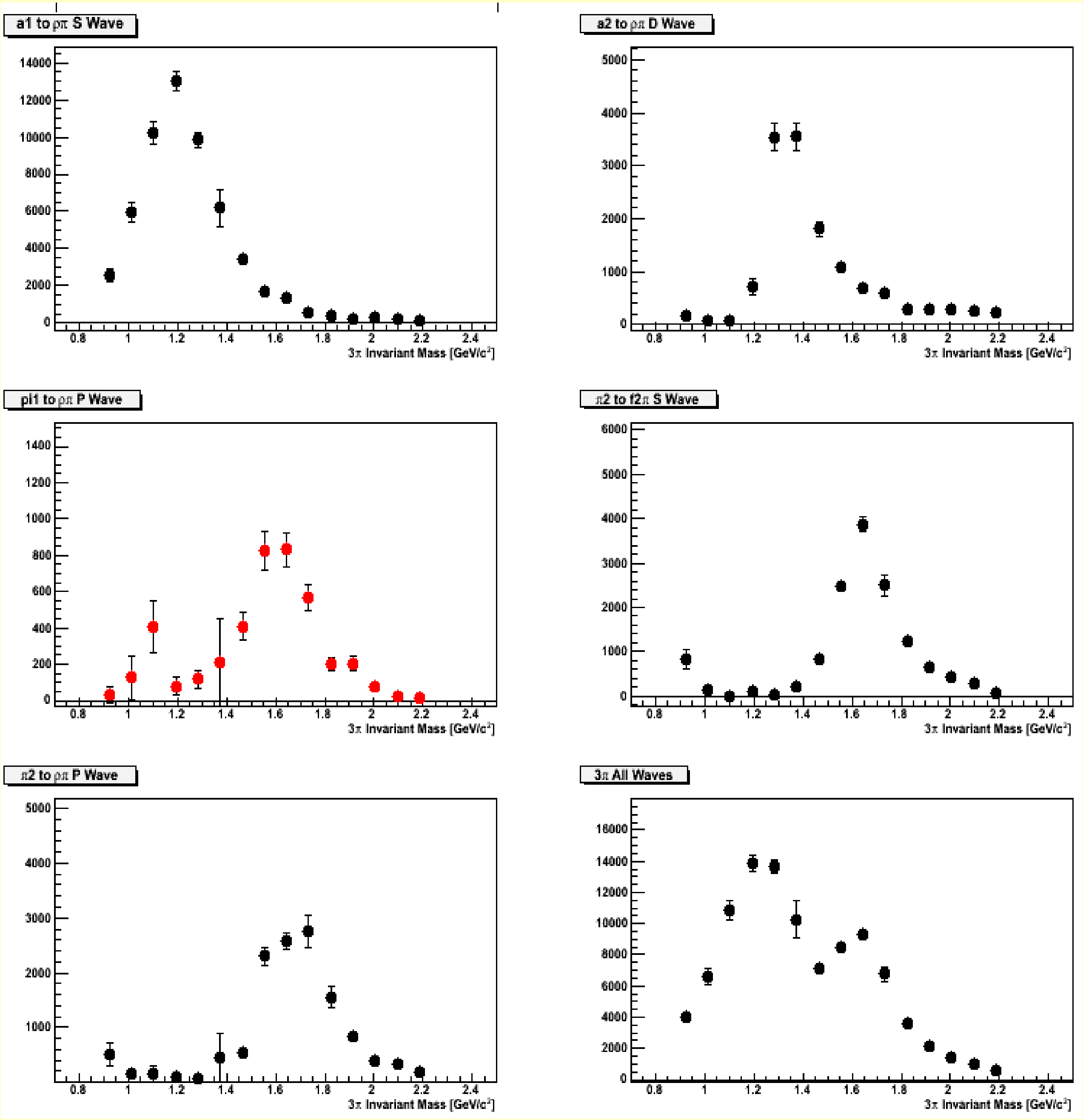
★ **The process is described as sum of 8 isobar channels:**

- **a2 → ρ π (D-wave)**
- **a1 → ρ π (S-wave)**
- **a2 → ρ π (D-wave)**
- **pi2 → ρ π (P-wave)**
- **pi2 → ρ π (F-wave)**
- **pi2 → f2 π(S-wave)**
- **pi2 → f2 π (D-wave)**
- **pi1 → ρ π (P-wave) (exotic)**

★ **Amplitudes calculated by A.Szczepaniak**

★ **CLAS12 acceptance projected and fitted**

PWA in CLAS12 is feasible !



Partial Wave Analysis

- **The development of robust PWA techniques is a crucial step for the succesful completion of any meson spectroscopy program**

- **Advancements in detectors, beam and experimental techniques are leading to a high precision and high statistics data sets**

Are the prently available PWA tools adequate for the new data that are and will be produced?

Workshop on Hadron Spectroscopy
INT - Seattle, November 9-13 2009
Organizers: M. Battaglieri, C. Munoz Camacho, RDV, J. Miller, A.P. Szczepaniak

- **~ 40 participants from the theoretical and experimental community**
- **address open issues in experimental techniques, pwa, and theoretical interpretation**
- **interest from the theory community to work with experimentalists to develop more sophisticated analysis approaches, going beyond the isobar model**
- **white paper being written**

Next meeting:

Workshop on Amplitude Analysis in Hadron Spectroscopy
ECT* - Trento, January 24-28 2011
Organizers: C. Hanhart, M. Pennington, E. Santopinto,
A.P. Szczepaniak (coordinator), U. Wiedner

Conclusions

Search for exotica in photoproduction experiments at CLAS12

- ✯ Jefferson Lab is providing new, precise and abundant data on hadron spectroscopy
- ✯ CLAS runs (up to 6 GeV) show real photon beams can be effectivly used to search for exotic particles
- ✯ PWA has been succesfully applied to meson photoproduction in CLAS
- ✯ We are proposing an extention of this program to CLAS12
- ✯ Low Q2 electroproduction is a complementary technique to the Hall-D coherent Bremsstrahlung
- ✯ Dedicated detectors and high intensity photon beams at JLab-12 are under construction, ready to run in a near future!