The Meson Spectroscopy Program at Jefferson Laboratory

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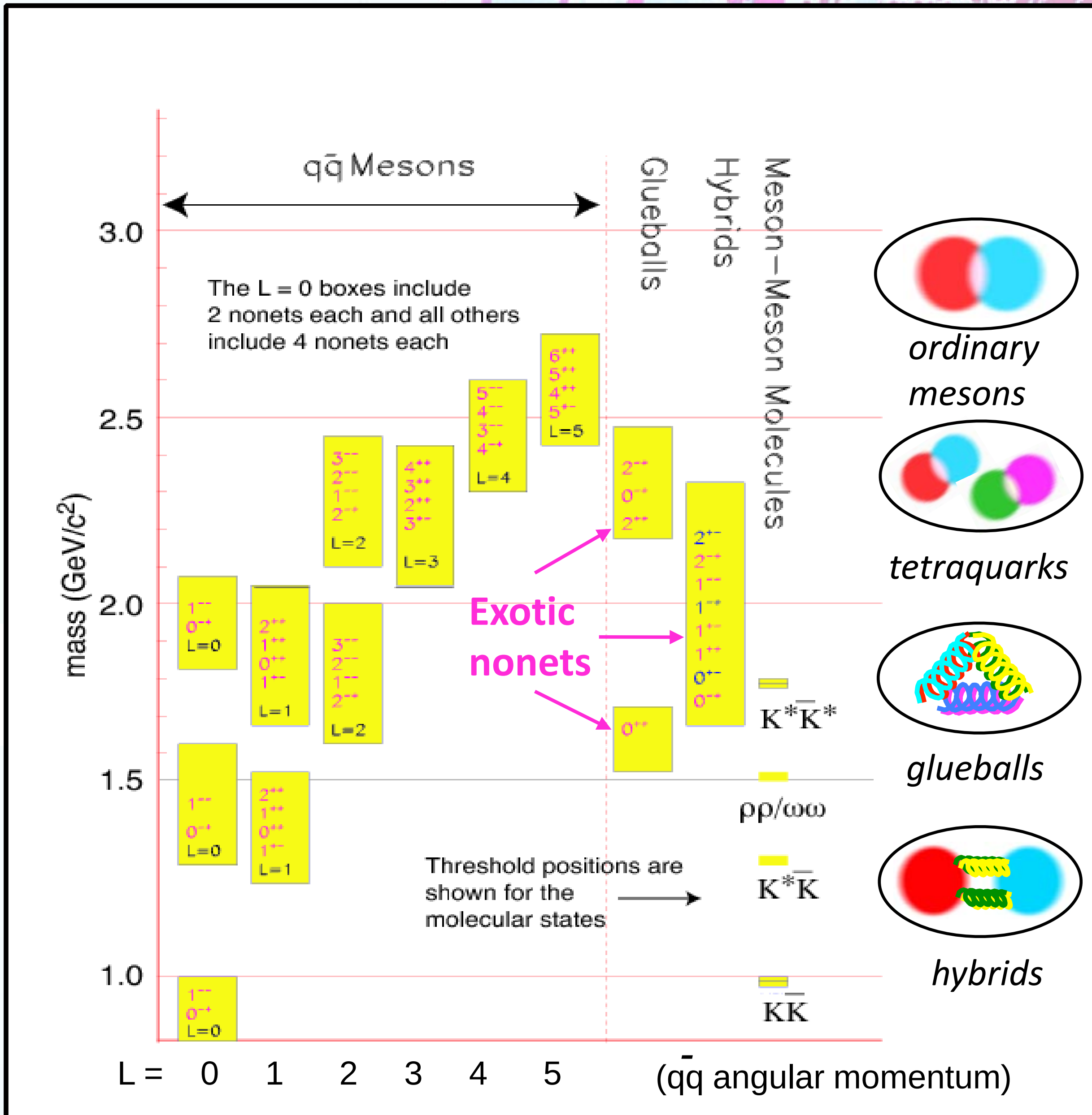
Outline of the talk

- Hadron spectroscopy: the light meson spectrum
- Meson spectroscopy with photons at JLAB-12 GeV
  - GlueX vs CLAS12
  - Real vs quasi-real photoproduction
- The Meson-EX experiment @CLAS12: the experimental setup
- Data analysis
  - PWA
  - test of performances and feasibility with CLAS12
  - … and beyond: towards a common and integrated framework
- Conclusions

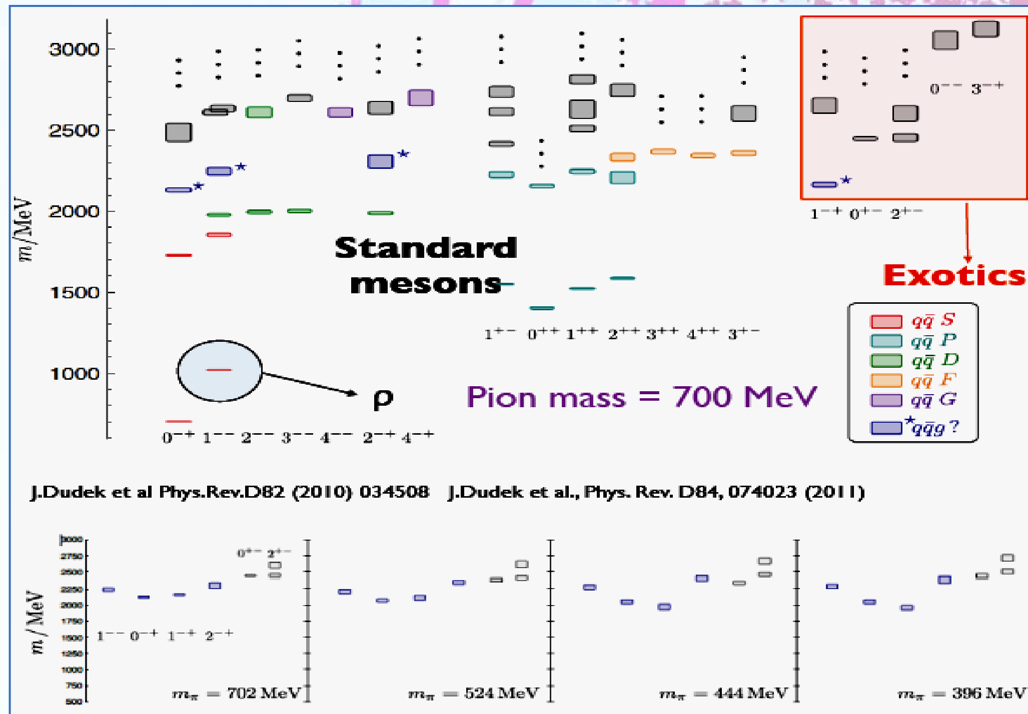
The meson spectrum + gluons: exotics

- The meson spectrum bears also the information about gluons, which bind quarks
- Which is the expected signature of gluonic degrees of freedom ?
  - Observation of extra states possibly with quantum numbers not allowed by CQM
- New states with gluonic content:
  - **Glueballs (ggg)**
  - **Hybrids ($q\bar{q}g$)**
  - **Multiquark/molecular states**
    - **EXOTICS**

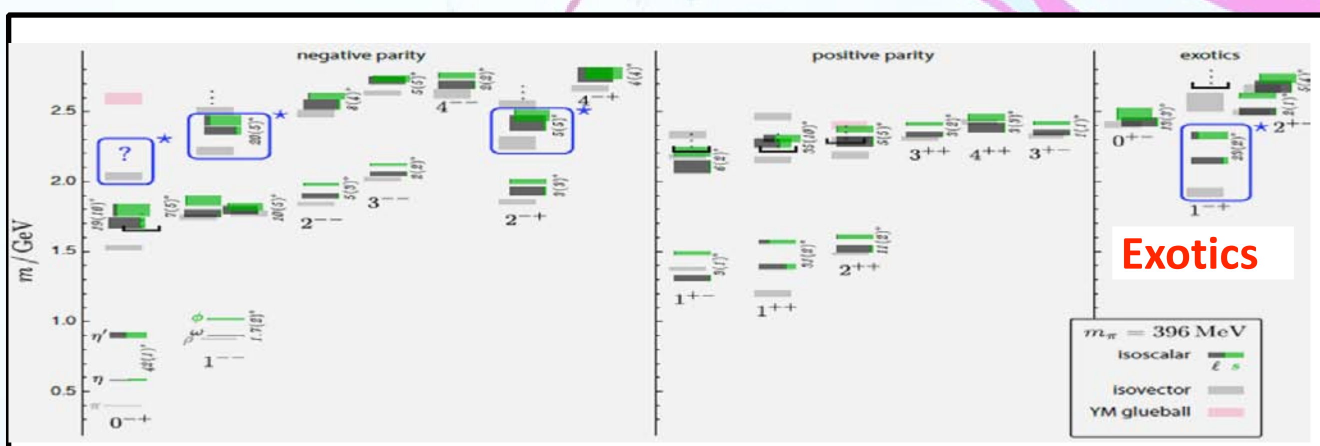


Lattice QCD calculations: mesons and hybrids

- Unquenched calculations with two light flavors + heavier 3rd quark (strange)
- **Good agreement between lattice computations and experimental data for conventional states**
  - Number of states
  - Mass hierarchy
- Predictive power to lead the search of new states



- LQCD predicts the **lightest hybrids and glueballs in the 1.4-3.GeV range**:
  - 0^{+-} : 2 GeV
  - 1^{-+} : 1.6 GeV
- Mass range perfectly accessible by experiments at JLAB

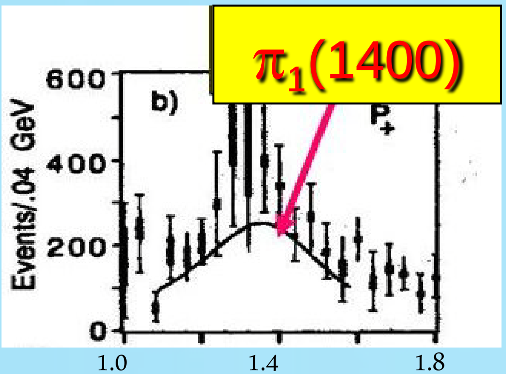


Observations of 1^{-+} states by BNL-E852 and CRYSTAL BARREL: $\pi_1(1400)$ and $\pi_1(1600)$

E852: Systematic study of the reactions

$\pi^- p \to \pi^- \eta p$ and

$\pi^- p \to \pi^0 \eta n$ @ 18 GeV/c

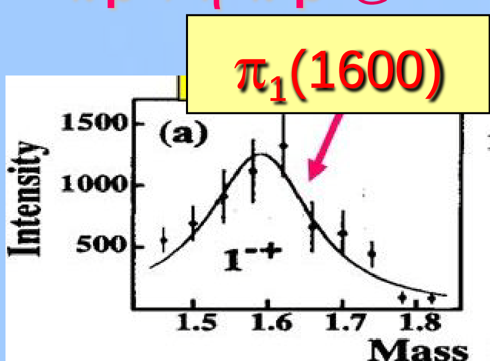


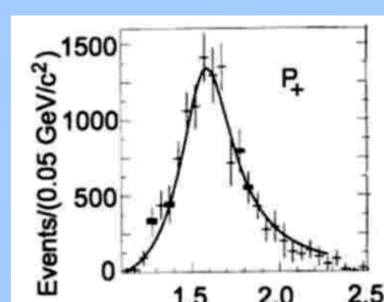
Confirmed by VES @ 37 GeV

State reported in $\eta'\pi$ and $\rho\pi$ channels

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

$\pi^- p \to \eta' \pi^- p$ @ 18 GeV/c





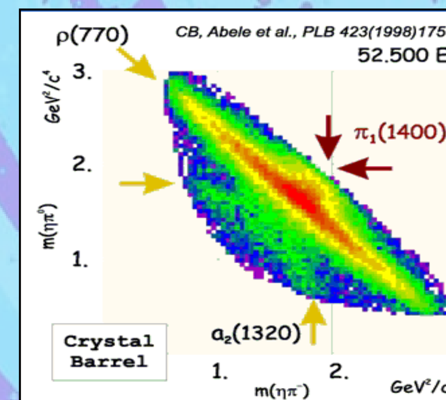
CRYSTAL BARREL: study of pp annihilations *at rest*

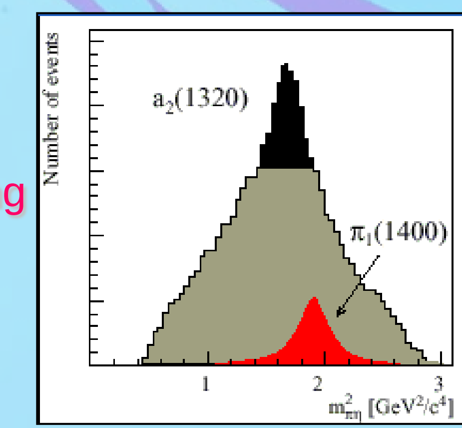
$\bar{p}n \to \pi^- \pi^0 \eta$

$\bar{p}p \to \pi^0 \pi^0 \eta$

The decays of σ and ρ into $\pi\pi$ and of $a_2(1320)$ into $\eta\pi$ do not describe the data correctly enough

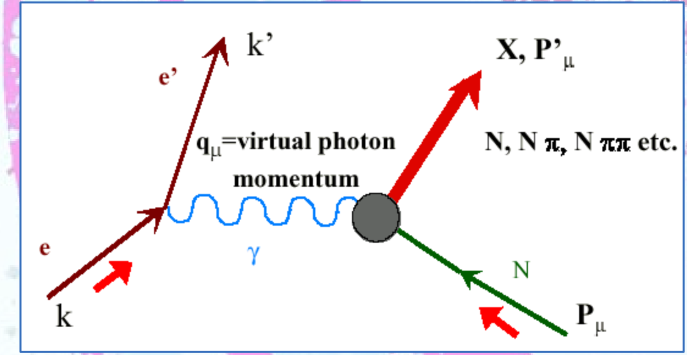
- The presence of a $\pi_1(1400)$ meson decaying into $\eta\pi$, is needed





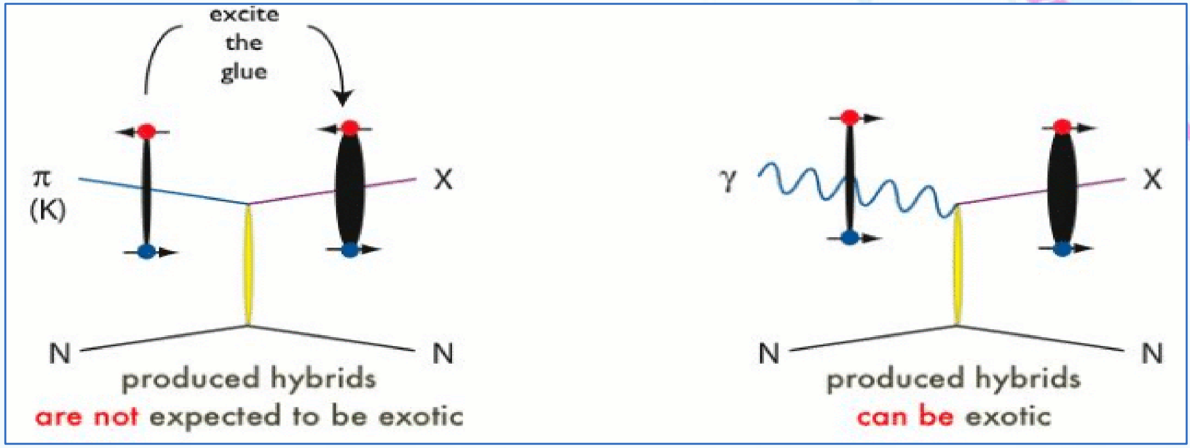
Meson spectroscopy with electromagnetic probes

- The electromagnetic interaction is weaker than the strong one and can be calculated perturbatively with high precision (based on well-known QED)
  - Scattering: one-photon exchange approximation



- Meson photoproduction: **high probability of spin-1 meson production from photons**

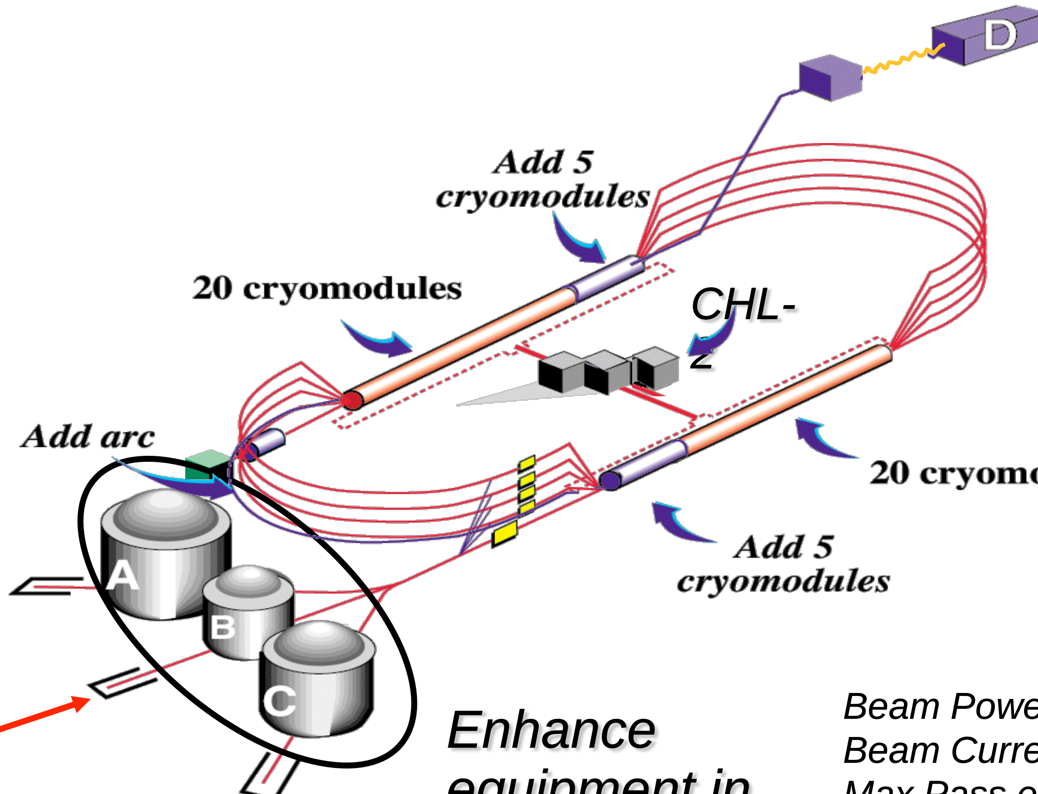
π (K)N:
Need spin-flip for exotic quantum number

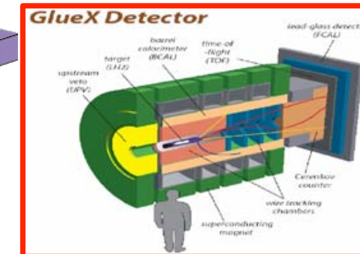


γN:
No spin-flip for exotic quantum number

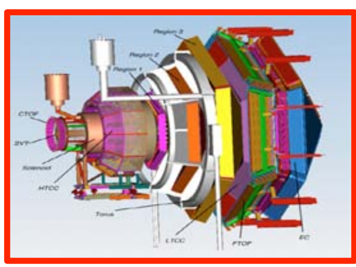
- Expected production rate for exotics and conventional mesons: comparable

CEBAF @12 GeV: the new electron machine at JLAB





GlueX



CLAS12

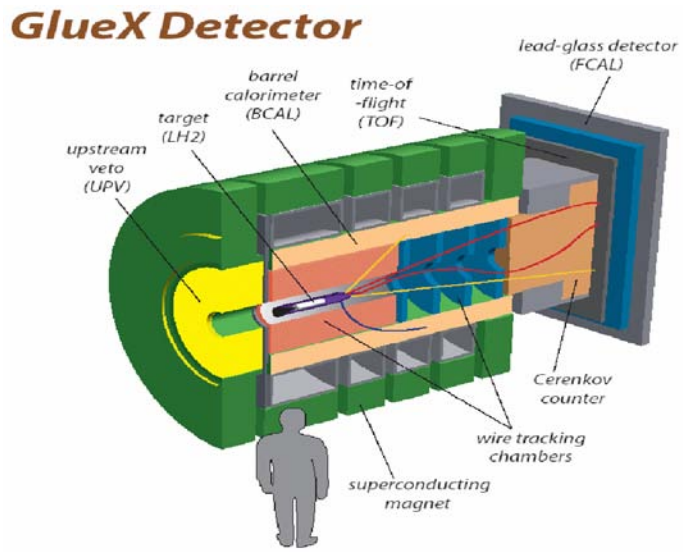
Enhance equipment in existing halls

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

JLAB experiments for meson spectroscopy in photoproduction

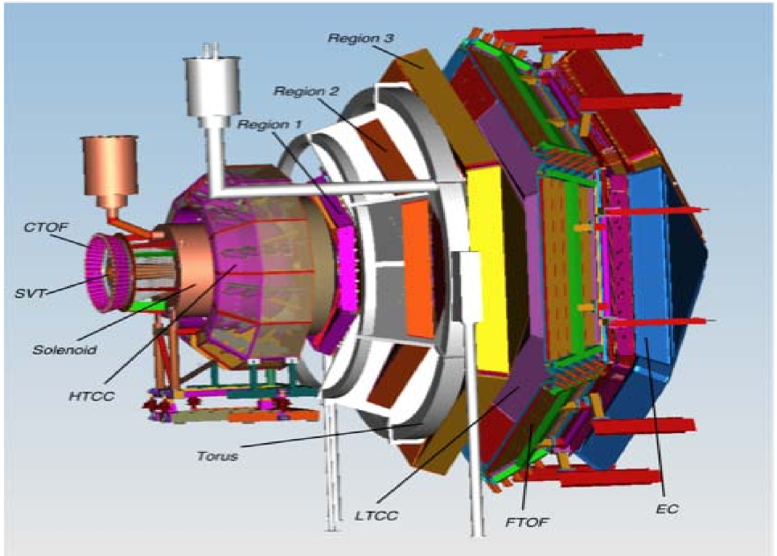
- Able to measure exclusively the production reactions and the decays of the emitted particles
- Requirements:
  - Good acceptance, momentum resolution, particle id capabilities

Hall-D - GlueX Detector



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

Hall-B - CLAS12 Detector



- Good resolution
- Good pID
- Resonable hermeticity
- NON-Uniform acceptance

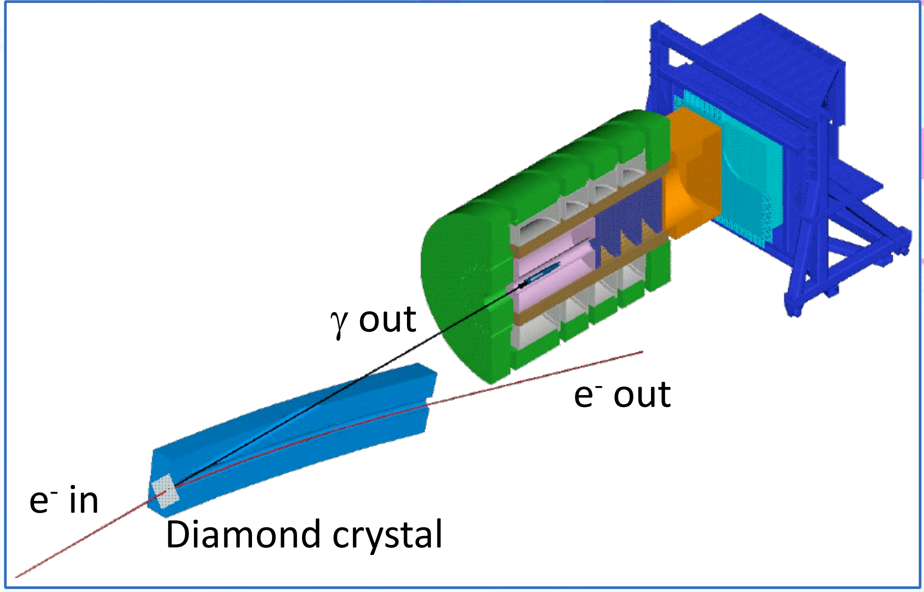
Photon beams at JLAB-12 GeV

- **Photon beam requirements**
  - High luminosity
  - Production information: photon tagging
  - Linear polarization if possible (to simplify PWA's and isolate the nature of t-channel exchange)

- Only few choices available with 12 GeV e^- beam
  - **Coherent tagged bremsstrahlung** (Hall-D – GlueX)
  - **Low-Q^2 electroproduction** (Hall-B – CLAS12)

Bremsstrahlung:
consolidated technique in Hall-B
@ 6 GeV for polarized photon beam

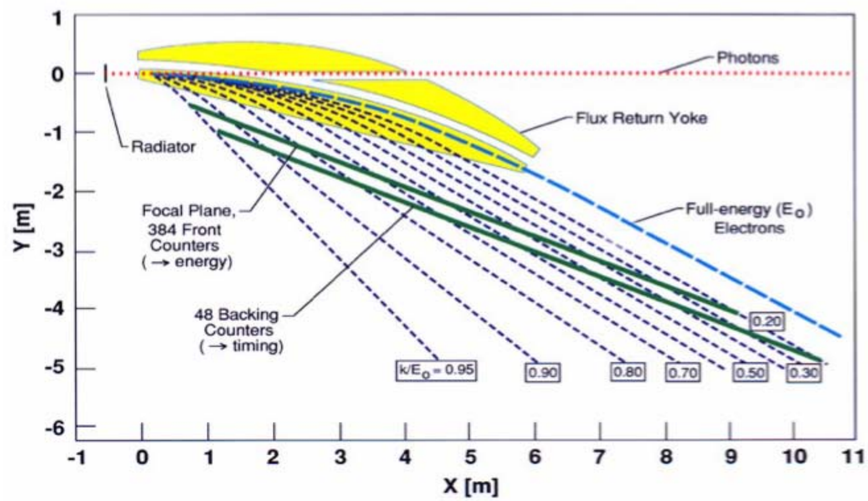
- E_γ= 6-9 GeV, 10 MeV resolution
- γ flux: 10^7-10^8 γ/s
- L ~ 10^{31} $cm^{-2}s^{-1}$ on a 30 cm LH_2 tgt
- linear polarization: 50%-15% (collective)

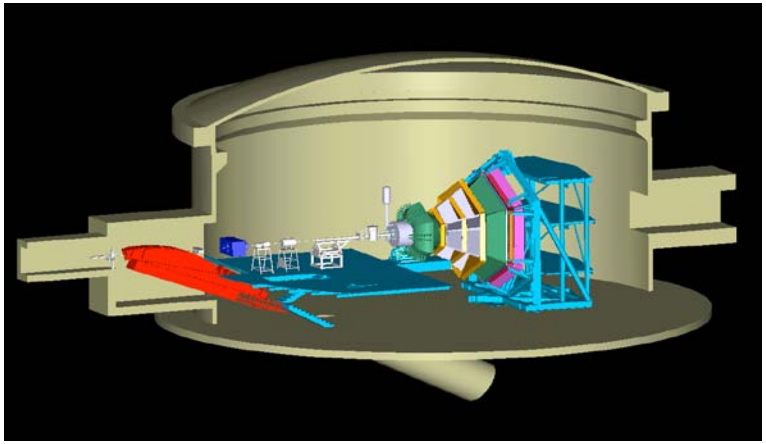


Photon production in Hall B

- The existing dipole magnet in Hall-B cannot deflect the 11 GeV electron beam on the beam dump

The Hall-B real photon tagger



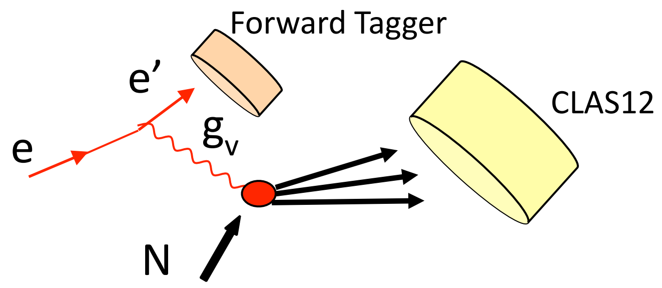


- New technique: quasi-real photoproduction at low Q^2
  - CLAS12 to be equipped with a tagging facility for the detection of the electron emitted at very small angles (2.5^o-4.5^o) and $Q^2 \sim 10^{-2}$ GeV^2 or lower (+hadronic final state measured in coincidence)

The Meson-Ex experiment @CLAS (Exp-11-005)

- Study of the meson spectrum in the 1-3 GeV mass range to identify gluonic excitation of mesons (hybrids) and other quark configurations beyond CQM
  - **Hybrid mesons and exotics**
    - Different final states
    - Charged and neutral decay modes
    - **$\gamma p \rightarrow n3\pi$, $\gamma p \rightarrow p\eta\pi$, …**
  - **Hybrids/exotics with hidden strangeness or strangeonia**
    - s quarks: links between long/short distance QCD potential
    - Requirements: good resolution and Kaon p.id.
    - **$\gamma p \rightarrow p\pi\varphi$, $\gamma p \rightarrow p\eta\varphi$, $\gamma p \rightarrow p2K\pi$, …**
  - **Scalar mesons**
    - f_0 and a_0 mesons in the 1-2 GeV mass range still poorly known
    - Theoretical indications for unconventional configurations ($\bar{q}\bar{q}qq$ or gg)
    - **$\gamma p \rightarrow p2\pi$, $\gamma p \rightarrow p2K$**

Low Q^2 quasi-real photoproduction



$E_{scattered}$	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

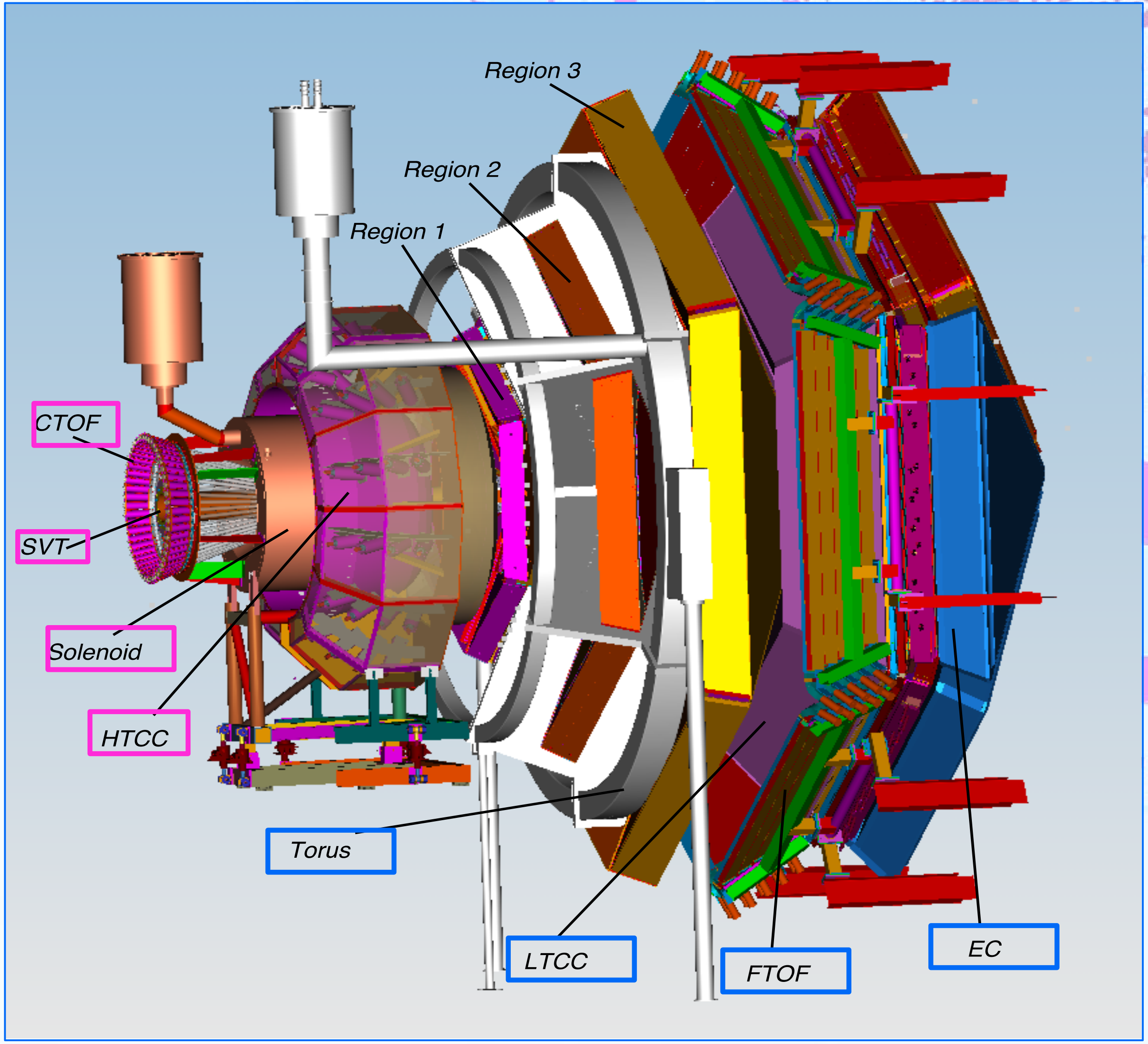
- Electron scattering at "0" deg (2.5°-4.5°)
  - Low Q^2 virtual photon ⇒ quasi real
- Photon tagging: detection of electron at small angles
  - High energy photons: 6.5 - 10.5 GeV
  - To be accomplished by a "Forward Tagger"
- **Quasi real photons: linearly polarized**
  - Polarization: 70%-10%, measured event by event
- High luminosity: $N_\gamma \sim 5\times10^8$, $L \sim 10^{35}\ cm^{-2}s^{-1}$ on 5 cm LH_2 target
  - Thin targets can be used

The CLAS12 Experiment

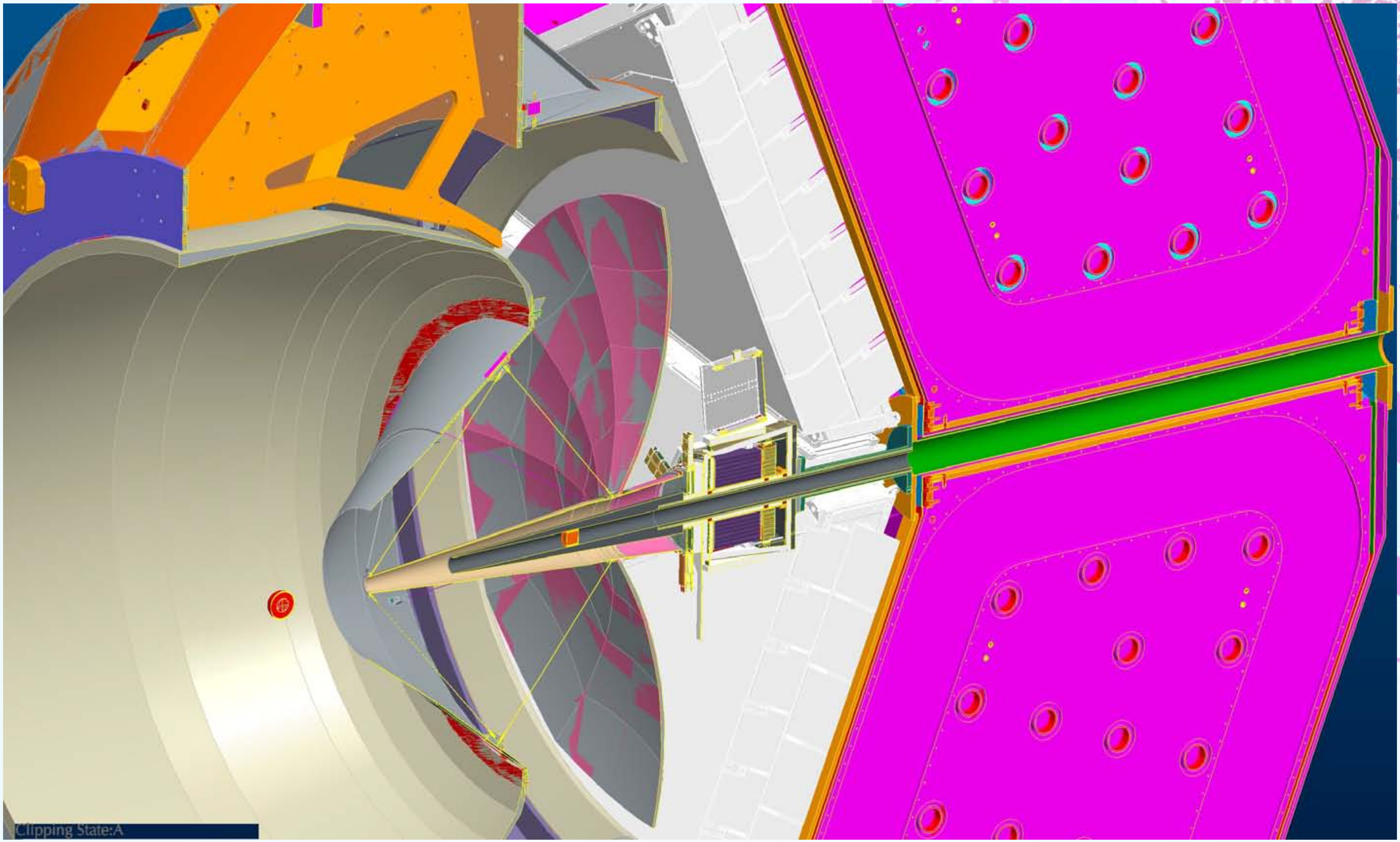
- **Forward detector**
  - Torus Magnet
  - Forward SVT tracker
  - HT Cherenkov counter
  - Drift chamber system
  - LT Cherenkov counter
  - Forward TOF system
  - Preshower calorimeter
  - EM calorimeter (EC)

- **Central detector**
  - Solenoid magnet
  - Barrel silicon tracker
  - Central TOF

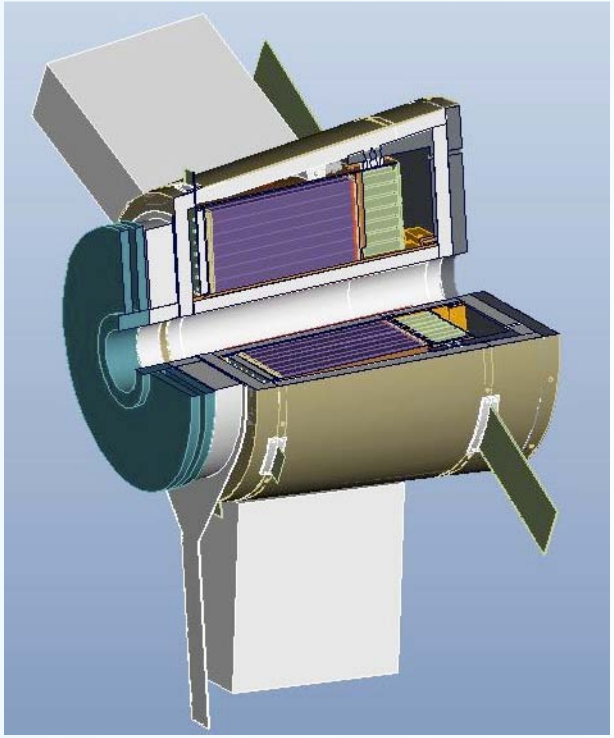
- **Proposed add-ons**
  - Micromegas (CD)
  - Neutron Detector (CD)
  - RICH Detector (FD)
  - Forward tagger (FD)



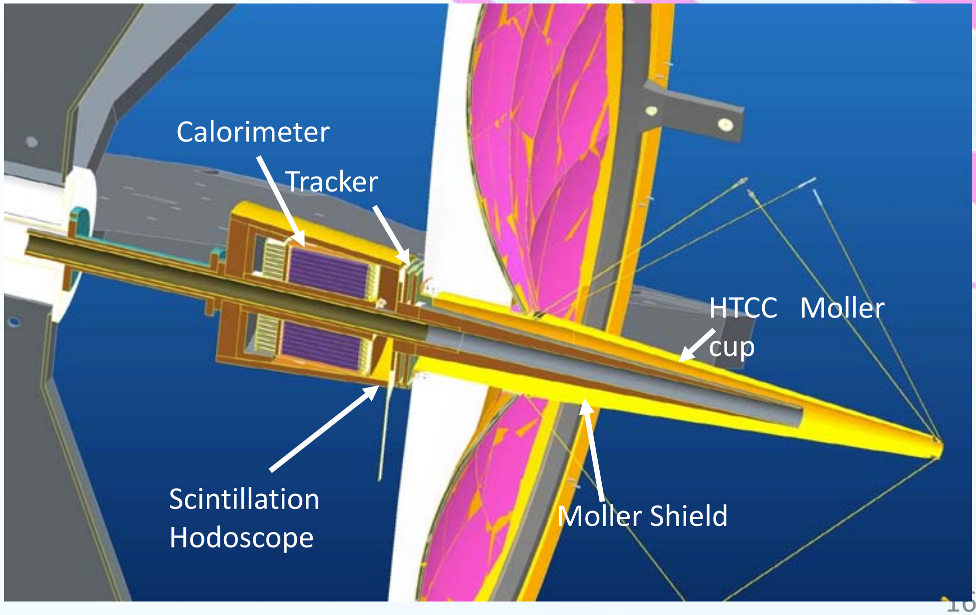
CLAS12: The Forward Tagger



CLAS12: The Forward Tagger



- **FT-CAL**: $PbWO_4$ calorimeter, to measure
  - Electron energy/momentum
  - Photon energy: $\nu = E - E'$
  - Photon polarization: $\varepsilon^{-1} \cong 1 + \nu^2/2EE'$
- **FT-Hodo**: scintillator tiles
  - Veto for photons



- **FT-tracker**: micromegas detectors
  - Measure electron angles and polarization plane

Data analysis: PWA techniques

- Partial Wave Analysis: parameterization of the cross sections via the sum of partial amplitudes
  - Function of quantum numbers: J, P, C, L, I
  - Dynamical functions of particle momenta
  - Models needed to describe each partial wave
    - Isobar model with coupled channels
    - Dispersion relations

- How reliable are the existent models?
- How effective to single out tiny effects?

- The problem can only be faced by comparing the production of the same final state in different reactions
  - Only abundant and precise experimental data can constrain the partial wave shapes

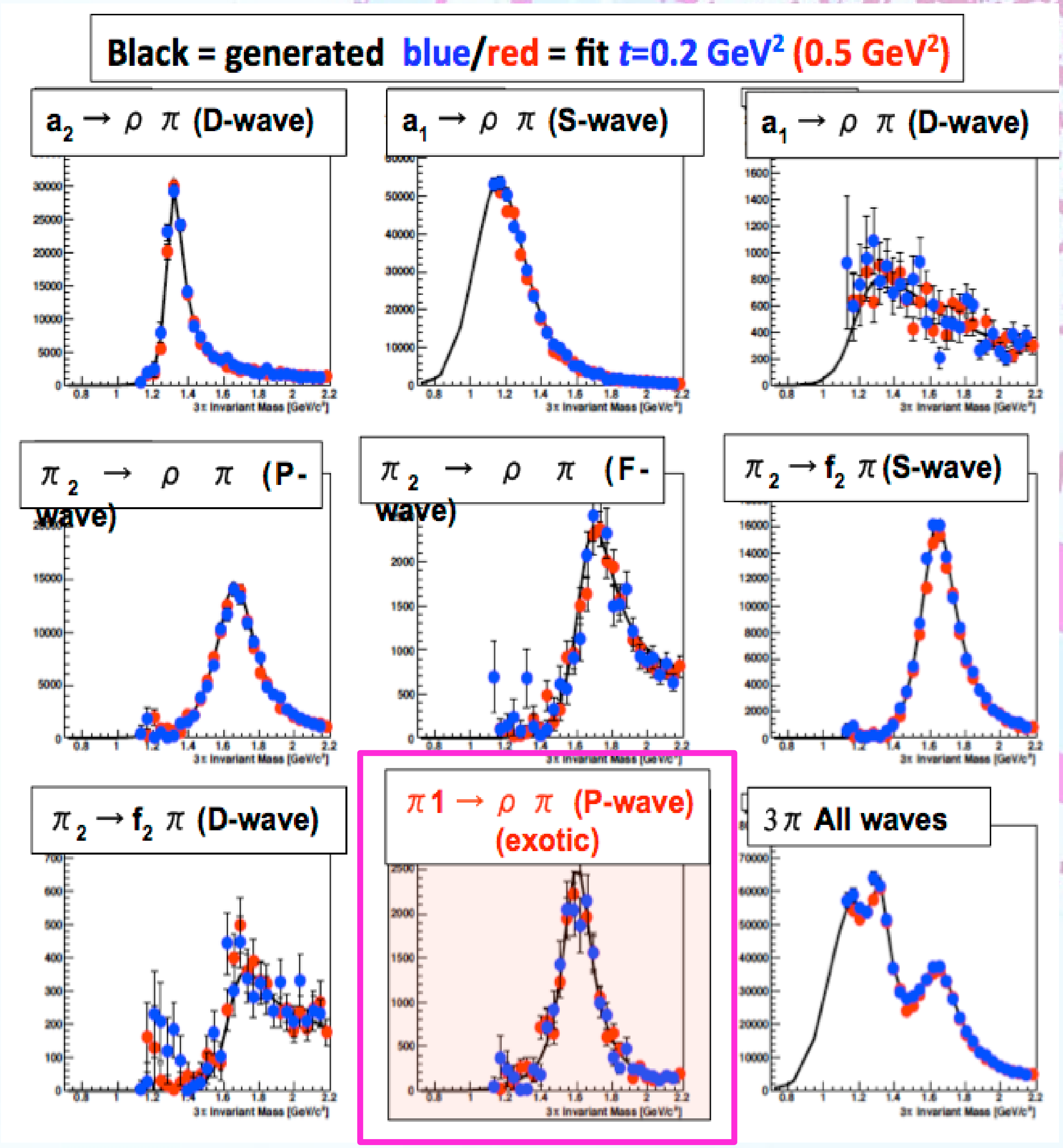
Will PWA be possible/successful in CLAS12?

- PWA analysis simulation: to what extent the detector acceptance and resolution distort the reaction mechanisms?
- Events generated using a realistic differential cross section, filtered through the full reconstruction chain, and fitting them with a set of partial waves in bins of kinematic variables (m, t)

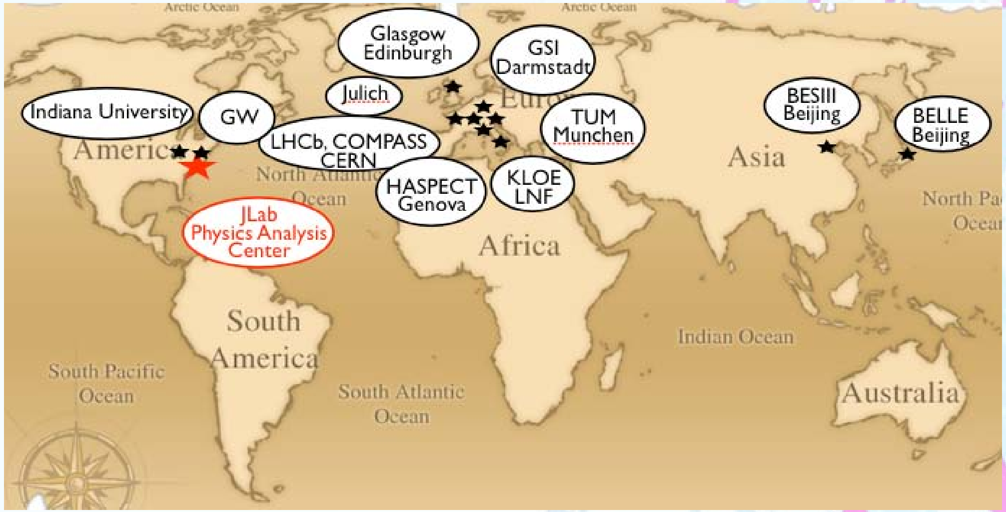
- Benchmark reaction:

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

  – sum of 8 isobar channels, in S, P, D wave + exotic signal
  – CLAS12 acceptance projected and fitted
  – The results are stable against acceptance distortions
  – **PWA is feasible in CLAS12!**



Towards a common and robust analysis framework



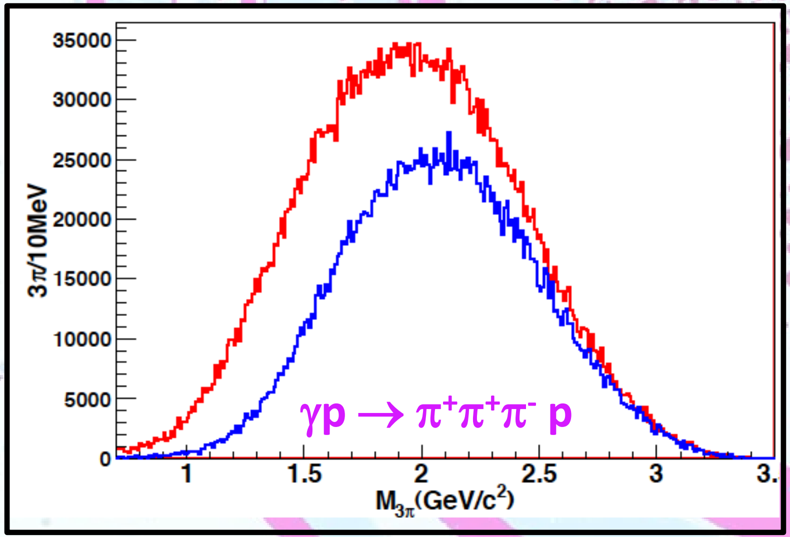
- Many communities all over the world involved with hadron spectroscopy
- Necessary to exploit information for all available reactions, and compare all experimental results in different channels: a comprehensive and integrated framework is mandatory
- Development of a network for the development of common tools, databases and computing resources
  - PWA techniques (ex. AmpTools)
  - Wide data access and distribution (cloud infrastructure, …)
  - Computing techniques: fitting procedures, GPU's, …
- Creation of a "Hadron Spectroscopy" (HASPECT) working group

Summary and conclusions

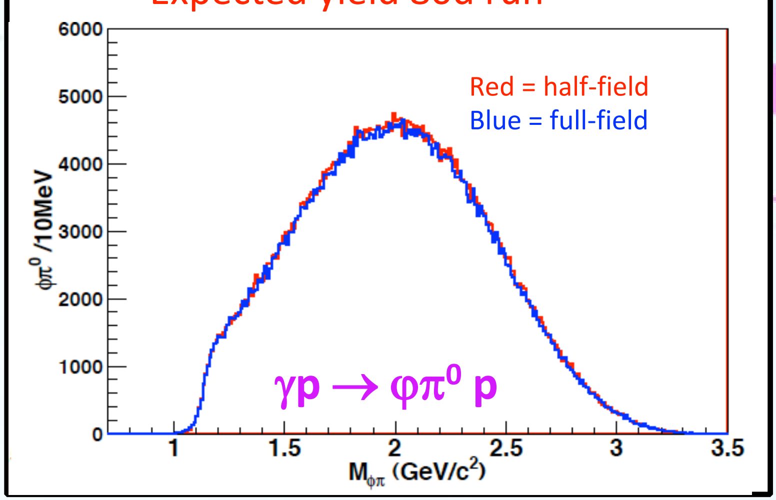
- A rich and comprehensive meson spectroscopy program is set for JLAB in the coming future: GLUEX and CLAS12
  - Complementary features and capabilities
- Photon beams of high intensity, linearly polarized produced in two experimental halls (real: hall D, quasi real: hall B)
  - Unprecedented quality of meson spectroscopy in photon induced reactions
- CLAS12 will exploit excellent resolution and pID capabilities to perform precision studies in the exotic and strangeness-rich meson sectors
- Great effort to provide a common and robust global analysis framework: several experimental groups synergy

Beam time request and expected statistics for Meson-EX run

- Required beam time (excluding commissioning and tests at low luminosity, total ~120 d):
  - 80 d @ full luminosity ($\sim 10^{35}$ $cm^{-2}s^{-1}$)
    - Run in parallel with e^- experiments
    - Determined by the smallest cross sections
      - apparatus acceptance for 4 track events: 15%
      - Strangeonia: ~ 10 nb
        - » 3000 events per mass bin
          - OK for PWA!
    - Total expected trigger rate: < 10 kHz



Expected yield 80d run



Lightest glueball candidate: $f_0(1500)$ seen by CRYSTAL BARREL and OBELIX @ LEAR