Hadron Spectroscopy and the CLAS12 Forward Tagger

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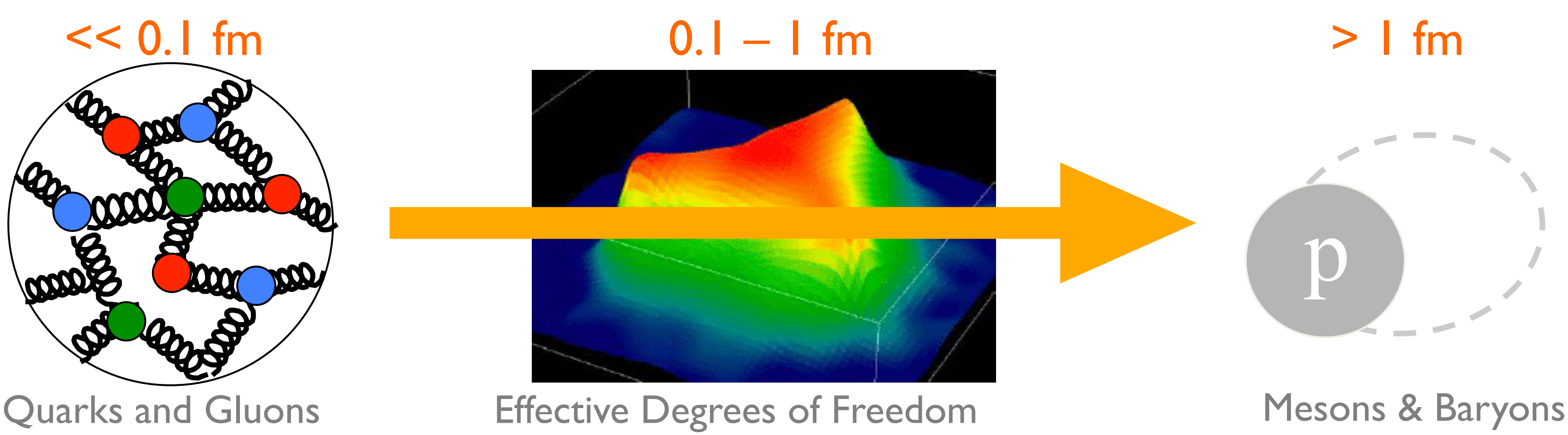
INFN –Genova

Frascati, December 19th 2012

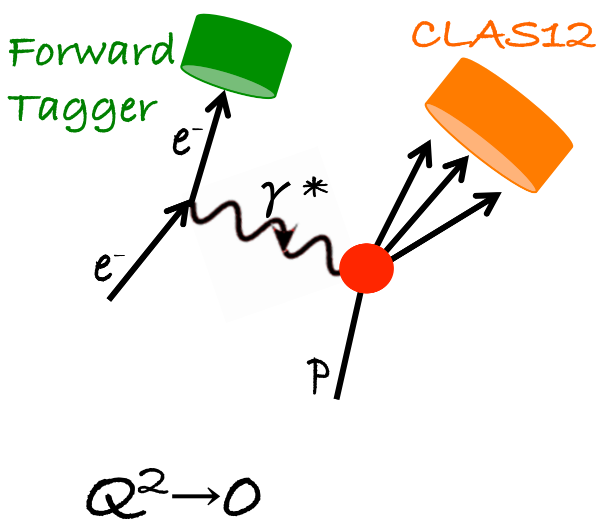
Why Hadron Spectroscopy

- QCD is responsible for most of the mass of matter that surrounds us
- Understanding the origin of this mass, i.e. the mass of hadrons, is a necessary step to reach a deep understanding of QCD
  - Revealing the nature of the mass of the hadrons
  - Identify the relevant degrees of freedom
  - Understand the role of gluons
  - Investigate the origin of confinement
- Hadron spectroscopy is a key tool to investigate these topics



Spectroscopy at CLAS12

The construction of a *Low Q Tagging Facility* or *Forward Tagger* has been proposed to launch a spectroscopy program with CLAS12 using quasi-real photo-production



- Electron scattering at "0" degrees (2.5° - 4.5°)
  - low Q^2 virtual photon ⇔ real photon
- Photon tagged by detecting the scattered electron at low angles
  - high energy photons $6.5 < E_\gamma < 10.5$ 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 $N_\gamma \sim 5\times10^8$ on 5-cm H_2 ($L=10^{35}$ cm^{-2}s^{-1})
- Multiparticle hadronic states detected in CLAS12
- High resolution and excellent PID (kaon identification)
- Complementary to tagged Bremsstrahlung photon beam

CLAS12

Forward Detector:

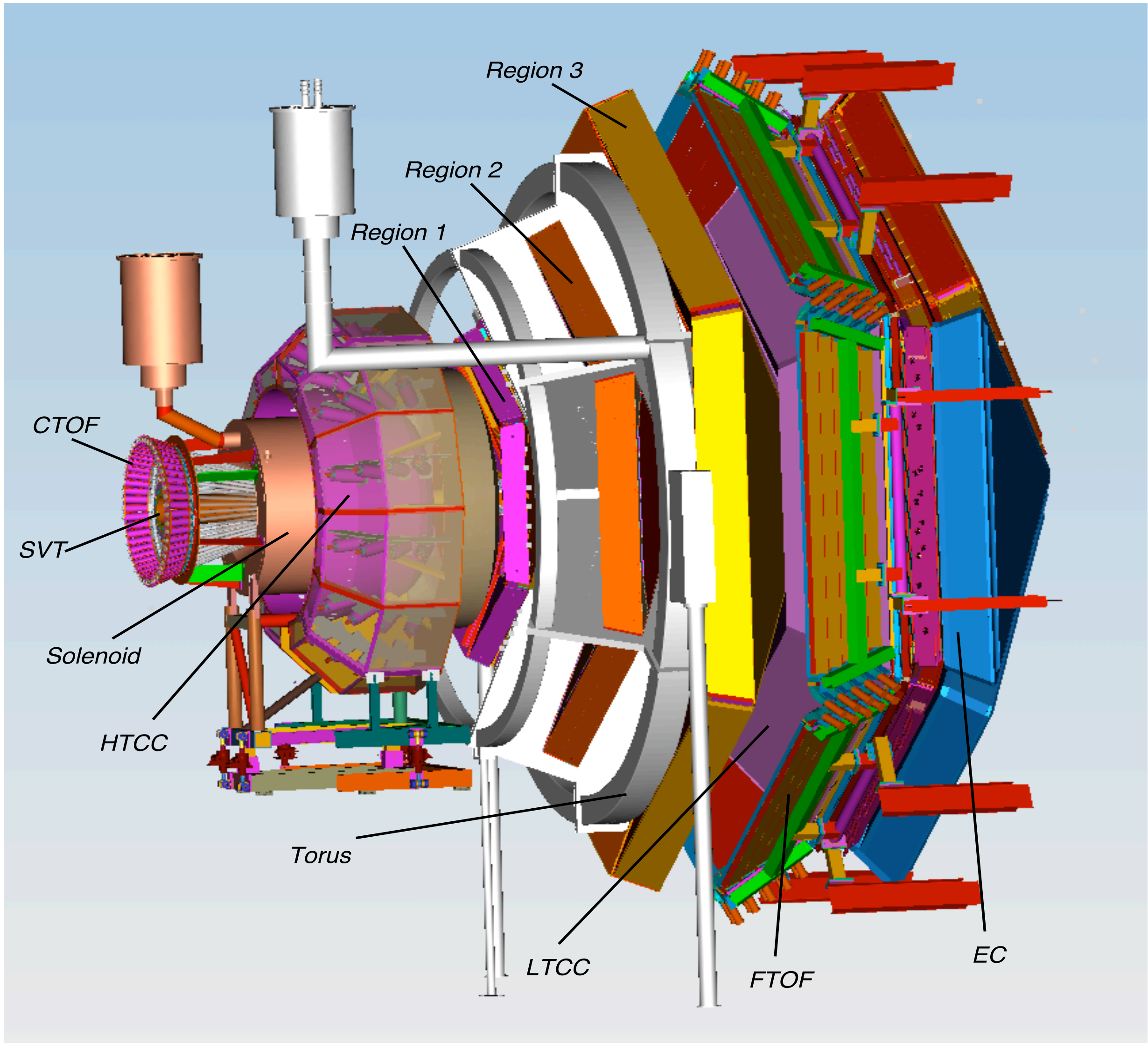
- TORUS magnet
- Forward SVT tracker
- HT Cherenkov Counter
- Drift chamber system
- LT Cherenkov Counter
- Forward ToF System
- Preshower calorimeter
- E.M. calorimeter (EC)

Central Detector:

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

Proposed upgrades:

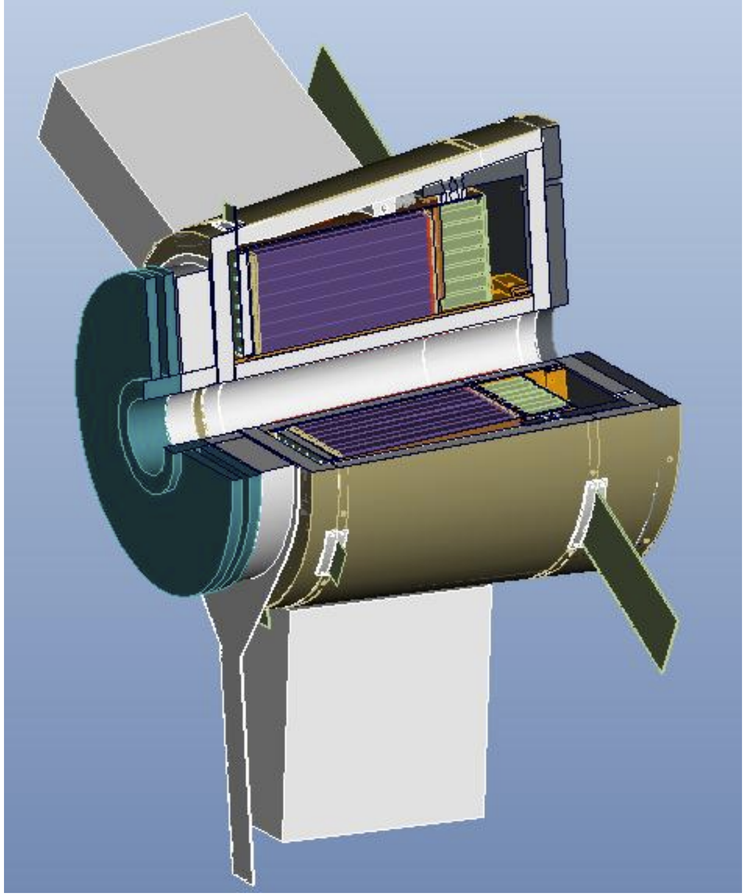
- Micromegas (CD)
- Neutron detector (CD)
- RICH detector (FD)
- Forward Tagger (FD)



The CLAS12 Forward Tagger

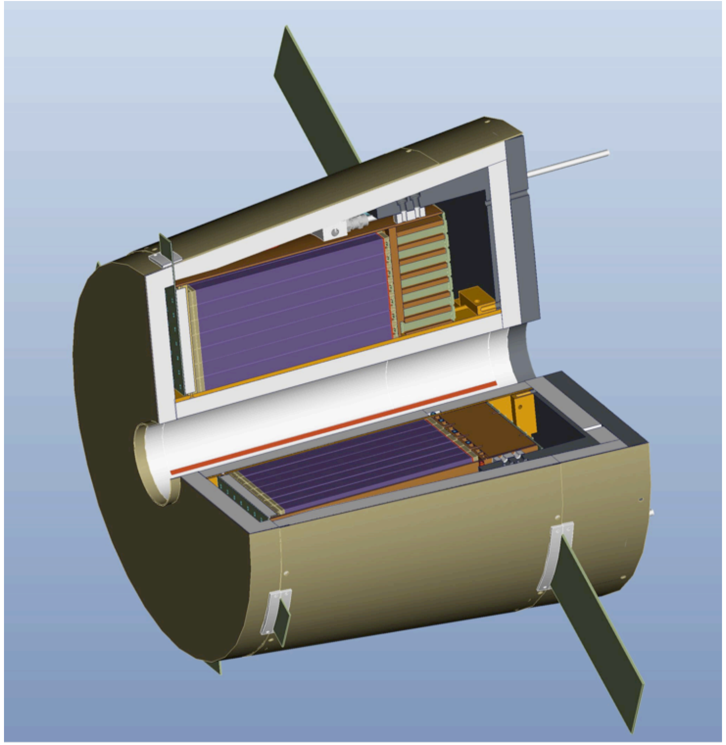
Electron detection via **Calorimeter + Tracker + Veto** proposed by INFN, JLab, CEA-Saclay, U. Edinburgh, U. Glasgow, JMU, NSU, Ohio U.

- *calorimeter* to determine the electron energy with few % accuracy → homogenous $PbWO_4$ crystals
- *tracker* to determine precisely the electron scattering plane and the photon polarization → micromegas
- *veto* to distinguish photons from electrons → scintillator tiles with WLS fiber readout



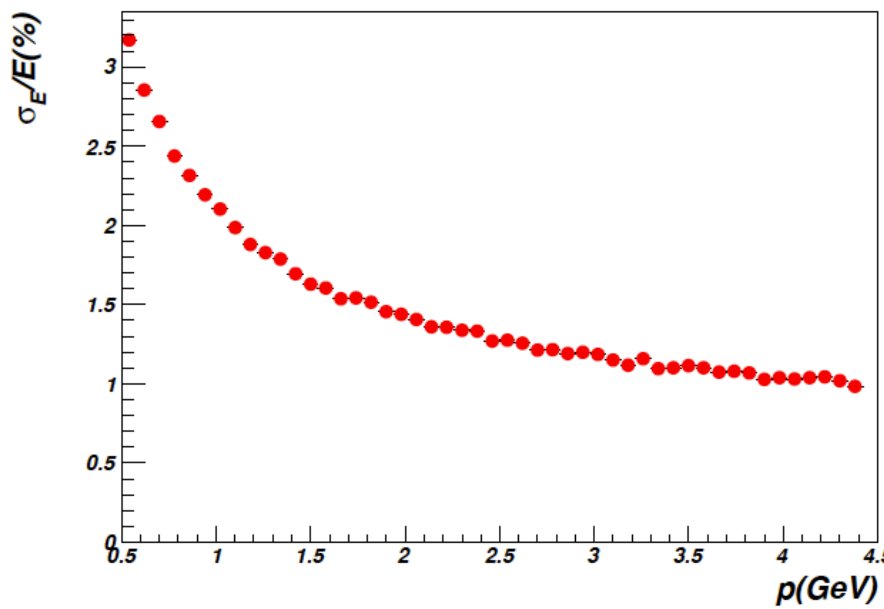
Forward Tagger	
E'	0.5-4.5 GeV
ν	6.5-10.5 GeV
θ	2.5°-4.5°
Q^2	0.007 – 0.3 GeV^2
W^2	3.6-4.5 GeV
Photon Flux	5×10^8 γ/s @ $L_e=10^{35}$

FT Calorimeter



Technology:

- PbWO-II Crystals: 332 elements, 15x15x200 mm^3
- Readout based on Hamamatsu LAAPD s8664-1010
- Custom FEE: IPN-Orsay preamplifiers
- Operating temperature: 0 °C



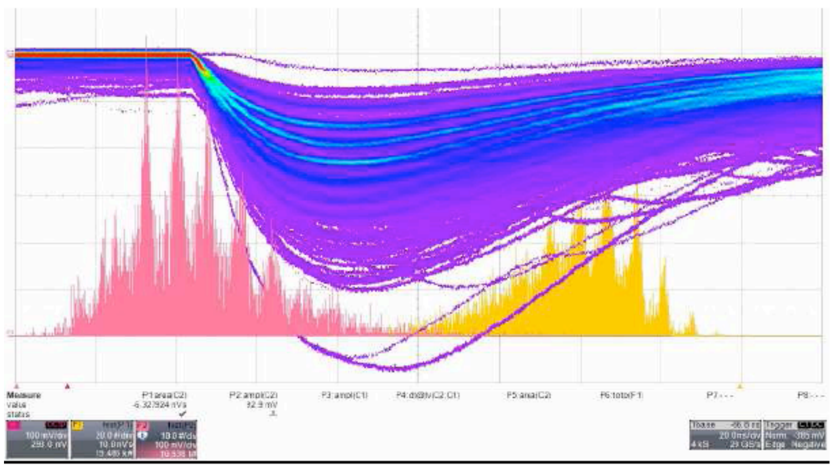
Performance:

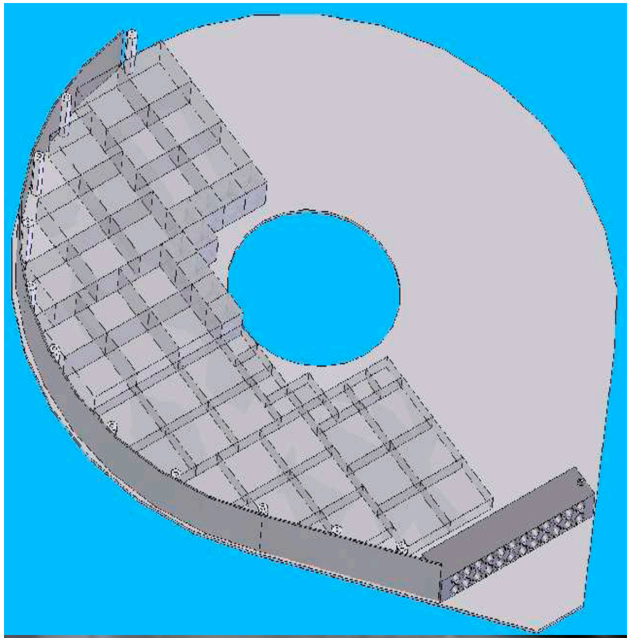
- Energy range:
  - 5 MeV (threshold on single crystal) to 8 GeV
- Angular range:
  - 2.5°-4.5°
- Energy resolution:
  - $2.3\%/\sqrt{E(GeV)} \oplus 0.5\%$

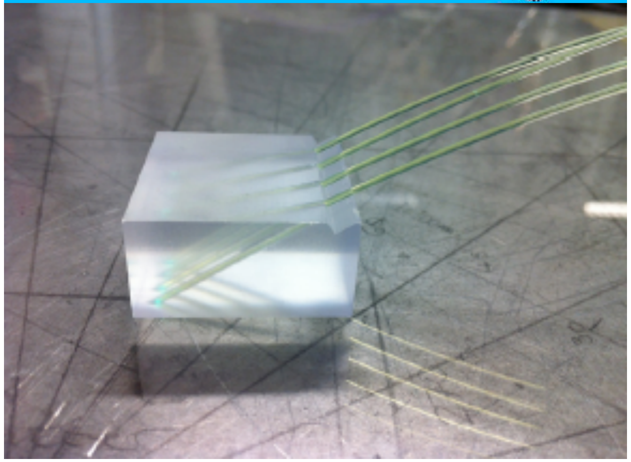
FT Hodoscope

Technology:
- Plastic Scintillator tiles: 2 layers with 116 elements, 30x30 and 15x15 mm^2
- Readout based on WLS fibers coupled to Hamamatsu 3x3 mm^2 SiPMs
- Custom FEE: INFN-Genova preamplifiers

Performance:
- > 20 p.e. measured on 15x15 tile (4-mm thickness)
- > 30 p.e. measured on 30x30 tile (4-mm thickness)



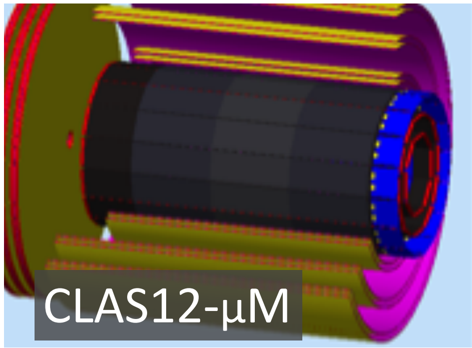


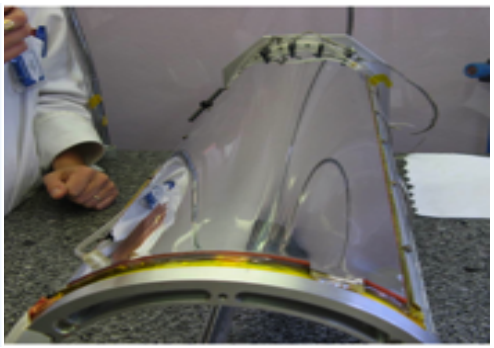


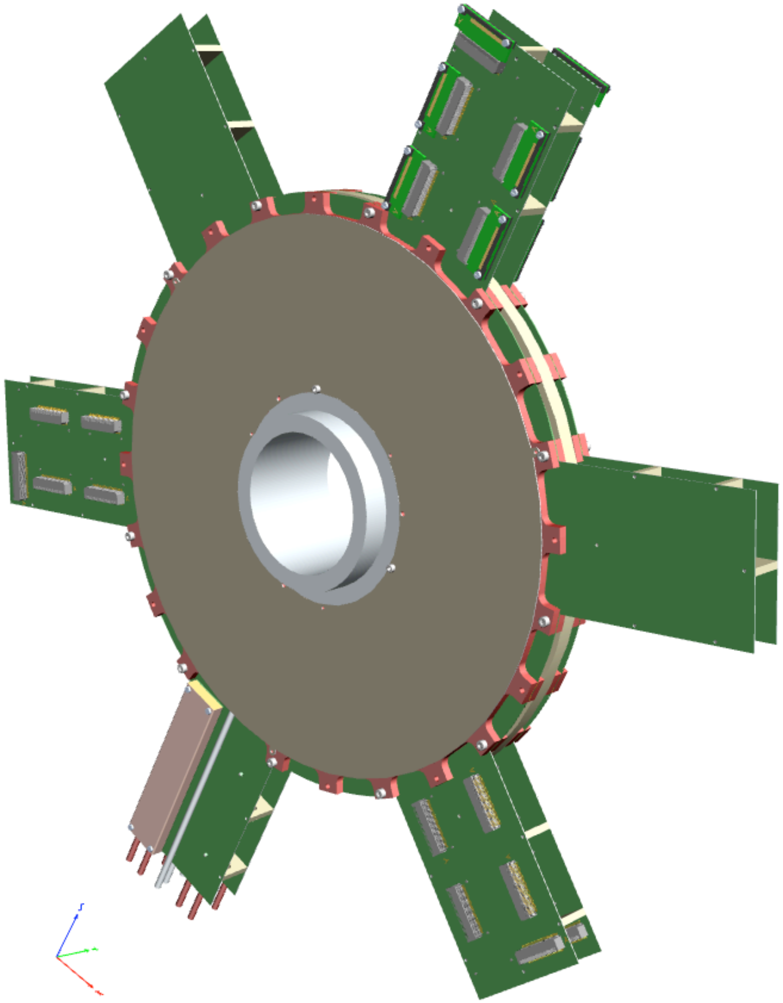
FT Tracker

Technology:
- Two double layers of bi-face bulk Micromegas with 500 µm strip readout
- Custom FE electronics (CEA): 3392 channels, based on DREAM Asic
- Same technology adopted for CLAS12 central tracker

Performance:
- Spatial resolution: < 150 µm
- Angular resolution < 0.2° in θ and <3° in φ







The Meson-Ex experiment

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 several different final states
  - Charged and neutral decay modes
  - $\gamma p \rightarrow n3\pi$, $\gamma p \rightarrow p\eta\pi$, ...
- Hybrids with hidden strangeness and *strangeonia*
  - Intermediate mass of *s* quarks links long to short distance QCD potential
  - Good resolution and kaon Id required
  - $\gamma p \rightarrow p\varphi\pi$, $\gamma p \rightarrow p\varphi\eta$, $\gamma p \rightarrow p2K\pi$, …
- Scalar Mesons
  - Poorly know f_0 and a_0 mesons in the mass range 1-2 GeV
  - Theoretical indications of unconventional configurations (*qqqq* or *gg*)
  - $\gamma p \rightarrow p2\pi$, $\gamma p \rightarrow p2K$, ...

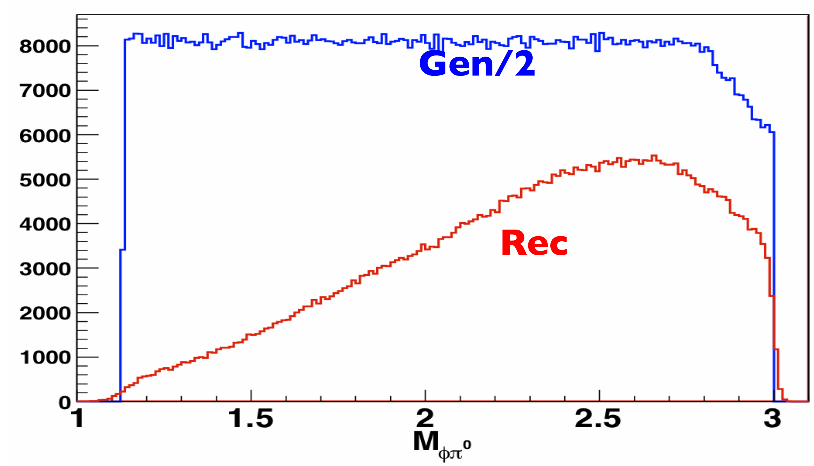
One of the most important fields in hadron physics and main motivation for the JLab 12 GeV upgrade

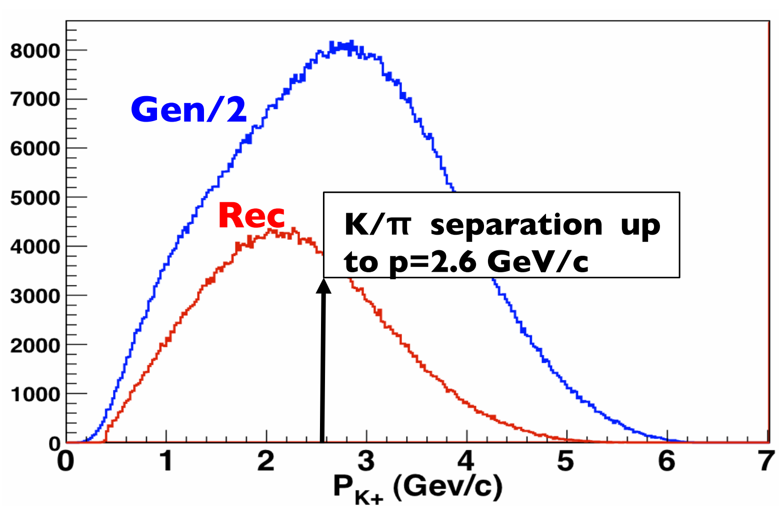
Search for Strangeonia in CLAS12

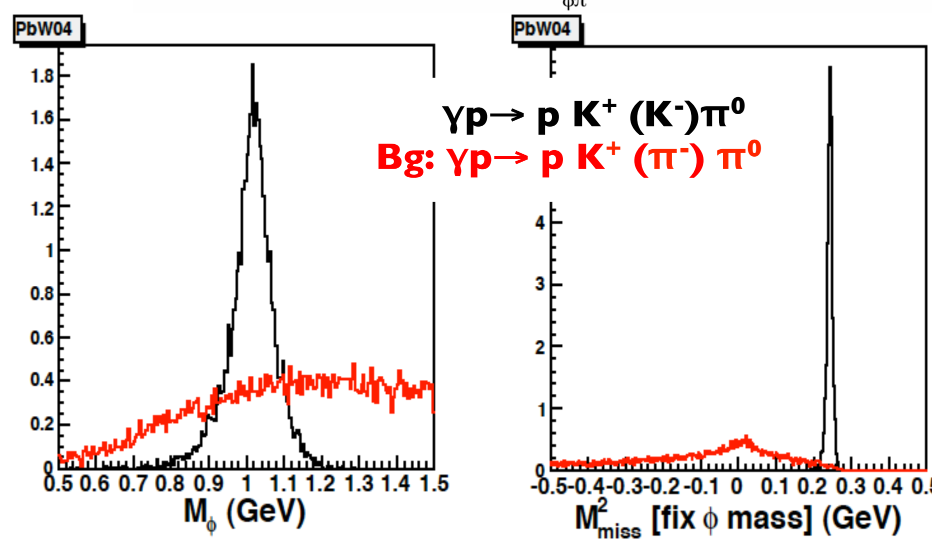
$\gamma p \rightarrow pX(M=1480, \Gamma=130 \text{ MeV})$

$\rightarrow p\varphi\pi^0 \rightarrow p\, K^+(K^-)\gamma\gamma$

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



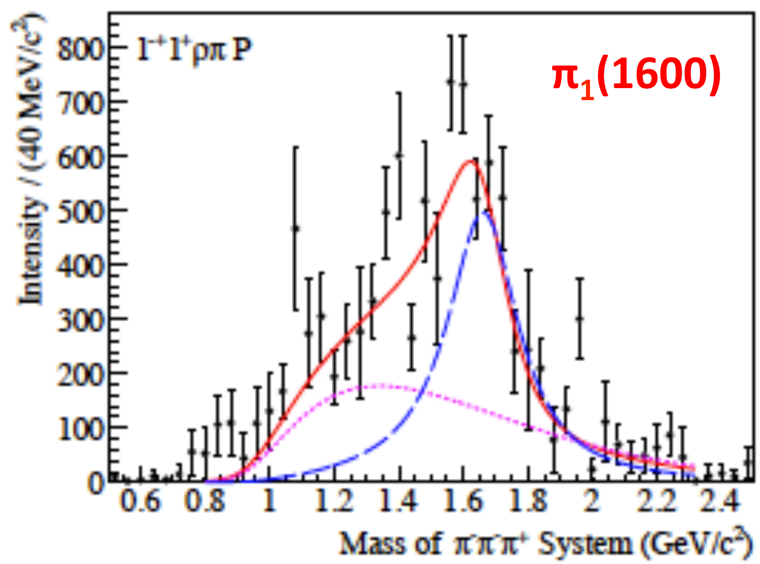




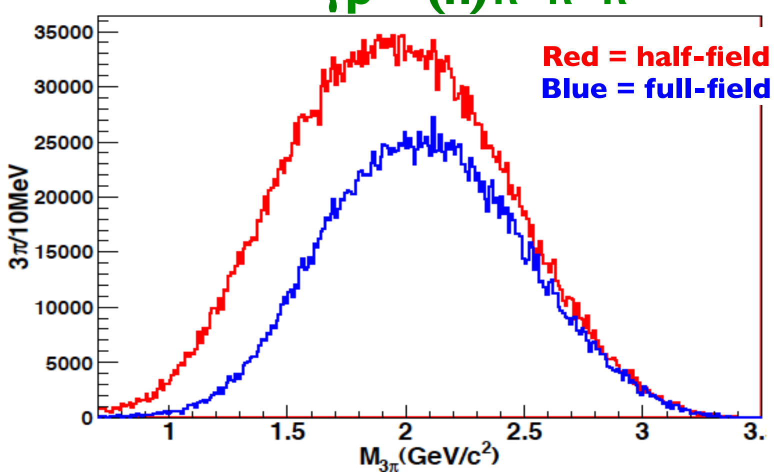
Search for hybrids in the 3π channel

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

- Possible evidence of exotic meson $\pi_1(1600)$ in $\pi^- p \rightarrow (3\pi)^- p$ (E852-Brookhaven)
- Not confirmed in a re-analysis of a higher statistic sample
- New evidence recently reported by Compass



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



CLAS12 expected results:

- Good acceptance for resonance masses in the range 1.4-2.4 GeV
- Broad angular coverage in the resonance decay angles
- Large statistics expected with limited run time

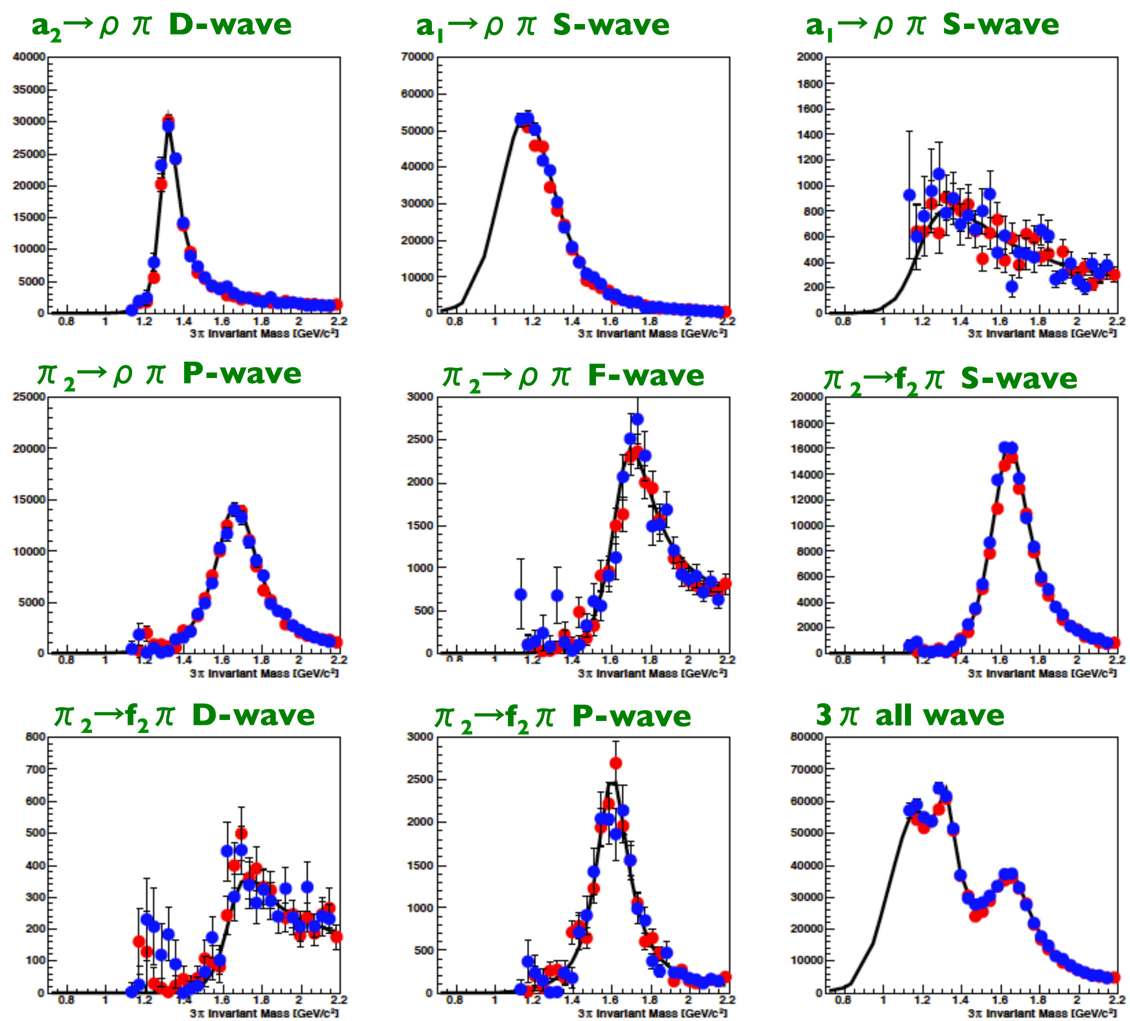
PWA in CLAS12

In preparation for the experiment, **PWA tools** are being developed and tested on pseudo data (Monte Carlo) for different reactions as $\gamma p \rightarrow n\pi^+\pi^+\pi^-$

Test for 2 t bins:

- line: generated wave
- $|t|=0.2$ GeV^2
- $|t|=0.5$ GeV^2

As a function of $M_{3\pi}$



The CLAS12 detector system is intrinsically capable of meson spectroscopy measurements

Future Developments

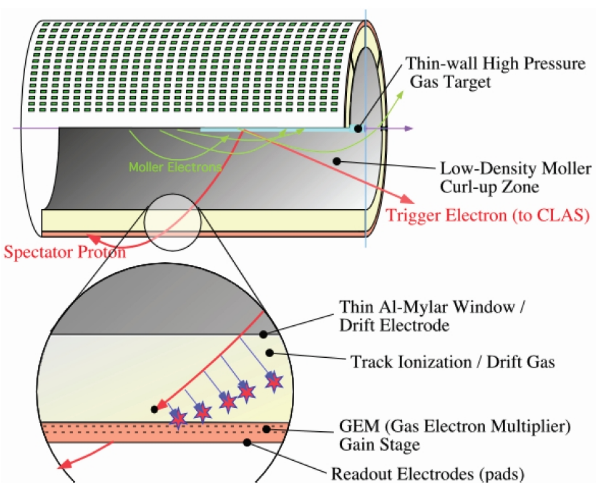
The completion of CLAS12+FT installation is foreseen for fall 2015 and the beginning of data taking on proton target early 2016

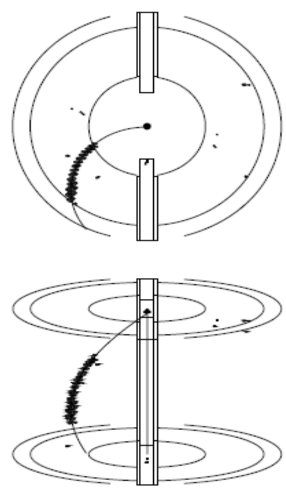
Next generation experiments with improved-extended equipment:

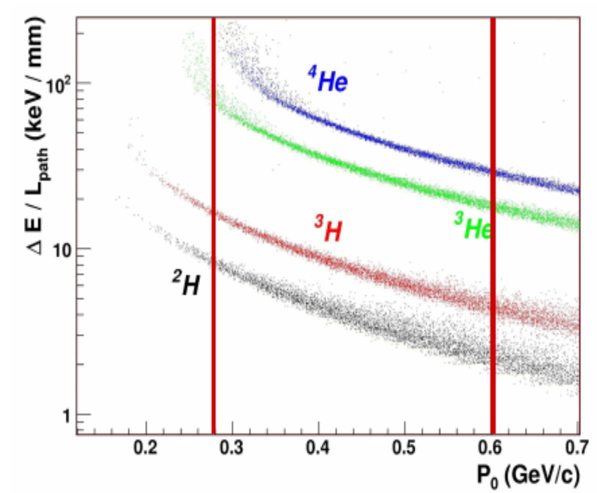
* Extension of physics program with particle identification over full momentum and angular range
* Improvement of CLAS12 acceptance for neutrals with addition of dedicated calorimeters
* Extension of spectroscopy program to thin targets

Meson spectroscopy in coherent production on ^{4}He

- Use coherent quasi-real production on nuclei (^{4}He) as spin and isospin filter
  - Suppress s-channel baryon resonance background
  - Results in simpler PWA: S=I=0 target acts as a filter on final state waves
  - Low Q electron-scattering results in high luminosity on thin gas target
- Requires detection of recoiling nucleus → Radial Time Project Chamber
- Tested on key reactions for the hybrid search ($\gamma^4He \rightarrow {}^4He\pi\eta, \gamma^4He \rightarrow {}^4He\pi\eta'$)







Future Developments

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Worldwide collaboration with experimental and theoretical groups for the development of new analysis tools:

- HAdron SPEctroscopy analysis CenTer (Haspect) in Genova
- Jefferson Lab analysis center
- International workshops (INT2009, ECT*2011, ATHOS 2012, …)

Summary

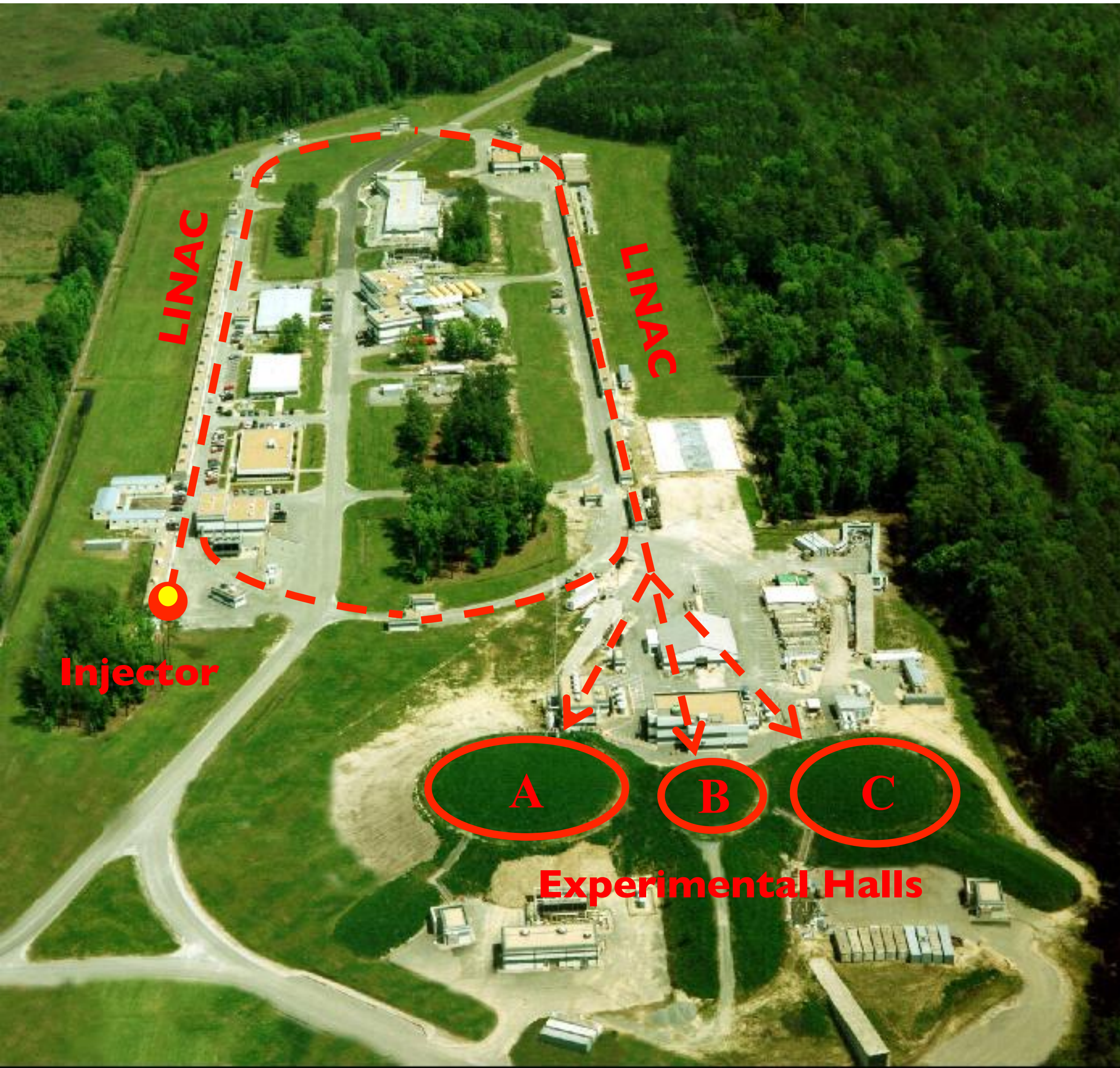
* Spectroscopy is a key field for the understanding of fundamental questions in hadronic physics and is one of the driving forces for the JLab 12GeV upgrade

* A new detector, the Forward Tagger, is being built to detect the scattered electron at small angle and perform quasi-real photo-production experiment

* A broad physics program to study meson spectroscopy in the light quark sector and search for exotic has been launched

* Second generation experiments, exploiting new and improved detection capabilities are foreseen

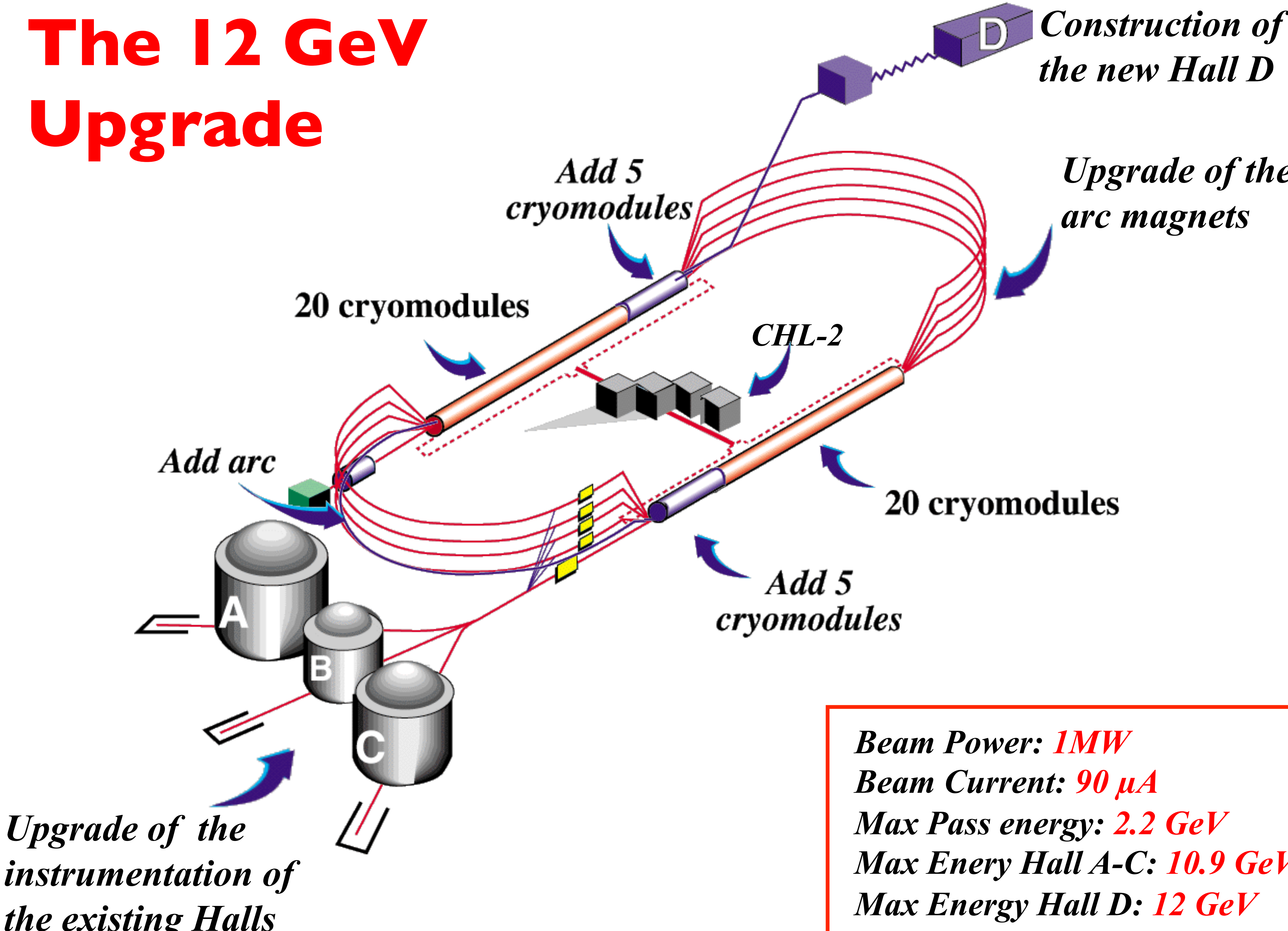
Jefferson Laboratory



Continuous
Electron
Beam
Accelerator
Facility

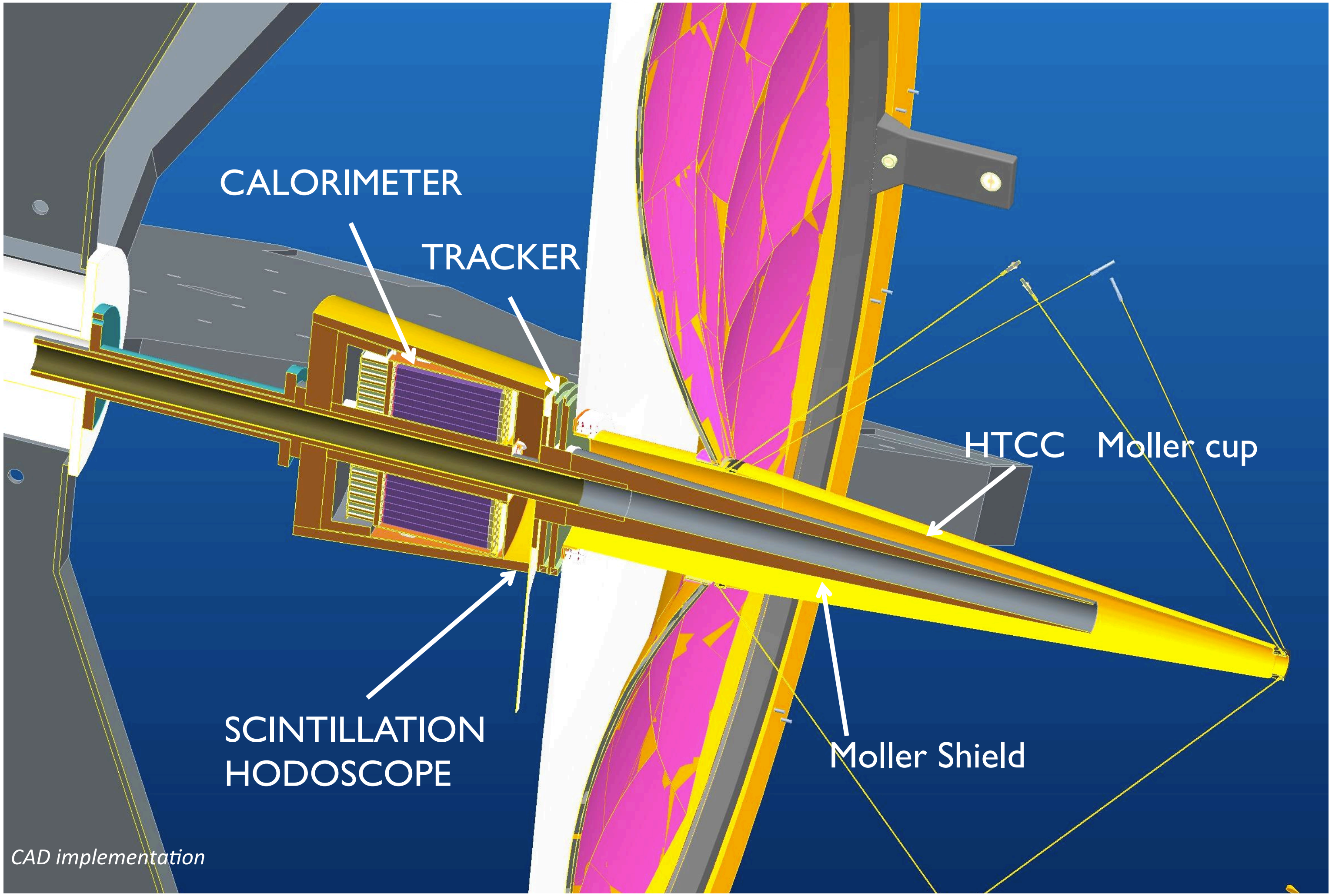
→ E: 0.75 –6 GeV
→ I_{max}: 200mA
→ RF: 1499 MHz
→ Duty Cycle: ~ 100%
→ s(E)/E: 2.5x10^{-5}
→ Polarization: 80%
→ Simultaneous distribution to 3 experimental Halls

The 12 GeV Upgrade

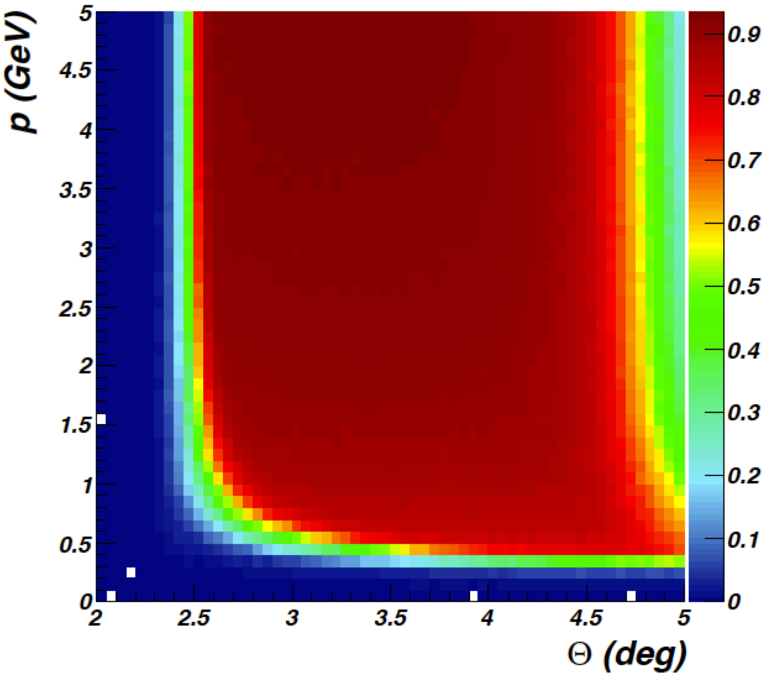


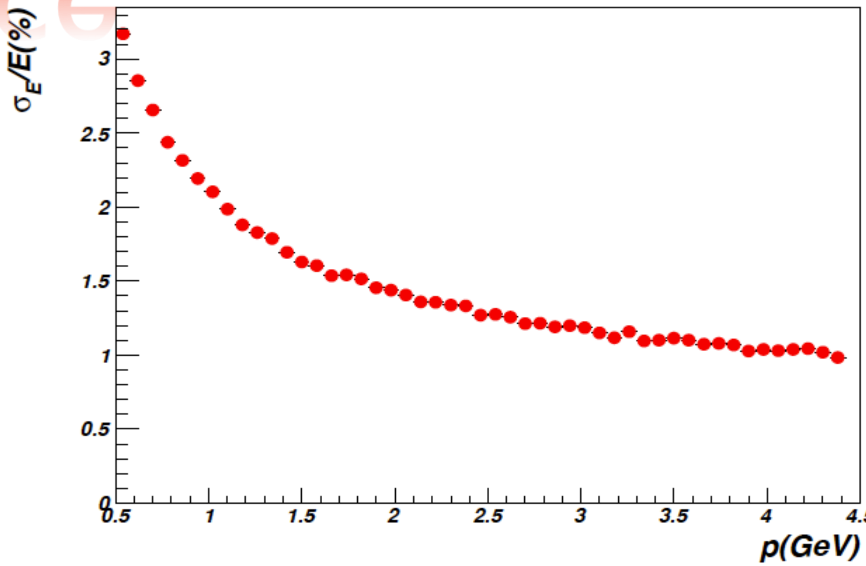
Beam Power: 1MW
Beam Current: 90 μA
Max Pass energy: 2.2 GeV
Max Enery Hall A-C: 10.9 GeV
Max Energy Hall D: 12 GeV

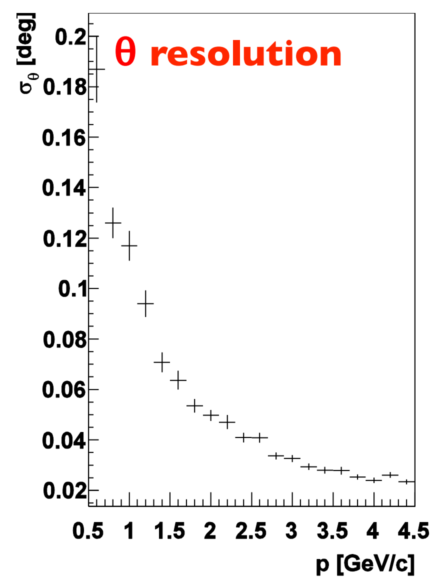
The CLAS12 Forward Tagger

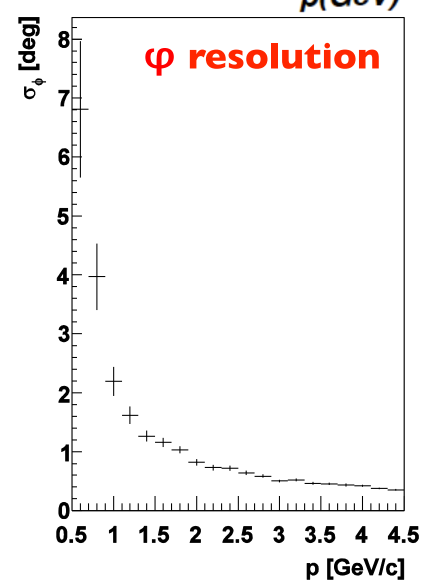


FT Performance







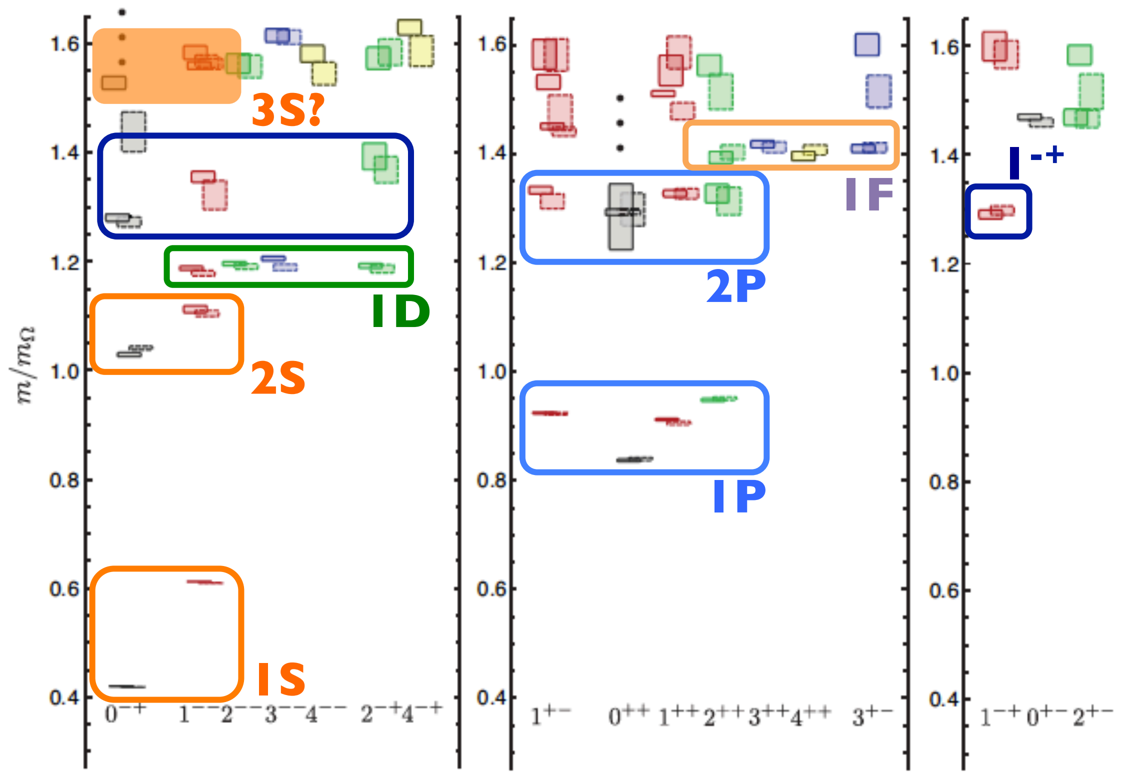


Lattice QCD

Existence of exotics is supported by LQCD

Fully dynamical calculation by the JLab Hadron Spectrum Collaboration:

- two flavors of light quarks and an heavier (strange) quark
- two lattice volumes
- large set of operators
- stable dependence on quark masses



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

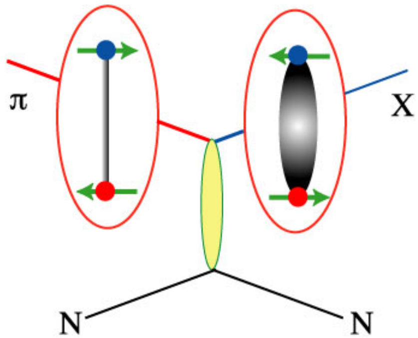
- Good agreement of regular meson spectrum with known states
- Exotic multiplets with quantum numbers 1^{-+},0^{+-} and 2^{-+} are predicted

Exotics in Photoproduction

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

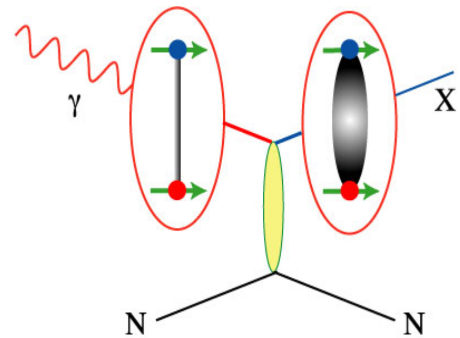
Pion Beam

Quark spins
anti-aligned
$J^{PC} = 1^{--}, 1^{++}$



Photon Beam

Quark spins
already aligned
$J^{PC} = 0^{+-}, 1^{-+}, 2^{+-}$

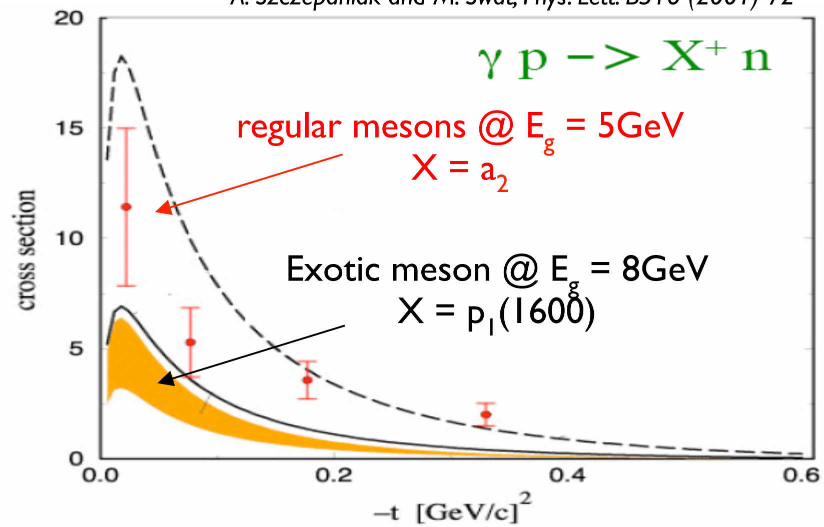


* Knowledge of the photon polarization can be used as a filter in the PWA

* Production rate for exotics is expected to be comparable to regular mesons

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

A. Szczepaniak and M. Swat, Phys. Lett. B516 (2001) 72



Hybrids and Exotics

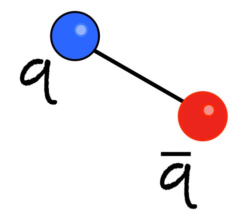
Another category of unconventional mesons are **hybrids**, i.e. states with $q\bar{q}g$ configuration

- In the flux tube model, hybrids arise from **excitations of the flux tube** that connects the quark and antiquark
- The excited flux tube carries **non-zero angular momentum** that contribute to the quantum numbers of the new system
- Excitation of the flux tube leads to a **new spectrum of hadrons** that can have both regular and **exotic quantum numbers**

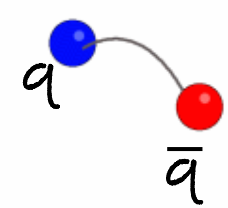
  $J^{PC} = 0^{-+}, 0^{+-}, 1^{++}, 1^{--}, 1^{-+}, 1^{+-}, 2^{-+}, 2^{+-}$

- For each J^{PC} combination a **nonet** of states is expected
- Masses of the lower states are predicted to be around 2 GeV

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



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



Expected Results

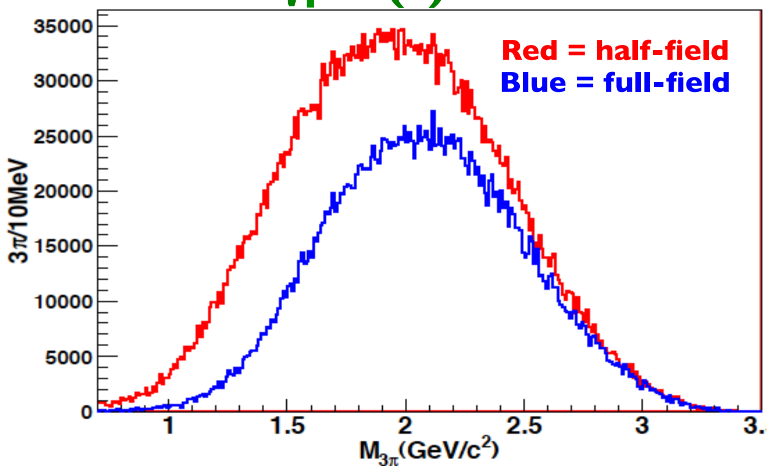
* Experiment approved for 80 days of production beam time + commissioning and low intensity calibration run (35d)
* Can be scheduled in parallel to other proton-target runs

Cross sections:

$\sigma(\gamma\ p \rightarrow n\ 3\pi)$	~ 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 in single mass bins > 5000 events
- Sufficient to run full PWA

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



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