



Meson spectroscopy at JLab



Jefferson Lab's accelerator site

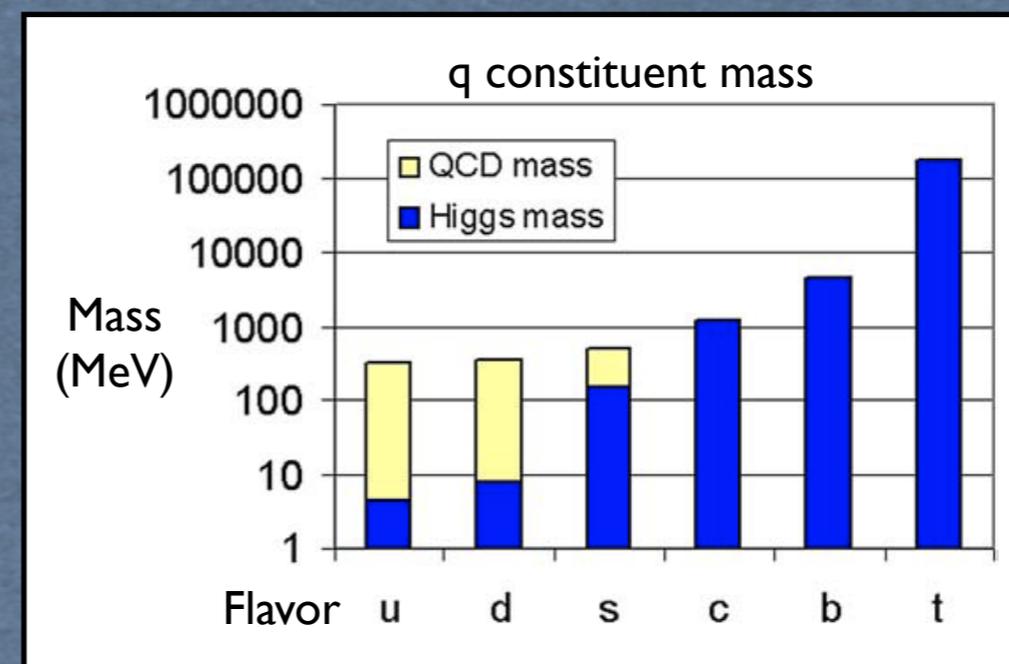
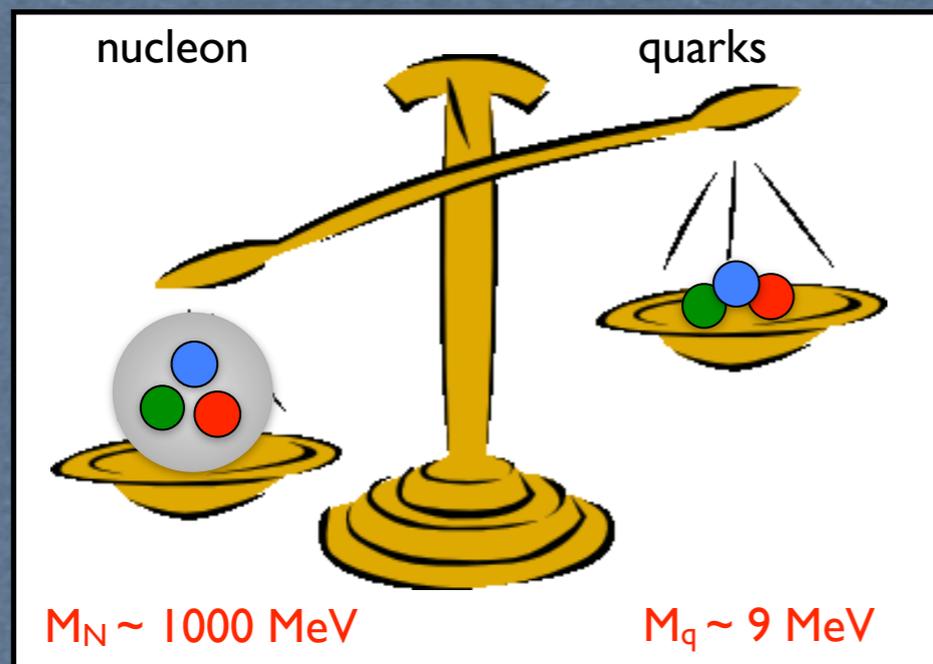


*M. Battaglieri
INFN - GE
Italy*



Why hadron spectroscopy

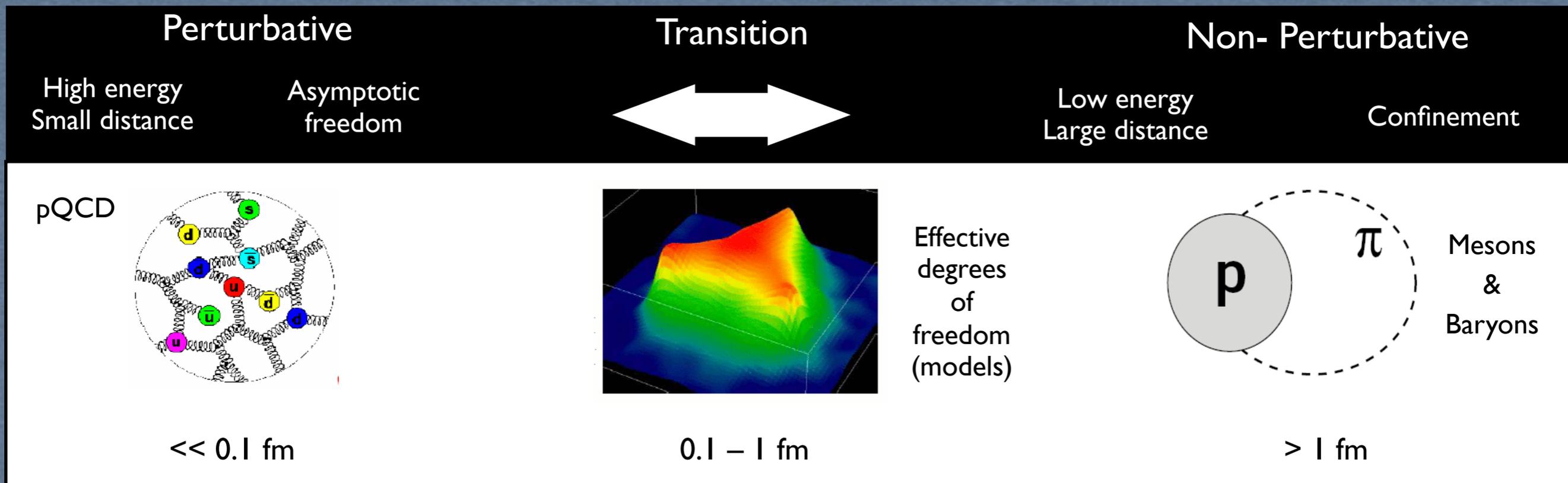
- * The mass of the universe is mainly due to hadrons (nucleons forming nuclei)
- * Quark masses only accounts for a small fraction of the nucleon mass: 99% is generated by dynamics of QCD confinement



- * Light quark visible mass is dominated by QCD dressing effects

Why hadron spectroscopy

- * Quantitative understanding of quark and gluon confinement
- * Revealing the nature of the mass of the hadrons
- * See the QCD degrees of freedom at work
- * Validate lattice-QCD predictions

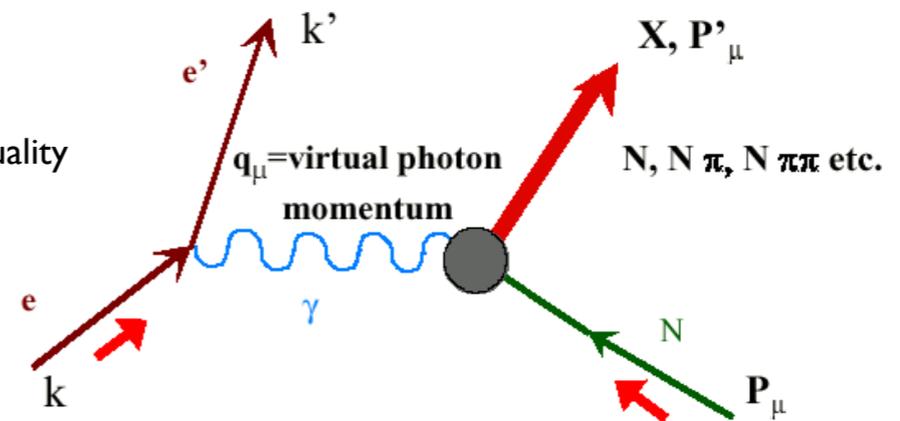


The tool: electromagnetic interaction

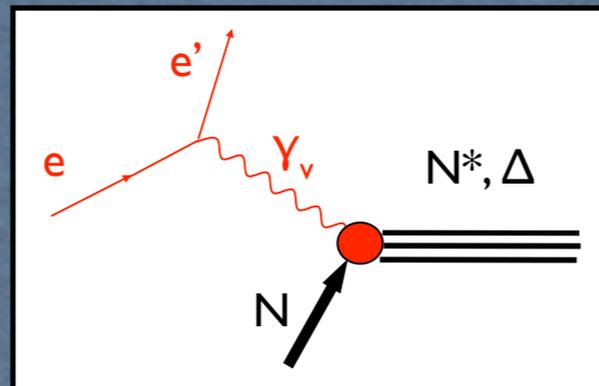
- weaker than strong interactions
- therefore calculable perturbatively
- based on the well-known QED

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

$-q^m q_m = Q^2 = \text{photon virtuality}$
 $s = \text{CM total energy}$
 $t = \text{momentum transfer}$



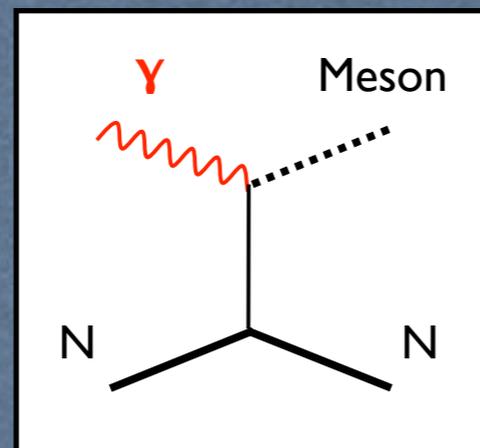
Baryon spectroscopy



- 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



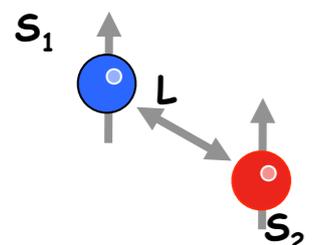
- $q\bar{q}$ system \rightarrow easier to study
- Access to gluonic degrees of freedom
- towards a quantitative understanding of quark and gluon confinement

JLab tomorrow!

The light quark meson spectrum

Constituent Quark Model

- Quark-antiquark pairs with total spin $S=0,1$ and orbital angular momentum L

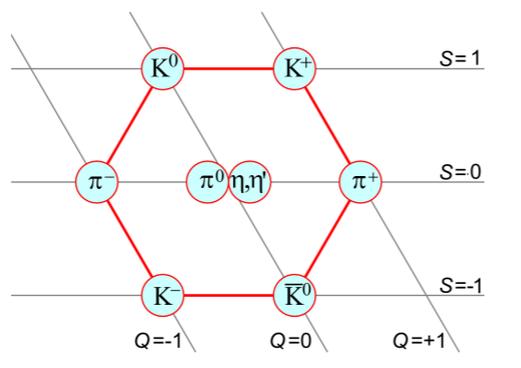


$S = S_1 + S_2$ $J = L + S$
 $P = (-1)^{L+1}$ $C = (-1)^{L+S}$

Not all the J^{PC} combinations are allowed:
 0^{++} 0^{+-} 0^{-+} 0^{--} 1^{++} 1^{+-} 1^{-+} 1^{--} 2^{++} 2^{+-} 2^{-+} 2^{--} 3^{++} 3^{+-} 3^{-+} 3^{--} ...

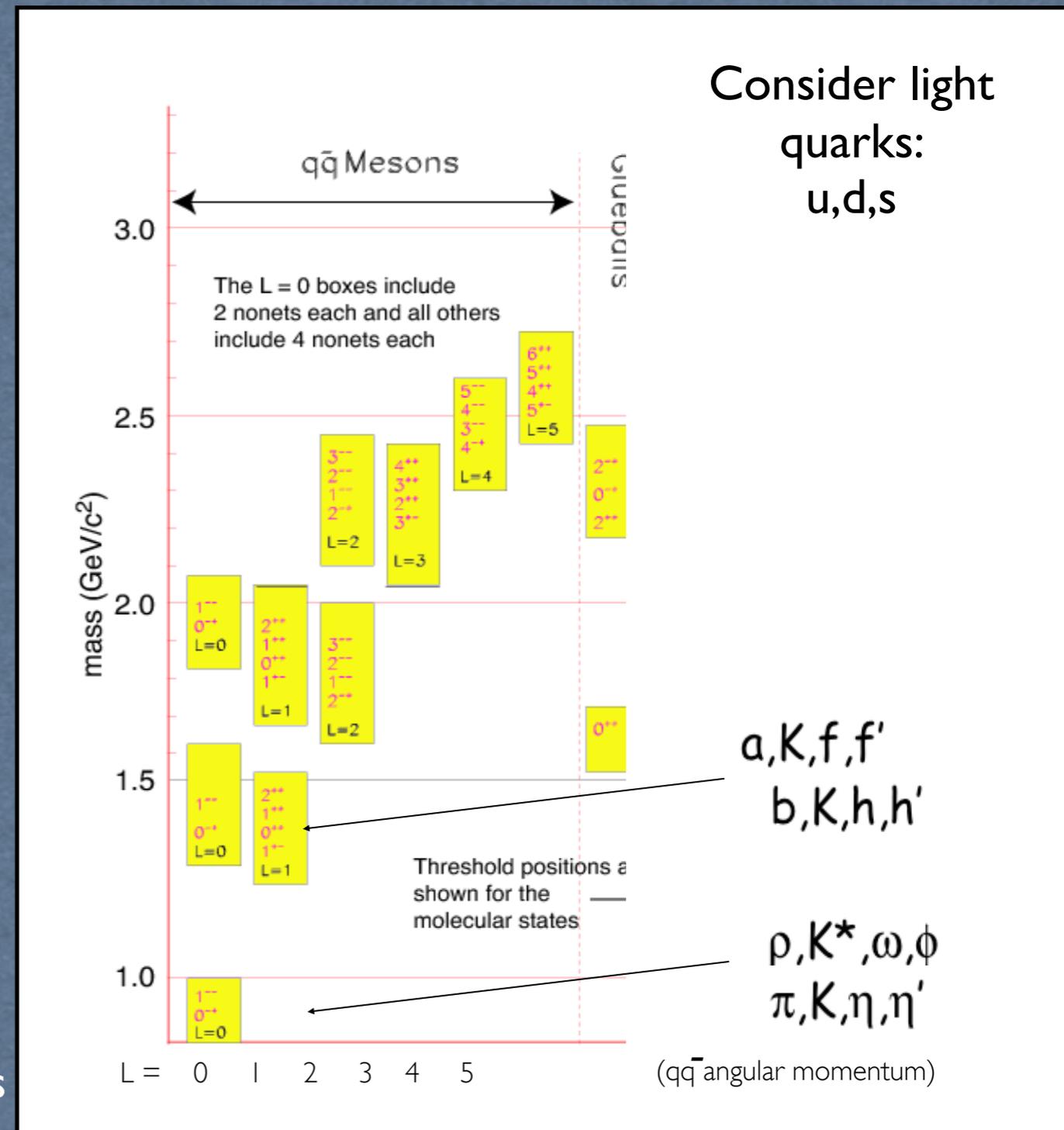
- SU(3) flavor symmetry
 → nonet ($8 \oplus 1$) of degenerate states

$J^{PC} = 0^{-+} \Rightarrow (\pi, K, \eta, \eta')$
 $1^{--} \Rightarrow (\rho, K^*, \omega, \Phi)$
 $1^{+-} \Rightarrow (b_1, K_1, h_1, h_1')$
 ...



- Great success in describing the lower mass states

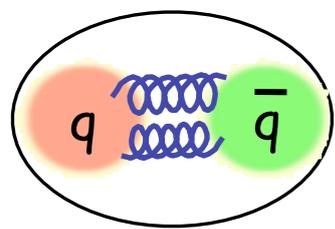
- A number of predicted states is not experimentally observed and assignments are uncertain



The gluons and the meson spectrum

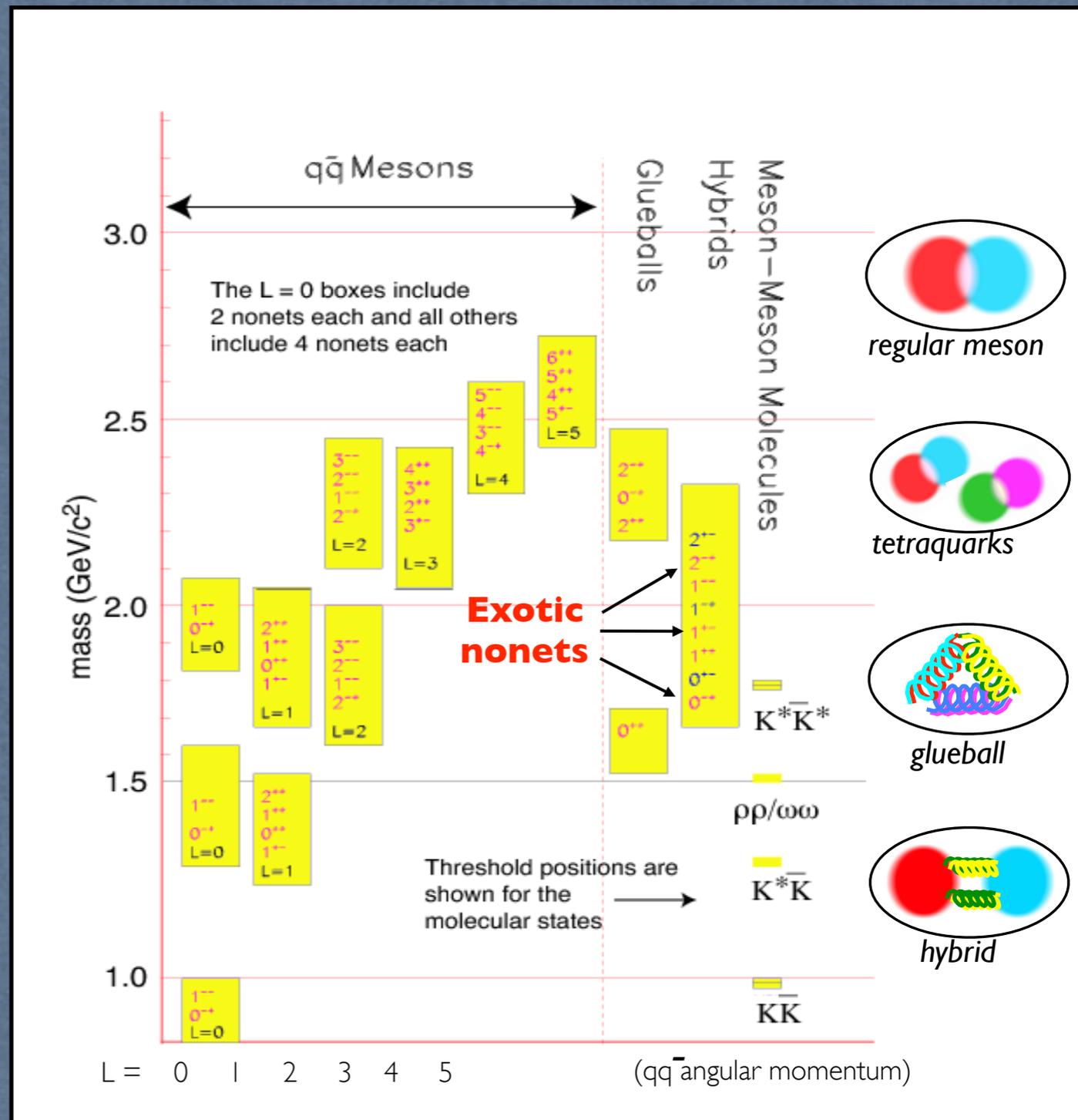
- Understanding gluonic excitations of mesons and the origin of confinement
- At high energy experimental evidence is found in jet production
- At lower energies the hadron spectrum carries information about the gluons that bind quarks
- Can we find hints of the glue in the meson spectrum?

Search for non-standard states with explicit gluonic degrees of freedom



hybrid mesons

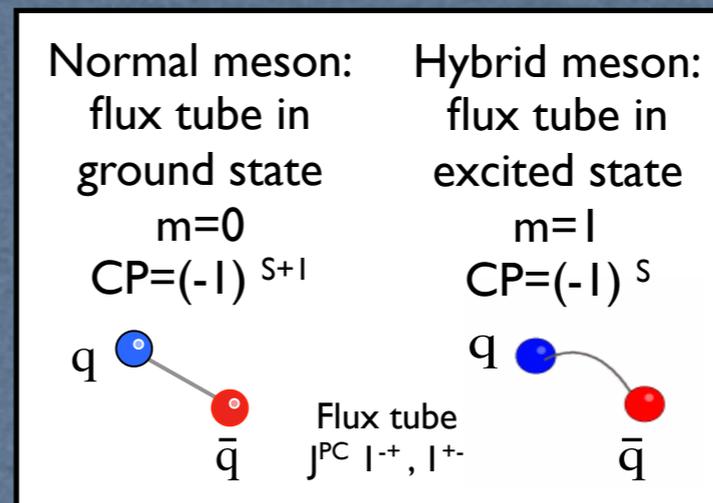
Not-allowed $J^{PC} = 0^{-}, 0^{+}, 1^{-}, 2^{+} \dots$
 Unambiguous experimental signature for the presence of gluonic degrees of freedom in the spectrum of mesonic states



Gluonic excitation models

Flux tube model

- Gluonic field confined in a tube between q and anti-q
- Linear Regge trajectories
- Hybrid mesons as transverse oscillation of the tube
- Flux-tube breaking give rise to meson decay



Lightest multiplet
 $(0, 1, 2)^{-+}, (0, 1, 2)^{+-},$
 $1^{-+}, 1^{+-}$

Bag model

- Quarks confined inside a cavity
- Full relativistic
- Gluonic excitation: gluonic field modes by boundary conditions

Lightest multiplet
 $(0, 1, 2)^{-+}, 1^{-+}$

CQM + constituent gluon

- qq + massive transverse quasi-gluon (J_g^{PgCg})
- Gluon adds in relative S-wave to a qq pair is S-wave or P-wave

qq in S-wave +
 $J_g^{PgCg} = 1^{-+}$ in S-wave

Lightest multiplet
 $(0, 1, 2)^{++}, 1^{+-}$

qq in P-wave +
 $J_g^{PgCg} = 1^{-+}$ in S-wave

Lightest multiplet
 $0^{-+}, (1^{-+})^3, (2^{-+})^2, 3^{-+}, 0^{-+}, 0^{-+}, 1^{-+}, 2^{-+}$

- Repulsive 3-body force selects $J_g^{PgCg} = 1^{+-}$ in relative P-wave added to a qq pair is S-wave or P-wave

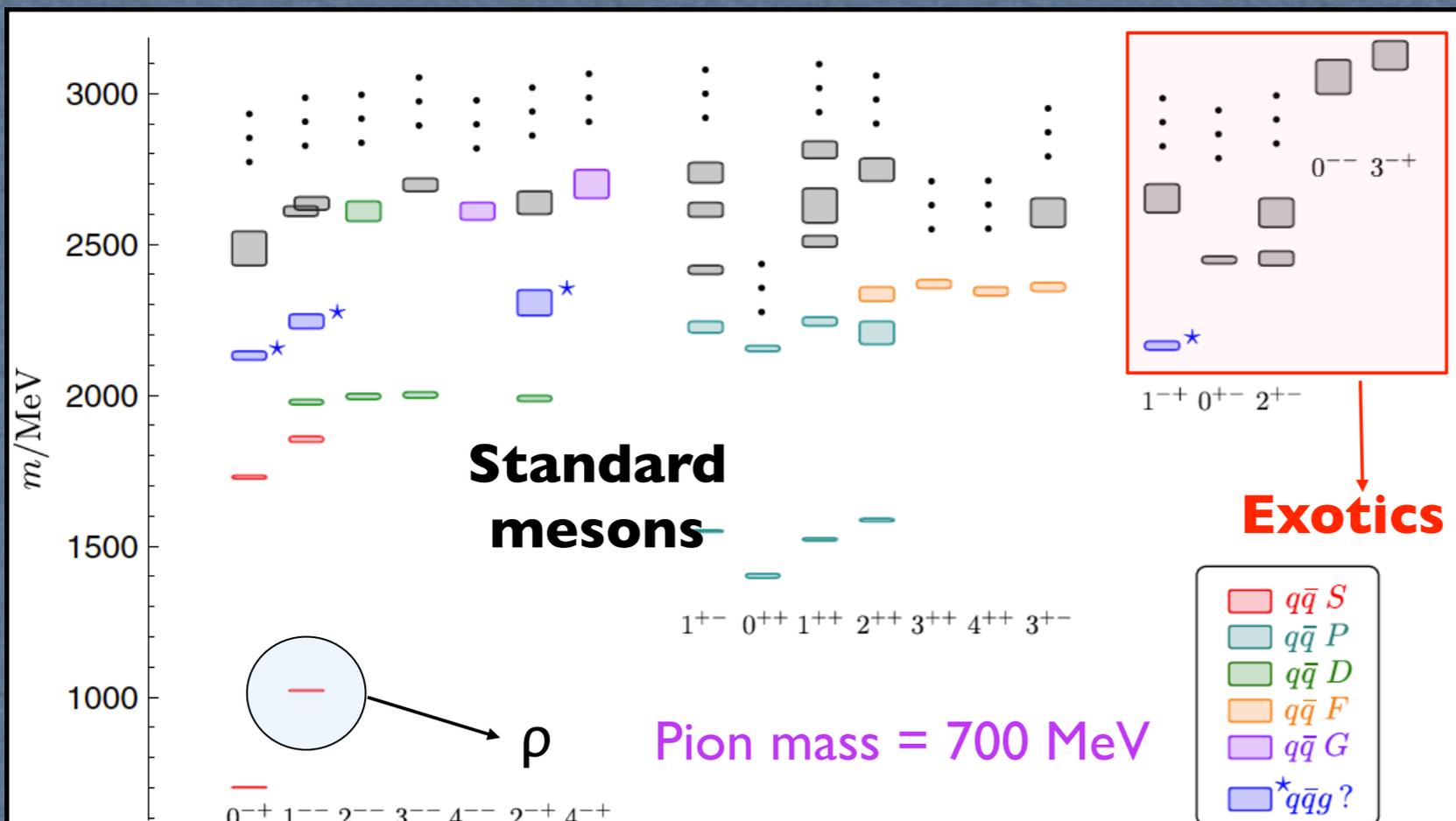
qq in S-wave +
 $J_g^{PgCg} = 1^{+-}$ in P-wave

Lightest multiplet
 $(0, 1, 2)^{-+}, 1^{-+}$

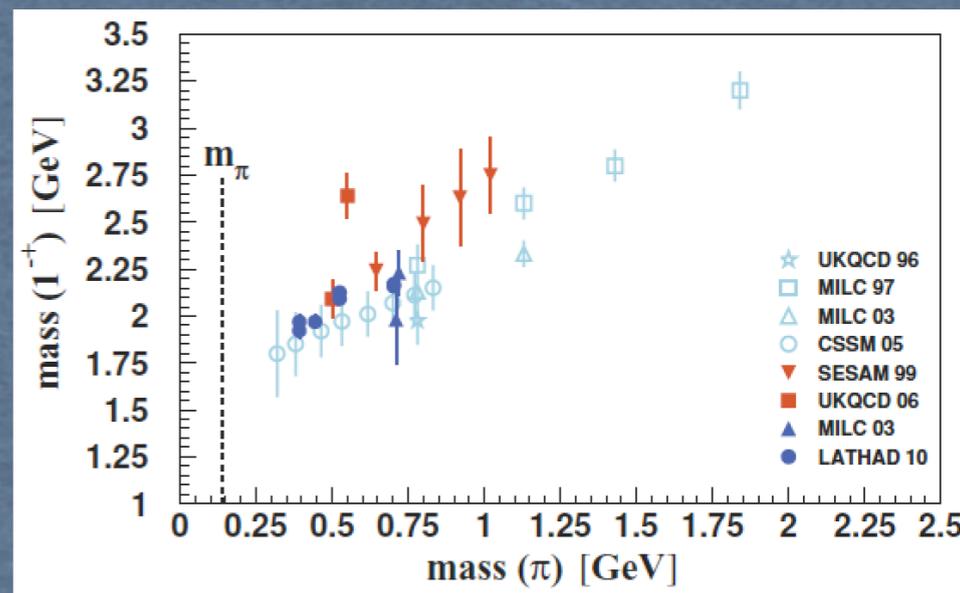
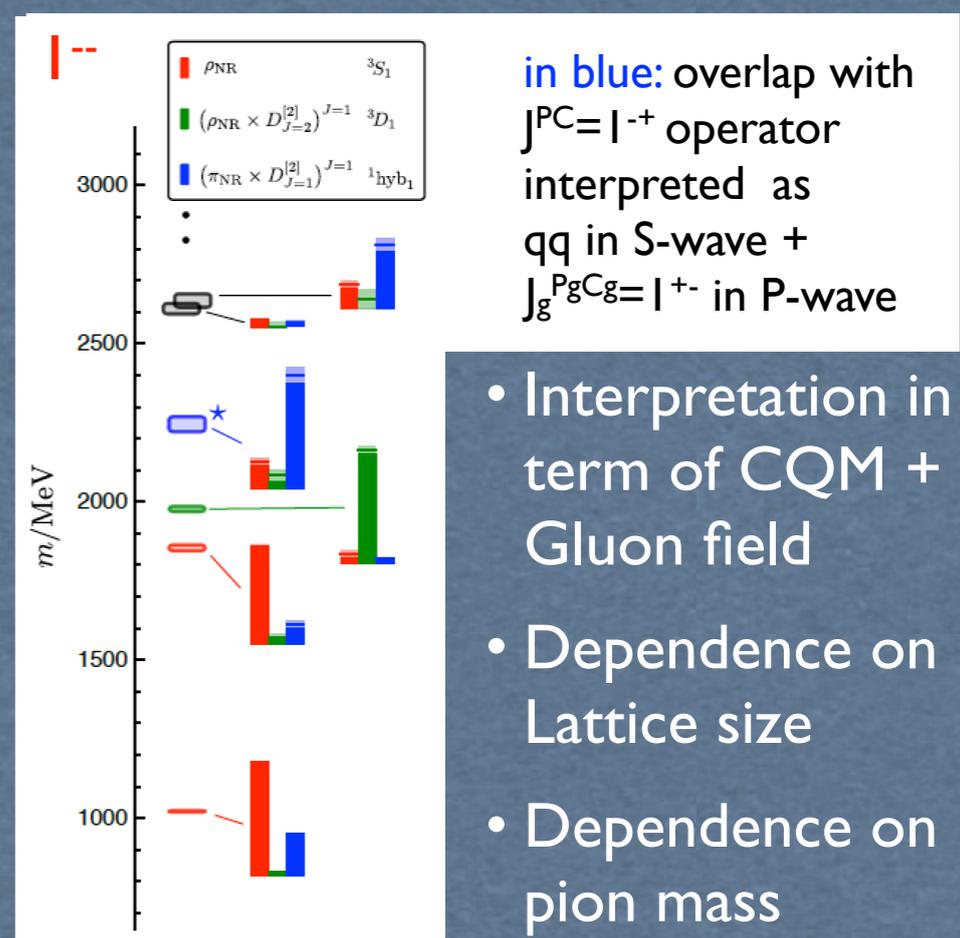
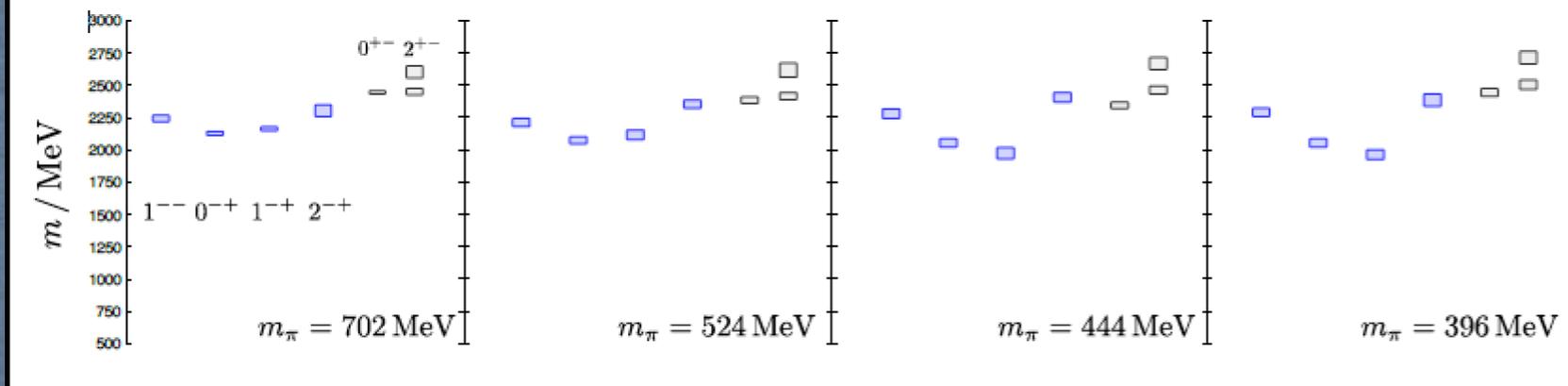
qq in P-wave +
 $J_g^{PgCg} = 1^{+-}$ in P-wave

Lightest multiplet
 $0^{+-}, (1^{+-})^3, (2^{+-})^2, 3^{+-}, (0, 1, 2)^{++}$

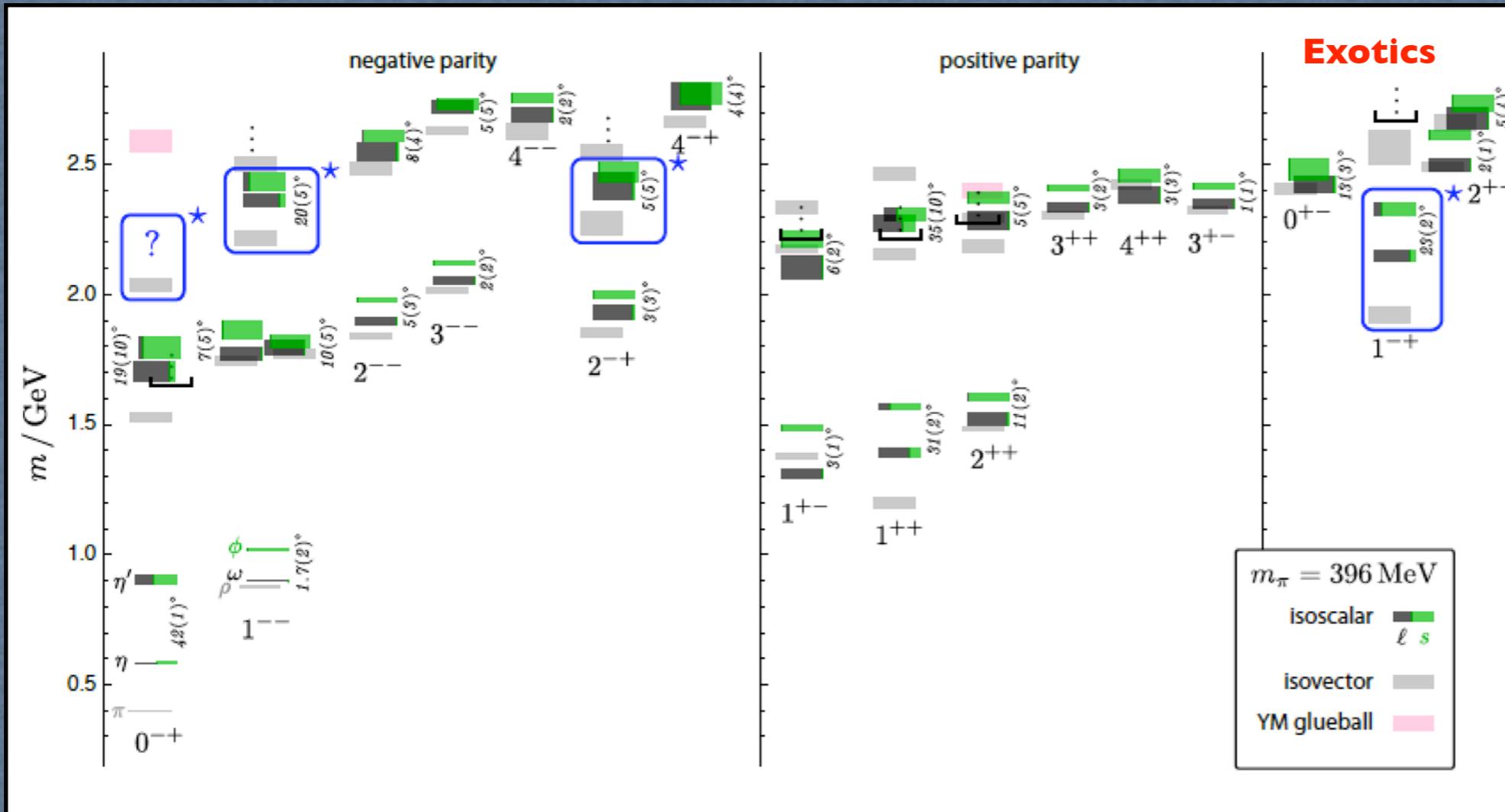
Lattice QCD calculations



J.Dudek et al Phys.Rev.D82 (2010) 034508 J.Dudek et al., Phys. Rev. D84, 074023 (2011)



QCD Lattice calculations



Lattice-QCD predictions for the lowest hybrid states

$0^{+-} \sim 2.0 \text{ GeV}$

$1^{-+} \sim 1.6 \text{ GeV}$

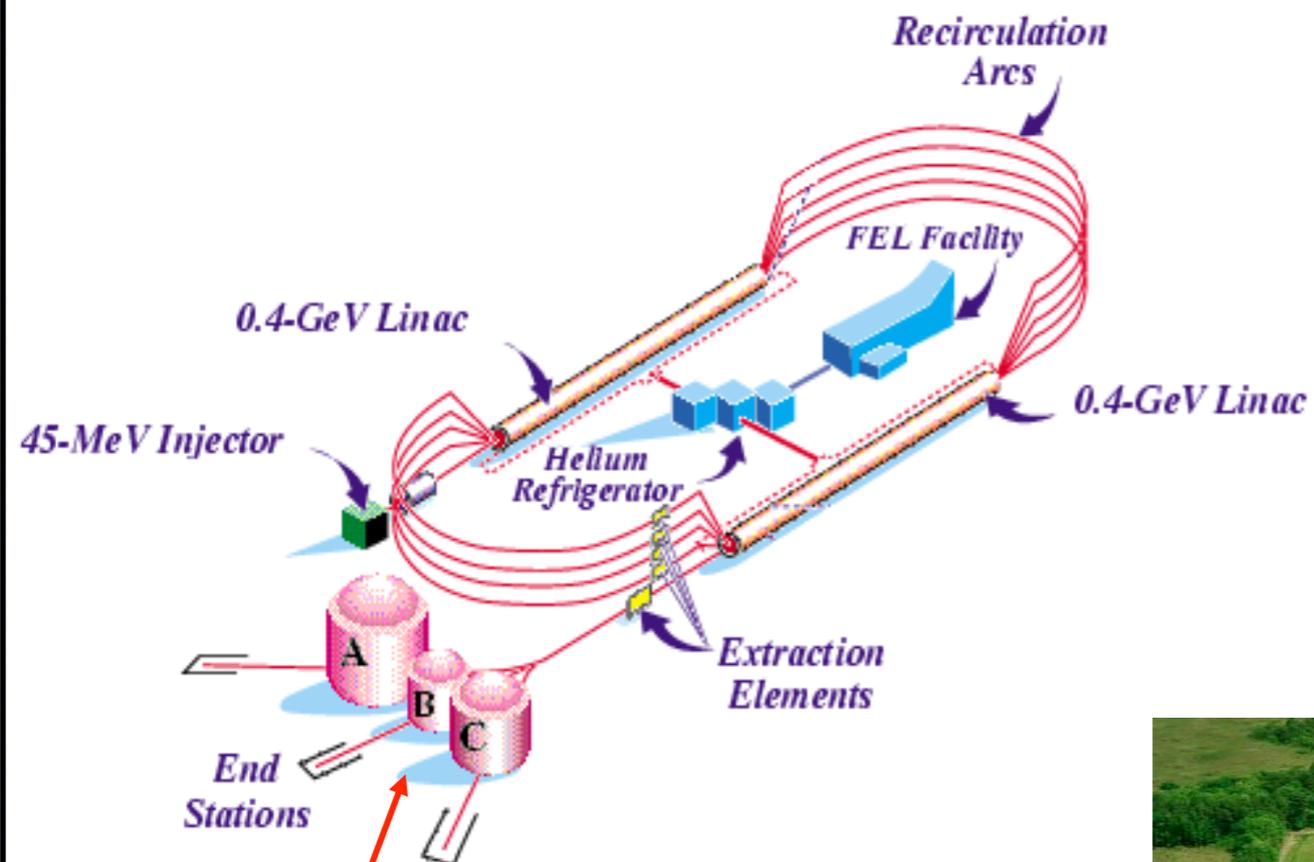
Hybrid mesons and glueballs mass range:

1.4 GeV - 3.0 GeV

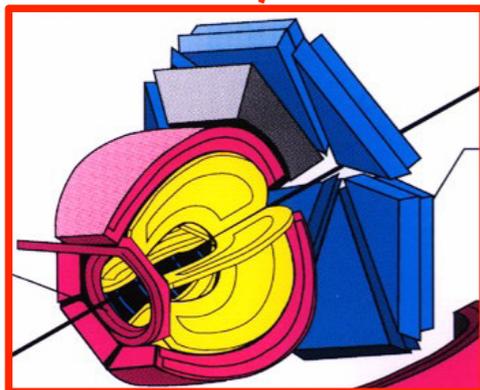
This mass range is accessible in photoproduction experiments with a beam energy in the range $5 \text{ GeV} < E_\gamma < 12 \text{ GeV}$

Perfectly matched to JLab I2 energy!

Jefferson Lab (yesterday)



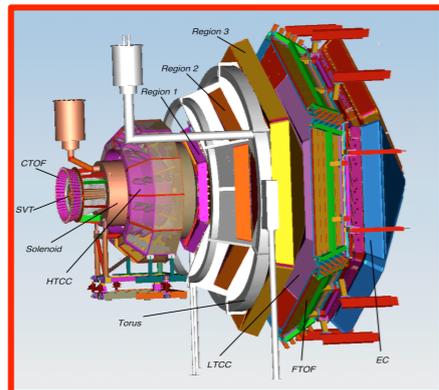
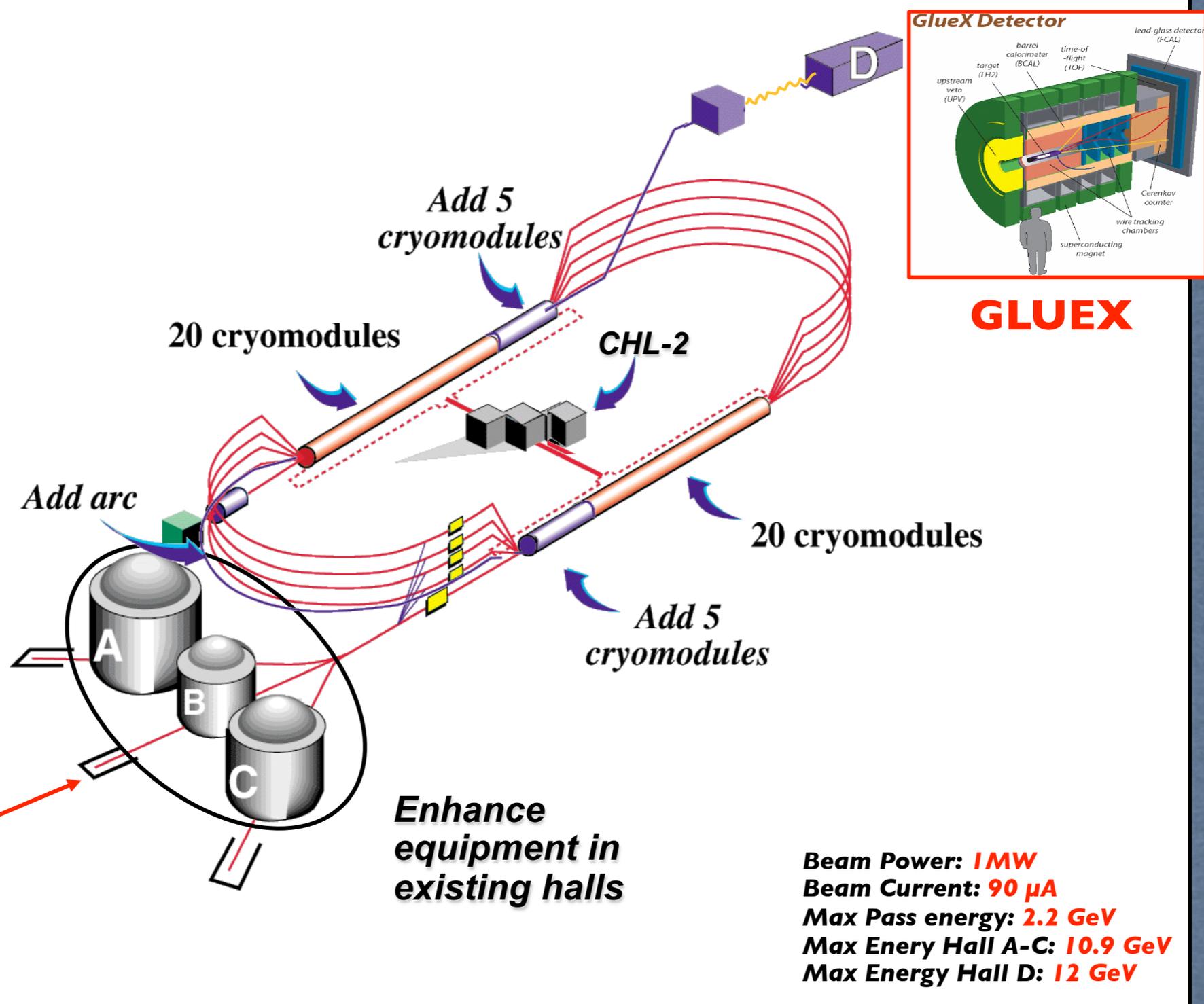
E_{\max}	$\sim 6 \text{ GeV}$
I_{\max}	$\sim 200 \mu\text{A}$
Duty Factor	$\sim 100\%$
σ_E/E	$\sim 2.5 \cdot 10^{-5}$
Beam P	$\sim 80\%$
E_γ	$\sim 0.8\text{-}5.7 \text{ GeV}$



CLAS



Jefferson Lab at 12 GeV



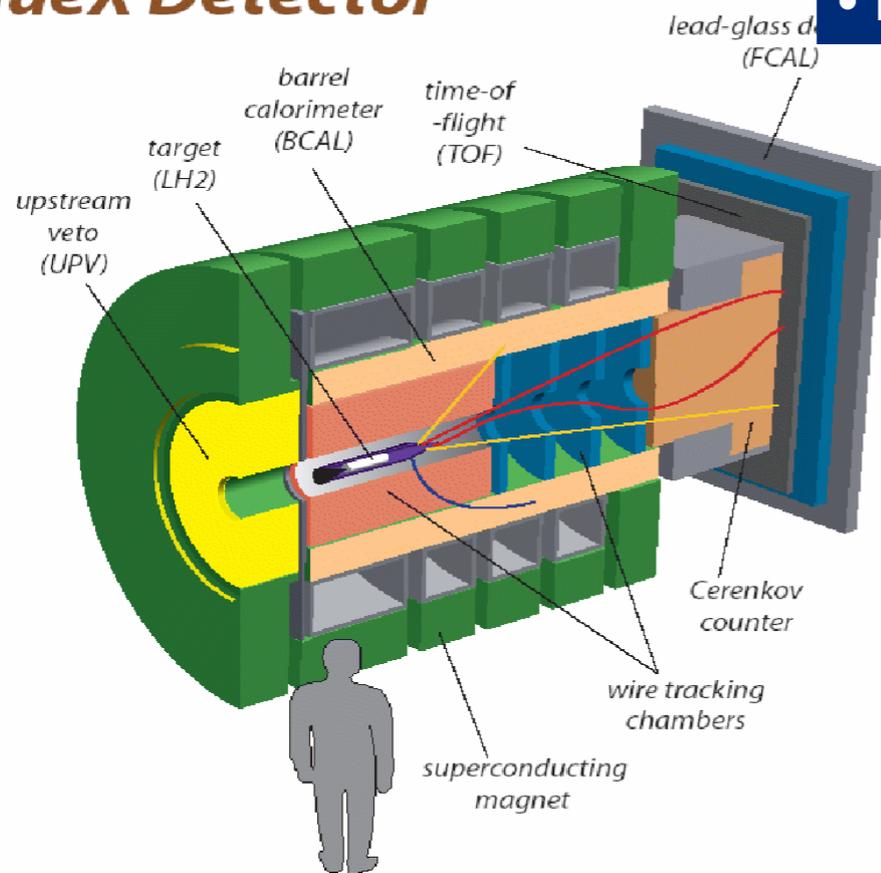
CLAS12

Meson spectroscopy with photons at JLab-12 GeV

- Determination of JPC of meson states requires PWA
- Decay and production of exclusive reactions
- Good acceptance, energy resolution, particle identification

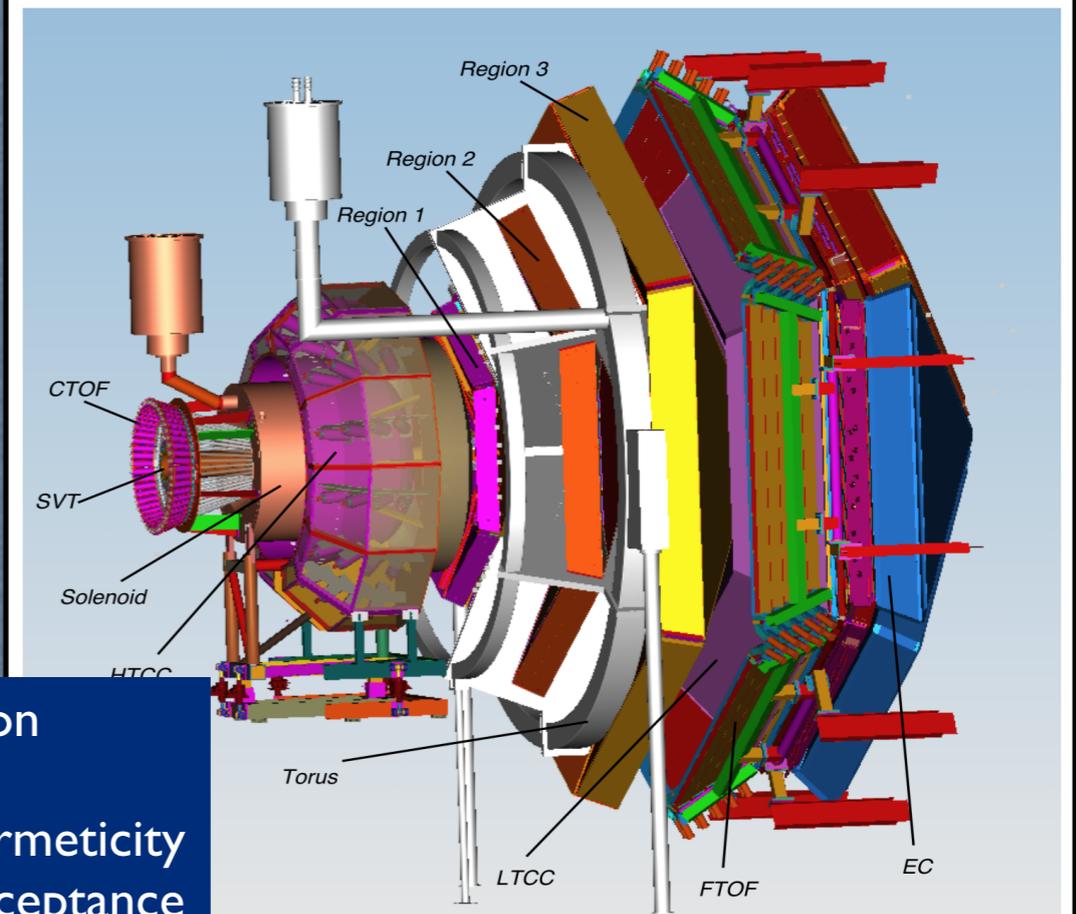
Hall-D - GlueX Detector

GlueX Detector



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

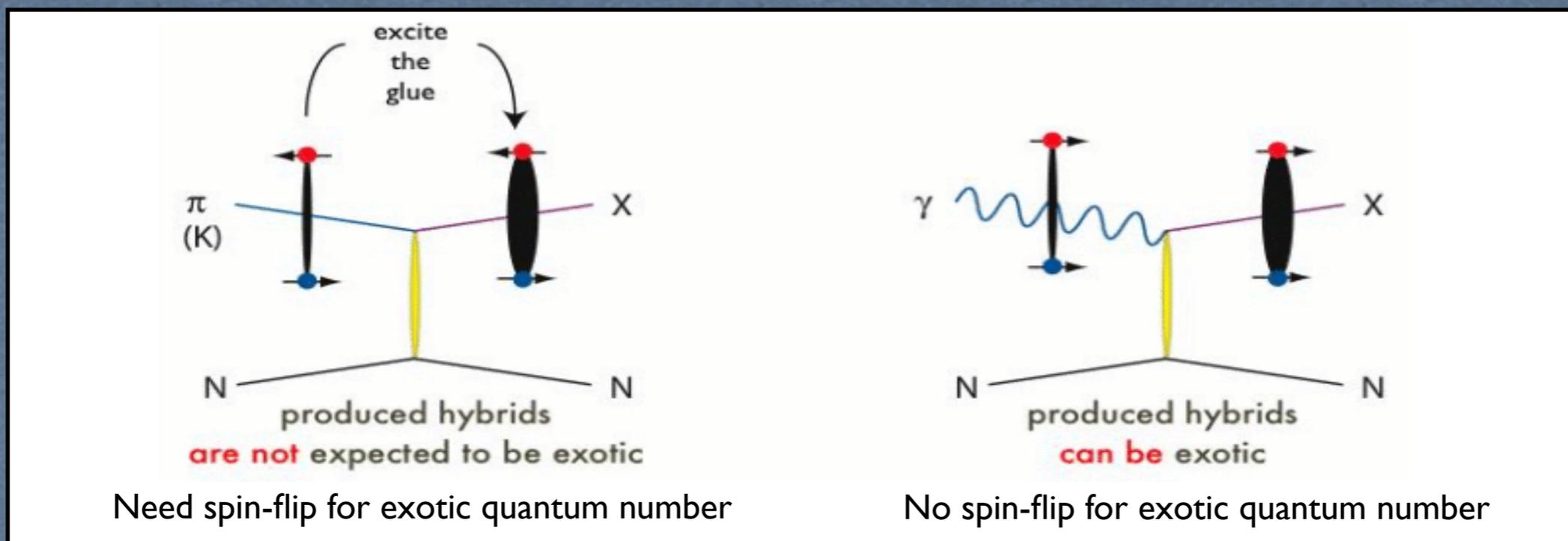
Hall-B - CLAS12 Detector



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

Why photoproduction

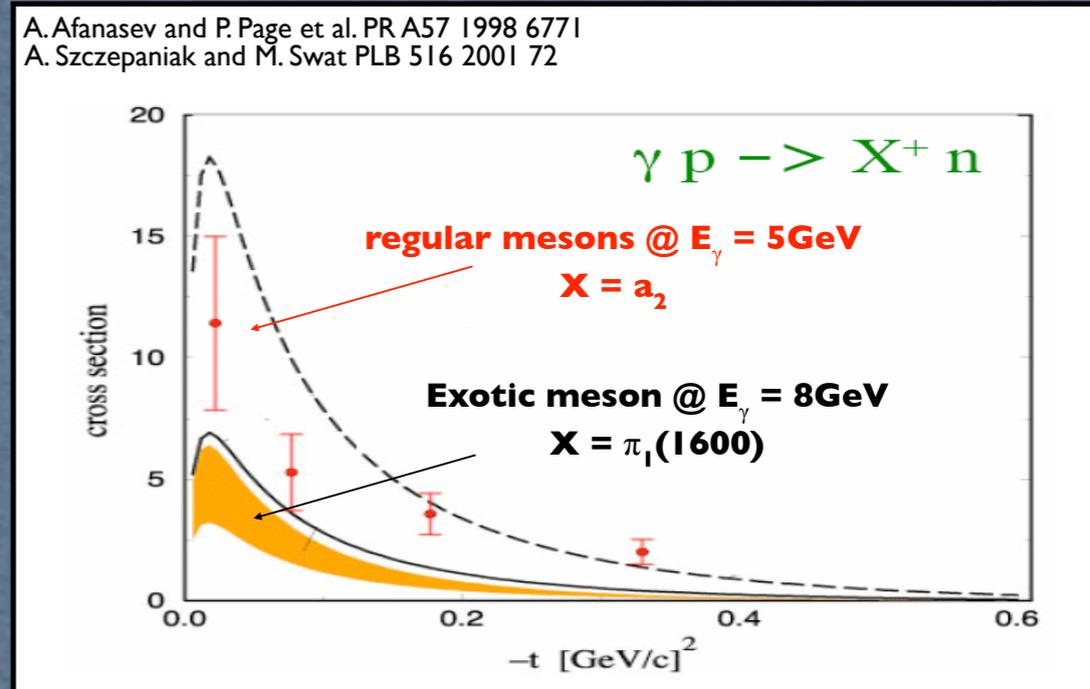
★ Photoproduction: exotic J^{PC} are more likely produced by $S=1$ probe



★ Linear polarization acts like a filter to disentangle the production mechanisms and suppress bg

★ Production rate for exotics is expected comparable as for regular mesons

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



Meson spectroscopy with photons at JLab-12GeV

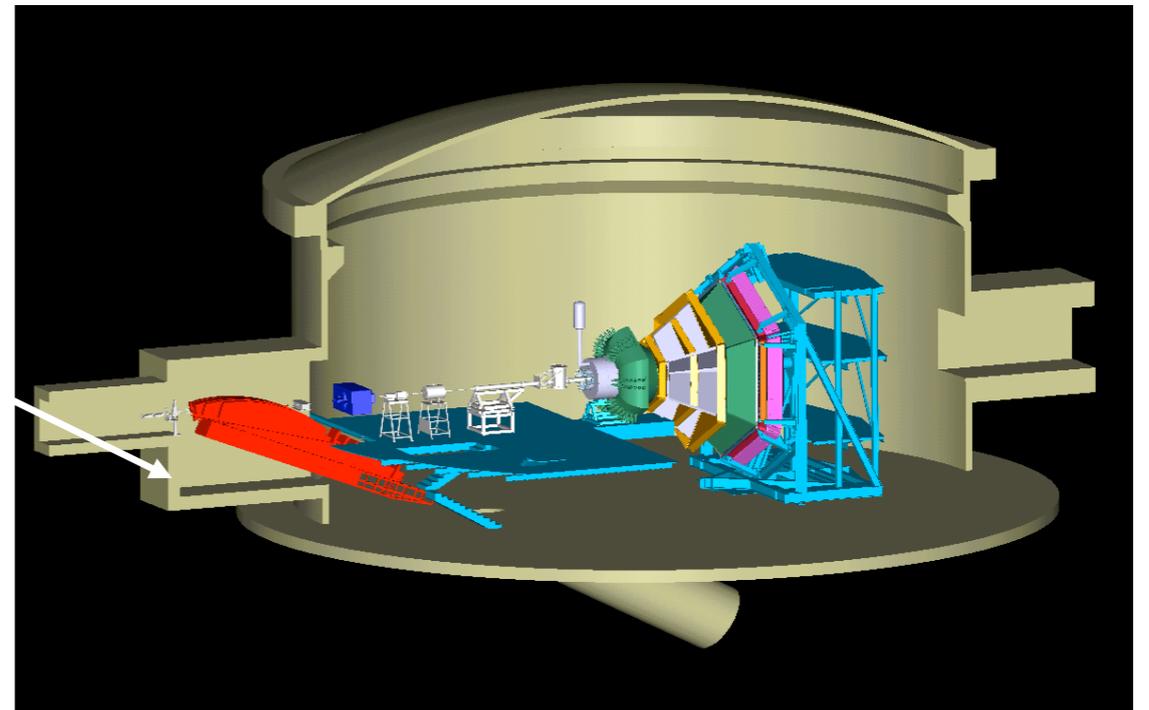
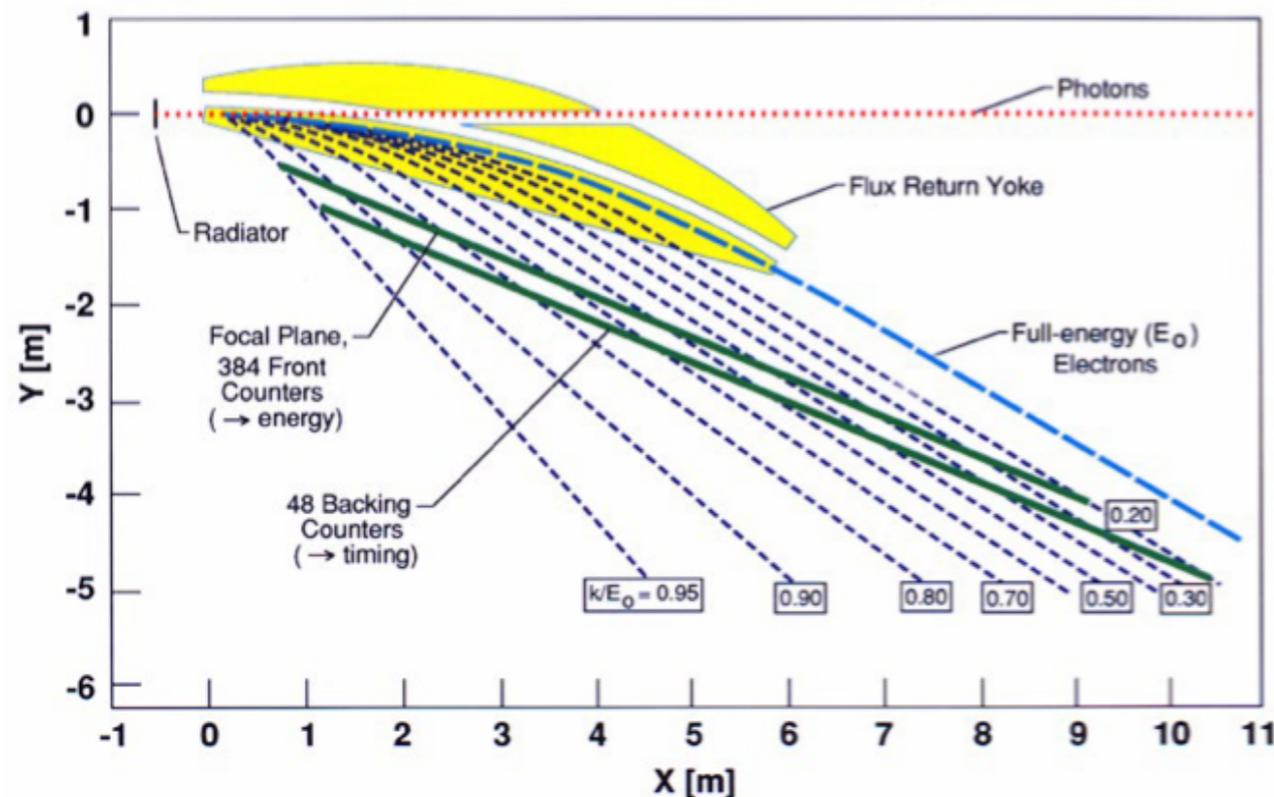
Photon beam requirement

- ★ 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

With a 12 GeV electron beam only few choices

- Bremsstrahlung (Hall-D)
- Low Q^2 electroproduction (Hall-B)

The Hall-B real photon tagger



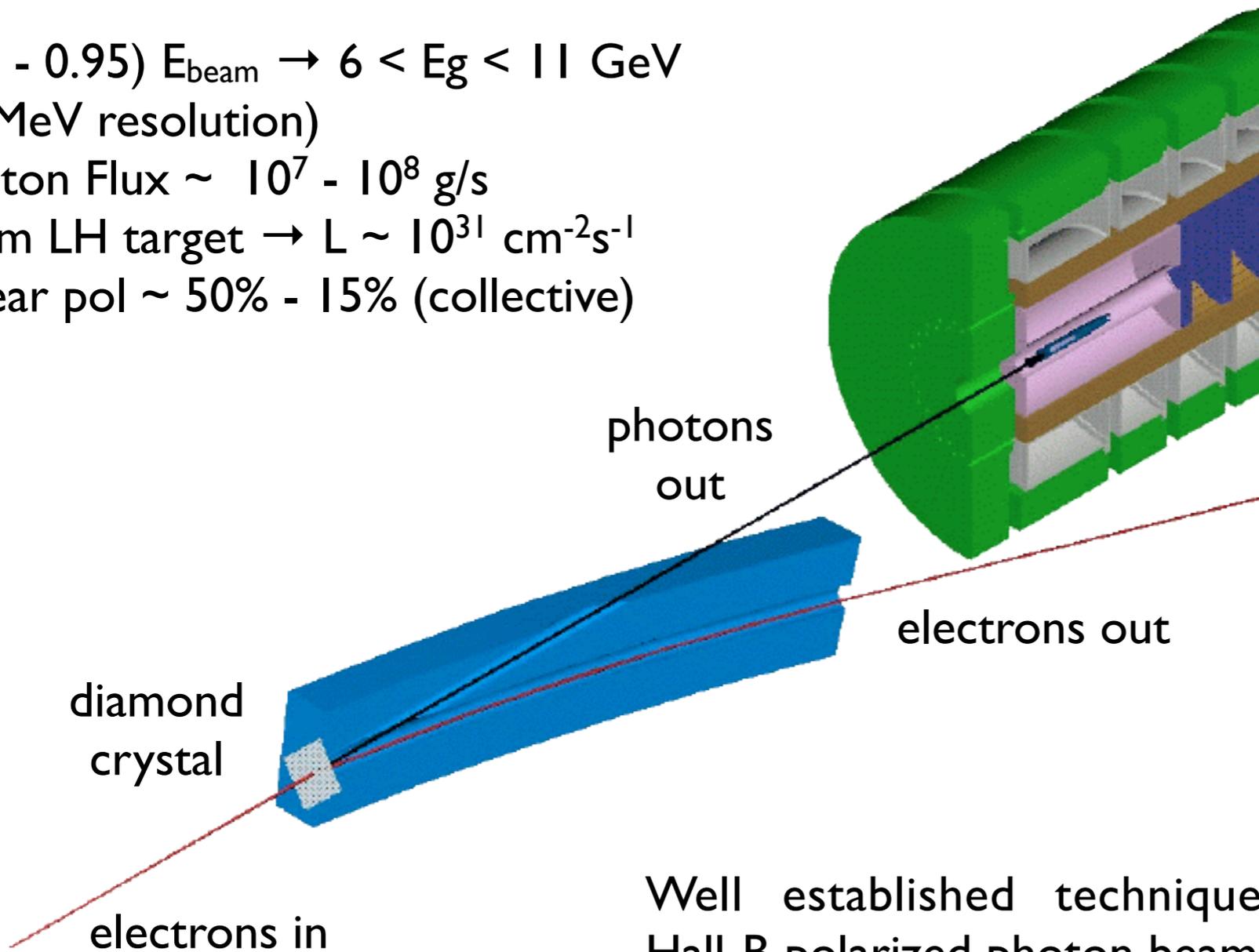
The Hall-B existing dipole magnet can not deflect the 11 GeV primary beam on the beam-dump

Meson spectroscopy with photons at JLab-12GeV

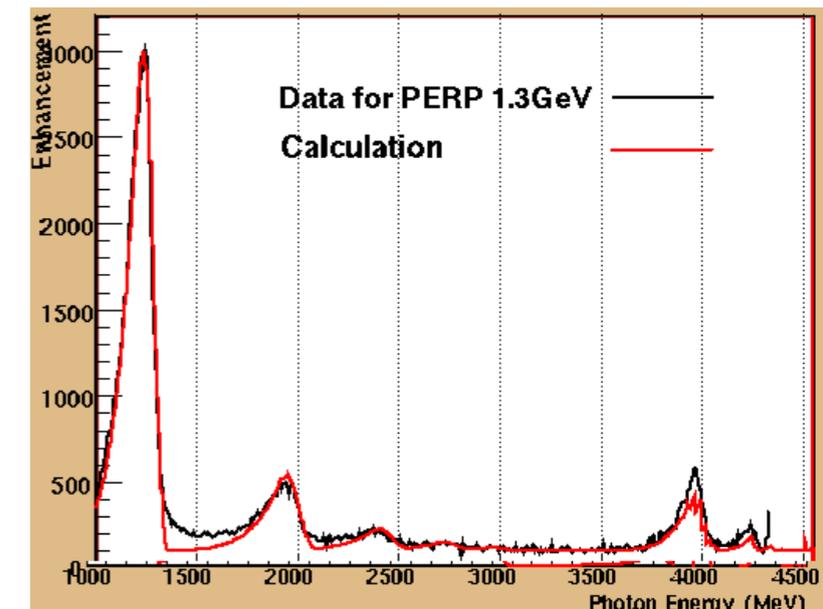
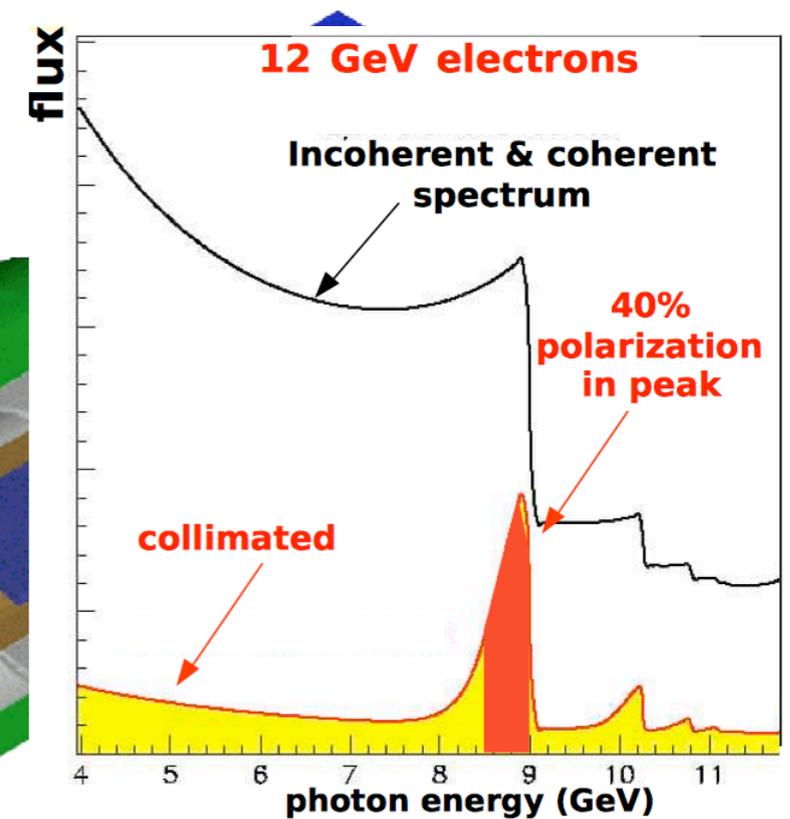
Coherent tagged Bremsstrahlung in Hall D

Performance

$(0.5 - 0.95) E_{\text{beam}} \rightarrow 6 < E_{\text{g}} < 11 \text{ GeV}$
 (10MeV resolution)
 Photon Flux $\sim 10^7 - 10^8 \text{ g/s}$
 30cm LH target $\rightarrow L \sim 10^{31} \text{ cm}^{-2}\text{s}^{-1}$
 Linear pol $\sim 50\% - 15\%$ (collective)



Well established technique:
Hall-B polarized photon beam



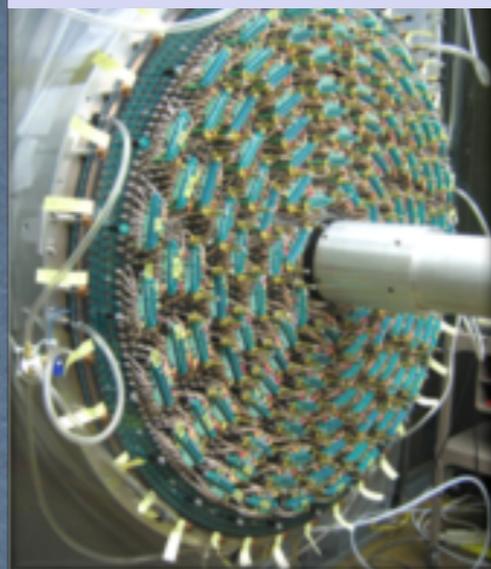
GLUEX in Hall-D



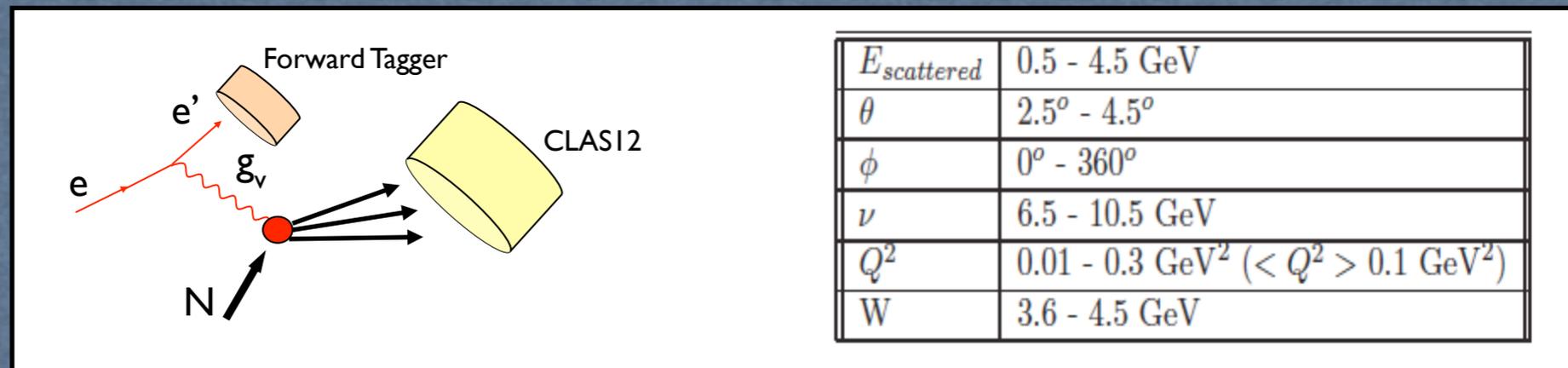
Hall D Forward Drift Chamber
(Jlab)



Hall D Central Drift Chamber
(Carnegie Mellon)



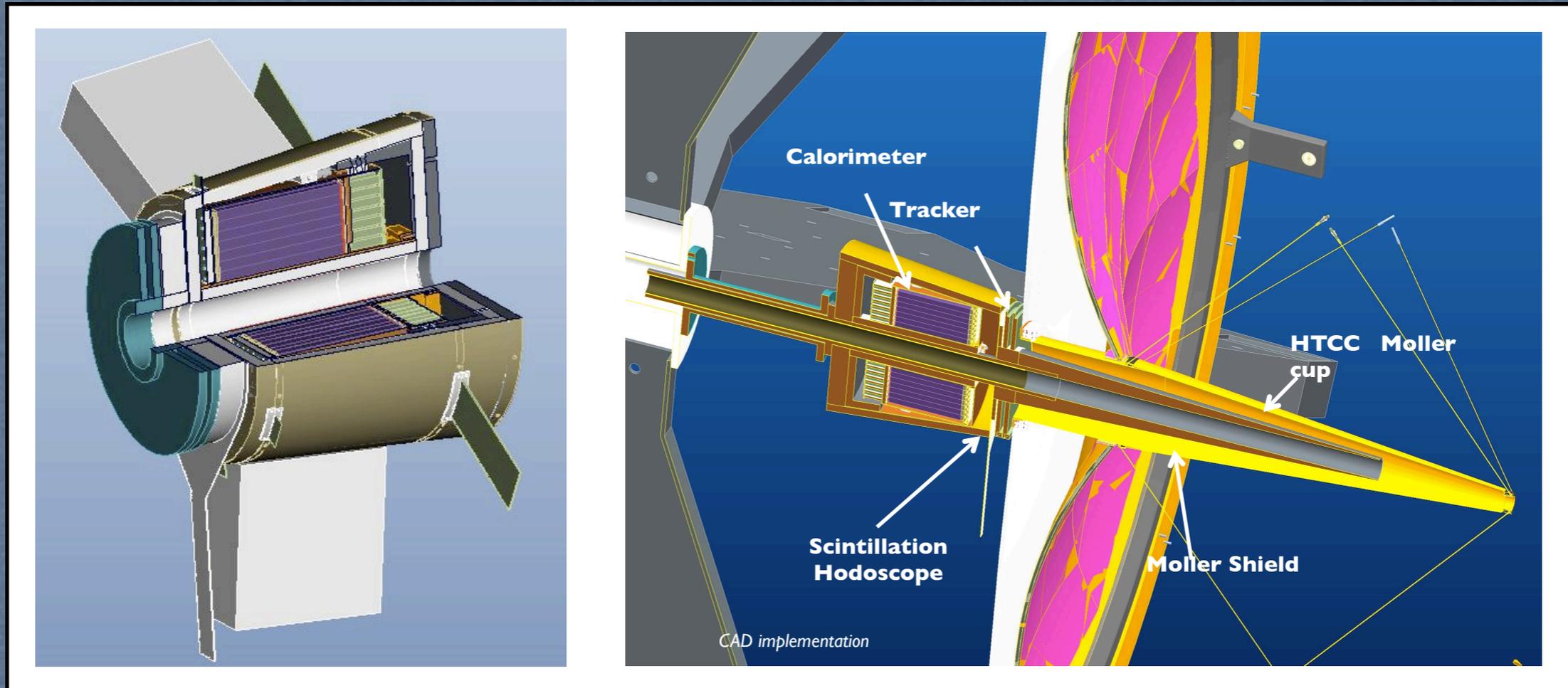
Quasi-real photoproduction with CLAS12 (Low Q^2 electron scattering)



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

Complementary to Hall-D (GLUEX)

The Forward Tagger for CLAS12

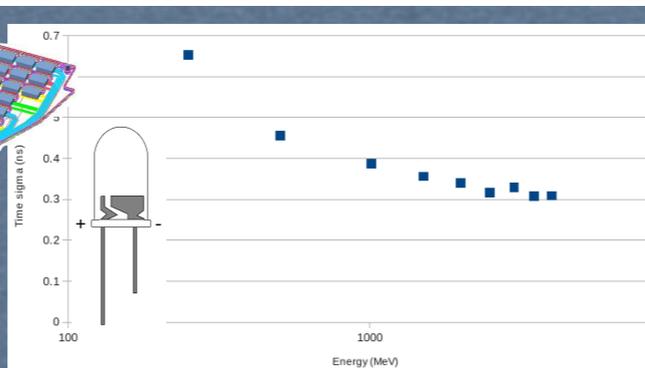
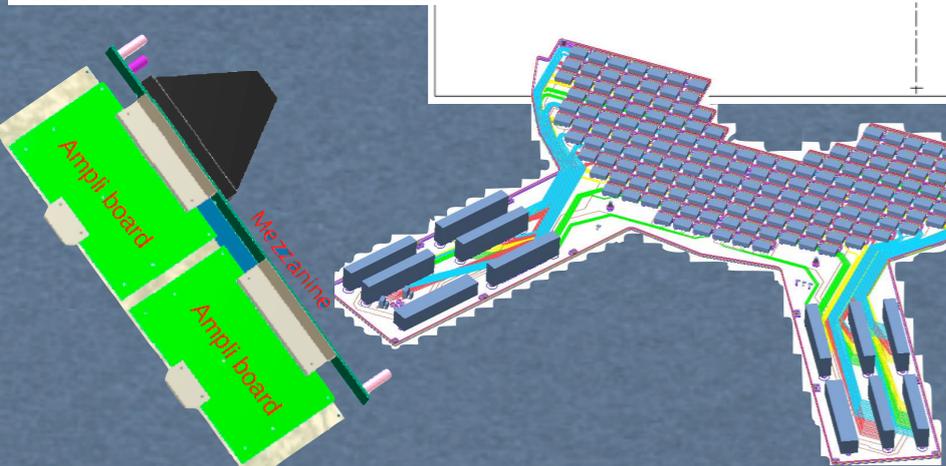
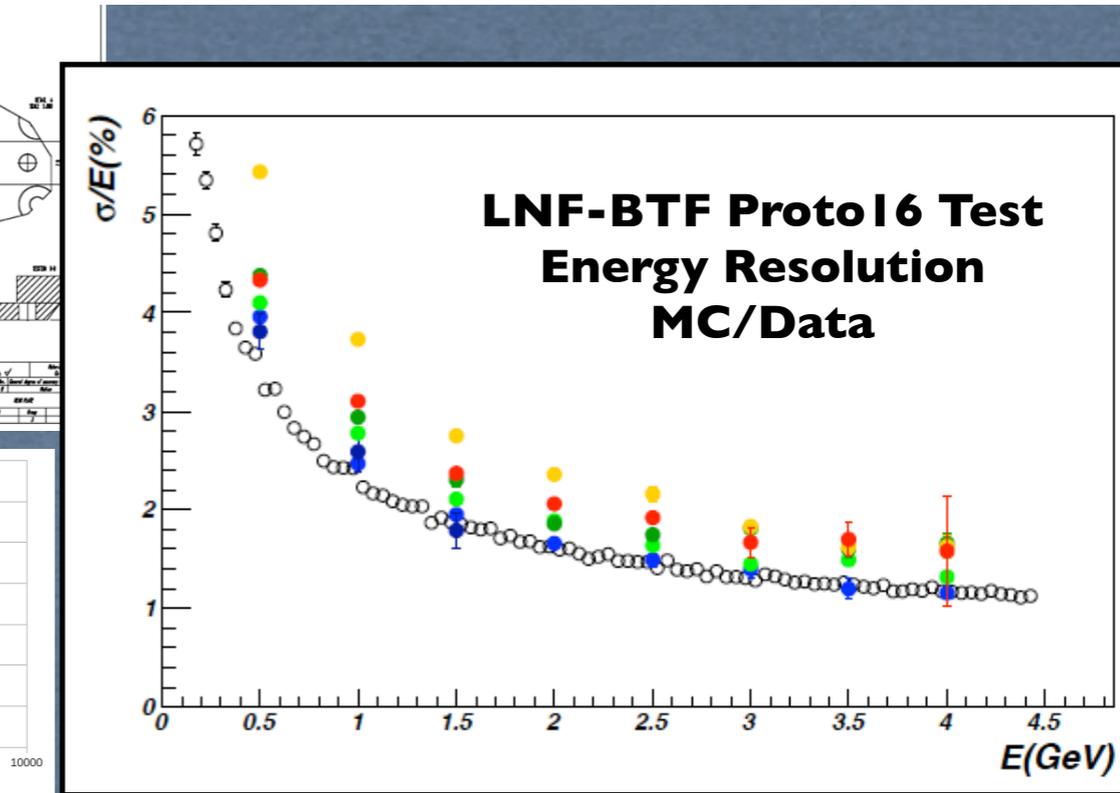
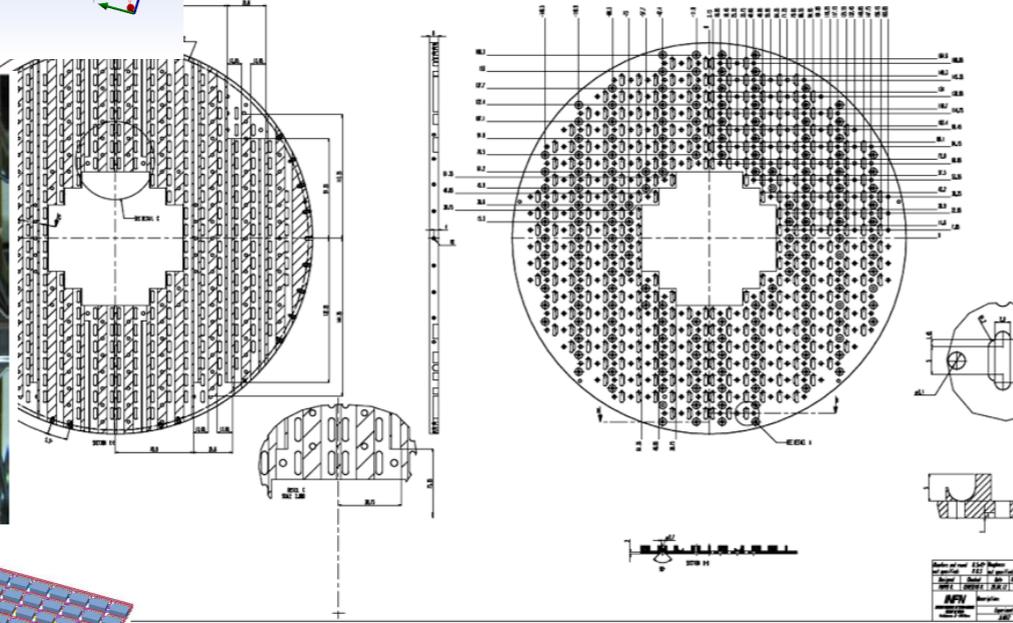
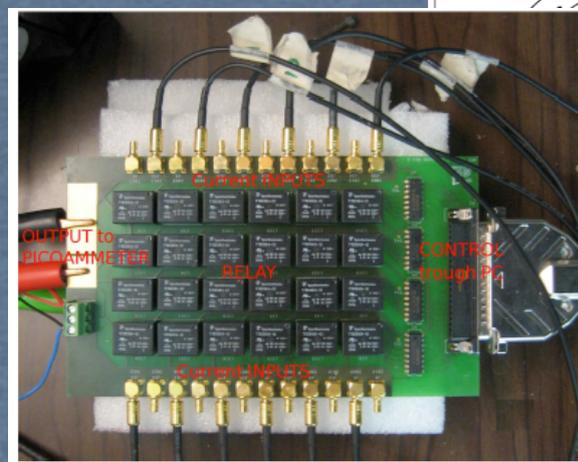
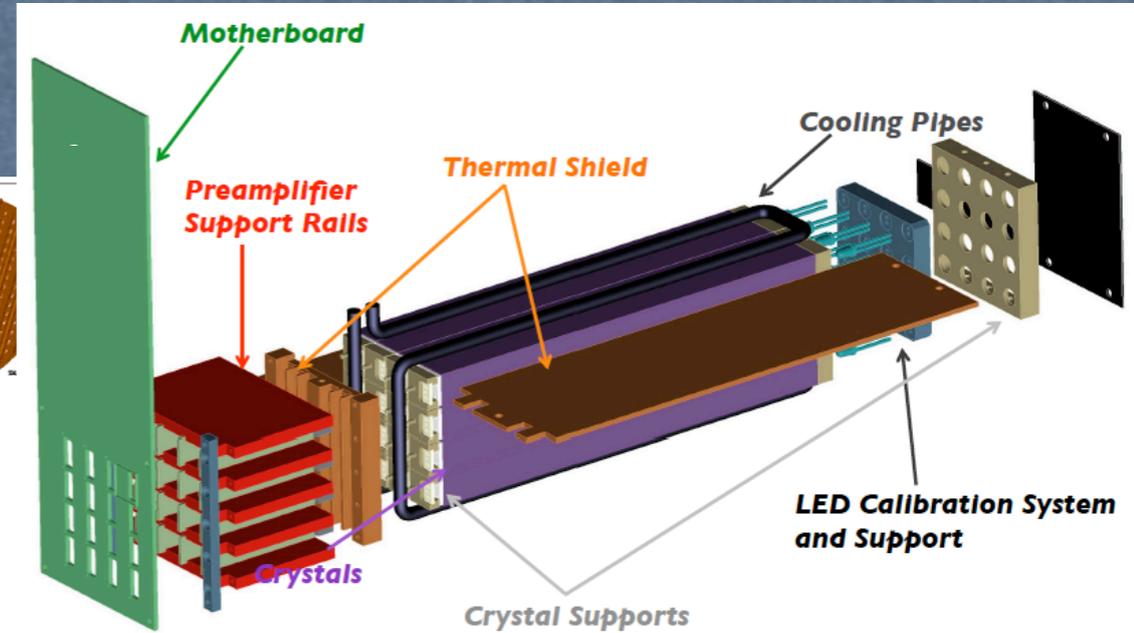
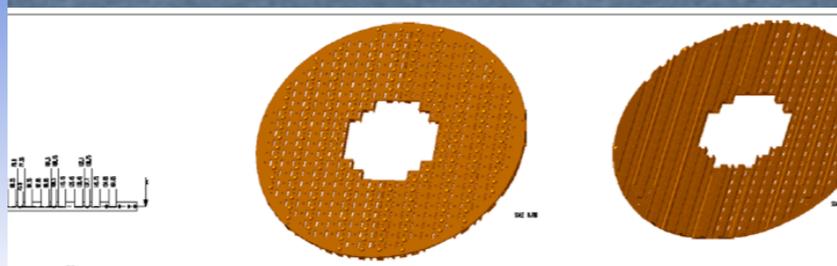
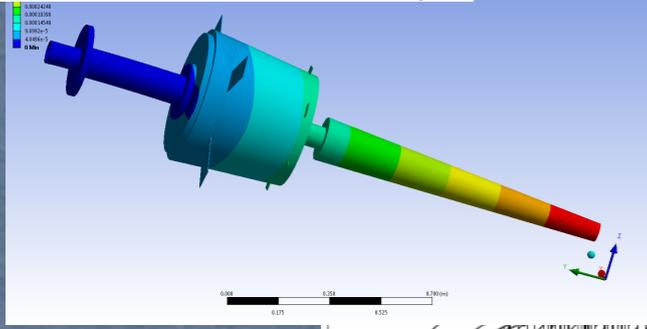
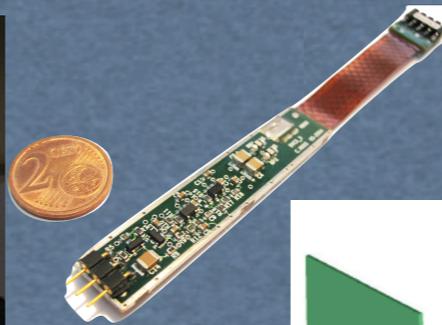
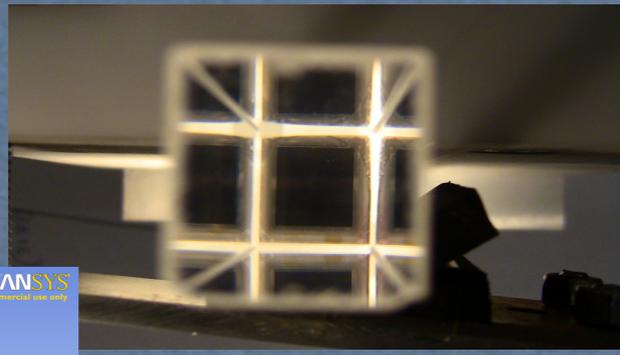
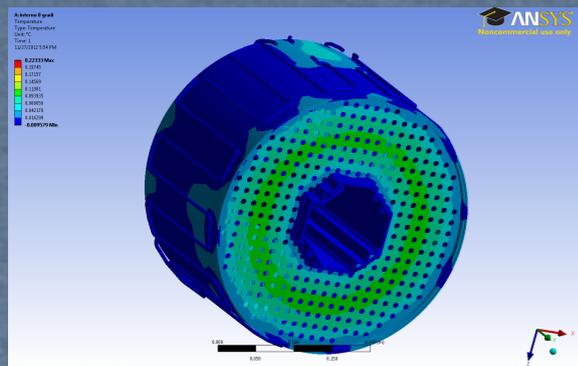


FT-Cal: PbWO_4 calorimeter
 electron energy/momentum
 Photon energy ($\nu = E - E'$)
 Polarization $\varepsilon^{-1} \approx 1 + \nu^2/2EE'$

FT-Hodo: Scintillator tiles
 veto for photons
Edinburgh+JMU+NSU

FT-Trck: MicroMegas detectors
 electron angles and polarization plane
Saclay + Ohio

FT design, prototyping and construction

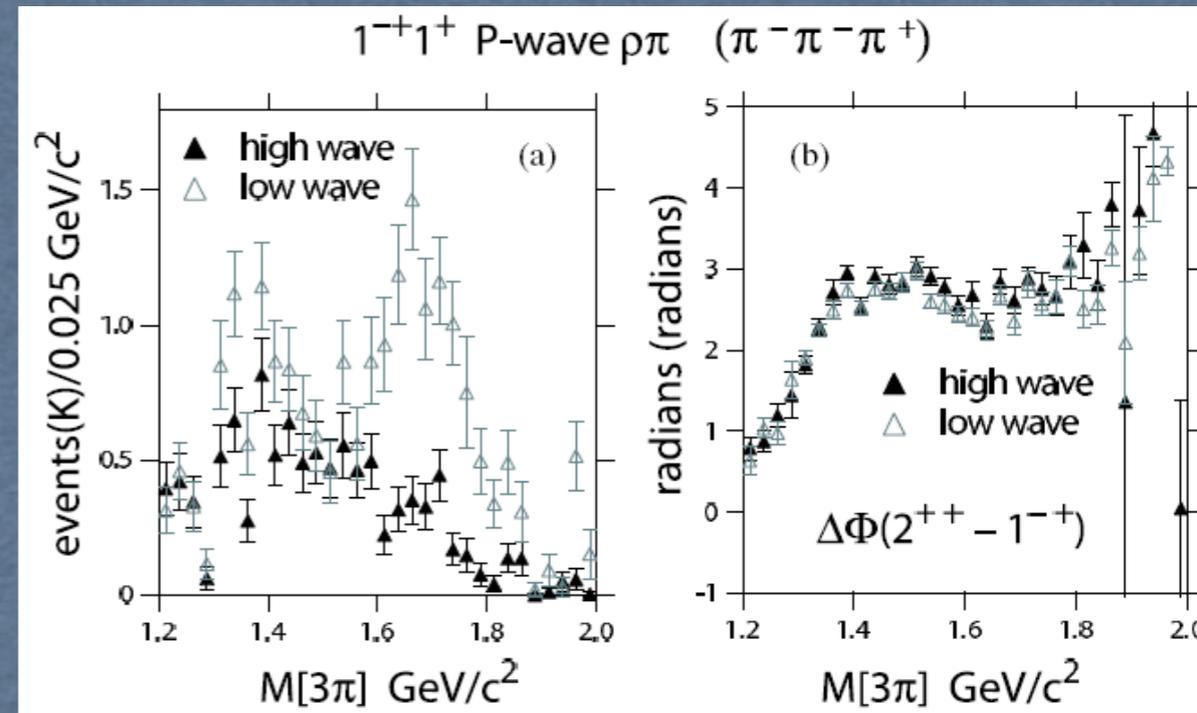


Partial Wave Analysis (PWA)

Reference reaction

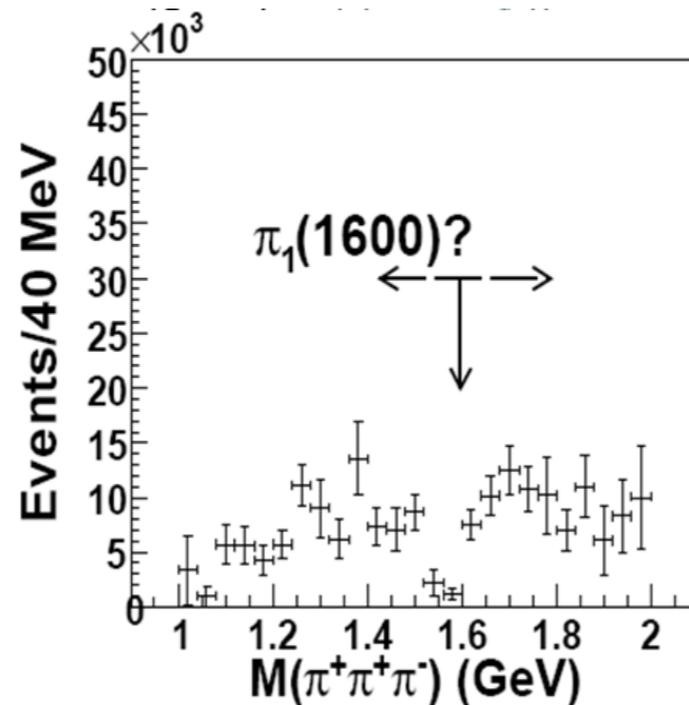
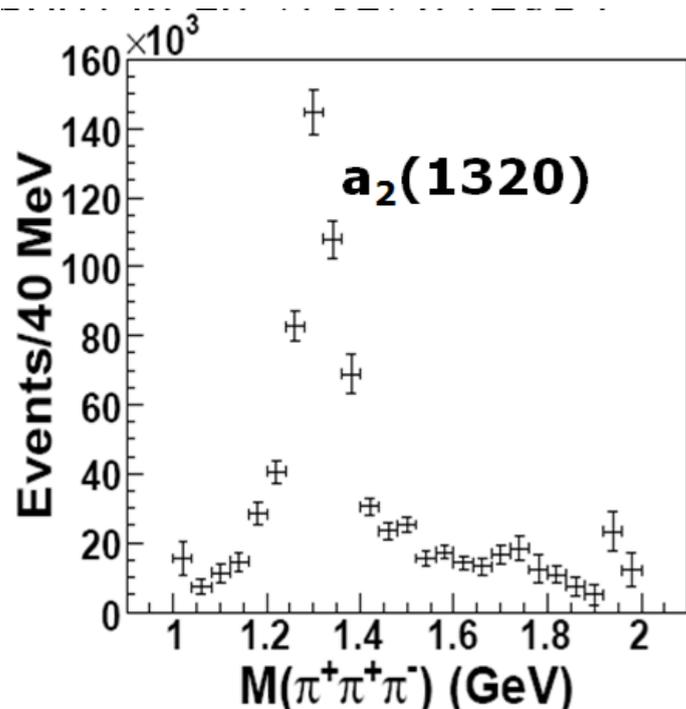


- * Possible evidence of exotic meson $\pi_1(1600)$ in $\pi^- p \rightarrow p \pi^- \pi^- \pi^+$ (E852-Brookhaven)
- * Not confirmed in a re-analysis of a higher statistic sample
- * Now confirmed by Compass
- * Simple final state with low bg



CLAS6

M.Nozar et al. PRL 102 102002 (2009)



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!

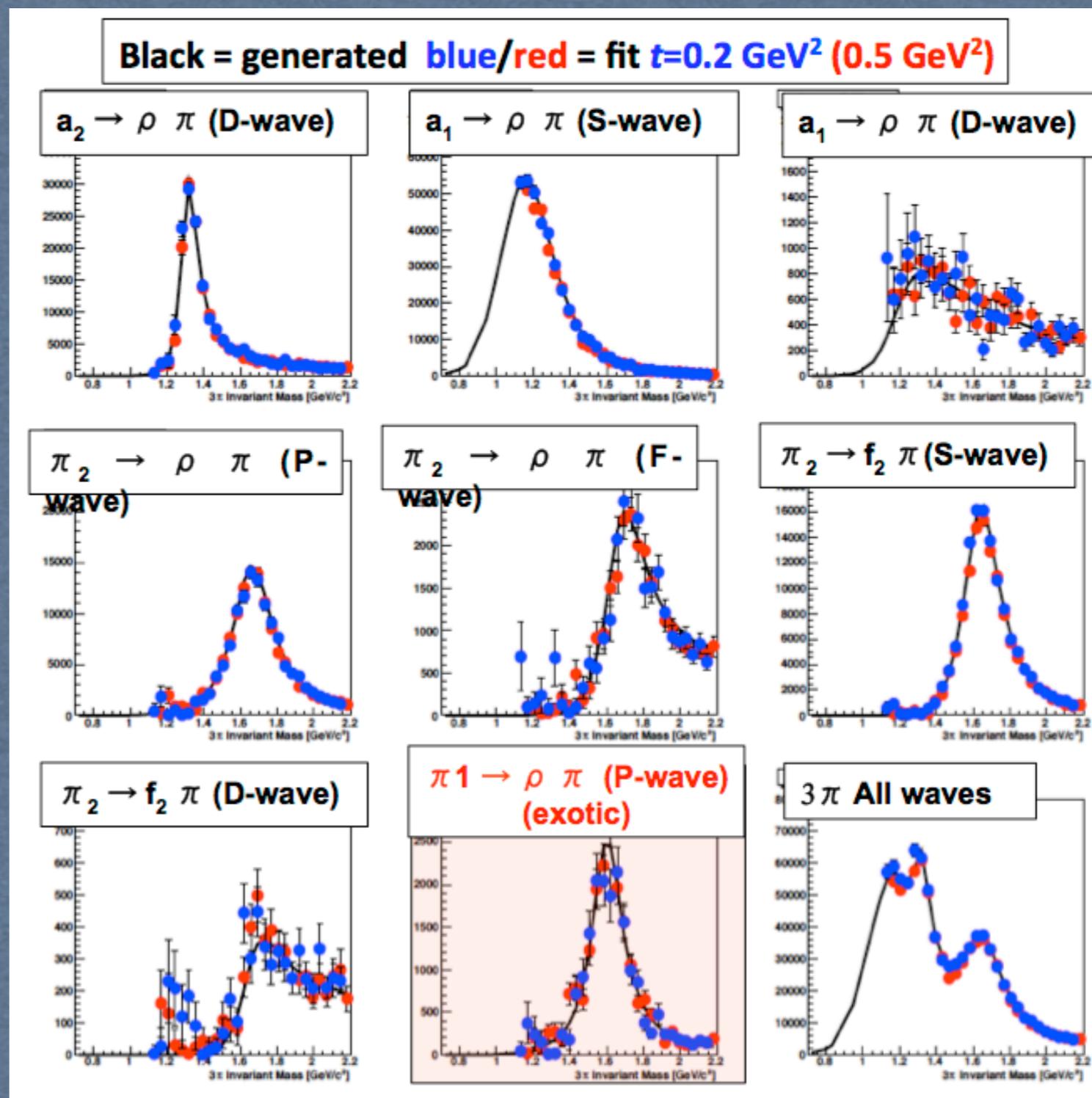
Another example is $\gamma p \rightarrow p \pi^+ \pi^-$
(R. De Vita talk yesterday)
and $\gamma p \rightarrow p K^+ K^-$ (S.Lombardo)

PWA with 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!



Data analysis: PWA and beyond

- ★ The unprecedented statistic and data quality requires an adequate analysis
- ★ PWA is on the boundary between experiment and theory
- ★ We need to develop a strong analysis framework

- * Beyond Isobar-Model
coupled-channel analysis

- * Analyze existing photoproduction data:

$\pi, \eta, \eta', \pi\pi, \pi\eta, \pi\eta', \omega\pi \dots$

- * Include baryon vertex in the amplitude description

$N\pi, N\eta, N\eta', N\pi\pi, N\pi\eta, N\pi\eta', N\omega\pi \dots$

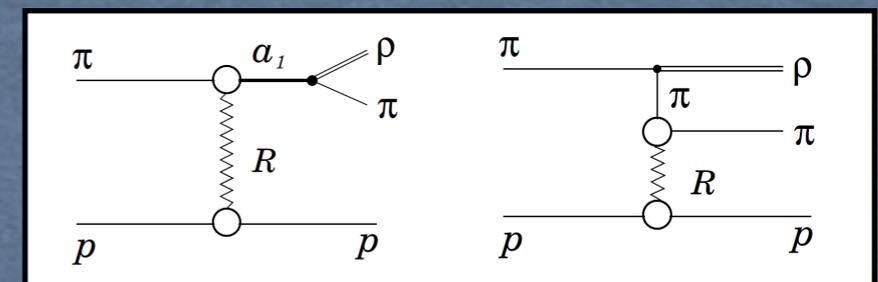
- * Use Regge theory to parametrize amplitude properties:
analyticity, unitarity, FSI

- * Use a combination of :

- Regge Born with low partial wave removed
- Explicit resonance parametrization in low waves
- FESR to constrain parametrized waves

- * Exploit the high statistics and accuracy of new data set
PWA in s and t bins + polarization observables (\neq beams)

- * Effective Lagrangians can be used now to provide a microscopic interpretation



**The ultimate test:
LQCD predictions**

Desiderata from LQCD:
calculation of 'observables' obtained within Regge theory

How to develop a strong analysis framework?

★ Implementing reliable amplitudes

- Check amplitudes with existing data

★ Developing common tools and procedures:

- Common PWA framework across different experiments (eg AmpTools)
- Wider data access and distribution
- Computing: fitting procedures, GPUs, etc.

★ Learning & teaching

- Promote exchanges between experimentalists and theorists
- “HS data analysis for dummies” and “HS theory revealed”
- Workshops and schools to share expertise and establish common rules

Prepare the framework for future experiments

Establish shared procedures and tests to claim a discovery of new physics

Promote a two-ways communication
EXP-THE

ECT* European Centre for Theoretical Studies in Nuclear Physics and Related Areas

□ PEOPLE @ ECT □ REACHING ECT* □ INFORMATION FOR VISITORS

2011 Conferences, Workshops

Amplitude Analysis in Hadron Spectroscopy

Registration Poster Program Talks Rep

Organizers:

- A. Szczepaniak (Indiana University)
- C. Hanhart (Institut fuer Kernphysik Forschungszentrum Jülich)
- M. Pennington (Jefferson Laboratory)
- E. Santopinto (INFN, Genova)
- U. Wiedner (Ruhr University)

Secretary in charge: Ines Campo

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Jefferson Lab Advanced Study Institute

EXTRACTING PHYSICS FROM PRECISION EXPERIMENTS: Techniques of Amplitude Analysis

WILLIAM & MARY UNIVERSITY, VIRGINIA, USA

May 30th, 2012 (Monday)

June 13th, 2012 (Tuesday)

Analysis of precision experiments at BESIII, JLAB@12 GeV, and PANDA@FAIR. Thomas Jefferson Accelerator Facility (JLAB) is organizing a week-long course covering *Techniques of Amplitude Analysis*, aimed at postdoctoral researchers and advanced doctoral students in nuclear and particle physics.

LECTURERS:

- Suh-Wei Chung (NSL/USTC)
- Jozsef Dudek (JLab)
- Baibhav Kishor (JLab)
- Hsiang-Long Lee (CUHK)
- Ben Meadows (CERN)
- Arturo Palano (JLab)
- Stavros Papakostas (JLab)
- Michael Pennington (JLab)
- Ronald Workman (JLab)

HASPECT week - Genova - November 27 - 30, 2012

Participants: Marco Battaglieri, Andrea Celentano, Raffaella De Vita, Stuart Fegan, Sal Lombardo, Vincent Vassallo, Jean-Marc Laget, Adam Szczepaniak, Andrea Vassallo

Remote connection: Dave Ireland

Agenda DRAFT

Tuesday, November 27

- Vincent and Andrea meeting for eta-pi channel
- Sal and Marco meeting for moments analysis

Wednesday, November 28

- Morning
 - 10:00 Beginning of the meeting
 - 10:10 - 12:30: the MesonEx physics program
 - Golden channels
 - Systematic measurements
 - Systematic amplitude calculations
 - Tasks assignment and resources: PhD projects, collaborations ...
- Afternoon: Individual meetings
- 14:00 - 15:00 Focused discussions: Adam, Elena, Marco on haspect day at JLab
- 15:00 - 16:00 Focused discussions: Andrea V. Elena and Adam
- 16:00 - 17:00 Focused discussions: Jean-Marc, Elena, Andrea V. and Vincent on Regge theory

Thursday, November 29

- Morning
 - 9:00 - 10:30 Individual meetings

International Workshop on NEW PARTIAL WAVE ANALYSIS TOOLS FOR NEXT GENERATION HADRON SPECTROSCOPY EXPERIMENTS

ATHOS 2012

June 20-22, 2012
Camogli, Italy
www.ge.infn.it/~athos12

General Information

The International Workshop on Analysis Tools for next generation Hadron Spectroscopy (ATHOS2012) will take place in Camogli, Italy, from June 20th to June 22nd, 2012.

The Workshop follows previous meetings organized at ECT* - Trento in 2011 and INT - Seattle in 2009, focused on the development of amplitude analysis tools for meson and baryon spectroscopy, and complements other programs as the school on Extracting physics from precision experiments: Techniques of Amplitude Analysis organized by the Jefferson Lab Advanced Study Institute from May 30th to June 13th.

The goal of the workshop is to bring together experts from the experimental and theoretical community to discuss the current issues in the field.

The format of the Workshop is based on plenary sessions including overview talks, a number of topical presentations and several discussion sessions with the aim of summarizing the state-of-the-art in hadron spectroscopy, highlighting the open issues and discussing the development of new tools for next generation experiments.

The Organizers:

- Marco Battaglieri (INFN)
- Annalisa D'Angelo (Università di Roma Tor Vergata)
- Raffaella De Vita (INFN)
- Denise Glazier (Edinburgh University)
- Mike Pennington (JLab)
- Elena Santopinto (INFN)
- Adam Szczepaniak (Indiana University)

Sponsors:

- INFN
- INDIANA UNIVERSITY
- Jefferson Lab
- THE UNIVERSITY OF EDINBURGH

ATHOS 2013
May 21 - 24 • Kloster Seeon

International Workshop on New Partial-Wave Analysis Tools for Next Generation Hadron Spectroscopy Experiments

METHODS AND TOOLS HEAVY MESON DECAYS

THE LIGHT HADRON SPECTRUM TESTING SYMMETRIES USING PWA

LOCAL ORGANIZING COMMITTEE

- Marco Battaglieri (INFN)
- Annalisa D'Angelo (Università di Roma Tor Vergata)
- Raffaella De Vita (INFN)
- Denise Glazier (Edinburgh University)
- Elena Santopinto (INFN)
- Adam Szczepaniak (Indiana University)

INTERNATIONAL ORGANIZING COMMITTEE

- Christine Barthelemy (INFN)
- Michael Pennington (JLab)
- Klaus Pader (JLab)
- Adam Szczepaniak (Indiana University)
- Shingong Zhu (JLab)

CONTACT INFORMATION: Karin Frank • MAIL: info@athos2013.de • PHONE: +49 89 288 12572 • FAX: +49 89 288 12570 • www.athos2013.de

HASPECT: Act locally but think globally!

Global strategy:

- *Creation of twin and parallel centers for both analysis and theory development
- *Collaboration and exchanges: personnel, short visits, ...
- *Coordination via JLab Pysics Analysis Center
- *Creation of a “Hadron spectrum” working group

Hadron Spectroscopy Portal

HOME EXPERIMENTS ANALYSIS THEORY MESONS LINKS

Jefferson Lab Thomas Jefferson National Accelerator Facility FAIR@GSI CERN Institute of High Energy Physics Chinese Academy of Sciences

This page contains details of how to parametrize two pions isobar.

Two Pions

- Descriptions
- Parametrization
- Applications
- References
- Comments
- Resources

TWO PIONS PARAMETRIZATION

Description

The $\pi\pi$ amplitude depends on two variables, the invariant mass squared s and the scattering angle in the center of mass θ . Final states are not eigenstates of the isospin. For neutral systems we have

$$\pi^0\pi^0 = -\frac{1}{\sqrt{3}}F^{(0)}(s, \theta) + \frac{2}{\sqrt{3}}F^{(2)}(s, \theta),$$

$$\pi^+\pi^- = +\frac{1}{\sqrt{3}}F^{(0)}(s, \theta) + \frac{1}{\sqrt{2}}F^{(1)}(s, \theta) + \frac{1}{\sqrt{6}}F^{(2)}(s, \theta)$$

Charged systems can be decomposed similarly. The isospin functions $F^{(I)}(s, \theta)$ do not depend on the isospin projection. The angular dependence is factorized via a partial wave expansion:

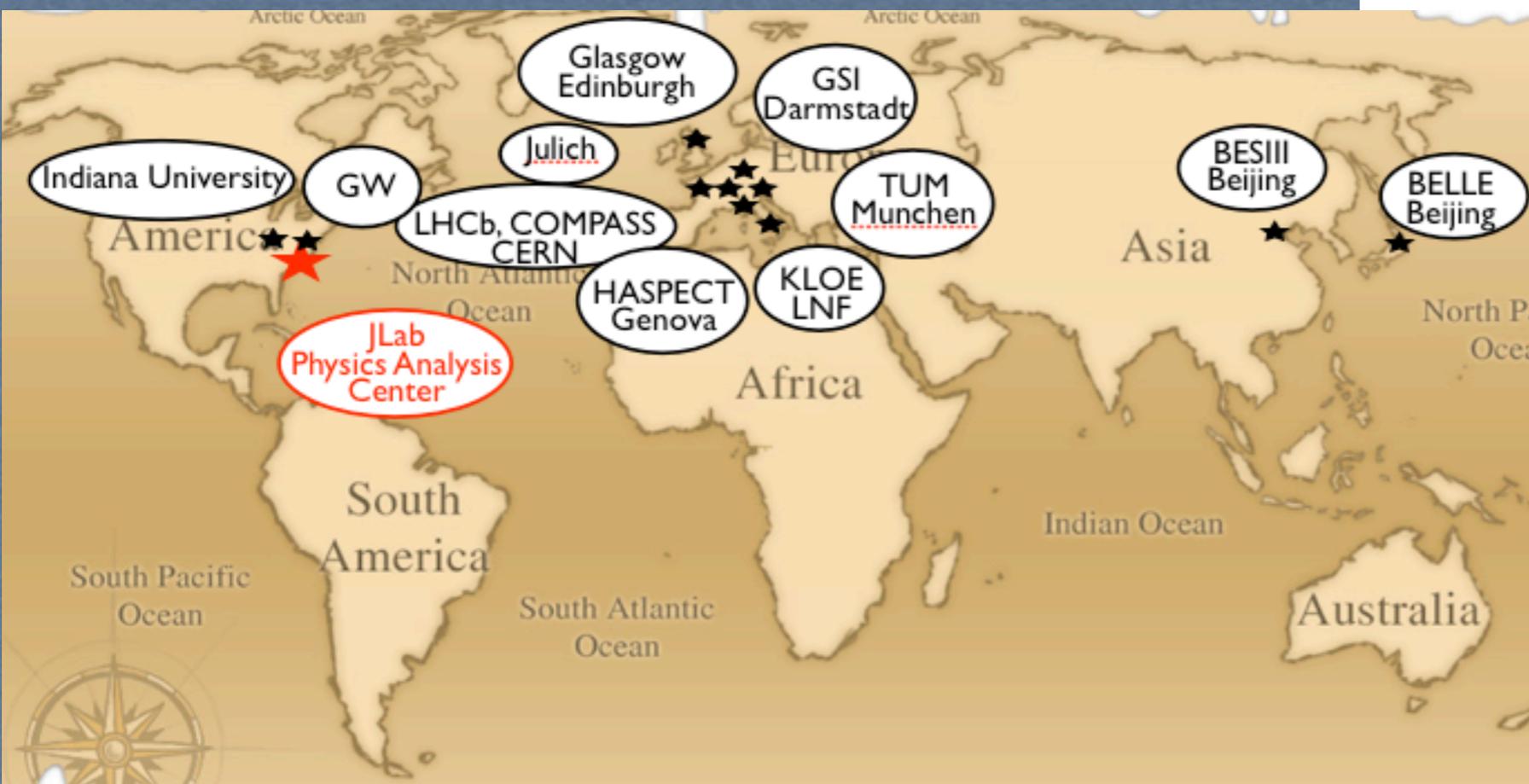
$$F^{(I)}(s, \theta) = (2 \times) \sum_{\ell} (2\ell + 1) P_{\ell}(\cos \theta) F_{\ell}^{(I)}(s).$$

The factor 2 comes from Bose symmetry between the two π^0 and the sum runs on even (odd) ℓ for even (odd) isospin I . For $\pi^+\pi^-$ there is no factor of 2 but the sum is also restricted to angular momentum of given parity by conjugation charge. In term of phase shift δ_{ℓ} , elasticity η and breakup momentum $\rho(s) = \frac{1}{2}\sqrt{s - 4m_{\pi}^2}$, we have for each wave:

$$F_{\ell}^{(I)}(s) = \frac{2\sqrt{s}}{\pi\rho(s)} \left[\frac{\eta_{\ell}^{(I)} e^{2i\delta_{\ell}^{(I)}} - 1}{2i} \right] \equiv \frac{2\sqrt{s}}{\pi\rho(s)} \hat{F}_{\ell}^{(I)}(s).$$

$\hat{F}_{\ell}^{(I)}(s)$ is defined to start at 0 at threshold.

V.Mathieu



*Common funding plans:

- European-FP7 (EU calls and local): HPH, Synergy grants
- DOE-Topical -collaboration proposals
- Helmholtz Virtual-Institutes

Conclusions

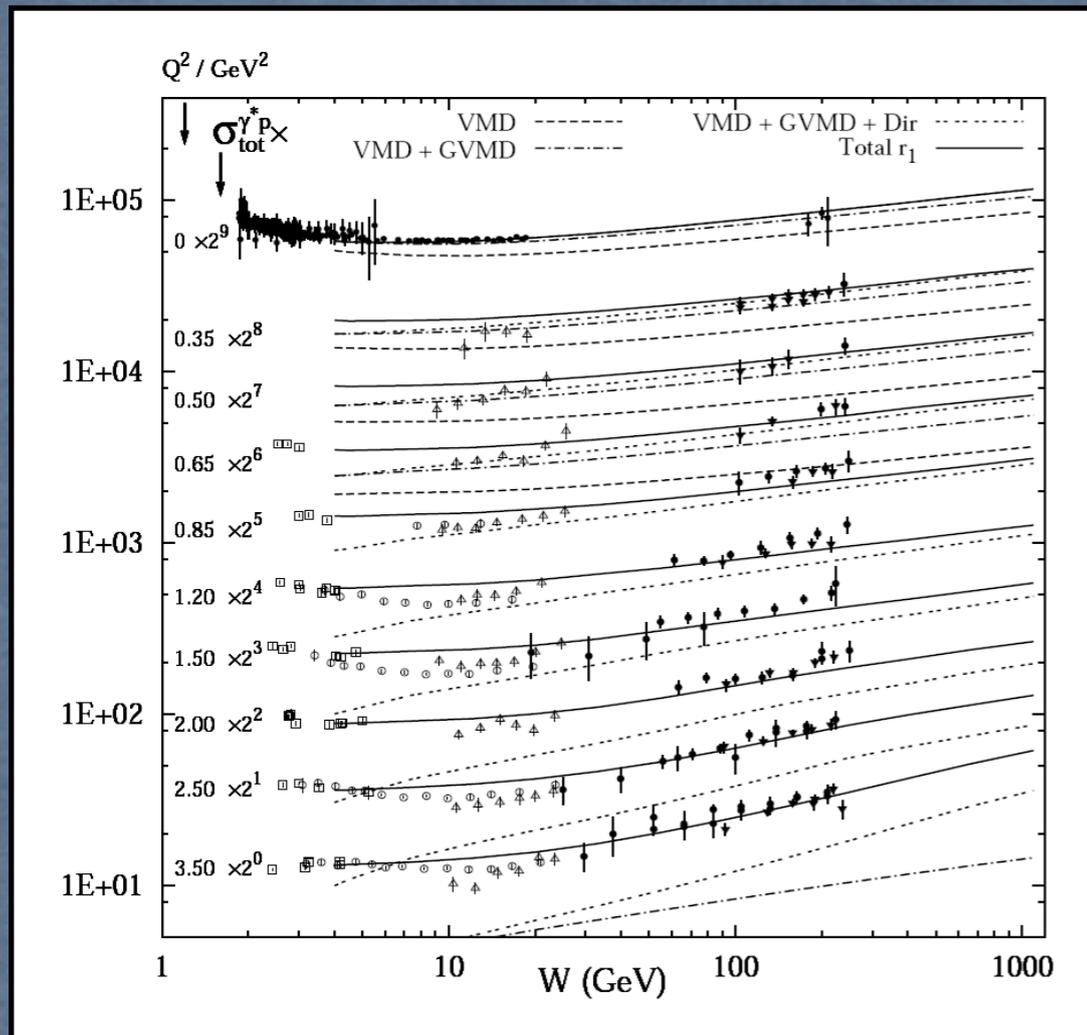
- * Recent LQCD results renew interest in Meson Spectroscopy
- * Comprehensive meson spectroscopy program at JLab (GlueX & CLAS12)
- * Full angular coverage for multi-particle final states with GlueX in Hall-D
- * Exotics and strangeness-rich mesons search with CLAS12 detector exploiting excellent resolution and particle ID
- * Bremsstrahlung and Low Q^2 electron scattering to produce a high intensity, linear polarized, real (Hall-D) and quasi-real (Hall-B) photon beam
- * New analysis framework: global effort to provide a robust analysis framework (PWA, amplitudes, FSI, ...)

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

Backup slides

Q² dependence of the Xsec

*Studies at large W (~100GeV) show a smooth transition between Q²=0 and Q²≠ 0

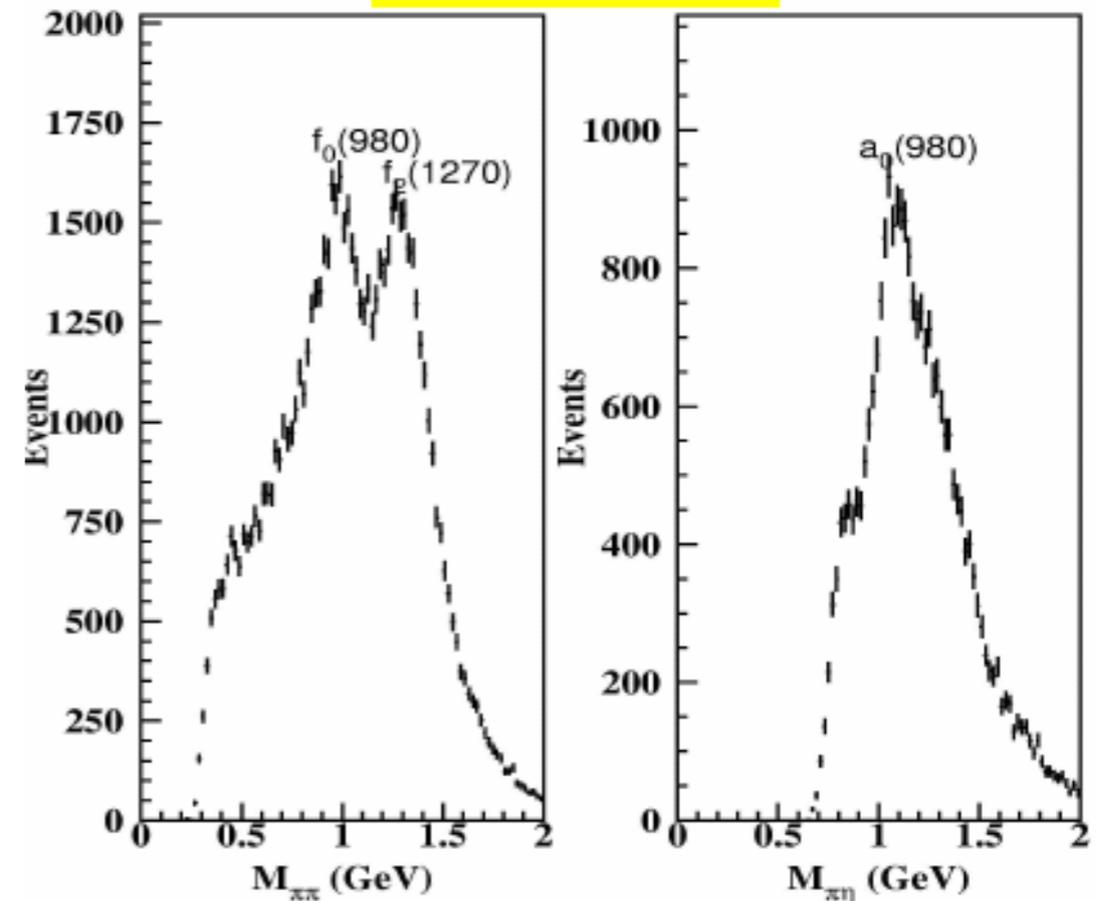


Well known technique used in hep
Q² < W²

COMPASS	<1 GeV ²	<Q ² > ~ 10 ⁻¹ GeV ²
ZEUS:	~ 10 ⁻⁷ – 0.02 GeV ²	<Q ² > ~5 10 ⁻⁵ GeV ²
HI:	<2 GeV ²	

Tested in CLAS

e p → p γγγγ X



e p → p π⁰ π⁰ (e')

e p → p π⁰ η⁰ (e')

**Bright meson peaks show up
The technique works!**

Meson spectroscopy with photons in CLAS12

Exp-11-005 "MesonEx"

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
- $\gamma p \rightarrow p 3\pi, \gamma p \rightarrow p \eta \pi, \dots$

* Hybrids with hidden strangeness and strangeonia

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

* 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)
- $\gamma p \rightarrow p 2\pi, \gamma p \rightarrow p 2K, \dots$

- Decay and production of exclusive reactions, different final states (charged/neutral)
- Detector requirements: good acceptance, energy resolution, particle Id
- Identification of exotic configuration via PWA

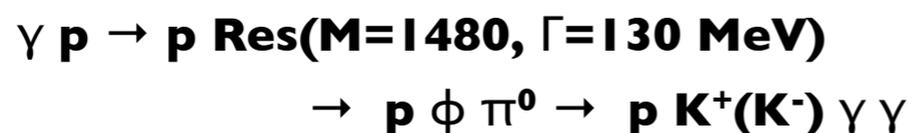
Requirements

- 1) High intensity 6-10 GeV photon beam
- 2) 4 π detector

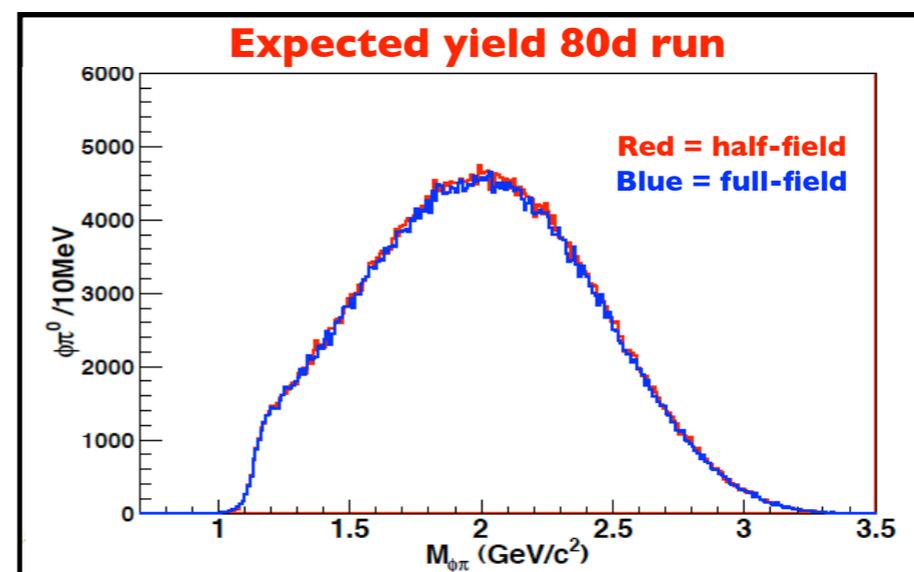
FT Reconstruction and Partial Wave Analysis (PWA)

★ Extensive and systematic investigation of CLAS12 capabilities

Expected results



- ★ Unusual BR in $\phi\pi$ (OZI suppressed)
- ★ $J^{PC}=1^{--}$ $\sigma \sim 10\text{nb}$
- ★ Tetra-quarks or hybrid
- ★ CLAS12 acceptance $\sim 10\%$



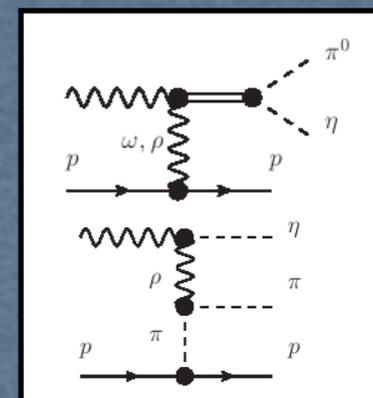
★ Analysis in progress:



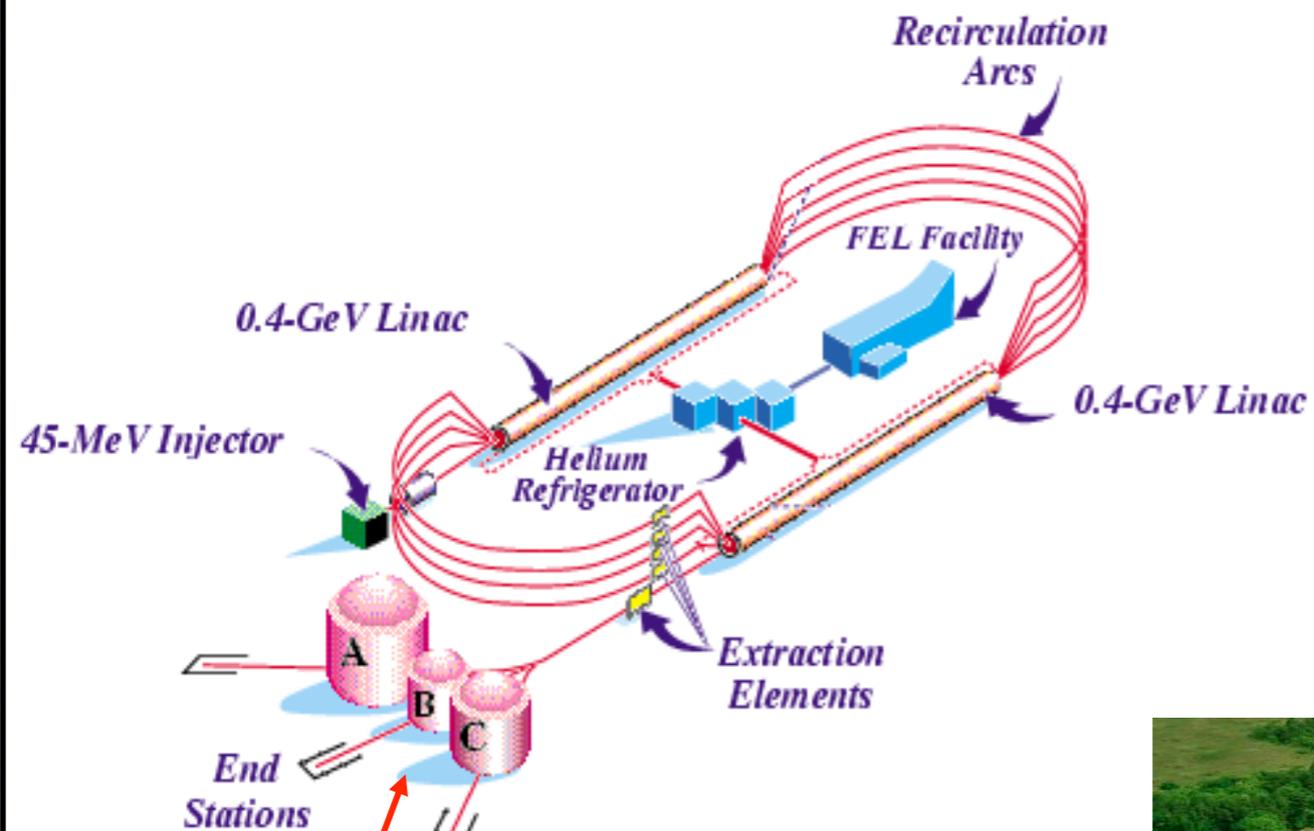
- A.Celentano (Genova) PhD Thesis
- Amplitudes provided by V.Mathieu (ECT*) and A.Szczepaniak (IU&JLab)
- Preliminary analysis on CLAS6 data to fix parameters
- Full projection on CLAS12 and PWA



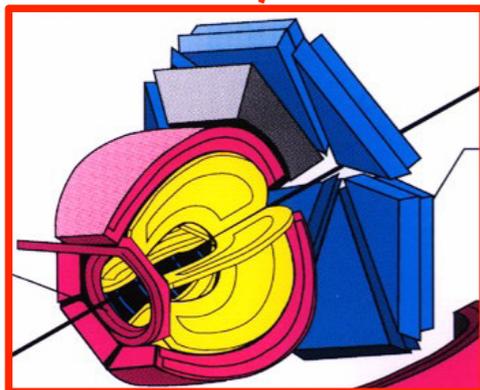
- Theoretical support: A.Szczepaniak, V.Mathieu, E.Santopinto (INFN-GE), A.Vassallo (GE)
- S.Fegan (INFN-GE), A. Filippi (INFN-TO), S.Hughes (Edinburgh), S. Lewis (Glasgow), S.Lombardo (IU), A.Rizzo (RomaTV), L.Zana (Edinburgh)



Jefferson Lab (now)



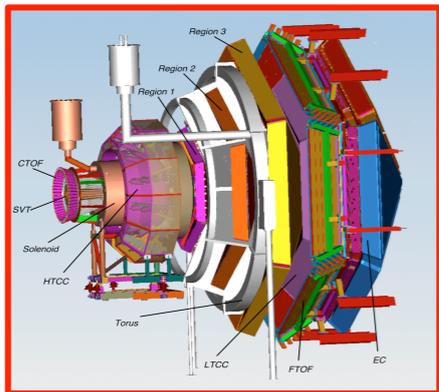
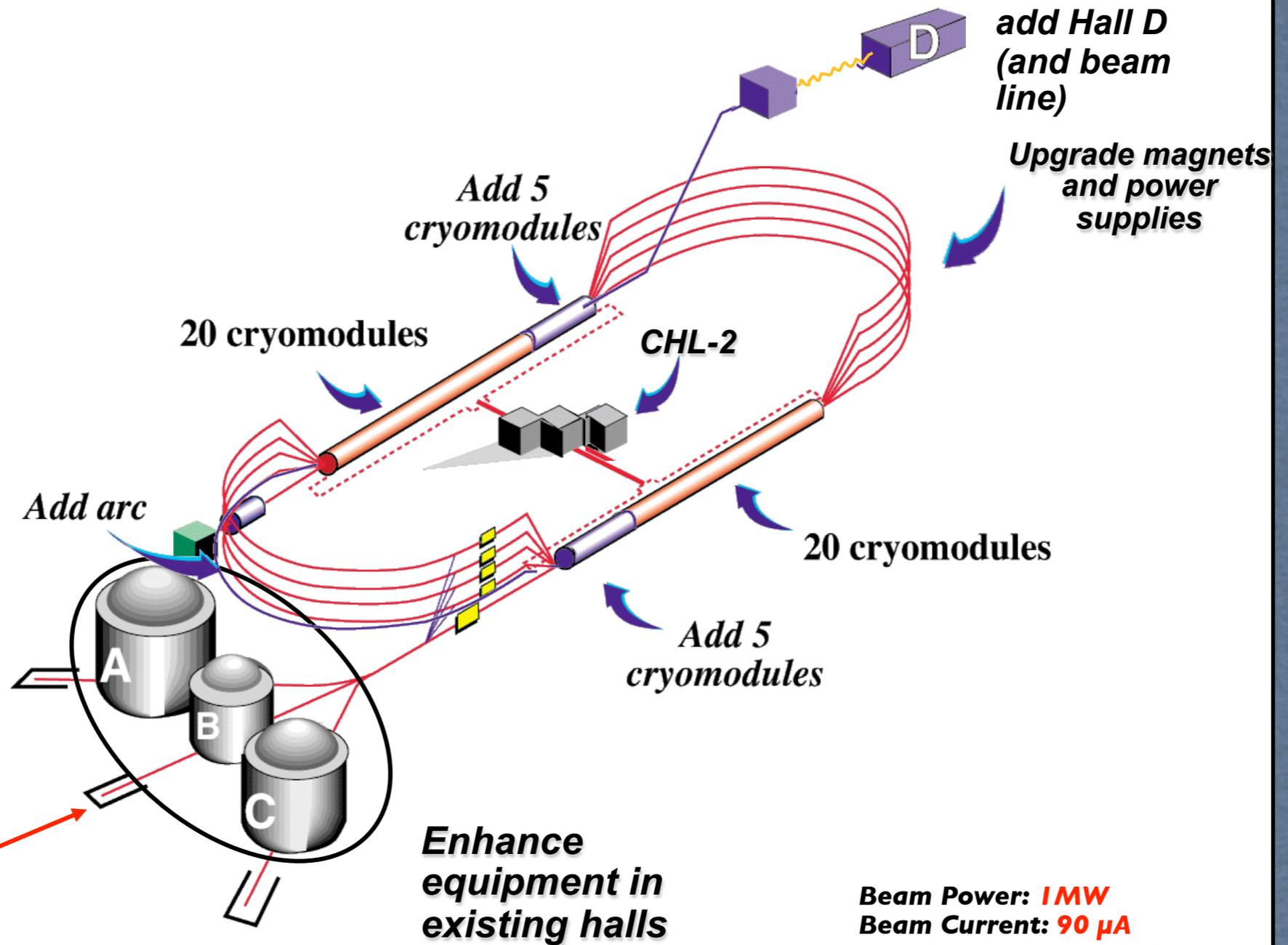
E_{\max}	$\sim 6 \text{ GeV}$
I_{\max}	$\sim 200 \mu\text{A}$
Duty Factor	$\sim 100\%$
σ_E/E	$\sim 2.5 \cdot 10^{-5}$
Beam P	$\sim 80\%$
E_γ	$\sim 0.8\text{-}5.7 \text{ GeV}$



CLAS



Jefferson Lab at 12 GeV



CLAS12

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