The 12 GeV Jlab Upgrade Project

Project Overview

Examples of Physics Topics
- Gluonic excitations
- 3D picture of the nucleon

Project Status

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Jefferson Lab

PANIC 2008
JLab accelerator CEBAF

Continuous Electron Beam
• Energy 0.8 — 5.7 GeV
• 200 μA, polarization 75%
• 1499 MHz operation
• Simultaneous delivery 3 halls
Add 5 cryomodules

20 cryomodules

CHL-2

Add arc

Enhance equipment in existing halls

Upgrade magnets and power supplies

Add Hall D (and beam line)
New Hall D

Hall C (SHMS/HMS)

Hall B (CLAS12)

Hall A (2 HRS + 11 GeV beam for large installations)
Normal Mesons – $q\bar{q}$ color singlet bound states

Spin/angular momentum configurations & radial excitations generate the known spectrum of light quark mesons.

Starting with $u - d - s$ we expect to find mesons grouped in nonets - each characterized by a given $J$, $P$ and $C$.

$J^{PC} = 0^{--} 0^{+-} 1^{--} 1^{+-} 2^{++} ...$  
Allowed combinations

$J^{PC} = 0^{--} 0^{+-} 1^{--} 1^{+-} 2^{++} ...$  
Not-allowed: exotic
Physics goals and key features of GlueX

Normal mesons: glue is **passive**

Hybrid mesons: glue is **excited**

The physics goal of GlueX is to map the spectrum of hybrid mesons starting with those with the unique signature of exotic $J^{PC}$.

Identifying $J^{PC}$ requires an amplitude analysis which in turn requires:

• **linearly polarized photons**
  - Breaks azimuthal symmetry

• detector with excellent acceptance and resolution
• sensitivity to a wide variety of decay modes which include photons and charged particles

This, coupled with a hybrid mass reach up to 2.5 GeV, requires **9 GeV photons** produced using coherent bremsstrahlung from **12 GeV electrons**.

See Eugenio in Parallel II: Hadronic structure: form factors
Search for QCD exotics

The GlueX Detector Design has been driven by the need to carry out Amplitude analysis.

\[
\begin{align*}
\pi_1 & \rightarrow \eta_1 \eta'_1 \\
 b_2 & \rightarrow h_2 h'_2 \\
 b_0 & \rightarrow h_0 h'_0
\end{align*}
\]

1\(^{-+}\) \quad 2\(^{+-}\) \quad 0\(^{+-}\)

Mass scale ~ 2 GeV

\[
\eta_1 \rightarrow a_1^+ \pi^- \rightarrow (\rho^0 \pi^+)(\pi^-) \rightarrow \pi^+\pi^- \pi^+\pi^-
\]

all charged

\[
h_0 \rightarrow b_1^0 \pi^0 \rightarrow (\omega\pi^0)\gamma\gamma \rightarrow \pi^+\pi^- \gamma\gamma\gamma\gamma\gamma
\]

many photons

\[
h'_2 \rightarrow K^+_1 K^- \rightarrow \rho^0 K^+ K^- \rightarrow \pi^+\pi^- K^+ K^-
\]

strange particles

To certify results, check different decay modes

e.g. \[
b_1 \rightarrow \omega \pi \left\{ \begin{array}{l}
\omega \rightarrow \pi^0 \gamma \rightarrow 3\gamma \\
\omega \rightarrow \pi^0 \pi^+ \pi^- \rightarrow 2\gamma \pi^+ \pi^- \end{array} \right.
\]

Photoproduction

\[
\frac{\sigma_{Exotic\,Meson}}{\sigma_{Meson}} \sim 1
\]

Pion production

\[
\frac{\sigma_{Exotic\,Meson}}{\sigma_{Meson}} \sim \text{spin f liq}
\]

\[
\gamma \rightarrow \pi, K, \gamma
\]

\[
p \rightarrow n, p
\]
Linearity Polarized Photon Beam

Rates based on:

- 12 GeV endpoint
- 20 μm diamond crystal
- 300 nA electron beam
- diamond - collimator: 76m
- collimator diameter: 3.5 mm

Leads to $10^7 \gamma$/s on target (after the collimator)

Design goal is to build an experiment with ultimate rate capability of $10^8$ tagged $\gamma$/s on target.

$\delta E/E = 0.1\%$
Pol = 40%
Hall D – GlueX detector

Hermetic detection of charged and neutral particles in solenoid magnet

Initial Flux $10^7 \gamma/s$
18,000 FADCs
4,000 pipeline TDCs
20 KHz L1 trigger
300 MB/s to tape

Tagger Spectrometer
(Upstream)

Barrel Calorimeter (Bcal)
Time-of-flight (tof)

Pb-glass detector (Fcal)

Superconducting 2 T solenoid

Future PID detector

Tracking
Cathode strips
Drift chambers
Straw tubes
Electronics and trigger (250 MHz)

All detector readout electronics pipelined: fADC (100 & 250 MHz) and F1TDC

Detector Signals

VXS Crate

fADC250
CTP Crate Trigger Processor
SD Signal Distribution
TI Trigger Interface
VXS Backplane

Custom Designed Boards by JLAB

Fiber Optic Link (~100 m)
(64 bits @ 125 MHz)

Fiber Optic Link
(16 bits @ 62.5 MHz)

Copper Ribbon Cable
(~1.5 m)
(32 bits @ 250 MHz)

Trigger Latency ~ 3 µs
(F1TDC pipeline ~3.9 µs)
Summary of Exotic Hybrid Mesons

- The physics goal of GlueX is to map the spectrum of hybrid mesons starting with those with the unique signature of \( J^{PC} \) quantum numbers.
- Detector designed with high acceptance and efficiency for charge and neutral particles.
- Study hybrid mass with masses up to 2.5 GeV.
- Expected sensitivity to exotic signals is at the level of a few percent of the production of normal hadrons.
Beyond form factors and quark distributions – Generalized Parton Distributions


Proton form factors, transverse charge & current densities

Correlated quark momentum and helicity distributions in transverse space - GPDs

Structure functions, quark longitudinal momentum & helicity distributions
DVCS is “golden channel”

\[
\frac{d\sigma}{dx_B dy dt d\phi} = \frac{\alpha^3 x_B y}{8\pi e^3 Q^2 \sqrt{1 + e^2}} \left( |T_{BH}|^2 + |T_{DVCS}|^2 + T_{BH}^* T_{DVCS} + T_{DVCS}^* T_{BH} \right)
\]

Beam Spin Asymmetry \( \sim Im(T_{DVCS}) T_{BH} \sim H(\xi, \bar{\xi}, t) \)....
CLAS12 - DVCS/BH- Beam Asymmetry

$Luminosity = 720fb^{-1}$

$E_e = 11 \text{ GeV}$

$Q^2 = 5.5 \text{ GeV}^2$

$x_B = 0.35$

$-t = 0.25 \text{ GeV}^2$
CLAS12 - DVCS/BH Beam Asymmetry

$\vec{e} p \rightarrow ep\gamma$

$E = 11 \text{ GeV}$

$\Delta \sigma_{LU} \sim \sin \phi \text{Im}\{F_1H+.\} d\phi$

Selected Kinematics

$L = 1\times10^{35}$
$T = 2000 \text{ hrs}$
$\Delta Q^2 = 1 \text{ GeV}^2$
$\Delta x = 0.05$
CLAS12 - Detector

Forward Detector

Central Detector
Figure 1-1. DOE Acquisition Management System.
- Hall A commissioning start October 2013
- Hall D commissioning start April 2014
- Halls B and C commissioning start October 2014
12 GeV Jlab Upgrade Project - Summary

Two major physics thrusts of the 12 GeV project have been touched on in this talk:

- Exploration of QCD and confinement: Existence and properties of exotic mesons
- 3-D View of Nucleon Structure: Generalized Parton Distributions

Project is on track with construction starting NOW!
New collaborators are welcome

**Successful Workshop on**

*Physics and methods in meson spectroscopy*

Int. Joint Workshop CERN COMPASS-Jefferson Lab-GSI FAIR

**October 22nd – 24th 2008**

http://www.universe-cluster.de/mesons_and_methods_2008

- Actively contacting groups in nuclear physics in the US and Europe
- Success till now:
  - admitted 2 new groups to the collaboration
    - Lanzhao, China
    - University of Santa Maria, Valparaíso, Chile
  - Yerevan and Edinburgh are on their way to join / very interested
  - Having CD-3 should prove to the community the project is real
    - more manpower
Quark binding and configuration of gluons

Flux tube forms between $q\bar{q}$

Confinement arises from flux tubes and their excitation leads to a new spectrum of mesons

From G. Bali

Hybrid Mesons

- transverse phonon modes
- \( \pi/r \)
- ground state

1 GeV mass difference

Hybrid mesons
Normal mesons
Mass Predictions

Lowest mass expected to be $\pi_1(1^{-+})$ at $1.9\pm0.2$ GeV

Lattice Calculations

- $\pi_1(1^{-+})$: $1^{-+}$, $1.9$ GeV
- $b_0(0^{++})$: $2^{-+}$, $2.1$ GeV
- $b_2(2^{++})$: $0^{+-}$, $2.3$ GeV
Quantum Numbers of Hybrid Mesons

Flux tube excitation (and parallel quark spins) lead to exotic $J^{PC}$
How do exotics decay?

Possible daughters:

\[ L=1: \ a, b, h, f, \ldots \]
\[ L=0: \ \pi, \rho, \eta, \omega, \ldots \]

The angular momentum in the flux tube stays in one of the daughter mesons \((L=1)\) and \((L=0)\) meson, e.g:

Example: \(\pi_1 \rightarrow b_1 \pi\)

flux tube \(L=1\)
quark \(L=1\)

simple decay modes such as \(\eta \pi, \rho \pi, \ldots\) are suppressed.
Photon beam and experimental area

Top View

75 m

North linac

East arc

Electron beam dump

Tagger area

Hall D

Counting House

Photon Beam dump

Radiator

Electron beam

Tagger Area

Coherent Bremsstrahlung photon beam

Collimator

Experimental Hall D

Solenoid-Based detector

Jefferson Lab
The GlueX Detector

- Linearly polarized photons
  - Initial rate: $10^7 \, \gamma/s$
  - Tagged 8.4-9 GeV (to .1%)
  - Up to: $10^8 \, \gamma/s$

- 30-cm long LH2 target

- Scintillator start counter

- Central straw tube drift chamber

- Pb scintillator sandwich calorimeter inside the solenoid. Also measure TOF of charged particles.

- Planar cathode drift chambers

- Plastic scintillator time-of-flight wall

- ~2.25 T solenoid magnet (refurbished and updated LASS/MEGA magnet)

- Pb Glass Calorimeter (glass from BNL E852)
Experimental equipment in Hall D

- Beam
- Collimator alcove
- AC ducts
- Pair Spectrometer
- Cryogenics platform
- Cable trays
- North Wall
- Penetrations for gas lines
- Overhead crane
- Electronics racks
- Upstream platform
- Electronics racks
- Cryogenics platform
- Truck ramp entrance
- Solenoid
- FCal / dark room
- Photon dump
Interpretation of the GPD’s

Analogy with form factors

\[ F(\bar{q}) = \int d^3 r e^{-i \vec{q} \cdot \vec{r}} \rho(\vec{r}) \]

Charge \( \leftrightarrow \) Form Factor

\[ \vec{r} \text{ measured relative to } \vec{R}_{cm} = \sum \frac{m_i r_i}{M} \]

Parton Distribution \( \leftrightarrow \) GPD’s

\[ H(x, q_{\perp}) = \int d^2 b_{\perp} e^{-i q_{\perp} \cdot b_{\perp}} f(x, b_{\perp}) \quad @ \xi = 0 \]

\[ b_{\perp} \text{ measured relative to } R_{\perp}^{CM} = \sum x_i r_{i \perp} \]

where \( f(x, b_{\perp}) \) is a parton density of quarks with momentum fraction \( x \) at a \( \perp \) distance \( b_{\perp} \) from \( R_{\perp}^{CM} \)
# Technical Performance Requirements

<table>
<thead>
<tr>
<th>Hall D</th>
<th>Hall B</th>
<th>Hall C</th>
<th>Hall A</th>
</tr>
</thead>
<tbody>
<tr>
<td>excellent hermeticity</td>
<td>luminosity $10 \times 10^{34}$</td>
<td>energy reach</td>
<td>installation space</td>
</tr>
<tr>
<td>polarized photons</td>
<td>hermeticity</td>
<td>precision</td>
<td></td>
</tr>
<tr>
<td>$E_{\gamma} \sim 8.5-9$ GeV</td>
<td></td>
<td>11 GeV beamline</td>
<td></td>
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<tr>
<td>$10^8$ photons/s</td>
<td></td>
<td>target flexibility</td>
<td></td>
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<tr>
<td>good momentum/angle resolution</td>
<td></td>
<td>excellent momentum resolution</td>
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<tr>
<td>high multiplicity reconstruction</td>
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<td>luminosity up to $10^{38}$</td>
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<tr>
<td></td>
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<td>particle ID</td>
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Hall D Complex - Site Plan

- Service Building
- Cryo Plant
- Counting House
- Existing Tunnel
- Tunnel Extension & Tagger Area
- Hall D
- Jefferson Lab
- Hall D Complex
- Canon Blvd
Rendering of Hall D Complex – Overhead View
DAQ & Trigger

● very challenging for nuclear physics experiment

several requirements need to be meet:

➤ major upgrade of DAQ
➤ all electronics has to be pipelined
  ➤ all boards are custom made
    > 1000 boards ➔ ~30000 channel
➤ 1st level trigger uses energy sum from calo’s and hit count from ToF, StartCounter, Tagger