The Hall D Project

The Search for Gluonic Excitations (Unusual Mesons) Using Photons

We are here to:

- **Tell you about this exciting new initiative at JLab**
- **Discuss the physics**
- **Show you how far we have progressed**
- **Ask for your help and guidance to carry out the R & D needed to:**
  - **complete the design**
  - **prepare the Conceptual Design Report**

A. Dzierba - 0verview (35 min)
A. Szczepaniak - Photon polarization (10 min)
C. Meyer - Detector and R&D (15 min)

Hall D Collaboration

US Experimental Groups

Support:

- **DN - DOE Nuclear**
- **DH - DOE HEP**
- **NSF - NSF Nuclear**

DN — **R. Clark, P. Eugenio, G. Franklin, C. A. Meyer (Co-Spokesperson), B. Quinn, R. Schumacher**
Carnegie Mellon University (Pittsburgh,PA)

NSF — **H.Crannell, D.Sober**
Catholic University of America (Washington, D. C.)

DN NSF — **D. Doughty, D. Heddle**
Christopher Newport U (Newport News, VA)

DN NSF — **R. Jones** *
University of Connecticut (Storrs, CT)

DN — **W. Boeglin, L. Kramer, P. Markowitz, B. Raue, J. Reinhold**
Florida International University (Miami, FL)

*** seeking support from DOE/NSF**

DN — **L. Dennis, P. Dragovitsch, G. Riccardi**
Florida State University (Tallahassee,FL)

DH — **A. Dzierba (Spokesperson), R. Heinz, E. Scott, P. Smith, C. Steffen, T. Sulanke, S. Teige**
Indiana University (Bloomington,IN)

DN — **D. Abbott, I. Bird, R. Carlini, H. Fenker, G. Heyes, R. Macleod, C. Sinclair, E. Smith (Hall D Group Leader), D. Weygand, E. Wolin**
Jefferson Lab (Newport News,VA)

DN — **R. Mischke, A. Palounek, J. C. Peng**
Los Alamos National Lab (Los Alamos,NM)

DN — **M. Khandaker, V. Punjabi, C. Salgado**
Norfolk State University (Norfolk,VA)

DN — **G. Dodge, A. Klein, S. Kuhn, P. Ulmer,L. Weinstein**
Old Dominion University (Norfolk,VA)

NSF — **D. Carman, K. Hicks**
Ohio University (Athens,OH)

NSF — **S. Dytman, J. Mueller**
University of Pittsburgh (Pittsburgh, PA)

NSF — **G. Adams, J. Cummings, A. Empl, J. Napolitano, P. Stoler**
Rensselaer Polytechnic Institute (Troy,NY)

Hall D Collaboration

Theory Groups

S. Godfrey
Carleton U(Ottawa, Ontario,Canada)

R. Kaminski, L. Lesniak
Institute of Nuclear Physics - Cracow, Poland

J. Goity
Hampton U (Hampton,VA)

DN C. Horowitz, T. Londergan, M. Pichowsky, A. Szczepaniak
Indiana U (Bloomington,IN)

DN P. Page
Los Alamos National Lab (Los Alamos, NM)

A. Afanasev
North Carolina Central U (Durham, NC)

DN E. Swanson
University of Pittsburgh (Pittsburgh, PA)

DN T. Barnes
U of Tennessee (Knoxville, TN)
Oak Ridge National Lab (Oak Ridge, TN)

NSF R. Davidson,N. Mukhopadhyay
Rensselaer Polytechnic Institute (Troy,NY)

Foreign Groups - (experimental)

S. Denisov, N. Fedyakin, A. Gorokhov, V. Samoilenko, A. Schukin
Institute for High Energy Physics (Protvino, Russia)

V. A. Bodyagin, A. M. Gribushin, N. A. Kruglov, V. L. Korotkikh, M. A. Kostin, A. I. Demianov, O. L. Kodolova, L. I. Sarycheva, A. A. Yershov
Moscow State U (Moscow, Russia)

V. Druginin, V. Ivanchenko, E. Solodov
Budker Institute of Nuclear Physics (Novosibirsk, Russia)

E. J. Brash, G. M. Huber, G. J. Lolos, Z. Papandreou
U of Regina (Regina, Saskatchewan,Canada)

J. M. Laget, M. Garcon
Saclay (France)

Additional Groups - (discussions in progress)

NSF J. Cameron *et al*
IUCF - Bloomington, IN

T. Nakano *et al*
SPring8 - Osaka, Japan

K. Helbing *et al*
Erlagen, Germany

W. Melnitchouk, A. Thomas, A. Williams
CSSM - Adelaide, Australia

The Hall D Project - Overview

Collaboration History

- **80 physicists from 25 institutions**
  - *- Spokesman (A. Dzierba), Co-Spokesman (C. Meyer) and Hall D Group Leader (E. Smith)*
    - *management plan being developed*
- **8 workshops since July, 1997 (at 6 institutions)**
- **Numerous meetings with JLab** *- management and accelerator*
- **LOI presented to PAC15 in Jan, 1999** *- enthusiastic response*
- **Design Report - ver 2** *- completed in August, 1999*
- **Cassel Review** *- December 6-7, 1999 - more details will follow*
- **MEGA/LASS Solenoid Assessment at LANL** *- March 9-11, 2000*
- **Collaboration Meeting at Indiana U/IUCF in Bloomington** *- April 6-8, 2000*
- **Memorandum of Understanding** *- to be completed in April, 2000*
- **Design Report - ver 3** *- to be completed in August, 2000*

From the NAS/NRC Report on Nuclear Physics

The Core of Matter / The Fuel of Stars

1. The Structure of the Nuclear Building Blocks
2. The Structure of Nuclei
3. Matter at Extreme Densities
4. The Nuclear Physics of the Universe
5. Symmetry Tests in Nuclear Physics

Can QCD account quantitatively for the confinement of quarks and gluons inside hadrons ?

Where is the Glue ??

The important remaining question is this:

- **Is QCD the correct theory of hadron structure ?**
- **What testable predictions does it make that arise inevitably from its mechanism of confinement ?**

Confinement arises in QCD from a simple but radical postulate: the gluons themselves carry a strong interaction charge, in contrast to photons which carry no electric charge.

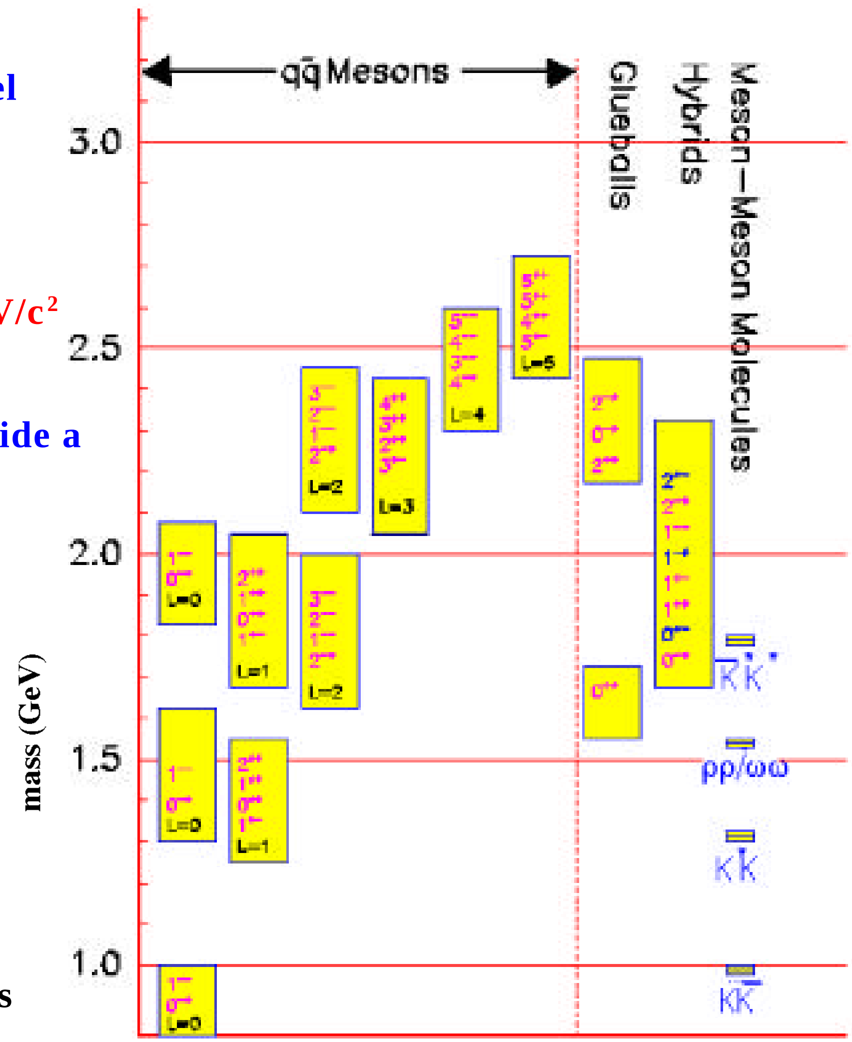
Prediction: **Mesons should exist in which gluons bind to each other with no quarks present (*glueballs*). Another possibility - hybrid mesons in which a gluon binds to a quark - antiquark (*hybrids*) and these can have quantum numbers not allowed by quark - antiquark (*exotic hybrids*).**

In the flux-tube picture, which is supported by lattice-gauge theory calculations, the gluons in a hadron are confined to flux-tubes. Conventional mesons arise when the flux-tube is in its ground state. Hybrid mesons arise when the flux-tube is in an excited state.

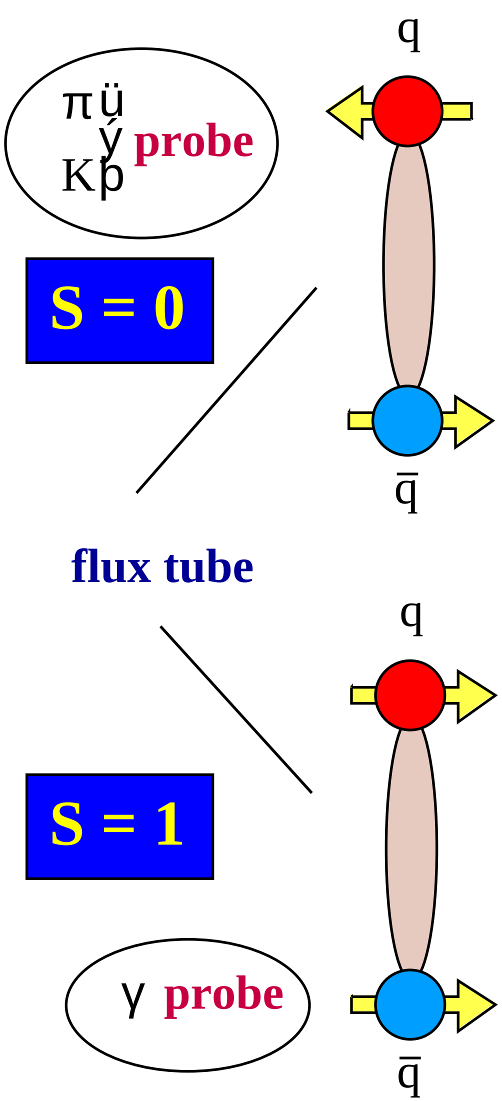
Search for QCD Mesons

- **QCD predicts mesons beyond the naive quark model**
  - **glueballs and hybrids (some with exotic J^{PC})**
  - **hard to find but tantalizing candidates exist**
  - **LGT and flux-tube converging on masses**
  - **expect to find in the mass range: 1.5 to 2.5 GeV/c^2**

- **Photoproduction of light quark exotic hybrids provide a clean sector for these searches**
  - **exotic hybrids do not mix with $\bar{q}q$**
  - **glueballs not likely to be photoproduced**
  - **photon probe ($\bar{q}q$ in spin-1) is likely to yield exotic hybrids (flux tube in 1st excited state)**
  - **hybrid searches in the charm and beauty sectors very difficult**
  - **vector hybrids suppressed in e^+e^- collisions**
  - **the one area where data on light quark mesons is non-existent is precisely where you expect to find them**



Search for QCD Mesons



Extensive data with π probes exist

Little data with γ probes exist

In the first excited state of the flux tube half of the possible J^{PC} are exotic only if S = 1

- **Photon beams are expected to yield rich results**
- **Optimal energy for study is 8 - 9 GeV for photons**
- **Requires electron energies of 12 GeV (flux and polarization)**
- **Hermetic detector design with excellent resolution and rate capability**
- **JLab is unique**
- **Unprecedented statistics compared to hadron data**
- **Guaranteed to provide important new information - independent of any theoretical model**

How to Search for Exotics

- **Determination of J^{PC} of Meson States requires a Partial Wave Analysis (PWA)**
  - **- need to kinematically identify an exclusive production process**
  - **- provides information on the production mechanism**
  - **- sensitivity to a variety of decay modes**

Note that flux tube and other models of gluonic excitations predict the production mode and decay modes of hybrids. Also - PWA can be complicated and consistent results among various decay modes will be important in isolating hybrid states.

- **Successful application of PWA puts demands on the experiment**
  - **need good acceptance - hermetic detector and good resolution**
  - **sensitivity to decay modes - particle ID: $\pi^{\pm}$, $K^{\pm}$, π^{o}, η, ..**
  - **identify the production mechanism - linear polarization**
  - **high statistics - photon flux and rate capability**
  - **appropriate beam energy - high enough to reach masses and have good acceptance**

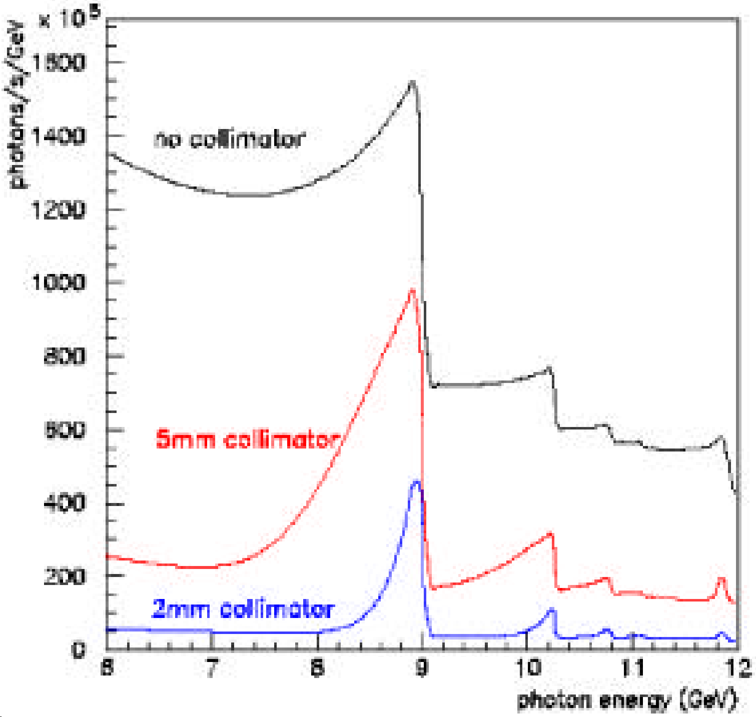
The Photon Beam and Linear Polarization

Linear Polarization is:

- **essential in identifying the production mechanism**
- **is helpful in extracting decay amplitudes**
- **is a filter for exotics**

more to follow: Adam Szczepaniak

- **Need for linear polarization implies:**
  - **coherent bremsstrahlung (will deliver necessary energy and flux)**
  - **Compton backscatter (requires high energy electrons and the required flux is not achievable)**



Bremsstrahlung Spectrum for:

- **15 micron diamond radiator**
- **1 μA 12 GeV electron beam**

Coherent and incoherent spectrum shown

Collimation of the beam will enhance the coherent component relative to the incoherent.

Vector rest frame

Linear Polarization Essential

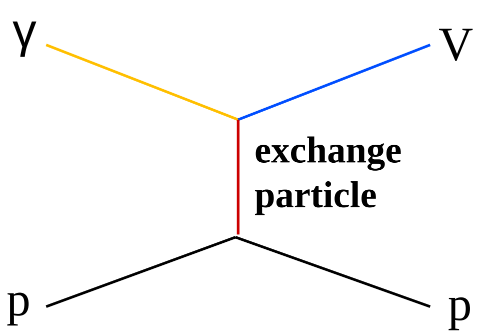
relative orbital angular momentum (L) cannot have projection along z axis

therefore, produced Vector has m = 1 if photon has m = 1 and has m= -1 if photon has m = -1

Possible values of L are 0, 1 or 2

Linear Polarization

a simple example



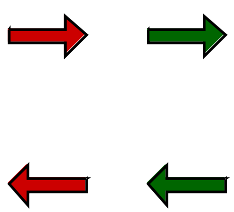
Parity Conservation

$$P_V = -1 = P_\gamma \; P_e \; (-1)^L$$

For our case, if the exchange particle has negative parity then L = 1 and if the exchange particle has positive parity then L = 0 or 2.

natural + unnatural exchange amplitudes contribute:

photon vector



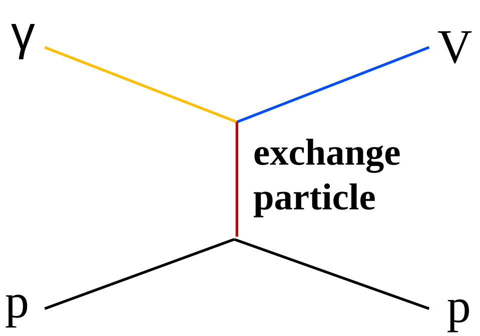
m = +1 $A^N + A^U$ $$e_x = \frac{-1}{\sqrt{2}}(e_R - e_L)$$

m = - 1 $A^N - A^U$ $$e_y = \frac{i}{\sqrt{2}}(e_R + e_L)$$

circularly polarized photons measure the sum or differences of amplitudes whereas linearly polarized photons allow a separation

more to follow: Adam Szczepaniak

Linear Polarization

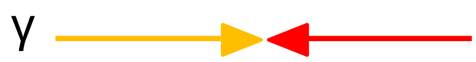


Linear Polarization Helps

$J^P = 0^+,\ 1^-,\ 2^+,\ \text{etc...}$ **natural parity exchange**

$J^P = 0^-,\ 1^+,\ 2^-,\ \text{etc...}$ **unnatural parity exchange**

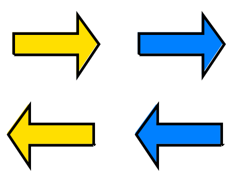
in the vector rest frame



exchange with J = 0

Suppose the vector decays into two spinless particles $V \rightarrow PP \quad \begin{cases} \rho \rightarrow \pi\pi \\ \phi \rightarrow KK \end{cases}$

w.f. for the decay:



m = +1 $Y_1^1 \quad \sin\theta \ e^{+i\phi}$

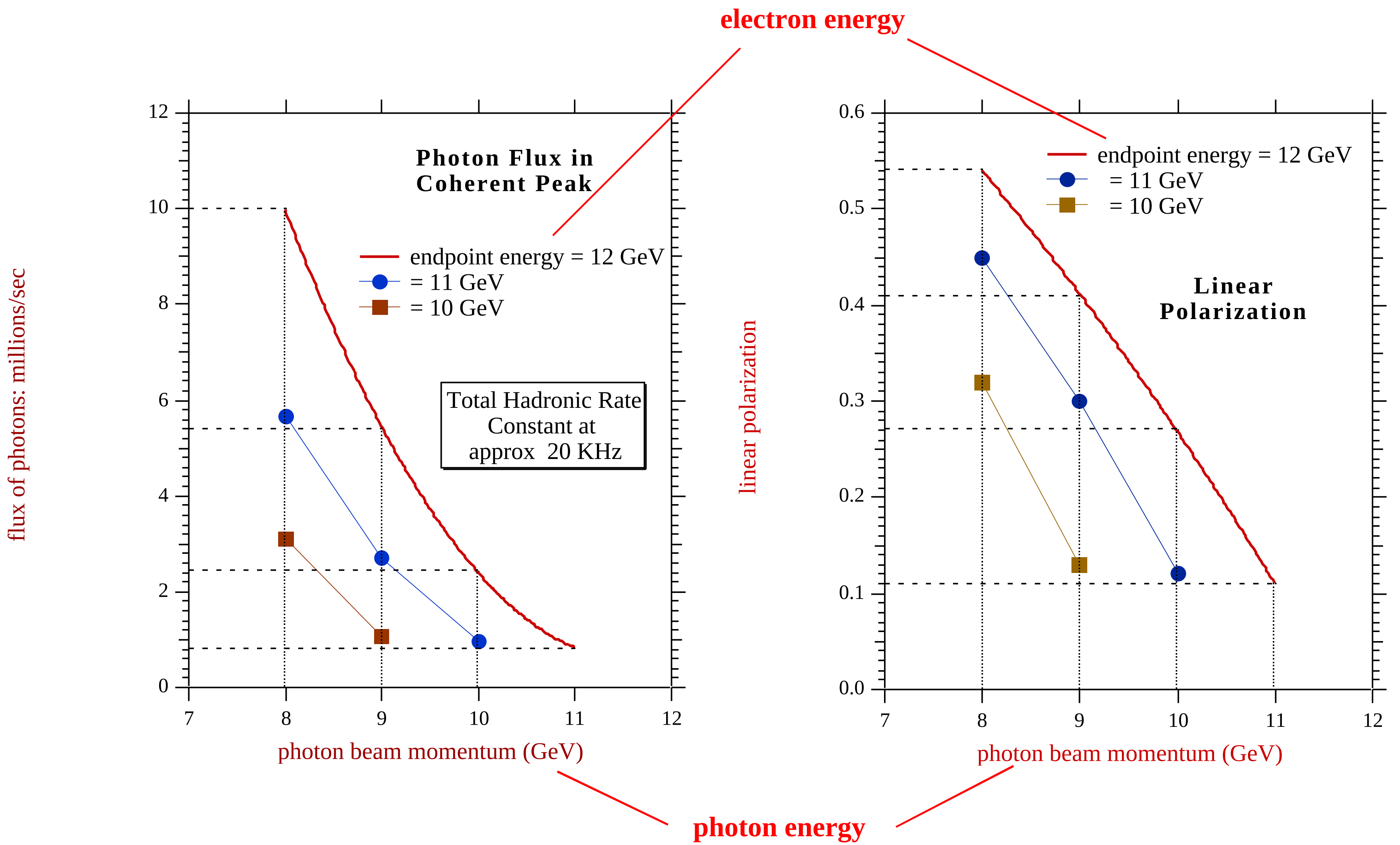
m = –1 $Y_1^{-1} \quad \sin\theta \ e^{-i\phi}$

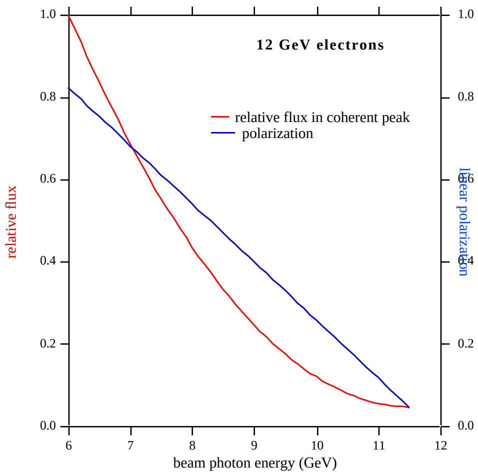
helicity of the vector follows that of the photon

$\left.\begin{array}{l}\text{circular} \\ \text{unpolarized}\end{array}\right\} \quad \frac{dN}{d\Omega} \quad \sin^2\theta$

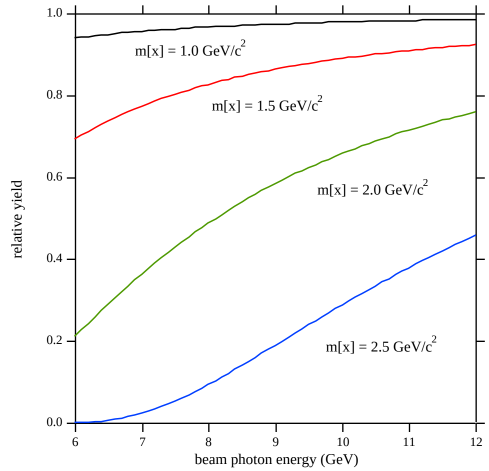
$\text{linear} \quad \frac{dN}{d\Omega} \quad \sin^2\theta \ \cos^2\phi$

Electron Energy

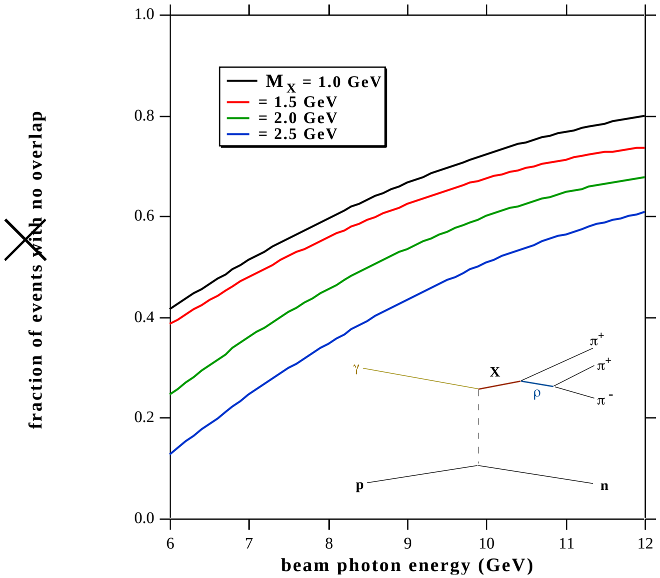




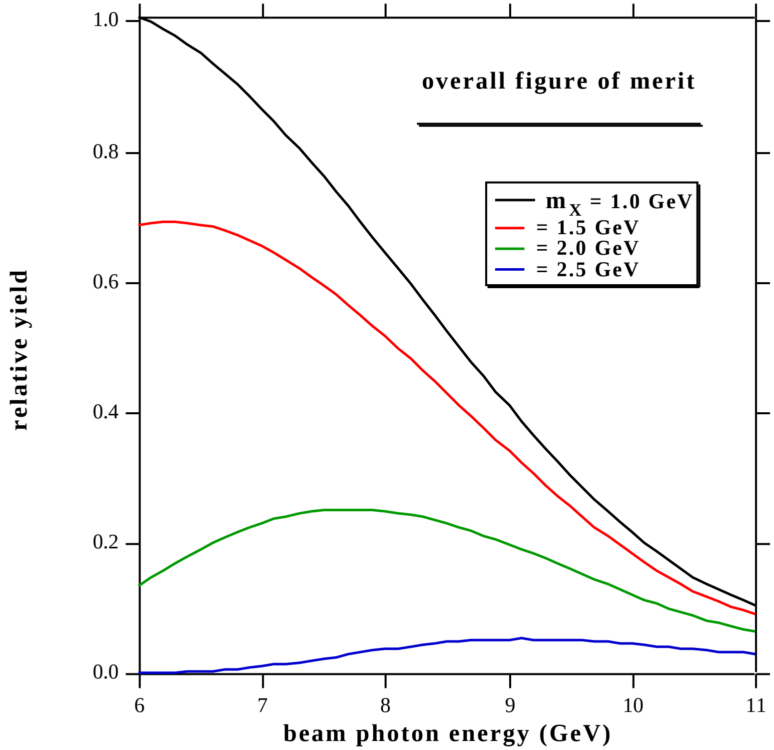
×



×



=



assume isotropic decay angles and a $\frac{dN}{dt} \quad e^{-8t}$ distribution:

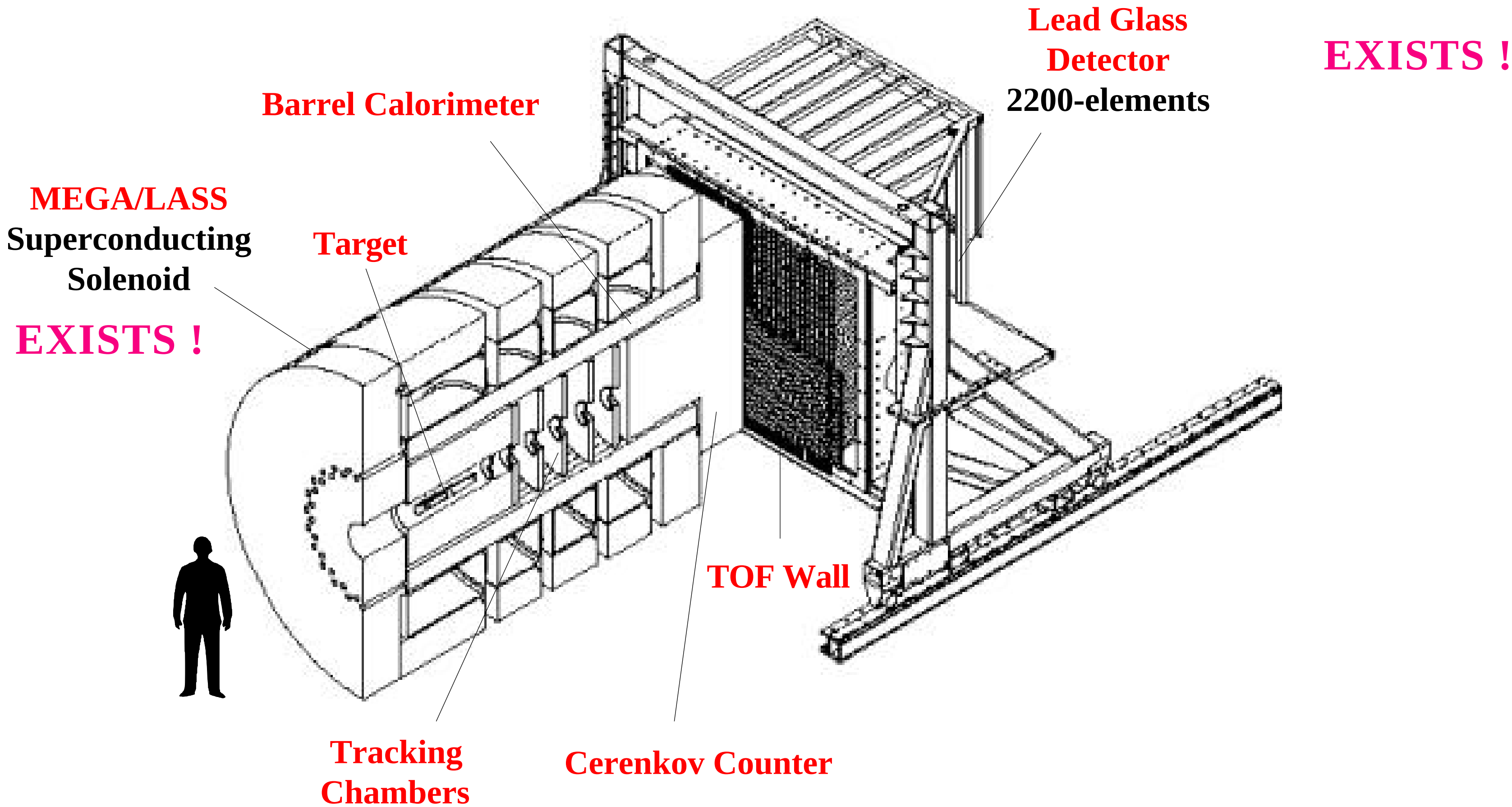
Optimal Photon Energy

Figure of Merit

Uniqueness of JLab

- **Photoproduction - an unexplored regime - extant data are paltry**
  - **- likely place to find exotic hybrids**
    - **photon is a $\bar{q}q$ with spins aligned and excitations of the flux tube leads to exotic J^{PC}**
  - **- photon beams at JLab unprecedented in**
    - **intensity**
    - **flux**
    - **duty factor**
    - **size**
    - **resolution**
    - **linear polarization**
- **Optimal photon energy (8 - 9 GeV) achievable with 12 GeV electrons**
- **Existing facilities cannot do the job**
  - **- SLAC - duty factor is 10^{-4} compared to 1**
  - **- FNAL - photon beams are tertiary (backgrounds, large spot size)**
  - **- ELFE - planned facility - uncertain future**

The Hall D Detector



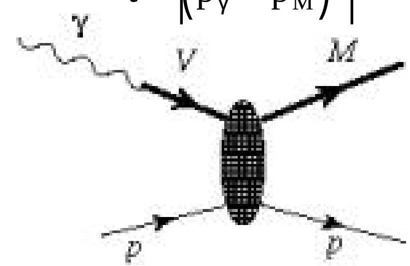
More to follow - from Curtis Meyer on the Detector Overview

Statistics Needed for PWA

- **Carry out a PWA in 10 MeV mass bins for 10 equally populated bins in | t |**
  - **mapping out the t-dependence provides information about the production mechanism**

- **Take the E852 signal reported in ρπ as a benchmark**
  - **exotic signal was 5 % of the a_2 signal in that experiment**

$$t = \left|(p_\gamma - p_M)^2\right|$$



With a flux of 10^7 photons/sec and a 30-cm LH_2 target and 1 year of data-taking:

Assuming an overall efficiency of 20 % (data-taking, acceptance,reconstruction, etc..)

Our yield will be 200 times that collected by E852 and we would have about 1500 events in the central 10 MeV bin of the exotic signal in one | t | bin

Rates and Doing the Analysis

Rates

- at 10^7 photons/sec we record 10 KHz (hadronic + accidental)

- pipeline electronics at the outset will eventually allow us to run at 10^8 photons/sec with high level software trigger

Analysis

- High analysis rate capability exists at JLab

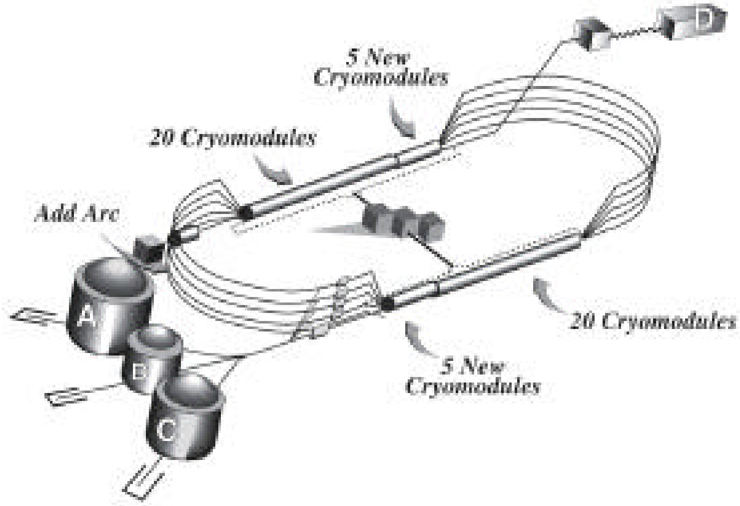
Physics Analysis

- Close collaboration of theorists/experimentalitsts
  - develop formalism for PWA and phemomenology
- Independent PWA teams

Costing the Experiment

Summary

Item	Cost ($K)
Detector Package	18200
Civil and Beamline	10000
Total Cost	**28200**



Detector

Item	Cost ($K)
Tracking	2600
Barrel Calorimeter	2700
Cerenkov Counter	700
Forward Calorimeter	600
Time of Flight Wall	800
Start Counter	750
Computing	1100
Electronics	4500
Hydrogen Target	200
Solenoid	750
Final Assembly	1500
Photon Tagger	2000
Total	**18200**

Civil & Beamline

Buildings		Cost ($K)
	Construction	2000
	Utilities	100
	Crane	150
	Access Control	50
	Fire Protection	100
	Mechanical	1500
	Electrical	1000
	Overhead	1500
Sub Total		**6400**
Beamline		**Cost ($K)**
	Diagnostics	500
	Service Building	100
	Elements	1200
	Labor	1800
Sub Total		**3600**
Total Civil & Beamline		**10000**

Cassel Review

Dec 6-7, 1999

David Cassel	Cornell (chair)
Frank Close	Rutherford
John Domingo	JLab
Bill Dunwoodie	SLAC
Don Geesaman	Argonne
David Hitlin	Caltech
Martin Olsson	Wisconsin
Glenn Young	ORNL

From the Executive Summary

- **The experimental program proposed in the Hall D Project is well-suited for <u>definitive</u> searches of exotic states that are required according to our current understanding of QCD**

- **JLab is <u>uniquely suited</u> to carry out this program of searching for exotic states**

- **The <u>basic approach</u> advocated by the Hall D Collaboration is <u>sound</u>**

- **The Collaboration will be ready to begin work on a Conceptual Design Report once a Project Office with a Project Director is in place**

- **An <u>R&D program is required</u> to ensure that the magnet is usable, to optimize many of the detector choices, to ensure that novel designs are feasible, and to validate cost estimates.**

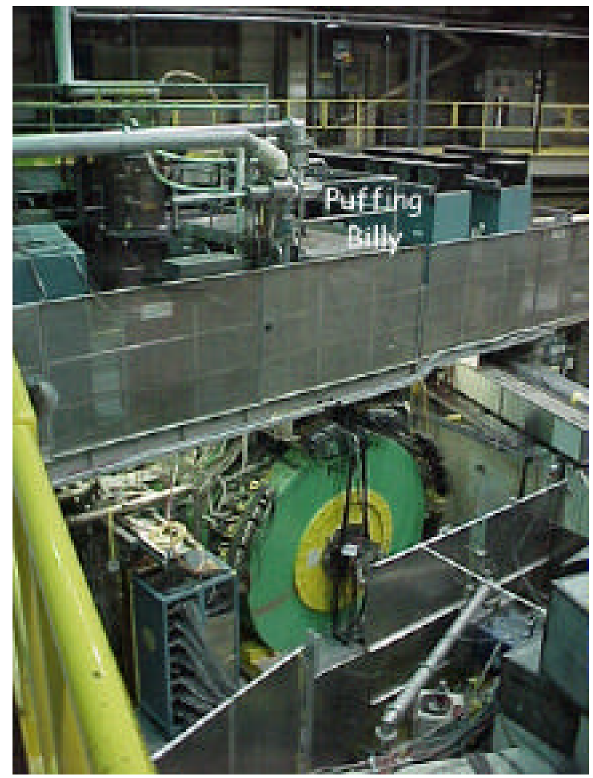
Solenoid

Superconducting solenoid originally for LASS (SLAC) then moved to LANL for MEGA - 250 tons and 2.5 T field

Review team at LANL March 9-11, 2000

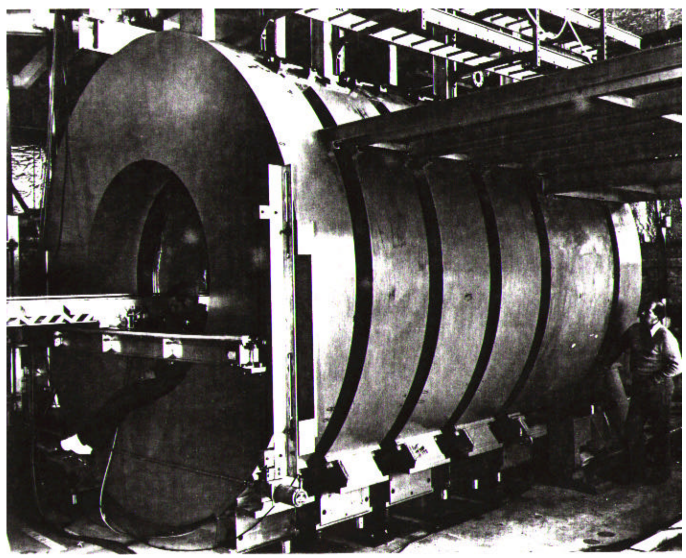
John Alcorn **Steve St.Lorant**	**designers of the original LASS magnet**
Paul Brindza	**JLab Systems Engineer for Experimental Equipment**

Team inspected 4th coil (only 3 were used in MEGA) and the MEGA magnet, interviewed LANL staff (current and retired) involved in the transferto LANL and operation and looked at documentation and logbooks.



Conclusions:

- **Magnet and 4th coil in excellent shape**
- **Replacement cost: $10M**
- **Moving and upgrade cost: < $1M**



Startup and R & D Funds

- R & D needs as per the Cassel Committee recomendations
- Needs shown below are in $K for two years
- R & D projects are of a generic nature
  - digital pipelines and digitizing for high rate experiments
  - tracking issues (e. g. sci/fi tracking)
  - calorimetry
- Solenoid and LGD moves - valuable resources for JLab

Theory Group needs for travel and postdoc/student support for 2 years: $420K

not covered by exisiting operating funds

Note: Numbers in this table for a <u>two-year total</u>.

	Equipment	Salaries/Travel	Total
Electronics	240	135	375
TOF	24	15	39
Cerenkov	48	124	172
Tracking	195	260	455
Beam	42	97	139
Barrel calorimeter	61	183	244
Solenoid move			500
LGD move			24
Total			**1948**

Note: Indiana U has already contributed $30K and has given strong indication of an additional $280K for FY00/FY01 - This will be used to cover costs of infrastructure in the electronics lab and a processor farm and postdoc for computer simulations. This does not apply to the above table.

Note: NSERC (Regina) funding at level of C$200K for next two years likely - this will apply to the barrel calorimeter in the table above.

Other Physics

Focused Physics Goal Presented Here

- Search for exotic hybrids

General Purpose Detector Allows for Other Physics

- $K\bar{K}$ threshold and the a_o/f_o
- Rare decays: ϕ, η
- Chiral dynamics
- Threshold Charm Production

Summary

Physics is Fundamental

Role of glue in strong QCD - Impressive strides in theory

Goal is Clear

Unambiguous identification of gluonic excitations starting with exotic hybrids

Photoproduction

Hybrids are expected to exist precisely where we have no current experimental information

Photon Beams

Needed energy, flux, duty factor and polarization are available at an energy-upgraded CEBAF

Detector

State of the art - based on several existing subsystems