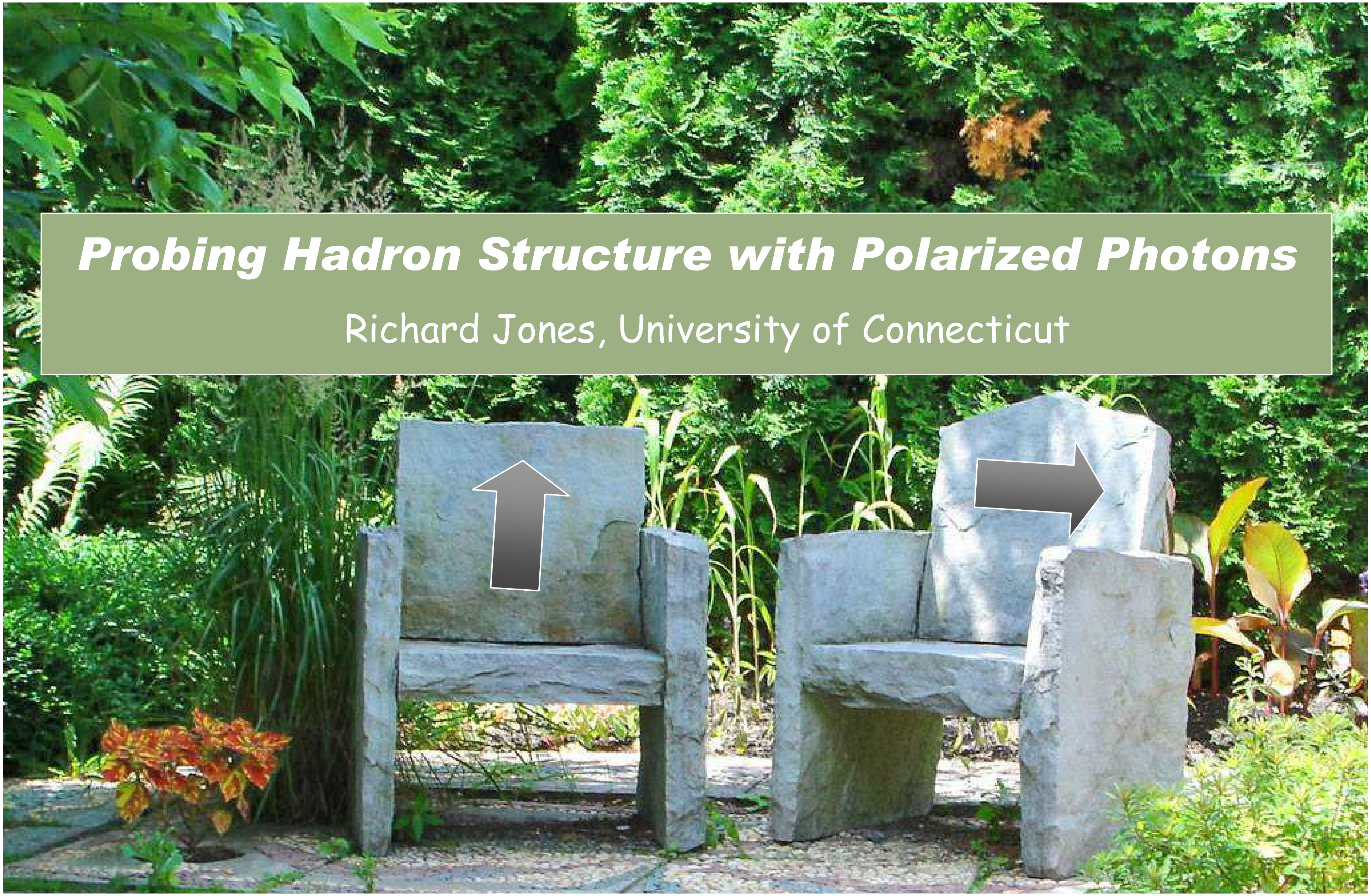
Probing Hadron Structure with Polarized Photons

Richard Jones, University of Connecticut



Symposium on Nucleon Structure and Electroweak Precision Tests: Past and Future, Champaign Illinois, May 19, 2010

Outline

- The photon as a probe of structure
- Hadrons at rest in QCD
- Exotic mesons
- Photoproduction
- The GlueX experiment
- Future outlook

Photon as a probe of structure

Historical perspective:

- Hydrogen atom
- Nuclear size, magnetic moments
- Nuclear structure, dynamics

Nuclear structure from photon scattering

R. Alarcon, **A.M. Nathan**, S.F Lebrun, and S.D. Hoblit, **PRC 39** no. 2, 1989.

Shell Model structure

Collective Model structure

ground state

1P1H excited state

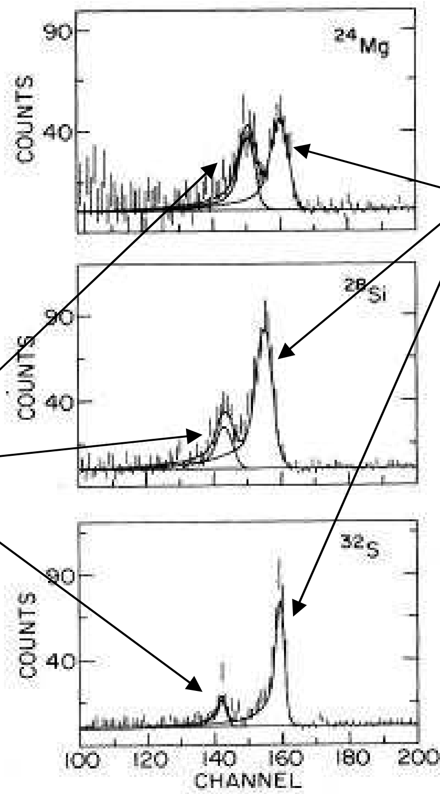


FIG. 1. Measured spectra of scattered photons from ^{24}Mg, ^{28}Si, and ^{32}S at 21.5 MeV incident energy. The curves are the results of a two-peak fit to the data in order to separate the scattering into elastic and 2_1^+ inelastic components.

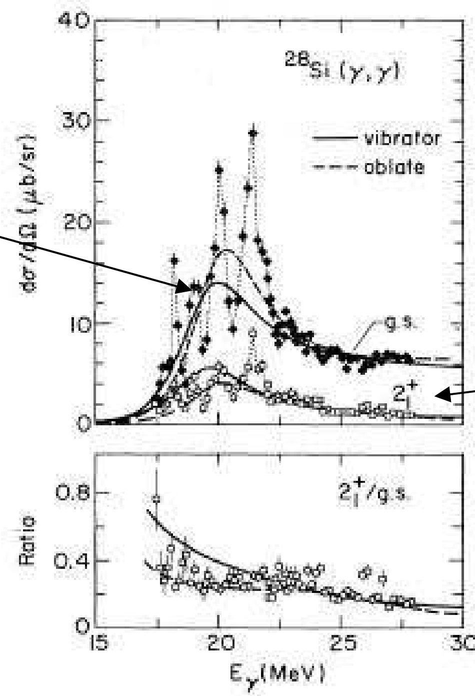


FIG. 3. Elastic and 2_1^+ inelastic cross sections at 135° on ^{28}Si. Also shown is the ratio of inelastic to elastic scattering. The curves are calculations based on the dynamic collective model. The solid curves assume that ^{28}Si is a spherical vibrator while the dashed curves assume that ^{28}Si is an oblate rotor.

1P1H excited state

Hadrons at rest in QCD

Most of what we know about hadron structure:

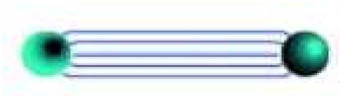
- Nucleons (or collections of them) at $p << m$
- Heavy quarkonium at rest

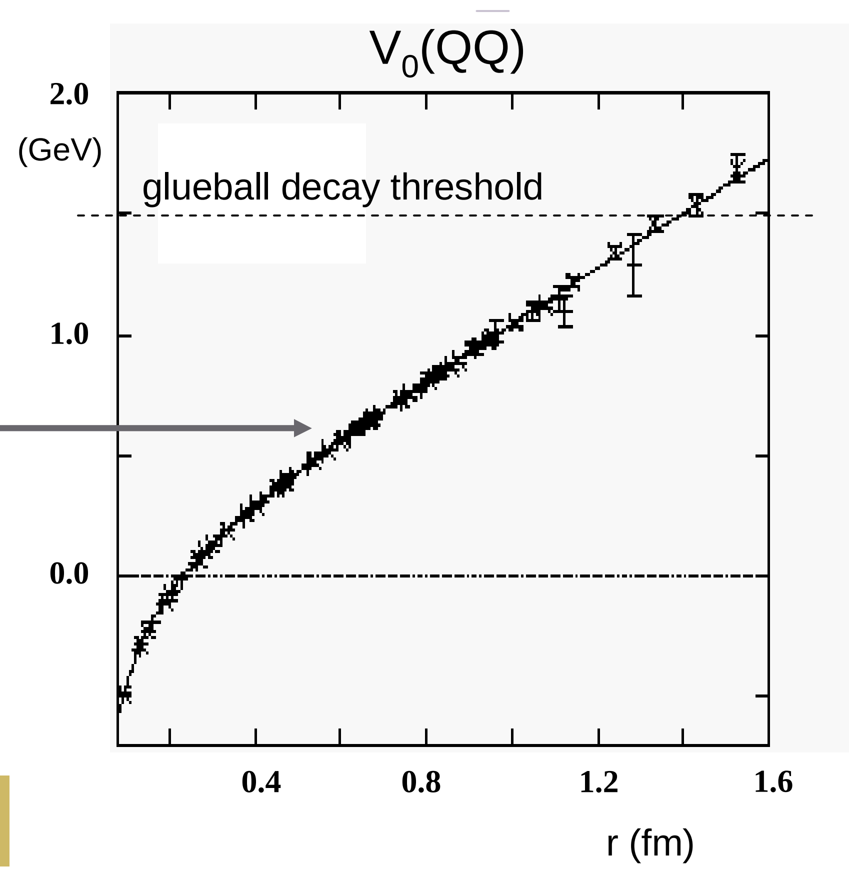
What can we learn from QCD about the structure and dynamics of the more general class of ***hadrons at rest?***

Starting Point: the hadron mass spectrum

Consider QCD with only heavy quarks:

- the only light mesons are glueballs
- $\bar{q}q$ mesons have the conventional positronium low-energy spectrum
- spectrum is distorted at higher excitations by a linear potential
- for r > 0.5 fm a tube of gluonic flux forms between q and $\bar{q}$



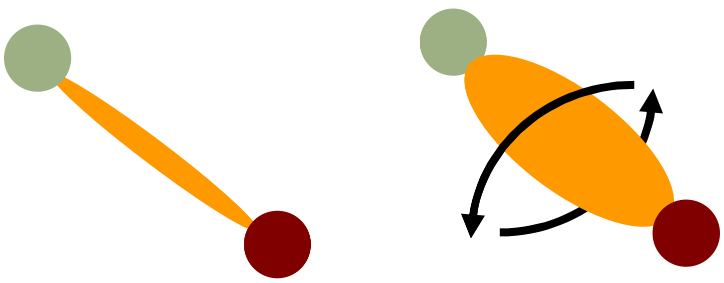


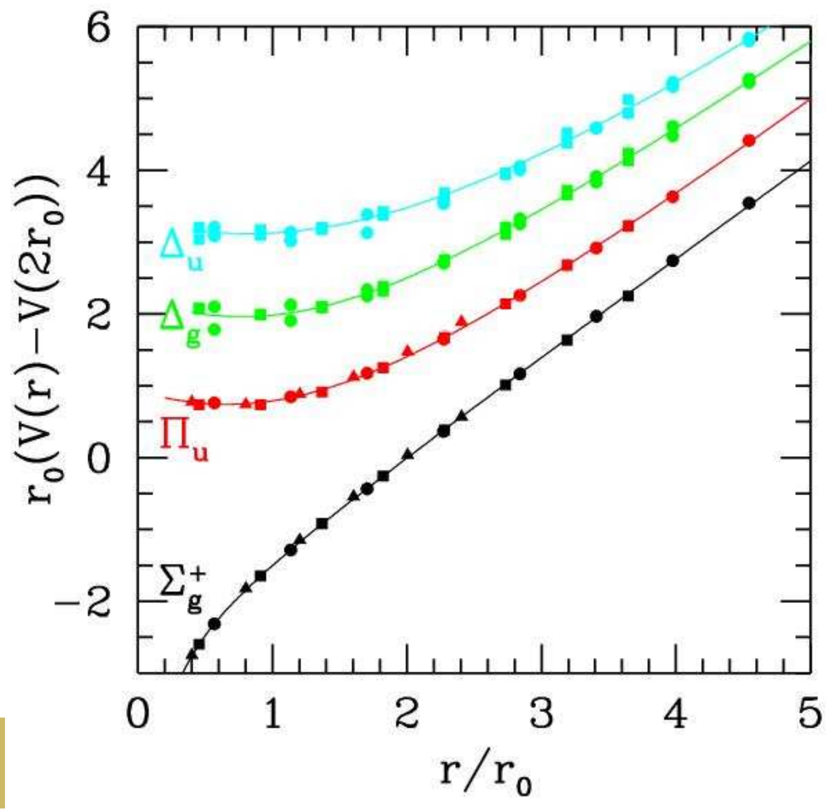
This corresponds to the NR quark model

Starting Point: the hadron mass spectrum

Consider QCD with only heavy quarks:

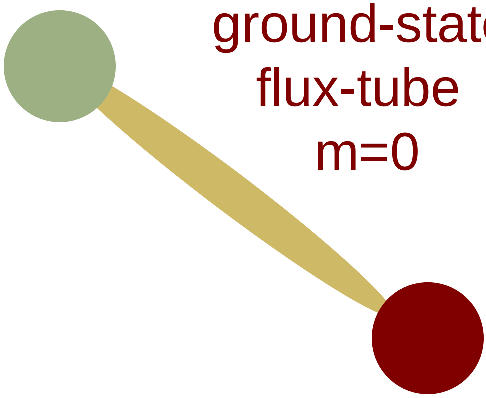
- gluonic excitations give rise to new potential surfaces
- gluonic excitations behave like quantized oscillations of the flux tube



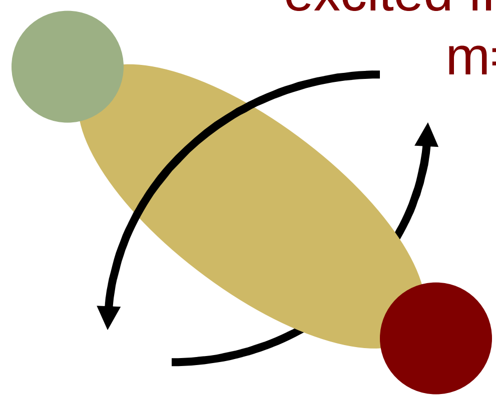


This corresponds to the "flux tube" model

Normal *vs* hybrid mesons in the flux tube model



ground-state flux-tube m=0



excited flux-tube m=1

1^{-+} or 1^{+-}

$$CP = (-1)^{L+S}\,(-1)^{L+1} = (-1)^{S+1}$$

Flux-tube Model

m=0 $CP=(-1)^{S+1}$

m=1 $CP=(-1)^{S}$

S=0, L=0	S=1, L=0
J=1 CP=+	J=1 CP=–
$J^{PC}=1^{++},1^{--}$	$J^{PC} = 0^{-+},0^{+-}$
(not exotic)	exotic $1^{-+},1^{+-}$
	$2^{-+},2^{+-}$

Challenge: extrapolation to light quarks

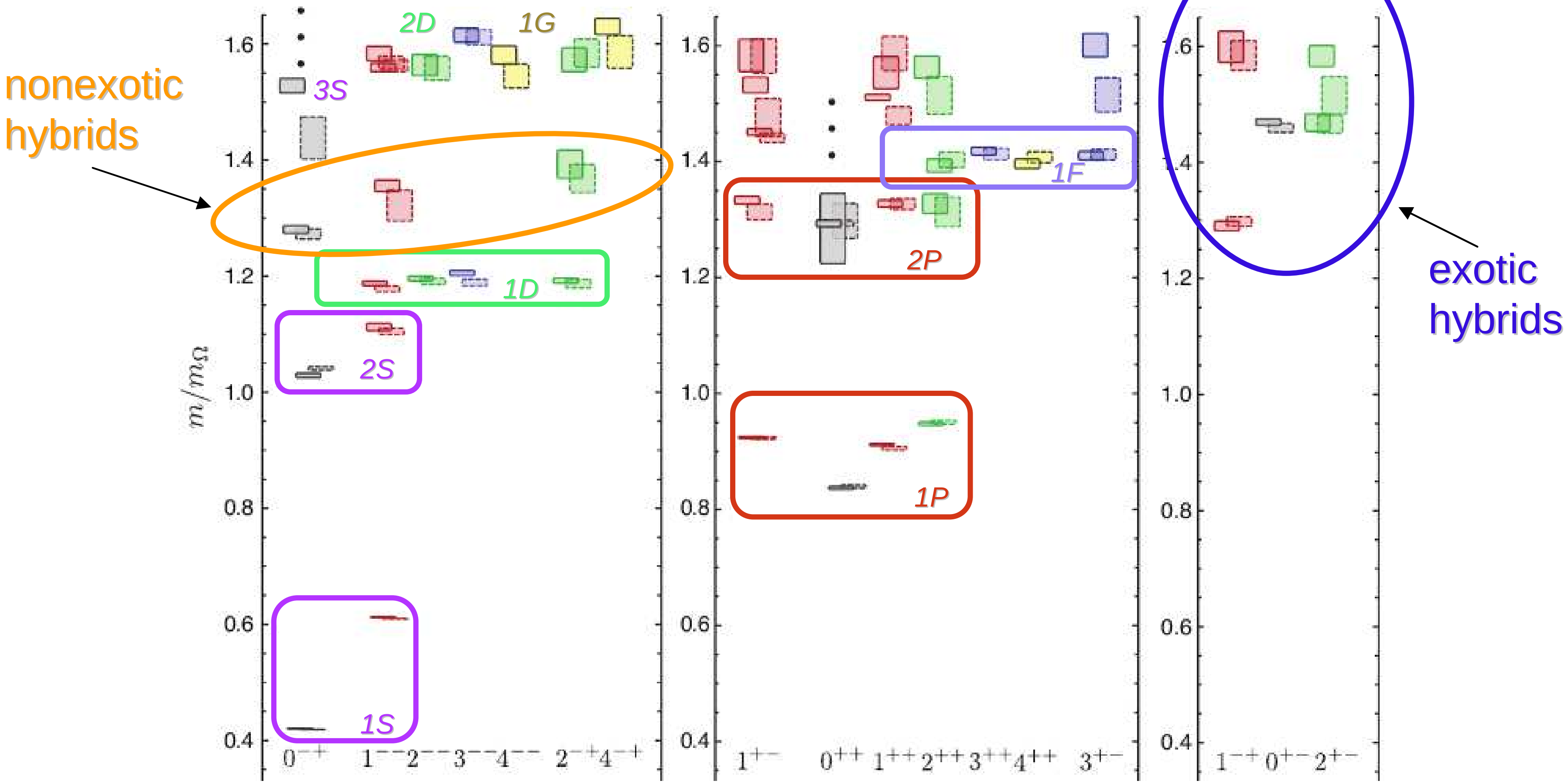
- Does the flux-tube picture still make sense for light quarks?
  - quarks are relativistic
  - Fock subspaces mix ($q\bar{q}$, $q\bar{q}q\bar{q}$, ...)
  - excited mesons are unstable (decays)
  - gluon fields modified by dynamical quarks (loops)

Accounted for in quenched lattice studies

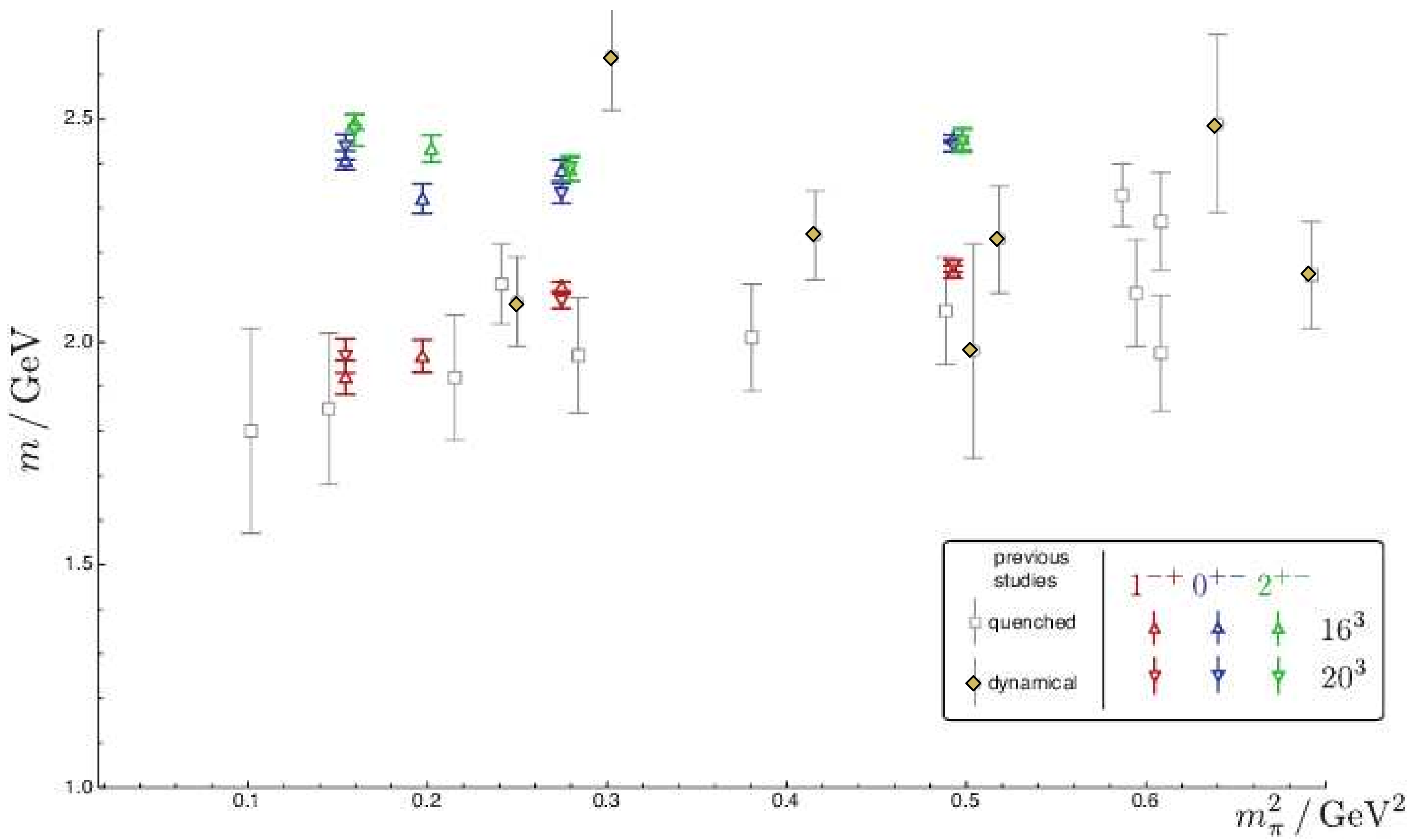
Requires unquenched lattice studies, advanced methods

Recent progress: LQCD spectrum @ m_π=700MeV

J.J. Dudek et.al., arXiv:1004.4930v1 (2010)



Survey of LQCD results for lightest exotic hybrids



Challenge: extrapolation to light quarks

- Does the flux-tube picture still make sense for light quarks?
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  - Fock subspaces mix ($q\bar{q}$, $q\bar{q}q\bar{q}$, …)
  - excited mesons are unstable (decays)
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- Can experiments actually observe exotic states?
  - resonances may be broad – difficult to observe individually
  - configurations mix – exotic identification may be ambiguous
  - hybrids are embedded in a continuum of lighter 2-meson states
    - $q\bar{q}$ selection rules do not apply to 2-meson states
    - strong mixing may occur

Accounted for in quenched lattice studies

Requires unquenched lattice studies, advanced methods

Exotic Mesons

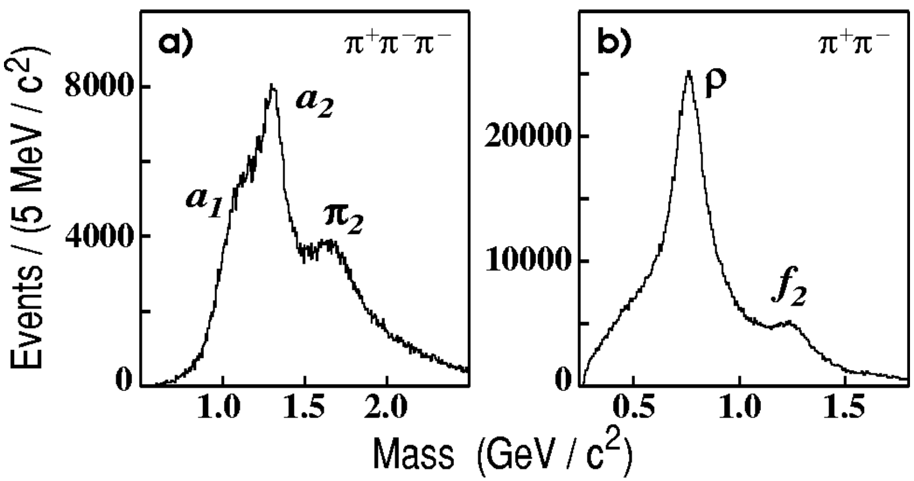
- Most of the attention is focused on 3 observed states:
  - $\pi_1(1400)$ – seen in $\eta\pi$ E852 Crystal Barrel
  - $\pi_1(1600)$ – seen in $\rho\pi$, $f_1\pi$, $b_1\pi$, $\eta'\pi$ GAMS VES E852 Compass
  - $\pi_1(2000)$ – seen in $f_1\pi$, $b_1\pi$ E852

Experiment: $\pi_1(1600)$ from BNL-852

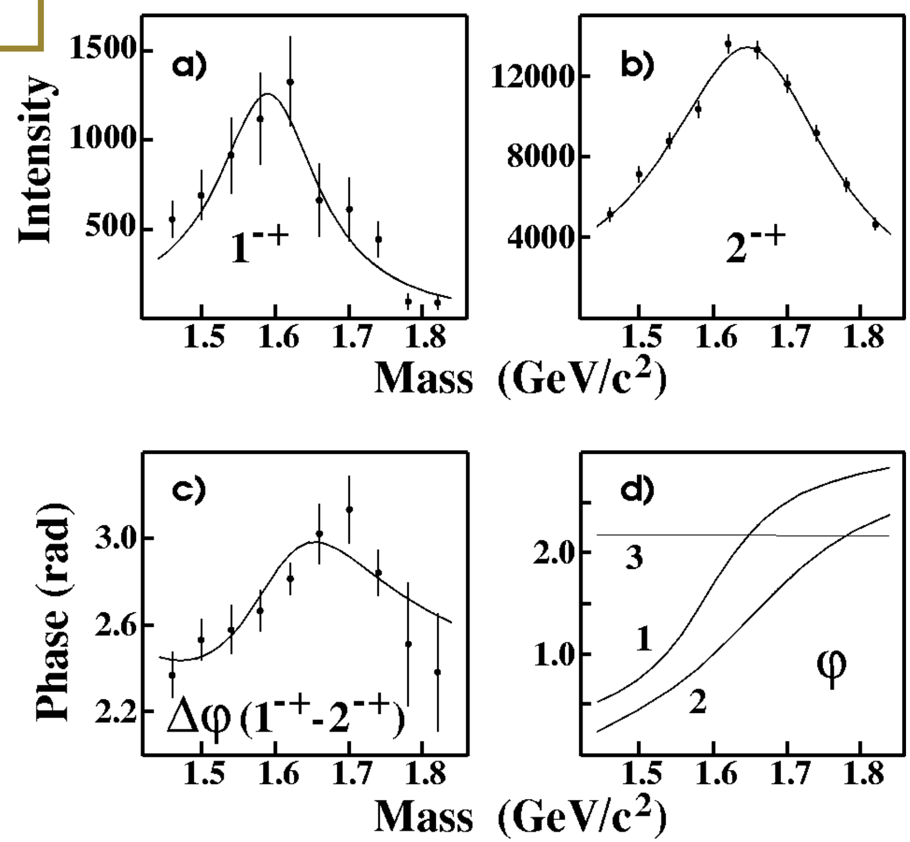
Mass = 1598 ±8+29-47 MeV/c^2
Width = 168±20+150-12 MeV/c^2

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

(~250,000 Events)



Partial Wave Analysis
$\pi_1(1600) \rightarrow \rho\pi$



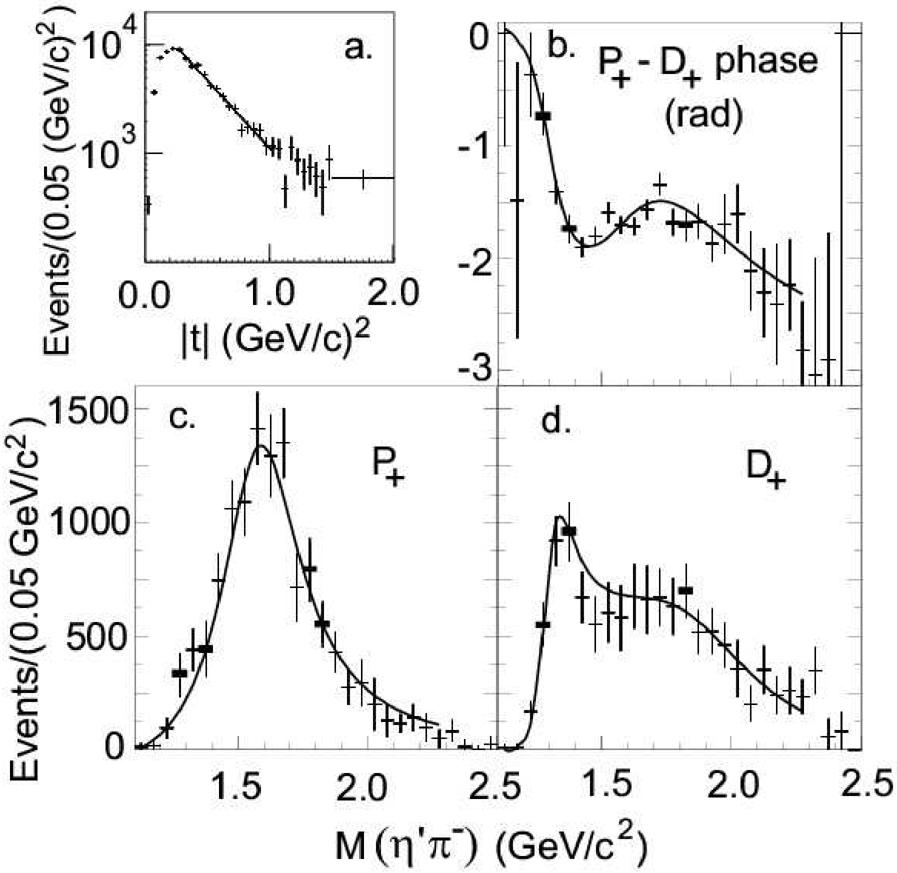
Experiment: $\pi_1(1600)$ from BNL-852

Mass = 1597±10+45-10 MeV/c^2
Width = 340±40±50 MeV/c^2

$\pi^- p \rightarrow \eta' \pi^- p$

The exotic wave is the dominant wave in this channel.

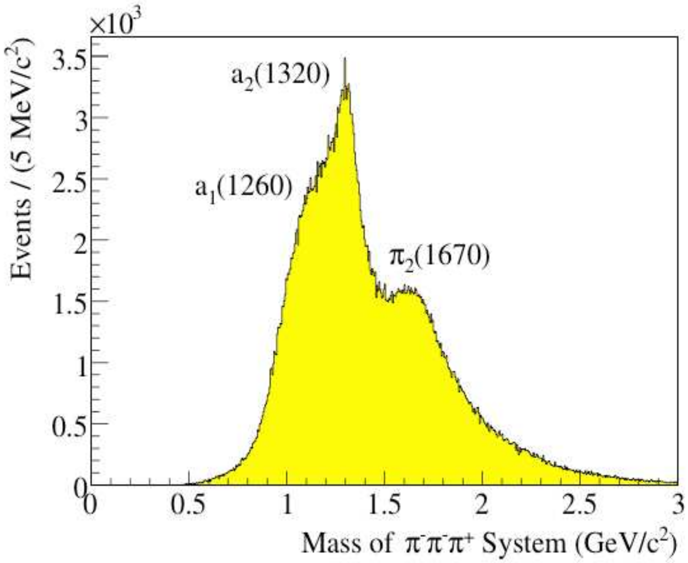
Partial Wave Analysis
(~6000 Events)



Experiment: $\pi_1(1600)$ from Compass

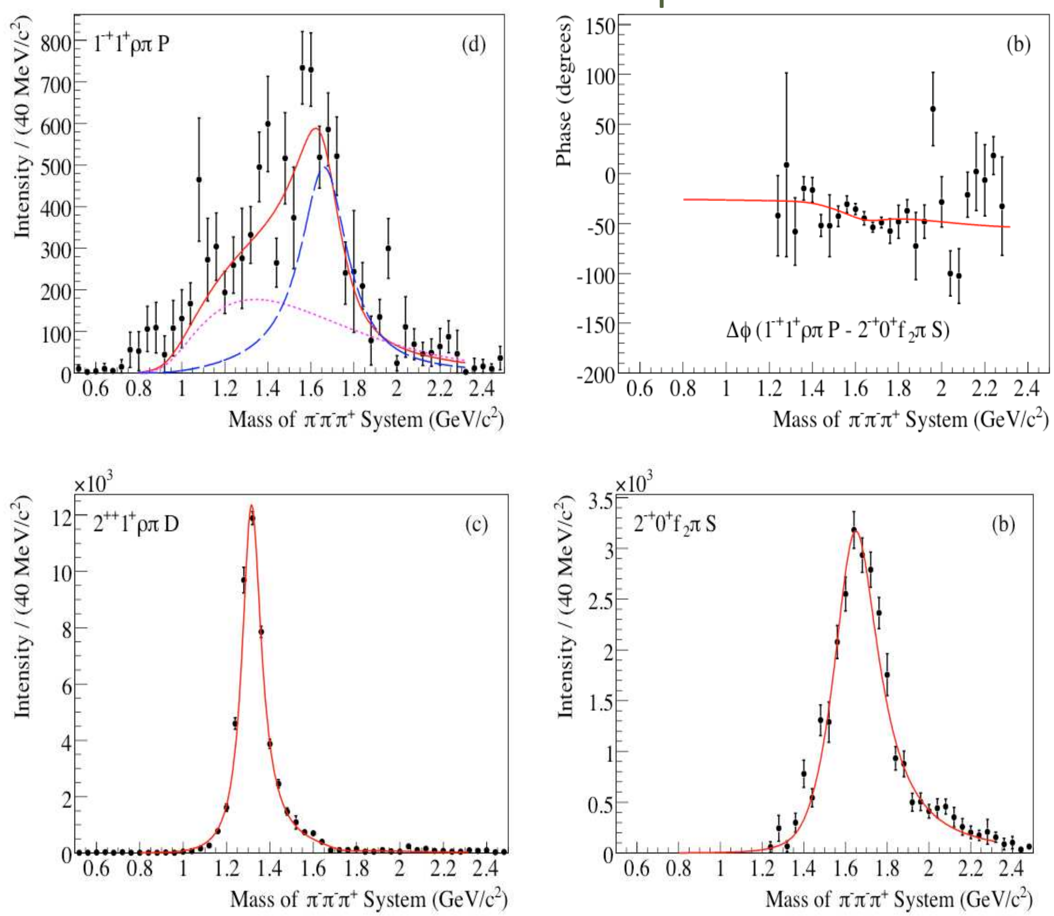
Mass = 1660 MeV/c^2
Width = 269 MeV/c^2

$$\pi^- Pb \rightarrow \pi^+\pi^-\pi^-(Pb)$$



(180 GeV pions, 420,000 events)

Partial Wave Analysis, preliminary
arXiv:0910.5842 – unpublished



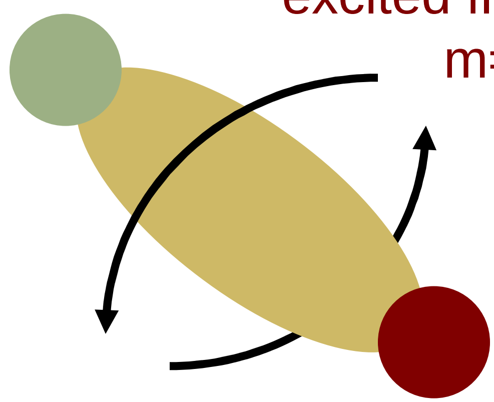
Photoproduction

- All experiments (except CB) used pion beams
- CB was a little too limited in mass reach to see 1.6 GeV
- General features for spectroscopy experiments
  - requires detection of exclusive multi-particle final states
  - requires large samples ($\sim 10^8$ in one exclusive channel)
  - requires good acceptance (uniform and well-understood)

Photoproduction vs pion production of hybrids

Quark spin argument:

excited flux-tube
m=1



1^{-+} or 1^{+-}

Initial state pion has S=0
quark configuration
***may* preferentially**
form non-exotic hybrids

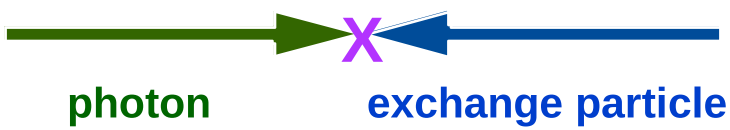
S=0, L=0	S=1, L=0
J=1 CP=+	J=1 CP=–
$J^{PC}=1^{++},1^{--}$	$J^{PC} = 0^{-+}, 0^{+-}$
(not exotic)	exotic $1^{-+}, 1^{+-}$
	$2^{-+}, 2^{+-}$

Initial state photon (ρ,ω,ϕ)
has S=1 quark configuration
may preferentially
form exotic hybrids

Photoproduction: role of beam polarization

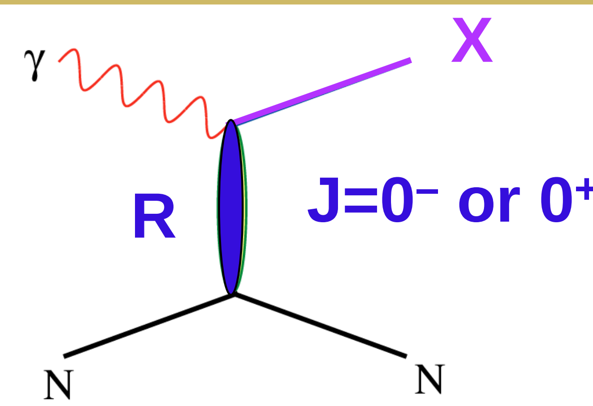
Gottfried-Jackson frame

for X with J = 1, R with J = 0



$$L = 0,\ 1,\ \text{or}\ \ 2$$

$$P_V = P_\gamma \cdot P_X \cdot (-1)^L$$



Suppose we want to distinguish the exchange: 0^+ from 0^- (A^N from A^U)

For circular polarization:

	photon		V = vector	
$\lvert R\rangle$	→	m = 1	→	$A^N + A^U$
$\lvert L\rangle$	←	m = -1	←	$A^N - A^U$

- With linear polarization we can isolate A^N from A^U
- Circular polarization gives access to their interference

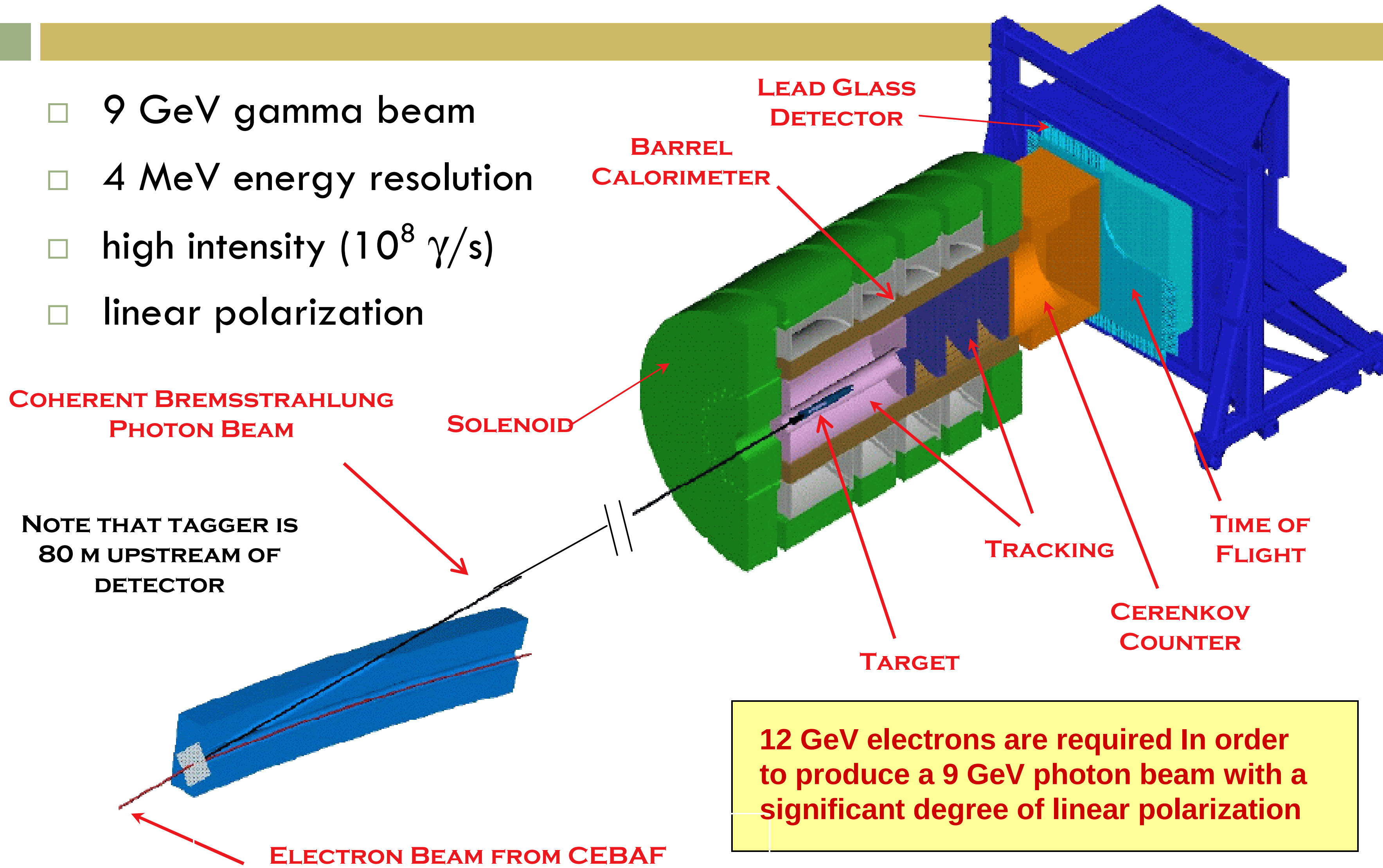
The GlueX Experiment

- Search for gluonic excitations in meson photoproduction, and map out their spectrum.
- Covers mass region up to 2.5 GeV/c^2
- Linearly polarized photon beam 8.4 – 9 GeV
- Part of the 12 GeV Upgrade of Jefferson Lab
- GlueX collaboration: 40 physicists, 10 institutions.
- Current spokesperson Curtis Meyer (CMU)

The GlueX Experiment

www.gluex.org

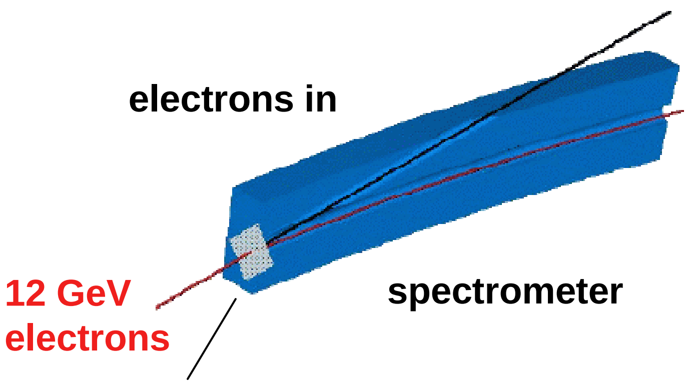
- 9 GeV gamma beam
- 4 MeV energy resolution
- high intensity (10^8 γ/s)
- linear polarization

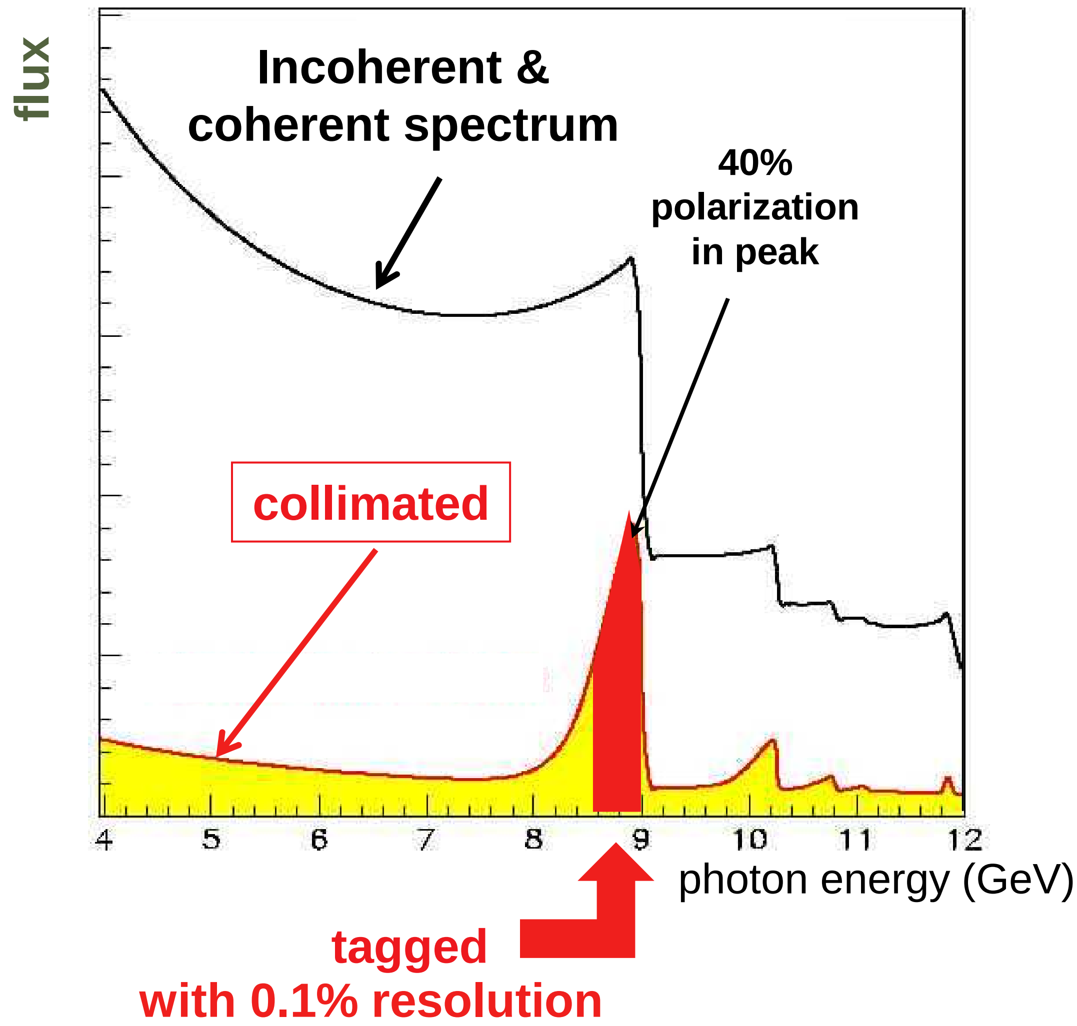


12 GeV electrons are required In order to produce a 9 GeV photon beam with a significant degree of linear polarization

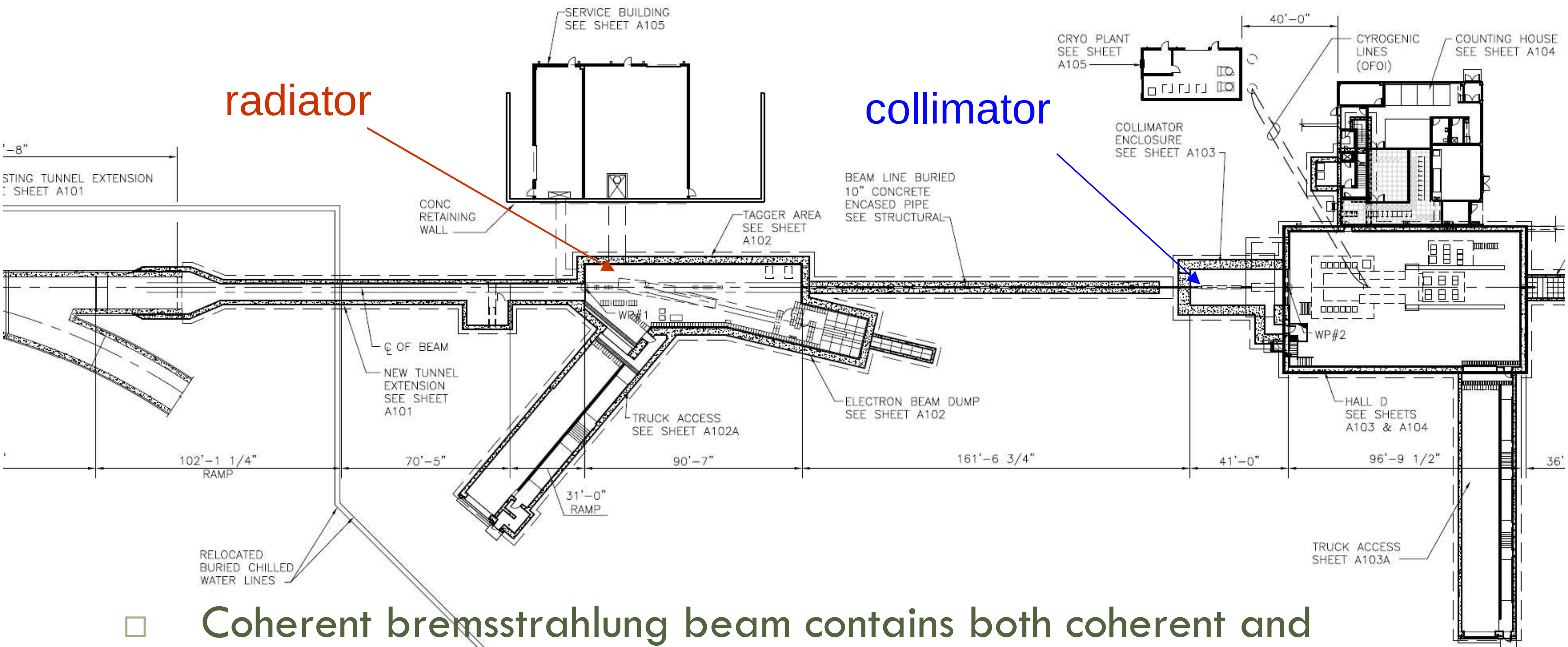
The GlueX Experiment: 9 GeV photon beam

The coherent bremsstrahlung technique provides requisite energy, flux and polarization



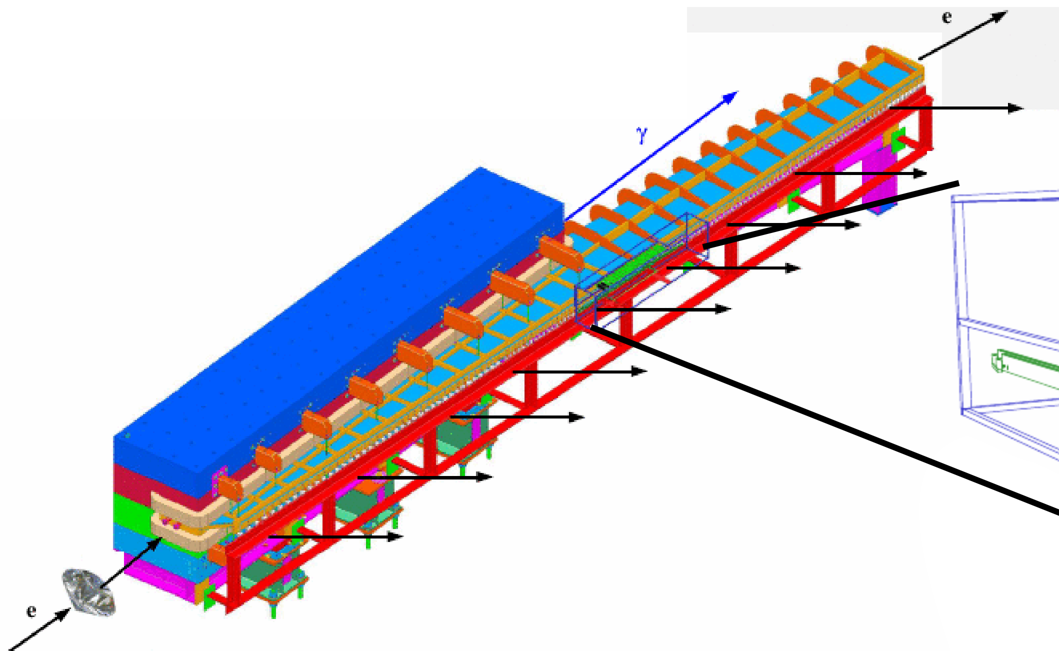


Hall D Beam Line



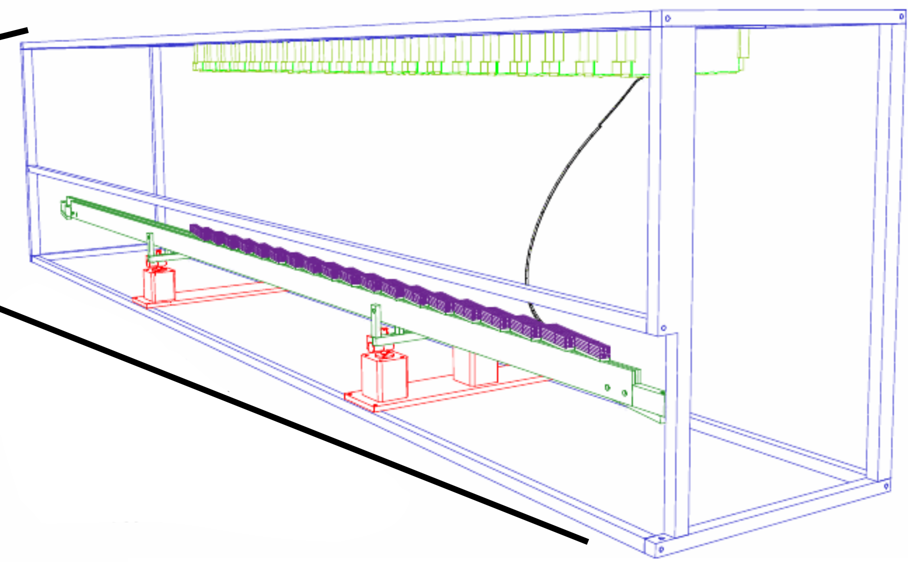
- Coherent bremsstrahlung beam contains both coherent and incoherent components.
- Only the coherent component is polarized.
- Incoherent component is suppressed by narrow collimation.

Photon tagging detector



- 1.5 T dipole, 6 m long, 30 mm pole gap
- Deflects electrons ($13.4° = 12$ GeV)
- 190 Hodoscopes: scintillator + PMTs (12 m long) → 3 - 11.7 GeV

Tagger "microscope"



scintillating fibers read out with SiPM's

Photon Tagging: an Illinois legacy

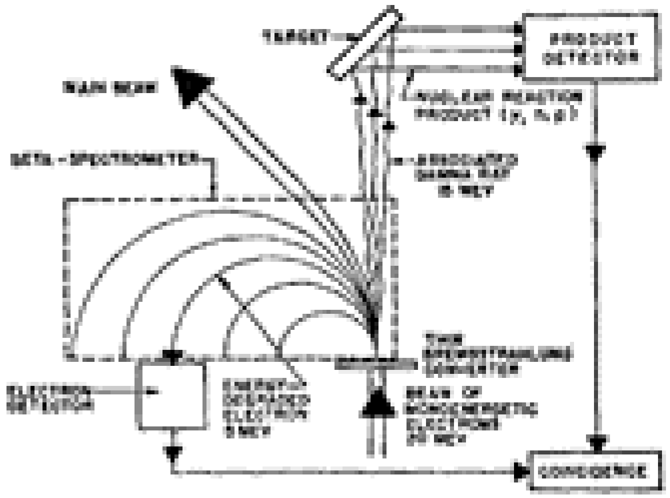
NUCLEAR STUDIES WITH TAGGED PHOTONS

Peter Axel
University of Illinois at Urbana-Champaign

Nuclear Physics with Electromagnetic Interactions: Proceedings of the International Conference, Held in Mainz, Germany, June 5–9, 1979. Editor: H. Arenhövel, D. Drechsel, Lecture Notes in Physics, vol. 108, p.256-265

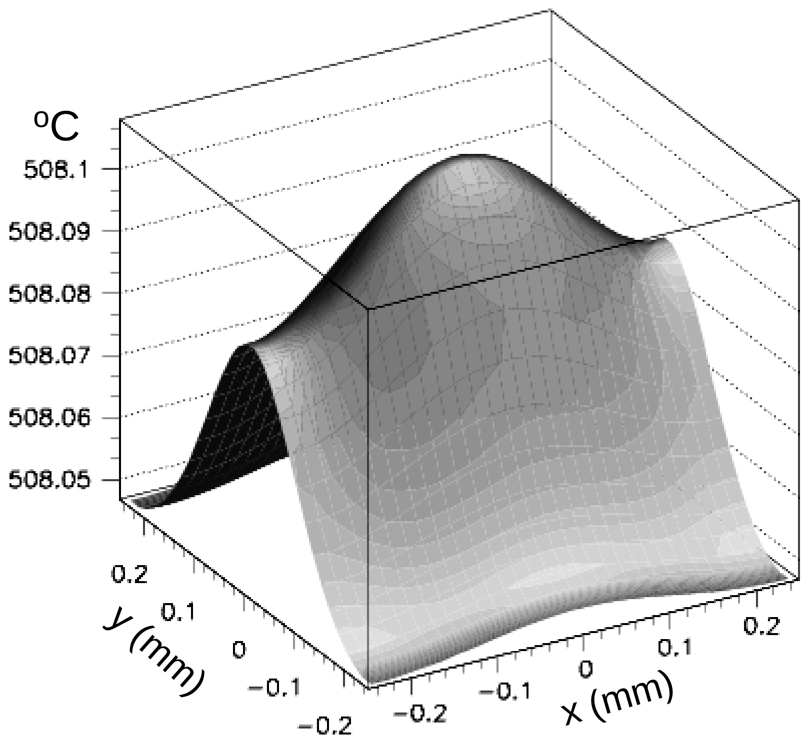
This paper will be subdivided into three parts. First, the photon tagging technique will be described schematically, and a brief history of photon tagging will be given, including the 20 year development of this technique at Illinois. In the second part some typical operating conditions will be indicated for our tagged photon facilities at Illinois. The photon fluxes and counting rate estimates that are given are associated with the use of a 100% duty cycle electron beam such as we have had from MUSL-2 (Microtron Using a Superconducting Linac) since 1977. The electron energy is variable up to the maximum energy of 69 MeV that we have obtained with a 6 traversal

Fig. 1 Schematic Diagram of Photon Tagging. An incident 20 MeV electron beam is shown incident on a thin converter. The spectrometer is set to transport a 5 MeV electron to a detector in the focal plane so that each such electron announces the tagging of 15 MeV gamma ray. About 99% of the electrons do not emit a photon; they are bent by the spectrometer so that they separate from the photon beam and are in the "main beam" shown in the upper left part of the figure.



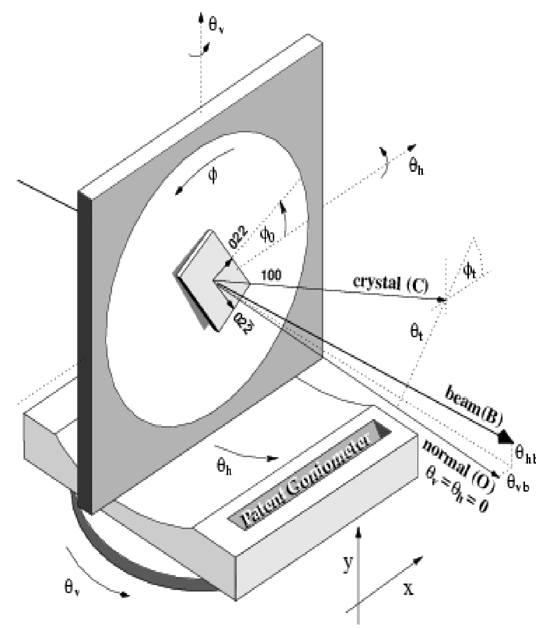
Diamond radiator requirements: mounting

temperature profile of crystal
at full intensity, radiation only



diamond-graphite transition sets in ~1200°C

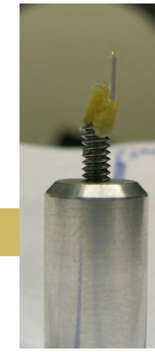
Heat dissipation specification for the mount is not required.



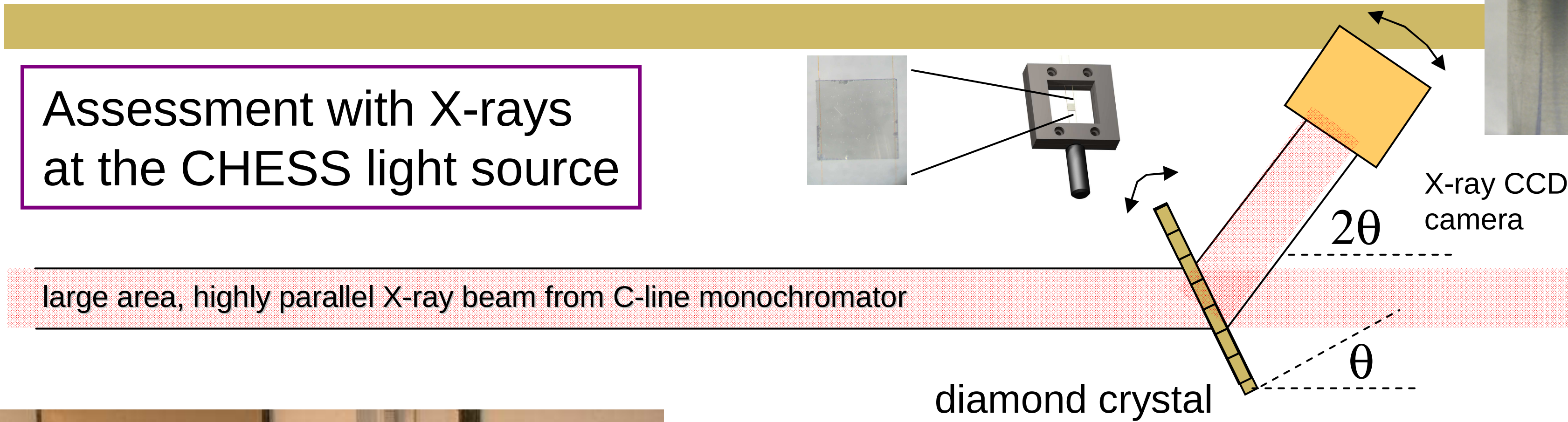
translation step: 200 μm horizontal
25 μm target ladder (fine tuning)

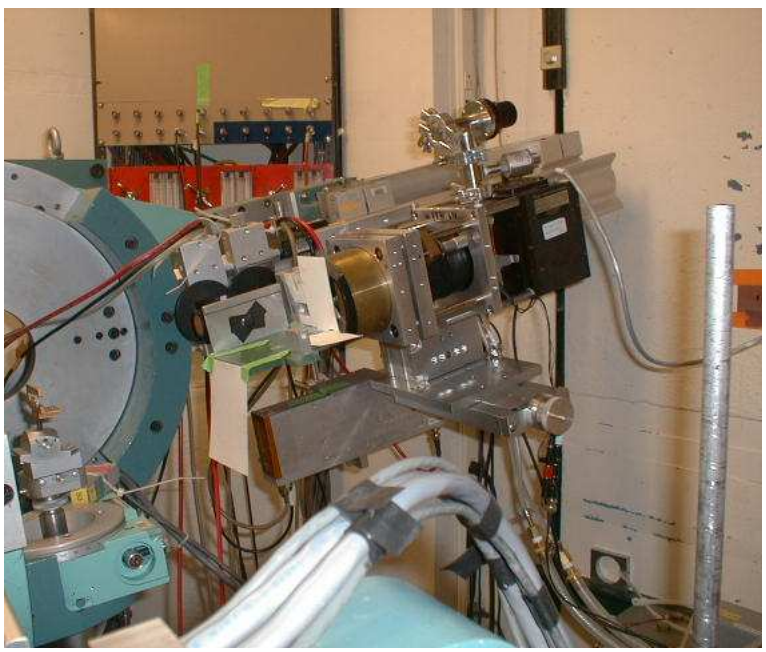
rotational step: 1.5 μrad pitch and yaw
3.0 μrad azimuthal rotation

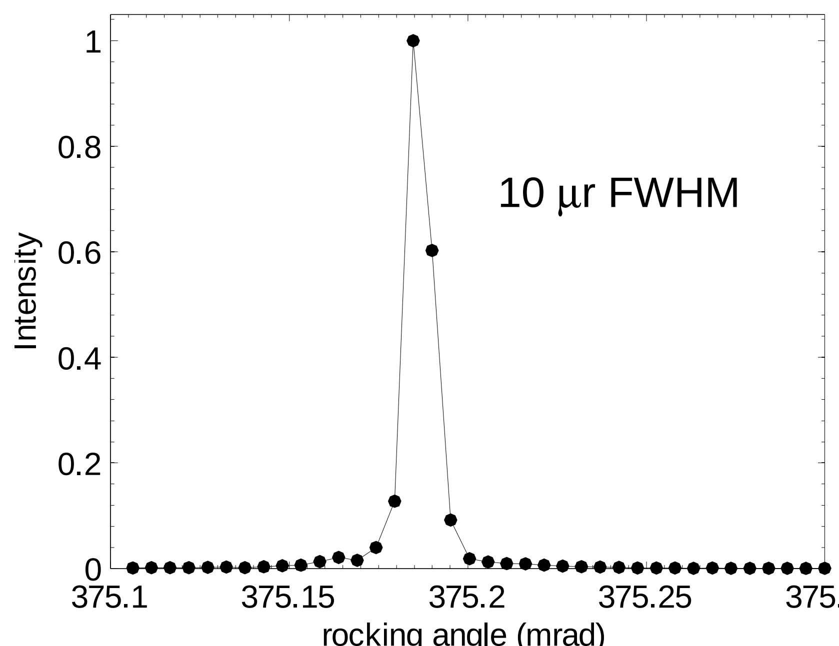
Diamond radiators for GlueX



Assessment with X-rays at the CHESS light source







Future Outlook

- *Will we ever achieve this for multi-meson final states at 2 GeV?*
- Tagged photons provide a tool with the potential to move us in that direction.

P.T. Debevec et.al., **PRC 45** no. 3, 1992.

Photodisintegration of the deuteron @ 70 MeV

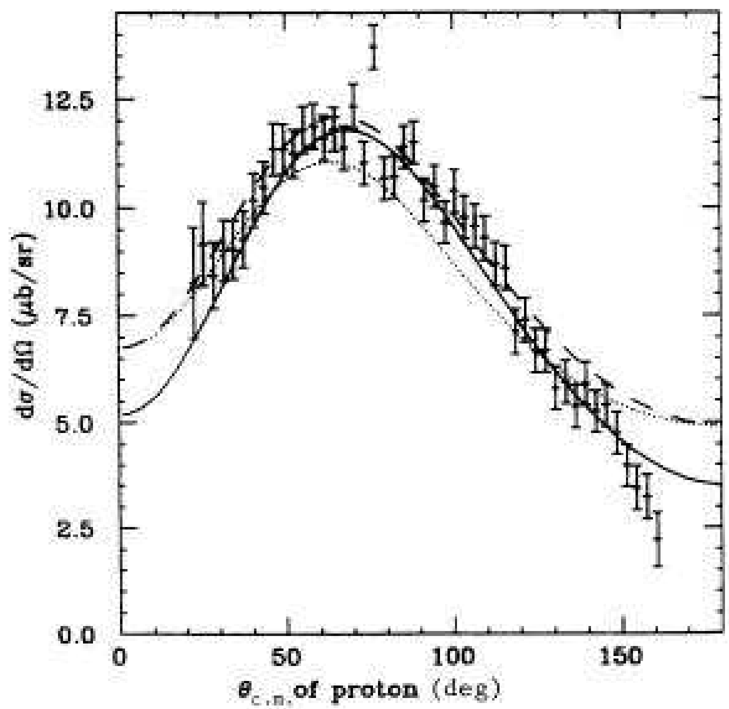


FIG. 7. Comparison of the present data with the CMR full calculation (IA+MEC+RC) (solid line), semicomplete CMR calculation (IA+MEC) (dashed line), and basic IA calculation by CMR (dotted line).