Latest Results from GlueX

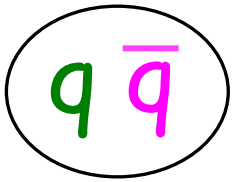
- Spectrum of Mesons
  - Quark model, lattice calculations
- The GlueX experiment
  - Status, performance
- Early physics
- Outlook

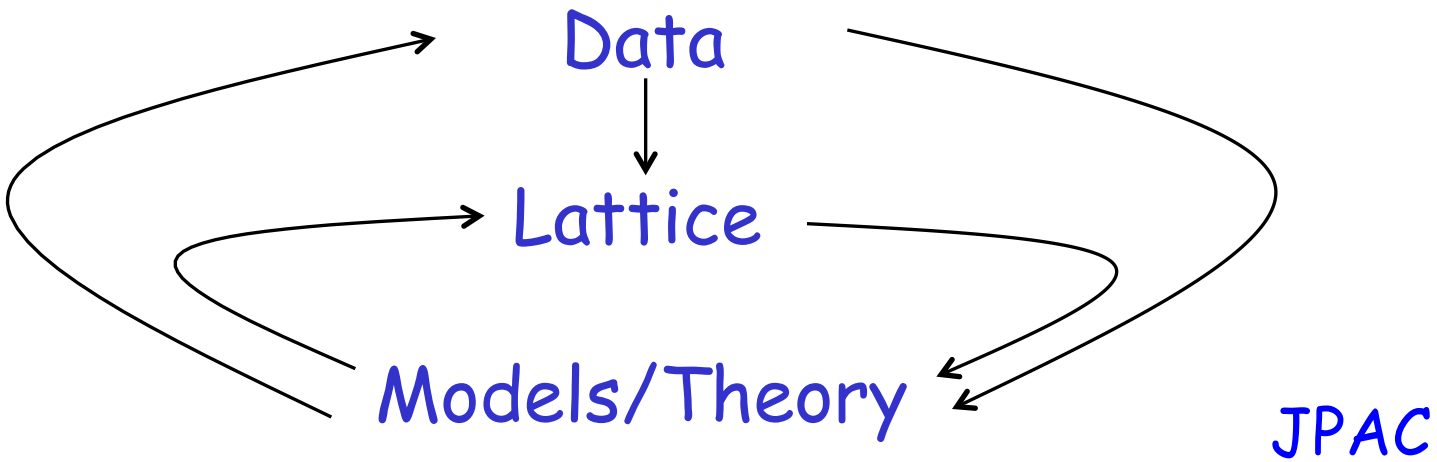
Elton S. Smith, Jefferson Lab

GHP Meeting – February 3, 2017

QCD $\leftrightarrow$ Spectroscopy

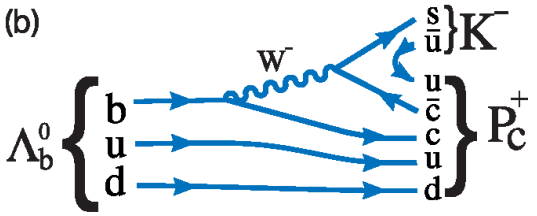
- Quark model is amazingly successful at describing the hadron spectrum.
- Yet most of the hadron mass is not due to quarks
- Search for glue using non-$q\bar{q}$ degrees of freedom



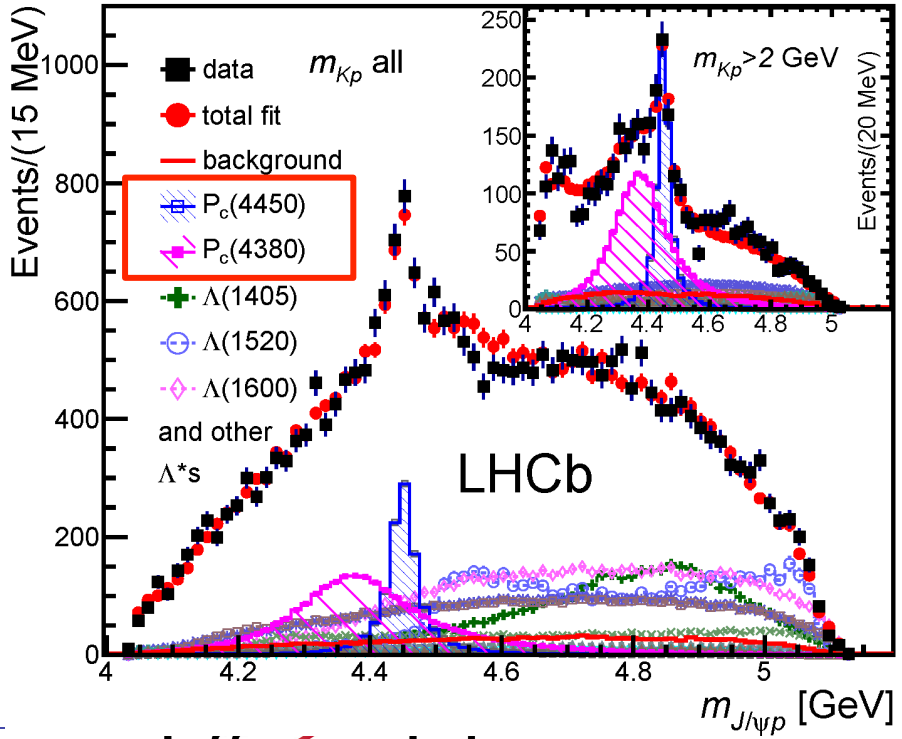


Pentaquarks and Tetraquarks (Heavy Quarks)

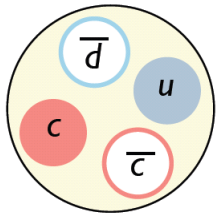
$\Lambda_b^0 \to J/\psi\, p\, K^-$



LHCb PRL 115 (2015) 072001

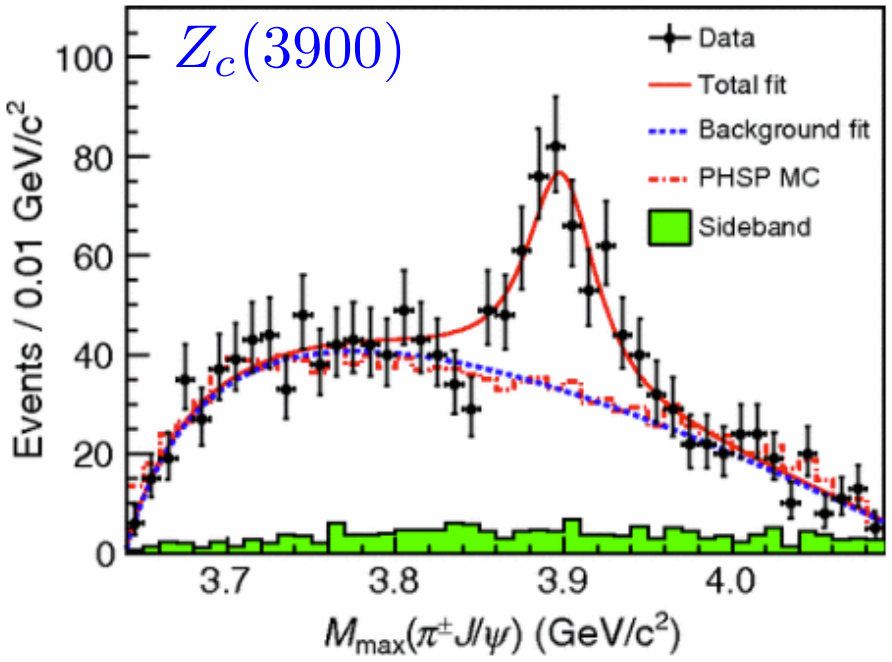


$e^+e^- \to \pi^+\pi^- J/\psi$



BESIII PRL 110 (2013) 252001

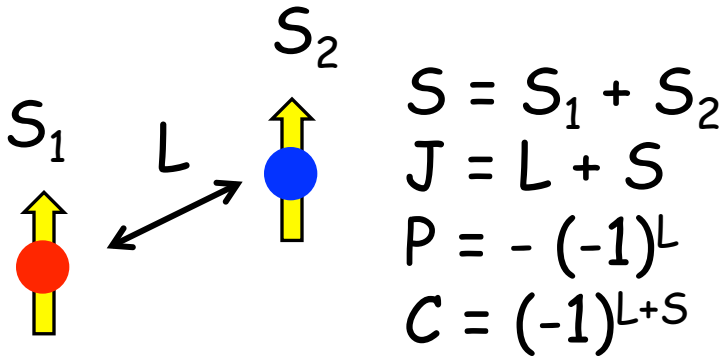
BELLE PRL 110 (2013) 252002

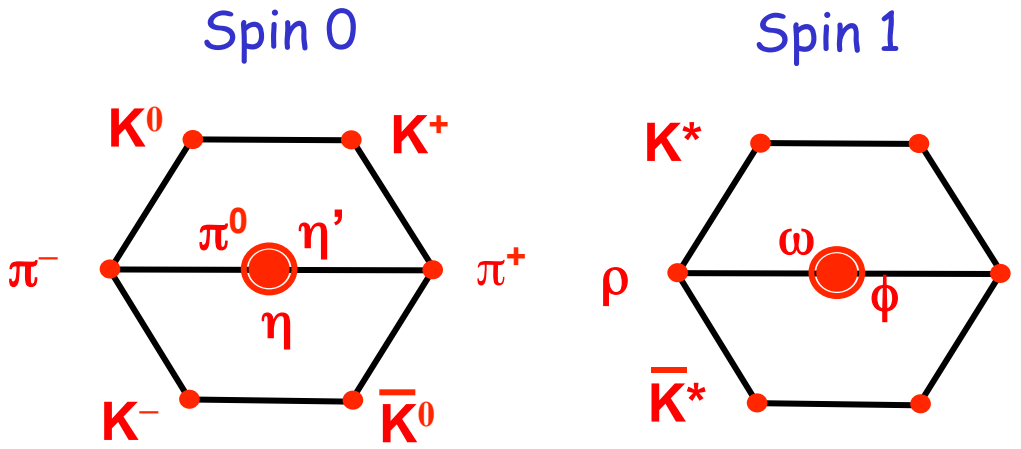


Normal Mesons – $q\bar{q}$ color singlet bound states

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.





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

Allowed combinations

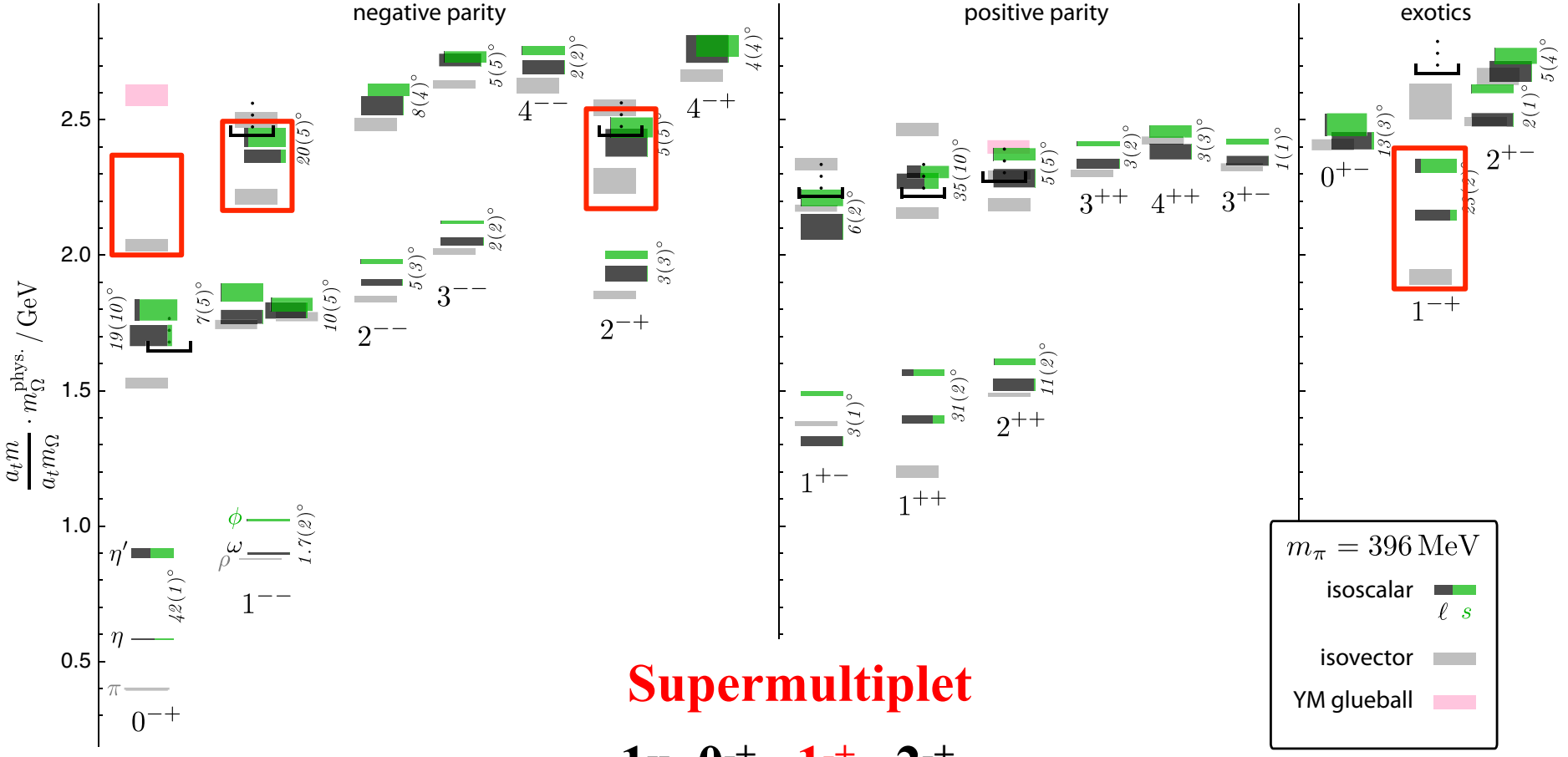
$J^{PC} = 0^{--}\ 0^{+-}\ 1^{-+}\ 2^{+-}\ldots$

Not-allowed: exotic

LQCD Meson spectrum for light quarks

Dudek PRD 83 (2011) 111502
Dudek PRD 84 (2011) 074023

M_π~400 MeV



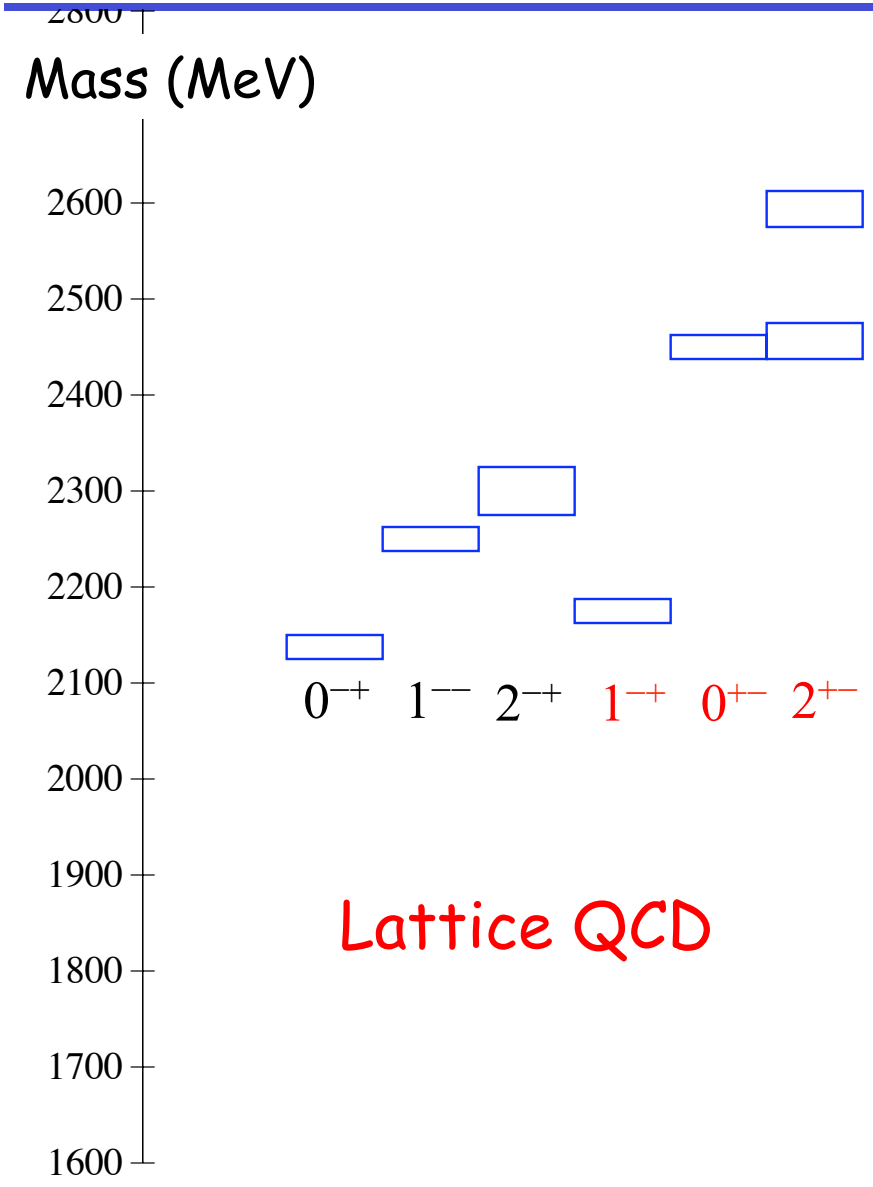
Supermultiplet

1^{--}, 0^{-+} , 1^{-+} , 2^{-+}

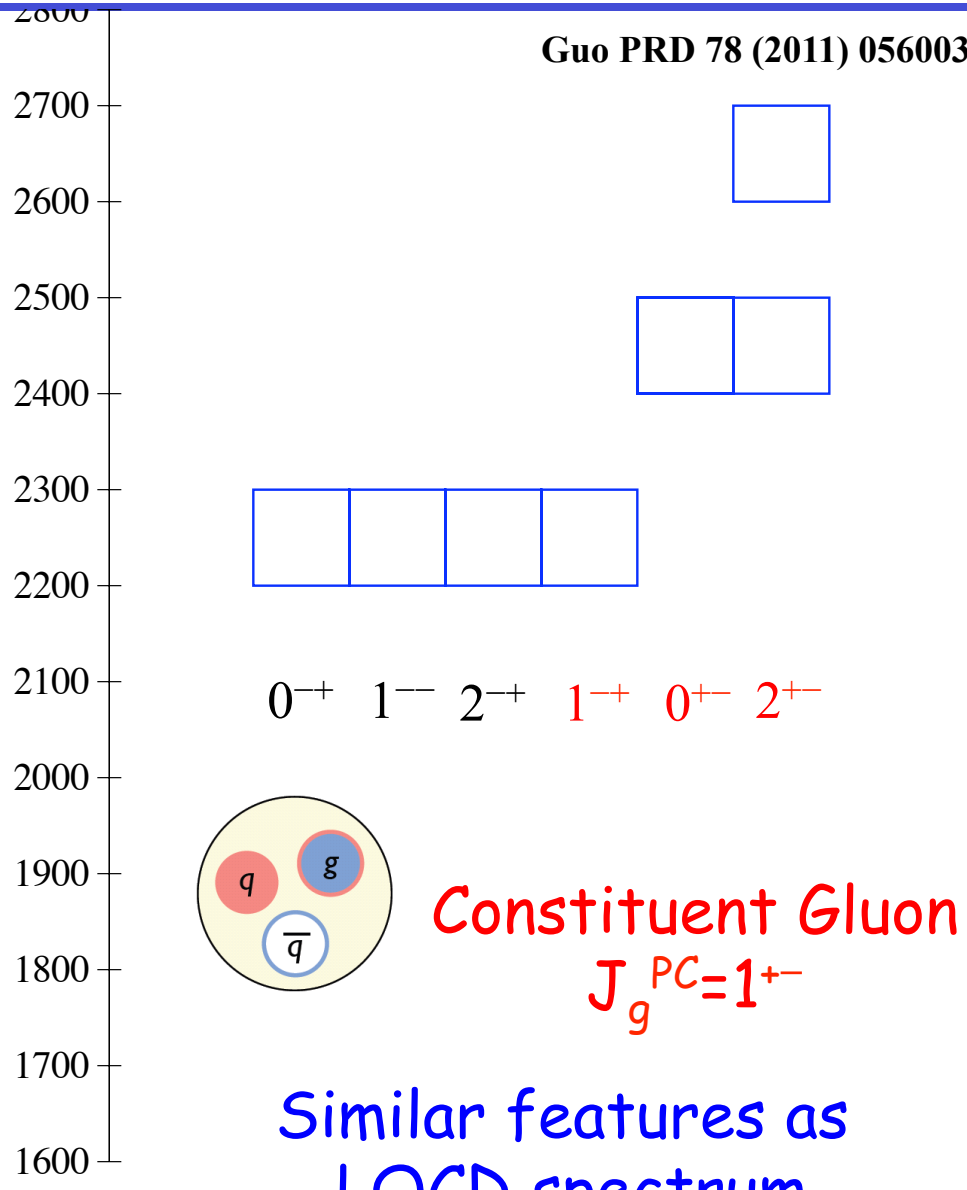
$\frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$ $\quad$ $\frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})$ $\quad$ $(s\bar{s})$

States with non-trivial gluonic fields $F_{j,\mu\nu} F_j^{\mu\nu}$

Models for hybrid mesons



Lattice QCD

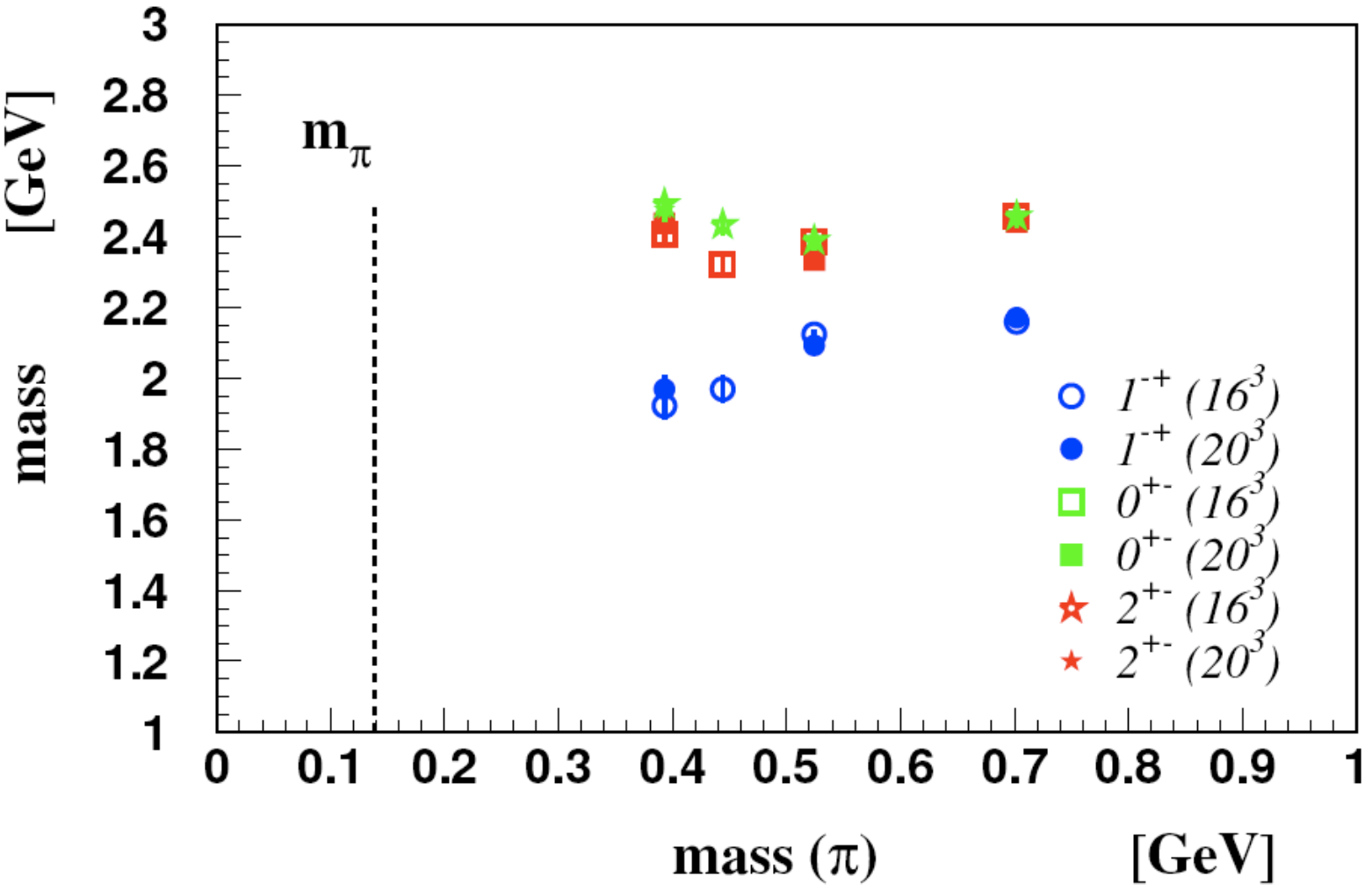


Constituent Gluon
$J_g^{PC}=1^{+-}$

Similar features as LQCD spectrum

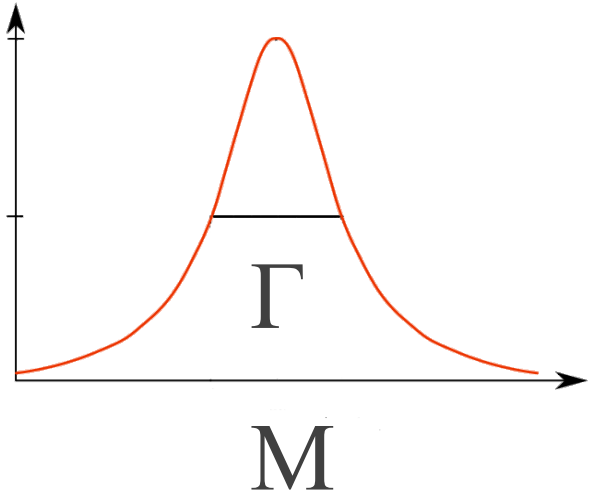
Extrapolation to physical mass

At m_π=400 MeV, mass (1^{-+}) ~ 1.9 GeV, mass (0^{+-}) ~ 2.5 GeV

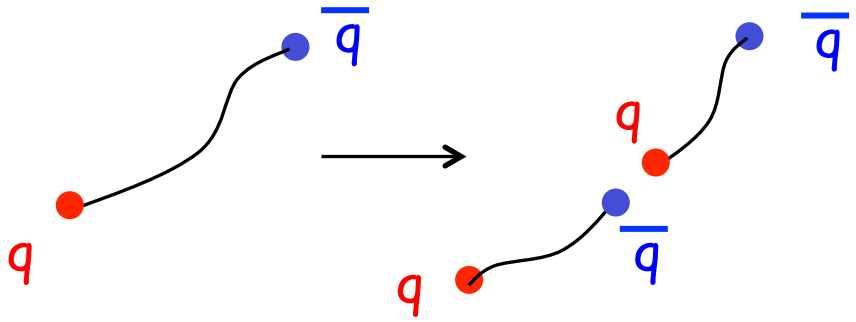


All hybrids decay before detection

- Excited mesons are "resonances"
  - Lifetime ~ 10^{-8} femtosecond
  - Natural width of resonance is ~ 20% of resonance mass
  - Only decay products are observed in detector



[GHP: Production and Decays – Raul Briceno]



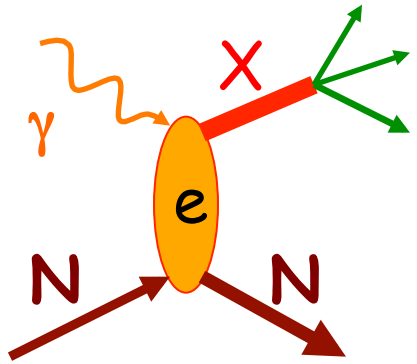
resonance

p (protons)
$\pi^{-/+}$ (charged pions)
π^0 (neutral pions) -> $\gamma\gamma$
η (etas) -> $\gamma\gamma$
ω (omega) -> $\pi^+ \pi^-\pi^0$
.....

decay products preserve information about the parent resonance

Photoproduction

- Very little photoproduction data in this energy range
- Approximately the 70% of total cross section in the energy region $E\gamma$ ~ 7-12 GeV has multiple neutrals and is completely unexplored
- Polarized photons may help disentangle different production mechanisms



$\gamma \Leftrightarrow \rho, \omega, \phi$

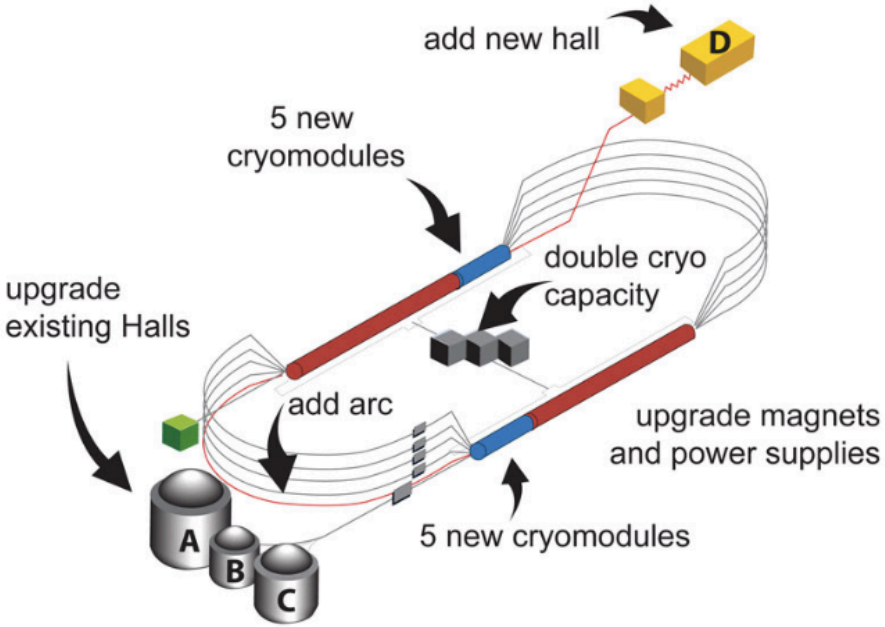
Couple to vector meson + exchanged particle

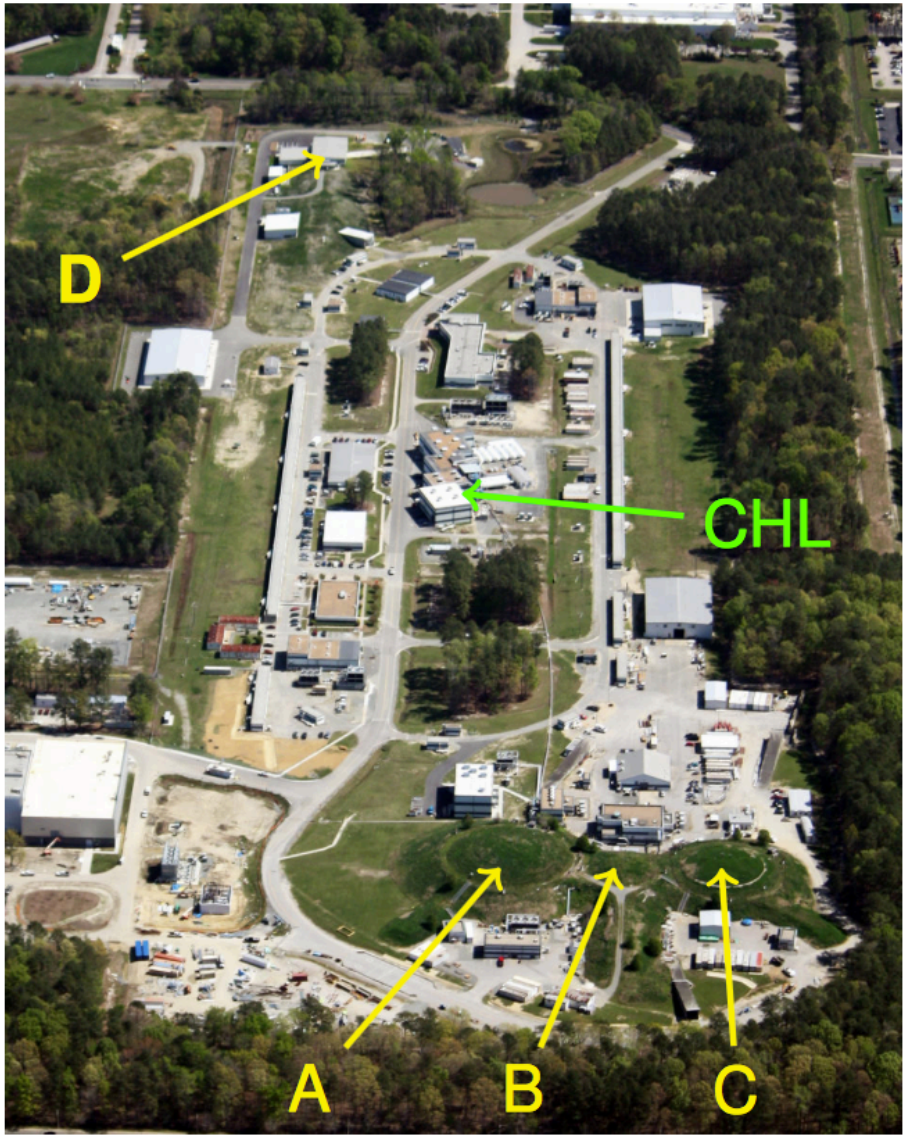
$\pi_1 \Leftrightarrow \rho\pi$

$\eta_1 \Leftrightarrow \rho b_1 \ , \ \omega\phi$

$\eta'_1 \Leftrightarrow \phi\omega$

Jefferson Lab / 12 GeV Project





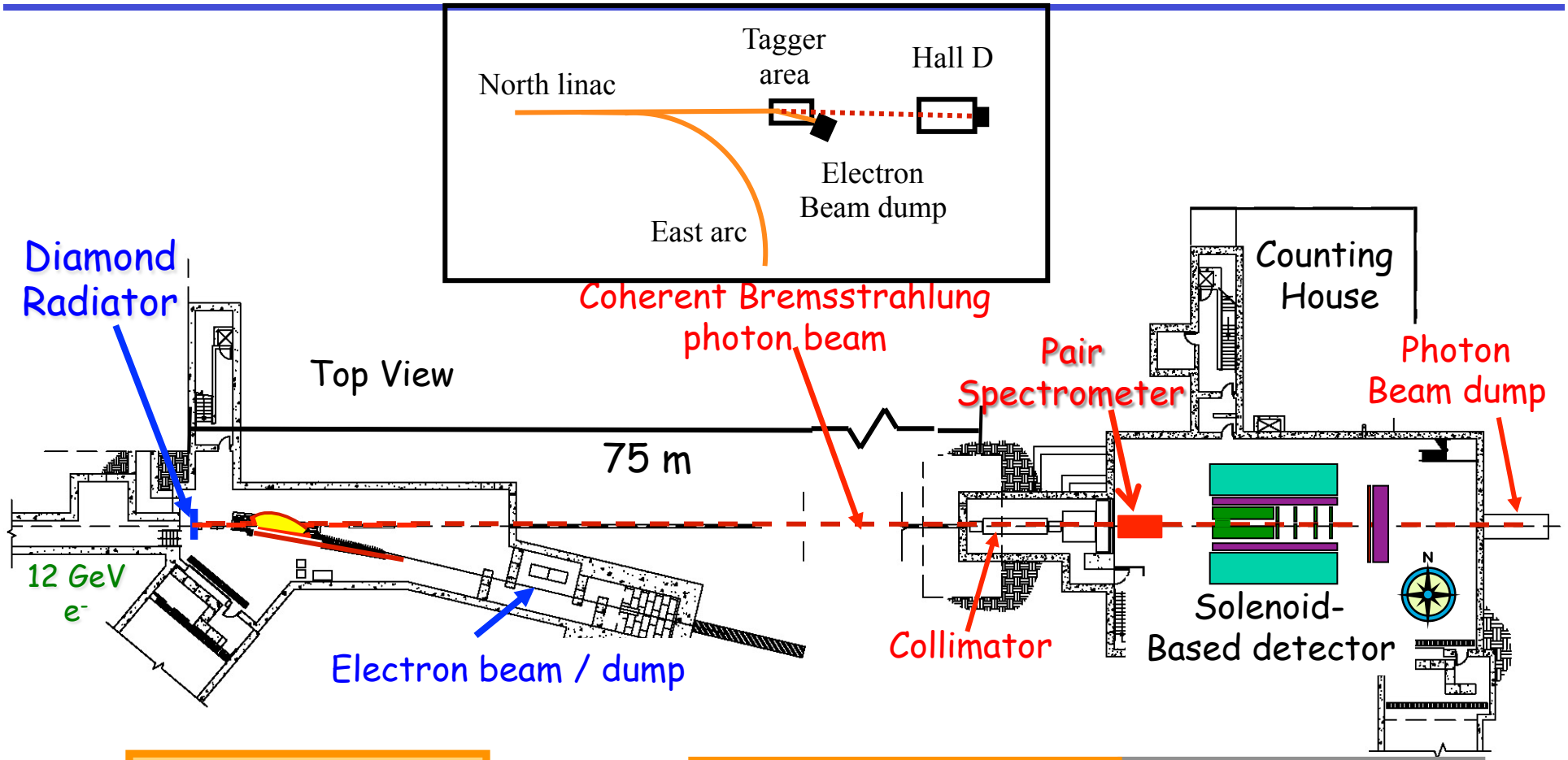
Upgrade Goals

- Accelerator: 6 GeV ⇒ 12 GeV
- Halls A,B,C: e^- <11 GeV, < 100 μA
- Hall D: e^- 12 GeV ⇒ γ-beam

Upgrade Status

- Halls A,D: finished
- Halls B,C: a year to go

Photon beam and experimental area



Tagger Area

Collimator Cave

Experimental Hall D

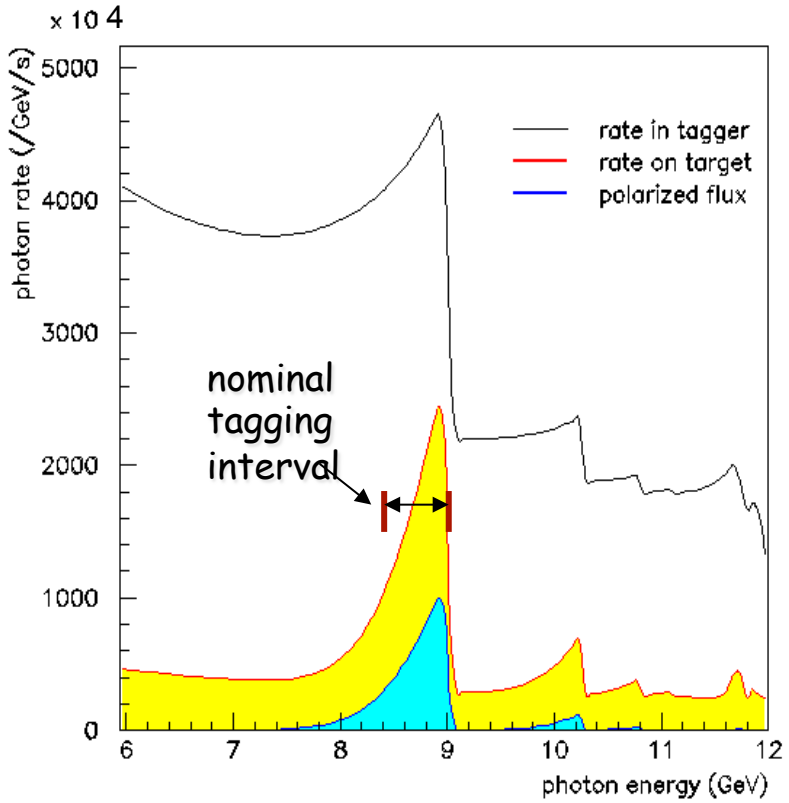
Radiation $e^- Z \rightarrow \gamma e^- Z$

Selection $\theta < 25\mu r$ polarized photons

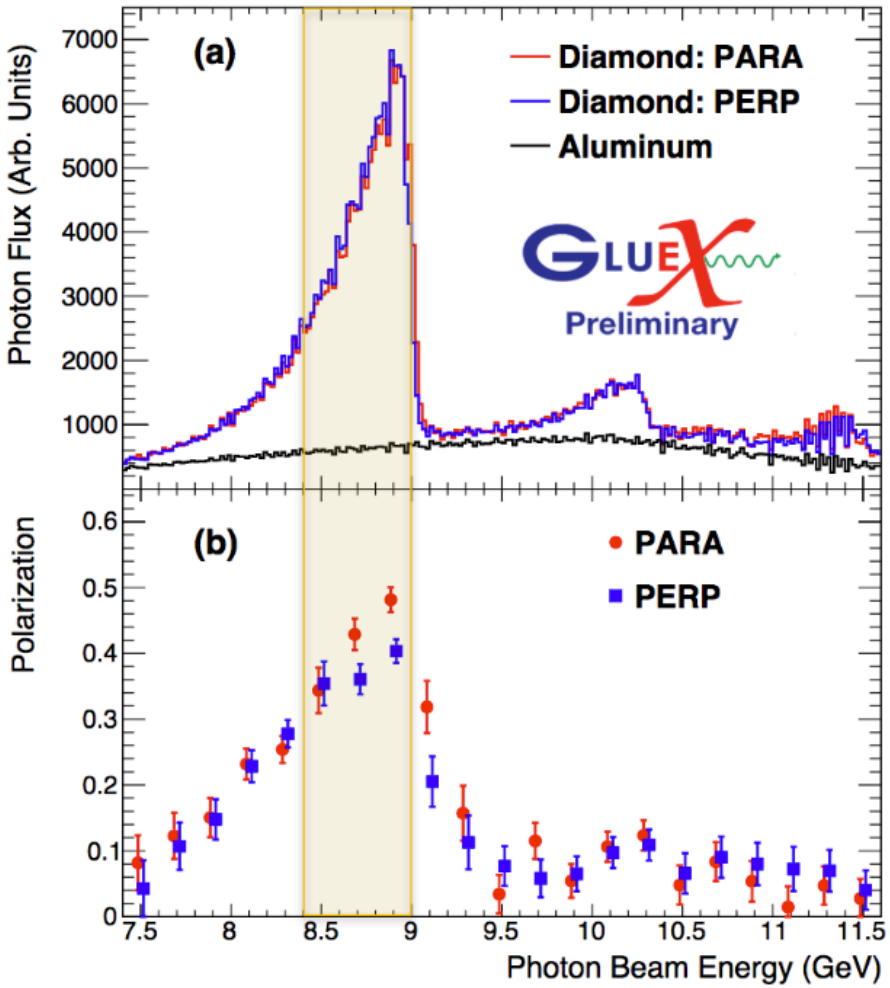
Target, Spectrometer

Linearly Polarized Photon Beam

Calculated Spectrum (12 GeV beam)



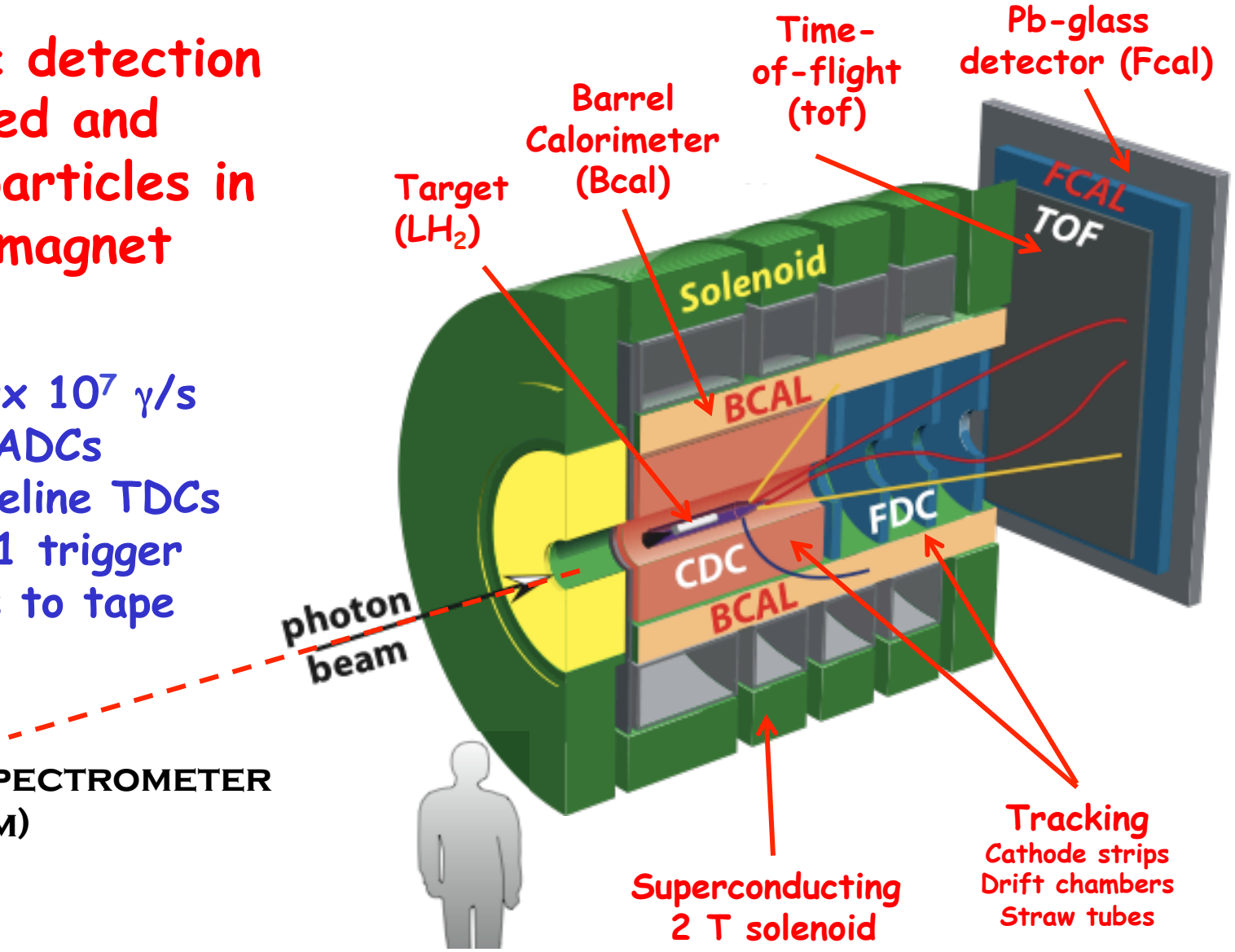
Measured Spectrum (over PS acceptance)



Hall D – GlueX detector

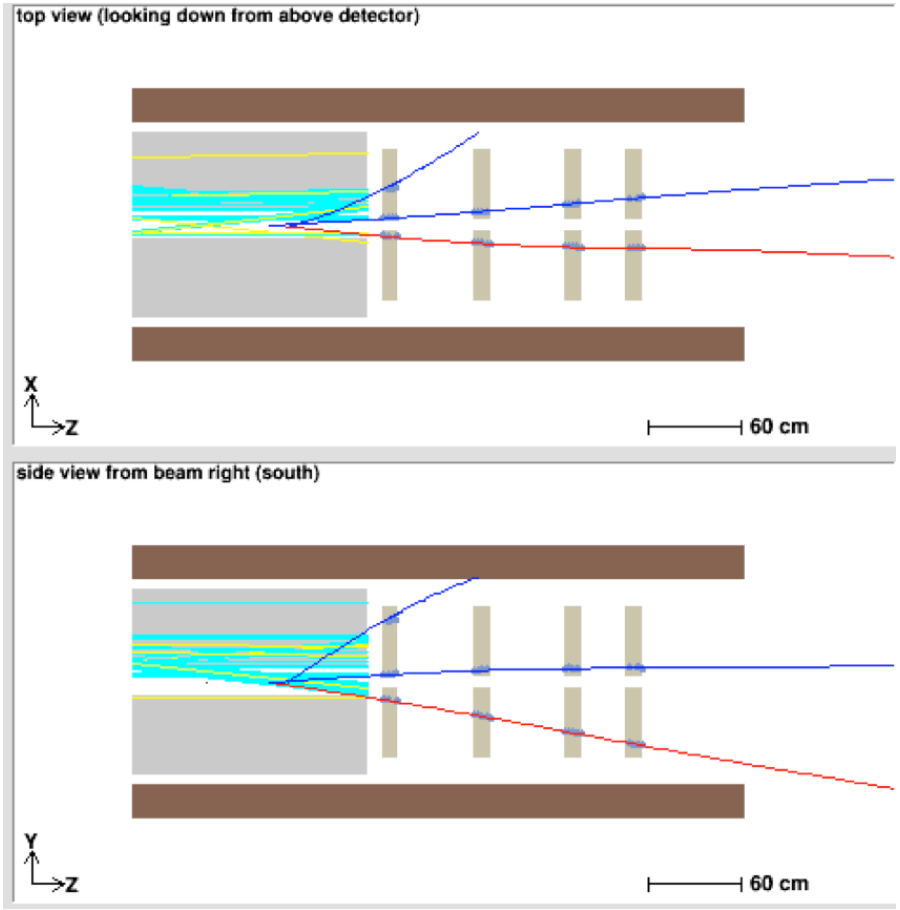
Hermetic detection of charged and neutral particles in solenoid magnet

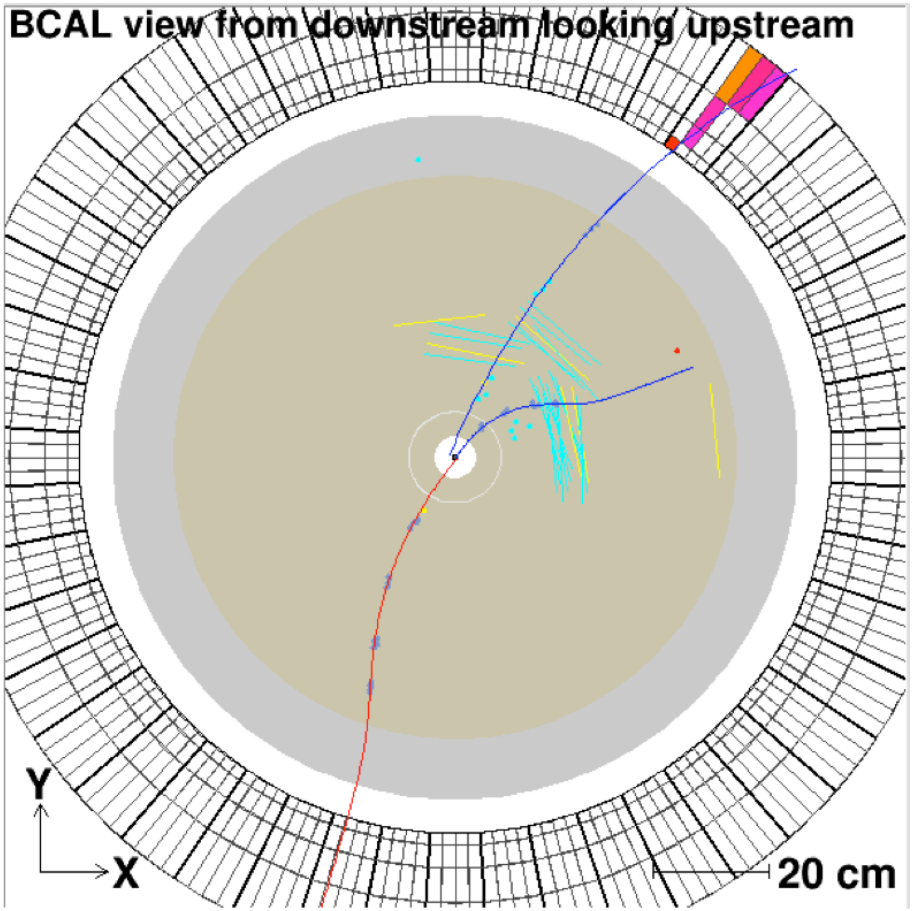
Initial Flux 10^7 γ/s
18,000 FADCs
4,000 pipeline TDCs
20 KHz L1 trigger
300 MB/s to tape



Reconstructed Events

- Tracks, calorimeter showers reconstructed

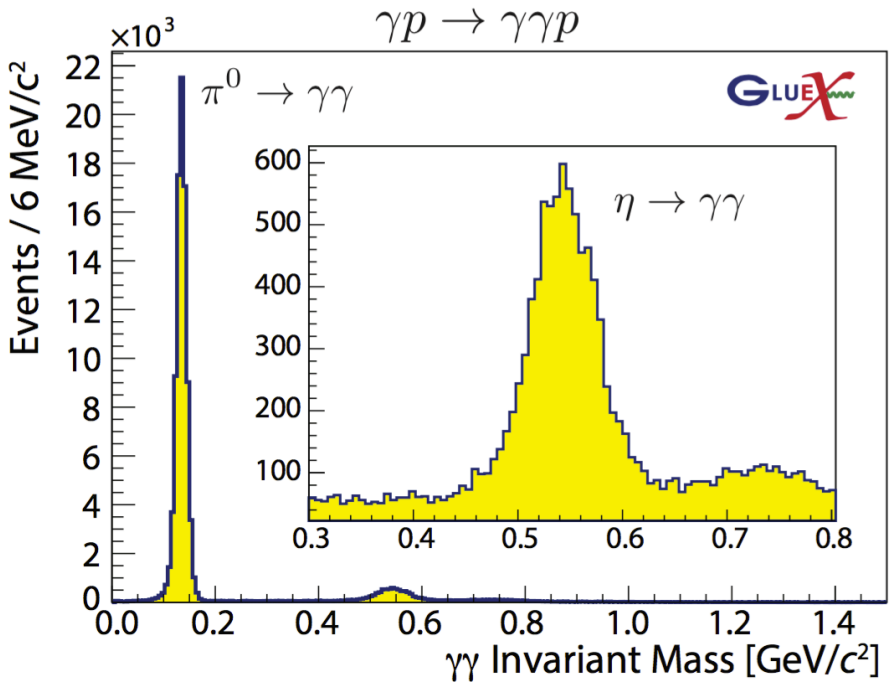


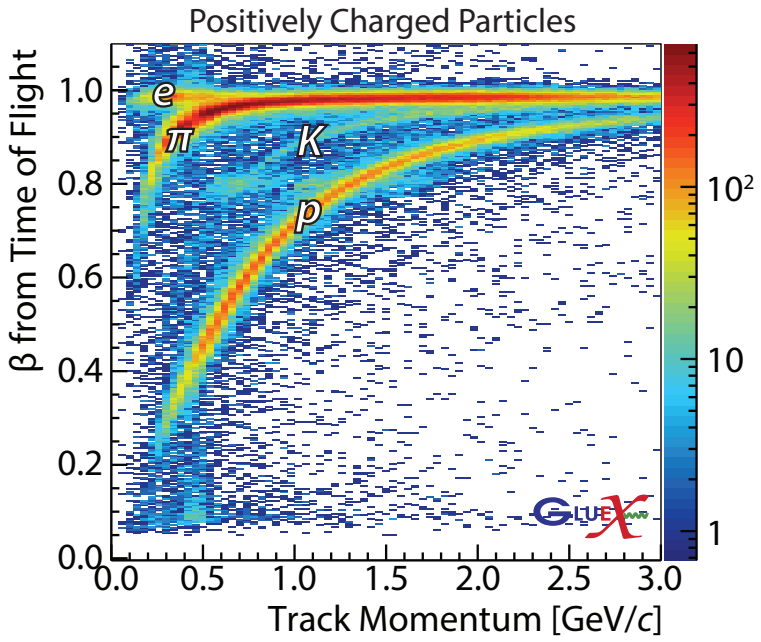


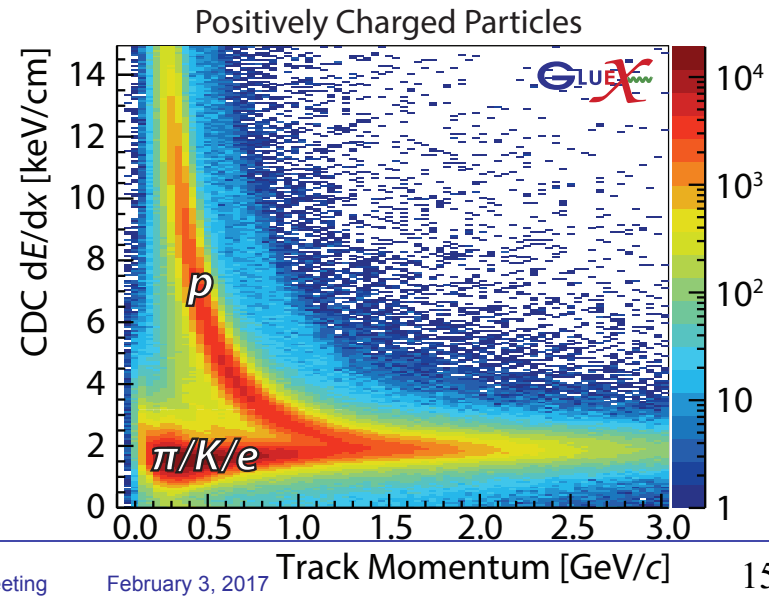
Detector performance

Tracking

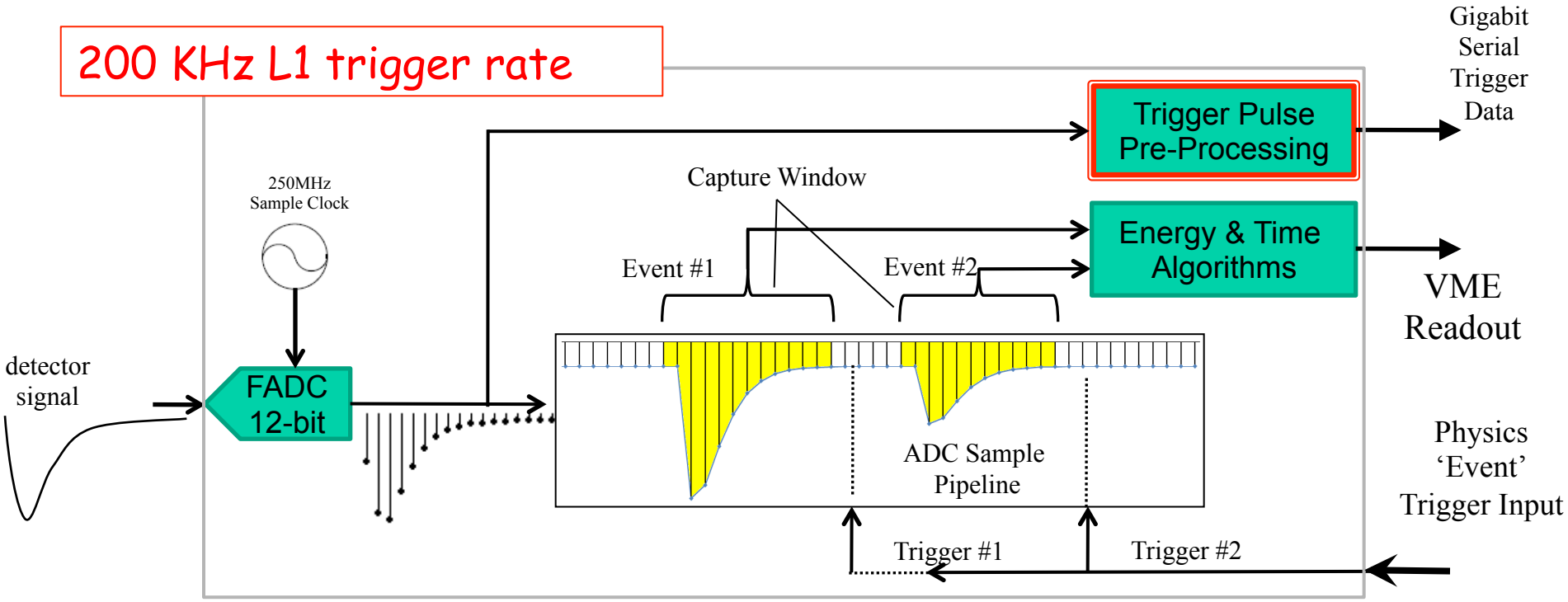
Calorimetry







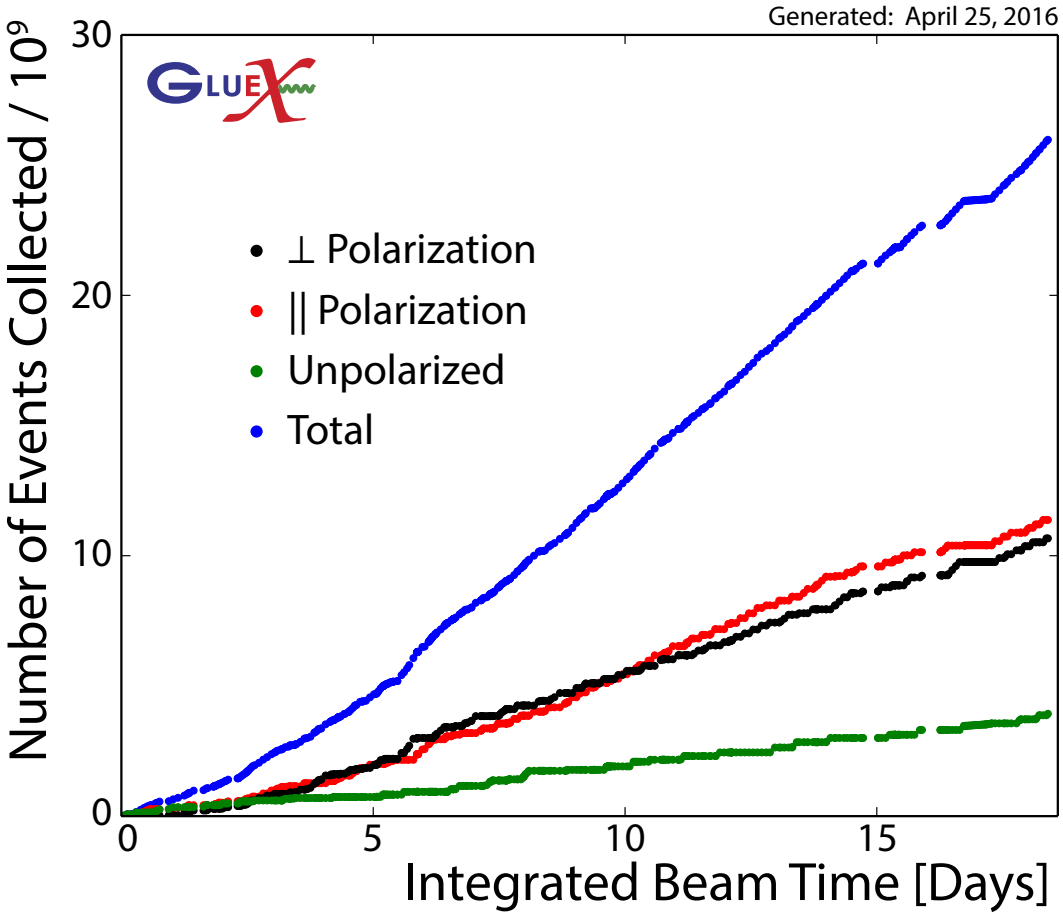
Modern method of signal capture: all pipeline



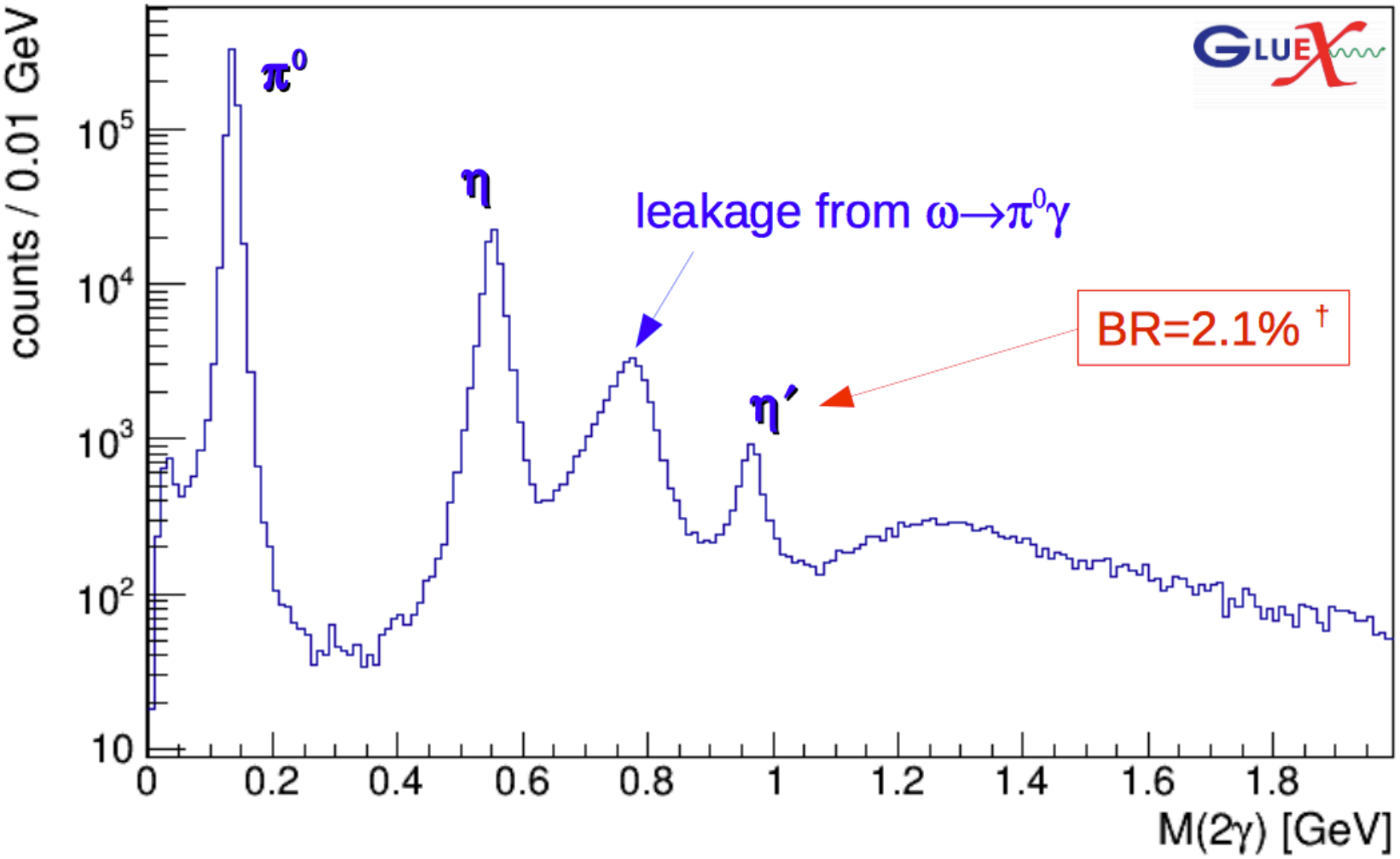
- 250MHz Flash ADC stores digitized signal in 8μs circular memory
- Trigger data contains detailed information useful for cluster finding, energy sum, etc.
- "Event" trigger extracts a window of the ADC data for pulse sum and time algorithms
- Hardware algorithms provide a huge data reduction by reporting only time & energy estimates for readout instead of raw samples

Collected triggers in spring 2016

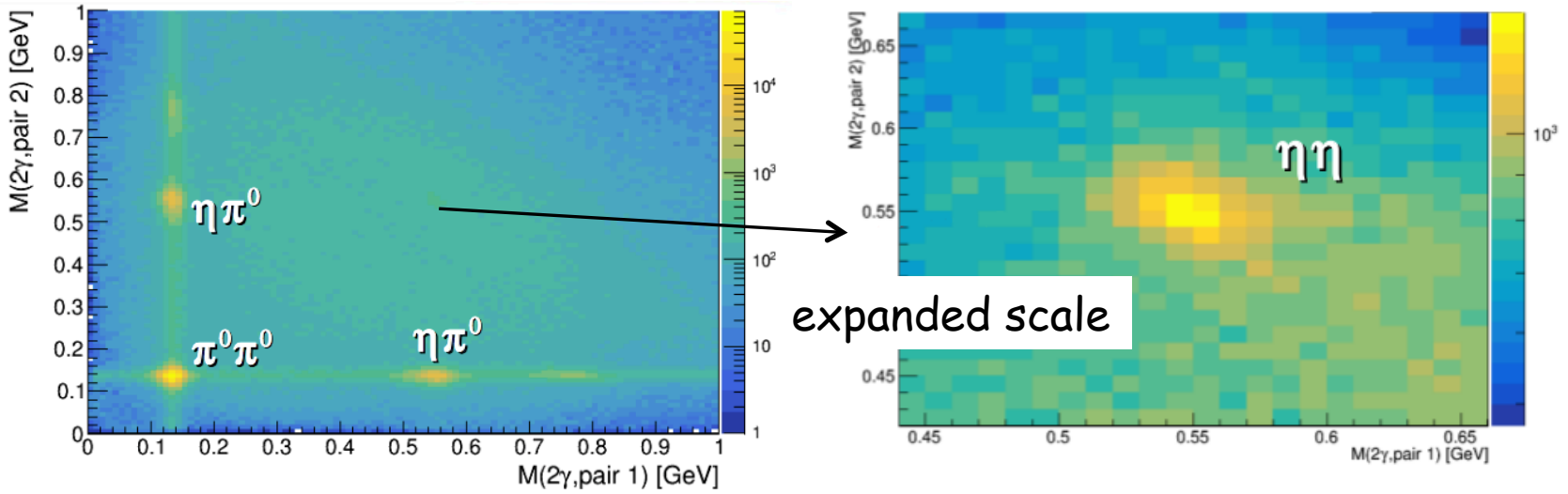
- Status: Detector commissioning and engineering runs completed
- Useful data obtained during these preliminary periods

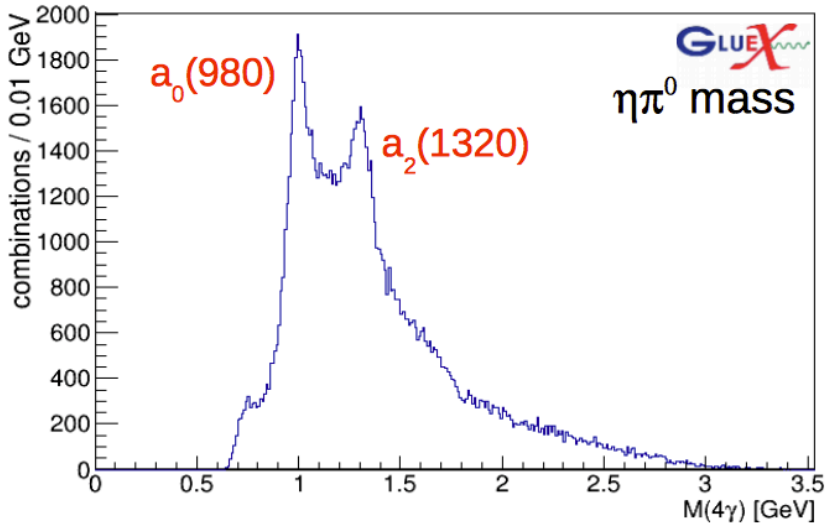


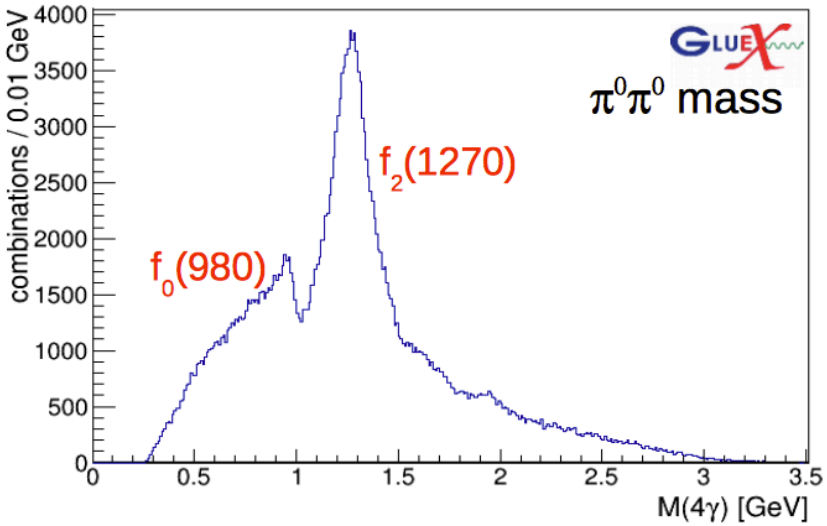
2γ mass peaks



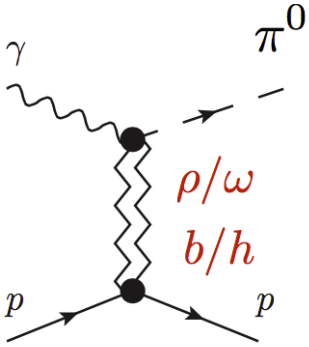
4γ mass peaks







π^0 and η azimuthal asymmetry

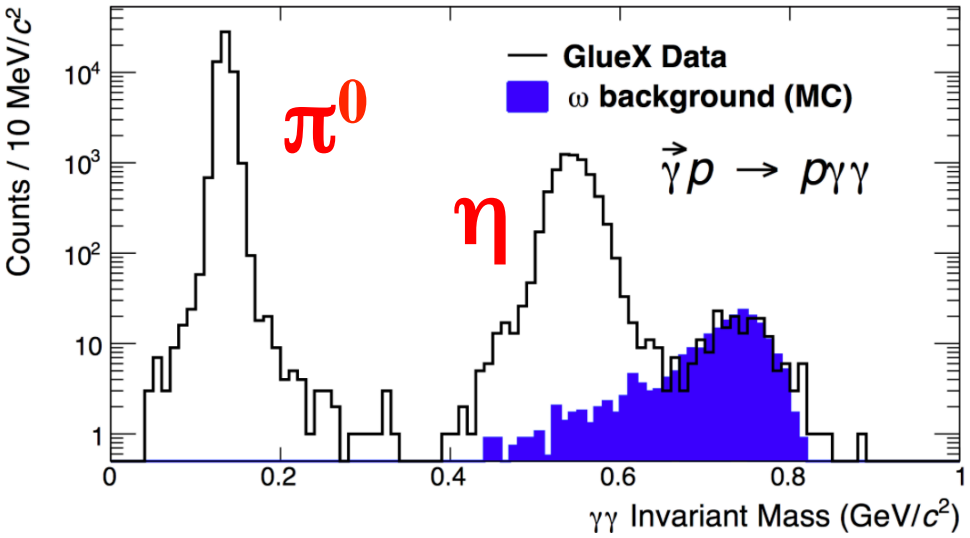


JPAC PRD 92 (2015) 074013

Exchange J^{PC}

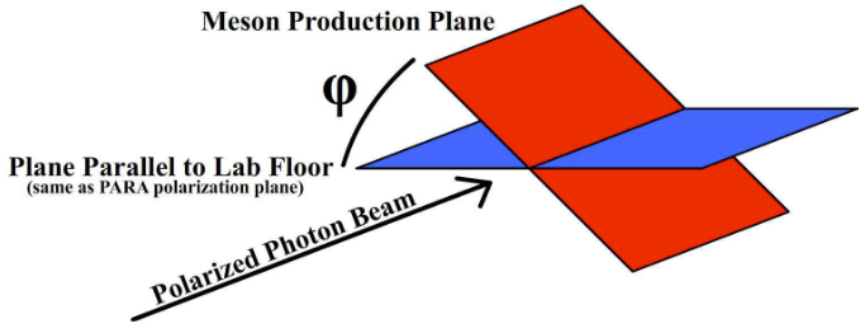
$1^{--} : \omega, \rho$

$1^{+-} : b, h$

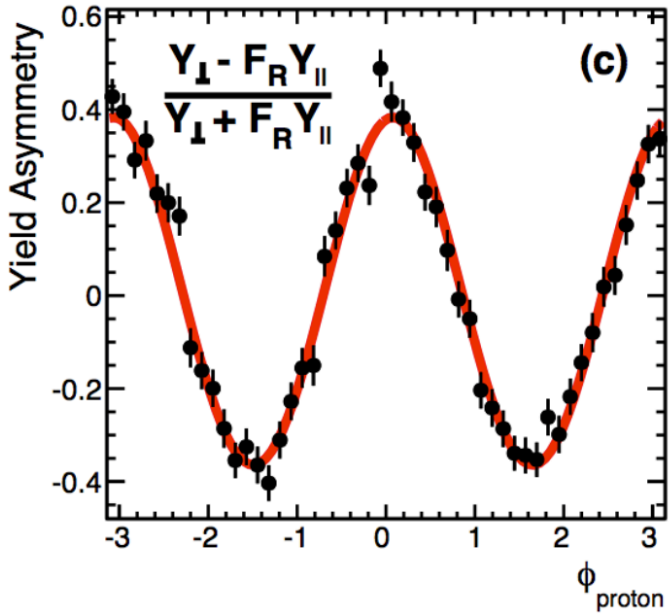


$$\frac{d\sigma}{dt} = \sigma_\perp + \sigma_\parallel = |\rho + \omega|^2 + |b + h|^2$$

$$\Sigma = \frac{\sigma_\perp - \sigma_\parallel}{\sigma_\perp + \sigma_\parallel} = \frac{|\rho + \omega|^2 - |b + h|^2}{|\rho + \omega|^2 + |b + h|^2}$$



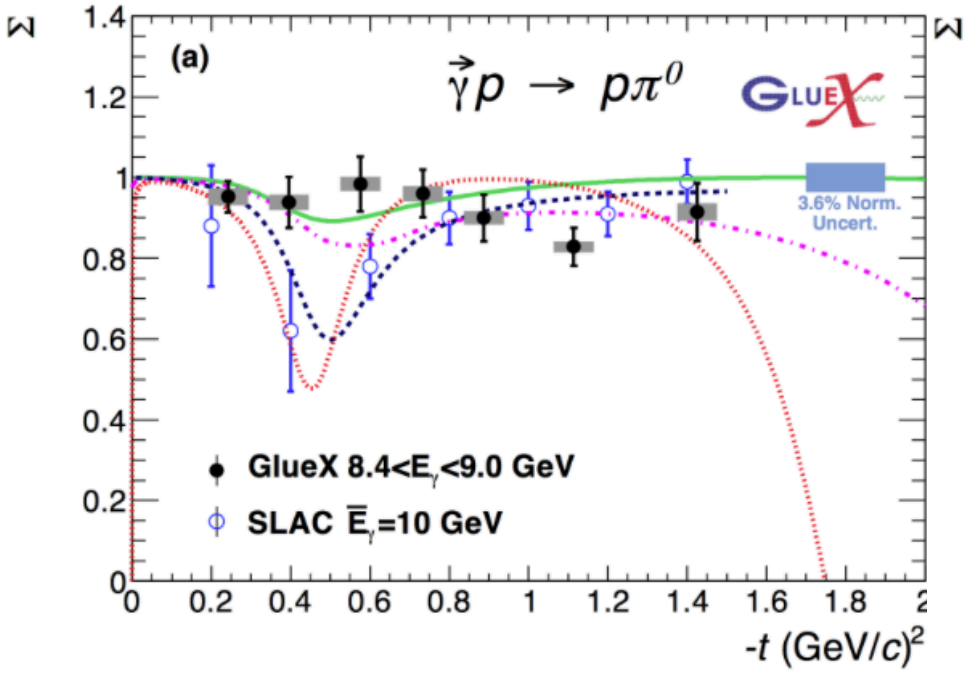
$$\frac{d\sigma}{d\phi_{\text{proton}}} \propto 1 - P\Sigma \cos 2(\,\phi_{\text{proton}} - \phi_\gamma\,)$$

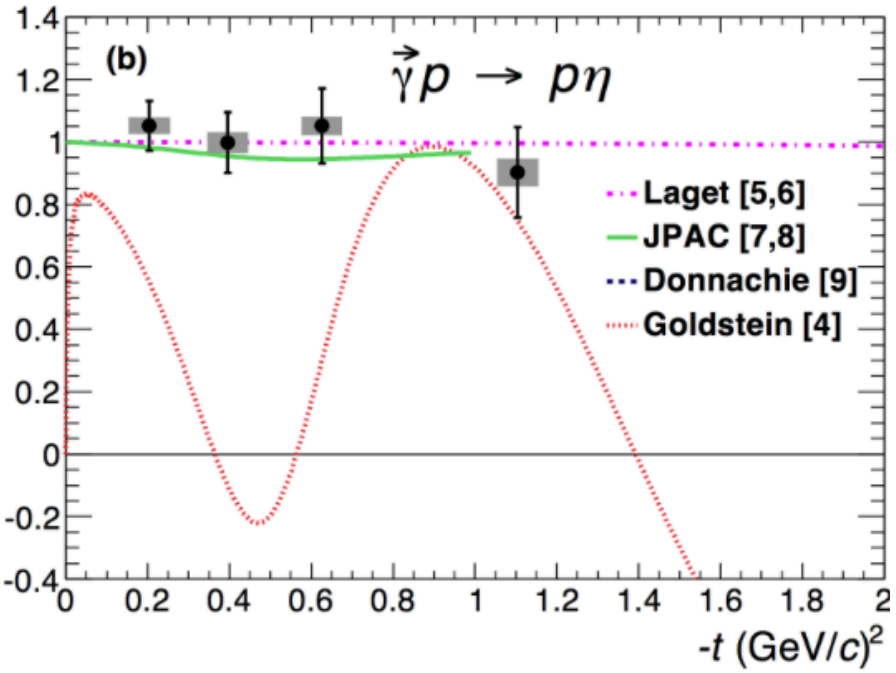


π^0 and η asymmetries

www.hepdata.net/record/76745

arXiv:1701.08123

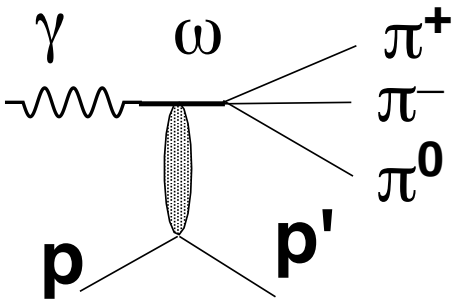


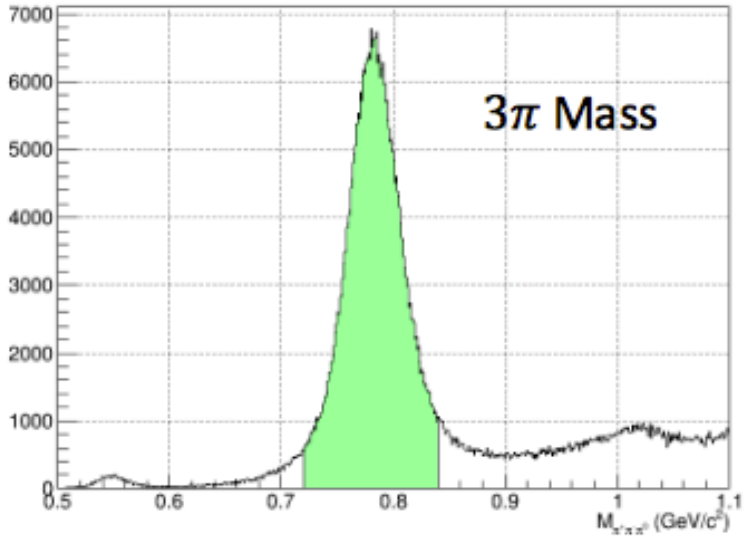


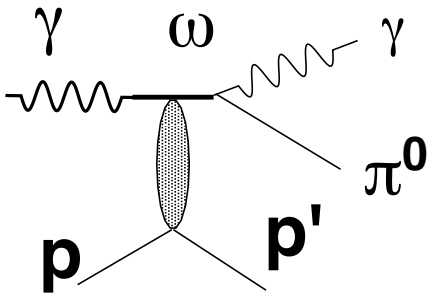
- π^0 and η azimuthal asymmetries measured for $0 < -t < 1.5$ GeV^2
- Measurements are being compared to model calculations to understand particle exchange mechanisms
- First asymmetry measurements for η at this energy

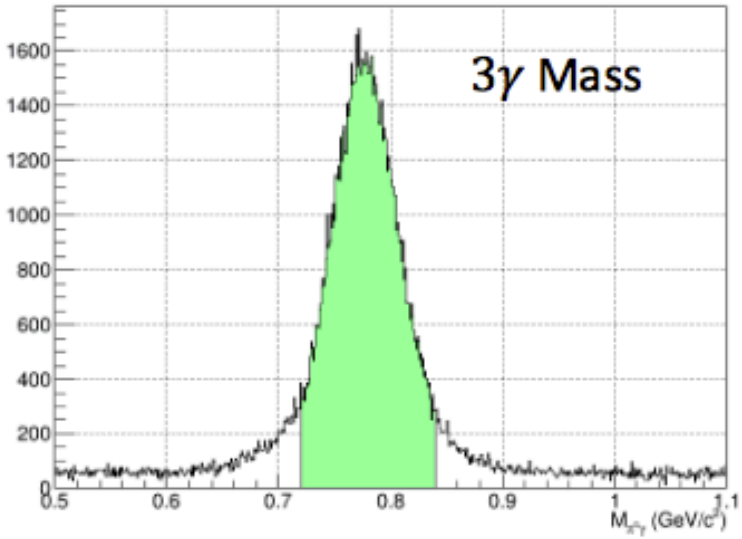
Omega production and decay

Use different decays to probe the same production mechanism









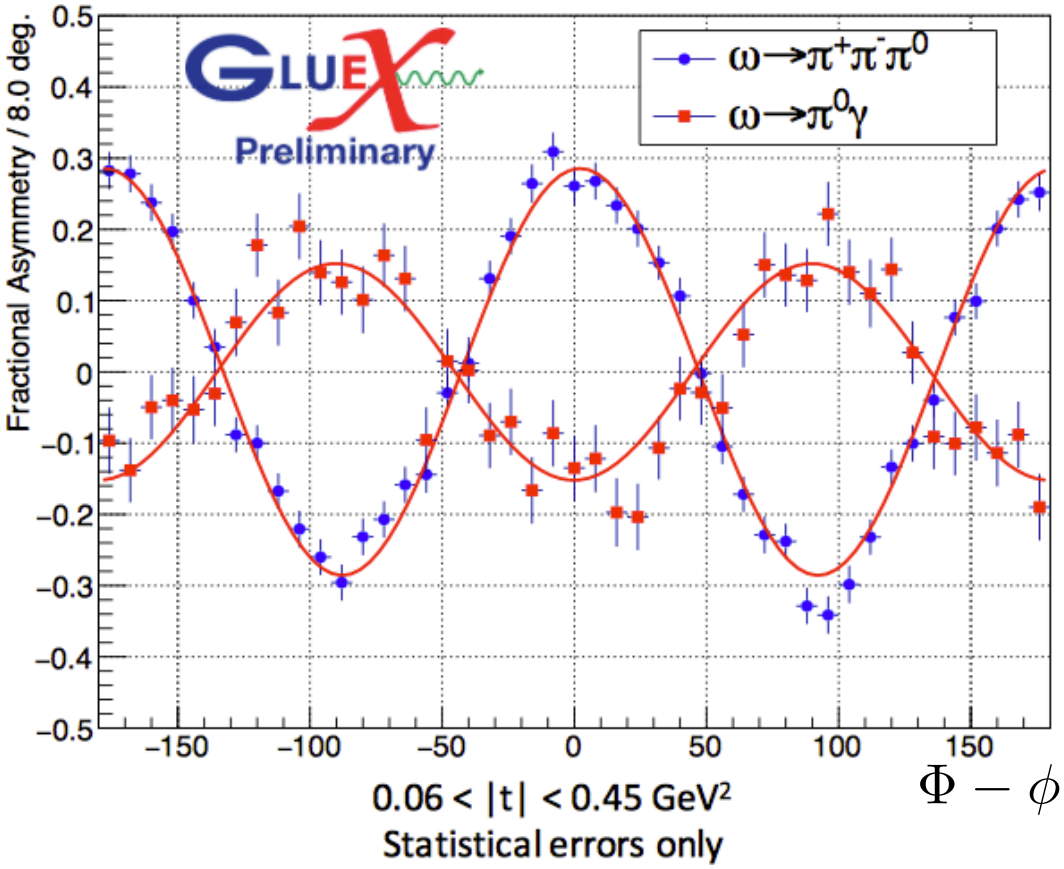
Titov PRC 78 (2008) 038201

Zhao PRC 71 (2005) 054004

ω asymmetry

Assuming Vector Meson Dominance (VMD), angles in helicity frame

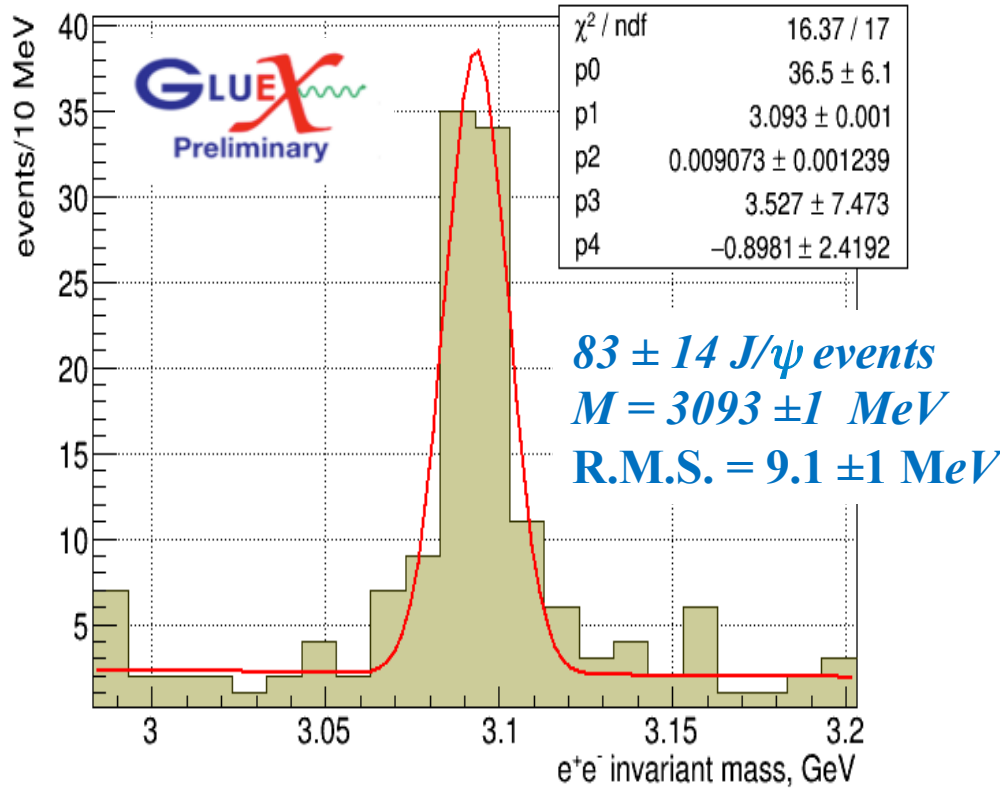
$$\mathcal{A}^{\pi\gamma} = -\frac{1}{2} P \cos 2(\Phi - \phi) \qquad \mathcal{A}^{3\pi} = P \cos 2(\Phi - \phi)$$



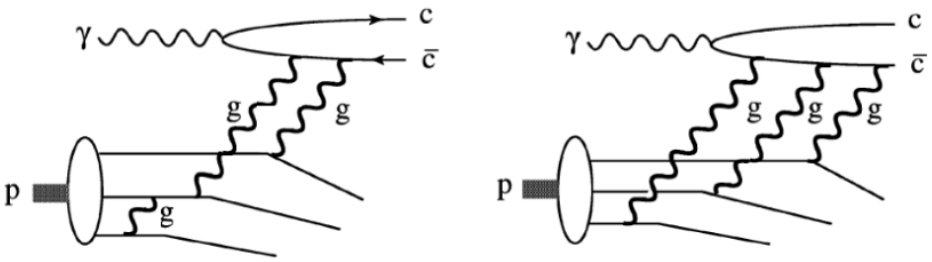
$$\frac{\mathcal{A}^{3\pi}}{\mathcal{A}^{\pi\gamma}} = -1.88 \pm 0.13$$

- Preliminary data consistent with VMD
- Goal is to determine the Spin Density Matrix Elements (SDMEs) to probe the production mechanisms in more detail.

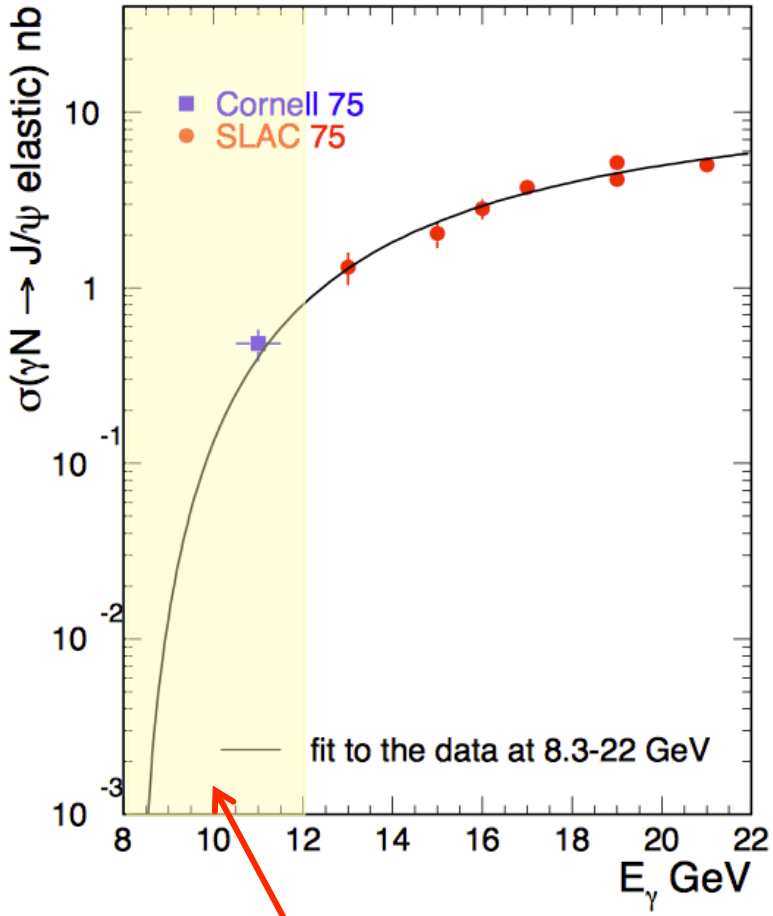
Charm production near threshold



83 ± 14 J/ψ events
M = 3093 ±1 MeV
R.M.S. = 9.1 ±1 MeV



Brodsky PLB 498 (2001) 23



GlueX Energy Range

[GHP: Photon-Hadron Physics - L. Pentchev]

Program and upgrades

Experiment	Description	Beam Time (days)
GlueX I	Study spectrum of light mesons and gluonic excitations (low intensity)	80
GlueX II	Study of hadron decays to strange final states (high intensity)	200+220(*)
Primakoff eta	Eta radiative decay width	79
CPP	Charged pion polarizability measurement	25
Jlab Eta Factory	Rare eta decays	42 (conditional)

(*) May run concurrently

- DIRC detector for enhanced π/kaon identification will be installed starting this summer
- Online computer farm will be added for high intensity running
- High resolution calorimeter is needed for parts of the JEF program

Summary

- We have mounted the GlueX experiment in Hall D at Jefferson Lab devoted to the study of hybrid mesons. Their existence and properties will yield fundamental information regarding the force that confines quarks.
- Some measurements of the azimuthal asymmetry of particle production with a polarized photon beam have already been completed. First paper submitted to PRL!
- We are starting physics production data this week
- During the summer break we will begin installing the DIRC for improved particle identification

Backup Slides

Naming Scheme for u,d Mesons

Name (I=1, I=0)	L	S	J^{PC}	$^{2S+1}L_J$	Examples
π, η	0	0	0^{-+}	$^1S_0$	π, η
ρ, ω	0	1	1^{--}	$^3S_1$	ρ(770), ω(782)
b, h	1	0	1^{+-}	$^1P_1$	$b_1(1235)$, $h_1(1170)$
a, f	1	1	0^{++}	$^3P_0$	$a_0(980)$, $f_0(980)$
a, f	1	1	1^{++}	$^3P_1$	$a_1(1260)$, $f_1(1285)$
a, f	1	1	2^{++}	$^3P_2$	$a_2(1320)$, $f_2(1270)$
π, η	2	0	2^{-+}	$^1D_2$	$\pi_2(1670)$
ρ, ω	2	1	1^{--}	$^3D_1$	$\rho_1(1700)$, $\omega_1(1600)$
ρ, ω	2	1	2^{--}	$^3D_2$	
ρ, ω	2	1	3^{--}	$^3D_3$	$\rho_3(1670)$
b, h	3	0	3^{+-}	$^1F_3$	
a, f	3	1	2^{++}	$^3F_2$	
a, f	3	1	3^{++}	$^3F_3$	
a, f	3	1	4^{++}	$^3F_4$	

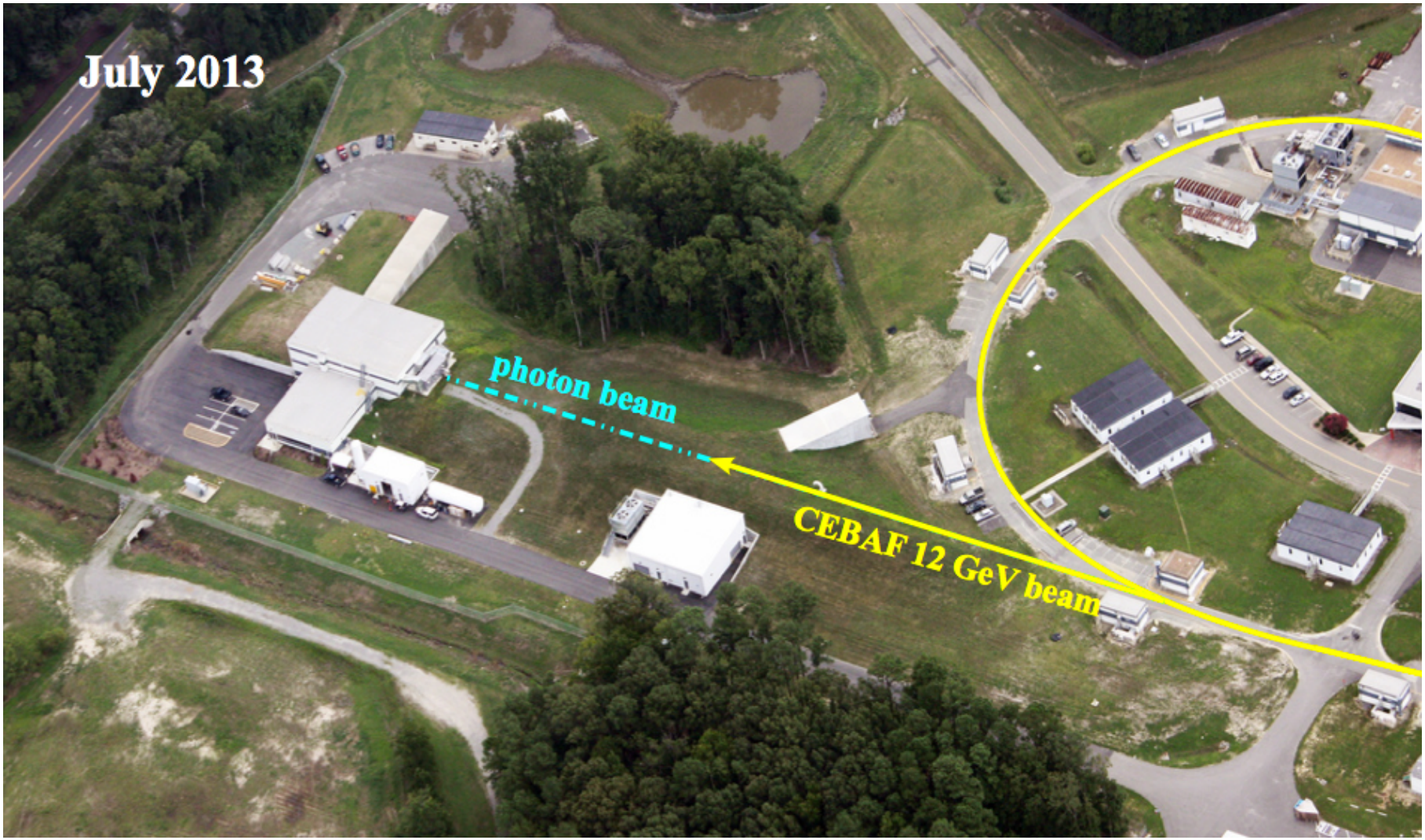
$P = (-1)^{L+1}$

$C = (-1)^{L+S}$

$PC = (-1)^{S+1}$

$G = C(-1)^{I}$

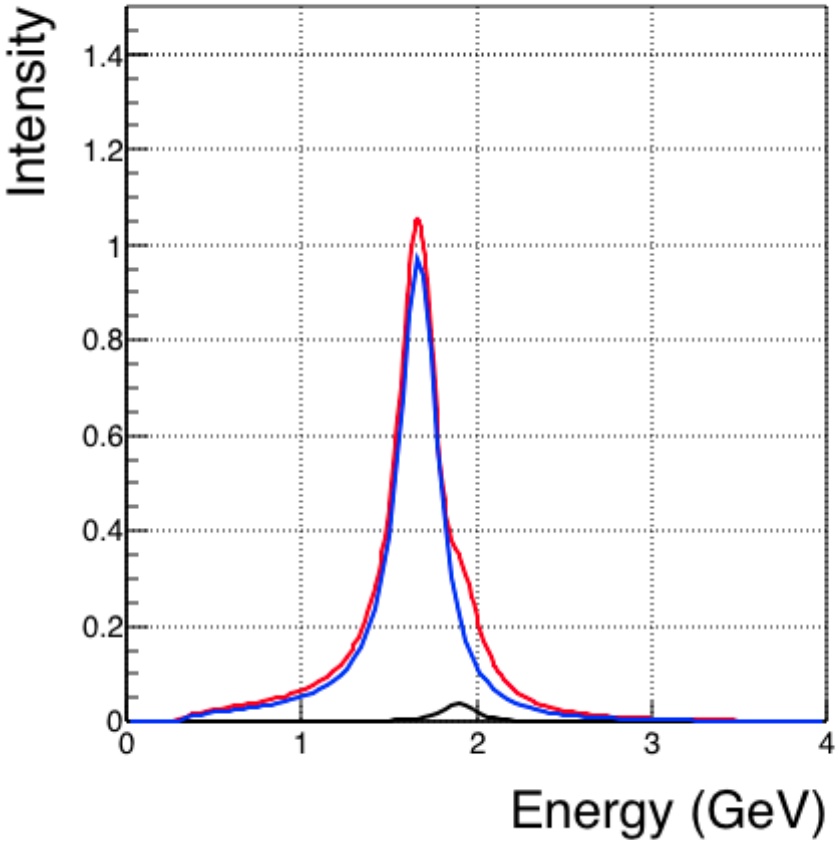
Experimental Hall D

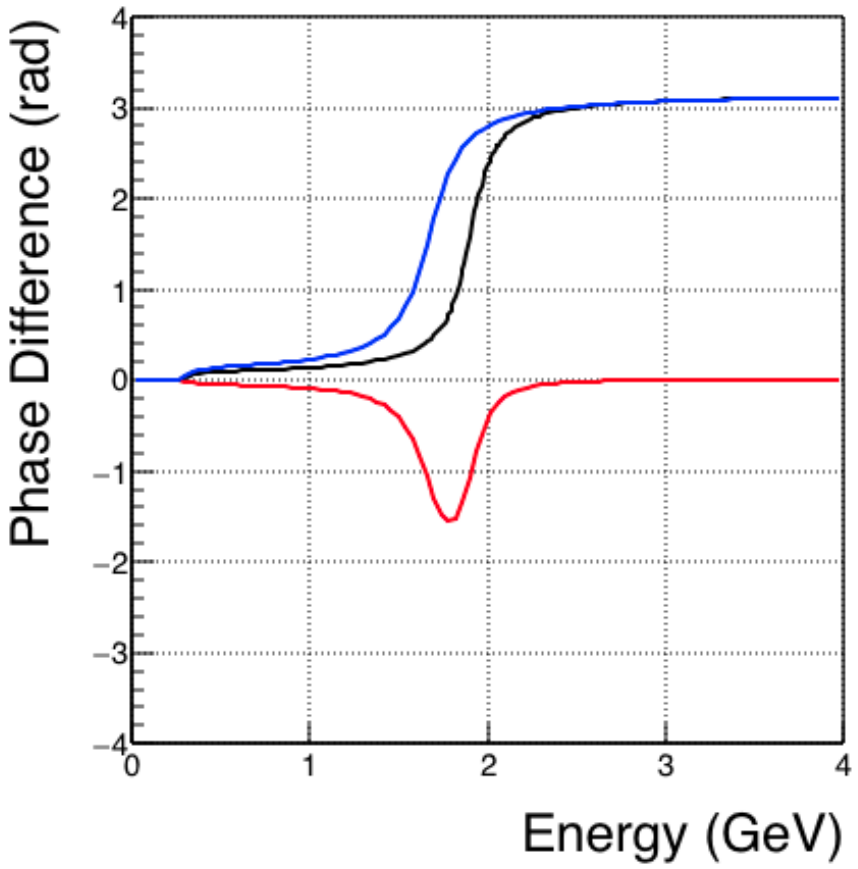


Resonances: intensities and phases

$$\mathcal{A} = \frac{M\Gamma}{(E^2 - M^2) + iM\Gamma}$$

Use phases to extract small signals





COMPASS: Exotic 1^{-+} $\pi_1(1600)$->$\pi^+\pi^-\pi^-$

Analysis of π^-Pb $\rightarrow$ $\pi^+\pi^-\pi^-$Pb at COMPASS

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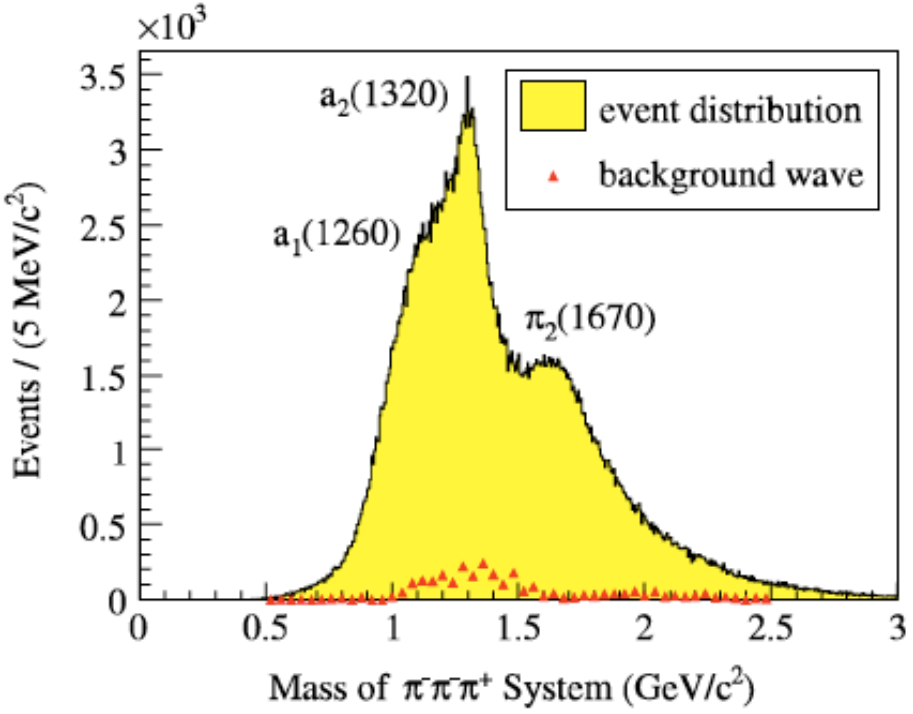
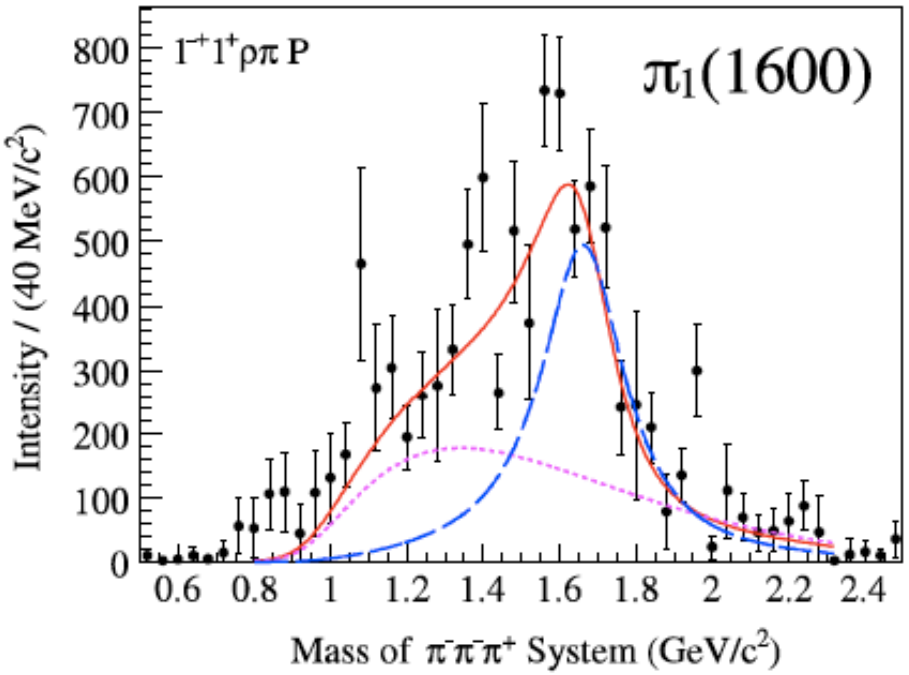




~0.4 M events

Intensity =1.7% of total

COMPASS: Phase Motion of Exotic

COMPASS PRL 104 (2010) 241803

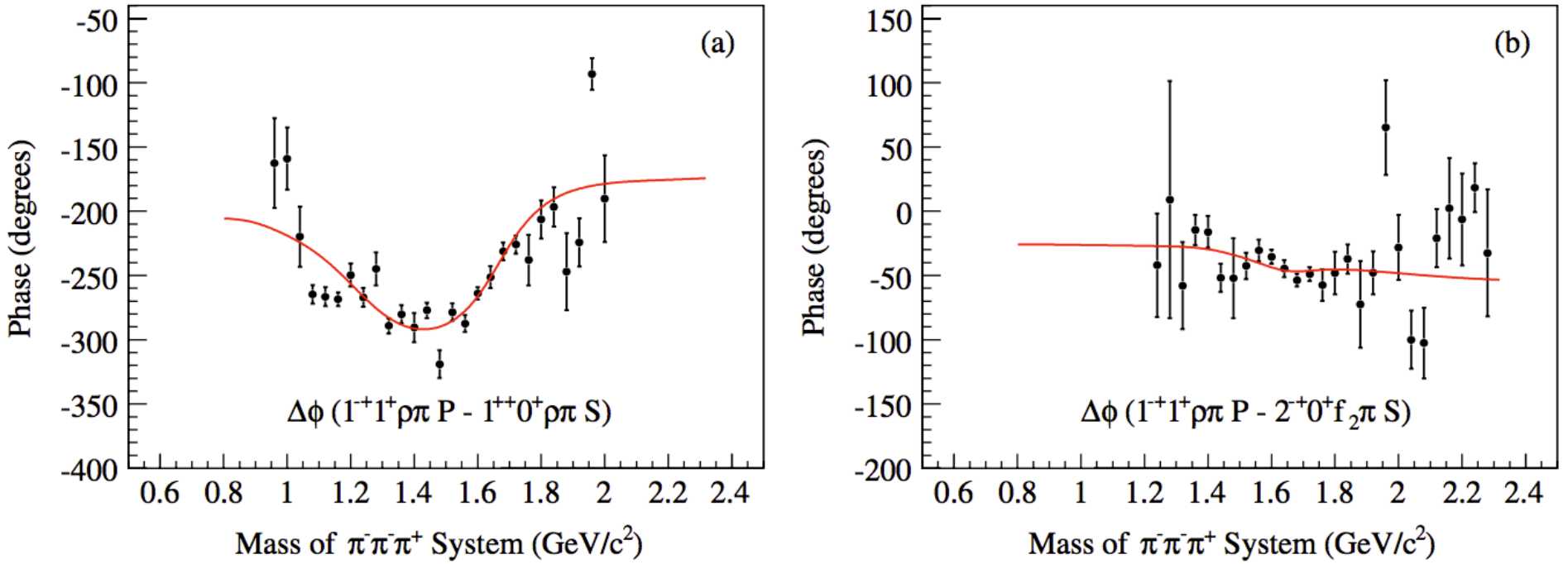
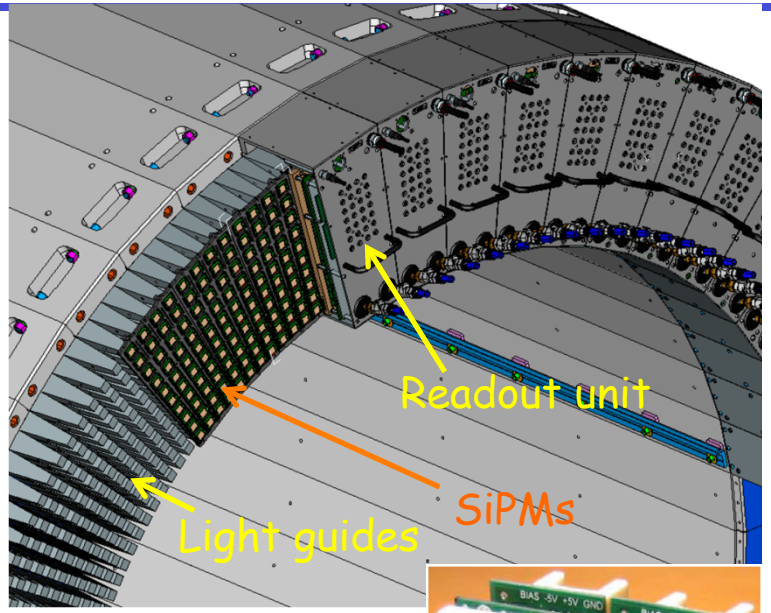
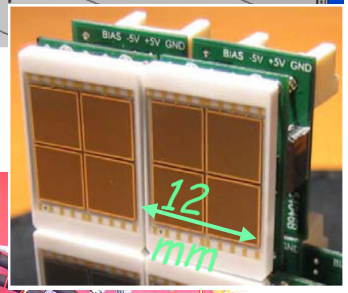


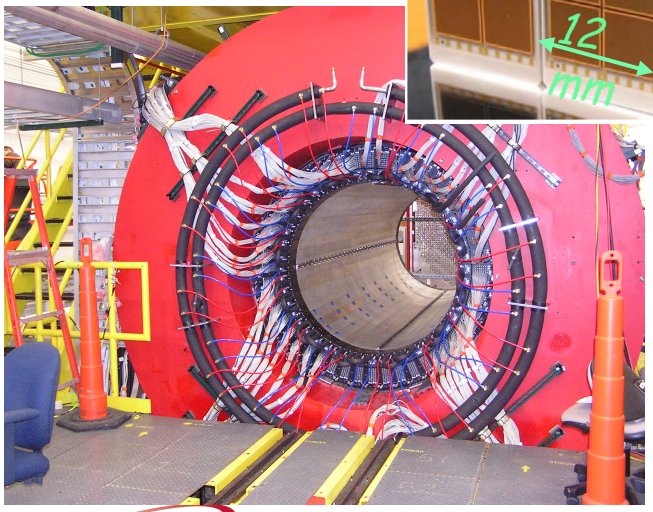
FIG. 3 (color online). Phase differences of the exotic $1^{-+}1^{+}\rho\pi P$ wave to the $1^{++}0^{+}\rho\pi S$ (a) and the $2^{-+}0^{+}f_2\pi S$ (b) waves. The data points represent the result of the fit in mass bins; the lines are the result of the mass-dependent fit.

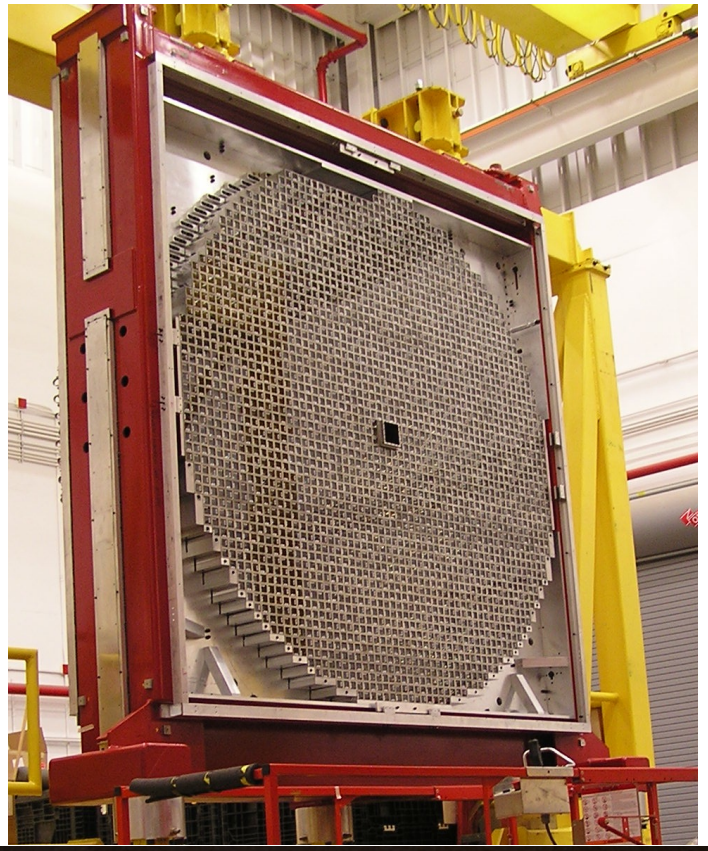
Barrel and Forward Calorimeters



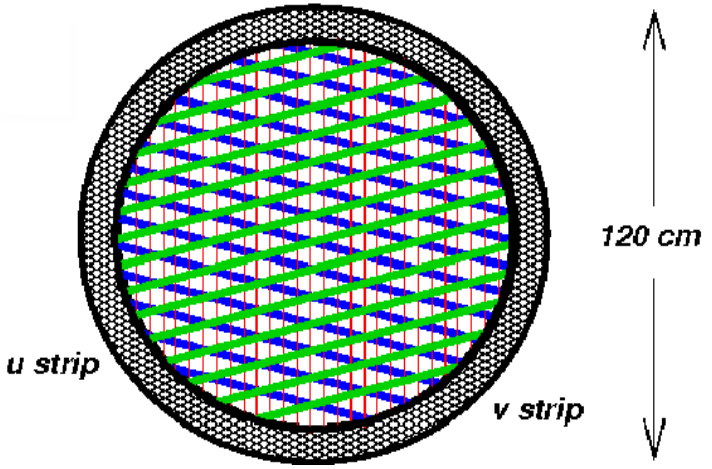
Immune to magnetic fields!



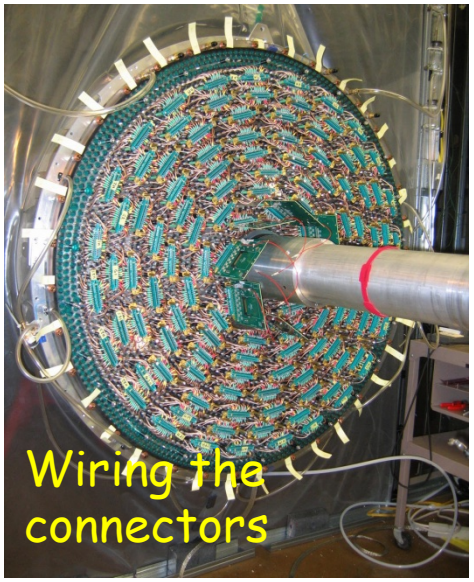


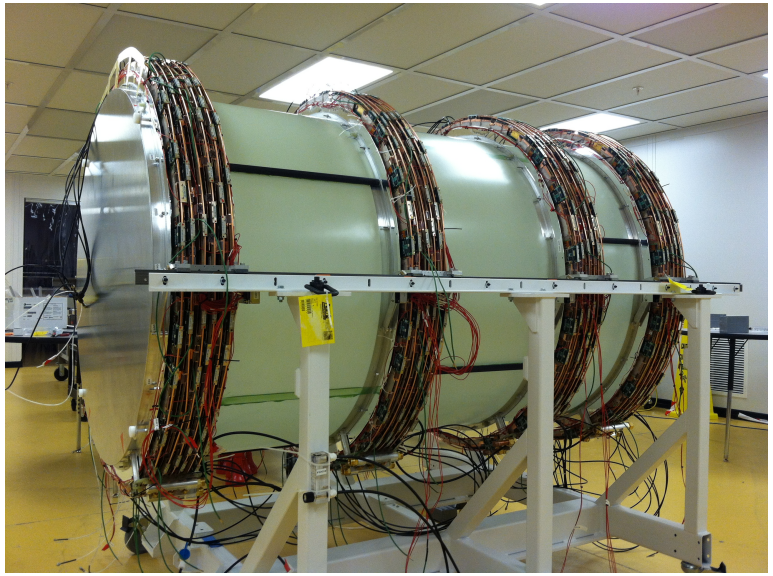


Central and Forward Chambers



4 packages × 6 planes





Particle Identification