Measurement of the J/ψ photoproduction cross section close to threshold

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Motivation

Measured: $\sigma(E_\gamma)$ for reaction $\gamma + p \rightarrow J/\psi + p$
at $8.22(\textit{threshold}) < E_\gamma < 12$ GeV

Existing data: two experiments from 1975 at $E > 11$ GeV

1. Photoproduction dynamics
   - $\sigma(E_\gamma)$ is sensitive to high-x gluons in the nucleon
2. Spectroscopy: search for the LHCb pentaquark
   - s-channel production $\gamma + p \rightarrow P_c(4450) \rightarrow J/\psi + p$ at 10.1 GeV
   - The P_c production would manifest itself as a peak in $\sigma(E_\gamma)$

The main topic of this presentation

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Exotic XYZ states: rich spectroscopy results

Belle, BaBar, CDF, D0, LHCb, BES have detected, mostly in B decays many mesonic states in $\bar{c}c, (\bar{b}b) + X$ final states, as:

$\chi_{c1}(3872)$ $0^+(1^{++})$ $\Gamma < 1.2\ MeV$ $\rightarrow J/\psi\pi\pi(> 3\%), \bar{D}^{*0}D^0(> 30\%)$ ... $\bar{c}c$?

$Z_c(3900)$ $1^+(1^{+-})$ $\Gamma = 28\ MeV$ $\rightarrow J/\psi\pi^\pm, \bar{D}^*D$... *exotic (not a $\bar{c}c$)*

The masses are close to the thresholds of some reactions (say, $\bar{D}^*D$)

The experimental evidence is very strong!

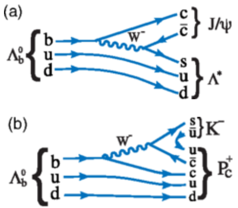
The interpretation is still uncertain:

- Tetraquark: diquark-antidiquark $\bar{3}_c \times 3_c \in 1_c$
- Molecule: meson-antimeson loosely bound $1_c \times 1_c \in 1_c$ "hadrocharmonium"
- Cusp - kinematical effect

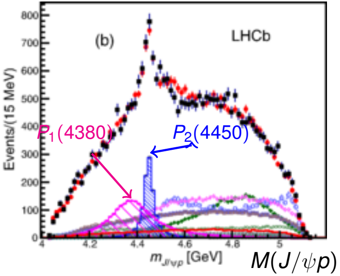
More information about their properties should help the interpretation

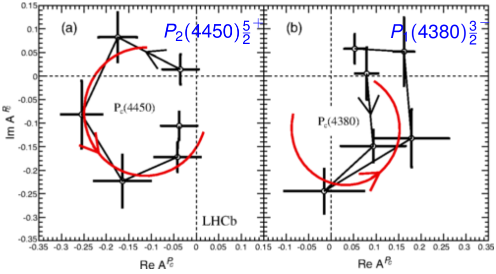
LHCb Pentaquark

LHCb PRL, 115, 072001 (2015) $\Lambda_b^0 \to K^-(J/\psi p)$



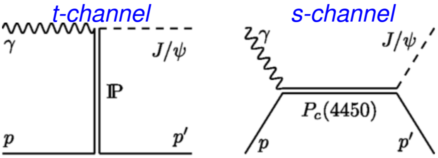
- No indications of $\Lambda^* \to K^- p$ reflections to $J/\psi p$
- PWA leads to two states for $P_c^+ \to J/\psi p$:
  - $M_1 = 4380 \pm 30, \Gamma_1 = 205 \pm 90$ MeV/c^2
  - $M_2 = 4450 \pm 3, \Gamma_2 = 39 \pm 20$ MeV/c^2
- J^{PC}: $(\frac{3}{2}^-, \frac{5}{2}^+)$ or $(\frac{3}{2}^+, \frac{5}{2}^-)$ or $(\frac{5}{2}^+, \frac{3}{2}^-)$



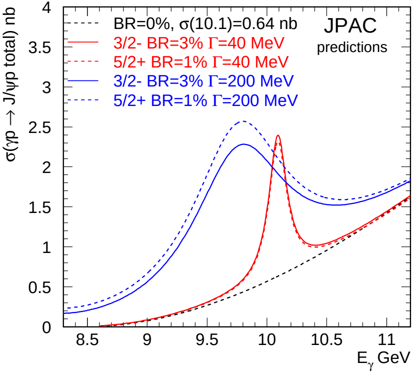


Threshold of $\Sigma_c(2455)\bar{D}^*(2007) = 4462$ MeV/c^2. The only mode detected $J/\psi p$

Photoproduction of the Pentaquark: Predictions



$E_\gamma \sim 10$ GeV



http://cgl.soic.indiana.edu/jpac/PentaQ_JPsi.php

In a *Broad-band photon beam*

$\gamma + p \to J/\psi + p$ may include

$\gamma + p \to P_c \to J/\psi + p$

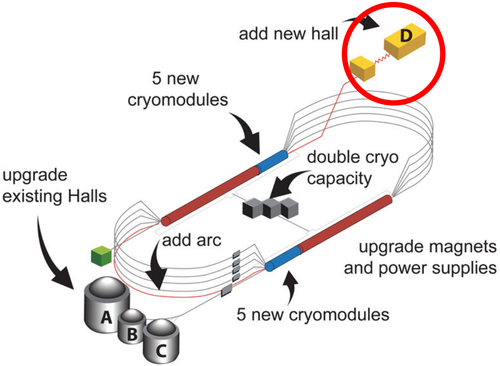
Addressed in a number of papers:

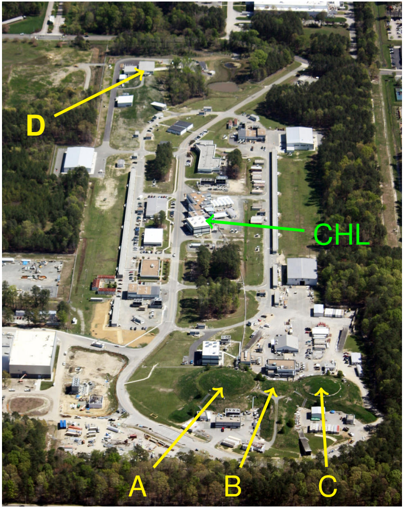
M. Voloshin et al PRD 92, 031502 (2015)
Q. Wang et al PRD 92, 034022 (2015)
M. Karliner et al PL 752, 329 (2016)
A. Hiller Blin et al PRD 94, 034002 (2016) JPAC

- $P_c \to J/\psi\ p \overset{VMD}{\Rightarrow} \gamma\ p \to P_c$
- Interference of *t*- and *s*-channels
- Using the measured $\Gamma(P_c)$ the full cross section is calculable with one free parameter:

$$\sigma_{\gamma p \to J/\psi p}(E_{peak}) \propto BR(P_c \to J/\psi p)^2$$

CEBAF at 12 GeV

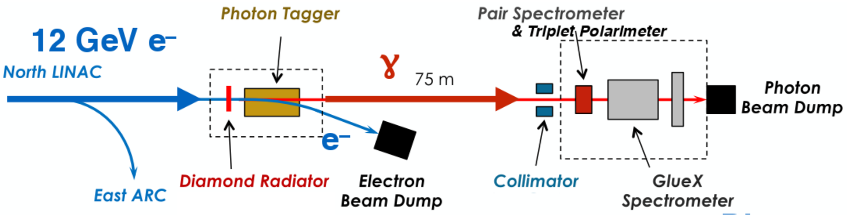




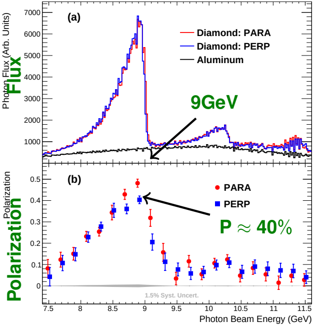
Beam runs

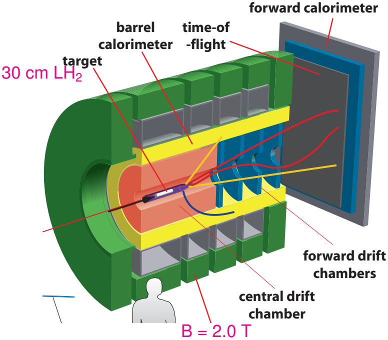
year	E_{MAX}, GeV			
	A	B	C	D
2016	10.9	-	-	12.0
2017	10.6	10.6	8.5	11.7
2018	10.6	10.6	10.6	11.7

Hall D/GlueX Meson Spectroscopy In Photoproduction



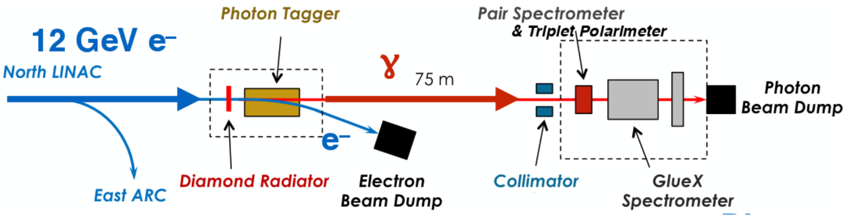
Photon Beam Spectrum



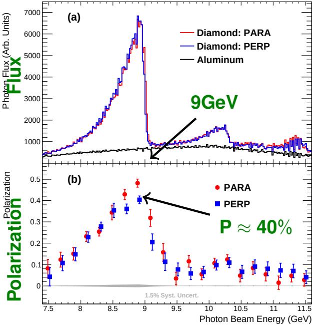


Jefferson Lab

Hall D/GlueX Meson Spectroscopy In Photoproduction



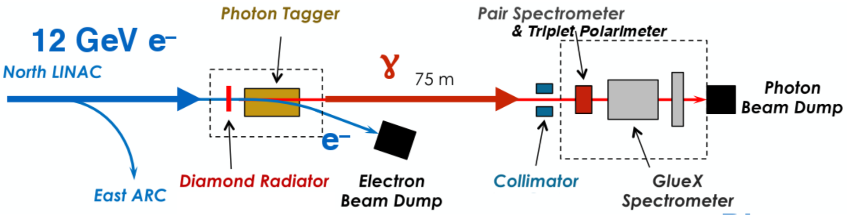
Photon Beam Spectrum



Spectrometer parameters

- Acceptance: $1^\circ < \theta < 120^\circ$
- Resolutions:
  $h^\pm$: $\sigma_p/p \sim 1-3\%$
  γ: $\sigma_E/E \sim 6\%/\sqrt{E} + 2\%$
- Beam energy tagging $\sim$0.1%
- Trigger: energy in the calorimeters

Hall D/GlueX Meson Spectroscopy In Photoproduction



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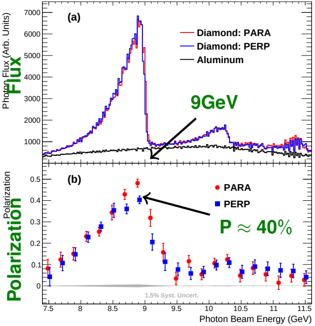


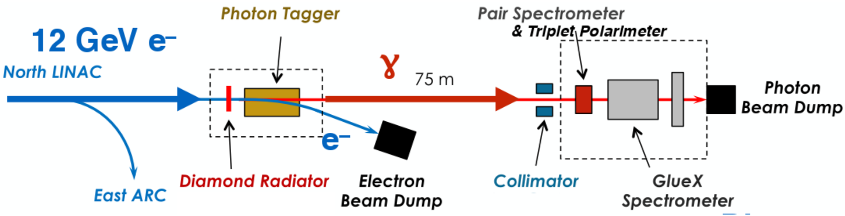
Experiment GlueX

- Designed for light meson spectroscopy
  Main goal: search for hybrid mesons
- Data taking 80% complete

run	E_{MAX} GeV	Int L pb^{-1}	status
2016	12.0	10	analyzed
2017	11.7	45	analyzed
2018	11.7	100	not yet analyzed

- Status of data analysis:
  complex final states reconstructed
  understanding the efficiencies: in progress

Hall D/GlueX Meson Spectroscopy In Photoproduction



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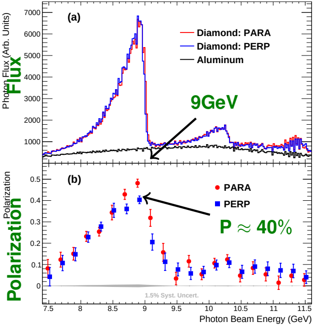
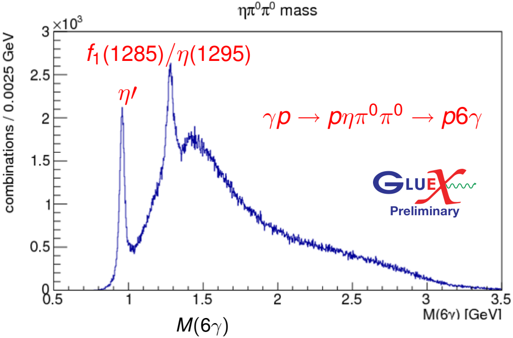


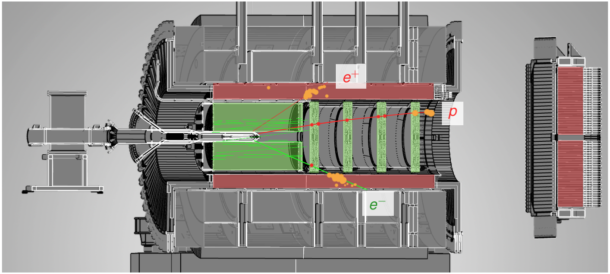
Example of event reconstruction:



Data Analysis for J/ψ

Reaction studied: $\gamma\, p \rightarrow J/\psi\, p, \quad J/\psi \rightarrow e^+ e^-$

$$\sigma(\gamma p \rightarrow \psi p) \times BR \sim 30 \text{ pb} \ \sim 0.3 \cdot 10^{-6} \times \sigma_{tot}(\gamma p \rightarrow hadrons)$$



Event identification:

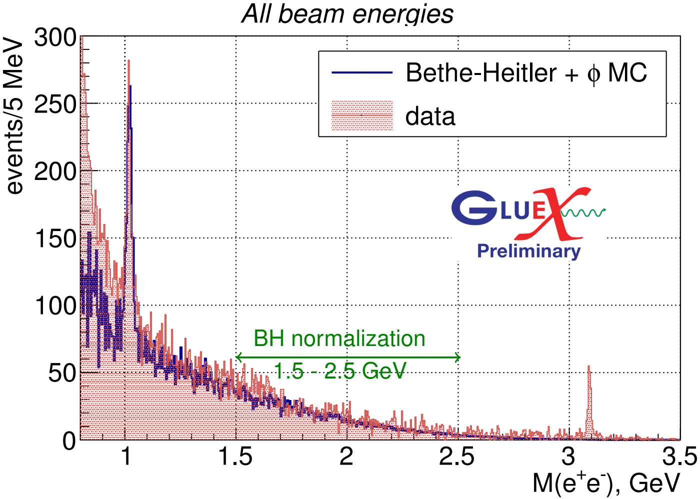
- PID for p: TOF, $\frac{dE}{dx}$ in drift chambers
- PID for $e^{\pm}$: EM calorimeters *(challenge: large BG from $\pi^+\pi^- p$ events)*
- Kinematic fit using the photon energy measured with a 0.1% resolution

The Bethe-Heitler reaction $\gamma\, p \rightarrow (e^+ e^-)p$ used for normalization

(absolute efficiencies are not fully understood yet)

Mass Spectrum of e^+e^-

GlueX Preliminary: not the final 2016+2017 data sample (about 70%).



BH simulation from R.Paremuzyan, based on E.Berger et al, EPJC 23:675 (2002)

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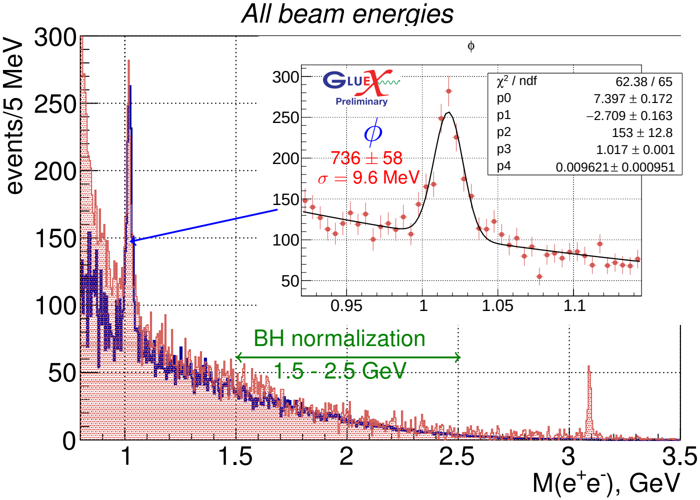

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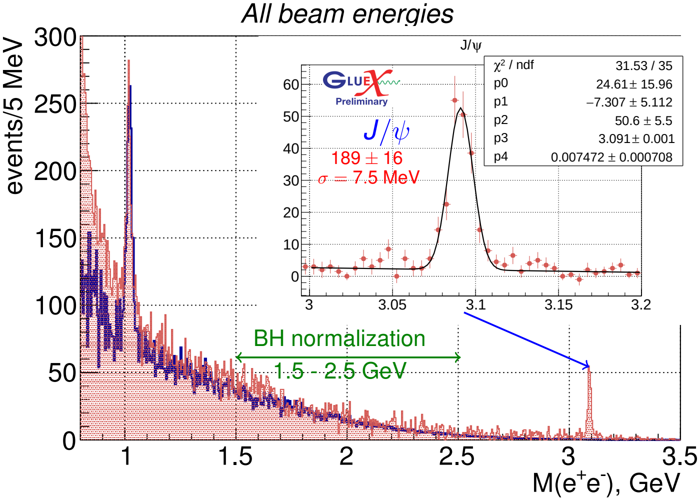

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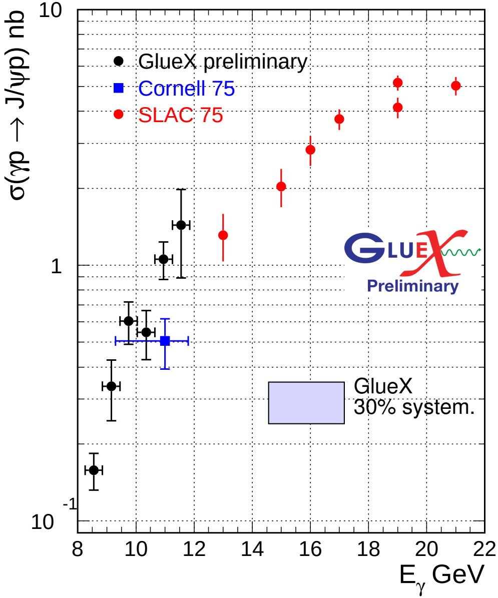
Energy dependence of the cross section



- SLAC:

  U.Camerini et al, PRL 35 (1975)

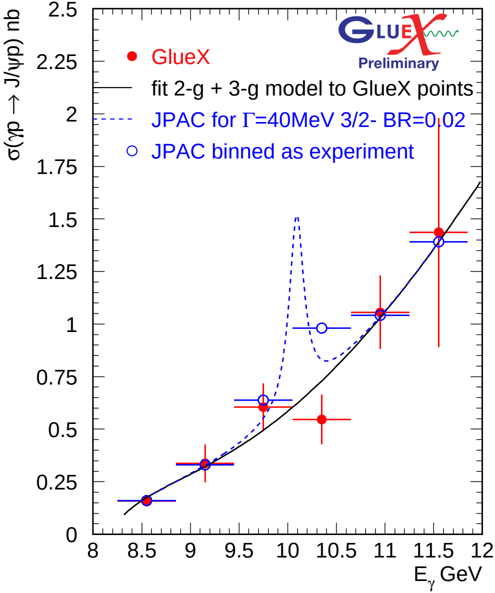
  Calculated from the measured $\frac{d\sigma}{dt}|_{t=tmin}$ assuming $\frac{d\sigma}{dt} \propto e^{a\cdot t}$, $a = 2.9\pm0.3$ GeV^{-2} measured at 19 GeV

- Cornell:

  B.Gittelman et al, PRL 35 (1975)

  t-slope $a = 1.25 \pm 0.2$ GeV^{-2} horizontal error bar represents the acceptance

Limit on the Pentaquark Production



Fit: 2 + 3-gluon exchange

Brodsky et al, PL 498 (2001)

2 free parameters $\chi^2/ndf = 0.8$

Limit for $P_c(4450)$ $\Gamma = 40$ MeV

JPAC model, assumptions:

$\sigma(10.1) = 0.64$ nb non-reson.

no wide state $P_c(4380)$ added

J^{PC}	BR	10.1 ± 0.6 GeV		(2 bins)
		JPAC nb	experiment nb	separation $\sigma(stat)$
3/2-	2.0%	0.81	0.58 ± 0.08	2.9
5/2+	0.7%	0.81	0.58 ± 0.08	2.9

Systematic to be addressed:

- *t* and *s*-channel interference
- VMD model dependence
- The wide state influence

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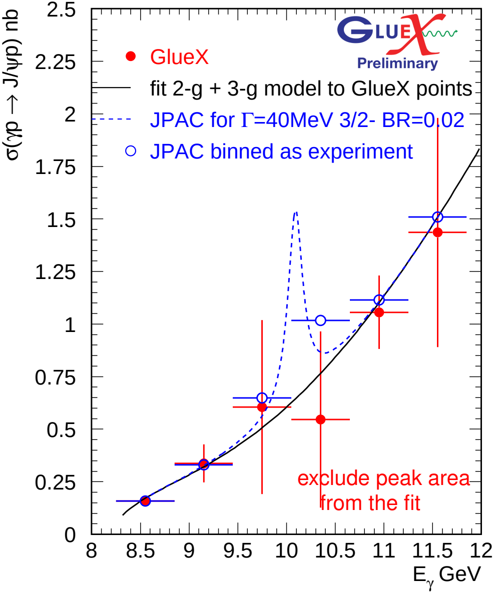

Fit: 2 + 3-gluon exchange

Brodsky et al, PL 498 (2001)

2 free parameters $\chi^2/ndf = 0.1$

Limit for $P_c(4450)$ $\Gamma = 40$ MeV
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3/2-	2.0%	0.84	0.58 ± 0.08	3.1
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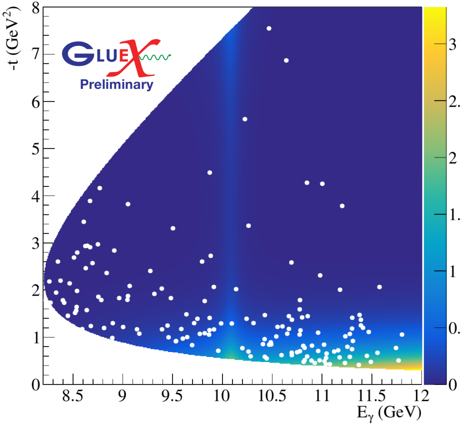
Unbinned distribution t vs E

The beam energy resolution is about 0.1% $\ll$ 0.6 GeV bins
The P_c is expected to produce broad t-distribution



- JPAC: $\frac{5}{2}^+$ $BR = 3\%$
- White dots: J/ψ events from the peak
- No indication of event concentration at 10.1 GeV

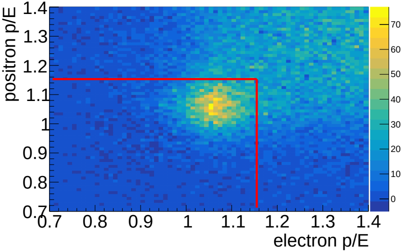
Summary & Outlook

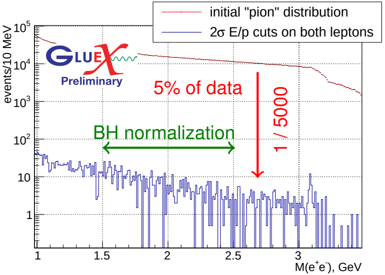
- Summary of the preliminary GlueX results
  - The first measurement of the cross section of the reaction $\gamma p \to J/\psi p$ close to threshold has been reported.
  - No statistically-significant evidence for the LHCb pentaquark has been observed. The model-predicted yield from $P_c(4450)(\frac{3}{2}^-) \to J/\psi p$, BR=2% (or $\frac{5}{2}^+$, BR=0.7%) is about $3\sigma(stat)$ above the experimental result.
- Outlook
  - GlueX is planning to analyze the full data sample and finalize the results before the end of the year. Also, we are planning to increase the sensitivity to the $P_c(4450)$ detection by using $t - E$ unbinned event analysis. Later, the 2018 data is expected to triple the statistics.
  - Other experiments at JLab (CLAS12 and Hall C) have been scheduled to the near future to measure the same process. Potentially, they would be able to reach a higher sensitivity.

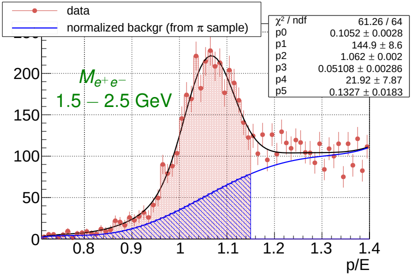
BACKUP

Identification of $e^{\pm}$

Using the track momentum p and the calorimeter energy E





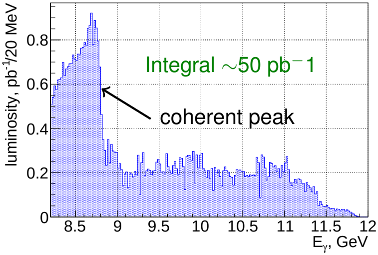


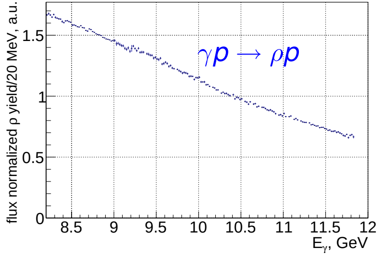
Pion background for BH sample

$1.5 < M(e^+e^-) < 2.5$ GeV

- One $e^{\pm}$ identified
- p/E for pions - shape measured
- Average background $36 \pm 1.2\%$
- Energy-dependent BG correction

Beam Flux Normalization





- Beam flux is measured with the Pair Spectrometer using e^+e^- pair production with a $\sim$ 0.1% converter
- "Tagged flux" measures photons in coincidence with the tagger detectors
- The structure of the tagged flux is caused by coherent peaks and the tagger geometry/efficiency
- Flux-normalized yield of $\gamma p \to \rho p$ is smooth

Systematic Error Budget

Systematic error source	Estimate, %
J/ψ to BH relative yield	18
BH cross section calculation	10
Pion contamination to BH	5
$\rho\prime$ contamination to BH	5
t-dependence of efficiency	9
Total	24

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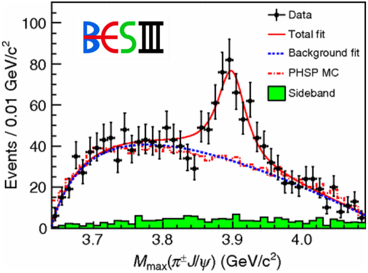
$Z_c(3900)\ 1^+(1^{+-})\ \Gamma = 28\ \rightarrow J/\psi\pi^\pm, \bar{D}^*D$... *exotic (not a $\bar{c}c$)*

The masses are close to the thresholds of some reactions (say, $\bar{D}^*D$)

$e^+e- \rightarrow \pi^\pm(Z_C^\mp \rightarrow \pi^\mp J/\psi)$ $\qquad$ $e^+e- \rightarrow \pi^\pm(Z_C^\mp \rightarrow (\bar{D}^*D)^\mp)$

BESIII PRL, 110, 252001 (2013)



BESIII PRL, 112, 022001 (2013)