

Threshold J/ψ Photoproduction with GlueX at Jefferson Lab

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We report preliminary results for the $\gamma p \rightarrow J/\psi p$ exclusive cross-section from the threshold, at 8.2 GeV, up to a photon energy of 12 GeV. These measurements have a direct relation to the pentaquarks, $P_c^+(4380)$ and $P_c^+(4450)$, reported by LHCb, expected to be seen in the s -channel photoproduction $\gamma p \rightarrow P_c \rightarrow J/\psi p$, allowing to put a limit on the $P_c^+(4450) \rightarrow J/\psi p$ branching ratio. The near threshold production mechanism is discussed, as well.

The GlueX experiment uses a tagged-photon beam produced by electrons from the 12 GeV CEBAF machine. The detector system is based on a 2 T solenoid and includes e.m. calorimeters and drift chambers providing full acceptance coverage. The J/ψ particles are registered by their decay into e^+e^- pairs identified in the calorimeters. Taking advantage of the exclusivity of the reaction and the precise knowledge of the beam energy, we achieve a high mass resolution and a very low background, allowing us to perform a more sensitive unbinned analysis.

KEYWORDS: charmonium, photoproduction, pentaquark, GlueX

1. Introduction

The upgraded 12 GeV Jefferson Lab accelerator has the unique opportunity (right energy, high intensity, and polarized beams) to study the J/ψ photoproduction right above the threshold (at beam energy of $E_\gamma = 8.2$ GeV) up to the maximum energy of 12 GeV. This energy range was poorly covered by previous old experiments [1, 2], while our measurements are the first that extend close to the threshold. The near threshold photoproduction of J/ψ has recently gained significant interest due to its direct relation to the two pentaquarks, $P_c^+(4380)$ and $P_c^+(4450)$, observed by LHCb [6] in their decay into $J/\psi p$. Several groups [7–9] immediately realized that by time-inverting of the pentaquark decay and adding a conversion of the beam photon into $c\bar{c}$ pair based on the VMD model, the existence of these resonances implies they have to be seen in the s -channels of the J/ψ photoproduction: $\gamma p \rightarrow P_c^+ \rightarrow J/\psi p$ at $E_\gamma \sim 10$ GeV. The only unknown parameter for such a mechanism is the branching fraction of the pentaquark decay into $J/\psi p$.

The near threshold charmonium exclusive production is an excellent probe to study the color charge distribution of the proton, which is another important aspect of the presented measurements. The heavy quark J/ψ interacts with the light quark proton by exchanging gluons. In [3] based on the dimensional scaling, two- and three-gluon exchange mechanisms near threshold are discussed. In [4] it is argued that the t -dependence of the exclusive reaction is defined by the proton gluonic form-factor for which in analogy with the electro-magnetic form factors (see Table I), we can assume a dipole form:

$$F(t) \sim 1/(1 - t/m_0^2)^2 \quad (1)$$

According to [5] the J/ψ photoproduction near threshold is dominated by the real part of the $J/\psi p$

Table I.: Analogy between electro-magnetic and gluonic form factors

	e.m. FF	gluonic FF
reaction	$ep \rightarrow ep$	$J/\psi p \rightarrow J/\psi p$
transverse size of probe	0	$\ll 1 \text{ fm}$
effective mass scale m_0	0.84 GeV (vector meson)	$\sim 1.1 \text{ GeV}$ (two-gluon mass)

elastic amplitude, which is critically important since it contains a term (trace anomaly) related to the fraction of the nucleon mass arising from gluons.

2. GlueX experimental set-up

The GlueX experiment is hosted by the experimental hall D at Jefferson Lab. The photon beam is produced from the 12 GeV electron beam incident on a diamond radiator via coherent Bremsstrahlung. The photons are tagged by the scattered electrons in a hodoscope array, allowing to achieve a very (up to 0.1%) beam energy resolution. The photon spectrum is shown in Fig.1. We will report on measurements with an accumulated luminosity of 68 pb^{-1} , which is about 30% of the total statistics so far.

The photon beam is collimated and directed into the GlueX detector (Fig.2). It is a hermetic detector with full azimuthal and $1 - 120^\circ$ polar angle coverage. The central part of the detector consists of a solenoid, with a hydrogen target, central and forward tracking systems, and a barrel electro-magnetic calorimeter inside. The forward direction is covered by a time-of-flight wall and a forward calorimeter.

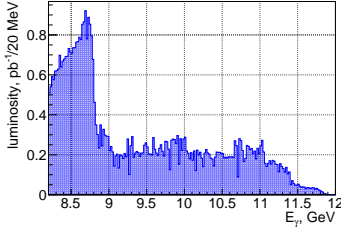


Fig. 1.: Accumulated luminosity as function of the photon beam energy.

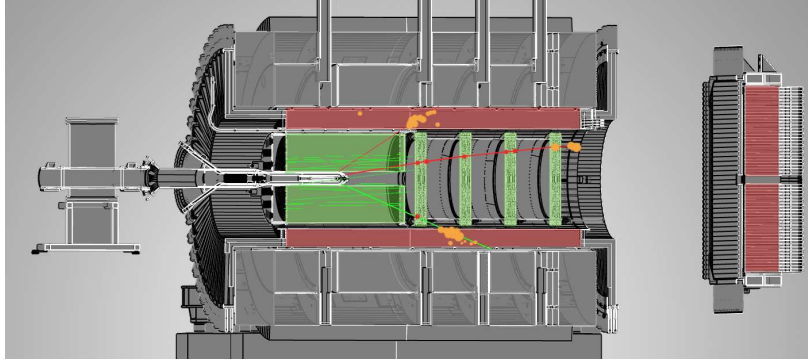


Fig. 2.: The GlueX detector: 2 T solenoid, 30 cm hydrogen target, drift chambers in central and forward region (green), barrel and forward calorimeters (red), time-of-flight system.

The J/ψ particles are identified by their decay into electron-positron pairs. Shown on Fig.2 is also one J/ψ event with the two leptons detected in the barrel calorimeter and the recoil proton in forward direction. From experimental point of view the main challenge is the suppression of the pions which are three orders of magnitude more numerous than the electrons. This is done mainly by using the E/p distributions, where the energy E of the particle is measured in the calorimeters and the momentum p by the tracking.

The exclusiveness of the reaction and the precise knowledge of the beam energy allows us to perform a kinematic fit that improves significantly the resolutions. Fig.3 shows the e^+e^- invariant

mass spectrum with the ϕ and J/ψ peaks and Bethe-Heitler (BH) continuum in between. We use the BH process in the 2 – 2.5 GeV mass range to normalize the J/ψ cross-section.

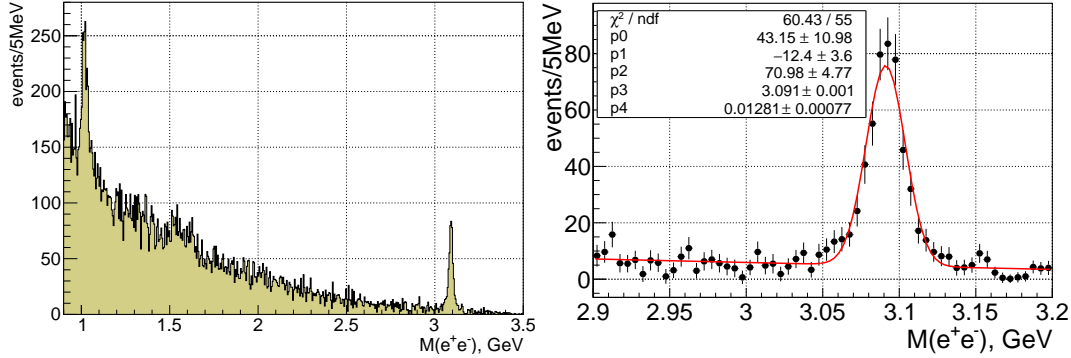


Fig. 3.: Electron-positron invariant mass distribution (left) and a fit with a linear function and a Gaussian of the J/ψ (right). In total we see 464 ± 25 J/ψ events with 12.8 MeV resolution.

3. Results and discussions

In Fig.4 we show the preliminary result for the t -differential cross-section as function of $-(t-t_{min})$ for beam energies in the 10 – 11.8 GeV region. The strong variation of t_{min} with energy doesn't allow us to include in this analysis the low energy region. We obtain a t -slope of $1.49 \pm 0.33 \text{ GeV}^{-2}$ (statistical error only), to be compared with the Cornell result [1] at $E_\gamma = 11 \text{ GeV}$ of $1.25 \pm 0.2 \text{ GeV}^{-2}$ and the SLAC result [2] at $E_\gamma = 19 \text{ GeV}$ of $2.9 \pm 0.3 \text{ GeV}^{-2}$. In Fig.5 we test the hypothesis [4] for a dipole t -dependence of the differential cross-section where in addition to the data used in [4] we have added our preliminary results. The beam energies of the different measurements and, correspondingly, the absolute cross-sections vary significantly. In order to compare only the slopes we have normalized them together and fitted each set individually with exponential functions. A global fit using Eq.1 results in a two-gluon mass parameter of $m_{2g} = 1.14 \text{ GeV}$. Thus, Fig.5 justifies the use of a form-factor-like dipole t -dependence and illustrates that the change of the t -slope with the beam energy can be explained by the change of t_{min} and the t -range of the different measurements.

Preliminary results from the GlueX experiment for the total cross-section in bins of beam energy are shown in Fig.6. The estimated systematic error at this stage of the analysis is $\sim 25\%$. In the same figure the Cornell [1] and SLAC [2] measurements are plotted. In fact the SLAC experiment measured $d\sigma/dt$ at $t = t_{min}$. In order to estimate the total cross-section we have integrated over t assuming the dipole t -dependence from Fig.5. The dimensional scaling calculations [3] predict only the shapes of the energy dependence of the cross-section in case of two- or three-gluon exchange. We have fitted (Fig.6) these two curves with two normalization factors as parameters to the GlueX data points. One can see, as expected, that the three-gluon exchange starts dominating when approaching the threshold since at threshold all the constituents should participate in the reaction. We have plotted also the theoretical curve from [5] multiplied by a factor of 1.9 to fit our data. These are absolute calculations, however according to the authors, there is up to a factor of three uncertainty in the normalization. Such comparison to the data allows to estimate the fraction of the nucleon mass arising from gluons, as it is part these calculations.

In Fig.7 we compare our results for the total cross-section with the predictions [9] for the $P_c^+(4450)$ resonance assuming a branching ratio $\text{BR}(P_c \rightarrow J/\psi p)$ of 2% for the two possible spin hypothesis [6].

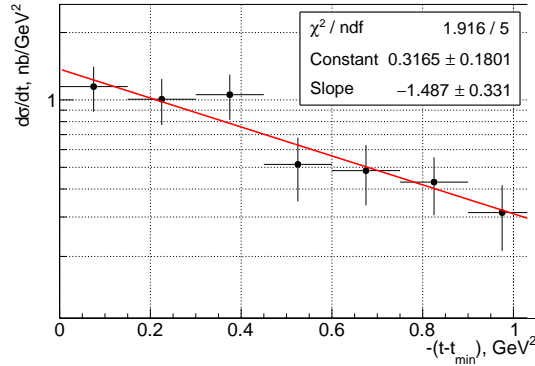


Fig. 4.: Preliminary results for the t -differential cross-section as function of $(t - t_{min})$ for $10 < E_\gamma < 11.8$ GeV.

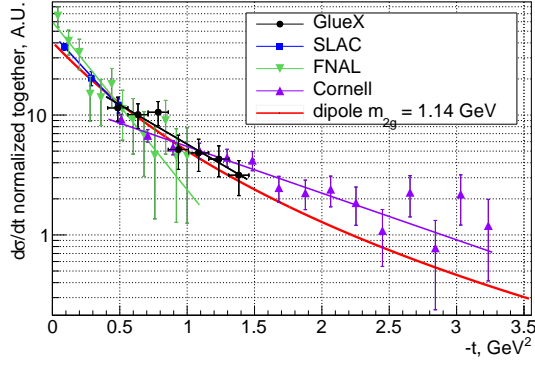


Fig. 5.: $d\sigma/dt$ normalized together from experiments with different beam energies: FNAL [10] 100 GeV (average), SLAC 19 GeV, Cornell 11 GeV, GlueX 10 – 11.8 GeV. Red curve – Eq.1 with $m_0 = 1.14$ GeV.

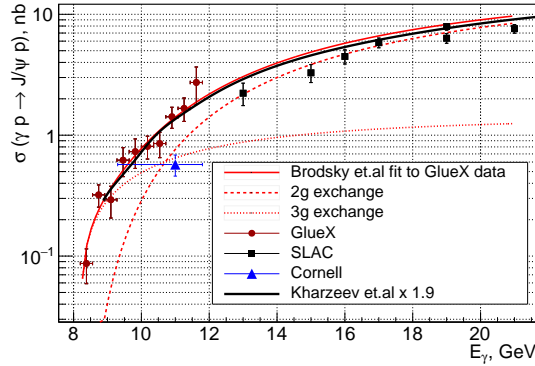


Fig. 6.: GlueX preliminary results for the total cross-section as function of beam energy, compared to Cornell [1] and SLAC [2] results and also to the theoretical predictions [3, 5] as discussed in the text.

No structure is observed in this region. Such comparison allows us to estimate an upper limit of the BR of the order of a few percent. The coarse binning of our data points is a result of the low statistic. However, we can take advantage of the precise knowledge of the beam energy and the low background (Fig.3), and perform unbinned analysis. Fig.8 illustrates this, where the individual J/ψ events are plotted as function of E_γ and $-t$ compared to the same [9] theoretical predictions. It should be noted that such a scattered plot reflects the initial photon spectrum which however doesn't have strong variations (Fig.1) in the pentaquark region. Nevertheless, neither the energy nor the t -dependence of the pentaquark is observed in the data where the t -channel dominates. The above analysis don't take into account the second resonance $P_c^+(4390)$ which is wider and requires much more statistics.

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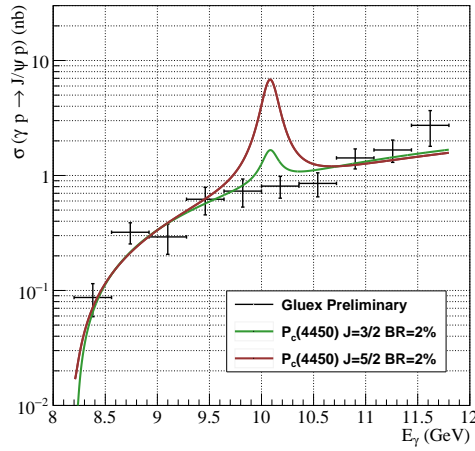


Fig. 7.: Comparison of GlueX data points with the pentaquark prediction from [9].

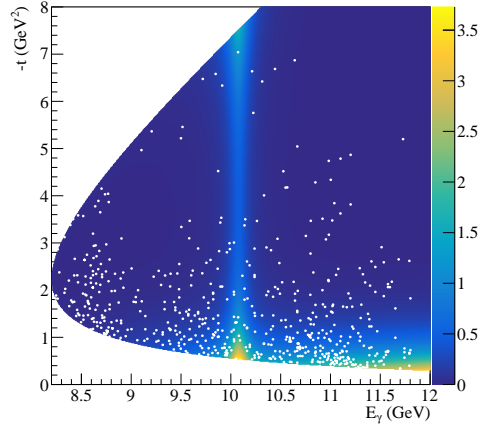


Fig. 8.: Scattered plot of the J/ψ events (white dots) as function of beam energy and t compared the the pentaquark prediction from [9] for 2%BR and spin of 5/2 (color coded in arbitrary units).

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