Comments on the Report of Referee A – LE17649/Ali

- Referee: *"My only real concern is the difficulty in normalizing the result with the Bethe-Heitler process. As the authors discuss, this is sensitive to the large pion background. I consider the statement at the end of the 2nd paragraph on page 2, that normalizing the J/Psi cross section to the Bethe Heitler cancels significant uncertainties as disingenuous. The detector efficiencies are sensitive to the differing kinematical distributions of the two processes and the pion background issue is severe."*

We agree that the suppression of the pion background, which varies between 30 and 60%, is a challenge as we discuss in page 2, left bottom paragraph. Unfortunately, we didn't have enough space in the paper to describe in detail the procedure for extracting the Bethe-Heitler (BH) yields (page 3 second paragraph from the top left). We describe the procedure below, and add a discussion of Figs. 1,2 to the Supplemental Material in order to provide more details on this important topic.

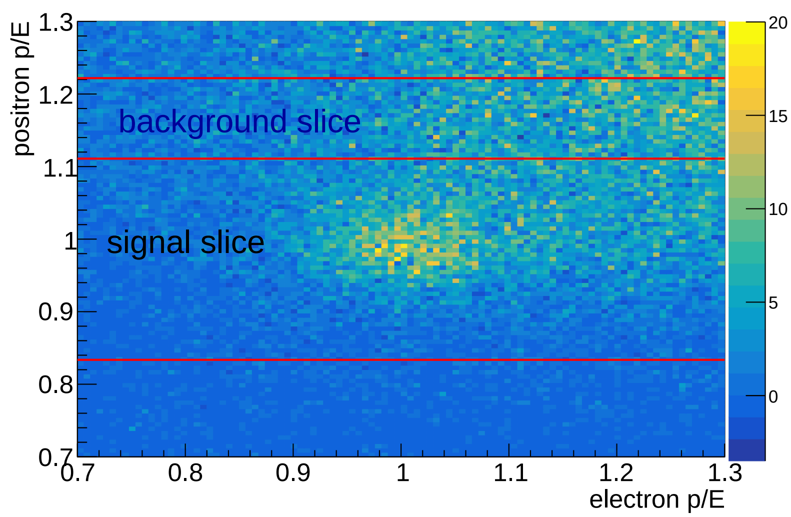


FIG. 1: p/E distribution of the two leptons. The background slice ($2\sigma < p/E - 1 < 4\sigma$ cut on the y-axis), and the slice containing the signal ($-3\sigma < p/E - 1 < 2\sigma$ cut on the y-axis) are indicated with horizontal lines.

On the two-dimensional p/E distribution, for each lepton separately (electron for example in Fig. 1), we identify a slice that represents the calorimeter response to pions (background slice), and a slice containing the signal due to electrons. The projection of the background

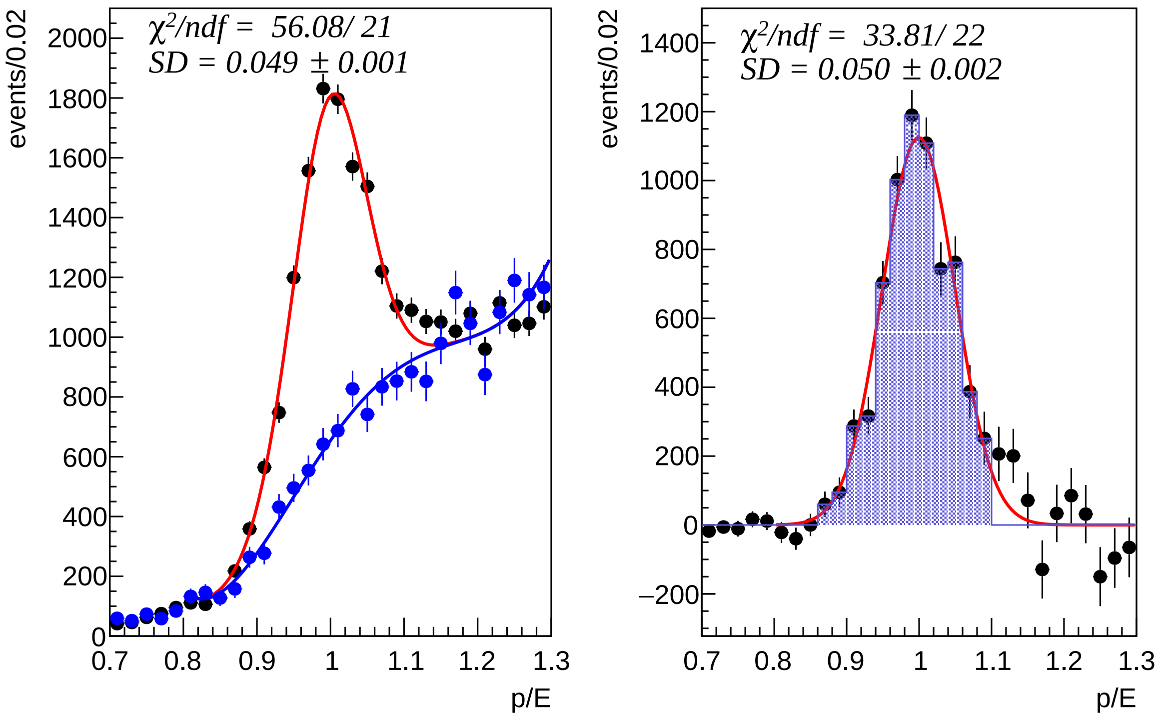


FIG. 2: Left plot: the signal slice from Fig.1 projected on the x-axis (black points) fitted with a background shape times a normalization parameter p_{norm} (blue line) plus a Gaussian (red line); the background shape is a polynomial fit of the projection of the background slice from Fig.1 (blue points normalized by p_{norm}). Right plot: the difference of the black and blue points from the left plot representing the electron/positron signal fitted with a Gaussian. The shaded histogram represents the events within $(-3\sigma, 2\sigma)$.

slice on the x-axis is fitted with a polynomial, that represents the background shape. The projection of the signal slice is fitted with the same background shape times a normalization parameter p_{norm} plus a Gaussian. In Fig. 2, left panel, we show the projection of the signal slice and the projection of the background slice times the normalization p_{norm}. On the next step we subtract the two histograms and count the number of events within $(-3\sigma, +2\sigma)$ of the peak, Fig. 2, right panel. Using this method, we are not so sensitive to the type of the function we are using to fit the background.

The procedure demonstrated above is applied separately for the two calorimeters and in bins of beam energy in order to obtain the final cross section results. The pion contamination varies between between 30 and 60%. The same procedure is applied also in bins of proton momentum and angle, p_p and θ_p, for the systematic studies shown below. Thus, we always analyze the calorimeter response to pions and electrons for the corresponding kinematical conditions. As part of the systematic studies we have varied the procedure for fitting the p/E signal distribution, using variable width of the Gaussian, or fixing it with the average value. As for the background distribution we have varied the slice range: $(2\sigma, 4\sigma)$ and $(3\sigma, 4\sigma)$. We assign the systematic error to the maximum deviation from the nominal.

- Referee: *"The disagreement with the Cornell measurement is not really discussed."*

There appear to be several inconsistencies in the Cornell measurement which makes it difficult to understand in any detail the disagreement with our measured values, as we discuss below. Since we are unable to make a concise statement about this difference, we limit the discussion to what is stated in the Introduction.

The experimental apparatus for the Cornell measurement [1] is very different than those used for our measurement. The Cornell measurement was inclusive and done on a beryllium target. The two leptons (electron and positron) were detected in two arms consisting of lead glass calorimeters with scintillator hodoscopes in front. The background particles were identified by their low deposition of energy in the scintillators. The J/ψ mass resolution was rather poor, ~ 150 MeV. The beam photon energy was reconstructed from the measured J/ψ energy and angle assuming elastic production. The production from beryllium was assumed to be 9 times that from a nucleon, and corrections were made to take into account the Fermi motion of the nucleons in the target.

The Cornell data point is assigned a central value of a beam energy of 11 GeV, corresponding to the maximum of their acceptance (Fig. 3 in [1]). However, their acceptance is very asymmetric and strongly dependent on beam energy, being much wider towards low energies. They also give results for three energy intervals, showing no energy dependence of the total cross-section, in contrast with fall towards the threshold that is expected and that we see.

Additionally, it was noticed in Ref. [2] that the slope of the t-dependence reported in the Cornell paper [1], 1.25 ± 0.2 GeV^{-2}, does not match the slope of the plot in Fig. 2 in that paper, which we estimate to be ~ 1.65 GeV^{-2}. Discussing this issue with one of authors of the Cornell paper did not help to resolve the problem [3].

We found a PhD thesis of another author [4], with detailed description of the detector setup. In an attempt to understand the above discrepancies, we performed toy Monte Carlo simulations of their setup and tried to reproduce their acceptance and the above results, but were not able to.

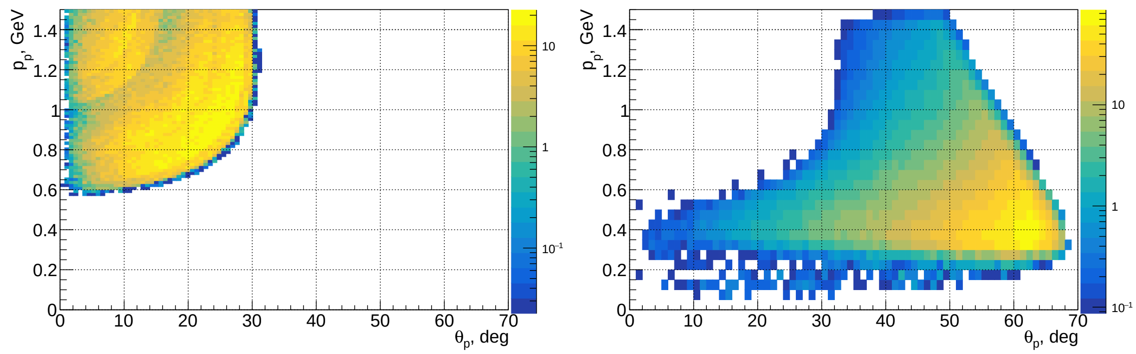
- Referee: *"I would like to be better convinced that the normalization error of 27% is appropriate since it dominates limits on the pentaquark states."*

First, we would like to note that the upper limits on the pentaquark states change by $\sim 15\%$ when varying the normalization by 27%, while there is a $\sim 25\%$ change when varying the resonance widths by 1σ from their measured value. Thus, the limits are dominated by the experimental uncertainties of the widths, as reported by the LHCb collaboration.

The main contribution to the normalization error comes from the relative, J/ψ-to-BH efficiency (page 3 top right paragraph). The J/ψ photoproduction and the BH process used for normalization occupy different kinematical regions and we have to understand the relative efficiency between them. To estimate the systematic uncertainty of the simulations used to calculate the efficiencies, we study the quantity $R = N_{BH}/(\sigma_{BH}\varepsilon_{BH})$ as a function of different kinematical variables that bridge the BH and J/ψ kinematical regions. Here N_{BH} is the BH yield extracted from the data using the procedure explained above, σ_{BH} is the calculated BH cross-section, and ε_{BH} is the MC-determined efficiency. This quantity can be best illustrated using the proton polar angle and momentum, p_p and θ_p in the BH mass region ($1.2 - 2.5$ GeV), as they provide the strongest constraints on the kinematic fit (see discussions at page 2 bottom right paragraph). The kinematical regions occupied by the leptons in the two processes have a significant overlap.

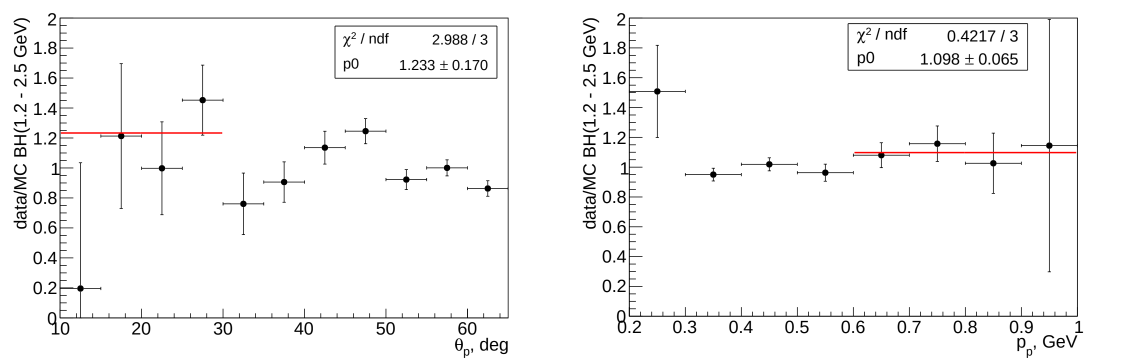
The two kinematical regions as a function of p_p and θ_p, obtained from simulations are shown in Fig.3. The ratios R, normalized to unity, as a function of the proton angle and momentum, separately, are shown in Fig.4. The regions that correspond to J/ψ are fitted with constants. A deviation from unity indicates that the variation of the efficiency from one kinematical region to another does not match the data. Based on such studies, we assign conservatively the systematic error to the maximum deviation of R which is in the case of the proton angle (Fig.4a).

We do not have sufficient statistics to study the ratio in the region where both proton angle and momentum are close to the J/ψ kinematical region. This is equivalent to studying the BH process in the $M(e^+e^-)$ region next to the J/ψ mass, where the BH cross-section is



(a) J/ψ (b) BH (1.2 – 2.5 GeV)

FIG. 3: J/ψ and BH yields from MC as a function of the proton polar angle and momentum, in arbitrary units.



(a) Proton polar angle (b) Proton momentum

FIG. 4: The data-to-MC ratio $R = N_{BH}/(\sigma_{BH}\varepsilon_{BH})$, normalized to unity, as a function of the proton polar angle and momentum. Shown are fits with constants in the J/ψ kinematical regions.

two orders of magnitude lower than the J/ψ one.

In addition, to make sure we understand the tracking efficiency in the J/ψ kinematical region, we study it with pions. We use the exclusive ω photoproduction process $\gamma p \to \omega p$, where $\omega \to \pi^+\pi^-\pi^0$. We reconstruct the ω peak using the missing mass off the proton and assume one of the charge pion is missing. The momentum of the missing pion is reconstructed from the rest of the final state particles. This allows us to estimate to efficiency of the reconstruction of the charged pions from the data and compare it with the MC efficiency. The MC and data efficiencies are shown in Fig.5 as function of the pion polar angle for different slices of the pion momentum that cover the J/ψ kinematical region with respect to the proton angle and momentum (Fig.3). We observe a good agreement of the two efficiencies.

Nevertheless, we recognize that tracking efficiency of the protons might be different, due to the different energy losses at low energies in the detector material. Therefore, we decided to keep the above estimation of 23% for the systematic uncertainty of the relative efficiency. The other contributions to the systematics of the normalization are less significant and they are briefly discussed in the paper and summarized in Table III in the Supplemental Material.

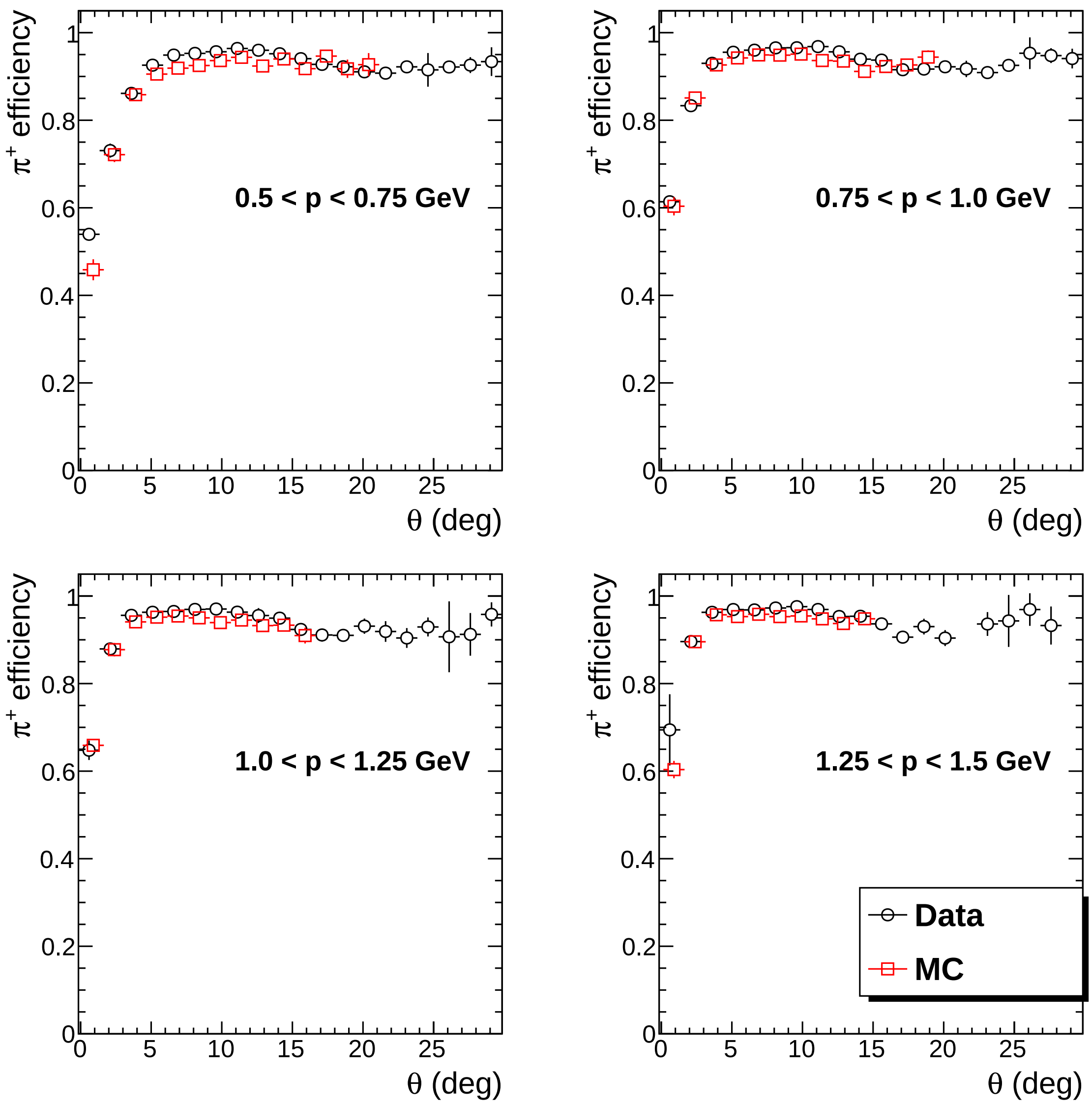


FIG. 5: Comparison of the charged pion reconstruction efficiency obtained from the data and MC as function of the pion polar angle for slices of the pion momentum.

[1] B. Gittelman, K. M. Hanson, D. Larson, E. Loh, A. Silverman, and G. Theodosiou, Phys. Rev. Lett. **35**, 1616 (1975).

[2] L. Frankfurt and M. Strikman, Phys. Rev. D **66**, 031502 (2002).

[3] M. Strikman, private communication (2018).

[4] G. E. Theodosiou, *Photoproduction of Narrow Resonances*, Ph.D. thesis, Cornell University, Cornell Archive Library (1978).