Inelastic and Elastic Cross section Curve Fits for J/ψ Photoproduction

RPC Technical Note #38

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1 Introduction

The cross-section of J/ψ photoproduction has been measured at various photon energies ranging from 11.0 GeV to 40 TeV for the cases of elastic,inelastic and coherent scattering. Values were collected and analyzed from the literature and, where necessary, converted to the necessary format to be conveniently plotted as σ (total observed cross section) vs. W (energy in the CM frame). Where the given source paper gives $d\sigma/dt$ (differential cross section) and/or E_γ (incident photon energy, lab frame) in lieu of σ and W, the necessary conversions have been made. Error bars were calculated using quadrature; the formalism of the conversions and error bar determination are detailed in Section 3. The slope parameter (b) has also been plotted as a function of W; the details of the data analysis for this plot are included in Section 5.

Once values were collected and plotted in a consistent manner, a curve of an appropriate form [9] was fit to the data, with the various parameters and the relative errors quantitatively defined. To date we have included results for elastic scattering only; results for the inelastic and coherent cases will be added to this note as ongoing analysis is completed.

2 Event Rate Fit for Elastic Photoproduction

Table 1 shows the compiled values for σ and W from eight different sources; E_γ is also included for convenience. Section 3 details how these values were calculated in the cases where the source data used inconsistent notation.

Figure 1 shows a log-log plot of σ vs. W; the equation

$$\sigma = \alpha_1 \cdot (1 - \frac{W_{th}^2}{W^2})^{\alpha_2} \cdot W^{\alpha_3} \tag{1}$$

was used to generate the fit line. W_{th} represents the threshold energy for J/ψ production in the CM reference frame. Given (from previous experiments) a

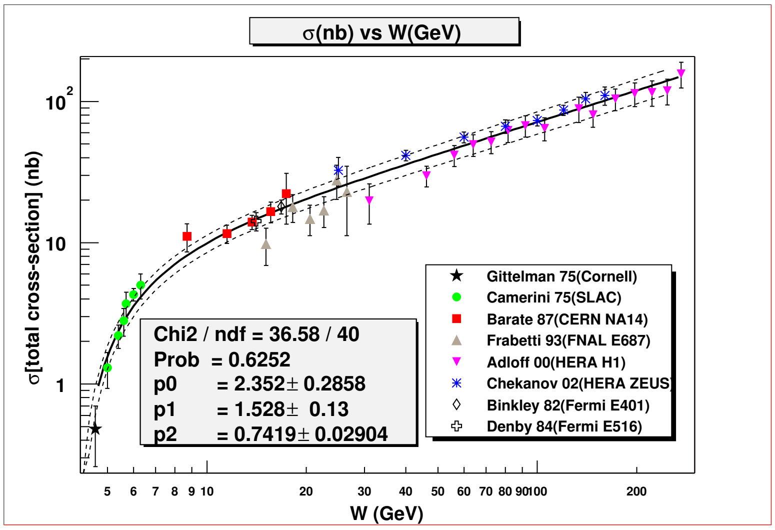

Figure 1: Observed total cross section of J/ψ production at energies ranging from near-threshold to highest observed energies.

photon threshold energy $E_{\gamma th} = 8.3$ GeV, the energy in the CM frame is easily determined to be $W_{th} = 4.0$ GeV (from Equation (3), below). This curve is best fit to the data by the (rounded) parameters $\alpha_1 = 2.37 \pm 0.296$, $\alpha_2 = 1.53 \pm 0.13$ and $\alpha_3 = 0.740 \pm 0.030$ when W is expressed in GeV and σ in nb. The resulting chi squared value is $\chi^2 = 36.5/40 = 0.91$.

To calculate the range of error on this fit, (1) was differentiated implicitly with respect to each parameter, and the resulting terms were added in quadrature, resulting in

$$\frac{d\sigma}{\sigma} = \sqrt{\left(\frac{d\alpha_1}{\alpha_1}\right)^2 + \left[\ln\left(1 - \frac{W_{th}^2}{W^2}\right) d\alpha_2\right]^2 + \left[\ln W d\alpha_3\right]^2} \tag{2}$$

This result, of course, is dependent on the assumption that the parameters α_1, α_2 and α_3 are uncorrelated. Thus, the error margin, marked by the dotted lines, represents the values between $\sigma \pm d\sigma$. One can see a good correlation between the existing data and the curve given by (1). Processing of the source data to plot the graph in Figure 1 is detailed in the next section.

3 Interpretation of Data and Error Bar Generation

In order to generate a fit with the existing data, it was necessary to convert some of the given data points in order to generate consistent units and error ranges. This is especially true in some of the older references, in which it was necessary to convert E_γ and $d\sigma/dt$ to W and σ, respectively. Error bars were generally calculated by combining the given statistical and systematic errors in quadrature. An explanation of how the data was processed in the case of each reference is given in this section; the reader who is only interested in the general curve fits and not the processing of the source data should skip to Section 4.

In all cases where the photon energy E_γ is given in lieu of the system energy in the CM frame W, we used relativistic mechanics to derive the equation

$$W = \sqrt{2E_\gamma m_p + {m_p}^2} \tag{3}$$

where m_p is the proton mass (∼938 MeV). (This is generally so small compared to the photon energy that the second term in (3) can be neglected.)

The first data point, represented by a star(★) is derived from a source reference [1] that gives the beam energy E_γ and a relationship between the differential cross section $d\sigma/dt$ and the momentum transfer t given by

$$d\sigma/dt = Ae^{bt} \tag{4}$$

The fit parameters A and b are given as $A = 1.01 \pm 0.20$ nb/GeV^2 and $b = 1.25 \pm 0.20$ GeV^{-2}. If we integrate and use $t = t_{min} = -0.41$ GeV^2 (at $E_\gamma = 11$ GeV), we obtain the equation

$$\sigma = \frac{A}{b} e^{bt_{min}} \tag{5}$$

Using (3) and (5), values for W and σ were found that correspond to those on the plots generated by Kharzeev[10]. To generate the error bar at this data point, we differentiated (5) with respect to A and b and squared both sides; this resulted in an error of $d\sigma = 0.22$ nb, which also correlates with the error bar on Kharzeev's plot. (Simply adding the errors on A and b in quadrature did not produce an error bar as large as Kharzeev's; there may be correlation between the two parameters.)

The six data points represented by circles(•) are taken from a source [2] that again gives E_γ and $d\sigma/dt$. Once again, W is calculated using (3); σ is found using the equation

$$\sigma = \frac{d\sigma/dt}{be^{b(t-t_{min})}} \tag{6}$$

This relation can be easily proven by algebraically solving for $d\sigma/dt$ and integrating over all values for t (that is, from $-\infty$ to t_{min}). Using a given value of $b = 2.9 \pm 0.3$ GeV^{-2} and the tabulated values of $d\sigma/dt$ and $t' \equiv t - t_{min}$ ([2], Table I) with this equation, we obtained σ for 11 data points. (Only $\psi(3100)$ resonances were included in our data.)

To find the total error ranges, the 15% systematic error for each result was added in quadrature to the statistical errors in each result; the assumption was made that the statistical and systematic errors were uncorrelated. The propagation of the error from $d\sigma/dt$ to σ was found by implicit differentiation of the equations

$$\sigma = \begin{cases} \frac{d\sigma/dt}{b} & \text{when } t - t_{min} = 0 \\ \frac{d\sigma/dt}{be^{b(t-t_{min})}} & \text{when } t - t_{min} \neq 0 \end{cases} \tag{7}$$

The errors $d\sigma$ were thus calculated by differentiating these equations implicitly (with respect to b and $d\sigma/dt$) and adding the terms in quadrature.

This left only the task of combining redundant data points; i.e. those representing results at the same photon energy. In particular, the source gives 5 values for $E_\gamma = 19$ GeV and 2 values for $E_\gamma = 15$ GeV. A weighted average was used for these points to obtain the one-to-one relations

$$\overline{\sigma} = \frac{\sum(\sigma_i/d\sigma_i^2)}{\sum(d\sigma_i^{-2})} \tag{8}$$

$$d\overline{\sigma} = \frac{1}{\sqrt{\sum(d\sigma_i^{-2})}} \tag{9}$$

This results in six relevant data points, which are plotted on Figure 1.

The five data points represented by squares(■) are taken from a source [3] that supplies a graph of σ vs. E_γ; however, no chart of numerical data is given for these results. Therefore, for all but one stated value ($E_\gamma = 100$ GeV), we had to resort to physically measuring along the axes of the graph to get numerical values for E_γ and σ. W was easily calculated from (3), and the error range $d\sigma$ was also measured from the graph; caution was taken such that any error in measurement would not result in a smaller error bar than that originally plotted in the source. (This assumes, of course, there is no error in the original plot of the values, an assertion that we could not check due to a lack of tabulated data.) Our measurement techniques did, however, supply the same range of accurate significant figures consistent with the one numerical value that was given in this paper ($\sigma = 14.0 \pm 3.8$ nb at 100 GeV).

The six data points represented by upright triangles(▲) are taken directly from a σ vs. W data table ([4], Table II.) that gives values for cross section normalized by two different methods, both of which present consistent values. The B.G.M. Normalization values are used in Figure 1.

The fifteen high energy data points represented by inverted triangles(▼) were also read directly from a data table ([5], Table 2). $\langle W_{\gamma p} \rangle$, representing the weighted average of the W energy bin, was used to plot the location on the horizontal axis. (In this energy region, there is no sharp increase in J/ψ cross section with energy as compared to the vertical error bars, so this assumption will have no discernable effect on the accuracy of the data.) The statistical and systematic errors have again been assumed uncorrelated and added in quadrature to produce the plotted error bars.

Similarly, the eight points represented by asterisks($*$)are likewise taken from a data table ([6], Table 1), which supplies values for W and σ. W is given in the

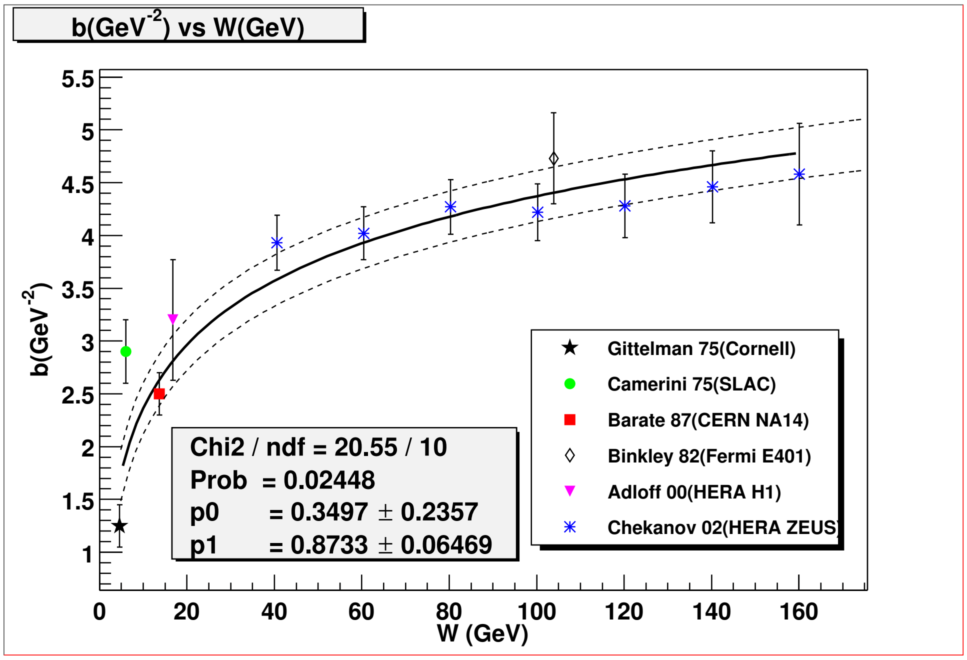

Figure 2: Slope parameter (b) vs. γ-p energy in the CM frame (W).

form of a bin. In the case of every data point, the weighted average of the bin $\langle W \rangle$ had a value that was within a fraction of 1 GeV from the median value; so it can be considered a valid assumption within our error range to assume W to be the median value of the bin. (The justification for this is basically the same as in the preceding paragraph. A more detailed explanation is given in the corresponding part of Section 5.) The error bars are generated by adding the two given errors (statistical and systematic) in quadrature, just as with the previous data set.

The remaining two data points are taken directly from other papers on J/ψ photoproduction. The lozenge($\Diamond$) data point is cited directly [7]; the cross(+) data point is taken from a data table ([8], Table II.), and the errors are again added in quadrature.

4 Curve Fitting to the Slope Parameter (b)

The dependence of the slope parameter b upon energy is determined by a simpler relation than the total cross section. The availability of data on the dependency of b on energy for J/ψ photoproduction is more limited than that on σ, but enough sources are available to generate a good curve fit. Figure 2 shows the dependency of b upon W, the γ-p energy in the CM frame.

Once again, the data was fitted with a curve of the appropriate form [9]. The b and W values have been related by the simple equation

$$b = b_0 + b_1 \ln W \tag{10}$$

When this is differentiated implicitly and added in quadrature (assuming, as usual, that b_0 and b_1 are uncorrelated) we derive the relation

$$\frac{db}{b} = \sqrt{db_0^2 + (\ln W db_1)^2} \tag{11}$$

which determines the range of error $b \pm db$ around our fit.

The parameters determined from this curve fit are $b_0 = 0.35 \pm 0.24$ GeV^{-2} and $b_1 = 0.87 \pm 0.06$ GeV^{-2}. The chi squared value from this fit is $\chi^2 = 20.6/10 = 2.1$. Note that this is not as good a fit as for the σ values; there is less data available to make this curve fit, but most of the existing data falls within the range of error of the calculated curve. The data is printed in numeric form on Table 2.

5 Interpretation of Data for b Curve Fit

This section contains a brief description of the data analyis process used to generate the data presented on Figure 2 and Table 2. Again, the reader who is only interested in the form of the curve and not the processing of the source data can skip this section.

A quick look at the data reveals that only one of the sources [6] tabulated values of b at different measured energies. For the other available sources, only one value for the parameter b is given; in these cases, we must either select the value of W for which the measurement of b is given, or the weighted values of the available energies must be found. This is done simply by integration:

$$\langle W \rangle = \frac{\int W \cdot W^{\delta} dW}{\int W^{\delta} dW} \tag{12}$$

The integration must be done over the full range of W for each energy bin.

In the case of the Chekanov '02($*$) data [6], we used the value $\delta = 0.69$ given in the conclusion of the paper. We found that the bin size was small enough that the quantity W can be considered to be at the median value of the bin. (See the corresponding description in Section 3.) Note that the lowest energy value (W=25 GeV) is not included, because no value for b is provided.

For the Adloff '00($\blacktriangledown$)[5] point, (12) was used again, integrating over the full energy range (W = 26-285 GeV), using $\delta = 0.83$, given in the paper's conclusion. The systematic and statistical errors on b were added in quadrature to get the displayed value.

The W-value of the Camerini '75($\bullet$)[2] data point was taken as $E_\gamma = 19$ GeV, as this is where the slope parameter is fit to the t distribution (see p.486 of this source for details.) The corresponding value for W was found using (3).

For the Barate '87(■)[3] point, the value of $b = b_{incoh} = 2.5 \pm 0.2$ GeV^{-2} at $E_\gamma = 100$ GeV from Table 1 was used, and the appropriate conversion to W was made.

The remaining two data points (Gittleman '75(★)[1] and Binkley '82(◊))[7] only provided one energy value, which was simply used for our W value (after appropriate conversion using Equation (3).)

The other papers cited for the σ vs. W curve fit did not provide accessible data for the value of b. Note that in all the above cases the error bars are simply taken to be the uncertainty given for b in the source data.

6 Analysis of Inelastic Photoproduction

Data for the double differential cross section $d^2\sigma/dp_t^2dz$ was collected from [15] and [14] and found in Table **??**. This cross section has W, p_t^2, and z dependence (where p_t^2 is the square of the transverse momentum and z is the fraction of the initial beam energy that the J/ψ carries: $z = E_\psi/E_\gamma$). We assumed at first that the equation for the double differential cross section was totally separable:

$$\frac{d^2\sigma}{dp_t^2dz} = f(z)g(p_t^2)h(W) \tag{13}$$

Our task was then to find a form for each of the functions and their corresponding parameters and then fit the data we had to the form $d^2\sigma/dp_t^2dz = \alpha \cdot X$ where X is calculated using the different values from the data sources of the three variables and α is the slope parameter.

6.1 Finding $h(W)$

In order to find the overall W dependence data was collected for the total cross section for inelastic photoproduction of the J/ψ. Since the majority of the data was for $z < 0.9$ we only included these total cross sections in the fit shown in Figure 3. The data is shown in Table 3. This data was fit using Eq. 1 while holding the parameters α_2 and α_3 fixed at the values found for the total cross section of the elastic data. We felt this action was justified since the inelastic world data is less comprehensive than the elastic and because the two curves should have the same shape. It made sense to use Eq. 1 for the W dependence.

6.2 Finding $g(p_t^2)$

On page 13 of [14] we found an equation for $g(p_t^2)$ that contained some z dependence in the exponent.

$$(p_t^2 + M_\psi^2)^{-n} \tag{14}$$

Where M_ψ is the mass of the J/ψ and n is some variable with z dependence. We fit a line to n vs. z using data included in the H1 paper to measure n's

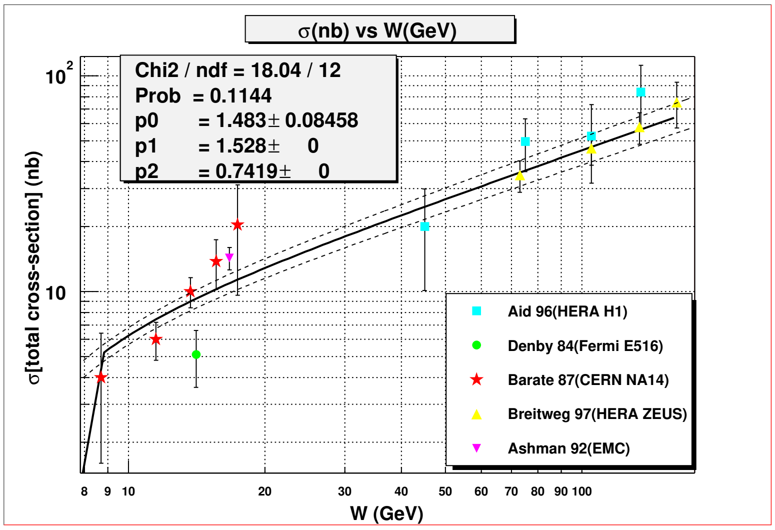

Figure 3: Observed total cross section of inelastic J/ψ production at energies ranging from near-threshold to 200 GeV.

dependence on z but this needed some adjustment for our double differential cross section fit, as will be explained later.

6.3 Finding $f(z)$

We found that the data for dσ/dz was contained in the sources only in graphs and not in tables, forcing us to resort to eyeball extrapolation of the data in Table **??** We normalized the data to the H1 value for $z \approx 0.7$ and fit to an equation of the form:

$$\alpha_6(1 + \alpha_4 e^{\alpha_5 z}) \tag{15}$$

The fit in Figure 4 may not represent what happens for high z values, but it was assumed adequate for our purposes.

6.4 Putting it all together (with some necessary refinements)

We now have a semi-separable model for the double differential cross section data shown in Eq. 16 with all of the parameters except for an overall multiplicative factor which was to be found by fitting the calculated number X to the values for the double differential cross sections.

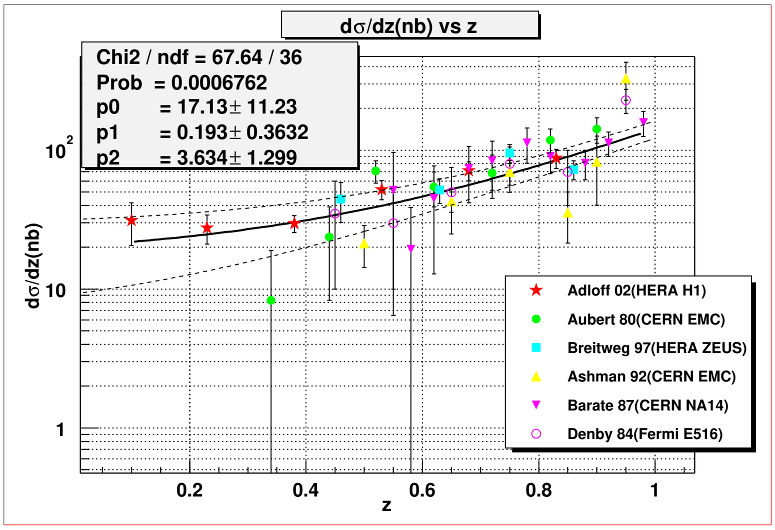

Figure 4: Data for dσ/dz from [14], [18], [16], [15], [3], [8] normalized to the H1 value for $z \approx 0.7$

$$\frac{d^2\sigma}{dp_t^2 dz} = \alpha_6 \frac{(1 - \frac{W_{th}^2}{W^2})^{\alpha_2} W^{\alpha_3}}{(p_t^2 + \frac{M_\psi^2}{\gamma})^{\alpha_0 + \alpha_1 z}} (1 + \alpha_4 e^{\alpha_5 z}) \tag{16}$$

By using the values in Table **??** we can calculate X (where X is everything in Eq 16 except for α_6). This is accomplished using the program ~nbaillie/xcalc.cc. The first fit used the parameter values α_0 = 3.823, α_1 = 1.132, α_2 = 1.528, α_3 = 0.7419, α_4 = 0.193, α_5 = 3.632, M_ψ = 3.09687, γ = 1, and W_{th} = 4.03. This fit produced the plot found in Figure 5

It was clear that the EMC data (low values of p_t^2) needed to be scaled up to fall in line with the H1 data. The first model that we used did not rise rapidly enough for low p_t^2. This can be rectified by dividing the value M_ψ by some factor. We tried values for this factor $1 \leq \gamma \leq 10$ and found that the best line was formed by a factor $\gamma = 2.5$ (see Figure 6)

The possibility that the mass parameter also contained some z dependence was also considered. When a (1-z) term was multiplied by the mass and raised to a fixed exponent of 4 (the approximate value from the H1 data) the shape of the exponential p_t^2 fit could be manipulated, however the X value is so sensitive to the exponential z dependence that the magnitude could not be adequately adjusted using a fixed value for the exponent. Thus we went back to the fits of p_t^2 (using Tables 8 and 10 in [14] and Table 2 in [15]) and found the parameters to be used in the X calculation by finding the relation between n and z (see Figure 7) Now, using the recalculated parameters α_0 and α_1 we calculated X with different values of $2.5 \leq \gamma \leq 5$. The values for X when $\gamma = 5$ provided a reasonable distribution of the EMC data and fit to a linear dependence. By then

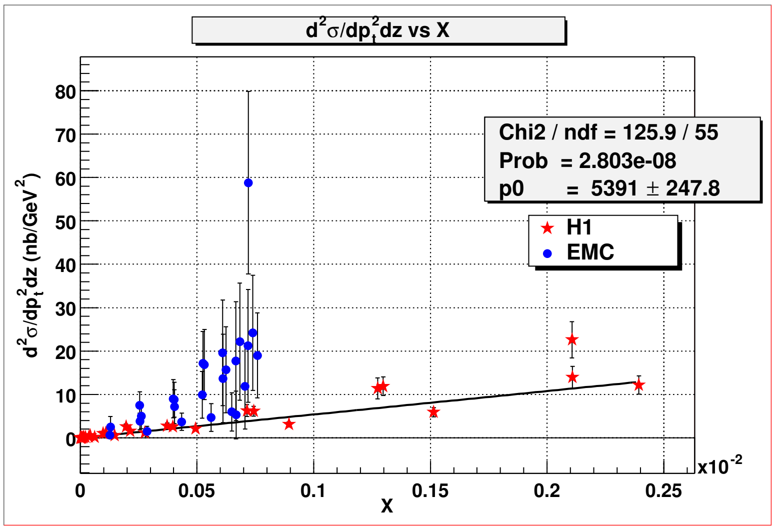

Figure 5: The calculated X values for the EMC data are out of line with the H1 data - leading us to believe that the factor M_ψ is too large for such low values of p_t^2

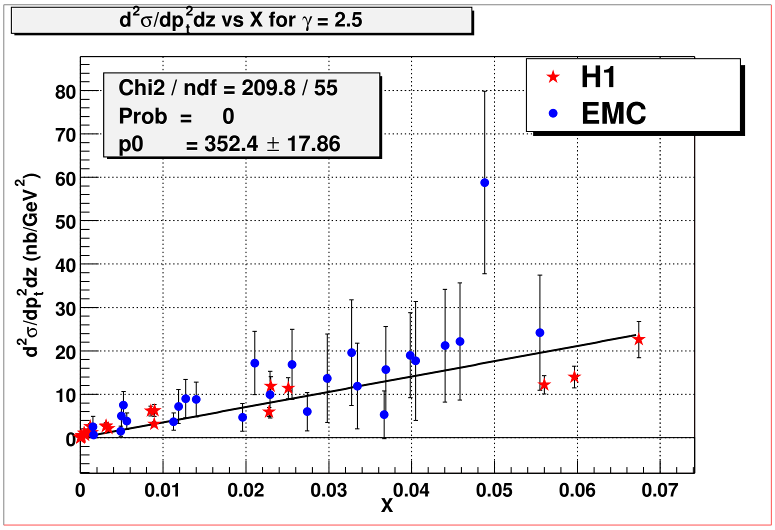

Figure 6: The mass value is scaled down by a factor of 2.5 and the fit is redone

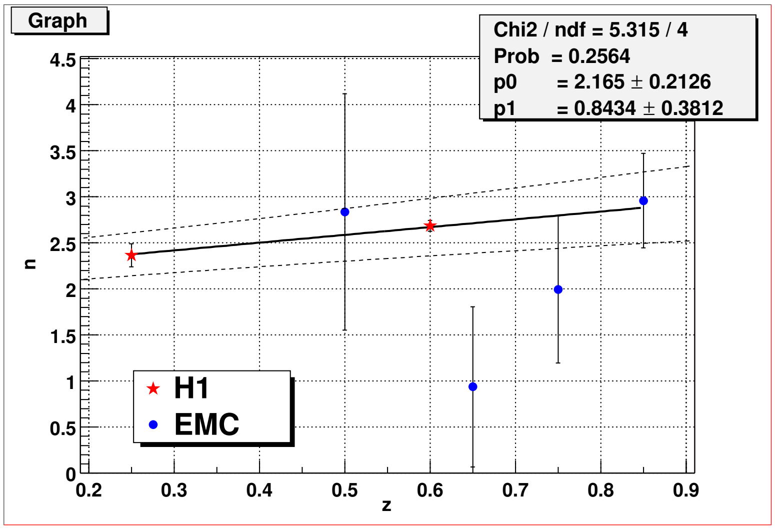

Figure 7: The exponential of the p_t^2 dependence is plotted over the range of z and fit to a line

finding the parameters α_0 and α_1 (again with the same technique as before only with $\gamma = 5$) and using them in conjunction with $\gamma = 5$ in Eq. 16 we obtained the values of X shown in Figure 8.

This tentative model for the dependence of $d^2\sigma/dp_t^2dz$ using the values previously noted can now give a relatively accurate prediction for the double differential cross section when the CM-beam energy, the transverse momentum squared and the ratio of J/ψ energy to beam energy are given. It would be interesting to do our fit using previously overlooked data from [19]. Furthermore to be able to fit a function of 2 or more independent variables in ROOT would be a powerful way of obtaining the parameter values and a helpful comparison to the brute force way in which this calculation was performed.

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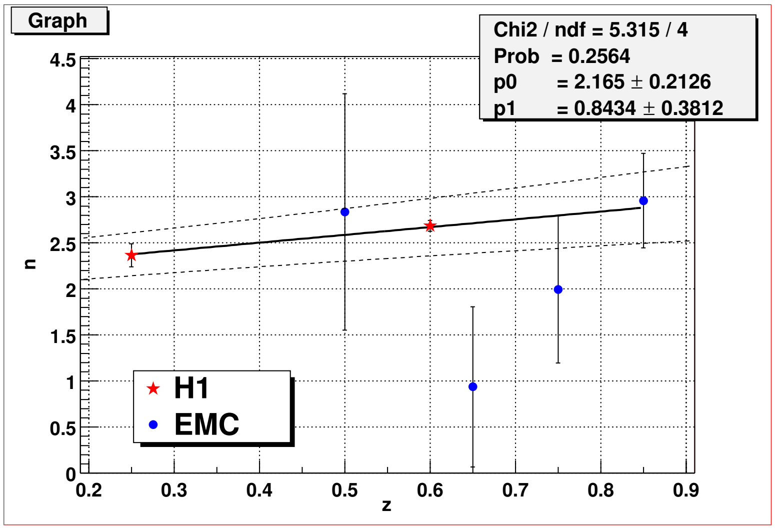

Figure 8: The distribution for $\gamma = 5$, $\alpha_0 = 2.165$ and $\alpha_1 = 0.8434$. Note the χ^2/degrees of freedom is lower because of the recalculated exponential parameters

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A Appendix: Root Programs

For the convenience of the reader, the root code used to print the included graphs is printed here. The first program is used for the σ fit, the second for the b fit.

The program for the σ fit:

```
{

//Following example on page 64 of user's guide

gROOT->Reset();

Int_t n = 43;

//create the coordinate arrays
Float_t x[n] = {4.6,5.0,5.4,5.6,5.7,6.0,6.3,8.7,11.5,13.7,15.6,17.4,15.1,18.2,
20.5,22.6,24.7,26.5,31.0,46.2,56.1,64.0,72.5,81.5,92.0,105.2,133.4,147.3,172.2
,197.1,222.4,247.4,272.4,25,40,60,80,100,120,140,160,16.8,14.1};
Float_t y[n] = {.48,1.3,2.2,2.8,3.7,4.3,5.0,11.1,11.6,14.0,16.6,22.2,9.8,17.9,
14.8,17.0,27.8,23.0,19.8,29.8,41.7,49.5,51.8,62.4,67.6,64.6,89.0,80.6,104.0,11
3.6,116.0,118.9,156.9,32.6,41.5,55.8,66.6,73.4,86.7,104,110,18,14.2};

//create the error arrays
Float_t ex[n] = {};
Float_t ey[n] = {.22,0.37,0.41,0.62,0.76,0.44,1.0,2.5,1.7,1.6,2.8,8.7,2.9,4,3.
6,4.2,7.5,11.8,6.3,5,7.1,8.7,9.1,11.1,11.7,12.1,18.3,15,18.2,21.7,23.7,24.6,32
.2,7.5,3.5,4.8,7.3,6.4,7.2,12.1,16.3,2,4.1};

//create the TGraphErrors and draw it
TGraphErrors *gr = new TGraphErrors(n,x,y,ex,ey);
TCanvas *c1 = new TCanvas ("c1","J/Psi Cross-Sections at Various Energies");
c1->SetFillColor(10);
//c1->SetGrid();
c1->GetFrame()->SetFillColor(24);
c1->GetFrame()->SetBorderSize(12);
gPad->SetLogx(1);
gPad->SetLogy(1);
gr->SetMarkerStyle(15);
gr->SetMarkerColor(0);
gr->SetMarkerSize(1);
gr->Draw("AP");



for (Int_t j=0;j<1;j++) {
```

```
  TMarker *m = new TMarker(c1->XtoPad(x[j]),c1->YtoPad(y[j]),22);
  m->SetMarkerSize(1.6);
  m->SetMarkerStyle(29);
  m->SetMarkerColor(1);
  m->Draw();
}
for (Int_t j=1;j<7;j++) {
  TMarker *o = new TMarker(c1->XtoPad(x[j]),c1->YtoPad(y[j]),22);
  o->SetMarkerSize(1);
  o->SetMarkerStyle(20);
  o->SetMarkerColor(3);
  o->Draw();
}
for (Int_t j=7;j<12;j++) {
  TMarker *p = new TMarker(c1->XtoPad(x[j]),c1->YtoPad(y[j]),22);
  p->SetMarkerSize(1);
  p->SetMarkerStyle(21);
  p->SetMarkerColor(2);
  p->Draw();
}
for (Int_t j=12;j<18;j++) {
  TMarker *q = new TMarker(c1->XtoPad(x[j]),c1->YtoPad(y[j]),22);
  q->SetMarkerSize(1.2);
  q->SetMarkerStyle(22);
  q->SetMarkerColor(24);
  q->Draw();
}
for (Int_t j=18;j<33;j++) {
  TMarker *r = new TMarker(c1->XtoPad(x[j]),c1->YtoPad(y[j]),22);
  r->SetMarkerSize(1);
  r->SetMarkerStyle(23);
  r->SetMarkerColor(6);
  r->Draw();
}
for (Int_t j=33;j<41;j++) {
  TMarker *s = new TMarker(c1->XtoPad(x[j]),c1->YtoPad(y[j]),22);
  s->SetMarkerSize(1);
  s->SetMarkerStyle(3);
  s->SetMarkerColor(4);
  s->Draw();
}

for (Int_t j=41;j<42;j++) {
  TMarker *t = new TMarker(c1->XtoPad(x[j]),c1->YtoPad(y[j]),22);
  t->SetMarkerSize(1.2);
  t->SetMarkerStyle(27);
```

```
  t->SetMarkerColor(1);
  t->Draw();
}

for (Int_t j=42;j<43;j++) {
  TMarker *u = new TMarker(c1->XtoPad(x[j]),c1->YtoPad(y[j]),22);
  u->SetMarkerSize(1.1);
  u->SetMarkerStyle(28);
  u->SetMarkerColor(1);
  u->Draw();
}

gr->SetTitle("#sigma vs. W for J/#psi Photoproduction");
gr->GetXaxis()->SetLabelSize(Float_t size=0.025);
gr->GetXaxis()->SetLabelOffset(Float_t offset=0.002);
gr->GetXaxis()->SetTitleOffset(Float_t offset=1.15);
gr->GetXaxis()->SetTitle("W (GeV)");
gr->GetYaxis()->SetTitle("#sigma[total cross-section] (nb)");
gr->GetXaxis()->CenterTitle();
gr->GetYaxis()->CenterTitle();
//gr->Draw("AP");

TF1 *f1 = new TF1("f1","[0]*(1-(16.24/(x^(2))))^([1])*x^[2]",4,250);
f1->SetParameters(30,2,1);
gStyle->SetOptStat();
gStyle->SetOptFit(0);
gr->Fit("f1");
TF1 *fit = gr->GetFunction("f1");
Double_t p0 = fit->GetParameter(0);
Double_t e0 = fit->GetParError(0);
Double_t p1 = fit->GetParameter(1);
Double_t e1 = fit->GetParError(1);
Double_t p2 = fit->GetParameter(2);
Double_t e2 = fit->GetParError(2);

TF1 *f2 = new TF1("f2","[0]*(1-(16.24/x^2))^[1]*x^[2]-sqrt([3]^2+([4]/(1-(16.2
4/x^2)))^2+([5]/x)^2)*[0]*(1-(16.24/x^2))^[1]*x^[2]",4,250);

f2->SetParameters(p0,p1,p2,e0/p0,p1*e1,p2*e2);
f2->Draw("SAME");
//f2->SetLineColor(50);
f2->SetLineStyle(2);
f2->SetLineWidth(1);
TF1 *f3 = new TF1("f3","[0]*(1-(16.24/x^2))^[1]*x^[2]+sqrt([3]^2+([4]/(1-(16.2
4/x^2)))^2+([5]/x)^2)*[0]*(1-(16.24/x^2))^[1]*x^[2]",4,250);
```

```
f3->SetParameters(p0,p1,p2,e0/p0,p1*e1,p2*e2);
f3->Draw("SAME");
//f3->SetLineColor(50);
f3->SetLineStyle(2);
f3->SetLineWidth(1);
c1->Update();
gStyle->SetOptFit(1111);

leg = new TLegend(.55,0.17,.87,0.5);
leg->SetFillColor(10);
leg->AddEntry(m,"Gittelman 75(Cornell)","p");
leg->AddEntry(o,"Camerini 75(SLAC)","p");
leg->AddEntry(p,"Barate 87(CERN NA14)","p");
leg->AddEntry(q,"Frabetti 93(FNAL E687)","p");
leg->AddEntry(r,"Adloff 00(HERA H1)","p");
leg->AddEntry(s,"Chekanov 02(HERA ZEUS)","p");
leg->AddEntry(t,"Binkley 82(Fermi E401)","p");
leg->AddEntry(u,"Denby 84(Fermi E516)","p");
leg->Draw();

}//end sigmaVSw.C
```

The program for the b fit:

```
{

//Following example on page 64 of user's guide

gROOT->Reset();

Int_t n = 12;

//create the coordinate arrays
Float_t x[n] = {4.6,6.0,13.7,103.9,40.6,60.4,
  80.3,100.2,120.2,140.2,160.1,16.8};
Float_t y[n] = {1.25,2.9,2.5,4.73,3.93,4.02,
  4.27,4.22,4.28,4.46,4.58,3.2};
```

```
//create the error arrays
Float_t ex[n] = {};
Float_t ey[n] = {.2,.3,.2,.43,.26,.25,.26,.27,.30,.34,.48,.57};

//create the TGraphErrors and draw it
TGraphErrors *gr = new TGraphErrors(n,x,y,ex,ey);
TCanvas *c2 = new TCanvas ("c2","b(GeV-2) vs W(GeV)");
c2->SetFillColor(0);
//c2->SetGrid();
c2->GetFrame()->SetFillColor(24);
c2->GetFrame()->SetBorderSize(12);
//gPad->SetLogx(1);
//gPad->SetLogy(1);
gr->SetMarkerStyle(15);
gr->SetMarkerColor(0);
gr->SetMarkerSize(1);
gr->Draw("AP");

for (Int_t j=0;j<1;j++) {
  TMarker *m = new TMarker(c2->XtoPad(x[j]),c2->YtoPad(y[j]),22);
  m->SetMarkerSize(1.6);
  m->SetMarkerStyle(29);
  m->SetMarkerColor(1);
  m->Draw();
}
for (Int_t j=1;j<2;j++) {
  TMarker *o = new TMarker(c2->XtoPad(x[j]),c2->YtoPad(y[j]),22);
  o->SetMarkerSize(1);
  o->SetMarkerStyle(20);
  o->SetMarkerColor(3);
  o->Draw();
}
for (Int_t j=2;j<3;j++) {
  TMarker *p = new TMarker(c2->XtoPad(x[j]),c2->YtoPad(y[j]),22);
  p->SetMarkerSize(1);
  p->SetMarkerStyle(21);
  p->SetMarkerColor(2);
  p->Draw();
}
for (Int_t j=3;j<4;j++) {
  TMarker *q = new TMarker(c2->XtoPad(x[j]),c2->YtoPad(y[j]),22);
  q->SetMarkerSize(1.2);
  q->SetMarkerStyle(27);
  q->SetMarkerColor(1);
  q->Draw();
```

```
}
for (Int_t j=4;j<11;j++) {
  TMarker *s = new TMarker(c2->XtoPad(x[j]),c2->YtoPad(y[j]),22);
  s->SetMarkerSize(1);
  s->SetMarkerStyle(3);
  s->SetMarkerColor(4);
  s->Draw();
}
for (Int_t j=11;j<12;j++) {
  TMarker *r = new TMarker(c2->XtoPad(x[j]),c2->YtoPad(y[j]),22);
  r->SetMarkerSize(1);
  r->SetMarkerStyle(23);
  r->SetMarkerColor(6);
  r->Draw();
}

gr->SetTitle("b(GeV^{-2}) vs W(GeV)");

gr->GetXaxis()->SetTitle("W (GeV)");
gr->GetYaxis()->SetTitle("b(GeV^{-2})");
gr->GetXaxis()->CenterTitle();
gr->GetYaxis()->CenterTitle();
gr->GetXaxis()->SetLabelSize(Float_t size=0.025);
gr->GetXaxis()->SetLabelOffset(Float_t offset=0.002);
gr->GetXaxis()->SetTitleOffset(Float_t offset=1.15);
//gr->Draw("AP");

TF1 *f1 = new TF1("f1","[0]+[1]*log(x)",4,200);
f1->SetParameters(30,2);
gStyle->SetOptStat();
gStyle->SetOptFit(1111);
gr->Fit("f1");
TF1 *fit = gr->GetFunction("f1");
Double_t p0 = fit->GetParameter(0);
Double_t e0 = fit->GetParError(0);
Double_t p1 = fit->GetParameter(1);
Double_t e1 = fit->GetParError(1);

TF1 *f2 = new TF1("f2","[0]+[1]*log(x)+sqrt([2]^2+[3]^2)",4,200);

f2->SetParameters(p0,p1,e0,p1*e1);
f2->Draw("SAME");
//f2->SetLineColor(50);
f2->SetLineStyle(2);
f2->SetLineWidth(1);
TF1 *f3 = new TF1("f3","[0]+[1]*log(x)-sqrt([2]^2+[3]^2)",4,200);
```

```
f3->SetParameters(p0,p1,e0,p1*e1);
f3->Draw("SAME");
//f3->SetLineColor(50);
f3->SetLineStyle(2);
f3->SetLineWidth(1);
c2->Update();

leg = new TLegend(.55,0.17,.87,0.5);
leg->SetFillColor(10);
leg->AddEntry(m,"Gittelman 75(Cornell)","p");
leg->AddEntry(o,"Camerini 75(SLAC)","p");
leg->AddEntry(p,"Barate 87(CERN NA14)","p");
leg->AddEntry(q,"Binkley 82(Fermi E401)","p");
leg->AddEntry(r,"Adloff 00(HERA H1)","p");
leg->AddEntry(s,"Chekanov 02(HERA ZEUS)","p");
leg->Draw();



}//end sigmaVSw.C
```

Symbol	E_γ (GeV)	W (GeV)	σ (nb)
★	11.0	4.6	0.48±0.22
•	13	5.0	1.3±0.37
•	15	5.4	2.2±0.41
•	16	5.6	2.8±0.62
•	17	5.7	3.7±0.76
•	19	6.0	4.3±0.44
•	21	6.3	5.0±1.0
■	40	8.7	11.1±3.8
■	70	11.5	11.6±3.4
■	100	13.7	14.0±3.8
■	130	15.6	16.6±5.0
■	160	17.4	22.2±10.3
▲	121	15.1	9.8±2.9
▲	177	18.2	17.9±4.0
▲	223	20.5	14.8±3.6
▲	272	22.6	17.0±4.2
▲	324	24.7	27.8±7.5
▲	374	26.5	23.0±11.8
▼	512	31.0	19.8±6.3
▼	1138	46.2	29.8±5.0
▼	1678	56.1	41.7±7.1
▼	2183	64.0	49.5±8.7
▼	2802	72.5	51.8±9.1
▼	3541	81.5	62.4±11.1
▼	4512	92.0	67.6±11.7
▼	5899	105.2	64.6±12.1
▼	9486	133.4	89.0±18.3
▼	11566	147.3	80.6±15.0
▼	15806	172.2	104.0±18.2
▼	20708	197.1	113.6±21.7
▼	26365	222.4	116.0±23.7
▼	32626	247.4	118.9±24.6
▼	39553	272.4	156.9±32.2
∗	333	25	32.6±7.5
∗	852	40	41.5±3.5
∗	1920	60	55.8±4.8
∗	3410	80	66.6±7.3
∗	5330	100	73.4±6.4
∗	7680	120	86.7±7.2
∗	10480	140	104±12.1
∗	13650	160	110±16.3
◊	150	16.8	18±2
+	105	14.1	14.2±4.1

Table 1: Numeric data for W (CM frame energy) and σ (total cross section) for J/ψ photoproduction. (These values are plotted on Figure 1 with the corresponding data symbols). Also included is E_γ (incident photon energy).

Symbol	E_γ (GeV)	W (GeV)	b (GeV^{-2})
★	11.0	4.6	1.25 ± 0.20
•	18.7	6.0	2.9 ± 0.3
■	99.6	13.7	2.5 ± 0.2
▼	5754	103.9	4.73 ± 0.43
$*$	852	40	3.93 ± 0.26
$*$	1920	60	4.02 ± 0.25
$*$	3410	80	4.27 ± 0.26
$*$	5330	100	4.22 ± 0.27
$*$	7680	120	4.28 ± 0.30
$*$	10480	140	4.46 ± 0.34
$*$	13650	160	4.58 ± 0.48
$\lozenge$	150	16.8	3.2 ± 0.57

Table 2: Numeric data for W (CM frame energy) and b (slope parameter) for J/ψ photoproduction. (These values are plotted on Figure 2 with the corresponding data symbols). E_γ (incident photon energy) is also included.

Symbol	E_γ (GeV)	W (GeV)	σ (nb)
★	11.0	4.6	0.48±0.22
★	11.0	4.6	0.48±0.22
★	11.0	4.6	0.48±0.22
★	11.0	4.6	0.48±0.22
★	11.0	4.6	0.48±0.22
•	13	5.0	1.3±0.37
■	4	8.7	11.1±3.8
■	70	11.5	11.6±3.4
■	100	13.7	14.0±3.8
■	130	15.6	16.6±5.0
▲	121	15.1	9.8±2.9
▲	177	18.2	17.9±4.0
▲	223	20.5	14.8±3.6
▲	272	22.6	17.0±4.2
▼	512	31.0	19.8±6.3

Table 3: Numeric data for W (CM frame energy) and σ (total cross section) for J/ψ inelastic photoproduction. (These values are plotted on Figure 3 with the corresponding data symbols). Also included is E_γ (incident photon energy).