ρ photoproduction at H1

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Abstract

The ρ decay is examined. For modeling the mass spectrum of the decay products the so called Kühn-Santamaria parametrization is employed following a recent ZEUS publication. Approximate values for the masses and width of the ρ-meson and two higher resonances, ρ' and ρ'', are obtained.

Contents

1 Introduction

In this work the decay of the ρ *meson* and its excited states is investigated. A *meson* is a particle that can be described in the framework of the *standard model* as composed of a *quark-antiquark pair*. Quarks are the fundamental particles, which constitute all *hadrons* (mesons and baryons, like protons and neutrons).
The experimental data for this analysis have been obtained with the H1 detector. H1 was one of the two multipurpose experiments at the *ep*-collider HERA (Hadron Elektron Ring Anlage). At this accelerator ring protons and electrons or positrons were accelerated and brought to a head on collision at a center of mass energy of $\sqrt{s} \approx 320\text{GeV}$ [1].
The analysis is modeled as in the recent paper of the ZEUS collaboration [4]. In this publication the Kühn-Santamaria (KS) parametrization is employed for the description of the ρ mass peak.

2 Theory

At high energies interactions between the electrons and protons occur, that are mediated by the fundamental forces, the electromagnetic-, weak- and strong force. Electrons are not subject to the strong force, but in the *ep* reactions new particles can be formed that can be directly or indirectly measured by the detector.

2.1 Scattering and Photoproduction

In the collisions of the beams scattering takes place. In the case of *ep* scattering the bulk of the interactions are called *neutral current* (NC) processes, because no charge is exchanged. These processes are mediated by a photon γ, or a Z boson. The Z exchange in this case is supressed due to the large Z mass[1]. In elastic scattering the same particles go in and come out of the collision: $A + B \to A' + B'$. The proton may dissociate or form an excited state. This is called a dissociative process. A large number of the events recorded in the collisions can be regarded as photon-proton interactions [2]. One type of these processes is the elastic photoproduction of vector mesons:

$$\gamma^* p \to Vp \qquad \textbf{with} \quad V = \rho, \omega, \phi, ... \tag{1}$$

The Feynman diagram for the photoproduction of the ρ meson in ep scattering is shown in Figure 1.
Because of energy-momentum conservation one can calculate the four momentum q of the exchanged particle as the difference of the four momenta of the electron coming in and and going out. For conventional reasons we define Q^2 as

$$Q^2 = -q^2 = -(k - k')^2 \quad . \tag{2}$$

[1]the factor of supression goes $\sim Q^2/(Q^2 + M_Z^2)$, Q^2 is defined in Eq. 2

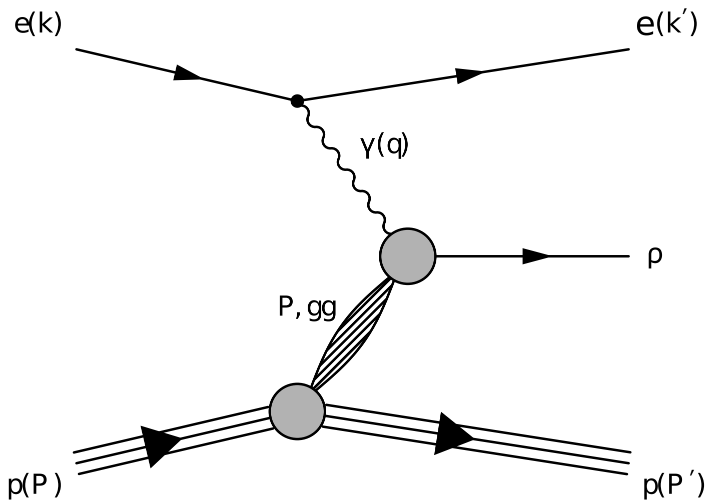

Figure 1: Feynman diagram of ρ photoproduction.

This quantity can be measured by capturing the scattered electron with a detector. When Q^2 is very low the electron is deflected too little and escapes detection, one speaks of a "quasi real" photon. When using this as a selection condition for the events taken into account, one can assume photoproduction.
The other important kinematical variables in the reaction are

$$|t| = (p - p')^2 \tag{3}$$

$$\textbf{and} \quad W_{\gamma p}^2 = (q + p)^2 \quad , \tag{4}$$

where t is the transfered four momentum at the proton vertex and $W_{\gamma p}^2$ is squared the center of mass energy of the γp system.
The so called *vector meson dominance model* (VDM) takes into account that the photon can fluctuate into pairs of quark and antiquark and temporary form mesons with the same quantum numbers as the photon. It describes the photon as a superposition of a QED photon and a hadronic part

$$|\gamma >= N|\gamma_{QED} > + \sum_h \frac{e}{\gamma_h}|h > \quad . \tag{5}$$

Since the strong force is much stronger than the electromagnetic force, the interaction of the photon with the proton is regarded as that of a vector meson with the proton mediated by a so called *pomeron* or a *gluon ladder*. This is described by *Regge-theory* [3].

2.2 The ρ decay

The lifetime of the ρ itself is too short to leave a track in the detector that can be used for measurement. Instead the decay products are used to identify and reconstruct the meson. The ρ mainly decays into two pions with a branching fraction of $\sim 100\%$. The energy and momentum of the pions can be measured from the tracks and calorimeter readout of the detector.

The mass and width of the decay are extracted from the invariant mass spectrum $M_{\pi\pi}$ of the system of the two decay pions. The invariant mass distribution of a particle generally follows the *Breit-Wigner* distribution. For the two pion system this is given as (e.g. [5])

$$\sigma(m_{\pi\pi}) = \sigma_{\mathbf{max}} \frac{\Gamma^2/4}{(m_{\pi\pi} - m_R)^2 + \Gamma^2/4} \quad . \tag{6}$$

Here $m_{\pi\pi}$ is the invariant mass of the two pion system, m_R mass of the resonance (i.e. the decaying particle), and Γ the width.

Often in particle physics a *relativistic Breit-Wigner* is used [5]:

$$\sigma(m_{\pi\pi}) = \sigma_{\mathbf{max}} \frac{M_0^2 \Gamma^2}{(m_{\pi\pi}^2 - M_0^2)^2 + \Gamma^2 M_0^2} \tag{7}$$

With M_0 being the mass of the particle.

Following [4], when examining reactions of the form $\gamma^* p \to \pi\pi p$ the invariant two pion mass spectrum can be related to the so called *electromagnetic form factor* of the pion $F_\pi(M_{\pi\pi})$.

$$\frac{dN(M_{\pi\pi})}{dM_{\pi\pi}} \propto |F_\pi(M_{\pi\pi})|^2 \tag{8}$$

The KS parametrization of the form factor in the range of the ρ resonance includes contributions from $\rho'(1450)$ and $\rho''(1700)$ as well.

$$F_\pi(M_{\pi\pi}) = \frac{BW_\rho(M_{\pi\pi}) + \beta BW_{\rho'}(M_{\pi\pi}) + \gamma BW_{\rho''}(M_{\pi\pi})}{1 + \beta + \gamma} \tag{9}$$

Where BW_V is a Breit-Wigner amplitude of a meson V the form

$$BW_V = \frac{M_V^2 \Gamma^2}{M_V^2 - M_{\pi\pi}^2 - i M_V \Gamma(M_{\pi\pi})} \quad . \tag{10}$$

Additionally the width $\Gamma_V(M_{\pi\pi})$ is taken to be momentum dependent and of the form

$$\Gamma_V(M_{\pi\pi}) = \Gamma_V \left(\sqrt{\frac{M_{\pi\pi}^2 - 4M_\pi^2}{M_V^2 - 4M_\pi^2}} \right)^3 \left(\frac{M_V}{M_{\pi\pi}} \right)^2 \quad . \tag{11}$$

3 Measurement

3.1 Data

The data used were taken at the H1 experiment from 2005 to 2007.

3.2 Selection

The data selection is carried out in two steps. An online trigger is used for live selection during the actual running of the experiment. For the offline analysis so called *cuts* are defined. These allow to exclude events with parameters outside the regions of interest after reconstruction.
Events where selected by application of the following conditions:

online selection

1. *Fast Track Trigger* (FTT) reconstructs 2 particle tracks (the pions)

offline selection

2. No scattered beam electron.
   As discussed, this is a signature of photoproduction.
3. 2 central tracks within the region $20 < \theta < 160$.
   θ is the polar angle.
4. Rapidity gap $|\eta| > 1$.
   This is the signature of a diffractive process.

The two pion invariant mass spectrum in the ρ resonance region after the event selection is shown in Figure 2.

3.3 The $\pi\pi$ mass fit

The mass distribution is fitted with the function from [4]:

$$\frac{dN(M_{\pi\pi})}{dM_{\pi\pi}} = A\left(1 - \frac{4M_\pi^2}{M_{\pi\pi}^2}\right)\left[|F_\pi(M_{\pi\pi})|^2 + B\left(\frac{M_0}{M_{\pi\pi}}\right)^n\right] \tag{12}$$

Figure 3 shows the fit function with all the parameters from the ZEUS electroproduction paper mass spectrum scaled to the H1 data. The features of the higher ρ resonances are more prominent in the ZEUS data and the background seems to be higher at least for the high end of the mass region.
When fitting the H1 data with the fit function as defined in eq. 12, the mass of the ρ' has to be fixed to give sensible values. The fit is shown in Figure 4. It describes the data qualitatively acceptable in the fit region but not very well ($\chi^2/ndf = 679/36$). Further restricting the fit region does not yield improvements. The contribution factors β and γ of the resonances are much bigger than in the ZEUS fit.

Table 1: Fit parameters and PDG and ZEUS values for comparison

fit range [GeV]	PDG	ZEUS	$0.7 < M < 3.0$	$0.7 < M < 2.0$	$0.7 < M < 2.0$
t cut [GeV^2]	-	$\|t\| \leq 0.6$	-	$\|t\| \geq 0.25$	$\|t\| \geq 0.25$
χ^2/ndf		28.8/24	679/36	26.23/15	124.6/16
m_ρ[MeV]	775.49 ± 0.34	771 ± 2	777 ± 0	770 ± 0	764 ± 0
Γ_ρ[MeV]	149.4 ± 1.0	155 ± 5	151 ± 1	153 ± 2	158 ± 2
β		-0.27 ± 0.02	-0.507 ± 0.010	-0.481 ± 0.013	-0.545 ± 0.016
$m_{\rho'}$[MeV]	1465 ± 25	1350 ± 20	ZEUS fix	1320 ± 9	1280 ± 5
$\Gamma_{\rho'}$[MeV]	400 ± 40	460 ± 30	467 ± 10	525 ± 17	479 ± 17
γ		0.10 ± 0.02	0.367 ± 0.005	0.165 ± 0.014	0.254 ± 0.003
$m_{\rho''}$[MeV]	1720 ± 20	1780 ± 20	1569 ± 4	1680 ± 5	1705 ± 8
$\Gamma_{\rho''}$[MeV]	250 ± 100	310 ± 30	450 *limit*	291 ± 25	450 *limit*
A			9261 ± 170	1480 ± 70	1740 ± 95
B		0.41 ± 0.03	0.120 ± 0.024	0.859 ± 0.226	no bckgrnd fix
n		1.30 ± 0.06	2.51 ± 0.21	1.49 ± 0.28	no bckgrnd fix
Figure			fig. 4	fig. 5	fig. 6

Interestingly introducing a $|t|$ cut enables the fit to obtain better probabilities. Figure 5 shows the fit with the new cut.
The background does not seem to describe the data well outside of the fitted region (intersects with the data at little higher masses). So one could try the fit without the background. Figure 6 shows the result. It is slightly worse than the one with background fit. In both cases changing the fit region does not yield much improvement.
Table 1 shows the results of the explained fits and the PDG [6] and ZEUS values next to it.

4 Conclusion

The method in the ZEUS paper [4] employing the KS parametrization for the F_π form factor has been used to try to describe the ρ resonance in photoproduction. The masses and width can be obtained in ranges close to the PDG values. But upon inspection there are difficulties with the description of the background and other parameters. For example do the results get much worse when expanding the fit range to slightly lower masses.

In the [2] and [3] other functions are used to describe the ρ peak without the higher resonances. Here skewing due to the pion background is taken into account. It would be the next step to incorporate this type of background description in the fit.

References

[1] H1 and ZEUS Collaborations, *"Combined Measurement and QCD Analysis of the Inclusive $e^{\pm}p$ Scattering Cross Sections at HERA"*, DESY 09-158 (October 2009)

[2] Ronald M. Weber, *"Diffractive ρ^0 photoproduction at HERA"*, Diss. ETH No. 16709 (June 2006)

[3] Niklaus E. Berger, *"Measurement of Diffractive ϕ Meson Photoproduction at HERA with the H1 Fast Track Trigger"*, Diss. ETH No. 17169 (2007)

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[5] Donald H. Perkins, *"Introduction to High Energy Physics"*, Cambridge University Press (2000)

[6] J. Beringer et al. (Particle Data Group), Phys. Rev. D86, 010001 (2012)

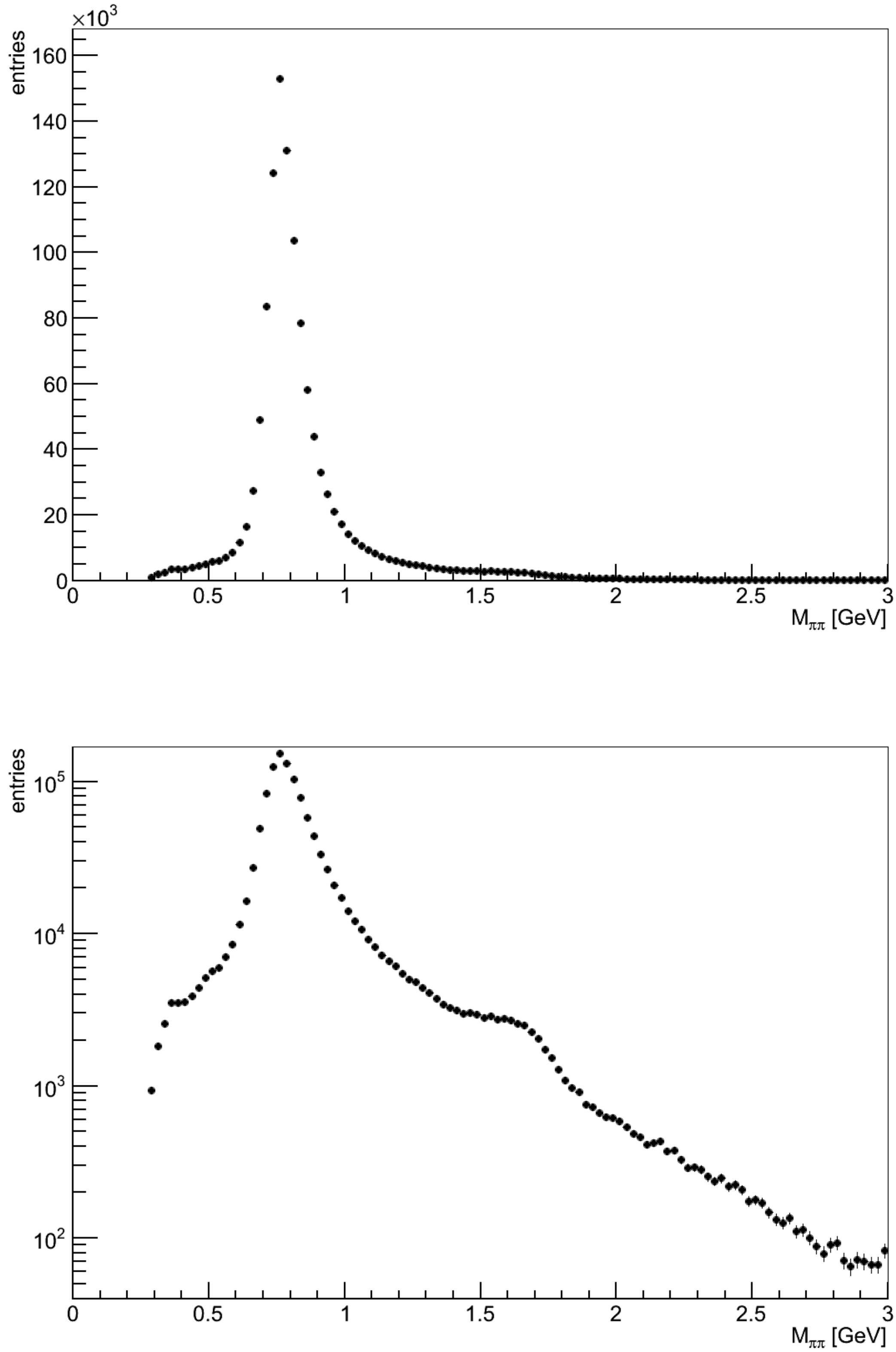

Figure 2: $M_{\pi\pi}$ invariant mass spectrum of the rho peak region after event selection in linear and logarithmic scale with a bin width of 25MeV.

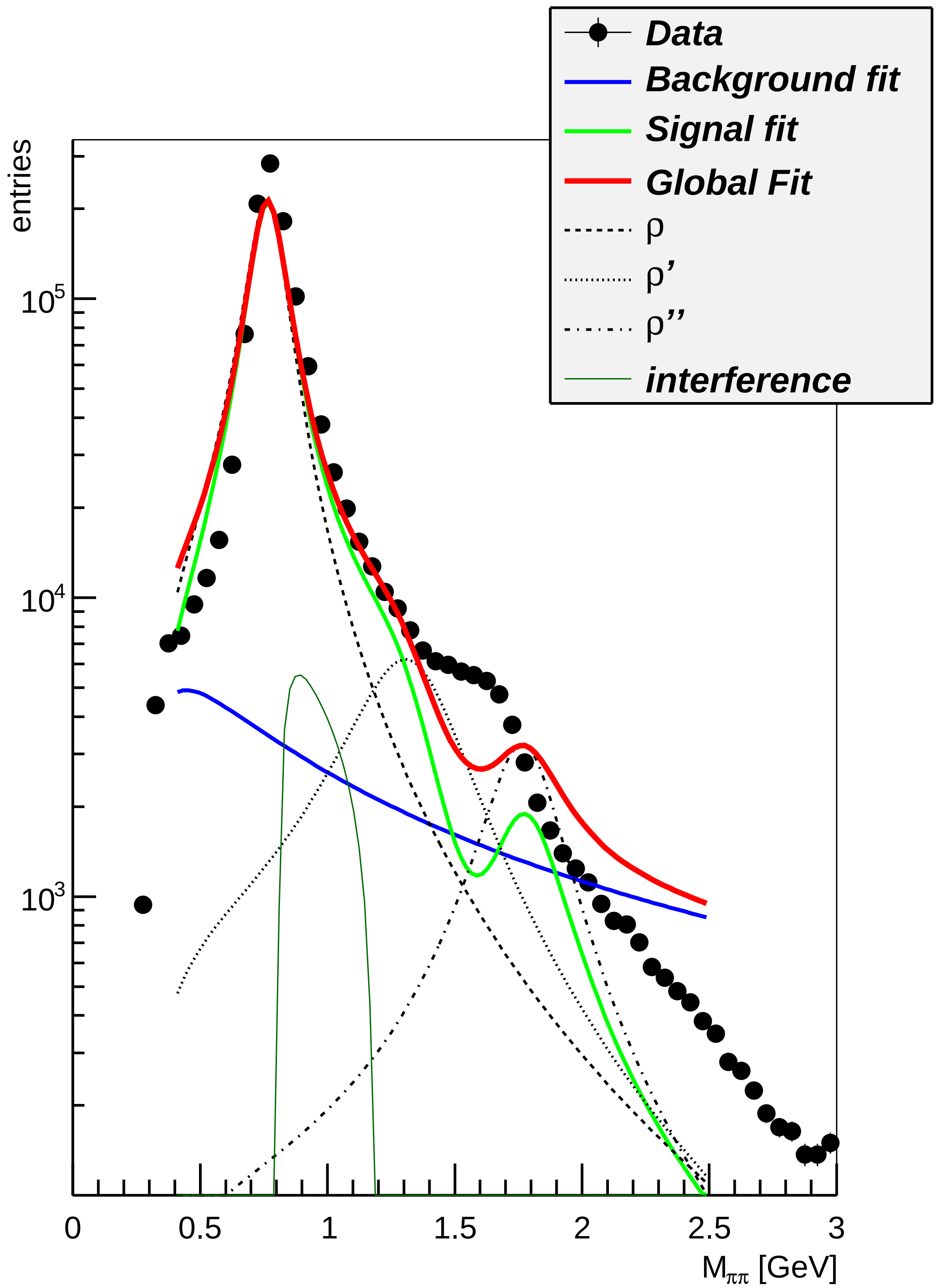

Figure 3: $M_{\pi\pi}$ ZEUS paper fit scaled to H1 photoproduction data with a binwidth of 50MeV. The overall fit, the signal contribution due to the F_π form factor and the background are shown as continous lines. The separate contributions of the three resonances to the signal are shown as dotted, dashed and dash-dotted lines.

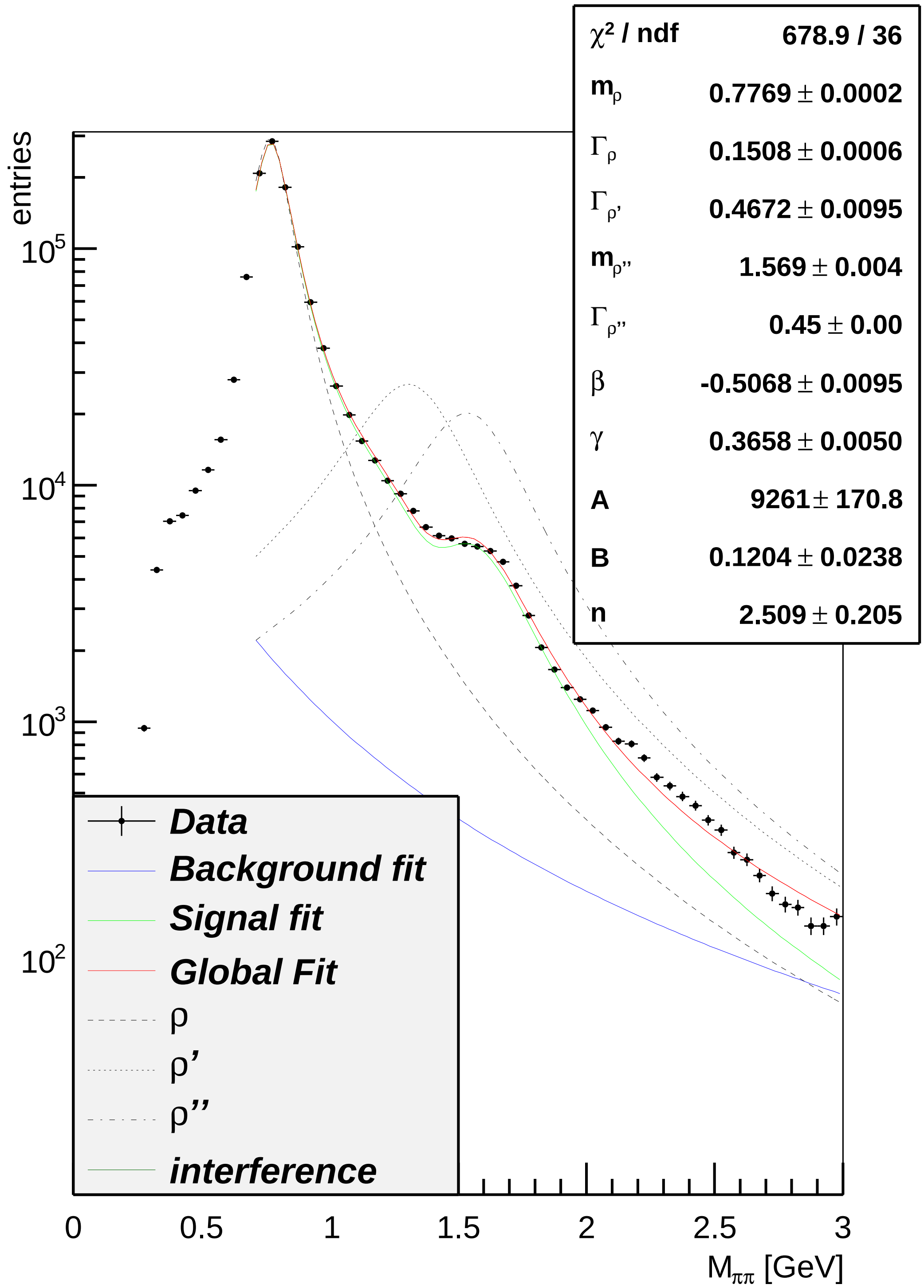

Figure 4: $M_{\pi\pi}$ Fit with no t cut in region $0.7 < M < 3.0$[GeV] and a bin width of 50MeV.

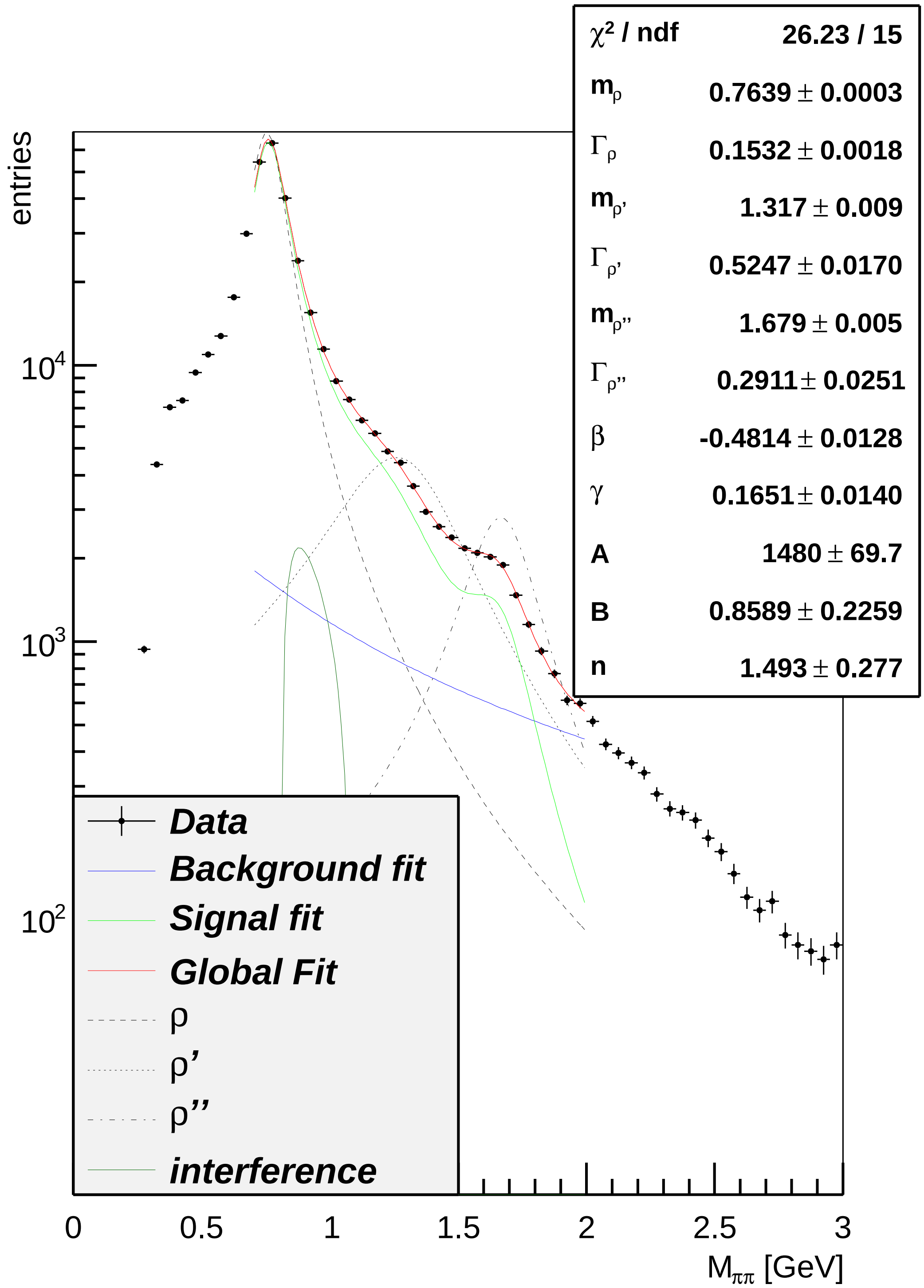

Figure 5: $M_{\pi\pi}$ Fit with $t \geq 0.25$ in region $0.7 < M < 2.0$[GeV] and a bin width of 50MeV.

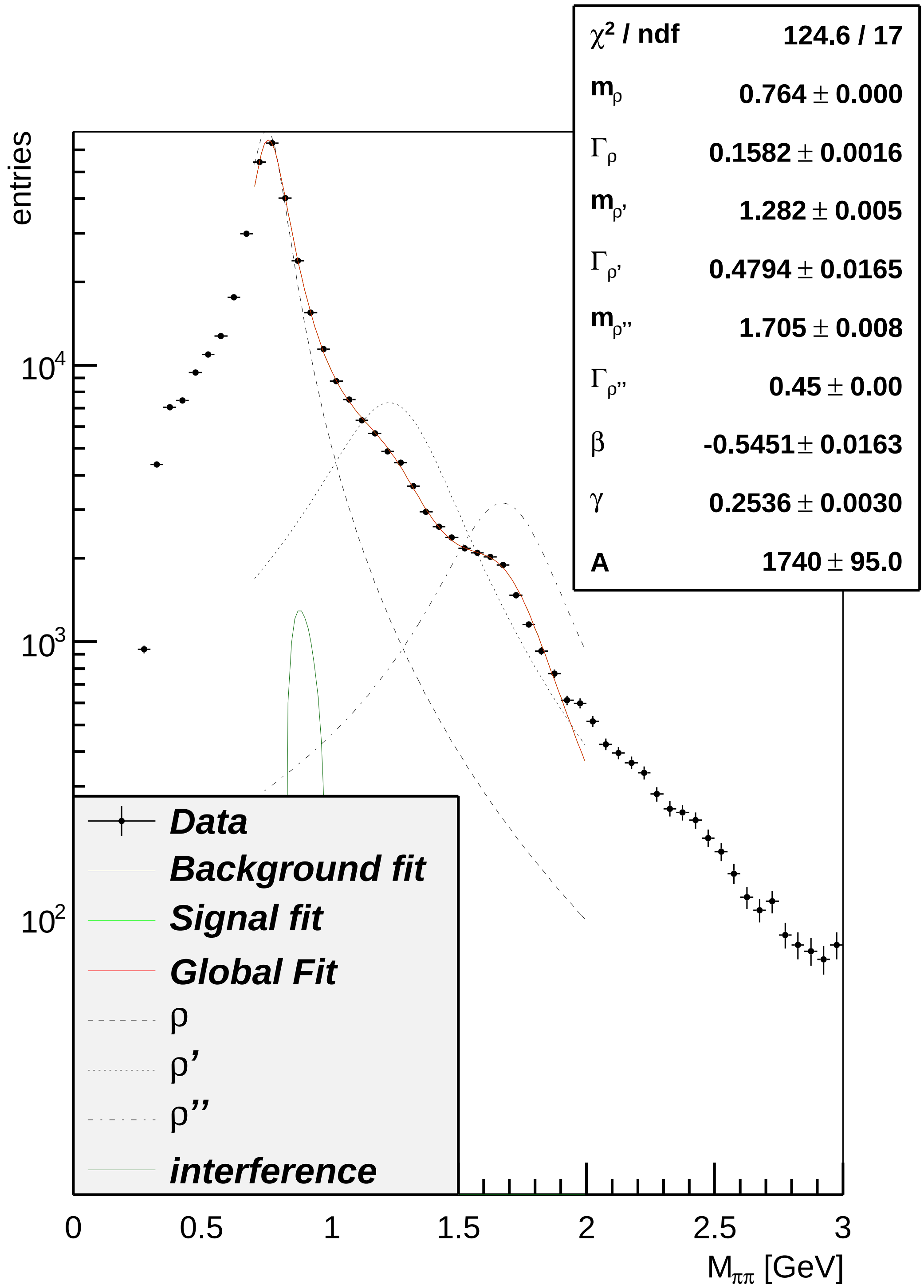

Figure 6: $M_{\pi\pi}$ Fit with $t \geq 0.25$ in region $0.7 < M < 2.0$[GeV] without background and a bin width of 50MeV.