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Measurement of the total $e^+e^- \to$ hadrons cross section near the $e^+e^- \to N\bar{N}$ threshold

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Abstract

A new measurement of the total $e^+e^- \to$ hadrons cross-section in the centre of mass energy range 1.8–2.5 GeV, performed by the FENICE experiment at the Frascati e^+e^- storage ring ADONE, is presented. The behaviour of the total cross section together with the proton electromagnetic time-like form factor is discussed in terms of a narrow vector resonance close to the nucleon-antinucleon threshold.

1. Introduction

The total multihadronic cross-section by e^+e^-annihilation at c.m. energies above the ϕ up to the J/ψ has been investigated by various experiments at the storage rings VEPP-2M [1], ADONE [2], SPEAR [3] and DCI [4] (the DM2 data on the total cross section are still unpublished [5]). Some of these experiments suggested the existence of structures in exclusive cross-sections near the nucleon-antinucleon ($N\bar{N}$) threshold [6]. Unfortunately these data suffered from low statistics and were not fully consistent with each other.

On the other hand a very steep behaviour of the

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proton electromagnetic form factor (FF) in the time-like region at threshold has been pointed out by the PS-170 Collaboration [7]. In order to explain this behaviour and the $N\bar{N}$ scattering amplitude near threshold the prediction of a $N\bar{N}$ quasinuclear bound state below threshold has been reminded [8], the so-called baryonium [9], searched and lusted for a long time. If there is a vector $N\bar{N}$ bound state just below the threshold it will essentially decay into mesons and it will appear as a small and narrow structure in the $e^+e^- \to$ hadrons cross-section. Therefore it is interesting to investigate with more accuracy the multihadronic production close to the $N\bar{N}$ threshold.

Furthermore a better accuracy in the measurement of the total $e^+e^- \to$ hadrons cross-section at these energies is also needed in the evaluation of the hadronic contributions to the $g_\mu - 2$ value and to the Z^0 parameters.

The FENICE experiment, which has carried out the measurement of the neutron time-like form factors, has also measured the total $e^+e^- \to$ hadrons cross section in the region above and below the $N\bar{N}$ threshold with a statistical accuracy higher than that of the previous experiments.

2. Data analysis and results

The FENICE experiment was performed at the e^+e^-storage ring ADONE in Frascati. ADONE was restored as e^+e^-collider in 1990 and shut down in 1993; it operated in a single bunch mode at c.m. energies from 1.8 to 3.1 GeV, with a peak luminosity of 10^{29} cm^{-2}s^{-1}.

Being the main goal of the FENICE experiment the first measurement of the neutron electromagnetic FF in the time-like region [10], the detector [11] was designed for the identification of the antineutrons coming from the process $e^+e^- \to n\bar{n}$. FENICE was a non-magnetic detector, with octagonal cross section, 2.5 m long and 3 m wide. It was made of limited streamer tubes for tracking, scintillators for trigger and time-of-flight measurements, and iron plates as absorbers. The inner part of the detector, consisting of only 8 layers of streamer tubes was used to distinguish charged from neutral particles coming from the ADONE interaction point, and it is referred to as Central Tracking Detector (CTD). The whole apparatus was surrounded by a concrete shield 1 m thick, covered with the cosmic veto system made of Resistive Plate Counters [13]. The total thickness of the detector was about 8 radiation lengths and 1.5 interaction lengths. The identification technique of the antineutrons was based on their annihilation on nuclei, characterized by a typical many prongs topology, and on the measurement of their velocity by means of the time-of-flight of the annihilation products with respect to the beam crossing time. With the FENICE detector it was also possible to measure the $e^+e^- \to p\bar{p}$ cross-section [12].

Two features made FENICE an efficient detector also for multihadronic events: the large geometrical acceptance, 76% of the whole solid angle for a fully penetrating particle and 90% for a particle detected in the CTD, and the low trigger threshold. In fact 10 fired scintillators over 192 were required not to worsen the $\bar{n}$ detection efficiency. Due to the absence of magnetic field and to the large amount of iron and scintillator material, where hadrons have a high probability of interaction, the detector was suitable for the measurement of the total multihadronic cross-section rather than the selection of multihadronic exclusive processes.

The integrated luminosity has been measured by means of wide angle Bhabha scattering in the apparatus and checked by means of the other QED processes $e^+e^- \to \mu^+\mu^-$and $e^+e^- \to \gamma\gamma$. The results of the three independent luminosity measurements are in agreement with one another and with the ADONE luminosity monitor based on single Bremsstrahlung [14], within a 6% systematic error mainly due to the event selection procedure.

An event has been defined to be multihadronic if it has at least 3 charged or neutral prongs and if at least one prong is a charged track. A prong is classified as a charged track if there are hits in the CTD pointing to the beam interaction point.

About 10000 many hadrons events have been selected with a 70% overall efficiency. This efficiency is the average over the relevant final states, with pions and kaons, weighted with their own branching ratios [5] measured or estimated on the basis of the previous experiments, and it does not depend on the c.m. energy. This assumption introduces an uncertainty on the total efficiency less than 3%. This value corresponds to the standard deviation of the efficiency distribution obtained allowing each branching ratio to

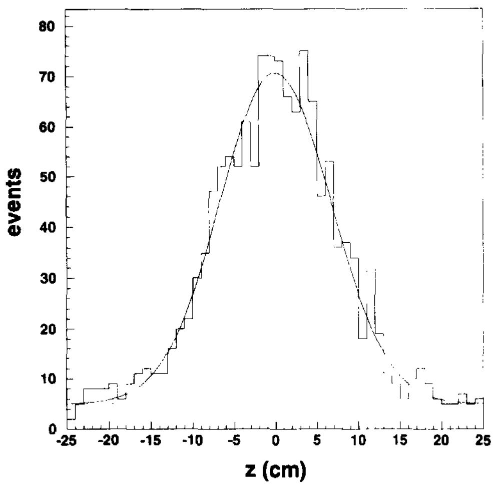

Fig. 1. Z-coordinate distribution of a sample of multihadronic events at $E_{c.m.} = 1.92$ GeV; a flat background (dotted line) underlies the multihadron signal.

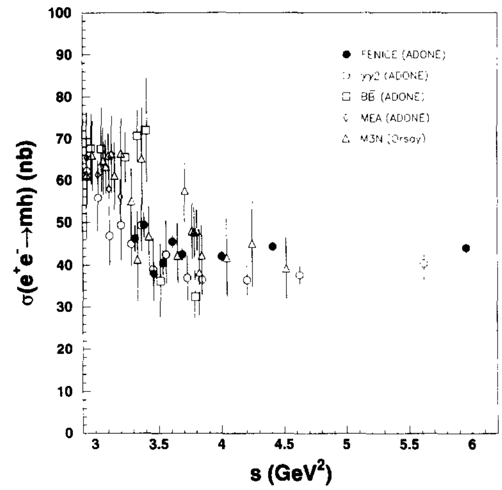

Fig. 2. Total $e^+e^- \to$ hadrons cross section, near the $N\bar{N}$ threshold; the error bars are statistical only.

Table 1
FENICE measurements of the total $e^+e^- \to$ hadrons cross-section; only statistical errors are quoted

s (GeV^2)	σ_{mh} (nb)
3.31	46.2 ± 3.1
3.38	49.3 ± 3.0
3.46	37.9 ± 2.7
3.53	40.5 ± 2.9
3.61	45.5 ± 1.5
3.69	42.5 ± 1.4
4.00	42.0 ± 1.1
4.41	44.3 ± 1.1
5.95	44.0 ± 1.2

vary within 50% of its measured or estimated value. This uncertainty is quite small in agreement with the large solid angle and the low trigger threshold.

There is less than 15% contamination, due to cosmic rays and machine background events, which has been subtracted by means of the distribution of the reconstructed z coordinate of the beam interaction point (Fig. 1).

Radiative corrections for the initial state radiation have been applied at the lowest order [15].

The FENICE results, with statistical errors only, are reported in Table 1 and in Fig. 2 and are compared to the previous measurements of the total $e^+e^- \to$ hadrons cross section [2]. An additional 7% systematic error has to be included, mainly due to the luminosity measurement.

Looking for any structure the FENICE results have been compared to the mean value of the previous measurements. To reduce the systematic error the previous experiments have been properly normalized with each other in the full energy range they overlap. The achieved normalization factors are in agreement with the quoted systematic uncertainties. In Fig. 3 the FENICE results are compared with the mean obtained in this way: they agree with each other and a narrow structure may be envisaged just below the $N\bar{N}$ threshold.

A fit of the total $e^+e^- \to$ hadrons cross section and of the proton time-like FF, close to the $N\bar{N}$ threshold, has been performed in order to test the hypothesis that the observed structure is produced by a resonance (a detailed description of the fitting procedure can be found in Ref. [16]). In short the multihadronic cross-section in the energy region outside the envisaged structure has been fitted apart as a superposition of broad resonances. Hence in the structure region a narrow resonance is introduced, which interferes with one of these broad vector mesons. The relative phase in the interference is established assuming the narrow resonance has a negligible coupling to $e^+e^-$and assuming mass mixing. The expectation is a dip, very similar to what was expected [17] in the case of a toponium on top of the Z^0. This fit is shown in Fig. 3a: the solid curve is the interference pattern produced by a resonance of mass (1.87 ± 0.01) GeV and total de-

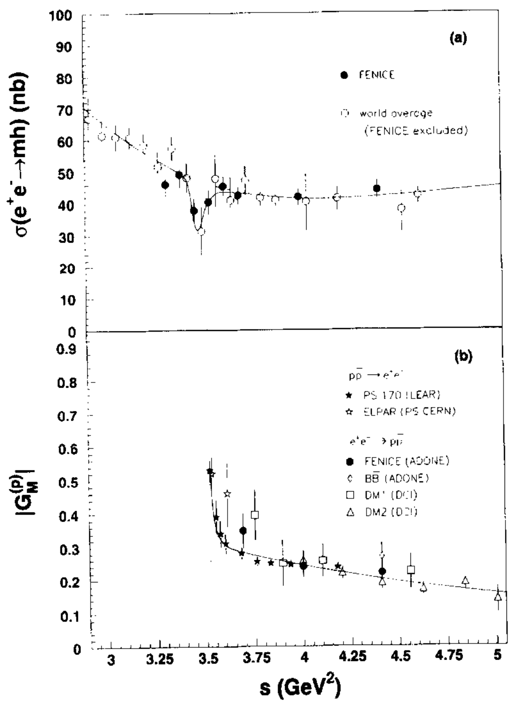

Fig. 3. (a) Total $e^+e^- \to$ hadrons cross-section, systematics is also included in the error bars; (b) proton time-like FF. The solid curves are the best fit assuming the interference with a resonance below the $N\bar{N}$ threshold (the dashed curve in (a) is the expectation without).

cay width (10±5) MeV, having a $\chi^2 = 3.9$ with 4 degrees of freedom corresponding to a 40% confidence level, while the the dashed curve (no resonance) of Fig. 3a has a $\chi^2 = 13.6$ corresponding to a $\sim$1% confidence level. The uncertainty on the colliding beam energy is included in the quoted errors.

With the same resonance parameters the time-like proton FF [7,18,19], including the FENICE measurements [12], has been fitted in the squared c.m. energy range from the threshold up to 6 GeV^2 and the result is shown in Fig. 3b.

3. Conclusions

The FENICE Collaboration has performed a new measurement of the total $e^+e^- \to$ hadrons cross-section near the nucleon-antinucleon threshold. These data are in agreement with the previous measurements and, together with the steep threshold behaviour of the proton time-like form factor, give indications for a resonance with $M \simeq 1.87$ GeV and $\Gamma \simeq 10$ MeV. However, in order to draw any conclusion on this subject, still more experimental data are needed exploring in more details and with higher statistics the $N\bar{N}$ threshold region.

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