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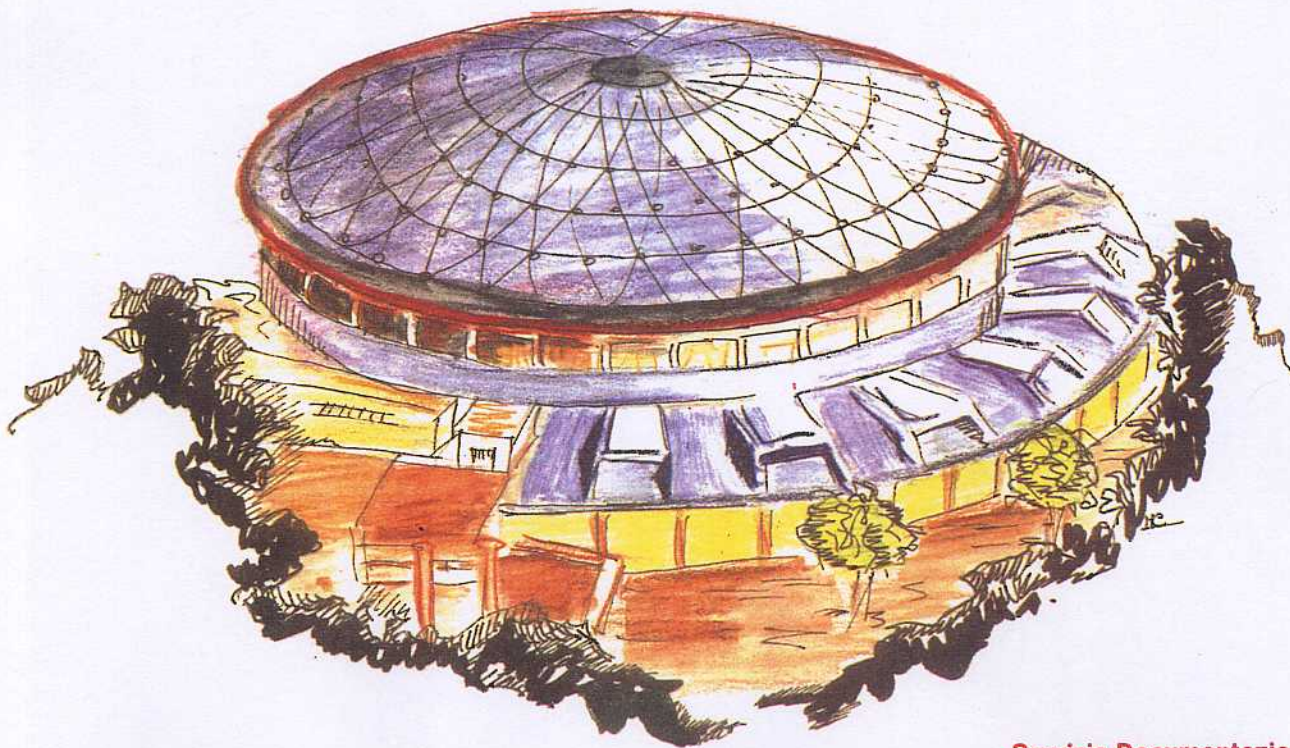
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A NEW MEASUREMENT OF J/Ψ → n $\overline{n}$

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A NEW MEASUREMENT OF J/Ψ → n n̄

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Abstract
     A new measurement of the branching ratio of $J/\psi \to n\bar{n}$, $B_{n\bar{n}} = (1.90 \pm 0.55) \cdot 10^{-3}$,
has been achieved by the FENICE detector at the e^+e^- storage ring ADONE in Frascati.

     The neutron time-like e.m. form factor has never been measured up to now. Theo-
retical expectations are vague and different models give predictions varying within more
than one order of magnitude[1,2]. Moreover it is worth collecting further data on the
nucleon structure, as widely demonstrated in the last years by unexpected experimental
results[3,4].

     In order to perform this measurement near the threshold the storage ring ADONE
in Frascati has been restored as e^+e^- collider for a fraction of its running time and a
specialized, non magnetic detector, FENICE, has been built. As a first measurement,
data have been collected at the J/ψ for calibration purposes. In spite of the small
integrated luminosity a significant improvement has been achieved on the measurement
of the branching ratio of

$$J/\psi \rightarrow n\bar{n} \tag{1}$$

as reported in this paper.

The FENICE detector is illustrated in Fig.1. More detailed descriptions of the detector are reported elsewhere[5]. It consists of a hadron calorimeter optimized to detect antineutrons, made of 18 layers of limited streamers tubes (LST), iron sheets 0.5 cm thick, interleaved with slabs of scintillators, for a total thickness of $\sim$ 2 collision lengths. Between the beam pipe and the calorimeter there are: a ring of thin scintillation counters around the beam pipe, 8 layers of LST to track particles coming from the beam interaction region, and 3 layers of thick scintillators, interleaved with LST, for a total thickness of 15 cm, mainly to detect neutrons in a fraction of the events. LST signals are readout from strips parallel and orthogonal to the colliding beams allowing to locate the streamers within ± 0.5 cm on each coordinate. In the first 4 layers the drift time is also recorded. This calorimeter is located in a hut with concrete walls and a barium-loaded roof. Two layers of resistive plate counters (RPC) are on the top of this shield
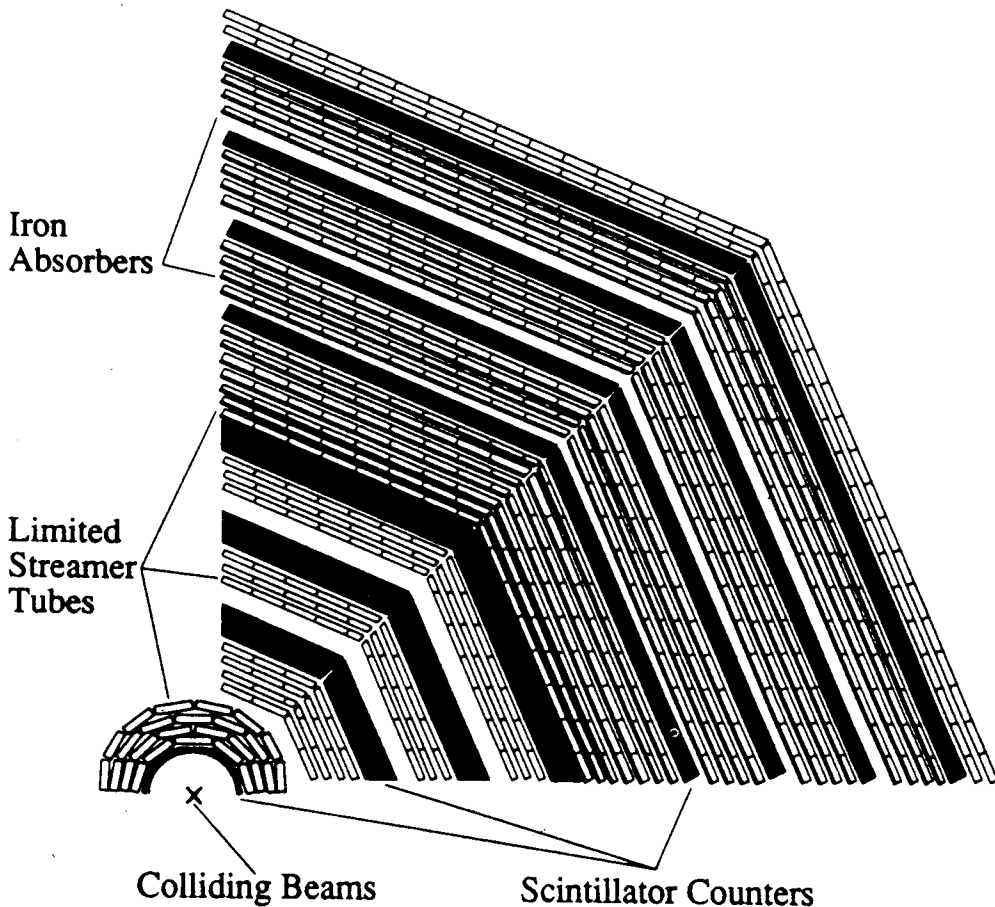

FIG. 1 – A sketch of a quadrant of the FENICE detector.

for triggering purposes. The trigger implemented is very loose, requiring a cluster of scintillators, at least 8 scintillators hitted and the RPC in anticoincidence to reduce cosmic rays at the trigger level. The probability that hadronic e^+e^- annihilation events could hit the RPC is less than 1%. Muon pair events can hit the RPC veto and a special trigger has been implemented to recover these events. The overall trigger rate was ~ 10 Hz and the dead time due to the data acquisition was $\sim 3\%$ with 30 mA beam current.

The features of FENICE, which allow to identify an antineutron, are: the LST pattern of the annihilation star, the total energy deposited in the scintillators, the time of flight of the retrieved annihilation vertex with respect to the beam crossing time. The energy calibration and resolution for e.m. and hadronic showers are measured analysing Bhabha and multihadronic events: it is obtained $\sigma = 23\%$ and $\sigma = 60\%$ respectively at 3 GeV. For each scintillator the time resolution is $\sigma \sim 0.7$ ns, once corrections have been applied for the dependence on the released energy, including the ~ 0.4 ns spread in the crossing time due to the bunch length.

The average luminosity was $\sim 10^{29}$ cm^{-2} s^{-1} with one bunch and with a lifetime of about 4 hours. The luminosity was continously monitored by looking at the single bremsstrahlung in the interaction region with colliding or separated beams. Bhabha events collected in the detector are in agreement with this luminosity measurement within $\pm 5\%$.

The energy region around the J/ψ has been scanned with 1 MeV steps taking into account the 1.5 MeV total energy spread. From the total multihadronic cross section integrated over this energy scan, taking into account radiative corrections, it has been obtained $\Gamma_{ee} = 5.3 \pm 0.3$ KeV[6], in fair agreement with the value quoted in the PDB[7].

In the following all the quoted branching ratios have been normalized through the total multihadronic J/ψ decay in order to cancel many systematic errors.

At the J/ψ mass an integrated luminosity of 33 nb^{-1} has been collected, corresponding to 43000 hadronic events, 3700 e^+e^- events and 1400 $\mu^+\mu^-$ events, in agreement with the expectations according to the branching ratios quoted in the PDB.

As a check events from the well known process[7]

$$J/\psi \rightarrow p\bar{p} \qquad (2)$$

have also been identified. The same features are expected for antineutron and antiproton annihilation stars. The $p\bar{p}$ events are selected by looking for hadronic events with two collinear tracks in the inner part of the detector and an annihilation star on one side. A final, very loose visual inspection has been performed and a sample of 51 candidate events has been selected. Looking to the difference between the time of the interaction vertex and the beam crossing time the antiproton candidate velocity $\beta_{\bar{p}}$ has been evaluated. The $1/\beta_{\bar{p}}$ distribution, reported in Fig.2a, is in agreement with the Montecarlo expectation[6] for events coming from reaction (2). The cosmic ray background is expected to be almost flat on this distribution and it turns out to be negligible. A background of 3 events is estimated to come mainly from $J/\psi \rightarrow K^+K^-$ and $J/\psi \rightarrow p\bar{p}\pi^0$.

Concerning $n\bar{n}$ events additional cuts on the mean time of the annihilation star with respect to the beam crossing and on the annihilation vertex position have been performed to avoid any background from charged events. The angular distribution of the tracks coming from the annihilation vertex with respect to the line of flight of
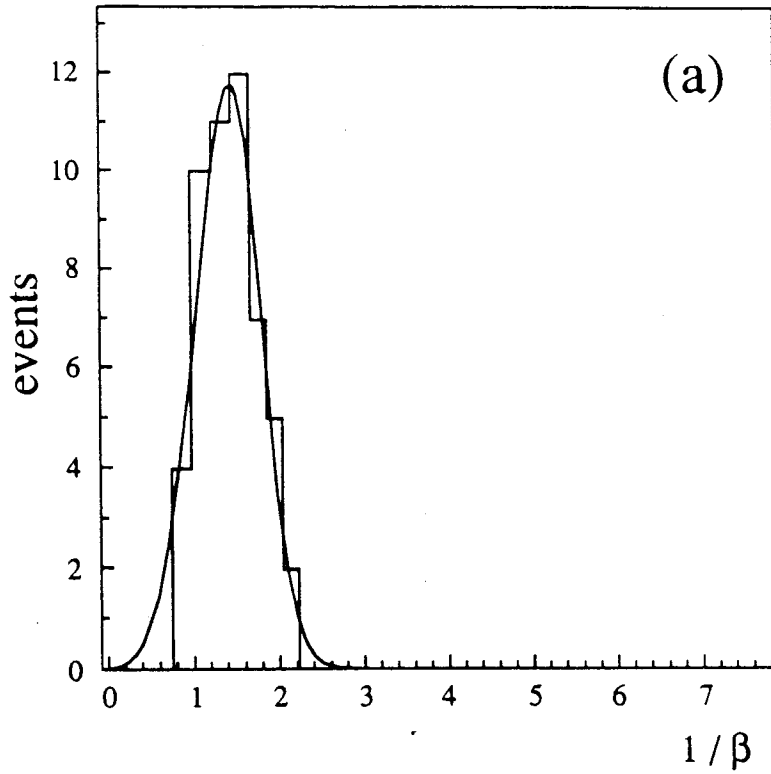
FIG. 2 (a) – $\beta_{\bar{p}}$ distribution of the candidates for the reaction (2). The continuous line is the prediction for $J/\psi \rightarrow p\bar{p}$ events.
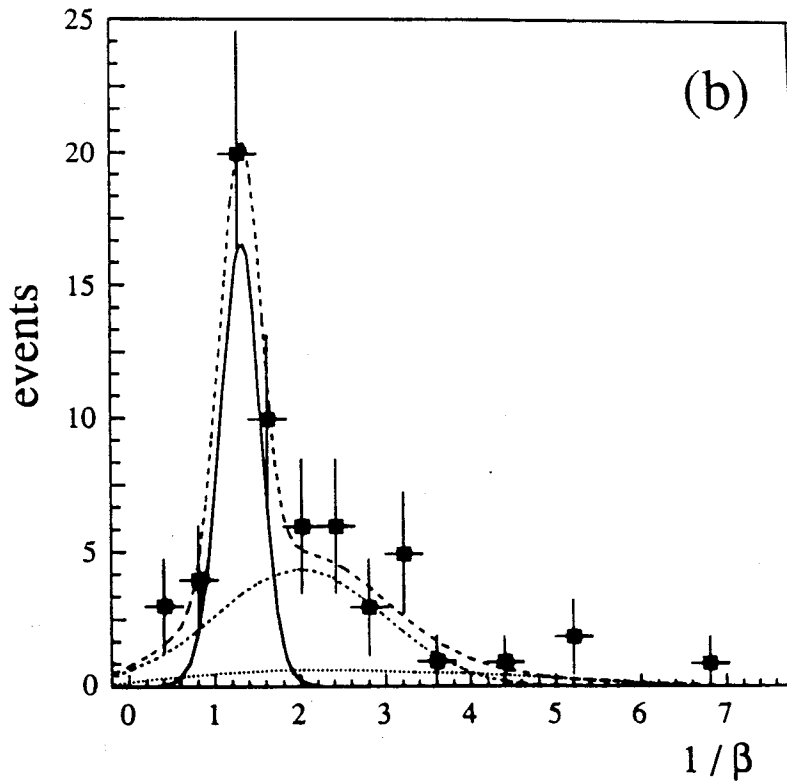

FIG. 2 (b) – $1/\beta_{\bar{n}}$ distribution of the candidates for the reaction (1). The continuous line is the prediction for genuine $J/\psi \rightarrow n\bar{n}$ candidates. The dot–dashed line is the prediction for events coming from $J/\psi \rightarrow n\bar{n}$ (π°,η). The dotted line is the cosmic ray background and the dashed line is the overall fit to the data.

the antineutron is consistent with the Montecarlo expectation[6], as well as for the antiprotons.

In the reaction (1), if only the antineutron is detected, the main background is due to $J/\psi \to n\bar{n}\,\pi^0(\eta)$ events producing photons undetected or hidden in the annihilation star. Since in these events the antineutron is less energetic, the $1/\beta_{\bar{n}}$ expected distribution is displaced with respect to genuine events from the reaction (1), allowing to disentangle this background. Very energetic cosmic neutrons, interacting in the calorimeter, give also a background. In general they belong to a cosmic hadronic shower and are strongly reduced by the RPC veto. They may also be evaluated by looking at the $1/\beta_{\bar{n}}$ distribution. A three component fit of this distribution gives a number of 25 ± 7 $n\bar{n}$ events out of 65 candidates, as reported in Fig.2b. Further 15 events with additional showers, pointing to the beam interaction region, have also been identified. Their number is consistent with the $J/\psi \to n\bar{n}\,\pi^0(\eta)$ background estimated by the fit.

In 9 candidates a neutron is also detected as expected from reaction (1), concerning direction and time of flight. Moreover these events are consistent with the expected overall efficiency for neutron detection ($\sim 40\%$ at these energies).

Assuming for $n\bar{n}$ and $p\bar{p}$ events the same angular distribution[8] it is obtained:

$$B_{p\bar{p}} = (2.0 \pm 0.3) \cdot 10^{-3},$$

in agreement with PDB [7] : $(2.16 \pm 0.10) \cdot 10^{-3}$, and:

$$B_{n\bar{n}} = (1.90 \pm 0.55) \cdot 10^{-3},$$

in agreement with the Bonanza measurement[9] : $(1.8 \pm 0.9) \cdot 10^{-3}$. The quoted errors are mainly statistical, the overall systematics being less than 10 percent. It turns out, within the errors, $B_{n\bar{n}} \simeq B_{p\bar{p}}$.

To have a prediction on $B_{n\bar{n}}$ it is possible to evaluate the e.m. corrections to $J/\psi \to B\bar{B}$, according to Fig.3 , from the measurements of $\sigma(p\bar{p} \to e^+e^-)$ near the J/ψ mass. That has been obtained recently by the Fermilab experiment E760[10] and there are other measurements at higher[10] and lower energies[4,11]. For this purpose the standard PQCD hypotheses are relevant: the J/ψ direct decay amplitude A and the J/ψ e.m. decay amplitude C are the most important and they are mainly real[12]. We obtain $|C_p/A| = 0.15 \pm 0.015$ from $\sigma(p\bar{p} \to e^+e^-)$ extrapolated at the J/ψ mass, assuming $|C_p/(A + C_p)|^2 \simeq B(J/\psi \to \mu\mu)\sigma(e^+e^- \to p\bar{p})/(B(J/\psi \to p\bar{p})\sigma(e^+e^- \to \mu\mu))$[13].

PQCD[2,12] foresees also $G_n \sim -0.5\,G_p$ (as in the space-like region) and our first measurement at $Q^2 = 4.0$ GeV/c^2 indicate $|G_n| = 0.42 \pm 0.06 \sim 1.5|G_p|$[14]: from that, still under the assumption of real amplitudes, it should be expected $B_{n\bar{n}} \leq 1.4 \pm 0.1$. This $B_{n\bar{n}}$ computed value and the FENICE result are different at a one standard deviation level. More data are needed to settle this point. This difference, if confirmed, might indicate that actually the above amplitudes are orthogonal to each other[15]. The same indication was obtained in all the other J/ψ decay channels where it was possible to measure the relative phase between direct decay and e.m. amplitudes[8]. By the way, important questions are still unanswered in the J/ψ decay [16].
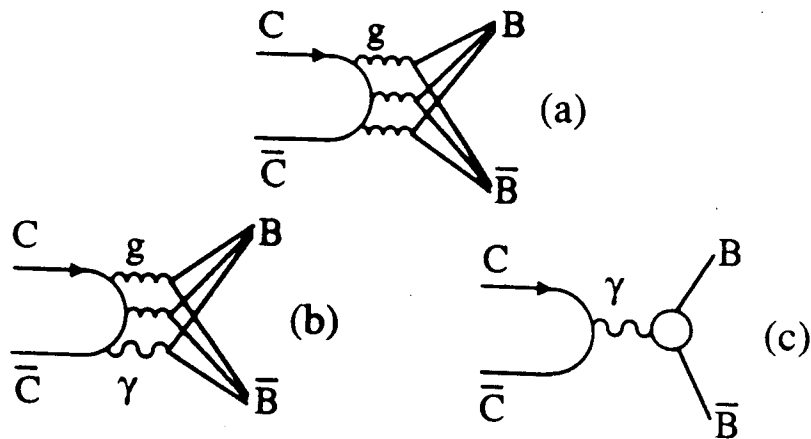
FIG. 3 – Expected contributions to the J/ψ → B$\bar{\text{B}}$ amplitude.

ACKNOWLEDGMENTS

REFERENCES

(1)   N. Cabibbo and R. Gatto, Phys. Rev. 124 (1961) 1577;
       R. Felst, Int. note DESY 73/56 (1973);
       J. G. Körner and M. Kuroda, Phys. Rev. D16 (1977) 2165;
       P. Cesselli, M. Nigro and C. Voci, Proc. of Workshop on Physics at LEAR, Erice (1982);
       E. Etim and A. Malecki, Frascati report LNF–89/023 (1989);
       S. Dubnicka, Nuovo Cimento A100 (1988) 1; A103 (1990) 469; A103 (1990) 1417; A104 (1991) 1075;
       S. I. Bilenkaya, S. Dubnicka, A. Z. Dubnickova and P. Strizenec, Nuovo Cimento A105 (1992).

(2)   V. L. Chernyak and I. R. Zhitnitsky, Nucl. Phys. B246 (1984) 52;
       S. J. Brodsky, Nucleon Structure Workshop (Frascati, October 1988);
       T. Hyer, SLAC–PUB–5889 (1992).

(3)   European Muon Coll., Phys. Lett. B206 (1988) 364.

(4)   G. Bardin et al., Phys. Lett. B255 (1991) 149;
       G. Bardin et al., Phys. Lett. B257 (1991) 514.

(5)   A. Antonelli et al. Frascati Report LNF–87/18(R) (1987);
       A. Antonelli et al., submitted to Nucl. Inst. Meth. (1992);
       A. Antonelli et al., 'LEAP90', Stocholm (1990).

(6)   C. Bini et al. , Winter School on Hadronic Physics–Folgaria (1991);
       A. Antonelli et al., Frascati Report LNF–92/097 (P).

(7)   Rev. of Part. Prop., Phys. Rev. **D45** (1992).

(8)   L. Kopte,N. Wermes, Phys. Rep. **174** (1989) 67.

(9)   H. J. Besh et al., Phys. Lett. **B78** (1978) 374.

(10) P. Dalpiaz et al, Yad Fiz. 55, 6, (1992) 1568;
      T. Armstrong et al., FERMILAB–PUB–92/224–E.

(11) D. Bisello et al., Z. Phys. **C48** (1990 23.

(12) H. Kowalksi and T. F. Walsh, Phys. Rev. **D14** (1976) 852;
      S. Rudaz, Phys. Rev. **D14** (1976) 298;
      M. Claudson, S. L. Glashow, M. B. Wise, Phys. Rev. **25** (1982) 1345.

(13) A PQCD–based approach gives an even larger value (K. Seth, private communication).

(14) M. Bertani et al., Workshop on Quark Cluster Dynamics, Bad Honnef (1992);
      R. Baldini et al., Hadron Structure 92, Stara Lesna (1992).

(15) M. Fukujita and J. Kwiecinski, Int. note RL–79–045 (1979).

(16) P. G. O. Freund, Y. Nambu, Phys. Rev. Lett. **34** (1975) 1645;
      S. J. Brodsky, G. P. Lepage, S. F. Tuan, Phys. Rev. Lett. **59** (1987) 621.