сообщения
объединенного
института
ядерных
исследований
дубна

E1-92-344

A.V.Bannikov, Yu.A.Gornushkin, B.Z.Kopeliovich,
Z.V.Krumstein, M.G.Sapozhnikov

DRELL-YAN LEPTON PAIR PRODUCTION IN ANTIPROTON ANNIHILATION FOR SEARCHING OF THE FOUR-QUARK STATES

1992

1 Introduction

One of the predictions of quark models is the existence of bound states of the diquark-antidiquark type. From the point of view of the colour structure a baryon differs from a meson by substitution of an antiquark by a diquark, which is a pair of quarks in the antitriplet colour state. It is natural to expect the existence of diquark-antidiquark bound states where another quark in a baryon is substituted by antidiquark. These states can decay like mesons by means of production of a quark-antiquark pair from the vacuum, but in this case a baryon-antibaryon pair is produced rather than two mesons. It is obvious, however, that it is allowed only if the mass of the 4-quark state exceeds the mass of two baryons, but is forbidden below the baryon production threshold. Such light 4-quarks can decay only to mesons by the quark rearrangement.

Theoretical predictions [1] concerning the properties of these states are rather uncertain both for the masses of 4-quark states and their widths. However, the lightest states seem to have a mass around 1 GeV. Recent reviews of the experimental situation with the searches for exotic states may be found in [2]. A candidate for the 4-quark state with hidden strangeness, C(1480)-meson was claimed in [3] and discussed in [4].

The antiproton-proton interaction is a natural source of 4-quark states because diquarks and antidiquarks are already stored in the colliding particles. However, in spite of a number of experiments on searching for exotic states in the $\bar{p}p$ annihilation at low energies practically no non-conventional resonances were discovered (the only exception is may be the $AX/f_2(1515)$ state, for reviews of experimental situation, see [5]).

One may try to explain this failure by the following reasons:

- low energies (E< 1 GeV) are not quite suitable for searches for exotic states because annihilation channels practically saturate the unitarity limit and shadow any exclusive channels within the impact parameter region of a few fermies [6]. For this reason it would be desirable to have energy of at least a few GeV to suppress the annihilation cross section;

- the exotic states X are searched usually in the production channels

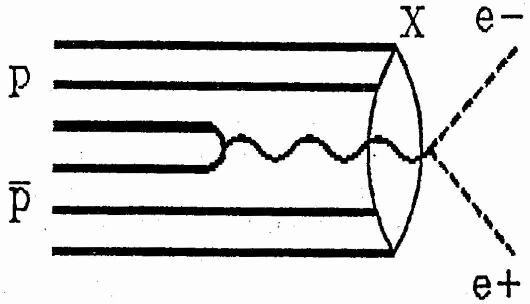

Figure 1: Diagram of Drell-Yan annihilation process.

like

$$\bar{p} + p \to X + m\pi, \quad m = 1, 2... \qquad (1)$$

where a considerable combinatorial background is unavoidable;

- the signal from decays of X is masked by decays of numerous ordinary resonances which produce the accompanying pions.

We propose to look for 4-quark systems formed in the Drell-Yan processes

$$\bar{p} + p \to e^+ + e^- + X \qquad (2)$$

The main idea is to use the lepton pair as a tag for 4-quark system formation, because the Drell-Yan mechanism guarantees that a pair of a valence quark and antiquark annihilates (see, Fig.1).

We have investigated the possibilities of registration of reaction (2) in the detector planned for the internal target on the SuperLEAR facility.

2 SuperLEAR internal beam detector

The SuperLEAR is an antiproton storage ring with variable energy between 2 and 12 GeV/c, capable of providing a luminosity at the level of $10^{32} cm^{-2} s^{-1}$. This storage ring is proposed to be construct at CERN as a development of the existing antiproton complex. The physics motivations of the SuperLEAR have been extensively discussed at the SuperLEAR Workshop in Zurich [7] and in a recent report [8].

One of the main physical goals of the SuperLEAR is to search for exotic charmonium states containing a valence gluon ($c\bar{c}g$) or four-quark states ($c\bar{c}q\bar{q}$) using the advantage of $\bar{p}p$ annihilation to populate directly all charmonium states. (Remember that in e^+e^- annihilation only states with $J^{PC} = 1^{--}$ are formed directly). The R704 experiment at CERN [9] and E760 experiment at FNAL [10] successfully demonstrated that $\bar{p}p$ annihilation provides precise measurements of the charmonium masses and widths which elude the e^+e^- experiments.

At least two big universal detectors are under discussion today. One is for the external beam and the other for the experiments on the SuperLEAR internal target. The later [11] is focused on measuring the excitation function for the resonance formation as a function of $\bar{p}$ momentum, e.g.

$$\bar{p} + p \to R \to J/\psi + f, \qquad J/\psi \to e^+e^- \qquad (3)$$

or

$$\bar{p} + p \to R \to \eta_c + f, \qquad \eta_c \to \gamma\gamma \qquad (4)$$

where R is a resonance state under investigation ($c\bar{c}g$, $c\bar{c}q\bar{q}$ or $c\bar{c}$) and f is an exclusive mesonic final state containing one or several neutrals.

A momentum scanning of the e^+e^- (or $\gamma\gamma$) yield in reactions (3),(4) could be done with a beam resolution $\sigma \sim 300$ KeV, i.e. narrow resonances with $\Gamma \sim 1$ MeV could be detected directly.

Fig. 2 shows a sketch of the apparatus. The detector will cover angles from 5° up to 153° with respect to the incident beam direction. The main part is a barrel of fast and radiation resistant scintillating crystals of an electromagnetic calorimeter. In the forward direction a finely granulated calorimeter, possibly with liquid krypton or xenon, is foreseen.

Electron-positron identification will be provided by i) a CO_2 gas Cherenkov counter at atmospheric pressure which will cover the polar angles beyond 27° and ii) a transition radiation detector (TRD) which will cover forward angles up to 27°. It is assumed that the detection of the $e^\pm$ from J/ψ or ψ' decay can be achieved offline with a total rejection power for charged pions at the level of 10^8. In that case the $e^\pm$ cross

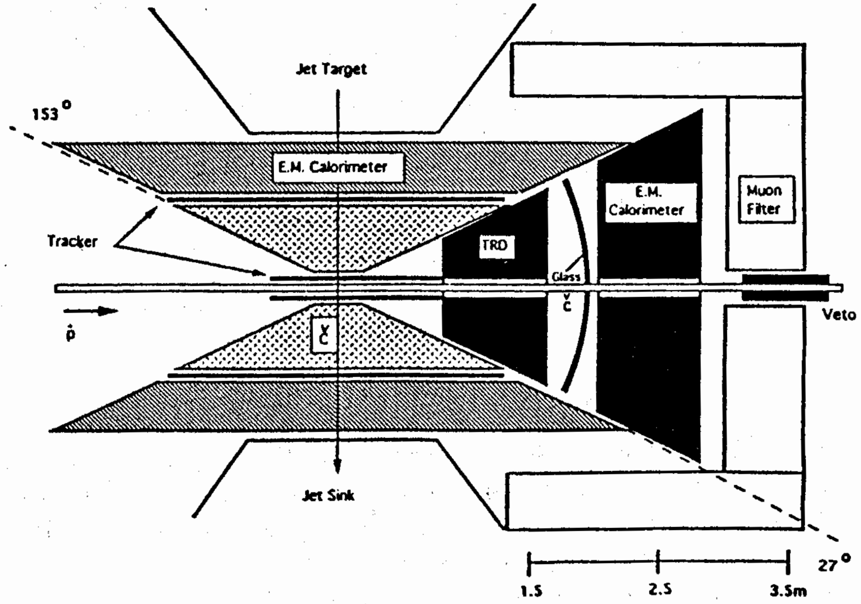

Figure 2: Schematic view of the detector. The apparatus is symmetrical around the beam axis.

sections as low as 1 pb can be measured with a good signal/background ratio.

3 Drell-Yan process simulation

We have investigated the possibilities of the registration of the Drell-Yan reaction (2) in the internal beam detector (Fig.2).

To be sure that the process under investigation is the Drell-Yan process one should select the energy where it dominates. It is known that the Drell-Yan mechanism is dominant in the dilepton production at high energies (starting from $s^{1/2} > 4$ GeV) and large lepton pair masses.

Because of the steep decrease of the cross section as a function of the dilepton mass M, one should select pairs with the mass beyond the light meson resonance region, but smaller than the mass of J/ψ,

$$1.5 < M < 3\ GeV \tag{5}$$

We have simulated the Drell-Yan pair characteristics in the reaction (2) under the following assumptions:

1) the x_F and p_T distributions were used from the parametrizations of the experimental results on Drell-Yan pair formation in $\bar{p}$N interactions at 125 GeV/c [12].

2) the p_T distributions were scaled to our energy interval using invariant values $2p_T/(s)^{1/2}$.

3) the differential cross section of the dilepton formation with mass M was written in the invariant form:

$$M^3 d\sigma/dM = f(\tau) \tag{6}$$

where $\tau = M^2/s$.

Then it was checked that at low $(s)^{1/2}$ $(0.25 < \tau < 0.5)$ one may parametrize (6) by the following formula

$$d\sigma/dM = 0.21 * exp(-11.7 * \tau)/M^3\ (\mu b) \tag{7}$$

here M is in GeV.

We have simulated an effective mass distribution for reaction (2) according to the prescriptions (5)-(7). The following trigger conditions were used:

1) the azimuthal angle between leptons should be greater than 90°;
2) the polar angle of a lepton is within 2° – 153°;
3) the energy of leptons should be greater than 500 MeV.

These trigger conditions are similar to those used in the E760 experiment [10].

In Fig.3 the effective mass of the X system for different energies of the antiproton is shown. The limit (5) on the dilepton mass was assumed. One can see that the spectrum of X is steeply falling down to the light X masses ($m_X \sim$ 1 -1.5 GeV) and the production of X with masses 2-3 GeV is more favorable for the antiproton momentum > 6-8 GeV/c.

In Fig.4 the acceptances of the detector for the dilepton mass M and the mass of X are shown for the antiproton momentum 6 GeV/c and $m_X > 0.9$ GeV. The acceptance was determined as the ratio between events passed the trigger to the simulated ones. It is seen that approximately 70-80% of generated events passed the trigger conditions and the X mass acceptance behavior is flat. The behavior of the acceptance weakly depends on the antiproton energy.

In Fig.5 the product of the dilepton cross section with the acceptance is shown. This value is proportional to the expected dilepton yield. The dashed line corresponds to the total dilepton production with masses $m_X > 0.9$ GeV whereas the solid line corresponds to the production of light X with masses $0.9 < m_X < 2$ GeV. One can see that for searching of light X the energy of the antiproton about 6 GeV/c is optimal, whereas for searching for heavy X the energy of antiprotons should be maximal.

4 Expected rates

Assuming the luminosity $10^{32} cm^{-2} c^{-1}$, the overall efficiency $\varepsilon = 0.5$, the trigger efficiency $\varepsilon_t = 0.7$ and the cross section from (7) one can obtain at antiproton momentum 12 GeV/c the following rate:

$N = L * \varepsilon * \varepsilon_t * \sigma = 10^{32} * 0.5 * 0.7 * 0.44\ 10^{-33} = 0.014\ c^{-1}$
$\sim$ 1200 ev/day

If we are interested in looking for light X, then the optimal antiproton momentum is around 6 GeV/c and the expected rate will be:

$N = L * \varepsilon * \varepsilon_t * \sigma = 10^{32} * 0.5 * 0.7 * 0.1\ 10^{-33} = 0.0033\ c^{-1}$
$\sim$ 288 ev/day

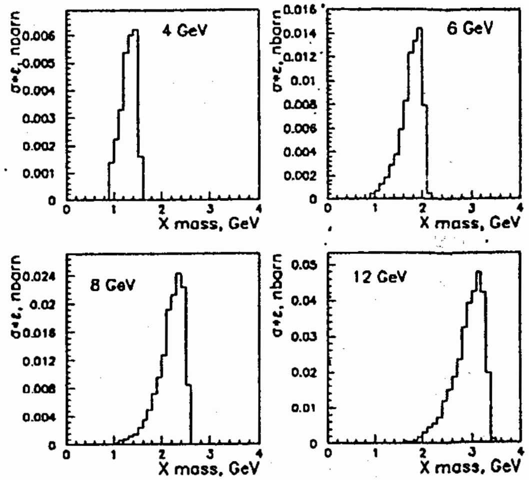

Figure 3: The effective mass of the X system for different energies of the antiproton.

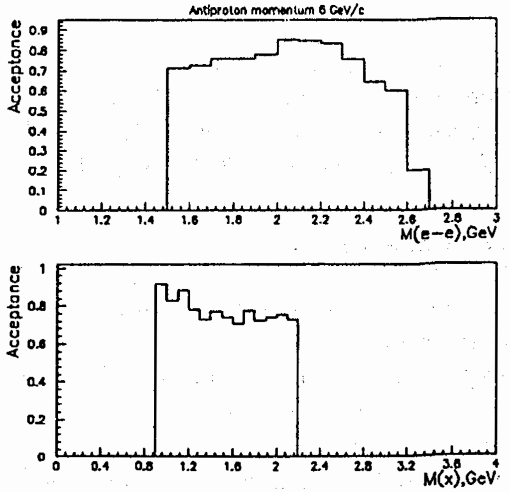

Figure 4: The acceptances of the detector for the dilepton mass M and the mass of X for the antiproton momentum 6 GeV/c and $m_X > 0.9$ GeV.

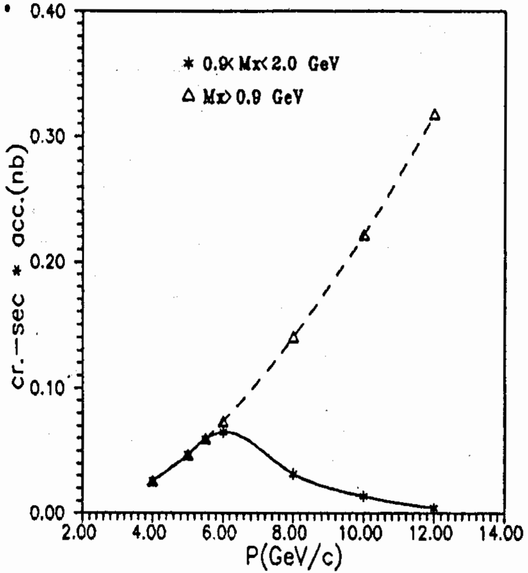

Figure 5: The product of the dilepton cross section with the acceptance.

These yields are small but comparable with those expected for production of different charmonium states. For instance, it is expected [2,11] that it will be possible to produce 480 η_c', 250000 J/ψ, 120 χ_0, 1700 h_c, 2 $^3D_1$, 200 $^1D_2$ – states per day at the SuperLEAR detector.

5 Demands to the detector

To estimate the demands to the detector we have evaluated the resolution in the X mass assuming, that

1) the energy resolution of the calorimeter is $\sigma(E)/E = 2\%/(E)^{1/2}$;

2) the angular resolution is 3 mrad

The characteristics of the lepton tracks were smeared by gaussians according to these resolutions and the mass of X was reconstructed taking into account these biases. It occurs that the overall missing mass resolution (for all masses of X) is $\sigma_X = 58$ MeV.

If one assumes more realistically that $\sigma(E)/E = 4\%/(E)^{1/2}$, then $\sigma_X = 83$ MeV.

From these considerations it is clear that demands to the detector

should be rather high. A really good calorimeter and tracking system are needed. The magnetic field for analysis of X decay products is also desirable.

In conclusion, the first analysis shows that the proposed experiment is not simple due to low cross sections and high demands to the detector. However, its main advantage is quite clean physical interpretation. The absence of the combinatorial background and the background from the ordinary resonance decays is also beneficial. It is possible to acquire statistics on the Drell-Yan pairs working in a parasitic mode with the searches for charmonium exotic.

This communications is a part of common Letter of Intent [11] on heavy and light meson spectroscopy with an internal target at SuperLEAR. We express our gratitude to Prof. C.Amsler for fruitful discussions.

References

[1] R.L.Jaffe, Phys.Rev. D15 (1977)267 ; ibid. D17 (1978) 1444
Chan Hong Mo, H.Hogaasen , Nucl.Phys. B136 (1978) 401
L.A.Kondratyuk, B.V.Martemjanov, M.G.Schepkin, Sov.J.Nucl. Phys. 1987, v.46, p.1552.
Guaraldo C., Kondratyuk L.A., Volkovitsky P.E. , preprint LNF-92/013 (P), Frascati, 1992.
F.E.Close and H.J.Lipkin, Phys.Rev.Lett. 41 (1978) 1263.

[2] Konigsman K. preprint CERN-PPE/91-160, Geneva, 1991.

[3] S.I.Bityukov et al. Phys.Lett. B188 (1987) 383

[4] F.E.Close, H.J.Lipkin, Phys.Lett. B196 (1987) 245
Dover C.B., Fishbane P.M., Phys.Rev.Lett., 1989, v.62, p.2917.
Landsberg L.G. Fiz.Elem.Chast.Yadr., 1990, v.21, p.1054.
Landsberg L.G., preprint IHEP 91-44, Protvino, 1991.
N.N.Achasov, Pis'ma Zh. Eksp. Teor. Fiz. 43 (1986) 410.

[5] Amsler C., Adv.Nucl.Phys., 1988, v.18, p.183.
Amsler C., Myhrer F., 1991. Ann.Rev.Nucl.Part.Sci.. 1991, v.41, p.219.

[6] B.Z.Kopeliovich Yad. Fiz., 45(1987)1742

[7] Proceedings of the SuperLEAR Workshop, University of Zurich, 9-12 October 1991, Institute of Physics Conf. Series N.124, Bristol, 1992, edited by C.Amsler and D.Urner.

[8] Amsler C. et al., preprint CERN-PPE 91-215, Geneva. 1991.

[9] Baglin C. et al., Phys.Lett., 1986, v.B171, p.135; ibid.B172, p.455; v.B187, p.191; v.B195, p.85

[10] Armstrong T.A. et al., Nucl.Phys., 1992, v.B373, p.35.; Phys. Rev.Lett., 1992, v.68, p.1468.
Cester R. , in ref.7, p.91.

[11] Ableev V.G. et al., CERN-SPSLC 92-36, Geneva, 1992.

[12] Anassontzis E. et al., Phys.Rev. D38 (1988) 1377.

Received by Publishing Department
on August 12, 1992.

Банников А.В. и др. E1-92-344

Рождение дрелл-яновских лептонных пар
в аннигиляции антипротонов как способ
для поиска четырехкварковых состояний

Предлагается провести поиск 4-кварковых состояний в дрелл-яновских процессах аннигиляции антипротонов типа $\overline{p} + p \to e^+ + e^- + X$. Поскольку дрелл-яновский механизм по определению гарантирует аннигиляцию пары кварк–антикварк, то лептонная пара служит меткой образования 4-кваркового состояния.

Мы исследовали возможности регистрации дрелл-яновских пар в детекторе, который планируется создать на внутреннем пучке накопителя SuperLEAR. При светимости 10^{32} см$^{-2}$с$^{-1}$ ожидаемый выход дрелл-яновских пар с эффективной массой $1{,}5 < M < 3$ ГэВ составит около 288 событий/день при импульсе антипротонов ≈ 6 ГэВ/с.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1992

Bannikov A.V. et al. E1-92-344

Drell-Yan Lepton Pair Production in Antiproton
Annihilation for Searching of the Four-Quark States

It is proposed to look for 4-quark systems formed in the Drell-Yan processes of antiproton annihilation, like $\overline{p} + p \to e^+ + e^- + X$. The lepton pair is a tag for 4-quark system formation, because the Drell-Yan mechanism guarantees that a pair of a valence quark and antiquark annihilates.

We have investigated the possibilities of registration the lepton pairs in the detector planned for the internal target on the SuperLEAR facility, the estimation of the expected rate was given.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1992