Letter of Intent for J-PARC: Study of antideuteron physics at K1.8BR beam line

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Abstract

Antimatter is a very mysterious existence in the universe. We still don't know where did they go after the big bang. Many interesting investigations on antiproton ($\bar{p}$) have been carried out. However, the property and interaction of antimatter with multiple antinulceons (antinucleus) are still unknown. We have confirmed the existence of a reasonable yield of the antideuteron at K1.8BR beam line. In this LOI, we outlined some possible physics program with $\bar{d}$ beam.

1 Introduction and physics motivation

Antimatter has been a popular topic in science fictions for a long time[1]. This phenomena in popular culture is a royal reflection for the fundamental motivation of human's quest for the unknown. The study of antimatter and its interaction with matter is directly related with one of the most profound questions for today's Physics: matter-antimatter asymmetry of our universe. During the past decades, antiproton ($\bar{p}$) has been the main target of study with various approaches: elastic scattering to derive optical potential[2], formation and measurement of antihydrogen[3], and production of glueball with $\bar{p}$[4]. It has been learned that there is a strong absorptive potential between $\bar{p}$ and ^{12}C (-20+60i[MeV])[2]; antihydrogen possesses the same transition pattern as hydrogen up to ∼2 parts in 10 billion[3]. It is worth to note that no matter how precise one can measure the antiproton property, it can not disclose the mystery of antimatter itself.[1]

A natural direction to extend the study of antimatter is to go for antinucleus with multiple antinucleons. However, due to the extremely low yield, the only practical candidate is antideuteron ($\bar{d}$)[5]. Even for this simplest antinucleus, we don't really know much yet except that it annihilates with matter[6]. There are many interesting questions one might ask for $\bar{d}$:

1. What is the ground state property of $\bar{d}$, such as its mass, spin and isospin?
2. What is the potential between $\bar{d}$ and matter?
3. What is the annihilation scenario between $\bar{d}$ and matter? Will the two antinucleons annihilate in one-step reaction or two-step?
4. Will the annihilation of $\bar{d}$ with matter produce some exotic form of matter such as a cold QGP?

[1]For a good analogy, please recall the role played by deuteron and proton in nuclear physics.

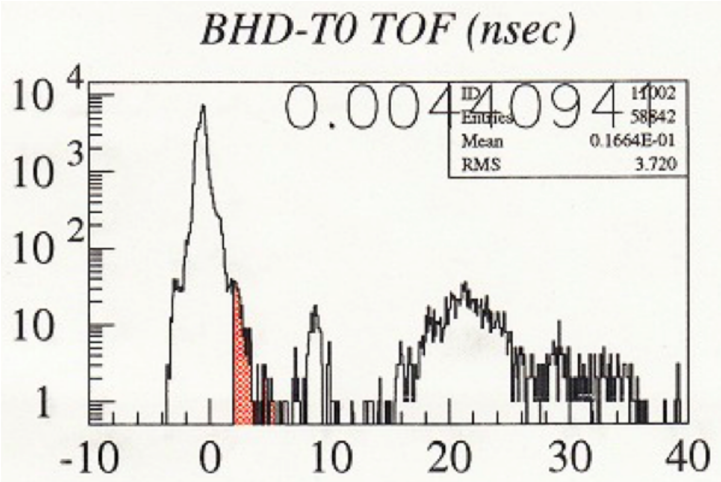

Figure 1: K18BR beam line TOF spectrum. The three peaks from the left is π^-, $\bar{p}$ and $\bar{d}$, respectively.

With the original prestudy carried out by one of the authors, Dr. Sakuma, we found that there is a reasonable yield of $\bar{d}$ of $\sim$1/spill (1 spill$\sim$6 seconds) at J-PARC K1.8BR beam line, which is consistent with a previous estimation by Dr.Iazzi[5] after scaling the actual beam power. Even though all the questions listed above are essential to understand the $\bar{d}$, one has to think about a practical approach given the $\bar{d}$ *beam* intensity at the present stage. We propose to start with full stop experiment with a bulk ^{12}C (low density graphite) target and carry out experiment with light target such as liquid deuteron and liquid hydrogen target later on. But before the data taking, it is also necessary to spend some dedicated beam time to optimize the $\bar{d}$ beam condition at K1.8BR beam line.

1.1 $\bar{d}$ yield optimization at K1.8BR beam line

Up to now, we (Dr. Sakuma) could only utilize a few hours beam time to confirm the existence of $\bar{d}$ with 1/spill yield around 1GeV/c as shown in Fig.1. A more dedicated $\bar{d}$ beam optimization is needed to efficiently use the beam time and achieve a more reliable beam time request.[2] We would like to point out that the production mechanism of $\bar{d}$ below 2GeV/c with higher energy proton is still largely unknown[5]. A detailed scan of $\bar{d}$ yield together with beam transportation calculation for K1.8BR beam line will given some insight to this topic too.

1.2 Full absorption setup

Given the low yield of $\bar{d}$ beam, we propose to start with full stop setup using thick ^{12}C graphite as target because of the 100% event rate per $\bar{d}$ particle. According to our estimation, a mass thickness of 20g/cm^2 graphite target is sufficient to fully stop and absorb the $\bar{d}$ of 1GeV/c. The majority of the $\bar{d}$ will annihilate with ^{12}C nucleus and a few percent of antineutron flies out after the accompanying antiproton annihilates. With this setup, we can study the annihilation mechanism of $\bar{d}$ and given answer to the question such as whether the annihilation is in one-step or two-step process.

The average multiplicity of stopped antiproton annihilates with proton is $\sim$5 pion tracks. If the two antinucleon inside $\bar{d}$ annihilate in a relative independent way (two-step process), the

[2] In this LOI, we will assume the $\bar{d}$ yield as 1/spill.

averaged multiplicity will not be much deviated from twice of the $\bar{p}p$ case. However, if the two antinucleons annihilate simultaneously with ^{12}C nucleus, one can expect the number of multiplicity has some enhancement due to the shielding effect of pion absorption[8].[3]

Another output from this setup is to search for the signal of a cold QGP production. The experimental observable will be the enhanced yield of strangeness[7]. A detailed study of the strangeness yield with $\bar{d}$ will also show the feasibility of future muti-strangeness physics such as KKpp system formation.

1.3 Light target setup

With higher $\bar{d}$ beam intensity, one can perform *semi-scattering* experiment. With a liquid hydrogen target, one could study the following two topics:

1. By requesting $\bar{p}$ annihilates with hydrogen and $\bar{n}$ flies out, one can probe the $\bar{n}$ momentum distribution and learn something about the $\bar{d}$ ground state.[5]

2. By measuring absorption cross section of $\bar{d}$ on a proton, one can address the Glauber shadowing correction due to the wave function of the $\bar{d}$.[8] (Is it just $\sigma_{\bar{p}p} + \sigma_{\bar{n}p}$ or less?)

It will also be interesting to directly compare the products of $\bar{p}$+d and $\bar{d}$+p reaction, which is a direct C-symmetry operation.

2 Experimental setup

A challenging task for studying $\bar{d}$ annihilation is to perform tracking for high multiplicity events, whose average multiplicity is ∼10. We propose to accomplish this by combining Cylindrical Tracking System (CDS) at K1.8BR beam line with a cylindrical scintillation fiber tracking system surrounding the target. The proposed experimental setup is given in Fig.2. The CDS at K1.8BR beam line is actively serving several experiments and has a established performance.[9] However, one needs to enhance its capability for high multiplicity tracking task. For this purpose, we propose to construct a Cylindrical fiber Tracker (CDT) as outlined as green parts of Fig.2.

2.1 Design of CDT

Based our experience for the K^- beam profile at K1.8BR beam line, we can expect the $\bar{d}$ particle has a traverse distribution of ∼7cm. In order to maximize the usage of $\bar{d}$ beam, we plan to employ low density graphite ^{12}C target with a diameter of 7cm. In order to minimize the transverse momentum loss of the annihilation products and suppress the absorption for low momentum mesons and nucleons inside target, we plan to use a low density graphite of ∼0.5g/cm^3, whcih is 25% of the normal graphite density. The longitudinal target mass thickness can be compensated by increasing the length of the target in z-direction. As a result, a 40cm long low density graphite will be used.

As mentioned in the Section 1, the average multiplicity will be ∼10. The Cylindrical Drift Chamber (CDC) inside CDS will be suffered from large combinatorial background caused by this high multiplicity. We propose to construct a Cylindrical fiber Tracker (CDT) surrounding the graphite target. The planned CDT has a inner diameter of 7cm and outer diameter of 8cm.

[3]For a more quantitative discussion, transportation model calculation such as GiBUU is indispensable. However, because the lack of experimental data, the theoretical investigation for $\bar{d}$ annihilation is still missing. Our result will inspire the relevant study.

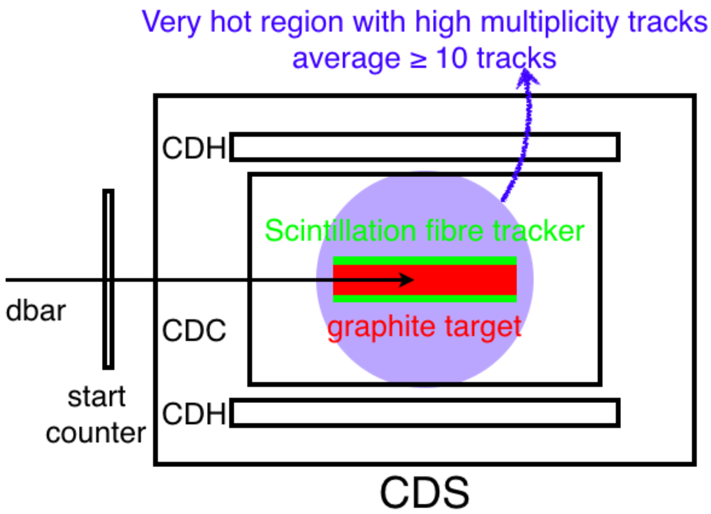

Figure 2: Conceptual experiment setup.

The scintillation fiber will have a diameter of 1mm and readout by Si PMT (MPPC). In total, ∼1k channels will be used. There will be ∼5 layers of fibers to help pin down the combinatorial background in CDC.

2.2 Antineutron detection

Most of the $\bar{d}$ will annihilate with ^{12}C nucleus in graphite target. However, there will be physical interest to measure the $\bar{n}$ flies out with liquid hydrogen target setup as described in Section 1. To achieve the measurement of $\bar{n}$, one can utilize the neutron counter constructed for E15 experiment[9].

2.3 Trigger design and data taking

Because of the large mass of $\bar{d}$, the time of flight of $\bar{d}$ will be much longer than the other type of beam particles. The beam line TOF can be used as online trigger for data taking. The signal from the MPPC of Cylindrical fiber Tracker (CDT) will be read out by Kalliope developed by KEK mainly for muon application[10] in common stop mode. The Kalliope has the time-over-threshold capability, whcih may help to do PID with energy deposit information. The data taken with Kalliope will merge into the existing K1.8BR DAQ system by applying the synchronised $\bar{d}$ beam trigger.

3 Cost estimation and beam time request

3.1 Cost estimation

The main part of the proposed setup, CDS and neutron counter (NC), are already exist. We can effectively save the cost for construting new apparatus except the Cylindrical fiber Tracker (CDT). According to our estimation, we can accomplish the construction with the budget of ∼20MYen. We will apply for the funding support from Kakenhi category.

3.2 Beam time request

0.5 day beam tuning; 1 day detector commissioning; 3 days beam time. 600/hour × 24 hours/-day × 3 days = 40k events

4 Acknowledgment

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