BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
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ACCELERATOR DEPARTMENT
Informal Report

ISABELLE FOR VERY LOW ENERGY PP EXPERIMENTS: WHIPLASH

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ISABELLE PROJECT

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Recent observations on $N\bar{N}$ annihilations at low energies (~ 15 MeV center of mass energy) suggest that interesting physics problems lie in this energy region. The observation of $\bar{p}p \rightarrow 2\pi^0$ at rest by Columbia-Syracuse (submitted to PRL) has seriously contradicted the decade long belief that captures at rest proceed via S-states. Alf ven in Physics Today V. 24(71) points out that the annihilation cross-section at ~ 1 eV is crucial for the matter-antimatter models of the universe. In spite of a decade of experimentation with antiprotons at low energies, we only have results on annihilation at rest (protonium in liquid hydrogen) and we know reliably the cross-sections $\gtrsim 250$ MeV/c (15 MeV cm energy).

I have considered over the years various schemes in order to be able to study low energies. Even with the most optimistic extrapolation of hardware and imagination the results came out to be discouraging. All these schemes had one point in common: the target being stationary in the laboratory system.

Starting with antiproton beams, the principal constraints are:

(a) The number of antiprotons annihilating in flight over those stopping decreases rapidly with decreasing energy. (b) The identification problem. This problem can in principle be solved by using a gas target, however, this will be done at the great expense of flux since $\delta p/p$ has to become small. Both these problems will be absent in the event that $\bar{n}$ beams could be made. I have examined

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the possibilities of $\bar{n}$ "beams" produced via $\bar{p}p \rightarrow \bar{n}n$. The smallness of $d\sigma/d\Omega|_{180^\circ}$ (which produces low energy $\bar{n}$); the difficulties of geometry and the difficulties associated with tagging the $\bar{n}$ energy by measuring the $\vec{p}_n$ are too great to make possible the study of $N\bar{N}$ at low energies with a stationary target.

The purpose of this note is to bring to attention that if antiproton-proton beams will be stored running in the same direction (WHIPLASH mode) very small cm $\bar{p}p$ energies can be achieved in contrast to the standard case (HEAD-ON) which yields very high energies. I will not discuss, here, the questions of physics in $N\bar{N}$ at low energies (eV-MeV range) except to point out that:

(a) At these low energies, the Coulomb, nuclear (pion range) and annihilation potentials will be contributing all in an important way and their superposition is bound to exhibit interesting variations. (b) Since the annihilations at rest have not provided a "nice" system - via s-captures -, we may still be able to define an energy in which S-waves are dominant and those test the prediction of symmetries.

I urge that serious thought be given for storing antiprotons in ISABELLE for high energy as well as low $\bar{p}p$ experiments. The high energy $\bar{p}p$ experiments together with the corresponding pp will give the only direct test of Pomeranchuk theorem at the highest possible energies. On the other hand, the low energy experiments will be the lowest possible energy experiments that we will ever do. It is my belief that many revealing surprises will lie at these low energies. The order of magnitude estimate for storing $\bar{p}$ without cooling made by R. Palmer (BNL16013)

are more than adequate for doing even "exotic" $\bar{p}p$ experiments at low energies. This proposal gives the basic parameters which have to be considered for WHIPLASH. It is clear from the above that such a facility will be unique.

1. The Principle of WHIPLASH

The total cms energy ($E \equiv Q+2m$) is given by

$$E^2 = (\omega + \omega')^2 - (\vec{p} + \vec{p}')^2$$

where $\vec{p}, \vec{p}'$ are the two beam momenta such that

$$|\vec{p} - \vec{p}'| \ll |\vec{p}|$$

With the approximation

$$\left[1 + \{ |\vec{p} - \vec{p}'|^2 - 2\vec{p} \cdot (\vec{p} - \vec{p}') \} / \omega^2 \right]^{1/2} \approx 1 + \{ |\vec{p} - \vec{p}'|^2 - 2\vec{p} \cdot (\vec{p} - \vec{p}') \} / 2\omega^2$$

and $E + 2m \approx 4m$ we obtain

$$4mQ = (\vec{p}_\perp - \vec{p}'_\perp)^2 + (p_\parallel - p'_\parallel)^2 \quad (1)$$

where the average $\vec{p}$ direction defines the transverse and longitudinal components. From (1) we see that by suitable choice of the two beam momenta any Q is possible. It also shows that the spreads in the longitudinal and transverse components in the beams will define the resolution in $Q(\delta Q)$, which defines the energy at which an experiment can be performed. In principle there is no limit in controlling $\delta \vec{p}_\perp$ and $\delta p_\parallel$ but this will have as a consequence, corresponding reflections on the beam fluxes. Any arbitrary δQ can be reached if the flux sacrifices are tolerable.

2. Interaction Rate

In head-on collisions, the bunches cross each other completely while transversing the interaction region (L_i) and consequently any one particle of one bunch has a chance of interacting with all other particles of the other bunch. In WHIPLASH, each particle sees only a fraction of the other bunch over the interaction region and this depends on the relative velocity (v) and the time (τ) that it takes to transverse the interaction region.

This overlap factor (f_o) is

$$f_o = \frac{v\tau}{L_b} = \frac{v}{c} \frac{L_i}{L_b} = 2\sqrt{\frac{Q}{m}} \frac{L_i}{L_b} \leq 1 \quad (2)$$

where L_b is the bunch length (assuming the same for both beams). The rates for WHIPLASH (R_w) and head-on (R_H), for otherwise identical beams, will be related through the overlap factor and their respective cross-sections..

$$R_w = f_o \cdot \frac{\sigma_w}{\sigma_H} \cdot R_H \quad (3)$$

The f_o cannot become greater than one by definition but it may become large by suitable adjustment of L_i/L_b .

It is known that the annihilation cross-section is increasing as $1/v$ at low energies, which is equivalent to $1/\sqrt{Q}$, and it is likely at very low energies (where the Coulomb field will be important) to approach the unitarity limit of $1/v^2$ ($1/Q$). Consequently, $f_o \sigma_w$ is likely to remain constant or increase with

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decreasing Q . At $Q = 45$ MeV (300 MeV/c Lab) $\sigma \approx 100$ mb and it is seen increasing as $1/\sqrt{Q}$. Moreover, $\sigma_H \sim 40$ mb and thus

$$f_o \frac{\sigma_w}{\sigma_H} \geq \frac{L_i}{L_b} \quad (4)$$

Consequently, even for the case of $L_i = L_b$, $R_w \geq R_H$! We thus conclude that the "rate problem" is equivalent to that for head-on ISR's or it may easily become "easier". The actual rates, however, will be determined by the fluxes which can be stored compatible with the resolution required.

3. Antiproton Flux

R. Palmer (BNL 16013) has estimated that in about two weeks the ISABELLE storage ring phase space can be filled with 2×10^{10} antiprotons with $\delta p/p = 10^{-2}$ at 2 GeV and a half beam angular spread of 2 mrad corresponding to a transverse momentum of 4 MeV/c. In this estimate, no cooling has been assumed. The largest annihilation experiments done up to now at low energies (at rest) consist of $\sim 10^7$ annihilation. Clearly, the total number of $\bar{p}$'s within Palmer's estimate will not be a problem for good annihilation-experiments. The resolution in Q will be due to $\delta p/p$. From (1) by substituting $\delta(p_{||} - p'_{||})^2 \approx (p \cdot \frac{\delta p}{p})^2$ we get

$$\delta Q \sim \frac{1}{4m} (p \cdot \frac{\delta p}{p})^2 = 0.1 \text{ MeV}$$

and thus experiments down to 100 KV can be done with high fluxes. By decreasing $\frac{\delta p}{p}$, the resolution is increasing $\propto (\frac{\delta p}{p})^2$ while the $\bar{p}$ flux goes linearly with $\delta p/p$ and consequently a wide range of

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Q's can be explored in the KV and MeV region and possibly in the ev.

Palmer also estimates that with $2 \times 10^{10} \bar{p}$ stored in the head-on configuration 10^4 interaction/sec will occur. In §2 we concluded that $R_W \sim R_H$ and consequently with $10^{10} \bar{p}$ stored many (100!) experiments, each consisting of $\sim 10^7$ annihilations, can be done over the course of a fraction of a year!

4. Experimental "Kinematics"

In contrast to the head-on experiments which have "forward-back" cones and arbitrarily large momentum transfers are possible, in WHIPLASH only a forward cone with a maximum half angle of $\sim m/p$ will only be present. Consequently, the 4π geometry required for studying annihilations at low energies with stationary targets is reduced to a small cone whose angle is controlled by the beam momentum. This, considerably simplifies the experimental requirements and it will make possible the design of experiments which are hard to do otherwise at low energies. The high energies of the annihilation products as well as the absence of a target will reduce corrections due to secondary interactions, Coulomb scattering etc.

5. Protonium Beams?

At very low energies protonium will be formed and it will be moving in free space with a momentum twice the beam momentum. In this case there will be no Stark mixing effect and the radiative transitions will compete with annihilations. Various esti-

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mates indicate that the radiative transitions will compete with the annihilation at the rate of $\sim 10^{10} \text{ sec}^{-1}$. Consequently, the protonium will transverse a distance of

$$10^{10} c \cdot \gamma = 3 \times \frac{p}{m} \approx 6 \text{ meters !}$$

at 200 GeV beam momentum! The radiative transition X-rays will have higher energies on the average by the factor γ and they will be mainly emitted forward and thus correlation experiments of annihilations from specific atomic states might be possible.