Summary Of the Fixed Target Architecture Group
at the Fermilab Beauty Workshop

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I. Introduction:

The fixed target approach to high sensitivity B physics has the important advantages of high luminosity, limited solid angle for acceptance of the reaction and the B decay products and the relatively high momentum of the B and its decay products. The last advantage is important for various triggers that have been considered for particular experiments[1]. On the other hand, the fixed target approach has the disadvantage of small signal to background with B production expected to be 10^{-7} to 10^{-6} of the total cross section at Fermilab fixed target energies. Therefore, the development of suitable experiment architectures and techniques, which allow separation of the B signal from the total cross section at both the trigger and analysis stages of a fixed target experiment in order to take advantage of the practically unlimited luminosity, is at a premium.

The broad goals of our workshop efforts were to attempt to answer the following questions:

1. Can the B signal be reliably separated from the backgrounds in a high rate fixed target experiment?

2. Is there an "ideal" architecture or an optimum strategy for a fixed target B spectrometer?

Central to both questions is the basic kinematic character of hadronic B production. Therefore, various Monte Carlo studies represented an important part of the workshop effort. The contribution of M. Purohit[2] to this workshop summarizes a number of useful results.

Question 1 can only be answered properly in the context of the ability of particular detector architectures and trigger strategies to separate specific decay modes from their backgrounds. Considerable work on this question has been done prior to the workshop by particular experiments which aim at obtaining large samples of B's (for example, E771[3] and the P789[4]). The general consensus of the participants in the workshop was that such experiments could be successfully executed if properly designed. It was also felt by the participants that the detailed calculation of signals and backgrounds was critical in evaluating any experimental architecture or strategy. A new contribution by Kaplan, Peng and Abrams and Stockdale[5] carried out at the workshop was the calculation of the size of signal for various B two body decay modes relative to backgrounds due to the charm decays in the proposed P789 Fermilab experiment.

With respect to question 2, no definitive answer was arrived at in the workshop but there was some prejudice that there was no ideal apparatus to do all things. This is partly because an optimum architecture or strategy is hard to arrive at in the absence of fundamental information about the B system such as production cross sections and branching ratios. But, in addition, the specificity of experiments which are optimized for particular modes is striking. Indeed, fundamentally different architectures may be required for different types of decays or even different aspects of B decay. A number of papers contributed to the workshop describe the proposed

architectures and some of the key devices they will contain (e.g. the distributed silicon target and the ring imaging Cerenkov counter for E771[6]). There were interesting new ideas on (particle) remote imaging systems for semiclosed architectures by Bjorken, Wehman and Jenson[7]. These and related ideas are discussed in somewhat more detail later in this summary. Only after more information is obtained about the B system will it become evident whether one optimum generalized architecture for B experiments exists. It may well be that the development of several specific architectures to study particular final states and different aspects of the B system will the correct approach to fixed target B physics.

Finally, we note that many topics which are critical to the design of a fixed target B spectrometer were covered in other sections of the workshop. These include studies of trigger schemes and processors, and data acquisition systems.

II. Acceptances

The calculations of Purohit and others[2,3,4] have several important consequences for fixed target B spectrometers. The key factor for determining the required maximum angular acceptance for the fixed target B spectrometers is the necessity for detecting all of the decay tracks from B decay. For the physics goals of the high sensitivity B experiments such as rare decays and CP violation, all of the tracks from a B decay must be detected. For experiments which, in addition, propose to detect the second B in the event for purposes of tagging the particle or antiparticle nature of the first B, this acceptance must be somewhat larger. However, because of the forward throw of the B decays due to the Lorentz boost of fixed target experiments, this acceptance for fixed target experiments need not be particularly large (unlike the case for TeV I B events). For 900 GeV/c proton-nucleon interactions, a maximum acceptance angle of approximately ±200 mr is all that is needed for an 80% containment probability (i.e. 80% of all decays will have all tracks from a given B in the acceptance of the apparatus).

In a similar way, the minimum angle of the B decay products to be detected must be determined. The calculations show that particles must be detected down to a few mr for good containment efficiency. For example, an acceptance which covers the angular range between 3 and 200 mr will have about 80% containment efficiency. For a minimum coverage angle of 10 mr this drops to 65%. Detailed containment efficiency contours are presented in reference 2 for a range of θ_{min} and θ_{max}.

III. Background Studies

A major new contribution by Kaplan et. al.[5] at the workshop was the detailed study of the backgrounds to two body B decay modes due to charm decays in a semiclosed geometry architecture of the proposed Fermilab experiment P789. They conclude that charm backgrounds are small compared to the two body (charmless) B decay modes in P789. An interesting insight gained from their study is that tuning the B acceptance for 90 degree decay in the B center of mass is an important factor in maintaining high B acceptance and low charm (background!) acceptance. It is also interesting (although this is a very specific study) that the results from "back of the envelope" calculations for these particular two body decay modes have been verified by this careful, detailed Monte Carlo study.

However, although charm is the only real physics background to the two body B decays, actual experiments taking into account real resolutions in vertexing, mass measurements, etc., will have many other sources of backgrounds in an experiment such as P789. These were qualitatively discussed at the workshop but no detailed calculations were carried out. There was a general consensus that it would be essential to have sufficiently redundant tracking in the vertex detection

so that false tracks will be kept to an acceptably low level.

As an example of an open architecture experiment, Fermilab experiment E771 was reviewed in the course of the workshop and its technique for rejecting background was discussed. This experiment plans to detect B's in an open geometry by their J/Ψ decay modes. The observation of a J/Ψ at a secondary vertex is an unambiguous flag that beauty is present. The backgrounds to such a study are the directly produced J/Ψ's from the primary vertex which are badly mismeasured and appear to form a secondary vertex. Monte Carlo estimates of the multiple scattering of the muons from the J/Ψ decays in the E771 silicon tracker (done prior to the workshop by the E771 experimenters) indicate that a rejection of directly produced J/Ψ's by several orders of magnitude was possible if the observed secondary vertex was required to be more than 50 microns away from the primary vertex in the plane transverse to the beam. This requirement is expected to eliminate only approximately one half of the real B decays. Therefore, the focus of the experiment on the μ pairs from secondary J/Ψ decays seems likely be a very powerful tool to greatly reduce the backgrounds to the B signal.

The general consensus of the the workshop was that the current round of proposed or approved fixed target experiments would cast a great deal of light on the ability of fixed target experiments to extract B signals. These experiments will also define more clearly the problems which will need solution for high rate, high sensitivity experiments to succeed. These results should become available in the near future.

IV. Architectures

The possible architectures for a fixed target B spectrometer fall into two broad categories:

1. Semi-Closed Designs

These designs "look' at the target with a rather small acceptance which serves to protect most of the detector components from the bulk of the radiation from the target. These designs permit high interaction rates which ideally, will more than compensate for the limited B acceptance. The salient principle on which such detectors must, therefore, work is the selection of a region of phase space which is relatively rich in B decays but which avoid most of the particles from the average total cross section events.

In some semi-closed approaches vertex detectors are used in the region close to the target. The proposal, P789 is an example of such a design and the problems of the silicon microstrip detector (track overlaps, and especially radiation damage) are major concerns in that approach. At the workshop, these problems did not appear to be intractable but considerable work remains to be done to verify this.

Another interesting semi-closed approach was developed by Bjorken and studied in detail by Wehman and Jensen. In this approach the charged particles emitted in the target region (direct and from downstream decays) are transported and imaged at a downstream location. The imaging is momentum dependent so the downstream detector, e.g., the silicon microstrip detector system, would have to have an appropriate longitudinal extent. This detector plays the role of the "classical" vertex detector and would be followed by a more or less conventional spectrometer to measure momentum, identify particles, etc.

At first sight, one might think that such a scheme would require unrealistic precision in the magnet transport and focussing system. A more thoughtful analysis, however, shows that this is

not the case and that a calibration procedure can be developed which in effect measures the relevant transport properties to adequate precision to permit the "transported" vertex detector to usefully identify particles originating downstream of the target (i.e., B decays).

In comparing the remote imaging design with the conventional semi-closed design, it seems that the B yield would be considerably larger for the conventional design. There is a large caveat, however, in that it remains to be demonstrated that silicon microstrip detectors can survive and work usefully in the intense radiation environment which would be unavoidable at the interesting levels of sensitivity.

One final comment applies to all semi-closed architectures. By design these geometries have small (few %) acceptances for B's. Therefore, they have a very small acceptance for what is called "tagging". Tagging refers to the determination of some important characteristics of one B (e.g., whether it is a B or a B) by studying the decay of the other B. Most CP and mixing studies require such knowledge. The semi-closed systems will not be useful for experiments which require particle by particle tagging. A strategy for searching for CP violation which may be feasible and which does not demand particle by particle tagging depends on the existence of production asymmetries (e.g. regions of phase space such as the large x_f region where more B's than B's may be produced). This strategy would involve determining where these special regions were and comparing certain aspects of the B or B decays (such as the time distributions) in these regions with the distributions from other regions of phase space. If such a technique for observing CP violation is not sensitive enough, then only open geometry spectrometers employing particle by particle tagging will be able to look for CP violation.

2. Open designs

Open design refers to spectrometer configurations which attempt to measure all tracks in a large portion of the forward hemisphere in order to pick up all B decay products. In the case of open geometry experiments the vertex detector is arranged for the most part along the beam although there are considerable differences in the possible arrangements. There are several spectrometers which fall into this general category such as the Tagged Photon Laboratory (E769), High Intensity Laboratory (E771), and Broad Band Photon Beam (E687) detectors which are either studying charm or, in the case of E771, planning to measure beauty production.

Many of the key technical issues of open geometry designs such as specific trigger strategies, design of high rate detectors and design of data acquisition systems are addressed in other sessions of the workshop. The intention of these deliberations is the specification of strategies and equipment which will allow the contradictory goals of large acceptance, high rates and excellent high resolution spectroscopy to be achieved in a high rate environment.

The fixed target architecture group had a considerable discussion of various aspects of different open spectrometer designs. The design of E771 which is intended to allow the experiment designed to run at rates of up to 10^7 Hz of 800-925 GeV/c proton-nucleon interactions, as mentioned above, was reviewed. This experiment operating at 10^7 interactions per second for running times of several 10^6 seconds might be expected, after acceptances, efficiencies, and cuts are taken into account, to reconstruct several thousand of these decays. Other experiments such as P789 might be expected to obtain similar numbers of events if backgrounds are not intractable.

One of the most important issues in the configuration of such open geometry experiments is the coupling between the silicon detector design and the beam configuration. In particular, the use of a proton beam allows some latitude in the choices for the design of the silicon detectors for open geometry experiments. These issues were discussed in the workshop. For example, in order to

minimize localized radiation damage while keeping the amount of silicon detector to be instrumented to a minimum, E771 has chosen to operate with a relatively large beam spot distributed over the active area of the silicon detector. An alternative configuration would be to have a tightly focussed proton beam (simulating as nearly as possible the 10 micron beam radius that is expected at the SSC). If that sort of spot size were possible with the Fermilab extracted proton beam, then a small aperture could be left for this "needle" beam through a relatively closely spaced, economically set of small planes. Unfortunately, even taking a relatively optimistic estimate of the emittance of the extracted proton beam, B. Baller has calculated that a superconducting quadrupole focussing system could produce a 100 x 180 micron beam (at the 3 σ point). For a 2.5 cm spacing between the target foil in the silicon tracker and the first measurement planes (an appropriate spacing which would allow for the decay of the majority of B's produced in 900 GeV/c interactions), this spot size would correspond approximately to θ^x_{min}=4 mr and θ^y_{min}=7.5 mr, already beginning to cut into the containment efficiency. A more realistic emittance will probably produce a considerably larger minimum beam spot leading to an unaccceptable loss of B's.

In the studies performed for the workshop by Purohit[2], the optimal disposition of the silicon in an open design spectrometer unconstrained by practicality and cost considerations was investigated. He points out an ideal solution which minimizes radiation damage to the detector due to both the beam and secondaries. In this solution, the planes closest to the target have relatively large holes in the detector (i.e. large θ_{min}) and the ones farther away have successively smaller holes (i.e. successively smaller θ_{min}). The layers are also spaced to minimize the effects of multiple scattering.

V. Summary and Conclusions

The workshop was very useful in clarifying issues and in educating the participants. The following conclusions can be drawn from our deliberations:

1. The utility of the fixed target approach for high sensitivity B physics continues to appear promising and competitive with other possibilities for B experiments.

2. Both semi-closed and open geometry architectures remain as potentially viable approaches.

3. The experience of the current round of fixed target experiments will be very important in evaluating the potential of fixed target approach to B physics. The results of the present experiments should indicate whether a generalized major detector initiative should or can be pursued or whether the proper approach is a highly developed set of specialized detectors pursuing specific decay modes and/or specific aspects of B decay.

We conclude with a comment on the organization of this workshop. As was appropriate to the stage of knowledge, this workshop was organized along what might be called subsystem lines with sessions on triggering, detectors, data acquisition, etc. What is now needed is an integrated study building on past work which will consider several designs and strategies in a comparative way. Each group working on a particular individual design should include relevant experts on each aspect of the detector. In this way a realistic estimate of the potential of each approach can be achieved. Hopefully the results of ongoing experiments will inspire the initiatives leading to such efforts in the future.

References

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