II.B VERTEX DETECTION

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The low cross sections, short lifetimes, and complex decay modes of particles containing heavy quarks require detectors that do not yet exist. This view is supported by the fact that although D's are relatively copiously produced even at today's lower energies, fewer than 100 have been detected to date.

A few of the relevant numbers discussed in this workshop are presented below for 1000 hours in a proton beam for (i) a counter experiment with 10^7 protons on a 5% target per 60 s cycle; (ii) a conventional bubble-chamber experiment with 10 expansions/s, 10 s/cycle, 10 tracks/expansion, 10% of an interaction length, and 600,000 expansions (1000 hours); and (iii) a 50ℓ emulsion stack with 700 beam tracks/mm^2.

Particle	σ_H	Events/ 1000 hrs (i)[a]	6×10^5 expansion of a B.C. (ii)	Events/ stack (iii)	Possible Decay	$c\tau$(cm)
Total	40 mb	3×10^{10}	6×10^7	3×10^8	–	–
D	10 μb	7×10^6	1.5×10^4	8×10^4	Kπ(2%) Kππ(16%) Kπππ(4%)	3×10^{-3}
B	10 nb	7000	15	80	π's D μDπ's	3×10^{-6}

[a]Section I assumed 10^7 protons/10 s cycle; faster electronics.

There are three major problems involved in detecting these particles: multiplicity of final states, short decay paths, and low cross sections.

Multiplicity

From the brief table given above, it is apparent that even if $B\bar{B}$ is produced with no additional particles, as might happen in a photon beam, the final state would contain 10-20 particles. $B\bar{B}$ production by a hadron beam at 1 TeV might easily involve 10 additional particles. Because of these complex final states, colliding-beam experiments and conventional counter experiments will have difficulty detecting the non-leptonic decay modes. Some form of vertex detection of the decay points would be very useful.

Resolution

The expected short lifetime of the B indicates that, with a γ of 20 (created at rest in the center of mass for a 1-TeV beam) it travels only 60 μm before decaying into several particles, and after about 6 cm it has perhaps 6 final decay products. A conventional counter experiment could not detect the B decay, and the D decay would be possible only with difficulty. However, a new device under development, an active target of silicon wafers (see Section III.A), shows promise of detecting and triggering on decays in the 50-100 μm range.

Emulsions have grain size in the 1 μm range, which means the B decay vertex could be seen, but they have other difficulties discussed in the section on rate.

There are two other common optical vertex detection devices: bubble chambers and streamer chambers. In the past, decays 1-3 mm from the vertex have been detected in bubble chambers with 200 μm bubbles. Streamer chambers have detected decays with about the same range but have had problems with flares obscuring the vertex region. Recent improvements have been made in most of these devices.

A small high pressure streamer chamber has been built (see Section III.B) in which 50 μm streamers have been photographed with image intensifiers. The use of image intensifiers means that the streamers can be photographed very early in their development, which reduces the problem of flares. The designers hope to be able to photograph 25 μm streamers with further improvements.

Bubble-chamber resolution is improved by using smaller bubbles. LEBC (Little European Bubble Chamber) is 15 Hz and has detected 0.3 mm decays. Another new development is that BIBC (Bern Infinitesimal Bubble Chamber) has been photographed with a laser. In the resulting hologram 8 μm bubbles can be clearly seen (see Section III.D). A prototype of a microsonic chamber (see Section III.C) has been photographed with ~30 μm bubbles, and the designers expect to get 1 μm bubbles in the final device.

Of interest in this discussion is a proposal to build a device FNHS (Fermilab Neutrino Hybrid Spectrometer) (see Section III.E) designed specifically for high rates in a neutrino beam. The design predicts 140 μm bubbles; this would permit detection of D's directly and perhaps B's from reconstruction.

Two very fast, triggerable electronic devices under development have spatial resolution in the 10 μm range, but few points per cm. Both devices can be triggered in about 10 μs, which makes them comparable to a streamer chamber. They also have some 50 ms dead time for film advance. A scintillation camera has 30 μm resolution and data points 100 μm apart (see Section III.H). A microchannel plate with an image intensifier has achieved 10 μm resolution and points 500 μm apart (see Section III.I). Both could detect D's easily and perhaps reconstruct B's. Both devices have possibilities for further improvement.

Detection Rates

D's are made at the rate of about 1 per 6×10^3 interactions or 1 per 6×10^4 pions; B's at the rate of 1 per 6×10^6 interactions or 1 per 6×10^7 pions. Extracting a sample of D's or B's to study requires very sophisticated triggering (see Section II.C), which tends to cut down the number of detected particles. The number of B's produced in a counter experiment is small, so some attention must be paid to increasing the number of incident particles, which means faster electronics. This same problem affects experiments with vertex detectors as discussed below.

On first glance the event rate in an optical device looks abysmally low, but again there have been promising recent developments. A typical number of measured interactions in an experiment with an optical vertex detector is about 10^5, which is comparable to the number of interesting events in the canonical counter experiment listed in the table. To increase the number of interactions in 1000 hours, one could increase the number of beam tracks per picture and/or the cycling rate of the device. The limit on number of beam tracks is a problem in information density; two high multiplicity events in a planar photograph can be disentangled. A hologram increases the number of interactions per photograph which can be disentangled because one has many "planes" of photographs, as in an emulsion stack. Holographic images of interactions with 160 beam tracks in BIBC have been made and were shown at the XX-ICHEP in Madison. Emulsions can take 700 beam tracks/mm^2 (or more, see Section III.J). With this kind of beam track density, one must select which of the interactions should be examined, i.e., the scanning must be triggered. This implies a high precision downstream spectrometer to project tracks back to an approximate vertex in the vertex detector. One experiment used a "removable sheet" to improve the spectrometer's spatial resolution near the target. High precision devices involving silicon strips are being developed as an improvement over PWC's and drift chambers (see Section III.K). Another device with similar precision is a liquid argon device with 10 μm strips 20 μm apart and 10 μm achieved resolution (see Section III.F).

A device which increases the cycling rate is the microsonic chamber, at 104 Hz. The streamer chamber described in Section III.B is about 10^6 Hz. Both of these devices have dead times after a selected, photographed event of about 50 ms for film advance, so again a sophisticated spectrometer is needed to trigger the device.

With all of these improvements, the rates for vertex detectors are comparable to those of a "counter" experiment as listed in column (i). The general consensus of the workshop was that vertex detection, fast electronics, and sophisticated spectrometers and triggering were crucial to studying the b and c quarks and do not yet exist but are achievable by the time the Tevatron exists.