Exploitation of Secondary Vertex Information at the CDF Detector

Final Report for Funding Period 1991-1994

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1. Introduction

In the proposal for this work, submitted in November 1990, I described the application of silicon micro-vertex tracking to hadron collider physics, and outlined a plan of involvement in the first such application, at the CDF Detector, studying $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV at the Fermilab Tevatron. The proposal included discussion on the use of silicon tracking in B physics measurements, and also some speculation on the ability of silicon tracking to aid in identification of the top quark. In the five years since this proposal, we have played a significant role in the installation and commissioning of the first such silicon tracking device at a hadron collider, and the utilization of this device in the discovery of the top quark and the study of B production mechanisms. This paper is a summary of this work.

2. Detector Commissioning and Radiation Protection

Several members of the Michigan group collaborated in the construction and commissioning of the Silicon Vertex Detector (SVX) at CDF. Our responsibilities included offline tracking software and radiation protection. Work on the offline tracking involved the integration of the device into the large CDF code package, as well as attention to the various details necessary for the optimization of the tracking. Our contribution included detailed understanding of the resolution function, the pattern recognition, and data compaction schemes. In addition, we had responsibility for maintaining the tracking algorithm library for the entire collaboration, as well as a broad based regimen of systematic checks on the algorithm.

The promise of the SVX would have been lost if the device could not be protected from degradation by radiation. The first SVX readout chip, mounted on the detector, was expected to suffer in gain and noise starting at integrated exposures of about 15 kRad. We therefore erected a system of radiation monitors near the beam pipe at CDF, and, with the assistance of the FNAL Accelerator Division, we used them to ascertain correlations between beam loss and certain Tevatron activities. We then went on to build and install a set of devices which could protect the silicon detector and its on-board electronics from damage produced by excessive radiation levels at the Tevatron. The most notable component of this protection is a monitor system, built in conjunction with the Tevatron Controls group, which can sense high radiation levels and initiate a Tevatron Abort. This device has performed flawlessly since its installation, and is now an accepted part of Tevatron diagnostics and tuning.

The CDF Silicon Vertex Detector was commissioned and active during the entire data taking period of Run 1A at the Fermilab Tevatron. The radiation protection system designed and operated by the University of Michigan group performed according to plan, and the detector survived the entire run. The total exposure and concomitant radiation damage was in agreement with our predicted extrapolation from the the previous Tevatron run. The Michigan group also played a key role in an optimization of the offline reconstruction

which recovered some of the efficiency loss from radiation damage.

Our contributions to the detector program as well as our work on the Radiation Protection scheme, is summarized in the enclosed article, *"The Silicon Vertex Detector of the Collider Detector at Fermilab"*, which was published in Nuclear Instruments and Methods.

3. Secondary Vertex B Tag and the Discovery of the Top Quark

During the period of this grant, I was appointed co-leader of a CDF Collaboration wide working group assigned to understand and apply a secondary vertex B hadron tag in the long awaited CDF top quark search. The idea here, as outlined in my proposal, is to separate the decay $t\bar{t} \rightarrow Wb$ from the large inclusive $W + \text{jet}$ background by using the precision tracking from the SVX to identify the long lived b quark. This idea worked, and lead the the first hint of a top signal as summarized in *"Evidence for Top Quark Production in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8 \text{ TeV}$ "*, published in Physical Review D50, 2966 (1994). A copy is enclosed.

The systematic work to establish and understand the tagged signal was carried out by the B Tag Group, which involved collaborators from my Michigan group, as well as CDF at large. The group defined a number of B tagging strategies, and developed techniques to evaluate efficiencies and backgrounds in the data. The Michigan group pioneered the use of a "jet probability" algorithm which uses a probabilistic comparison with measured resolution functions to assess the likelihood that the ensemble of tracks in a jet are attached to the origin. This work is summarized in CDF Internal Note 2023 *"B Identification with Jet Probability"* and CDF Internal Note *"Top Search with the SVX Jet Probability B Tag"*, copies enclosed. The Michigan group also worked on a general understanding of the systematics of B tagging with all of the candidate algorithms; we found that all techniques gave efficiencies of about 30 % in top events, balanced against fake tag rates on order of 1 %. Some of this work is summarized in CDF Internal Note 1962 *"Measurement of SVX B Tag Efficiency"*, and CDF Internal Note 2005 *"Search for Top in Lepton + Jet Events with B Tag"*, copies enclosed.

The Top Search with Secondary Vertex B Tag, which grew, in part, out of the ideas in this proposal, has since become a prime tool in the identification of top events, and plays a key role in the recent discovery, as summarized in *"Observation of the Top Quark in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8 \text{ TeV}$ "*, published in Physical Review Letters 74, 2626 (1995).

4. Other Secondary Vertex Physics with B's

In addition to the top work at the high mass frontier, the CDF data set is rich with other experimental applications of vertex information. A student wrote a thesis on the extraction of the beauty hadron fraction in an inclusive muon sample using the muon impact parameter, as summarized in CDF Internal Note 2004 *"Measurement of B Quark Production Cross Section Using Inclusive Muons and SVX Based B Fraction"*, enclosed. Finally, a Research Fellow has developed a technique for extracting heavy flavor fractions from the

shape of the probability distributions returned by the "jet probability" algorithm. This has lead to the first high statistics measurement of correlated heavy flavor production in a hadron collider. A preliminary summary is available in CDF Internal Note 2819, " μ - b Differential Cross Sections" (copy enclosed), and work is continuing.

5. Conclusion and Thanks

All of the evidence above, including the discovery of the top quark, suggests that there is no longer any doubt about the need for **"Exploitation of Secondary Vertex Information at the CDF Detector"**. I thank the U.S. Department of Energy for their generous support in this endeavor.