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The CDF RunIIa Silicon Detector and its upgrade RunIIb ⋆

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Abstract

The CDF RunIIa silicon detector made the transition from commissioning to data taking. CDF's online and offline tracking algorithms, the performance of Layer 00 and the RunIIb silicon upgrade project are covered in this article.

Key words: Silicon, CDF, RunIIa, RunIIb

1 The CDF Silicon Detector in RunIIa

The Collider Detector at Fermilab (CDF) pursues a broad physics program at Fermilab's Tevatron proton-antiproton collider. With a expected luminosity of $2 - 8\,\text{fb}^{-1}$ it will allow precise measurement of the top quark and W boson masses, measurement of CP violation and B_s–mixing, and also perform searches for new physics signatures. To realize these goals lepton identification and heavy quark tagging is needed with large acceptance. Hence, CDF replaced the RunI silicon detector with an entirely new detector for the start of RunIIa of the Tevatron[1]. The RunIIa silicon detector has nearly twice the coverage of both the luminous region and pseudorapidity (η), the ability to do three dimensional tracking, and enhanced impact parameter resolution for better B tagging than the RunI silicon detector. The 8 layer, 704 ladder, 722432 channel RunIIa silicon detector consists of three subdectors: SVXII, ISL and Layer 00. The commissioning of the CDF RunIIa silicon detector [2,3] was completed in June 2002 and 92.5% of modules are operating, of which 87%

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are good ladders with an error rate below 1%. CDF has been taking data with 98% of the silicon detector on, meaning that the CDF RunIIa silicon detector has been recording reliably physics quality data.

1.1 Silicon Tracking Algorithms

The data recorded by the silicon detector is used to reconstruct online and offline tracks. Online, the innovative secondary vertex trigger (SVT) [4] reconstructs axial tracks in the SVXII detector within $15\,\mu sec$ with a tracking efficiency of 80%. Speed is achieved with custom VLSI pattern recognition, linearized track fitting, pipelining, and parallel processing. SVT's $35\,\mu$m impact parameter resolution enables CDF's level 2 trigger to distinguish long-lived decays, and hence to collect large samples of hadronic bottom and charm decays. SVT's impact parameter resolution for $p_T \simeq 2\,$GeV is comparable to that of offline tracks. CDF developed several offline silicon tracking algorithms, which complement one another. These are a drift chamber (COT) seeded outside-in, a calorimeter seeded outside-in silicon tracking and an un-seeded silicon standalone tracking algorithm. The un-seeded silicon standalone and the calorimeter seeded silicon tracking, exploits the forward coverage of ISL to allow tracking in the forward region. Currently the collaboration is also working on the development of an inside-out seeded silicon tracking algorithm. We will concentrate in this article on the outside-in silicon tracking algorithms. The COT seeded algorithm uses COT tracks and a progressive road search to attach silicon hits. The track fitting incorporates the passive material distribution in the detector volume and is done in two passes: r-ϕ, r-z. The outside-in COT silicon track reconstruction is fast enough to be used in the level 3 trigger. The average tracking efficiency of this algorithm is 94% and it has a fake rate of 1.18%, which is half of the RunI fake rate. The mass resolution for J/Ψ is 15 MeV. The decay length resolution for two COT outside-in seeded silicon tracks is $63\,\mu$m. The acceptance of the COT is limiting this algorithm to seed silicon tracks only in the central detector region ($|\eta| < 1.1$). However, the calorimeter seeded outside-in silicon tracking is enabling CDF to reconstruct silicon tracks, outside the COT acceptance, in the forward region ($|\eta| > 1.1$) with high efficiency and low charge mis-identification rates. Tracks are seeded by using position and energy measurements from the calorimeter and the primary event vertex. These three quantities are defining the helix (the seed track), which is used instead of a COT track to seed silicon tracks. The same silicon pattern recognition algorithm is used for both of CDF's outside-in silicon tracking algorithms. Efficiencies of 55%-80% and charge mis-identificatioin rates between 1% to 10% for $1 < \eta < 2$ are achieved with the calorimeter seeded outside-in silicon tracking algorithm, see Figure 1.

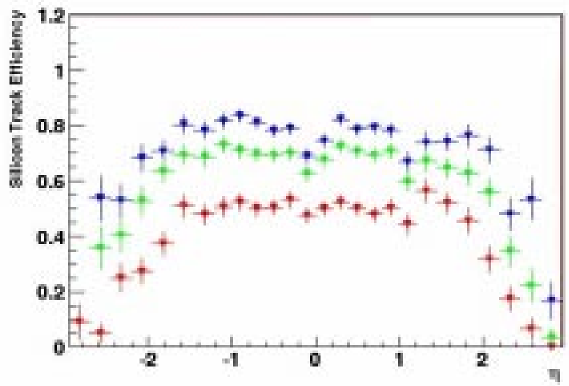

Fig. 1. Efficiency in data of the calorimeter seeded outside-in silicon tracking versus pseudorapidity for tracks with three(blue), four(green) and five(red) silicon hits.

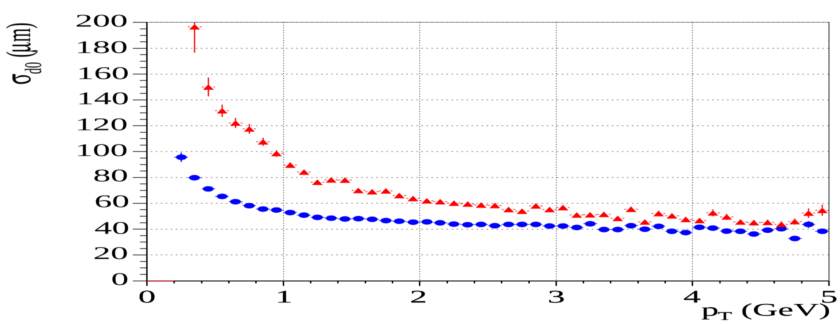

Fig. 2. Impact parameter resolution as function of p_T for silicon tracks passing through passive material. Red: Tracks without Layer 00 hits. Blue: Tracks with Layer 00 hits.

1.2 Layer 00

Multiple scattering in passive material from the readout electronics and support structure of the other layers degrades the resolution for low momentum tracks, $p_T < 3\mathrm{GeV/c}$. Layer 00[5,6] was designed to recover that resolution with a low-mass layer of silicon mounted directly on the beam-pipe. Furthermore, the use of newer radiation hard silicon designs developed for the LHC and active cooling ($-5°C$) gives L00 a longer life-expectancy to maintain b-tagging capability beyond the point when the inner layer of SVX-II succumbs to radiation damage. With recently improved alignment, studies in data demonstrate the improvement in impact parameter resolution is dramatic, particularly for tracks passing through passive material in SVXII. Figure 2 shows the impact parameter resolution in data as function of p_T for tracks with and without Layer 00 hits passing through passive material. The improvement is largest at low p_T, where multiple scattering are the dominant component to the impact parameter resolution.

2 RunIIb Silicon

The RunIIa silicon detector made the transition from commissioning in June 2002 to physics operation and enables CDF to achieve its physics goals. The RunIIa silicon detector is designed for a $2\,fb^{-1}$ run, but is expected to last for $6\,fb^{-1}$ [7]. With a planned integrated luminosity of $15\,\mathrm{fb}^{-1}$ the SVXII and Layer 00 detectors would not tolerate the radiation dose associated with high luminosity, and RunIIb silicon upgrade project [8,9] was approved in 2002 to replace Layer 00 and SVXII. The design goals were to build a radiation hard detector with a simple design for fast assembly. For the new readout chip, SVX4 [10], the SVX3 chip [11] was translated to $0.25\,\mu$m CMOS technology. The sensors are single sided and are placed in a compact structure, called a stave, with integrated readout and cooling systems (silicon is actively cooled to $-5\,C^o$). It is longer than RunIIa (1.2 m; compare to RunIIa: 0.9 m) and will therefore provide a larger acceptance for tagging jets with B hadrons. The radial coverage is expanded ($2.1-16.4$ cm; compare to RunIIa: $1.3-10.6$ cm). Material present in the tracking volume is expected to be less or comparable to RunIIa in spite of usage of single sided sensors, active cooling and expanded radial coverage. This is achieved by a dramatic reduction in hybrid size and placement of all readout cables and services at larger Z coordinate. The RunIIb detector also uses more axial layers (7+L0 compared to RunIIa 5+Layer 00) to strengthen pattern recognition compensating for the dense tracking environment expected at the Tevatron highest luminosity and efficiency losses at the COT innermost layers. Prototype barrels and bulkheads have been made. 60 outer axial and 53 outer small angle stereo prototype sensors were manufactured by Hamamatsu Photonics on $6''$ wafers. Detailed electrical characterization has been performed and shows that the prototype sensors have excellent performance. Most of the sensors do not exceed $0.2\,\mu$A at 950 V and only two out of 115 showed noticeable micro-discharge. The estimated dead channel fraction is 0.08%. Out of the 2770 ordered production sensors, 300 have been delivered. To test the radiation hardness of the sensors, three sensors were irradiated to $1.4 \times 10^{14} n/cm^2$ and two to $0.7 \times 10^{14} n/cm^2$. The I-V curves are good up to 1000V without micro-discharge and depletion voltage is 100 V (40-50 V) for $1.4(0.7) \times 10^{14} n/cm^2$. The single strip leakage current is $0.98\,\mu A$ at $T \simeq -5C^o$, the interstrip capacitance is 3pF and the interstrip resistance is $1\,\mathrm{G}\Omega$ at $V_{bias} = 300\,V$, meaning that the sensors do have a good signal to noise ratio at 300 V. Tests of the performance of the staves were done by reading out staves with the full CDF DAQ system. A small amount of pickup is seen, and the pedestal variation after the real-time event-by-event pedestal subtraction is negligible. Overall the RunIIb silicon project is in excellent shape. The preproduction parts are all in hand and the 2nd version of the chip is the production chip. The module construction has started and placement of production orders was planned for the end of 2003 with full production in spring 2004. However, the luminosity expectations of the Tevatron have been revised downward to 3-6 fb^{-1}. The RunIIa silicon detector is expected to survive RunII, which led recently to the decision by the Fermilab director to cancel the RunIIb silicon upgrade.

3 Conclusions

The commissioning of the RunIIa silicon detector was completed in June 2002. Since then the detector is operating smoothly and is taking high quality physics data. Layer 00 is aligned and first data looks very encouraging showing that it is improving the impact parameter resolution of silicon tracks. SVT continues to perform very well and is improved further. Central and forward silicon tracking efficiency are high. CDF is producing physics results using the new capabilities of the RunIIa silicon detector, which is expected to last for the entire RunII data taking period.

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