The CDF RunIIa Silicon Detector and its upgrade RunIIb ⋆

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Abstract

Status of the CDF RunIIa silicon detector is presented, which made the transition from commissioning to physics 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 $2 - 8\,\mathrm{fb}^{-1}$ it will allow a precise measurement of i.e. the top and the W mass, measurement of the CP violation and B_s–mixing,and also perform searches for new physic signatures. To potentiate this goals lepton identification and b,c quark tagging up to very high pseudo–rapidities is needed. Hence, CDF replaced the RunI silicon detector with an entirely new detector for the start of RunIIa of 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 out of three subdectors: SVXII, ISL and Layer 00. The commissioning of the CDF RunIIa silicon detector was completed in June 2002 and 92.5% of modules are operating, of which 87%

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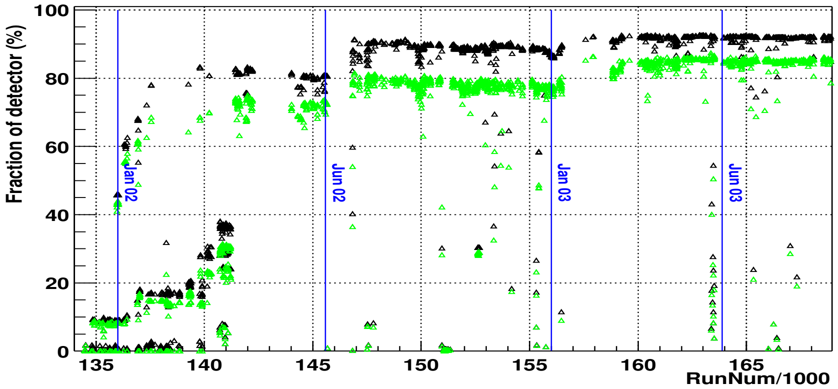

Fig. 1. Silicon commissioning progress as function of run numbers. The black dots are the fraction of operational and the green dots are the fraction of good ladders (error rate below 1%).

are good ladders with an error rate below 1%, see Figure 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 physics data recorded by the silicon detector is used to reconstruct online and offline tracks. Online the innovative secondary vertex trigger (SVT) [2,3] reconstructs axial tracks in the SVXII detector within 15 μsec with an tracking efficiency of 80%. Speed is achieved with custom VLSI pattern recognition, linearized track fitting, pipelining, and parallel processing. SVT's 35 μsec impact parameter resolution enables CDF's level 2 trigger to distinguish primary and secondary particles, and hence to collect large samples of hadronic bottom and charm decays. SVT's impact parameter resolution for $p_T \simeq 2\,\mathrm{GeV}$ is comparable to that of offline tracks, that do not use Layer 00.
CDF developed several offline silicon tracking algorithms, which do complement one another. These are the drift chamber (COT) outside-in seeded, the calorimeter outside-in seeded silicon tracking and the silicon standalone tracking. The silicon standalone and the calorimeter seeded silicon tracking, exploiting the forward coverage of ISL, are allowing tracking into 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 outside-in silicon tracking algorithm is using COT tracks to seed tracks in the silicon. It is using a progressive road search for finding 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.

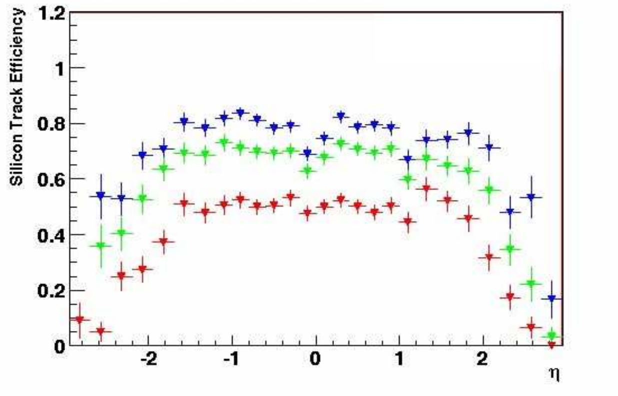

Fig. 2. Efficiency in data of the calorimeter seeded outside-in silicon tracking versus pseudorapidity for tracks with three(blue), four(green) and five(red) silicon hits.

The average tracking efficiency of this algorithm is 94% and it has a fake rate of $1.18\% \pm 0.08\%$, which is half of the RunI fake rate. The mass resolution for J/Φ is $15\,\mathrm{MeV} \pm 0.1\,\mathrm{MeV}$. The decay length resolution for two COT outside-in seeded silicon tracks is $63.22\,\mu\mathrm{m} \pm 0.23\,\mu\mathrm{m}$. 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 misidentificatioin rates between 1% to 10% for $1 < \eta < 2$ are achieved for the outside-in seeded calorimeter silicon tracking algorithm, see Figure 2.

1.2 Layer 00

Up to now Layer 00 hits were not used in CDF's silicon tracking algorithms due to misalignments. Recently, Layer 00 was sufficiently enough aligned and first studies in data show, that attaching Layer 00 hits to the silicon tracks is improving the impact parameter resolution especially of tracks passing through passive material in SVXII. This effect is important for achieving high secondary vertex tagging rates resulting from b quark decays. Figure 3 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.

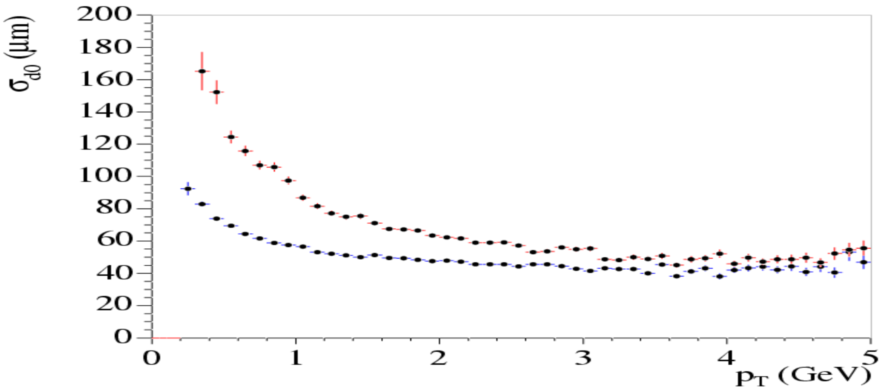

Fig. 3. Impact parameter resolution as function of p_T for silicon tracks passing through passive material. Red: Tracks without Layer 00 hits. Blue: Tracks with Layer 00 hits.

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 to last $2\,fb^{-1}$ and is expected to last for $6\,fb^{-1}$ [4]. 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 [5] was approved in 2002 to replace Layer 00 and SVXIIa. The design goals were to build a radiation hard detector with a simple design for fast assembly. For the new readout chip,SVX4, the SVX3 chip 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) and the portcard electronic has been moved outside the tracking volume. RunIIb posses more axial layers to strengthened the inner layers (7 + Layer 0; compare to RunIIa: 5+Layer00). The prototype barrels and bulkheads are made. 60 outer axial and 53 outer small angle stereo prototype sensors were manufactured by Hamamatsu Photonics on $6''$ wafers. Detailed electrical characterization were performed and are showing that the prototype sensors do 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 were so far delivered.
To test the radiation hardness of the sensors, three sensors were irradiated to $1.4x10^{14}n/cm^2$ and two to $0.7x10^{14}n/cm^2$. The I-V curves are good up to

1000V without micro-discharge and depletion voltage is 100 V (40-50 V) for $1.4(0.7)x10^{14}n/cm^2$. Good signal to noise ratio at 300 V is achieved due to single strip leakage current of $0.98\,\mu A$ at $T \simeq -5C^o$, interstrip capacitance of 3pF and an interstrip resistance of 1 GΩ at $V_{bias} = 300\,V$.
Test of the performance of the stave were done by reading out staves with the full CDF DAQ system. Small pickup is seen and the pedestal variation after the real-time event-by-event pedestal subtraction are 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 placing production orders were planned end of 2003 and full production in spring 2004. However, the luminosity expectations of Tevatron were revised 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 than 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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