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Performances of the ATLAS and CMS silicon tracker

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Abstract. An overview of the ATLAS and CMS silicon trackers is presented. The silicon tracker is a key element for the discovery potential of the ATLAS and CMS detectors at LHC. The performances of the two systems, which are designed to operate with a 40 MHz bunch crossing frequency in a high particle flux density and hard radiation environment, are discussed.

1 Introduction

Physics at the LHC put severe requirements on tracking detectors, due to the high interaction rate, particle density and received radiation dose. At high-luminosity (10^{34} cm^{-2}s^{-1}), on average 20 minimum bias events are produced per bunch crossings, which will produce more than 1000 tracks in the tracker acceptance, leading to very high detector occupancy. The resulting charged track density is expected to be about 1 track/cm^2 per bunch crossing at a radius of 10 cm. A very fine granularity is needed to resolve nearby tracks. Since the time between bunch crossing is 25 ns, detectors and electronics with fast response time are required. Inner detectors are also required to survive a harsh radiation environment with particle fluxes of between 10^{13} and 10^{14} equivalent 1 MeV neutrons/cm^2/year and they are designed in order to continue working for at least ten years. Furthermore, material in the tracking detectors must be minimised to avoid compromising the calorimeter performance for challenging electromagnetic channels such ad H$\rightarrow \gamma\gamma$.

ATLAS and CMS, the two general purpose experiments which will be operated at LHC, have been designed in order to explore the full range of physics that can be accessed at LHC. A robust tracking system inside a strong magnetic field is a key element to fulfill this task. The tracker has to be able to resolve and measure precisely all tracks, in order to identify those belonging to interesting interactions. A transverse momentum resolution of 1–2% for 100 GeV/c tracks is required to be able to reconstruct narrow heavy objects and impact parameter resolution of 10-20μm is needed for b and τ tagging with displaced vertices.

Two different solutions have been chosen by ATLAS and CMS. The ATLAS tracking system is based on three different technologies: pixel detectors, silicon strips and a straw-tube tracker with transition radiation detection capability (TRT), while the CMS tracking system features an all-silicon layout consisting of a pixel detector and a silicon-microstrip tracker.

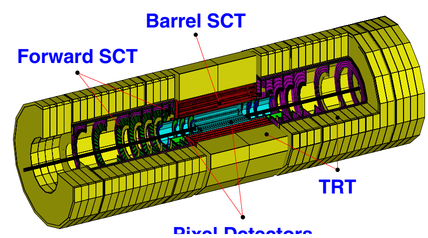

Fig. 1. Layout of the ATLAS Inner Detector

2 The ATLAS inner detector

The layout of the ATLAS inner detector (ID) is shown in Fig. 1. The ID is a 110 cm-radius, 7 m long tracker, located inside a nominal 2 T magnetic field provided by a superconducting solenoid. A detailed description of the layout and performance of the ID can be found in [1,2,3]. Since the time of the Physics TDR, several changes have been adopted to the original layout. In particular the pixel detector has been extensively redesigned [4]. It now features a "fully insertable" layout which allows the insertion and removal of the pixel detector. The design changes allow for better maintenance and upgrades, however the material in the pixel is increased by a factor 1.5 playing the most significant effect on tracking performance (see Sect. 4). The pixel detector is close to the beamline and consists of three cilindrical barrel layers now located at radii of 5.05 cm ($B - layer$), 9.85 cm and 12.25 cm, and three symmetric end-cap disk pairs located at $|z|$ =49.5 cm, 56.0 cm and 65.0 cm. With this layout only 2% of tracks up to $|\eta| < 2.5$ have less than three measurement points. The basic element of the system is the module, which has an active area of 16.4 x 60.8 mm^2. A total of 1456 modules in the barrel and 288 in the end-caps are foreseen. The pixel modules have a spatial resolution of 12 μm in the $r - \phi$ plane and 60 μm in the $r - z$ plane.

The semiconductor tracker (SCT) occupies the radial region between 25 and 50 cm and consists of four barrel layers and nine disks in each end-cap. Each layer is

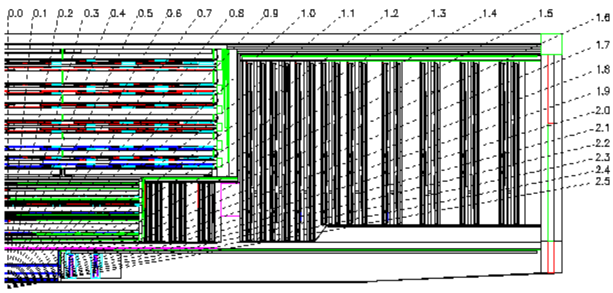

Fig. 2. Layout of the CMS Silicon Tracker

equipped with two sets of single-sided silicon strip detectors, glued back-to-back with a stereo angle of 40 mrad. In the barrel, the module have an active area of 12.52 x 6.16 cm^2, with 768 axially oriented strips of 80 μm pitch, while the end-cap modules have a trapezoidal shape with 768 keystone-shaped radially oriented strips with pitches ranging from 63 to 85 μm. With 4088 modules in total, the SCT has an active area of 61 m^2. The SCT modules have a spatial resolution of 16 μm in the $r-\phi$ plane and 580 μm in the $r-z$ plane.

Altogether the ID provides seven precision space points per track (three from the pixel and four from the SCT) to be combined with the 36 in the TRT, ensuring a coverage up to $|\eta| < 2.5$.

3 The CMS silicon tracker

CMS has chosen for its tracking system an all-silicon layout [5], relying on few measurements layers, each able to provide precise and robust coordinate determination. In order to fulfil the requirement on transverse momentum resolution, the tracker is immersed in a 4 T solenoid magnetic field. A sketch representing 1/4 of the tracker is shown in Fig. 2. Going from inside to outside, the tracker is composed by a Pixel detector, providing up to three hits, followed by the Silicon Strip Tracker (SST) providing up to 14 hits per track.

The pixel detector covers the innermost part: three cylindrical barrel layers, located at radii of 4.4 cm, 7.5 cm and 10.2 cm, and two pairs of end-cap disks, located at $|z| = 34.5$ cm and 46.5 cm, ensure a coverage up to $|\eta| < 2.2$. The pixel size is 150 x 150 μm^2 and the hit resolution is about of 10 μm in the $r-\phi$ plane and 17 μm in $r-z$.

The SST covers the radial region between 20 and 110 cm. It is divided in four parts. The barrel region ($|z| <$120 cm) is split into an Inner Barrel (TIB), constituted of four cylindrical layers, and an Outer Barrel (TOB), made of six layers. The TIB is enclosed by three pairs of disks (TID), while the TOB is enclosed by nine End-Cap (TEC) disks ($120 < |z| < 280$ cm), each made by seven rings. The first and second layer of the TIB and the TOB, as well as the first two rings of the TID and rings 1, 2 and 5 of the TEC are instrumented with two sets of single-sided detectors glued back-to-back with a stereo angle of 100 mrad.
Detectors of the TIB, TID, and the first four rings of the TEC are made of a single sensor of 320 μm thickness and have strip lenghts of about 10 cm and pitches of about 100 μm. In the outer part (TOB and the three outermost TEC rings), in order to reduce the number of channels, the strip lenght and pitch are increased by a factor two, daisy-chaining two sensors. In these regions, 500 μm-thick sensors are used to compensate the increased noise due to larger capacitance. The SST is thus composed of 6136 thin and 18192 thick sensors with an active area of 210 m^2 of silicon and $9.6\dot{1}0^6$ channels. With this fine granularity, the tracker has an average occupancy in the 1% range or below.

4 Performances

The performances of the ATLAS Inner Detector combined with the TRT system and the ones of the CMS Silicon Tracker in terms of track reconstruction efficiency, transverse momentum resolution, vertex reconstruction and b and τ tagging, are quite similar. Track reconstruction efficiencies are of the order of 98% - 100% for muons in most of the pseurapidity range, while it drops to 90 - 95% for pions, mostly due to nuclear interactions, with a fake rate at high luminosity below 10^{-5}.

The design changes in the ATLAS ID result in some loss of detector performance w.r.t the Physics TDR, in particular in the single track transverse momentum and impact parameter resolution, as shown in Fig. 3, in which the parameter a gives the asymptotic resolution at infinite momentum, while b represents the dependence on multiple scattering at low momentum. The increase of material and the change in radius of the first pixel layer are the main reasons of this degradation. Despite the changes, however, the performance of the ID is being maintained to meet the ATLAS physics goal.

Indeed, material effects are a crucial issue for both ATLAS and CMS trackers: multiple scattering degrades substantially the momentum resolution for low-p_T muons and affects the high-pT muons as well; nuclear interactions are the main source of pion reconstruction inefficiency and bremsstrahlung is the limiting factor for the electron tracking efficiency. Since the material in the tracking volume affects the performance in all physics channels, in the desing of the detectors and services, all efforts have been made to minimize the material budget.

The transverse momentum and transverse impact parameter resolutions for the CMS Tracker are shown in Fig. 4. The p_T resolution is better than 2% for $p_T < 100$ GeV/c, in the range $|\eta| < 1.7$; at large pseudorapidity the resolution degrades due to the reduction of the lever arm. The transverse impact parameter resolution is better than 20 μm in the whole pseudorapidity region covered by the tracker, for muons of $p_T = 100$ GeV; at lower energy the performance is degraded by the multiple scattering. It has been demostrated that a sufficient precision in track reconstruction is already achievable with the pixel hits and four silicon strip hits. This demonstrate the robustness and redundancy of the CMS tracker and, on the same

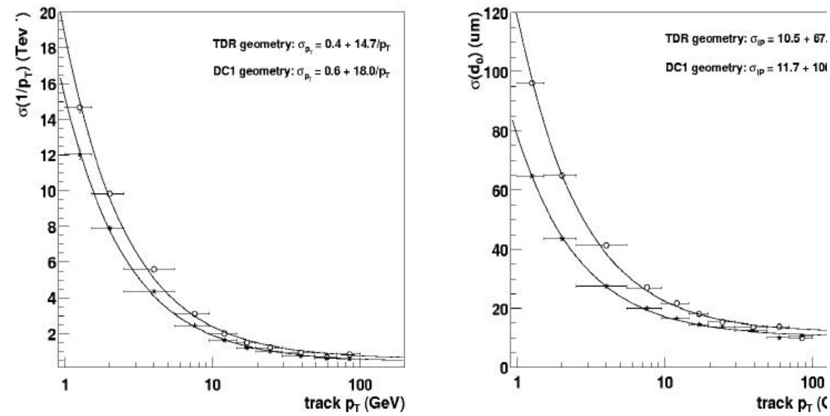

Fig. 3. Transverse momentum and impact parameter resolution versus p_T for the TDR (*full circle*) and the new geometry (*DC1-open circle*) of the ATLAS detector, together with fitted parameterizations (*see text*)

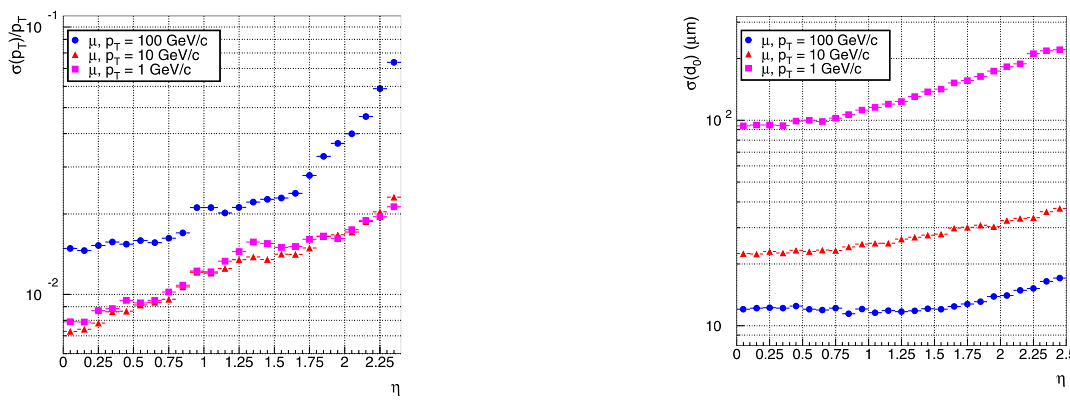

Fig. 4. Transverse momentum (*left*) and transverse impact parameter resolution (*right*) of the CMS Tracker

time, offers the possibility to perform a "fast track reconstruction", very useful for the High Level Trigger [6].
The identification of primary and secondary vertices is also a key element for the physics at LHC. Pixel detectors allow for fast reconstruction of the primary vertex with resolution ranging from 20 to 50 μm, depending on the complexity of the physics channel. The resolution can be improved also using the microstrip tracker information but at the expense of CPU time. Secondary vertex reconstruction is very important for the B-Physics program and for b and τ tagging. Several algorithms have been developed based on exclusive secondary vertex reconstruction, impact parameter information, semileptonic decays, etc. This is an ongoing process, and new ideas continue to be explored in order to improve the performances of both detectors waiting the start of data taking.

5 Conclusions

Physics at LHC impose unprecedented requirements on the tracking detectors, due to the high interaction rate, particle density and received radiation dose: fine granularity and fast response time detectors and redout electronics are needed. An extensive R&D program was carried on in the past years in order to desing detectors which meet these requirements. The design is now completed and construction of various components has already started.

Both the ATLAS and CMS Trackers are expected to have robust performances, which meet the design figures. The relatively large amount of material inside the tracking volume remains the main limiting factor for tracking efficiency and resolution.

References

1. ATLAS Collaboration: *Detector and Physics Performance Technical Design Report*, CERN/LHCC/99-14, May 1999
2. ATLAS Collaboration: *Inner Detector Technical Design Report*, CERN/LHCC/99-16 and 17, April 1997
3. ATLAS Collaboration: *Pixel Detector Technical Design Report*, CERN/LHCC/98-13, May 1998
4. R. Hawkings: EPJdirect A **1**, 1 (2003)
5. CMS Collaboration: *The Tracker Project Technical Design Report*, CERN/LHCC/98-6, April 1998; CMS Collaboration: *Addendum to the CMS Tracker TDR*, CERN/LHCC/2000-016, February 2000
6. CMS Collaboration: *Data Acquisition & High-Level Trigger Technical Design Report*, CERN/LHCC/2002-26, December 2002