# 1 Introduction

This paper describes the pixel detector system for the ATLAS experiment at the Large Hadron Collider (LHC). ATLAS is a general purpose detector for the study of primarily proton-proton collisions at the LHC [1]. The pixel detector system is a critical component of the inner tracking detector of ATLAS [2]. The ATLAS Inner Detector provides highly efficient charged-particle track reconstruction over the pseudorapidity range $|\eta| < 2.5$ [3]. The pixel detector, with approximately 80 million channels, is essential to provide pattern recognition capability to meet the track reconstruction requirements of ATLAS at the full luminosity of the LHC of $\mathscr{L} = 10^{34}$ cm$^{-2}$s$^{-1}$. The pixel detector system is the innermost element of the Inner Detector. It is the most important contributor to the identification and reconstruction of secondary vertices from the decay of, for example, particles containing a b-quark and for b-tagging of jets. In addition, it provides excellent spatial resolution for reconstructing primary vertices in the proton-proton interaction region within ATLAS even in the presence of the many multiple interactions present at the LHC design luminosity.

In the sections below, we first present the performance requirements for the pixel detector. This is followed by an overview of the system and its relationship to the Inner Detector. We then describe the principal components of the pixel detector system–electronics, sensors, modules, mechanical systems and services. Finally, we summarize results from test beam studies of the pixel components and the operation of about 10% of the pixel system using cosmic ray tracks.

# 2 Performance Requirements and Design Choices

The performance requirements for the ATLAS Inner Detector (ID) were formulated in the Inner Detector Technical Design Report (TDR) [2]. The pixel system is an important part of the ID and plays a major role in fulfilling these requirements.

The general performance requirements for the pixel system are:

- coverage of the pseudorapidity range $|\eta| < 2.5$;
- excellent transverse impact parameter resolution;
- good resolution on the longitudinal $z$-coordinate, allowing primary vertex reconstruction of charged tracks with $\sigma(z) < 1$ mm;
- good 3D-vertexing capabilities;
- very good jet b-tagging capabilities both in the high level trigger and in the offline reconstruction;
- minimal material for all elements of the system in order to reduce multiple scattering and secondary interactions;
- excellent efficiency for all pixel layers; and
- radiation hardness of the pixel detectors elements to operate after a total dose of 500 kGy or $10^{15}$ 1 MeV-n$_{eq}$/cm$^2$.

These performance requirements lead to the following major design choices:

- three pixel hits over the full rapidity range. The requirement to have three pixel layers has been confirmed by a detailed study comparing a layout with two pixel hits versus a layout with three pixel hits [4];
- minimal radius of the innermost layer (b-layer), set at 5 cm due to the practical limitations of clearances around the interaction region beam pipe vacuum system;

- the smallest pixel size, which is set to 50 $\mu$m $\times$ 400 $\mu$m by electronics design limitations;

The expected dose rate for the innermost layer is expected to reach 500 kGy after about the first five years of LHC operation. The other layers are expected to reach the 500 kGy dose after 10 or more years of LHC operation (with maximum luminosity of $10^{34}$ cm$^{-2}$s$^{-1}$).

# 3 System Overview

In this section we present a brief overview of the pixel system and its relationship to the Inner Detector. The basic parameters of the pixel system are also summarized in this section. The pixel detector is the innermost element of the Inner Detector as shown in Figure 1. The pixel tracker is designed to provide at least three points on a charged track emanating from the collision region in ATLAS. The pixel detector and the other elements of the Inner Detector span a pseudorapidity range $|\eta| < 2.5$.

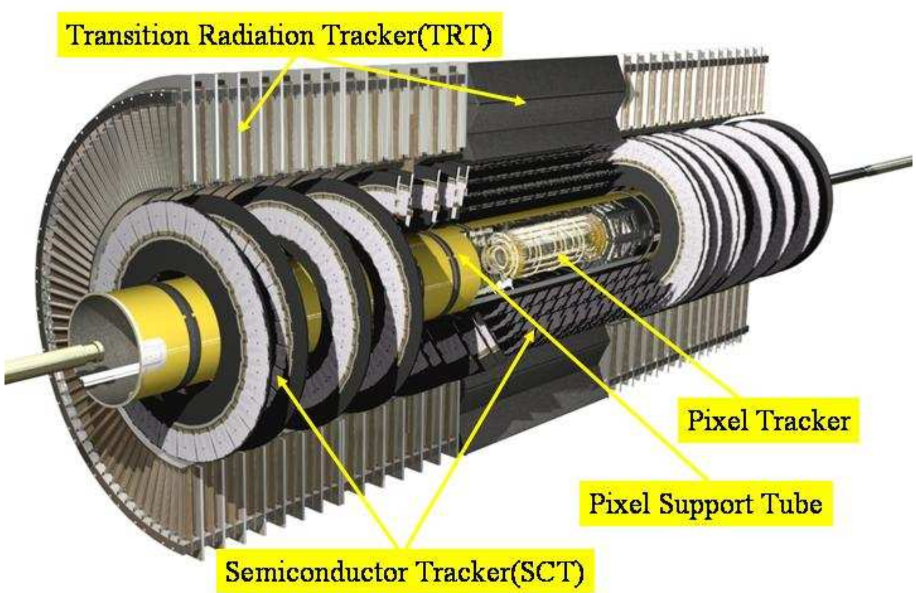


Figure 1: The ATLAS Inner Detector.

The principal components of the pixel tracking system are the following:

- the active region of the pixel detector, which is composed of three barrel layers and a total of six disk layers, three at each end of the barrel region;
- internal services (power, monitoring and cooling) and their associated mechanical support structures (also supporting the interaction region beam pipe) on both ends of the active detector region;
- a Pixel Support Tube into which the active part of the pixel detector and the services and related support structures are inserted and located; and
- external services that are connected to the internal services at the end of the Pixel Support Tube.

The active region of the pixel detector is shown in a schematic view in Figure 2. The active part of the pixel system consists of three barrel layers–Layer 0 (so-called b-layer), Layer 1 and Layer 2–and two identical endcap regions, each with three disk layers.

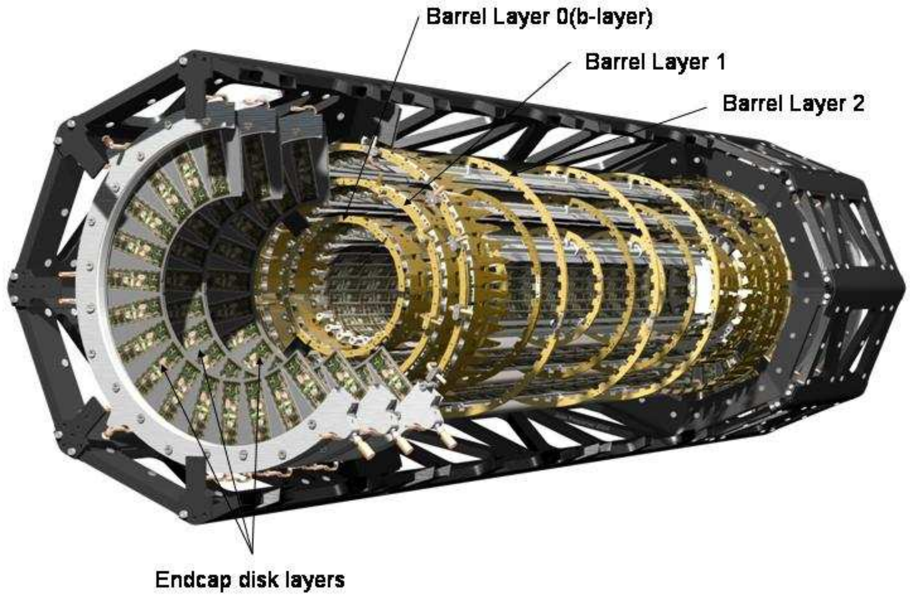


Figure 2: A schematic view of the active region of the pixel detector consisting of barrel and endcap layers.

The basic building block of the active part of the pixel detector is a module (section 6) that is composed of silicon sensors (section 5), front-end electronics and flex hybrids with control circuits (section 4). All modules are functionally identical at the sensor/integrated circuit level but differ somewhat in the interconnection schemes for barrel modules and disk modules. The pixel size is 50 microns in the $\phi$ direction and 400 microns in $z$ (barrel region, along the beam axis) or $r$ (disk region) apart from a few special pixels in the overlap region between integrated circuits on a module–see sections 5 and 6. There are 46,080 pixels in a module.

The essential parameters for the barrel region of the pixel detector system are summarized in Table 1. Modules are mounted on mechanical/cooling supports, called staves, in the barrel region. Thirteen modules are mounted on a stave and the stave layout is identical for all layers. The active length of each barrel stave is about 801 mm. More details are given in section 7.

The two endcap regions are identical. Each is composed of three disk layers and each disk layer is identical. The basic parameters of the endcap region are given in Table 2. Modules are mounted on mechanical/cooling supports, called disk sectors. There are eight identical sectors in each disk.

The total number of pixels in the system is approximately 67 million in the barrel and 13 million in the endcaps, giving a total active area of about 1.7 m$^2$.

The expected instantaneous fluence of charged hadrons in the Inner Detector volume is shown in Figure 3. One can see that the highest fluences are in the region of the pixel detectors, requiring radiation hard sensors, radiation hard electronics and operation at low temperatures.

The contribution of the Pixel Detector to the total Inner Detector material budget as a function of pseudorapidity is shown in Figure 4 (radiation lengths) and Figure 5 (interaction lengths). The beam

| Layer Number | Mean Radius (mm) | Number of Staves | Number of Modules | Number of Pixels | Active Area ($m^2$) |
|---|---|---|---|---|---|
| 0 | 50.5 | 22 | 286 | 13,178,880 | 0.28 |
| 1 | 88.5 | 38 | 494 | 22,763,520 | 0.49 |
| 2 | 122.5 | 52 | 676 | 31,150,080 | 0.67 |
| TOTALS | | 112 | 1456 | 67,092,480 | 1.45 |

Table 1: Basic parameters of the barrel region of the ATLAS pixel detector system.

| Disk Number | Mean $z$ (mm) | Number of Sectors | Number of Modules | Number of Pixels | Active Area ($m^2$) |
|---|---|---|---|---|---|
| 0 | 495 | 8 | 48 | 2,211,840 | 0.0475 |
| 1 | 580 | 8 | 48 | 2,211,840 | 0.0475 |
| 2 | 650 | 8 | 48 | 2,211,840 | 0.0475 |
| TOTAL ONE ENDCAP | | 24 | 144 | 6,635,520 | 0.14 |
| TOTAL BOTH ENDCAPS | | 48 | 288 | 13,271,040 | 0.28 |

Table 2: Basic parameters of the endcap region of the ATLAS pixel detector system.

pipe contribution is also presented.

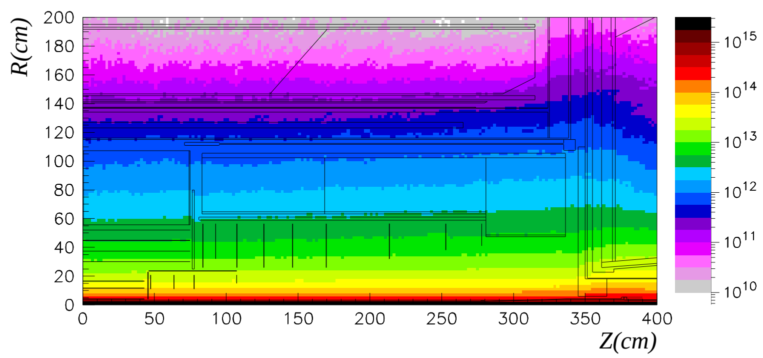


Figure 3: Fluence of the charged particles in the ID detector per $cm^2$ per year at the LHC design luminosity of $10^{34}$ $cm^{-2}s^{-1}$.

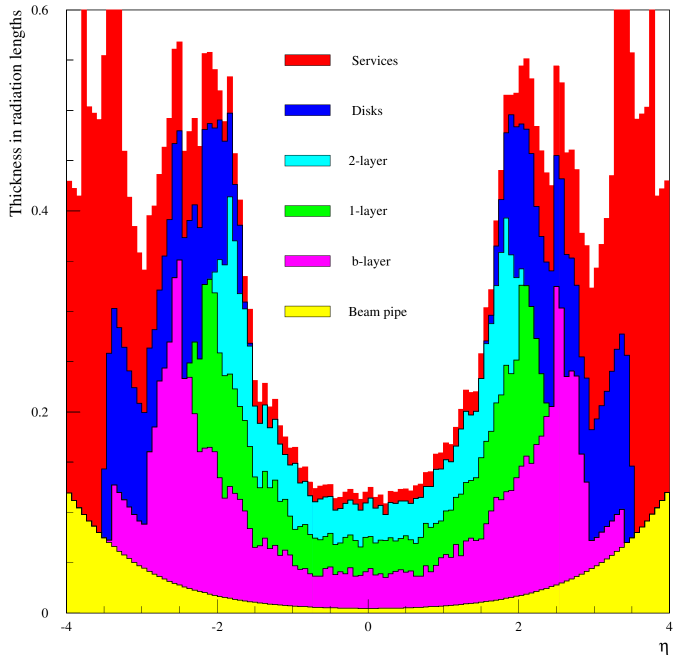


Figure 4: Material budget of the pixel detector in radiation lengths.

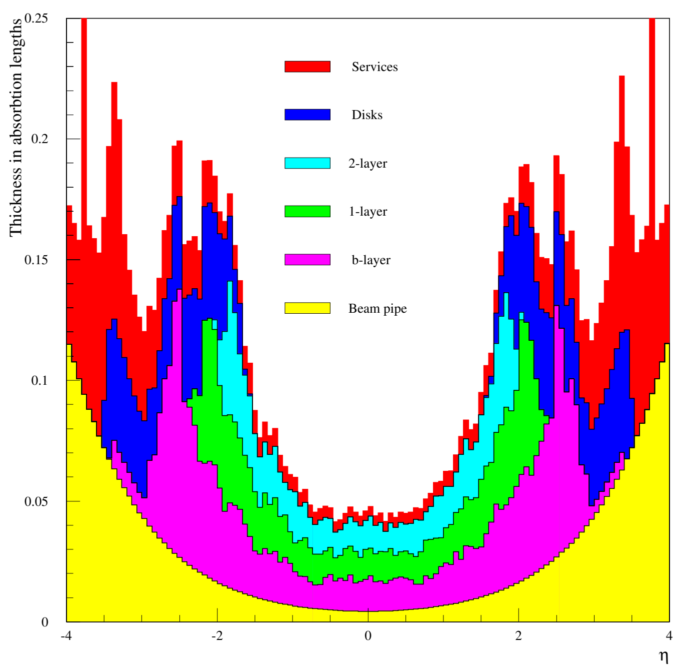


Figure 5: Material budget of the pixel detector in nuclear absorption lengths.

## References

[1] ATLAS Collaboration, ATLAS Detector and Physics Performance, Technical Design Report, Volume I and Volume II, (CERN/LHCC, 99-14 and 99-15).

[2] ATLAS Collaboration, ATLAS Inner Detector, Technical Design Report, Volume I and Volume II, (CERN/LHCC, 97-16 and 97-17).

[3] ATLAS Pixel Collaboration, ATLAS Pixel Detector, Technical Design Report, (CERN/LHCC, 98-13).

[4] S. Correard, V. Kostioukhine, J. Levêque, A. Rozanov and J. B. de Vivie, ATL-PHYS-2004-006 (2003).