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ATLAS NOTE

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Introduction, Overview, Performance of the ATLAS Pixel Detector

The ATLAS Collaboration

Abstract

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1 Introduction

This paper describes the pixel detector system for the ATLAS experiment at the Large Hadron Collider (LHC). The ATLAS detector 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 (ID) of ATLAS [2]. The ATLAS Inner Detector provides highly efficient charge-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 therefore the most important contributor to the precision needed for efficient identification and reconstruction of secondary vertices from the decay of, for example, particles containing the b-quark (b-tagging). In addition, it provides the essential resolution required to reconstruct 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 of 10^{34} cm^{-2}s^{-1}.

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

2 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 **??**. The pixel tracker is designed to provide at least three points on a charged tracking emanating from the center of the collision region in ATLAS for pseudorapidity $|\eta| \leq 2.5$, as are the other tracking systems in the Inner Detector.

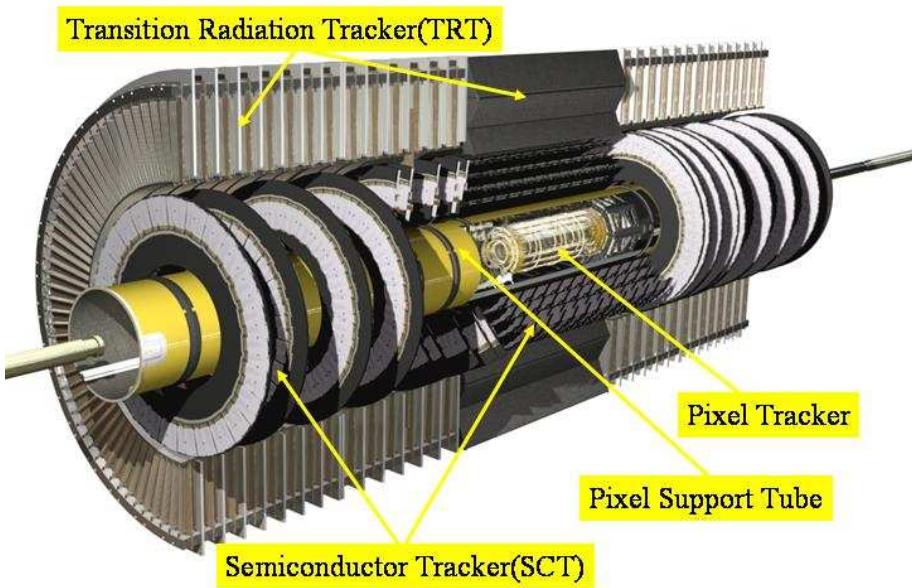

Figure 1: ****Placeholder*** Need different figure, more labels.

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

- active region of the pixel detector, which itself 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 either end of the active detector region;
- a Pixel Support Tube into which the active region and the services and related support structures are inserted and located; and
- external services (not shown in figure **??**) 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 **??**. 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.

The basic building block of the active part of the pixel detector is a module (section **??**) that is composed of silicon sensors (section **??**) and front-end and control integrated circuits (section **??**) along

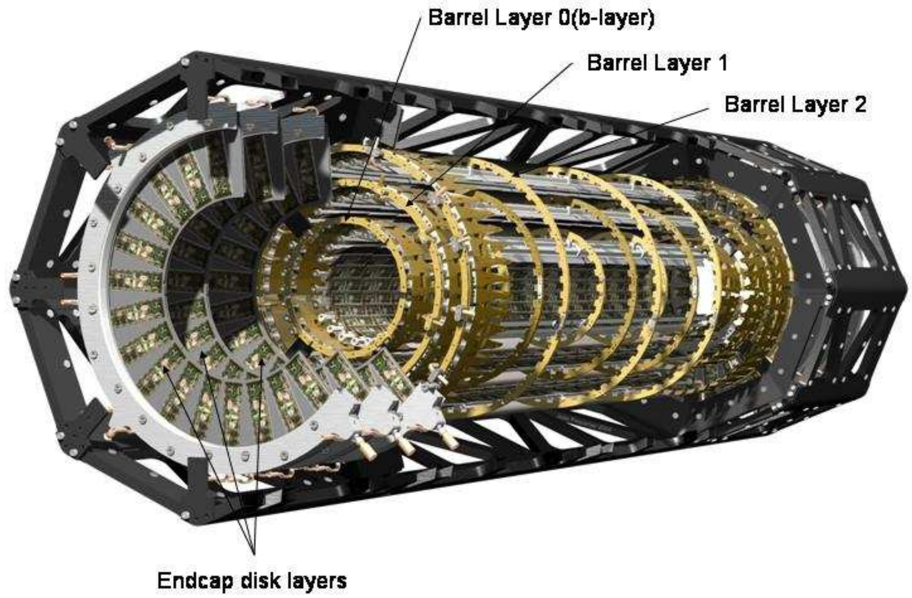

Figure 2: ***Placeholder**** Need higher res, better labels, already shown?

with module interconnections (flexible circuit board hybrid). 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 ϕ 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 **??** and **??**).

Need good drawings with dimensions or at least better end views than exist now if we want to include figures for barrel layout and disk layout**

The essential parameters of the barrel region of the pixel detector system are summarized in table 1. Modules are mounted on mechanical/cooling supports–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 approximately 801 mm. More details are given in section **??**.

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	1.53

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

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–sectors. There are eight identical sectors in each disk.

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.

The total number of pixels in the system is approximately 80 million and the active area is about 1.7 m^2.

3 Performance Requirements and Design Choices

The performance requiremnets of the full 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 with 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 in all elements of the system in order to reduce multiple scattering and secondary interactions;
- Excellent efficiency of pixel layers;
- Radiation hardness of the pixel detectors to a total dose of 300 kGy or $10^{15} n_{eq}$ cm^2 accumulated after 10 years of LHC operation (three years with low luminosity of 10^{33} cm^{-2}s^{-1} followed by seven years of high luminosity of 10^{34} cm^{-2}s^{-1}).

These performance requirements lead to the following major design choices:

- Minimal radius of the innermost layer, which is set to 5 cm due to the practical limitations of clearances around the interaction region beam pipe vacuum system;
- The smallest pixel size, which was finally set to 50 μm $\times$ 400 μm by electronics design limits;
- Three pixel hits over the full rapidity range. The necessity to have three pixel points with good efficiency has been confirmed by a detailed study comparing a layout with two pixel hits versus a layout with three pixel hits [4];
- in b-layer the accumulated dose is by a factor 5 bigger and the dose of 300 kGy is accumulated already after 5 years in ATLAS, so the replacement of the b-layer is normally required after 5 years of operation.

The expected instantaneous fluence of charged hadrons in the Inner Detector volume is shown in figure 1. One can see that the highest fluences are in the region of pixel detectors, requiring radiation hard sensors, radiation hard electronics and operation at low temperatures.

The part of the pixel detectors in the total Inner Detector material budget as a function of pseudorapity is shown in figure 2. The contributions of the different layers and services are shown in figure 3.

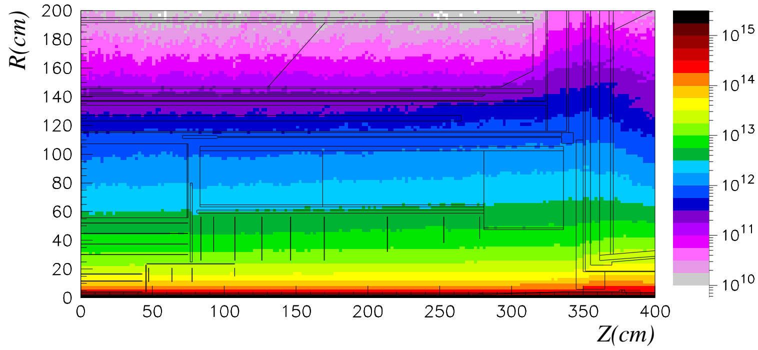

Figure 3: Fluence of the charged particles in the ID detector per cm^2 per year.

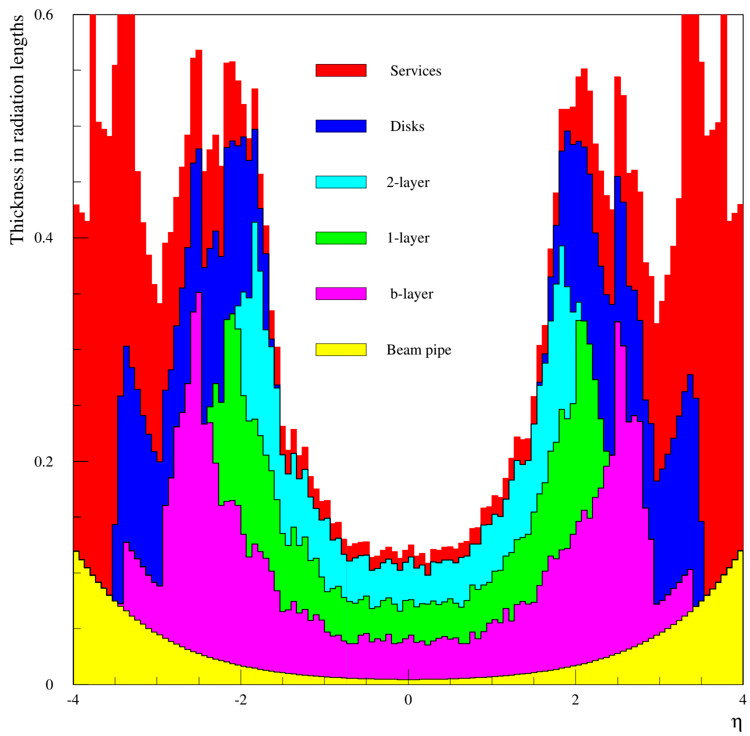

Figure 4: Material budget of the pixel detector in radiation lengths.

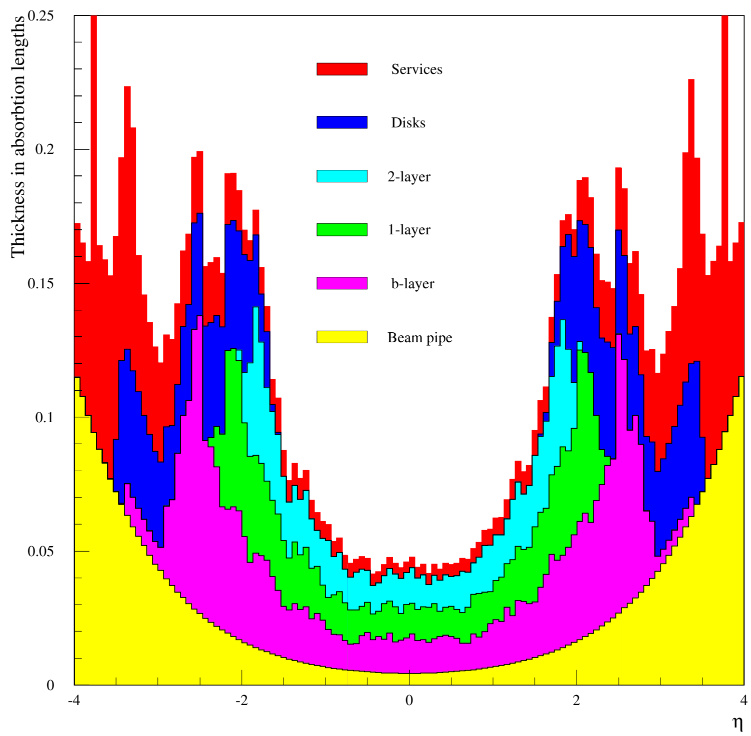

Figure 5: Material budget of the pixel detector in nuclear absorption lengths.

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).