3 Inner Detector

Last modified: 24 September 1998

Do not worry about English, spelling or details at this stage.

To Do

- TR function effect of modular geomerty and dE/dx
- PR in jets and effects of solenoidal field
- Update on V0's and tau's
- Alignment/Calibration

COLOUR FIGURE: R-z view of ID 97_6 Layout.

The performance of the ATLAS Inner Detector (ID) was described extensively in the ID TDR [3-1]. In this chapter, a summary of the results which are of most interest to physics analysis are given. In addition, updates arising from changes in the layout and further study are included. Despite various layout changes, the resolutions of the subdetectors and the number of hits on tracks have changed very little, hence the overall performance expected of the ID is very similar to that presented in the ID TDR.

The ID consists of three subdetectors covering the range $|\eta| \le 2.5$:

Pixels	3 layers of pixel detectors, with a vertexing B-layer at a radius of 4 cm. Each pixel is 50 μ m in R ϕ and 300 μ m in z/R.			
SCT	4 double layers of silicon strips. Each layer consists of ϕ -strips and strips rotated by a 40 mrad stereo angle. The strips are 80 μm pitch and 12 cm long.			
TRT	${\sim}36$ layers of 4 mm diameter straw tubes with resolutions ${\sim}200\mu m$ interspersed with a radiator to stimulate transition radiation from electrons.			

Colour Figure XXX shows the 97_6 layout as described by the GEANT simulation and used extensively for the studies in this report. The differences between this layout and the final layout in explained in a subsequent section.

3.1 Introduction

3.1.1 Pattern Recognition Programmes

Three pattern recognition programs (iPatRec, Pixlrec and xKalman) have been used extensively for studying the ID performance. These programs were described in some detail in Section 2.5.2 of the ID TDR. In brief, their principle features are:

iPatRec Searches for track using space-points formed in the Pixels and SCT. Candidates are extrapolated to the TRT and drift-time hits added.

PixIRec	Searches for tracks in the Pixels. Candidates are then extrapolated to the SCT and then the TRT.
xKalman	Searches for tracks in the TRT using fast histogramming of straw hits. Can- didates are extrapolated to the SCT and Pixels to provide confirmation. The improved tracks are then extrapolated back into the TRT and drift- time hits added.

Both Pixlrec and xKalman use Kalman Filter techniques to extrapolate the tracks and remove wrong hits.

The resulting tracks are described by their helix parameters (all quantities are measured at the point of closest approach to the nominal beam axis x=0, y=0).

In x-y plane, fit:

1/p _T	Reciprocal of the transverse momentum (with respect to beam-axis).
φ	Where $tan\phi \equiv p_y / p_x$.
d ₀	Transverse distance to the beam axis; signed according to the reconstructed angular momentum of the track about the axis.

In the R-z plane, fit:

cotθ	Where $\cot\theta \equiv p_z/p_T$,
z ₀	z position of the track at the point of closest approach.

3.1.2 Standard Track Quality Cuts

A set of track quality cuts have been developed in the context of b-tagging (see Section 5.2 of ID TDR). These cuts prove very useful in general, especially when it is important to ensure that a track comes from the primary vertex or a short-lived particle, such as a b-hadron. These cuts are particularly valuable in rejecting conversion electrons and help reduce the background to prompt muons from π/K decays. While the cuts may not be optimal for any individual physics analysis, they have been used extensively. The **basic track quality cuts** are:

- Number of precision hits \ge 9 (out of a maximum of ~11, ignoring overlaps).
- Number of pixel hits ≥ 2 (out of a maximum of 3, ignoring overlaps).
- At least one associated hit in the B-layer.
- Transverse impact parameter < 1 mm.

Where it is important to ensure high track quality or the TRT transition radiation information is required, an additional cut on the TRT is useful. The **extended track quality cuts** include:

• Number of TRT straw hits ≥ 20 .

3.2 Detector Evolution since the ID TDR

A variety of simulated layouts have been used for recent studies. These are:

ID TDR (96_12)	Used for the ID Performance TDR, Vol I. Does not completely correspond to hardware description in Vol. II, because of time delays.			
97_6	Corresponds to hardware description in ID TDR, Vol. II [3-2].			
98_2	Identical to 97_6 for ID description.			
Pixel TDR	Updated from 97_6 to describe the layout in the Pixel TDR [3-3].			
Material Report	Updated from Pixel TDR layout to provide the most up to date description of the ID material [3-5].			
Final	The final layout.			

The majority of studies undertaken for this TDR have used the 98_2 (97_6) layout. The principle changes associated with the various layout are described below. In the studies which are described in this chapter, wherever the differences in the layout are significant, they will be highlighted.

98_2 (97_6) Layout

- GaAs detectors in the SCT replaced by silicon strips.
- The sign of the tilt angle of all pixel detectors reversed to reduce cluster sizes.
- Improved description of the ID services (including the rerouting of the B-layer services out along the beam pipe) and the ID material.

Pixel TDR

- New module design with new dimensions used for both barrel and end-caps.
- 5 pixel disks in each end-cap, rather than 4¹.
- Small modifications to radii, number of staves and tilt angles.
- The detector thickness has been increased to 250 μm (200 μm in the B-layer).
- The binary ice cooling has been replaced by the evaporative cooling option (less material).
- The front-end chips are behind the pixel sensors in the barrels ('behind' as seen from the vertex).

Material Report Layout

In addition to the changes for the Pixel TDR, the following changes were made to improve the description of the ID material, to bring the simulation in-line with the engineering designs:

Jo to supply details.

•

^{1.} In the 4-disk design, 3 of the disks had an inner and outer ring of modules; in the 5-disk design, all disks have a single ring.

Final Layout

As the engineering of the ID progresses, so the design is converging. Since the Pixel TDR, the following changes have taken place:

- The 4th and 5th Pixel disks have been moved to |z| < 78 cm to ensure that the Pixel system is contained within the ID barrel to avoid beam pipe supports having to penetrate the Pixel end-caps. This only affects $|\eta| > 2.0$.
- There has been some fine-tuning of the SCT wheels to ensure hermeticity between different rings on the same wheel. The need for this is a result of the increased wheel thickness arising from careful design, including the cooling pipes.
- There is some discussion about moving the NEG pumps into smaller |z|. Apart from significant mechanical considerations, this will have consequences for the backgrounds in the detector. This has been considered separately.

3.2.1 Material Distributions

Since the ID TDR, there have been two sets of studies to consider the material in the ID. The first was in Autumn '97 where consideration was given to the possibility to reduce by one the number of precision layers [3-4]. This corresponded to an improved description of the material to bring the simulation in line with the engineering design presented in the ID TDR [3-2], resulting in layout 97_6 (equivalent to 98_2). At this time, there was a significant increase in the material estimate from the simulation. The second study in Spring '98 produced the Material Report Layout [3-5] where the net change from 98_2 was very small.

Figure 3-1 shows the material distribution for the ID corresponding to the 98_2 layout. This layout has been use for much of the simulation used in this report and provides a good estimate of the material to be expected in the final design.

3.2.2 Magnetic Field

The ATLAS solenoid is 5.3 m long, compared with the 6.7 m length of the tracking volume of the Inner Detector; consequently, the field deviates significantly from uniformity. Maps of the field are shown in Figures 3-2 and 3-3. It can be seen that B_z falls to about 1.0 T at the end of the solenoid and 0.4 T at the end of the tracker. B_R only becomes important for |z| > 2 m, with a maximum of about 0.6 T at the coil aperture.

The consequences for the performance of the deviation of the field from uniformity are not major - the main effect is a need for more complex tracking algorithms which are slower (this is concern for the LVL2). Most of the simulation in this report has been undertaken with a uniform 2 T field. However the track parameter resolutions presented in Section 3.3 specifically consider the effects of the solenoidal field, while the consequences for pattern recognition are examined in Section 3.5.4.



Figure 3-1 Material distribution of the ID vs $|\eta|$ for the TDR design, as used in the 98_2 simulation. The various bands include all services and supports within the corresponding fiducial volumes. The *pixel band* also includes the beam pipe. The *upper band* includes the outer TRT services and all external services.**MAKE WITH TDRFIG**

3.3 Track Parameters

The track parameter resolutions have been estimated using the analytic calculations which were outlined in Chapter 4 of [3-1]. These calculations have been shown to be in good agreement with the full DICE simulation. Any small discrepancies between the full simulation and the analytic calculation are probably no bigger than the uncertainties in the real detector performance which can be expected.

The calculations have been updated to allow for improved understanding in the material distributions and the modifications to the Pixel layout. The net result of all changes relative to the ID TDR [3-1] is small. The largest changes are in the impact parameter resolutions caused by modifications to the pixels: the transverse resolution at high- p_T has improved slightly while the longitudinal resolution is slightly worse; at low- p_T , the resolutions are degraded by increases in the material in the Pixels. Detailed comparisons can be found in the Pixel TDR [3-3].



Figure 3-2 B_z as a function of z and R.

Figure 3-3 B_R as a function of z and R.

In the ID TDR, the parameter resolutions were shown for a uniform 2 T magnetic field. In the plots which follow, the baseline configuration is with the *solenoidal field*. Where appropriate, a *transverse beam constraint* has been included in the calculations.

3.3.1 Resolution in 1/p_T



Figure 3-4 p_T resolution as function of $|\eta|$ for muons of various momenta.

Figure 3-4 shows the resolution in $1/p_T$. The degradation in resolution caused by the solenoidal field in contrast to the uniform field is clearly visible for $|\eta| > 1.5$. The use of the beam constraint only improves the resolutions by a few percent.

3.3.2 Resolution in $\boldsymbol{\phi}$



Figure 3-5 ϕ resolution as function of $|\eta|$ for muons of various momenta.

Figure 3-5 shows the resolution in ϕ . The degradation in resolution caused by the solenoidal field is only apparent at high-p_T. The improvement from the use of the beam constraint is significant at lower p_T.

3.3.3 Resolution in $\cot\theta$



Figure 3-6 $\cot\theta$ resolution as function of $|\eta|$ for muons of various momenta.

Figure 3-6 shows the resolution in $\cot\theta$. Measurements in the R-z plane are fairly insensitive to the distortions in the B-field and the use of a transverse beam constraint.

3.3.4 Resolution in d₀



Figure 3-7 Transverse impact parameter (d_{n}) resolution as function of $|\eta|$ for muons of various momenta.

Figure 3-7 shows the resolution in d_0 . Since the determination of d_0 is dominated by measurements near to the primary vertex, a region where the B-field is fairly uniform, there is a relatively small dependence on the field distortions.

3.3.5 Resolution in $\sin\theta \times z_0$



Figure 3-8 Longitudinal impact parameter (z_0) resolution projected transversely to the track direction as function of $|\eta|$ for muons of various momenta.

Figure 3-8 shows the resolution in z_0 . What is generally of most interest is the projection of z_0 on to the plane transverse to the track direction - this is achieved by multiplying by $\sin\theta$. This corresponds to the quality which is of most interest for vertexing and b-tagging and can be compared more directly with the transverse impact parameter d_0 .

3.3.6 Simple Parametrisations

If the tracking system (measurements, material and B-field) is uniform as a function of the transverse radius R, then the resolutions can be expressed approximately in a simple form A $\oplus B/p_T$ [3-6]. The uniformity is approximately achieved by design; however it deviates due to a reduced radial lever-arm at high $|\eta|$, variations in detector spatial resolution as a function of $|\eta|$, a complex material distribution aimed at minimising material and including services, and a non-uniform field.

Approximate forms for the resolutions as a function of p_T (in GeV) and θ for a solenoidal field without a beam constraint are:

Need numbers from Helen.

- $\sigma(1/p_T) \approx A \oplus B/p_T \sqrt{\sin\theta} \text{ (TeV}^{-1)}$
- $\sigma(\phi) \approx A \oplus B/p_T \sqrt{\sin\theta} \text{ (mrad)}$
- $\sigma(\cot\theta) \approx A \oplus B/p_T \sqrt{\sin^3\theta}$
- $\sigma(d_0) \approx A \oplus B/p_T \sqrt{\sin\theta} \ (\mu m)$
- $\sigma(z_0) \approx A \oplus B/p_T \sqrt{\sin^3\theta} \ (\mu m)$

Without the above approximations, the complete resolutions obtained for muons from the analytic calculation have been parametrised as a function of p_T and $|\eta|$ for various configurations [3-7][3-8] so that they can be used for fast simulation with the ATLFAST package [3-9] - see Section XXX.

The p_T -dependence of the impact parameter resolutions is shown in Figures 3-9 and 3-10.



Figure 3-9 d₀ resolution as a function of p_T .



3.3.7 Correlations



Figure 3-11 Correlations between track parameters for 0.5 GeV p_T muons.

The most important correlations occur between parameters in the transverse x-y plane $(1/p_T, \phi, d_0)$ and between those in the R-z plane (cot θ , z_0); however the two sets of measurements are largely decoupled. Figures 3-11 and 3-12 show the normalised correlation coefficients for very low and very high p_T .

At low- p_T , the fitted angles and impact parameters are strongly correlated since they are dominated by the scattering at the material at the lowest radius (in particular that in the B-layer).



Figure 3-12 Correlations between track parameters for 1000 GeV p_T muons.

3.3.8 Other Particles

The resolutions shown in the previous sections correspond to muons. These represent charged particles in the idealisation that there are no interactions. The distributions of reconstructed muon track parameters are very close to Gaussian, and in the absence of PR problems, do not have any significant tails (see Figures 3-15 and 3-16). Small deviations from true Gaussian shapes arise from non-Gaussian components in the simulation of multiple-scattering and incomplete description of the simulated material in the track fitting.

3.3.8.1 Pions

To first order, reconstructed pion track parameters look like those of muons. However, since pions are subject to nuclear interactions, and in catastrophic collisions, a pion track may stop in the ID, the distributions of the reconstructed parameters do deviate from perfect Gaussians and obtain tails. To describe reconstructed pion tracks in the fast simulation with the ATLFAST package [3-9] (see Section XXX), the distributions have been parametrised as a function of p_T and $|\eta|$ [3-8] as the sum of two Gaussians. The first Gaussian describes the core of the distribution, while the second, which attempts to describe the tails, is typically 2–3 times wider with a normalisation which varies between 10% and 30% of that of the core. The description of the pion distributions by two Gaussians is not very robust since there are large correlations between the fitted parameters. Neverthless, it is found that the description works remarkably well.

3.3.8.2 Electrons

Electrons traversing the ID tend to emit bremsstrahlung radiation as they cross the material (see Figures 7-1 and 7-2). This introduces distortions to the track which cause the resolutions of the fitted parameters to be degraded and there is a tendency for the reconstructed parameters to be biased. By using the so called Bremsstrahlung Recovery Procedures (discussed in Section 7.2.1.1), it is possible to improve the reconstructed electron track parameters compared to the results which would be obtained using the same fitting procedure adopted for minimum ionising particles. In what follows, electron track parameters have been obtained using bremsstrahlung recovery in the ID alone, as implemented in xKalman.



Figure 3-13 Reconstructed electron p_T, normalised by the Monte Carlo generated p_T for electrons of various p_{T} , integrated over $|\eta|$.

Figure 3-14 Reconstructed transverse impact parameter vs reconstructed p_T for 20 GeV electrons.

Figure 3-13 shows distributions for reconstructed electron p_T. The distributions are significantly non-Gaussian (even for $1/p_T$) due to the bremsstrahlung which reduces the track curvature causing the electrons to be reconstructed with a lower p_T. Since the radiation is almost colinear with the electron, it significantly affects all of the reconstructed track parameters in the bending plane $(1/p_T, \phi, d_0)$, but hardly affects those in the non-bending plane (cot θ , z_0). The correlation between the reconstructed transverse impact parameter and the reconstructed p_T is shown in Figure 3-14. The scatter plot contains structure (bands running top-left to bottom-right, at different angles) which corresponds to hard bremsstrahlung from different planes of material in the precision tracker.

1.5

Using distributions like those above for a variety of generated p_T 's, parametrisations of the reconstructed electron track parameters have been derived as a function of p_T and $|\eta|$ [3-8] so that they can be used for fast simulation with the <code>ATLFAST</code> package [3-9] - see Section XXX. For a given electron track in the fast simulation, the parametrisation is derived from the location of a single hard bremsstrahlung chosen randomly from the appropriate distribution.

3.3.8.3 Comparison between Muons, Pions and Electrons



Figure 3-15 Difference between the reconstructed and generated p_T for single 20 GeV particles.



Figure 3-16 Difference between the reconstructed and generate transverse impact parameter for single 20 GeV particles.

Figures 3-15 and 3-16 compare the reconstructed $1/p_T$ and d_0 distributions for muons, pions and electrons. The muon distributions are very Gaussian, the pion distributions have small tails while the electron distributions are significantly distorted. To compare the distributions, Gaussian fits have been made to the cores of the distributions in exactly the same way for muons, pions and electrons. Since the electron distributions are significantly skewed, it is not simple to choose the range for the fit: for the $\Delta 1/p_T$ (Δd_0) distribution, the fit has been made in the range ± 1 (± 2) times the r.m.s about the peak. The fitted quantities are:

Peak The location of the peak.

R.m.s. The r.m.s. of the Gaussian fitted to the core.

Tail FractionThe fraction of tracks not contained in the Gaussian - the Gaussian is fitted
in a limited range, but the area is evaluated from the extrapolation of the
curve over the complete range.

In Figure 3-17, these quantities are shown for 20 GeV p_T particles. The distributions for $\cot\theta$ and z_0 are very similar for all particles. It can be seen that the peaks of the distributions are well centred for muons and pions, but there are significant biases for electrons. The resolutions for muons and pions are similar, but even in the core region for electron tracks, the resolution is noticably poorer. While the muons and pions have tails which are at the level of a few percent (these tails are sensitive to the fit range and are measures of the deviation from a perfect Gaussian - the actual number of muon 'outliers' is very small), the electron tails are very significant. Similar effects are seen at $p_T = 1$ GeV, although the electron tails are reduced by about a third.



O muon, ▲ pion, ▼ electron, $p_T = 20 \text{ GeV}$

Figure 3-17 Comparison of distributions of reconstructed $1/p_T$ and d_0 for muons, pions and electrons. See text for more details.

3

3.3.9 Charge Determination

The specification on the p_T resolution (at high- p_T) is set by the desire to be able to investigate the charge asymmetries in the decays of possible heavy gauge bosons W' and Z'. It is required that at $p_T = 0.5$ TeV, that the sign of an electron should be determined to better than 3 σ . This means that the intrinsic resolution $\sigma(1/p_T)$ should be at least as good as 0.6 TeV⁻¹. From Figure 3-4 ($p_T = 1000$ GeV), it can be seen that this is satisfied for muons up to $|\eta| \sim 2.2$, beyond which the resolution degrades like $1/R^2$ due to the reduced lever-arm as tracks fail to cross the full radial extent of the ID.

For electrons, the reconstruction of tracks is complicated by bremsstrahlung and subsequent conversions. However, in reducing the electron's momentum, the bremsstrahlung can also improve an electron's charge determination. Pile-up does not affect the charge measurement significantly, it's main effect being to reduce the reconstruction efficiency by ~3%. More details can be found in Section 4.2 of [3-1].

Using full simulation with additional smearing on $1/p_T$ to allow for the solenoidal field, the wrong sign fraction for electrons and muons after a beam constrained fit (integrated over $|\eta|$) has been found as a function of p_T . The results are shown in Figure 3-4 and summarised in Table 3-1. The muons are well described by the intrinsic resolution; for electrons, this is only true at very high- p_T . The



Figure 3-18 Wrong sign fraction as a function of p_T for muons and electrons.

effect of the B-field distortions is not great. It is clear that the ID should be able to determine the sign of the charge of electrons up to very high energies; the muon charge will be determined by the Muon system.

p _T (GeV)	Wrong sign fraction (%)			
	Uniform B field ^a		Solenoidal B field	
	Muons	Electrons	Muons	Electrons
500	0.04 (0.02)	1.2 (0.03)	0.2	1.4
1000	0.9 (0.9)	3.6 (1.2)	1.9	4.4
2000	9.2 (9.1)	11.5 (10.1)	11.6	13.3

Table 3-1 Wrong sign fraction for high-p_T muons and electrons.

a. Numbers in brackets are what would be expected from a Gaussian distribution with the nominal resolution.

3.4 Electron Identification by Transition Radiation (1 page)

Include summary of performance taken from work reported in ID TDR Section 4.6 in Electron and Photon ID (Section 7.2.1) - **although may move that text to here**.

3.4.1 Effect of Modular Geometry (Luehring)

Will reduce TR performance!

3.4.2 Particle Detection by dE/dx (Rousseau)

This is new work (23/9/98).

3.5 Pattern Recognition

The performance of the pattern recognition programs has been extensively analysed in Chapter 5 of the ID TDR [3-1]. In this section, a consistent presentation of the efficiencies for reconstructing isolated muons, pions and elctrons is given and in the case of the jets, the results have been updated for the Final Layout, including improvements to the pattern recognition (PR) programs.

3.5.1 Isolated Tracks

The reconstruction efficiency for muons is determined mainly by the tightness of the quality cuts (see Section 3.1.2), while for pions and electrons, it depends strongly on interaction suffered by the particles and their momenta. The rate at which the PR programs reconstruct **fake tracks**¹ at design luminosity which pass the quality cuts is very low: typically 3 orders of magnitude less than the rate of pile-up tracks and this can be reduced further by cutting on the TRT information. In addition to fake tracks, there are **spoilt tracks** whose reconstructed track parameters are distorted by the inclusion of incorrect hits. For isolated tracks, these effects are generally less than those arising from interactions/bremsstrahlung (see Section 3.3.8).

Figure 3-19 shows the track reconstruction efficiency at low luminosity for muons, pions and electrons of various p_T 's (the efficiencies averaged over $|\eta|$ are summarised in Table 3-2). The first three plots are shown for the **basic track quality cuts**. The muons and pions are less affected by the requirement of TRT hits for the **extended track quality cuts**; by contrast, the electrons are more strongly affected due to bremsstrahlung - their efficiency after the TRT cut can be seen from the last plot. The efficiencies are derived from <code>xKalman</code>. Since <code>iPatRec</code> does not start from the TRT, it is less susceptible to interactions in the precision tracker, and tends to result in somewhat higher efficiencies. Nevertheless, after the application of a TRT cut, the two programs should give comparable results. The results presented in Figure 3-19, should be taken as *indicative*, since only in the case of decays of massive objects to leptons would one expect to find well

^{1.} Fake tracks are those where \leq 50% of the hits come from a single Monte Carlo track or which are associated with a Monte Carlo track to which another reconstructed track is already associated.

isolated tracks and further, the efficiencies do depend on the algorithms used and the cuts applied. The single particle efficiencies have been parametrised as a function of p_T and $|\eta|$ [3-8] so that they can be used for fast simulation with the <code>ATLFAST</code> package [3-9] - see Section XXX.

Table 3-2 Summary of reconstruction efficiencies (from xKalman) corresponding to Figure 3-19 and integrated over $|\eta|$.

p _T (GeV)	Reconstruction Efficiency (%)				
		Basic Cuts			
	Muon	Pion	Electron	Electron	
1	96.8	84.0	76.4	69.4	
5	98.2	89.5	90.4	84.4	
200	98.6	94.9	95.9	94.8	



Figure 3-19 Track reconstruction efficiencies as a function of $|\eta|$ for muons, pions and electrons with basic cuts and for electrons with extended cuts (see Section 3.1.2). Efficiencies are shown for tracks of $p_T = 1$, 5 and 200 GeV as reconstructed by xKalman.

In principle, I should update the plots for newer layouts (ID TDR datasets used) and improved xKalman. Will depend on time available.

3.5.2 Tracks in Jets (Barberis, Ros)

The quality of the reconstructed tracks can be measured by comparing them to the corresponding simulated tracks. For this study, jets produced by the decays of 400 GeV Higgs were considered and all tracks with $p_T > 1$ GeV and within a cone of $\Delta R < 0.4$ from the jet axis were analysed. Figures 3-20 and 3-21 show the probability of having unique (correct), spoilt (merged) and wrong hits associated with a given track, for the Pixels and SCT respectively. The frequency with which tracks in jets pick up bad hits is significantly greater than isolated tracks. These hits can have serious consequences for b-tagging, where they cause large tails in the reconstructed impact parameter distribution - this is discussed more in Chapter BTAG.



Figures 3-22 and 3-23 show respectively the reconstruction efficiency and the probability of fake tracks as a function of $|\eta|$. The effects of the material distribution are clear in these figures. The average track reconstruction efficiency over all $|\eta|$ is XXX% and the average fraction of fakes is XXX%.



Results from Pile-up in Autumn 1998.

Nice to have plots of Eff vs ΔR and Eff vs p_T (track).

May be some (all) of this goes to b-tagging chapter.

3.5.3 Effect of Improved TRT Simulation (1 page) (Luehring)

3.5.3.1 Comparison of Pile-up Strategies

Compare SLUG pile-up with Fred's improved approach - single tracks or jets?

3.5.3.2 Effect of Modular Geometry

Shouldn't change much.

3.5.4 The Effect of the Solenoidal Field (1 page) (Poppleton, Gavrilenko)

3.5.5 Robustness

The robustness of the PR programs has been considered for various scenarios for isolated tracks and tracks in b-jets - the latter is discussed in more detail in Chapter BTAG.

3.5.5.1 Pile-up

It was shown in the ID TDR (Figure 5-6) that there is little dependence on the presence of pileup at design luminosity. Despite high occupancies at design luminosity (10–40%), the TRT continues to function well for PR even in stand-alone mode, due to the large number of straws (this is illustrated in Figure 12-2 of [3-2]). In Section 3.5.2 it was shown that the efficiency to reconstruct tracks in jets is little affected by pile-up, although the time taken by the PR programs is significantly increased. This is not too surprising since in a high-p_T jet, the local occupancy arising from the jet tracks dominates that from pile-up tracks (see Tables 3-14 and 3-15 in [3-1]).

3.5.5.2 Noise

Figure 3-24 shows the fake rate at design luminosity and reconstruction efficiency for single tracks as a function of the fraction of noisy strips in an SCT module. The fake rates are shown for relaxed cuts in order to have an observable number of fakes. If the cut on the number of precision hits is tightened from 7 to 9, then the fake rate will fall by an order of magnitude. The fake rate rises dramatically with the fraction of noisy strips, and for ~1% noisy strips (albeit with the relaxed cuts), approaches the rate of real pile-up tracks with $p_T > 2$ GeV which is 2×10^{-2} in a 'cone' $\Delta \eta \times \Delta \phi = 0.2 \times 0.2$. In practice the noise occupancy is expected to be $O(10^{-4})$ (See Figure 11-67 of [3-2]). However, should the noise increase, the thresholds will be raised to restore the low occupancy. Figure 3-25 shows the consequences of increased noise where the thresholds are set to 4 times the r.m.s. of the noise - the expected noise is around 2000 e⁻. It is clear from the figure that by adjusting the threshold, the fake rate can be kept at an acceptable level without significant loss of efficiency. The occupancy from noise hits should be compared with those from pile-up at design luminosity and as found in the core of a high-p_T jet which are ~0.5% and 1.5% respectively in the SCT (Table 3-15 in [3-1]).



Figure 3-24 Fake rate and reconstruction efficiency as a function of the fraction of noisy strips in an SCT module. **USE TDRFIG**

3.5.5.3 Inefficiencies

Figure 3-26 shows the effect of reduced efficiency of the SCT strips (allows for intrinsic efficiency, bonding faults, faults in the electronics etc.) - the pixel efficiency is held constant at 97%. The SCT strip efficiency at the start of running is anticipated to be around 97%. It can be seen that the PR is fairly insensitive to variations in the SCT strip efficiency, although if the pixel efficiency is varied at the same time, it is found that there are significant losses arising from the insistence on a B-layer hit. In practice, should the efficiency of a module fall below ~90%, then it may well be replaced. More details on the effect of noise and inefficiencies in the SCT can be found in [3-10].

3.5.5.4 Removal of Layers



Figure 3-25 Fake rate and reconstruction efficiency as a function of the noise in the SCT strips (with a variable threshold). **USE TDRFIG**



Figure 3-26 Fake rate and reconstruction efficiency as a function of the efficiency of SCT strips. USE TDRFIG

In an effort to reduce material in the ID, lay-

outs with one less superlayer of silicon were studied [3-4]. This study also served to highlight the consequences of large regions of the precision tracker becoming inefficient. Most of the emphasis was on b-tagging, as is discussed in Section BTAG.

LVL2 Rates for Electrons

If one superlayer of silicon is moved, by reducing the number of hits required, the electron efficiency at LVL2 using just the silicon can be maintained but with a \sim 40% increase in the background rate from jets. If the TRT is included, then there is little degradation. However, if two

superlayers of silicon are removed, even with the TRT there will be a loss of electron efficiency of \sim 3%.

K⁰s

With the loose cuts used in [3-1], a minimum of 4 single (ϕ or stereo) hits are required. Should one superlayer of the SCT be removed and the SCT reoptimised, then the volume in which K_{s}^{0} 's can be identified is reduced causing the acceptance to fall by ~5%.

3.5.5.5 Misalignment

The targets for the uncertainties on the alignment of the ID detector elements are typically less than half of the intrinsic resolution of the devices (see Chapter 9 of [3-1]). To a large extent these should be achieved by surveying techniques and in-situ monitoring. The alignment will be verified and improved by using tracks from pp collisions. To ensure that tracks can be found in the first place, the internal cuts used by the PR programs will need to be loosened. However, after the initial alignment is achieved, the remaining misalignments should be sufficiently small so as not to perturb the PR.

3.6 Primary Vertex Reconstruction

May need to be compressed a bit.

At the LHC the interactions will be produced with a Gaussian spread: $\sigma_x = \sigma_y = 15 \,\mu\text{m}$ and $\sigma_z = 5.6 \,\text{cm}$. For most of the analyses, this information (especially that in the transverse plane) is already sufficient, but for some analyses, a better knowledge of the position of the primary vertex is desirable.

In Section 6.4 of the ID TDR [3-1], it was shown how, at low luminosity, it is possible to determine the position of the primary vertex on an event-by-event basis by an iterative procedure which tries to fit all the reconstructed tracks to a common vertex, removing at each step those tracks which look inconsistent with the hypothesis that they come from the primary vertex (true secondaries from interactions, particles with a lifetime and mismeasured tracks). With this procedure, the primary vertex position resolution becomes basically a function of the total number of tracks (and of the their quality) which can be successfully attached to the same vertex. Due to the fact that the event vertex spread in the transverse plane is already very good, the fitting procedure was found to improve the transverse resolution only for high track multiplicity events (more than 30 tracks in the primary vertex fit, as in H(400) \rightarrow bb events). Additional improvements can be obtained by combining this method with some other independent estimate of the transverse position of the primary vertex, such as the beam-spot position determined on a runby-run basis (as done in some of the LEP experiments and in CDF), by using the d₀- ϕ correlation of the tracks in the event.

Significant improvements in the z-direction can be achieved: a resolution in the range 22–50 μ m (although with some non-negligible tails) for track multiplicities ranging between 36 and 10. These figures are well inside the ATLAS physics performance specification of 1 mm for the z-co-ordinate primary vertex resolution with at least four tracks [3-11]. An updated summary of the results for low luminosity is shown in Table 3-3.

	σ (μ m)			r.m.s. (μm)		
Sample	x	У	z	x	У	z
Min. Bias	32	30	49	59	58	72
Н(100) →үү	22	22	41	32	33	49
H(400)→b b	10	10	22	14	14	27
$\mathbf{B_{d} \rightarrow J/\psi K_{s}}$	23	23	35	38	38	50
$B_s \rightarrow D_s \pi$	24	22	38	39	38	51

Table 3-3 Widths of residual distribution for position measurements of the primary vertex for various samples of physics events at low luminosity. Both Gaussian widths of the core and the r.m.s.'s are given.

At high luminosity, the problem of multiple interactions in the same bunch-crossing needs to be addressed. An average of 24 minimum bias pile-up events are expected to be superimposed on a signal event in the Inner Detector (the TRT will in fact see hits from about 32 minimum bias events, however, due to the fact that tracks having only hits in the TRT are not reconstructed, 24 is the number which matters in the discussion that follows). In principle one needs to reconstruct only the signal event, and in some cases, this could be identified easily because minimum bias events will have a smaller charged track multiplicity and a smaller total transverse momentum. Unfortunately this is not always true and in some analyses the selection of the signal event based on these selection criteria might introduce dangerous biases. Therefore, it would be preferable to reconstruct as many as possible of the primary vertices in a triggered event and leave the selection of the signal event for later in the analysis chain. Further, in the reconstruction and analysis process, more sophisticated information about the event is available (including the presence of leptons, photons, jets, b-jets, tau's, etc.) and so the identification of the signal event can be made more reliably.

A generalisation of the algorithm used in the low luminosity case has been developed. In a first step the algorithm assumes that all tracks are coming from the beam-line in the transverse plane (this is a good approximation due to the small transverse beam-spot size) and determines the z-coordinate of each tracks. Each of these values constitutes the entry of an histogram with a 500 μ m bin size. This histogram is then scanned to look for locations where the tracks cluster as they should do if they are coming from the same vertex. A minimum of 4 track is required to define a cluster. For each cluster, a list of the tracks attached to it is defined. The tracks in each list then constitute the input to the same algorithm used at low luminosity. If the fit is successful, the vertex is retained and added to the final list of primary vertex.

The algorithm has been applied to a sample of H(100) $\rightarrow \gamma \gamma$ events. Charged tracks have been reconstructed using the xKalman algorithm and then selected using the same quality cuts described in Section 6.4 of the ID TDR. The only difference is that a higher track p_T threshold (1 GeV instead of 0.5 GeV) has been applied in xKalman in order to save CPU time. The analysis will be repeated with a lower- p_T threshold.

In Figures 3-27 and 3-28, two examples of histograms of the z-coordinate of the tracks for two particular events are shown. The z-coordinate of the reconstructed tracks (bottom) is compared to the distribution of the z-coordinate of tracks from the KINE bank (top). An arrow on the KINE histograms indicates the signal event. In Figure 3-27, it can be seen that the signal event is associated with the cluster which has the highest track multiplicity, however, this is not true for the event shown in Figure 3-28.







Figure 3-27 Distribution of the intersection of the tracks with the z-axis for one particular event at KINE level (top) and after reconstruction (bottom). The arrow indicates the $H \rightarrow \gamma \gamma$ vertex.

Figure 3-28 Distribution of the intersection of the tracks with the z-axis for another event at KINE level (top) and after reconstruction (bottom). The arrow indicates the $H \rightarrow \gamma\gamma$ vertex.

On average, the algorithm reconstructs 5 primary vertices. This number is considerably lower than the 25 vertices present in one beam-crossing. This difference has not been studied in detail, however, it is thought to be due to the fact that the vertices merge and superimpose so become indistinguishable and due to track losses resulting from the 1 GeV p_T cut. (The efficiency to reconstruct the primary vertex in minimum bias events was already found lower than that of the other sample studied in section 6.4 of the ID TDR Vol. I: 72% against a 95% efficiency for the other samples. This value is expected to undergo a further decrease due to the higher pt cut. Not very clear.)

With a requirement of a minimum of 2 tracks to define the primary vertex, the primary vertex of the signal event is found inside the list of reconstructed vertices 72% of the time, The z-resolution is about 48 μ m with an r.m.s of 106 μ m, compared to values of 41 μ m and 49 μ m respectively observed on the same sample at low luminosity. This means that while the core of the distribution change slightly, there is a clear increase in the tail of the residual distribution at design luminosity.

Residuals distribution in the x- (the y-coordinate is similar) and z-coordinate are shown in Figures 3-29 and 3-30 respectively.

3.7 V⁰ Reconstruction (0.5) (Tartarelli)

Francesco hopes to have something by end of Oct.

K⁰ track resolution and efficiency (without straying into B-physics).

May fit better elsewhere in TDR.





Figure 3-29 Residuals on the x-measurement of primary vertex for $H \rightarrow \gamma \gamma$ with pile-up. Superimposed is a Gaussian fit to the core of the distribution.

Figure 3-30 Residuals on the z-measurement of primary vertex for $H \rightarrow \gamma \gamma$ with pile-up. Superimposed is a Gaussian fit to the core of the distribution.

3.8 Lifetime Measurements (0.5)

Measurements of vertices displaced by O(1) mm from the primary vertex will be essential for B-physics (see Chapter XXX), b-tagging (for example $H \rightarrow b\overline{b}$) (see Chapter XXX) and life-time measurements.

B Decays

The decay channel $B_s^0 \rightarrow D_s^- \pi^+$ followed by $D_s^- \rightarrow \phi^0 \pi^-$ and $\phi^0 \rightarrow K^+K^-$ has been studied in ATLAS for the measurement of x_s , the mixing parameter in the B_s^0 system. In the Pixel TDR [3-3], it was shown that a resolution of the proper time of 0.073 ps could be obtained. The proper time residuals are shown in Figure 3-31.



Tau Decays (Osculati)

Figure 3-31 Residual distribution for proper time measurements of B_s .

3.9 Alignment Strategy Etc. (2)

Using Physics events for ultimate precision. Superb precision required for M_w measurement.

Refer to hardware considerations in Chapter 9 of ID TDR.

See discussion document on Web: ID -> Performance -> Alignment

3.9.1 Alignment (Peeters)

- Muons p_T > 6 GeV, moderate-p_T particles, Cosmics?
- Use of overlaps, connections between layers, connections between subdetectors

3.9.2 Momentum Scale (Snow, Haywood?)

May appear in Chapter 3.8 on mass scale.

- Understanding B-field measurements and constraints on field. Steve hopes to have something by December.
- Use of Z mass.

3.9.3 Material Distributions (Clifft)

- Reconstructed conversions
- Also reference to E/p in E/gamma chapter.

3.10 References (1)

- 3-1 ATLAS Collaboration, Inner Detector Technical Design Report Vol. I, CERN/LHCC 97-16.
- 3-2 ATLAS Collaboration, Inner Detector Technical Design Report Vol. II, CERN/LHCC 97-17.
- 3-3 ATLAS Collaboration, Pixel Technical Design Report, CERN/LHCC 98-13.
- 3-4 D. Barberis eta al., ATLAS Internal Note, INDET-NO-188.
- 3-5 ATLAS Internal Note, INDET-NO-207.
- 3-6 S. Haywood, ATLAS Internal Note, INDET-NO-91.
- 3-7 E. Buis et al., ATLAS Internal Note, INDET-NO-197.
- 3-8 E. Buis et al., ATLAS Internal Note, INDET-NO-XXX.
- 3-9 ATLFAST???
- 3-10 L. Drage and A. Parker, ATLAS Internal Note, INDET-NO-181.
- 3-11 D. Froidevaux and A. Parker, ATLAS Internal Note, INDET-NO-46. Referenced ??