The University Of Sheffield.

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SemiConductor Tracker Barrel Module Distortions

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Outline

- **Introduction to the SCT**

  What, where, why

- **The Barrel Modules**

  Description and distortions

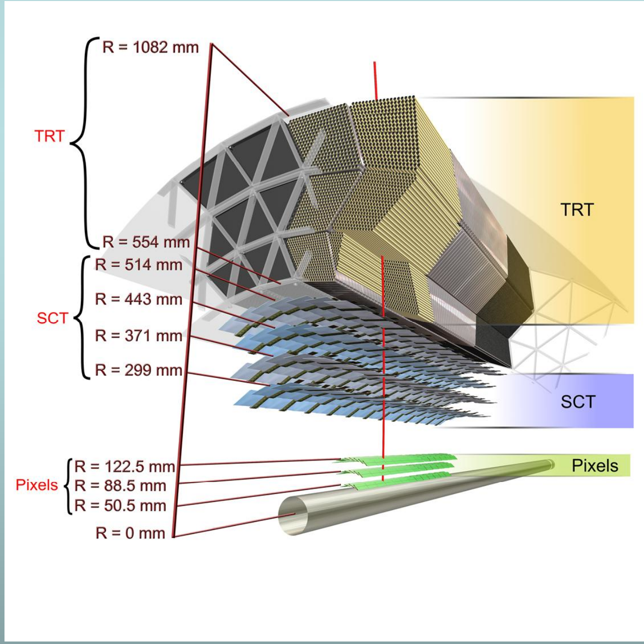
- **Module Survey**

  Overview of the measurements taken

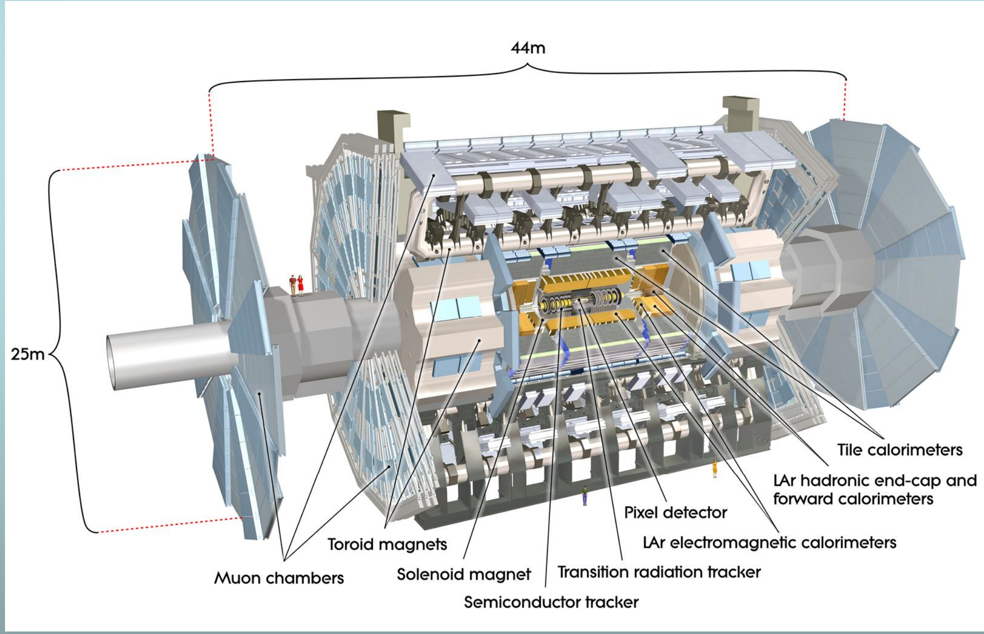
- **Simulating the Distortions**
- **Correcting the Distortions**
- **Application to Data**
- **Conclusions and Future Work**

Introduction to the SCT

- The Semi-Conductor Tracker is part of the ATLAS Inner Detector. It lies outside the Pixel detector and inside the TRT
- The Inner Detector is surrounded by the ElectroMagnetic Calorimeter and the Hadronic/Tile Calorimeter
- These are encompassed by the Toroid Magnets and finally the Muon Detector



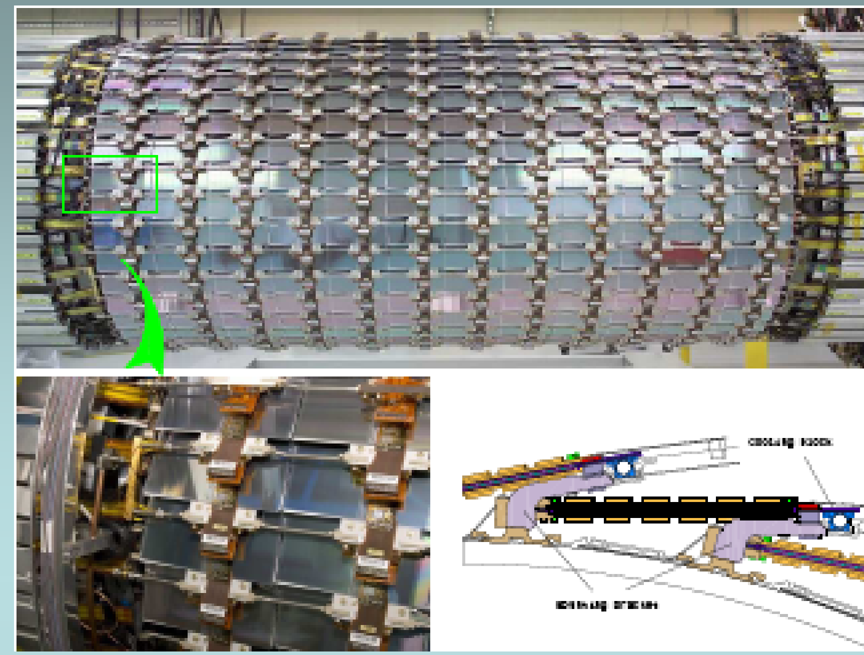
Inner Detector Layout (1)



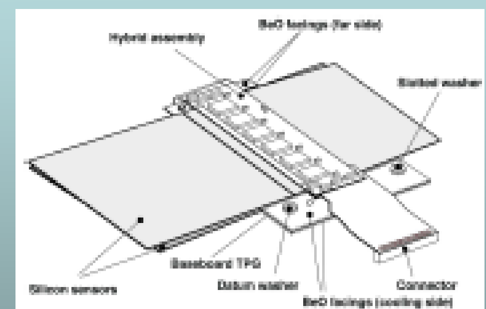
ATLAS Detector Layout (2)

Introduction to the SCT

- The Semi-Conductor Tracker is part of the ATLAS tracking system
- Accurately measuring the tracks of particles produced by a collision helps identify the types of particle and their momentum
- The SCT is made up of the barrel (shown top) and endcaps (9 at each end of the barrel)
- This study focuses on the barrel modules as the effect of the distortions in the endcaps are known to be negligible
- The barrel is made up of 4 concentric layers of silicon detector modules
- There are a total of 2112 modules attached to the SCT barrel



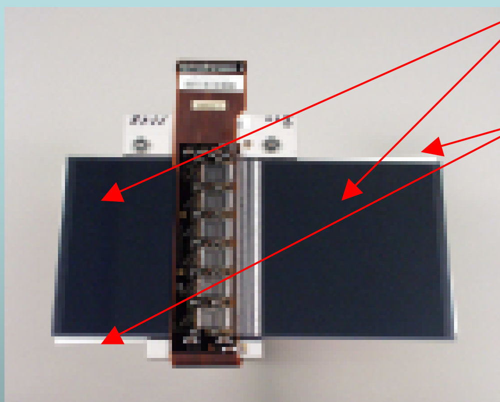
The Semi-Conductor Tracker Barrel (3)
Radius ~ 514mm, Length ~ 1.5m



Barrel Module Components (4)

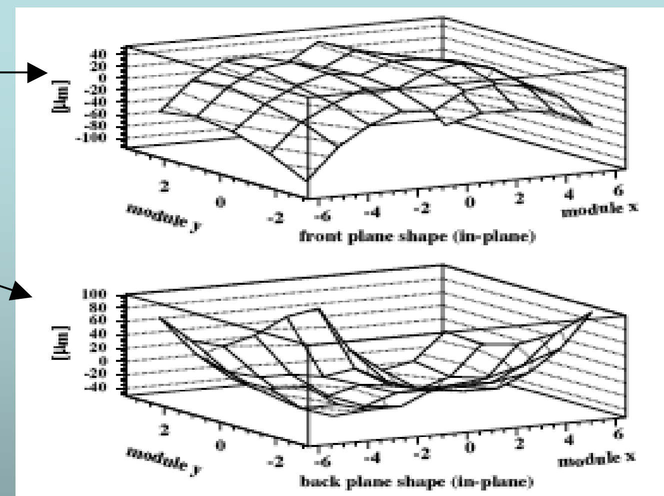
The Barrel Modules

- Each module is made up of 4 silicon wafers. These are glued to a base board back to back at an angle of 40 mrad, 2 wafers on the upper surface, 2 wafers on the lower surface
- Each module has 768 silicon micro-strips per side. This allows for accurate reconstruction of the x and y coordinate of a particle hitting the module
- In our Simulation and Reconstruction software we consider these modules to be flat
- Surveys carried out on the modules at the assembly sites have shown that the modules are distorted, such that the corners of the upper and lower surfaces bow toward each other



SCT Barrel Module (5)

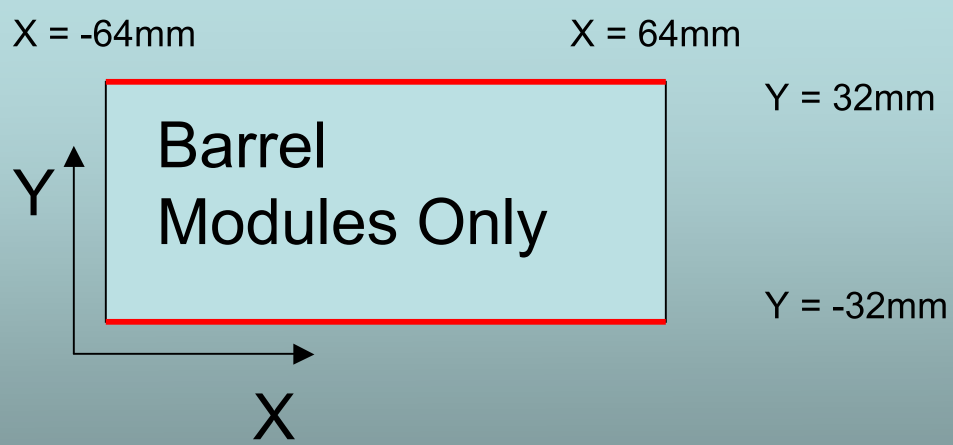
Two Wafers of Upper surface (grey)
Edges of lower surface (white)
Semantics:
2 Wafers = 1 Surface
1 Module = 2 Surfaces
= 4 Wafers



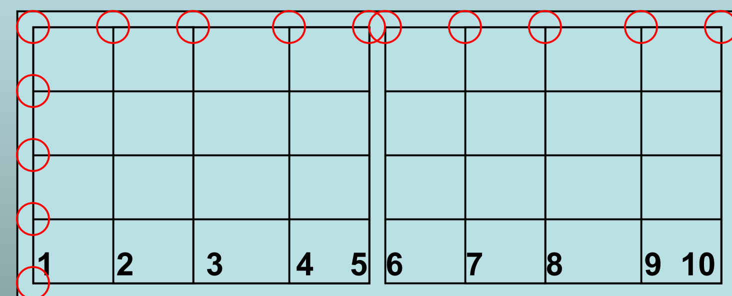
Barrel Module Distortions (6)

Module Survey

- The modules were each assembled and surveyed at one of 5 assembly sites
- During the survey the x, y and z coordinates were measured across a 5 x 10 grid on each of the surfaces for every module
- Survey observed a maximum deviation from flat of ~ 150 microns
- Module wafers are glued to a base board that has a smaller surface area than the module surface
- As only the centre of the module surfaces are glued down the edges are free to distort

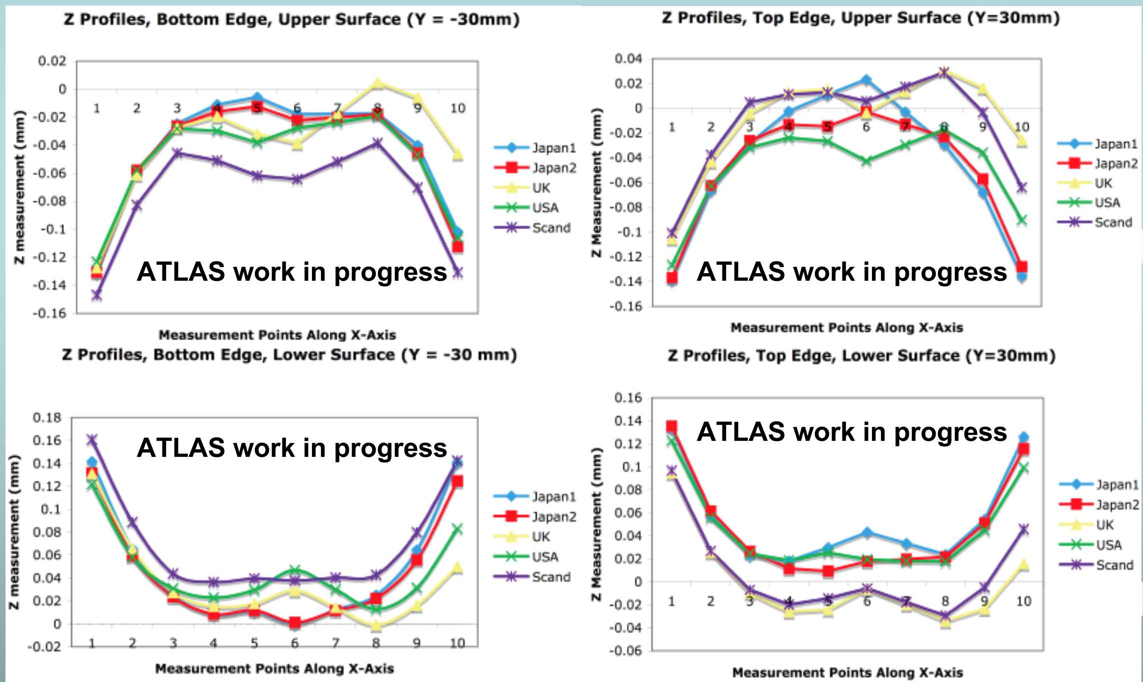


Each surface has 50 Points of Measurement
(at intersections in diagram)



Module Survey

- After a study on the measurements themselves there is no obvious correlation between the different sections of the modules and the degree of distortion
- Very impractical to use and store 100 measurements for every single module
- Average over the modules for each assembly region to produce 5 common profiles, for each module use the common profile for the appropriate assembly site



Common profiles shown with different colours for different assembly sites

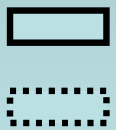
Top 2 plots: Upper Surface
Bottom 2 plots: Lower Surface

Left plots are of the edge with Y=-30mm

Left plots are of the edge with Y=30mm

Simulating the Distortions

- To understand the effect of the distortions simulate it in Monte Carlo data
- As opposed to modeling the module shape we can move the x and y coordinates of the track hitting the module to where it would be if the modules were described with the distortions suggested by the survey measurements
- The correction to the hit position is straight forward trigonometry:



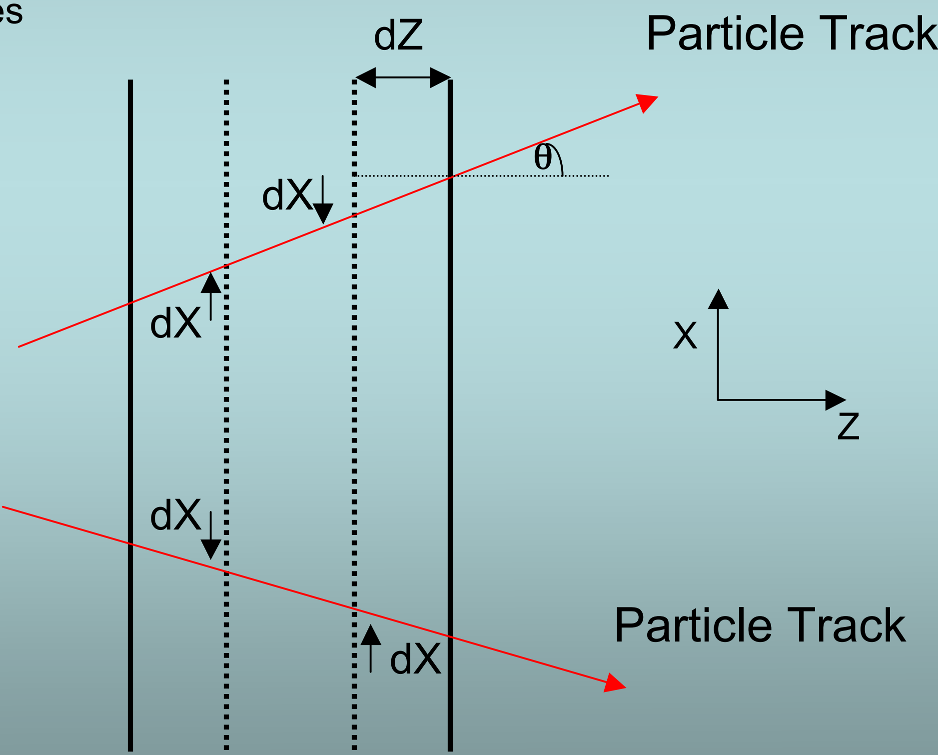
Shift the X and Y position of the hit by:

$dX = dZ \tan(\theta)$

$dY = dZ \tan(\theta')$

The direction of the x and y shift is dependent on the angle of the track and the side of the module

Study the effect using 25000 single muon events

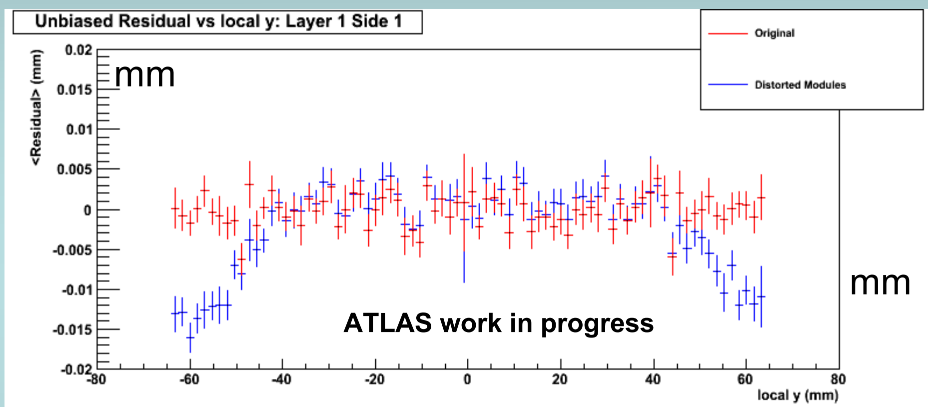


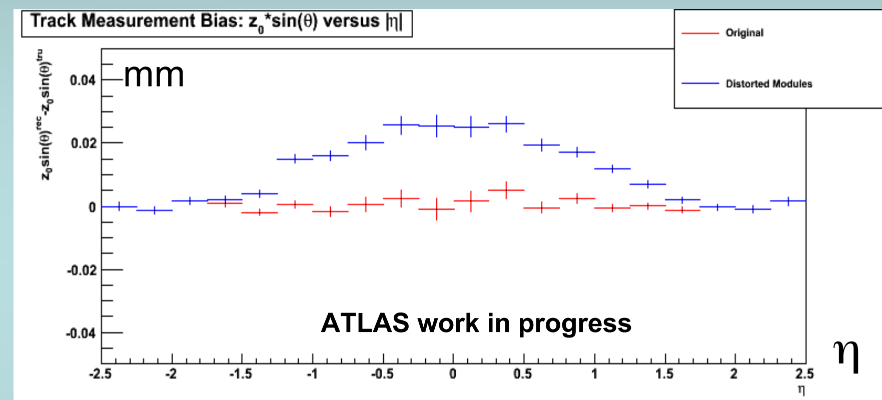
Simulating the Distortions

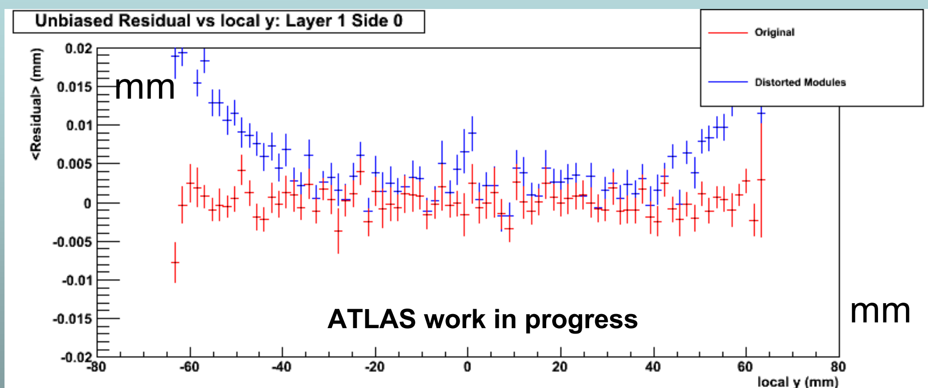
- The effect of the distortions can be clearly seen in the longitudinal track parameters (Z0 and θ) and the track residuals
- Residual = x position of cluster - x position of fitted track through that module (a cluster is a collection of hits)
- **Track parameters:**
    - The perigee parameters of a track are the coordinates of the closest point of approach of that track to the origin of the event
    - D0 = Transverse impact parameter (global x,y component)
    - Z0 = Longitudinal impact parameter (z runs in direction of beam)
    - θ = Polar angle (between z-axis and x, y plane)
    - ϕ = Azimuthal angle (between x and y axis, x-axis points to LHC centre, y-axis points up) q/p = Magnitude of charge over momentum
    - $\eta = -\ln[\tan(\theta/2)]$

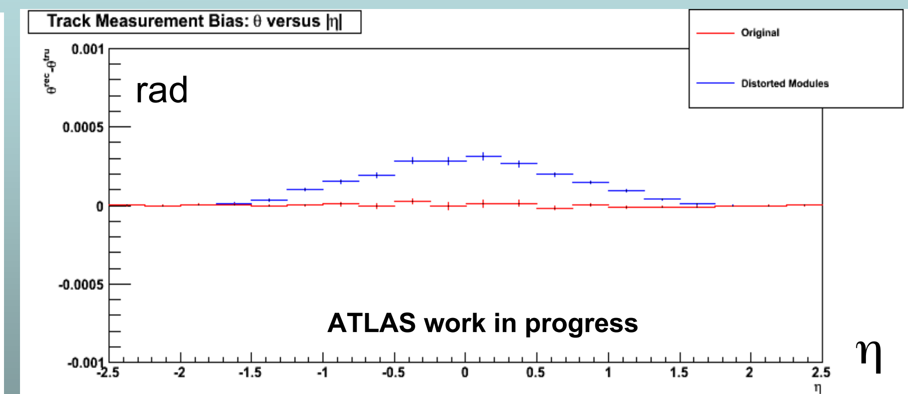
Simulating the Distortions

- The **non distorted** MC distributions are in red, distributions **with the distortions** are in blue (just two of the mean residual distributions are shown below and the mean bias (reco - true) distributions for θ and Z0)
- Distortions have a small but noticeable effect on these distributions. They can be ignored in the short term but may need to be included for ultimate design precision









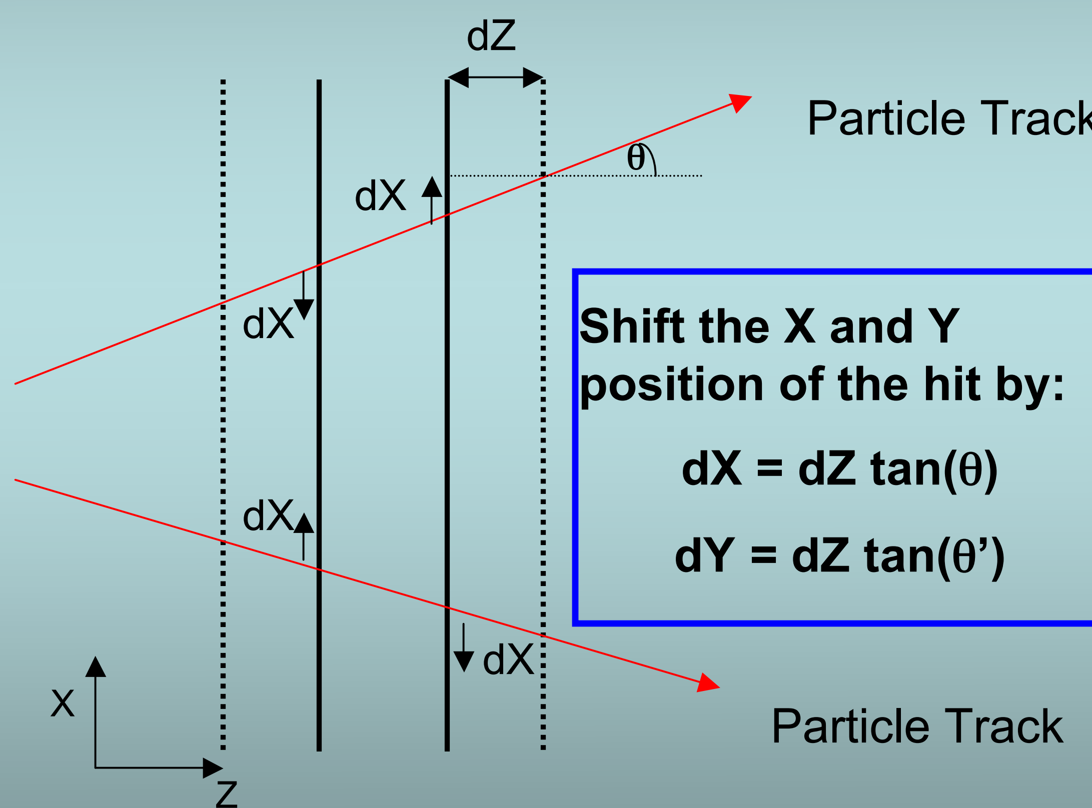
Correcting the Distortions

- Successfully simulating the distortions in Monte Carlo data allows for a correction to be applied during the Reconstruction of events
- This correction is what will be applied to data and must remove all the changes seen in the tracking parameters and residuals caused by simulating the distortions

The position of the module surfaces as seen by the Reconstruction sw

The module surfaces are effectively moved apart to correct for the bowing

Again the direction of the x and y shift is dependent on the angle of the track and the side of the module. The signs of the shifts are opposite to that for the simulation.



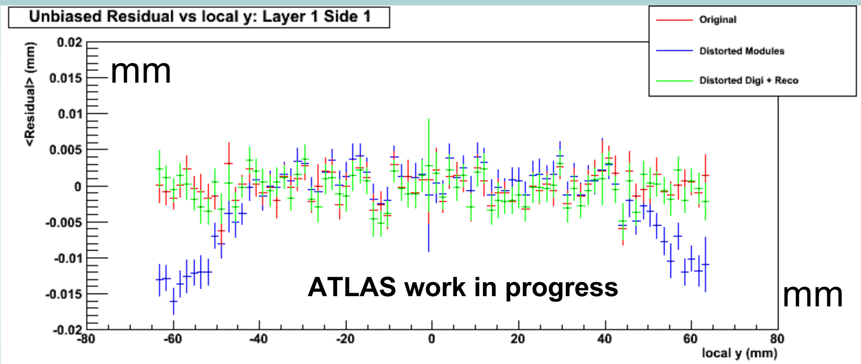
Shift the X and Y position of the hit by:

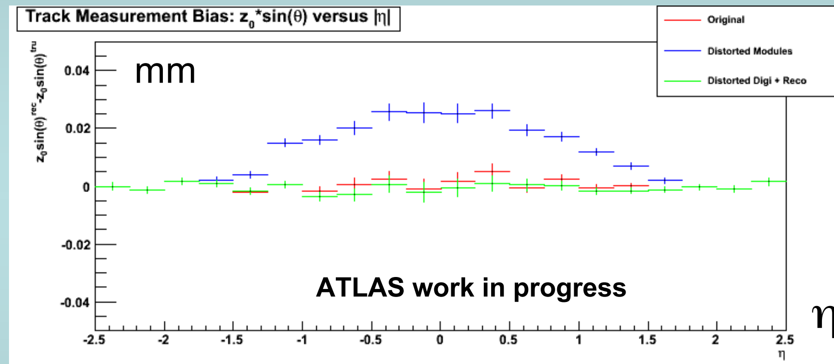
$$dX = dZ \tan(\theta)$$

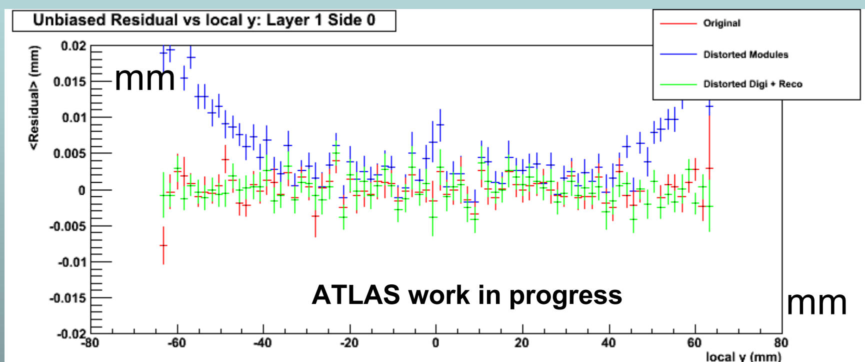
$$dY = dZ \tan(\theta')$$

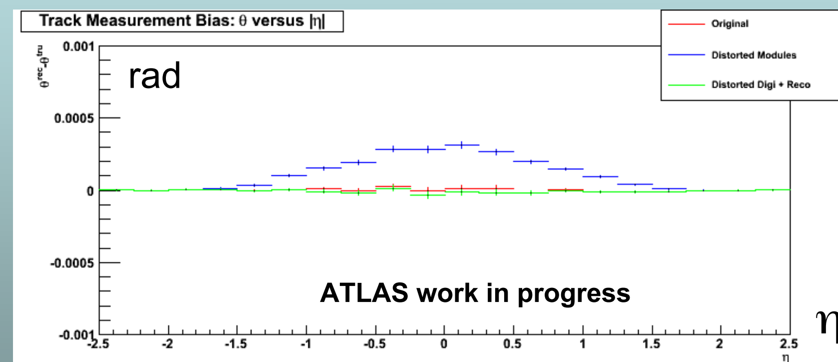
Correcting the distortions

- Clearly see difference between non distorted distributions (red) and those with the simulated distortions (blue)
- Correcting the distortions in the Reconstruction (green) brings the distributions back to the original









Application to Data

- As the correction is working well in Monte Carlo data we can look in to applying the correction to data (cosmic events)
- Blindly applying the correction to data during Reconstruction does not improve the tracking residuals
- This is an effect of the Alignment procedure, the distortions are effectively “aligned out”
- During the Alignment of the detector the positions of the different components of the detector are moved around (slightly) to reduce the residuals of tracks and better describe the current positions of these components
- In order to avoid this a new set of alignment constants must be made where the alignment algorithms are run over real data with the distortions correction applied
- Applying the correction during the Reconstruction of data with these new alignment constants will show how much of an improvement to the residuals the distortions correction will provide
- If the correction is deemed worth while the barrel module shape will be parameterised appropriately and added as additional degrees of freedom to the Alignment

Conclusions and Future Work

- The barrel modules in the SCT are known to be distorted but are described as flat in the Simulation and Reconstruction of events
- It has been shown that the effect of these distortions during the simulation of Monte Carlo events can be successfully removed during the Reconstruction of events
- The distortions also need to be taken in to account during the Alignment procedure, as the modules are considered to be flat here also. Currently working on applying the distortions correction during Alignment to produce new constants
- If the correction in the Alignment and Reconstruction of data improves the track residuals the barrel modules will be parameterised appropriately
- The Alignment procedure can use this parameterisation as a starting point for the shape of the modules and can modify them accordingly during the Alignment
- Instead of using a common profile to describe and correct the distortions during the Reconstruction of events it will be more sensible to use the shape of the modules determined during Alignment
- Hopefully we will have a more accurate description of the detector and improved tracking

Thanks!

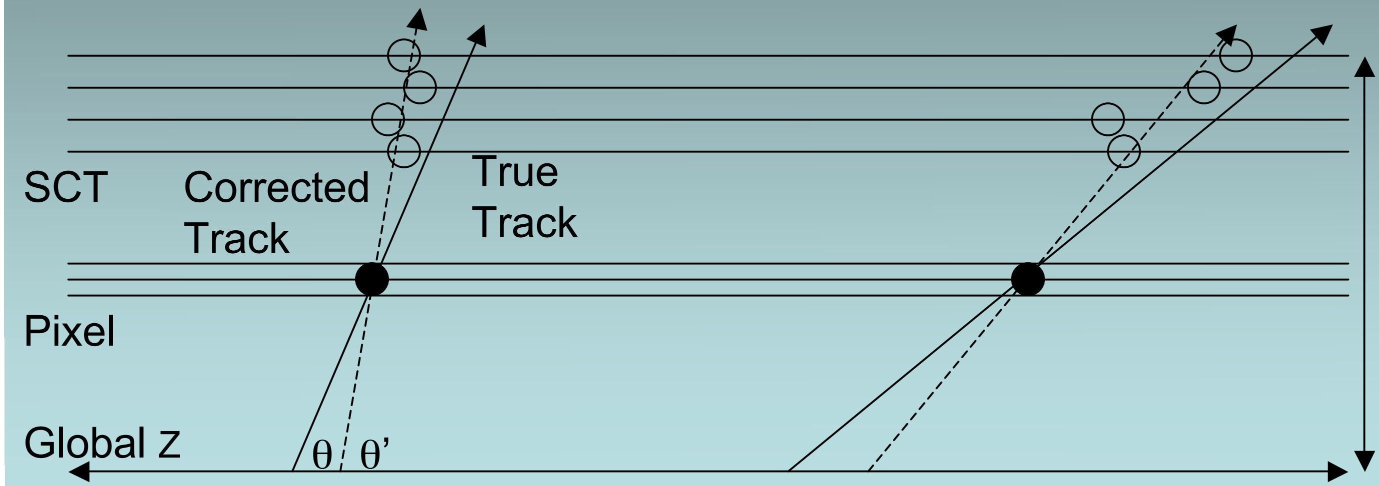
References for Images

(1), (2), (3), (4) and (5) from ATLAS collaboration, *The ATLAS experiment at the CERN Large Hadron Collider*, IOP Publishing Ltd and SISSA (JINST 3 S08003), 2008 (Figures 4.2, 1.1, 4.29, 4.7, 4.7 respectively)

(6) Lars Eklund, *The ATLAS SemiConductor Tracker-overview and status*, NIM A 494 (2002) 102-106

Back Up

Effect on transverse track parameters: **Theta bias peak**

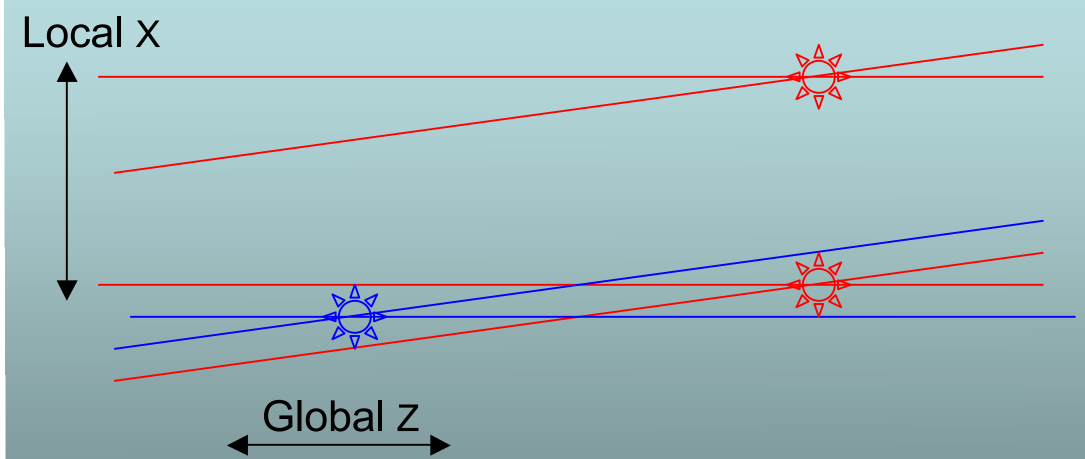


$\tan\theta \sim R/Z$

$\tan\theta' \sim R/(\Delta Z - \text{shift})$

If Z >> shift (ie high eta), effect on θ smaller, hence peak in theta bias at 0

Effect on transverse track parameters: **Transverse only**



2 strips shown, one from upper surface and one from lower surface with stereo angle = 40 mrads
2 strips give x and y coordinate of hit
Distortions move surfaces of the module closer
Strips before distortion Strips after distortion

Distortions cause the spacepoint to move a significant amount in the global Z direction only (eg a shift of ~750microns for a track at 11 degrees to module with a distortion of 15 microns)