ATLAS SCT Endcap C Efficiency Measurement

Nicholas Austin

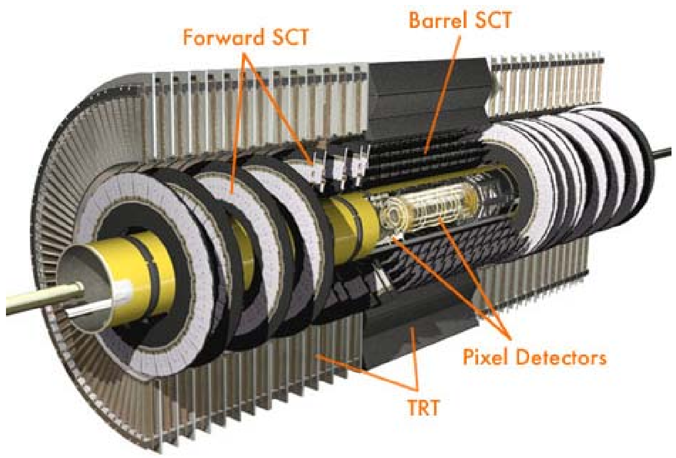
austin@hep.ph.liv.ac.uk

naustin@mail.cern.ch

UNIVERSITY OF LIVERPOOL

IoP Conference April 2009

The ATLAS Inner Detector



- Provides tracking of charged particles for $|\eta|<2.5$

- Consists of 3 sub-detectors:
  - Pixel Detectors
  - Semicondictor Tracker (SCT)
  - Transition Radiation Tracker (TRT)

Silicon strips/pixels detect particles

Many layers of gaseous straw tubes interlaced with Transition Radiation foils.

- During normal running, tracking volume surrounded by 2T magnetic field.

The SCT consists of:
- 4 concentric barrels.
- 2 endcap sections: 9 disks - labelled 0-8 in what follows.

Endcap Disk	Ring			Total Number of Modules
	Outer $\eta = 0$	**Middle $\eta = 1$**	**Inner $\eta = 2$**	
0	$\Phi = 0 - 51$	$\Phi = 0 - 39$	/	92
1-6	$\Phi = 0 - 51$	$\Phi = 0 - 39$	$\Phi = 0 - 39$	132
7	$\Phi = 0 - 51$	$\Phi = 0 - 39$	/	92
8	$\Phi = 0 - 51$	/	/	8

SCT Modules

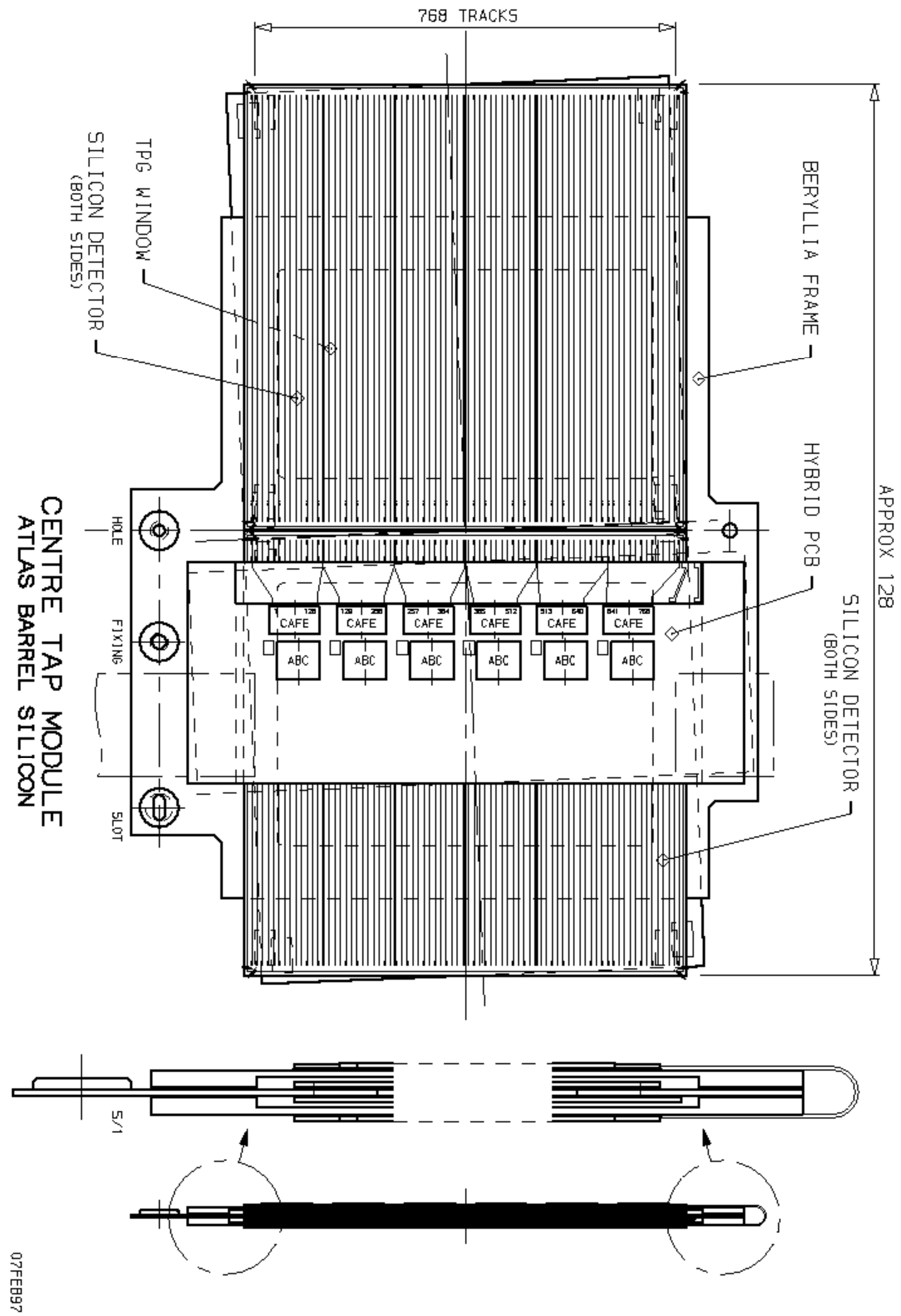
Most modules consist of 4 silicon sensors:

• 768 sensor strips ~12cm in length (bondgap in middle).

• 2 sides glued back to back at a stereo angle of 40 mrad to provide space points.

• Strips in the barrel are aligned parallel to the solenoid field and beam axis and are at a constant pitch of 80 μm.

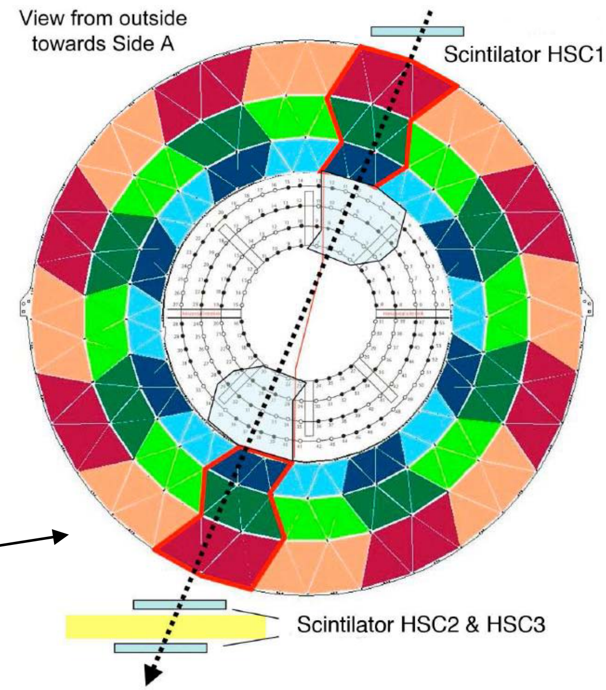
• Sensors in the end caps are aligned radially and are wedge shaped, their pitch varies(57-94 μm) and widens towards larger radii.



Over-ground Cosmic Tests (in SR1)

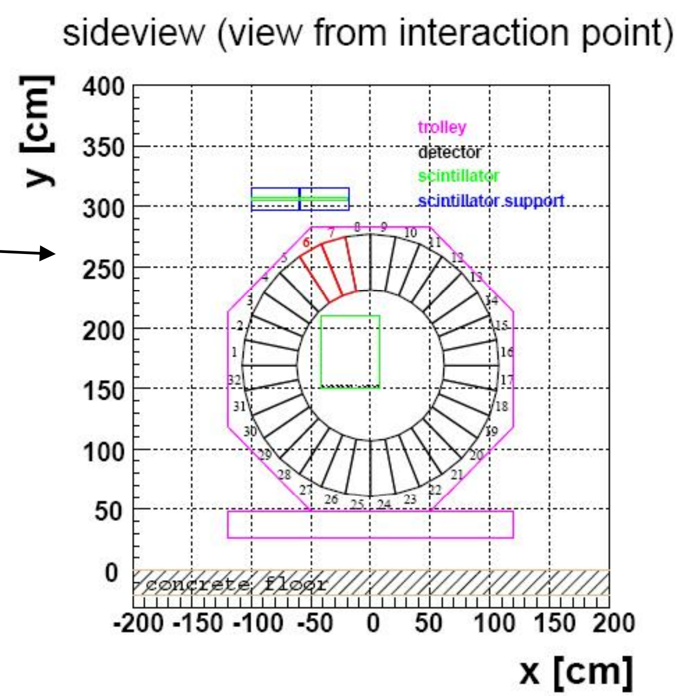
Barrel Tests: April – June 2006.

Endcap Tests: October – December 2006.



- Cosmic rays triggered with 3 layers of scintillator strips.
- Arranged for large angular distribution of cosmic rays hitting scintillators & instrumental sectors of the TRT & SCT whilst balancing demands of selecting tracks of decent length whilst maintaining an acceptable track rate.

- **Barrel Setup:**
  - Opposite sectors of the SCT and TRT barrels were cabled and tested. 1/8 of TRT barrel and ¼ of SCT barrel (468 SCT modules).
  - Recorded 450,000 events.
- **Endcap Setup:**
  - One quadrant of SCT endcap C (247 modules) and 1/16 of TRT endcap C wheels were tested.
  - Recorded 2.5 million events.



Motivation for my work…

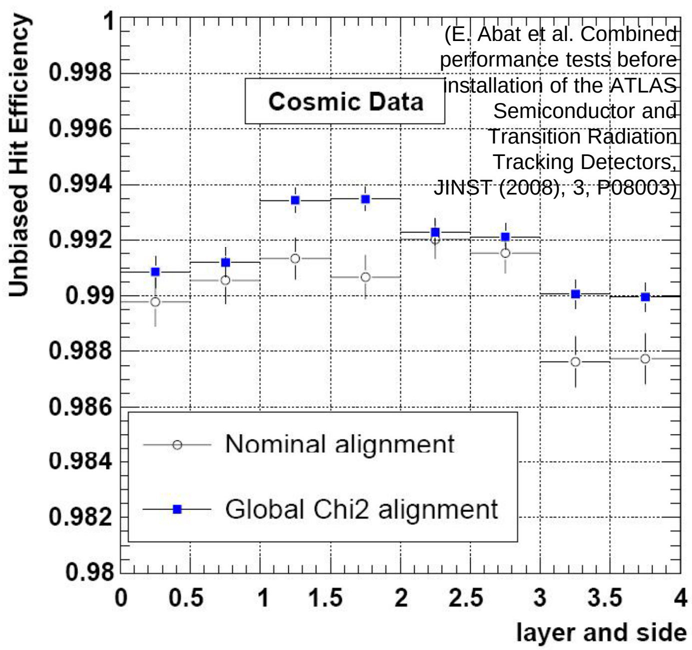
SCT Barrel Efficiency Measurement – As performed by Dr Helen Hayward (E. Abat et al. Combined performance tests before installation of the ATLAS Semiconductor and Transition Radiation Tracking Detectors, JINST (2008), 3, P08003)

Method

For each reconstructed track in an event that remained after a **track quality cut** the algorithm:

- **Removes hits** located on the SCT barrel layer under investigation (active layer).
- **Refits track** excluding these hits.
- **Extrapolates** refitted track to the active layer (using perigee parameters) to obtain an intersection point with a module.
- If intersection point is **within sensitive area of module** (**Fiducial)** it is included in the **denominator** of the efficiency calculation.
- If **SCT cluster** is found to be located within a set "**Road Width**" from predicted position, an entry is also made of the **numerator** of the efficiency calculation.

Results



- Distances between clusters and predicted track positions plotted as residuals.
- No magnetic field: Residuals can be quite large (low momentum cosmic rays, large scattering effects).
- 2 mm road width chosen to neglect multi scattering effects.
- Results from data before and after global χ^2 alignment performed.
- After alignment unbiased hit efficiency in all barrel layers is measured to within specifications (>99%).

And now my work…

SCT Endcap Efficiency Measurement: Method 1: Method

Method

For each reconstructed cosmic event that remained after an **initial quality cut** the algorithm:

- **Removes Space Points** located on the layer under investigation (active layer).
- **Fits a track** excluding these hits.
- **Extrapolates** fitted track to the active layer to obtain an intersection point with a module.
- If intersection point is **within sensitive area of module** (**Fiducial)** it is included in the **denominator** of the efficiency calculation.
- If **Module strip** is found to have registered a hit is located within a set "**Road Width**" from predicted position, an entry is also made of the **numerator** of the efficiency calculation.

Cuts

- **Track Quality:** See later.
- **Fiduciality:** Anywhere within module that is at least
  - 2 mm from bondgap.
  - 1.5 mm from module edges.
  - 1.5 mm from any masked strips of disks.
- **Road Width:** Choice of 6 mm used in code development to avoid scattering and misalignment effects.

$$E_{ij} = \frac{N\,(\text{predicted hits with strip hits near by})_{ij}}{N\,(\text{predicted hits})_{ij}}$$

Where predicted hits are from extrapolations passing quality cuts.

SCT Endcap Efficiency Measurement: Method 1: Track Fitting and Extrapolation

Originally hoped to use internal software back tracking tools, however I found these not to be suited for these tasks. I therefore utilised my my own custom made algorithms:

Track Fitting

- Least square fit of space points outside active disk.
- Require 3 SP's outside active disk (for meaningful x2)
- Algorithm fits track $z = p_1x+p_2 = q_1y+q_2$ to n data points at (x_i,y_i,z_i).
- Minimises action S to find parameters.

$$S = \sum_{i=1}^{n}(z_i - (p_1x_i + p_2))^2 + \sum_{i=1}^{n}(z_i - (q_1y_i + q_2))^2$$

$$\frac{\partial S}{\partial p_1} = -2\sum_{i=1}^{n} x_i(z_i - (p_1x_i + p_2)) = 0 \qquad \frac{\partial S}{\partial p_2} = -2\sum_{i=1}^{n}(z_i - (p_1x_i + p_2)) = 0$$

$$\frac{\partial S}{\partial q_1} = -2\sum_{i=1}^{n} y_i(z_i - (q_1y_i + q_2)) = 0 \qquad \frac{\partial S}{\partial q_2} = -2\sum_{i=1}^{n}(z_i - (q_1y_i + q_2)) = 0$$

$$p_1 = \frac{n\sum_{i=1}^{n} x_iz_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} z_i}{n\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2} \qquad p_2 = \frac{1}{n}(\sum_{i=1}^{n} z_i - p_1\sum_{i=1}^{n} x_i)$$

$$q_1 = \frac{n\sum_{i=1}^{n} y_iz_i - \sum_{i=1}^{n} y_i \sum_{i=1}^{n} z_i}{n\sum_{i=1}^{n} y_i^2 - (\sum_{i=1}^{n} y_i)^2} \qquad q_2 = \frac{1}{n}(\sum_{i=1}^{n} z_i - q_1\sum_{i=1}^{n} y_i)$$

Track Extrapolation

- Extrapolate track with initial position $X_0 = (x_0,y_0,z_0)$ and direction $\underline{p}$ to a position $X_l = (x_0+sp_x,y_0+sp_y,z_0+sp_z)$ on a module on the active layer.
- $s = (X_m.\underline{n}-X_0.\underline{n})/\underline{p}.\underline{n}$
  X_m is the position of the module centre and $\underline{n}$ is the normal to the module.

SCT Endcap Efficiency Measurement: Method 1: Track Quality

- Fitted tracks are subjected to a quality cut.
- Define $\chi 2$/ndf quantity to measure quality of fit.

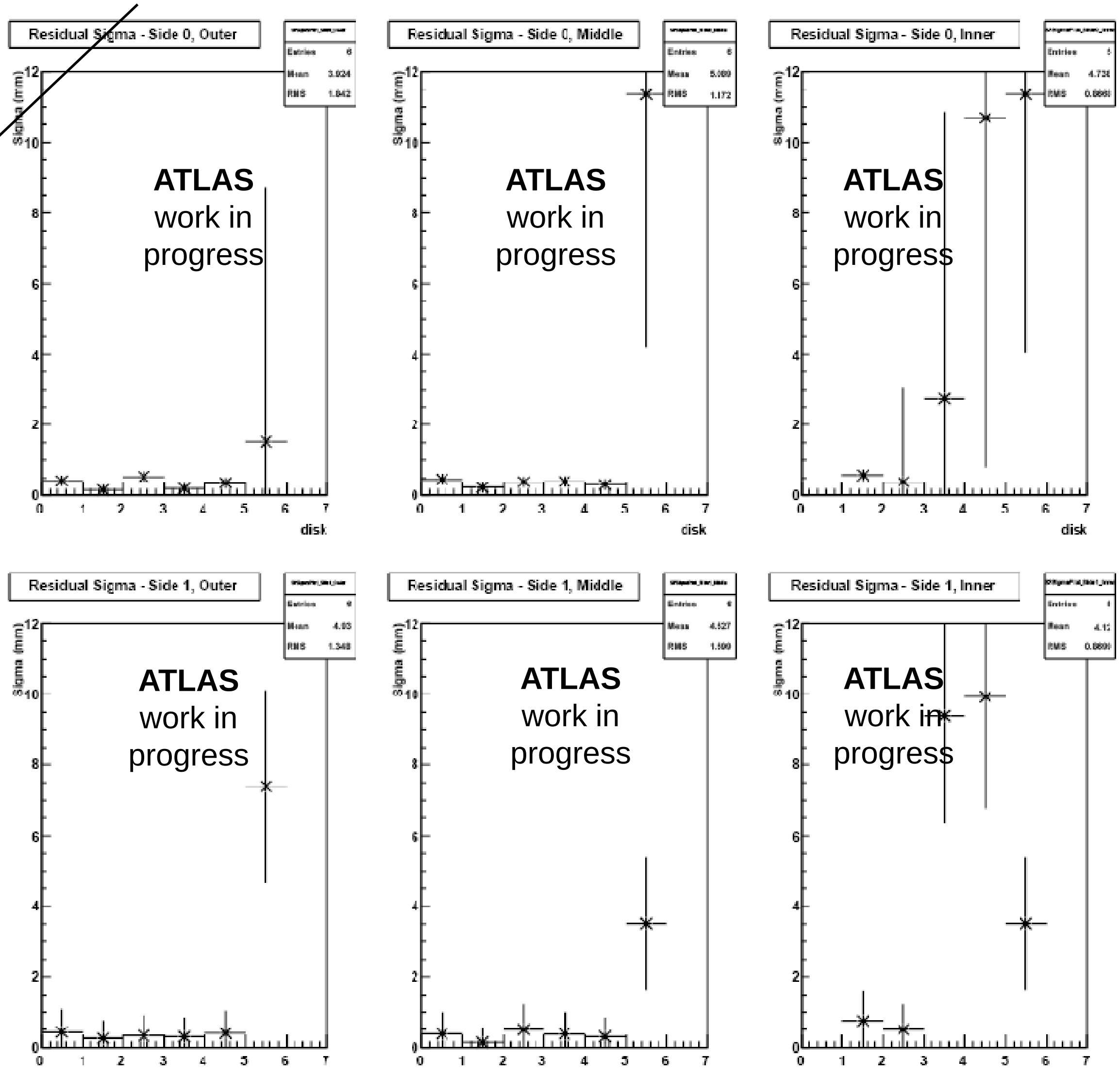
Sigma's taken from widths of residuals obtained with no $\chi 2$ cut.

Differences in x and y coordinates between fitted track and space points used to fit the track at the z coordinate of the space point.

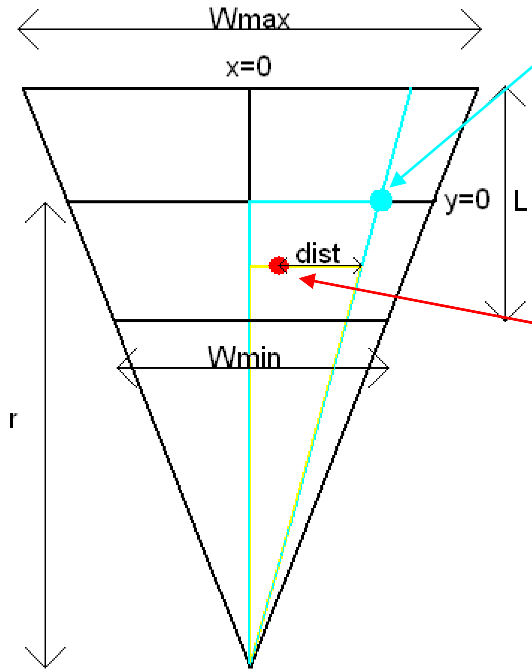
$$\frac{\chi^2}{ndf} = \frac{\sum_{i=1}^{n} \frac{(\delta x_i)^2 + (\delta y_i)^2}{\sigma^2_{disk_i}}}{n+2}$$

Errors in 2D (x and y)

n space points used to fit the track, i = 1,..,n



SCT Endcap Efficiency Measurement: Method 1: Fan Type Geometry of Modules



Strip hit = centre of a strip that has detected the cosmic particle, $(x_s,0)$

Extrapolated 'Predicted Position at (x_p,y_p)

Using similar triangles:

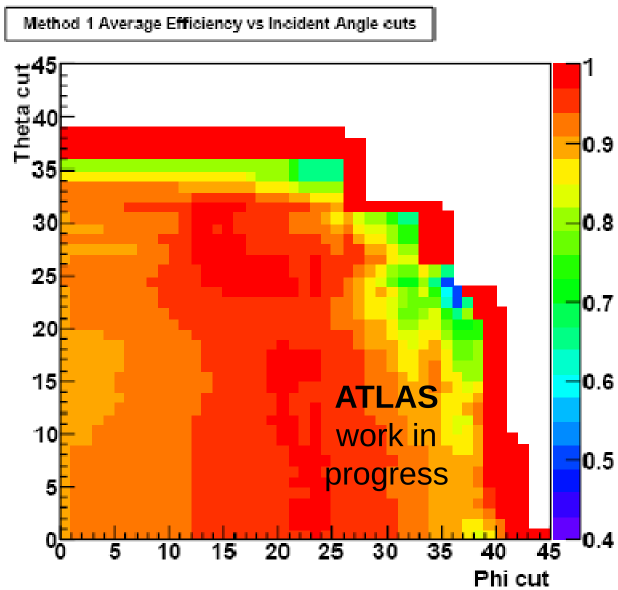
- W = (Wmax + Wmin) / 2
- r = W*L / (Wmax – Wmin)

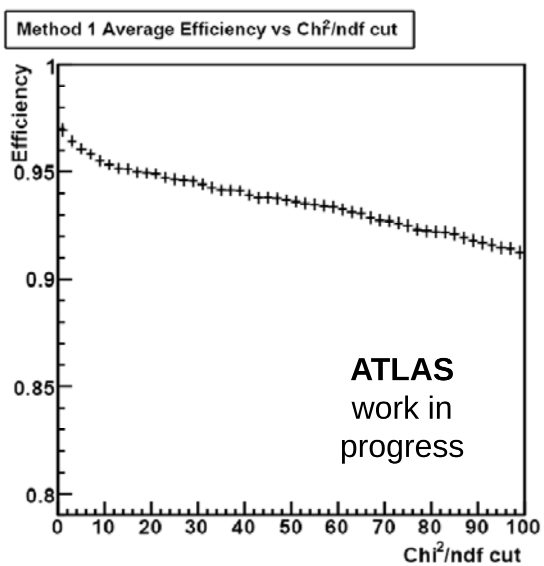
Again using similar triangles can show that the distance we want to measure is:

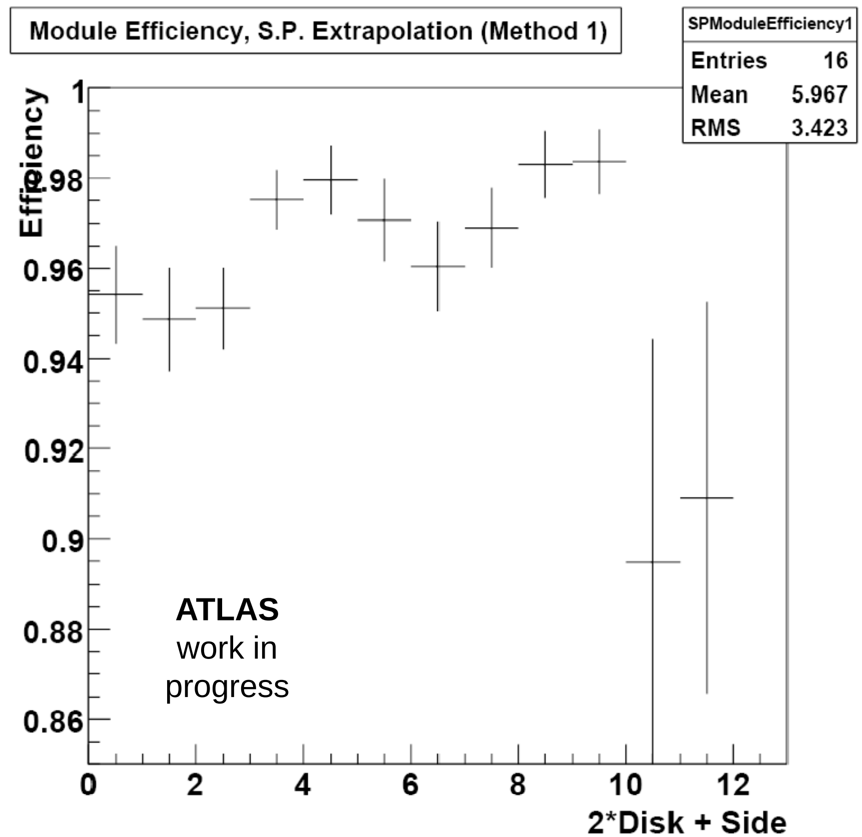
$$d = \left| x_s \left(1 + \frac{y_p}{r}\right) - x_p \right|$$

SCT Endcap Efficiency Measurement: Method 1: Efficiency Results

(with χ^2/ndf < 3.0 and incident $\phi > 23^o$)







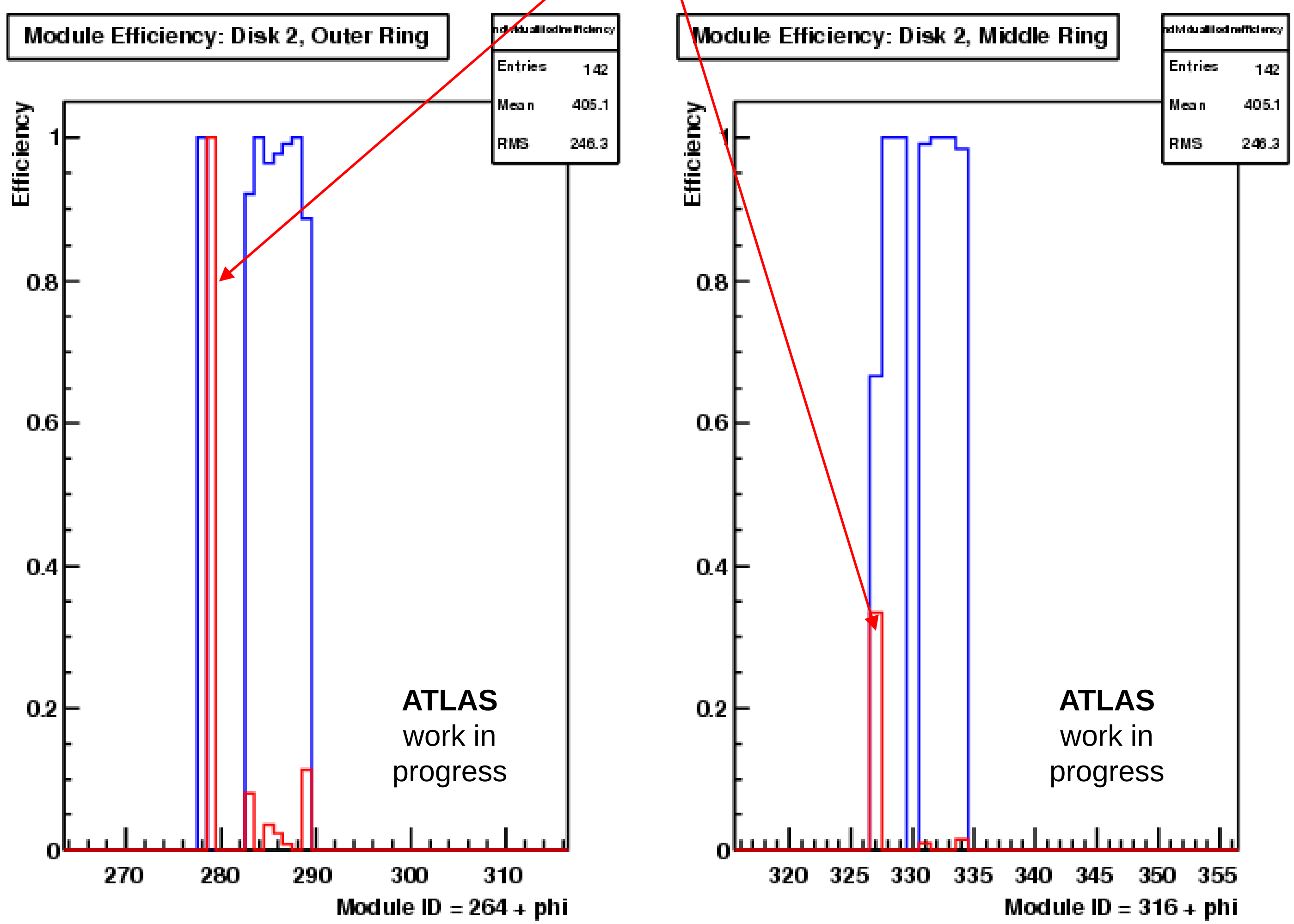
Average efficiency throughout detector → 97% as χ^2/ndf → 0

Efficiencies lower than expected

Suspect cuts are still not successfully separating all the good tracks from all the bad.

SCT Endcap Efficiency Measurement: Method 1: Individual Module Efficiencies (with χ^2/ndf < 3.0 and incident $\phi > 23^o$)

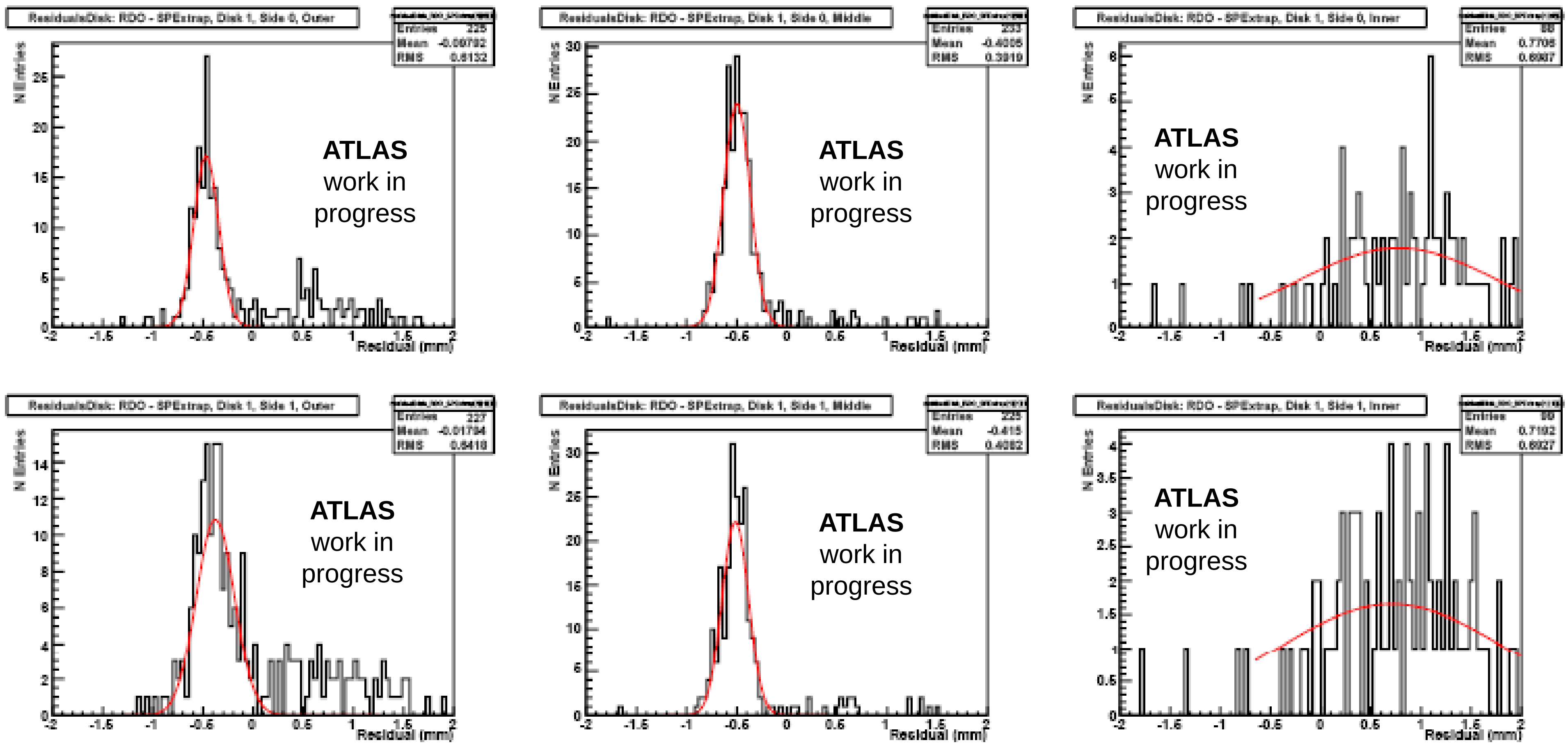
- **Can use this method to calculate efficiencies for each individual module.**
- **Useful monitoring tool for identifying modules with problems!**



SCT Endcap Efficiency Measurement: Method 1: Resolution Results

(with χ^2/ndf < 3.0 and incident ϕ 23^o)

Residuals for Disk 1:



Distributions are not centred on 0 → Misalignments!

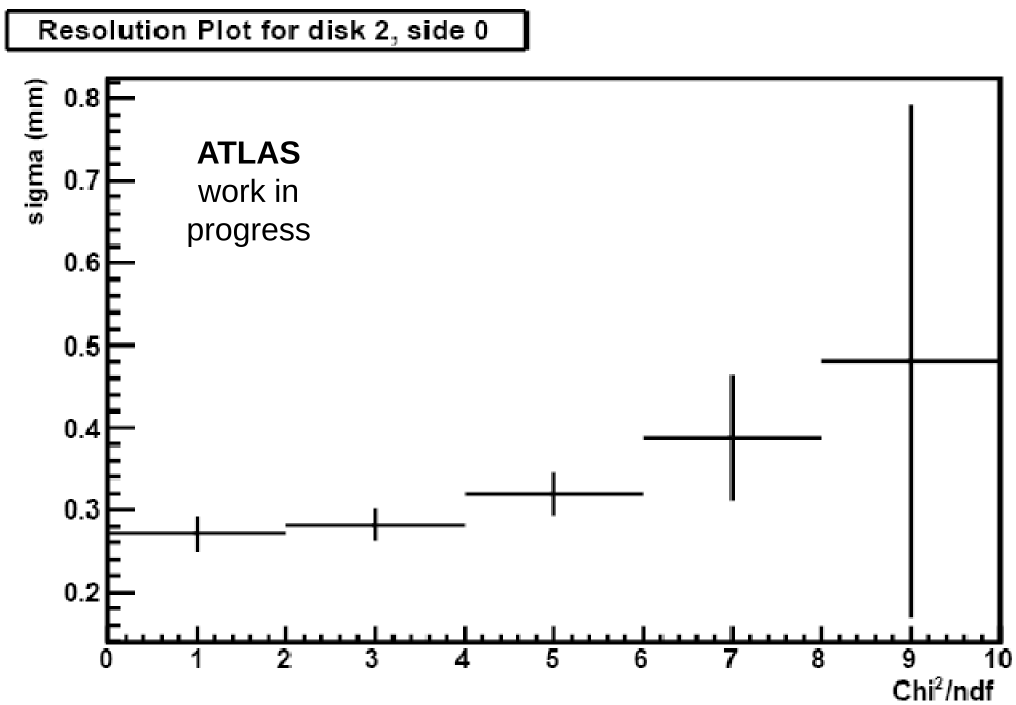
All residuals are within roadwidth, but σ >> 23 μm (design detector resolution).

(For mean's and sigma's of all distributions see backup slides).

SCT Endcap Efficiency Measurement: Method 1: Resolution Results

(with χ^2/ndf < 3.0 and incident ϕ 23°)

- Can extract Module Resolution (σ) from residual distributions by subtracting track prediction and alignment correction uncertainties.
- Residuals larger than expected detector resolution (23 μm) due to multiple scattering.
- Module resolution can be extracted by plotting σ in bins of χ^2/ndf of the unbiased track. As this quantity decreases track uncertainty becomes negligible.
- Plotted here for disk 2, side 0 to maximise statistics.



Low statistics mean bigger binning than in barrel case.

Resolution obtained factor of 10 higher than it should be.

Scattering effects and Misalignments!

SCT Endcap Efficiency Measurement: Method 2

Due to problems of Method 1 discussed already a further efficiency measurement approach was considered.

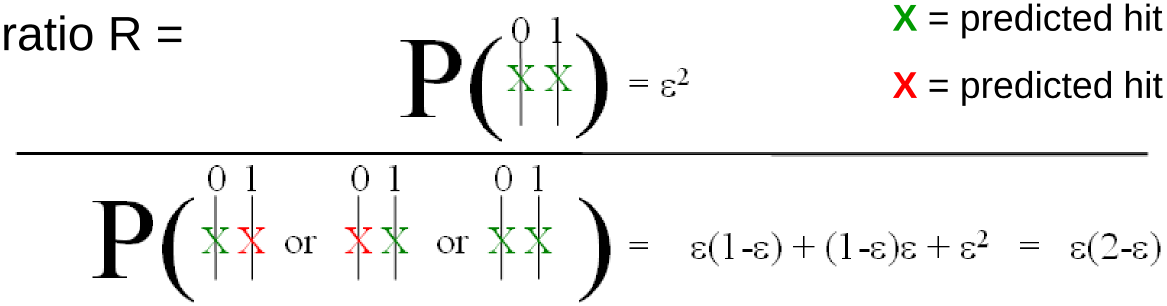
This measures the ratio of single to double hits in the layers of the SCT endcap.

Define ε = efficiency of one side of a particular disk.

Define ratio R =

X (green) = predicted hit with strip hit within road width.

X (red) = predicted hit without strip hit nearby



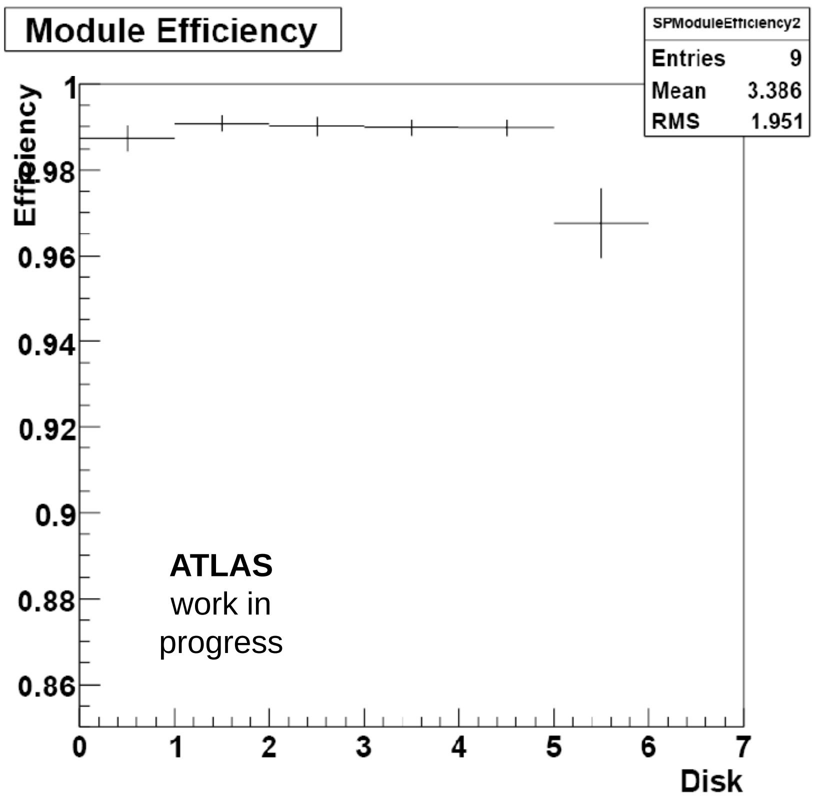
= N(hitonside0 && hitonside1)/N((hitonside0 && predonside1) || (hitonside1 && predonside0))

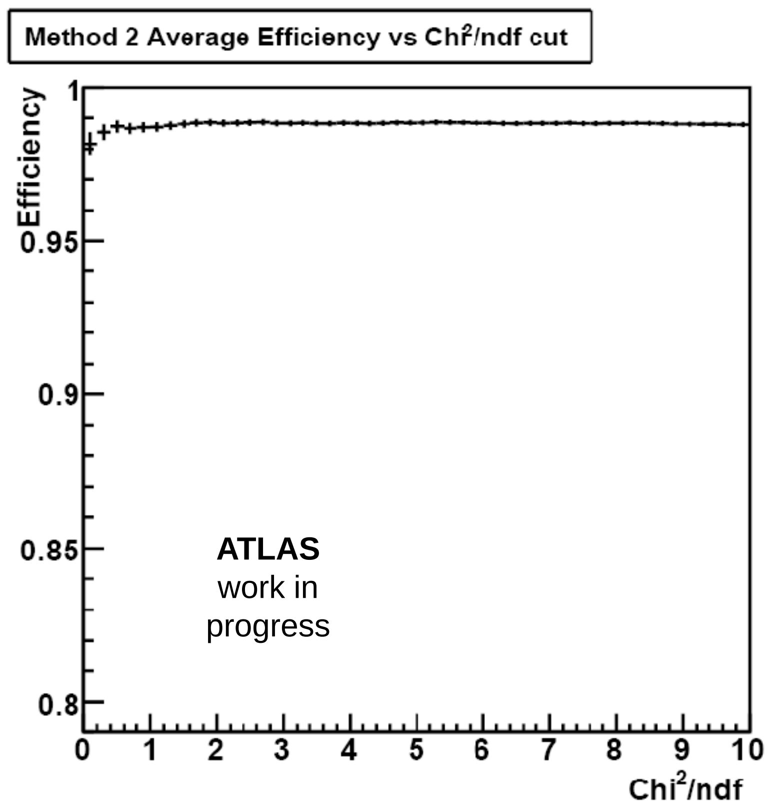
= $\varepsilon/(2-\varepsilon)$

➔ $\varepsilon = 2R/(1+R)$

Since in general $\varepsilon \neq \varepsilon_0 \neq \varepsilon_1$, what we are really measuring is $\varepsilon = 2\varepsilon_0\varepsilon_1/(\varepsilon_0+\varepsilon_1)$

SCT Endcap Efficiency Measurement: Method 2: Results





✓ Only extrapolations resulting in at least one efficient hit on one side of the active module are entered into the efficiency calculation.

✓ Only uses good events!

✓ No dependence on χ^2/ndf cut…

✓ Throw as many bad tracks as you like at it and the efficiencies measured will still be accurate.

SCT Endcap Efficiency Measurement: Method 2: Results

Can separate ε_0 and ε_1 by measuring the following ratios:

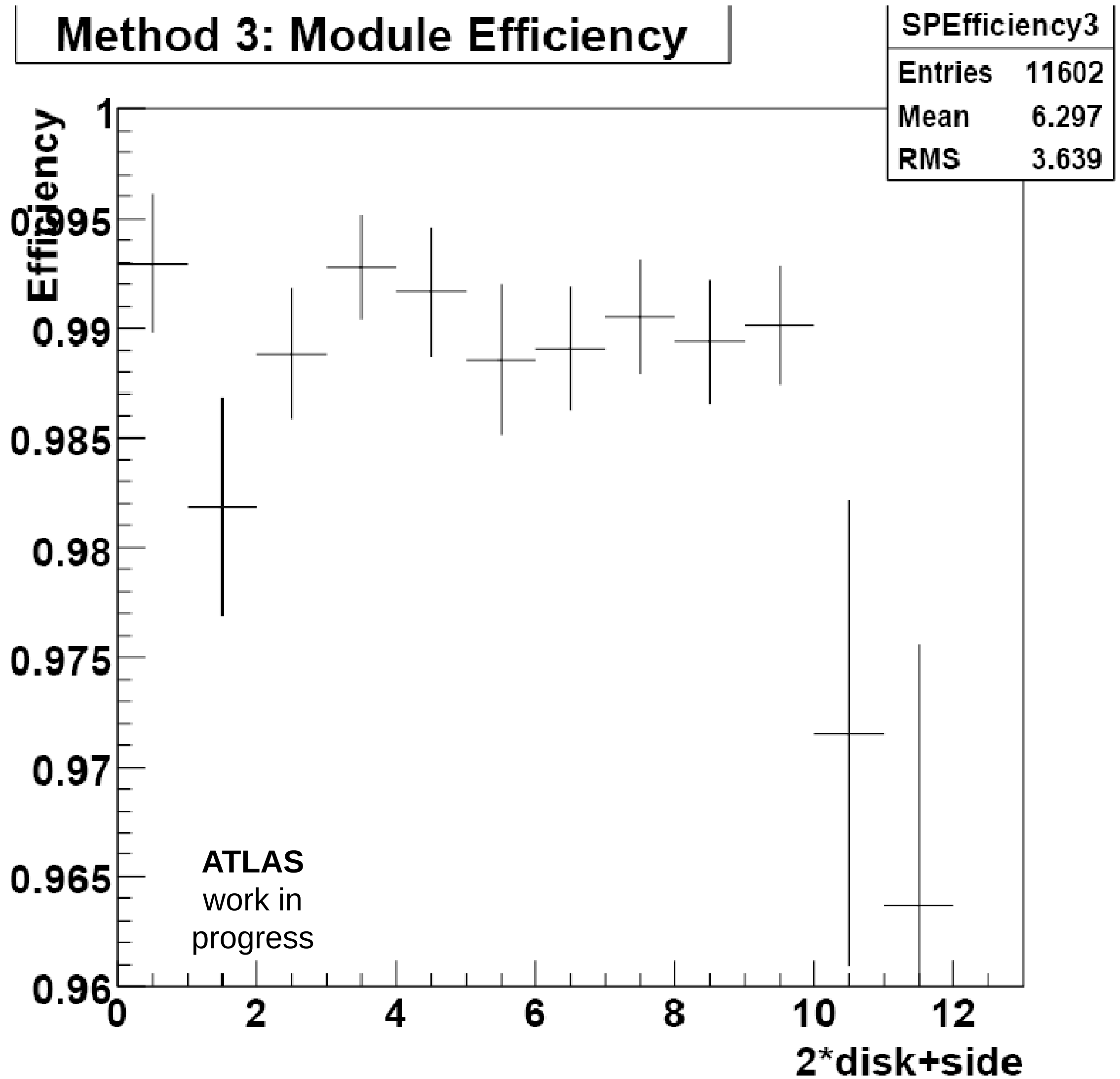
$R_0 = N(xx)/(N(ox)+N(xx))$

$= \varepsilon_0\varepsilon_1/((1-\varepsilon_0)\varepsilon_1+\varepsilon_0\varepsilon_1) = \varepsilon_0$

And:

$R_1 = N(xx)/(N(xo)+N(xx))$

$= \varepsilon_0\varepsilon_1/(\varepsilon_0(1-\varepsilon_1)+\varepsilon_0\varepsilon_1) = \varepsilon_1$



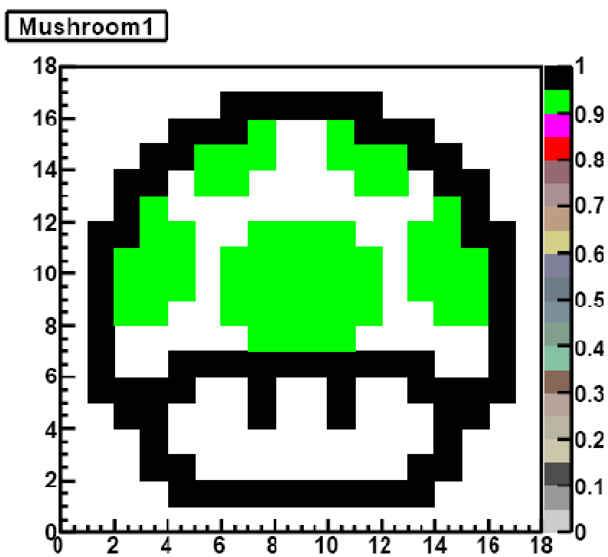
All efficiencies in first 5 disks are around the design specifications value of 99% ☺

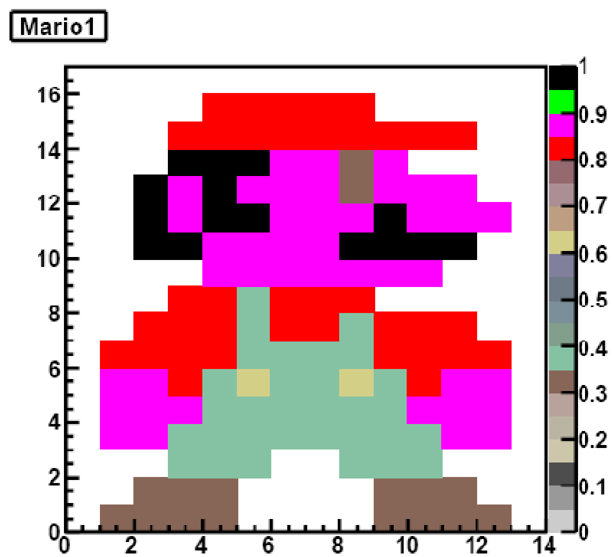
Not enough good statistics for other disks

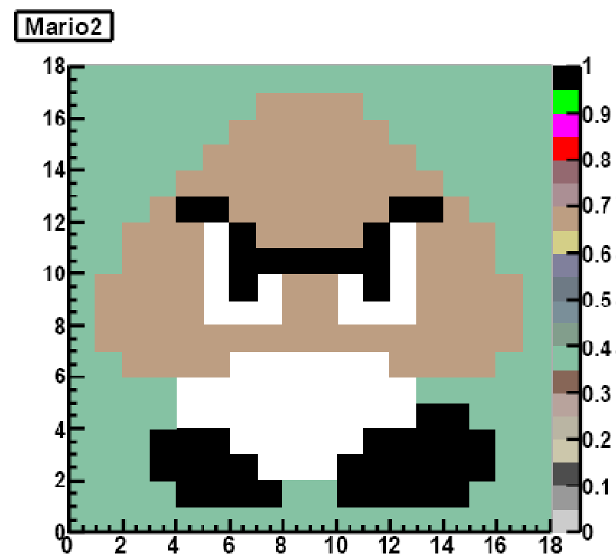
Conclusions

- Despite a data sample full of multiple scattering, low energy events, I have developed an algorithm to accurately measure the module efficiencies of the SCT endcap.
- Residuals (and low efficiencies in method 1) show bad resolution and misalignment problems that need sorting.
- Cut based efficiency method 1 works but is contaminated by bad tracks. However it is useful for identifying modules with problems.
- By requiring an efficient hit on at least one side of the module under investigation, good tracks can be isolated. Method 2 measures disk efficiencies to be within the design specifications (~99%).

Thank you for listening... Any questions?





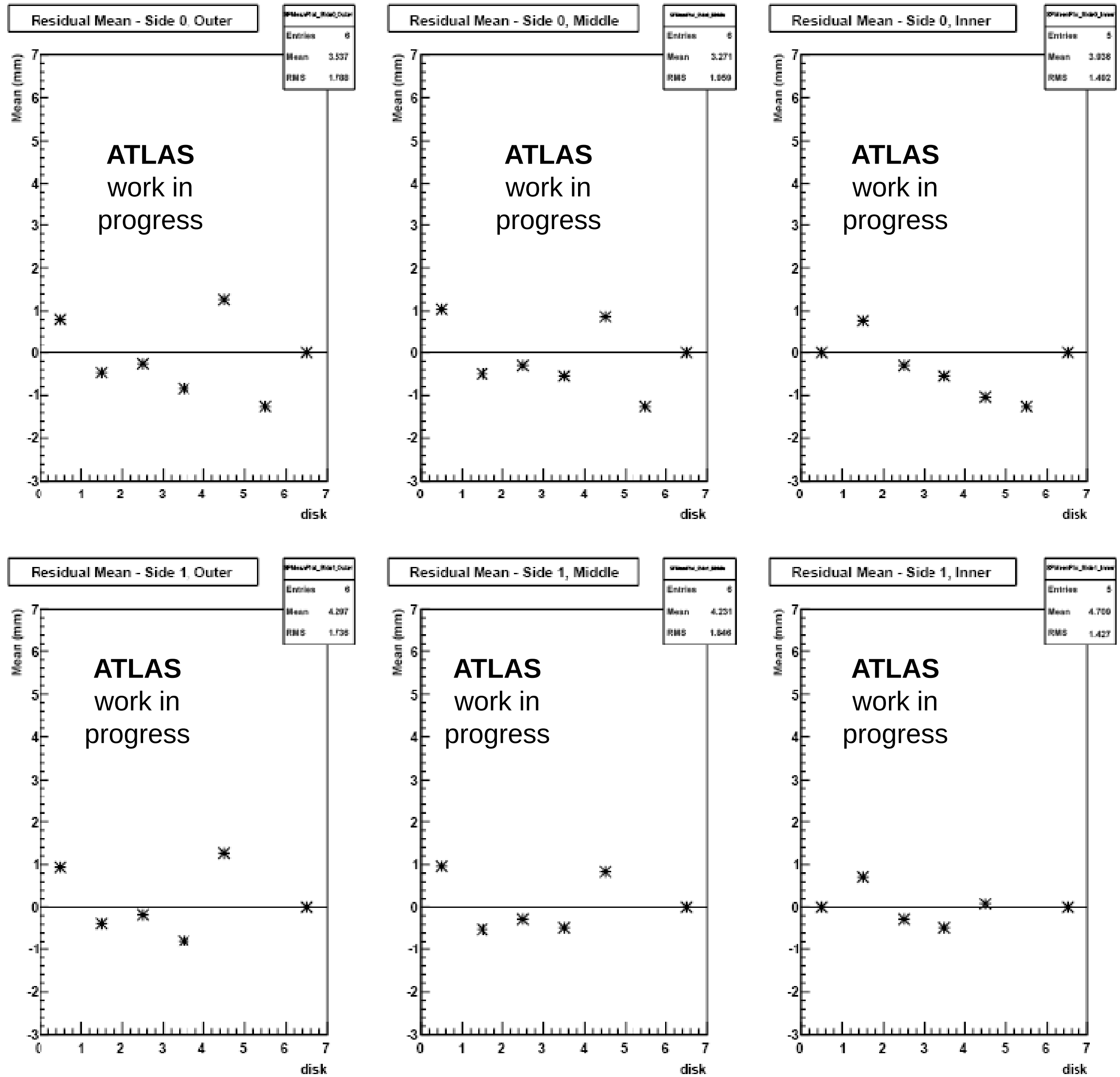


Backup Slides

SCT Endcap Efficiency Measurement: Method 1: Resolution Results

(with χ^2/ndf < 3.0 and incident ϕ 23^o)

Mean of Residuals



Show large misalignments!

But no alignment data has been included in the software setup, so this is expected.

SCT Endcap Efficiency Measurement: Method 1: Resolution Results

(with χ^2/ndf < 3.0 and incident ϕ 23^o)

Sigma of Residuals