# Inner Detector Alignment at the MPI

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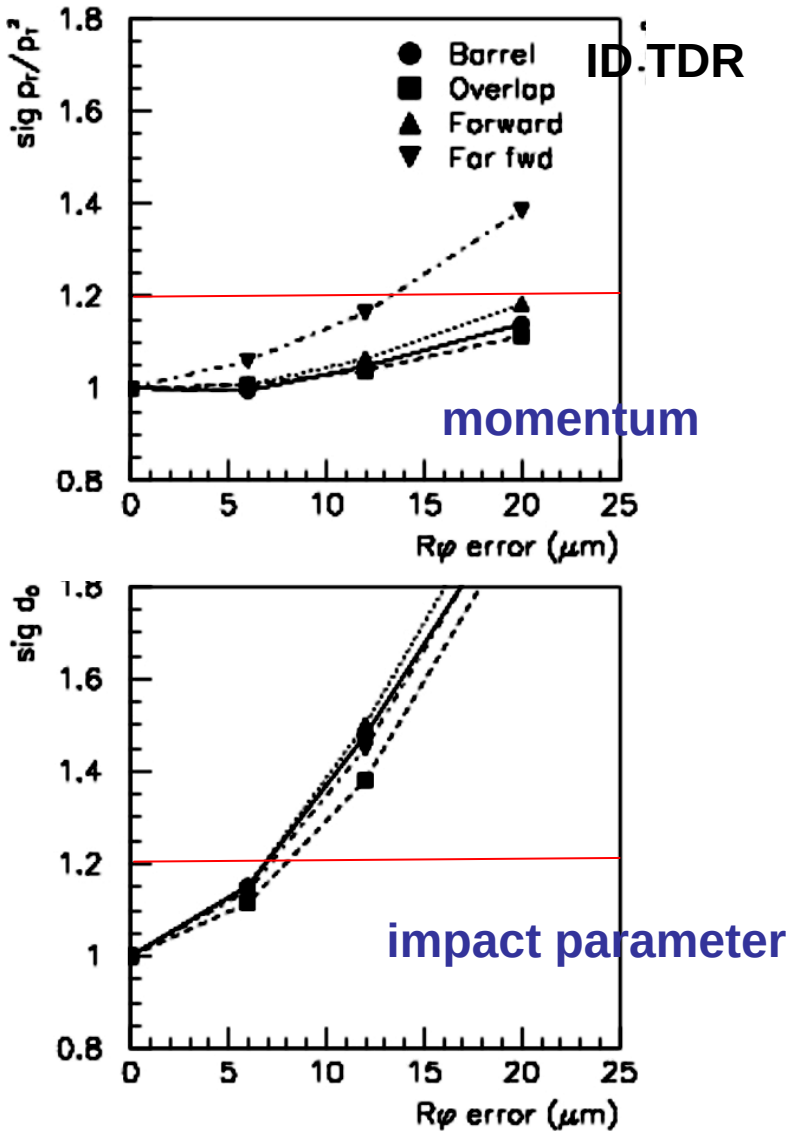
- Required Precision for Physics Analysis
- Inner Detector Alignment Activities and future Plans at the MPI
- Other Alignment Activities within ATLAS

# Requirements from Tracking

- alignment requirements
  - degradation of tracking resolution less than 20%
    - Pixel: 7μm in rΦ
    - SCT: 12 μm in rΦ
    - TRT: 30 μm in rΦ

(W-mass measurement to 25 MeV requires 1μm alignment precision)




S. Haywood, ATL-INDET-2000-005

# Impact of Misalignment on B-tagging

- random misalignment in SCT and Pixel

| | | $\sigma_{R\phi} = 5\ \mu m$ $\sigma_Z = 15\ \mu m$ | $\sigma_{R\phi} = 10\ \mu m$ $\sigma_Z = 30\ \mu m$ | $\sigma_{R\phi} = 20\ \mu m$ $\sigma_Z = 60\ \mu m$ |
|---|---|---|---|---|
| $2D\ R_u/R_0$ | $\epsilon_b = 50\%$ | 0.95 | 0.89 | 0.65 |
| | $\epsilon_b = 60\%$ | 0.98 | 0.91 | 0.74 |
| $3D\ R_u/R_0$ | $\epsilon_b = 50\%$ | 0.99 | 0.91 | 0.67 |
| | $\epsilon_b = 60\%$ | 0.97 | 0.92 | 0.71 |

S. Corréard et al, ATL-COM-PHYS-2003-049

- similar result by S. Gibson estimating the impact of misalignment with reduced tracking performance as seen by CDF
- aim for alignment accuracy better than 10μm
- light jet reduction reduced by about 10%

# Accuracy from Survey

R. Hawkings et al., ATL-INDET-INT-2005-002

| alignment precision | SCT Barrel (in μm) | SCT Endcap (in μm) |
|---|---|---|
| x | 100 | 50 |
| y | 100 | 50 |
| z | (500) | (500) |

| alignment precision | Pixel Barrel (in μm) | Pixel Endcap (in μm) |
|---|---|---|
| x | 50 | 20 |
| y | 50 | 20 |
| z | (500) | (500) |

"educated guesses"

- good initial alignment for tracking at the beginning
- track based alignment necessary to reach required precision
- last microns are the toughest

# MPI: Robust local $\chi^2$ Approach

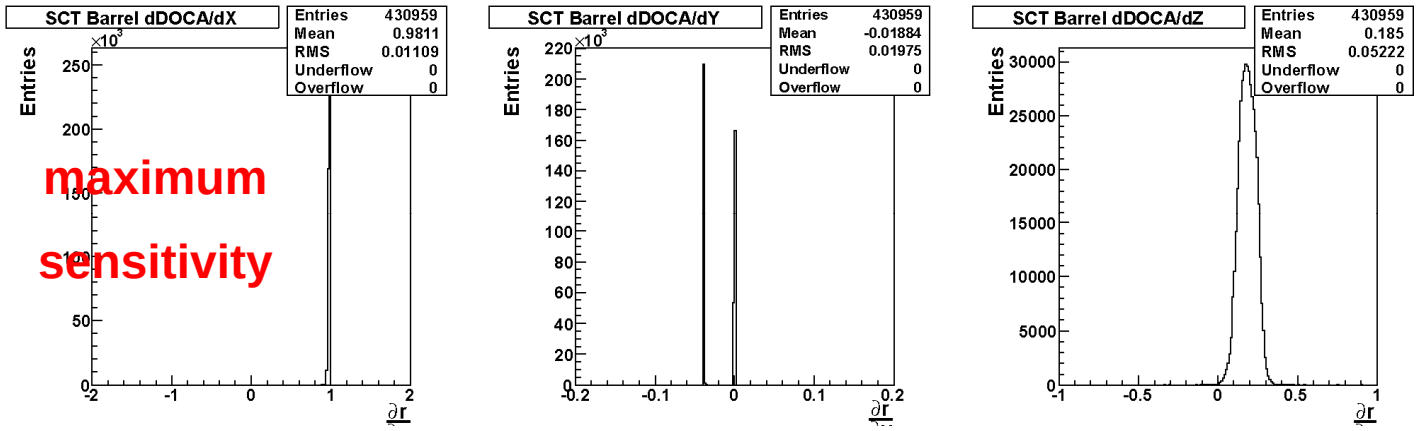
- build $\chi^2=(\mathrm{DOCA}/\sigma)^2$ term using track information
- 3D residuals, geometry completely described
- minimize $\chi^2$ with respect to 6 alignment parameters for each SCT and Pixel module separately
- correlations between modules will be taken into account by iteration

input

$$\Delta a_i = \left[ \sum_{hits} \left( \frac{2}{\sigma^2} \frac{\partial r}{\partial a_j} \frac{\partial r}{\partial a_i} \right) \right]^{-1} \cdot \sum_{hits} \left( \frac{2}{\sigma^2} r \frac{\partial r}{\partial a_i} \right)$$

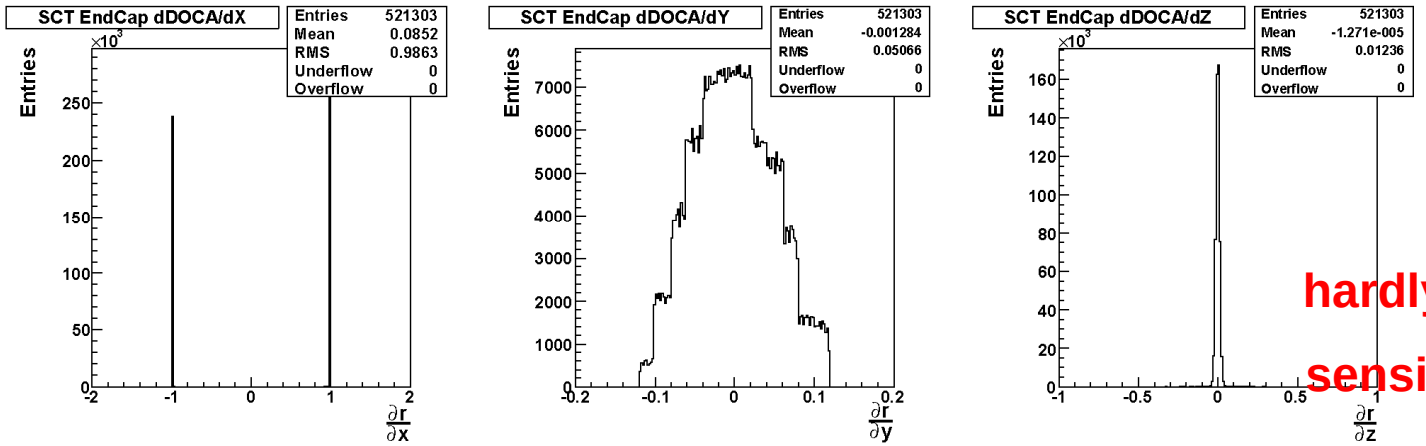
# Derivatives of Residuals

- derivatives calculated numerically




maximum sensitivity

SCT Barrel

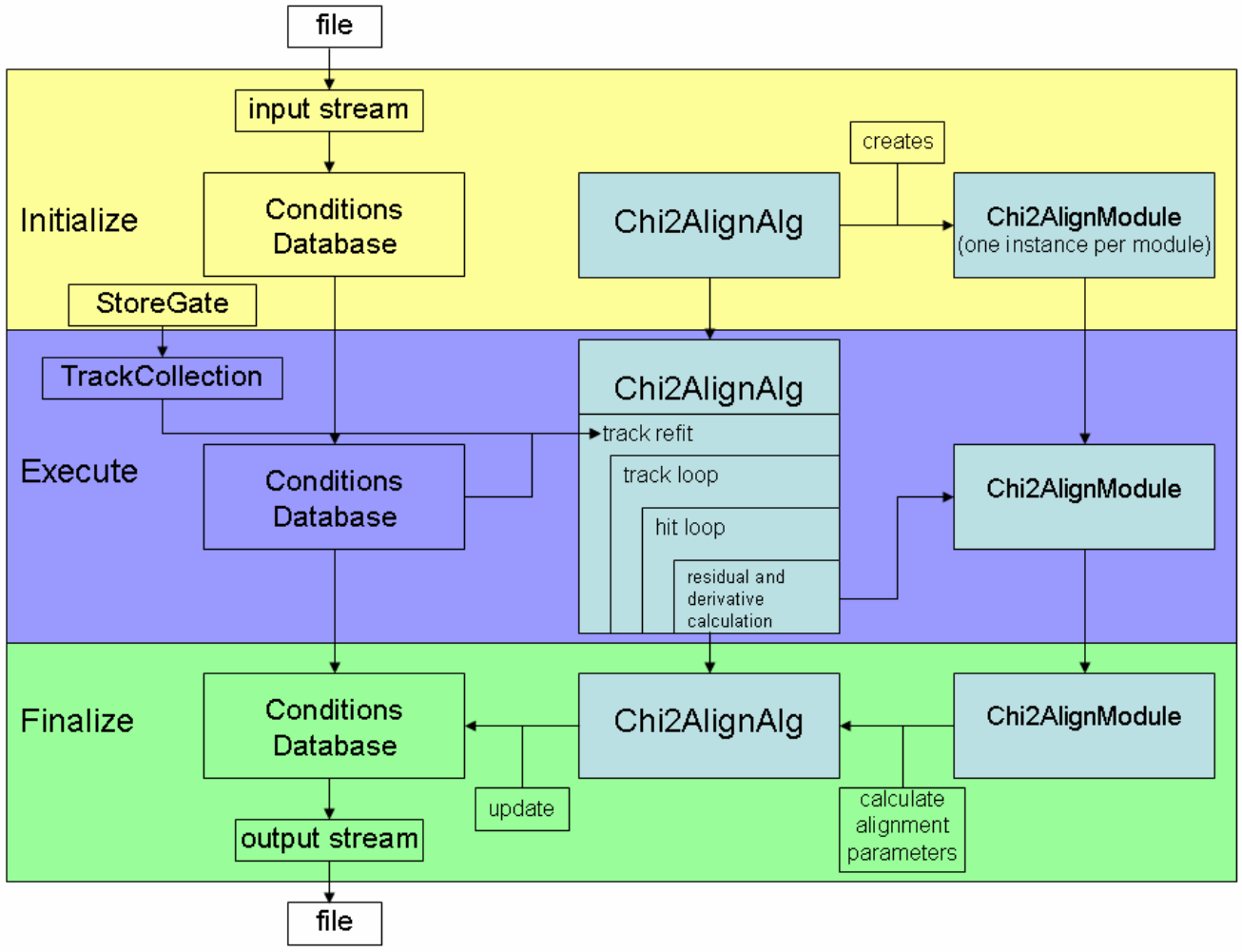



SCT Endcap

hardly any sensitivity

- derivatives reproduces directly sensitivity of local coordinates

# Robust local $\chi^2$ Approach

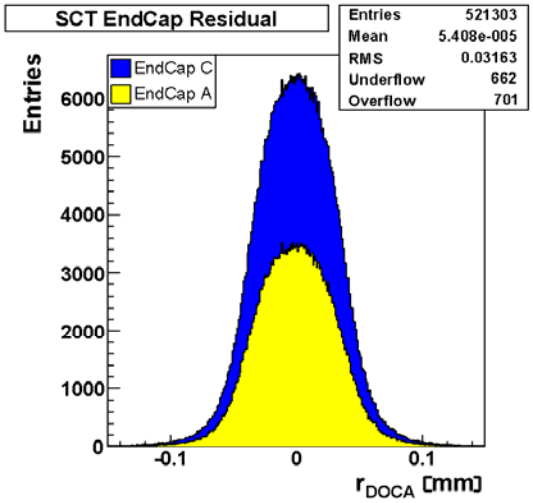


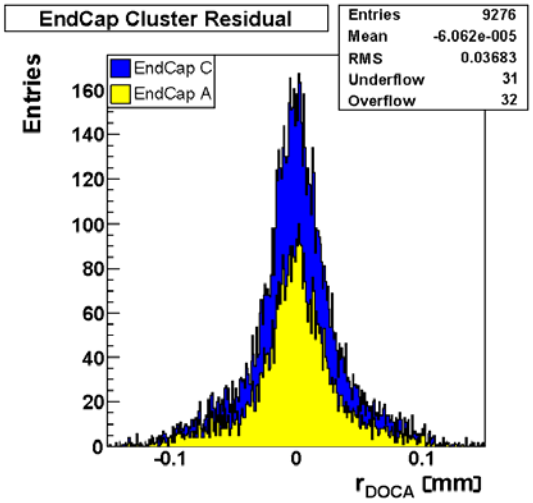

Implementation of the alignment algorithm in ATHENA

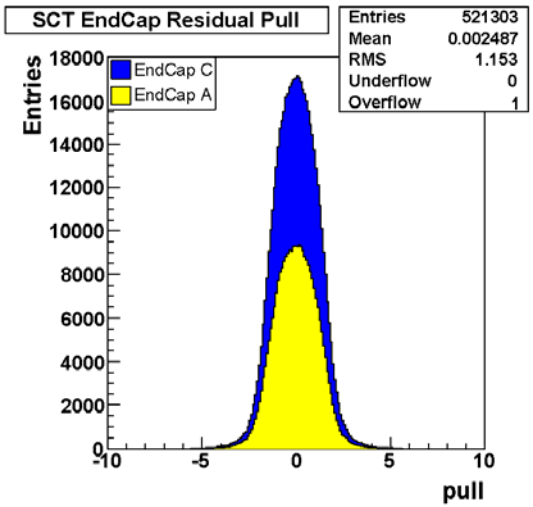
**Diplomarbeit R. Härtel**

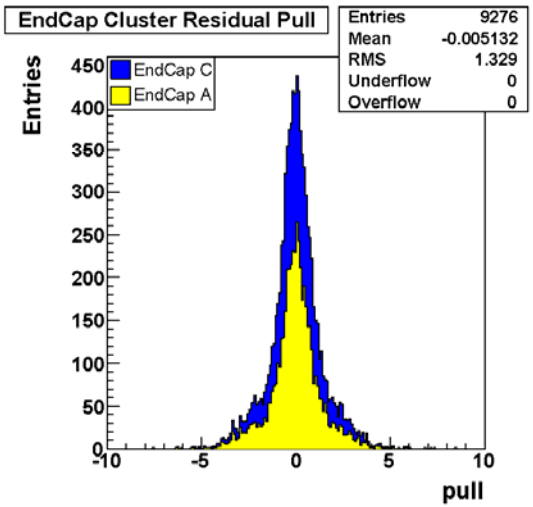
# Alignment Input: Residual

**ATHENA**




- 130k single pion events produced with release 10.3.0, reconstructed with 10.5.0
- average 250 hits per module (at least 100 hits)

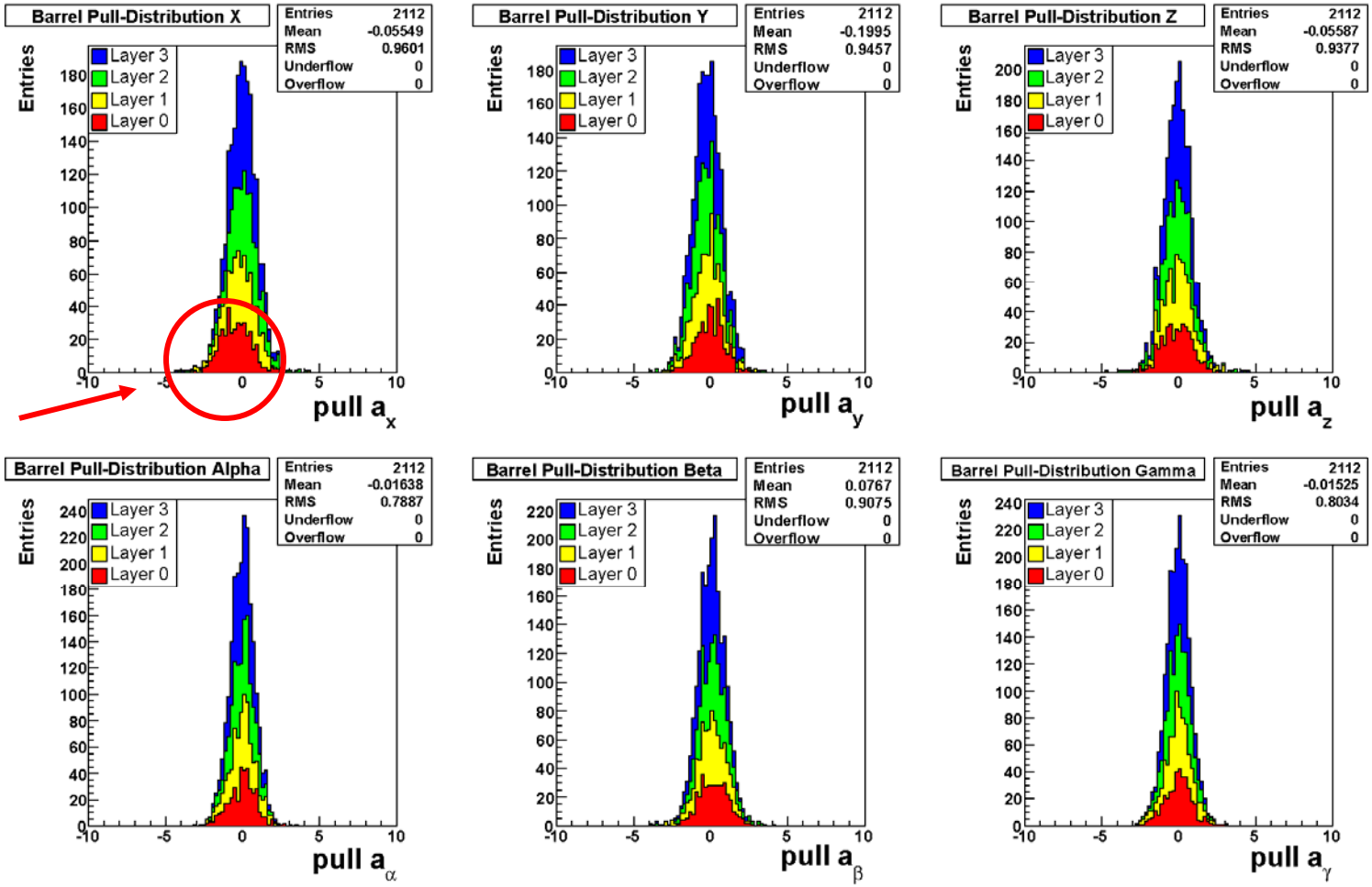
**SCT: Diplomarbeit R. Härtel**

# Pull of Alignment Constants

1st iteration with perfect initial alignment (null-alignment)

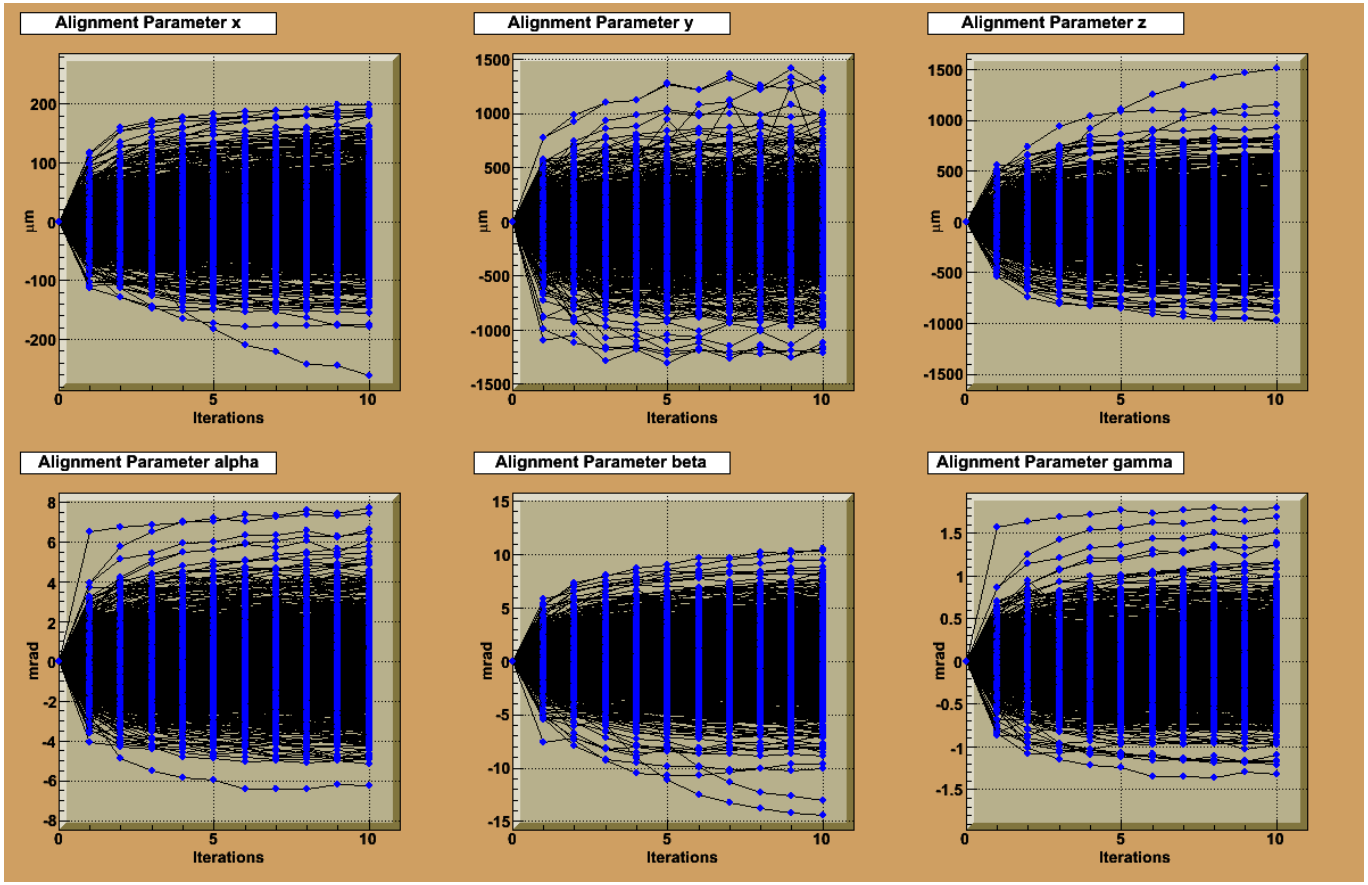
lorentz-shift problem propagated from pixel detectors (release 10.5.0)

SCT only



# Alignment Parameter flow

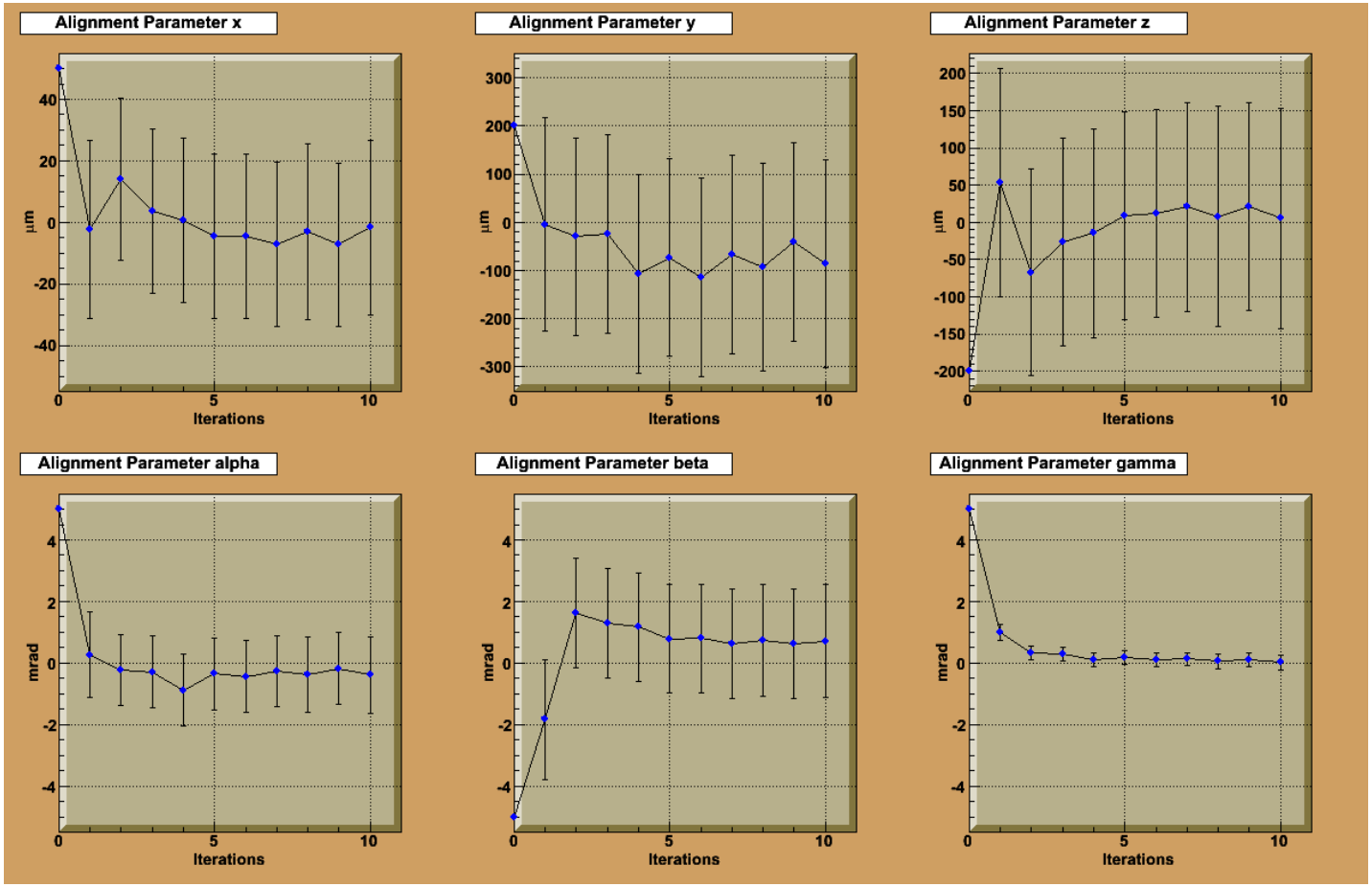
- perfect initial alignment




- performance and accuracy of local $\chi^2$ algorithm

# Alignment of single misplaced module

- Alignment parameter flow through ten iterations




module 2/2/0/2/8-4 (SCT barrel layer 2)

- recovery of misaligned module after few iterations

# Alignment Accuracy reached

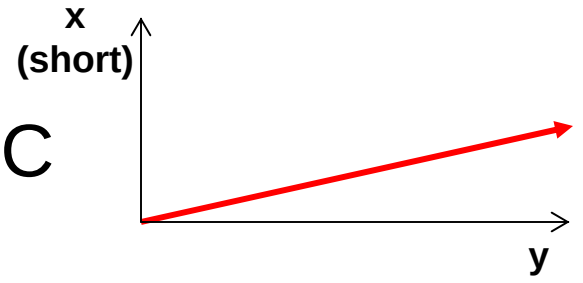
| alignment parameter | SCT Barrel | | | | SCT EndCap | | | |
|---|---|---|---|---|---|---|---|---|
| | 68 % CL | $\sigma_{stat}$ | as built | TDR req. | 68 % CL | $\sigma_{stat}$ | as built | TDR req. |
| $a_x$ [μm] | 48 | 29 | 100 | 12 | 19 | 4.9 | 50 | 12 |
| $a_y$ [μm] | 253 | 169 | 100 | 50 | 145 | 57 | 50 | 50 |
| $a_z$ [μm] | 245 | 149 | 500 | 100 | 1100 | 300 | 500 | 200 |
| $a_\alpha$ [mrad] | 1.5 | 1.2 | | | 21 | 8.5 | | |
| $a_\beta$ [mrad] | 2.6 | 1.8 | | | 13 | 5.0 | | |
| $a_\gamma$ [mrad] | 0.33 | 0.25 | | | 0.38 | 0.13 | | |

**after 10 iterations**

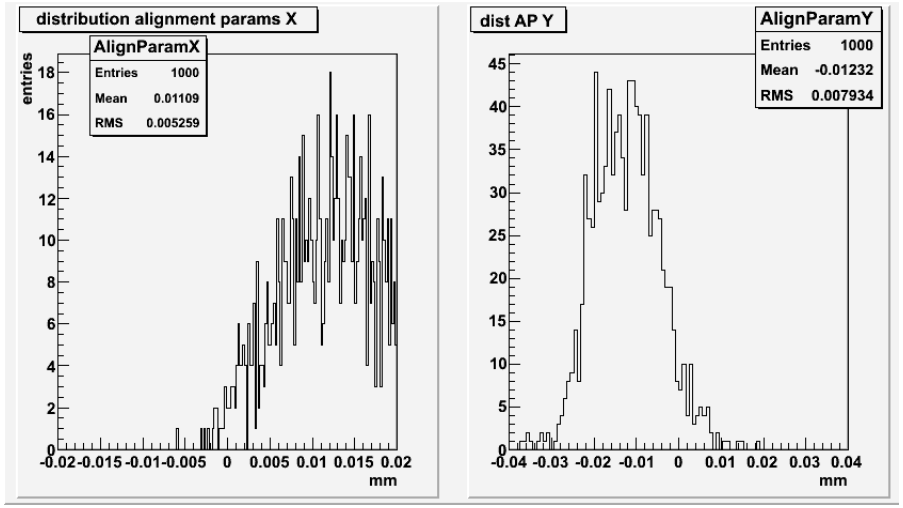
- estimated accuracy for robust $\chi^2$ approach using 130k $\pi$ tracks and initial perfect alignment
- differences between $\sigma_{68\%CL}$ und $\sigma_{stat}$ estimate systematic uncertainty

# Alignment of Pixel Modules

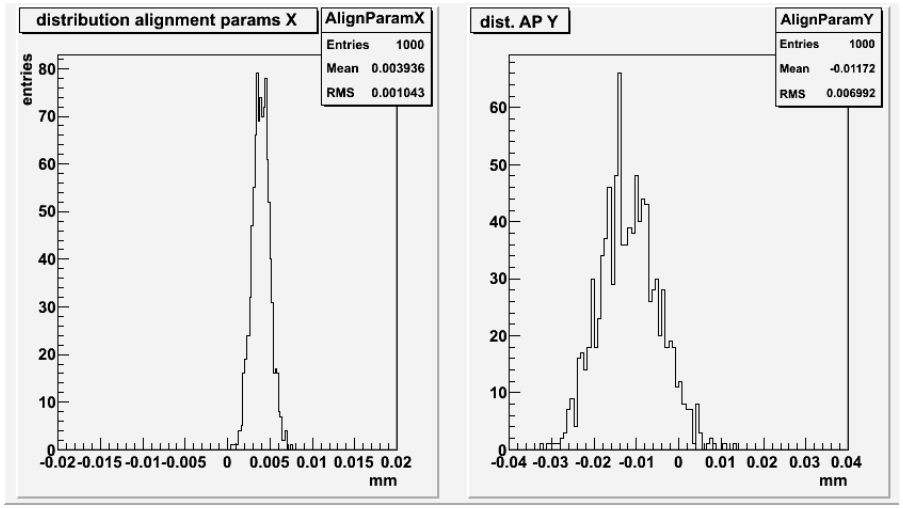
**Pixel: Diplomarbeit T. Goettfert**




- proof of principle using ROOT toy MC
  - $r_{xy}$ residual versus $r_x$,$r_y$ residuals




single 3D residual, $r_{xy}$

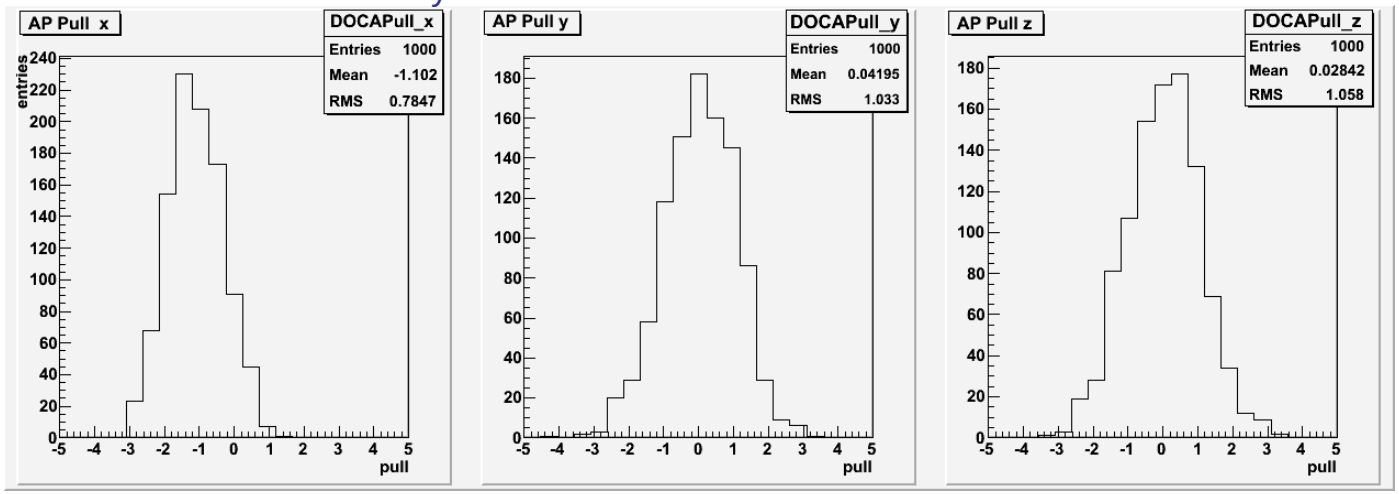



two orthogonal 3D residuals $r_x$, $r_y$

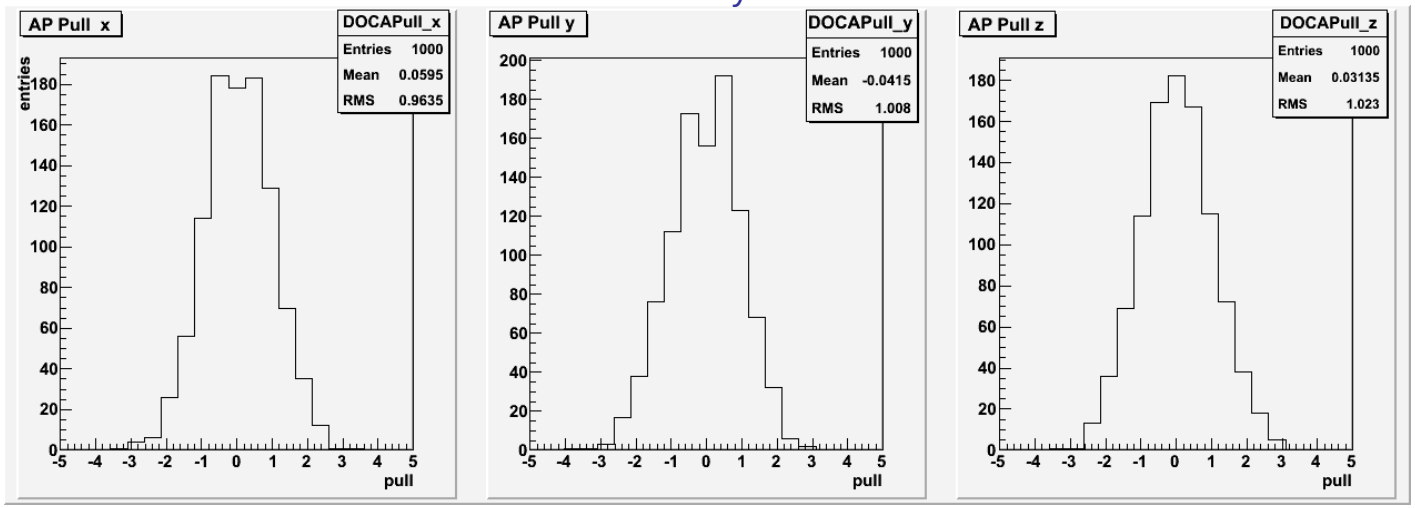
- misalignment: x: 4 μm, y: -12 μm
- 1k samples of 1k tracks

# Alignment of Pixel Modules

single 3D residual $r_{xy}$




two orthogonal 3D residuals $r_x$, $r_y$

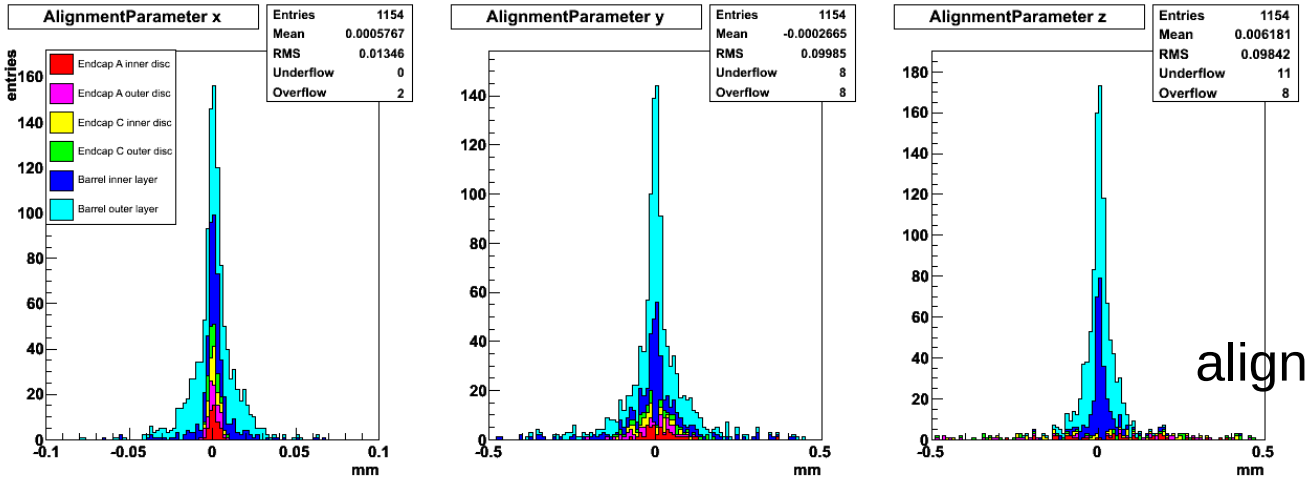



**pull distribution**

good under-standing of statistical alignment errors

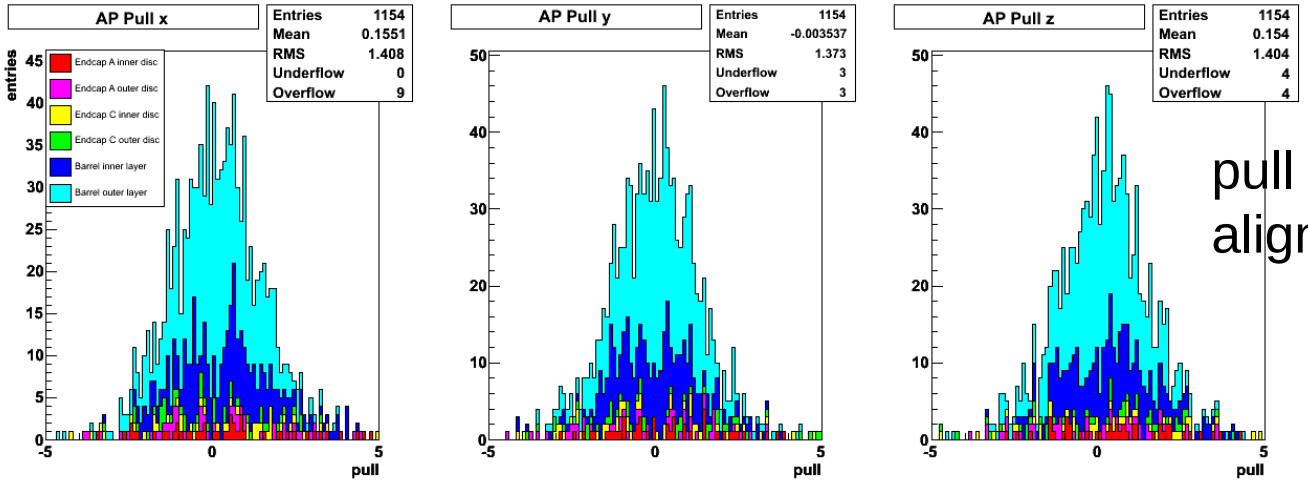
# Alignment of Pixel Modules

## ATHENA, null alignment




Release 11.0.3

alignment parameters




pull distributions of alignment parameters

oversimplified handling of cluster hit errors

average 250 hits/module

# Future Plans at the MPI

- combined high statistic tests of SCT & Pixel
- understand testbeam data
- understand improve systematic
  - enhance overlap hits, vertex (and mass) constraints, add survey constraints,…
  - “Kalman-Filter-Approach“
    - update detector geometry event-by-event
  - global and local alignment
- studies on track quality and selection cuts

# Alignment Activities within ATLAS

- analysis of testbeam data
- preparation for analysis of SR1 cosmics
- global $\chi^2$ approach (Rutherford)
  - takes correlations between modules directly into account
- alignment using overlap hits only (Oxford)
  - aims for robustness
- TRT alignment  (Copenhagen)
- usage of survey measurements (LBL)
- Frequency Scanning Interferometer (FSI) (Oxford)

# Conclusion

- understanding of alignment crucial for b-tagging performance
- MPI Munich develops simple robust local $\chi^2$ algorithm within ATHENA framework
  - first results promising
  - works for SCT and Pixel in barrel and endcap
  - future work: algorithm refinement to improve systematic, testbeam analysis, large scale tests, global alignment, track selection
- 3 senior scientists and 4 students