ATLAS
EXPERIMENT

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Alignment of ATLAS Inner Detector Tracking System

Shih-Chieh Hsu on behalf of ATLAS
Lawrence Berkeley National Lab

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A Toroidal LHC Apparatus

Outline

- Introduction
- Methodology
focus on track based alignment
- Strategy
- Results (2009~2010)
- Validation
- Summary

Inner Detector: Pixel/SCT/TRT

Introduction

- **Inner Detector Specification**
 - transverse momentum resolution required to be less than 30% at 500 GeV p_T
 $\sigma(p_T)/p_T = 0.05\% p_T [\text{GeV}] \oplus 1\%$
 - Good b-tagging performance (50% b-jet efficiency with light-jet rejection factor 1000 for top analysis)
 Impact parameter resolution ($0.25 < |\eta| < 0.5$)
 $\sigma(d_0) = 10\mu\text{m} \oplus 140\mu\text{m} / p_T [\text{GeV}]$
- **Alignment Challenges**
 - More than 35000 degree of freedom
 PIX: 1744 SCT: 4088 TRT: 176
 - Different scale of resolution
 PIX: $O(10\mu\text{m})$
 SCT: $O(30\mu\text{m})$
 TRT: $O(140\mu\text{m})$

- **Hardware: Assembly/Survey Measurements**
external measurement during installation
- **Hardware: Interferometry**
laser interference monitors of SCT structure in real time
- **Software: Track Based Alignment**
(Focus of this talk. All methods are iterative)
 - **Global χ^2**
correlate all modules along the same track to construct alignment with full systems
 - **Local χ^2**
correlate modules through iterations to solve alignment constants with smaller system
 - **Robust Alignment**
use residual (equivalent to constant hit errors) and overlap residuals

$$\chi^2 = \sum_{\text{hits } i} \left(\frac{m_i - h_i(x)}{\sigma_i} \right)^2$$

$$\Delta\alpha \equiv \alpha - \alpha_0 = - \left(\frac{d^2\chi^2}{d\alpha^2} \bigg|_{\alpha_0} \right)^{-1} \frac{d\chi^2(\alpha_0)}{d\alpha}$$

Alignment Levels

- Multi stage alignment following the assembly structure
 - Level1: Rigid Body O(mm)

	Objects	DoF
Pixel	1	6
SCT	3	18
TRT	3	17

- Level2: Disks/Staves O(mm)

	Objects	DoF
Pixel	9	54
SCT	22	132
TRT	176	960

- Level3: Module O(10 μ m)

	Objects	DoF
Pixel	1744	10464
SCT	4088	24528
TRT	350K	700K

- Intermediate Level, e.g. half shell

Computing Model

- Dedicated ID calibration stream for alignment
- Successfully test each computing element in the GRID May 2010

Alignment Strategy

- 2008**
- **Commissioning Phase**
 - Broaden hit errors to guarantee hit efficiency; Start from nominal
 - Cosmic alignment with non-uniform illumination rate. Endcap has poor illumination
- 2009 Dec**
- Combined collision and cosmic data to align detector and suppress various weak mode systematics
- 2010 ~ March**
- **Operation Phase**
 - Start from commission alignment. Use precision errors. Add beam spot constraint to pursue better alignment
 - Routinely monitor alignment quality by using dedicated processing stream and Grid resource

Dedicate TRT Trigger to record ID tracks efficiently for alignment

High statistics Calorimeter Cosmics Trigger to record events in parallel with stable beams

Dedicate ID Calibration stream to record isolated high p_T tracks for alignment

This is where we are

Cosmic 2008 and 2009

- By the end of June 2009, 0.75M ID tracks (at least 1 pixel hit in each) are recorded

Basic Validation: Cosmic

- Use upper-lower half tracks to measure track parameter resolution

Parameter	Asymptotic resolution	
	Cosmic-ray data 2008	Monte Carlo
Track $p_T > 30$ GeV		
d_0 [μm]	22.1 ± 0.9	14.3 ± 0.2
z_0 [μm]	112 ± 4	101 ± 1
ϕ_0 [mrad]	0.147 ± 0.006	0.115 ± 0.001
θ [mrad]	0.88 ± 0.03	0.794 ± 0.006
q/p [GeV^{-1}]	$(4.83 \pm 0.16) \times 10^{-4}$	$(3.28 \pm 0.03) \times 10^{-4}$

Cosmic and Collision Data

- Detector operates with high efficiency
- Accumulated high quality tracks ($n_{Si} \geq 6$) for alignment

SubDetector	Channels	Operation
Pixels	80M	97.90%
SCT Silicon Strips	6.3M	99.30%
Transition Radiation Tracker	350K	98.20%

First Alignment Using 900 GeV Collision Data

Dec 2009: Immediately after first 900GeV collisions, we have improved endcap alignment with 50K tracks with $p_T > 2\text{GeV}$

narrow	Pixel		SCT		TRT	
Gaussian width	Barrel	EndCap	Barrel	EndCap	Barrel	EndCap
Data(μm)	34	28	43	86	165	208
MC(μm)	22	25	36	46	-	-

TRT:
wider residual
is due to older
reconstruction
release

Refined Alignment in 900 GeV

Feb 2010: Using full cosmic and 900GeV collision data and Robust + Global alignment to refine residual performance

	Pixel		SCT		TRT	
FWHM/2.35	Barrel	EndCap	Barrel	EndCap	Barrel	EndCap
Data(μm)	28	23	43	45	147	167
MC(μm)	23	20	38	40	145	143

Alignment Performance in 7 TeV

May 2010: Precision error and beam spot constraint are applied to pursue ideal resolution and eliminate systematic distortions

	Pixel		SCT		TRT	
FWHM/2.35	Barrel	EndCap	Barrel	EndCap	Barrel	EndCap
Data(μm)	25	20	42	44	142	161
MC(μm)	18	19	34	38	143	135

TRT:
Improved
digitization and
higher p_T cut

Future Validation: Resonances

- Resonance mass peak and width is sensitive to alignment effect

$K_s, J/\Psi, Y, Z$

- Monte Carlo systematics studies with 9 simplified weak mode deformations:

$(\Delta r, \Delta \phi, \Delta z) \times (r, \phi, z)$

Curl (r vs $\Delta \phi$)

Large 300um

Small 20um

Summary

- ATLAS ID alignment applies state-of-the-art techniques: commissioned with cosmic and collision data
- Cosmic alignment is a great help and is served to reconstruct the first LHC alignment
- Alignment has moved from commission phase to precision phase. Looking forward more high p_T tracks
- Restructured alignment code to integrate alignment algorithms and combined Si/TRT alignment
- Ready for higher luminosity data-taking and physics discovery in 2010

First Alignment Using 900 GeV Collision Data

Dec 2009: Immediately after first 900GeV collisions, we have improved endcap alignment with 50K tracks with $p_T > 2\text{GeV}$

Further Alignment at 900 GeV

Feb 2010: Using full cosmic and 900GeV collision data and Robust + Global alignment to achieve finest precision

Alignment Performance in 7TeV

May 2010: Precision error and beam spot constraint are applied to pursue ideal resolution and eliminate systematic distortions