Geospatial World Forum
Large Scale Metrology at CERN
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Antje BEHRENS, Dirk MERGELKUHL
(CERN - Geneva - Switzerland)
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Presentation of CERN

- CERN is world’s largest laboratory for particle physics
- Founded in 1954, near Geneva it sits astride the Franco-Swiss border
- One of Europe’s first joint ventures (21 member states)
- Today more than 12,000 scientists from more than 100 countries

CERN goals:
- Fundamental research in particle physics
- What is matter? Where does it come from?
- Bring nations together in a common project
- Technology transfer and education/formation
Accelerator complex and experiments

The main tools at CERN are:

- particle accelerators like the LHC
- more than 60 km of beam lines
- experiments like ALICE, ATLAS, CMS and LHCb.
Key data of LHC accelerator

- 60-140 m underground
- 27 km circumference
- 4 large experiments
- Beam size at IP:
  - 16 µm
- ~1750 cryo-magnets and other elements
- Temperature: 1.9 K
- Magnetic Field:
  - 8.33 Tesla
  - (Earth 0.025-0.065 Tesla)
- Energy in magnets:
  - 10 G joules
- Energy of collisions:
  - 14 TeV (? TeV presently)
- *1 TeV is an energy unit used in particle physics. 1 TeV corresponds approximately to the energy of a flying mosquito. What makes the LHC exceptional is its ability to concentrate this energy in a space equivalent to the mosquito size * 10^-12.
Mandate of Large Scale Metrology Section

- Definition/maintenance of reference frame and linked geodetic aspects
- Dimensional metrology of accelerator components and of experiments (magnets, detectors...)
- Positioning and alignment of these elements on beam lines and their maintenance
- Quality controls (infrastructure, installations, components)
- The R&D related to these tasks for existing and future installations
Fiducialisation of LHC magnets

- Link of beam pipe, external fiducial marks (CERN socket) and magnetic axis – precision ~ 50 µm
Principle for Accelerator Alignment

- Measurements are treated in the classical way 2D+1D
- Each magnet has at least two fiducials and a tilt surface

The best geometrical links with upstream injector and particle detectors

monitoring in the critical areas
Stretched wire measurements

To be obtained:

- relative accuracy between elements
  - 0.15 mm for neighboring elements
- Manual and automatic ecartometers
- Comparison:
  - offset 0.05 mm/100 m = 0.03 mgon
  - Theodolite = 0.15 mgon
Levelling of LHC

- relative accuracy between elements
  - 0.15 mm on neighboring elements
- Optical levels as DNA03, NA2
- Accelerator plane inclined
- Difference Ellipsoid to Geoid
  - up to 100 mm due to Jura and lake
Monitoring of Machine Experiment Interface

- Most critical area are final focus magnets.
- Limit exposure of personnel to radiation.
- Permanent monitoring.
- Sensors need to be radiation hard and to resist high magnetic fields.
HLS, WPS and DOMS Sensors

- System monitors the co-linearity of focusing magnets
- Systems based on capacitive sensors HLS, WPS and DOM
- Electronics separated from sensors
- Each measures at a precision of few microns (10µm range)
- Relative precision of elements ~ 20 µm

HLS: Monitoring a ‘large’ plane within a few µm
  - water surface

WPS: Monitoring a ‘long’ direction within a few µm
  - conducting stretched wire

DOMS: Monitoring a ‘short’ distance within a few µm
  - distance + calibrated invar rod
Motorized Jacks

- Manual adjustment is time consuming
- ALARA – As Low As Reasonably Achievable
- Magnets are adjustable remotely using jacks, stepper motors, reducer, angular encoders, DAQ system
- Load sensors on top of jacks (magnet ~ 15 t)
Adjustment of final focus magnet

- Short term monitoring during adjustment
- Displacement of 220 µm within 5 µm (HLS+WPS)
- Sensibility of HLS shows earth tides
- Perturbations due to geophysical movements
Construction principle of experiments

Russian puppet design – smallest most critical but only largest visible!

Different demands from:

- **Engineers** (quality control, integration, envelopes, assembly)
  - Prototypes, deformation tests, quality control, (pre-)assembly, alignment
  - Provide forms, dimensions and positions for all elements
  - During assembly and when all is closed

- **Physicists**
  - Position wrt beam geometry as approximate coordinates for physics

What we see...

What we want to know...
ATLAS detector

Facts:

- Diameter: 25 m
- Length: 46 m
- Weight: 7000 t
- Data 3200 TB/year
- 3000 scientists from 38 countries

Pieces are new, unique and partly prototypes!
No serial production, no pre-defined procedures!
References 887 holes
Measurement of TGC wheel

Summary for TGC3-C

- Object diameter ~25 m
- Distance to object 5-6 m
- Photos ~960
- Observations ~ 90000
- Unknowns ~9400
- Points ~1200
  - 130 coded
- RMS adjustment ~0.1 mm
- Controls by theodolite
  - Precision ~0.5 mm
- Use 17 mm and 24 mm lens
- Data ~1.9 GB (jpg)
- In field ~1 day
Alignment for ATLAS Pixel detector

- Extraction of beampipe
- Insertion of IST
- Insertion of IBL and beampipe in cavern
- Real scale mock-up for validation
- Alignment of different tooling
- Typical relative precision 0.1 mm

Main tools:
- Laser tracker
- Total station
- IBL installation
  07.05.2014
HIE-Isolde project

Constraints:
- Ultra high vacuum 10^{-8} bar
- Temperature 4K (cryo)
- Through windows
- Large number of targets
- Integration

Demands:
- Alignment and monitoring of the Cavities and Solenoids
- Online system
- Precision asked along radial and height axis at 1 sigma level:
  - +/- 300 µm for the Cavities
  - +/- 150 µm for the Solenoids
Sensors are HBCAM developed by Open Source Instruments
- Focal ~ 50 mm
- 659p × 494p, 7.4 microns
- ~ 100 mrad x 70 mrad
- Integrated synchronized flash
  - Relative precision: 3 µrad
  - Accuracy of 50 µrad to absolute
  - Passive targets in cryo-modules
  - High-index balls (n=2) as reflectors
  - Measurements through viewports
  - Ceramic/stainless steel balls
    - Relative precision: 5 µrad
    - Accuracy of 50 µrad to absolute
  - High index glass balls (n ~2)
    - Solution n°2: BCAM + Prisme
CLIC study

General facts:
• Linear collider of ~50 km length
• Electron - positron, energy 3 TeV
• Modules of 2 m length
• Beam size 40 nm x 11 nm

Challenging points:
• Radial alignment tolerance: +10 µm over 200 m window
• Need of active pre-alignment
• ~ 20000 components
• Temperature difference ~20°C
Alignment principle for CLIC

CLIC global alignment in 3 steps:
- Mechanical pre-alignment ~0.1 mm
- Active pre-alignment ~ few microns
- Beam based alignment ~ sub-micron
  (Fiducialisation at micron level for each component)

Baseline in feasibility study:
- Mechanical pre-alignment by Laser tracker
- Overlapping stretched wire of 200 m for horizontal alignment WPS sensors
  - Tests with wires of 100-240 m (partly up to 400 m)
  - Sigma < 1 micron reached (days)
- HLS sensors for vertical alignment
  - Sigma < 1.8 micron (days)

Geoid measurements:
- Absolute gravity
- Relative gravity
- Zenithal camera

CLIC test facility CTF3 and R&D ongoing
Thanks for your attention!

Candidate Event Selected in Higgs Search Analyses

Run Number: 209109, Event Number: 86250372
Date: 2012-08-24 07:59:04 UTC
backup slides
Sensibility of HLS sensors

- Earth tides
- Perturbations by Earthquakes