PHENIX VTX alignment and other aspects of precision

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Based on the ATLAS Muon X-ray tomograph experience (2 ± 2 μm accuracy achieved in the working area 2 x 0.6 m) and detector geometry reconstruction with tracks in the Atlas Muon chambers (MDT and CSC, nominal assembly accuracy 20 μm) and other experiments

Overview of PHENIX VTX precision task

- Assume desirable vertex precision goal: 50 μm
- Geometry must be known with precision at least 15 – 20 μm (other sources exist like detector intrinsic precision, fitting errors including correlated ones, pattern recognition / background / inefficiencies / common mode noise errors)

Mechanical precision

- Sensor structure accuracy assumed OK (otherwise additional constraint should be considered, not discussed in this talk) but anyway must be checked (quality of the strips/pixels, thickness)
- Ladder and detector assembly accuracy around 15 μm requires

1. Special assembly alignment tools
   - For ladders
   - For detectors (barrel and end caps)
2. Obligatory checking of at least few first ladders (and possibly random sampling of all others)

Two ways to achieve the mechanical precision

1. Assembling/alignment with high enough accuracy: may appear very expensive and may be not achieved at the end due to unexpected problems what, for example, happened with some MDT chambers in the Atlas Muon Spectrometer.
2. Assembling/alignment with relatively good accuracy and geometrical measurements of all detectors afterwards (must be stored in the database). Note, that bad assembly precision usually does not allow to achieve good detector precision even with a lot of software alignment efforts (many examples exist).

Mechanical stability

1. Temperature. Carbon fiber materials, silicon have small dilatation coefficient (a few µm), should not be a problem. What about other construction materials (how barrel and end caps will be fixed each relative the others)? 10 – 20 µm/°C/m may cause problems (due to FEE heating, for example) in the detector shape as well as in alignment. In the cooling system report the value 80 µm of the detector bowing in some circumstances is mentioned.
2. Humidity. Carbon fiber materials are moisture consuming (resulting in change of sizes).
3. Support. Non-kinematical support may introduce changes in shape and alignment (for example, simple strengthened bolt introduces additional linear and rotating tensions enough to spoil 20 µm shape and alignment accuracy). It may change in time as well.

Choice between two assembly/alignment ways

My personal experience tends to the way 2:

- Cheaper (usually essentially), less assembly time and manpower.
- In spite of it requires permanent monitoring of the alignment and the shape (if not proved to be stable enough) of the detectors, it anyway is necessary in the light of the temperature, humidity and mechanical stability control in time.
- Examples.
  1. Atlas Muon X-ray tomograph achieved 2 µm 2-D precision over 2x0.6 m working space (compare, direct optical measurements of the tomograph calibration ruler on industrial table had 3, 3, 8 µm accuracy in 3-D space and required to develop the autocalibration tomograph procedure to achieve desirable precision).
  2. Atlas Muon MDT chambers claimed to have 20 µm mechanical precision during production (the first assembly way was chosen). About half (from 12) of the production sites failed to achieve that and had to be calibrated with X-ray tomograph facility (in fact, the second assembly way had to be used).

How to monitor the alignment

- It was mentioned that anyway the assembly/alignment of the vertex detector must be as accurate as possible, the final alignment monitoring precision is usually proportional to the assembling accuracy.
- How to monitor?

1. Dedicated alignment monitoring system. It looks impossible to use it in PHENIX because of lack of space (all such systems use laser beam requiring laser sources, lenses in the middle of the laser beams and CCD matrices at other ends of the beams). In addition it may appear expensive enough.
2. Monitoring with tracks. Looks attractive alternative but has some particularities.

Alignment monitoring with tracks

- Number of tracks approximately may be estimated from equality

$$R_{des} = R_{det} / \sqrt{N}$$

(R_{des} – desirable precision of the alignment, R_{det} – precision of the detector, N – number of tracks), that is $N=(R_{des}/R_{det})^2=2500$ (assuming R_{des} =1 μm, R_{det}=50 μm ?factor ?12 is omitted because of uncertainties in the track pattern recognition). In reality (due to good track filtering, for example), the number of tracks required must be a few times larger, about 10000 tracks/sensor.
- All 6 parameters (for example, position of the center and angles of rotation around it) of the sensor may be found if there are external tracks good enough (better than resolution of the Si detector itself, otherwise number of tracks must be correspondingly increased).
- If the internal tracks (made from the Si detector itself) are used, additional constraints will appear (large correlations between parameters will exist, number of correlations will increase if straight tracks are used for alignment and increase more if the straight tracks are parallel, for example, in beam tests.).
- In all cases an investigation of the constraints of the parameter correlations found with tracks must be done using Monte Carlo studies.

Second coordinate requirements

- Hit precision is deteriorated with the bad second coordinate if the alignment of the sensor is bad (remember the note about the alignment of the sensors which must be as good as possible). Indeed, if the sensor is rotated around perpendicular to its surface by the angle ?, the coordinate in the sensor system of coordinates relative to some global one will be $x_{sensor}=x_{global}+y_{global} * ?$. For example, for the strip layers uncertainty of the second coordinate is $?y_{global}=1000$ µm, therefore, if the alignment angle accuracy equals 50 mrad, it will introduce 50 µm uncorrectable error in the detector measurements.

Conclusion

- To achieve the VTX detector precision 50 μm the following points must be considered and checked with high attention
  - Final (together with monitoring) mechanical precision must be 15-20 μm.
  - Assembly and alignment must be made as well as possible even if the monitoring is supposed to be made.
  - The temperature, humidity and the detector support structure must be tested from the point of view of the precision of the detector (with tracks? Some other approaches?).
  - Monitoring with tracks is in fact the only way to continuously monitor the detector mechanical stability (about 10000 tracks sample needed to achieve necessary precision of monitoring).
  - The constraints of the parameter correlation found with tracks must be studied using Monte-Carlo method.
  - Second coordinate uncertainty effect must be understood.