SiD Answers to IDAG Tracker Alignment Questions

Presentation of Draft Answers

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Questions:

- What is your plan for aligning your tracking systems?
- What is the precision required?
- Are there special operations needed for alignment after push-pull prior to data taking, and what time is required?
- How many degrees of freedom need to be considered after a move?
- How do the alignment needs affect the design of your detector?
- Is any real-time monitoring of the tracker alignment envisioned (e.g., related to power pulsing and long term stability)?

We have put together a draft document to address these questions: (attached to agenda page)

- Some questions can be answered readily

- For others, more work is needed, but we provide estimates / guesstimates

This presentation is a summary of the draft document:

Currently ~10 pages – Too long? What is needed?

Q1 – What is your plan for aligning your tracking systems?

Six elements in alignment strategy:

- Robust, rigid structure with kinematic mounts
- Precise fabrication and assembly
- Frequency Scanned Interferometry (FSI)
- Laser-track method
- Optical Fiber Sensor (OFS) deformation monitor
- Track-based alignment

Q1 – What is your plan for aligning your tracking systems?

Fabrication and assembly

- Sensor alignment measured w.r.t. fiducials of modules
- Module installed on stable carbon-fiber support cylinders & disks
- Good thermal stability
- Gravity deflections < 10μm
- Modules installed in groups within 10 μm
- Module groups positioned to within 10 μm of reference points on cylinders/disks
- Accomplished with large coordinating measuring machine (or special FSI setup)

Q1 – What is your plan for aligning your tracking systems?

Fabrication and assembly

• Barrels & disks mate with ball-and-cone mounts with 3 μm reproducibility
• Use CMM or FSI to measure reference features on each object
→Expect ~20 μm precision on relative sensor locations after tracker assembly

• Outermost tracking cylinder supported via kinematic mounts from ECAL
• Rest of tracker supported from outer cylinder
→ Stable internal tracker alignment even with push-pull operations

Q1 – What is your plan for aligning your tracking systems?

<u>Fabrication and assembly</u>

• Vertex detector supported independently of outer tracker with two half-cylinders

Treat tracking system as three pieces:
• Outer tracker (barrels and disks)
• Upper half of vertex detector
• Lower half of vertex detector

Monitor relative alignment of three pieces with FSI

Monitor internal alignment of outer tracker with FSI and laser-track system

Final alignment corrections based on tracks

Q1 – What is your plan for aligning your tracking systems?

Frequency Scanned Interferometry (FSI)

- FSI uses ~1000 interferometers fed by optical fibers, monitoring absolute distances between reference points on tracker, Ecal, beampipe, etc.

- Overconstrained system allows reconstruction of position, orientation, global deformations (twist, bending, stretching, etc.)

- Real-time system taking data continuously

Q1 – What is your plan for aligning your tracking systems?

Frequency Scanned Interferometry (FSI)

- Have bench-demonstrated sub-micron precision on distance measurements under unfavorable conditions using dual-laser system

- Can measure both time-averaged quantities and vibrations (up to Nyquist frequency of sampling)

- Suitable for internal tracker alignment and relative alignment w.r.t. rest of detector

- Hope to use during fabrication & assembly

Q1 – What is your plan for aligning your tracking systems?

Laser-track System

- Shine infrared lasers through selected module sensors via few-mm apertures in metal backings
- Mimicking infinite-momentum tracks
- Uses standard data acquisition channels for readout
- Arbitrarily high statistics for selected sets of modules
- Gives “bottom line” measure of relative alignment
- Expect precision of 2-3 μm
- Different systematics from FSI method

Q1 – What is your plan for aligning your tracking systems?

Optical Fiber Sensor (OFS) deformation monitor

- Embeds optical fibers with Fiber Bragg Grating (FBG) into support structure to sense strain
- Different grating pitches used in different regions to identify strain location
- Can be used as alarm trigger during push-pull moves.
- Immune to E/M fields, high voltage, temperature variation, radiation
- Very lightweight
- Remote and fast readout
- Sensitive to μstrain

Q1 – What is your plan for aligning your tracking systems?

Track-based Alignment

- Final alignment of individual sensor modules based on detected tracks, accumulated between push-pull moves
- Time required for high statistics is long enough to warrant real-time monitoring (FSI, laser-track)
- Six parameters to describe position, rotation
- Most critical is measured coordinate, but two rotations important too

Q1 – What is your plan for aligning your tracking systems?

Track-based Alignment

- To attain alignment precision of σ/10 requires O(100) tracks per module
- Estimate O(>10^4) tracks / module / month at design luminosity
(based on extrapolation from Tim's LCWS2006 slides – need to pin down better)

- Can exploit back-to-back, equal-p_t tracks in some processes to increase constraints

Q2 – What is the precision required?

Not (yet) a consensus among us about requirements:

Keith:

Should aim for $\sigma/10$ (~1 μm) so that alignment adds negligibly to momentum uncertainty for all tracks

→ Reduces tail of $1/p_t$ distribution to mitigate backgrounds in new-physics high-p_t candidate samples

Iván:

Should aim for few μm – diminishing returns from doing better

Q2 – What is the precision required?

Bill:

There is a tendency to consider what can be achieved rather than what is needed for physics.

We should probably look at multiple scattering effects more carefully.

Outer tracker barrel modules:

- 3 μm transversely at each module end
- 20 μm radially near barrel ends, proportionately less closer to z = 0

Outer tracker disks

- 3 μm transversely at each strip end
- 25 μm radially at each strip end
- 3 μm in Z at each strip end at the outermost radius, increasing appropriately for more forward modules

Vertex detector sensors

- 1 μm in each coordinate transverse to a track over the entire sensor
- 10 μm in the track direction

Q2 – What is the precision required?

Detailed simulations needed to address this issue quantitatively

One approach:

State that σ/3 is likely required for outer tracker, but full simulations may reveal that σ/10 is significantly safer

Q3 – Are there special operations needed for alignment after push-pull prior to data taking, and what time is required?

- Monitored during detector moves (no added time)
  - Beam pipe
  - Ends of outer tracker
  - LumiCal
- At end of motion (< 2 hours expected)
  - Align final quads
  - Align LumiCal
  - Align beam pipe
  - No alignment of outer tracker
- Tune-up of beam (the time depends upon accelerator procedures)

Q4 – How many degrees of freedom need to be considered after a move?

Following are best guesses

Outer tracker:

Six fundamental degrees of freedom (rigid body):

- Two transverse positions per end (4 DOF’s)
- One azimuth
- One longitudinal position

Possible deformations: (should be small)

- Twist, bending, expansion

Q4 – How many degrees of freedom need to be considered after a move?

Vertex detector:

- Twelve degrees of freedom
- Two transverse positions per barrel end (4 DOF's)
- Two transverse positions per support cylinder end (4 DOF's)
- One azimuth per support cylinder end (2 DOF's accommodate twisting)
- One z-position per support cylinder end (2 DOF's address thermal contraction)

Beam pipe near LumiCals:

Two transverse measurements per end (4 DOF's)

Q5 – How do the alignment needs affect the design of your detector?

To provide a good starting point for alignment

- Support structures are designed to have high stiffness
- Modules are installed accurately
- Barrels and disks are aligned to one another accurately

Frequency scanned interferometry

- Paths must be kept clear for fibers
- Retroreflectors need to be installed, both on the outer tracker support structures and on vertex detector support structures

Laser track method

- Small apertures need to be provided in the aluminum backing of a subset of the detector modules
- Module design must maintain appropriate clear apertures

Optical fiber sensor deformation monitors

- Embedded in CF structures
- Paths are needed for fibers

Q6 – Is any real-time monitoring of the tracker alignment envisioned (e.g., related to power pulsing and long term stability)?

Yes, during data taking and during push-pull moves

Frequency scanned interferometry DOF's: (data taking & push-pull moves)

- Transverse and longitudinal positions of the ends of each outer tracker barrel layer at 8-16 azimuths
- Transverse positions of each barrel layer at approximately 8-16 azimuths and 1-3 additional locations along the layer length
- Overall length of each barrel layer at 8-16 azimuths
- Transverse and longitudinal positions of each disk near its outer periphery at 8-16 azimuths
- Beam pipe transverse positions just inboard of each LumiCal location
- Transverse and longitudinal positions of each vertex detector support cylinder at each end (approximately four azimuths)

Q6 – Is any real-time monitoring of the tracker alignment envisioned (e.g., related to power pulsing and long term stability)?

Laser-track method (data taking)

Continuous monitoring of relative alignments of subsets of modules

Optical fiber sensor deformation monitors (push-pull moves)

Set alarms if excess strain detected anywhere in support structure