IDAG questions:

1. What is the plan for aligning your tracking system?

2. What is the precision required?

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

4. How many degrees of freedom need to be considered after a move?

5. How do the alignment needs affect the design of your detector?

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

I can make comments on the questions 2 and 1.

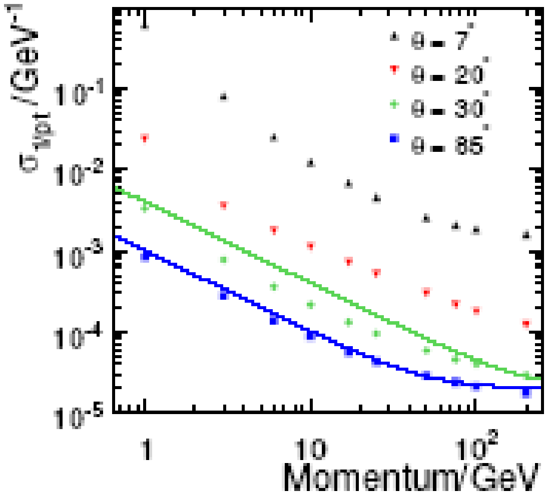
2. What is the precision required?

At Snowmass, we talked about limiting distortions to those that increase the momentum resolution by 5%. Note: $((1.05)^2 - 1)^{1/2} = 0.32$, so we are interested in distortions that lead to a resolution contribution that is 32% of the base.

In answering this question, I first want to understand contributions to the momentum precision, shown in the LOI, figure 3.2-3.

I use a toy Monte Carlo (no digitization) including measurement precision and scattering.

5-layer VTX, 2.8 micron, 0.015, 0.026, 0.037, 0.048, 0.060
2-layer SIT, 7 micron, 0.165, 0.309
224 layer TPC, 100 micron, RL = 117m, { 0.395 : 1.733 }
1-layer SET, 7 micron, 1.835
(materials as in LOI)



P (GeV)	d(1/P) (/Gev)	LOI(**blue**)	ratio
1	2.03×10^{-3}	1.0×10^{-3}	2.03
10	1.57×10^{-4}	1.0×10^{-4}	1.57
50	3.54×10^{-5}	3.0×10^{-5}	1.18
100	2.32×10^{-5}	2.2×10^{-5}	1.05
200	1.92×10^{-5}	2.0×10^{-5}	0.96
500	1.82×10^{-5}		

Understand the contribution from the TPC.
One might think that, with all this added silicon,
the TPC might not have a significant contribution to the momentum resolution.

Numbers are relative to the baseline, from my MC.

P (Gev)	relative d(1/P) 150 micron TPC	relative d(1/P) 70 micron TPC
1	1.13	0.90
10	1.11	0.93
50	1.13	0.91
100	1.16	0.88
200	1.18	0.85
500	1.19	0.83

So, the TPC does make a significant contribution to the momentum resolution; changes in the TPC resolution by a factor of 1.5 result in 18% changes in the system momentum resolution.

(I, too, am surprised that the scaling extends to low momentum.
I should check this.
But, I do not want to digress onto a long discussion.)

Understand the contribution of the SET.
And, understand the effect of degraded silicon resolution.

P (Gev)	relative d(1/P) without SET	relative d(1/P) without SET with 50 micron TPC	relative d(1/P) 1.6σ, all silicon with 70 micron TPC
1	1.00	0.82	0.81
10	1.26	1.03	0.89
50	1.35	1.02	0.93
100	1.45	0.99	0.97
200	1.55	0.98	1.00
500	1.53	0.94	1.02

Removal of the SET degrades the system resolution by 50%.
Compensation would require a 50 micron TPC (which may be possible).

If all silicon resolution is degraded by 1.6
(i.e., 4.5 micron in the VTX, 11 micron in the SIT, SET),
the system resolution can be restored with a 70 micron TPC.

Now, I will address the question: “what is the precision required?”
I use the Snowmass criteria, that the system momentum resolution is degraded by less than 5%, $((1.05)^2 - 1)^{1/2} = 0.32$,
which means that an effect must contribute less than 32% of the nominal d(1/P).

I considered 6 cases of distortions to address this question.

1) This is a particular internal distortion in the TPC.
This is similar to one of the cases I considered at Snowmass. It is a curvature resulting from some uncorrected magnetic field distortion.
I modeled this as 1-cycle of a V-shape (sawtooth) with the amplitude stated in the chart.
The TPC distortion is centered on the silicon.

2) A global misalignment of the TPC.

3) A misalignment of the SIT.

4) A coherent misalignment of 2 layers of the VTX.

5) A coherent misalignment of all layers of the VTX.

6) A misalignment of the SET

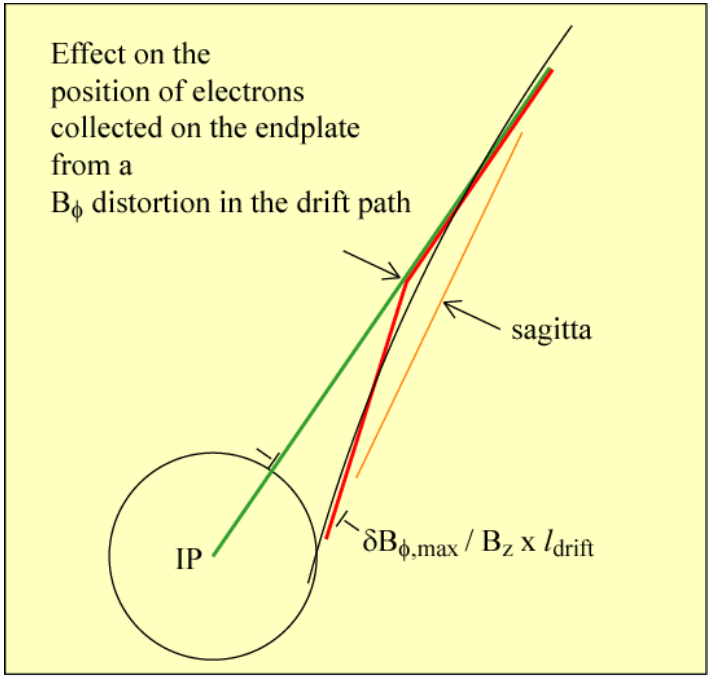


figure from Snowmass 2005

Various distortions with resulting contributions to system momentum resolution:

P (Gev)	rel. d(1/P) 20 μm TPC "V-shape" all layers	rel. d(1/P) 10 μm TPC global displacement all layers
1	0.01	0.00
10	0.05	0.10
50	0.16	0.49
100	0.28	0.71
200	0.32	0.88
500	0.33	0.94

TPC: limit of distortions (for the shape used)
is 20 microns in amplitude, goes from -20 to +20, 40 micron full-swing.

TPC: limit of global misalignments is 32/88*10 microns = 3.6 microns
i.e., ~ the resolution of the silicon.

Various distortions with resulting contributions to system momentum resolution:

P (Gev)	rel. d(1/P) 7 µm SIT displacement 2 layers	rel. d(1/P) 2.8 µm VTX displacement 2 layers	rel. d(1/p) 2.8 µm VTX displacement 5 layers	rel. d(1/p) 7 µm SET displacement 1 layer
1	0.01	0.01	0.01	0.00
10	0.03	0.02	0.05	0.06
50	0.36	0.03	0.17	0.20
100	0.51	0.09	0.31	0.34
200	0.64	0.09	0.35	0.39
500	0.69	0.08	0.36	0.43

SIT: alignment must be know to ~3.5 microns, 50% of intrinsic resolution.

The misalignment of 2 layers of the VTX, by the intrinsic resolution,
does not change much.

VTX: coherent alignment must be known to ~2.8 microns, the intrinsic resolution.

SET: alignment must be known to 6 microns, ~ intrinsic resolution.

The distortion limit (for the case of the V-shape shape that I applied) is
an amplitude of 20 microns, or 40 micron full-swing.

The fitted sagitta for this shape would be about 1x amplitude, 20 microns.
This can be used to say something about
the magnetic field calibration requirement.

In the Snowmass talk, a sagitta limit of 6 microns was developed from other arguments.
In ILD tracking system, there is more weight on the silicon for determining the momentum; that may be why the TPC sagitta limit is relaxed.

With a sagitta limit of 20 microns, roughly 3x the Snowmass value,
the magnetic field calibration requirement is… 3x 2 x 10^{-5}, or $6x10^{-5}$.
This is a more attainable goal !

1. What is the plan for aligning your tracking system?

Using tracks defined (not fit) by the TPC,
align the silicon components to the level of about 3 μm, 6 μm for the SET.

Question about the number of tracks required must be answered elsewhere.

Track fits, internal to the TPC, must be used for both :

internal alignment of the TPC readout components to 20 μm (broad trends), and

improvement of the B-field calibration from about $dB/B = 10^{-4}$ to 6×10^{-5}.

The B-field requirement is not as critical as the Snowmass result,
but we expect to still use non-track-based methods to
pre-align the TPC components to about 50 μm.

After the internal alignment of the TPC,
the TPC must be globally aligned to the silicon system to 4 μm.
This is one reason why we need the DID-clear region in the center of the detector
to serve as an anchor to other parts of phase space.