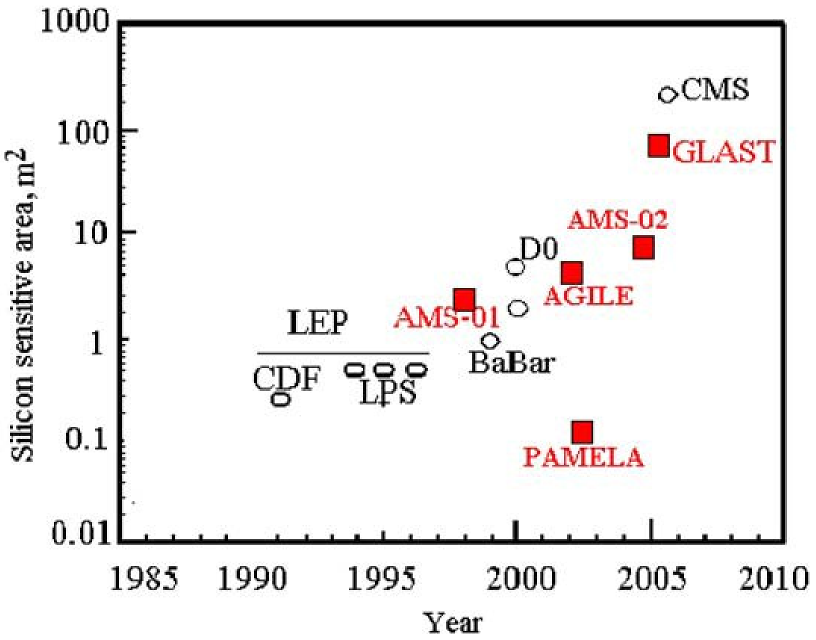
Silicon tracker alignment;

ILD alignment task force



Marcel Vos (IFIC – U. Valencia/CSIC)

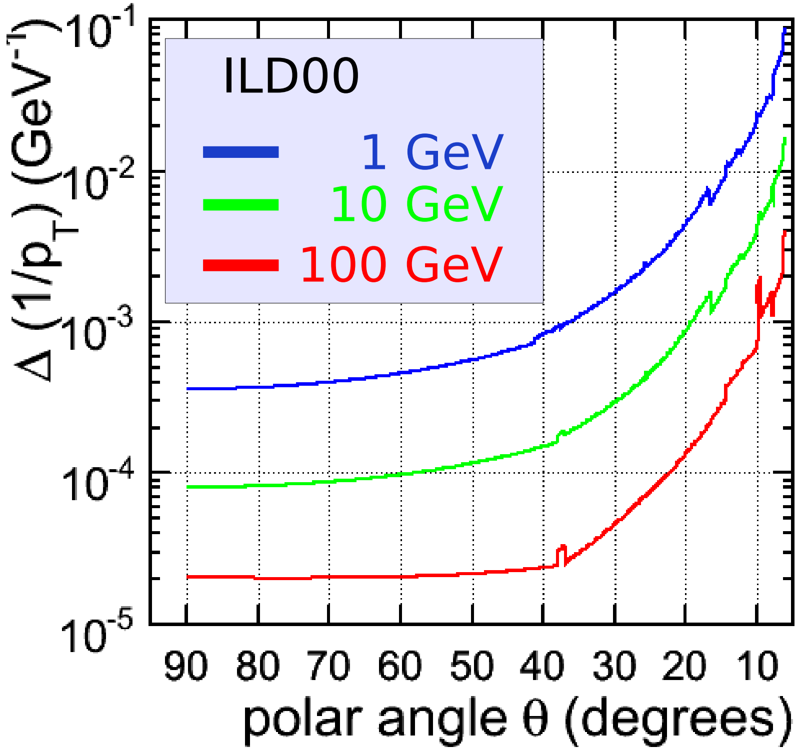
Alignment

Finding the set of constants that relates the local measurement (in units of strip number) to the global detector reference frame

To achieve this, all detector elements must be aligned to better than their intrinsic resolution(*)

<< 2.8 μm in VXD
<< 7 μm in silicon
<< 50 μm in TPC

* Assume the magnetic field map is determined precisely



Today: discuss relation between engineering constraints, hardware and track-based alignment.

IDAG question 2: what is the precision required?

Mounting precision

The precision with which detector structures are mounted:

Sensor:

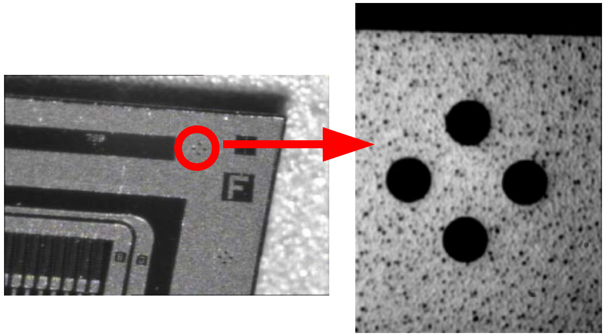
Segmentation: very precise, related to fiducial marks
Thickness: 5 %
Flatness: +/- 200 μm (ATLAS SCT spec. to avoid *significant* feedthrough in measured coordinates)

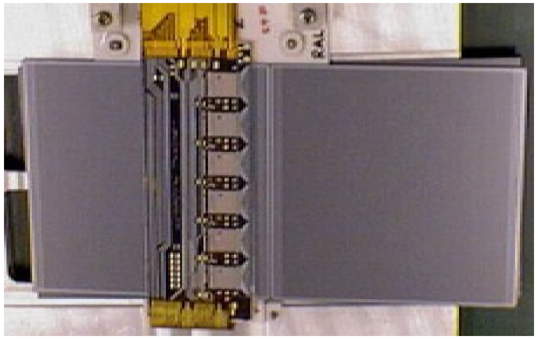
actual wafers much flatter when unstressed)

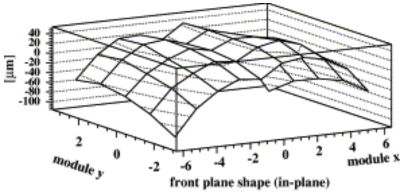
Module:

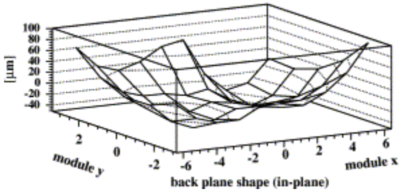
In-plane sensor-sensor alignment 5 μm (ATLAS spec.)
Front-to-back alignment 10 μm (ATLAS spec.)
~100 μm (CMS)
Flatness: 100 μm
Note: placing a wafer with 5 μm precision is trivial, keeping it in that position while the glue cures (24 hours) is a bit harder

Module mounting uses precise (short-range) stages and optical recognition of fiducial marks.
Note: even this lowest level object is NOT aligned to ILC requirements









L. Eklund, P.Modesto, ATLAS SCT

Mounting precision

Ladder:screw modules on precision mounting pin, 10s of μm (CMS TOB)

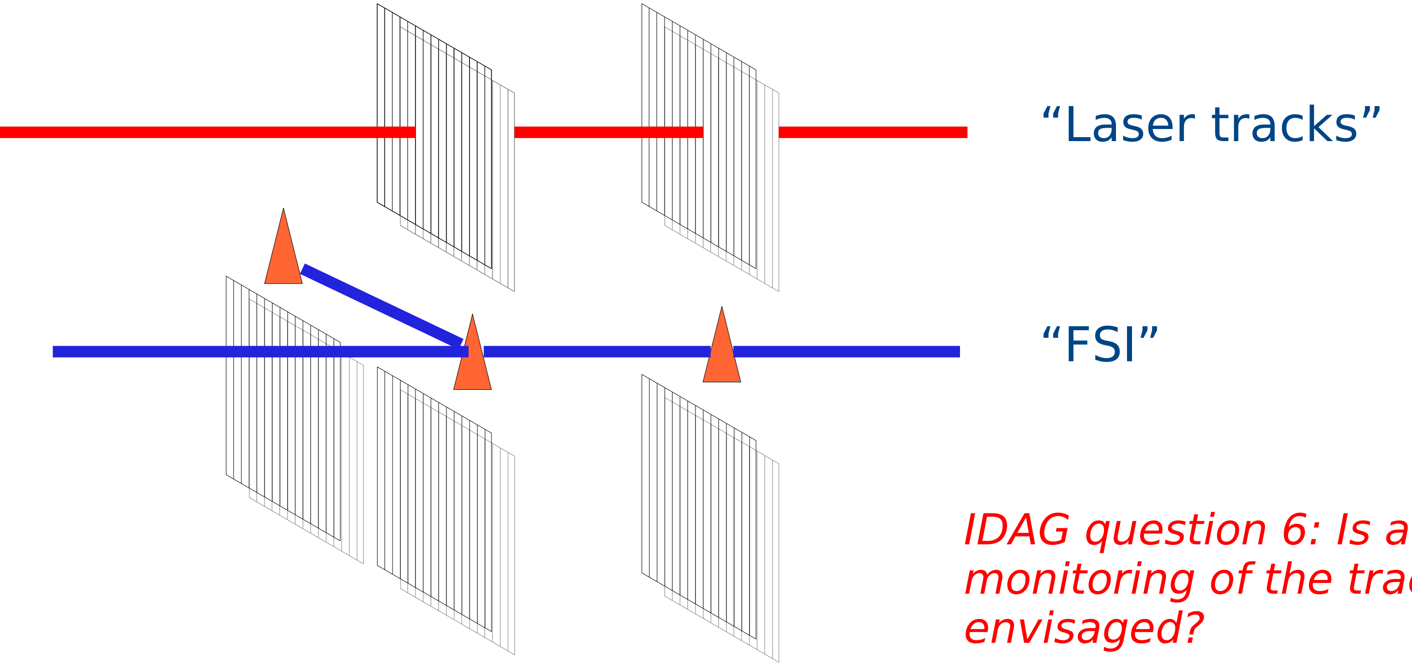
Survey of cylinders: 500 μm (CMS TIB)

The bottom line: a hierarchy of decreasing precision for larger structures

www.mitutoyo.com

2000 barrel modules, ATLAS SCT

Hardware alignment system



IDAG question 6: Is any real-time monitoring of the tracker alignment envisaged?

Two approaches on the market offer little additional material in tracking volume and fast response

- Laser tracks (AMS/CMS)
  ILD group from IFCA Santander (I. Vila)
  Constrains the "important" positions
  Directly relates to the local coordinate system
- Frequency Scanning Interferometry (ATLAS)
  ILC group from Michigan (K. Riles)
  Constrains complex grid of distances between "jewels"
  Transfer of position from jewel to sensor

Track-based alignment

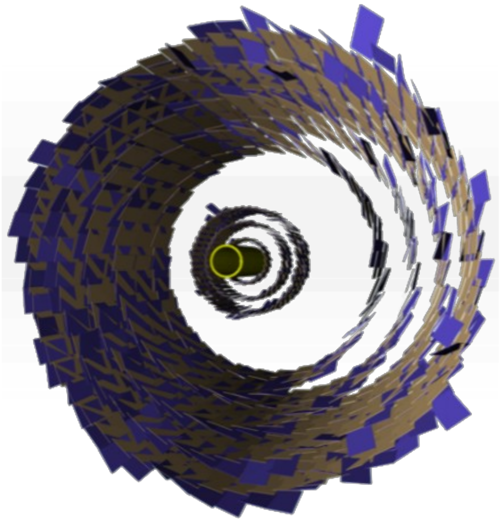
Track-based alignment

Collect a sample of tracks from collisions, cosmics, beam halo, hardware alignment system

Fit tracks and construct residuals for 6 degrees of freedom in each *detector element*

Define χ^2 from residuals initial engineering constraints + FSI / laser alignment system

Find set of alignment parameters that minimizes χ^2



To be performed on different levels

Sub-detectors O (10) DOF (VXD, SIT, FTD,...)

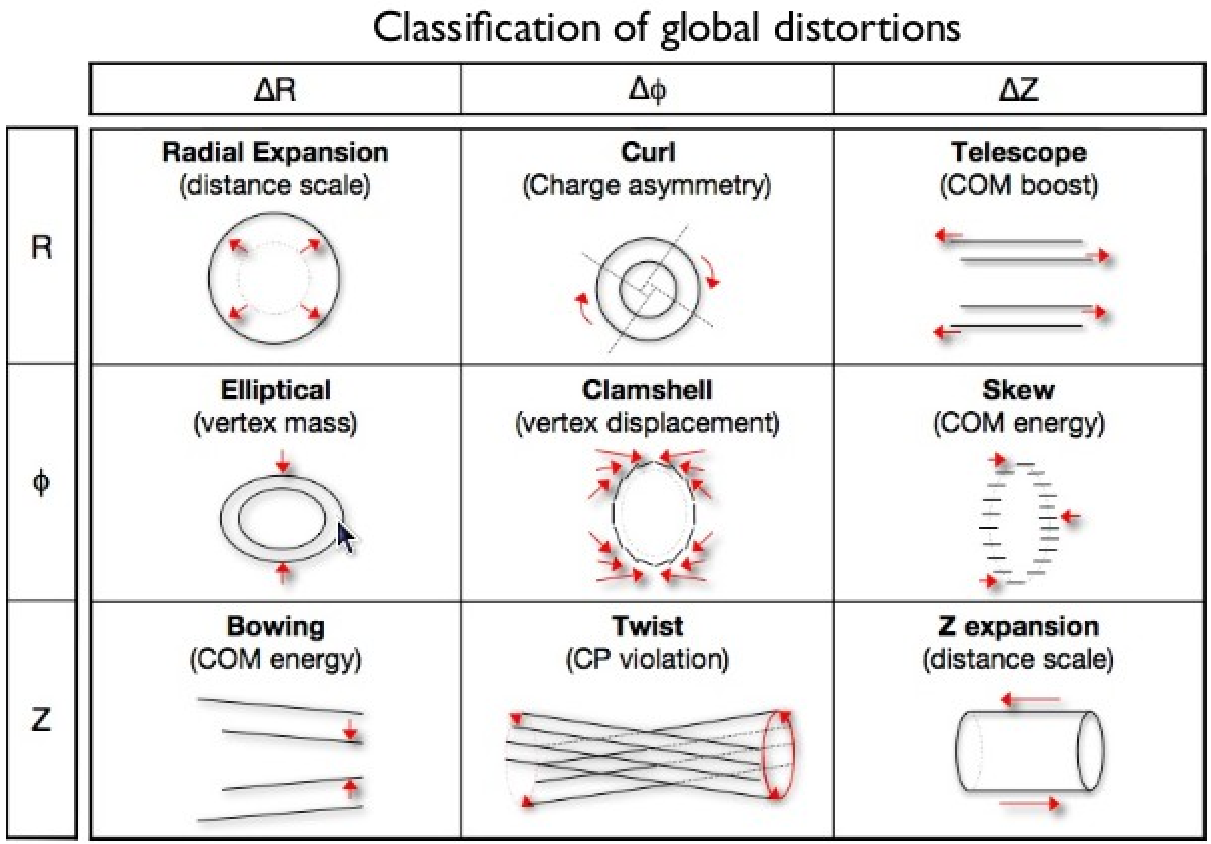
Layers O (100) DOF (SIT1,SIT2, FTD1, ...)

Single wafer O(100.000) DOF
O (10.000 in innermost tracker)

IDAG Question 4: how many degrees of freedom need to be considered after a move?

Track-based alignment

Tracks yield strong constraints on overlapping modules and connect modules in different layers (only few combinations of modules)
Leaves quite some freedom for movements (weak modes: collective movements that do NOT affect residuals, but DO affect the momentum measurement)



Non-IP tracks, resonances with known mass and laser or FSI lines help to resolve global minimum

LHC experience

ATLAS experience (S. Martí):
“The more information we have, the better it is”
“It is a mistake to believe that track-based alignment will solve everything”

Track-based alignment methodology complete
The smallest alignment element is a half-module
(wafer bow measured and taken into account)
36.000 DOF can be aligned each day (realignment will be triggered by monitoring of J/psi or Z-mass).
Intermediate-level alignment (preferred) more often.
Large-structure metrology not used yet (but very important to have this)
Hardware alignment system (FSI) not used yet, but is an important source of additional constraints

Currently, the ATLAS inner detector is aligned to 20 μm using 1 million cosmics. MC studies with additional constraints show that desired alignment precision (<< 23 μm) can be achieved.

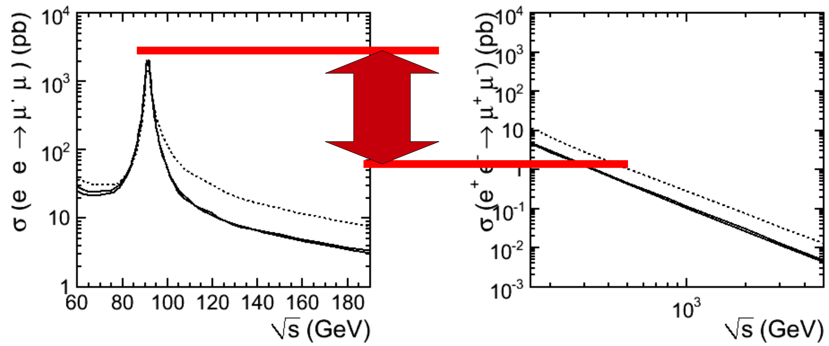
Time

Align once – valid for ever? Each month?

- *Magnet ramp leads to O(mm) displacement of large iron structures*
- *Ground movement?*
- *Thermal excursions: (night/day), pulsed powering*

Position of detector as a whole will vary. What about internal degrees of freedom? Some monitoring (and correction) tools are required.
Track-based alignment of all degrees of freedom is too slow to correct for fast movements:

$$\sigma(e^+e^- \rightarrow \mu^+ \mu^-)_{pT\,(\mu) > 10\ GeV/c} \sim 440\ fb$$



Factor 1000 from “mini Giga-Z”

Luminosity	10^{32} cm^{-2}s^{-1}		$2 * 10^{33}$ cm^{-2}s^{-1}		
Time Int. Luminosity	few weeks 100 pb^{-1}	6 months 1 fb^{-1}	1 day	few weeks 1 fb^{-1}	one year 10 fb^{-1}
$W^\pm \rightarrow \mu^\pm \nu$	700K	7M	100K	7M	70M
$Z^0 \rightarrow \mu^+\mu^-$	100K	1M	20K	1M	10M

Compare rates at the LHC
$\sigma\,(pp \rightarrow \mu^+ \mu^-)_{pT\,(\mu) > 10\ GeV/c} \sim 1000$ pb

Time

IDAG question 6: Is any real-time monitoring of the tracker alignment envisaged?

The O(100) degrees of freedom to align the different subdetectors can be constrained within hours

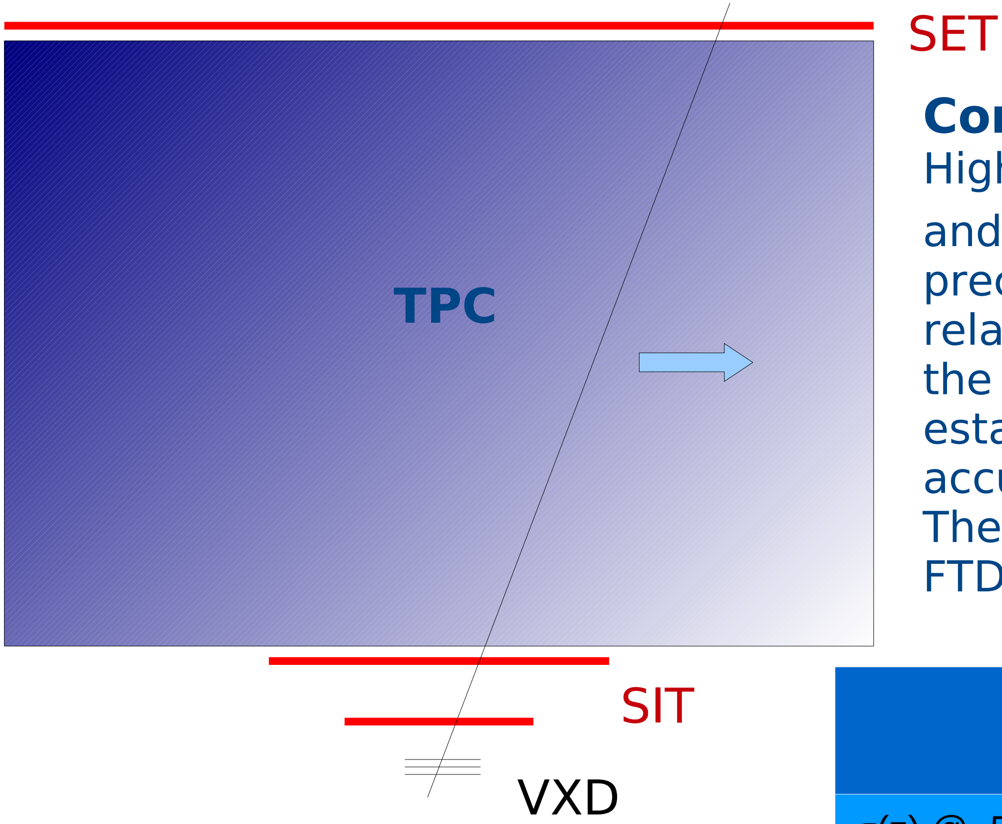
The hardware alignment system can monitor movements of O(1000) degrees of freedom down to a time-scale of seconds

Distortions due to pulsed power (each millisecond) are too fast. However, we can reconstruct periodic movements by sampling at different phases over a longer time.

Our detector design should make sure that the internal degrees of freedom of each structure (cylindrical layer, disk) are stable!

IDAG Question 5: how do the alignment needs affect the design of your detector?

Silicon-to-TPC

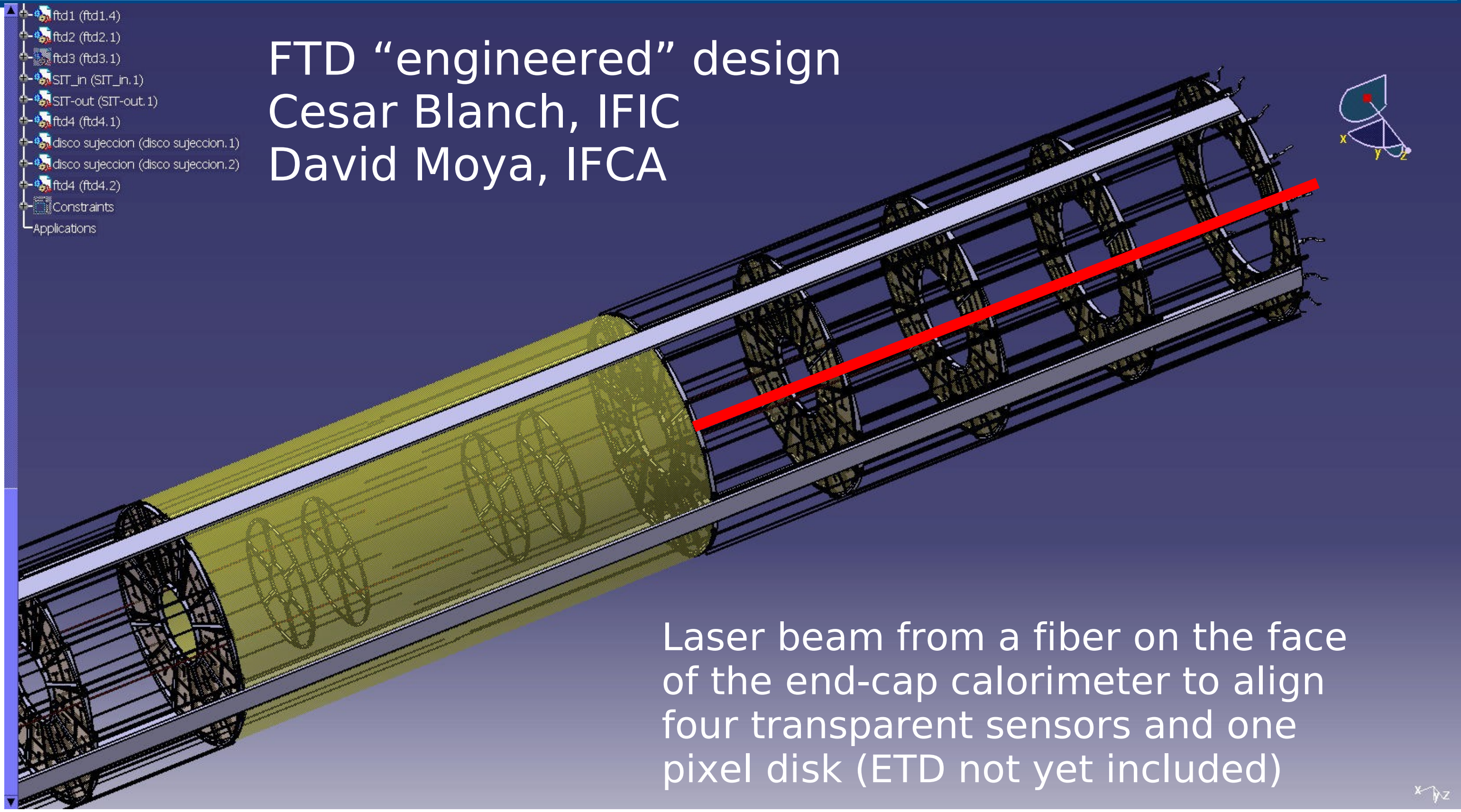


Connection silicon-to-TPC.
High p_T tracks reconstructed in VXD, SIT and SET can be used to predict pretty precise space points in the TPC volume. A relation between silicon measurements and the time coordinate of the TPC can thus be established. This requires, however, an accurate z-measurement on SIT and SET. The same is true for the r-measurement of FTD and ETD.

	VXD	VXD +SIT	VXD +SET
σ(z) @ 50 cm	35	16	28
σ(z) @ 100 cm	77	39	30
σ(z) @ 118 cm	118	50	39

IDAG Question 5: how do the alignment needs affect the design of your detector?

A real design



Similarly, VXD and SIT (and TPC field cage) could be connected

IDAG Question 5: how do the alignment needs affect the design of your detector?

Summary

This talk contains (my) answers to the IDAG questions

Important design requirements that derive from alignment:

- module flatness to be constrained to 10s of micron
- substructures (cylindrical layers, disks) must be rigid objects, unaffected by phenomena on short time-scales (magnet ramp, push-pull, ground movement)
- hardware alignment system integrated in detector design
- connection of both coordinates helps to measurements over single-sided?