ATLAS SCT
Real-time Alignment & Survey

Pawel Bruckman, Paul Coe, Jonathan Cox, Mohamed Dehchar, Ellie Dobson, Johan Fopma, Stephen Gibson, David Howell, Takanori Kohno, Mark Jones, Ankush Mitra, Sandra Muijs, Richard Nickerson, Kamil Sedlak, Georg Viehhauser

Frequency Scanned Interferometry

X-ray Tomography

Alignment

- Resolution r-ϕ ~ 14μm
- Alignment goal < 20% loss in P_t resolution
- Goal of < 5μm from alignment
- Use tracks, but time to collect non-zero
- Very large system, low mass, large power fluctuations
- Dissimilar materials, stresses unpredictable.
- Motion on short time scales at level of 10s μm not excluded by engineers

Purpose of SCT real-time alignment system is to track short-time scale changes in the support structure shape.

X-ray Survey

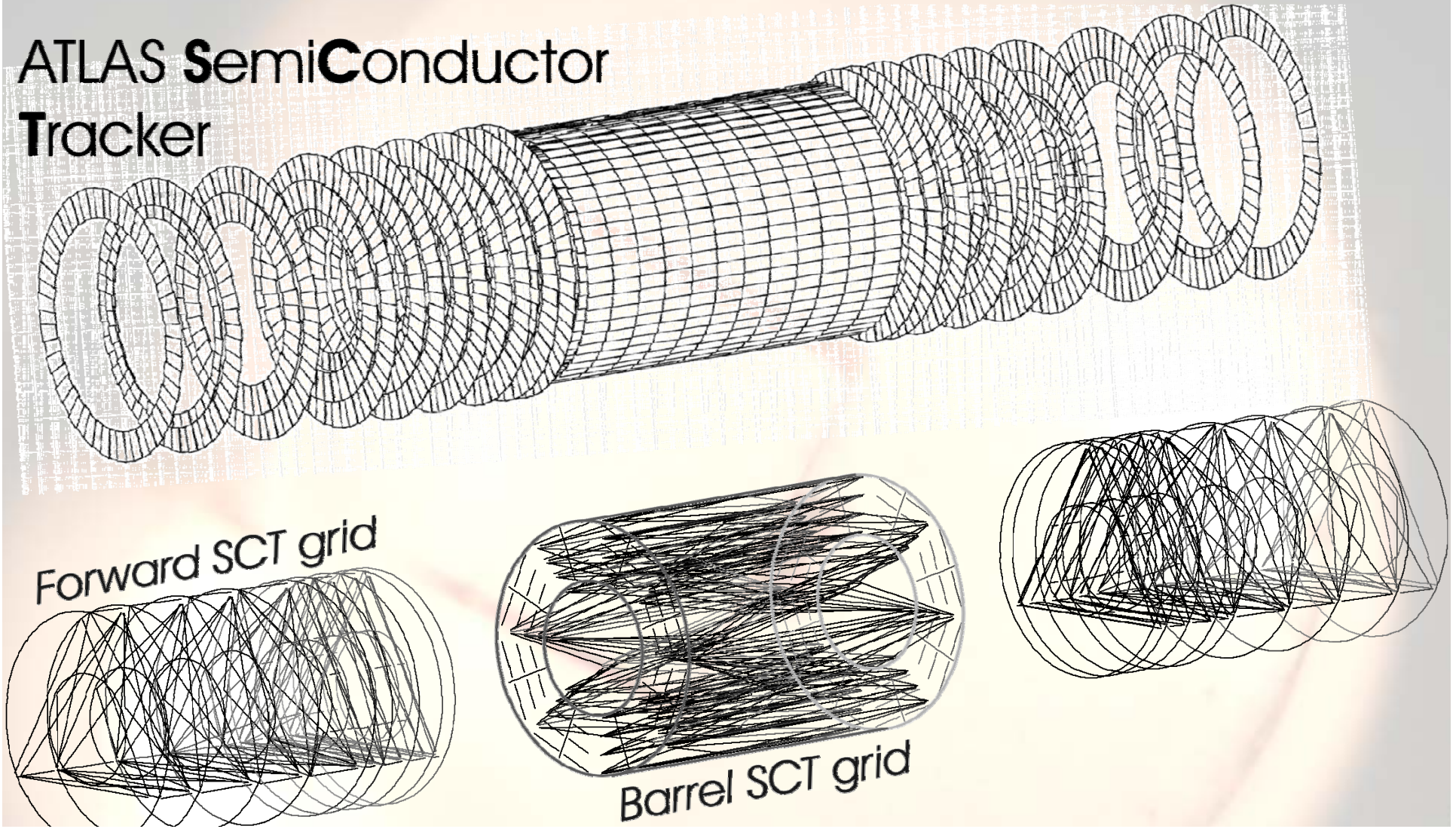
- Initial survey of detector element locations
- Stereo X-ray beams from inside detector capable of locating individual elements to a few microns accuracy.
- Coupled with real-time alignment gives accurate and ‘immediate’ alignment constants.

Purpose of x-ray survey is to provide an initial track-independent alignment with an accuracey comparable to that required for a fully aligned tracker.

Not used due to schedule problem.

Many (>800) accurate 1-D length measurements
Arranged in over constrained geodetic grid
~ 5μm space point accuracy

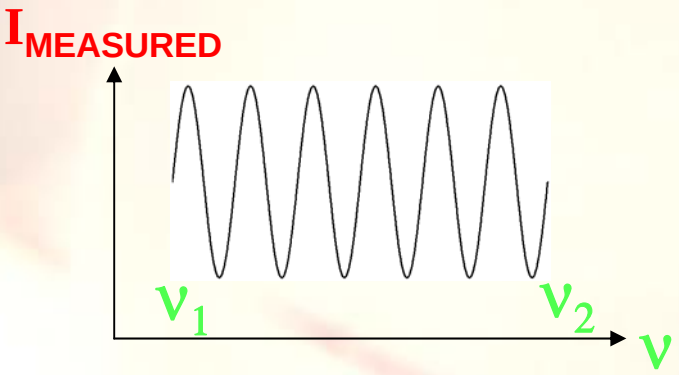
Real-time Alignment



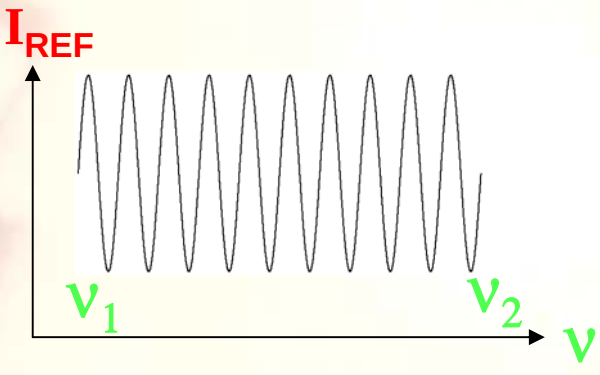
Frequency Scanned Interferometry - principle

To interferometer with length to be measured

Reference Interferometer with fixed length

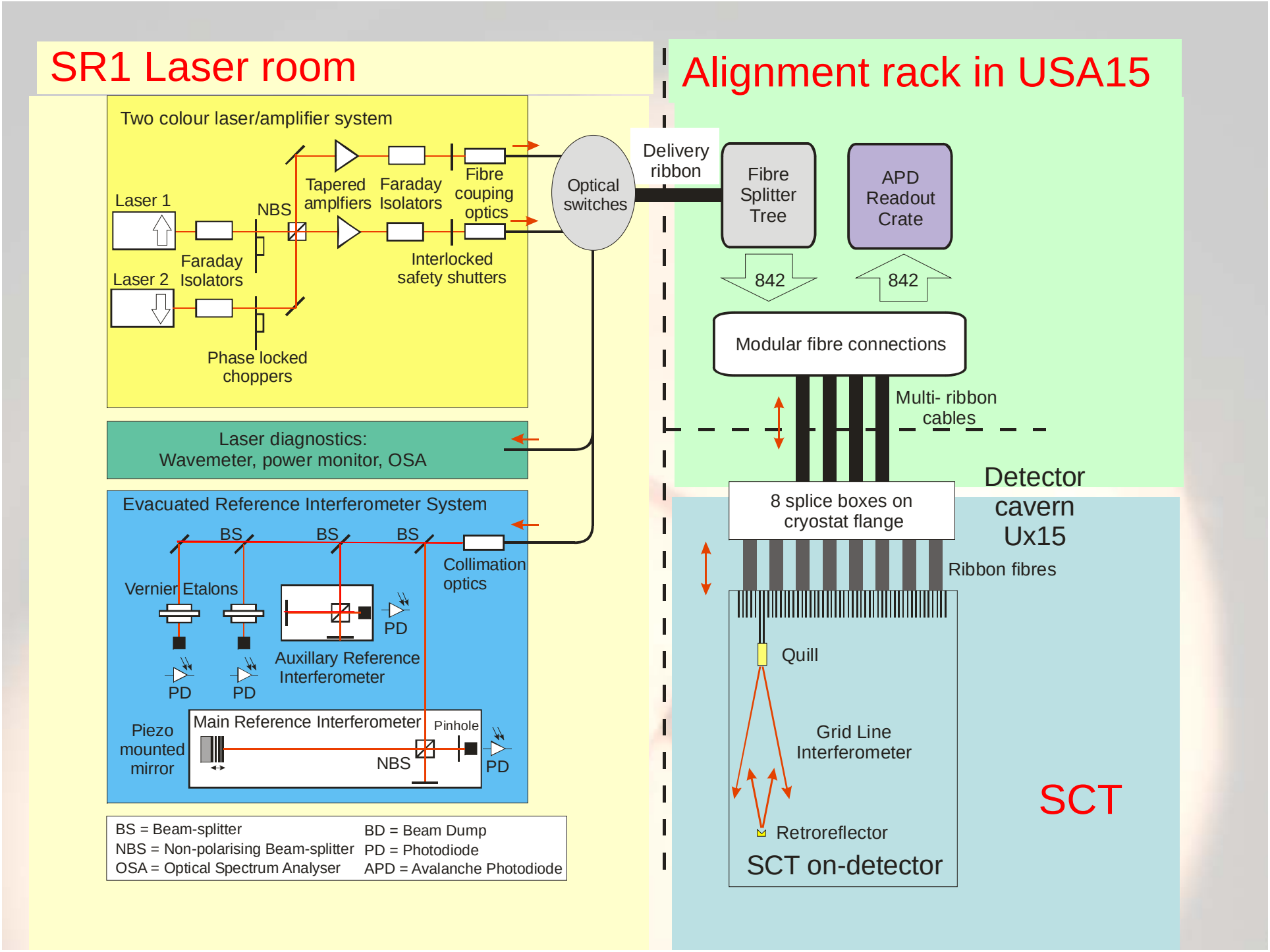


$$\Delta\vartheta = [2\pi/c]D\Delta\nu$$



$$\Delta\Phi = [2\pi/c]L\Delta\nu$$

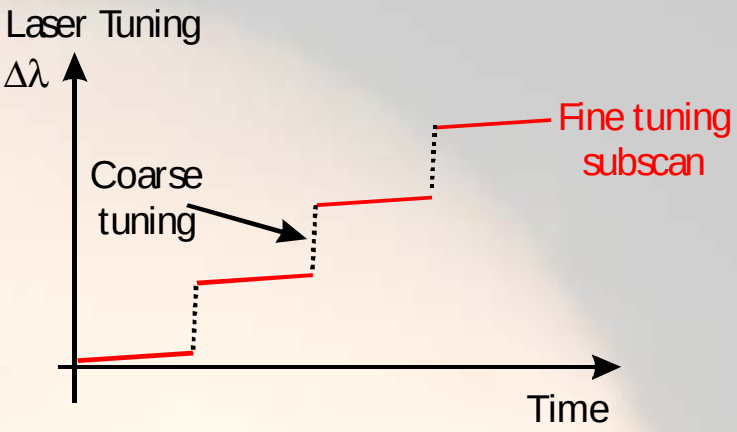
Ratio of phase change = Ratio of lengths

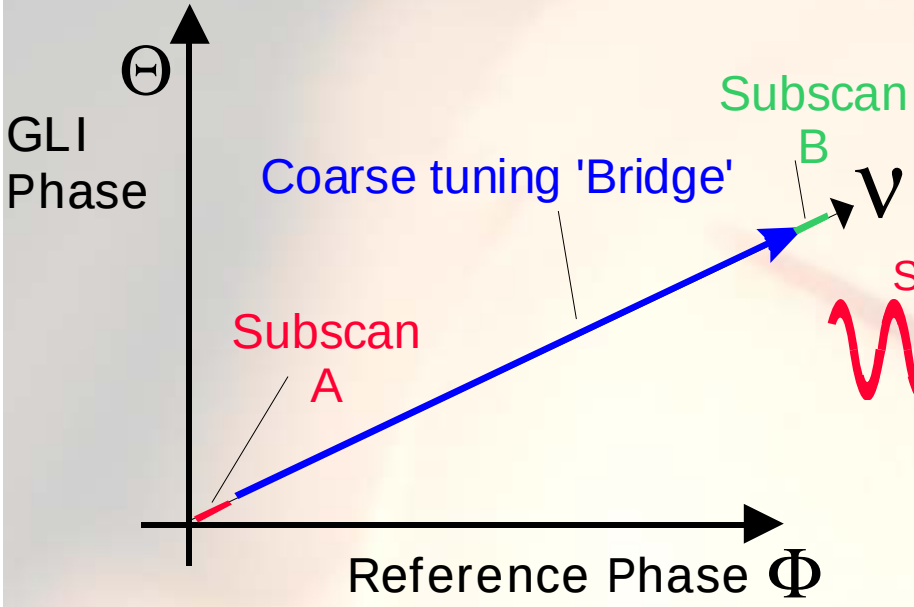

SR1 Laser room
Two colour laser/amplifier system
Laser 1
Laser 2
NBS
Faraday Isolators
Tapered amplfiers
Faraday Isolators
Fibre couping optics
Interlocked safety shutters
Phase locked choppers
Optical switches
Laser diagnostics:
Wavemeter, power monitor, OSA
Evacuated Reference Interferometer System
BS
BS
BS
Collimation optics
Vernier Etalons
PD
PD
PD
Auxillary Reference Interferometer
Piezo mounted mirror
Main Reference Interferometer
Pinhole
NBS
PD
BS = Beam-splitter
NBS = Non-polarising Beam-splitter
OSA = Optical Spectrum Analyser
BD = Beam Dump
PD = Photodiode
APD = Avalanche Photodiode
Alignment rack in USA15
Delivery ribbon
Fibre Splitter Tree
APD Readout Crate
842
842
Modular fibre connections
Multi- ribbon cables
Detector cavern Ux15
8 splice boxes on cryostat flange
Ribbon fibres
Quill
Grid Line Interferometer
Retroreflector
SCT on-detector
SCT

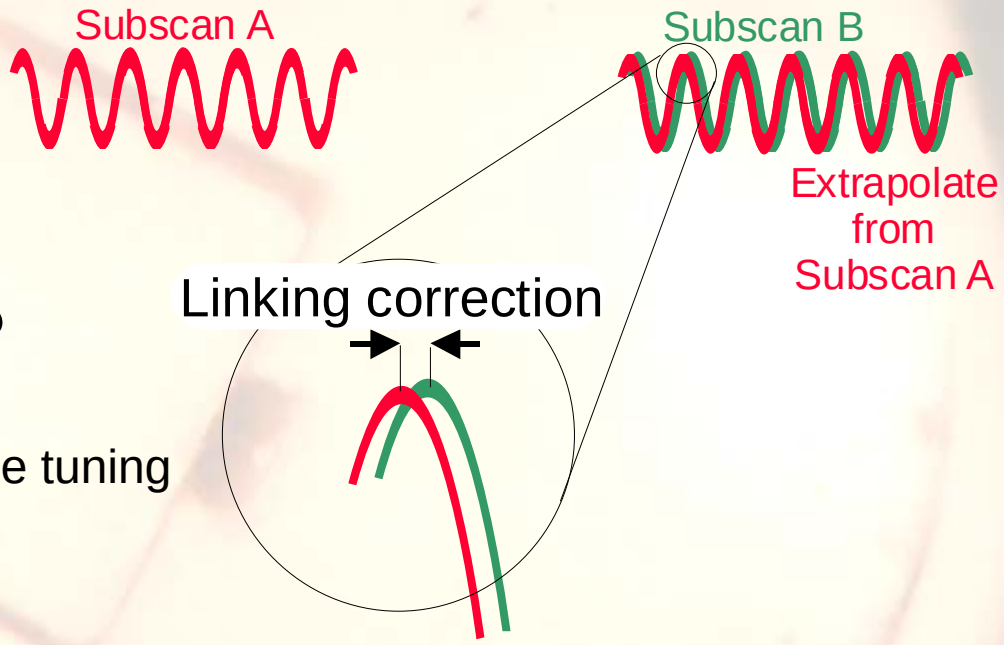
Fine tuning range of lasers is limited.

Frequency interval increased recorded series of fine tuning subscans (60GHz) interspersed with rapid coarse tuning (~THz).

But cannot directly measure phase during coarse tuning.



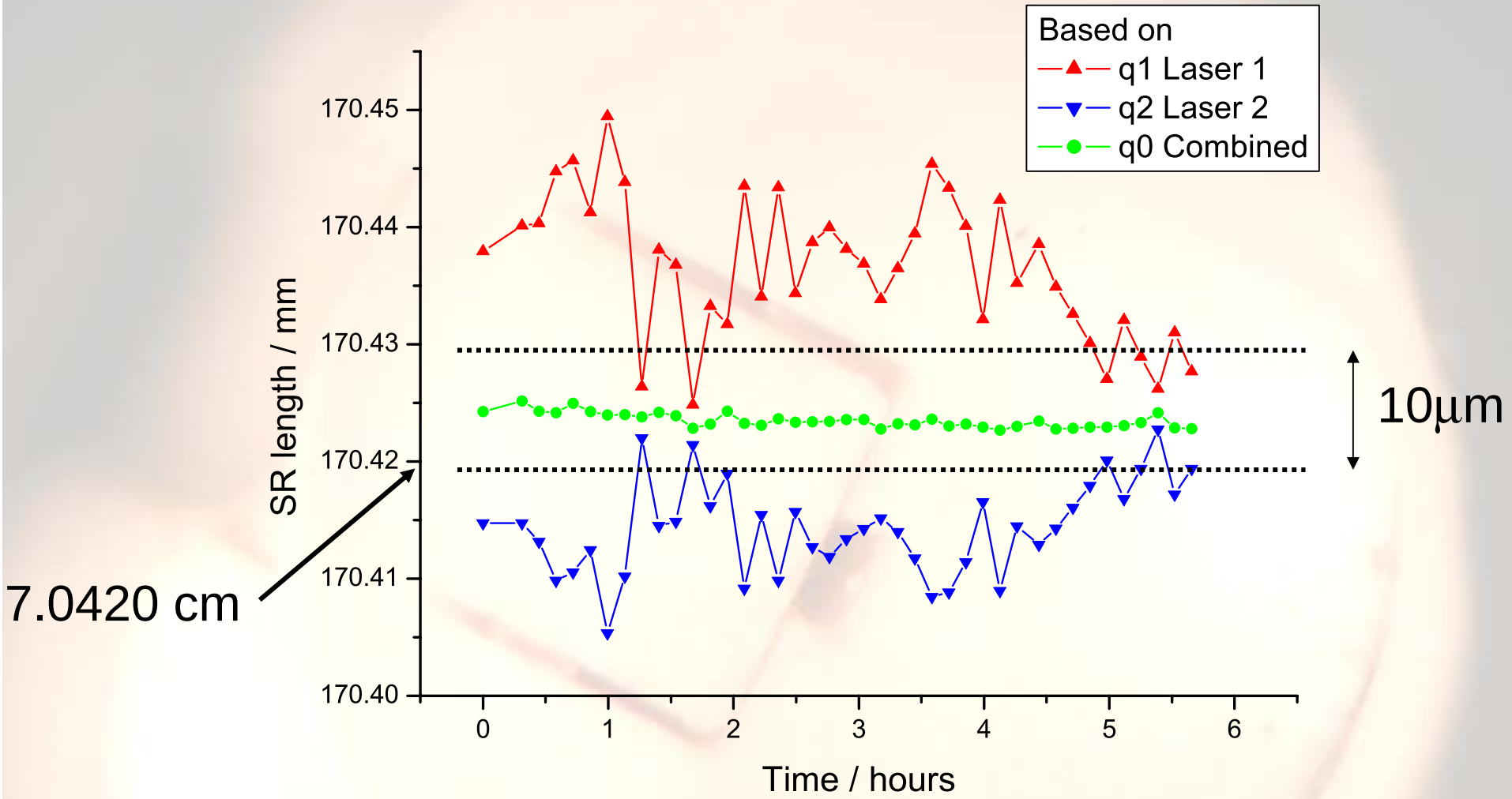


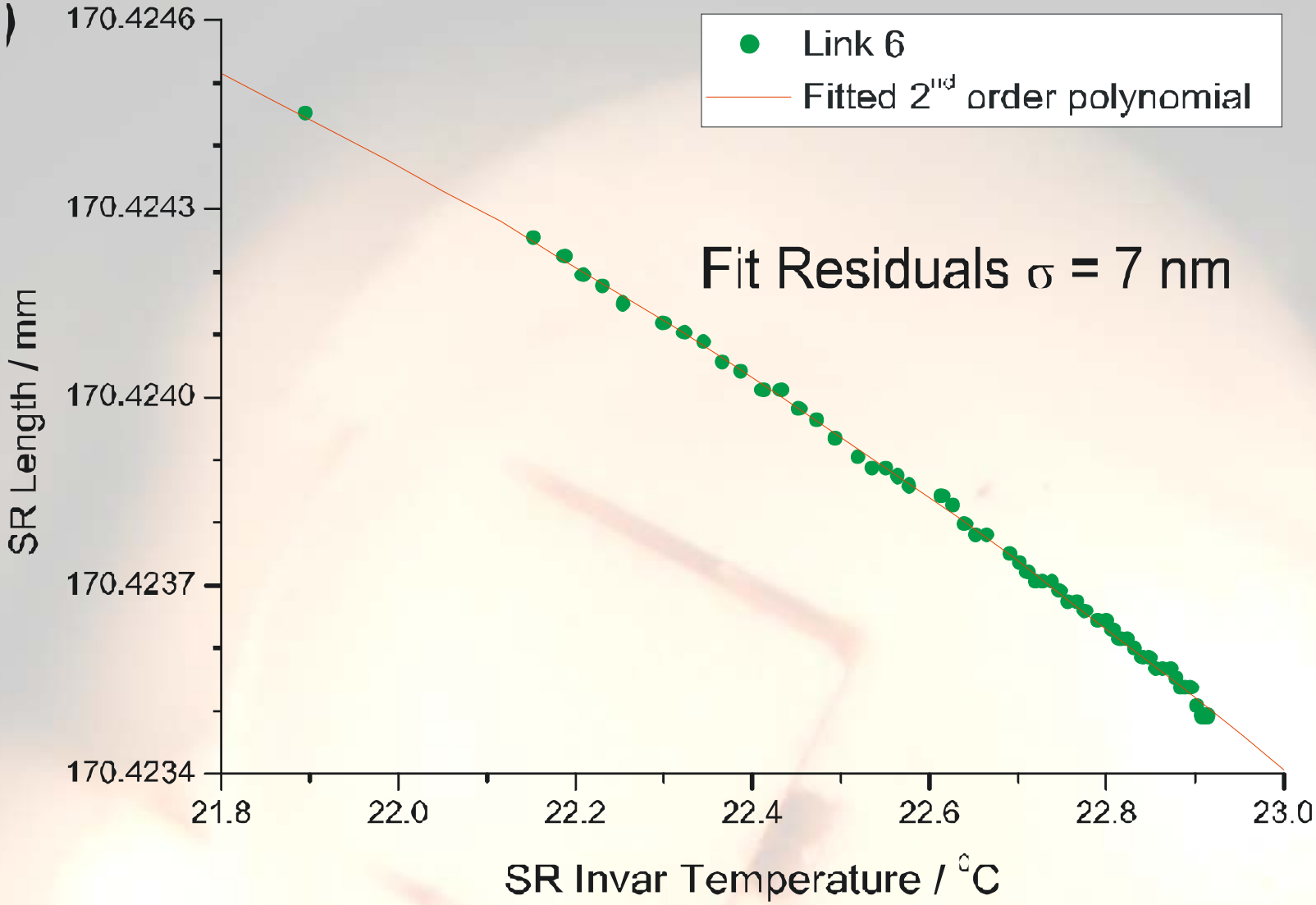


Extrapolate using estimate of coarse tuning bridge from counting Etalon peaks.

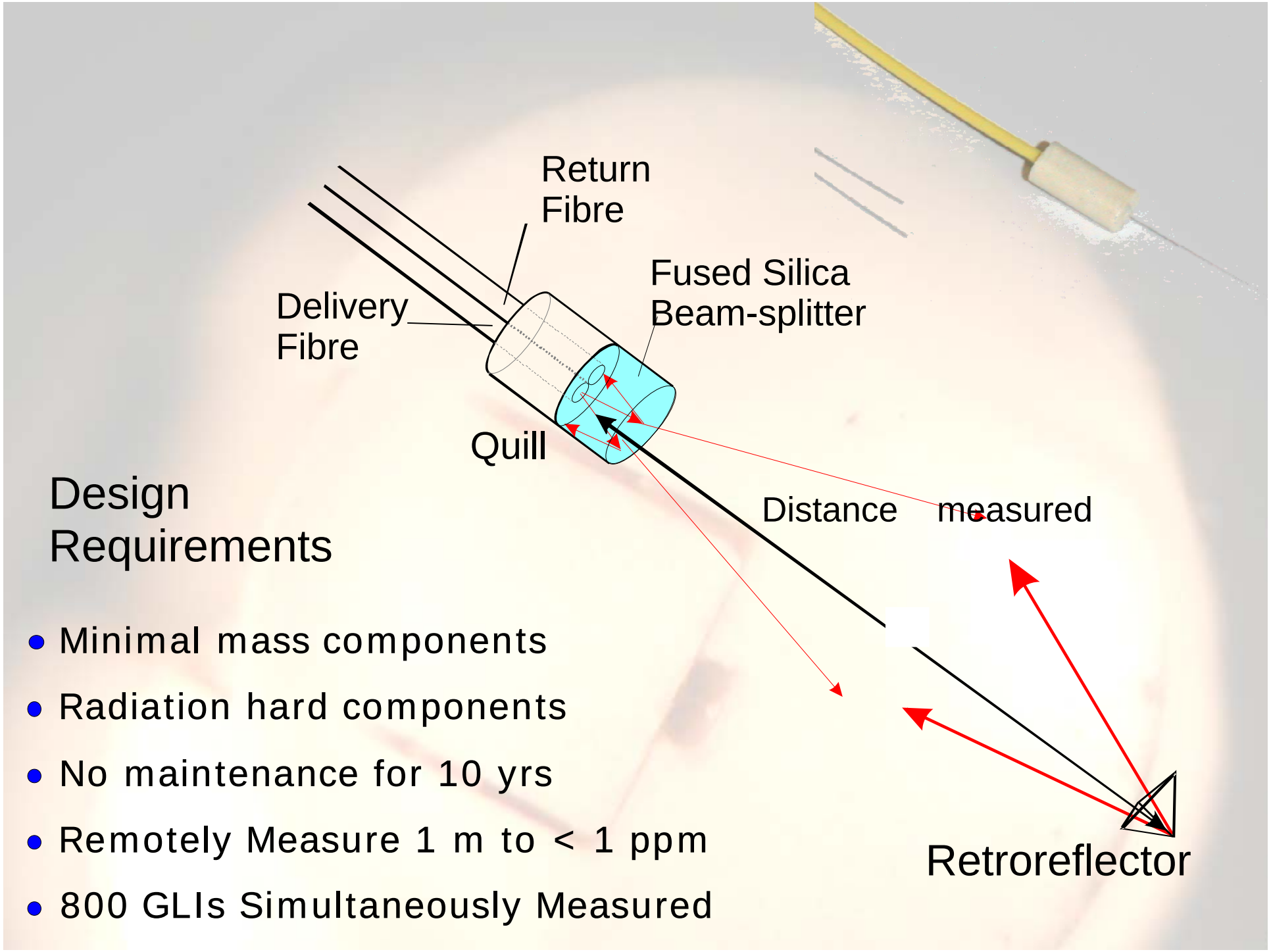
Michelson fringes will be present during scan – temperature drift

Use two lasers scanning in opposite directions to cancel interferometer drift errors.



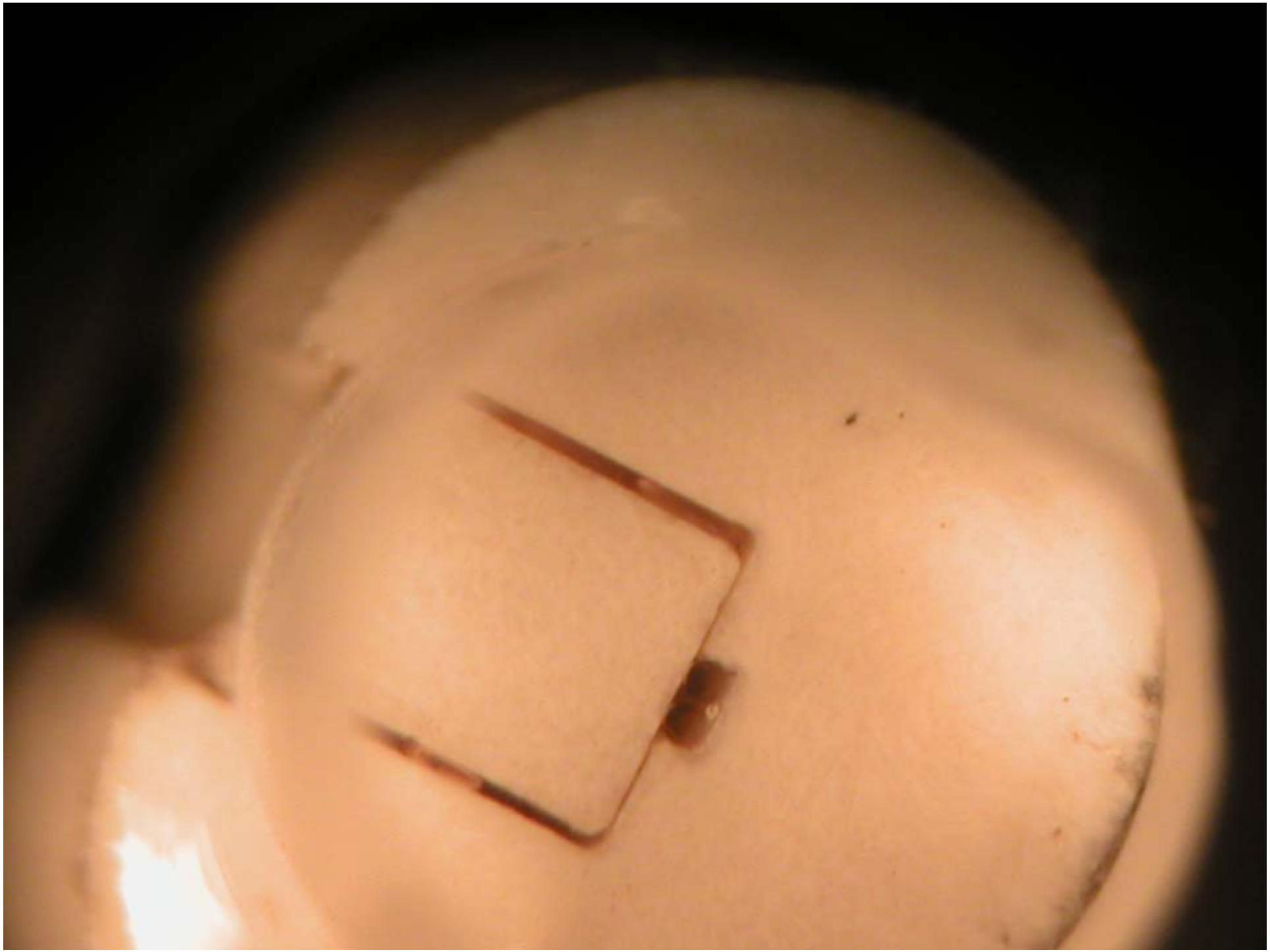


- This result is using a ‘perfect’ GLI equivalent
- Real installed interferometers are designed to be better than 1μm

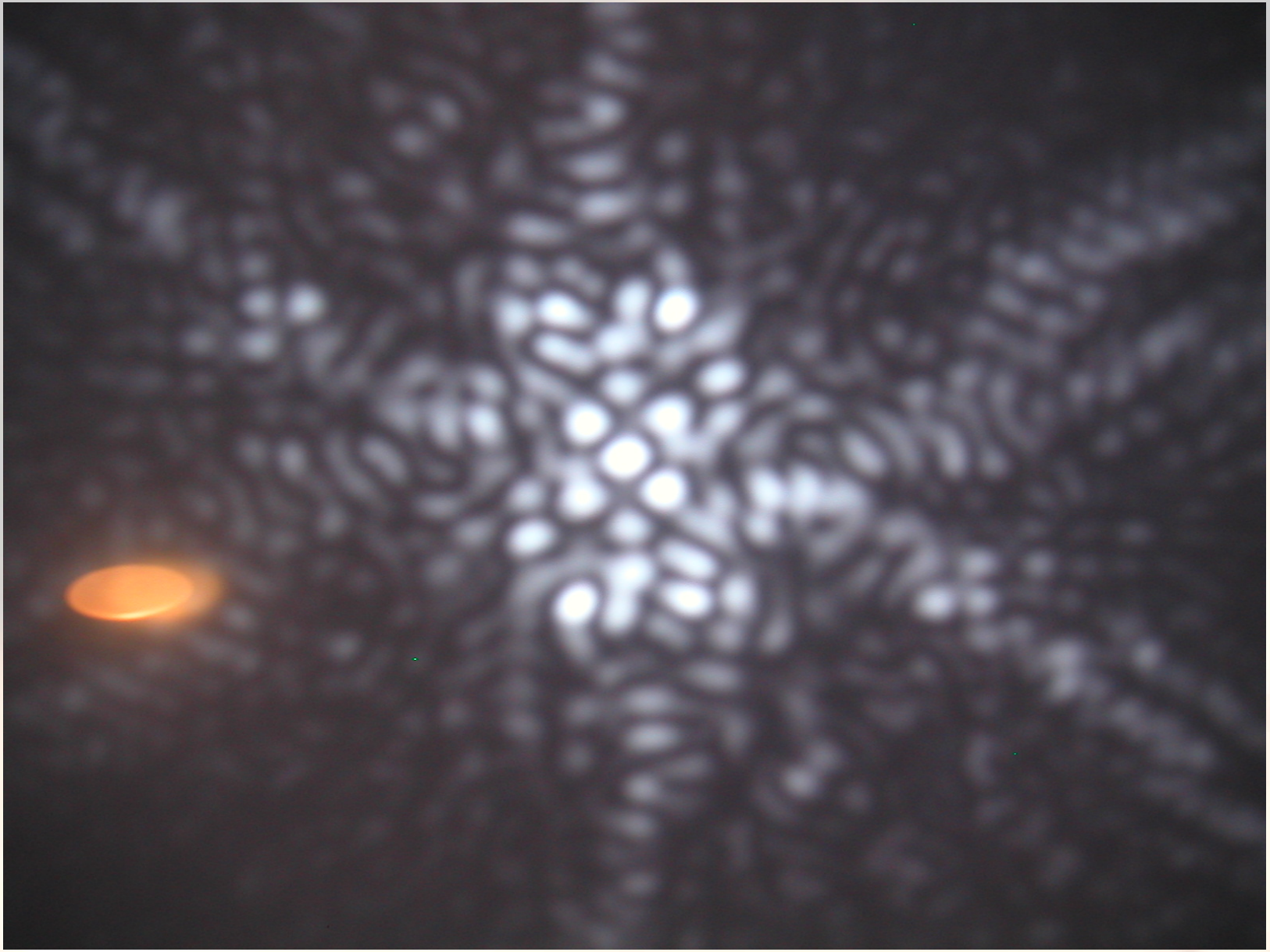


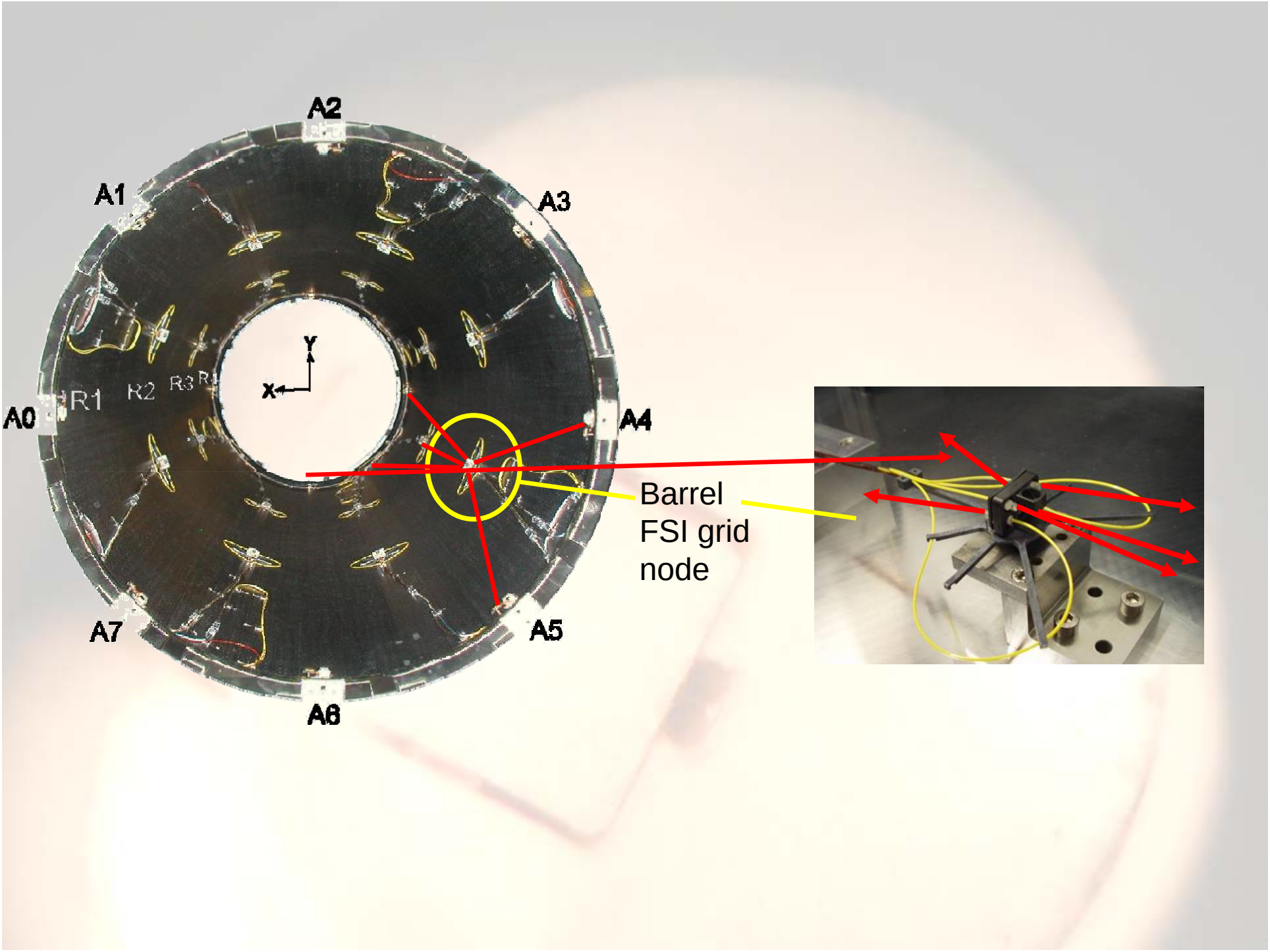
Design Requirements

- Minimal mass components
- Radiation hard components
- No maintenance for 10 yrs
- Remotely Measure 1 m to < 1 ppm
- 800 GLIs Simultaneously Measured

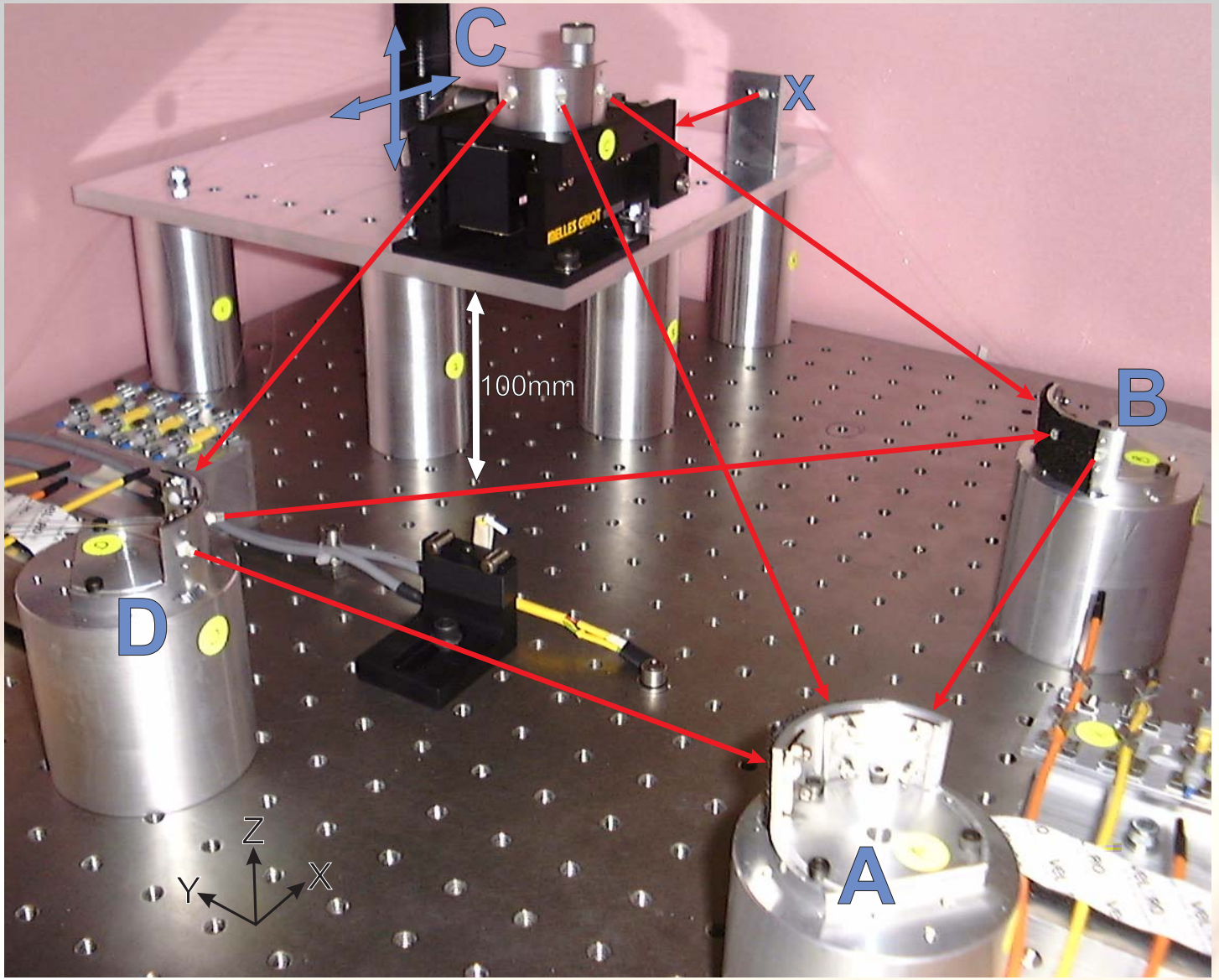



NC 346
NC 346
NC 346
12 MAY 2003
330pm
NC 146
16 MAY

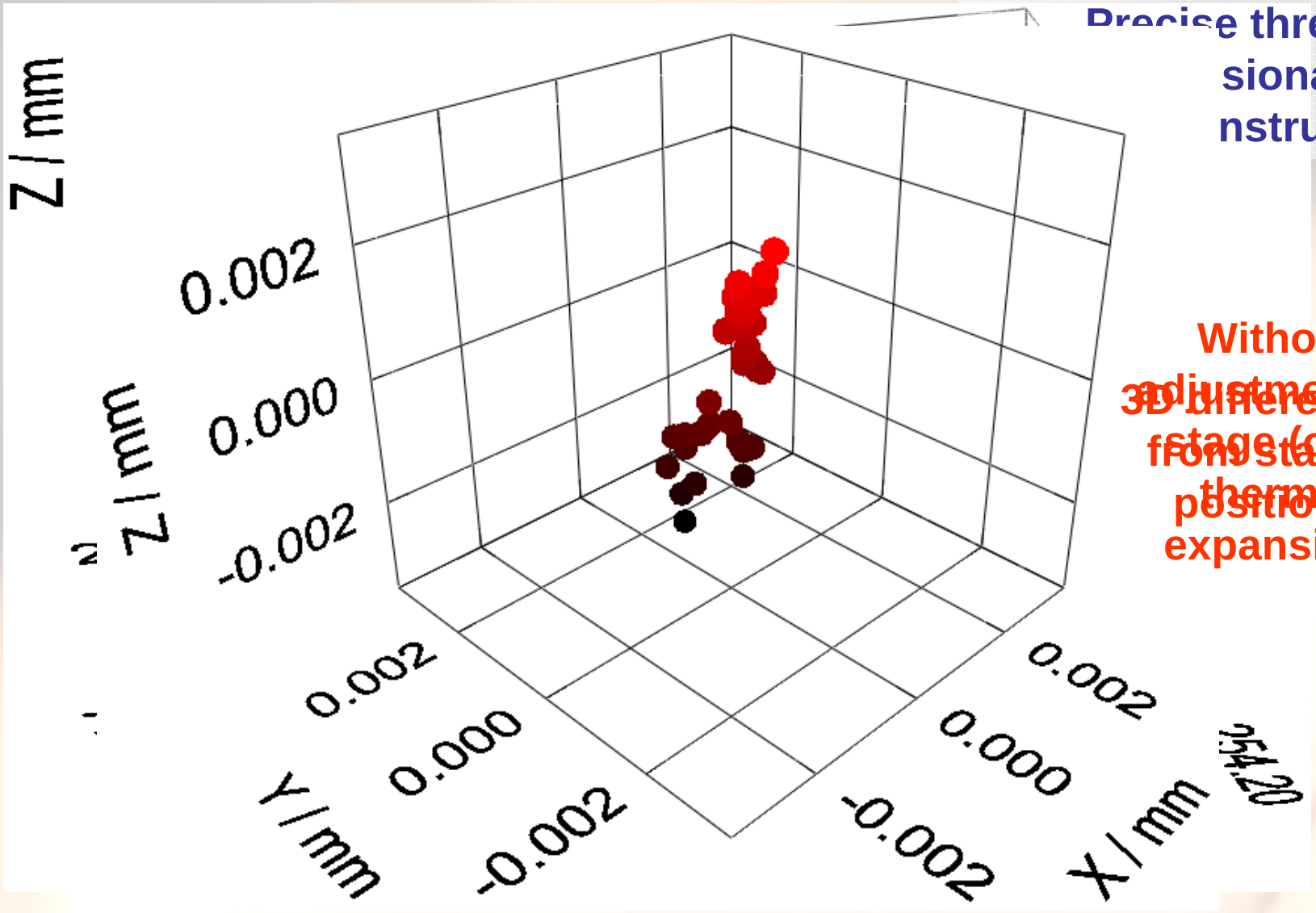



A2
A1
A3
A0
A4
A7
A5
A6
R1
R2
R3
R4
Y
X
Barrel
FSI grid
node

Prototype 3D FSI Geodetic Grid



Reconstructed 3D co-ordinate of node C follows pattern of stage movements

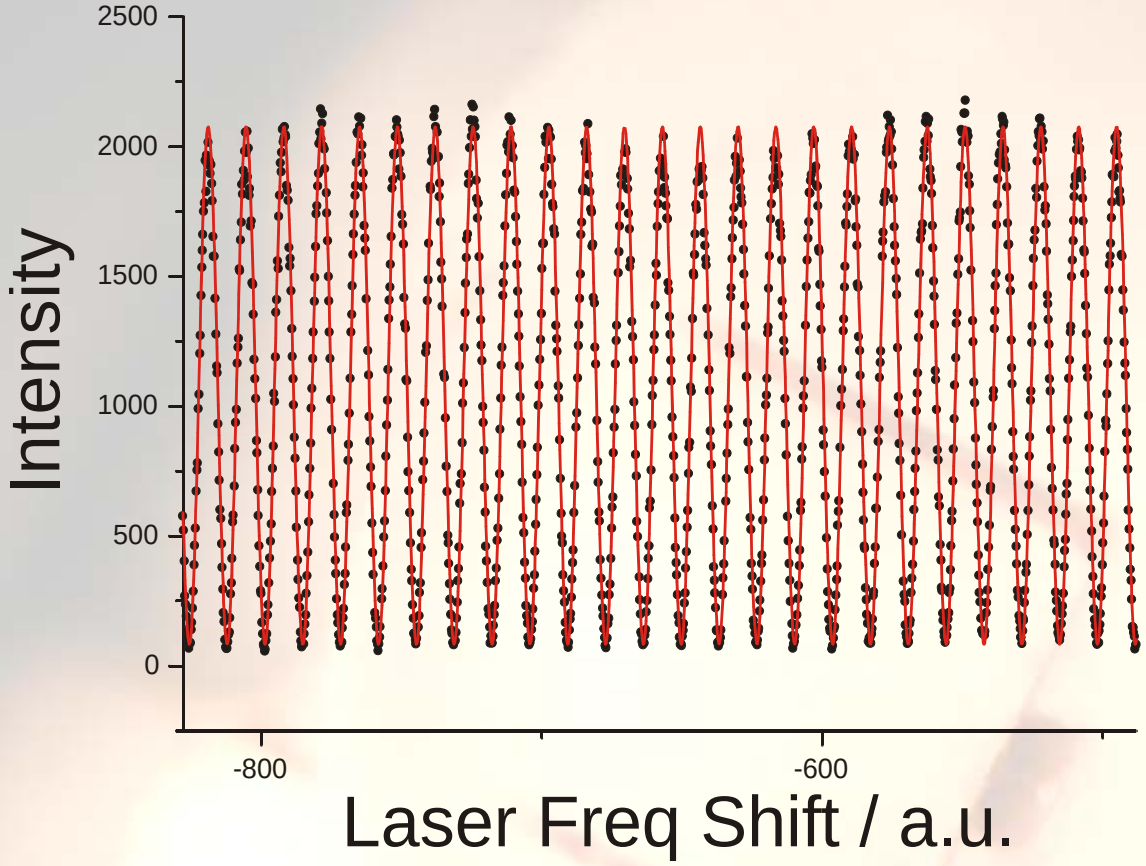


Precise three sional nstruction

3D difference from stage position

Without adjustment of stage (only thermal expansion)

Some data from an ‘as-installed’ GLI

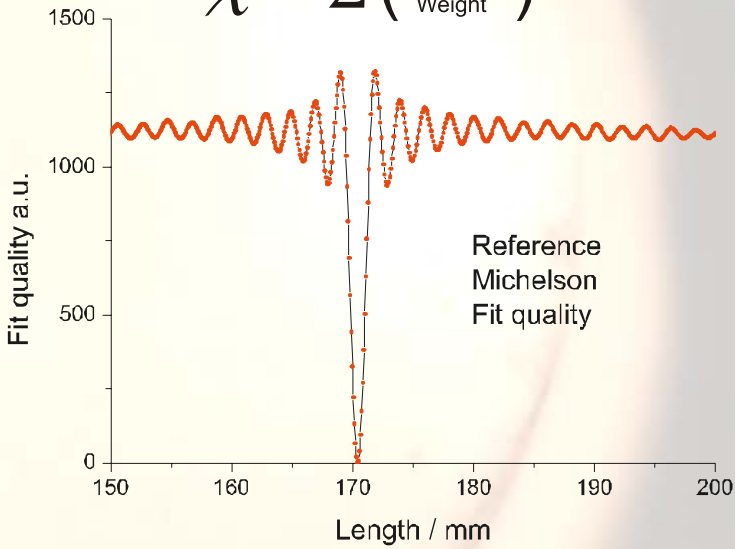


4 PARAMETER FIT FUNCTION

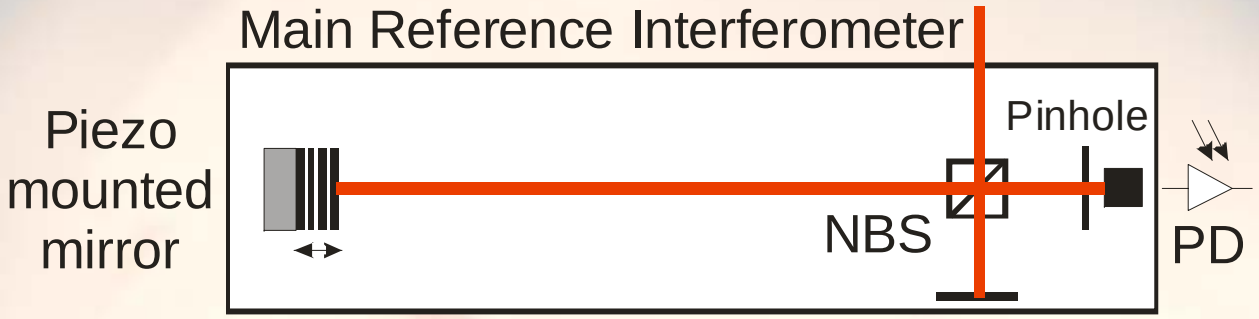
$$Y_{FIT}=I_{DC}+I_{AC}\cos\left(\frac{\Phi_i}{q}+\alpha\right)$$

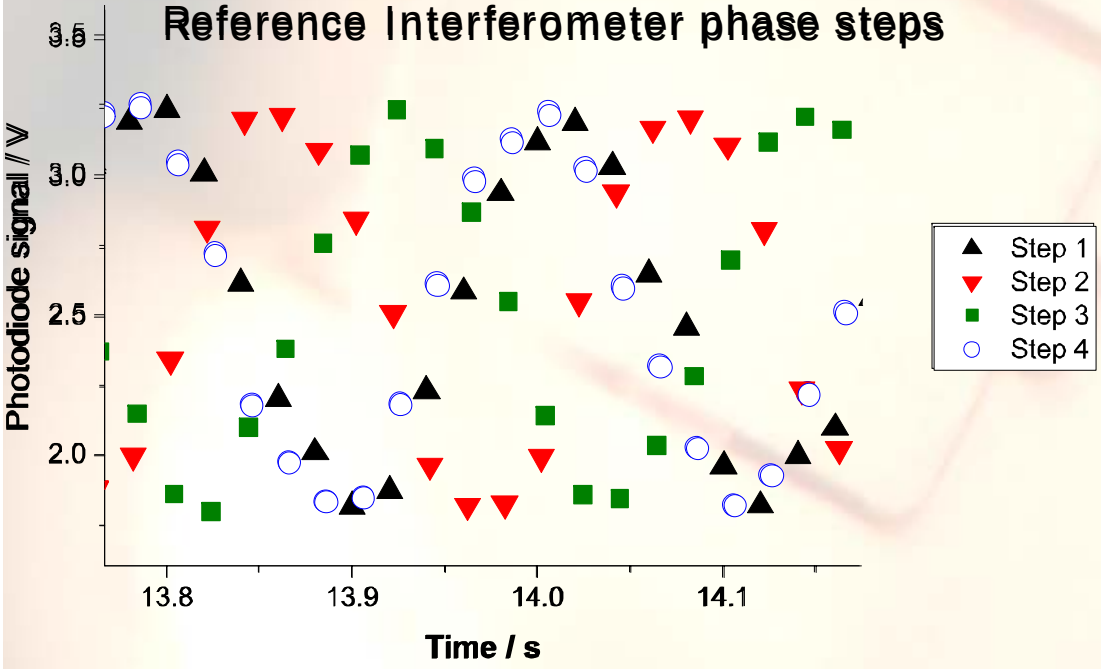
Search for minima using MINUIT

$$\chi^2=\Sigma\left(\frac{\text{Fit - Data}}{\text{Weight}}\right)^2$$



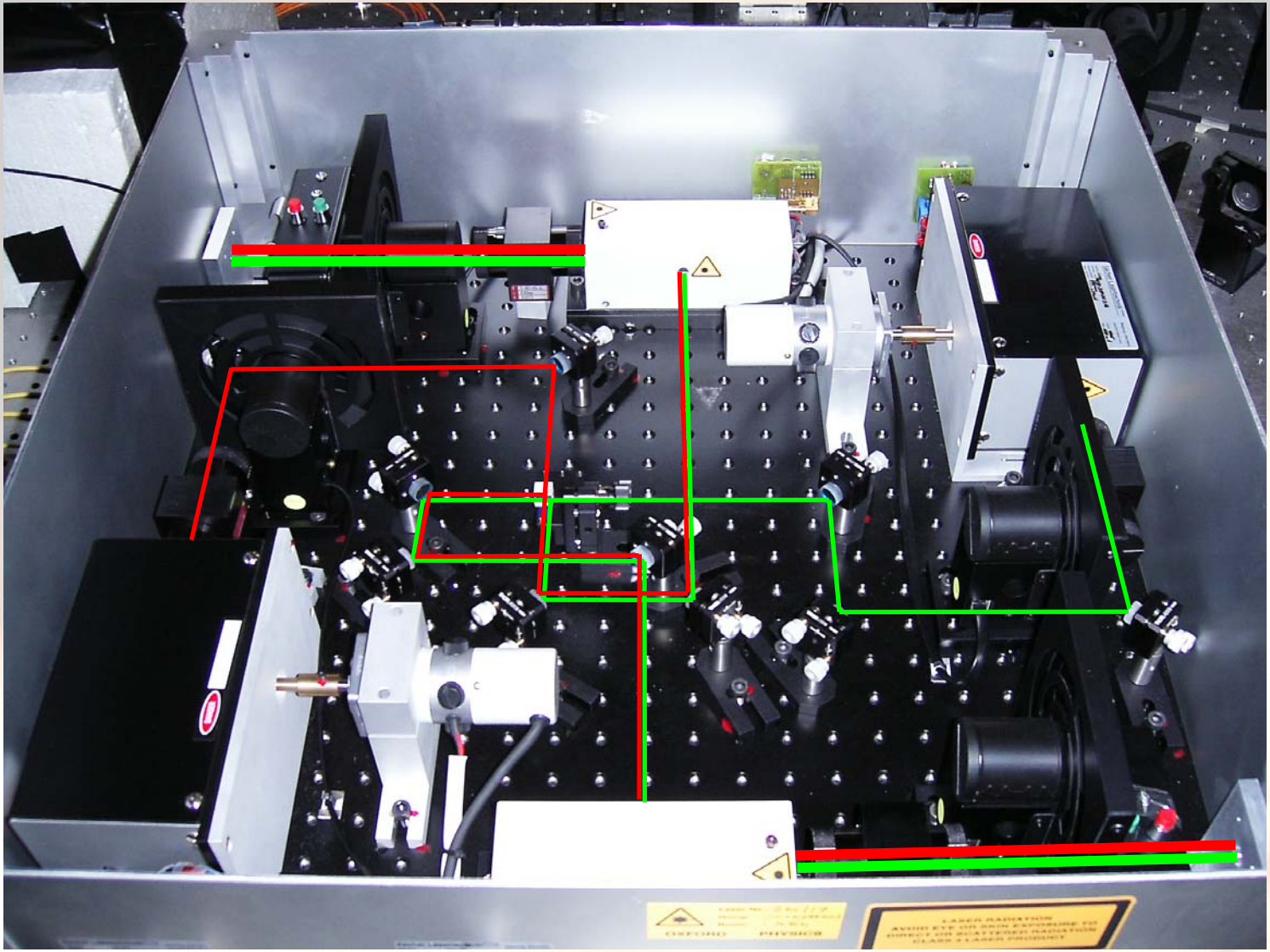
Laser frequency tuning is not linear with time so frequency is monitored during fine tuning using phase stepping in the reference interferometer:

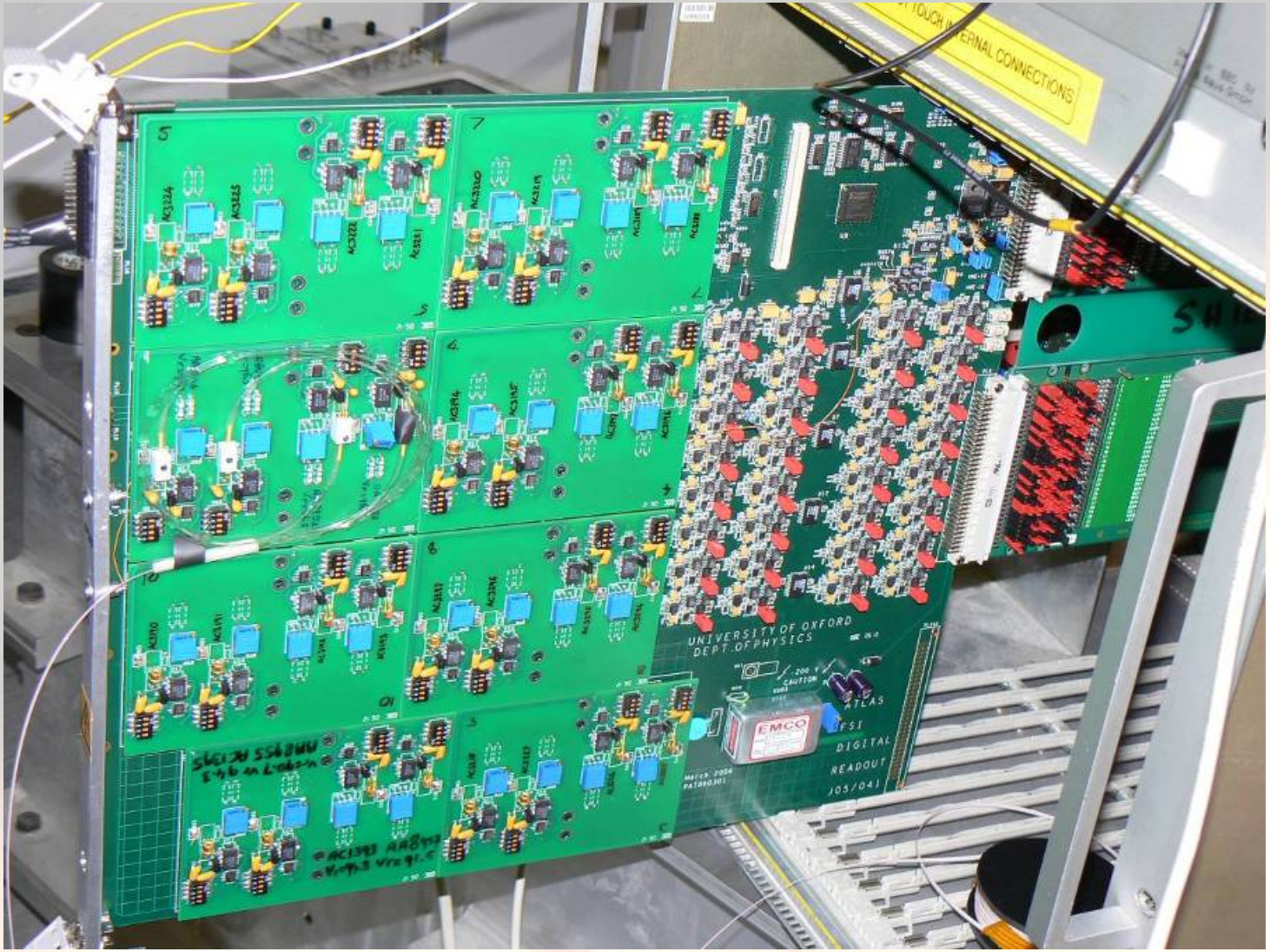




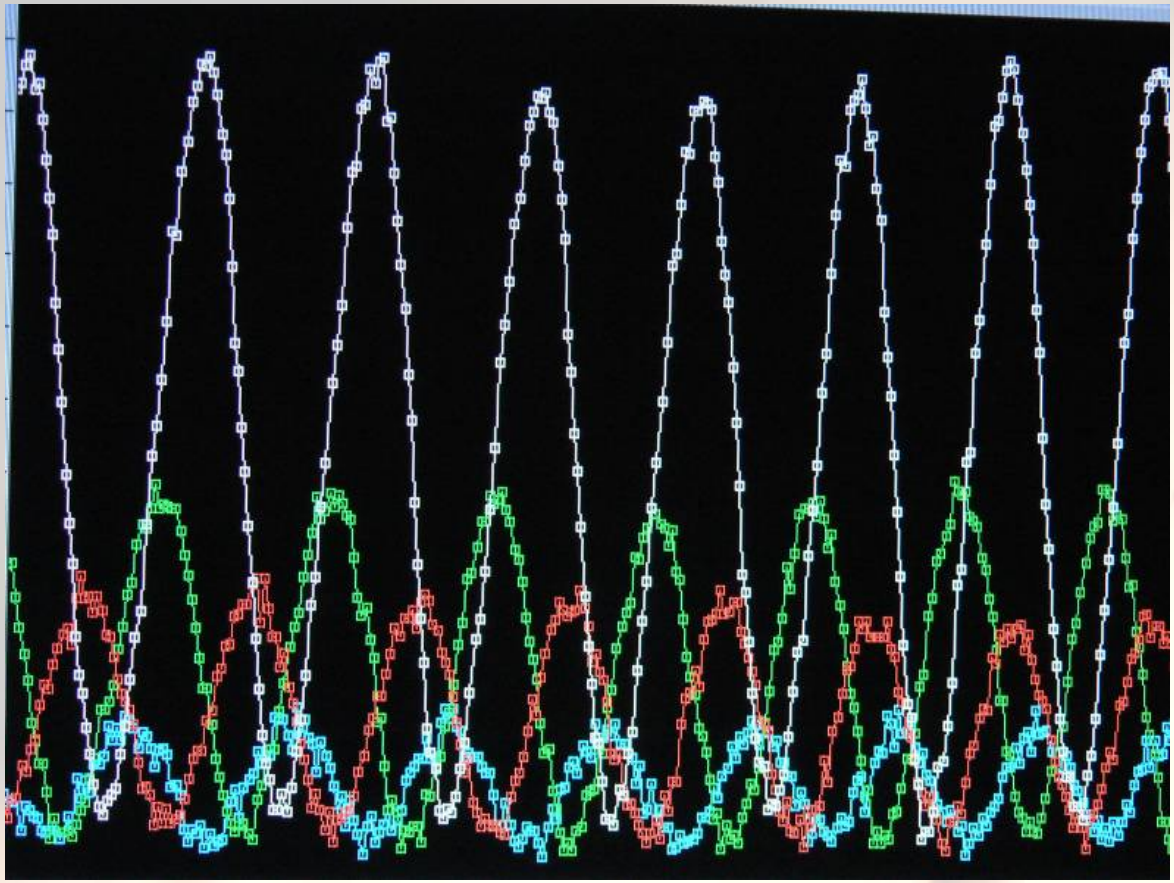
In addition, to tune without mode-hops it is necessary to tune crystal temperature at the same time as the cavity is altered, and this is coarse tune dependent

Original design called for 2 x Ti Sapphire lasers with 60kW of pump laser





APDs, Amplifiers, 16bit ADC, 1ms time slicing, 256Mbyte store
VME read-out, 64 fibres in per board – 8 x 8 way ribbon



Dual laser ~pW interferences fringes from two interferometers were read out simultaneously by one APD as the optical frequency, ν, was scanned (in this plot $\Delta\nu$ ~ 8GHz).

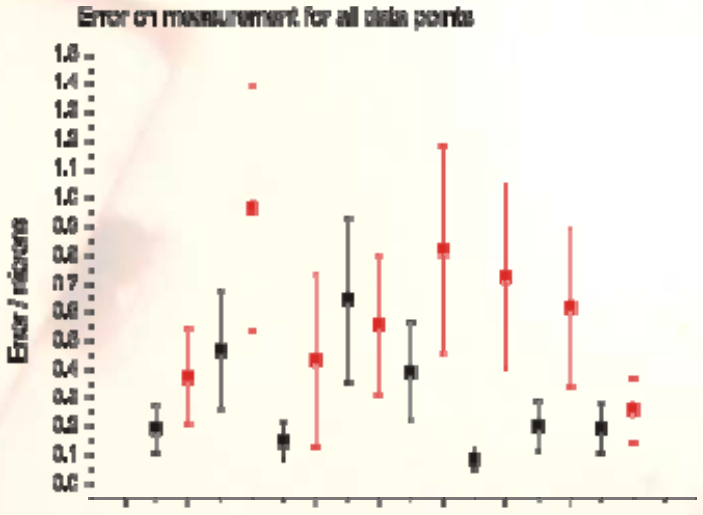
- Overall, the spatial nodes should be measured to better than 5µm in 3-D space.

- Time per complete set measurements - ~ 1 minute – few minutes

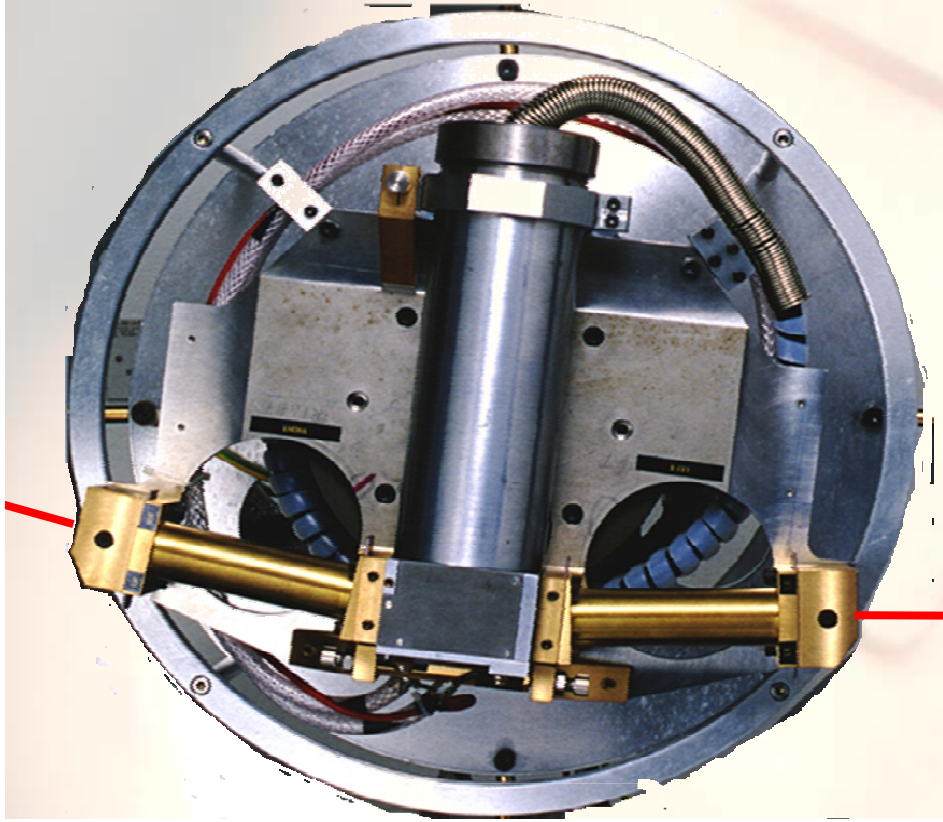
- System also measures vibrations up to few 100Hz

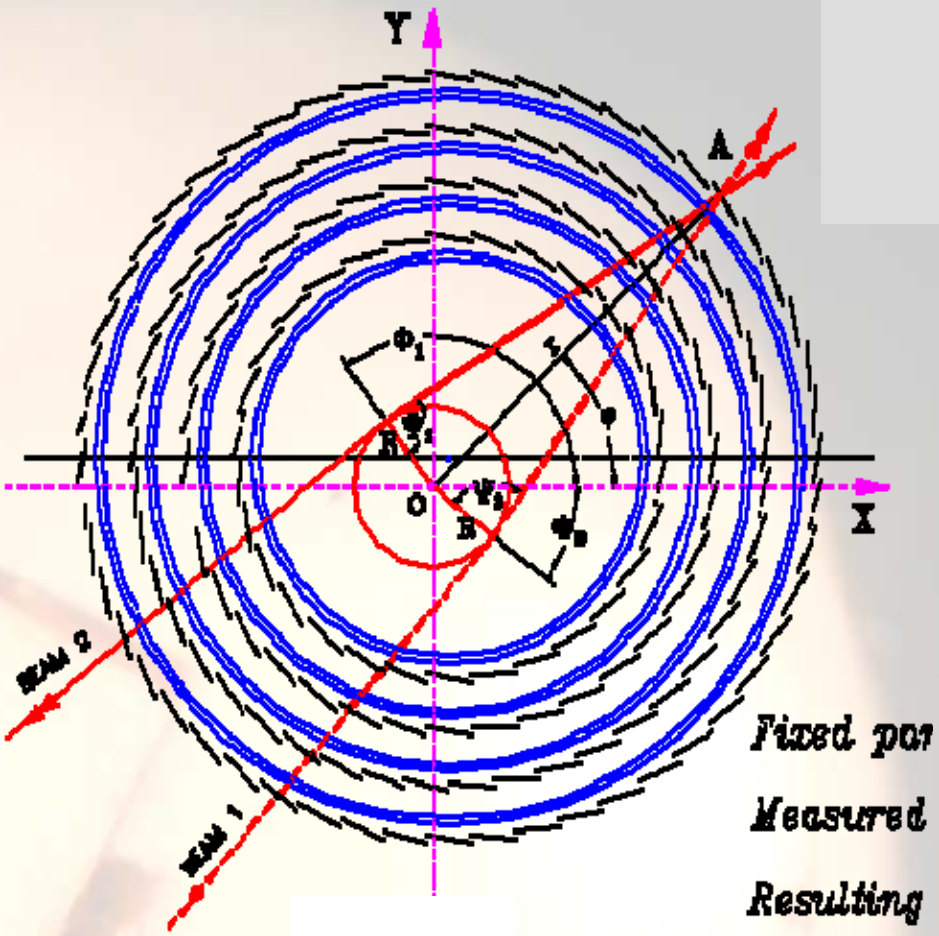
- And can be configured to work as a set of Michelsons

Comparison of with and without the MEMMS switch

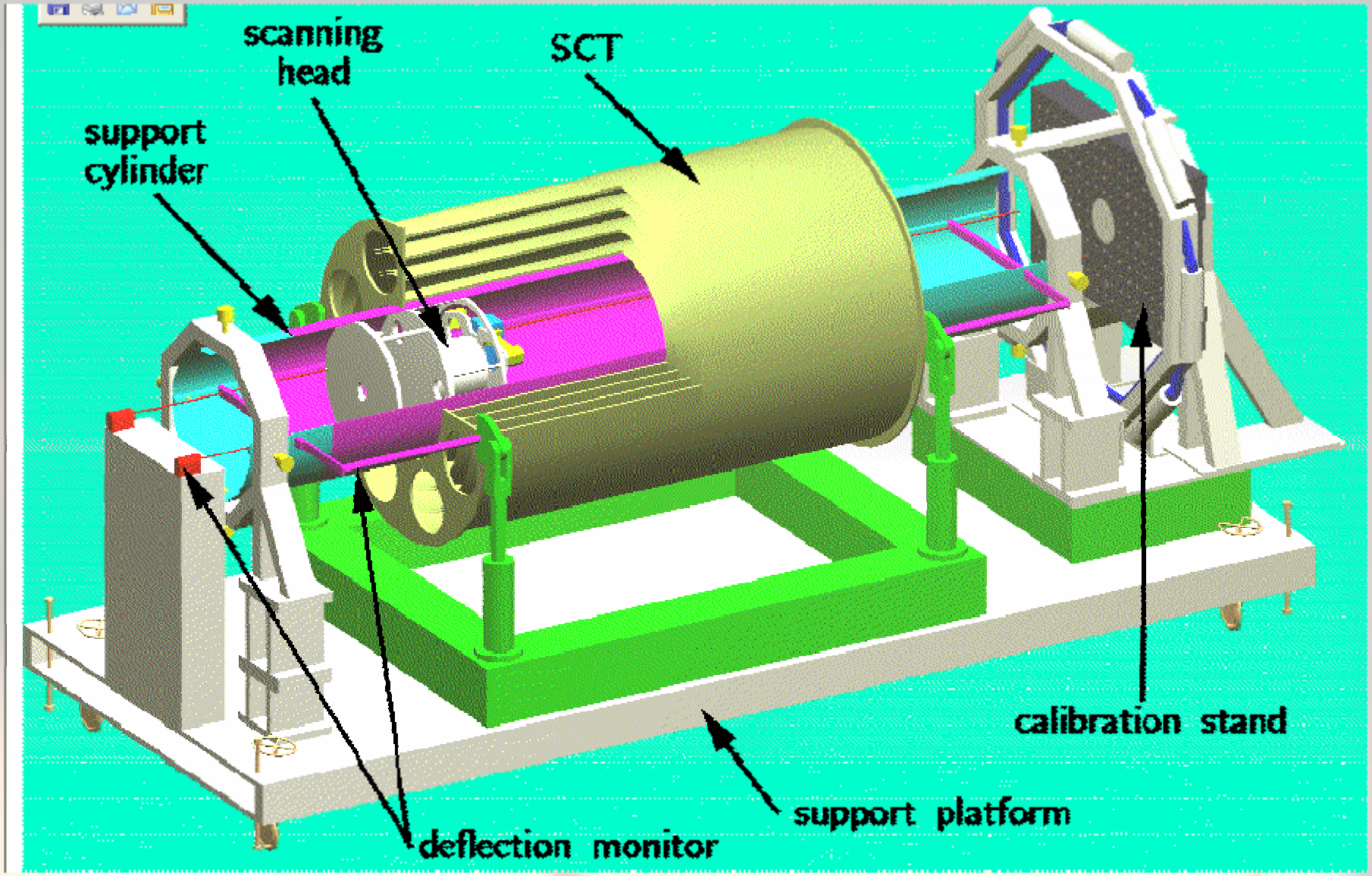


X-ray Survey





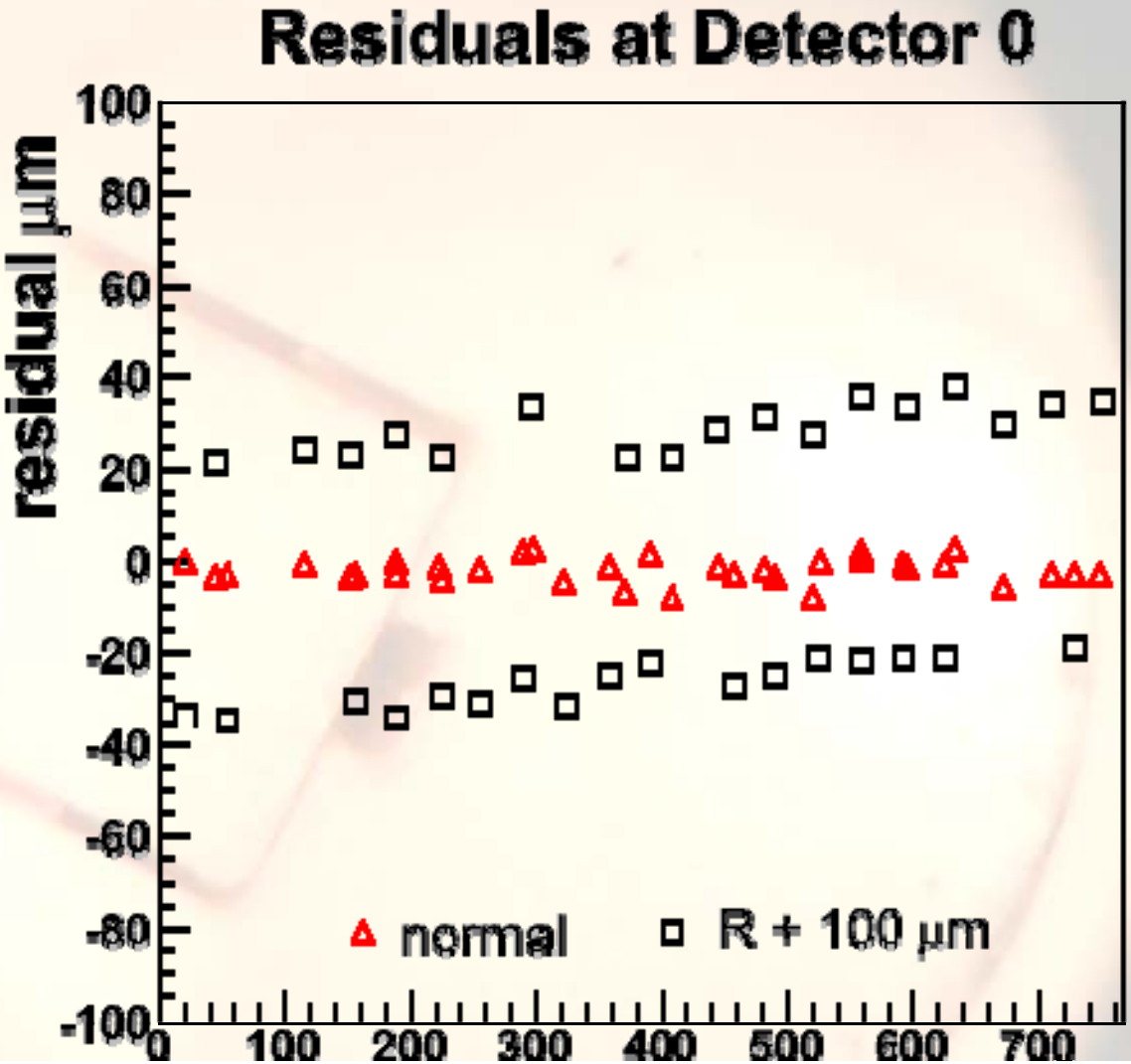
Wide Beam
Narrow Beam


scanning
head
SCT
support
cylinder
calibration stand
support platform
deflection monitor

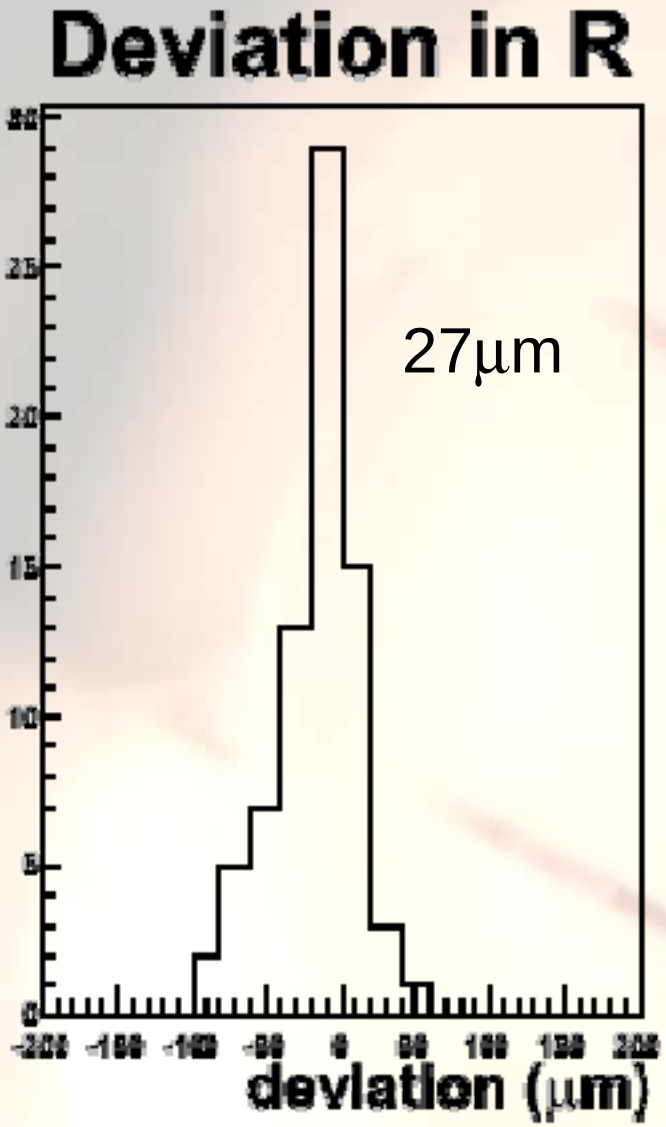
Self-calibrating using fixed strip separation to extract x-ray system parameters.

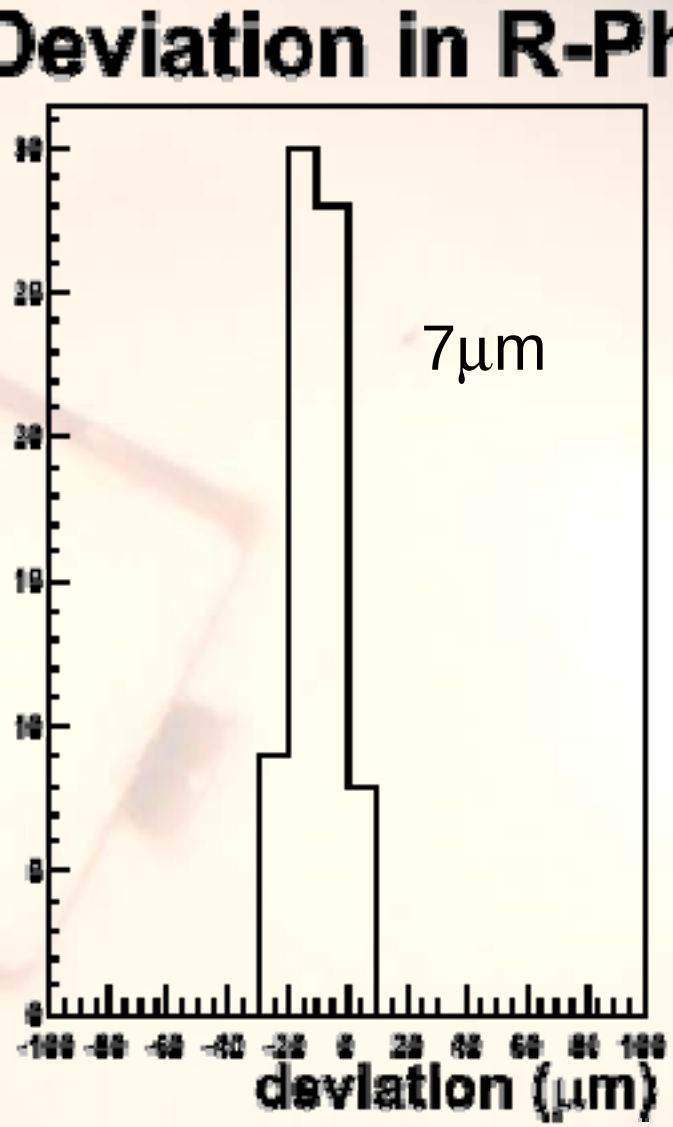
Plot shows residuals for x-ray hit position – best fit position
And impact of artificially introducing a 100μm error in the R determination

Within one data set
1μm in r-phi
Few μm in R



Including ‘long term’ systematic effects





Summary

- SCT Real-time Alignment System Installed on ATLAS SCT detector.
- FSI seems to be a practical, if challenging,
  method to make absolute distance measurements
- Low mass, rad-hard, miniature interferometers providing
  1-D measurement to < 1μm at ~CHF1.5 k each demonstrated
- Recent developments in SS lasers make systems viable
- 'Self calibrating' X-ray survey appears to work, with
  resolutions considerably better than 10μm readily achievable.