KEK, Tsukuba, Japan.
15 February 2008.

First data from the ATLAS Inner Detector FSI Alignment System

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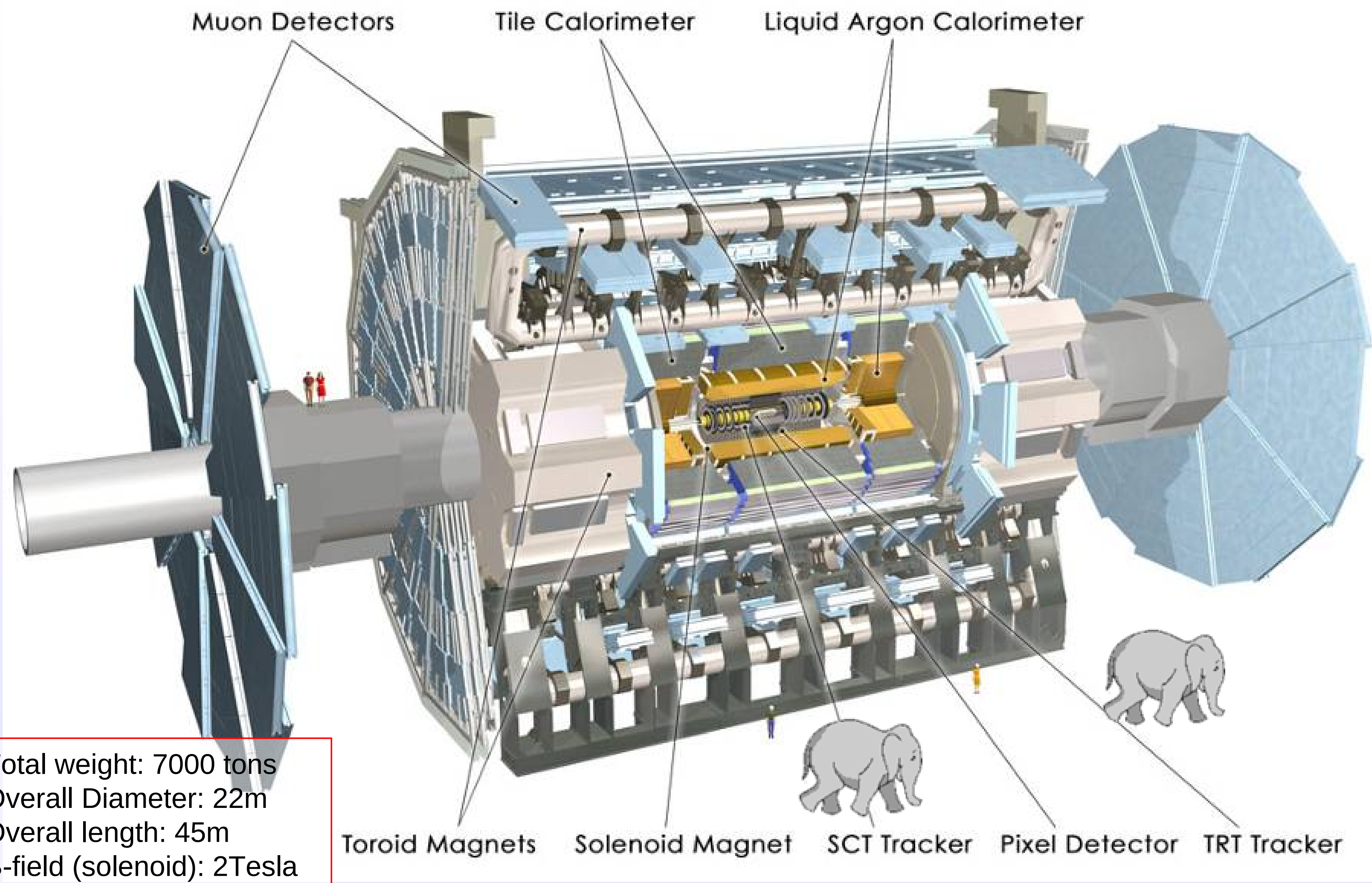
Overview

- Motivation
  - ATLAS ID alignment
- Frequency Scanning Interferometry
  - On-detector grids.
  - Reminder of technique
  - System Overview
- Improved performance
  - Evacuated reference chamber
  - Super-Invar interferometers
  - Vernier etalons.
- Light distribution and read-out
  - Fibre splitter tree (planar lightwave circuits)
  - Multi-channel read-out system
- Status and outlook

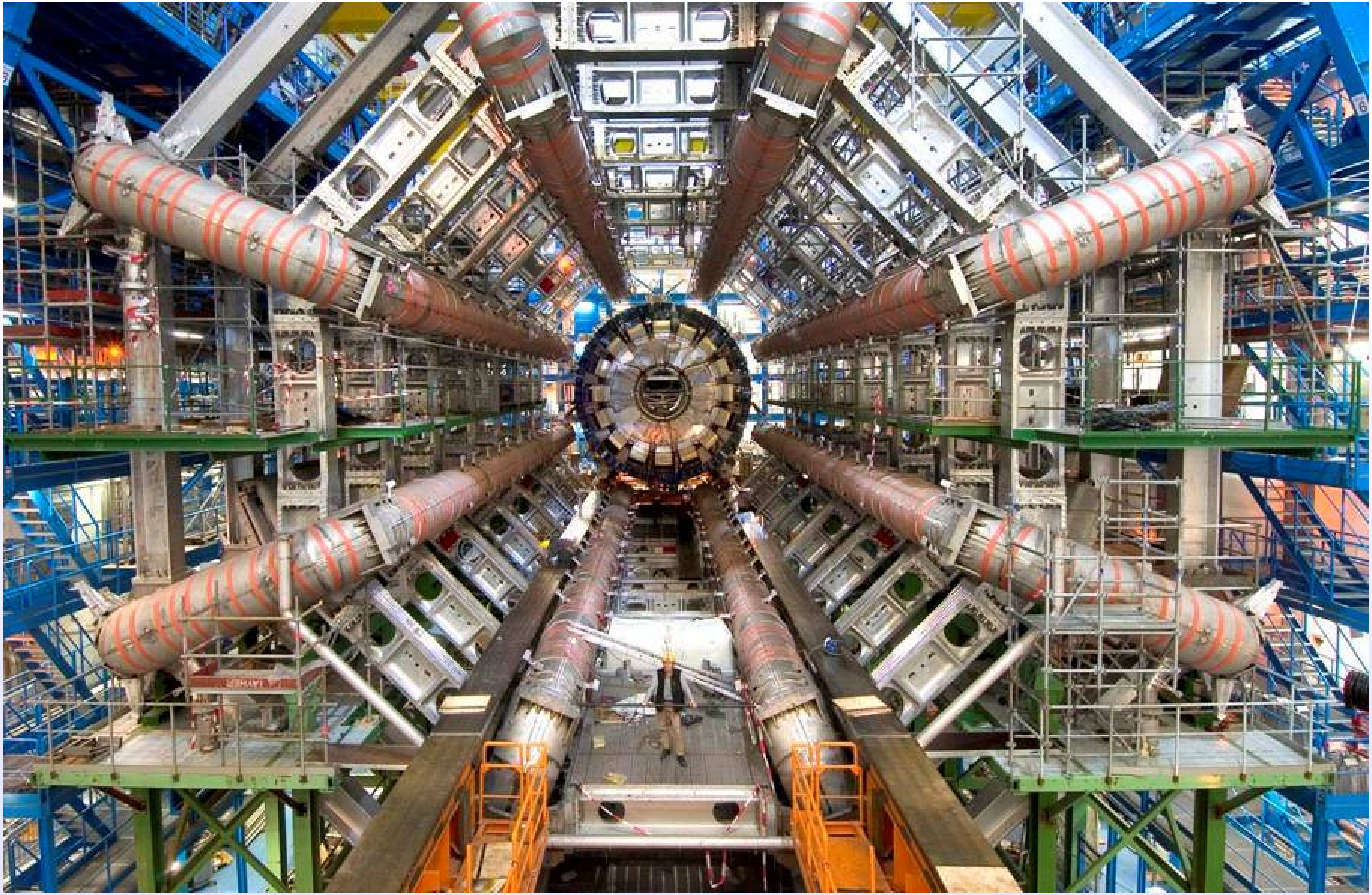
Motivation:
ATLAS Alignment Challenge

ATLAS at the Large Hadron Collider

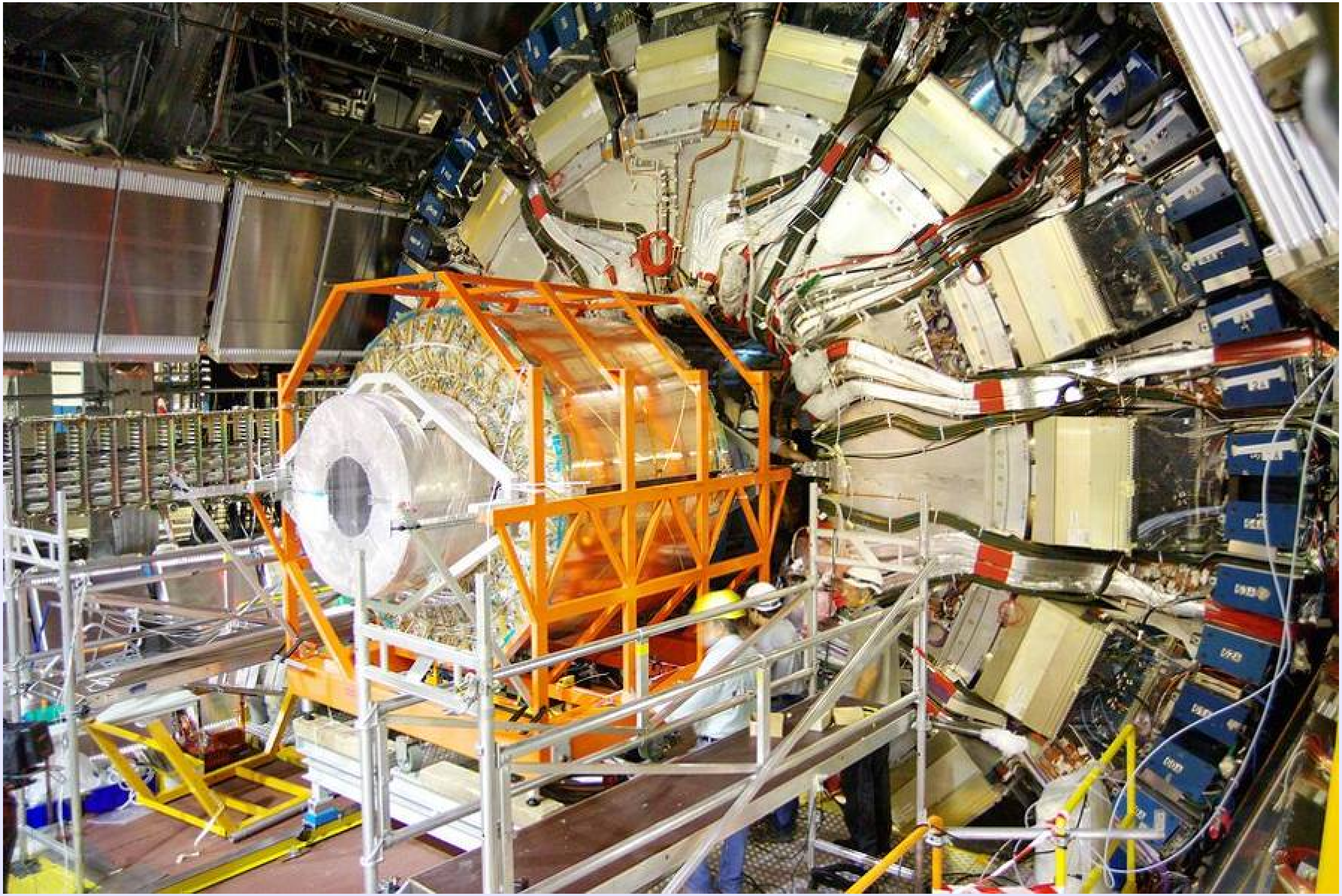


Total weight: 7000 tons
Overall Diameter: 22m
Overall length: 45m
B-field (solenoid): 2Tesla

Progress in the ATLAS cavern:



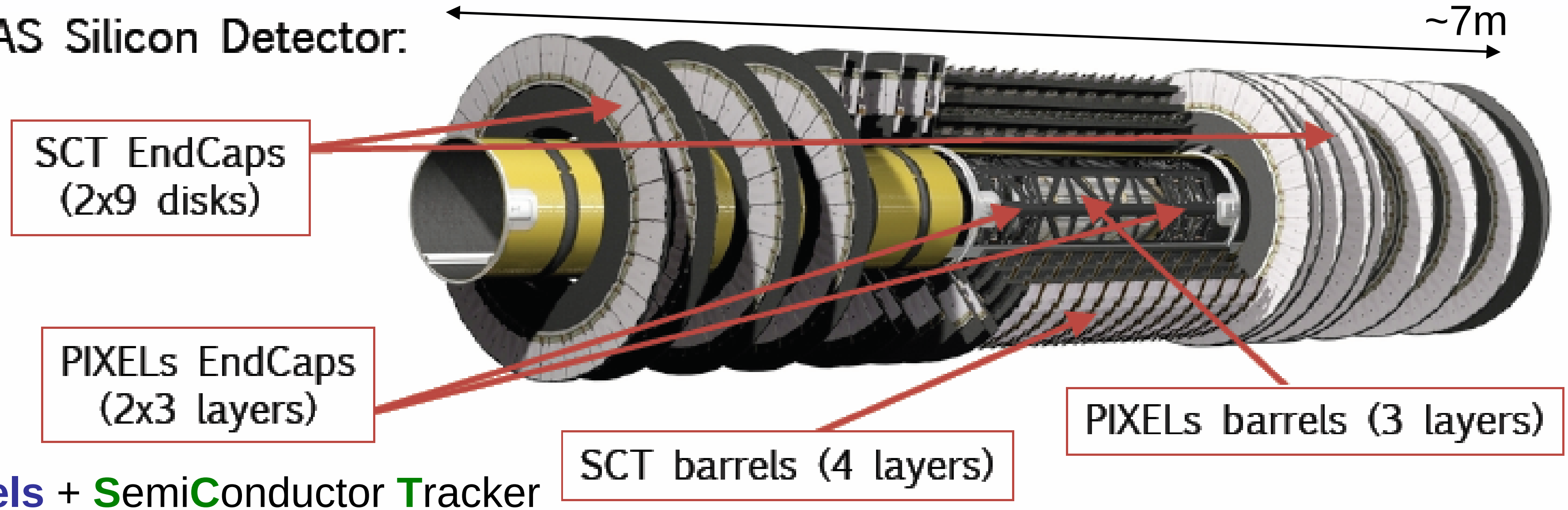
Inner detector installed at heart of ATLAS…



…and cabled for first LHC data!

ATLAS silicon alignment requirements:

ATLAS Silicon Detector:



Pixels + **S**emi**C**onductor **T**racker

Silicon based detectors with high granularity. (80M pixels + 6M strips)

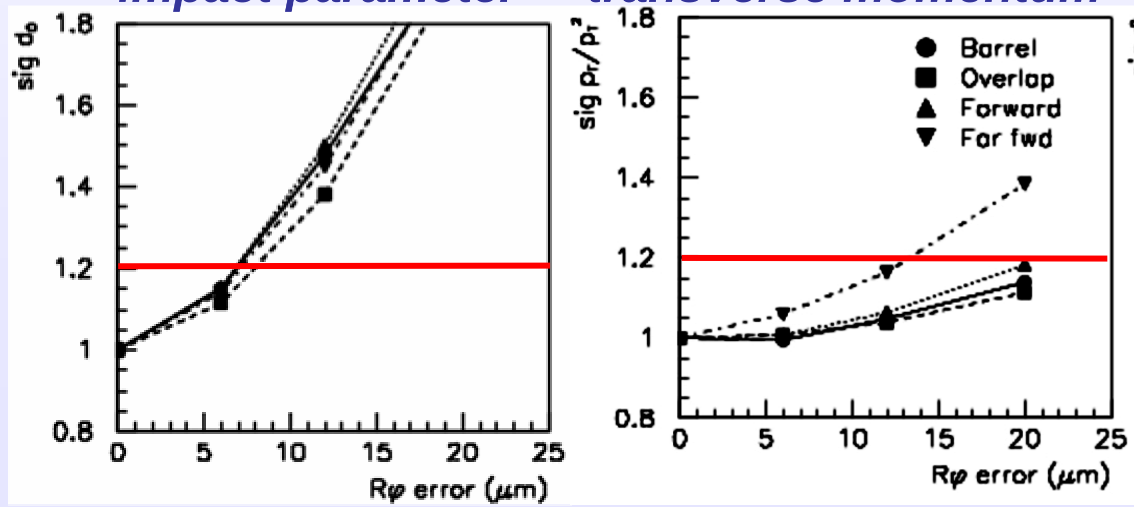
Require misalignment does not degrade track parameters by more than ~20%:

Pixels: $\sigma_{R\Phi}$ = 7 μm
SCT: $\sigma_{R\Phi}$ = 12 μm

(Need $\sigma_{R\Phi}$~1μm for W mass measurement!)

ATLAS TDR

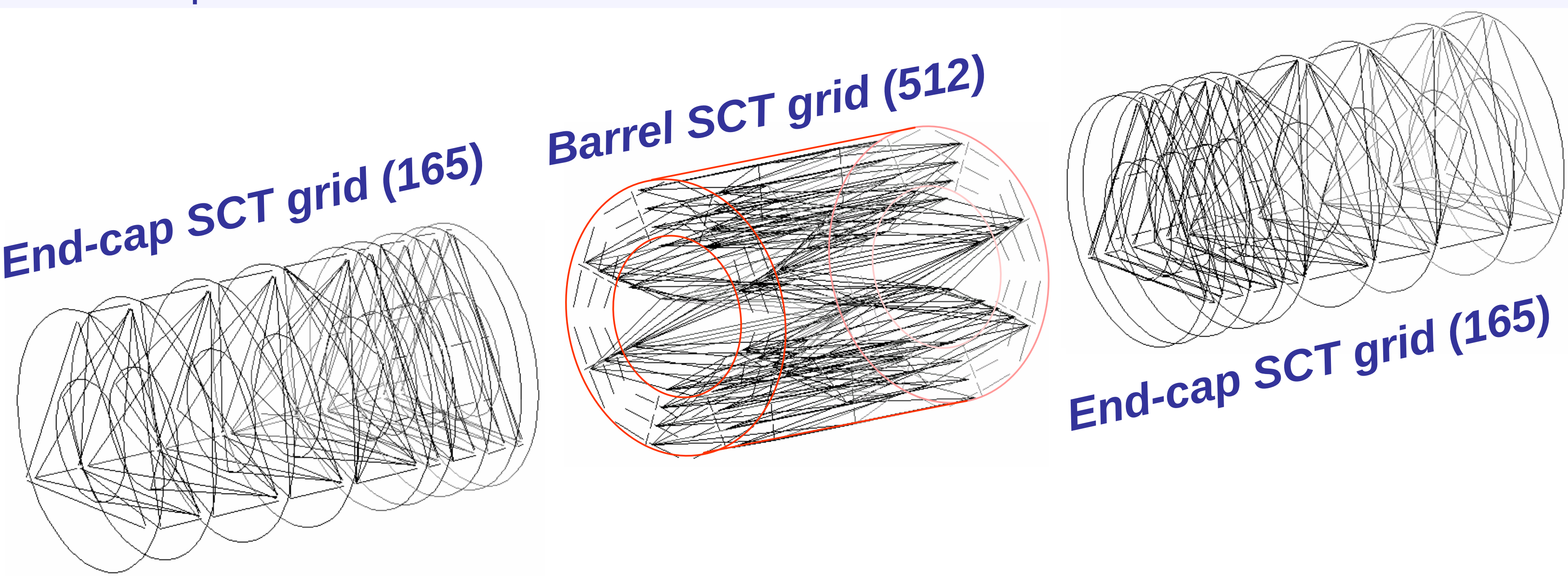
impact parameter ***transverse momentum***



Frequency Scanning Interferometry

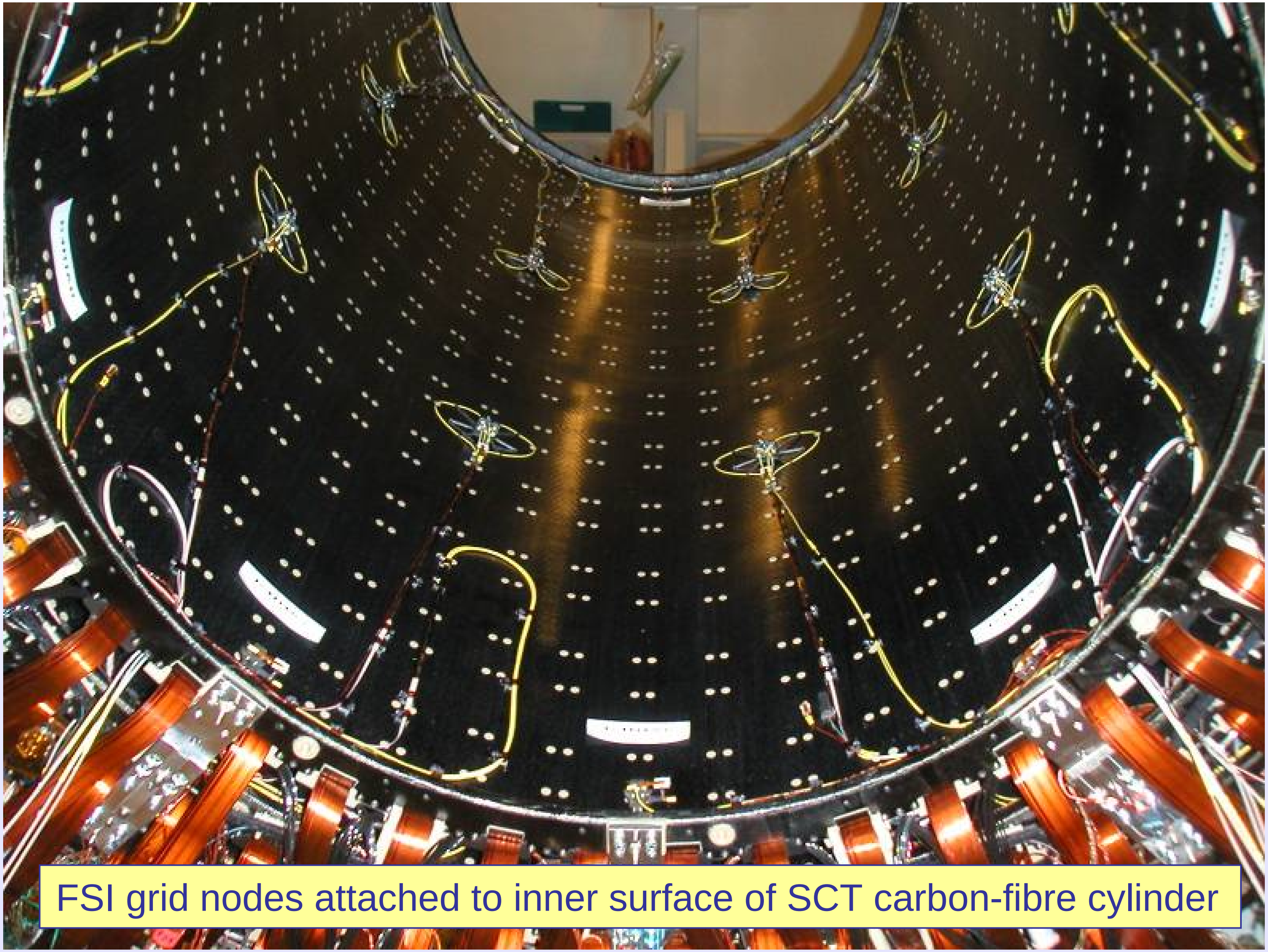
Frequency Scanning Interferometry

- Challenge
  - We need to monitor the 3D shape of an operational particle tracker at the micron level.
- Solution: Frequency Scanning Interferometry
  - A geodetic grid of length measurements between nodes attached to the SCT support structure.
  - All 842 grid line lengths are measured simultaneously using FSI to a precision of <1micron.



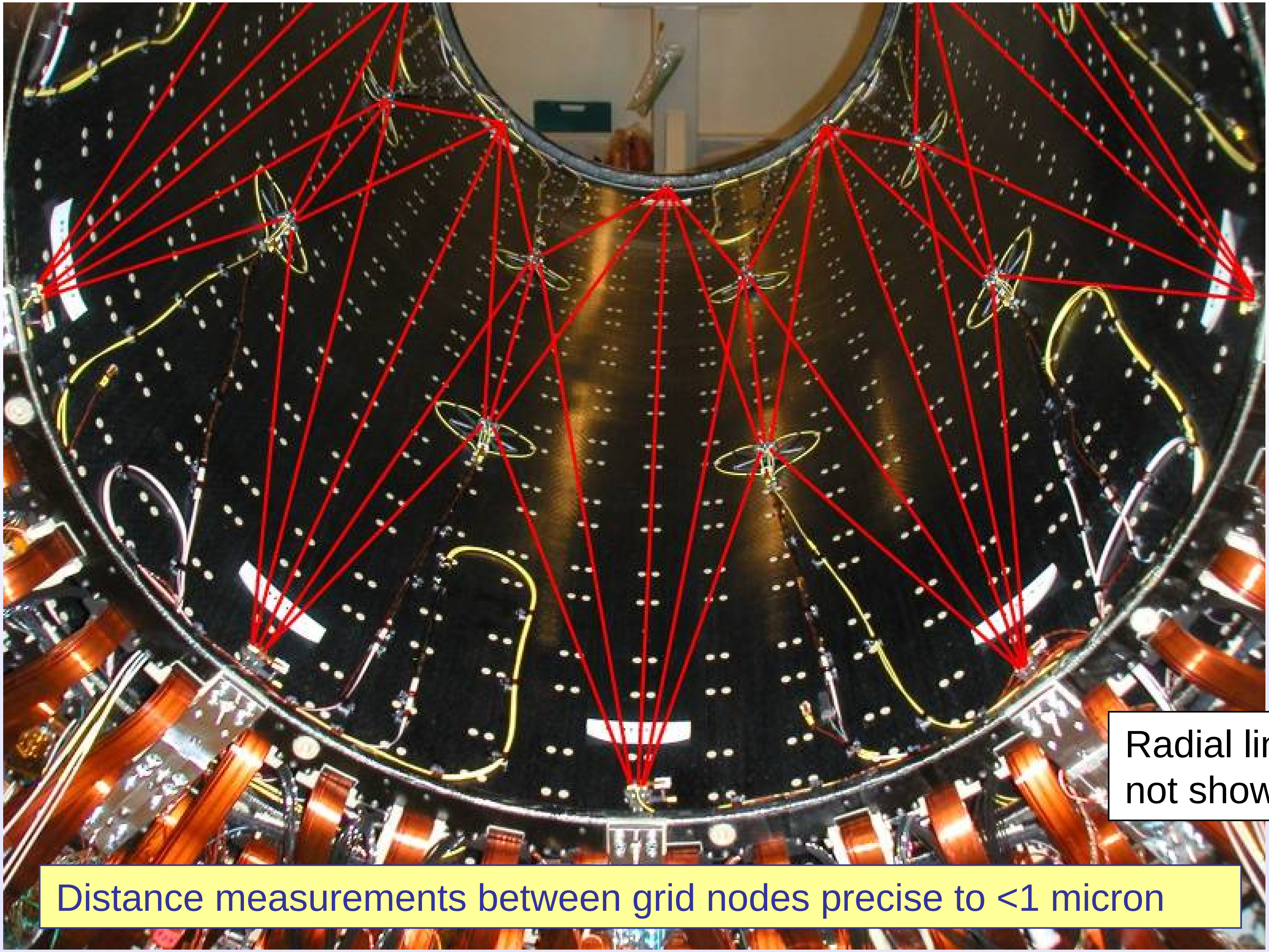
Semi Conductor Tracker Barrel

On-detector FSI System



FSI grid nodes attached to inner surface of SCT carbon-fibre cylinder

On-detector FSI System

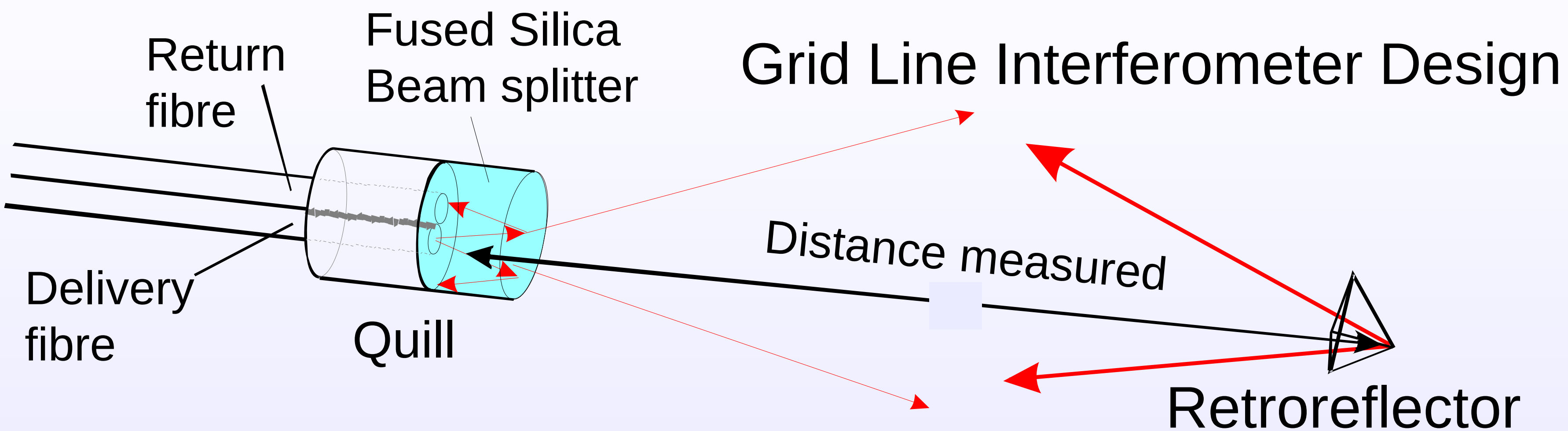


Radial lines not shown

Distance measurements between grid nodes precise to <1 micron

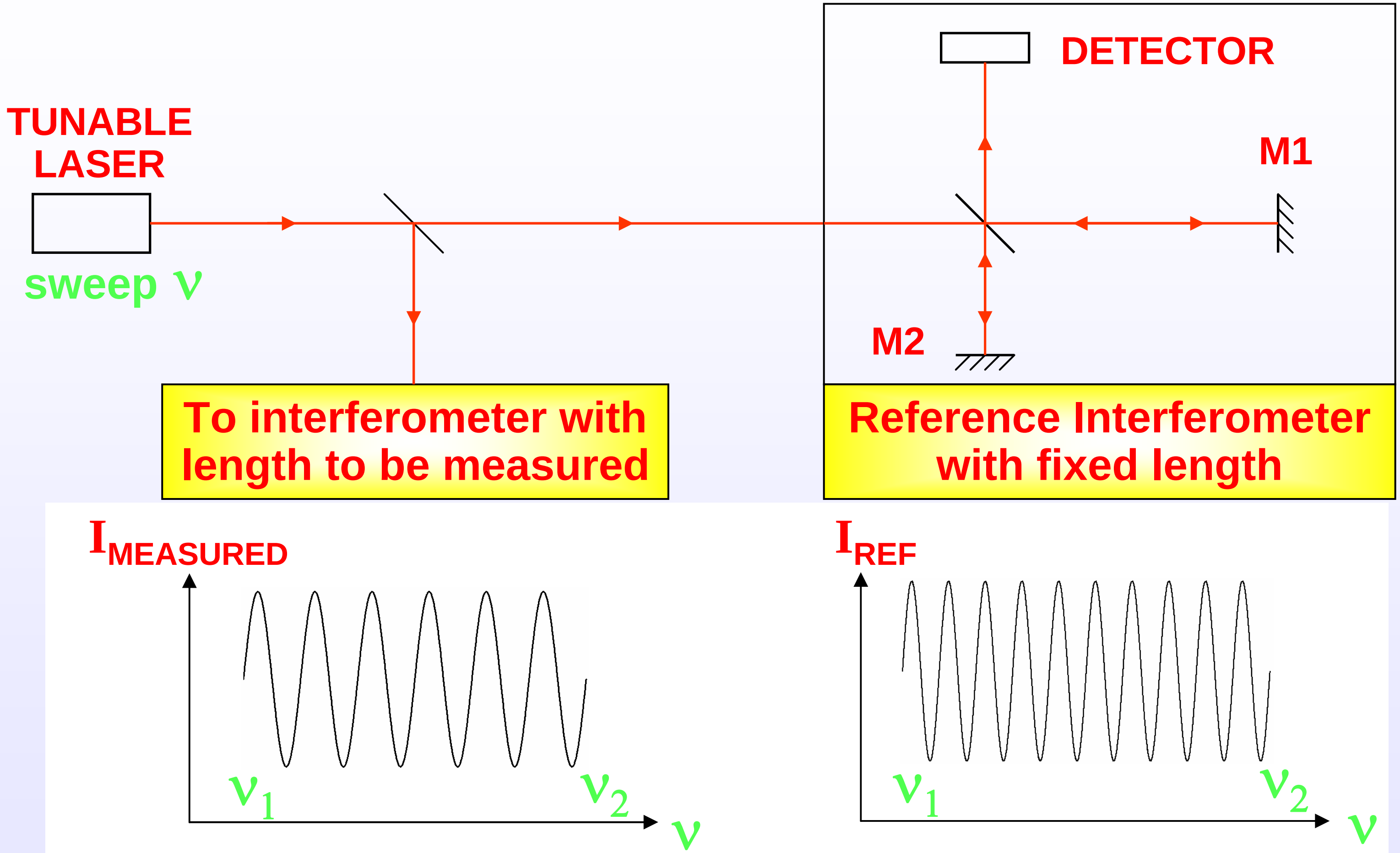
Benefits of FSI

- The FSI grid operates within the inaccessible, confined spaces and high radiation levels of ATLAS, where a conventional survey is not possible.



- The Grid Line Interferometers are measured remotely via optical fibres.
- A full grid measurement is repeated every ten minutes so that rapid shape changes can be monitored.
- FSI is sensitive to low spatial frequency modes of tracker distortion, which are under constrained with track based alignment methods
- Track alignment precision is improved by combining many different stable alignment periods, with FSI correcting for the interim shape changes.

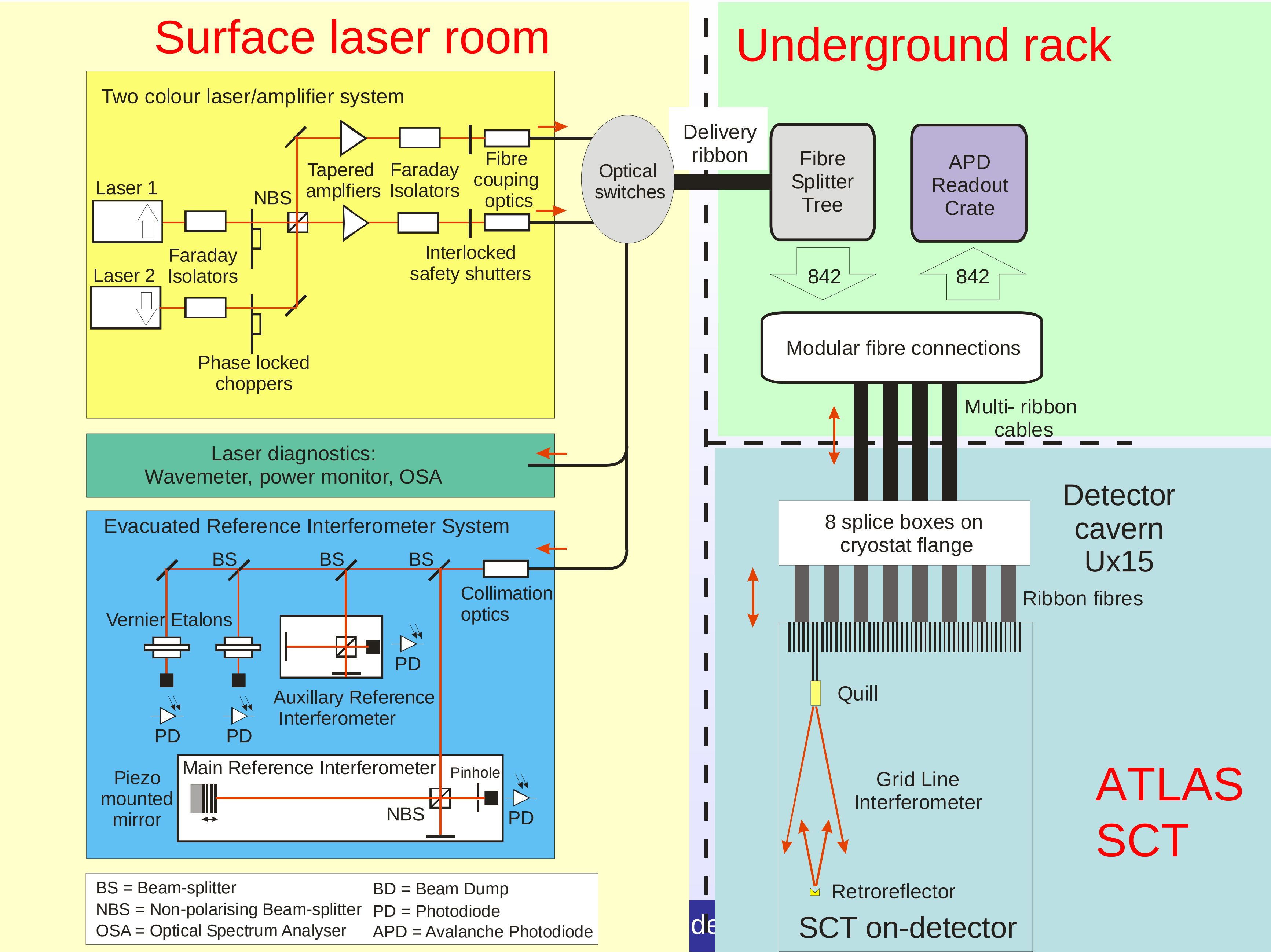
Principle of FSI



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

Ratio of phase change = Ratio of lengths

FSI System Overview

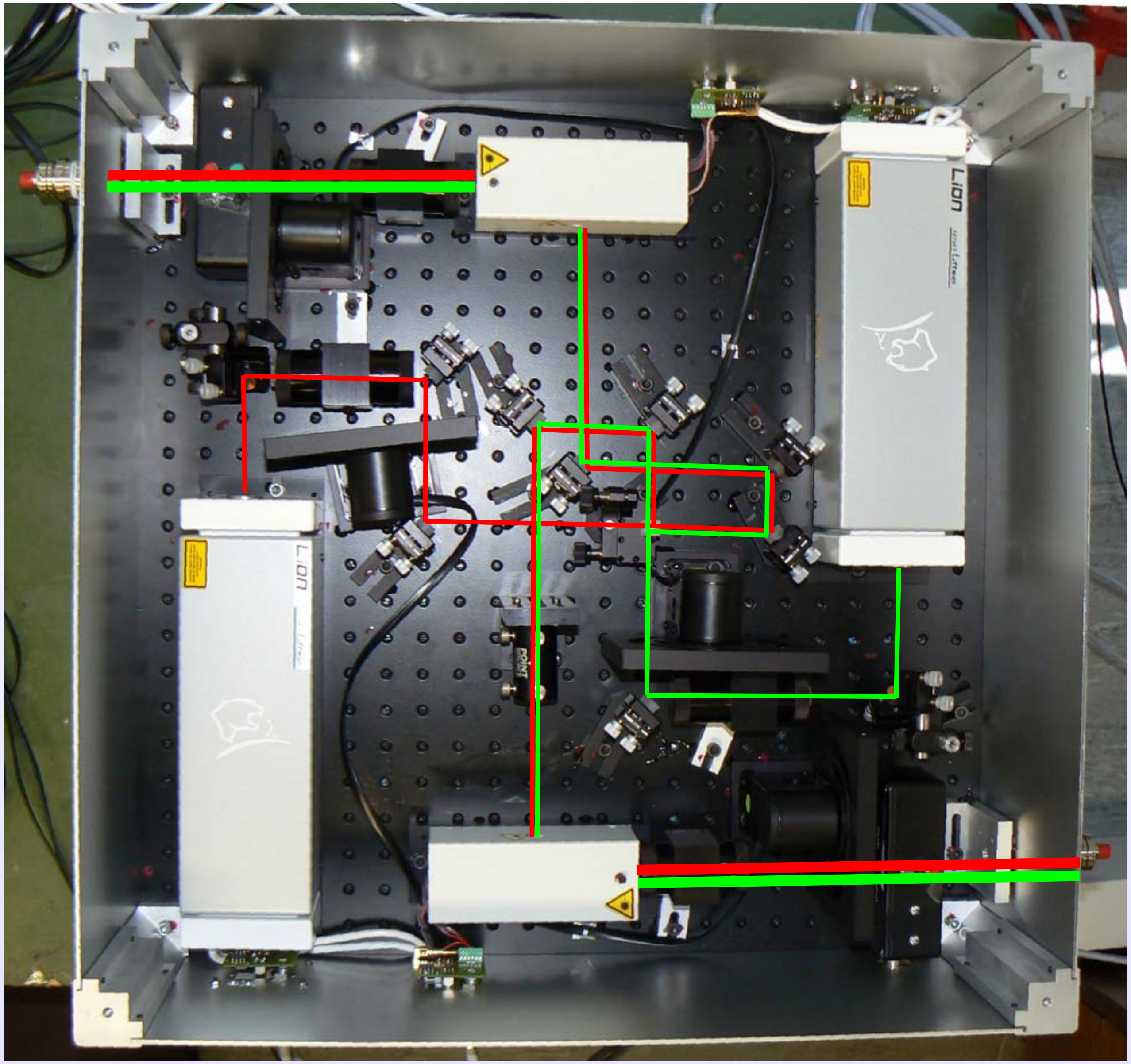


Improved performance:
Lasers &
Reference Inteferometry System

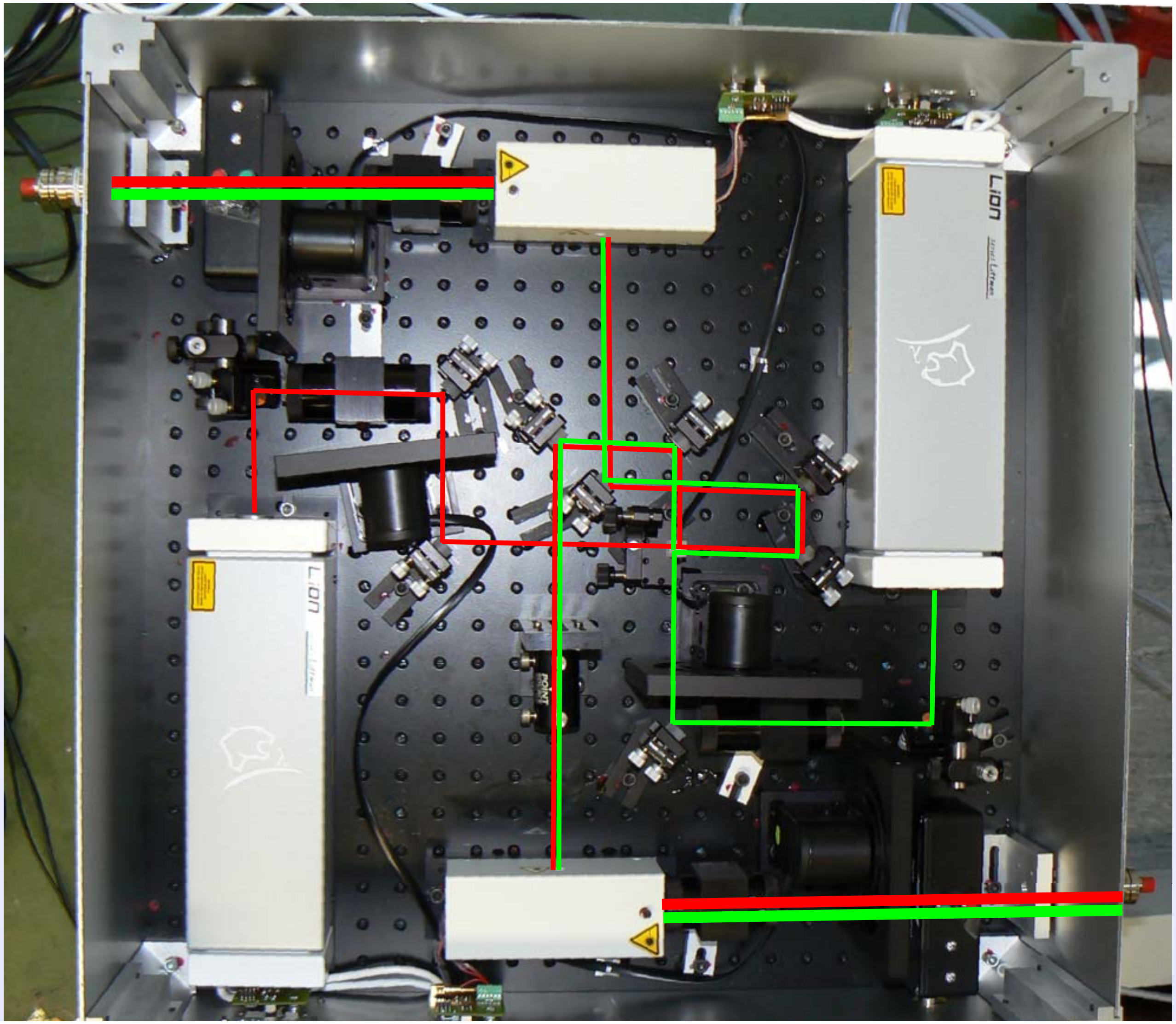
FSI laser room at CERN

Class 4 two colour laser/amplifier system

Two colour laser amplifier system

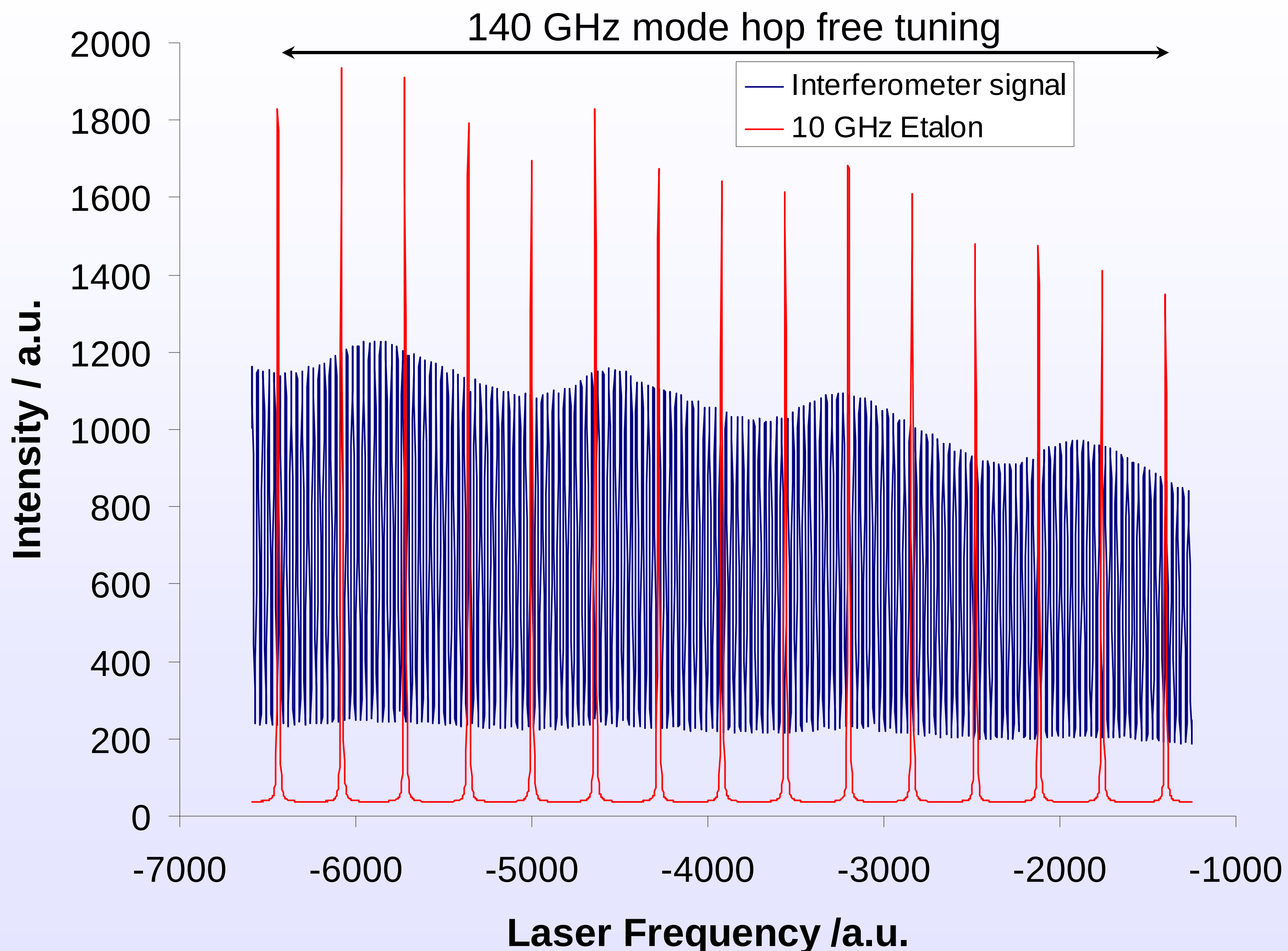


Two colour laser amplifier system

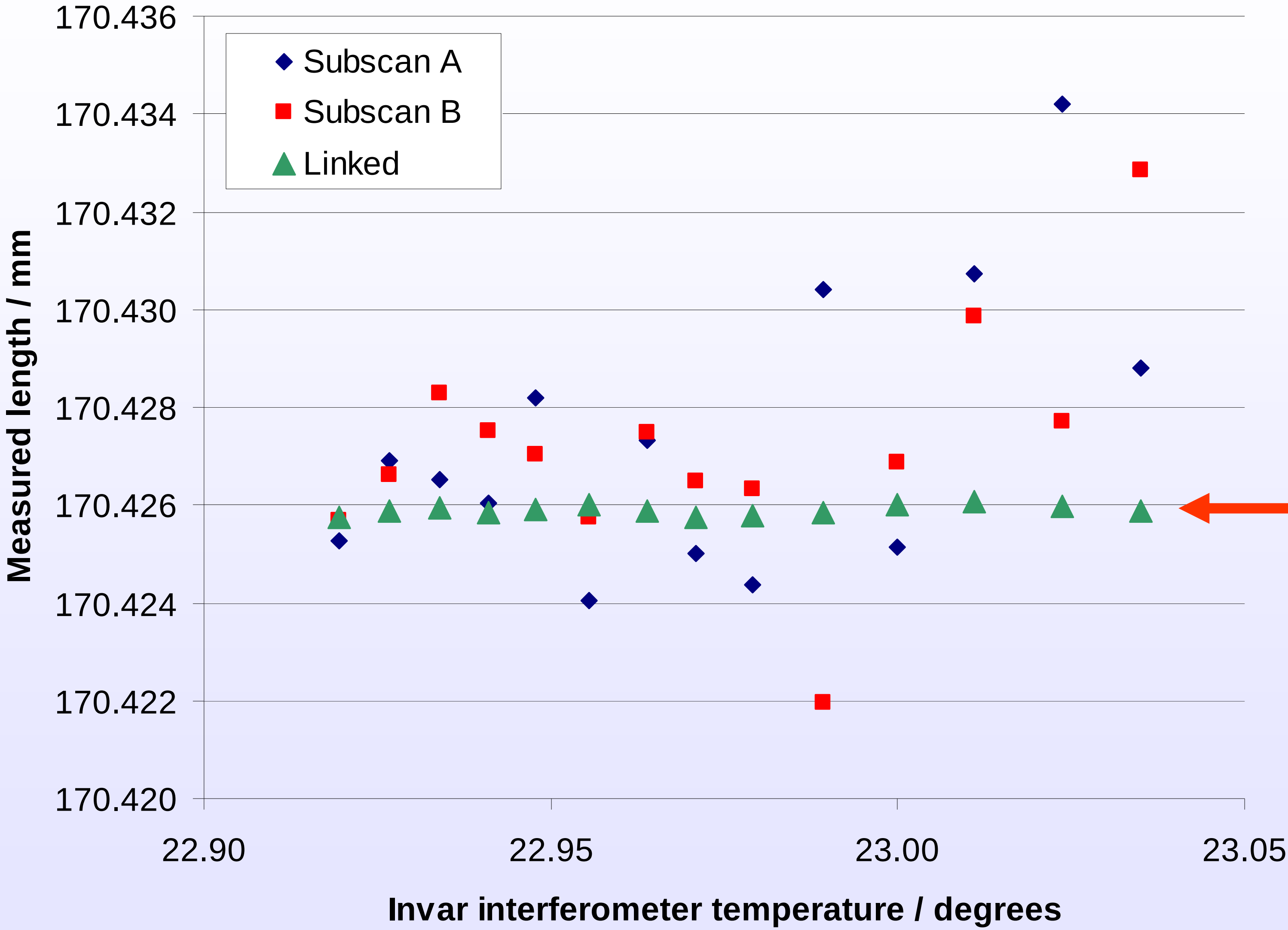


Phase locked choppers so only one laser illuminates system at any time

Frequency scanning with new system



Preliminary Results (2nm link)



σ= 96nm resolution

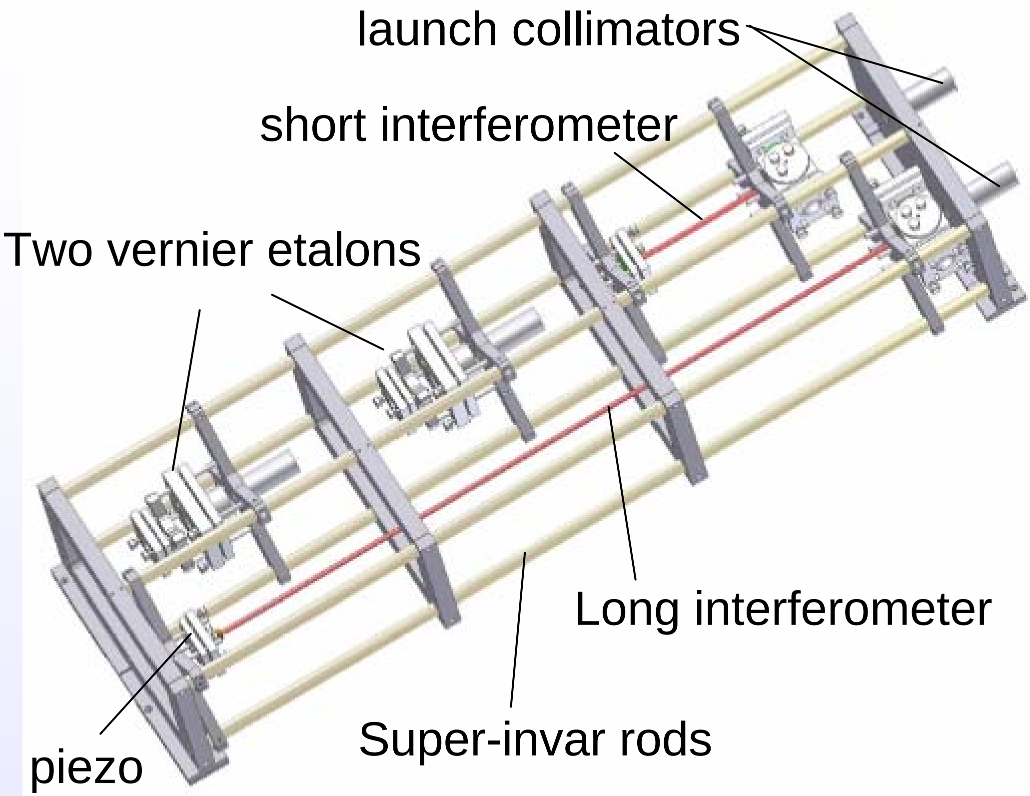
RIS Vacuum chamber

This vacuum chamber houses the
Reference Interferometry System:
all grid lengths measured with respect to this stable reference interferometer length.

Why use a vacuum?

1. Reduces errors due to pressure differences between laser room / ATLAS cavern.
2. Eliminates systematic drift during scan due to refractive index changes / turbulence
3. Thermally isolates reference from surroundings to reduce changes in length.

Reference Interferometry System



- Fibre collimators provides low M^2 beam.
- Super-invar / steel thermally compensating design to balance CTEs. $\Delta T(C_1 L_1 - C_2 L_2) = 0$.
- Both interferometers have four-fibre read-out for instantaneous phase measurement.
- Long reference has piezo for phase stepping.

Vernier etalons

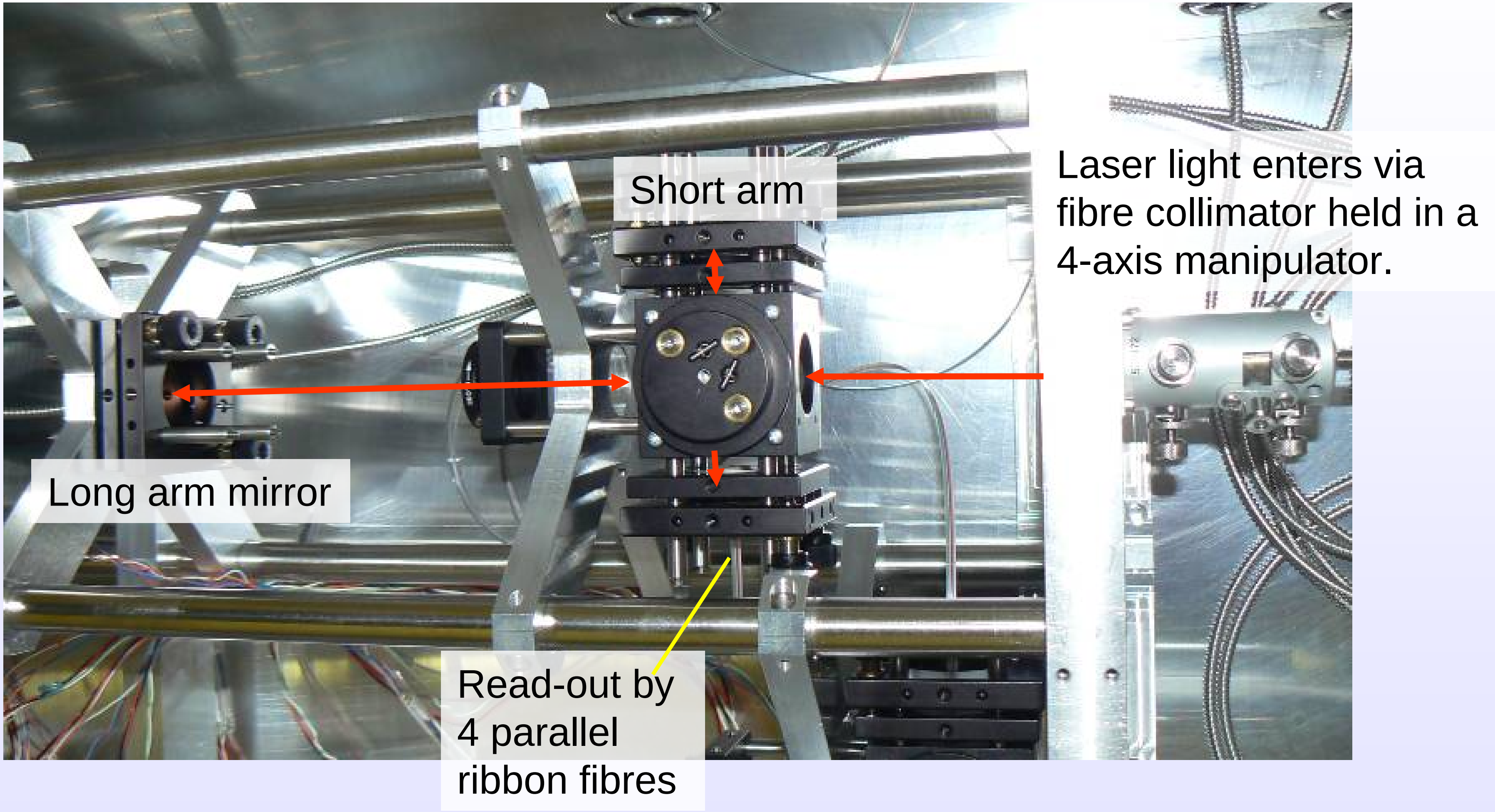
- The vacuum chamber contains a pair of Fabry Perot etalons with slightly different Free Spectral Ranges:
  10.00GHz and 10.05Gz

- Each etalon produces a comb of peaks as the frequency is scanned.

- The FSRs were chosen to provide a beat pattern repeating over 2010GHz (Repeat cycle = N2 FSR-1 = N1 FSR2)

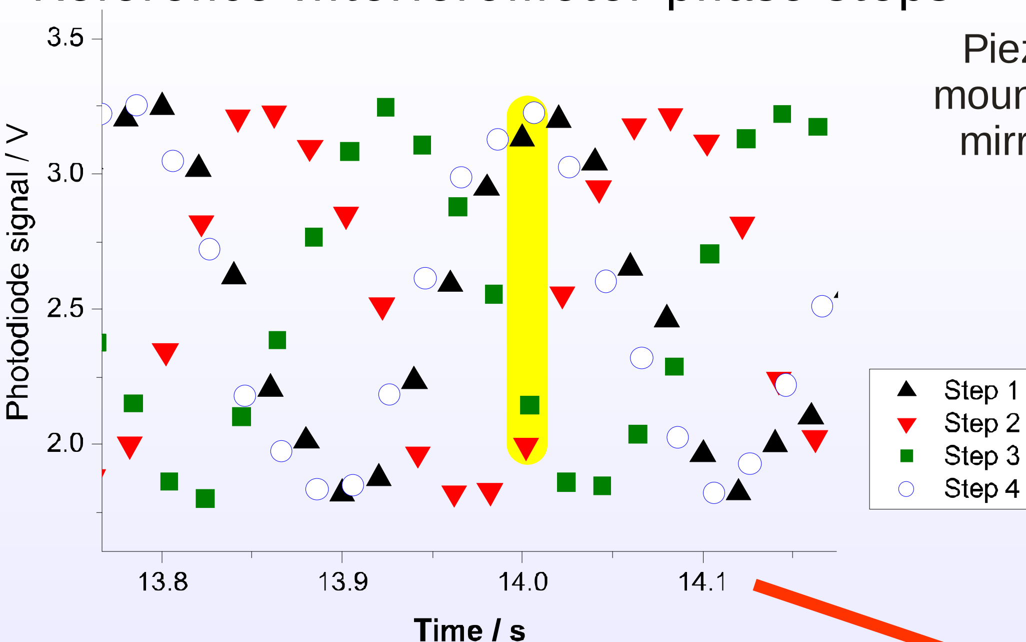
- This vernier scale allows frequency intervals between sub scans to be determined.

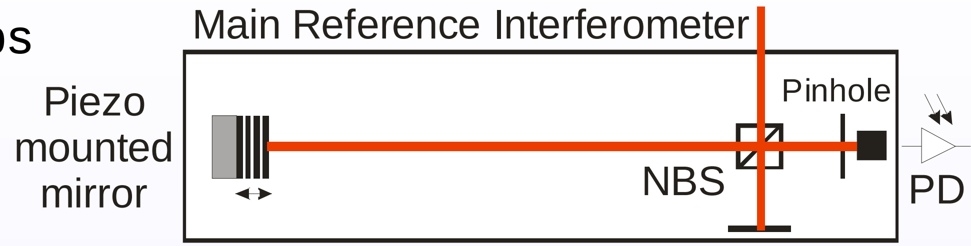
(Short) Reference Interferometer



Phase stepping of piezo mounted mirror

Reference Interferometer phase steps

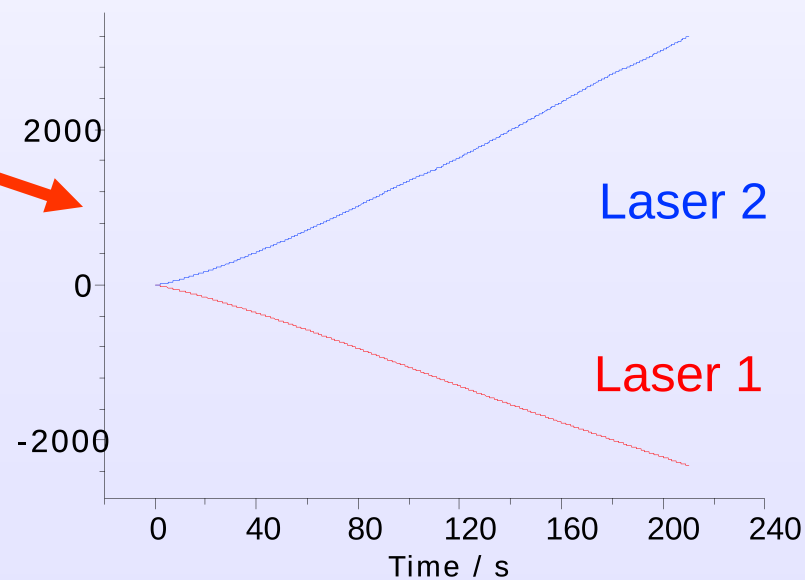




Phase extracted from RI intensity at 4 step positions of mirror.

Phase extraction and unwrapping

FINE-TUNING CURVE

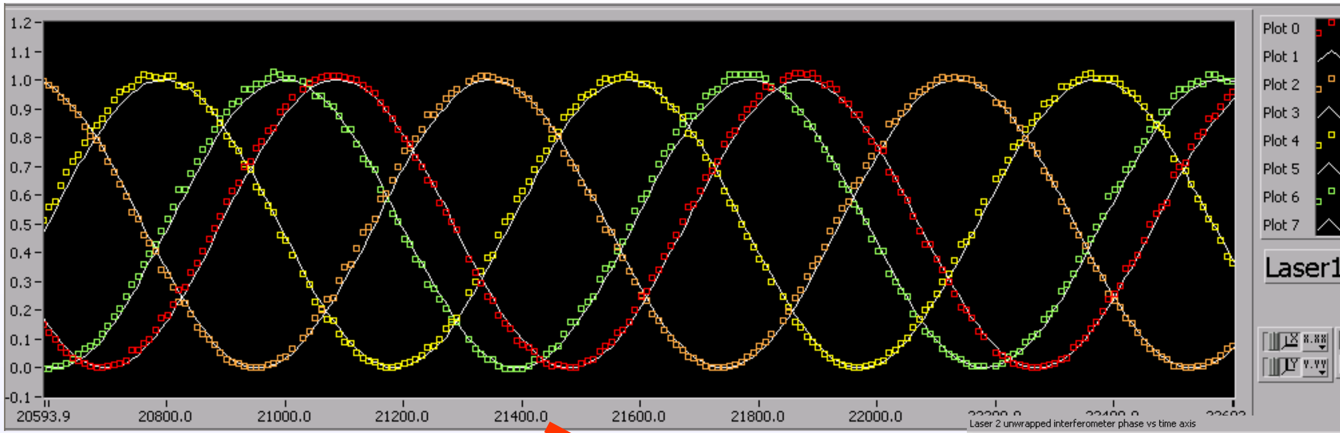


Limitations

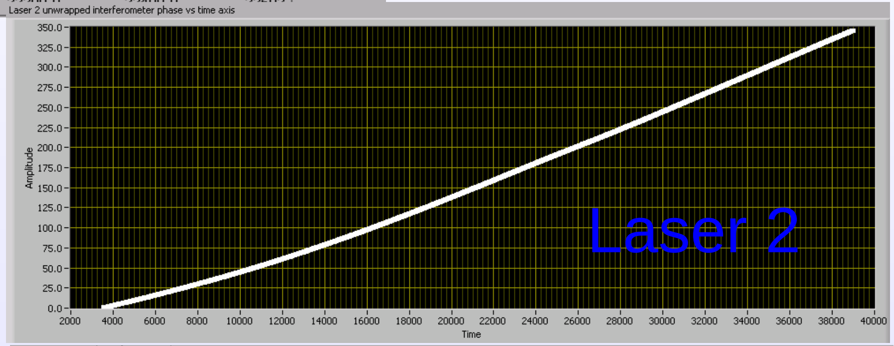
- Four DAQ cycles are required for each phase measurement.
- DAQ rate is limited by maximum driving frequency of the piezo.

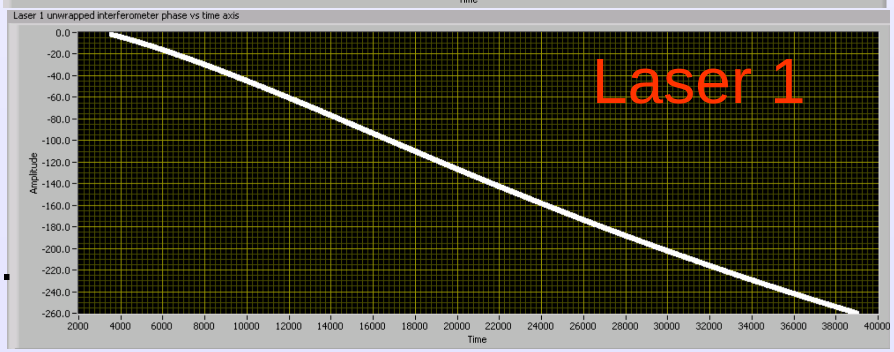
New: Four-fibre phase extraction

Four interference signals coupled simultaneously into four parallel fibres



Phase extraction
and unwrapping





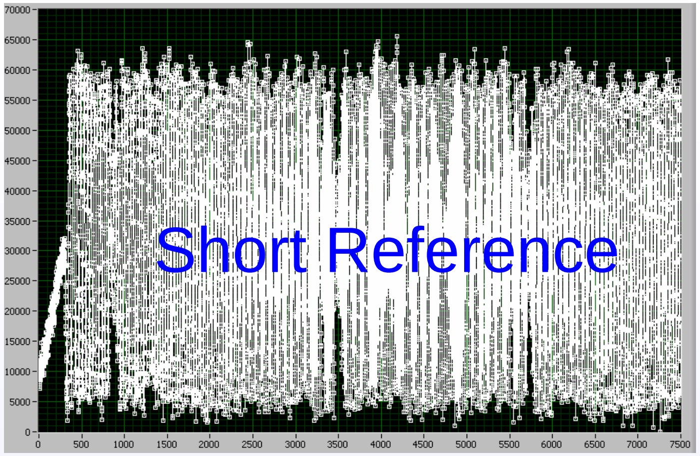
Advantages of new method:

- Instantaneous phase measurement.
- Not limited by piezo vibration rate.
- Permits much faster frequency scans.

➢ This reduces interferometer drift errors and improves the measurement precision.

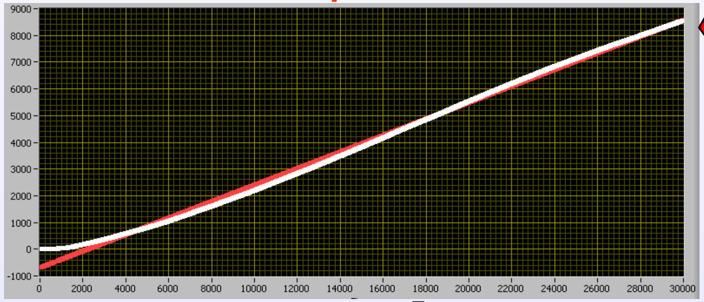
Very new: Dual interferometer phase extraction

Directly measure phase in both RIs

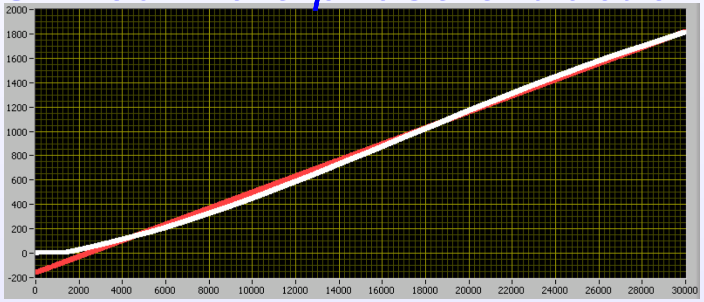


Interferometer intensity vs time

LR four fibre phase extraction



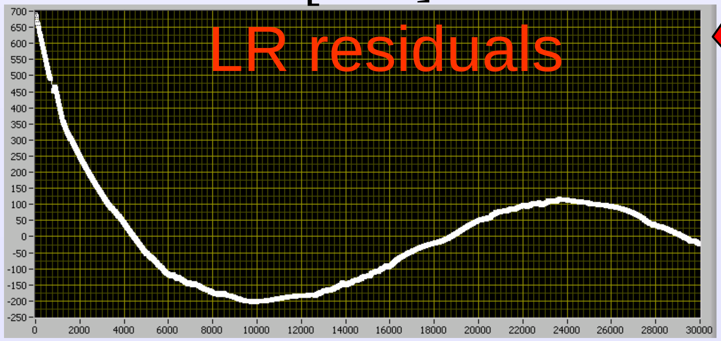
SR four fibre phase extraction

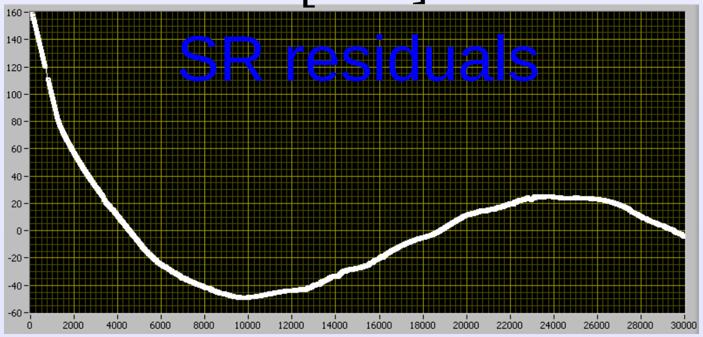


Extracted phase vs Time

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

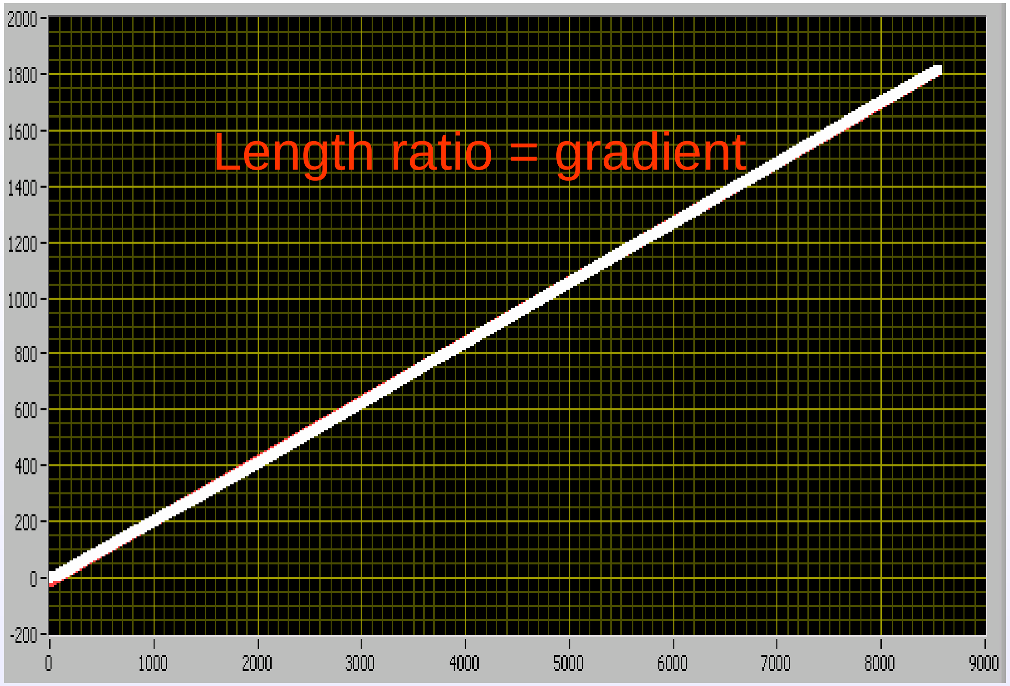
$$\Delta\vartheta = [2\pi/c]D\Delta\nu$$





Phase residuals vs Time *(non-linear laser frequency scan)*

Very new: Direct length ratio measurement

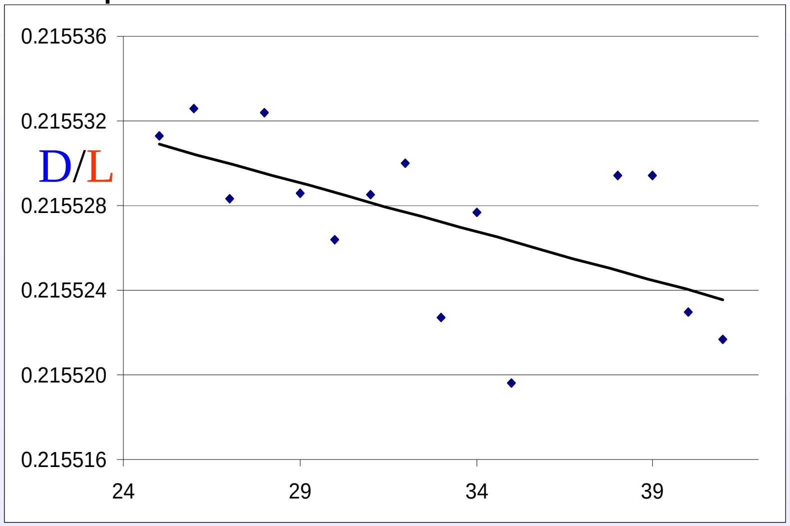


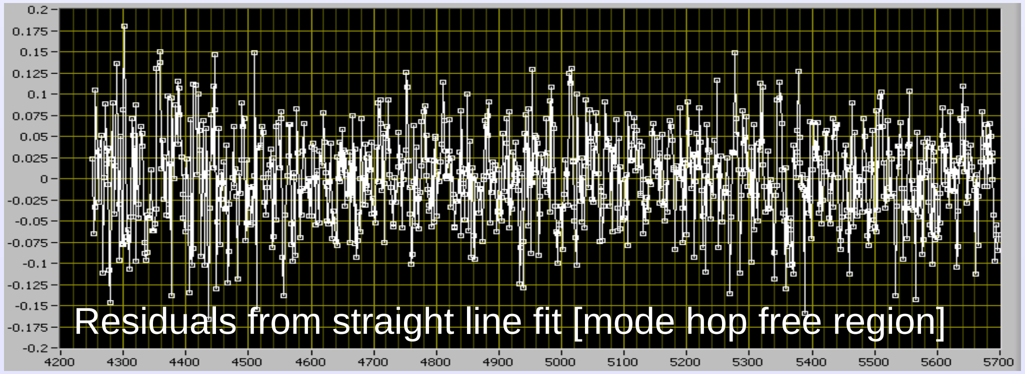
$\Delta\vartheta = [2\pi/c]D\Delta\nu$

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

$\Delta\vartheta/\Delta\Phi = D/L$

Repeat for 15 subscans:





Preliminary result:

(single laser only, short range $\Delta\nu$=34 GHz)

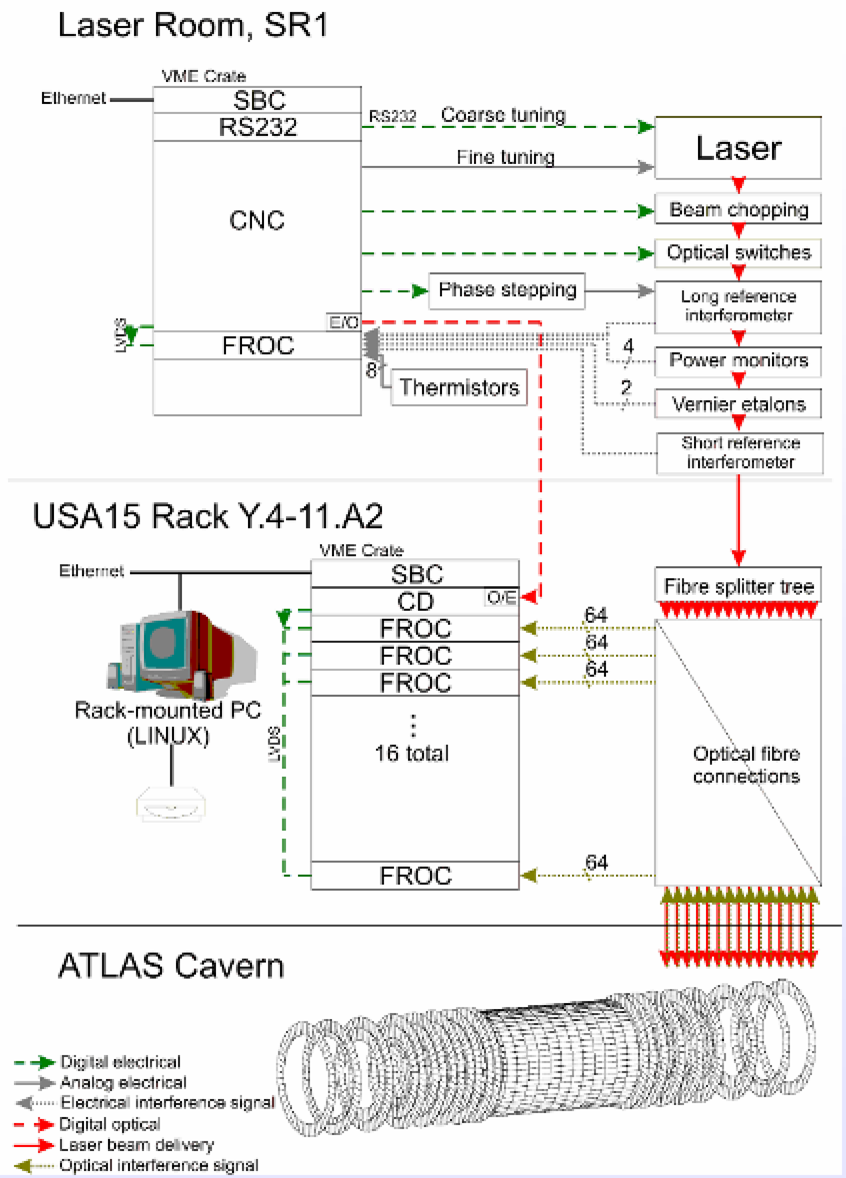
SR/LR length ratio, D/L = 0.2155274 +/- 0.000003

Equivalent to 3 μm on SR length.

$\Delta\nu$ currently limited by laser mode hops.

Light distribution
and
Read out

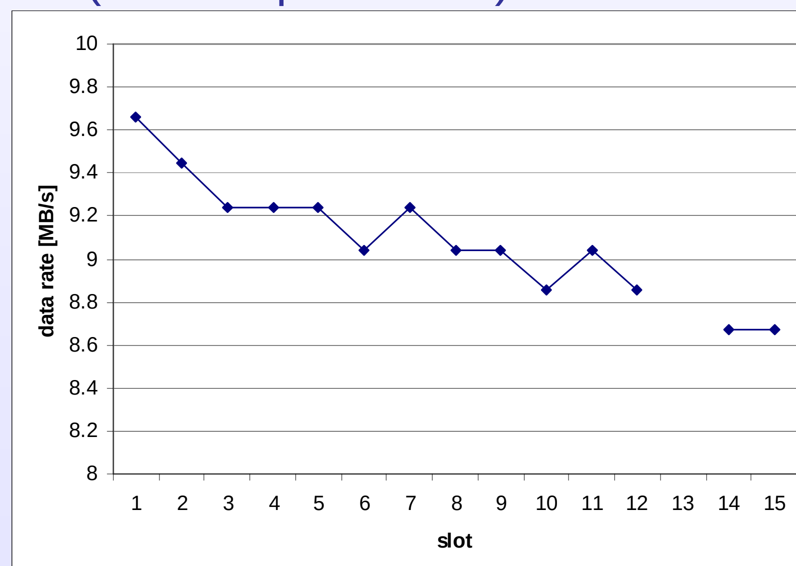
Control and data acquisition



- 2 VME crates
  - Laser room: Control crate
    - control of lasers
    - 2 FROCs: for inteferometers, etalons, diagnostics + vacuum chamber pressure, temperature measurements.
  - USA15: Readout Crate
    - readout of 842 GLIs
- Optical link between crates to synchronise DAQ.
- Optical link runs in same ribbon cable as fibre delivering high power laser light to rack.
- Laser light is divided between 842 interferometers using a fibre splitter tree, based on Planar Lightwave Circuits.
- DAQ uses custom FSI Read Out Cards (FROCs), which each record 64 optical channels multiplexed to 32 electronic channels.

Commissioning the FSI Read-Out Cards

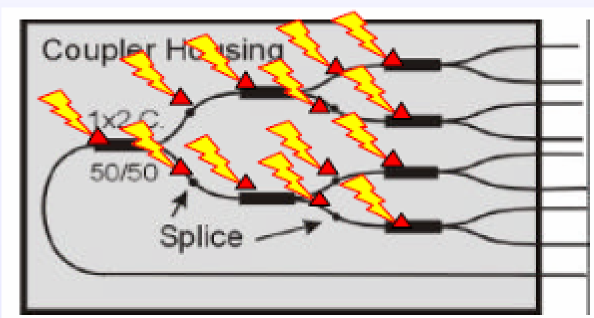
- 2006: cables to empty rack.
- June '07: Crate,and first FROC installed. Communication established via SBC.
- August '07 shipment: 6 FROCs + CNC card installed. Block transfer achieved.
- October '07 shipment: all 15 FROCs installed. Full data rate test successful: 65536 triggers (~4.5Mb per FROC).



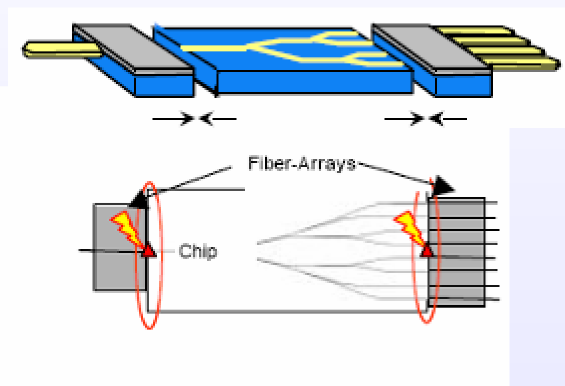
13th FROC (!) had a broken trace in the multilayer board. Repaired in Oxford, now back at CERN

Fibre Splitter Tree Installation

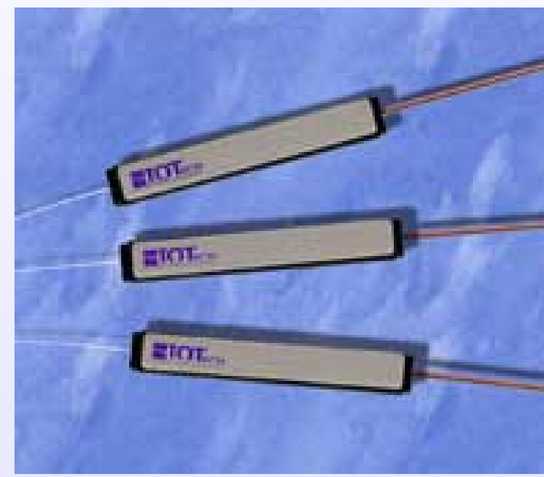
- Purpose – to split fibre coupled laser light between 842 interferometers.
- Tree built using Planar Lightwave Circuit technology (PLCs) rather than fused biconic couplers.
    - Fibre-like waveguides created using ion-exchange in glass.
  - 1x8, 1x16, 1x32 split multiplicity possible in single device.
    - Need far fewer devices with similar / better optical losses to couplers.
    - Compact form allows easier installation at rack.



1x8 FBT coupler



1x8 planar splitter



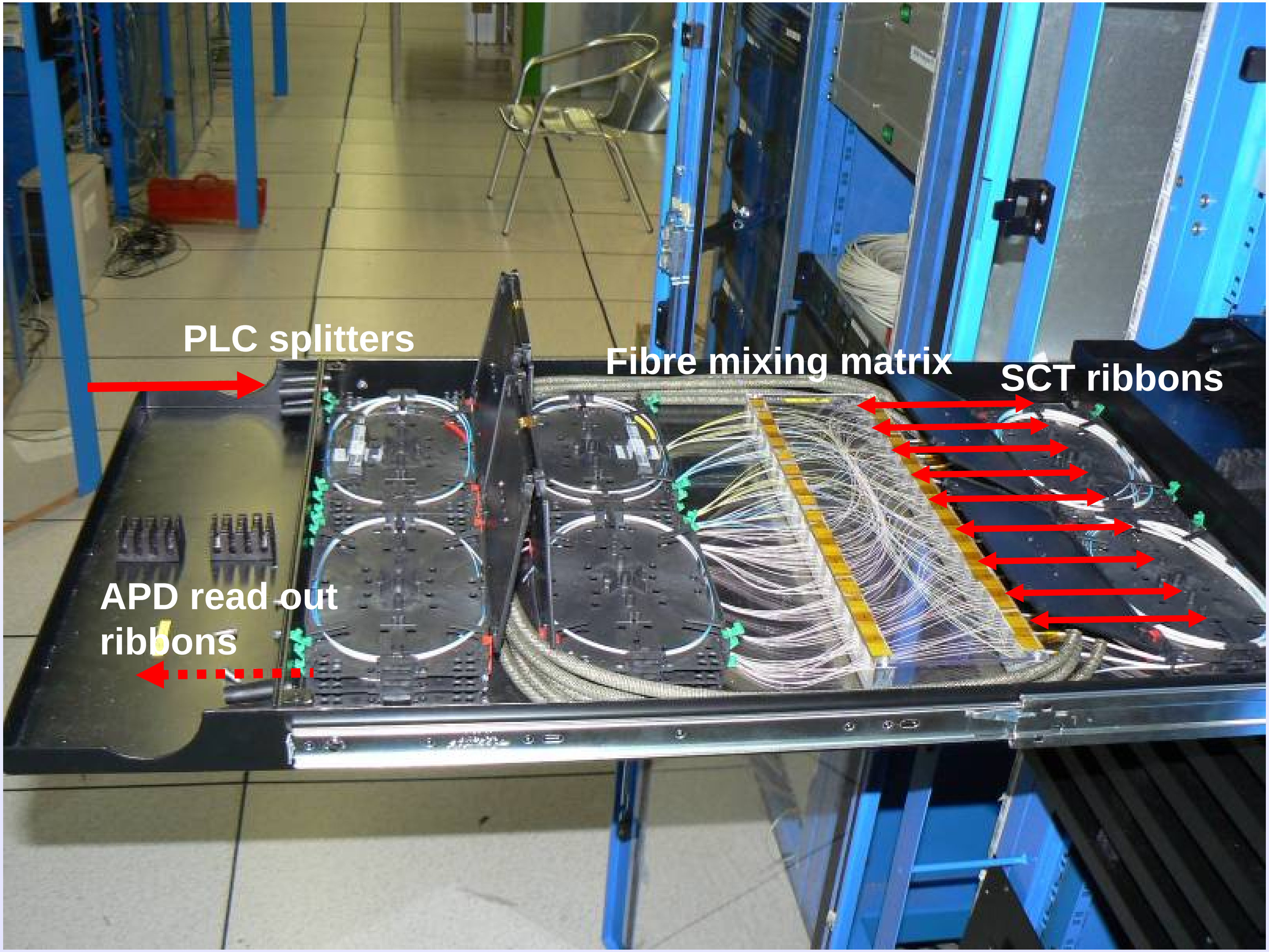
– PLC chip was mode matched to specialist radiation tolerant ribbon fibre to reduce splice losses.

– Splitter tree made in 15 x 1U modules of fibre mixing matrices manufactured in Oxford over summer and shipped to CERN, in August and October. [1684 individual fibres routed].

Splitter tree modules in underground rack

- 9 x 1U splitter tree modules installed on sliding runners at the rack.
- Each module divides fibre coupled light from the lasers between up to 64 grid line interferometers on the SCT, and routes the return light to the read-out crate (one FROC per splitter module).

Splitter tree module in counting room rack



Status and outlook

- The FSI system is in place at CERN and the commissioning phase has started.
- Read-out system tested successfully with fast data transfer rate achieved.
- Four-fibre phase extraction technique developed to improve precision.
- Dual reference interferometers provide simultaneous phase extraction.
- First data indicate improved performance is possible using extended analysis techniques and frequency tuning capabilities of the new lasers.

Acknowledgements:

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