Linear Collider Alignment

(why it is important and how to get it)

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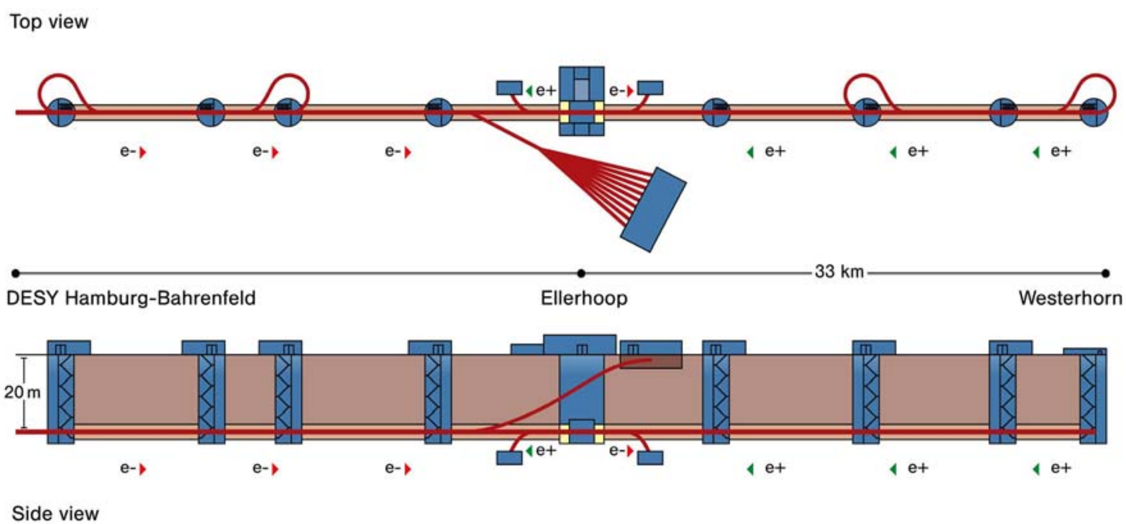
Workshop on Higgs Physics at Future Colliders, Warszawa, 22 XII 2004

Introduction and motivation

- **Detector vs. “machine”**
- **Accelerator: the real challenge**
- **e+/e- high intensity sources**
- **High beam energy**
- **High luminosity (colliding nano-meter size beams)**
- **Polarisation**
- **beam diagnostic (laser wires, BPM,…)**
- **Beam-based feedback to IP**
- **Accelerator alignment and stabilisation:**
- **-- main liniac**
- **-- beam delivery and final focus (final doublet)**

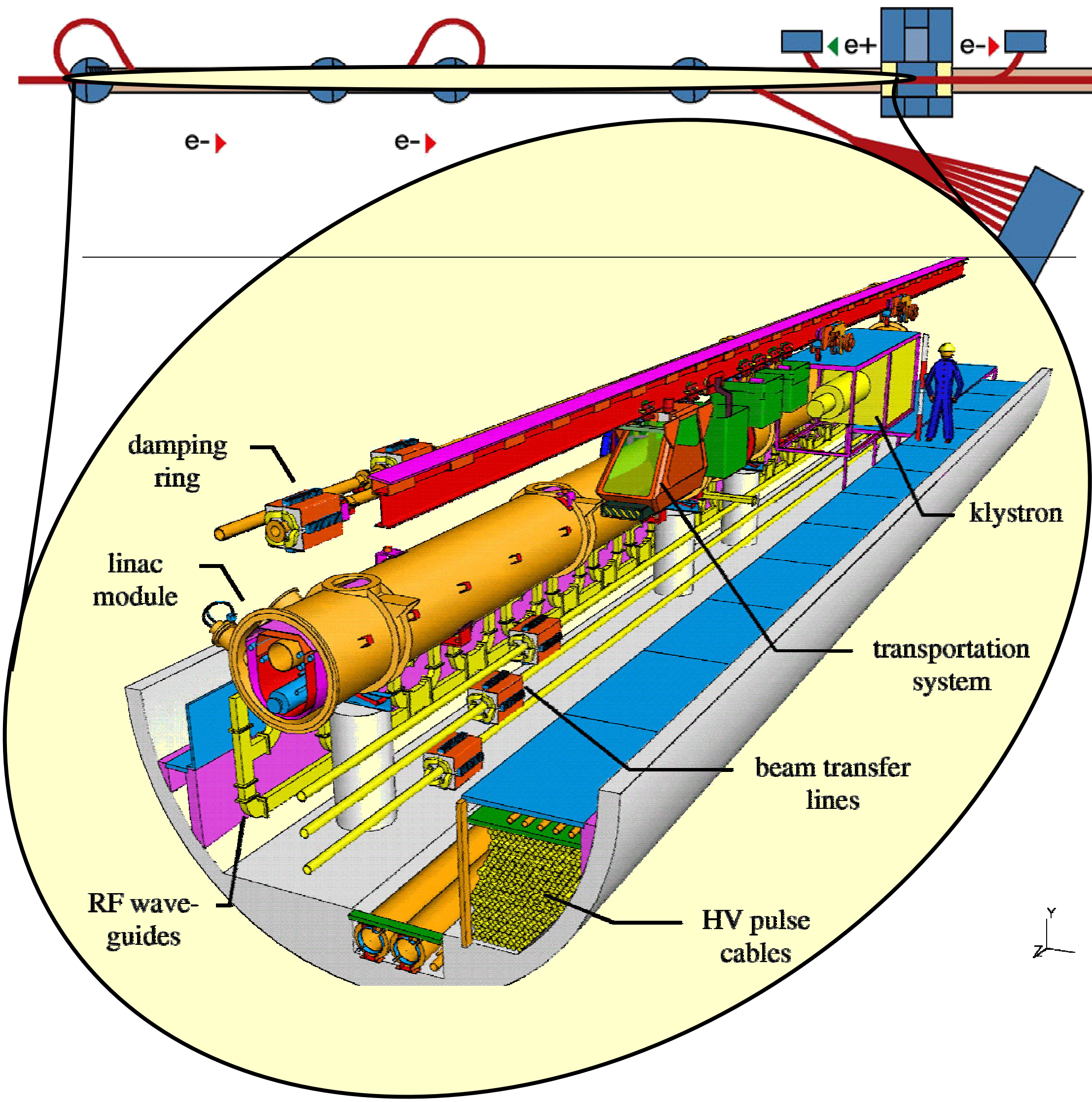
Linear Colliders
(using Tesla specification)

Linear Colliders
(for example Tesla)



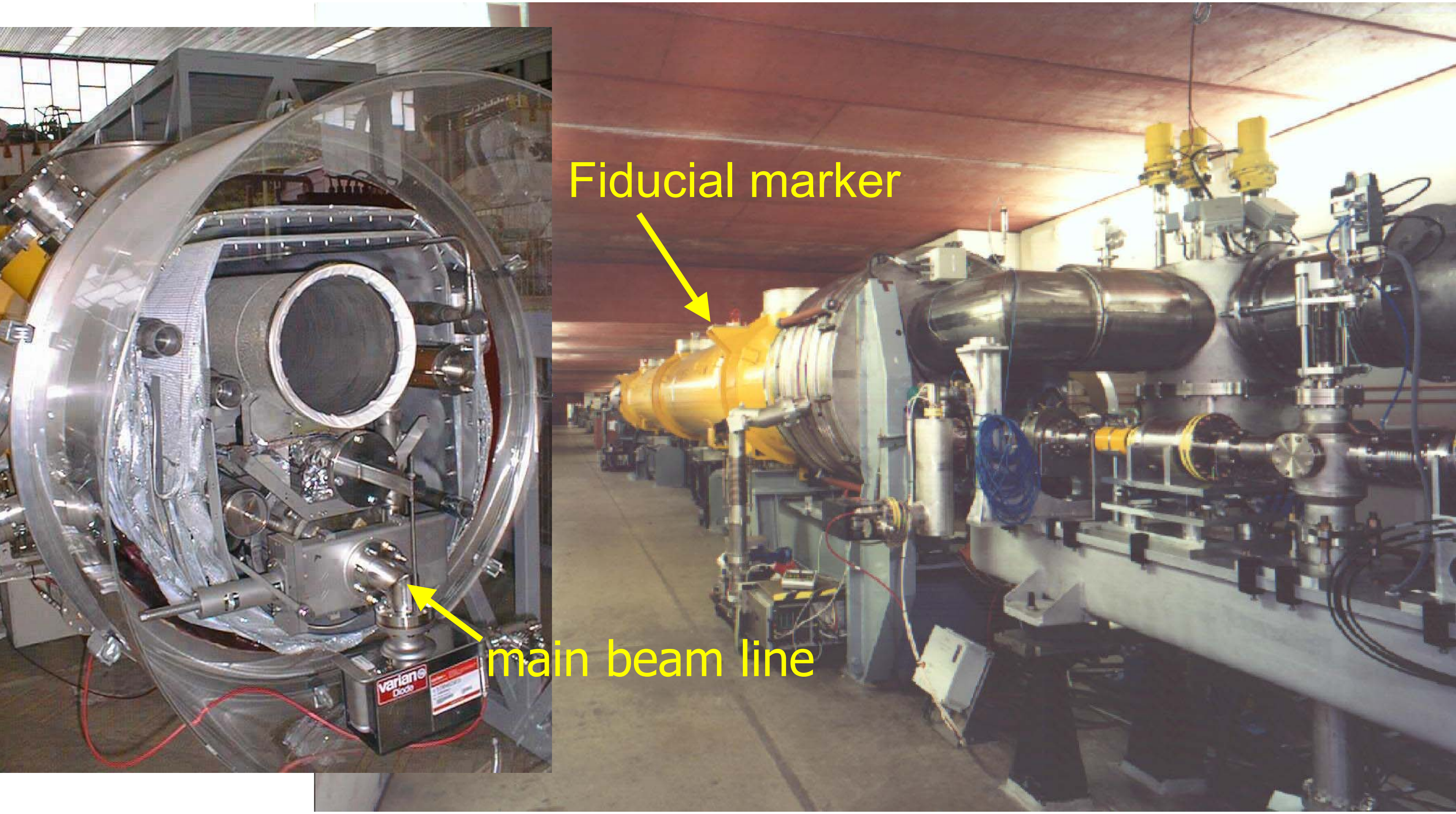
- Beam energy O(500GeV)
- Beams start at O(0.1μm)
- beams end up O(1nm) at interaction point
- no recirculation, you just have one shot to collide a given bunch

Survey and Alignment Problem



- Long tunnel (~33 km)
- Tight space (~1m wide)
- Curved tunnel sections
- Significant slopes possible
- Some sections follows geoid, others are geometrically straight
- Temperature and pressure gradients in tunnel
- Electrically noisy environment
- Automated measurement needed

LC Survey Problem



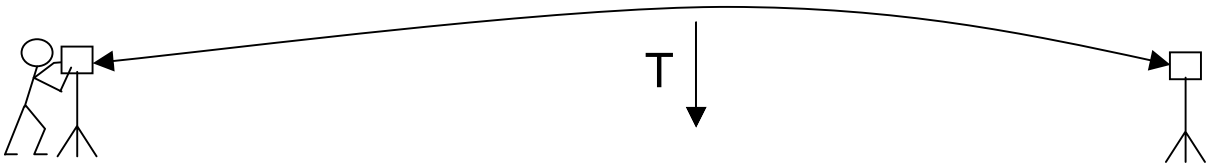
Survey and Alignment Problem

- **TESLA Specification:**
  - **200 μm vertical over 600 meters (=betatron wavelength)**
- Survey procedure is needed during:
  - Tunnel construction
  - Installation of collider components
  - Accelerator maintenance/repairs
- Open air survey too slow and too inaccurate
- Need new instrument that matches requirements
- New technology : FSI – Frequency Scanning Interferometry (distance measurement) and Laser Straightness Monitors (LSM)

200μm over 600m

Why is this hard ?

- Temperature & pressure gradients inside collider tunnel affect open-air measurements



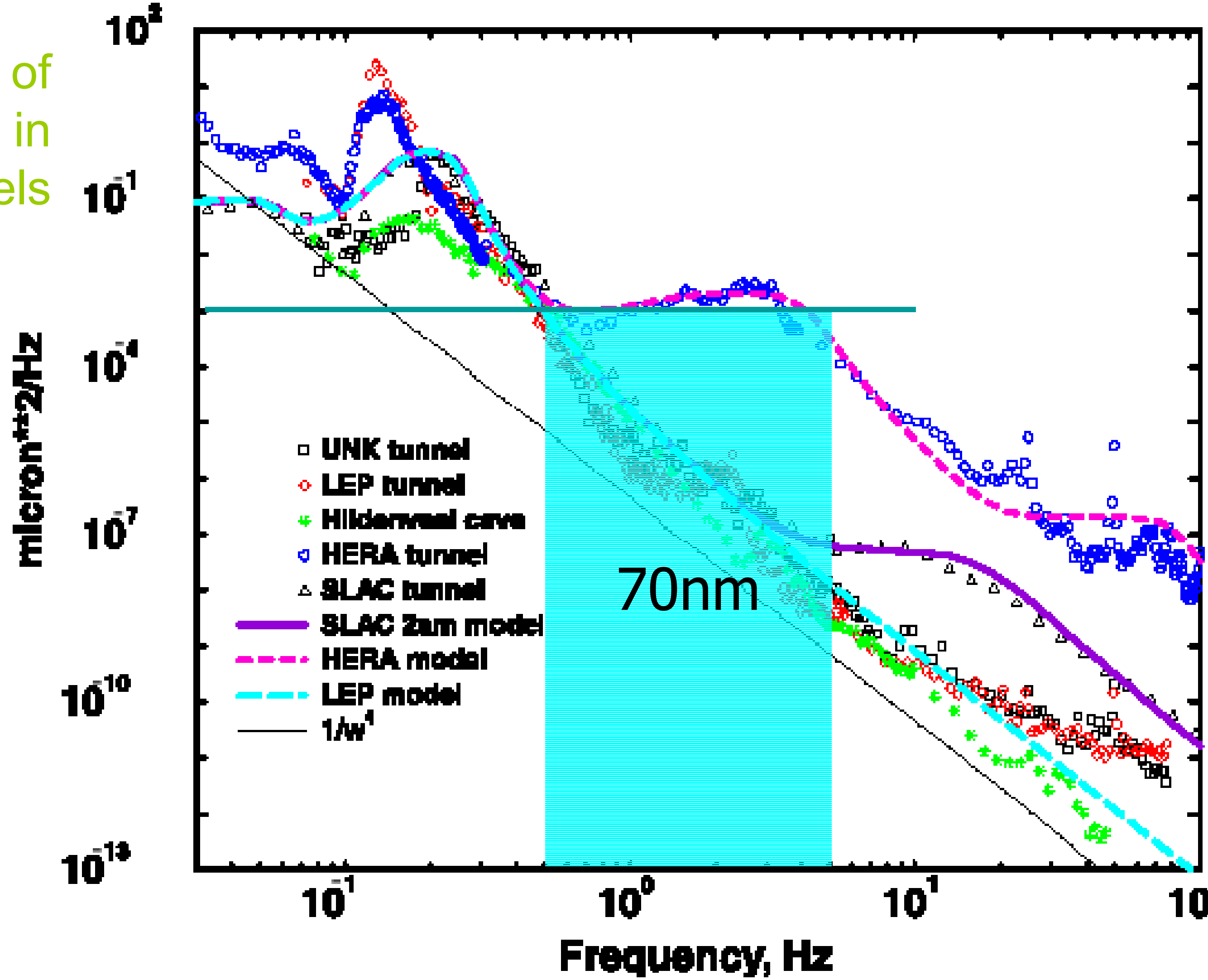
Light gets bent by air refraction

- Ground motion will misalign collider; so survey must be quick

- This prevents use of conventional open-air surveying techniques

LCs move… (time scales of ground motion)

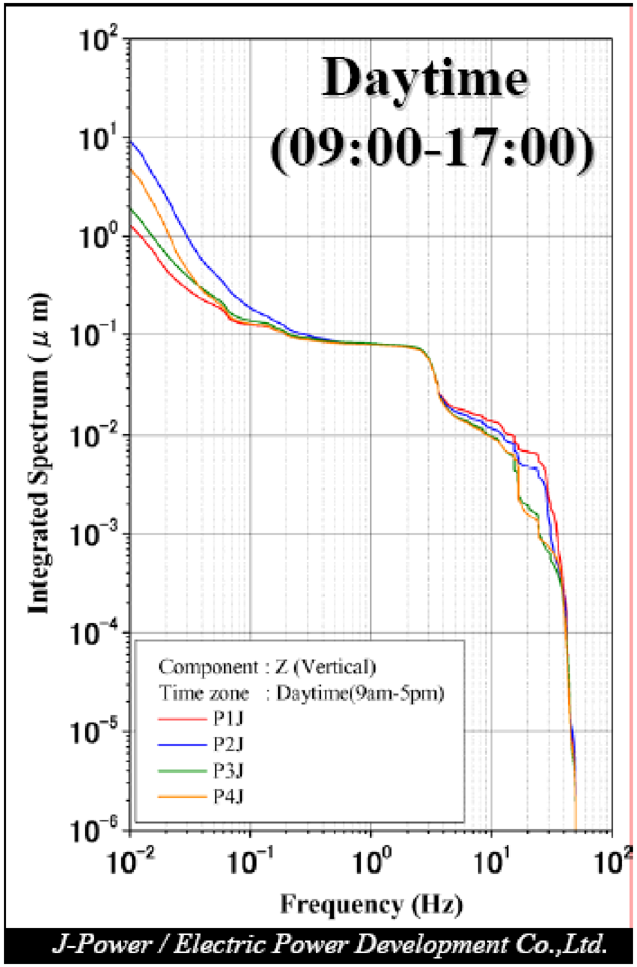
Powerspektrum of ground motion in various HEP tunnels



LEP:
60 to 180 μm/Jahr

Parameters to Consider (KEK data)

- Stabilize: 0.01 – 100 Hz
- Movements up to 10 μm
- **Stabilize Vertical axis only!**
- Stabilization to a precision of ~10 nm



Integrated spectrum of vertical motion

Generic Solution for LC tunnel

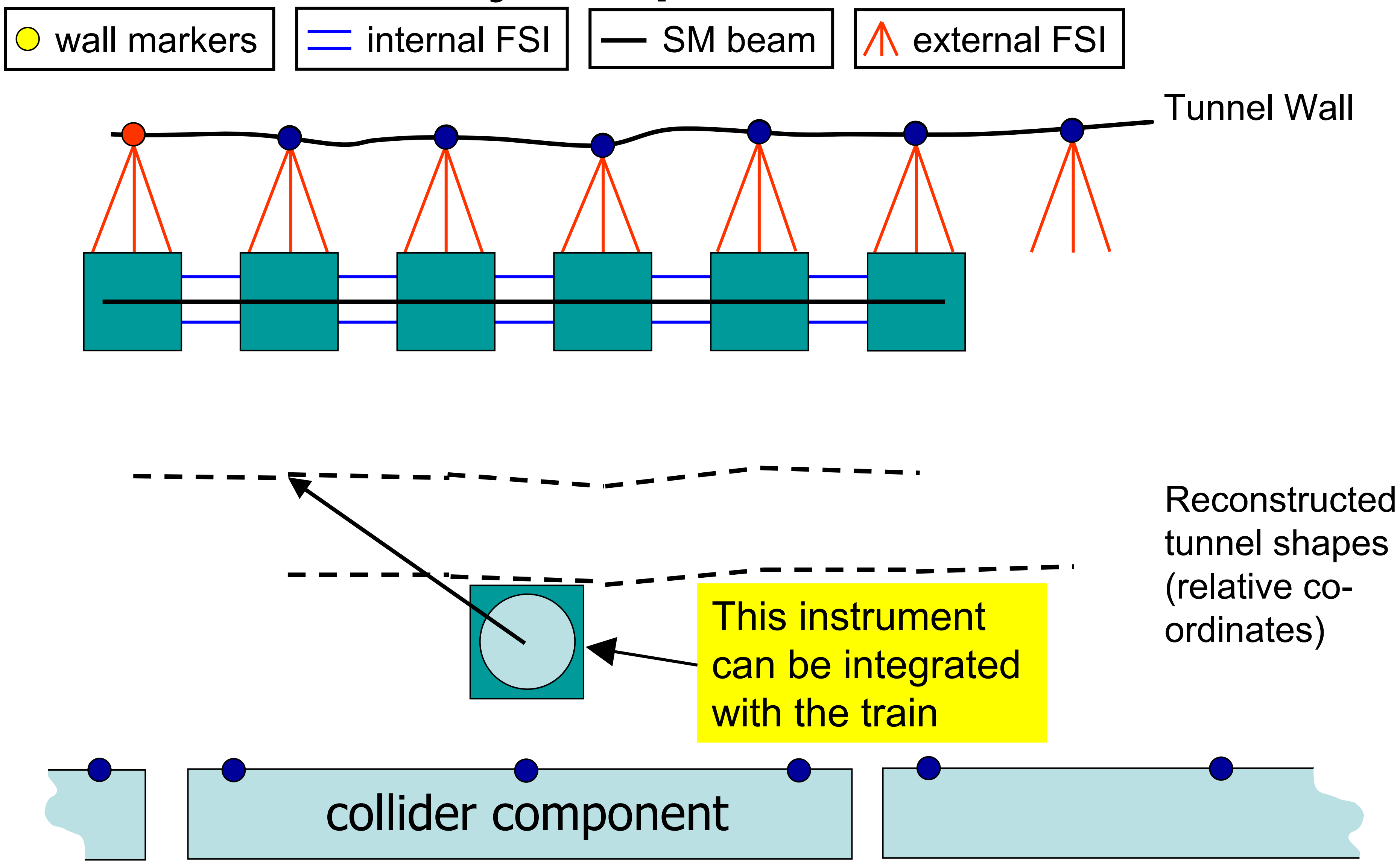
- Collider has large number of marker (many lines)
- Collider markers are irregular (not good for automation)
- Tunnel needs to be surveyed long before collider is installed
- Use a two step process

1. Survey regularly spaced markers in tunnel wall
2. Survey collider components against markers

Concept developed by Oxford LiCAS group and Applied Geo-DESY team.

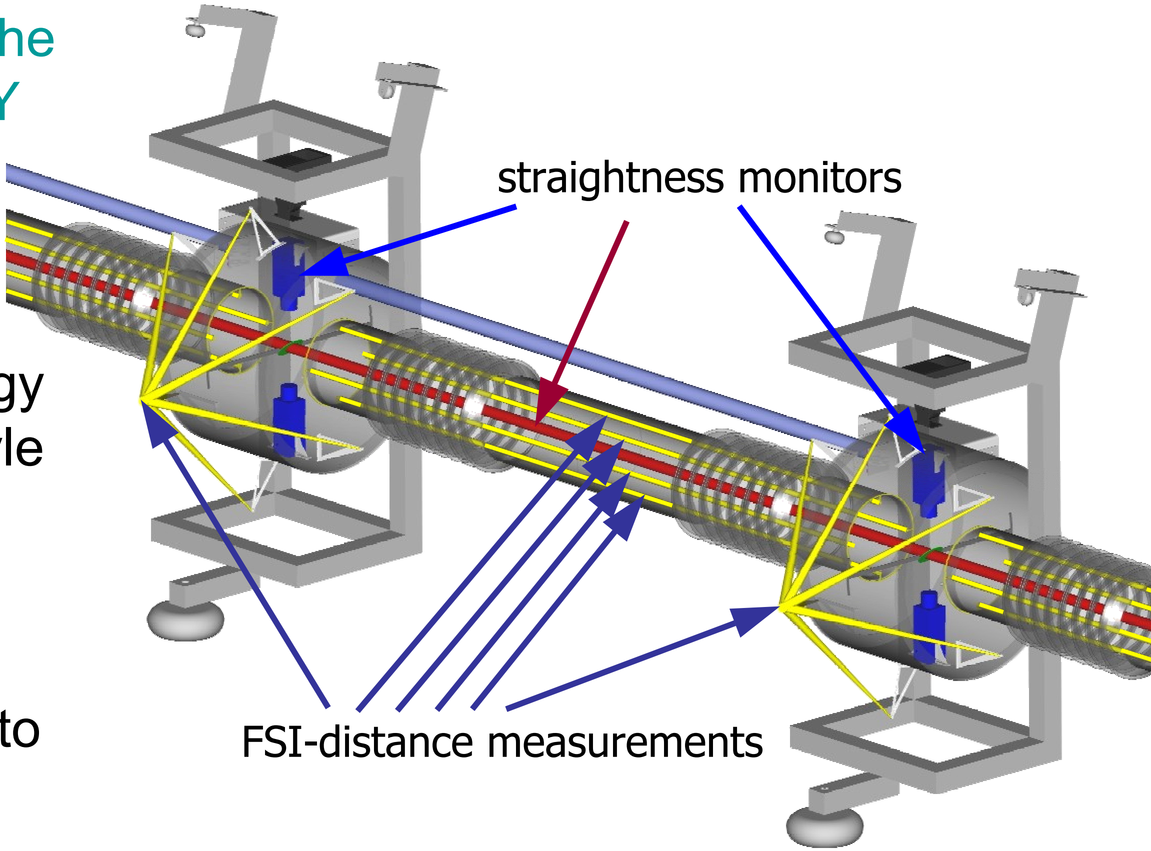
LiCAS = Linear Collider Alignment and Survey

Survey Implementation



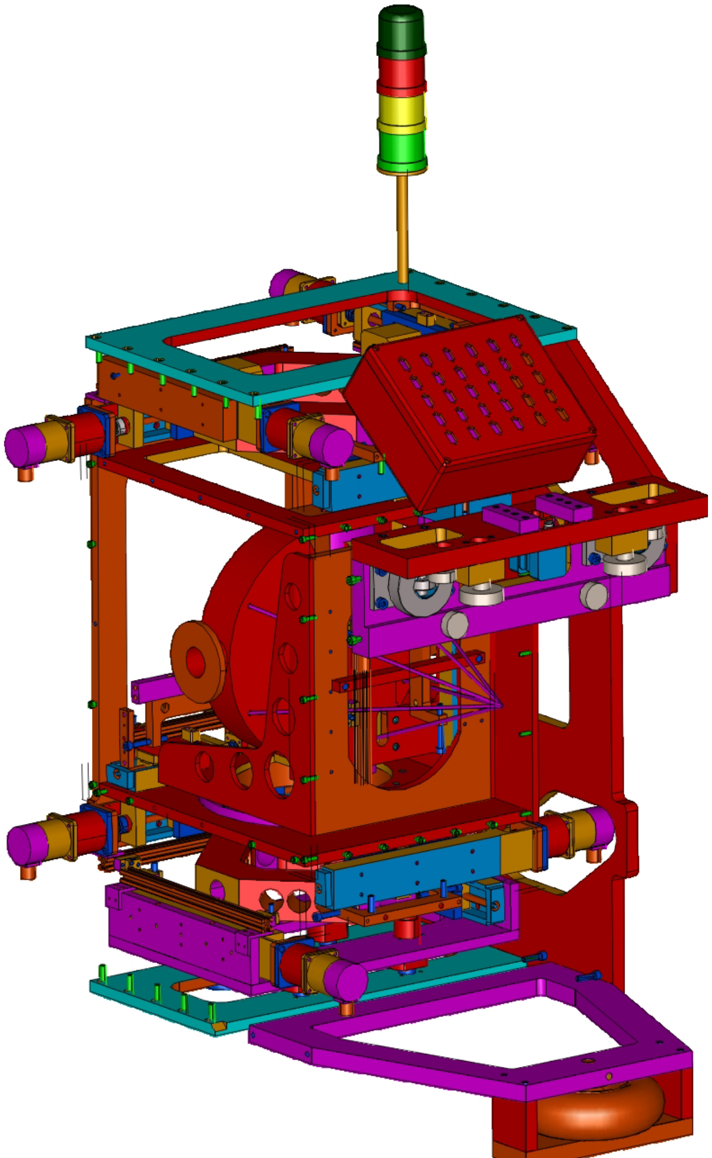
LiCAS Implementation

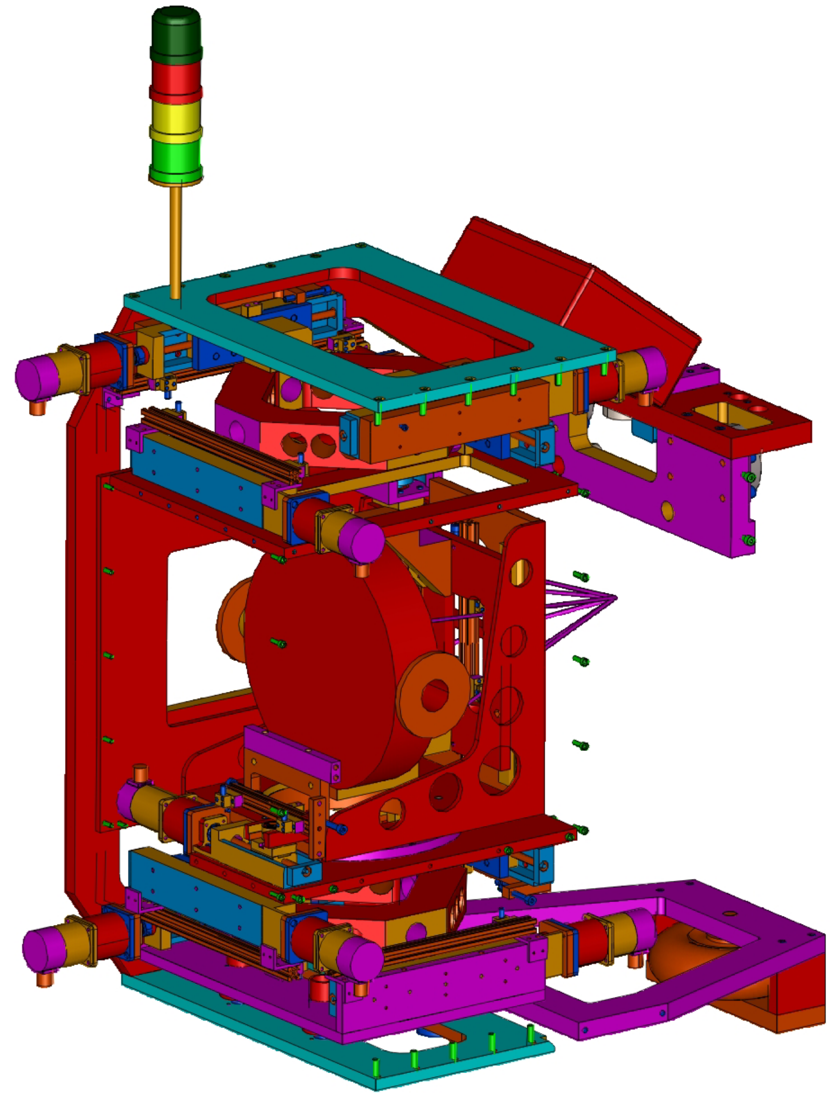
- Mechanical concept of the train developed at DESY
- Internal Laser lines (FSI,SM) operate in vacuum
- Scalable laser technology (EDFA & TELECOM style infrared lasers)
- Prototype @DESY in dedicated test tunnel
- Advantages comparing to conventional HLS systems:



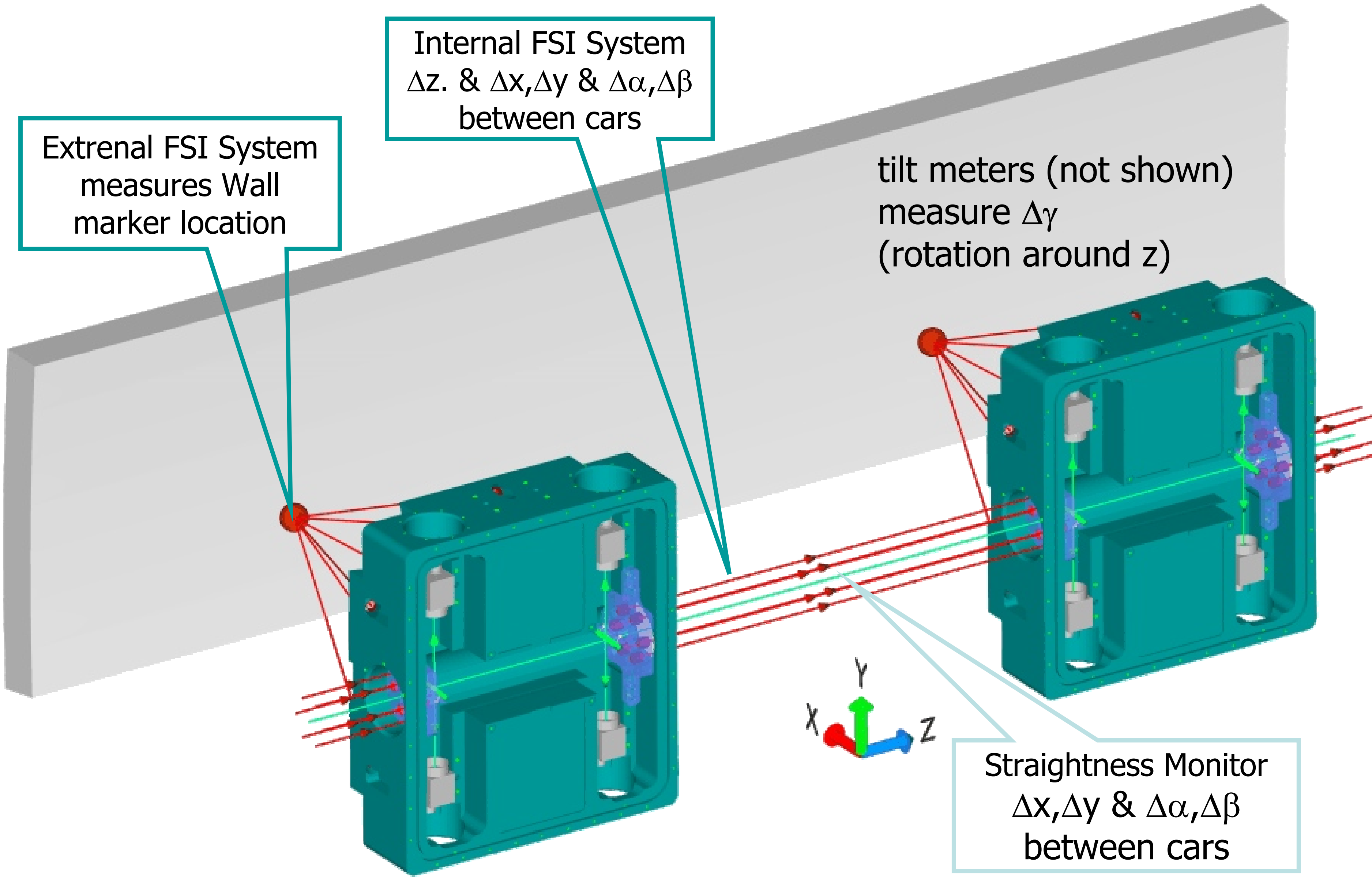
- Operates in inclined and curved tunnels
- Higher intrinsic resolution and faster survey
- cheaper

LiCAS Mechanical Design & …





LiCAS Principle



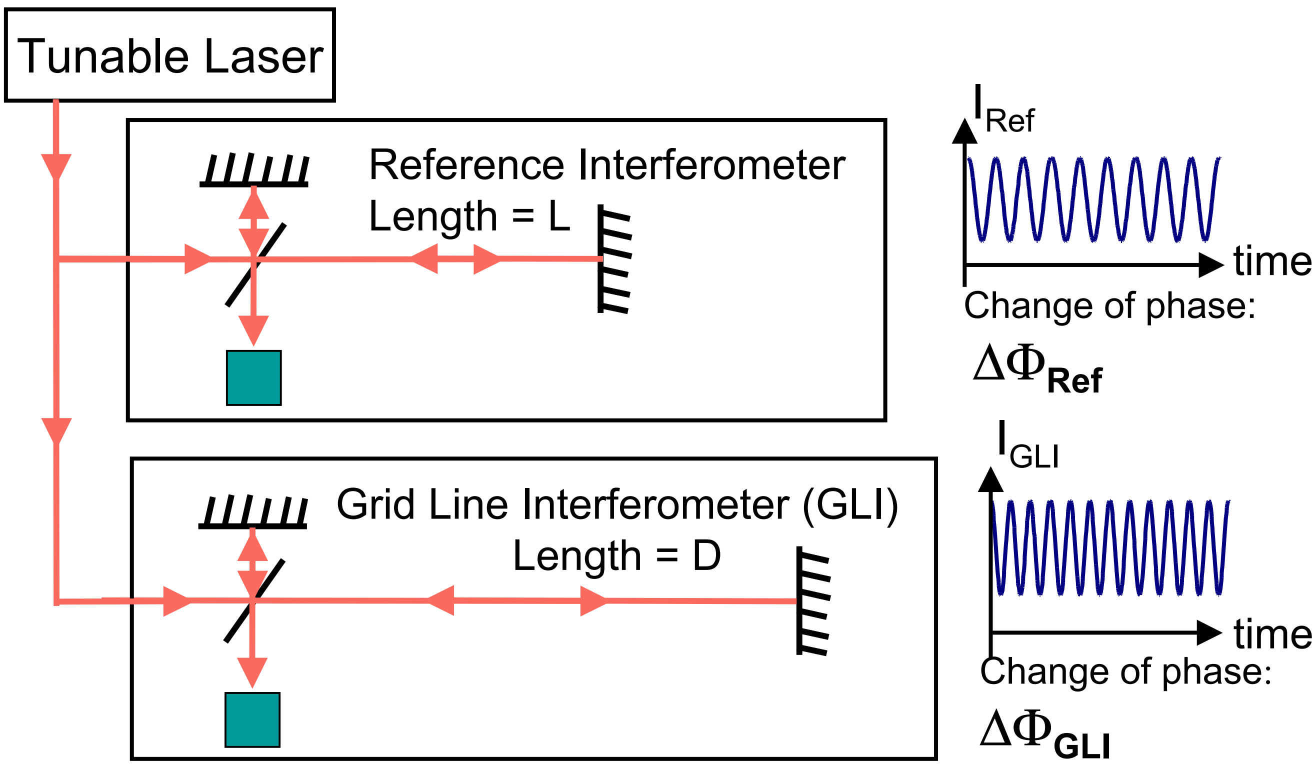
Mechanical Reality

Mechanical body of a car that will hold the LiCAS sensors and move them into a straight line.

Now with all motors in fully functional test stand at DESY

FSI Principle

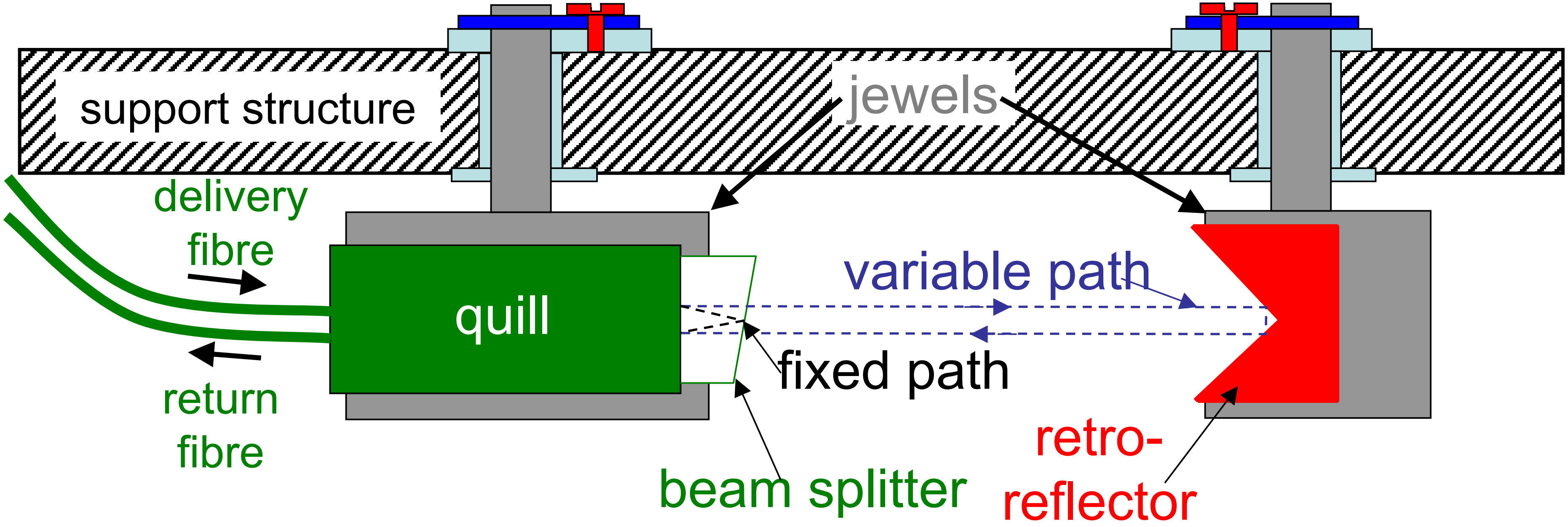
- Interferometric ABSOLUTE length measurement system
- Originally developed at Oxford for online alignment of ATLAS SCT tracker
- Required measurement precision is 1μm over 5m



$$\frac{\Delta\Phi_{Ref}}{\Delta\Phi_{GLI}} = \frac{L}{D}$$

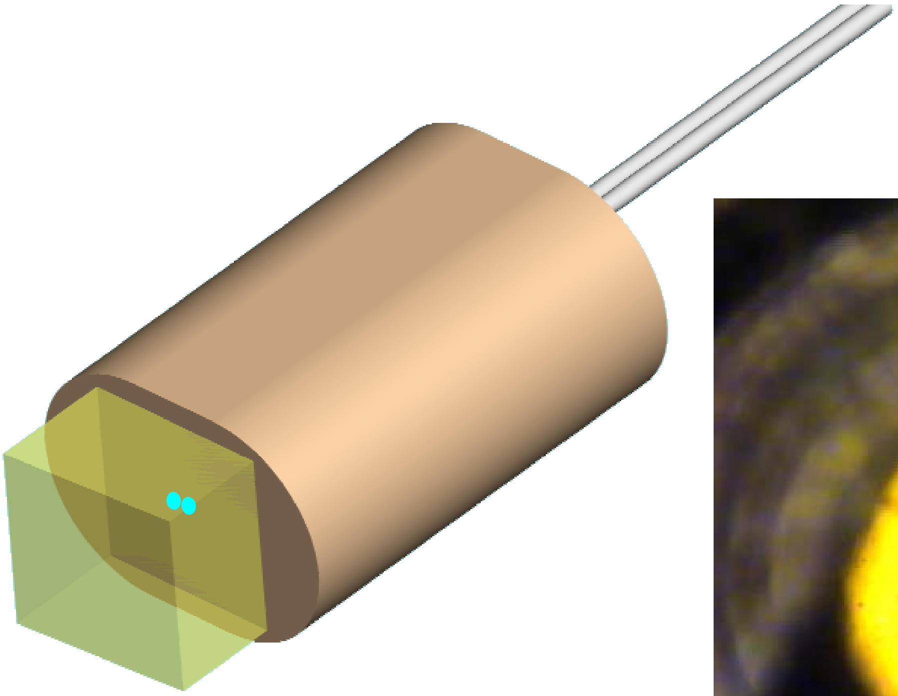
ATLAS Grid line interferometers

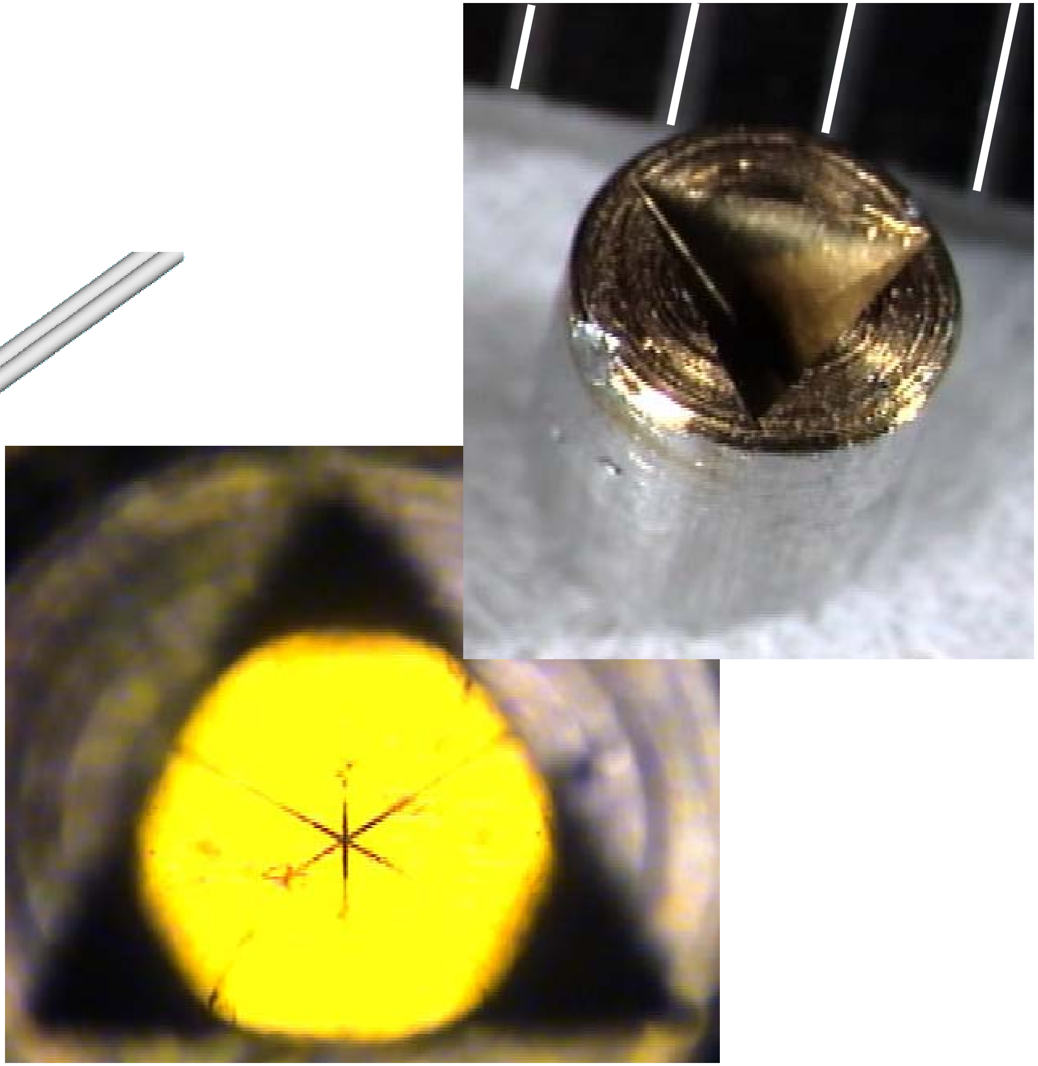
- GLI's do the length measurement



ATLAS FSI components

- Retro Reflectors
- Quills

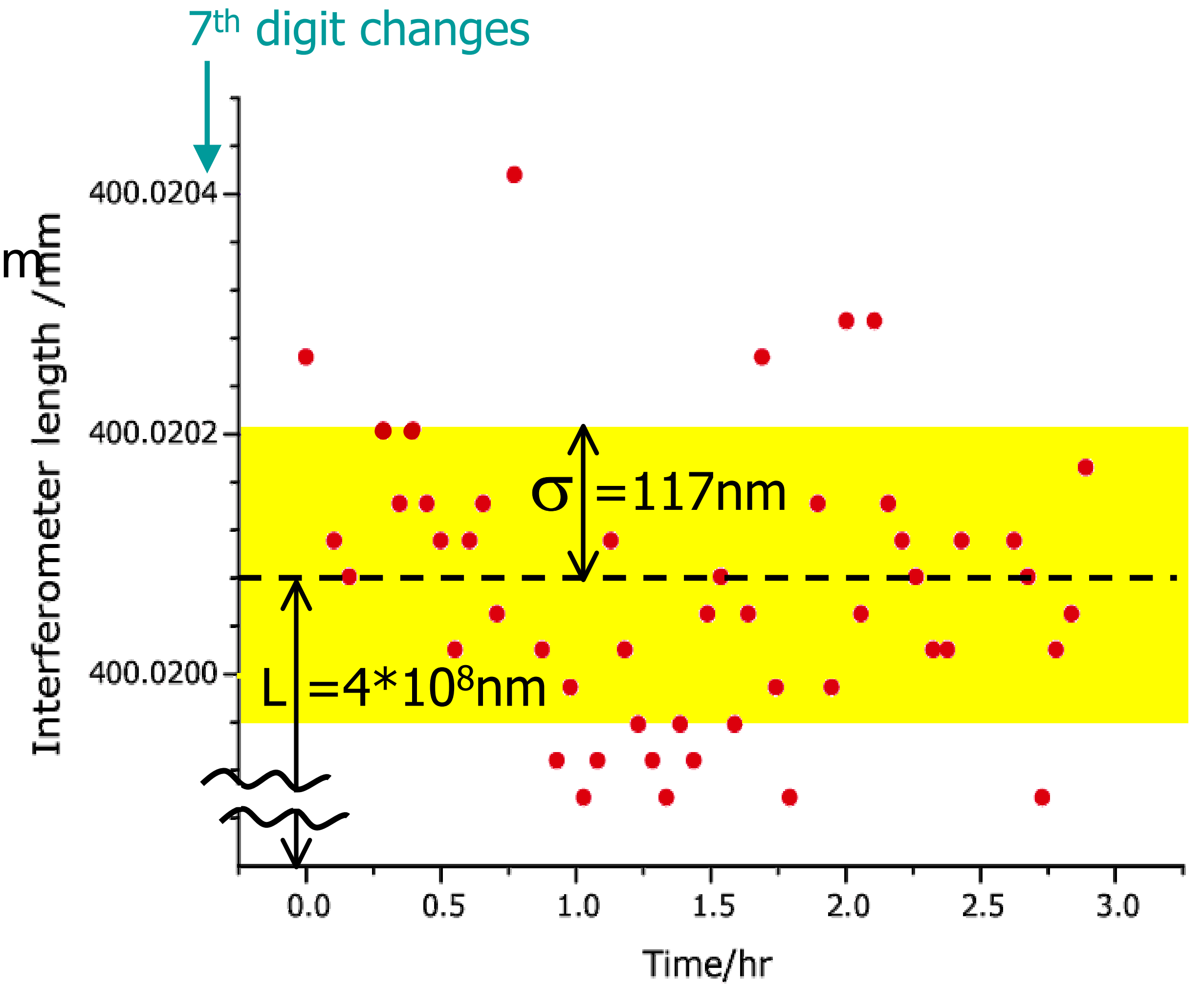




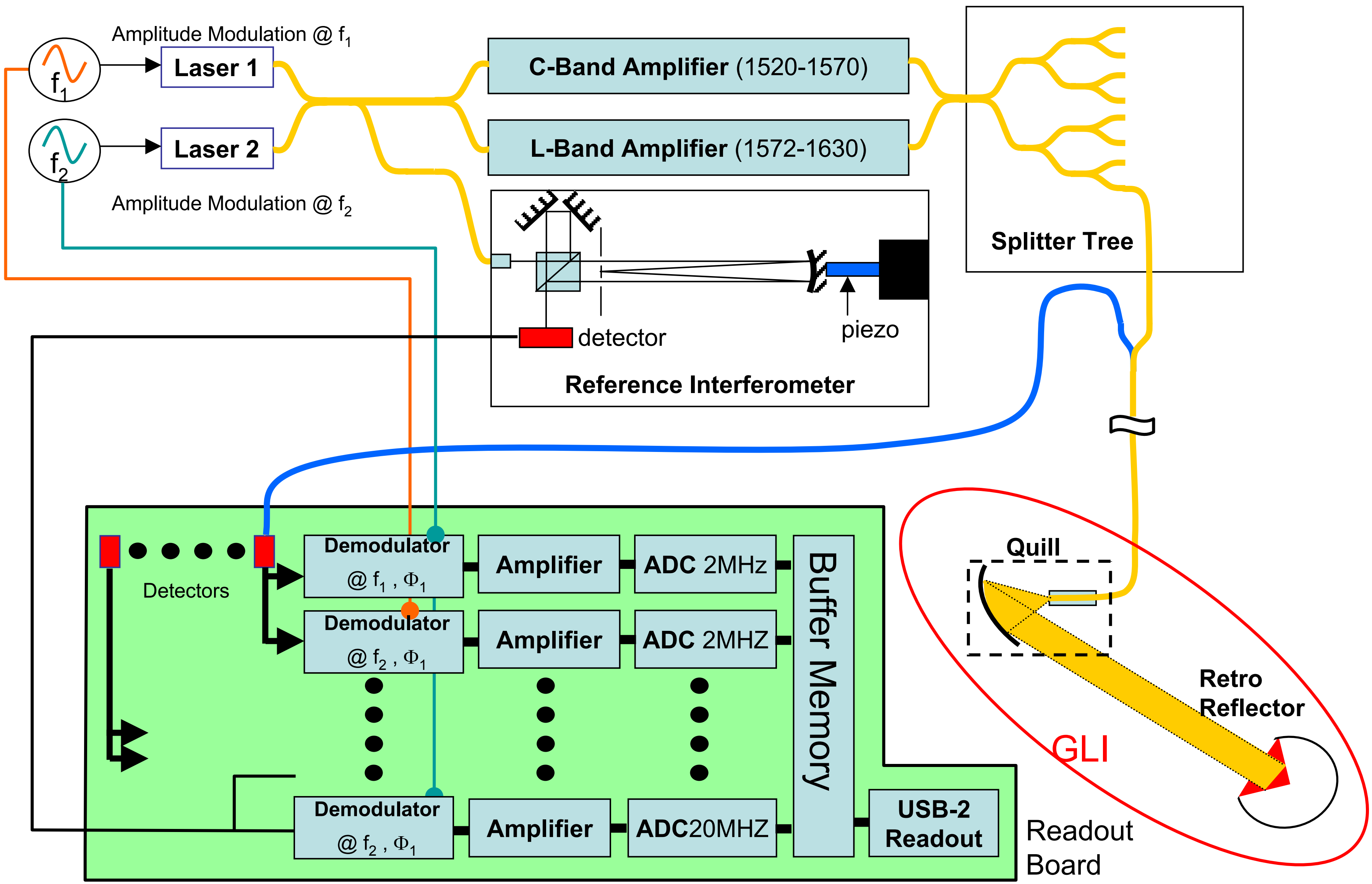
FSI: resolutions

FSI extrapolation

- Today:
  - σ = 117 nm @ L=0.4m
  - σL/L = 0.29 ppm
- Phase I:
  - σ=1 μm @ L=5m
  - σL/L = 0.5 ppm
- Phase II:
  - σ=1 μm @ L=10m
  - σL/L = 0.1 ppm



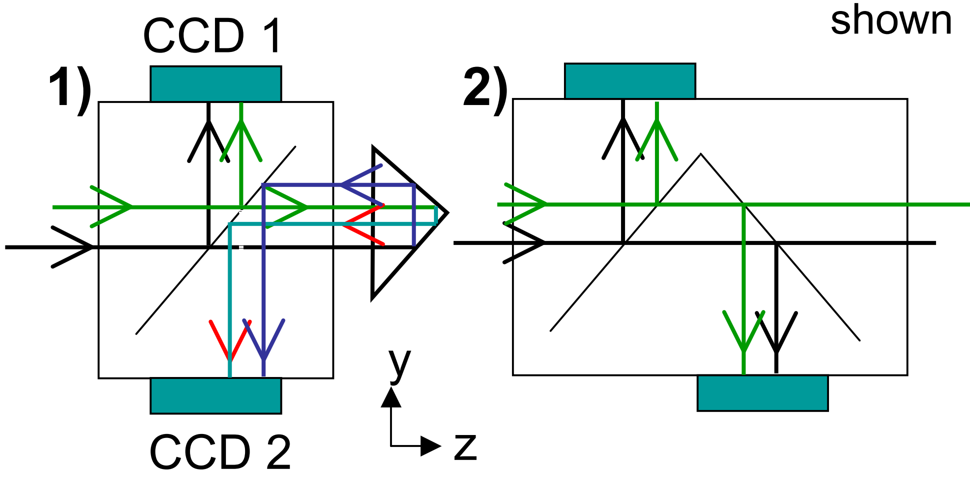
FSI System



Amplitude Modulation @ f_1
f_1
Laser 1
f_2
Laser 2
Amplitude Modulation @ f_2
C-Band Amplifier (1520-1570)
L-Band Amplifier (1572-1630)
Splitter Tree
detector
piezo
Reference Interferometer
Detectors
Demodulator @ f_1 , Φ_1
Amplifier
ADC 2MHz
Demodulator @ f_2 , Φ_1
Amplifier
ADC 2MHZ
Demodulator @ f_2 , Φ_1
Amplifier
ADC20MHZ
Buffer Memory
USB-2 Readout
Readout Board
Quill
Retro Reflector
GLI

Straightness Monitor

- Two parallel laser beams
- Low coherence length diode laser to avoid interference on CCD
- Two possible splitter configurations
- Measure transverse translations
- Need 1μm precision over length of train
- 1:10 demagnification optics to increase dynamic range → 0.1 μm CCD resolution
- Measure rotations around x and y axis



Two beams shown

One beam shown in Configuration 1)

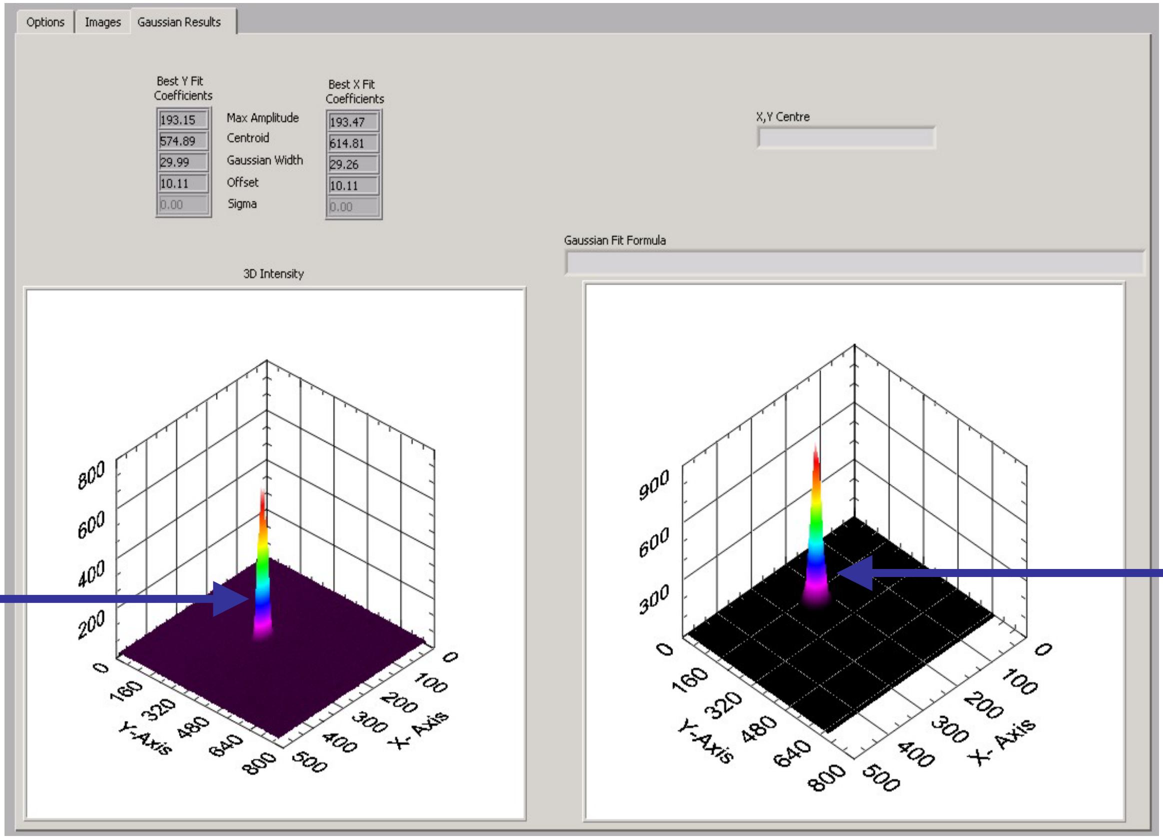
<u>Translation:</u>
Spots move same direction

<u>Rotation:</u>
Spots move opposite directions

SM: Results

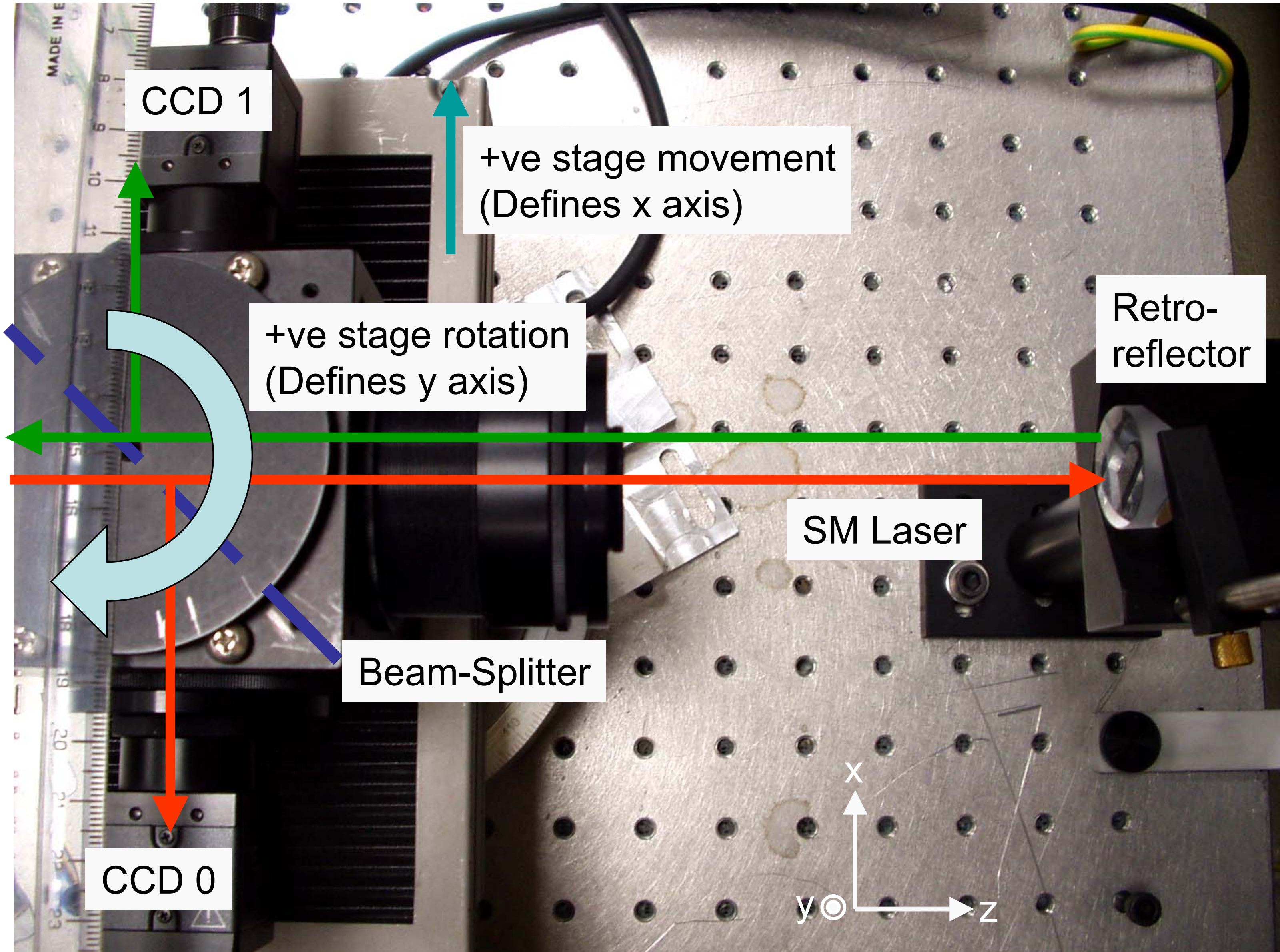
Basic SM optics has been set-up.

Camera looking at low-coherence laser



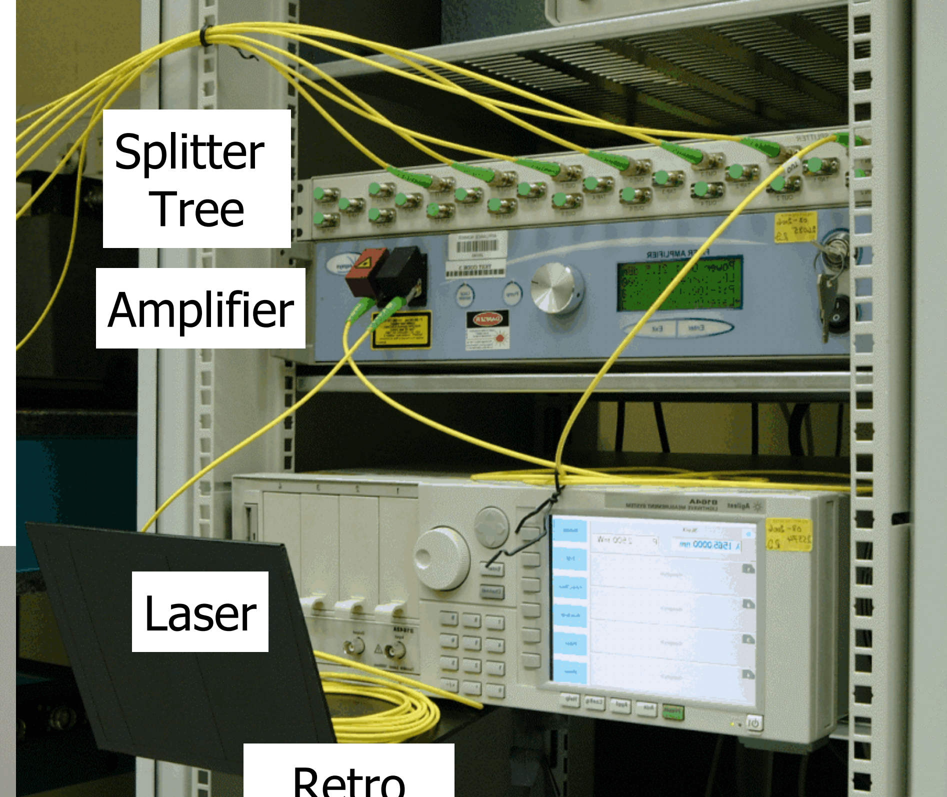
Fitted Gaussian to camera image

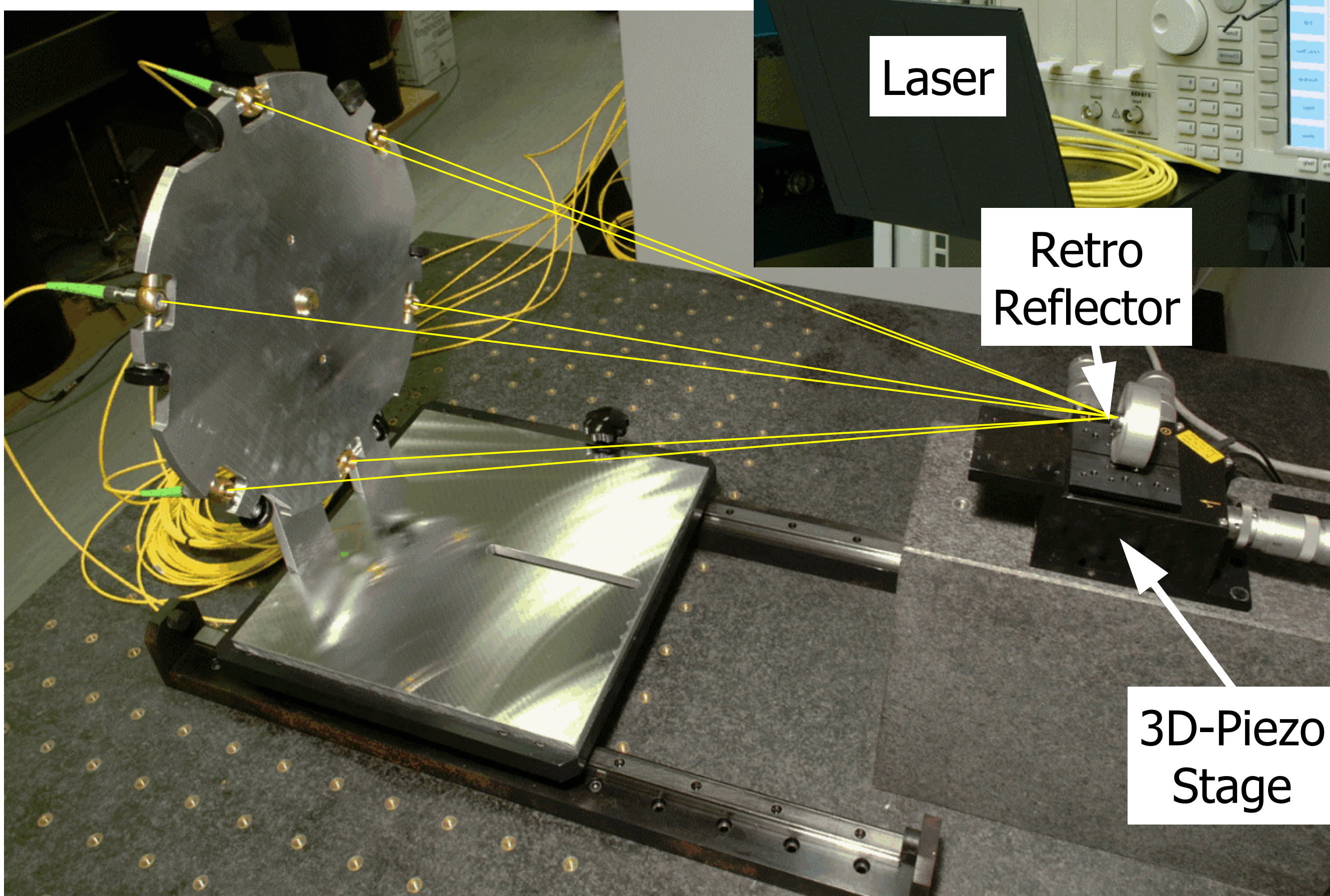
Current SM Setup



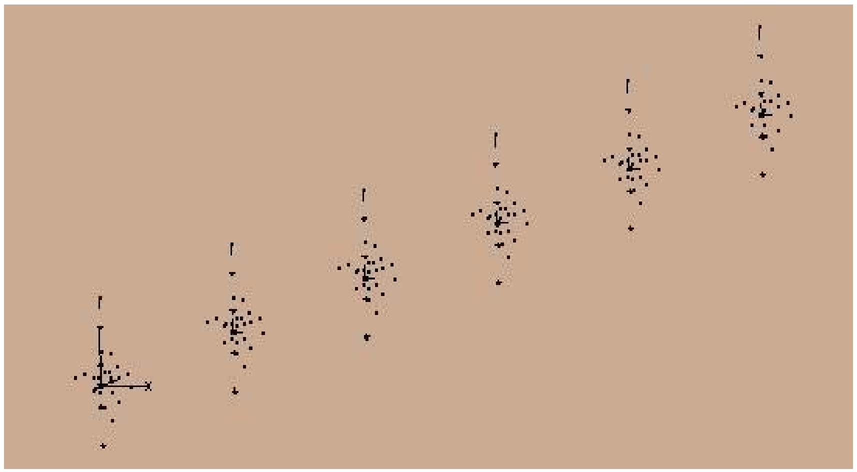
New FSI Work

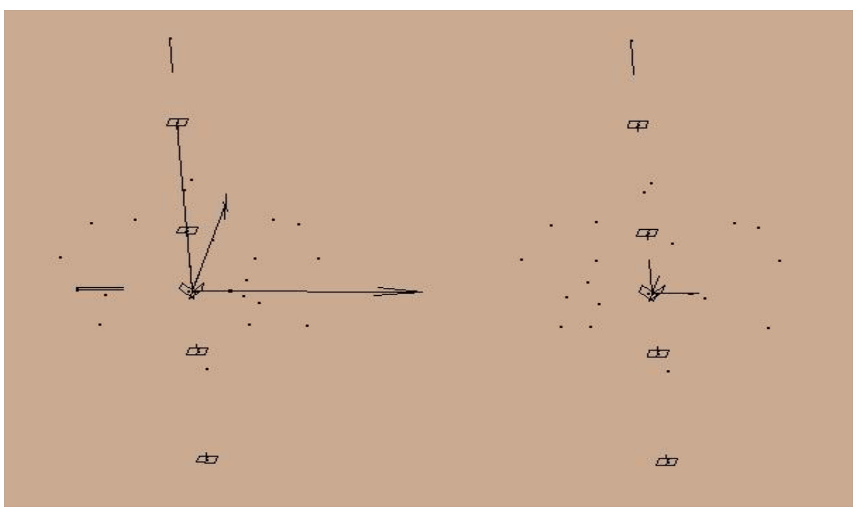
- Short 6-line FSI system for 3D wall marker reconstruction. Expect data December 04





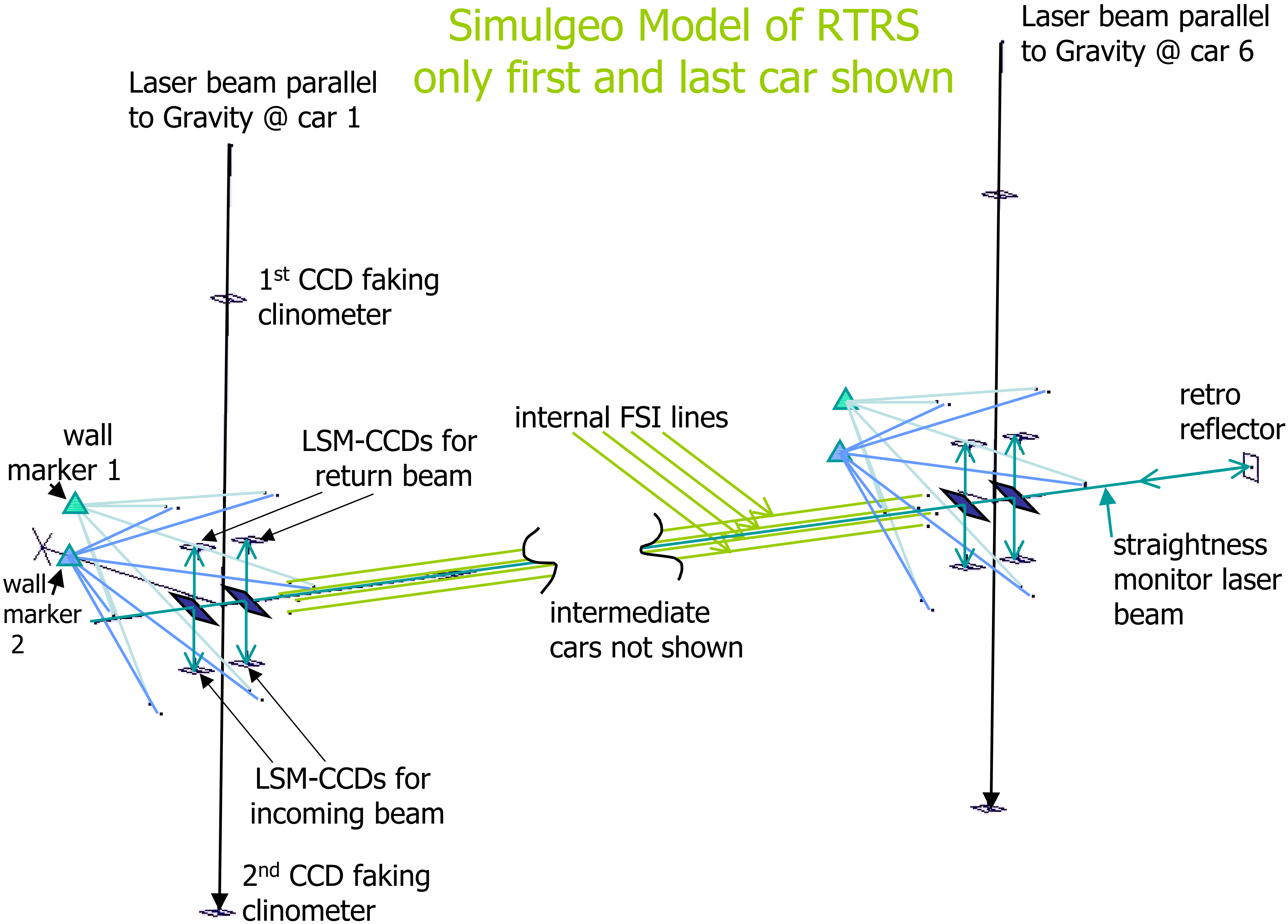
Simulation Software





- Simulgeo: simulation and reconstruction software for optogeometrical systems.
- (L. Brunel, CMS note 1998/079)
- Many features:
  - Laser beams
  - CCD cameras
  - Mirrors
  - Distancemeters
  - ...
- Description of mechanical support by grouping various objects into local frames

Simulgeo Model of RTRS
only first and last car shown



Next Mile-Stones

- Full custom DAQ by end 2004
- Full sensor integration by spring 2005
- First car works in Oxford Summer 2005
- 3-car LiCAS prototype in DESY tunnel by autumn 2005
- The 3-car prototype works end 2005
- Next generation train for X-FEL mid 2006

Future Plans

- Get 2nd generation LiCAS train into X-FEL tunnel
- Stake-Out instrument to measure accelerator components against wall markers
- Michelson enhanced FSI (M-FSI) for fast stabilisation of final focus magnets
- Accelerator simulations with realistic survey boundary conditions
- Fiducialisation of accelerator components