Zróbmy to prosto

(czyli jak ustawić akcelerator liniowy)

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LiCAS

Linear Collider Alignment & Survey

Seminarium Fizyki Wielkich Energii; Warszawa; 14 X 2005

Linear Collider Challenge

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

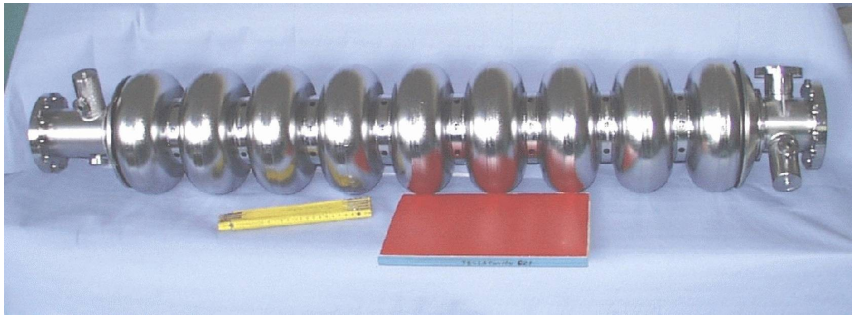
Outline

- Motivation for Linear Collider
- Importance of Accelerator Alignment
- Proposed Solution: New Instrument
- Technology used: FSI and LSM
- Performance Simulations
- Summary/Plans

Current LC R&D Efforts

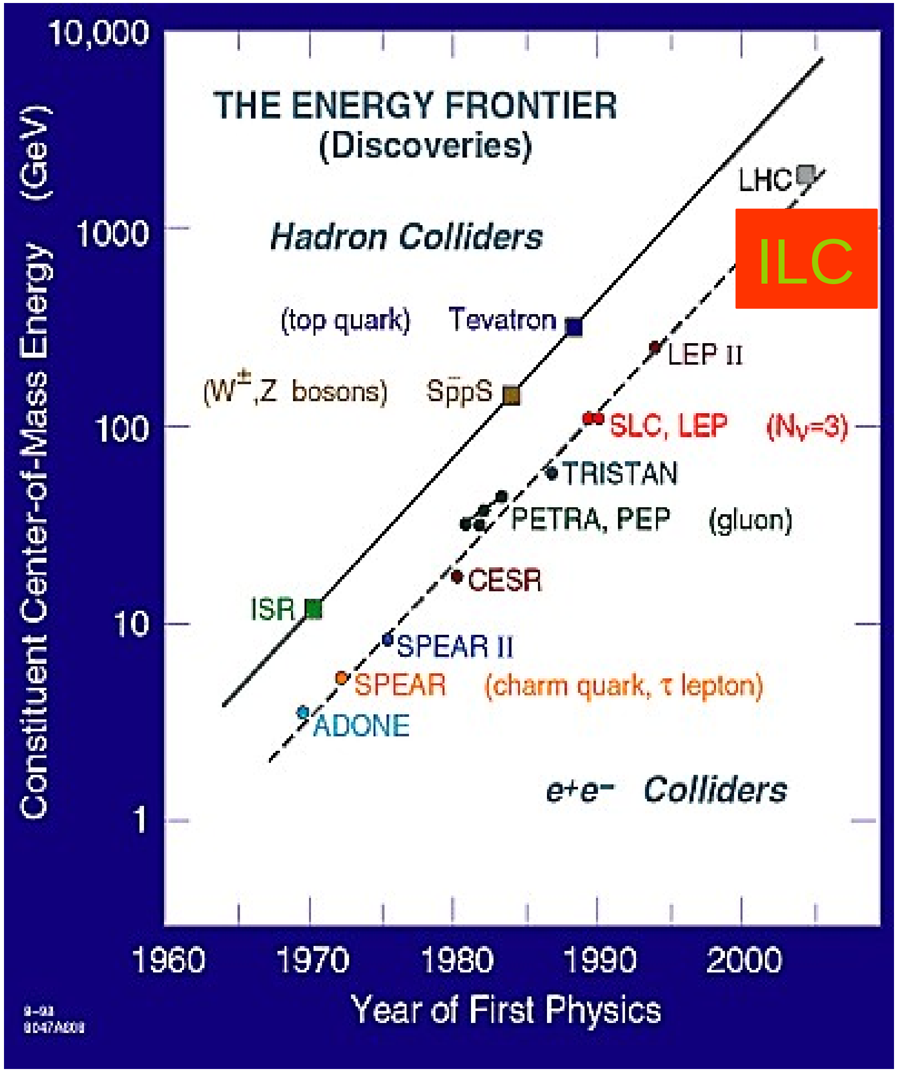
The ILC will be based on SCRF (TESLA Technology), but will be designed by a global collaboration.

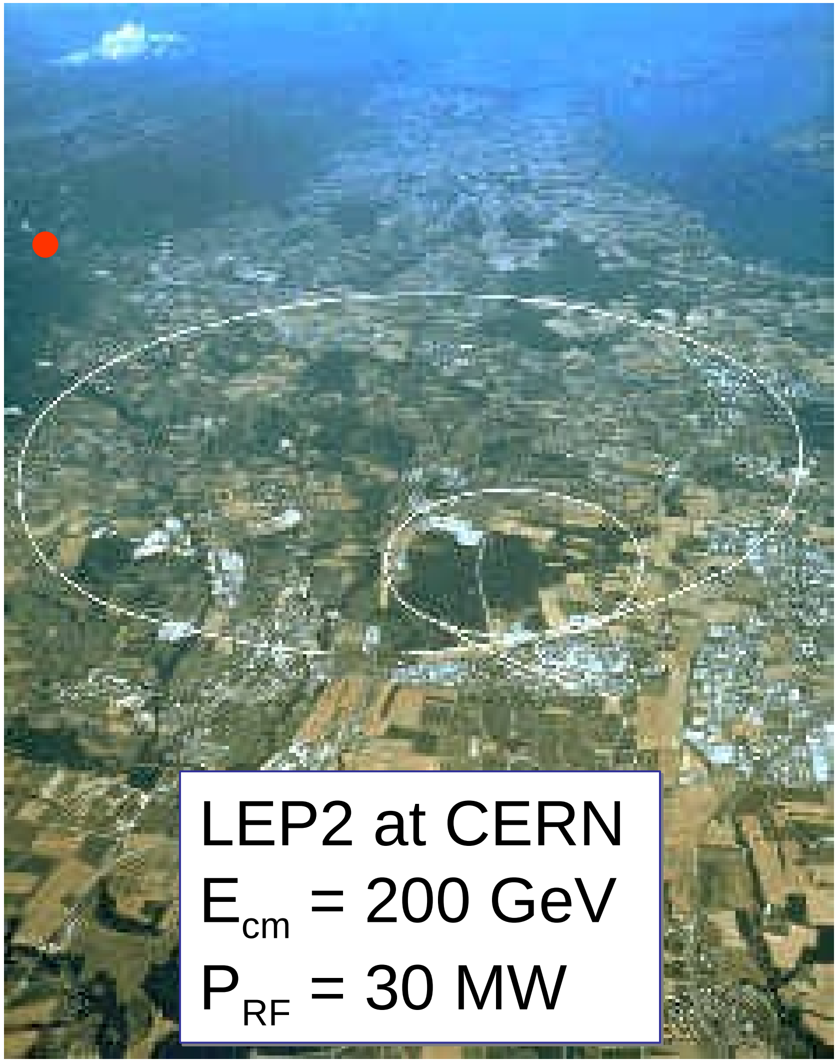
Much of the layout & parameters will be re-evaluated in light of what has been learnt over the last few years (US-Options study (NLC), JLC,…)



R&D on the two-beam CLIC concept continues as possible future path to multi-TeV

Colliders Energy Frontier

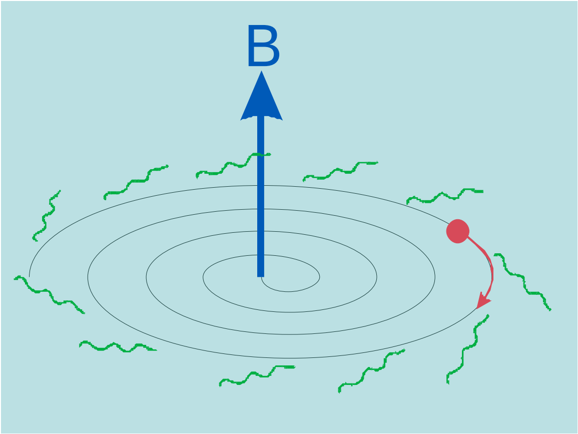




Why build linear collider ?

Synchrotron Radiation:

$$\Delta E / rev = \frac{C_\gamma E^4}{\rho} \qquad P_\gamma = \frac{e^2 c^2}{2\pi} C_\gamma E^2 B^2$$



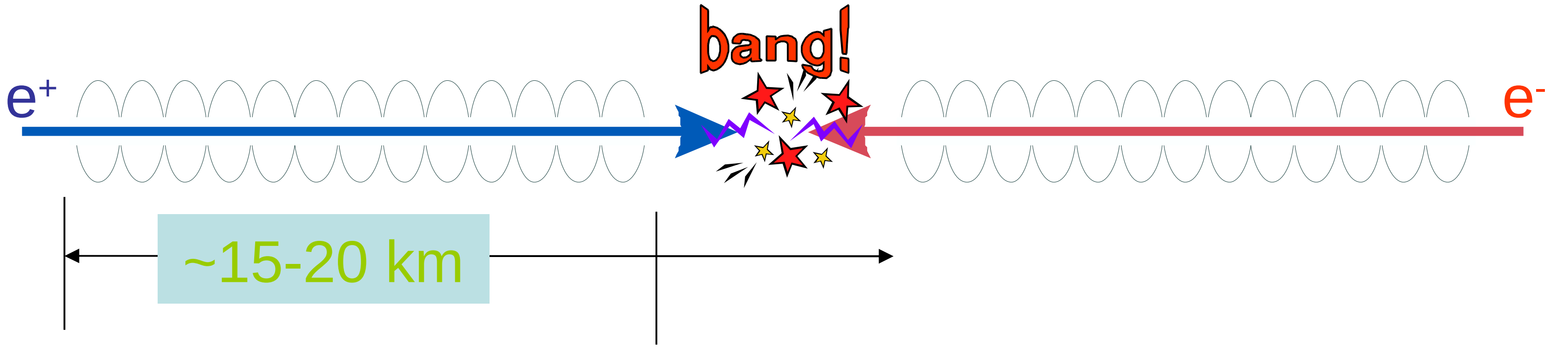
- **For ~1% Synchrotron radiation loss**

	LEP II	Super-LEP
Energy	200 GeV	500 GeV
dE / Rev	2.0 GeV	5 GeV
Radius	4.3 km	168 km

Energy loss must be replaced by RF system
cost scaling \$ $\propto E_{cm}{}^2$

Solution: Linear Collider

No Bends, but *lots* of RF!



For a E_{cm} = 1 TeV machine:

Effective gradient G = 500 GV / 15 km

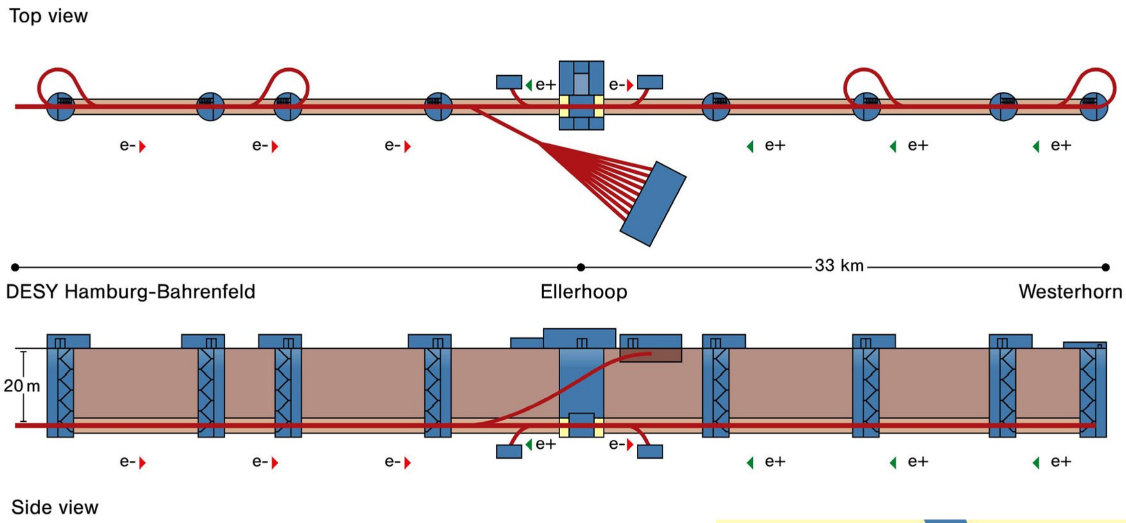
~ 35 MV/m

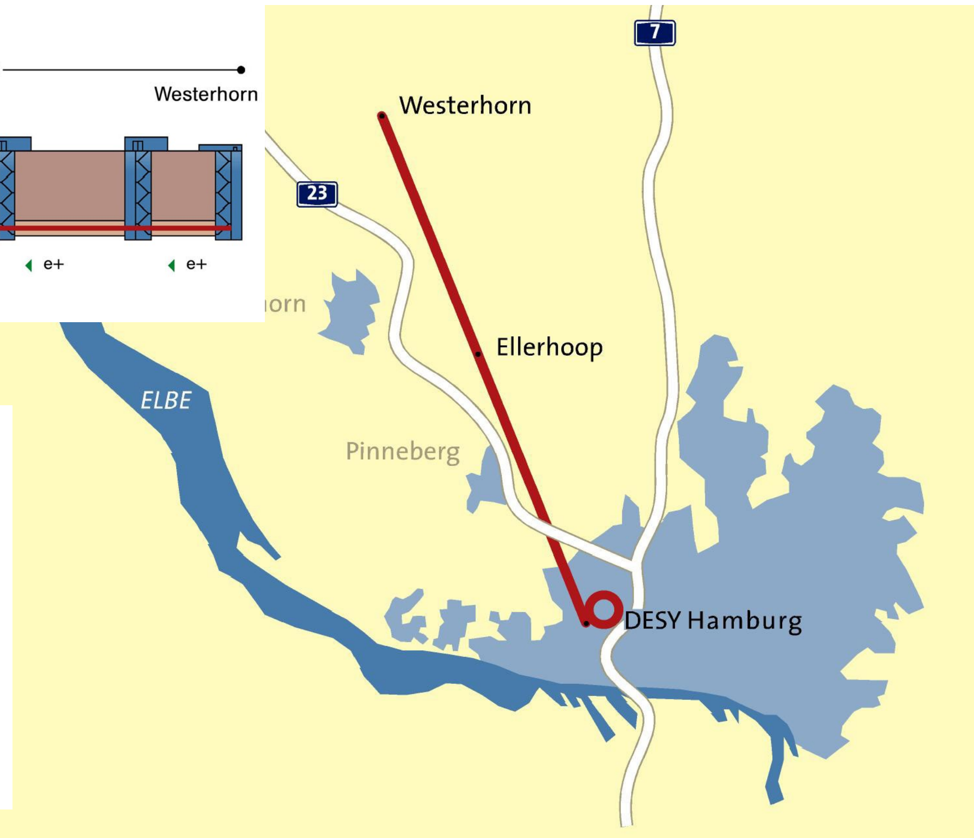
Note: for LC, $\$_{tot} \sim E$

However: Perfect Alignment crucial for High Luminosity

Linear Collider

(for example Tesla)





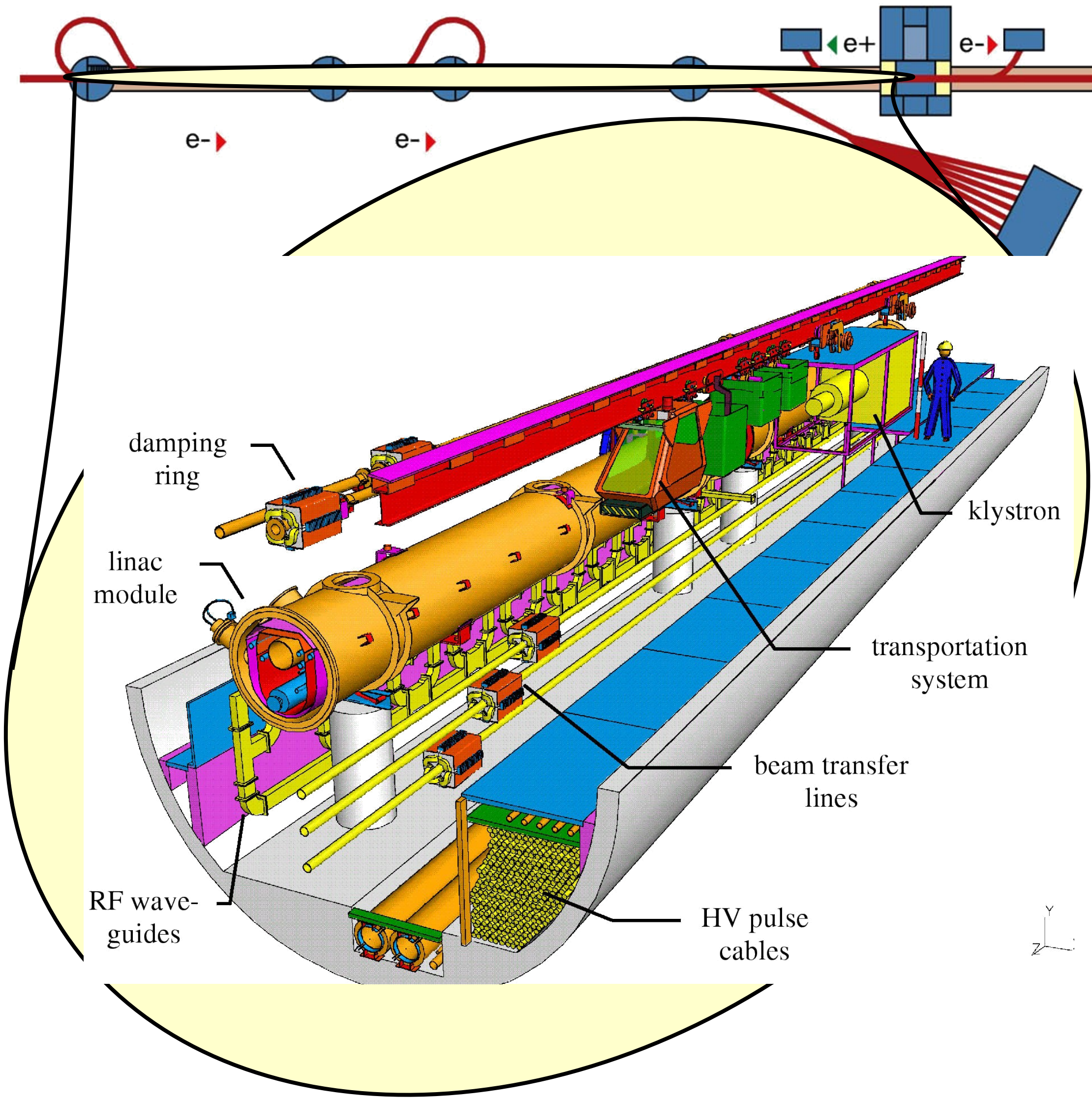
- Beam energy O(500GeV)
- Beams start at O(0.1μm)
- beams end up O(1nm) at interaction point
- no recirculation, you just have one shot to collide a given bunch

Survey Problem

(survey happens often)

- Continuously survey tunnel during construction
- Frequently survey empty tunnel to determine if it has settled sufficiently to install collider.
- Survey collider during installation.
- Re-survey parts of collider when alignment problems arise.
- Re-survey parts of collider during maintenance, component exchange, other instrument installation.
- Survey final focus parts after experiment access

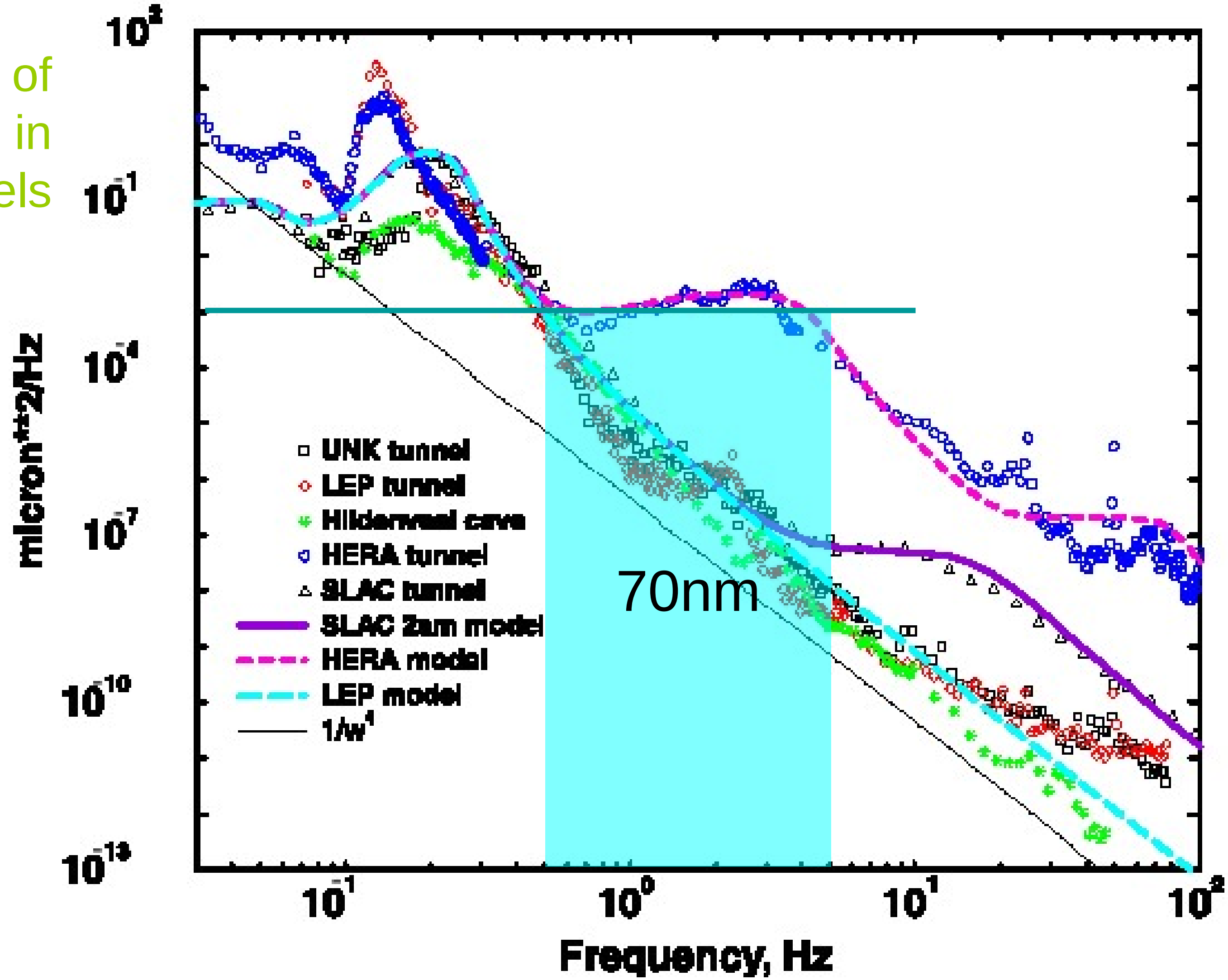
Survey and Alignment Problem



- Long tunnel (~30 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

LCs move… (time scales of ground motion)

Powerspectrum of ground motion in various HEP tunnels



LEP:
60 to 180 μm/year

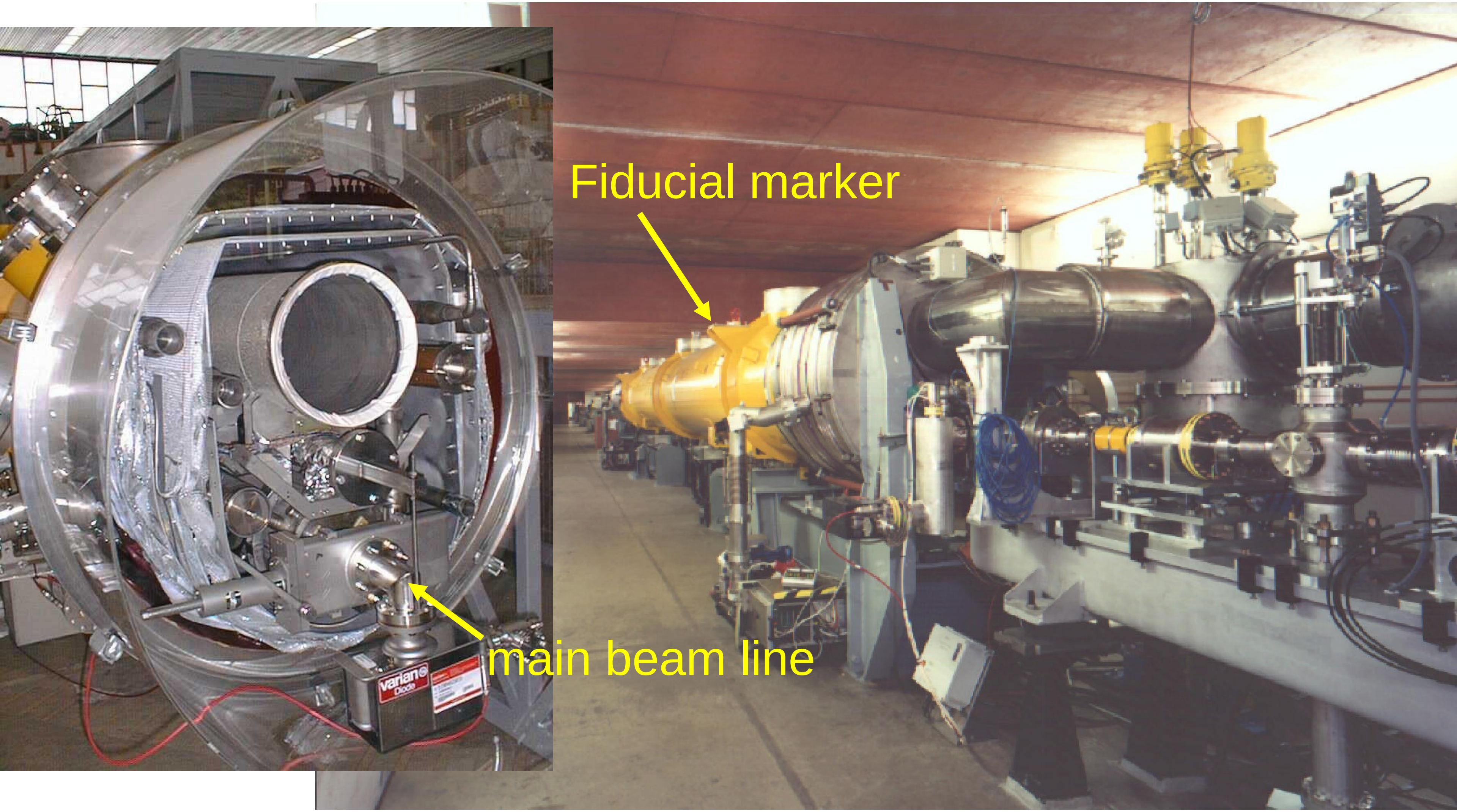
The ILC survey and alignment process
(in the tunnel)

- Reference survey (the hard part): s<200microns/600m
  - **establish co-ordinates of regular array of reference markers along entire tunnel wall**
- Stake out: s<50microns any point
  - **Relate external accelerator component's markers to reference markers**
- Alignment: s<100microns any point
  - **adjust position of accelerator element to get closer to nominal**

The ILC survey and alignment process
(outside the tunnel)

- Fiducialisation:
  s~200 microns
  - **Relate external markers to relevant active centre line of accelerator element**
- Build tolerances:
  - **Internal to an accelerator element** s~100microns
    - **static variation of several active elements around the centre line (scatter of cavities in cryo-module)**
    - **dynamic changes of elements with load, current, trim, external temperature, etc.**

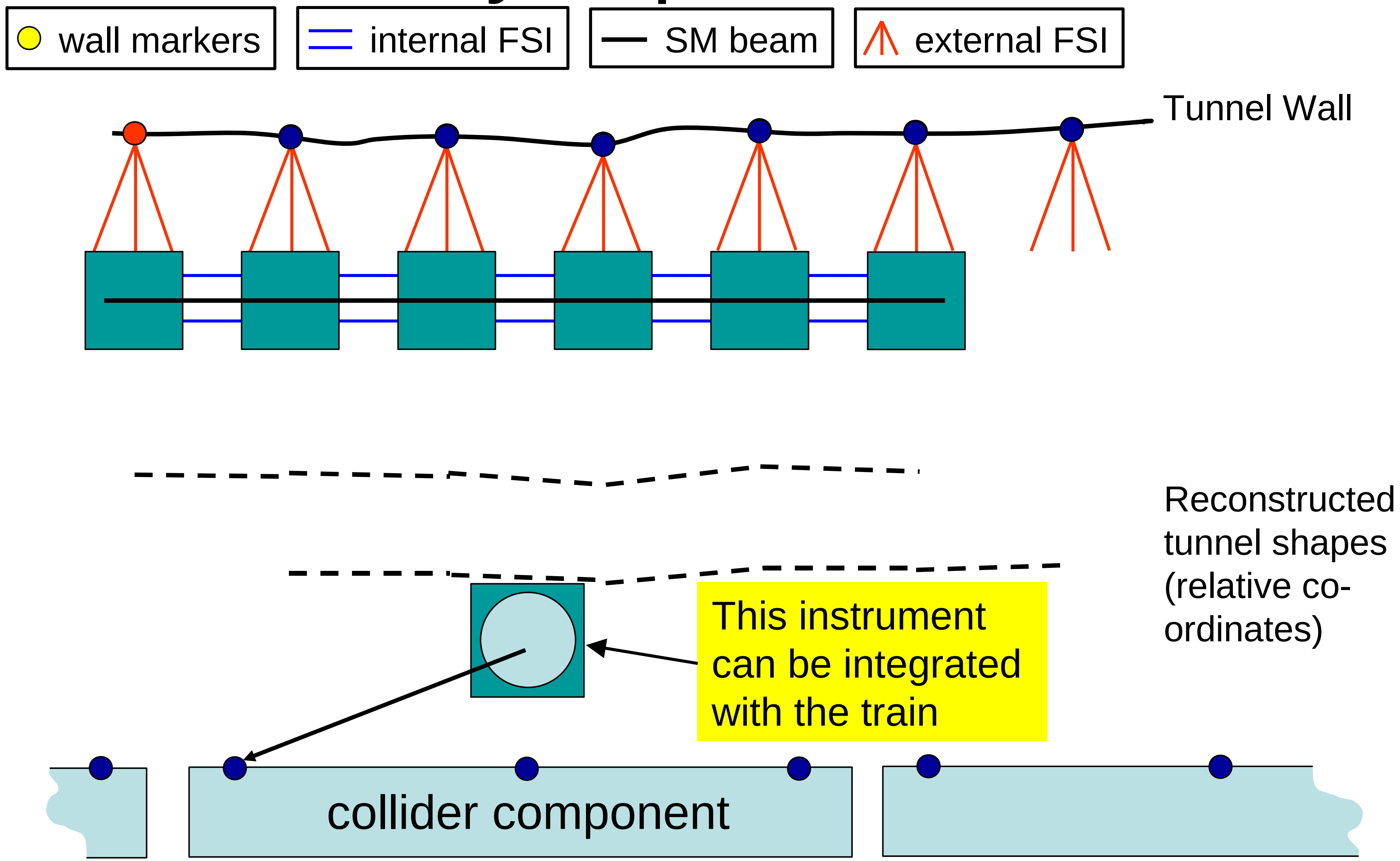
TTF: cryo-module structure



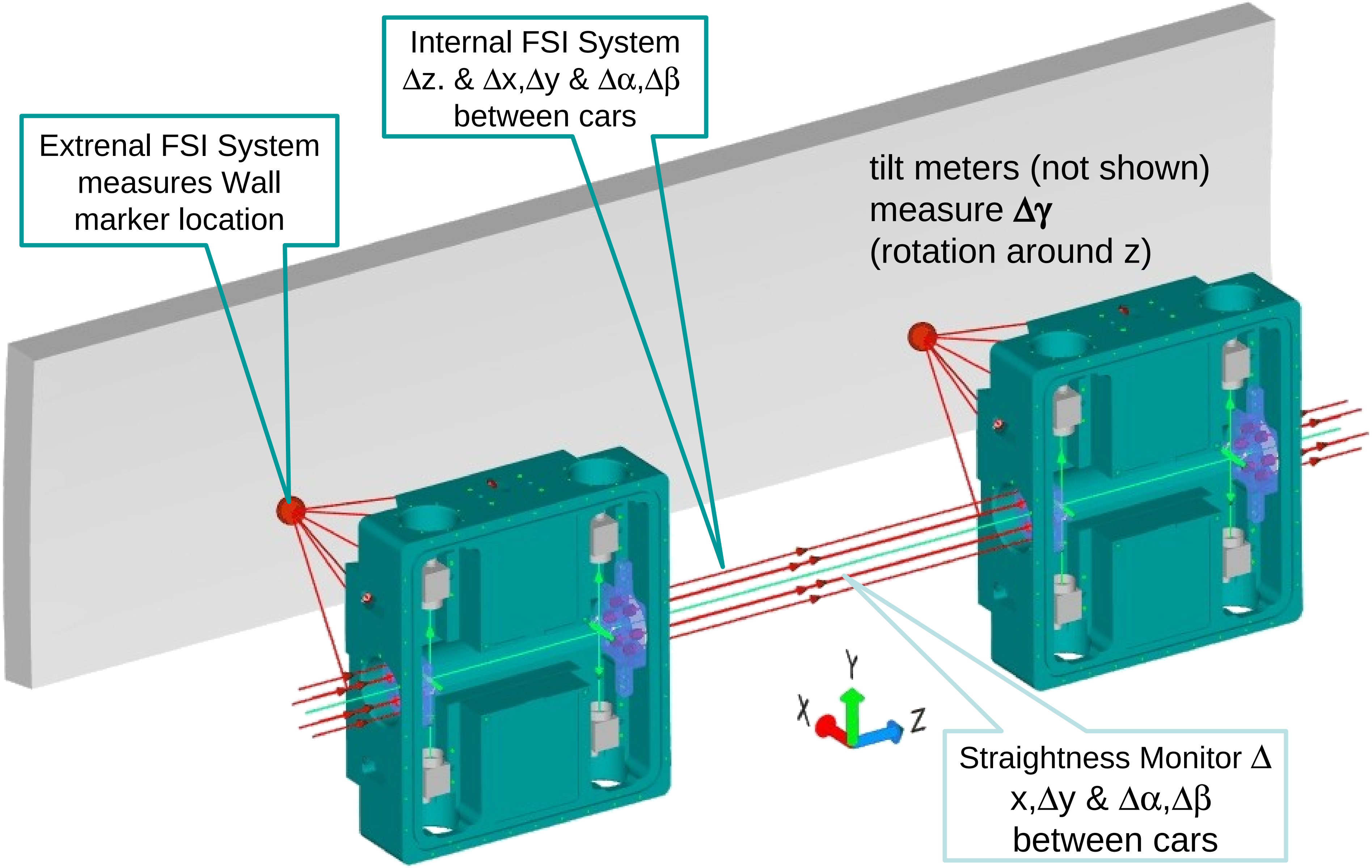
Survey and Alignment: novel solutions needed

- **TESLA Specification (reference survey):**
  - **200 µm vertical over 600 meters (=betatron wavelength)**
- Open air survey too slow and too inaccurate
- Need new instrument that matches requirements
  RTRS (Rapid Tunnel Reference Surveyor)
- New technology : FSI – Frequency Scanning Interferometry (interferometric distance measurement) and Laser Straightness Monitors (LSM)
- Automated measurement needed

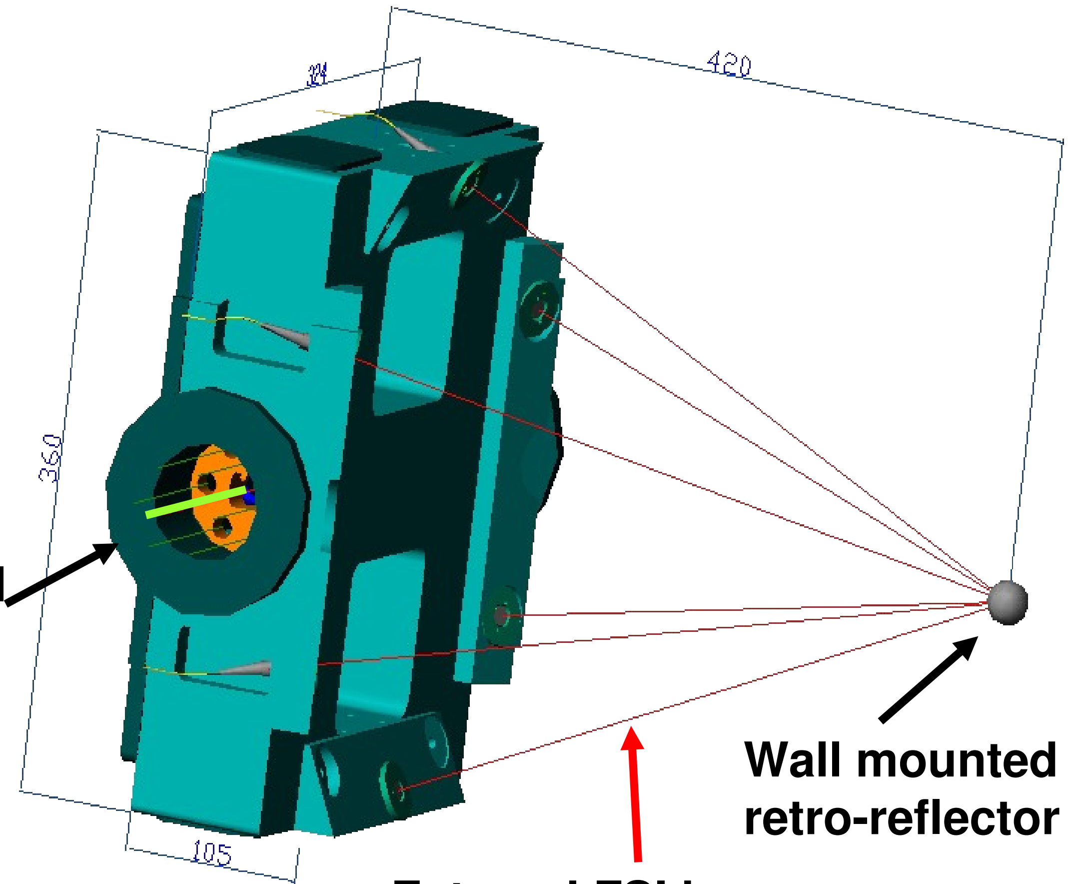
Survey Implementation



LiCAS sensing modules



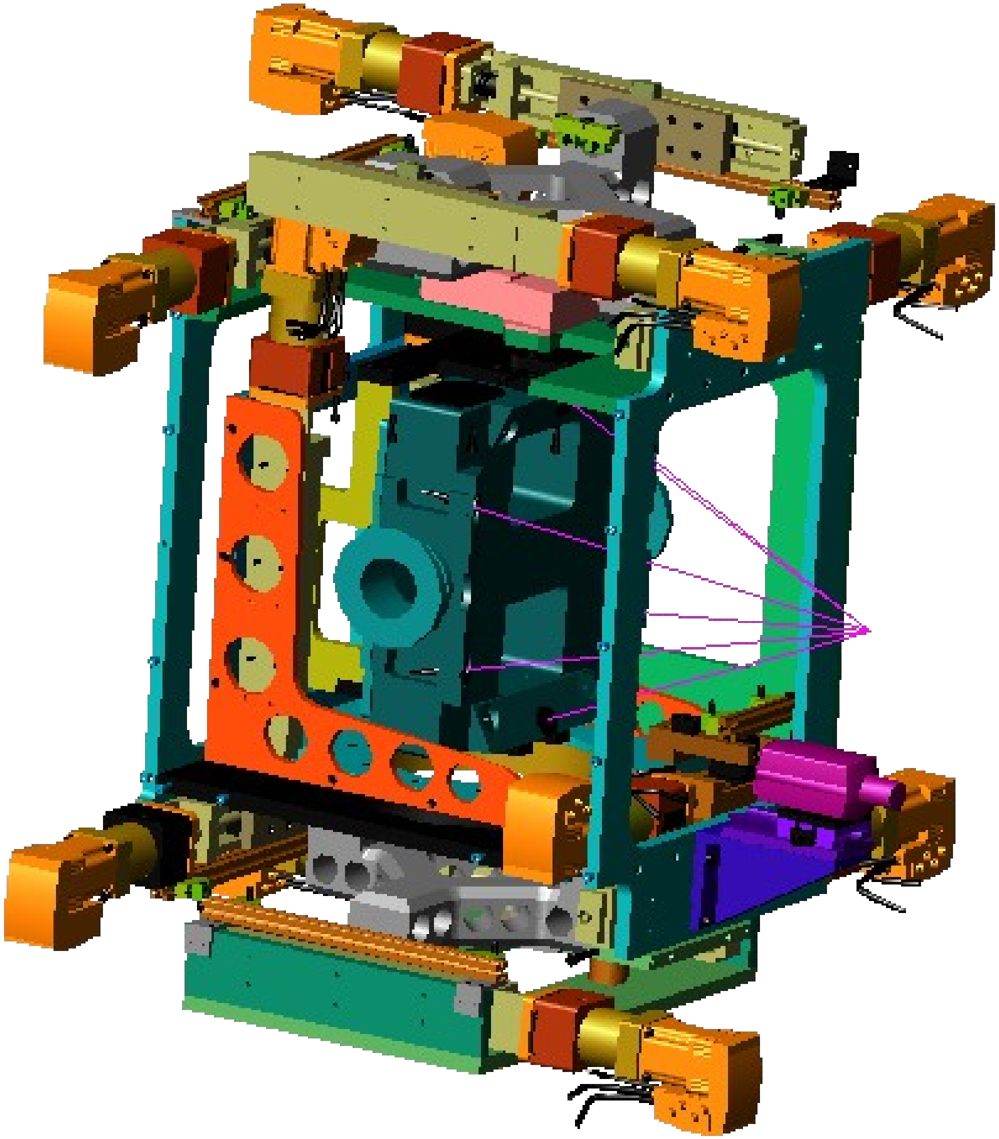
LiCAS Measurement Unit



- **Internal FSI lines operate in vacuum**
- **Scalable TELECOM style infrared lasers**
- **EDFA light amplifiers**

All measurements in mm

Inner Chassis



- Inner Chassis provides
  - 6-DOF motion for unit alignment
  - vibration damping
  - sensing of tunnel bar codes

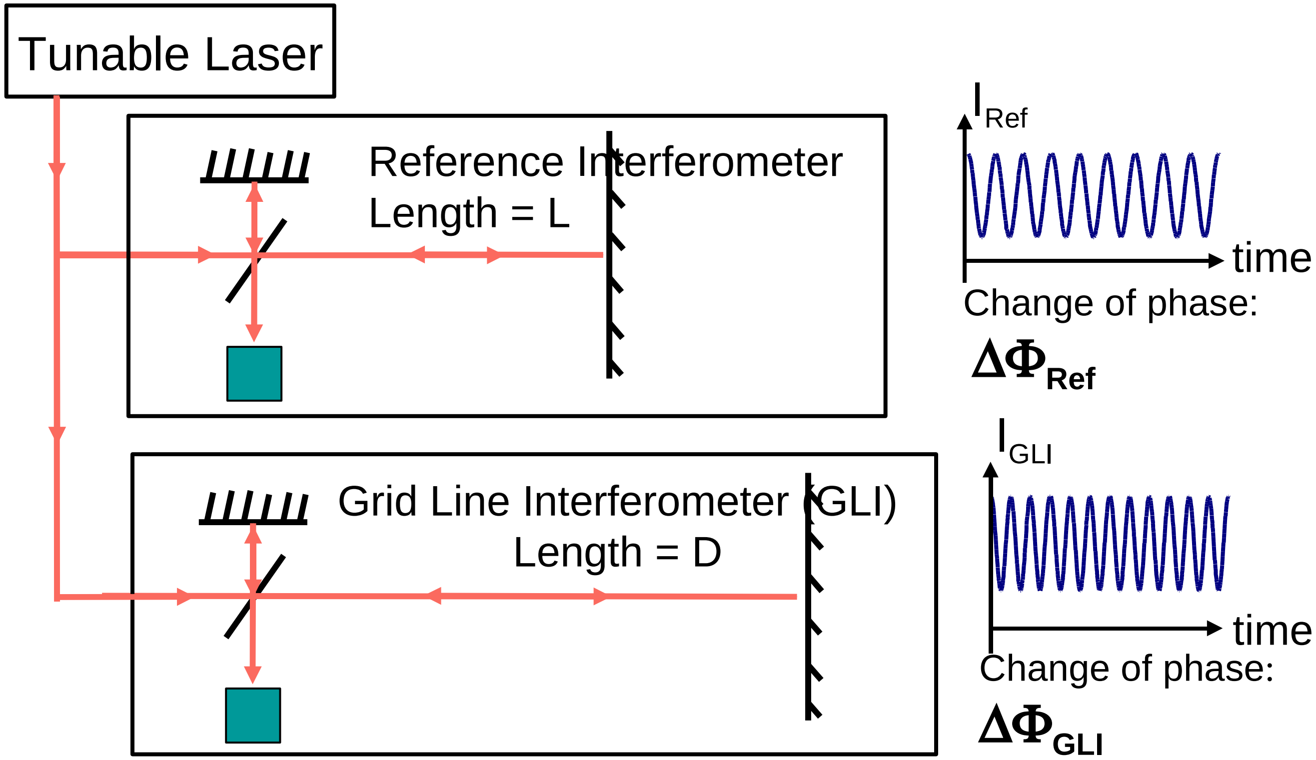
Previous Generation RTRS (DESY)

FSI =

Frequency Scannig Interferometry

FSI Principle

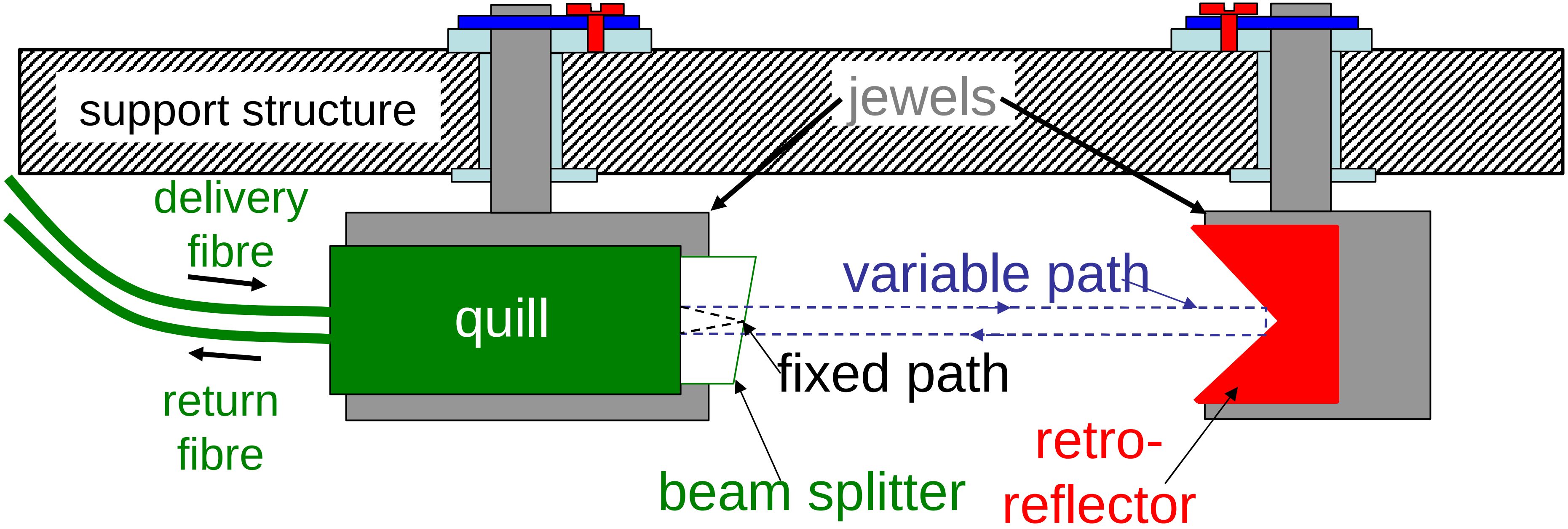
- Interferometric ABSOLUTE length measurement system
- Originally developed at Oxford for online alignment of ATLAS SCT tracker
- Measurement precision is 1μm over 5m



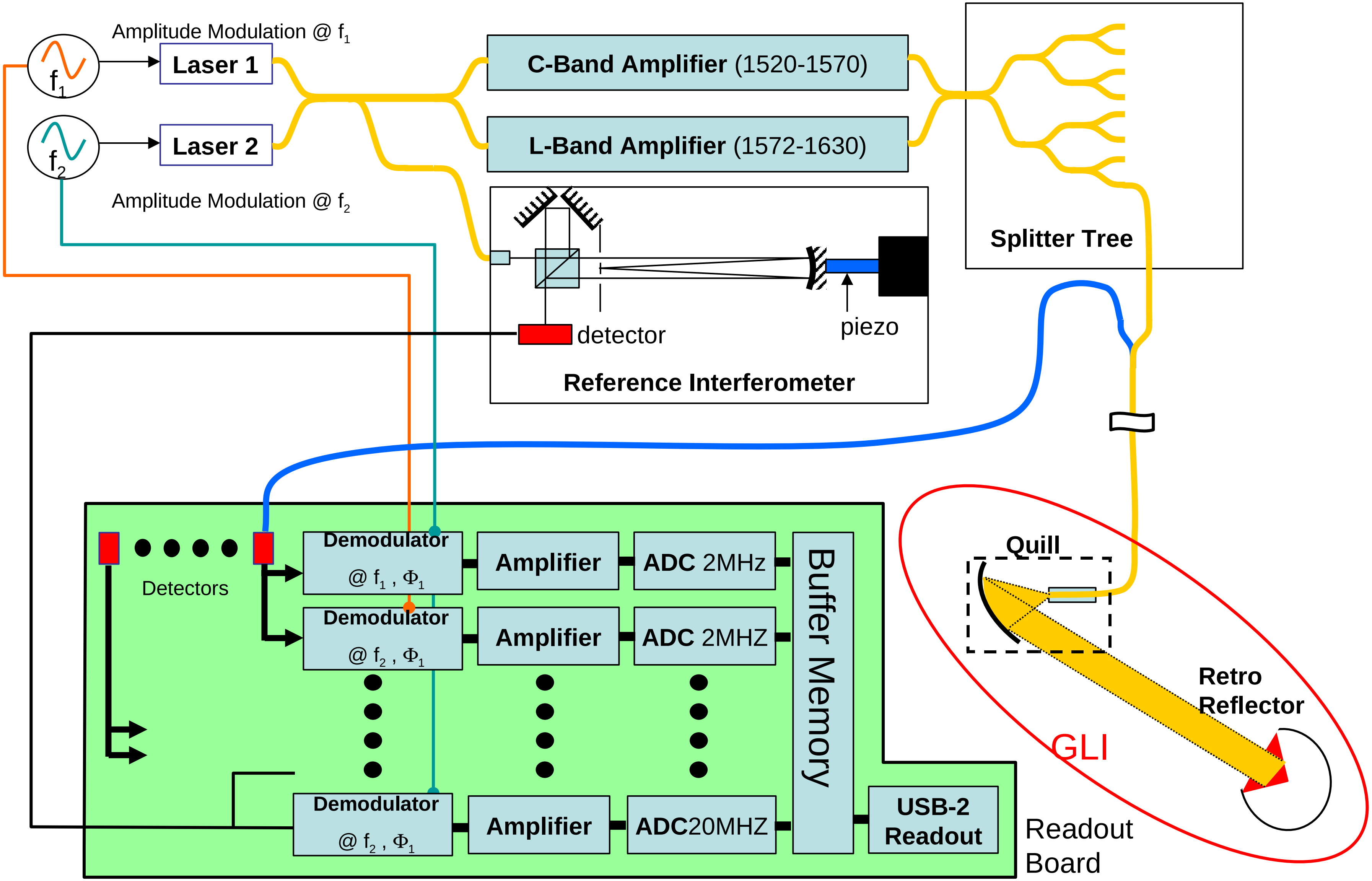
$$\frac{\Delta\Phi_{Ref}}{\Delta\Phi_{GLI}} = \frac{L}{D}$$

FSI (cont.)

- GLI's do the length measurement



FSI System



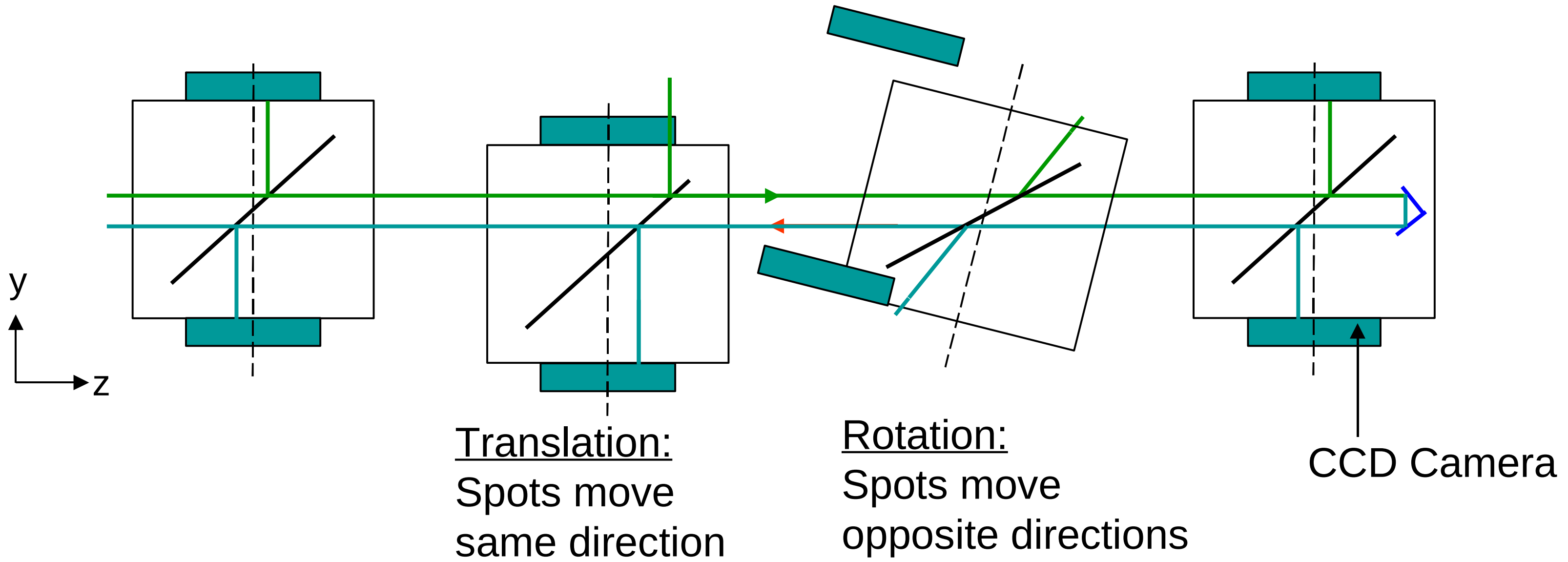
Amplitude Modulation @ f1
f1
Laser 1
f2
Laser 2
Amplitude Modulation @ f2
C-Band Amplifier (1520-1570)
L-Band Amplifier (1572-1630)
Splitter Tree
detector
piezo
Reference Interferometer
Detectors
Demodulator @ f1 , Φ1
Demodulator @ f2 , Φ1
Demodulator @ f2 , Φ1
Amplifier
Amplifier
Amplifier
ADC 2MHz
ADC 2MHZ
ADC20MHZ
Buffer Memory
USB-2 Readout
Readout Board
Quill
Retro Reflector
GLI

LSM =

Laser Straightness Monitor

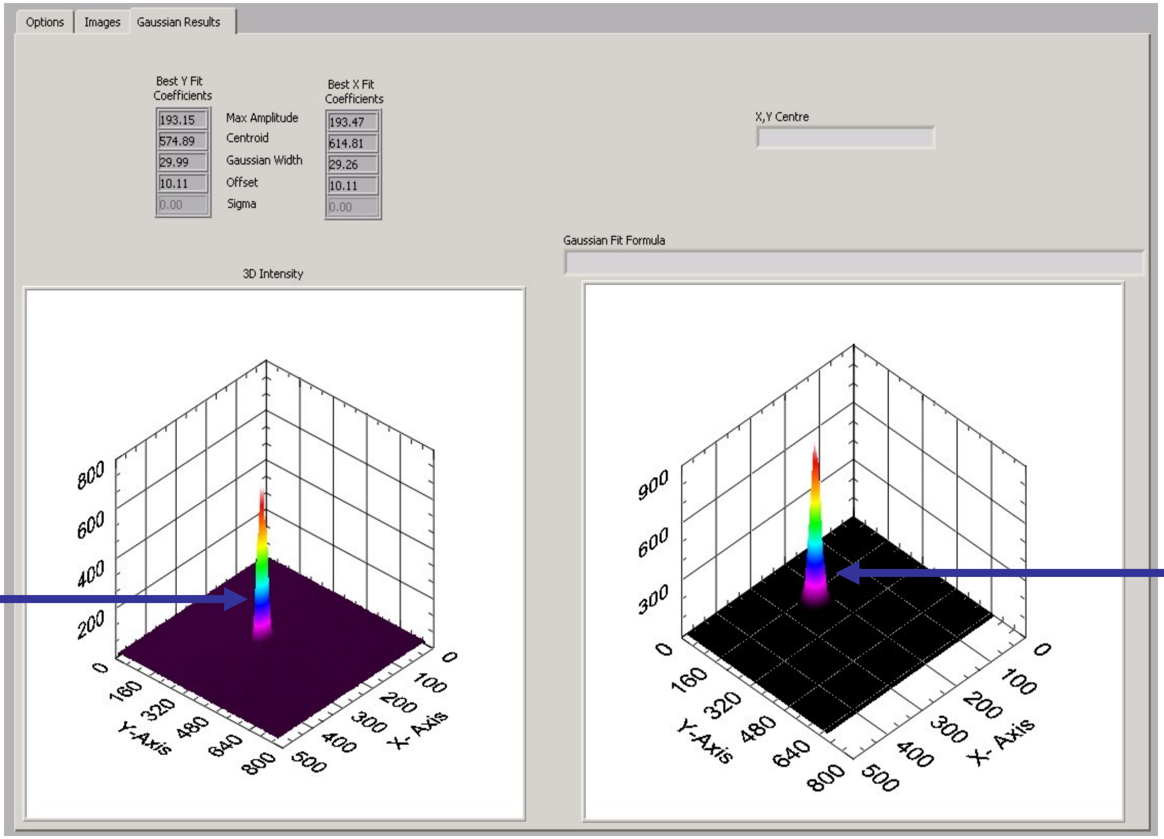
LSM Principle

- Light beam define the reference straight line
- Used to measure carriage transverse translations and rotations
- Low coherence length diode laser to avoid interference on CCD
- Aprox. 1micron precision over length of train



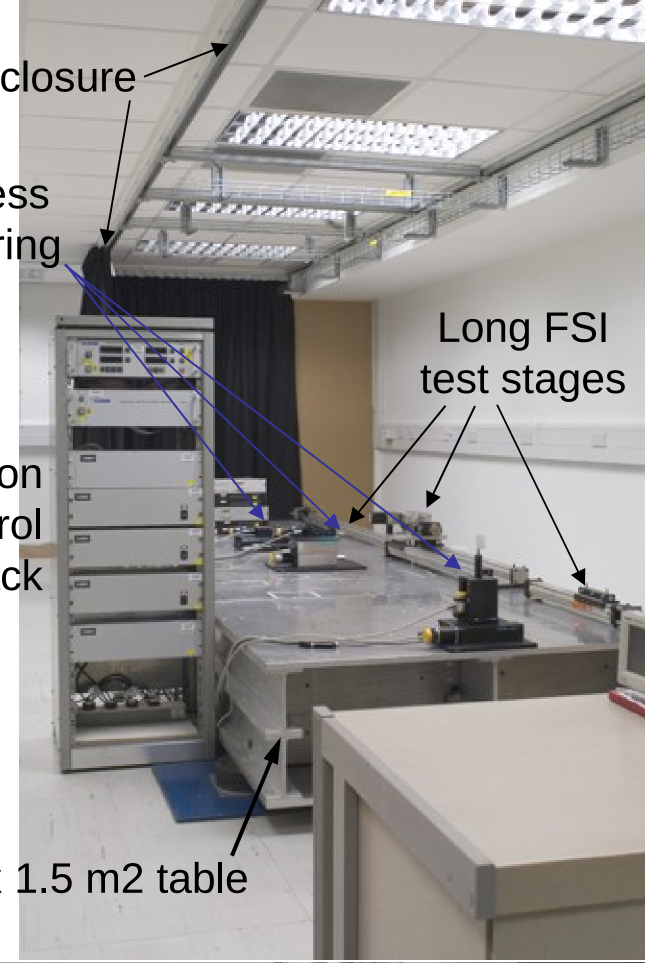
LSM: LAB tests

Camera looking at low-coherence laser

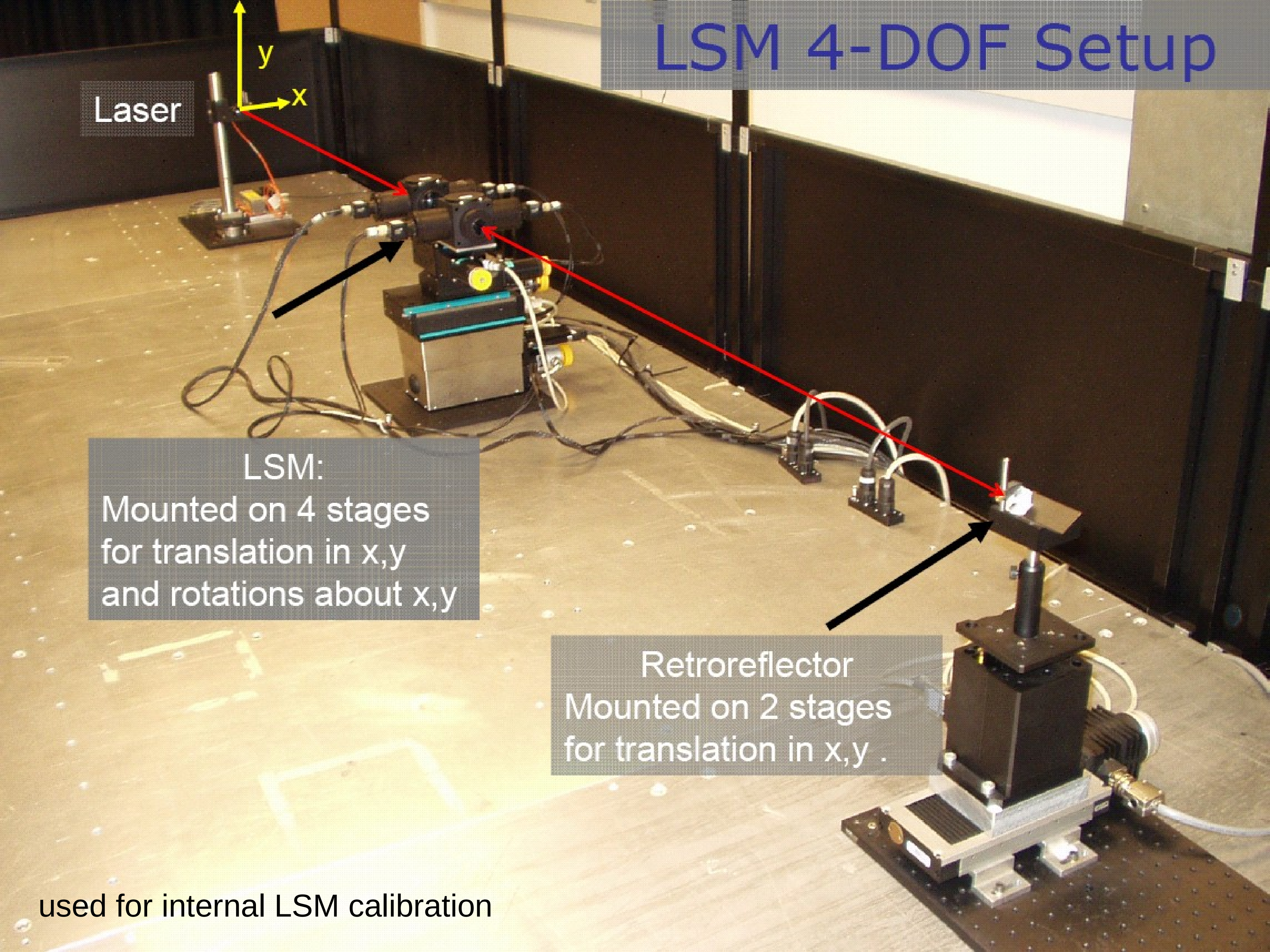


Fitted Gaussian to camera image

LiCAS Lab @Oxford



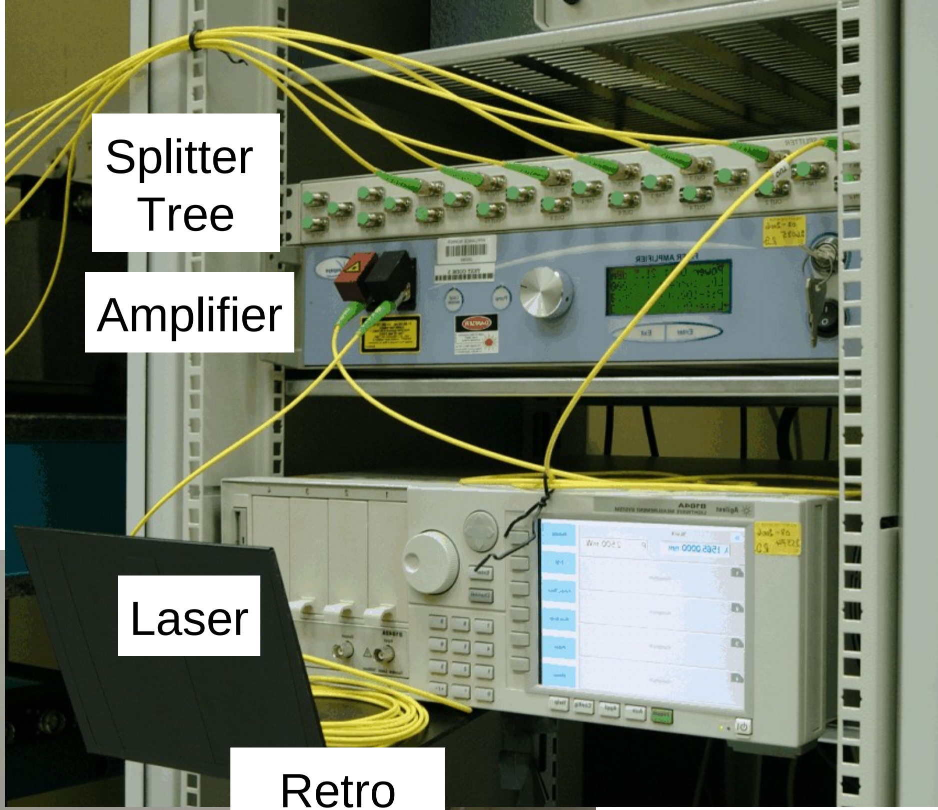
LSM 4-DOF Setup

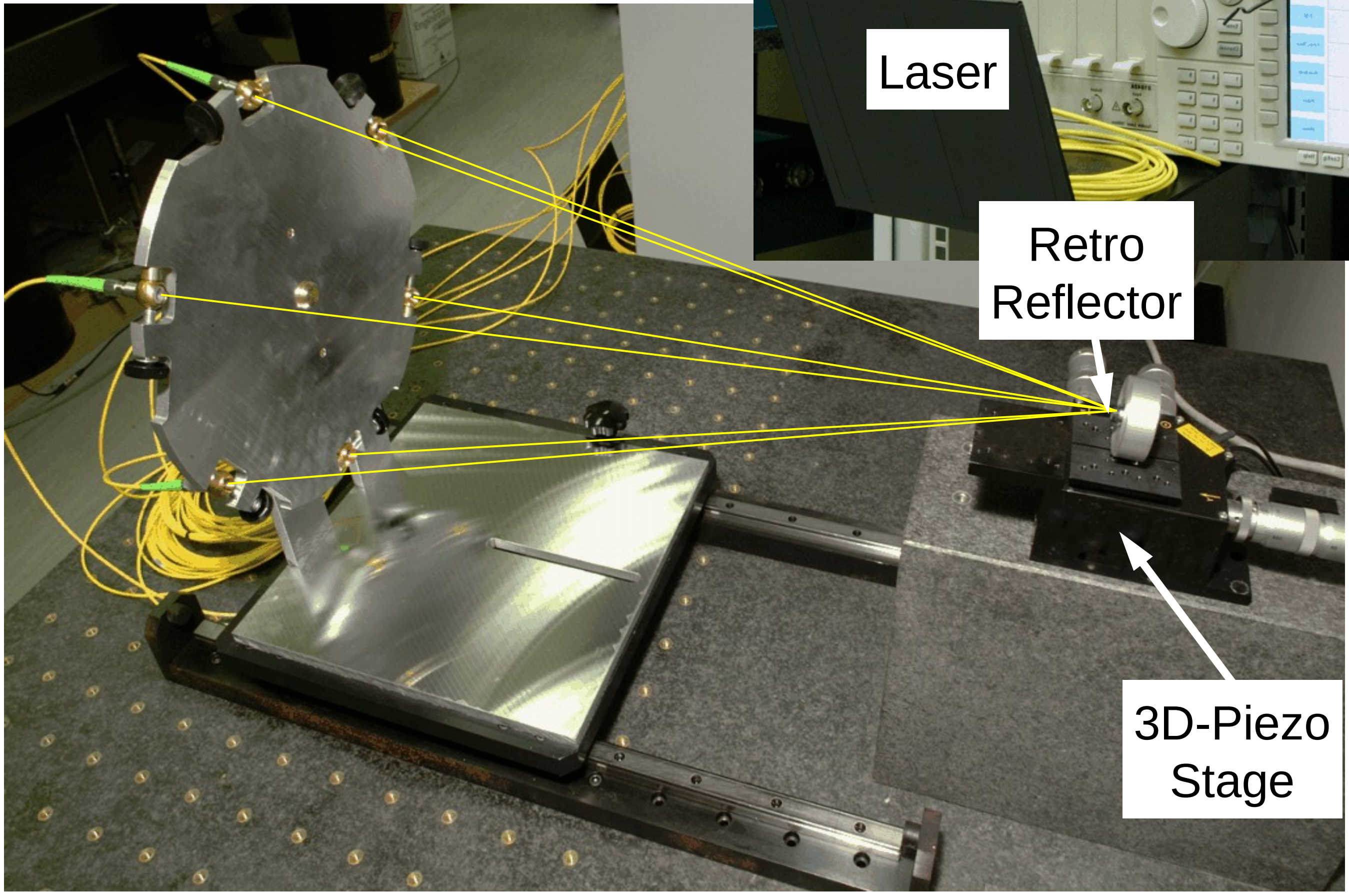


used for internal LSM calibration

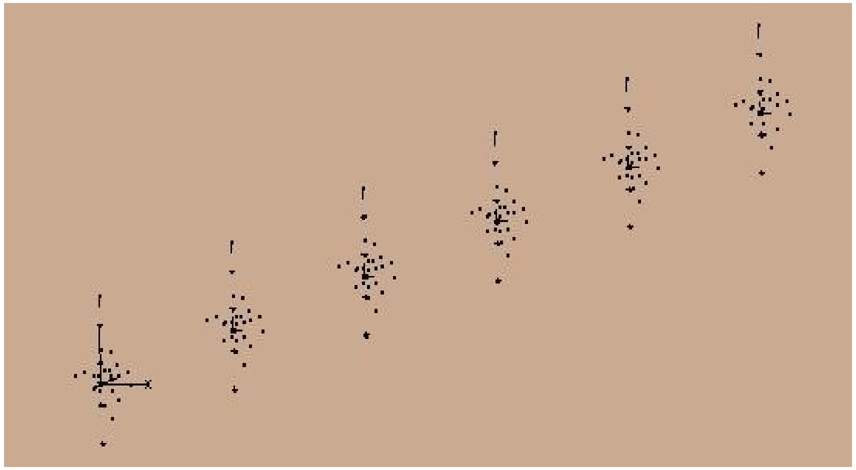
New FSI Work

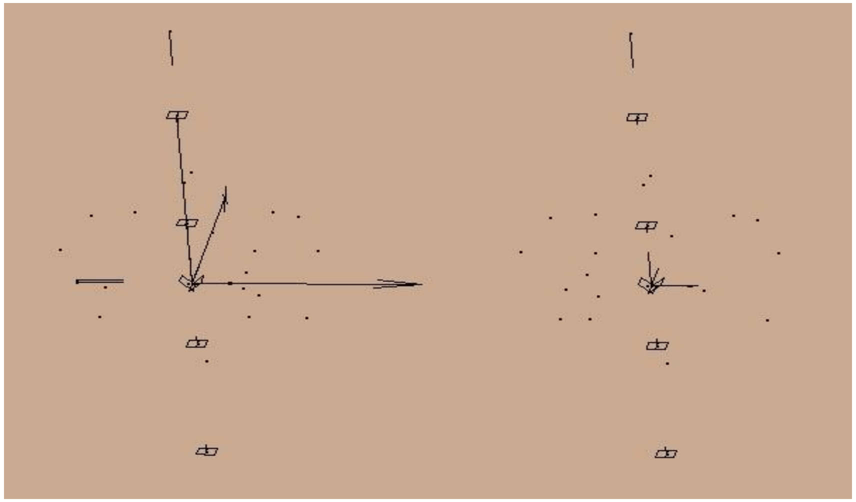
- Short 6-line FSI system for 3D wall marker reconstruction.





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**

Reference Survey Simulations

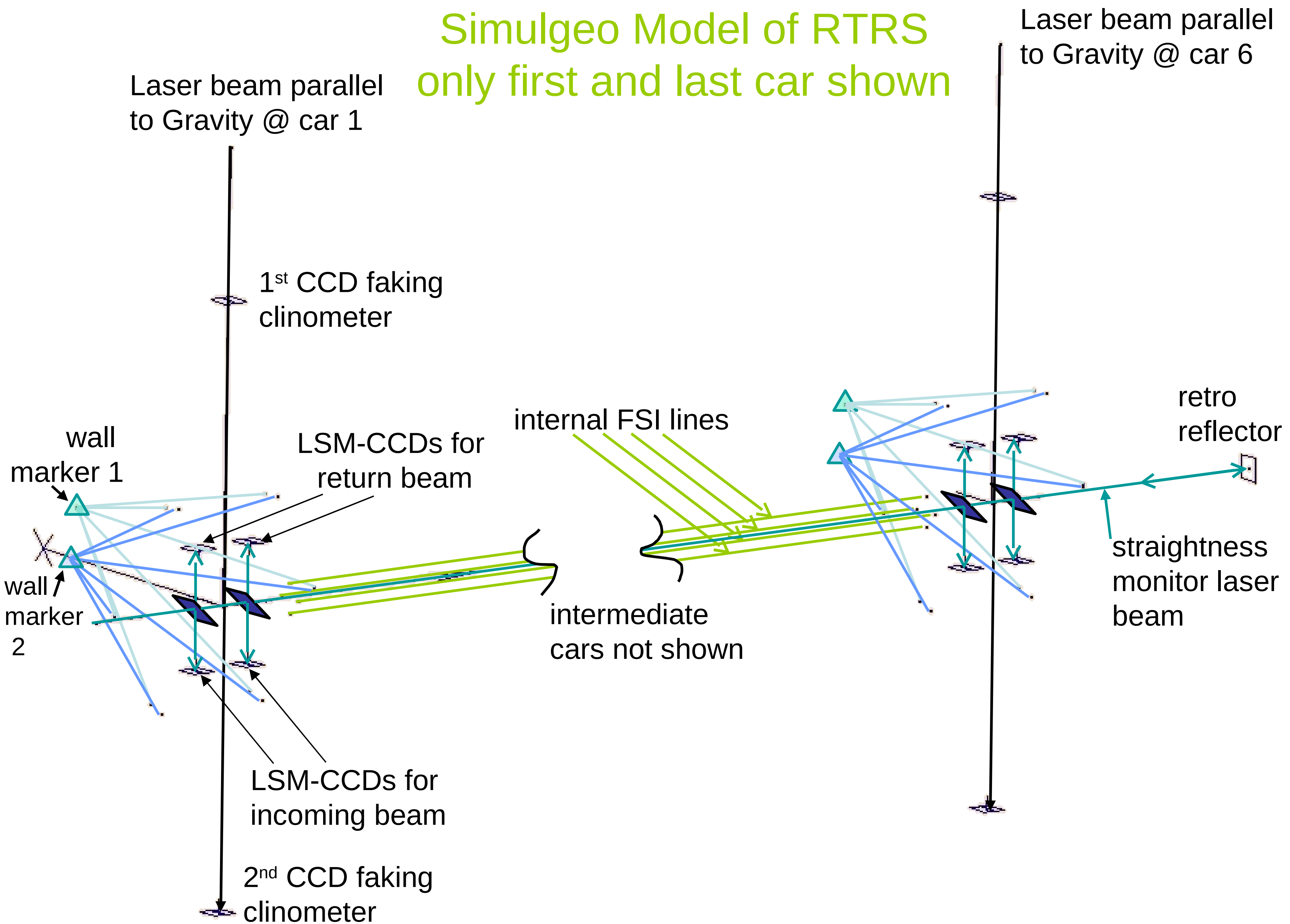
(FULL SIMULATION: short distance < 100m)

- **Build opto-geometric model of all measurements in a 6-car train and all reference wall markers using SIMULGEO**
- **Add up to 20 trains in advancing locations into the model**

  model consists of 20 trains measuring 26 wall markers.

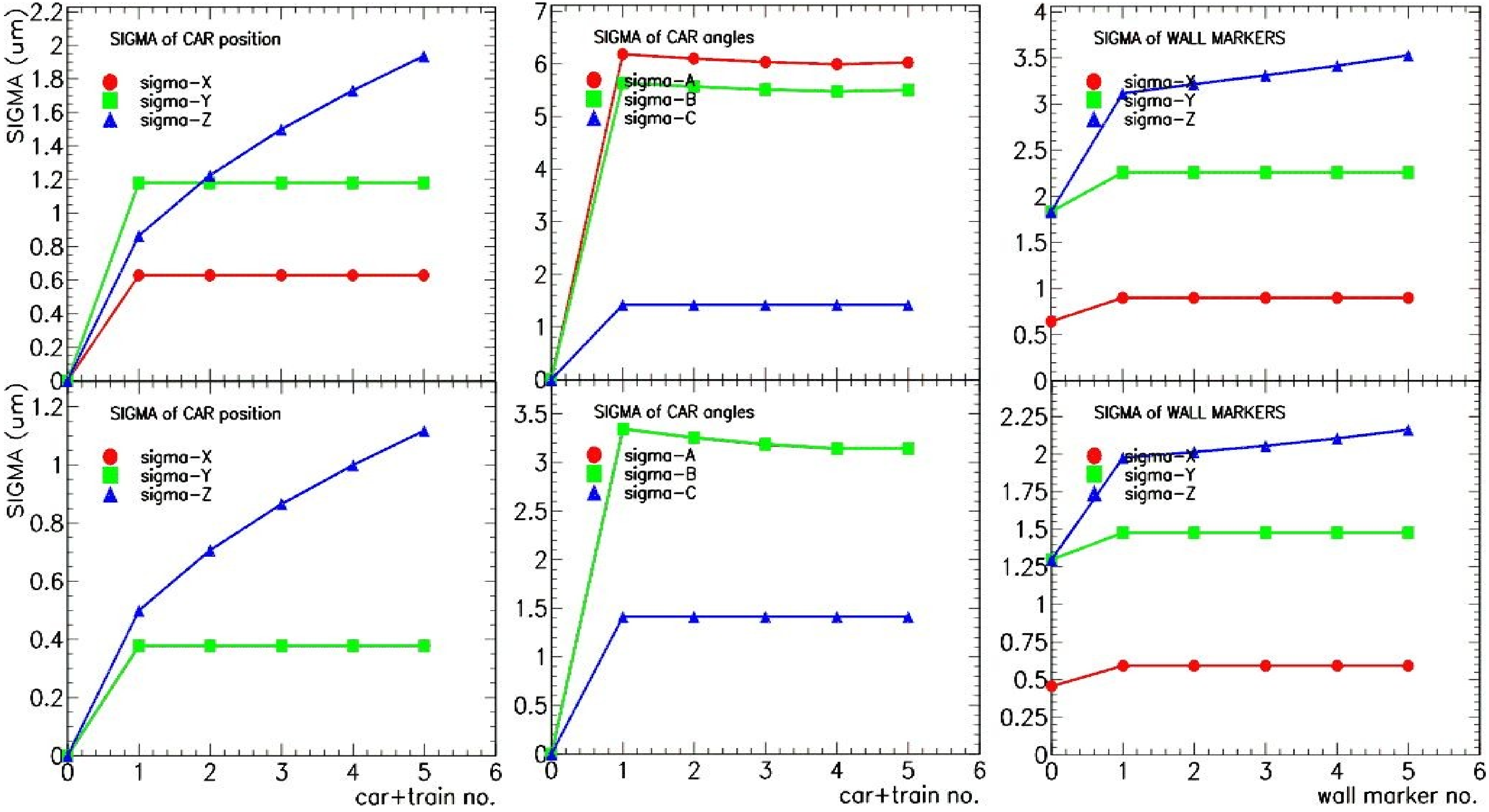
  total of O(10.000) elements and measurements with individual errors
- **Most wall markers get measured 6 times in overlapping measurements this is how trains correlate with each other**
- **Perform error propagation**:
  - **from: position errors of elements in the cars and measurement errors**
  - **to : errors of wall markers,**
  - **i.e. invert error matrix of rank $N^2 = 10.000^2$**
- **Limit of this procedure is memory of computer 20 trains need close to 1 GByte and 34h on 2GHz CPU**

Simulgeo Model of RTRS only first and last car shown



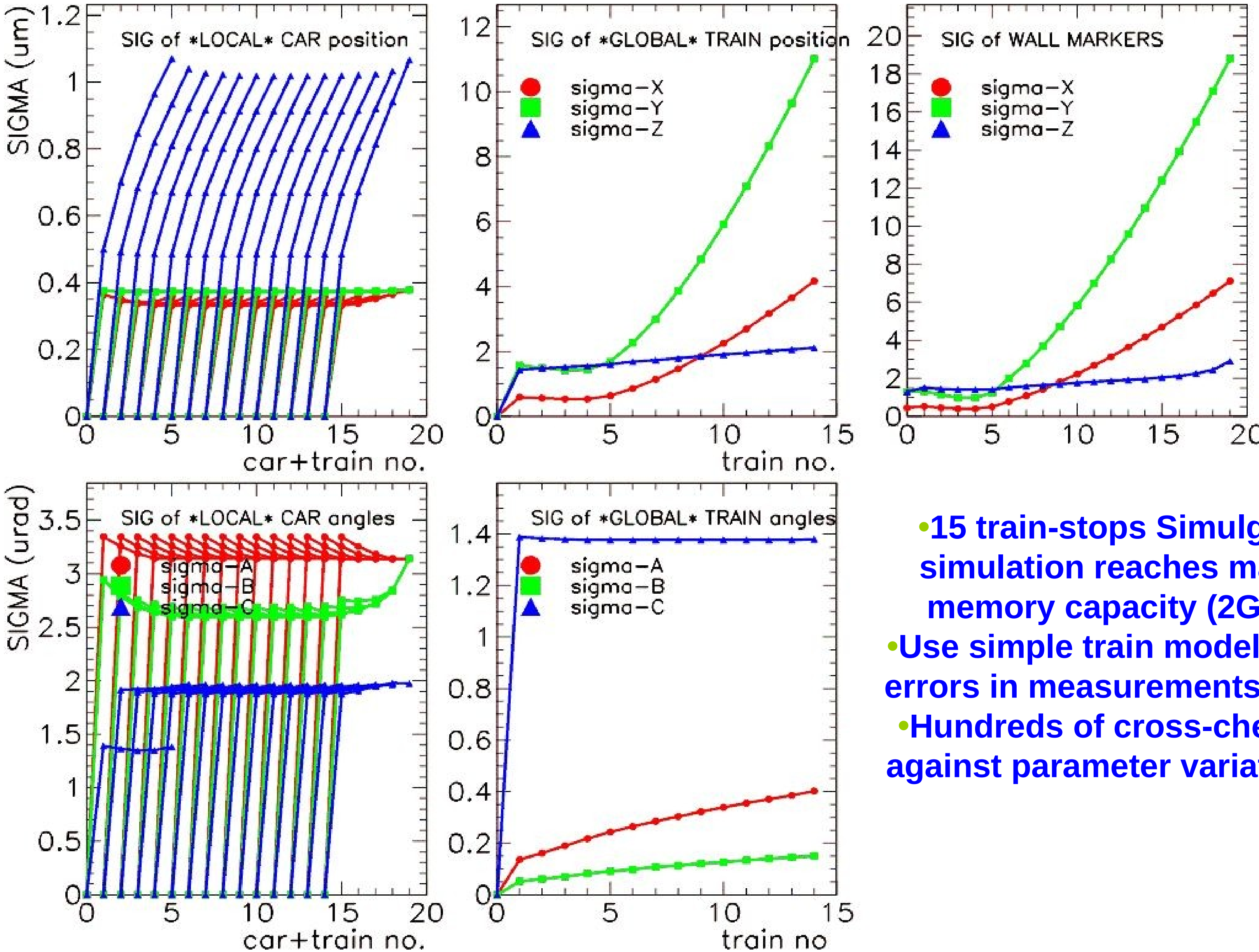
Single Train Simulations

Measurements and all geometrical objects have random errors in position and angle



Only measurements have errors

Multi Train Simulations

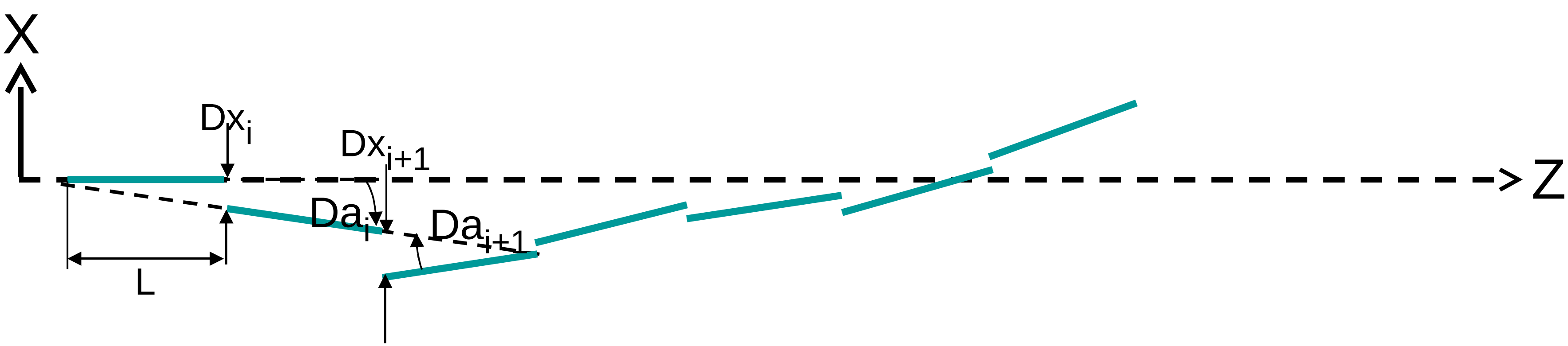


- 15 train-stops Simulgeo simulation reaches max. memory capacity (2GB)
- Use simple train model with errors in measurements only
- Hundreds of cross-checks against parameter variations

Random Walk Model

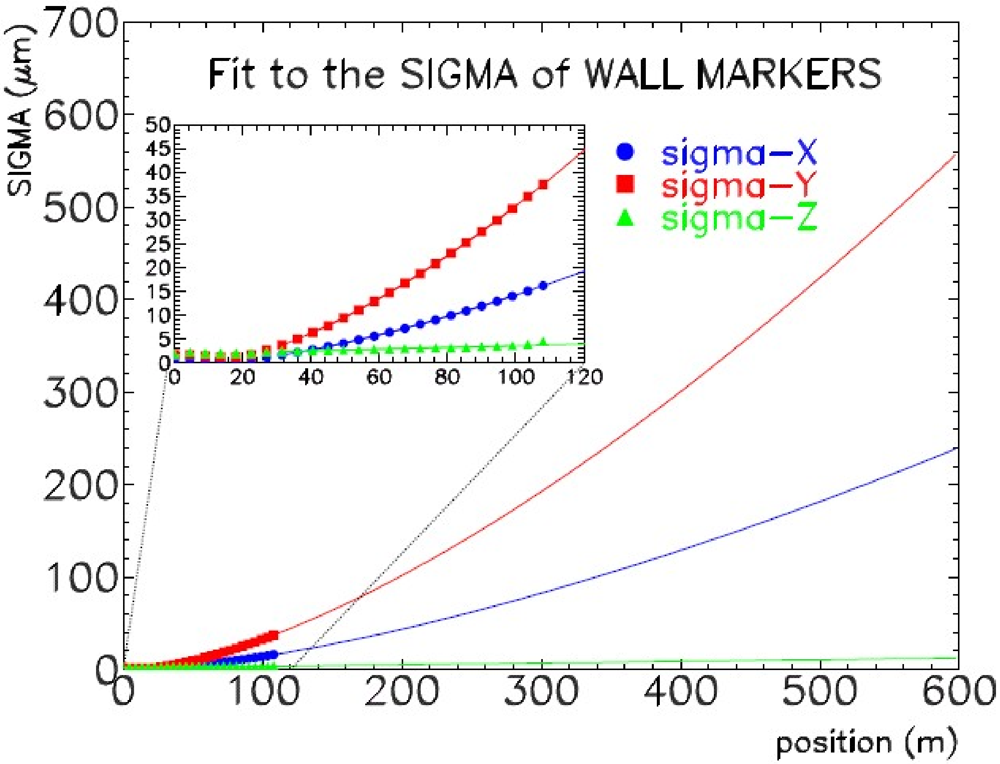
- Fit MC of random walks against Simulgeo model
  - obtain s(Da), s(Db), s(Dx), s(Dy) from the fit

Analytically compute errors in the n’th step:

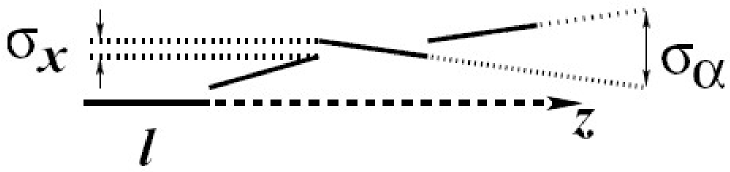


Reference Survey Simulations

(long distance >100m)



- extrapolation using random walk model:

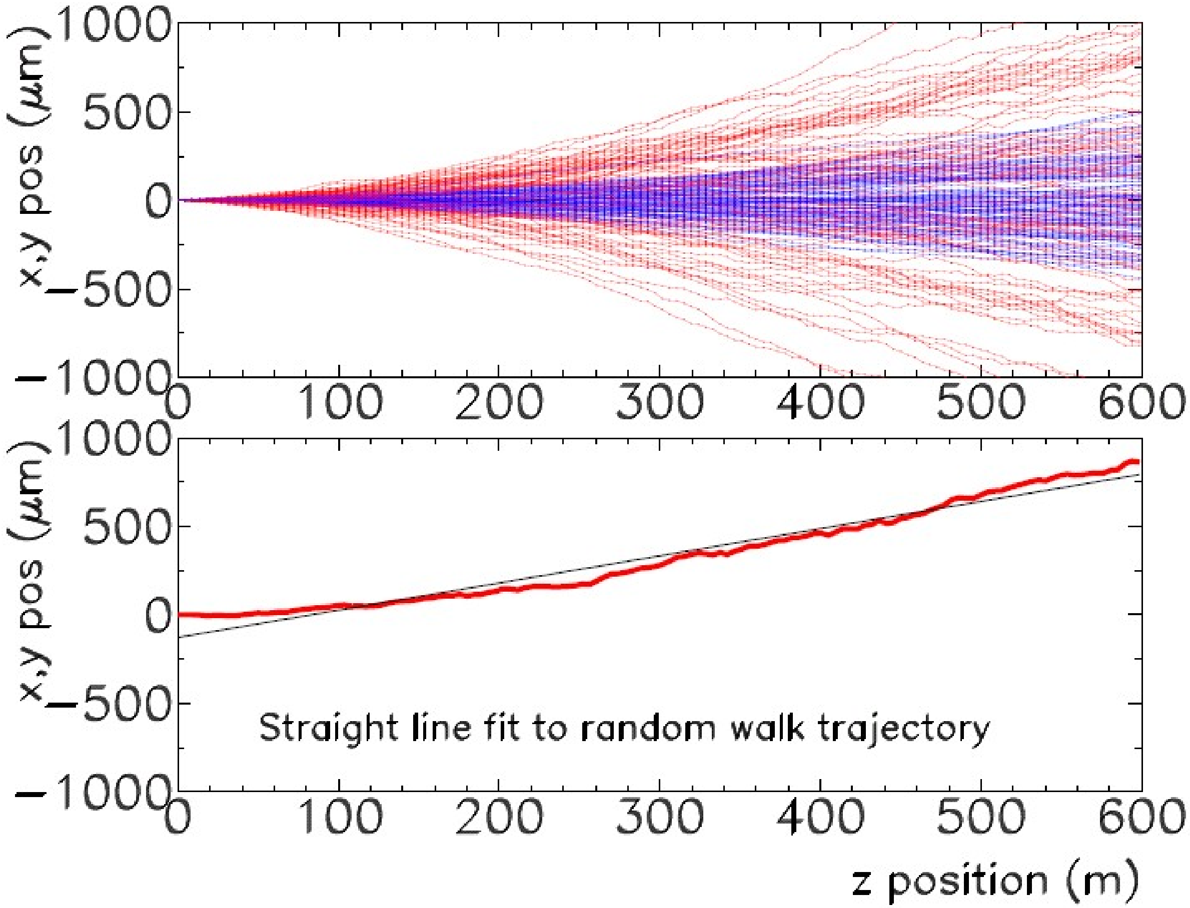


- off-sets and angles are relative to the previous "ruler"
- asymptotic behaviour: $\sigma_{xy,n} \sim n^{\frac{3}{2}}, \quad \sigma_{z,n} \sim n$

$$\sigma_{xy,n} = \sqrt{l^2 \sigma_\alpha^2 \frac{n(n+1)(2n+1)}{6} + \sigma_{xy}^2 \frac{n(n+1)}{2}}, \quad \sigma_{z,n} = \sqrt{\sigma_z^2 \frac{n(n+1)}{2}}$$

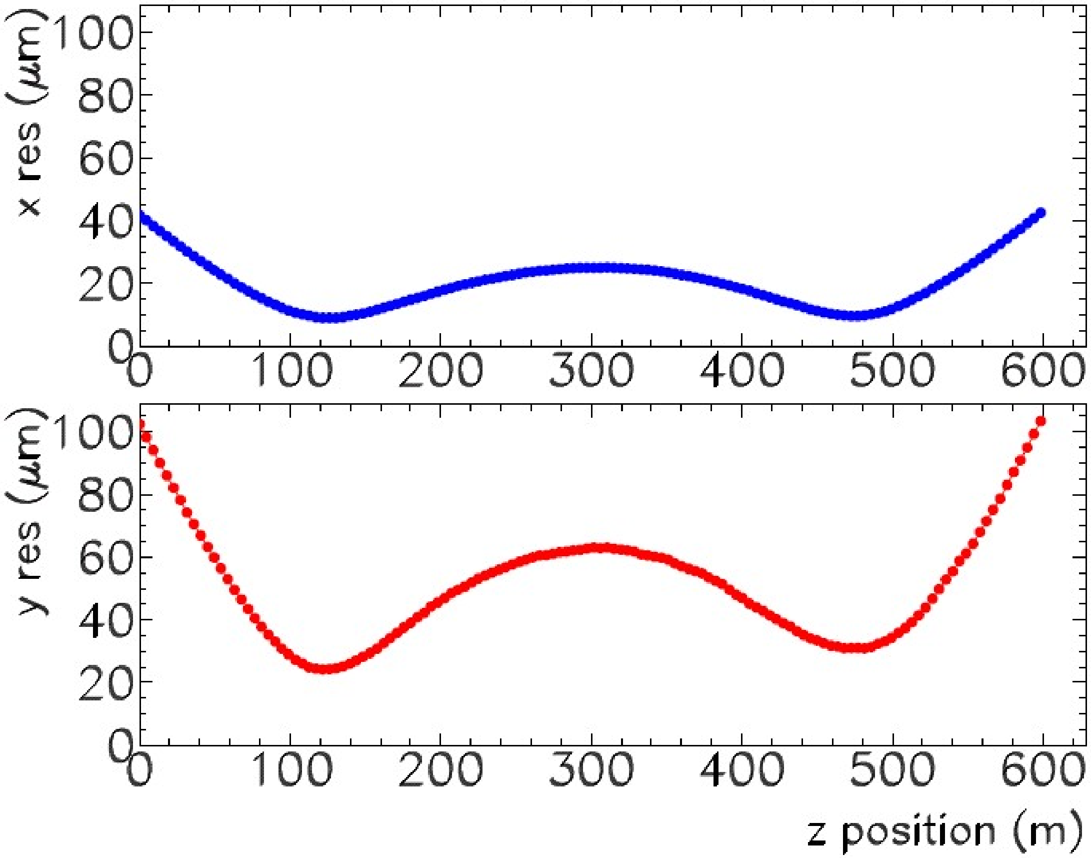
n – wall marker number, l – effective length of the ruler (here: distance between cars),
errors: σ_α – angular $(\sim 0.1\,\mu rad)$, σ_{xy} – transverse $(\sim 0.5\,\mu m)$, σ_z – longitudinal $(\sim 0.1\,\mu m)$

Random Walk Monte Carlo: trajectories, fits



- trajectories generated from Random Walk Monte Carlo using parameters from the fit to SIMULGEO points (X, Y) direction
- good news: points along trajectories are strongly correlated (ie.: small 'oscillations' observed)
- straight line fits to the Random Walk paths for $600\,m$ tunnel section
- repeating this procedure for many "numerical experiments"...

Random Walk Monte Carlo: residua



- mean deviation from straight line fits (X, Y) direction
- realistic input to the simulations of beam dynamics

- well below specification: $\sigma_x = 500\mu m$, $\sigma_y = 200\mu m$
- however: only statistical errors included

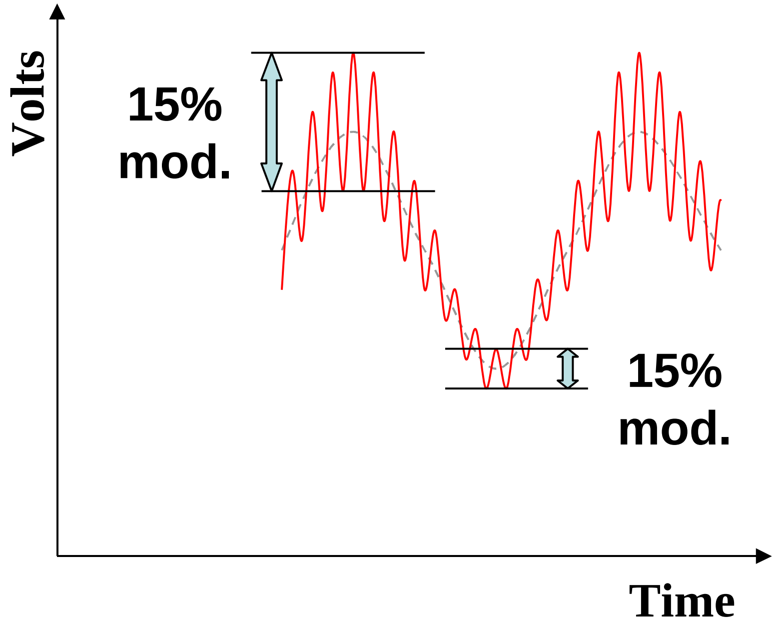
Test Tunnel Preparation

- **55m long service tunnel at DESY**
- **tunnel tests showed walls stable enough**
- **air conditioning**
- **installed high speed WLAN and LAN**
- **installing laser interlocks and safety systems**
- **ready for use well before RTRS prototype expected to arrive**

Summary and Plans

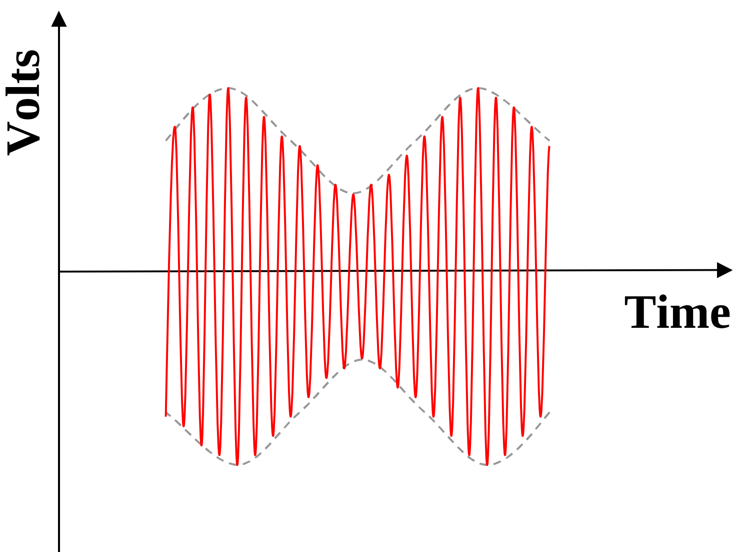
- LiCAS technology is capable to measure the ILC tunnel to required precision
- Work in progress on hardware and software
- The 3-car prototype beginning of 2006
- Get 2nd generation LiCAS train into X-FEL tunnel
- Stake-Out instrument to measure accelerator components against wall markers
- Michelson enhanced FSI (M-FSI) for fast stabilisation of final focus magnets

Recent Developments



• Amplitude Modulation on FSI fringe @ 40 & 80 kHz (now) 0.5 & 1MHz (later)

• High Pass Filter



• FSI fringe stored as amplitude on Carrier (a'la AM radio)

• Demodulation reproduces FSI Fringes

Recent Developments