Status and Plans of the Oxford LiCAS group
(Linear Collider Alignment and Survey)

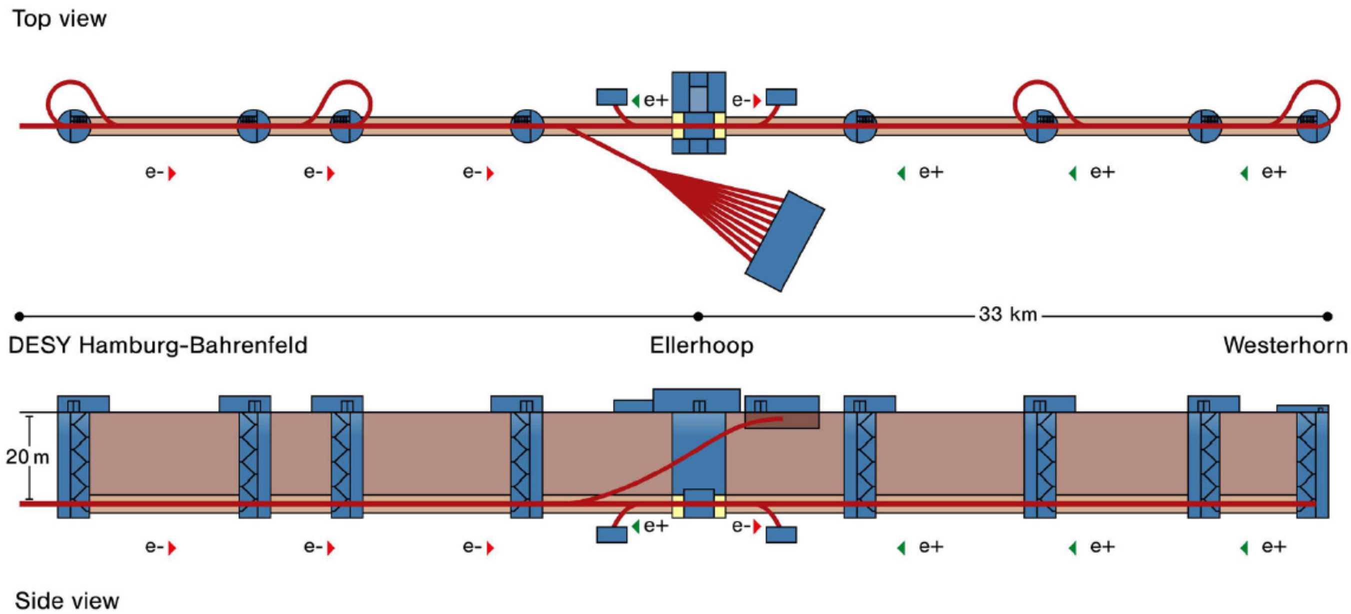
Paul Coe, Grzegorz Grzelak, Ankush Mitra,
Armin Reichold, Roman Walczak
University of Oxford

Nanobeam Workshop, 2–6 September 2002, Lausanne.

Overview:

- Introduction
- Example of the LC: the TESLA accelerator
- Proposed Survey Technology
- Existing solutions and issues to be solved
- FSI: Frequency Scanning interferometry
- SM: Straightness Monitor
- Summary

TESLA: an example of planned Linear Collider

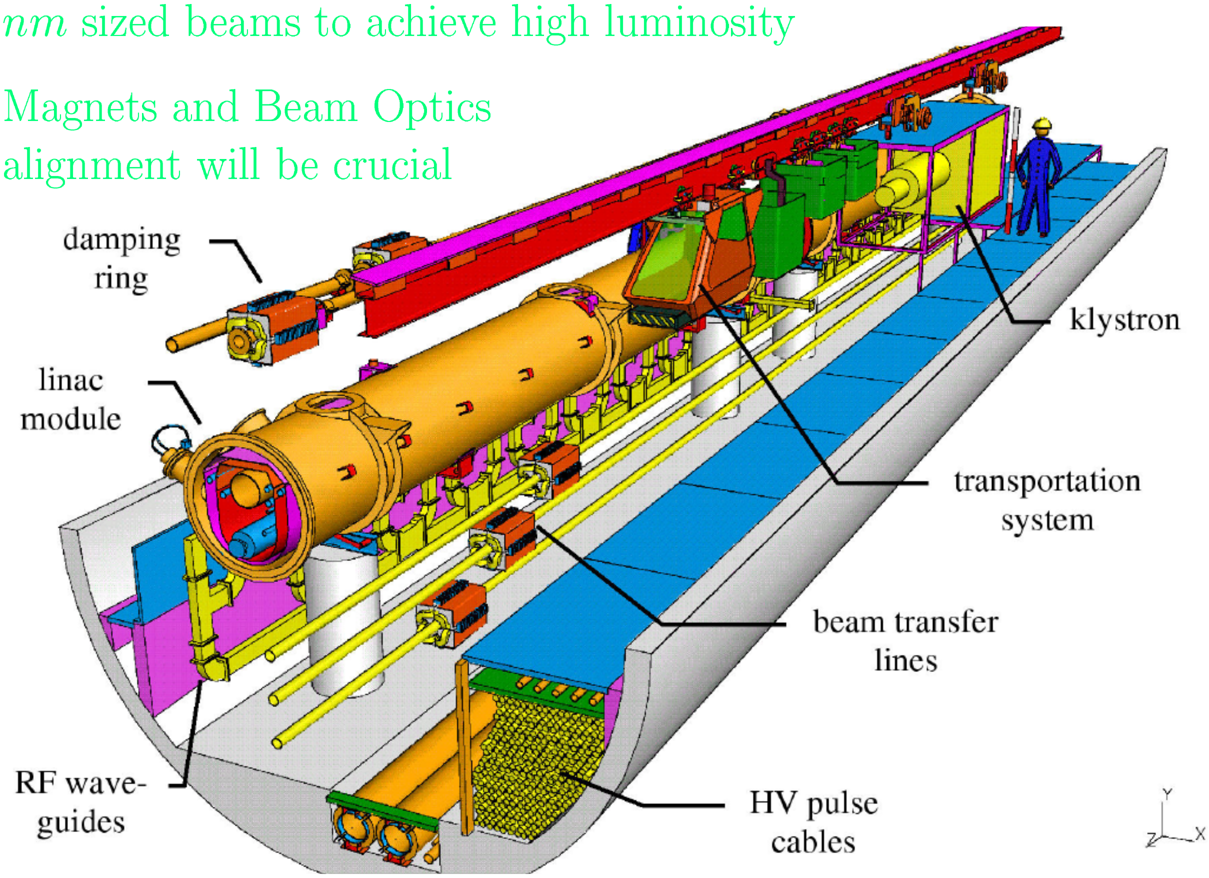


Basic beam parameters:

- beam energy $\mathcal{O}(500\,GeV)$
- beam alignment at injection $\mathcal{O}(0.1\,\mu m)$
- beam alignment at interaction point $\mathcal{O}(1\,nm)$
- no recirculation, just one shot to collide a given bunch !!

Requirements and boundary conditions in TESLA

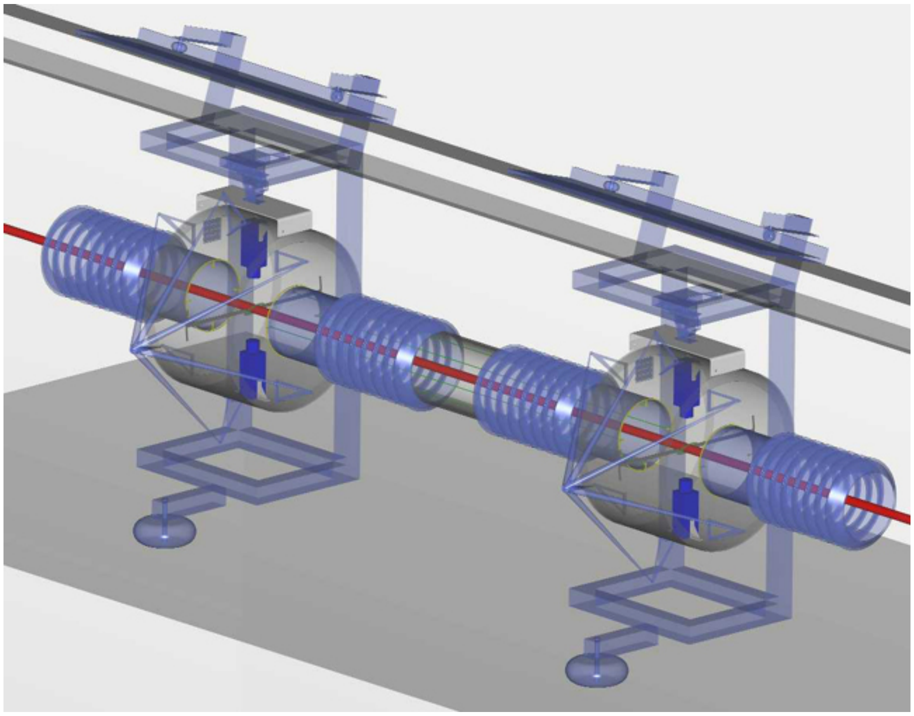
- Linear e^+e^- Collider will accelerate nm sized beams to achieve high luminosity
- Magnets and Beam Optics alignment will be crucial



Boundary conditions in case of TESLA:

- tight space ($\approx 1\,m$ wide, used also as emergency escape route)
- automated measurement (induced radiation environment, re-align without breaking the collider interlock)
- vertically and horizontally curved tunnel sections ($R_{min} > 500\,m$) ($R = 145\,m$ in Damping Ring, scalable solution needed)
- some tunnel sections follows geoid, others are geometrically straight
- significant slopes possible ($\rightarrow$ HLS problem !)
- electrically noisy environment
- no long term stable reference monuments (LEP: $100\,\mu m/year$)

Proposed Technology



Mechanical concept of the survey train developed at DESY for TESLA

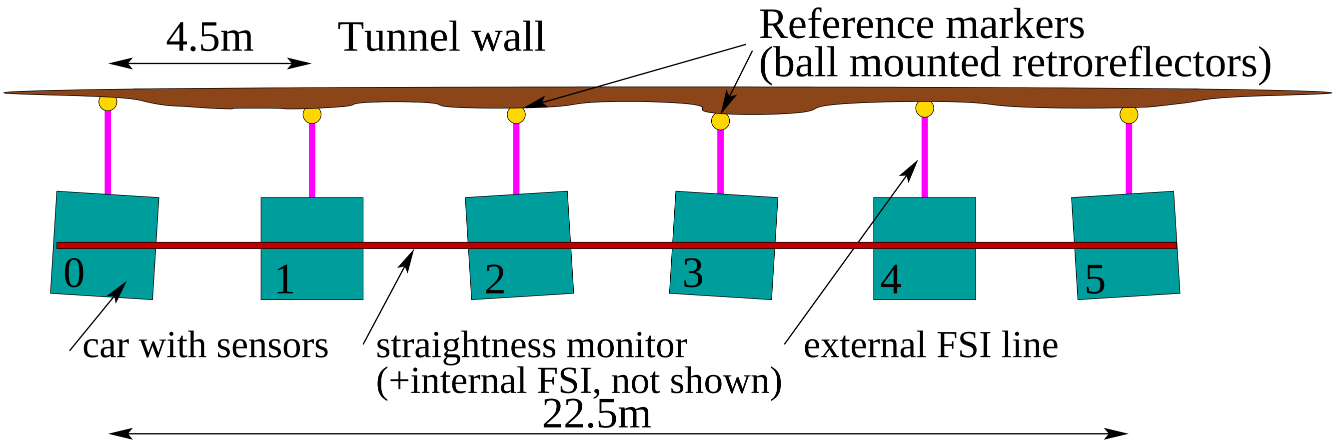
- collider alignment at construction stage 200 μm over 600 m in vertical
- present open air survey technology not sufficient

→ our ideas:

- use FSI (ATLAS) and Straightness Monitors (ZEUS, ATLAS)
- extend these technologies:
  - automatic train measures reference markers (i.e. defines the reference frame)
  - later measure collider position w.r.t. the above co-ordinate system
  - scalable laser technology (not large monolithic lasers) using fibre optical amplifiers
  - internal laser beam lines in vacuum
  - test the prototype at DESY during FEL installation

Challenges: LiCAS Phase I and II

Over-constrained, redundant straight line measurement.



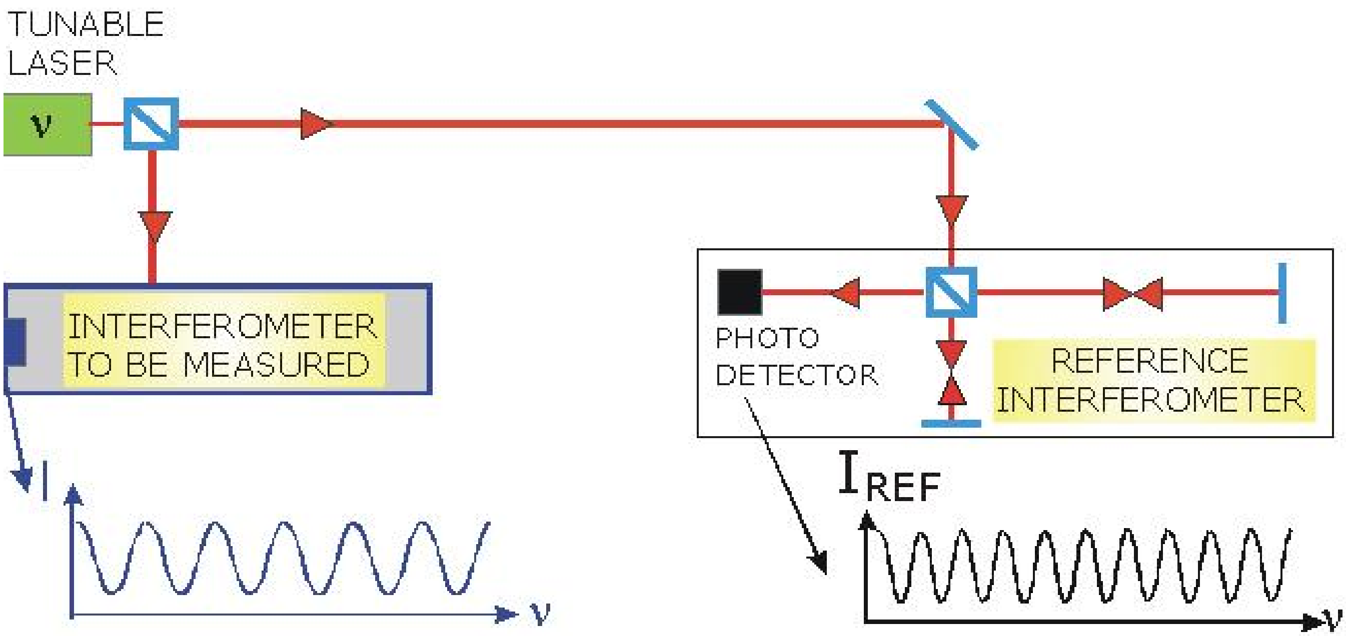
♦ Phase I

- construct automated, self propelled, high precision ruler
- combine FSI and straightness monitor in large scale instrument
- total length of the survey is 30 km

♦ Phase II

- fixed alignment grid on most sensitive components
  (beam delivery and final focus), fast on-line 3D measurement
- total length $\mathcal{O}(1\,km)$, number of lines $\mathcal{O}(5000)$
- add fixed frequency laser to FSI system, use it in Michelson Mode
  $\mathcal{O}(1\,nm)$ stabilisation $\rightarrow$ optical anchor grid
  (faster readout $1\,min \rightarrow 10\,Hz$)

Principle of the FSI measurement



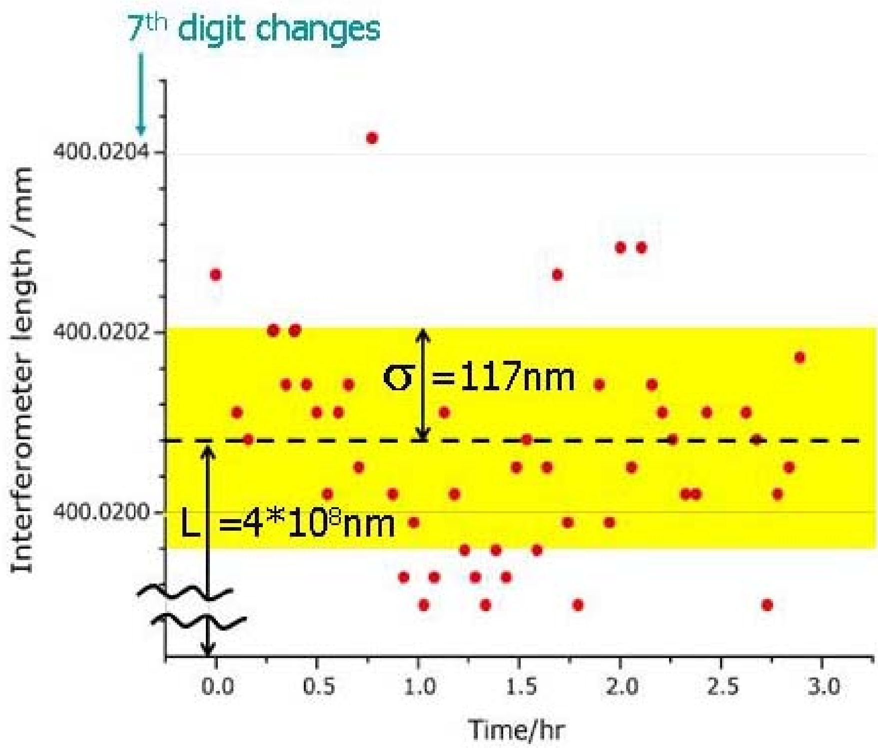
- Technology developed in Oxford for the ATLAS experiment
- Like a Michelson interferometer with fixed arm lengths which is operated using variable frequency light
- Length measurement related to the phase shift:
  (counting the interference fringes)

$$\Phi(t) = \frac{2\pi}{c} L\nu(t)$$

$$L = L_{ref} \frac{\Delta\Phi}{\Delta\Phi_{ref}}$$

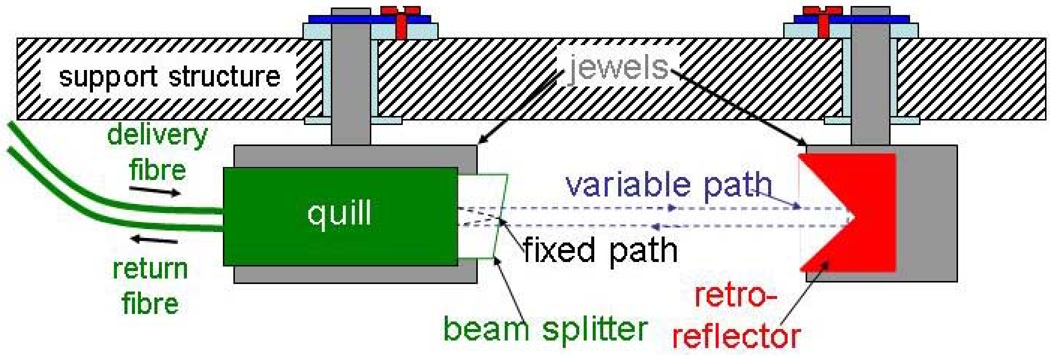
  where L is the unknown path length difference between the interferometer arms

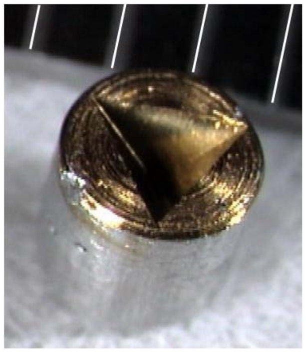
FSI Resolution



- Present performance:
  - $\sigma_L = 117\,nm$ at $L = 0.4\,m$
  - $\sigma_L/L = 0.29\,ppm$
- LiCAS Phase I:
  - $\sigma_L = 1\,\mu m$ at $L = 5\,m$ (once every minute)
  - $\sigma_L/L = 0.2\,ppm$
- LiCAS Phase II:
  - $\sigma_L = 1\,\mu m$ at $L = 20\,m$ (once every minute)
  - $\sigma_L/L = 0.05\,ppm$
  - Michelson (differential) Mode:
  - $\sigma_{\Delta L} = 1\,nm$ at $L = 20\,m$ (at $\mathcal{O}(10\,Hz)$)

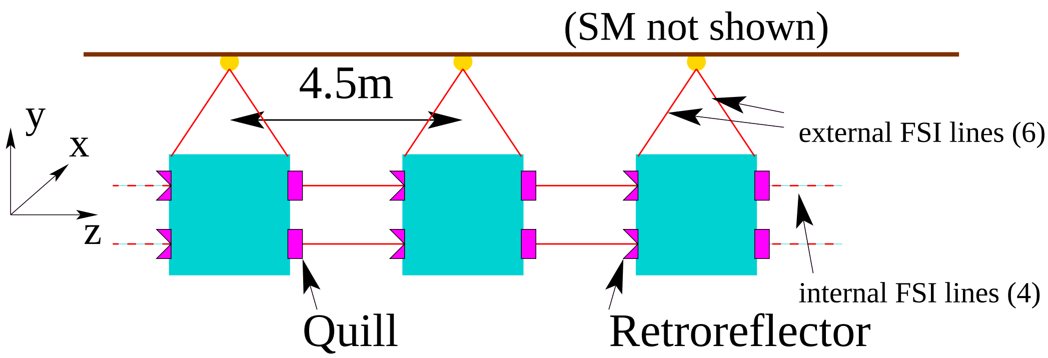
FSI: The ATLAS implementation





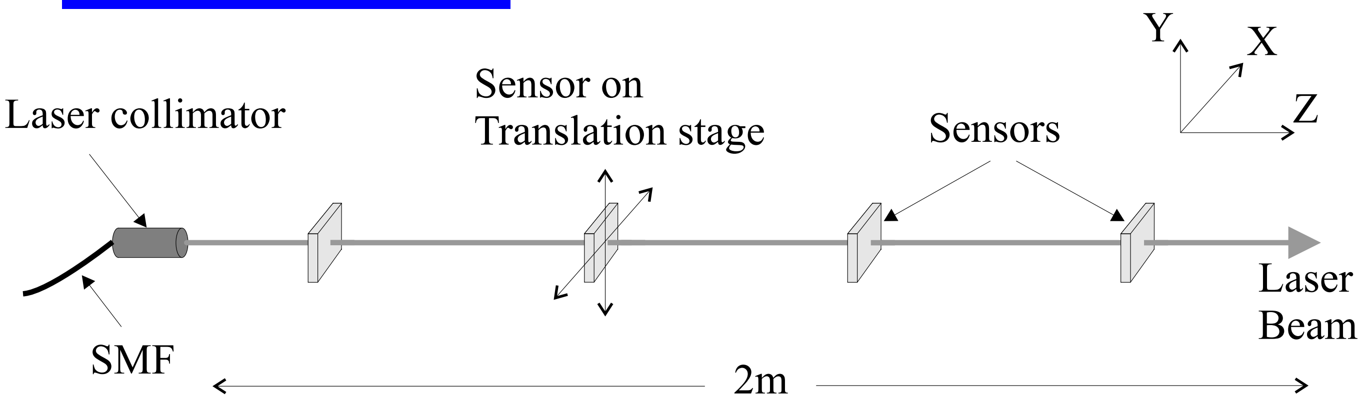
- GLI: Grid Lines Interferometers
- optimised for minimum mass
- gold coated aluminium retroreflectors
- large scale $\mathcal{O}(600)$ FSI grid for the ATLAS inner detector

In case of LiCAS:



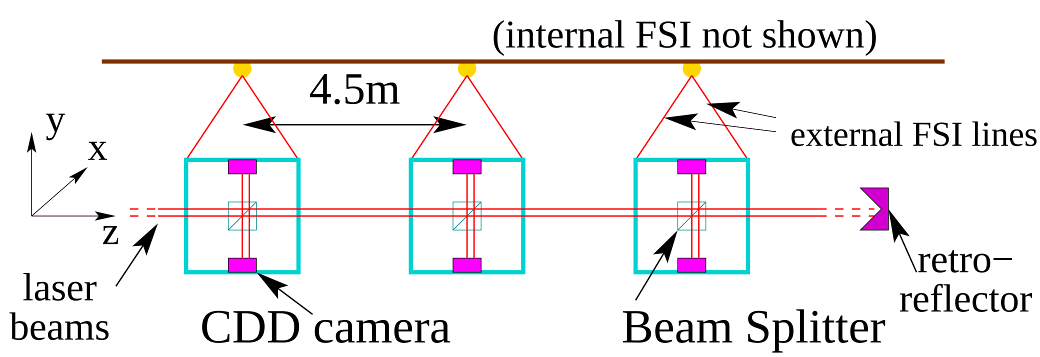
- no constrains on the mass of the system
- use the collimation optics to extend the measurement range ($\approx 5\,m$)
- use the infrared tunable lasers (change the wavelength from $0.85\,\mu m$ to $\approx 1.5\,\mu m$ and the tuning range from 10 to $100\,nm$)
- internal FSI lines operate in vacuum
- sensitive to Z–distance and $R_{X,Y}$–rotation

Straightness Monitor



- ZEUS MVD solution: semi-transparent sensors
- but... no longer available on the market

In case of LiCAS:

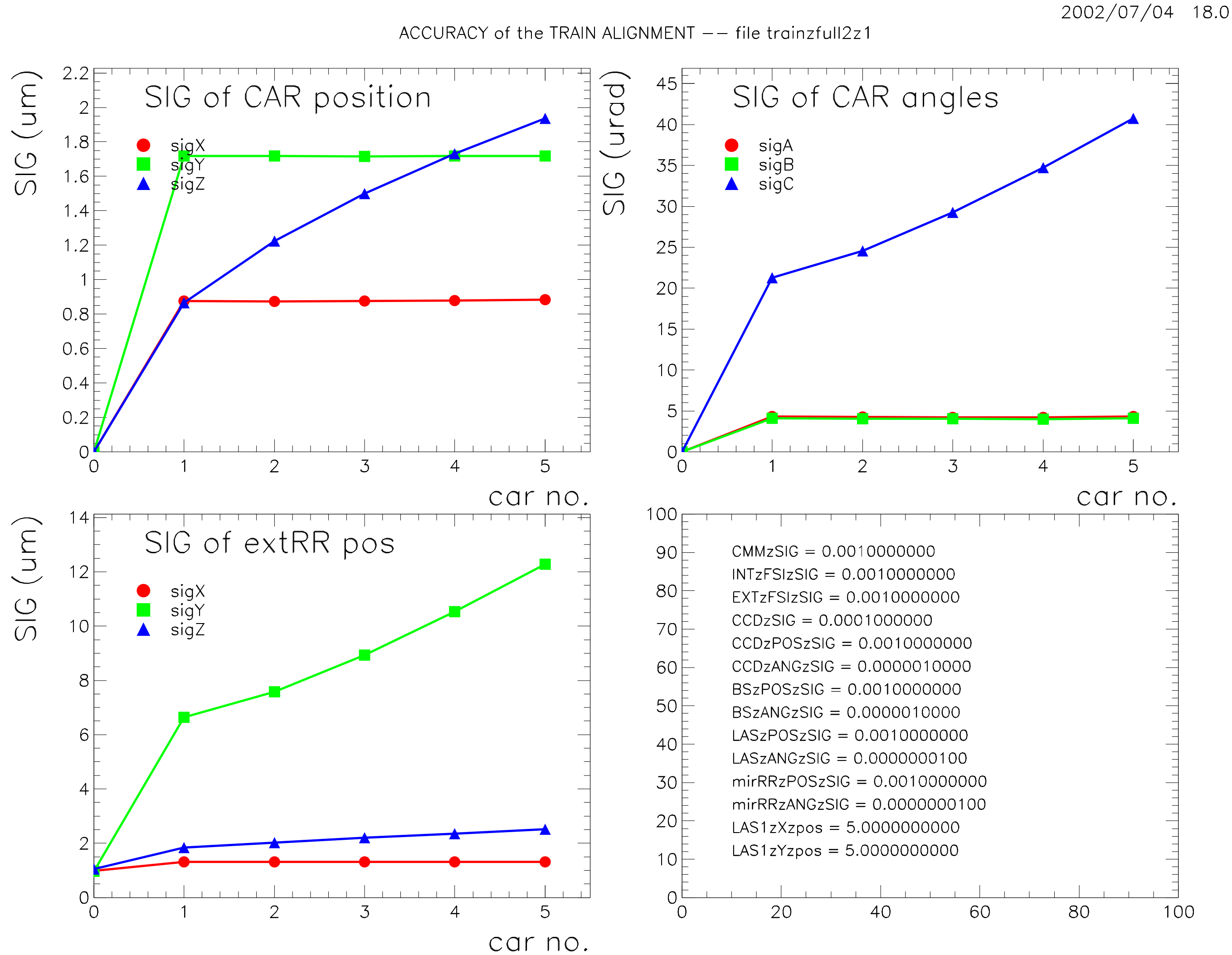


- two "laser" beams (super luminescan diodes, 850 nm) to avoid unwanted interference (coherence length $\mathcal{O}(10\,\mu m)$)
- collimation optics
- beam splitters and CCD cameras ($8 * 6\,mm^2$, $\approx 10^6$ pixels, 10 bits, sensitivity to 920 nm, power 1.5 W)
- sensitive to X, Y–position and $R_{X,Y,Z}$–rotation

What is novel ?

- long base lines $\approx 5\,m$ ($\approx 20\,m$ in Phase II), (absolute precision $\approx 1\,\mu m$)
- use Telecom (cheap and very good) infrared lasers for interferometry (larger tuning range $\rightarrow$ higher accuracy)
- optical fibre amplifiers (EDFA) for scalable laser system with many interferometers
- collimation optics
- proper simultaneous tuning of two lasers in all interferometers via amplitude modulation and lock-in amplification
- combining FSI with Michelson interferometry $\rightarrow$ higher accuracy and faster readout $1\,min \rightarrow 10\,Hz$ (differential measurement is a small correction to the FSI, fast on-line calculation possible, no need of CPU consuming fitting)

SIMULGEO: Simulation of the system performance



- SIMULGEO:
  "Simulation and reconstruction package for opto-geometrical systems";
  developed by Laurent Brunel in CMS collaboration
- Simulation includes the whole system: internal and external FSI lines and the straightness monitor
- study of the overall performance of the system
- simulate combined system resolution,
  optimise the resolution of different sub-components (FSI, CCD, ...)

Conclusions/Summary

- ## Modern Survey Approach

  Using the latest achievements developed
  for ATLAS and ZEUS

- ## General Purpose Alignment System

  Presented solutions were discussed within the TESLA
  framework but the design is very flexible
  → could be adopted for any large scale facility
  (LC, NLC, Synchrotron Radiation Sources, ...)

- ## New LAB under construction:

  Equipment: Laser, Power Meter, CCD-cameras,
  DAQ (ADC/DAC), Motion Stages, ...

- ## Advanced study of the system calibration

  not presented here...

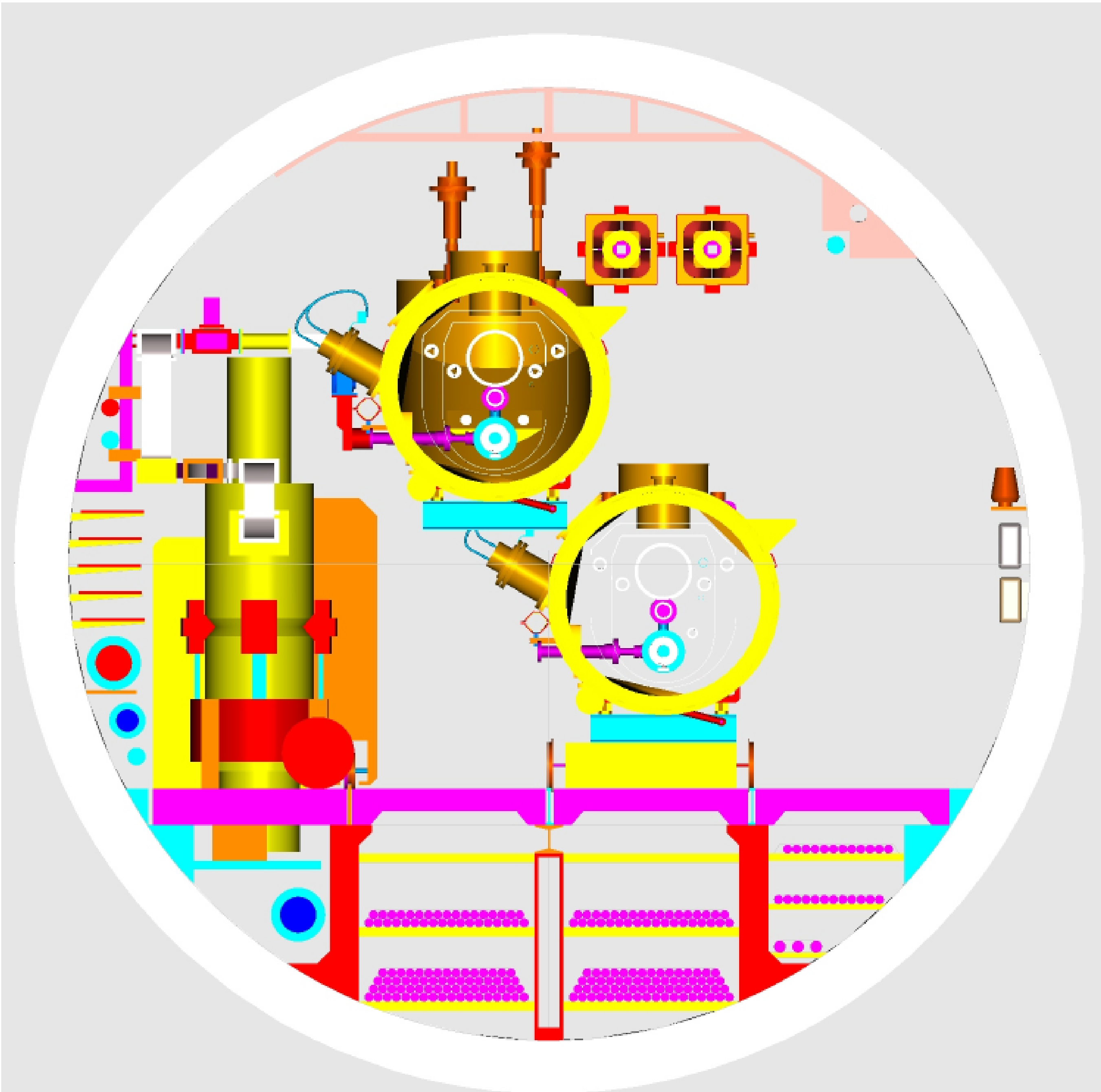
- ## Man power:

  3.5 FTE (2002), 6 FTE (2003)

- ## We are looking forward

  to collaborate on the developing and testing of this system

Latest TESLA tunnel layout



- beams and magnets are hanging from the roof
- transportation system is located on the tunnel floor