An alignment and stabilisation system for future linear colliders

Frequency scanning and Michelson interferometry combined in a geodetic network

Overview

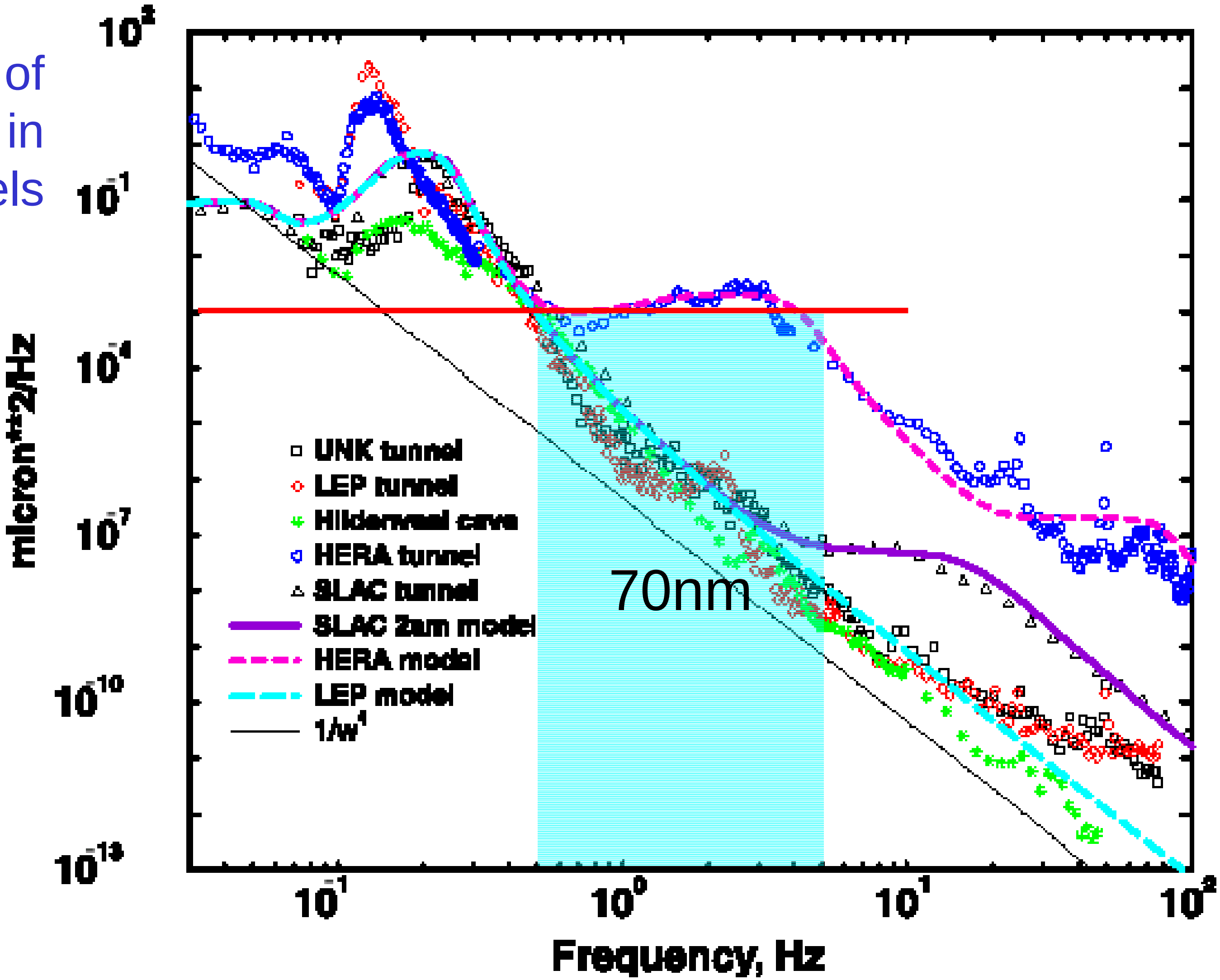
- Motivation
- Concept
- Grids
  - geometry
  - simulations
- FSI
- M-FSI

Motivation

- Linear e^+e^- Colliders have to collide nm sized beams at the IP to achieve high luminosity.
- To do this one needs to
  - Transport O(100nm) sized beams over O(30km) without emittance growth.
  - Align most magnets to O(1μm)
  - Align "final-focus" Magnets to O(1nm)
- But...

The ground moves...

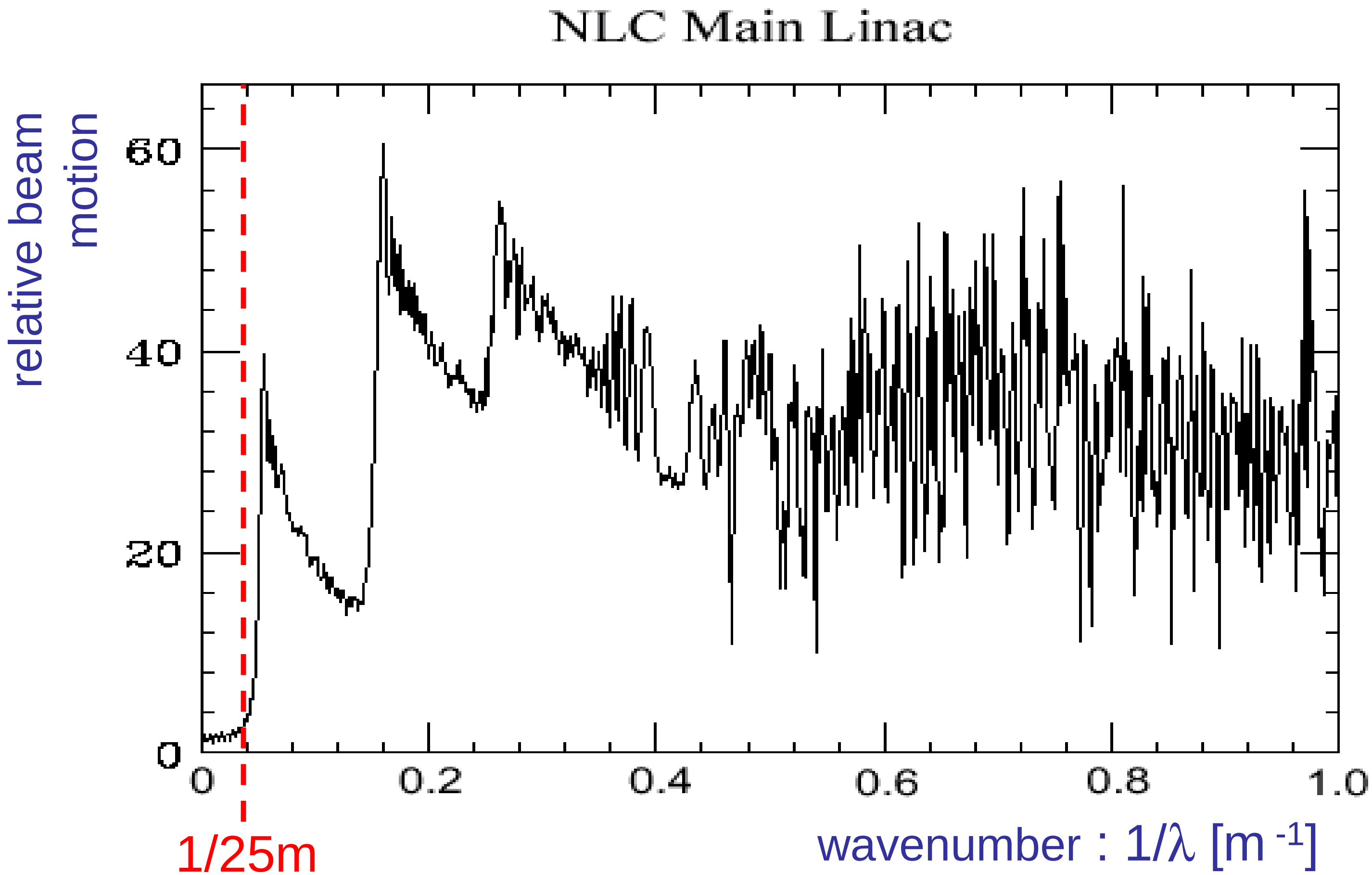
Powerspektrum of ground motion in various HEP tunnels



LEP:
60 to 180 µm/Jahr

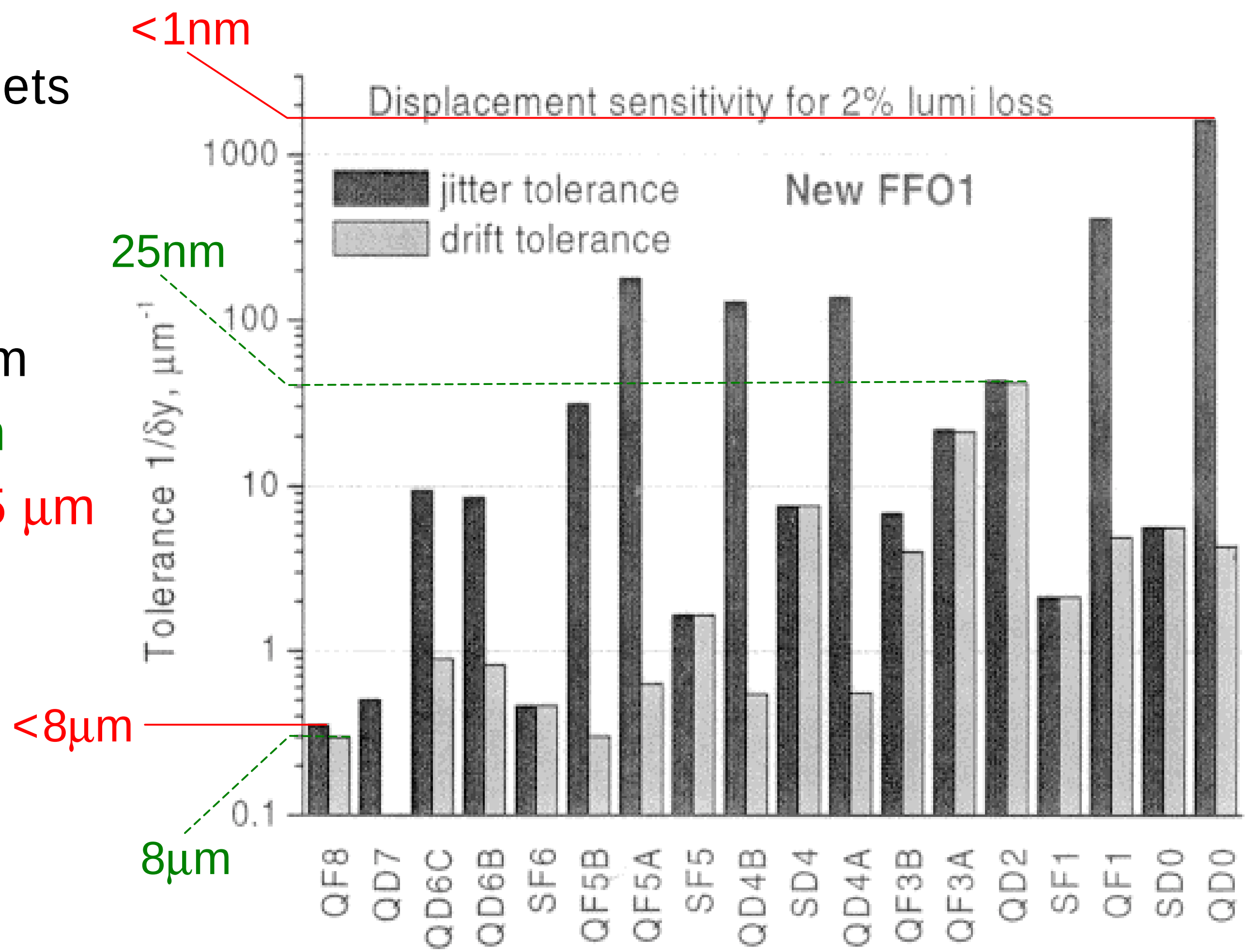
...and so does the beam

- Relative beam motion vs. wavenumber of ground motion
- But wavelength > 25m (Betatronlength) do not matter



Sensitivities

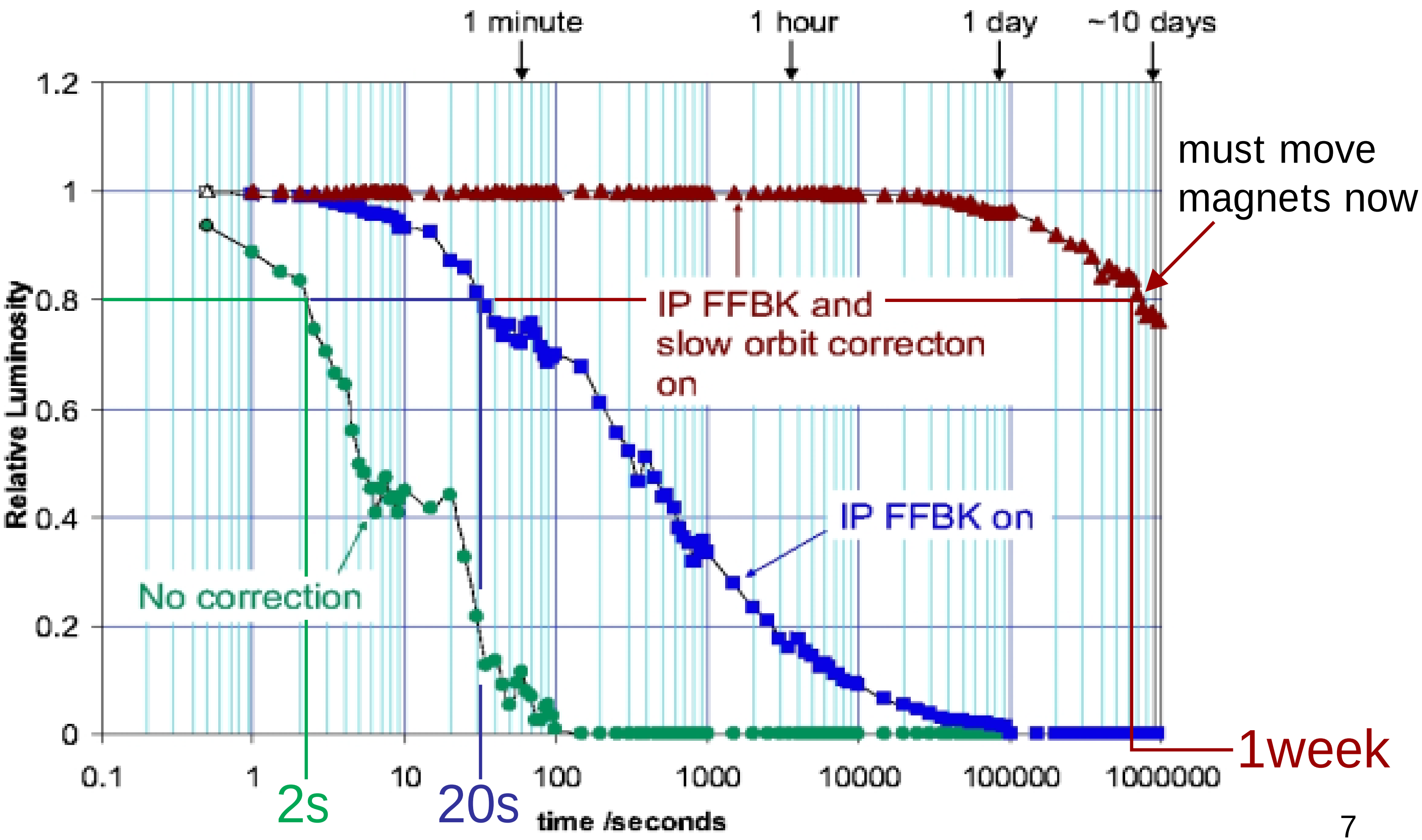
- Sensitivity S of magnets in FF of NLC
- Drift < 5Hz < Jitter
- Drift assumed to be corrected for by beam
- S(Drift): 25nm - 8µm
- S(Jitter): 0.5nm - 2.5 µm



Beamcorrections

TESLA Luminosity versus log(time/sec)

assume: ideale beam corrections, ATL groundmotion (HERA)

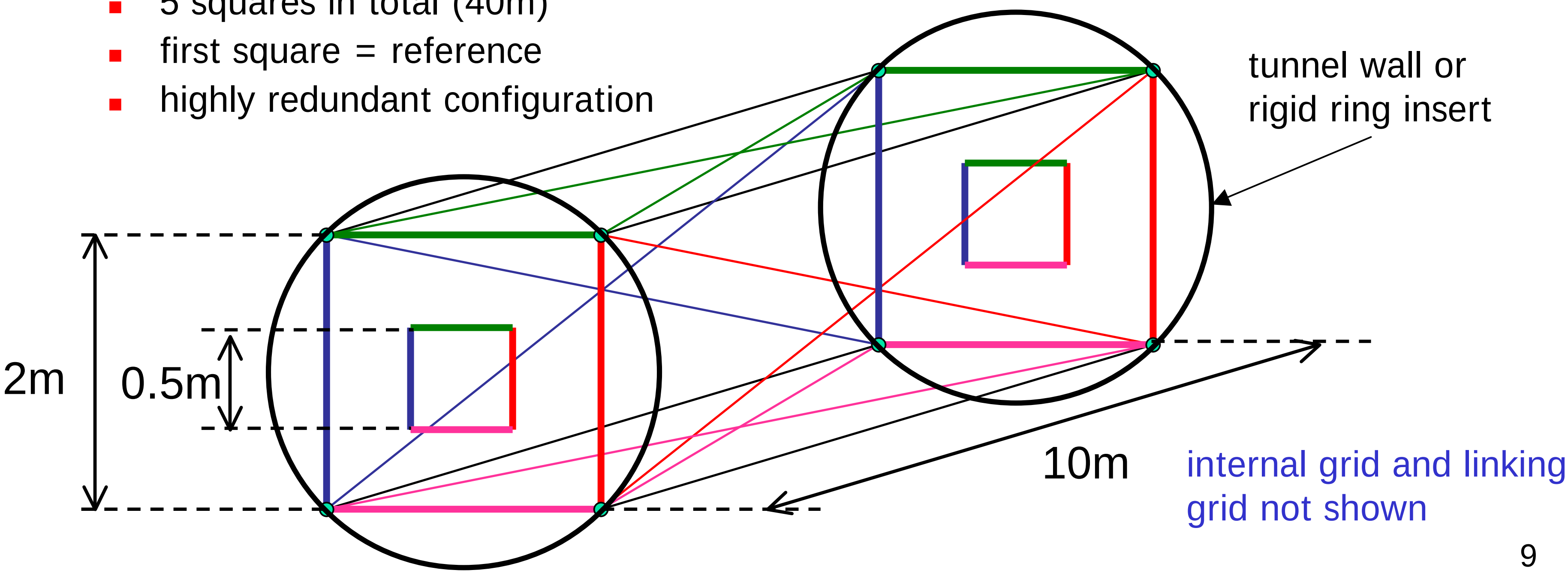


Concept (basic idea)

- Align magnets to external geodetic grid a`la surveyors
- Grid needs absolute measurements (length=FSI, +optionally angle=straightness monitor)
- Keep grid permanently installed
- Use same grid also for higher sensitivity deflection measurements (length=Michelson) a'la optical anchor
- ...but this anchors agains the grid, not against deep rock
- do not need to assume stability of rock

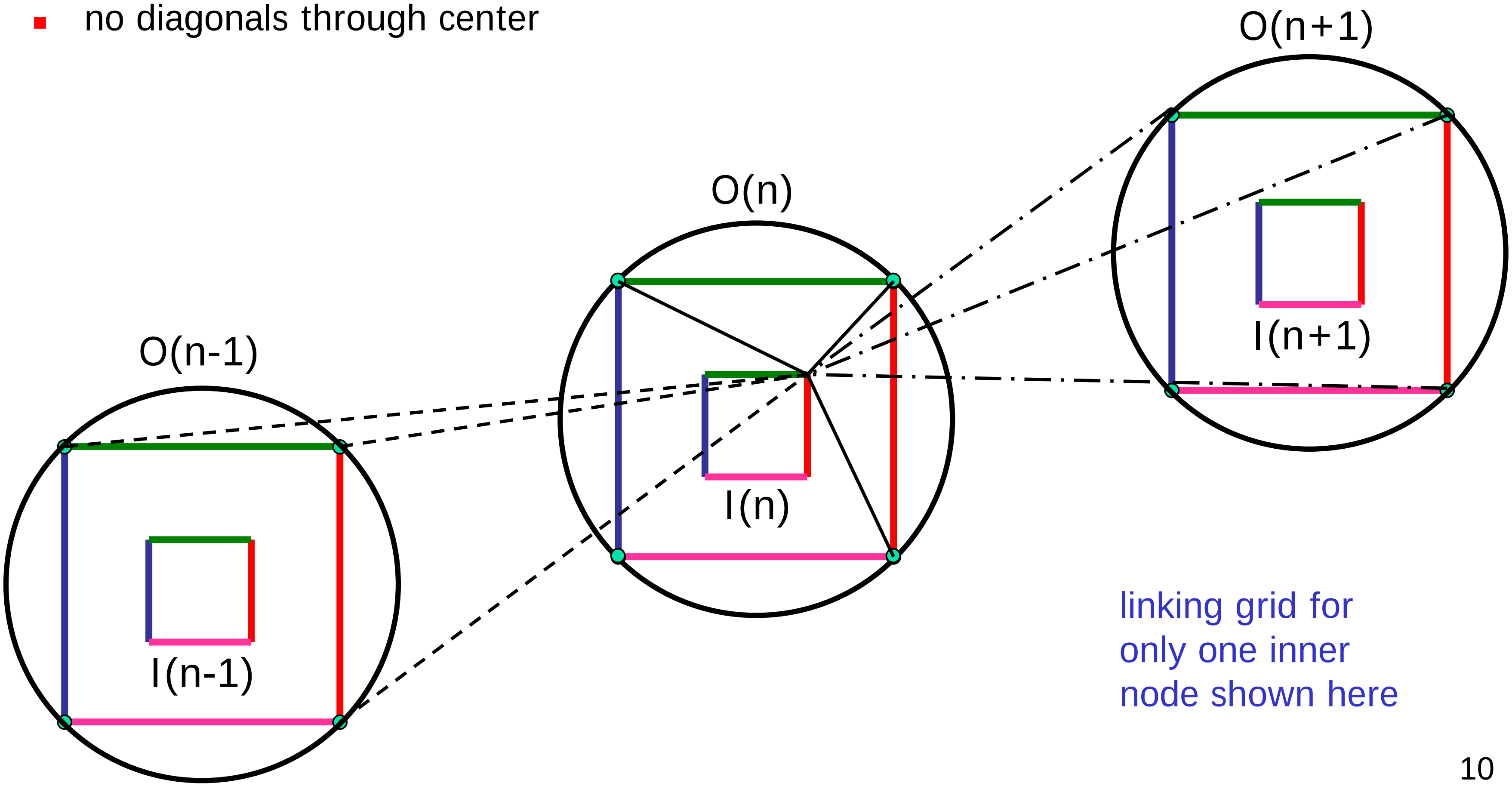
Grids (very simple conceptual geometry)

- General:
  - square box grids
  - no diagonals through center
  - 10m square spacing
  - inner grid same as outer grid
  - inner grid linked to outer grid
  - linking grid see next slide
  - 5 squares in total (40m)
  - first square = reference
  - highly redundant configuration
- Inner grid:
  - on magnets
  - 0.5m square width & height
- Outer grid:
  - on tunnel walls
  - 2m square width & height



Grids (very simple conceptual geometry)

- Linking grid:
  - 3 outer squares O(n-1), O(n), O(n+1) look at inner square I(n)
  - 3 lines from each of above outer squares to any node on inner square
  - no diagonals through center



linking grid for
only one inner
node shown here

Grids (simulation assumptions)

- Only distance measurements used (no angles yet)
- Each measurement has same error (0 ... 1μm)
- Each outer node is point-like and has 3 DOF
- Inner square nodes rigidly connected to magnet
  - Nodes on inner grid can not move w.r.t each other
  - 4 nodes on inner grid have only 6 degrees of freedom (DOF) total
- Reference points
  - in simulations without linking grid
    - I(0) or O(0) are reference
    - nodes on any square 0 do not move w.r.t. each other
  - in simulations with linking grid:

    i) O(0) rigidly fixed to I(0) (stable reference structures)

    ii) only I(0) is fixed and each node on O(0) is free in 3 DOF

Grids (simulation results)

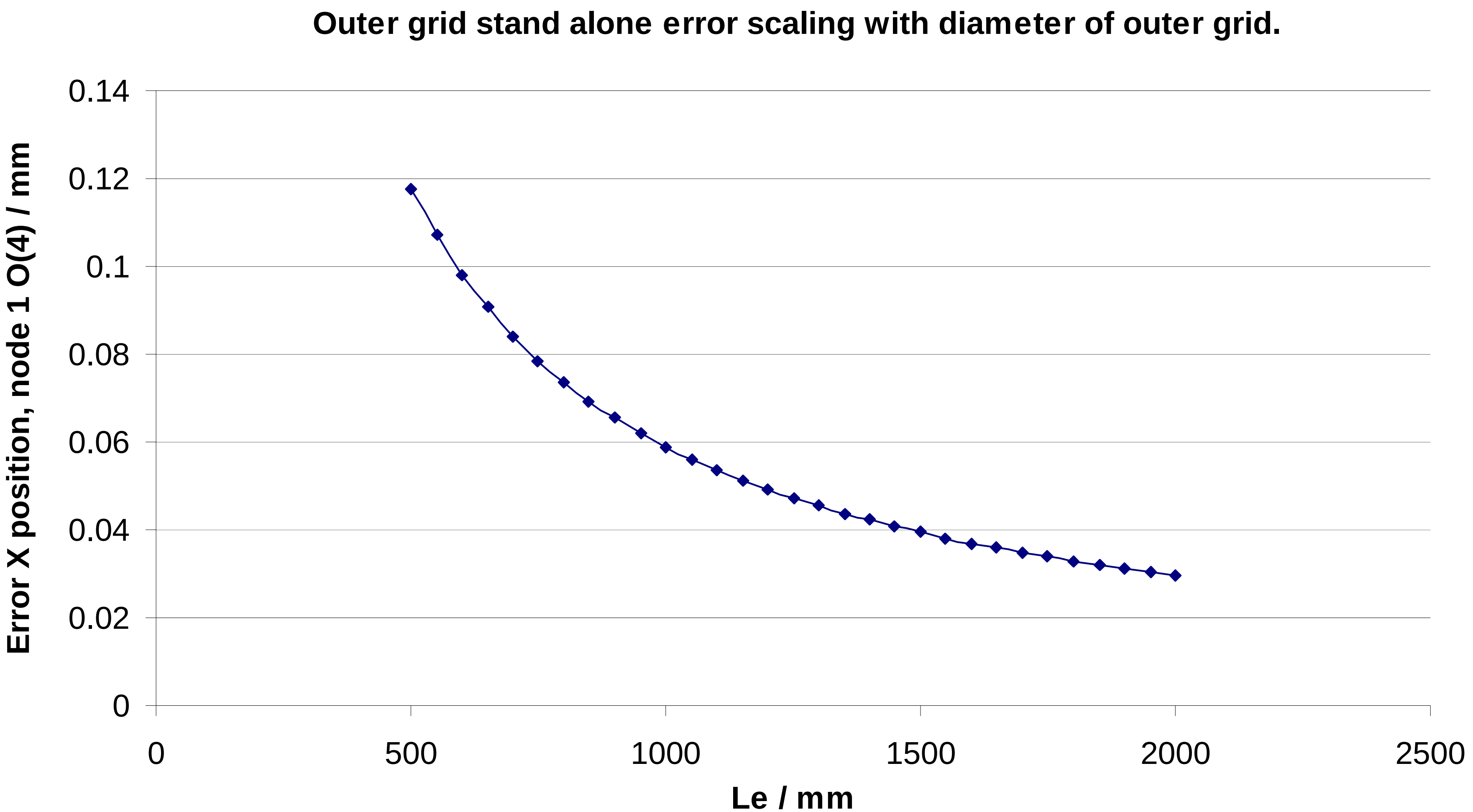
- Outer grid only
- Errors of node on O(n) w.r.t. O(0)
- All lines 1 μm accuracy

Z [m]	dX [μm]	dY [μm]	dZ [μm]
10	4.77	4.77	0.77
20	11.00	11.00	1.09
30	19.28	19.28	1.34
40	29.66	29.66	16.73

- Inner grid only
- Errors of one node on I(n) w.r.t. I(0)
- All lines 1 μm accuracy

Z [m]	dX [μm]	dY [μm]	dZ [μm]
10	12.26	12.26	0.28
20	26.47	26.47	0.41
30	45.30	45.30	0.50
40	67.86	67.86	0.57

Grids (simulation results)



Grids (simulation results)

- Linked grids
- I(0) fixed to O(0) as ref.
- All lines 1 μm accuracy

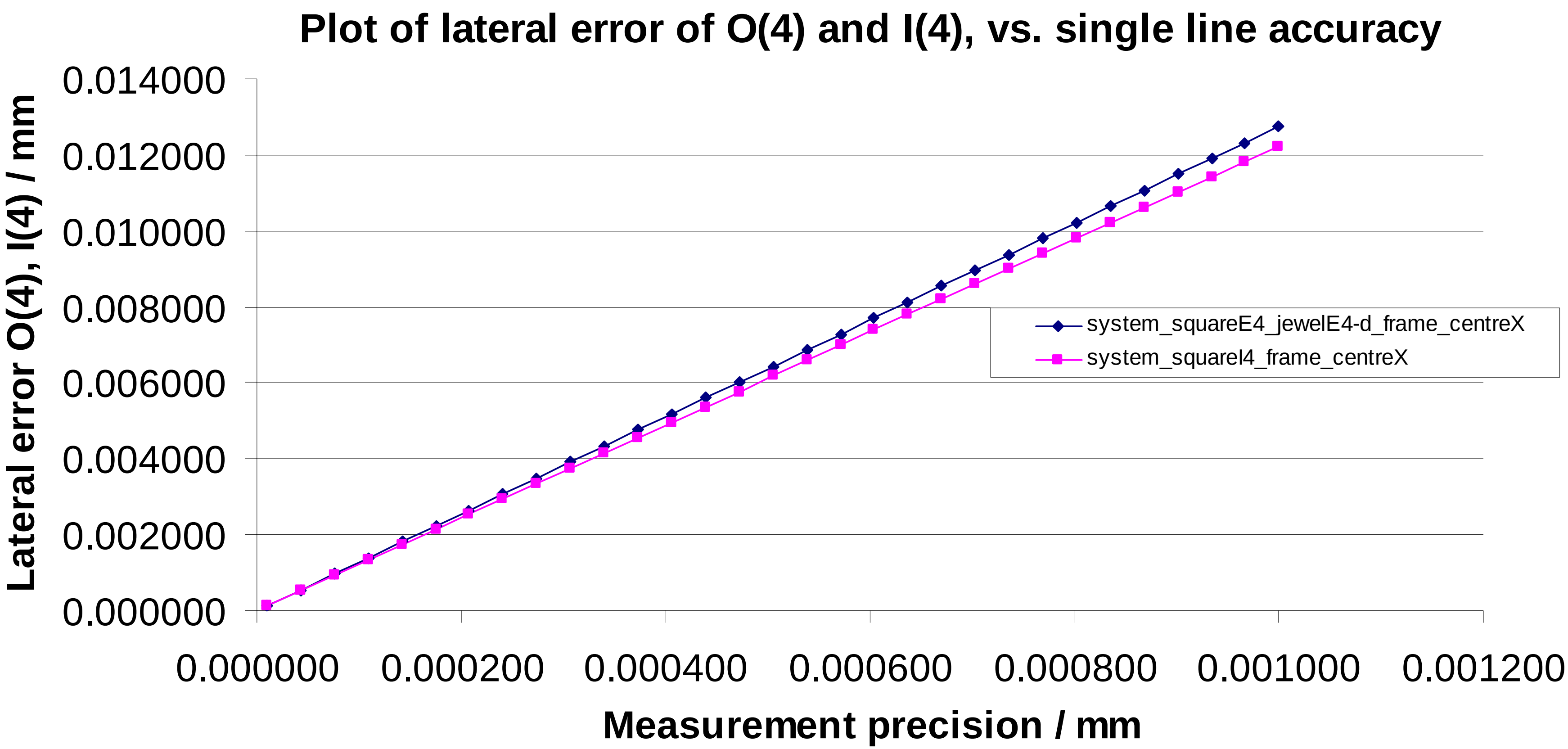
Z [m]	dX_O [μm]	dZ_O [μm]	dX_I [μm]	dZ_I [μm]
10	2.73	0.43	2.01	0.17
20	5.27	0.58	4.68	0.23
30	8.63	0.70	8.11	0.27
40	12.74	0.83	12.22	0.33

- Linked grids
- I(0) fixed as ref, O(0) free
- All lines 1 μm accuracy

Z [m]	dX_O [μm]	dZ_O [μm]	dX_I [μm]	dZ_I [μm]
10	8.66	1.20	8.43	2.29
20	16.88	1.26	16.68	2.73
30	25.37	1.32	25.18	3.10
40	34.15	1.39	33.95	3.58

Grids (simulation results)

- Linked with I(0) fixed to O(0) (best configuration)
- error scaling with measurement precision
- slope ~ 10

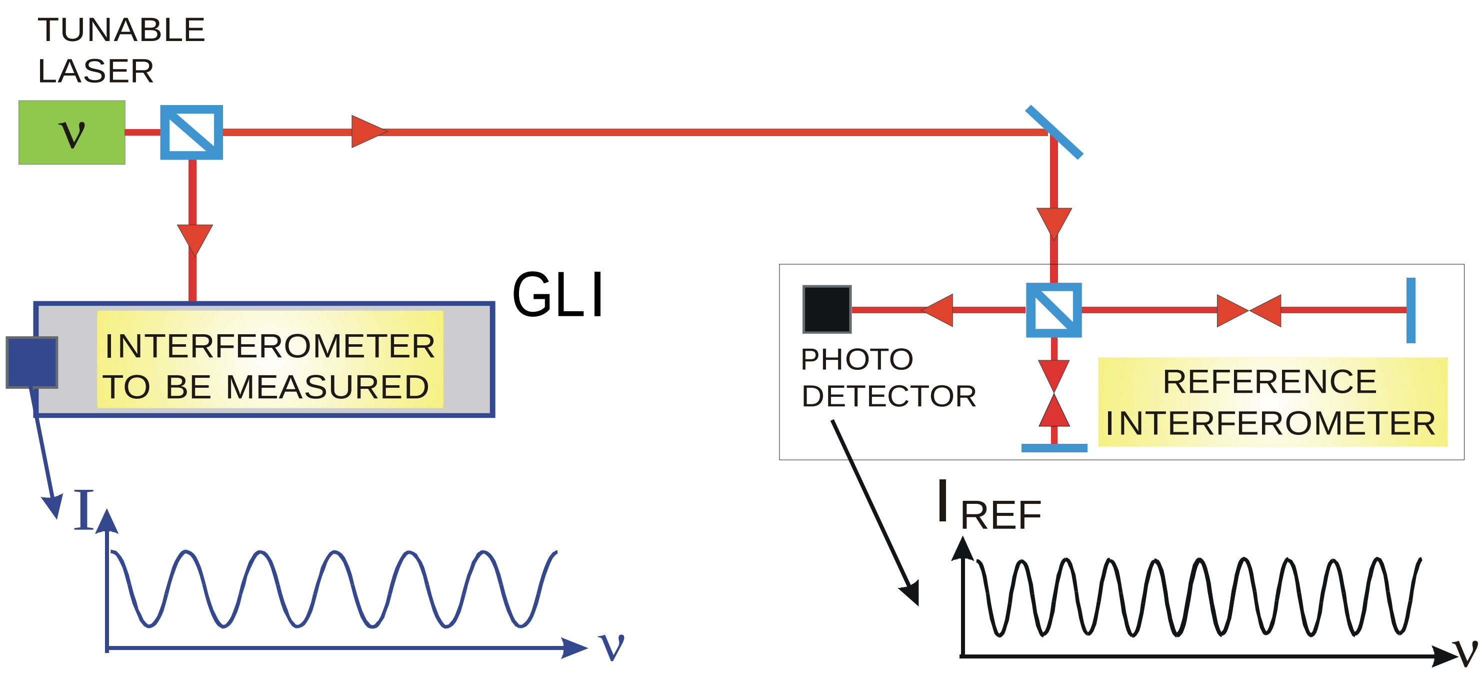


Grids (things to do)

- Include lines from n to n±2
- Include straightness monitors
- Make realistic nodes (not point like)
- Use more mechanical constraints (stiff structures)
- Check redundancy (drop lines)
- Fit into real tunnel

FSI (principles)

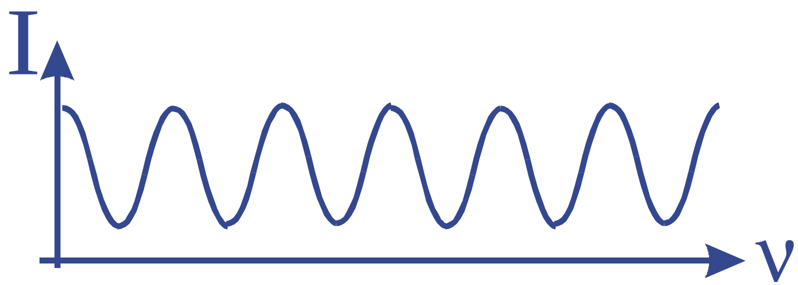
- Frequency Scanning Interferometry
- Use tunable laser to compare lengths of interferometers
- Interferometers are fed and read via fibres



FSI Phase Shift → Laser tuning range / Interferometer Length

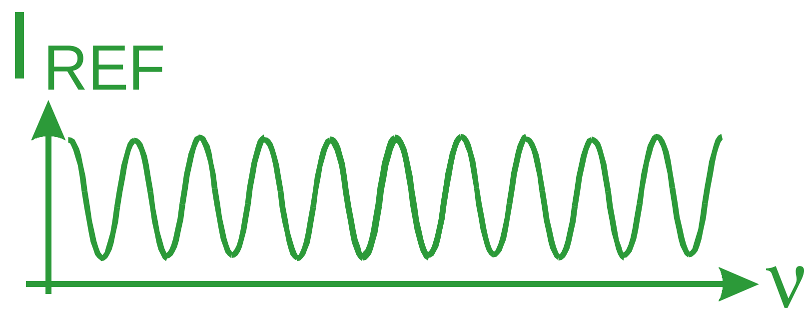
FSI (principles)

Grid Line Interferometer (GLI)



$$\Delta\Theta = \left[2\pi/c\right] D \Delta\nu$$

Reference Interferometer



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

$$D = L\,\frac{\Delta\Theta}{\Delta\Phi}$$

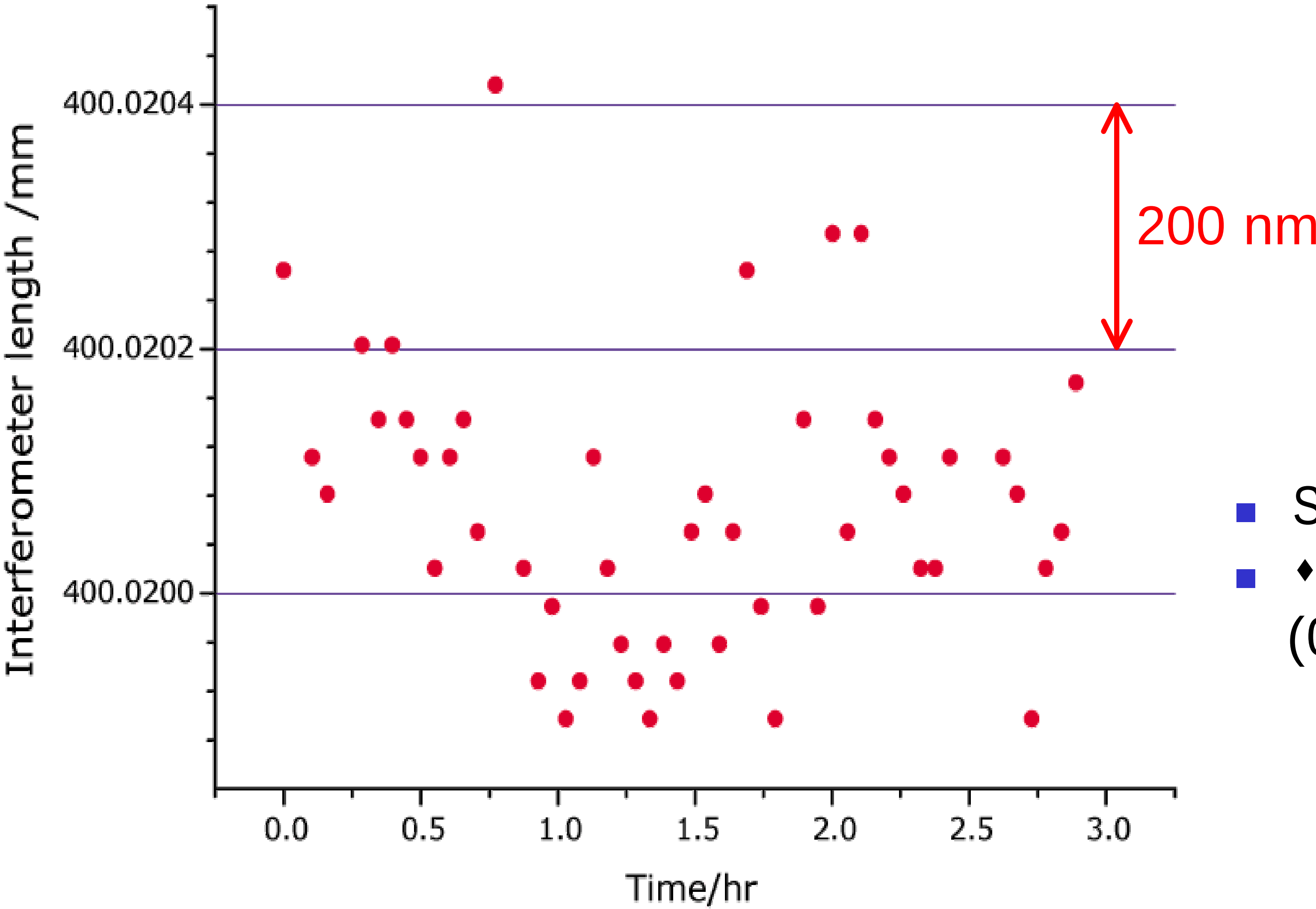
D , *L* assumed constant (unrealistic)

FSI (practical issues)

- Refractive index
  - Measure gas temperature and pressure
  - keep lines in closed tubes wherever possible
- Non-linear laser tuning
  - Phase stepping in reference interferometer
- Insufficient fine tuning range
  - Sub-scan linking
- Thermal drift
  - Dual laser drift correction

- These are difficult !

FSI (result, 5 years of R&D later)



- Steel GLI
- ♦ = 117nm (0.29 ppm)

FSI (differences between ATLAS and LC)

- ATLAS = low power system in tracking detector
  - no collimation optics = photon noise limited
  - no real retro reflectors
  - no absolute node calibration
- LC = real geodesic system
  - long path with collimation optics
  - different lasers (telecom style)
  - absolute calibration for nodes

Next step (idea, not quite “out of the blue”)

- Send stabilised fixed frequency laser down GLI and into reference cavity
- Continuously measure phase of both (piezo in cavity, accusto optic modulator in GLI)
- Use GLI as a Michelson
  - Would normally not work (laser drift, unbalanced arms)
  - But we know the arm length accurately from FSI
  - Combine knowledge of length with both phase signals
  - extract true Michelson fringes
- Call it M-FSI (when it works)
- Get O(nm) resolution per line in M-mode