GINGER External Metrology System (GEMS)

Meeting presentation
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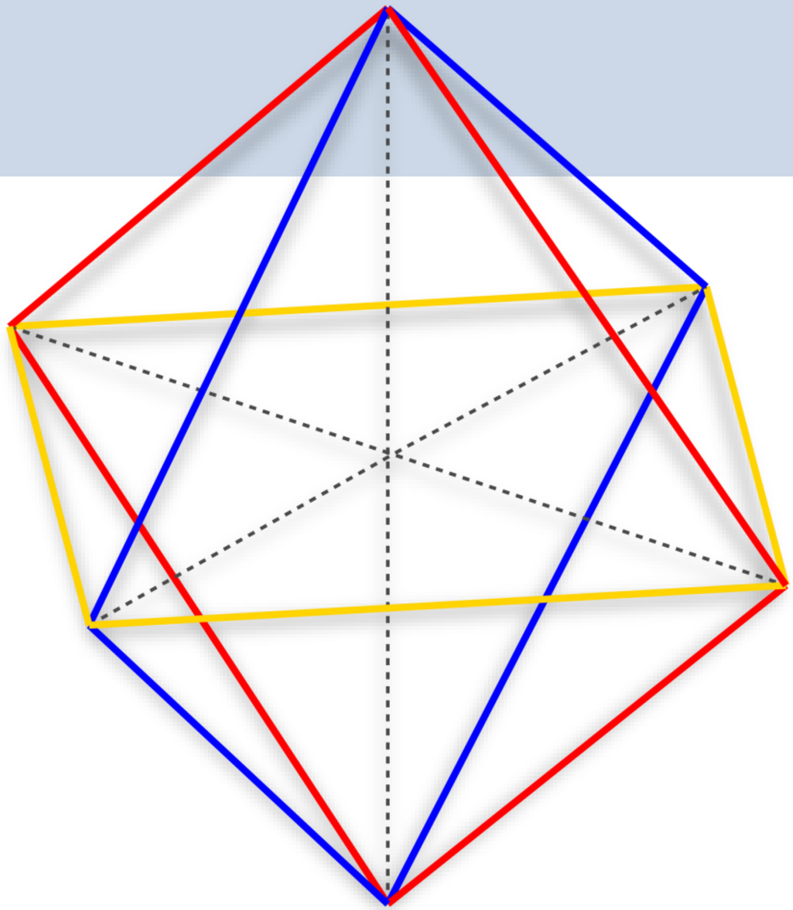
Alberto Donazzan[1]

M. G. Pelizzo[2]
G. Naletto[1]

[1] Dipartimento di Ingegneria dell'Informazione, Università di Padova (PD)
[2] Consiglio Nazionale delle Ricerche, Istituto di Fotonica e Nanotecnologie (PD)

GEMS requirements



Geometry locking:

Scale factor has to be held constant to much better than 1 part in 10^{10}

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Mirror relative *position* and *orientation* should be accurate to better than 1nm and 1nrad

Octahedron: 6 x 3 DoF = 18 DoF

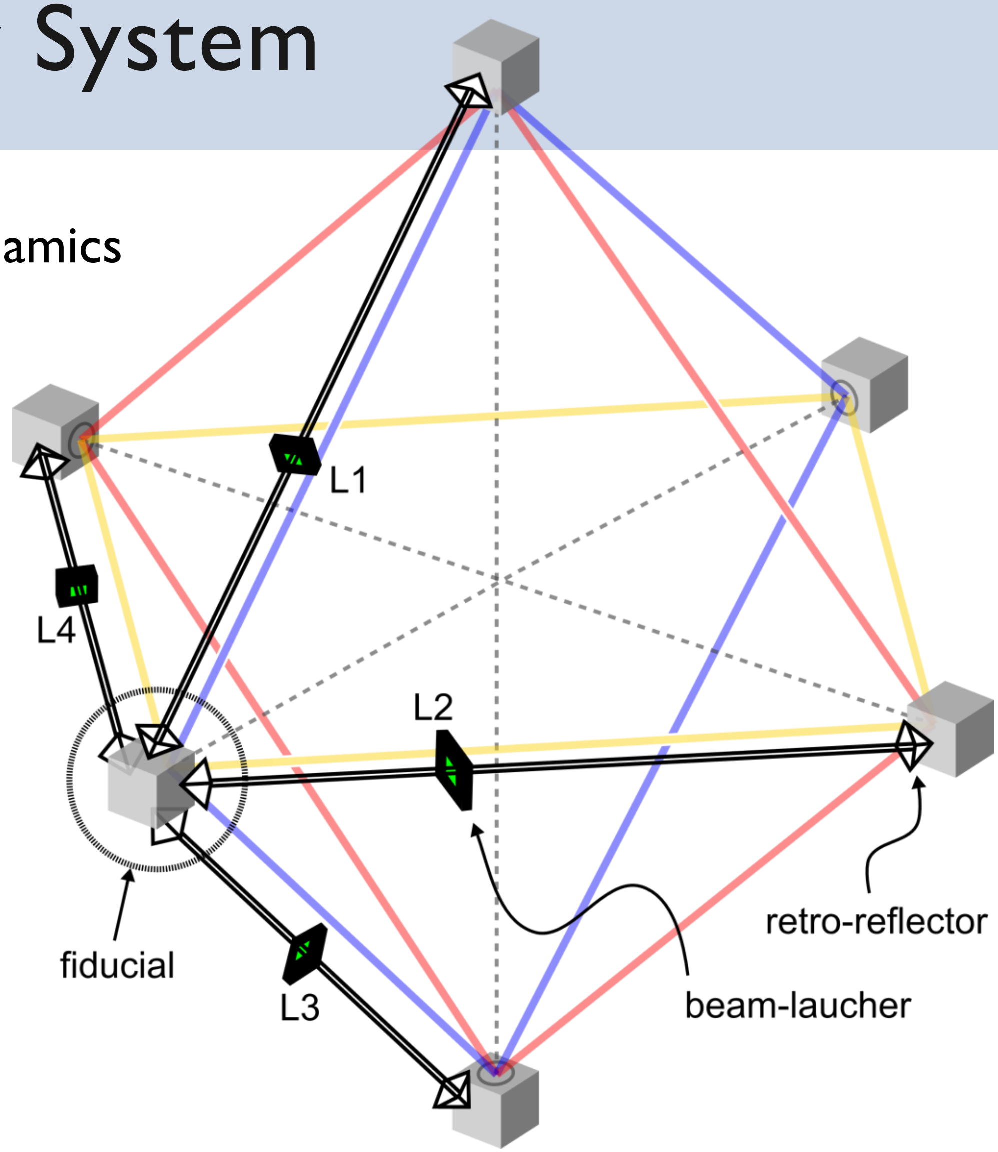
- Rigid body translations: 3 DoF
- Rigid body rotations (calibration): 3 DoF
- 12 remaining DoF to be removed, possibly by monitoring:
  - ring-laser cavities' perimeters
  - diagonal cavities' lengths
  - polyhedral edges with External Metrology System

External Metrology System

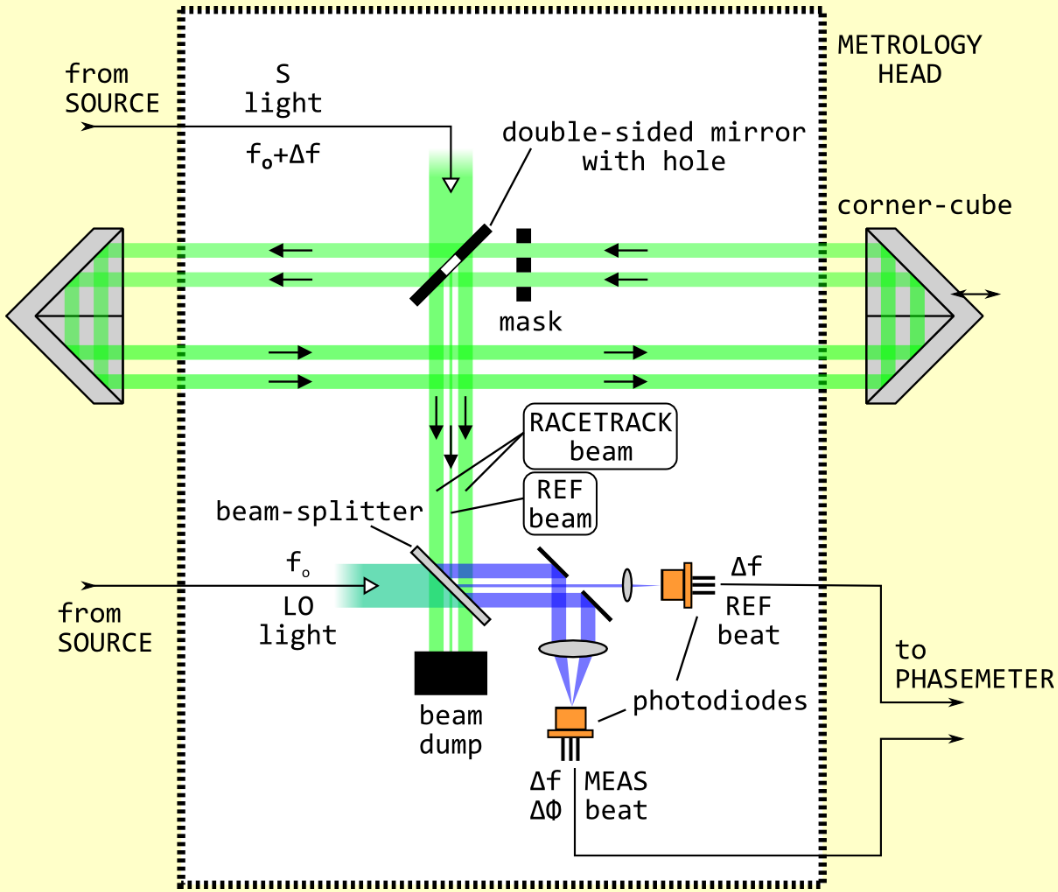
- indipendent from ring-lasers' dynamics
- 1 nm precision

Every vertex is a multiple reference point (*fiducial*)

Each edge's length is provided by a compact heterodyne laser interferometer (*beam-launcher*)



BEAM-LAUNCHER



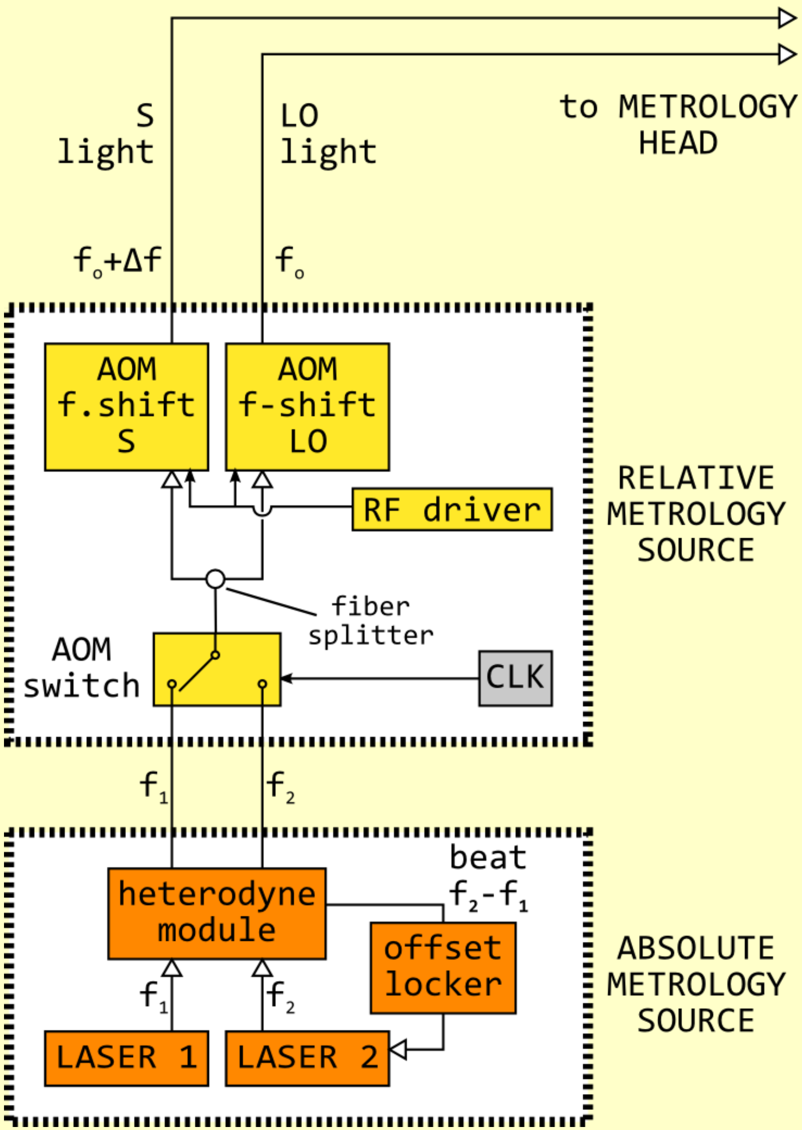
Heterodyne interferometer

Two spatially isolated beams:

- Reference beam (inner)
- Racetrack beam (outer)

- Beat signals at frequency Δf
- Distance is given by phase difference between REF and RACETRACK beats

$$\Delta\Phi = 2 \cdot \frac{2\pi}{\lambda} \Delta L$$



LASER Source & Absolute Distance Measurement

- Two colors LASER source: f_2-f_1~10 GHz
- AOMs alternate between the two laser outputs, hence Δϕ is measured at two different λ and it is possible to deduce the absolute distance.
- In the "relative metrology" mode the switching is stopped and only one laser is continuously selected to feed the frequency shifters.

CHALLENGES

Optical Layout

Reference and measurement paths have to match exactly (keeping separate), except for racetrack!

Avoid:

- Mechanical displacements, vibrations
- Refractive index variations:
  - Temperature gradients
  - Air turbulence
- Optical "cross-talk":
  - Mixing of REF and RACETRACK beams due to diffraction and misalignments
- Source instability:
  - Frequency (phase) noise

Monitoring and Control

- Identify minimum number of required distances
- Integration with other measuring techniques (diagonals, perimeters, …)
- Geometry estimate and control

Electronics

- Low phase noise
- Linearity

Mechanics

- Integration with GINGER: fiducials, vacuum systems, …

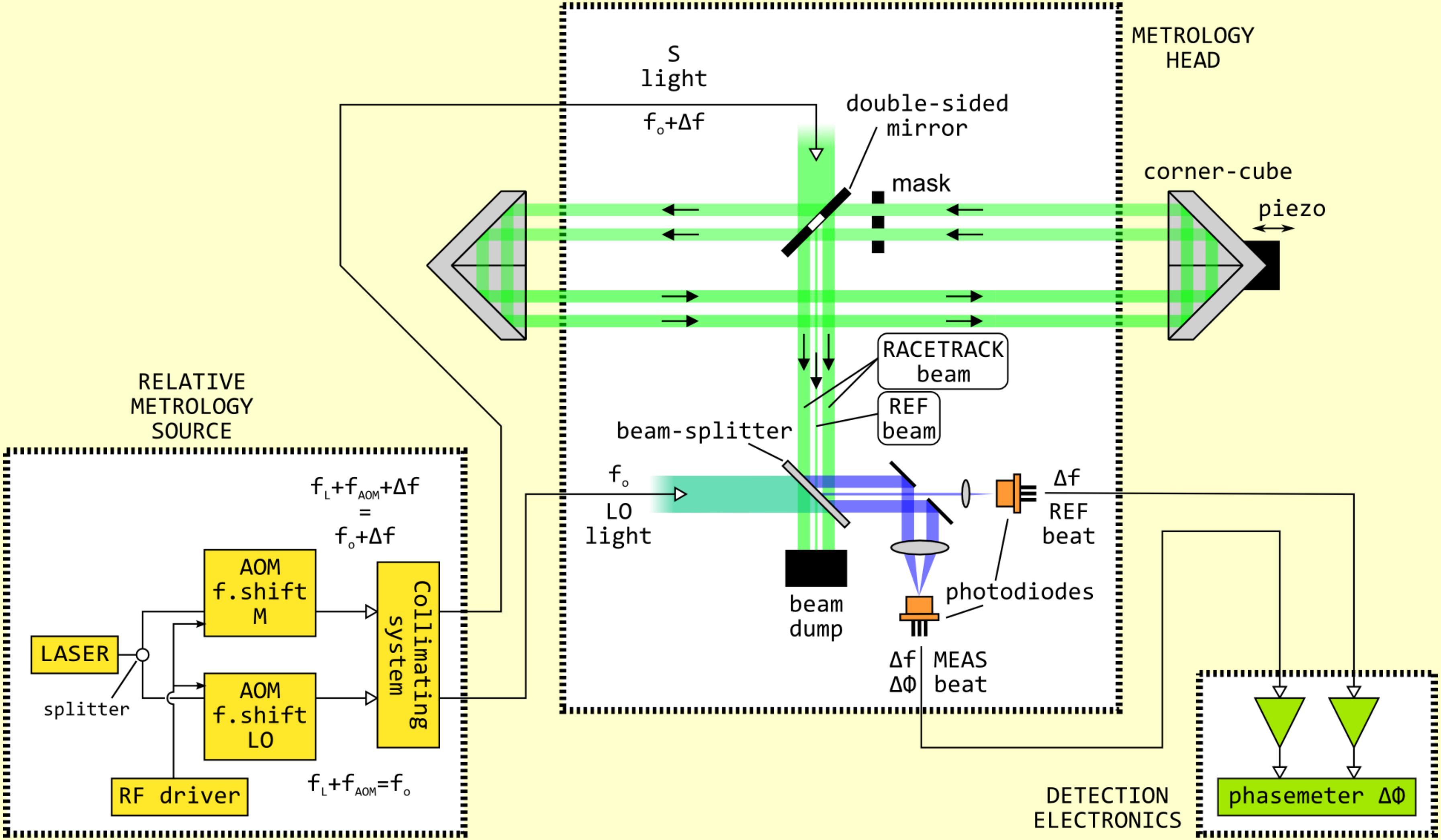
GEMS Prototype (GEMS-P)

GOALS

Evaluate parts behavior,
alignment issues,
links between single components and overall system performances

FEATURES

- Free-space source, Fiber ready (compactness!)
- NO absolute metrology source
- Vibration isolated optical table
- In-air environment



METROLOGY HEAD
S light
$f_o+\Delta f$
double-sided mirror
mask
corner-cube
piezo
RACETRACK beam
REF beam
beam-splitter
f_o
LO light
Δf
REF beat
photodiodes
beam dump
Δf $\Delta\Phi$
MEAS beat
RELATIVE METROLOGY SOURCE
$f_L+f_{AOM}+\Delta f$ = $f_o+\Delta f$
AOM f.shift M
AOM f.shift LO
Collimating system
LASER
splitter
RF driver
$f_L+f_{AOM}=f_o$
DETECTION ELECTRONICS
phasemeter $\Delta\Phi$

ROADMAP
(1st year)

- Study and characterization of the LASER heterodyne interferometer

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- Definition of parts requirements
- Purchase

↓

- Prototype assembly, alignment and test

↓

- Prototype evaluation

ROADMAP
(1st year)

- Study and characterization of the LASER heterodyne interferometer

- Definition of parts requirements
- Purchase

Finding optimal Source-AOM couple…

- Prototype assembly, alignment and test

- Prototype evaluation

MATLAB simulation of beats from two (noisy) sine waves

1. Build (noisy) sine waves:

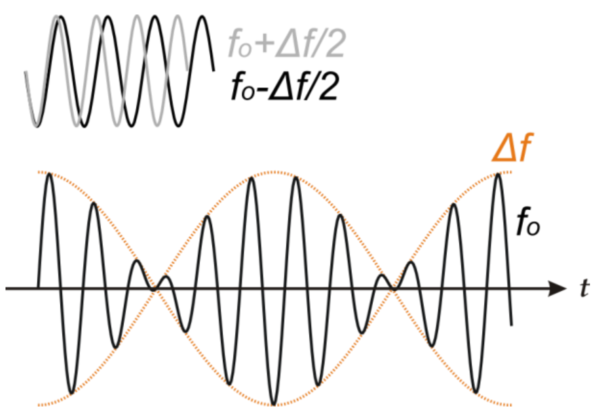
$$A_{1n} \cdot \sin(2\pi f_{1n} t) = (A_1 + \alpha_{1n}) \cdot \sin[2\pi\, (F_1 + f_{1n}) \cdot t]$$

$$= (A_1 + \alpha_{1n}) \cdot \sin[2\pi \mathrm{F}_1 t + 2\pi f_{1n} t]$$

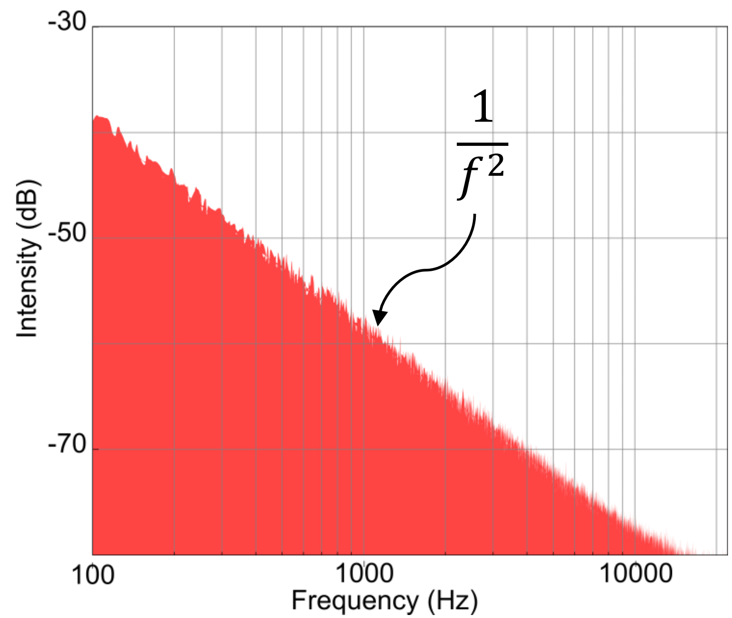
$\alpha_n \sim \mathcal{N}(0, \sigma_A)$ is a white gaussian amplitude noise

$f_n \sim \mathcal{N}(0, \sigma_f)$ is a white gaussian frequency noise

⟹ $2\pi f_n t$ is a red phase noise*



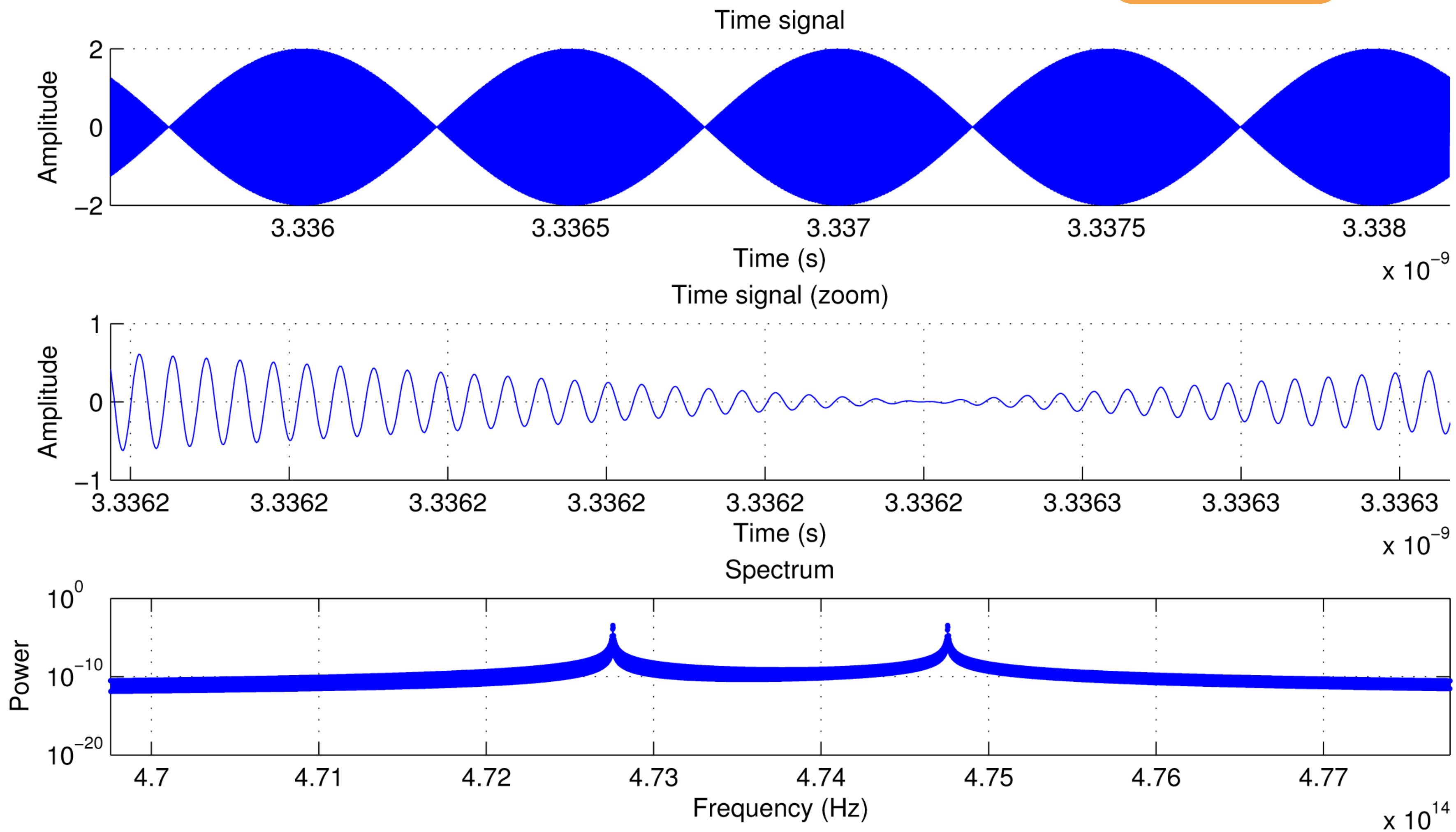
2. Sum them and check beating visibility
3. Forward time-shift (equal length path, racetrack)
4. Compute power spectrum



* red noise is generated by integrating white noise

An example: optical freq. $f_0 = 473.8\, THz$ (632,8nm)
beats freq. $\Delta f = 2\, THz$

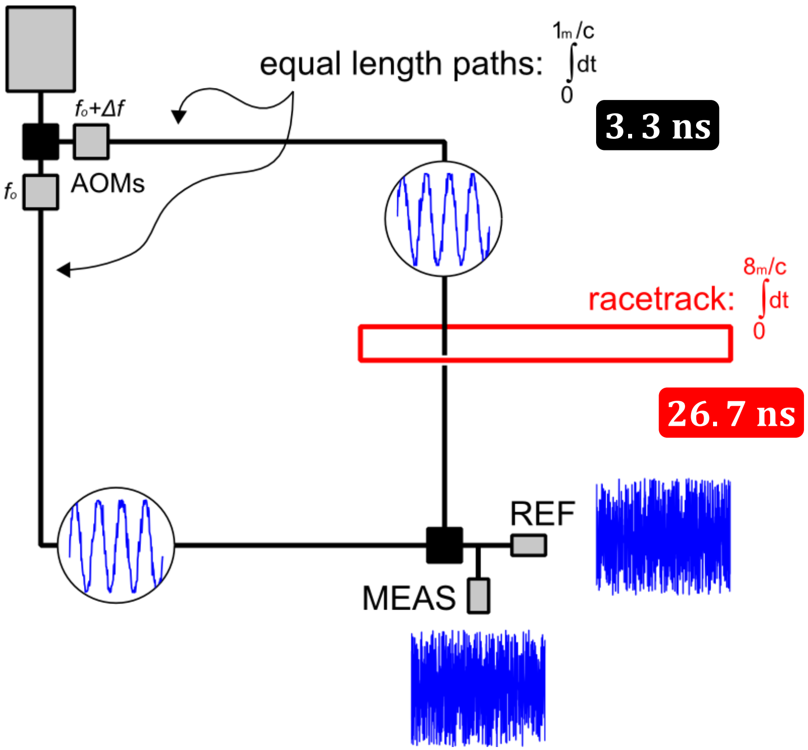
Noiseless beats



SHORT coherence length

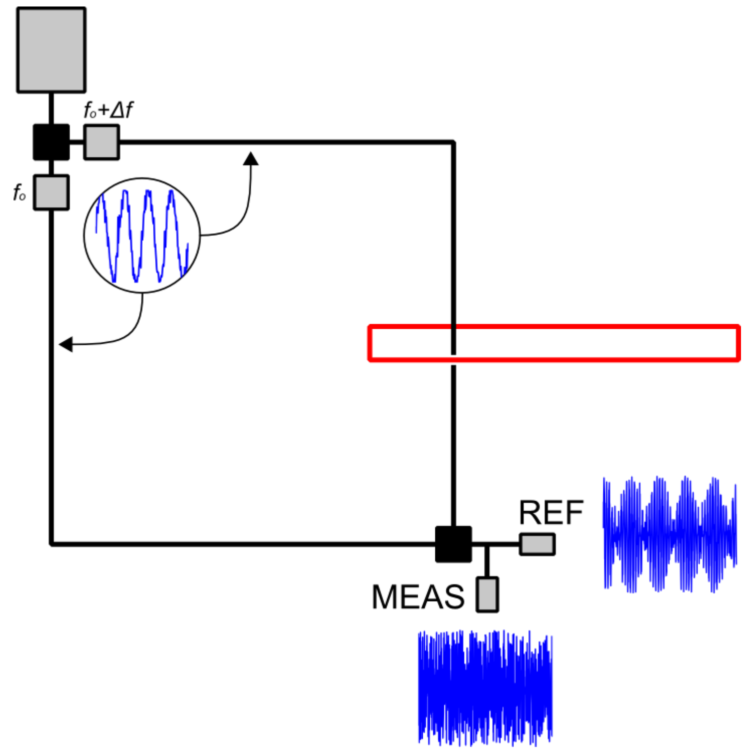
UNCORRELATED noises

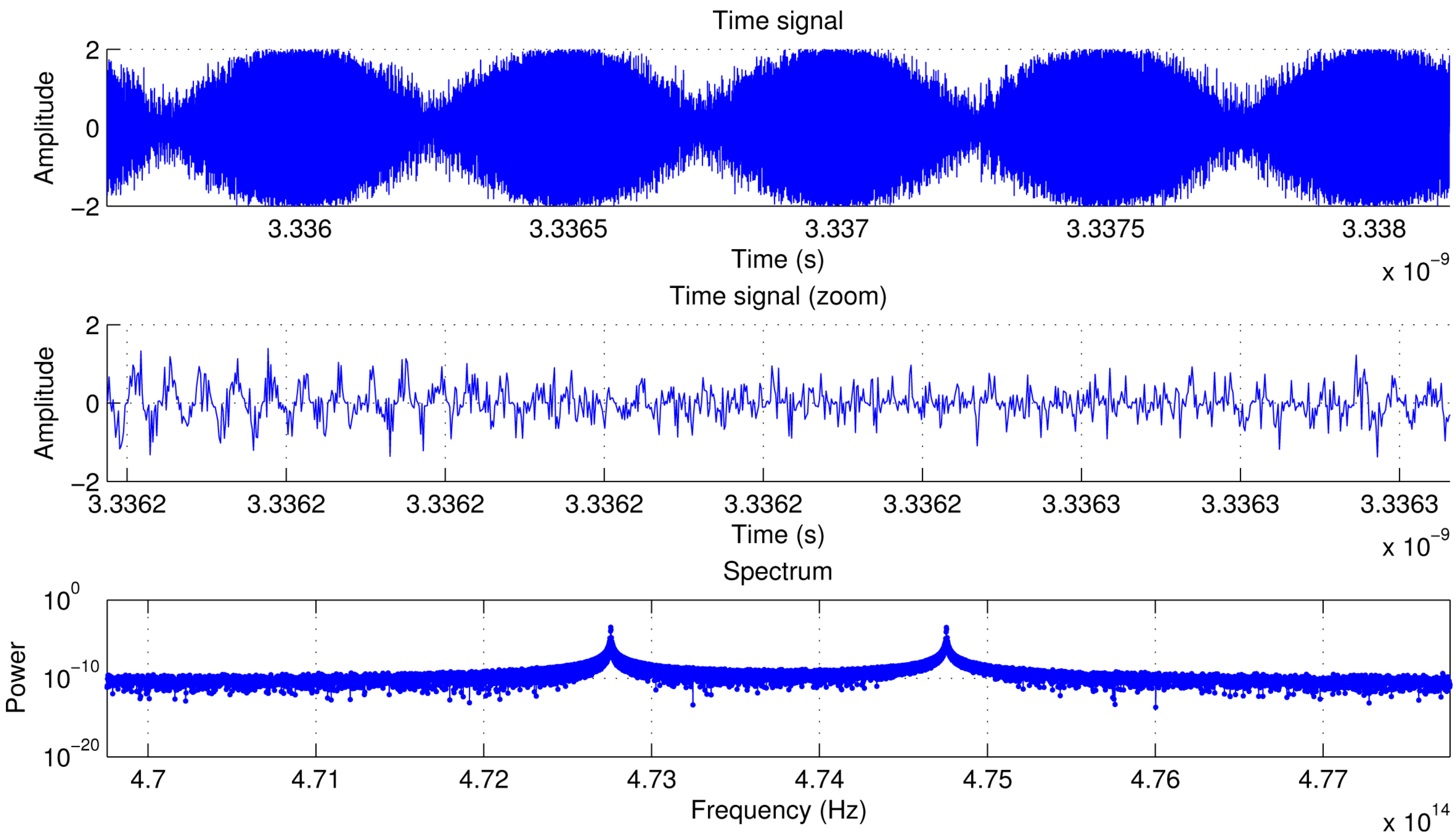
- Two independent LASERs sources and/or
- Independently driven AOMs



CORRELATED noises

- One splitted LASER source and same AOMs' driver

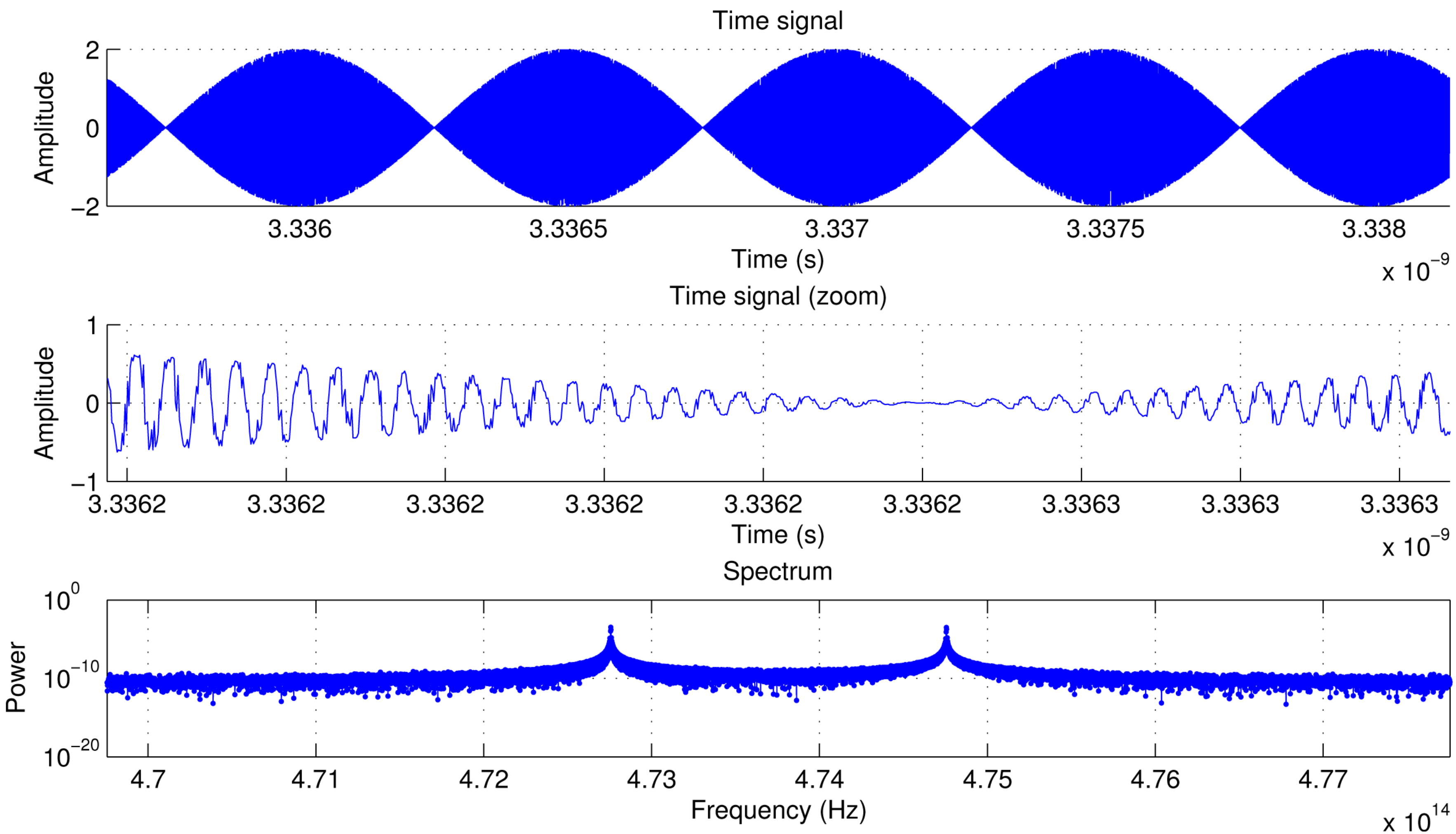




REFERENCE beat

Uncorrelated noises

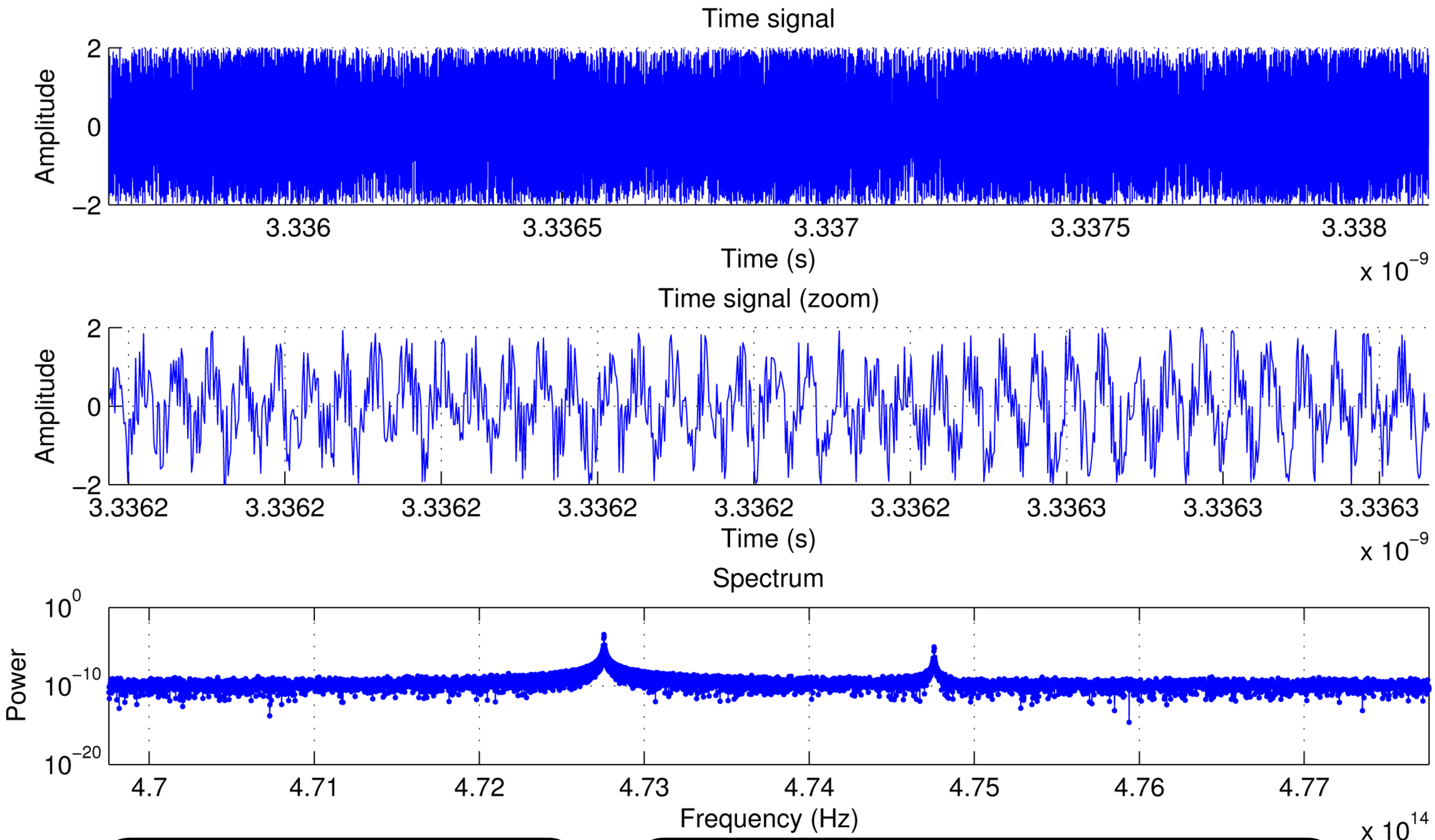
$10m$ coherence length ($30MHz$ linewidth)



REFERENCE beat

Correlated noises

$10m$ coherence length ($30MHz$ linewidth)



RACETRACK = loss of correlation

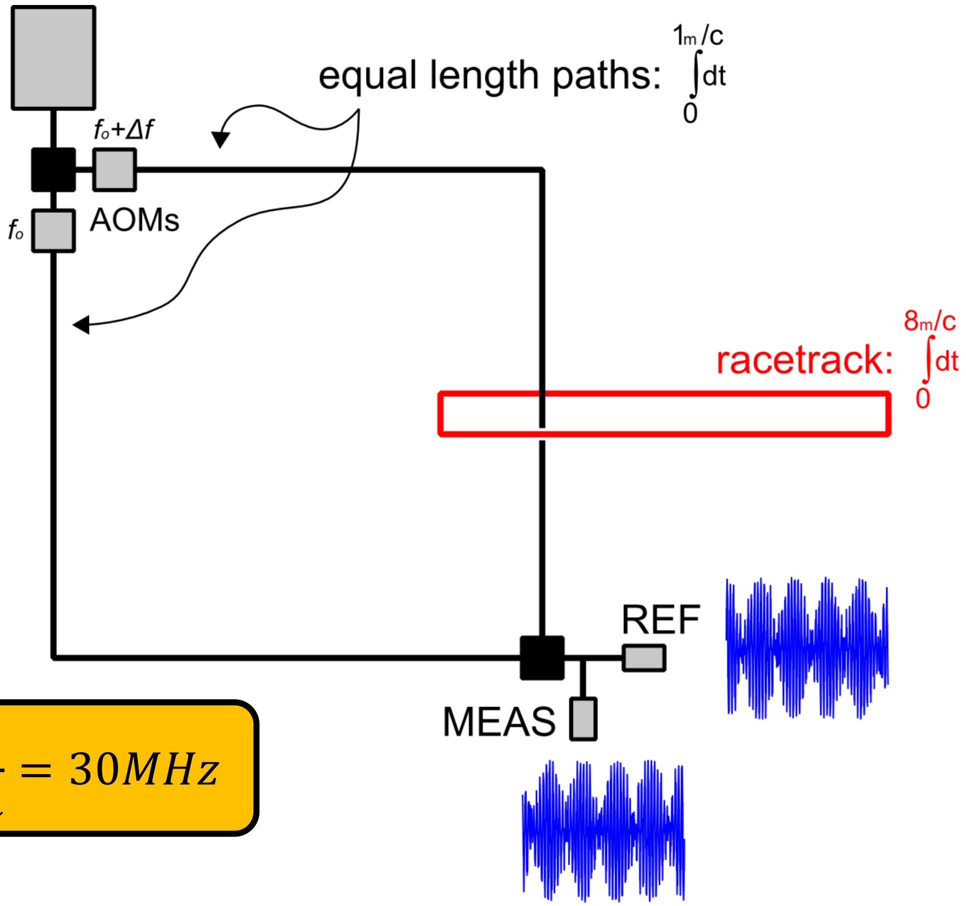
MEASUREMENT beat

Correlated noises

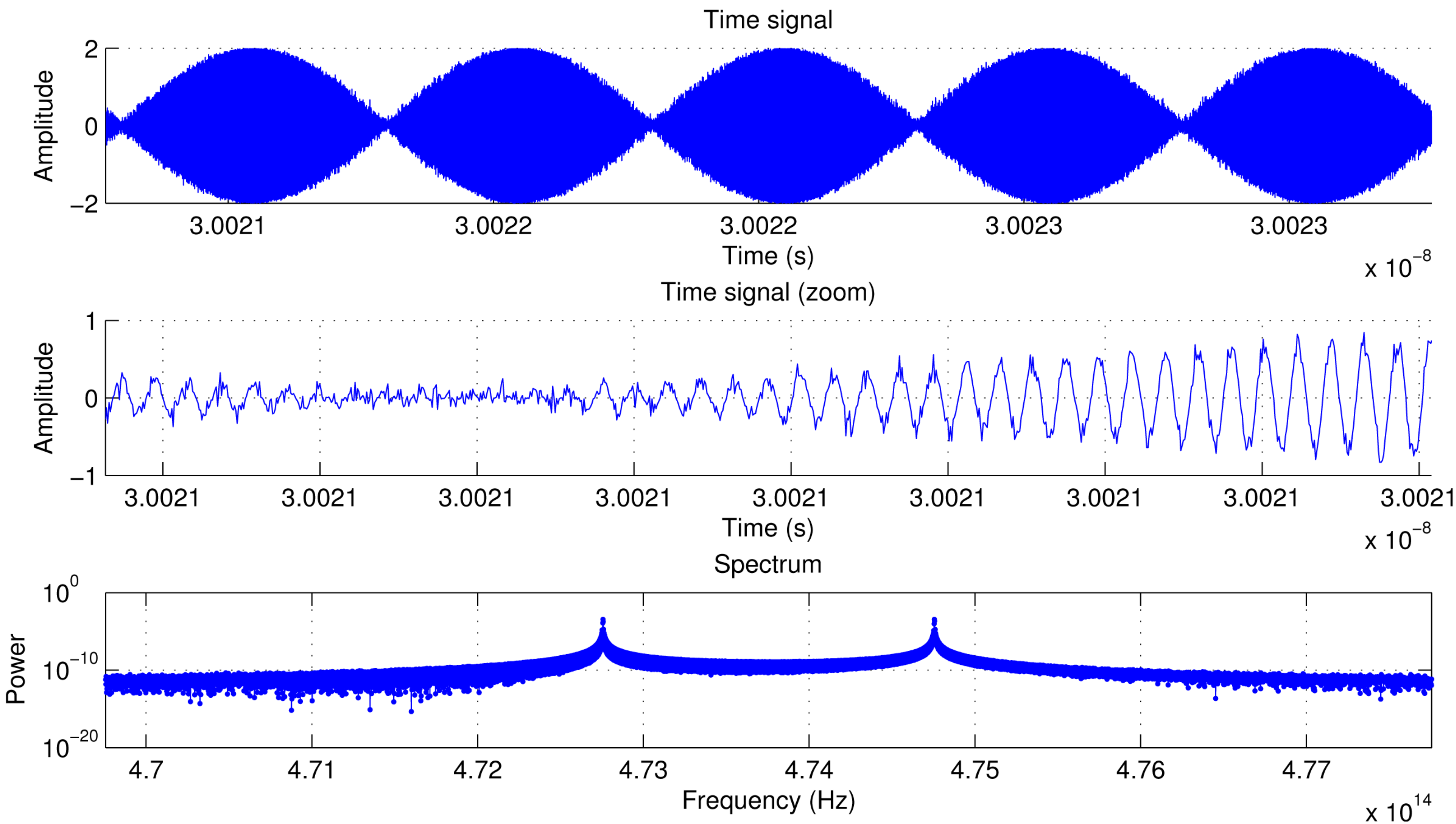
$15m$ coherence length ($20MHz$ linewidth)

LONG coherence length

With both UNCORRELATED and CORRELATED noises, visibility never worsens



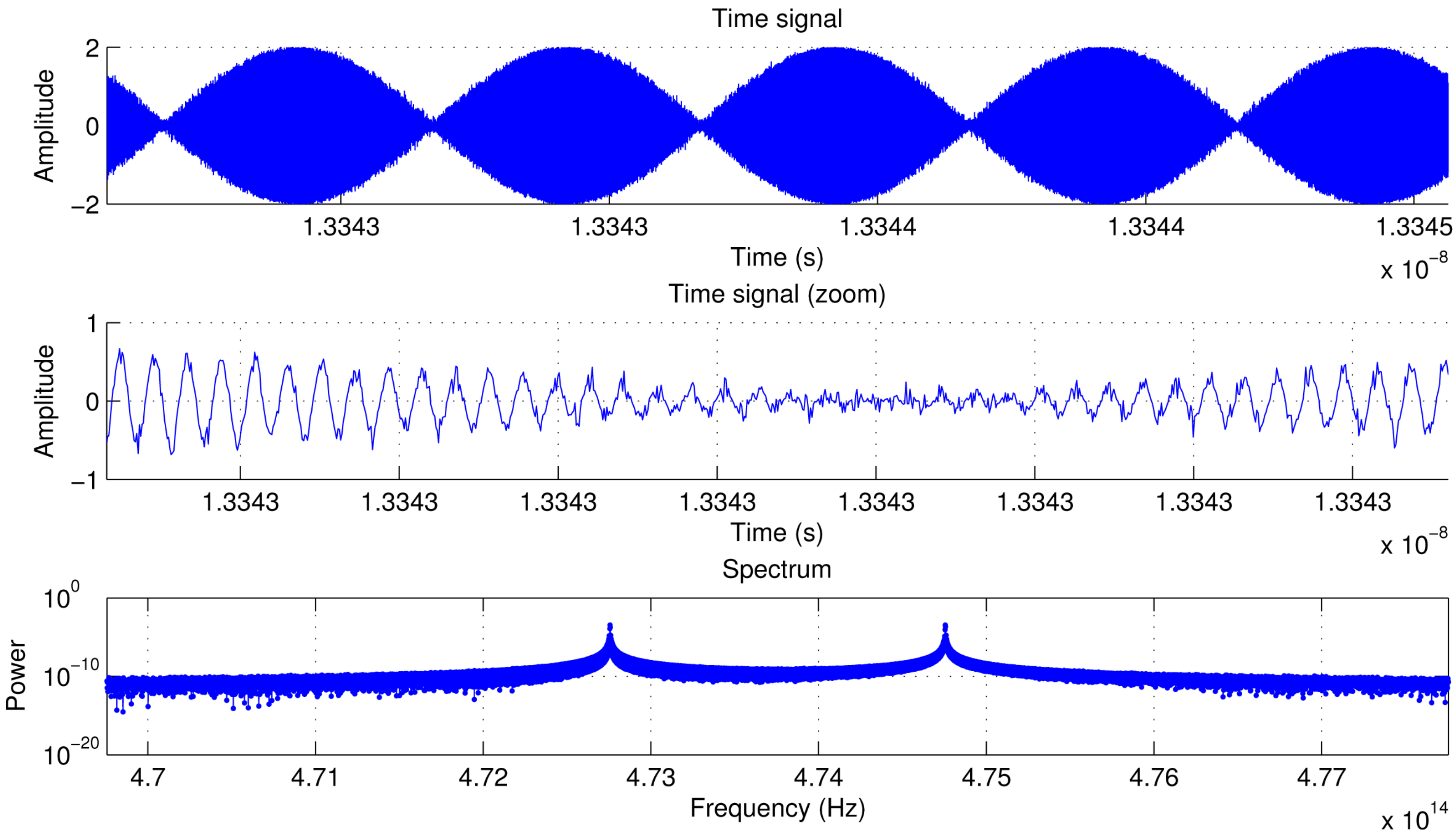
$$linewidth \ll \frac{c}{10m} = 30MHz$$



MEASUREMENT beat

<u>Uncorrelated noises</u>

$300m$ coherence length ($1MHz$ linewidth)



MEASUREMENT beat

Correlated noises

$300m$ coherence length ($1MHz$ linewidth)

ROADMAP
(1st year)

- Study and characterization of the LASER heterodyne interferometer

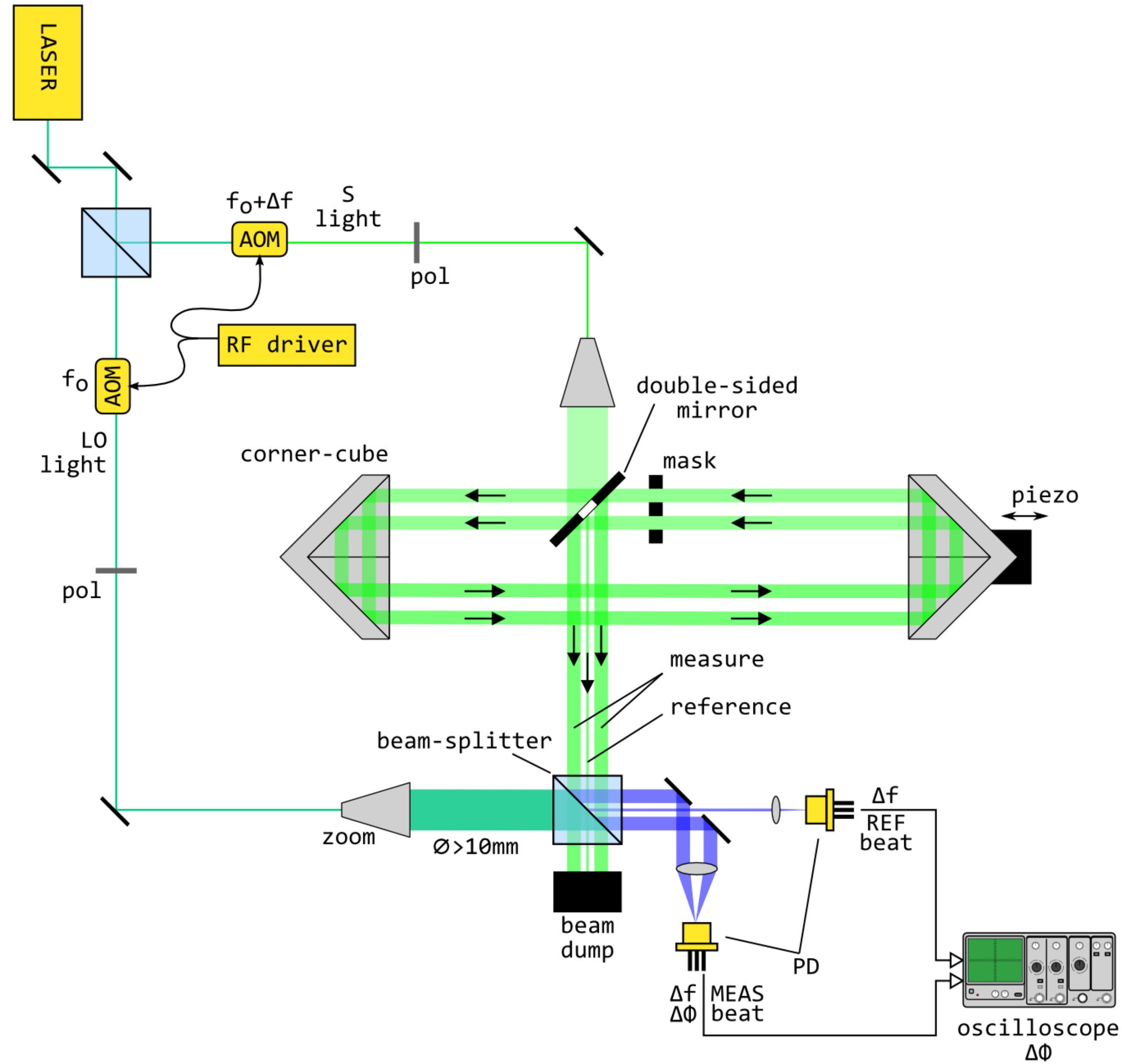
- Definition of parts requirements
- Purchase

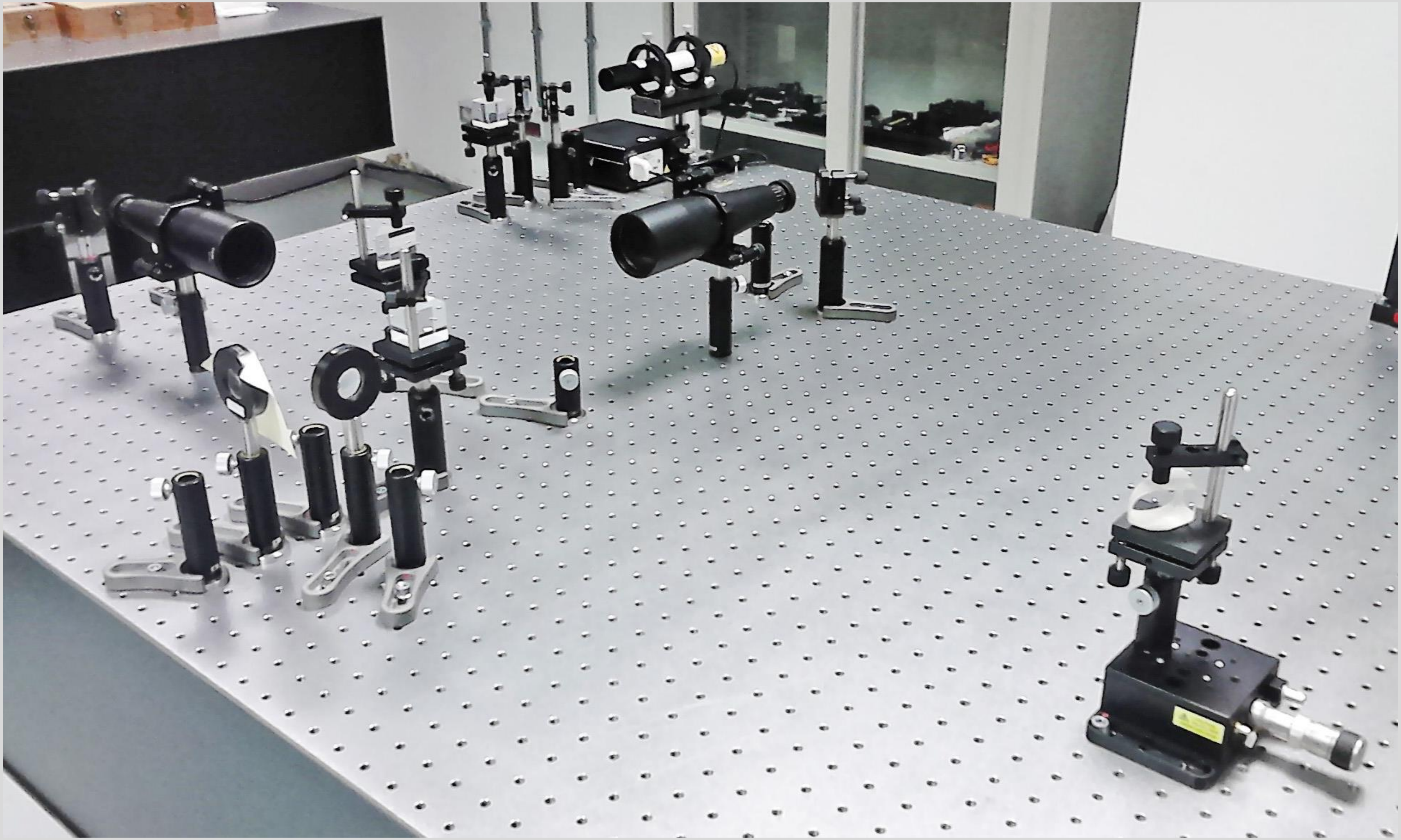
- Prototype assembly, alignment and test

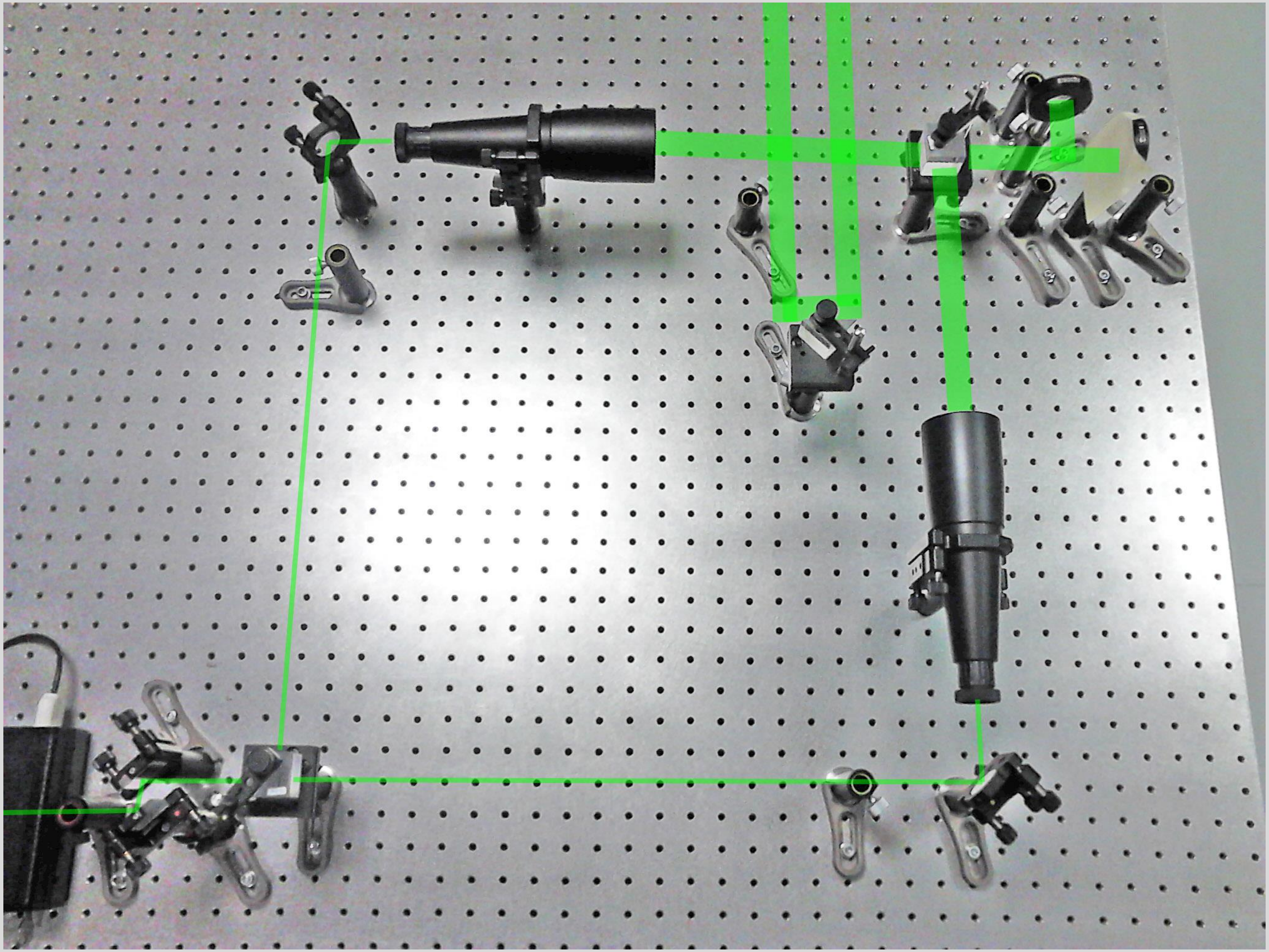
- Prototype evaluation

Footprint
Optomechanics

Optical layout

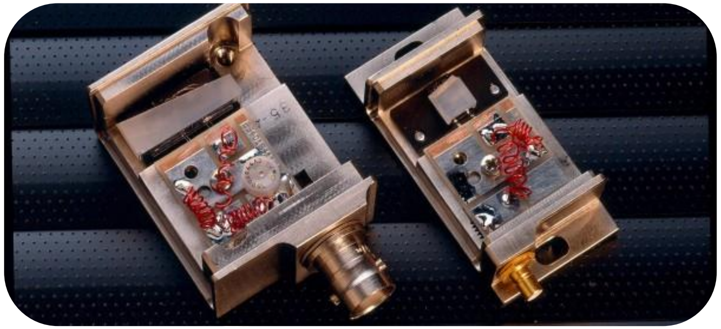






Required parts

- Single-frequency LASER source
  - $532nm$
  - >$100mW$ (lab upgrade required)
  - <1Mhz linewidth
  - thermal and mechanical stabilization
  - free-space output + fiber coupler

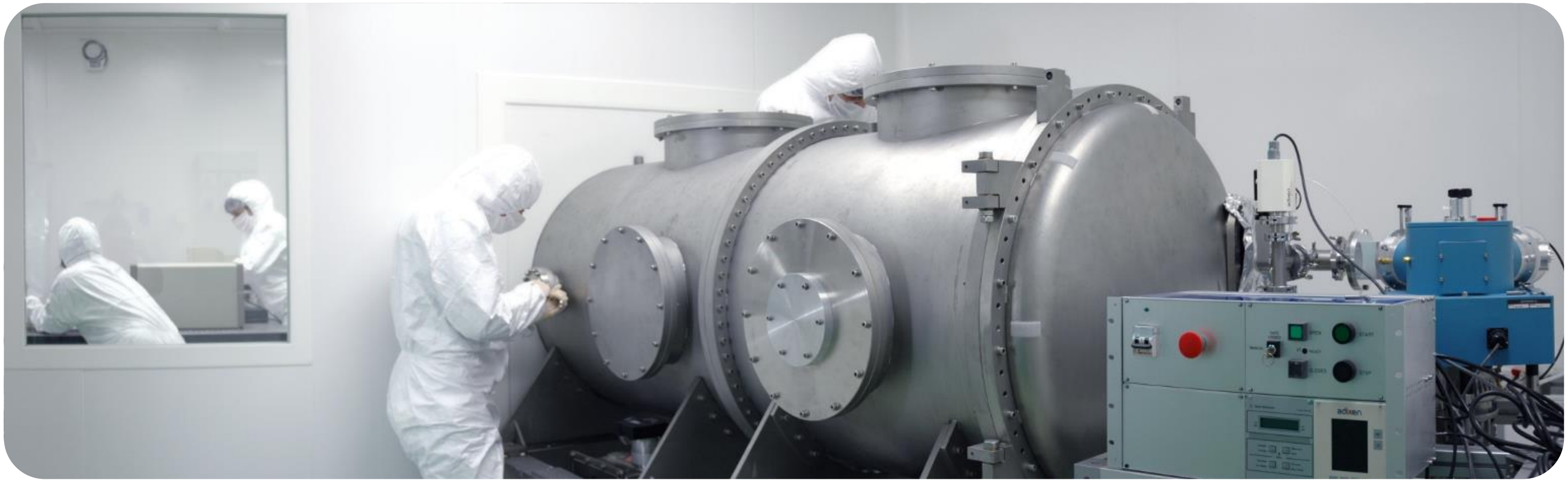


- 2x AOMs
  - VIS spectral range
  - free-space input/output
  - driver with double RF output

- 2x Photodiodes
  - VIS spectral range
  - >10MHz bandwidth
  - integrated Transimpedance amplifier

Backup Slides

Laboratory resources at CNR-IFN (1)

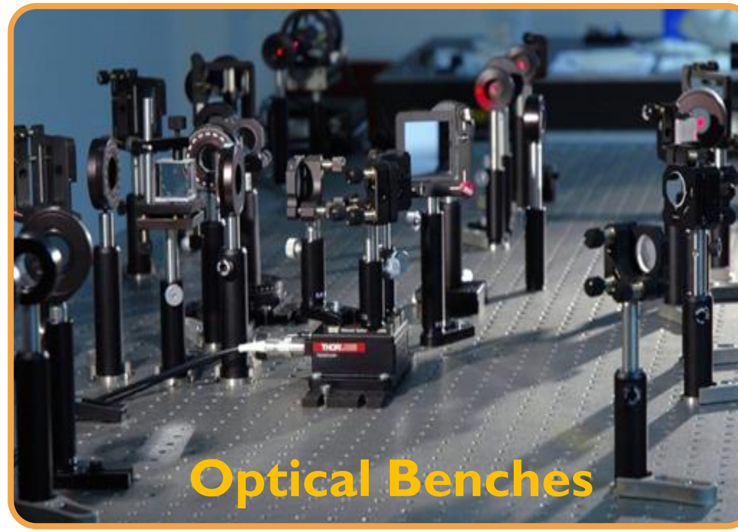


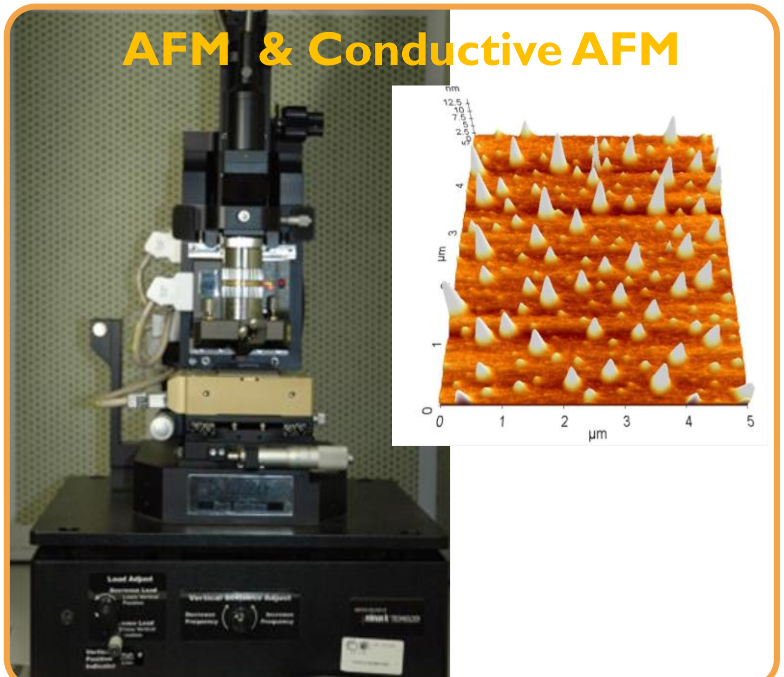
Large Vacuum chamber

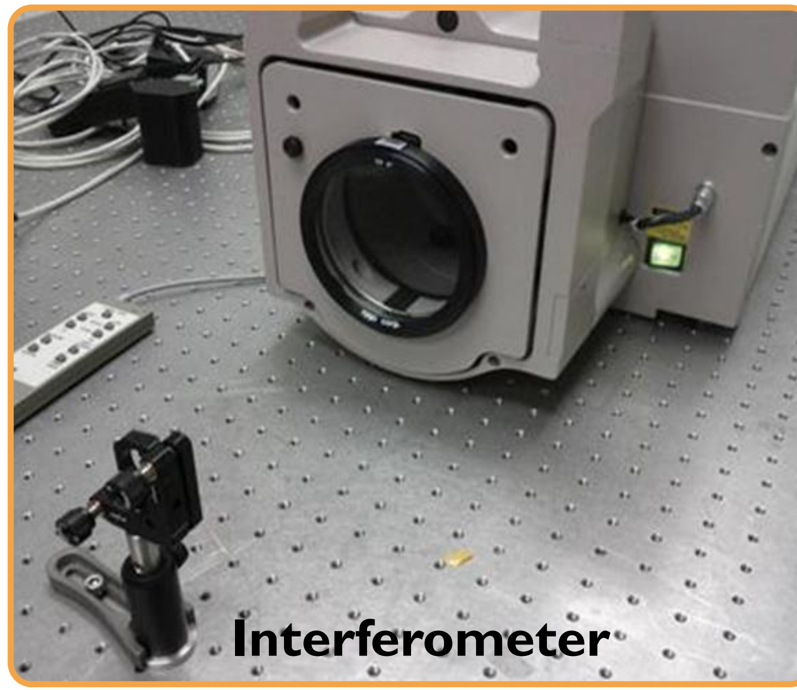
Cleanroom 46sqm:

- Area 1 (ISO7 class), pre-cleanroom area
- Area 2 (ISO6 class), 23 sqm

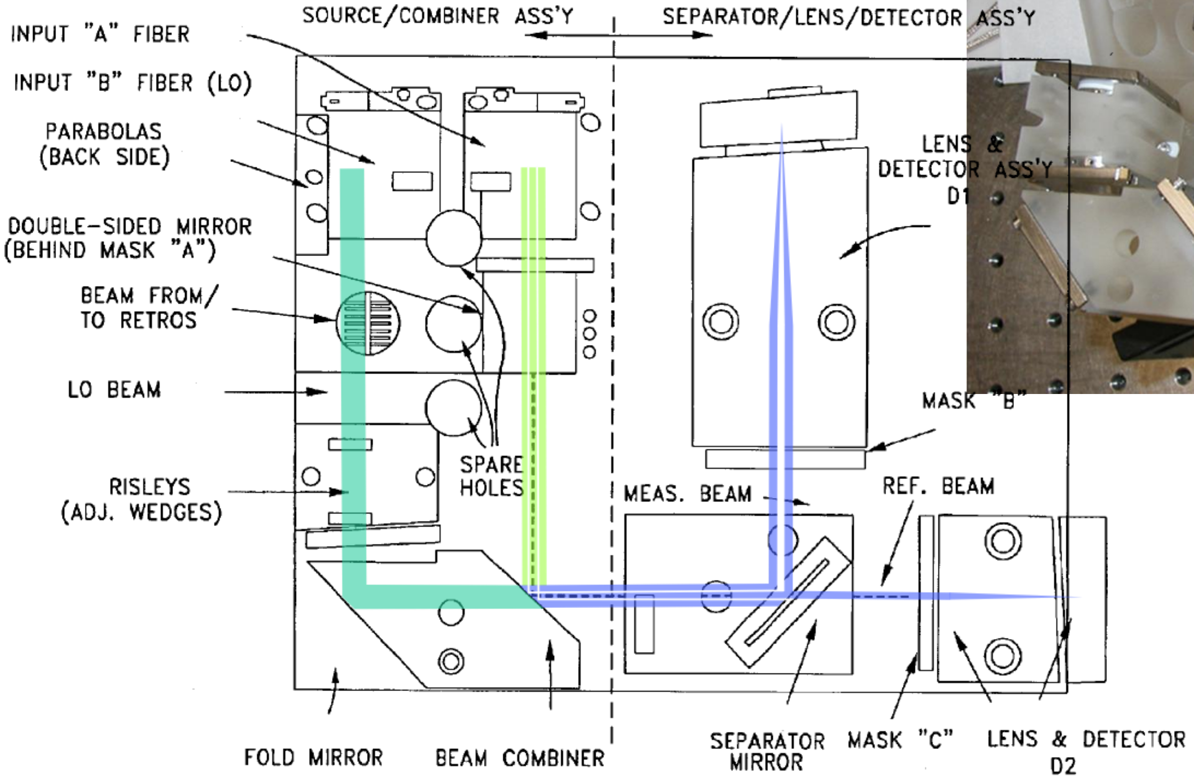
Laboratory resources at CNR-IFN (2)

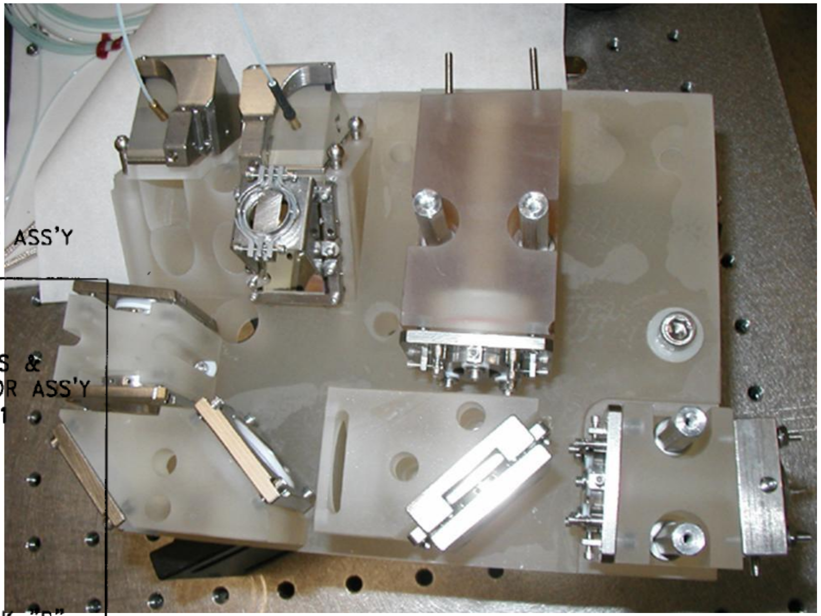




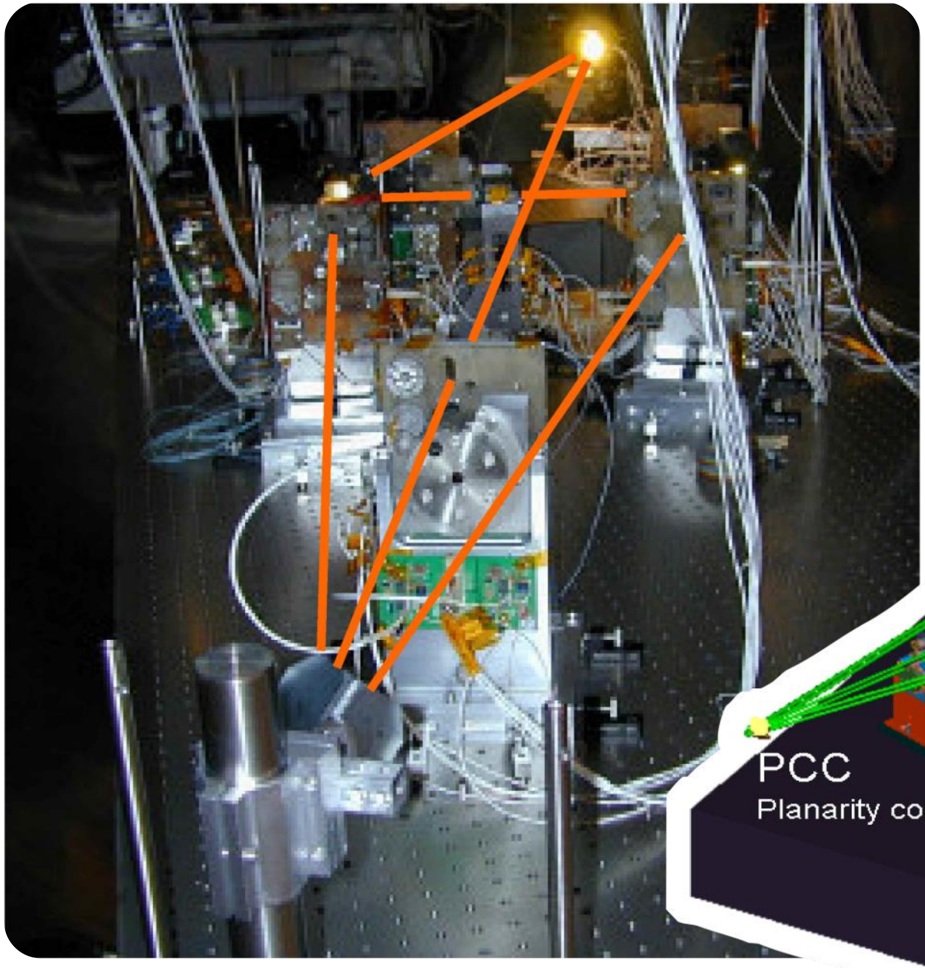


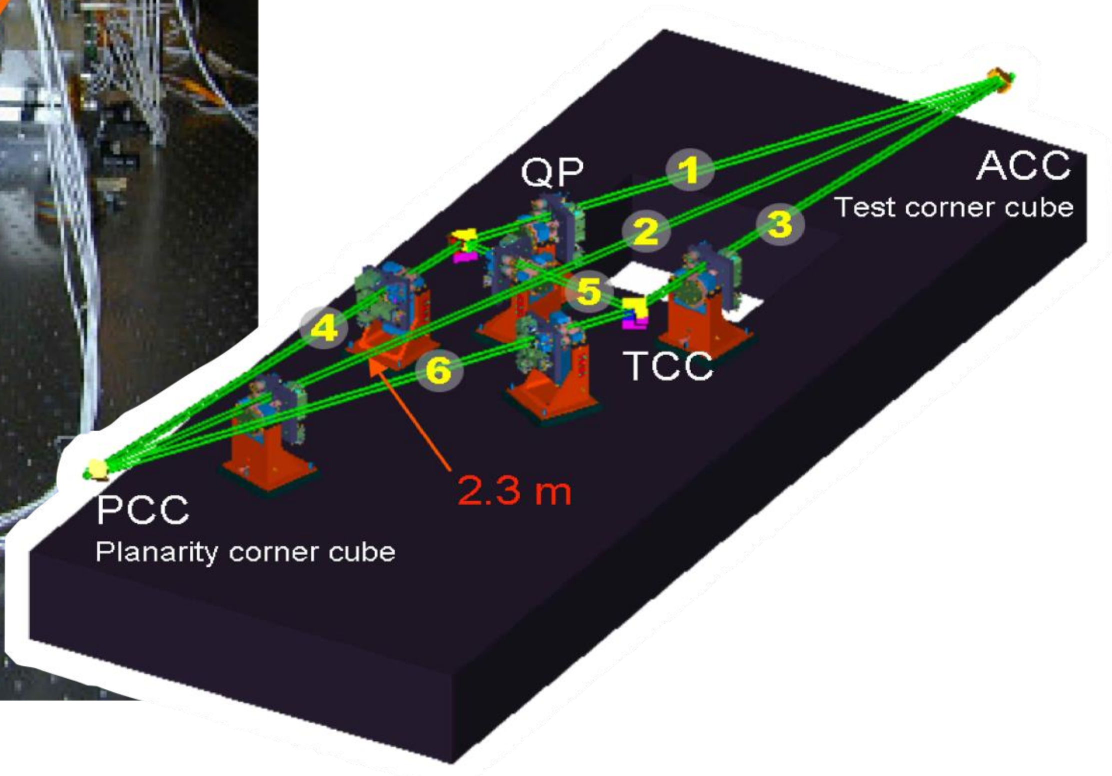
NASA's SIM External Metrology





NASA's KITE experiment





Proved <10 pm accuracy!