Tutzing, 21 June 2016

Discussion on the ring-laser sensitivity and accuracy

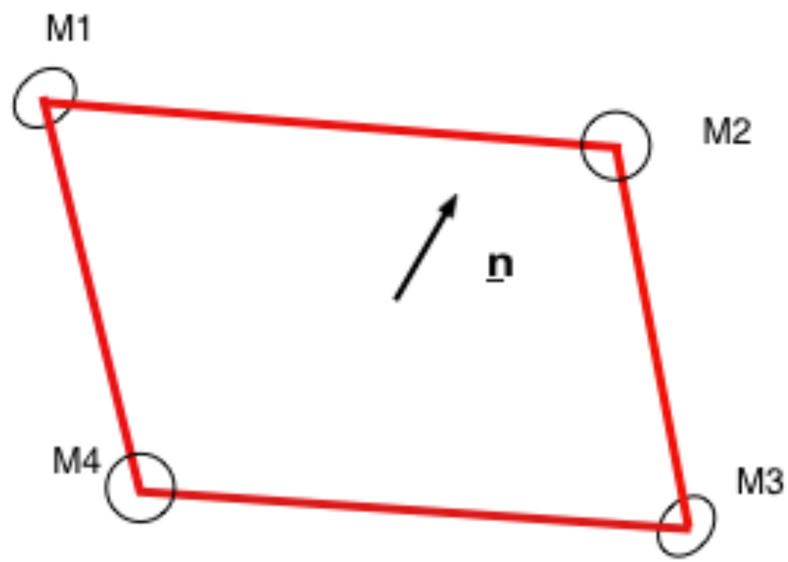
Angela D. V. Di Virgilio
INFN-Pisa. Italy

Why we push to increase the sensitivity

INFN-Fundamental Physics Research

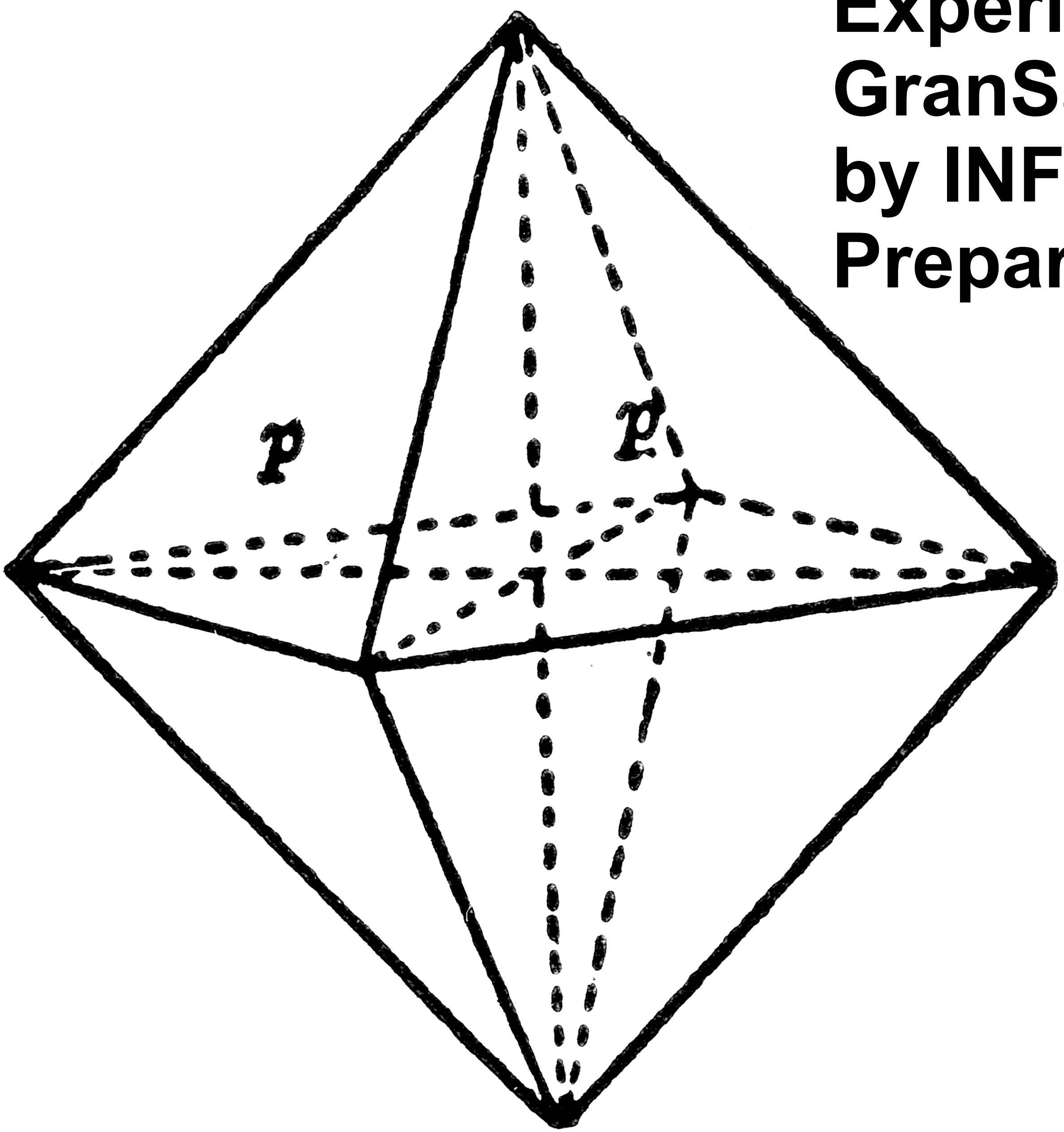
GINGER- General Relativity test on a Earth based laboratory

Improvement at low frequency of the GW interferometric antennas

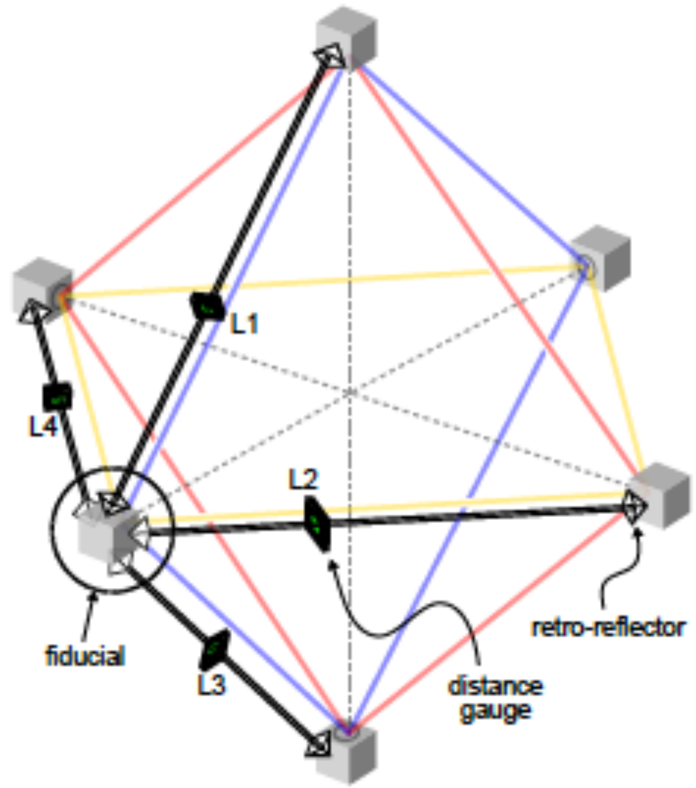


the ringlaser gyroscope is described by **n** and its scale factor **S**

GINGER The octahedron is a 3D rigid figure

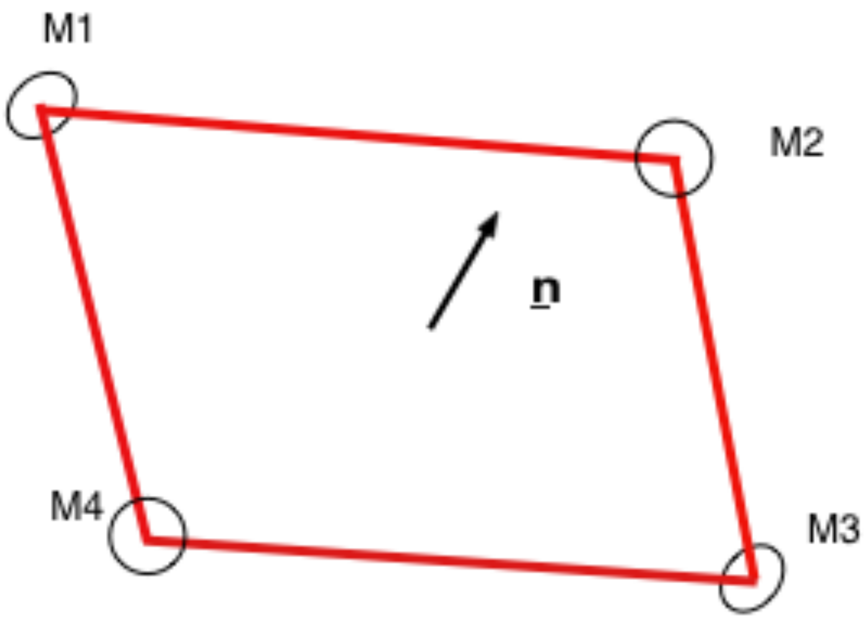


Experiment G-GranSasso-R&D financed by INFN Group II→ Preparation of GINGER

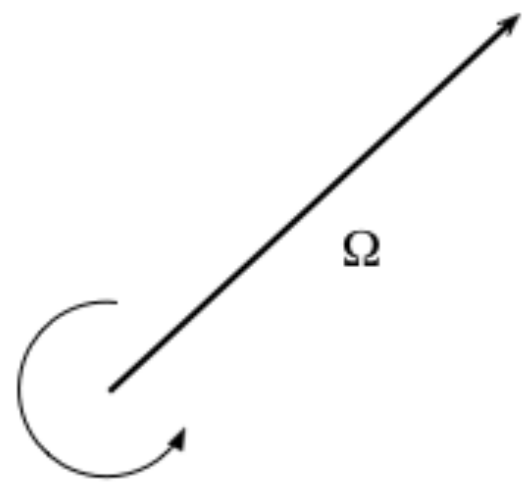


Basic of the ring-laser

$S = S_{eff} = (S_0+K_{bs})$ $\nu_{Sagnac} = S\times\Omega\cos(\theta) + K_{0\text{-shift}}$



the ringlaser gyroscope is described by
n and its scale factor **S**



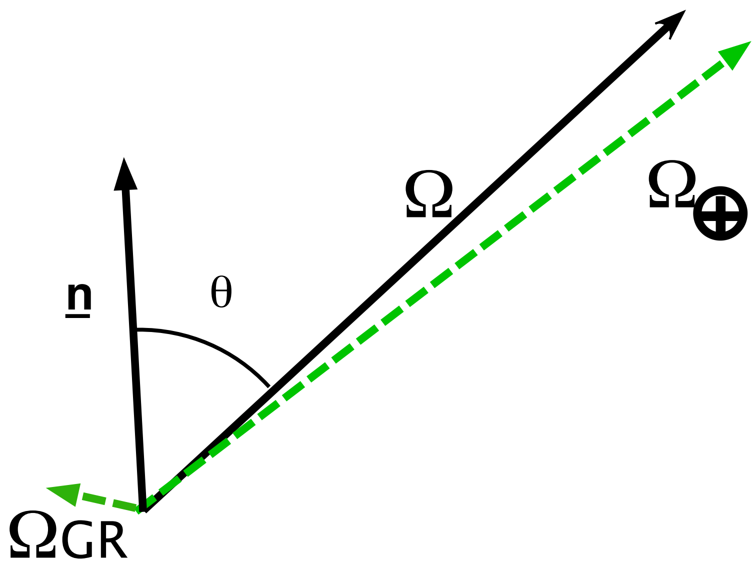
the ring-laser signal in more detail….

The ring laser frequency is proportional to the kinematical term $\Omega_{\oplus}$ and other relativistic terms, the two main terms are:

$$\boldsymbol{\Omega}_G = -(1+\gamma)\frac{GM}{c^2R}\sin\vartheta\Omega_{\oplus}\boldsymbol{u}_{\vartheta},$$

$$\boldsymbol{\Omega}_B = -\frac{1+\gamma+\frac{\alpha_1}{4}}{2}\frac{GI_{\oplus}}{c^2R^3}[\boldsymbol{\Omega}_{\oplus} - 3(\boldsymbol{\Omega}_{\oplus}\cdot\boldsymbol{u}_r)\boldsymbol{u}_r],$$

The equations are very complicated but in practice



- We measure Ω
- We know $\Omega_{\oplus}$
- We want to know Ω_{GR}
- **$\langle\Omega\rangle$ is sum of this two terms**

- **Increase the sensitivity**
- **Necessary to know the orientation**
- **Necessary to link Ω and $\underline{n}$ with high precision (θ)**

Ring Laser/ Shot Noise Limit

Quantum limit $\Omega_{SN} = \frac{c\,p}{2QA}\sqrt{h\frac{\nu_L}{P_{out}\,t}}$

- improves quadratically with L (Q & A/p)
- P_{out} room for improvements **20 nW→ 500nW** in principle feasible?
- shorter wavelength poses several problems (mirrors, diffusion etc)
- Squeezing?

Increase Sensitivity

Increase the size L

Mirror: low loss and the same time high transmission

High transmitted power

Shorter λ

$$3\times10^{-13}\left(\frac{Losses}{\frac{2ppm}{m}}\right)\left(\frac{7\times7}{L^2}\right)\left(\frac{\lambda}{633nm}\right)\sqrt{\frac{500nW}{Pout}\times\frac{1}{t}}\frac{rad}{s}\sqrt{Hz}$$

mirror transmission 1ppm, it is part of the Losses

Short Discussion on Mirrors

Status of the art:

substrates + coating+ care in handling

Total losses **~ 1-2 ppm**

Transmission should be of the same order at least for one of the mirrors

Characterization of each mirror should help (select the best…)

We know how to obtain such mirrors, and improvements on mirror quality does not seems feasible in the near future

In practice

High sensitivity ring lasers are feasible

Next step→ build arrays and ROMY is the first array

Alignment of the rings

The sensitivity is not an issue, the absolute and relative alignment of the rings is the present limitation for the reconstruction of the signals, especially for General Relativity tests and Geodesy

In the first GINGER set up relative alignment of rings determined at nrad precision

Some details on our experimental work

Our prototype

GP2: the geometry control

GINGERino, please follow N. Beverini, J. Belfi and A. Simonelli for details

Our prototypes

GINGERino/ underground laboratory of GranSasso

GP2, prototype in Pisa

GEMS external metrology, DEI-Padova, Italy

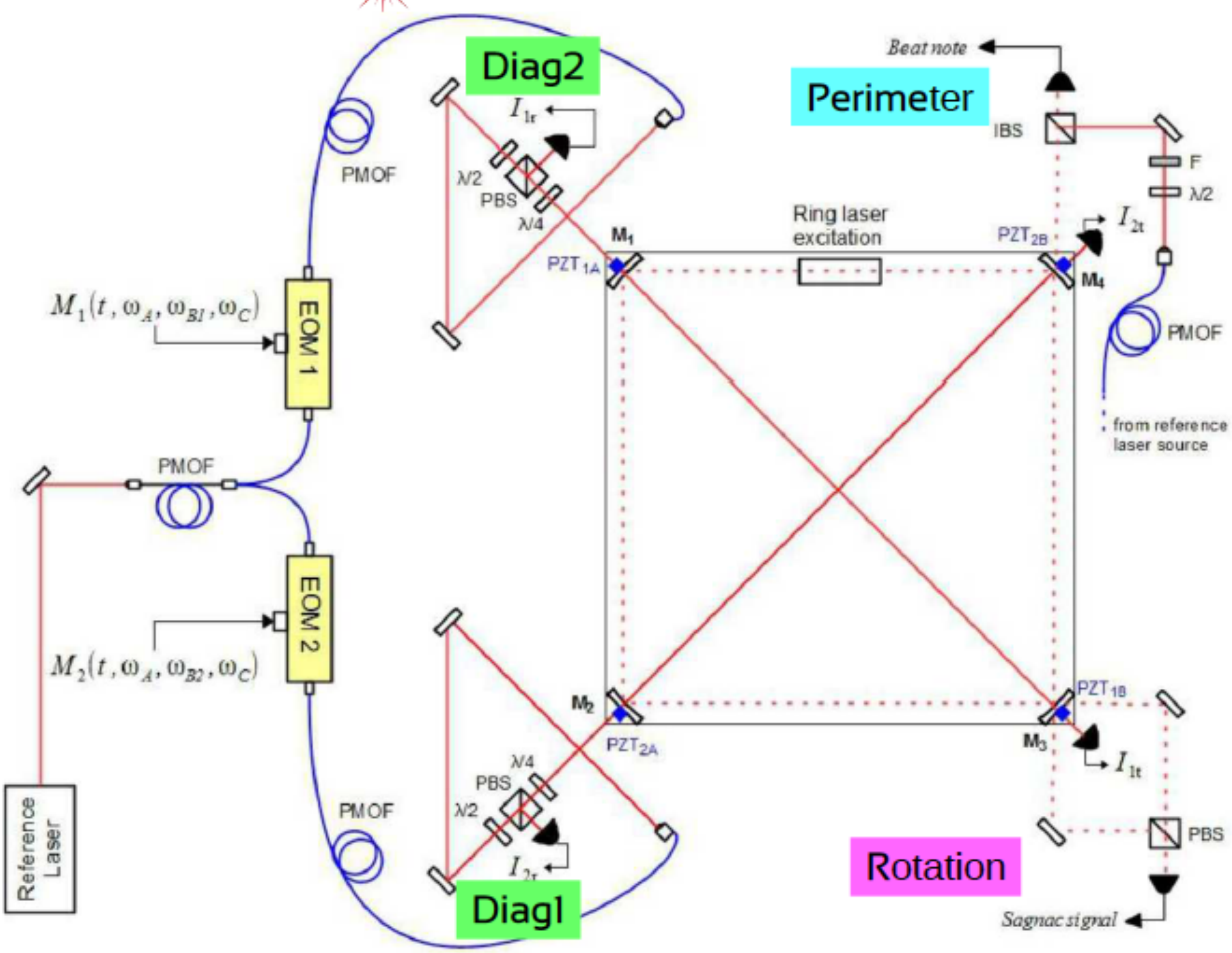
Hetero-lithic ring laser and its geometry control

Basic element of the array

the control of each ring →

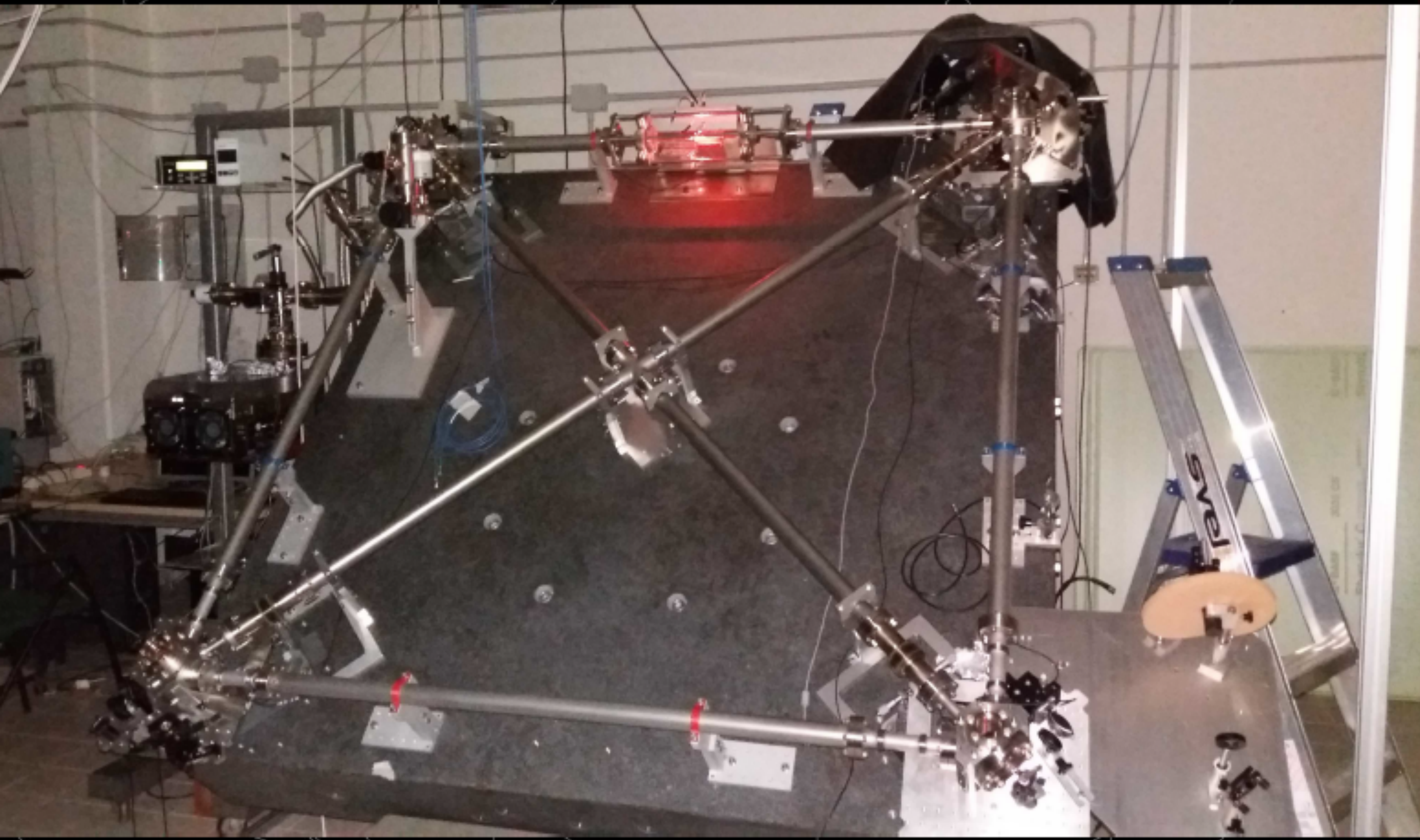
- bring the ring close to the ideal square and
- keeping constant the length of the diagonals
- keeping fixed the perimeter

GP2: Optical setup



GINGER

GINGER



GP2

INFN-Pisa

Status of GP2

Ring laser on and the two diagonals resonating (mirrors are suitable for 45^{o} and 90^{o} incidence)

GP2 has been working continuously for few days controlling the diagonals

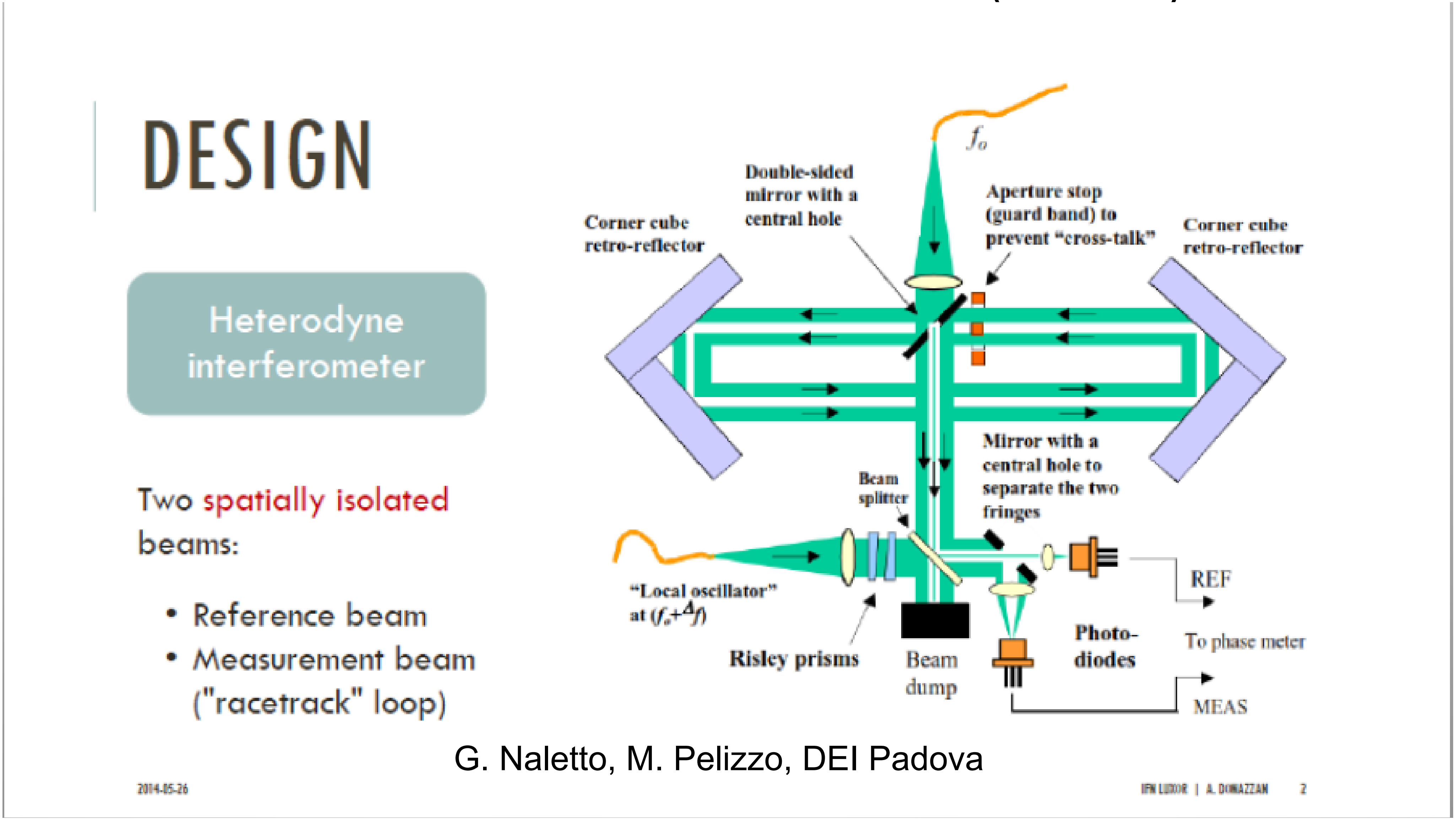
We hope to complete the test in one year

work in progress

External metrology, GEMS

- relative angle between rings

  absolute measurements of mirrors distances (accuracy of scale factor)



G. Naletto, M. Pelizzo, DEI Padova

GINGER?

- the future of GINGER is at the moment under discussion
- we are working at a small array composed of 2 rings

But it should be guaranteed that:

- the work on the control of GP2 will be completed (1-2 years)
- GINGERino INFN-INGV, <u>agreement for 3 years at least in preparation</u>

Evolution of interconnections with Gravitational Waves research is not clear at the moment

- The improvement of the GW antennas at low frequency is one of the present issue for Ligo and Virgo (BH-BH mergers are mainly low frequency signals and the analysis in the high frequency part is very difficult, since it is regulated by strong GR fields)
- Tilt meters will play a role (low frequency disturbances and Newtonian noise subtraction)

Conclusions

◆Focus of our research:

✓ heterolithic device/control

✓As much as possible-Spatial reconstruction of the velocity/alignment of the rings

◆In the near future it will be clear if an array will be financed in Italy

Istituto Nazionale di Fisica Nucleare

Two papers with the analysis of tele-seismic events:
both Love and Rayleigh waves

References

[1] J. Belfi et al. "First Results of GINGERino, a deep underground ringlaser". In: (2016). arXiv: 1601.02874.

[2] A. Simonelli et al. "First deep underground observation of rotational signals from an earthquake at teleseismic distance using a large ring laser gyroscope". In: *Annales of Geophysics* 59 (2016), Fast Track 4. DOI: 10.4401/ag-6970.

[3] R. Santagata et al. "Optimization of the geometrical stability in square ring laser gyroscopes". In: *Classical and Quantum Gravity* 32.5 (2015). DOI: 10.1088/0264-9381/32/5/055013.

[4] J. Belfi et al. "Interferometric length metrology for the dimensional control of ultra-stable ring laser gyroscopes". In: *Classical and Quantum Gravity* 31.22 (2014). DOI: 10.1088/0264-9381/31/22/225003.

[5] D. Cuccato et al. "Controlling the non-linear intracavity dynamics of large He-Ne laser gyroscopes". In: *Metrologia* 51.1 (2014), pp. 97–107. DOI: 10.1088/0026-1394/51/1/97.

[6] Angela Di Virgilio et al. "A ring lasers array for fundamental physics". In: *Comptes Rendus Physique* 15.10 (2014), pp. 866–874. DOI: 10.1016/j.crhy.2014.10.005.

[7] Alessandro Beghi et al. "Compensation of the laser parameter fluctuations in large ring-laser gyros: a Kalman filter approach". In: *Applied Optics* 51.31 (2012), pp. 7518–7528. DOI: 10.1364/ao.51.007518.

[8] J. Belfi et al. "A 1.82 m(2) ring laser gyroscope for nano-rotational motion sensing". In: *Applied Physics B-Lasers and Optics* 106.2 (2012), pp. 271–281. DOI: 10.1007/s00340-011-4721-y.

[9] Jacopo Belfi et al. "Horizontal rotation signals detected by "G-Pisa" ring laser for the M-w=9.0, March 2011, Japan earthquake". In: *Journal of Seismology* 16.4 (2012), pp. 767–776. DOI: 10.1007/s10950-012-9276-9.

[10] Jacopo Belfi et al. "Performance of "G-Pisa" ring laser gyro at the Virgo site". In: *Journal of Seismology* 16.4 (2012), pp. 757–766. DOI: 10.1007/s10950-012-9277-8.

[11] F. Bosi et al. "Measuring gravitomagnetic effects by a multi-ring-laser gyroscope". In: *Physical Review D* 84.12 (2011). DOI: 10.1103/PhysRevD.84.122002.

[12] J. Belfi et al. "Active control and sensitivity of the "G-Pisa" gyrolaser". In: *Nuovo Cimento Della Societa Italiana Di Fisica B-Basic Topics in Physics* 125.5-6 (2010), pp. 557–567. DOI: 10.1393/ncb/i2010-10859-5.

[13] A. Di Virgilio et al. "A LASER GYROSCOPE SYSTEM TO DETECT THE GRAVITO-MAGNETIC EFFECT ON EARTH". In: *International Journal of Modern Physics D* 19.14 (2010), pp. 2331–2343. DOI: 10.1142/s0218271810018360.

[14] Angela Di Virgilio et al. "Performances of 'G-Pisa': a middle size gyrolaser". In: *Classical and Quantum Gravity* 27.8 (2010). DOI: 10.1088/0264-9381/27/8/084033.

1