Preventivi 2014

G-GranSasso-RD, GINGER (Gyroscpes IN GEneral Relativity)

July 1, 2013

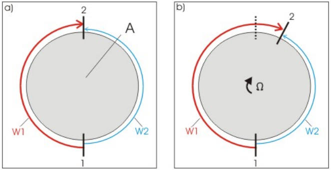
G-GranSasso (Angela Di Virgilio)

- The Sagnac effect and GINGER (Gyroscope IN GEneral Relativity), LenseThirring effect at 1 %
- preliminary results of 'GINGERINO' the first installation inside LNGS
- Latest statement of the Scientific Committee of LNGS regarding GINGER
- Proposed 2014 plan

The Sagnac Effect

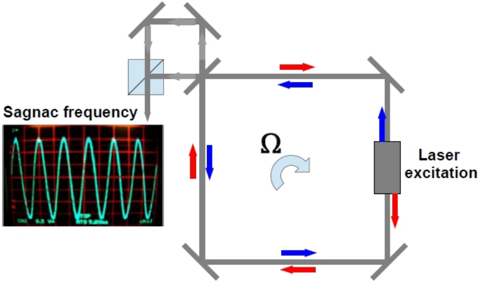
two beams counter-propagating inside a ring of radius R complete the path at different time if the ring is rotating with angular velocity Ω

$$\Delta t = \frac{4\pi R^2 \Omega}{c^2} \tag{1}$$



Several instruments have been developed for different purpose, in general inertial navigation (air-plane, submarine...) **Geodesy and Geophysics**

The Ring-Laser



When the cavity rotates with frequency Ω, the bit note, δf_{Sagnac}:

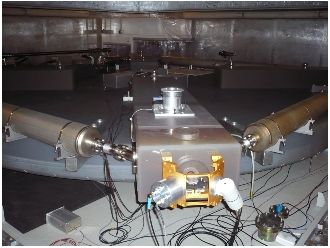
$$\delta f_{Sagnac} = K\ \Omega \cdot n$$

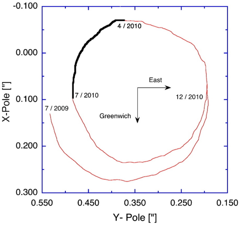
where **n** is the area vector and K is scale factor of the instrument, $K = \frac{4A}{\lambda P}$, λ is the wavelength, and A and P area and perimeter.

High Sensitivity RingLaser and G-Wettzell

There are few large frame(few m side) ring-lasers, in NewZealand, US and Germany

Geodesy and Geophysics



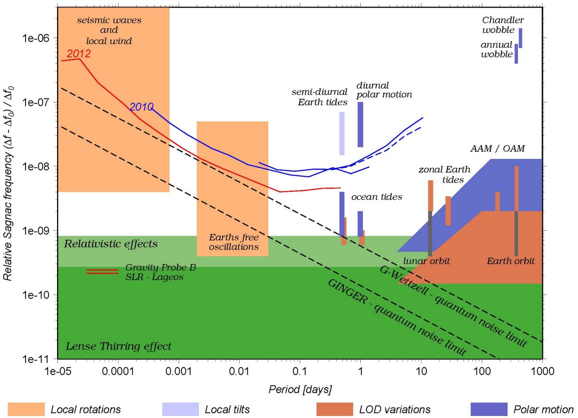


G in Wettzel is a monolithic device, a huge **'unique'** Zerodur block, with mirrors optically contacted.
U. Schreiber et al., PRL 107, 173904 (2011), highlighted paper
The data of G are combined with VLBI data (short term formal

RingLaser with sides larger than 1m are shot noise limited

The Shot Noise

$$\delta\omega_{sn} = \frac{cP}{4AQ}\sqrt{\frac{h\nu_l}{WT}}\, rad/s$$



Limitation of the measurement

$$\Delta f_{Sagnac} = K_R(1+K_A)\Omega + \Delta f_0 + \Delta f_{BS}$$

$\boxed{K_R \quad \text{resonator part: depends from resonator geometry}}$ $\rightarrow$ $K_R = \frac{4A}{\lambda P}\left[1+\delta\left(\frac{A}{P}\right)\right]$

K_A **atomic part**: contribution of the active medium (fluctuations of gain, pressure, gas temperature....)

Δf_0 **null shift**: due to amplitude non-reciprocities

Δf_{BS} **backscattering**: coupling of beams due to mirror impurities or plasma inhomogeneities

Ω is the scalar product of whole vector $\mathbf{\Omega}$ with the normal $\mathbf{n}$ of the ring area PhD R. Santagata, Univ. Siena

Problems connected with the non linearity of the Laser: BackScattering

$$
\begin{aligned}
\frac{2L}{c}\frac{\dot{E_+}}{E_+} &= \alpha_+ - \beta_+\sqrt{E_+} - \theta_\pm\sqrt{E_-} - 2r_-\frac{E_-}{E_+}\cos(\Psi+\varepsilon_-) \\
\frac{2L}{c}\frac{\dot{E_-}}{E_-} &= \alpha_- - \beta_-\sqrt{E_-} - \theta_\mp\sqrt{E_+} - 2r_+\frac{E_+}{E_-}\cos(\Psi-\varepsilon_+) \\
\omega_+ + \dot{\phi_+} &= \Omega_+ + \sigma_+ + \tau_\pm\sqrt{E_-} - \frac{c}{L}r_-\frac{E_-}{E_+}\sin(\Psi+\varepsilon_-) \\
\omega_- + \dot{\phi_-} &= \Omega_- + \sigma_- + \tau_\mp\sqrt{E_+} - \frac{c}{L}r_+\frac{E_+}{E_-}\sin(\Psi-\varepsilon_+) \qquad ,
\end{aligned}
$$

Kalman filters are used to off-line subtract backscattering
PhD D. Cuccato, Univ. Padova

GINGER, Gyroscopes IN GEneral Relativity

In Collaboration with U. Schreiber (TUM), H. Igel (LMU) and JP Wells (ChristChurch NZ):

Geodesy-Geophysics-Fundamental Physics

I have been invited to present GINGER to the 100 year celebration of the Sagnac Effect, which will take place October the 10th at Fondation Simone et Cino del Duca of the Institut de France

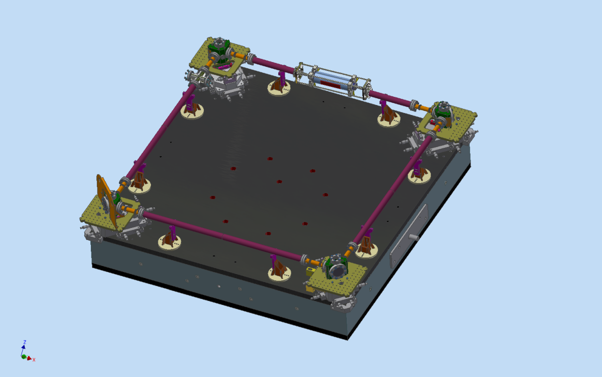
What is necessary to do in order to test GR

The ring-laser has a mature technique, G Wettzell is a factor 5 far from what is necessary, but:

- tri-axial device
- increase as much as possible the integration time (Underground location necessary)
- relative orientation of the planes must be monitored with nrad accuracy
- absolute calibration of the instrument necessary
- accuracy 1 in 10^{10}, necessary in order to cancel out the pure Sagnac term

The heterolithic ring-laser

Necessary to make the 'heterolithic' structure even more stable than the monolithic one (G) using control strategy. The new prototype GP2 in Pisa will be dedicated to this purpose and to investigate the systematics of the laser



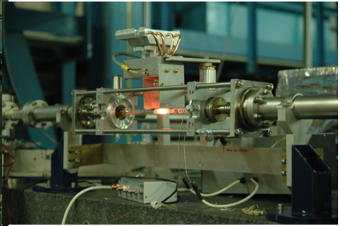
the LNGS installation

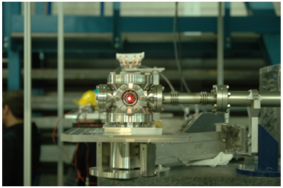
Our first prototype G-Pisa has been moved to LNGS last spring.
The aim of installation is qualify LNGS for GINGER

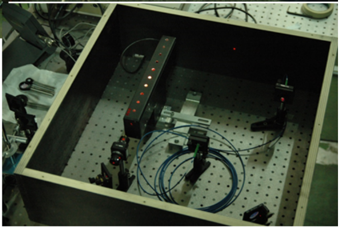
- first installation in Hall B, data taking ended in May
- restart data taking as soon as it will be possible to move it inside the ex Warp green cage (this operation has been delayed since the area has been cleared)
- in 2014 rearrange G-Pisa in order to form a 4m side ring-laser

in 2015 we should be able to say if LNGS is a good location

G-Pisa at LNGS (GINGERino)

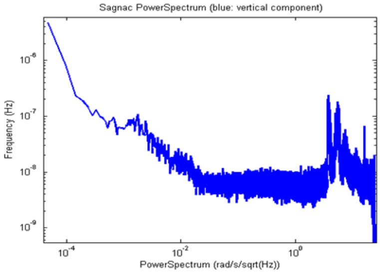


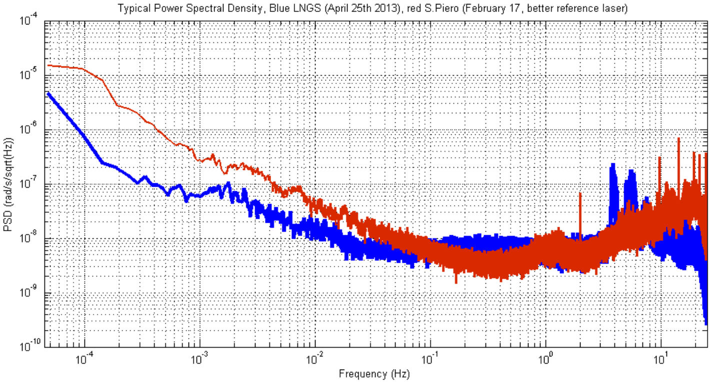




Main Characteristics

- Q of the cavity around 10^{11} (this depends on the mirrors, could be higher)
- PSD(noise floor) 4-5 nrad/s/sqrt(Hz) (sometime better...)
- Two seismometers are co-located (3 axis each)
- One nano-tiltmeter (2 axis)
- Few environmental monitors: temperature, pressure and humidity
- Below 10mHz the instrument is backscattering dominated




Typical Power Spectral Density, Blue LNGS (April 25th 2013), red S.Piero (February 17, better reference laser)
PSD (rad/s/sqrt(Hz))
Frequency (Hz)
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}

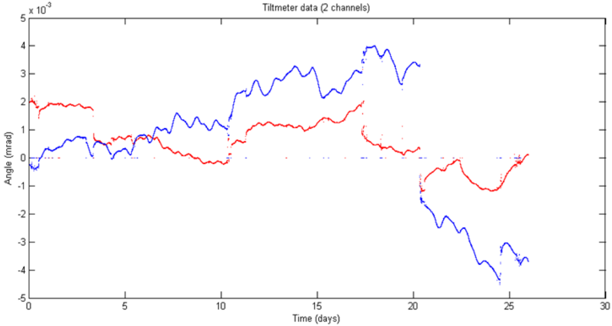
Some About TiltMeters nrad

Environmental data

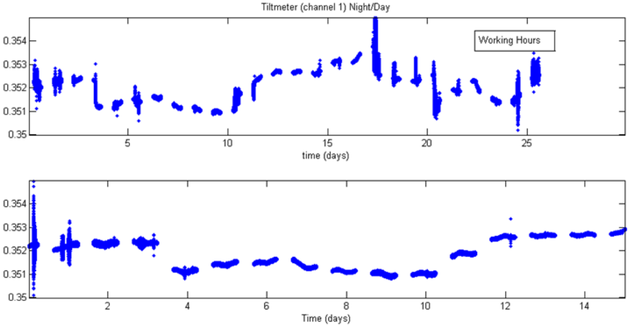
Stating time April 19, 0:00 UTC

The Tiltmeter on top of the monument

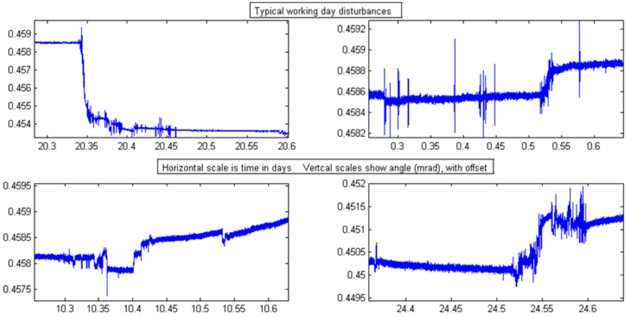
The Monument was not attached to the floor

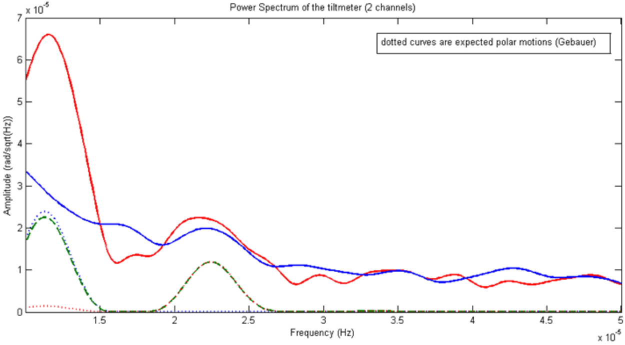


Tiltmeter data (2 channels)
x 10^-3
5
4
3
2
1
0
-1
-2
-3
-4
-5
Angle (mrad)
0
5
10
15
20
25
30
Time (days)



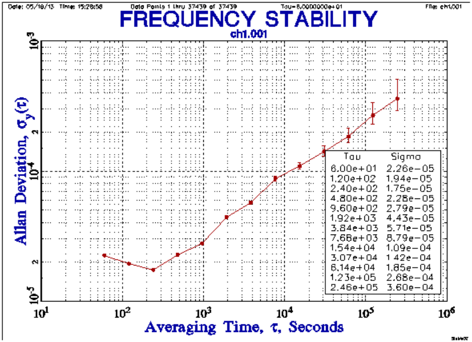
Tiltmeter (channel 1) Night/Day
Working Hours
0.354
0.353
0.352
0.351
0.35
5
10
15
20
25
time (days)
2
4
6
8
10
12
14
Time (days)


Typical working day disturbances
Horizontal scale is time in days   Vertcal scales show angle (mrad), with offset

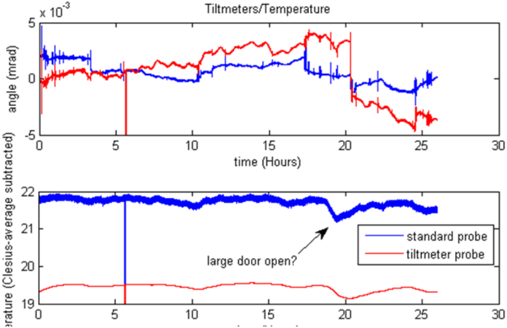


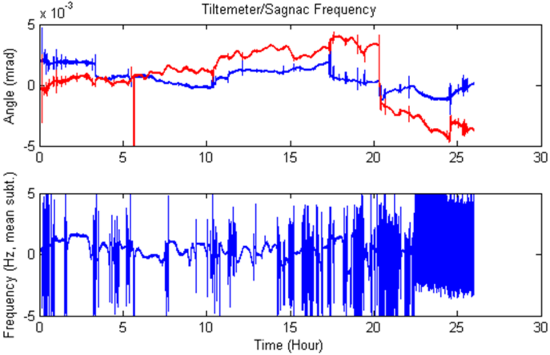
Power Spectrum of the tiltmeter (2 channels)
x 10-5
dotted curves are expected polar motions (Gebauer)
Amplitude (rad/sqrt(Hz))
Frequency (Hz)
x 10-5
0
1
2
3
4
5
6
7
1.5
2
2.5
3
3.5
4
4.5
5

Long Term TiltMeter stability working hours and big jumps have been eliminated



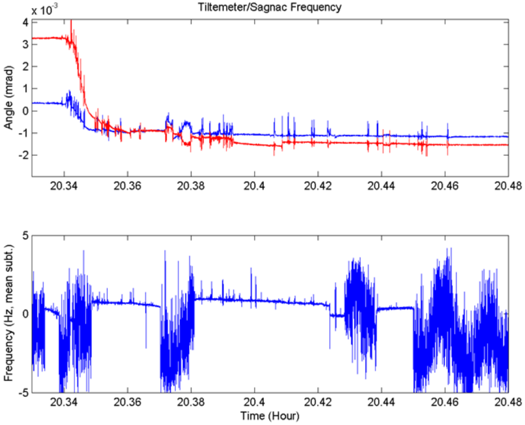
TIltMeter/Temperature-Monitors




Tiltemeter/Sagnac Frequency
x 10^-3
Angle (mrad)
Frequency (Hz, mean subt.)
Time (Hour)

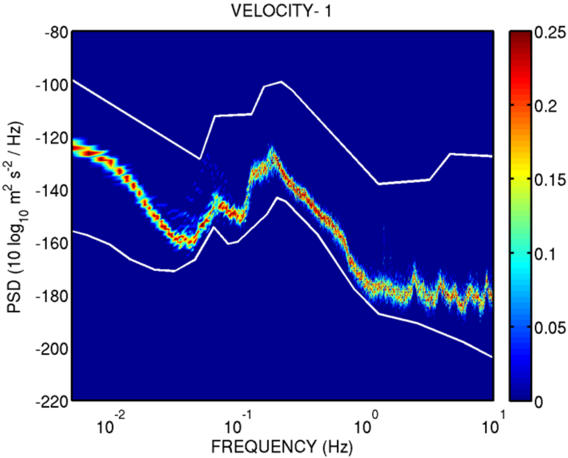
A detail

Is the monument moving with the tiltmeter?

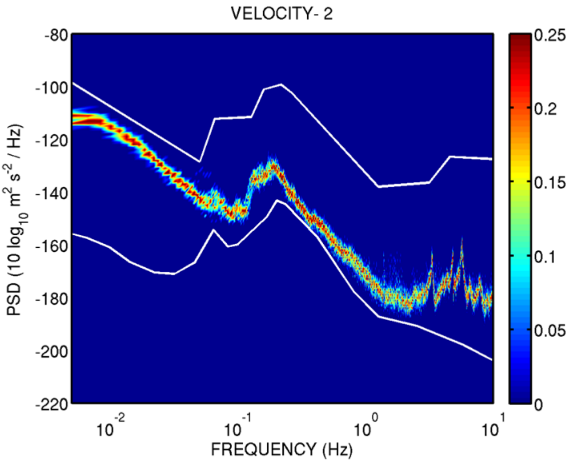


Seismometer STS-2 Streckeisen

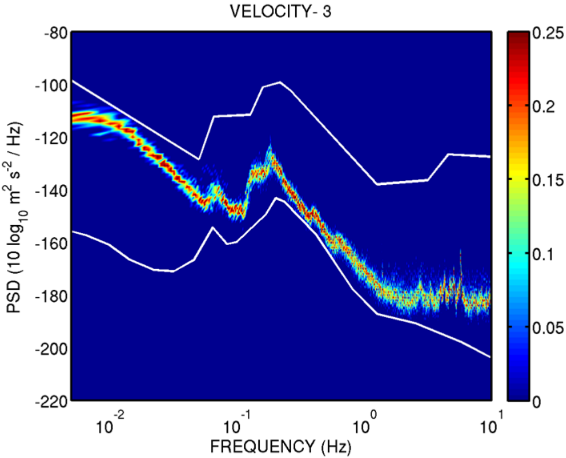
- ST-2 co-located with G-Pisa, on top of the granite table
- Confrontation with the USGS New Low Noise Model



G. Saccorotti INGV-Pisa

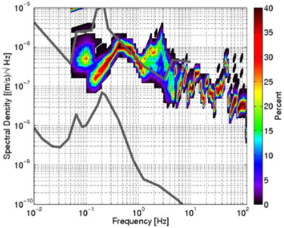


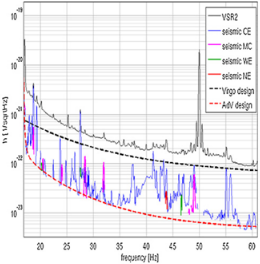
G. Saccorotti INGV-Pisa



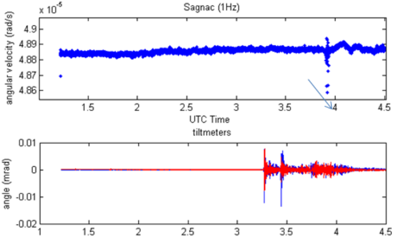
G. Saccorotti INGV-Pisa

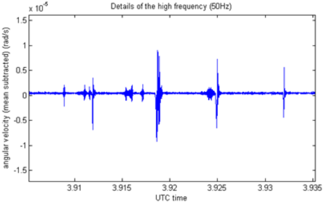
Typical PSD on the top surface (VIRGO)





EarthQuake April 19





Conclusions

- G-Pisa has been moved to LNGS with its equipment
- A first set of data (approx. 1 month) has been recorded
- The first set of data shows that LNGS is close to the typical LNM, this gives us a good motivation to go on with the measurements
- necessary to enlarge the ring up to 4m side (a factor about 9 improvement in sensitivity)
- together with our German colleagues we are working to make GINGER a reality

LNGS Scientific Committee summary about GINGER (Spring 2013 meeting)

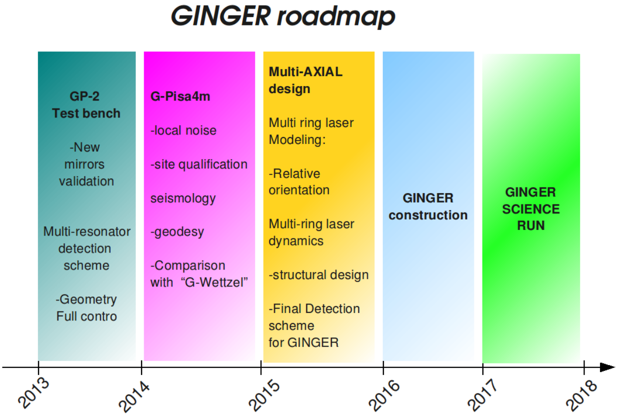
GINGER

As noted in the previous meeting the SC appreciates the scientific interest of General Relativity tests as well as geophysics goals pursued by ring lasers. The 10% precision on the Lense-Thirring effect already obtained by satellite experiments and the precision of a few % aimed by the LARES space mission underway will be interesting to check on Earth. The ultimate 1% accuracy goal of GINGER depends on the reduction of noise; the new period of the G-Pisa instrument operation ("Gingerino"), installed in LNGS since the last SC meeting, is a pathfinder that will test the reduction factor of surface noise and the quality of the LNGS environment.
The SC appreciates the progress achieved with the installation in Hall B and the first encouraging observation: the noise appears lower than at S. Piero a Grado (Pisa). Whether this is a feature of the depth of the site remains to be understood. The analysis has just begun, various unexpected features of the spectrum have to be understood. In the first data the noise floor is at $Df/f = 10^{-5}$, very high with respect to the Ginger goal, 5 orders of magnitude better. The first trivial instrumental problems have been solved, the perimeter control is operational. Foreseen improvements concern the mirrors, the tilt-meter etc. It will be interesting to see what is the margin of improvement of Gingerino.

When the current apparatus will be understood and the feasibility assessed, the Ginger project will have to be specified based on the new data and a proposal should be prepared. The following items should be made more precise and quantified in the full proposal to the SC: for the various scientific goals, explain the advantage of deep underground as the LNGS as opposed to another shallower, but quiet underground location far from other experimental activities, traffic in the road tunnel and seismic activity; progress in the understanding of the relevance of various error sources, possibilities to optimize the laser power, scaling factor and other issues, thus demonstrating the required technology for the full GINGER project. The proposal should also include details about the involved institutes, manpower, funding, distribution of tasks and the collaboration management. The seed of the collaboration can be the 3 groups currently involved in this research: TUM (U. Schreiber, which runs the Gross Ring G inside the laser ranging station of Wettzell), LMU (H. Igel, Seismology) and the Italian G-GranSasso-RD Group (Pisa, LNL, Napoli, Torino and Padova). All three are applying for funding and exchange scientific information. The TUM group has not chosen a site for the next experiment, and Gran Sasso can be an option. The SC encourages intensive collaboration among the 3 groups.

Assuming that the pathfinder project is essentially self-supported (in terms of human and financial resources) the SC gives a positive recommendation for the continuation of the Gingerino operation in the laboratory.

We are preparing a document (GINGER road map) which will be presented to the Scientific Committee in October



- complete the two experimental set-up (GP-2 and LNGS)
- move G-Pisa inside the 'GreenBox', and restart G-Pisa operation with a good contact with the floor
- G-Pisa rearranged with 4m sides
- good acoustic and thermal shielding

Things to do

- Nuova scarica hardware
- G-Pisa-4m: 4 piccoli monumenti
- Tubi e supporti
- GP-2 Crociera diagonali
- Completamento allineamento rough

richieste in Sezione

- alte tecnologie
- 4m LNGS 2MU
- bosi 20%
- disegnatore 2MU
- GP-2 1 Mu
- Richieste officina 2MU
- Richieste elettronica 3MU (elettronica di controllo)
- Richiesta calcolo 1MU

People %

- Di Virgilio 80
- (M. Allegrini 40)
- Beverini 50
- Carelli 50
- Calamai 40
- Cella 20
- Maccioni 30
- Santagata 100
- Fiodor Sorrentino 20

3.7 FTE (4.1 FTE)
ci stiamo operando per avere nel 2014 un ricercatore TD pagato su fondi esterni
Collaborazione con LNL e Napoli

richieste finanziarie 2014

Missioni	....
12 4Xsettimana LNGS	33.5
2 riunioni in Italia	8
2 riunioni in Germania	10
Consumi	....
ottiche da banco (lamine specchi, polarizzatori etc), fibre	20
supporti per banco ottico	5
fotomoltiplicatori in fibra e fotodiodi a valanga	5
consumi vuoto (getters, orings, miscela HeNe)	7
consumi elettronica (sostituzioni/riparazioni)	2
scarica per GP-2 (da fare in officina)	1.5
elettronica per nuova scarica	1.5
tubi e supporti per 4m a LNGS	5
elettronica per GPS a LNGS	3
lettori di pressione, temperatura etc.	3
volume per getters con passante	2

richieste finanziarie 2014

Inventariabile	....
Data Acquisition PXI	21
Nano-Tiltmeter 2 canali	15
sistema di pompaggio con sensori	12
valvola di alto vuoto per getters	3
Modulatori elettro e acusto ottici	15
ECDL	20
(tavoli di granito per GP2)	21
Costruzione Apparati	....
sistema di allineamentp 'rough' (4 sistemi)	8
'small monuments' per AG-Pisa 4m	8
tubi e supporti per 4m	5
elettronica di controllo	30
crociera per diagonali GP-2	5