EUROPEAN GRAVITATIONAL OBSERVATORY

High power fibered electro-optical components for the next generations of Gravitational Waves detectors

Seminario di pretesi
September, 28th 2016
Università di Pisa

Matthieu Gosselin

MARIE CURIE ACTIONS

GraWIToN
GW Initial Training Network

Summary

- Introduction and motivations
- High power laser beam delivery with optical fibers
- Electro-Optic Modulator
- Conclusion and perspectives

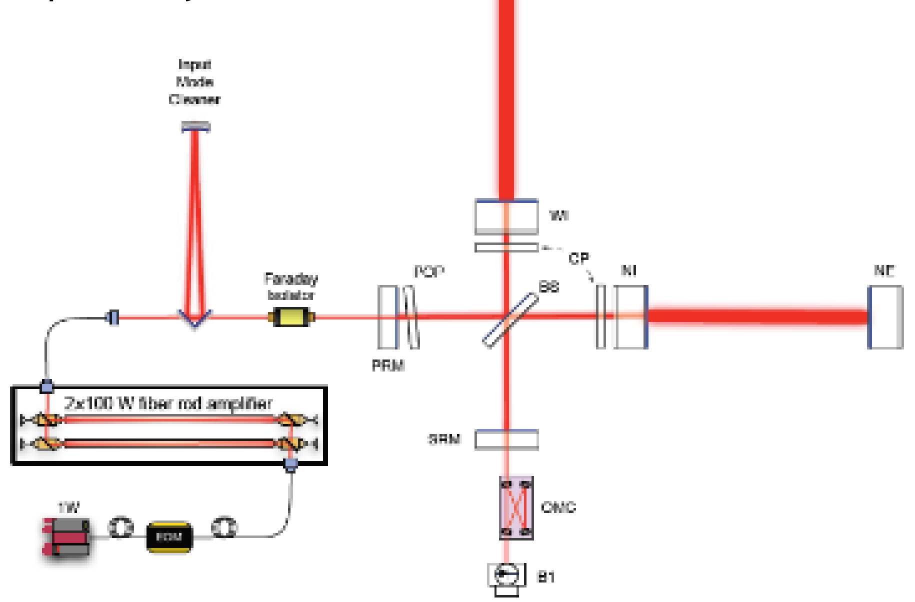
GraWIToN
GW Initial Training Network

Summary

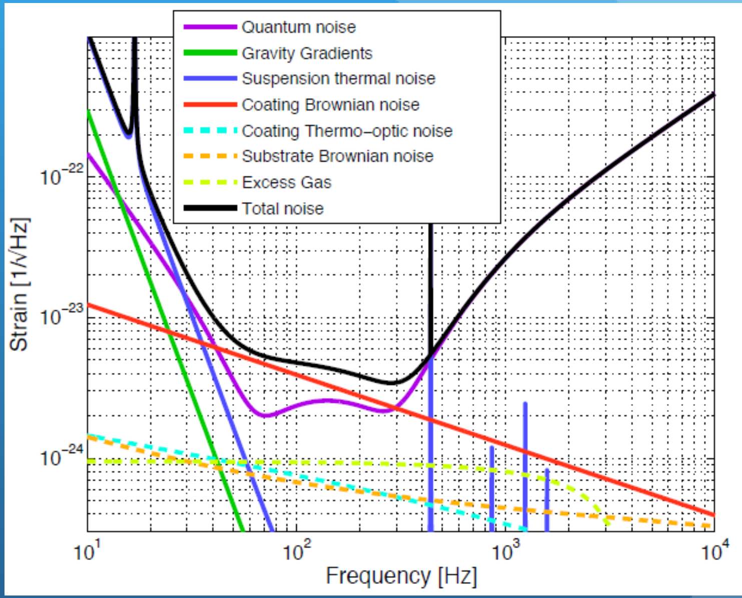
- Introduction and motivations
- High power laser beam delivery with optical fibers
- Electro-Optic Modulator
- Conclusion and perspectives

Advanced Virgo

Optical layout



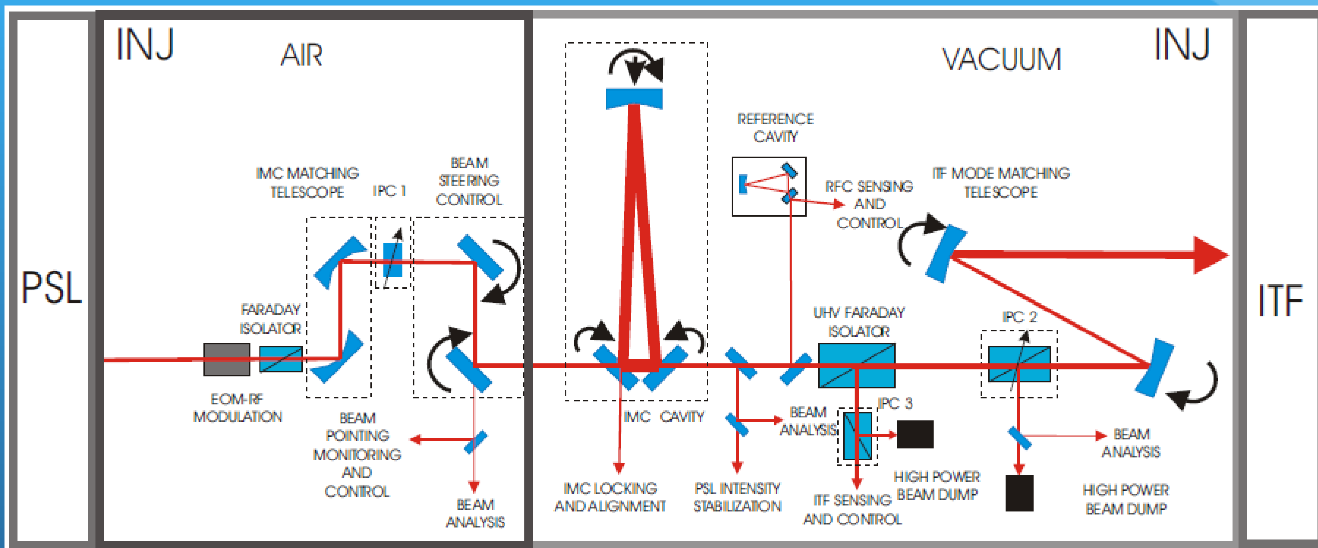
Expected sensitivity of Advanced Virgo



- 3km Michelson interferometer, differential change of length ~10^{-21} m
- Need to decrease all noises until reaching a level for which we can detect GW

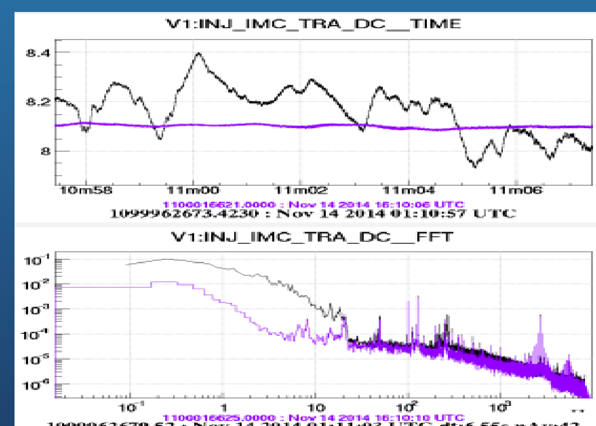
EGO EUROPEAN GRAVITATIONAL OBSERVATORY

Injection subsystem



Noises due to the free space propagation

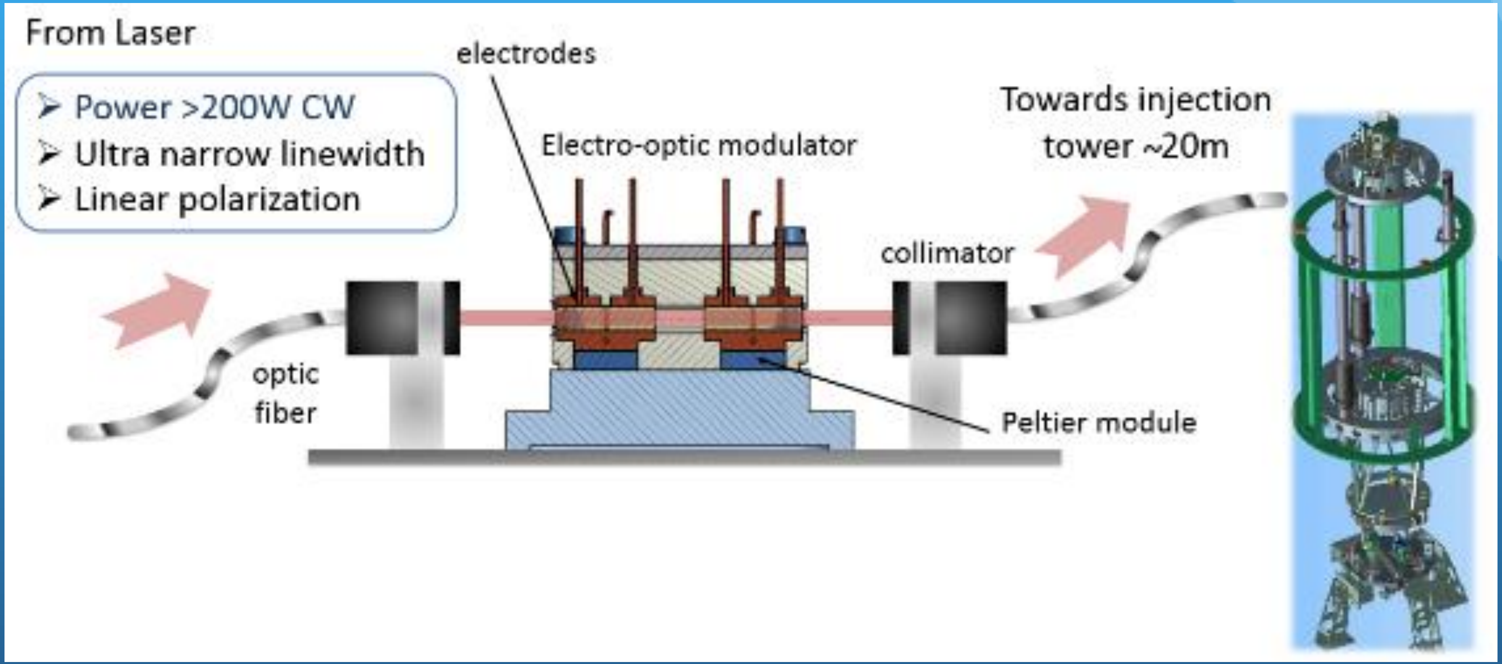
- Already improved by covering the beam path
- Could be improved by fibering everything



GraWIToN
GW Initial Training Network

EGO EUROPEAN GRAVITATIONAL OBSERVATORY

Fibering expectations



- Better control on the propagation
- No alignment issues, beam jitter
- Fiber can be directly brought inside the tower

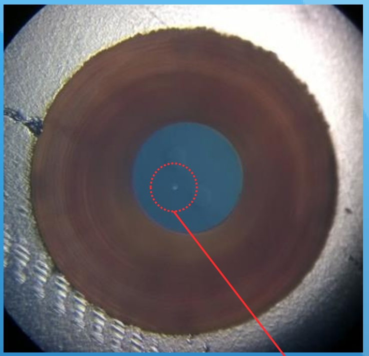
- Fibering will induced other noises that have to be characterized
- Phase noise induced by the fiber can be canceled with a retroaction loop on the EOM or other "phase" actuators

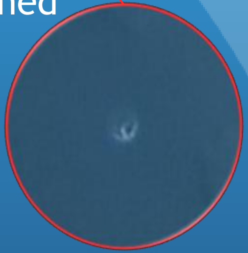
Summary

- Introduction and motivations
- High power laser beam delivery with optical fibers
- Electro-Optic Modulator
- Conclusion and perspectives

Power densities

- High power densities : 200W on a 6µm core radius ➔ ~200MW/cm^2
- Heating of the connectors, need to cool down

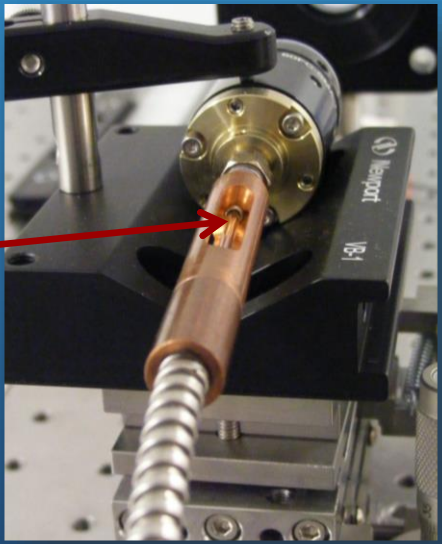


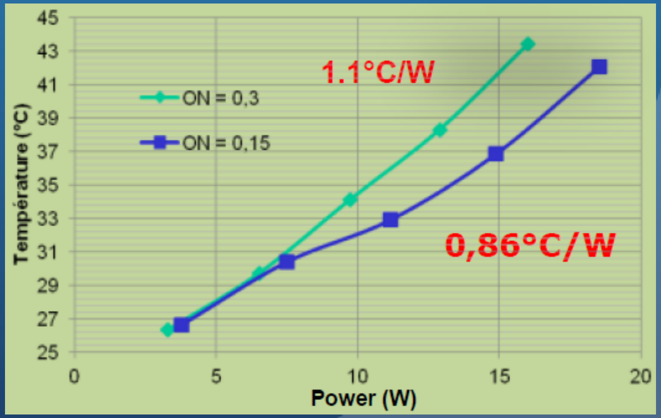


10W misaligned
- end facet melted

Strip out the mismatched light

Temperature elevation ~7°C/W

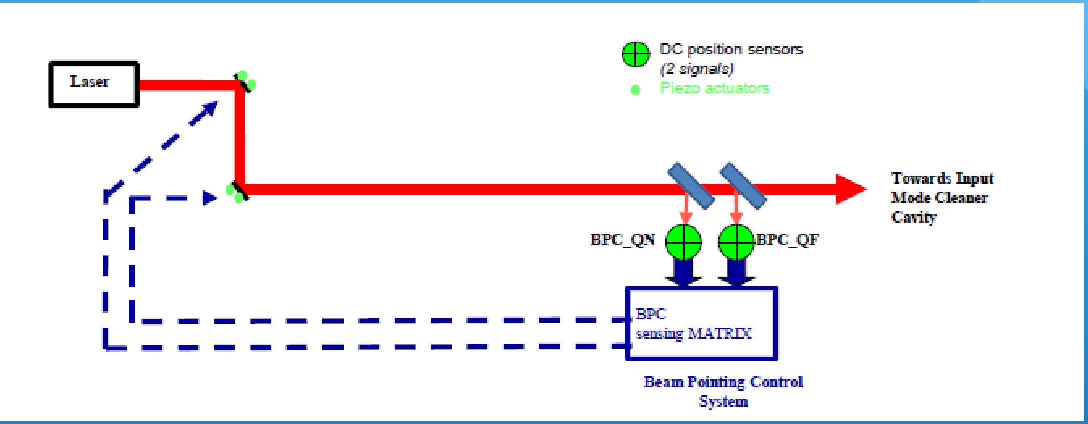


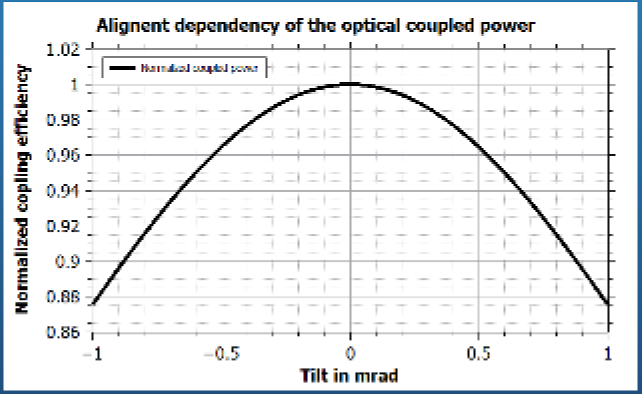


New connectors with better cool down

GraWIToN
GW Initial Training Network

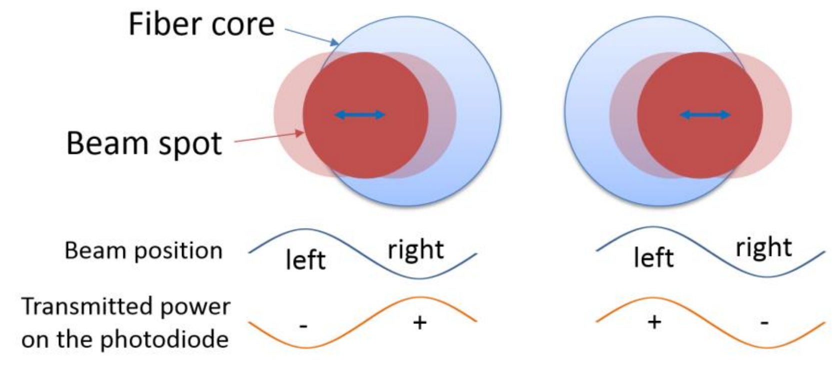
Alignement dependency

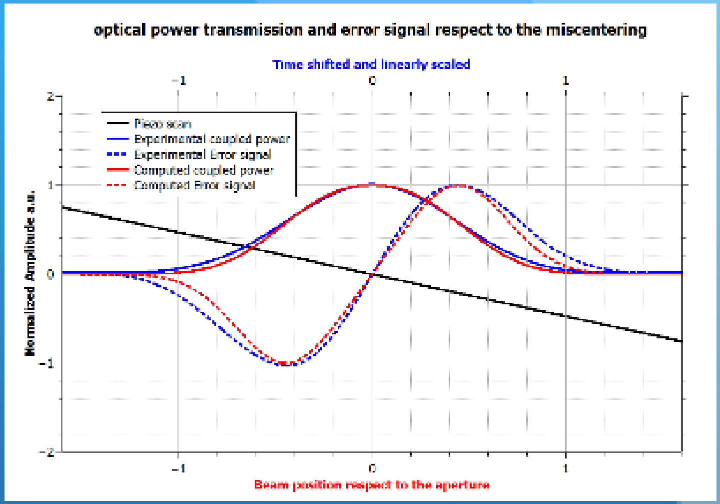




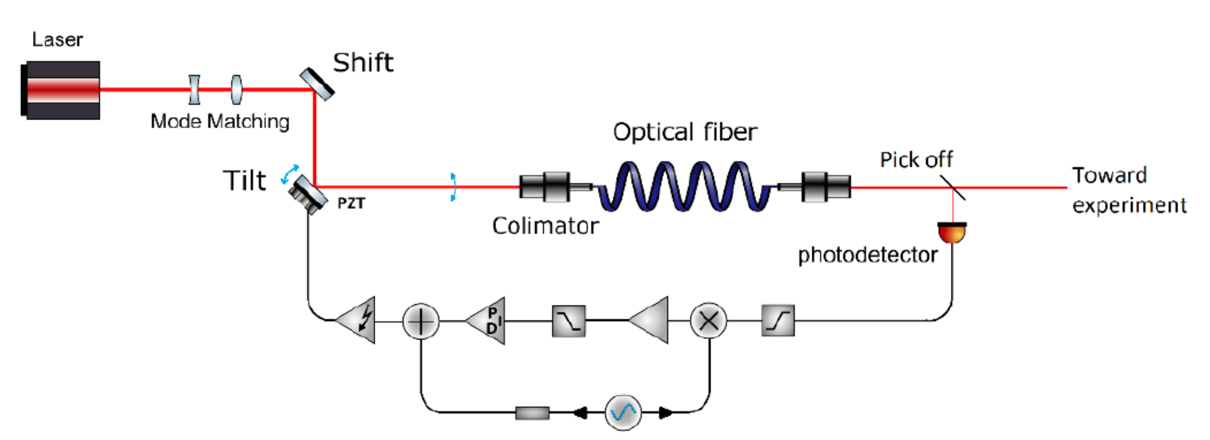
- Coupling into the fiber very sensitive to the tilt
- Near field – Far field method using quadrant photodiode
- Disadvantage of an external reference : sensible to the drift between the quadrant photodiodes and the target

Automatic Alignement





Using the core of the fiber as a reference by scanning the input with a PZT. The sign of the demodulated transmitted signal at the excitation frequency is changing



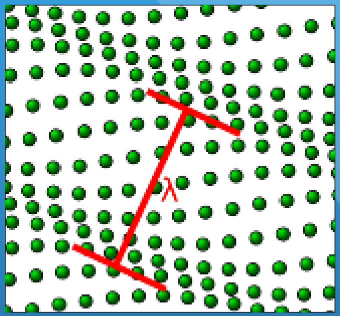
- Automatically keep the coupled light to its maximum
- Reduce the beam jitter to the lines at scanning frequency

Stimulated Brillouin Scattering

- Non linear effect while using narrow linewidth laser
- Density variations induced by electrostriction
- Light is back reflected

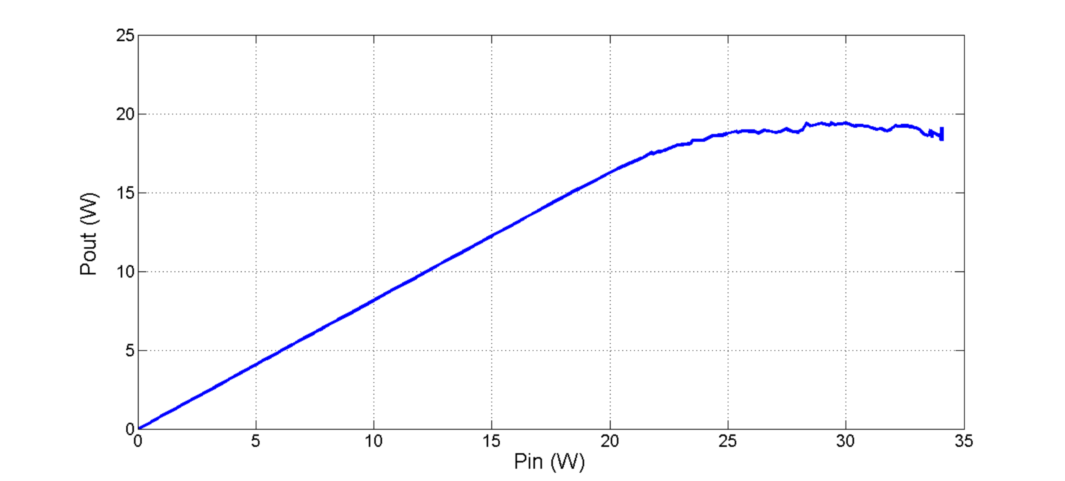
$$P_{th} \approx \frac{21bA_{eff}}{g_B L_{eff}}$$

A_{eff} : effective core area of the fiber
L_{eff} : effective length of the fiber
g_B : Brillouin gain (4.10^{-11} m/W)
b : polarization factor (1<b<2)

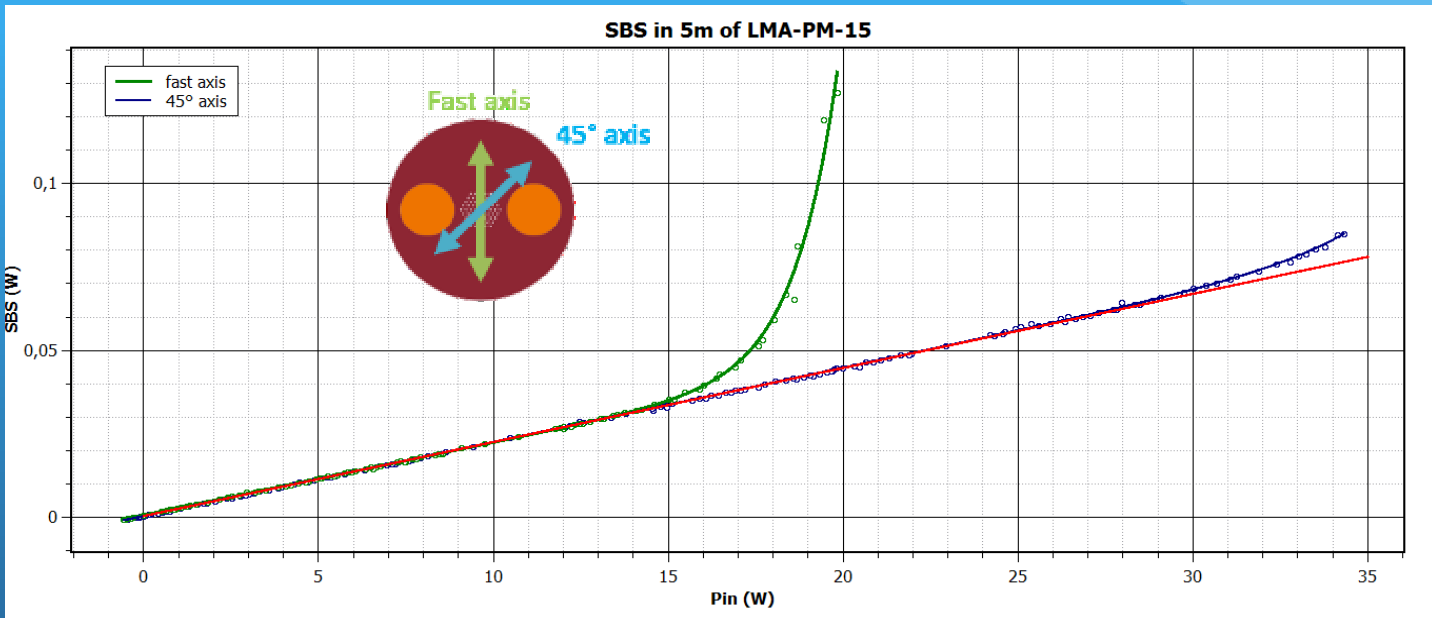


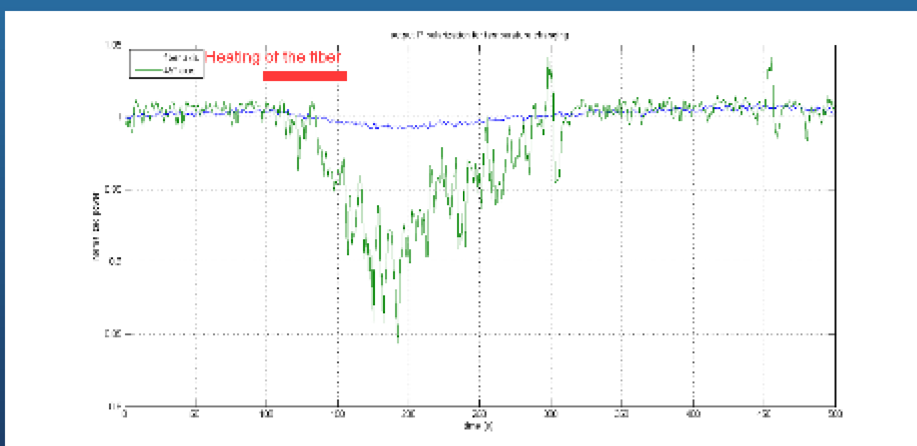
Currently 5m of LMA-PM-15 (core radius 6.25 µm)

$$P_{th} \approx 13W \; for \; b = 1$$
$$P_{th} \approx 26W \; for \; b = 2$$



SBS polarization dependency





By setting the polarization at 45°

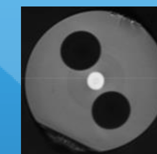
- Double the maximum power
- More sensitive to the external mechanical stress
- Keep the same Polarization Extinction Ratio

Achievements and future fibers

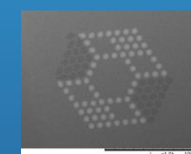
	Fast axis	45 axis
SBS P_{th}	15W	30W
Max output power [1]	21W	28W[2]
RIN	0.03	0.21
PER	18dB	18dB

[1] with a coupling efficiency of about 82%

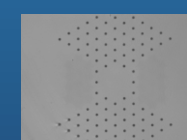
[2] limited by the input power available 35W



30/250 PLMA Double Clad Fiber
Nufern

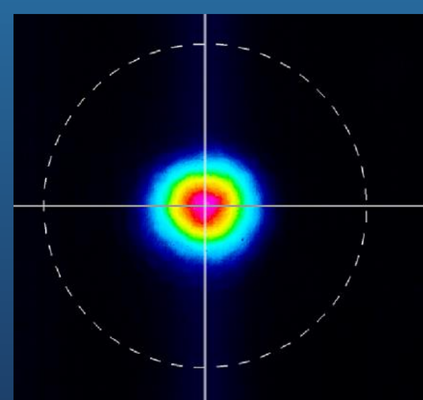


PLMA photonic BandGap fiber
PHLAM , Lille France



LMA-PM-40
NKT Photonics

- Coming fibers with cores of about 30-40 µm
- Could increase the power by a factor 10
- Worst beam quality
  Gaussian fit ~80%

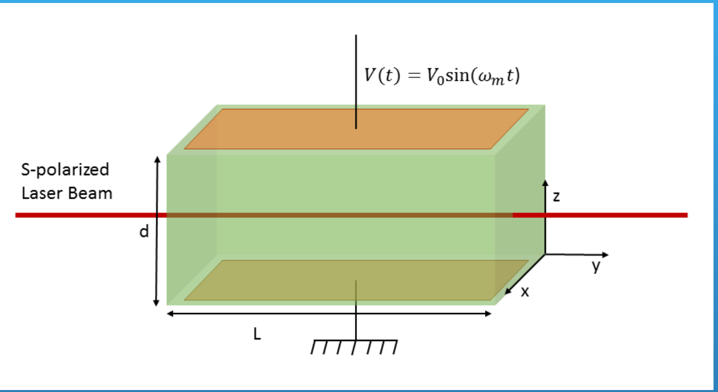


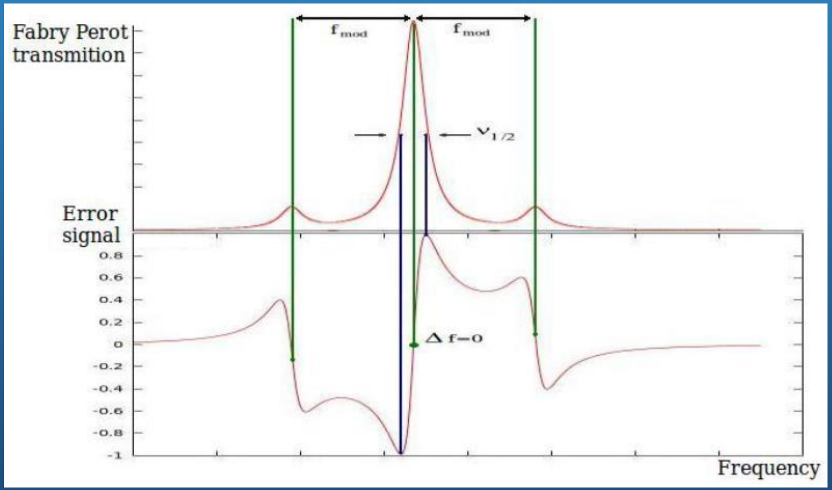
Summary

- Introduction and motivations
- High power laser beam delivery with optical fibers
- Electro-Optic Modulator
- Conclusion and perspectives

GraWIToN
GW Initial Training Network

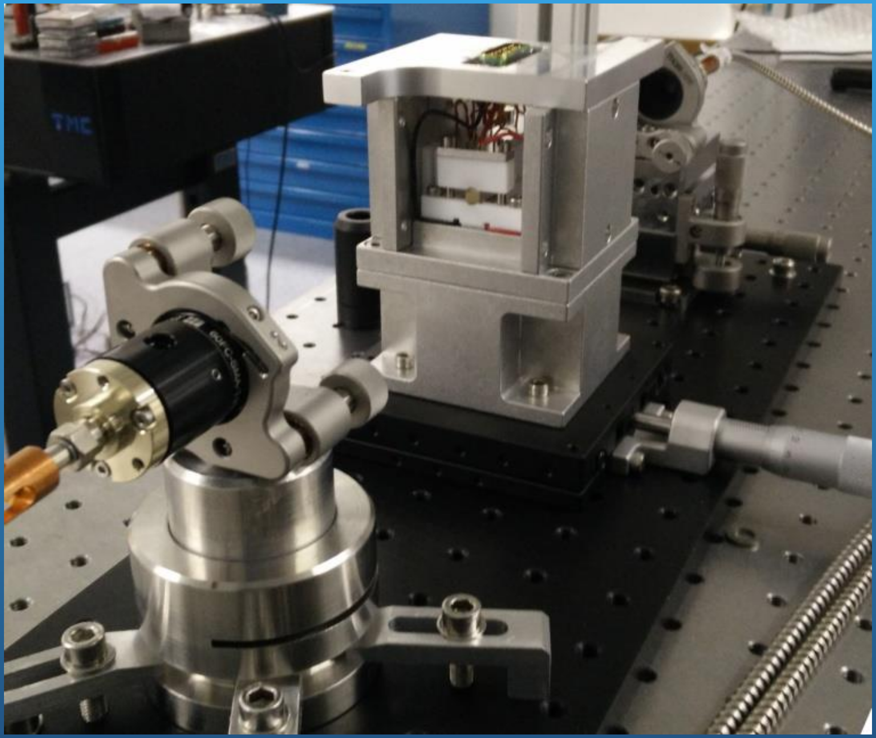
EOM theory and use



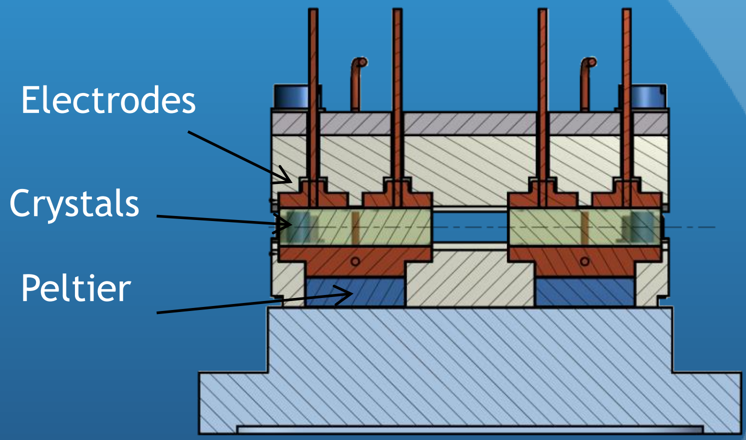


- Modulation of the refractive index by applying a voltage on the crystal
- Creation of the sidebands used in the Pound Drever Hall error signal
- This error signal is used to lock the cavities of the interferometer on the laser frequency

Electro-optic modulator



Design with the mechanics and electronics department of EGO



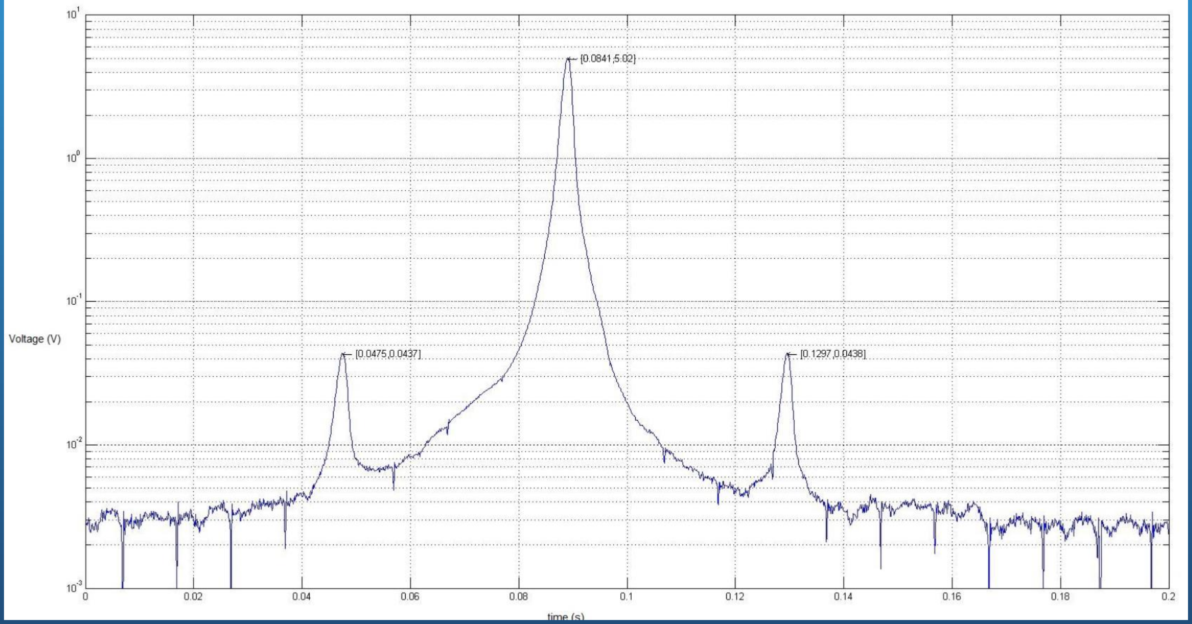
- Tested for power up to 50W

EUROPEAN GRAVITATIONAL OBSERVATORY

Modulation depth

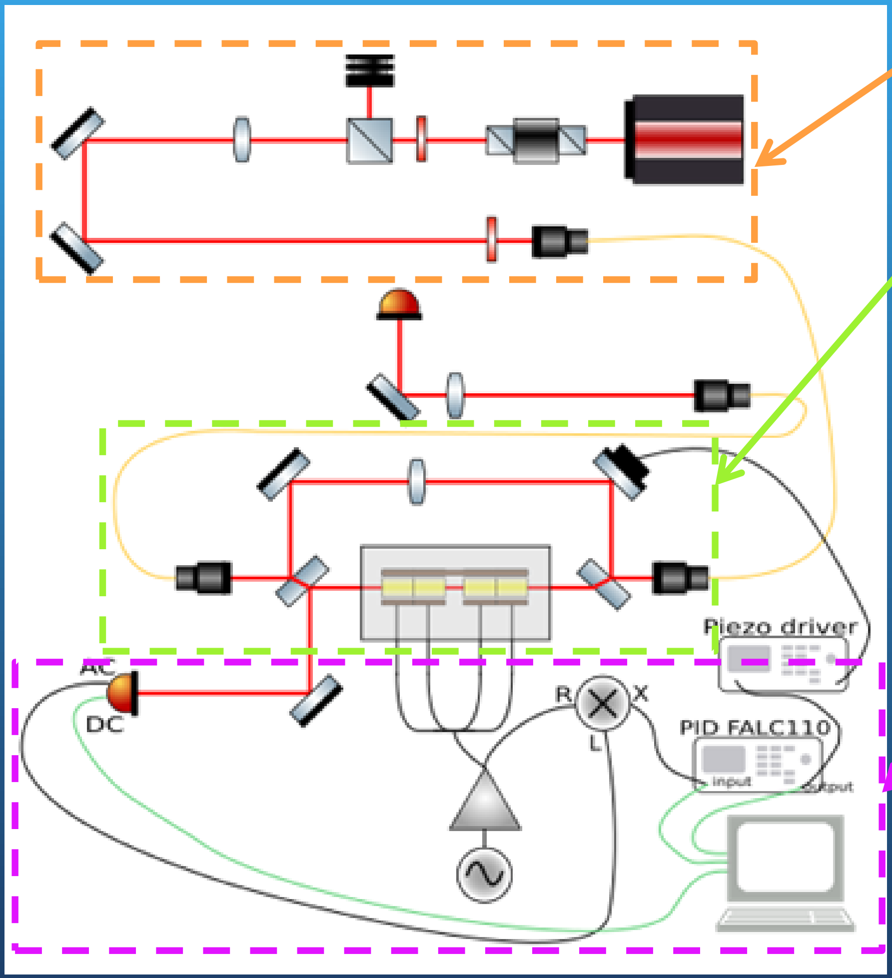
$$E(t) = E_0 e^{i\omega_0(t)}(1 + imsin(\omega_m t))$$
$$= E_0(e^{i\omega_0(t)} + \frac{m}{2}e^{i(\omega_0-\omega_m)t)} - \frac{m}{2}e^{i(\omega_0+\omega_m)t)})$$

$$m = \frac{\pi L n_e^3 r_{33} V_0}{\lambda d}$$



- We reached m~0.2 that is required for Advanced Virgo
- The quality of the lock depends on the quality of the modulation
- Still have to carry some tests on the long term stability

Phase noise

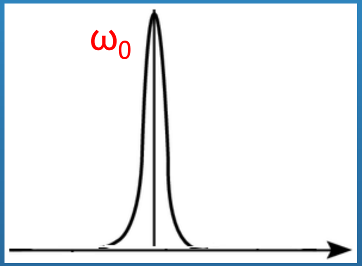


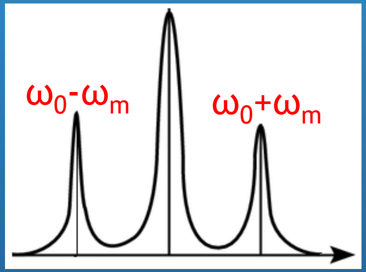
Injection part

87% coupling through the all fibered EOM

Mach-Zehnder interferometer

Beating between the incident light and the modulated light

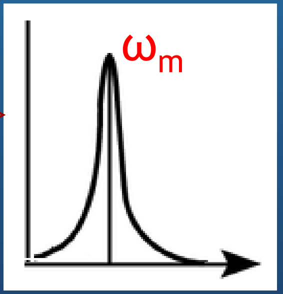




Electronics layer

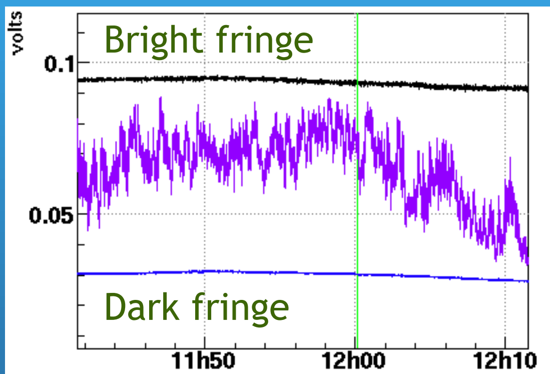
Mixing with the reference signal

Study the characteristics of the sidebands

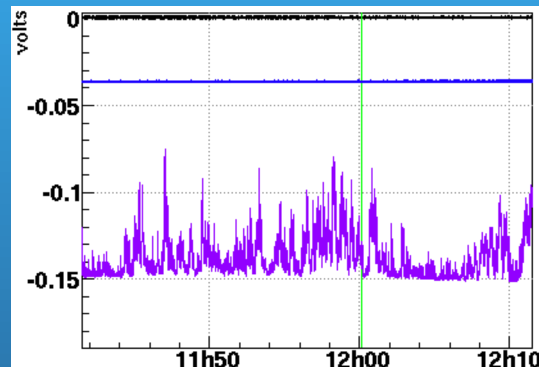


Lock Mach-Zender

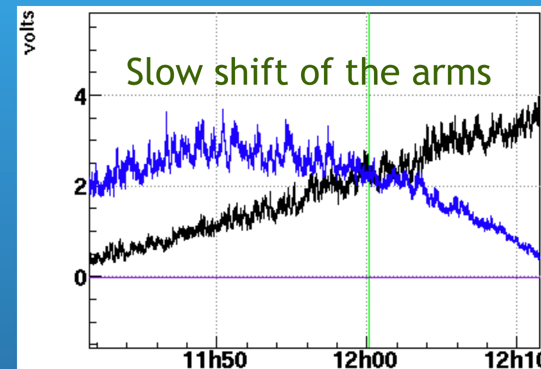
Output power

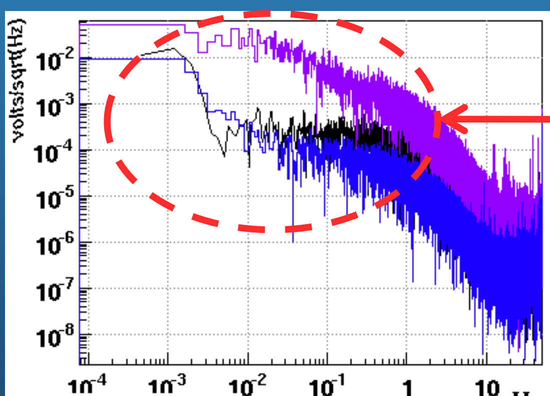


Error Signal



Apply correction





- Lock of the Mach-Zehnder interferometer in order to cancel its phase noise
- Give us an upper limit of the phase noise induces by the modulator

EGO EUROPEAN GRAVITATIONAL OBSERVATORY

Summary

- Introduction
- High power laser beam delivery with optical fibers
- Electro-Optic Modulator
- Conclusion and perspectives

GraWIToN
GW Initial Training Network

Conclusion and perspectives

- Power into fibers limited by SBS
  Up to 50W with a broadband laser
  Up to 20W with narrow linewidth laser
  Up to 40W with narrow linewidth laser with

- Waiting for the next generations of fibers with larger core

- EOM characteristics already investigated but need to be fully characterized

- Works on Faraday Isolator (depolarization, thermal lenses…) already started but not presented

EGO EUROPEAN GRAVITATIONAL OBSERVATORY

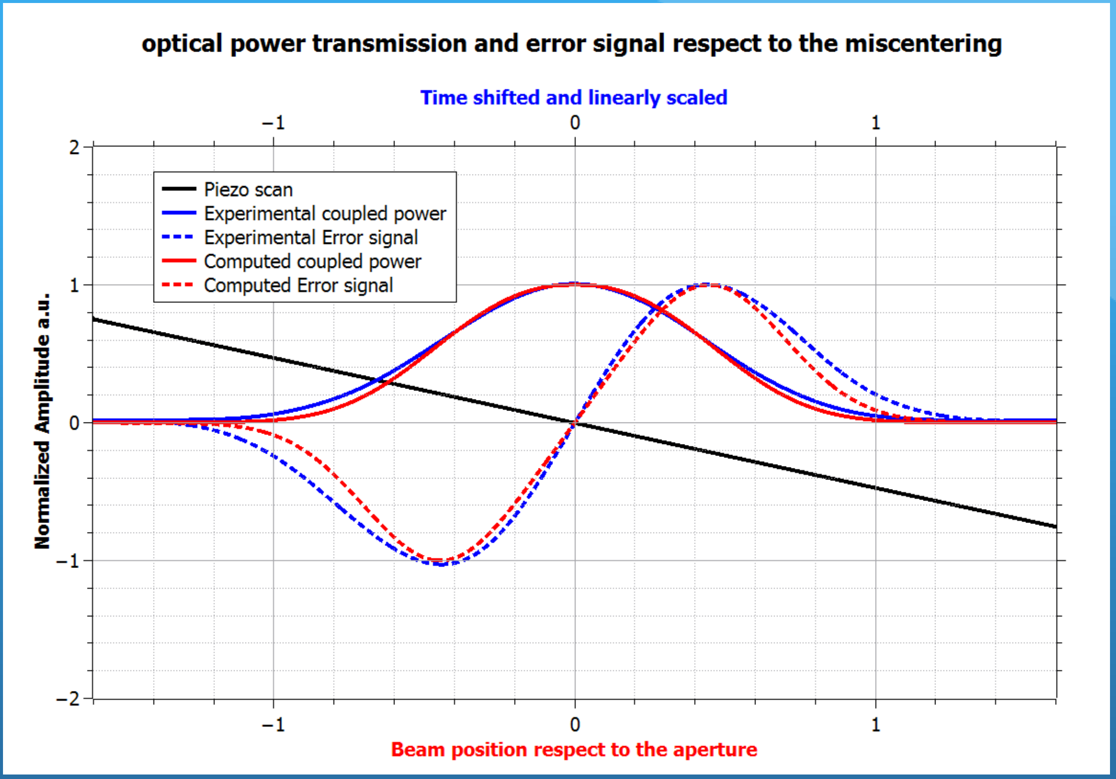
Thank you for your attention

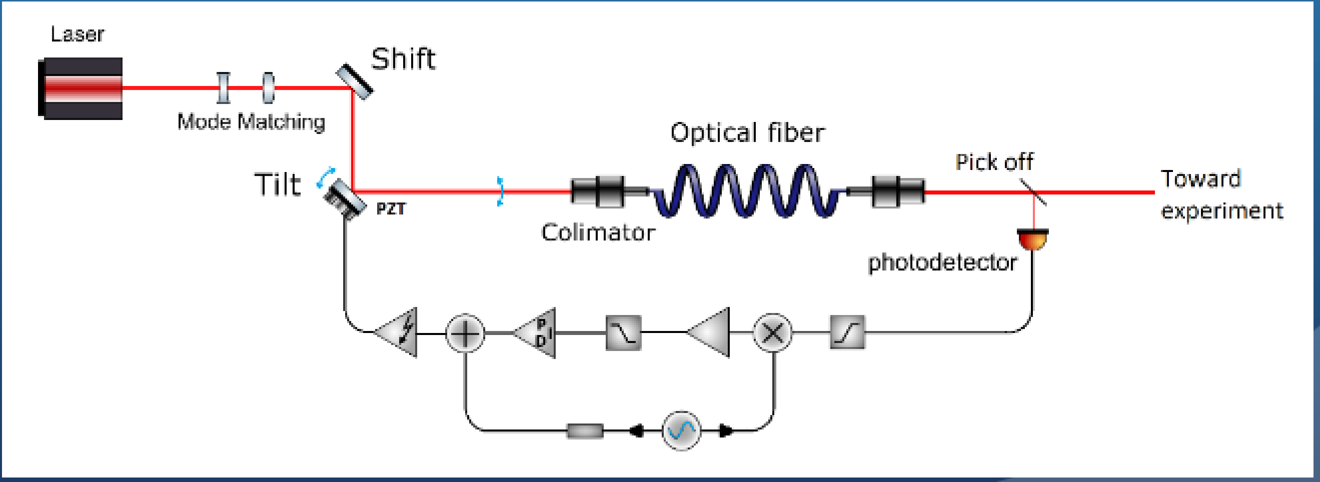
Matthieu Gosselin, gosselin@ego-gw.it

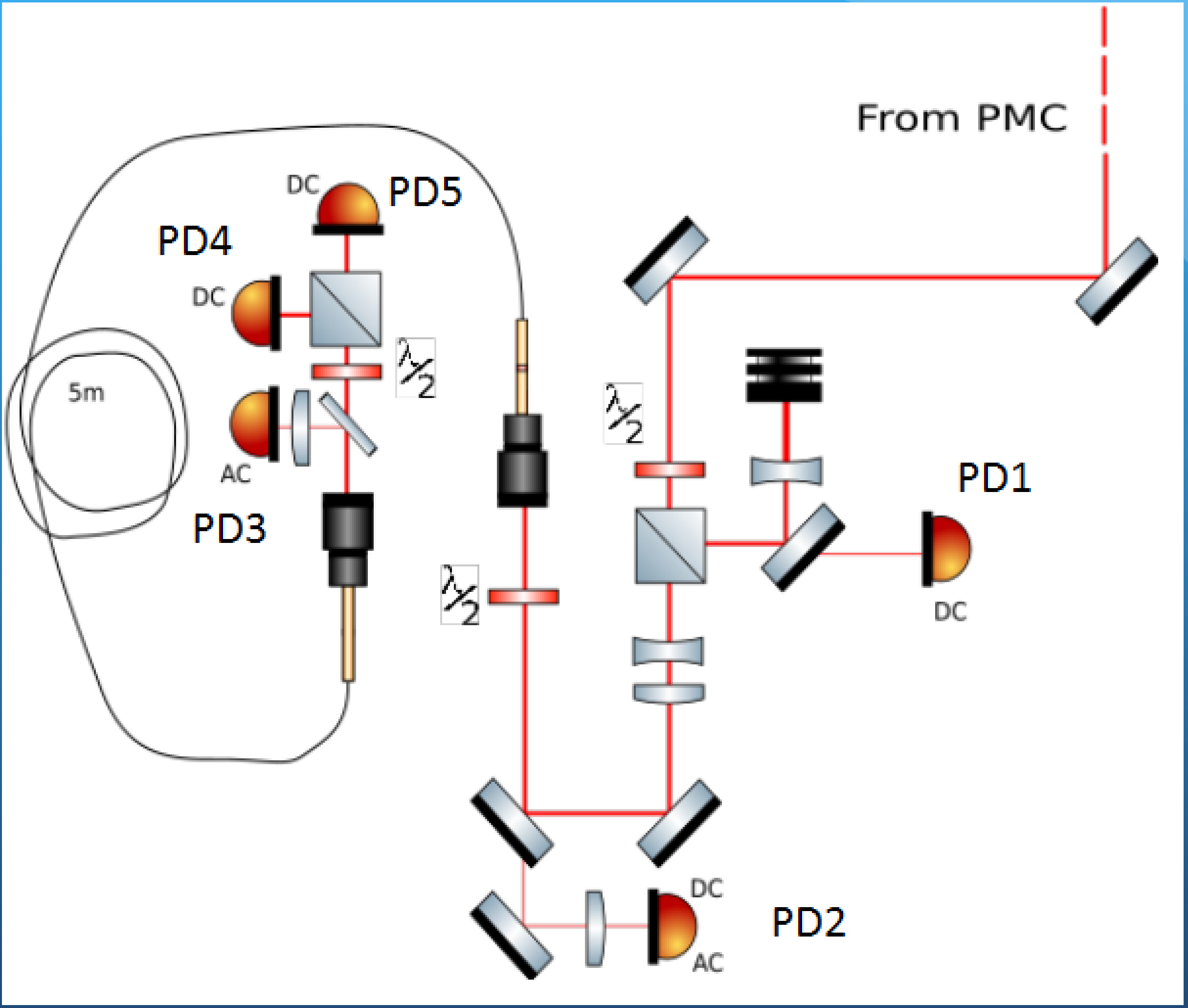
MARIE CURIE ACTIONS

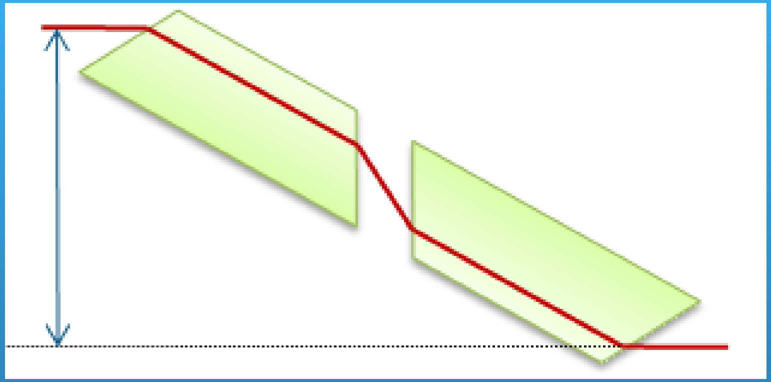
GraWIToN
GW Initial Training Network

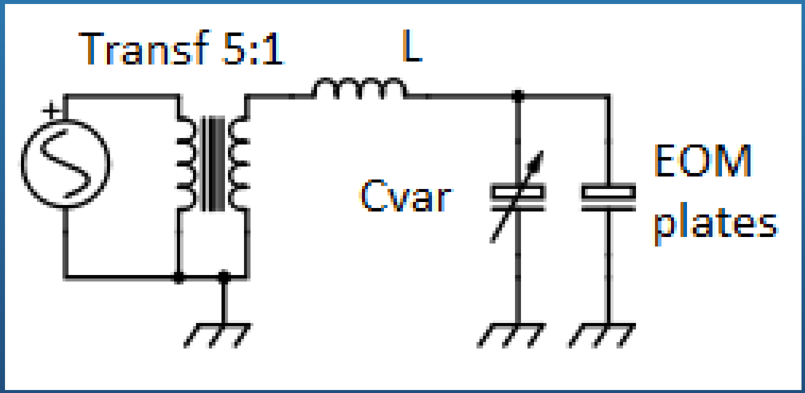
Back up slides

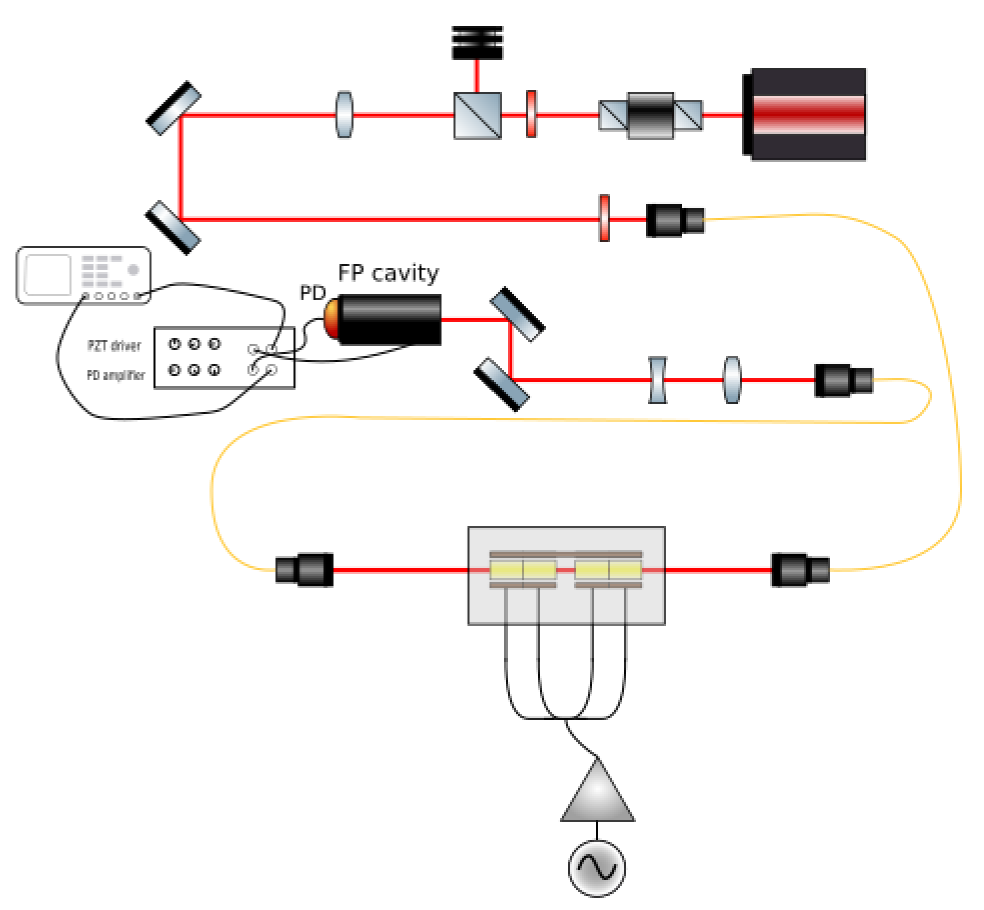

optical power transmission and error signal respect to the miscentering
Time shifted and linearly scaled
Normalized Amplitude a.u.
Piezo scan
Experimental coupled power
Experimental Error signal
Computed coupled power
Computed Error signal
Beam position respect to the aperture
−1
0
1
2
−2


Laser
Shift
Mode Matching
Optical fiber
Pick off
Tilt
PZT
Toward
experiment
Colimator
photodetector


From PMC
PD5
DC
PD4
DC
λ/2
AC
PD3
5m
λ/2
λ/2
PD1
DC
DC
PD2
AC




Transf 5:1
L
Cvar
EOM
plates


FP cavity
PD
PZT driver
PD amplifier

Residual Amplitude Modulation