Investigation of effects associated with electrical charging of fused silica test mass

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Introduction

Fused silica mirrors — dielectric bodies suspended in high vacuum

They can trap and store electrical charges

These charges interact through electrostatic coupling with the environment and electrostatic actuators in particular

Result of this interaction may be:

- ***additional loss*** $\Rightarrow$ ***degradation of mechanical Q*** $\Rightarrow$ ***additional thermal noise***
- ***accidental variation of electrical charge*** δ***q*** $\Rightarrow$ ***variation of Coulomb force*** $\Rightarrow$ ***additional noise***

Mechanical loss in fused silica oscillators due to electrical charges or electric field

A number of experiments which have demonstrated the effects of electrical charge on mechanical loss:

- Univ. of Glasgow (Class. Quantum Grav., 14 (1997) 1537
- Moscow State Univ. (Phys. Lett. A., 278 (2000) 25
- MIT (Rev. Sci. Instrum., 74 (2003) 4840

The mechanism of loss is not clear (only hypotheses were proposed)

Nevertheless it is likely that the additional thermal noise associated with charges is not dangerous for Adv. LIGO if the electrical charge on mirrors is not unduly large

Experimental setup

Vacuum **p <** *10^{-7} Torr*

All fused silica bifilar pendulum:

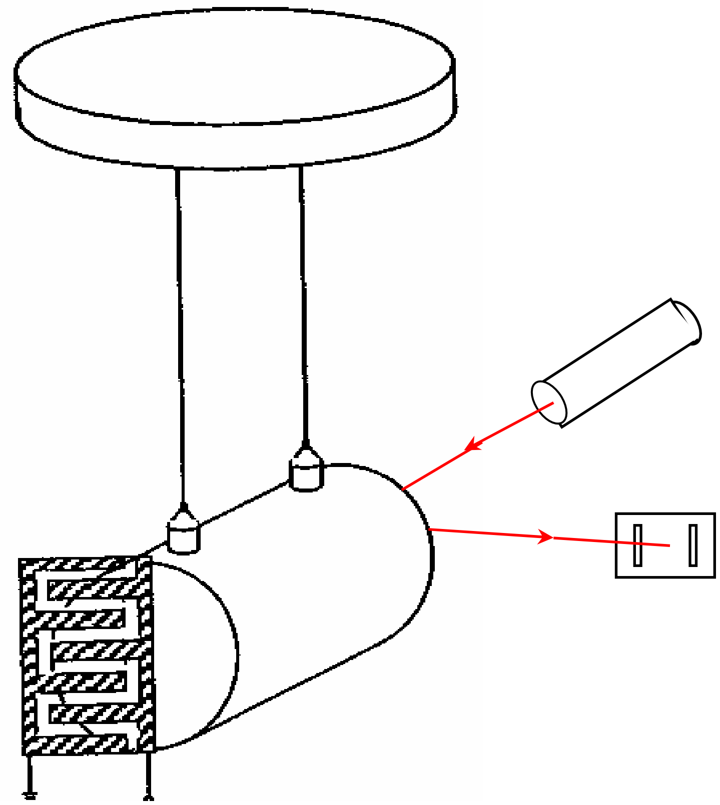
*Mass **M** = 0.5 kg, Fibers: **L** = 25 cm, **d** =200 μm,*

*Torsion mode **f** ≈ 1.14 Hz,*

*Quality factor **Q** ≈ 8×10^7 ,*

Relaxation time τ ≈ 2.2×10^7 sec,*

*Initial amplitude **A** ≈ 0.07 rad*



Multistrip capacitive probe
(two sets of gold strips sputter-deposited on fused silica plate) connected with high impedance amplifier.

Probe voltage ***U = k×q×A***

q *– electrical charge on the pendulum (distribution of charge is unknown)*

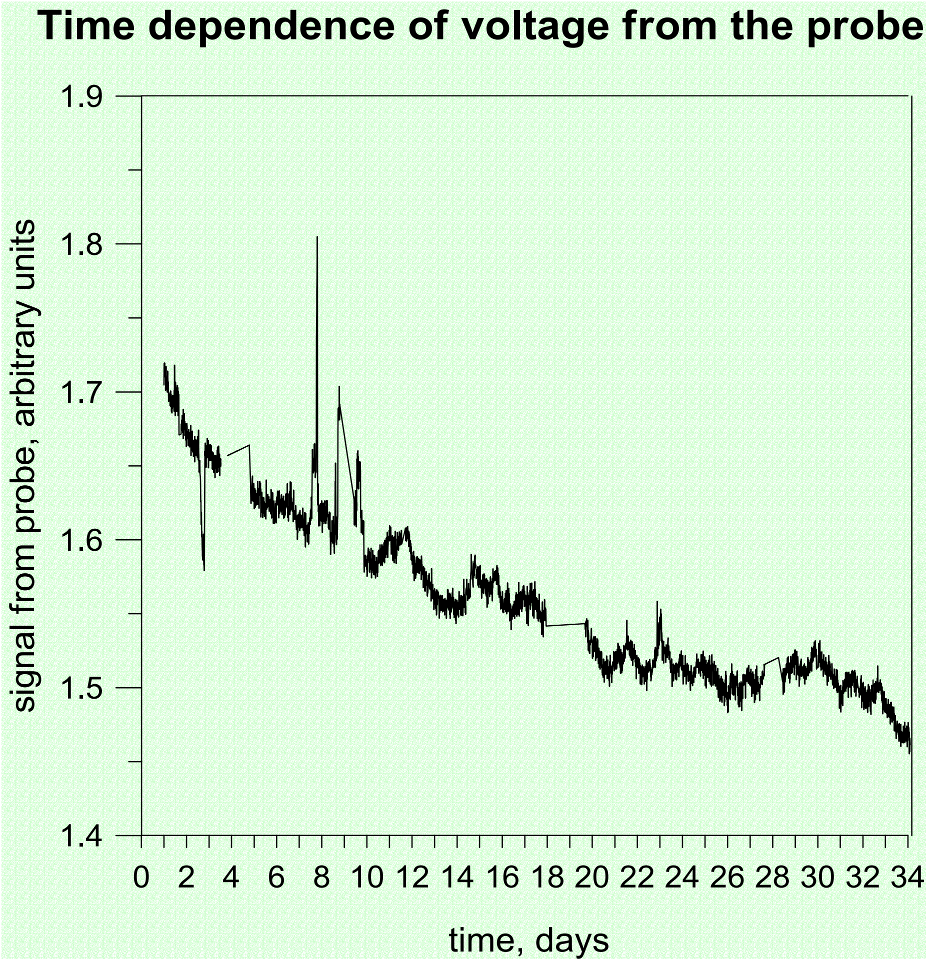
Long-term measurements of probe signal in process of free decay of the cylinder oscillation

About 2 years of observation
a lot of runs (each run is about 30 days)

- ***Averaged rate of charge variation:***
  $\approx 10^4$ e/cm^2 day
  (assuming uniform distribution of charge on the end face of the cylinder)

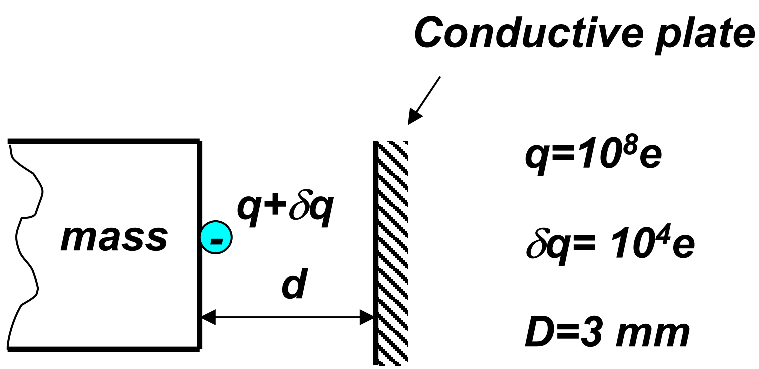
- ***Charge variation corresponds to negative charging of the cylinder***

- ***Resolution in measurement of charge is limited by seismic noise and parasitic effects***



Why we continue to study behavior of electrical charges on fused silica test masses?

1)



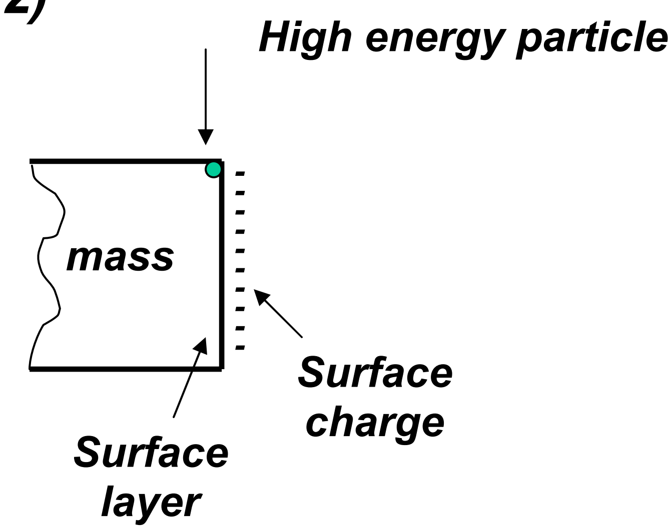
$q=10^8 e$

$\delta q = 10^4 e$

D=3 mm

$$\delta F_{el} = \frac{q \times \delta q}{8\pi\varepsilon_0 d^2} \approx 10^{-11}\,N > F_{gr}$$

2)



- *Generation of mobile charges within surface layer of the material*
- *Their separation in electric field of surface charges*

Rare big jumps of signal from the probe synchronous with fast decrease of the cylinder amplitude

4 events in 12 runs of measurements

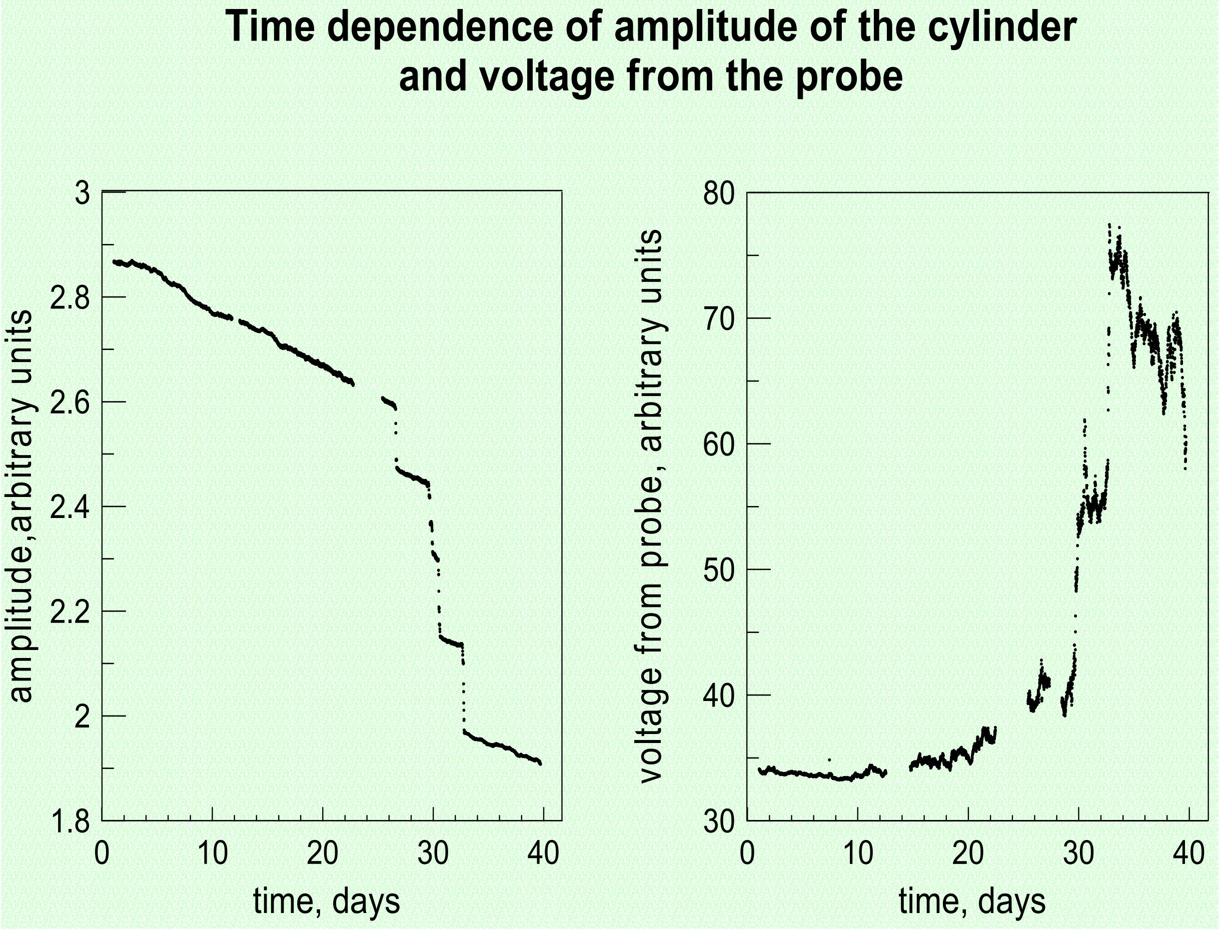
multistep structure of jump

- *Initial charge density: of order of 10^6 -- 10^7 e/cm^2*
- *After the jump: of order 10^8 e/cm^2*

(assuming uniform surface free charge density)

Change of amplitude in the process of jump corresponds to damping Q^{-1} of order of 10^{-4}

Resolution of details is determined by averaging time – 70 sec

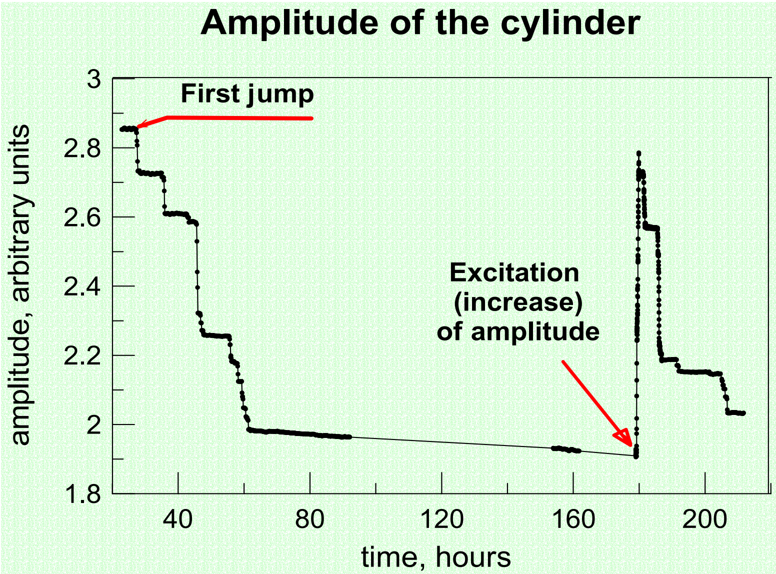


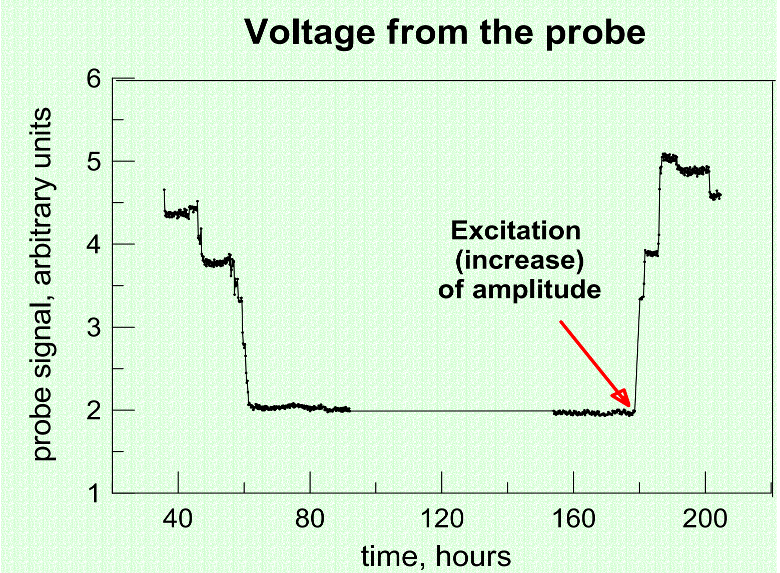
Behavior of the system after the first jump

After the first jump:

Repeated increase of torsion amplitude by means of electrostatic excitation results in a new cascade of jumps of amplitude and voltage from the probe (spoiled state of the system "fused silica pendulum – nearby electrodes")

With time elapsed from the first jump fast changes of the probe's voltage decrease. Spoiled state transfers to the original state within relaxation time of order of one month





Possibility that the pendulum modes of the cylinder causes it to touch the electrode

- ***A contact electrification can take place if the pendulum is swinging far enough to touch the electrode plate due to seismic excitation***

- ***Only torsional amplitude is well measured by the optical sensor***

  The electrometer signal on the pendulum frequencies give information about pendulum amplitudes with large uncertainty

  So we can not control the touching or close approach of the pendulum to the electrode plate in this set up

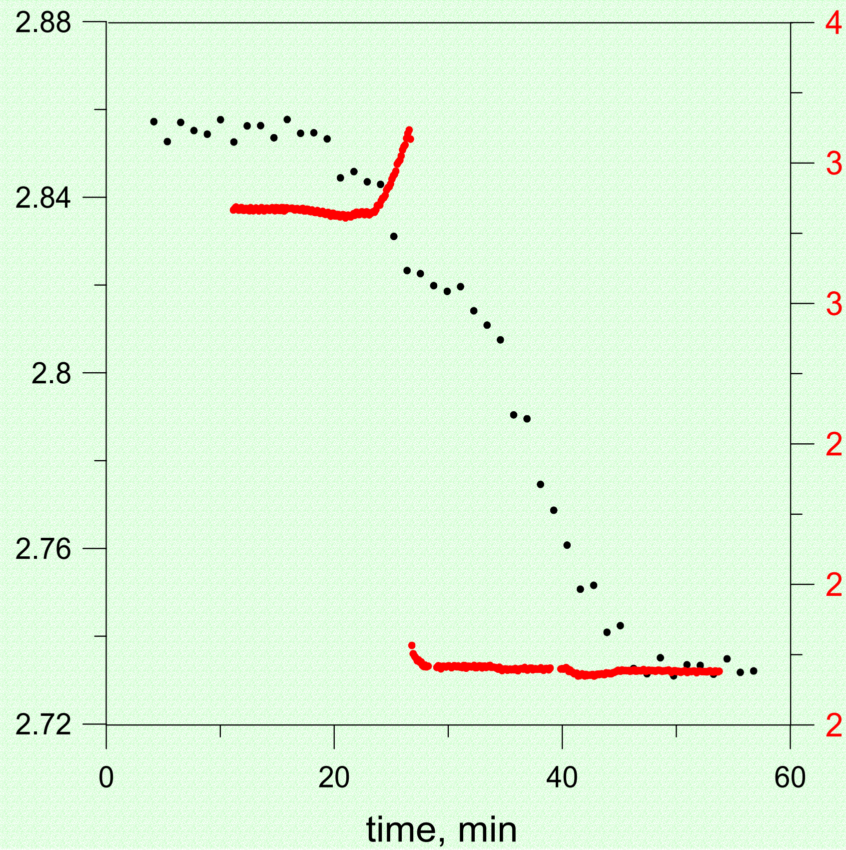
Changes of torsional amplitude and probe signal in the case of provoked touching

For the provoked touching behavior of the system is much the same as it is in the case of our "jumps": decrease of amplitude and increase of probe signal as well as transfer to the "spoiled" state

There are at least two distinctive property of provoked touching:

- *In the case of provoked touching change of amplitude and probe signal is fast (within the time resolution)*

Change of torsional amplitude in the case of "jump" (black) and of touching (red)

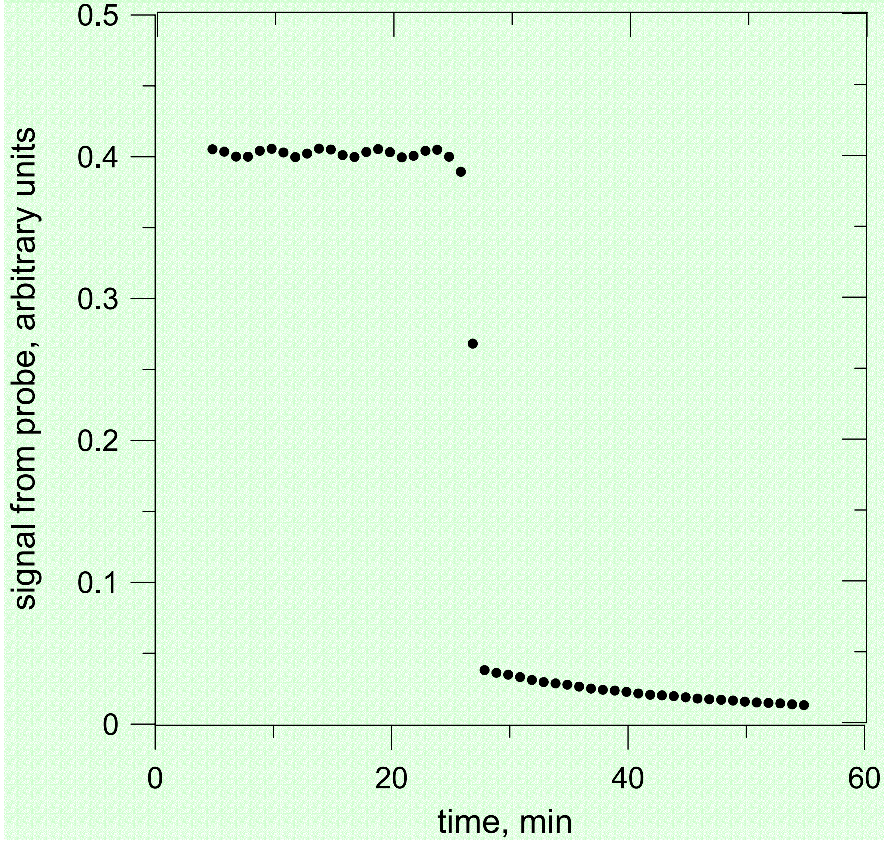


Changes of torsional amplitude and probe signal in the case of provoked touching

- ***Admission of small portion of air into the chamber results in significant drop of probe signal (supposedly due to gas breakdown). After the "jump" the probe signal can be reduced only by electrical discharge in rough vacuum***

✓ ***These facts can not be the evidence for the absence of touching in our experiments. It is worth further investigation***

Change of probe signal after admission of air

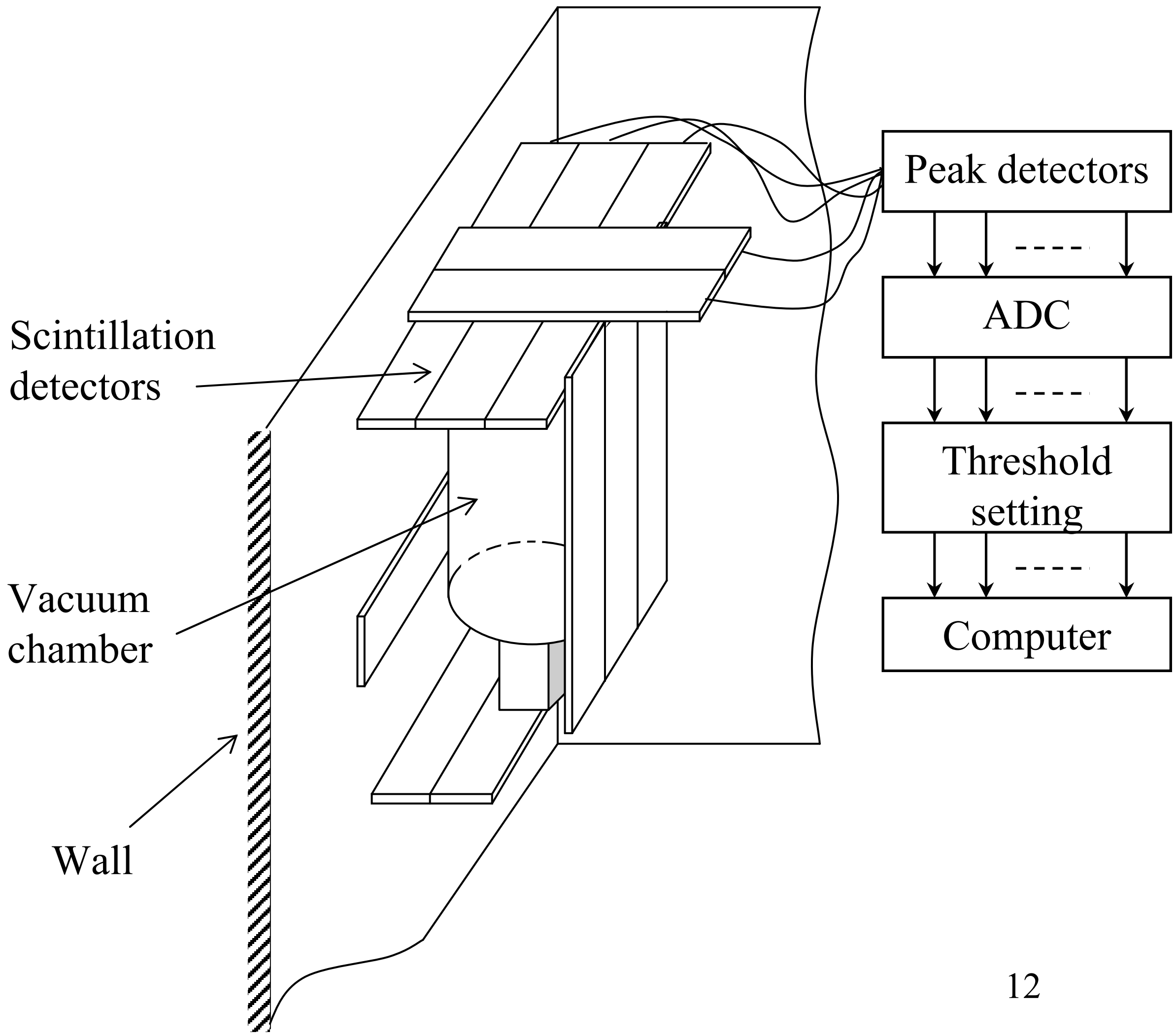


Search for correlation between signals from the probe and cosmic ray detectors

Cosmic ray detector system

11 particle detectors (plastic scintillator paddles $180\times18\times0.8$ cm^3) supplied by photomultipliers were installed around the vacuum chamber with the pendulum

Selection of events with maximum summarized voltage from all paddles



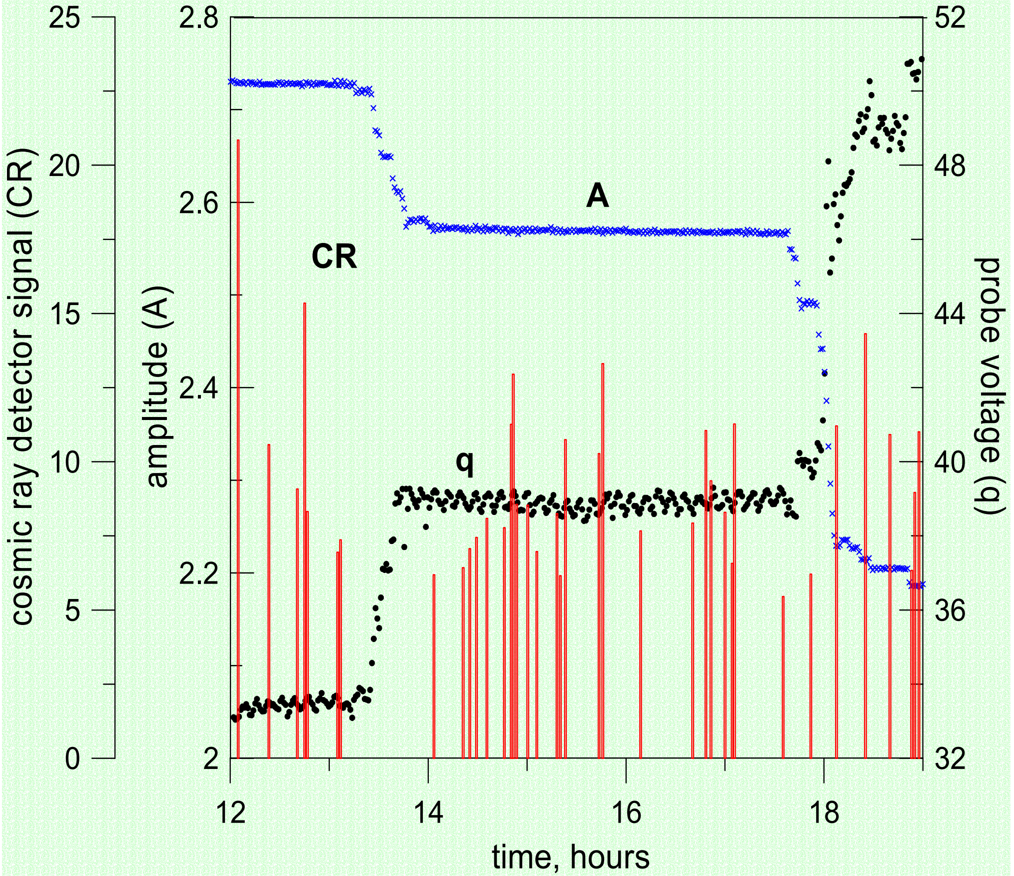
Result of measurements

We have not found statistically significant time coincidences between large signals from detectors and jumps of charge and amplitude in the "spoiled" state of the test mass

But we can not exclude correlation with:

low energy particles passing locally through the surface layer of the test mass

Fragment of record of amplitude and signals from the probe and scintillation detectors



Conclusion

- ***We have a number of empirical facts but we can not unambiguously interpret these facts yet***
- ***We suppose that the electronic properties of the surface of dielectric mirror can play the important role but they are poorly studied till now***
- ***We do not yet ready to say that electrical charges are not dangerous for LIGO***