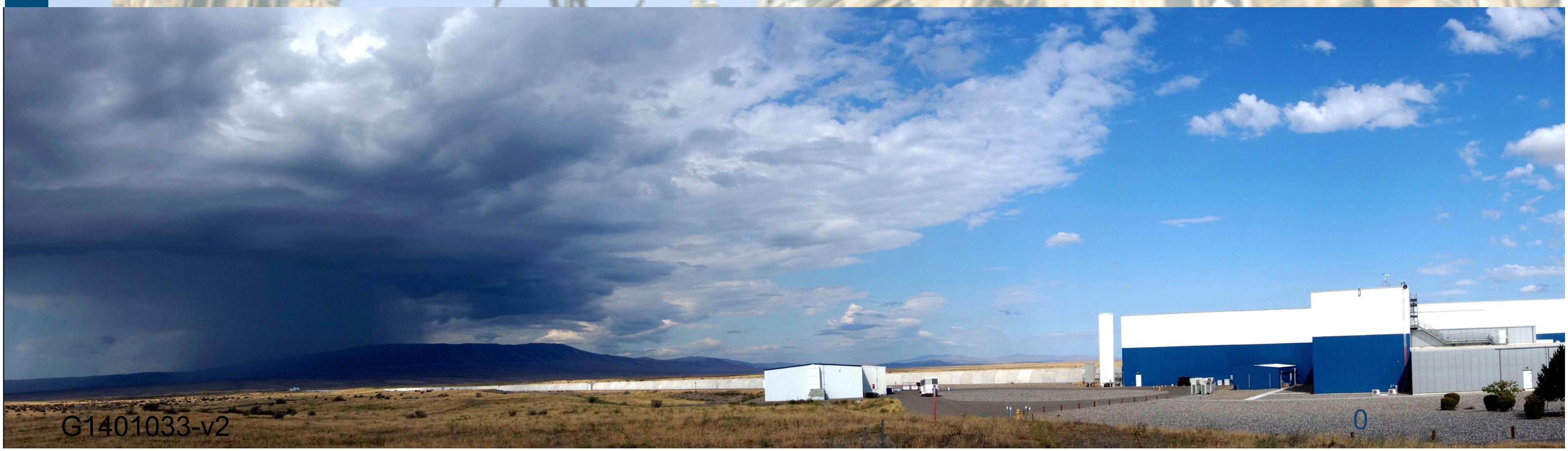
Charging issues at the sites

B. Sorazu for the LIGO sites

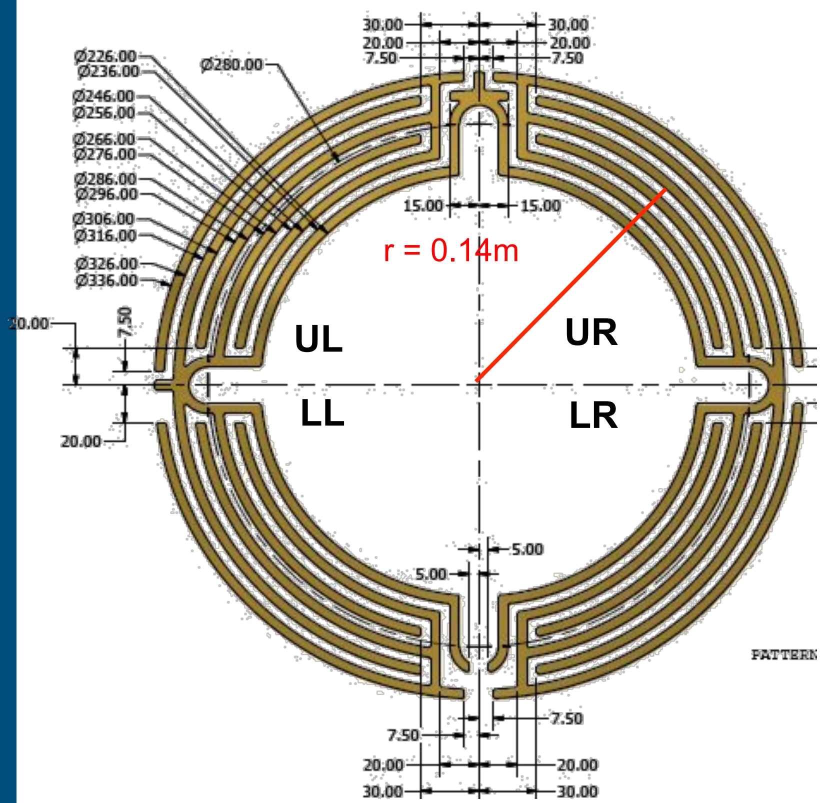
Stanford LVC meeting August 2014

LIGO-G1401033-v2



Electrostatic actuators - ESD

- aLIGO QUADs use electrostatic drive (ESD) system instead of coil-magnet actuators on lowest stage to reduce noise coupling due to magnets.

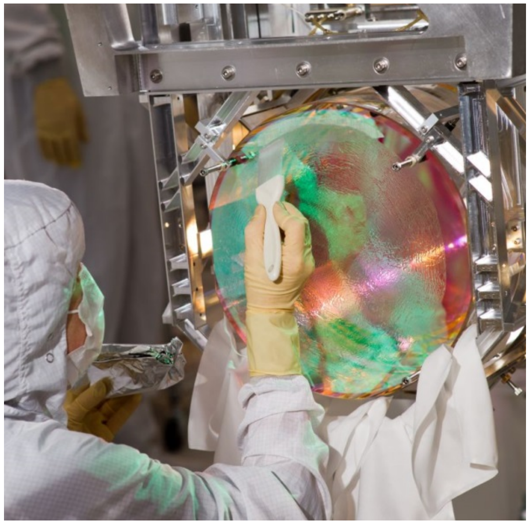


- ESD: on reaction mass at ITMs and ETMs.
  - 4 pairs of electrodes, coated onto reaction mass.
  - Each pair of electrodes forms a capacitor, whose fringe field attracts the test mirror surface (dielectric). Distance between electrodes and ETM is 5mm.
  - 5 channels to drive electrodes; 1 common BIAS, 4 driving channels (1 per quadrant).

- Surface charge on the test masses is a potential source of low frequency displacement noise.

Charge on the test masses

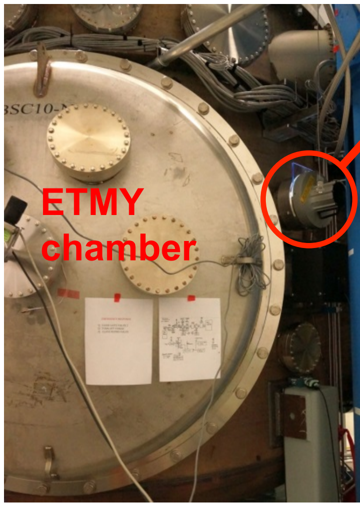
- LASTI tests showed: charge on aLIGO test masses was small and stable (if charged deliberately). See T1100332
- At the sites the situation is different:
  - Test masses discovered to be significantly charged.
  - The charge is not static.
  - Different story from each test mass



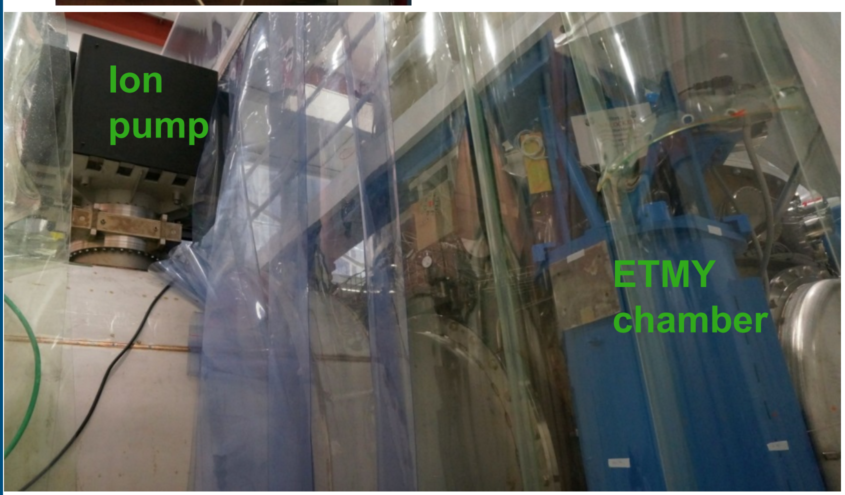
- But Why? Lots of potential sources of charge…
  - *First contact* - *Chamber Illuminators*
  - *Electrical connections* - *Inter-chain EQ stops*
  - *Cold Cathode Pressure Sensor*
  - *532 [nm], 2-photon interactions* - *Ion Pumps*

LHO charge results – What is charging ETMY?

- Four possible charging candidates:
  - ***Seismic rubber stops:*** through Silica to Silica friction. LASTI tests used them and saw no effect on the charge.



  - ***LED illuminators:*** Photoeffect. Turned on to monitor ETMY surface during discharge runs, ON since. Broad angle not extremely bright LED difficult to charge mass in 1 day.
  - ***Cold-cathodes:*** Very low pressure sensor at the top of ETMY chamber. It operates in a similar fashion to an ion pump but much smaller scale. It is closer to the ETMY mass.

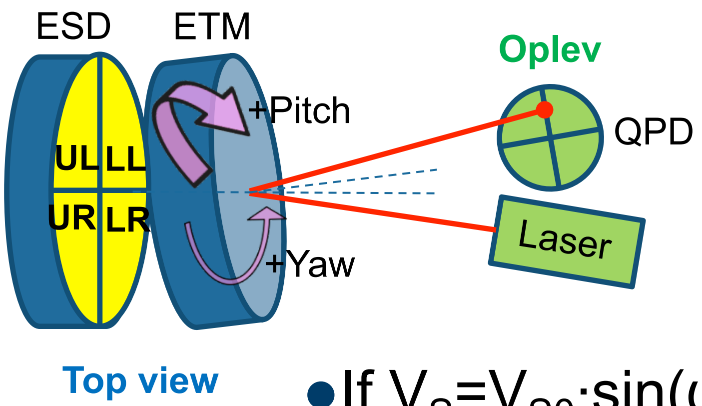


  - ***Ion pump:*** Never used at LASTI. They are known to charge suspensions due to UV radiation [2] and emission of charged particles. Far from ETM in chamber.

[2] S. Rowan *et al Investigations into the effects of electrostatic charge on the Q factor of a prototype fused silica suspension for use in gravitational wave detectors*, CQG **14**, 1537, 1997

- lots of potential sources…
- **How to measure and monitor the charge of the test masses once they are installed at the sites?**
- By driving the ESD quadrants at a frequency away from resonances and monitoring the test mass movement [1].
- Optical levers (oplevs) are used to monitor the angular variation (Pitch and Yaw) of the test masses.

[1] M. Hewitson *et al Charge measurement and mitigation for the main test masses of the GEO 600 grav. wave observatory*, CQG **24**, 6379, 2007



- Total force of the ESD over the dielectric ETM:

4.2e-10[N/V²] for ETM

$$F_T = -\alpha(\varepsilon, \varepsilon_r, d, a)(V_S - V_{BIAS})^2$$

distance between test mass and reaction mass; factor depending on geometry of electrode pattern; ESD driving signal

- If $V_S = V_{S0} \cdot \sin(\omega t)$, linear term of force is: $F_T(\omega) = 2\alpha V_{BIAS} \cdot V_S(\omega)$

- Linear Force / Torque term is **zero** if no bias voltage.
- Linear, angular motion θ of ETM due to torque of one ESD quadrant:

$$\tau = r \cdot cos\left(\frac{\pi}{4}\right) \cdot \frac{F_T(\omega)}{4} = I \cdot \omega^2 \cdot \theta$$

I= moment of inertia ETM =0.58[kg/m²]

$F_T(\omega)$=0.3e-4[N], with V_{BIAS}=390V and V_{S0}=91V

r=0.14[m] and *ω=2π·4=25[rad/s]*

→ ***θ = 2e-3[μrad]***

Oplev noise = *1e-9[rad/√Hz]*

For BW=0.01Hz → SNR = 20

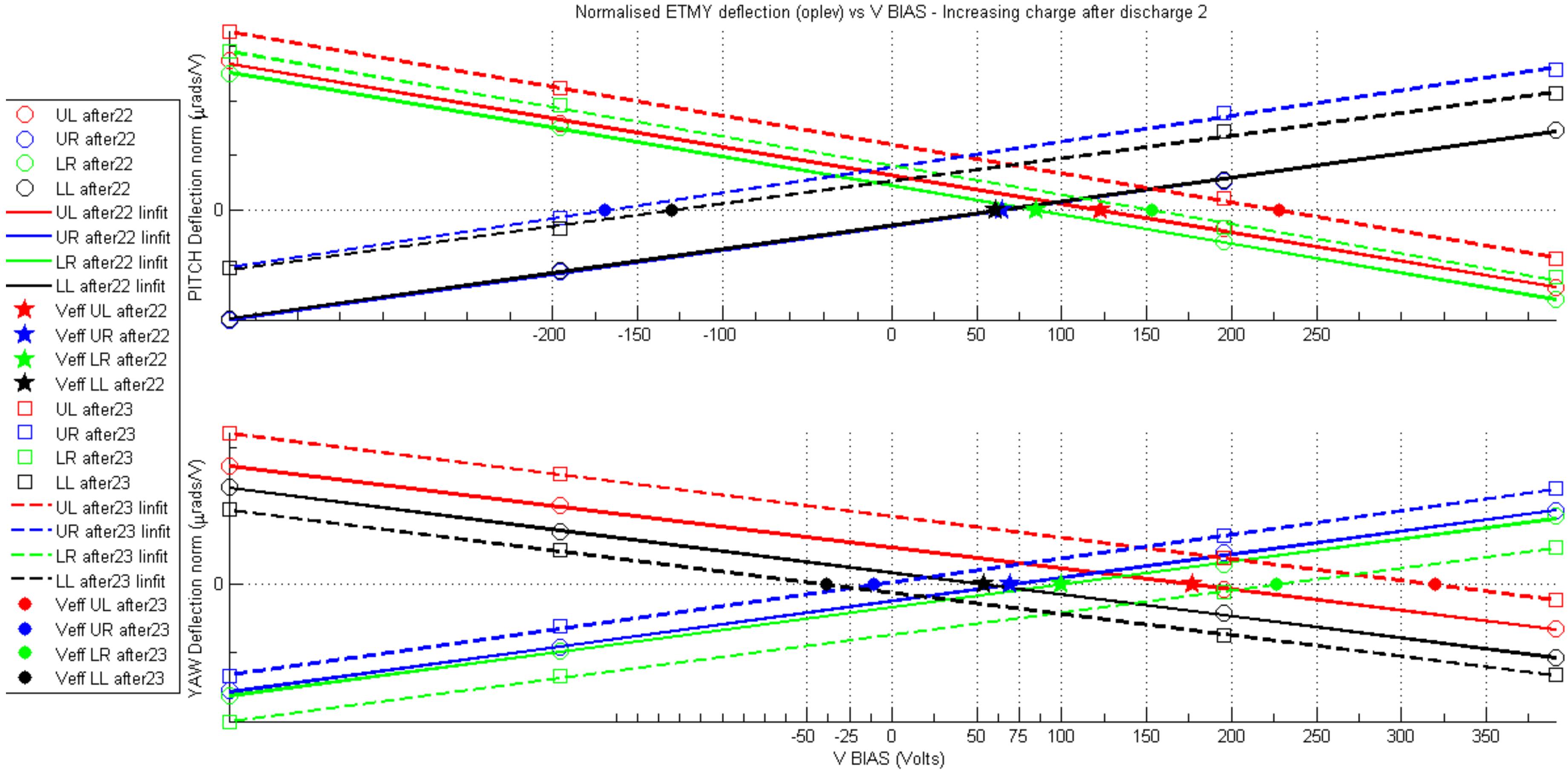
Charge measurement scheme

- When charge is added to the test mass then an additional force linearly proportional to the driving signal acts upon the mass:

$$F_T(\omega) = 2\alpha V_{BIAS} \cdot V_S(\omega) + \beta \cdot V_S(\omega) = 2\alpha(V_{BIAS} + \beta') \cdot V_S(\omega)$$

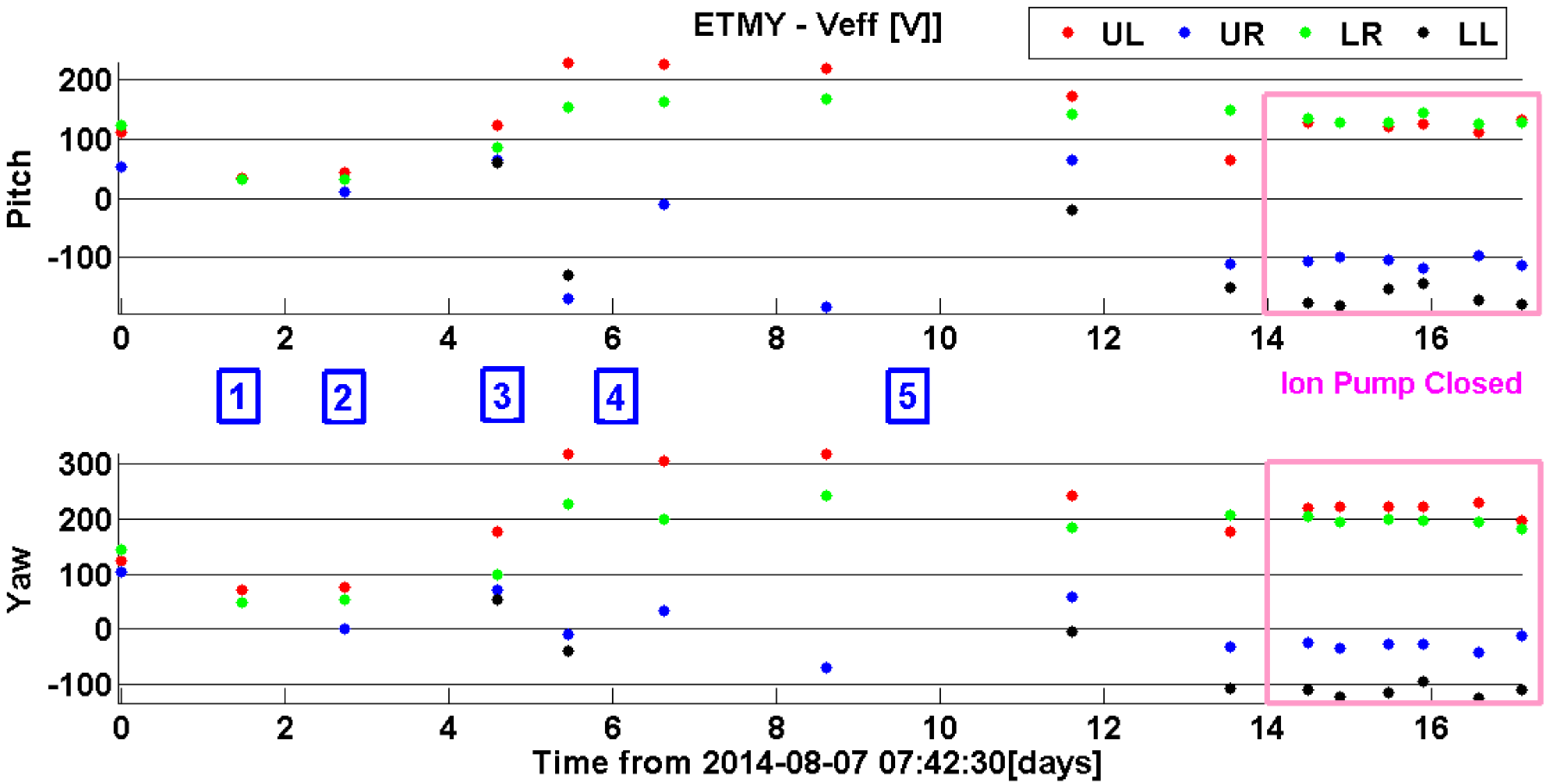
- β depends on the added charge and ESD electric field.
- The added charge gives rise to an $V_{eff} = \beta'$, such that when $V_{BIAS} = -\beta'$, the test mass does not move $\theta = 0$.
- If we measure θ as a function V_{BIAS}, for the same excitation amplitude $V_S(\omega)$, the bias voltage where $\theta = 0$ (and therefore $F_T(\omega)=0$) is a direct measure of β'.

Charge measurement example plot



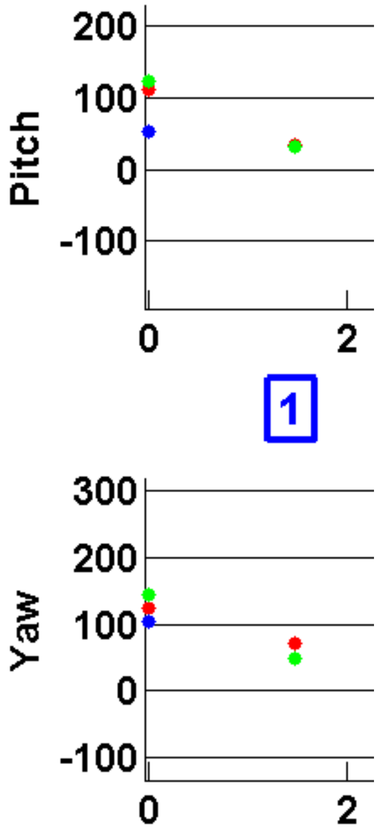
- Zero crossing gives V_{eff} (in pitch and yaw for each ESD quadrant).
- Sign of V_{eff} corresponds to the sign of the charge.

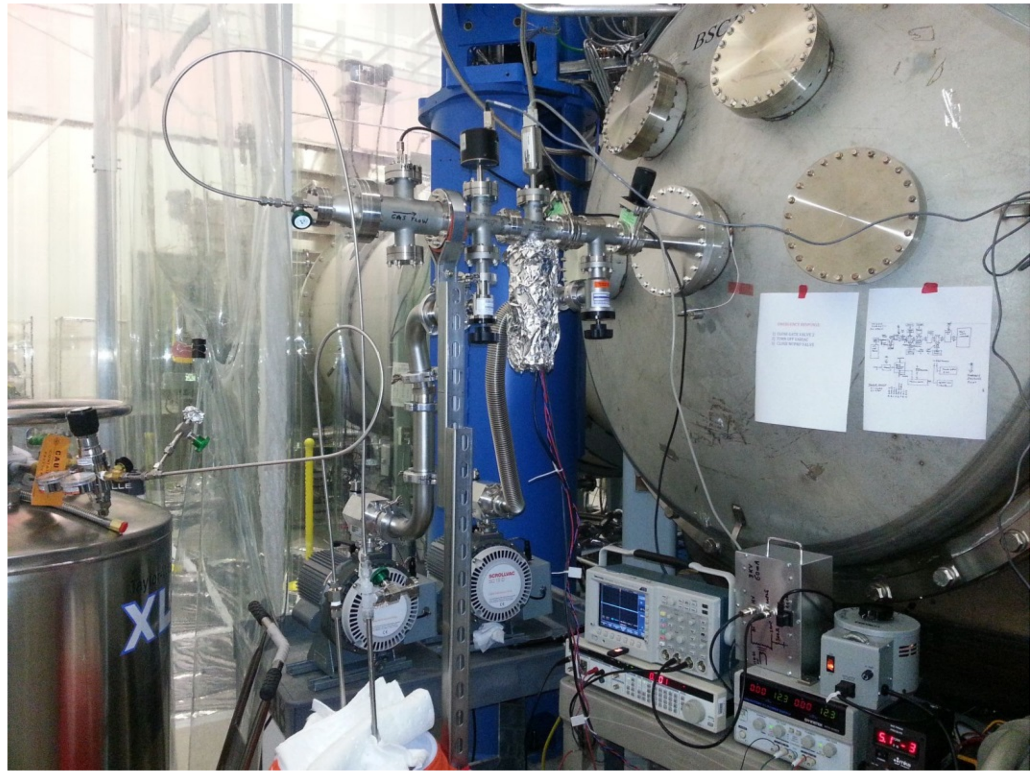
LHO charge measurements results: V_{eff}-ETMY



- Big charges in ETMY, they are not static and change sign.
- The blue numbers represent changes in the experimental conditions.

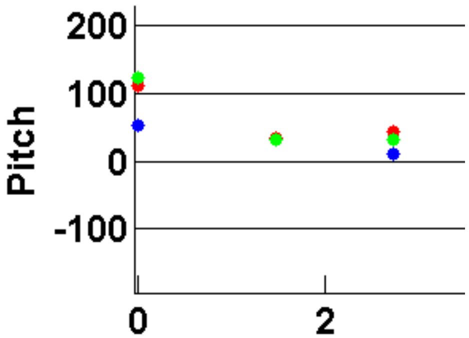
LHO charge results – 1st ionizer discharge run





- First ionizer discharge run.
- Positive surface charge neutralized by introducing positive and negative ions in a clean carrier gas (nitrogen). See T1100332
- Observed **discharge between 40% and 1%** depending on ESD quadrant.

LHO charge results – 2nd ionizer discharge run



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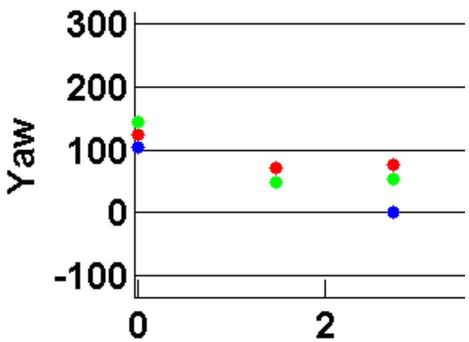


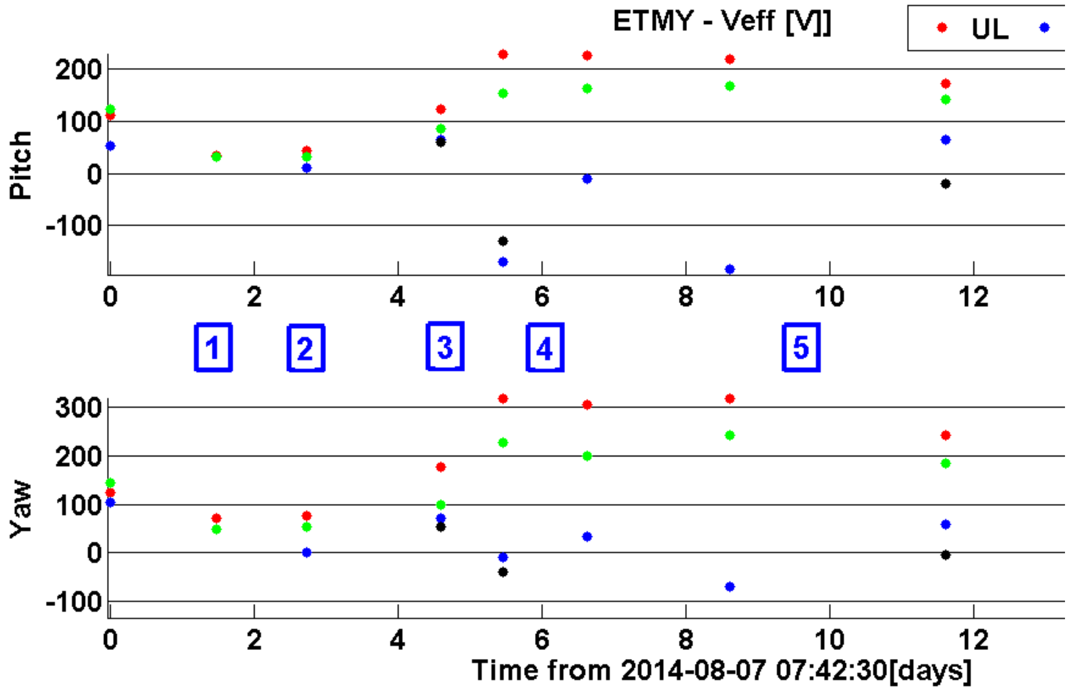
parameter	test1	test2	comments
pressure on needles torr	300	130	
voltage on needles rms 60Hz kV	30 variac 3kV	13 variac 1.3kV	voltage set to avoid discharge
pressure in input line psi	20	1->5	
pressure in s[illegible]			
sampled + ion current amp 0.01 of main flow	$5x10^{-9}$	$1.7x10^{-8}$	
sampled – ion current amp 0.01 of main flow	$5x10^{-10}$	$2.5x10^{-9}$	
initial pressure in chamber torr	$4 x 10^{-8}$	$4 x 10^{-8}$	after both tests pressure in chamber returned to original value within 12hours
final pressure in chamber torr	42	28	
final pressure in ionizer output torr	45	45	
filling time minutes	29	51	stopped test1 when ionizer got too cold
gas flow while filling atm*liters/sec	2	0.75	
gate valve chamber opening	full open	1/10 or less	test2 flow limited by "O" ring labyrinth
gas inlet Nupro valve opening	full open	full open	
pressure in ionizer before gas input torr	$2.0x10^{-3}$	$2.0 x 10^{-3}$	
pressure in ionizer and fill lines before gas input torr	$2.0x10^{-3}$	$2.0x10^{-3}$	after liquid N_2 trap was filled
Liquid N_2 and reheater on input fill line	only liqN_2	both	

after both tests pressure in chamber returned to original value within 12hours

- Summary of the conditions of both discharge runs. See T1400535

- 2nd ionizer discharge run.
- Positive and negative currents higher than 1st run but no further discharge. Maybe because gate valve to ETMY not fully open.
- Ratio positive to negative ions of 10 (1st run) and 7 (2nd run).

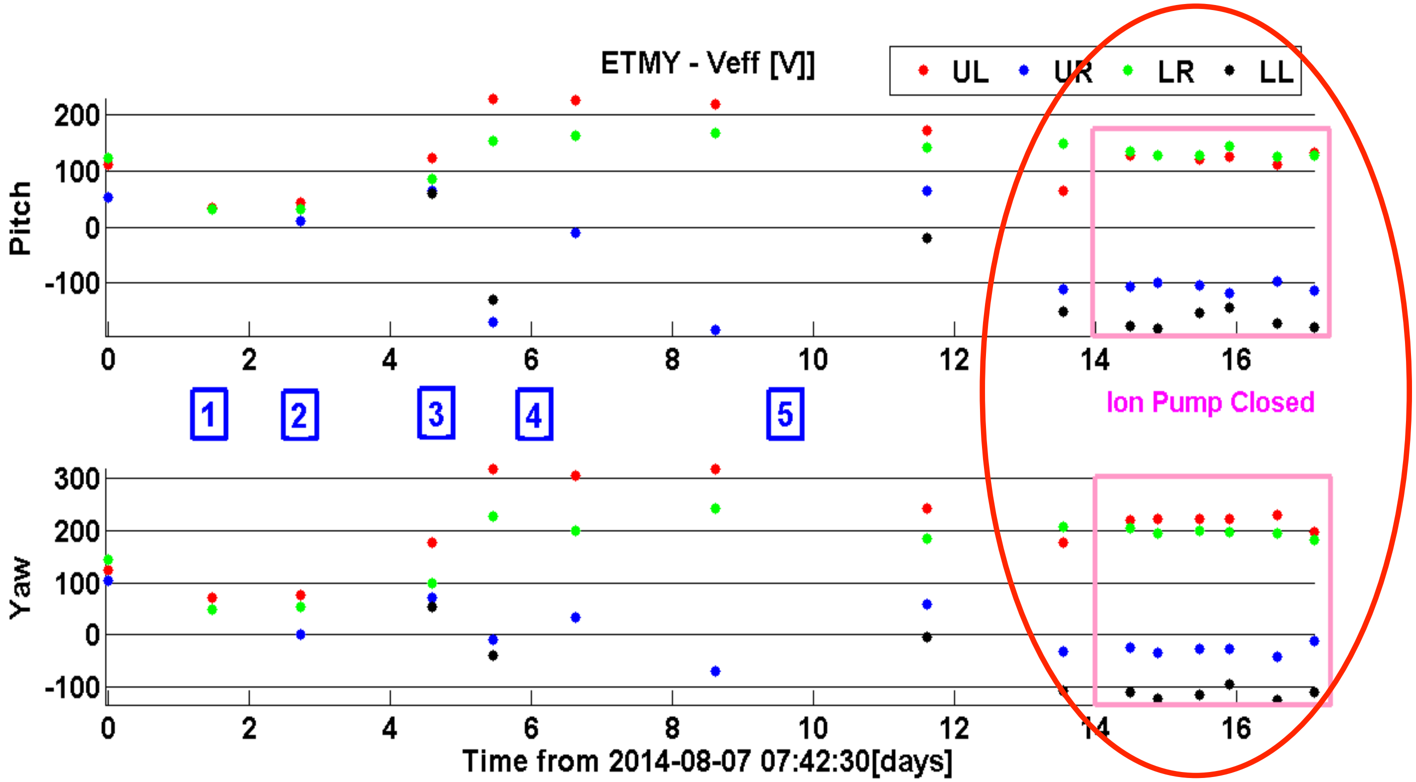
LHO charge results – Wrong ESD wiring



- ESD low pass filter for the BIAS.

- After 2nd discharge, test mass got charged again. More than before, including charge sign flips.
- During measurements quadrant labelled LL could not be driven.
- Due to an old wiring Kerfuffle (see G1400578) the LL driving wire was sent to the ESD low pass filter instead of the BIAS wire.
- The wiring configuration was changed back and forth to see effect in charge (points 3 to 5 on plot). No direct effect observed.

LHO charge results – What is charging ETMY?

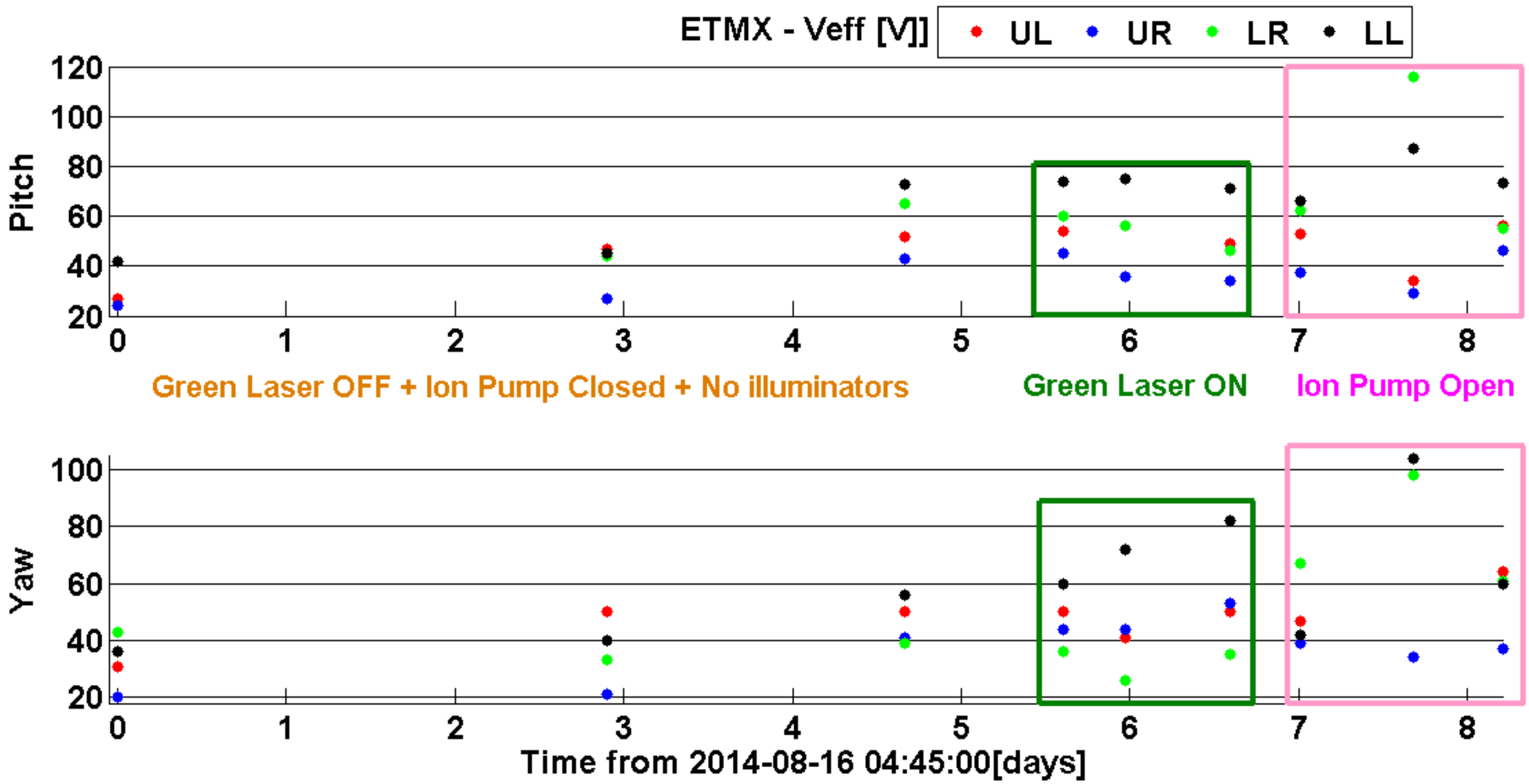


- Gate valve of ion pump was closed for 62 hours.
- During this time charge measurements from all quadrants and orientations were very stationary.
- **Did we find the culprit?** Still need to see what happens when we open the gate valve (being done at the moment).

LHO charge results – At the same time at ETMX

- ETMX became available to experiment with during the ion pump experiments at ETMY.
- ETMX good test bed; no illuminators, ion pump gate valve closed since venting 1 month ago. Cold cathode ON.
- Small and stationary positive charge was measured for a period of 3 days. Probably leftovers of the recent removal of first contact.
- Test charging effect of green laser light and ion pump.

LHO charge results – At the same time at ETMX



- 46mW of green light power at ETMY showed **no charging** for 2 days. This is ¼ of the resonant power during LHO operation.
- Opening the ion pump gate valve showed no charging trend for 37 hours.

LHO charge results – At the same time at ETMX

- What is different between ETMX and ETMY regarding charging effect of the ion pump?

1) The Earth magnetic field.

2) The pressure by an order of magnitude. Pressure in X is 2.7e-7 torr, while in Y is 4.8e-8 torr. A higher pressure reduces movement of the ions, but also increases the charge emitted by the ion pump.

3) Both ion pumps were costume made to the same specifications. They are made of 50 smaller ion pumps with maybe different configuration and different charge emissions.

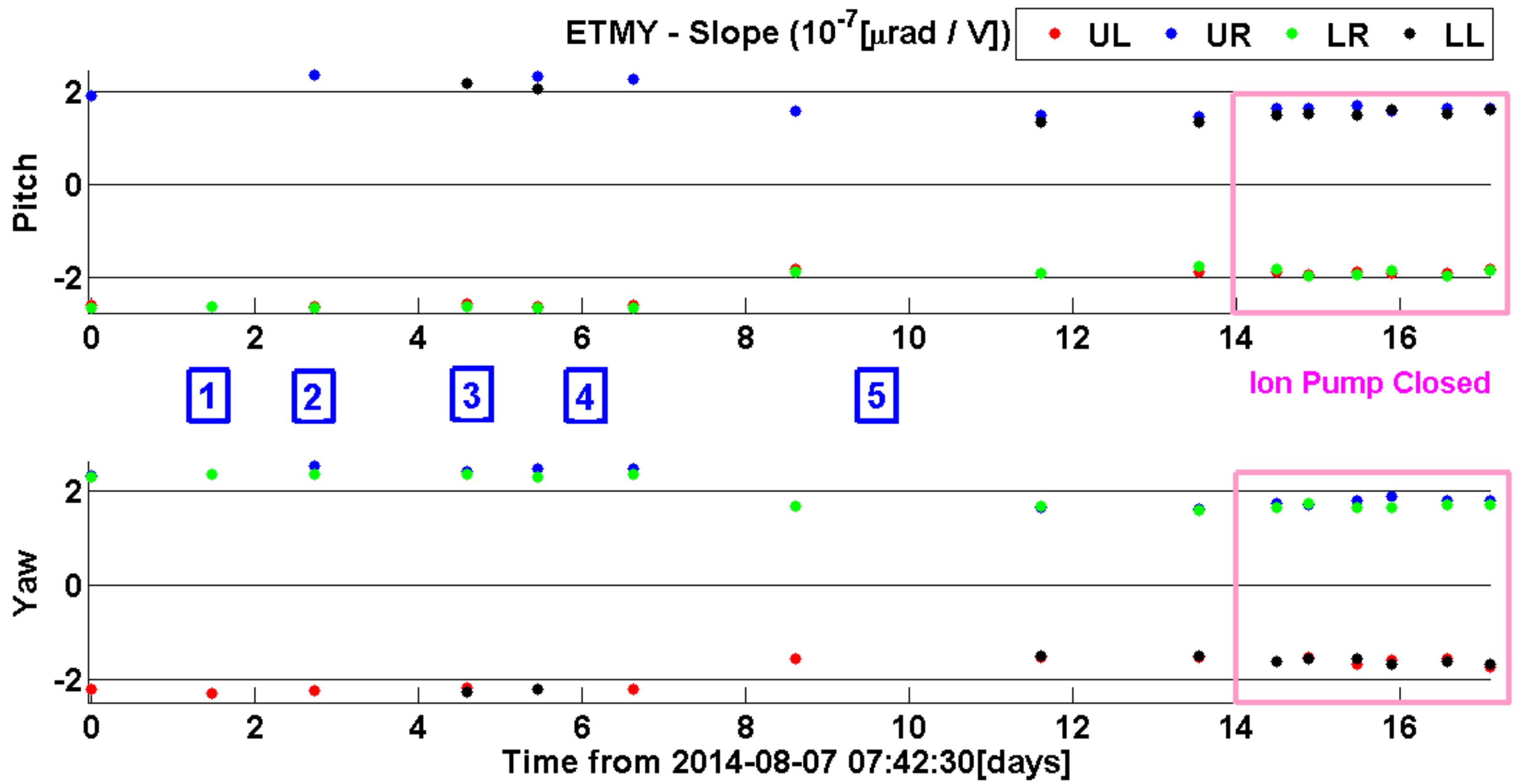
Conclusions and Action Items

- aLIGO suffering from charging of test masses vs. electrostatic drive
- Arduous measurement campaign to identify the problem
- Ruled out sources of charge:
  - Cable swapping
  - ALS 532 [nm] two-photon exposure
  - Illuminators
  - Cold Cathode
- Best guess “confirmed” sources
  - Ion Pumps
  - First Contact
- Story is on-going – stay tuned!

Thanks Borja!

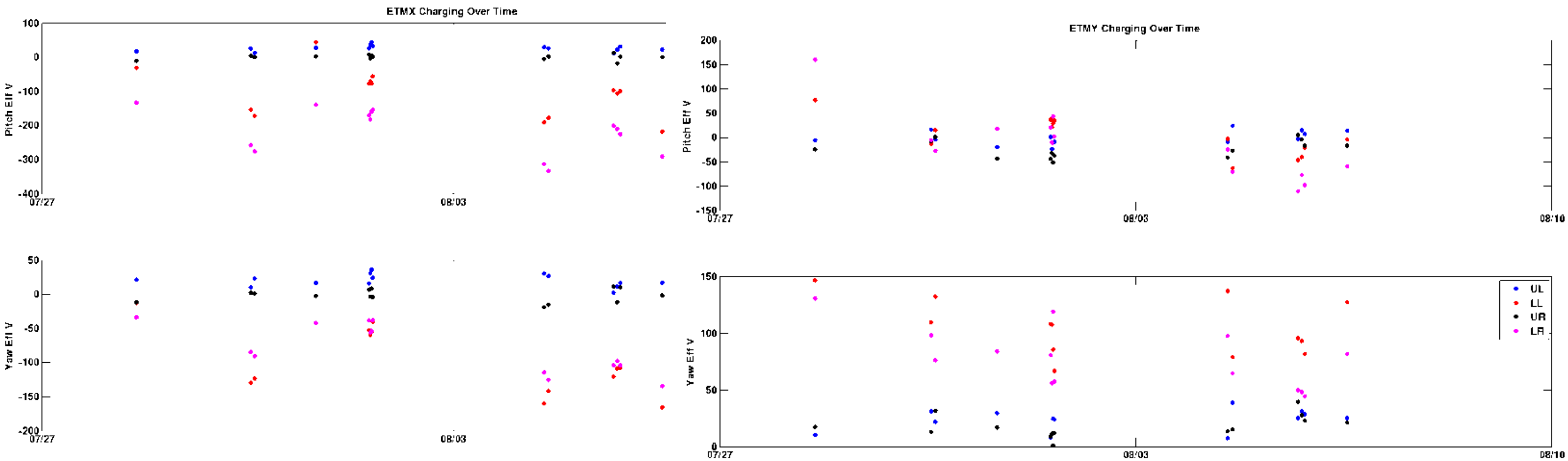
Others involved:
Rai Weiss, MIT
Jeff Kissel, LHO
Stuart Aston, LLO
Bryan Barr, Glasgow
Keita Kawabe, LHO
Richard McCarthy, LHO
Norna Robertson, CIT
Margo Phelps, CIT
Calum Torrie, CIT
Rich Abbott, CIT
Carl Adams, LLO
Peter Fritschel, MIT

LHO charge measurements results: slope-ETMY



- As expected the slope does not change much.
- This information allow us to identify the actual ESD quadrants being driven which differ from the CDS labelling (Kerfuffle). In the ETMY plots UL and LL are swapped.

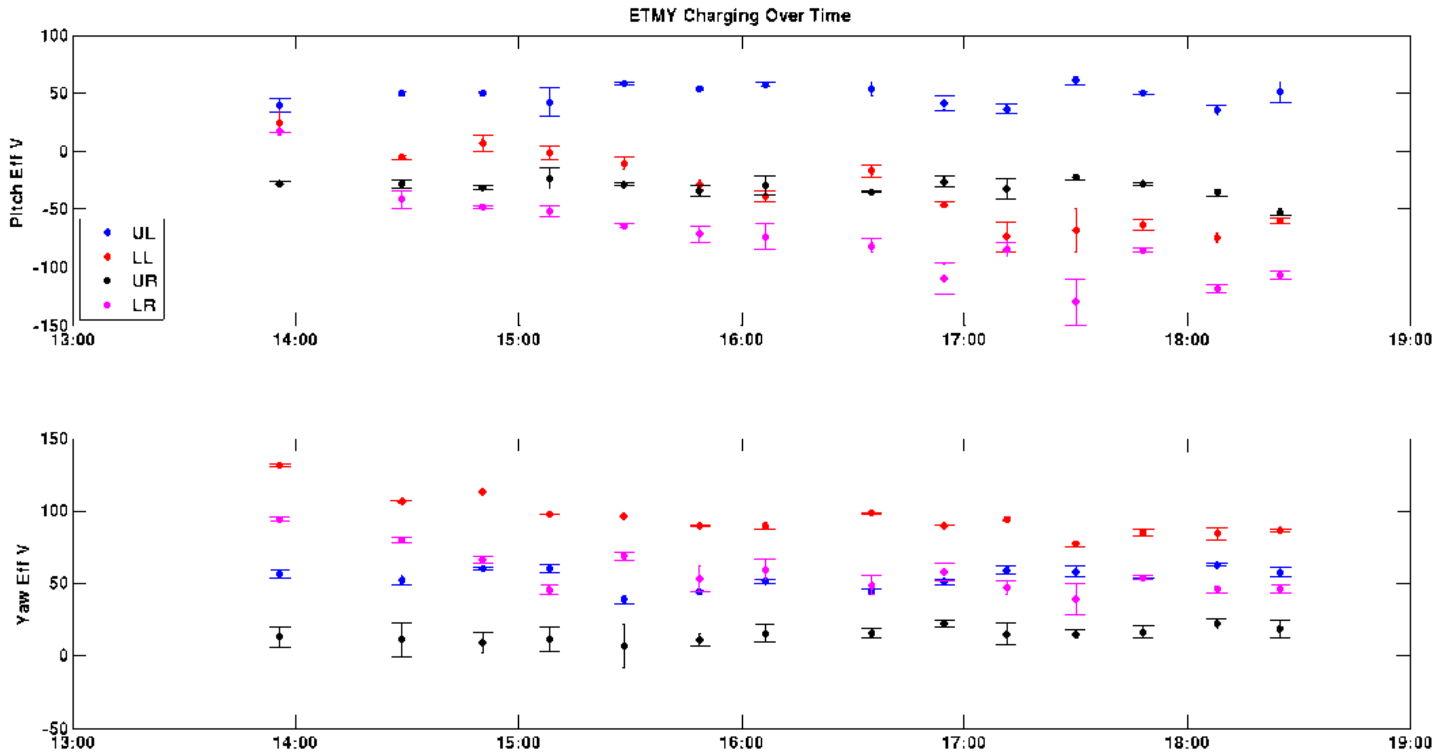
- Livingston long term charging measurements with automation code. Data plots taken from aLogs: aLog 13958, several days



- Upper quadrants reasonably consistent (within about +/-20V over time) while the lower quadrants appear to be very variable.
- ETMX seems to be more consistent than ETMY.

LLO charge measurements

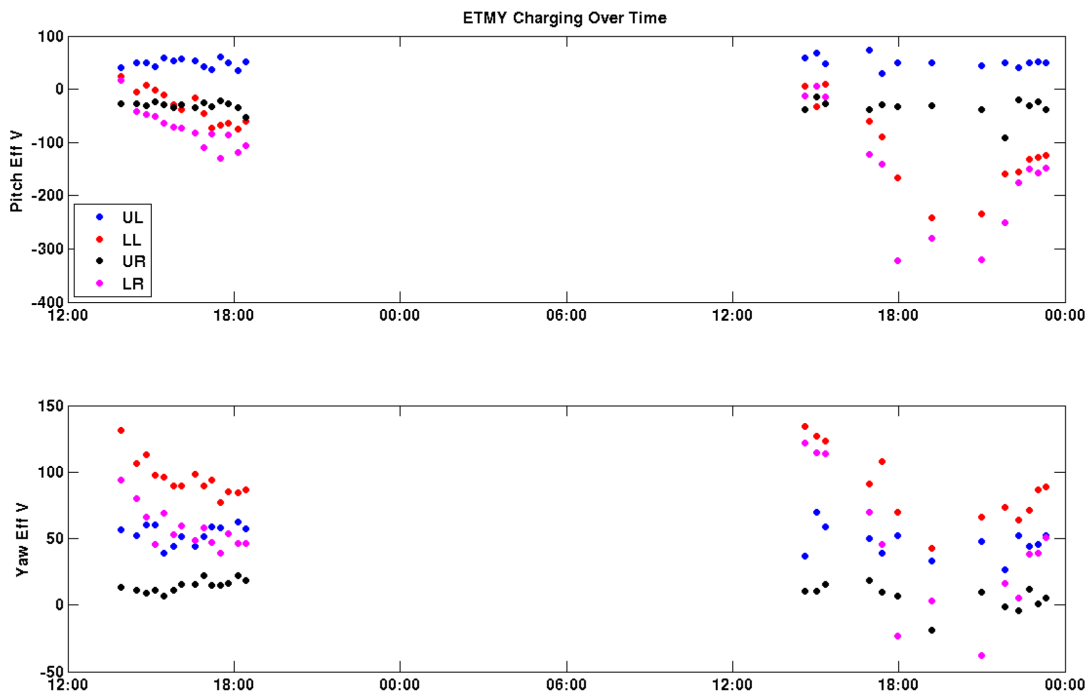
- Livingston long term charging measurements with automation code. Data plots taken from aLogs: aLog 14039: several hours



- ETMY data shows a distinct downward trend for the two lower quadrants, while the two upper quadrants are consistent to within a 20V range. The charging mechanism is under investigation.

LLO charge measurements

- Livingston long term charging measurements with automation code. Data plots taken from aLogs: aLog 14071, 1 day



- Charge trending back up again! This suggests that we're not dealing with a trend that changes with, say, effects from e.g. bias changes from the commissioning work but rather something cyclic - possibly thermal.
- As before, variations only occur on the lower quadrants.