Testing photo-emission of Au-coated surfaces for the LISA Gravitational Reference System (GRS)

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LISA Maximum Charge Requirement

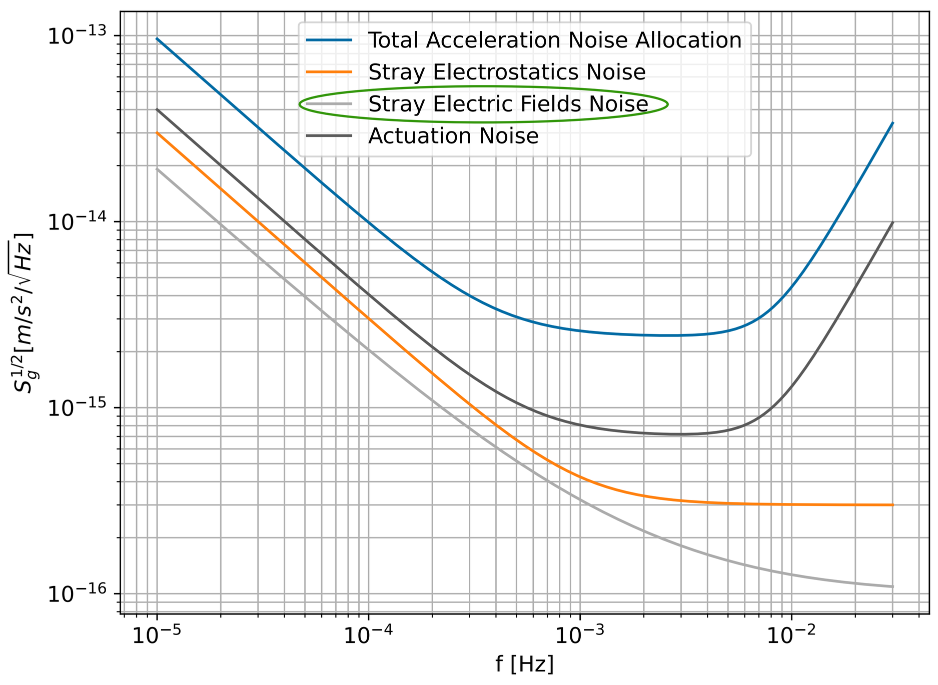
LISA GRS has to protect the free-fall motion of the Test Mass
Stray Fields and TM Charge couple into a force noise along the measurement

TM total charge — Total capacitance along x — The Sensing/Actuation electrodes produce random Stray Fields — TM-EH total capacitance

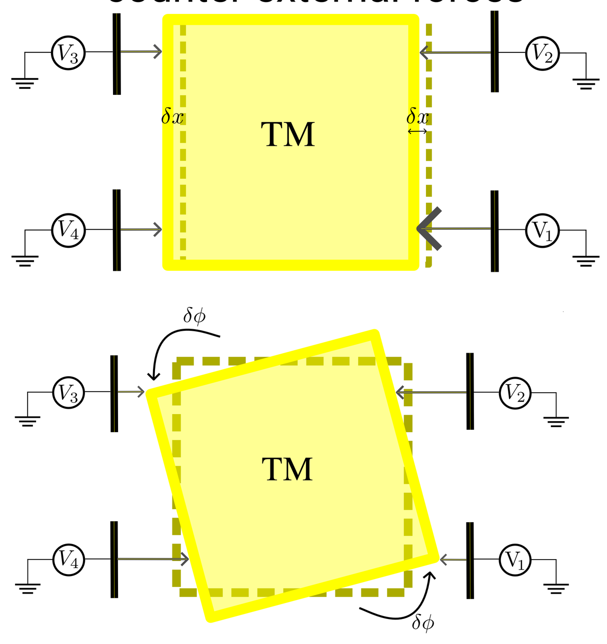
$$F^{Q_{TM}}_{x,noise} = -\frac{Q_{TM}}{C_{TM}}\left|\frac{\partial C_x}{\partial x}\right| \Delta_x$$

$$S_g^{\Delta_x}(f) = \left(\frac{1}{M_{TM}}\frac{Q_{TM}}{C_{TM}}\left|\frac{\partial C_x}{\partial x}\right|\right)^2 S_{\Delta_x}(f) = \left[2\,\frac{\text{fm}}{\text{s}^2\sqrt{\text{Hz}}} \times \left(\frac{Q_{TM}}{2.4\,\text{pC}}\right)\left(\frac{S_{\Delta_x}^{1/2}}{200\,\mu\text{V}/\sqrt{\text{Hz}}}\right)\right]^2$$

$|V_{TM}| \leq 70\,\text{mV}$



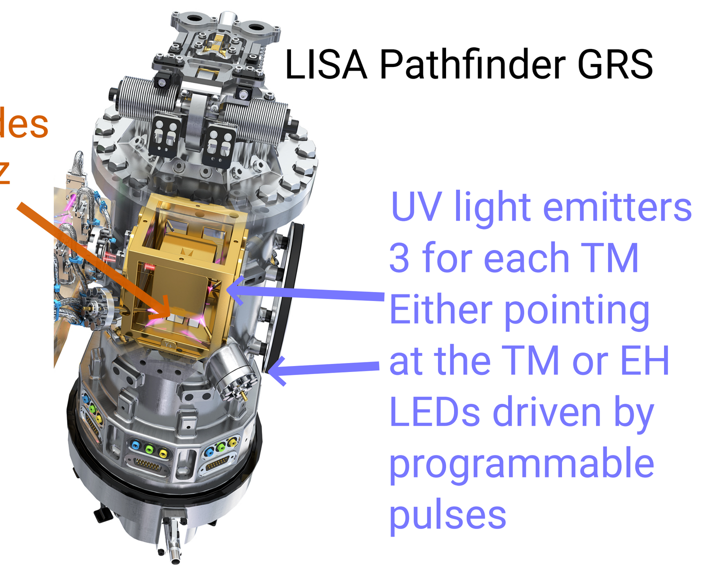
Sensing/Actuation Electrodes counter external forces

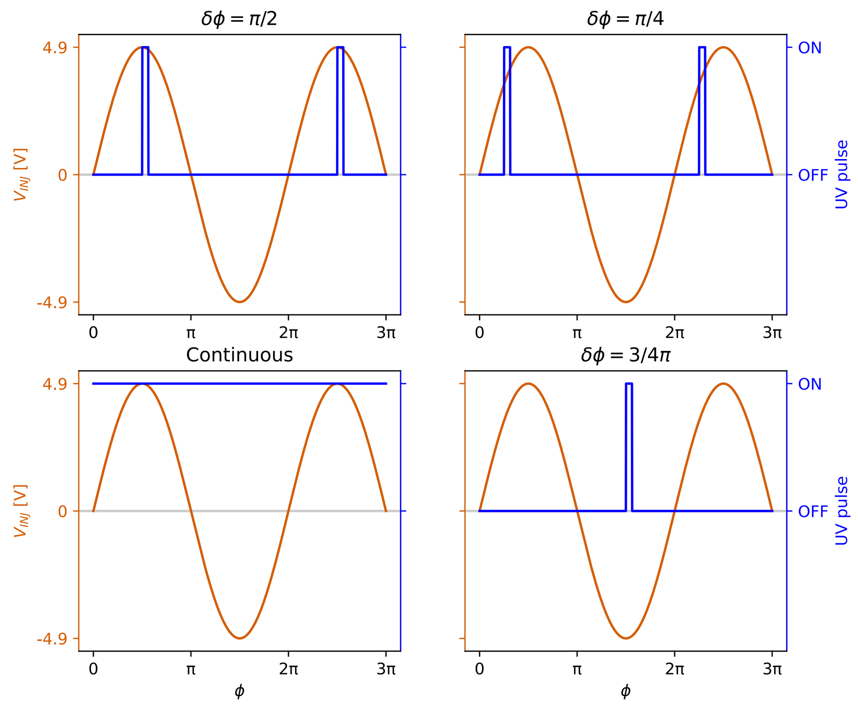


GRS Charge Management System

Cosmic rays charge the free-falling TM at a rate λ = 1-100 e/s ==> i = 10[-17] A
To avoid touching the free-falling TMs, photo-electrons are extracted from the surfaces illuminating with ~250 nm light(UV)

Injection Electrodes ±4.9 V at ~98Khz sine





Pulsed Illumination

- UV light in short pulses (~1μs)
- Photo-electrons are subject to Phase/delay "DC" fields determined by the instantaneous injection potential
- Reduces charge noise during sicence operations

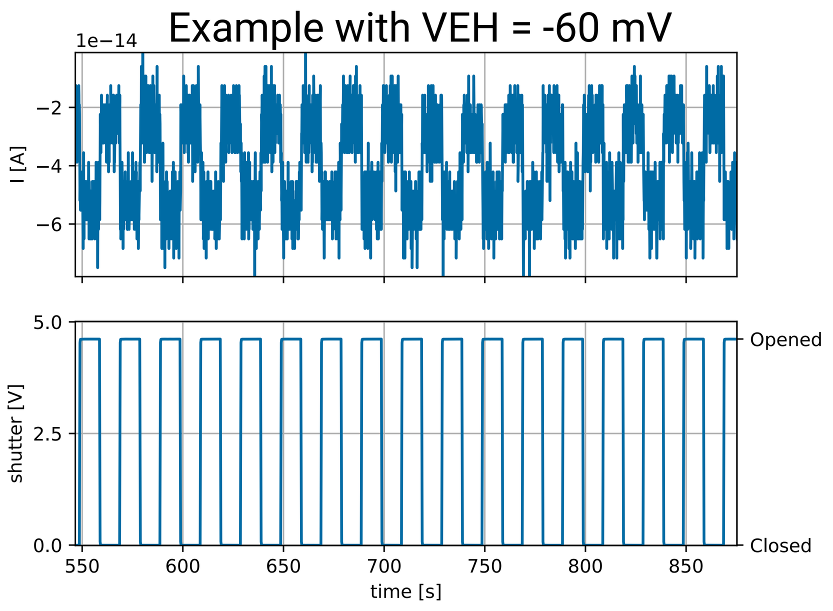
Continuous illumination

- Train of pulses at 100 kHz
- More charges near the TM
- Main Strategy of LPF, kept as backup in LISA

Photo-Current Measurement Facility

The facility core are prototype Test Mass and Electrode Housing of LPF era
All surfaces are Au-coated
The UV light is modulated via an in-fiber shutter so that the source is not perturbed
EH Z face is illuminated

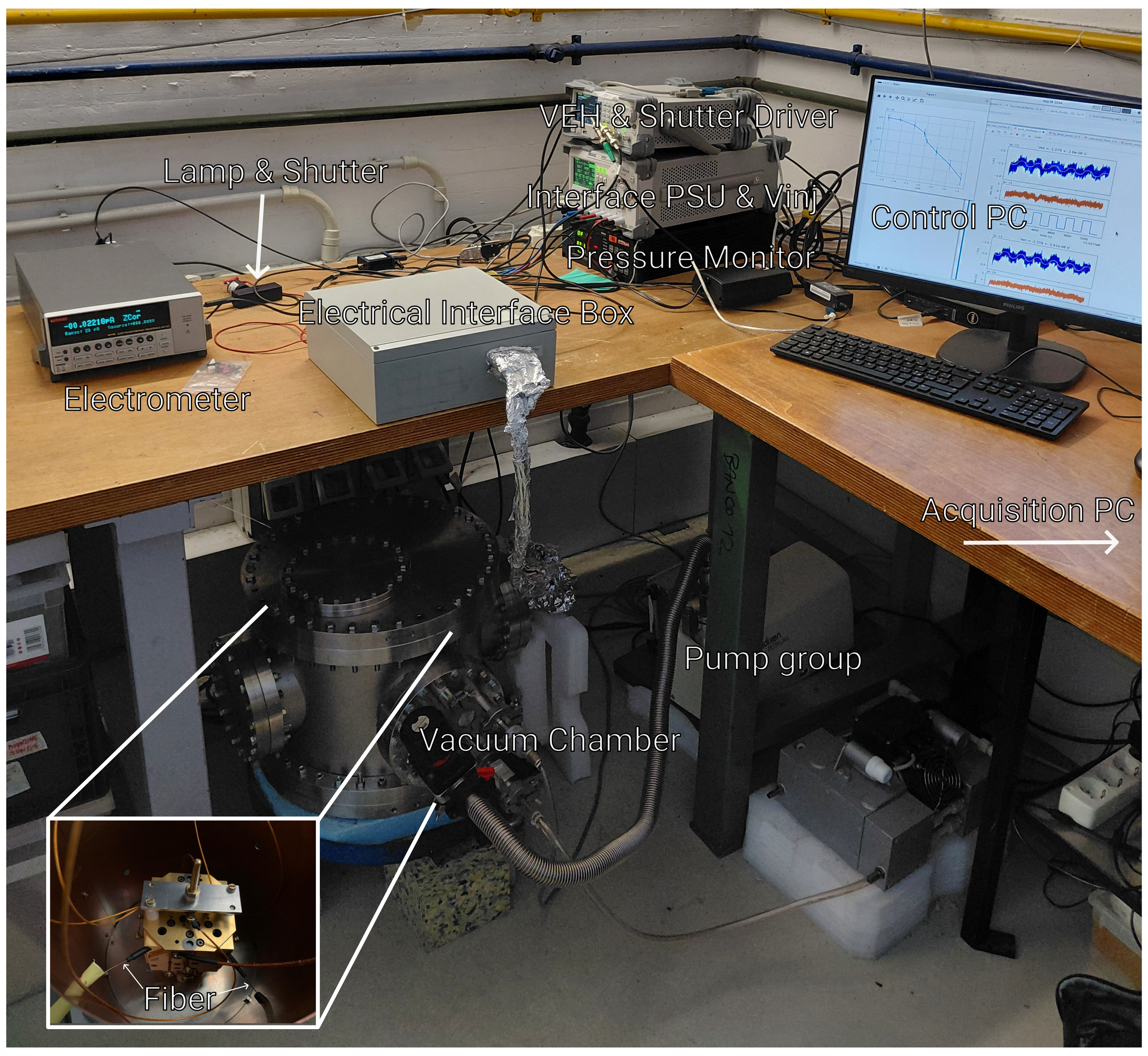
Example with VEH = -60 mV

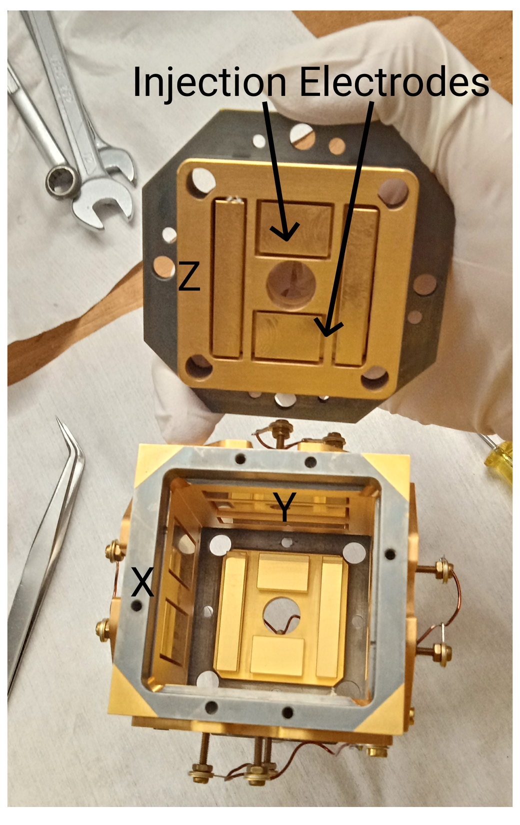


The measurement of current can be converted via known paramters to the surfaces Apparent Yield

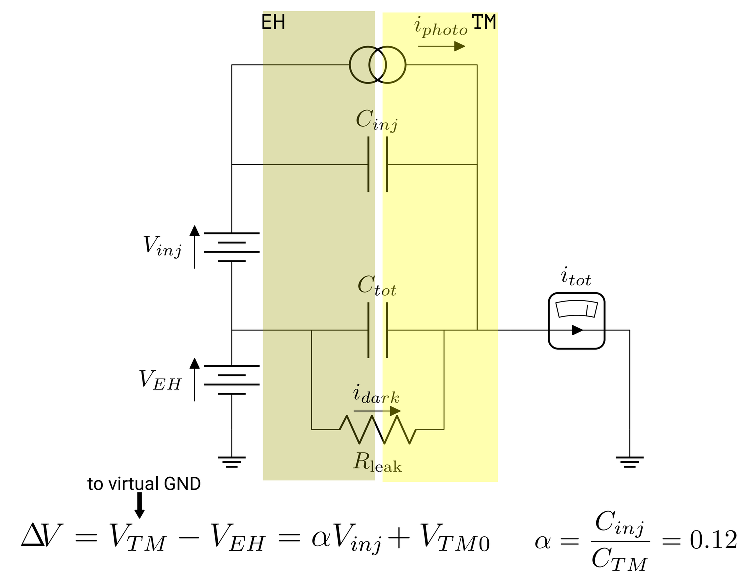
$$Y(\Delta V) = \frac{I(\Delta V)/e}{P_{UV}\lambda_{UV}/hc}$$

Defined as the ratio of emitted electrons against incident photons





Electrical Configuration



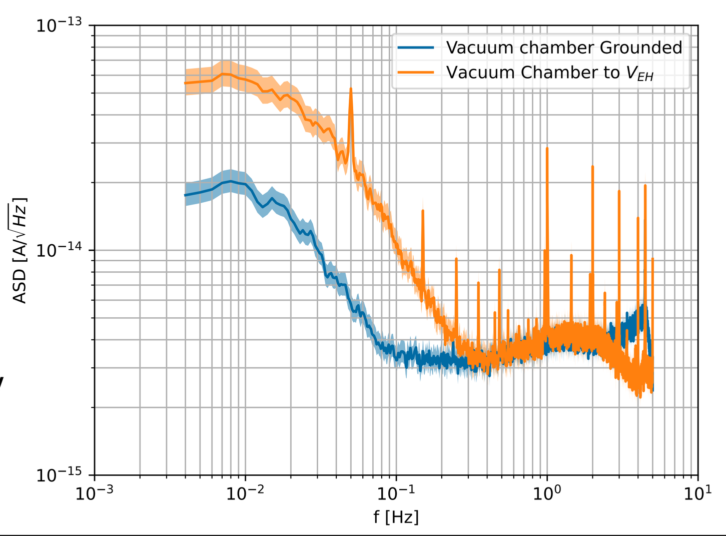
$\Delta V = V_{TM} - V_{EH} = \alpha V_{inj} + V_{TM0}$ $\alpha = \frac{C_{inj}}{C_{TM}} = 0.12$

V_{TM0} emulates the free charge on the TM
V_{EH} sets the istantaneous TM potential
V_{inj} appliyed with respect to V_{EH}

Performance

With a 10 minutes measure
$S_i^{1/2}(50\,\text{mHz}) = 25\,\text{fA}/\sqrt{\text{Hz}}$
↓
$\sigma(50\,\text{mHz}) = 1\,\text{fA}$

The electrometer is set to 10 NPLC integration implying sampling frequency of 1.6 samples/s



Reference for LISA noise, charging and discharging mechanisms and more

LISA RedBook

UV Source

LED from Univeristy of Florida TRL4 CMD
$\lambda_{UV} = 258.87\,\text{nm}$ $HWHM = 5\,\text{nm}$
Power output inside the EH $P_{UV} = 49(1)\,\text{nW}$

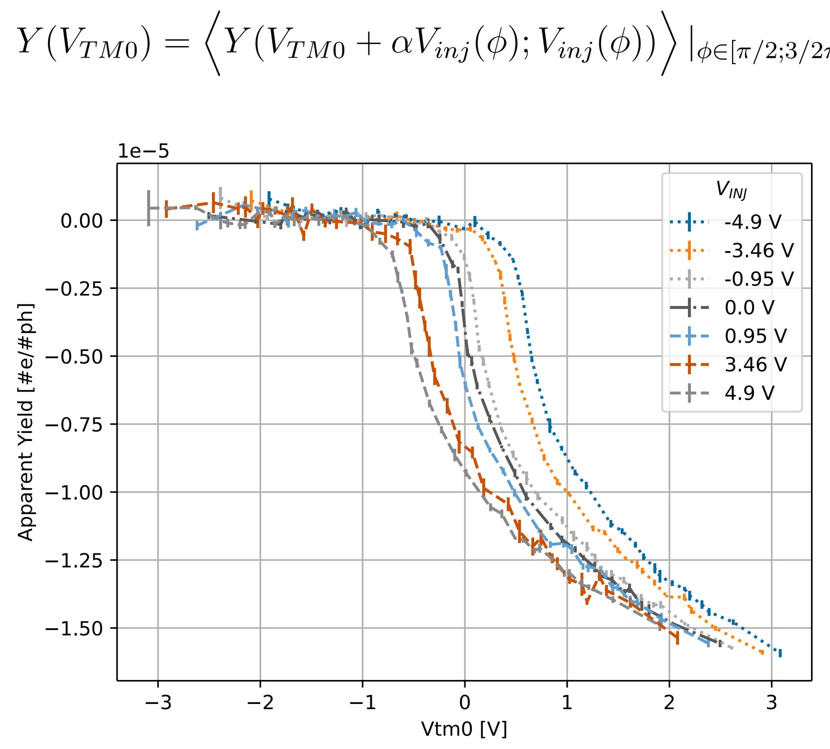
Injection Potential DC emulation

- For a set of V_{inj} measure a discharge curve
- Makes the local DC fields as $V_{TM0} + \alpha V_{inj}$
- Measure feasible on EM,QM and FM of LISA
- For the complete set
  $17\#V_{inj} \times 40\#V_{EH} \times 100s \times 6\,cycles \approx 4\,days$
- Directly measures Pulsed Illumination Yield

$$Y(-V_{EH}) = Y(V_{TM0} + \alpha V_{inj}; V_{inj}) = Y(V_{TM0} + \alpha V_{inj}(\delta\phi); V_{inj}(\delta\phi))$$

- Continuous Illumination Yield estimated as average

$$Y(V_{TM0}) = \left\langle Y(V_{TM0} + \alpha V_{inj}(\phi); V_{inj}(\phi))\right\rangle|_{\phi\in[\pi/2;3/2\pi]}$$



Yield pumping time dependency

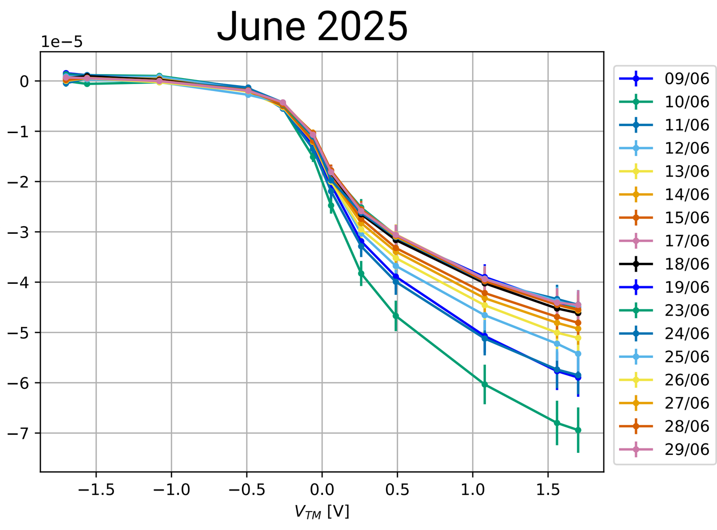
From LISA Pathfinder era Yield changes over time were observed by P. Wass et al. on a span of 14 days after putting Au-Coated samples in vacuum

Ref. Peter J. Wass et al.; Effective decrease of photoelectric emission threshold from gold plated surfaces; Review of Scientific Instruments (06 2019) vol. 90(6) p. 064,501; ISSN 0034-6748;

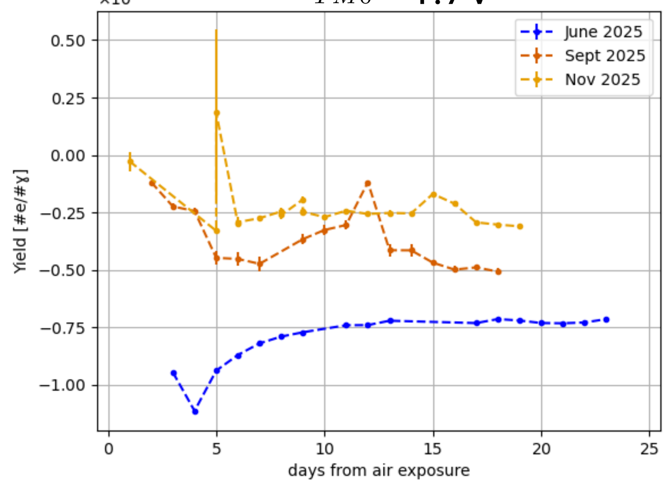
More investigation on this topic is needed:

- Preference for reducing yield upon first days of pumping?
- No specific clean atmosphere was used in the measurements at Trento
- Consistent time of stabilization of Yield around 20 days in two different runs

June 2025

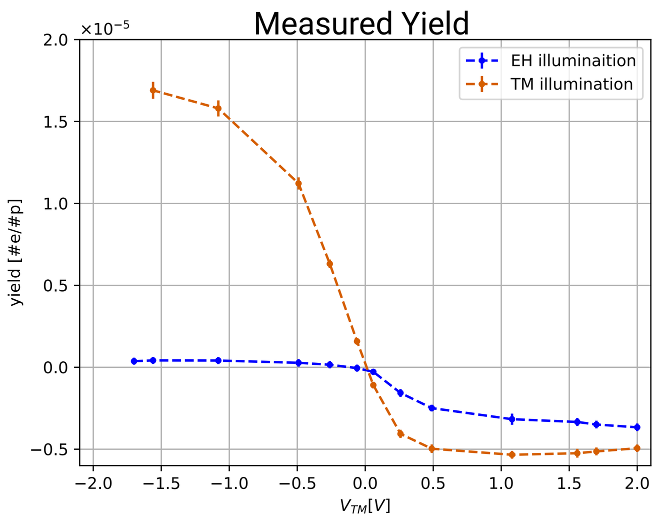


V_{TM0} = 1.7V



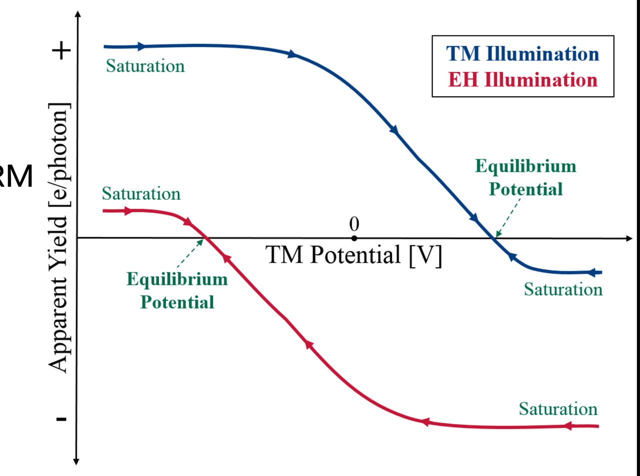
TM and EH illumination Yields

Measured Yield

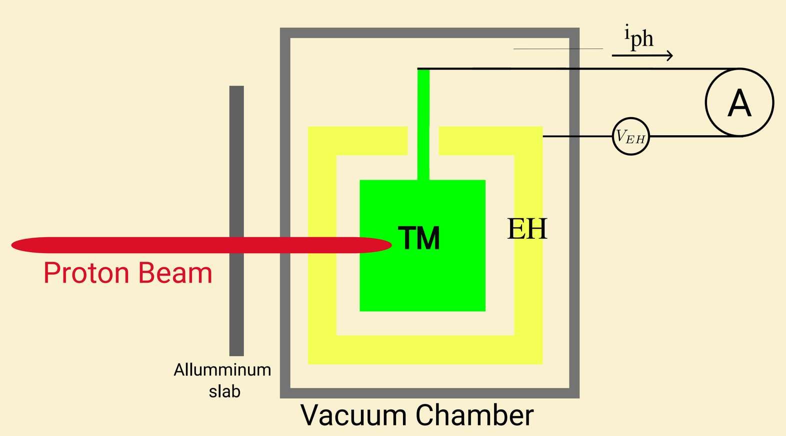


Imbalance most likely due to GPRM holes not closed and light emitter mmanual spositioning

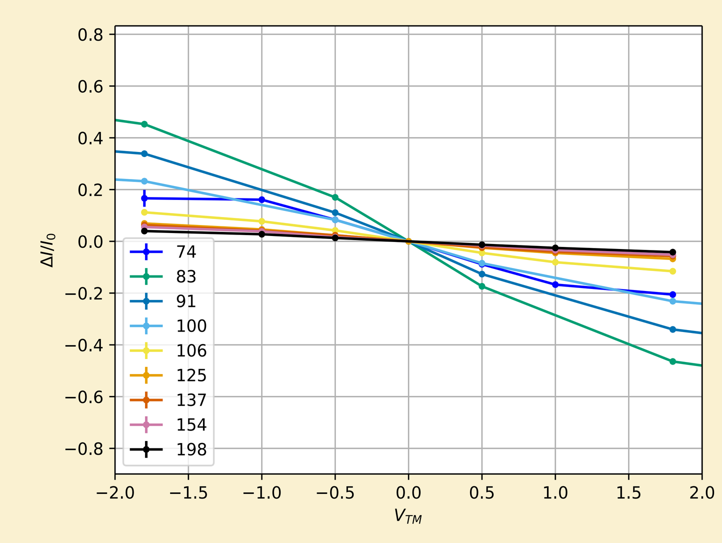
Typical Yield



BART
Beam Assisted Radiation Test



Twin facility used to directly measure the effect of secondary electrons during a SEP, simulated by a single energy proton-beam in the range 70-228 MeV



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