Sensor R&D for the stable operation of the LZ detector

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Introduction

- LZ is a next generation liquid xenon (LXe) dark matter detector
- Highly sensitive detector
  - pushing down towards the level of 10^{-48} cm^2
- Monolithic design and volume brings about challenges
  - Issues with delivery and stability of HV - see A. Tomas
  - Precision monitoring of all detector parameters required
    - Temperature, liquid level, pressure… etc

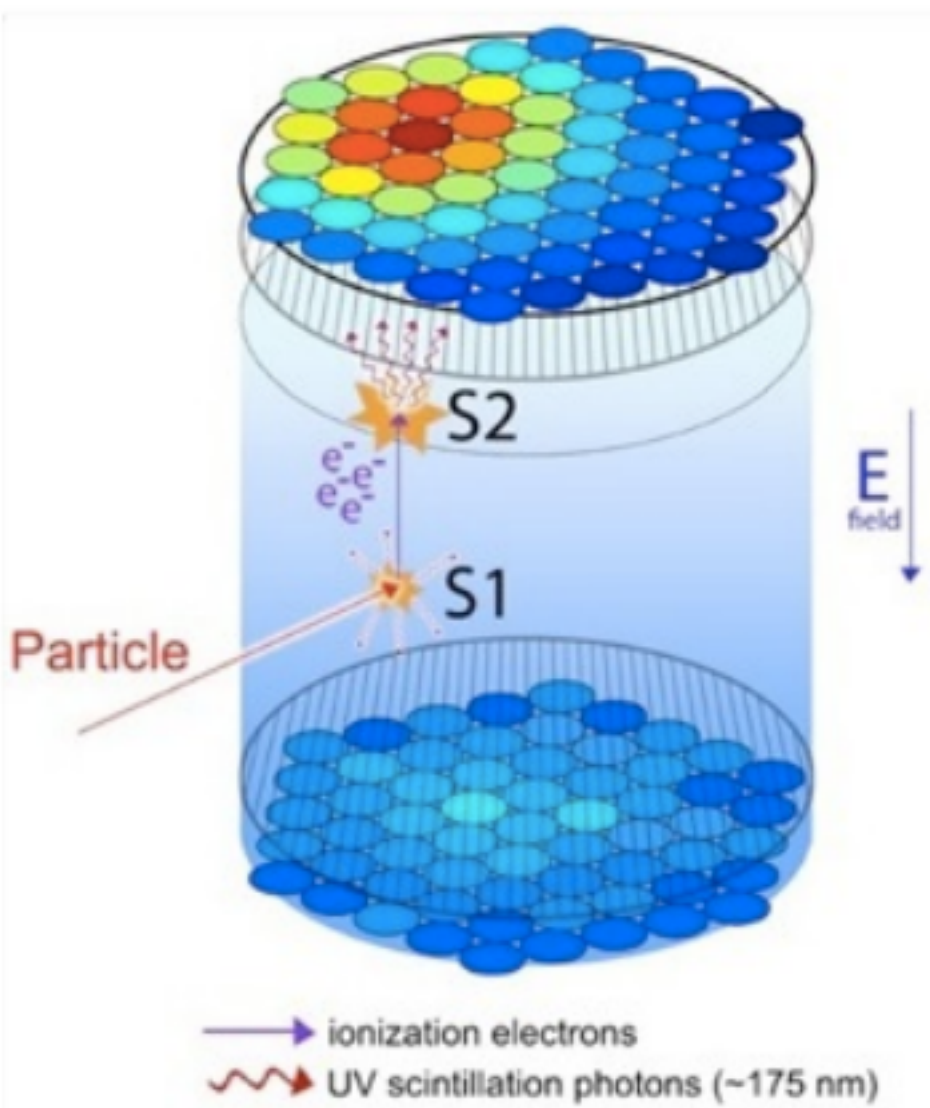
Introduction

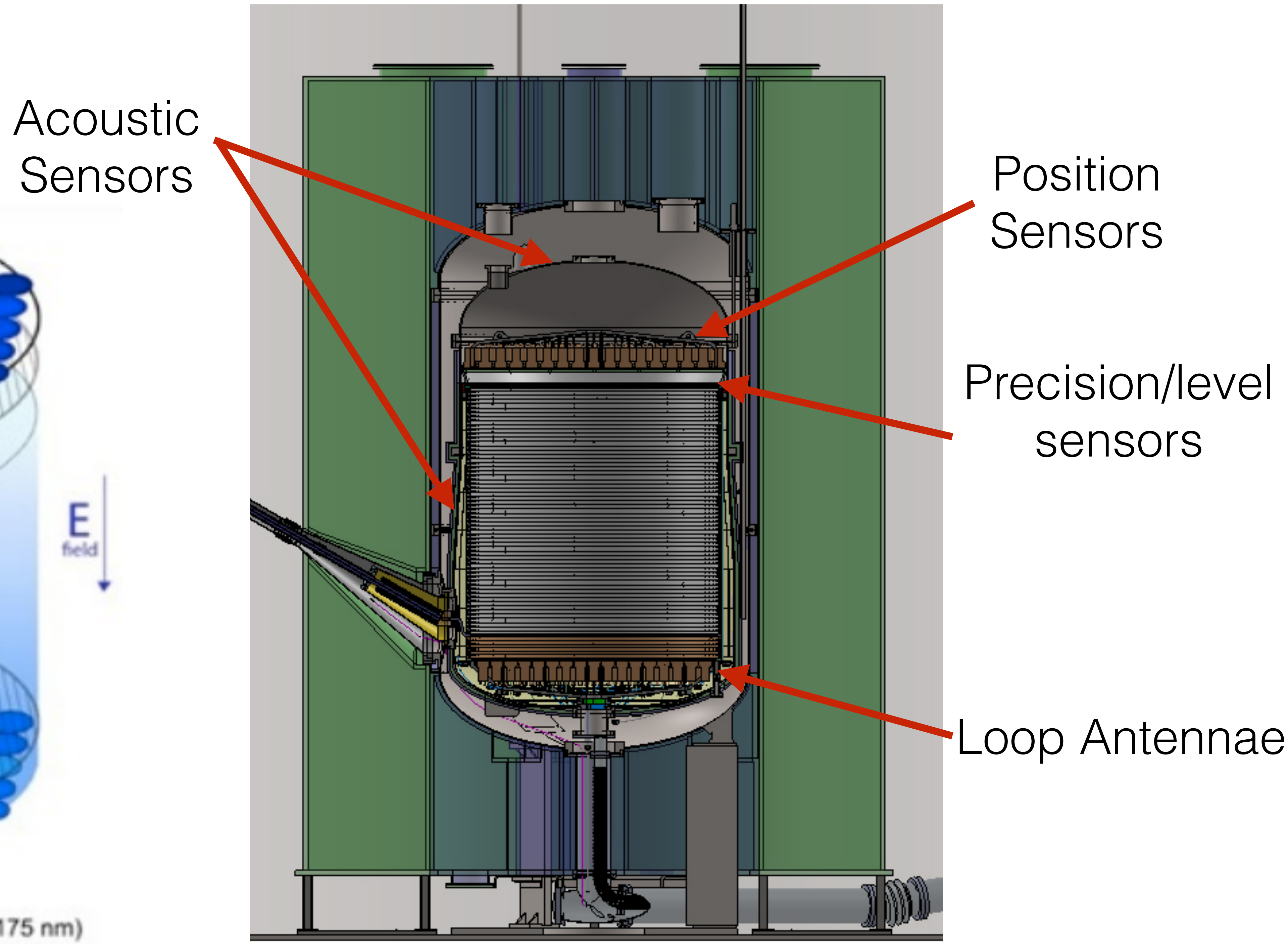
- R&D at Oxford to monitor these parameters
  - Act as feedback to the control systems
  - Protect systems that can't be replaced
  - Use information to correct data
- All sensors must conform to stringent radio-purity requirements
  - Within xenon volume - radon out-gassing of particular importance
  - Minimise use of “commercial” sensors

The Sensors

- Position sensor - measures shrinking/warping of TPC
- Level sensors - measure liquid level/surface stability
- Acoustic sensors - detect bubbles breaking surface
- Loop antennae - detect electronic discharges

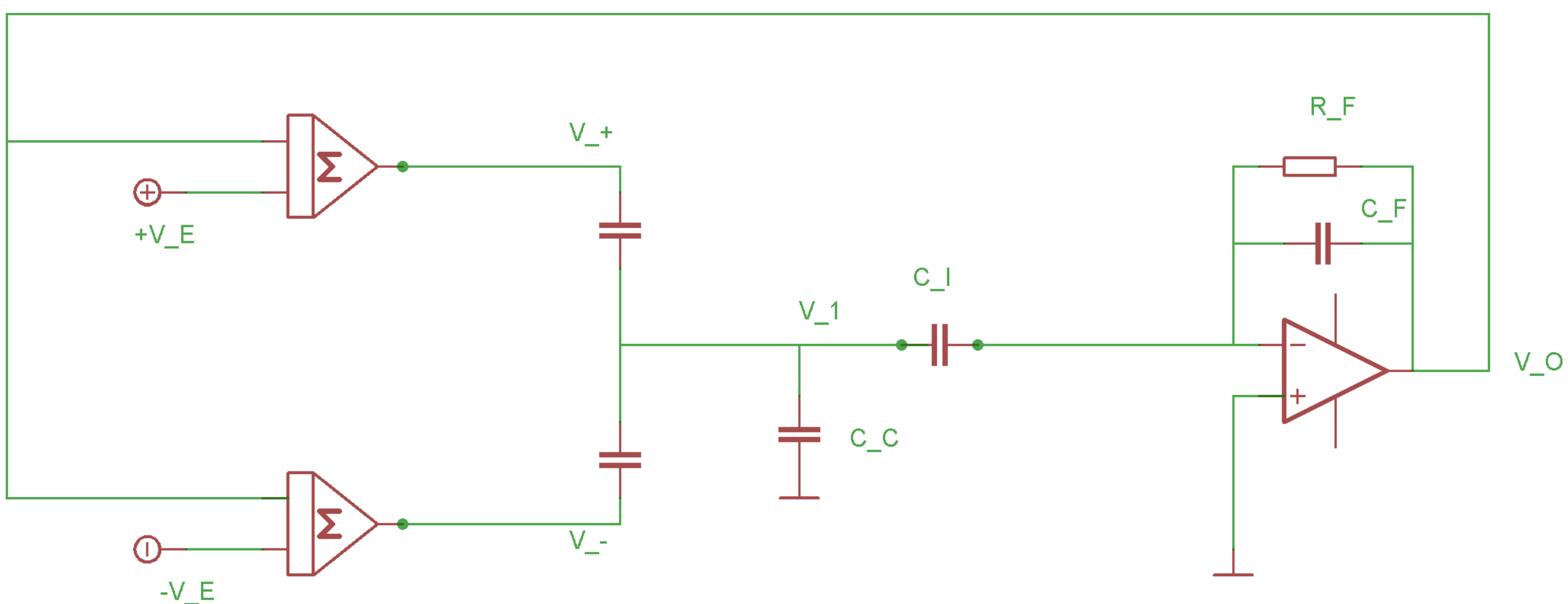
Monitoring TPC Stability

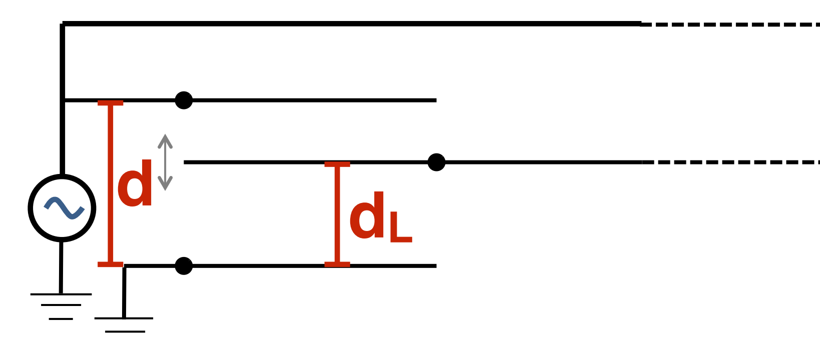




Electronics

- Single electronics solution for all **capacitive** sensors
  - Position and level

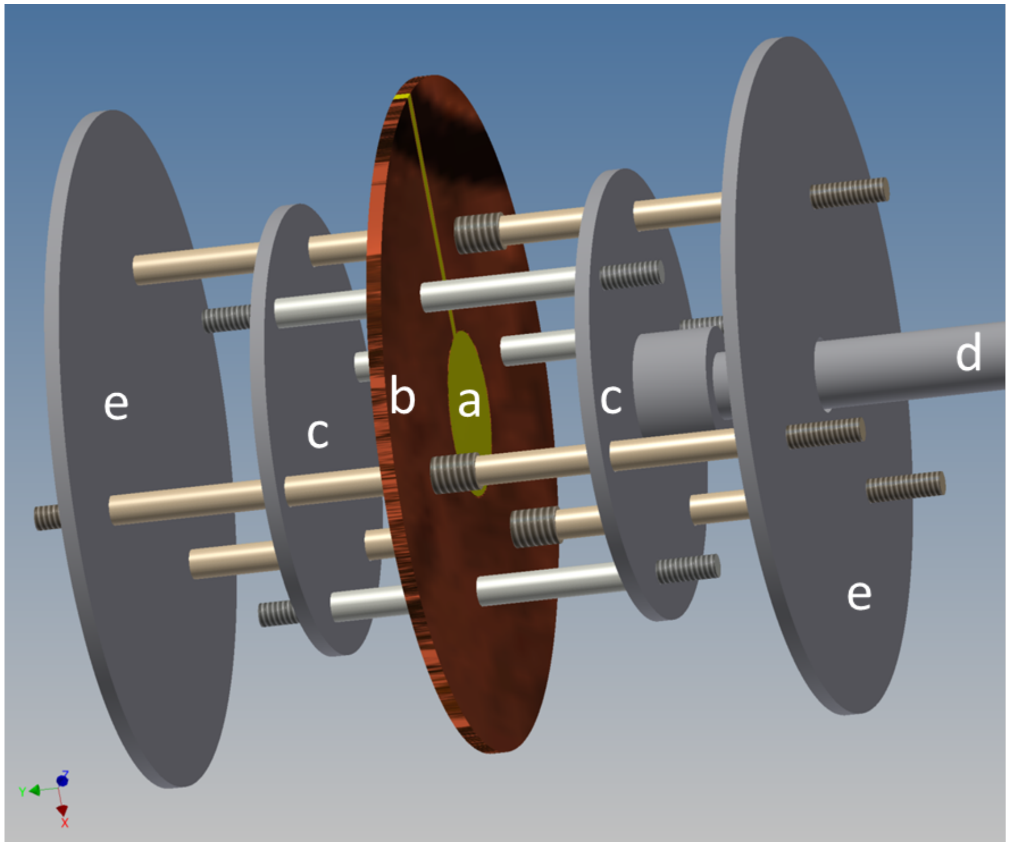




$$V_O = \frac{(C_L - C_U)}{(C_L + C_U)\left(1 + \frac{C_F}{C_I}\right) + C_F(1 + \frac{C_C}{C_I})} V_E \quad \Rightarrow \quad V_O = \frac{(d - 2d_L)}{d + \frac{C_F}{\varepsilon_0 A}(d - d_L)d_L} V_E$$

Monitoring TPC stability

- TPC constructed using PTFE with titanium field shaping rings.
    - During cool down, thermal expansion coefficient of PTFE means it will shrink
- Precision sensors used to monitor and shrinking and warping
    - Allows corrections to be made to e.g. PMT map



Key:

a. Sensing electrode

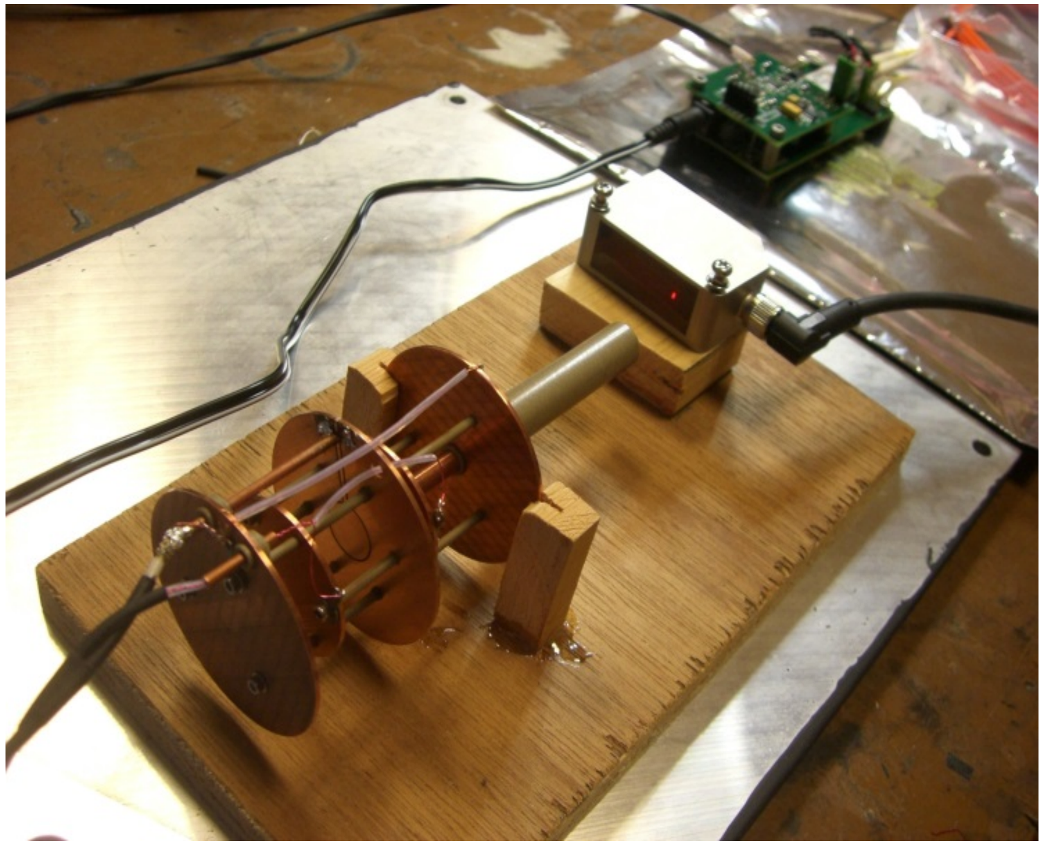
b. Guard electrode

c. Plates carrying excitations

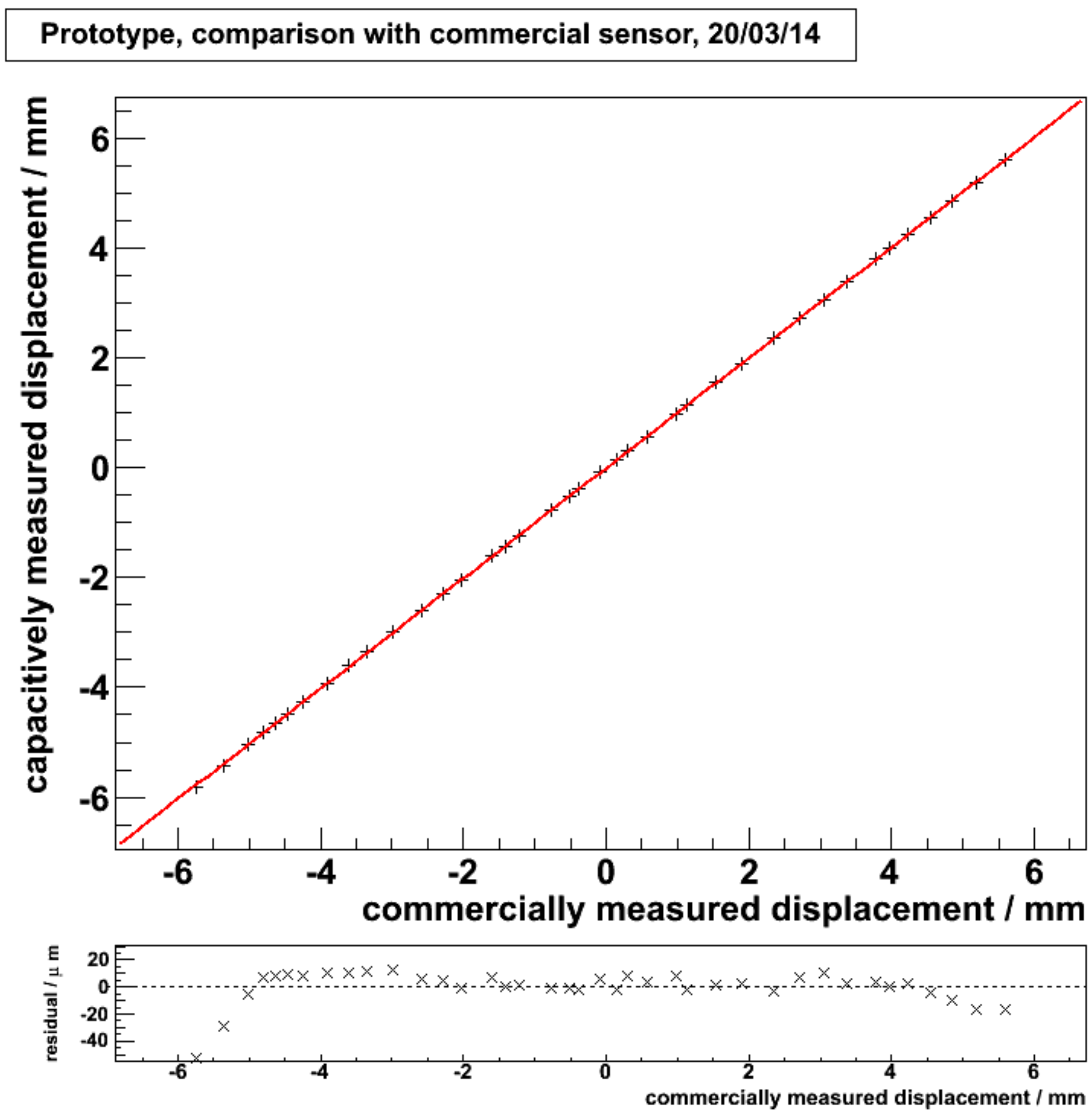
d. Plunger to move excitation plates

e. Grounded guard plates to minimise stray fields

f. Struts to hold the three large plates apart



Initial tests

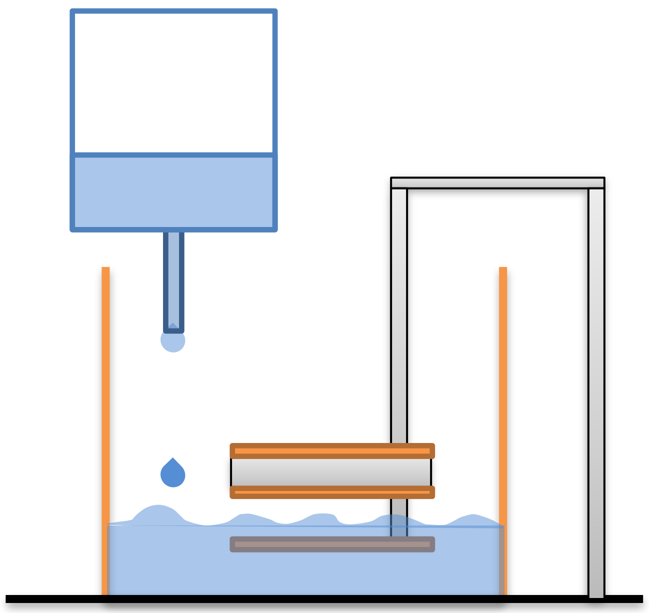


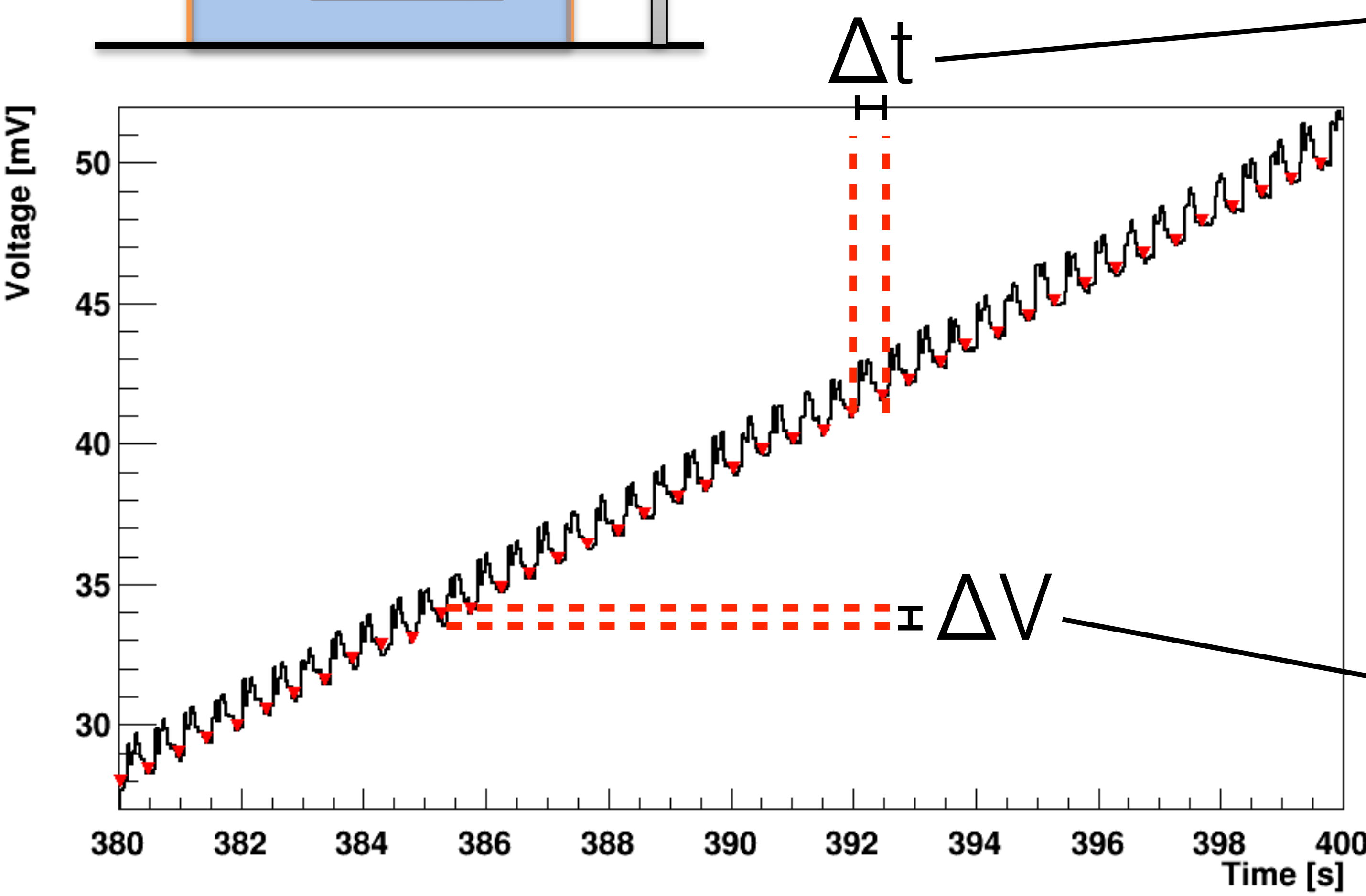
- Good agreement between commercial and constructed sensors
- Remaining residual shows a small systematic
- Already to within ~20 um over 12 mm ~ 1:600
- LZ movement expected to be ~1-2 cm

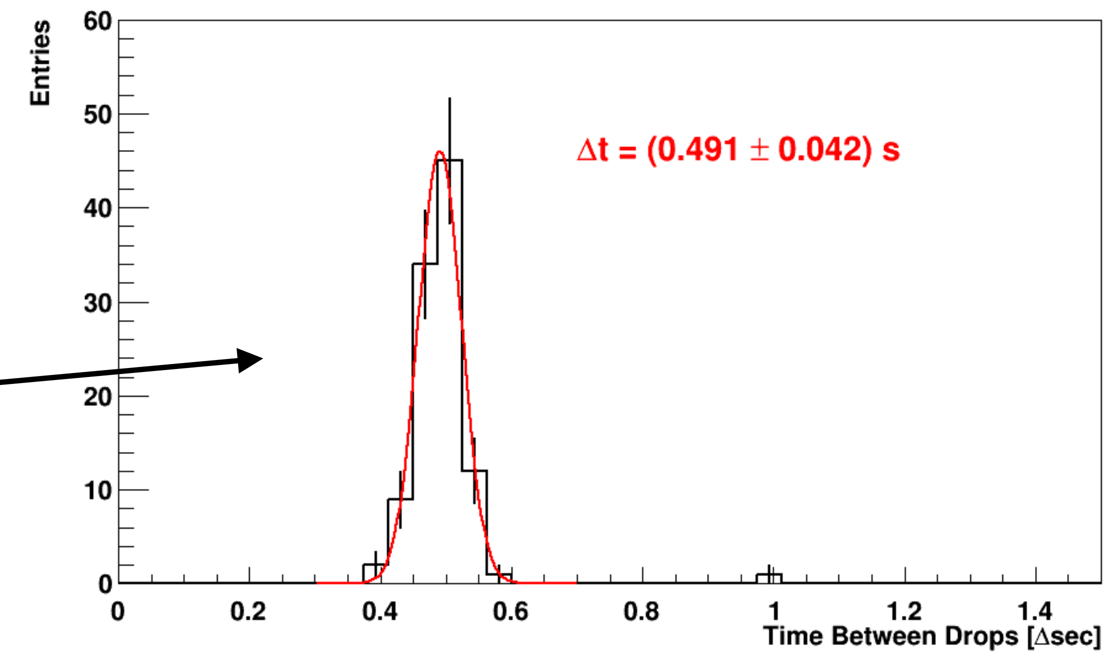
Monitoring liquid level

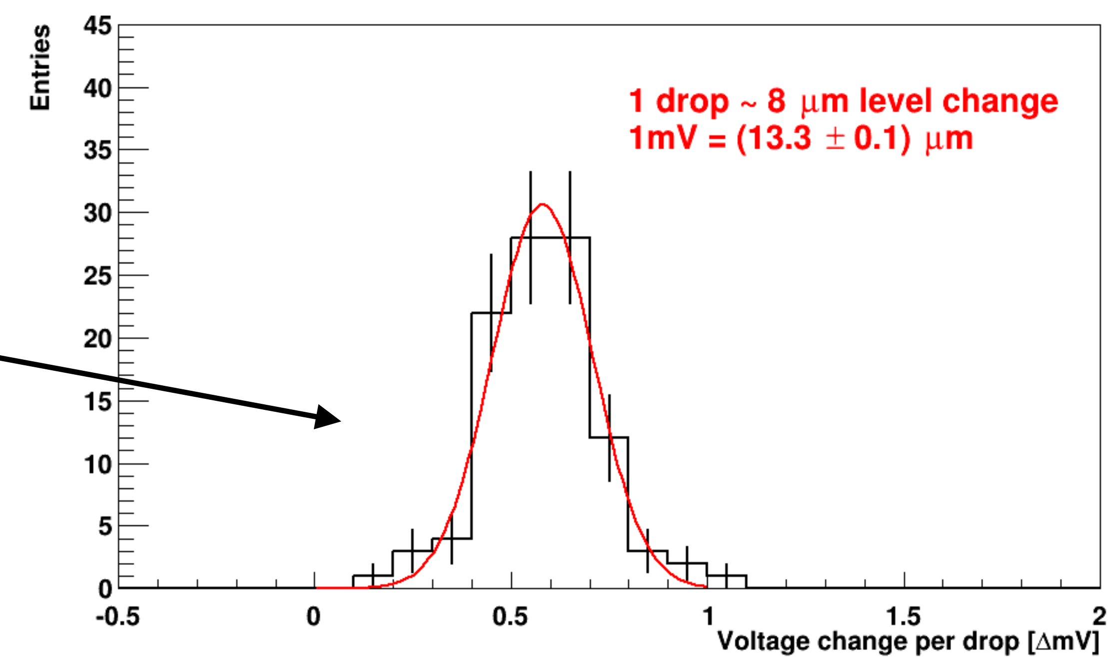
- As with the position sensor - uses parallel plate measurement
- Liquid level between plates determines measured capacitance
- Fast digitiser used to monitor for fluctuations due to ripples
- Initial test using oil - to test electronics response
- Dielectric constant 2.0 - good analogue for xenon (1.8)

Precision Sensor tests

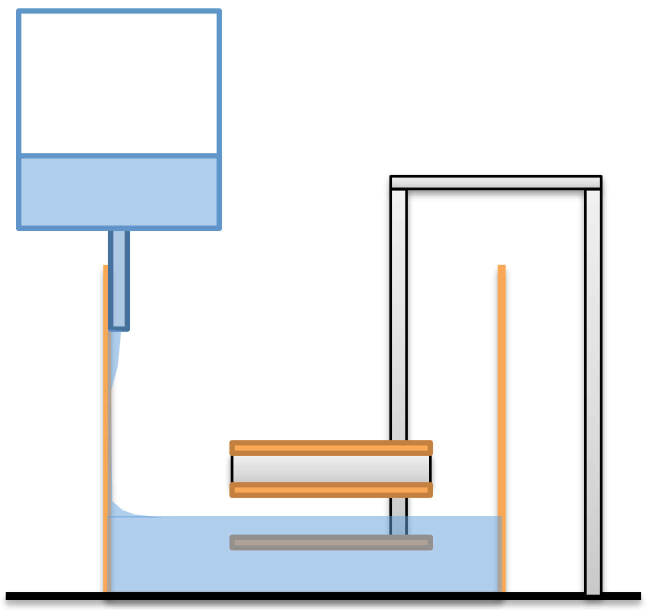


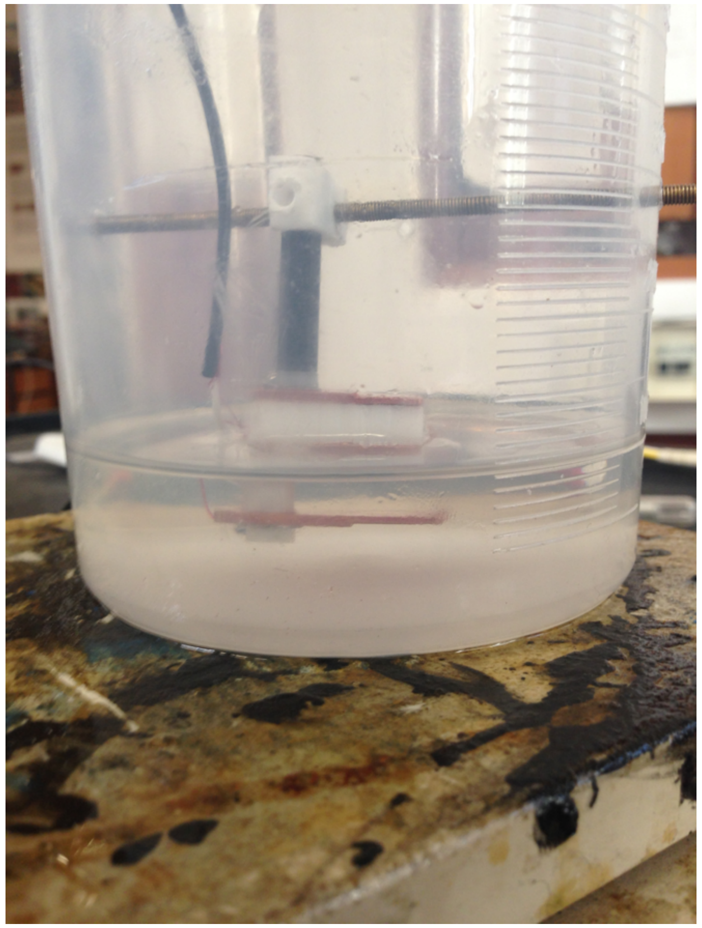






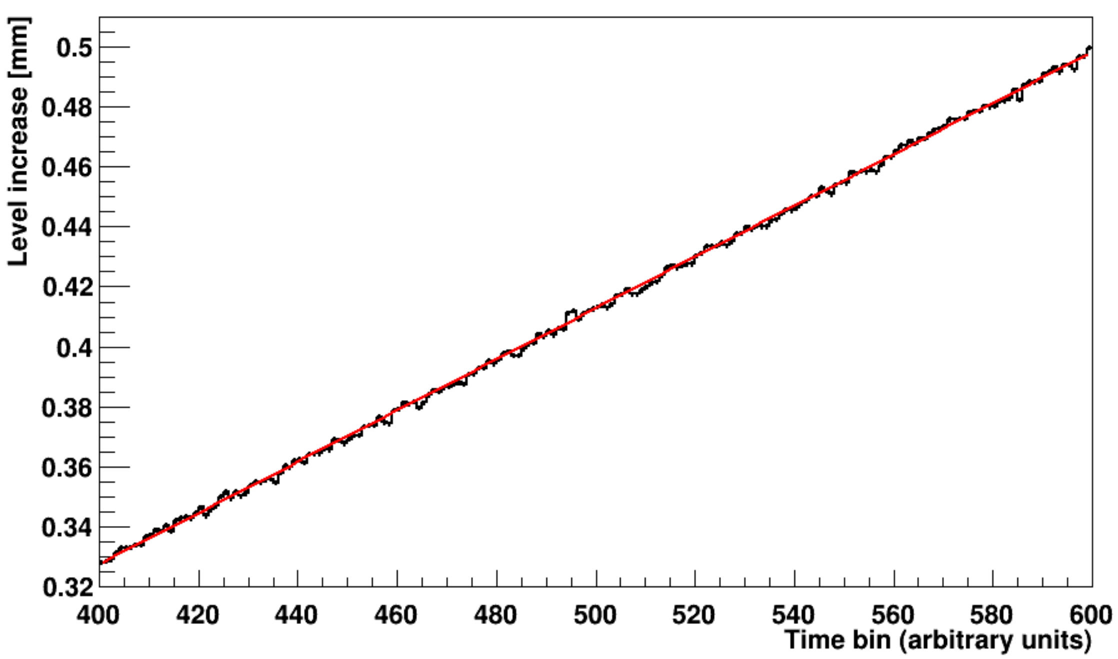
Continuous Fill

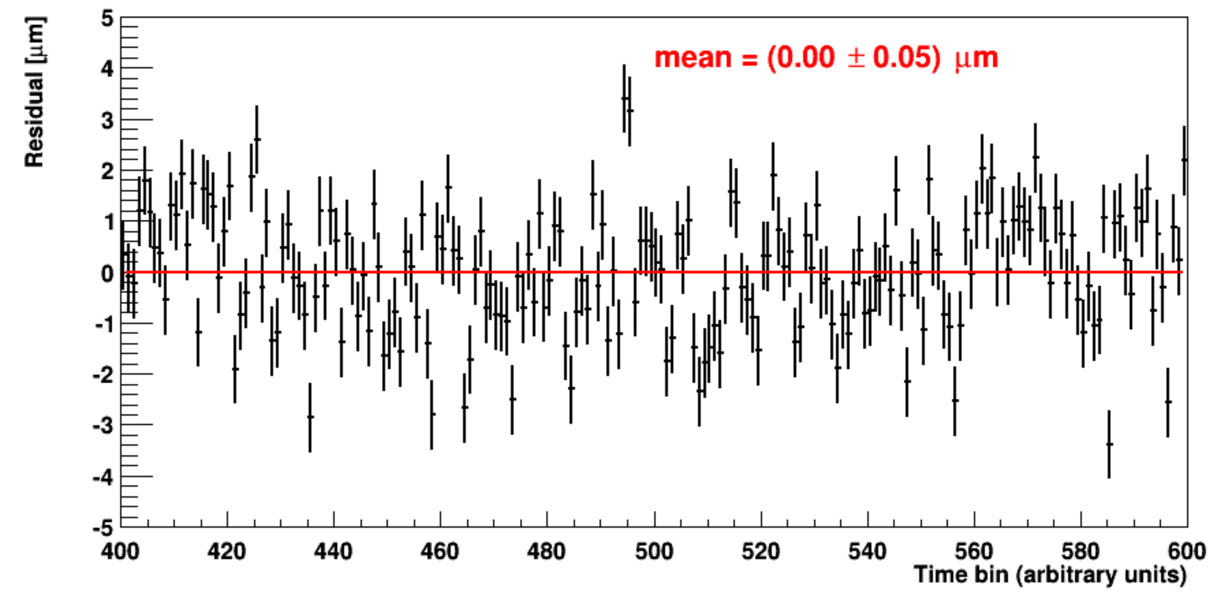


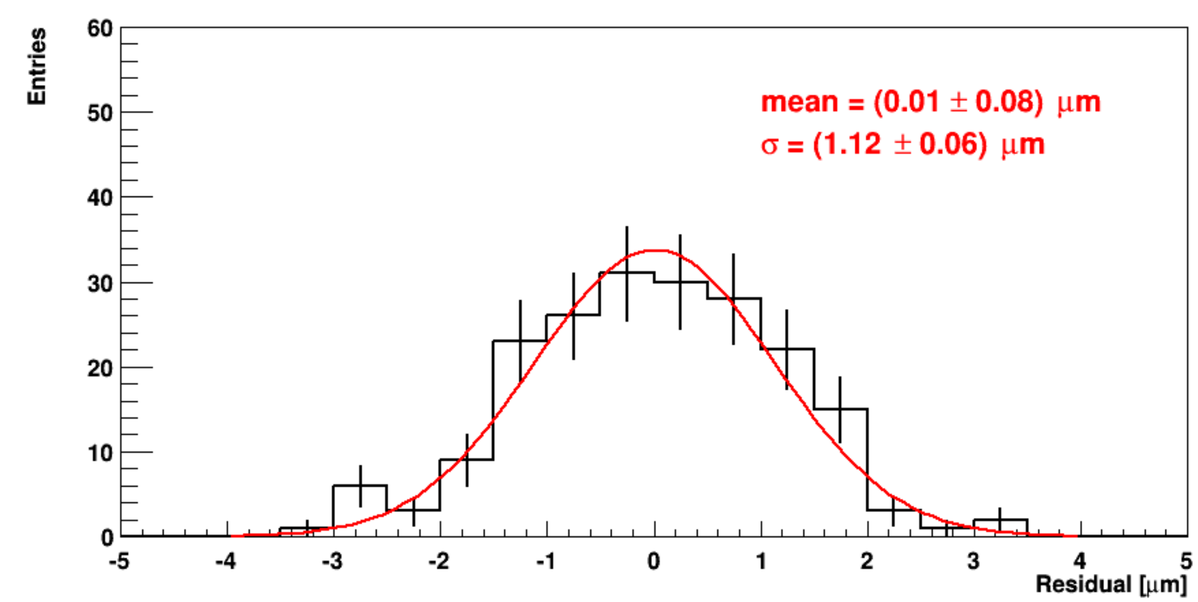


- Level increase calculated using previous relationship
  - Full scale consistent with 5mm plate separation

Continuous Fill



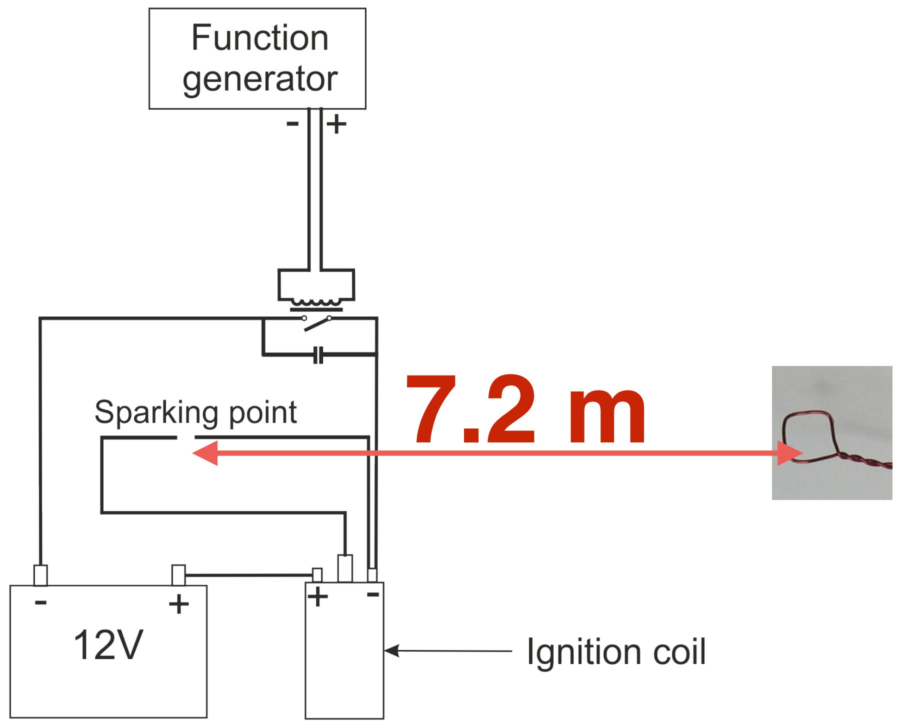


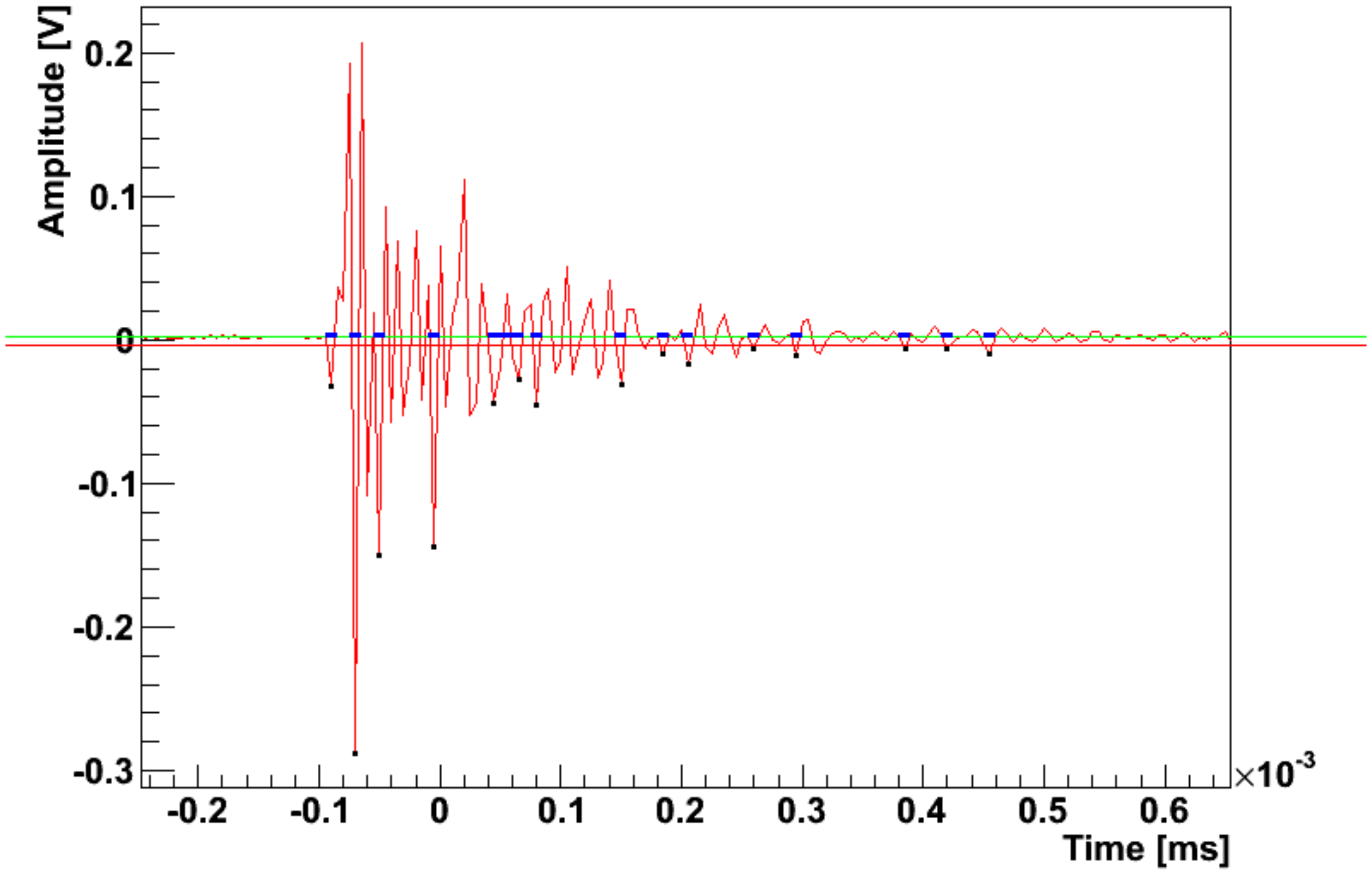


- Mean consistent with 0
- Data symmetrical around mean
- $\sigma = 1.1\ \mu m$
- Similar sensitivity across full 5mm range

Loop Antennae

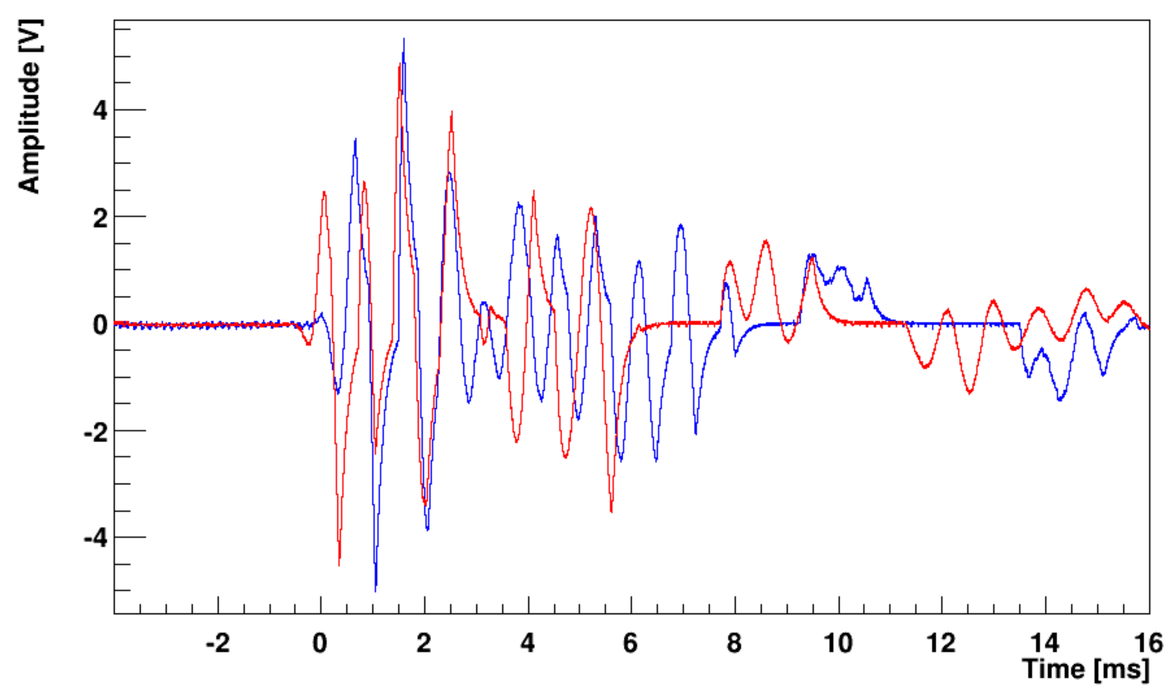
- Loop antennae to detect discharging in the TPC
  - Act as failsafe to protect internals from damage
  - Act as veto for dark matter run





Acoustic Sensors

- "Listen" for bubbles breaking the LXe surface
    - Complement the measurement of liquid surface stability
    - Speed of sound in LXe may allow some triangulation
    - Use low-background components - PVDF Piezoelectric film



Conclusions

- Highly precise monitoring of conditions within detector is essential
- Oxford R&D is investigating how to achieve this
- Prototypes have been constructed and tested
    - Very encouraging results
- R&D not limited to the sensors discussed
    - Also plans for internal camera and LXe recirculation flow rate monitoring
- Integration with LZ prototype setups planned