Development and Qualification of a Fiber Optic Sensor Package for ITk Environmental Monitoring

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OUTLINE

- **MOTIVATION**
- **THEORY, ANALYSIS AND RESULTS**
- **CONCLUSION AND FUTURE WORKS**
- **BACKUP**

MOTIVATION

ATLAS Inner Tracker (ITk) upgrade at High Luminosity LHC for mid 2030 commissioning:

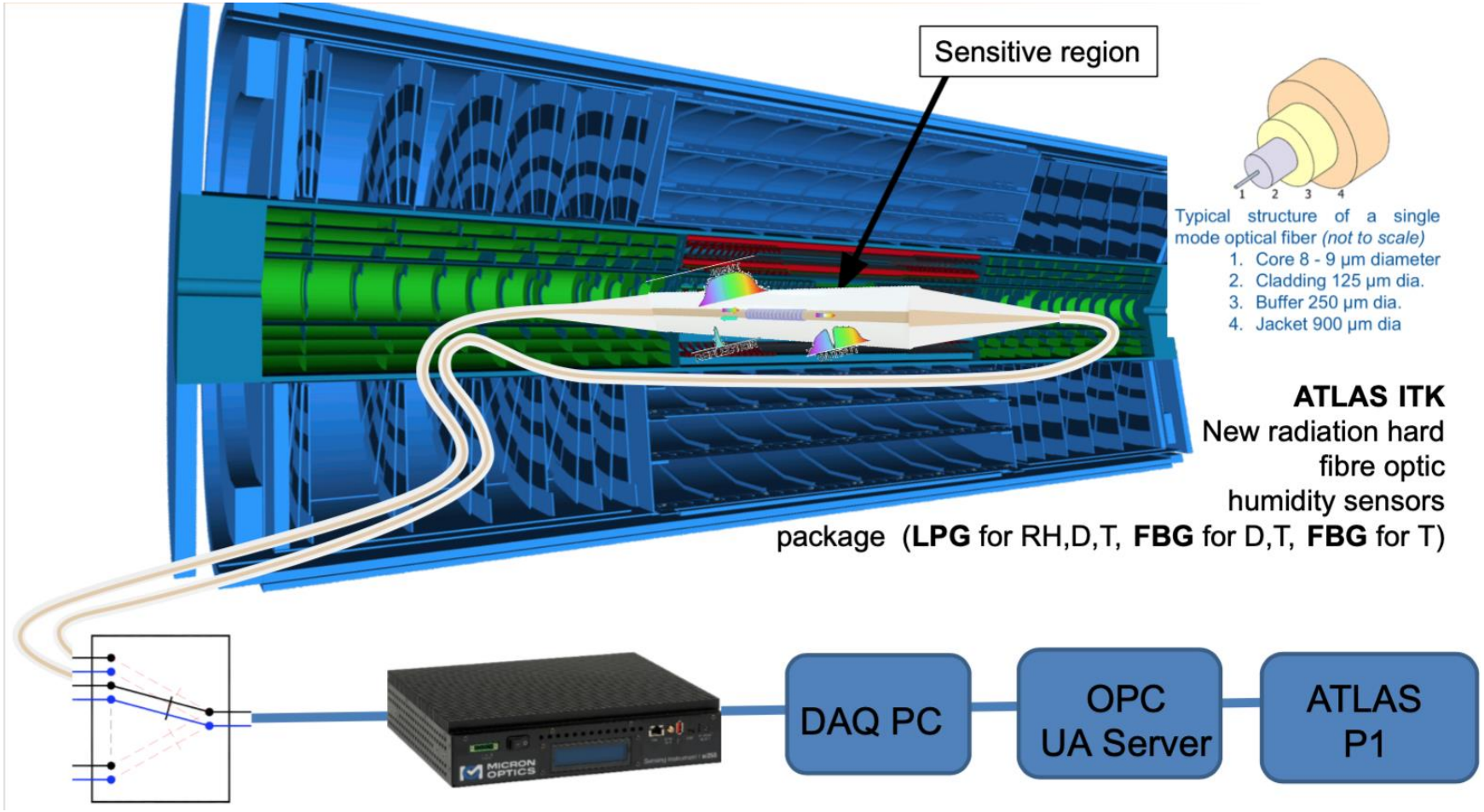
- Water condensation damages expensive detector electronics.
  - Humidity and temperature must be monitored to assess DewPoint temperature
  - Sensors must survive harsh conditions: **high radiation, low temperature & low humidity (<10%)**

Parameter	Value
Accuracy	$\varepsilon_{RH} < 3.5\%$ (between 0 and 10% RH) $\varepsilon_{RH} < 10\%$ (above 10% RH)
Precision	$\sigma_{RH} < 1.7\ \%$ (between 0 and 10% RH), $\sigma_{RH} < 5\ \%$ (above 10% RH)

Motivation

- **Solution:** Fiber Optic Sensors (FOS) technology based on Long Period Grating (LPG) and Fiber Bragg Grating (FBG) have been combined to provide a remarkable sensing device.
  - Requires extensive sensor R&D with tests under irradiation.
  - Software development in data acquisition (DAQ).
- Presented is the QA/QC done on FOS package at 25^{o} C.
  - Preliminary checks on the T-sensitive FBGs in comparison to a T reference sensor.
  - Analyses on the Pre-Irradiation, Irradiation, and Post-Irradiation.
  - Investigation on the T-sensitive FBGs with the LPG/reference sensor readouts as the baseline.

ATLAS ITk LAYOUT

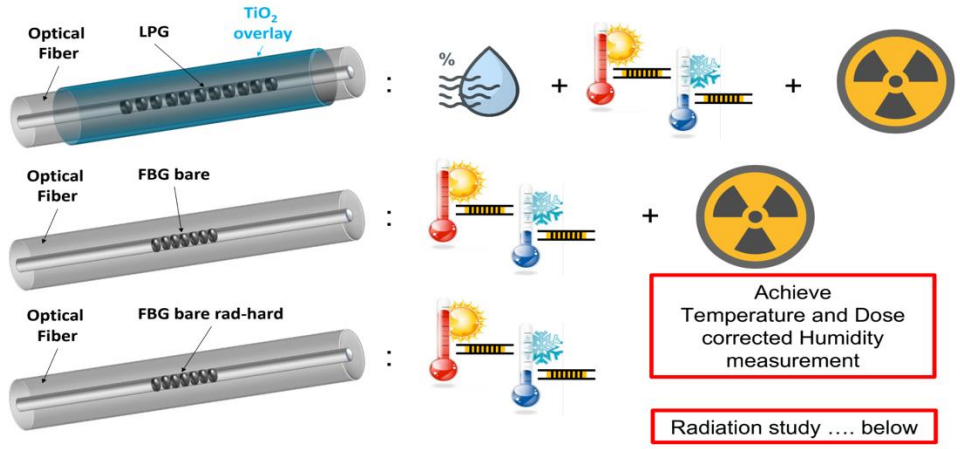


THEORY, ANALYSIS AND RESULTS

FOS sensing method

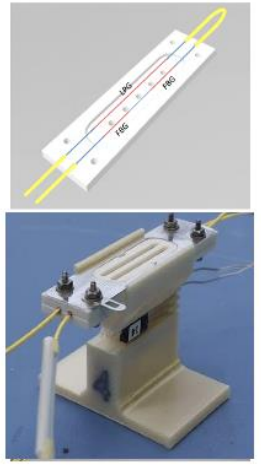
A FOS package with three sensors allows us to measure:

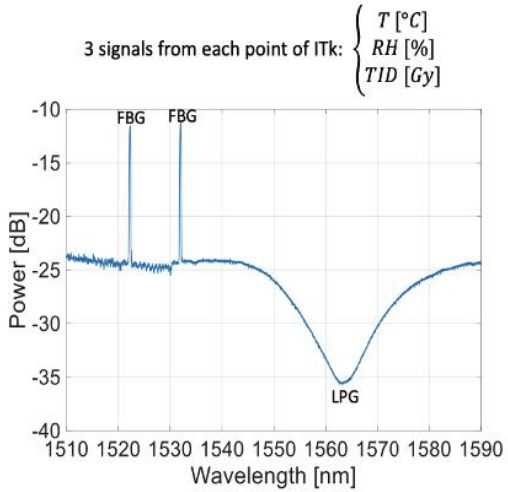
- Relative Humidity (RH)
- Temperature
- Radiation dose



Final Product

- **Neo-ceram** housing.
- Integrated Pt10k + HIH sensors.
- **Pcb** grounding solution.
- PEEK wire used to connect commercial sensors.



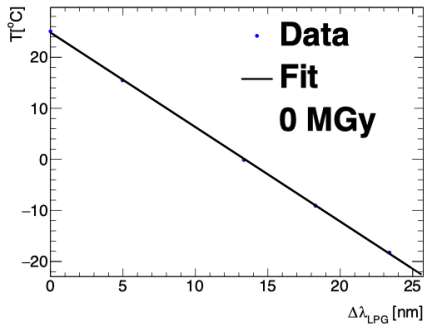


FOS Calibration: T and RH

For T and RH calibration, the custom-built climatic chamber conditions are measured.

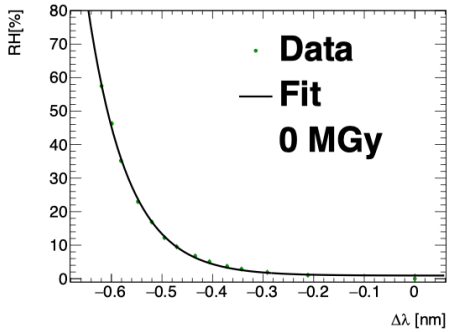
- FOS calibrated against standard commercial sensors.
  - Pt10k for temperature.

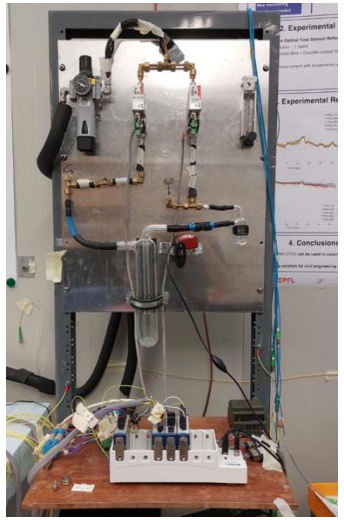
$$(t,\ \lambda_{\mathrm{FOS}})\ \&\ (t,\ T_{\mathrm{pt10k}}) \longrightarrow (T,\ \lambda_{\mathrm{FOS}})$$



  - HIH for RH.

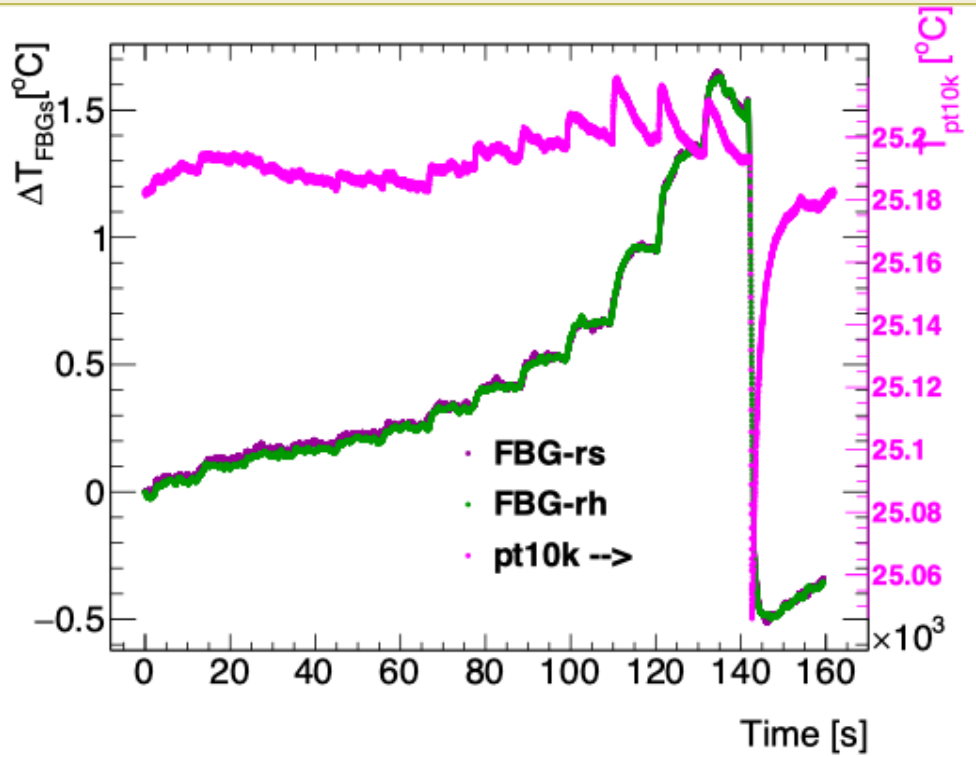
$$(t,\ \lambda_{\mathrm{FOS}})\ \&\ (t,\ \mathrm{RH}_{\mathrm{HIH}}) \longrightarrow (\mathrm{RH},\ \lambda_{\mathrm{FOS}})$$

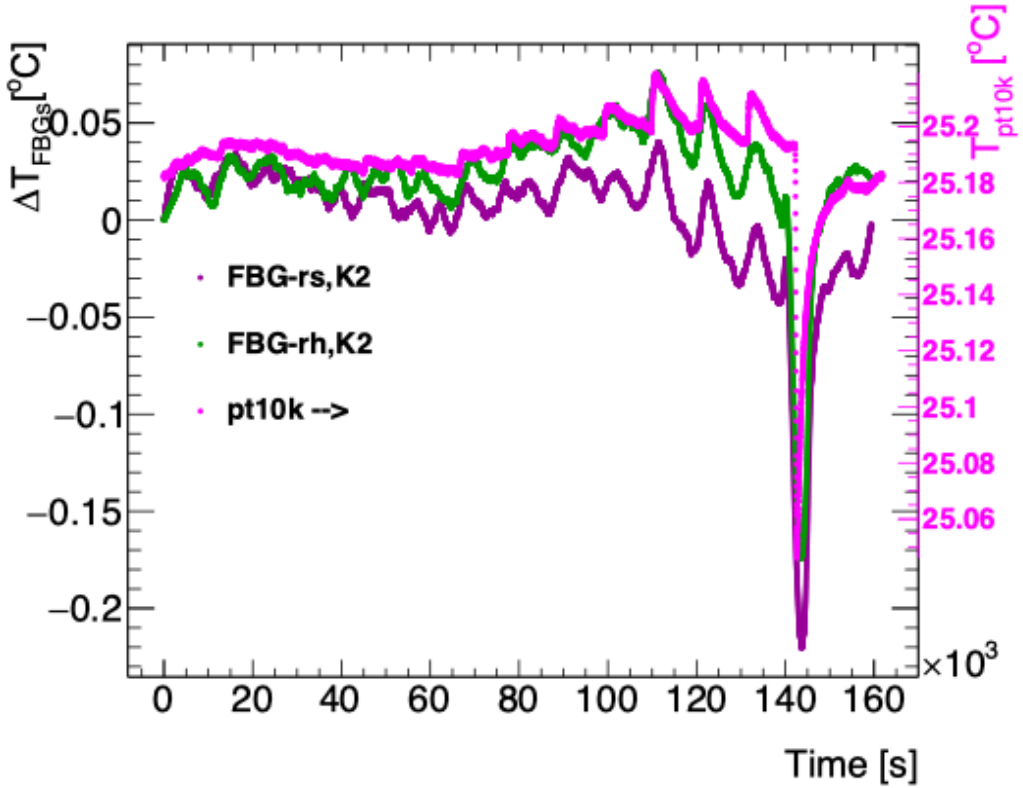




Climatic chamber setup used to calibrate fiber optic sensors

Investigation on T response: FBGs vs. pt10k





Left: FBGs in the FOS package used in this analysis.

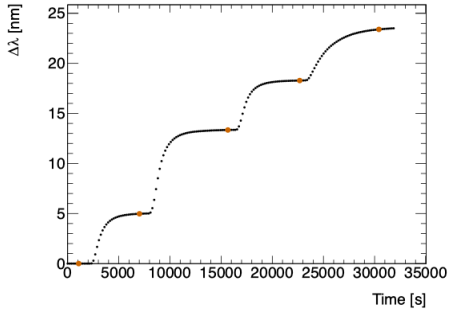
Right: FBGs in another companion FOS package with the same pt10k.

Due to the discrepancy, the ever-available pt10k temperature measurement was used in this analysis.

Characterization: T and RH on the LPG

The set-up is used to regulate the T and RH to determine their thermo-hygrometric response.

- T characterization:
  - RH = constant,
  - T = varied by steps



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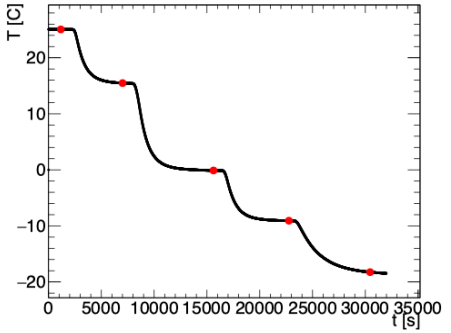
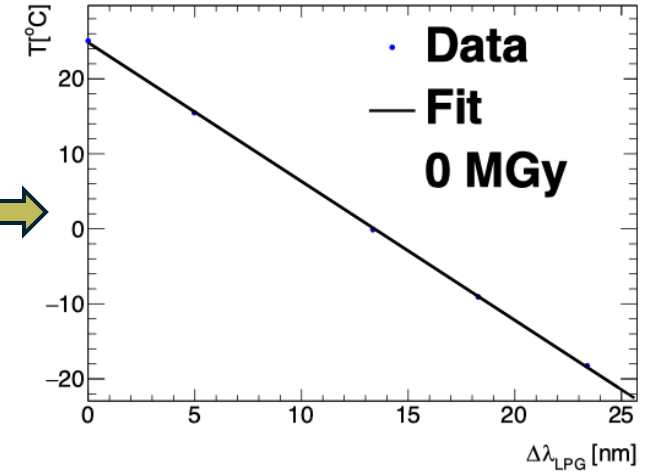
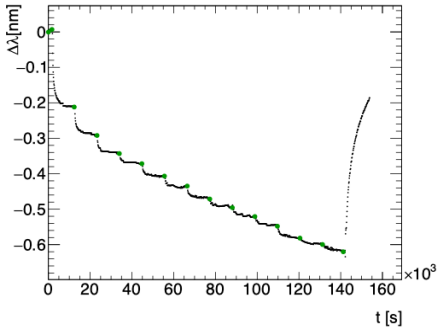




- RH characterization:
  - T = constant,
  - RH = varied by steps



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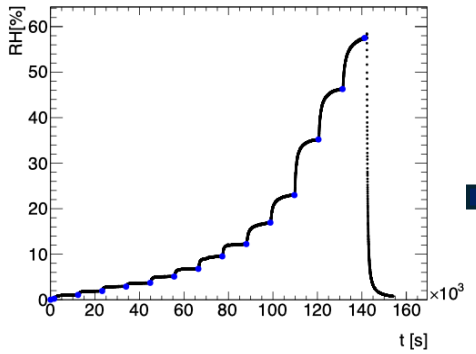
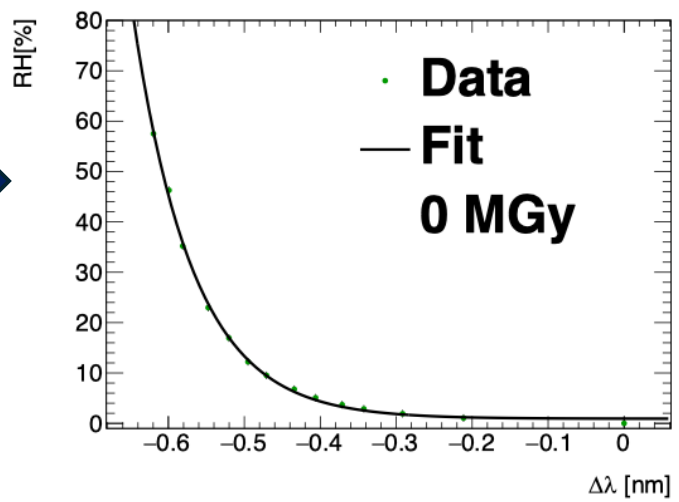


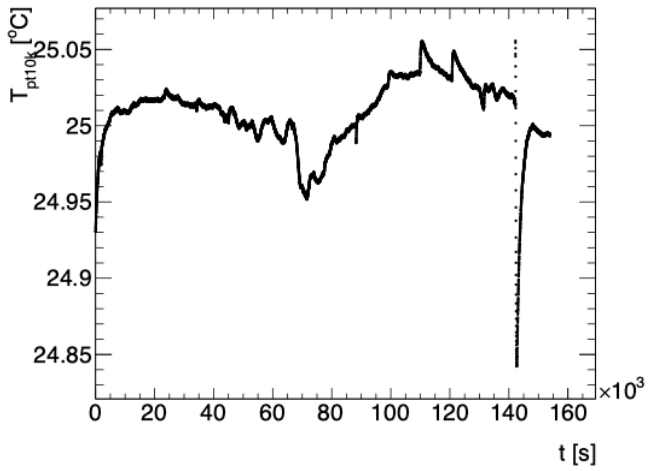


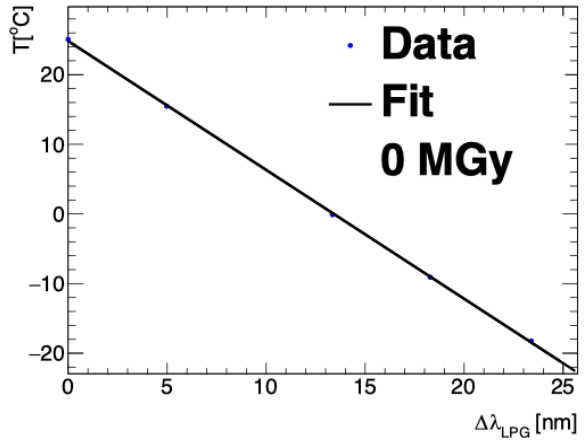
- Used for calibration

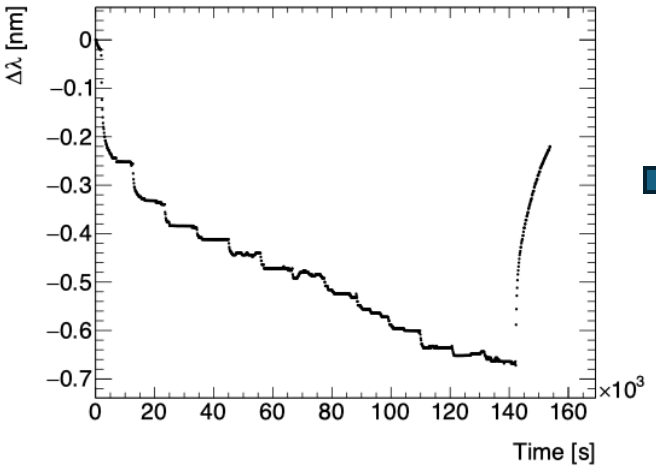
RH raw spectra: Temperature compensated

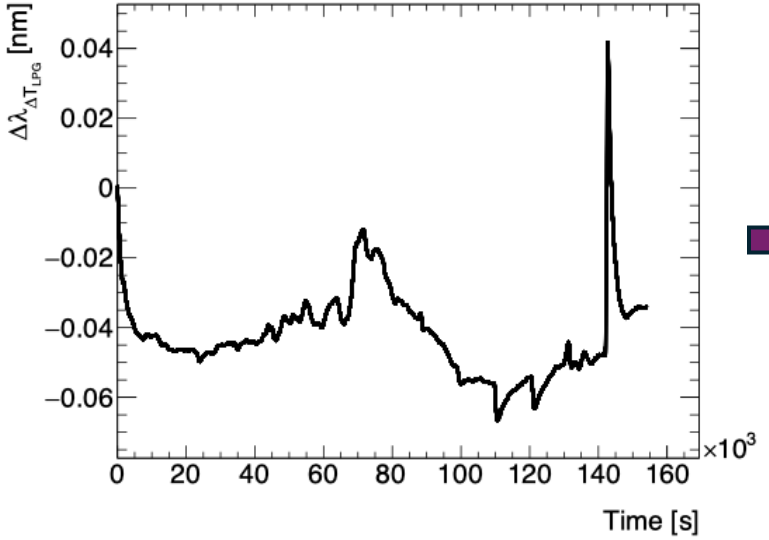
$$\frac{T_{\mathrm{pt10k}}}{\left(\frac{T}{\Delta\lambda}\right)_{\mathrm{LPG}}} = \Delta\lambda_{\Delta T_{\mathrm{LPG}}}$$

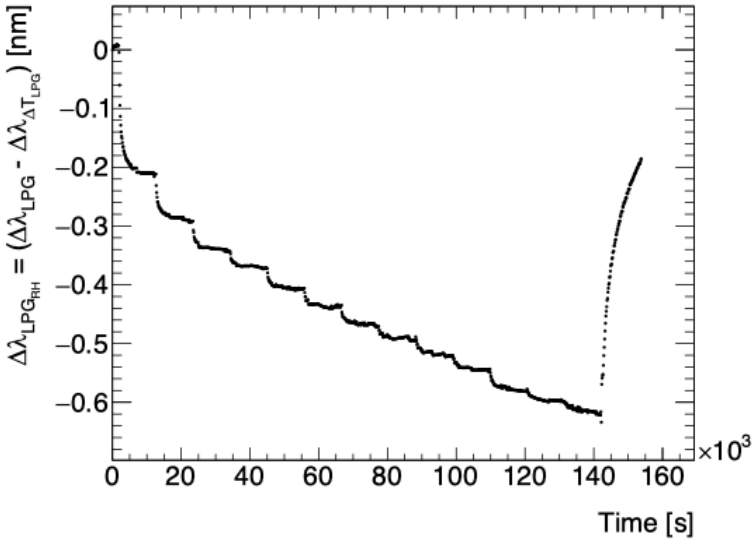
$$\Delta\lambda_{\mathrm{raw}} - \Delta\lambda_{\Delta T_{\mathrm{LPG}}} = \Delta\lambda_{\mathrm{LPG_{RH}}}$$



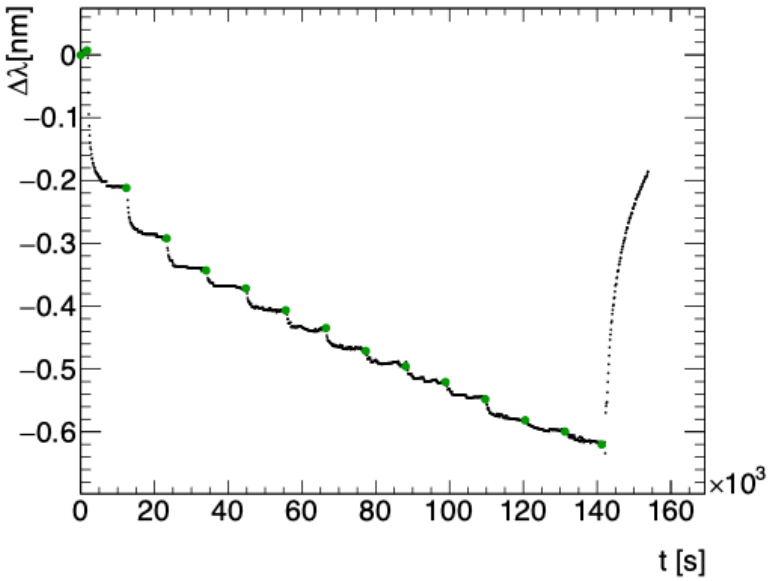


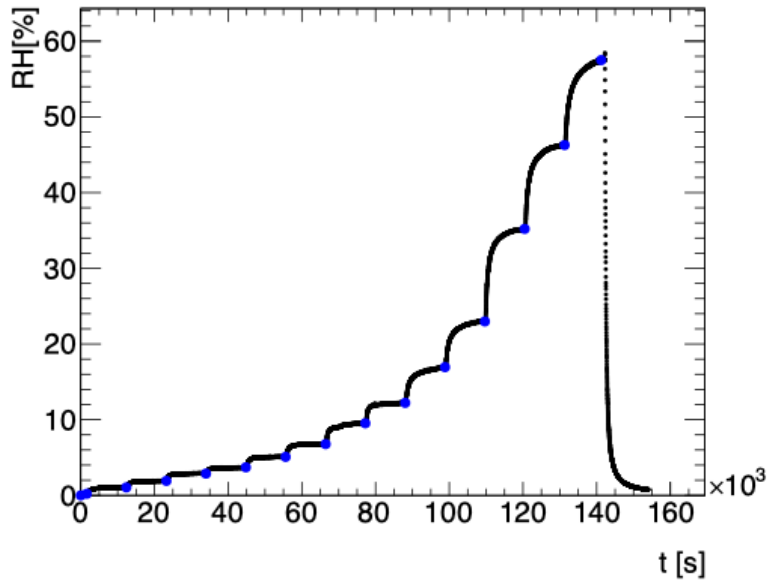


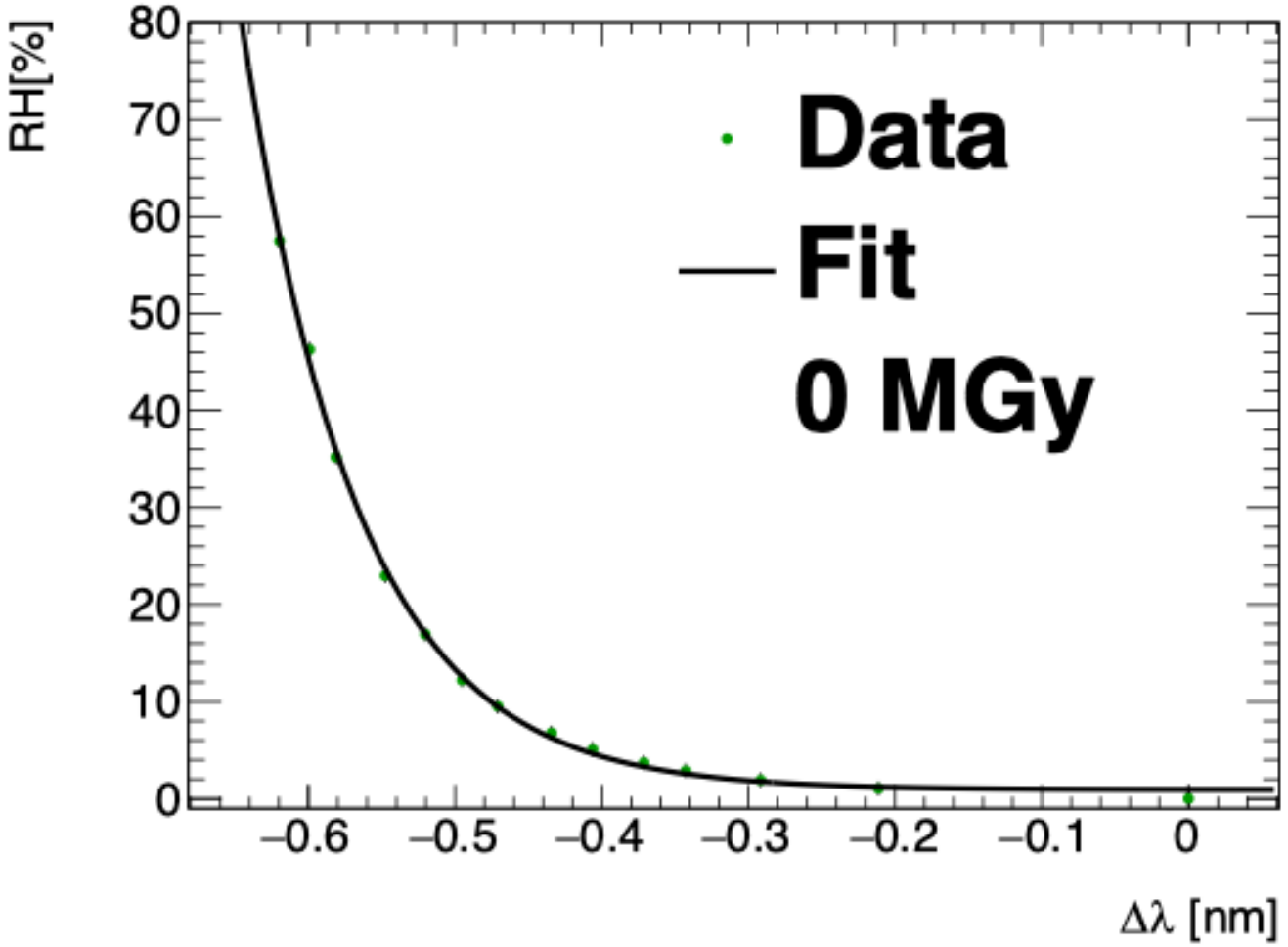




Stable points used for RH Calibration curve

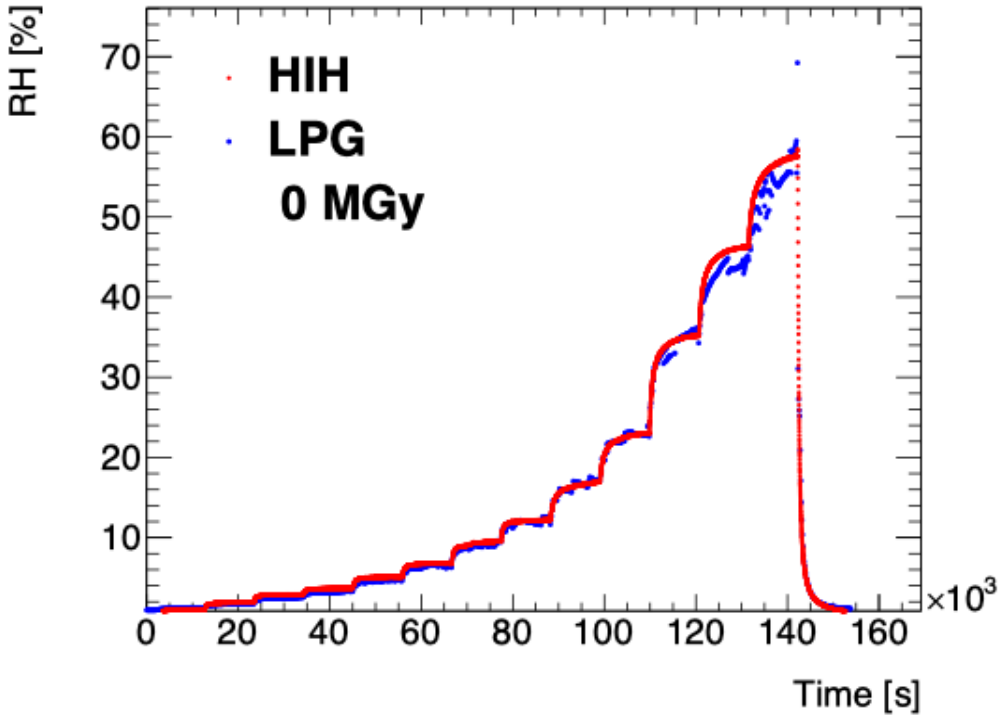




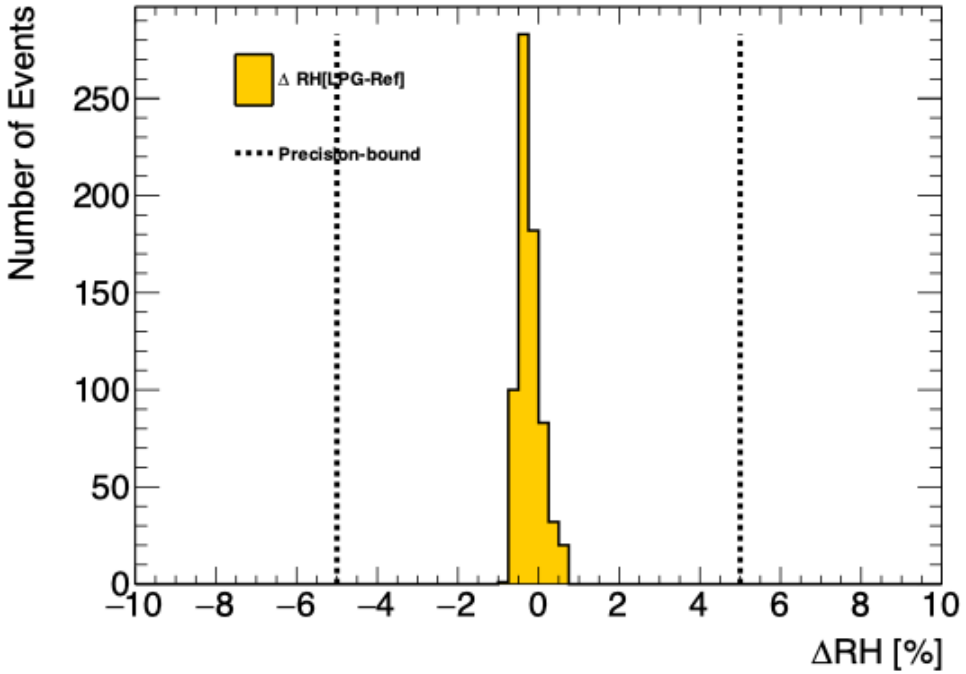


FOS meets the specification before Irradiation

- FOS RH readout comparison to conventional sensor HIH (left plot)
- FOS **almost exactly matches** conventional sensor (left plot)
- Variance is within precision bounds (right plot)



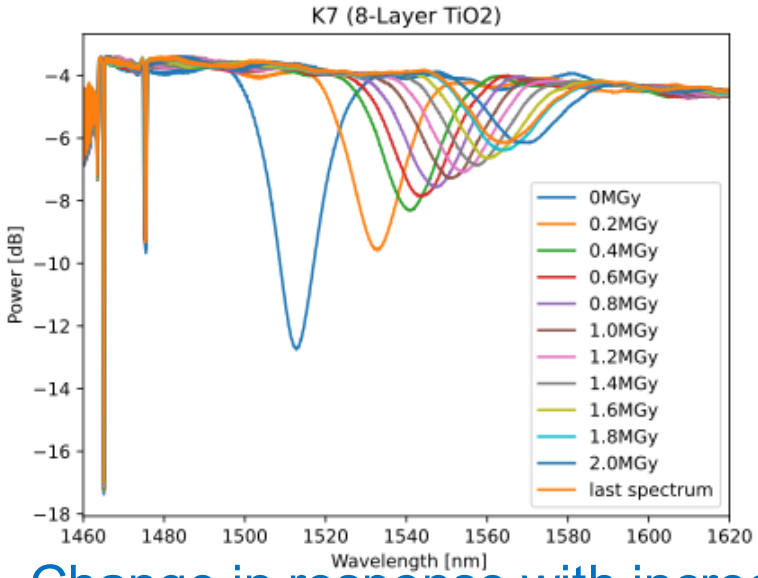
RH over time – FOS vs HIH sensor



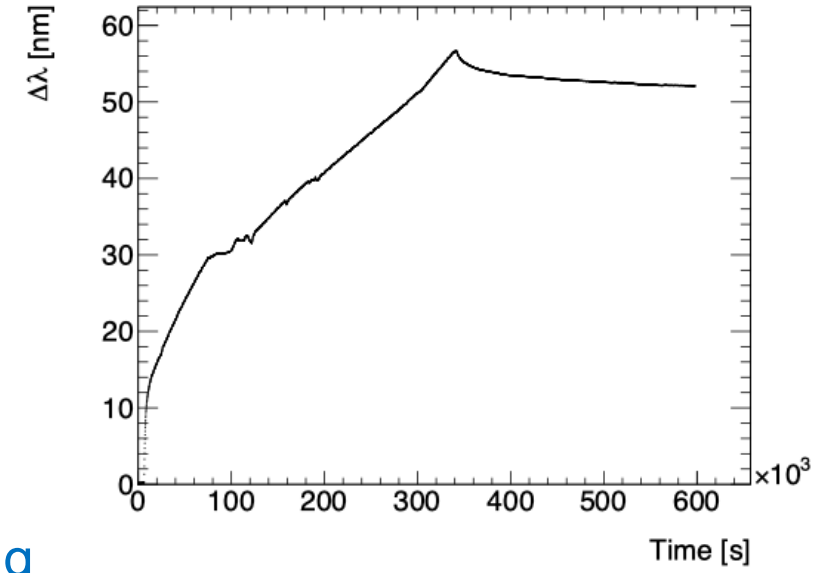
RH Variance :FOS readout minus HIH readout

Functionality under irradiation

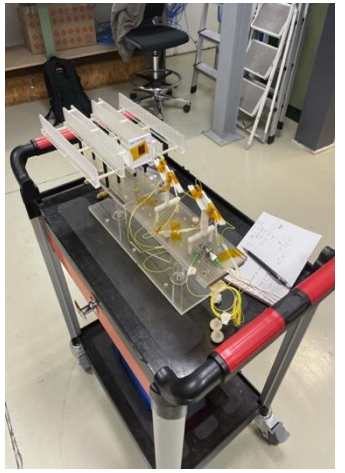
- Irradiation campaign at CERN IRRAD facility
- 24 GeV/c proton beam applies cumulative fluence of $7.56\ X10^{15}$ protons per cm^2 for 1 week.
- Sensors still function after 2.06 MGy ionizing dose.
- **Sensor functionality survives radiation.**



Change in response with increasing radiation dose



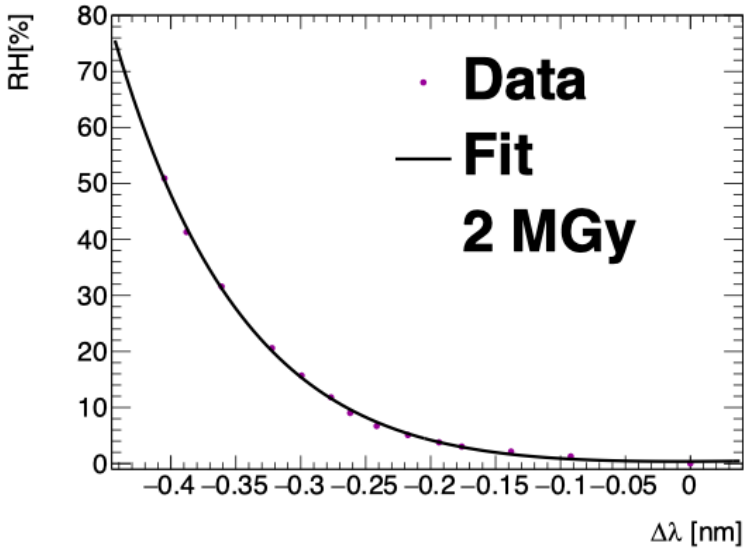
Wavelength shift with increasing radiation dose



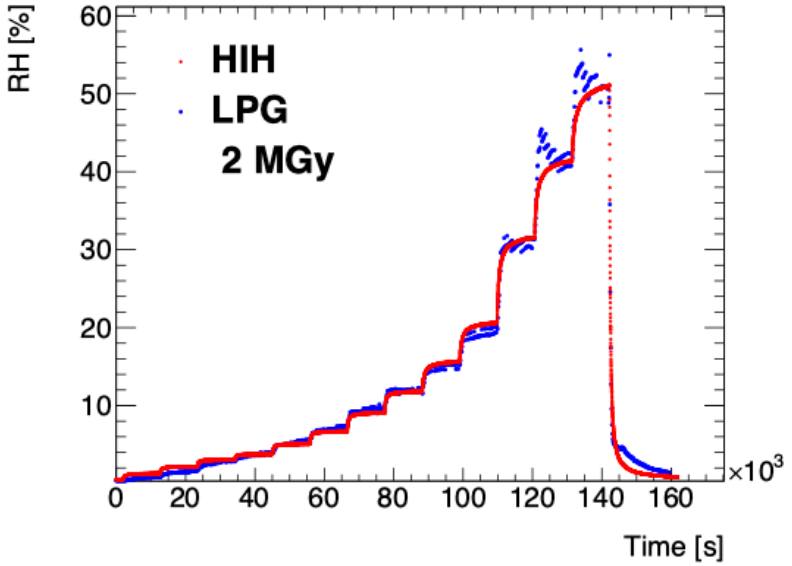
Sensor mounted for irradiation at CERN'S IRRAD facility

Characterization after Irradiation

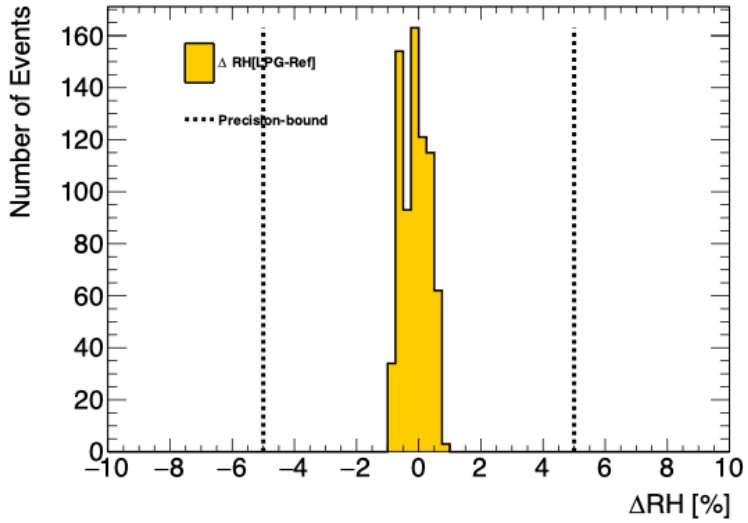
- RH calibration curves of irradiated FOS at T = 25°C.
- Sensor still work after irradiation



Post-Irrad RH calibration curve



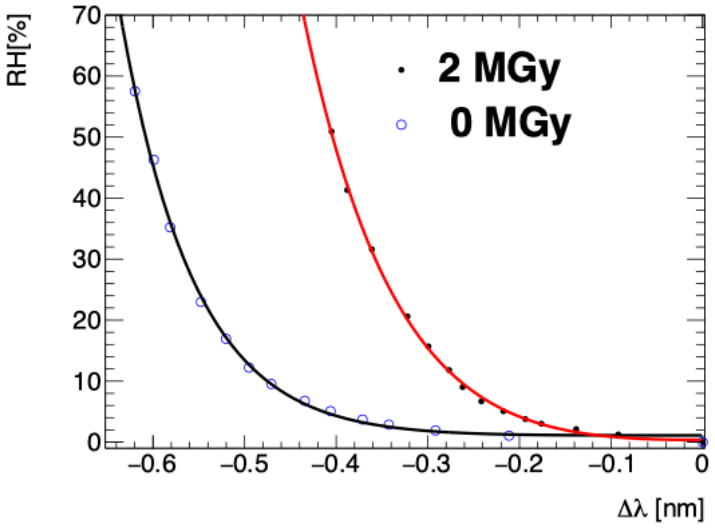
RH over time – FOS vs HIH sensor



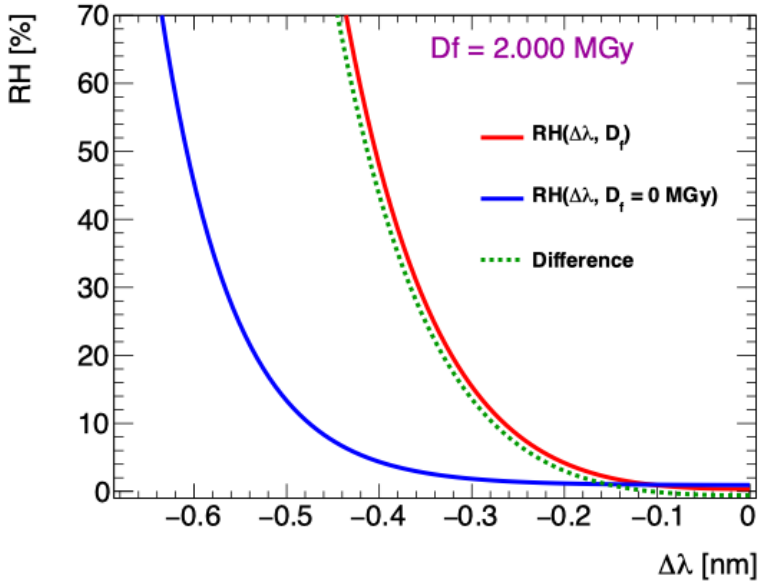
RH Variance :FOS readout minus HIH readout

Calibration curves at different radiation dose.

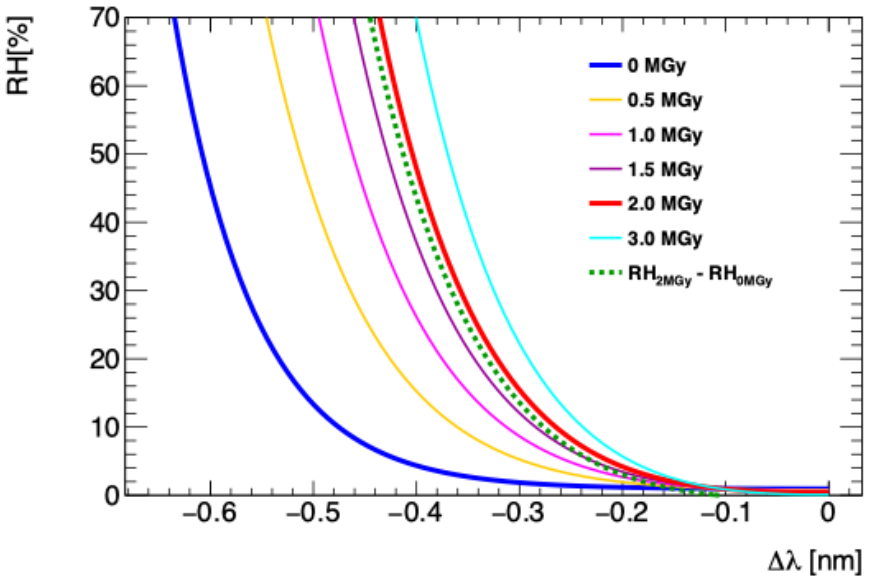
- At different radiation dose, interpolation and extrapolation function acquired from real data-driven RH calibration curves



Real data



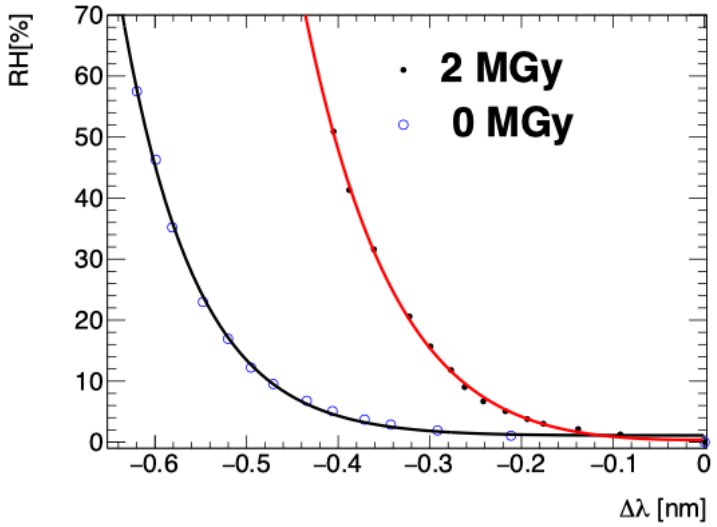
Interpolated function



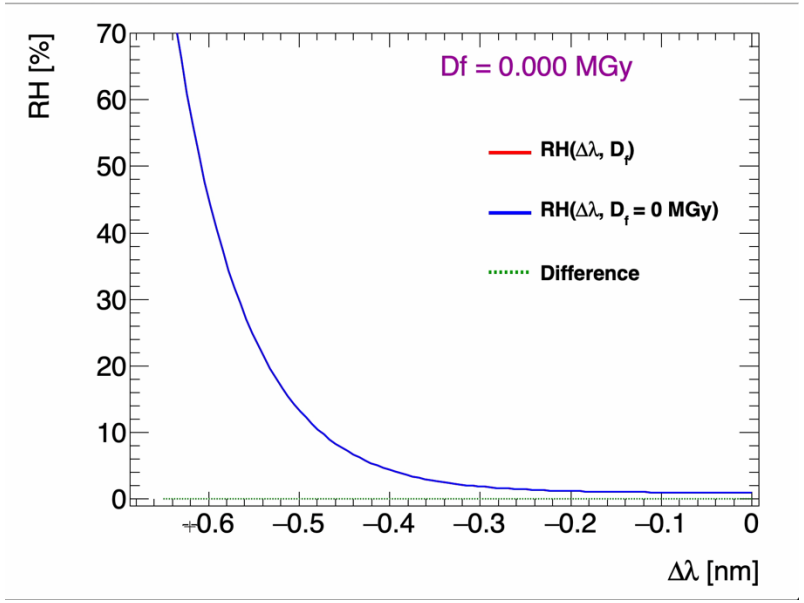
Interpolated/extrapolated function at several dose exposure

Calibration curves at different radiation dose (live).

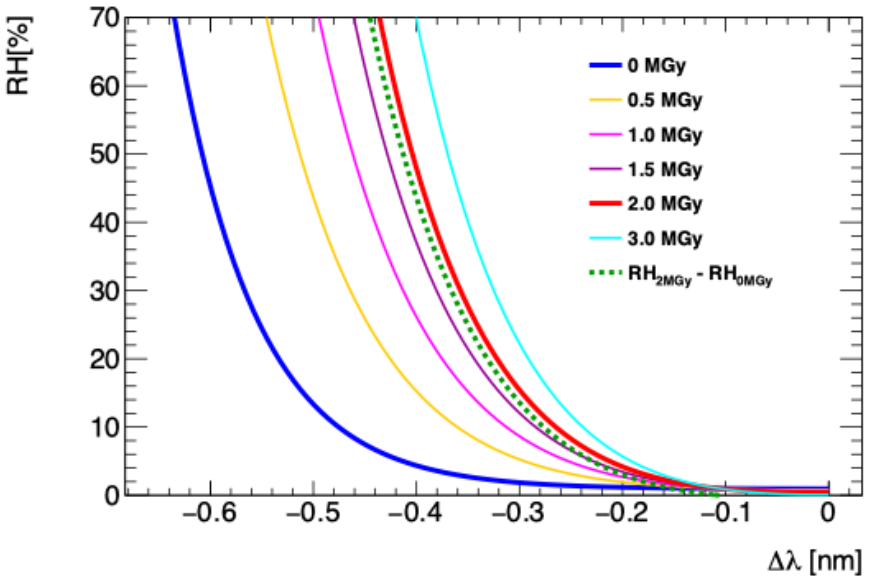
- At different radiation dose, interpolation and extrapolation function acquired from real data-driven RH calibration curves



Real data

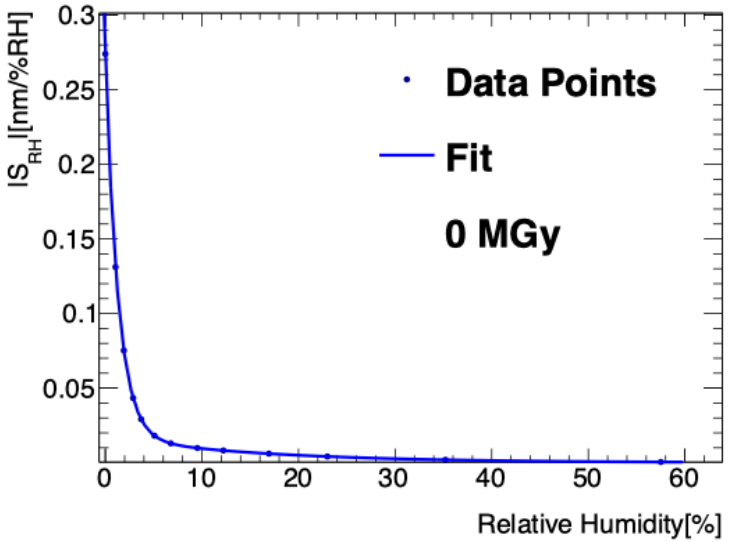


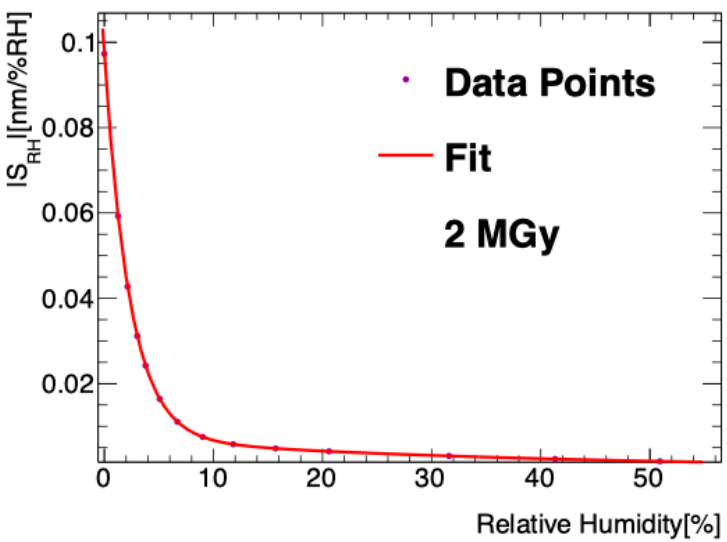
Interpolated function (live movie)

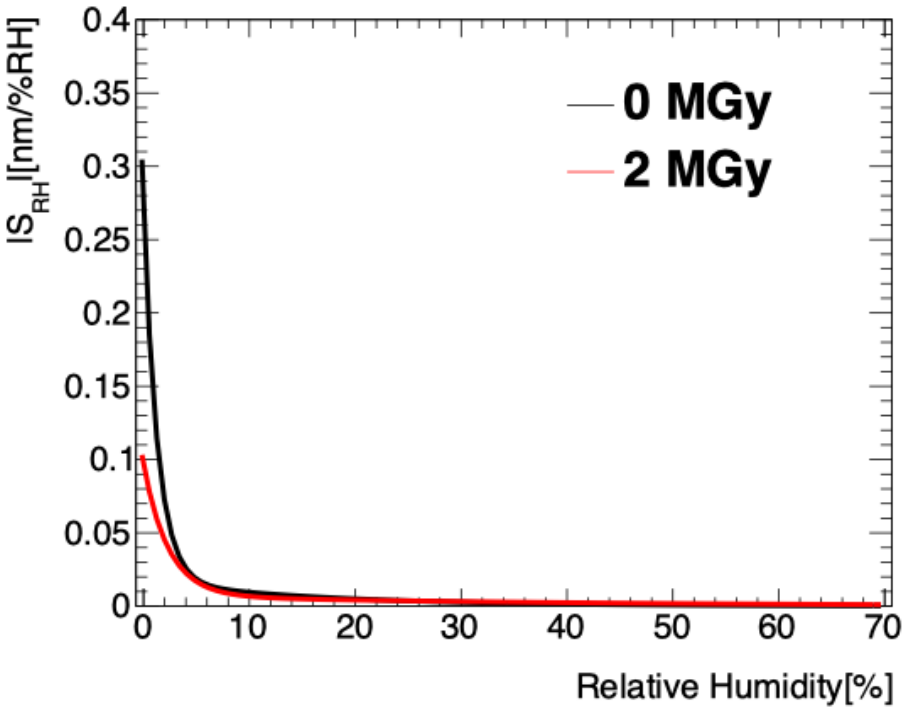


Interpolated/extrapolated function at several dose exposure

RH Sensitivity: Pre-Irrad. & Post-Irrad.



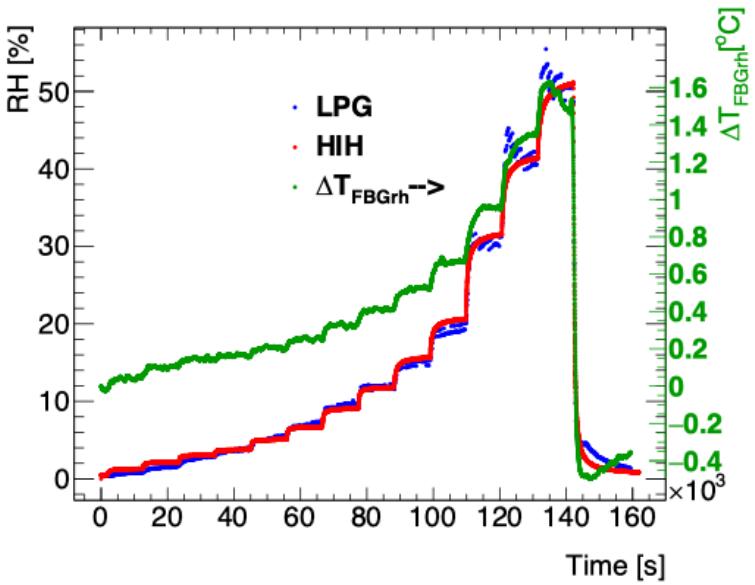


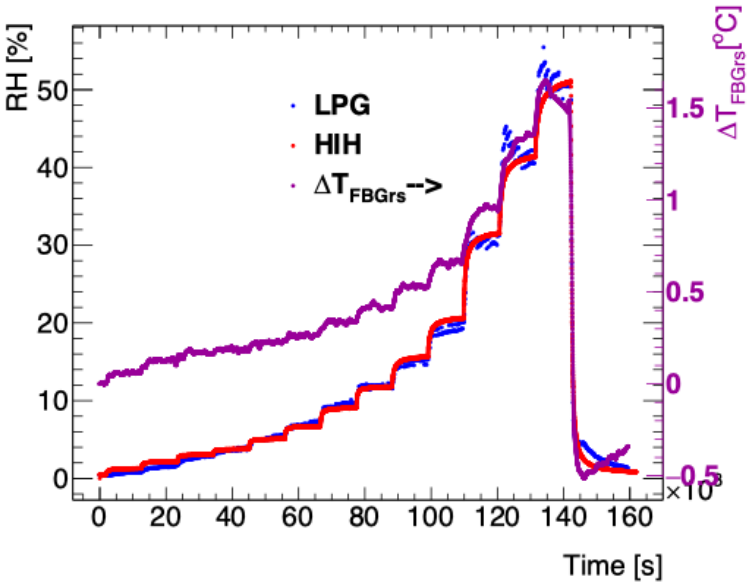


Despite radiation dose exposure which diminished the sensitivity of the LPG sensor, it still works.

T-sensitive FBGs anomaly response

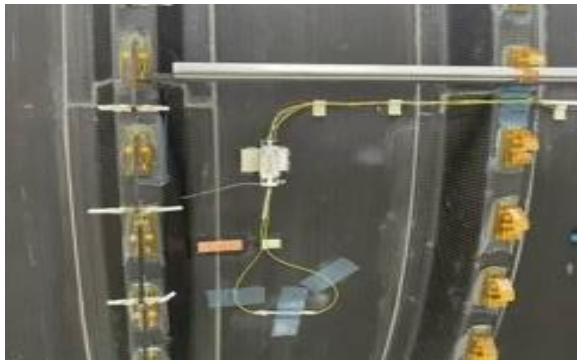
- Both FBGs are not supposed to be sensitive to both T and RH.
- Using the RH readout from the LPG and HIH sensors as baseline, the FBG spectra mimics their topology.
- For this particular FOS package, there appears to be cross – sensitive and packaging effect problem.
- In discussion with the supplier of these FBG sensors

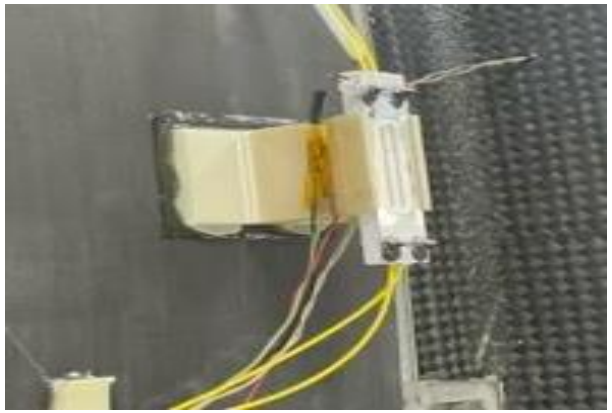




CONCLUSION AND FUTURE WORK.

- The QA/QC has been done a FOS package.
- With the pt10k ever available, any temperature anomaly measurement can be checked and corrected where necessary.
- FOS meets the specification before and after Irradiation.
- Some FOS packages have been delivered to ATLAS since **July 2024**
- Shown in the pictures are FOS packages installed in ITk Strips Barrels.
- More FOS packages have been requested, and new packages are being assembled with QA/QC to be done on them.

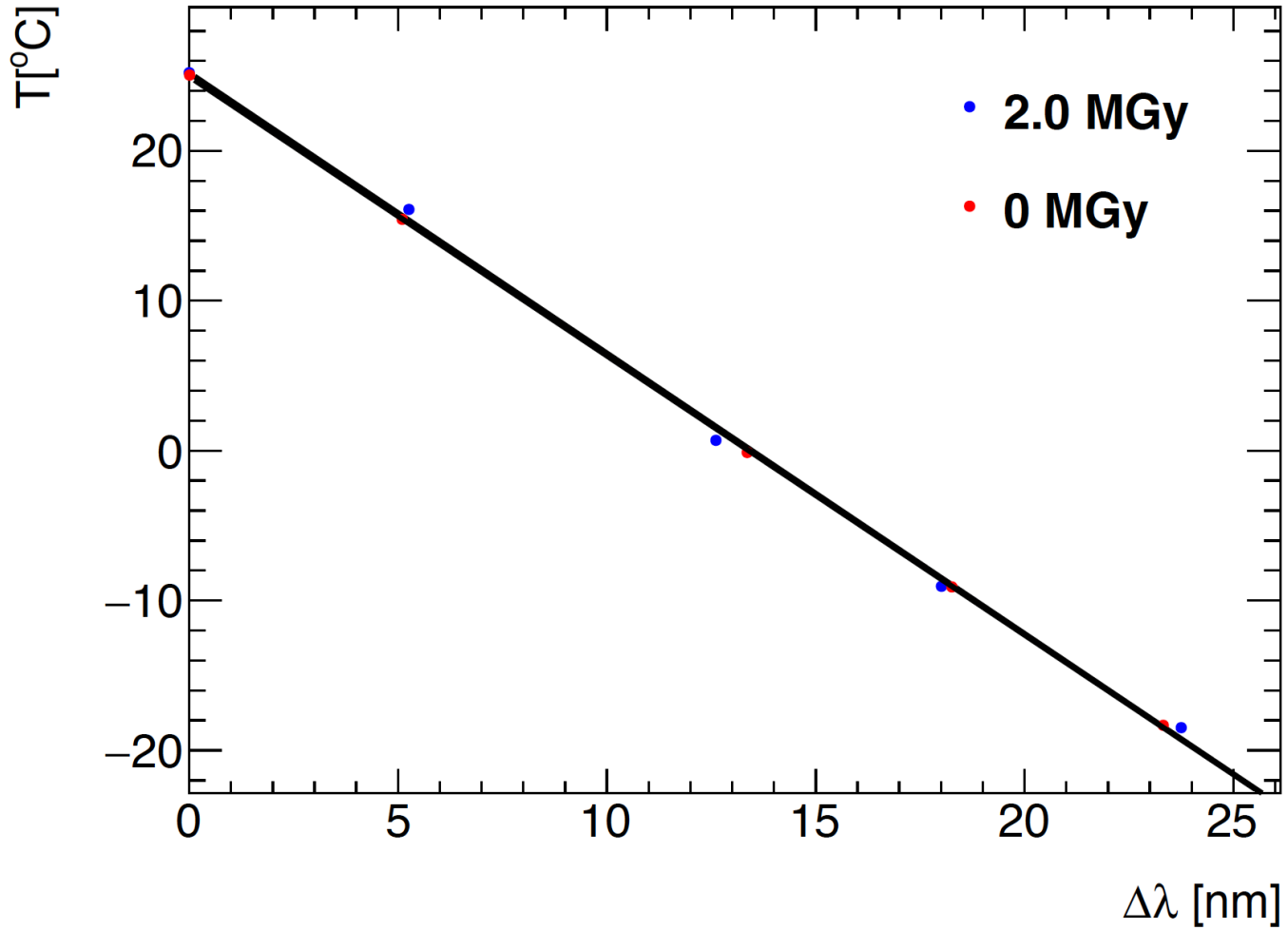




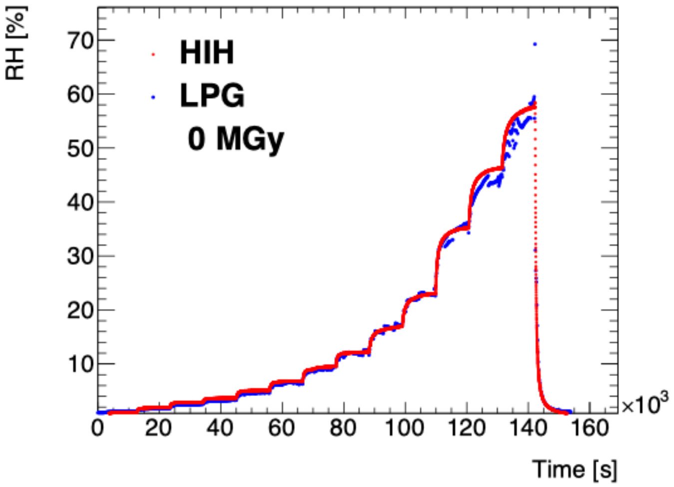
THANK YOU

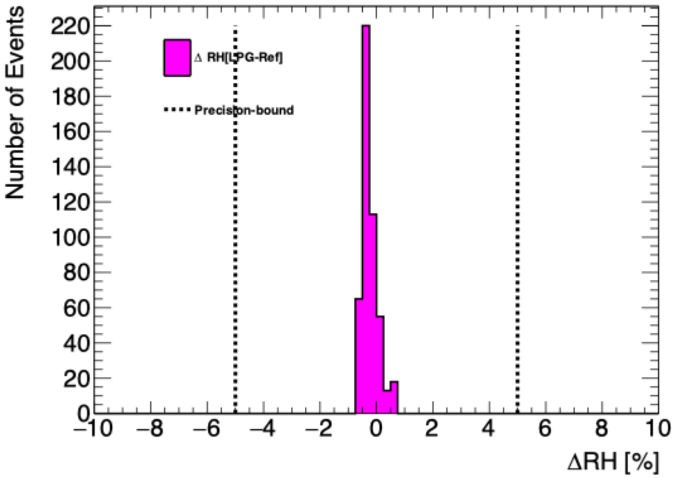
BACKUP

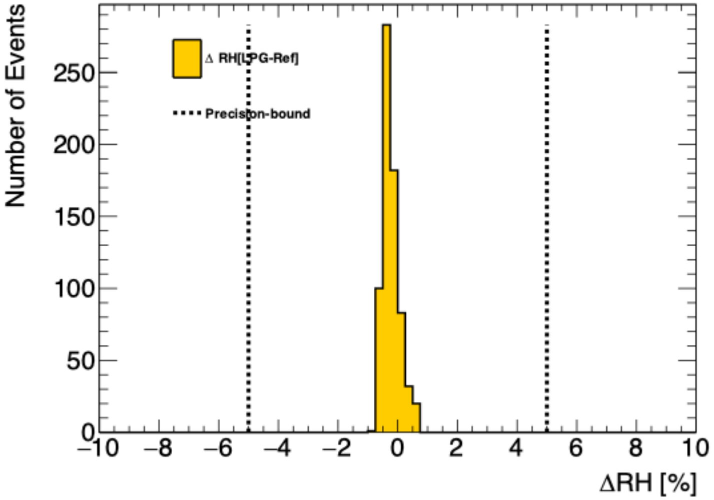
LPG T Calibration: Unchanged.

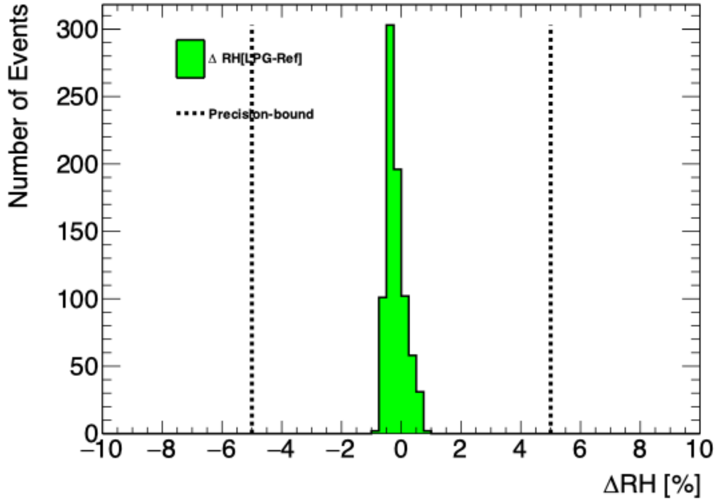


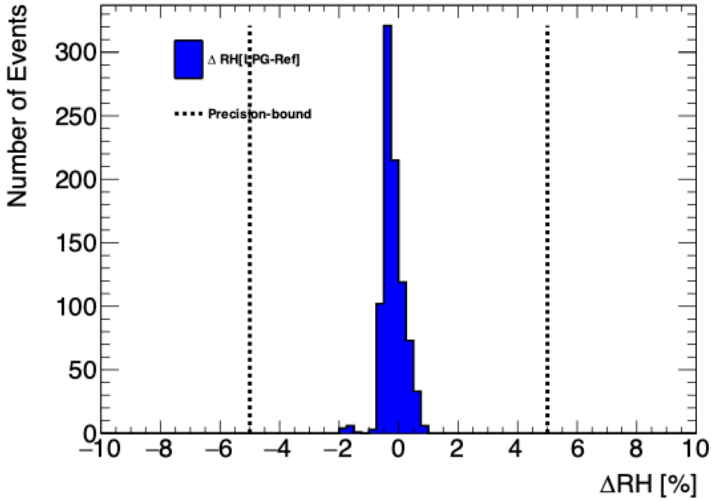
LPG-RH Variance: (FOS – HIH)readout

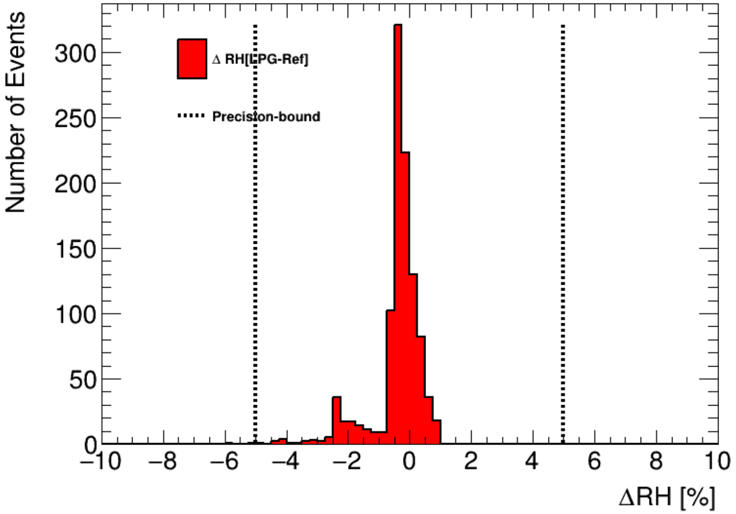












LPG-RH Variance: (FOS – HIH)readout