# Laser Absorption Spectroscopy
## for Methane Sensing in SPCs for the NEWS-G Experiment

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# Dark Matter – A Quick Recap

**Dark Matter (DM)** is a mysterious form of matter theorized to comprise nearly 85% of the total mass density of the universe

**Main Pieces of Evidence:**

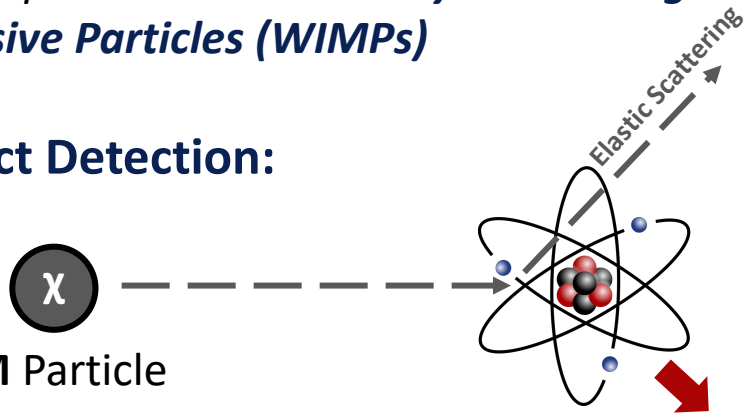
- Gravitational Signatures:
  - Rotation curves of some galaxies
  - Gravitation lensing (e.g., as observed in the Bullet Cluster as seen on the right)
- Cosmic Microwave Background

*Many models exist for **DM** but many experiments focus on an unknown type of exotic particle called **Weakly-Interacting Massive Particles (WIMPs)***

**The Bullet Cluster**

*Example of Gravitational Lensing due to **DM***

**Direct Detection:**



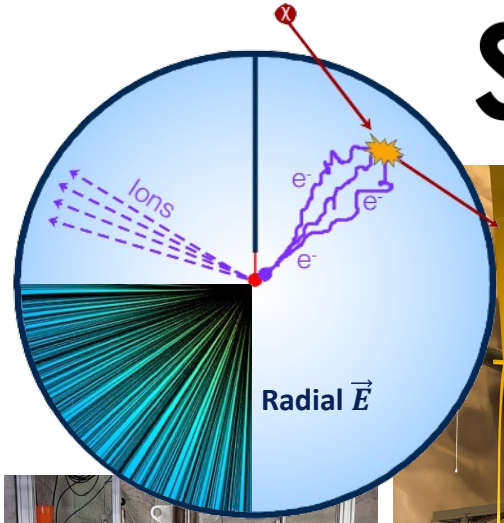

*Energy signatures from the effects of elastic scattering of **DM** off **atomic nuclei** can be observed by direct detection experiments…*

# NEWS-G: New Experiments With Spheres - Gas

**DM** experiment specializing in SPCs (Spherical Proportional Counters) in searching for low-mass (light) WIMPs

**SPC:** metallic vessel filled with a noble gas mixture; high voltage sensor held at the centre

- Focus on low-A target atoms
- Sensitivity to single-ionization events via Townsend Avalanche




**SNOGLOBE:** a 140 cm SPC currently installed in SNOLAB (Sudbury, ON)

- Plans for measurement campaign using Ne + $CH_4$ (10%)
- One of NEWS-G's UofA team's focus is on enhancing/developing SNOGLOBE's gas handling system

**SNOGLOBE in the SNOLAB Cube Hall**

# Use of Methane ($CH_4$) in SPCs

## $CH_4$ serves two main purposes in SPCs:

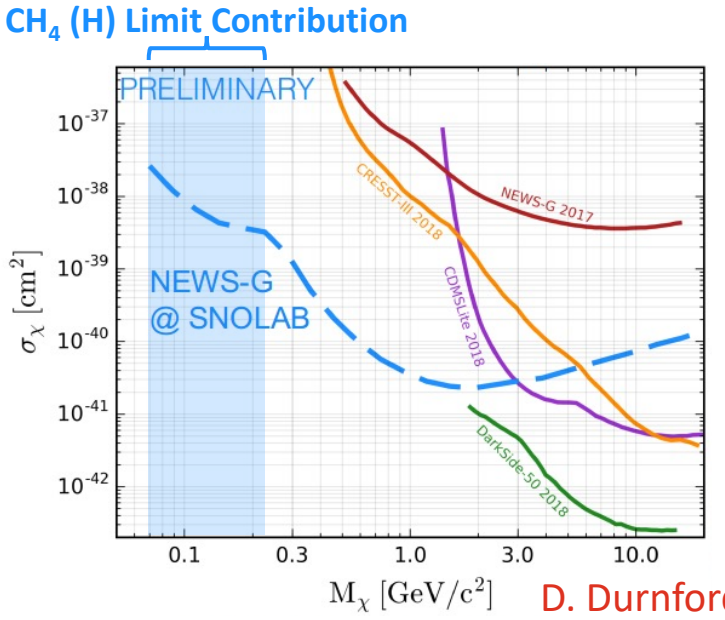
1. Target gas for WIMP interactions (*H-rich)
   - Used pure $CH_4$ during LSM campaign!
2. Gas quencher

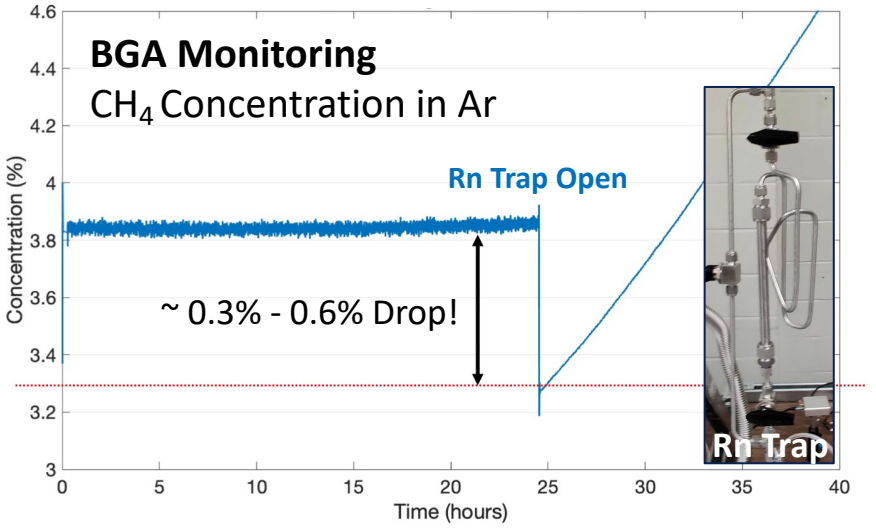
*$CH_4$ has less-restrictive flammability limits (i.e., safer to use) and is less leak-prone compared to a pure $H_2$ target*

- NEWS-G's SPCs do not have a <u>reliable</u> means for monitoring $CH_4$ concentrations
- $CH_4$ can be lost due to the **radon-trap system (b. right)** and potential leaks

## UofA Goals:

1. Develop a system for live-monitoring the <u>absolute</u> concentration of $CH_4$
2. Demonstrate measurement reliability near 6%-10% $CH_4$ concentration levels



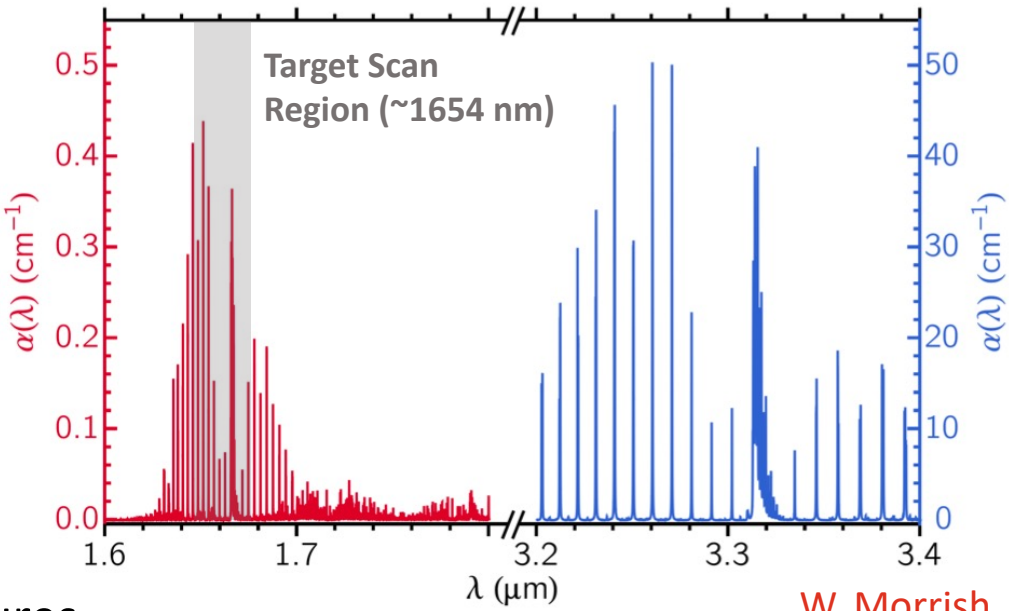
# Laser Absorption Spectroscopy (LAS)

**Laser Absorption Spectroscopy**:
A technique for measuring the concentrations of gases using a λ-tuned laser matching the absorption features of said gas

*This method is <u>already tested</u> at UofA by Prof. Al Meldrum's group (**working in collaboration!**)*

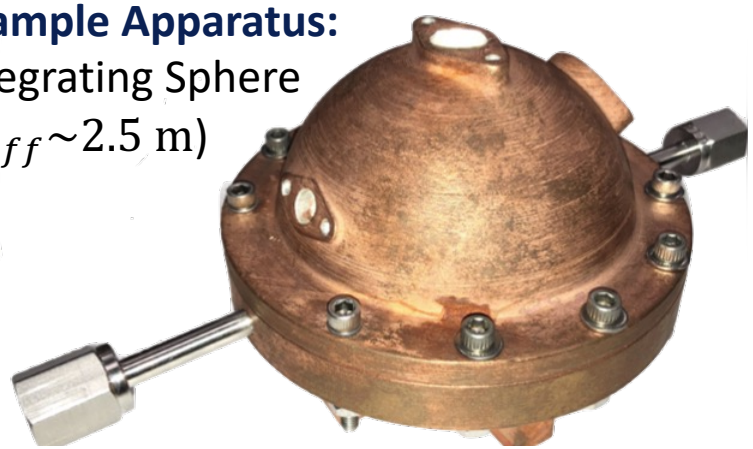
- Scan laser λ about absorption features (t. right) to observe losses in laser intensity
- Apparatus varies depending upon concentration limits (↓*concentration* ↑*effective laser path length needed*)
- Provides absolute, <u>potential ppb</u>, measurement precision [1]

**Absorption Spectra for $CH_4$**




W. Morrish

**Example Apparatus:**
Integrating Sphere
($L_{eff}$~2.5 m)



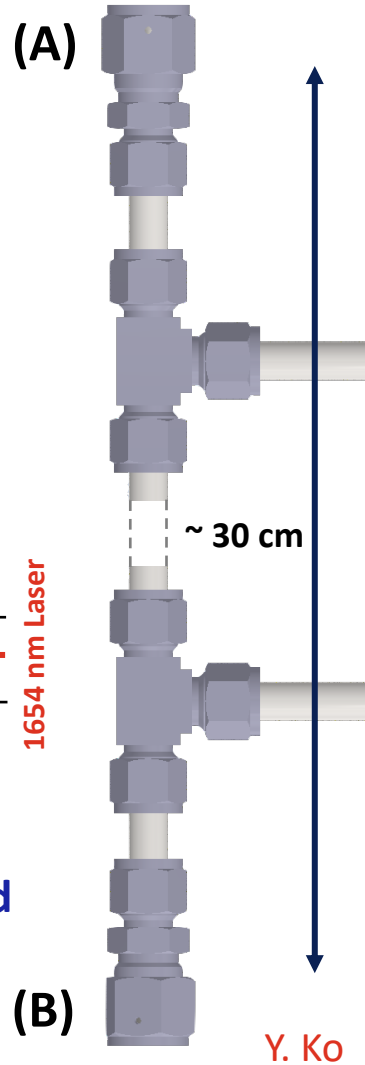
[1] Y. A. Bakhirkin et al, Appl. Opt. 43, 2257-2266 (2004)

# LAS Prototype Apparatus Design

**Tube-styled prototype (right) designed to have $L_{eff}$~30 cm, the same diameter as a small SPC (e.g., UofA's S30 SPC)**

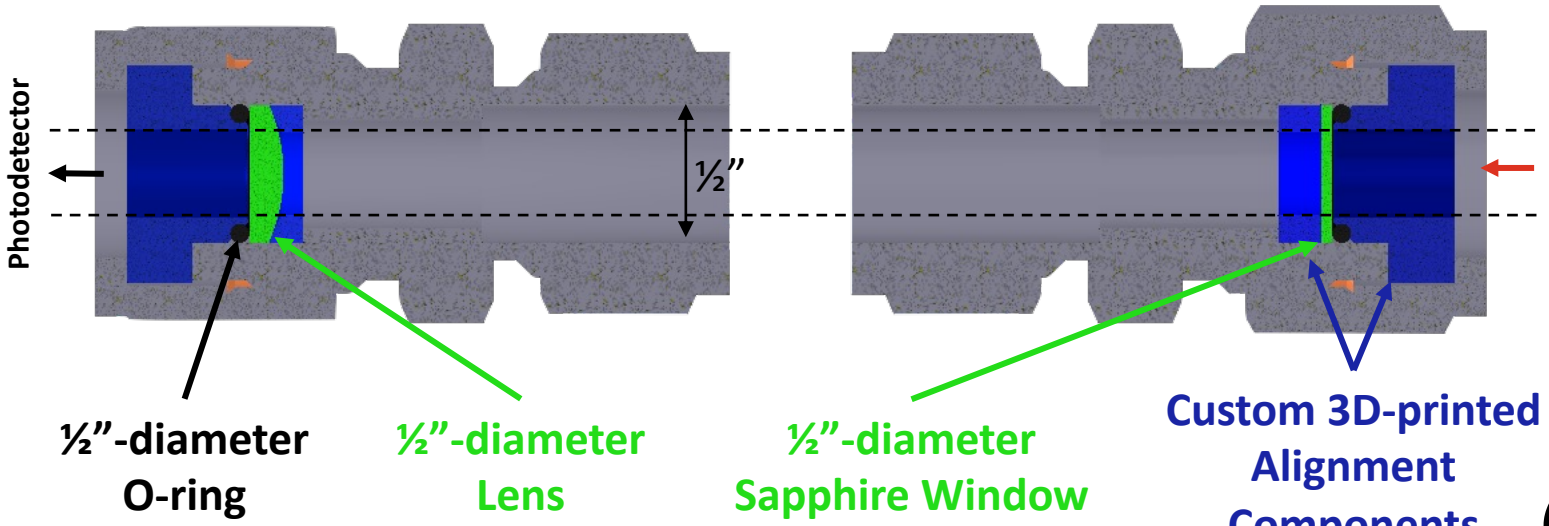
- Swagelok component-based; custom end caps (below)
- ½" stainless steel piping
- Vacuum and leak tested with He-leak checker
- Compatible with NORCADA 1654 nm laser diode

## CAD Model

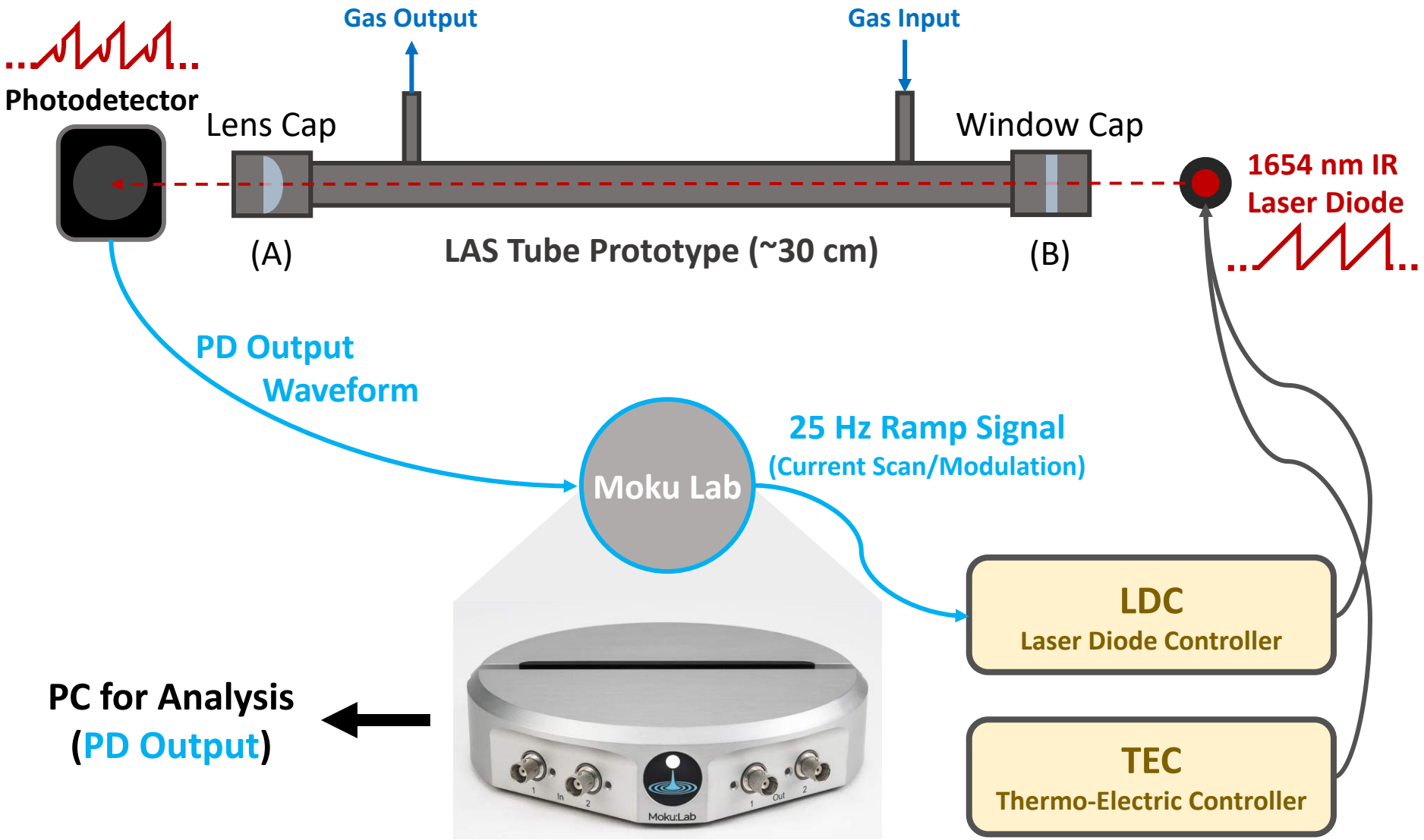



## (A) Lens End Cap

## (B) Sapphire Window End Cap

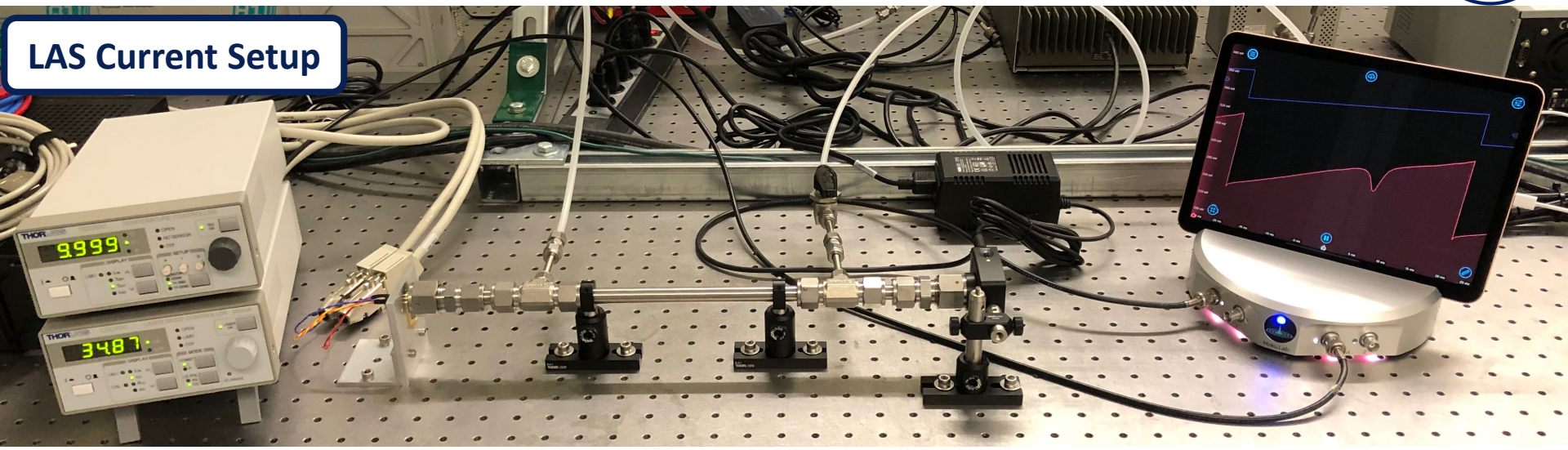


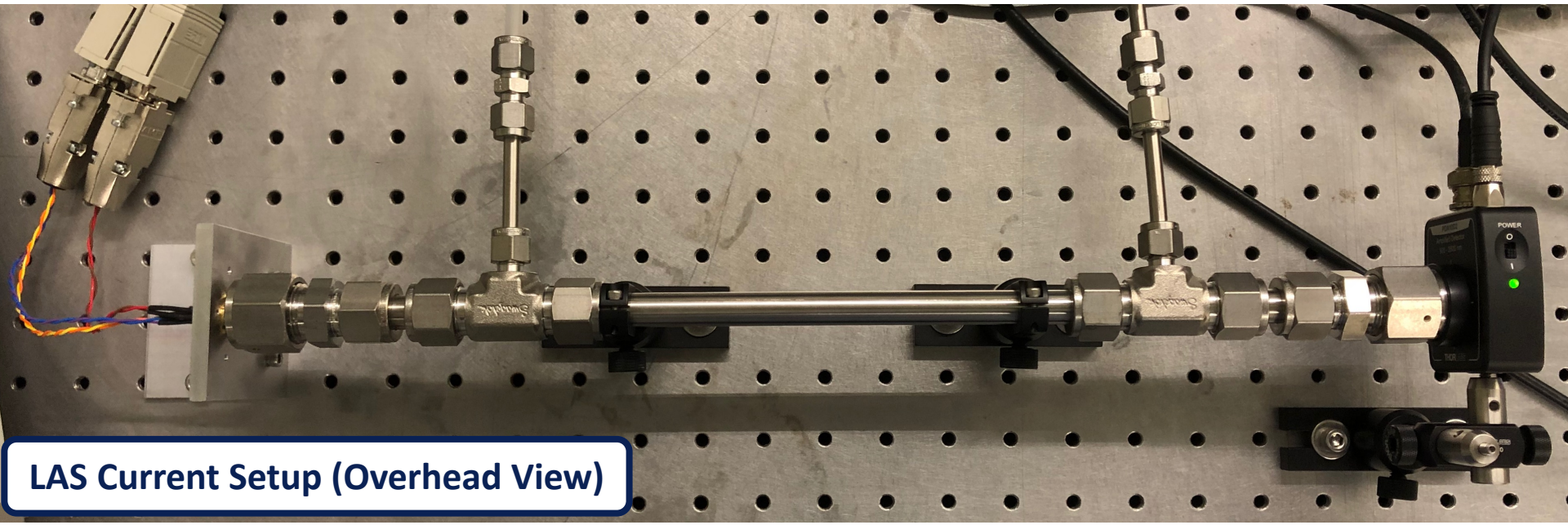
# LAS NEWS-G Prototype Setup




Liquid Instruments Case Study: https://www.liquidinstruments.com/blog/2022/04/27/advancing-the-search-for-dark-matter-with-mokulab/

# LAS NEWS-G Prototype Setup



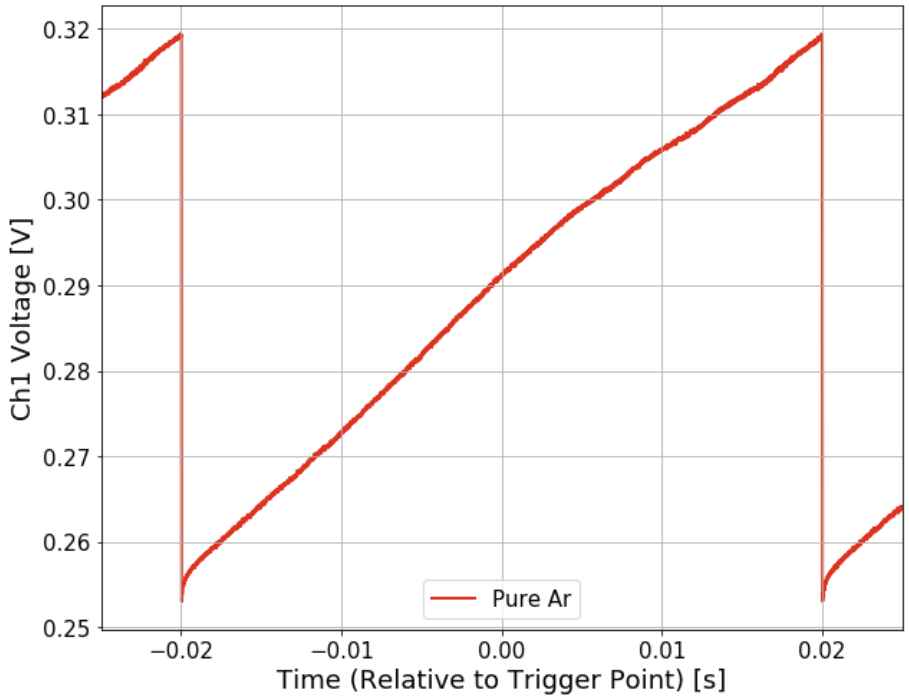



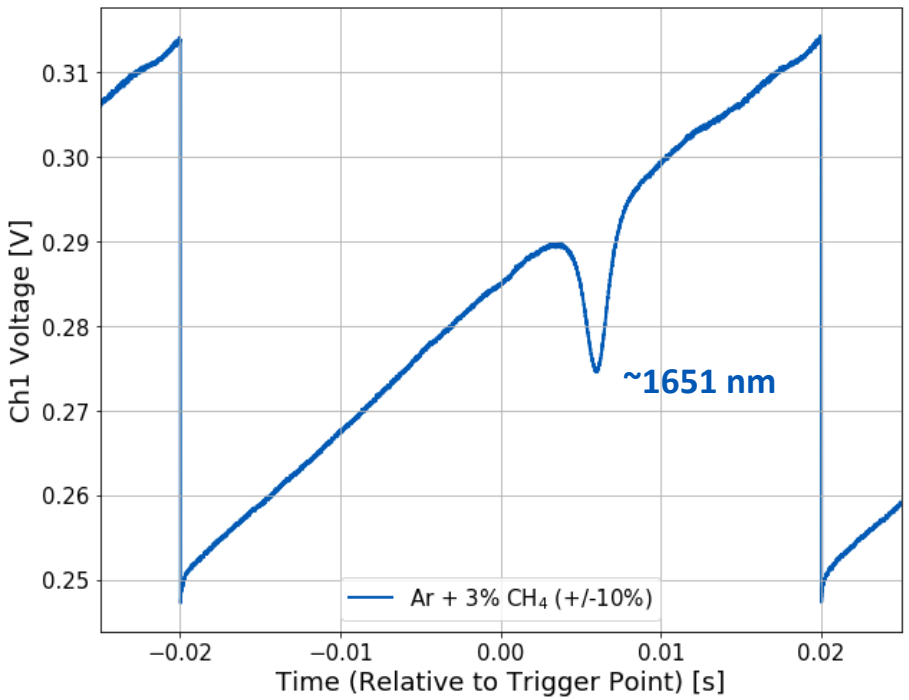
# LAS Example Signal

For our target absorption signal, the 1654 nm laser diode is operated at an average drive current of ~34 mA using a 10 kΩ thermistor resistance (~25° C)

The drive current is modulated with a 25 Hz 400 $mV_{pk-pk}$ ramp signal, scanning the drive current by ±10 mA → wavelength scans between ~1650.7 nm and ~1651.1 nm

Observed example waveforms are given below without (left) and with (right) $CH_4$ present:



# LAS Signal Analysis + $CH_4$ Measurement

To get a $CH_4$ concentration measurement, we first perform cleaning cuts on the signal to isolate the absorption peak

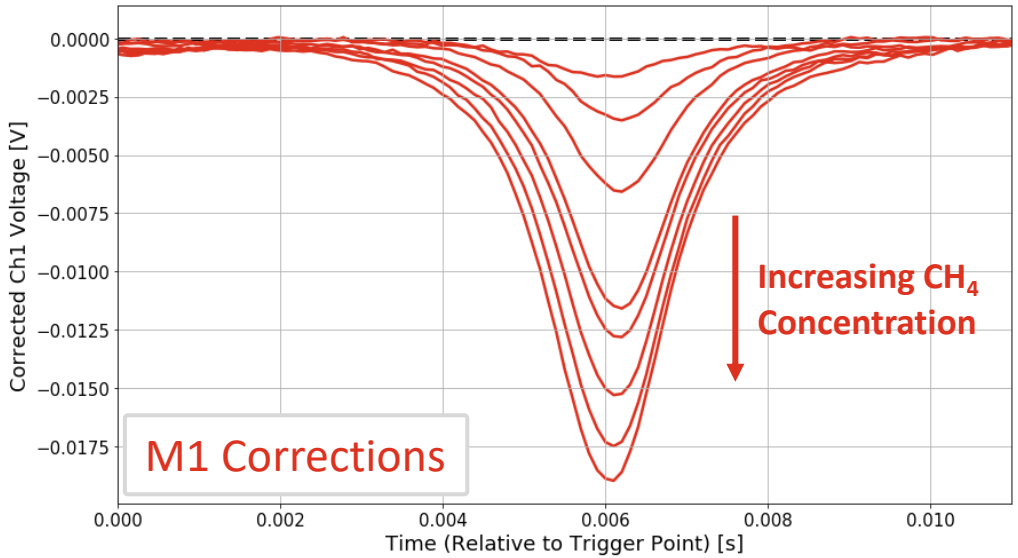
**Cut Method 1 (M1):**

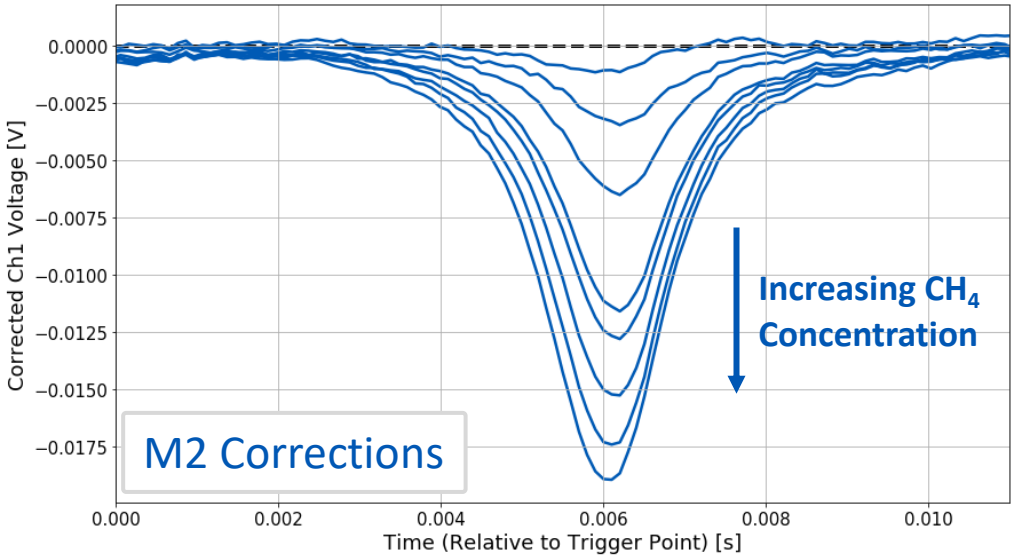
- Perform linear regression on tail regions of waveform
- Perform quadratic regression on 0 ppm data near peak location
- Subtract both regression from data
- *General method by W. Morrish*

**Cut Method 2 (M2):**

- Background-subtract 0 ppm waveform
- Correct baseline to 0 V

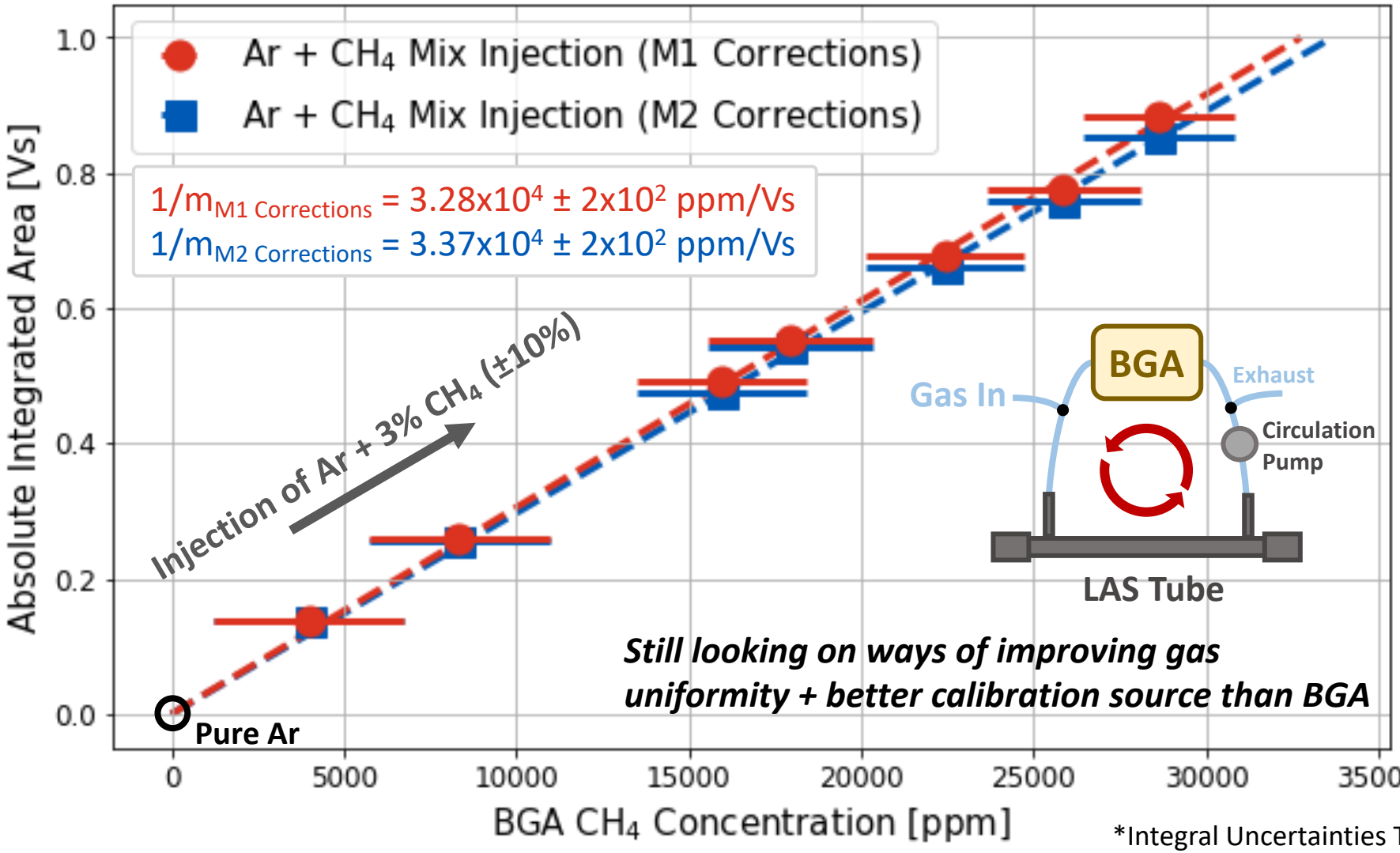
The integral (sum) of these final waveforms can then be compared to a calibration plot to extract a final measurement (next slide)!



# Early $CH_4$ Measurement Calibration

Data points recorded with **B**inary **G**as **A**nalyzer and LAS system in series

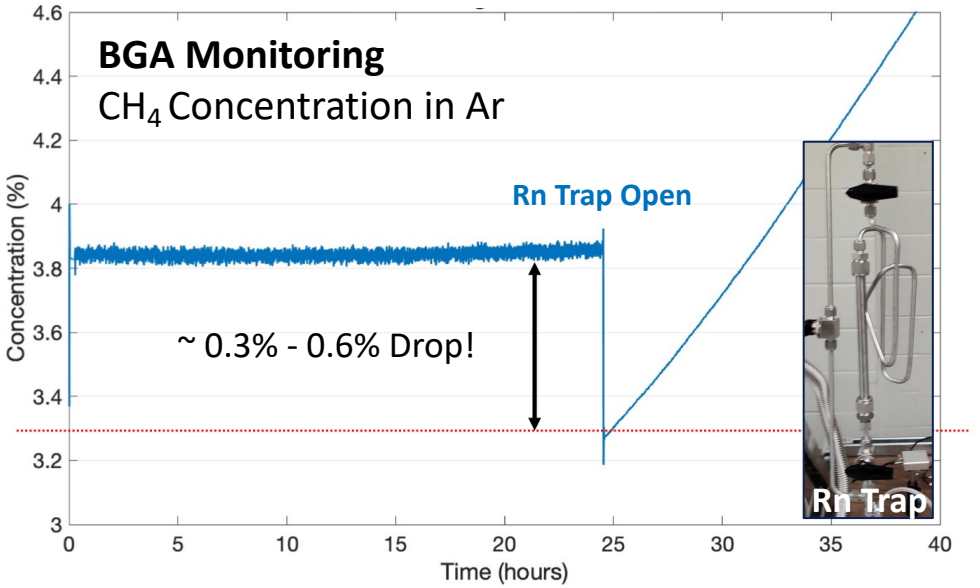



*Integral Uncertainties TBD

# Future Plans for LAS and NEWS-G

## Radon Trap Measurements

- Perform measurements for verifying $CH_4$ losses with UofA's SPC radon trap system (right)
- *Use of live-monitoring system!*




## Future Studies

- Look at more advanced analysis / measurement techniques such as *Wavelength Modulation Spectroscopy* (WMS) [2]
- Try alternative apparatuses like *integrating spheres* to compare measurement capabilities near 10% $CH_4$ concentration
- General iterative equipment/apparatus improvements (laser, PD, etc.)

## SNOLAB Preparation

- **MAIN GOAL:** Prepare LAS package (hard/software) for use with SNOGLOBE

[2] K. Sun et al, 2013 Meas. Sci. Technol. 24 125203

# The NEWS-G Collaboration

**Queen's University, Kingston** - G Gerbier, G Giroux, R Martin, S Crawford, G Savvidis, A Brossard, K Dering, V Millious, M Van Ness, M Chapellier, P Gros, JM Coquillat, L Balogh, N Rowe

**IRFU (Institut de Recherches sur les Lois fondamentales de l'Univers) / CEA Saclay** – I Giomataris, M Gros, JP Mols

**Aristotle University of Thessaloniki** – I Savvidis, A Leisos, S Tzamarias

**LPSC/LSM (Laboratoire de Physique Subatomique et Cosmologie / Laboratoire Souterrain de Modane), Grenoble** – D Santos, C Beaufort, A Dastgheibi-Fard, O Guillaudin, M Zamppaolo, JF Muraz

**Pacific Northwest National Laboratory** – E Hoppe, R Bunker

**RMCC, Kingston** – F Kelly, E Corcoran, L Kwon, P Samuleev

**SNOLAB, Sudbury** – P Gorel, S Langrock

**University of Birmingham** – K Nikolopoulos, P Knights, I Katsioulas, I Manthos, R Ward, T Kneep, J Matthews

**University of Alberta, Edmonton** – MC Piro, D Durnford, Y Deng, C Garrah

**SUBATECH, Nantes** – P Lautridou, F Vazquez de Sola Fernandez

**TRIUMF, Vancouver (associated lab)** – F Retiere

The NEWS-G Collaboration

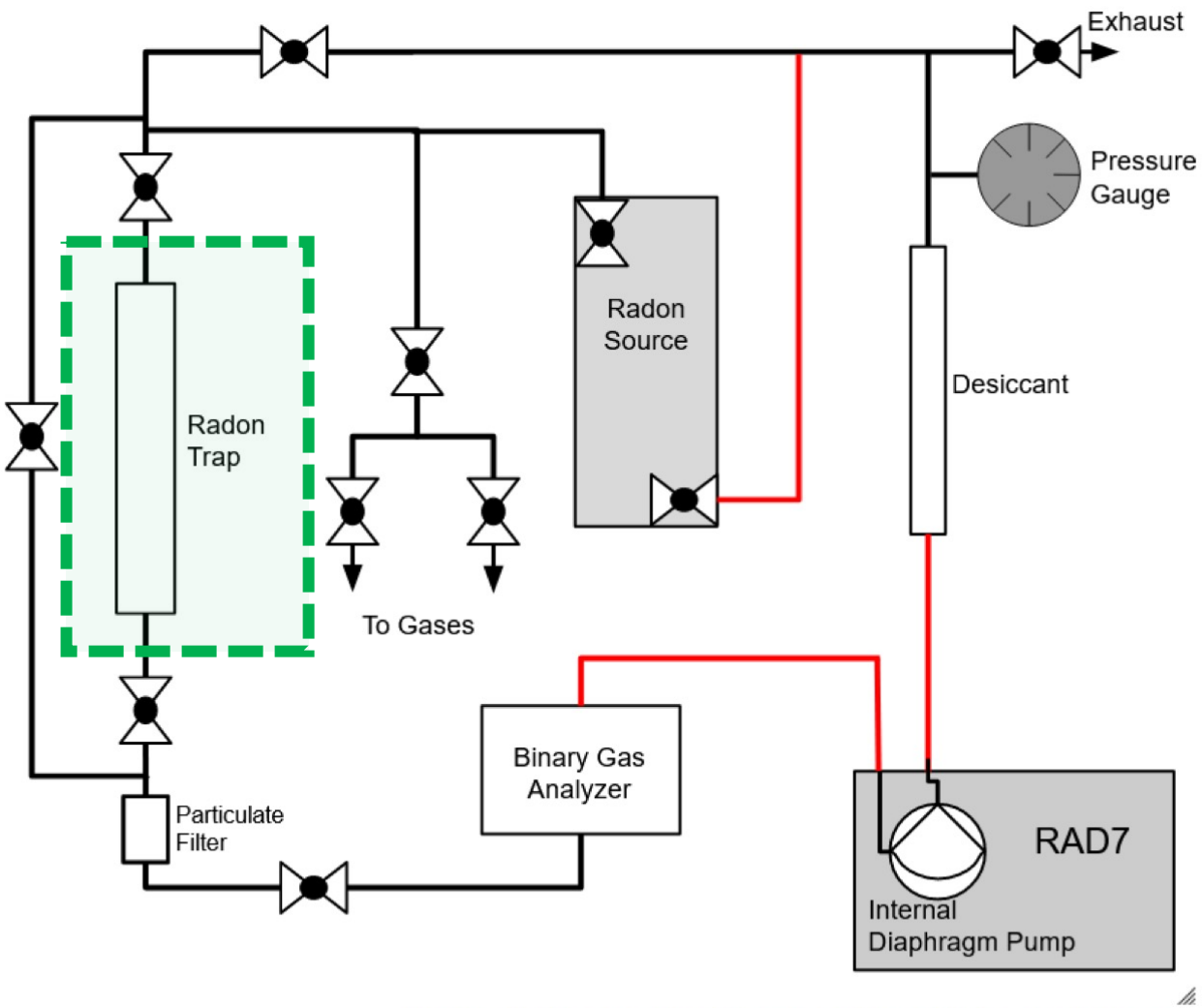
# Questions?

# Extra slides

# UofA Radon Trapping System

- Radon Trap designed by P. O'Brien at UofA
- Tested with carboxen and silver zeolite as a trapping medium
- With silver zeolite capable of reducing Rn by a factor of ~1000 at room temp!

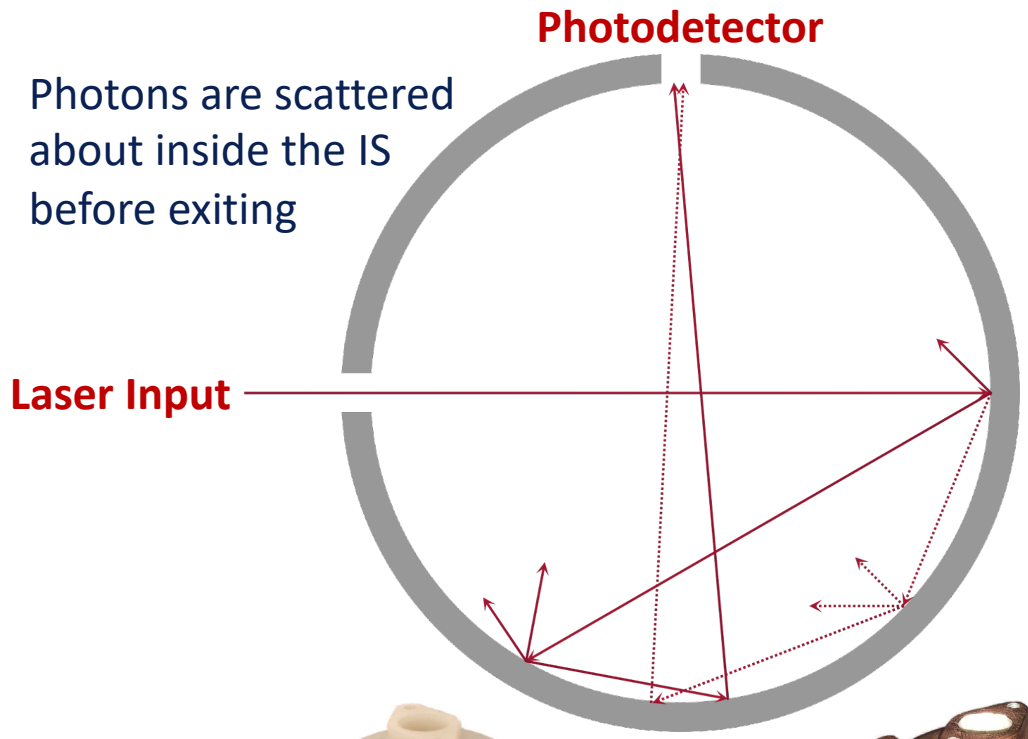
Radon Trap

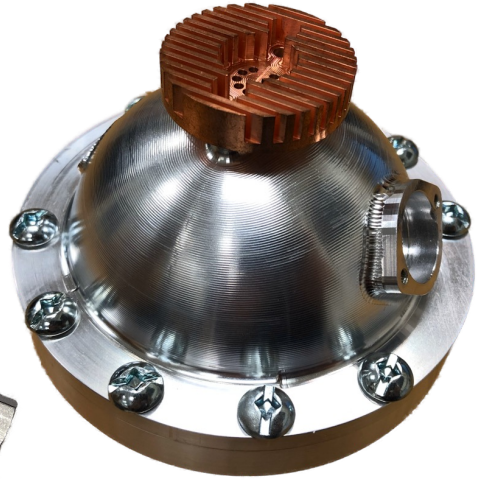



* Red lines indicate flexible tubing

P. O'Brien

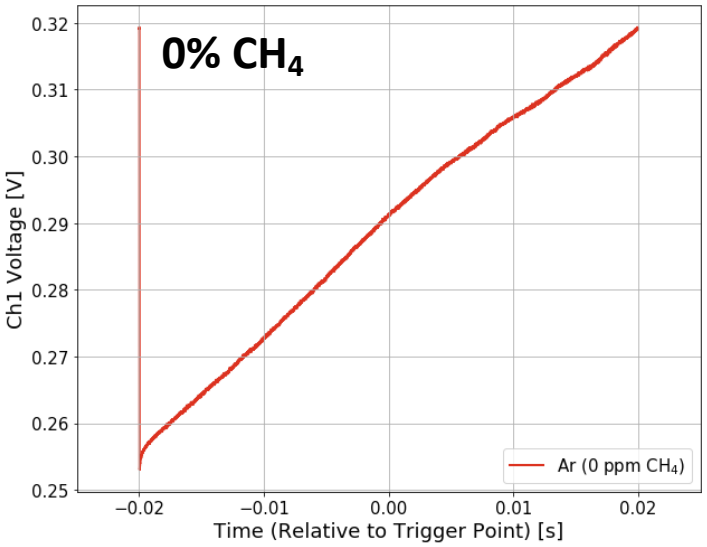
# Integrating Spheres



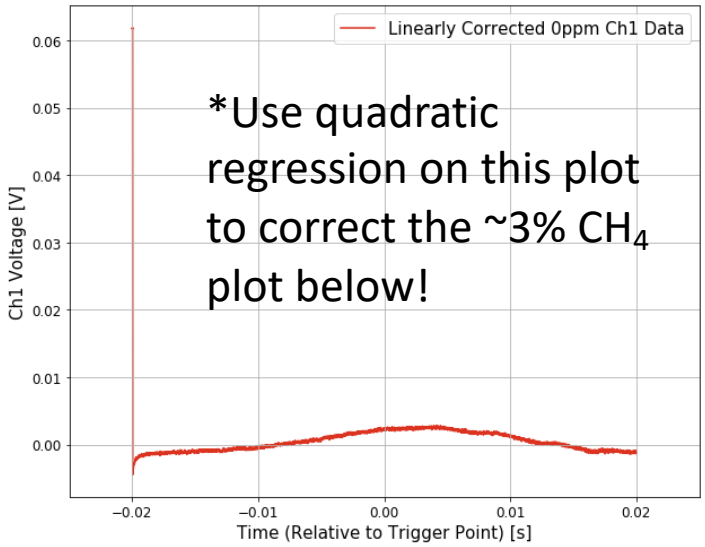



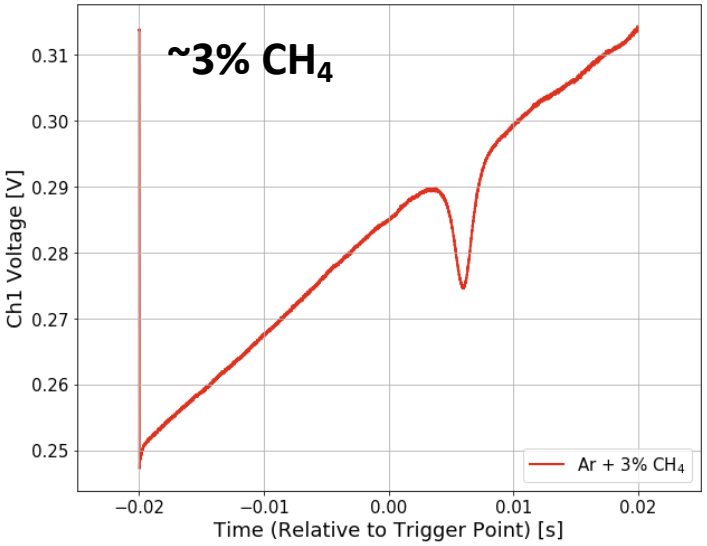
Examples of Integrating Spheres used at Prof. A. Meldrum's Lab at UofA (images via W. Morrish)

# Waveform Cleaning Cuts: Method 1 (I)

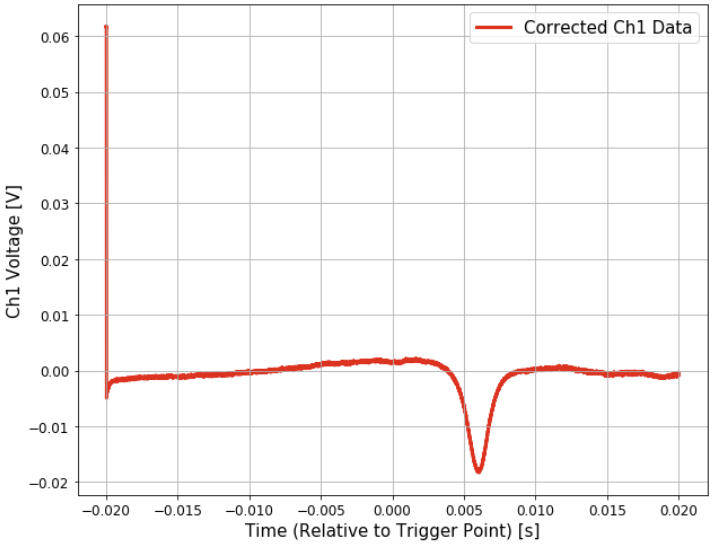



**Linear Correction**



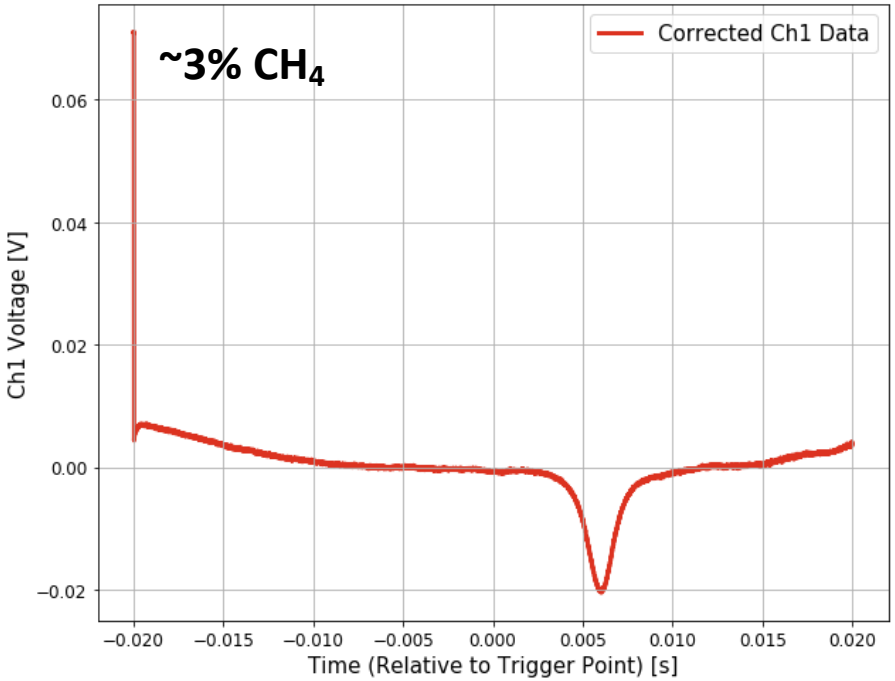



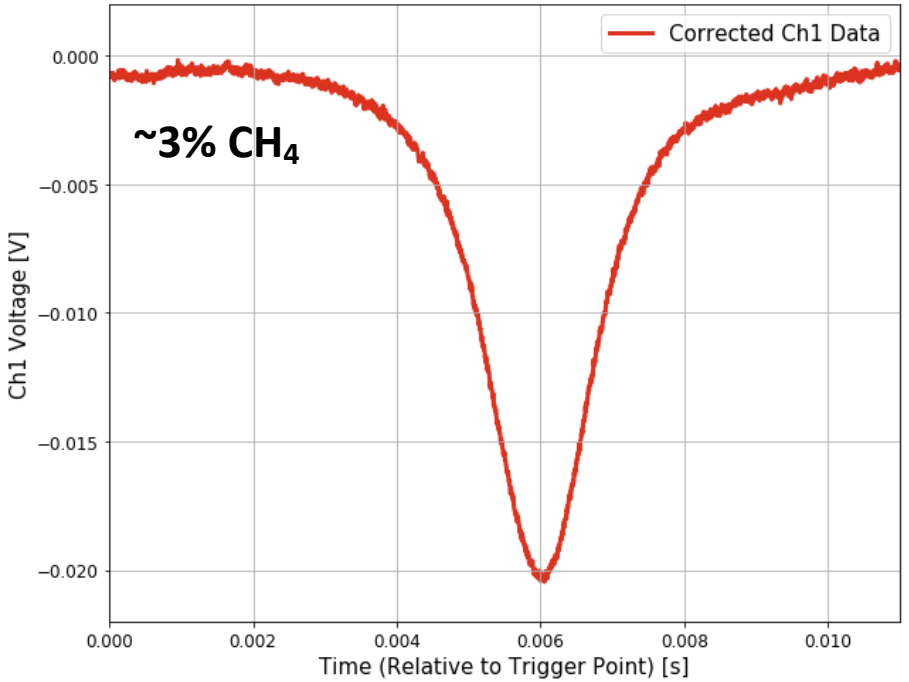

**Linear Correction**



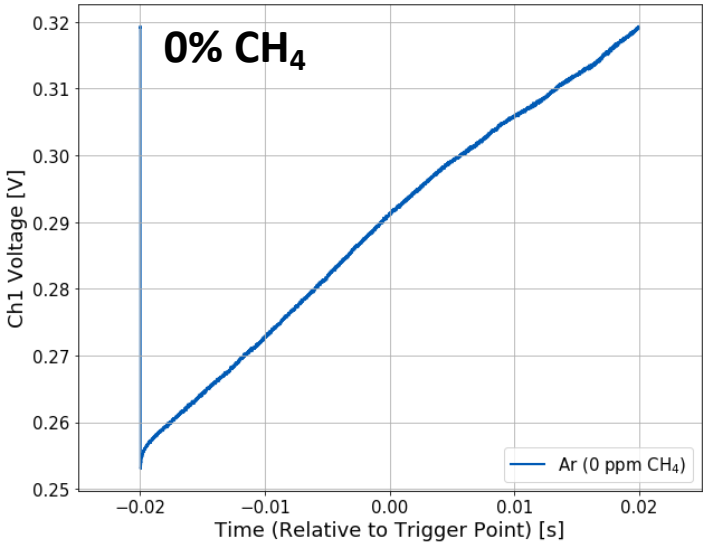
# Waveform Cleaning Cuts: Method 1 (II)

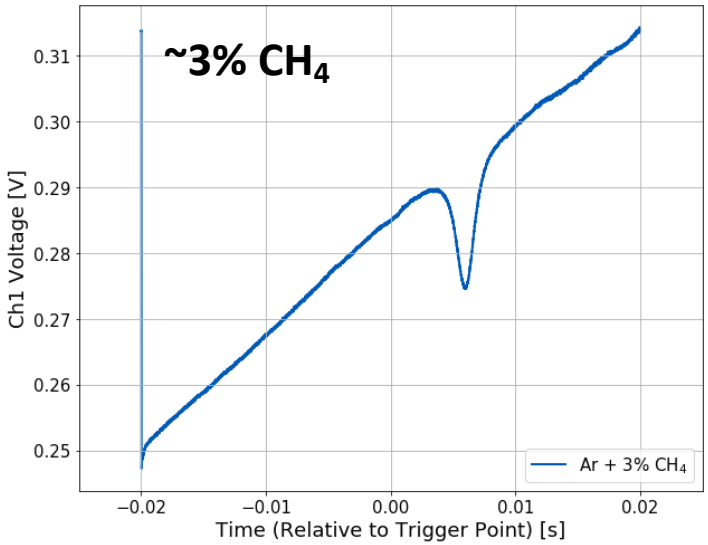
~3% $CH_4$ waveform plot after applying quadratic regression correction extracted from 0 ppm waveform (zoomed view on right, used for $CH_4$ concentration measurement)



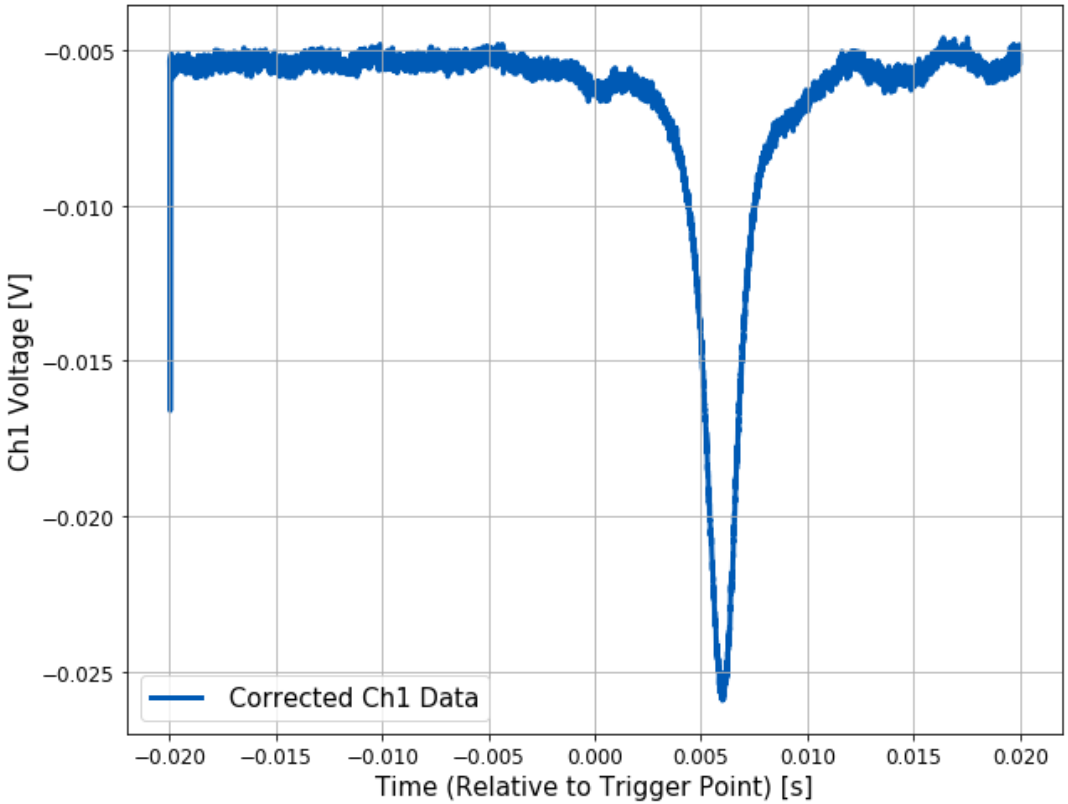



# Waveform Cleaning Cuts: Method 2 (I)



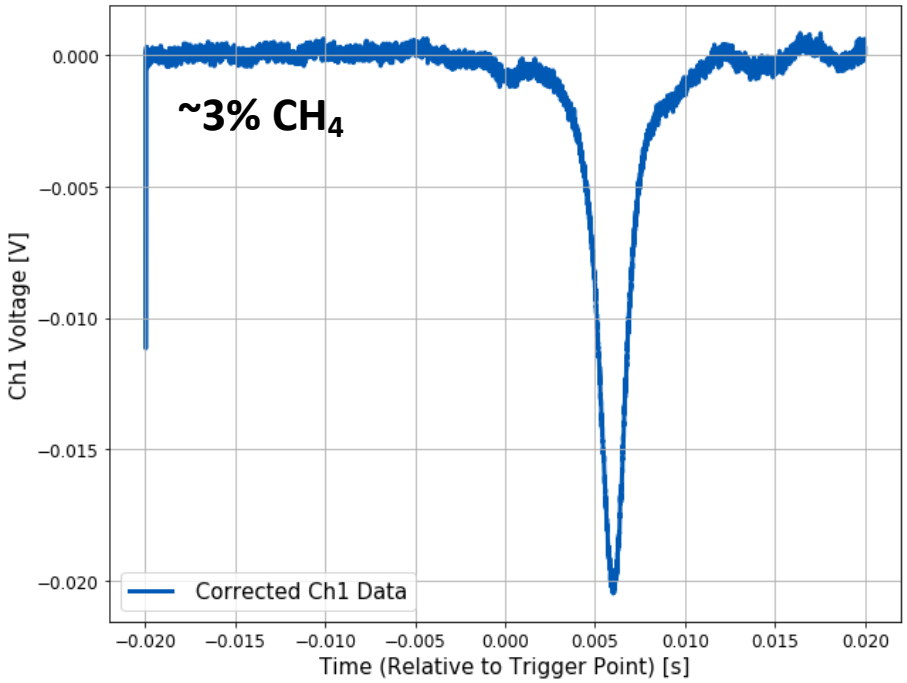



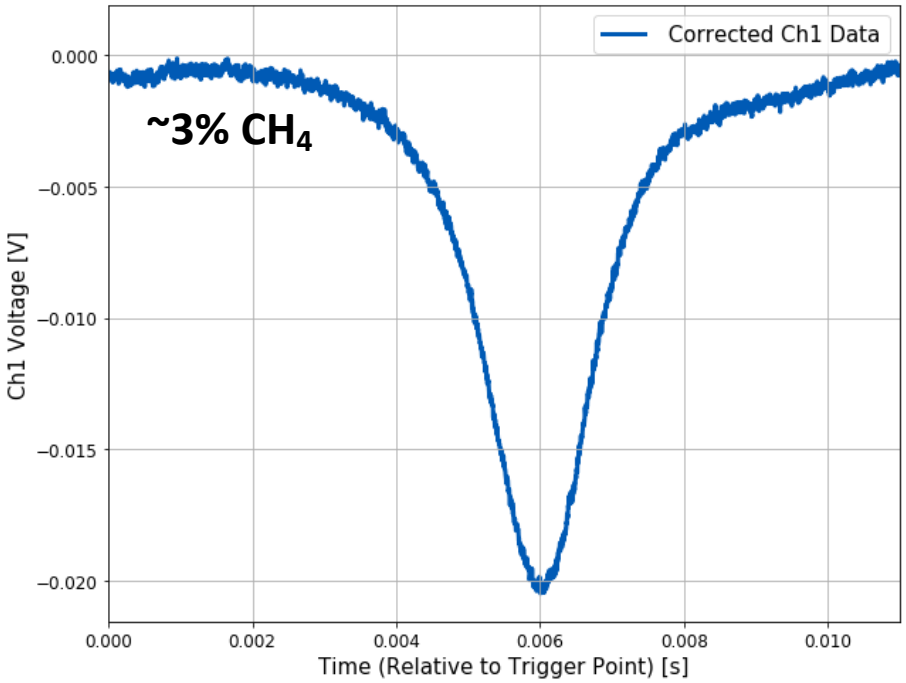

~3% $CH_4$ Waveform after removing 0 ppm Background



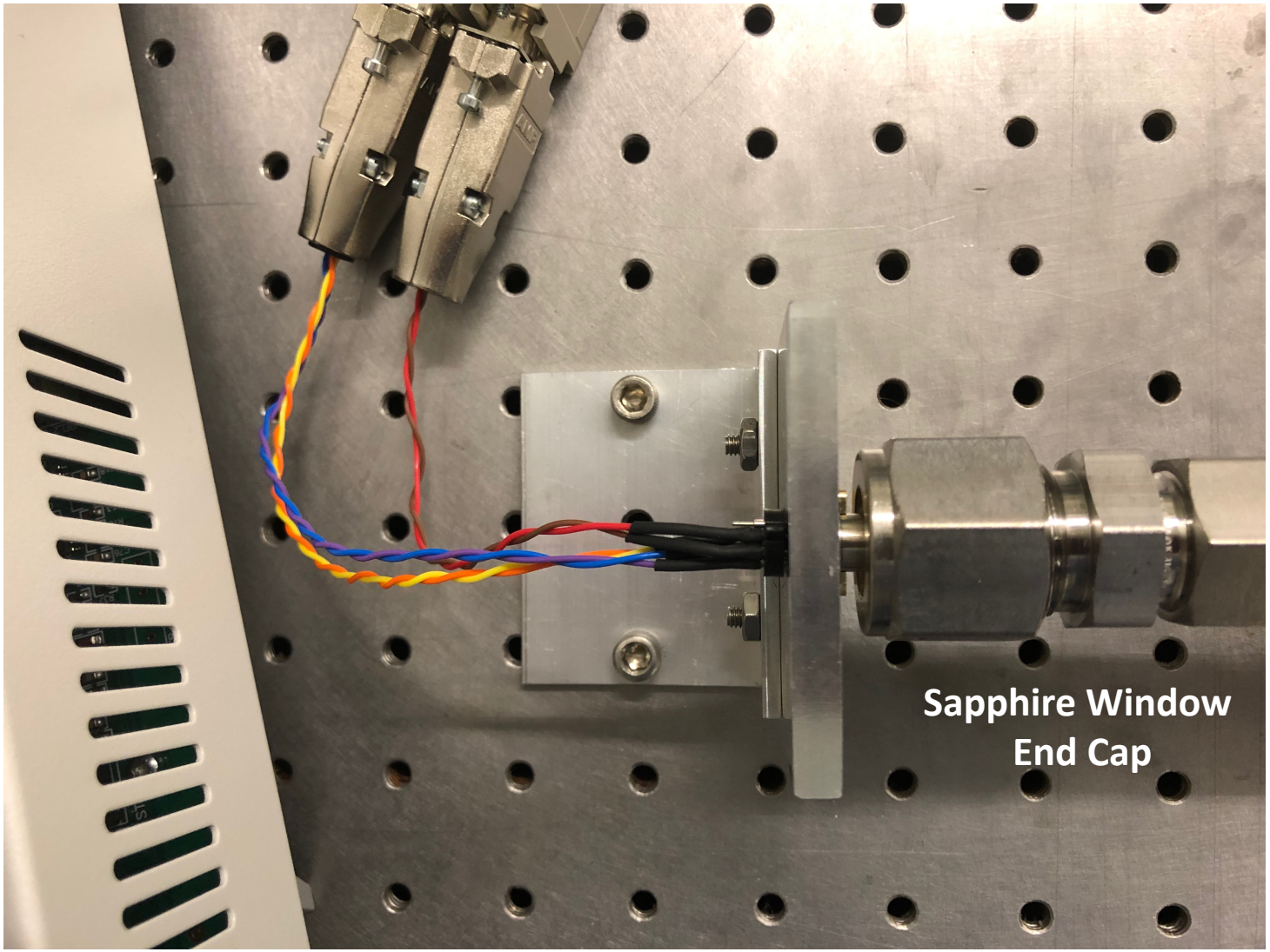
# Waveform Cleaning Cuts: Method 2 (II)

~3% $CH_4$ waveform plot after correcting for baseline offset post-background subtraction cut (zoomed view on right, used for $CH_4$ concentration measurement)



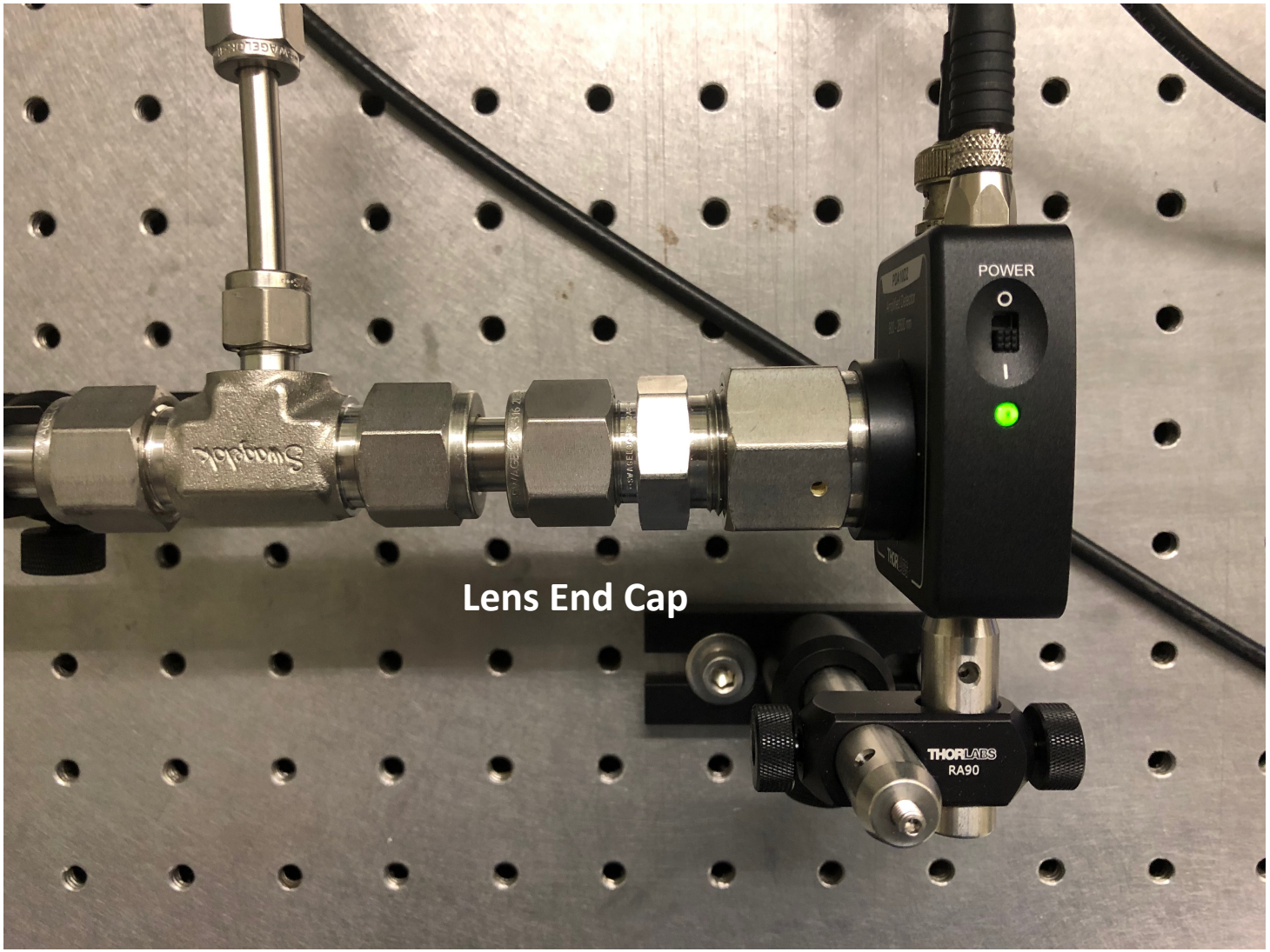



# More LAS Photos (I)




**Bracket-Mounted NORCADA 1654 nm Laser Diode**

# More LAS Photos (II)




**Thorlabs PDA10D2 InGaAs Amplified Photodetector**