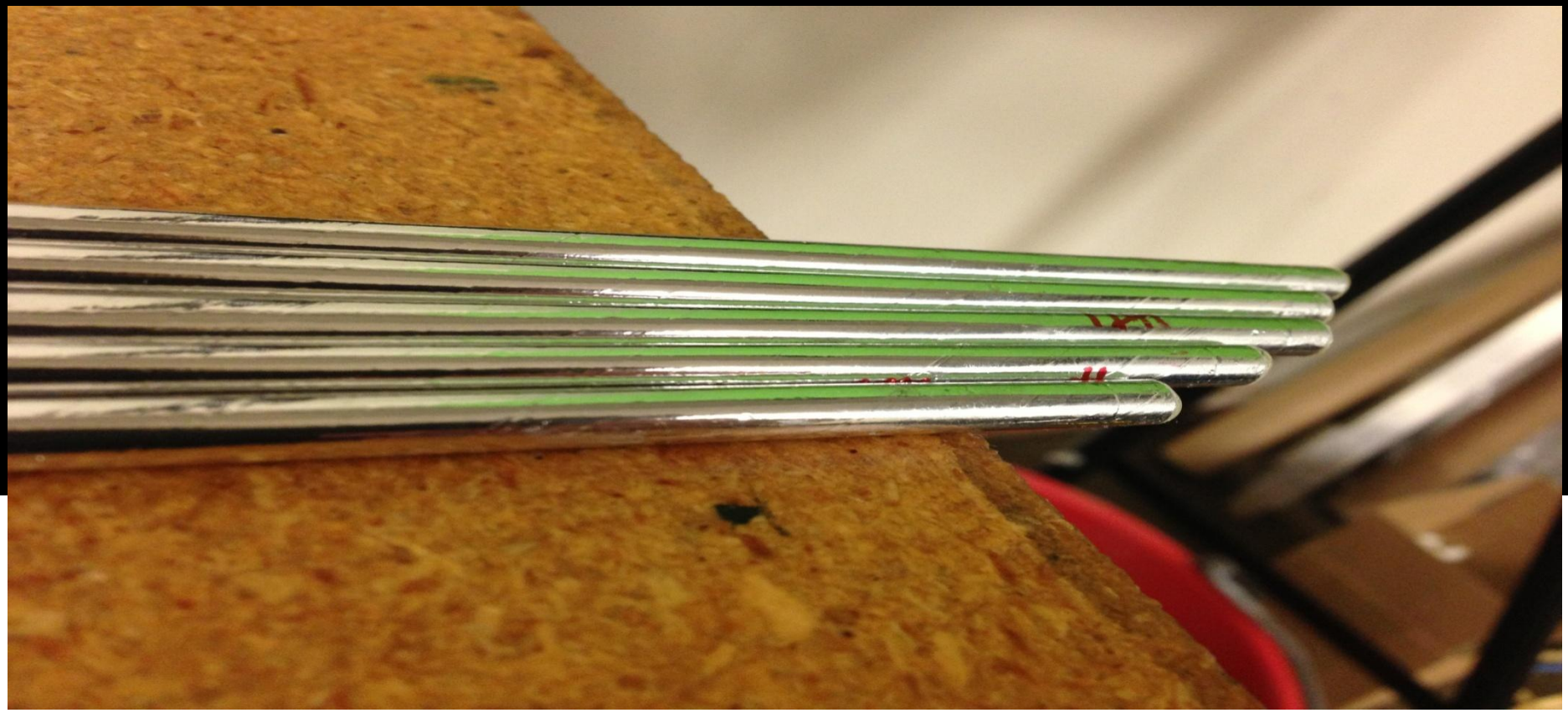
Straw CO_2 Leak Testing



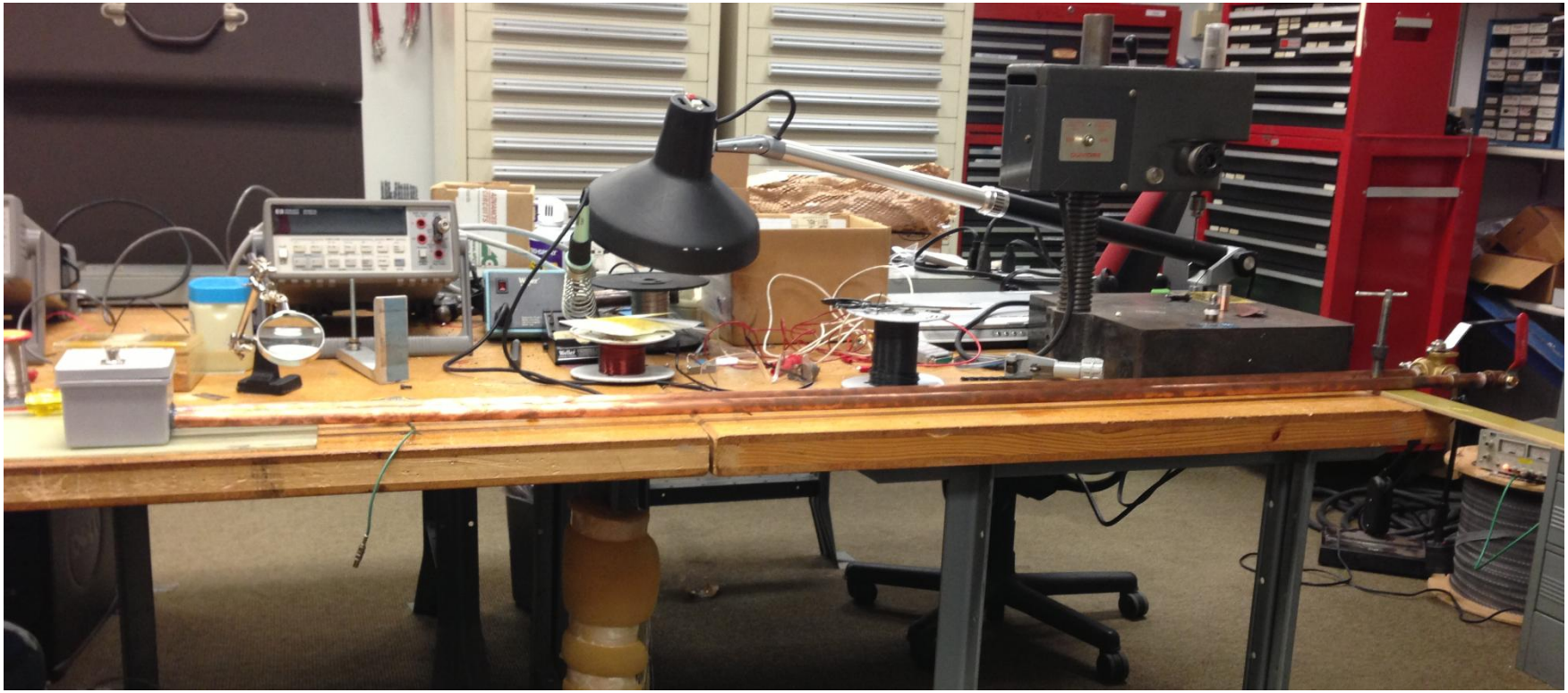
Preparation of the Straws (Brief)

- The ABS end pieces printed on a Fermilab 3D printer are cleaned in an ultrasonic cleaner with isopropyl alcohol or ethanol (either works well with ABS) for 10 minutes inside a water bath
- The pieces are allowed to dry
- A 24-h Epoxy is prepared by mixing Epon Resin 828 with Epikure Curing Agent 3155 in a 100/70 ratio
- The epoxy is applied to the end pieces and pieces are inserted on each end of the straw
- The Epoxy is then allowed to cure at room temperature for an hour

Preparation continued

- The ends of the straw are then heated to ~60 °C using heating pads
- The Epoxy is allowed to cure at this temperature for 4 hours

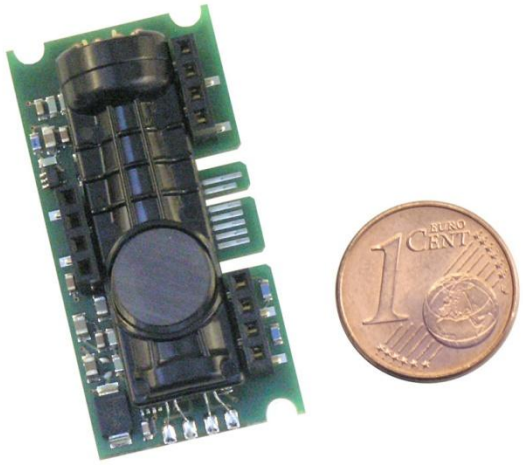
CO_2 Leak Testing



Approximate Volume of Chamber: 733 mL

CO_2 Sensors

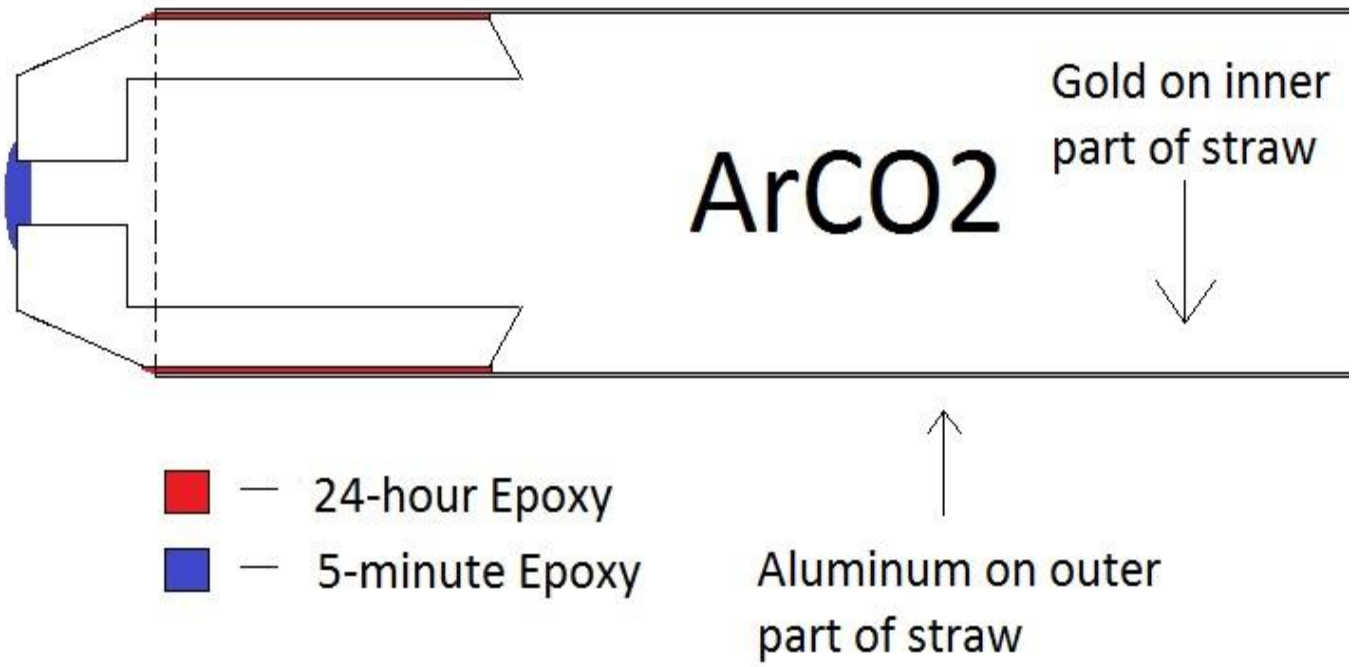
- The sensors in our CO2 chamber are made by E+E Elektronik
- Both the older model EE892 and the newer model EE891 were utilized
- A LPC2103 microcontroller was used to communicate to the sensors via the E2 interface



EE891

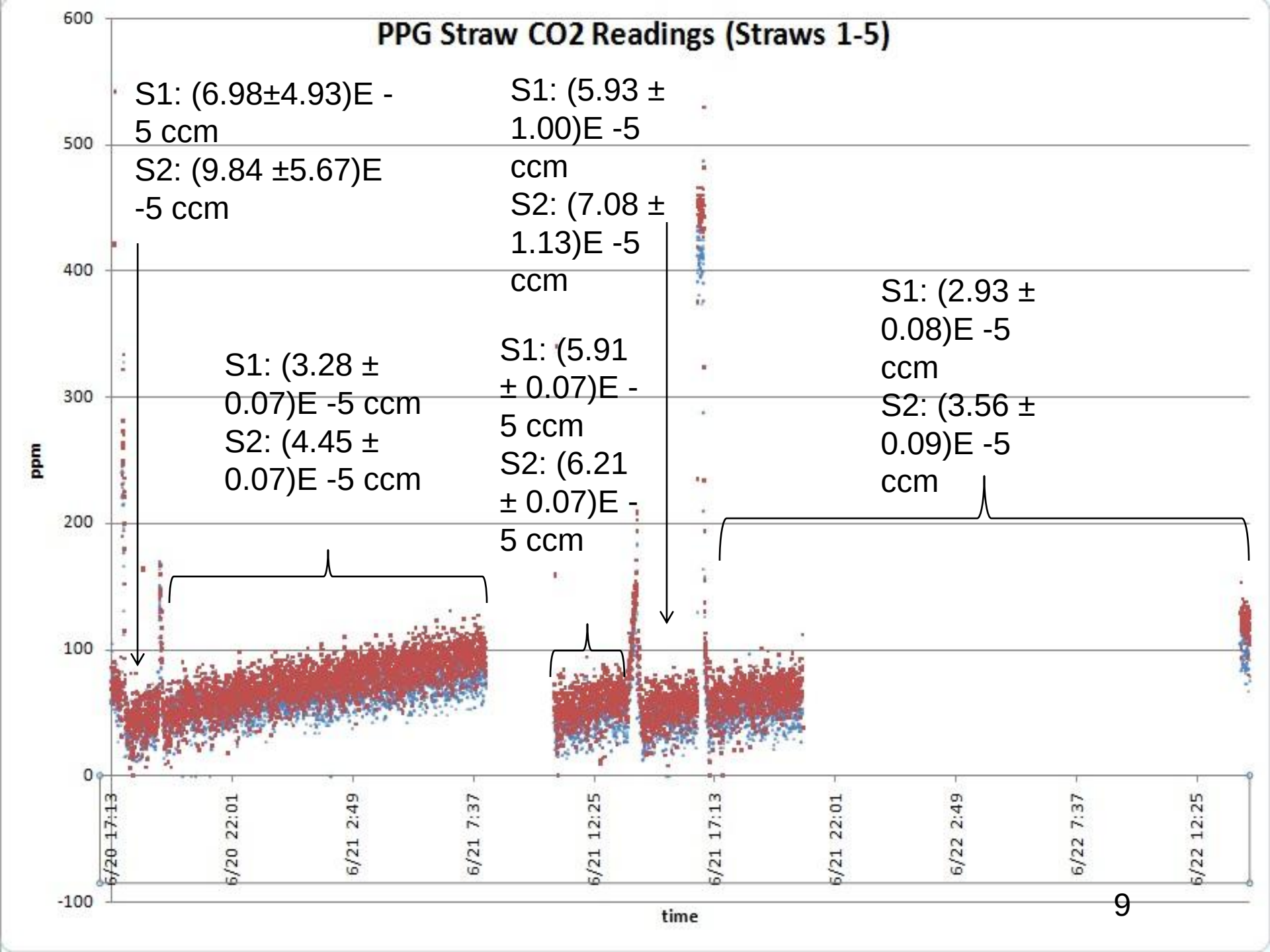
PPG Straw Leak Testing

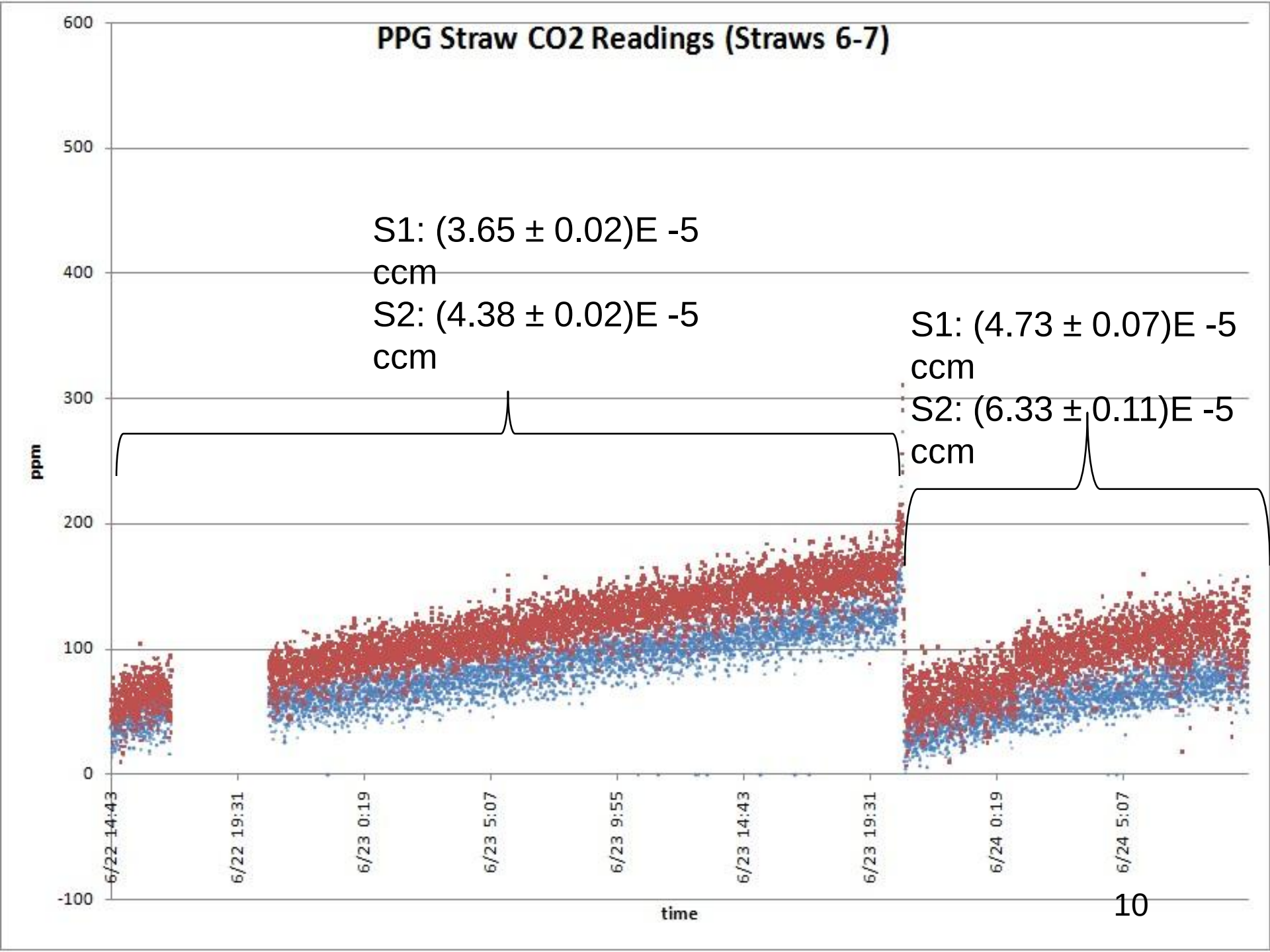
- PPG Straws
- Flush with $ArCO_2$ for ~5 minutes (less time is fine with higher flow rate, usually 1 L/m)
- Seal ends with 5 Minute Epoxy
- Allow Epoxy to cure at room temperature for about 10 minutes
- Open valve to air and insert straw into chamber
- Purge with N_2 for 5 minutes


ArCO2
Gold on inner part of straw
24-hour Epoxy
5-minute Epoxy
Aluminum on outer part of straw

Leak Rates

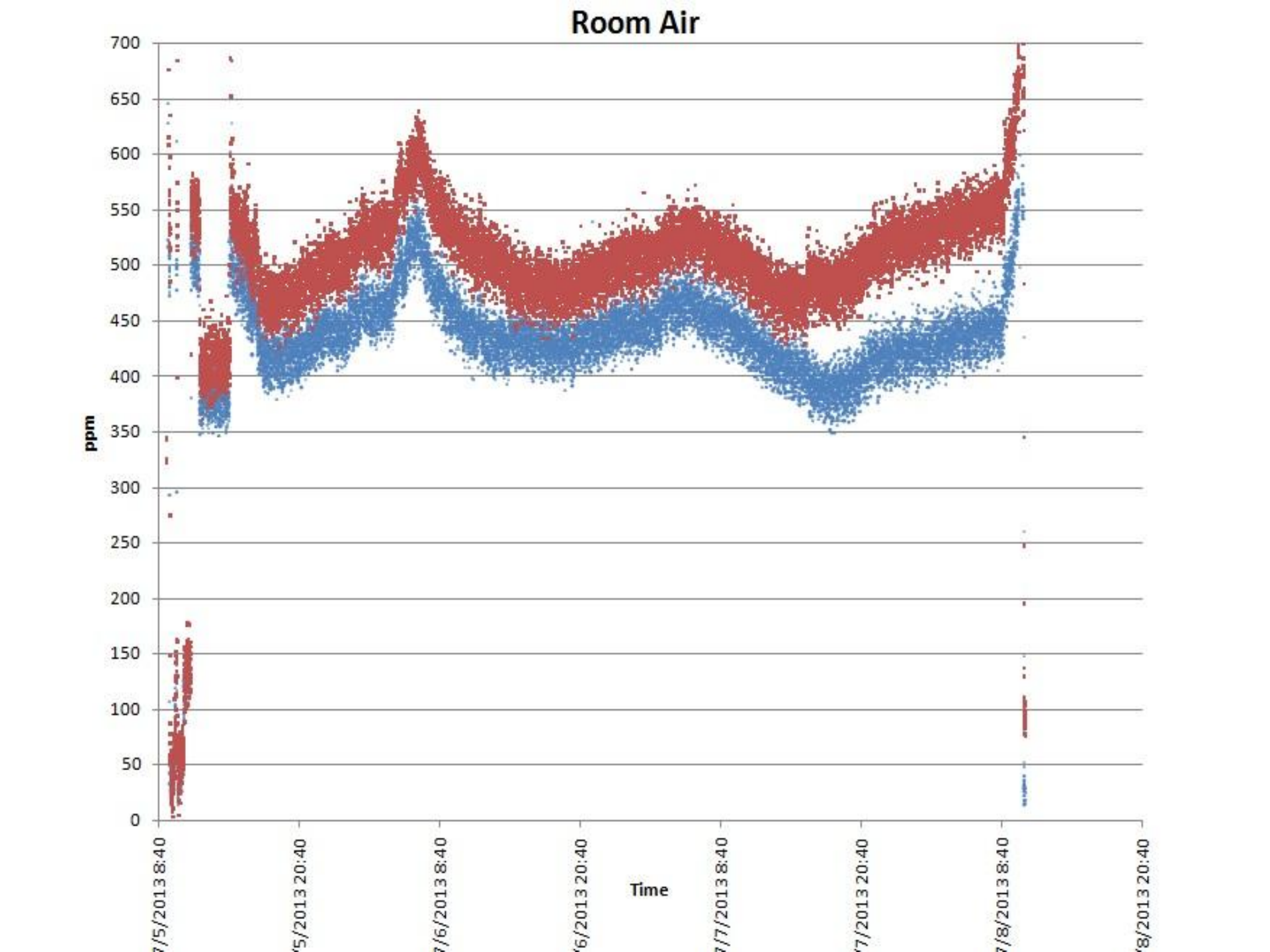
- The upper limit on the leak rates for the straws to be used in the detector is $40x10^{-5}$ ccm (per straw)
- The leak rate tests performed on the PPG straws that will be used for the Mu2e detector all were well below this limit ranging from below 1E-5 ccm to ~10 ccm
- In the worst case scenario the highest leak rate from this batch was ~15E-5 ccm (taking into account the error in the slope)


PPG Straw CO2 Readings (Straws 1-5)
S1: (6.98±4.93)E -5 ccm
S2: (9.84 ±5.67)E -5 ccm
S1: (3.28 ± 0.07)E -5 ccm
S2: (4.45 ± 0.07)E -5 ccm
S1: (5.93 ± 1.00)E -5 ccm
S2: (7.08 ± 1.13)E -5 ccm
S1: (5.91 ± 0.07)E -5 ccm
S2: (6.21 ± 0.07)E -5 ccm
S1: (2.93 ± 0.08)E -5 ccm
S2: (3.56 ± 0.09)E -5 ccm
ppm
600
500
400
300
200
100
0
-100
6/20 17:13
6/20 22:01
6/21 2:49
6/21 7:37
6/21 12:25
6/21 17:13
6/21 22:01
6/22 2:49
6/22 7:37
6/22 12:25
time


PPG Straw CO2 Readings (Straws 6-7)
S1: (3.65 ± 0.02)E -5 ccm
S2: (4.38 ± 0.02)E -5 ccm
S1: (4.73 ± 0.07)E -5 ccm
S2: (6.33 ± 0.11)E -5 ccm
ppm
600
500
400
300
200
100
0
-100
6/22 14:43
6/22 19:31
6/23 0:19
6/23 5:07
6/23 9:55
6/23 14:43
6/23 19:31
6/24 0:19
6/24 5:07
time

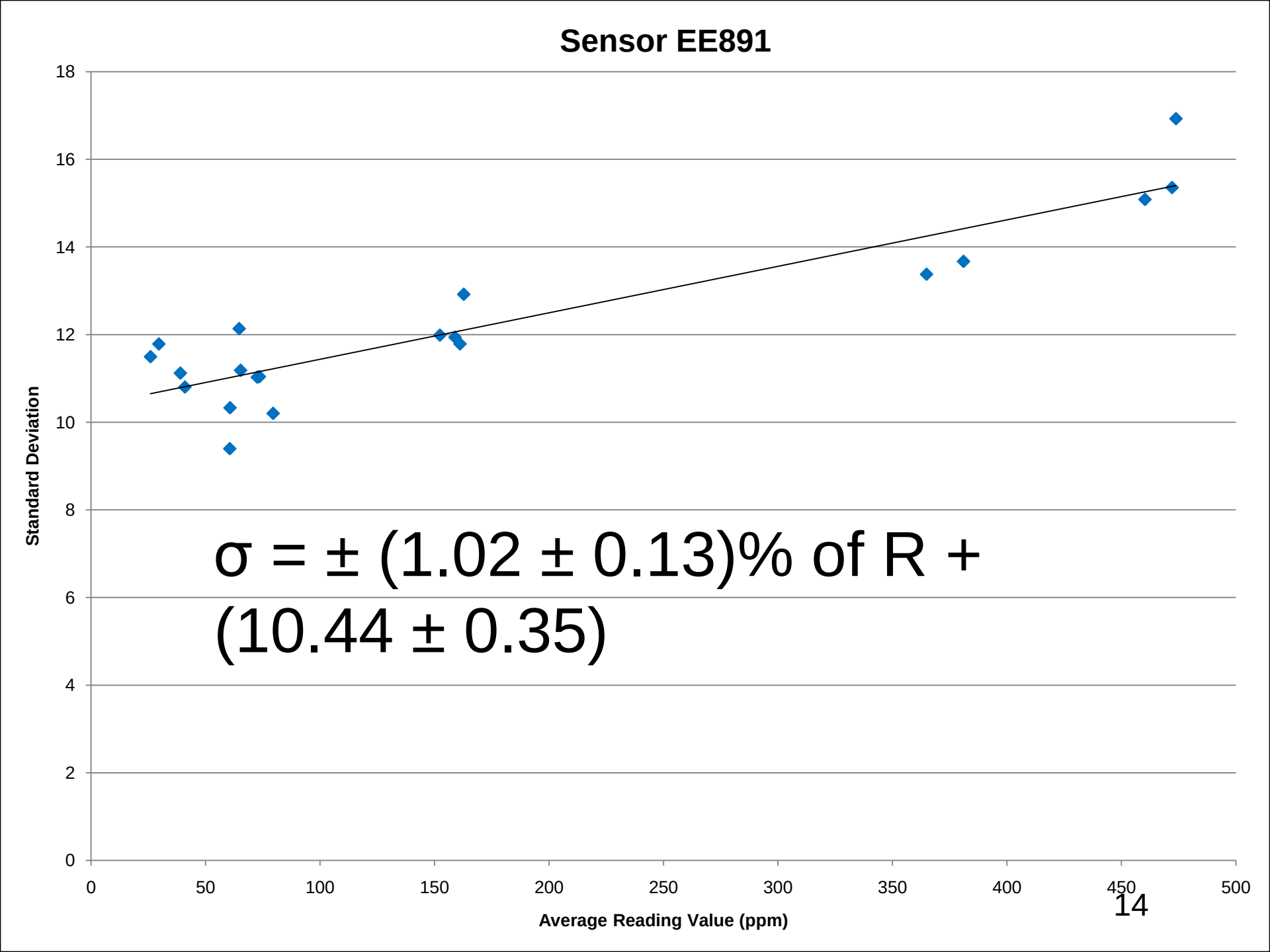
Room Air

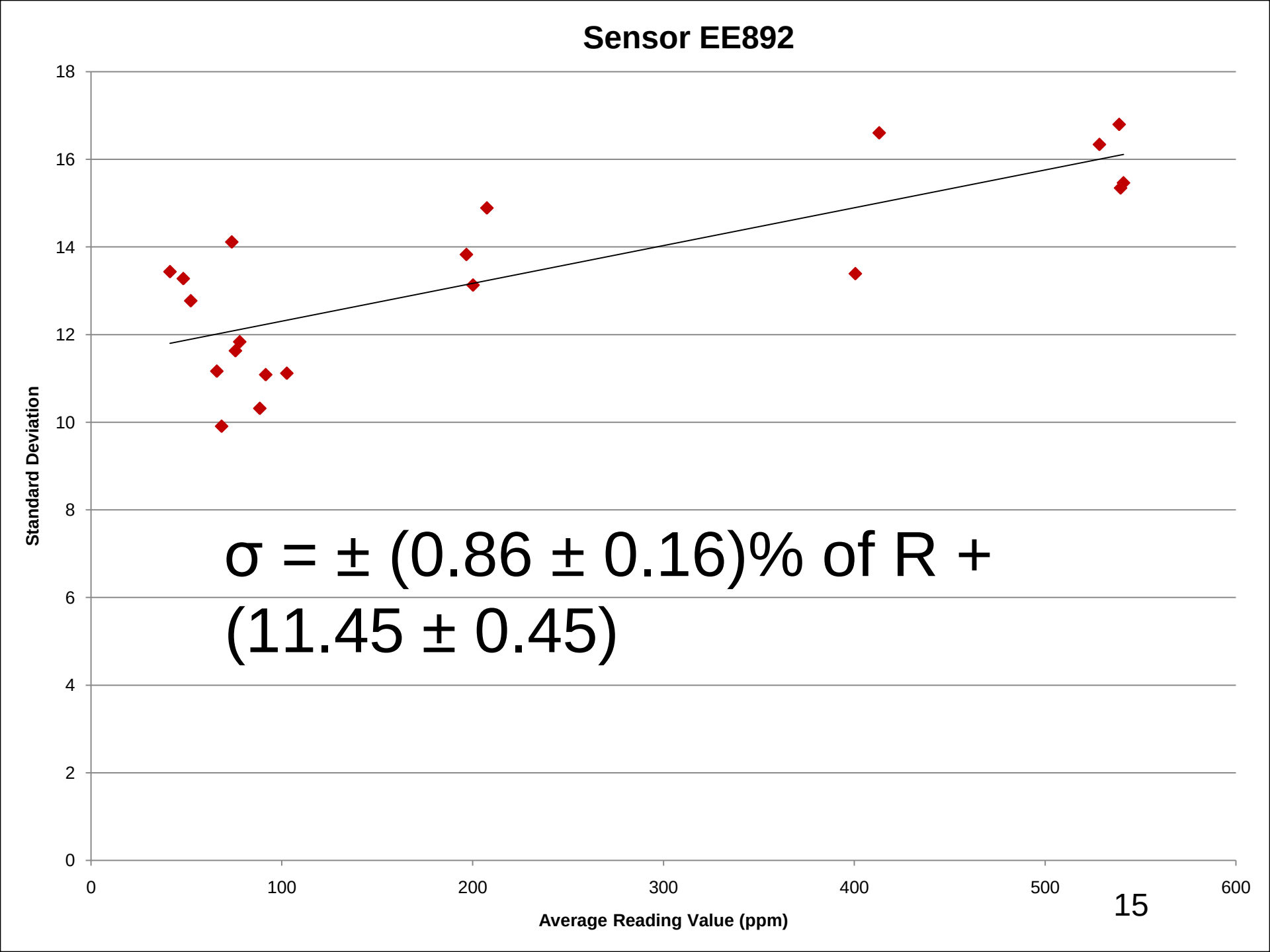
- Left straw valve open to air over night and over a weekend
- The ambient CO_2 levels fluctuated throughout the weekend (see next slide)
- The fluctuations seemed to peak early in the morning on Monday, most likely due to people walking into the room
- Conclusion: Room air would not be suitable for a background, due to lack of control


Room Air
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
ppm
Time
7/5/2013 8:40
7/5/2013 20:40
7/6/2013 8:40
7/6/2013 20:40
7/7/2013 8:40
7/7/2013 20:40
7/8/2013 8:40
7/8/2013 20:40

N_2 vs. Dry Air

- Reasons for purge:
  - Our sensors are set to take readings in the range of 0-2000 ppm
  - Allowing the chamber to equilibrate with air takes a long time
  - This is more controlled and we can directly compare leak rates between straws by following the same protocol
- The manufacturer quotes the error for the newer sensor (EE891) as being: ±(50ppm + 2% of reading value)
- Hence the error increases as the reading value increases, and overall the sensors are more precise when concentrations of CO_2 are low
- A plot of standard deviation vs. average reading value was preformed on small 30-60 minute segments or segments in the plot which remained flat
- The error was calculated based on this plot and it would appear that the error is in fact lower than what the manufacturer quotes but it is still significant in that it is still directly proportional to the reading value


Sensor EE891
Standard Deviation
Average Reading Value (ppm)
0
2
4
6
8
10
12
14
16
18
0
50
100
150
200
250
300
350
400
450
500
σ = ± (1.02 ± 0.13)% of R +
(10.44 ± 0.35)


Sensor EE892
Standard Deviation
Average Reading Value (ppm)
0
2
4
6
8
10
12
14
16
18
0
100
200
300
400
500
600
σ = ± (0.86 ± 0.16)% of R +
(11.45 ± 0.45)

- Conclusion: Starting with a lower reading value will yield results with reduced spread, a purge with nitrogen is controlled and can reduce the reading value to near zero

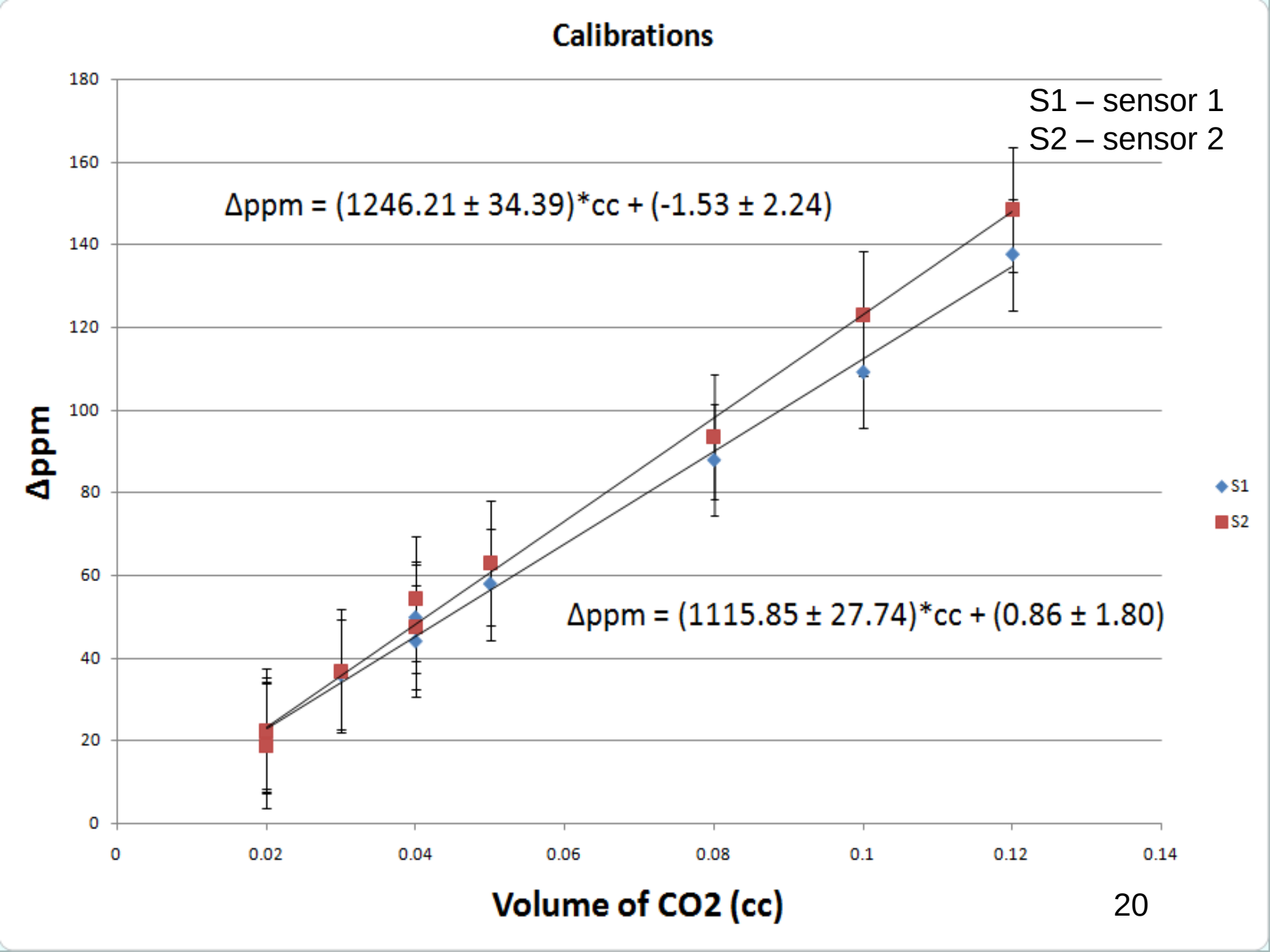
Modification

- A small hole .0135 inches in diameter was drilled by hand into the top of the box, housing the sensors and the fan
- The box was leak tested to ensure that the leak resulting from the drilling of the hole was not too large
- Multiple backgrounds were taken to test the effectiveness of taping over the hole with tape
- The best results were achieved using blue 3M Scotch tape


0
μ2e
Leak test with
CO_2 sensors

Calibration Results

- The calibrations were performed by injecting different amounts of $ArCO_2$ using a 0.3 mL syringe
- The results are consistent with a linear fit with a y-intercept of zero, i.e. there is no offset in the observed change in ppm recorded by the sensors


Calibrations
S1 – sensor 1
S2 – sensor 2
Δppm = (1246.21 ± 34.39)*cc + (-1.53 ± 2.24)
Δppm = (1115.85 ± 27.74)*cc + (0.86 ± 1.80)
Δppm
Volume of CO2 (cc)
S1
S2
0
20
40
60
80
100
120
140
160
180
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14

Notes

- There is a tendency for the CO2 in the straws to leak
- Should not leave them sealed once they are leak tested, they collapse