A Raspberry pi project for HEP research

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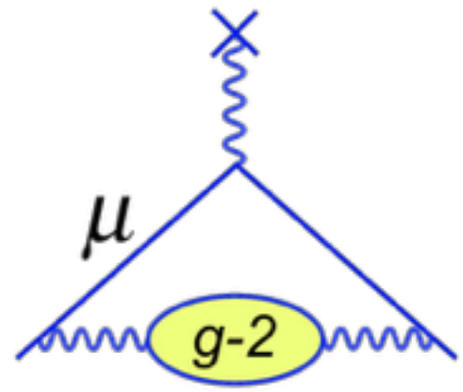
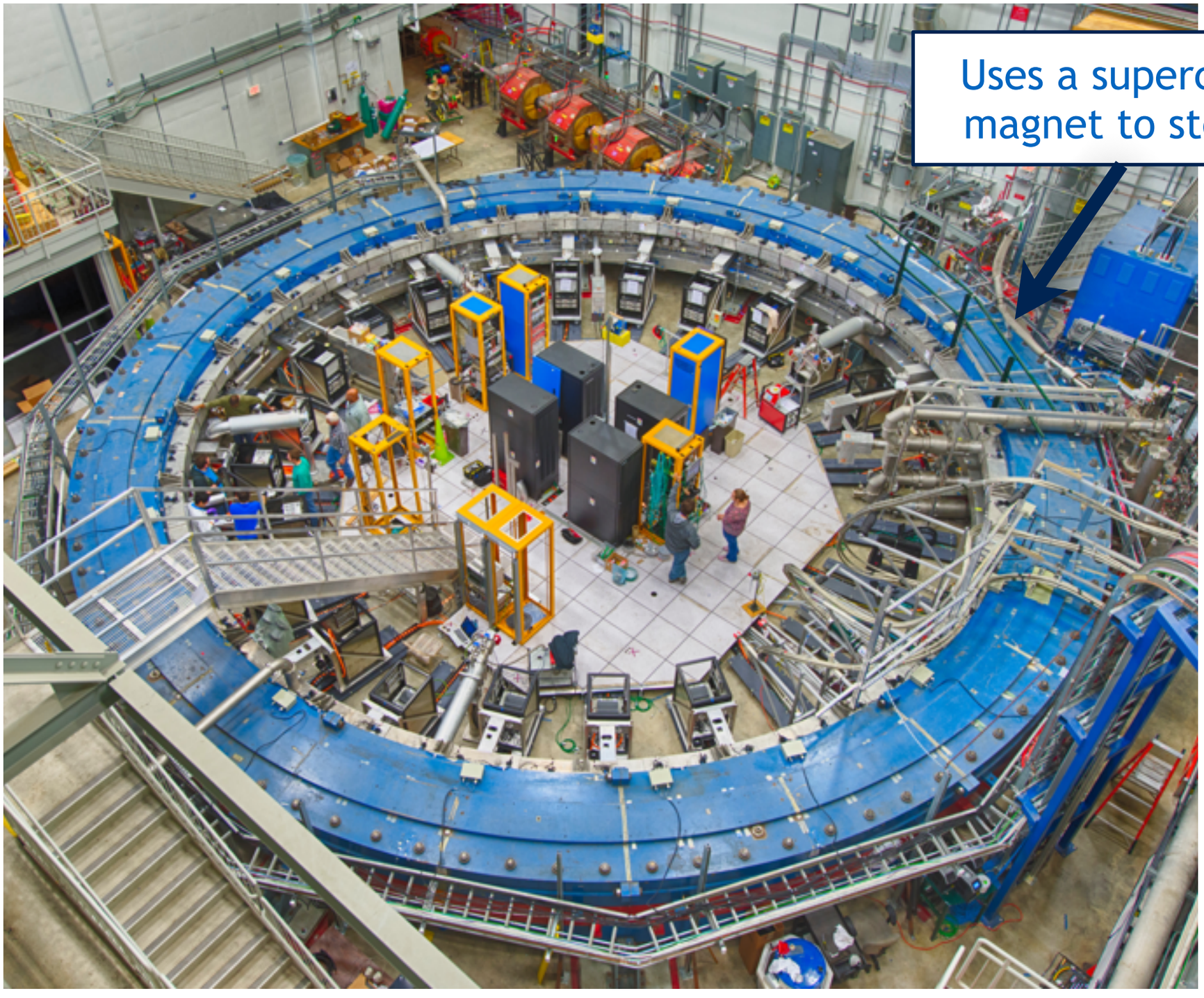
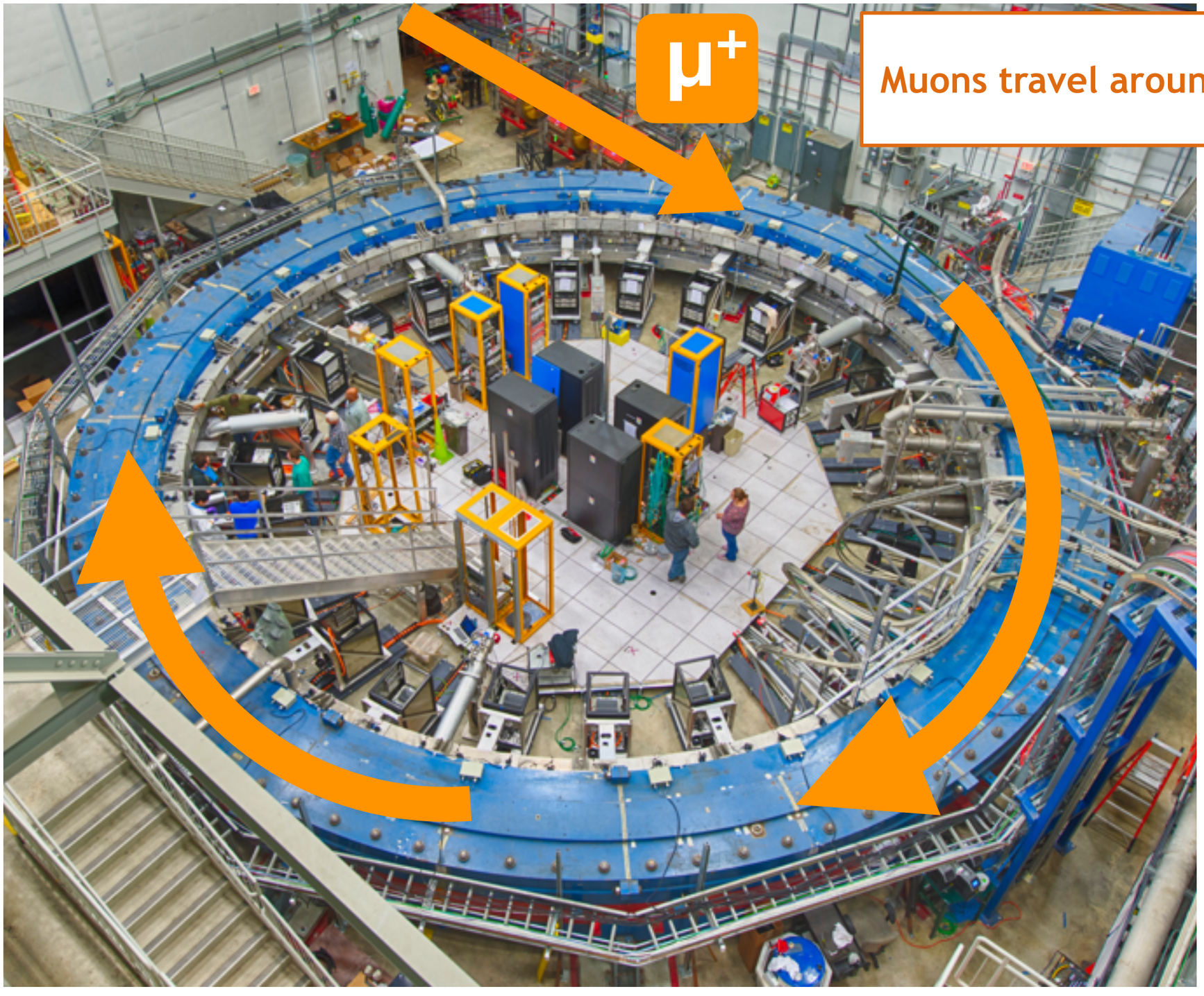


The Muon g-2 experiment

A precision test of the Standard Model at the Fermilab Muon Campus.



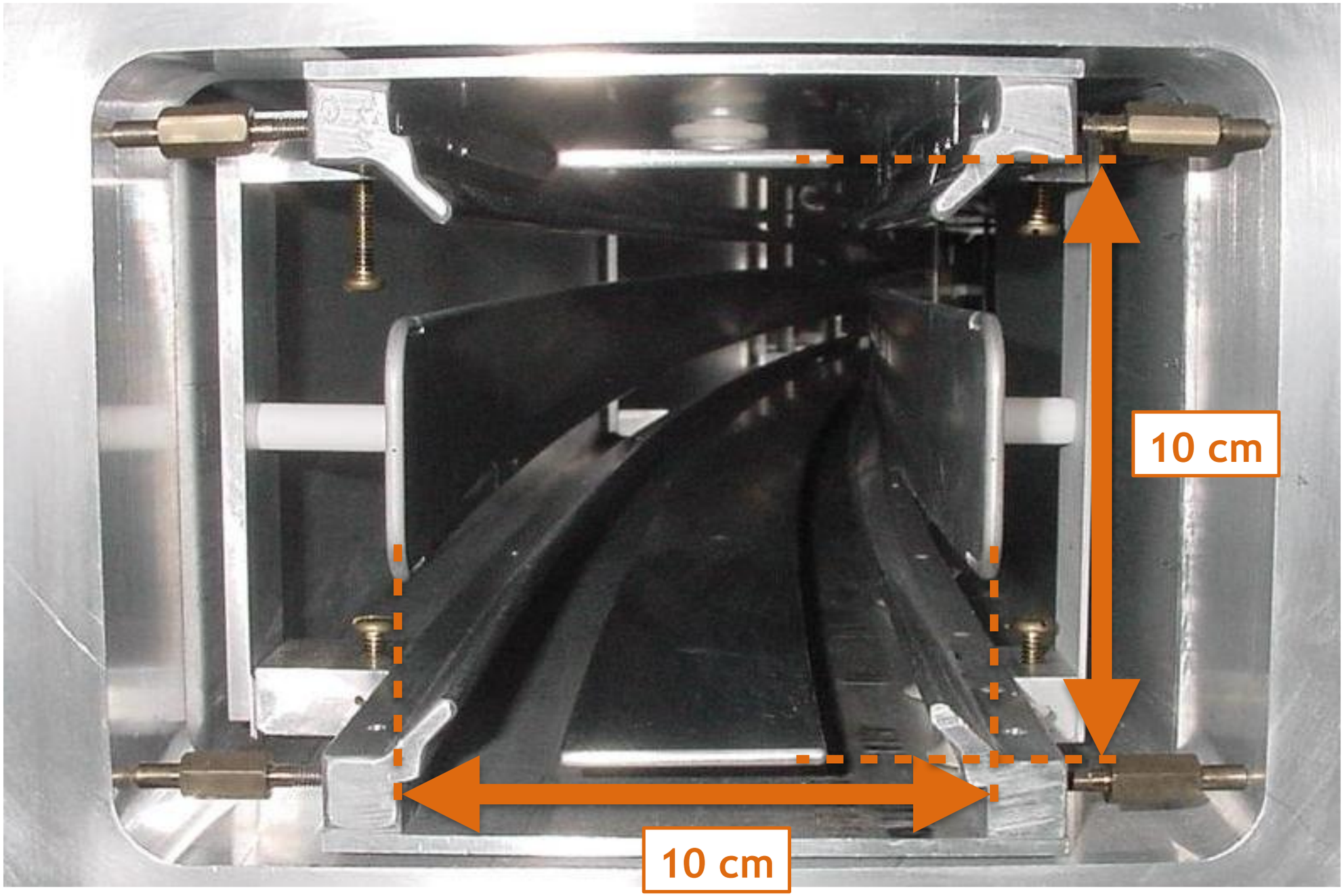
The Muon g-2 experiment



A muon's perspective

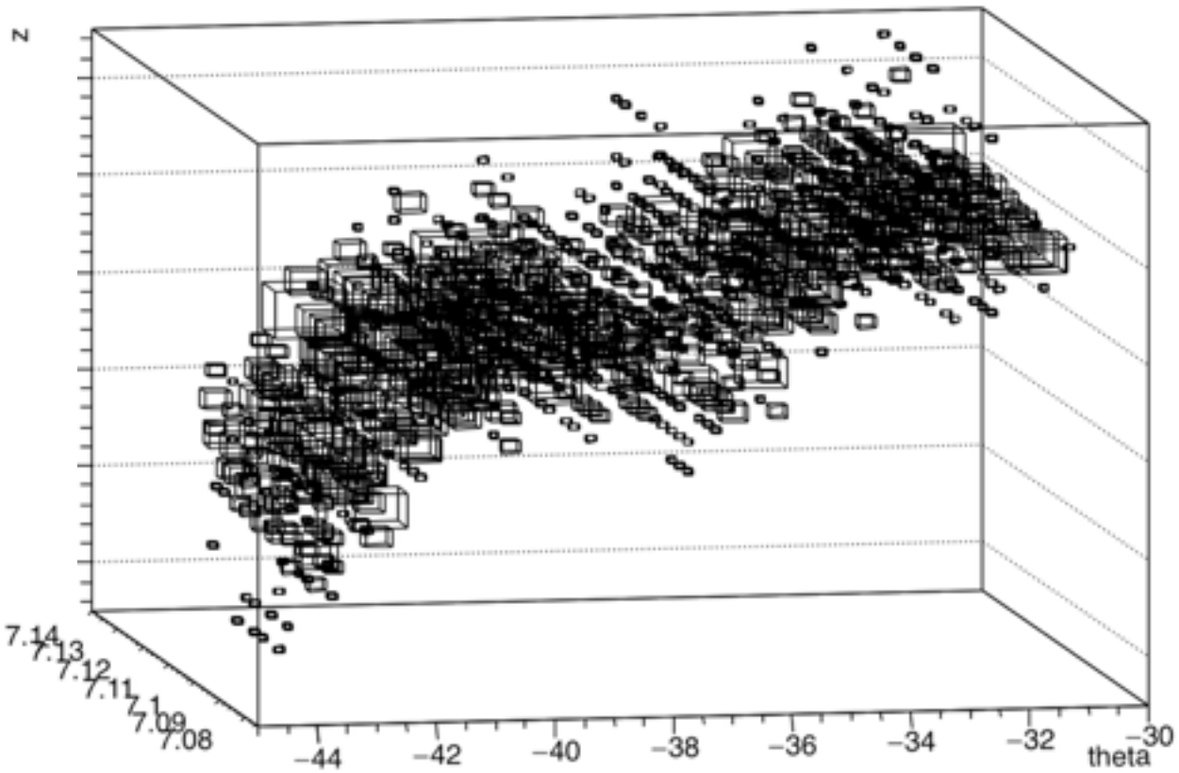
From simulation, and from a trolley inside the storage ring

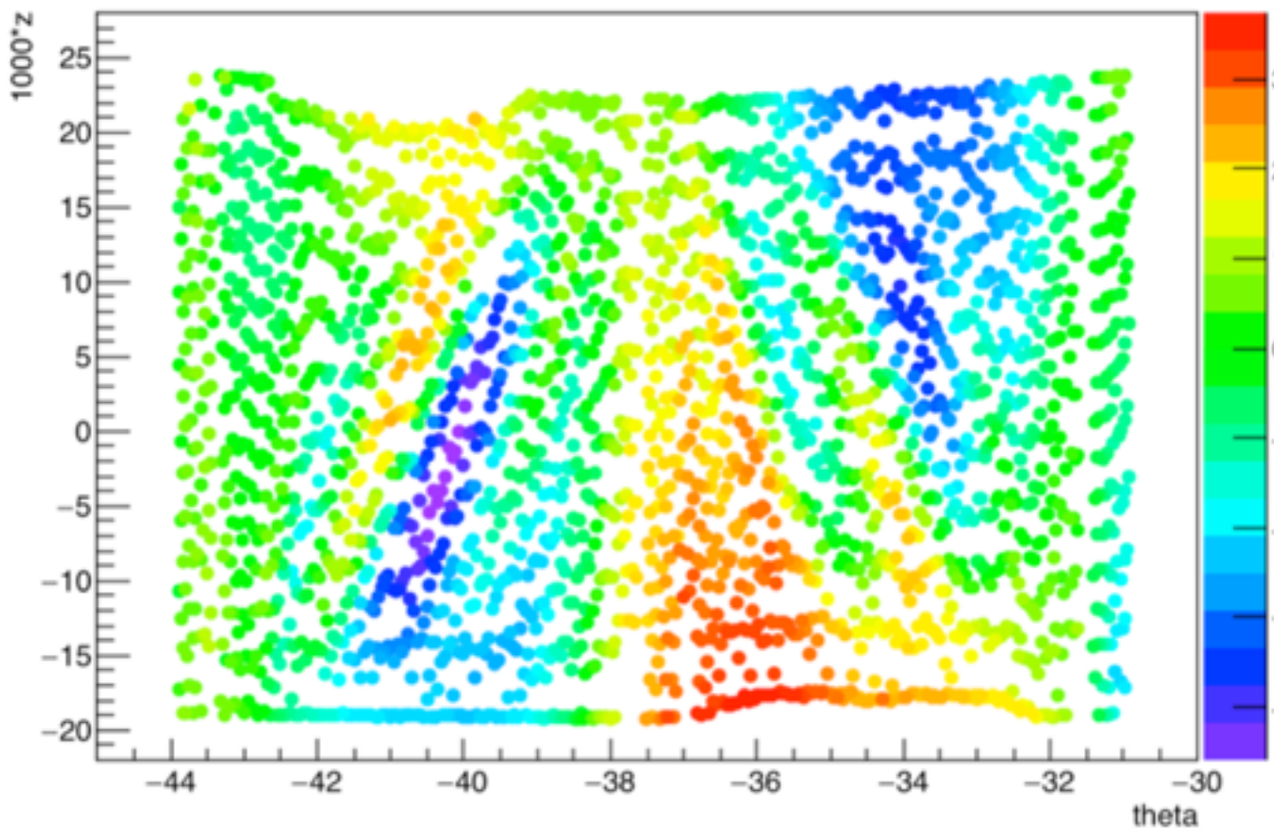
The field from these Electrostatic Quadrupole plates focuses muons vertically



For accurate simulations, we need to know their exact location with **sub-mm precision**

The location of the plates was sampled by the Alignment and Metrology Department with a laser scanner, providing a very rich dataset.





But! This data was taken before the plates were inserted in the ring.

We need some confirmation, **after** they were inserted in the vacuum chambers.

The uncertainty of the plates location is an input to systematic uncertainties.

Problem:

Access inside the vacuum chambers is extremely difficult

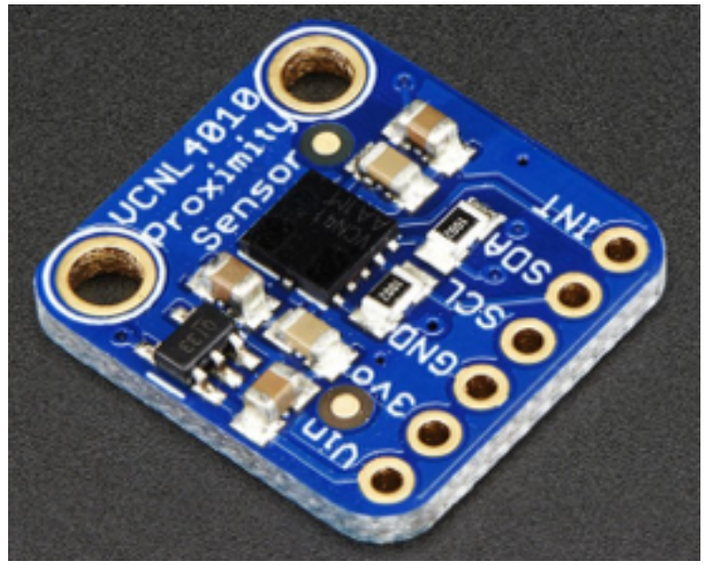
– tiny area, must not interact with plates, access only through flanges

AMD was considering purchasing a specialized sensor

– possibly in the many K range, for sub-mm precision

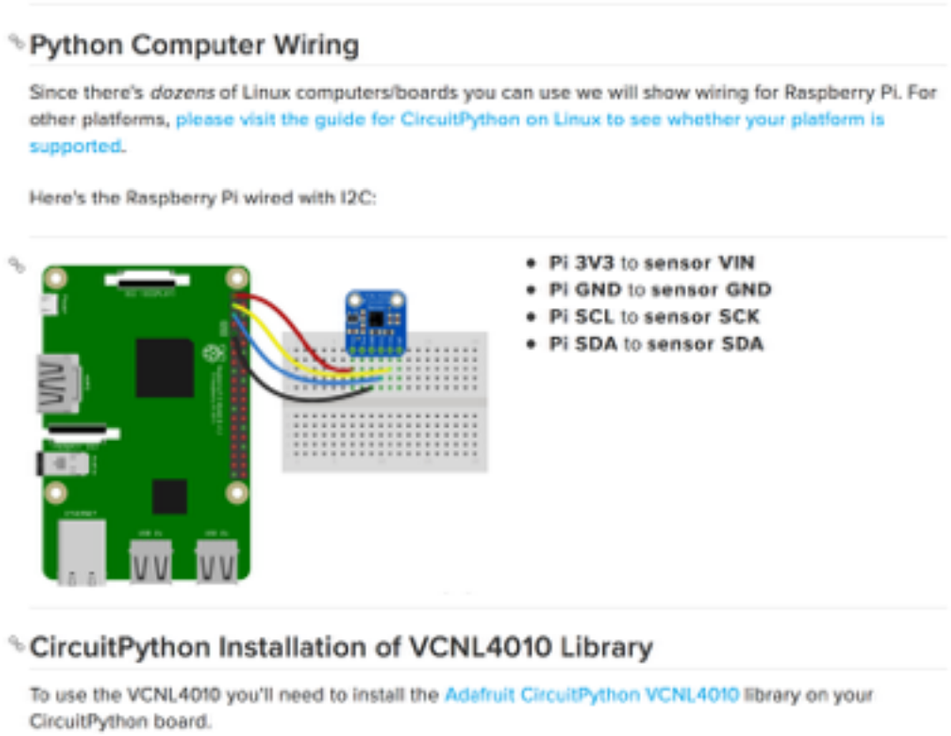
– and still very difficult to come up with a solution that would sample more than just a few points

VCNL sensors controlled by Raspberry pi



VCNL proximity sensors, ~$5-10

- Hobby electronics can achieve sub-mm precision.
  - uses IR LED and photodiode
  - used in robot designs for obstacle avoidance
- Can be controlled from Raspberry pi
  - Arduino also possible, but I'm most familiar with Rpi
  - I2C interface x2
- Libraries, modules, wiring, easy to set up with available resources, even for a novice



Python Computer Wiring

Since there's *dozens* of Linux computers/boards you can use we will show wiring for Raspberry Pi. For other platforms, please visit the guide for CircuitPython on Linux to see whether your platform is supported.

Here's the Raspberry Pi wired with I2C:

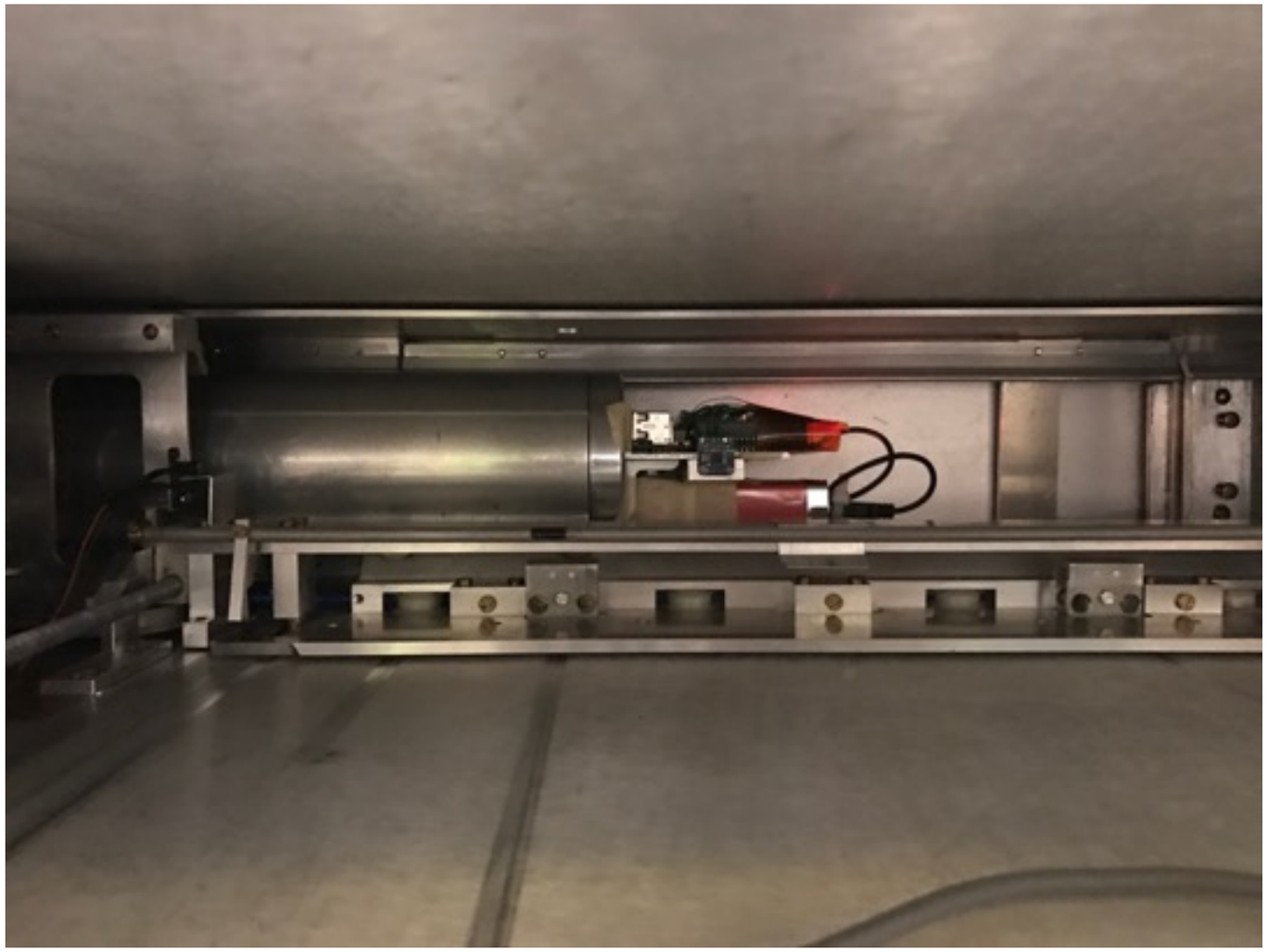
- **Pi 3V3** to **sensor VIN**
- **Pi GND** to **sensor GND**
- **Pi SCL** to **sensor SCK**
- **Pi SDA** to **sensor SDA**

CircuitPython Installation of VCNL4010 Library

To use the VCNL4010 you'll need to install the Adafruit CircuitPython VCNL4010 library on your CircuitPython board.

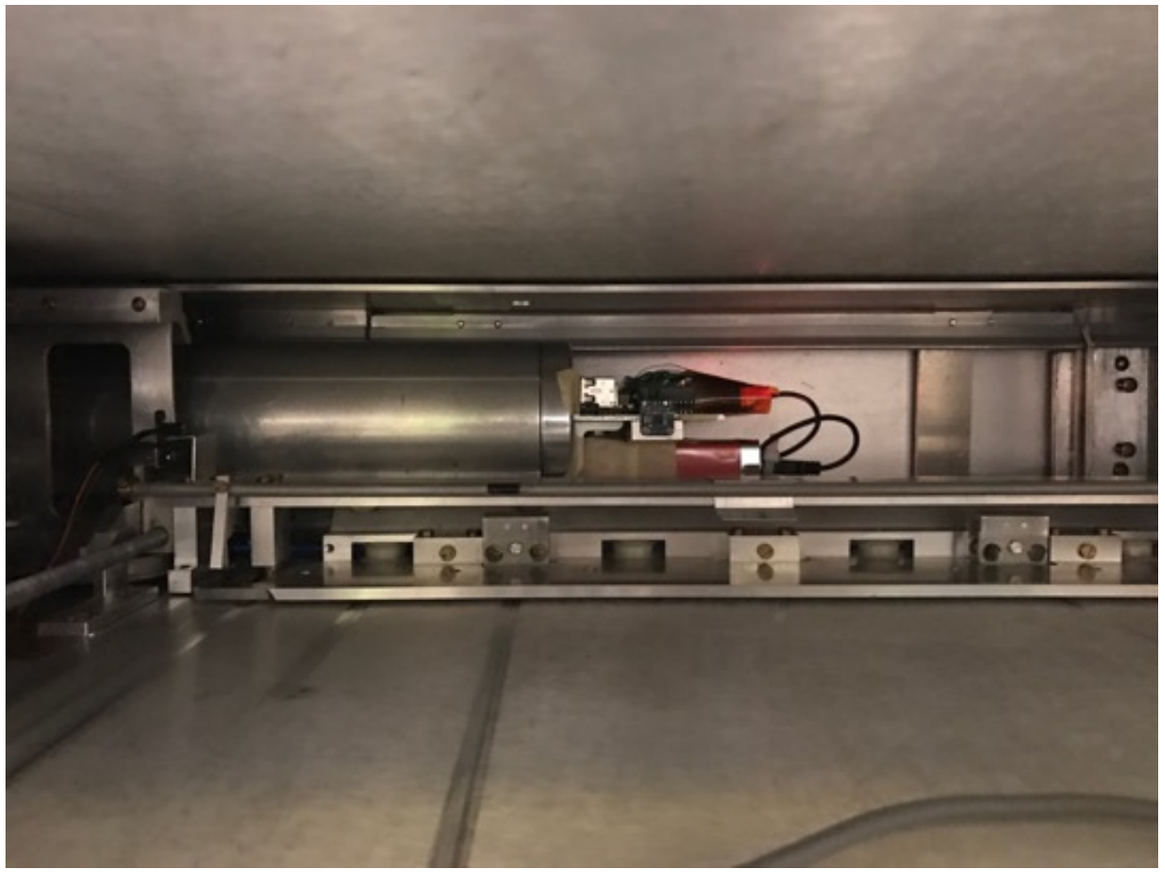
Entire fixture small enough to fit inside vacuum chamber

- Raspberry pi powered by battery
  - Completely autonomous, can run around ring
  - Soldering to fit cable in tight space
- Fixture mounts on 9mm diameter vertical surface of trolley
  - Same trolley as in video earlier
- Therefore all plates can be sampled
- The sensors have rather small range, and were ~1 cm from plates (not ideal)
  - Misalignment and interaction with plates was a concern

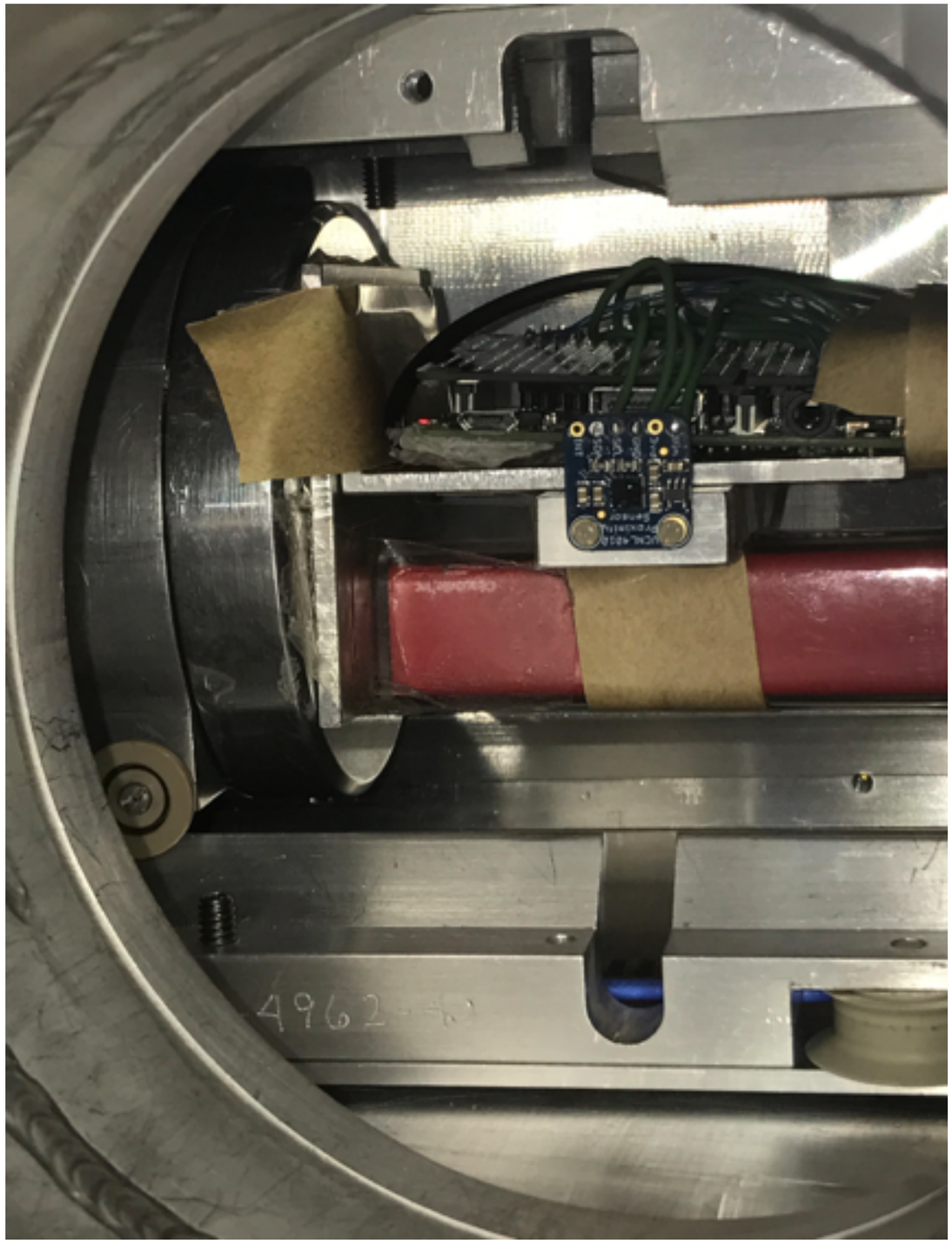


Communication issues

- Communication with the Raspberry pi was the hardest part of the project
- Could not set up ssh that would respect Fermilab security requirements
- Not having live readout was potentially dangerous for interaction with the plates
  - As misalignment was possible in difficult mounting position
- Initial scheme to upload data and fetch from web, but networking inside the vacuum chamber difficult
- Ended up confirming mounting alignment with ethernet cable, then running blind around the ring
  - Other schemes were considered (local network?) but this worked

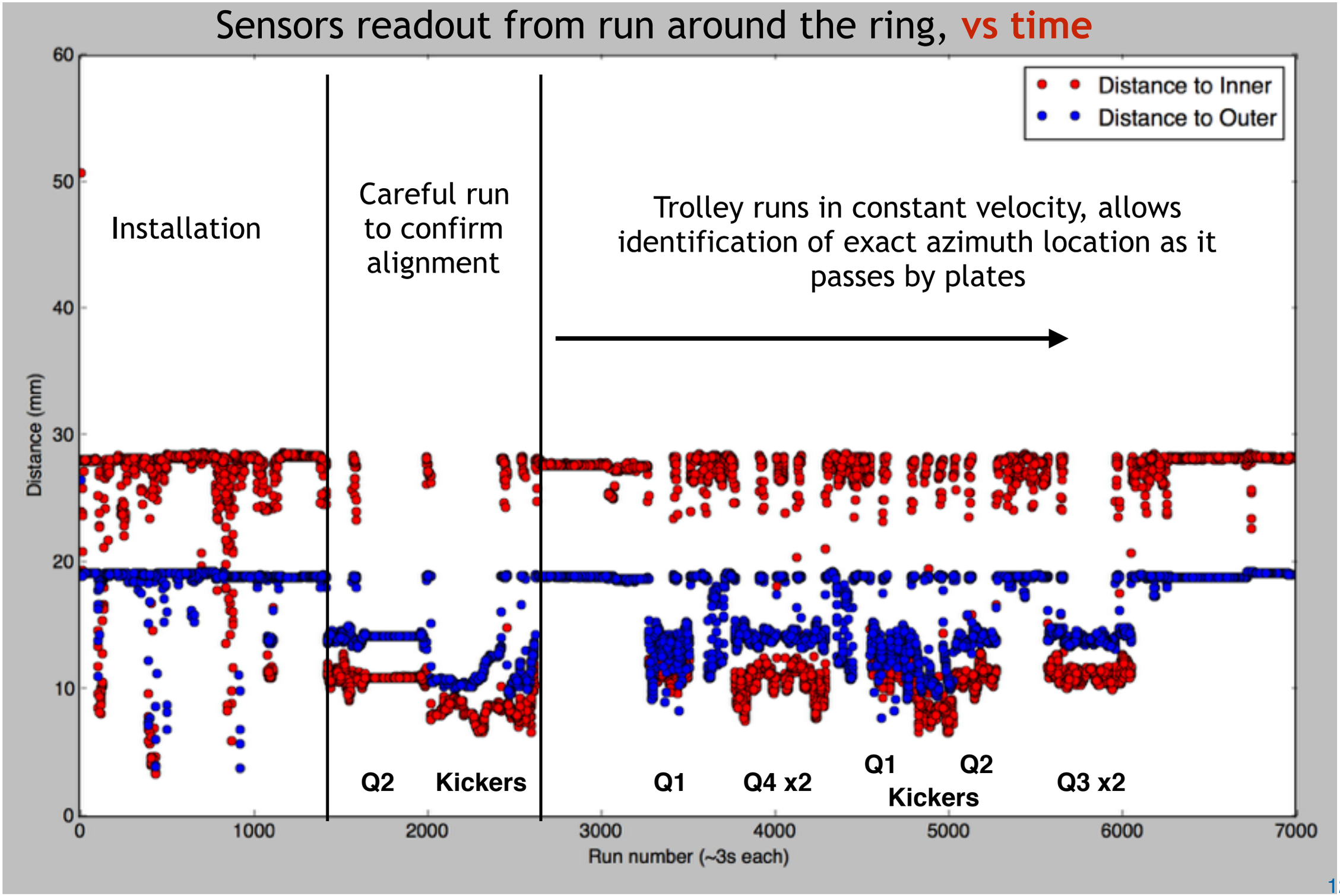


Mounted with a lot of care and tape



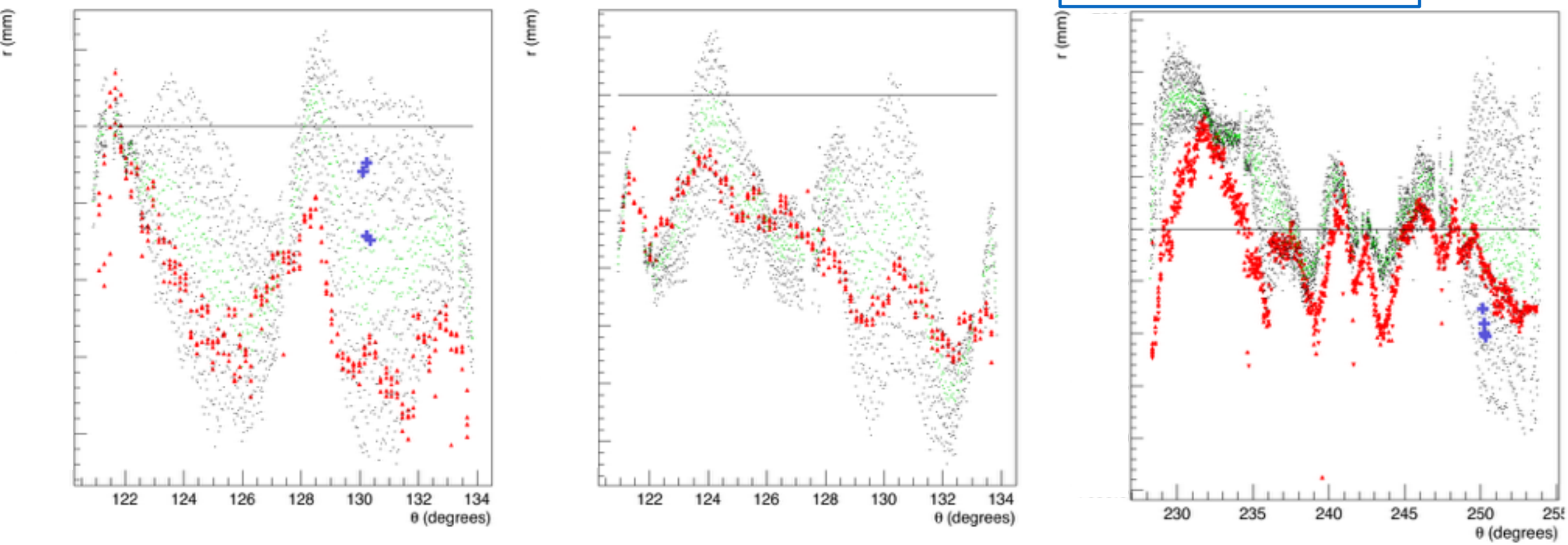
Good alignment was confirmed visually and over ethernet readout

Results


Sensors readout from run around the ring, vs time
Distance to Inner
Distance to Outer
Installation
Careful run to confirm alignment
Trolley runs in constant velocity, allows identification of exact azimuth location as it passes by plates
Q2
Kickers
Q1
Q4 x2
Q1
Kickers
Q2
Q3 x2
Distance (mm)
Run number (~3s each)
0
10
20
30
40
50
60
0
1000
2000
3000
4000
5000
6000
7000

Results

Old laser scan data
Survey from trolley



- Comparison with old data confirms plates location inside ring at needed level
- Or, disagreement is estimate of uncertainty
- For 4 plates: location was completely unknown, now we have a great handle

Summary

- A challenging measurement with a very specific set of requirements
- Microcontrollers and hobby electronics offer powerful (and cheap) solutions
- You can do a lot of cool stuff with them, and available resources make it easy