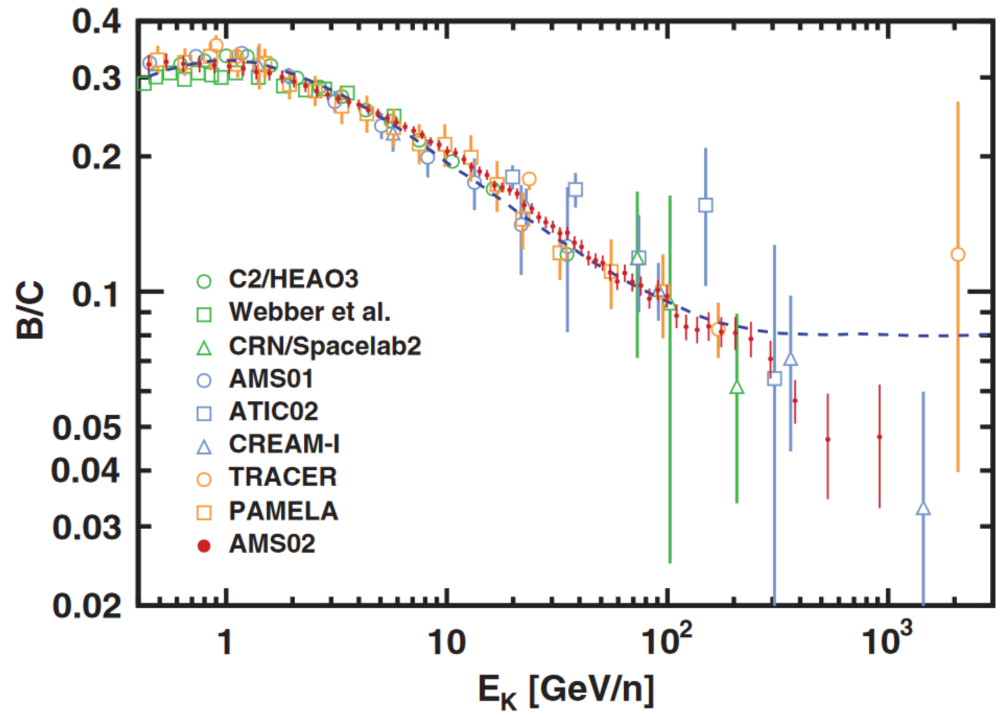
MEASURING COSMIC-RAY ISOTOPES WITH THE HELIX BALLOON

LUCAS BEAUFORE

HELIX

COSMIC RAYS

- Energetic charged particles traveling through space, mostly atomic nuclei.
- Cosmic rays are a way to sample matter arriving from outside our solar system, and can tell us about the structure and evolution of our galaxy and the universe.
- Understanding the propagation of cosmic rays is critical to interpreting them.
- Elemental secondary-to-primary ratios are useful probes of the material pathlength traversed on their way to Earth
  - Insufficient to constrain all parameters



Source: AMS Collaboration, https://doi.org/10.1103/PhysRevLett.117.231102

COSMIC RAY ISOTOPE RATIOS

- Isotopic abundances can serve as an additional probe.
- HELIX will measure these abundances of light cosmic rays, Z=1 (protons) to Z=10 (Ne).
- Energy range 0.2 GeV/n to ~3 GeV/n, will be upgraded to ~10 GeV/n in its second flight
- Optimized for the $^{10}Be/^{9}Be$ isotope ratio, a “propagation clock”.
  - Be is produced by interactions of heavier cosmic rays with the ISM, not stellar nucleosynthesis.
  - Solely determined by the mechanics of cosmic ray propagation.
  - β–decay half-life of 1.39 Myr is close to the containment time of cosmic rays.
  - Higher energies lead to higher time dilation, increasing the region probed.

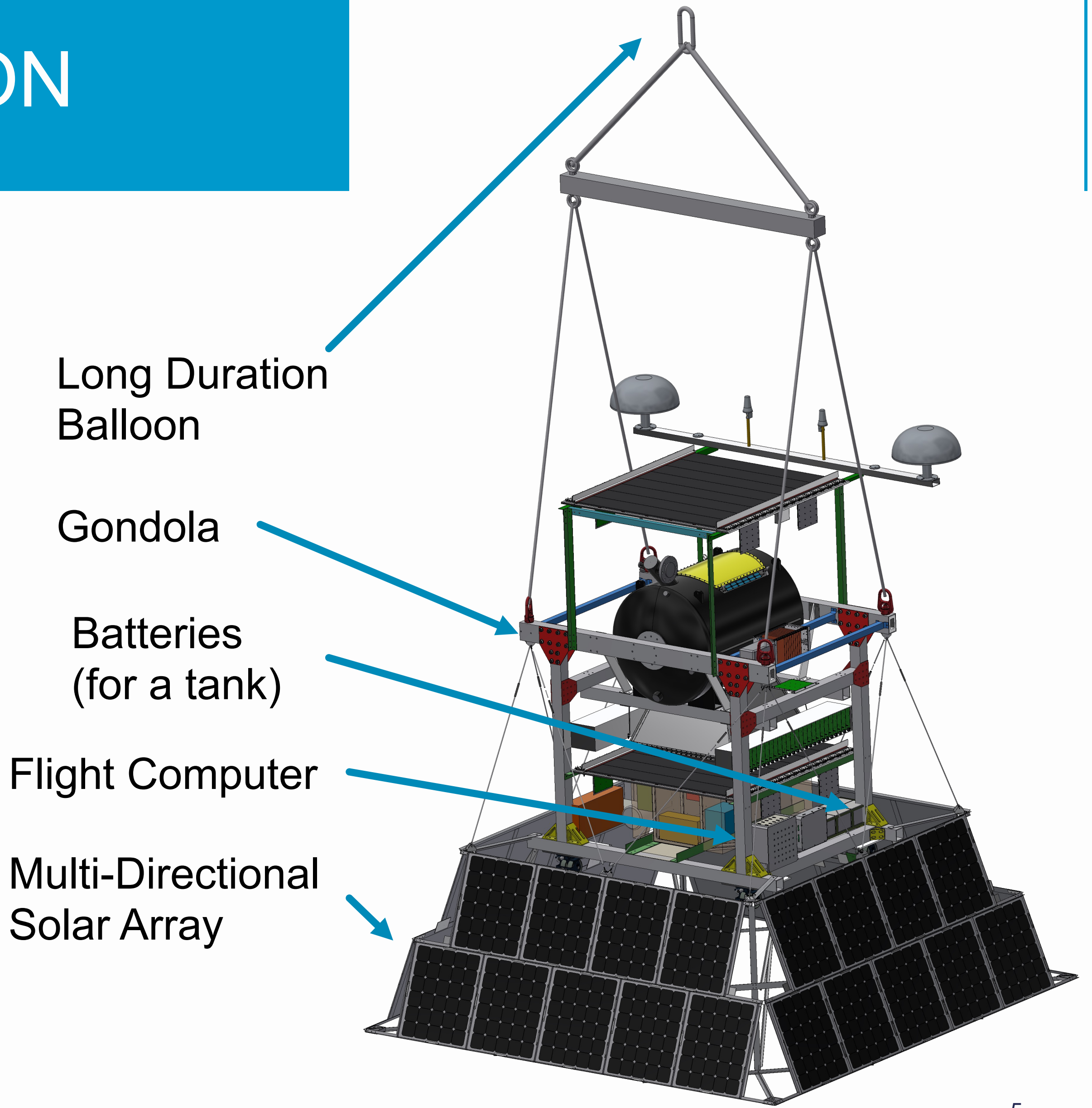
Be

HELIX OVERVIEW - BALLOON

- HELIX is a magnet spectrometer that will fly on a Long-Duration Balloon.

$$m = \frac{RZe}{\gamma\beta c}$$

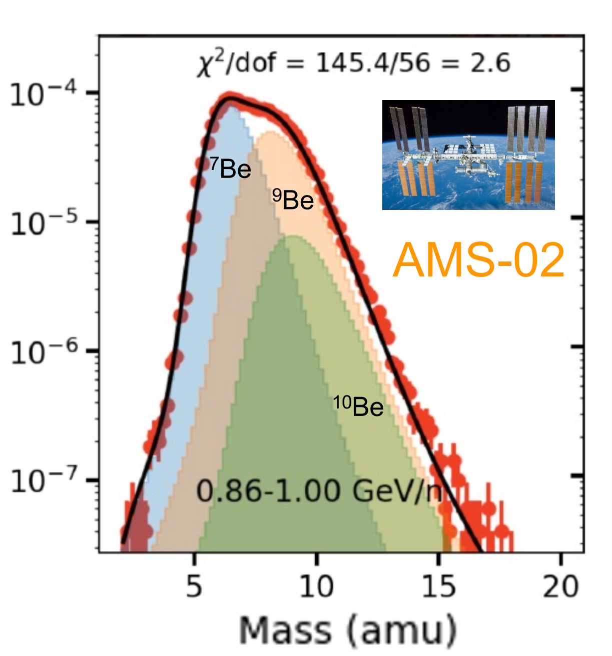
- These balloons are the thickness of a Ziplock bag (0.002 cm) and can reach the size of a stadium.
- HELIX plans to fly from Kiruna, Sweden to Canada in 2024.



COSMIC RAY ISOTOPE RATIOS - MASS RESOLUTION

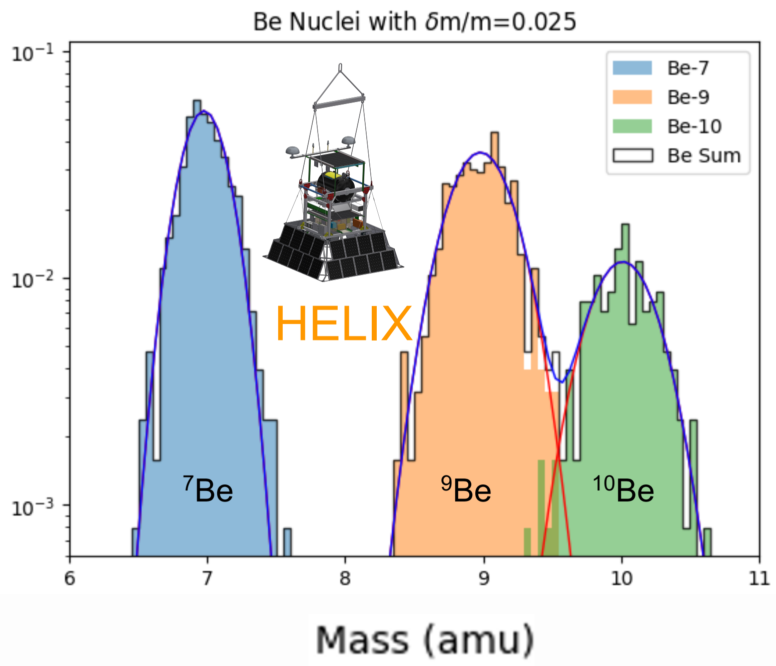
$$\left(\frac{\delta m}{m}\right)^2 = \left(\frac{\delta R}{R}\right)^2 + \gamma^4 \left(\frac{\delta \beta}{\beta}\right)^2$$

- HELIX is designed to achieve a mass resolution of < 2.5% for Be isotopes.
- In comparison, AMS-02's rigidity resolution alone is > 10%[1] and so uses template fitting for their Be isotope ratio.
  - HELIX's stronger magnetic field and lower detector mass density allow for an improved resolution



Left: AMS-02 Be mass histogram from 2021 ICRC, with ^{7}Be, ^{9}Be, and ^{10}Be in blue, orange, and green, respectively.

Source: L. Derome, AMS-02 Collaboration, Cosmic-Ray Lithium and Beryllium Isotopes with AMS02, Proc. 37th ICRC (Berlin)



Right: Be mass histogram for a 2.5% mass resolution instrument, in the 2.0-2.3 GeV/n bin, with a total live-time of 10 days.

[1] G. Ambrosi, et al., In-flight operations and efficiency of the ams-02 silicon tracker, Proc. 33rd ICRC (Rio), 2013.

INSTRUMENT OVERVIEW

Time of Flight (TOF)

Charge and **Velocity at lower energies**

Drift Chamber Tracker (DCT)

Rigidity

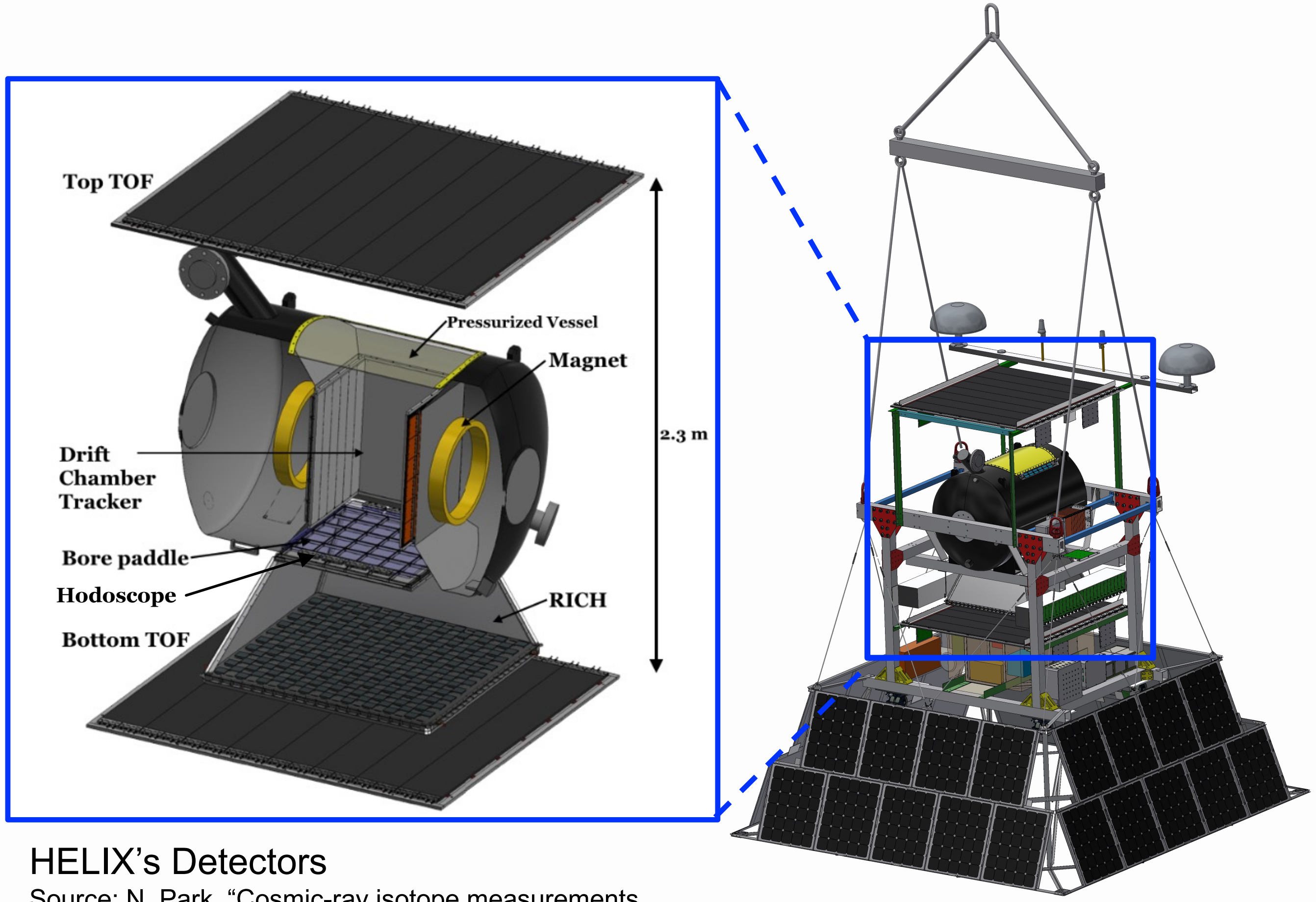
$R = pc/Ze$

Hodoscope

Improves tracking resolution

Ring Imaging Cherenkov Detector (RICH)

Velocity at higher energies



HELIX's Detectors

Source: N. Park, "Cosmic-ray isotope measurements with HELIX", ICRC 2019

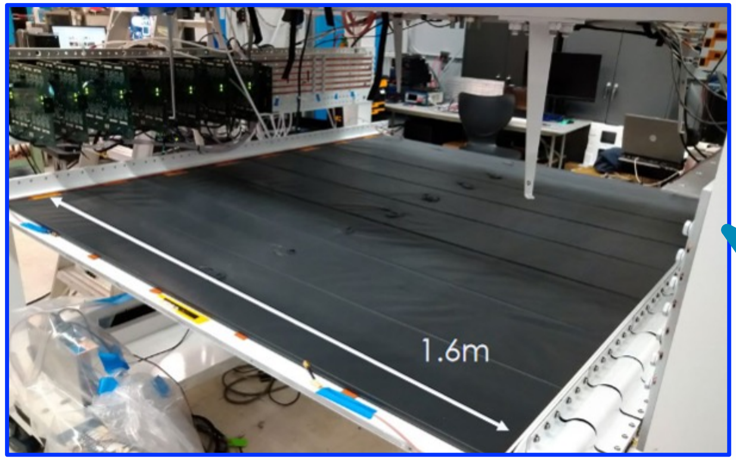
INSTRUMENT OVERVIEW

$$m = \frac{RZe}{\gamma\beta c}$$

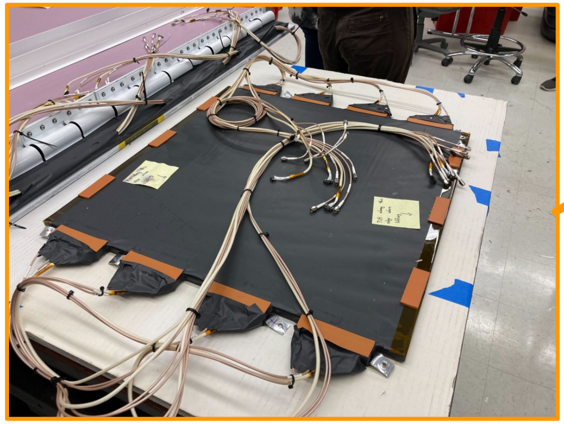
Time of Flight (TOF)

Charge and **Velocity at lower energies**

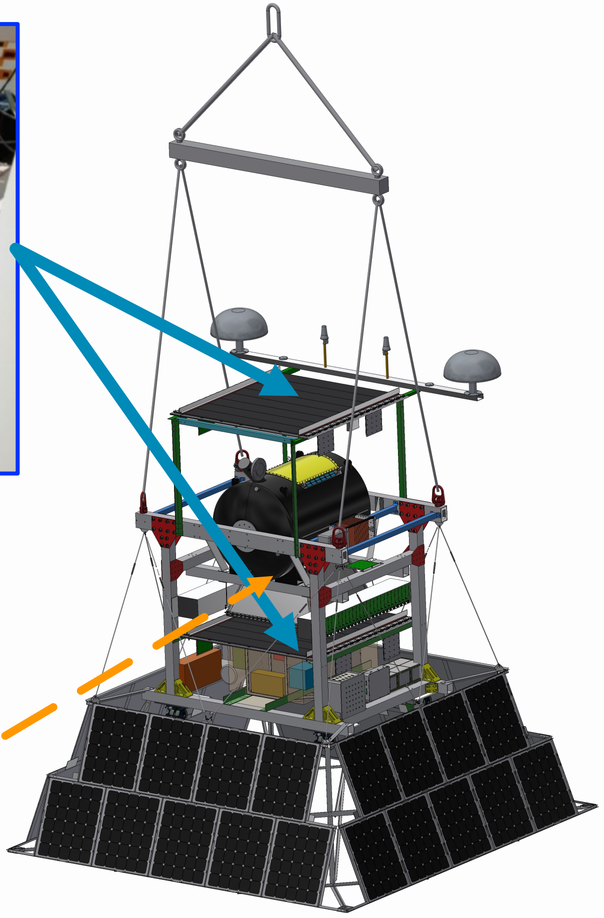
- HELIX's ToF is two layers of 1-cm thick fast plastic scintillator paddles.
- An additional paddle, placed in the magnet bore, is used to define the instrument trigger.
- The amount of light produced is used to find the **charge**, and the timing between the top and bottom layers is used to find the **velocity**.



ToF Layer



Bore Paddle



INSTRUMENT OVERVIEW

$$m = \frac{RZe}{\gamma\beta c}$$

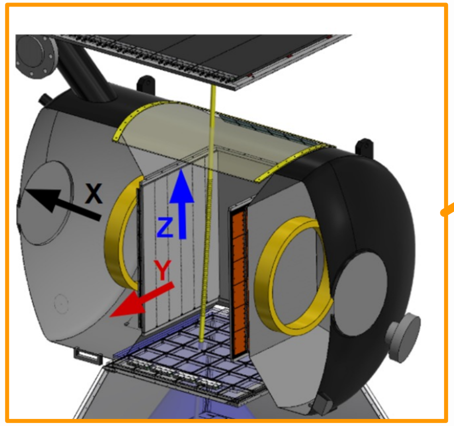
Drift Chamber Tracker (DCT) and Magnet

Rigidity

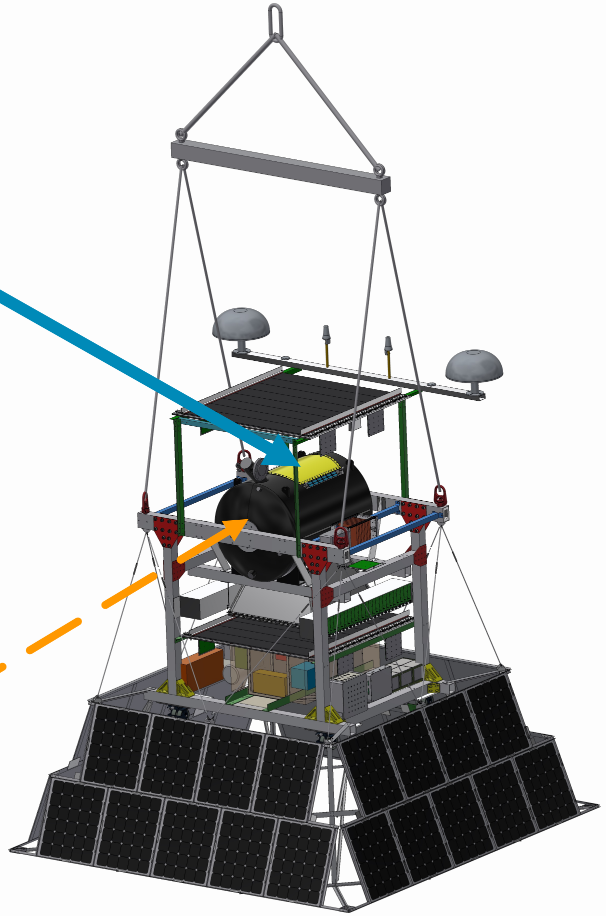
$$R = \frac{pc}{Ze} = \rho B$$

- 1 Tesla LHe cooled superconducting magnet.
- As a charged nucleus traverses the instrument, its bends with gyroradius ρ due to the magnetic field.
- Layers of high voltage wires are used to “drift” the ionization tracks to sense wires for readout.
- Stored in a hermetically sealed vessel, which is then installed in the bore of the magnet.

DCT (Rev. A)



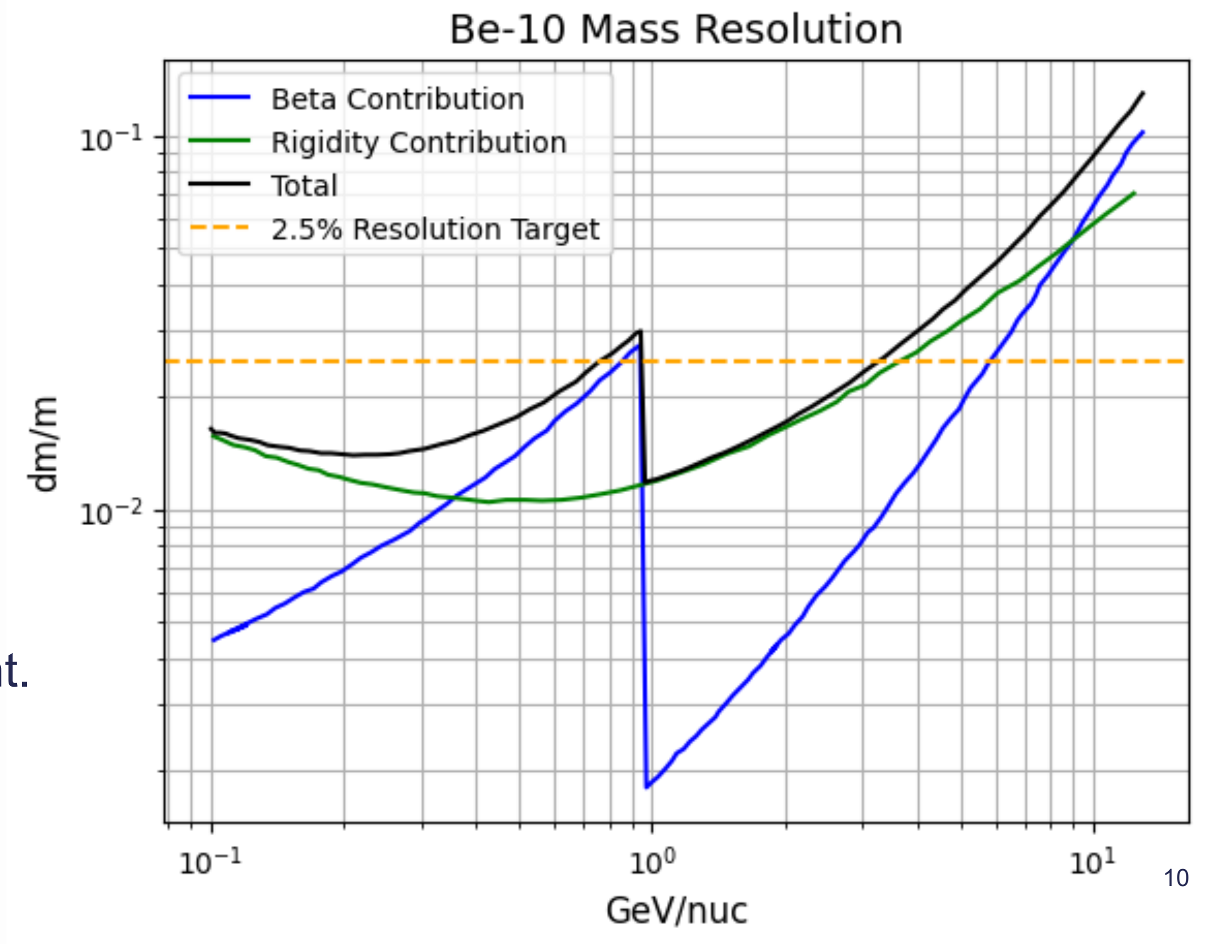
HELIX Magnet



RESOLUTION REQUIREMENTS

$$\left(\frac{\delta m}{m}\right)^2 = \left(\frac{\delta R}{R}\right)^2 + \gamma^4 \left(\frac{\delta \beta}{\beta}\right)^2$$

- Our “resolution budget” is split between rigidity and velocity.
- First flight will target up to 3 GeV/nuc.
- Second flight will target up to 10 GeV/nuc.
  - This will require a scalable velocity instrument.



Contributions to HELIX’s Mass Resolution

INSTRUMENT OVERVIEW

$$m = \frac{RZe}{\gamma\beta c}$$

Hodoscope

Improves tracking resolution

Ring Imaging Cherenkov Detector (RICH)

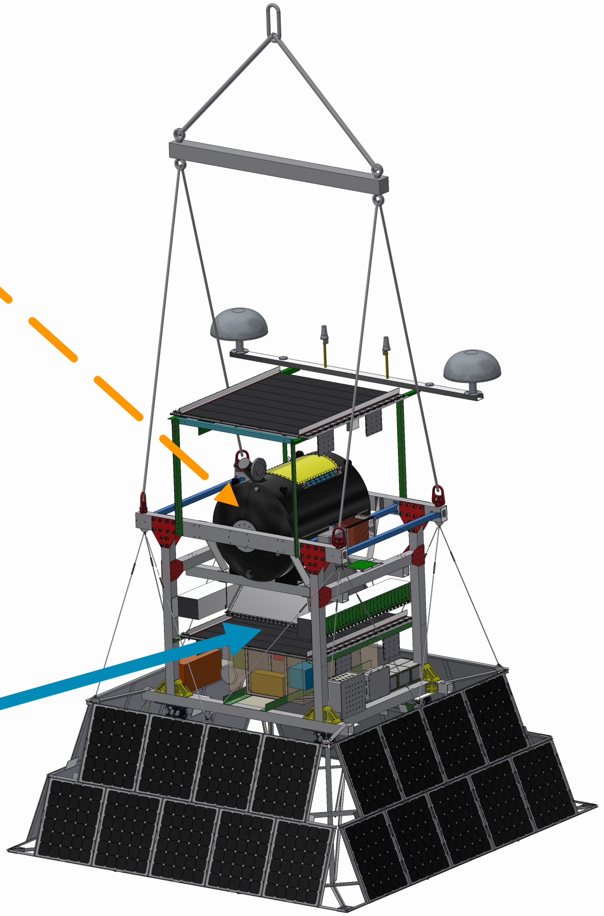
Velocity at higher energies (>1 GeV/n)

- 1 m x 1 m focal plane made of custom Hamamatsu Silicon Photomultipliers (SiPMs)

$$\beta = \frac{1}{n \cos\theta_c}$$

Hodoscope

RICH

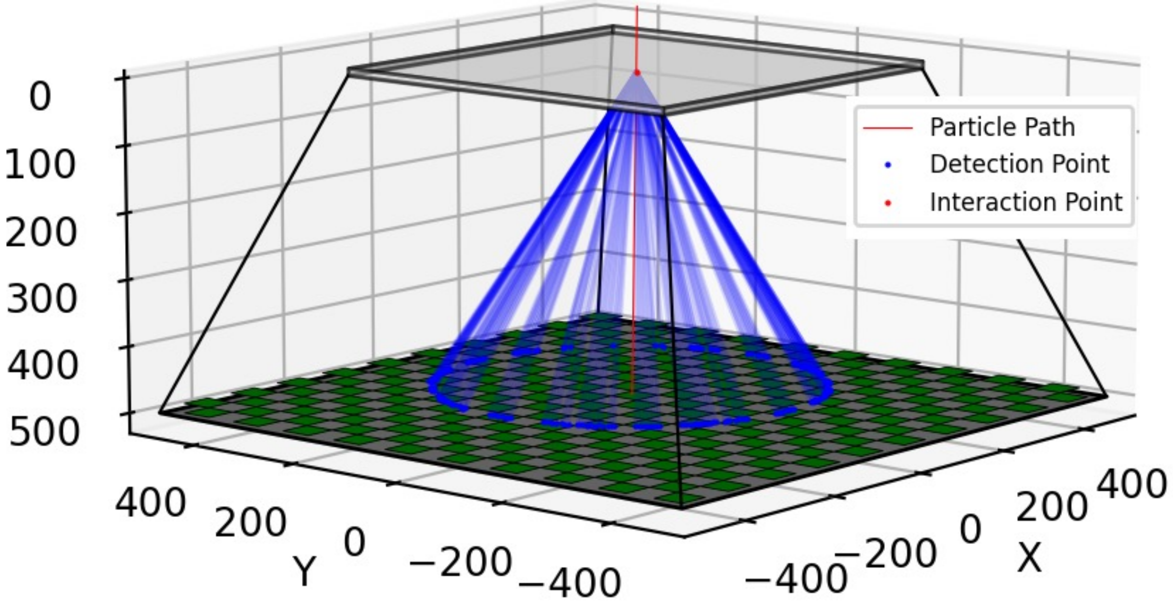


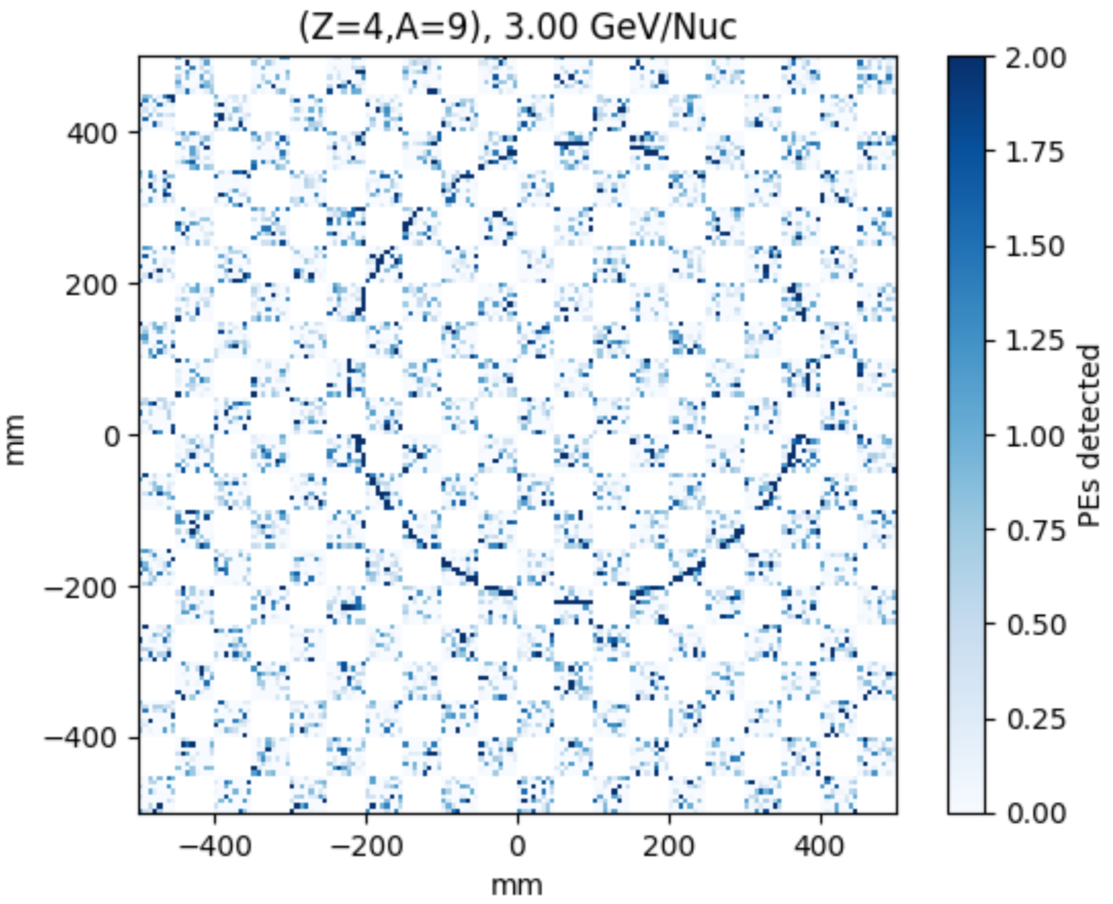
THE RING IMAGING CHERENKOV DETECTOR (RICH)

- Used to measure particle velocity above ~1 GeV/n

$$\beta = \frac{1}{n \cos \theta_c}$$

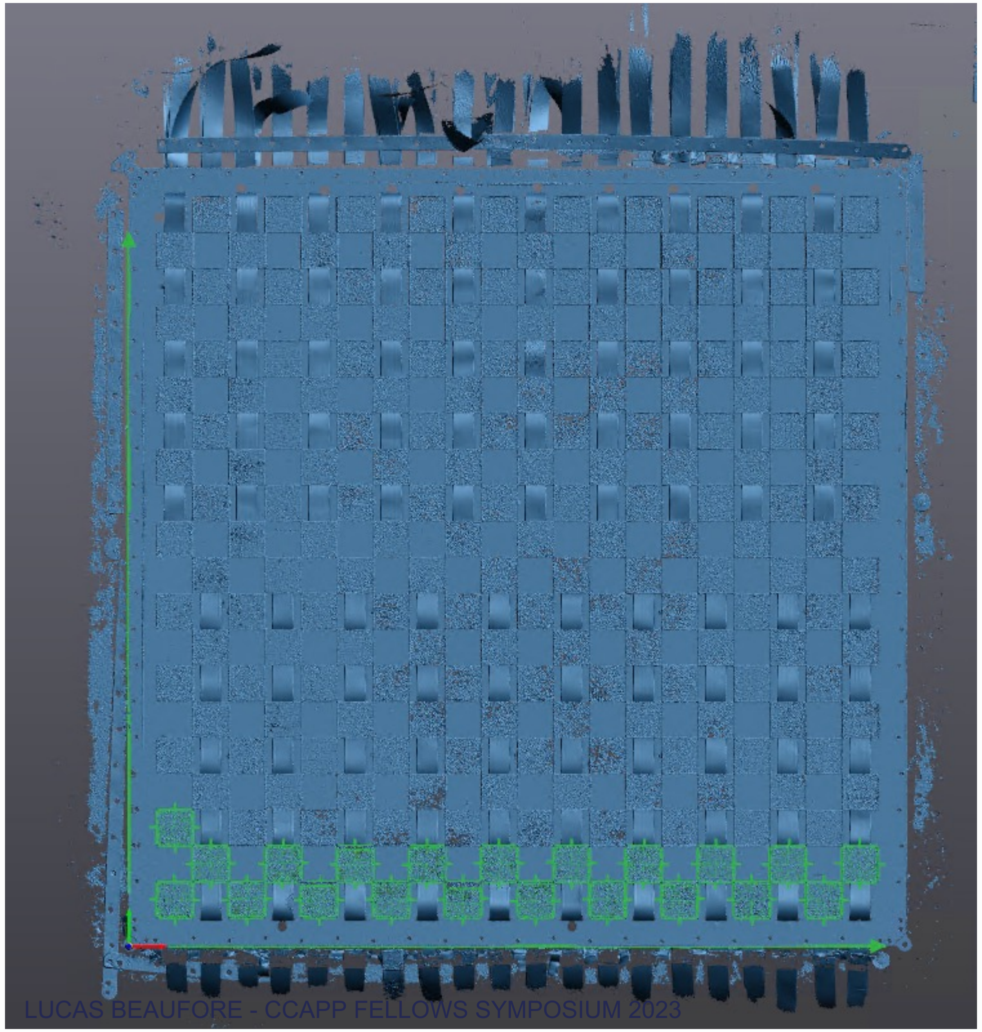
- 1 m x 1 m focal plane made of custom Hamamatsu Silicon Photomultipliers (SiPMs)

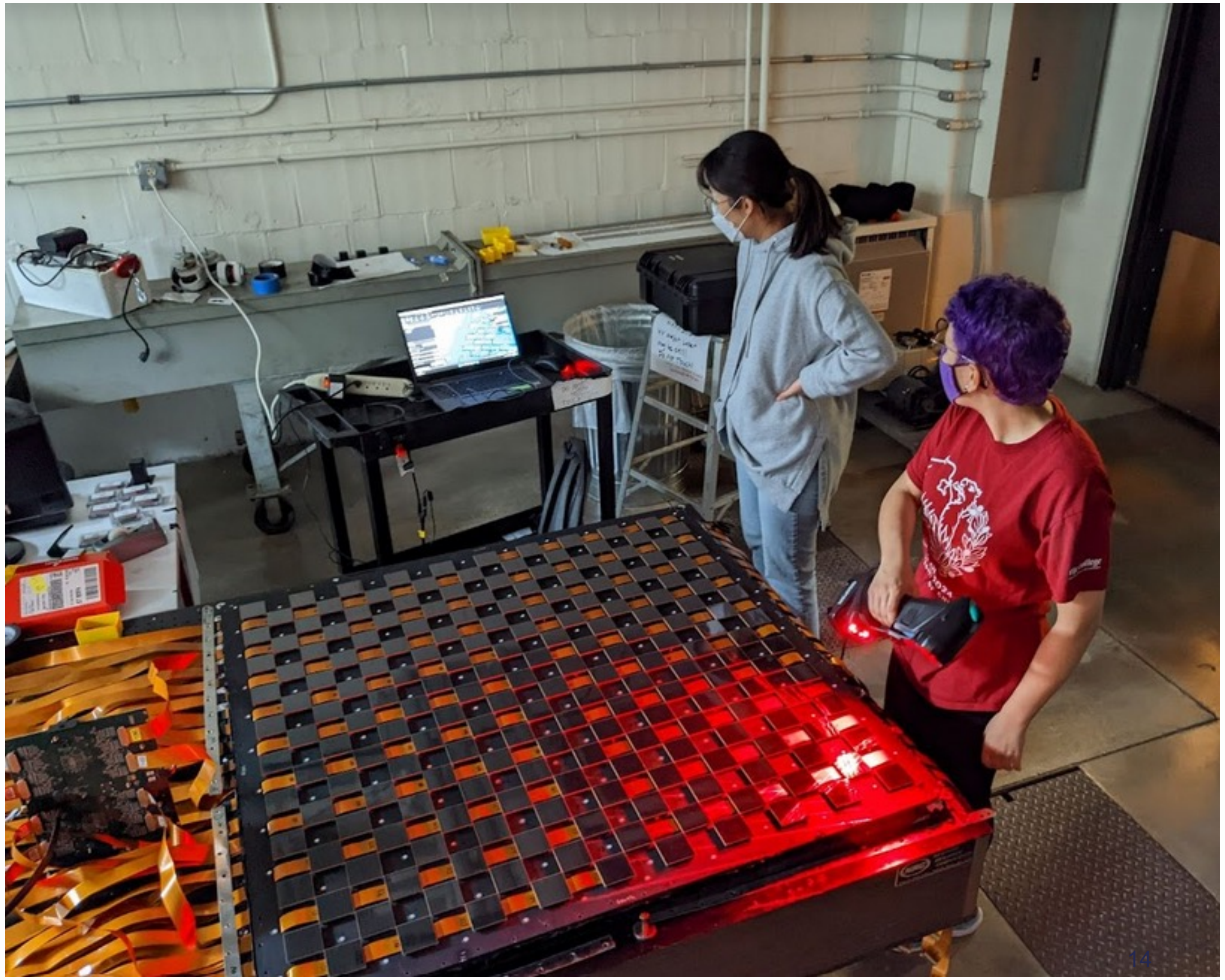




FOCAL PLANE CONSTRUCTION

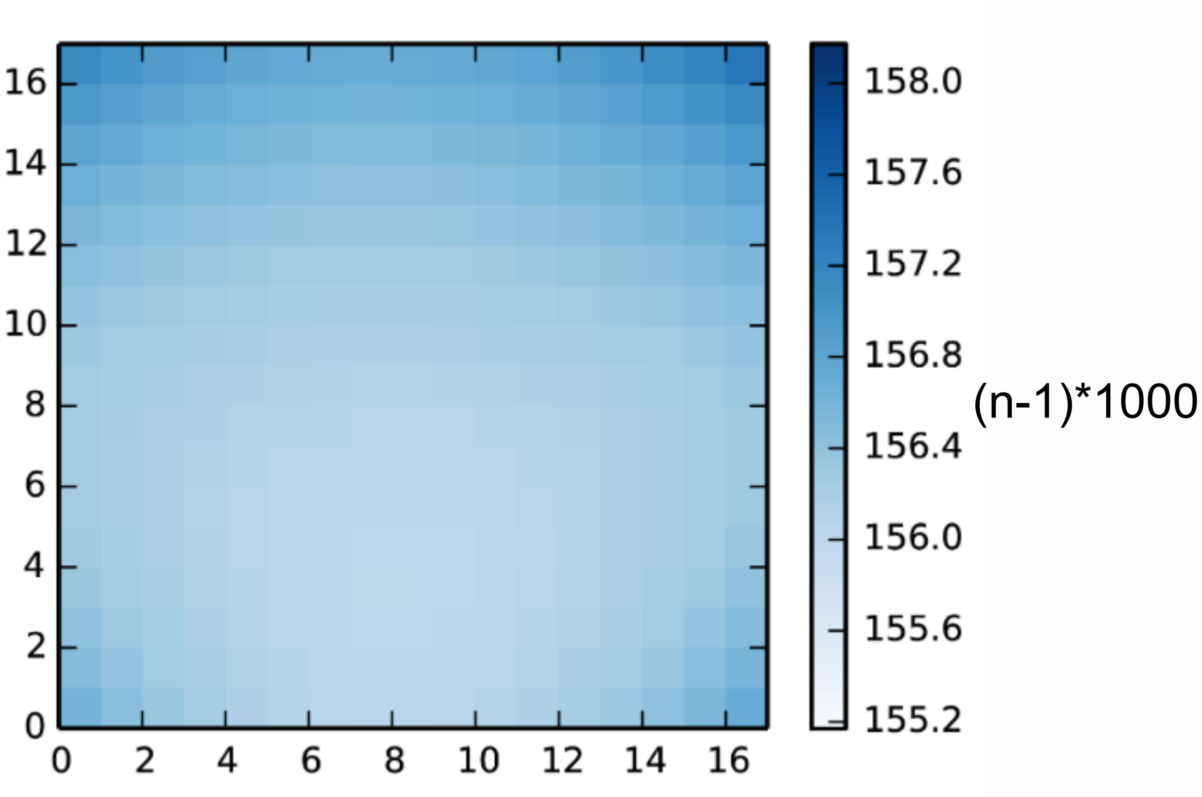
RICH FOCAL PLANE METROLOGY – 3D SCANNING





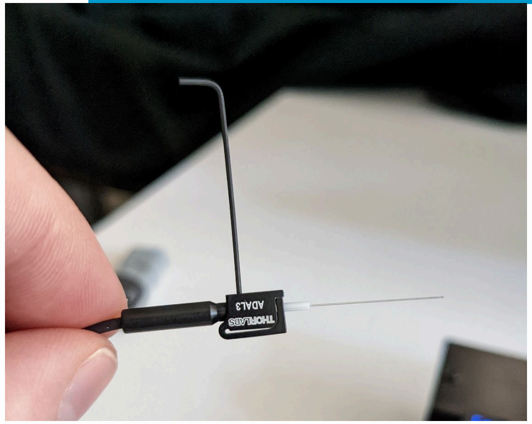
RICH – AEROGEL RADIATOR

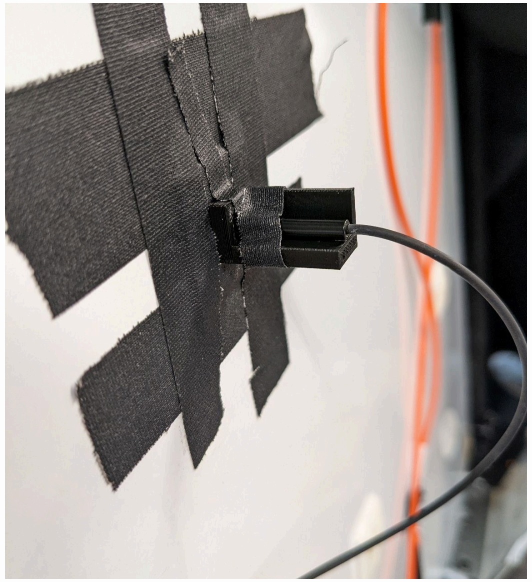
- The radiator plane of HELIX's RICH is a 6x6 grid, primarily composed of n~1.15 aerogel tiles
- Each tile is 10x10 cm^2
- The index of refraction of the tiles has been mapped extensively by the HELIX group at McGill university
- 4 NaF (n=1.33) tiles for lower energy threshold cross-calibration

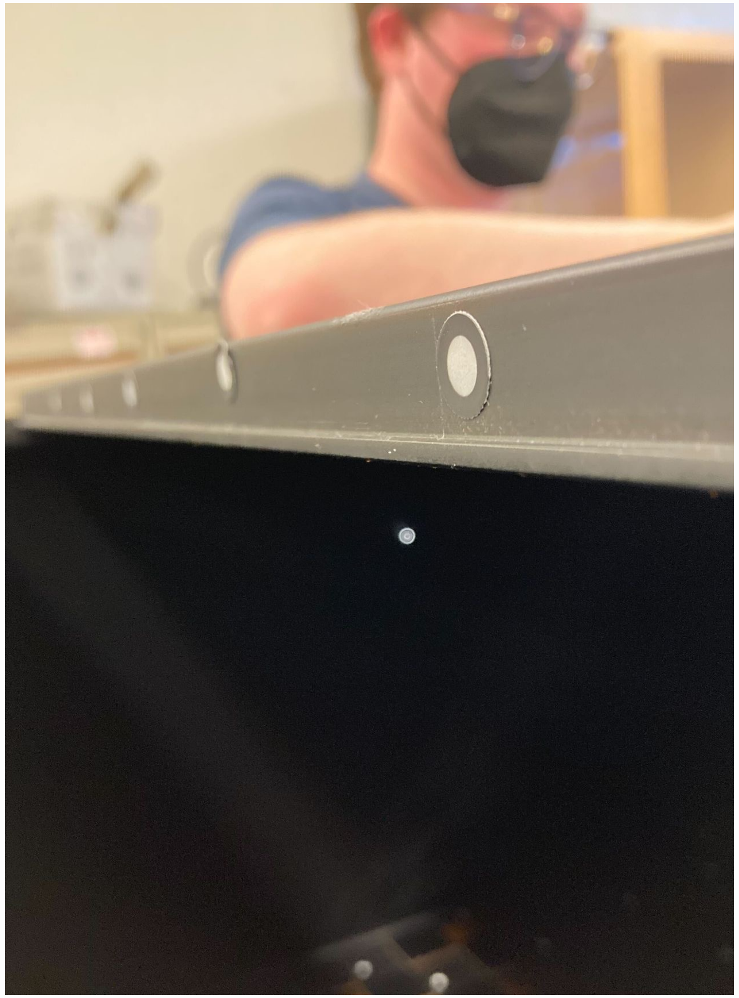


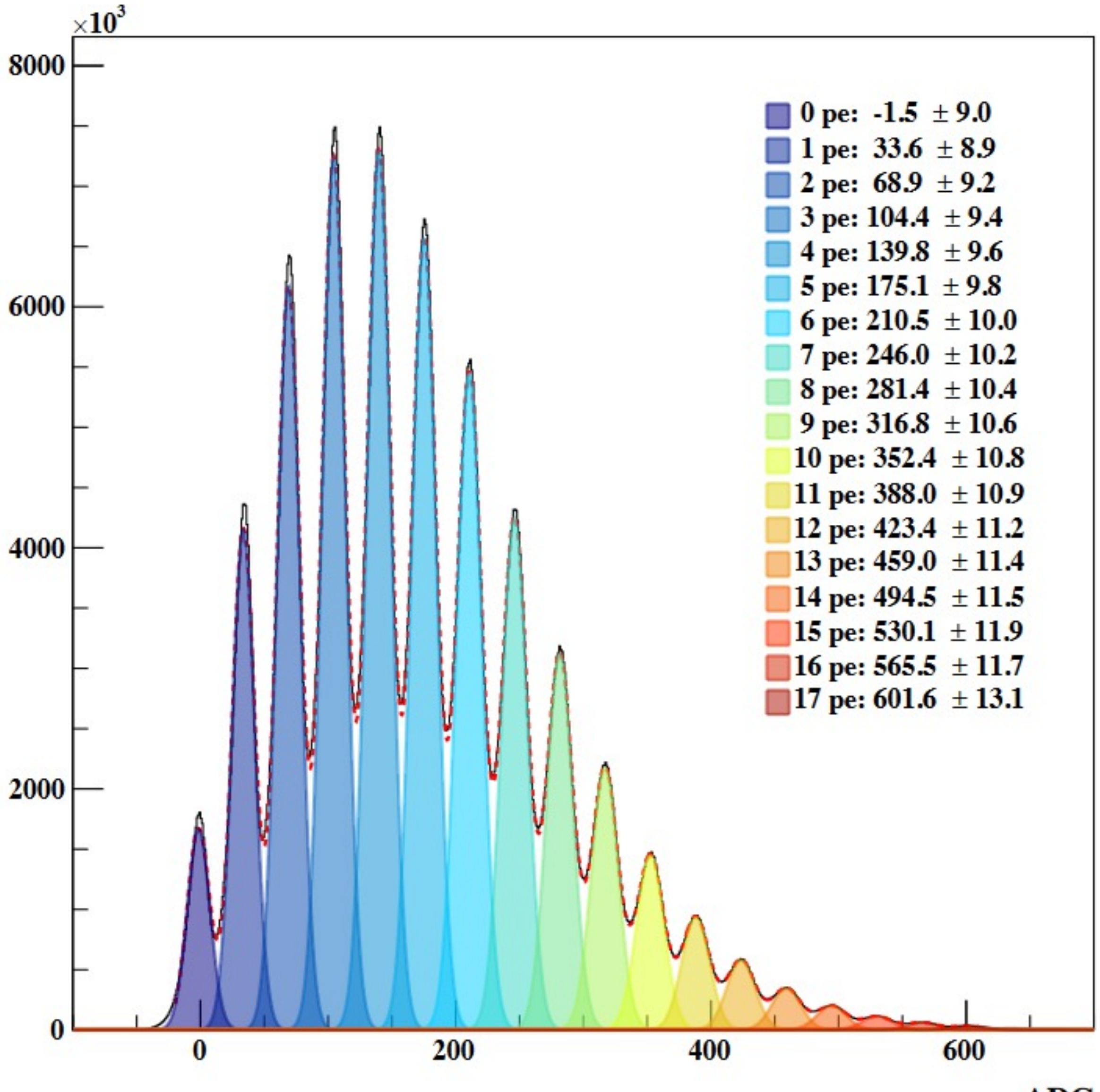
Source: T. Rosin and E. Ellingwood, "Calibration of the Aerogel Tiles for the HELIX RICH", ICRC 2019

FULL GAIN MATCHING





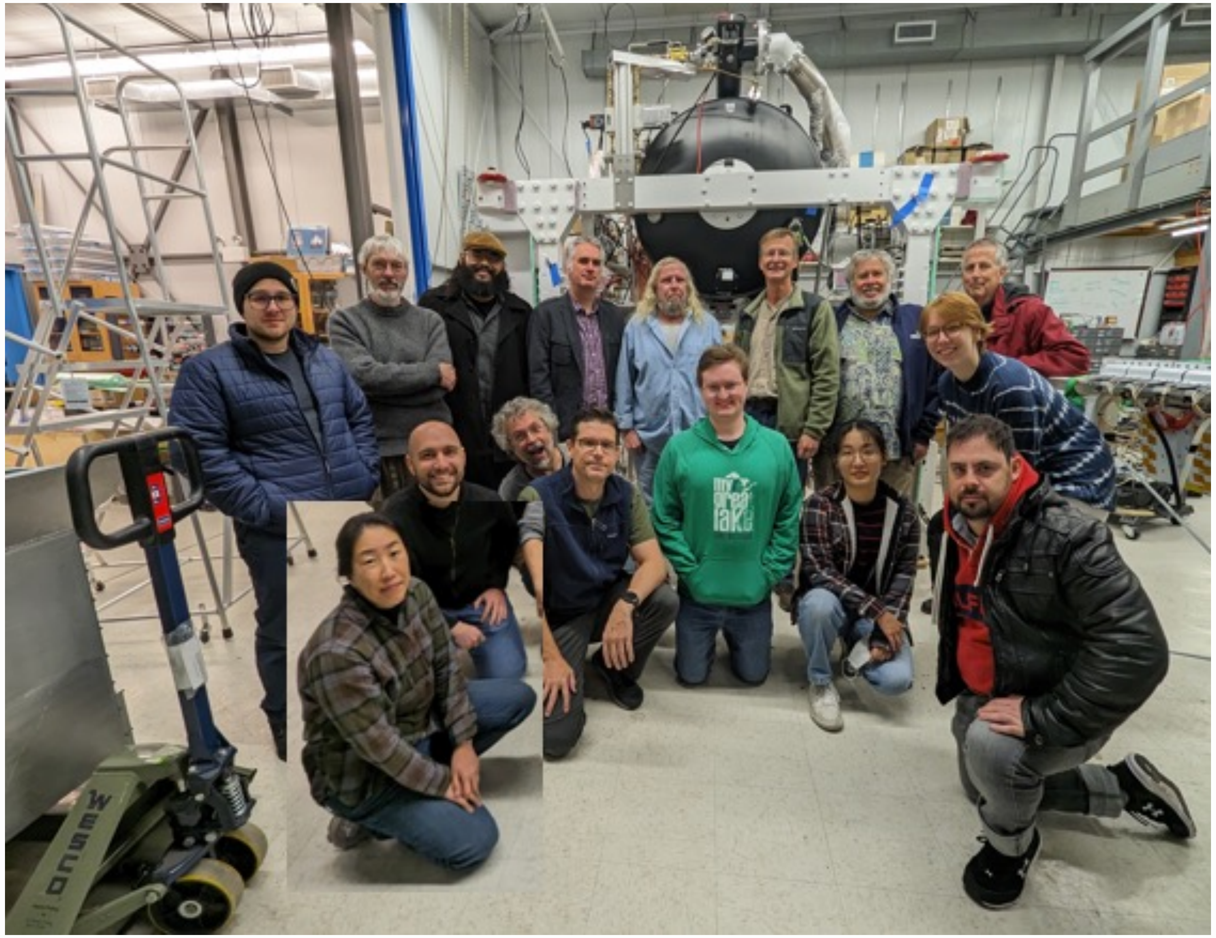




Credit: Dr. Kenichi Sakai

CONCLUSION

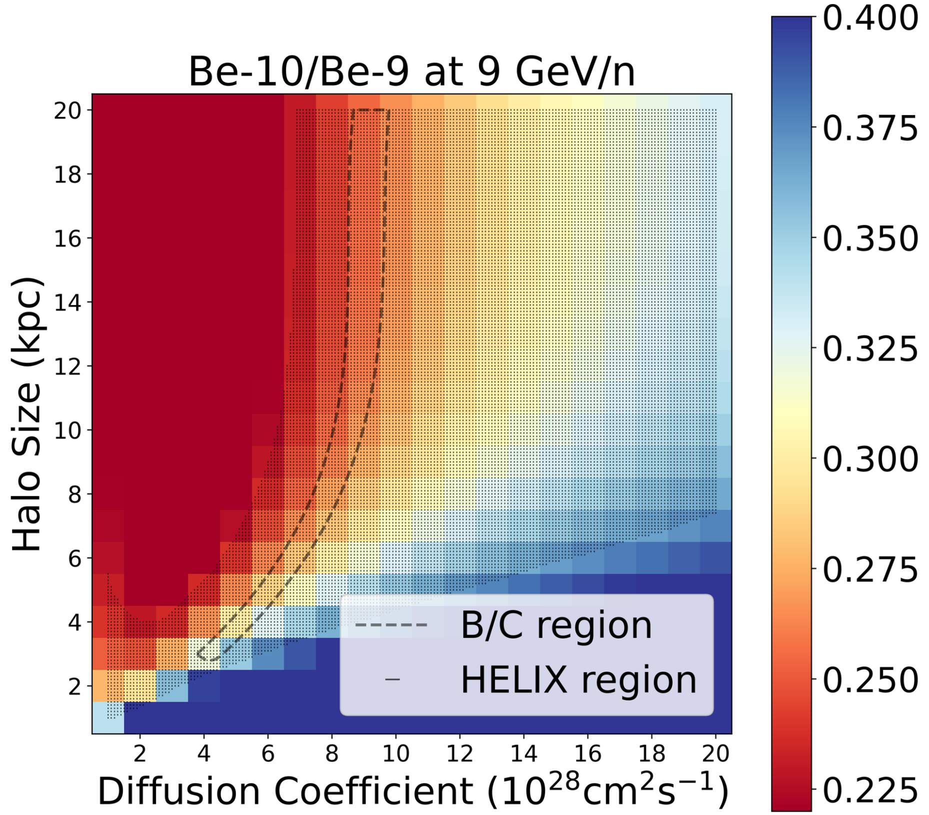
- HELIX's RICH is constructed and has been installed into the payload.
- The RICH's readout electronics have been developed, tested, characterized, and installed.
- The DCT, ToF, and Hodoscope are installed.
- Integration is underway at the University of Chicago.
- HELIX will plan to fly in Spring of 2024.

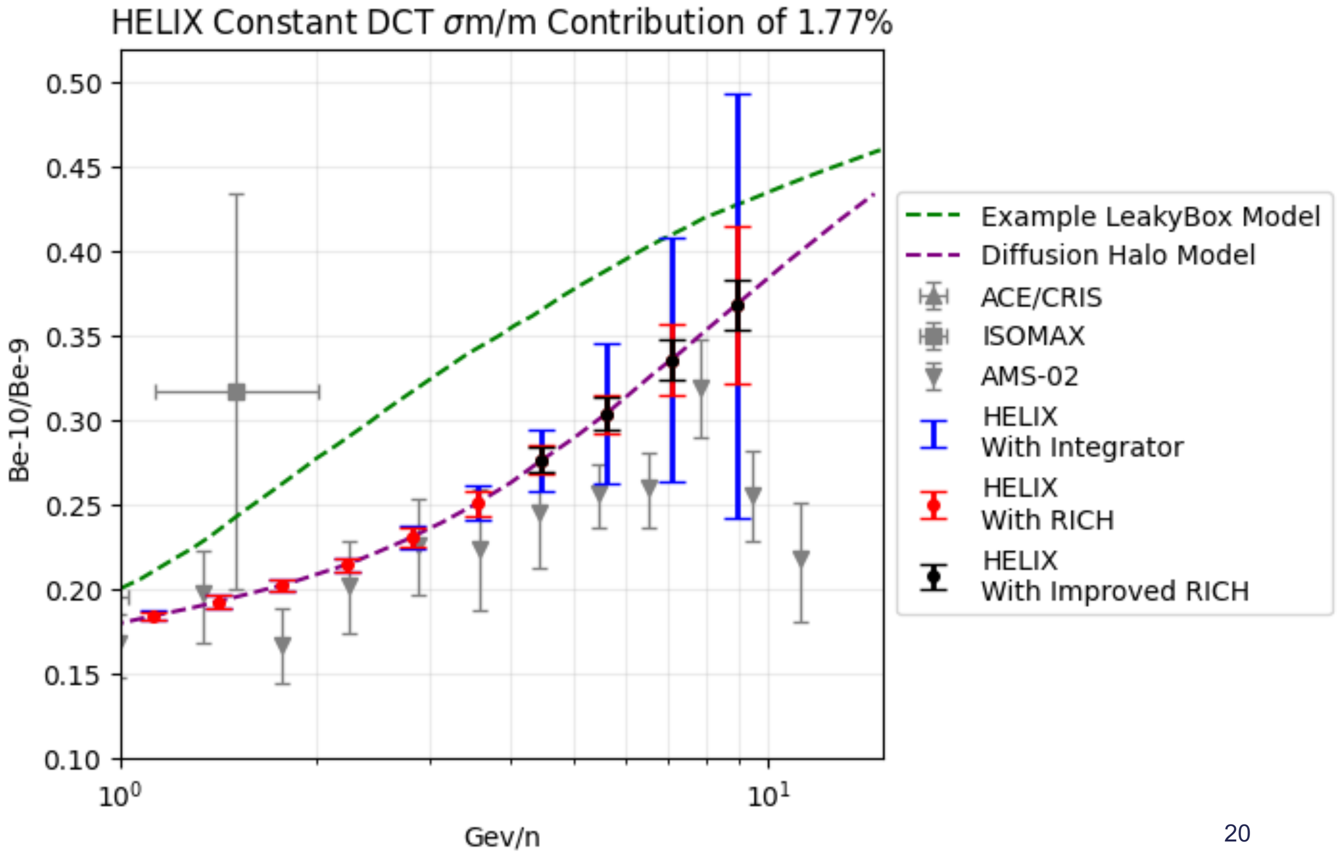


QUESTIONS?

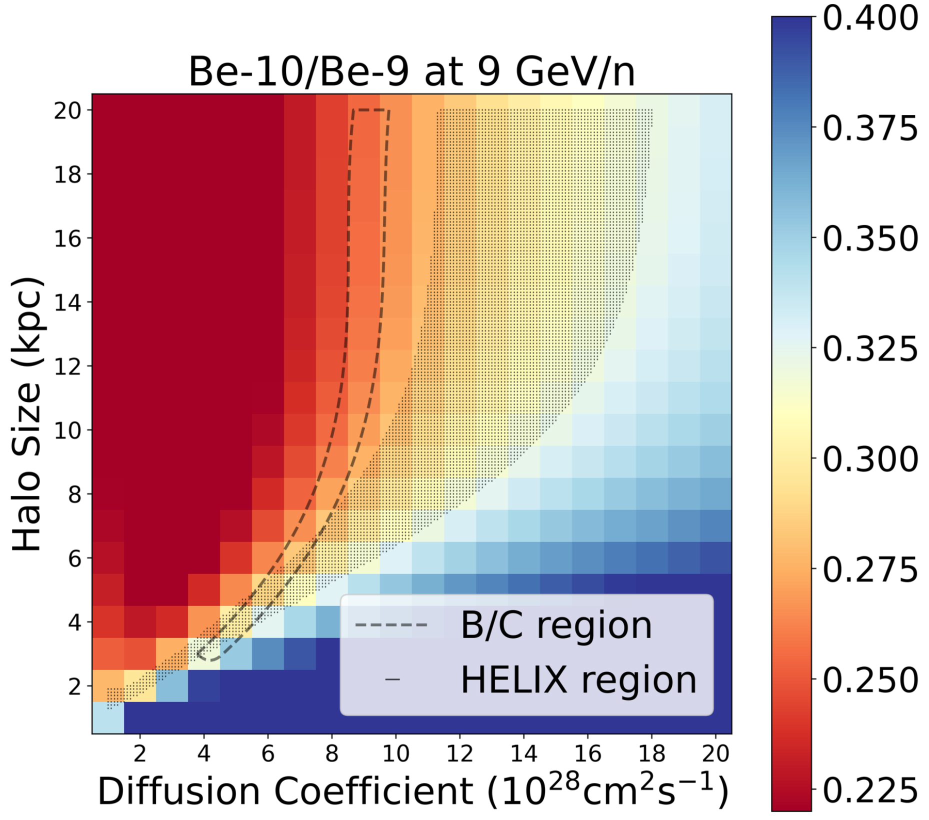
BACKUP

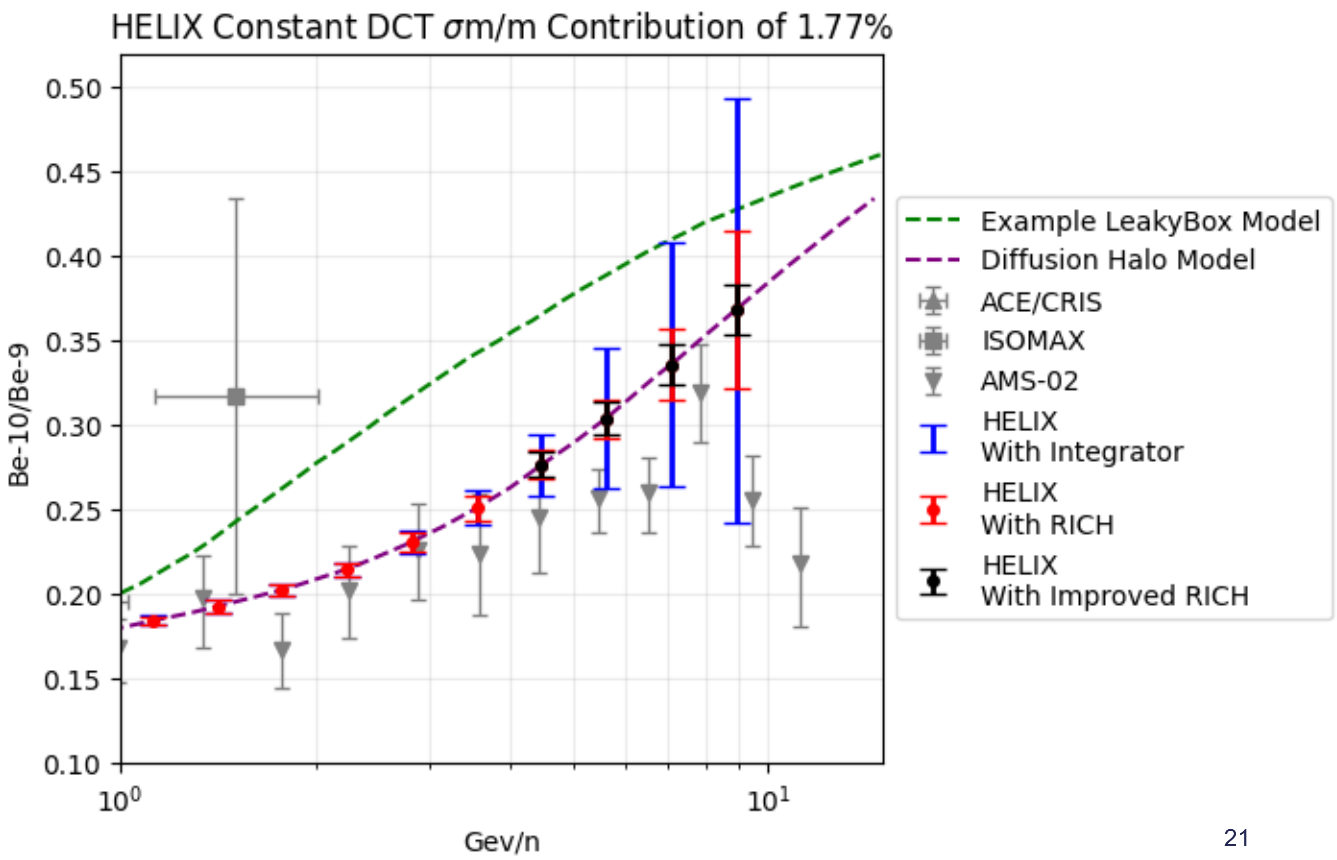
HELIX RICH – SIMULATION WITH INTEGRATOR



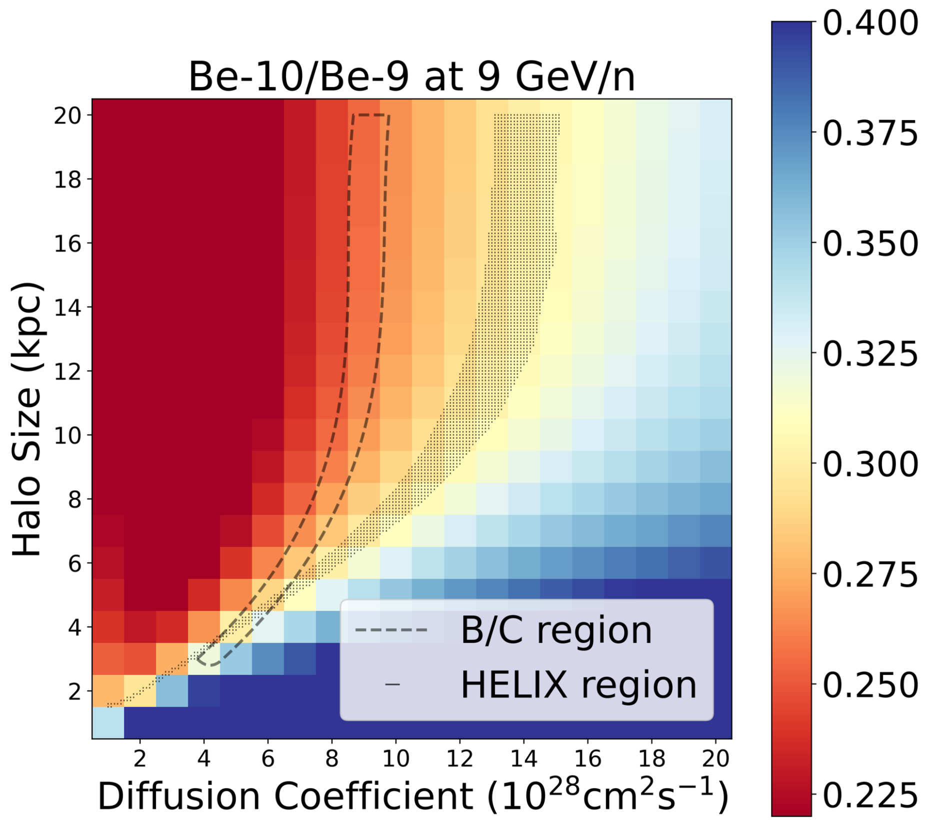


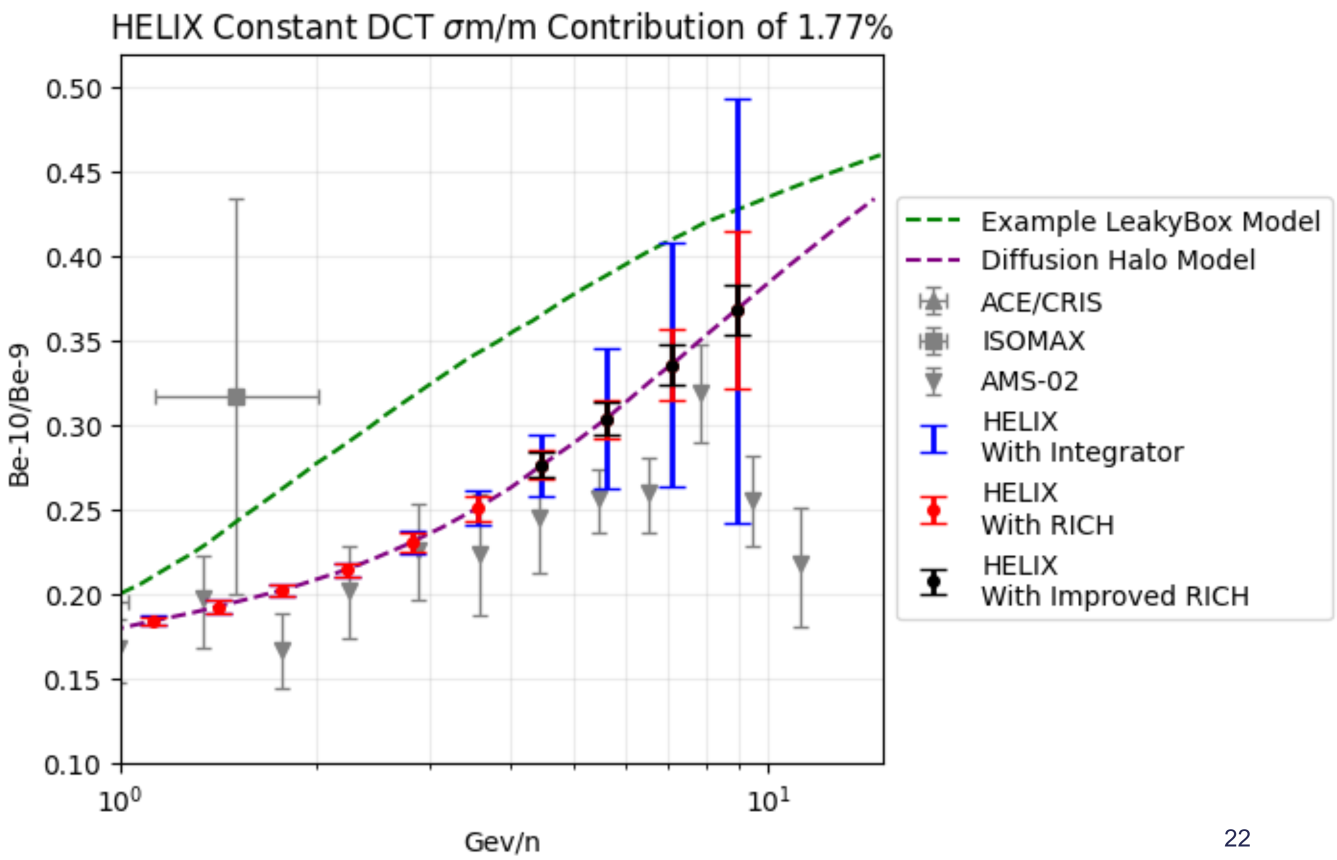
HELIX RICH – SIMULATION WITH RICH IN STAGE 1





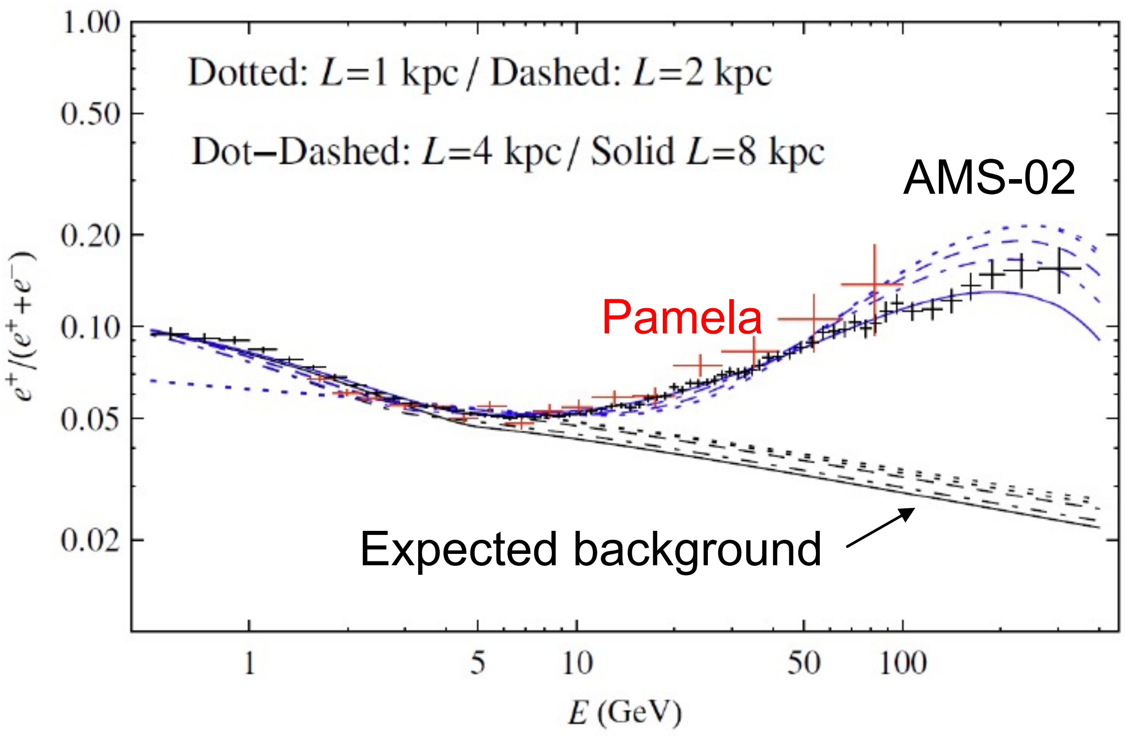
HELIX RICH – SIMULATION WITH RICH IN STAGE 2





RISING POSITRON FRACTION

- A remarkable increase in the observed positron fraction in cosmic rays, $e^+/(e^+ + e^-)$, has been reported by the PAMELA, AMS-02, and Fermi/LAT collaborations.
- Prior to this measurement, it was predicted that the fraction would decrease with energy.
  - Positrons were expected to be the products of cosmic-ray interactions.
- Explanations range from different propagation models, to production in pulsars, to even DM annihilation or decay.
- Strong discrimination between these models can be achieved with high quality $^{10}Be/^{9}Be$ data.



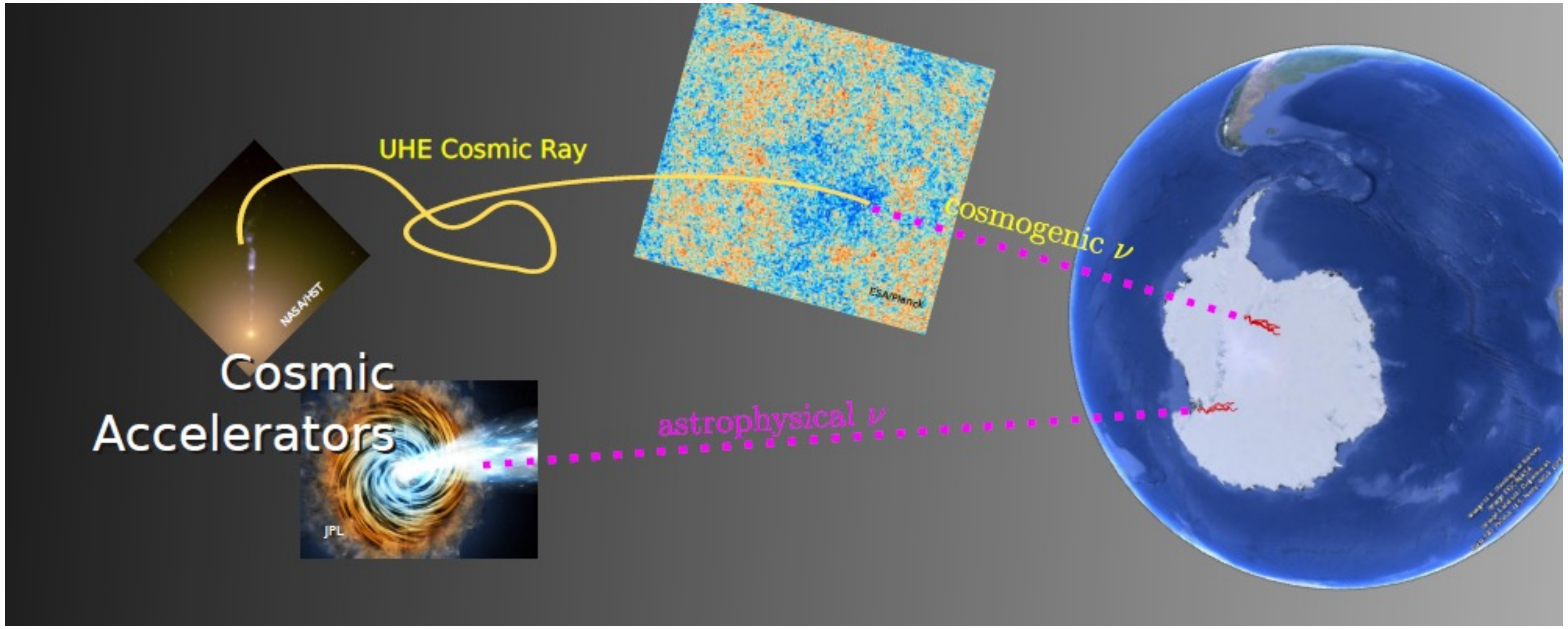
DM Models of the positron fraction from I. Cholis, D. Hooper, Dark matter and pulsar origins of the rising cosmic ray positron fraction in light of new data from AMS, Phys. Rev. D88 (2) (2013) 023013. arXiv:1304.1840, doi:10.1103/PhysRevD.88.023013.

PUEO

Thanks to William Luszczak and Cosmin Deaconu for figures

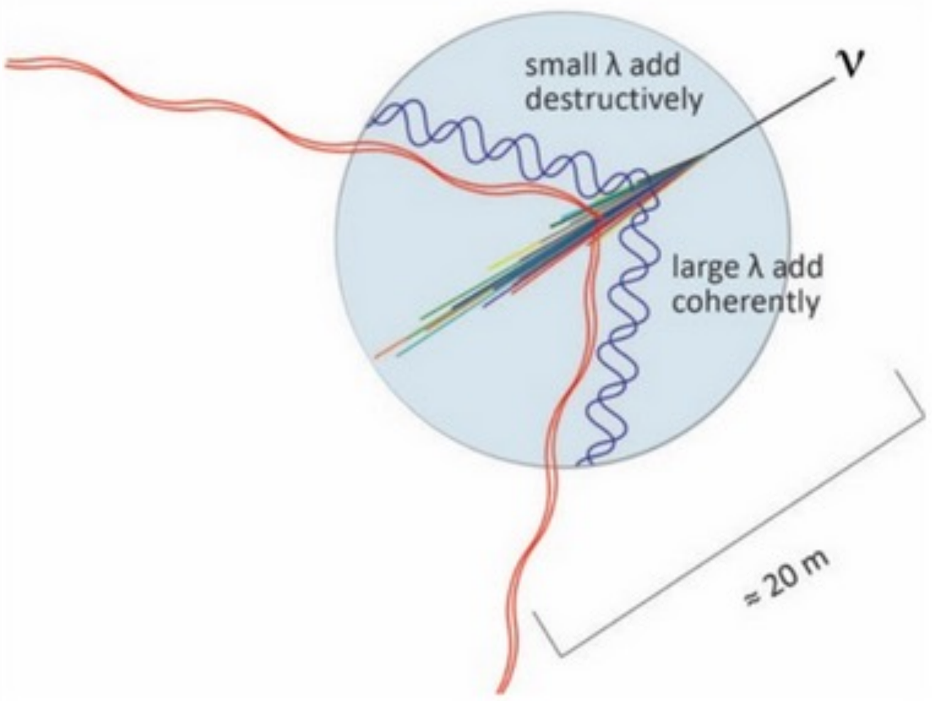
ULTRAHIGH ENERGY NEUTRINOS

- Neutrinos are excellent probes of ultrahigh-energy regimes in the universe.
- As they have a low cross section and do not bend in the presence of magnetic fields, they travel unimpeded from their sources.
- However, at ultrahigh energies their low flux makes their detection a difficult (read: interesting) problem.

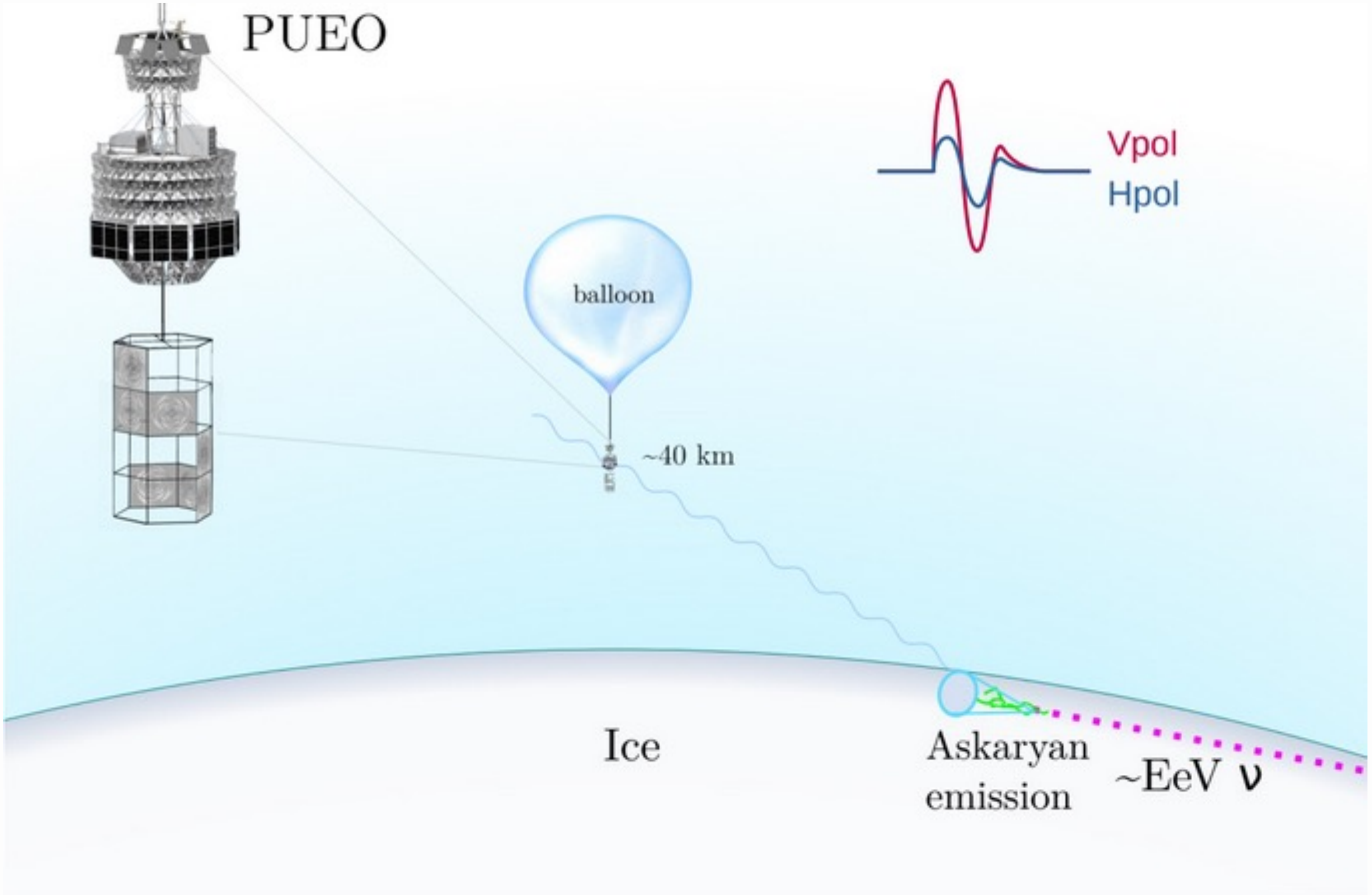


SO HOW DO YOU DETECT THEM?

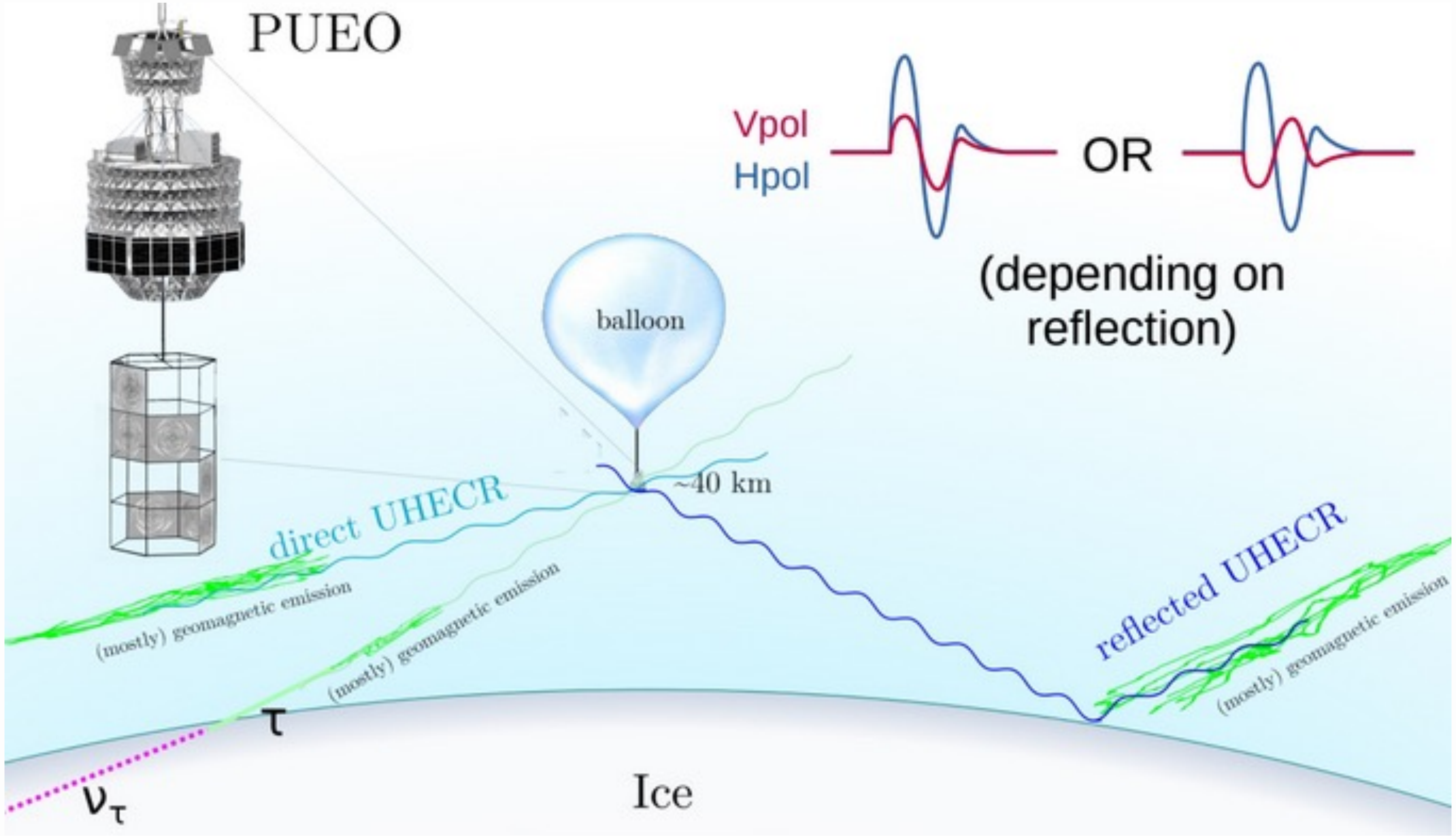
- Neutrino interactions in ice will produce a shower with an order ~20% negative charge excess.
- This charge excess will produce Cherenkov radiation in the medium, and wavelengths longer than the lateral width (~10 cm) of the shower will add coherently.
- As ice is radio-clear, this allows us to detect events that occur within a huge volume!



PUEO – ASKARYAN

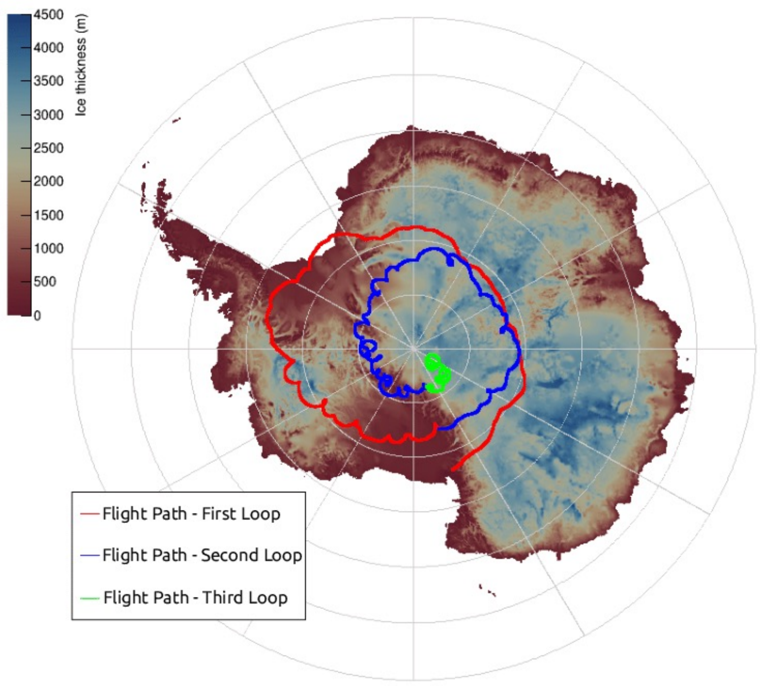


PUEO – OTHER CHANNELS

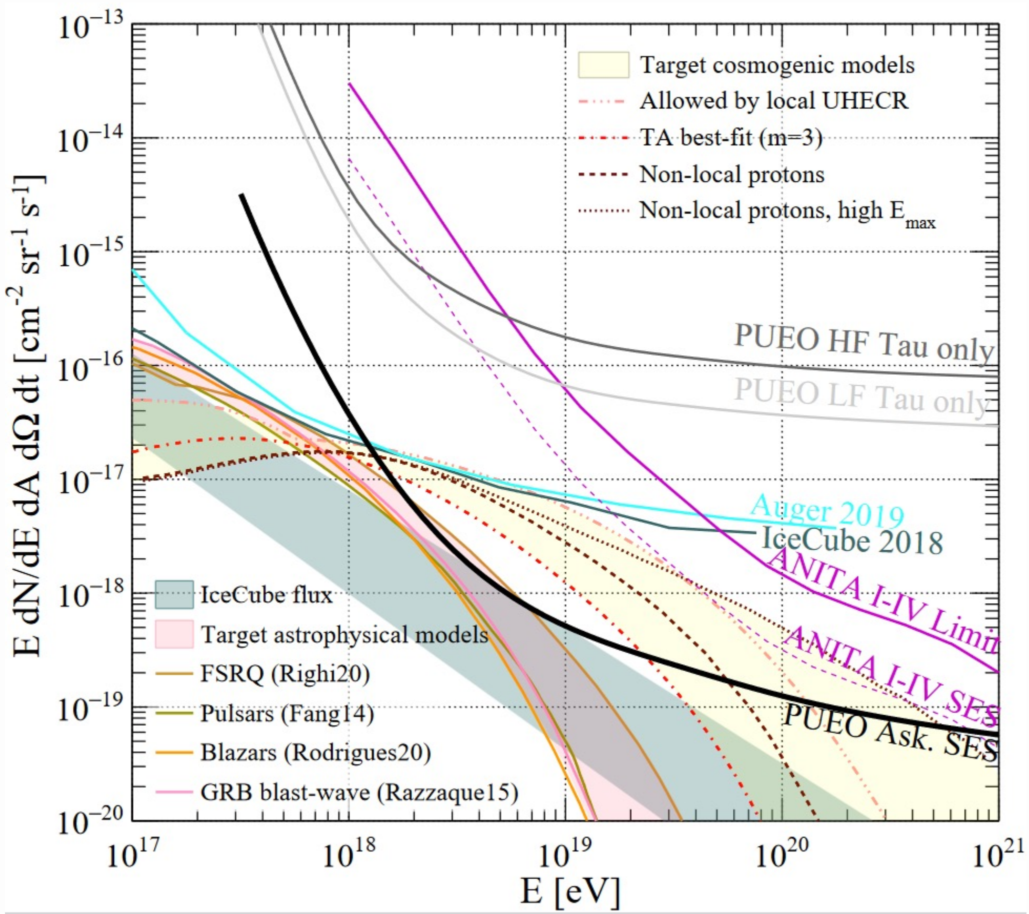


PUEO

- Planning for a launch in 2025 in Antarctica!

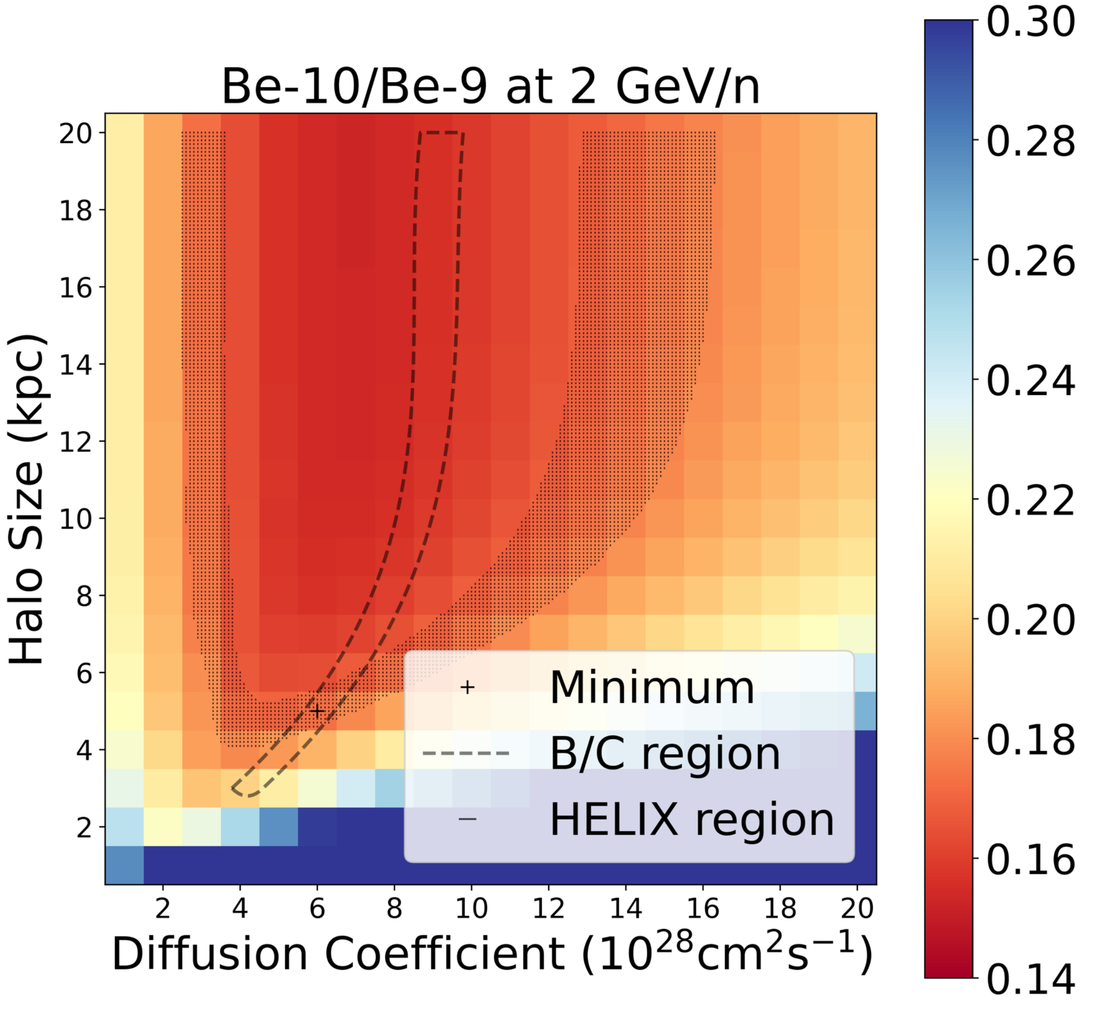


ANITA-IV Flight Path



COSMIC RAY ISOTOPE RATIOS

- Related to the containment time of cosmic rays and ISM density they pass through are Halo Size (L) and Diffusion Coefficient (D) parameters.
- Simulations using a diffusive halo model in GALPROP show how the values of the ^{10}Be/^{9}Be vary with these parameters.
- Boron/Carbon ratio data from AMS-02 can be used to constrain models of the L-D phase space.
  - In standard diffusion-convection models, B/C is proportional to L/D
- Clock isotopes can probe confinement time.
  - $\tau_{esc} \sim L^2/D$



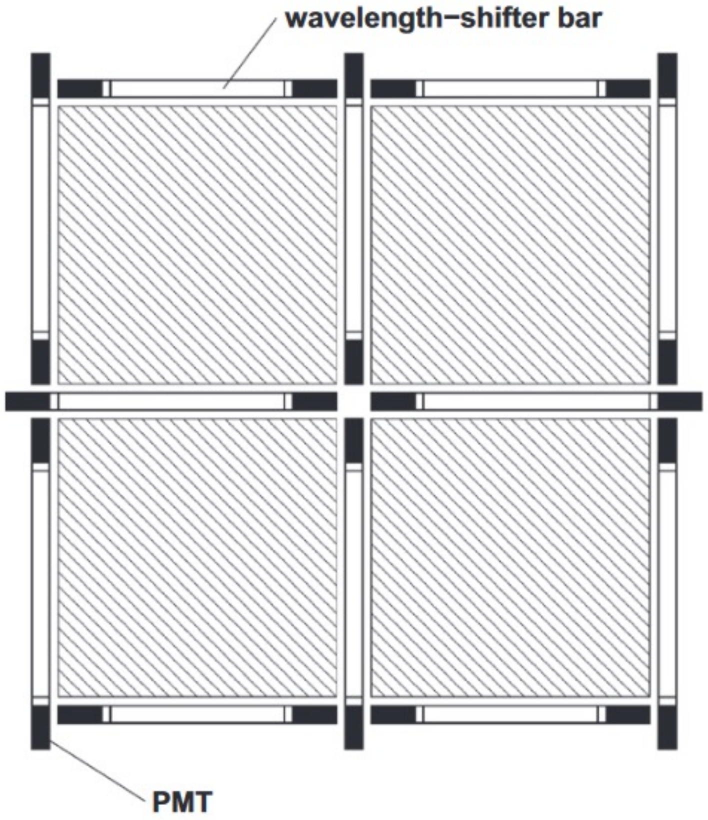
Source: Keith McBride

RICH PERFORMANCE SIMULATIONS

EASY SOLUTION – INTEGRATING CHERENKOV

- Directly measure the number of Cherenkov photons produced in a radiator.
  - Done in the TRACER Balloon Experiment.
- Easy to build, and velocity can be calculated by the Frank-Tamm formula.

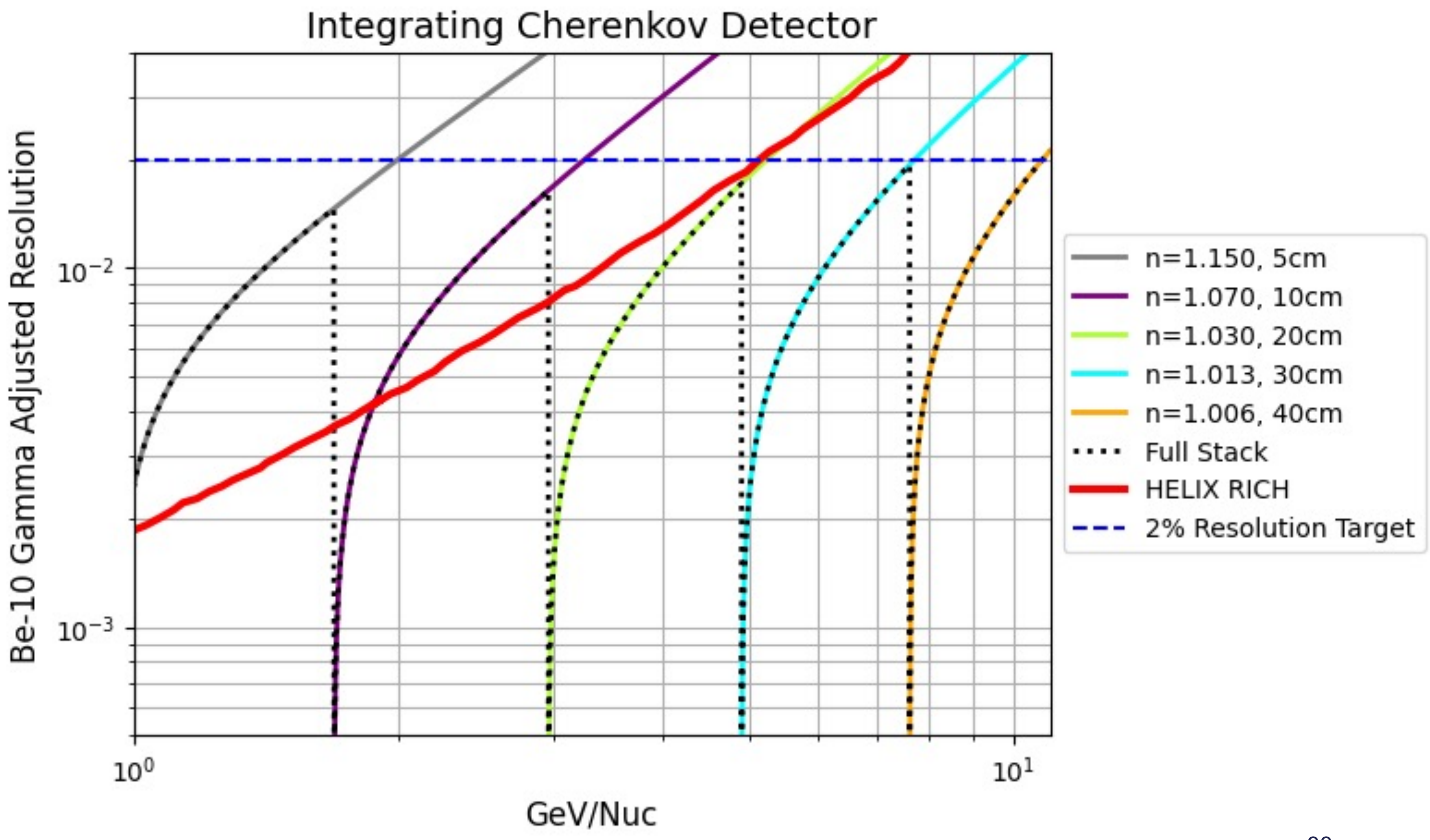
$$\beta \approx \frac{1}{n}\sqrt{\frac{1}{\left(1 - \frac{N_{ph}}{370 * L * Z^2}\right)}}$$



TRACER's Integrating Cherenkov Detector
Source: The TRACER instrument: A balloon-borne cosmic-ray detector
M. Ave, et al.

INTEGRATING CHERENKOV ISSUES - SCALABILITY

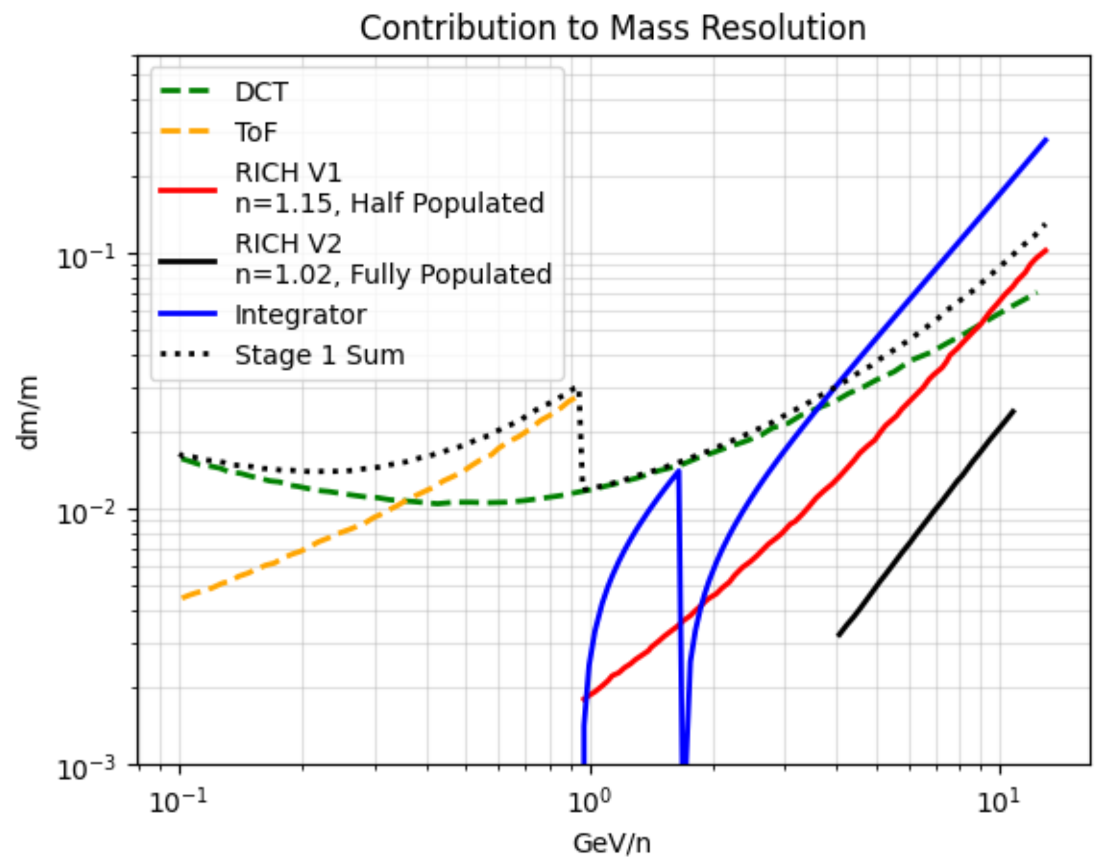
- Difficult to scale to higher energies, requires a stack of detectors
  - Radiators require smaller indexes of refraction, and therefore more material to produce enough photons
- To reach HELIX's second stage: target of 10 GeV/nuc would require >1m of radiator pathlength.
  - Bulky
  - Difficult
  - Greatly Reduced Acceptance



My simulation of an integrating Cherenkov detector for HELIX

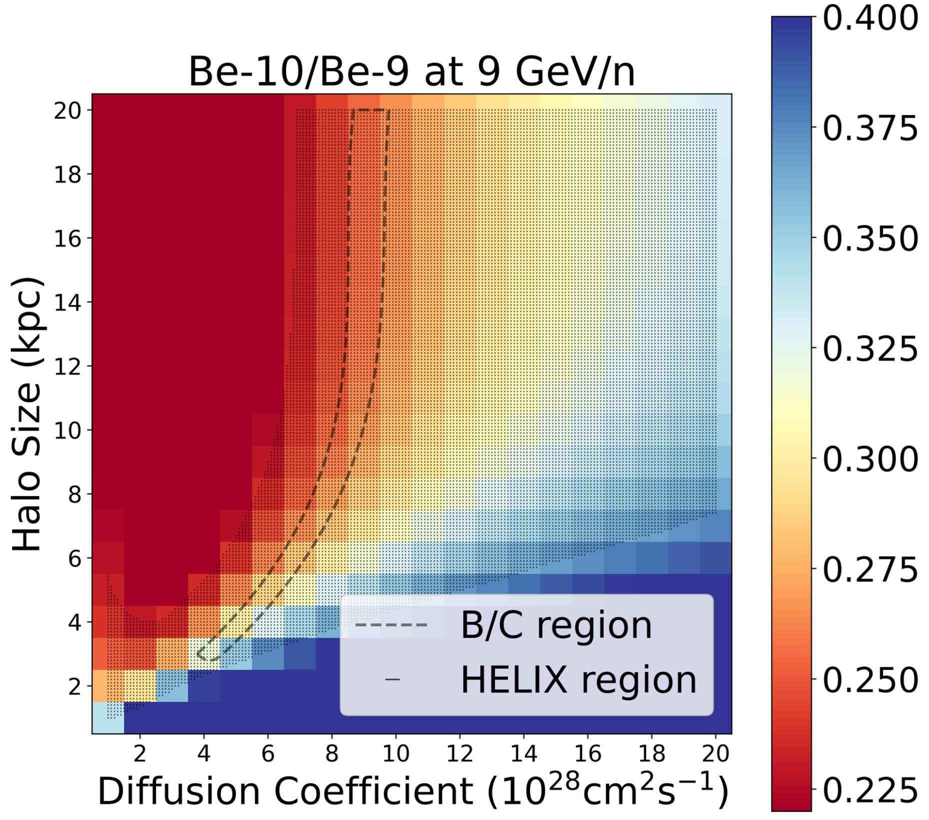
THE RING IMAGING CHERENKOV DETECTOR (RICH)

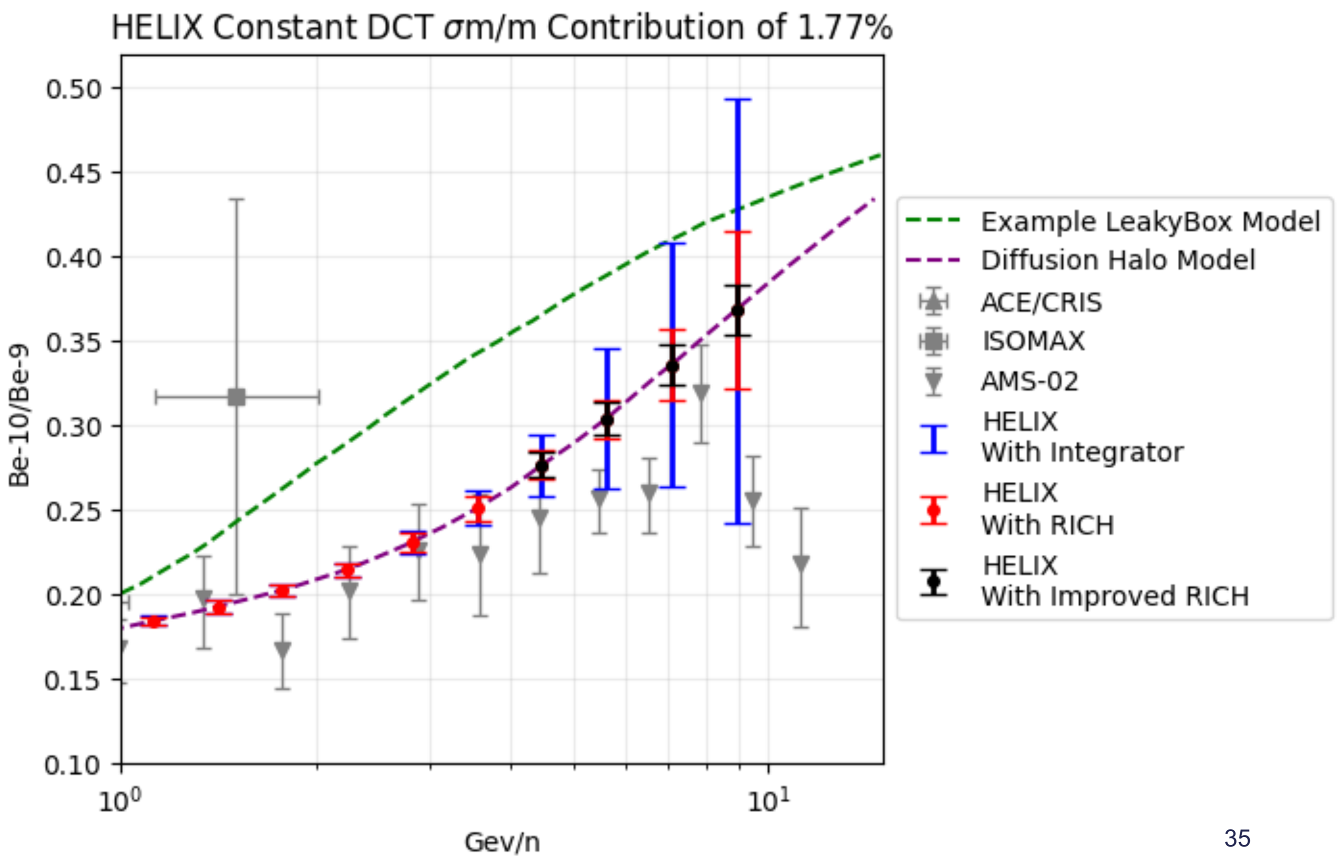
- HELIX's RICH can easily be upgraded to reach higher energies.
  - Replace the radiator with a lower index of refraction material.
  - Fully populate the focal plane.
- A stacked, two-index radiator design can be used to cover a larger energy range.
- HELIX plans to fly in two stages, so these upgrades will be applied to the second stage flight



Comparison of mass resolution contributions

HELIX RICH – SIMULATION WITH INTEGRATOR





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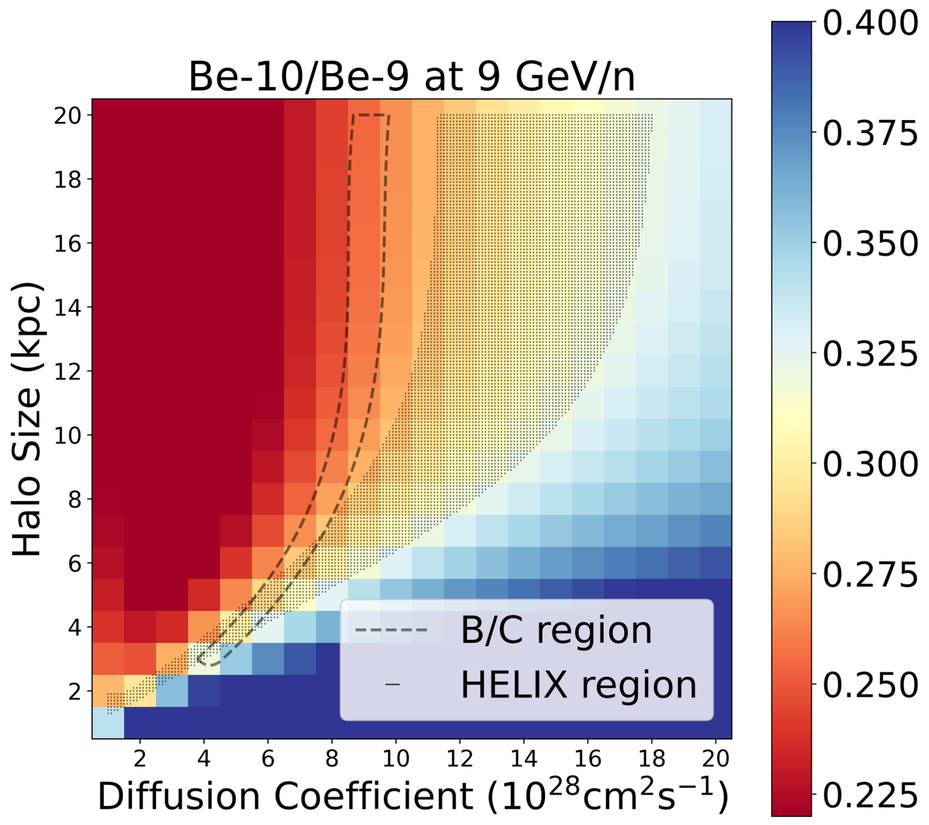
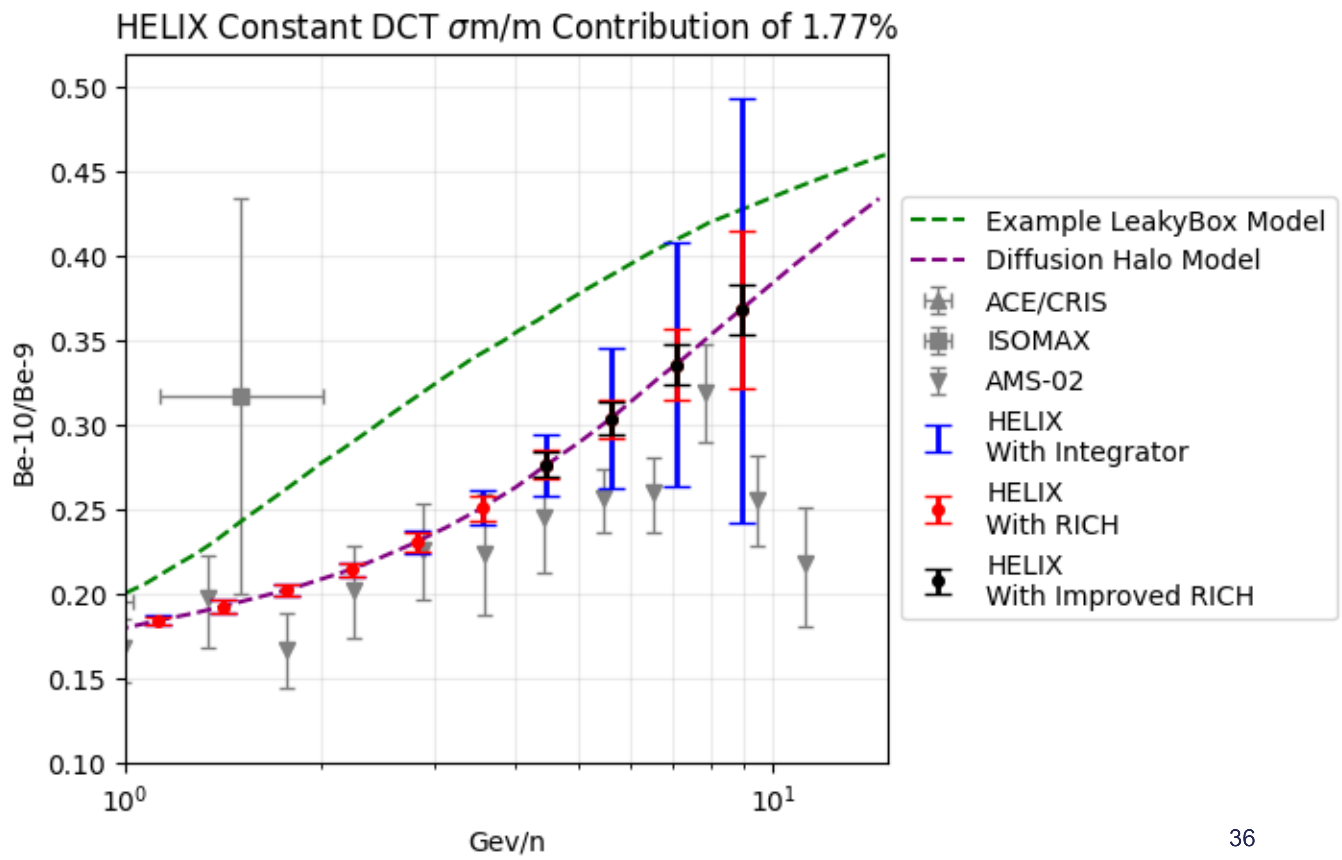
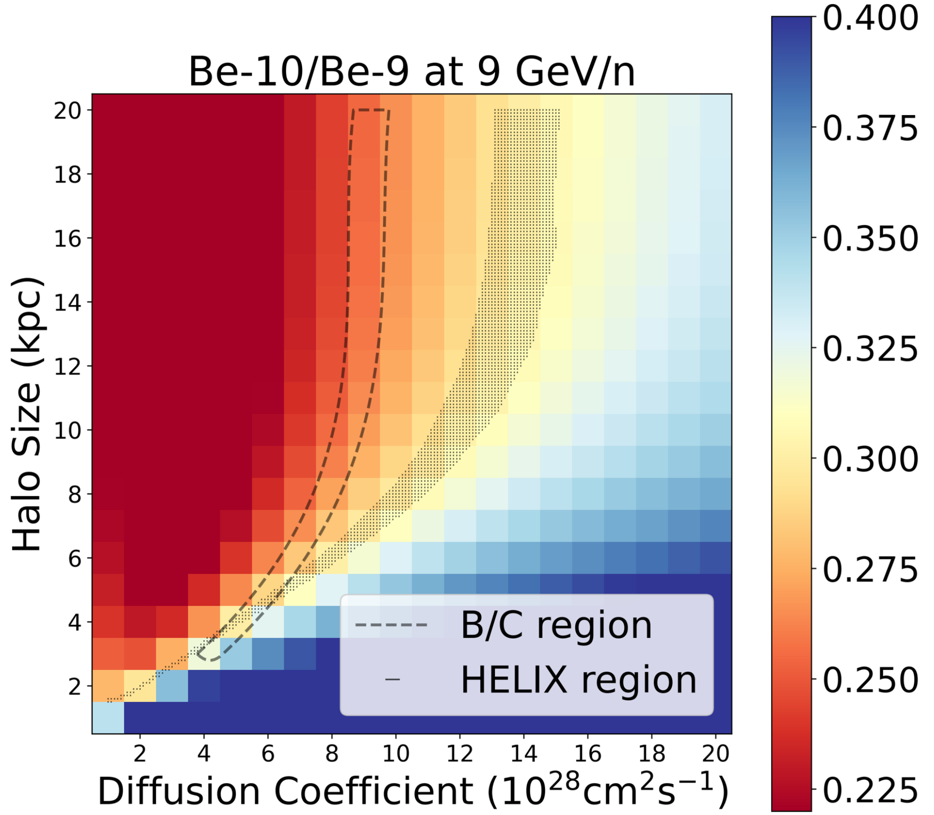
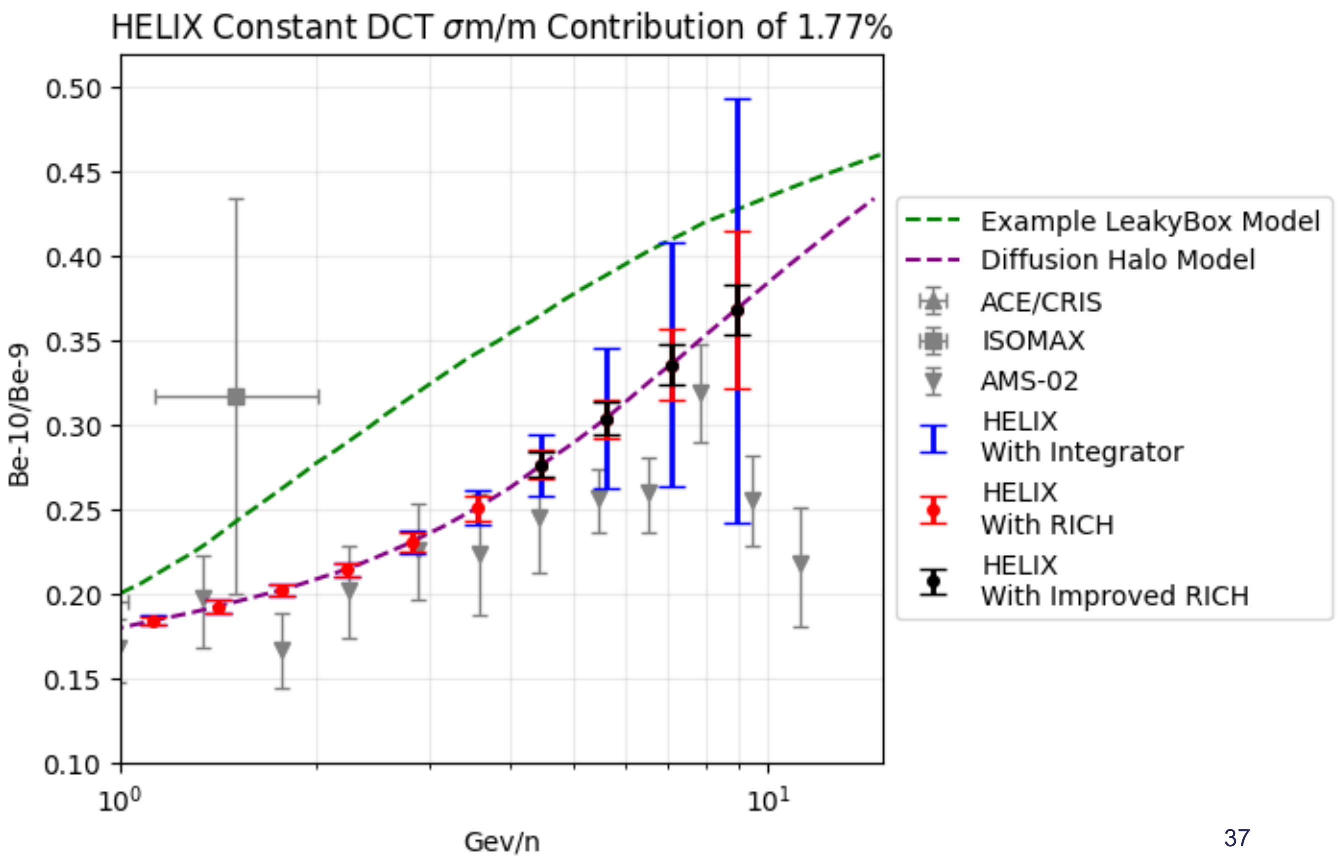




HELIX RICH – SIMULATION WITH RICH IN STAGE 2





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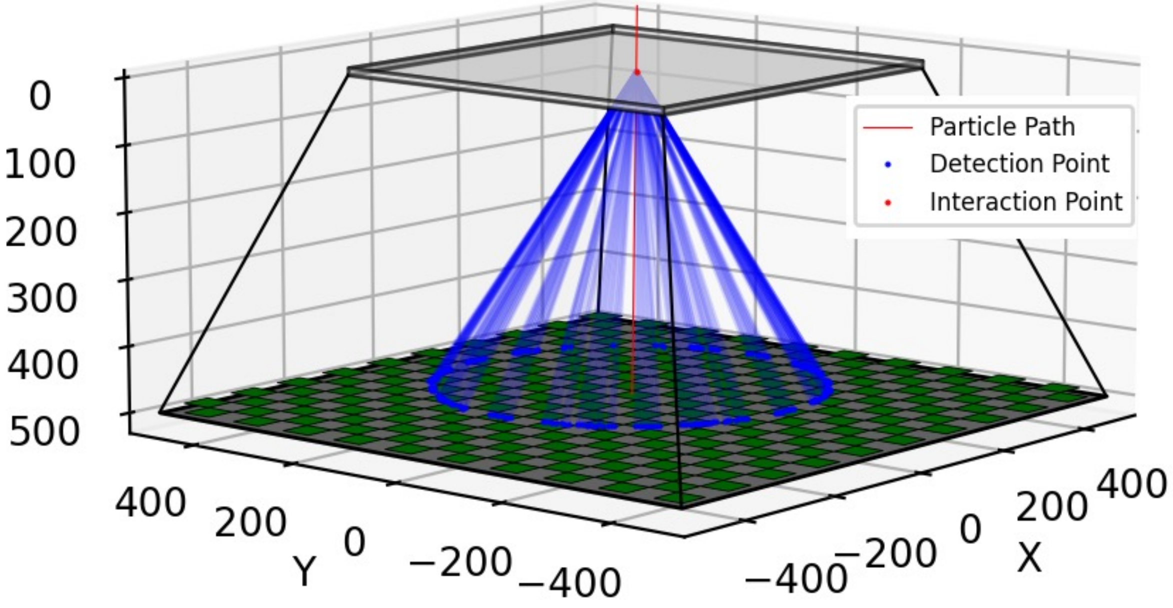

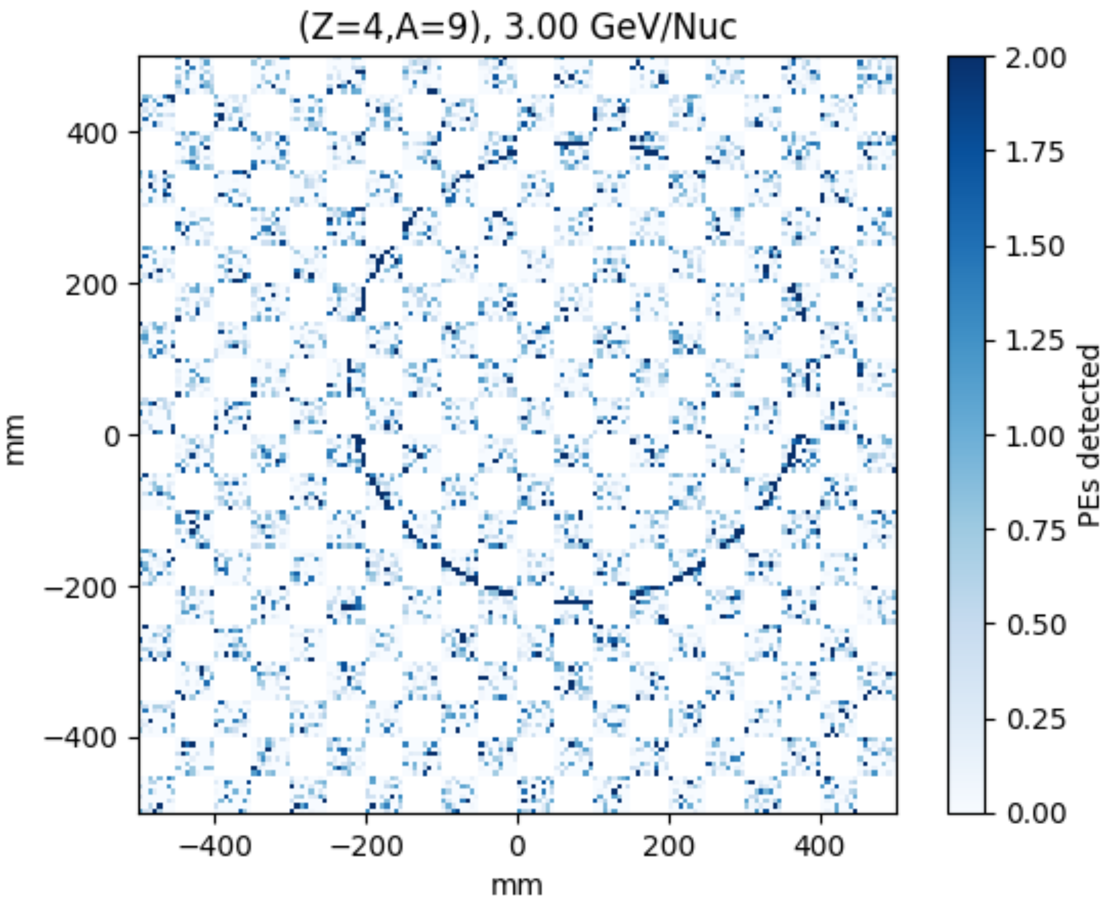

My simulation of HELIX's Ring Imaging Cherenkov Detector

FOCAL PLANE CONSTRUCTION

RICH – AEROGEL RADIATOR

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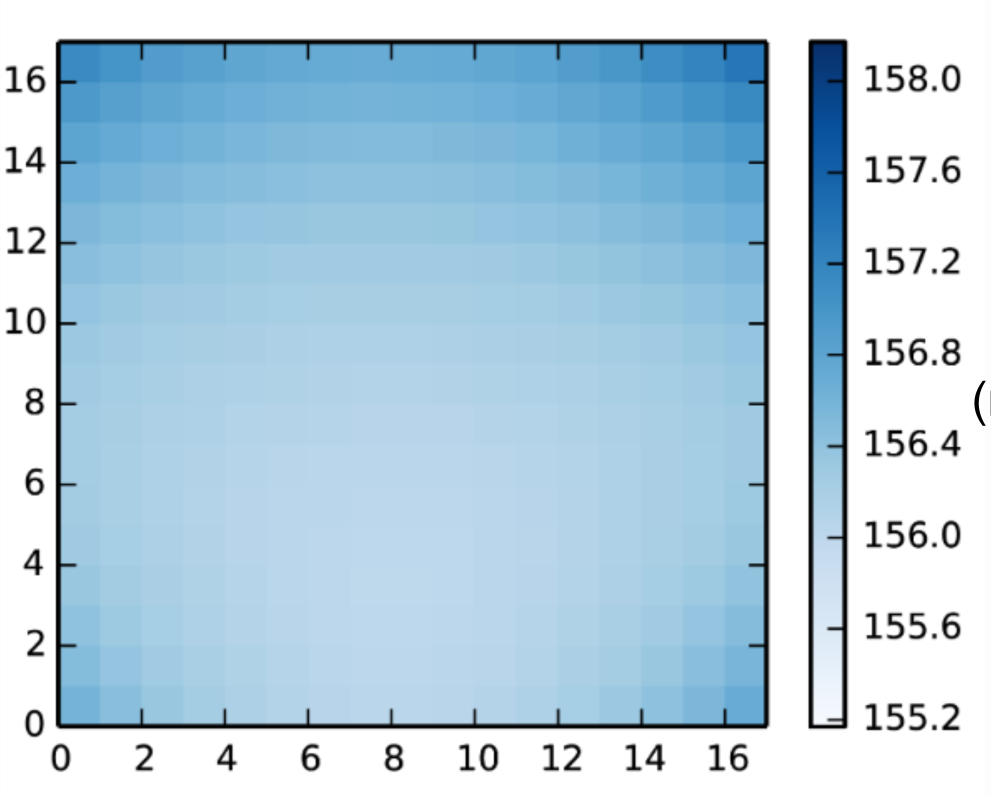
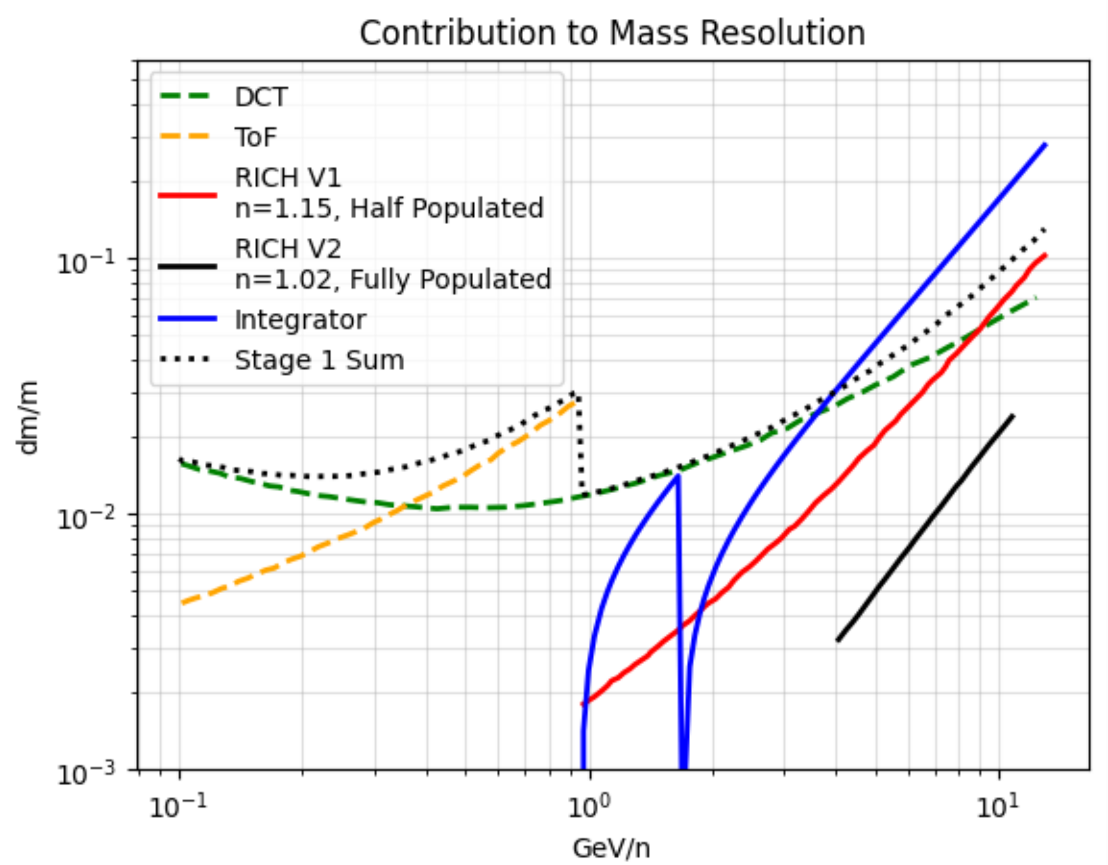


Source: T. Rosin and E. Ellingwood, "Calibration of the Aerogel Tiles for the HELIX RICH", ICRC 2019

THE RING IMAGING CHERENKOV DETECTOR (RICH)

- HELIX's RICH can easily be upgraded to reach higher energies.
  - Replace the radiator with a lower index of refraction material.
  - Fully populate the focal plane.
- A stacked, two-index radiator design can be used to cover a larger energy range.
- HELIX plans to fly in two stages, so these upgrades will be applied to the second stage flight

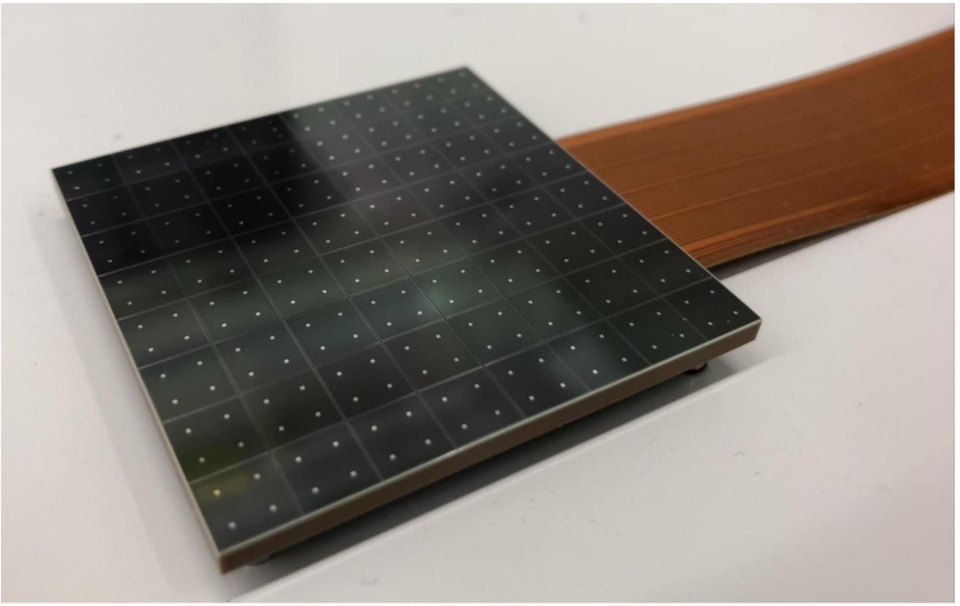


Comparison of mass resolution contributions

SILICON PHOTOMULTIPLIERS

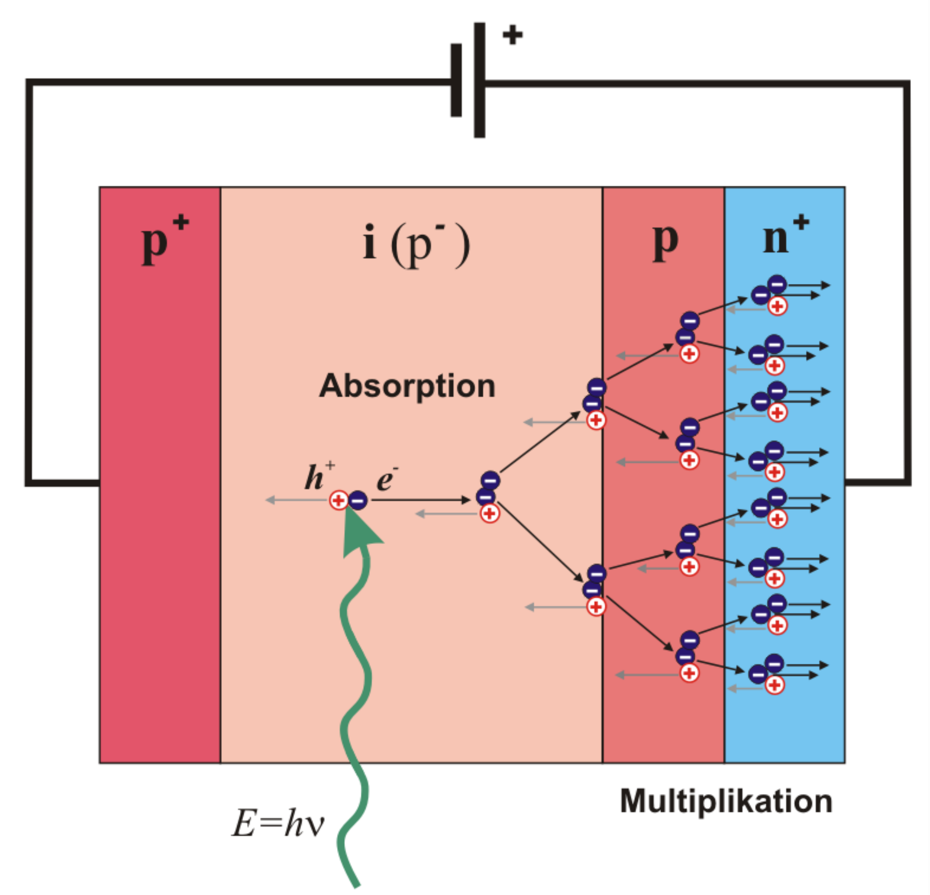
SiPMs

- The RICH's focal plane is made of 200 8x8 arrays of SiPMs.
  - Each SiPM is 6 mm x 6 mm
  - Manufactured by Hamamatsu.
- HELIX's Hodoscope will use the same arrays.
- SiPMs have many advantages over traditional PMTs
  - Most importantly for HELIX, they are unaffected by the presence of strong magnetic fields



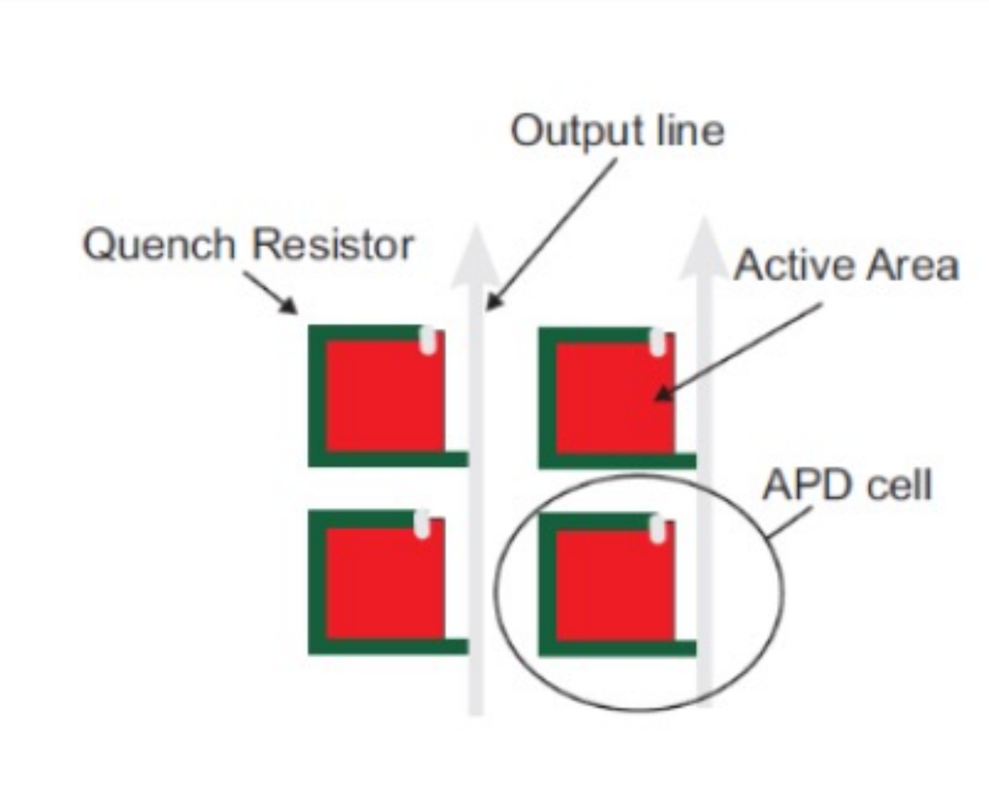
One 8x8 SiPM Array
Photo Credit: Ian Wisher

SiPMs AND AVALANCHE PHOTODIODES (APDs)



Avalanche Photodiode

https://commons.wikimedia.org/wiki/File:APD3_German.png

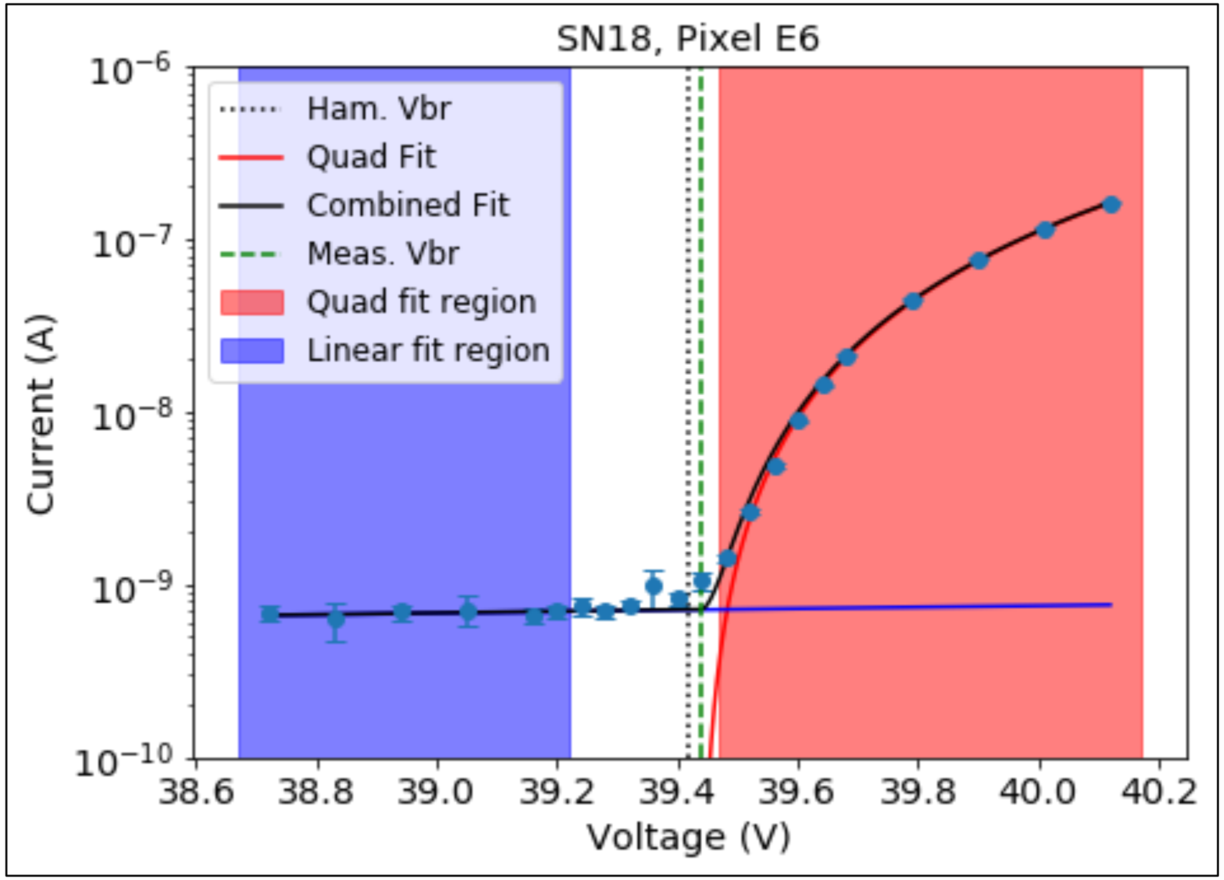


Silicon Photomultiplier Structure

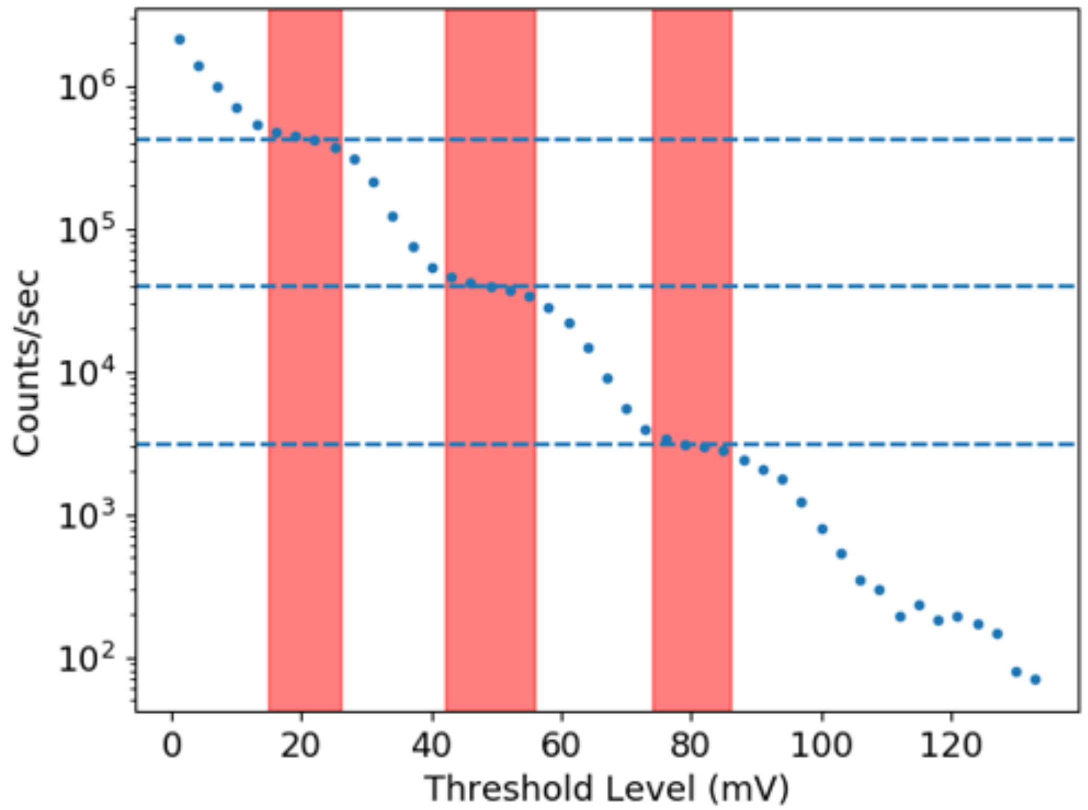
A Nepomuk Otte. Sipm's a very brief review. In International Conference on New Photodetectors, volume 252, page 001. SISSA Medialab, 2016.

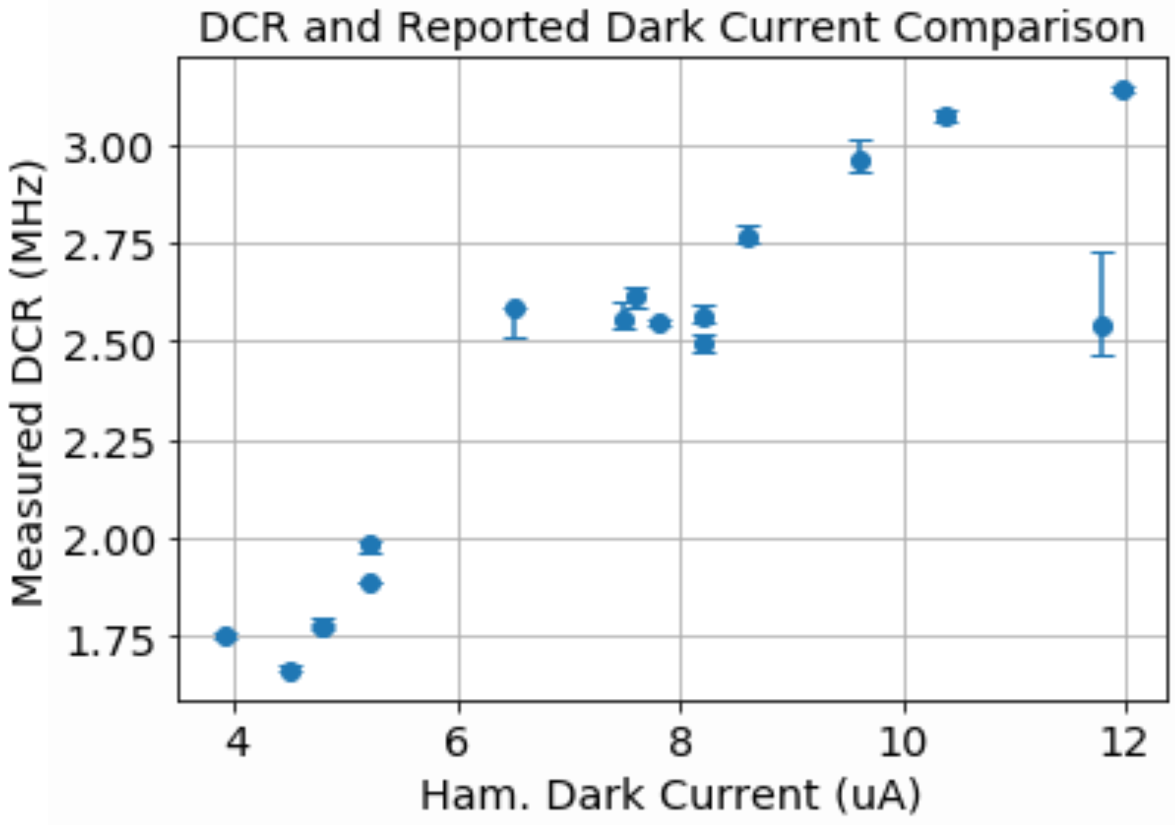
SiPMs – BREAKDOWN VOLTAGE

- Each SiPM channel has a different breakdown voltage – the voltage at which the SiPM “turns on”.
- The bias voltage above breakdown determines the gain, the efficiency, and noise characteristics.

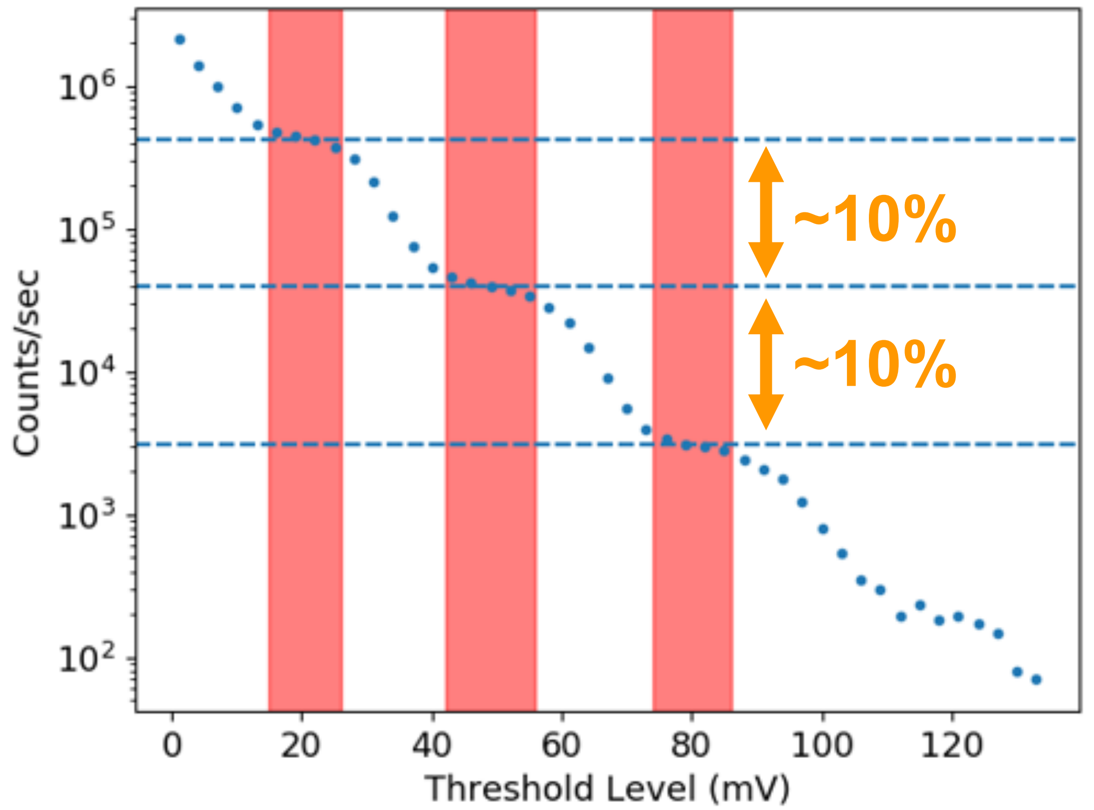


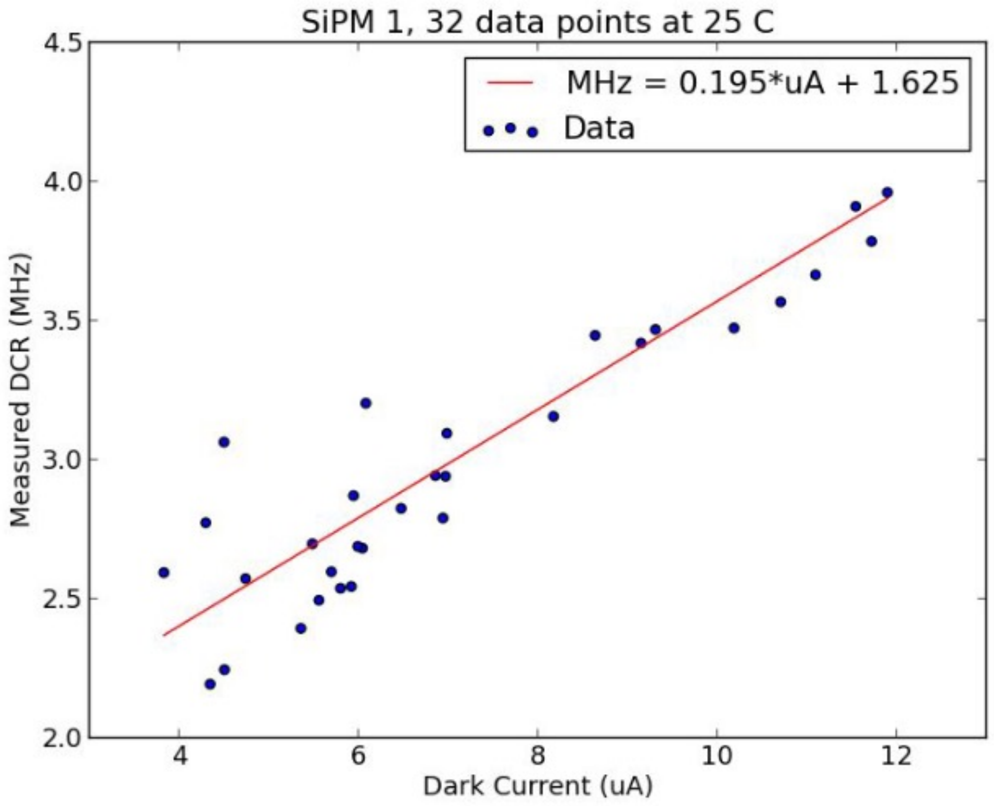
SiPMs – Dark Current And Crosstalk



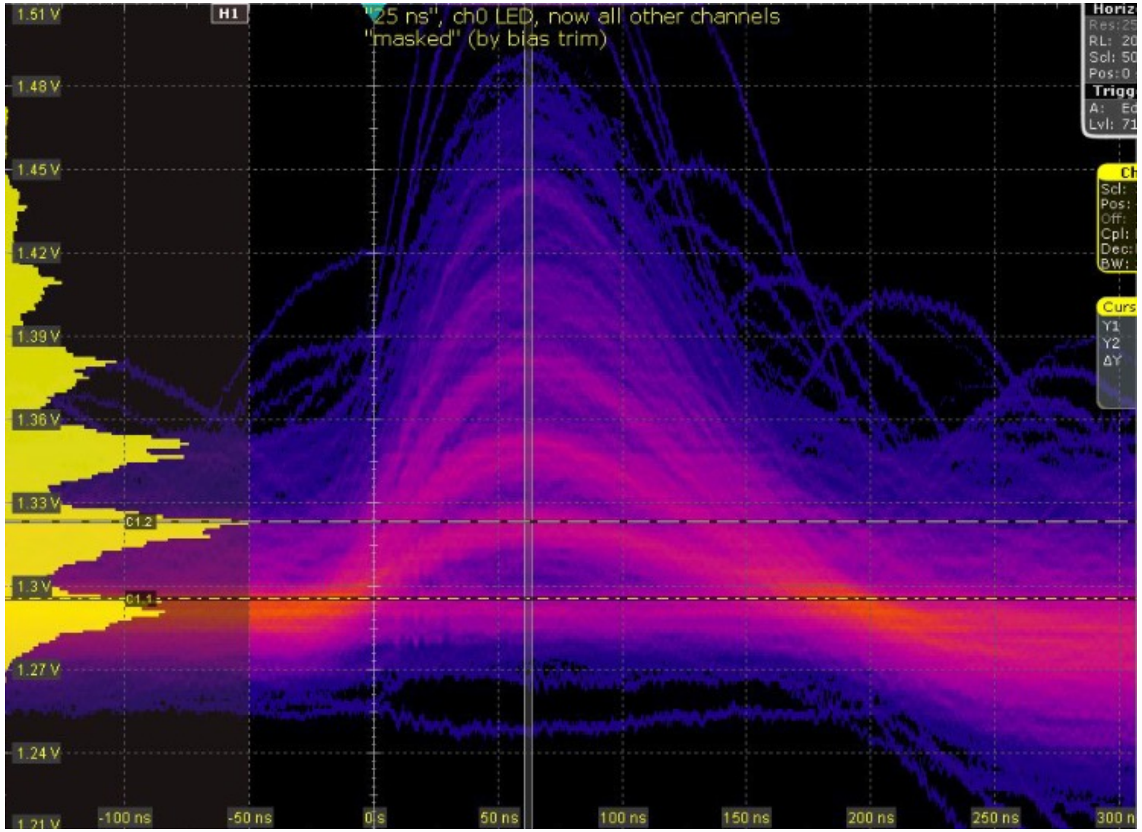


SiPMs – Dark Current And Crosstalk

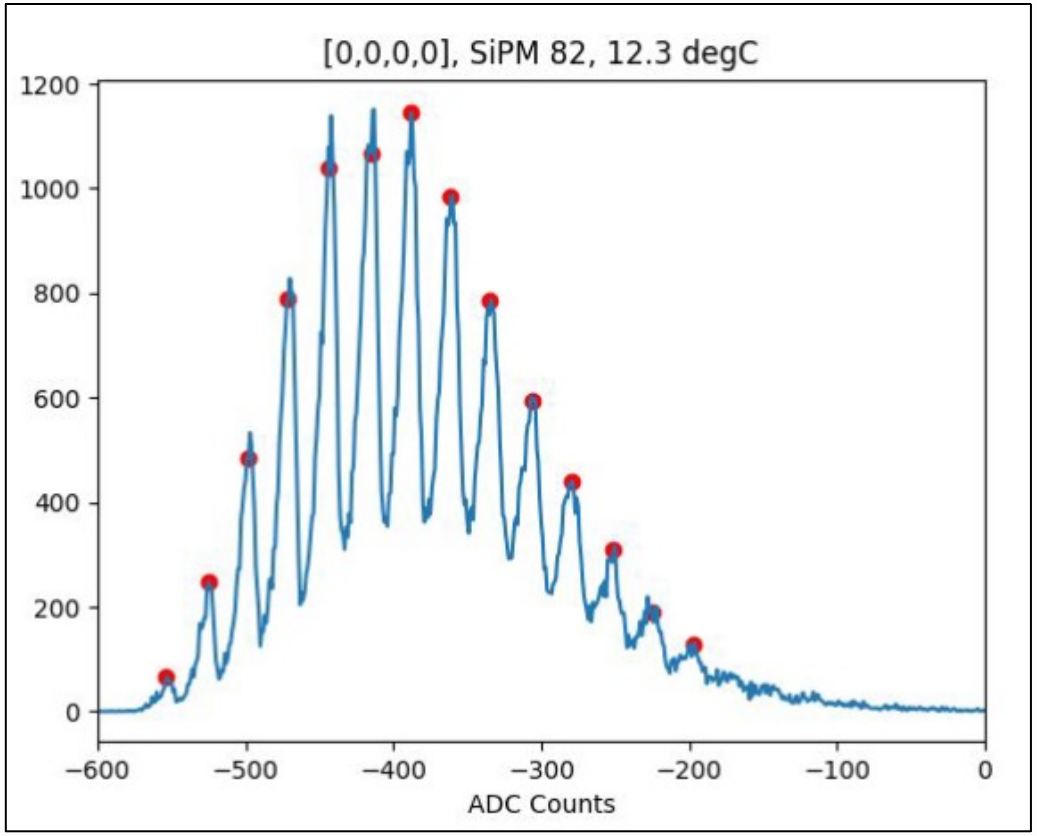




SiPMs – SPECTRUM

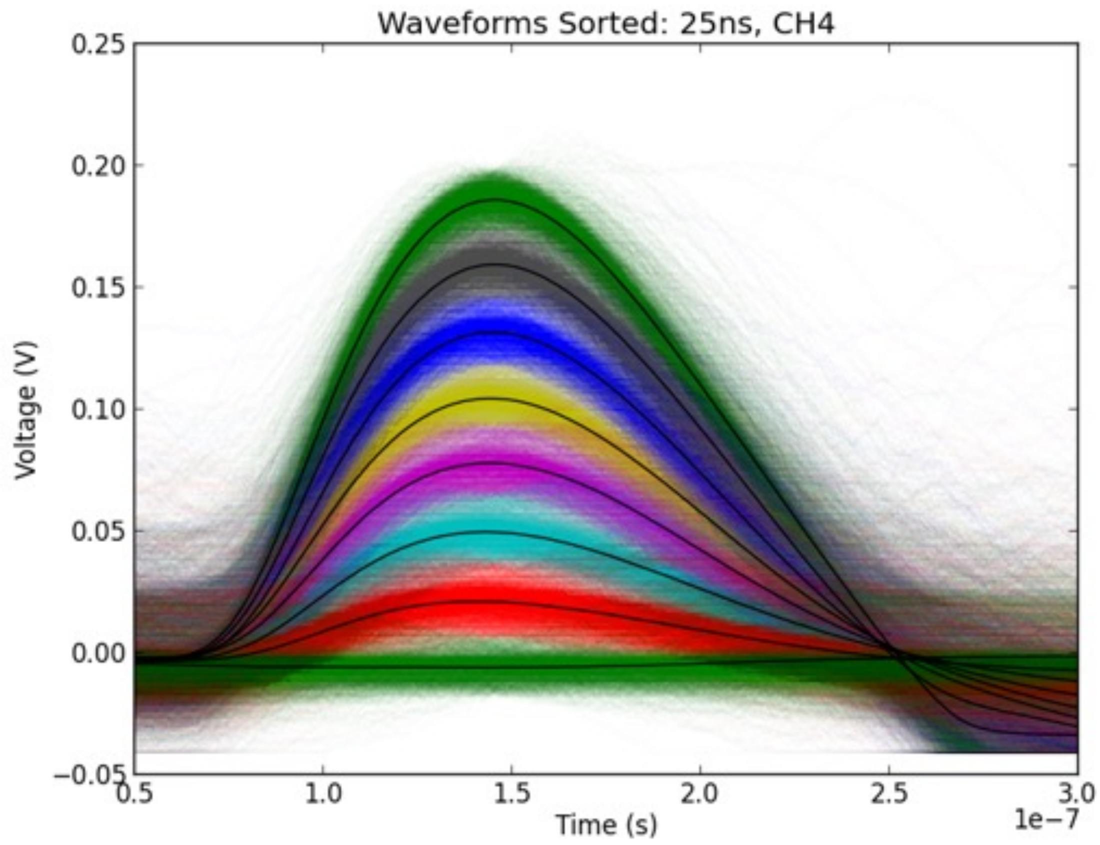


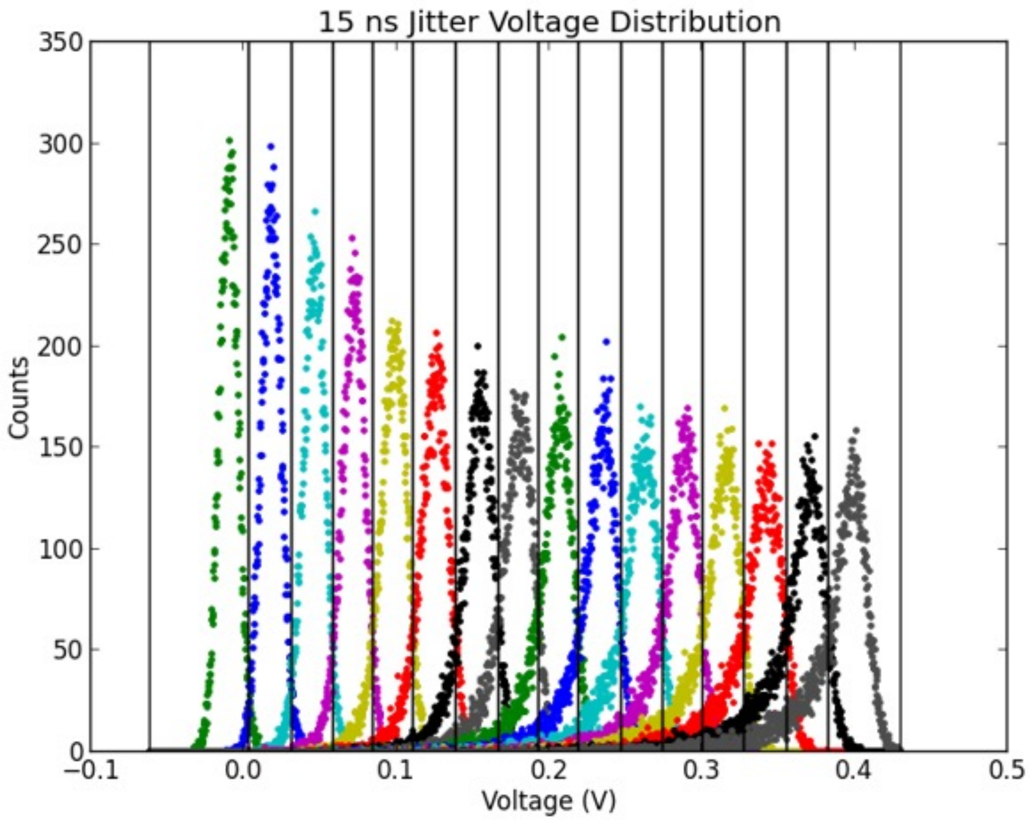
Oscilloscope traces of one SiPM + CITIROC ASIC Channel
Photo Credit: Gerard Visser



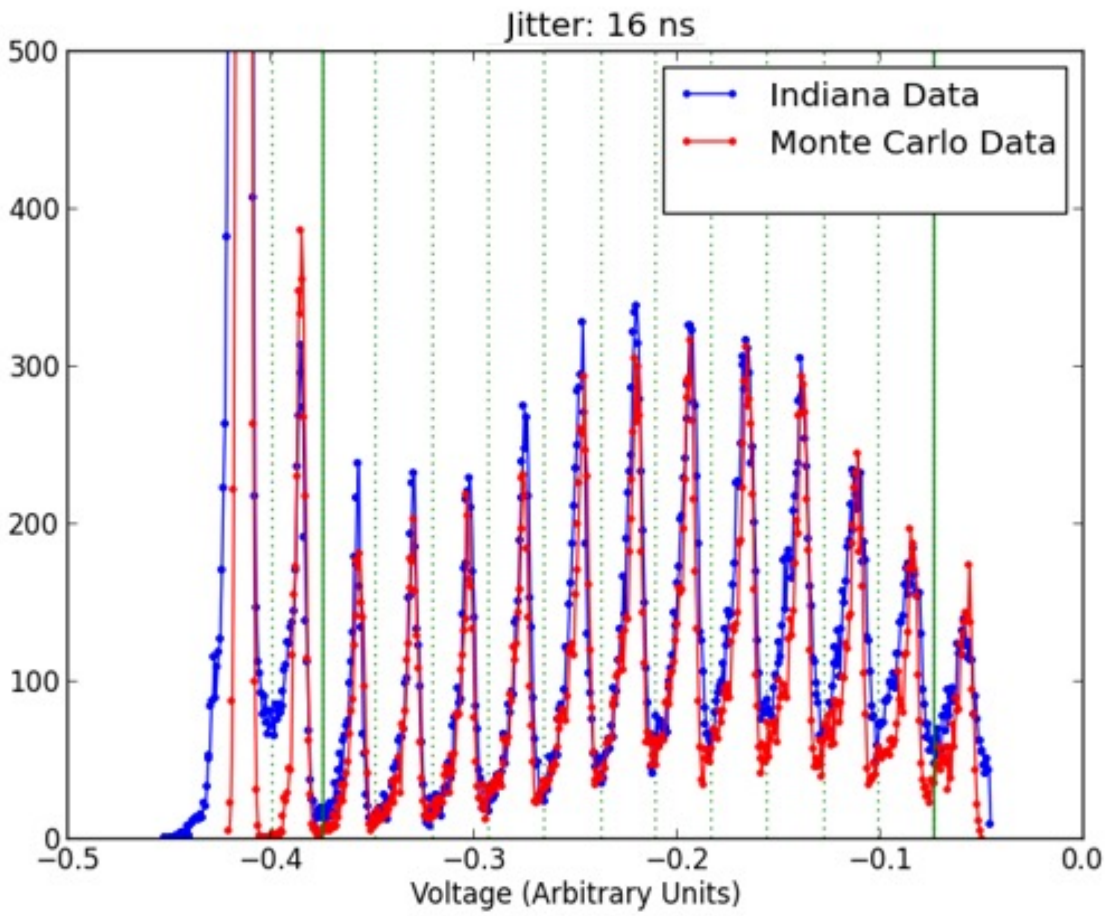
PE Spectrum of one SiPM + CITIROC ASIC Channel

SiPMs – SIGNAL MONTE CARLO





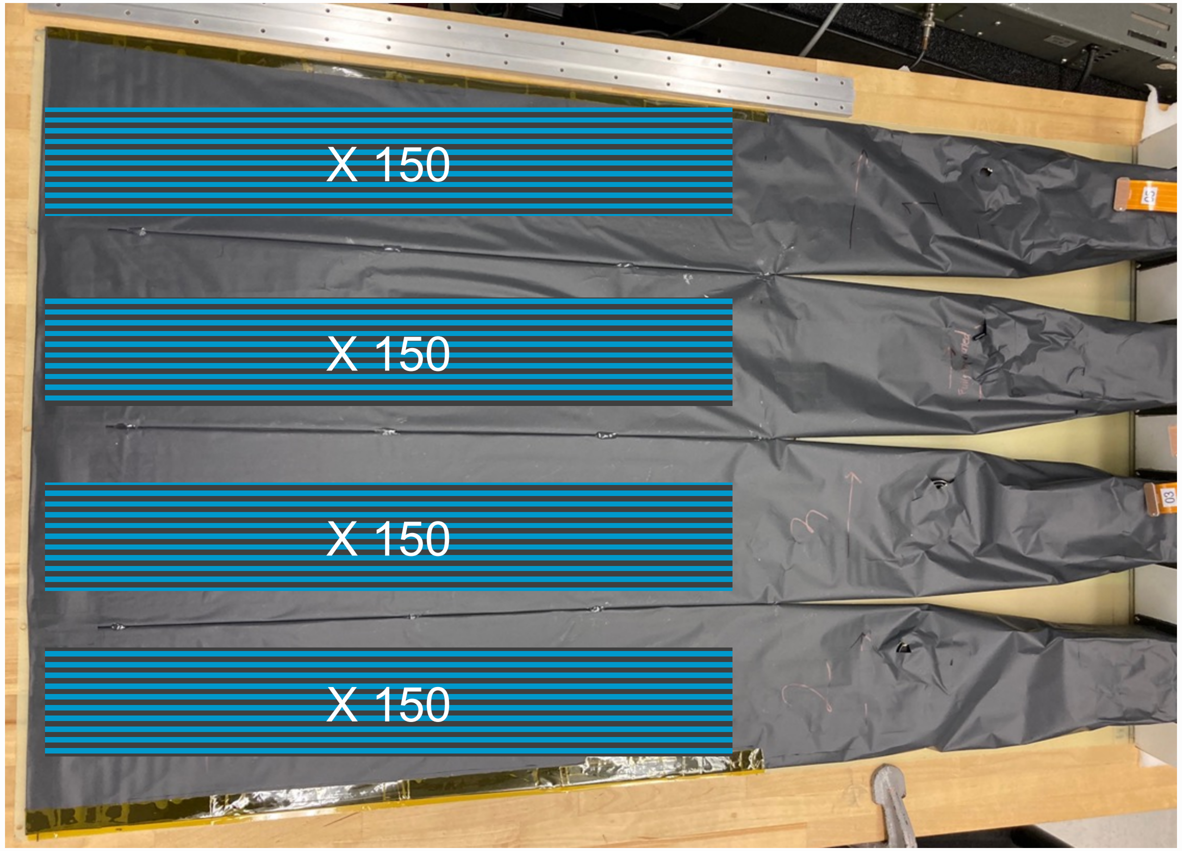
SiPMs – SIGNAL MONTE CARLO



DETECTOR DEVELOPMENT PROJECTS

HELIX – HODOSCOPE

- Hodoscope will improve tracking resolution in the non-bending plane.
- This is needed to properly reconstruct the Cherenkov angle in the RICH.
- 1mm square scintillating fibers, sliding in above the aerogel.
- Uses as much RICH hardware as possible.

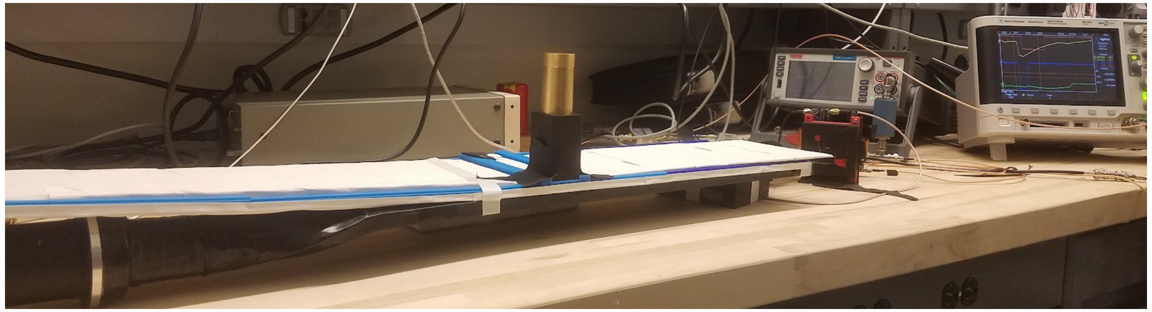


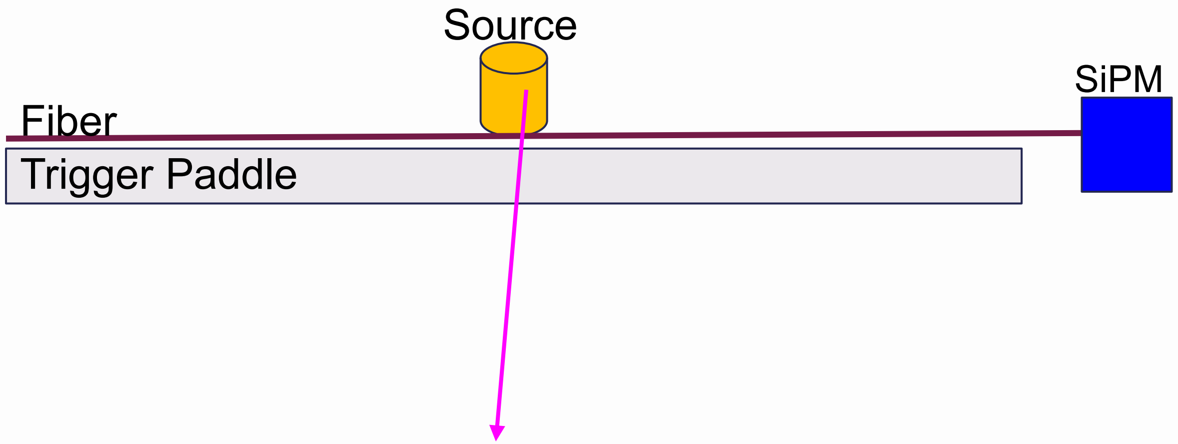
Four wrapped hodoscope ribbons, ready for insertion

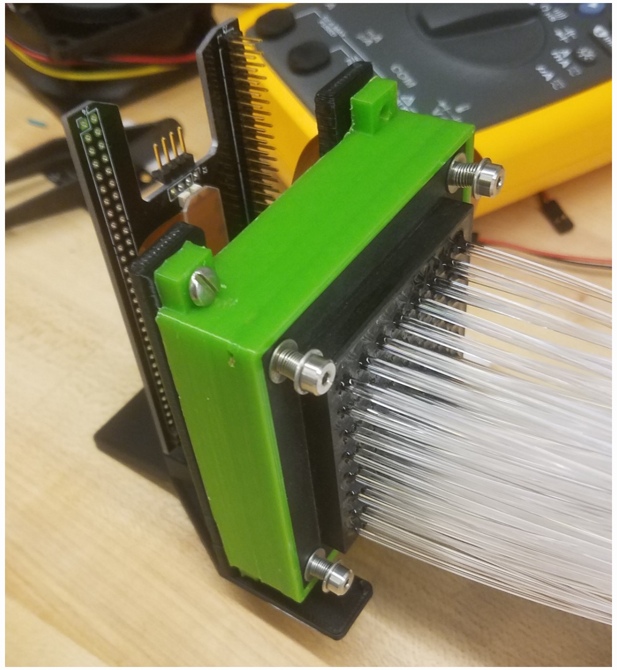
Image Credit: Hyebin Jeon

HODOSCOPE CHARACTERIZATION

- Beta source in brass collimator
- A scintillator paddle below triggers
- 3-D printed parts
  - Collimator mount
  - Fiber track
  - SiPM casing
- Proof of concept for cookie mount successful

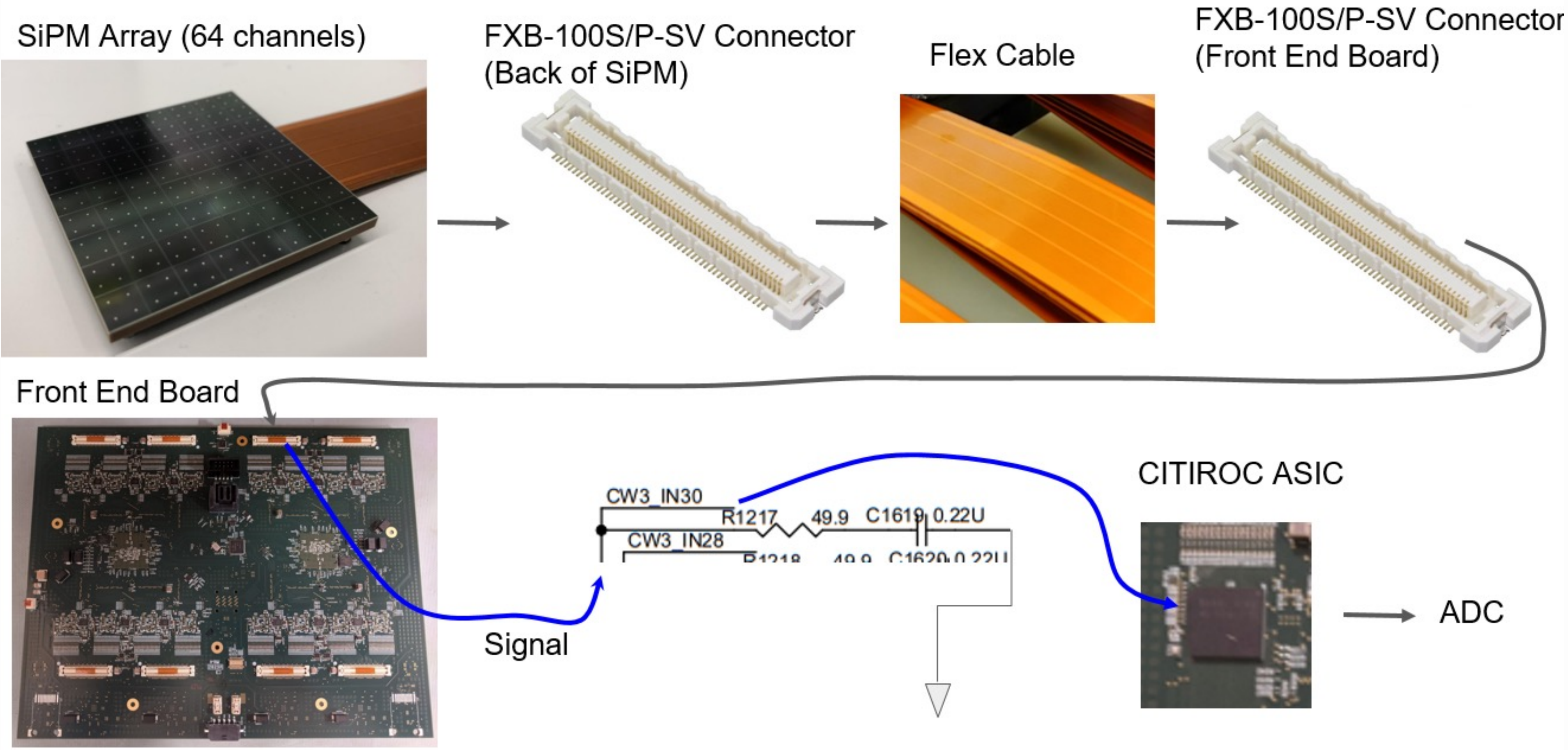




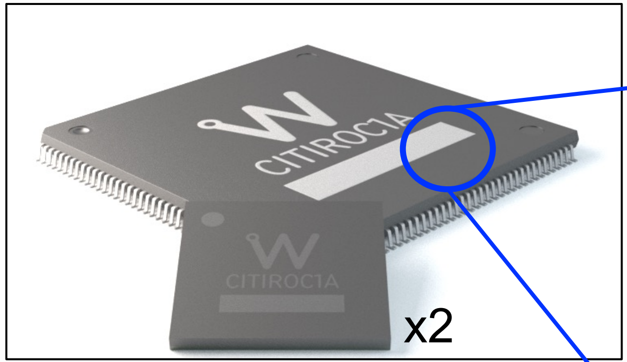


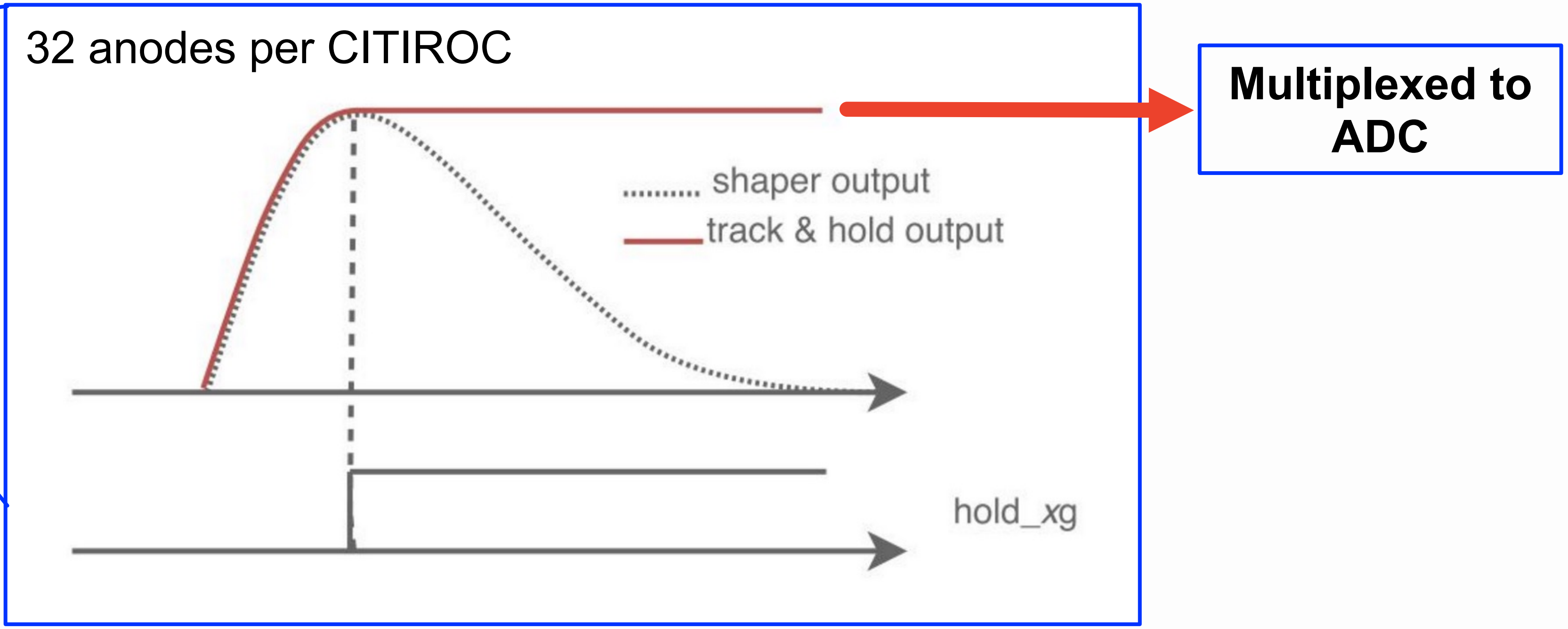
Delrin cookie in 3D printed SiPM mount, with spring loaded bolts for reliable contact

RICH FRONT END BOARDS



CITIROC ASIC



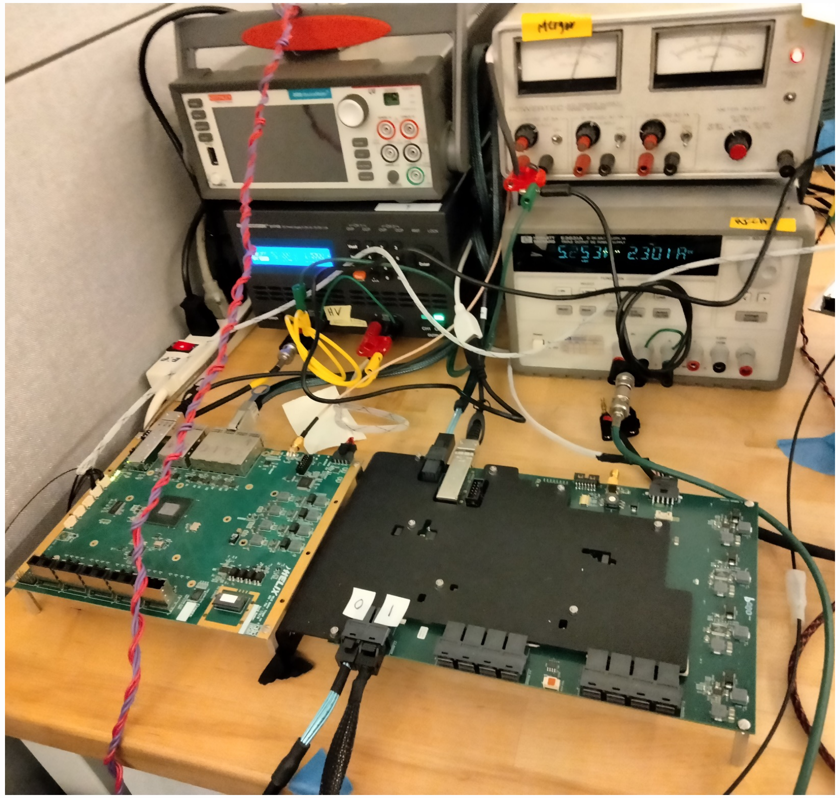


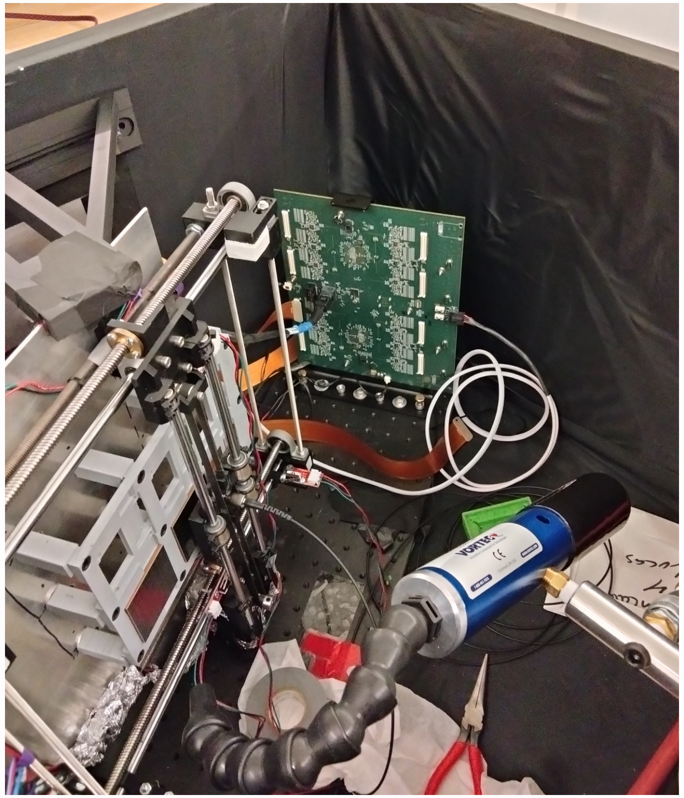
Source: CITIROC1A Datasheet

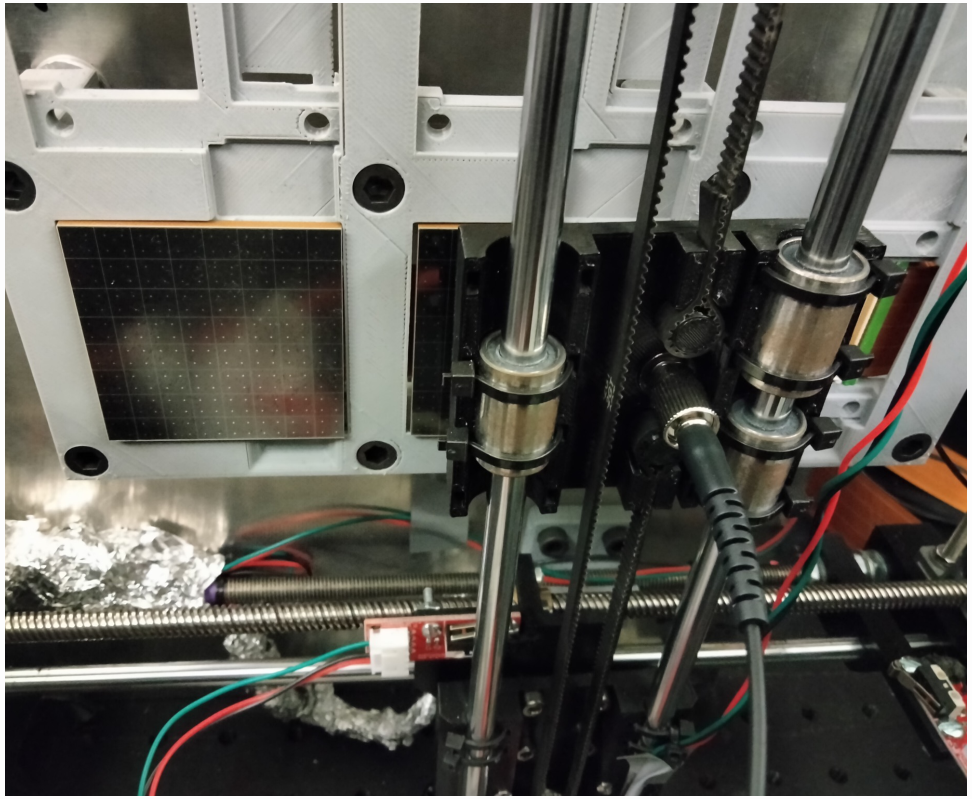
The CITIROC also provides

- Bias trimming via a “virtual ground”
- Preamplification
- Pulse shaping
- A separate fast shaper with internal discriminator

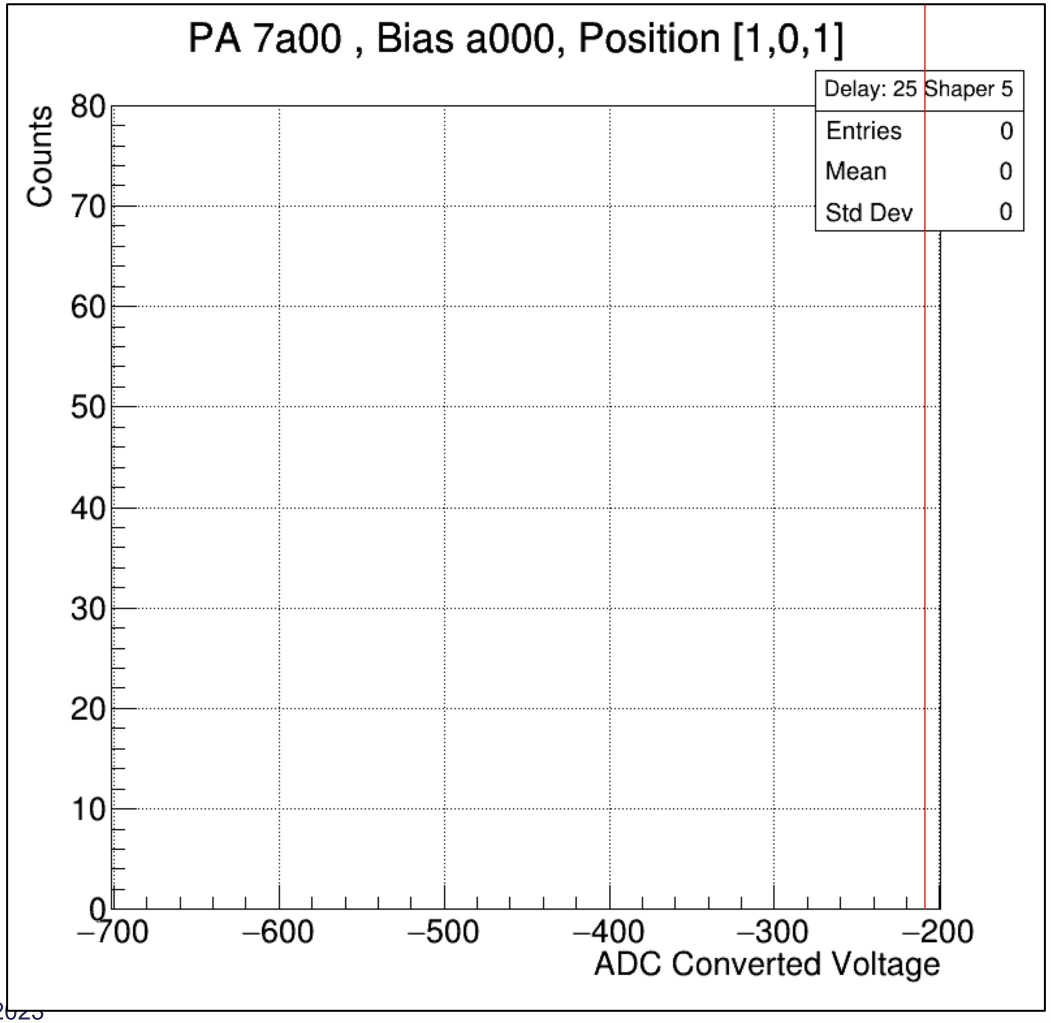
SIPM AND RICH TEST STAND





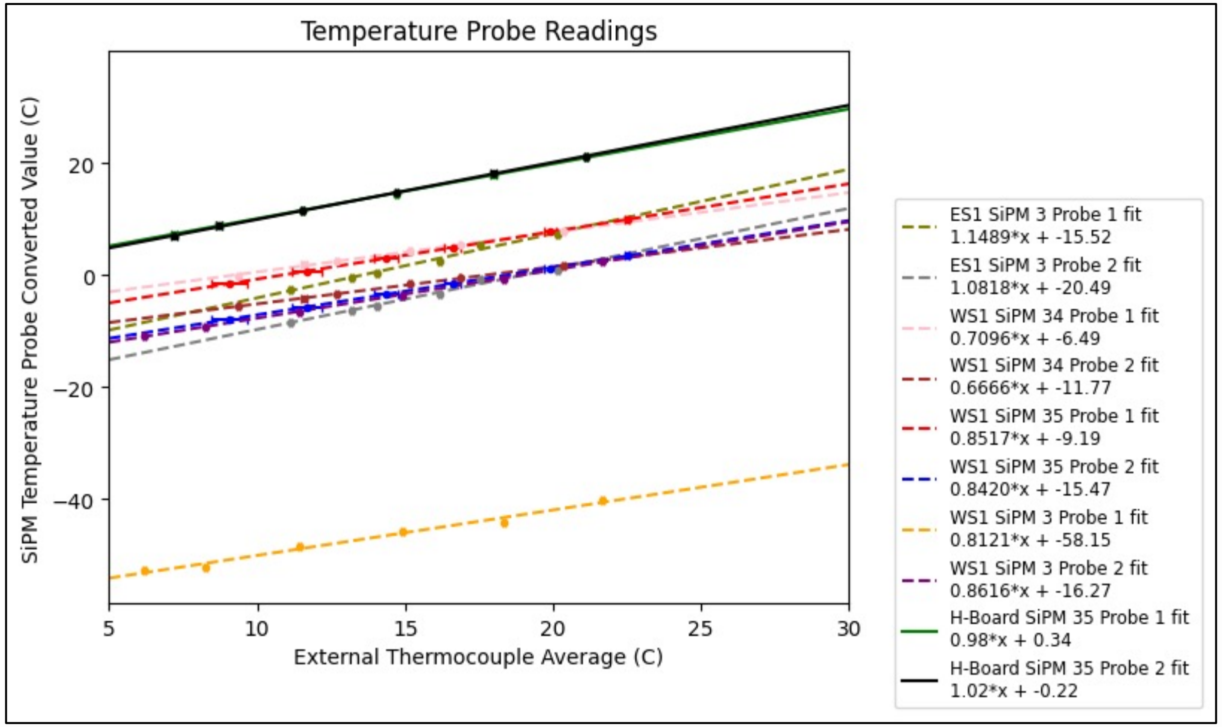


FIRMWARE – ZERO SUPRESSION

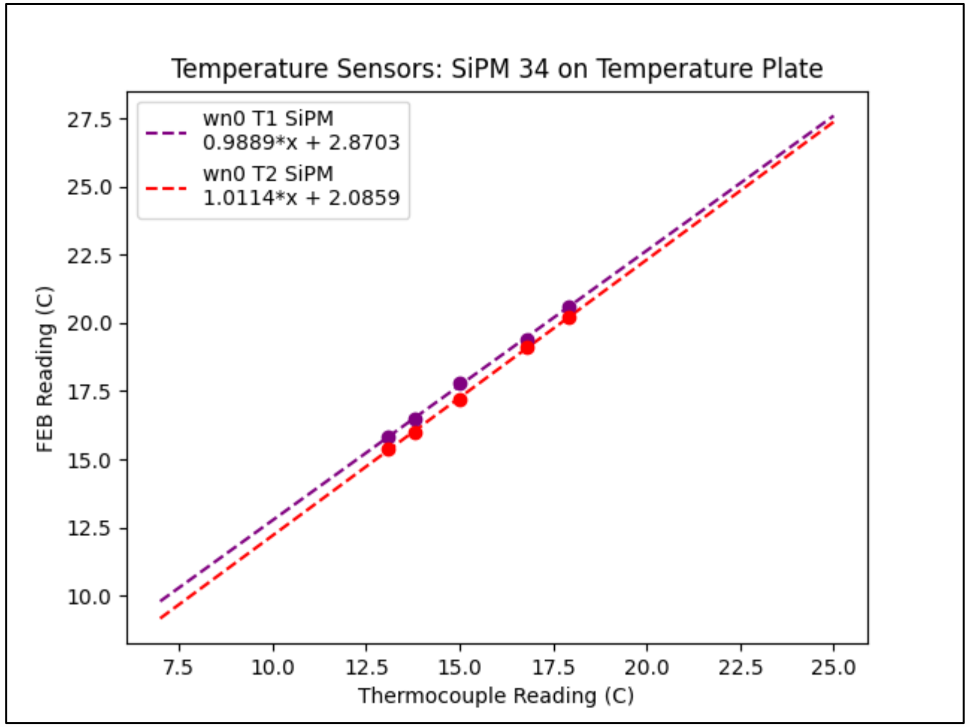


SIPM TEMPERATURE MEASUREMENT

Before Firmware Timing Fix

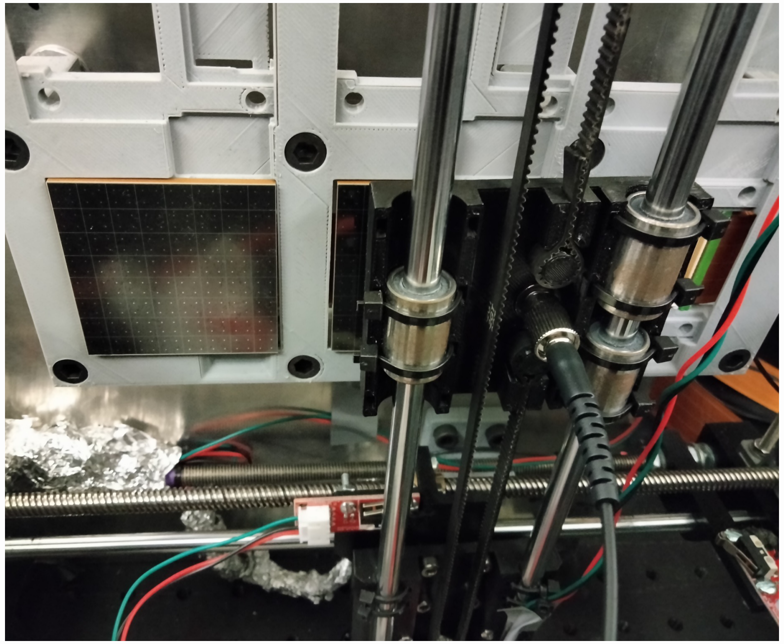


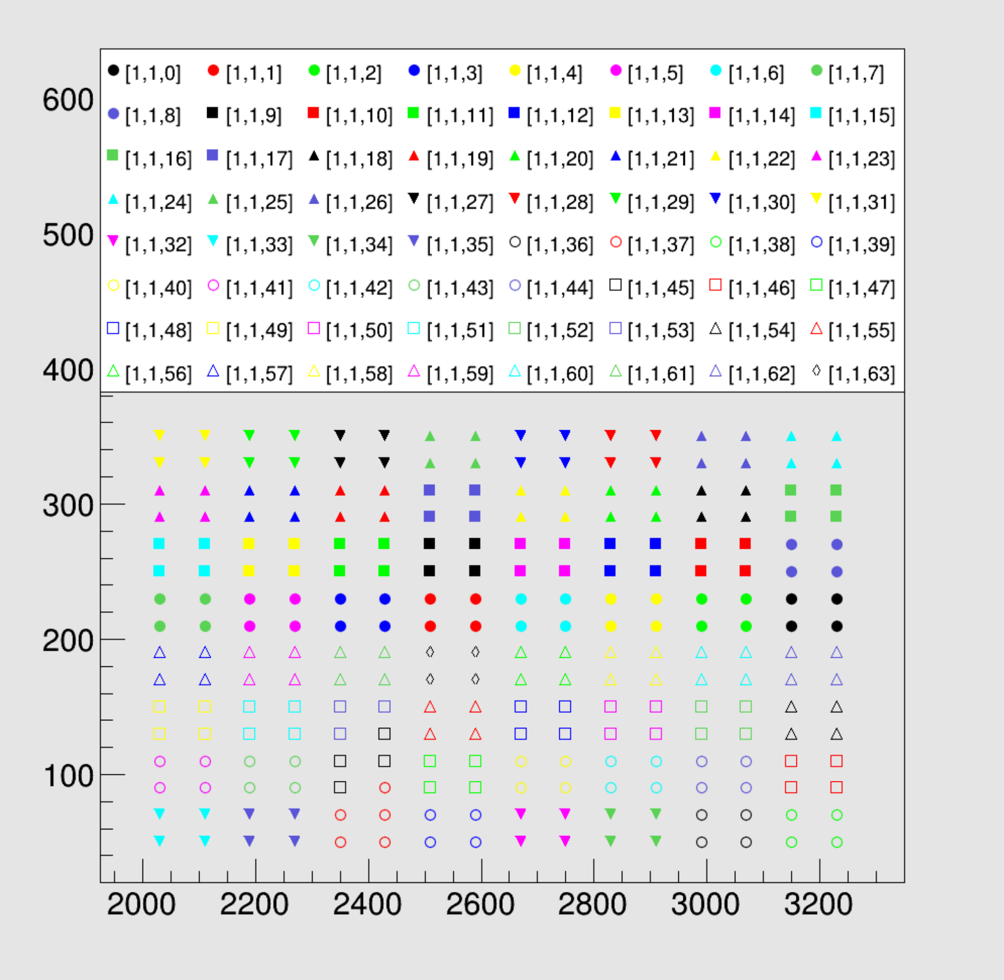
After Firmware Timing Fix



SIPM MAPPING

- The SiPM arrays have been geometrically mapped to their final-step channels
- The coordinates to the right are [FPGA, SiPM Array Position, SiPM Channel]





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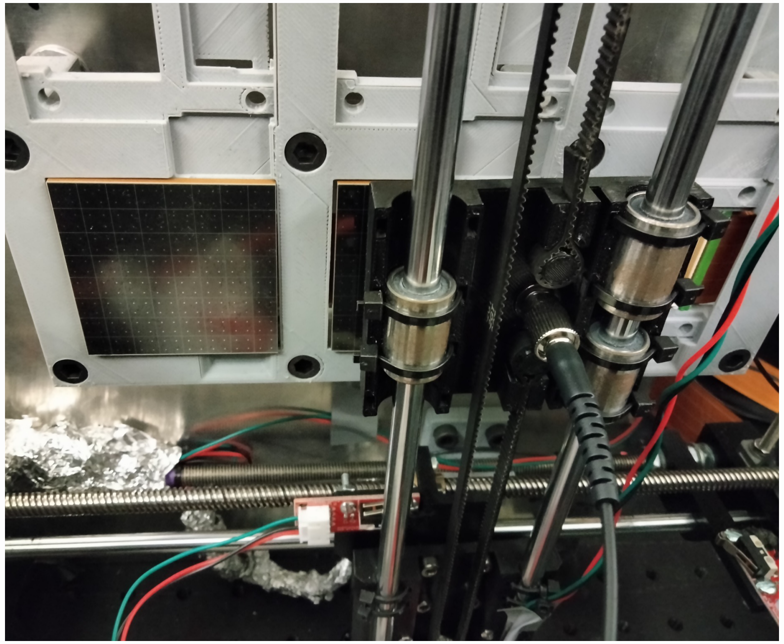
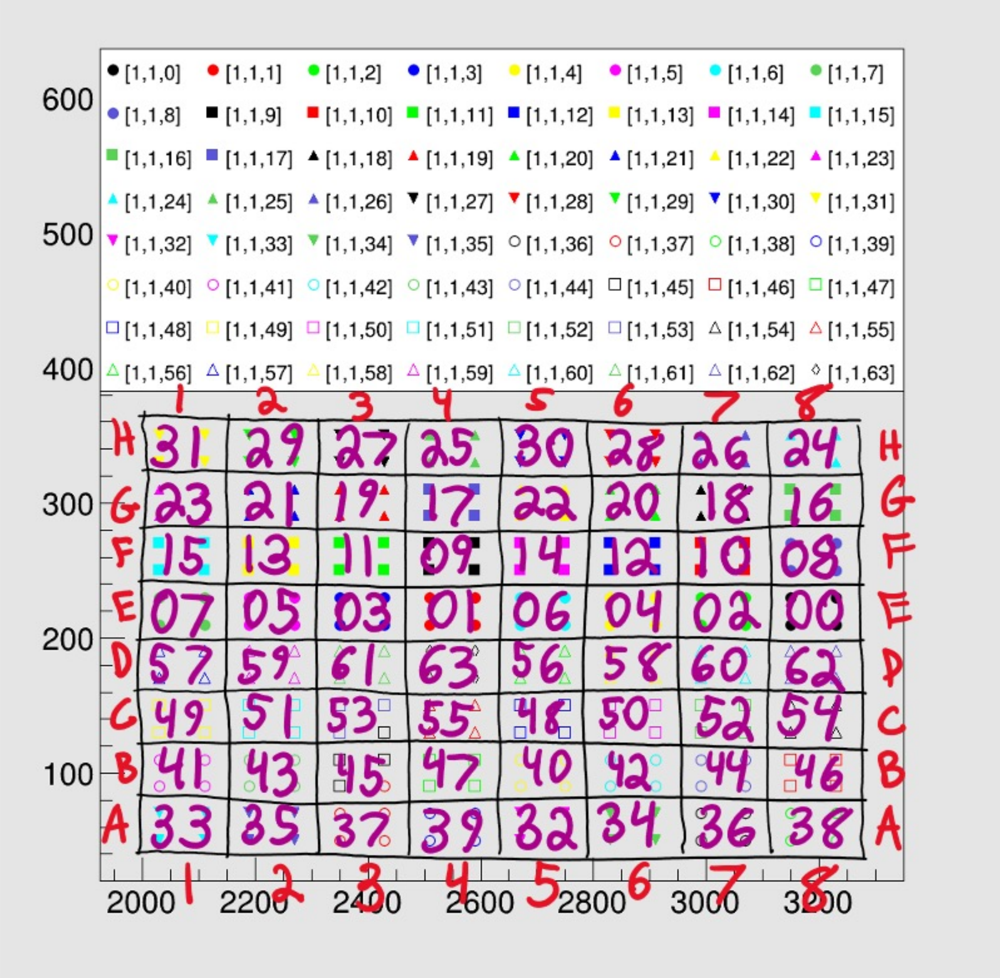
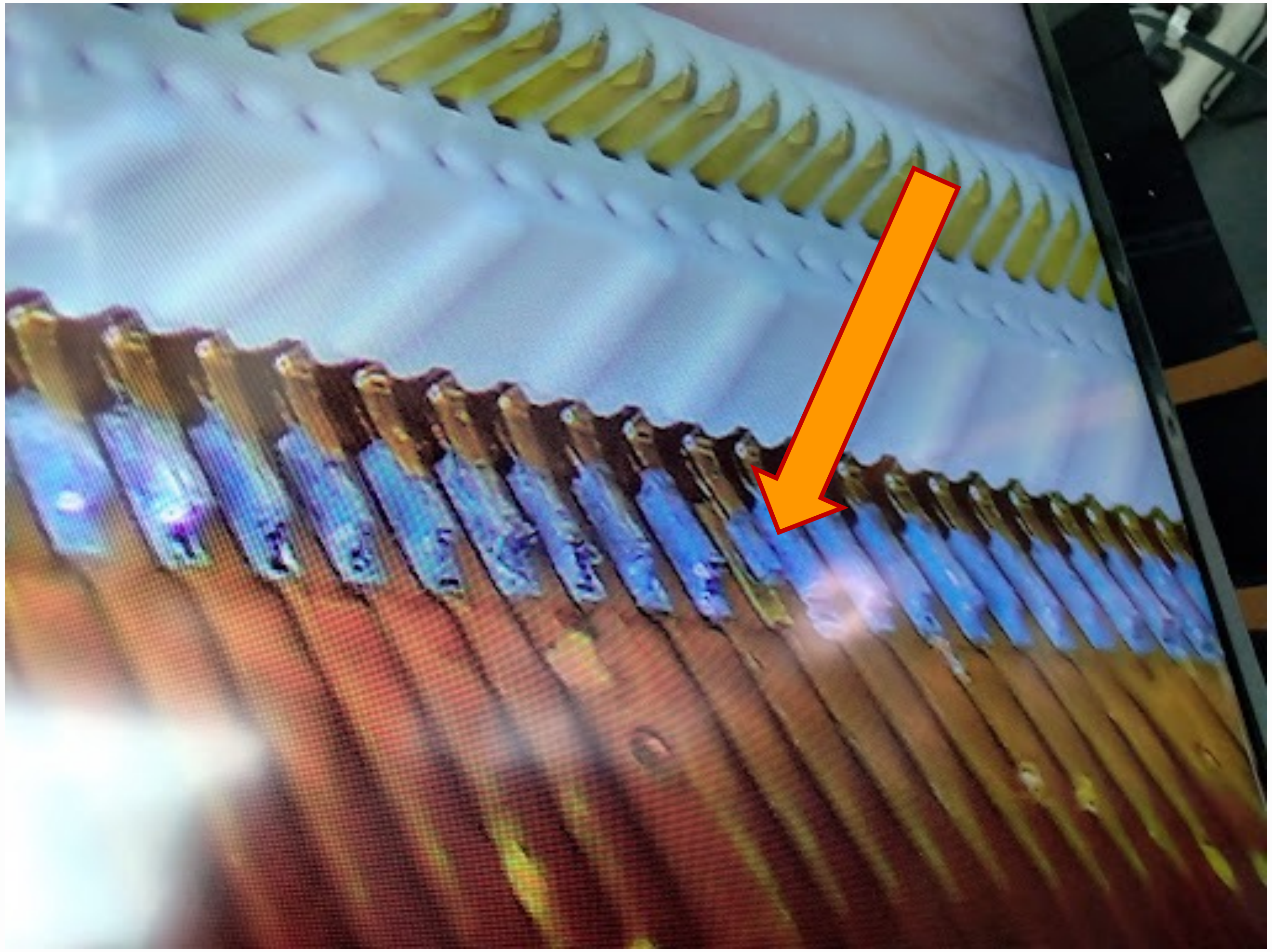
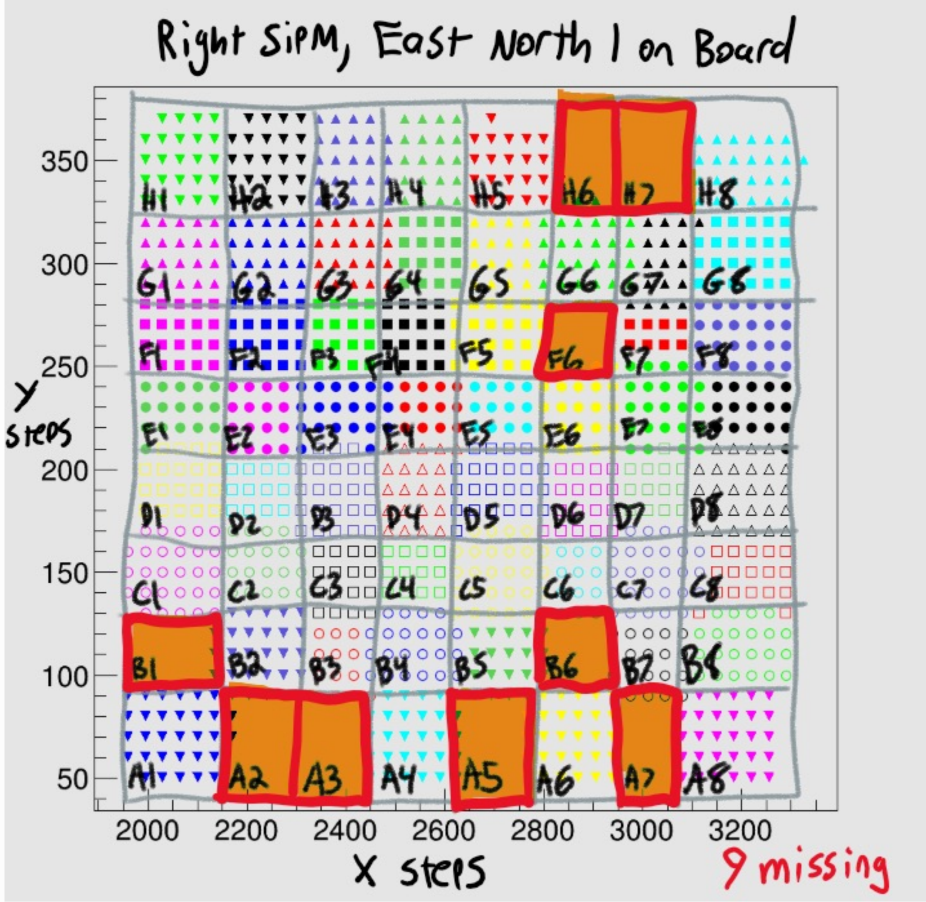


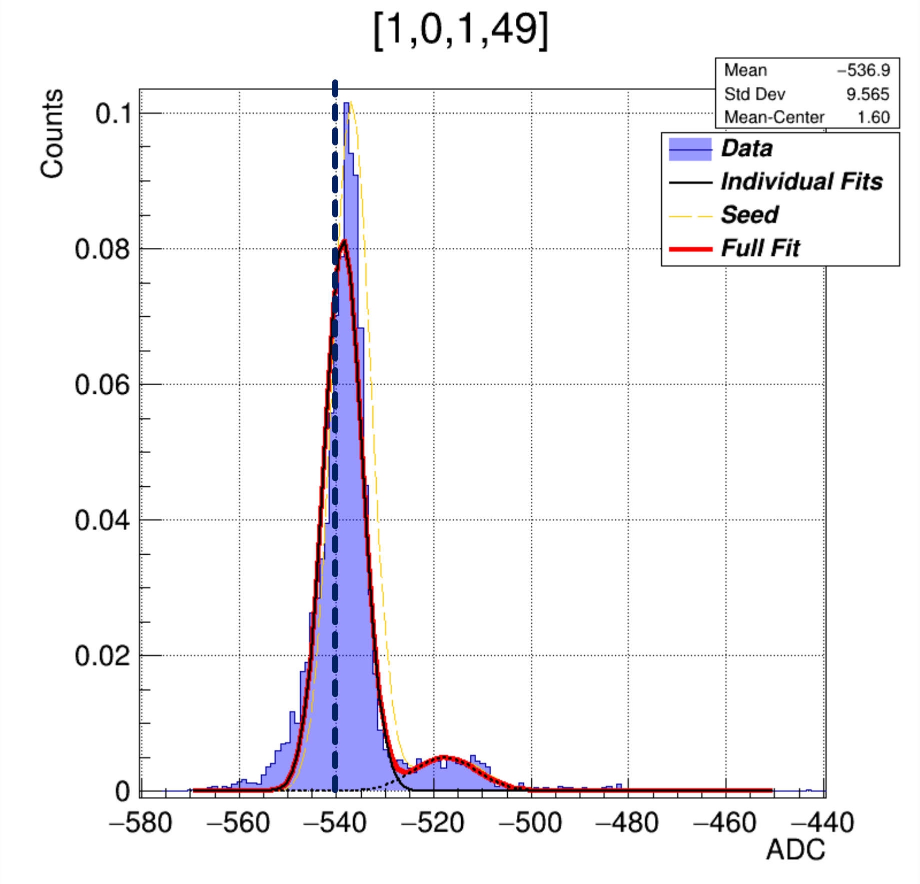


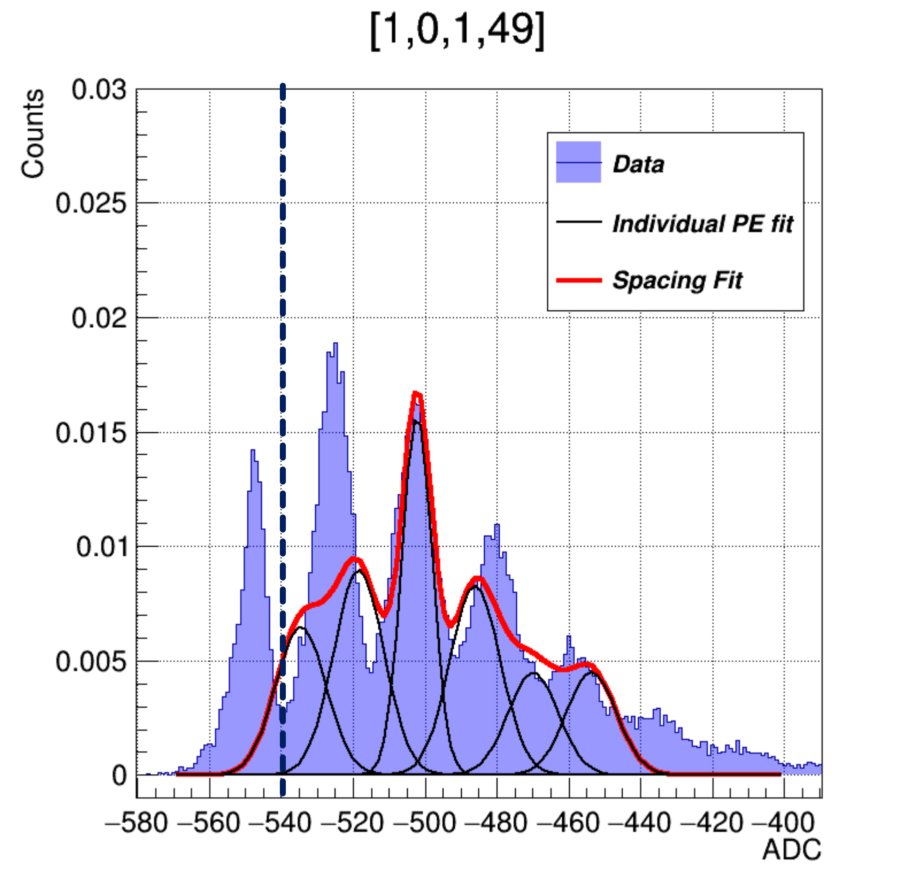
DEAD CONNECTIONS



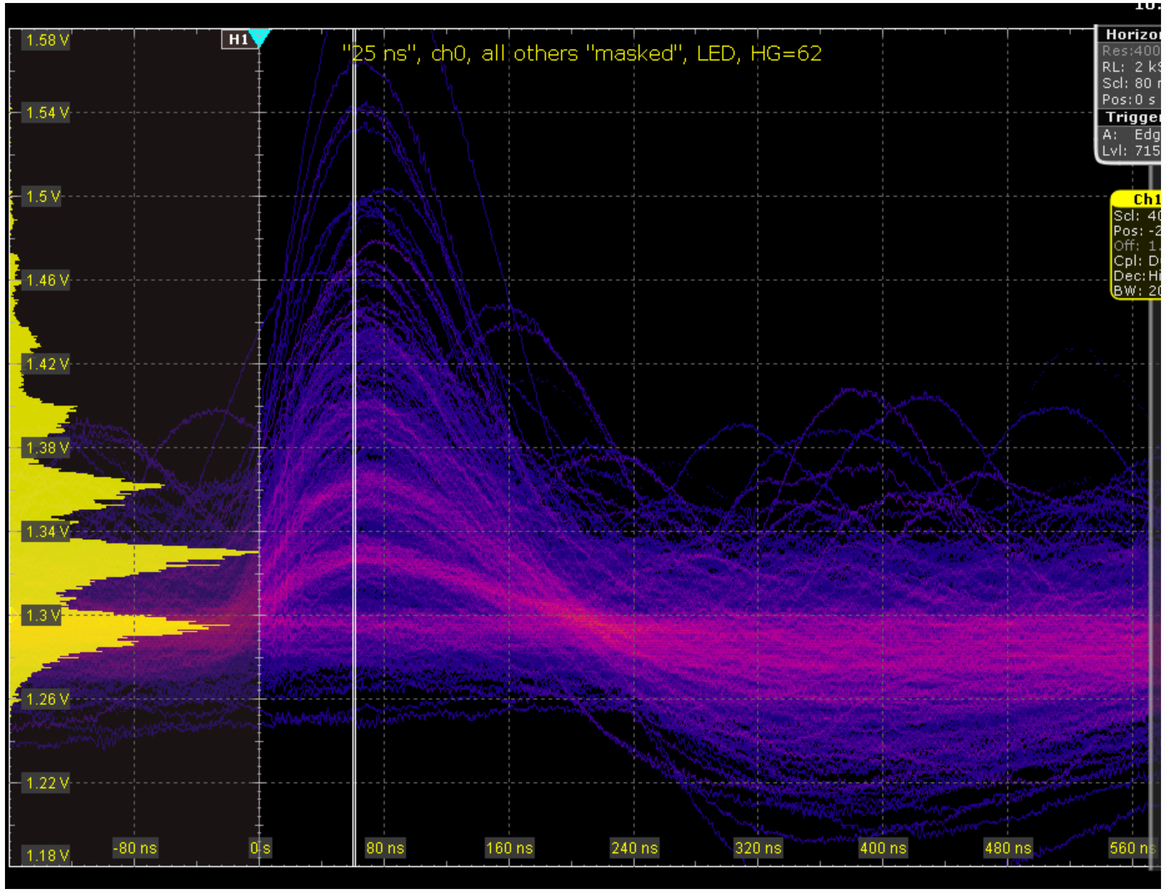


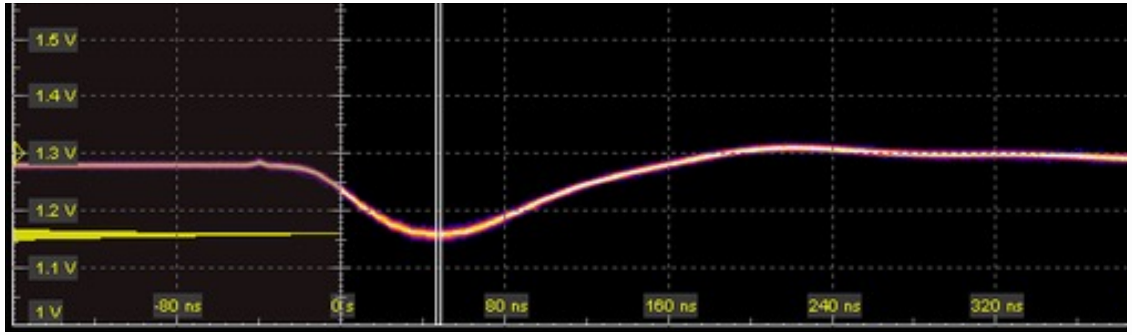
BASELINE SHIFT



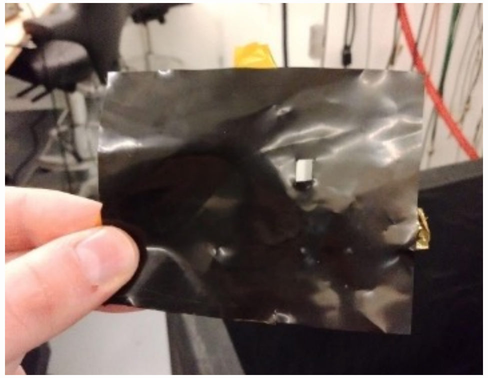


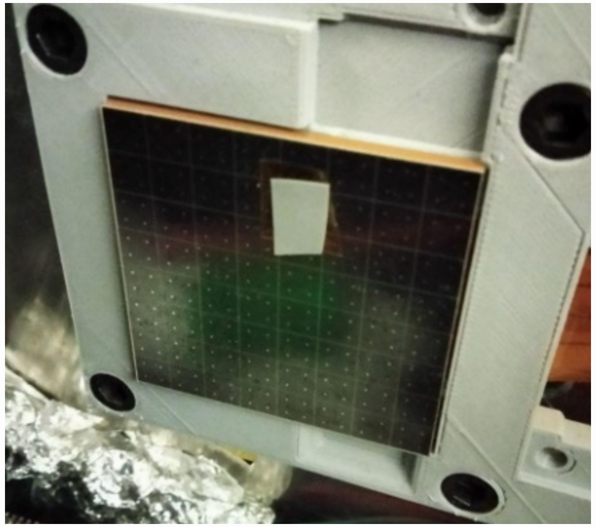
BASELINE SHIFT

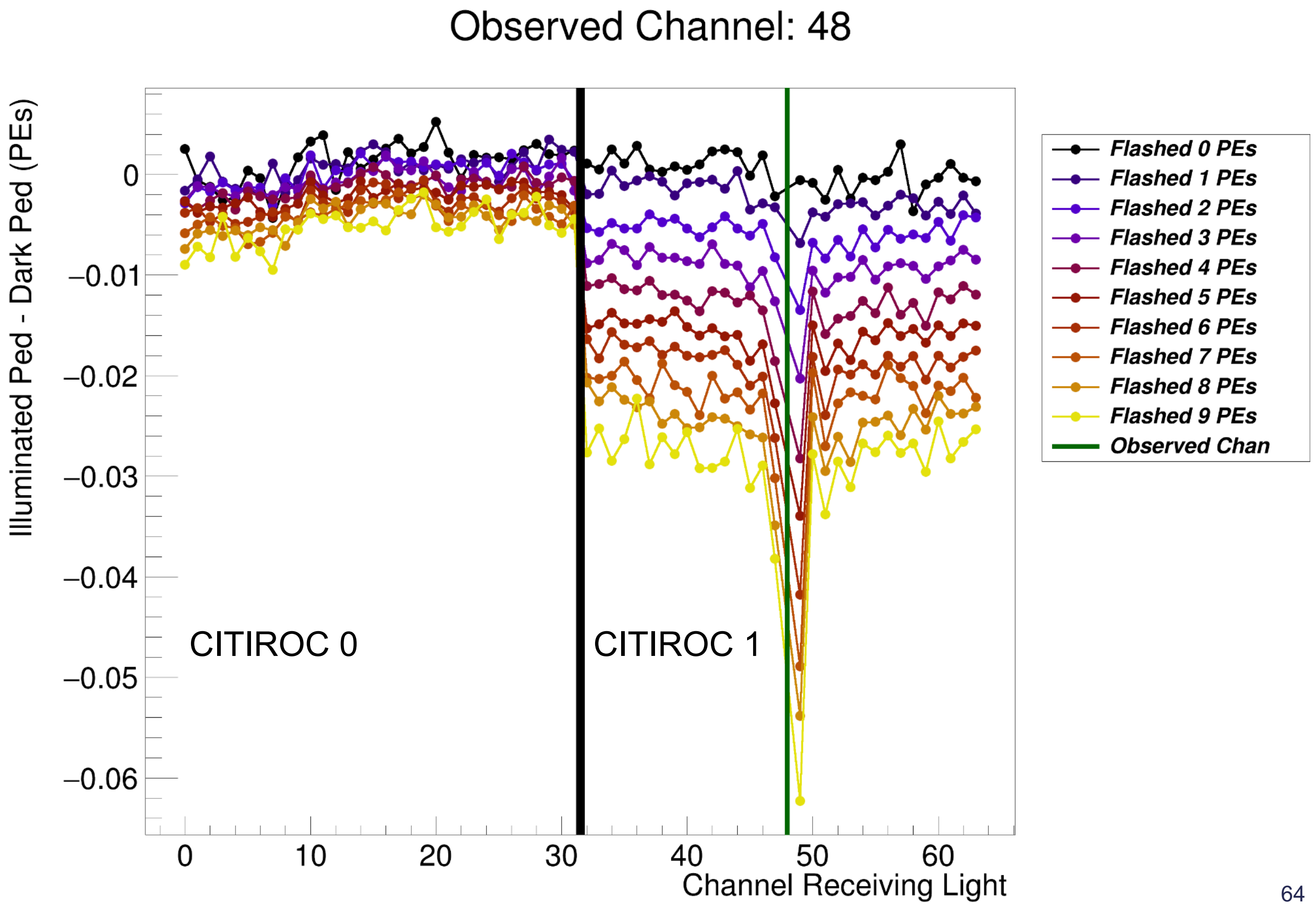




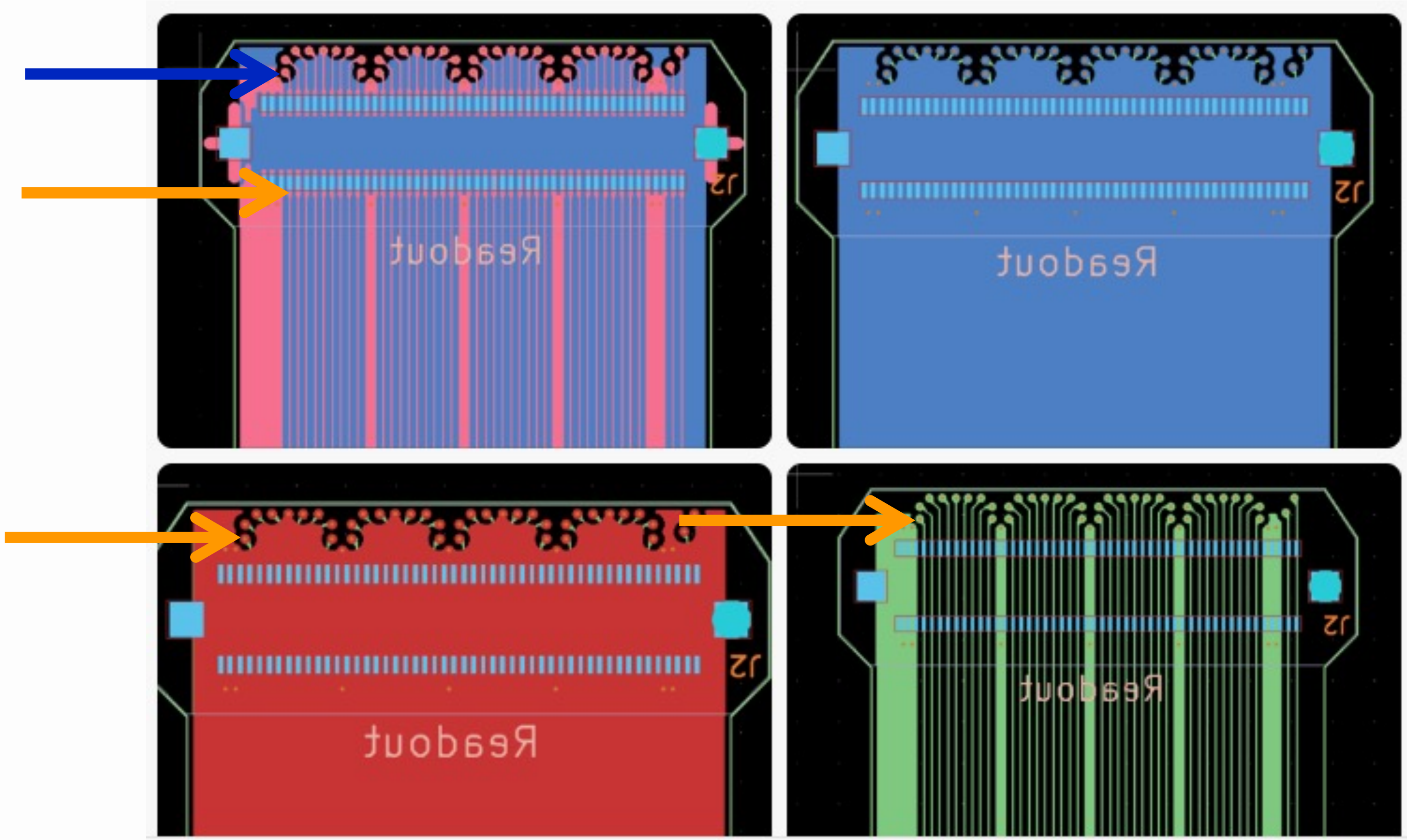
BASELINE SHIFT - PATTERNS







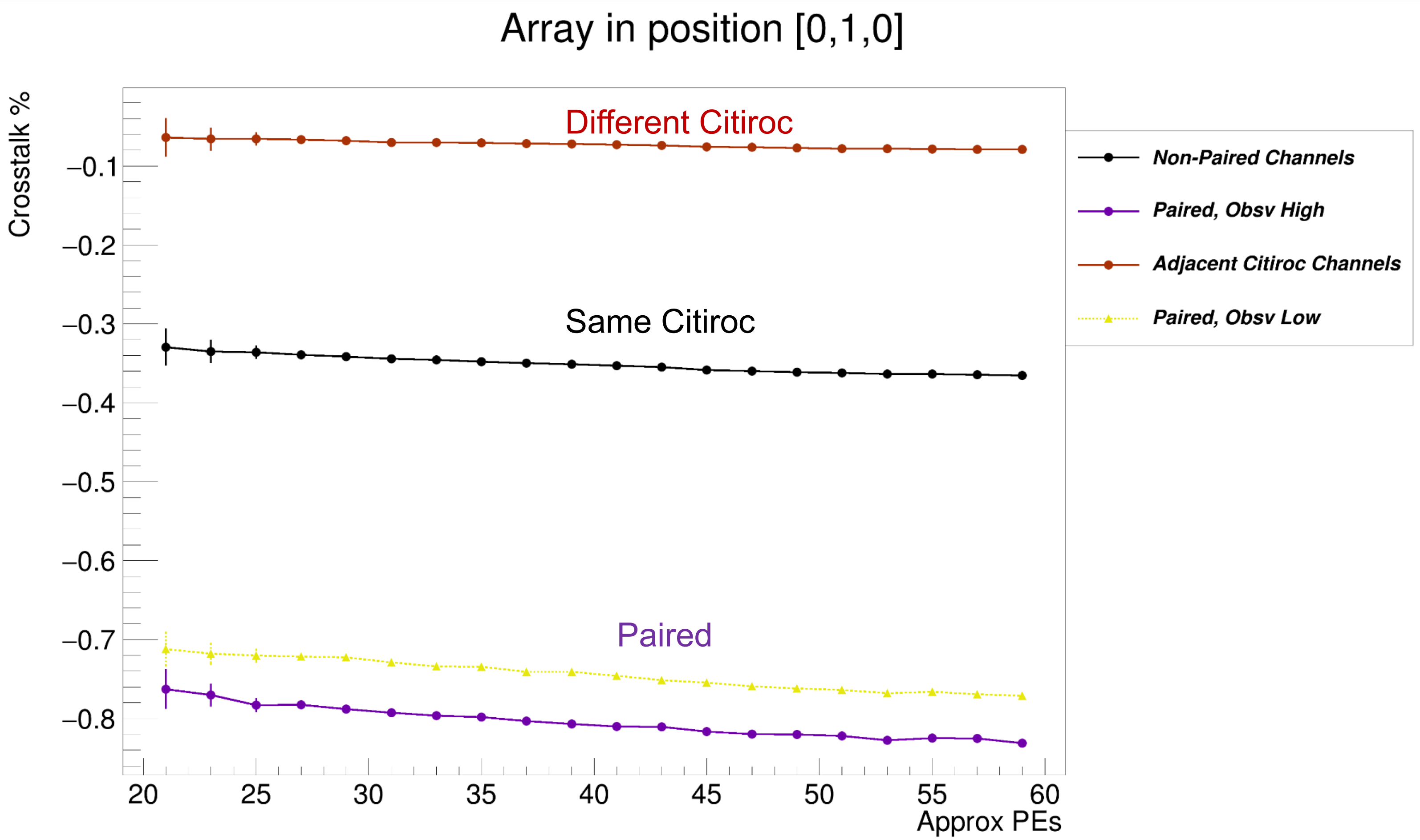
"PAIRED" CHANNELS



Four-layer schematic of the SiPM Flex Cables

NEGATIVE CROSSTALK

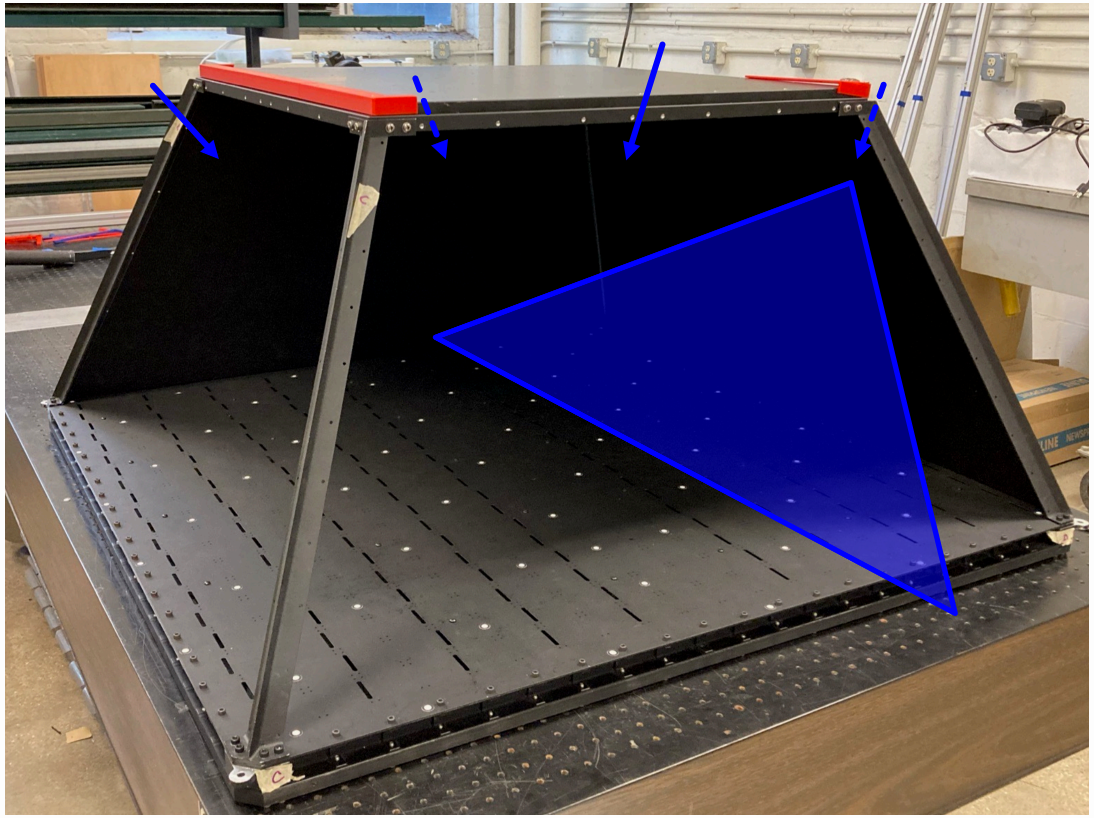
- Crosstalk on "paired" channel: ~ **-0.75%**
- Crosstalk on "unpaired" channel, same Citiroc: ~ **-0.35%**
- Crosstalk on different Citiroc, same SiPM Array: ~ **-0.1%**
- Repeatable in multiple positions
- Analysis level baseline shift removal tool



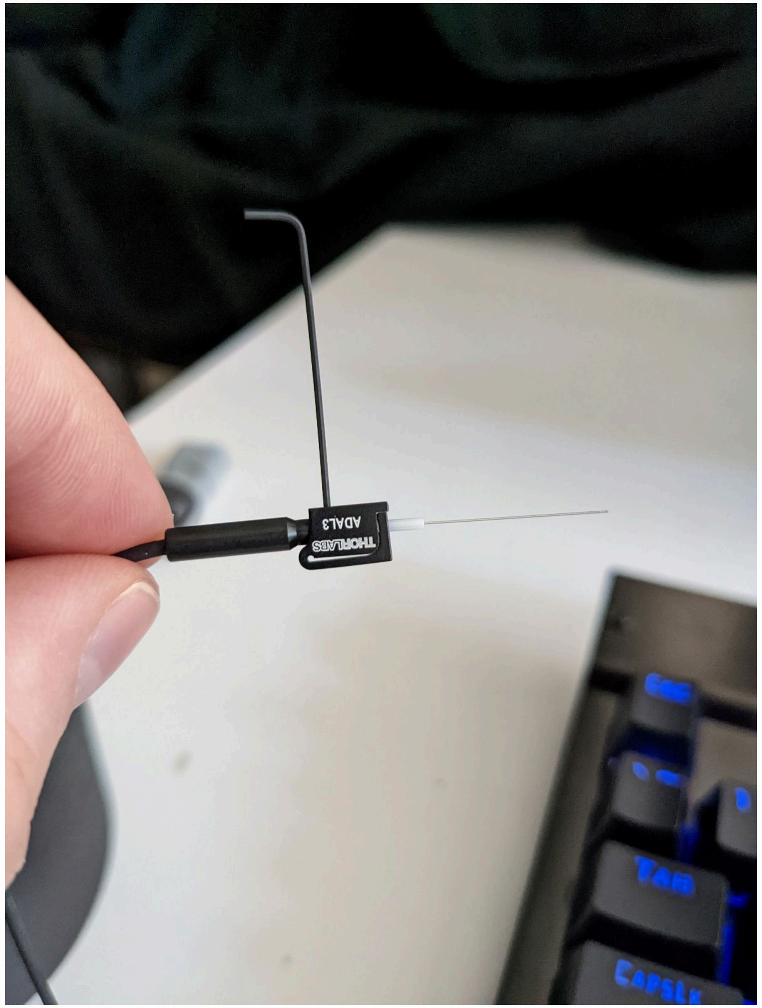
RICH CONSTRUCTION

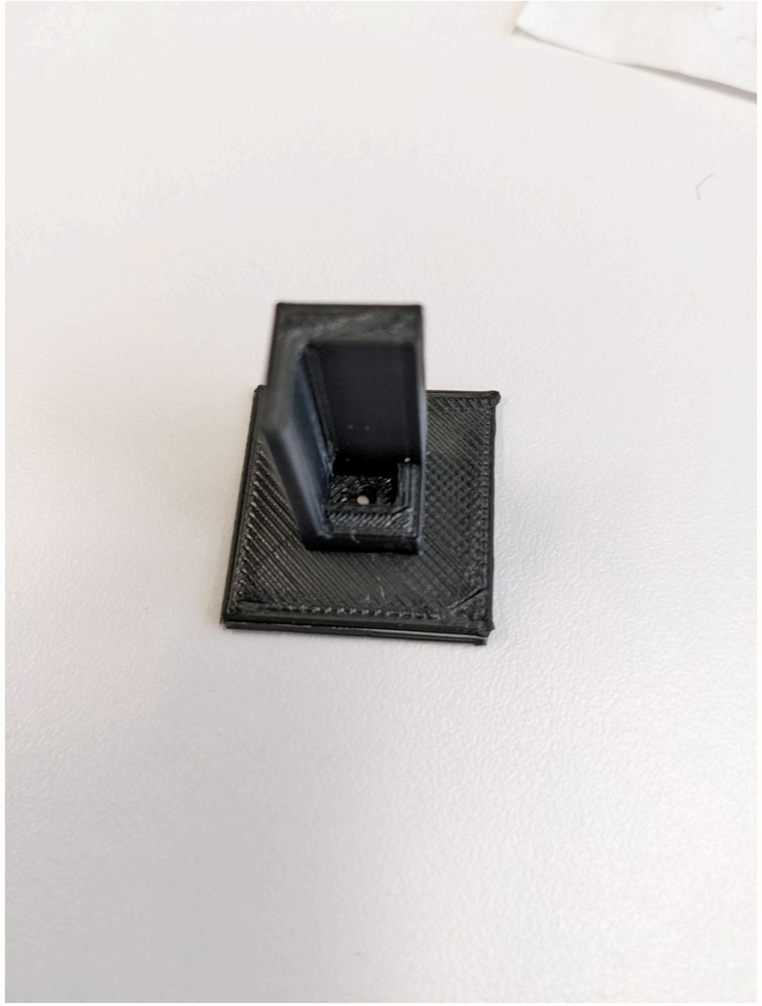
CALIBRATION FLASHERS

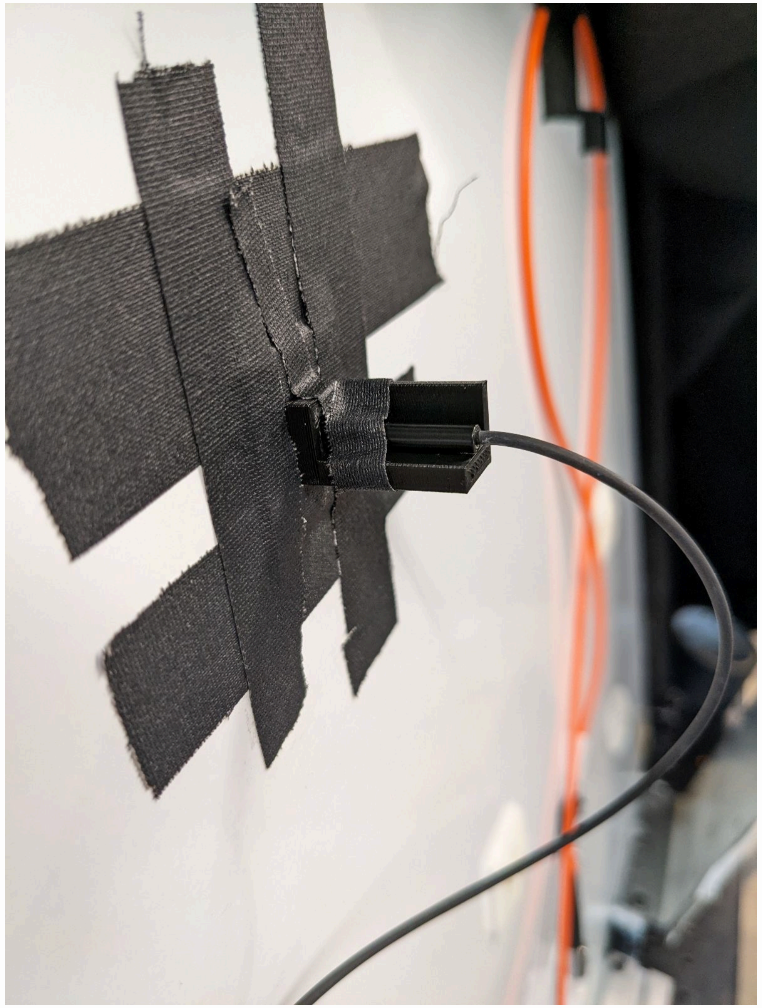
Cannula With Diffuser Tip



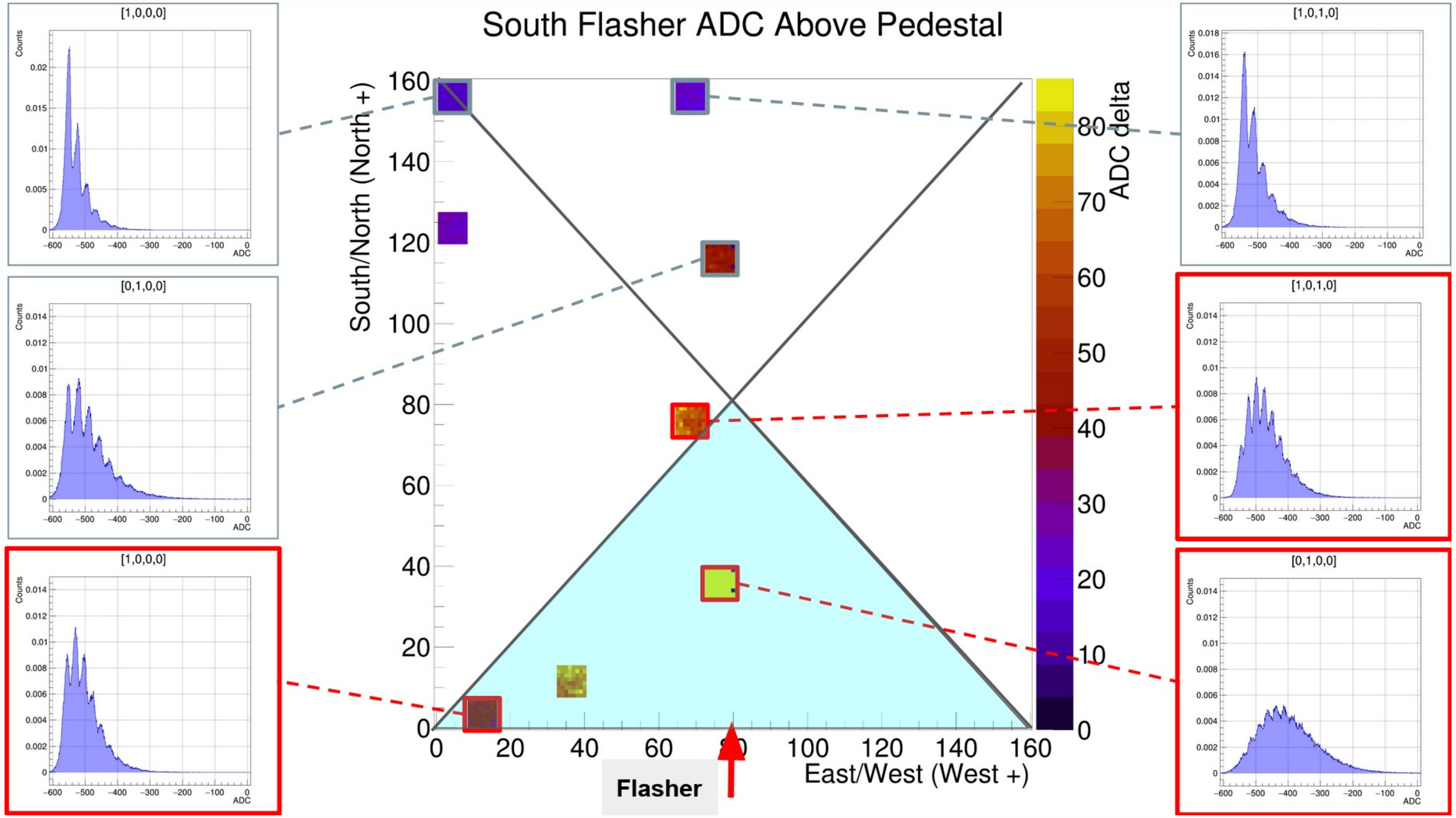
CALIBRATION FLASHERS



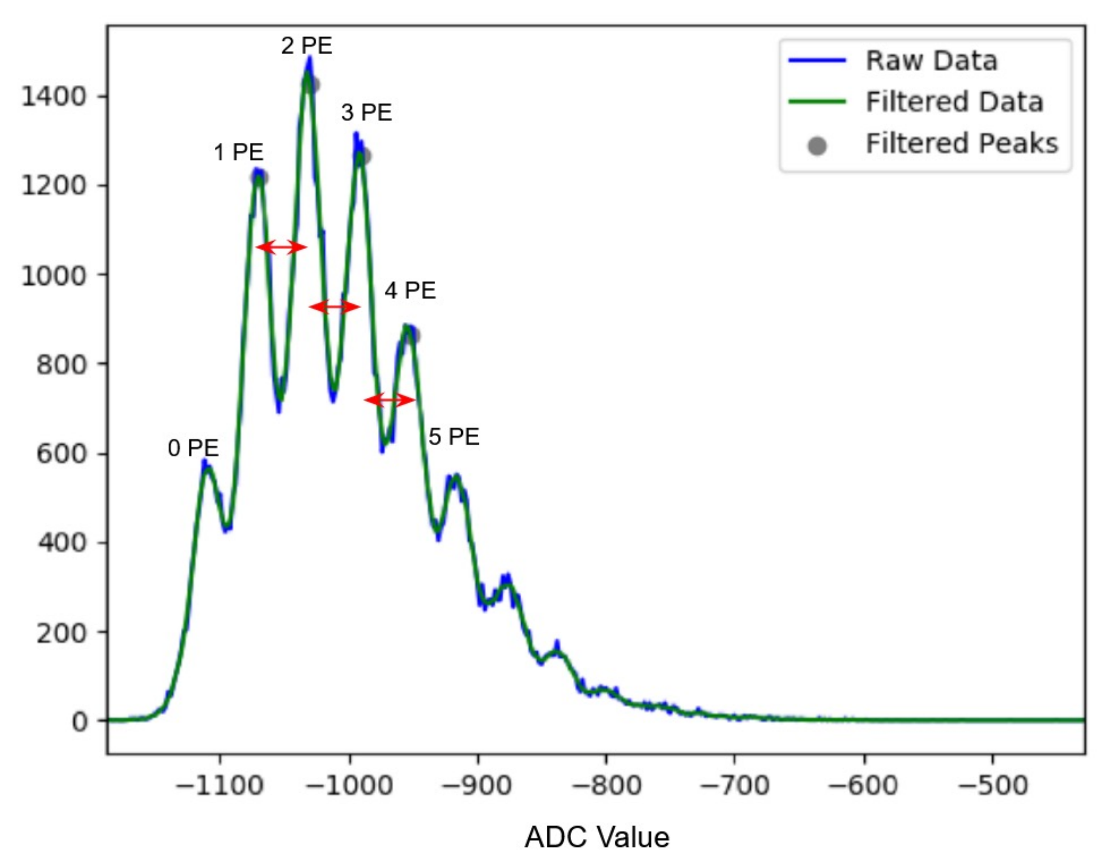


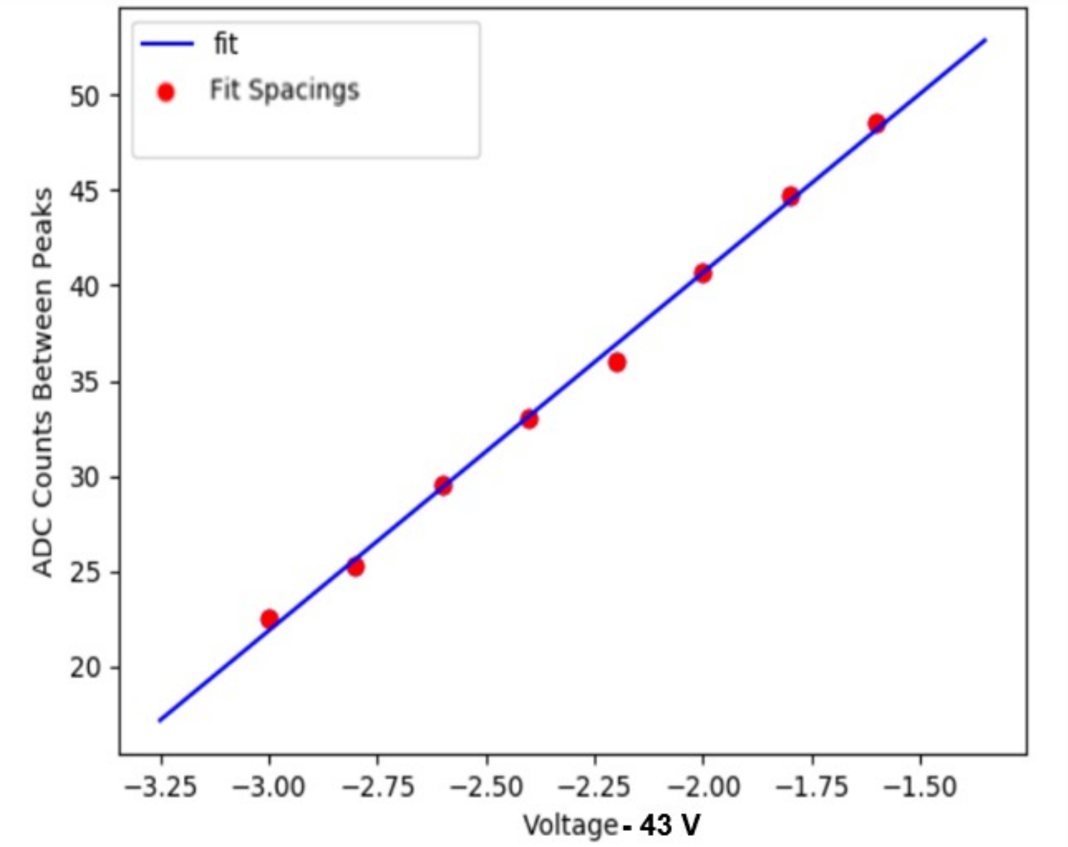


CALIBRATION FLASHERS

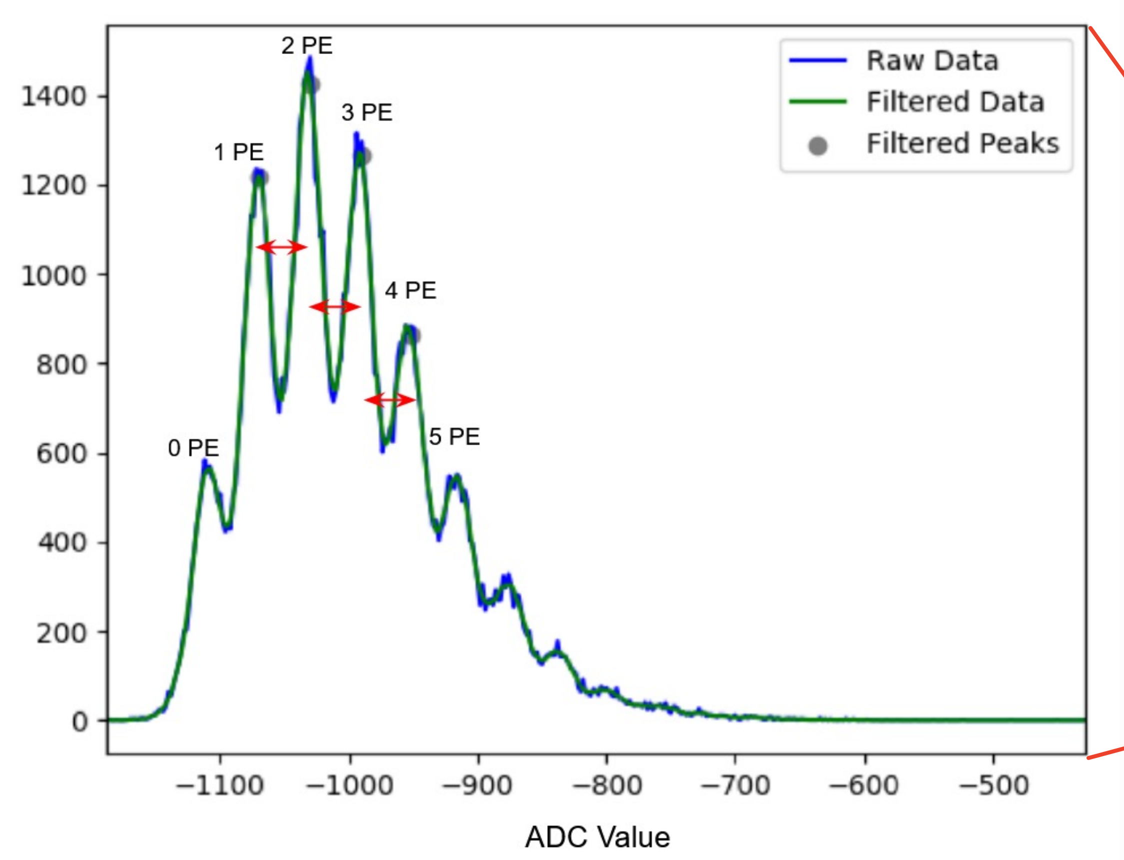


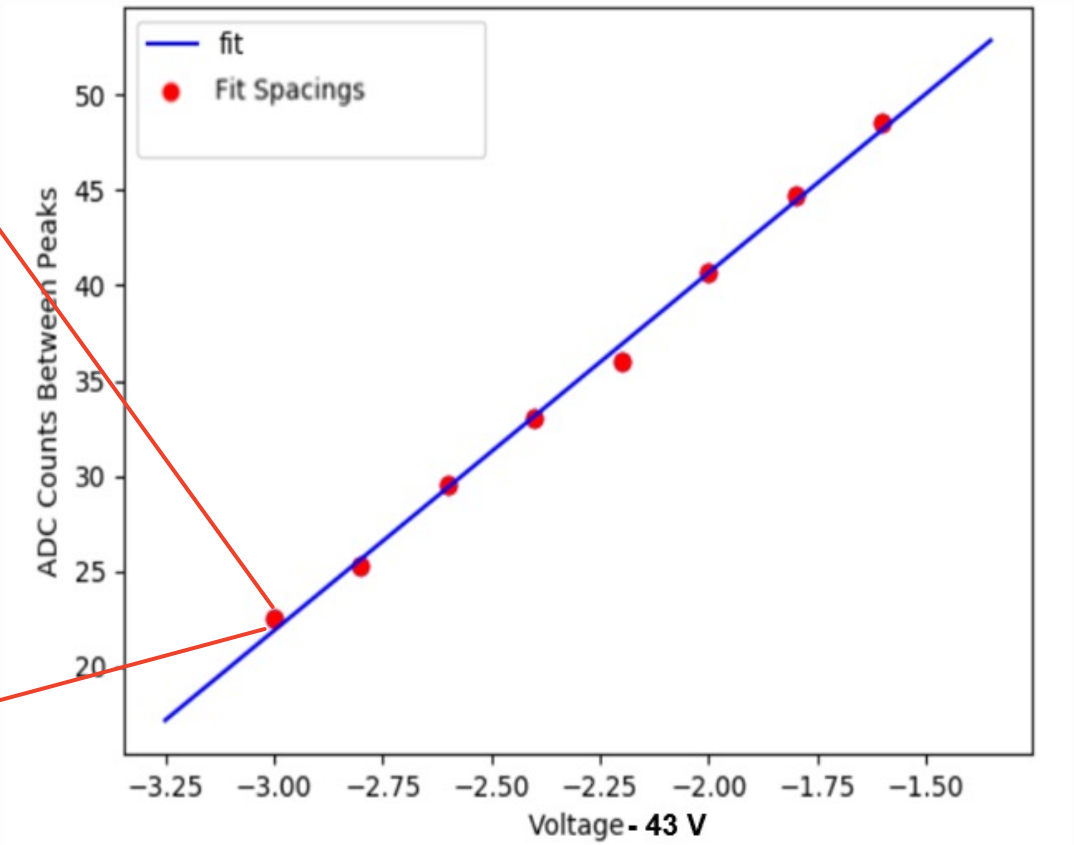
GAIN MATCHING PROCEDURE (PER CHANNEL)





GAIN MATCHING PROCEDURE (PER CHANNEL)





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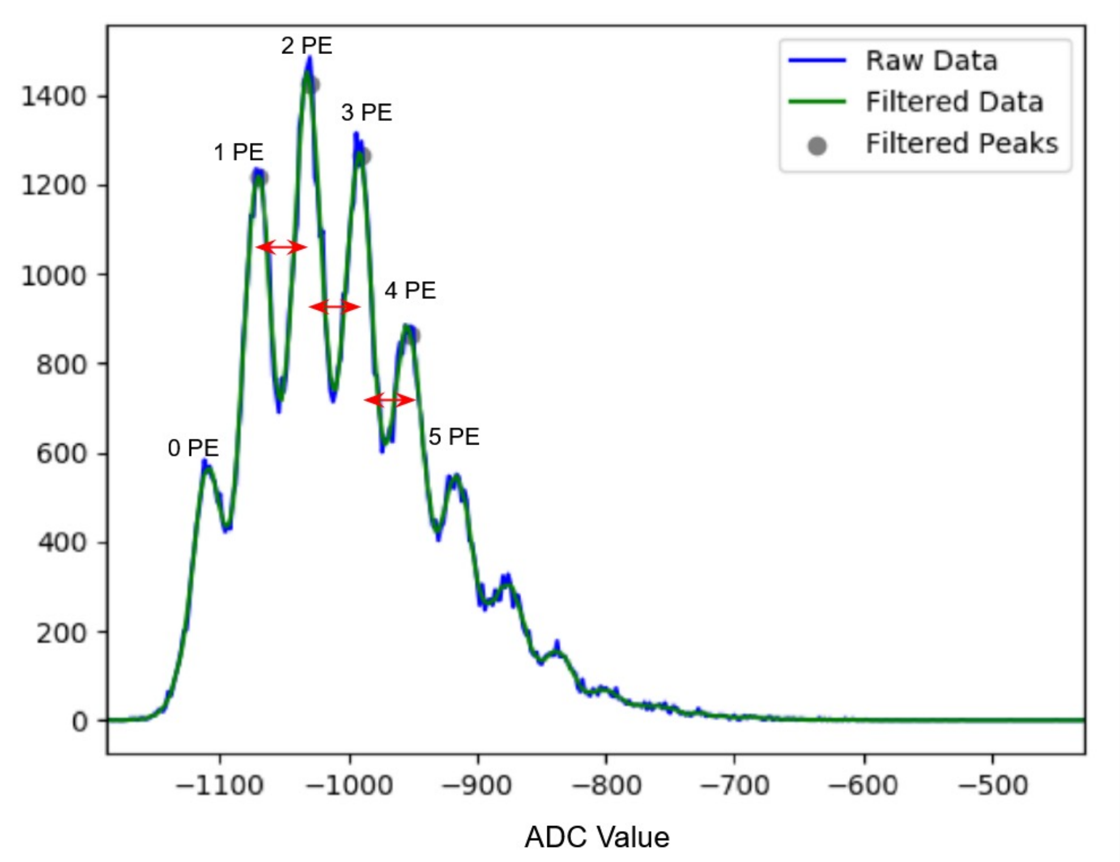
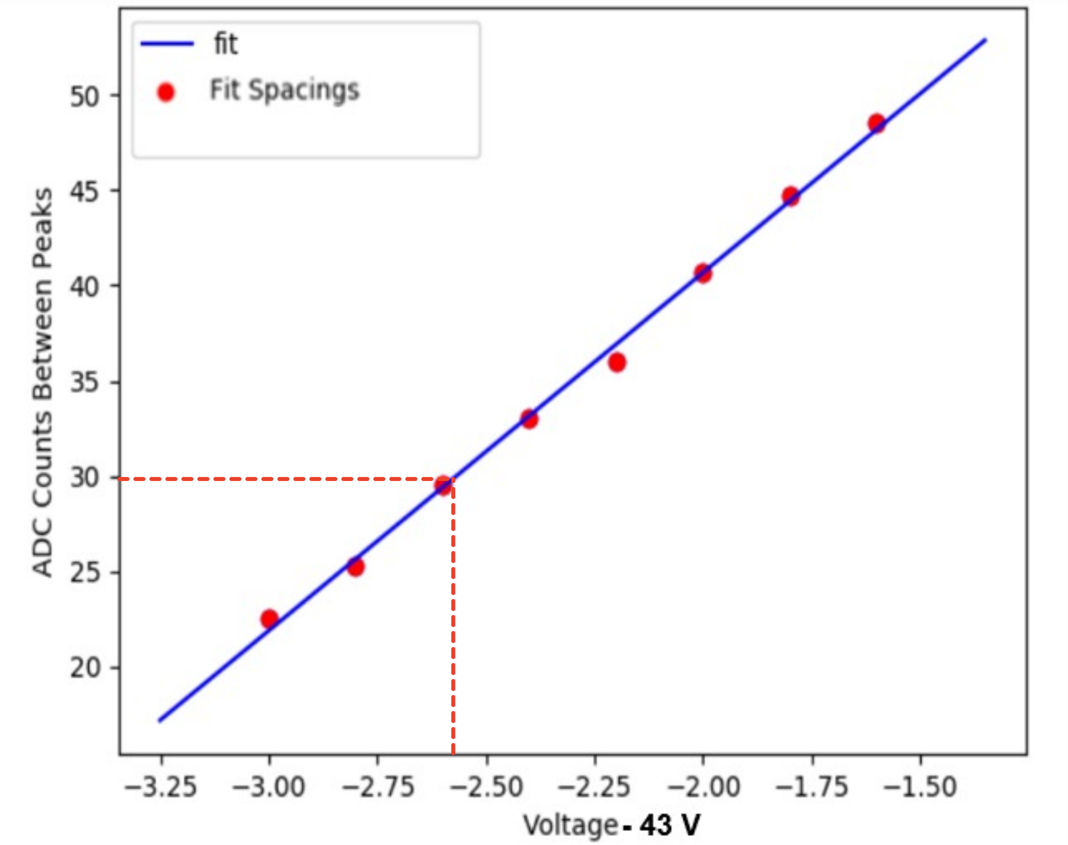
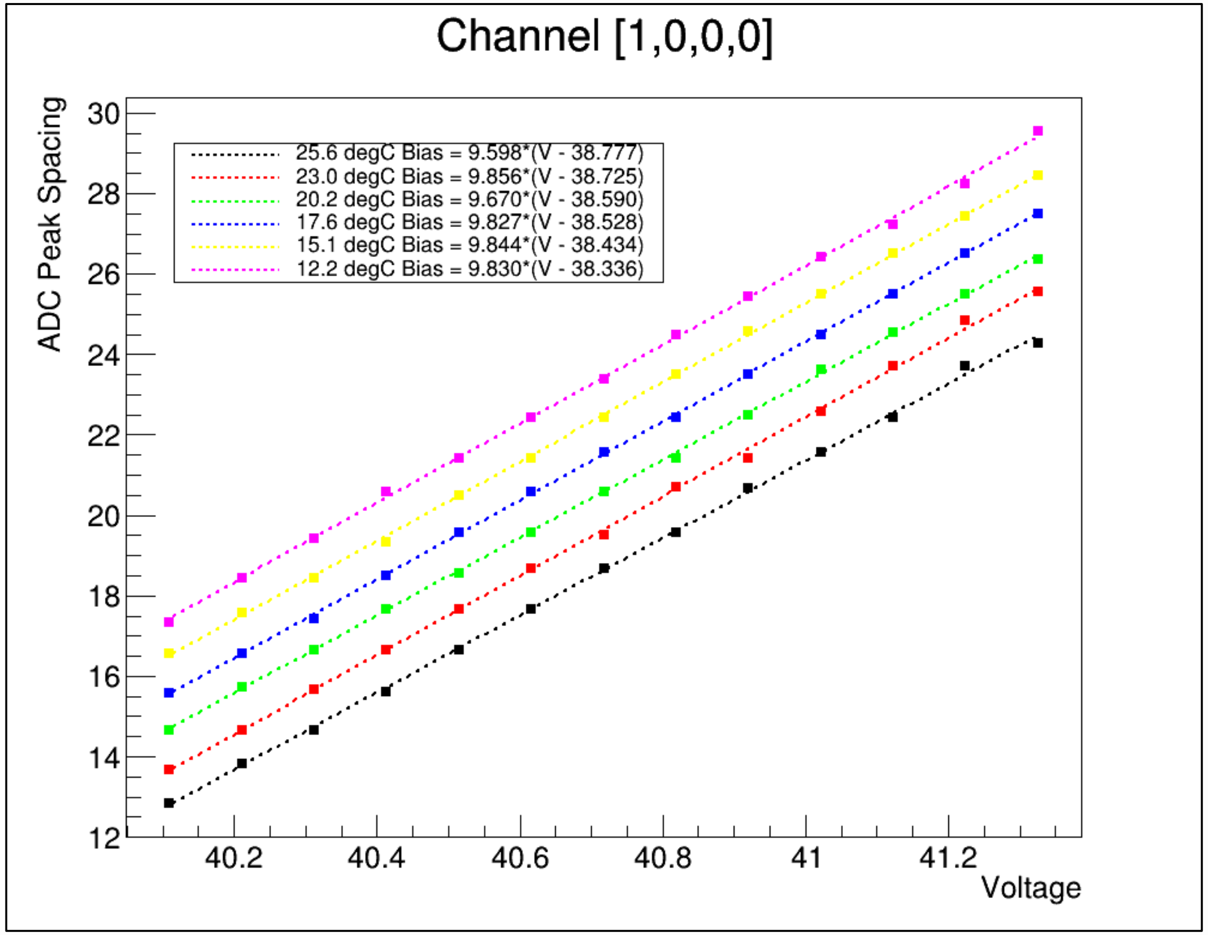
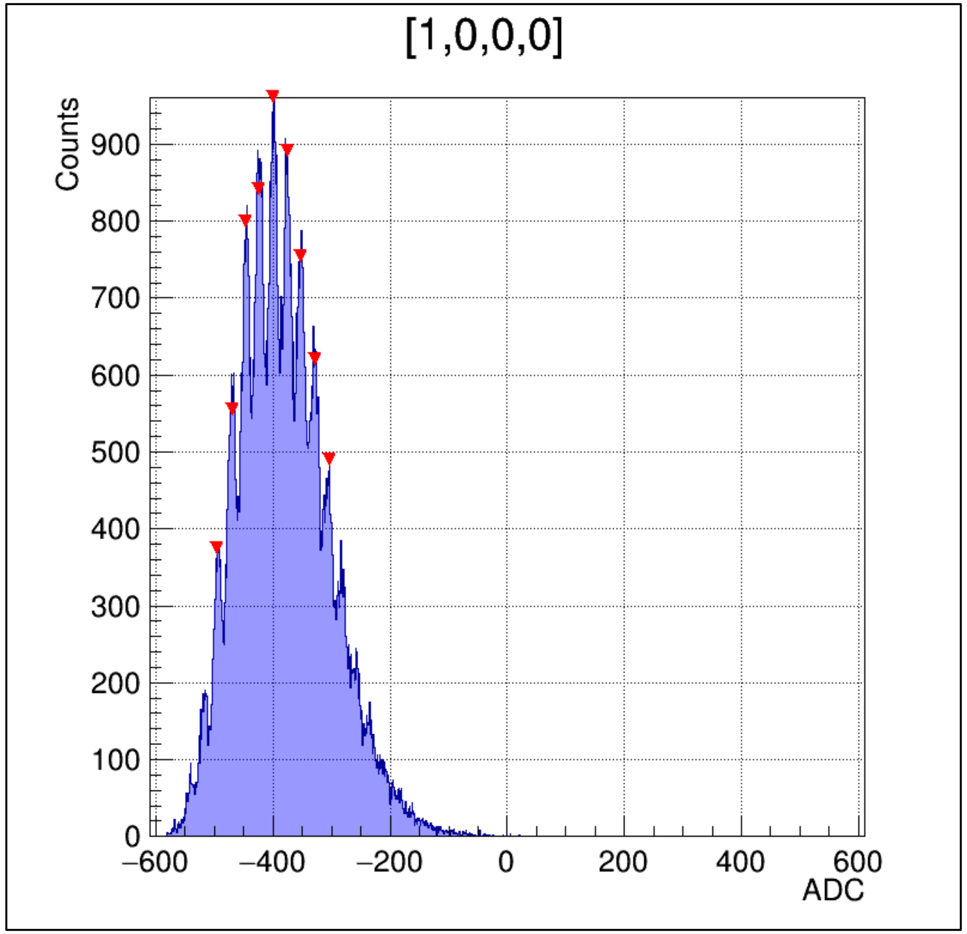




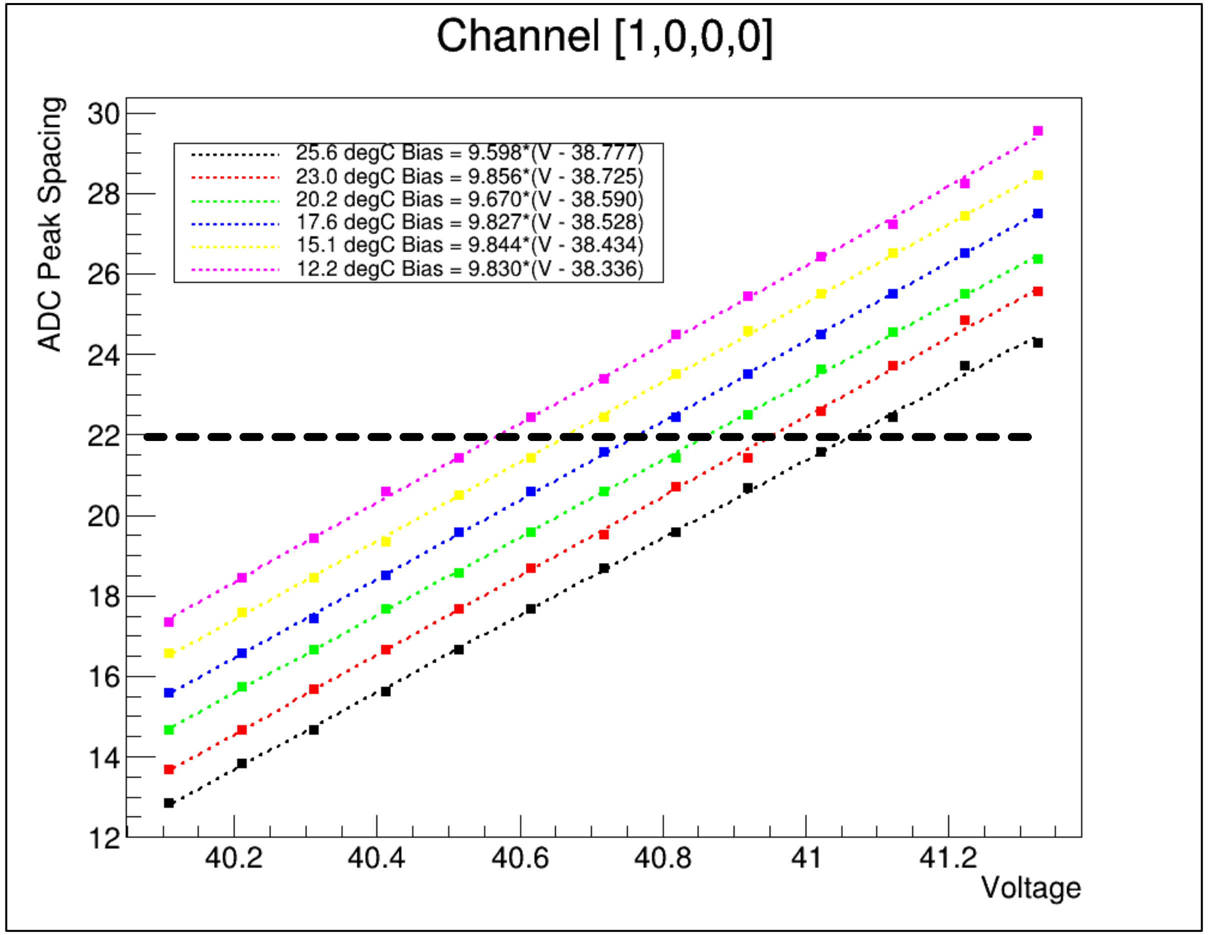
SiPMs – TEMPERATURE DEPENDENCE

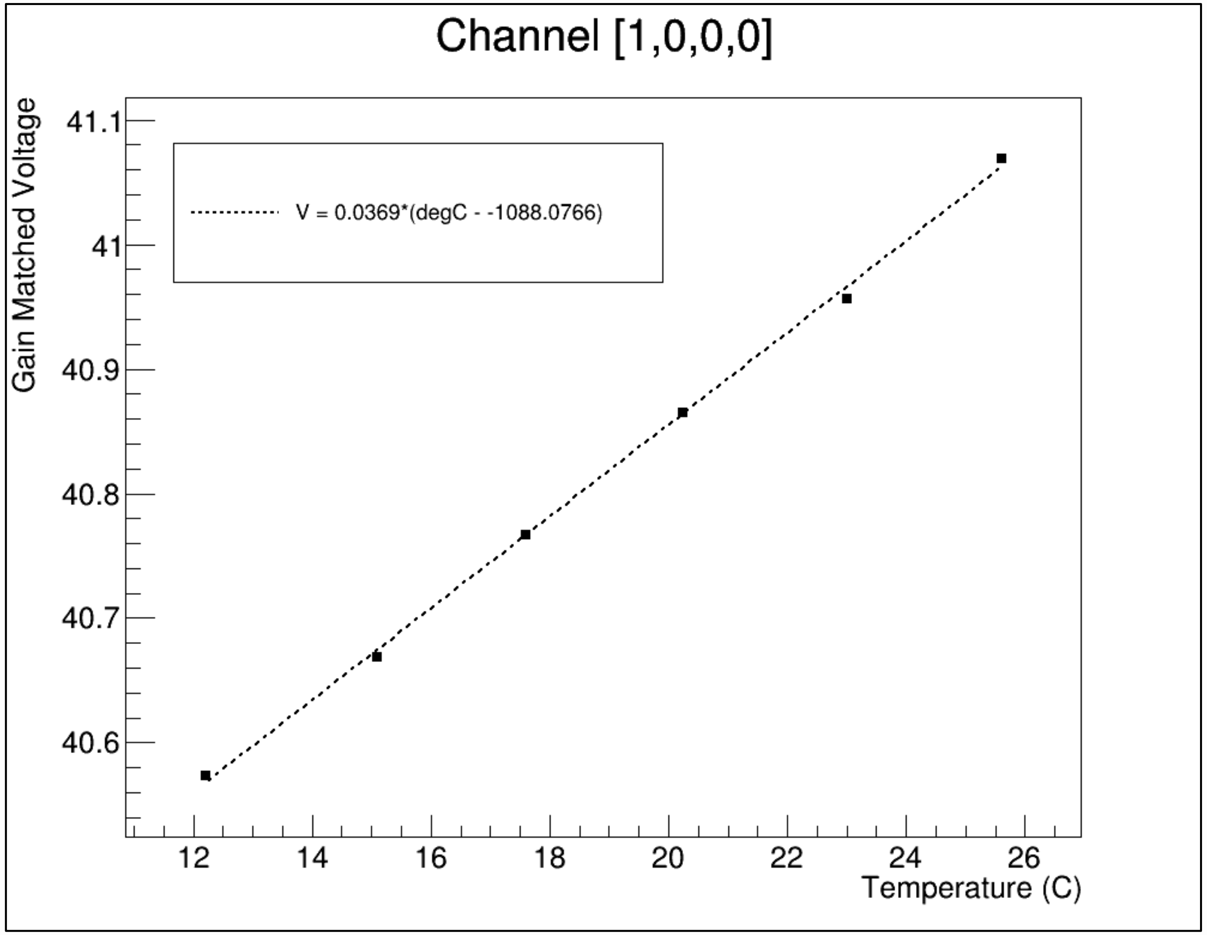




SiPM Array PE spacing, per bias voltage and temperature

SiPMs – TEMPERATURE DEPENDENCE





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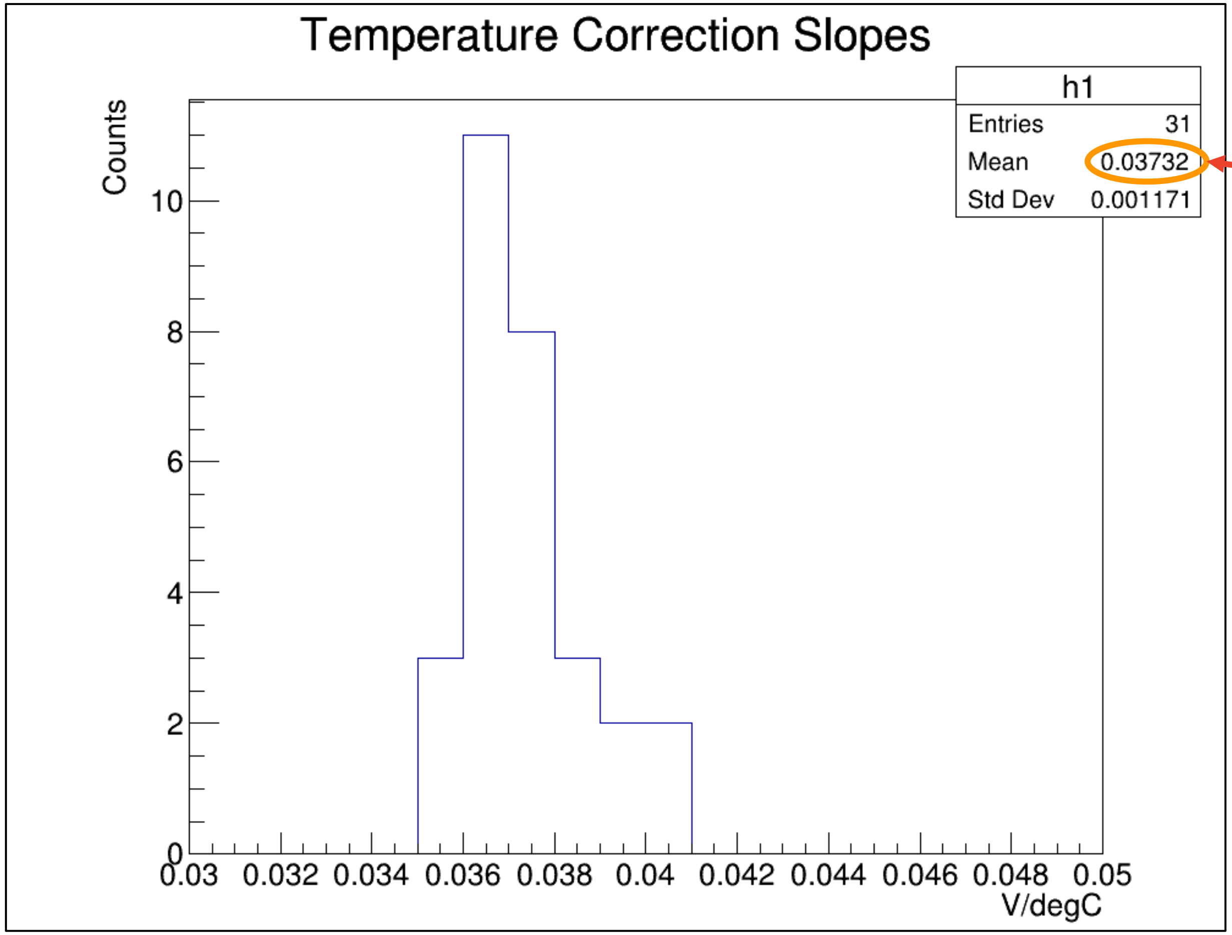
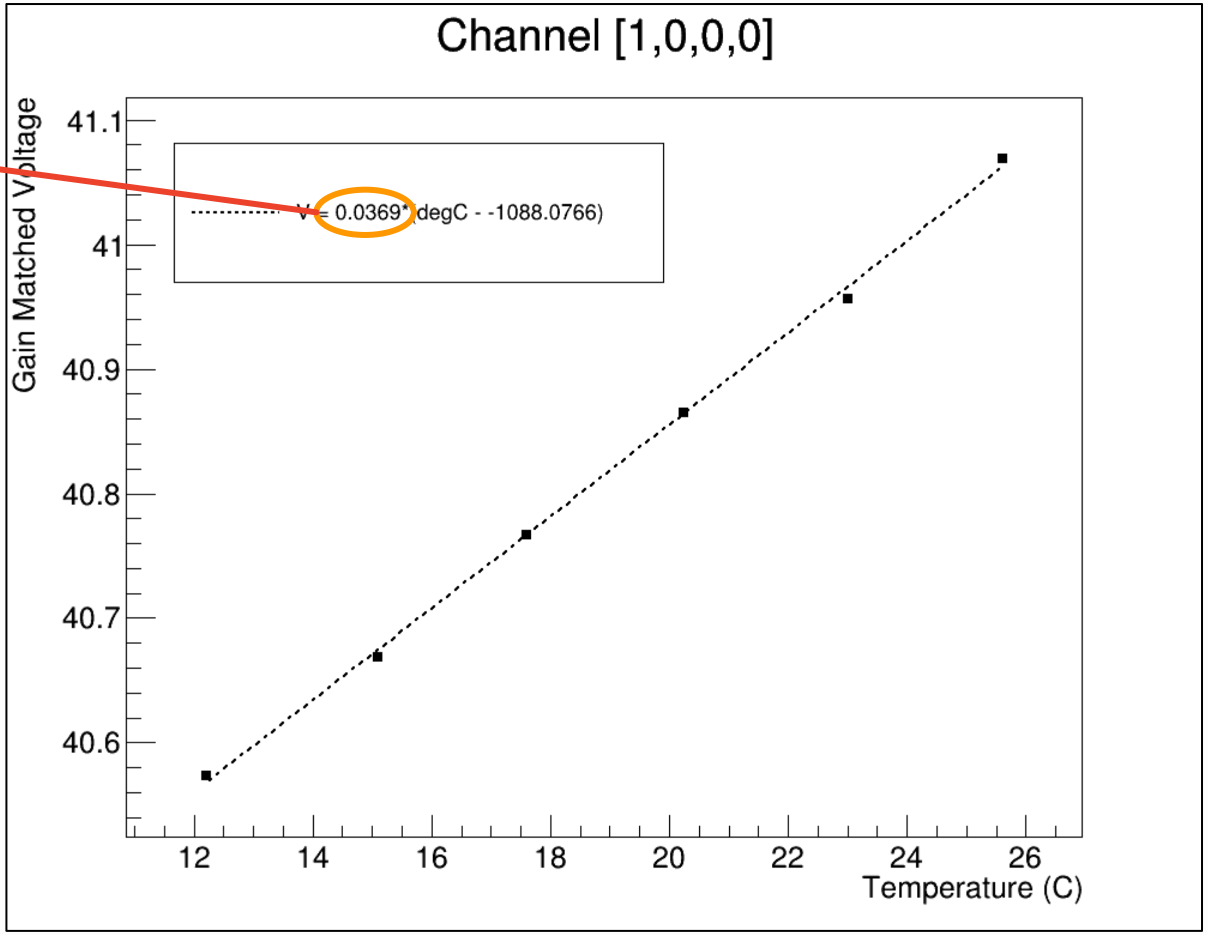
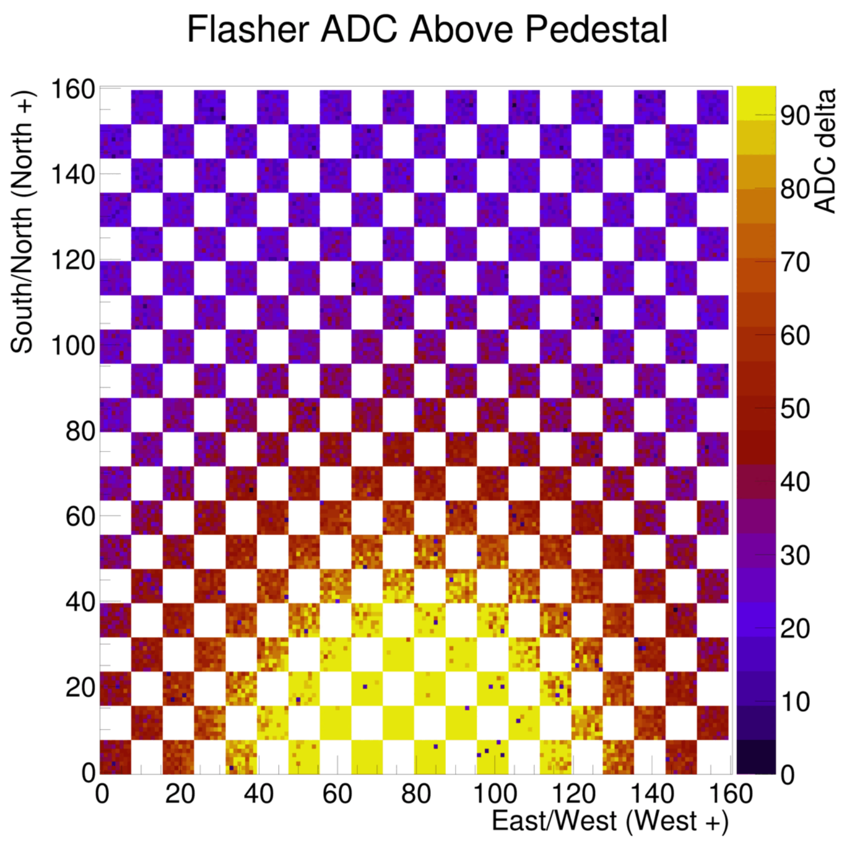


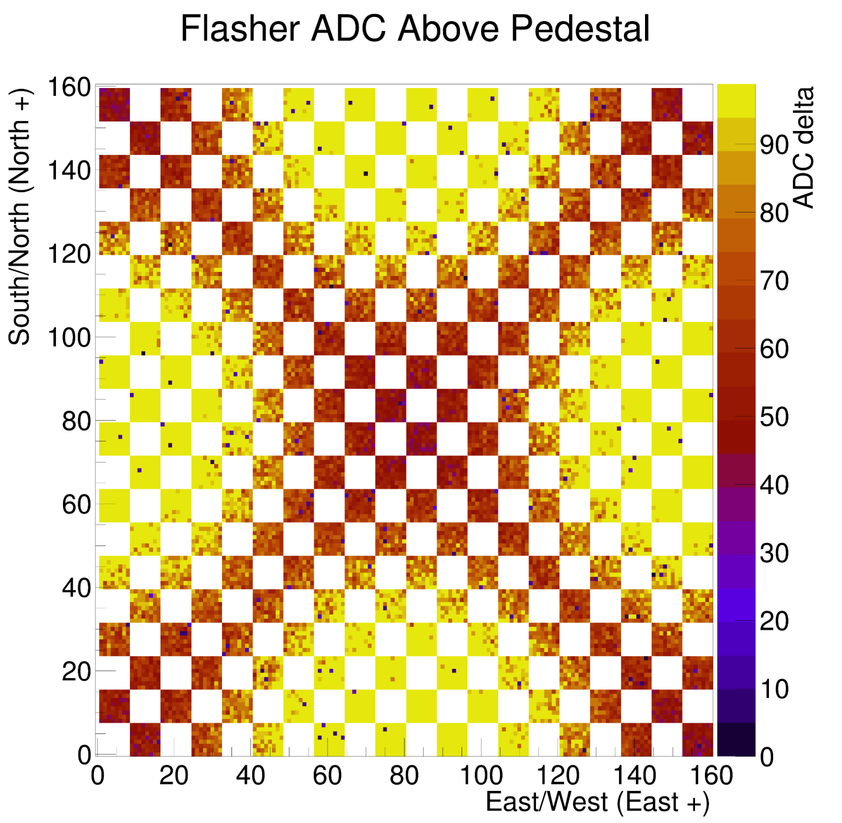


RICH INSTALLATION

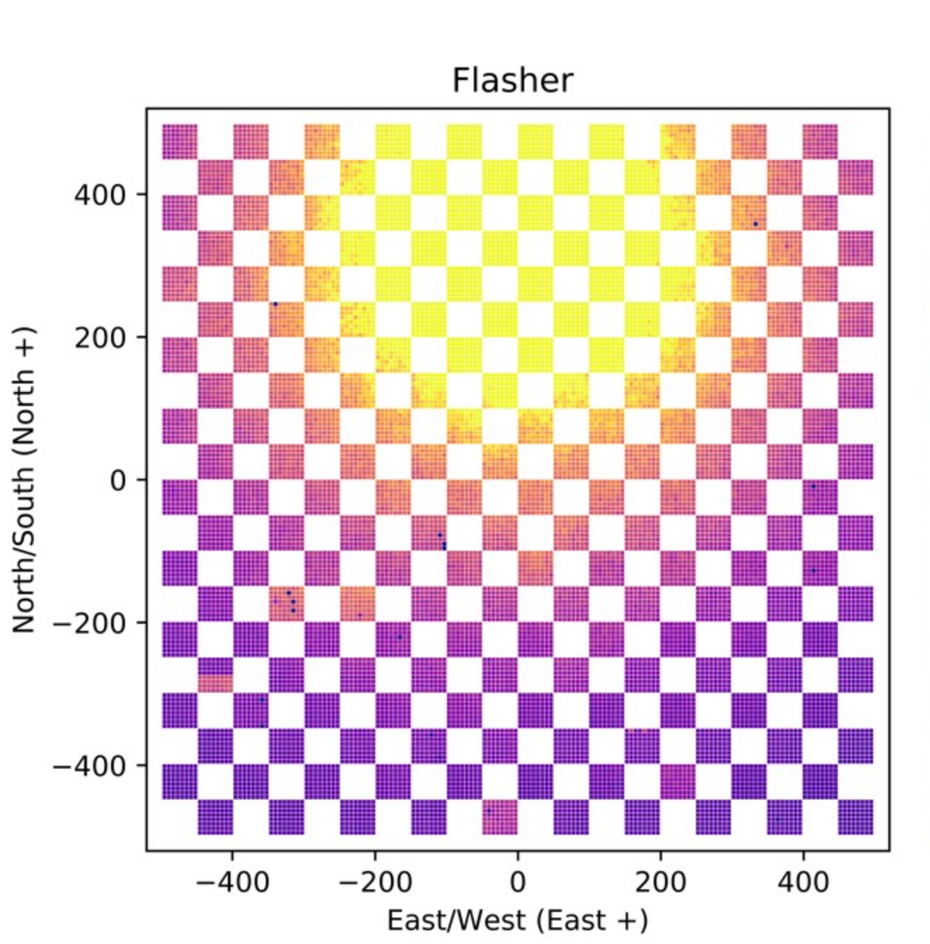
SiPM SPECTRUM MONTE CARLO

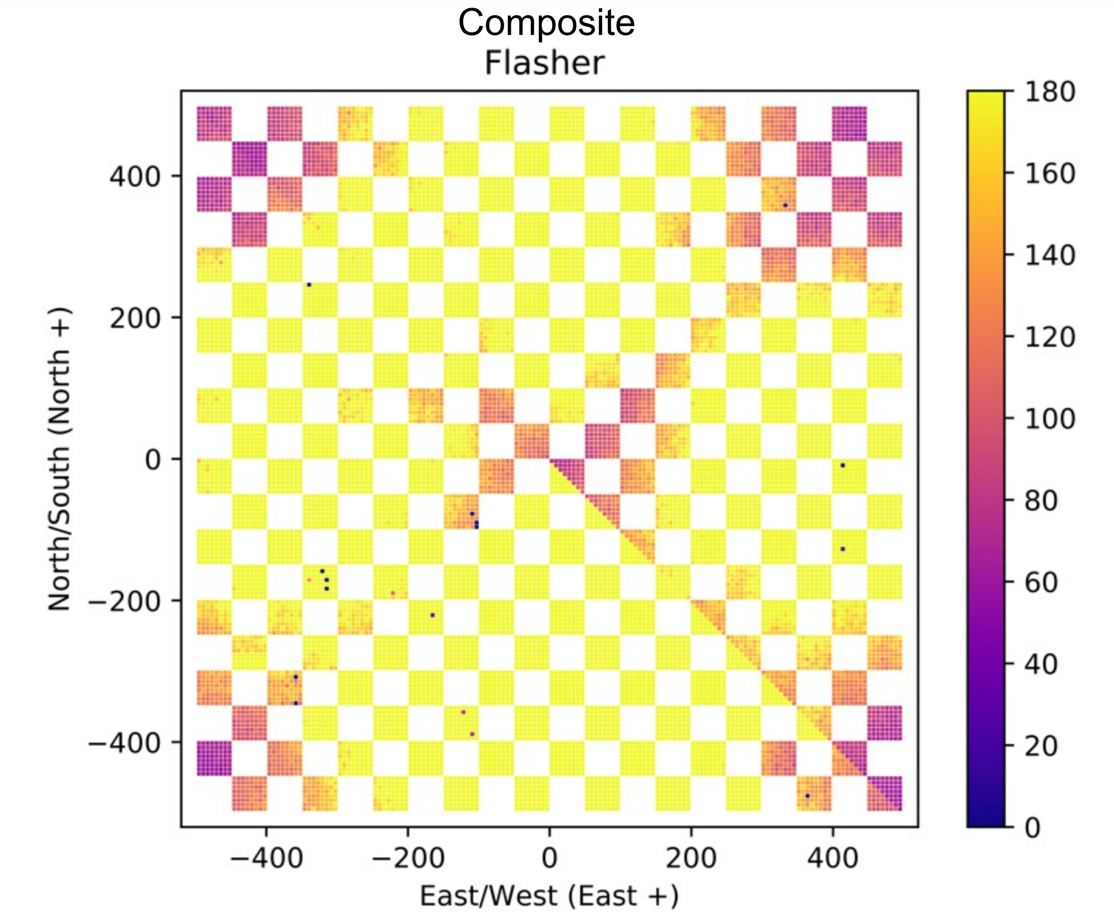
- A simulated focal plane is used to verify the accuracy of the gain matching algorithm
- Using samples of data from the 8-10 arrays measured in the focal plane, the behavior of the flasher can be extrapolated
  - $1/r^2$ dependence
- Dependence of gain and resolution on temperature and bias voltage are inferred from prior measurements
- Dead channel rate estimated from 8-10 array sample





REAL DATA FROM FOCAL PLANE

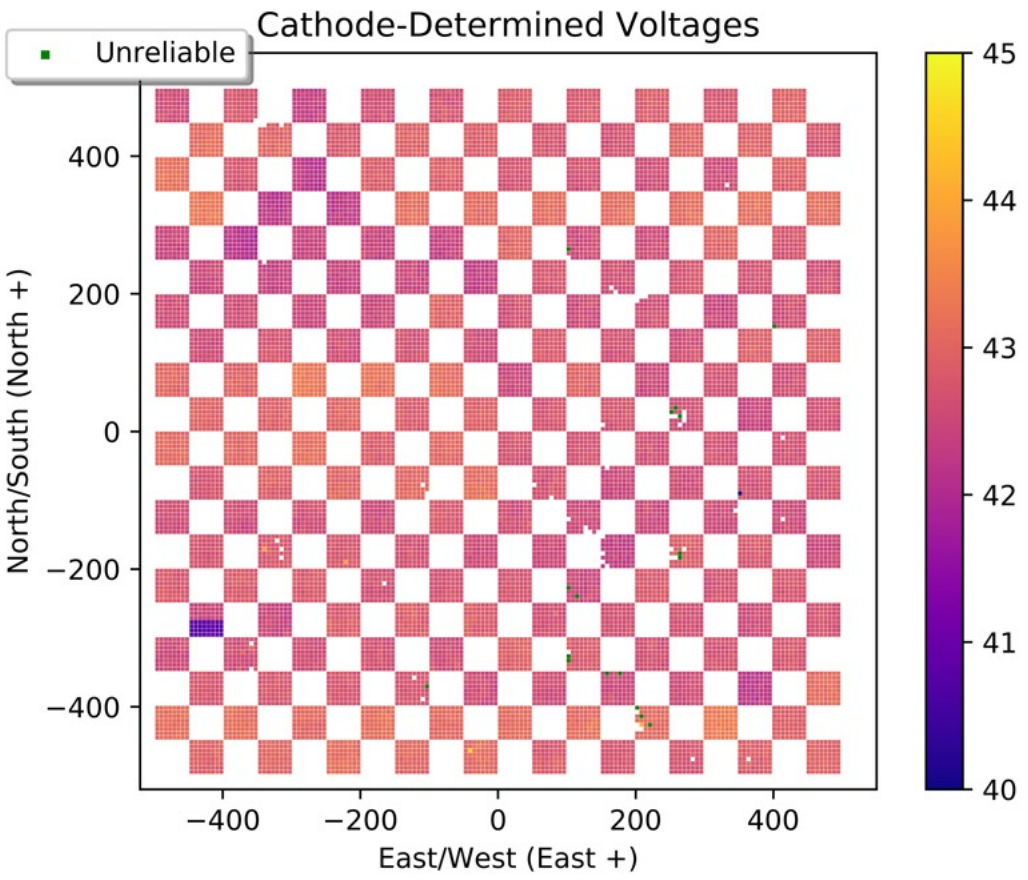




TWO STAGE GAIN MATCHING

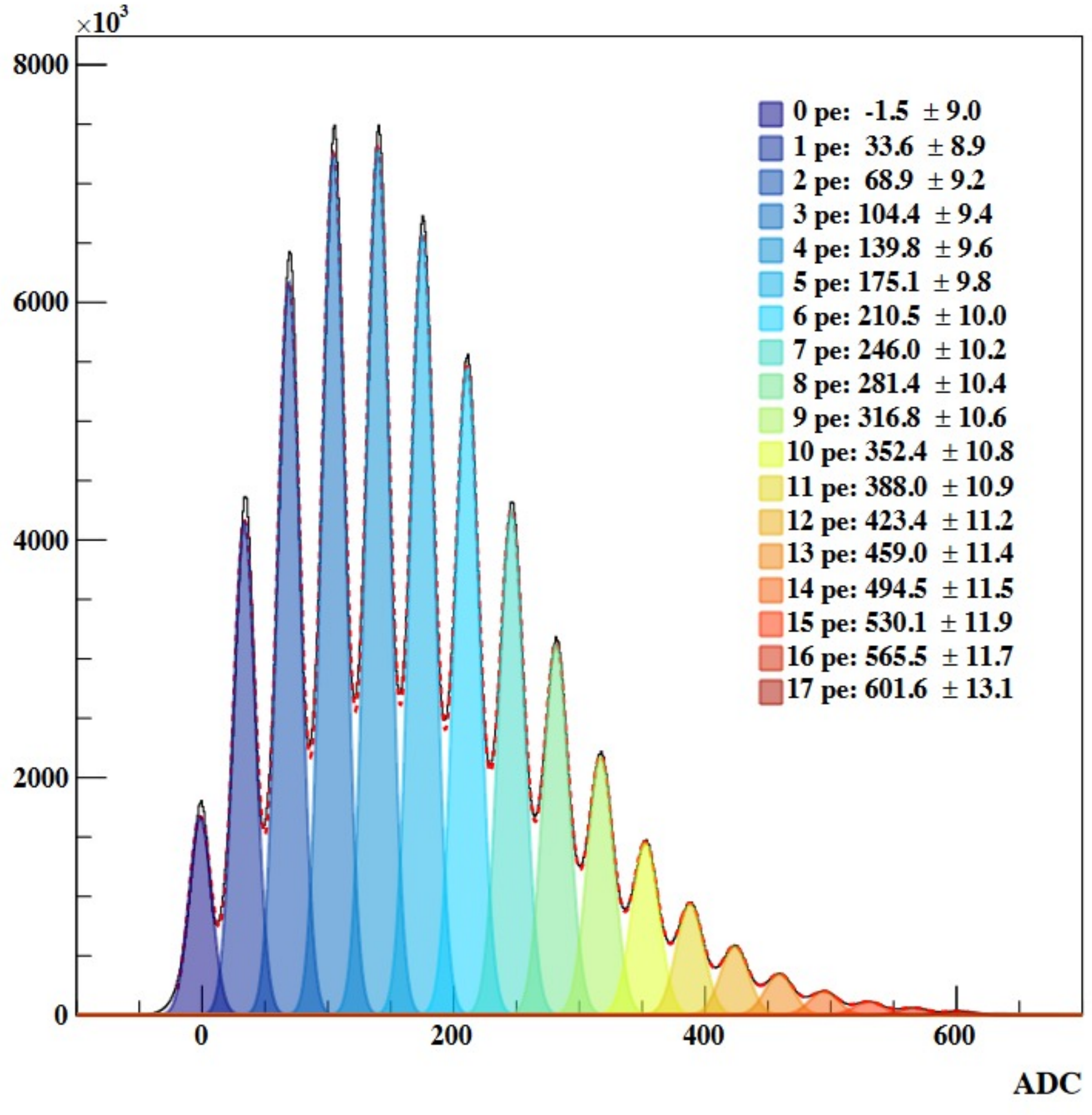
1. Scan cathode bias and determine what each array will need to be set to so anode trim can cover needed voltage range
2. Scan anode biases with cathodes set to values determined in 1 to get DAC to voltage function independent gain matching

First test is shown to the right, values are not final, but the vast majority work well. Channels with issues are, so far, measurements of physical truth about noisy or damaged channels.



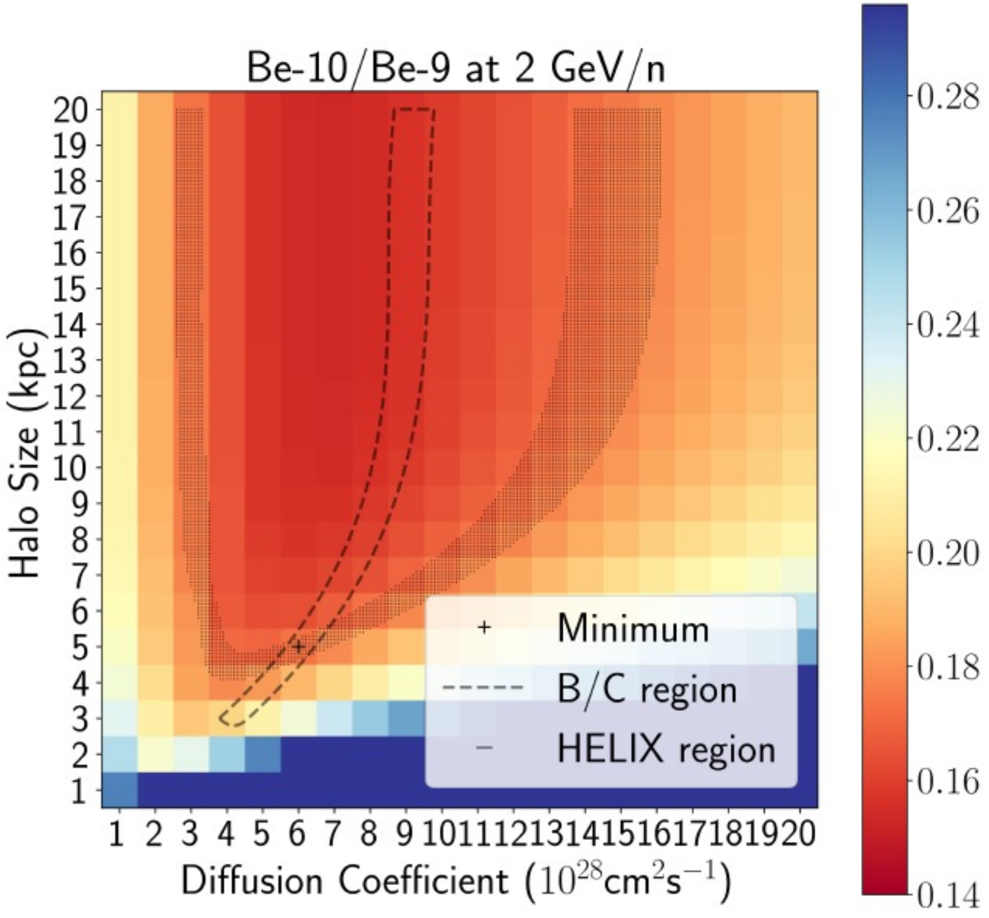
FULL GAIN MATCHING

- Gain matching program fully created, used in multiple debugging cycles.
- Turned over my program and instructions to Dr. Kenichi Sakai, who showed it functioned without my intervention.
- Results of all functioning channels shown combined on the right (plot made by Dr. Kenichi Sakai).



PROJECT STATUS

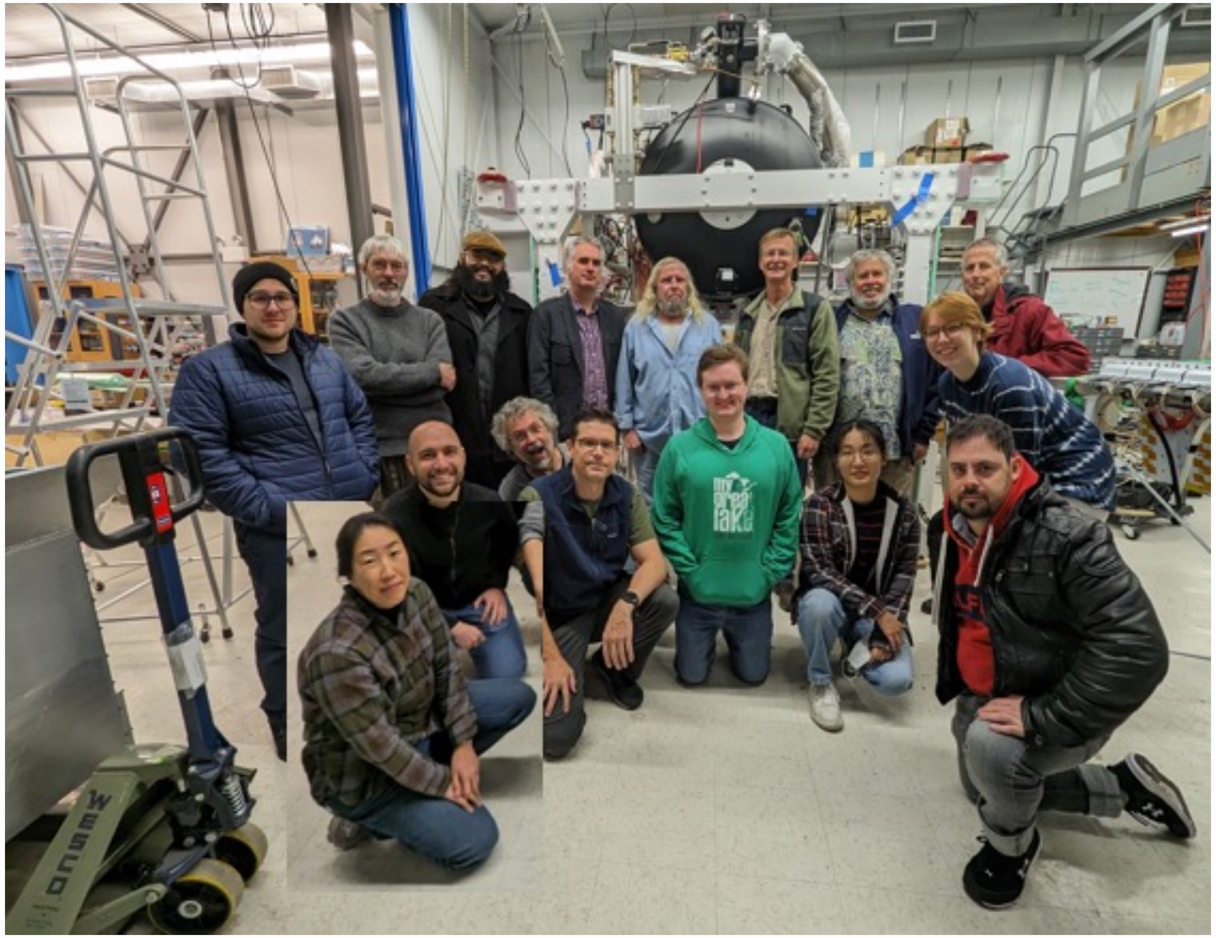
- The RICH construction and calibration have shown that the focal plane performs as required to make a high quality measurement of cosmic ray isotopes such as Be.
- With the RICH detector installed, and integration of the full payload well underway, HELIX is posed to provide critical insight into the propagation of cosmic rays.



Source: Keith McBride

CONCLUSION

- HELIX's RICH is constructed and has been installed into the payload.
- The RICH's readout electronics have been developed, tested, characterized, and installed.
- The RICH focal plane gain matching program has been demonstrated to work.
- HELIX will plan to fly in Spring of 2024.
- I will be joining OSU's physics department as a postdoc, continuing to work on balloon-based experiments.



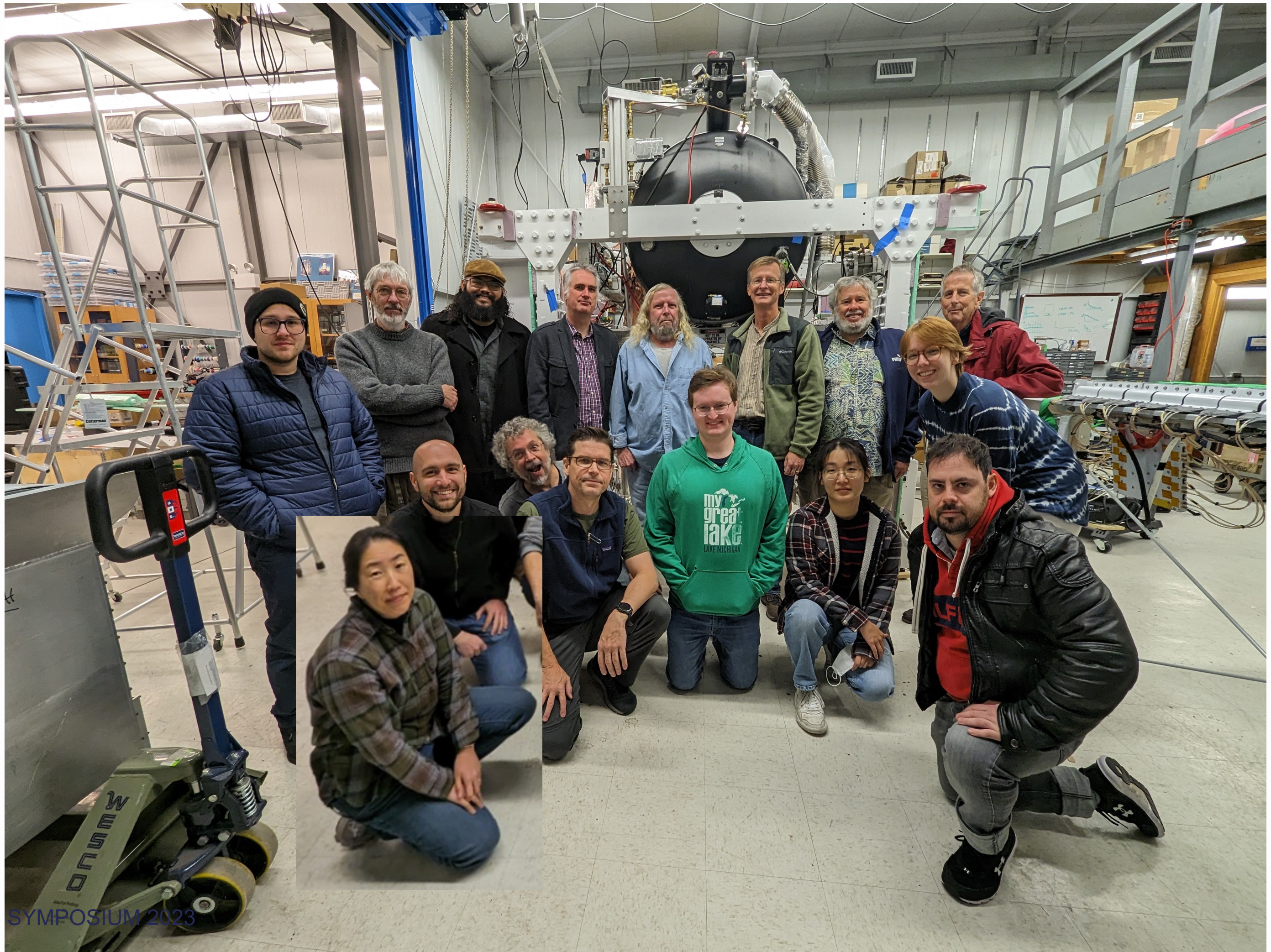
THE HELIX COLLABORATION

NKU NORTHERN KENTUCKY UNIVERSITY

PennState

CHIBA UNIVERSITY

INDIANA UNIVERSITY



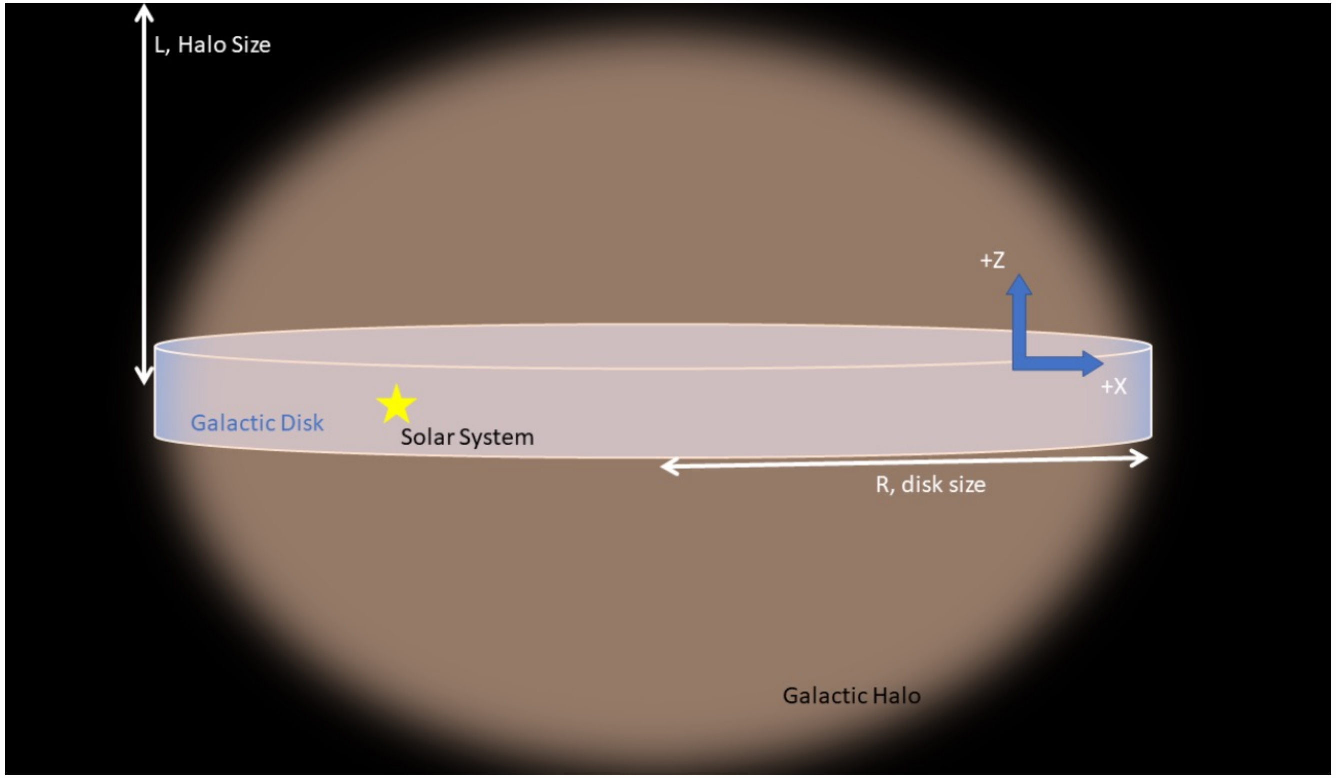
McGill UNIVERSITY

Queen's UNIVERSITY

UNIVERSITY OF MICHIGAN

THE UNIVERSITY OF CHICAGO

THE OHIO STATE UNIVERSITY

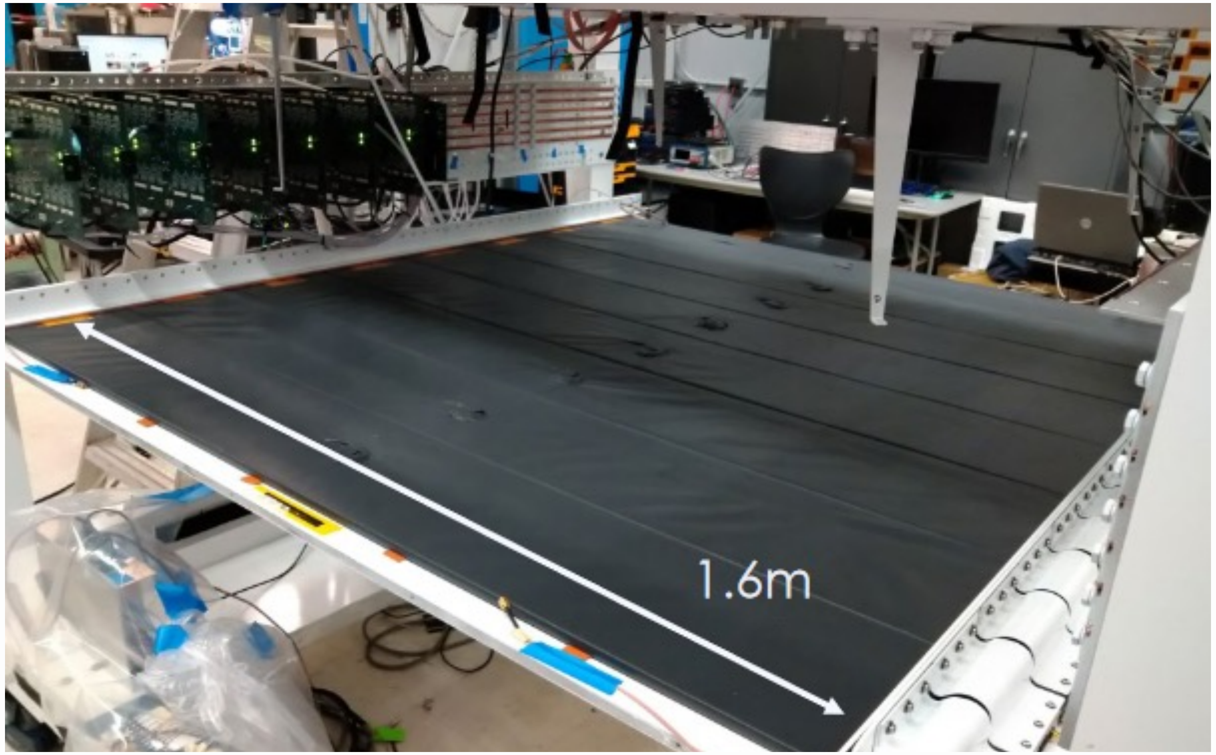


Source: Keith McBride

TIME OF FLIGHT – CHARGE AND VELOCITY

- HELIX's ToF is two layers of 1-cm thick fast plastic scintillator paddles
  - 8 paddles of 20x160 cm^2 for each layer
  - Wrapped in reflective Teflon and light-tight Tedlar
  - Gain matched SiPM readout
- An additional 60.6x60.6 cm^2 paddle, placed in the magnet bore, is used to define the particle trigger

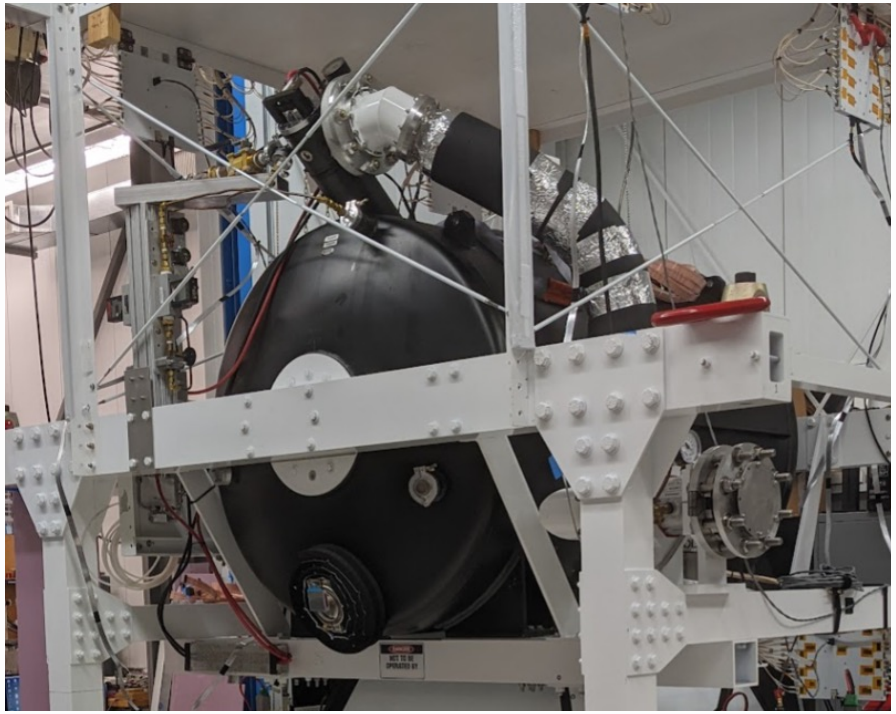
Bore Paddle



Lower TOF Paddles

SUPERCONDUCTING MAGNET

- Magnet recycled from the successful HEAT balloon experiment
- 1 Tesla field in the magnet bore
- Cooled with liquid helium to 4K
- 7 days of hold time, no in-flight refills
- In addition to flight heritage, it has been successfully tested in vacuum environments on multiple occasions

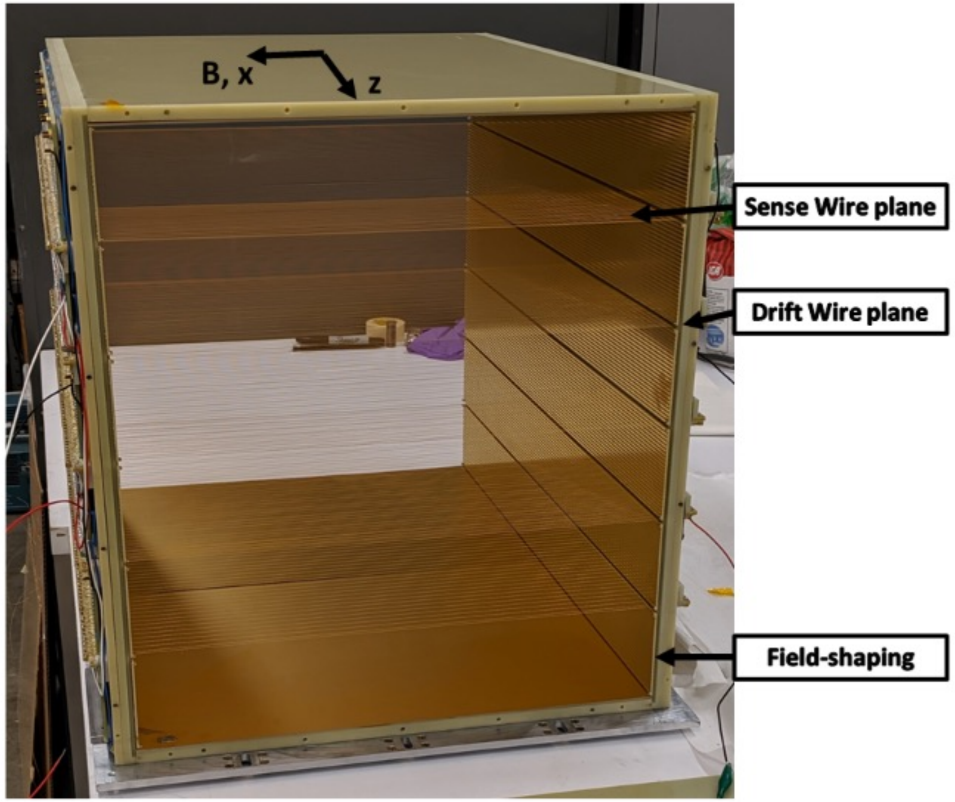


HELIX's superconducting magnet, installed in the gondola

Me, purging the magnet of liquid nitrogen in preparation for a liquid helium fill at NASA's Neil A Armstrong Test Facility

DRIFT CHAMBER TRACKER (DCT) – RIGIDITY

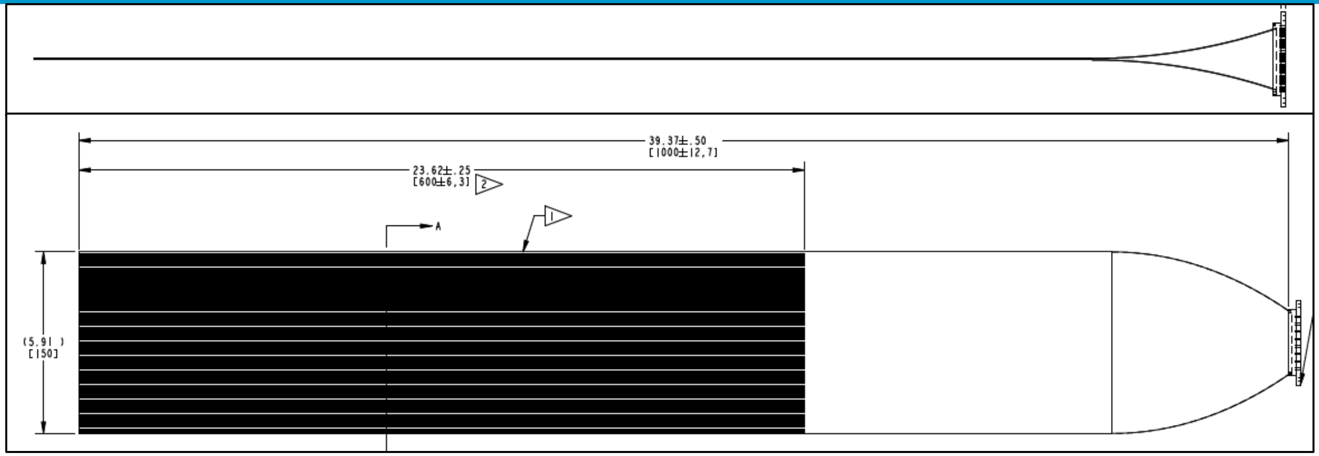
- Measures the rigidity of the particle.
  - $R = \frac{pc}{Ze} = \rho B$
- As a charged nucleus traverses the instrument, its bends with gyroradius ρ due to the magnetic field .
- The detector uses ionization tracks in the detector gas to measure the particle's deflection in the magnetic field.
- Layers of high voltage wires are used to "drift" the ionization tracks to sense wires for readout.
- Stored in a hermetically sealed vessel, which is then installed in the bore of the magnet

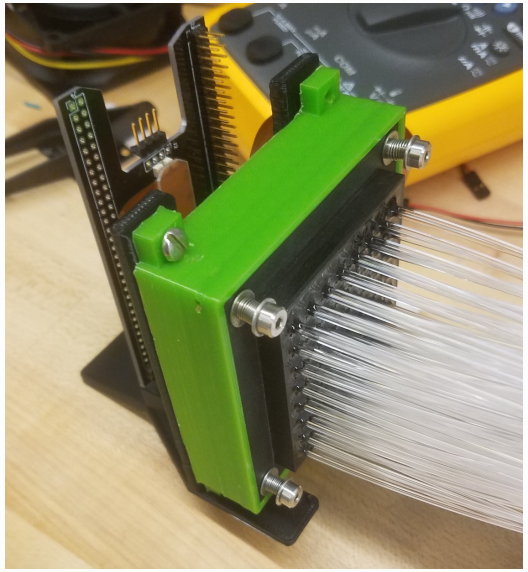


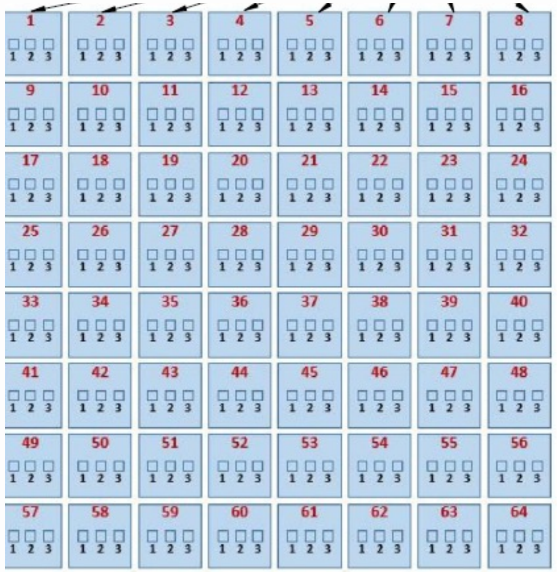
Inside of the DCT (Rev A)
Source: McBride, Cosmic Ray Instrumentation and Simulations (2021)

HODOSCOPE – TRACKING RESOLUTION

- Hodoscope will improve tracking resolution in the non-bending plane
- 150 scintillating fibers per ribbon
  - Each fiber has a 1mm square cross section
  - 4 ribbons for 600x600mm square area
- Each fiber ribbon is woven and glued into a cookie
  - Aligns up to 3 fibers on each SiPM in the array







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Four wrapped hodoscope ribbons, ready for insertion

Image Credit: Hyebin Jeon

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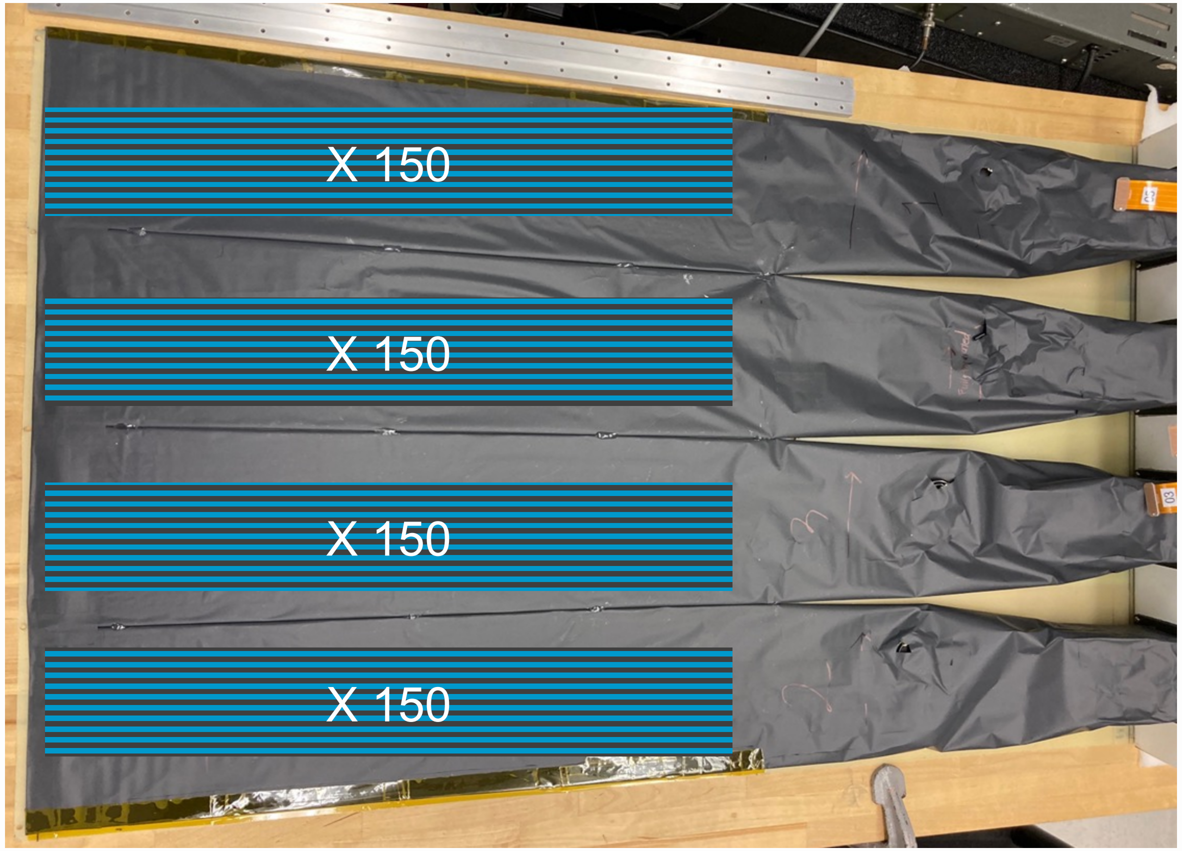
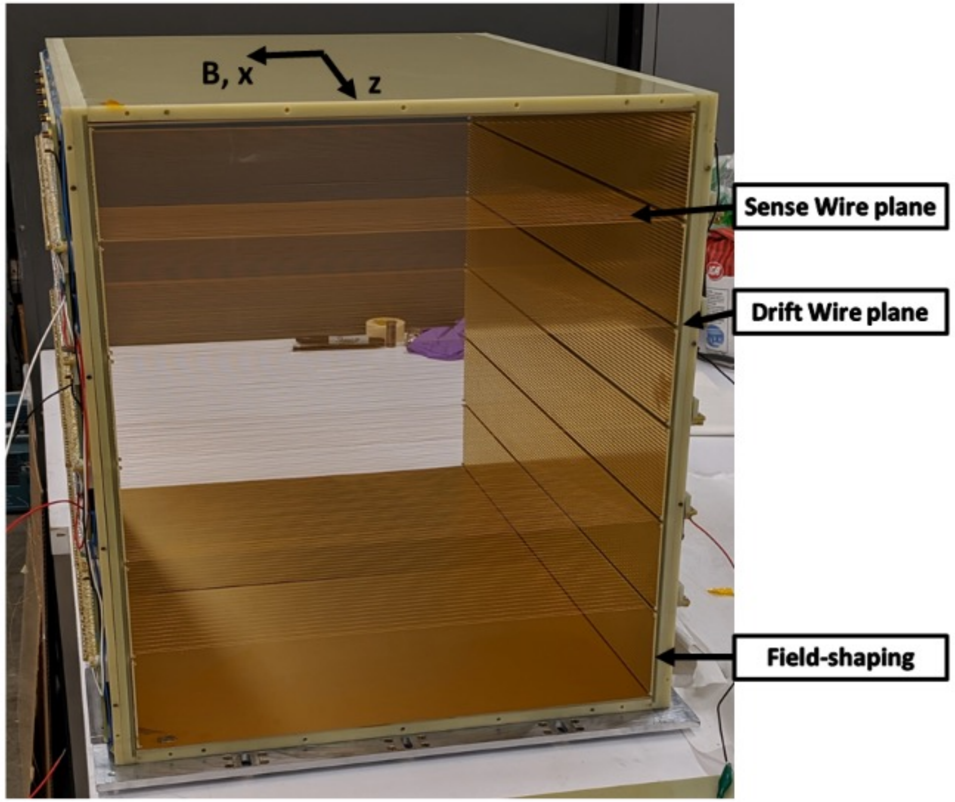


Four wrapped hodoscope ribbons, ready for insertion

Image Credit: Hyebin Jeon

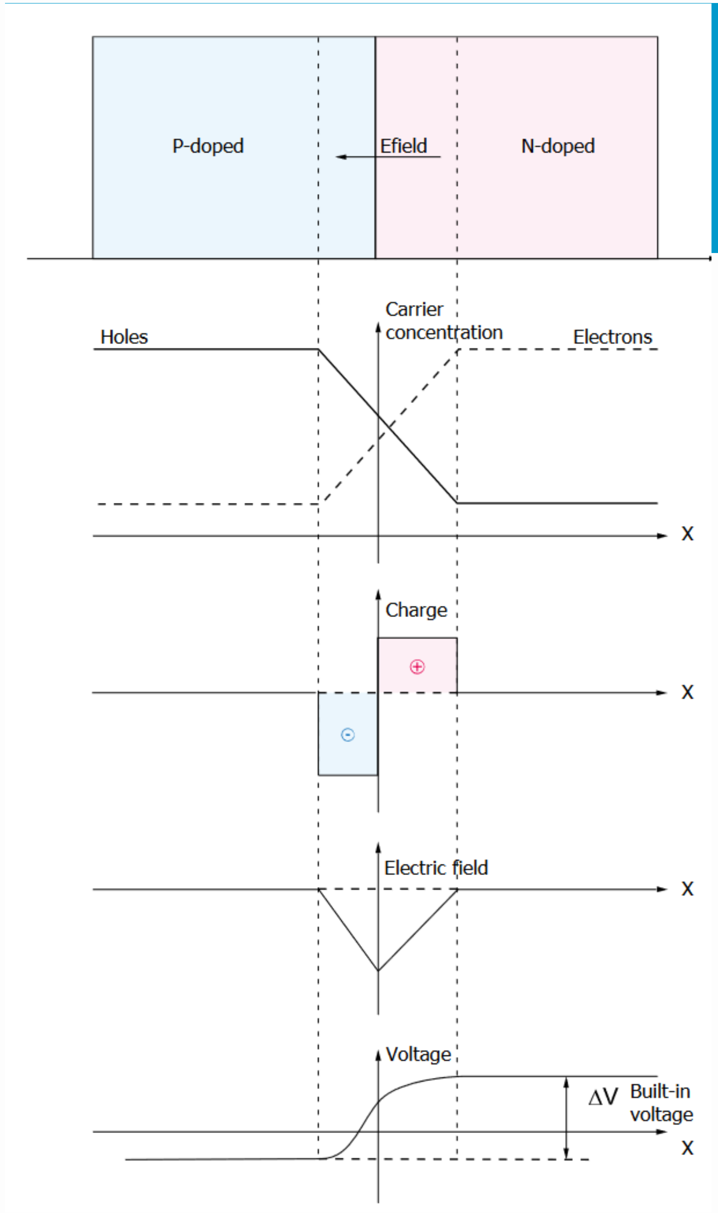
DRIFT CHAMBER TRACKER (DCT) – RIGIDITY

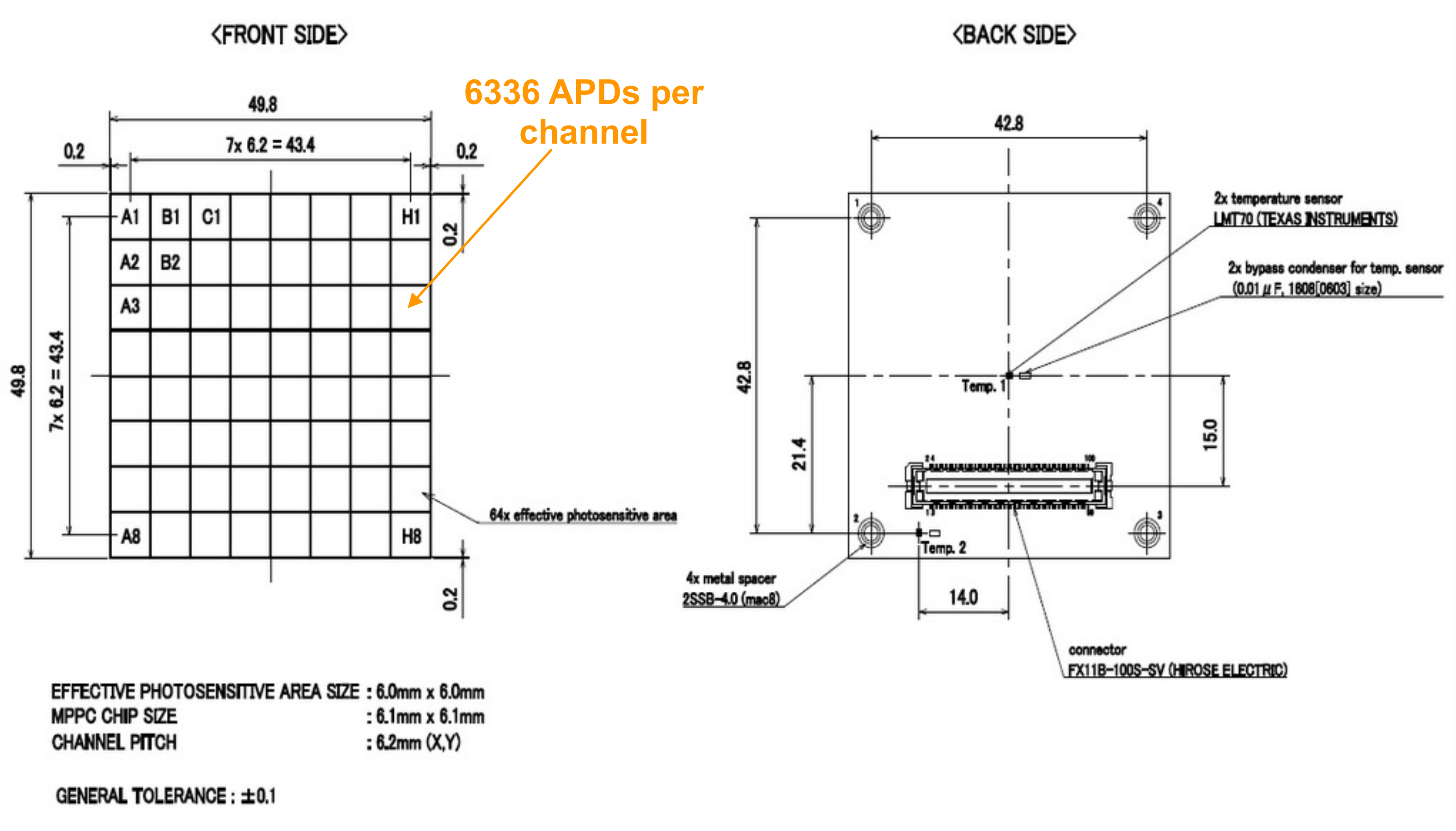
- Measures the rigidity of the particle
  - $R = \frac{pc}{Ze} = \rho B$
- 72 tracking measurements
  - 2 drift planes with potential wires held at -10 kV
  - 3 sense planes, with grounded sense wires read out by ADCs and additional potential wires at -3.5 kV
- Stored in a hermetically sealed vessel, which is then installed in the bore of the magnet
- Contains a gas mixture of CO_2 and Ar
- Drift field is a uniform 1.3 kV/cm



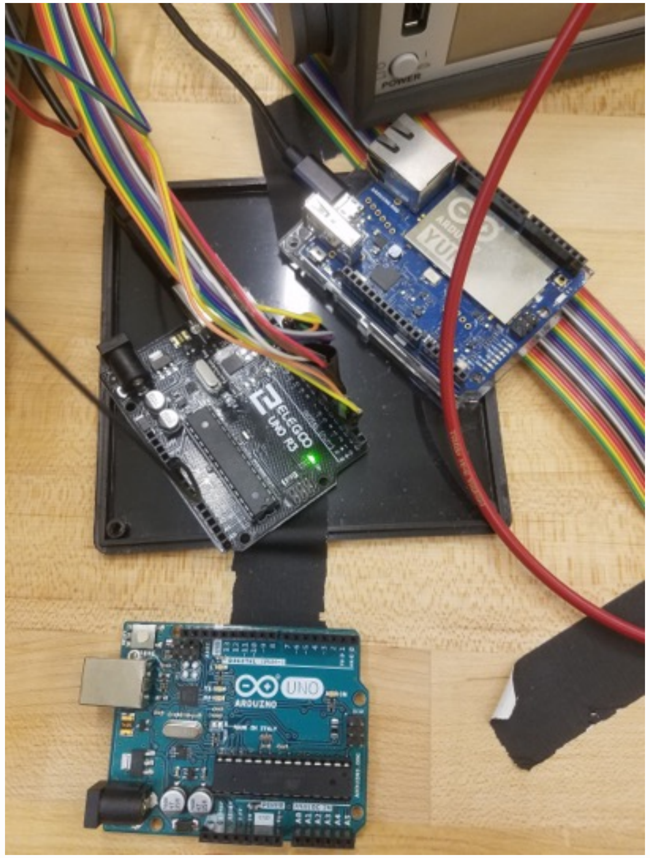
Inside of the DCT (Rev A)
Source: McBride, Cosmic Ray Instrumentation and Simulations (2021)

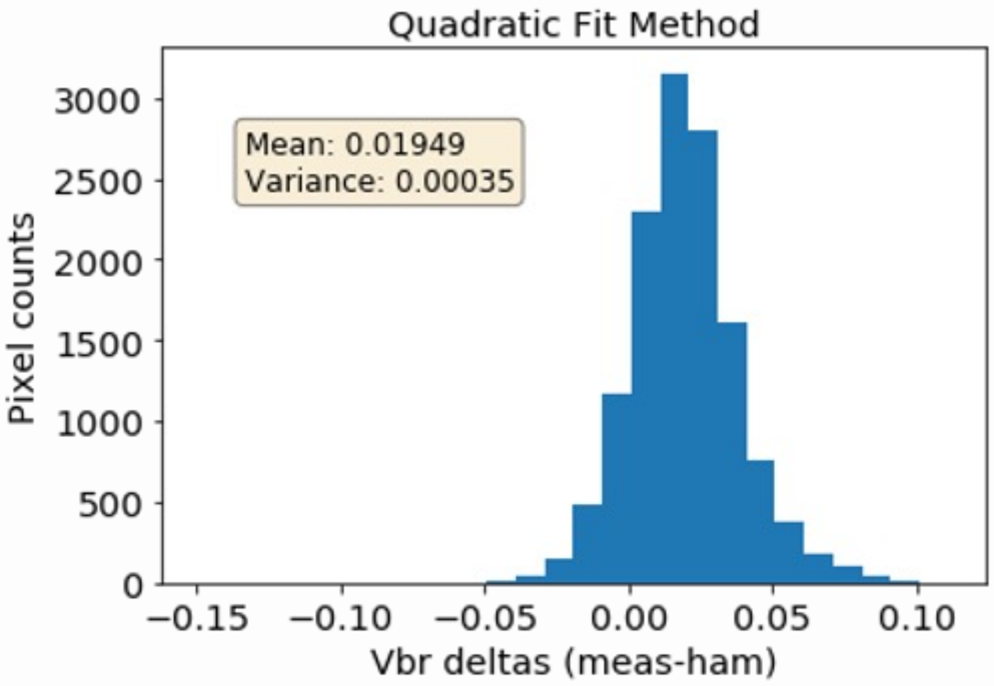
AVALANCHE PHOTODIODES AND SiPM BASICS





SiPMs – BREAKDOWN VOLTAGE

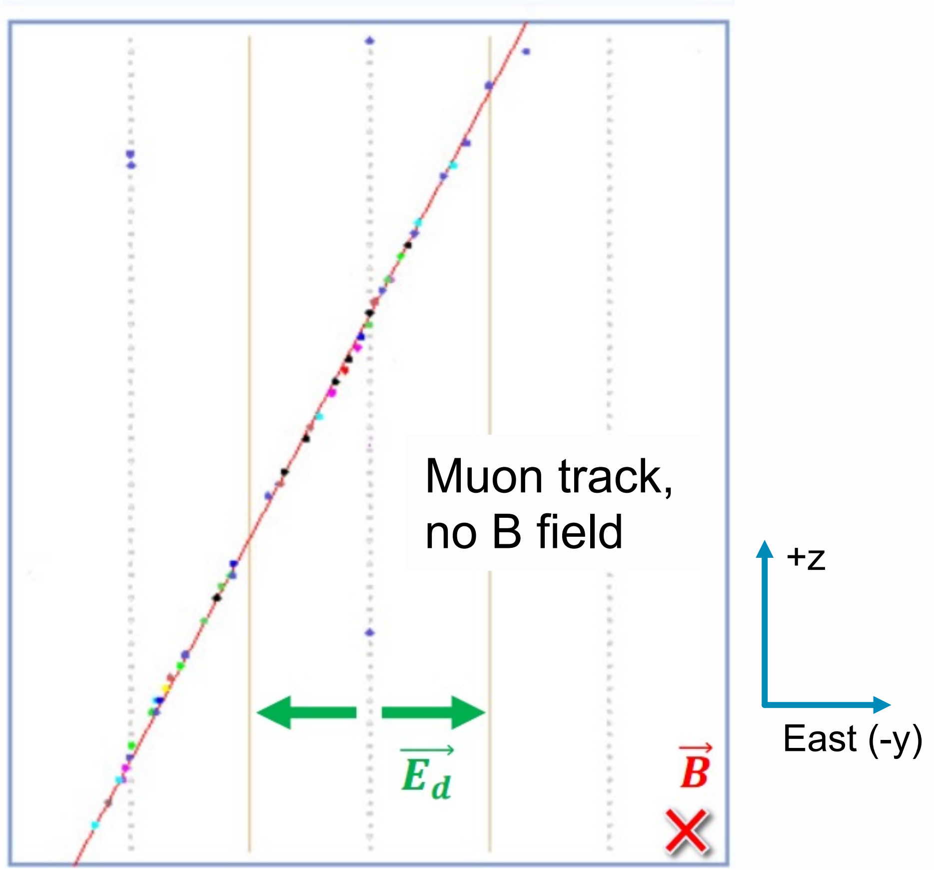




DRIFT CHAMBER TRACKER (DCT) – RIGIDITY

- As a charged nucleus traverses the instrument, its bends with gyroradius ρ due to the magnetic field
- The nucleus ionizes the gas in the tracker, leaving a path of charged particles
- The charged particles are then accelerated in the E field, inducing a current on the sense wires
- The sense wires are read out at both ends - the pulse length is used to find the drift time of the ions, which can then be used to find the distance from the wire they were created
- Charge division between the ends of the resistive wire can be used to find the non-bending plane coordinate
- The DCT is designed for a mean spatial resolution of 65 μm for Z>3 particles

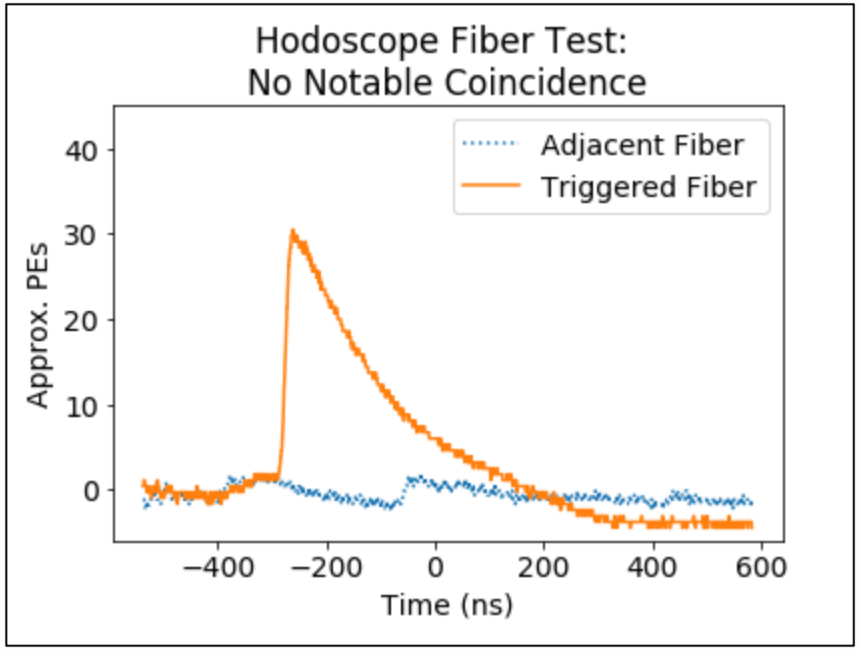
DCT Bending Plane

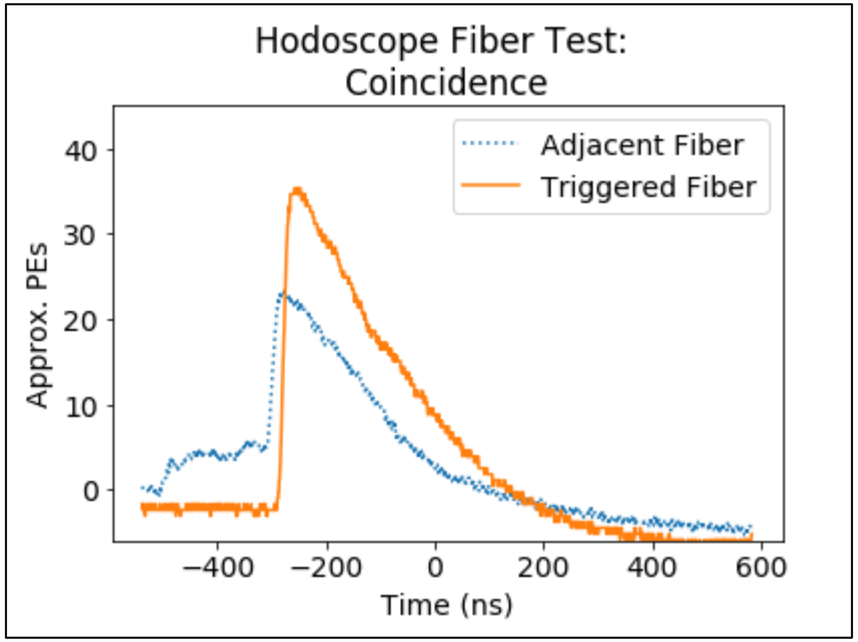


Source: McBride, " Isotopic composition of cosmic rays with the HELIX balloon project" TevPa 2022. https://indi.to/L4wDv

PROJECTS – HODOSCOPE CHARACTERIZATION RESULTS

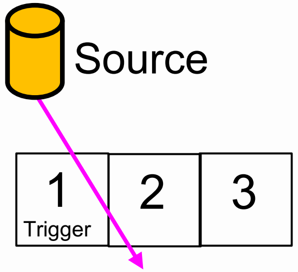
- Crosstalk measurements between adjacent fibers



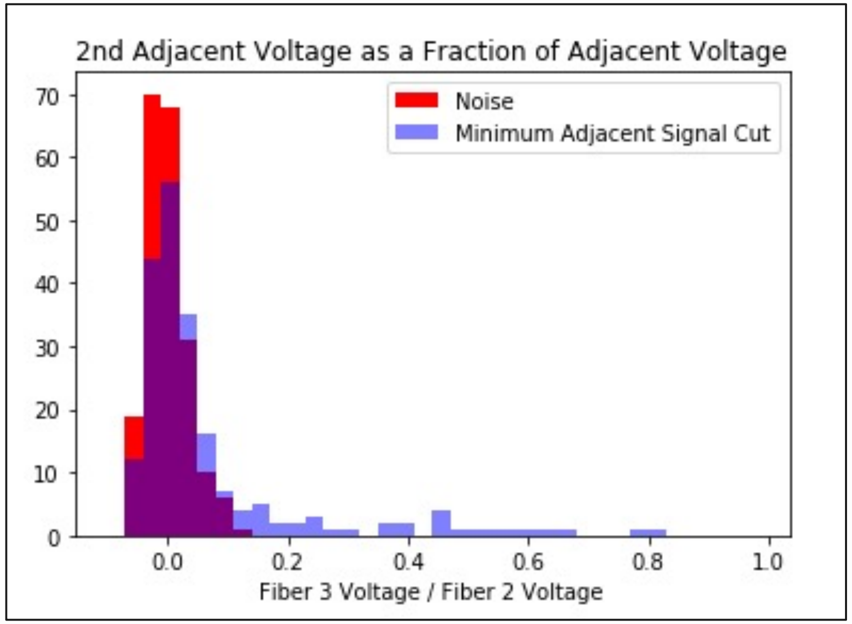


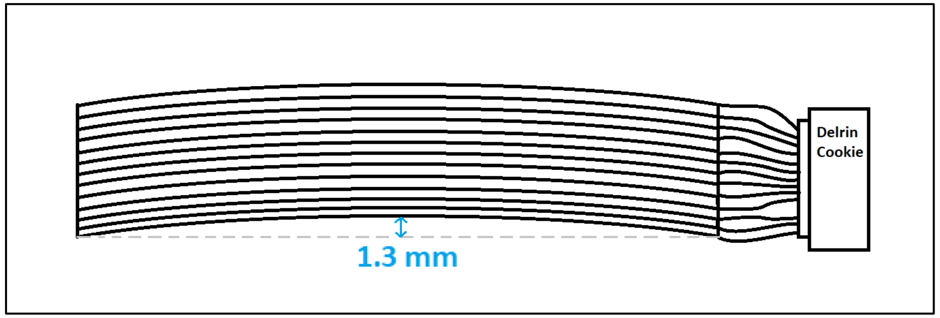
PROJECTS – HODOSCOPE CHARACTERIZATION RESULTS

- Geometrically excluded non-crosstalk events by requiring particle pass through Fibers 1 and 2, have a higher signal in Fiber 1, and measuring crosstalk between 2 and 3:



- The median of the fractional crosstalk distribution was 1.7 percentage points above the noise distribution – well within our requirements.
  - Toy Monte Carlo showed even 5% crosstalk would still allow hodoscope to be fully effective.
- Discovered a curvature that will need to be accounted for.



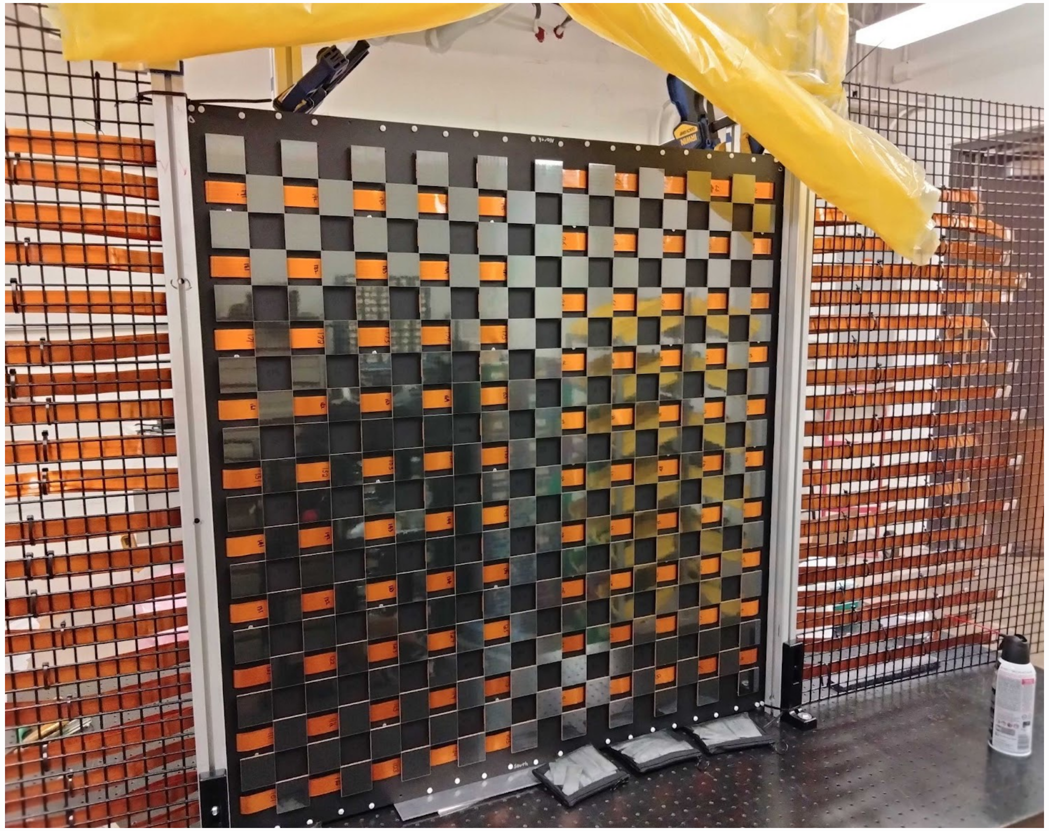


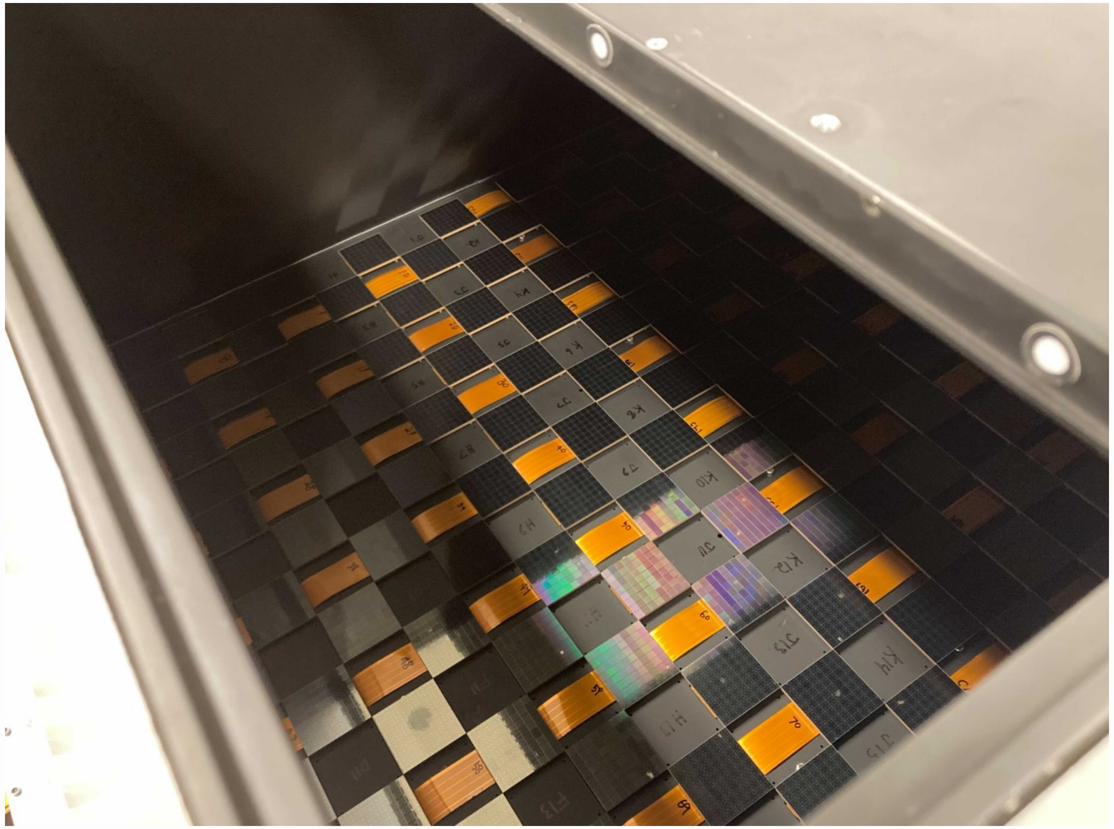
PROJECTS - SOFTWARE

- Housekeeping
  - Software interface for pressure sensor, flowmeters, thermal probes
  - Software runs on TI microcontroller
- Menu Interface Program
- Master merger test software improvements

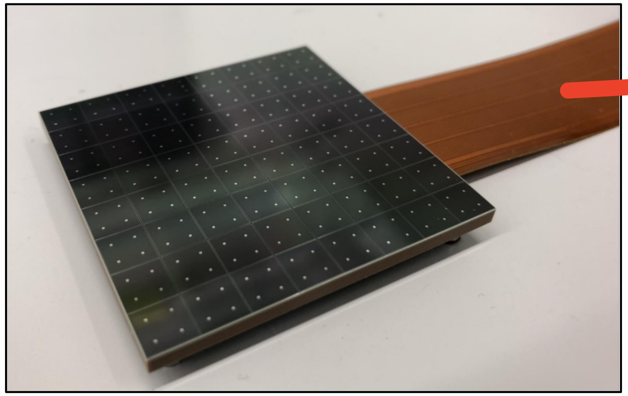
Eat your heart out *Zork*…

SiPMs IN THE FOCAL PLANE



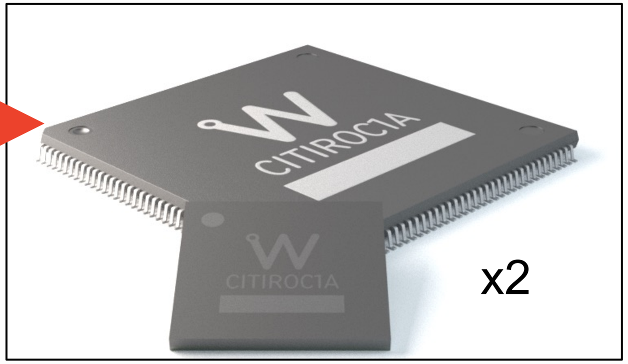


FRONT END READOUT CHAIN



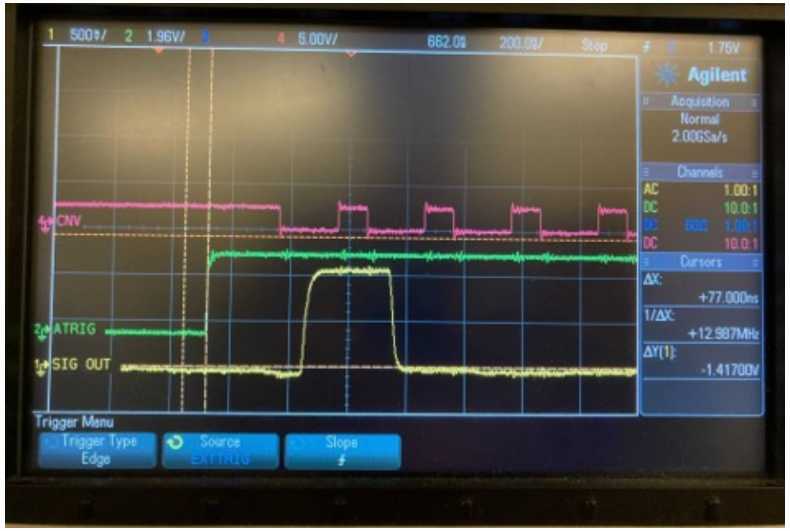
64 SiPMs per Array

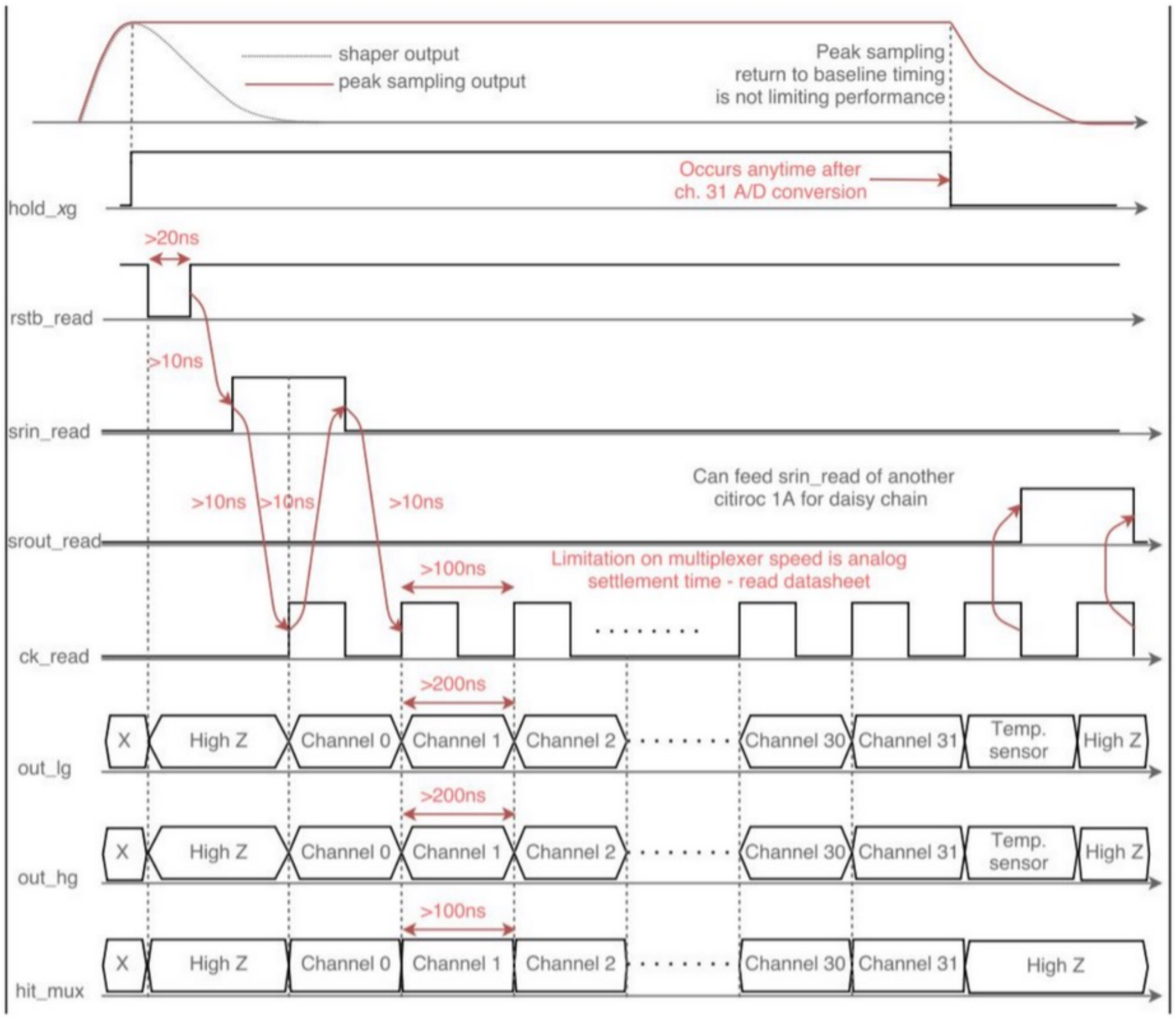
Flex cable carries 64 anodes, shared cathode, and temperature probe lines

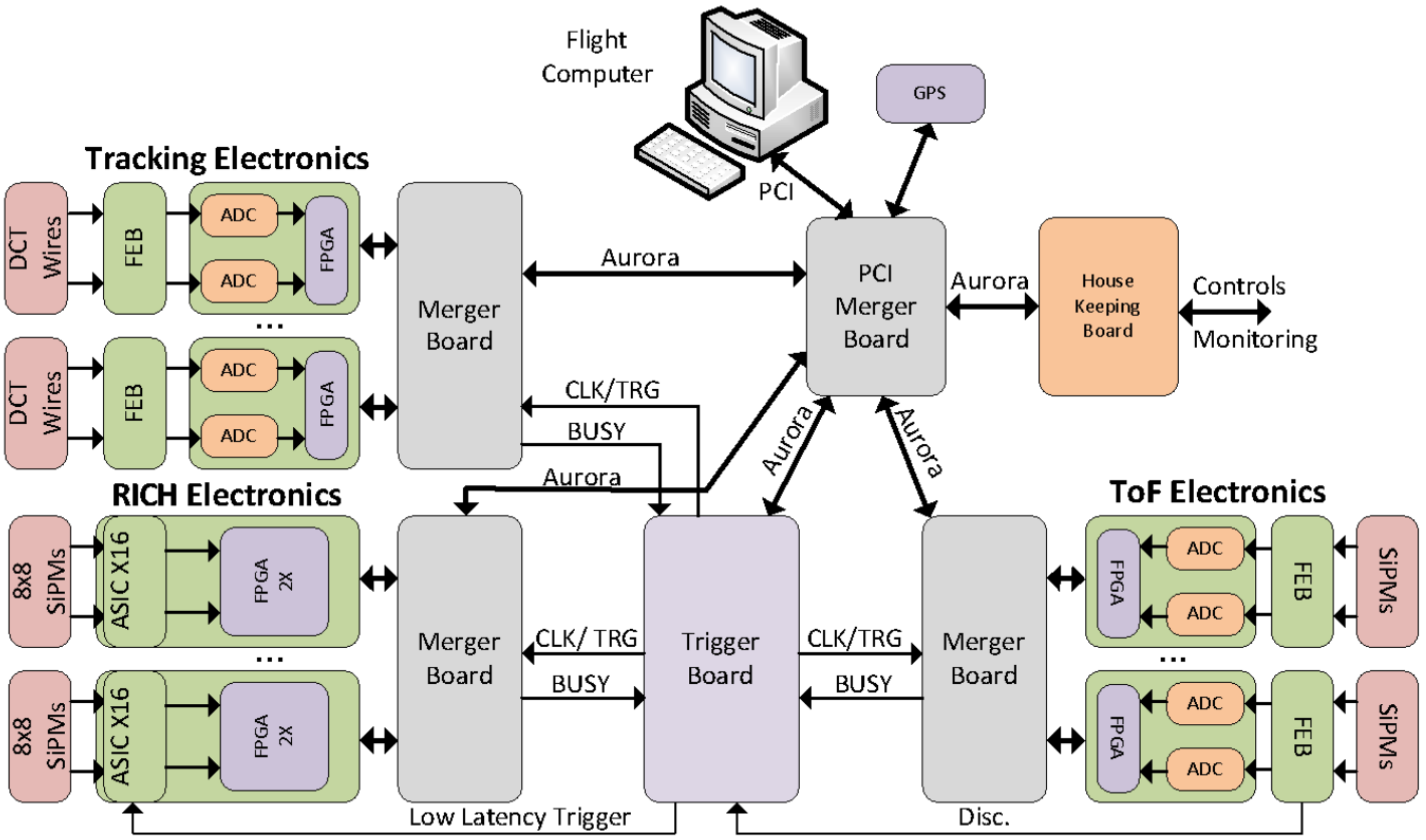


32 anodes per CITIROC ASIC

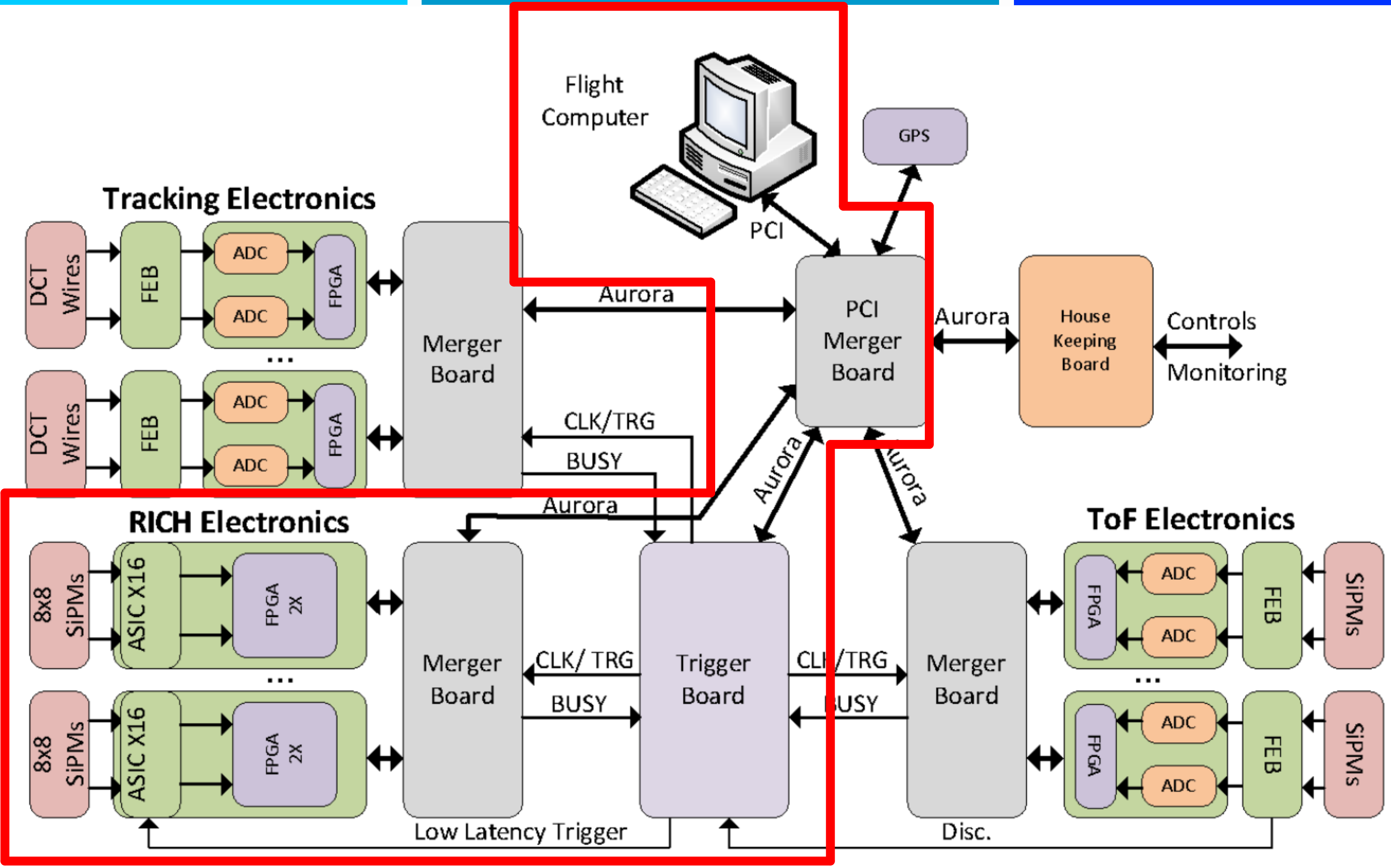
CITIROC ASIC







Flight
Computer
GPS
PCI
Tracking Electronics
DCT Wires
FEB
ADC
ADC
FPGA
DCT Wires
FEB
ADC
ADC
FPGA
Merger Board
Aurora
PCI Merger Board
Aurora
House Keeping Board
Controls
Monitoring
CLK/TRG
BUSY
Aurora
Aurora
Aurora
RICH Electronics
8x8 SiPMs
ASIC X16
FPGA 2X
8x8 SiPMs
ASIC X16
FPGA 2X
Merger Board
CLK/ TRG
BUSY
Trigger Board
CLK/TRG
BUSY
Merger Board
ToF Electronics
FPGA
ADC
ADC
FEB
SiPMs
FPGA
ADC
ADC
FEB
SiPMs
Low Latency Trigger
Disc.



Flight Computer
PCI
GPS
Tracking Electronics
DCT Wires
FEB
ADC
ADC
FPGA
DCT Wires
FEB
ADC
ADC
FPGA
Merger Board
Aurora
PCI Merger Board
Aurora
House Keeping Board
Controls
Monitoring
CLK/TRG
BUSY
Aurora
Aurora
Aurora
RICH Electronics
8x8 SiPMs
ASIC X16
FPGA 2X
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BUSY
Trigger Board
Merger Board
ToF Electronics
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FPGA
FEB
SiPMs
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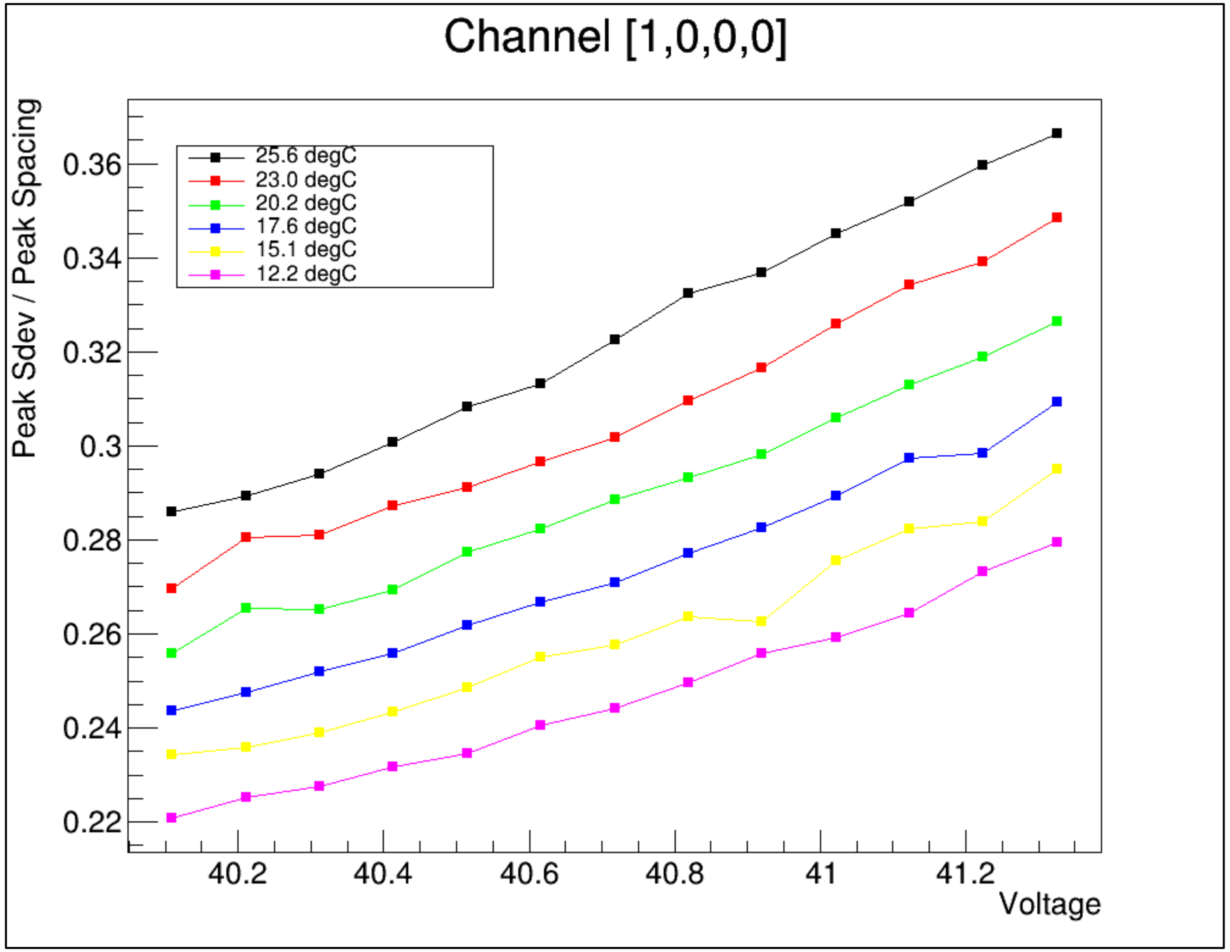
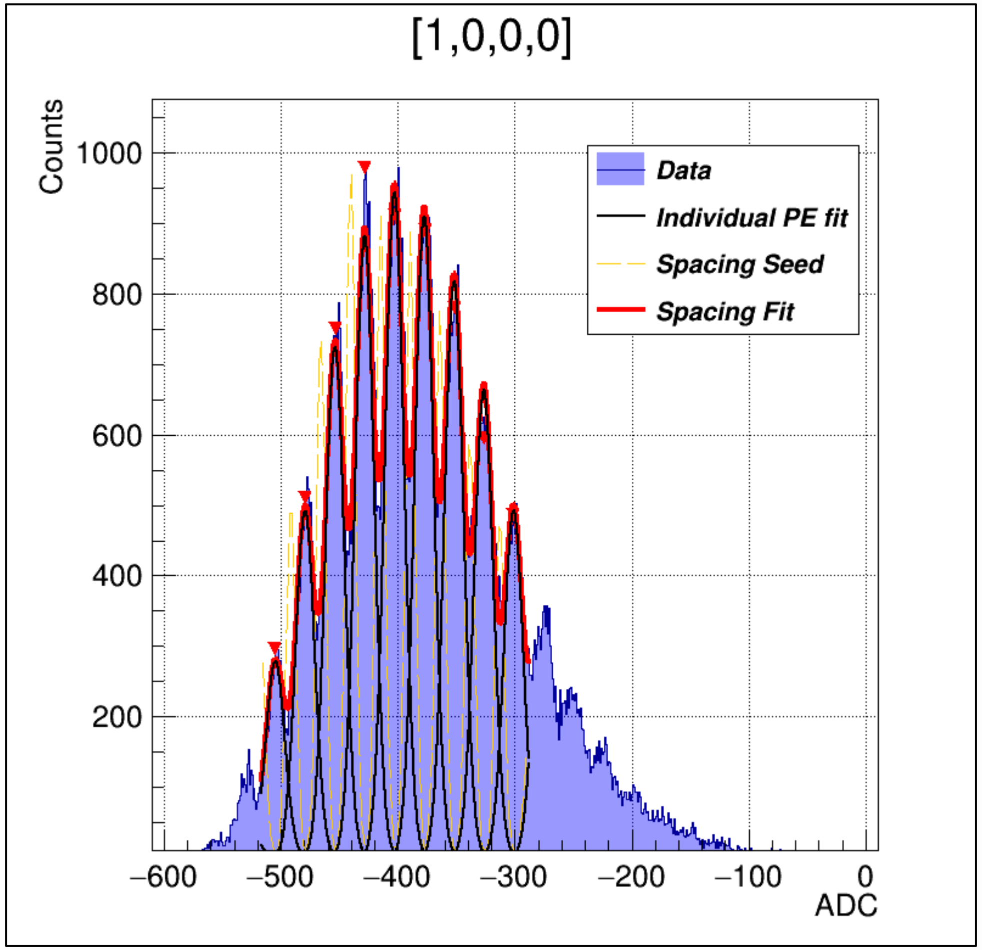
SiPMs
Low Latency Trigger
Disc.

SiPMs – RESOLUTION AND TEMPERATURE





Standard deviation divided by the spacing between the peaks. The lower this value, the better the resolution.

RICH FOCAL PLANE METROLOGY – 3D SCANNING