ePIC
Barrel Imaging Calorimeter (BIC)
Parasitic Beam Test in Hall D

Maria Zurek for the BIC DSC

ePIC TIC Meeting, Jun 8, 2026

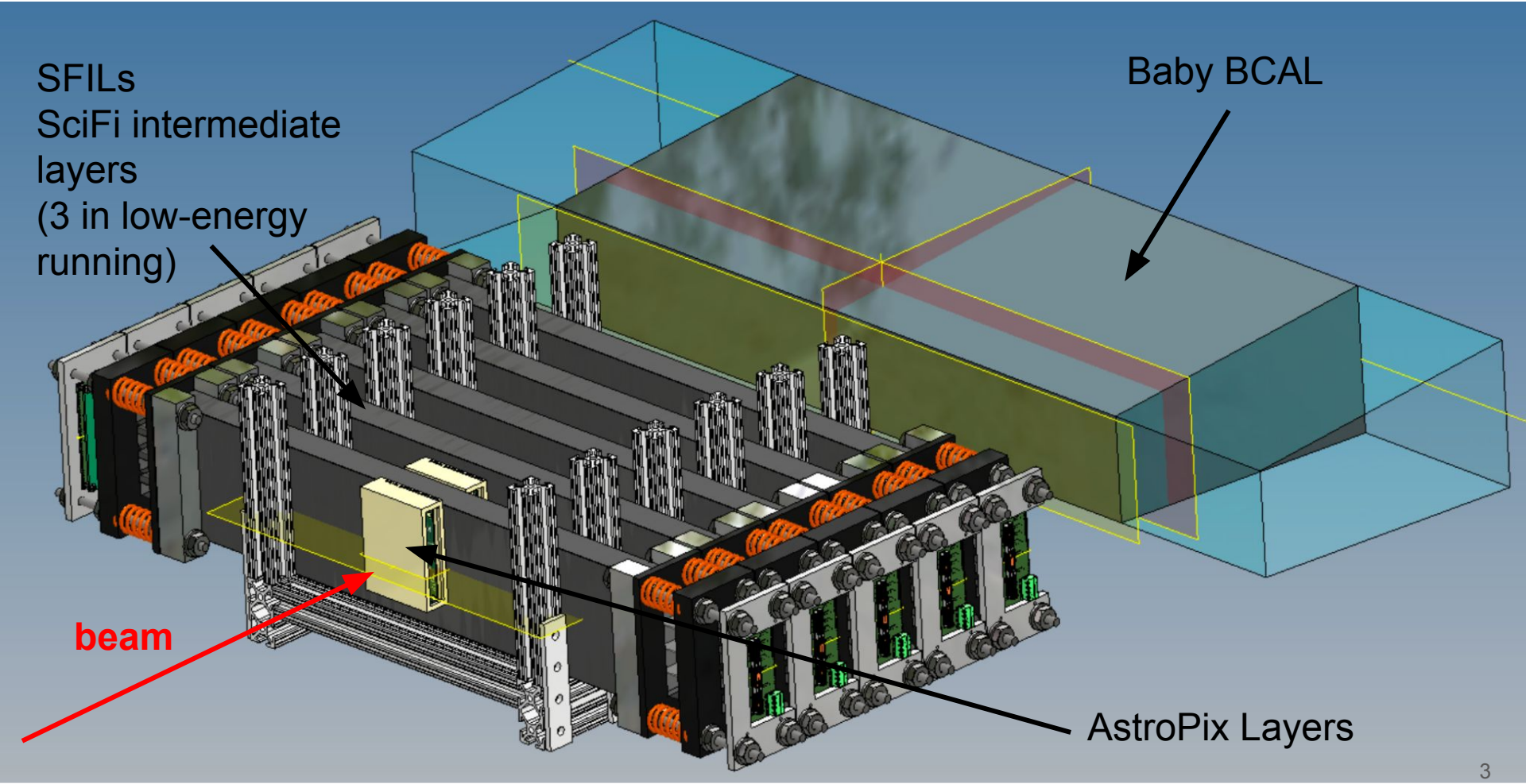
Beam Test Goals

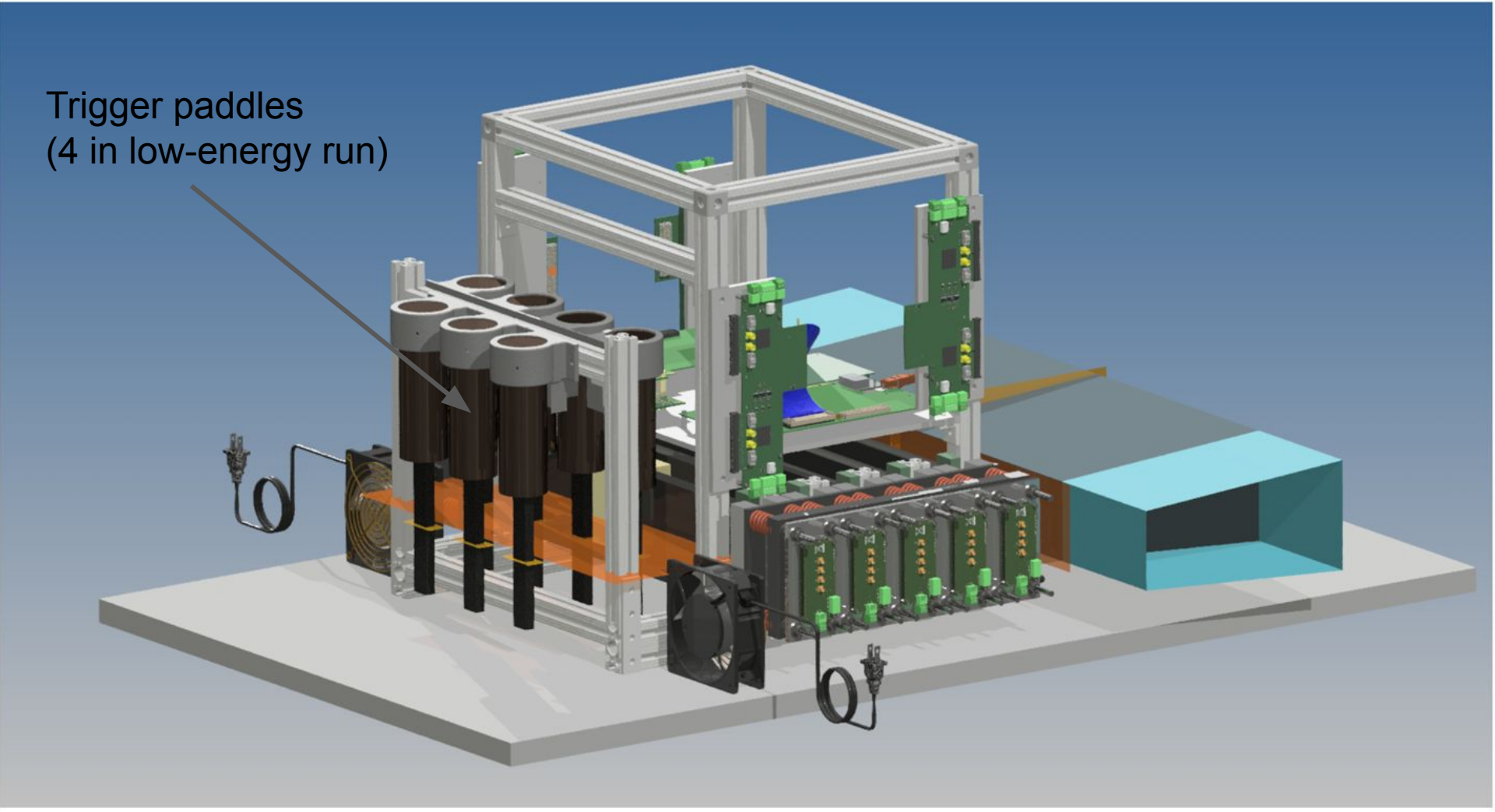
March Commissioning (low energy):

- Commission for the first time the readout with HGCROC.
- Test synchronization between AstroPix and HGCROC readout.
- Benchmark low-energy response (~0.5 GeV) within the nominal and August Beam-Test dynamic range, at different energy points.

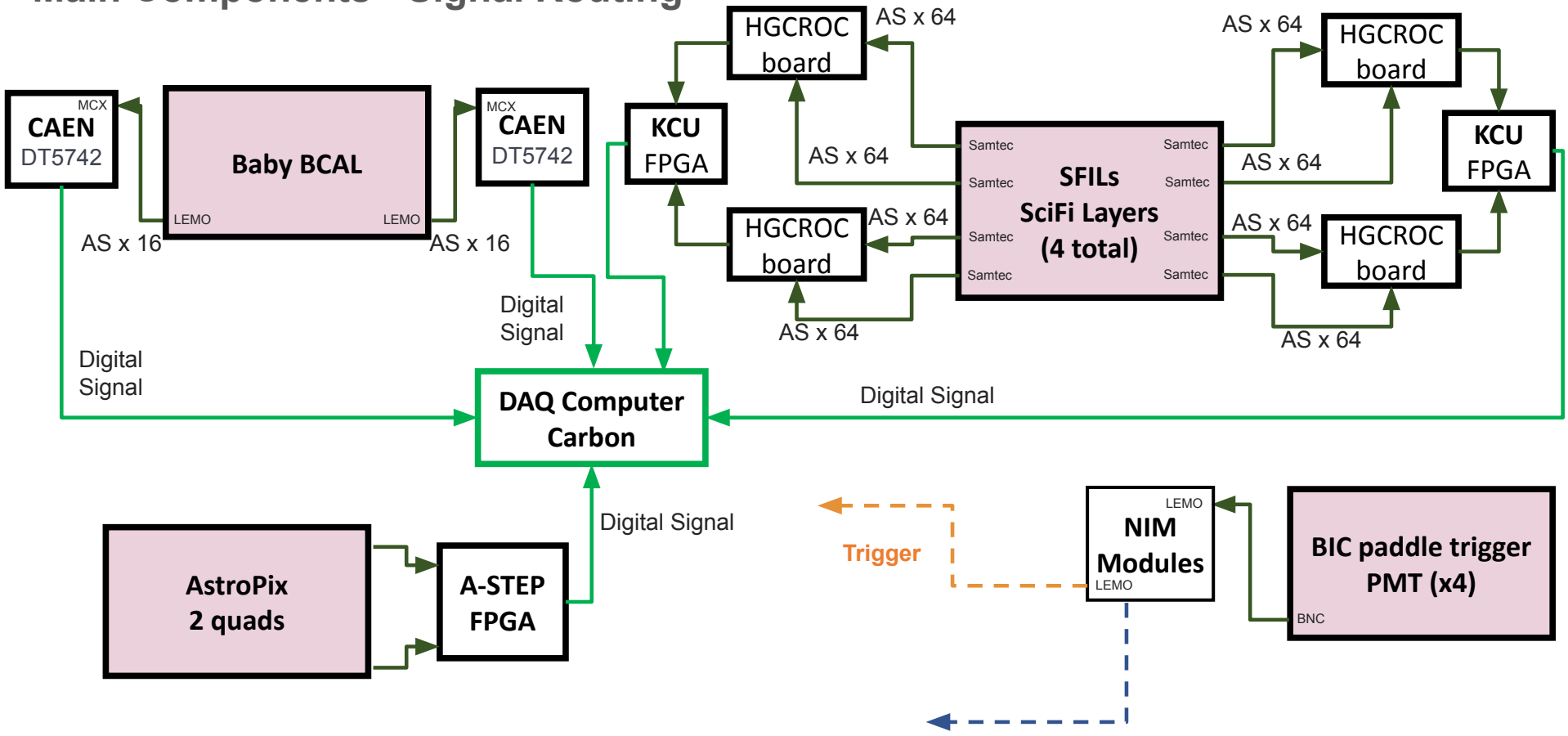
August (high energy):

- Benchmark energy and timing resolution within 3-6 GeV energy range with full HGCROC readout and show shower imaging event by event.


SFILs
SciFi intermediate layers
(3 in low-energy running)
Baby BCAL
beam
AstroPix Layers

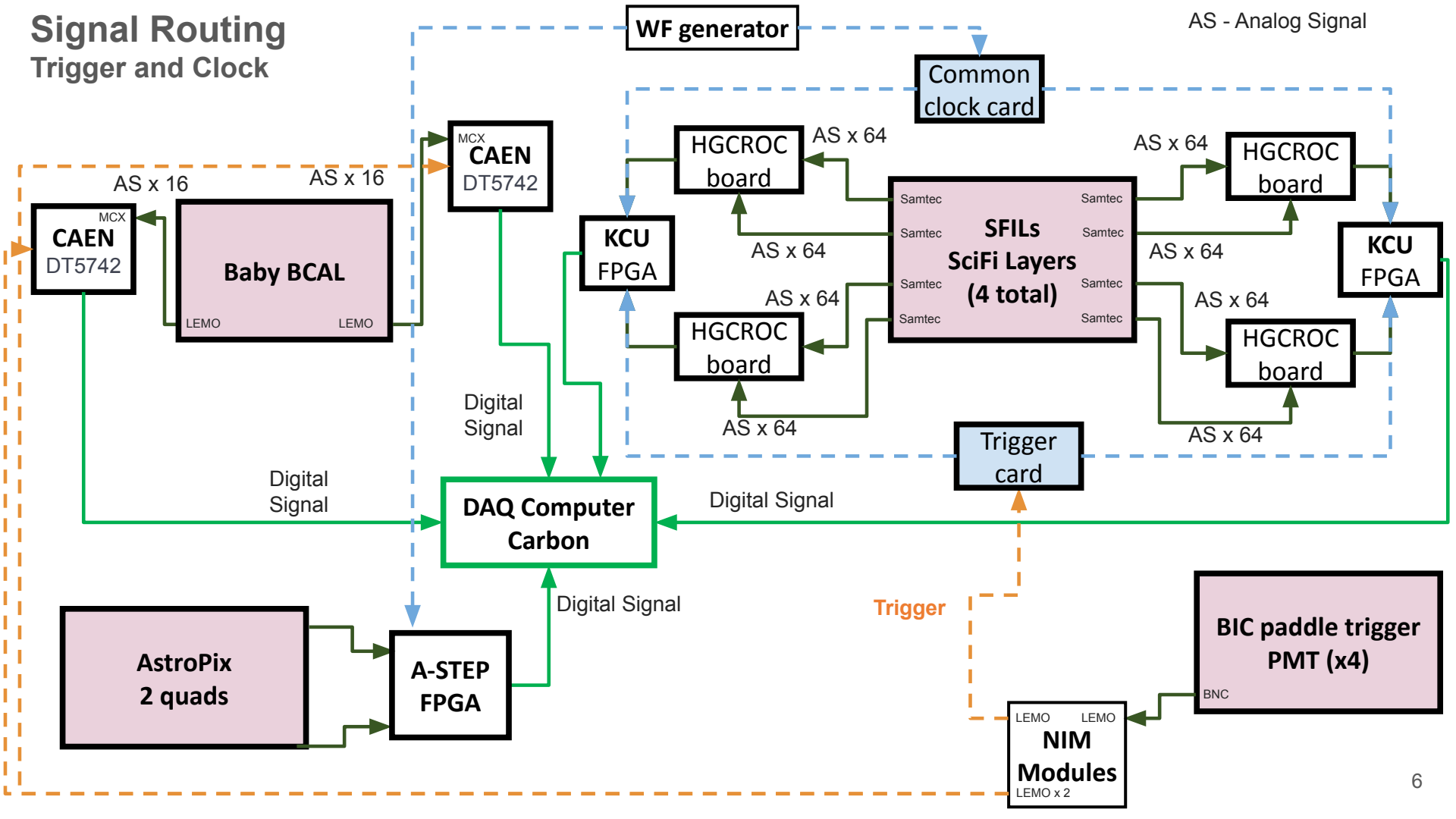

Trigger paddles
(4 in low-energy run)

Main Components - Signal Routing



AS - Analog Signal
DS - Digital Signal

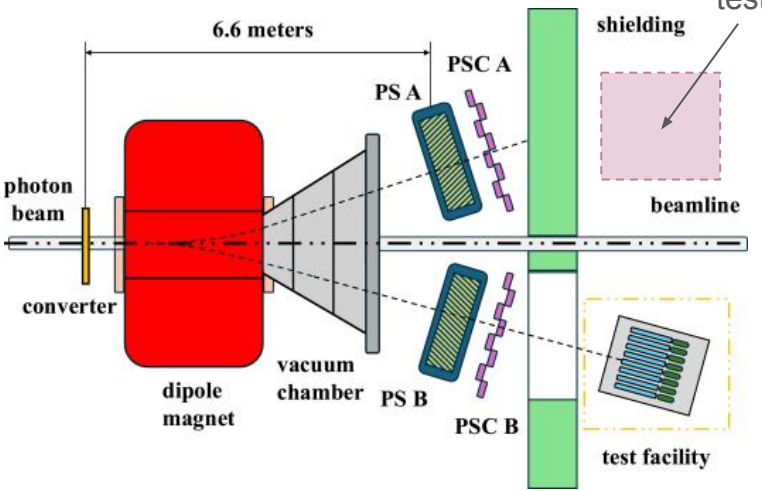
Signal Routing
Trigger and Clock



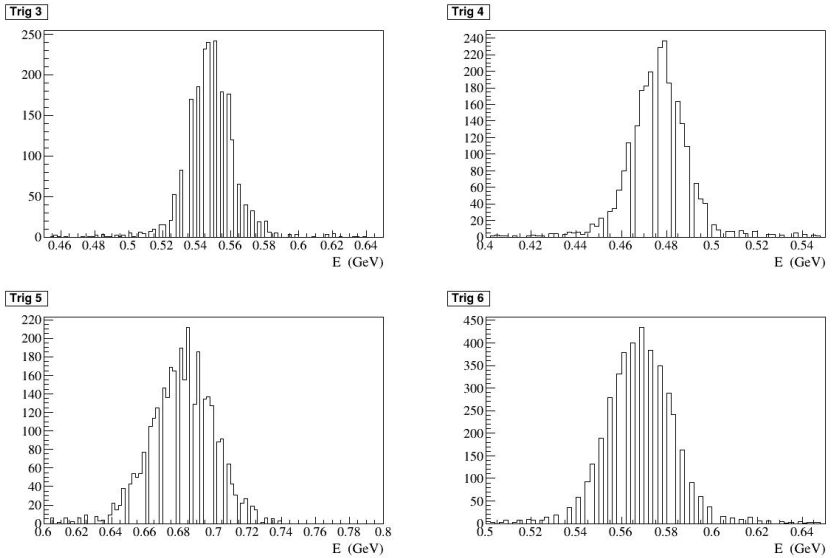
Sasha Somov

Running Conditions

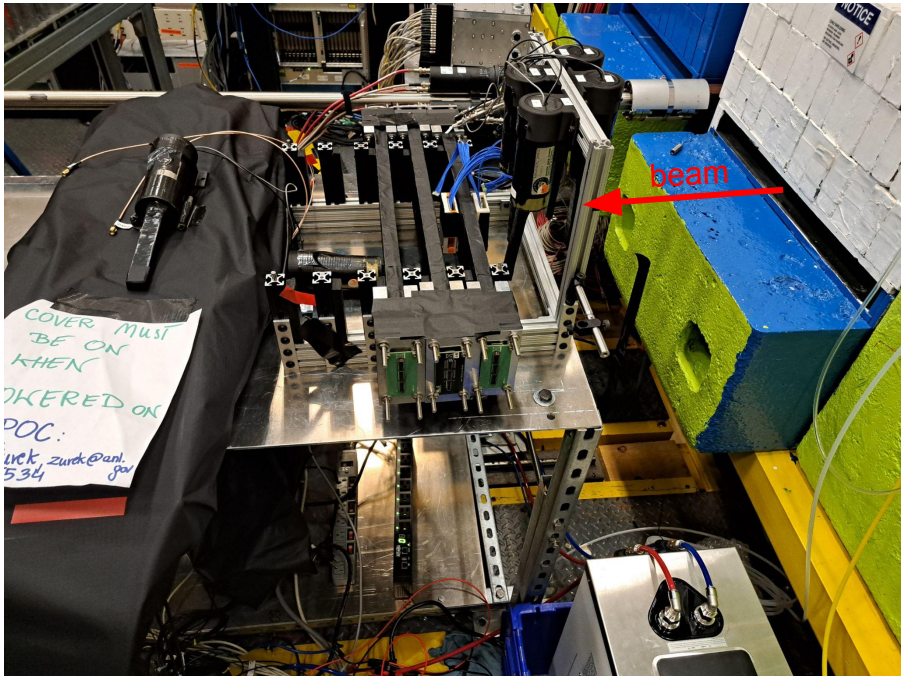
Pair Spectrometer area in Hall D

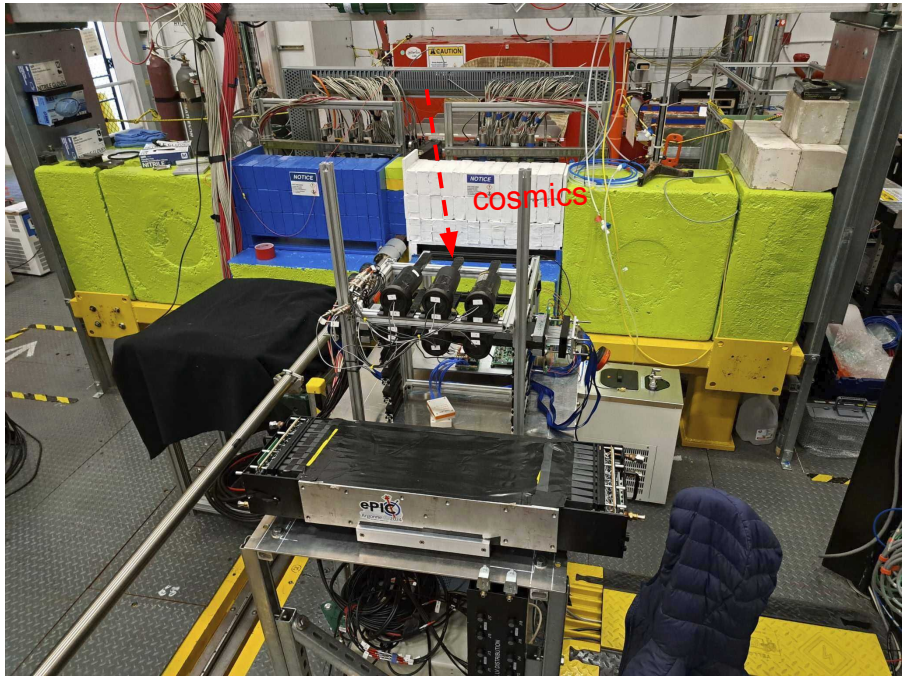


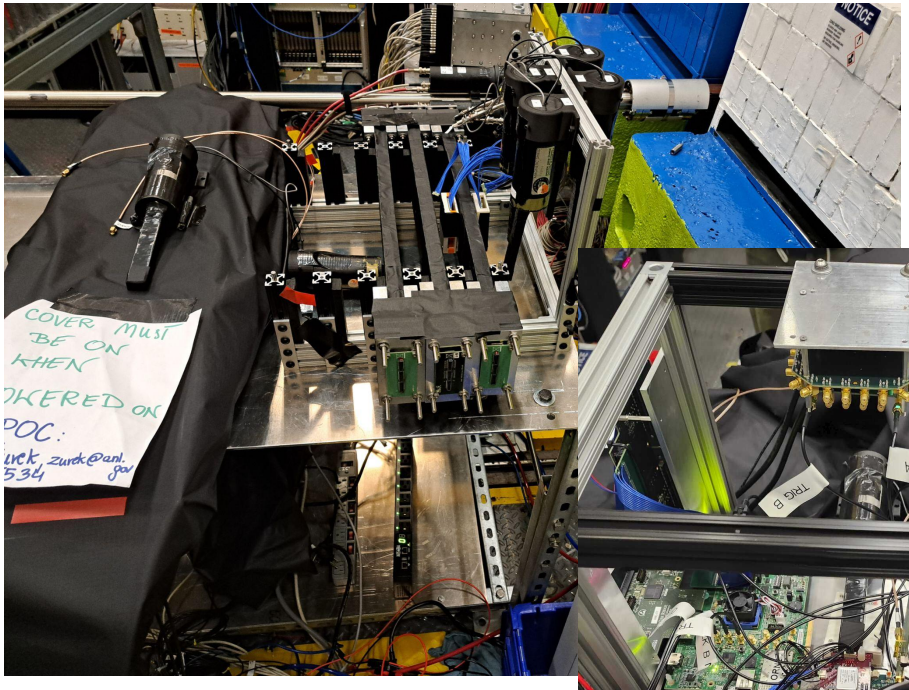
Our trigger paddles energy ranges

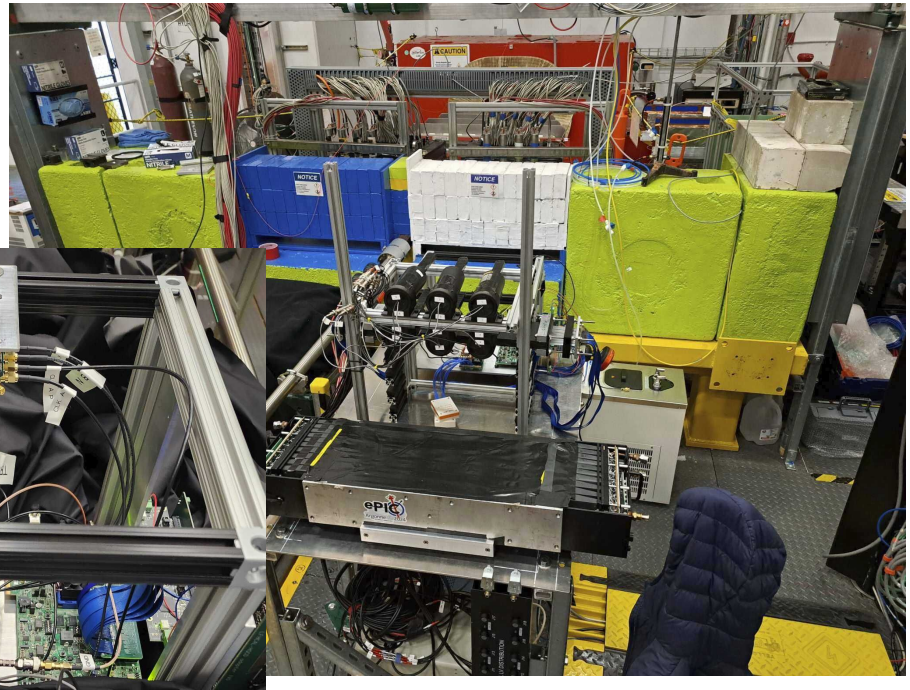


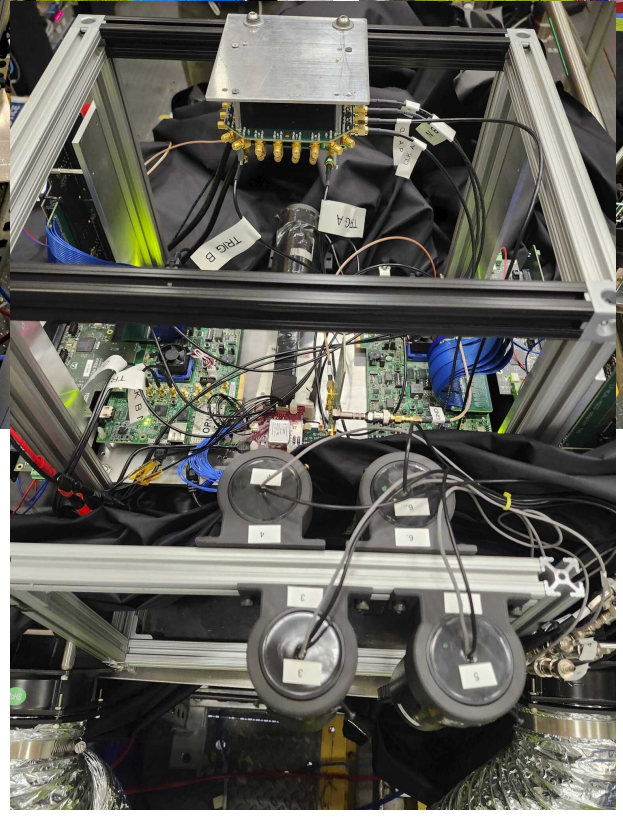
- Parasitic running with GlueX
- With lots of delays in CEBAF beam delivery to Hall D (planned start beginning of March, Hall D started receiving beam May 2nd + a week for beam commissioning)
  - No scheduled maintenance days, no planned opportunities for the hall entry
  - Relaying on remote operations and opportunistic entries with the personnel we had on site
- Before beam started collected some data with cosmics for debugging


beam
COVER MUST
BE ON
WHEN
OKERED ON
DOC.:
5.34


cosmics
CAUTION
NOTICE
ePIC


NOTICE
COVER MUST
BE ON
WHEN
OKERED ON
DOC.:
zurek@anl.
5.34

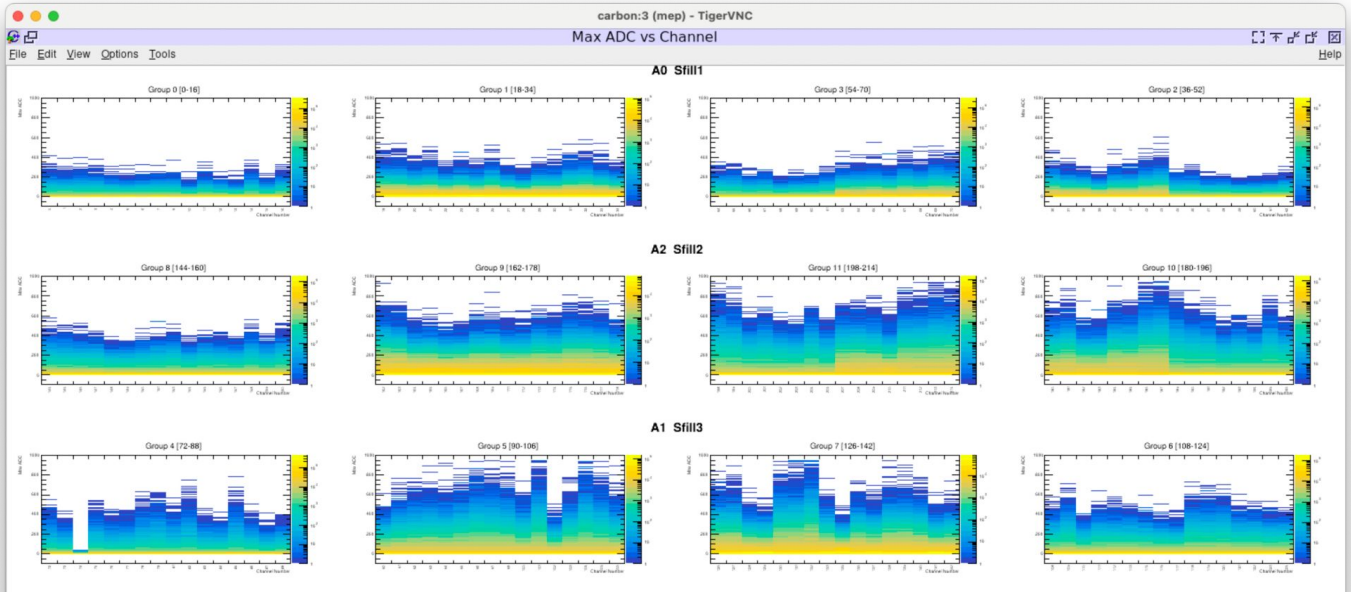

CAUTION
NOTICE
NOTICE
ePIC


TRG B
TRG A

First look into the data

HGCROC - SFILs with beam

beam

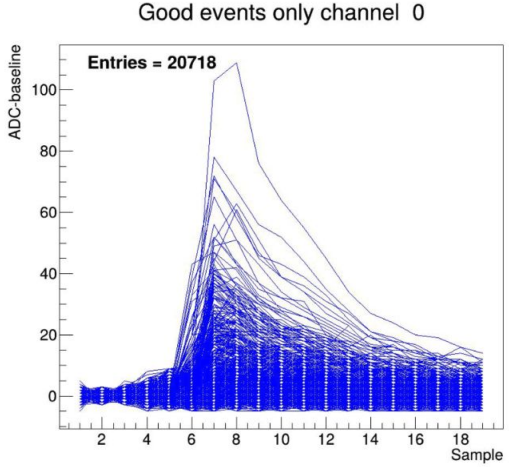


Akshaya Vijay

First look into the data

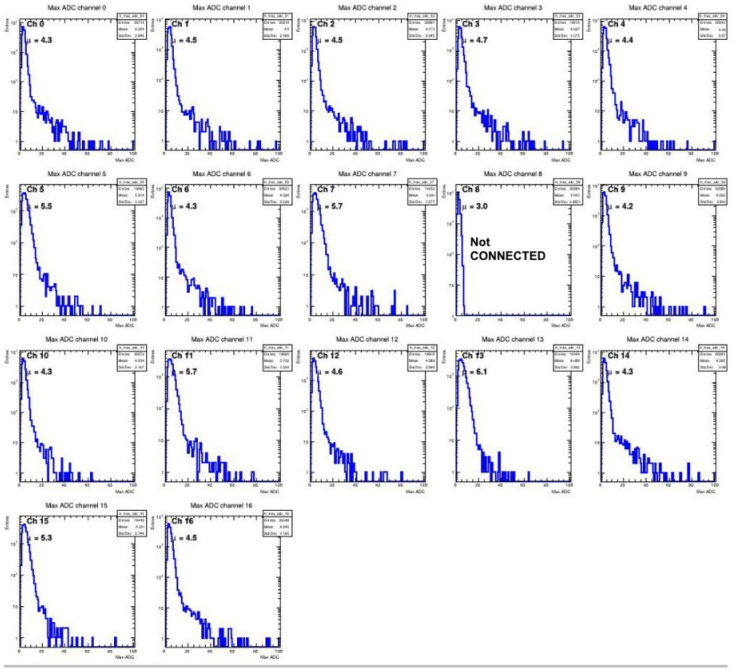
HGCROC - SFILs with cosmics (beam geometry trigger paddles)

Run # : 530,597,636,685,686,687



Events quality cut:

- a positive pulse amplitude (max ADC≥0),
- no large negative ADC(min ADC ≥ -5),
- and a pulse peak occurring within (5 ≤ s_max ≤ 17).

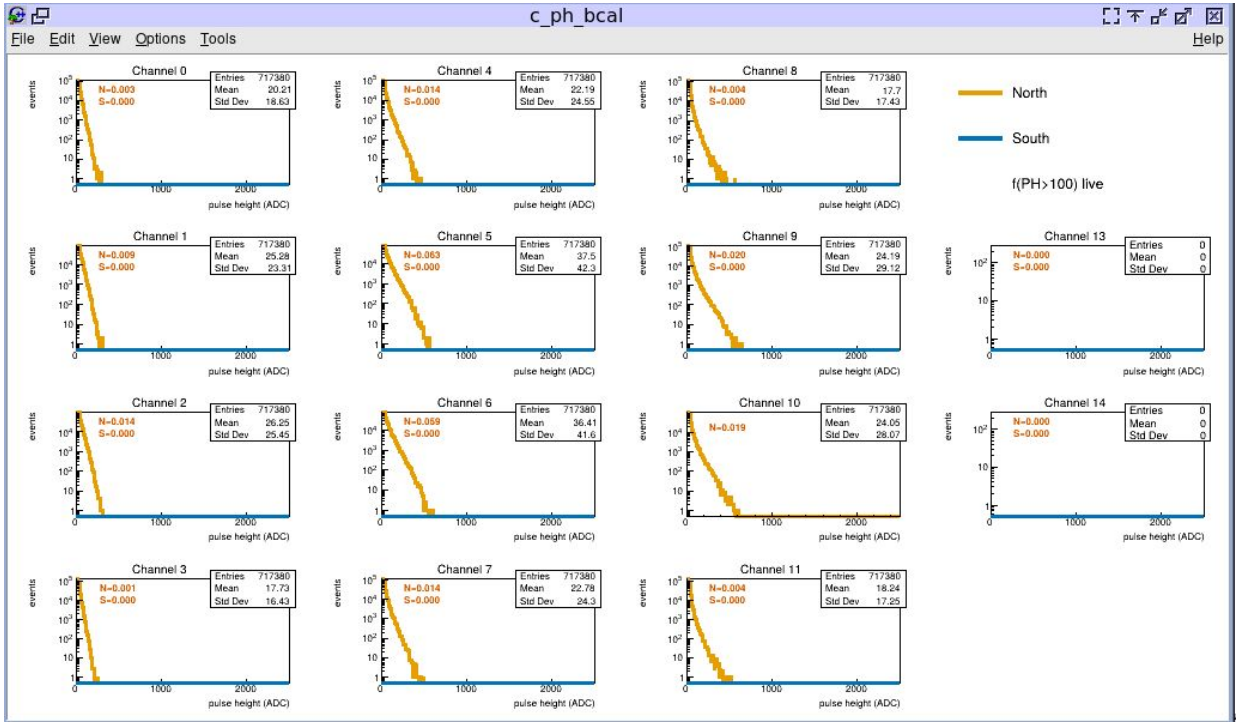


1 SiPM array example, SFIL 1, close to the trigger paddle

First look into the data

Baby BCAL

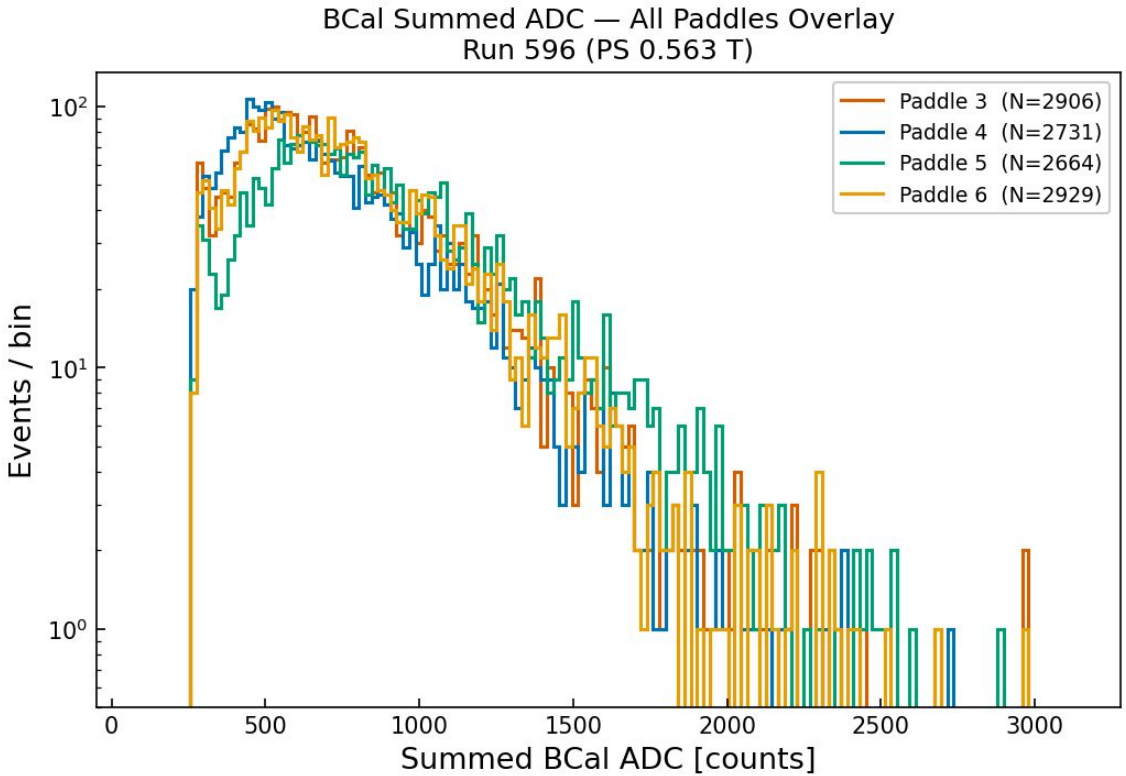
beam



Henry Klest

First look into the data

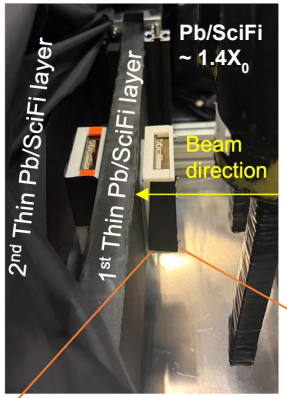
Baby BCAL

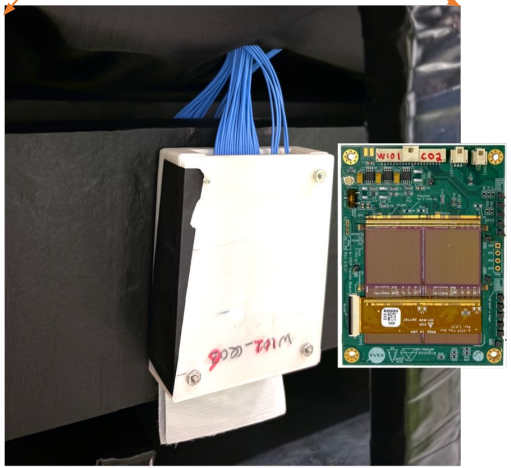


Trig 3	0.55	+- 0.01 GeV
Trig 4	0.48	+- 0.01 GeV
Trig 5	0.68	+- 0.02 GeV
Trig 6	0.57	+- 0.01 GeV

First look into the data

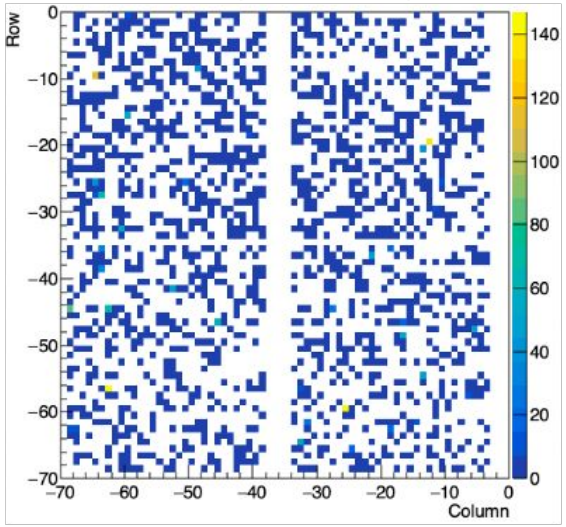
AstroPix: 1st layer of Astropix quad-chip

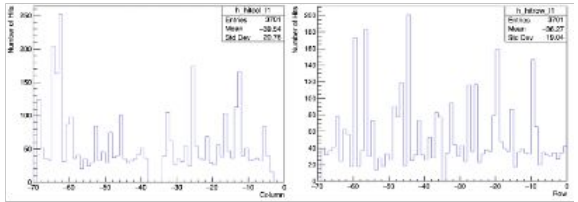




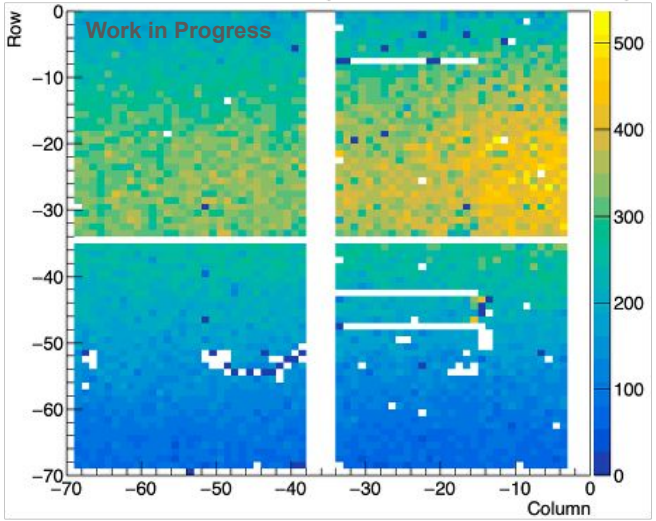
- Two Quad-chips + A-STEP (Astropix multichip/multilayer prototype readout system)
  - ✅ confirmed the stable operation up to ~1.2 kHz beam rate at KEK beam test last year; **promising stable operation under Hall D beam conditions.**

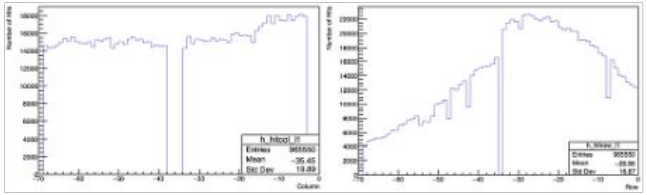
- No beam (cosmic run)





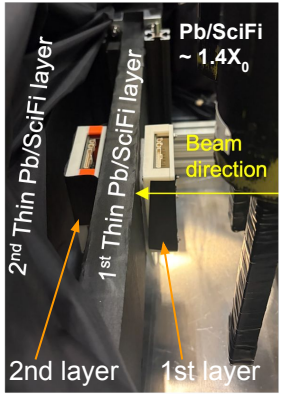
- Run1318 – 1324 (Total 61,416 events)





First look into the data

AstroPix: Two-layer of Astropix quad-chips

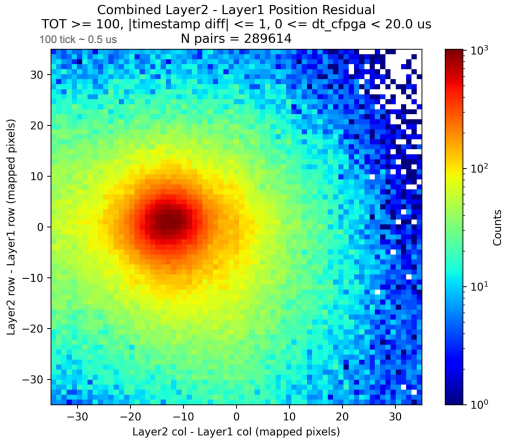


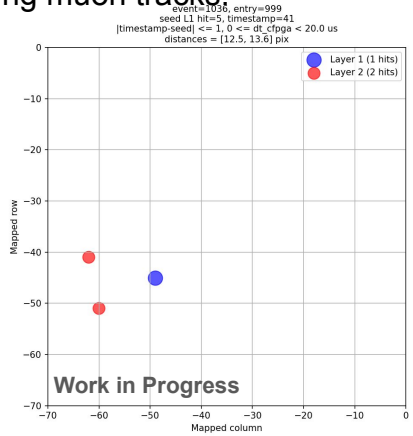
Applied cut

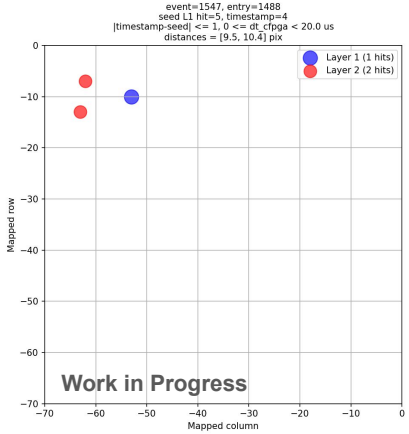
- Selected Layer-1 seed hits with ToT > 0.5 μs (100 tick) due to reduce noise
- Matched Layer-2 hits with $|\Delta$AstroPix timestamp$| \leq 1$ (sharing AstroPix timestamp clock among all AstroPix layers)
- Required $0 \leq \Delta$FPGA timestamp< 20 μs

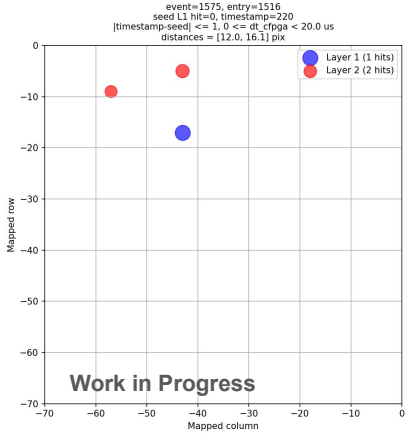
Example position residual plot and event display plots

- The observed **~6 mm offset of col** is attributed to both the parasitic beam trajectory and the relative misalignment of the AstroPix layers.
  - The relative misalignment between the AstroPix layers can be corrected through software alignment using muon tracks.





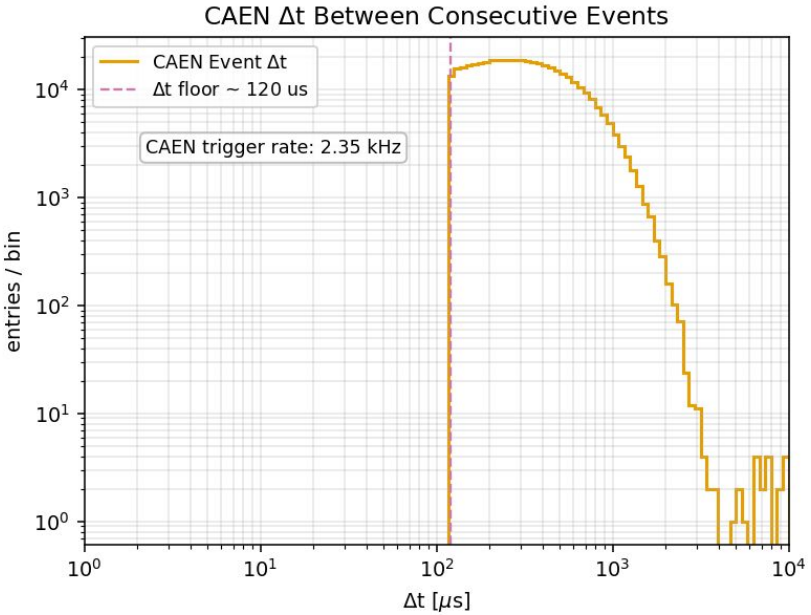


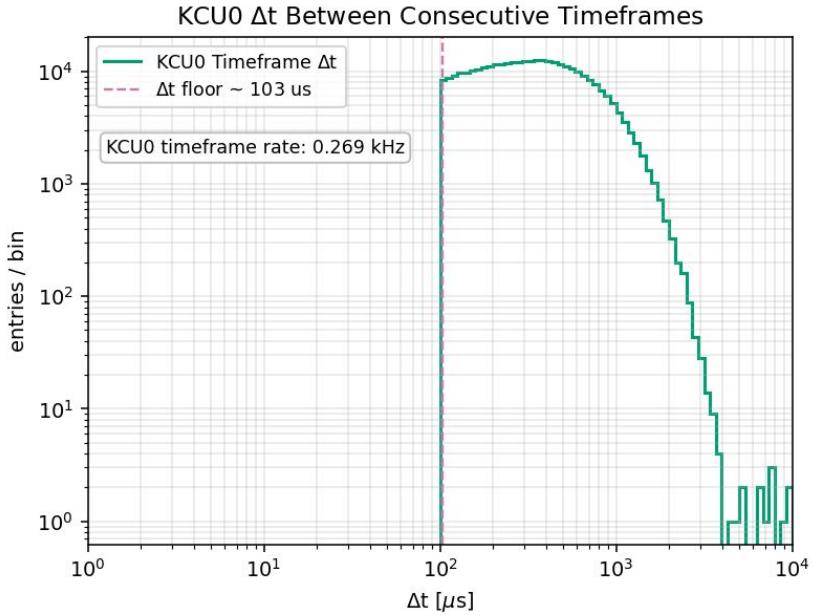


First look into the data

Synchronization

Operating in a region with non-negligible deadtime, so cannot match events using pure event number





First look into the data

Synchronization

Operating in a region with non-negligible deadtime, so cannot match events using pure event number

Information available to assist with cross-system matching:

- CAEN, KCU0, KCU1, AstroPix FPGA timestamps
- “Real-time” clock corresponding to event arrival time at PC (large jitter)
- Precise 10 Hz pulser triggering CAEN and KCU readout (empty event signature)
- Energy deposit patterns and total deposited energy (as cross-checks)

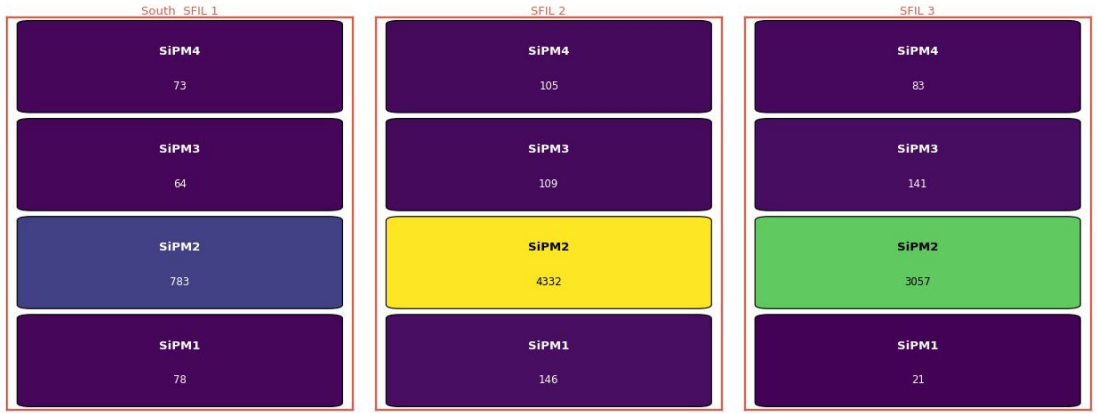
Need to do a fit of “shifting” and “squeezing” event timelines to maximize the number of matching events, output from the fit is ratio of FPGA clock speeds and initial run-start offsets

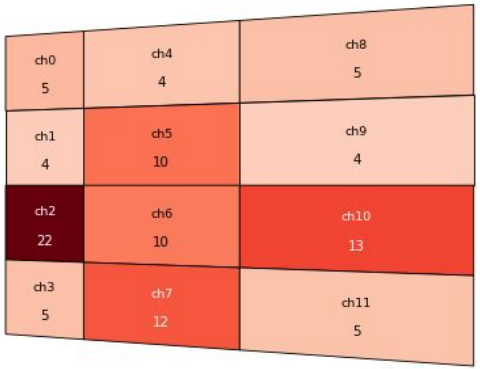
First look into the data

Synchronization

Candidate matched event display, shower in SFIL and tail in Baby BCal

500 MeV e





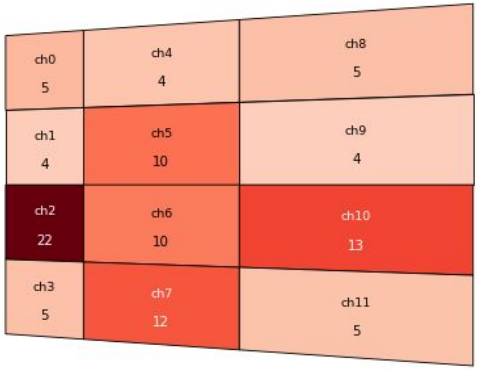
SFIL SiPMs are summed together in this display, but all 16 sub-array channels are available

First look into the data

Synchronization

Candidate matched event display, shower in SFIL and tail in Baby BCal

500 MeV e



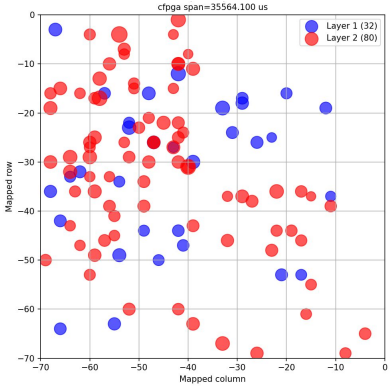
First look into the data

AstroPix Sync

- Key Considerations for Synchronization
  - FPGA timestamp clocks: 160 MHz for H2GCROC (6.25 ns/tick) and 40 MHz for AstroPix (25 ns/tick)
  - Common 40 MHz external clock distributed to both independent DAQ systems
  - Different readout architectures
    - SFIL + H2GCROC: external-triggered event-based readout
    - AstroPix: self-triggered streaming readout
  - Time alignment between DAQ systems
    - FPGA timestamp offset
    - Trigger and buffering latency differences

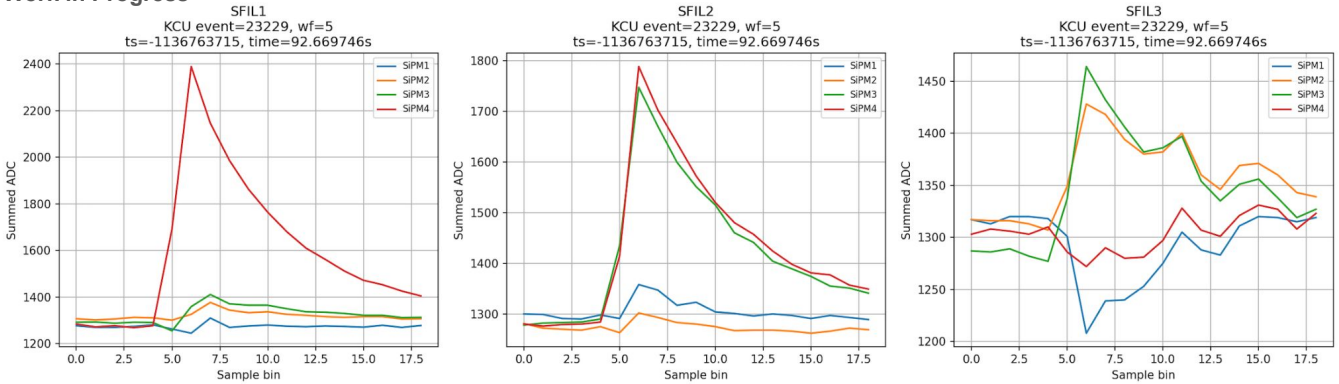
- FPGA timestamps converted to acquisition time and validated against the overall data-taking duration
- Example plots: Candidate AstroPix event block (~35 ms) and a selected KCU0 waveform from three SFILs
- Ongoing work: timing corrections for true event coincidence matching

Work in Progress

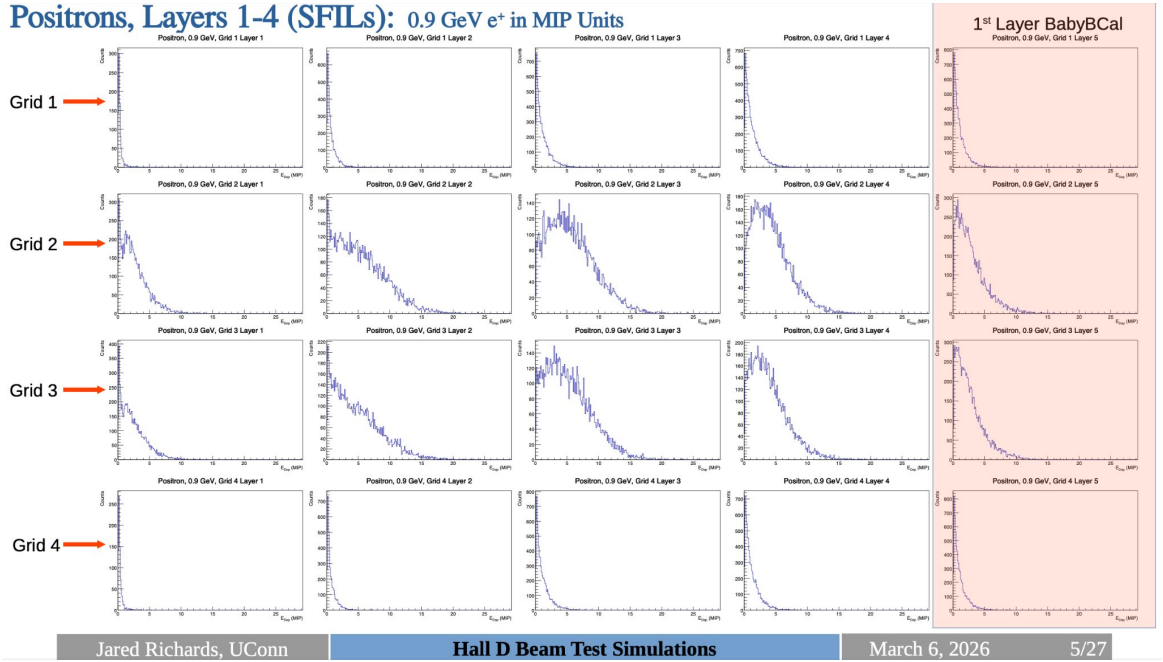


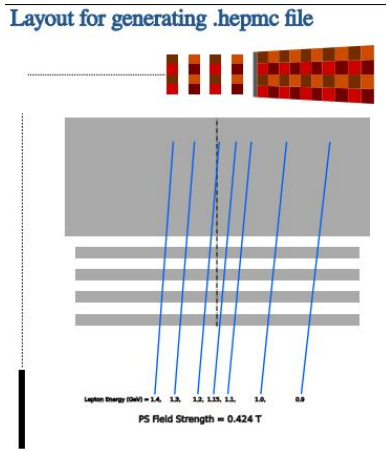
+

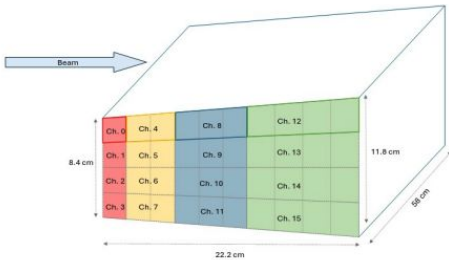
Work in Progress



Simulations





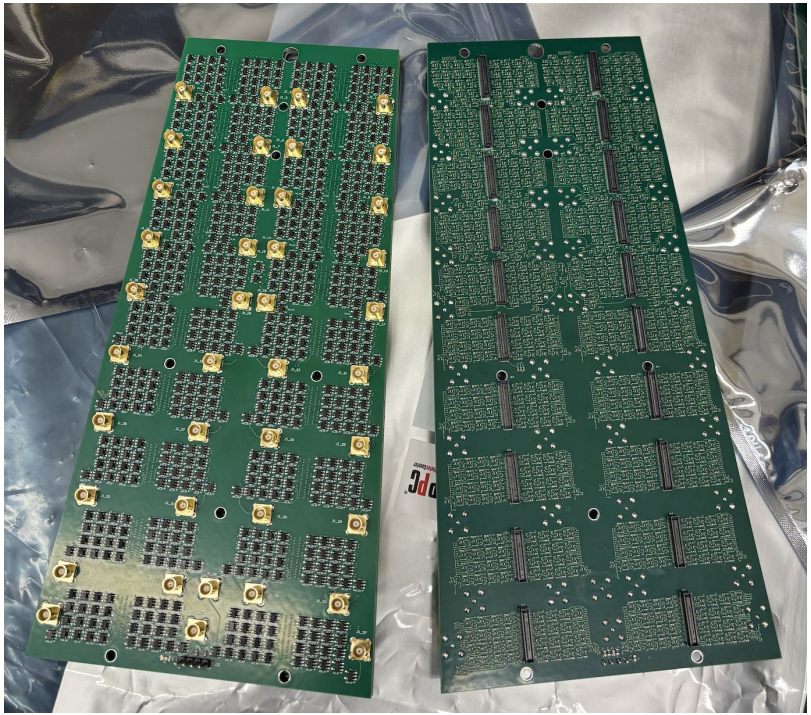


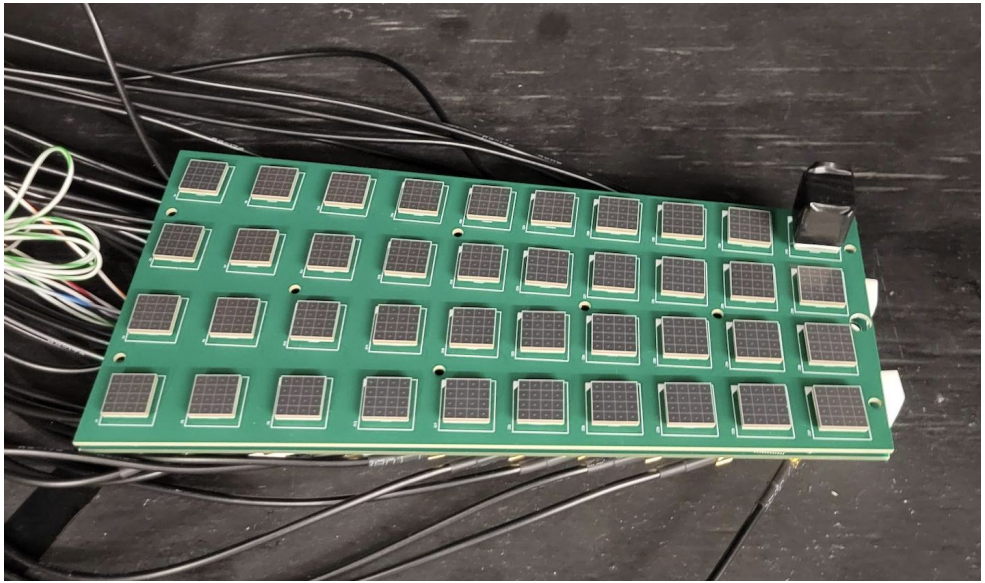
Adjustments ongoing based on detailed setup metrology

Summary and next steps

- A major logistics and integration push was completed for the Hall D beam-test setup and readout commissioning
- The setup is substantially new compared to previous tests:
  - mechanically, it is a completely new configuration
  - from the readout point of view: first beam tests of HGCROC with BIC test articles
  - DAQ fully independent from the GlueX DAQ
  - all readout components integrated into RCDAQ
- The setup has been successfully assembled, commissioned, and is now stored in Hall D until the August beam test
- The electronics are back at ANL and ORNL for SiPM summing-board tests before August
- The SFIL-related electronics are in hand and available for these tests
- The Baby BCAL SiPM board is also expected to be available for the August beam test
- Overall, the key infrastructure and commissioning steps are in place, positioning us well for the August run

New Baby BCAL boards (URegina)





Backup

ePIC Requirements for BIC

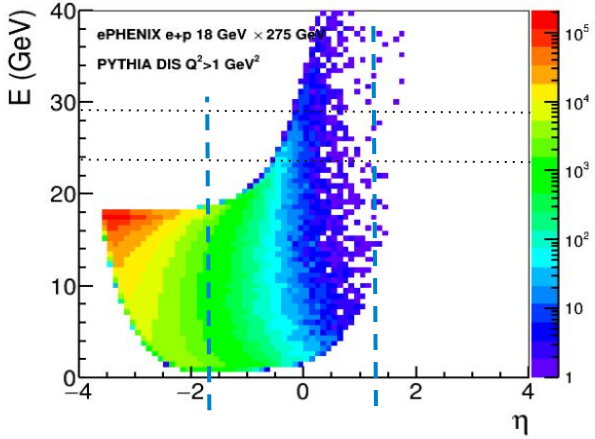
Identify scattered electrons and measure their energy, in high Q^2 events, also decay electrons, e.g. from vector or heavy flavor meson decays, and to measure DVCS photons and decay photons (G-DET-ECAL-BAR.16.10.05)

- **Electron ID up to 50 GeV and down to 1 GeV** and below (F-DET-ECAL-BAR.16.10.05)
- Energy resolution **< 10%/√(E) + (2-3)%** (P-DET-ECAL-BAR.16.10.05)
- High power for **e/π separation down to 1 GeV/c** (P-DET-ECAL-BAR.26.10.05)
- **Photon measurements up to 10 GeV** (F-DET-ECAL-BAR.26.10.05)
- **γ/π^0 separation up to 10 GeV** (F-DET-ECAL-BAR.36.10.05)
  - Distinguishing two showers with opening angle down to 30 mrad (P-DET-ECAL-BAR.36.10.05)

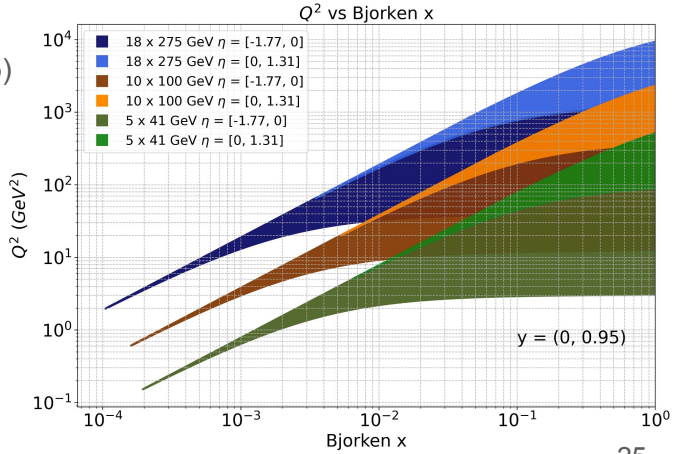
Assist with muon identification (G-DET-ECAL-BAR.36.10.05)

Sufficient dynamic range to **detect MIP** signals in all layers (P-DET-ECAL-BAR.56.10.05)

DIS electrons

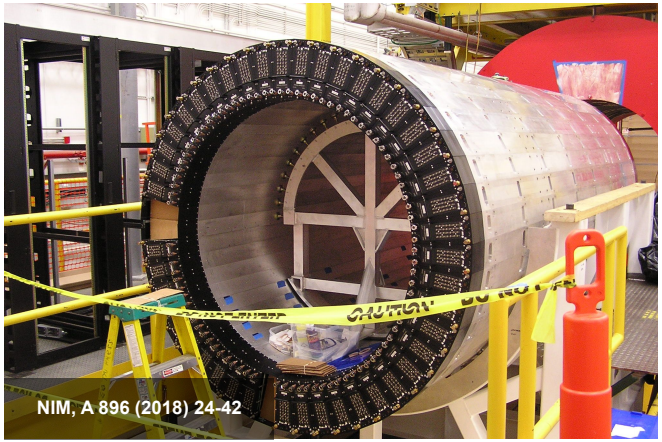


BIC x-Q^2 coverage



A Novel Hybrid Imaging Calorimeter

Combination of a high-performance sampling calorimeter with silicon sensors for shower profiling



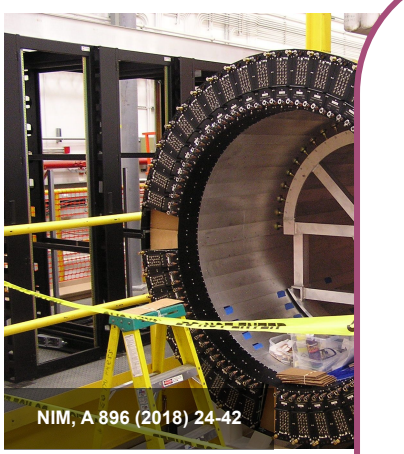
Start from mature layered Pb/ScFi technology with side-readout (same as the GlueX calorimeter) for state-of-the-art sampling calorimeter performance

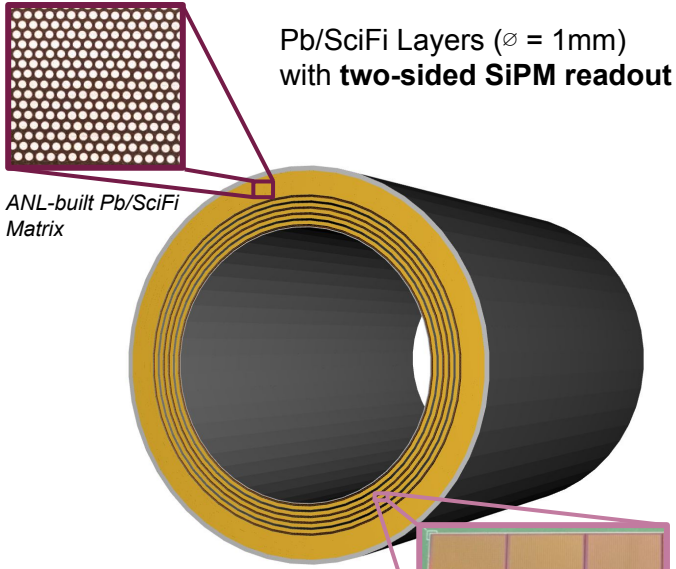
Insert layers of monolithic AstroPix sensors (ultra-low-power silicon sensor developed for NASA) in the first half of the calorimeter to capture a 3D image of the developing shower

455-cm long, 80-120cm radially, US$23M, ~40 metric tons

A Hybrid Imaging Calorimeter

Combination of a high-performance sampling calorimeter with silicon sensors for shower profiling





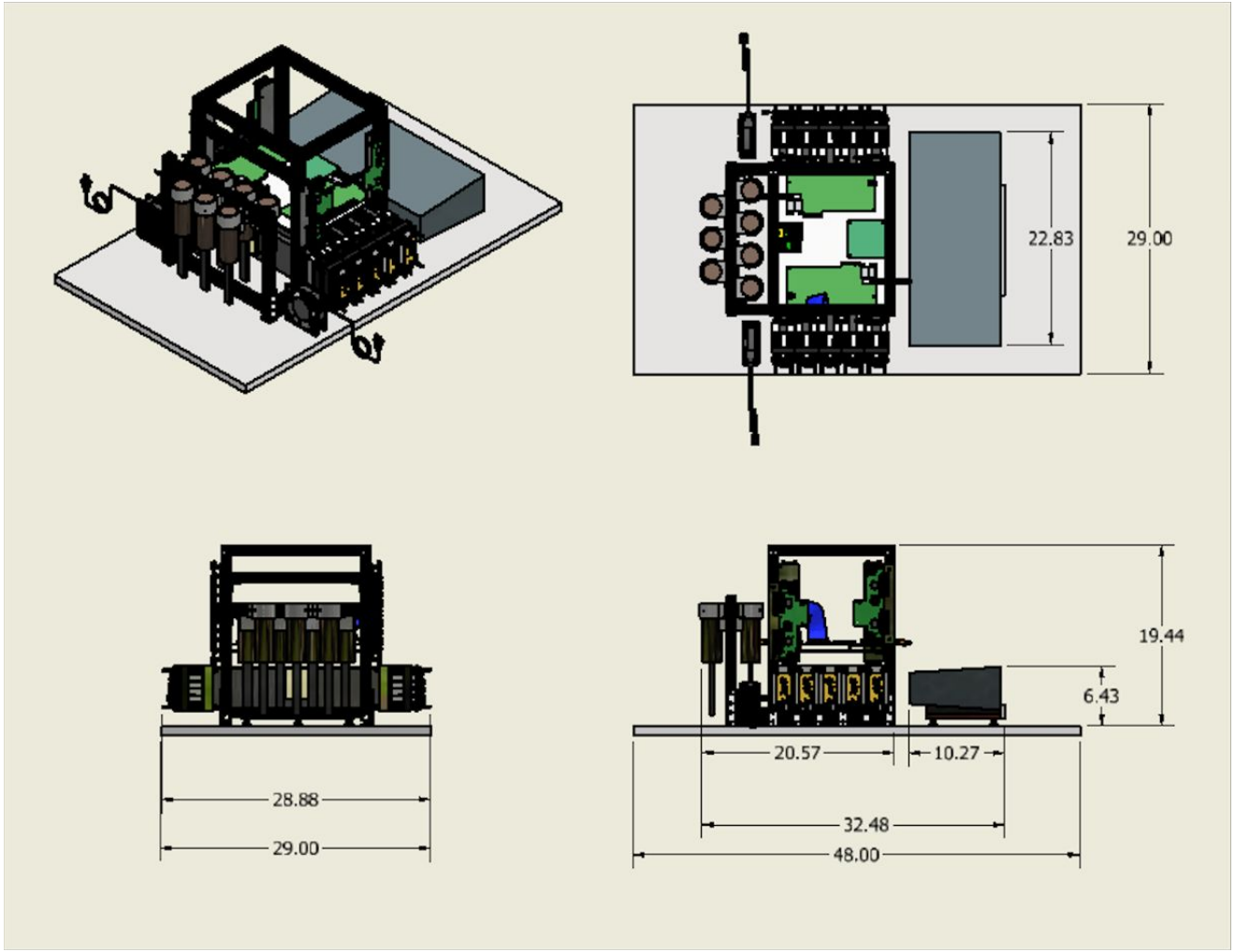
Barrel Imaging Calorimeter

Footprint

LxWxH
35”x30”x20”

Adjustable table by JLab

Weight: < 300 pounds (fully loaded)



Beam Test Schedule

Past beam tests with Baby BCAL: Hall D (2023), FNAL (2024)

Week	date	Energy	Left arm (tracking)	Right arm (CAL)
W1	March 30	Low	BIC	HAll-D HiCAL
W2	April 8	Low	BIC	HAll-D HiCAL
W3	April 15	Low	BIC	HAll-D HiCAL
W4	April 22	Low	MPGD	HAll-D HiCAL
W5	April 29	Low	MPGD	HAll-D HiCAL
W6	May 6	Low	MPGD	MOLLER
W7	May13	Low	TRD/ FPGA	MOLLER
W8	May 20	Low	Short week / SWITCH TO HIGH ENERGY	MOLLER
W9	May 27	Low	SWITCH TO HIGH ENERGY	SWITCH TO HIGH ENERGY
W10	June 3	Low	Short week/ SWITCH TO HIGH ENERGY	SWITCH TO HIGH ENERGY
W11	June 10	High	HALL-D TRD	HALL-D TAG-M
W12	June 17	High	HALL-D TRD	HALL-D TAG-M
W13	June 24	High	HALL-D TRD	HALL-D TAG-M
W14	July 1	High		CRYTOR
W15	July 8	High		CRYTOR
W16	July 15	High		CRYTOR
W17	July 22	High	LUMI	HAll-D HiCAL
W18	July 29	High	LUMI	EEECAL
W19	Aug 5	High	BIC	EEECAL
W20	Aug 12	High	BIC	EEECAL
W21	Aug 19	High	SVT/MPGD	EEECAL
W22	Aug 26-Aug 30	High	SVT/ MPGD	

Beam Test Goals

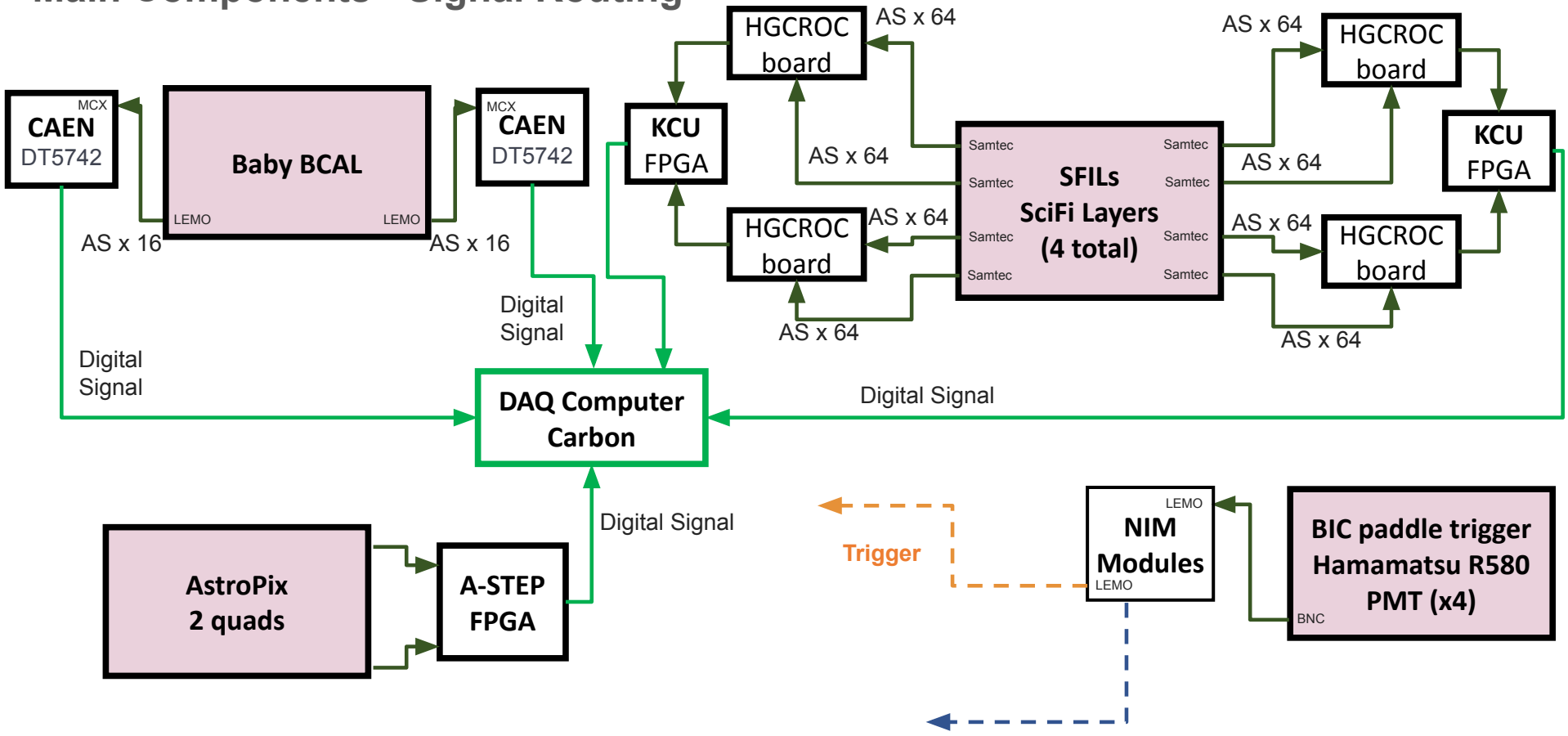
March (low energy):

- Commission for the first time the readout with HGCROC.
- Test synchronization between AstroPix and HGCROC readout.
- Benchmark low-energy response (~1 GeV) within the August Beam-Test dynamic range and full BIC Dynamic range.

August (high energy):

- Benchmark energy and timing resolution within 3-6 GeV energy range with full HGCROC readout and show shower imaging event by event.

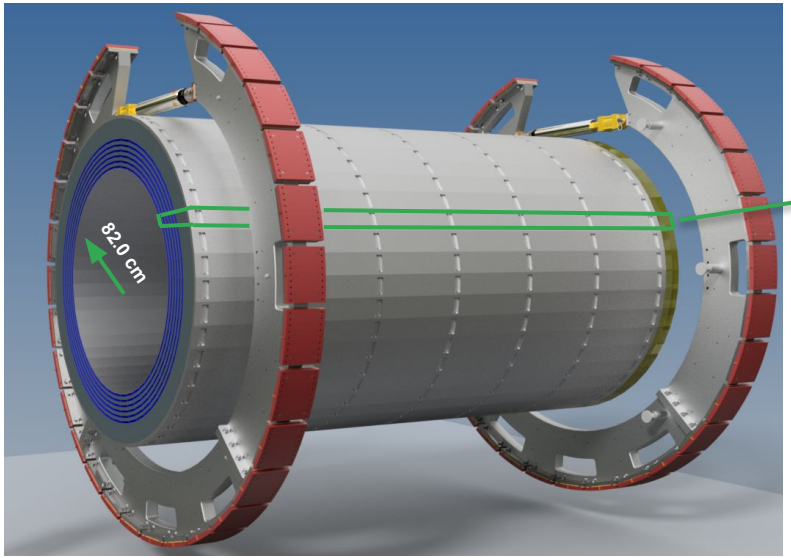
Main Components - Signal Routing



AS - Analog Signal
DS - Digital Signal

Barrel Imaging Calorimeter

Sector Mechanics

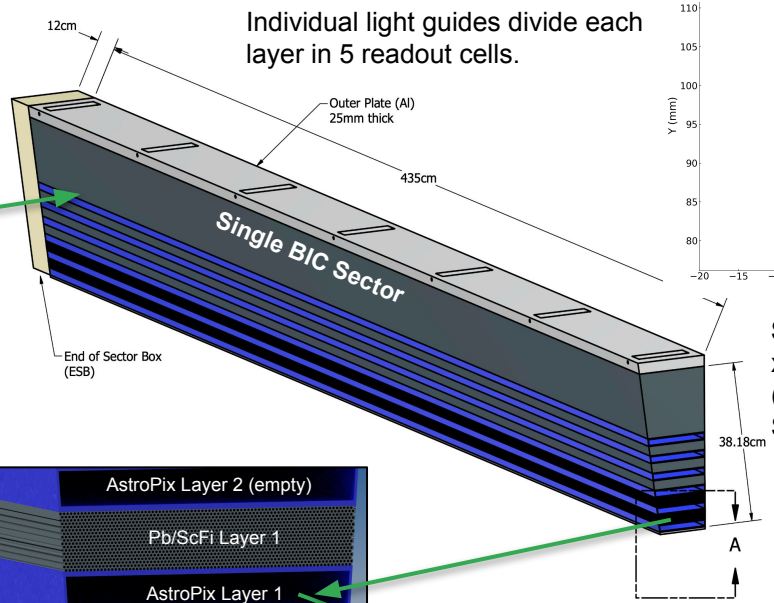


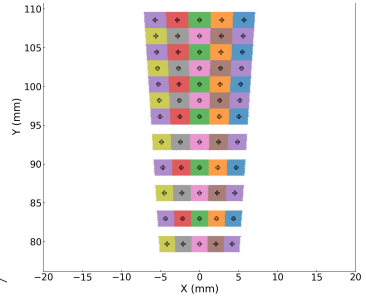
Total BIC weight ~42.5 US tons

Pb/SciFi Layers - 17 rows of fiber between corrugated lead.

Each sector has 12 Pb/ScFi layers.

Individual light guides divide each layer in 5 readout cells.



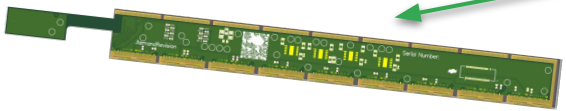


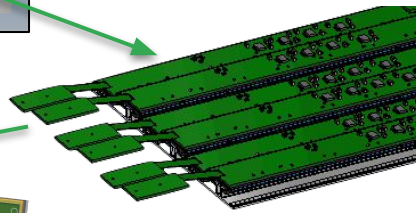
SiPMs - 5 per layer x 12 layers = 60 (Hamamatsu S14161-3050)

AstroPix Module - Nine AstroPix sensors daisy-chained together on Flex PCB.

A stave consists of 12 modules.

A tray contains of 6-8 staves.





Tray - Structure holding the AstroPix staves for a single layer (217.5 cm long).

Electrical Diagrams
Power supply channel and electrical outlets count

Summary of outlets, crates, etc

Crates/ Slots in Crates:

- Slots for 3 MPOD Modules (1 x ISEG 100 V power supply, 2 x Wiener 16 V power supplies) - close to the setup (platform). We can bring our own crate if needed.
- 1 Slot for the NIM Crate (NIM logic for trigger and HV supply for trigger paddles - HV Supply Bertan Model 365). We can bring our NIM crate or use the available one. Preferably upstairs.

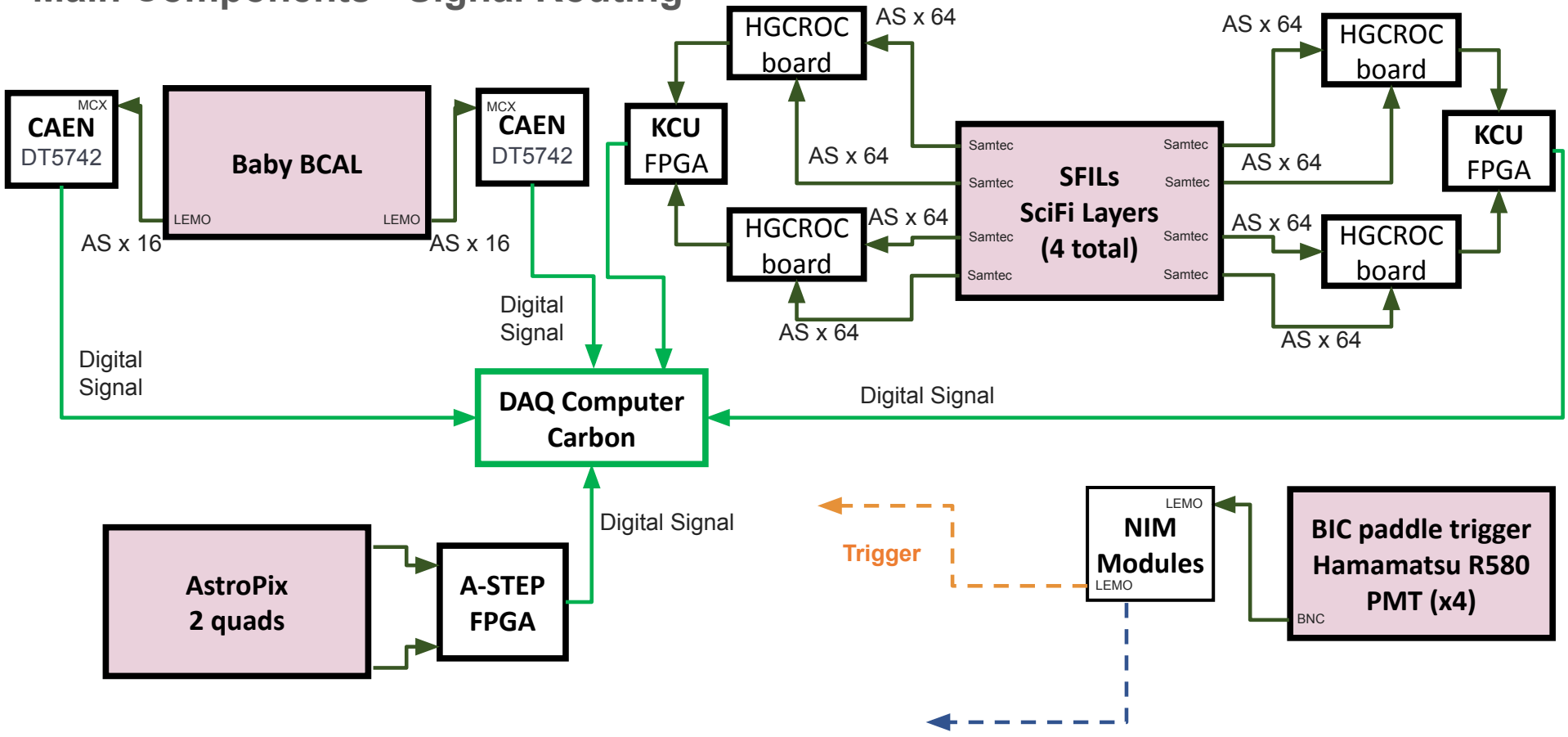
Remote controlled power strip slots:

- 2 outlets for CAEN DT5742 WF Digitizers
- 1 outlet for DAQ Computer
- 2 slots for KCU FPGA
- 1 outlet for WF Generator

Outlets/power strip slots:

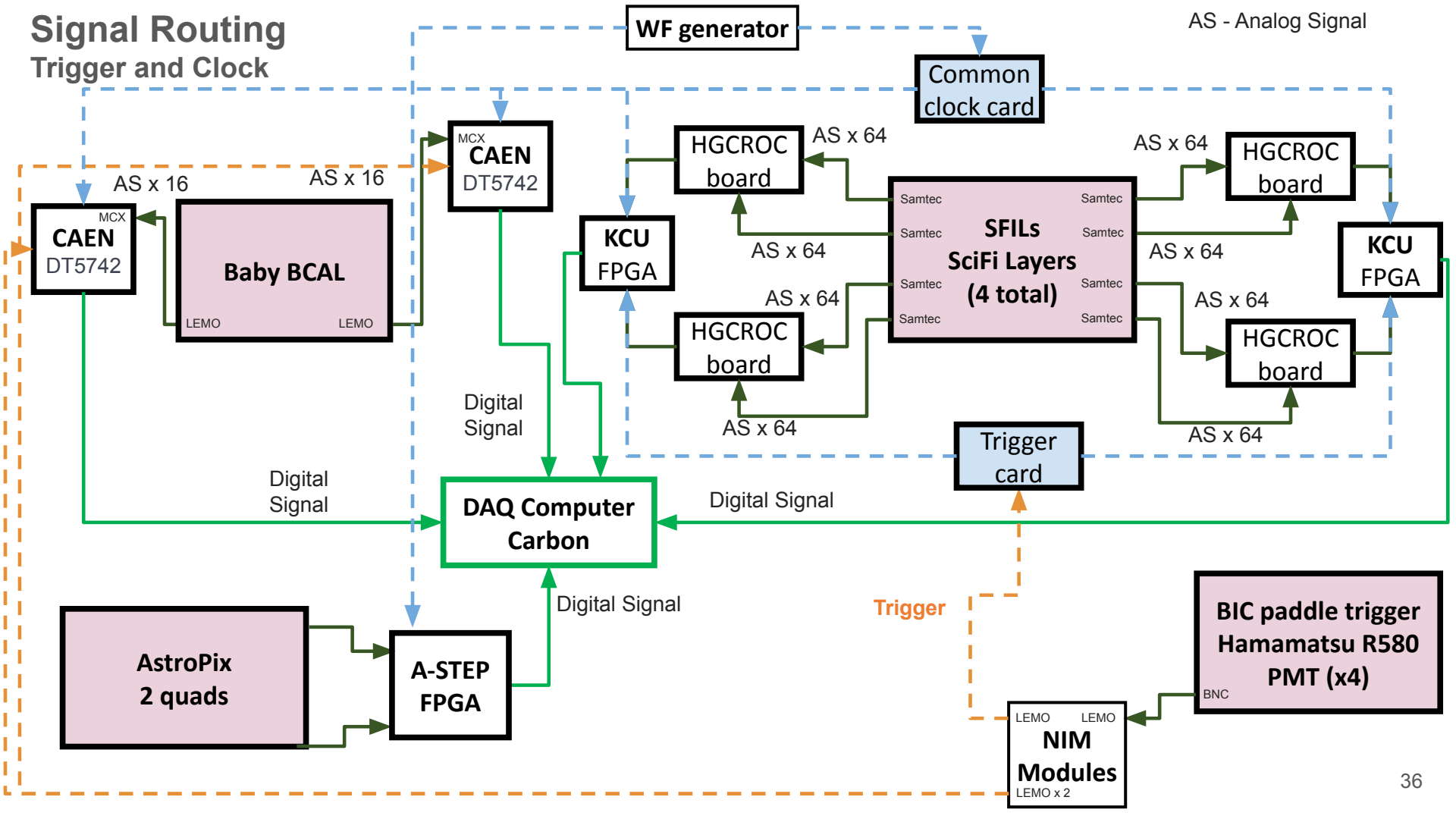
- 1 for the chiller (cooling)
- 4 for fans (cooling)
- 2 outlets for R&S Power Supplies NGA142
- 2 outlets for R&S Power Supplies HMP4040

Main Components - Signal Routing

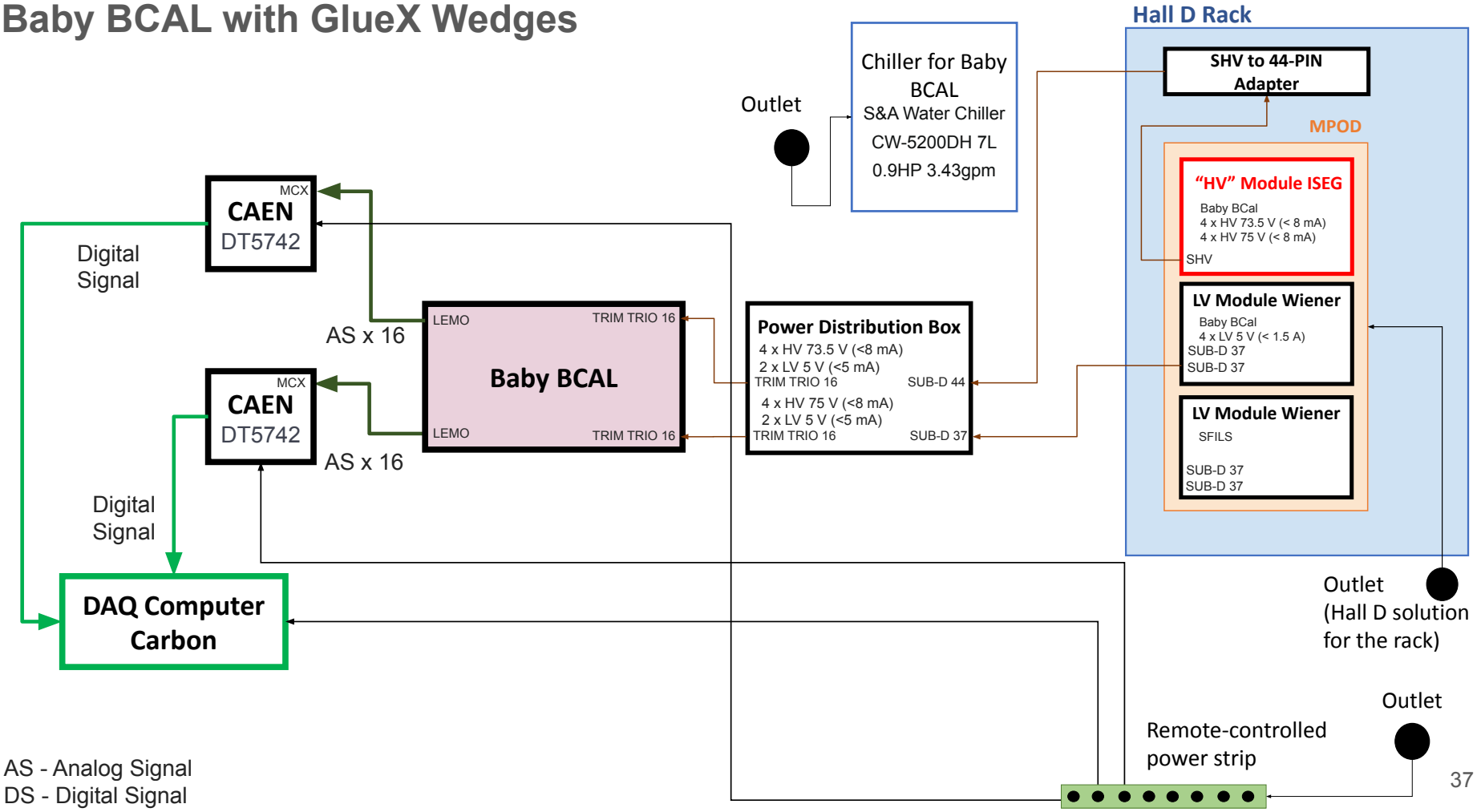


AS - Analog Signal
DS - Digital Signal

Signal Routing
Trigger and Clock

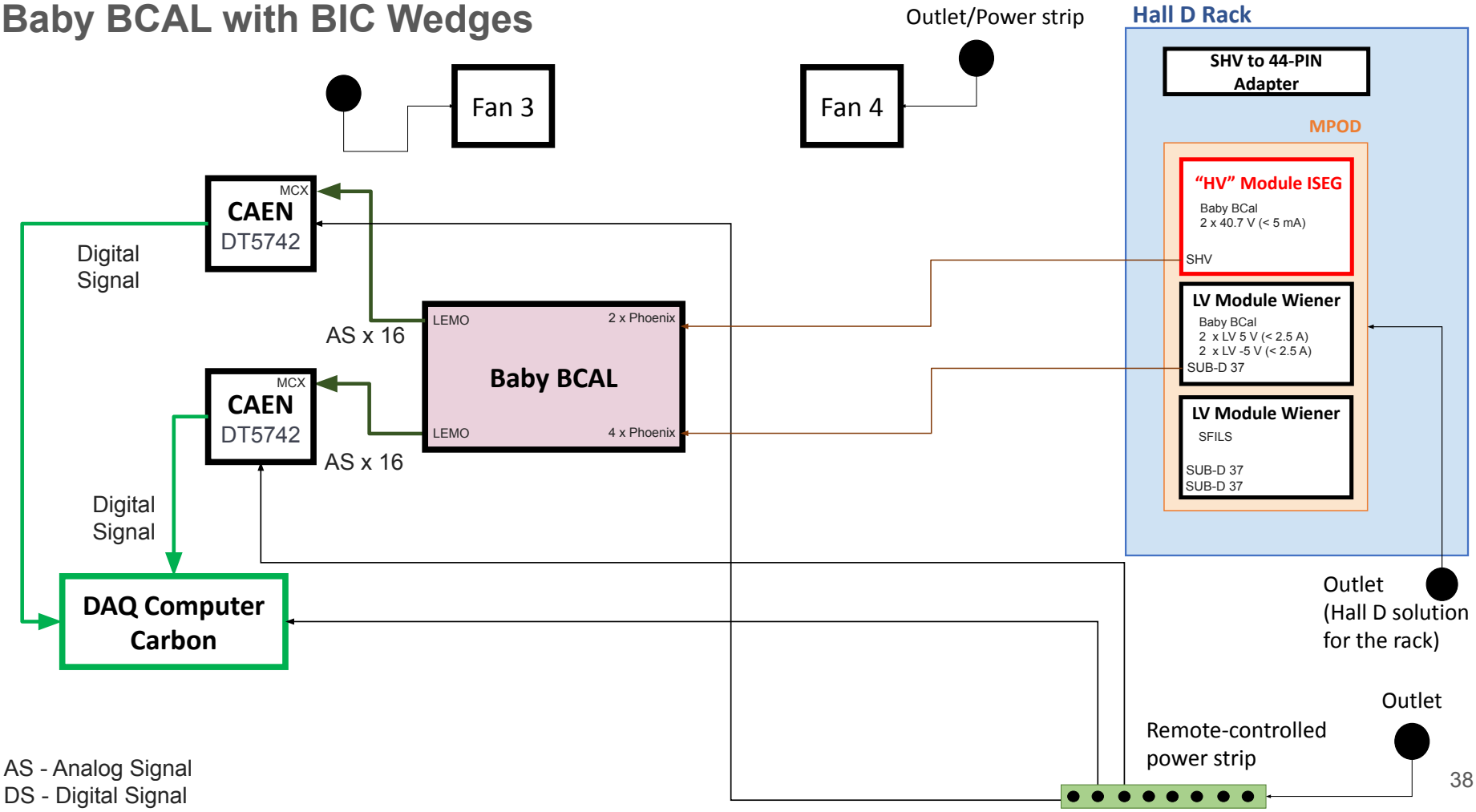


Baby BCAL with GlueX Wedges



AS - Analog Signal
DS - Digital Signal

Baby BCAL with BIC Wedges



AS - Analog Signal
DS - Digital Signal

Total Count - Baby BCAL

Outlets:

- 2 outlets for CAEN DT5742 WF Digitizers (Remote-controlled power strip)
- 2 outlets for fans
- 1 outlet for DAQ Computer (Remote-controlled power strip)
- 1 outlet for the chiller (I expect this will need to be in the wall outlet)
- 2 slots in MPOD crate for power supply modules or we can bring our own crate if no space in the existing one. (platform, limited by the power cable lengths - they are borrowed from GlueX)

Question to Andrew: What needs to be the wall outlet and what the power strip?

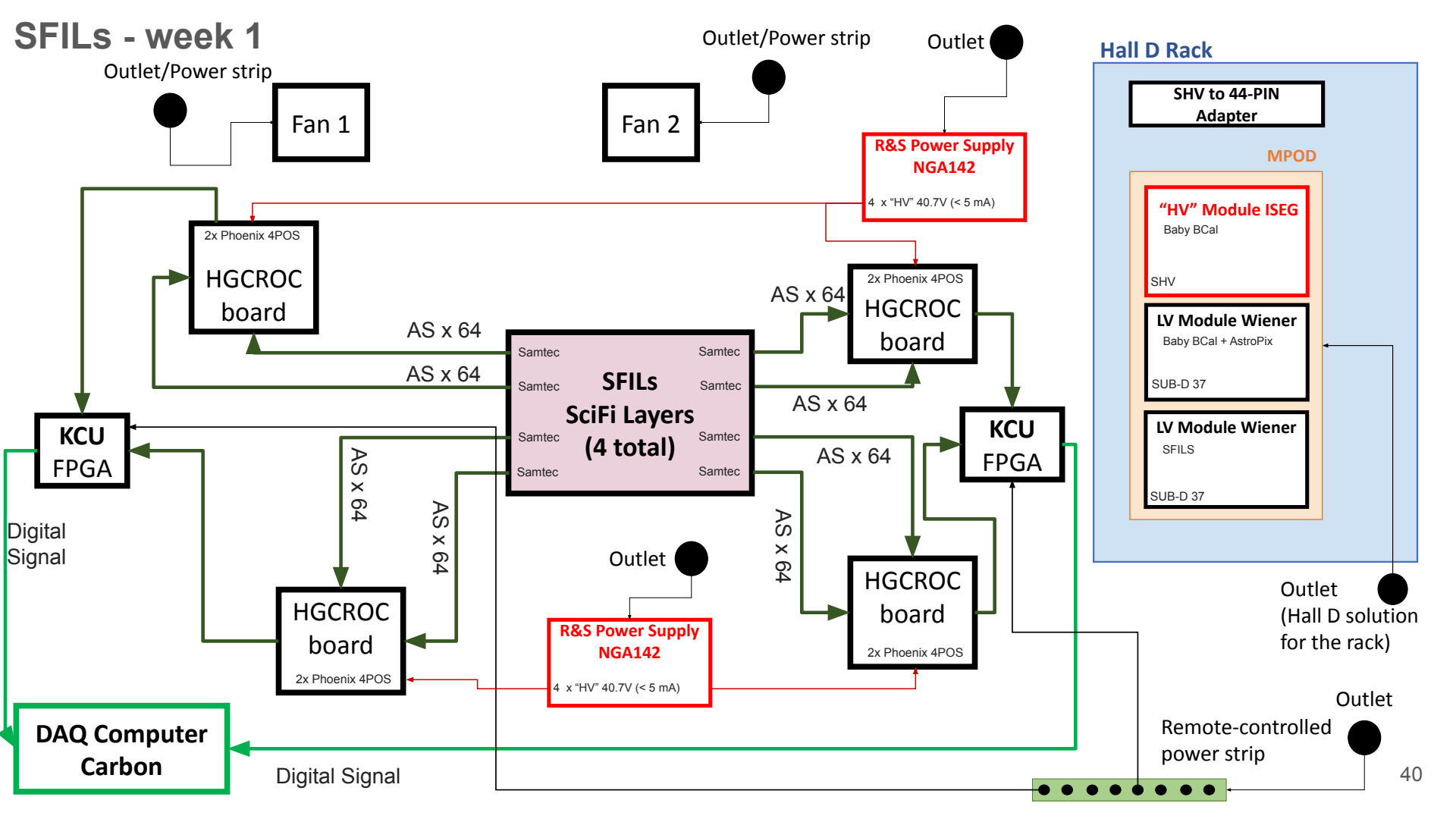
Power line count: (see the diagram on previous page)
GlueX Wedges (March)

- 8 x 75V (MPOD ISEG) - GlueX Cable
- 4 x 5V (MPOD Wiener) - GlueX Cable

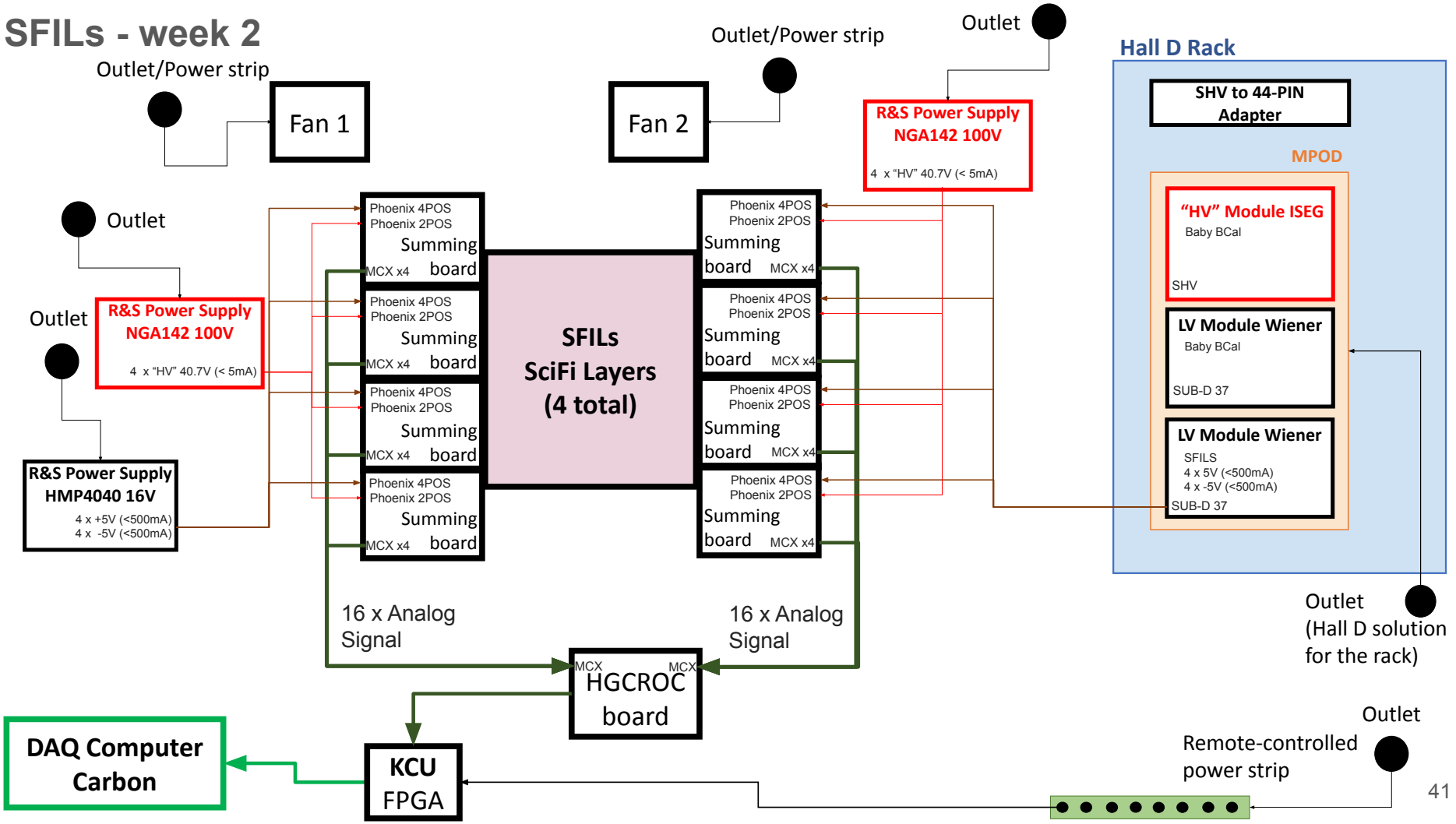
BIC Wedges (August)

- 2 x 40.7V (MPOD ISEG)
- 2 x 5V (MPOD Wiener)
- 2 x -5V (MPOD Wiener)

SFILs - week 1


Outlet/Power strip
Fan 1
Outlet/Power strip
Fan 2
Outlet
R&S Power Supply NGA142
4 x "HV" 40.7V (< 5 mA)
Hall D Rack
SHV to 44-PIN Adapter
MPOD
"HV" Module ISEG
Baby BCal
SHV
LV Module Wiener
Baby BCal + AstroPix
SUB-D 37
LV Module Wiener
SFILS
SUB-D 37
2x Phoenix 4POS
HGCROC board
AS x 64
AS x 64
SFILs SciFi Layers (4 total)
Samtec
AS x 64
AS x 64
KCU FPGA
Digital Signal
AS x 64
AS x 64
AS x 64
HGCROC board
2x Phoenix 4POS
Outlet
R&S Power Supply NGA142
4 x "HV" 40.7V (< 5 mA)
Outlet (Hall D solution for the rack)
Outlet
Remote-controlled power strip
DAQ Computer Carbon
Digital Signal

SFILs - week 2


Outlet/Power strip
Fan 1
Outlet/Power strip
Fan 2
Outlet
R&S Power Supply
NGA142 100V
4 x "HV" 40.7V (< 5mA)
Hall D Rack
SHV to 44-PIN
Adapter
MPOD
"HV" Module ISEG
Baby BCal
SHV
LV Module Wiener
Baby BCal
SUB-D 37
LV Module Wiener
SFILS
4 x 5V (<500mA)
4 x -5V (<500mA)
SUB-D 37
Outlet
Outlet
R&S Power Supply
NGA142 100V
4 x "HV" 40.7V (< 5mA)
R&S Power Supply
HMP4040 16V
4 x +5V (<500mA)
4 x -5V (<500mA)
Phoenix 4POS
Phoenix 2POS
Summing
board
MCX x4
SFILs
SciFi Layers
(4 total)
16 x Analog
Signal
16 x Analog
Signal
MCX
MCX
HGCROC
board
DAQ Computer
Carbon
KCU
FPGA
Outlet
(Hall D solution
for the rack)
Outlet
Remote-controlled
power strip

Total Count - SFILs

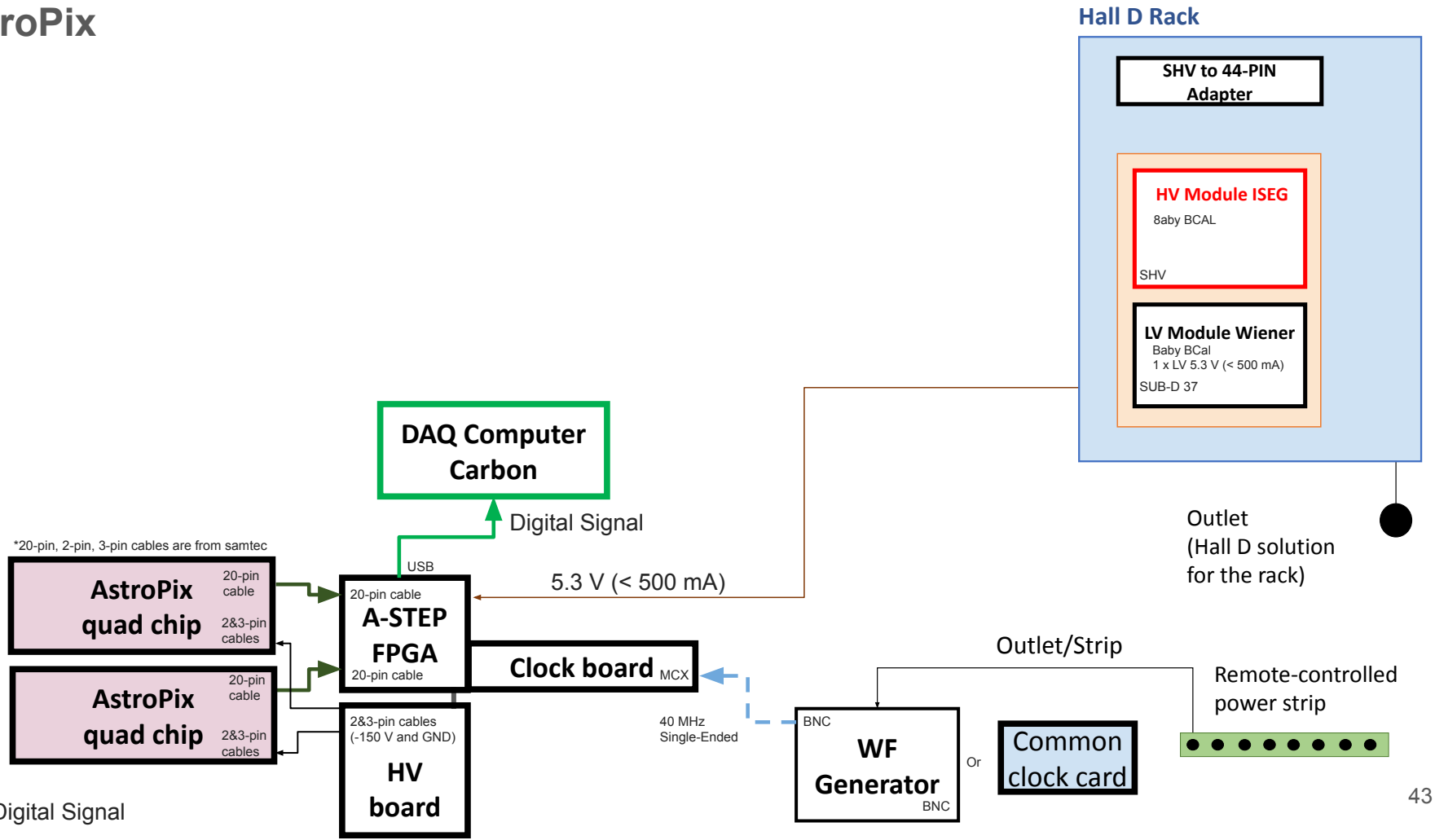
Outlets:

- 2 outlets/slots in power stip for 2 fans (cooling)
- 2 slots for KCU FPGA (remote controlled strip)
- 1 slot in MPOD crate for LV power supply modules or we can bring our own crate if no space in the existing one. (platform)
- 2 outlets for R&S Power Supplies NGA142
- 1 outlet for R&S Power Supply HMP4040

Power line count: (see the diagram on previous page, max from 2 setups is taken)

- 8 x +5V (MPOD Wiener, 8 ch power supply) - Summing boards
- 8 x -5V (R&S HMP4040, 4 ch power supply) - Summing boards
- 8 x 40.7V (2 x R&S NGA142, 2 ch power supply) - SiPM bias

AstroPix



DS - Digital Signal

Total Count - AstroPix

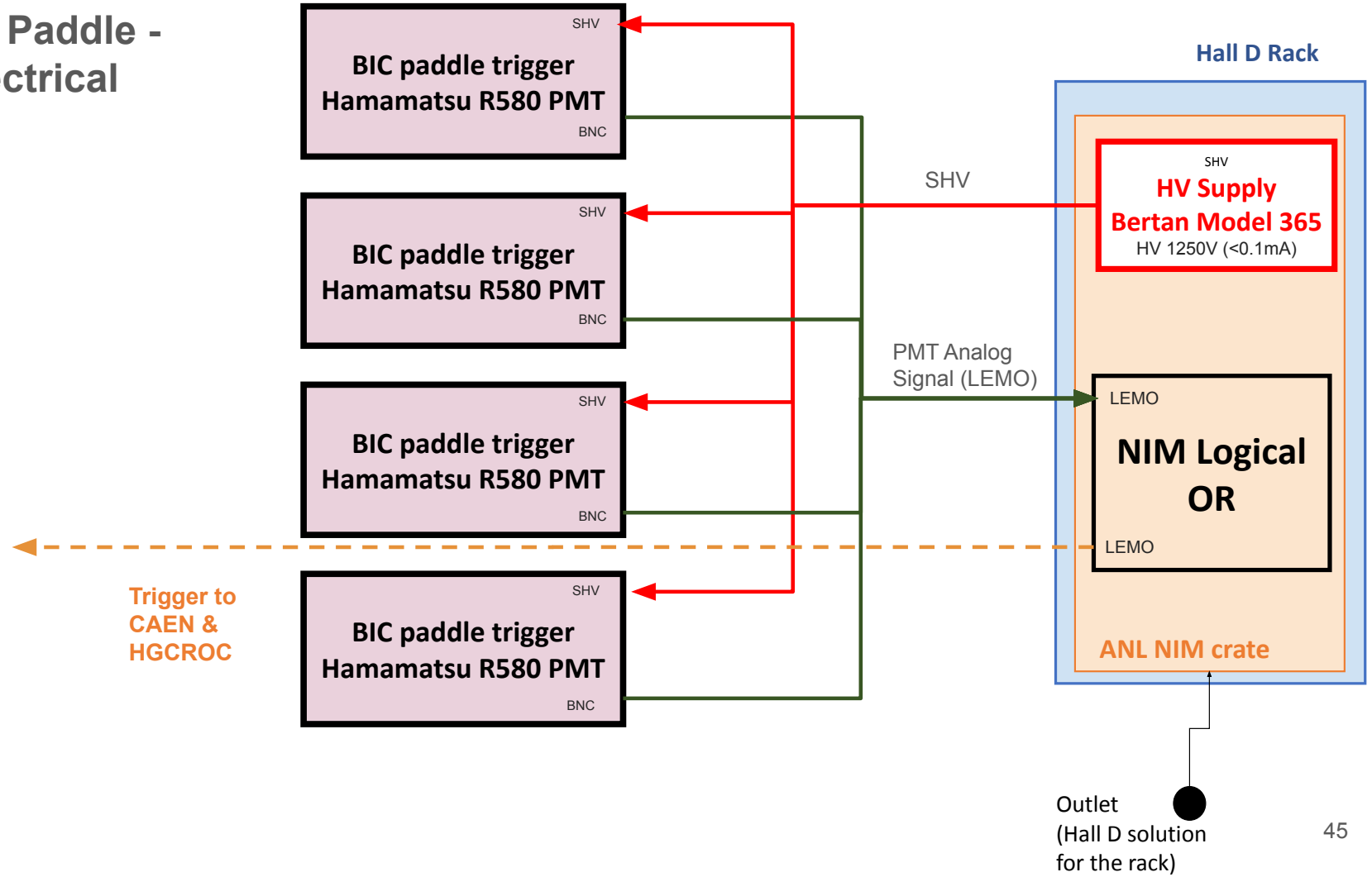
Outlets:

- 1 outlet for WF Generator (Remote-controlled power strip)
- Same MPOD LV Module as for Baby BCAL

Power line count: (see the diagram on previous page)

- 1 x 5.3V (MPOD Wiener)

Trigger Paddle - Full Electrical



Total Count - Trigger

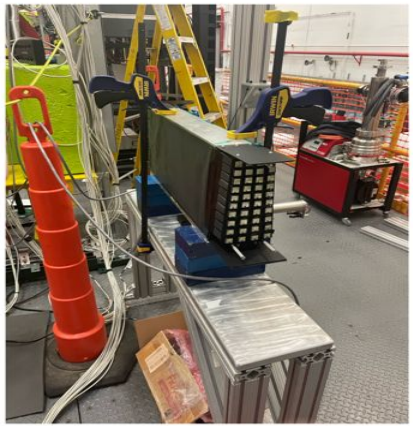
Crates/Outlets:

- 1 Slot for the NIM Crate (NIM logic for trigger and HV supply for paddles - HV Supply Bertan Model 365)

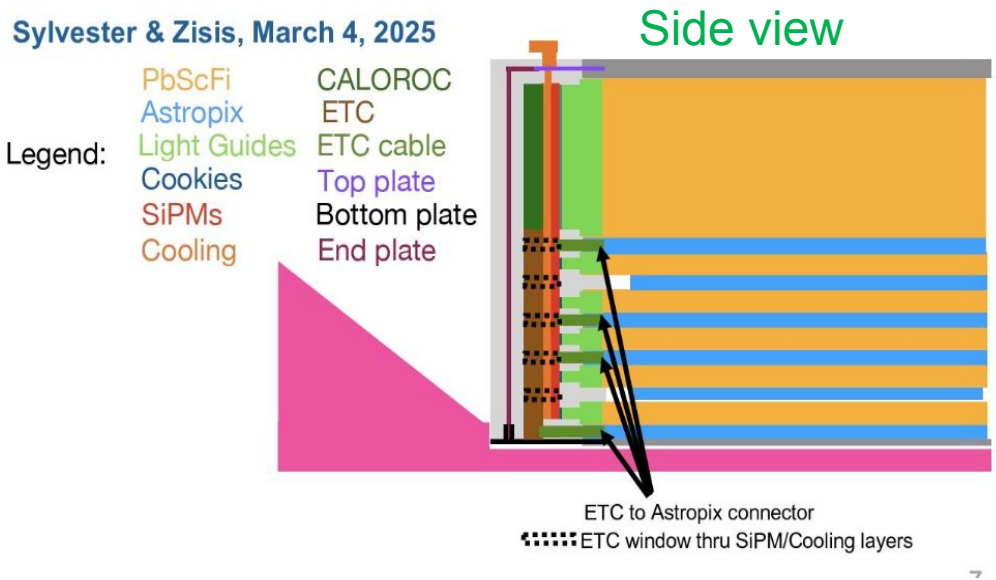
Power line count: (see the diagram on previous page)

- 4 x HV 1250V (<0.1mA)

Hall D Setup - Beam Tests 2023

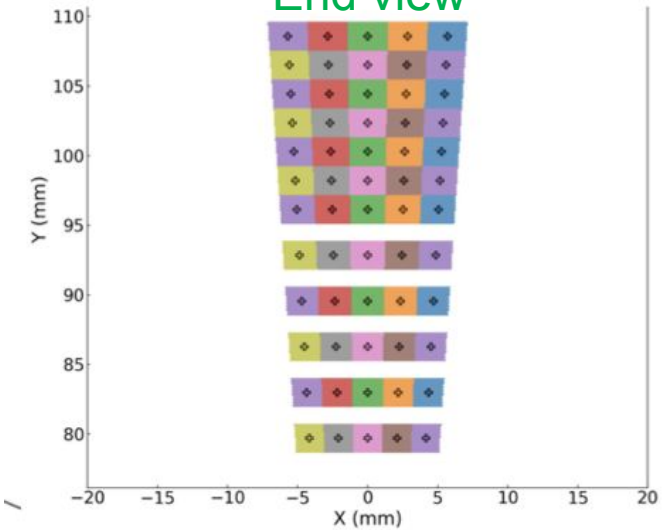


Overview of the BIC Sci/Fi readout



Side view

End view



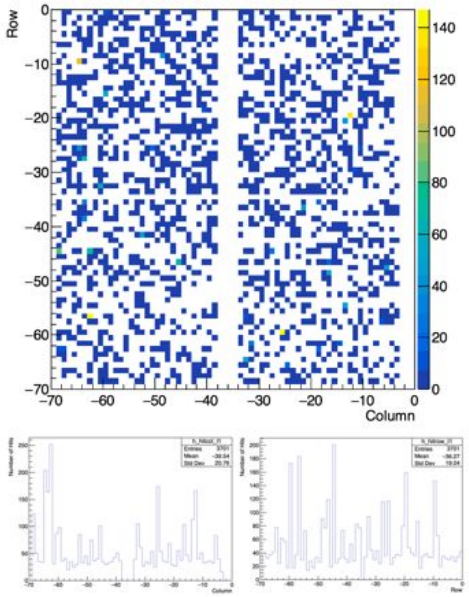
The Sci/Fi layers have lightguides with a SiPM 4x4 arrays at the end.
In one sector there are:

- 12 layers of SciFi; 5 columns; In total 60 x (4x4 3x3mm^2 array)
- Signals from individual SiPM's are summed

Design for Baby BCAL now, BIC design will follow

Hall D Beam Test: Beam profile measurement

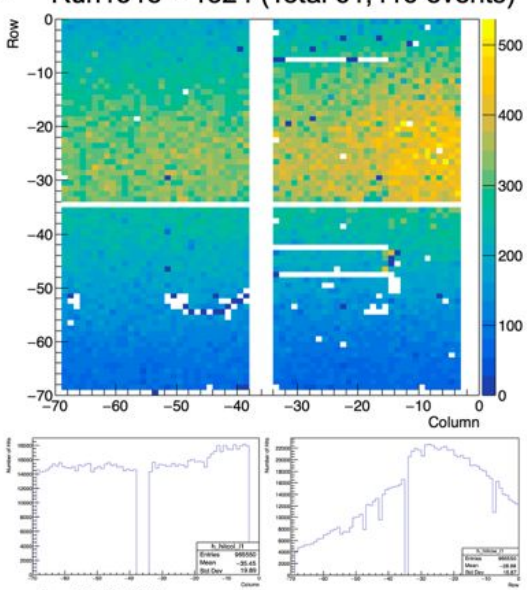
- No beam (cosmic run)



Run 1181-1191 (No beam (cosmic run))

- Expected cosmic-muon statistics: ~1,300 muons in a 4 cm×4 cmsensor over 2 h 44 min (~ $1\ \mathrm{cm^{-2}\ min^{-1}}$, $\cos^2\theta$ distribution).

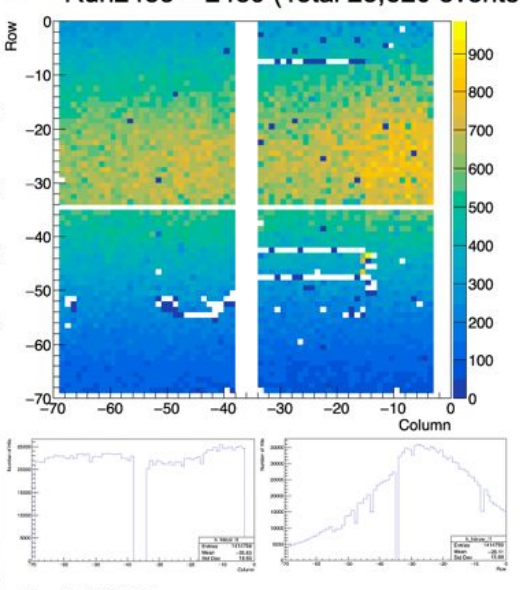
- Run1318 – 1324 (Total 61,416 events)



Run 1318-1324

- Hit map over 2 hours 20 mins of data-taking (5/13 6:45~9:06 AM)
  - ~ 100.6 Hz per matched hit
- <I> = 17.89~26.06 nA
- PS field: 0.190 T (~100A setting)
- Rad: JD70-107 55um 45/135 deg
- PSrad: HOME (out of beam) @ 0.000 mm
- TPOL: C (Be ~750μm?) @ 101.667 mm

- Run2483 – 2489 (Total 23,520 events)



Run 2483-2489

- Hit map over 47 mins of data-taking (5/28 20:37~21:24)
  - ~ 100.6 Hz per matched hit
- <I> = 27.97~35.56 nA
- PS field: 0.244 T (~100A setting)
- Rad: JD70-107 55um 45/135 deg
- PSrad: HOME (out of beam) @ 0.000 mm
- TPOL: C (Be ~750μm?) @ 101.667 mm