GEn-RP Status & Summary

A report on the work performed thus far and planned for the GEn-RP GEM stacks. Includes a final status summary of the current state of the setup

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1 GEn-RP Cosmic Runs

1.1 GEn-RP GEM Cosmic Stand

The GEn-RP polarimeter consists of 3 separate "stacks" of GEMs:

- Inline stack: 8 total GEM layers.
  - 2 INFN Layers (3 GEM modules each)
  - 6 UVa XY Layers (4 GEM modules each)
- Right Polarimeter: 2 UVa UV Layers (1 Layer = 1 GEM module)
- Left Polarimeter: 2 UVa UV Layers (1 Layer = 1 GEM module)

The following is a schematic drawing of the experimental layout of the GEn-RP SBS setup.

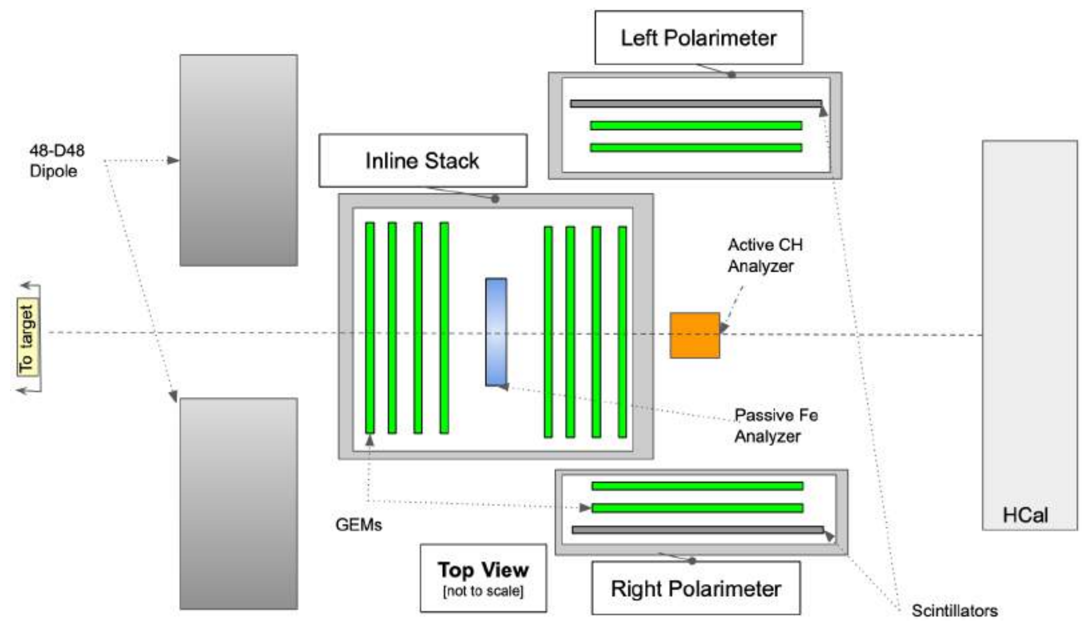


Figure 1: Drawing of the GEn-RP setup for the SBS

In order to more easily and directly get data across all the GEM layers simultaneously while the setup is situated in EEL 125 this nominal setup has been rearranged such that the 3 stacks are "lined up". The inline stack is in effect sandwiched between the left and right polarimeters, as shown below.

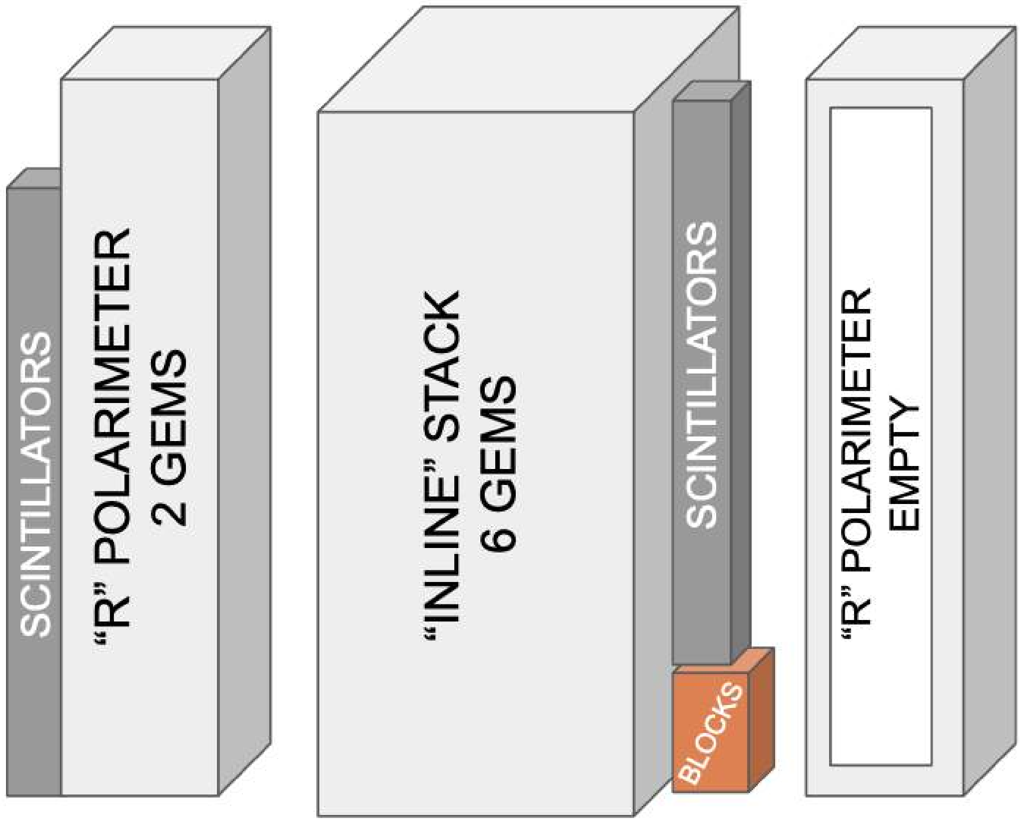


Figure 2: Drawing of the GEn-RP stacks lined up.

Given the current, partially completed, status of the GEM layers for the Left Polarimeter, those layers are not currently installed in the Left Polarimeter Stack frame. Therefore, even though the Left Polarimeter Stack weldment is physically in place and in line with the Right Polarimeter and Inline Stacks, it contains no GEM layers and is not within the acceptance area of the scintillators used for triggering cosmics. The two INFN GEM layers are also not currently installed onto the Inline Stack. The status of those layers and the estimates of those timelines can be referenced in Section 5.2.

The scintillators used for triggering cosmics in this setup do not fully cover the active area of a single GEM layer. They approximately cover the area of 3 GEM modules in a single layer. For instance, The length of all 4 GEM modules in a single layer is a bit over 2 meters while the length of the scintillators are about 1.5 meters. In order to acocomadate this and increase our acceptance coverage and trigger efficiency the scintillators have been biased such that one side "elevated" up on blocks and thus sits higher than the other side of scintillators. This can be seen in figure 2 and the photos that follow. The effects of this coverage mis-match can be seen in the hitmaps.

1.2 Physical DAQ and Gas System Setup

In total the GEn-RP setup will require a total of 78 MPDs. This will require four VME crates that each contain MPD 20 slots (apart from one crate which can only operate 19 slots due to the requirement of a TS module). These MPDs will then be fed into two VXS crates. The current GEn-RP GEM Cosmic Stand in EEL 125 consists of the following equipment:

- 2 VXS Crates: both enabled to handle up to 40 fibers.
- 3 VME Crates: Currently installed with 56 MPDs.

Figure 3: The 3 GEn-RP stacks in line with each other. From left to right: Right Polarimeter, Inline Stack, Left Polarimeter (EMPTY).

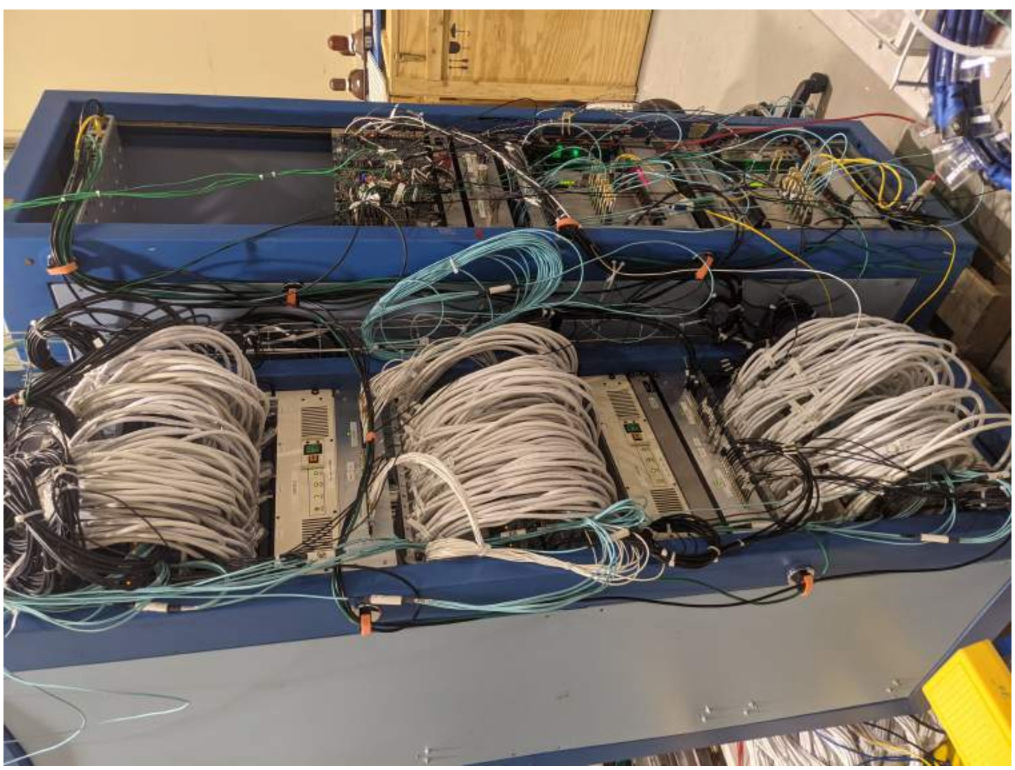


Figure 7: Two racks containing the DAQ equipment for the GEn-RP stacks.

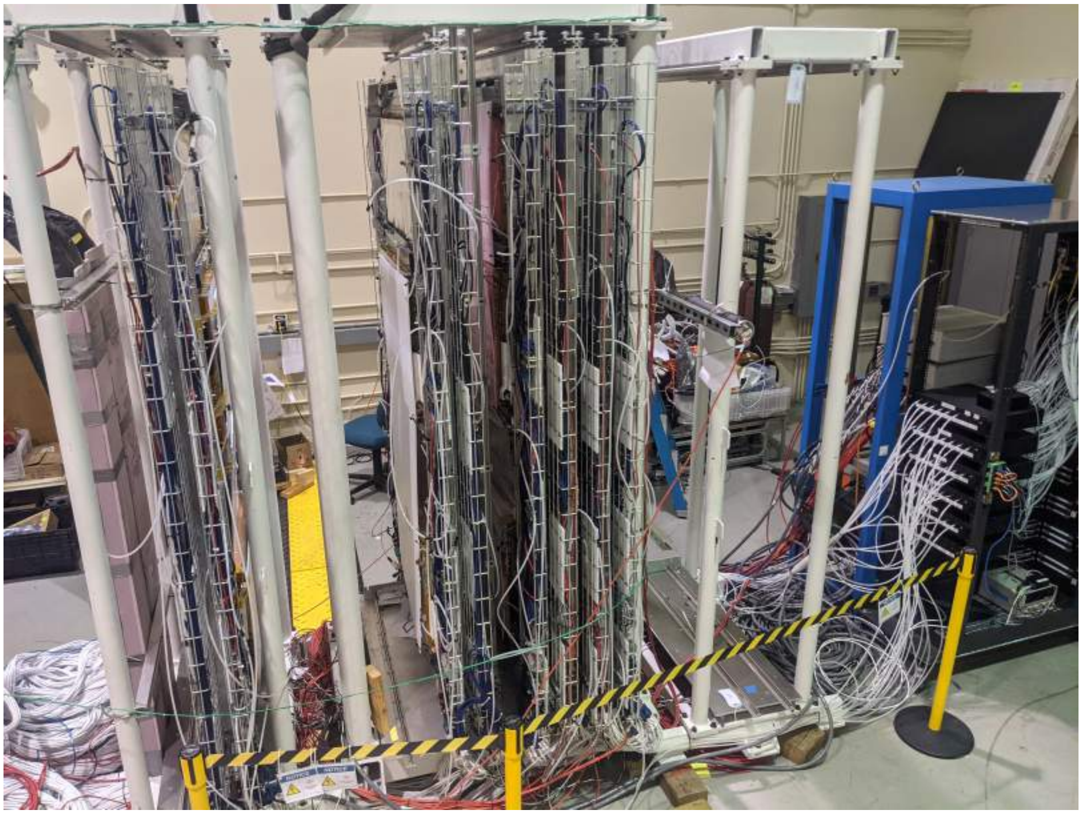


Figure 4: A closer view of the 3 GEn-RP Stacks

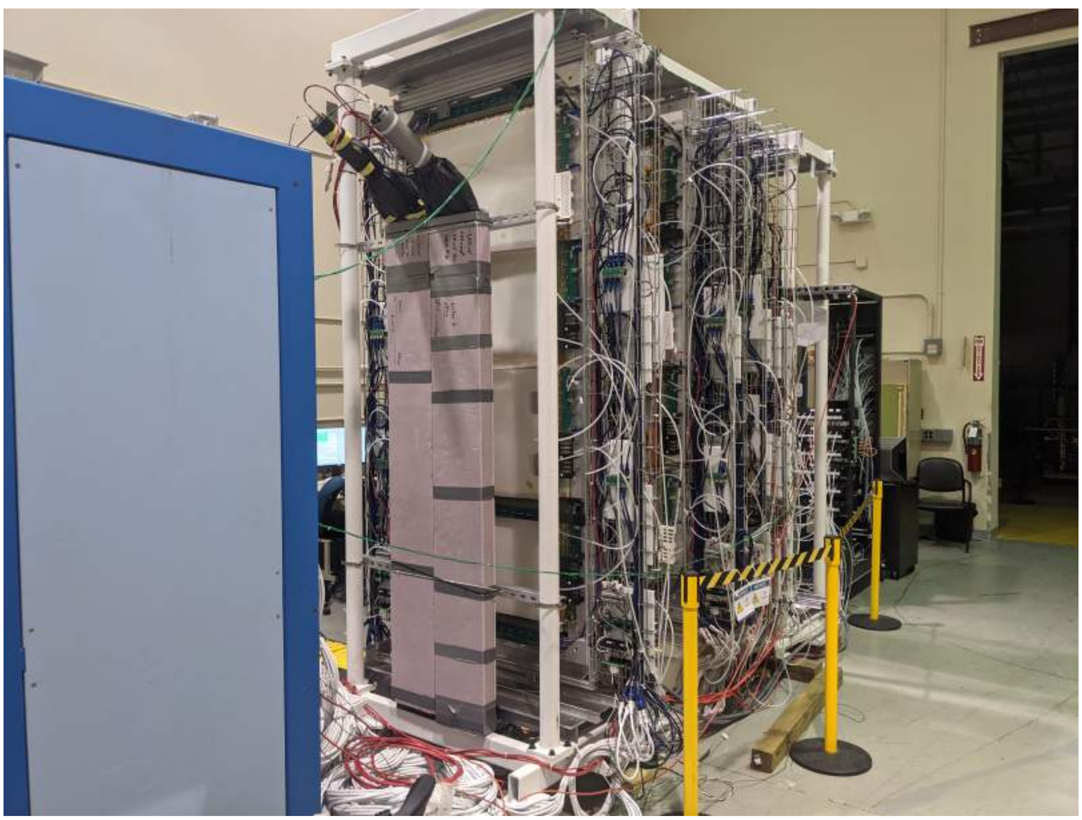


Figure 5: View showing the "lower" scintillators which sit on the outer plane of the Right Polarimeter

Figure 6: A view showing the “upper” scintillators which sit on the plane of the Inline Stack which faces the Left Polarimeter. ***NOTE: There is a small scintillator shown in this picture. This was only used for initial trigger calibrations and is not part of the overall setup

Figure 8: Left: Gas control panel for all GEMs/Layers. Right: Voltage control crates for the Low Voltages (top 2 crates) and High Voltages (lower crate).

All of the roto-meters which control gas flow to each GEM Chamber are situated in a single rack/panel. In total there are 42 roto-meters installed on the panel (Left side of Figure 8). Currently, only 32 of these are being used (4 GEMs per layer, and 8 layers total). All of the voltage (both high and low) control modules are in their own racks as well (Right side of Figure 8).

Just like the BigBite setup, this SBS GEn-RP setup has an GUI for the flow rates for each other roto-meters. A screenshot is below:

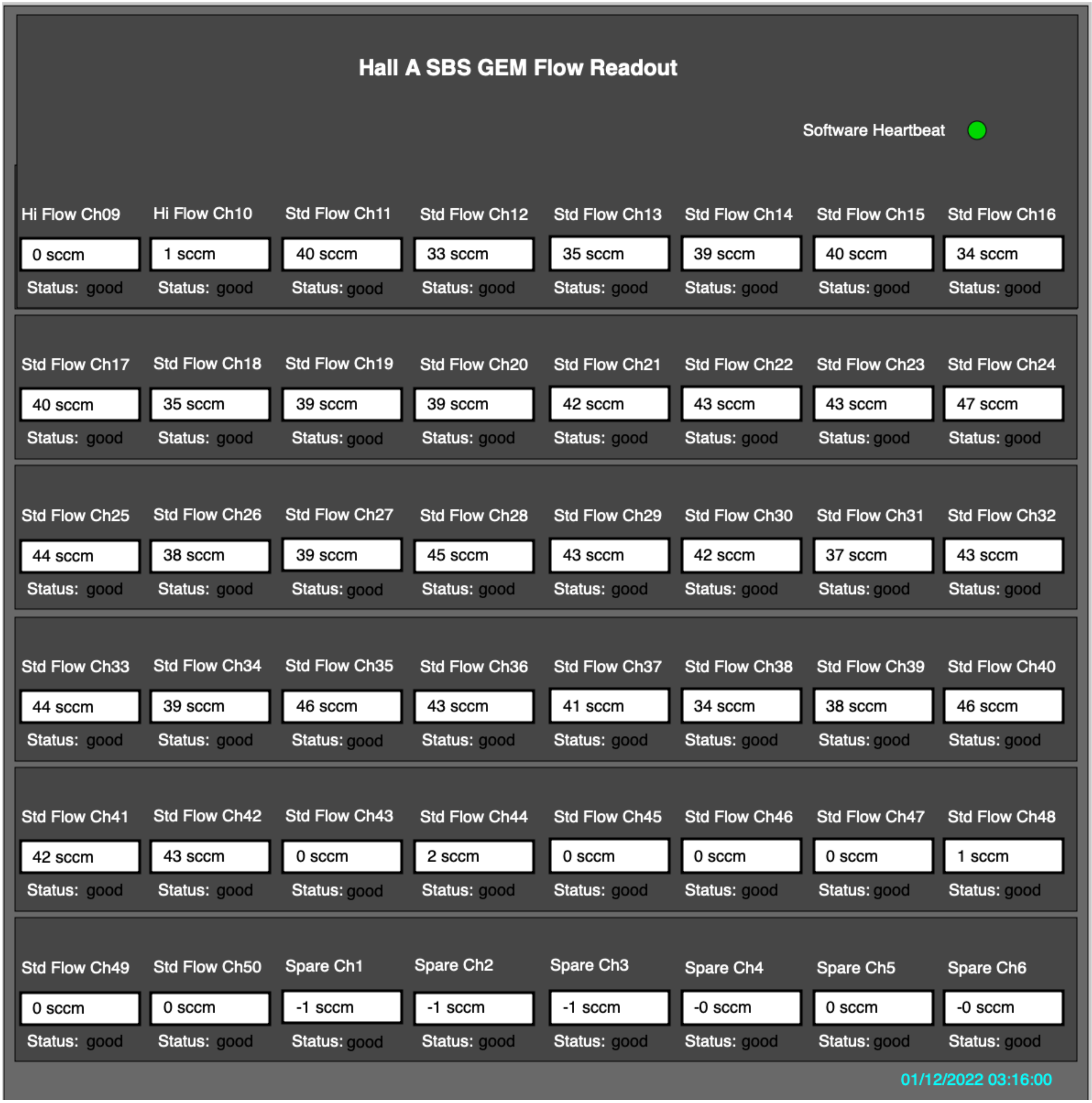


Figure 9: Gas flow rate GUI for GEn-RP setup.

2 Current status of DAQ and GEM Functions

2.1 Low-level diagnostic tests

Low-level diagnostic tests were performed earlier on right after finishing the assembly of the setup in EEL/125. The purpose of these low level test were to diagnose issues such as,

- Loose HDMI cable connections either at the detector end or MPD end
- Loose/faulty low voltage connections
- Malfunctioning APVs, backplanes, or MPDs

These issues should be resolved before attempting to start data acquisition with CODA as error messages generated by CODA is not always very useful or straightforward for debugging these kind of issues.

We mainly used a standalone program called "MPD Library Test" ("MPDLibTest" in short) to perform this task. MPDLibTest is a straightforward test tool to troubleshoot loose analog or digital HDMI cables, faulty low voltage connections, APVs that have been loosen from the back planes, and bad "clock phase" values in the MPD configuration files.

See Figure: 10 for a positive result from MPDLibTest for a set of 12 APV cards; A positive results is characterized by a one sharp peak at 500 units and another sharp peak at around 2500 - 3000 units. In figures: 11, 12, and 13 a several instances of MPDLibTest with faulty results are shown with explanations on what the issues are.

Another low level test that was performed is the "Clock-phase scan". Clock phase essentially determines the time difference between the instances of APVs receiving trigger, and MPDs getting the analog signal from the APVs. This value needs to be properly set in the MPD configuration files for the signals to fall within the time window that is being looked at by the DAQ. A clock phase scan for a set of 12 APV cards is shown in the Figure:14. The clock phase is the X-axis in these plots. Good clock phase values are the ones where the gap between the two crossing curves are maximum. For example, when all the 12 APVs shown in Figure:14 are considered, a clock phase value of around 20 could be used as a good value.

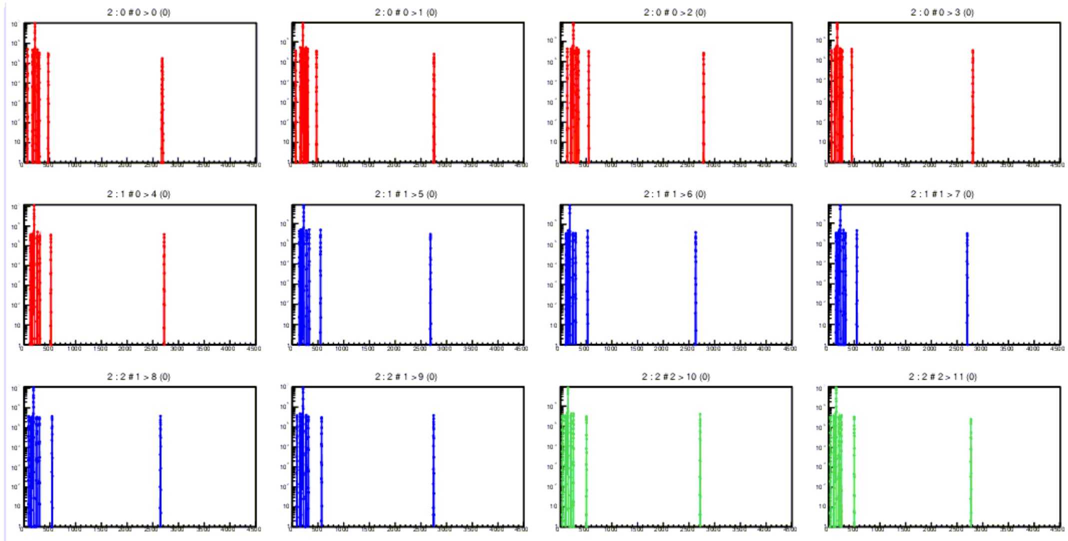


Figure 10: A plot showing a positive MPDLibTest result for a set of 12 APV cards (attached to a single 12 slot back-plane).

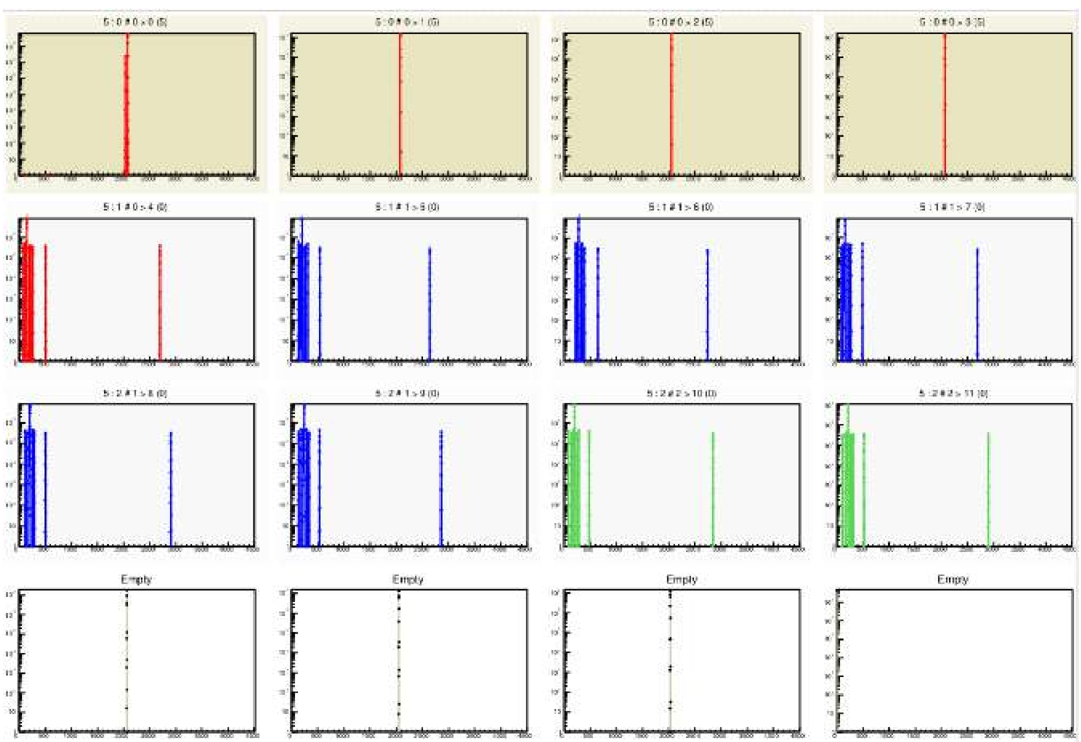


Figure 11: MPDLibTest result for a 12 slot back plane where one of the 3 analog HDMI cables is loosely connected to the back plane. The first row of plots represents the 4 APV cards that is carried by the loose analog cable.

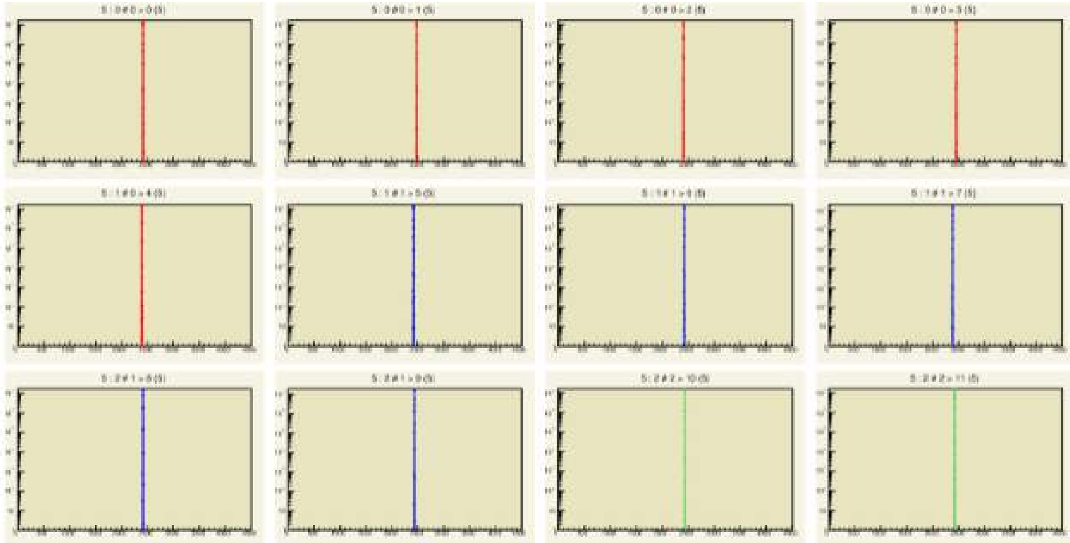


Figure 12: MPDLibTest result for a 12 slot back plane where the low voltage cable supplying power to the back plane and APV cards is loose.

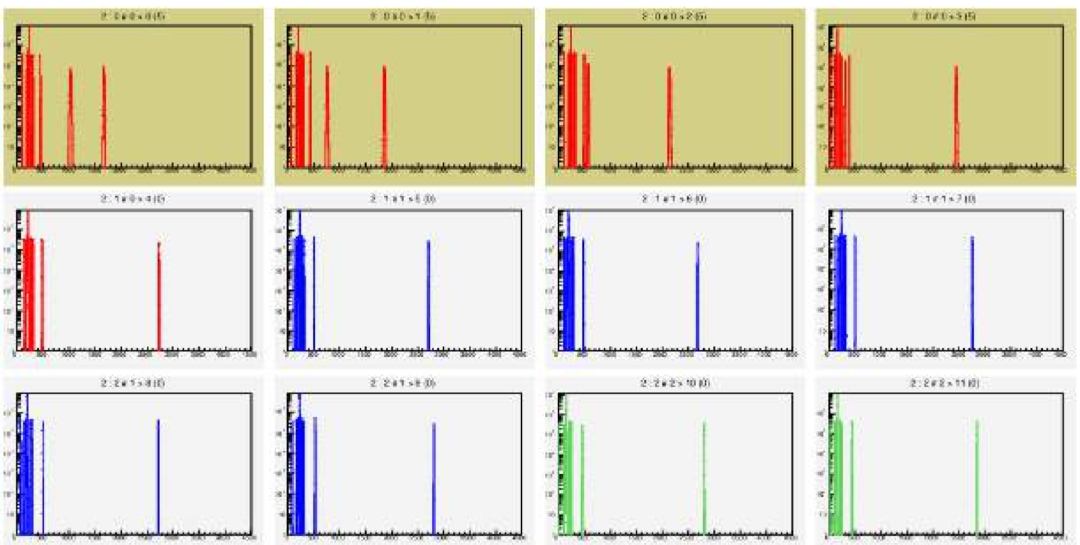


Figure 13: MPDLibTest result with a bad clock phase value in the MPD configuration file.

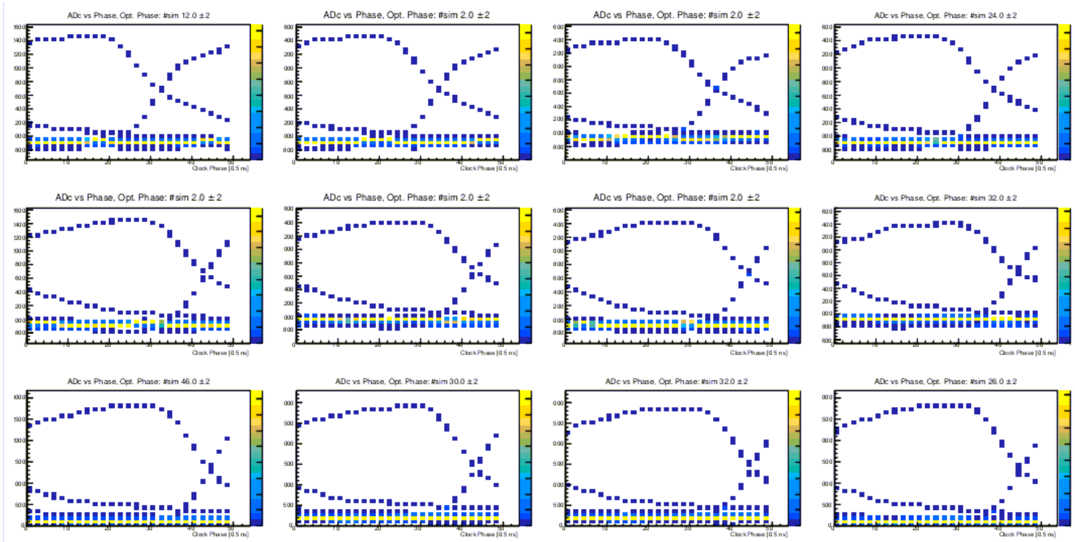


Figure 14: A clock phase scan result for a set of 12 APV cards in a 12 slot back-plane

2.2 Cosmic tests

In addition to performing low-level diagnostic tests and evaluations of the GEM and DAQ hardware (APVs, back-planes, cables, MPDs, transceivers, etc.) it is very useful to develop cosmic muon 2D hit/cluster maps for the GEM layers. Often, low-level tests may seem all well and fine but a 2D cluster map can often illuminate operational issues in the setup.

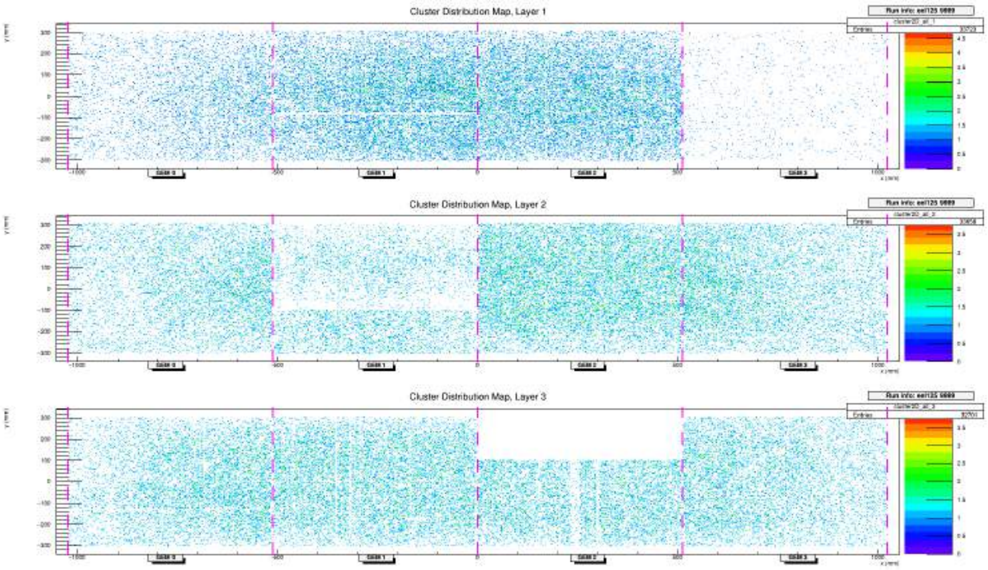
Once the DAQ was confirmed to be operational for data-taking data sets were collected from incident cosmic muons across all layers and formed into 2D cluster maps.

Initially we could not get Layer 5 of the setup to initialize properly and had to disable from the first comprehensive layer scan.

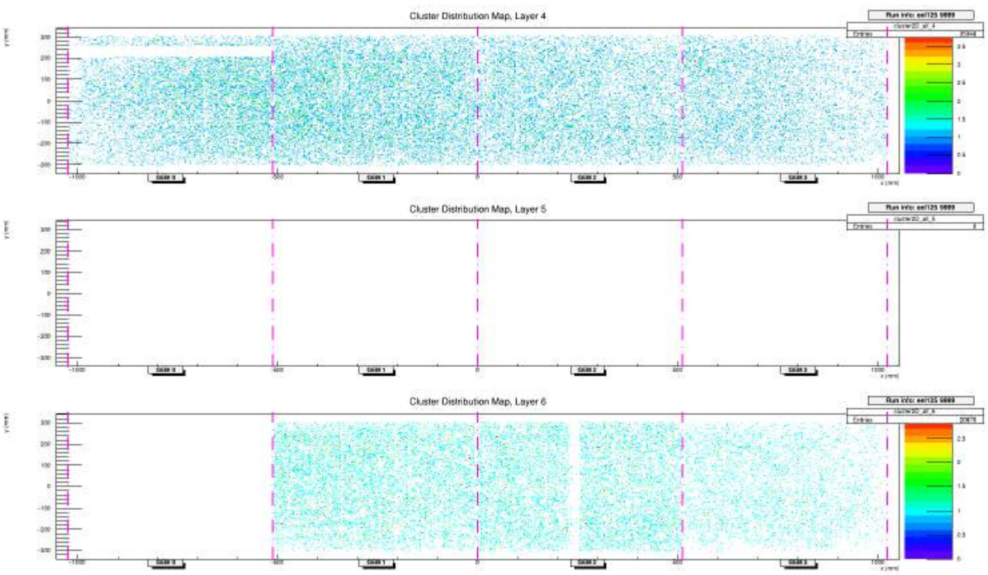
Before analyzing any of the raw data/maps we must first note the following expected disabled components:

- Layer 4, GEM 0: 1 APV disabled due to persistent initiation errors.
- Layer 5: fully disabled.
- Layer 6, GEM 0: fully disabled.
- Layer 7, GEM 3: 1 known dead sector.
- Layer 8, GEM 3: 1 known dead sector.

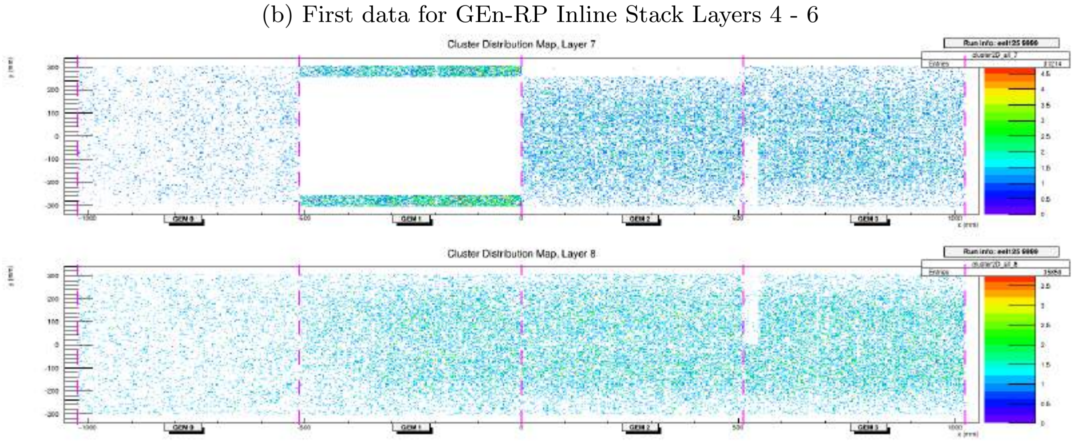
The following figures are the first set of cluster maps for the EEL125 GEn-RP setup:



(a) First data for GEn-RP Inline Stack Layers 0 - 3



(b) First data for GEn-RP Inline Stack Layers 4 - 6



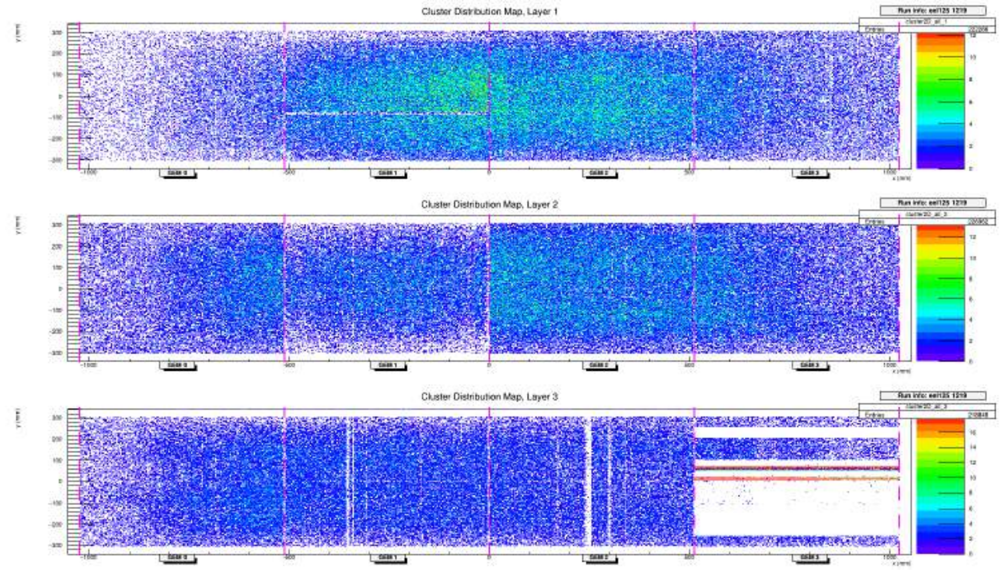
(c) First data for GEn-RP Right Polarimeter Stack Layers

Figure 15: Most recent histograms for cosmics on the GEn-RP test setup.

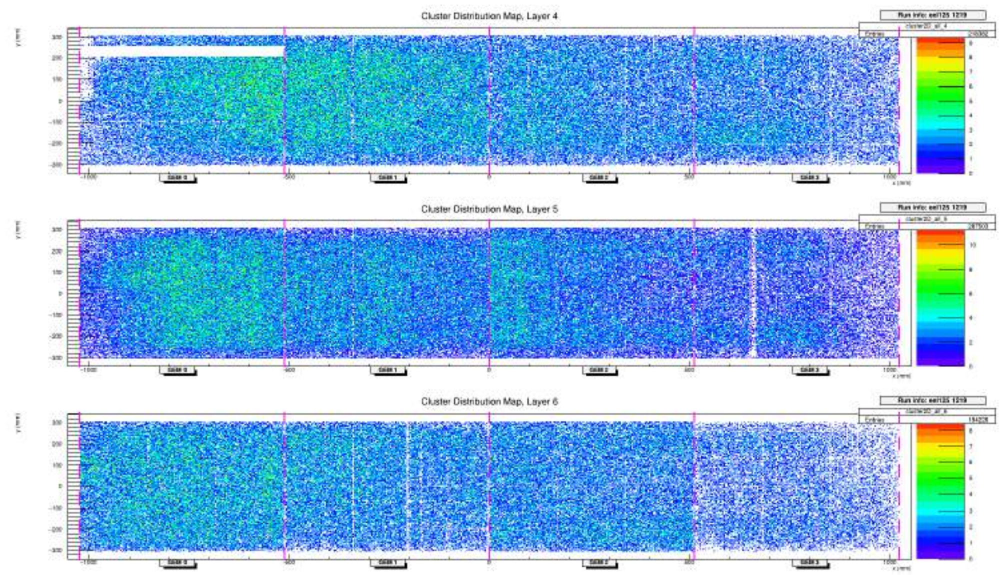
From this we can see the following issues to be addressed:

- Layer 1, GEM 3: Module appears to be low-efficiency. Plan is to turn up the operational HV.
- Layer 2, GEM 1: Module appears to show an area with low-efficiency. This problem is expected to be due to a bad MPD.
- Layer 3, GEM 2: Appears that 4 out of 12 APVs on the 12-slot backplane are disconnected – probably due to a loose cable.
- Layer 4: All modules as expected.
- Layer 5: Disabled
- Layer 6, GEM 2: One APV in one of the 5-slow backplanes seems to be malfunctioning or unplugged.
- Layer 7, GEM 1: Many APVs not showing up. High intensity/occupancy showing up on 2 APVs. The initial thoughts were that this could be caused by an improper mapping file. It was discovered that multiple cables in the MPDs associated with that module were disconnected and/or loose.
- Layer 7, GEM 2: One APV not showing up. This APV shows persistent errors and often hangs. The low-level plots also don't look great. This APV is in a hard-to-reach location (lower level in a "staggered GEM layer") and will be disabled until we can schedule replacing the APV.

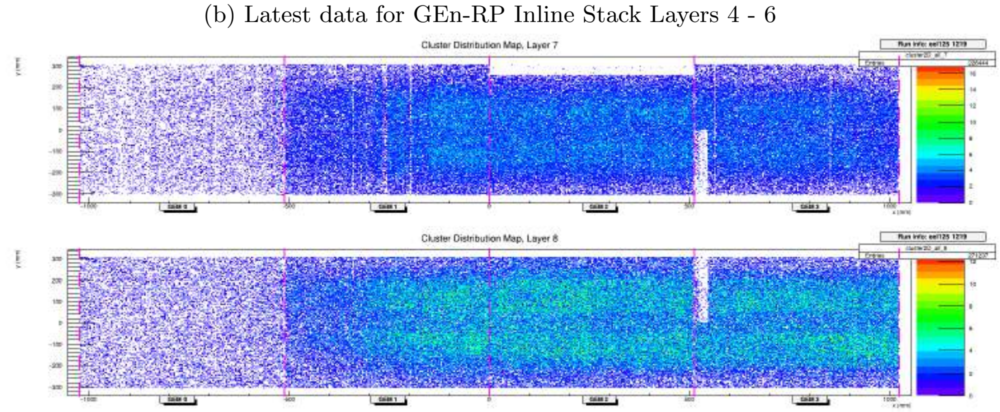
After addressing the previous issues and performing fixes another set of data was taken (Figure 16)



(a) Latest data for GEn-RP Inline Stack Layers 0 - 3



(b) Latest data for GEn-RP Inline Stack Layers 4 - 6



(c) Latest data for GEn-RP Right Polarimeter Stack Layers

Figure 16: Most recent histograms for cosmics on the GEn-RP test setup.

With this most recent data we can see some issues that still exist. We will disregard the APVs that have been disabled in the DAQ configuration. We have the following:

- Layer 3, GEM 3: This appears to have had some cables/APVs get disconnected. This was confirmed to be true – **More information on this in subsection 2.2.1**
- Layer 7, GEM 0: Low occupancy due to region being outside of the scintillator region (See Figures 5 and 1).
- Layer 8, GEM 0: Low occupancy due to region being outside of the scintillator region (See Figures 5 and 1).

2.2.1 Layer 3, GEM 3

Figure 16a shows some faults in GEM 3 of Layer 3. Previous cosmic runs showed no issue with this particular GEM. This plot indicates that there may be loose connections in the cabling and/or hardware. After visual inspection it was clearly identified to be caused by loose connections between APVs and either their respective backplane or the GEM module readout board itself.

The white space and markings in Figure 16a indicate an issue with the 12-slot backplane of Layer 3, GEM 3. Upon visual inspection some of the screws which fasten the APVs to the backplanes were either loose or completely detached between the cards and PCB. Figure 17 shows these APVs on the backplanes and it can be seen that a screw is missing in one location. Figure 18 shows the area just below this layer where screws have come completely loose and are laying on the frame.

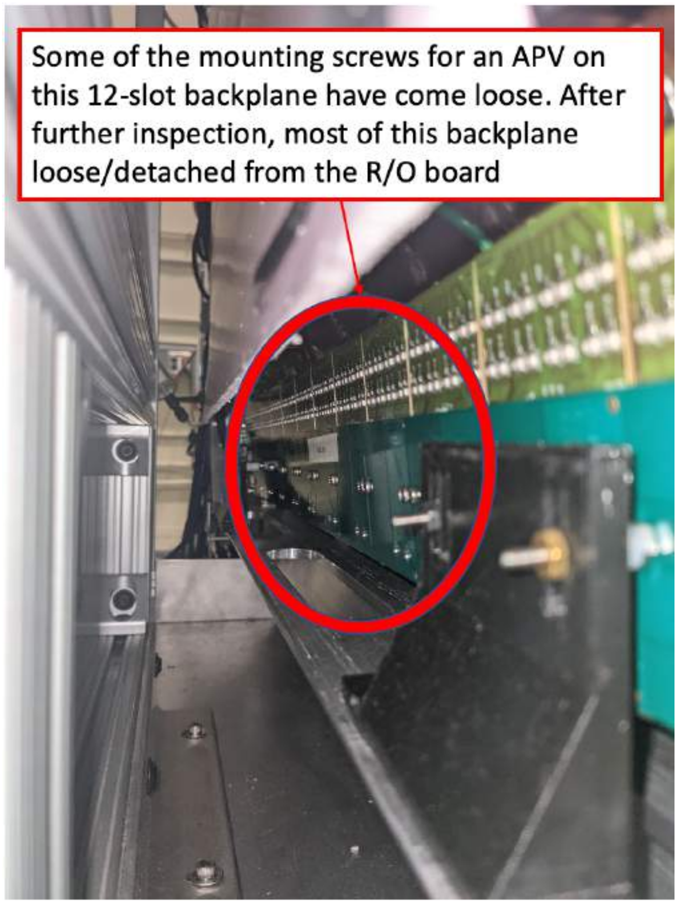


Figure 17: Image showing locations on APVs attached to a 12-slot backplane where mounting fasteners have come loose or fallen off.

Figure 18: Image showing some loose screws and nuts sitting on the GEn-RP frames.

Upon reaching into this area of the stack with our arms we were able to determine that some APVs have a very poor, or no, connection with the 12-slot backplane at all. The connections were so poor that even inspecting them with our hands caused them to immediately come loose. This resulted in the plot in Figure 16a. The data set just before this showed about half as much white space. It was only after we reached up and tried to push APVs back in that more connections were lost and we are left with the final state as described above.

Given the difficulty of attaching APVs to backplanes and the lack of physical access to this location it has been decided that we will wait until we slide the entire layer out from the Inline Stack so that we can re-attach the hardware. This will be most easily done when the remaining layers of GEn-RP setup are ready for installation.

Currently there are 8 GEM layers installed – 6 UVa XY layers on the Inline Stack and 2 UVa XY layers on the Right Polarimeter. Remaining are 2 UVa XY layers for the Left Polarimeter and 2 INFN layers for the Inline Stack. Scheduling for their installation has yet to be determined.

3 MPD and APV Inventory

Status of the electronic items for GEn-RP experiment (09/27/2021)

Items	Needs (GEn-rp)	Needs (10 UVa GEMs)	Needs (2 INFN GEMs)	Good on hands (UVa GEMs)	Good in n hands (INFN GEMs)	Spares	Missing ?	Need repair	promised	Ordered	Comments/location
APV cards	988	880	108	733	All		155	112			EEL 124/INFN lab
MPDs	78	70	8	70	8	2	0	22			EEL 124/ INFN lab
12-slot BP	40	40	N/A	37	N/A		2	17			EEL 124
5-slot BP	80	80		84		4	0	3			EEL 124
VME (St)	4	4	1	3*	1		0				EEL 124/ INFN lab
Controller	4	4	1	3*	1		0				EEL 124/INFN lab
VTPs	2	1	1	1	1		0				Hall
VXS	2	1	1	1	1		0				EEL 124/INFN lab
TI	2	1	1	1	1		0				EEL 124/INFN lab
CPU	2	1	1	1	1		0				Hall
Signal distribution for VTP	2	1	1	0	0		2				
Trigger distribution	5	4	1	3	1		1				EEL 124/INFN lab
Optical fibers	10						10			AC:10	

*UVa GEM will share one INFN crate and one controller

Figure 19: Tabulated inventory of GEn-RP Hardware/Equipment

- MPDs received from Michael Kohl: 9 (two MPDs were returned to PSI recently will be brought soon)
- MPDs received from Dustin and Chandan: 6 (Returned in December)

4 Tracking Analysis

The "SBS-offline" package is expected to be used for tracking analysis of the cosmic data taken. The amount of data accumulated up to now should be sufficient to perform decent tracking analysis.

Extensive cosmic-ray tracking analysis were performed (using "SBS-standalone" package) with the data taken from EEL/124 cosmic stand over last two years for these UVA-XY GEM layers. The following GEM detector characteristics have been studied via cosmic ray tracking-analysis:

- Tracking efficiency
- Position resolution
- Detector gain

The purpose of performing cosmic ray tracking analysis in the current EEL/125 setup is mainly for "software commissioning" for the GEn-RP experiment rather than detector characterization (which was extensively performed in EEL/124 cosmic stand setup as mentioned earlier) itself. All the tracking software already exists in the "SBS-offline" package. It is currently installed on the local computer (eel124gemdaq) in EEL125. The installation has been tested against known data from the Gmn experiment. Data was transferred to the local drive of the computer and "replayed" and then analyzed with no error. In order for it to be fully capable of running for the GEn-RP setup certain databases and configuration files need to be implemented. These database files contain information such as all of the geometrical position information and the APV/MPD configuration information. This work is on-going and it is expected to be completed by the time frame of end of February 2022. /

5 INFN GEMs for GEN-RP

Two INFN GEMs are required for the GEN-RP stack. The two layers planned for GEN-RP are referred to as J1 and J3. Currently these two layers are in Test Lab 1128A on the cosmic stand. Both layers have RF shielding attached and in process of preparing to take cosmic data. This is after previous modifications to both layers to improve APV connections to the GEM detector.

5.1 Recent Cosmic Data

Over the course of November and December of 2021, preliminary cosmic data was taken to evaluate both GEM high voltage over long periods of time and the connections of GEM electronics for layers J1 and J3. The cluster plots from the cosmic data can be found in Figures 20, 21, 22. Significant work has already been done to remove the RF shielding from J1 and reconnect APV cards for the middle and top modules. Pedestal RMS plots for each APV in consideration were compared for improvement prior to RF shielding being reattached. For J1 cosmic data still needs to be taken to reevaluate the APV card performance. So for J1 present cosmic data would most likely be better than what is presented in Figure 20. For J3, work has been done to improve the APVs on the middle module. This is apparent by comparing Figures 21 and 22. However, Figure 22 presents a different striped behavior. The cause of this striped behavior is not fully understood. Current thoughts for this include either an improper mapping for the cluster analysis or a piece of readout electronics in a bad state. Another iteration of cosmic data was going to attempt to investigate this striping behavior more for J3.

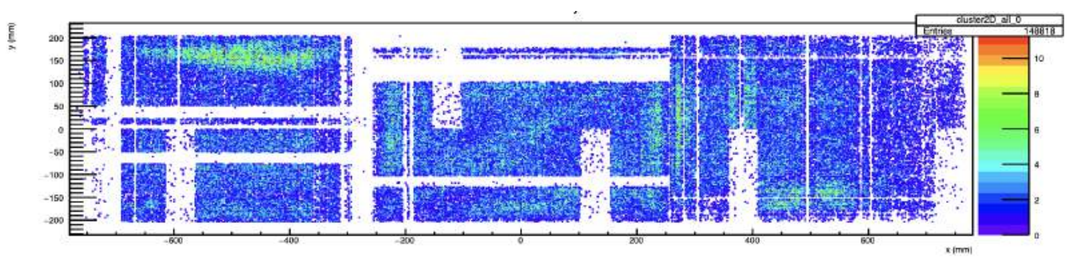


Figure 20: Layer J1 cosmic data (bottom on right, top on left) before working on APV connections. From run 1028 in Test Lab

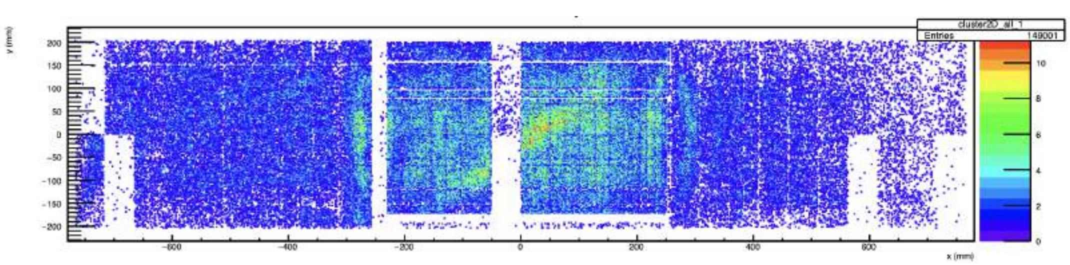


Figure 21: Layer J3 cosmic data (bottom on right, top on left) before working on APV connections. From run 1028 in Test Lab

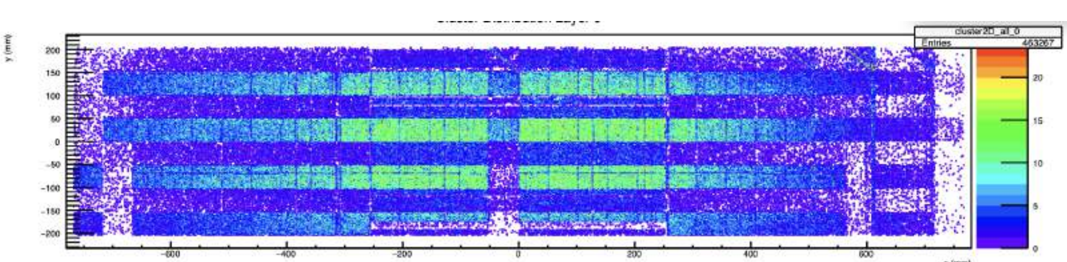


Figure 22: Layer J3 cosmic data (bottom on right, top on left) after working on some APV connections. From run 1029 in Test Lab

5.2 Remaining Tasks

Currently J1 and J3 are on the cosmic stand in Test Lab. The immediate task would be to ensure that the two layers are connected to the DAQ via HDMI cables and LV. Generally speaking checking connections and ensuring long stable DAQ running takes about 2-3 days. Once the DAQ is ready, then turning on GEM HV is straightforward and one can begin taking cosmic data. For 1 million events of cosmic data (10 Hz event rate) takes about 27 hours. Generally, anywhere from 500,000 to 1 million events is reasonable. To verify the analysis mapping, run the cluster analysis, and create plots takes about 1 day. Then an assessment will need to be made to ensure that the GEM detectors are performing as expected and the APV cards are reading out correctly. If there are still performance issues with the GEM detectors, then one would iterate on hardware improvements and cosmic data retests.

If everything looks good one can consider moving J1 and J3 from Test Lab to the GEN-RP stack in EEL. This move to GEN-RP would require moving the detectors, electronics, and cables. Most likely this would require 5-8 work days to physically move objects and integrate the two detectors into the GEN-RP stack. Once the two layers are in the GEN-RP stack, then it would be necessary to verify connections in the DAQ, test HV for a long time, and take cosmic data to evaluate GEM layer performance.

Another consideration is the implementation of an improved INFN HV divider, which is currently under investigation by Evaristo Cisbani. This modified HV divider could be available within 3 weeks and it would be straightforward to implement it in Test Lab instead of in EEL. As the RF shields on J1 and J3 do not cover the HV dividers, unlike previous designs. But the exact timing and implementation of modified INFN HV dividers should be more of a discussion. Though not essential for SBS experts, efforts will be made to use or repair components of INFN J4, J0 and J2 so that 2 spare INFN GEM layers are available. This of course is less of a priority, so the time scale is more difficult to determine.

6 Remaining Plans

6.1 GEMs and Hardware

The current setup only contains eight out of ten UVa GEM layers and only eight out of twelve total layers. We are finalizing the remaining two UVa layers and this is expected to be completed by the end of February 2022. One of these layers already has GEM modules installed, but they are without most of the APV and related hardware installed. This layer was previously in a completed state but then some of the APVs had to be taken out to be used in one of the new BigBite UV detectors which was made as a replacement for an INFN-Roma layer. The second layer is at a stage where it is about 50% complete. The GEM mounting frame and cable trays with all the cables are ready for this layer. Four GEM modules need to be put on this layer and APV and related readout electronics should to be hooked up. This prep work and configuration is factored into the estimate of finishing by March of 2022.

Two of the twelve total layers in the GEn-RP Inline Stack are INFN-Roma layers. Once their layers are ready (schedule as determined by INFN-Roma), we will assist them with installation. From there we will expand the DAQ system to accommodate these additional GEMs.

6.2 Data-taking, Database Configuring, and Analysis

We are currently in the process of setting up the proper database (for "SBS-offline") coordinate mapping for the GEMs in their layers and in the assembly stack as a whole. We are currently configuring the analysis database to be fed in data to be used in reconstructing particle tracks. We have collected enough data in the current configuration, however the analysis database will require some development and re-structuring before we reach the process of testing and debugging the tracking analysis software.

6.3 Move into Hall A

The complete GEn-RP assembly is due to be installed, debugged, and experiment-ready by the start of second SBS Run Plan (July 2022). They will not be used in the experiments that run in July however we are hoping to parasitically do in-beam tests and calibration of the full SBS/GEn-RP setup. In order to allow sufficient time for the full battery of tests and debugging required after any move and re-installation, we plan to have the full system in-place and ready by June of 2022.

Currently, the GEn-RP stacks are configured in a line such that the rows of GEM layers are aligned along their normal axes (see Figures 2 and 3). The final configuration of the GEn-RP SBS Polarimeter setup does not have all of the layers aligned in this way. See Figure 1. Once we move the setup into the Hall we will need to reconfigure the analysis software, database, mapping, etc. to match the final layout. Hopefully, this will not be too difficult of an extension but we will allow for a few weeks in schedule to get this sorted out.