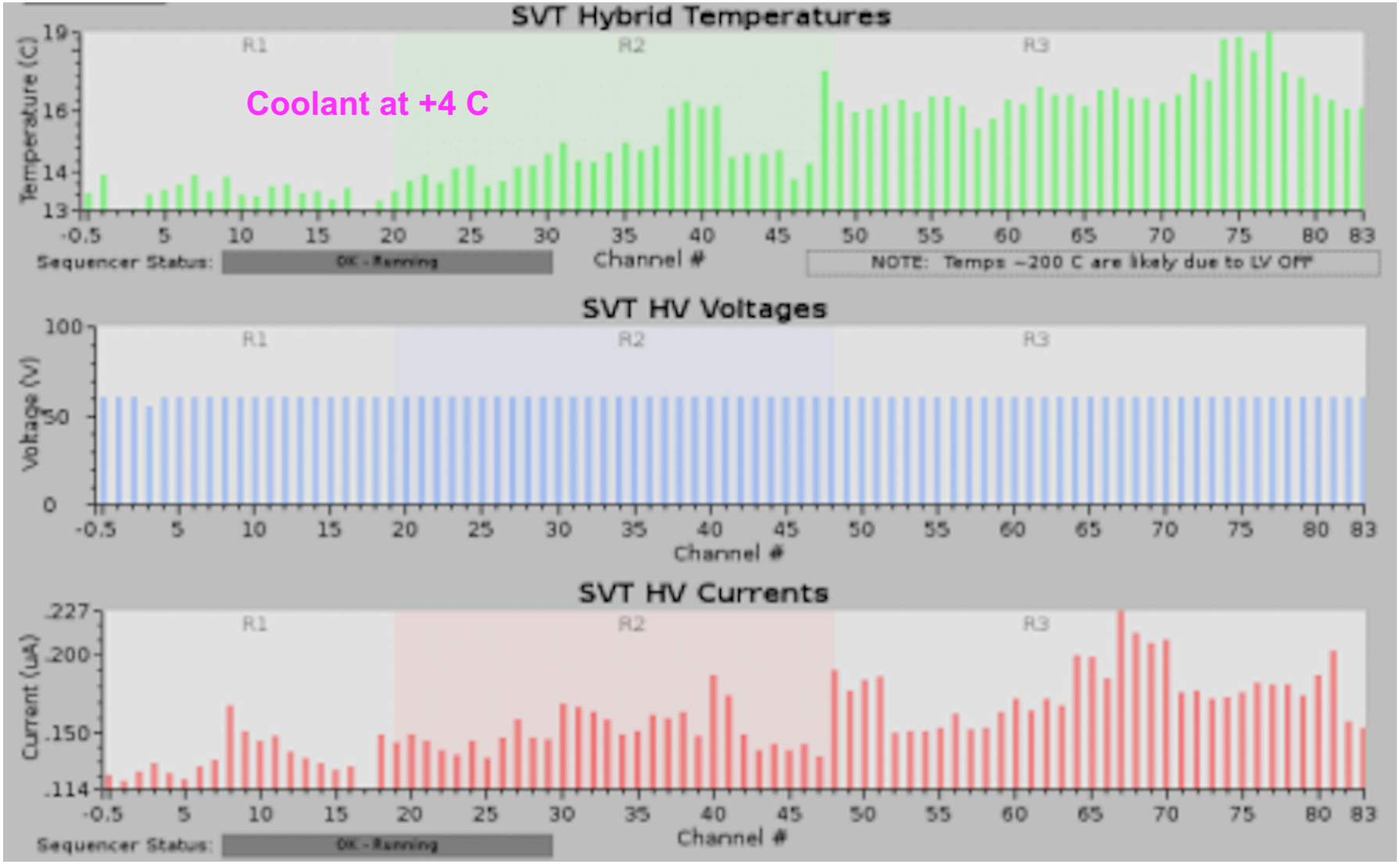
CLAS12 Silicon Vertex Tracker

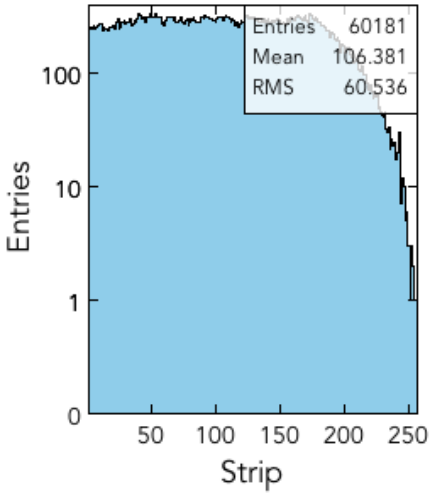
Status and Plans
Operational Performance
Settings
Calibration

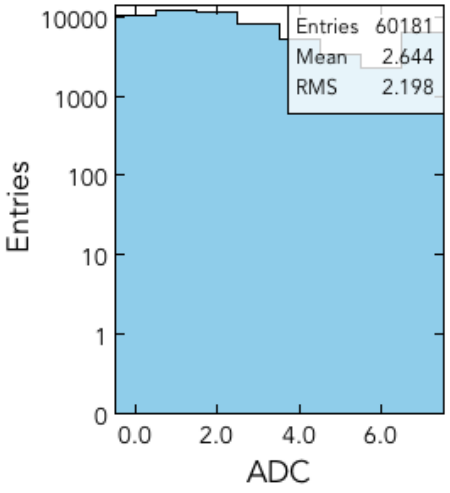
CLAS Collaboration Meeting
03/06/2018

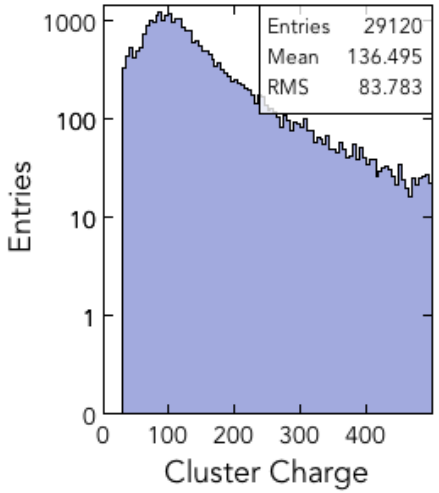
SVT Operation After Installation

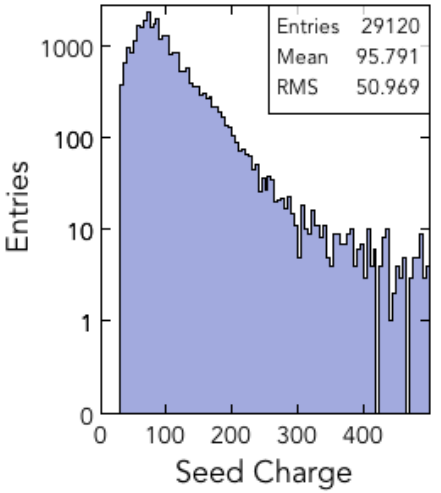


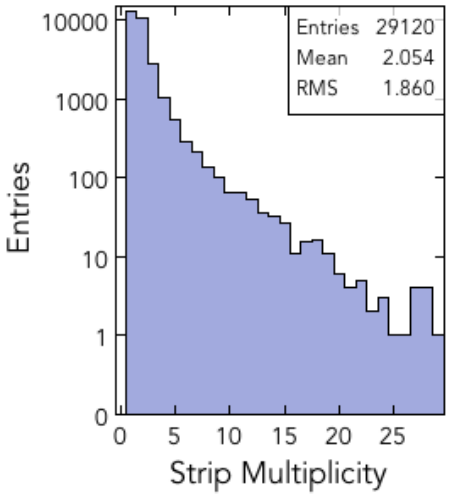
SVT Monitoring: Solenoid at 5T, cosmic run

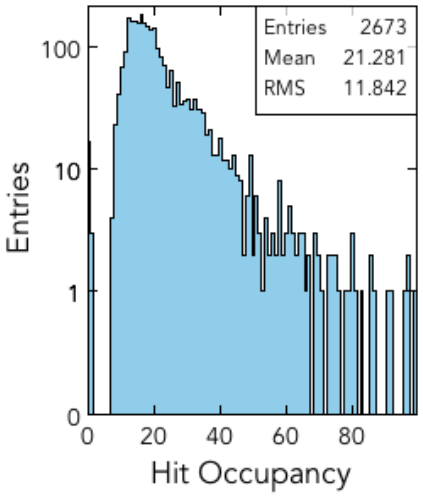


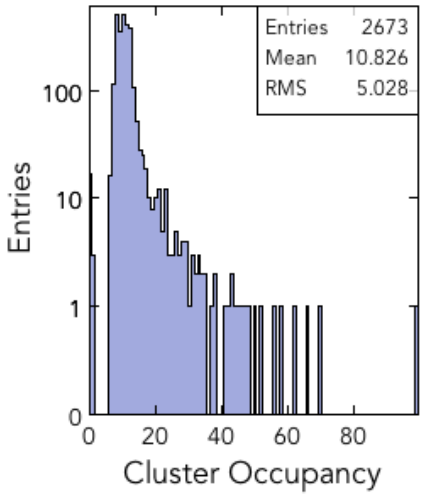


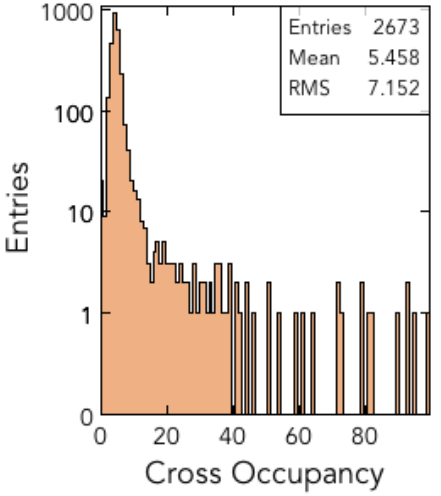




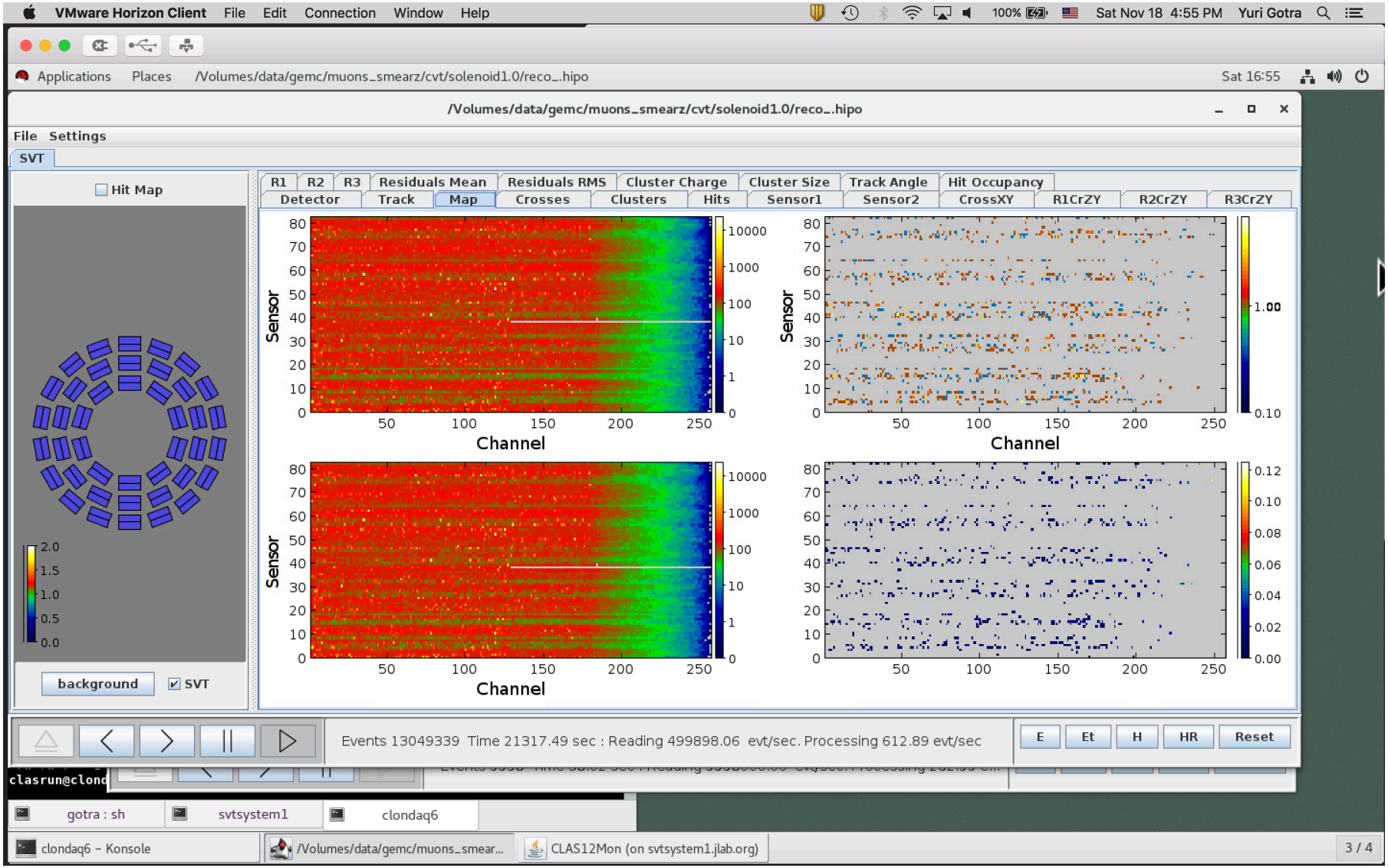




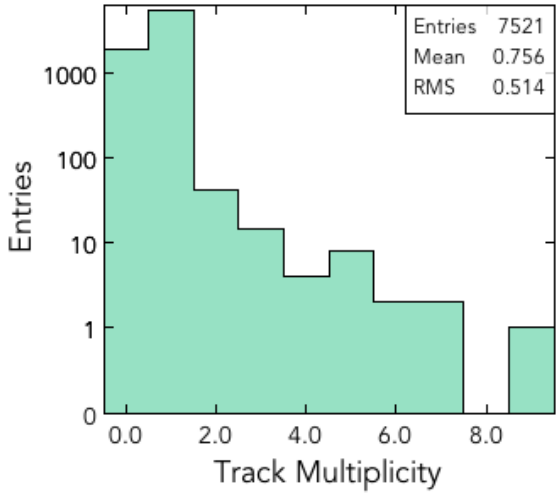


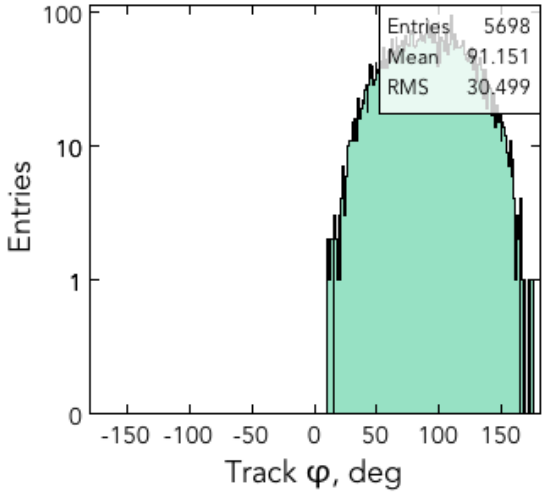


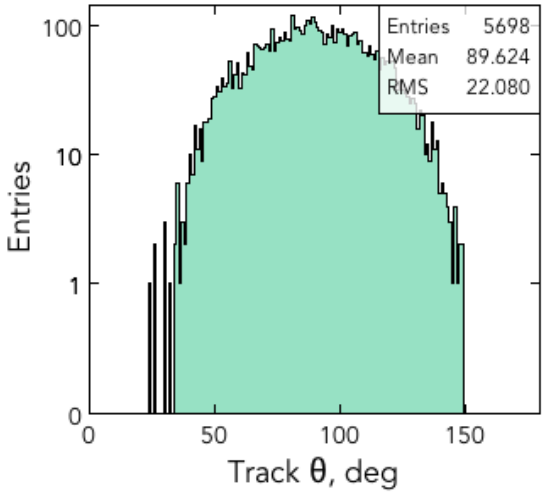
SVT Monitoring: Solenoid at 2.5 T, run 1537

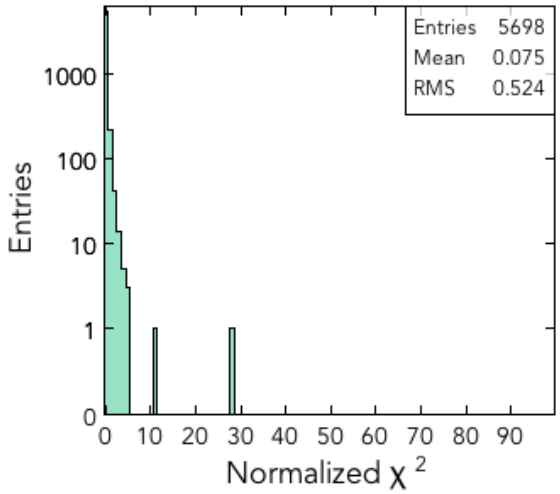


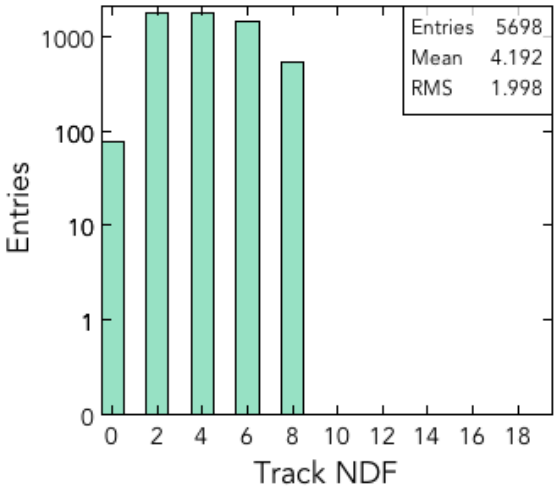
SVT Monitoring: Solenoid at 5T, Cosmic Tracking

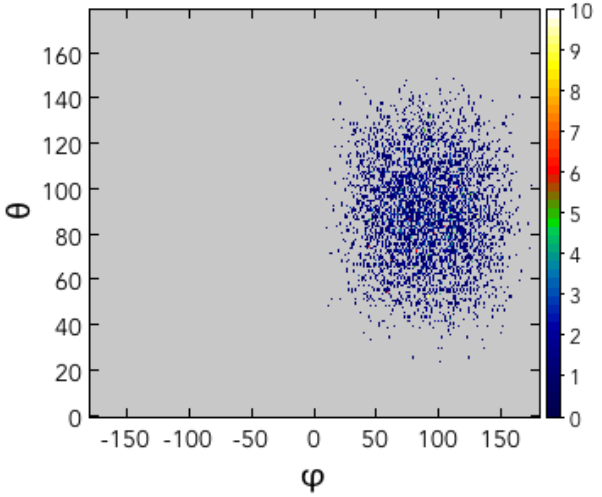






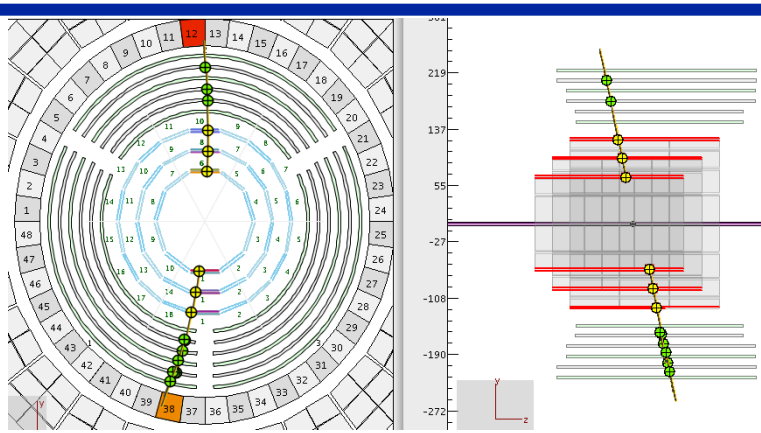


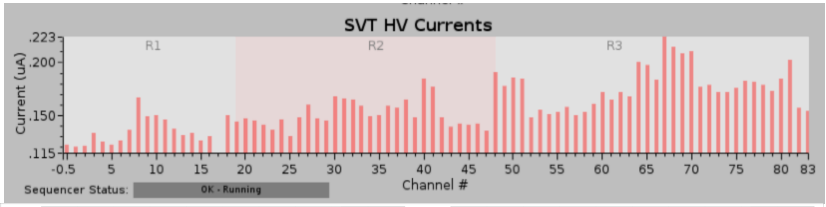


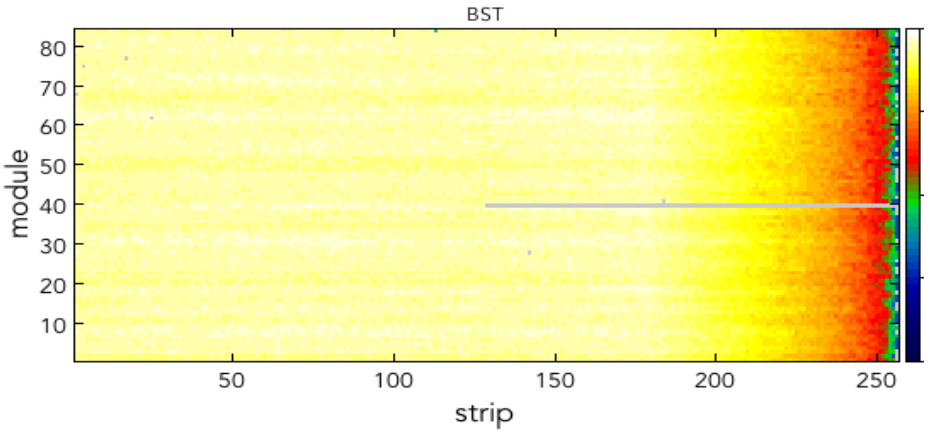


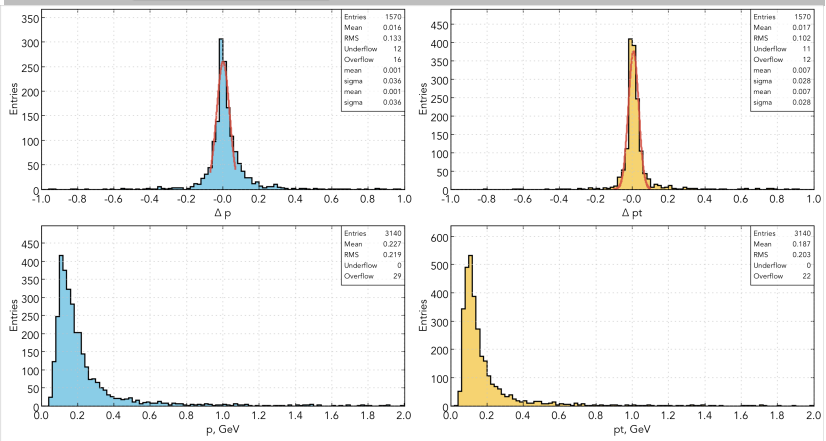
SVT Status on 12/06/2017

- Stable operation:
  - Cooling system operational
  - Ambient conditions normal
  - Leakage currents below 250 nA
- No change in calibration:
  - mean noise 1600 e
  - Mean gain 87 mV/fC
  - 99.4% channels operational:
    - Intermittent readings in 1 chip (R2S6U2, shorter strips)
    - 6 open channels (R2S7N55, R2S8N13, R3S2N1, R3S9N3, R3S11N16, R3S14N24)
    - 1 dead channel (R3S18N112)
- No DAQ issues observed
- Data integrity and tracking performance validated
- Online monitoring on ET tested

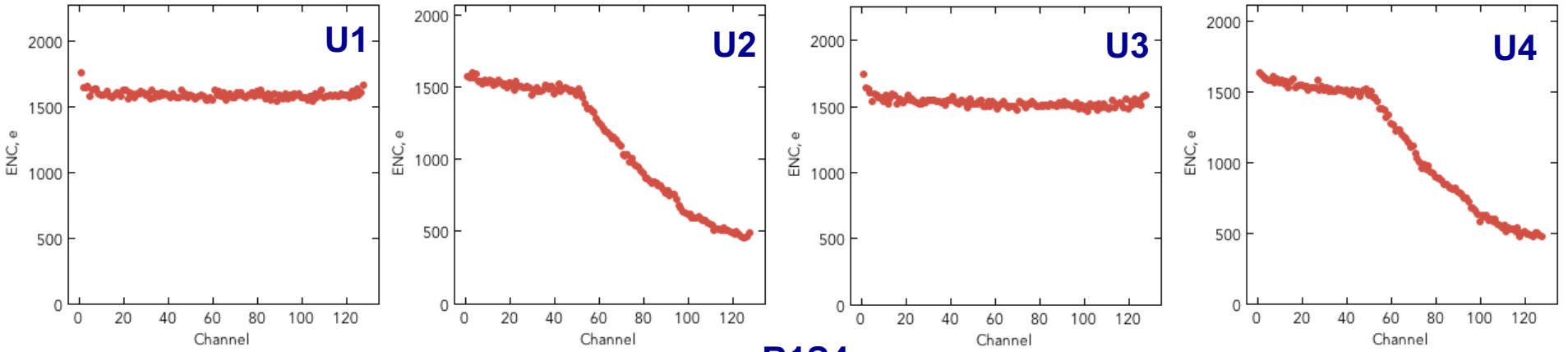




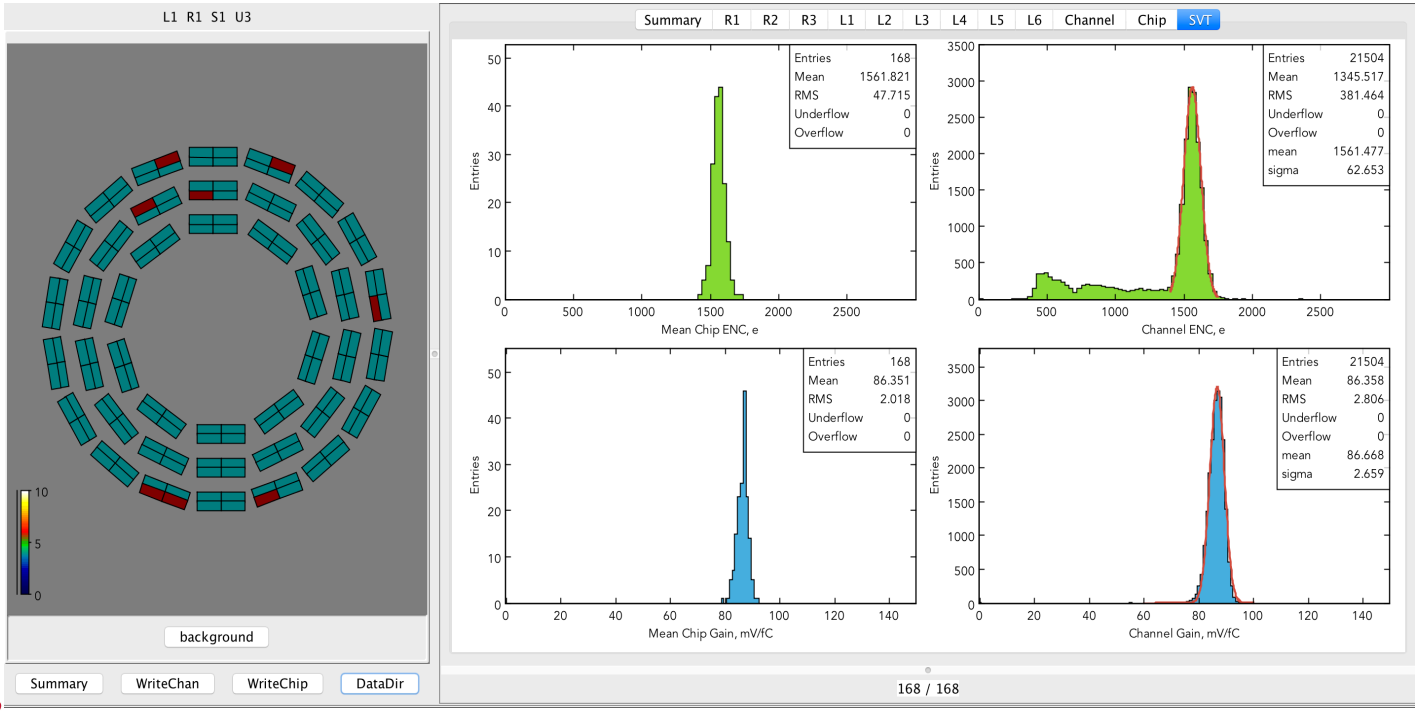




SVT Calibration before Engineering Run



R1S4



Investigation of SVT radiation damage during initial beam tuning

SVT operational conditions before beam delivery:

- leakage currents below 230 nA at 60 V and coolant at 4 C, mean noise 1600 e, 7 bad channels out of 21504

SVT conditions during beam tuning:

- **HV/LV PS off** (to protect the front-end electronics against beam induced failures), sensors at room temperature, nitrogen purging, ambient temperature and humidity sensors operational

Operational safety regulations during initial beam tuning:

- Beam line fully commissioned, all slow controls and interlocks operational
- Neutron shield upstream of the CLAS detector
- 20 mm and 14 mm collimators upstream of the detectors
- Fast beam shutdown monitors, BOM/halo counters operational
- Initial beam tuning on the tagger dump
- Beamline expert supervision of possible beam loss
- Minimal beam current
- Solenoid field on to protect the detectors from the backgrounds
- MCC operators are aware of acceptable radiation conditions for the CLAS detectors

Beam to the Hall B was delivered on 12/08/2017. Beam tuning continued through the night shift on 12/09/2017. Several operational safety conditions were not met which led to beam loss on the beamline components and large radiation dose delivered to the SVT, exceeding the estimated dose over the lifetime of the experiment.

At 11:30 am on 12/09/2017 with no beam to the hall, SVT detector was powered up to verify it's conditions after the beam tuning.

Observations:

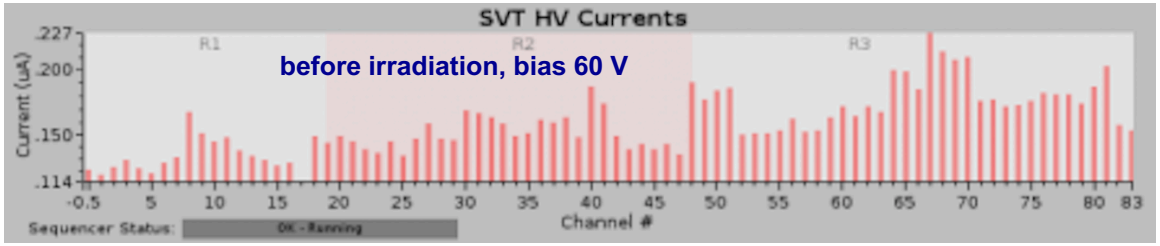
- SVT sensors suffered high radiation damage, predominately at lower radii.
- Sensor leakage currents increased up to 15 times (conservative estimate)
- No pinholes observed
- Preamplifier gains did not change, no signs of front-end or readout electronics or PS damage

Results of the measurements were posted on the HBLOG and reported to the run coordinator and the shifters.

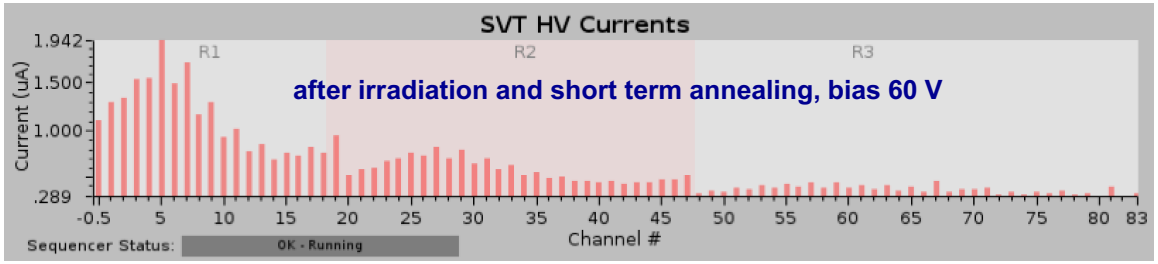
SVT operational conditions after the radiation damage

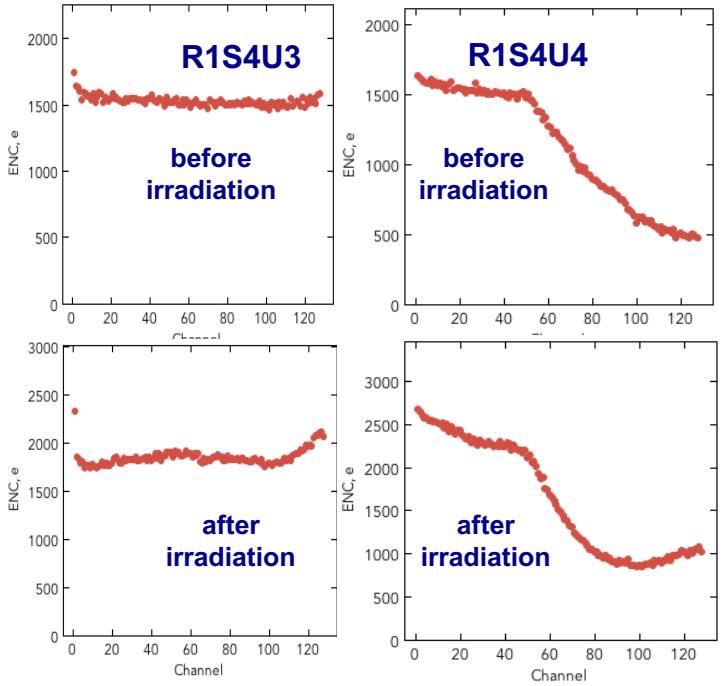
After initial short term annealing the sensor leakage currents have decreased to less than 1.5 μA.
To ensure safe operation of the SVT during the engineering run, bias voltage of the inner layer was decreased to 50 V.
Software warning limits were readjusted, hardware and software current trip limits remained unchanged to ensure detector safety.
Bias voltage of the sensor R1S2B was lowered to 27 V due to high current. Does not hold the bias voltage.
SVT performance during the engineering run monitored by the system experts, system performed stable up to the maximum delivered beam current.

In normal operation conditions SVT front-end electronics is cooled by water at 4 C, sensors are close to room temperature.
When silicon sensors suffer radiation damage, after beneficial short term annealing the long term reverse annealing could substantially degrade performance of the sensors up to the point where they become un-operational.
The time constant of reverse annealing depends on sensor temperature.

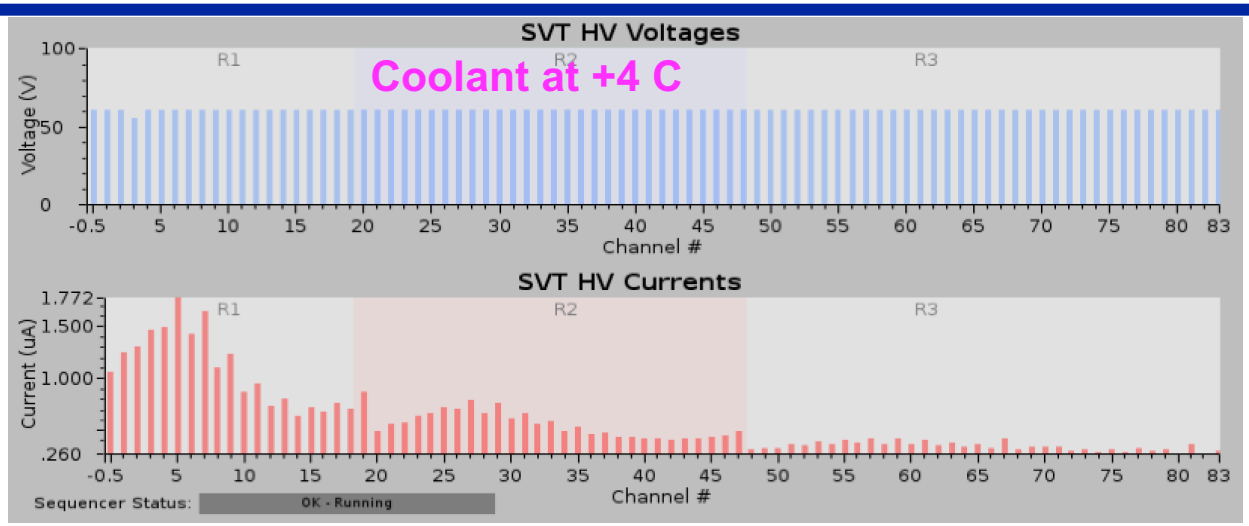


Coolant at +4 C





Mitigation Plan

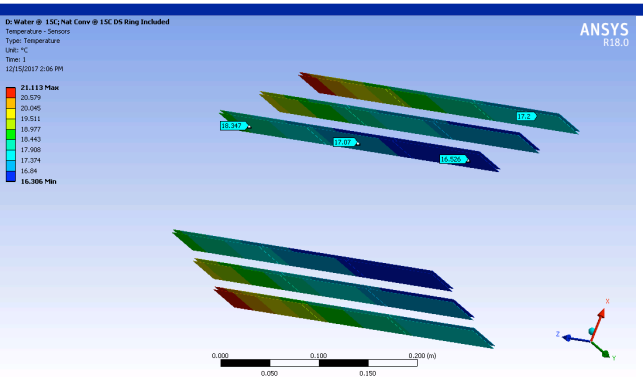


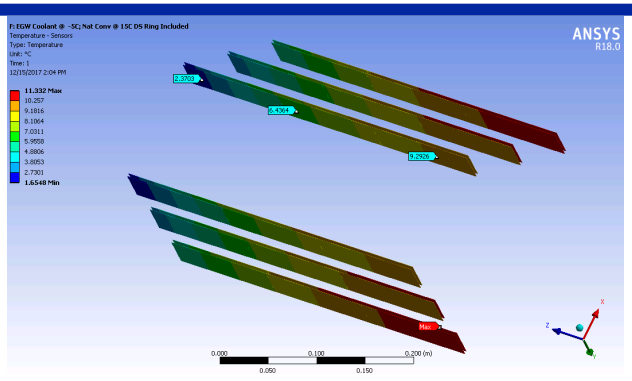
- Leakage currents increased 2-10 times
- Permanent sensor radiation damage (not recoverable)

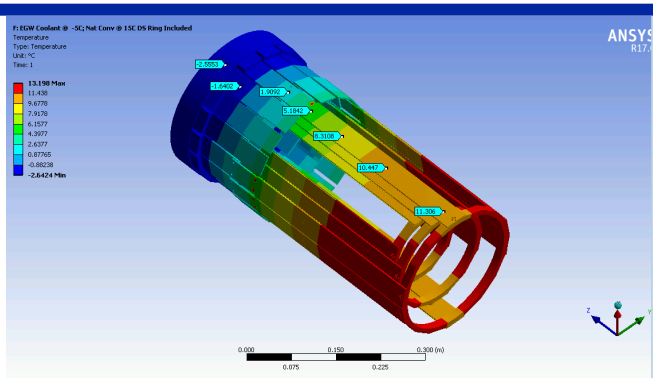
Mitigation plan:

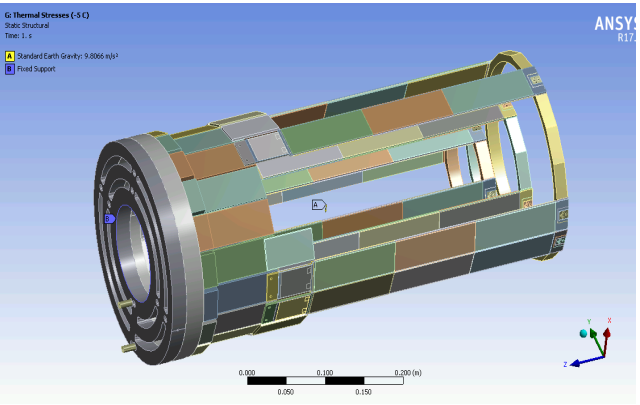
- Develop and implement a new cooling model of the central tracker with sensors at lower temperature reducing the effects of reverse annealing
  - replacing water with glycol
  - improving insulation of the cooling pipes
  - lowering the temperature of the purging nitrogen
  - Installing the thermal shield over the tracker
- Lower sensor bias to reduce leakage currents
- Modify the cooling system, change coolant type to go below 0 C
- Modify gas purging system to operate at lower temperatures

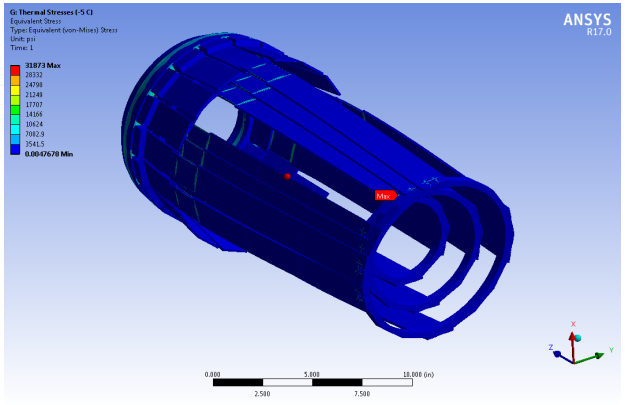
FEA Model of the SVT cooling and mechanical stress

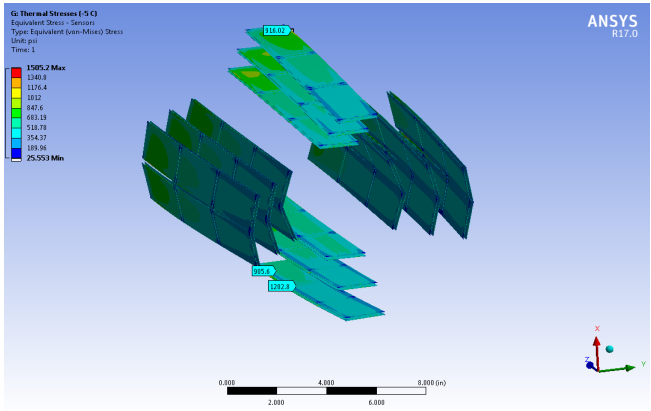


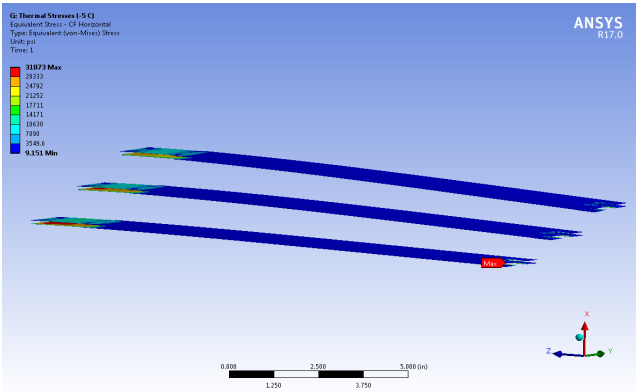


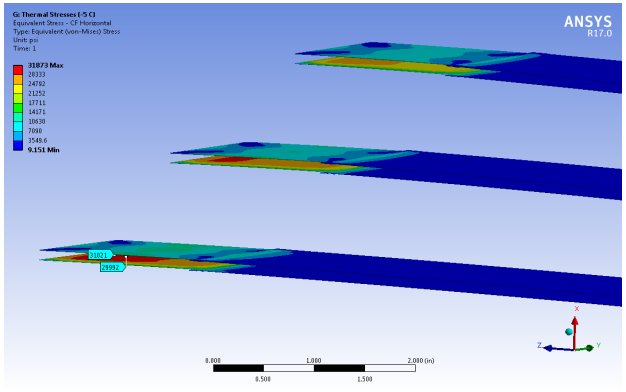


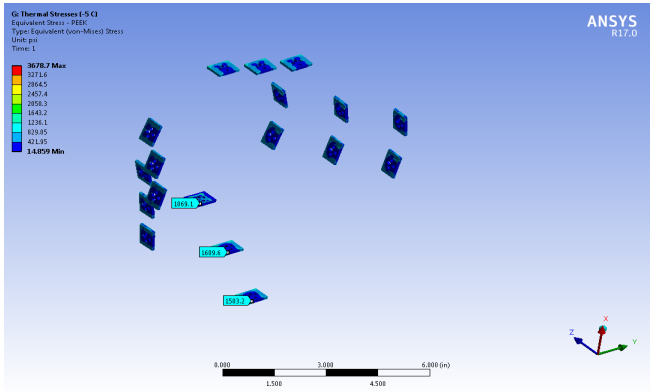




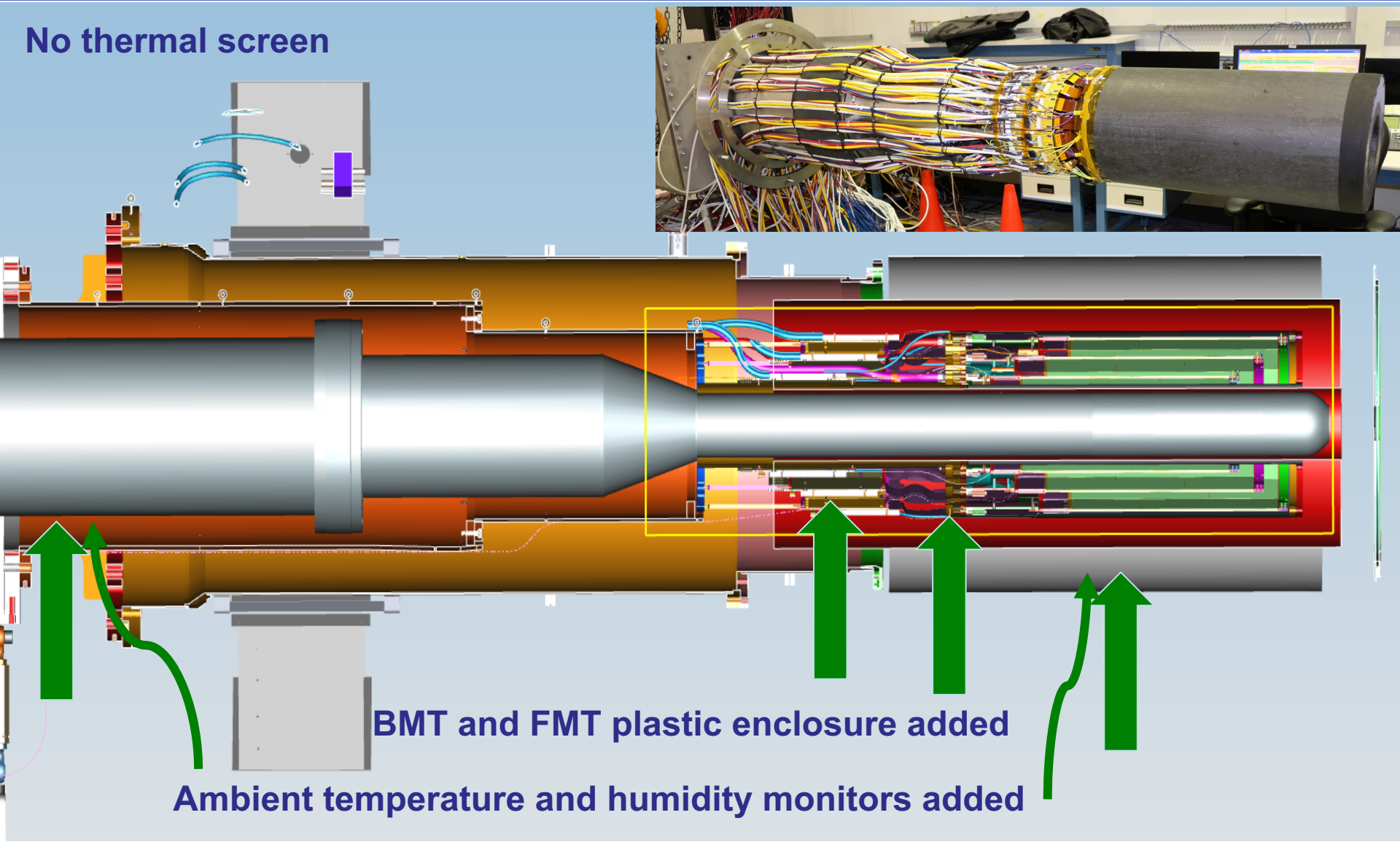




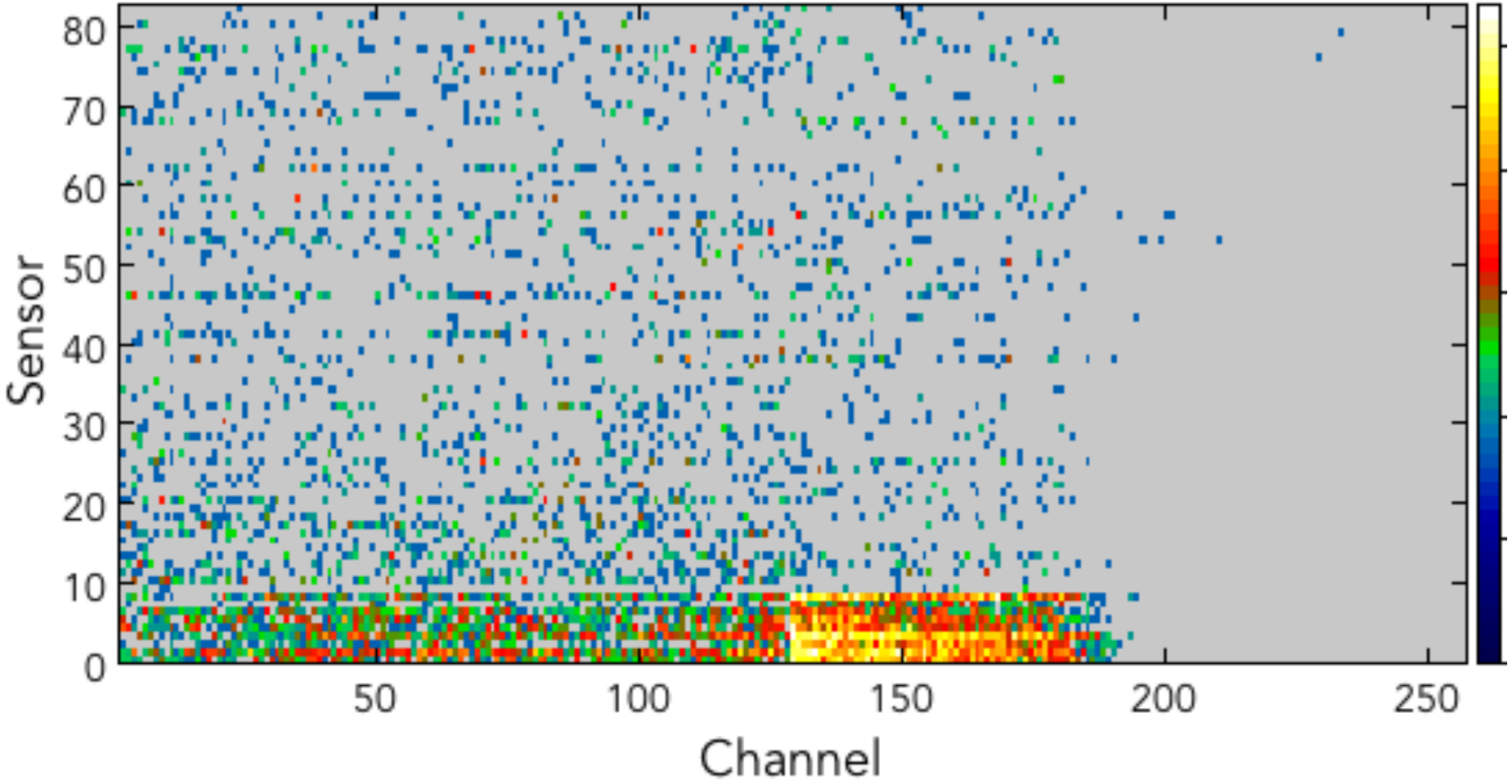




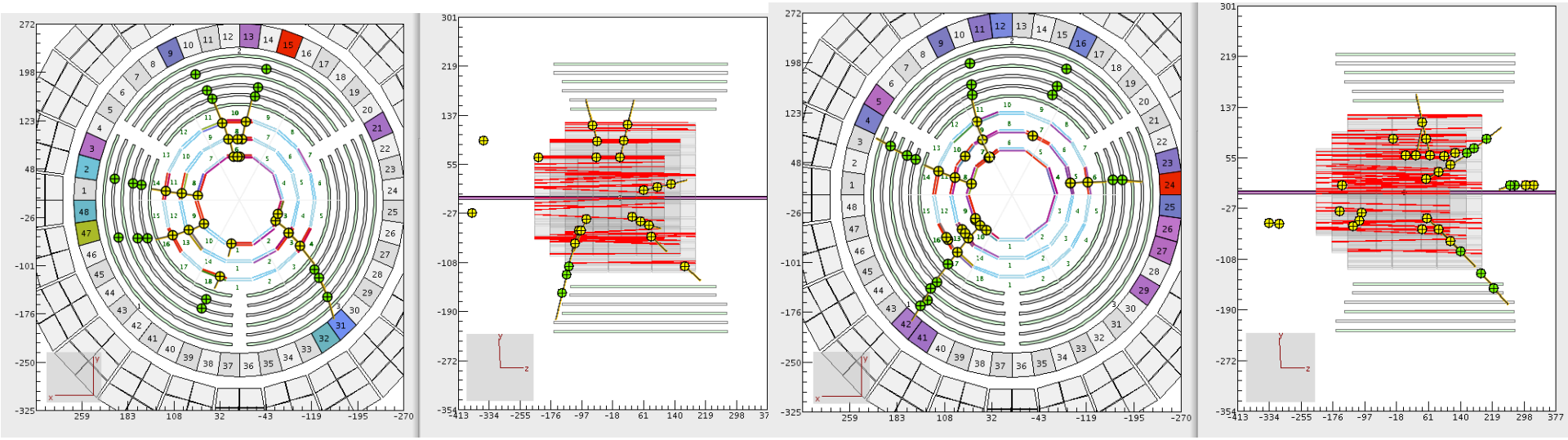
CVT Nitrogen Purging System: dealing with humidity issue at low temperature

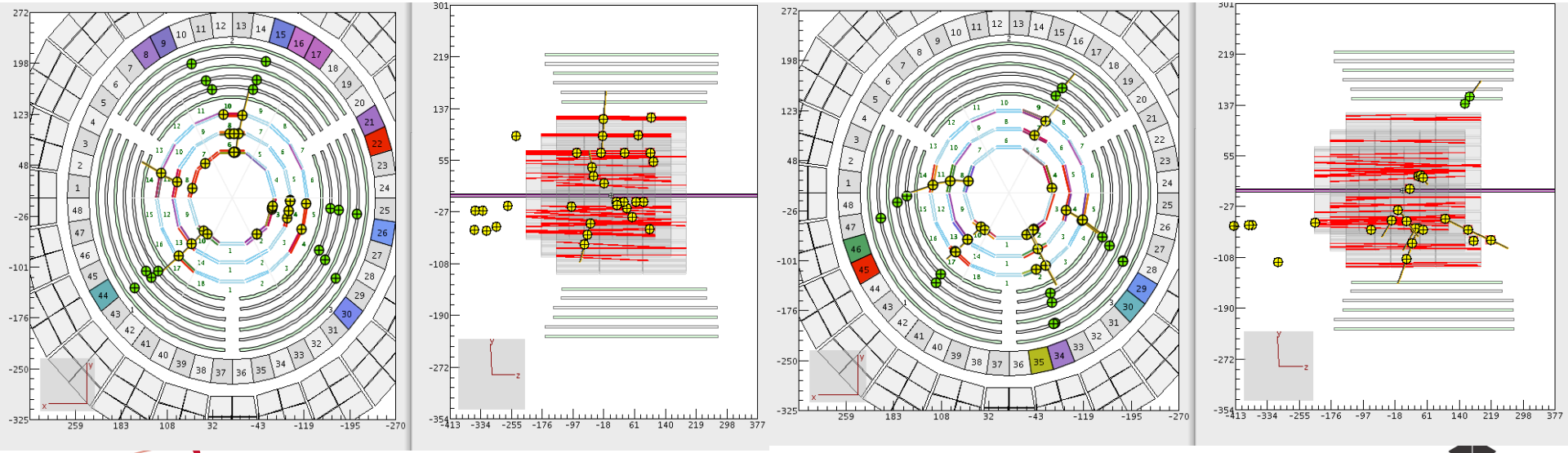


Run 1909, no beam, channel hit occupancy

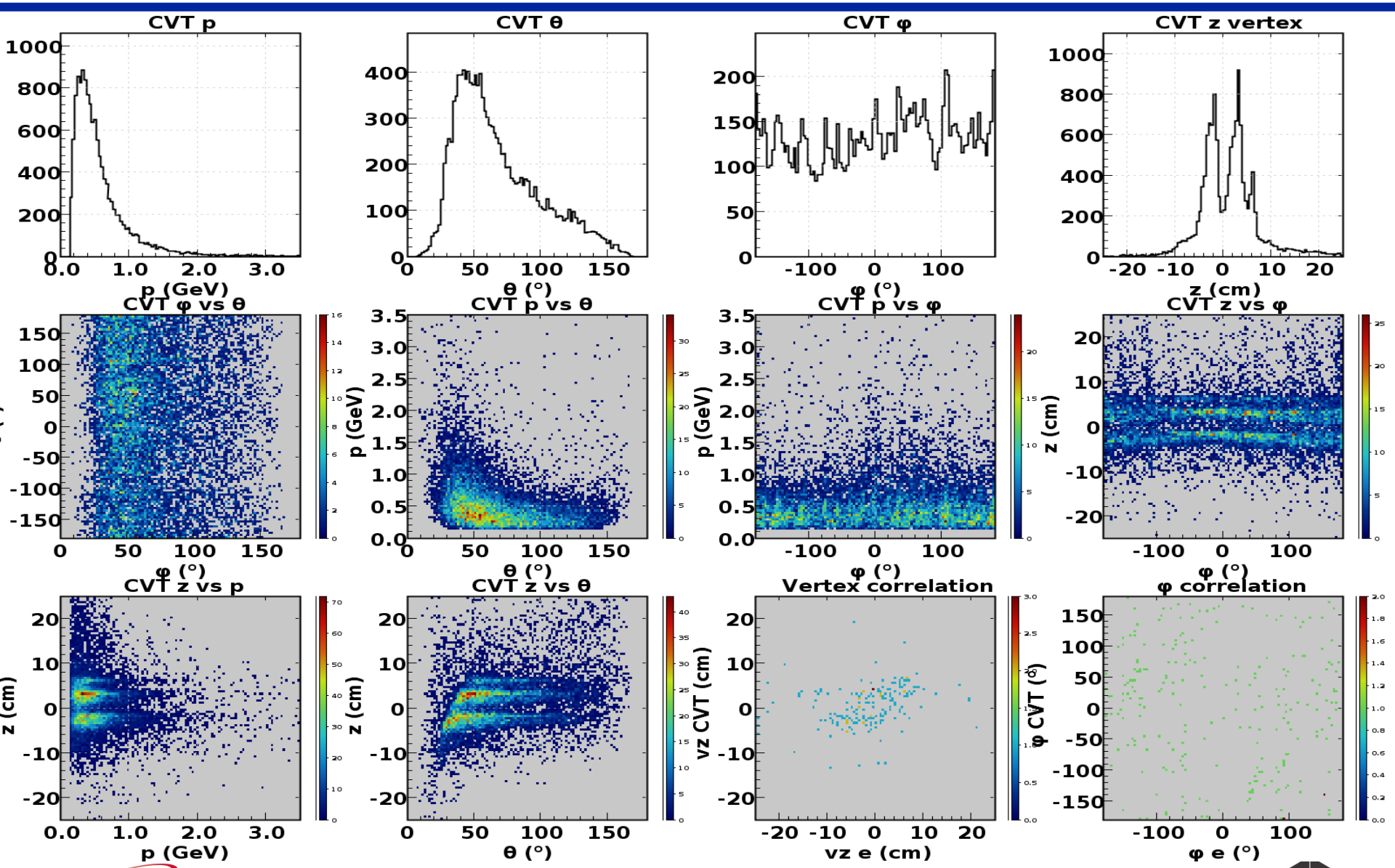


Reconstructed CVT tracks, empty target, beam current 5 nA

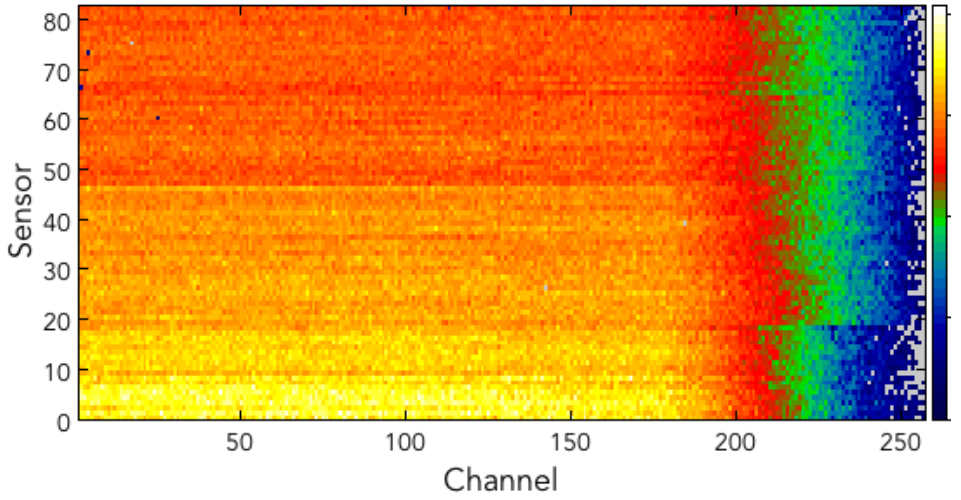


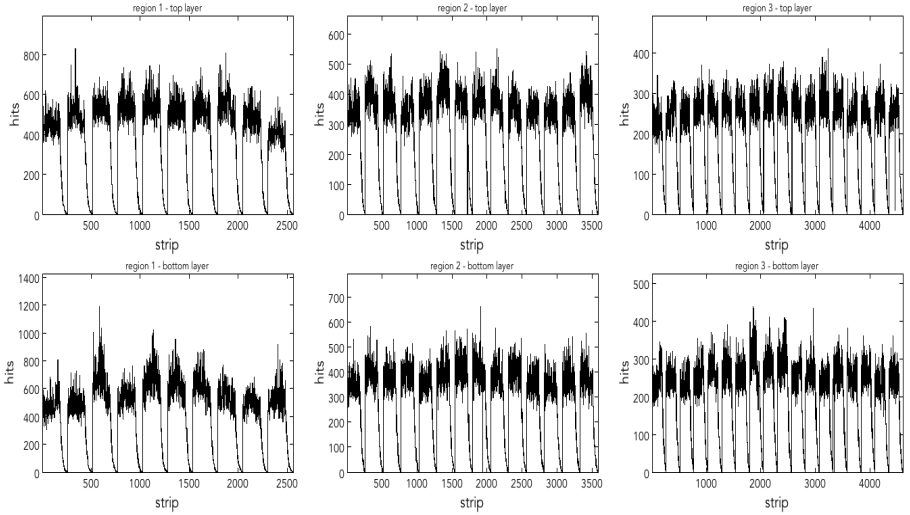


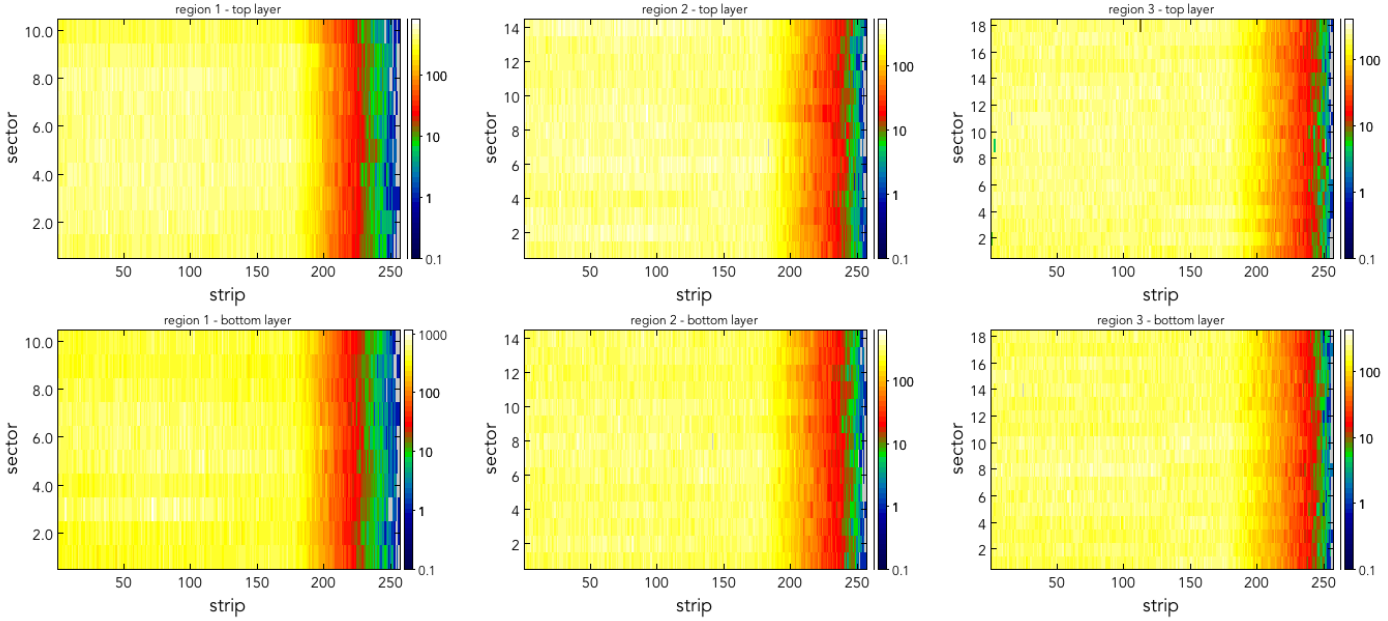
CVT reconstruction, run 1985, empty target, beam current 5 nA



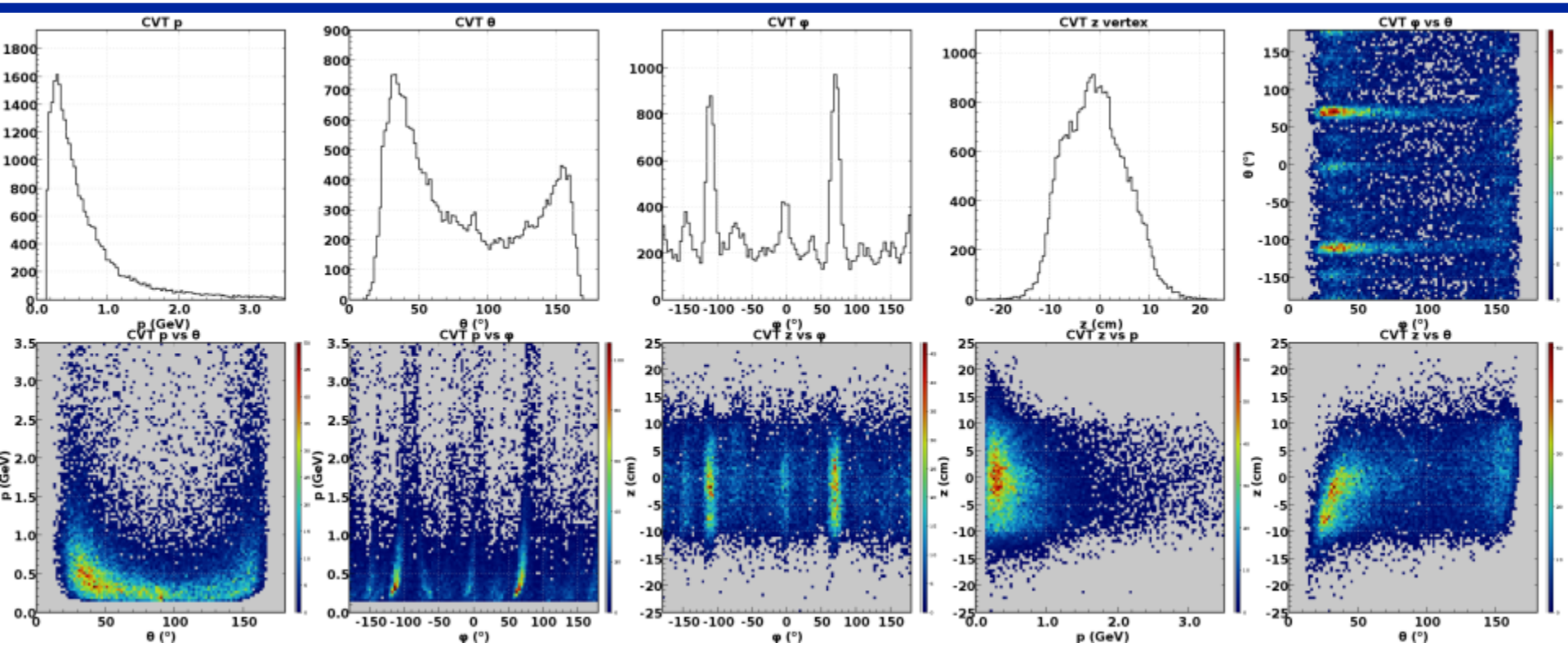
Run 2091, IH_2 target, beam current 10 nA





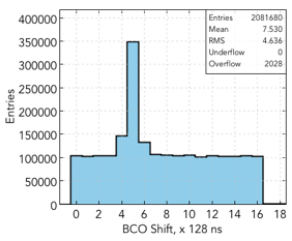


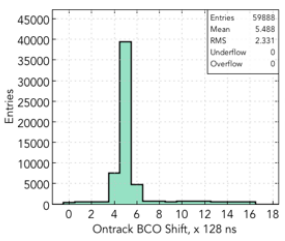
CVT reconstruction, run 2136, IH_2, beam current 30 nA

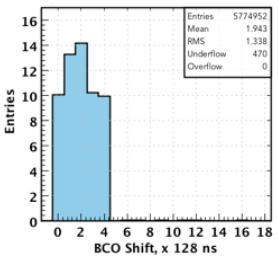


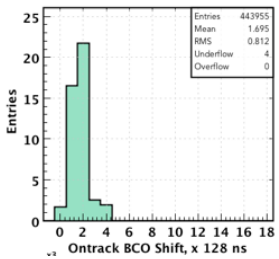
Trigger window, hit/no-hit thresholds:

- Run < 2124: 2048 ns, 30 % MIP
- 2124: 768 ns, 30 % MIP
- Run > 2126: 768 ns, 30 % MIP
- except layer 1, 45 % MIP



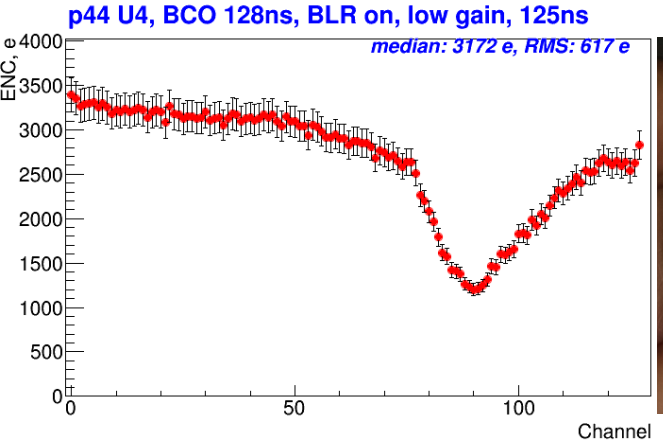


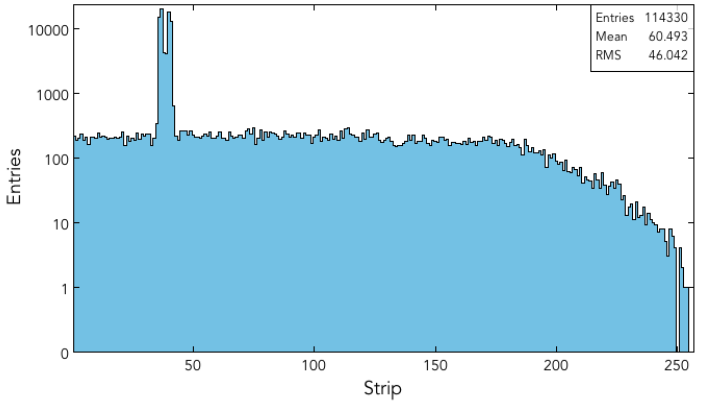




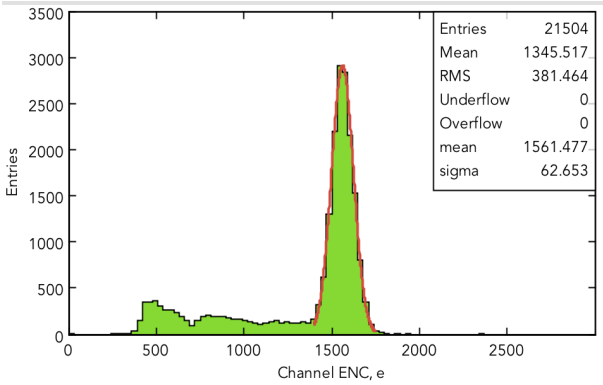
Problem Solving During the Run

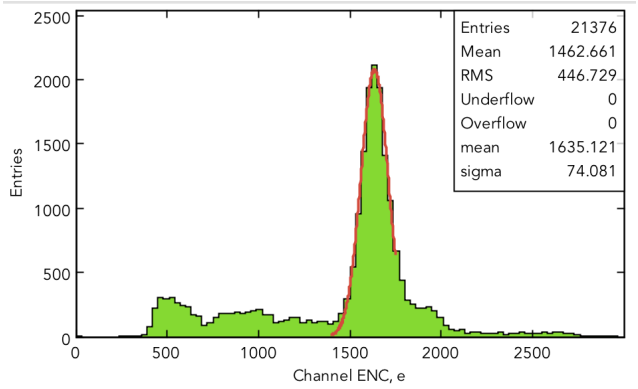
- Sensor radiation damage
- Chiller failures
- Interlock system (hardware failures, software issues)
- Network errors
- EPICs/CSS timeouts
- Flow meter failures in solenoid field
- Shielding Region 1 with tungsten foil

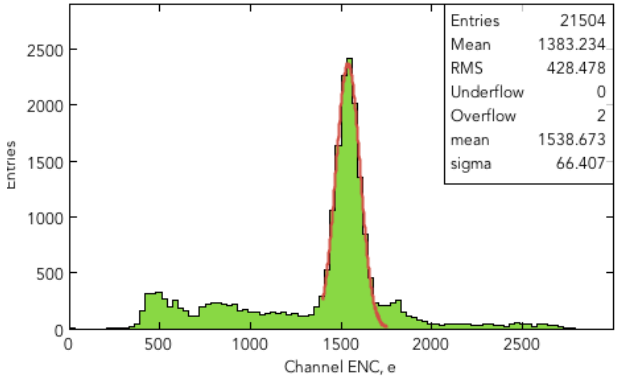


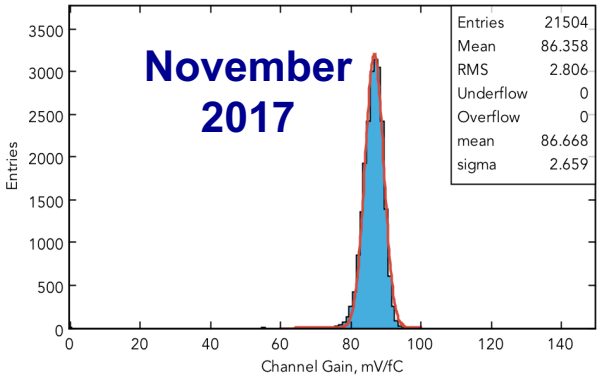


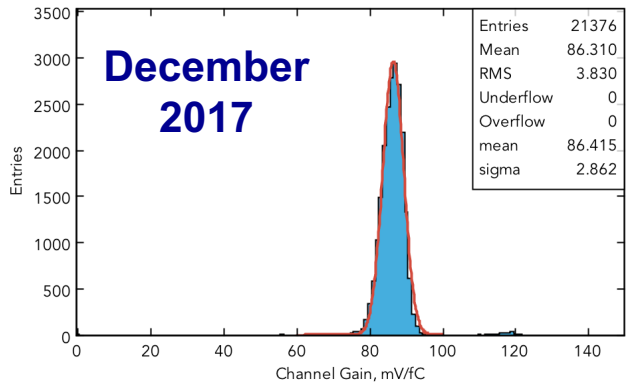
SVT Calibration

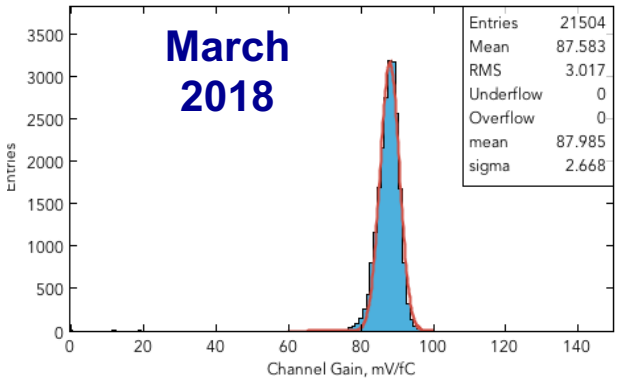












Water cooling

Glycol cooling

SVT settings, performance

Trigger Latency and Integration Window

- Window 128 * 4 = 512 ns, Latency (lookback) 979 * 8 = 7832 ns,
- BCO clock frequency 7.8 MHz (128 ns) (80 979 16, as in the VSCM config, in 8 ns units)

Discriminator Thresholds

- Layer 1: hit/no-hit 39 keV (MIP 87 keV) / 45 (MIP 100), 60, 75, 90, 105, 120, 135, 150
- Layers 2-6: hit/no-hit 26 keV (MIP 87 keV) / 30 (MIP 100), 45, 60, 75, 90, 105, 120, 135

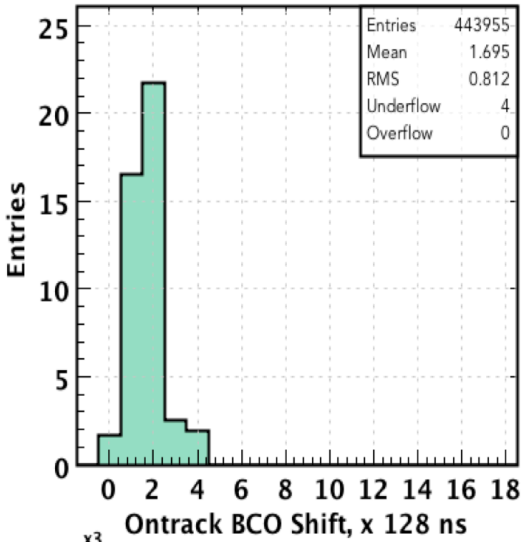
Rates and Occupancy

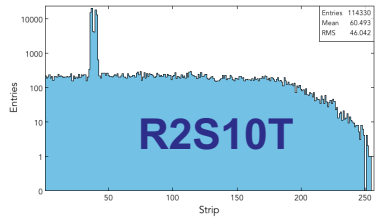
- ~2% at nominal luminosity (10.7 GeV, 75 nA beam current)
- Noisy strips in R2S5B, R2S10T

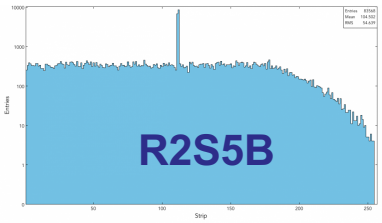
DAQ/ Readout issues

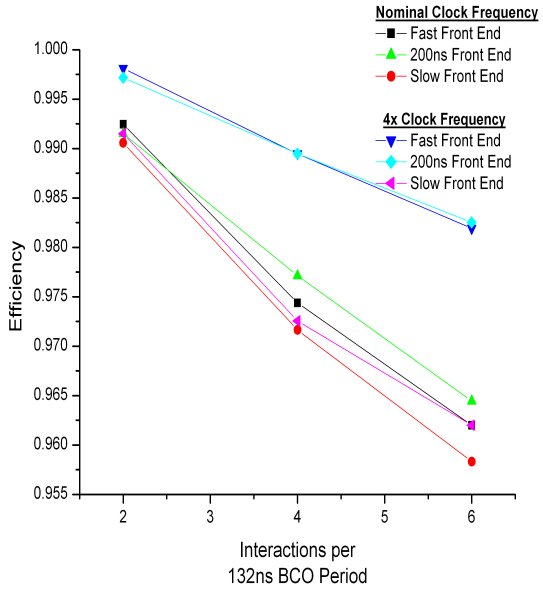
- R2S6U2: intermittent readout problems

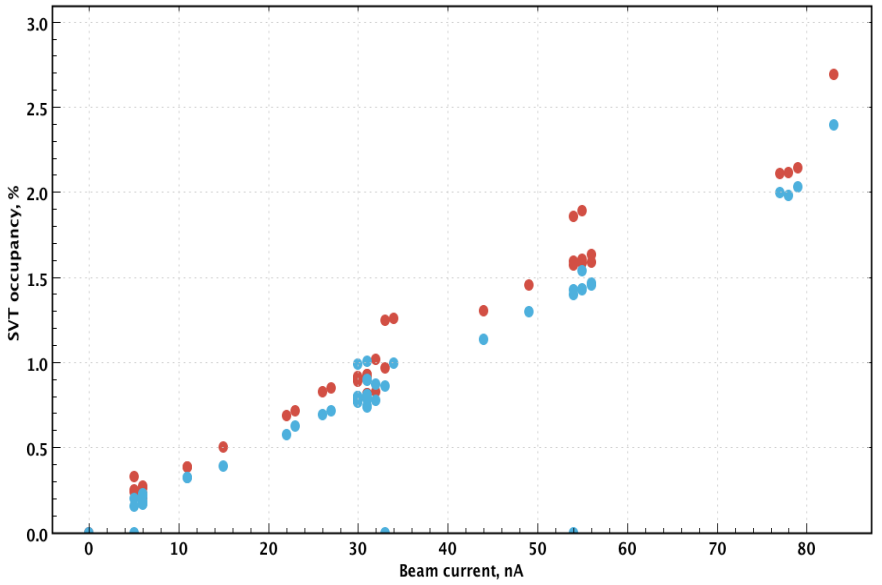
Sensor radiation damage caused substantial degradation of detector performance











SVT settings, performance

HV PS settings
- Layer 1: S1:50 V, S2: 17 V, S3: 35 V, S4: 40 V, S5: 50 V, S6-S10: 60 V
- Layer 2: S1, S2, S6-S10: 70 V, 4 sensors at lower bias
- Layers 3-6: 75 V
- BCO clock frequency 4 MHz (128 ns) (80 979 16, in 8 ns units)

Sensor Leakage
- Region 1: 600-800 nA
- Region 2: 400-600 nA
- Region 3: 400-600 nA

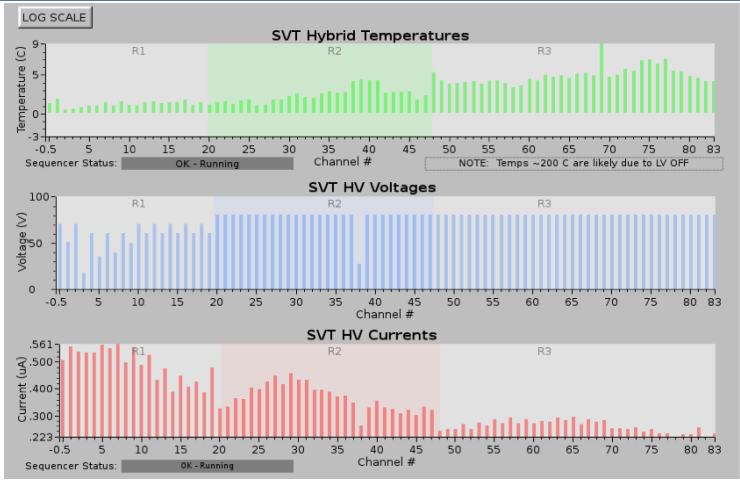
LV currents
- Analog: 300-350 mA, Digital: 140-180 mA

Hybrid temperatures
- 3-9 C

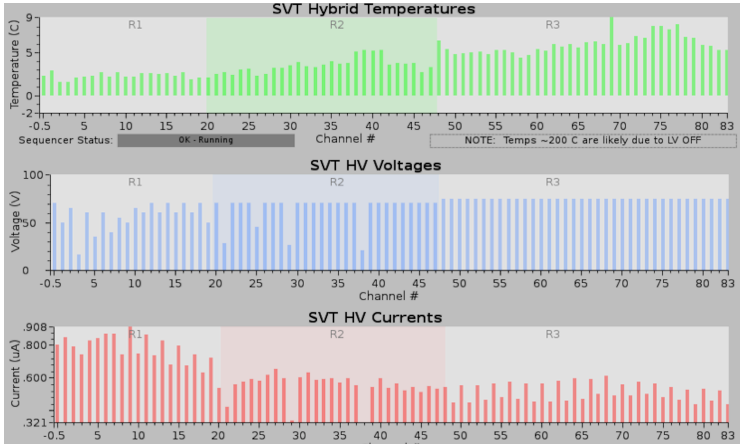
Ambient temperatures and humidity
- -1 - +5 C, 2%
- Chiller Temperature Settings
- Main chiller (Lauda): -18 C

Gas purging
- Nitrogen: 5-20 lpm

Noise and Gain
- Mean ENC: 1600 e, Mean Gain: 88 mV/fC
- Noise shoulder, mostly in the layer 1
- Possible pin-holes, 4 sensors in R2

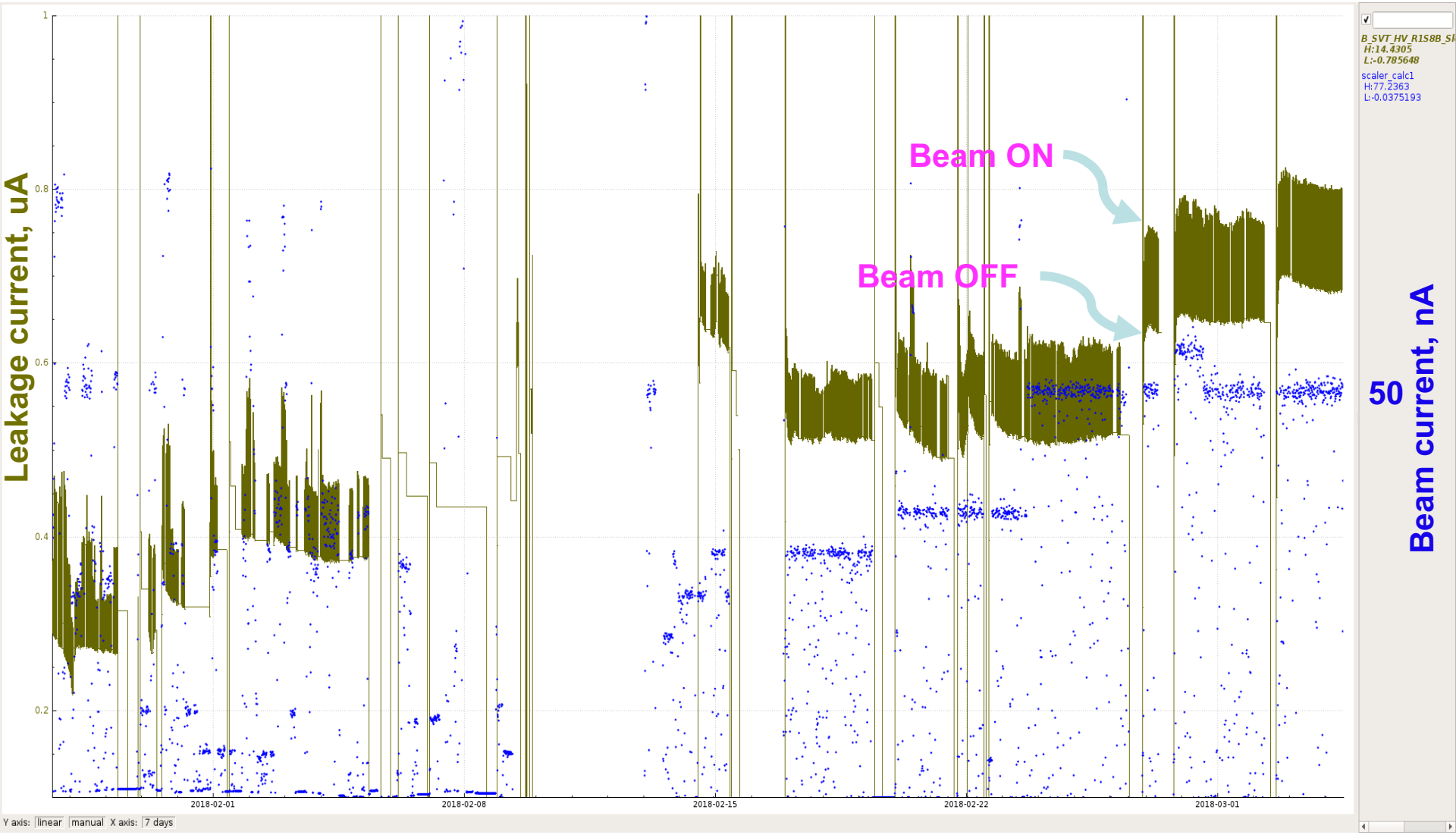


02/09/2018 coolant -14 C

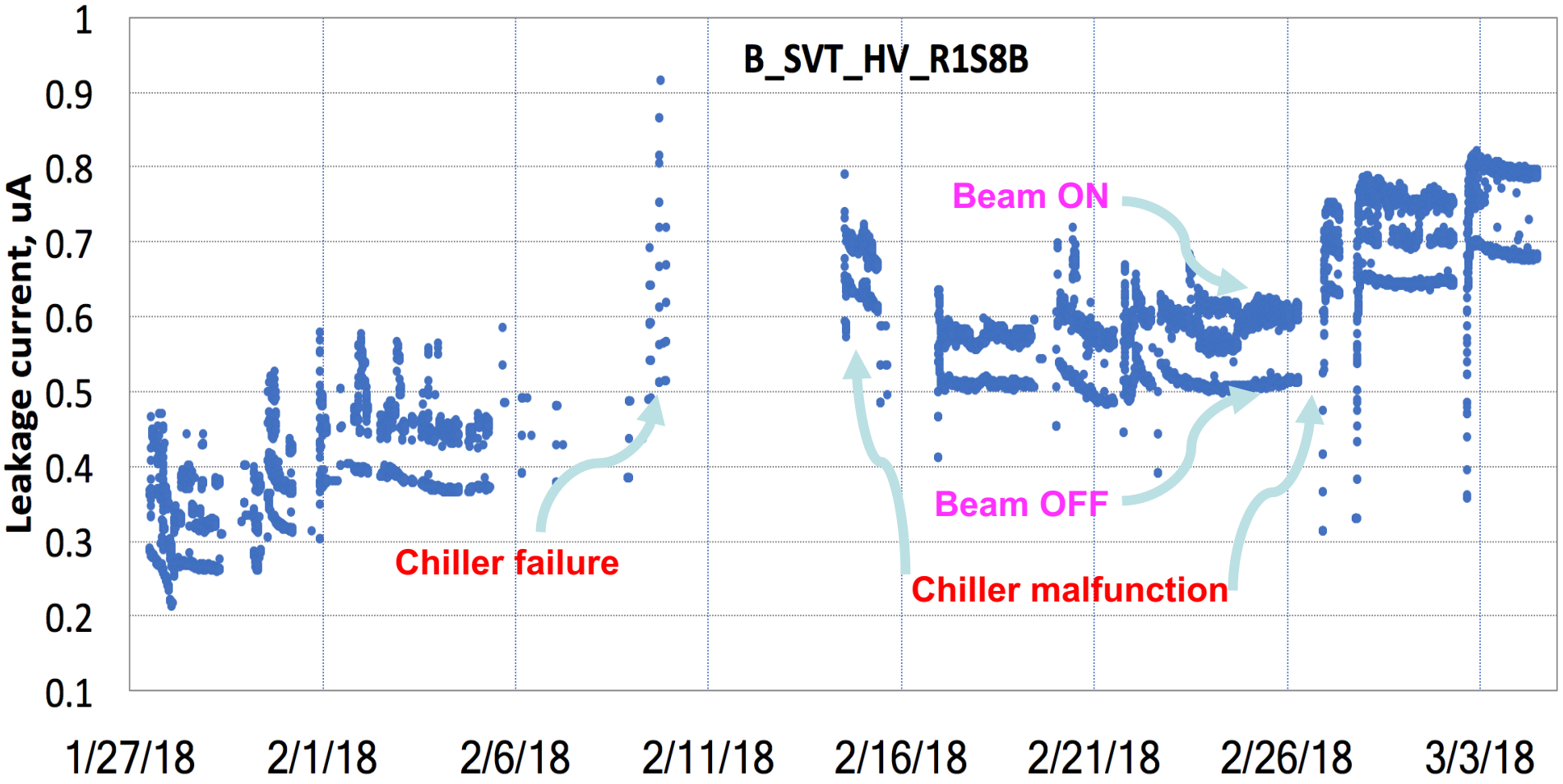


03/05/2018 coolant -18 C

Sensor Leakage History



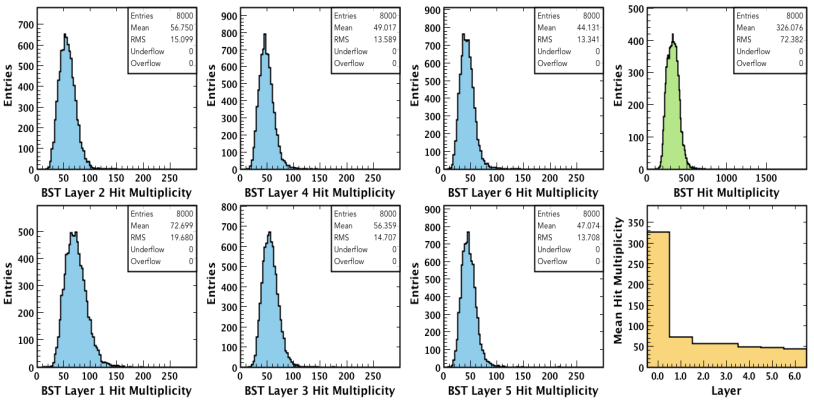
Sensor Leakage History

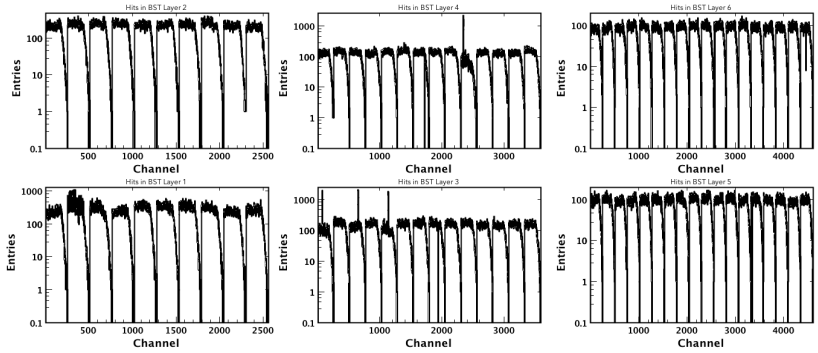


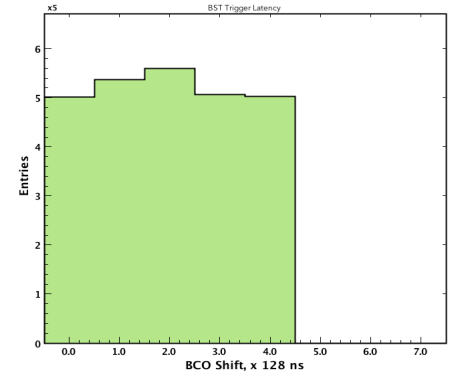
Current Status

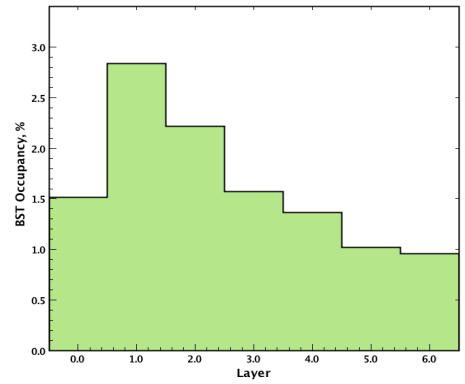
SVT performance is validated up to the design luminosity
Operational stability is not affected by the beam current up to 70 nA
Noise, gain, and signal stable for most of the sensors, good agreement with performance before the engineering run
Increase of the leakage current and performance degradation on modules received large radiation dose due to mistake with beam tuning in the first engineering run shift
Sensor leakage current is gradually increasing due to radiation damage
Four region 2 sensors developed pin holes (high leakage current, saturated preamps, strips with high occupancy)
Observed issues are caused by sensor radiation damage
Performance degradation due to reverse annealing continues, leakage current increased by 100-300 nA
Currently the maximum leakage current (at 55 nA beam current) is ~900 nA
Most of the sensors are biased at 70-75 V
Sensor bias for the sensors with high leakage current is lowered to prevent breakdown
Sensor bias on several modules is close to the limit
Sensor degradation due to reverse annealing is not recoverable
Sensor temperatures are still too high to prevent degradation, despite actions taken to lower them (coolant change, sealing, purging system modifications). Hybrid temperatures are within 3-9 C. Ambient humidity ~2%.
Cooling system cannot support operational stability due to additional load at low temperatures
Negative results from testing the nitrogen cooling system
Investigating possible scenarios to improve sensor operational conditions
Trigger latency is optimized, integration window is set to 4 BCO clocks (512 ns)
Discriminator hit/no-hit thresholds are set to 26 keV except in layer 1 chips (39 keV)
Hit occupancy in the SVT has linear dependence on the beam current, 2% at 70 nA
Higher occupancy (4%) in the innermost layer
Tungsten shielding tested, removed due to noise pick up in region 1
Slow controls, monitoring, and interlocks are functional, changes made based on experience with the system during the engineering run
Online monitoring operational
Front-end electronics functional, currents and voltages are within the specs
No issues with DAQ or data observed

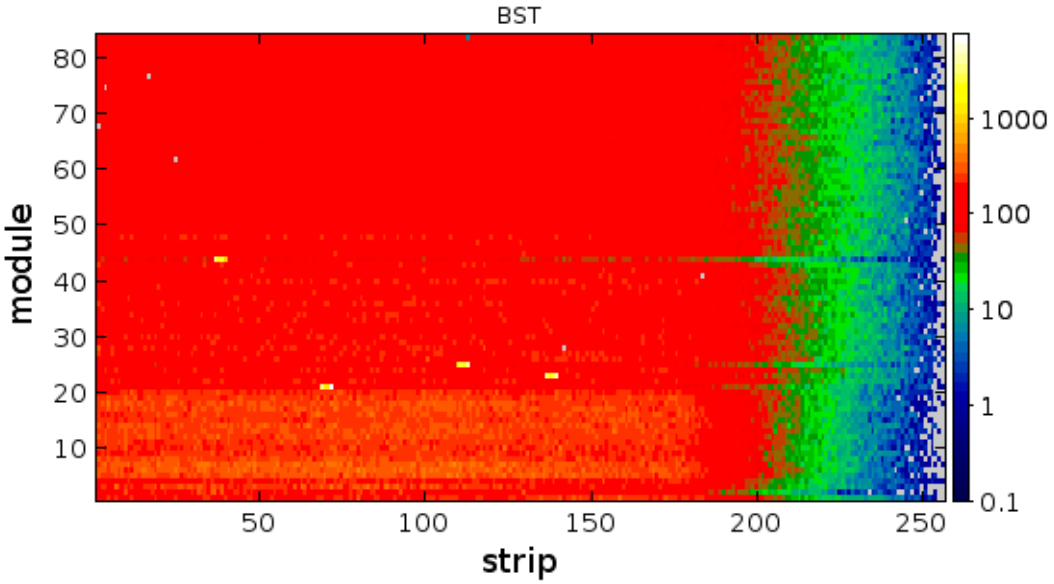
SVT Operation and Performance at 50 nA beam current

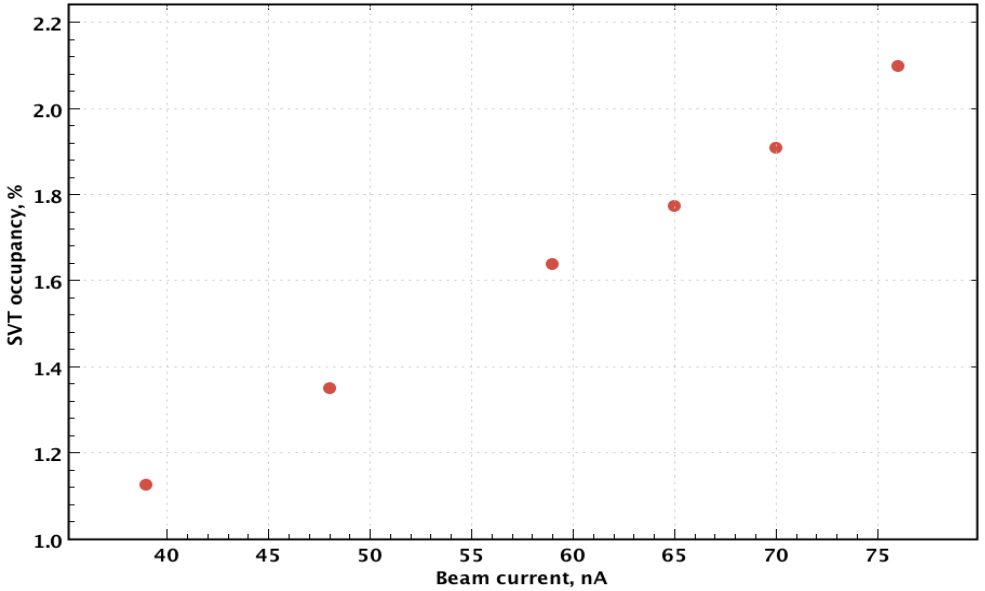




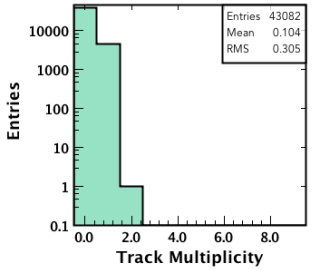


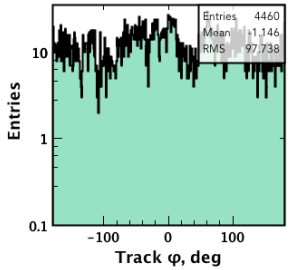


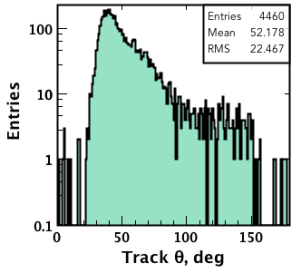


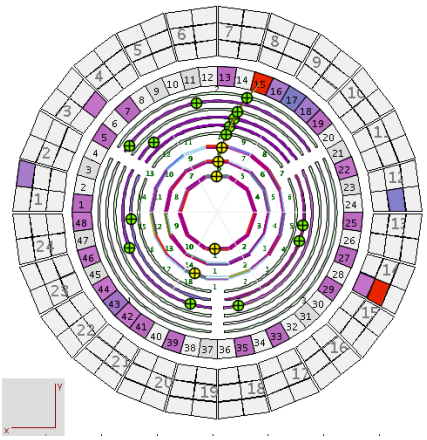


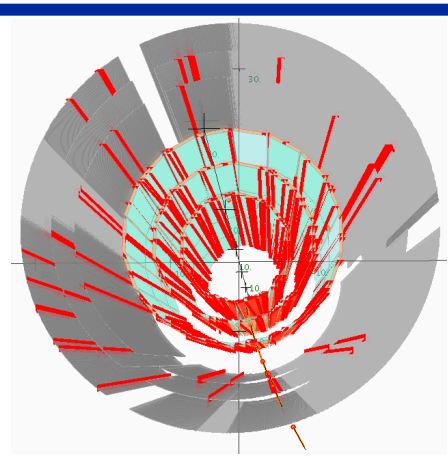
Tracking and Vertexing at 50 nA beam current

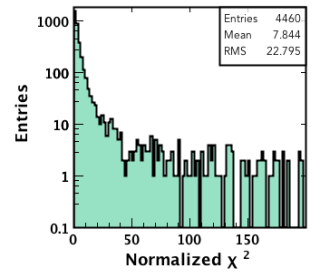


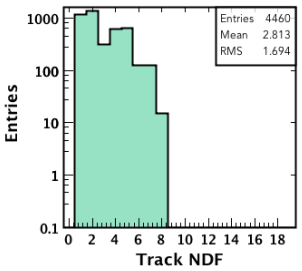


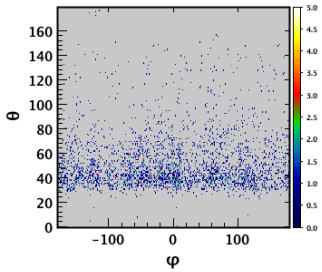


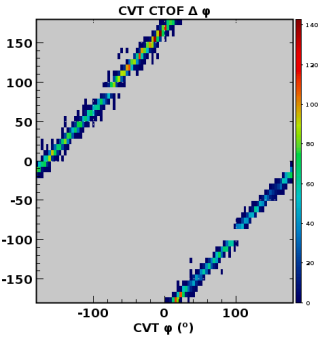


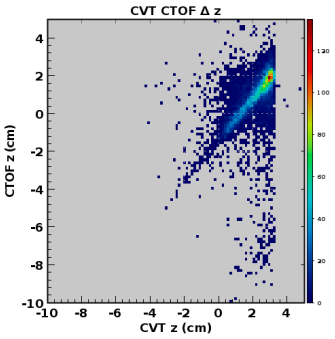


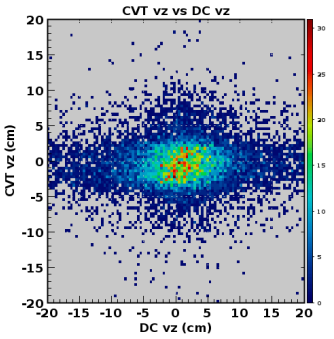


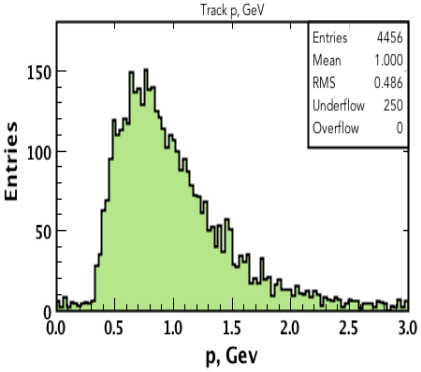


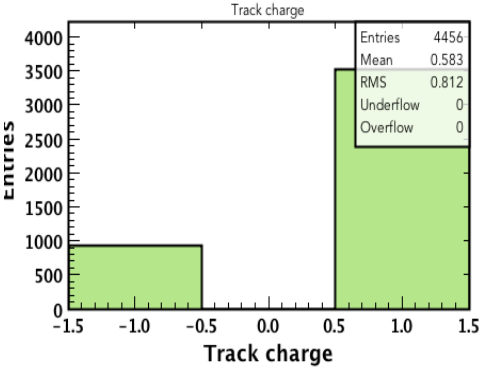


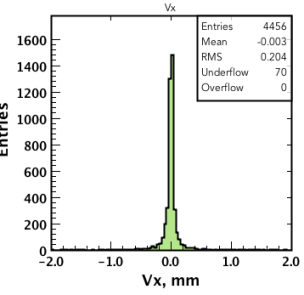


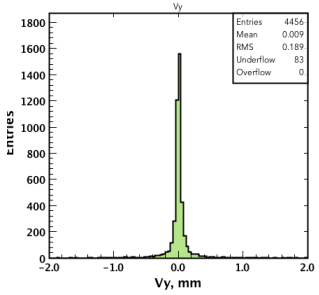


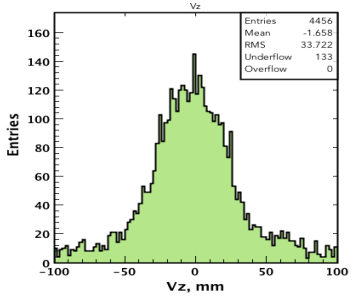


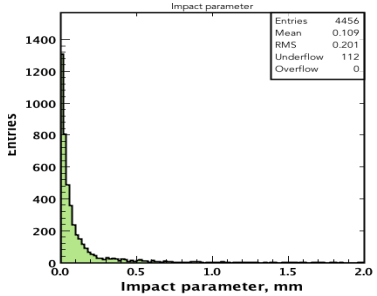


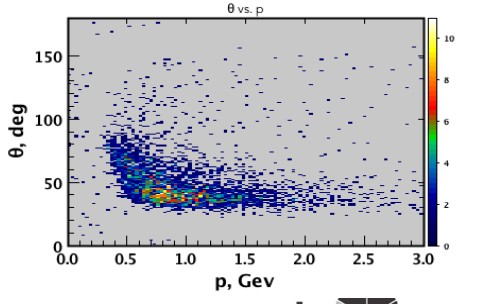










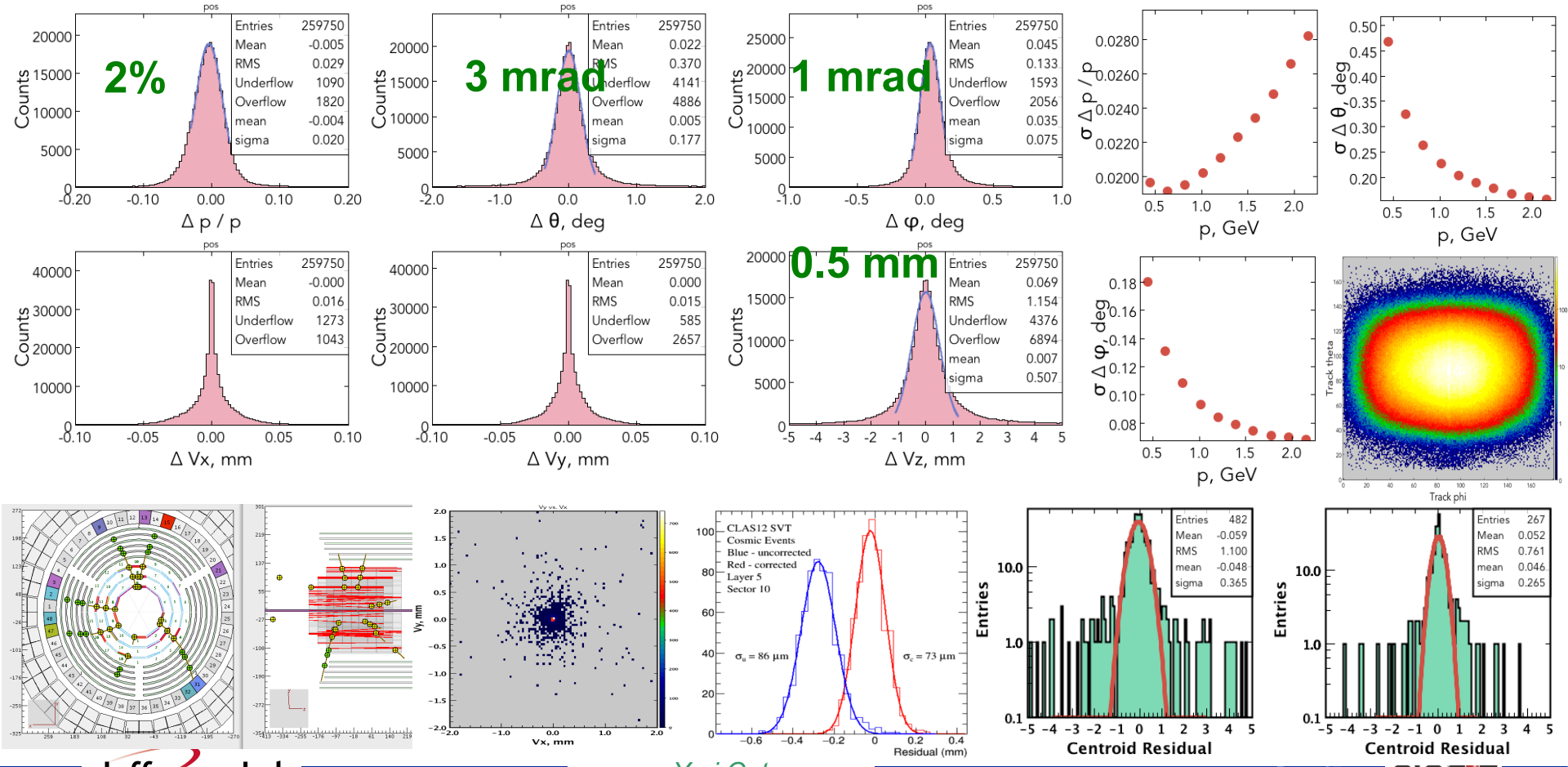


CVT Tracking and Vertexing Performance

The **CLAS12 SVT** system is a part of the Central Detector and will be used to measure the momentum and determine the vertex of charged particles emerging from the target. The SVT system includes 4 regions with 10,14,18, and 24 sectors of double-sided modules (silicon sensors on both sides of the backing structure) instrumented with digital readout ASICs, FSSR2s.

The system is designed to operate at a luminosity of 10^{35} $cm^{-2}s^{-1}$ and to have a momentum resolution of ~5% for 1 GeV particles emerging from the target at $\theta = 90^{o}$.

Angular coverage θ	35°–125°
Angular coverage Φ	~2π
Spatial resolution	50-65 μm
Momentum resolution	~6%
θ resolution	10–20 mrad
ϕ resolution	~5 mrad
Designed to operate at a luminosity of	10^{35} $cm^{-2}s^{-1}$



Outstanding Issues and Path Forward

- Operational stability (increasing of sensor leakage current)
  - Modifying cooling system
  - Working with chiller vendors (SPScientific, Lauda, Lytron)
  - Planning for possible replacement of R1/R2 modules
  - Evaluating installing the thermal shield around SVT
- Failed hardware interlock cRio processor (03/06/2018)
  - Installing loaner processor, ordering replacement
- Hardware interlock issues (leak detection, inlet temperature, ambient temperature)
- Integration of SVT hardware interlock to CSS
- Patch panel modification
- Fabricate and install V450 filters (Fast Electronics group)
- Survey misalignments (local and global) in tracker geometry
  - Validating misaligned geometry
  - Adding global misalignments
- Track based alignment using the alignment sample at 0 field
  - Development of alignment algorithm in progress
- Low track finding efficiency at current luminosity
  - Working on improvements of the tracking algorithm
  - Evaluating options on reducing beam backgrounds
- Analysis of commissioning data