In Flight Calibration of the Magnetospheric Multisale Mission Fast Plasma Investigation

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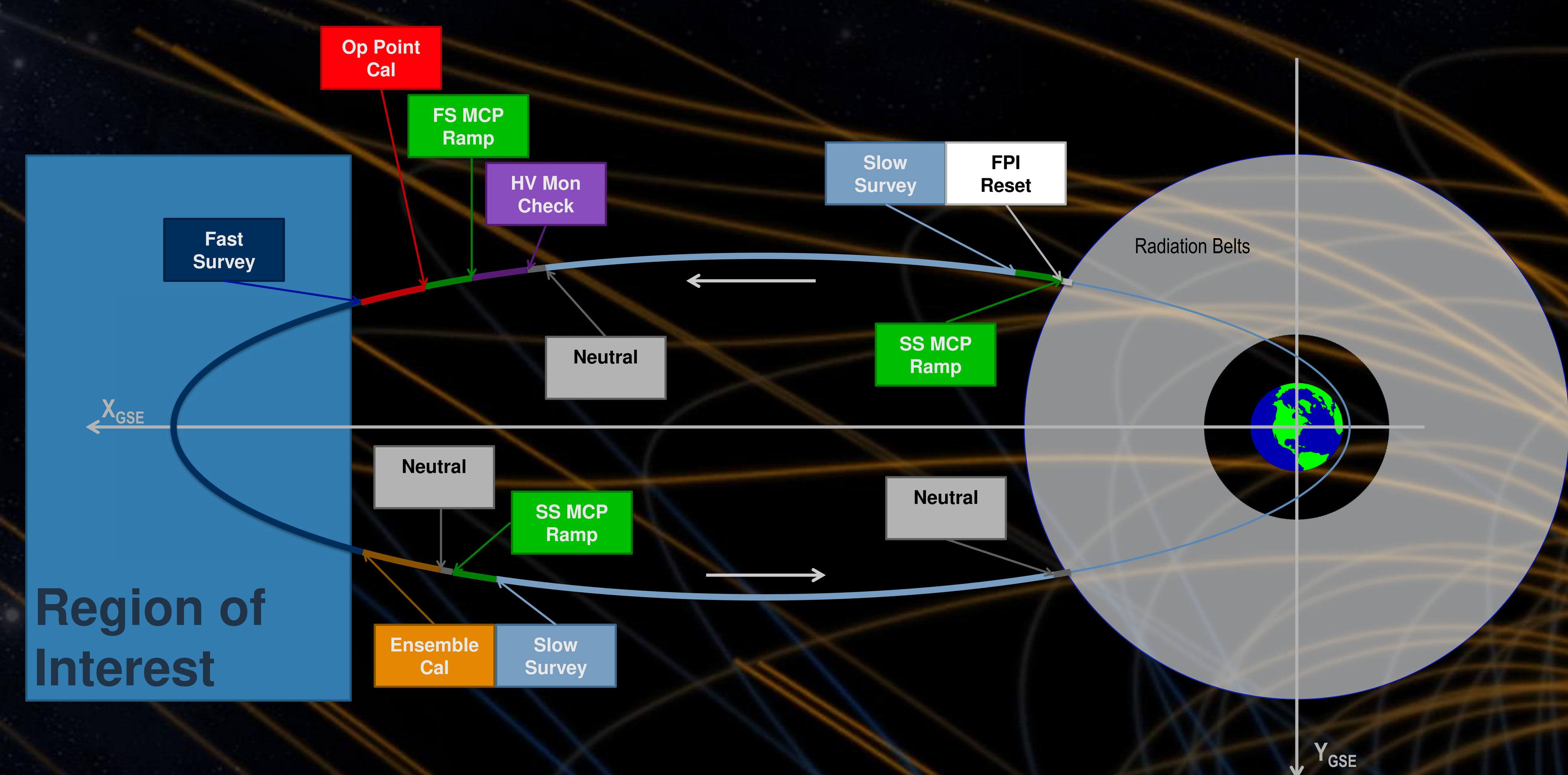
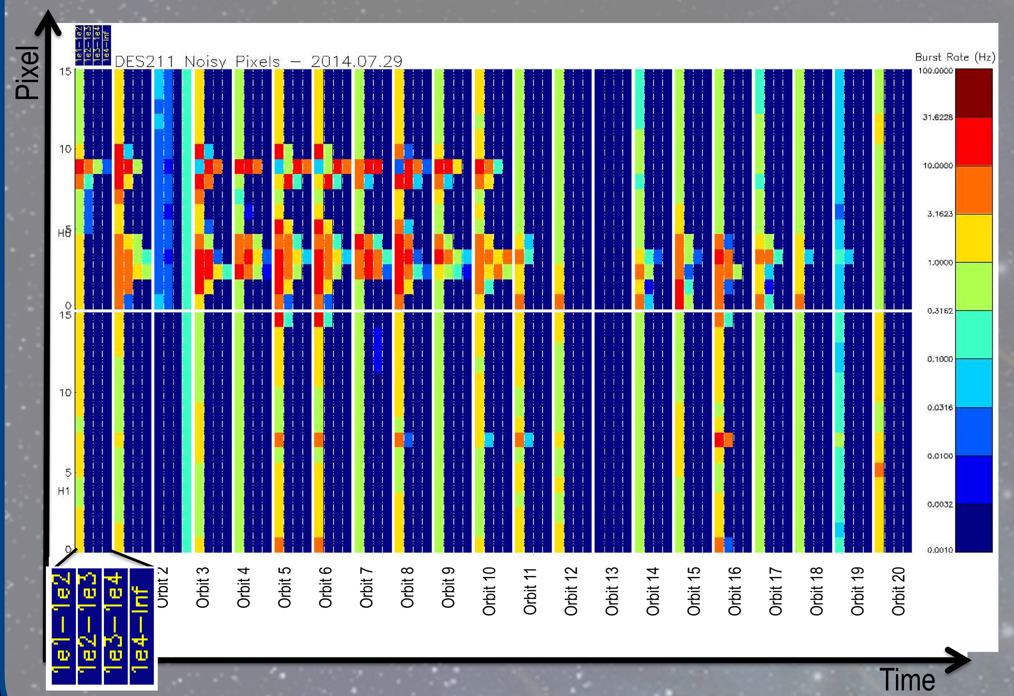
Abstract: The Fast Plasma Investigation (FPI) on the Magnetospheric Multiscale mission (MMS) combines data from eight spectrometers, each with four deflection states, into a single map of the sky. Any systematic discontinuity, artifact, noise source, etc. present in this map may be incorrectly interpreted as legitimate data and incorrect conclusions reached. For this reason it is desirable to have all spectrometers return the same output for a given input, and for this output to be low in noise sources or other errors. While many missions use statistical analyses of data to calibrate instruments in flight, this process is insufficient with FPI for two reasons: 1. Only a small fraction of high resolution data is downloaded to the ground due to bandwidth limitations and 2: The data that is downloaded is, by definition, scientifically interesting and therefore not ideal for calibration. FPI uses a suite of new tools to calibrate in flight. A new method for detection system ground calibration has been developed involving sweeping the detection threshold to fully define the pulse height distribution. This method has now been extended for use in flight as a means to calibrate MCP voltage and threshold (together forming the *operating point*) of the Dual Electron Spectrometers (DES) and Dual Ion Spectrometers (DIS). A method of comparing higher energy data (which has low fractional voltage error) to lower energy data (which has a higher fractional voltage error) will be used to calibrate the high voltage outputs. Finally, a comparison of pitch angle distributions will be used to find remaining discrepancies among sensors.



MCP Ramp

Each orbit, the MCPs will be ramped from 0 to full operating voltage before operating point cal and before each slow survey leg. During the main MCP ramp before operating point cal, integrate commands will be performed every 200V for the 1200V at and preceding the operating voltage. These integrates will be used to examine the aging behavior of the MCPs.

A sample plot of the pixel noise burst rates is shown. Each panel has 4 columns. Each of the 4 columns represents a decade in burst rate. For example, the first column represents how many times per second a burst of between 10 and 100 Hz occurred. A value of 5 in this column would mean that 5 times per second, a burst occurred with a count rate corresponding to between 10 and 100 Hz. Each panel represents a single complete ramp.

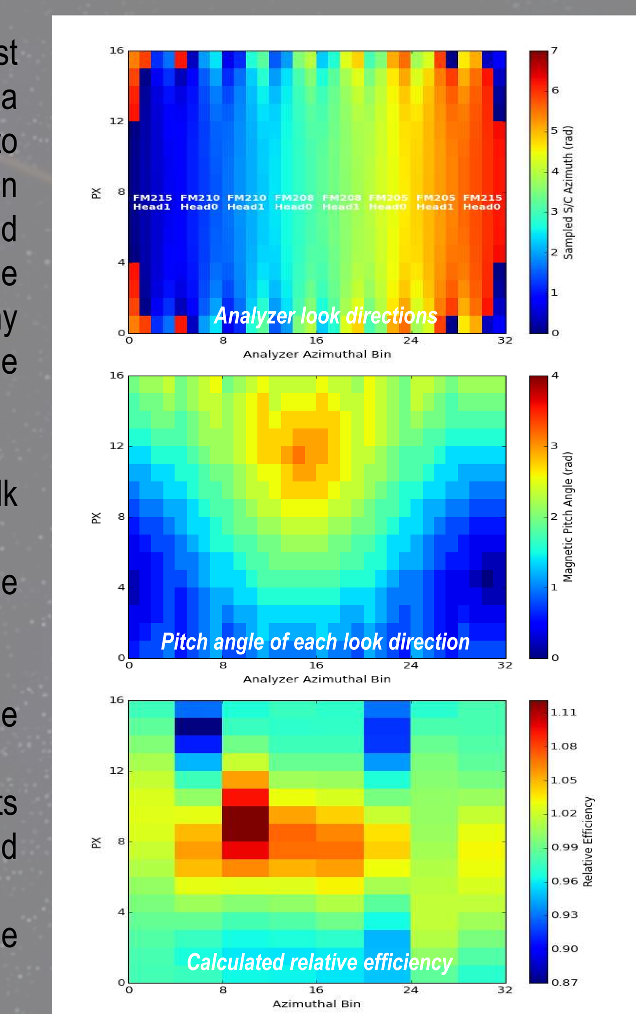


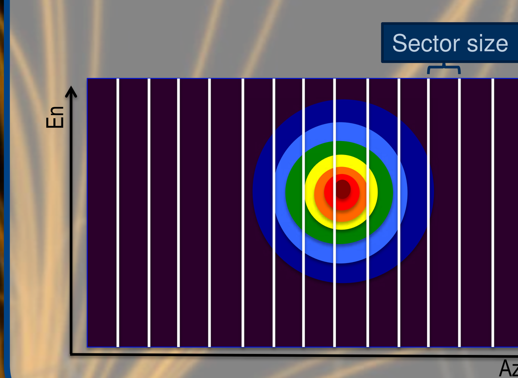
Burst Data Calibration

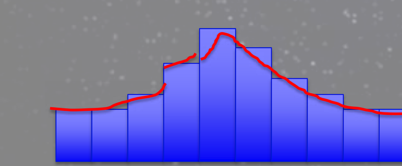
Burst Data Cal is a method of acquiring burst resolution data for a period of one spin (20s) at a chosen point in each orbit and using this data to perform statistical analyses of various calibration errors. This data is chosen by the FPI team and marked for download through a similar interface to the Scientist in the Loop. This activity does not require any commanding to the spacecraft as it occurs on the ground via the data ranking system.

For gyrotropic plasma with a small (<30 km/s) bulk velocity (e.g., plasma sheet),

1.For each burst map, calculate magnetic pitch angle sampled by each pixel using 'true' polar and azimuth targets
2. Accumulate counts from pairs of pixels that sample the same magnetic pitch angle
3.Form large (sparse) matrix of equations that asserts that each pixel measuring the same pitch-angle should report the same phase space density
4. Solve the matrix (linear least-squares) for the 'effective efficiency' of each pixel



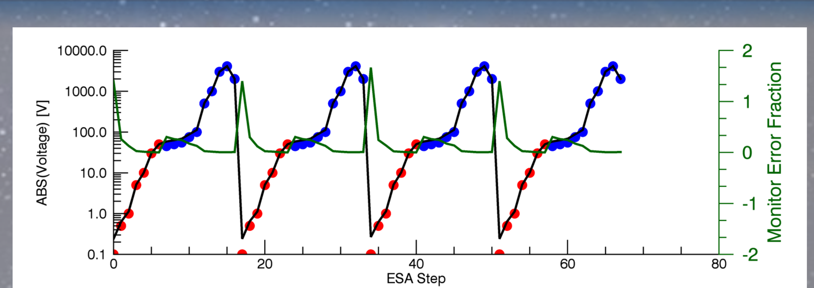


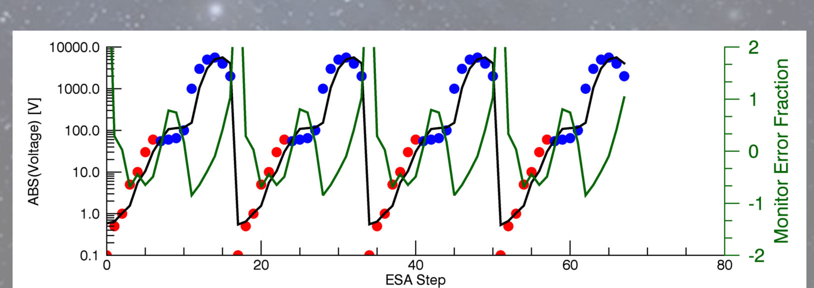


Single image washes out discontinuity, but integrated solution over all maps resolves discontinuity allowing offset to be determined

Burst data calibration will also be used to calibrate the HV deflection steppers. As highly structured plasma passes across the set of analyzers, look directions can be calibrated based on the observed location.

HV Monitor Check





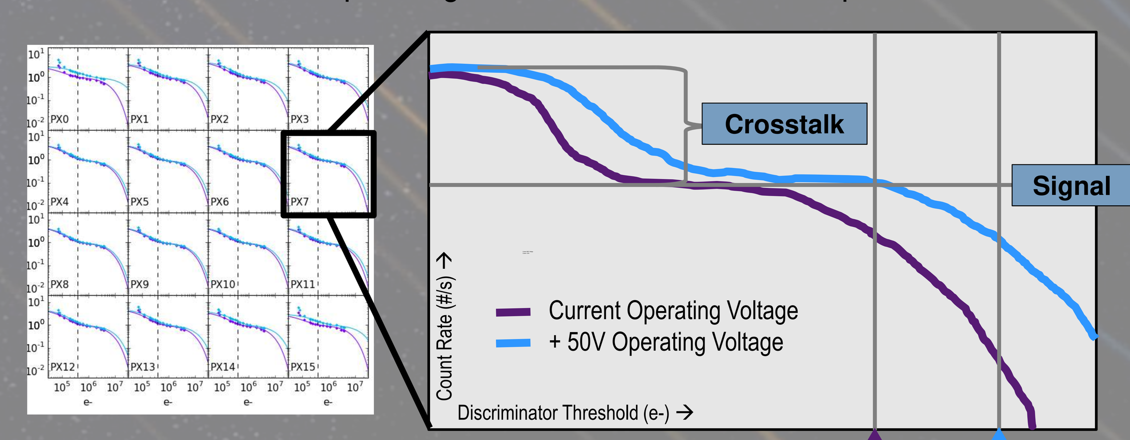
Over time, radiation will alter the behavior of the HVPS, requiring periodic recalibration of the voltage command settings. The purpose of the *HV Monitor Check* is to determine the extent to which the HV stepper values have drifted and to check for early signs of component failure within the HVPS.

The housekeeping packet returns the HV *monitor* values, which can drift independently of the actual output voltage. For this reason, the HV monitor by itself cannot be used for calibration – ie a monitor offset of 5V, does not mean that the voltage should simply be adjusted by 5V. Rather, the drift of the monitor over time gives an idea of the effect of radiation on the HVPS in general indicating that a more involved calibration is required.

Current is also measured with high voltages applied on each stepper. Elevated current at high voltages is a sign of pending component failure, which may be mitigated if detected early.

Operating Point Calibration

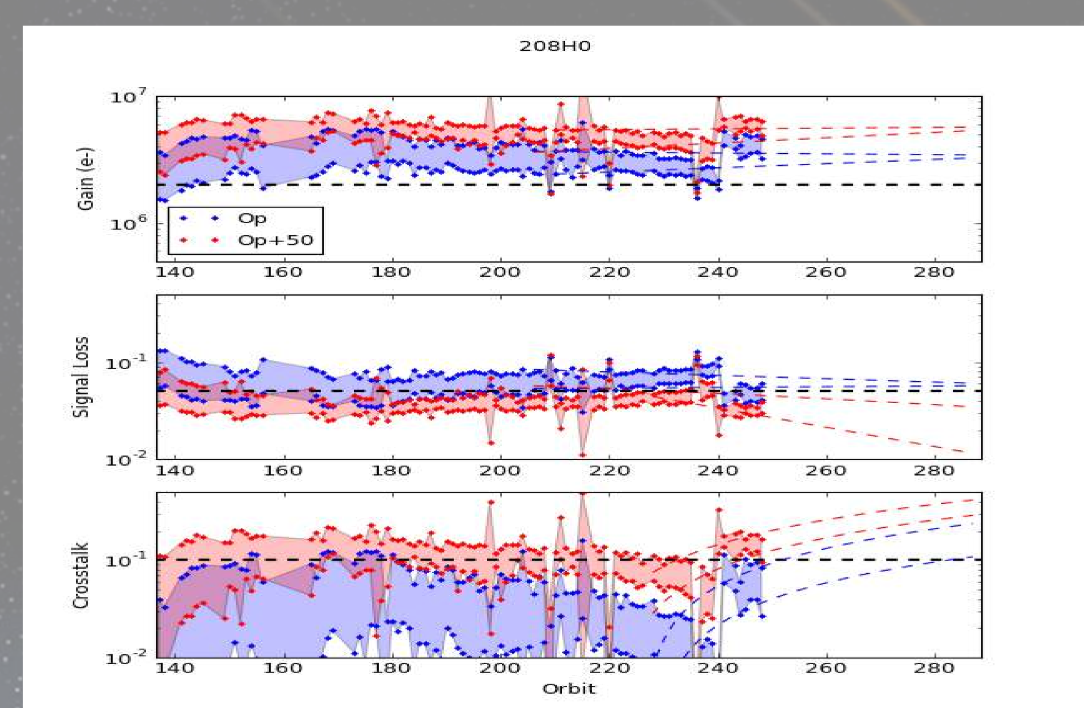
Operating Point Cal Threshold Sweeps



- Only time to test two MCP voltages
- Choose voltage to maintain desired gain

Gain is defined to be the point where 50% of the primary signal is resolved

- Performs sweeps of **16 discriminator thresholds** to determine gain
  - Each sweep takes ~ 2 seconds
  - Performed at **8 energies**
  - Repeated **16 times**
- Calibration process is performed at **current VMCP, and VMCP+50V**
- A MCP voltage is chosen that will minimize signal loss and crosstalk

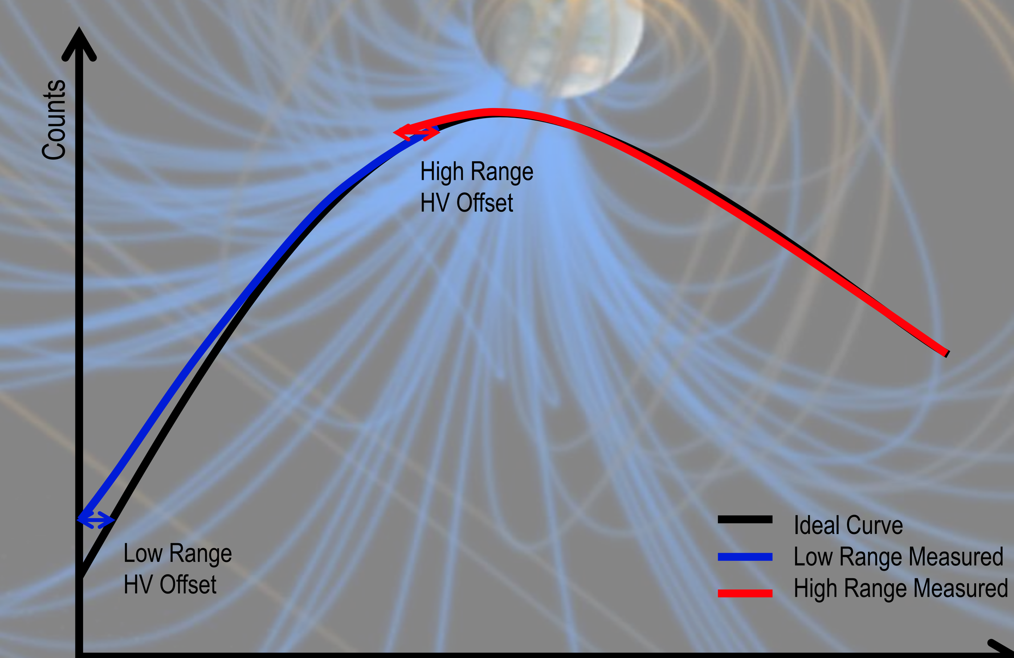


Loop Structure:

For 2 MCP Biases
For 8 Iterations
For 8 Energies
For 16 Thresholds
Integrate Counts

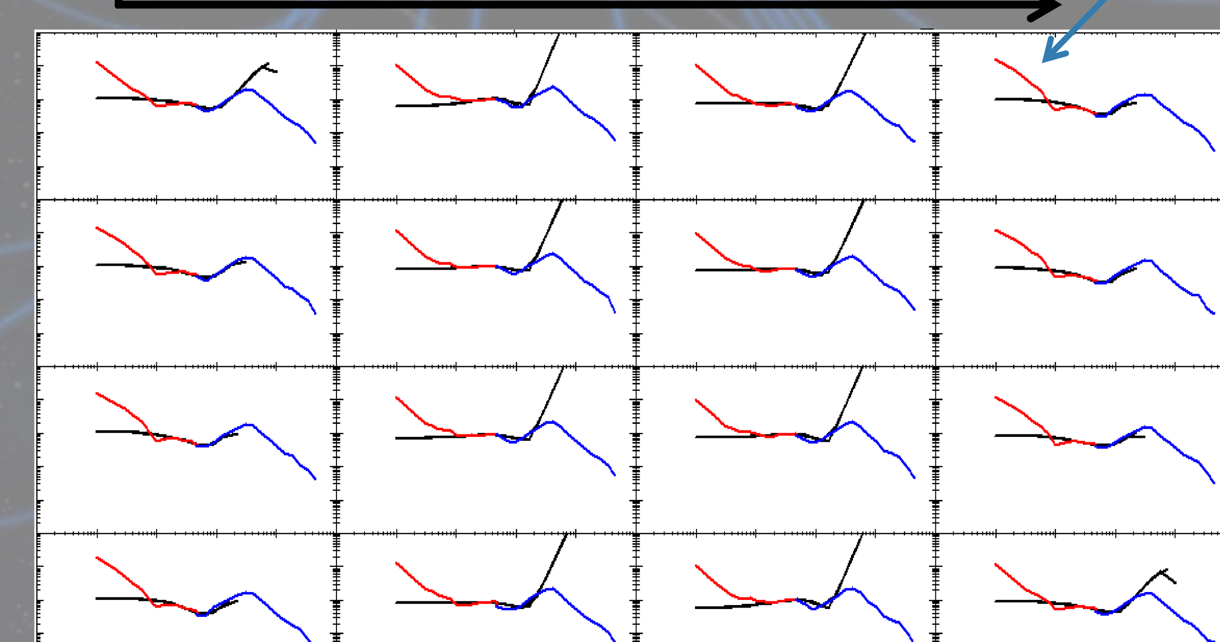
Gain, signal loss, and crosstalk will be trended over time as a function of MCP bias. Voltage will be periodically updated as gain droops (~ 1/month)

Ensemble Calibration



- The HV Monitor Check will reveal drift in the HV system due to radiation exposure – Ensemble Cal will attempt to calibrate the ESA stepper
- The HVPS changes from low to high range at 50V and 60V for DES and DIS, respectively
- The error in stepper voltage is in the form of a constant offset, which will be more noticeable at lower voltages within the range
- The high range can control down to 0V (i.e. there is overlap)
- A sweep of counts over stepper voltage (energy) will yield a discontinuity that directly leads to the voltage offset (error)

Larger than expected photoelectron signature makes reconstructing Low Range offset difficult



16 Pixels showing curve fits across low/high range boundary

Ensemble cal will be run immediately after exit from the region of interest. Its primary function will be to correct for HV stepper errors due to drift over time.

The ensemble cal data is collected simultaneously in all spectrometers for **16 spacecraft spins (each at a different MCP bias)**, making a best effort to show all spectrometers (on a given deck) the same plasma environment. The calibration is followed by 5 minutes of fast survey data to bracket the test with fast survey data on both sides for reference.

The cal mode data consists of two messages: a **32 step table of energy/deflection** summed over a 20s spin, and two of the 32 steps broken out into every 16ms integration (not averaged over a spin).

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