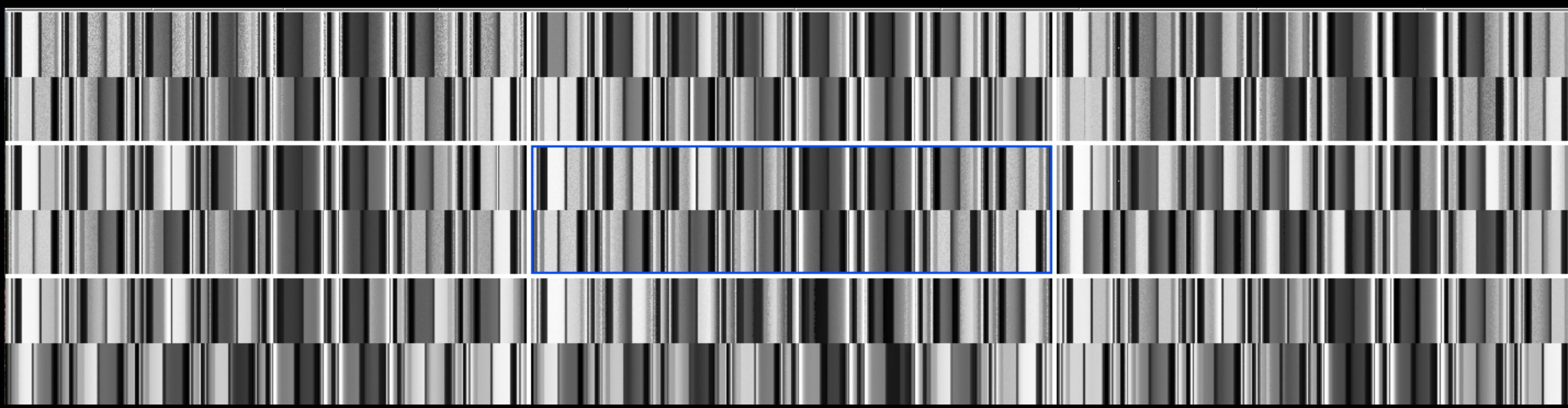
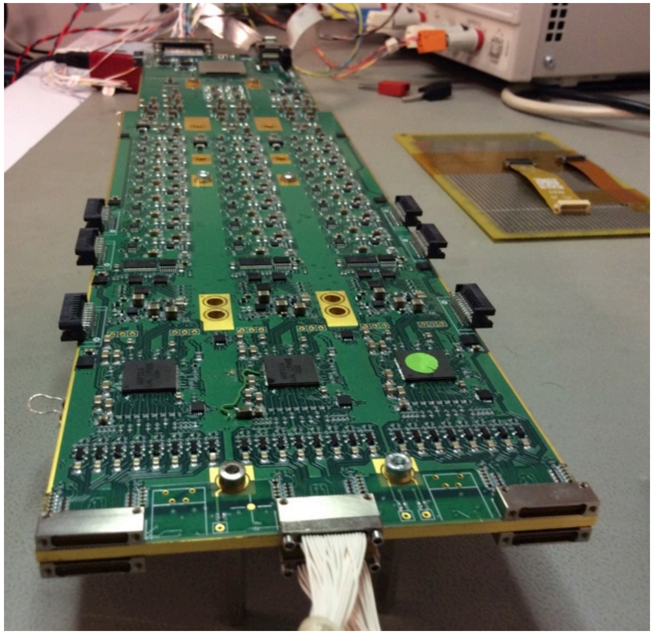
Diagnostic tools and CCD readout optimization in the first rafts of LSST



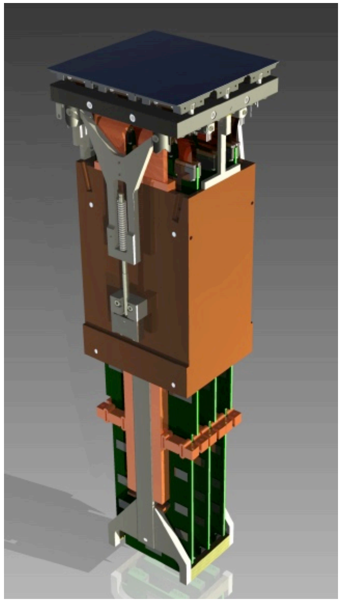
Claire Juramy

Scientific Detector Workshop 2017

Monitoring and diagnostic challenges



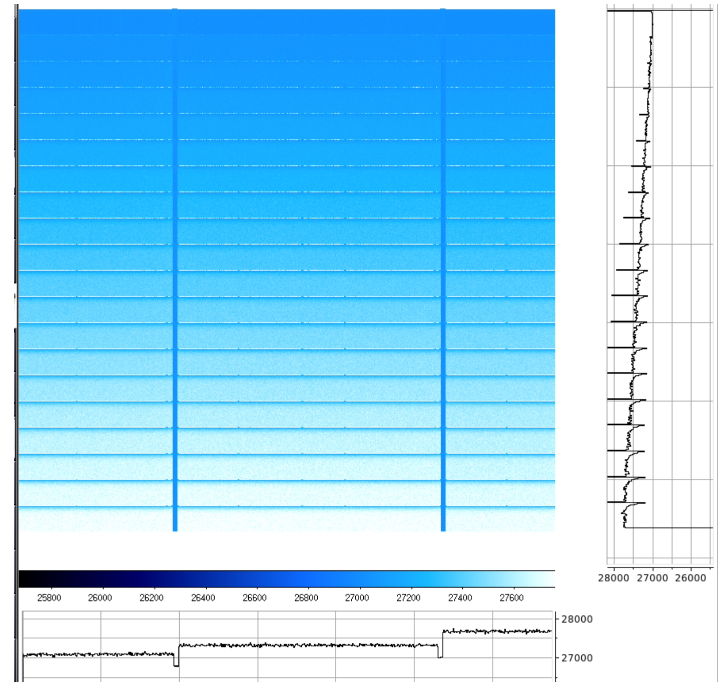
- LSST Focal Plane: 21 Camera Science Rafts: 9 CCDs, 12x12 cm footprint
- Control and readout of CCDs: Raft Electronics Board (REB): 3 CCDs, 48 video channels, 1 FPGA
- All in-cryostat
- On-board monitoring of DC values
- Diagnostic of video channels: ?



Raft Tower Module (BNL)

CCD readout: FPGA sequencer

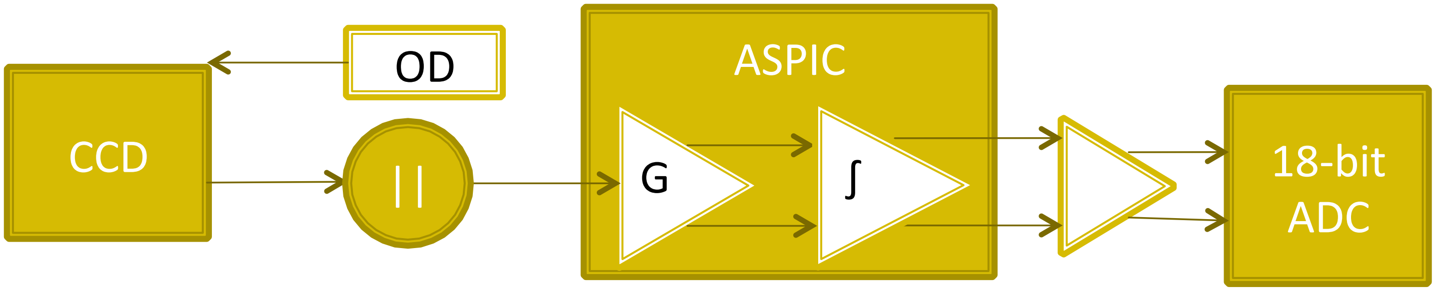
- Sequencer block in firmware of FPGA (Stefano Russo): controls parallel clocks, serial clocks, readout clocks, including sampling trigger for ADC
  - functions: linear sequence of clock states
  - program memory: subroutines, calls to functions and other subroutines
  - pointers: storing constants and addresses in dedicated registers
- Scan mode / scope mode: the ADC sampling trigger is delayed by increments of 10 ns each time it is sent, up to 2550 ns.




```
[functions]
ReadPixel:  # Single pixel read
    clocks:          RG, S1, S2, S3, CL,RST, RD, RU,TRG
    slices:
        TimeS        = 1,  0,  1,  0,  0,  0,  0,  0,  1
        BufferS      = 1,  0,  1,  1,  0,  1,  0,  0,  0
        BufferS      = 0,  0,  0,  1,  0,  1,  0,  0,  0
        220 ns       = 0,  0,  0,  1,  1,  1,  0,  0,  0
        ISO1         = 0,  0,  0,  1,  0,  0,  0,  0,  0
        RampTime     = 0,  0,  0,  1,  0,  0,  1,  0,  0
        BufferS      = 0,  1,  0,  1,  0,  0,  0,  0,  0
        ISO2         = 0,  1,  0,  0,  0,  0,  0,  0,  0
        RampTime     = 0,  1,  0,  0,  0,  0,  0,  1,  0
        BufferS      = 0,  1,  1,  0,  0,  0,  0,  0,  0
    constants:       P2=1, P3=1
```

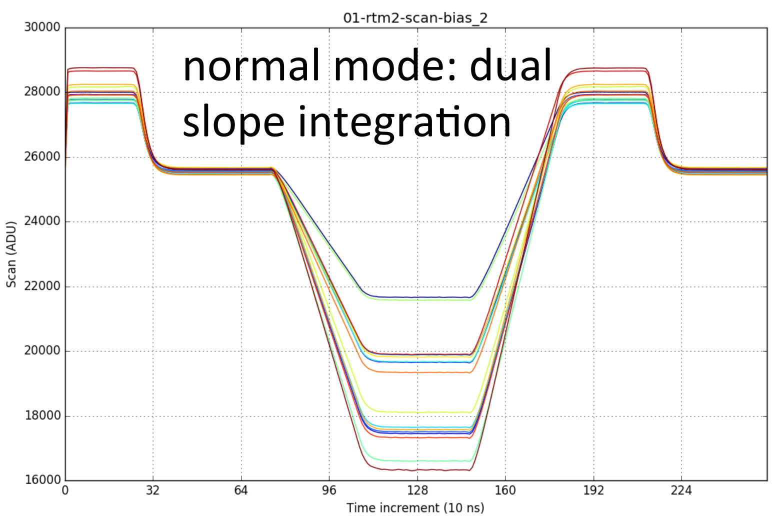
```
[subroutines]
WindowLine:  # Line readout
    CALL    TransferLine
    CALL    SerialFlush     repeat(@PreCols)
    CALL    ReadPixel       repeat(@ReadCols)
    CALL    SerialFlush     repeat(@PostCols)
    RTS

ReadFrame:  # Readout and acquisition of a CCD frame
    JSR     FlushLine       repeat(@PreRows)
    CALL    StartOfImage
    JSR     WindowLine      repeat(@ReadRows)
    CALL    EndOfImage
    JSR     FlushLine       repeat(@PostRows)
    RTS
```

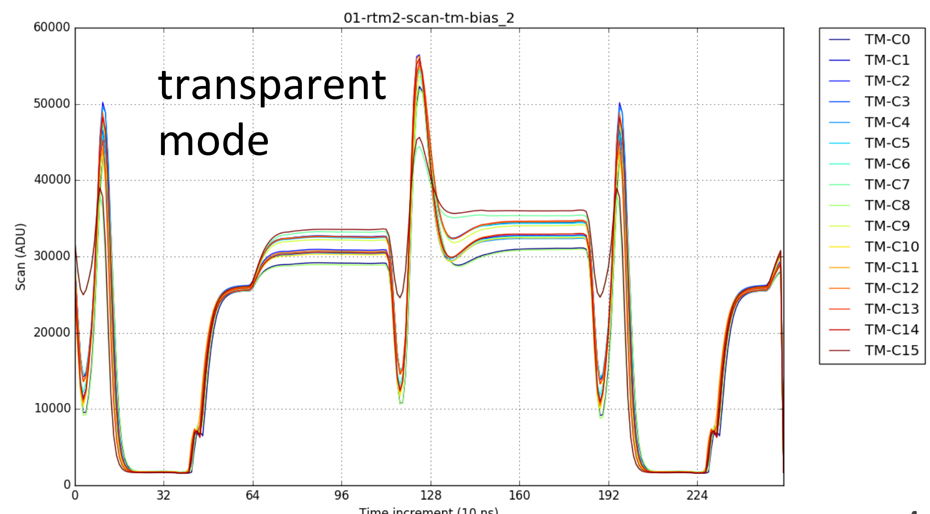
CCD readout: REB video chain



- ASPIC: Analog Signal Processing IC: amplification (x1.9), differential signal, and Dual Slope Integration
- "Transparent Mode" bypasses the integrator stage: the ASPIC output becomes a replica of the CCD output
- Acquired through the video pipeline, with 18-bit resolution and low noise

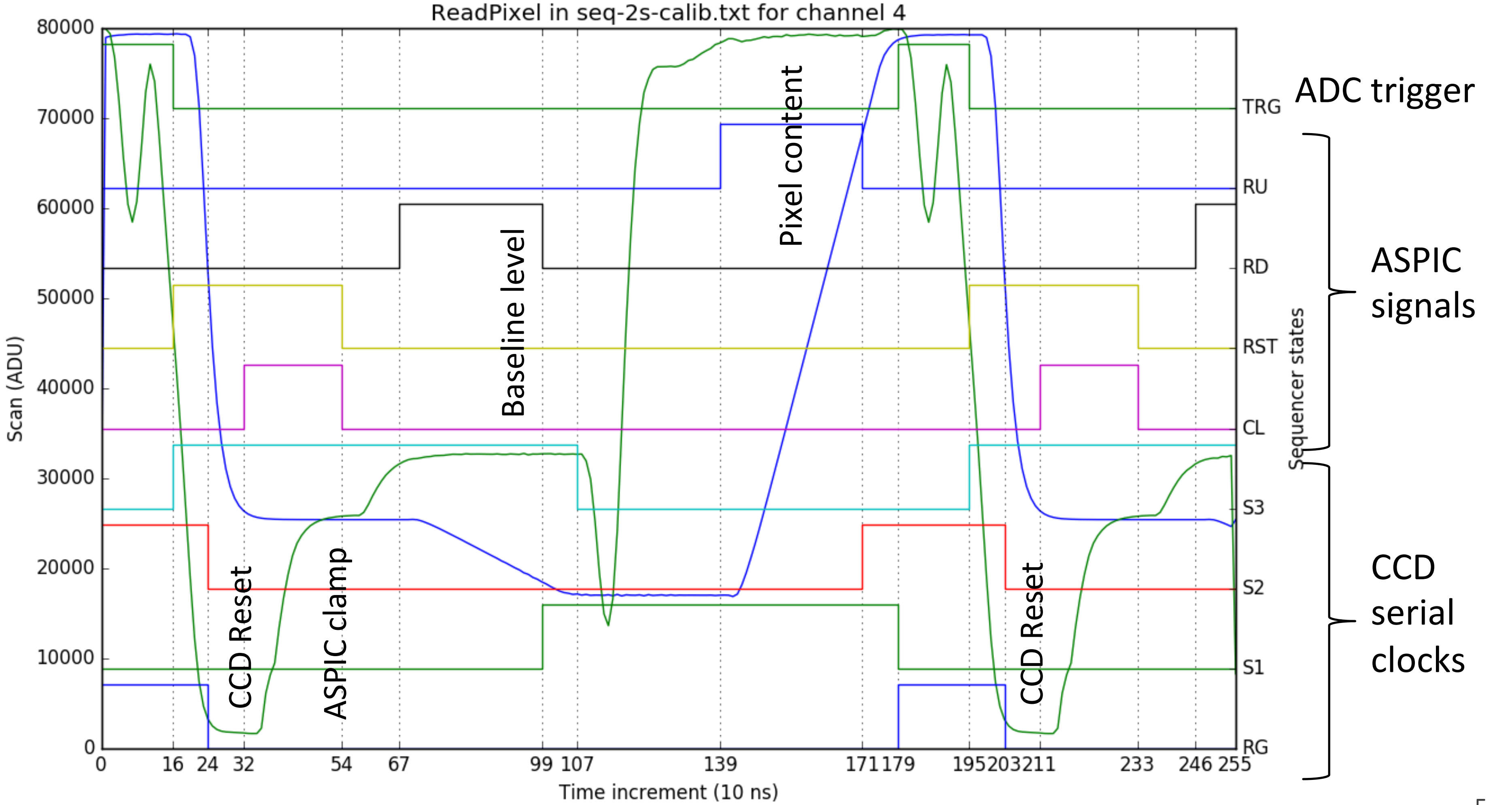
Note: ADU value increases when OS voltage decreases





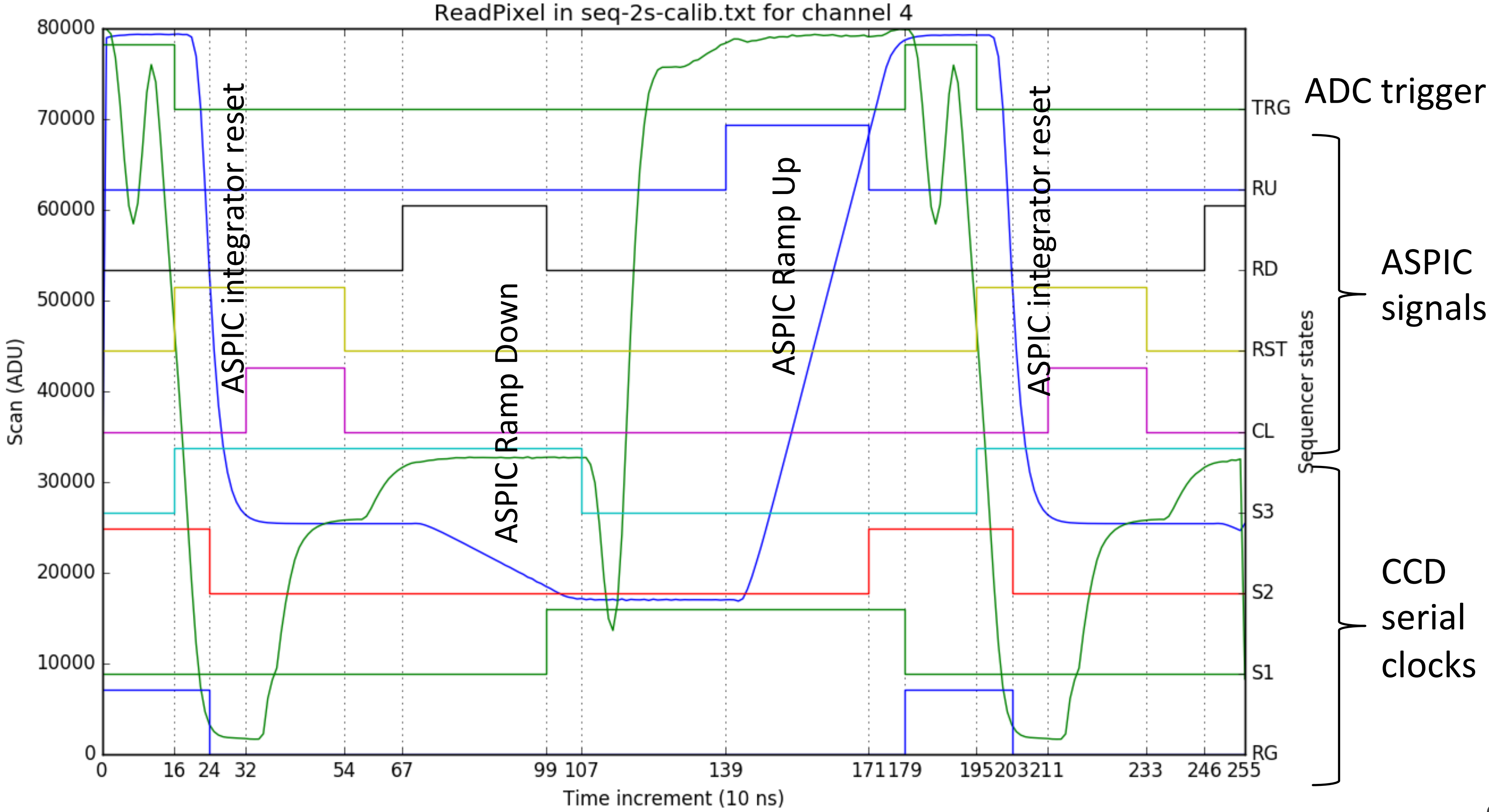
Pixel scan and clocks: Transparent Mode

Raw OS
Integrated

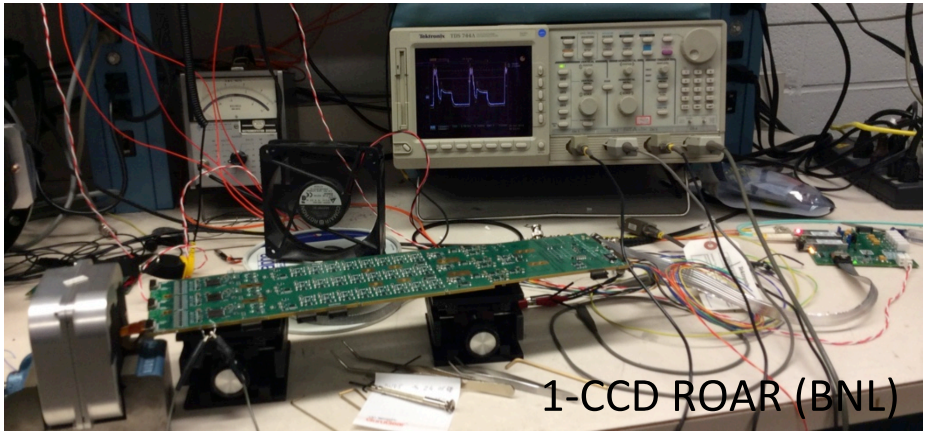


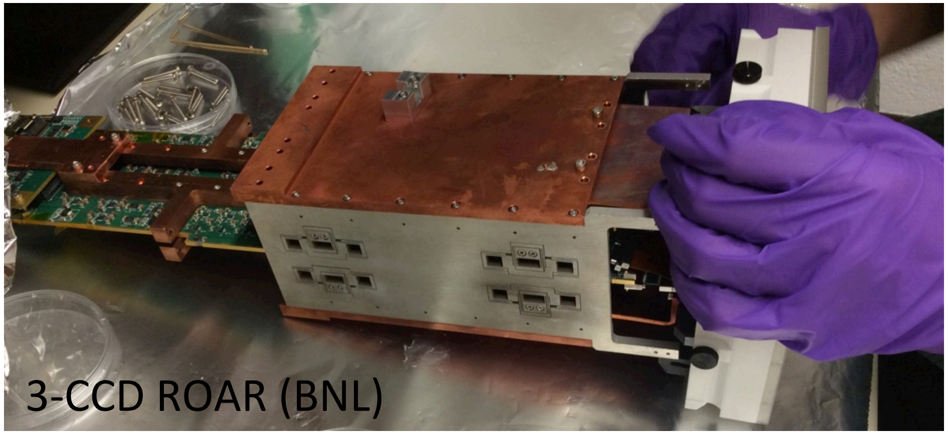
Pixel scan and clocks: Dual Slope Integration

Raw OS
Integrated

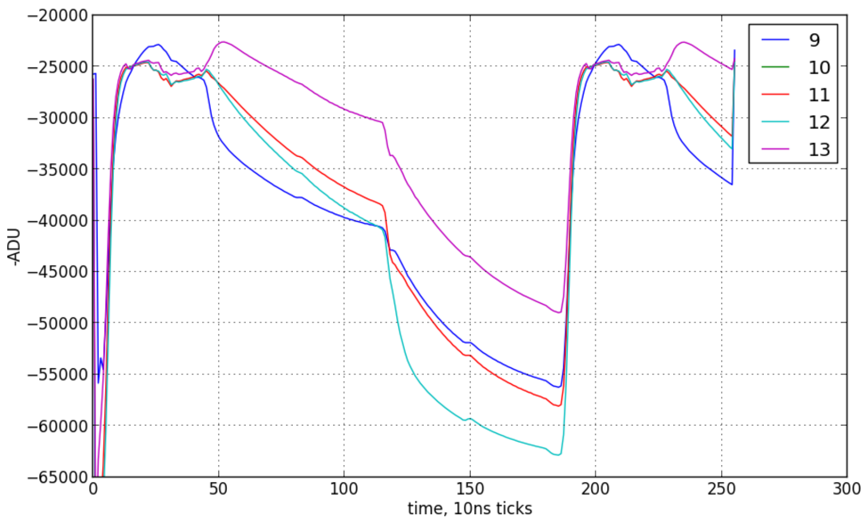


Deployment in prototype test stands

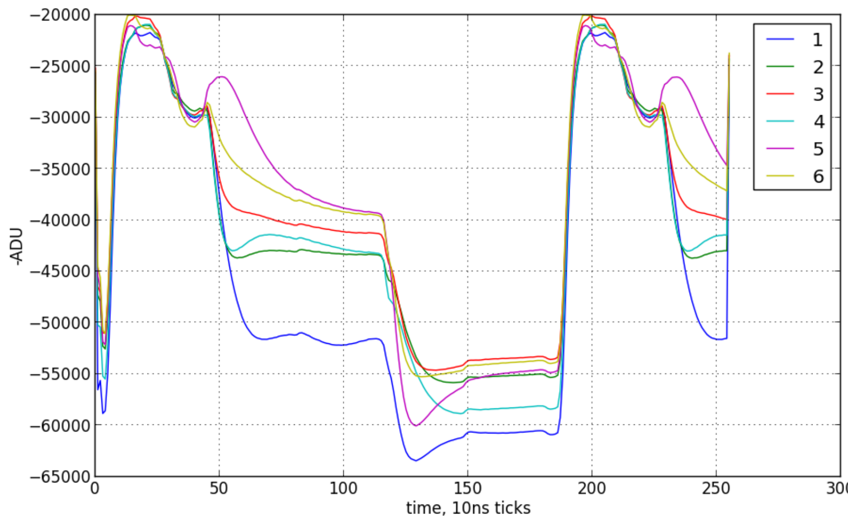




- Early adjustments on readout sequences with prototype LSST electronics
- Evaluation of the “active flex cable” solution for ITL sensors



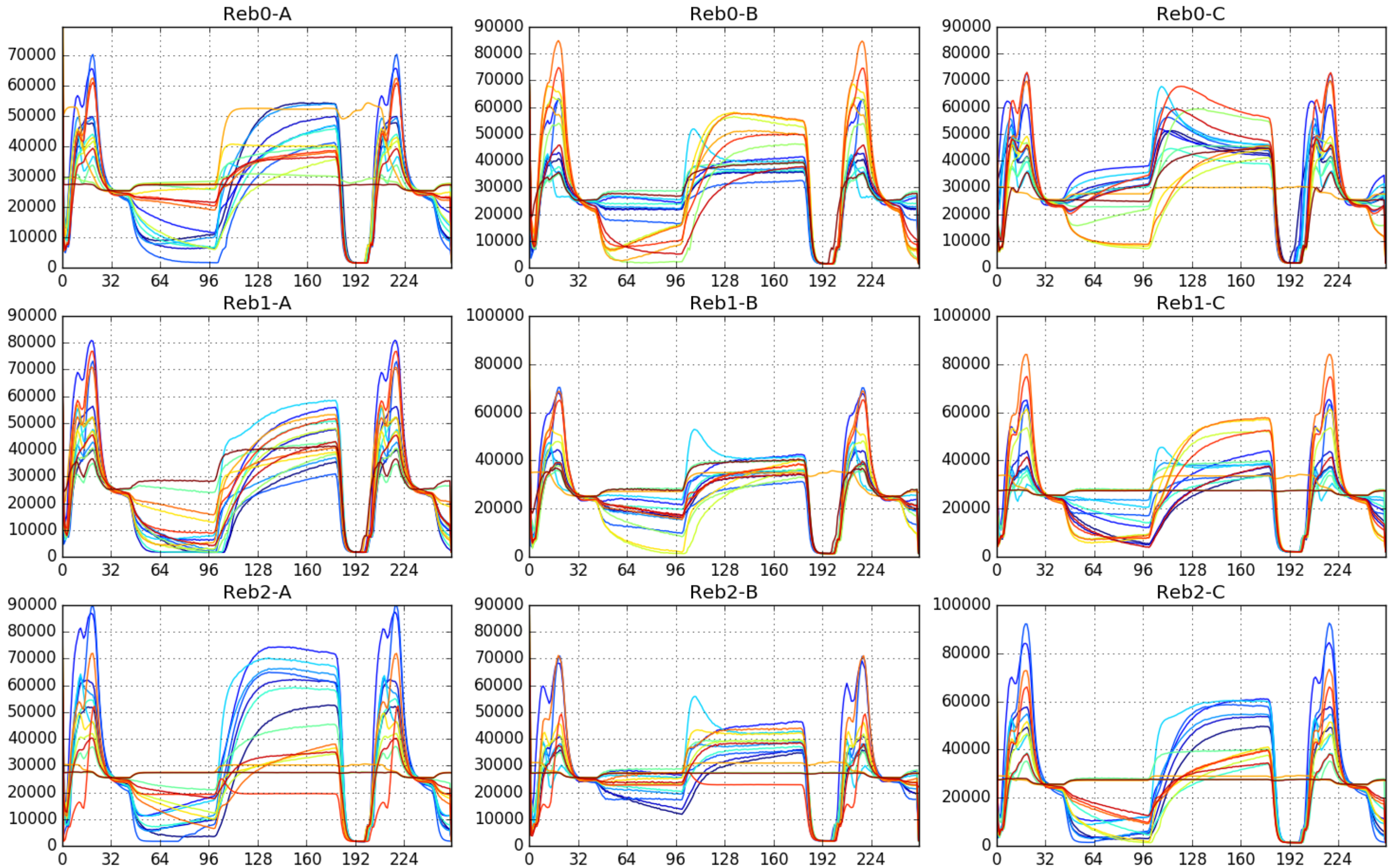
Channels with passive cable



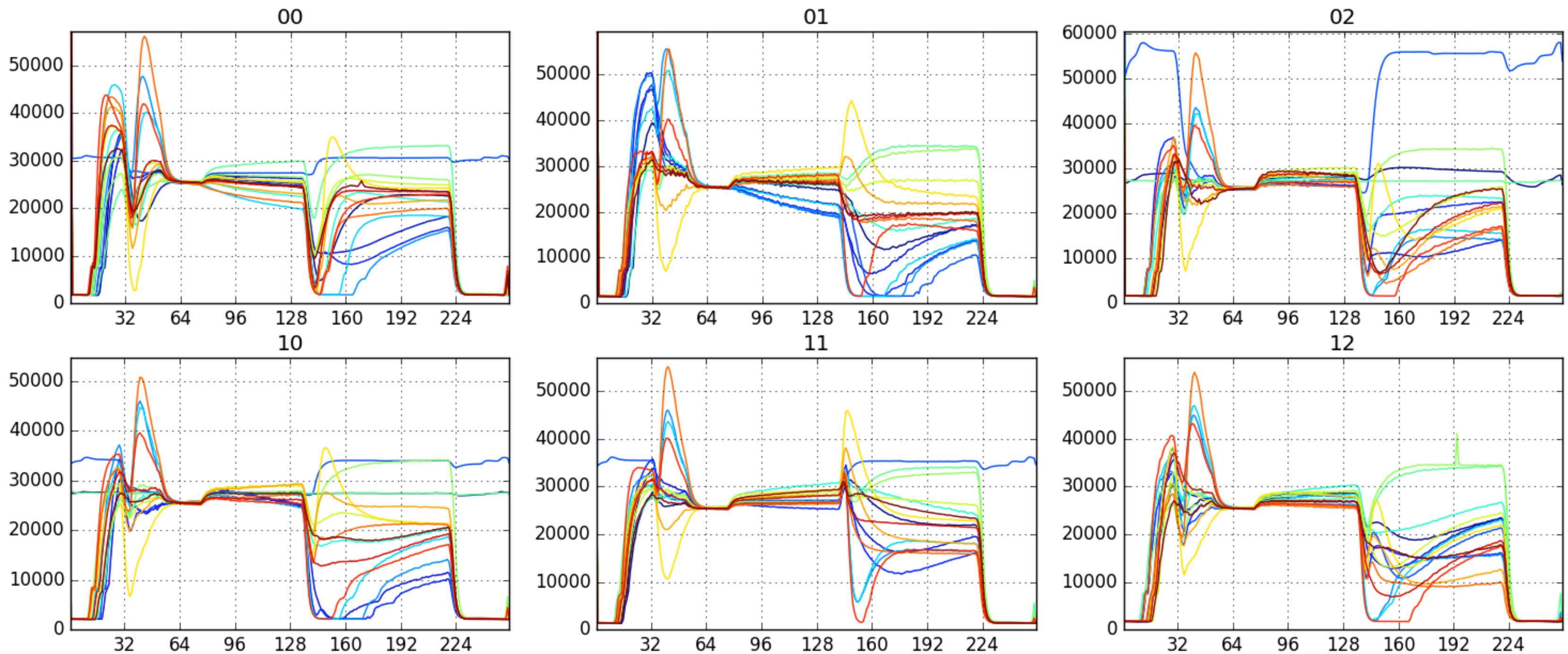
Channels with active cable

Diagnostic on Engineering Test Unit #2

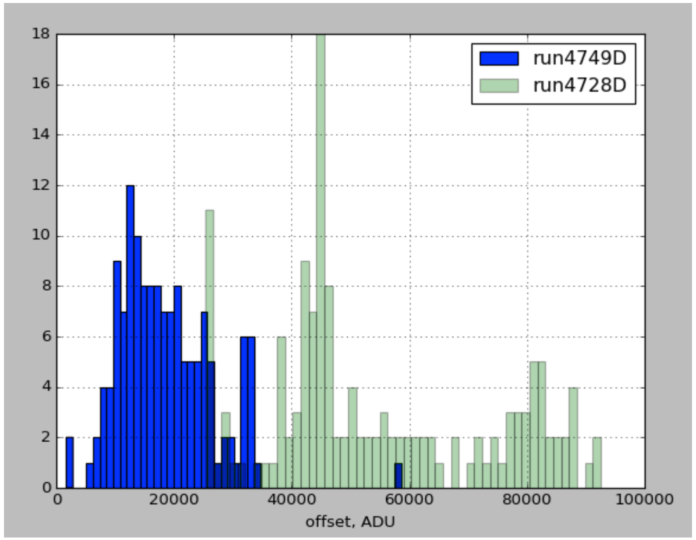
- Issues with excess noise and very high bias levels
- Original readout sequence: similar to CCD test stands
- Scan mode showed origin of bias: very strong crosstalk from serial clocks (quantified with "single-clock" scans)



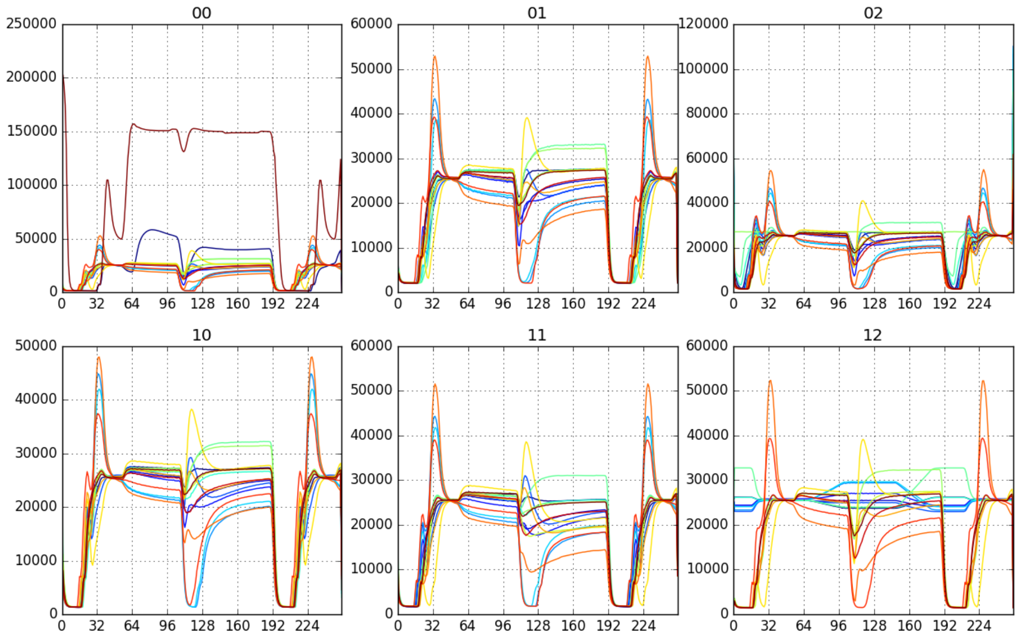
ETU2 with modified sequence

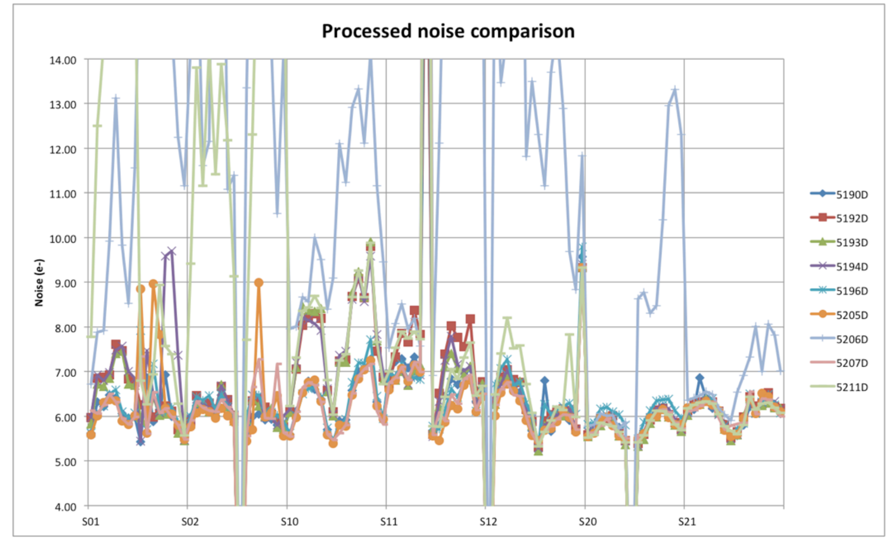


- Moved serial clock to have clock crosstalks neutralize each other
- Lowered biases and spread of values
- Brought noise in line with expectations



Raft Tower Module #1: the road to 2s

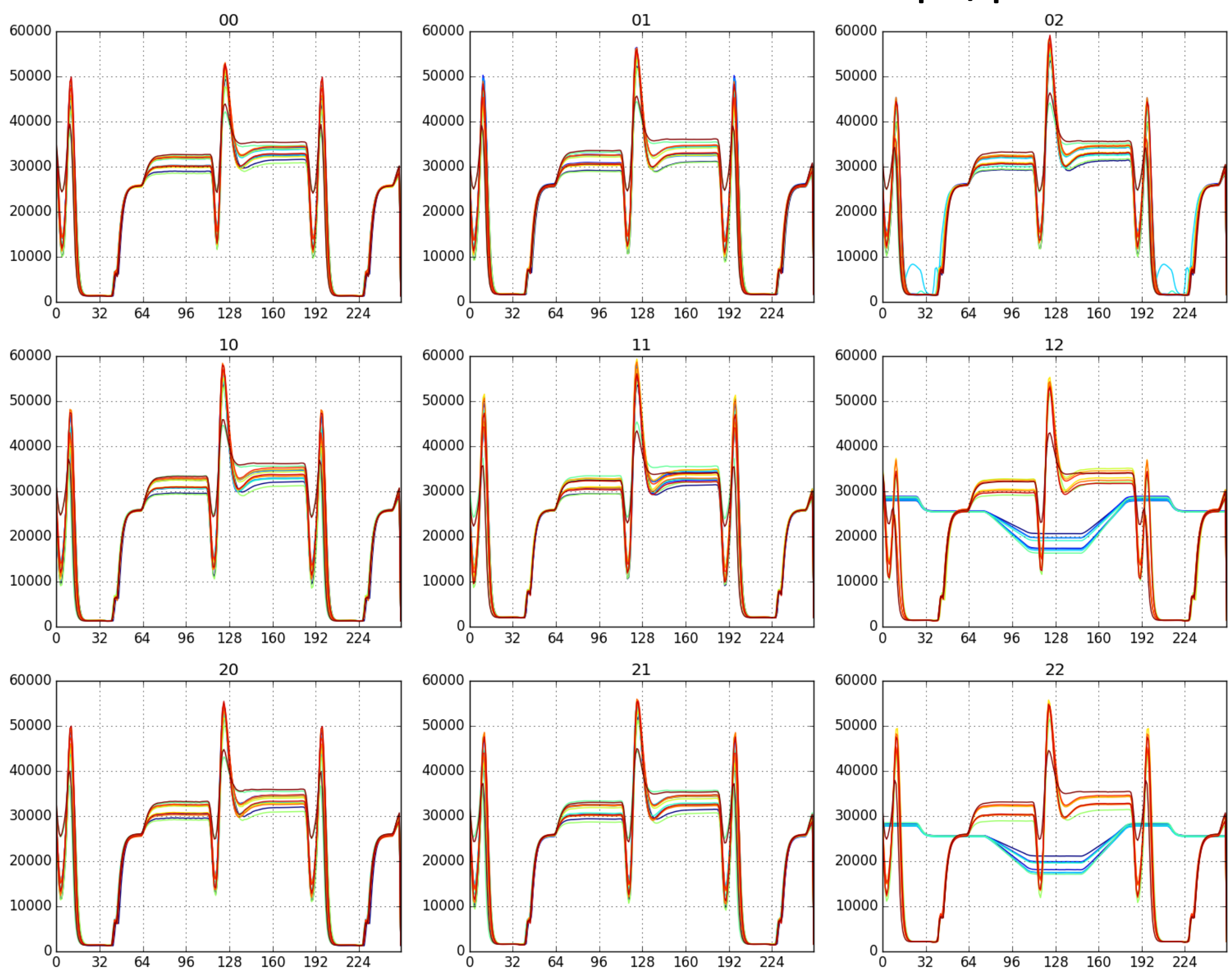




- Sequence from ETU2 optimization was 2.39 µs/pixel, for a median noise of 5.9 e- on RTM1
- Target to read the nominal frame size in 2s: 1.81 µs/pixel
- Iterative tests over noise + checks on gain, CTI
- Reached 1.79 µs/pixel for a median noise of 6.0 e-

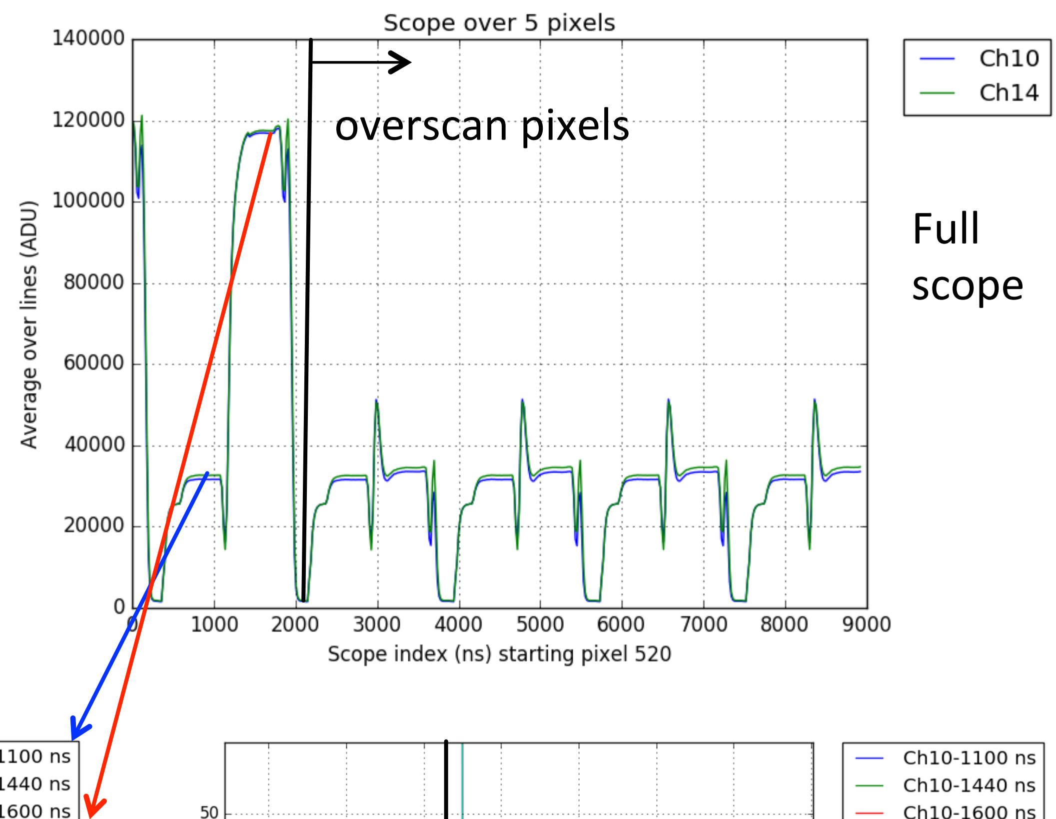
Raft Tower Module #2

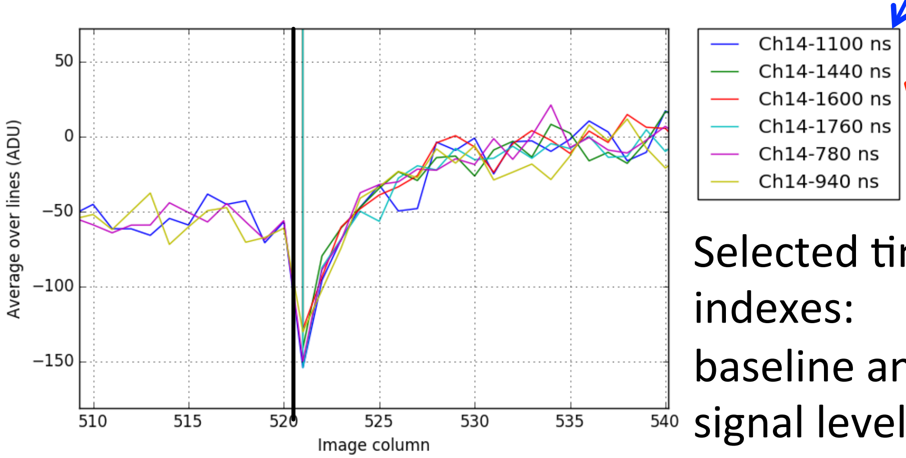
- First raft with E2V sensors
- Readout tested at LPNHE with REB + single CCD
- Reached 4.7 e- median noise at 1.79 µs/pixel



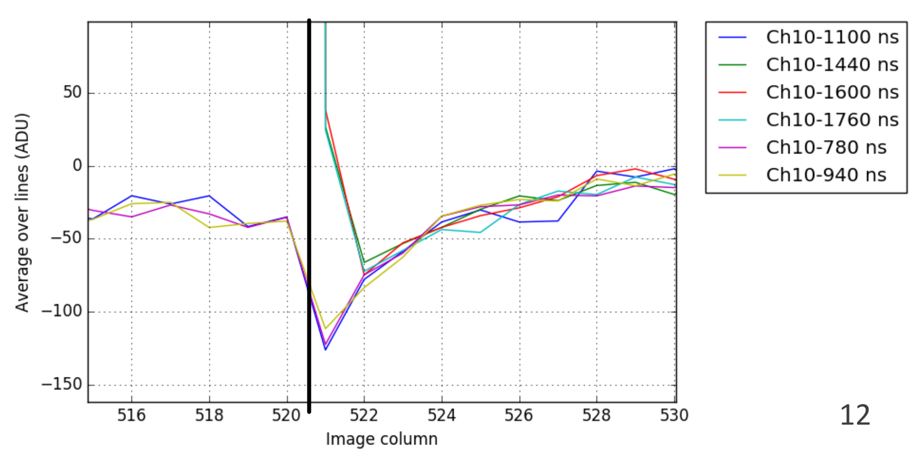
Super-scan

- Limitation of scan mode: time index = pixel
- Super-scan: stack of frames with 1 time index per frame + ASPIC Transparent Mode
- Super-scans combine spatial and temporal information: Charge Transfer Inefficiency, drifts over time



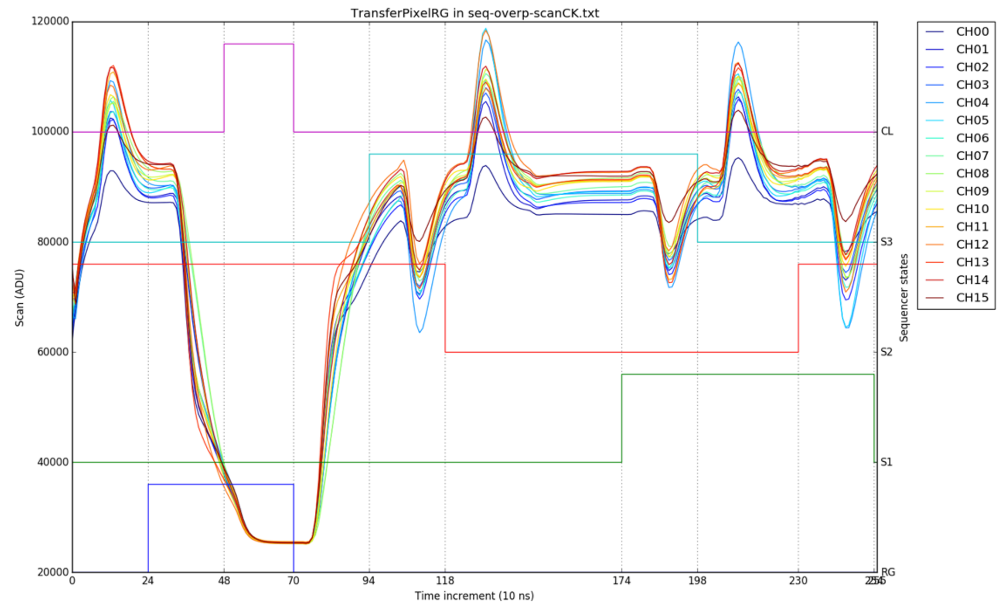


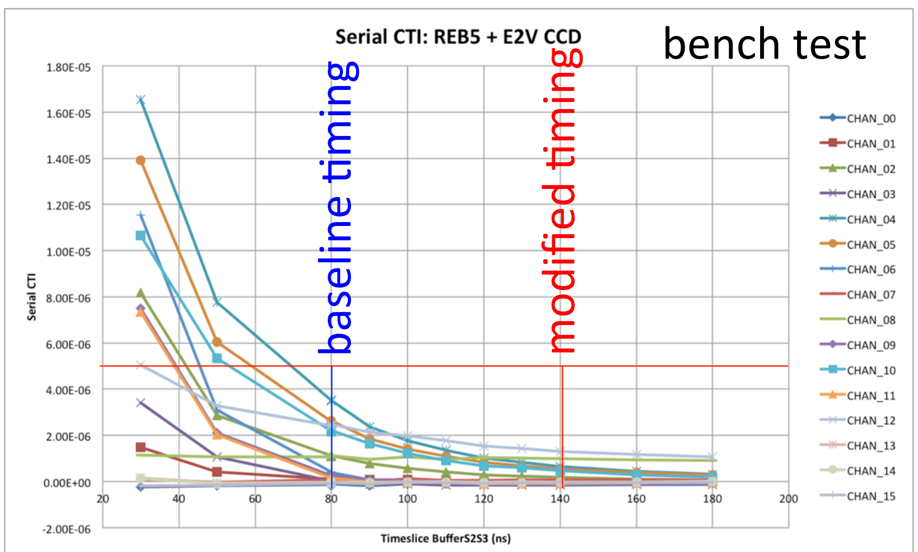
Selected time indexes: baseline and signal levels

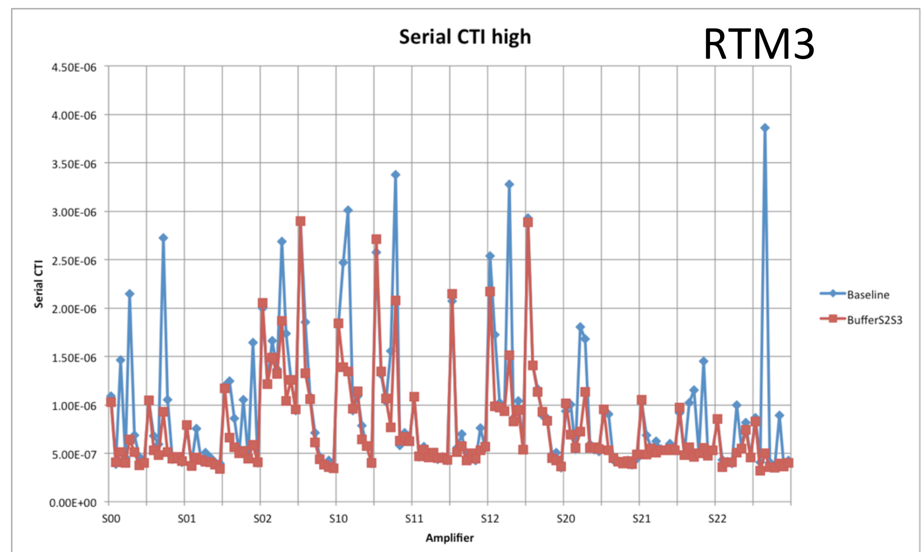


Serial transfer: high flux

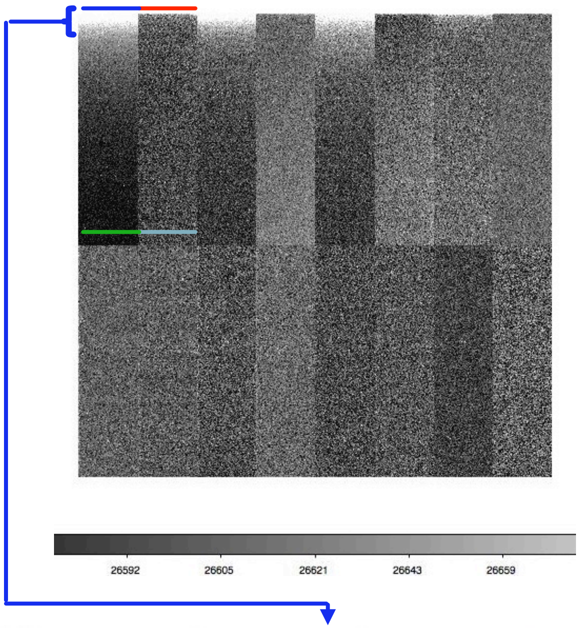
- Serial CTI at high flux ~5ppm on some channels
- Dependent on readout timing
- Scan mode: timing of actual clock transitions vs sequencer state transitions



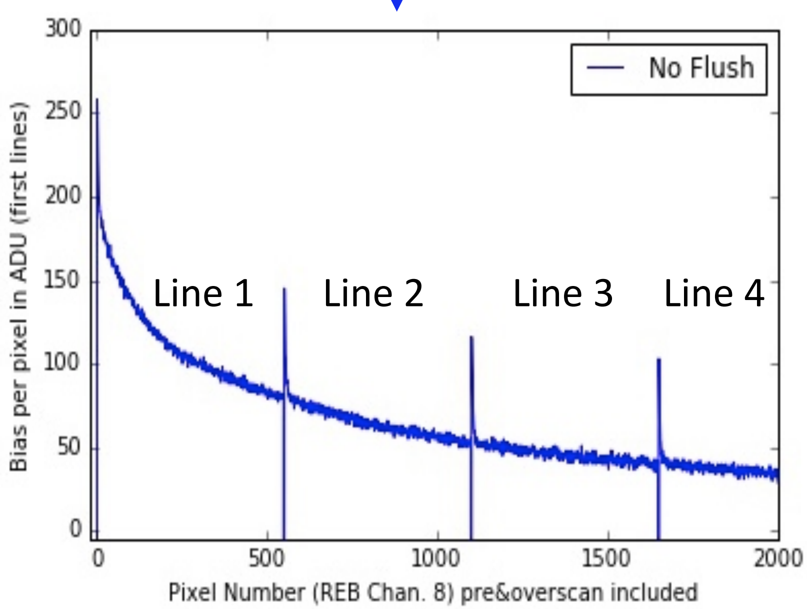


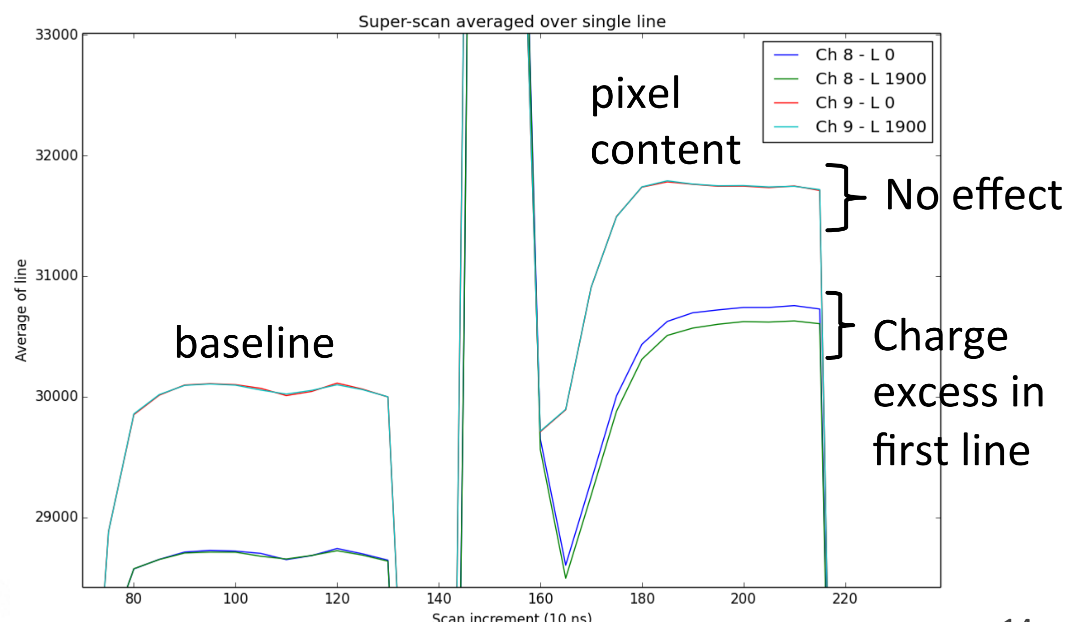


Study of the "bias drift"



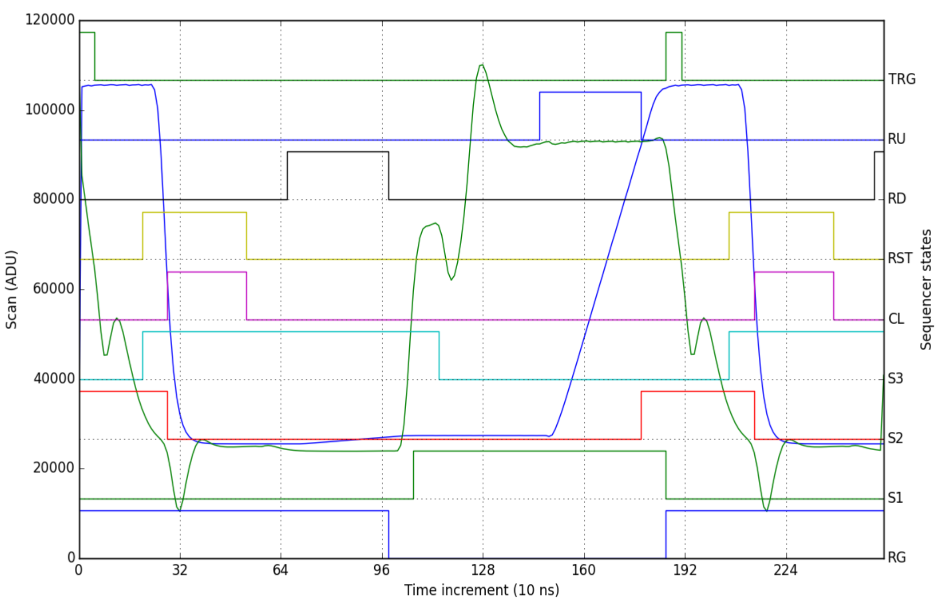
- Bias in some channels is continuously decreasing over the 100 first lines
- Suppressed by flushing the serial register before readout (50,000 + pixels)
- Not actually a bias drift, but an injection of charges



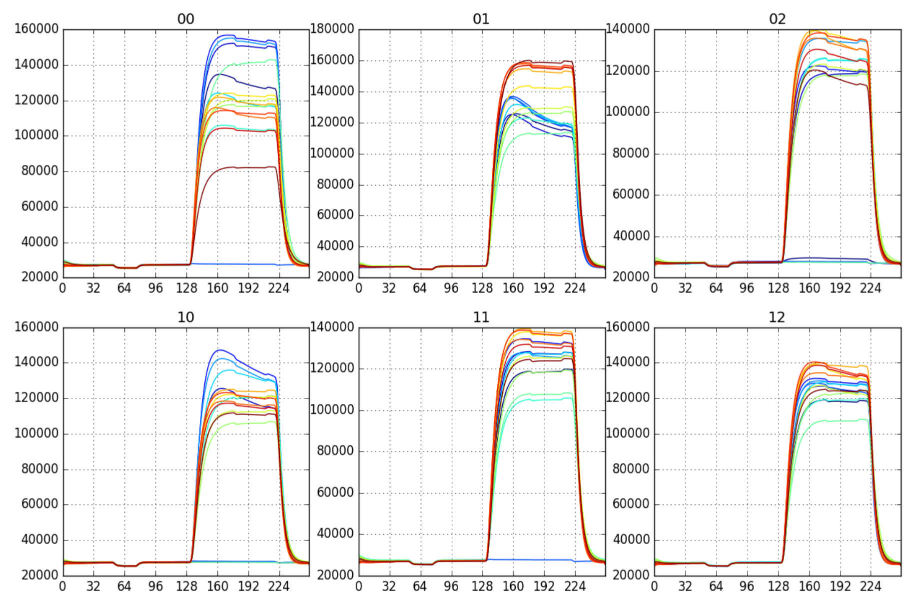


Injecting the CCD reset level

- Reset of pixel content with CCD Reset Gate clock: (positive) voltage jump on the CCD output
- RG high as baseline, RG low as "pixel content"
- Simulates a pixel with signal ~ 55,000 e- (3% dispersion on E2V sensor), kTC reset noise (~ 40 e-)



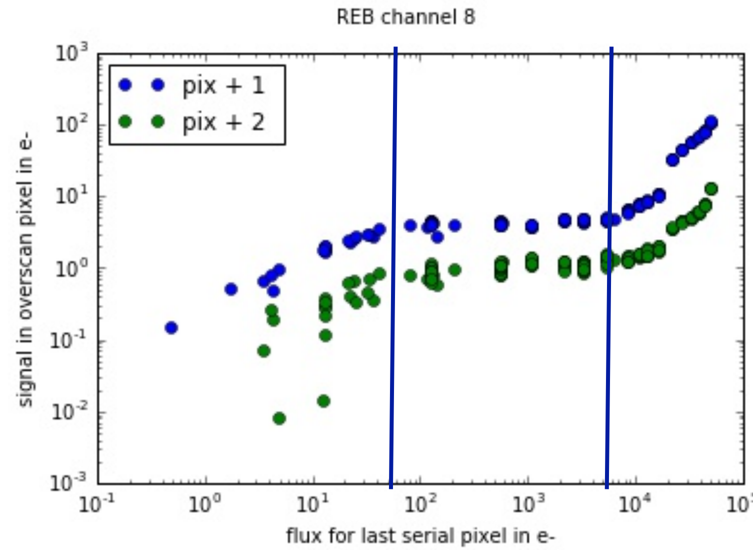
Fake pixel readout

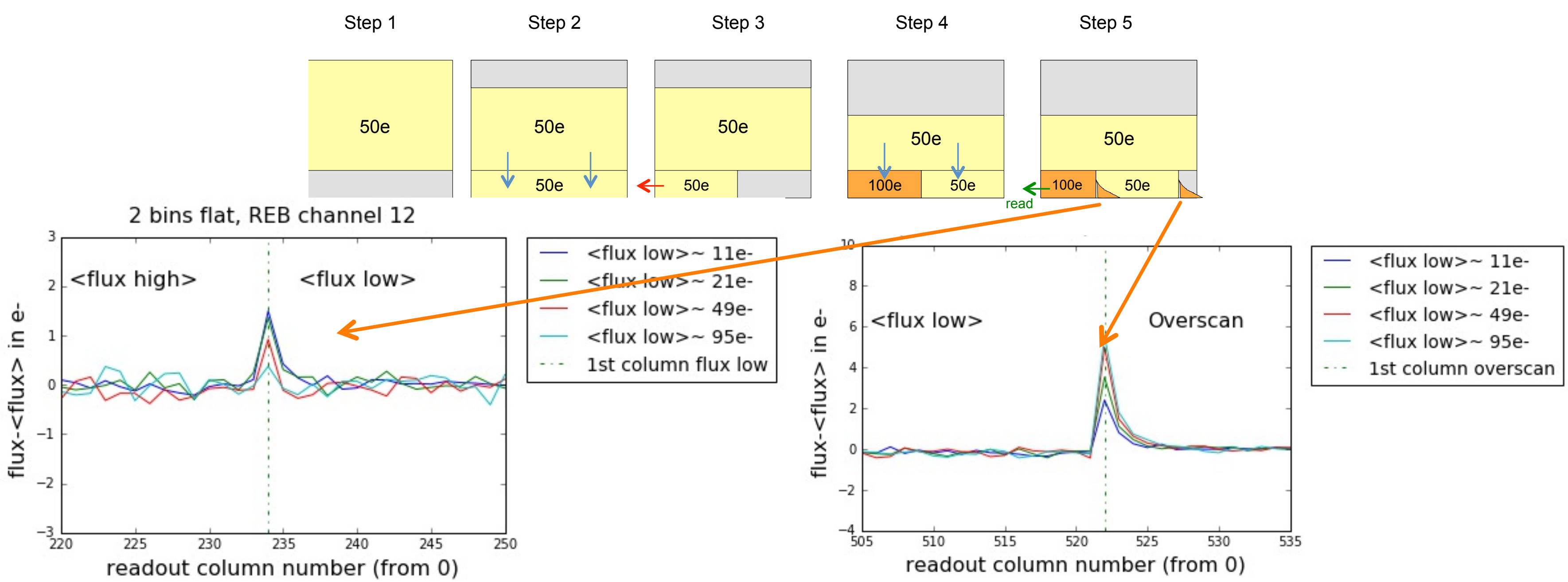


RG only, ETU2

Serial transfer: low flux

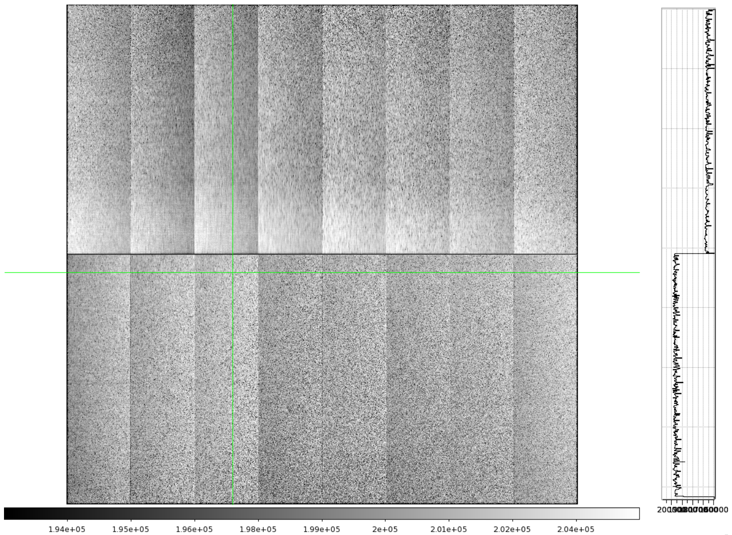
- Serial CTI >5 ppm in a few channels when measured from a ~ 800 e- flat field
- Trapped electrons <10 e- are sufficient to generate this "CTI"
- Should not affect science data due to sky background

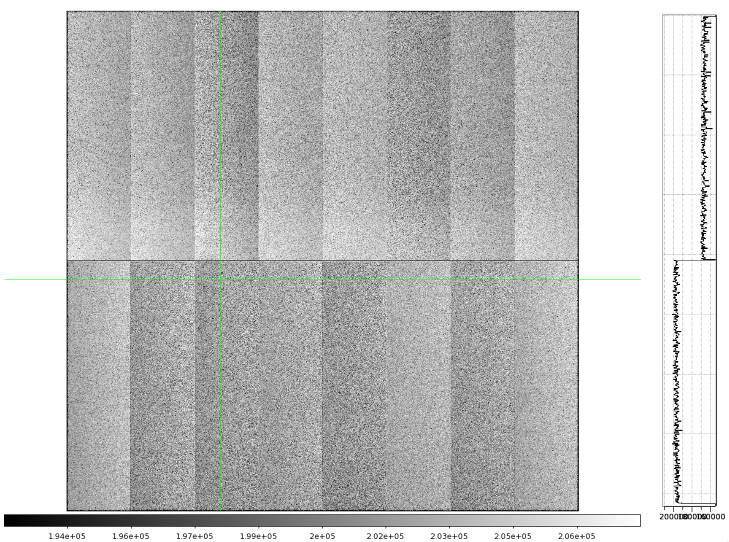


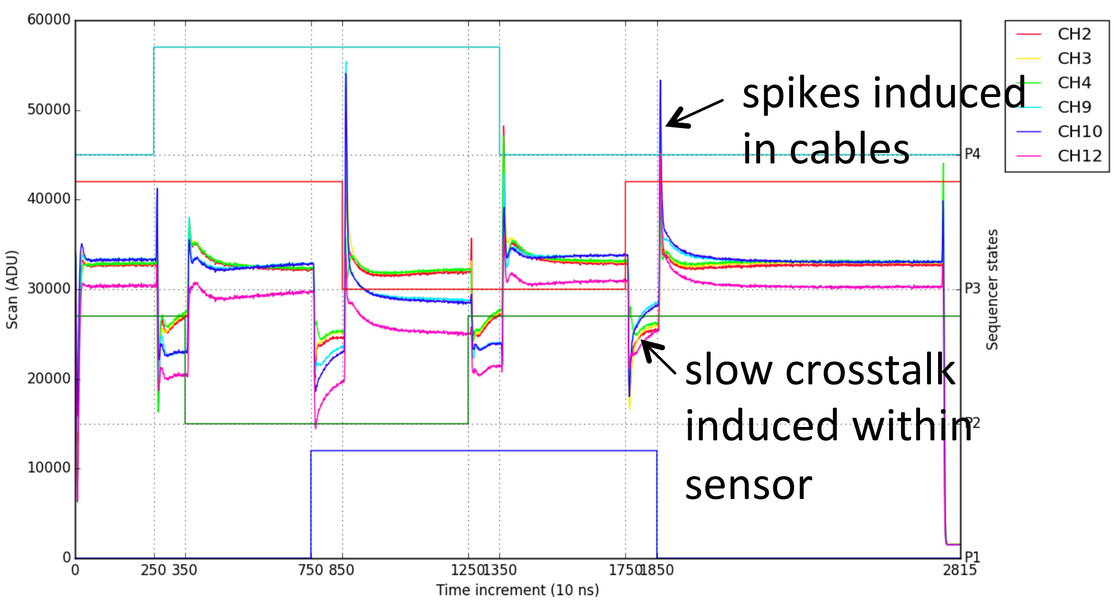


Parallel transfer

- 4-phase transfer: overlaps or crossings?
- Smearing of charges near saturation
- Scanning the video channels during parallel transfers

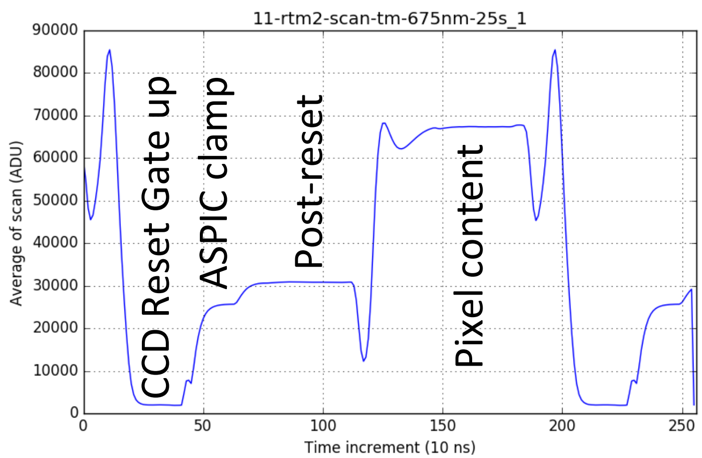


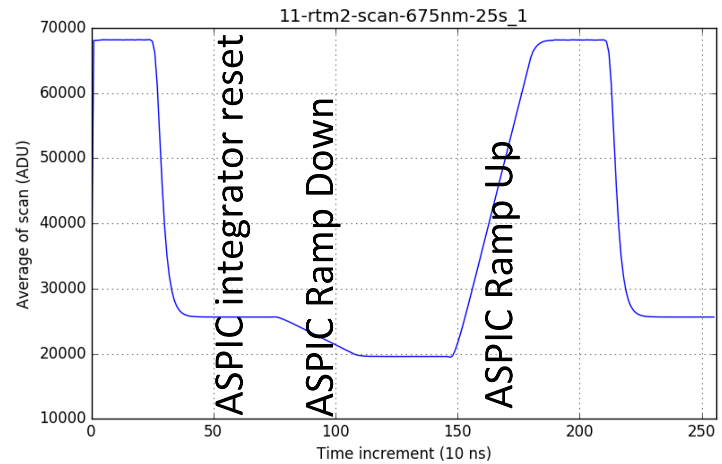


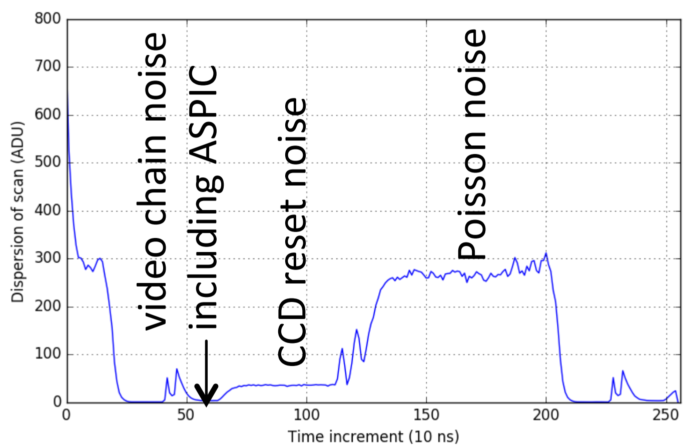


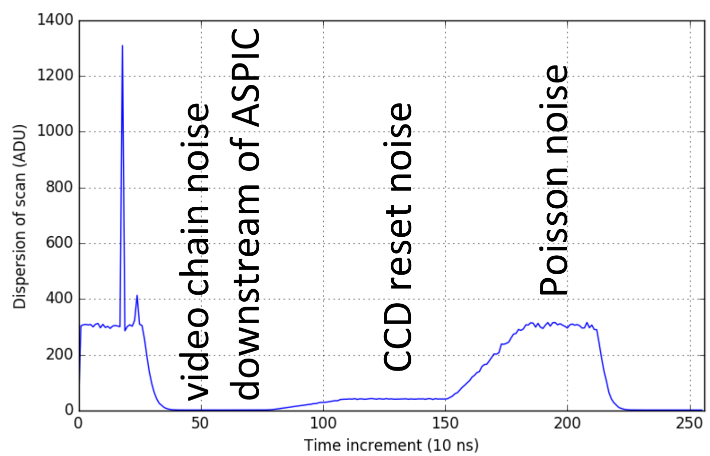
Statistics on scan mode frames

- Statistics along rows of scans
- Information on noise sources









Variations across channels

- Compared here with rough PTC result
- Low dispersion of injected charges (see channel 15)
- Noise: 60 ADU ~ 42 e-
- CCD kTC reset noise
- Coherent with CCD µV/e- gain, which is node capacity times internal gain

$$\sqrt{k_B T C_{node}} = \sqrt{1.38 \times 173 \times 19 \times 10^{-38}}\, C = 42 e^-$$

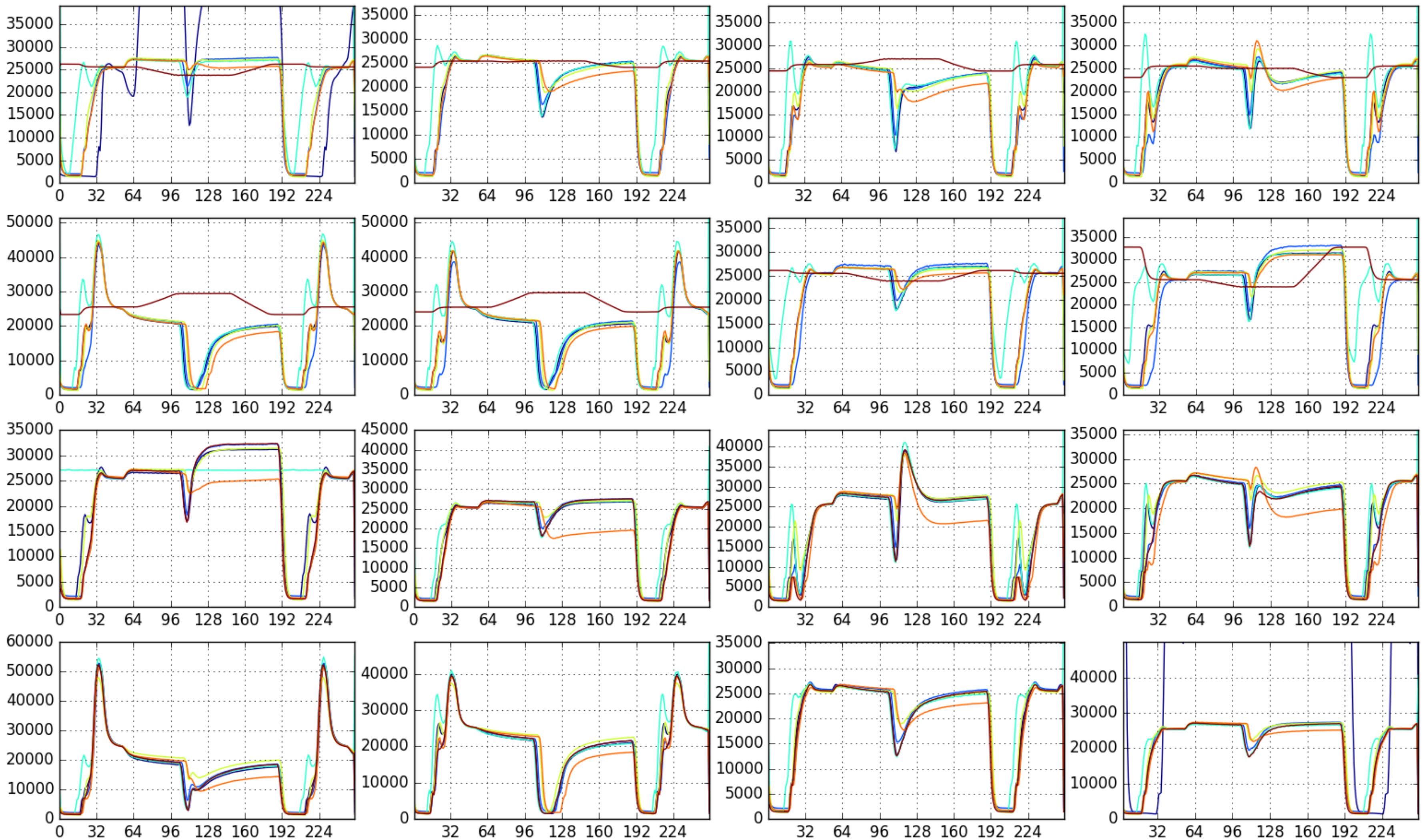
$$C_{node} = \frac{1.6 \times 10^{-19} C}{5.75 \times 10^{-6} V / G_{CCD}} = 19\, fF$$

$$G_{CCD} = \frac{19 \times 5.75 \times 10^{-21}}{1.6 \times 10^{-19}} = 0.68$$

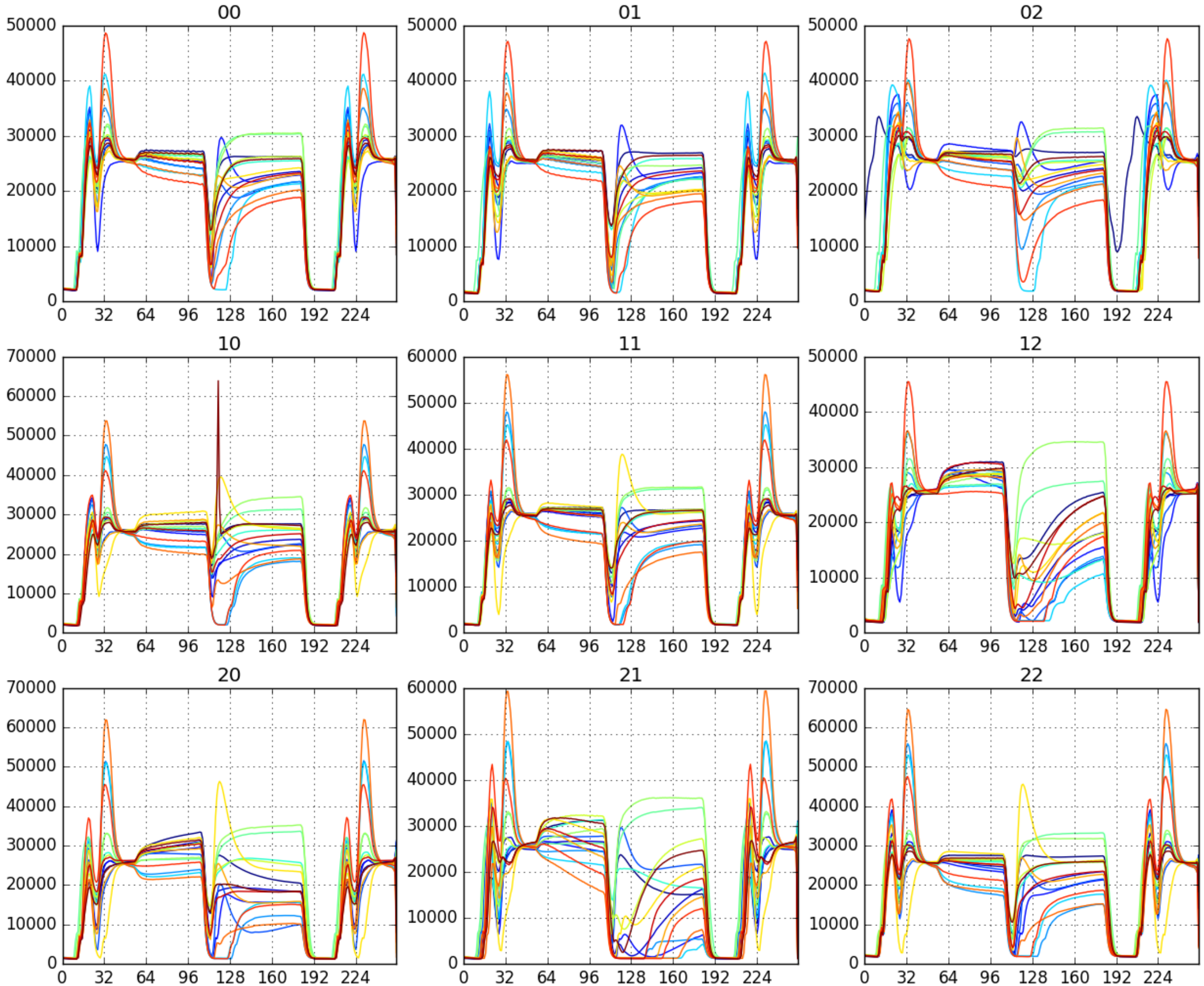
Channel	Average (ADU)	Est. gain (e/ADU)	Calib signal (e)
0	107028.27	0.711	56377.50
1	104736.61	0.702	53968.42
2	106070.27	0.682	53610.19
3	104523.11	0.690	53123.15
4	105753.81	0.682	53119.66
5	101787.07	0.683	50848.83
6	105095.69	0.697	53887.53
7	100942.79	0.690	50571.11
8	107388.24	0.671	53570.22
9	106052.11	0.686	53764.06
10	106023.91	0.684	53905.62
11	105044.83	0.686	53187.97
12	107529.08	0.690	55291.72
13	106124.02	0.689	54408.95
14	109340.34	0.698	56969.59
15	92165.07	0.853	55524.92
Dispersion	3.75%	6.00%	3.13%

RTM1: reshuffling the scans

- Each plot shows the same channel (position) on different CCDs



ETU1 scan



ETU1 noise and biases