Commissioning of the Mu2e Data AcQuisition system and the Vertical Slice Test of the straw tracker

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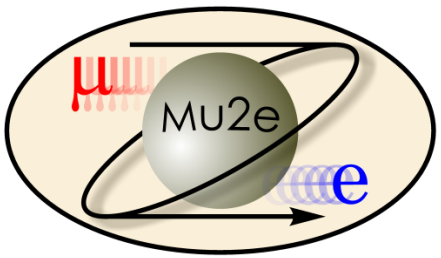
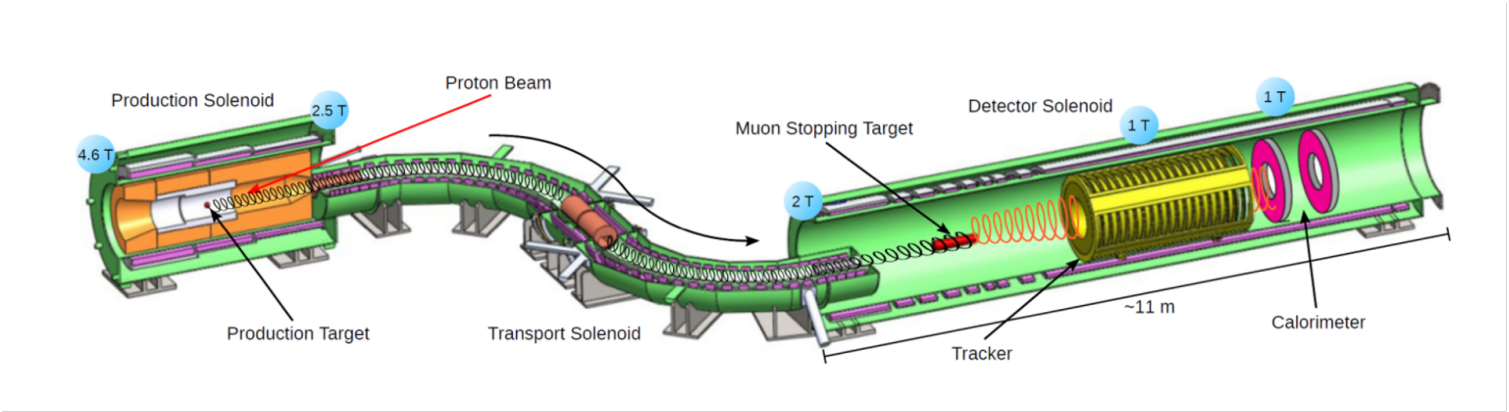


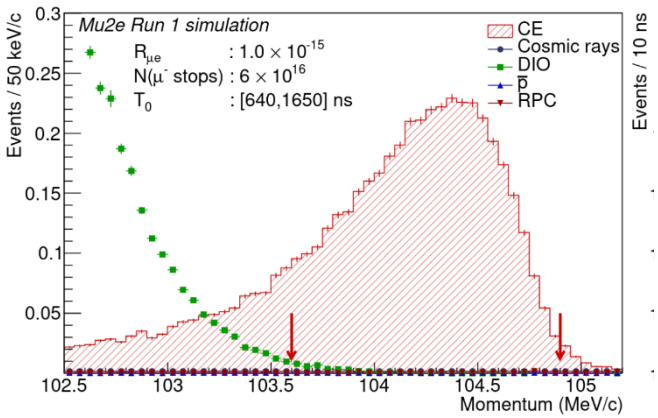
Mu2e experiment at Fermilab

$$\mu^- + \mathrm{Al} \rightarrow e^- + \mathrm{Al}$$



- Looking for Charged Lepton Flavour Violation;
- Mu2e will improve SINDRUM II limit ($7.0{\cdot}10^{-13}$) by 4 orders of magnitude;
- Momentum resolution: 2 MeV/c FWHM (SINDRUM II) to 1 MeV/c (Mu2e);
- Three years of running:
  - $3.6 \cdot 10^{20}$ protons;
  - Expected background level below 1 event.

Signals and backgrounds

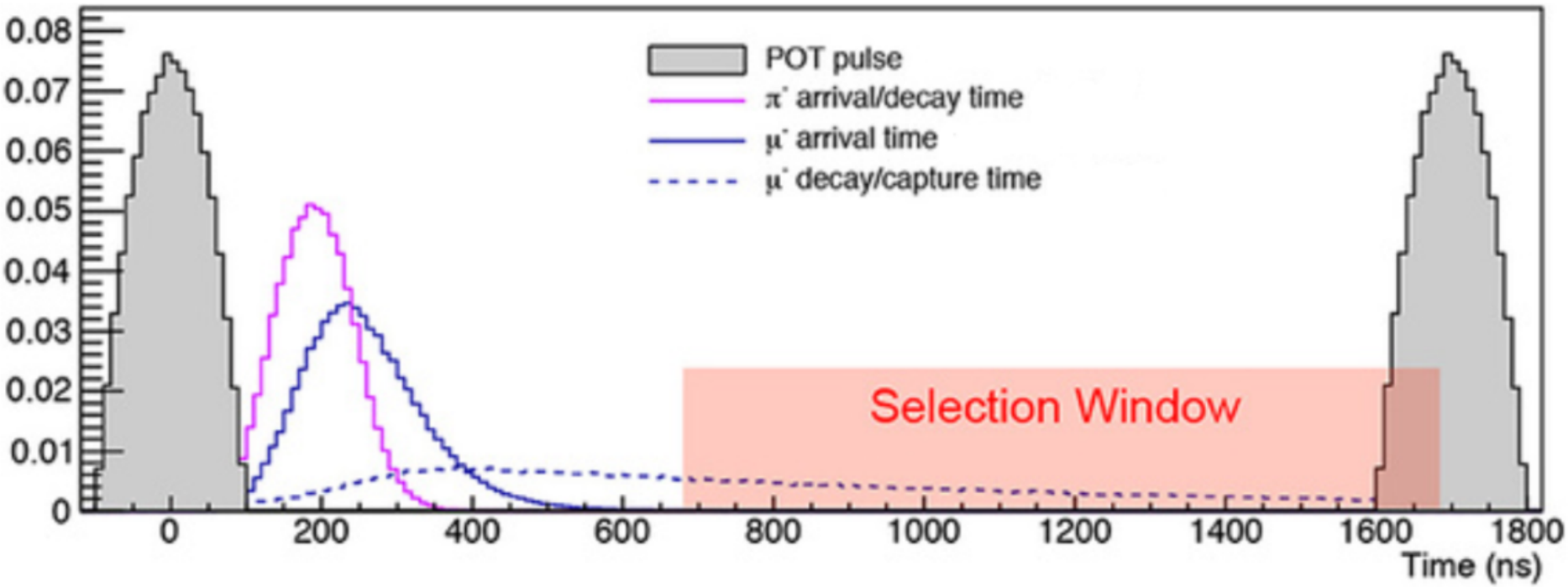


$$E_{CE} = m_\mu - E_{rec} - E_{bind}$$

Sources of background e^- (around 105 MeV/c):

- Cosmic particles, CRV;
- DIO of μ^- entering the DS;
- $\bar{p}$ by the proton beam and annihilation (absorption elements in the TS);
- RPC: rapidly falls in time. Requirement: delayed live-time window with respect to the proton pulse arrival at the production target.
- e^- entering the DS and scattering in the Al (delayed live-time window and an excellent proton beam extinction);
- RMC, similar to RPC, but with a lower maximal energy.

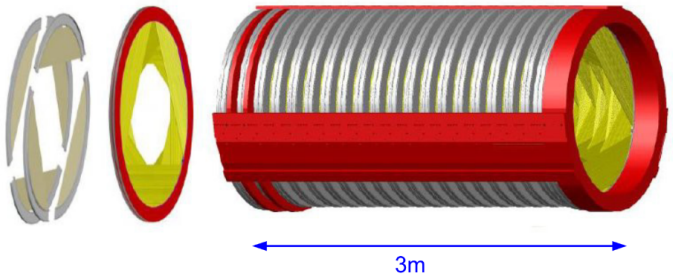
RPC and timing

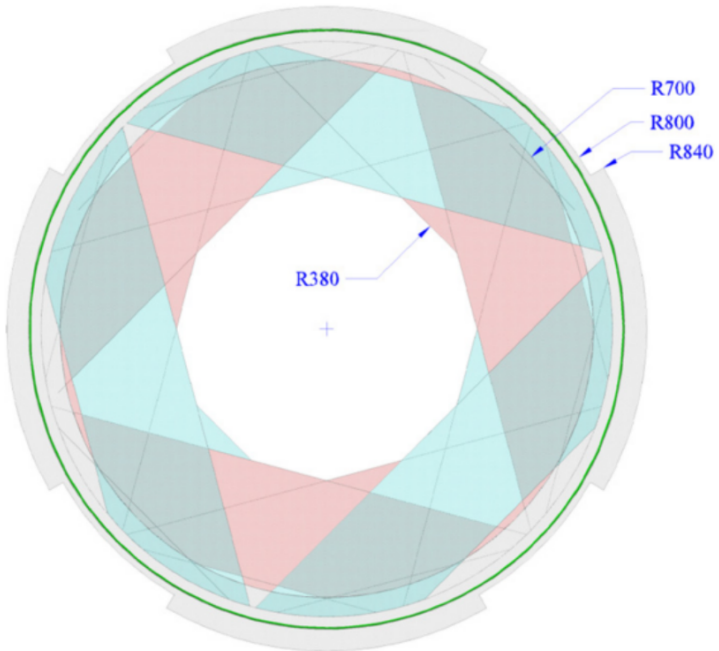


- Proton pulses, separated by a time window of 1695 ns;
- RPC rapidly falls in time;
- Selection window after 640 ns.

The tracker

- 3 m long tracker, 18 stations;
- 3 m downstream of the stopping target in the uniform 1 T region of the DS magnetic field;
- 5 mm diameter and 40-110 cm long straws;
- straw tubes filled with a 80%:20% Ar:CO_2 mixture at a pressure of 1 atm;
- the whole detector will be in vacuum;
- covering radii between 38 cm and 68 cm;
- 96 straws per panel;
- 6 panels per plane;
- 2 planes per station;
- 18 tracking stations: 216 panels.

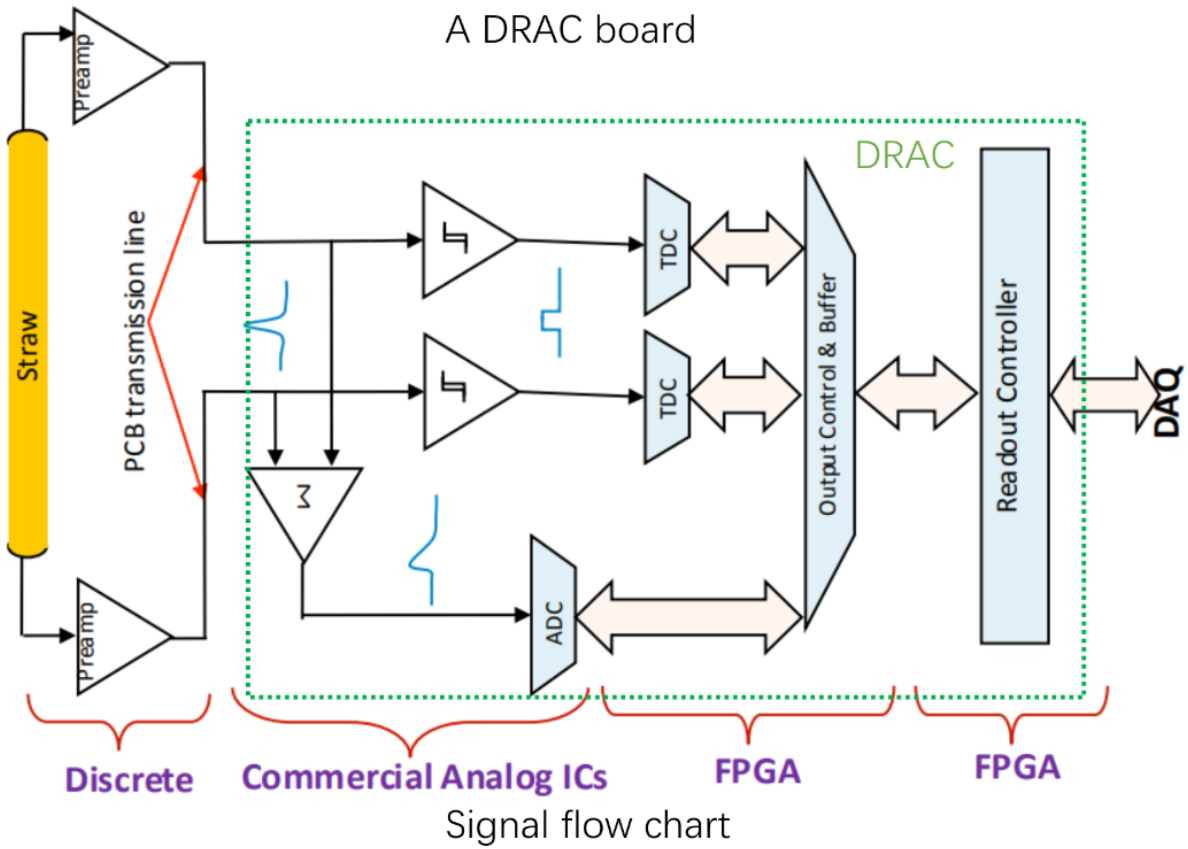




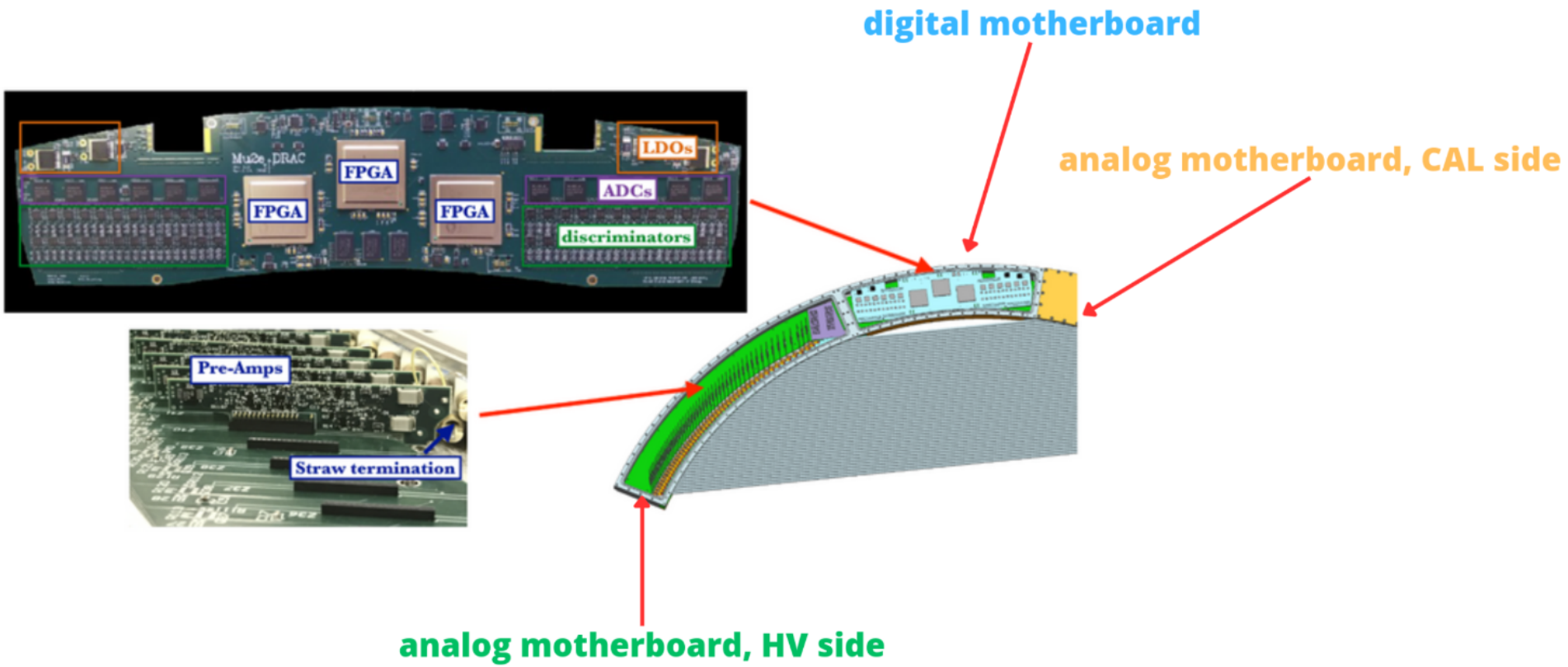
- Mu2e is starting commissioning;
- To commission the tracker we need the DAQ working;
- DAQ needs to be commissioned first;
- The rest of the talk is about DAQ;
- We are learning about things that are working and things that do not work.

Tracker readout

- Signals are readout from the ends of each straw on the panel and amplified;
- Signals sent to digitizer electronics;
- From each straw we get 2 times and a hit waveform (charge);
- DRAC: Digitizer Readout & Assembler Controller.

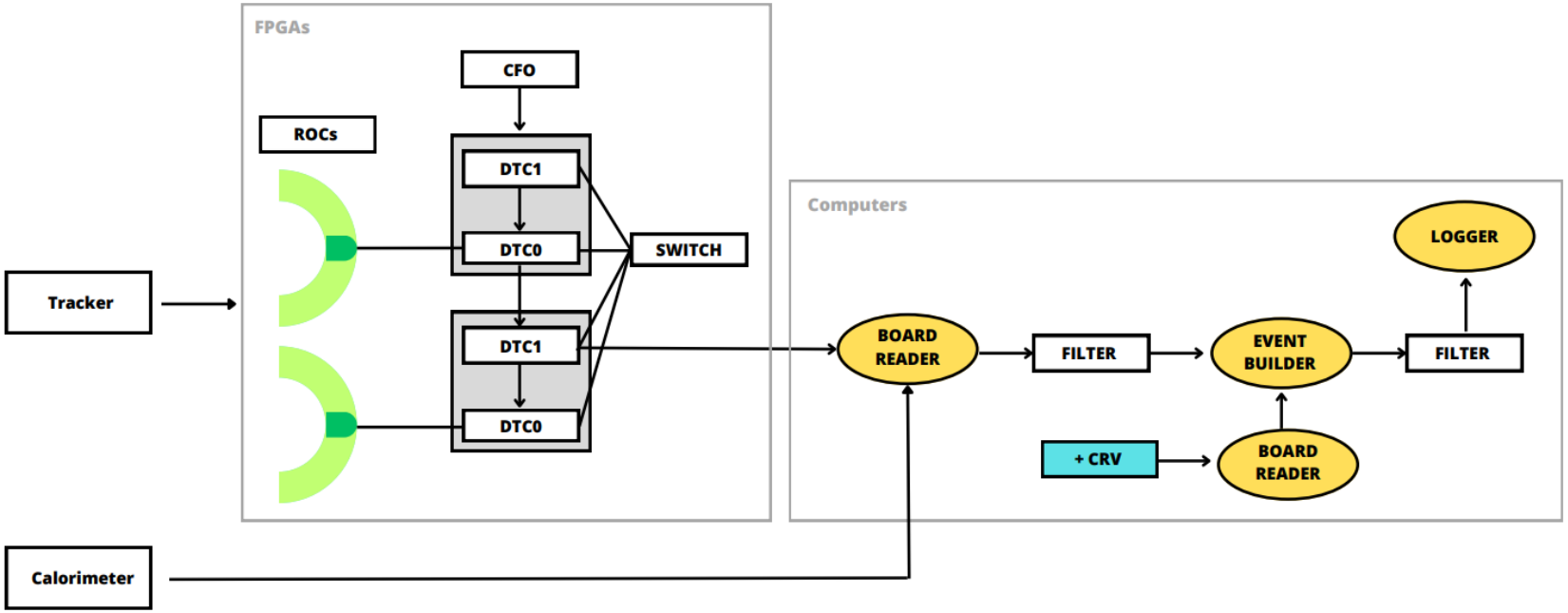


Tracker readout-2



- TDCs are implemented in FPGAs.

Mu2e DAQ components diagram



- ROC: ReadOut Controller;
- DTC: Data Transfer Controller (module). One DTC can read 6 ROCs;
- CFO: Command FanOut (module). It synchronizes and checks DTCs;
- CRV: Cosmic Ray Veto.

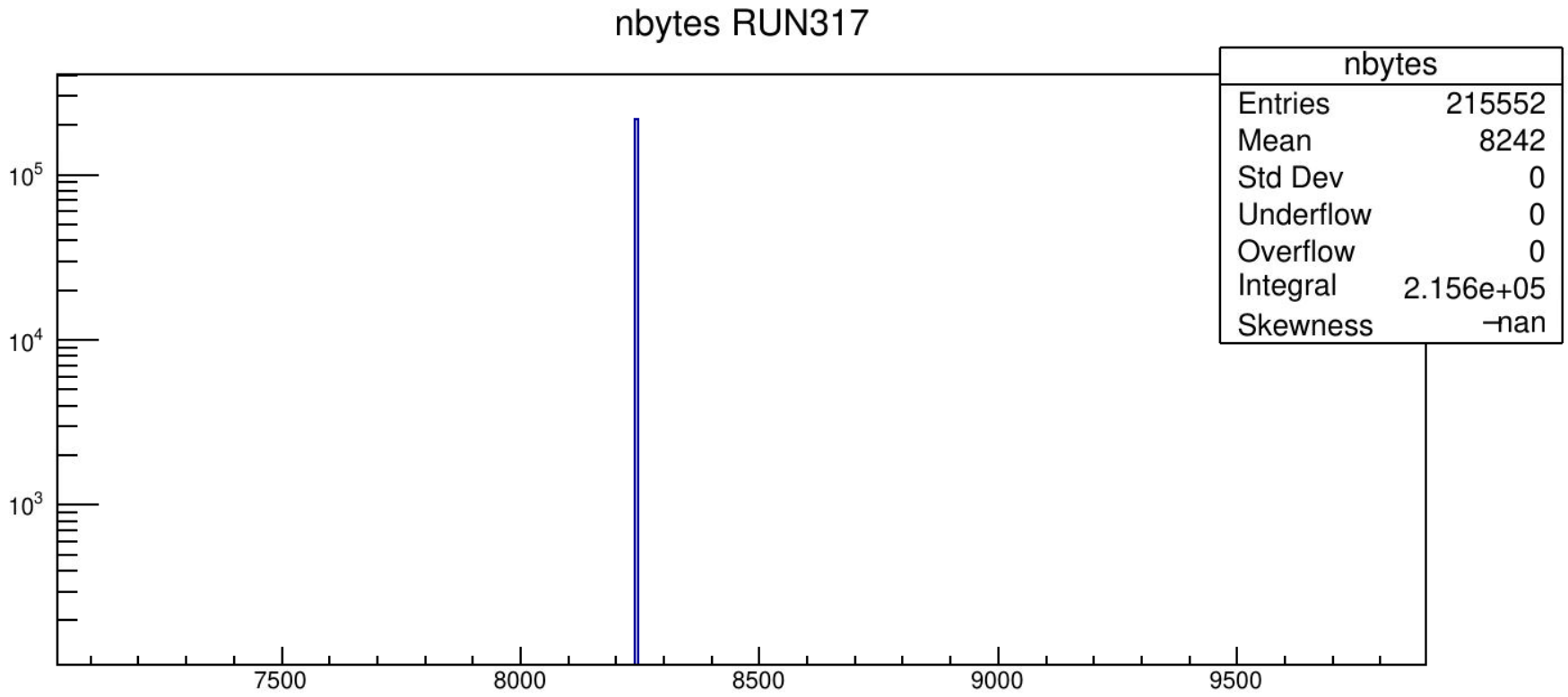
What did we find and understand last time?

- Structure of a valid event;
- Different event size distributions;
- 3 types of failure modes:
  - Non-existent channel ID's;
  - Events marked as non-valid;
  - Events with extra 16 and 32 bytes.

What are we reading out?

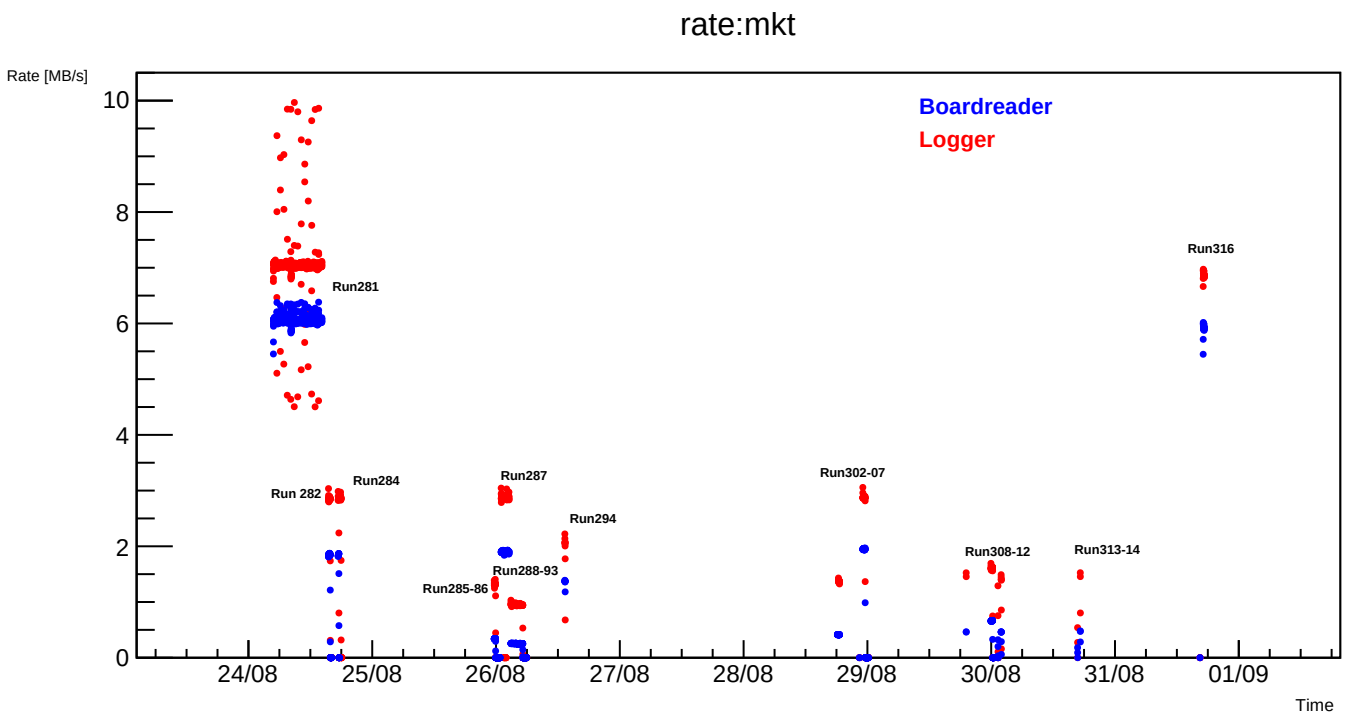
- Reading 1 ROC, which is the equivalent of one panel;
- ROC has 96 channels;
- Generator sends pulses to channels at 250 kHz and 60 kHz;
- We vary the event window which is the equivalent of the difference between proton pulses;
- Event window and generator frequency define the number of *hits per event*;
- ROC buffer has space for 255 hits:
  - $N_{gen} < 255$: $N_{readout} = N_{gen}$;
  - $N_{gen} \geq 255$: $N_{readout} = 255$, because the buffer is already full.

Event size distribution



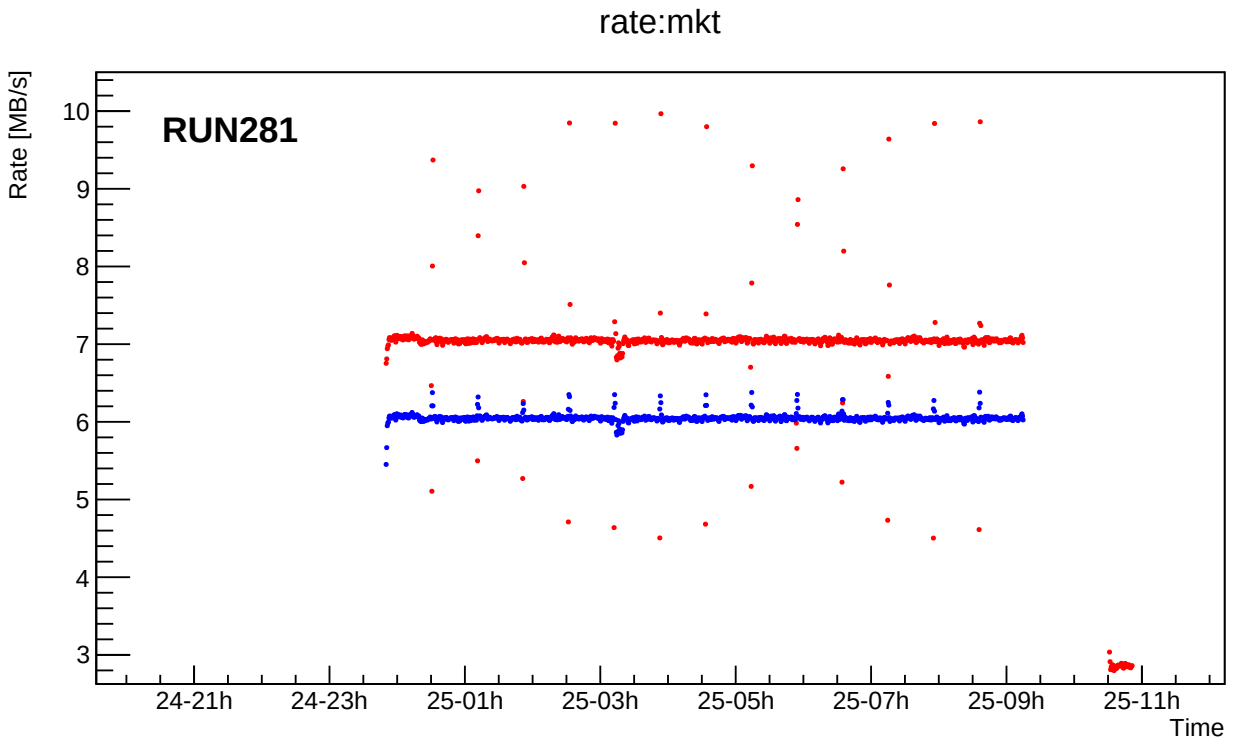
- Time window of 50 μs and 96 channels read out;
- Improvements in firmware;
- Finally starting seeing peaked event size distribution!

Analysis of logger and boardreader rate



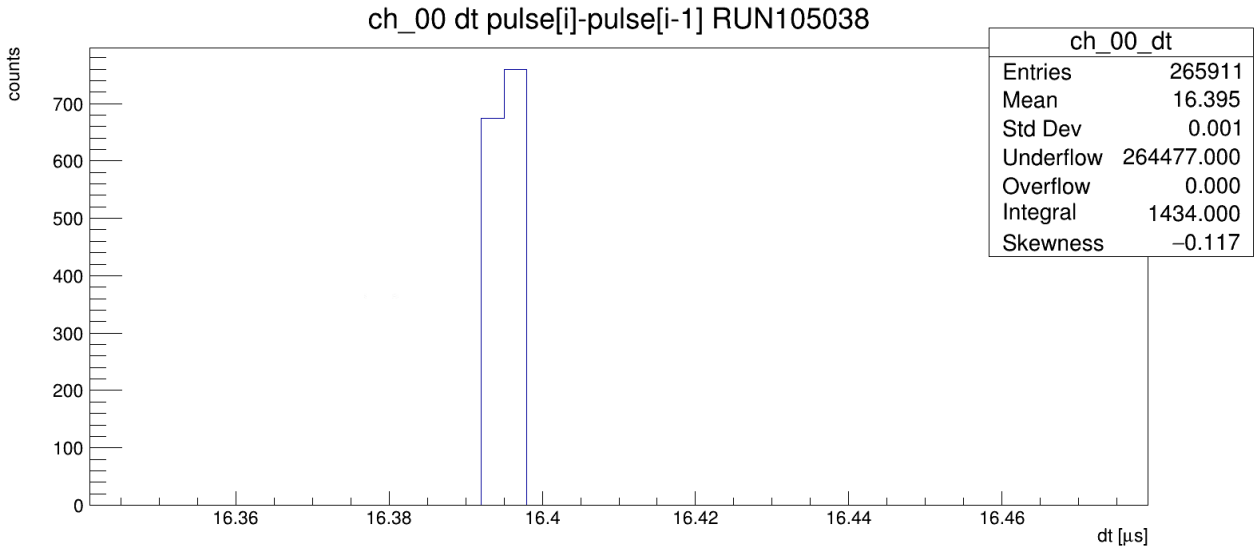
- Rates reported by boardreader (DAQ input) and logger (DAQ output);
- multiple runs, varying:
  - number of ROCs : one or two;
  - number of channels per ROC: 4-96;
  - length of the time window 12.5 - 50 μs.
- $R_{br} < R_l$: work on understanding in progress;

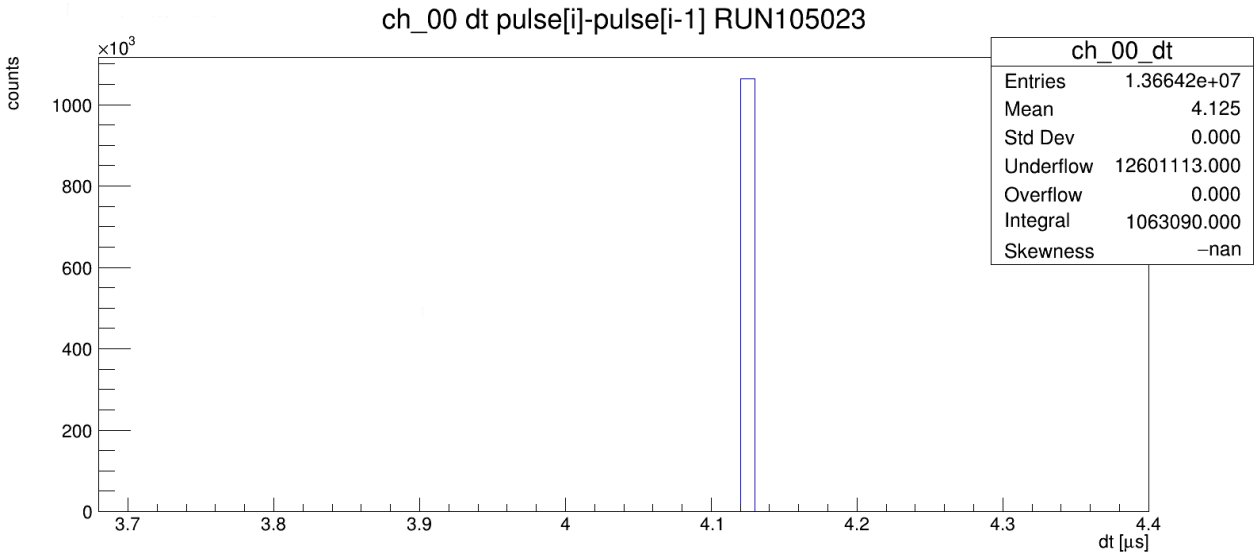
Zooming on each RUN



- rate spikes in RUN281 (longest one - 1 ROC): closing output files.
- RUN294: read 2 ROCs with 96 channels each:
  - the rate dropped down by a factor of 3: work in progress.
- 500MB in 13 min $\rightarrow$ 0.7MB/s but ARTDAQ reports 7MB/s: need to understand why!

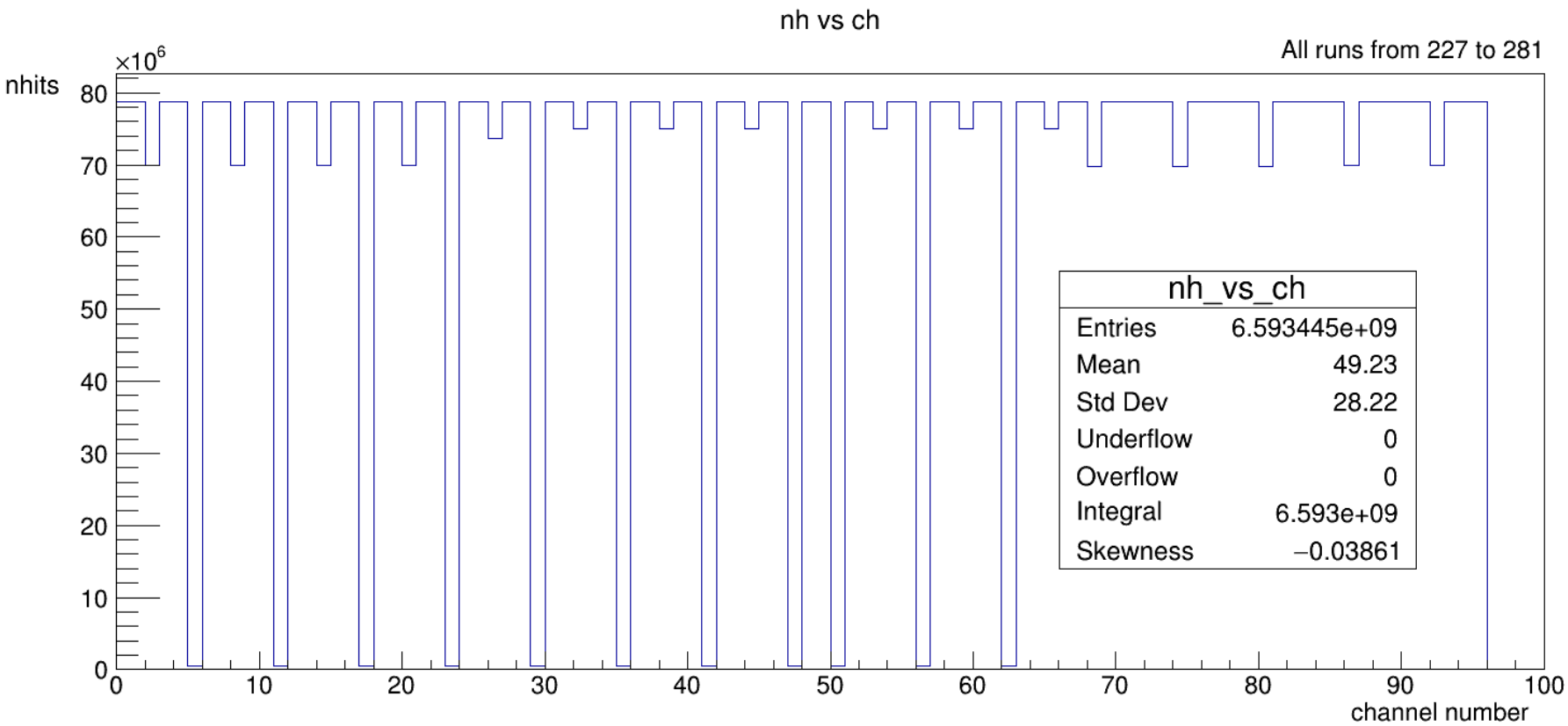
Validation of generator frequency





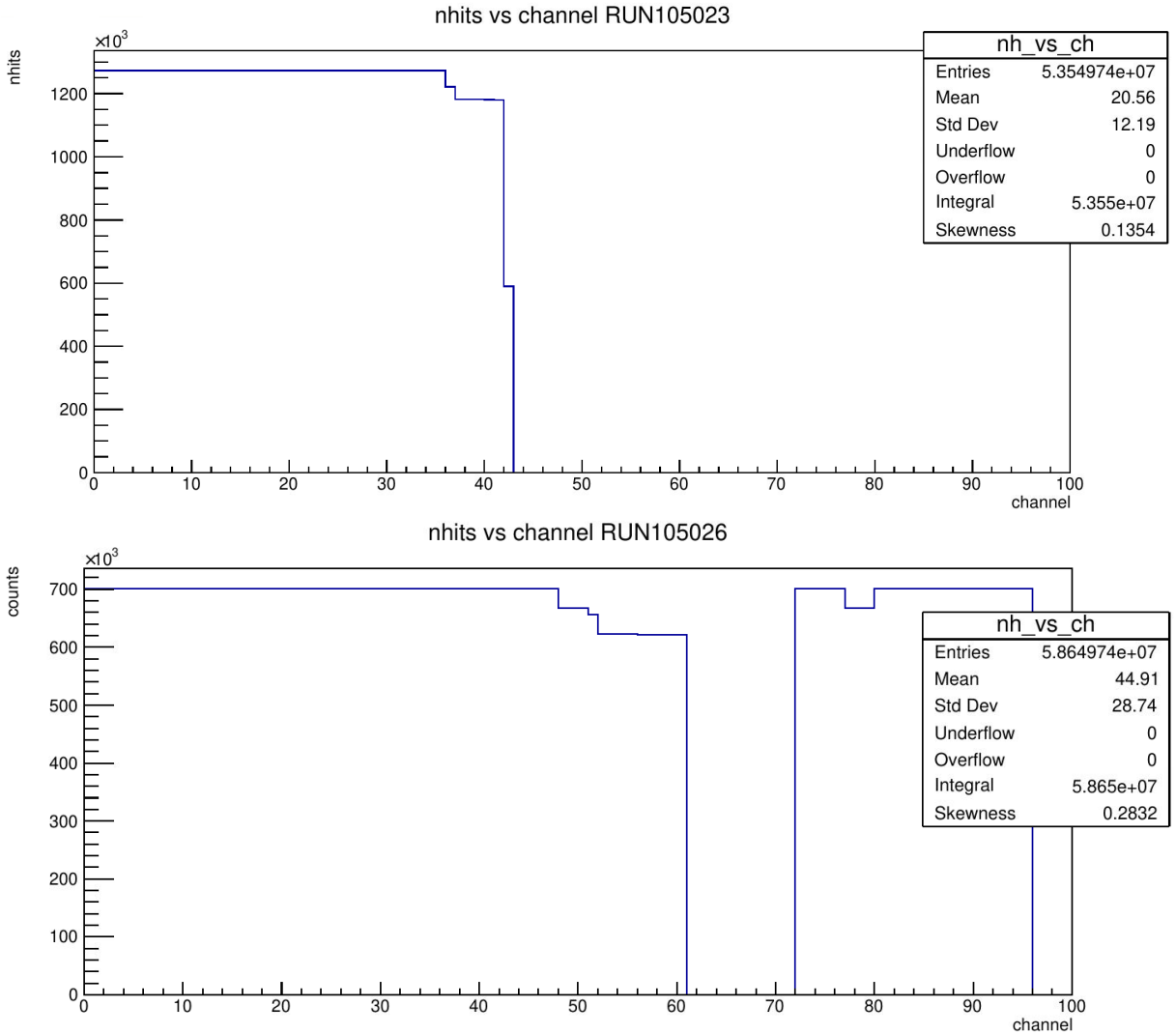
- Generating *hits* in each channel at 31.29 MHz/(2^7+1) and 31.29 MHz/(2^9+1);
- Generator frequency validated with accuracy better than 20 ps.

Occupancy: number of hits vs channel number



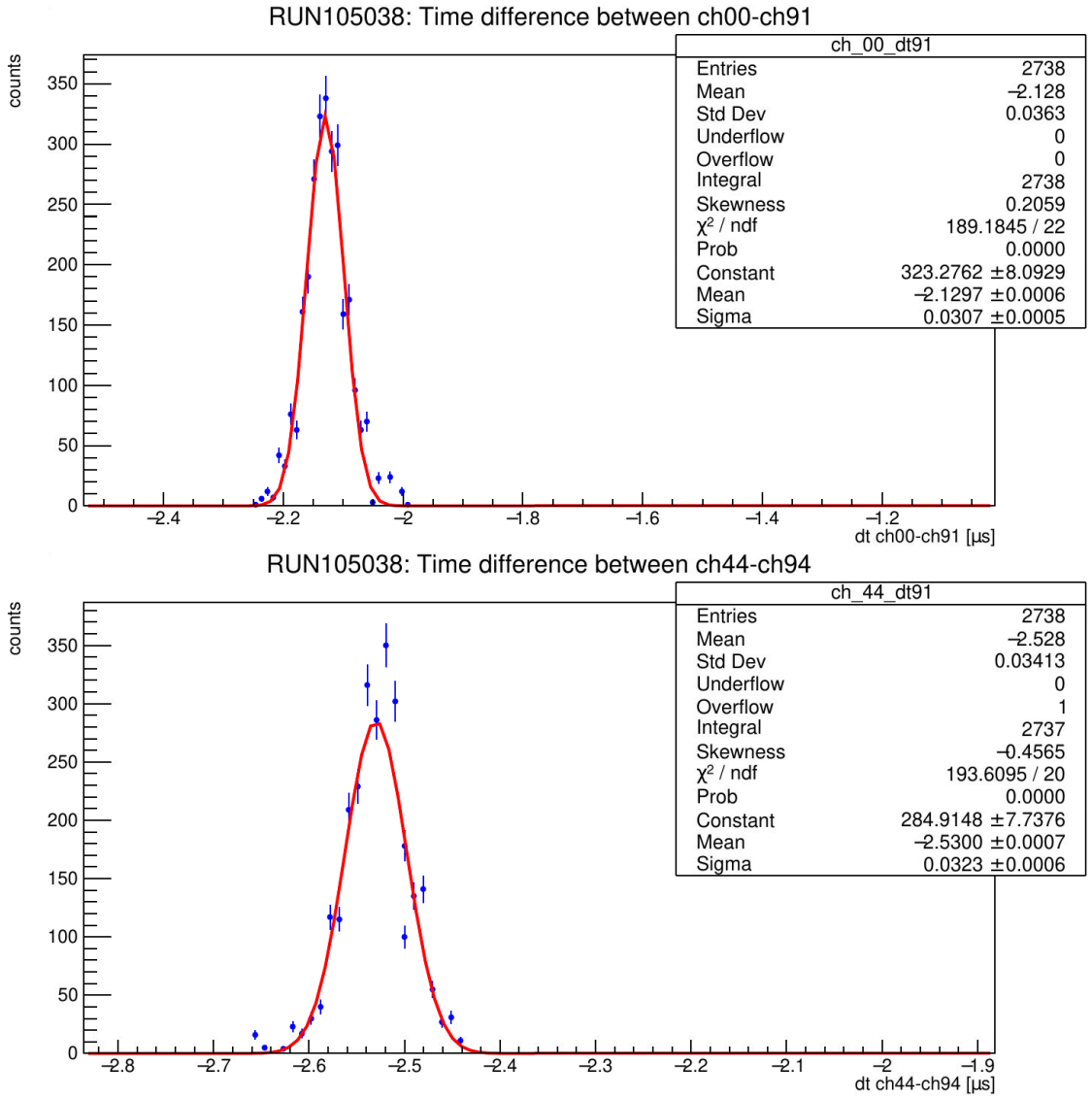
- Mode of overflowing hit buffer;
- Not a uniform distribution of number of hits vs channels;
- Not the same occupancy for all channels.

Occupancy: "expected" order



- Tried to change event window and frequency;
- We expected that the buffer gradually fills with channels;
- Probably channels are in a different order.

Calibration of the time difference between channels



- time difference between ch00 and ch91 (first channel of first FPGA);
- time difference between ch44 and ch94 (first channel of second FPGA).

Next steps

- Simulate ROC readout and reproduce plots;
- We are now able to read 1MB/s (1 DTC and 1 ROC): our goal is to read 600MB/s with one DTC!
- Late fall-early winter: Vertical Slice Test;
- Happy to continue on Mu2e with my Master Thesis.

Thank you for your attention!

In particular a big thank to Pasha, to prof. Donati, to all my new friends I met these two months and to Ray Culbertson, who is working from home and borrowed me his office with a view and minibar!

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