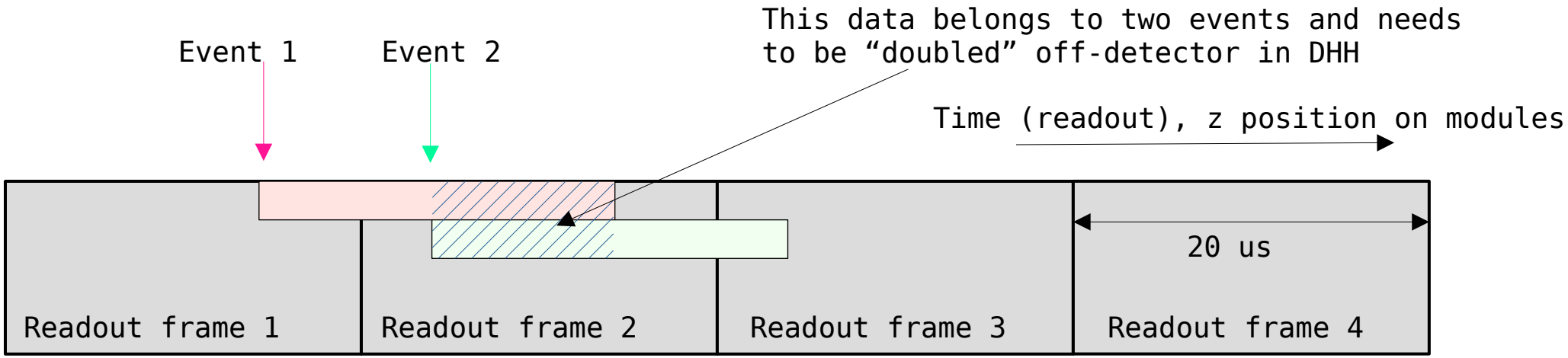
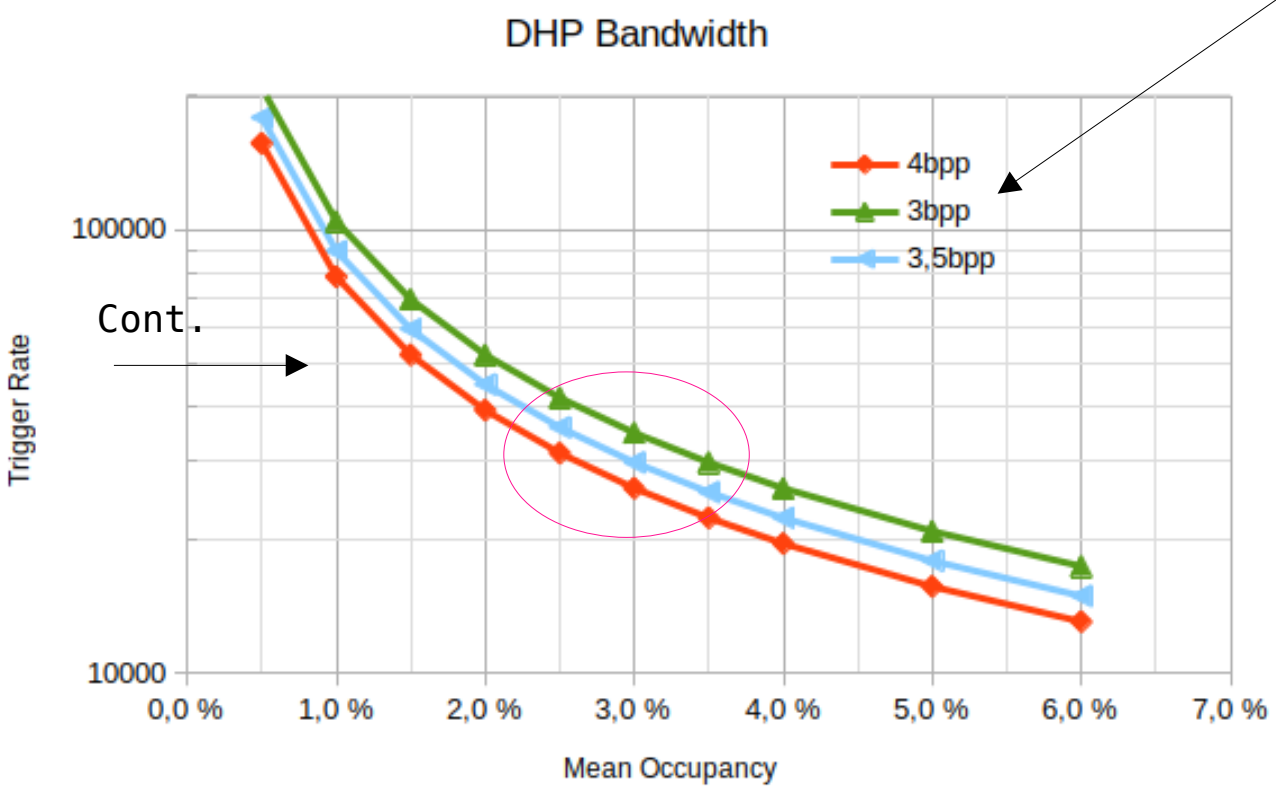
Introduction: Detector and FEE Properties

- **Rolling shutter** readout: frame 20 us = 50 kHz (this is "trigger-less")
  - Data is continuously sampled by DCD and written to DHP memory
- **All** data is always available from the DHP chip memory!
- Classic "triggering":
  - Tell the DHP which part of memory to send out → DHE takes care of formatting the data into "events".
  - All data can (in principle) be read out, limited by DHP output FIFO and bandwidth between DHP and DHE
- **30 kHz trigger rate is "not far" from a continuous readout!**
  - (random trigger distribution: time wise overlap → 30 kHz is not 30/50 but more like 20/50 of overall data)





Depends on the distribution of hits on the sensor and cluster topology/size
4 - all unrelated
3 - realistic for large occupancy
2<x<3 - for injection noise

Overlapping trigger effects are not included, thus numbers >20kHz are too pessimistic

We can never send out more data from the ASIC than in the continuous readout case, even if the trigger rate exceeds 30, 50, 100 kHz

(Short) Summary

- PXD readout on chip level is basically a free-running readout (trigger-less)
- PXD readout limited by ASIC (DHP) on modules and bandwidth to outside detector (DHH) above current design luminosity/background → this cannot be changed without building a new detector
- Within these limits, continuous readout (or trigger rates >50kHz) would be in principle possible. But limitations on detector occupancy would apply (esp for inner layer) → we would lose our safety factor.
- Firmware would need to be rewritten (DHH). New concept for data reduction would be needed.
- Injection-trigger-veto currently saves us from the majority of high occupancy events. Some internal veto from DHE to DHP would be needed (similar to what is already in development).

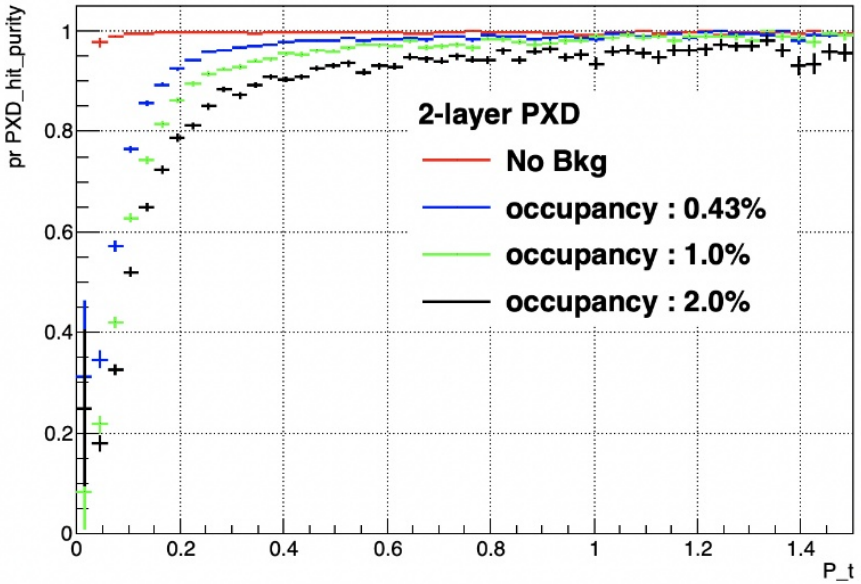
- Remark 1: As the current limit is already on the ASIC soldered on the sensor, a new readout (new clustering hardware+direct input to EB1/HLT) will not change the picture.
- Remark 2: Any change in readout concept is unlikely to happen in view of a possible replacement of VXD with a different detector concept in the mid term future

Backups

- Some more details on where the limits arise …

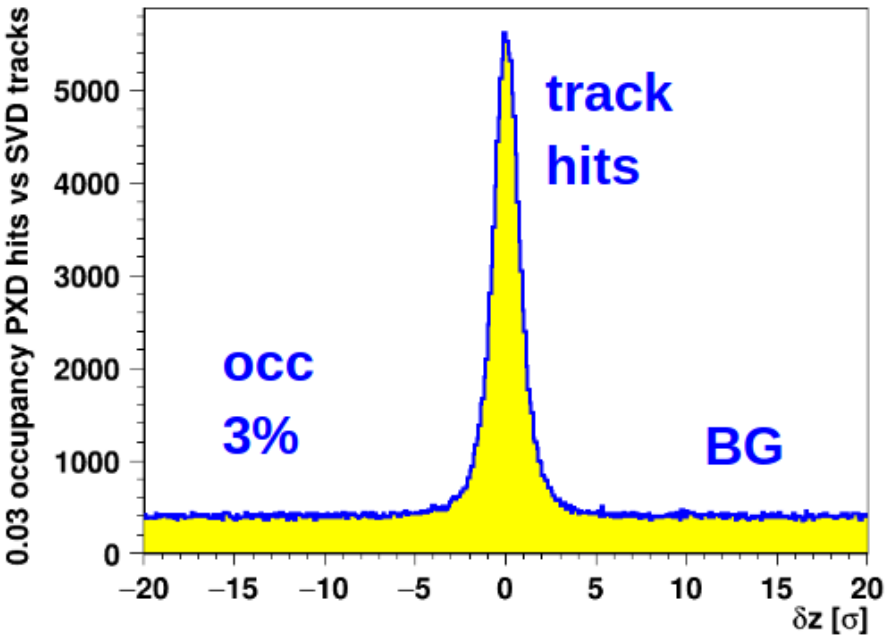
The 3% Myth

- ~1% (in the inner layer!) expected from simulation, hardware design with safety factor at 3%.
  - Same number applied for DHH/ONSEN etc
- Even below 3% tracking become worse (wrong hit assignment), lower purity
- PXD-DAQ can stand 3% @ 30kHz, but the resulting data would not be optimal.
- A 3% **mean** indicates that we have event with higher occupancy, injection noise with 30%(!) observed. Nowadays data is truncated at 4% +4%. Also within the detector the (local) occupancy varies.
  - Several events triggered with >3% may clog FIFO due to bandwidth limit. → workaround: reset pipeline automatically after 2s of no-data



https://indico.belle2.org/event/7891/contributions/47087/attachments/19199/28544/PXDANA_2-layerPXD_performance_20220117.pdf

Residuals



Available Bandwidth

- DHP → DHE
  - 1.5Gbit/DHP → 6.0Gbit per module (allows for >3%@30kHz)
  - Overlapping triggers; data belonging to two triggers is transmitted only once
- DHE → DHC
  - 40 x 2.5 Gbit (carrier design issue, hardware update in progress for 5 Gbit)
- DHC → ONSEN
  - 32 x 6.25 Gbit ; 620 MB/s/link ← works with load balancing
- ONSEN → EB2
  - 32 x 1 Gbit Ethernet. Expect only 30MB/s/link in worst case
  - 110MB/s tested with current system w/o any problems (back pressure to trigger)

System designed for 3%, 30 kHz @ full luminosity
(3% includes safety margin from expected 1.5%)
Occupancy L2 < L1, worst case scenario is inner layer
L1/L2 allows for "load balancing" → downscale ONSEN 40→32 subunits

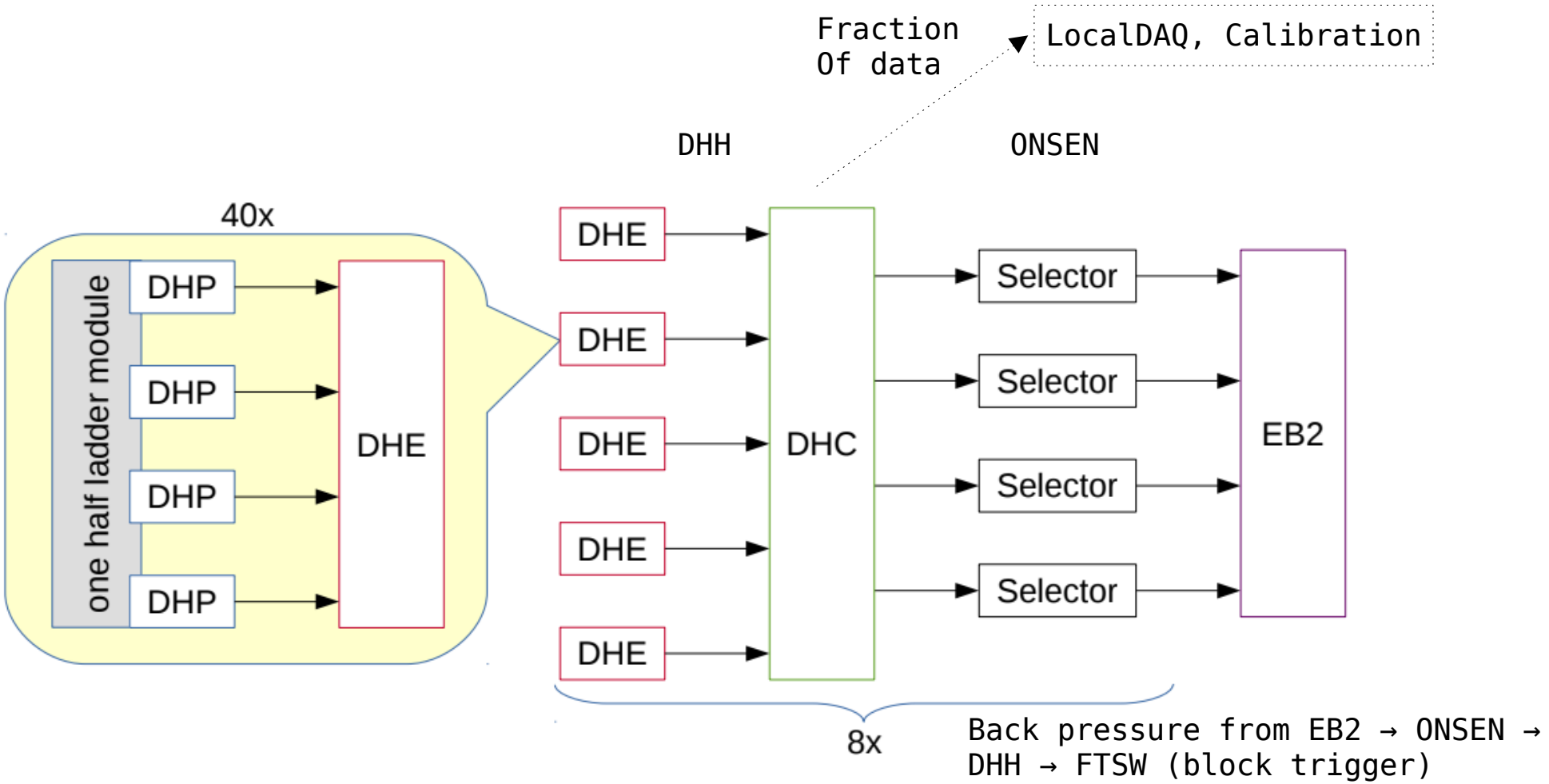
No issue with projected occupancy/trigger rate
Todo: install DHH carrier fix and 2nd half of DHH

Looking at Specific Bottlenecks

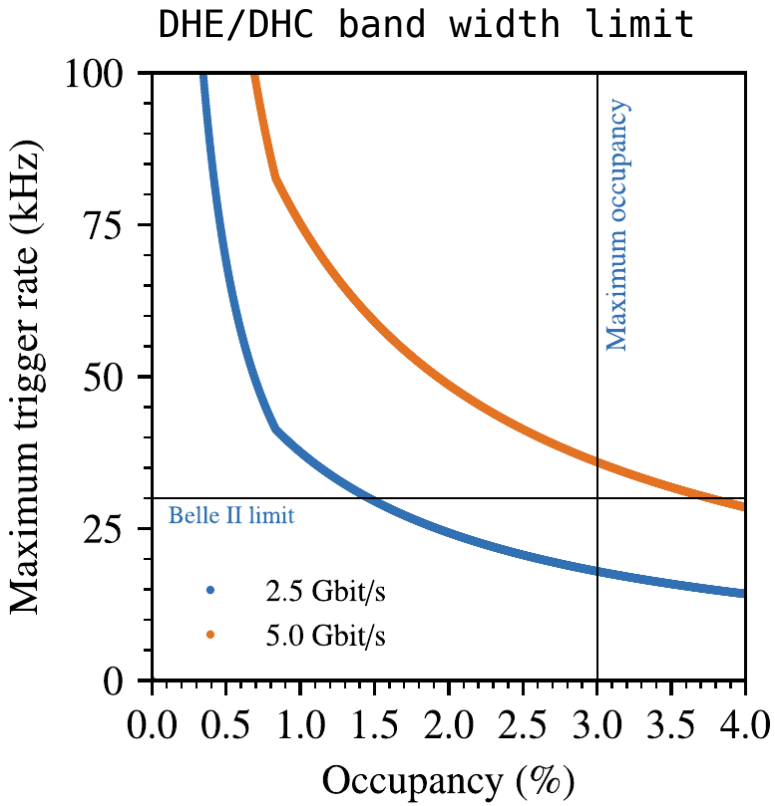
- DHP output:
  - Increasing trigger rate → saturates/approach maximum (=continuous readout)
  - Due to poisson-like trigger distribution (overlaps), even at 50 kHz (frame rate) not yet at maximum
  - Limit by data rate: exceeding 30kHz → 100 kHz (or continuous) would reduce the acceptable (mean) occupancy to ~1.5% (depending on cluster topology)
- DHE/DHC
  - Design 3%@30kHz
  - Due to doubling of data of overlapping triggers, data rate scales linear with trigger rate
  - Continuous readout (need new firmware!) equivalent to 50kHz trigger rate
- ONSEN
  - Design 3%@30kHz with guaranteed HLT processing time
    - No direct limit on trigger rate if HLT decides fast enough
  - ROI filtering would not work for continuous readout, different concept needed

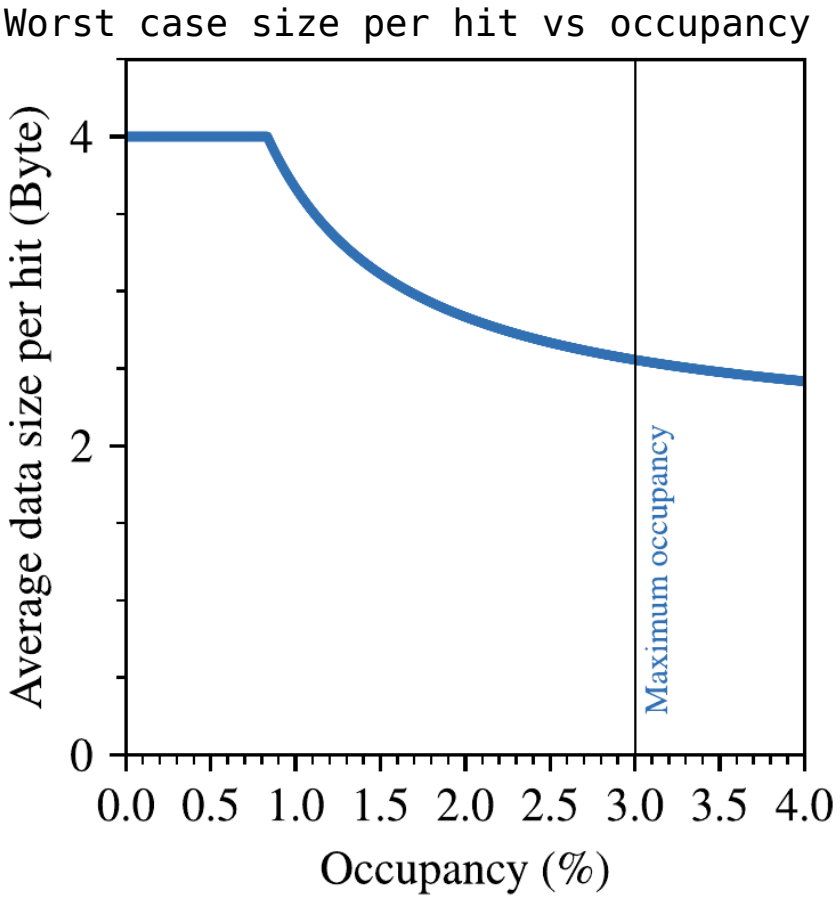
PXD DAQ – Main Data Flow

- Module (DHP ASIC)
- DHH
- ONSEN
- (HLT/DATCON → ONSEN not shown)



- Worst case size per hit vs occupancy
- DHE/DHC band width limit





- Remaining slides need to be updated and re-checked or removed

More Topics

- Data Rates ↔ Occupancy
  - Defined by data format
- Mean data rates != Maximum data rates
  - Instant peak values (f.e. injection spikes)
  - “Bursts” of large events
- Distribution of Occupancy not flat
  - Inner layer > outer layer
  - Z and Phi dependence
  - Spikes, rolling shutter looks 20us into past/future

- Tracking:
  - Local occupancy is important for track matching, cluster overlapping
  - Random distribution of pixel vs clusters (cluster size)

Example

- Assume 1% Occupancy uniform in all layers, ~1 hit per DHP double row → ~4 bytes/pixel
- N_pixel = 768*250*1%/4 = 480 pixel per DHP
- 20*4*480*4bytes = 153600 bytes (20 modules, 4 DHP)
- Sum: 156224 bytes /event
- → 1.7% is overhead

- Data rate depends on trigger rate:
- Assume 30 kHz and no ROI selection, HLT filtering 1/3:
  → 4686*10^6 bytes/s, 1562*10^6 bytes/s (filtered)
- 16 links → EB2: 98*10^6 bytes/s/link
- DHC→ ONSEN (16 links): 293*10^6 bytes/s/link
- DHE→ DHC (20 links): 234*10^6 bytes/s/link

1/3 is very conservative
Ongoing run is 1/11
(~1/8 in size)

Example PXD2

- Assume 3% Occupancy uniform in all layers, ~1 hit per DHP double row → ~4 bytes/pixel
- N_pixel = 768*250*3%/4 = 1440 pixel per DHP
- 40*4*1440*4bytes = 921600 bytes (20 modules, 4 DHP)
- → 0.6% is overhead (ignored)

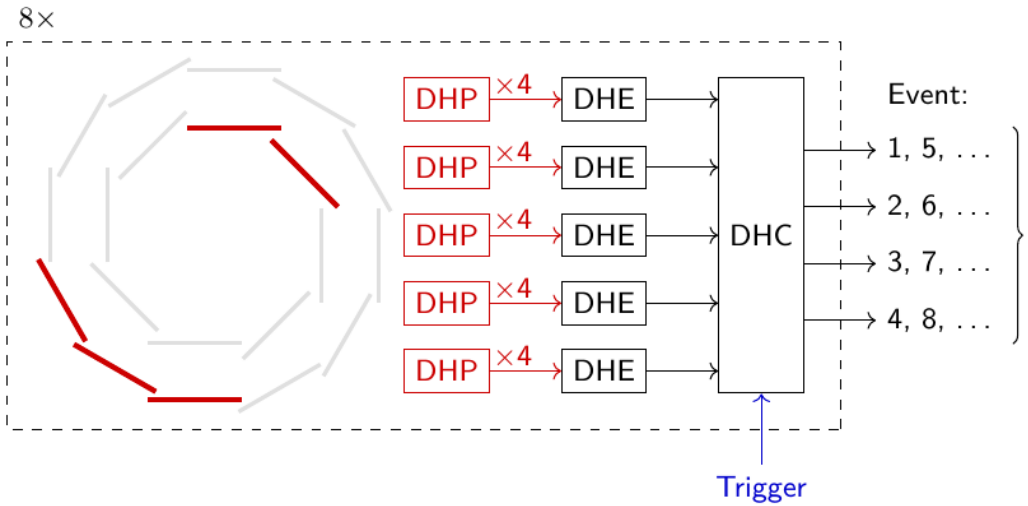
- Data rate depends on trigger rate:
- Assume 30 kHz and with ROI selection, HLT filter
- → $27.6*10^9$ bytes/s
- 32 links → EB2, ROI red to 10%, HLT filter 1/3:
  - $29*10^6$ bytes/s/link
- DHC→ ONSEN (32 links): $866*10^6$ bytes/s/link
- DHE→ DHC (40 links): $693*10^6$ bytes/s/link

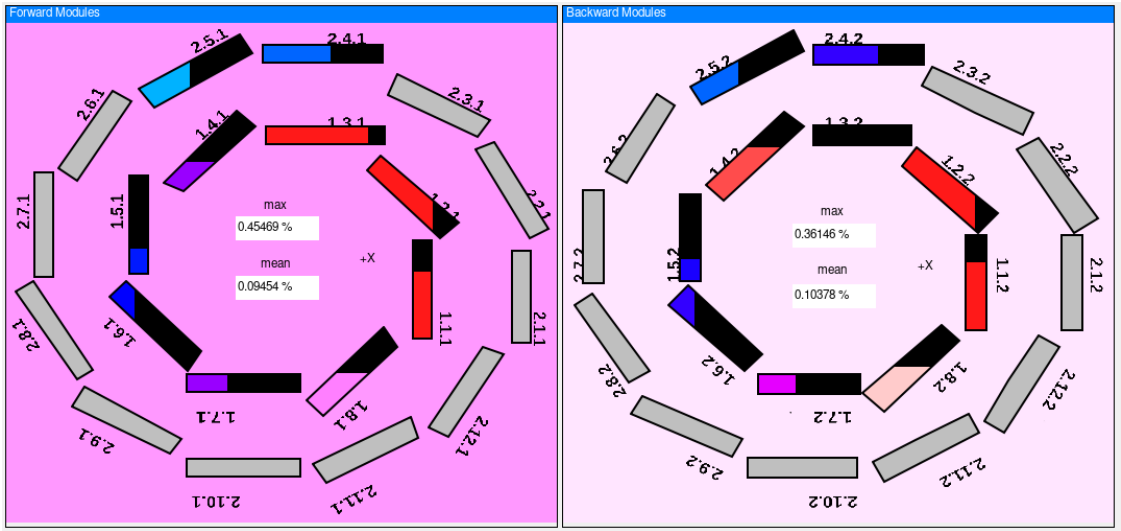
1/3 is very conservative
Ongoing run is 1/11
(~1/8 in size)

DAQ group requested header data for rejected events
→ some additional overhead is missing here

Remarks

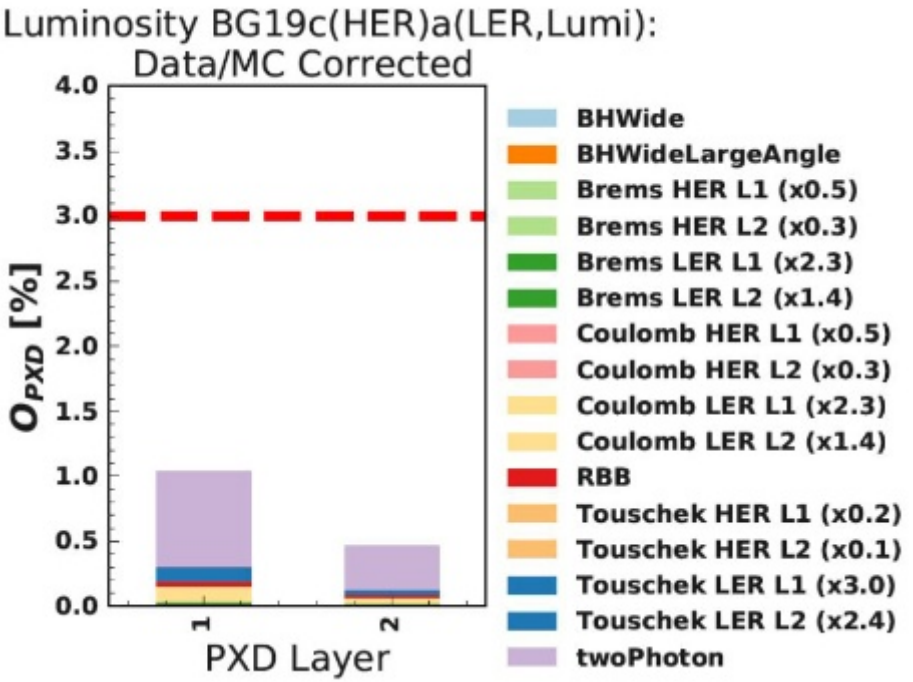
- Worst case assumptions for design consideration!
  - **Mean** rate of the most busy module should not exceed 3%
  - 3% was already including a safety margin
- Optimization
  - Outer layer < inner layer ; phi dependence:
    - → Load balancing (2 inner + 3 outer modules in one DHC), reduces mean rate on DHC output





Occupancy / Background Projection

- We will not reach 3% at design luminosity (Analysis by Sally → Talk by Lu Cao)
  - (and our final luminosity may be lower)

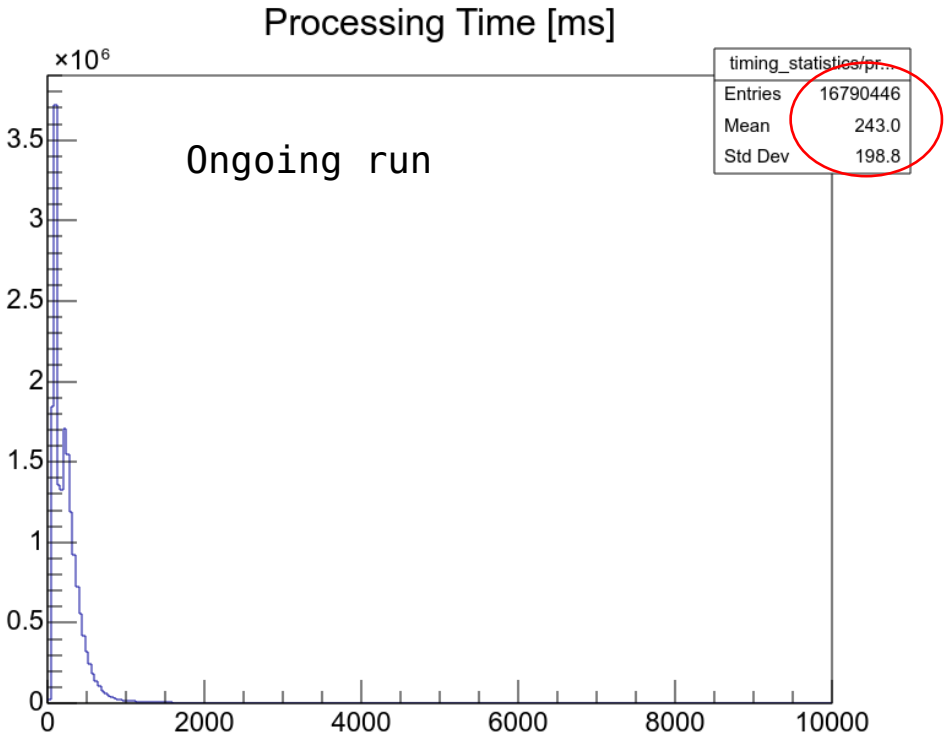


Buffering for HLT Decision/ROI Filtering

- PXD data is buffered in ONSEN until HLT decision (ROIs)
  - 1.5GB*16 (32) = 24 (48)GB
  - LUT for 30s @ 30kHz
- Memory occupancy depends on event size (occupancy), trigger rate and HLT (mean) processing time
  - Assume 1MB size (3% for 20 mod)
    - → 24000 events can be stored at a given time
    - Assume 30kHz trigger rate
    - → accept 800ms mean delay for HLT decision
  - Hard to predict the future HLT processing time
    - Newer hardware, change in software etc
    - Tracking complexity for busy events

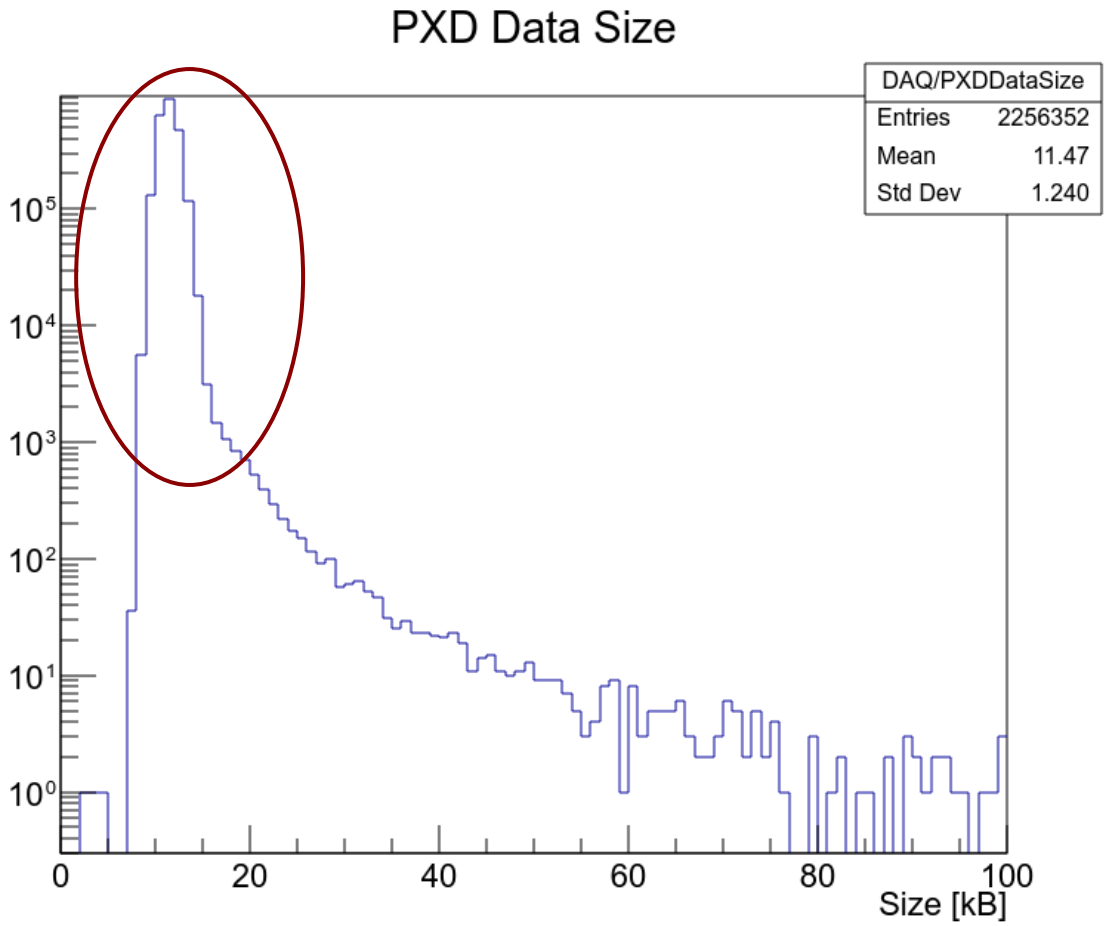
Combination of mean event size,
mean processing time and trigger rate
determines buffer occupancy.

No issue as long as HLT is fast enough.

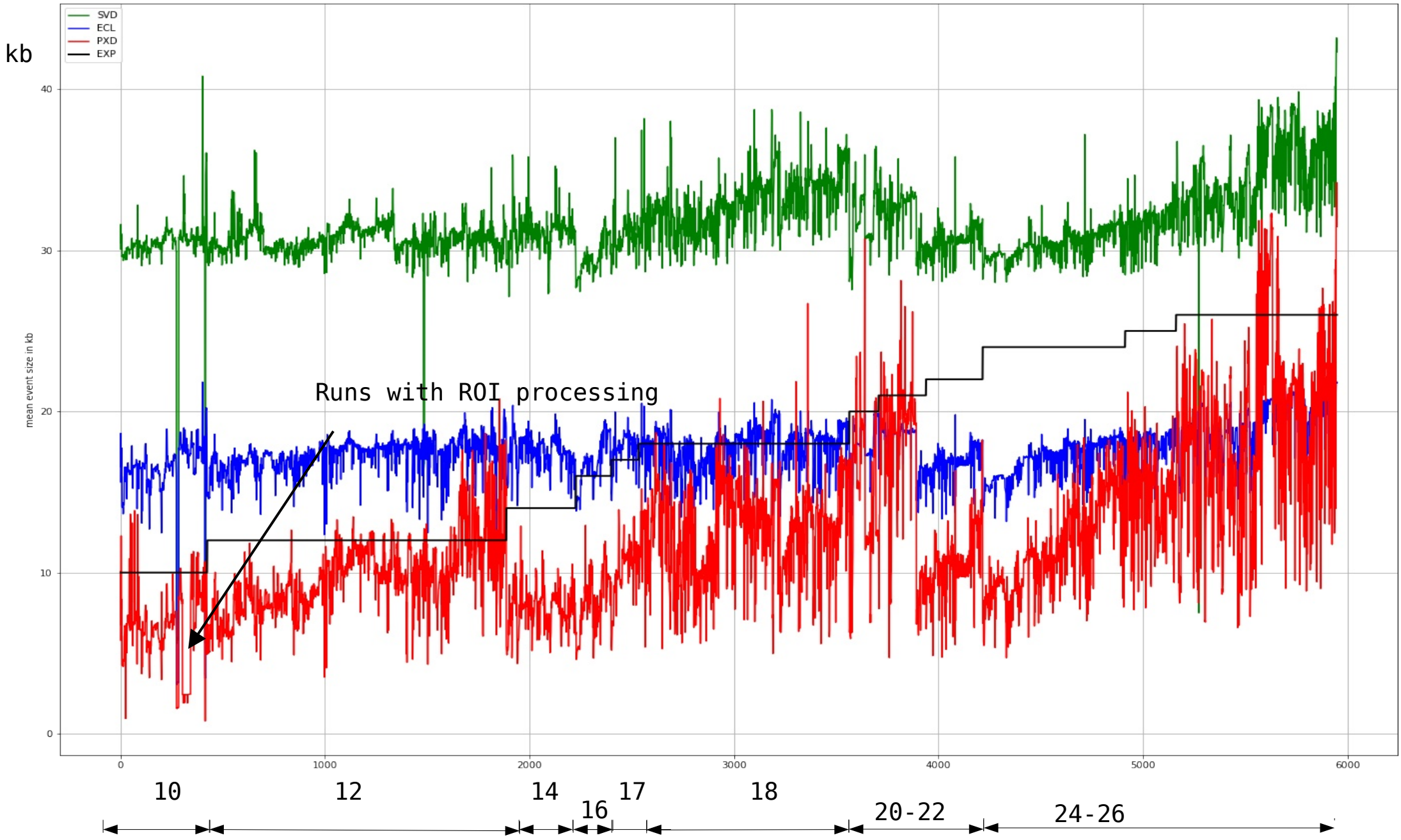


Other Limits

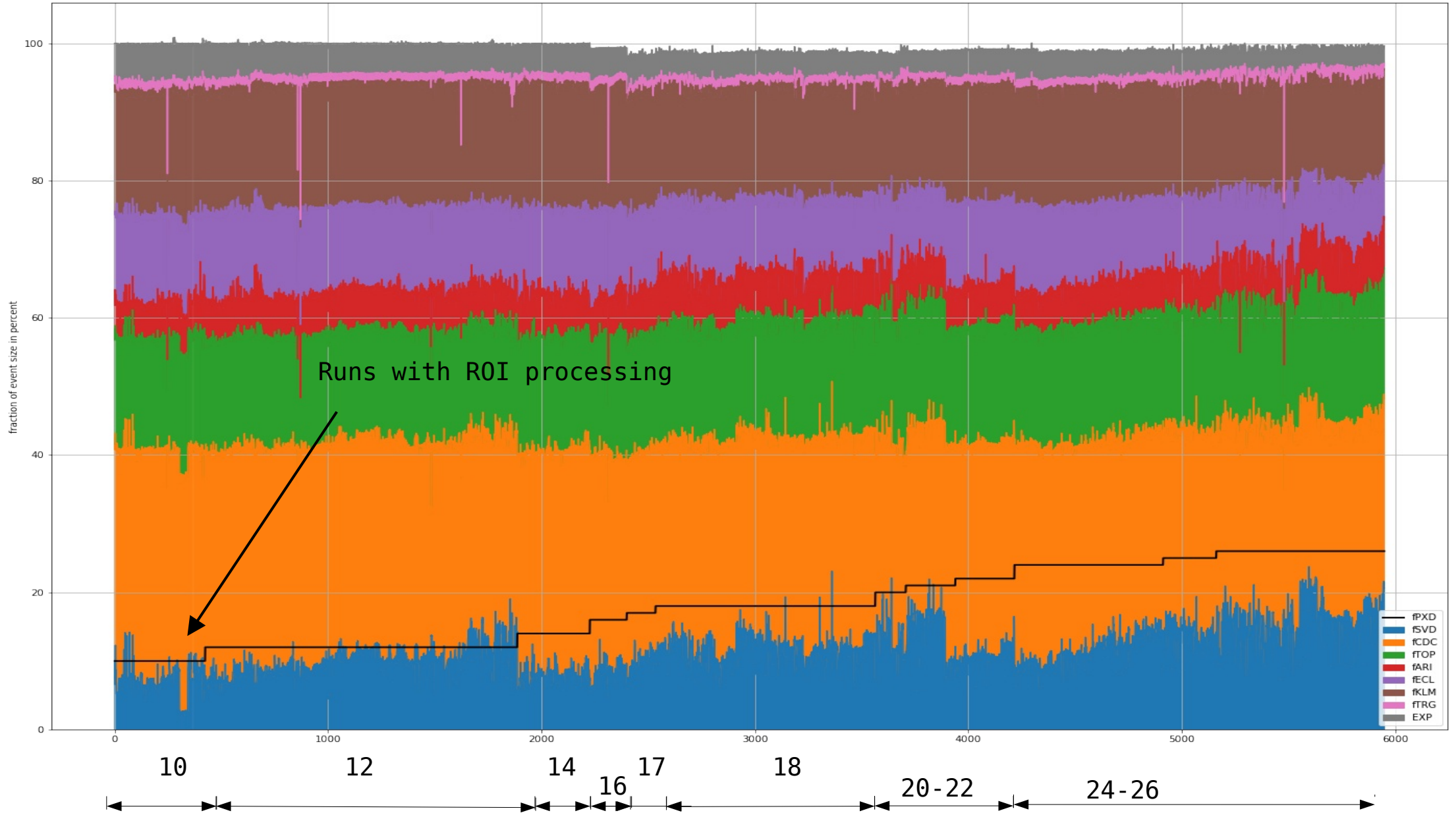
- Event (storage) size, fraction of PXD in raw data
- Tapes = Money, thus no principle design problem



Exp 10 – 18, Raw Size (in kb)

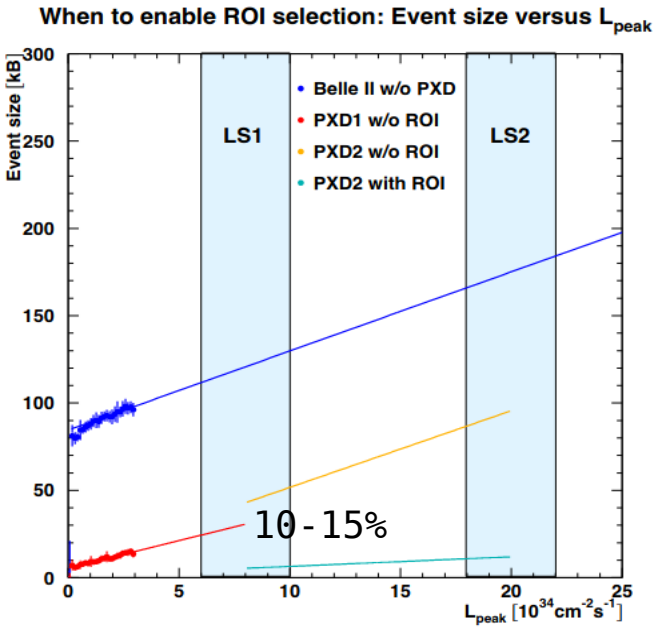


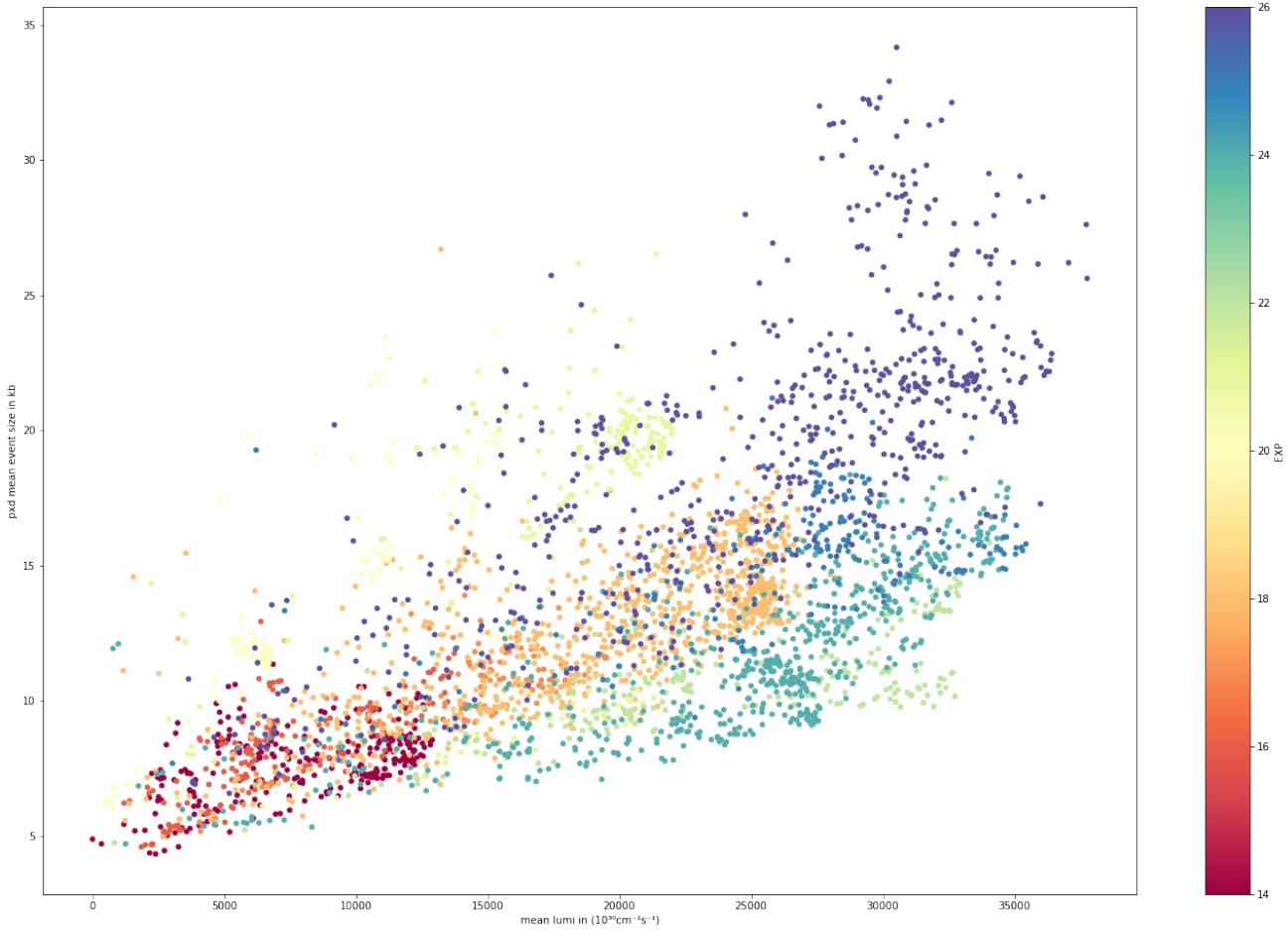
Exp 10 – 16, Fraction of Raw Size



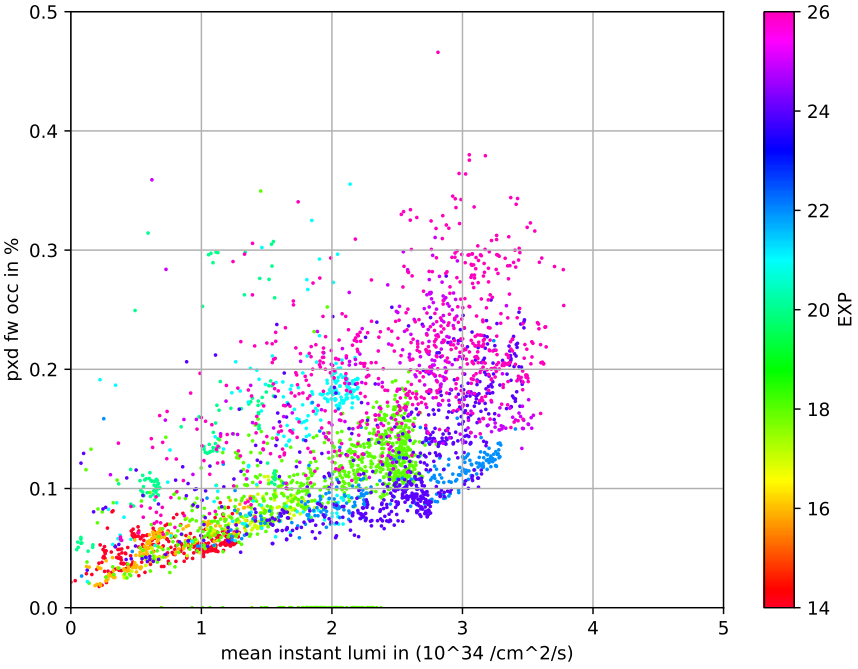
Projection

- Plotting against Lumiosity
  - Seems PXD data is not the major contributor to overall event size
  - No need to turn on ROI filtering in the near future



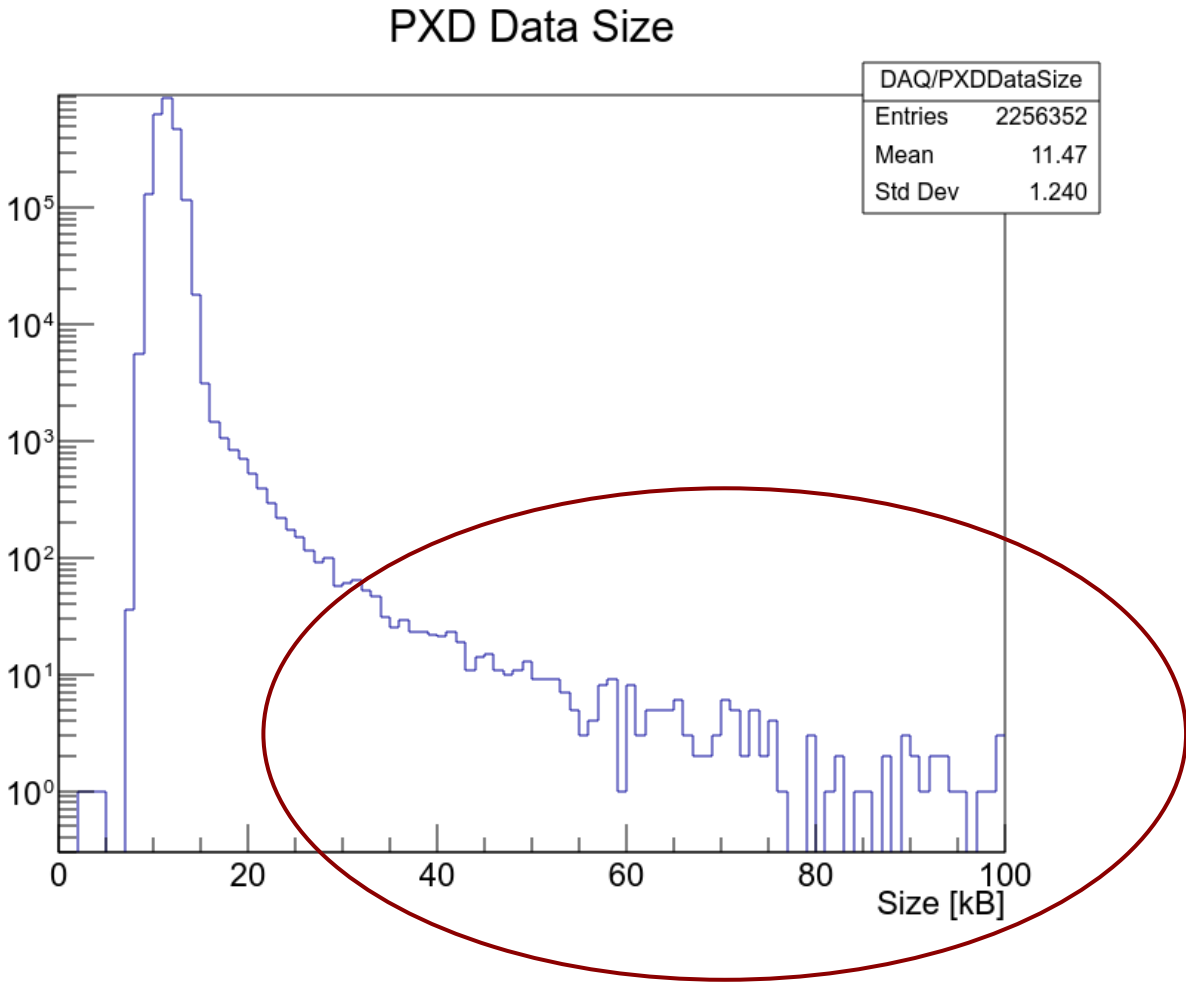


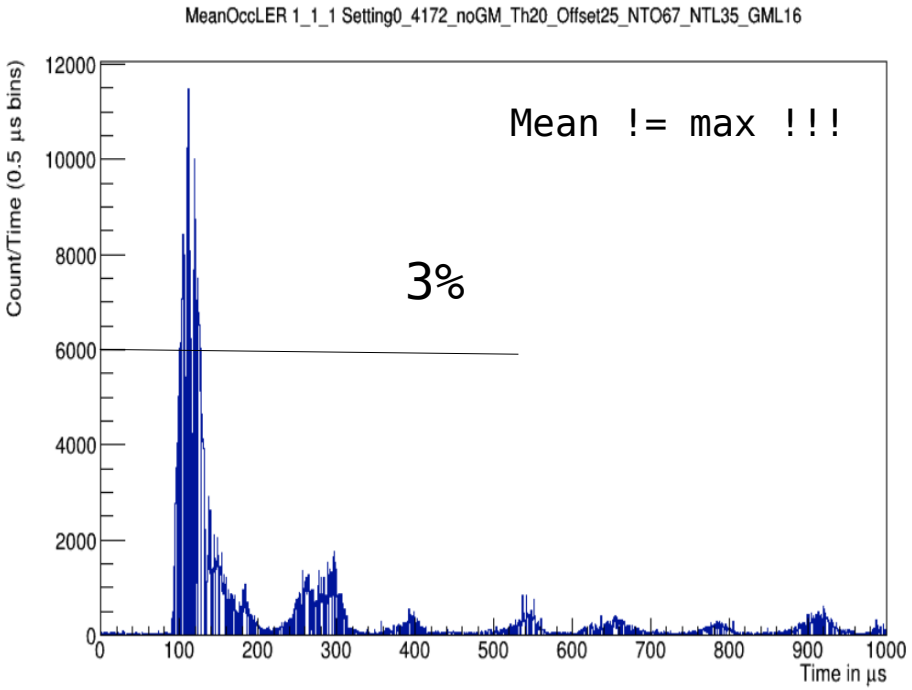
Be aware that this maybe an



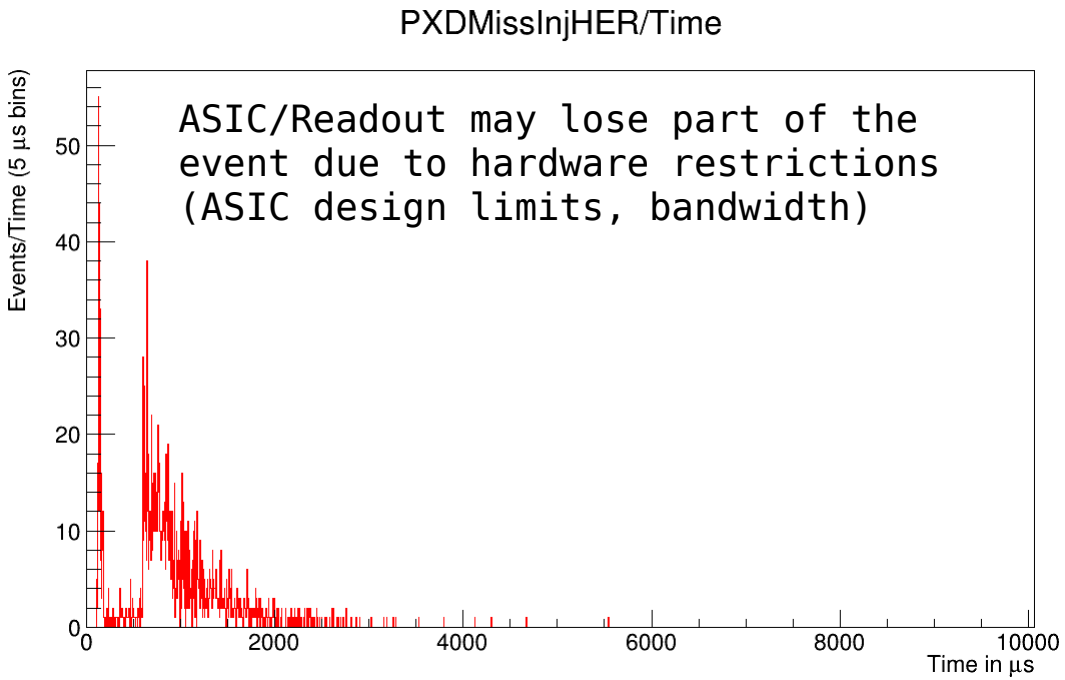
Other Limits

- Injection spikes
  - Few but large events
- (has nothing do to with slow pion reconstruction)

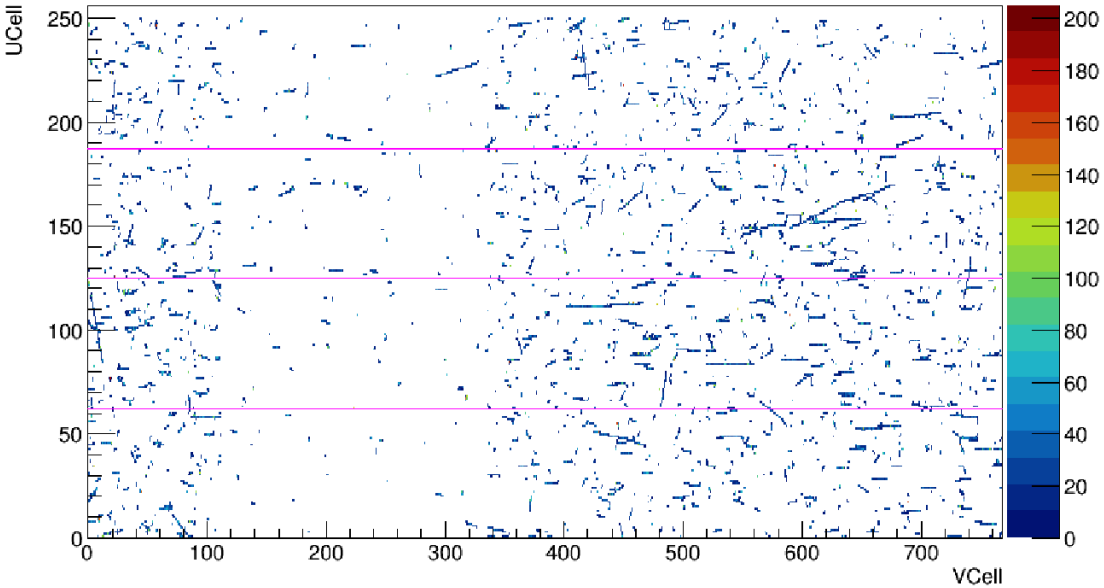




Events close to injection may exceed 3% by far (30% and more observed)



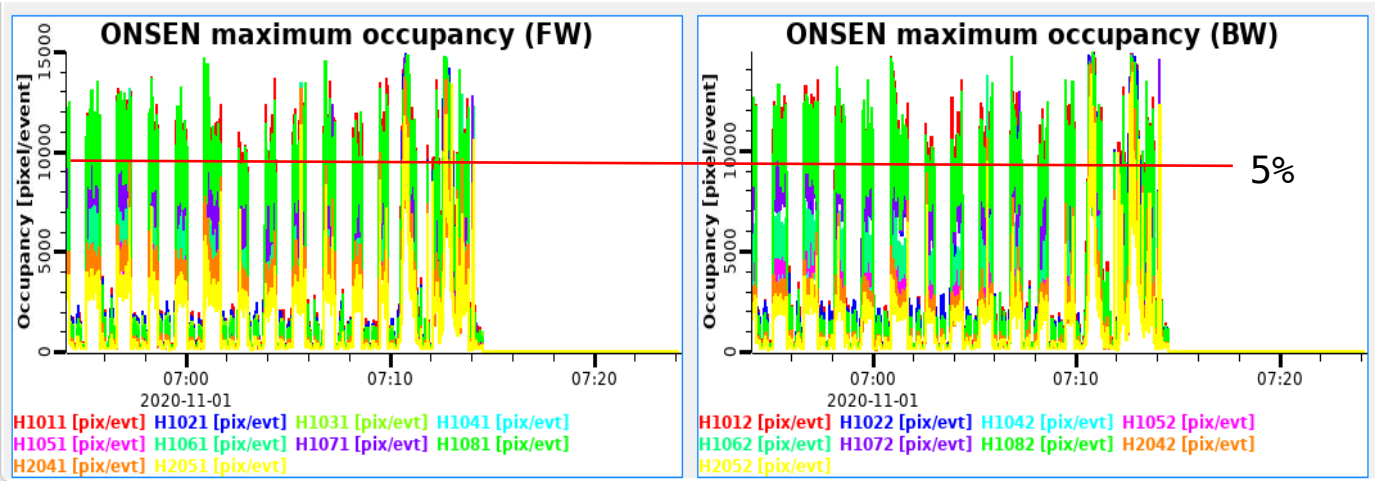
Non uniform occ by rolling shutter

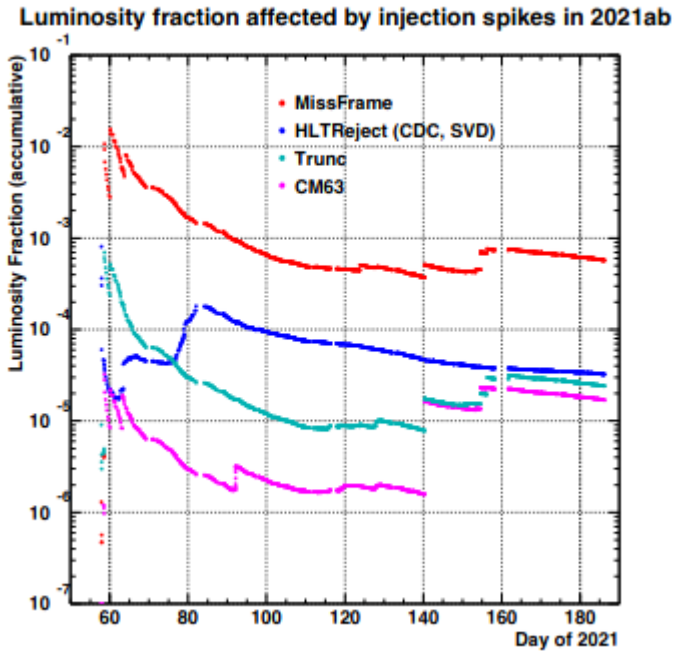


Injection Backgrounds

- Overall background not an issue to PXD in the foreseeable future
  - Data rate acceptable even w/o ROI selection for the moment
- Injection (spikes) background poses other problems, e.g. events>>3%
- Limits:
  - DHP Fifo; DHP→ DHE, frame nr slip
- DHP Fifo → CM63 error (we need much more than 3% to trigger this
- Frame Nr slip happens if we have have overlapping triggers with huge occupancy → readout one frame takes so long that frame counter increased twice → cannot match frame to trigger
- Unphysical events can be truncated only on DHE input (currently: 2*5%)
  - Losses typically dominated by handful of incidents
  - No issue for PXD DAQ stability!

This will not change with clustering/PCIe readout





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Truncated Event

- Events exceeding a defined occupancy (here 3% per DHP frame) are truncated to prevent congestion in DHE