

High-rate X-ray measurements with VMM3a/SRS

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Motivation

- VMM has high-rate capability (up to ~ 4 MHz per channel)
- Channel rate capability combined with token readout scheme \rightarrow limits the number of hits which can be received from the VMM
- SRS has several stages which could limit the bandwidth (e.g. HDMI cable, Gbps Ethernet)
- **February 2020:** we did not reach these limits
- **Since then:** lots of efforts to improve the rate capability of the VMM within the SRS, especially by Patrick Schwäbig (Bonn) and Dorothea Pfeiffer (ESS) on the firmware level
 - \rightarrow <https://indico.cern.ch/event/911950/contributions/3912256>
 - \rightarrow <https://indico.cern.ch/event/889369/contributions/4049193>
 - \rightarrow <https://indico.cern.ch/event/989298/contributions/4212816>
- **Now:** probably reached the maximum for continuous mode
- Tests so far: **testpulses** \rightarrow how is the situation under application conditions? \rightarrow **X-rays!**

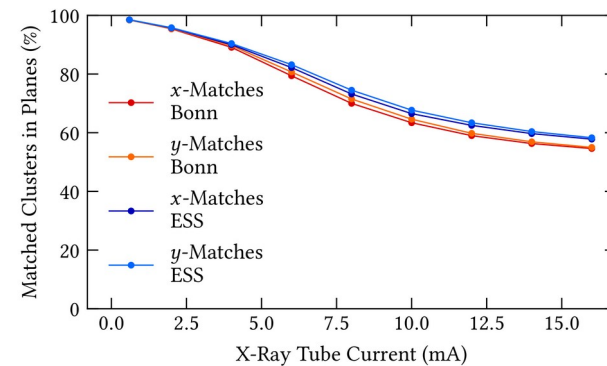
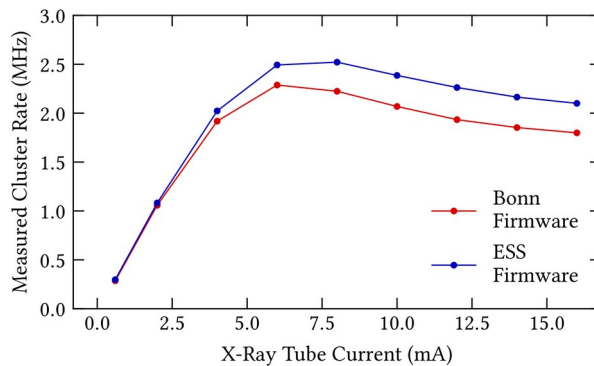
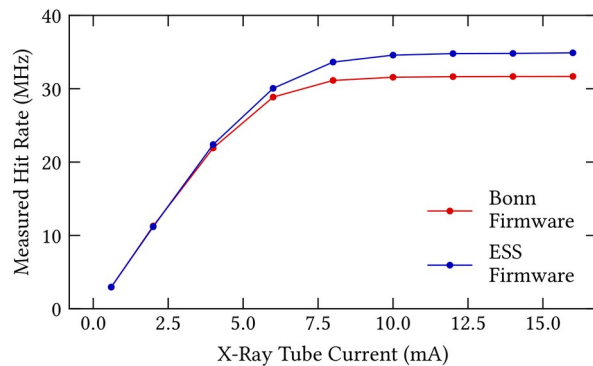
Experimental set-up

- 10 x 10 cm² triple-GEM detector
- Uniform irradiation of with soft X-rays (copper target X-ray tube)
- Use of 'extreme' electronics set-up
 - 2 FECs
 - 2 Hybrids
 - 1 Hybrid per FEC
 - 1 CTF (works nicely)

→ Only 5 x 5 cm² read out! Rest of the area covered with shielding
- From test pulse measurements
 - <1.5 hybrids (3 VMMs) could saturate the gigabit Ethernet
- **Test a system with as less avoidable bandwidth limits as possible**

Rate saturation

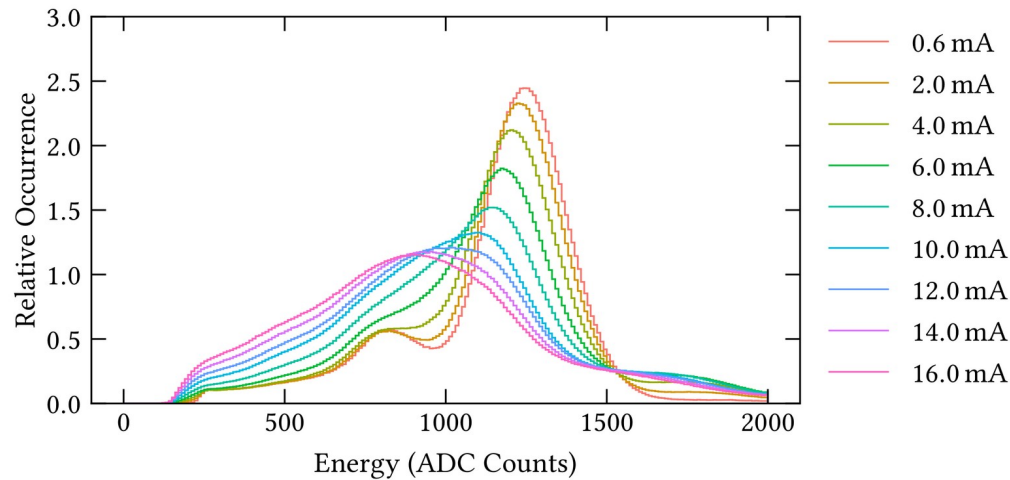
- Theoretical maximum: **41.6 MHz hits** (1 hit = 1 active channel)
 - 1 hit = 48 bits @ FEC level, 2 FECs used, each FEC has 1 Gbps output
- Average cluster size of **~ 5 strips** in x/y-direction → **4 MHz cluster rate**



- Observed saturation:
 - **31 MHz hits** and **2.3 MHz clusters** (Bonn)
 - **35 MHz hits** and **2.5 MHz clusters** (ESS)

Other observation

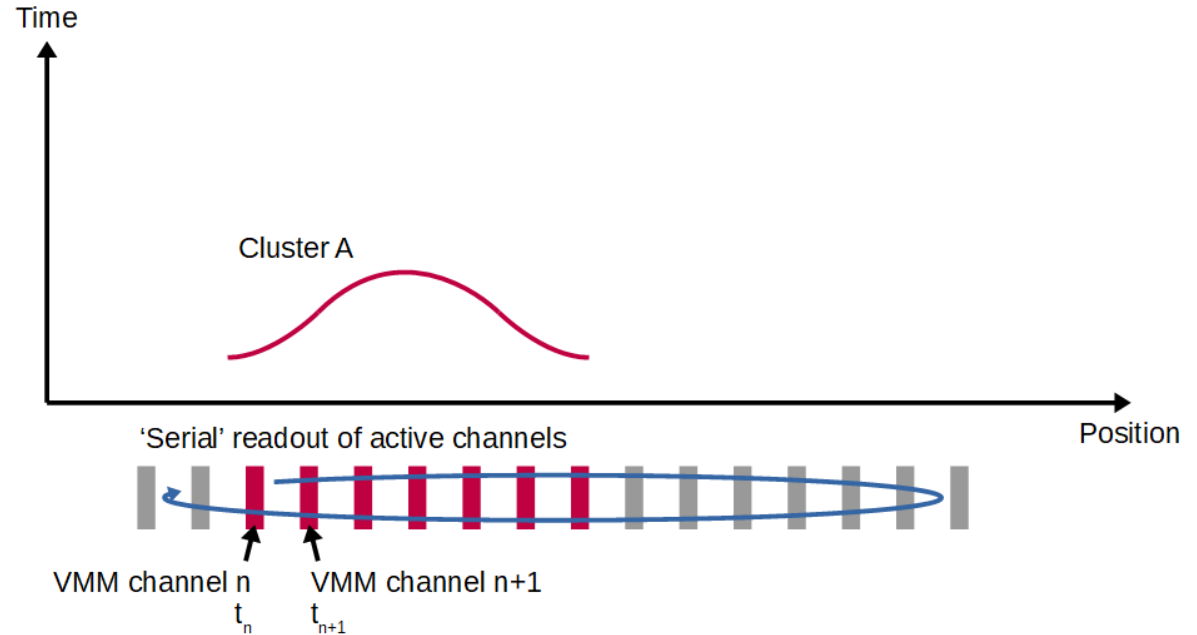
- In addition to the expected rate saturation
- Change in X-ray spectra



- 25 cm² of irradiated area
- Rate per area is O(100 kHz/cm²) → cannot be space charge effects

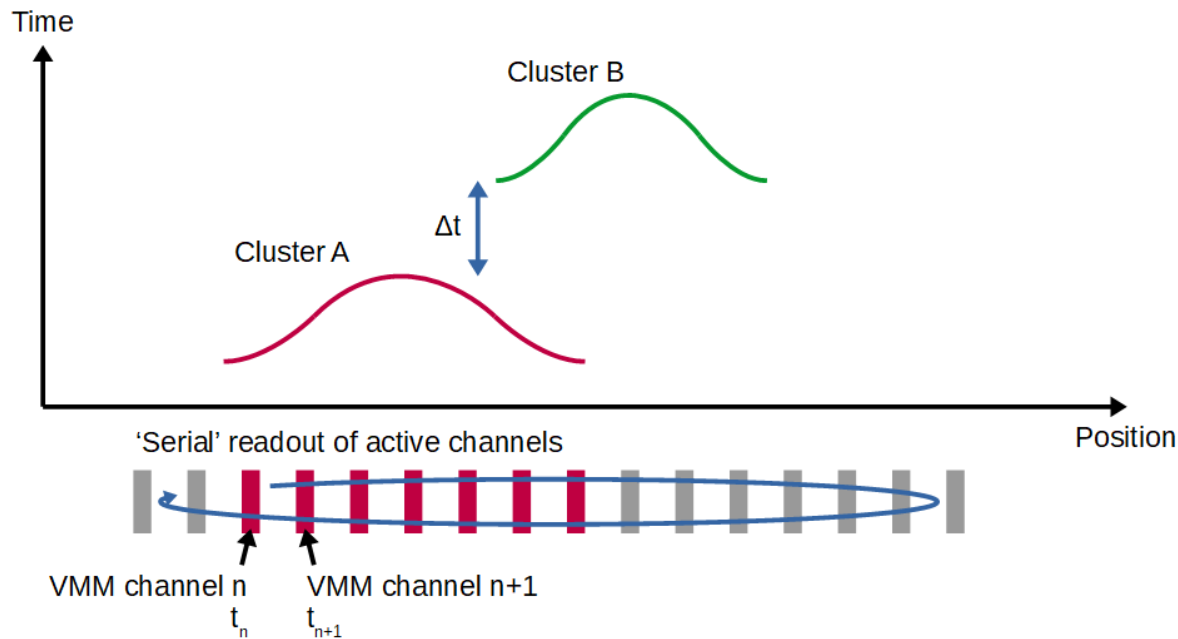
Explanation: readout scheme

- Token is passed to all channels with a stored hit
- At high rate \rightarrow high occupancy
- When lots of channels have data, the token passing is not quick enough \rightarrow while waiting for being read out, the new data cannot be written and are thus lost



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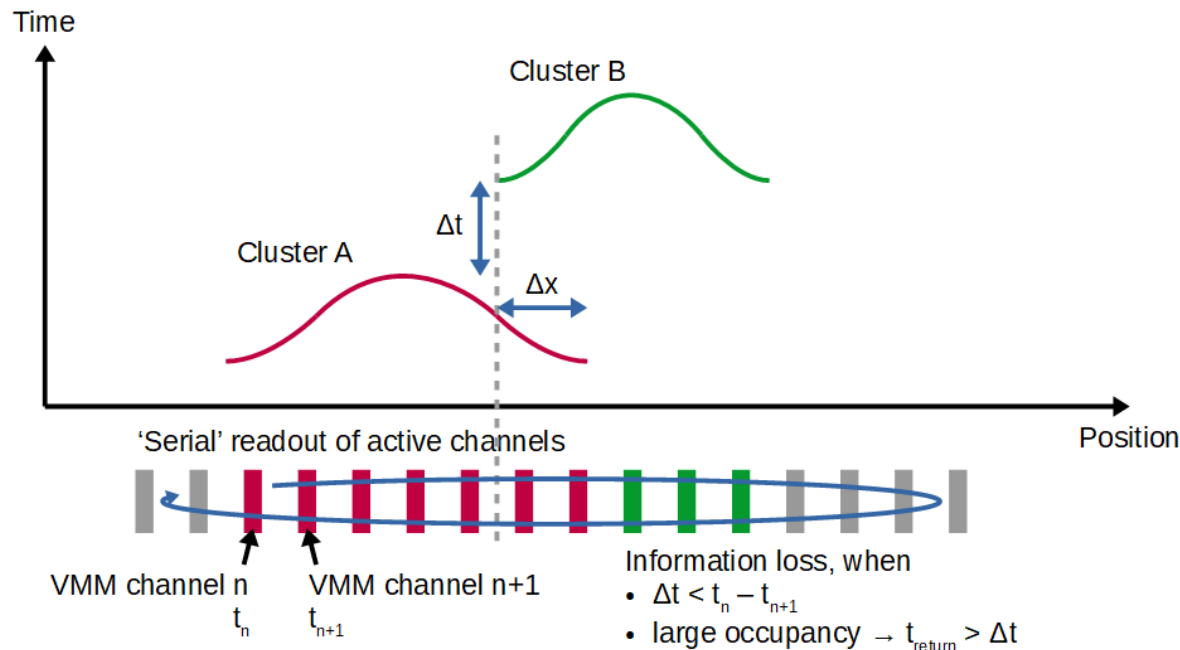


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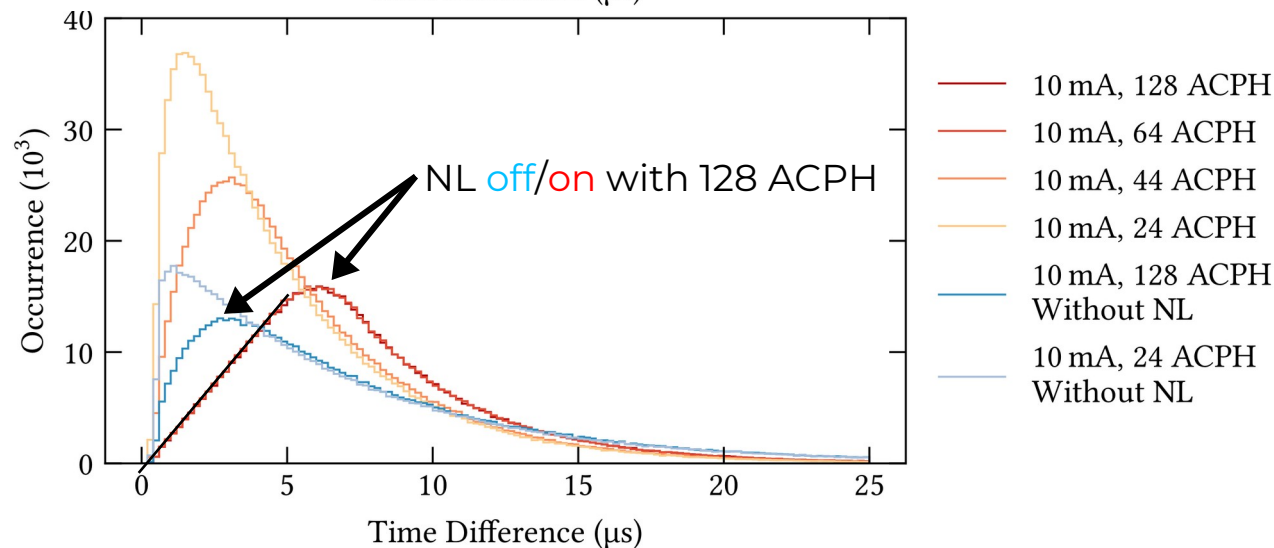
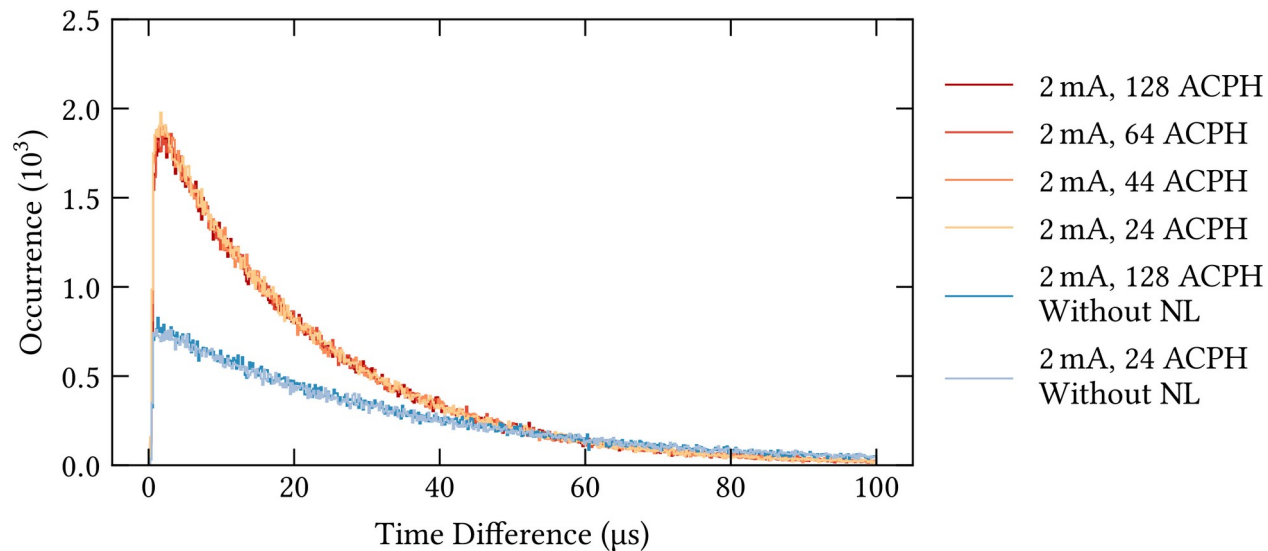
Important:

Dorothea Pfeiffer was able to confirm together with *Gianluigi De Geronimo* the suspicion by *Patrick Schwäbig*, that in non-ATLAS continuous mode (which is the current VMM3a/SRS default), **the 4-hit-deep FIFO per channel does not exist.**



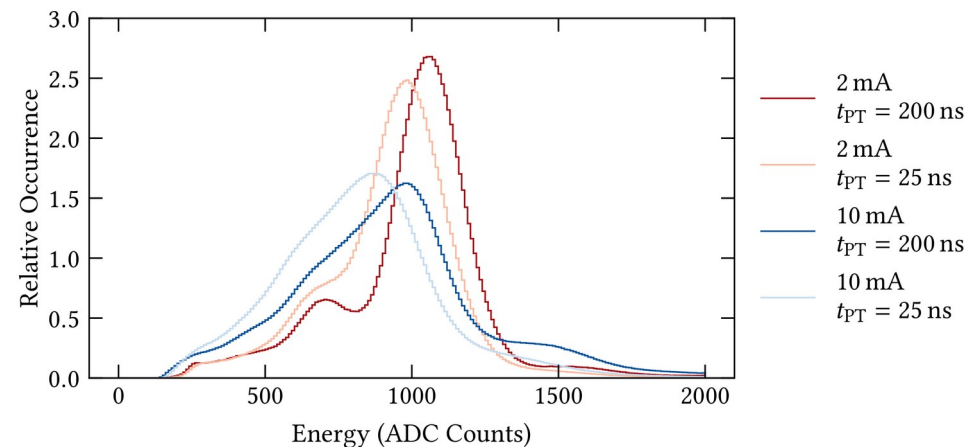
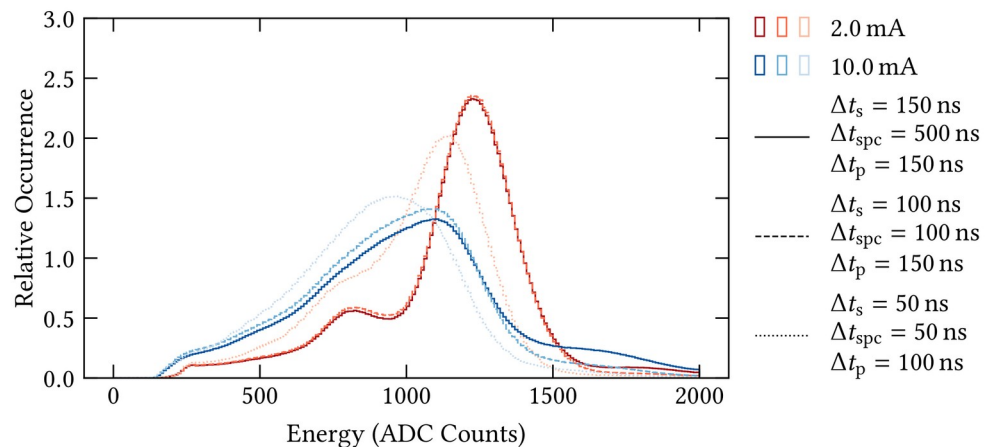
Confirmation

- Mask VMM channels
 - less active channels per hybrid (ACPH) relaxes the token passing
 - more channels can be read out before the data are overwritten
- Look at the time difference between two hits on a single channel
- If related to the token, difference should be observed



Further tests

- Not related to the cluster reconstruction
 - nicest spectra with most relaxed cluster timing conditions
- Not related to peaking time, so the return time from peak to the baseline

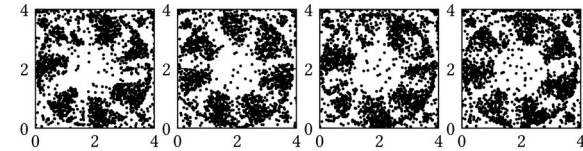
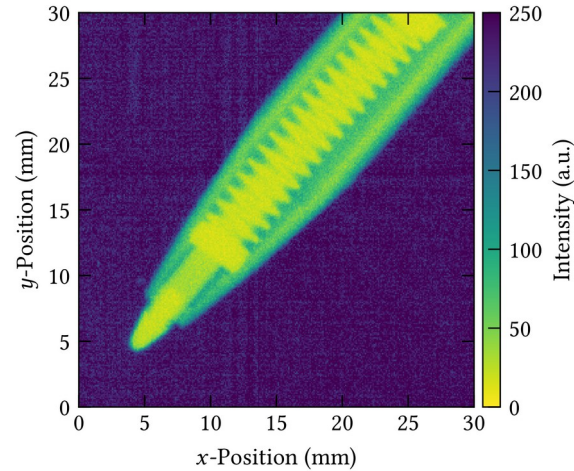
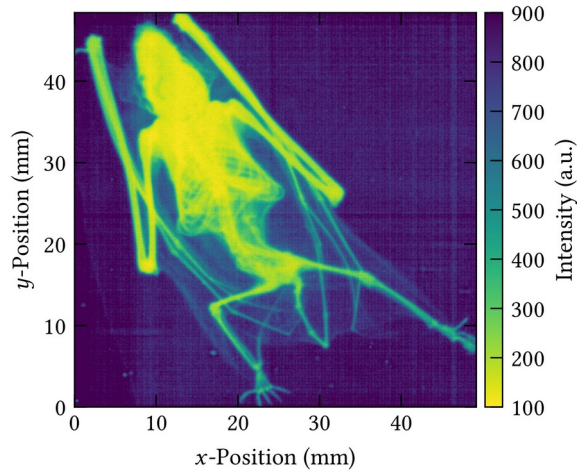


Summary of results

- The rate capability of VMM3a/SRS drops with increased numbers of active channels
- This sort of bandwidth problem is expected → max. rate per VMM is 9 MHz hits
- To possibly reduce bandwidth effects by tuning the set-up
 - calculate the expected event rate per hybrid, including cluster size
 - each hit is 40-bit (on Hybrid) or 48-bit (on FEC)
 - Hybrid can push out up to 800 Mbps
 - FEC can push out up to 1 Gbps
- **Full occupancy** (all channels active at the same time):
 - rate per hybrid: 140 kHz hits → 28 kHz clusters (5 channels per cluster)
 - with less active channels → higher rate capability!

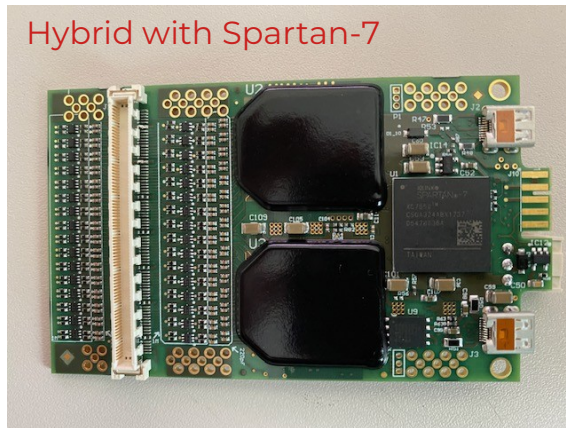
Some pictures...

- **Bat:** 277 million clusters in 3 minutes ~ 1.5 MHz clusters
- **Pen:** 50 million clusters in 30 seconds
- **Fan:** 2 ms frames, each with 4000 clusters

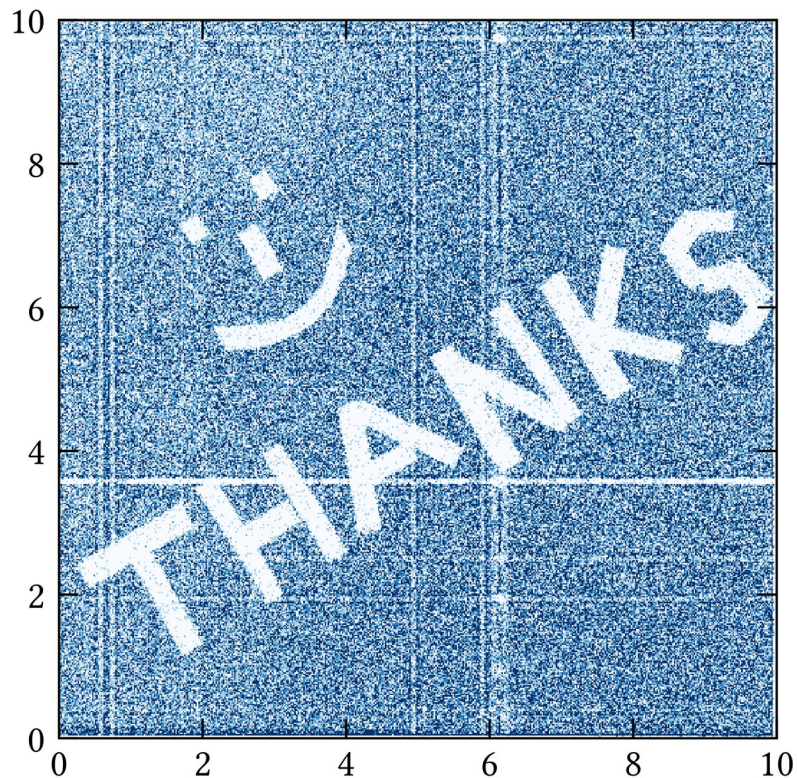


...and an outlook

- **Until now:** continuous mode of VMM3a in SRS, using Spartan-6 FPGA on hybrid
- What if the rate of the incoming particles gets 'de-randomised'? → triggered mode
 - Can we profit from the 64-event-deep FIFO on each channel (Level-0 mode)?
 - Smaller hits per channel (32-bit instead of 40-bit)
 - faster readout
 - more complex timing and event mapping
 - ART auto-trigger?
- **Ongoing developments:**
 - Spartan-7 on hybrids → current firmware has been successfully ported and is working
 - SRSe with 20 Gbps eFEC (long term)
- Triggered mode could profit from the more powerful FPGA on the hybrid (Spartan-7)
 - larger buffers on the FPGA
 - buffers are very good for beam spills! For continuous operation (e.g. constant X-ray/neutron flux) not so much...



Credits: Alexandru Rusu



for your Attention

