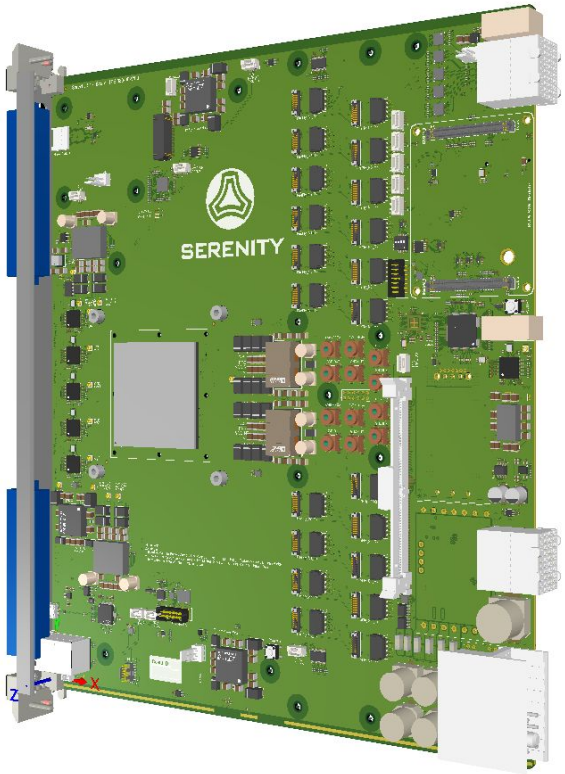
SERENITY

Lessons learned while developing the Serenity-S1 ATCA card

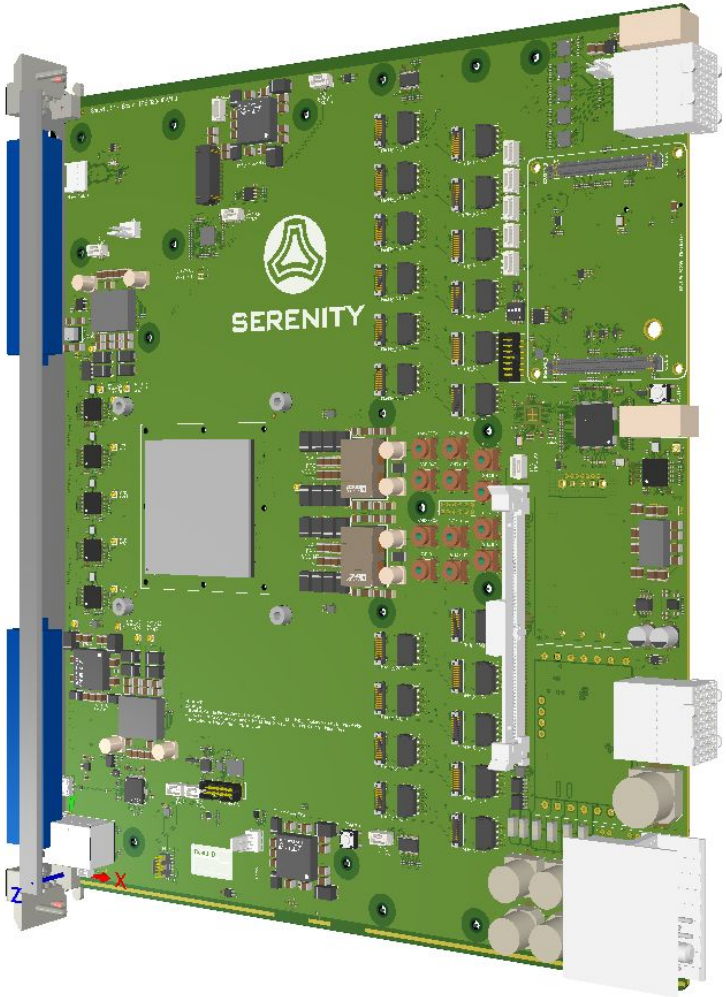
Torben Mehner on behalf of the Serenity consortium
and the CMS Tracker group



5th October 2023

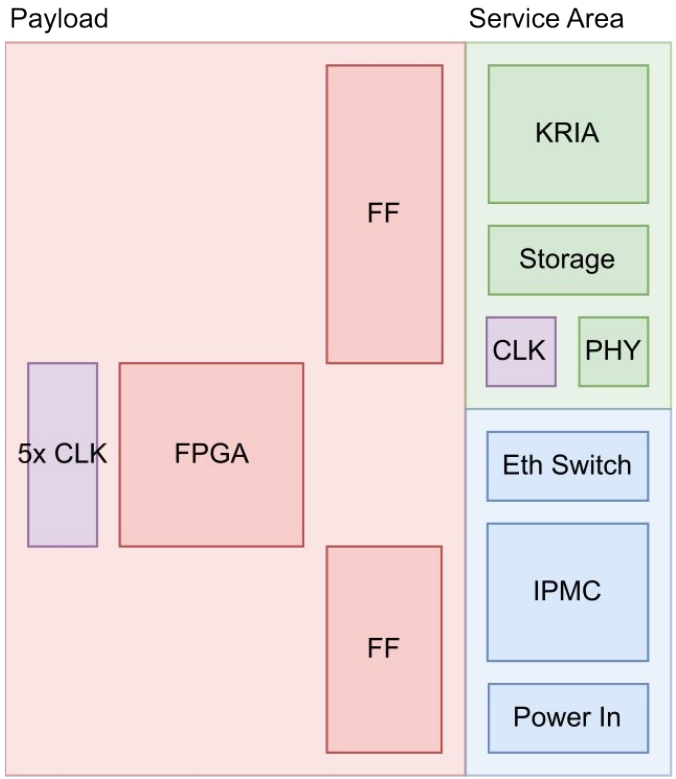
Serenity-S1

- Serenity-S1 ATCA cards will be used in HL-LHC upgrade
- More than 700 cards will be used in various CMS systems
- Derived from successfully tested Serenity-Z and Serenity-A boards
- Developed in git-controlled Altium project in a collaboration with multiple institutes.



https://indico.desy.de/event/28053/contributions/97454/attachments/63827/78124/MT_DTS_2021_CMS_TT.pdf

Board Overview

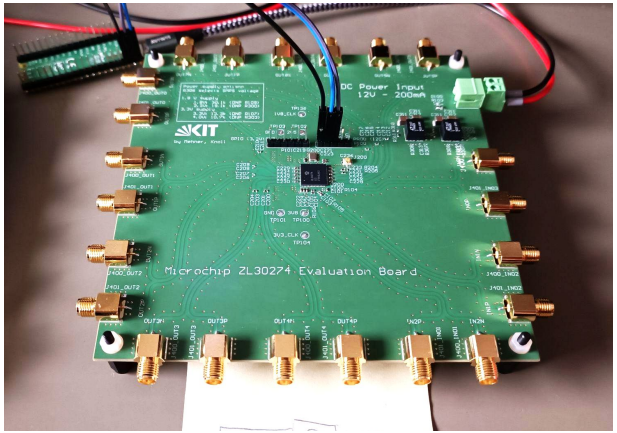


- Board Infrastructure
  - Xilinx KRIA SoM
  - Clock, power, PHY
  - SD, SSD
- ATCA Infrastructure
  - Backplane connectors
  - IPMC (OpenIPMC DIMM module)
  - Power input
  - Ethernet switch
- Payload
  - FireFly optical transceivers
  - VU13P FPGA
  - Clocks

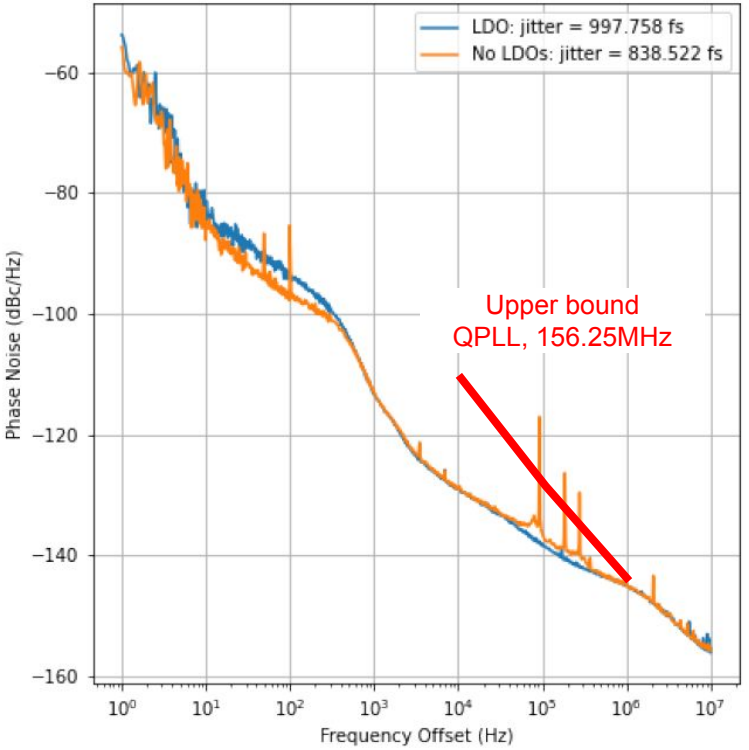
ZynqMP board management: https://iopscience.iop.org/article/10.1088/1748-0221/17/03/C03009
OpenIPMC: https://ieeexplore.ieee.org/document/9465210

Component Shortage Mitigation – PLL

- Zero-delay jitter cleaner phase-locked loop
- Skyworks Si5395A not available
- Evaluated ZL30274 (dual PLL) - P. Hazell, S. Baron
- Accumulated jitter <1ps (1 kHz - 10 MHz)
    - Virtex Ultrascale+ requirements met with LDO power supply

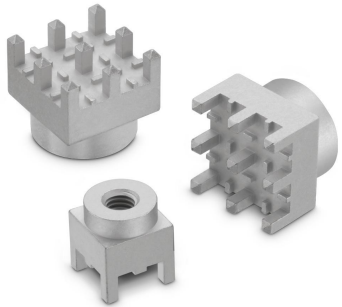


Phase noise measured vs. max phase noise requirements [dBc/Hz]



Component Shortage Mitigation – Power Supply

- Multiphase power supply for FPGA based on TPS56637 (I. Mirza)
- LTM4700 hardly available
- Attachable PCB for evaluation on Serenity-S1 using WE REDCUBE terminals
- BOM cost reduces to $ 40 instead of $ 300
- Design soon to be produced



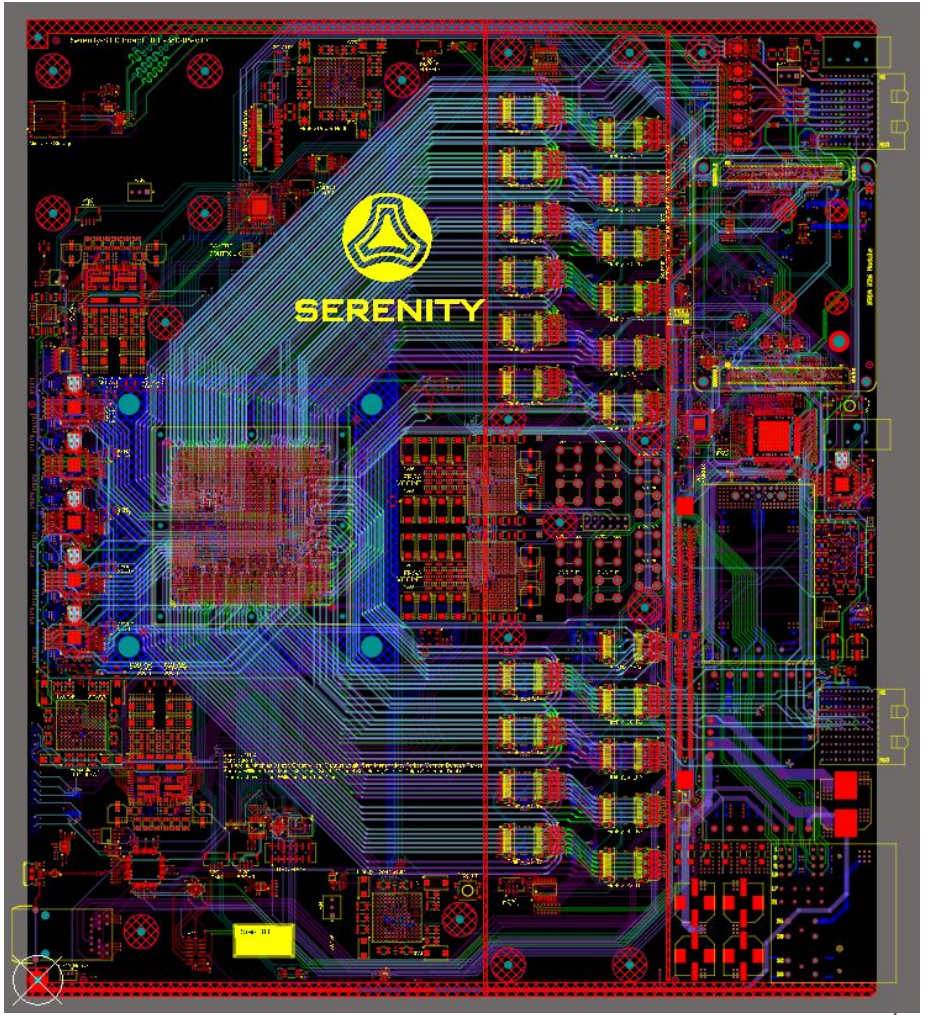
WE REDCUBE Terminals capable of transferring up to 50A per terminal

Component Shortage Mitigation – ATCA connectors

- TE has stopped producing Zone 1 connectors
- EPT will stop production in May 2024
- Zone 1 connectors are still produced by
  - Positronic VPB series
  - Conec ATC22* series
- Adapt footprint to be multi-vendor compliant
  - Mechanical alignment pins
- CERN has bought all connectors for Serenity production (Zone 1 and Zone 2) + 15%

Design Challenges

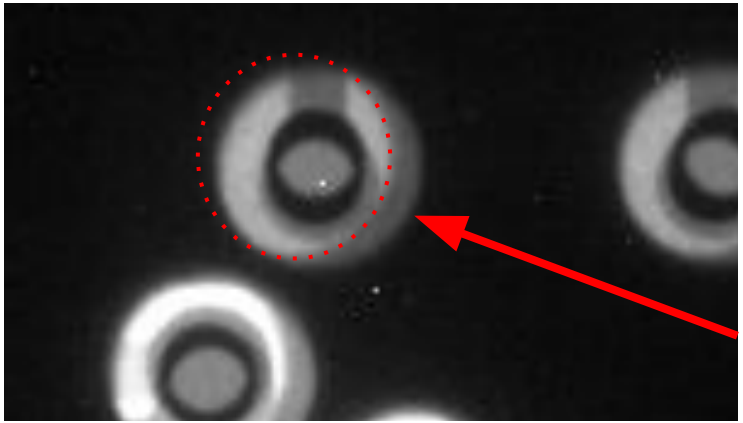
- 124 high speed links exceeding 25 Gbit/s
  - At least 3 stub- and impedance-controlled, shielded layers necessary
- FPGA supplied with 6 rails from 8 A to 200 A
  - Considerable voltage drop over power planes (100 mV at 115 A on Serenity-A evaluation card)
  - We need multiple, thick power planes
- Halogen-free material
  - Few manufacturers have experience with halogen-free, high-speed material (Isola Terragreen, EMC EM-890K, Thunderclad TU-883A)



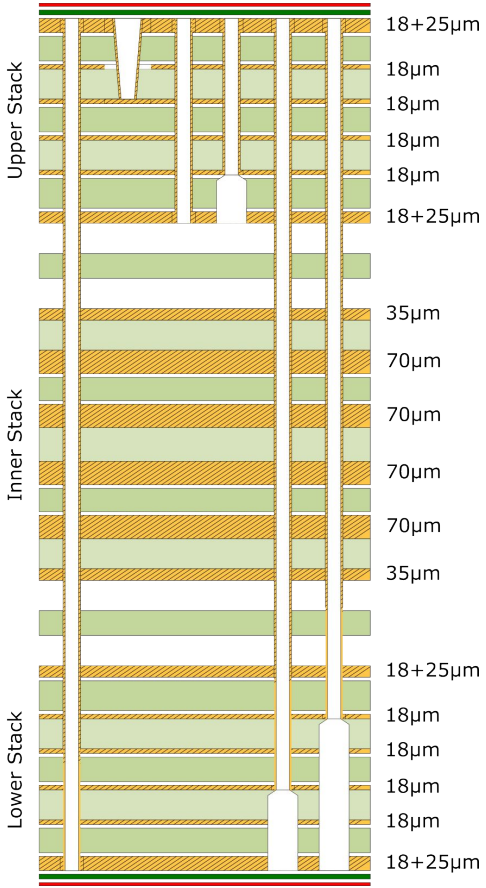
Triple Sub-Stack PCB

- 4x impedance-controlled layers shielded by GND layers
- Stub-less layer changes from Top to each routing layer
- 4x 70 µm copper planes for power distribution
- Inner stack was first fabricated in low-speed material to save cost.

  Expansion did not match the high speed stacks and shorts appeared.
- We had to accept some failures, but expanded our supplier list
- Do not mix different materials to save cost

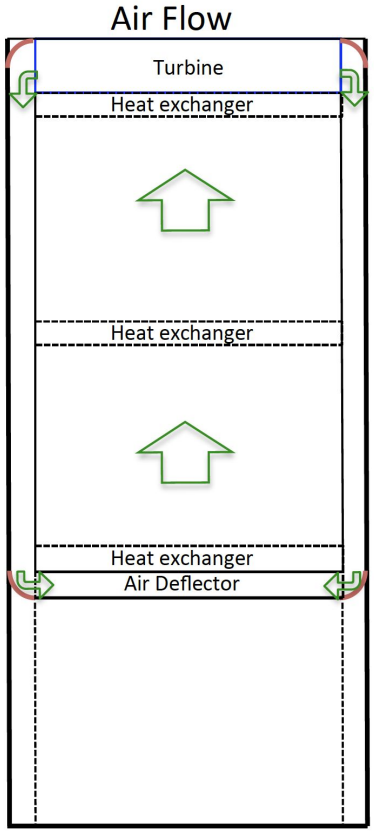


Inner layers short with via due to different expansion



Rack cooling tests

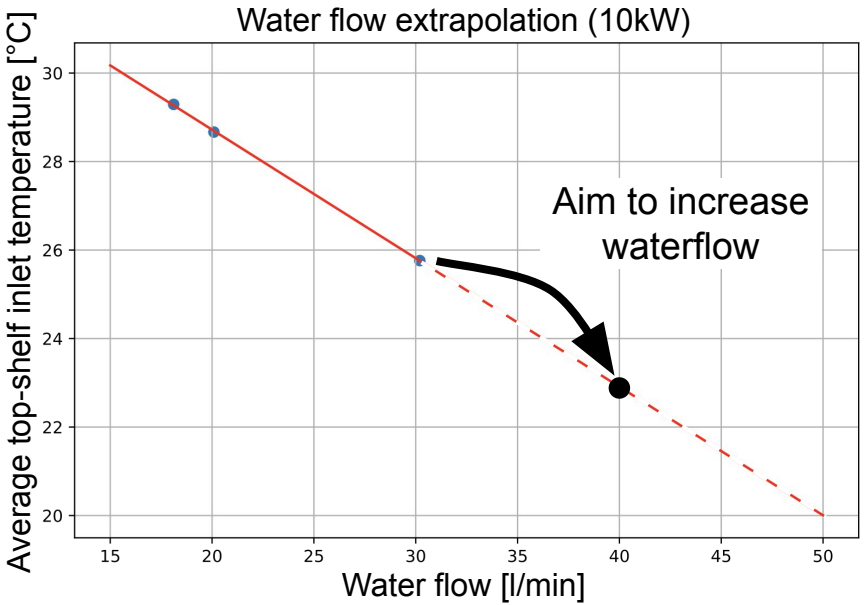
- Two crates per rack in CMS
  - Boards are air-cooled by rack internal loops
  - Heat extracted with water-cooled heat exchangers
- Cooling performance studies for a full rack (10 kW)
  - Measurements were made in the tracker integration facility (TIF) and in the CMS service cavern (USC55) using heater cards
  - Cooling-critical components are optical devices (<50 °C) for longevity (10 years of operation)



Tracker Integration: https://iopscience.iop.org/article/10.1088/1748-0221/18/01/C01041

Ways to improve cooling

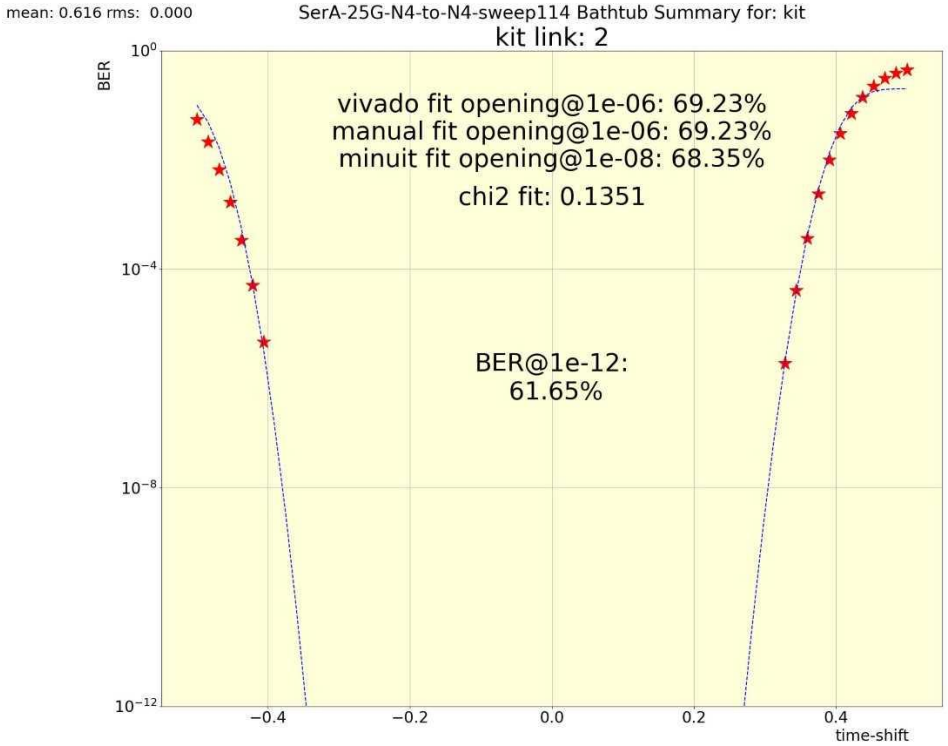
- Inlet air temperature determines ΔT and therefore cooling performance
- We can only leverage the water flow rate to decrease inlet air temperature
  - Extrapolation shows linear correlation between water flow rate and inlet air temperature (at working point)
  - Increase in the water flow rate would be beneficial (currently 30 L/min, aim is 40 L/min)
- Currently studying different rack layout configurations
  - additional/different heat exchangers



FireFly Long Trace Evaluation at 25 Gbit/s

- Long high-speed traces on Serenity-S1
  - Longest traces are 270 mm
  - Serenity-A had 260 mm
  - Bathtub opening around between 59.10 % and 63.94 % at 1E-12 BER
  - Detailed parametrization possible through specialized tools
- News from FireFlys
  - Production parts are expected at the end of October

Serenity-A 25G long trace (N4-N4) bathtub summary



Measurements on Serenity-A long traces

Pilot Production

- First 12 PCBs scheduled to arrive soon
  - 2 PCBs will be assembled at KIT with Ironwood FPGA socket
- Initial tests will be run at KIT
  - Power supply test
  - Slow control test
  - Copper SerDes loopback test
- Extended tests will be run at CERN and Imperial College London
  - Temperature cycle test
  - Optical tests
  - SerDes lane performance characterization

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Production

- Separate market survey for PCB manufacture and assembly released
- Followed by invitation of tender in February 2024
  - Complex board, 2300 components, 0201 to large 2500 pin FPGA
  - Critical components will be supplied for pre-production
  - Demand for high yield due to high cost and limited pre-supplied components
  - Try to not deter companies with too many entry barriers

October 2023

- First 4 Pilot boards assembled

October 2024

- 50 Pre-series boards assembled

February 2025

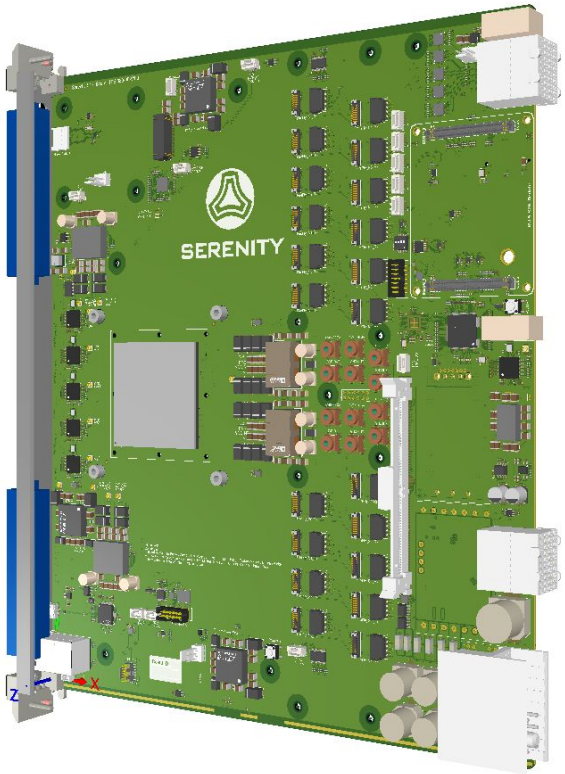
- Start of main-series production

December 2025

- All main series cards have been fabricated and tested

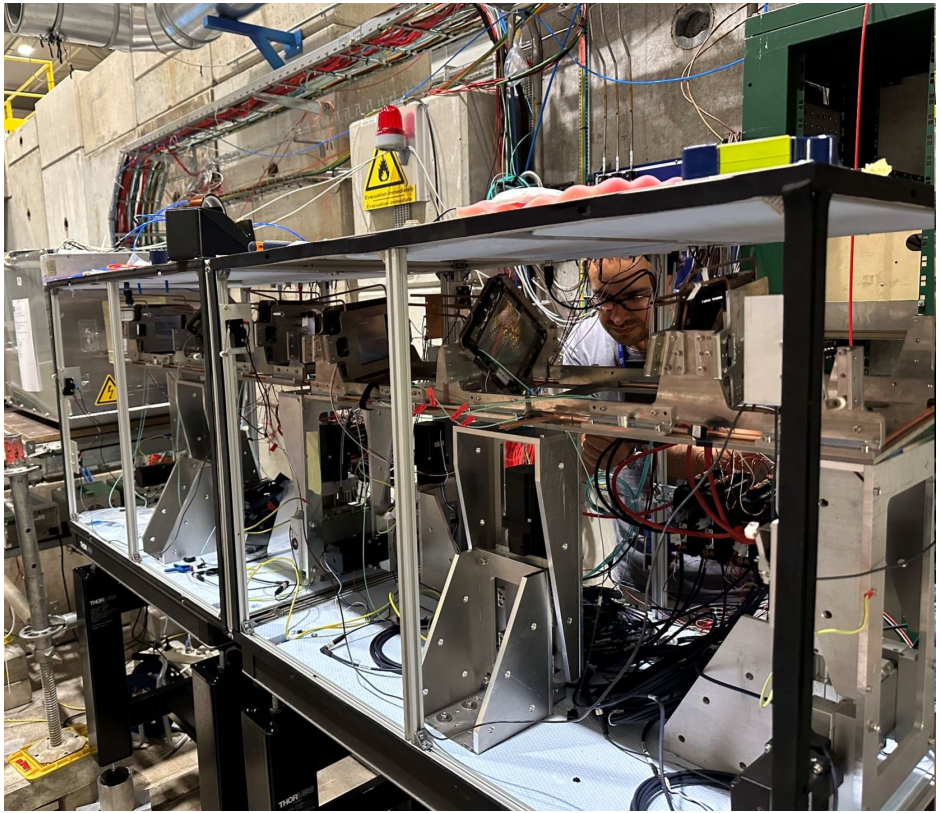
Lessons Learned

- If time allows, build evaluation systems. We learned a lot from Serenity-A and Serenity-Z.
- Determine critical components and replace them if necessary or determine 2nd sources
- ZL30274 is a good replacement for Si5395A
- Allow plenty of time for PCB suppliers to gain experience of using new halogen-free materials, perhaps building PCBs with old & new materials in parallel.
- Mixing different PCB materials adds risk
- Qualify multiple suppliers early in large projects
- Consider cooling issues at the system level (i.e. rack and multi-rack level), particularly in the underground service cavern where there are additional constraints.



Conclusion

- Evaluation cards are functional and already in use
    - Has allowed the development of both infrastructure & application firmware/software
- OpenIPMC and Zynq-based board management have been successfully evaluated
- First production cards are being assembled once PCBs arrive
- Production of 721 boards will take place in 2024 and 2025



Beam test using Serenity-Z as back-end

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Cavern cooling test results

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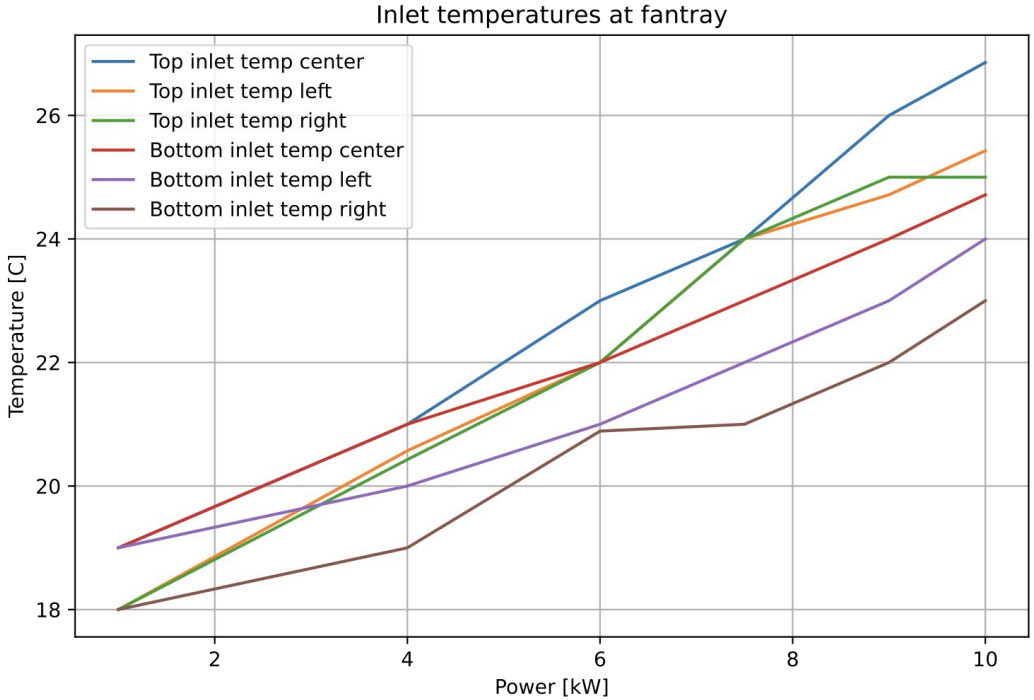
- Inlet air temperature is indicator for cooling performance
  - Measurements show that the inlet air in the crate can reach more than 28°C, while we assumed a cooler air



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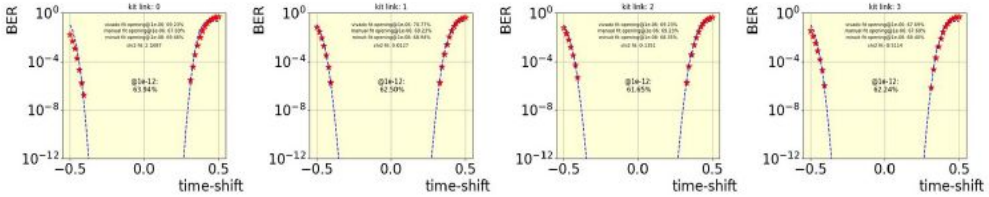
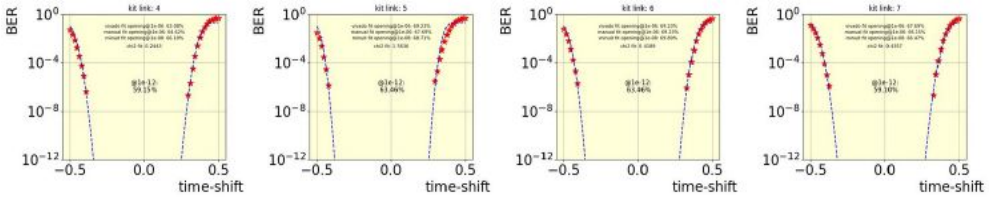


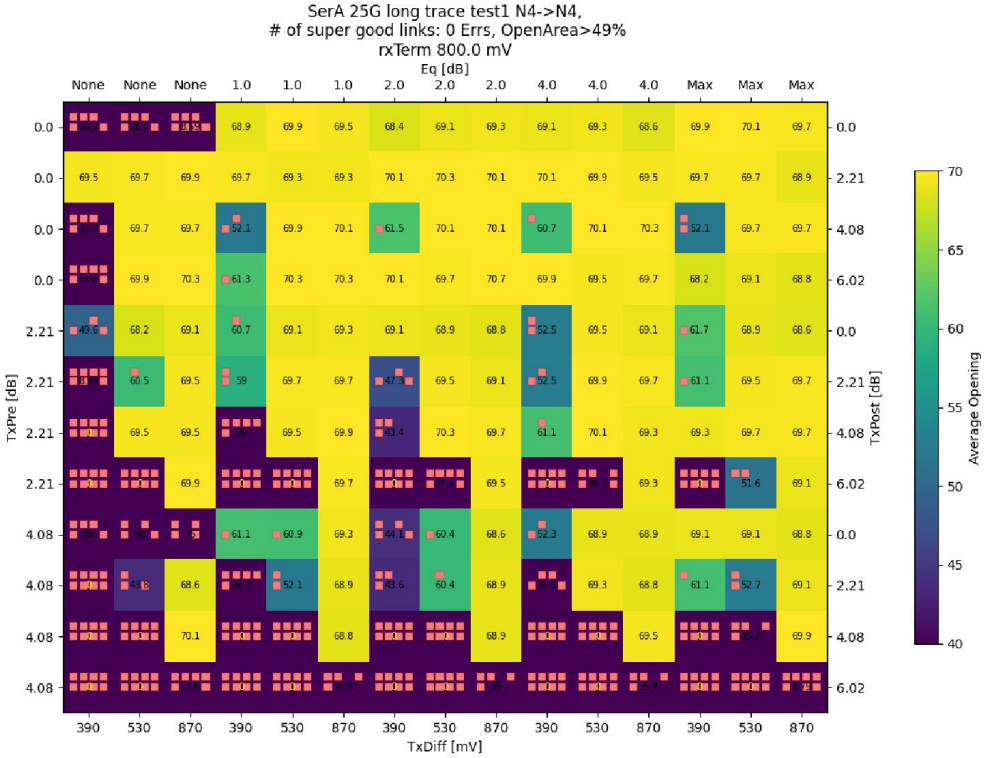
63.94% 62.50% 61.65% 62.24%



59.15% 63.46% 63.46% 59.10%

Measurements on Serenity-A long traces

FireFly Long Trace Evaluation



Measurements on Serenity-A long traces

CMS Level-1 Trigger in HL-LHC

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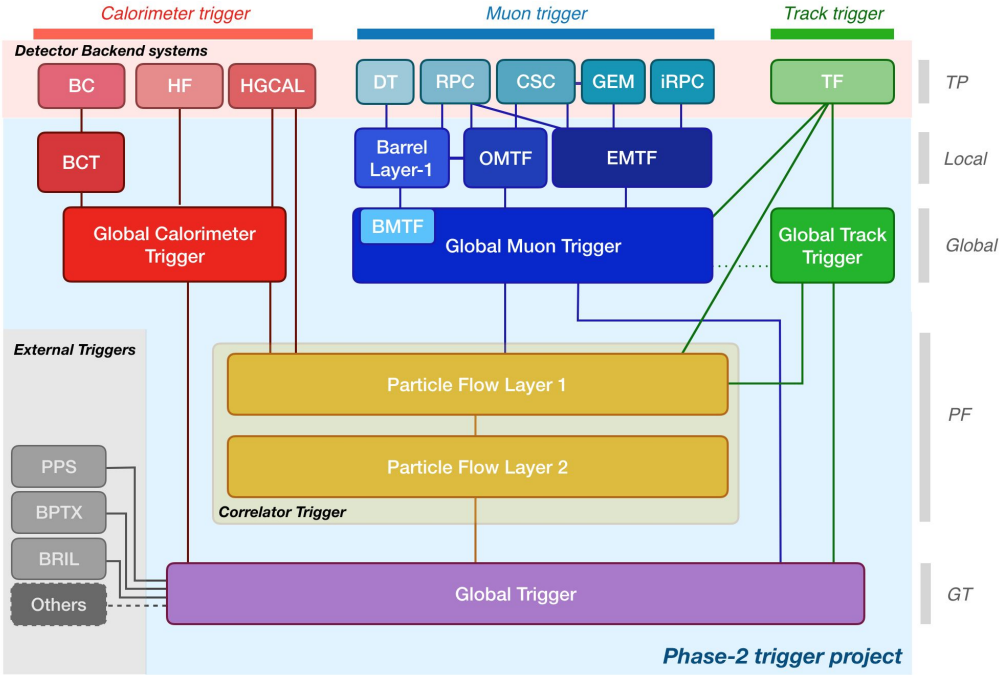
4 complementary trigger types

- Calorimeter Trigger
- Muon Trigger
- Track Trigger
- Particle Flow Trigger

Serenity boards intended to be used in

- HGCAL
- DTC, GTT
- Correlator L1, Correlator L2
- GT
- MTD, BRIL



https://lss.fnal.gov/archive/2020/pub/fermilab-pub-20-712-cms.pdf