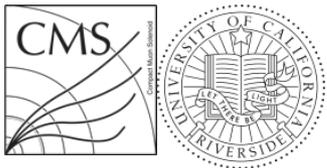


Commissioning and Operation of the New CMS Phase-1 Pixel Detector

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On Behalf of CMS Phase1 Pixel upgrade team



DPF Meeting 2017
Fermilab, Jul31-Aug04

Motivation & Overview

Motivation:

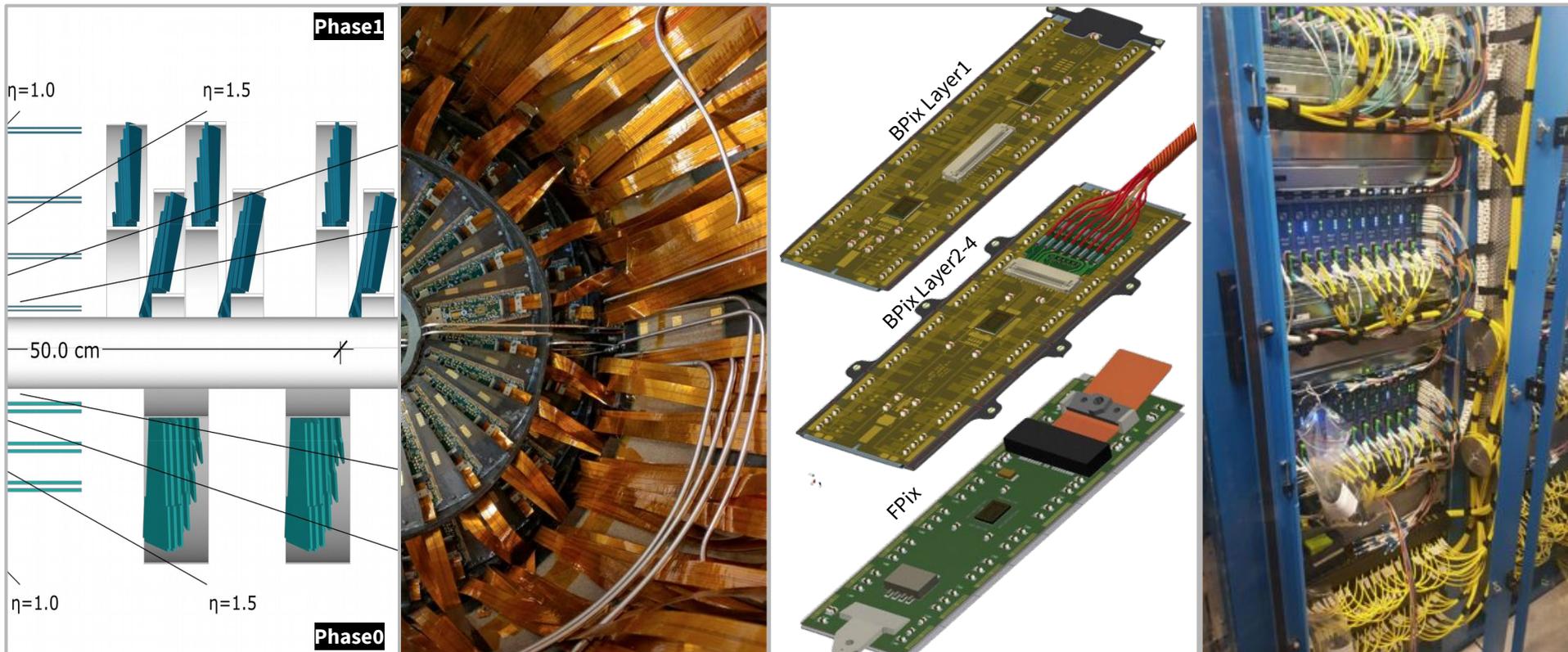
Original detector not suited for operation at $L \sim 2 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$

- Limited bandwidth readout chip to backend

Overview:

- CMS Phase1 pixel detector general introduction
 - Upgrade
 - DAQ system
 - Readout and control
- Detector calibration example
- Detector commissioning
 - High (random) trigger rate test
 - Cosmic data-taking
 - Collision data-taking
- Detector status
- Conclusion

CMS Phase1 Pixel Detector



★ Additional layer,
87.8% more pixels
→ closer to beampipe,
4 hit coverage

★ New CO₂ cooling
system
→ reduce material
budget

★ New ROC: Read Out Chip
New TBM: Token Bit
Manager
→ analog → digital
→ handle higher data rate

★ New μ TCA based
DAQ

CMS Phase1 Pixel Detector

For constructions, see
M. Alyari's talk earlier

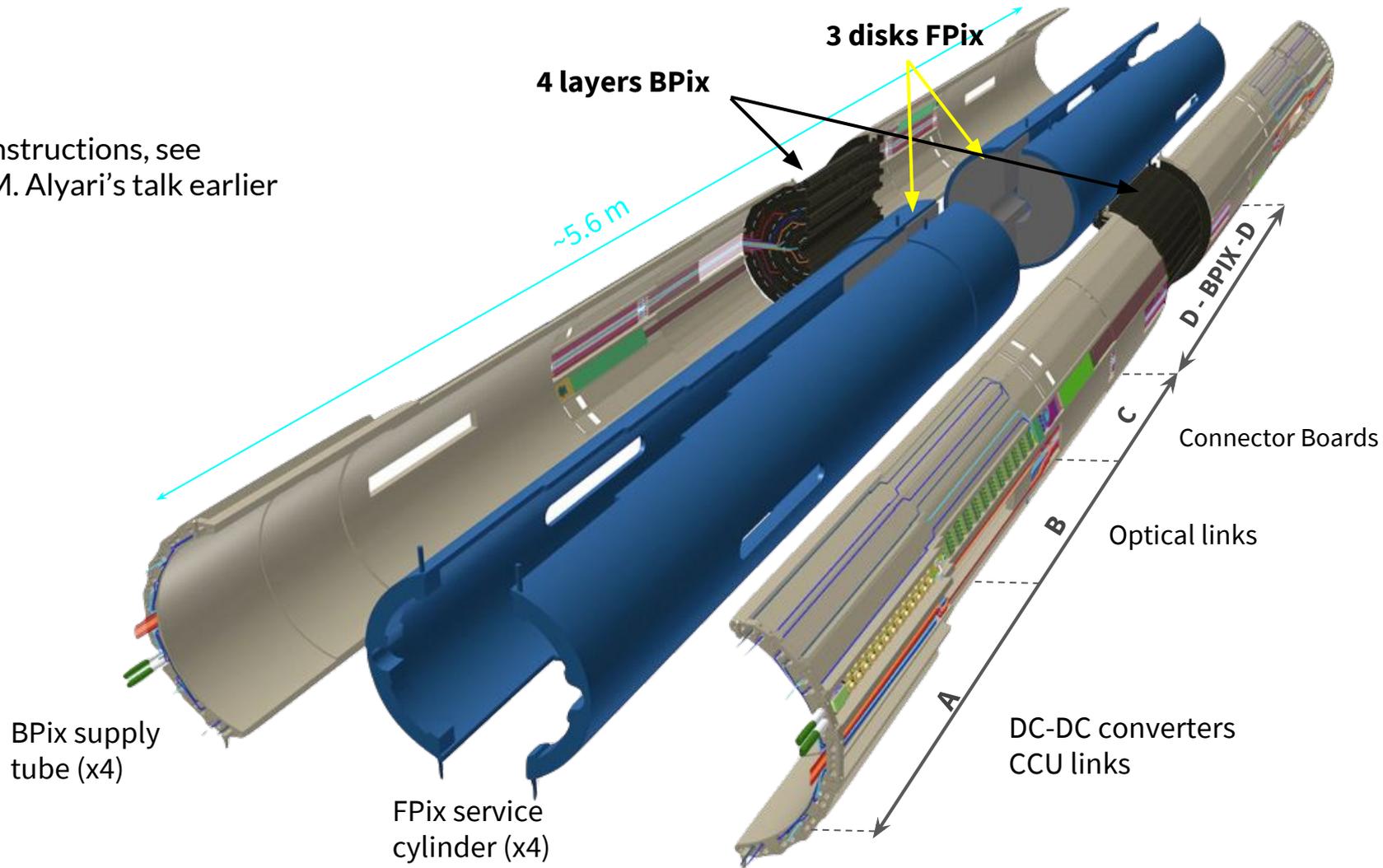


Figure: Mechanic view of Phase1 pixel detector

DAQ System

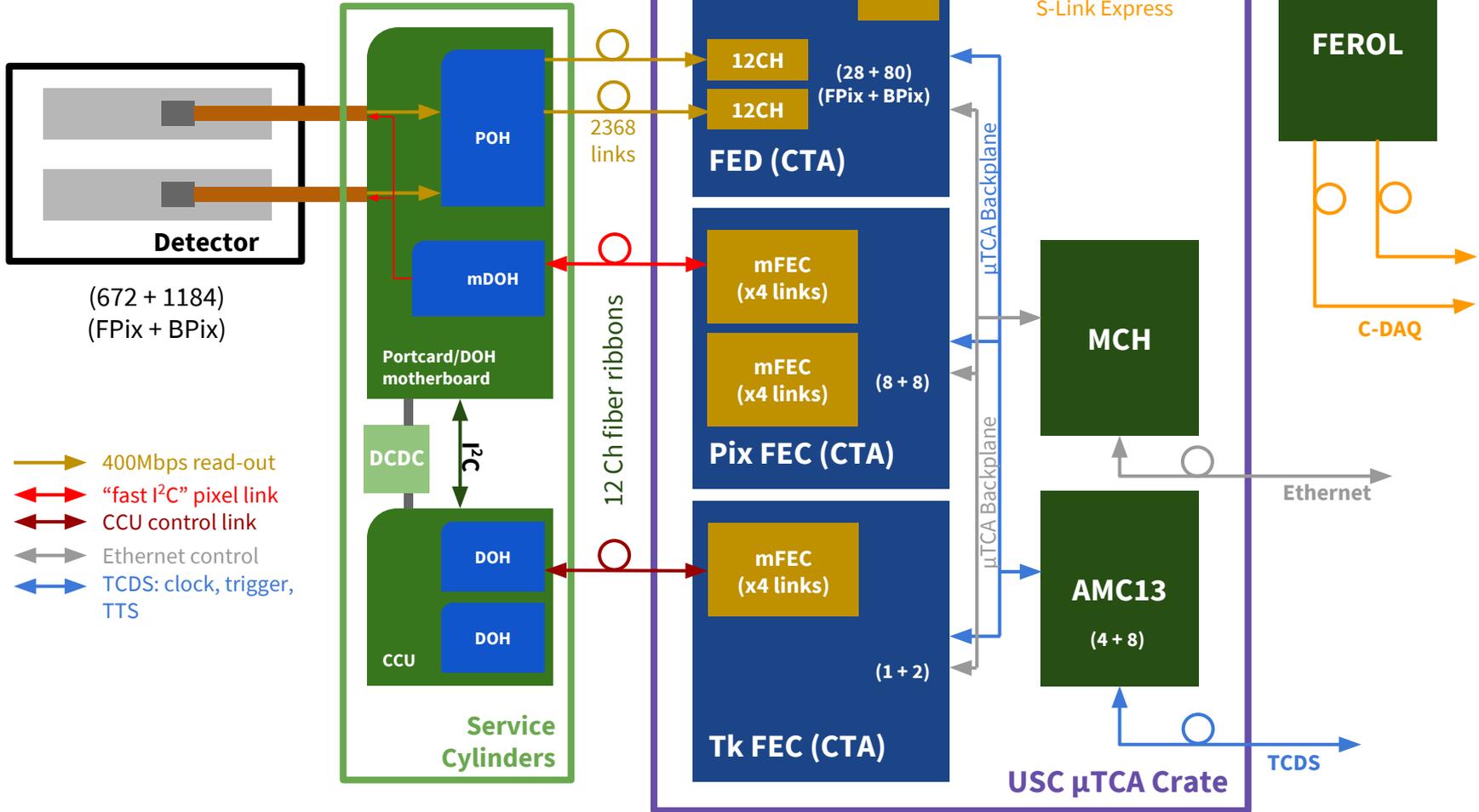


Figure: Complete overview of the μ TCA DAQ system of Phase1 pixel detector

DAQ System

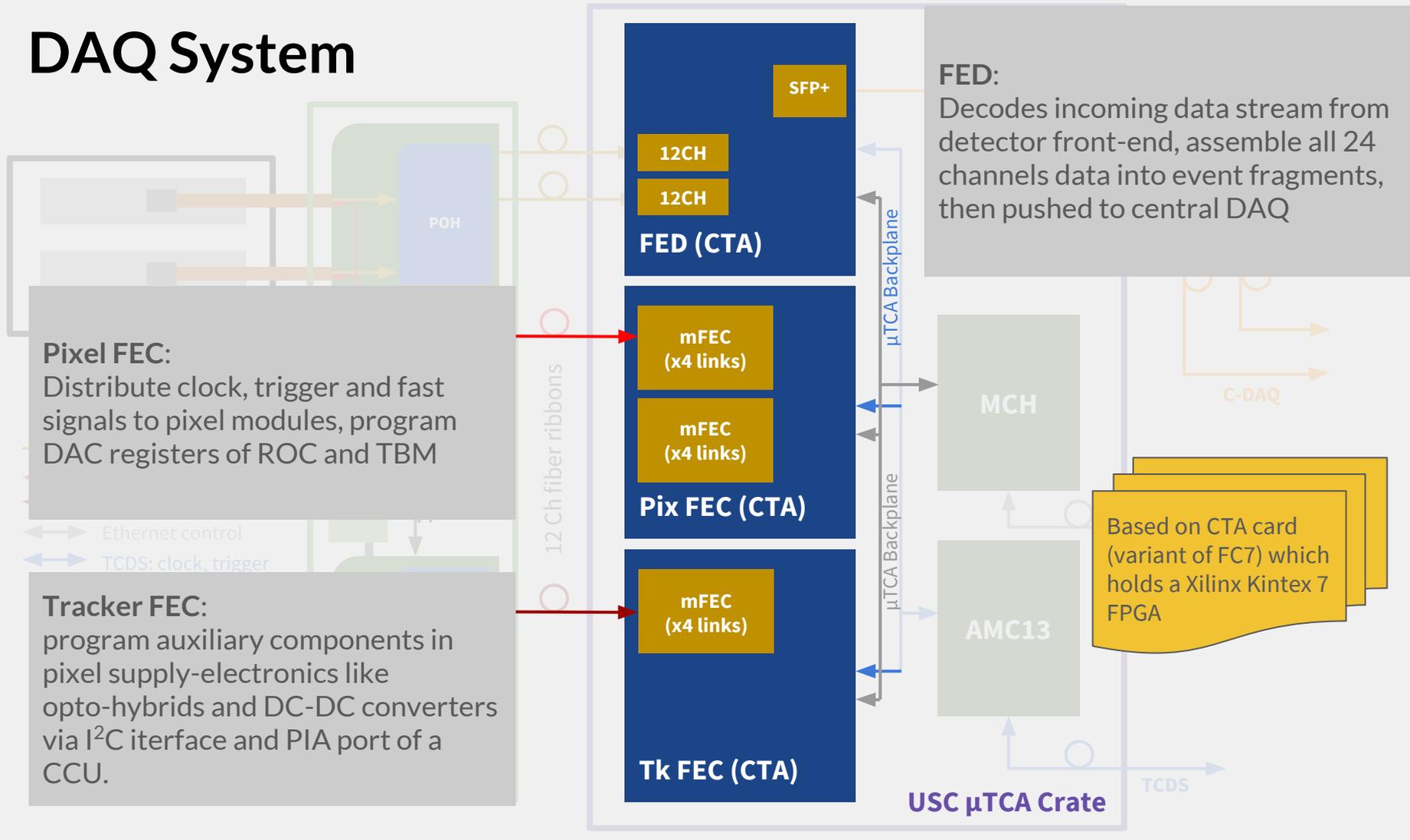
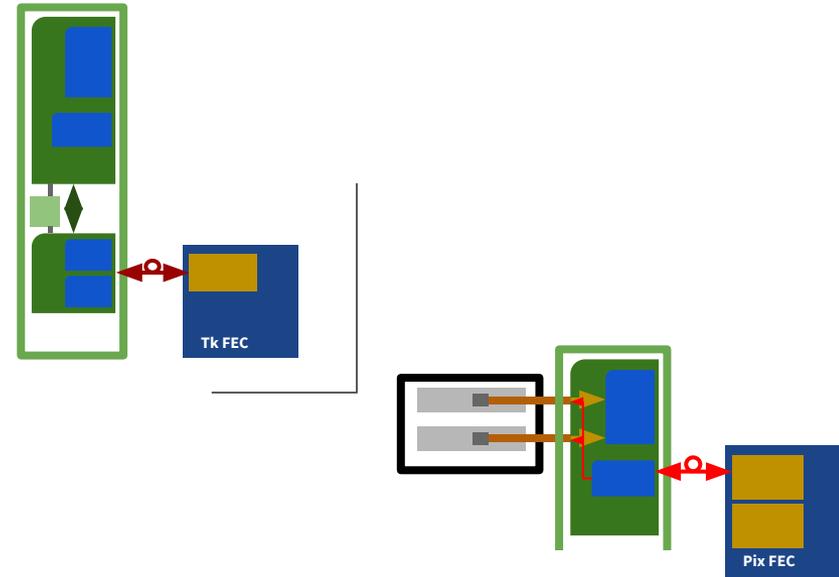


Figure: Complete overview of the μTCA DAQ system of Phase1 pixel detector

System Control & Readout

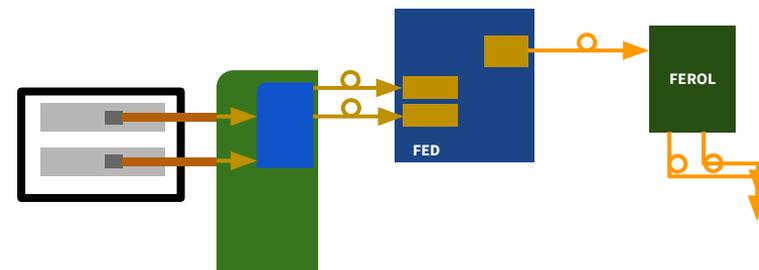
Control:

1. tkFEC programs auxiliary electronics
 - a. DC-DC converters → powering
 - b. delay25 → data/clock alignment for pxFEC
 - c. TPLL, QPLL → decoding trigger, clock
2. pxFEC programs front-end ASICs
 - a. TBM settings
 - b. ROC settings



Readout:

1. Pixel hit information cached in buffer waiting for trigger and token acknowledgement
2. Datastream properly formatted and encoded, converted into optical signal and transmitted to FED through portcard
3. FED collects data from all 24 fibers (48 channels) and build event fragments, then pushed to cDAQ

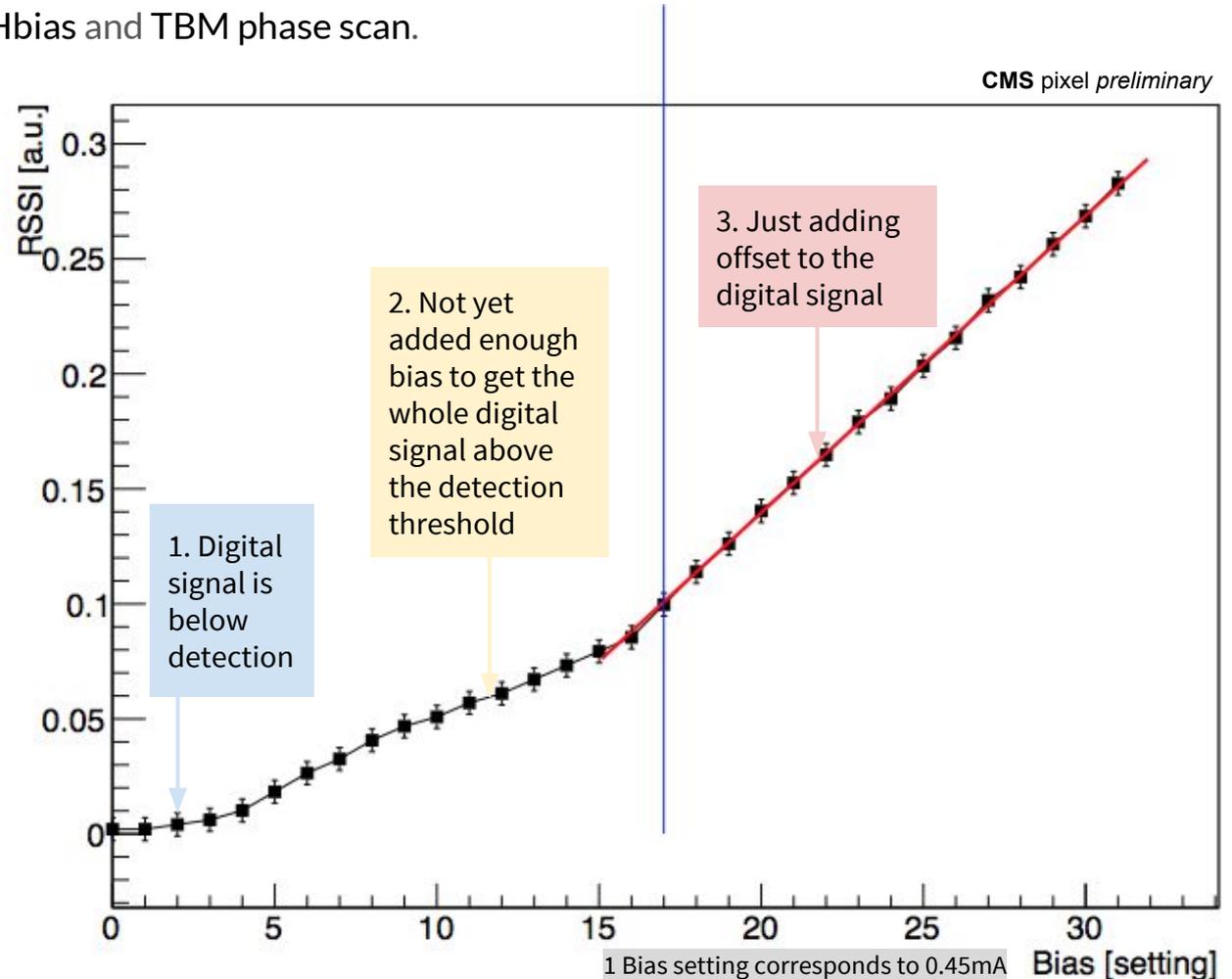


Detector Calibrations

- ❖ Compared with the old system, the differences are mainly on readout electronics.
- ❖ We recycled a lot of the software and extended it since much of the functionality of phase1 was also in phase0.
- ❖ Two new calibrations: POHbias and TBM phase scan.

POHbias

- POH bias controls the amount of light sent from detector to DAQ.
- As POH bias increases, more light is sent, and the RSSI (Received Signal Strength Indication) values on the FED also increase.
- The bias value of the laser diode is chosen right after the second slope change as indicated by the blue line.

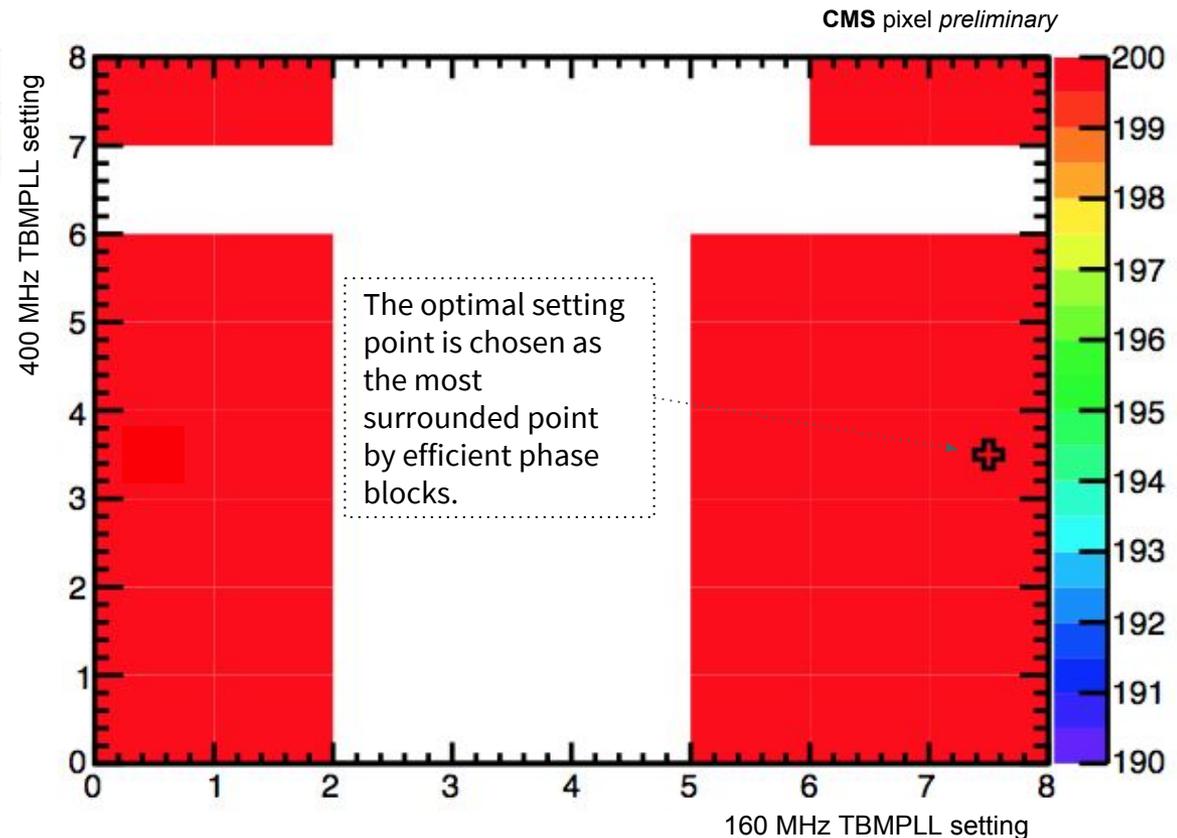


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TBM phase scan

- For each of the 48 channels of the FED, this calibration scans over all possible 400MHz and 160MHz TBM delay setting phase space.
- For each setting point in the 2D plot, a score (200 is the “perfect” score) is calculated based on data stream structure.



Detector Commissioning

Important phases of commissioning:

1. Test under high trigger rates of random triggers
2. Cosmic data taking for gross time alignment of pixel system
3. Data taking with pp collisions for fine time and final alignment

FEDTester: Full emulator of pixel module optical output

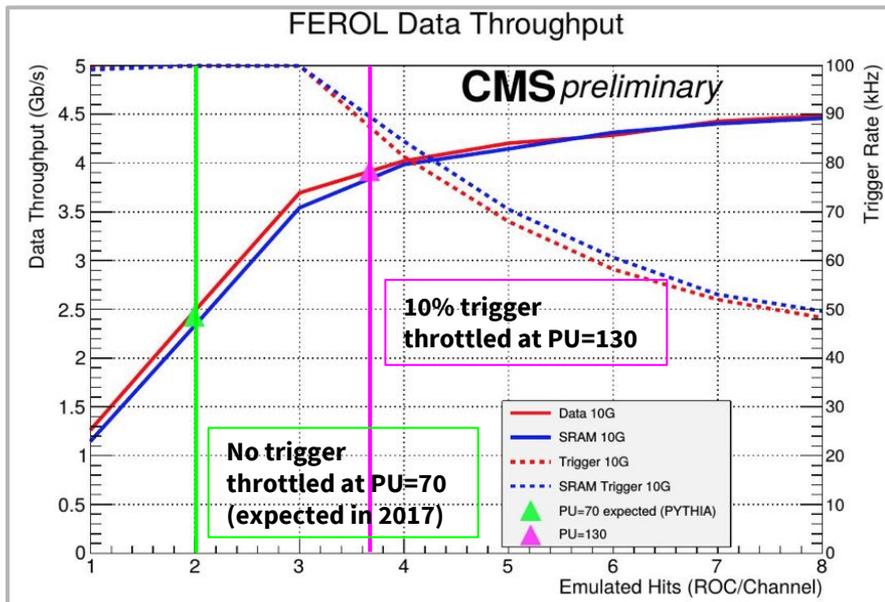
- GLIB based μ TCA board connected to CMS trigger system
- Test and validate FED fw before deployment
- Test and validate FED throughput to CMS cDAQ



Workbench setup



Link to CMS cDAQ in a test crate



- Send 100kHz random triggers (L1 rate in CMS)
- Load FED with emulated hits
- Readout through 10Gbps link of FEROL
- Trigger rates get throttled according to the FED status

Detector Commissioning

Important phases of commissioning:

1. **Test under high trigger rates of random triggers**
2. Cosmic data taking for gross time alignment of pixel system
3. Data taking with *pp* collisions for fine time and final alignment

- FED internal emulator
 - 3 emulated hits/ROC (Pile Up ~ 105) in all FEDs (108)
 - Experience from pilot blade system with μ TCA readout (commissioned in CMS in 2016) helps a lot!
- **NO problems**
- ◆ Not blocking cDAQ



Workbench setup



Detector Commissioning

Important phases of commissioning:

1. Test under high trigger rates of random triggers
2. **Cosmic data taking** for gross time alignment of pixel system
3. Data taking with *pp* collisions for fine time and final alignment

- FPix join global cosmic run | Apr.07, 2017
 - Saw hits, but timing setting not optimal
 - Timing setting scans
 - Masking noisy pixels
- Cooling system redundancy test
- BPix join global | Apr.17, 2017
- Magnet B=3.8T | Apr.19, 2017
- Private Resync → reducing dead time from pixels
 - Pause triggers
 - Pause m_1 orbits
 - Send Pixel only Resync command
 - Pause m_2 orbits
 - Re-enable triggers
- Beam commissioning | May23, 2017



07/04/17
Fri 17:54:37

LHC: SHUTDOWN
NO BEAM

PIXEL

IN

Running

TRACKER

IN

Running

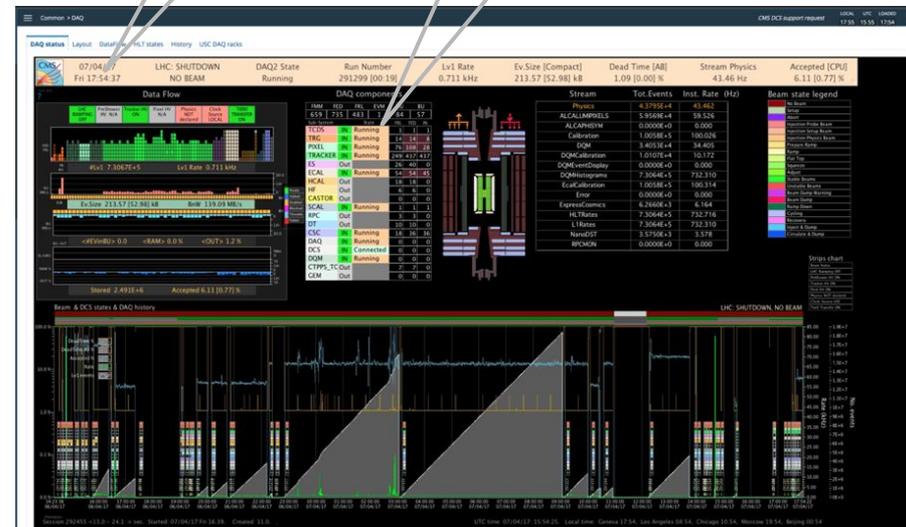


Figure: CMS DAQ status page

Detector Commissioning

Important phases of commissioning:

1. Test under high trigger rates of random triggers
2. **Cosmic data taking for gross time alignment of pixel system**
3. Data taking with *pp* collisions for fine time and final alignment

First data with the new detector:

- Time alignment of detector
 - Local calibrations to find optimal TBMPLL settings
 - Very small part of the detector inactive
 - “Resets” evolve as we learn about performance and needs
- ➔ **Observation accumulated, experience gained**

Finer timing scans with first stable beams, optimal timing setting from cosmic runs as starting point.

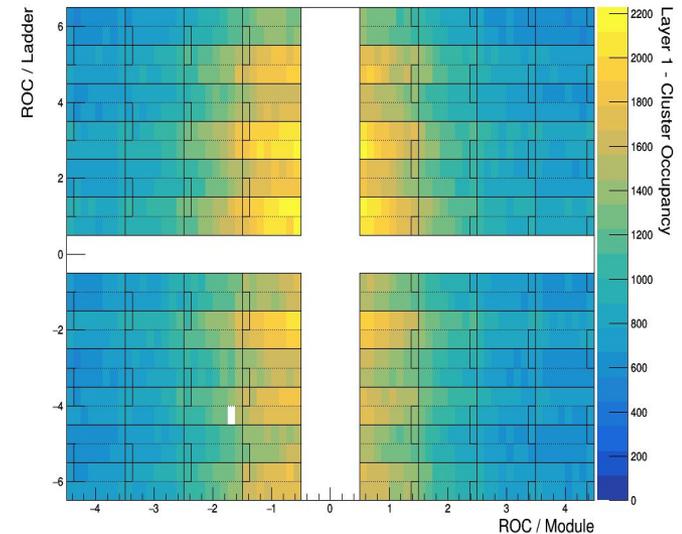


Figure: Occupancy map of BPix layer1 during cosmic run

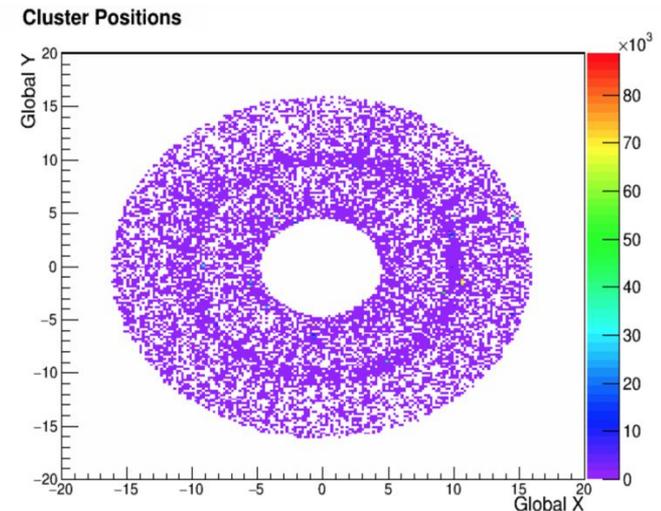


Figure: Cluster position map of FPix during cosmic run

Detector Commissioning

Important phases of commissioning:

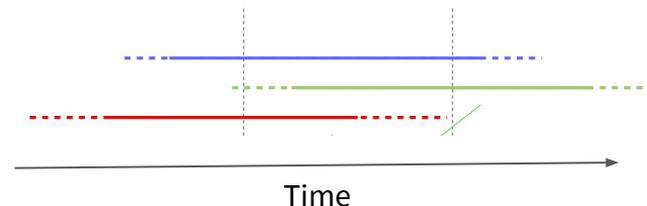
1. Test under high trigger rates of random triggers
2. Cosmic data taking for gross time alignment of pixel system
3. **Data taking with pp collisions for fine time and final alignment**

- First stable beam, LHC Fill5698 | May23, 2017

- **Pixel timing**

- In first timing scan, we observe Layer1 is shifted w.r.t. Layer2 by $\sim \frac{1}{2}$ clock.
- Investigating shift in timing of *PROC600* and *PSI46dig*.
 - Layer1 using PROC600, Layer2-4 & FPix using *PSI46dig*.
 - Time alignment of Layer 1 and 2, which share a common programmable time delay, was difficult due a faster Layer 1 ROC.
- We recently succeeded in establishing an optimal common plateau of efficiency with values close to **99%** for all pixel layers and disks at luminosities $L=1.6 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$.
 - The timing is chosen to favour the Layer 1 performance.
 - Additional steps are being taken to robustify the timing against possible issues as the LHC luminosity is increased and to improve even further current Layer 2 performance.
- FPix and BPix Layer3&4 timing are well set and yields optimal performance.

L34
L2
L1



Detector Commissioning

Important phases of commissioning:

1. Test under high trigger rates of random triggers
2. Cosmic data taking for gross time alignment of pixel system
3. **Data taking with pp collisions for fine time and final alignment**

- First stable beam, Fill5698 | May23, 2017
- Pixel timing
- **Stuck TBM with collisions (not reacting to trigger)**
 - Dependent on luminosity
 - Not dependent on trigger rate
 - Most probably caused by SEU (SingleEventUpset) on new flip-flop in the new ROC
 - Recoverable by power-cycle
 - Working on automatic regional power-cycle via DC-DC

A **single event upset (SEU)** is a change of state caused by one **single** ionizing particle (ions, electrons, photons...) striking a sensitive node in a micro-electronic device, such as in a microprocessor, semiconductor memory, or power transistors.

Single event upset - Wikipedia
https://en.wikipedia.org/wiki/Single_event_upset

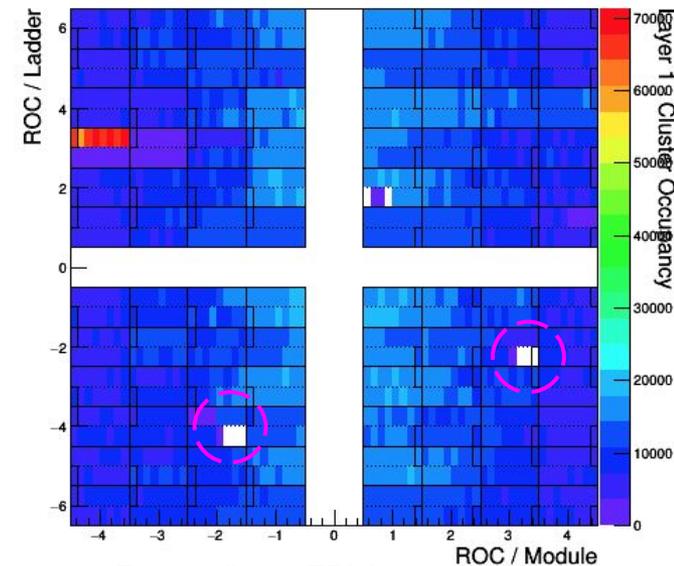
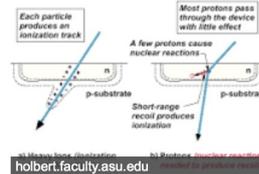


Figure: Stuck TBMs appear as "holes" in cluster occupancy map

Detector Commissioning

Important phases of commissioning:

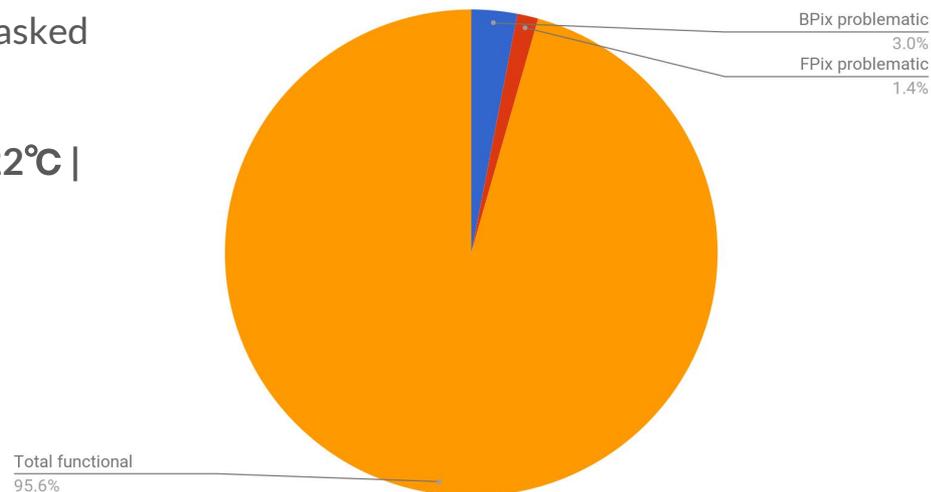
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2. Cosmic data taking for gross time alignment of pixel system
3. **Data taking with pp collisions for fine time and final alignment**
 - First stable beam, Fill5698 | May23, 2017
 - Pixel timing
 - Stuck TBMs

→ FPix 10344/10752 functional ROCs

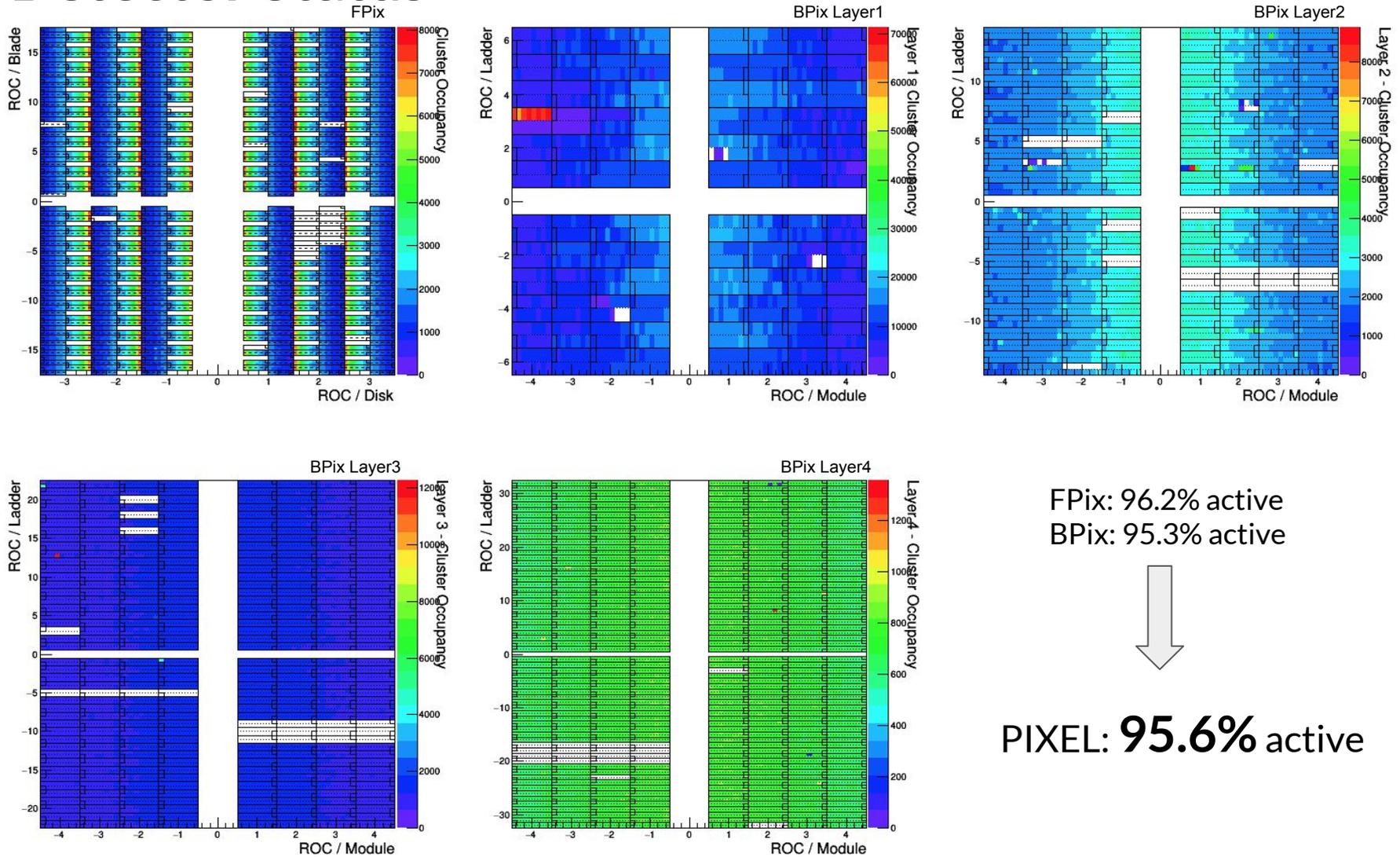
→ BPix 18052/18944 functional ROCs

- **Soft error recovery** to bring back channels masked from DAQ software
- LHC Technical Stop
 - Temperature lowered from -20°C to -22°C | Jul04, 2017
 - Gain/PH optimization

Figure: Percentage of functional and problematic ROCs



Detector Status



FPix: 96.2% active
BPix: 95.3% active

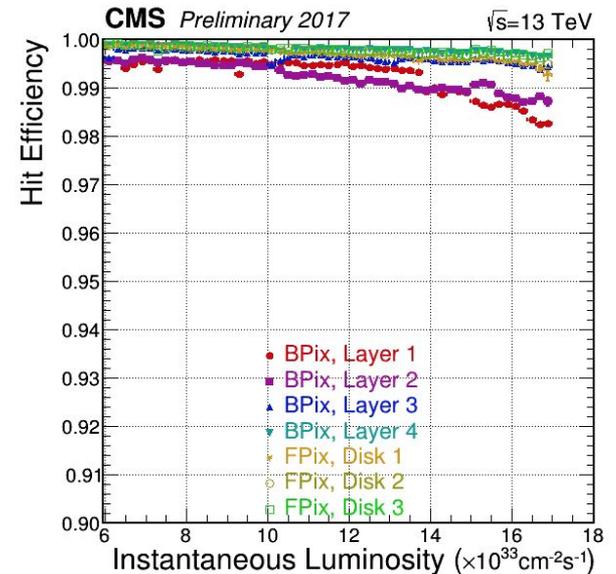


PIXEL: 95.6% active

Figure: Cluster occupancy map of Pixel detector during collisions

Conclusion

- Phase1 pixel system has been commissioned successfully and taking data.
 - Cosmic data-taking is great and valuable.
 - Collision data-taking on-going!
- DAQ is performing smoothly.
- Initial studies show that performance of more complex functions like *b*-tagging, vertexing, and *HLT* electron reconstruction is already better than with the old pixel detector, which would not have been able to cope with the rates in the first place.



CMS went through a challenging, but successful commissioning of the new pixel detector.
We are proud to offer you fresh 2017 data!

Backup

DAQ Acronyms

- CTA: CMS Tracker AMC
- AMC: Advanced Mezzanine Card
- LPC: Low-Pin-Count
- FMC: FPGA Mezzanine Card
- TTS: Trigger-Throttle Signal
- POH: Pixel-Opto-Hybrid
- DOH: Digital Opto Hybrid
- mDOH: modified DOH
- mFEC: FEC optical mezzanine
- CCU: Communication & Control Unit
- Rx-FMC: Receiver FMC
- TCDS: Trigger and Command Distribution System
- FEROL: Front-End Readout Optical Link
- TPLL: Tracker Phase-Locked Loop
- QPLL: Quartz Phase-Locked Loop
- FC7: FMC Carrier xilinx series 7
- MCH: MicroTCA Carrier Hub