CMS HCAL phase 1 upgrade

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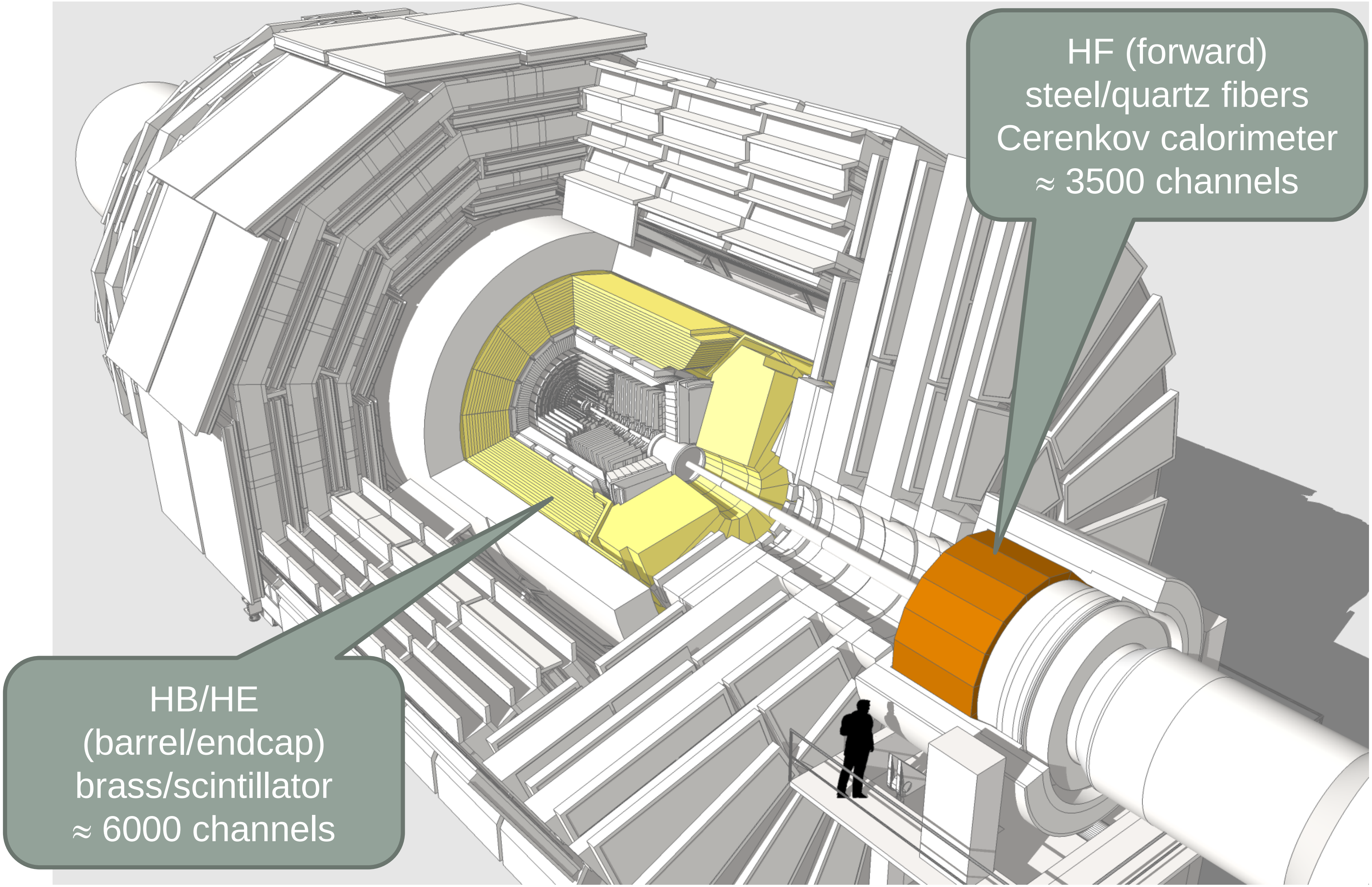
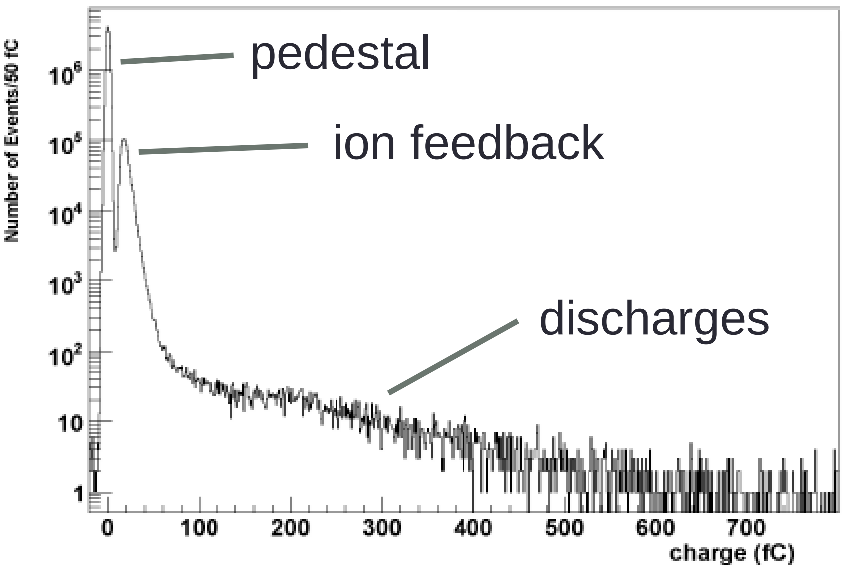
for the CMS HCAL group

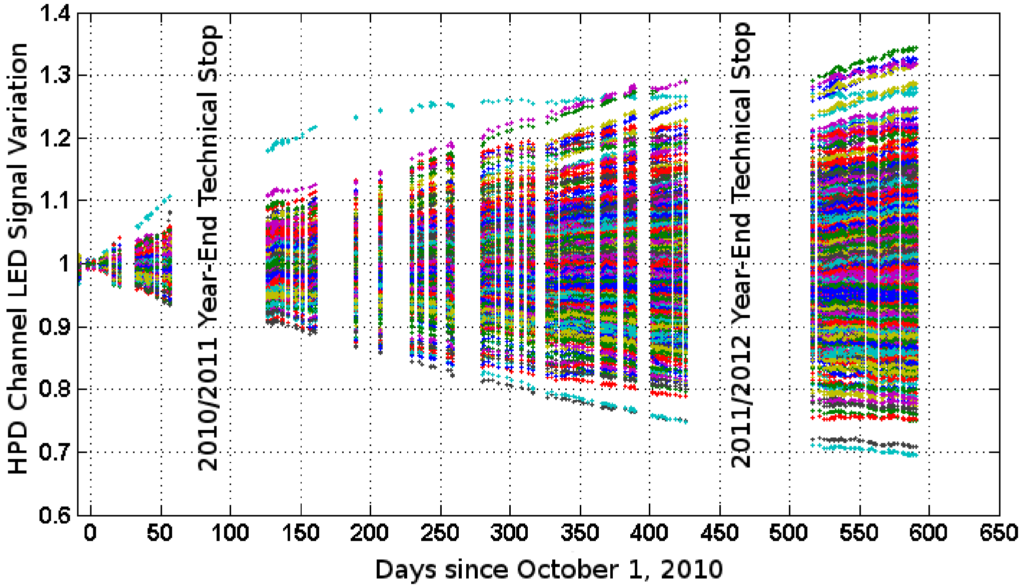
CMS hadron calorimeters



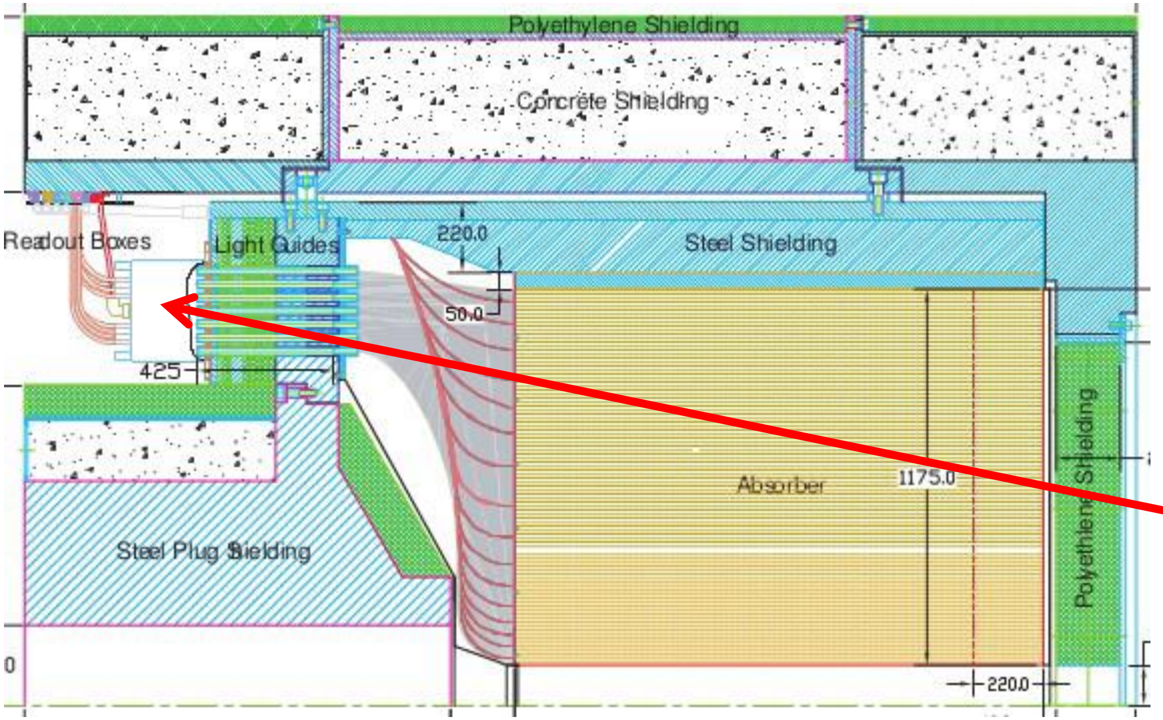
HB/HE performance

- Hybrid Photodiodes (HPDs)
  - can be operated in magnetic field and provide gain > 2000
  - require large electric field (8 kV over 3mm gap)
  - electrical discharges when operating in field of CMS magnet
  - drift in pixel response
  - replace to reduce backgrounds and preempt potential failure of HPDs





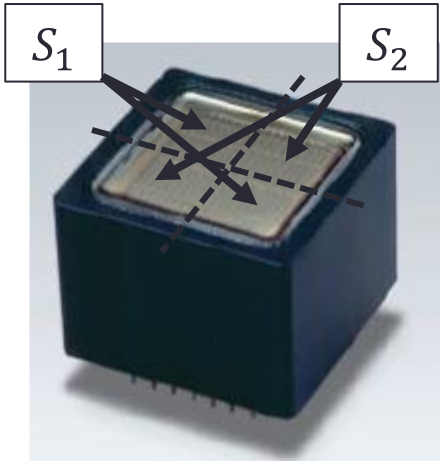
HF performance



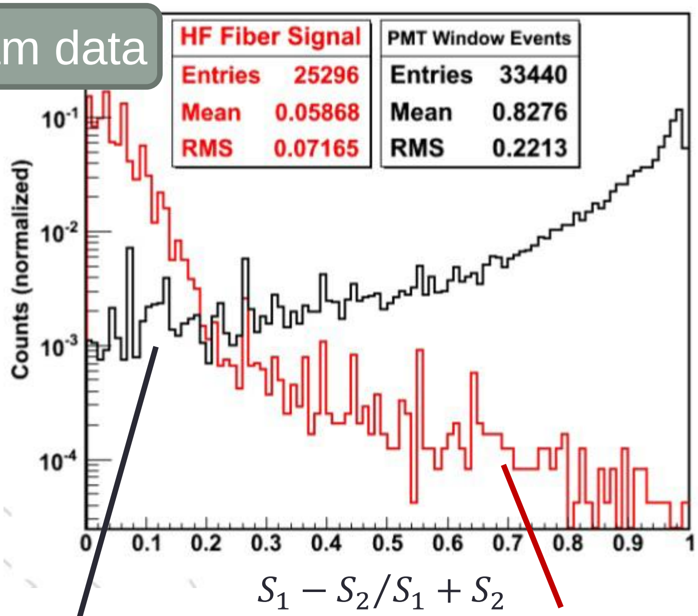
- spurious signals
  - direct hits of particles from showers, in flight decays on PMTs
  - arrive ≈ 5 ns earlier than Cerenkov signal from showers
  - during 50 ns operation mitigated by phasing HF integration clock to move spurious hits into “empty” 25 ns integration window between crossings
  - during 25 ns operation all signals will be integrated with real signals

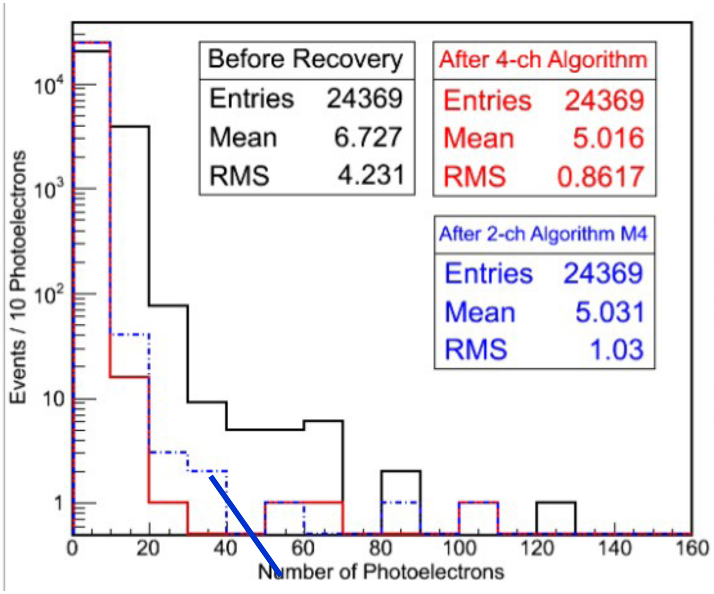
mitigation of HF spurious signals

- new multi-anode PMTs
  - reduced amount of glass reduces frequency of spurious signals by factor four
  - four anodes ganged into two channels provide ability to identify residual spurious signals



test beam data





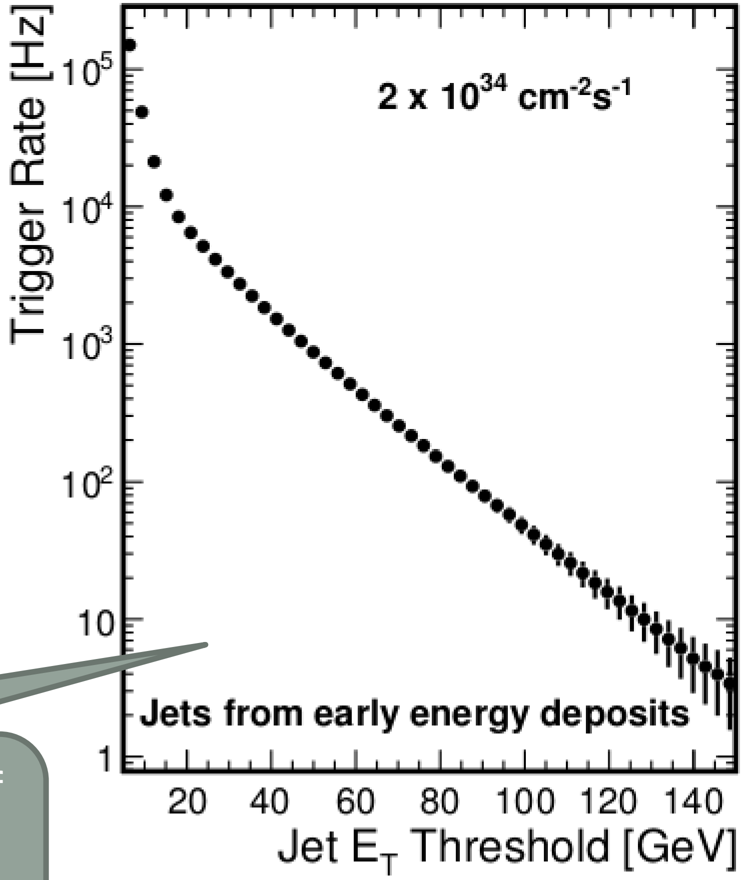
spurious signals primarily illuminate one channel

Cerenkov light from showers illuminates all anodes evenly

remove channel with spurious signal and recover HF signal from other channel

mitigation of HF spurious signals

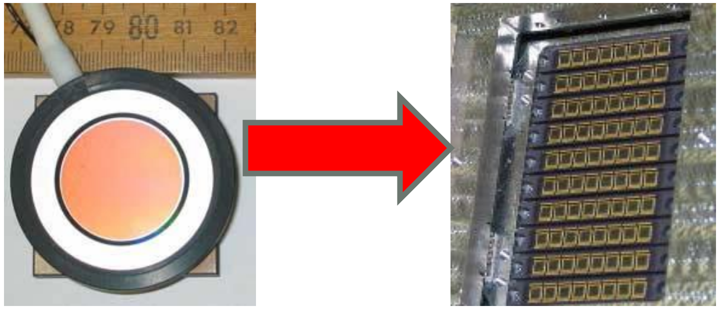
- even with the new PMTs there are residual spurious signals
- need ability to measure signal arrival times with sub-ns resolution

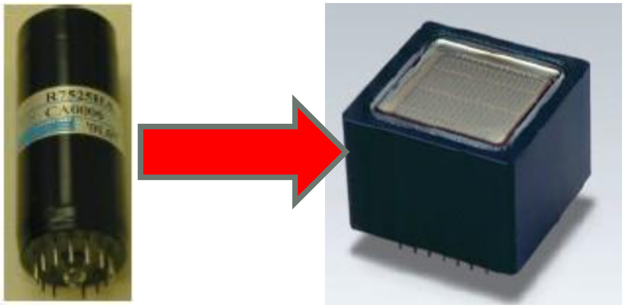


L1 calorimeter trigger rate based on out of time energy deposits in 24 multi-anode PMTs installed during 2012 run at $\sqrt{s} = 8\ \mathrm{TeV}$.

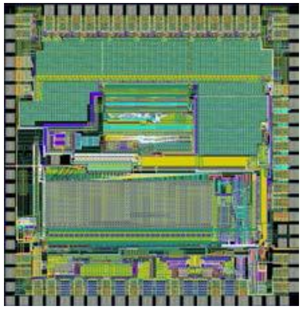
phase 1 upgrade overview

- replace photodetectors



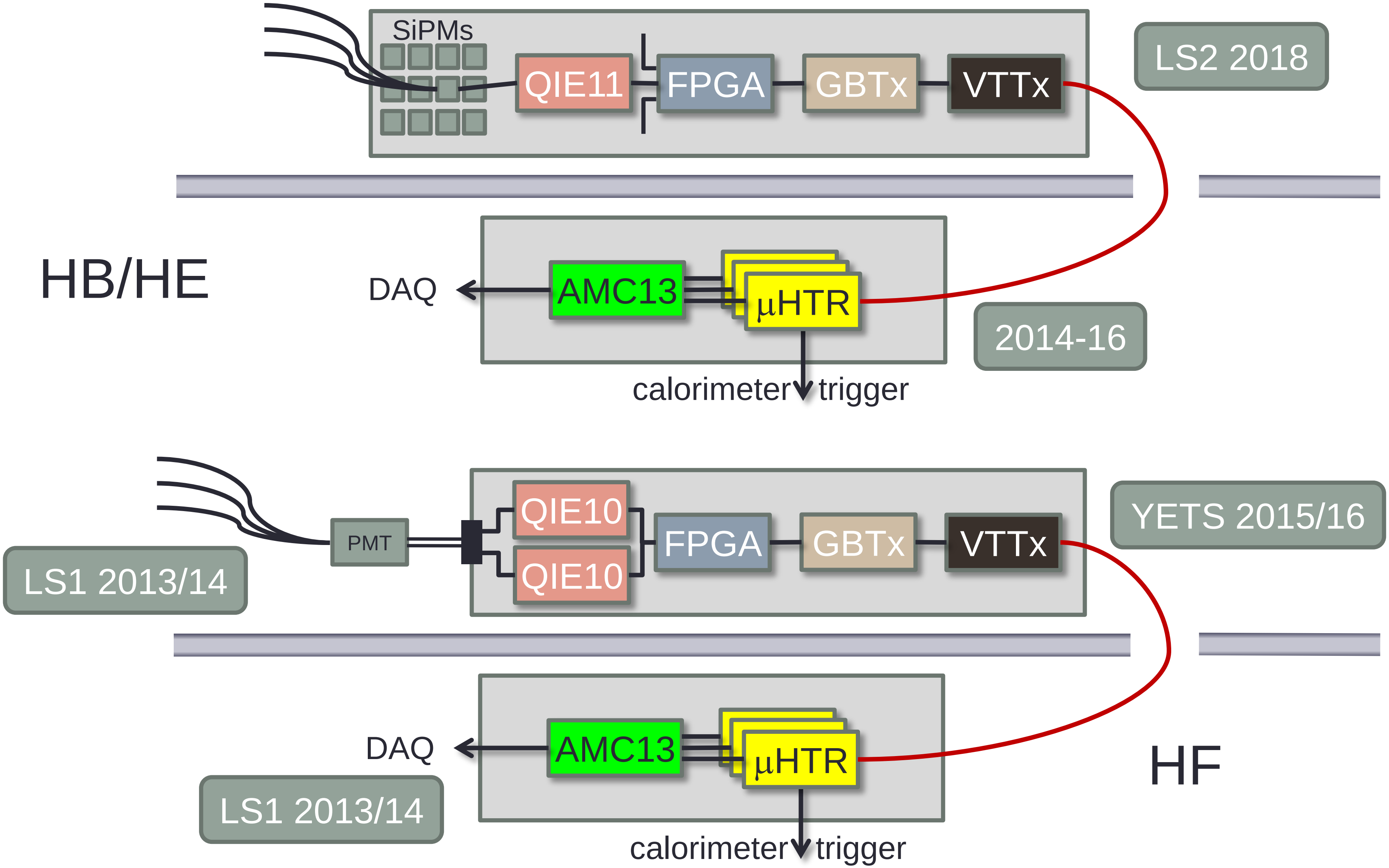


- new front-end electronics
  - new integrator and digitizer ASIC with TDC capability
  - new faster data link
  - more channels
  - higher radiation tolerance
  - improved calibration and redundant control paths



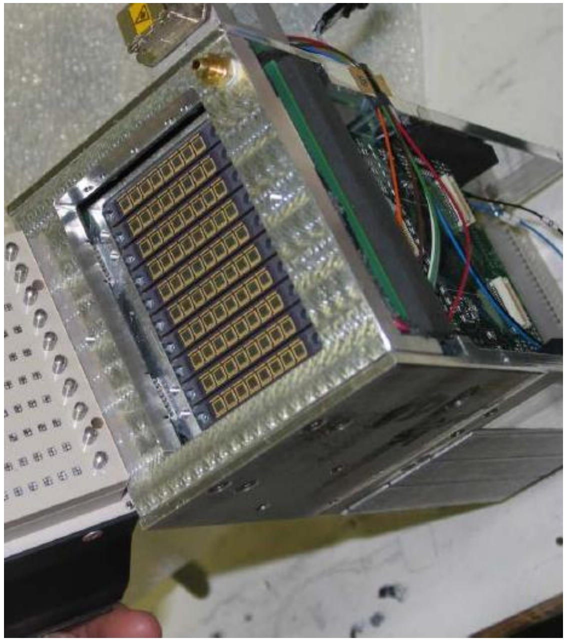
- new back-end electronics
  - handle increased data volume
  - install and commission during CMS operations

electronics architecture/schedule



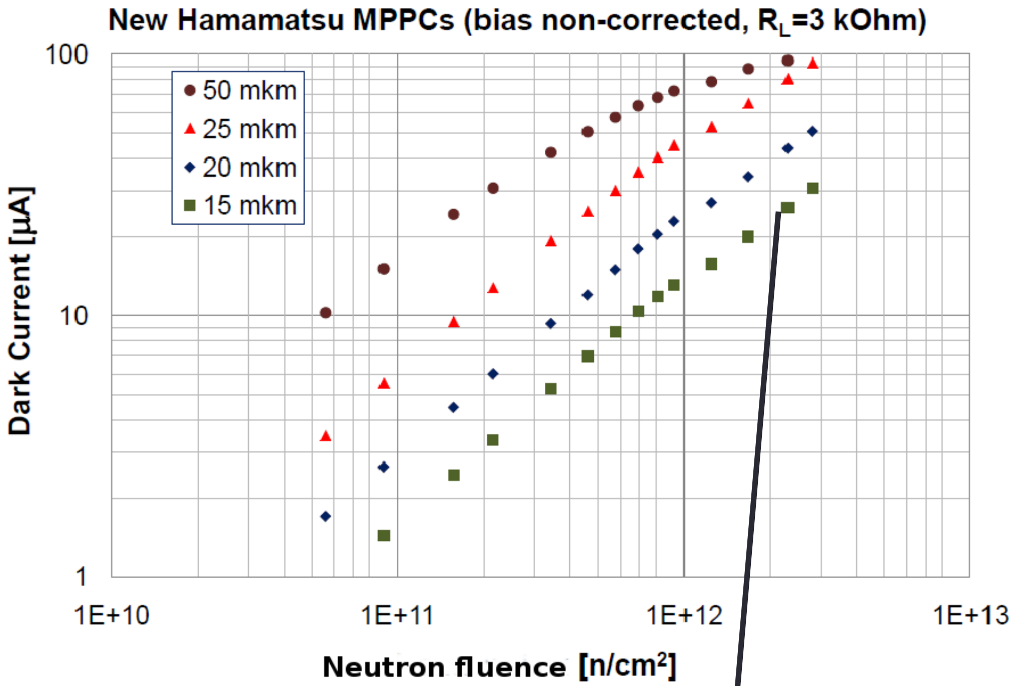
SiPM performance/rad hardness

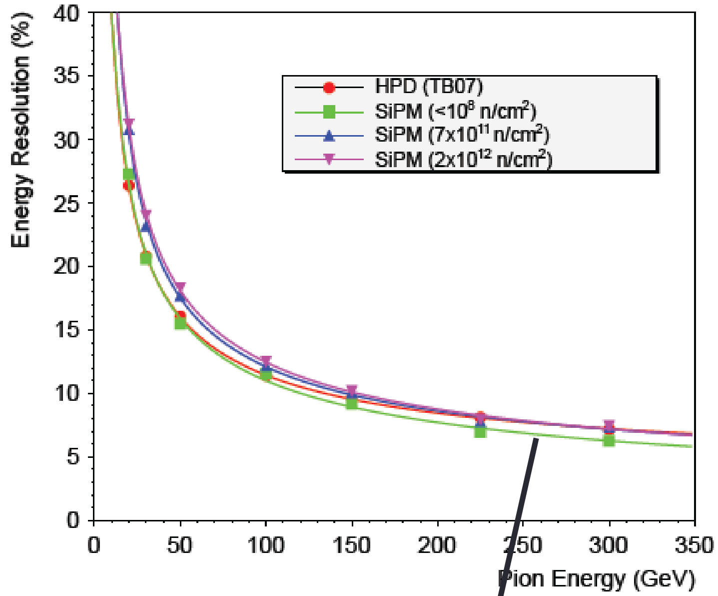
- pixelated avalanche photodiodes in Geiger mode
- low operating voltage
- high gain
- large dynamic range
- insensitive to magnetic fields
- critical characteristic: pixel recovery time
  - < 10 ns
  - else responds shifts as a function of pileup
- radiation tolerant
  - expected dose in CMS: 14 Gray, $7 \times 10^{11}/\mathrm{cm}^2$
  - target tolerance: 100 Gray, $2 \times 10^{12}/\mathrm{cm}^2$



SiPM performance/rad hardness

- radiation causes bulk damage and increases leakage current
- can tolerate up to 200 μA for 2.2x2.2 mm^2 device



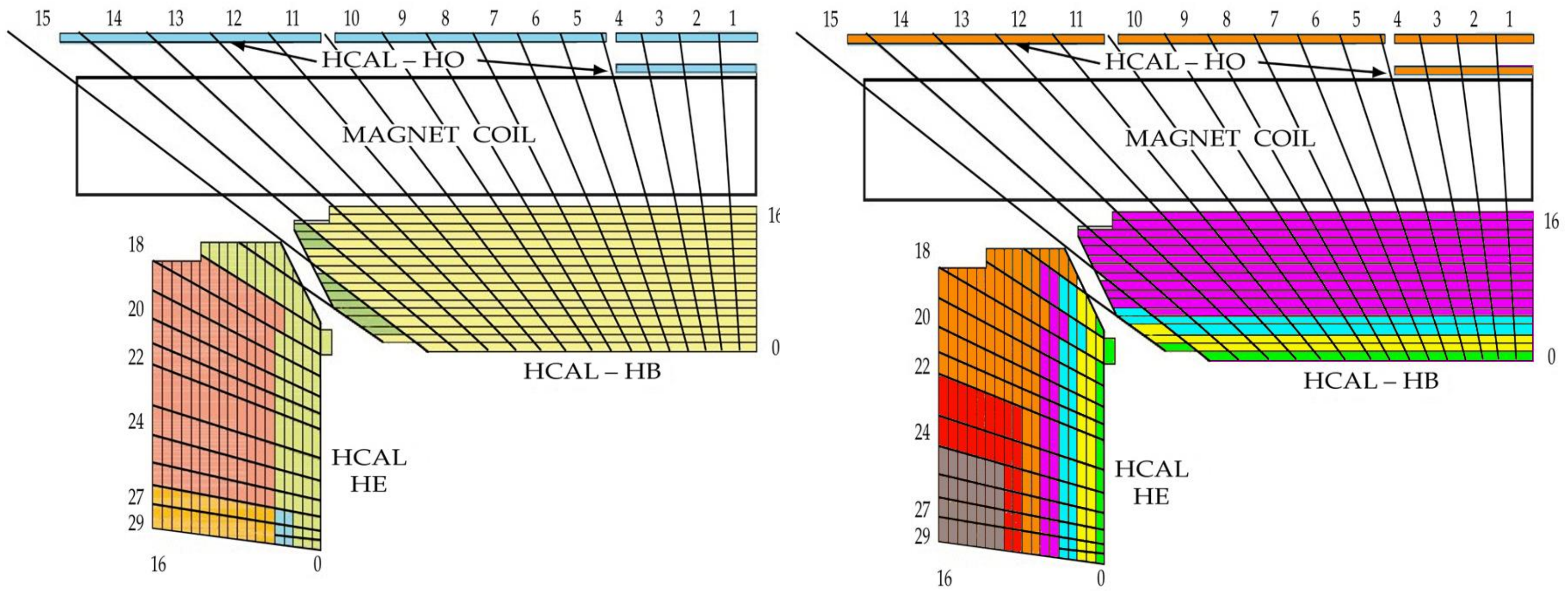


leakage current for Hamamatsu SiPMs of various cell sizes irradiated at CERN IRRAD facility. For 15μm cells after $2x10^{12}/cm^2$ the leakage current is $25\mu A/mm^2$

resolution of SiPMs is slightly worse than that of HPDs after irradiation

depth segmentation

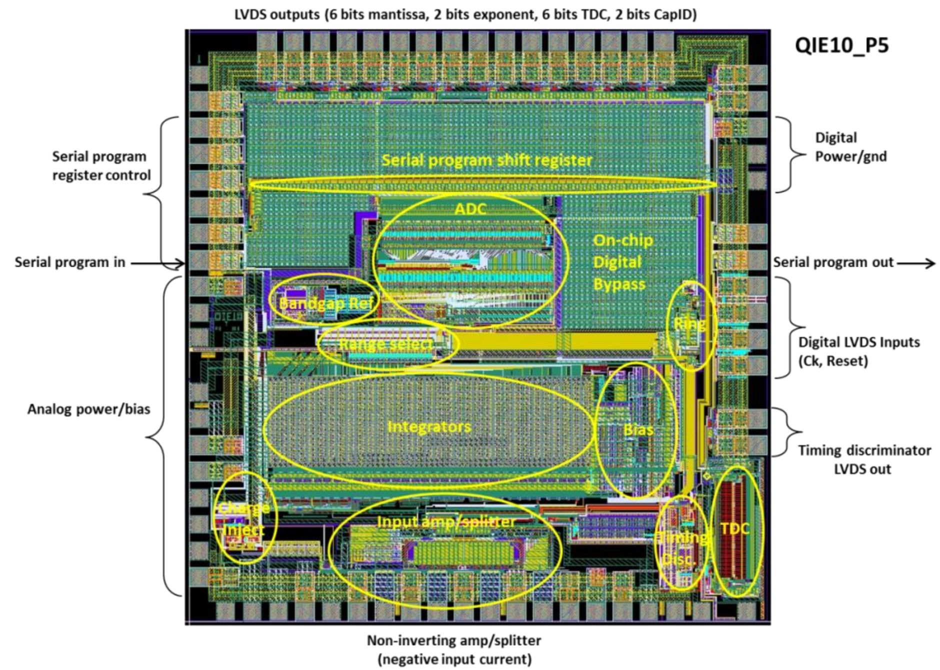
- SiPM readout allows increased number of channels which can be exploited to increase depth segmentation in HB/HE



- more robust against radiation damage to inner scintillator layers
- suppress effects of soft pileup particles which are absorbed in inner layers
- use inner layer to trigger on MIPs for calibration of calorimeter

charge integrator and encoder (QIE)

- deadtimeless integration and digitization of charge in 25 ns buckets
- rising edge TDC, resolution < 800 ps
- timing discriminator output
- large dynamic range
  - 3fC – 330pC (1 pe to 1 TeV)
  - driven by HB/HE SiPMs
  - → 17 bits
- digitization error < resolution
  - 2-3% → requires 6 bits
- digitize in four gain ranges
  - 6 bit mantissa and 2 bit exponent

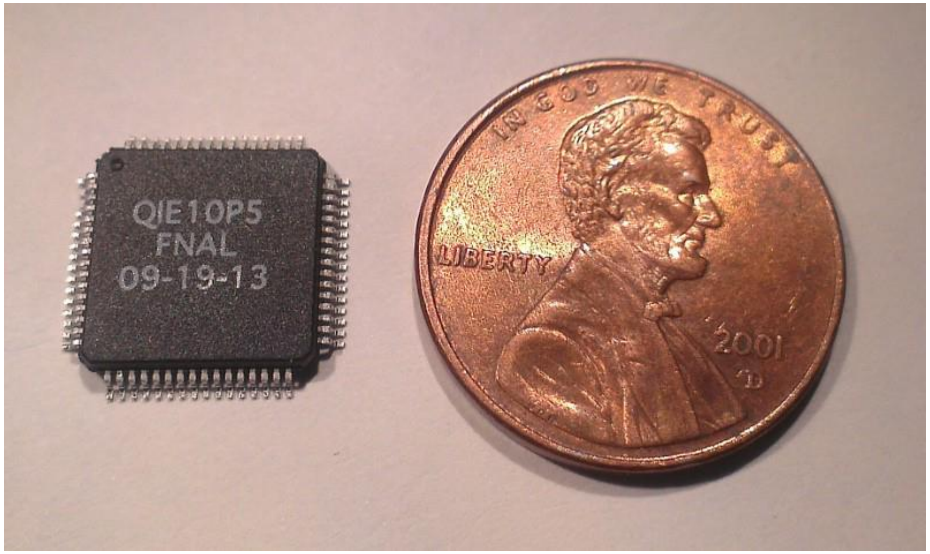


- match input impedance to new photodetectors
  - QIE10 for HF PMTs → 50Ω impedance
  - QIE11 for SiPMs → programmable gain, low impedance

charge integrator and encoder (QIE)

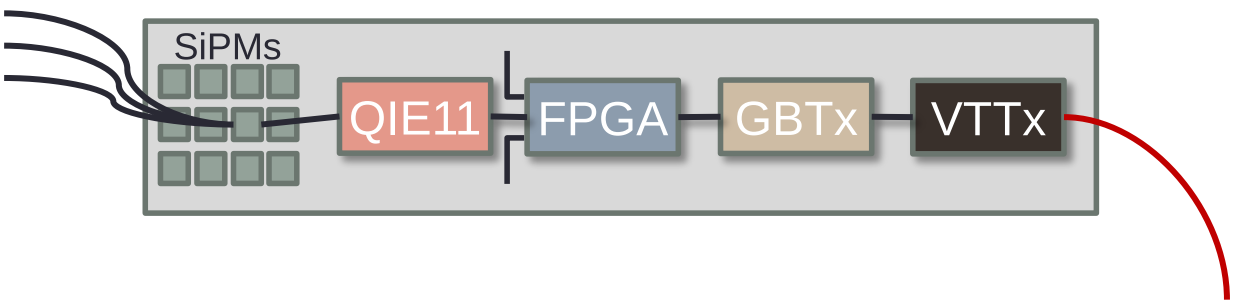
- radiation tolerance (AMS 0.35μm SiGe BiCMOS process)

R=3m, z=12m	expected	tolerance target
total ionizing dose	1.5 Gy = 150 rad	100 Gy = 10 krad
1-Mev equiv. neutron fluence	$2x10^{11}/cm^2$	$2x10^{12}/cm^2$
charged hadron fluence	$6x10^{8}/cm^2$	$10^{10}/cm^2$

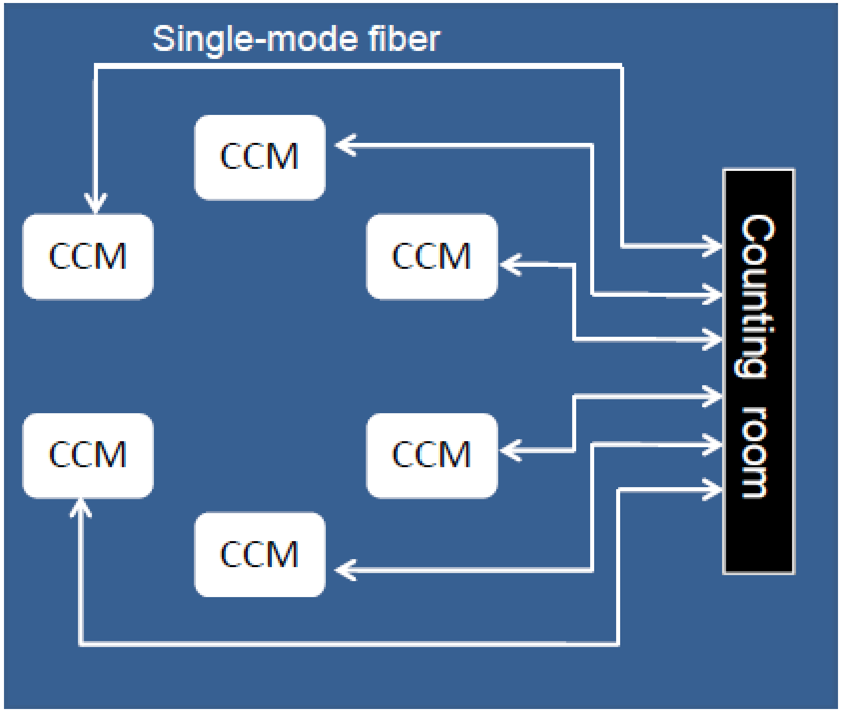


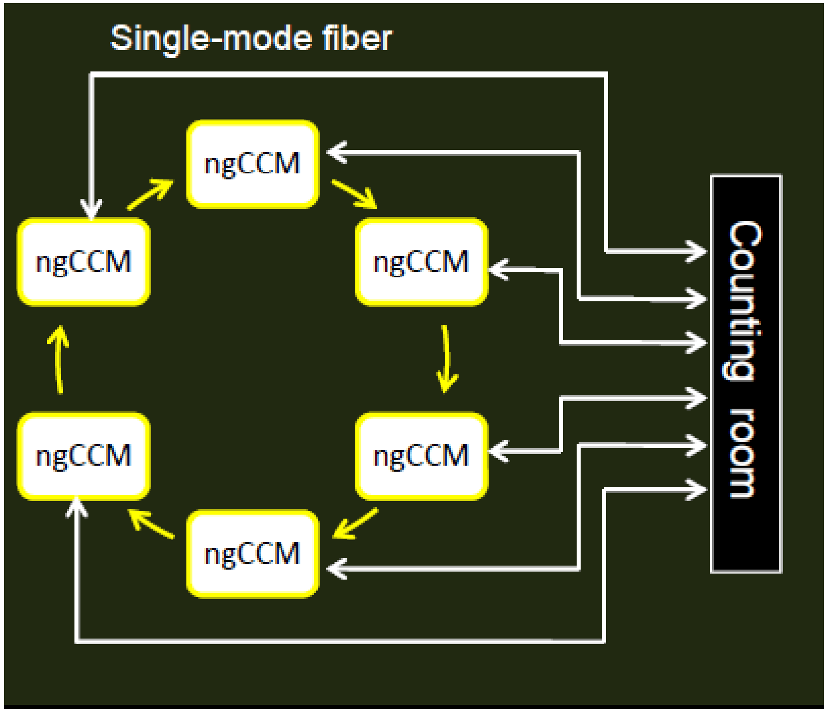
front-end electronics

- QIE
  - digitized signal and arrival time information
  - timing discriminator output
- rad tolerant FPGA (ProASIC3E from Microsemi)
  - synchronizes and formats data from several QIEs
  - determines pulse width from time discriminator output
- GBTx (4.8 Gbps data link – CERN)
  - serializes data for transmission to back-end electronics in counting room



redundant control paths

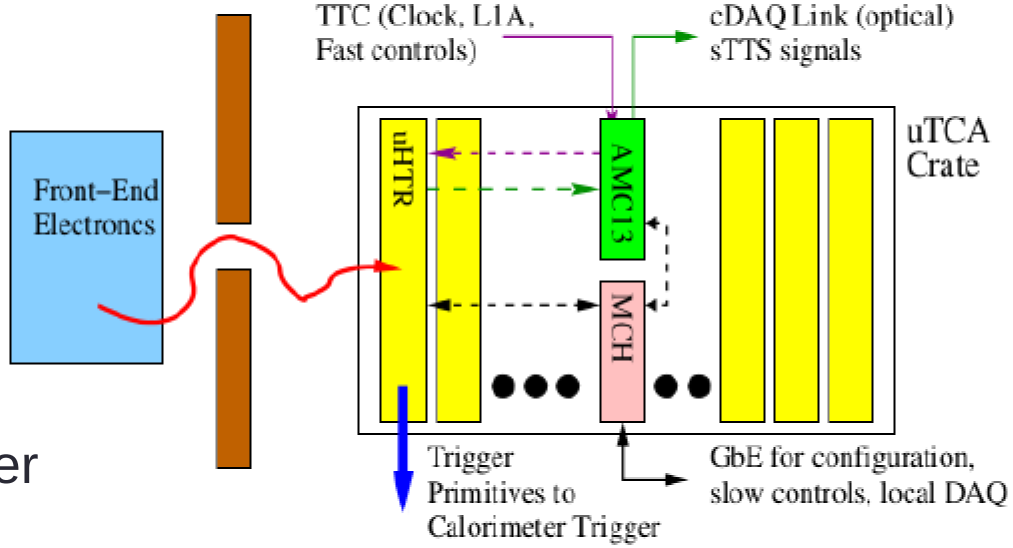


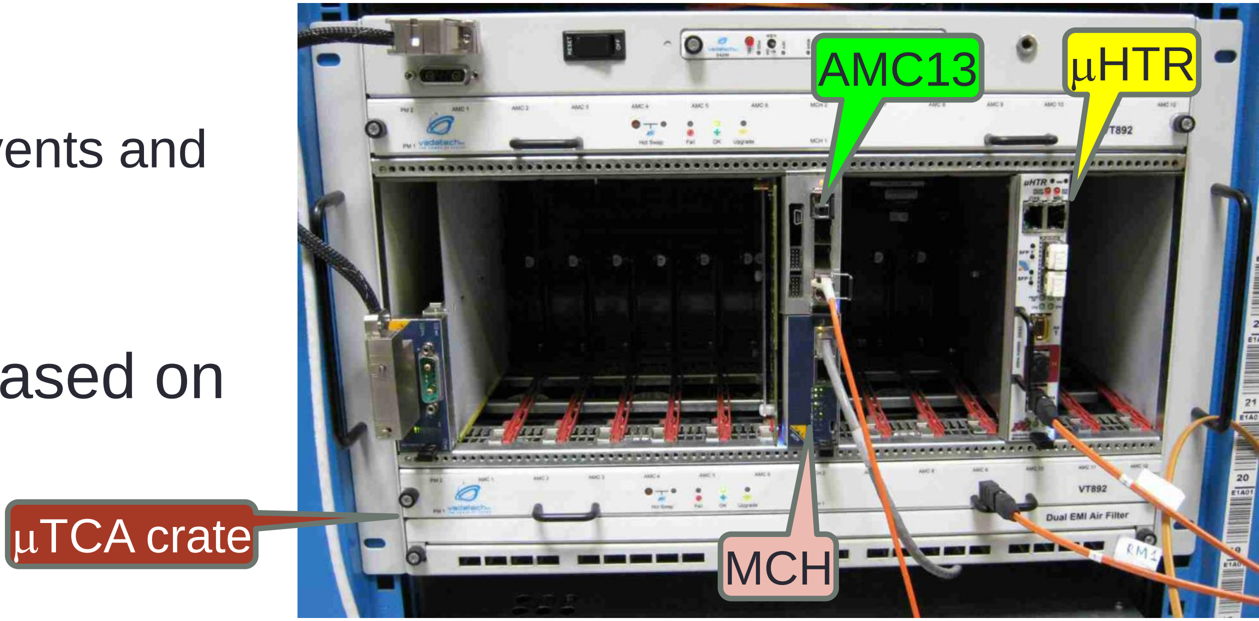


- old system
  - each clock & control module (CCM) controls all channels in a crate
  - point to point communication between CCM and control room
  - if link fails are channels are lost
- upgraded system
  - each CCM is linked to another CCM
  - this link can provide clock and essential commands if main link breaks

back-end electronics

- μHTR
  - receive data from front-end
  - compute trigger information, transmit to L1 calorimeter trigger
  - buffer data for readout
- AMC13
  - on L1 accept build events and transmit to DAQ
- upgraded back-end electronics will be based on μTCA form factor





summary

- CMS HCAL phase 1 upgrade will improve performance of HCAL to cope with luminosity expected in Run 2
- new photodetectors
  - reduce spurious signals and improve reliability
- new front-end electronics
  - provide signal timing to further reduce spurious signals
- new back-end electronics
  - handle increased data load
- phased installation
  - HF PMTs and backend in LS1 2013/2014
  - HF front-end in YETS 2015/2016
  - HBHE backend during operation in 2014-2016
  - HBHE SiPMs and frontend in LS2 2018