Electronics and triggering challenges for the CMS High Granularity Calorimeter for HL-LHC

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on behalf of the CMS collaboration

Contents

- On-detector electronics challenges
- Off-detector electronics challenges
- Looking ahead

Not covered in this talk

- Power distribution
- Cooling
- Mechanical design

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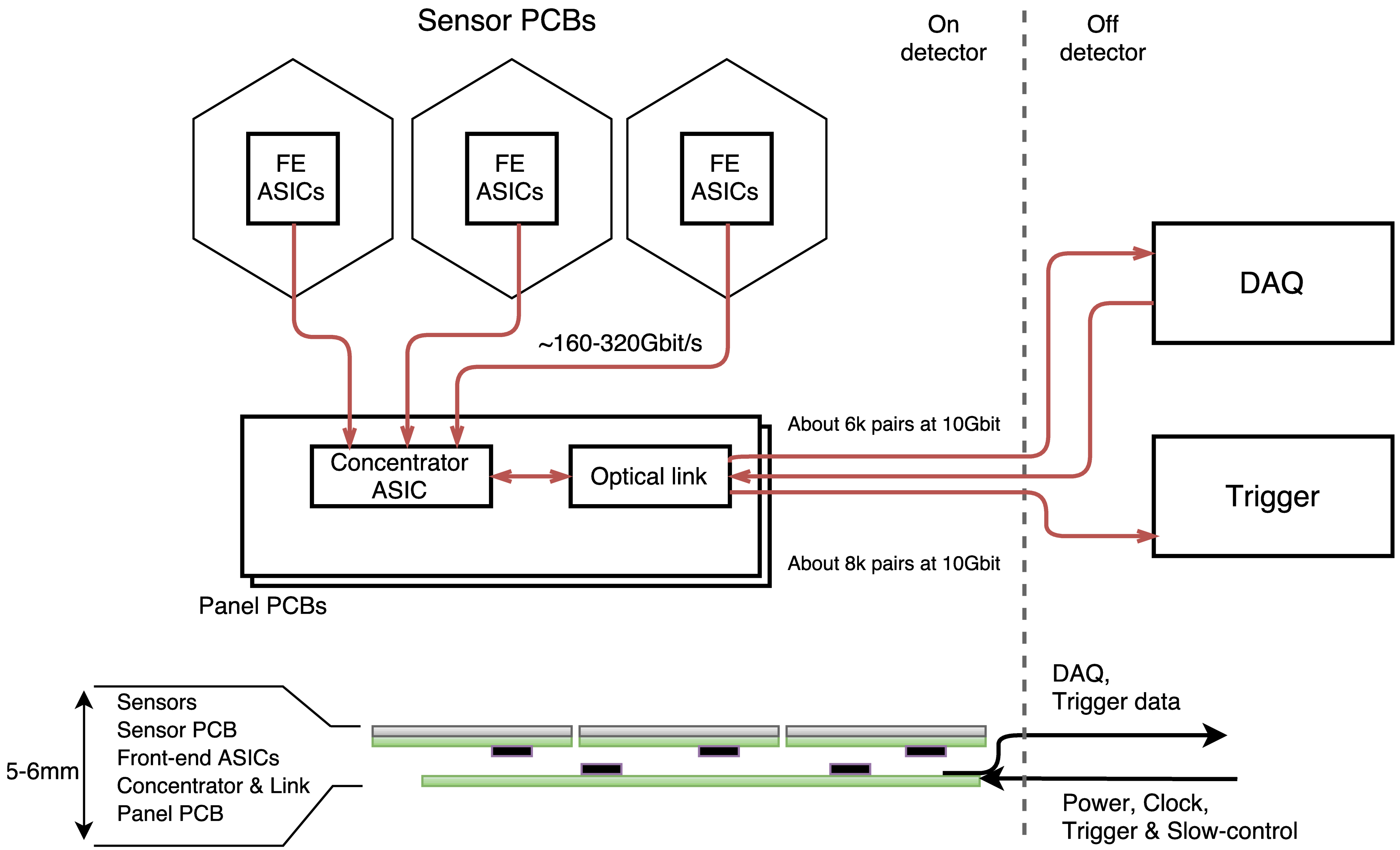
The High Granularity Calorimeter

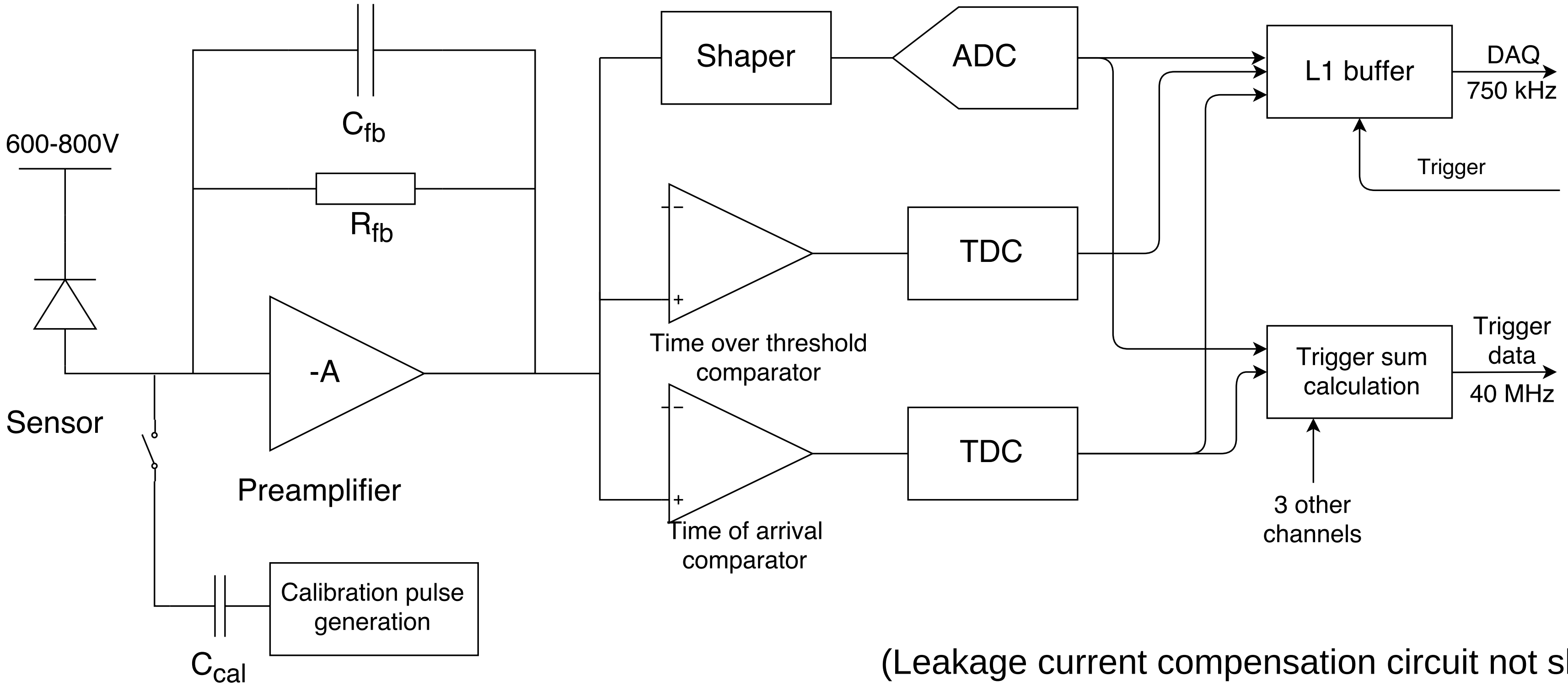
- 6M channels+
- 40 MHz acquisition rate, almost 40% occupancy in some layers
- Full data stored on-detector for 12.5 μs, up to 750 kHz trigger readout rate
- Whole system cooled to -30°C to keep sensor radiation damage manageable
- Max 10 mW/channel (front-end)
- Single-MIP sensitivity for calibration and possible particle tracking
  - Minimum sensor MIP charge: 4000 e- after 3000 fb^{-1}
  - Front-end specification: <2000 e- (0.32 fC RMS) noise
- 10 pC full-scale measurement range (15-bit dynamic range)
- 50 ps timing resolution
- Sends reduced resolution data at 40 MHz to L1 trigger

System overview



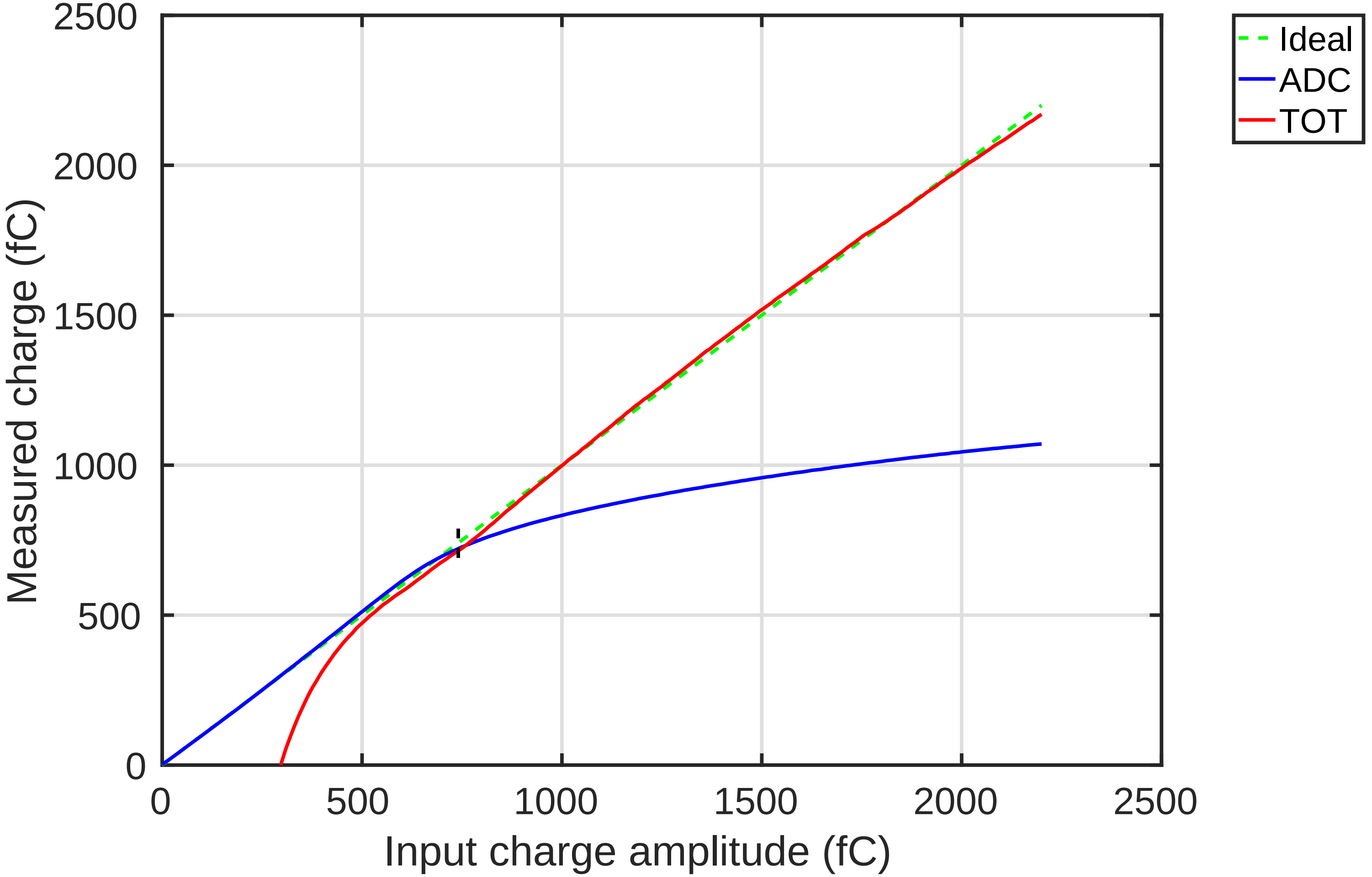
Front-end architecture

- 40 MHz 11 bit (preliminary) successive approximation analog to digital converter (ADC) for digitizing small signals (up to $\approx$100-500 fC)
- A Time-over-threshold (TOT) circuit for digitizing signals up to 10 pC
- A Calibration signal injection capable of injecting signals over both the ADC and TOT ranges
- A Time of arrival measurement circuit
- Trigger sum calculation
- 12.5 μs data buffer



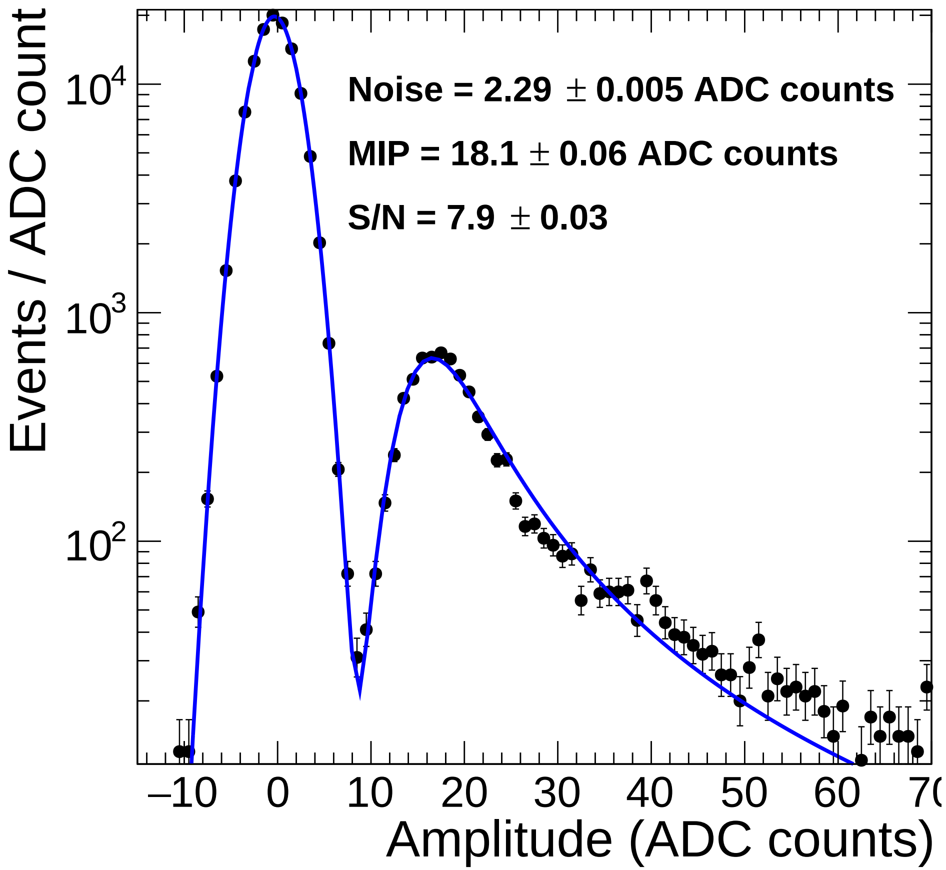
(Leakage current compensation circuit not shown)

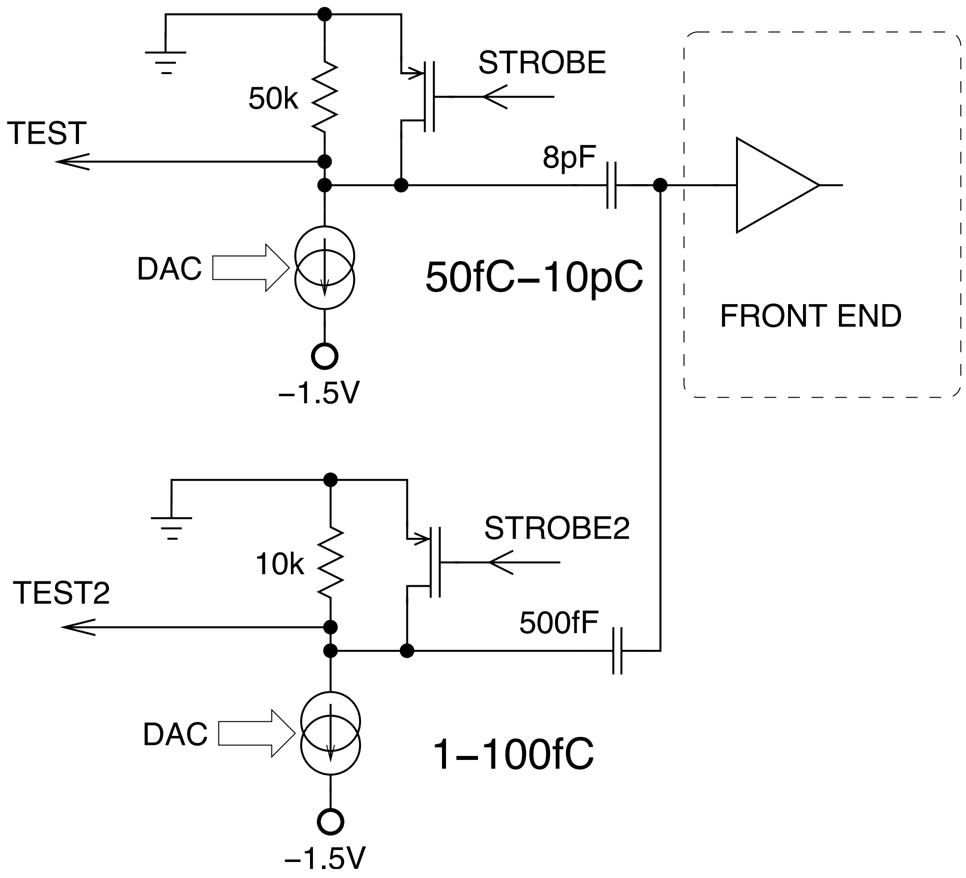
ADC/TOT transfer changeover



- Simple concatenation OK for trigger purposes, full linearization can be implemented in off-line reconstruction, but the small overlap makes direct calibration difficult

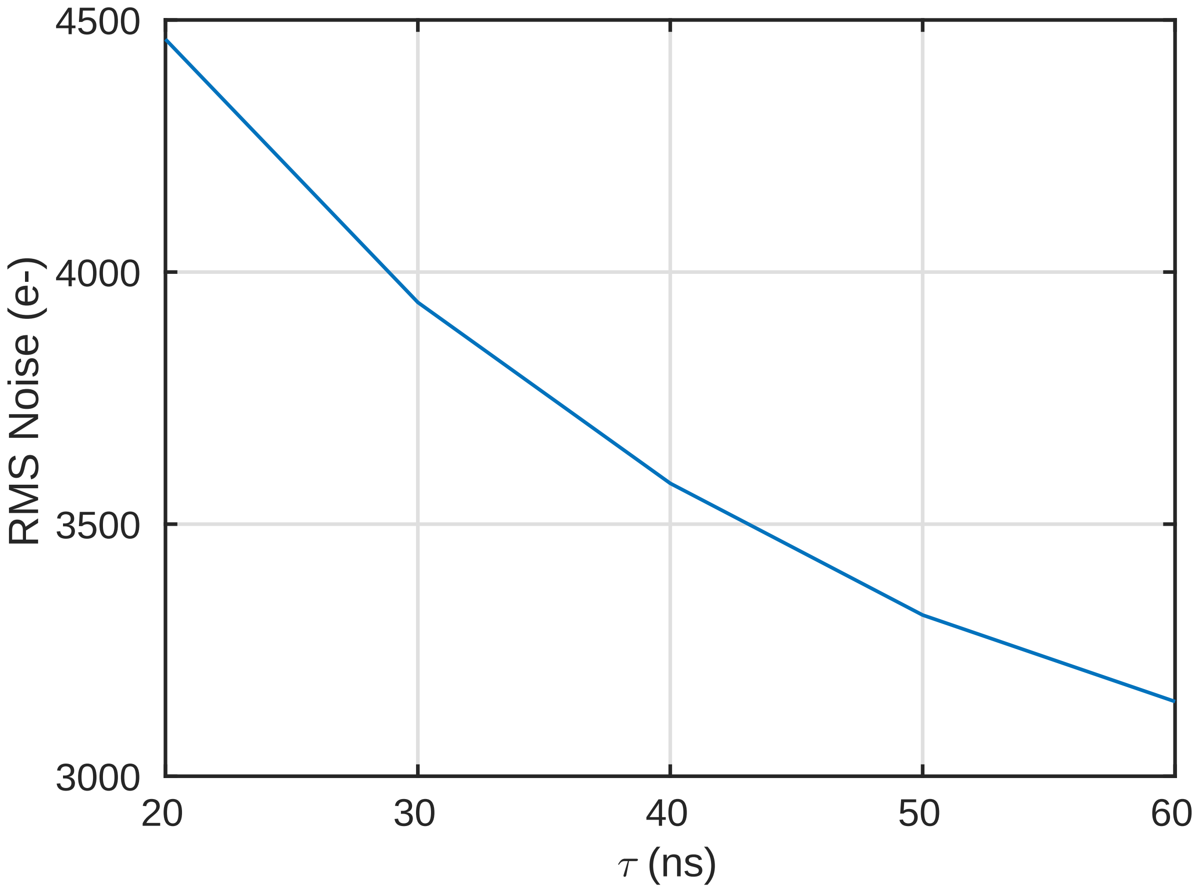
MIP Calibration





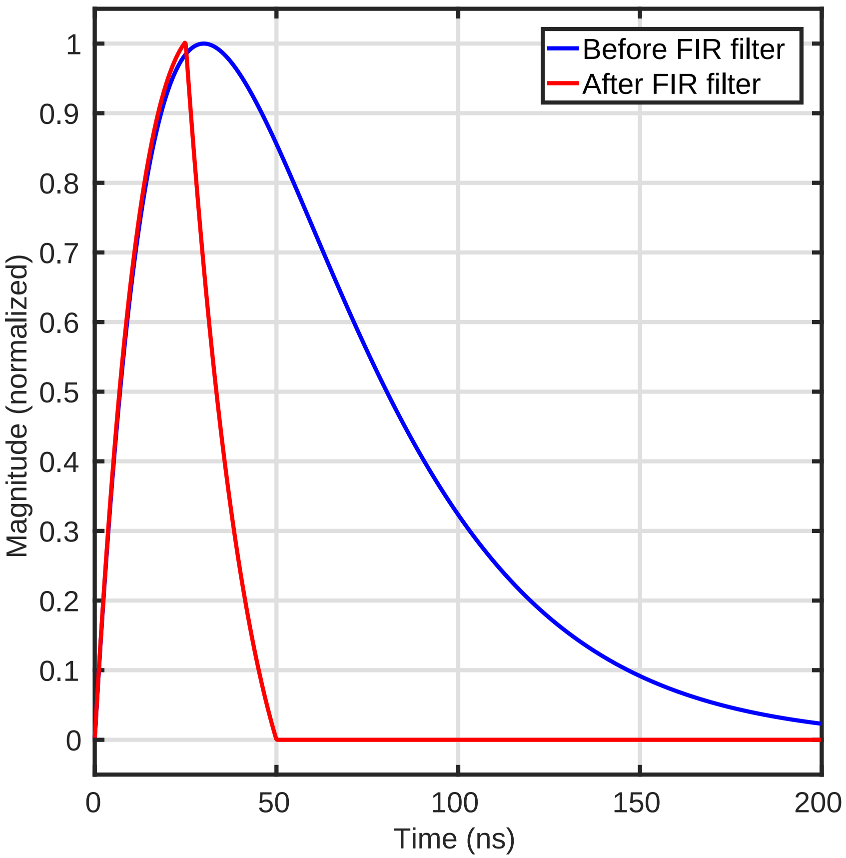
- A charge injection circuit with a large dynamic range will be used for covering both the ADC and TOT ranges

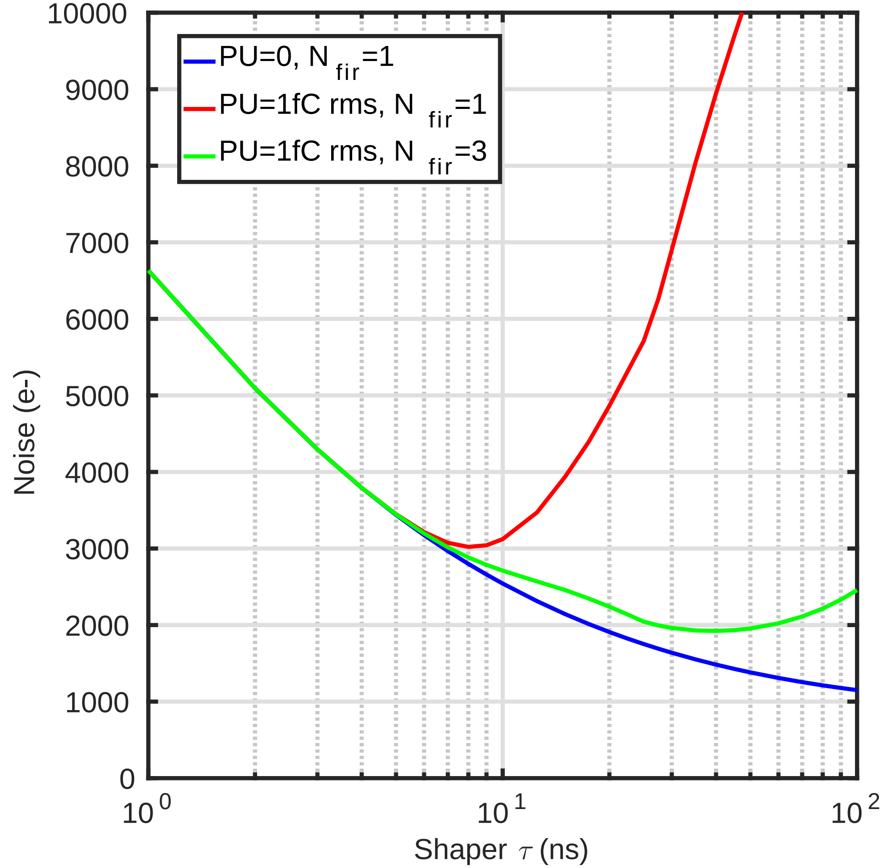
Noise and shaping time



- Measurements from the SKIROC2_CMS currently used for HGCAL testbeams
- Highlights the increasing difficulty of achieving good noise performance at short shaping time

Using FIR filters to manage occupancy

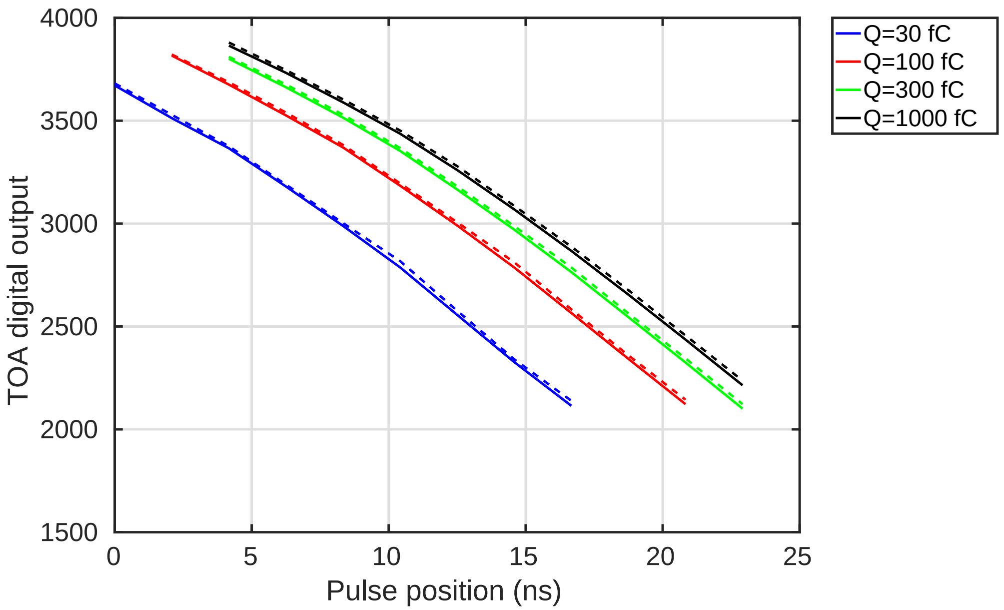


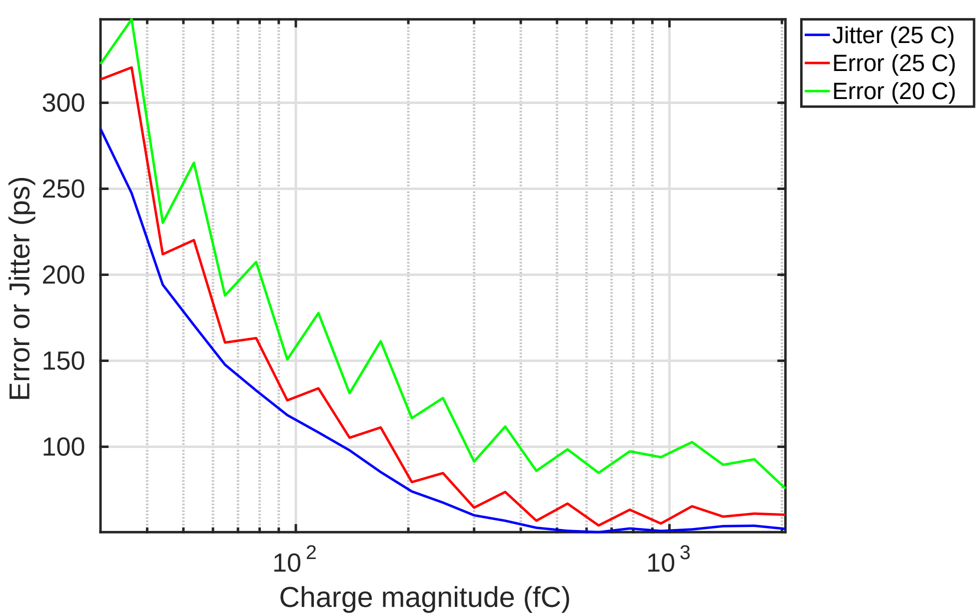


- 3-coefficient analog or digital finite impulse response (FIR) filters can help managing the high occupancy
- Simulated for e_n=0.5 nV/$\sqrt{Hz}$, C_d=80 pF, 10-bit signal to noise ratio after the preamplifier, with and without 1 fC (6250 e-) pileup noise in preceding samples

Time of arrival measurements

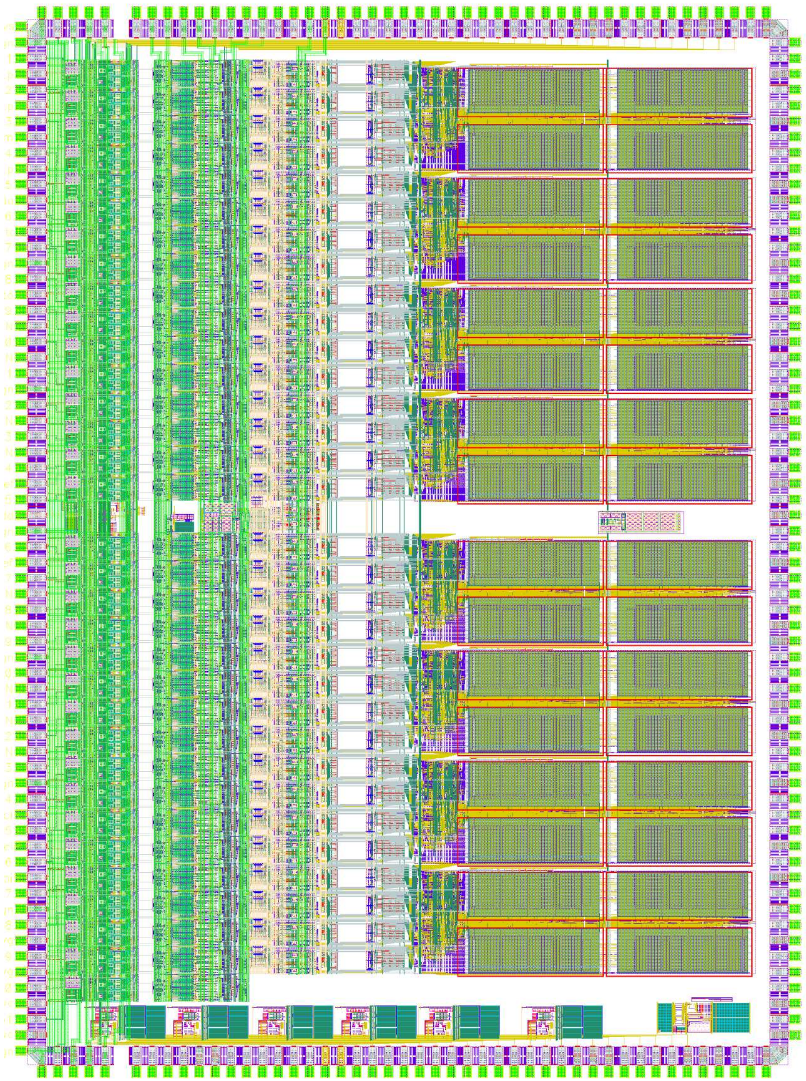
- No constant fraction discriminator
- Off-line time-walk correction
- Studies of the SKIROC2_CMS time-walk and time-walk correction give encouraging results
  - Jagged shape is due to imperfect interpolation between characterization measurements.
  - Temperature stability (as planned) is required to keep the calibration relevant





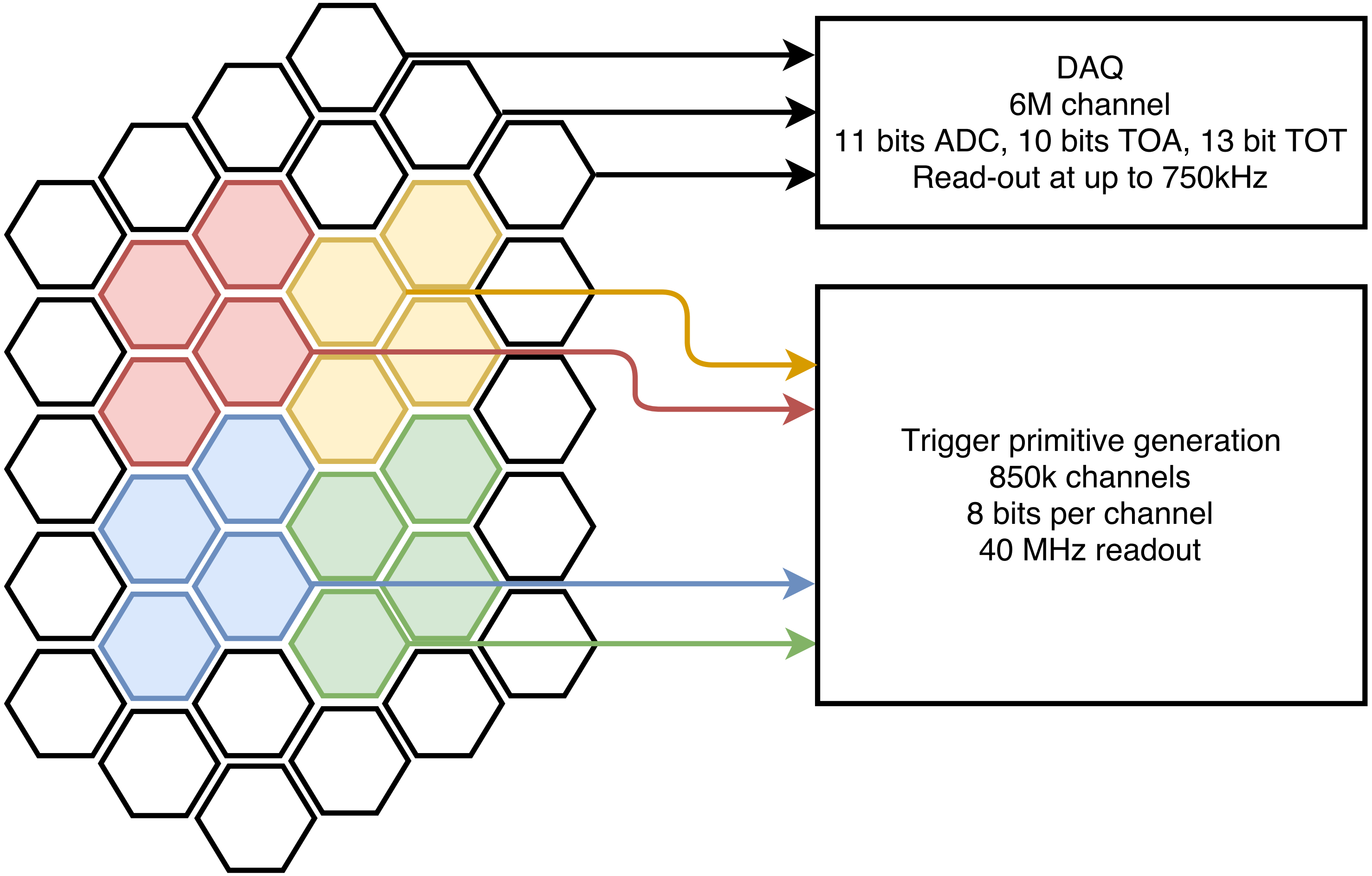
Current work in progress: HGROC_V1

- TSMC 0.13μm (selected for good radiation tolerance)
- 32 Channels
- 11-bit 40 MHz ADCs
- Improved time over threshold circuit
- New time to digital converter circuits
- On-chip L1 buffer memory
- To be submitted for manufacture early June
- Measurements will start early autumn

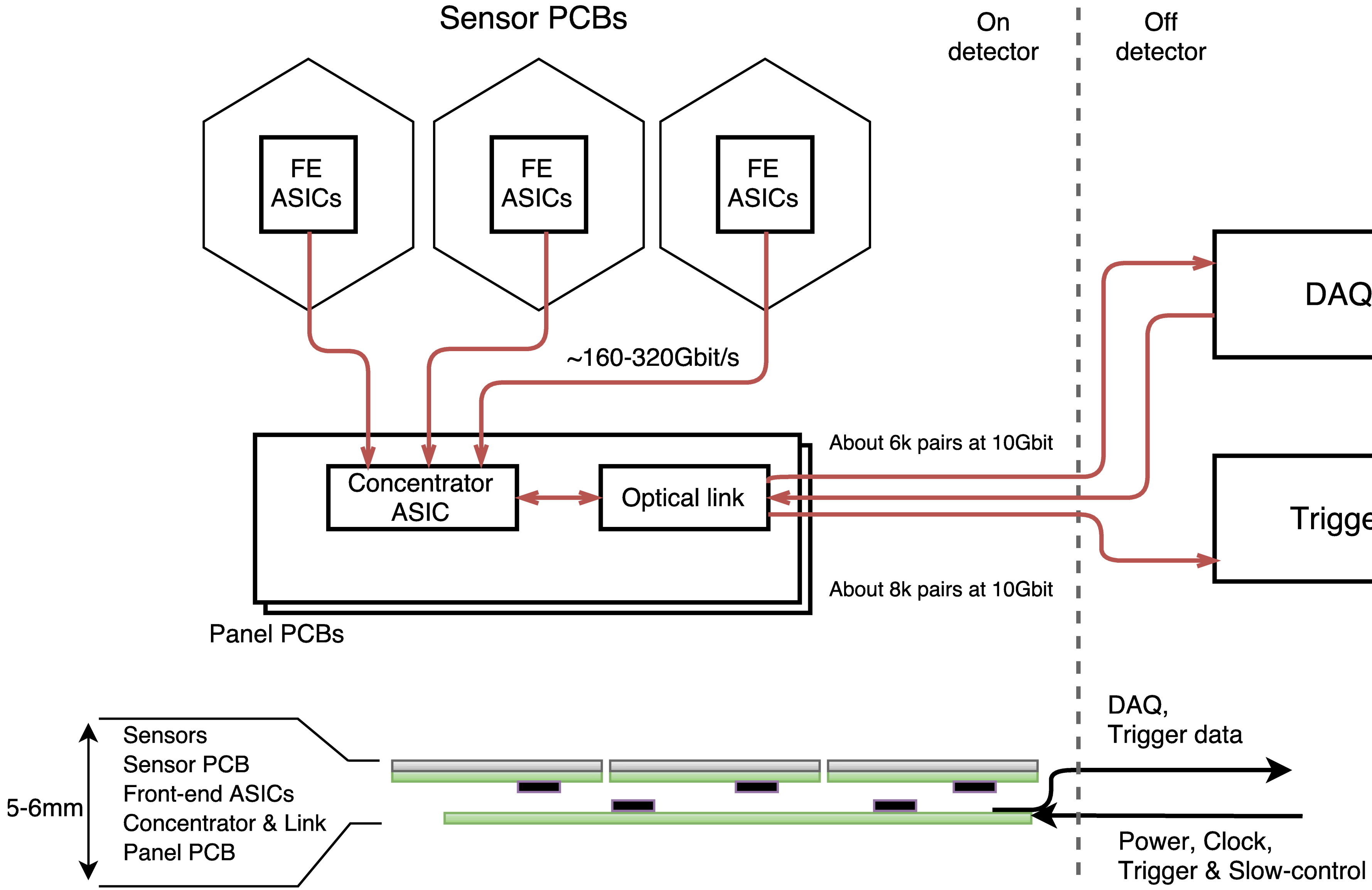


Preliminary layout

Sensor cell DAQ and trigger readout



Data handling



Off-detector trigger preprocessing

- The current approach is based on finding connected regions around “seed” hits on each layer to from 2D clusters
- The 2D clusters are then associated in depth to form 3D clusters which should correspond to the incoming particles
- To be implemented in FPGA firmware, probably on ATCA form factor boards
- 64-96 inputs and output (10-16Gbit) per board
- Time-multiplexing will likely be used to allow data from a complete layer or a whole endcap to be accumulated into one FPGA

Conclusions

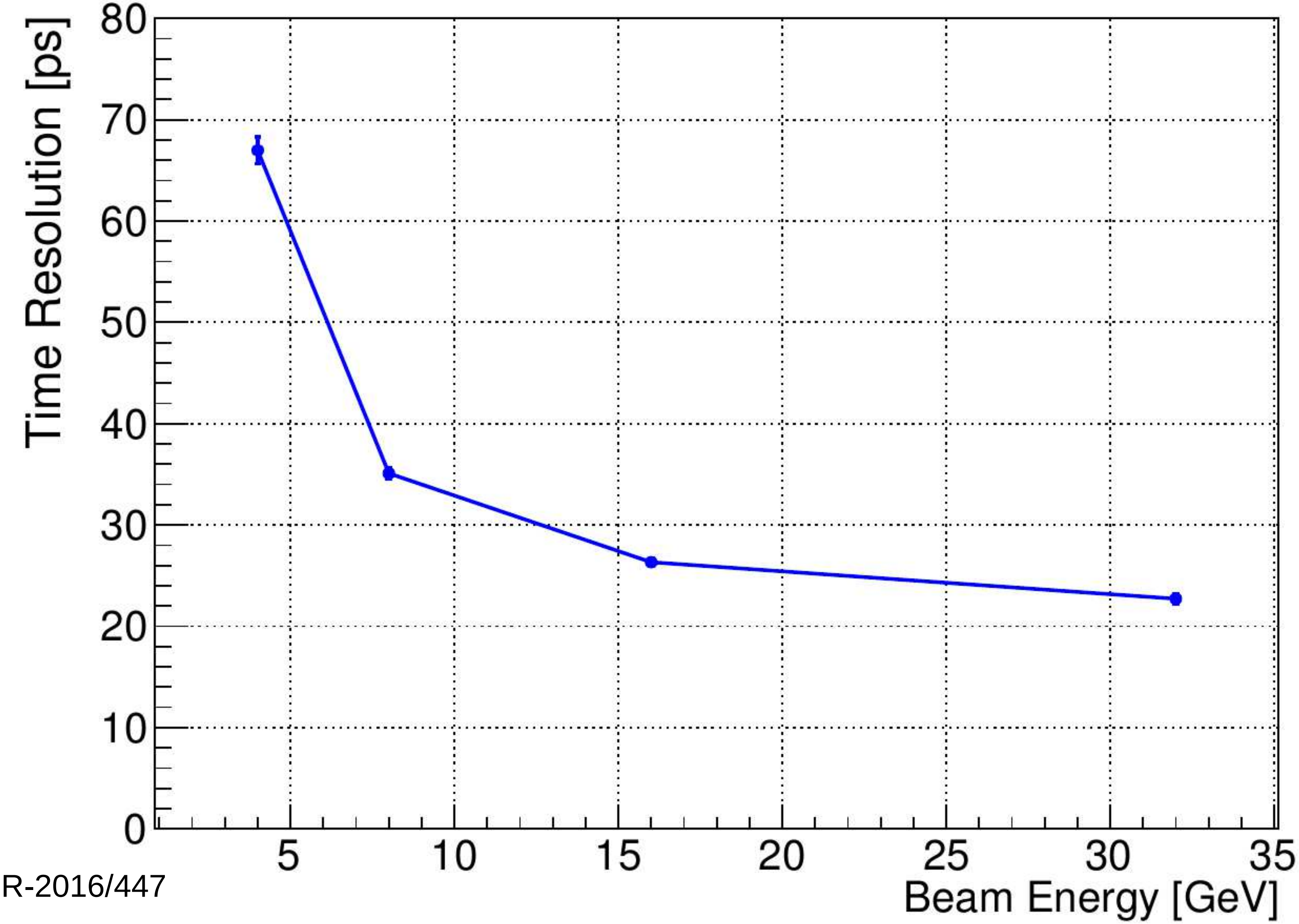
- A challenging detector
  - Very large: 600 m^2 of silicon sensors
  - To be designed and built on a tight schedule
  - Rapid progress thanks to R&D performed for Calice
- Beamtests used to validate basic architecture

  Construction and first beam-tests of silicon-tungsten prototype modules for the CMS High Granularity Calorimeter for HL-LHC
  by Francesco Romeo (Tuesday@14:18)
- Next steps
  - Submission followed by characterization of the HGROC_V1 ASIC
  - Further work towards resource efficient trigger-cell clustering
  - Technical Design Report due in November 2017
  - Full-architecture system tests being planned for 2018
  - Production starts in 2020
  - Installation in 2023/2024

Work supported by Grant: H2020 - ERC-2014-ADG 670406 - Novel Calorimetry

Backup

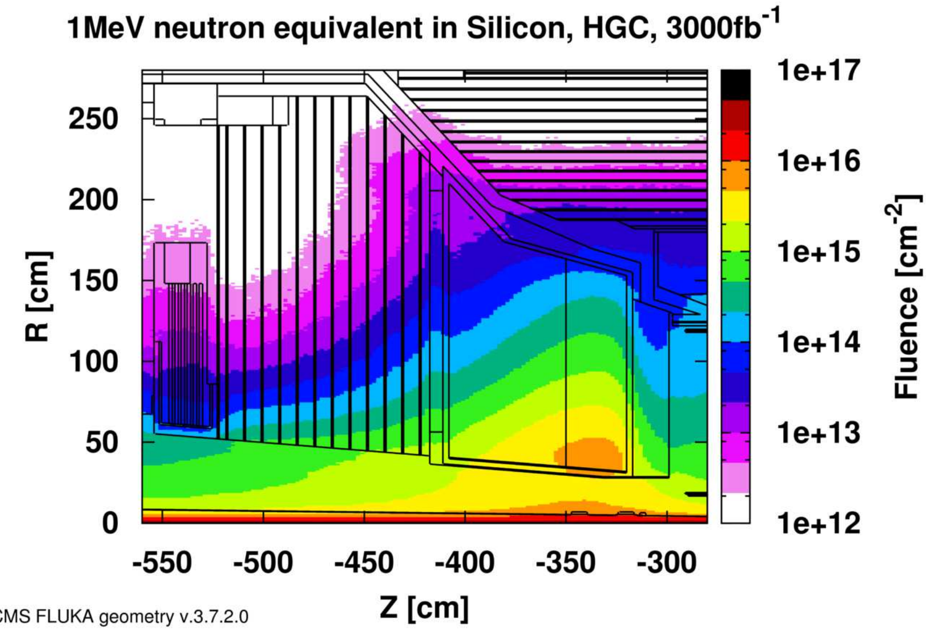
Time of arrival precision of Si sensors



CMS CR-2016/447

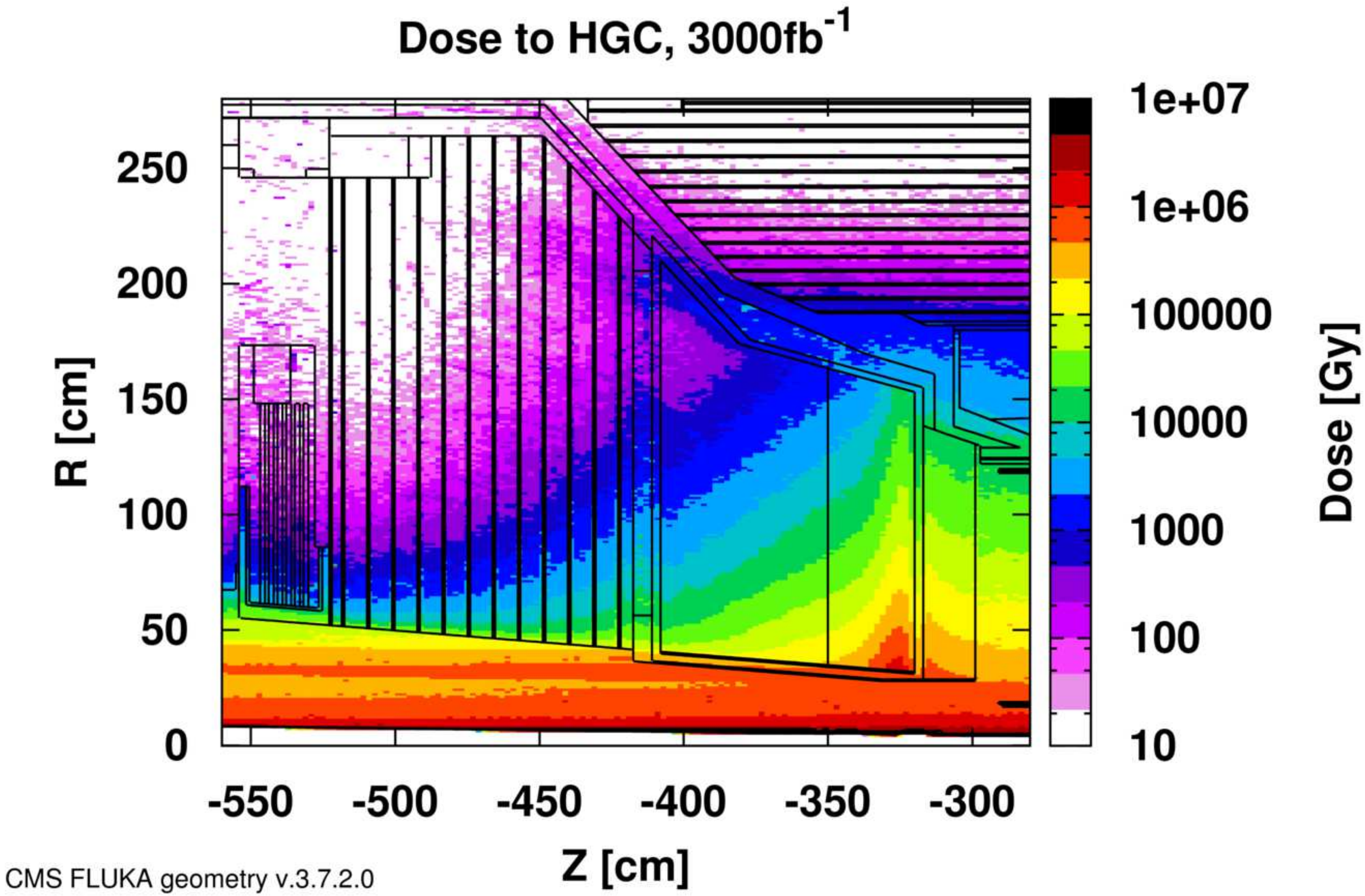
Sensor characteristics

- Thin sensors are required in high-dose regions to limit the leakage current
- Small sensors required to keep the capacitance, and thus the noise manageable
- Small sensors also reduces the occupancy, but increases the data volume



Sensor thickness (μm)	300	200	100
Maximum dose (MRad)	3	20	100
Maximum n fluence (cm^2)	6×10^{14}	2.5×10^{15}	10^{16}
Cell size (cm^2)	1.05	1.05	0.53
Cell capacitance (pF)	40	60	60
MIP charge, initial (e-)	22000	15000	9000
MIP charge, after 3000 fb^{-1}, (e-)	10000	6000	4000
MIP S/N (after 3000) (fb^{-1})	6.5	2.7	1.7

Total ionizing dose



Sensor charge collection degradation