Readout IC with 40 MSPS in-pixel ADC for future vertex detector upgrades of Large Hadron Collider

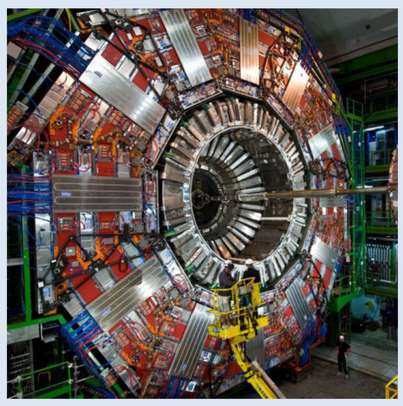
Benjamin Parpillon, Amit Trivedi, Farah Fahim

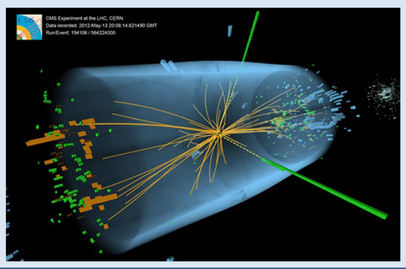
Fermi National Accelerator Laboratory, Batavia, Illinois, USA

Fermilab

APPLICATION

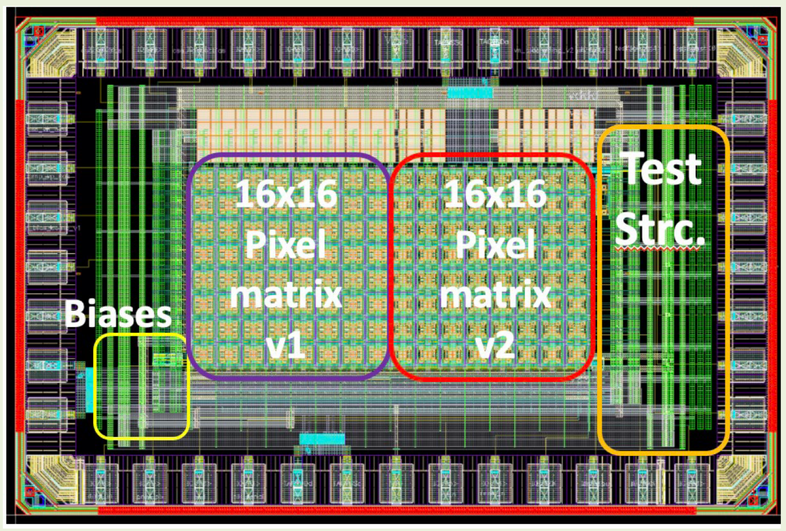
Phase III upgrade for HL-LHC CMS





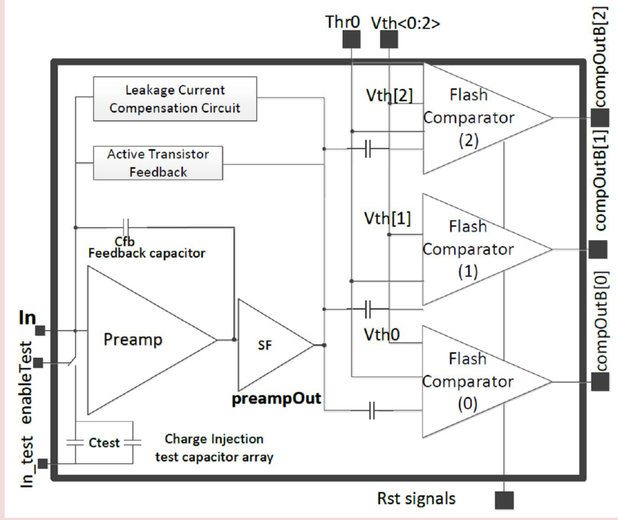
PROTOTYPE OVERVIEW

Pixelated Particle Detector

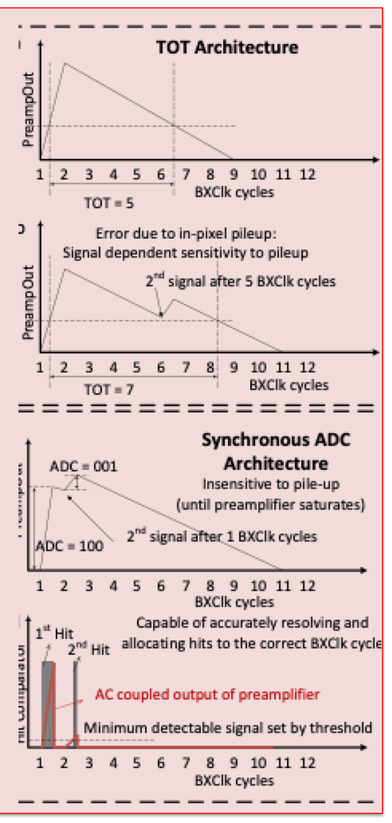


- The pixel prototype is designed in TSMC 28nm.
- It contains an array of 16x32 pixel of 25µm x 25µm each
- The ASIC is 1.5mm^2

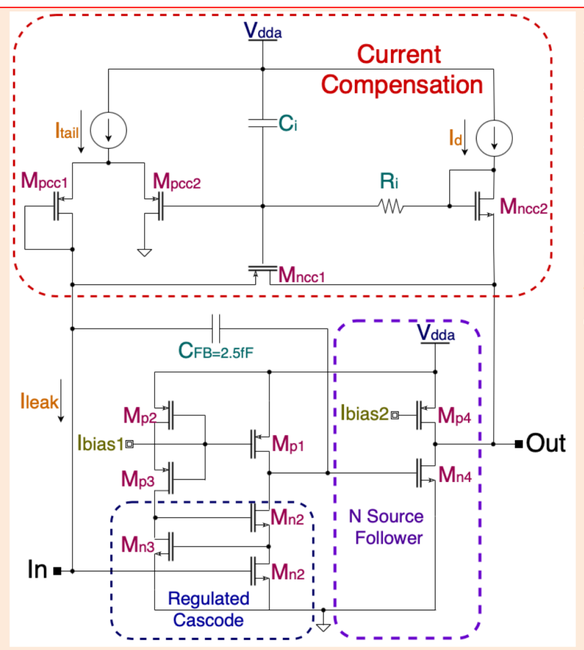
PIXEL ARCHITECTURE



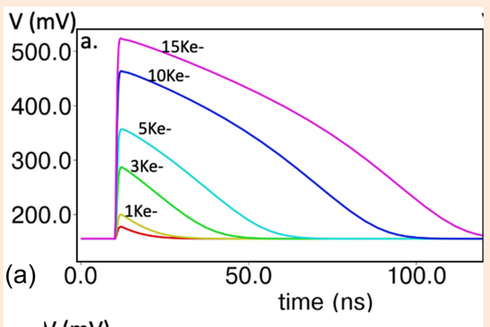
- → Low noise, low power Preamplifier
- → Leakage Current Compensation
- → AC coupled 40MSPS in-pixel 2-bit Flash ADC
- → Synchronous Auto-Zero comparators

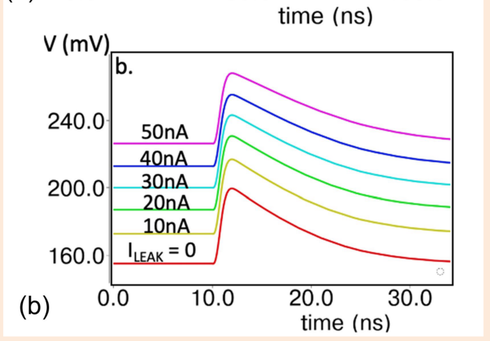


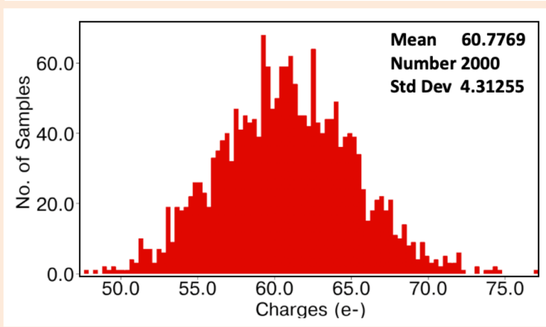
PREAMPLIFIER



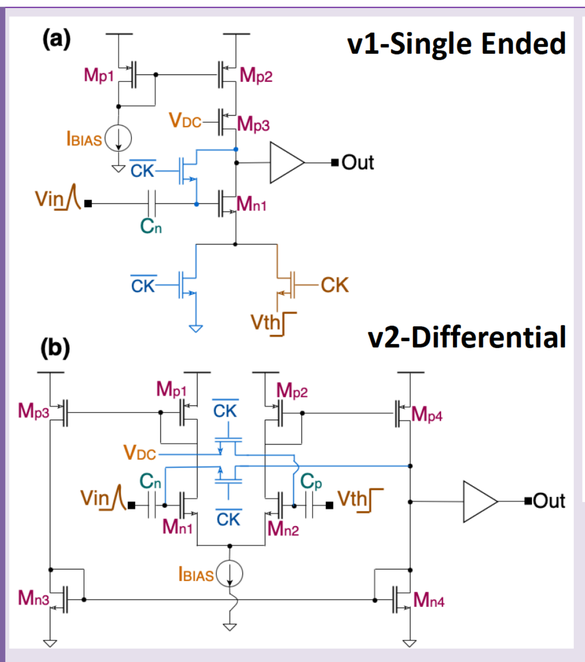
- Dynamic range 64aC – 2.1fC
- Equivalent noise charge (ENC) 61e-
- Power ~3uW
- Regulated Cascode core amplifier design
- Active transistor feedback resistor (Mncc1)
  - → Large signals behaves as a constant current source
  - → Small signals R_F = 1/gm
- Novel Leakage current compensation up to 50nA. Uses a differential amplifier Mpcc1 and Mpcc2 with a tail current greater than the sum of detector leakage current and the bias current of Mncc2 (Id)

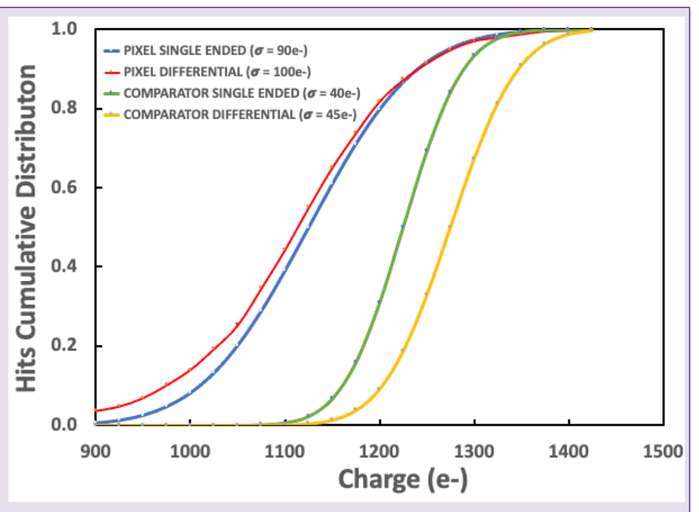






TWO 40MSPS COMPARATORS





Result	v1	v2	unit
Power	0.5	1	μW
Threshold Dispersion	40	45	e-
Area	17.5	30	μm^2
Auto-zero	yes	yes	
Dead time	250	0	ps

The equivalent charge dispersion (ECD) is extracted by performing a combination of hundred noise transient runs, and a hundred MC runs on both pixel variants while sweeping the signal amplitude from 900e- to 1,500e- with the comparator threshold set to 1,000e-. The noise transient simulation extracts the total ENC of each pixel variant, including the flicker and thermal noise from the devices in the preamplifier and the flash ADC, as well as the kickback noise contribution due to switching of the comparators. The MC simulation computes the total threshold dispersions Q_{TH} of the two-pixel designs, including the mismatch contributions. A total of 10,000 runs were completed for each of the signal amplitude sweeps.

SUMMARY

Performance

Improved state-of-the-art compared to RD53B designs (CROKv1[1] and ITKv1[2])

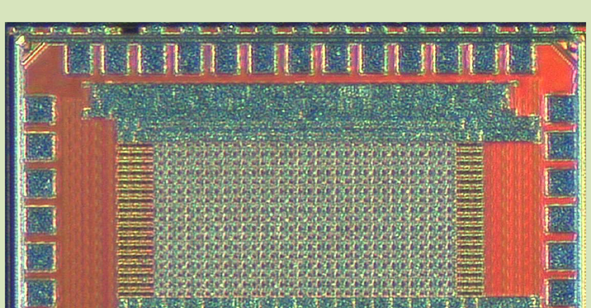
- 4x improved granularity
- 2.5x power reduction
- 2.5x improvement in threshold detection
- Insensitive to pile-up

Result	v1	v2	unit	comments
Power	3.7	5.2	μW	Per pixel
Total Equivalent Charge Dispersion	90	100	e-	Includes: • ENC • Qth • Baseline fluctuation • kickback
Min Threshold	430	475	e-	4.75 σ
Analog Area	169	211	μm^2	

Reference:

[1] A. Papadopoulos and on the CMSTracker Group, "Analog performance of the crocv1 pixel readout chip for the cms phase-2 tracker upgrade," Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 18, 2023.

[2] E. A. Stefano Terzo, Maurizio Boscardin, "Novel 3d pixel sensors for the upgrade of the atlas inner tracker," Frontiers in Physics, vol. 9, 2021.

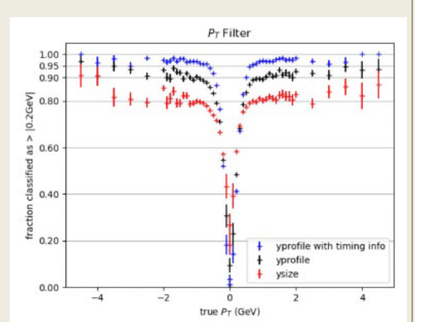


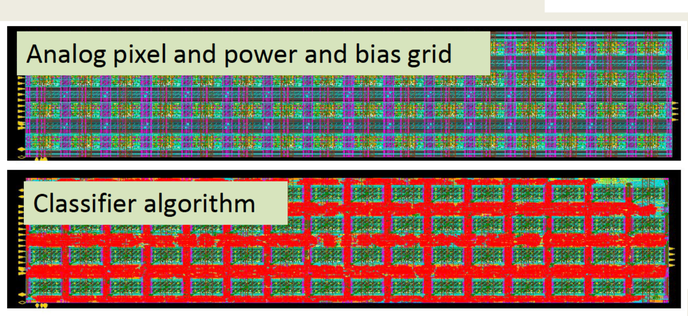
Chip fabricated and test setup is starting

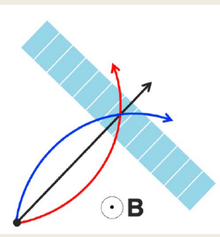
FUTURE WORK

Smart Pixel Implementation

Future Prototype design will implement a DNN classifier in the matrix to reduce data at source by rejecting low momentum events







Track correlates with momentum

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Contact: bparpill@fnal.gov, farah@fnal.gov