Analog front-end characterization of the RD53A chip

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on behalf of the CMS collaboration

CMS needs

CMS inner tracker requirements for the phase-2 upgrade:

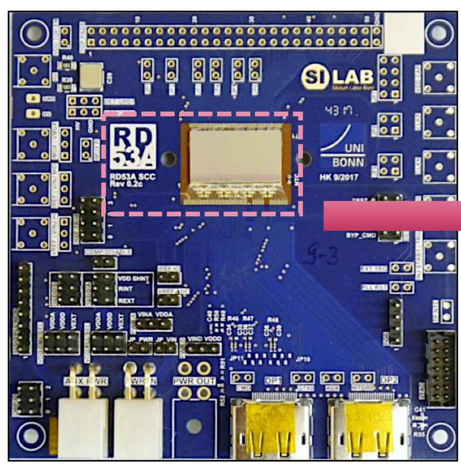
- Operation at low threshold: 1000 e^- / 1200 e^-
- Noise occupancy below 10^{-6}
- 1% Dead time in layer 1 ⟶ fast discharge of the preamplifier (3000 e^-/25 ns)
- Radiation hardness up to 1.2 Grad + operation with leakage current

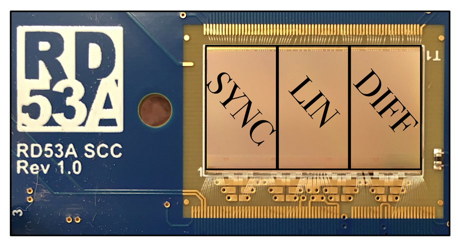
New pixel chip

- Developed by RD53 collaboration for ATLAS and CMS phase-2 upgrades
- TSMC 65 nm CMOS, 50x50 μm² pixel pitch
- **RD53A**: Large scale demonstrator chip, containing design variations
  ⟶ **3 different analog front-end designs**
- **CMS needed to chose ONE front end**
  ⟶ thorough review and comparison of the 3 designs
  ⟶ dedicated evaluation program against CMS requirements

One pixel chip, three front ends

RD53A chip, wire bonded on a single chip test card (Scale 1:1)



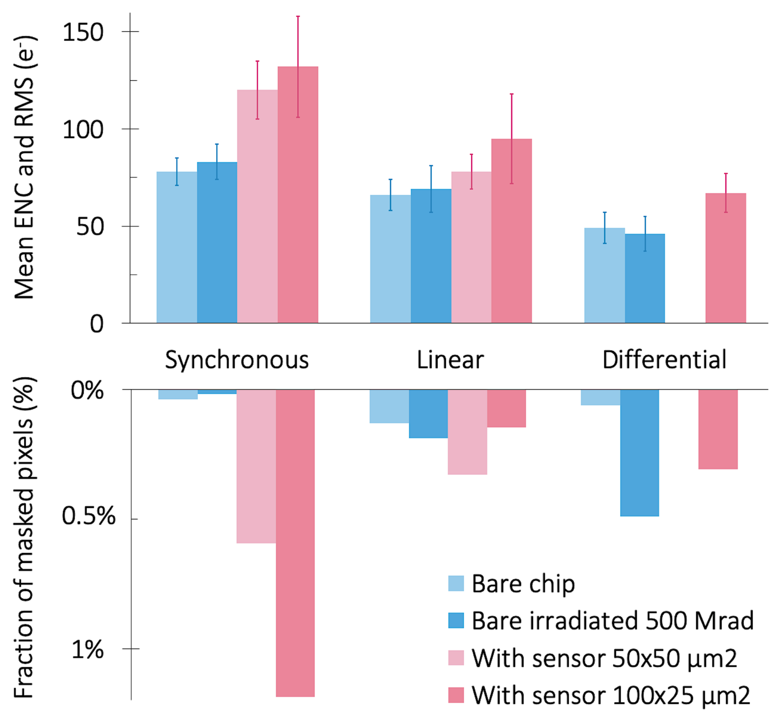


RD53A divided in 3 parts:

	SYNCHRONOUS	LINEAR	DIFFERENTIAL
Charge sensitive amplifier with	Krummenacher feedback	Krummenacher feedback	Fast feedback + leakage current compensation
Comparator	Synchronous to the clock	Asynchronous	Asynchronous + differential precomparator
Threshold trimming	Auto-zeroing	4-bits (5-bits in the new version)	5-bits
Time Over Threshold counting	20 – 300 MHz Fast TOT: local clock	40 MHz (80 MHz in the final chip)	40 MHz (80 MHz in the final chip)

Key measurements

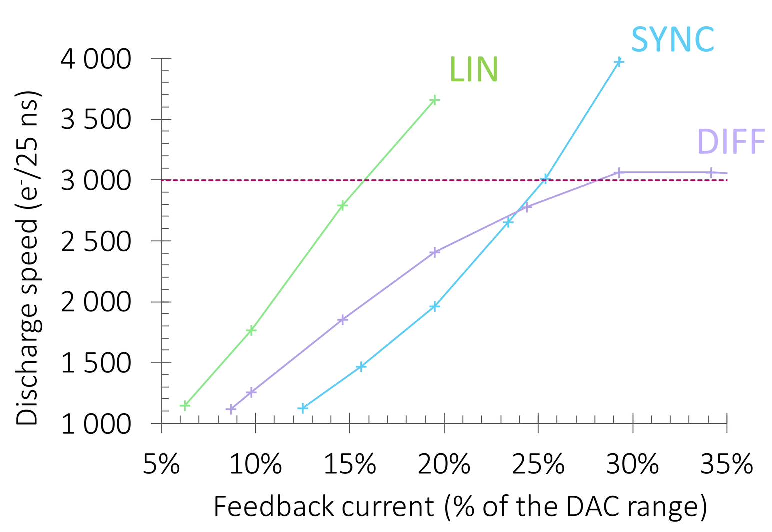
1 Equivalent noise charge



method: A million triggers is sent, with no charge injection and each pixel having at least one hit is masked. The equivalent noise charge (ENC) is then evaluated for remaining pixels from the slope of the S-curves.

- Assemblies noisier than bare chips
- Noise: SYNC > LIN > DIFF
- **SYNC + sensor ⟶ larger noise**

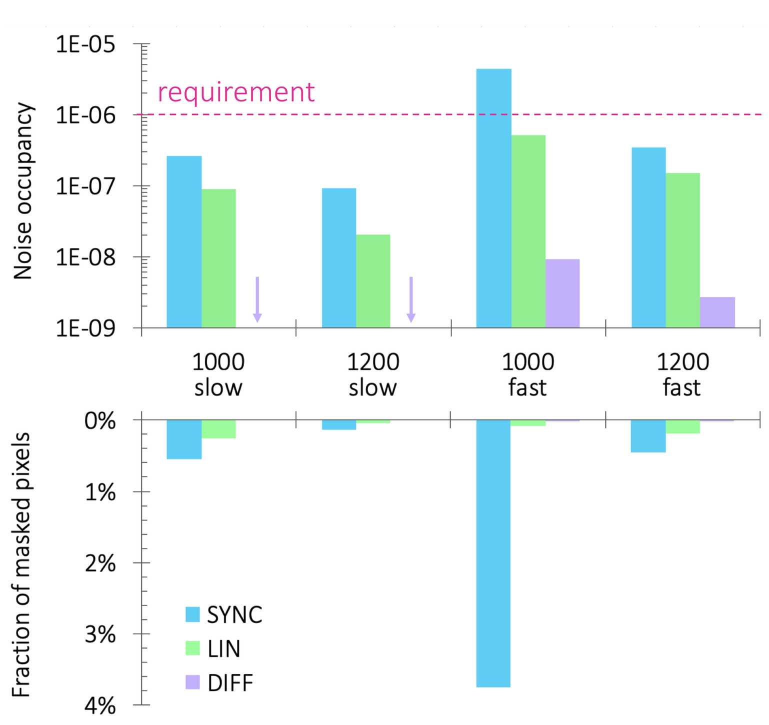
2 Discharge speed



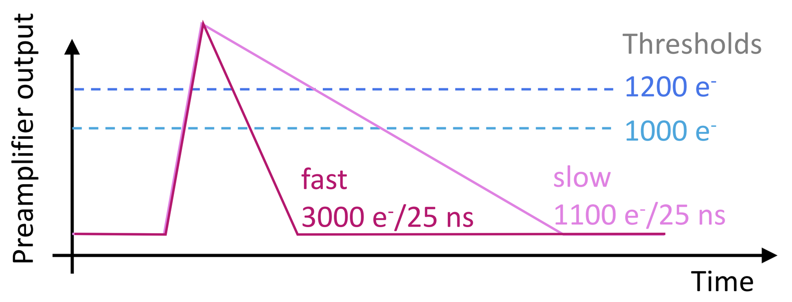
method: The discharge speed of the preamplifier can be modified by varying the feedback current. It is evaluated by injecting 6000 e^- to each pixel and then dividing this charge by the mean time over threshold (unit: e^-/ns).

- Target fast discharge (3000 e^- / 25 ns)
  ⟶ reached by all front ends
- LIN and SYNC can discharge also faster
- **DIFF feedback current DAC saturates**

3 Noise occupancy

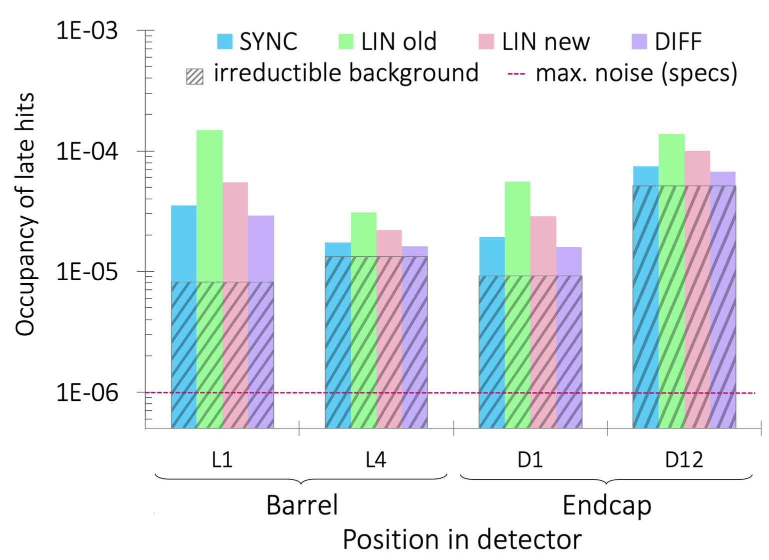


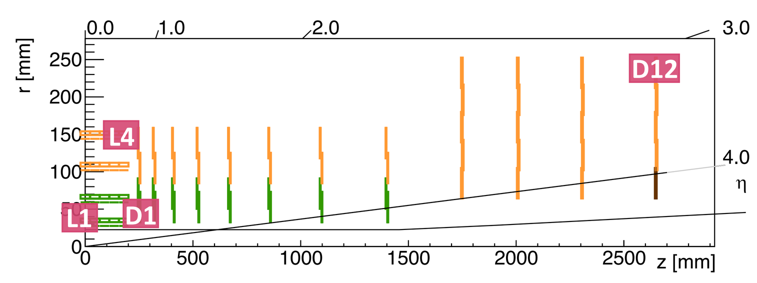
method: A million triggers is sent, with no charge injection and all pixels with 100 hits or more are masked. Then another million triggers is send, to estimate the noise occupancy after masking.



- Noise occupancy: SYNC > LIN ≫ DIFF
- Low threshold & fast discharge
  ⟶ **critical for SYNC FE**

4 Late hit analysis





method: The time response of the front end is measured by injecting different charges with different time delays and checking whether the hit was found in a given time window. The occupancy of late hits is then obtained by combining the time response with time of arrival of particles from simulation.

- Occupancy of late hits between 10^{-4} and 10^{-5} for all positions in the detector
- Late hits dominating over noise hits
- **New design of LIN FE**
  ⟶ greatly improved detection speed

CMS choice: Linear front end

Synchronous FE

✓ Very fast FE, no trimming needed
✗ Higher noise occupancy
✗ Origin of the noise not well understood

Differential FE

✓ Excellent noise performance
✗ Saturation of the fast discharge current DAC
(✗ Limited radiation hardness) [*]

Linear FE — CMS choice

✓ Well understood architecture
✓ Recommended as lowest risk option by the review
✓ Drawbacks addressed through design improvement

To know the full story ☺ [*]

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