



Development of Front-end ASIC for Silicon-strip Detectors of J-PARC Muon g-2/EDM Experiment

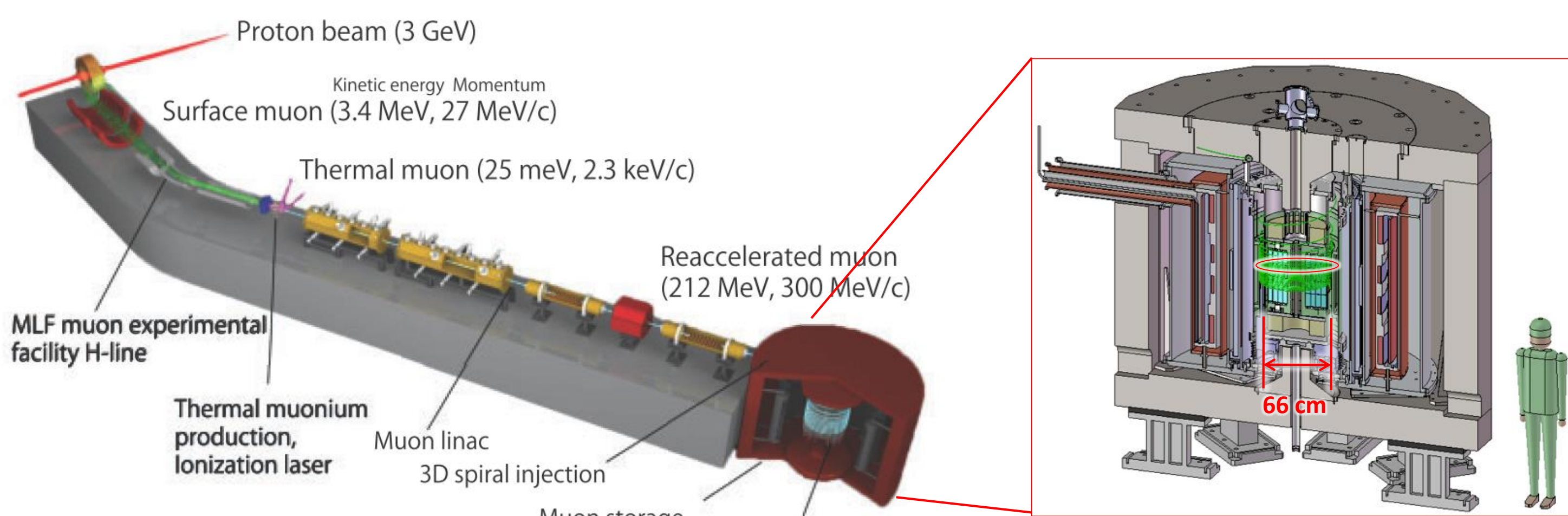
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Abstract

We are developing a front-end ASIC for silicon-strip detectors of the J-PARC muon g-2/EDM (E34) experiment, which aims to measure the muon anomalous magnetic moment (g-2) and electric dipole moment (EDM) to search for new physics beyond the Standard Model. Since the timing of the muon decay is key information in the experiment, the front-end ASIC is required to tolerate a high hit rate of 1.4 MHz per strip and to be stable to the change of hit rate by a factor of 1/150. To accommodate the pulsed muon beam at J-PARC, the ASIC has large buffer memory to save the binary hit information. The prototype ASIC “Slit128B” was fabricated using the Silterra 180-nm CMOS process. We report the performance of Slit128B chip and future prospect.

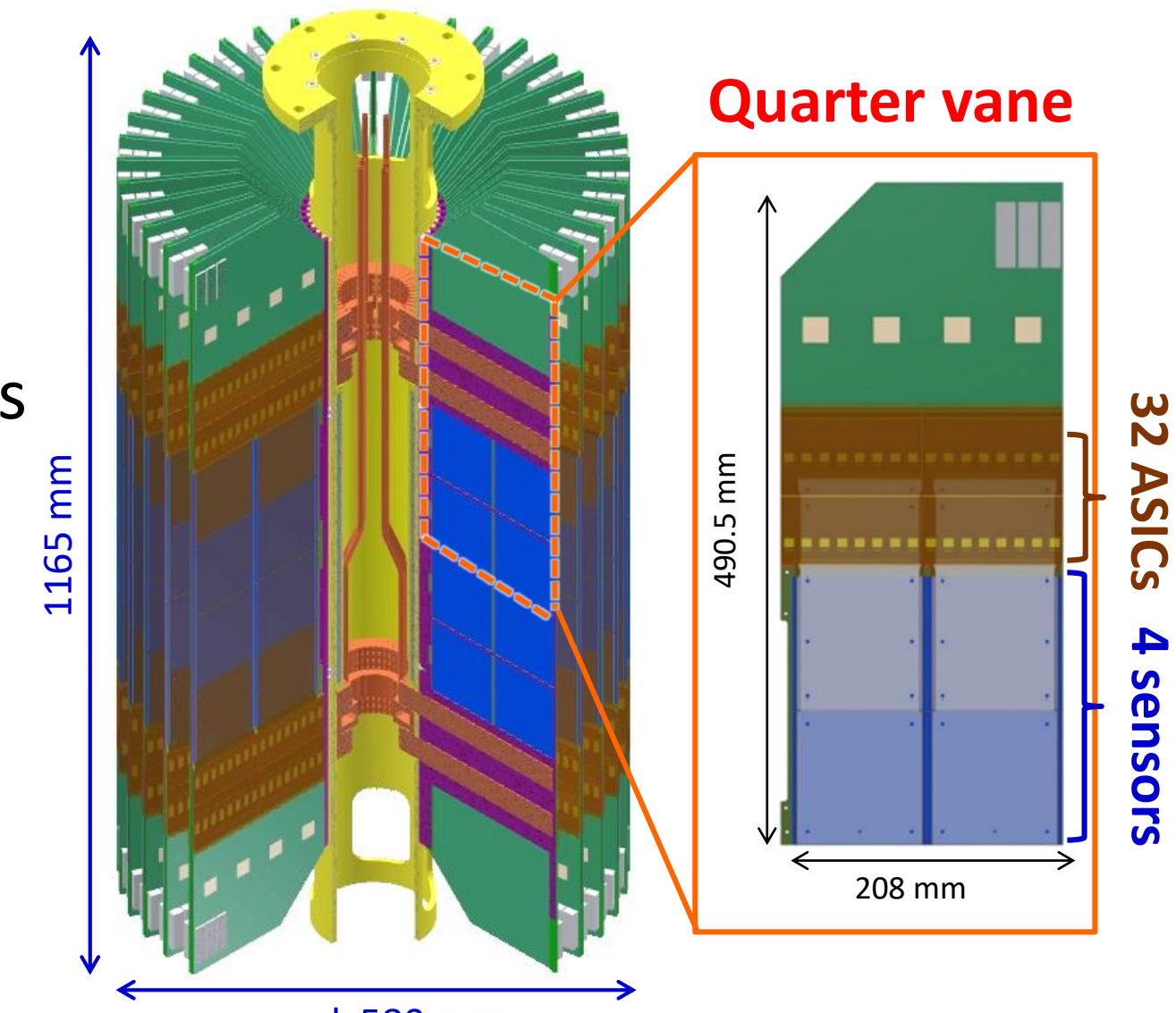
1. J-PARC muon g-2/EDM experiment



- There is 3.8 σ discrepancy between the measurement of muon g-2 by BNL E821 [1] and the SM prediction.
- J-PARC muon g-2/EDM experiment [2] aims to measure g-2 with a precision of 0.1 ppm and search for EDM with a sensitivity of 10^{-21} e \cdot cm with a different method from BNL E821 and Fermilab E989 experiment.
 - Reaccelerated thermal muon beam with no strong focusing
 - MRI-type storage magnet with a good injection efficiency & high uniformity of local B-field
 - Full-tracking detector with large acceptance**

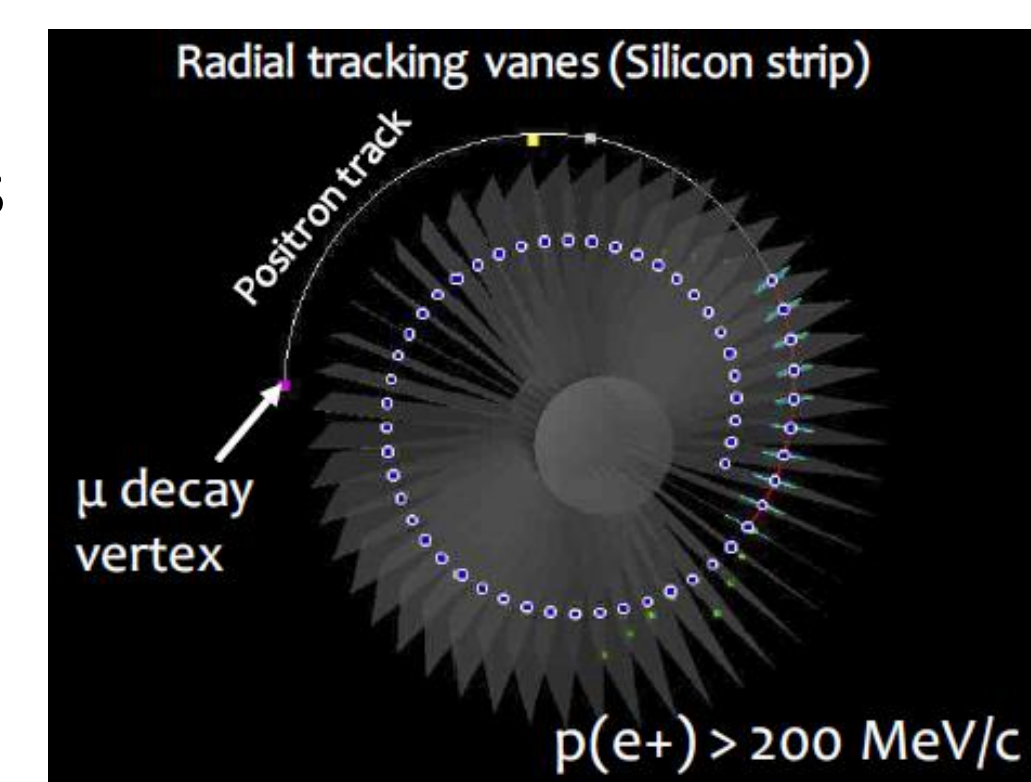
2. Silicon-strip Detector

- Positron tracks from muon decays are measured by silicon-strip detector. It consists of 40 vanes, and one vane consists of 4 quarter-vanes. Each quarter-vane has 4 single-sided silicon strip sensors. Two-dimensional position is measured by the two layers of the silicon strip sensors.
 - 640 sensors
 - 5120 ASICs (=655,360 channels)



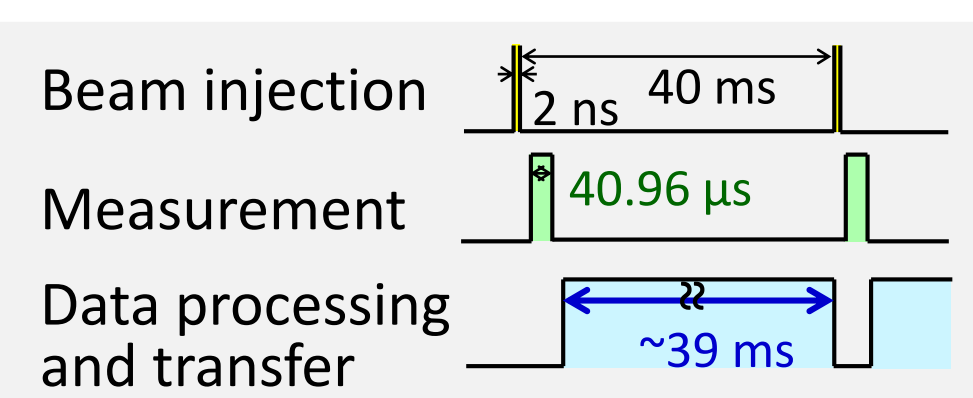
Requirements to detector

- High tracking efficiency for 100-300 MeV positrons
 - At most 30 muon decays per 5 ns
 - Event rate : 1.4 MHz per strip (max.)
- Stability to hit rate changes
 - Event rate : from 1.4 MHz to 10 kHz per strip.
- Operation in 3T magnetic field and vacuum and no contamination of EM field to the muon storage region.



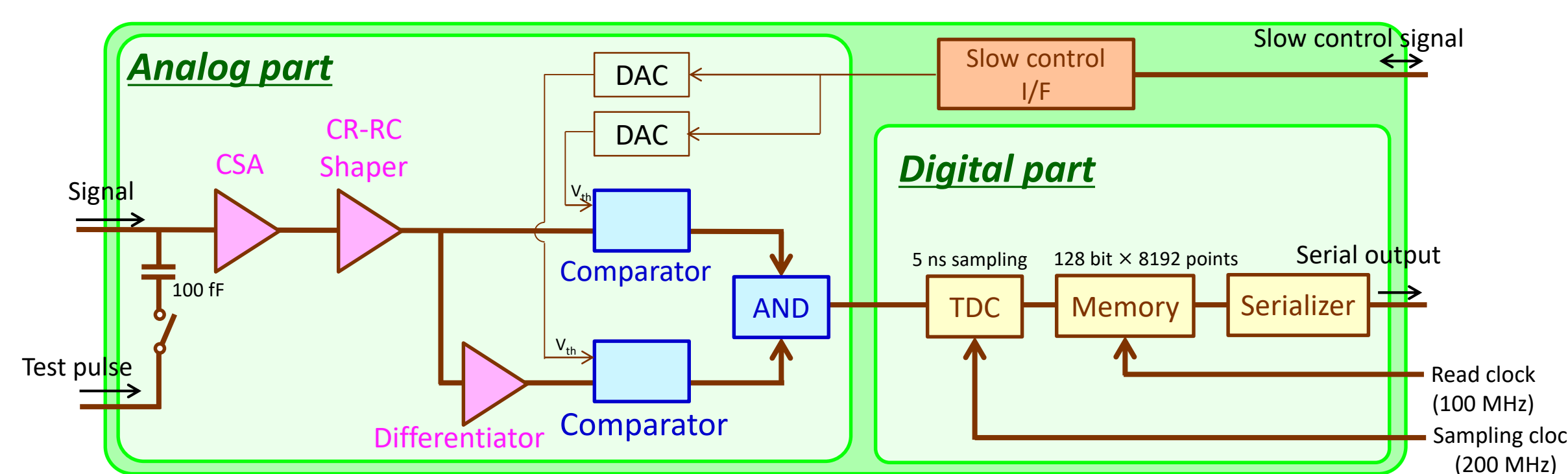
3. Prototype Front-end ASIC “Slit128B”

- Timing stability is important for the measurement of the muon g-2.
 - Fast response to tolerate a high hit rate**
- Readout sequence is designed for pulsed muon beam at J-PARC.
 - Binary readout with 5 ns time stump and larger memory buffer**, in which the data with a period of 40.96 μ s can be stored.



History of development of ASIC “Slit”

- 2012 **SlitA** (16ch, analog) : 1st prototype [4].
- 2013 **SlitA2013** (64ch, analog) : the pulse width was improved [5]. (UMC CMOS 250-nm \rightarrow Silterra CMOS 180-nm)
- 2015 **Slit128A** (128ch, analog+digital) : full-scale prototype with analog and digital part [6].
- 2017 **Slit2017TEG** (64ch, analog) : time-walk was improved by differentiator [7].
- 2018 **Slit128B** (128ch, analog+digital) : **report in this poster**



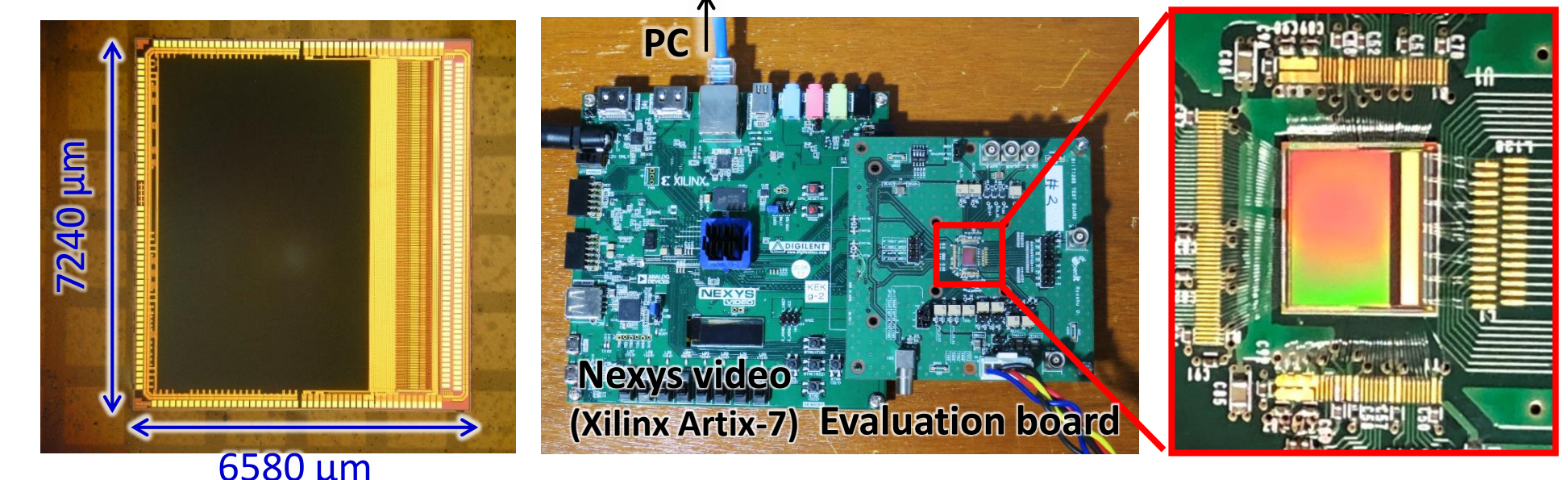
Requirements to ASIC

- Peaking time < 50 ns
- Pulse width < 100 ns
- Dynamic range > 4 MIP (1 MIP = 24,000e)
- Noise : ENC < 1600 e @C_{det} = 30 pF
- Time walk < 1 ns
- Power consumption : 5 mW/ch

- A full-scale prototype ASIC “Slit128B” was designed and fabricated.

- Slit128B was mounted on an evaluation board by wire-bonding with 25- μ m aluminum wire. The evaluation board was connected with commercial FPGA board (Nexys video) through FMC connector.

Photo of Slit128B and its evaluation board

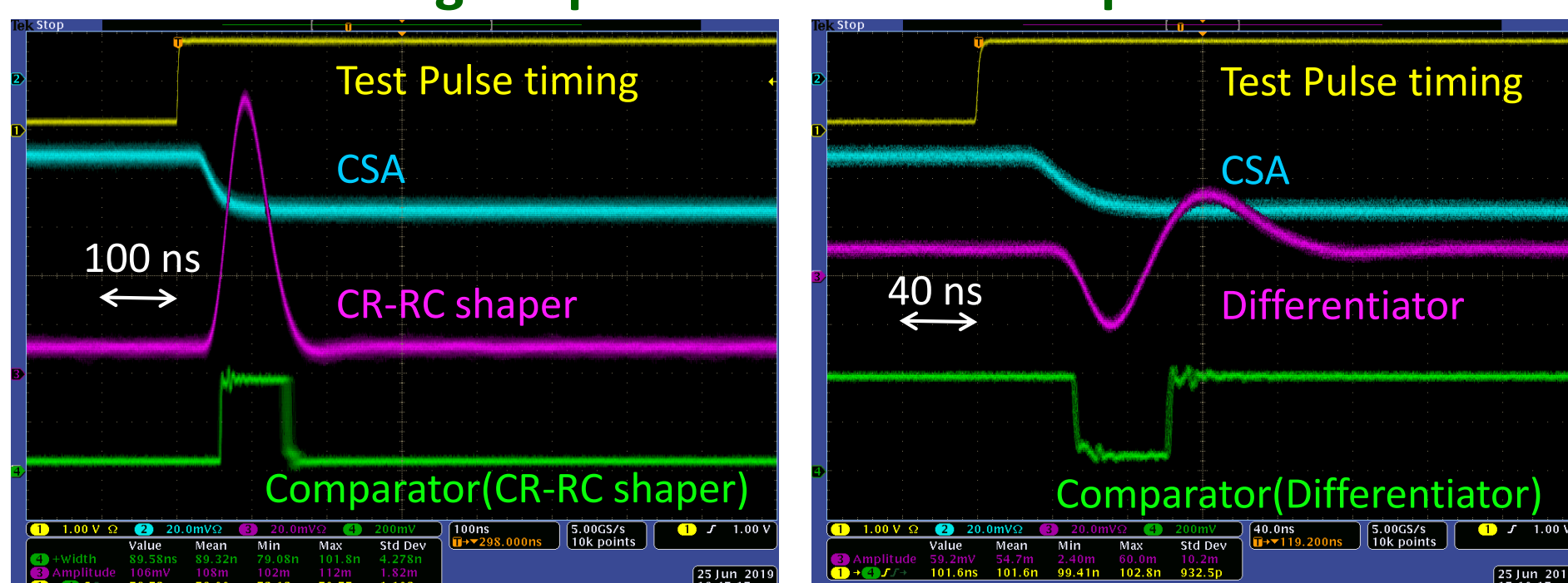


4. Performance Test

Peaking time and pulse width

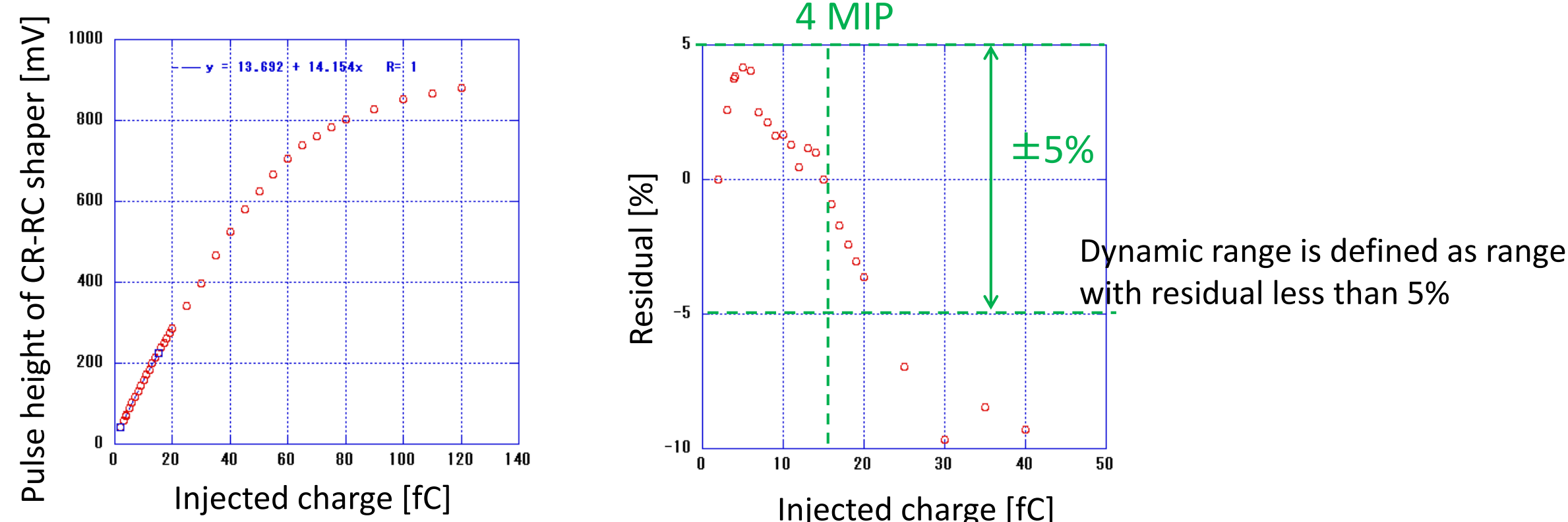
- Analog outputs from CSA, CR-RC shaper, differentiator, and their comparators are observed through monitor lines.
- Peaking time is less than 50 ns and pulse width is less than 100 ns. 😊

Analog outputs with 1 MIP test pulse



Dynamic Range

- Dynamic range is derived to be more than 5 MIP from the pulse height of CR-RC-shaper as a function of injected charge. 😊

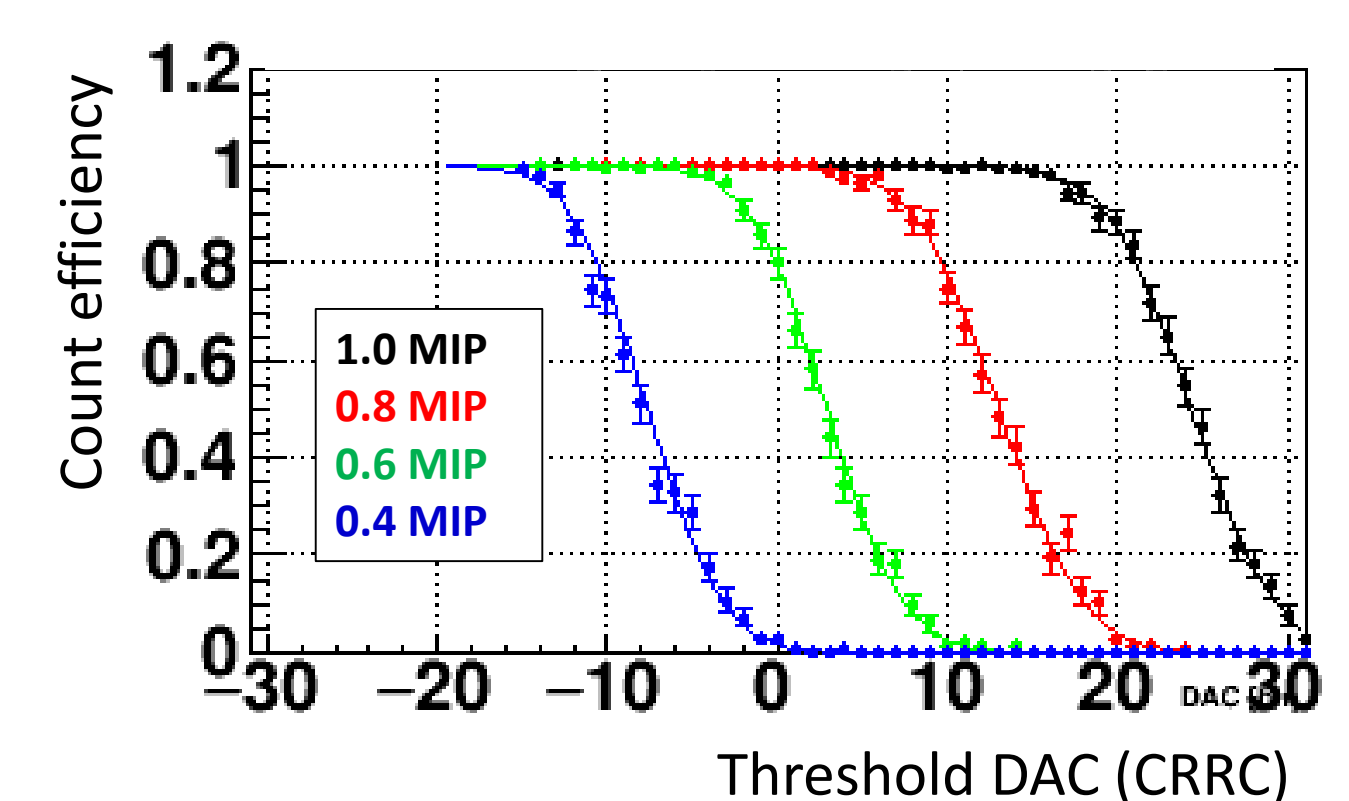


Power consumption

- Power consumption is estimated to be 0.44 W, which is less than the requirement (< 0.64W/chip). 😊

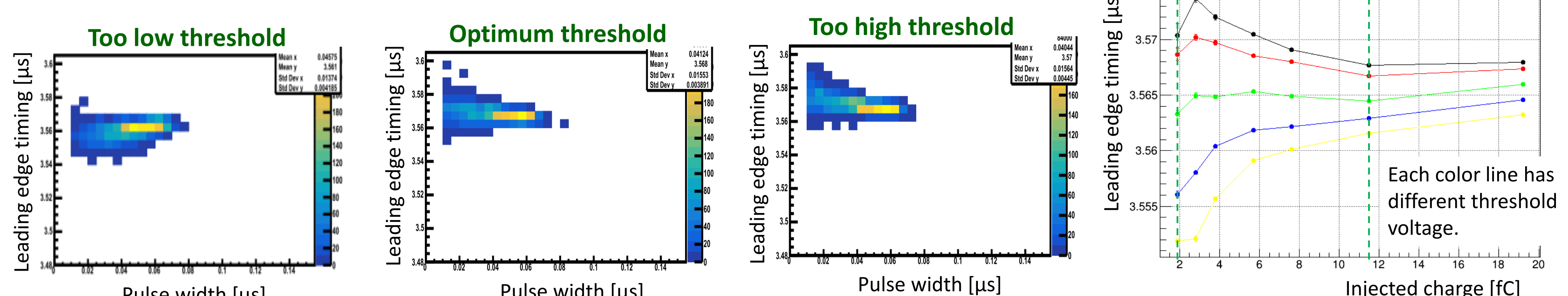
Noise

- “S-curve scan” is performed to estimate the noise.
 - A fixed amount of charge is injected, changing the threshold voltage of comparator. Response function is error function, which is step function smeared by noise.
- Noise is estimated to be 1746 ± 57 electrons with a detector capacitance of 33 pF. 😊



Time-walk

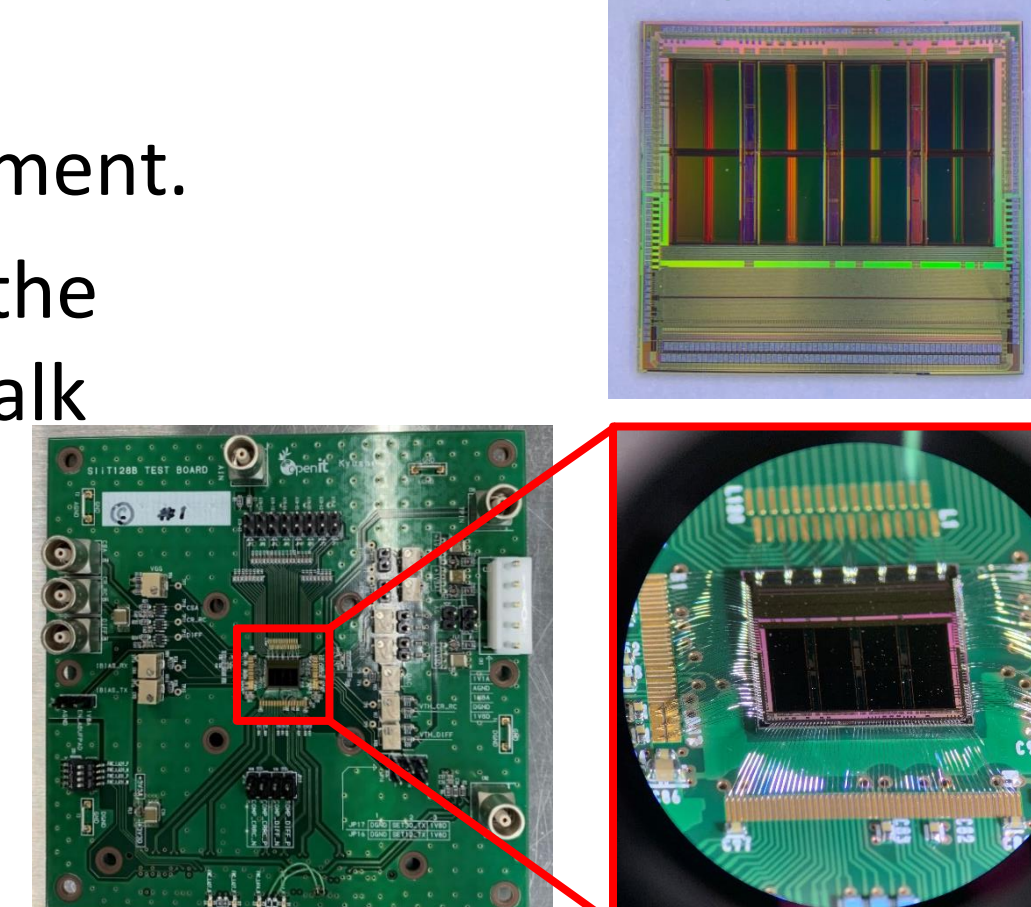
- Time-walk effect is reduced by adjusting the threshold voltage for differential circuit.
- Time-walk is about 2 ns between 0.5 MIP and 3.0 MIP with the optimum threshold voltage. 😊
 - It gets close to the requirement (<1 ns).



5. Summary and Prospect

- We are developing Front-end ASIC “Slit” for J-PARC muon g-2/EDM experiment.
- Prototype ASIC “Slit128B” has been fabricated and we confirmed most of the requirements are met. A little more improvement especially about time-walk will be done by minor optimization of the circuit design.
- Based on the result of Slit128B, we designed and fabricated next version of the ASIC “Slit128C”. The performance test of Slit128C is starting.
- The production version of the ASIC will be fabricated next JFY.

Slit128C



References

[1] G.W. Bennett et al., “Final report of the E821 muon anomalous magnetic moment measurement at BNL”, PRD 73, 072003 (2006)

[2] M. Abe et al., “A new approach for measuring the muon anomalous magnetic moment and electric dipole moment”, PTEP 2019, 053C02 (2019)

[3] T. Aoyagi et al., “Development of a silicon strip detector with high rate capability for pulsed beams”, arXiv:1910.13087, submitted to JINST.

[4] K. Ueno, et al., “Fast Readout ASIC for Si-Strip Detector in the J-PARC Muon g-2/EDM Experiment and Other Related Applications”, IEEE NSS/MIC Conference (2013), NP02-220

[5] S. Shirabe, et al., “An Improved Fast Readout ASIC for Si-Strip Detector in the J-PARC muon g-2/EDM experiment and Other Related Applications”, IEEE NSS/MIC Conference (2014), N03-15.

[6] Y. Sato et al., “Performance of Front-end ASIC and its evaluation with Silicon Strip Sensor for J-PARC Muon g-2/EDM Experiment”, IEEE NSS/MIC Conference (2017), doi: 10.1109/NSSMIC.2017.8532754

[7] Y. Tsutsumi et al., “Prototype Front-end ASIC for Silicon-strip Detectors of J-PARC Muon g-2/EDM Experiment”, PoS(TWEP2018)090