Irradiation test on FD-SOI Readout ASIC of Pair-monitor for ILC

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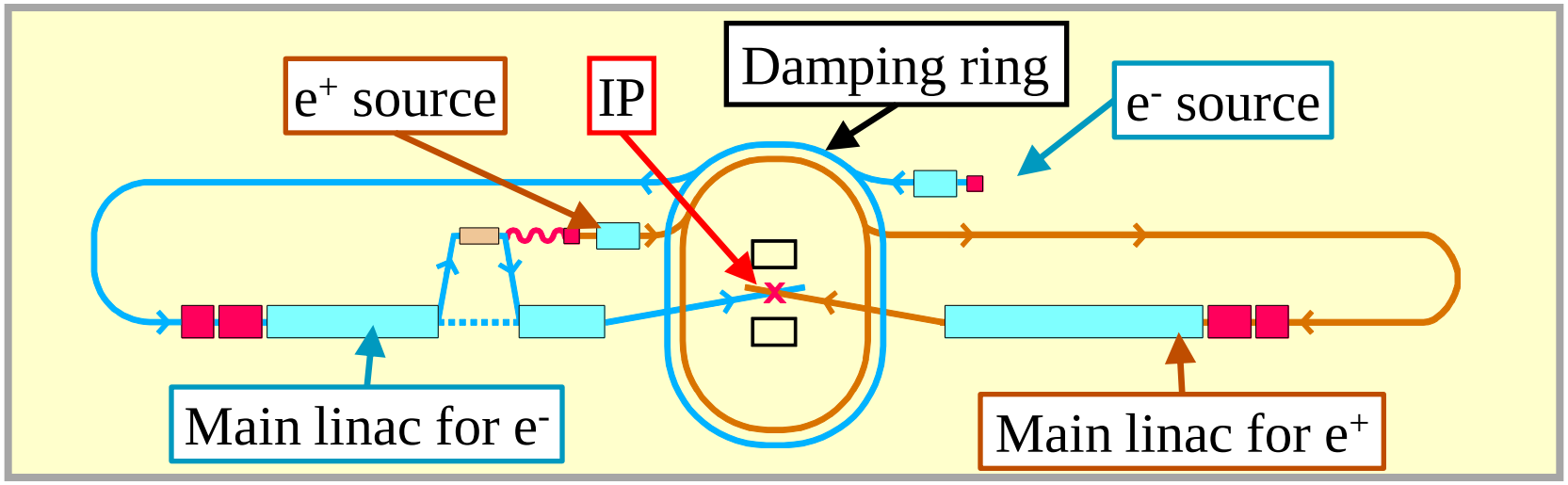
International Linear Collider

ILC is a next generation of the high-energy e^+ e^- collider.



Purposes

- Study higgs sector
- Search new physics

Parameters

- CM energy : 500 GeV (upgrade to 1 TeV)
- Integrated luminosity (4 years) : 500 fb-1
- Beam size

$(\sigma_x,\sigma_y,\sigma_z) = (639\ \text{nm}, 5.7\ \text{nm}, 300\ \mu\text{m})$

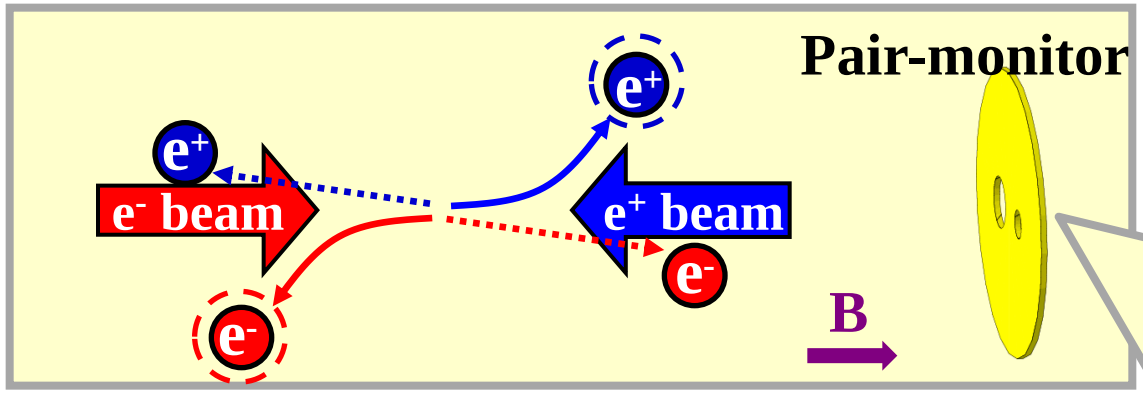
→ Beam Profile monitor is necessary to keep the high luminosity.

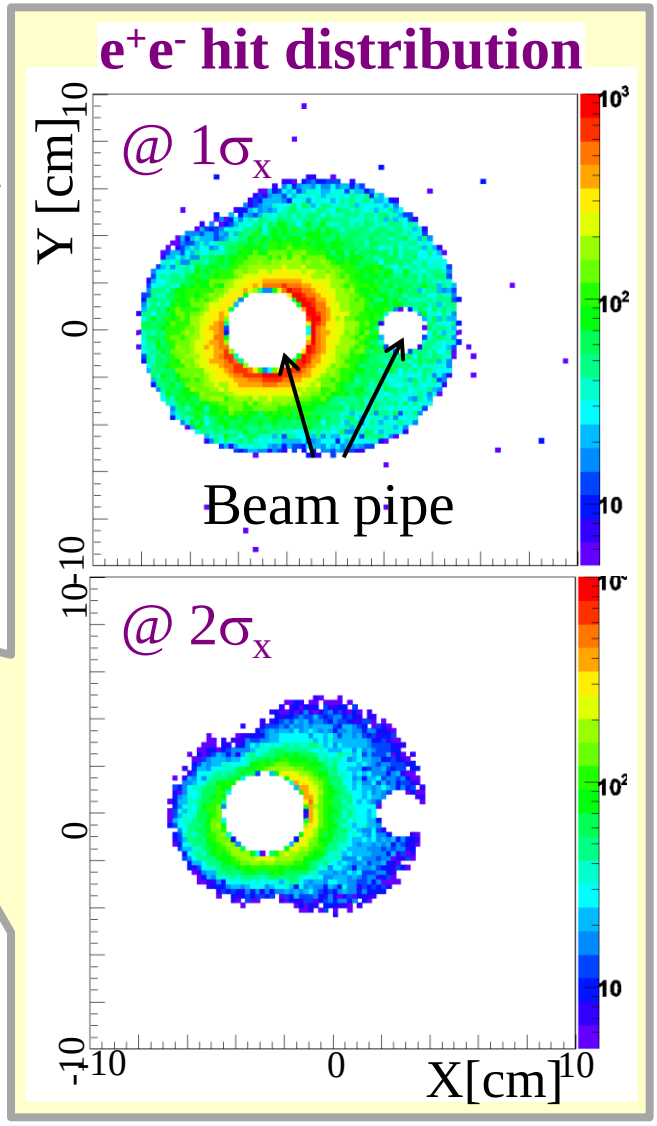
→ Pair-monitor

Pair-monitor

Pair-monitor is a silicon pixel detector to measure the beam profile at IP.

- The distribution of the pair B.G. is used.
  - The same charges with respect to the oncoming beam are scattered with large angle.
  - The scattered particles have information on beam shape.





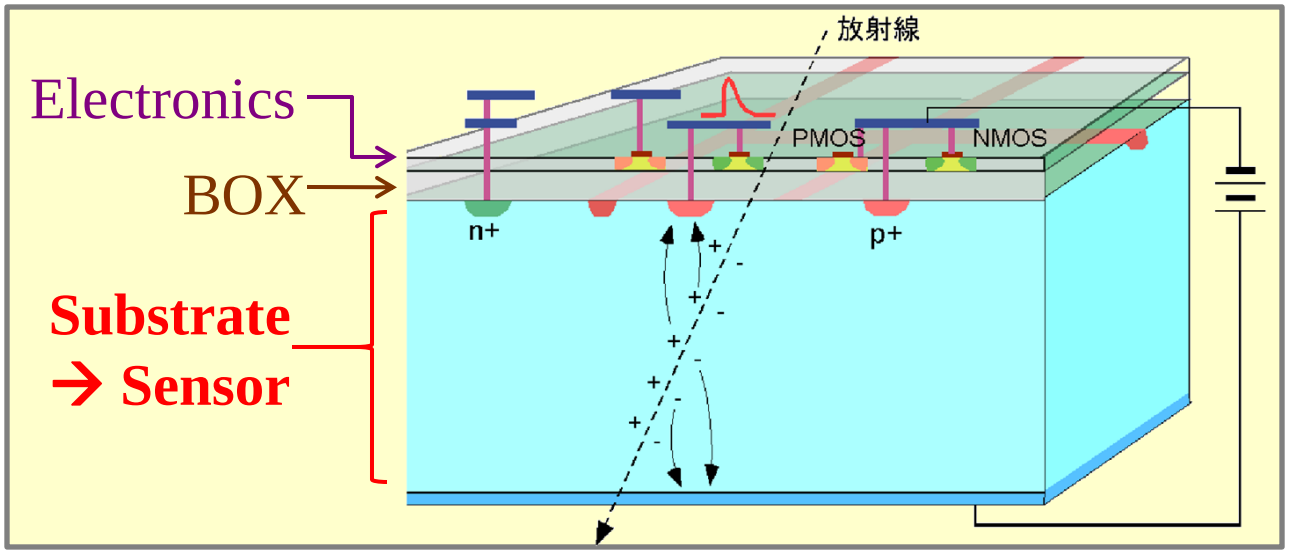
The beam size can be derived from the pair B.G. distribution.

Development of Pair-monitor with SOI technology

The pair-monitor is developed using the SOI technology.

SOI (Silicon On Insulator) pixel detector

- SOI pixel group at KEK is currently developing.
- The sensor and electronics are integrated in a SOI wafer.
  - Monolithic device
  - High speed
  - Low power
  - Thin device
  - Low material



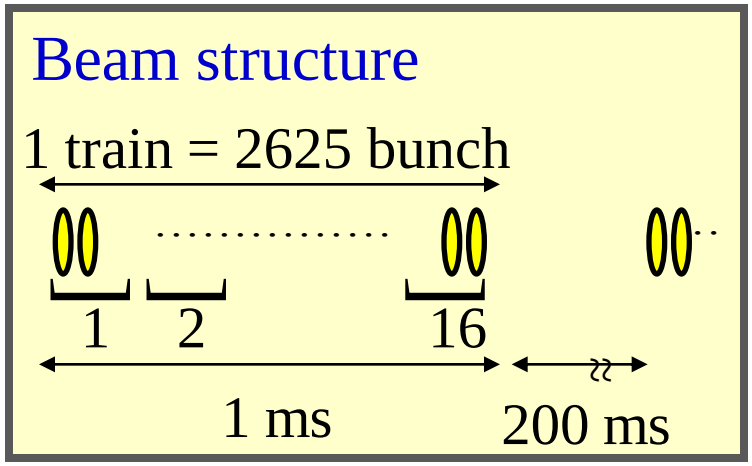
The prototype ASIC for the pair-monitor was fabricated via the MPW Run organized by the SOI pixel group.

- This prototype is not monolithic (Substrate is not a sensor).

Requirement to readout ASIC

Required performance

1. Time resolution : < 260 nsec
   (less than bunch space)
2. Noise level : < 1000 e
   (typical signal level : 15,000 e)
3. Radiation tolerance : > a few Mrad/year
4. Time-dependent measurement
   – Measure the pixel hit count in 16 time slice per train,
   and hit counts are read out during the inter-train gap of 200 ms.

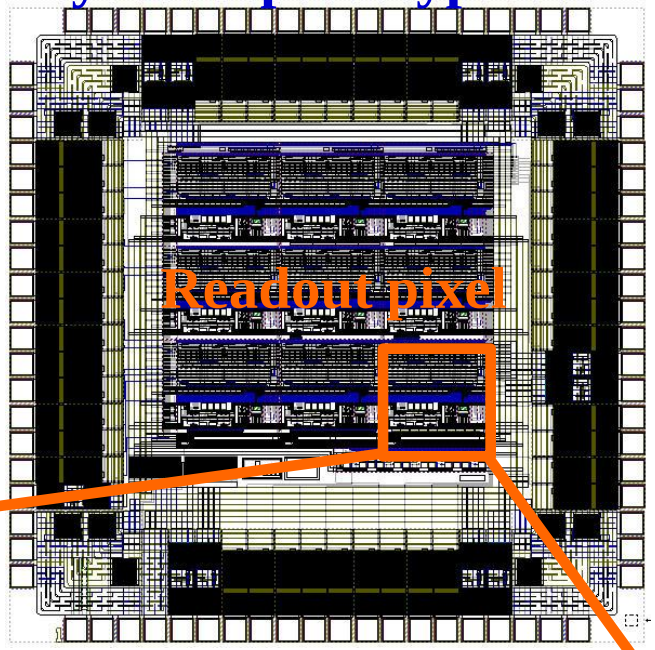


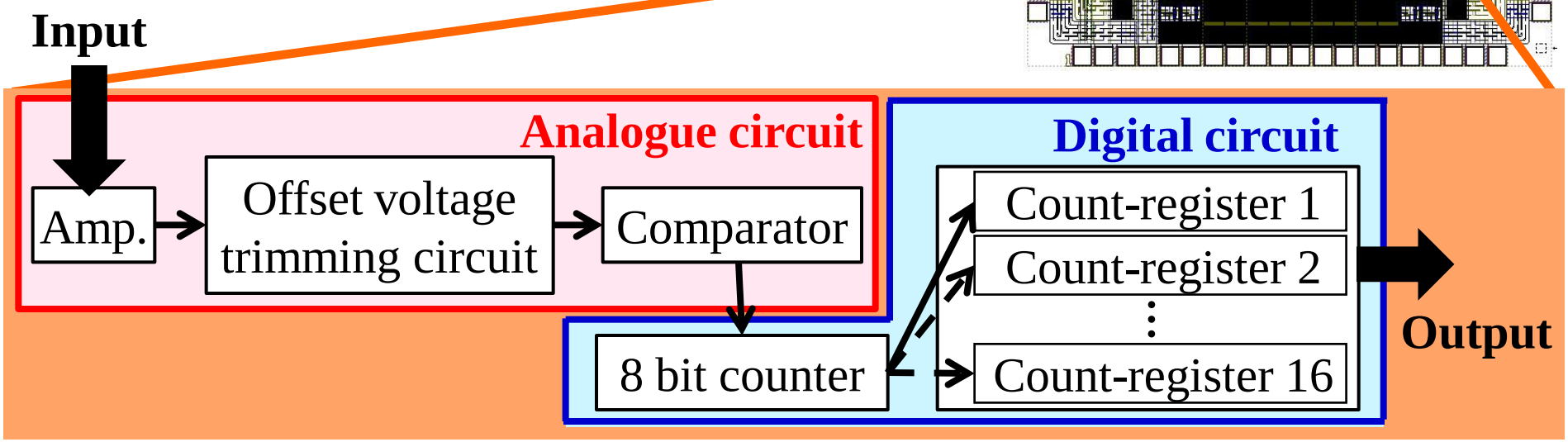
The prototype readout ASIC was designed to satisfy these requirements.

Prototype readout ASIC

- Process : FD-SOI CMOS 0.20 μm
- Chip size : 2.5 x 2.5 mm^2
- # of pixels : 9 (3x3)
- Pixel size : 390 x 350 μm^2
- Each pixel has different detector capacitance.

Layout of prototype ASIC

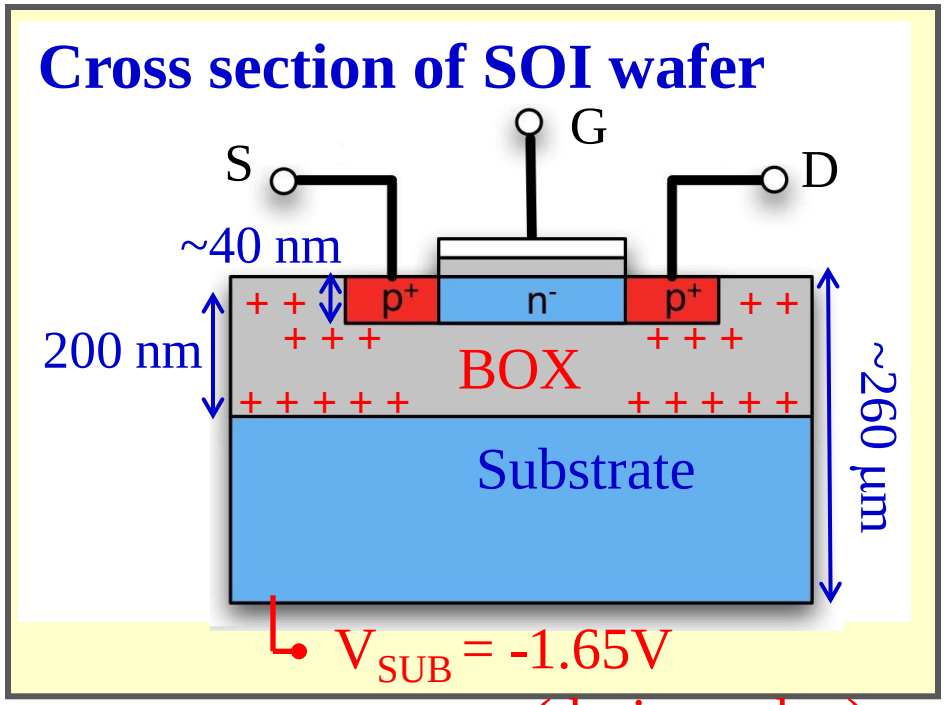




Irradiation test

Irradiation test was performed to test the radiation tolerance and observe the radiation effect.

- X-ray generator : Rigaku FR-D
  - Target : Cu (~ 8 keV photon)
- Doses : up to 2 Mrad



Radiation effect

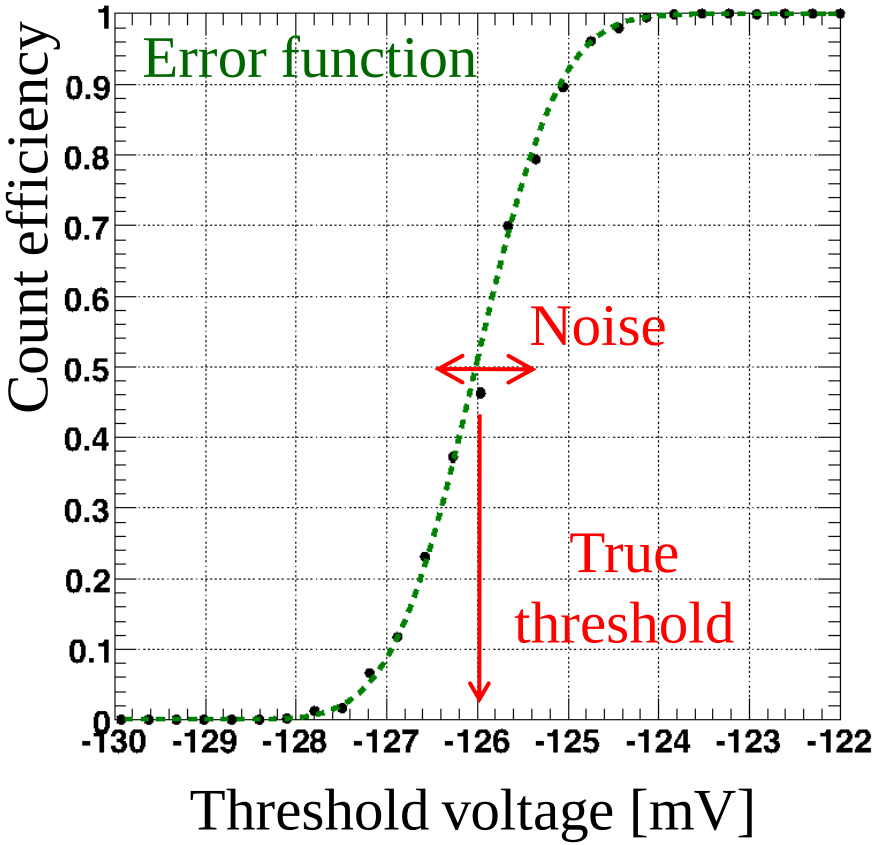
- **Single event effect (SEE)**
  - Caused by single energetic particle.

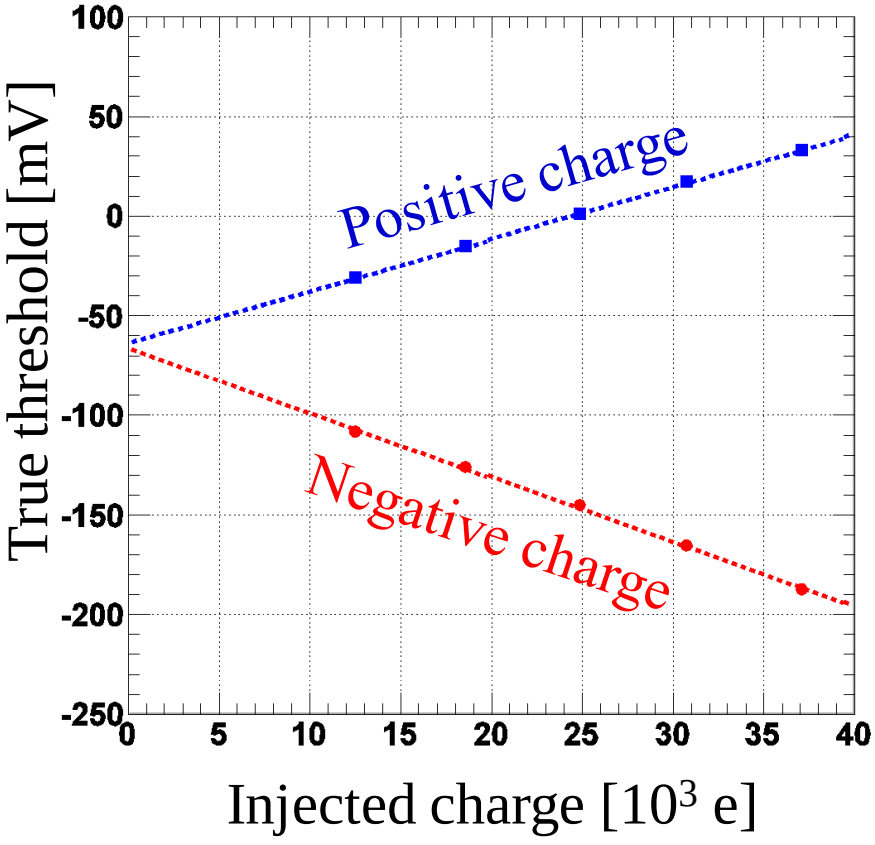
  → SOI device is known as rad-hard for SEE
- **Total dose effect (TDE)**
  - Caused by charge trapped in the oxide layer.

Oxide trapped charged could be compensated by the substrate voltage (V_{SUB}).

Measurements

- Signal shape at pre-amplifier
- Gain
- Linearity
- Noise level

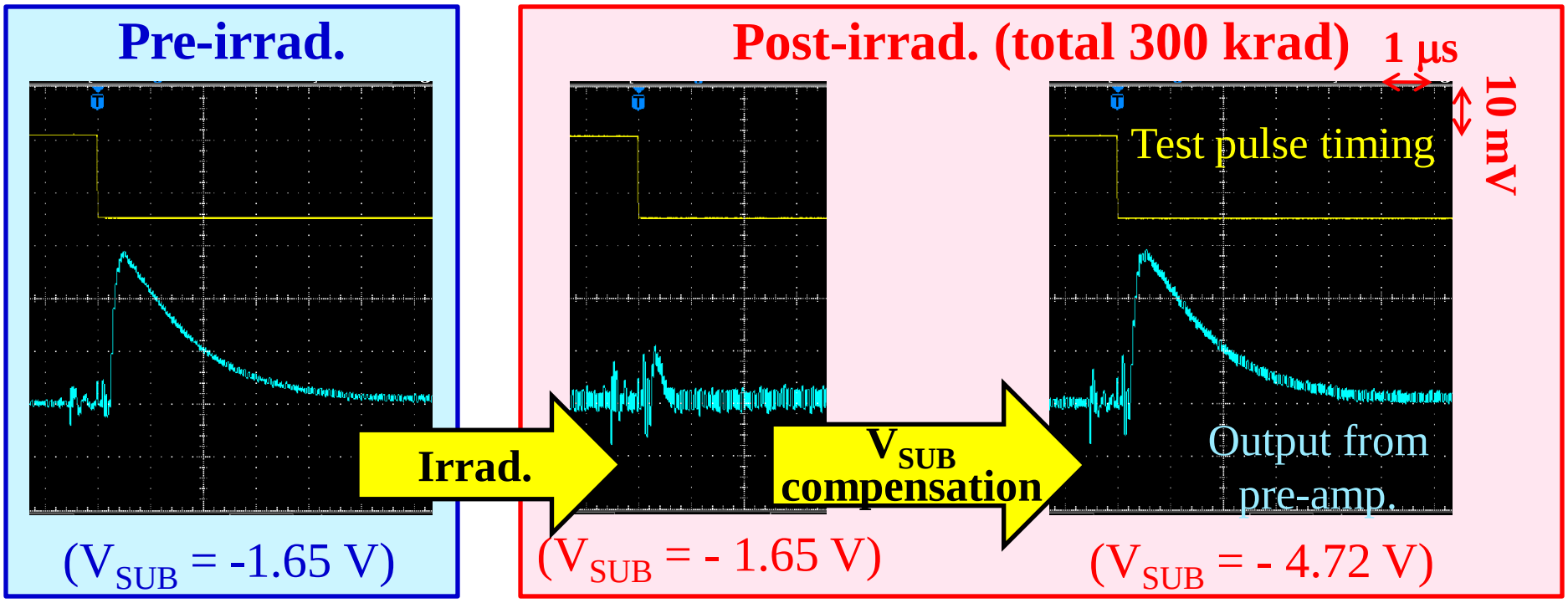




Signal shape

The signal shape at the pre-amp. was compared.

- By irradiation, the signal shape becomes smaller and vanished at the post-irrad. of larger 1 Mrad.

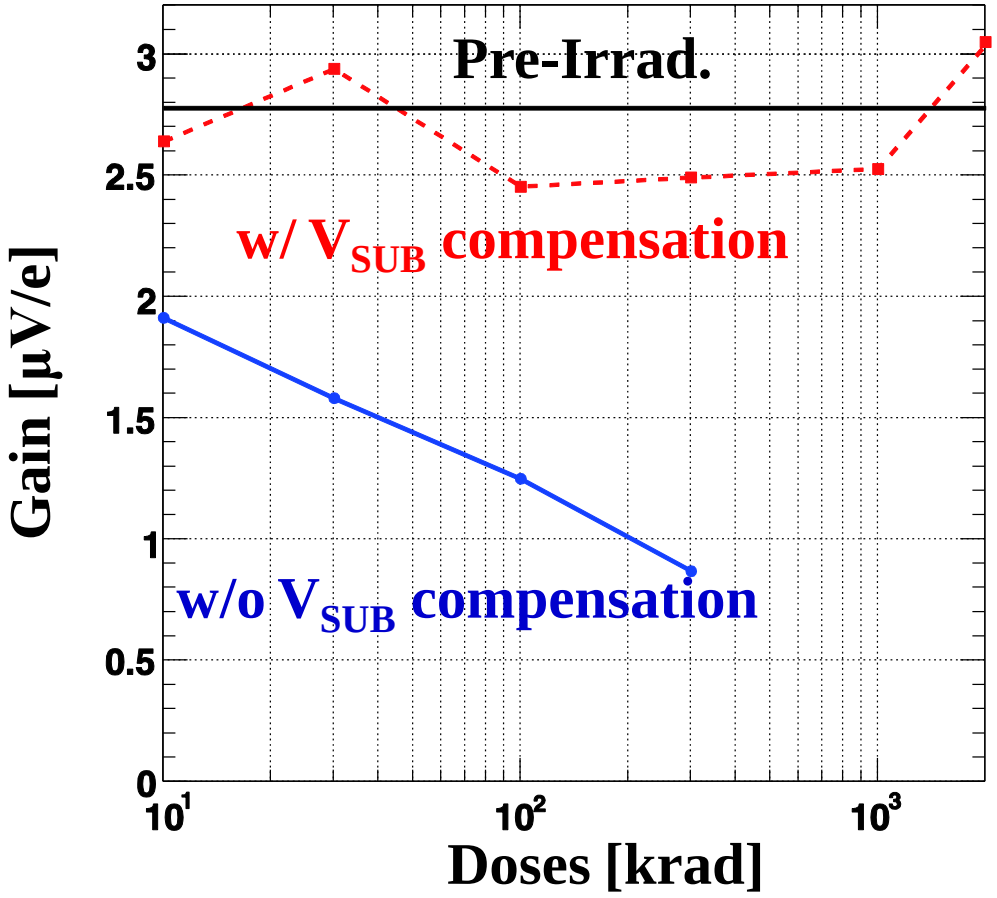


The signal shape of post-irradiation can be returned to that of pre-irradiation by V_{SUB} compensation.

Gain

The gain was compared.

- By the irradiation, the gain becomes smaller.



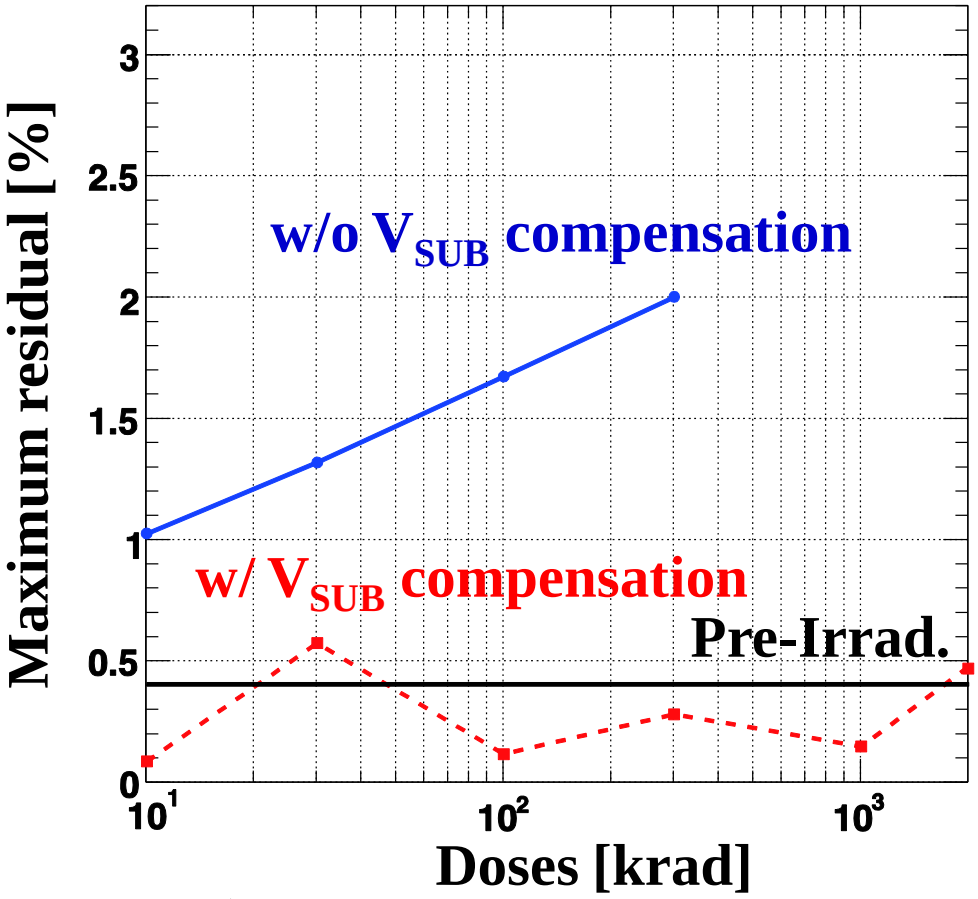
The gain can be restored by V_{SUB} compensation.

Linearity

The linearity was compared.

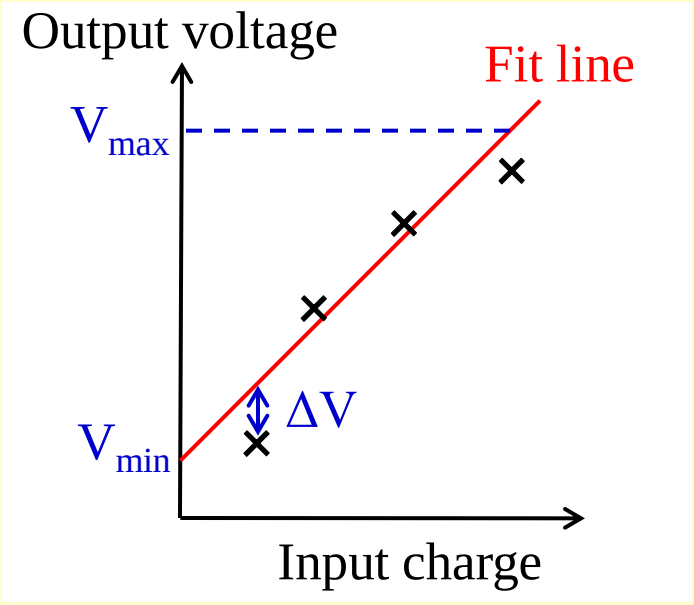
(fitting region : 7,000 ~ 45,000 e)

- By the irradiation, the linearity becomes worse.



Residual

$$\text{Residual}\,[\%] \equiv 100 \times \frac{\Delta V}{V_{max} - V_{min}}$$

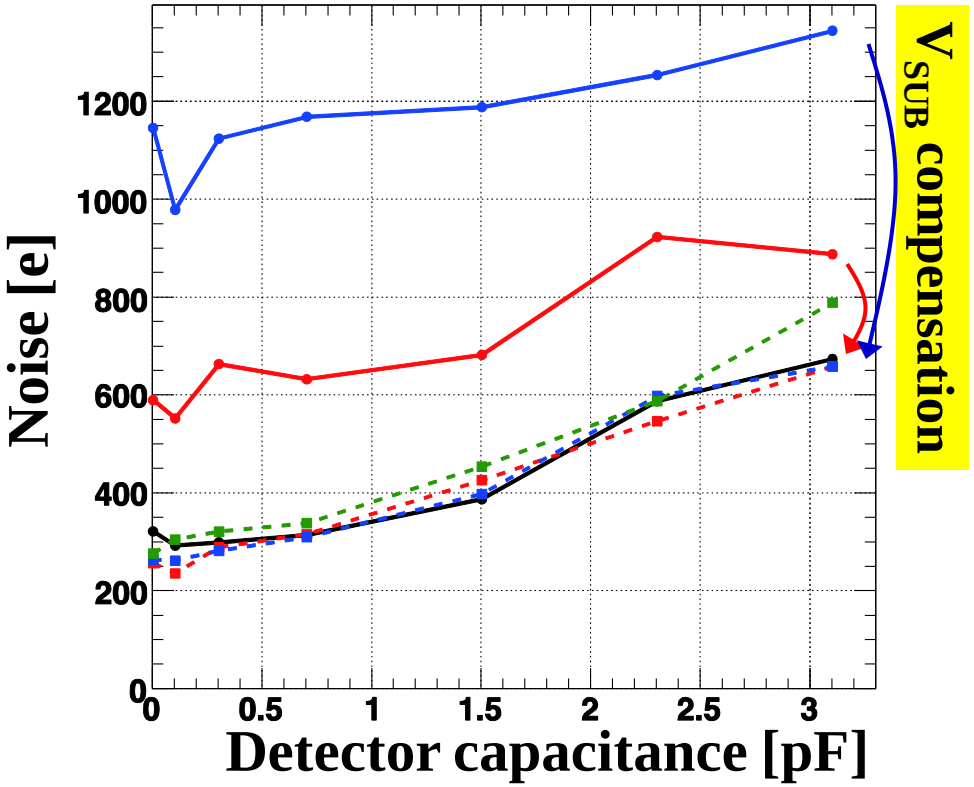


The linearity can be restored by V_{SUB} compensation.

Noise level

The noise level was compared.

- By irradiation, the noise level becomes bigger.



Pre-Irrad.
Post-Irrad. (100krad)
Post-Irrad. (300krad)
Post-Irrad. (2Mrad)

※ Dashed line means w/ V_{SUB} compensation.

The noise level returns to that of pre-irrad. by the V_{SUB} compensation.

The radiation tolerance up to 2 Mrad was confirmed and oxide trapped charge was compensated by V_{SUB}.

Summary

Pair-monitor is a silicon pixel detector to measure the beam profile at IP and developed with SOI technology.

- The first prototype which is only readout ASIC was produced and the irradiation test was performed successfully.
  - The radiation tolerance up to 2 Mrad was confirmed.
  - The oxide trapped charge was compensated by the substrate voltage.

Plan

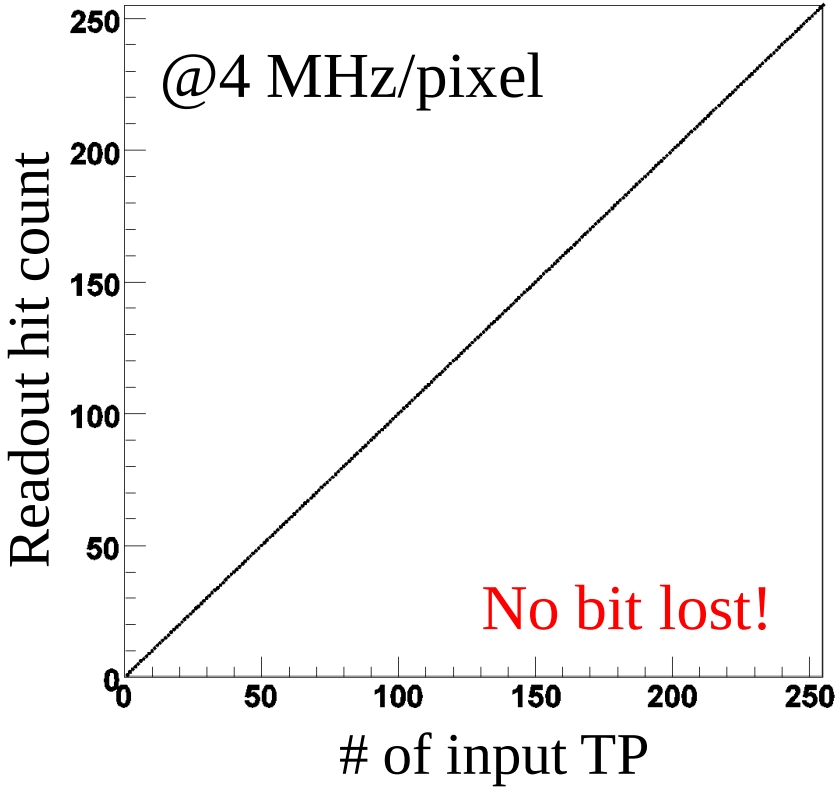
- Investigation into the next prototype
  - Monolithic or hybrid ?

Backup

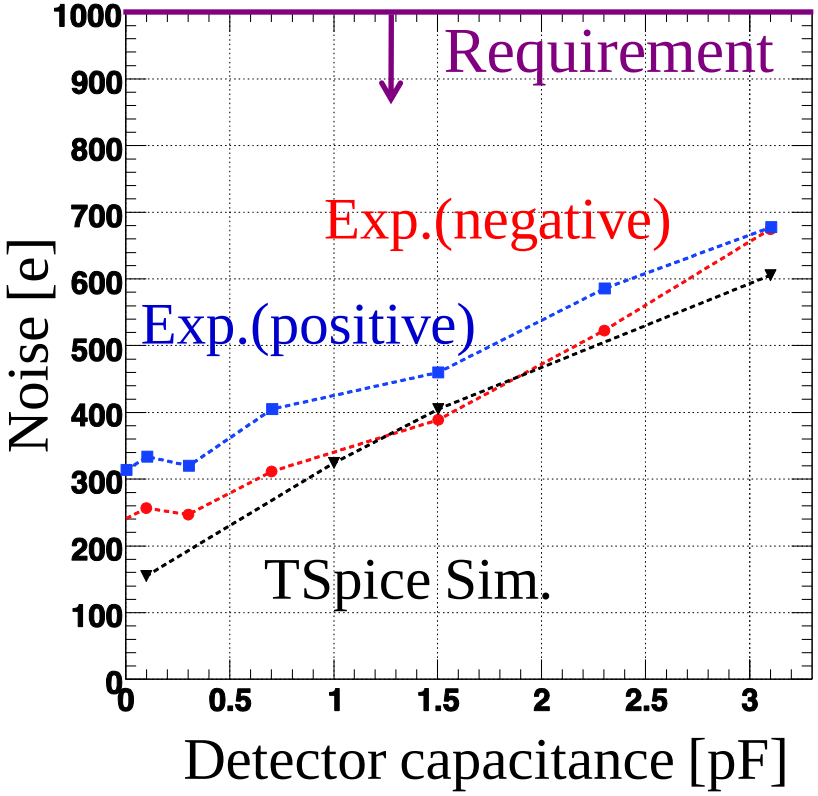
Operation test

Operation test was performed successfully.

Time resolution & Time-dep. measurement



Noise level



Prototype meets the requirement of time resolution, time-dependent measurement and noise level.

Radiation doses

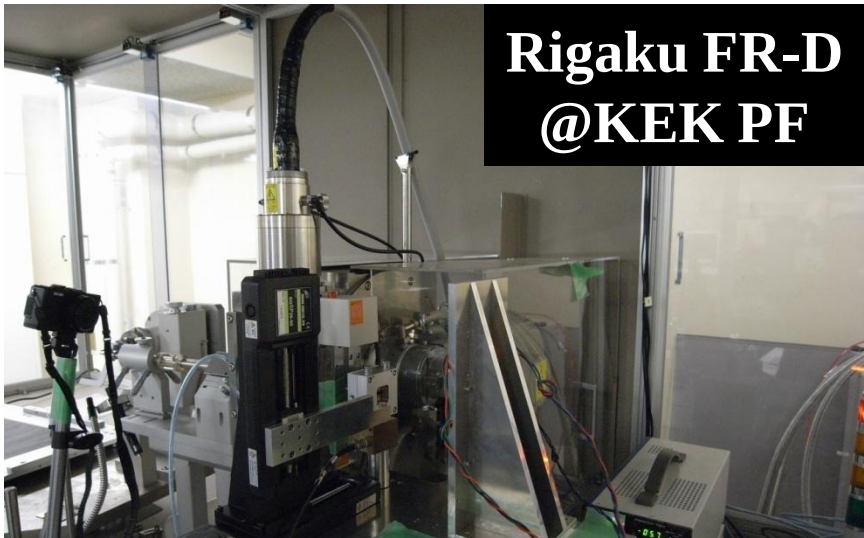
Total Doses = (#photon) × (Doses per a photon)

The number of photons

- Evaluated by the photoelectron of diode.
  - $k = 2.5 \times 10^9$ [photon/μA]

Doses per a photon

- Energy of photon : 8.19 keV
  - Weighted average of Kα (8.04 keV) and Kβ (8.91 keV)
  - All the photons are assumed to be absorbed within an attenuation length ($\lambda \sim 66$ μm)
- Silicon density $d = 2.33$ g/cm^3



Voltage of substrate voltage (V_{SUB})