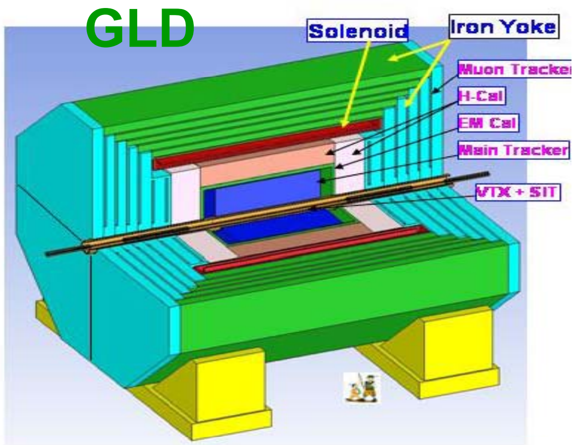
Current status of the silicon strip sensor development in Korea

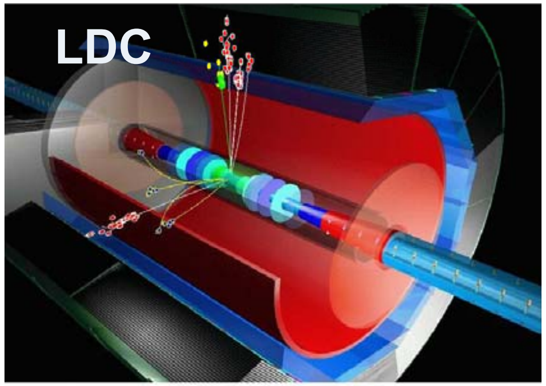
1. Introduction
2. Silicon Inner tracker configuration for ILC
3. Silicon strip sensors development
4. Beam test and radiation damage test
5. Prospect

H.J.Kim (KyungPook National U.)
For Korean silicon tracker collabortion

ACFA9, Feb. 6/2007

Silicon Tracker R&D (SiLC group)



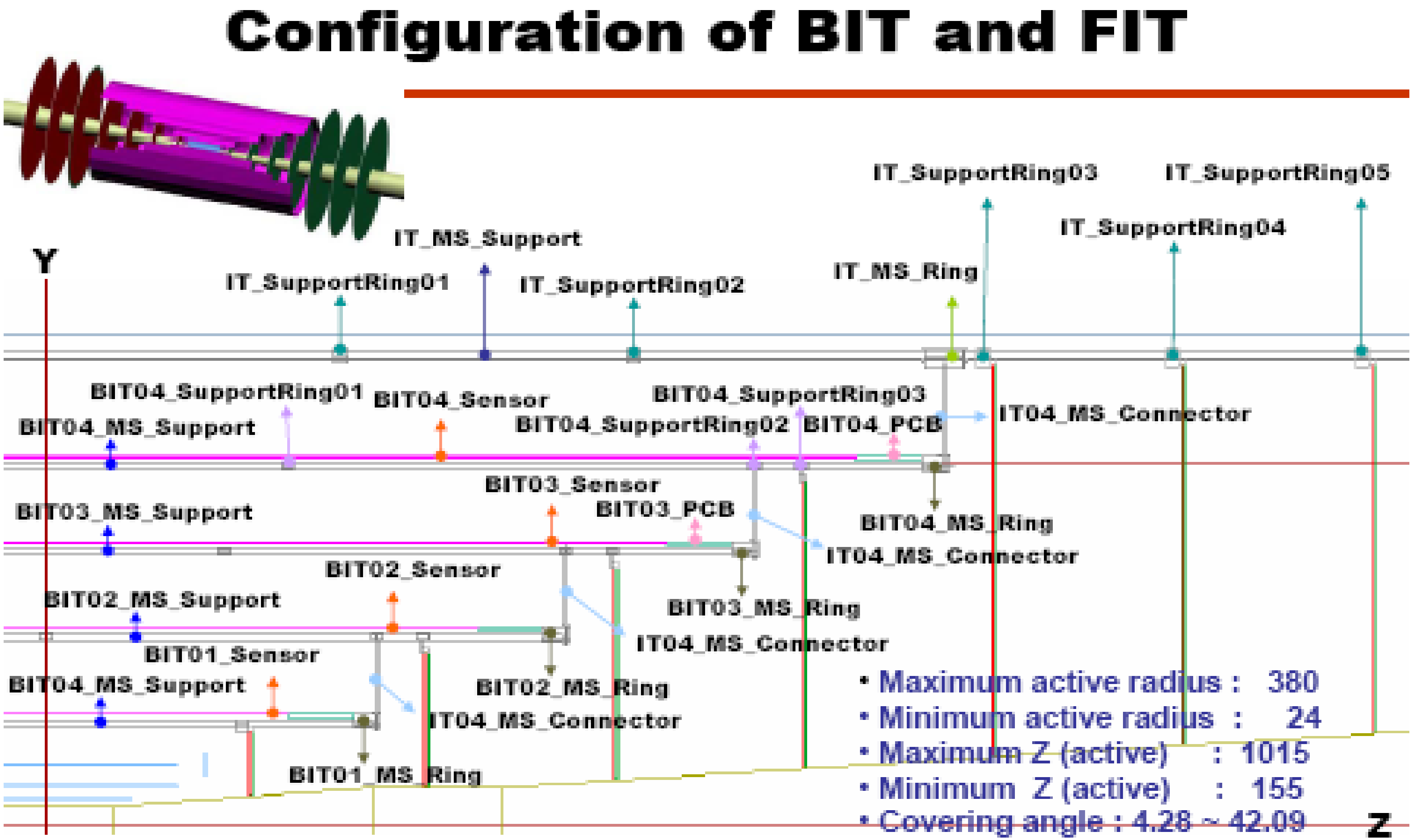


1. VTX (FPCCD)
2. Barrel Inner tracker
3. Endcap Inner tracker

1. VTX
2. Intermediate tracker
3. Endcap tracker

1. VTX
2. Whole tracker

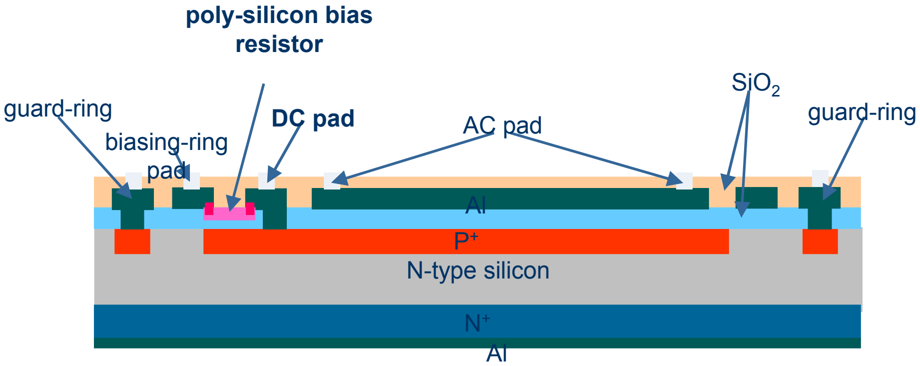
Inner Tracker in GLD



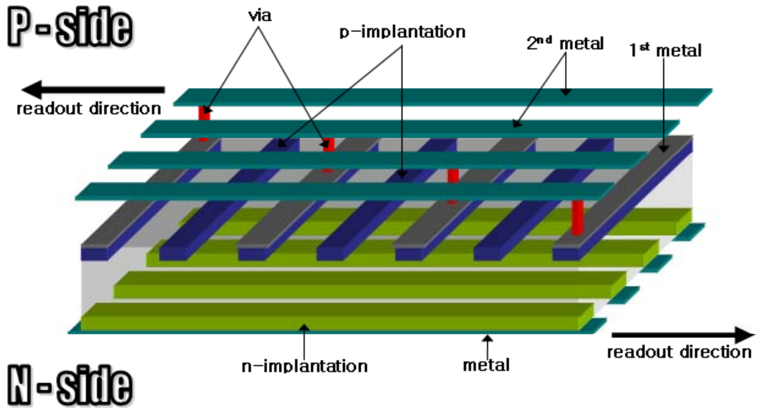
Concept of Silicon Strip Sensor

type	fabrication	readout
DC	relatively simple	readout electronics is connected directly to the strips
AC	relatively complicate	- **coupling capacitors** are made by separating strip implantation and metallization - **biasing resistors** are made in poly-silicon

readout	fabrication	position
single-sided	relatively simple	1-dimensional
double-sided	complicate, low yield	2-dimensional

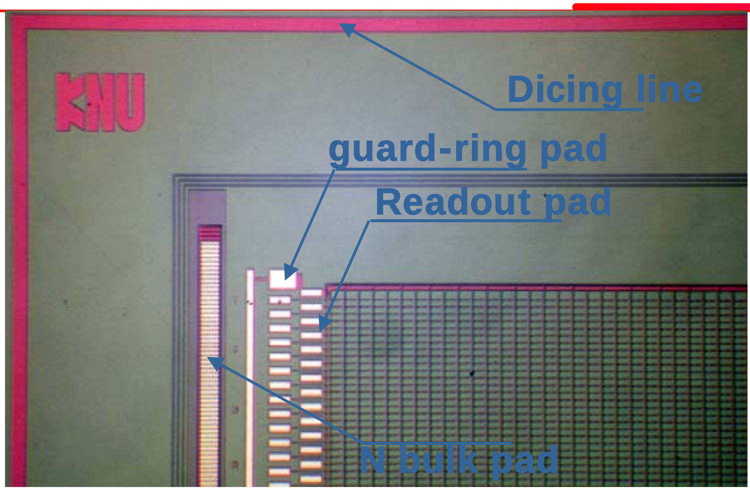


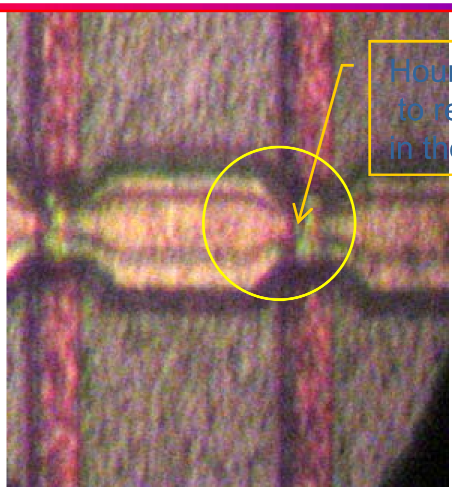
AC-type single-sided strip sensor



DC-type double-sided strip sensor

DC Double-sided Silicon Strip Sensor

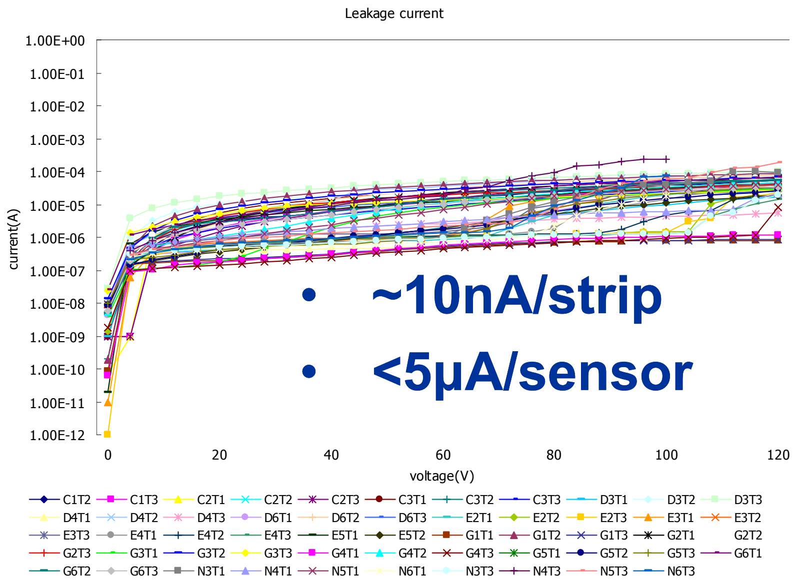




Hour-glass pattern on the p-side to reduce the capacitance in the double metal structure

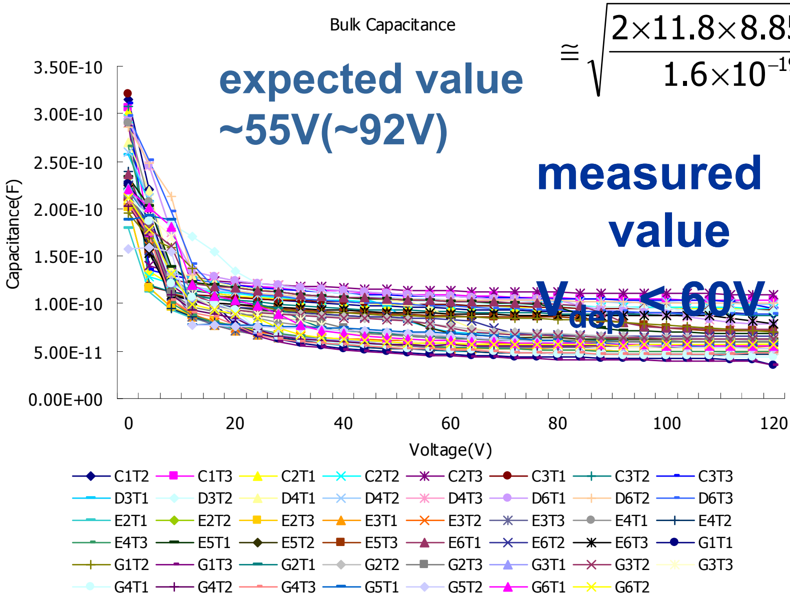
$$d = \sqrt{\frac{2\varepsilon\varepsilon_0}{qN_D}V_{dep}}$$

$$\cong \sqrt{\frac{2\times 11.8\times 8.854\times 10^{-14}}{1.6\times 10^{-19}\times N_D}V_{dep}}$$



- ~10nA/strip
- <5μA/sensor

I_d v.s. V



expected value ~55V(~92V)

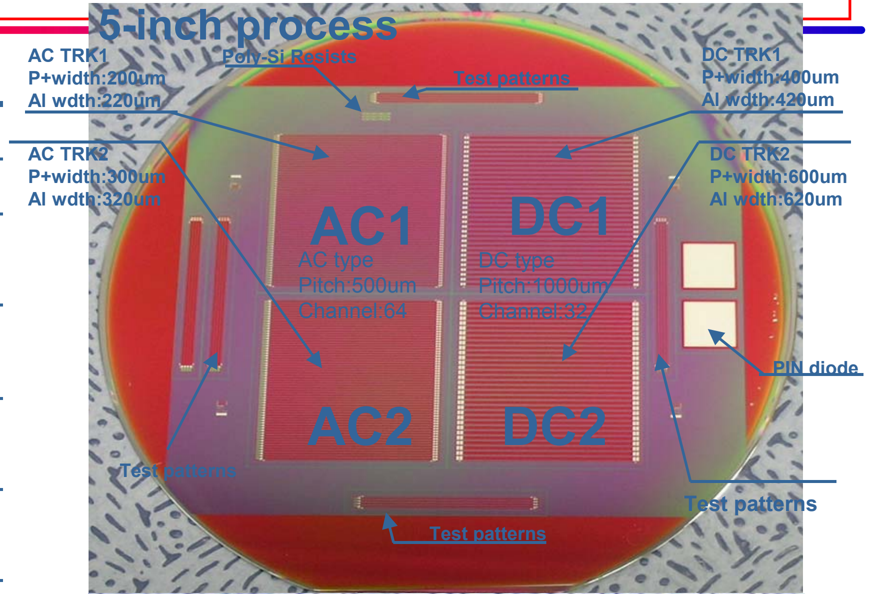
measured value V_{dep} < 60V

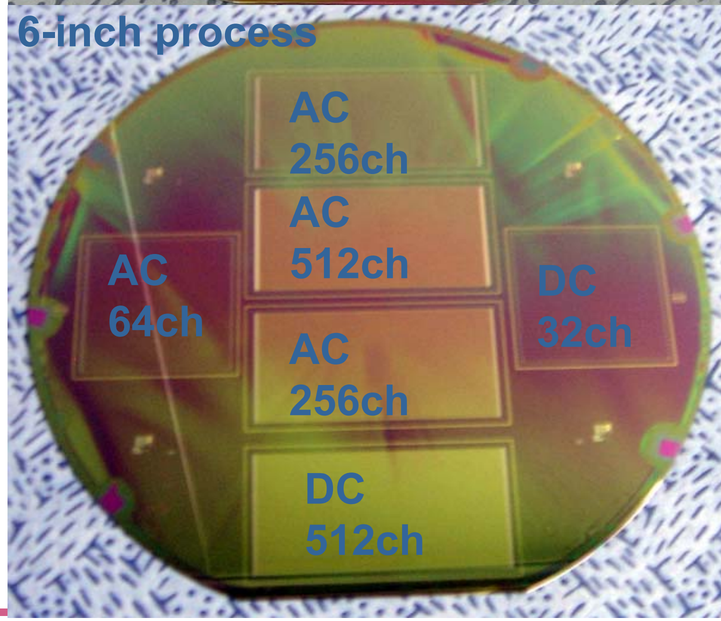
C v.s. V

Fabrication of AC/DC SSD

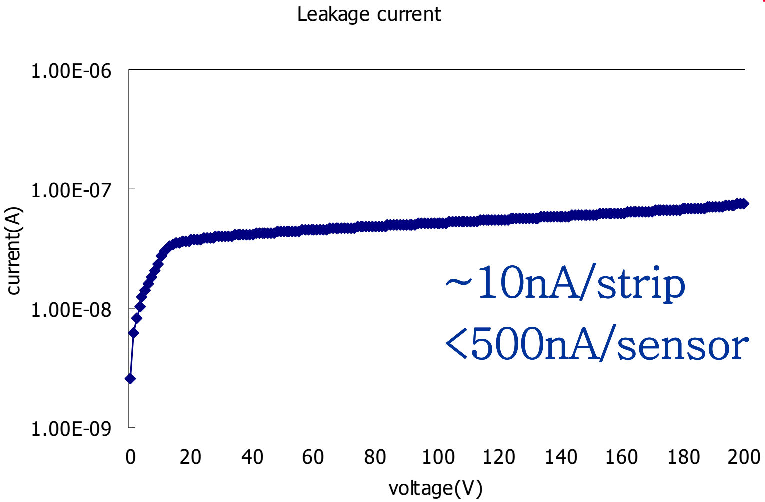
AC-coupled Single-sided Silicon Strip Detector

	5-inch		6-inch	
thckness(μm)	380		400	
Area (μm^2)	35000 × 35000		55610 x 29460	
Effective area (μm^2)	31970 × 31970		51264 x 25178	
SiO_2 layer thickness (nm)	1000		250	
Polysilicon length (μm)	10		8	
Polysilicon width (μm)	13500		480	
sheet resistance(kΩ)	~25		~400	
	Type 1	Type2	Type 1	Type2
Number of strips	64	64	256	512
Strip pitch (μm)	500	500	100	50
Strip width (μm)	200	300	8	8
readout width (μm)	220	320	12	12

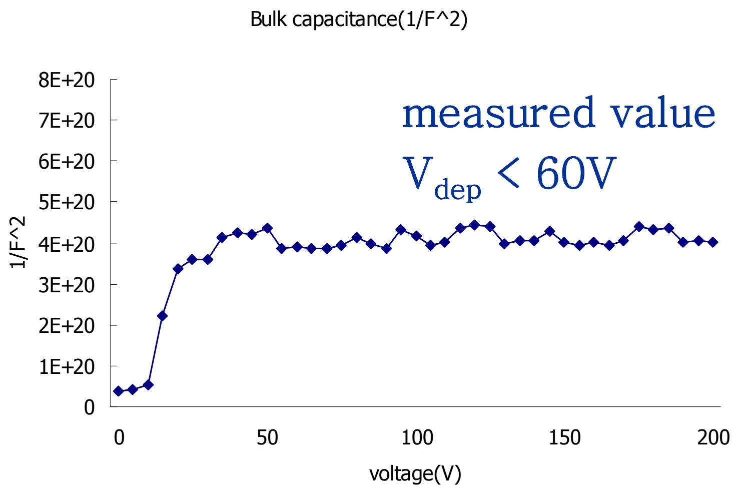




Electrical test of SSD



I_d v.s. V



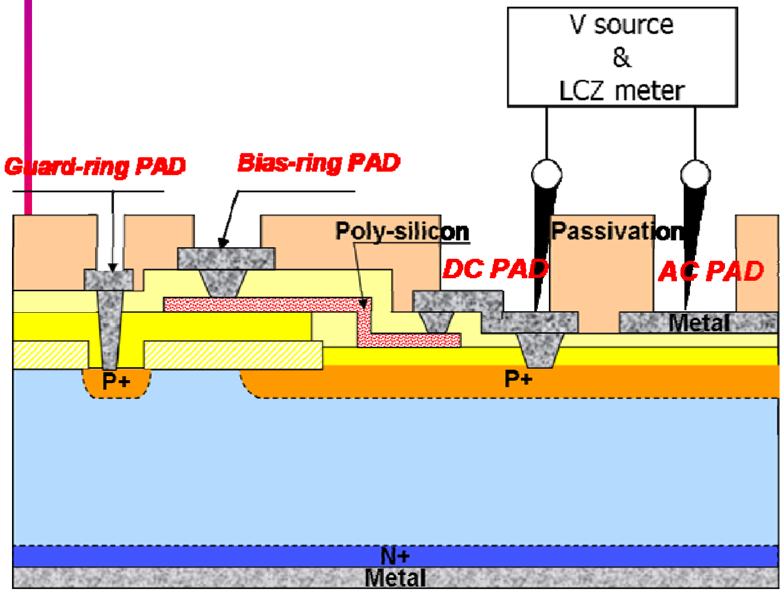
$1/C^2$ v.s. V

Electrical characteristic of each channel in one of the AC-SSD

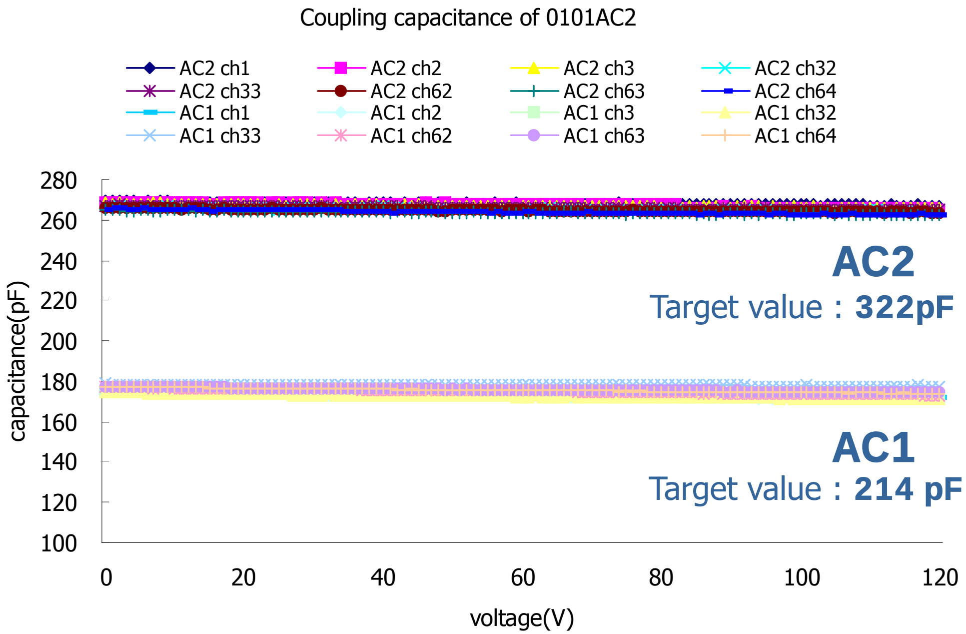
channel	Current@60V (nA)	$C_{coupling}$@60V (pF)	bias resistance (MΩ)
ch1	8.1	260.0	22.0
ch2	3.0	260.0	22.0
ch3	3.1	259.0	21.0
ch4	3.2	259.0	21.0
ch5	3.3	260.0	21.0
ch6	3.3	260.0	21.0
ch7	3.4	259.0	21.0
ch8	3.5	259.0	21.0
ch9	3.6	259.0	21.0
ch10	3.7	259.0	21.0
ch34	4.5	257.0	23.0
ch35	4.4	256.0	23.0
ch55	4.3	256.0	22.0
ch56	4.2	256.0	22.0
ch57	4.2	256.0	22.0
ch58	4.1	255.0	22.0
ch59	4.0	255.0	22.0
ch60	3.9	255.0	22.0
ch61	3.9	255.0	21.0
ch62	3.8	255.0	22.0
ch63	3.8	255.0	22.0
ch64	3.9	256.0	21.0
AVE.	4.0	257.3	21.6

AC coupling capacitance

- Coupling capacitance (C_c)
  - Target value : AC1 214pF / AC2 322pF
  - Measured value : AC1 177pF / AC2 257pF
  - Differences are due to different permittivity depending on SiO_2 layer
  - And due to the limitation of SiO_2 layer thickness in the our fabrication process.



Probing for coupling capacitance measurement

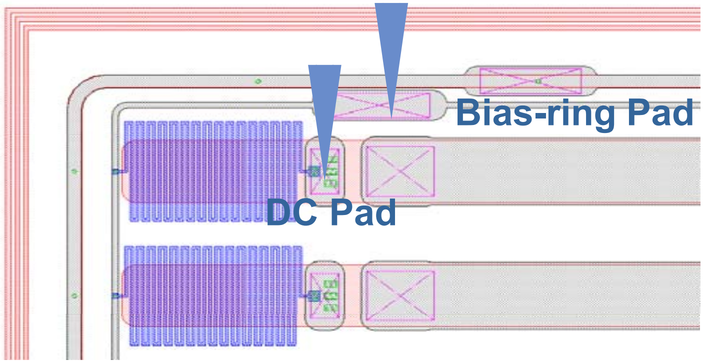


Measured capacitances of the AC SSD

Biasing structure

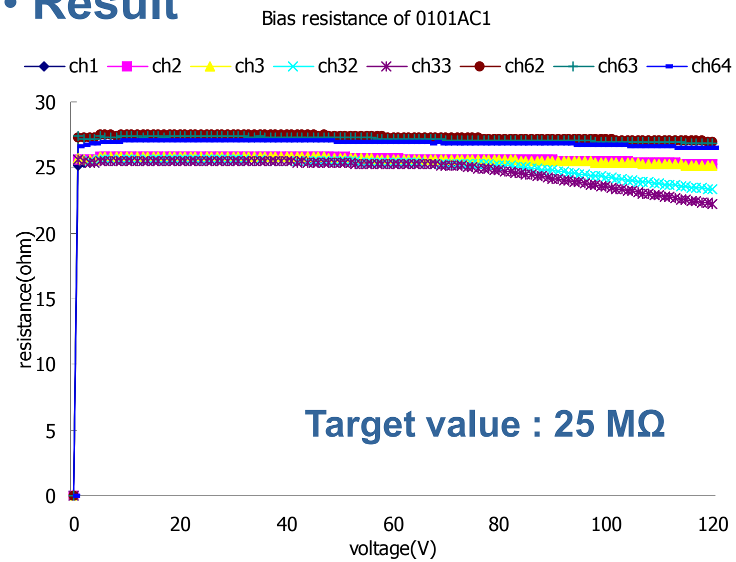
- Bias resistor structure
  - Purpose and advantage :
    - Isolation of each strip
    - Automatic biasing of total strip
    - total leakage current is measured easily with only one connection on each surface
  - $R = R_s \times \frac{Length}{Width}$

here, R_s=20 KΩ
width=10 μm
length=12700 μm



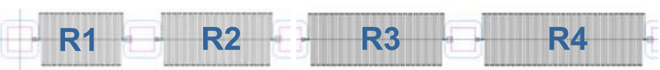
Probing for Biasing resistance measurement

- **Result**



The Bias resistance of the AC-coupled SSSD

- **Test patterns**



	length(μm)	width(μm)	Rs(kΩ)	expected(MΩ)	measurement(MΩ)
R1	12710	10	20	25	26.04
R2	16810	10	20	34	34.04
R3	20910	10	20	42	41.85
R4	25010	10	20	50	49.38

Resistances of various test patterns

Silicon Strip Sensor Summary

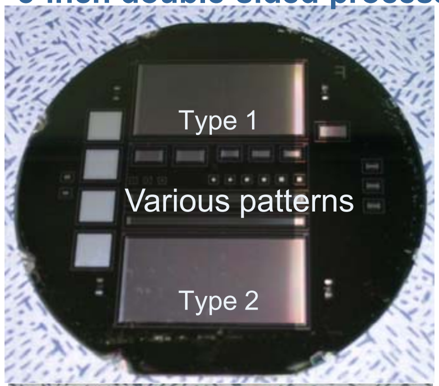
- **yields**

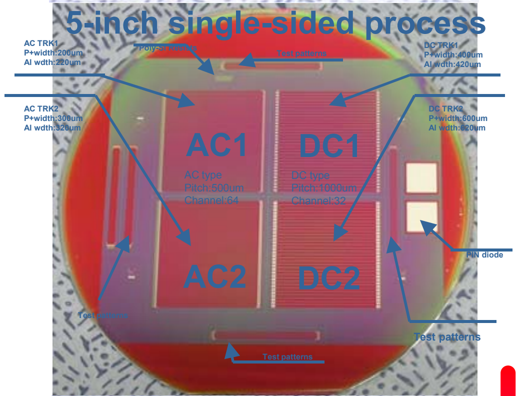
type	DC-type	AC-type
single-sided	90%	80%
double-sided	< 30%	N/A

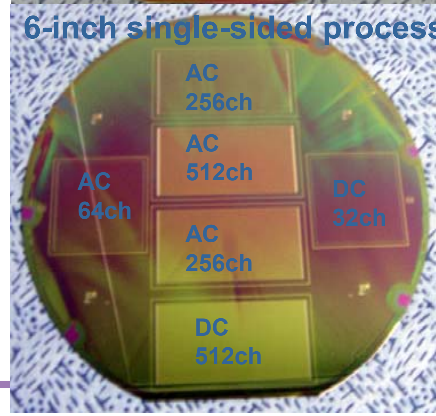
- **fabrication line**

line	DC-type	AC-type
5 inch	double/single-sided	single-sided
6 inch	single-sided	single-sided (in progress)
8 inch	thickness (725 um, can be thinned ~500 um)	

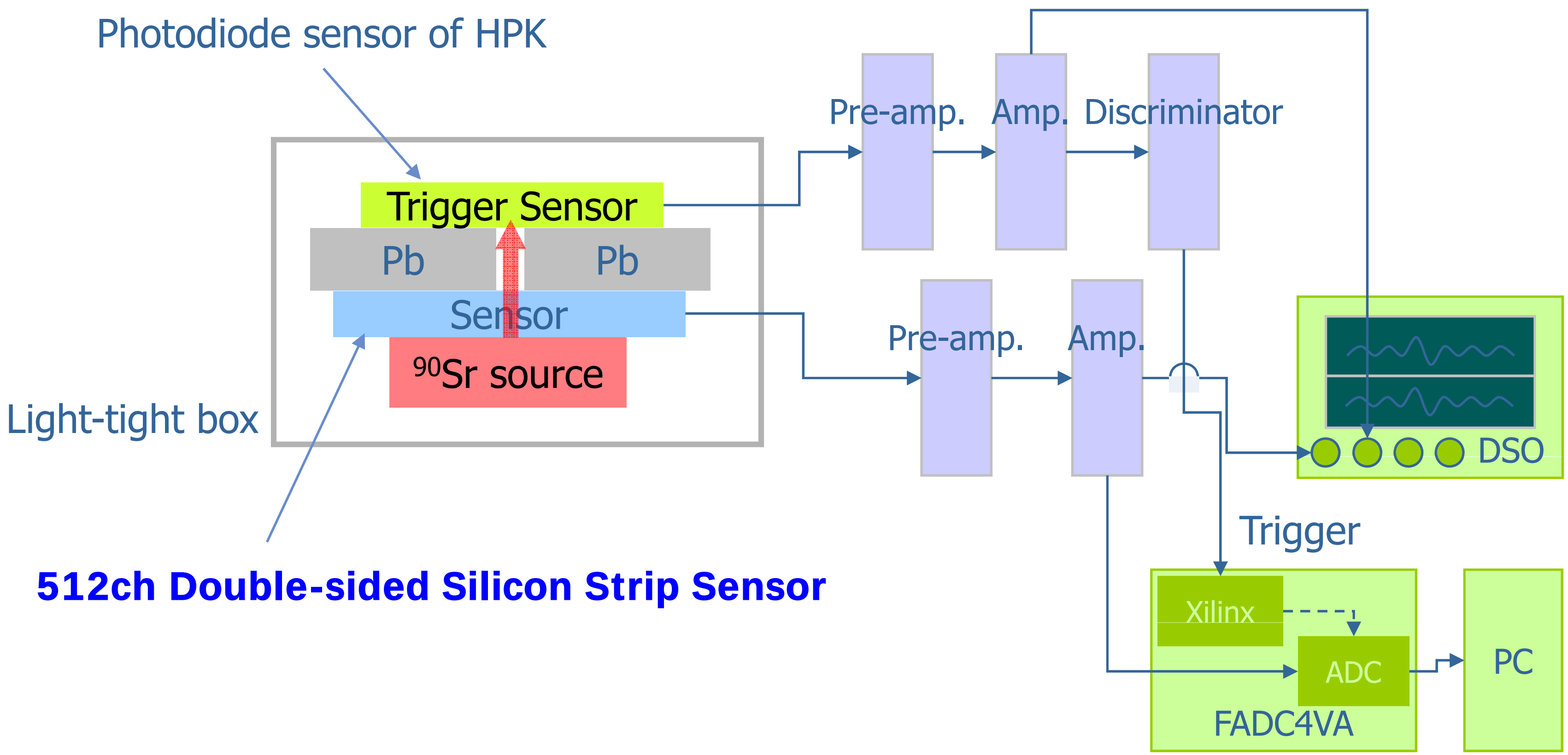
5-inch double-sided process



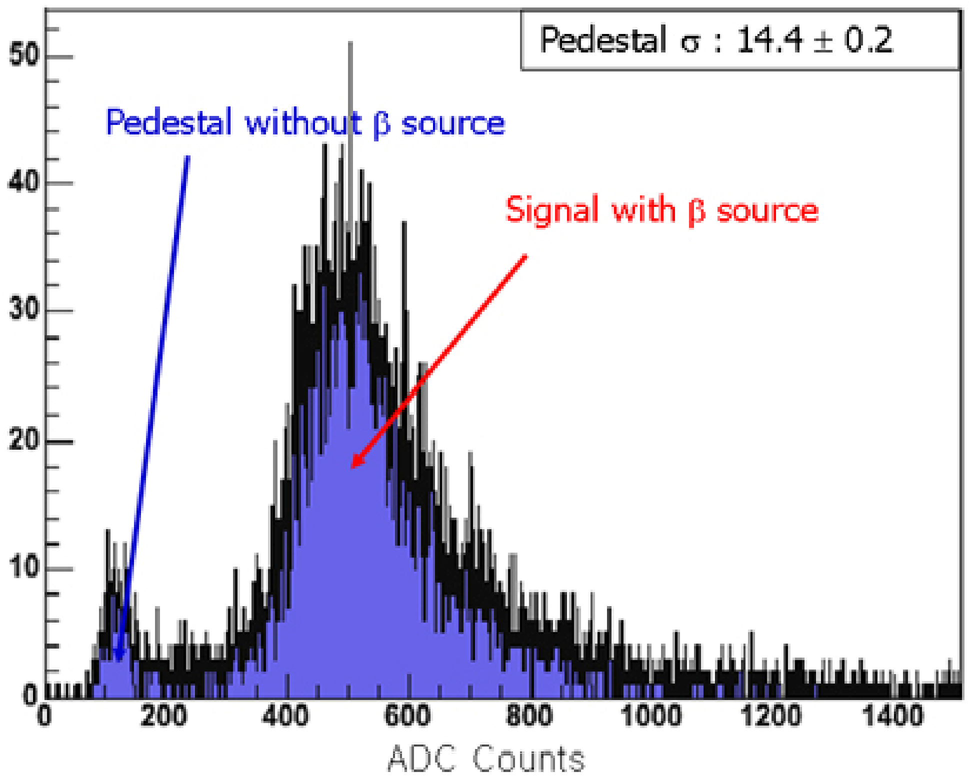




Radioactive source test block diagram



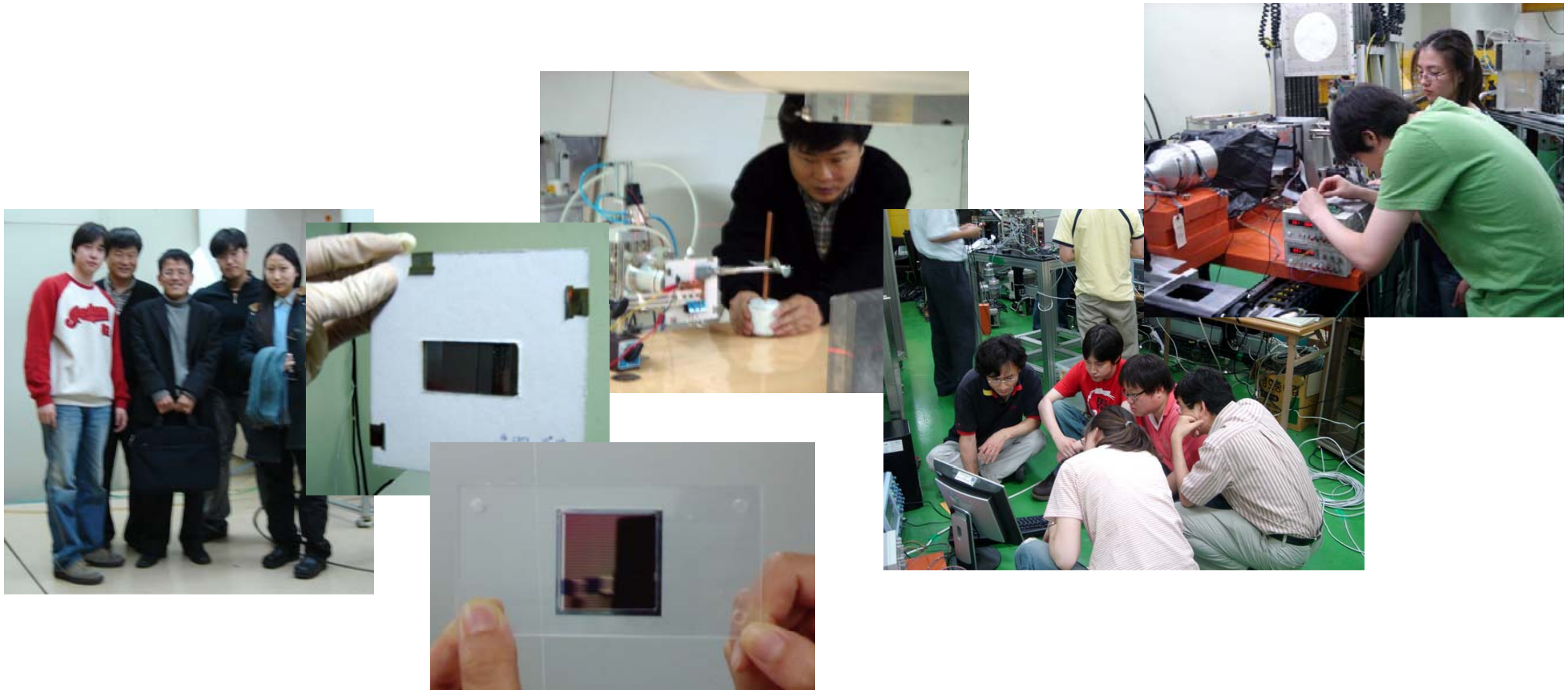
Source Test Measurement Result



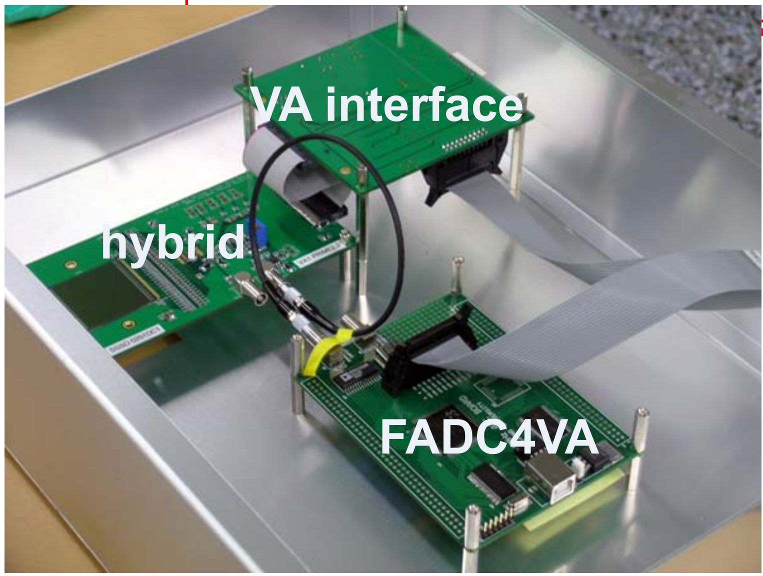
- Signal-to-noise ratio is measured to be 25.0

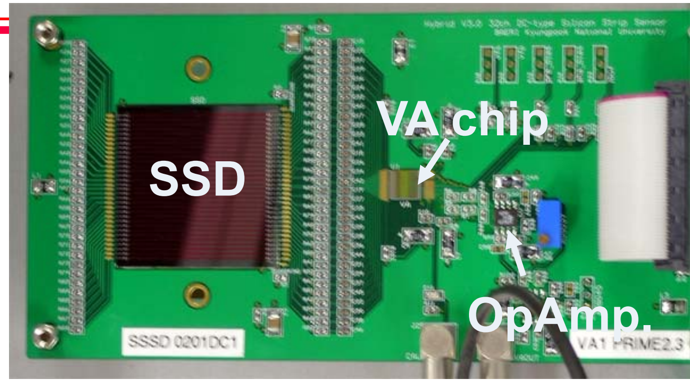
Beamtest & Radiation damage test

- Korea Institute of Radiological And Medical Science
- Beam energy from 35 ~ 45MeV
- Beam current from 0.2nA ~ few micro A



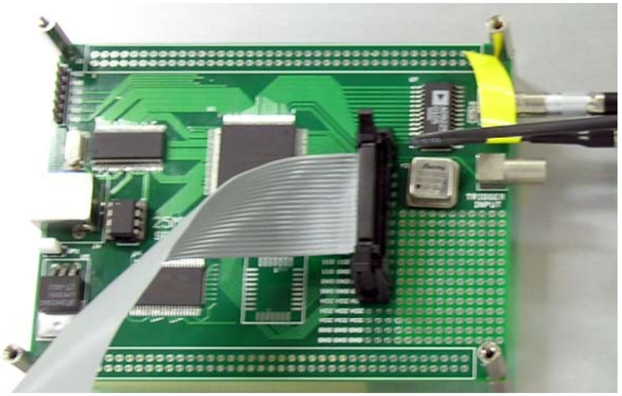
Front-end electronics for SSD (DC type)





VA Hybrid board

This VA1 chip has 128 channels, and a low noise charge sensitive preamp, a shaper, and a sample and hold for each channel.
Analog signals are serially clocked out by control via a shift register.



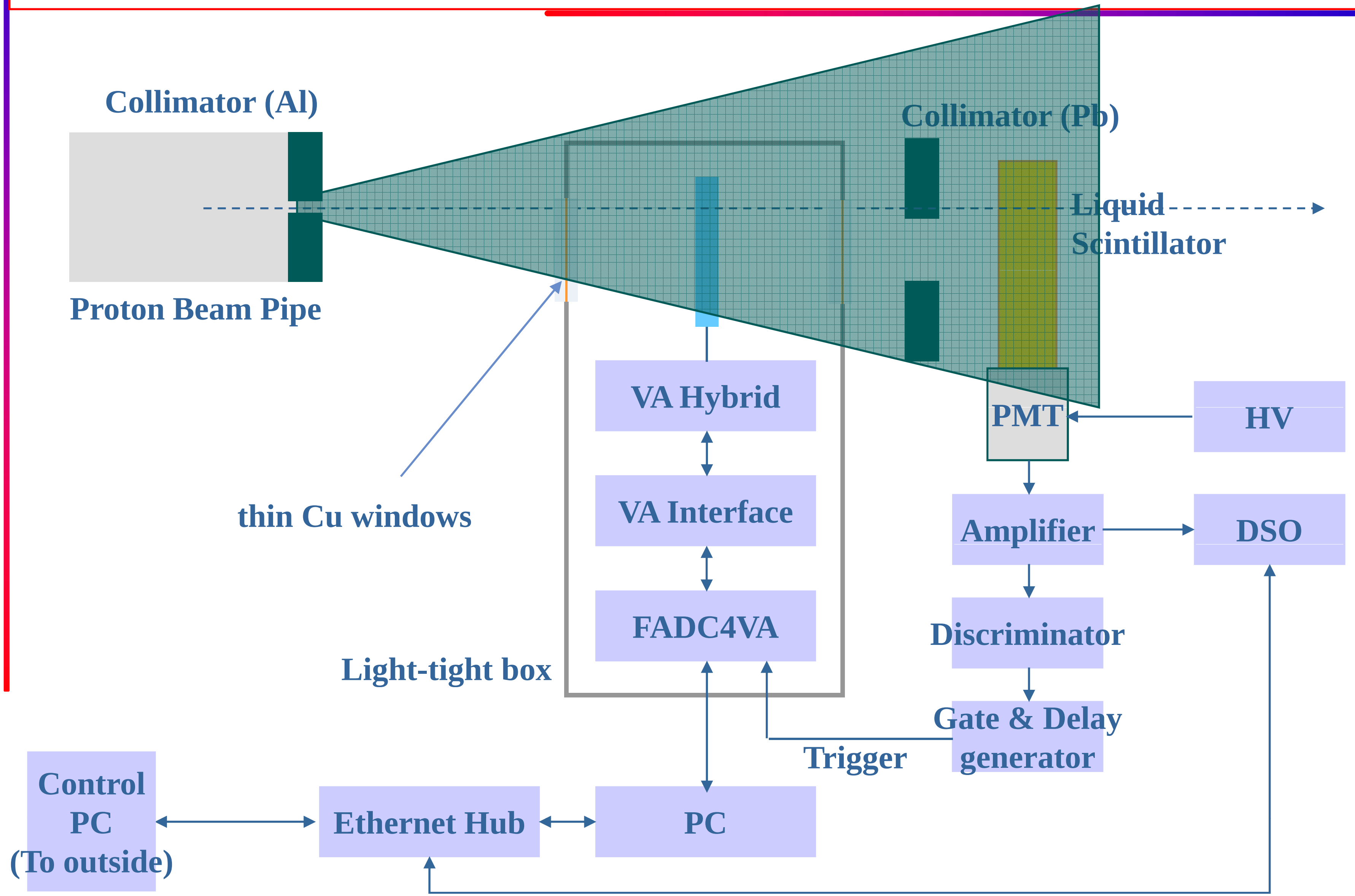
VA Interface board

Power supply to VA and silicon strip sensor
Logic converter for interfacing between VA and Xilinx

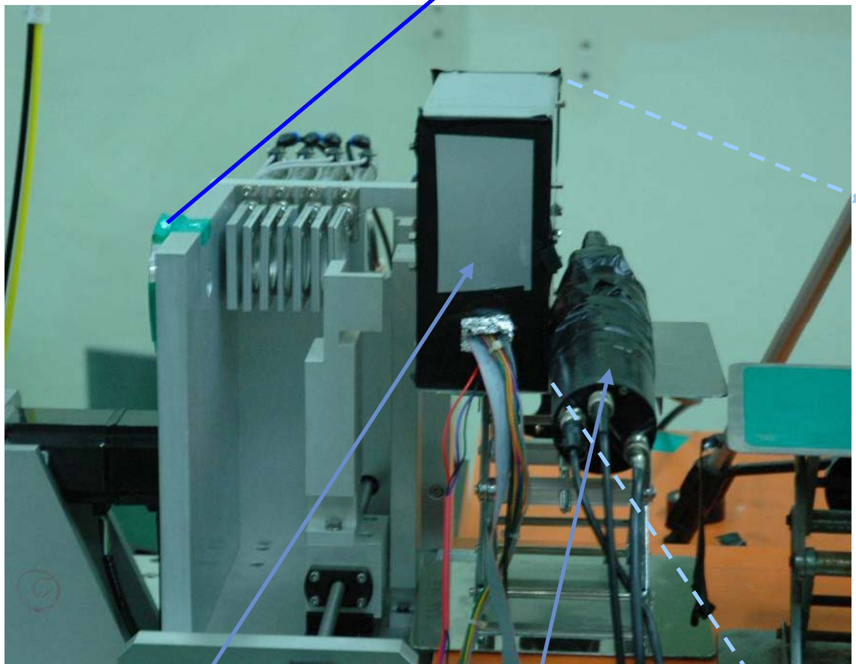
FADC4VA board

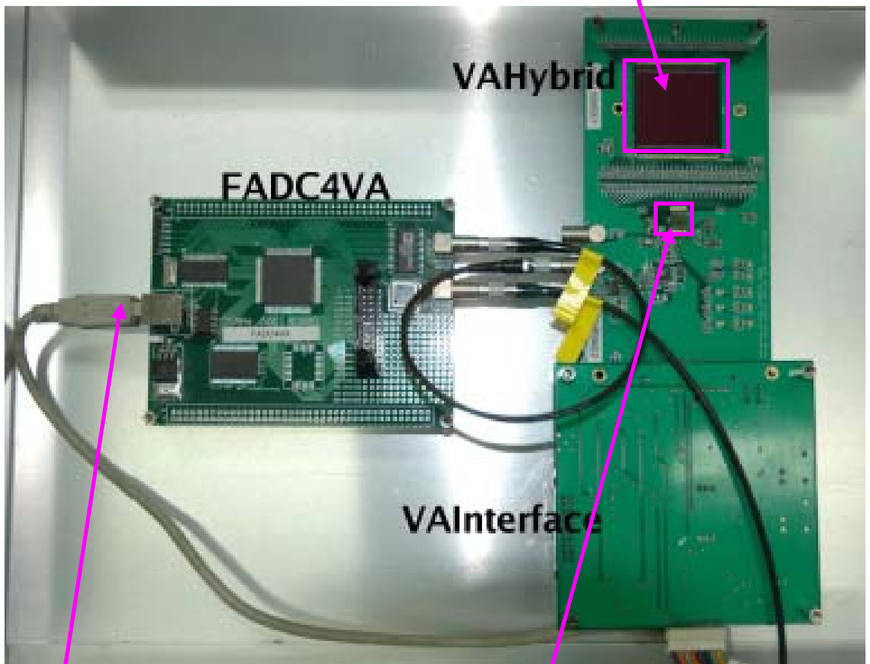
Xilinx chip on Flash ADC4VA board makes a control logic and distributes it to VA and ADC chip converts analog signal to digital signal.
Digital signal from ADC is sent to PC through USB2 bus for data analysis

Block Diagram of Experimental Set-up for Beam Test

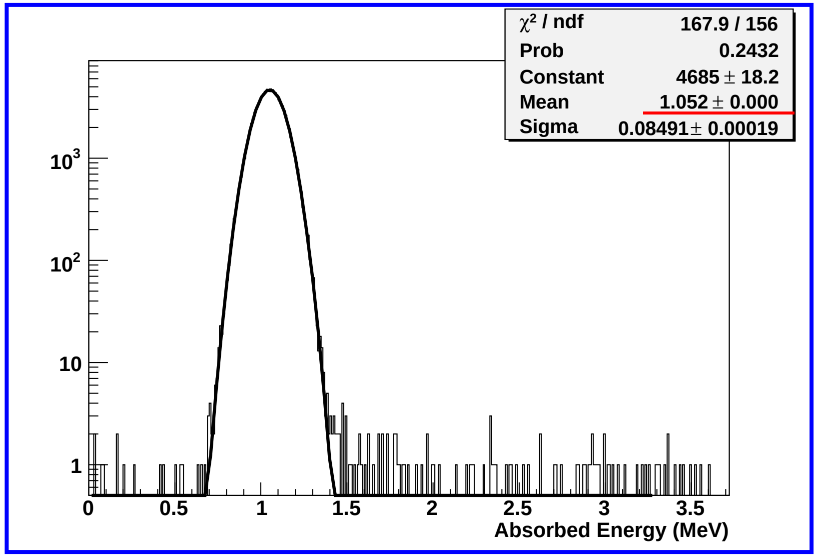


Experimental Set-up



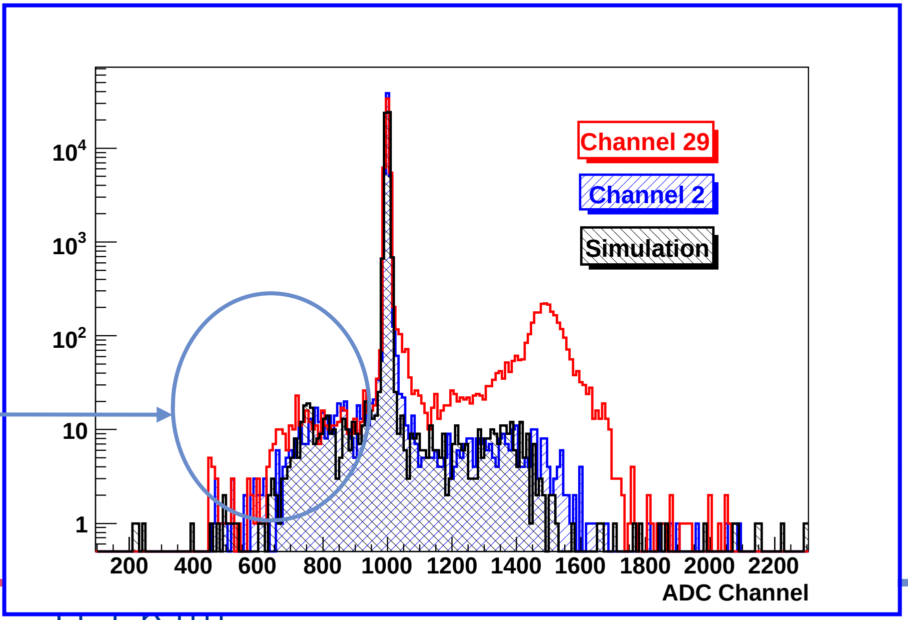


Test results

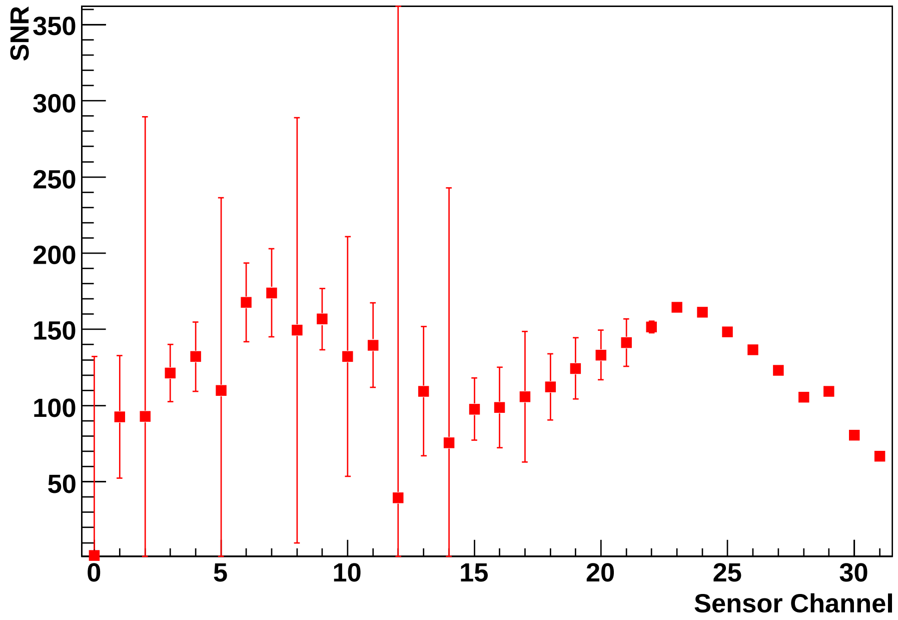


Simulated absorbed energy spectrum of 37.5 MeV proton impinging onto 380 um silicon sensor

This problem is well understood : random trigger due to misalignment



Results of beam test : S/N



- The SNR is defined as the ratio of the most probable energy deposit in the sensor to the noise RMS.
- The estimated SNRs of channels 0 ~ 22 have large errors because of only few properly triggered events. Channels 23 ~ 31 show good SNRs of 164 ~ 67 for as 37.5 MeV proton, which corresponds to be 16.4 ~ 6.7 for a Minimum Ionizing Particle.

Radiation damage test

- Irradiation

  45 MeV proton beam from MC-50 cyclotron at KIRAMS fluence normalization based on NIEL scaling hypothesis

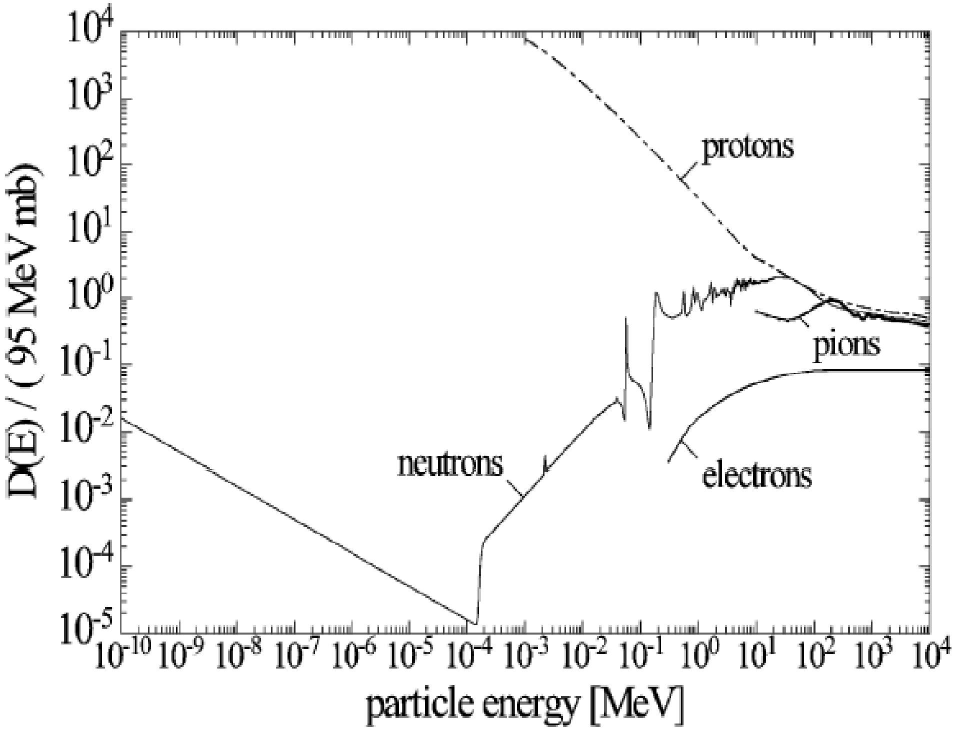
  – for different particles

  – for different energy ranges

- The standard for particle fluence is to normalize all damage to the equivalent damage caused by 1 MeV neutron.

$$\Phi_{eq} = \kappa \Phi_{tot}$$

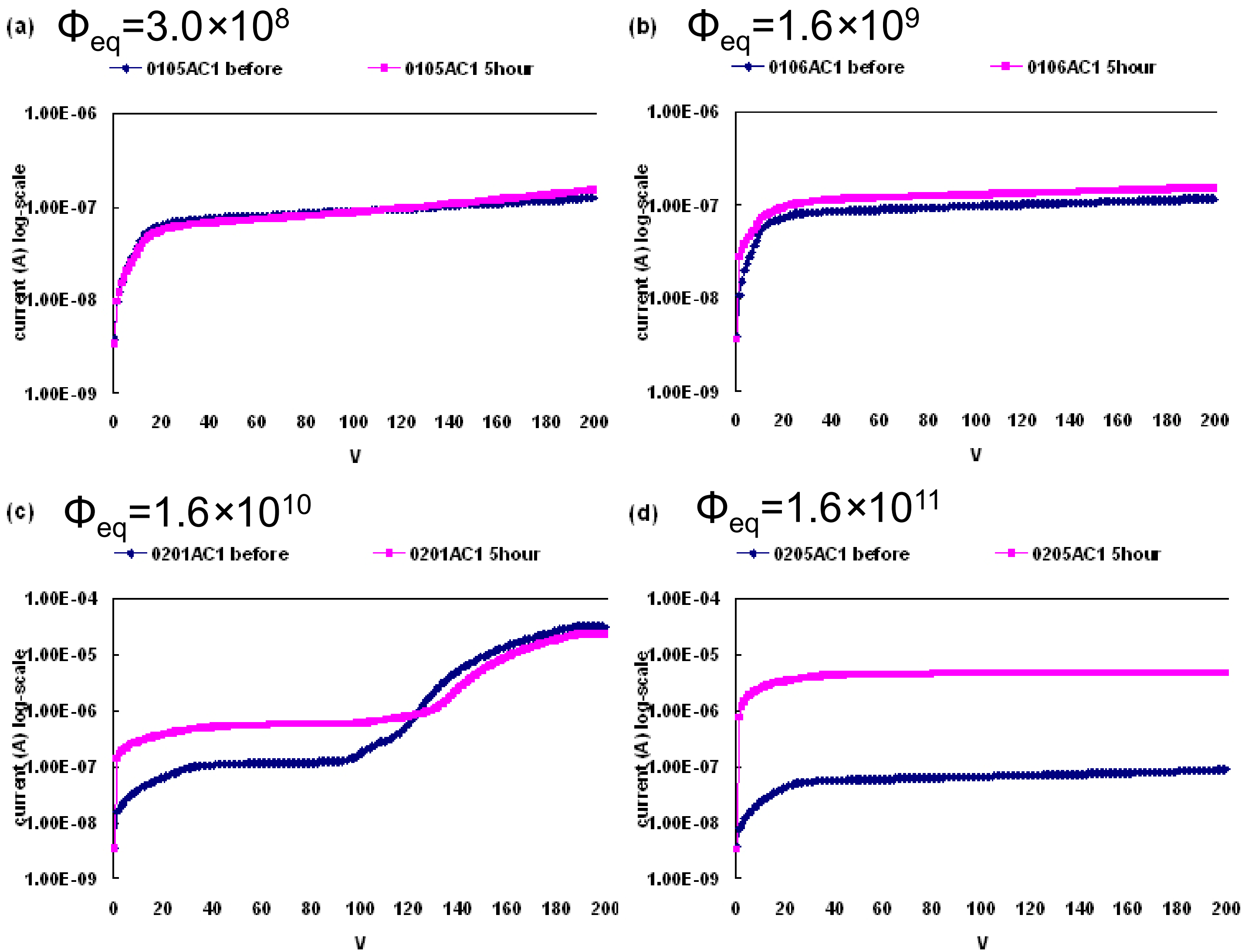
κ is "hardness factor" = $D(E)/D_{neutron}(1MeV)$



Energy dependence on NIEL in silicon for different particle types and energies

Radiation damage test results

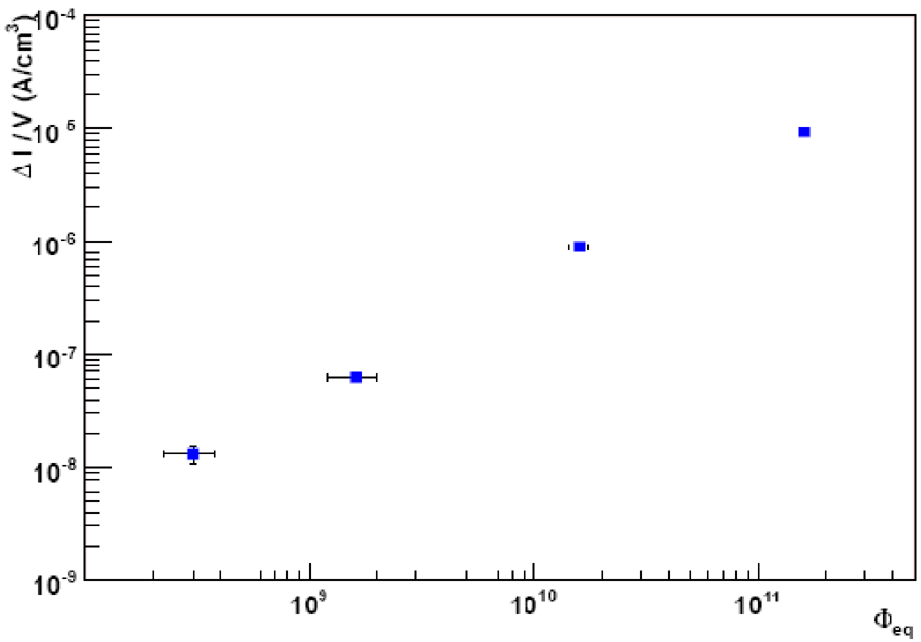
- Increase in leakage currents



Leakage currents as a function of bias voltage

Radiation damage effects

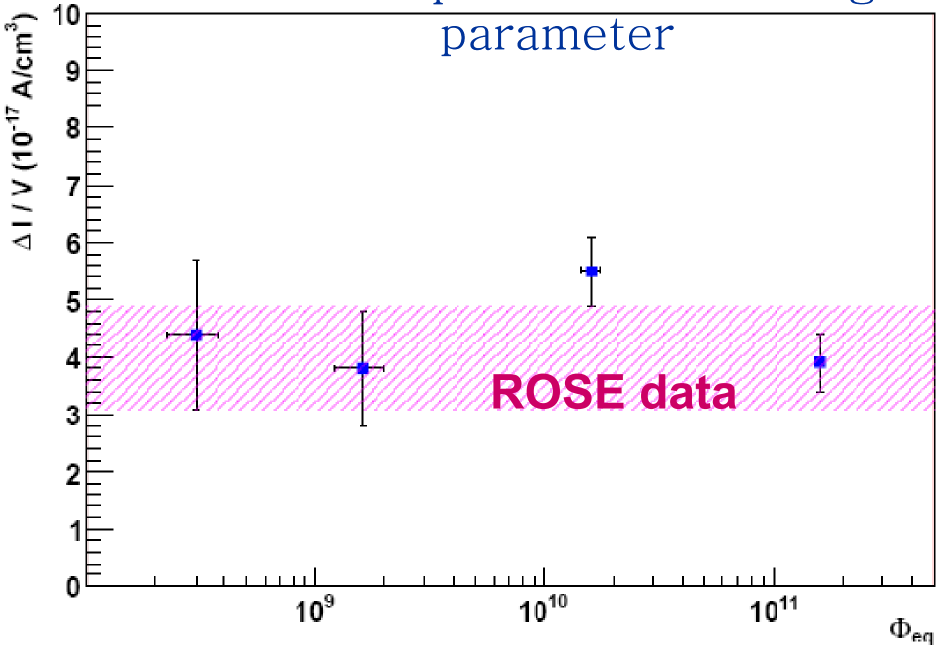
Fluence dependence of leakage



•current increase is strictly proportional to fluence

•Damage induced bulk

Fluence independence of damage parameter

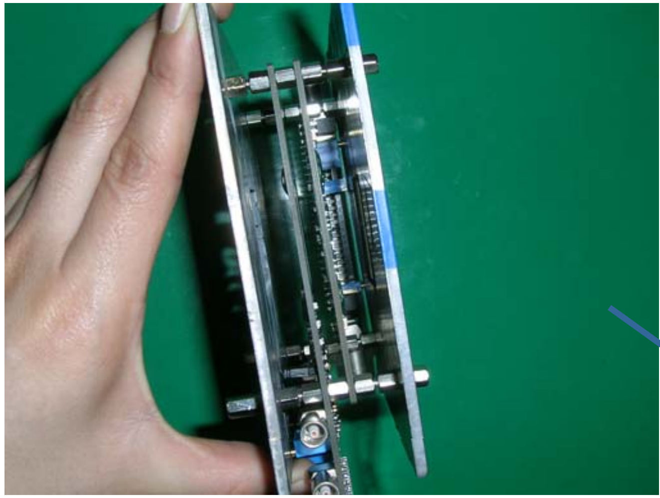


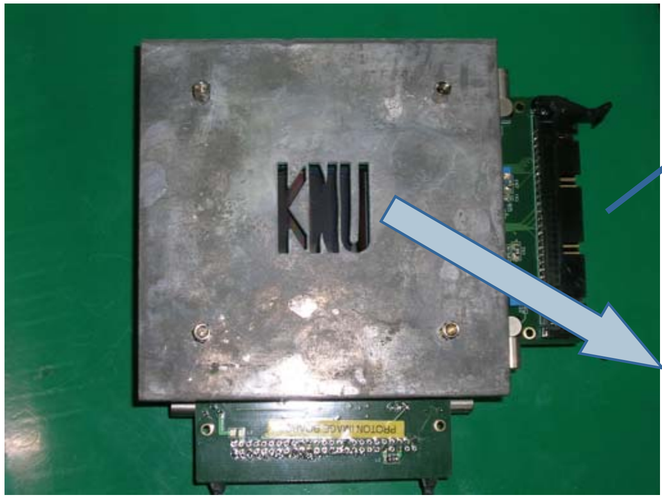
•current related damage rate α is expected to be independent of irradiation

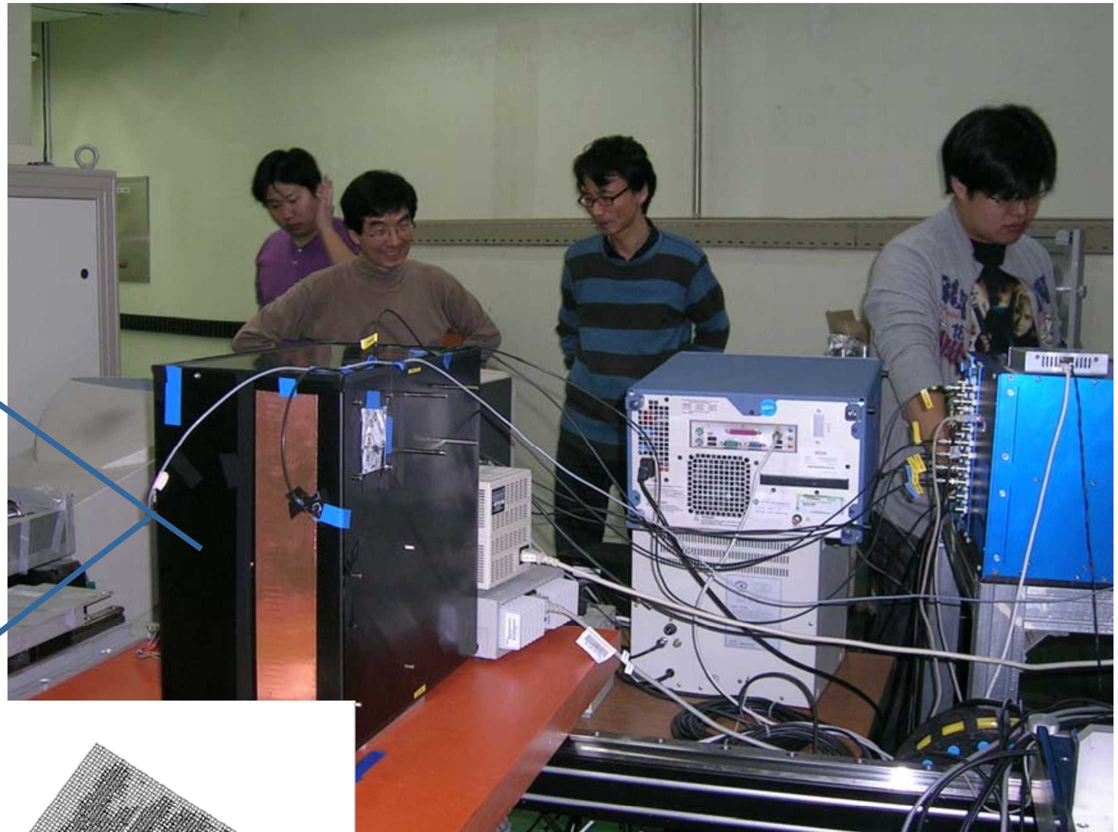
• $$\Delta I / V = \alpha \cdot \Phi_{eq}$$

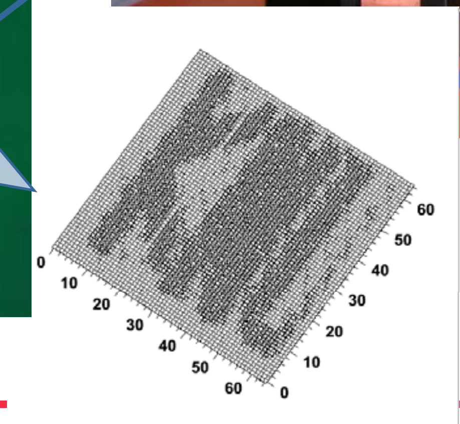
• α can be used to monitor the particle fluence

More Beam Test at KIRAMS on 2007 :analysis ongoing

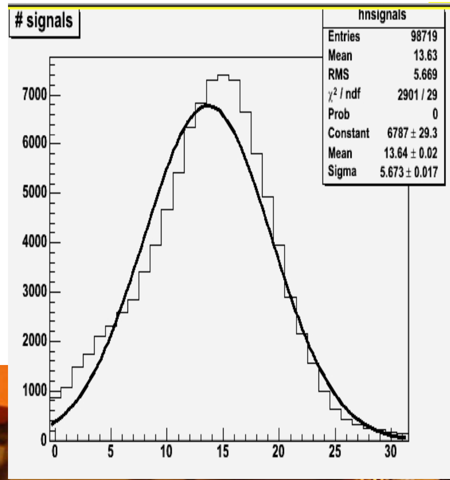


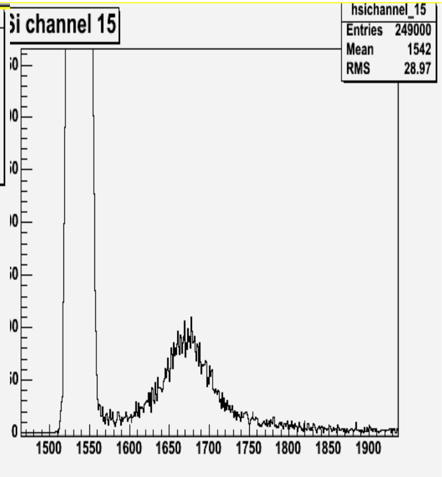




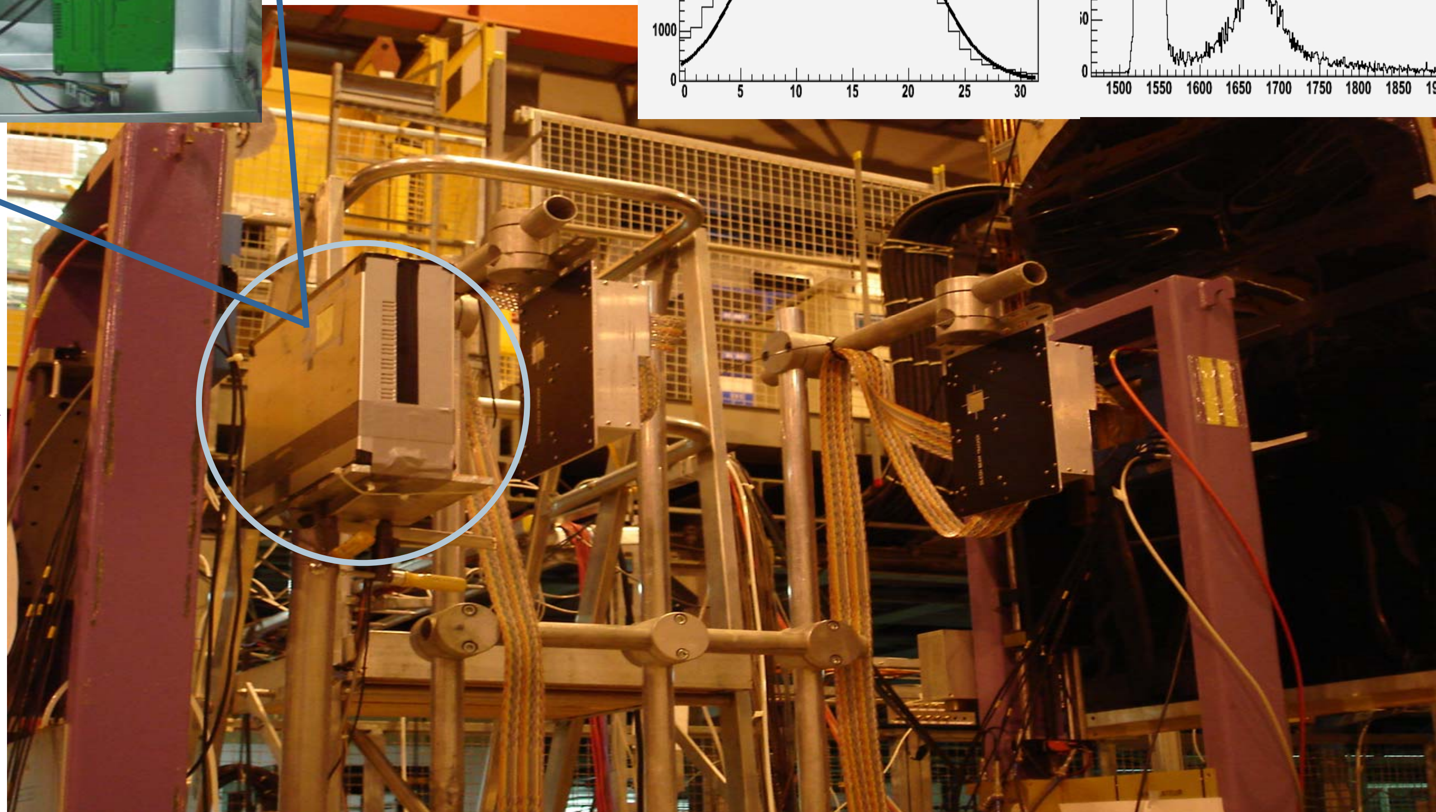


Beam Test at CERN on 2006 : analysis on going





150 GeV electron beam



Summary and Prospect

- Double sided silicon sensor, DC-type single sided silicon sensor and AC-type single sided silicon sensor was successfully produced and tested.
- Beam test and radiation damage shows that developed sensor can be used for the ILC environment.
- Radioactive source test and beam test showed that S/N ratio is good enough for the ILC environment.
- Electronics R&D is under progress.