CCD Vertex Detector and Beam Background

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- Study of CCD sensors
  - Spatial resolution - Beam test results
  - Radiation hardness test
- Beam background and R_{min}

Study of CCD Sensors

R&D goal :

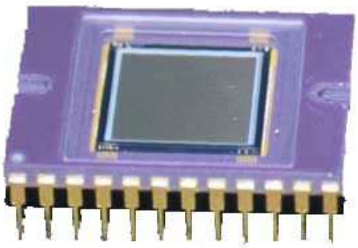
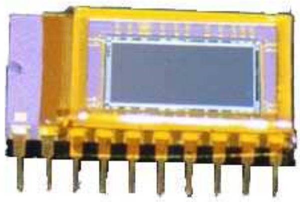
Normal temperature (> 0 deg.) operation of CCD vertex detector in the environment of JLC experiment

- Avoid thermal distortion of wafers
- Free space (no cryostat) for forward-tracker and beam monitors

Collaboration:

KEK
Saga Univ.
Tohoku Univ.
Niigata Univ.
Toyama Nat. Col. of Maritime Tech.

CCD samples

	Hamamatsu S5466	EEV CCD02-06
		
Pixel size	24 μm	22 μm
Epi. thickness	10 / 50 μm	20 μm
Gate oxide	SiO_2	SiO_2-Si_3N_4
Clock	2-phase	3-phase
Gain	2 μV/e	1 μV/e
Mode	Inverted	Inverted

(Surface current is strongly suppressed with inverted mode)

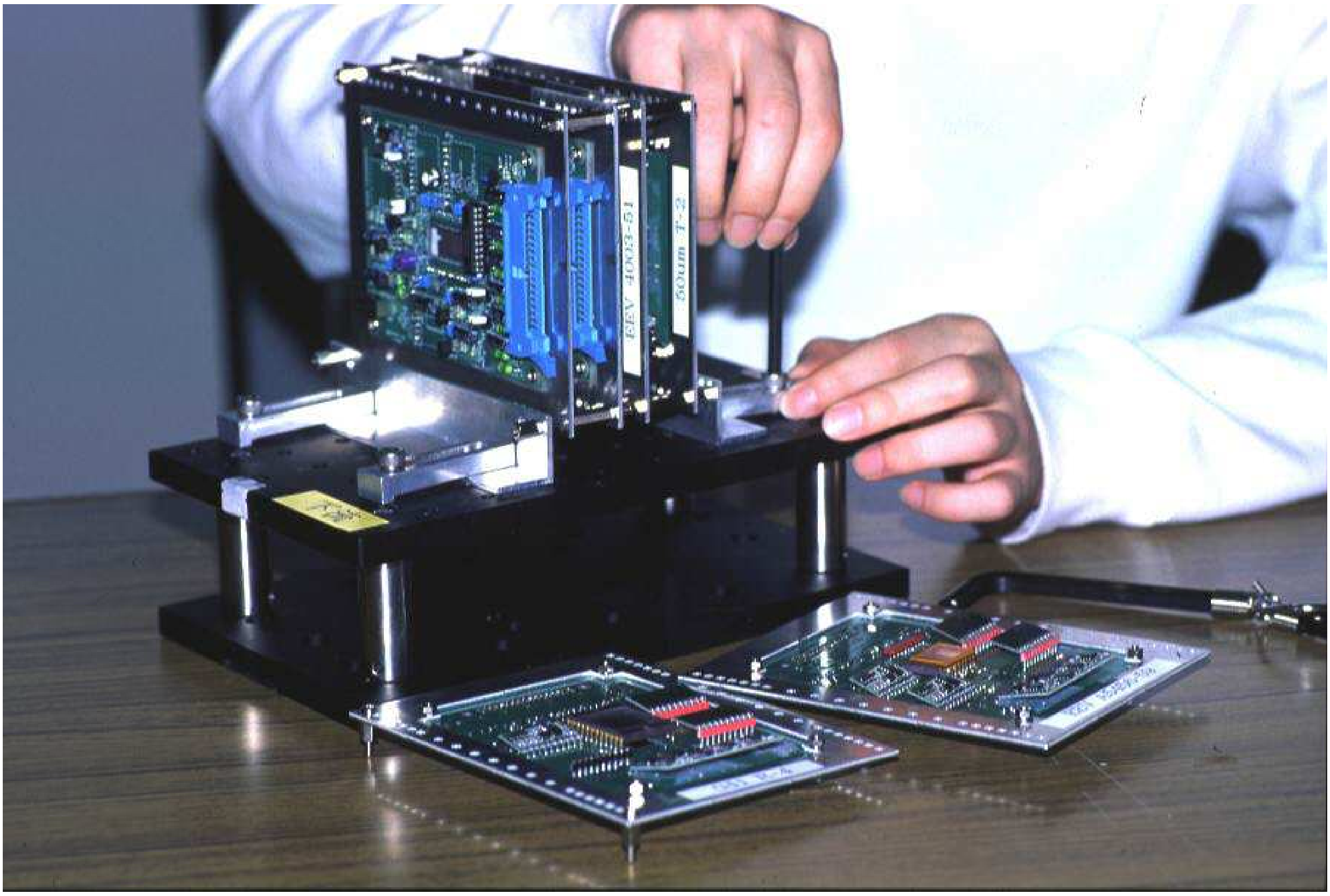
Study of spatial resolution

Test beam experiment:

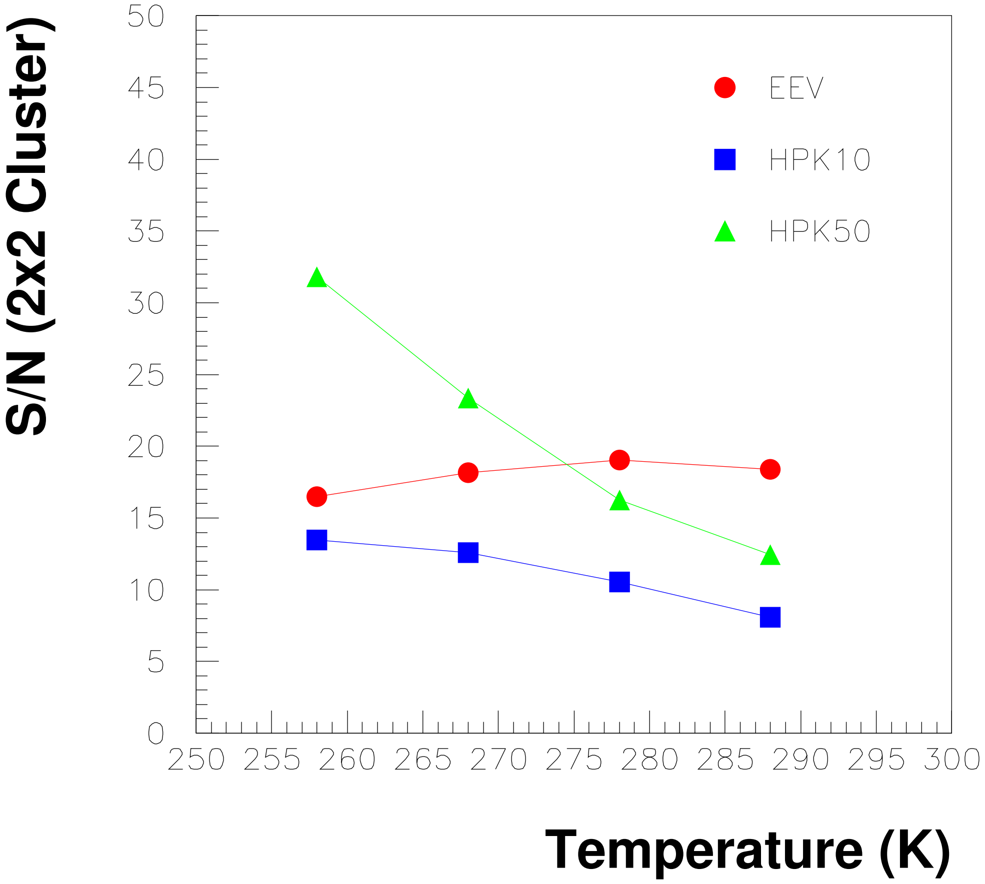
- 0.5, 0.7, 1.0 and 2.0 GeV/c p- beam
- Incident angles of 0, 45, and 60 degrees
- Operation temp. -15 ~ +15 degrees
- Readout cycle; 3 sec (= PS machine cycle)
- 4 layers of CCD samples

    1st, 2nd, 4th layers: HPK 10μm

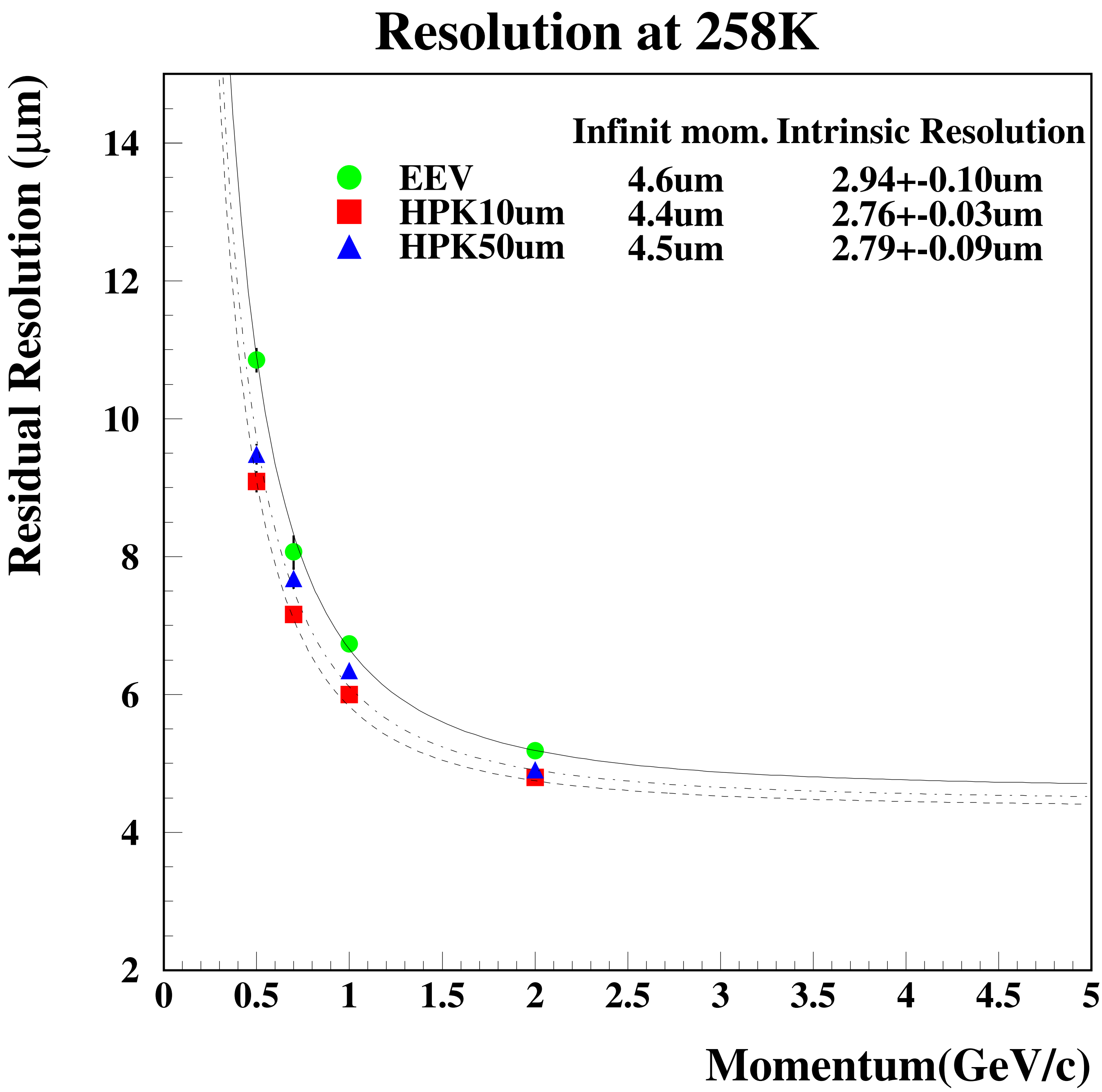
    3ed layer: HPK 10μm, 50μm, EEV 20μm



S/N ratio


EEV
HPK10
HPK50
S/N (2x2 Cluster)
Temperature (K)
0
5
10
15
20
25
30
35
40
45
50
250
255
260
265
270
275
280
285
290
295
300

Spatial resolution



$$\delta^2 = 2\sigma^2(L_1^2+L_2^2+L_1L_2)/L_1^2+(\theta_{MS}L_2)^2$$

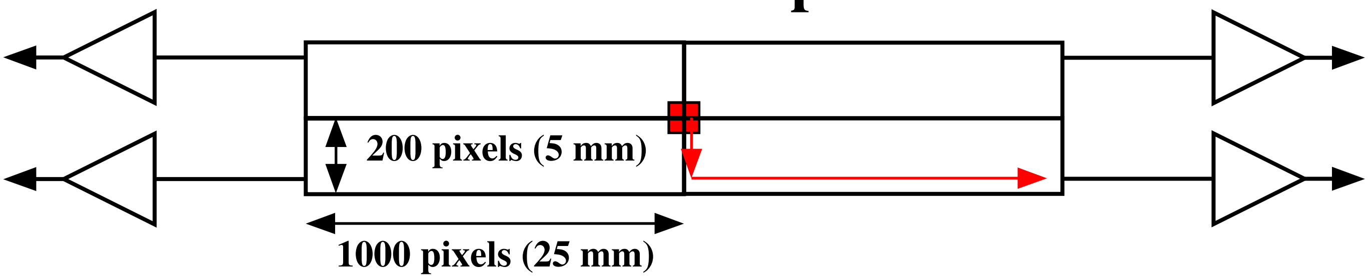
(δ : residual resolution, σ : intrinsic resolution)

Radiation hardness test

Radiation damage on CCD sensors

- Increase of dark current (surface, bulk)
- Shift of operation voltage (surface)
- Increase of charge transfer inefficiency(CTI) (bulk)

Model chip



Requirement for CTI:

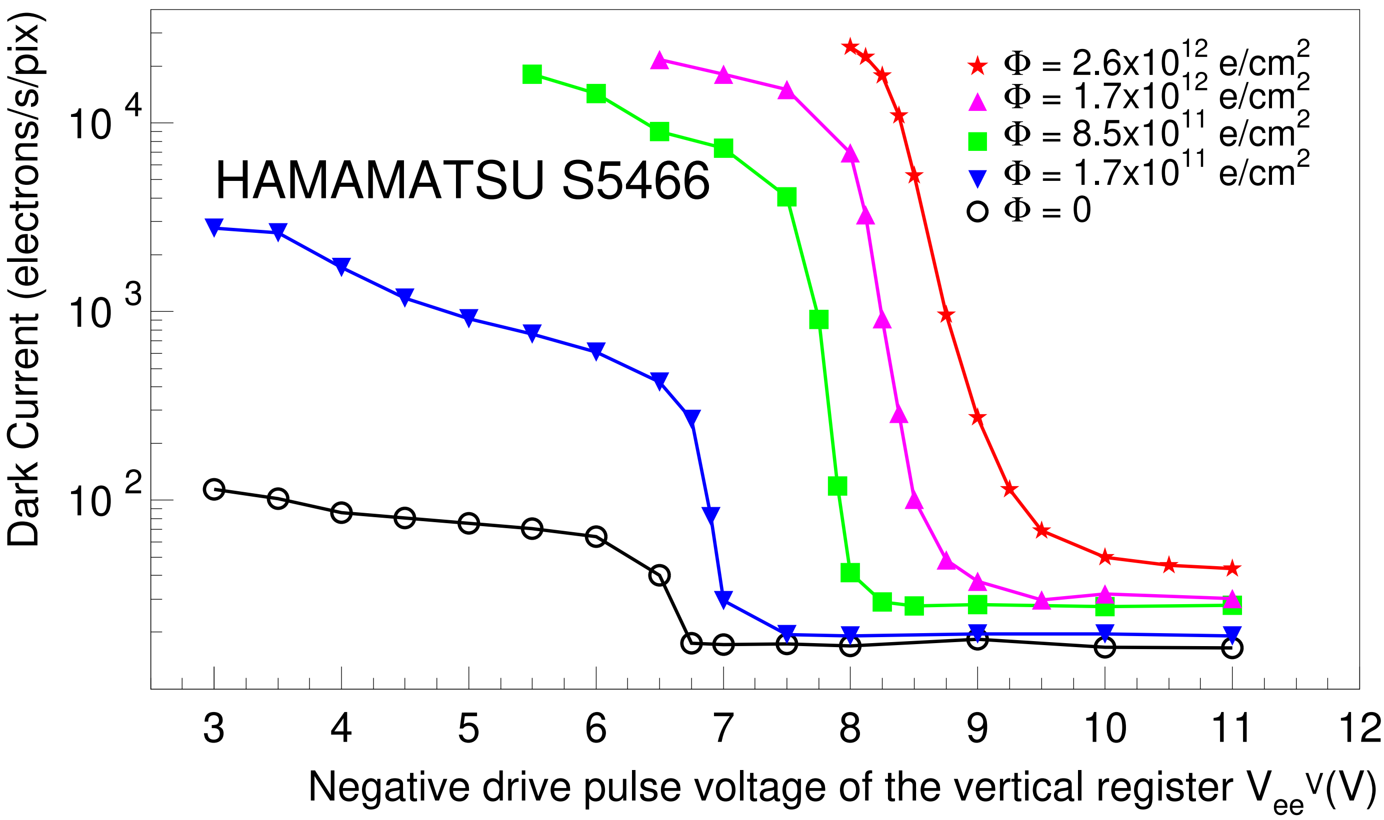
Vertical CTI < $1*10^{-3}$: $(1-0.001)^{200} = 0.82$

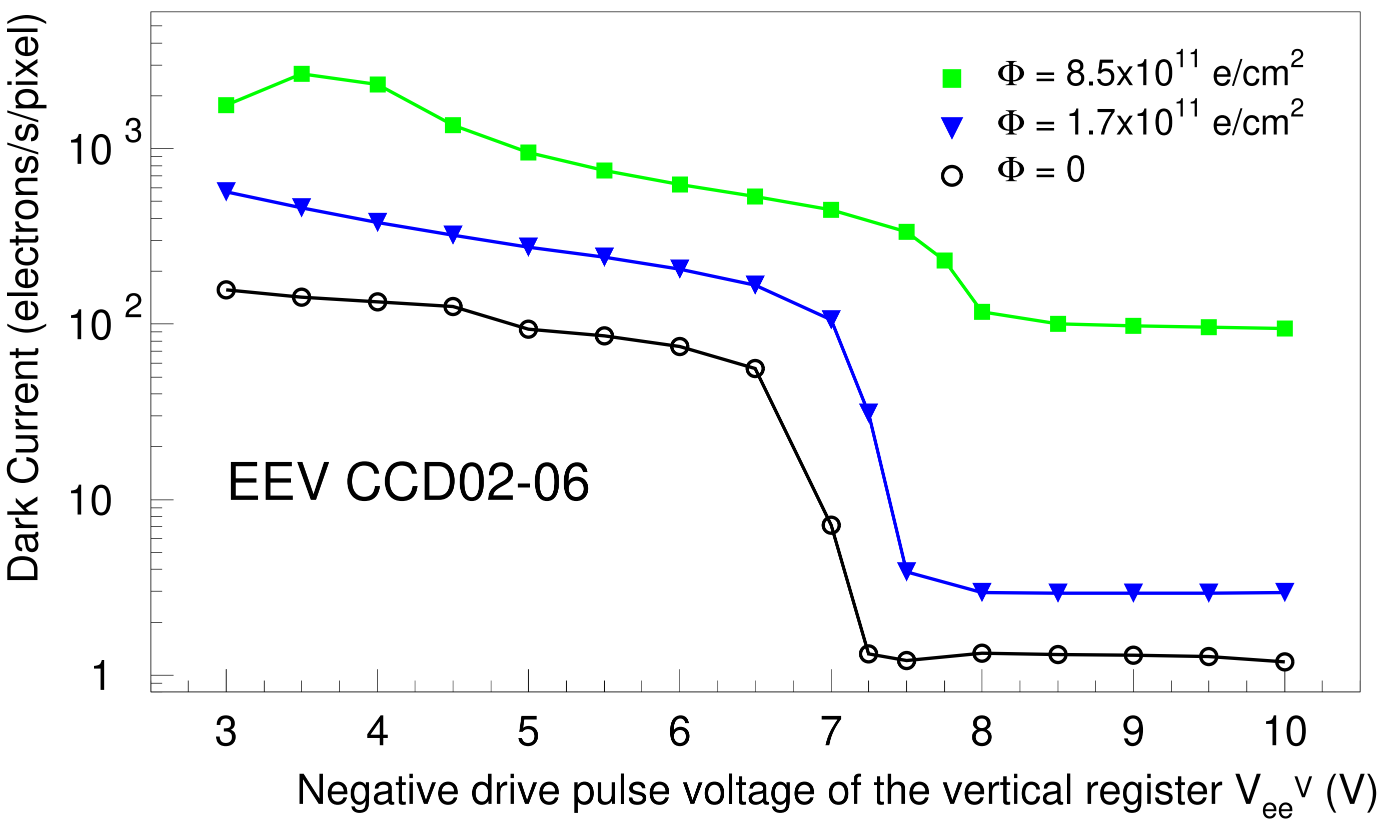
Horizontal CTI < $0.2*10^{-3}$: $(1-0.0002)^{1000} = 0.82$

-> Worst case: $0.82*0.82 = 0.67$

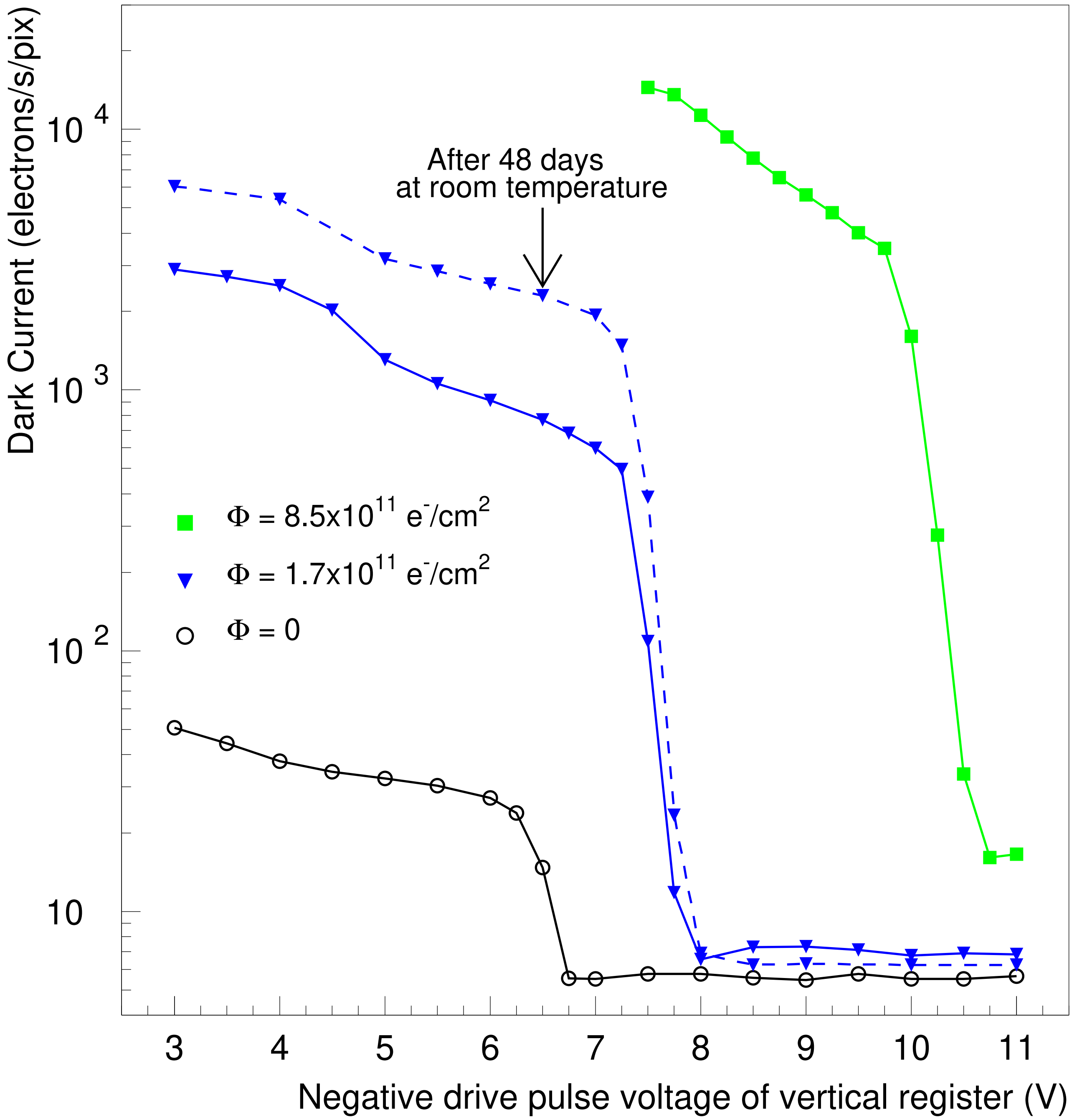
Electron damage - ^{90}Sr

Dark current at -30 deg. (all pins grounded during irradiation)

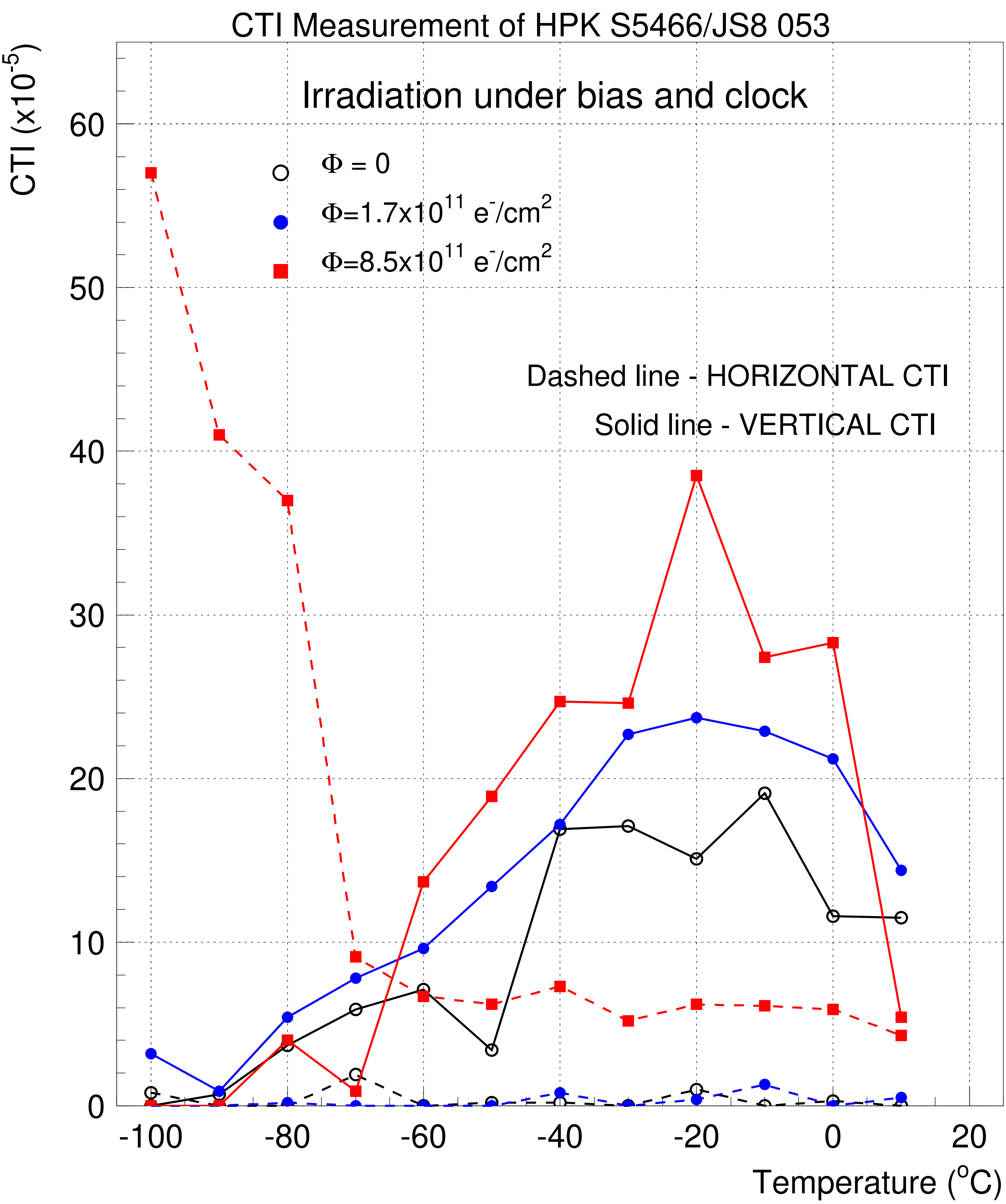




Dark current at -30 deg. (with clocking during irradiation)



Note that surface damage by MIP electrons is 1/3 smaller than ^{90}Sr electrons

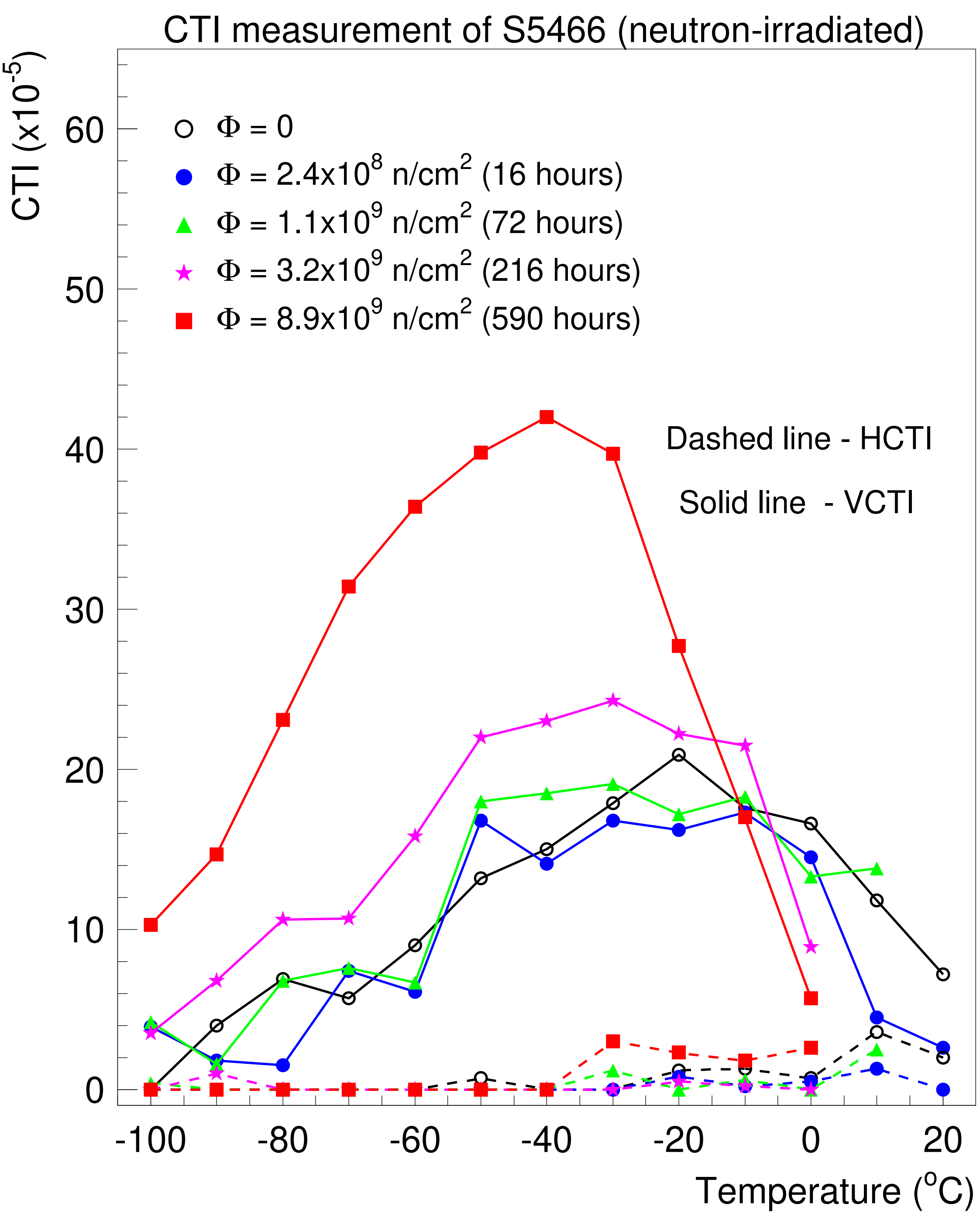


-> Limit ~ $1.5*10^{12}$ e/cm^2

Note that bulk damage by MIP electrons is stronger (few times but less than x10) than low energy (~1 MeV) electrons.

-> Limit > $1.5*10^{11}$ e(MIP)/cm^2

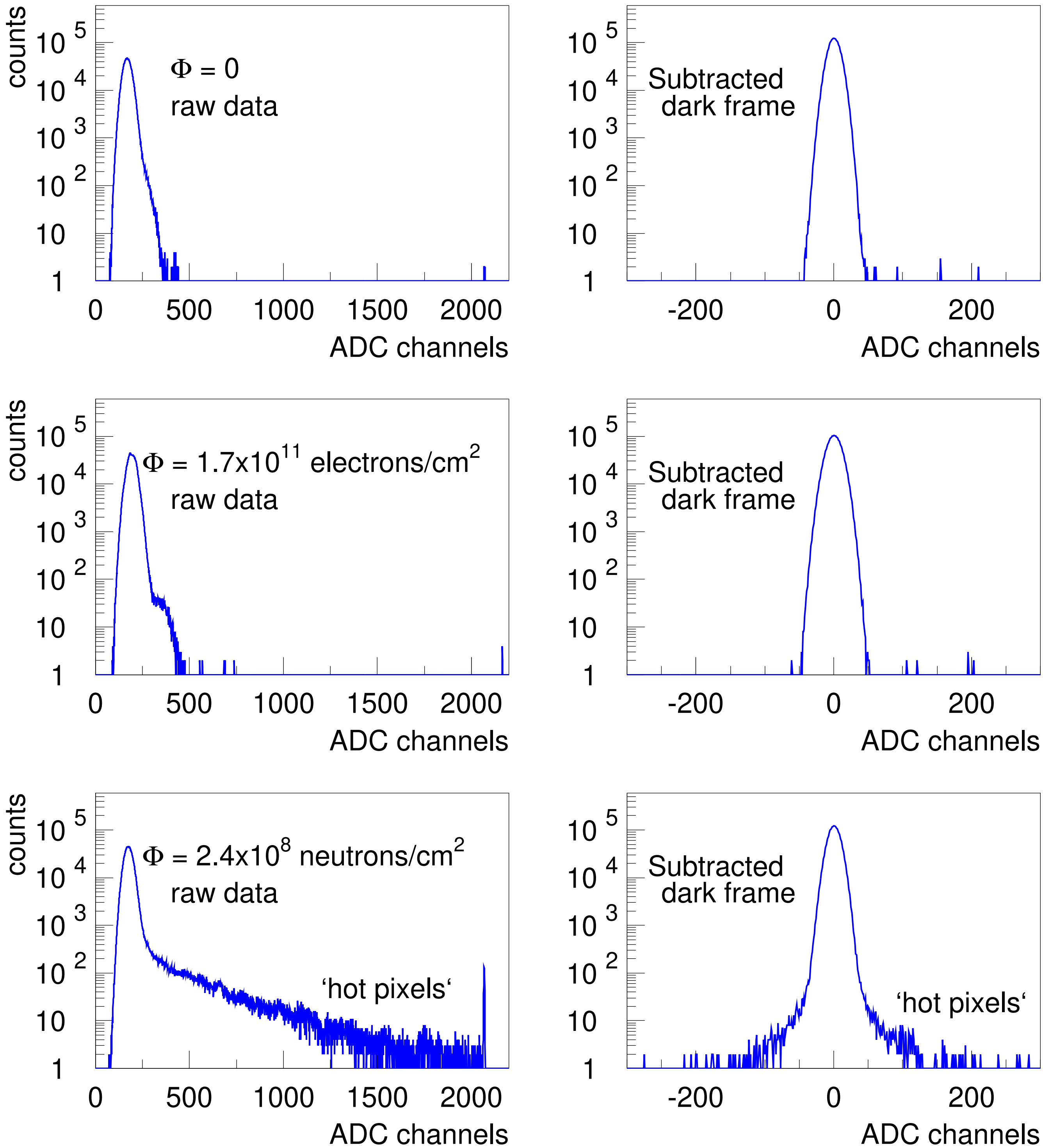
Neutron damage - ^{252}Cf



-> Limit ~ 1.5*10^{10} n/cm^2

Dark current spectrum

Comparison between electron- and neutron irradiation at +10°C, Hamamatsu



Beam background and R_{min} of the vertex detector

Neutron background : $1*10^9$ /cm^{2}y -> OK

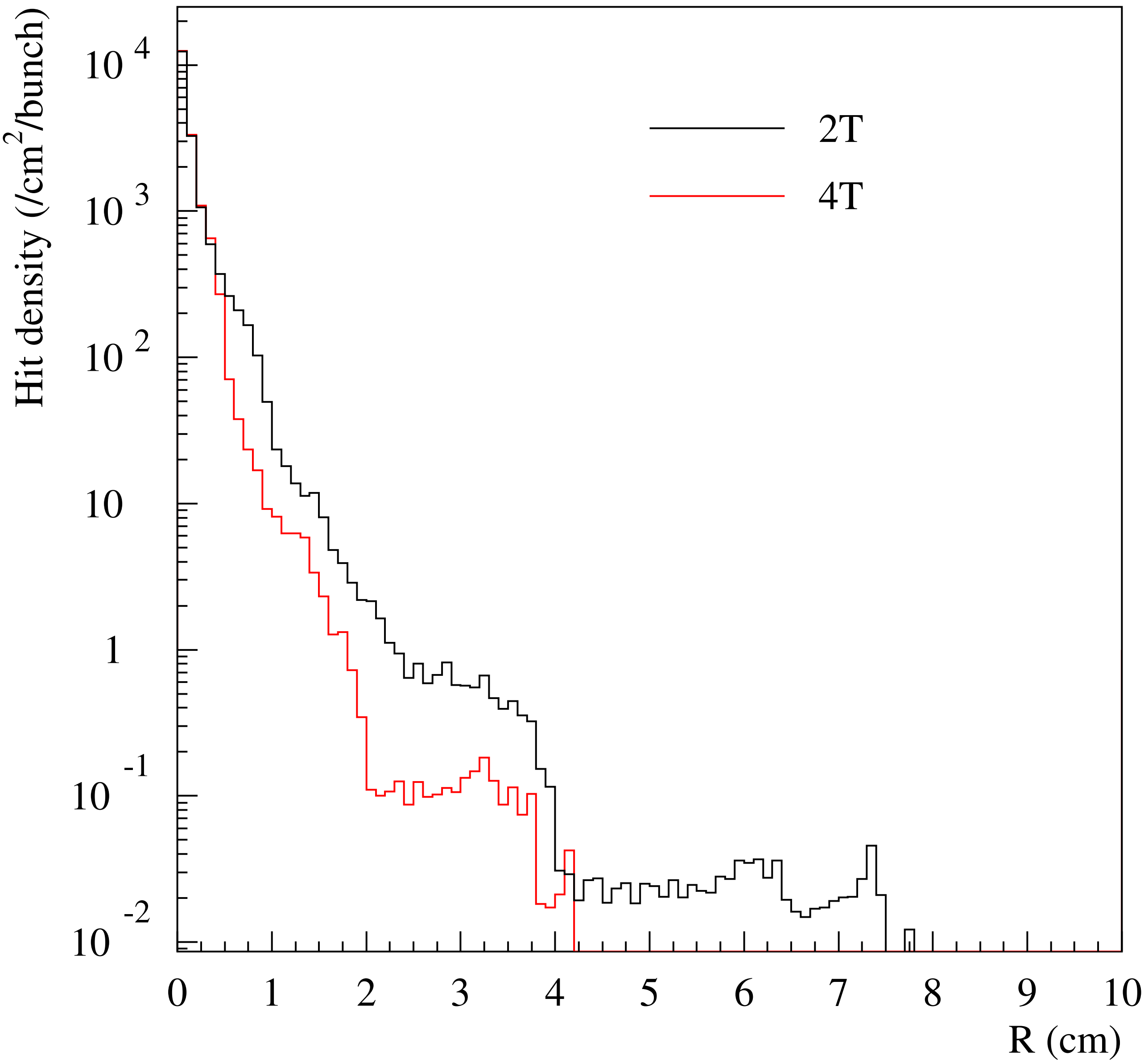
e^+e^- pair background : $1.5*10^{11}$ /cm^{2}y @2.4cm
-> OK
What about smaller R?

How to make R_{min} smaller?

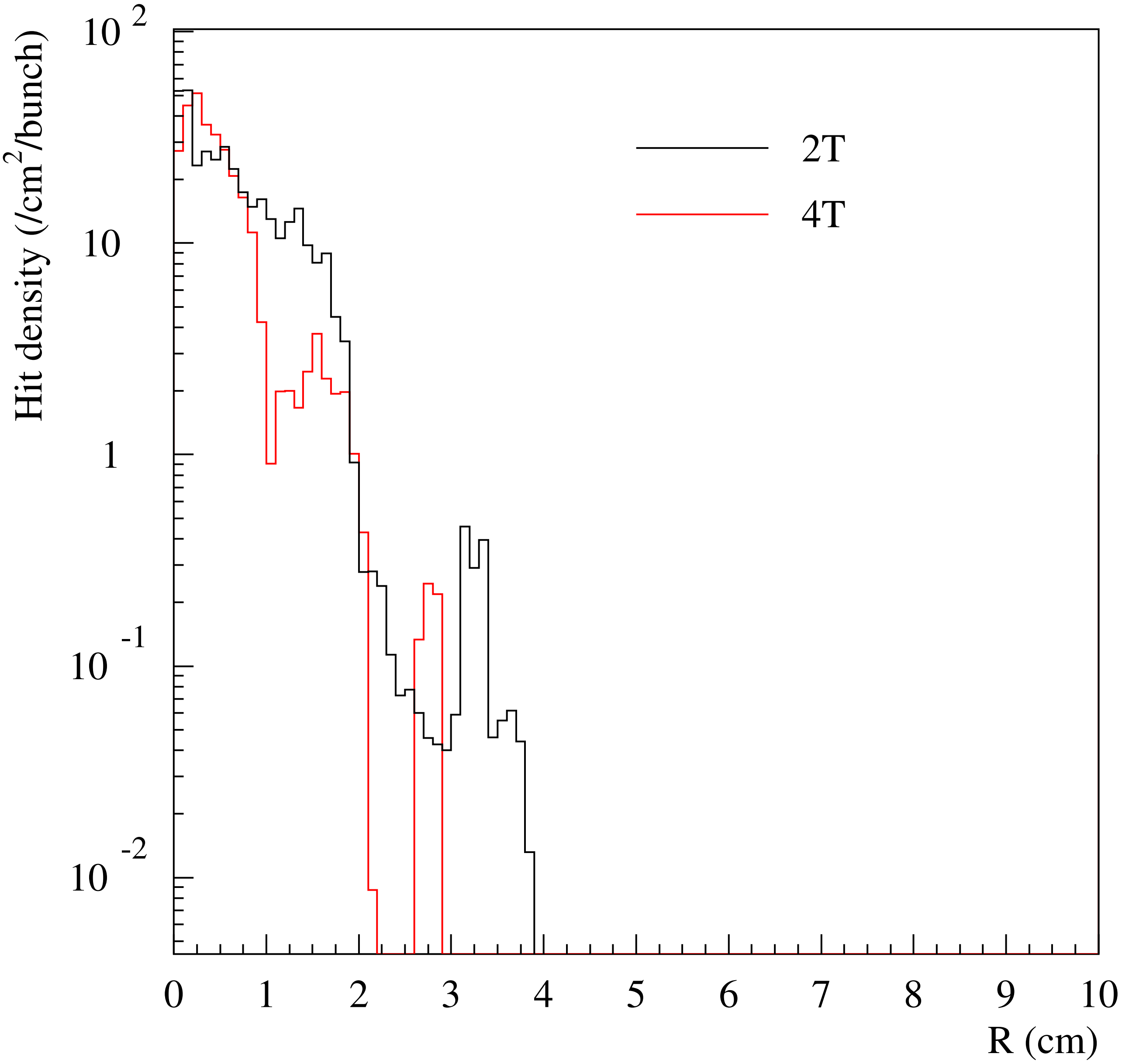
Stronger B field

Hardening of CCD
- Narrower transfer channel
  (reduce # of traps)
- Fat-zero charge injection
  (fill up traps)
- High speed operation
  (readout signal before trapped)
- Low temperature operation
  (suppress ejection from traps)

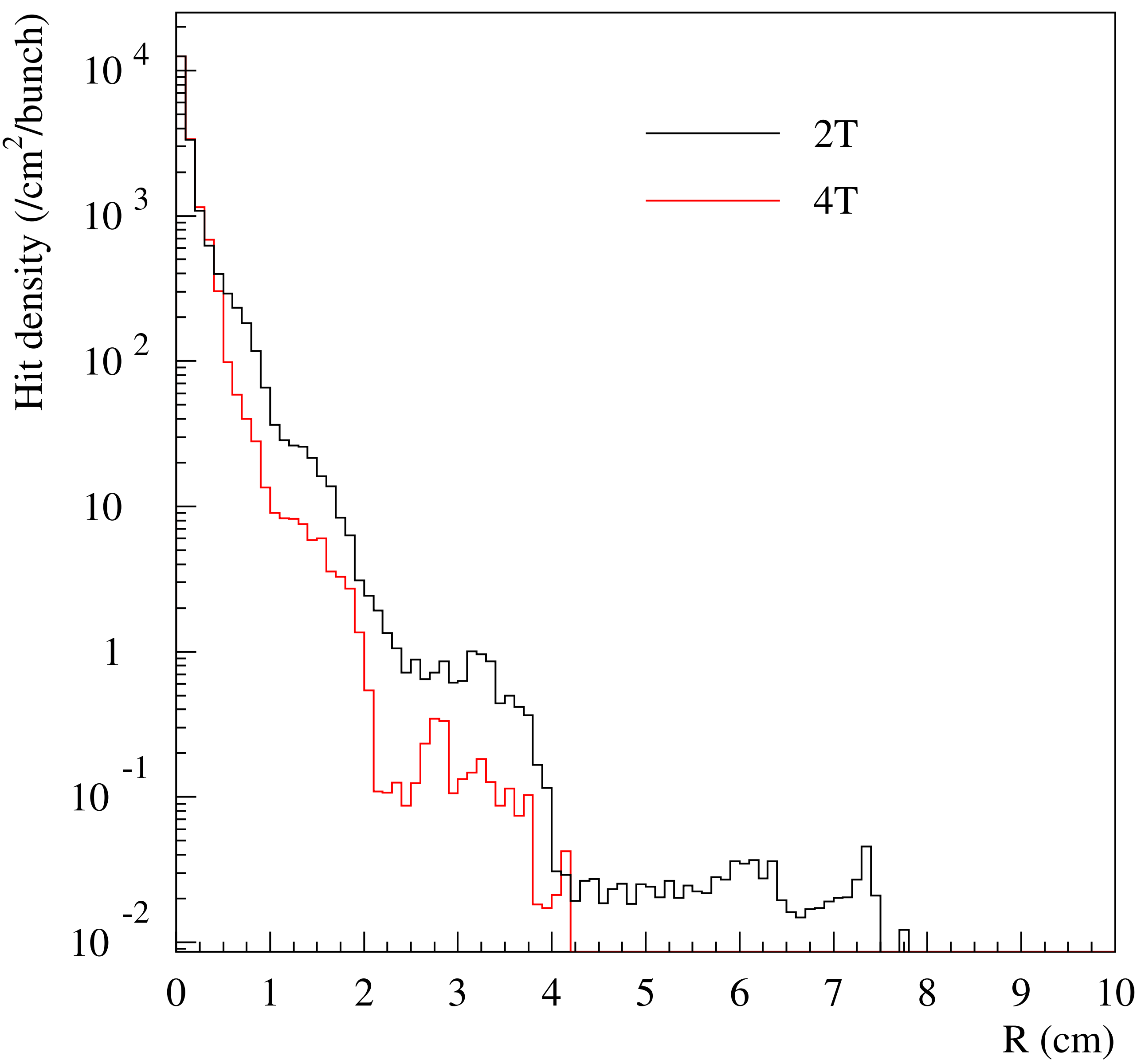
1 hit /cm^2/bunch = 1.5*10^{11} /cm^2y



Direct hit



Backscatter



Hit density (/cm^2/bunch)
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
2T
4T
0
1
2
3
4
5
6
7
8
9
10
R (cm)

Total hits

Summary

- CCD vertex detector can achieve

  - S/N > 10 even at normal temp.(> 0 deg.)
  - Spatial resolution < 3 μm
  - Radiation tolerance

    $1.5*10^{12}$ /cm^2 for e$^-$ from ^{90}Sr

    $1.5*10^{10}$ /cm^2 for neutrons

    -> CCD can be put at R=24 mm in the JLC experiment

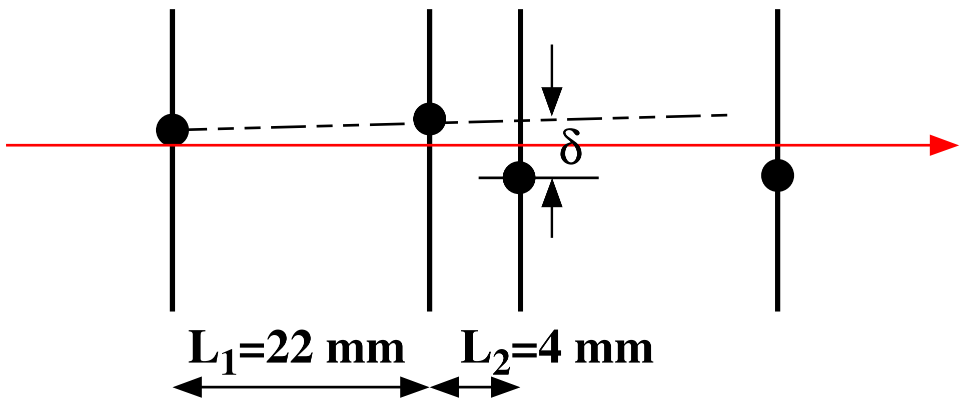
    Several times better tolerance is anticipated with hardening technology

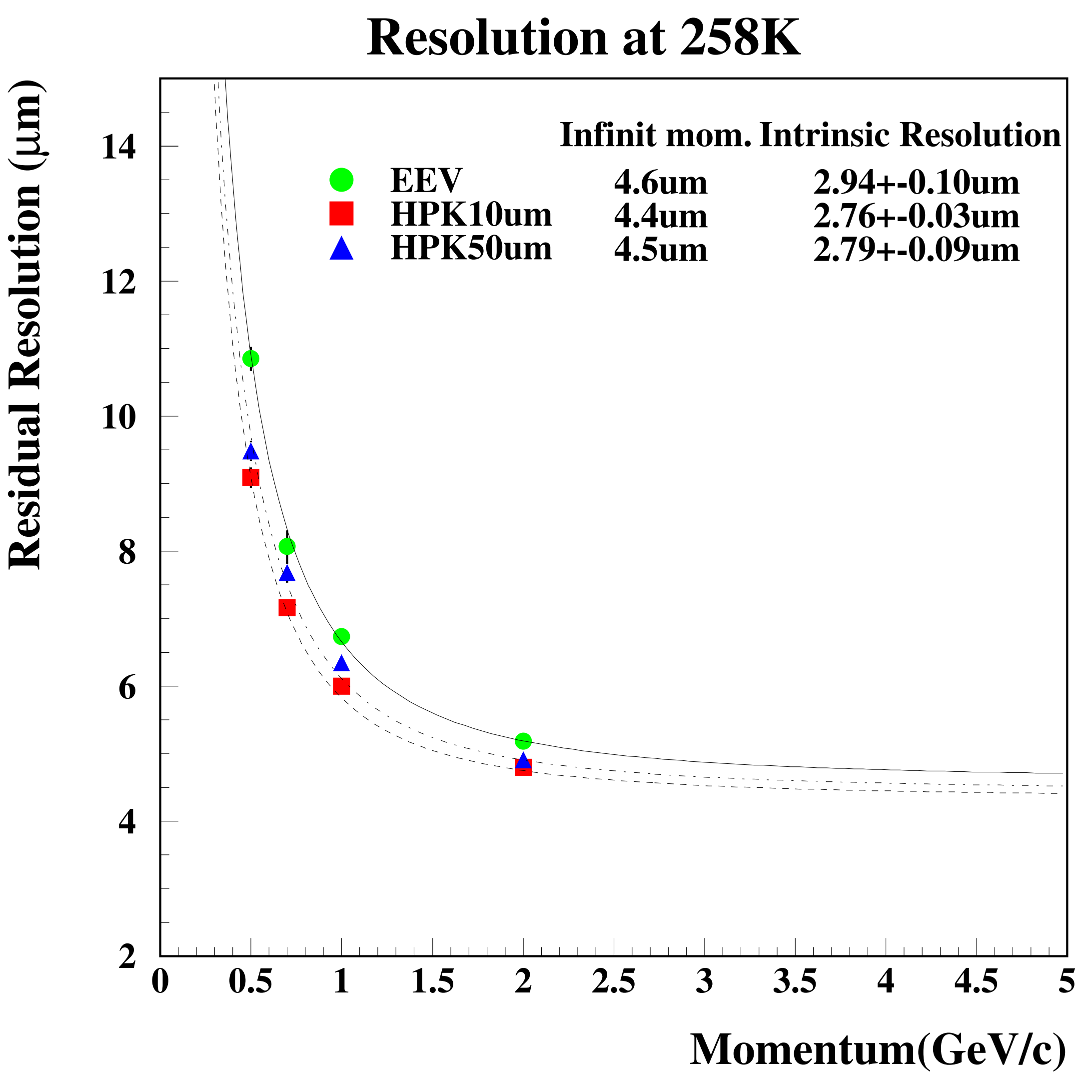
    If operated at -100 degrees, 5 ~ 10 times better tolerance can be obtained

- To make R_{min} of the vertex detector smaller

  - Stronger B field is preferable.
  - Otherwise, more R&D effort and/or low temperature operation is needed.

Spatial Resolution





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