Radiation monitoring in Mrad range using FET transistors

Samo Stanič
University of Tsukuba
For Belle Monitoring Group

JPS Meeting, Hakata
2004/03/30

Introduction: Necessity of radiation monitoring

In many ongoing particle physics experiments a Si based vertex/tracking detectors are situated extremely close to the interaction point, which results in high radiation backgrounds in these detectors.

In the case of Belle experiment at e^+e^- collider in KEK, the major part of the background are scattered beam particles (~70%) and synchrotron radiation (~30%). Rates in present IR design are ~200kRad/year

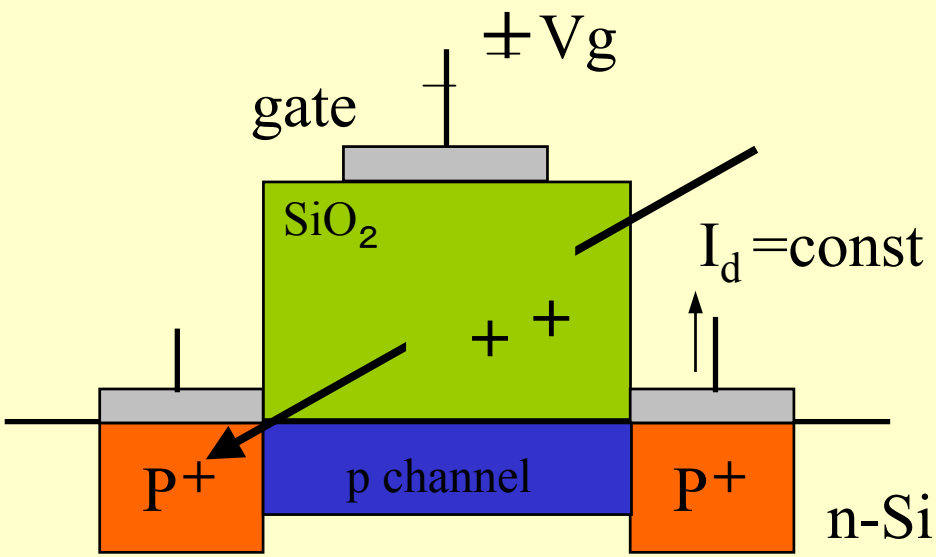
To ensure maximal lifetime and performance of these devices, the dose rates and total doses need to be monitored and used as a feed-back to accelerator operation and design parameters.

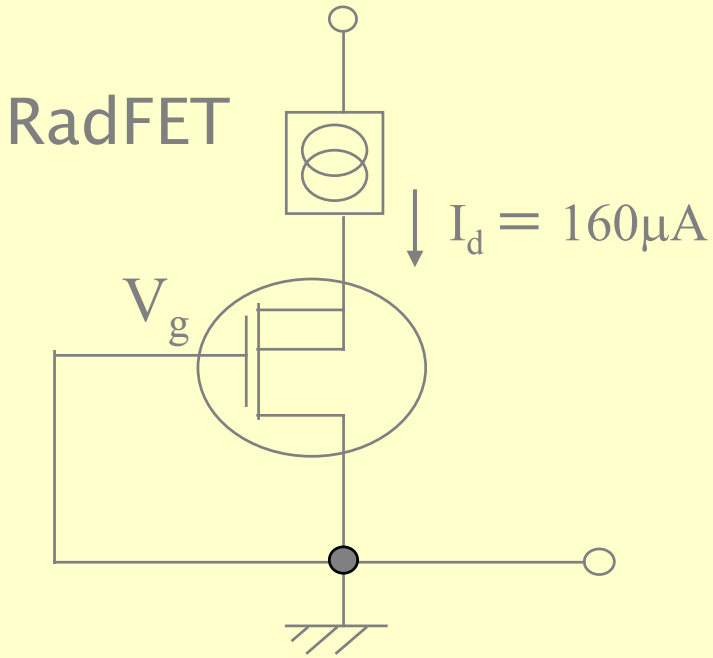
In our case, we are interested in surface damage of Si detectors.

Radiation monitors

RadFET (radiation sensitive MOSFET) transistors for measuring the integrated dose

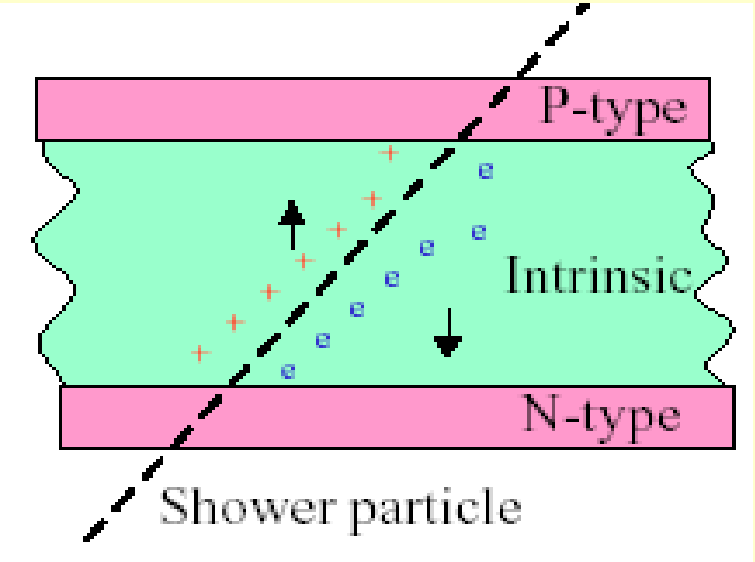
- radiation damage is detected as a threshold shift of the transistor (at constant current of 160μA) due to charge accumulation in the gate insulator – same damage mechanism as CMOS chips

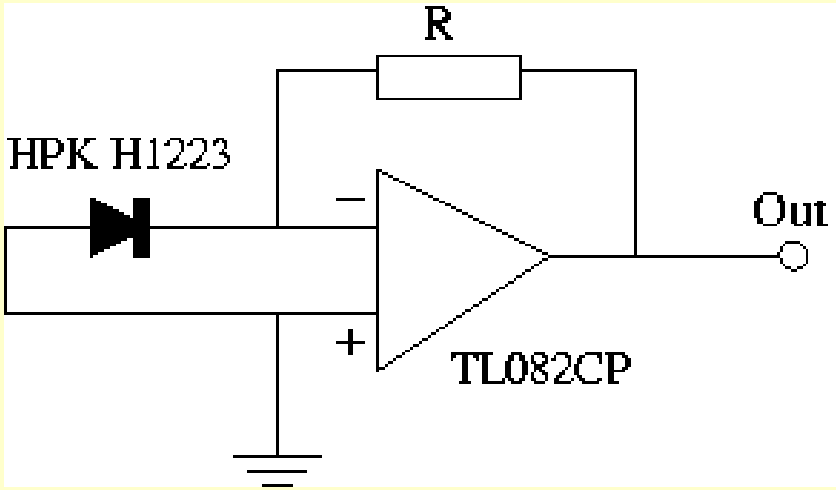




PIN diodes HPK H1223 (4x6x0.3mm^2) for measuring the instantaneous dose rate

- Used unbiased in order to reduce temperature drift of dark current
- Enough S/N due to close proximity of front-end amplifier to the PIN
- Accumulated dose related to created charge (time integration of induced current)





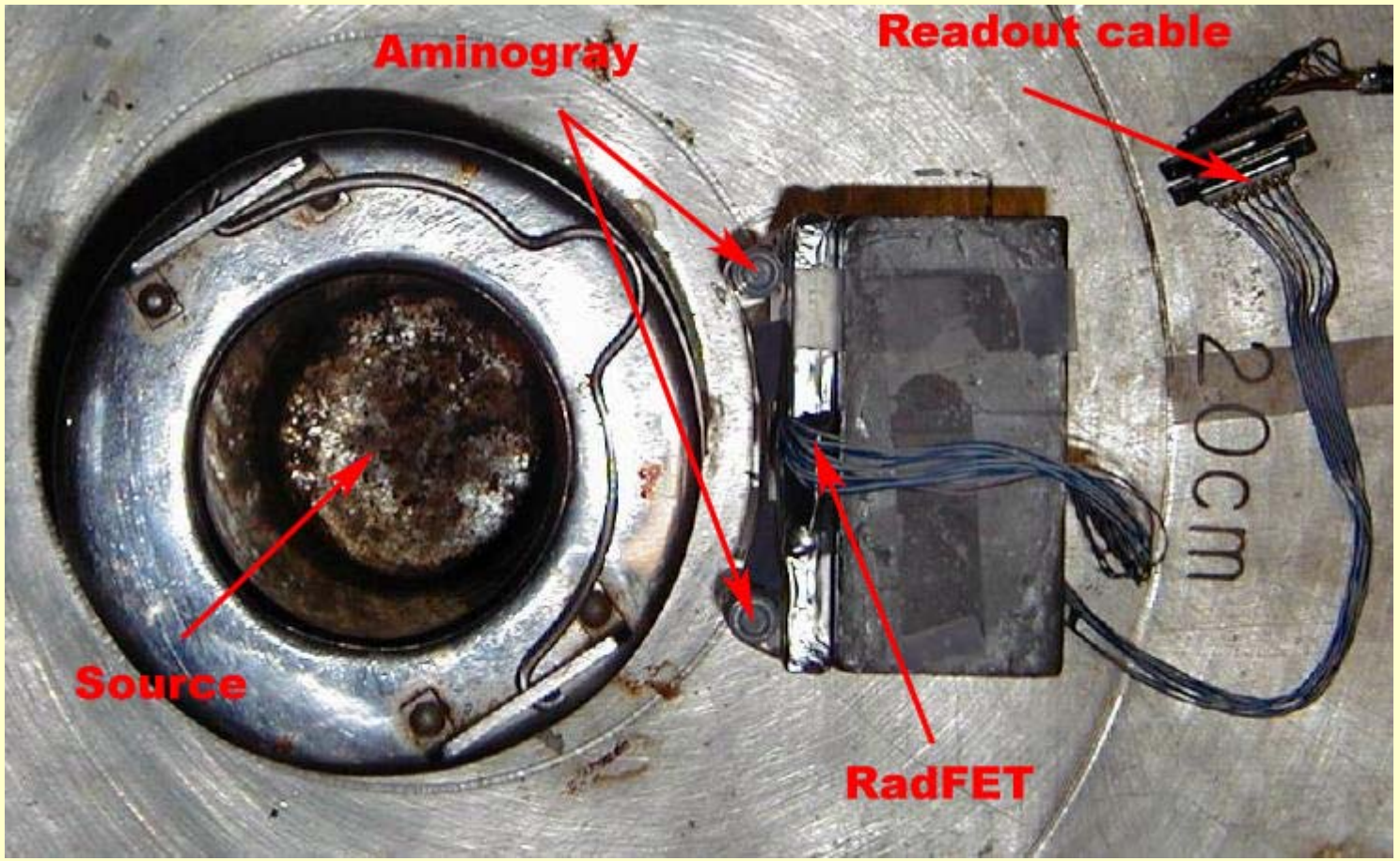
Calibration of RadFET/PIN

Both types of sensors have to be calibrated by a radiation source with known activity to be able to use them for absolute measurements!

- For survival and calibration reasons both PIN and RadFET have to be tested up to the expected doses – more than 2MRad for Belle / SuperBelle
- RadFET response is not linear with dose. To correctly estimate radiation damage, we calibrated the RadFET (at constant current of 160μA) with 15% error.
- PIN diodes initially calibrated relatively to RadFET, as we found that their gain decreases with dose. Now, an independent calibration and gain decrease study is in progress.

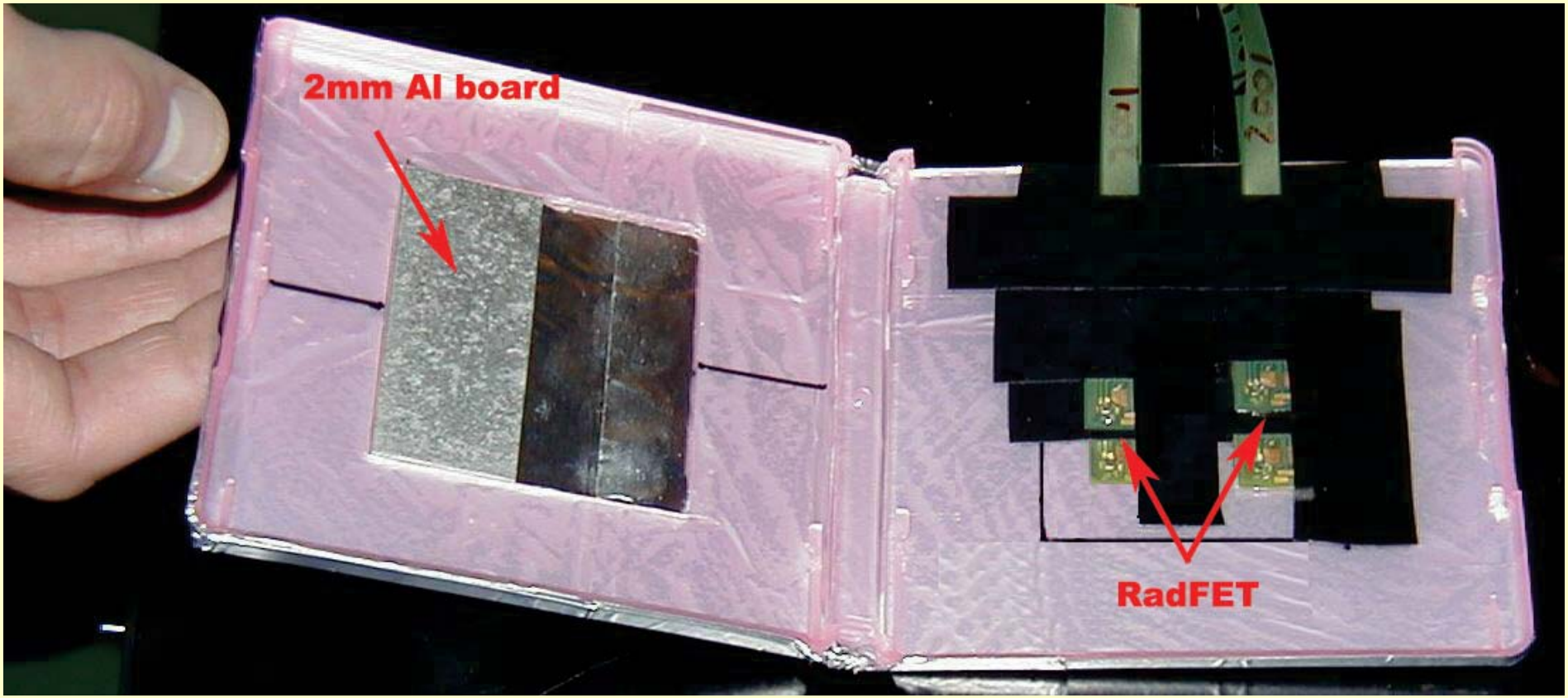
Irradiation

Irradiations were done with a calibrated Co-60 source at TIT in Tokyo. All doses were confirmed by our own dosimetry (using commercial AMINOGRAY aniline dosimeters from Hitachi).



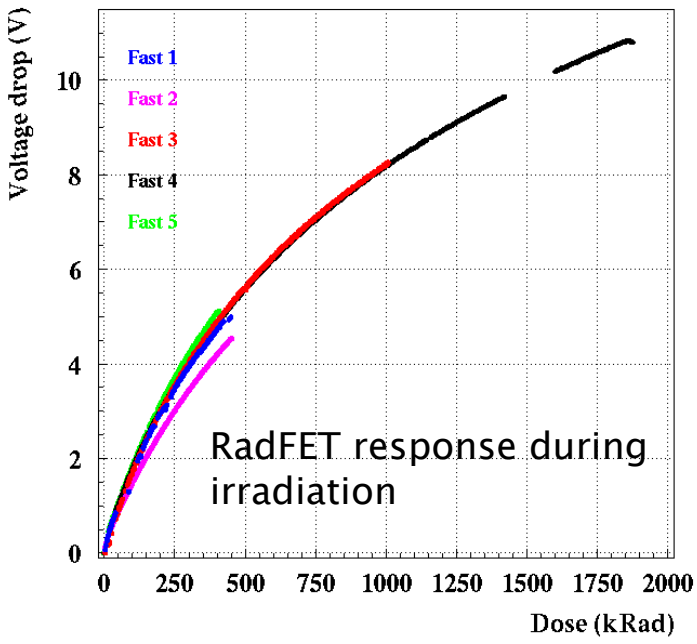
Compton Scattering

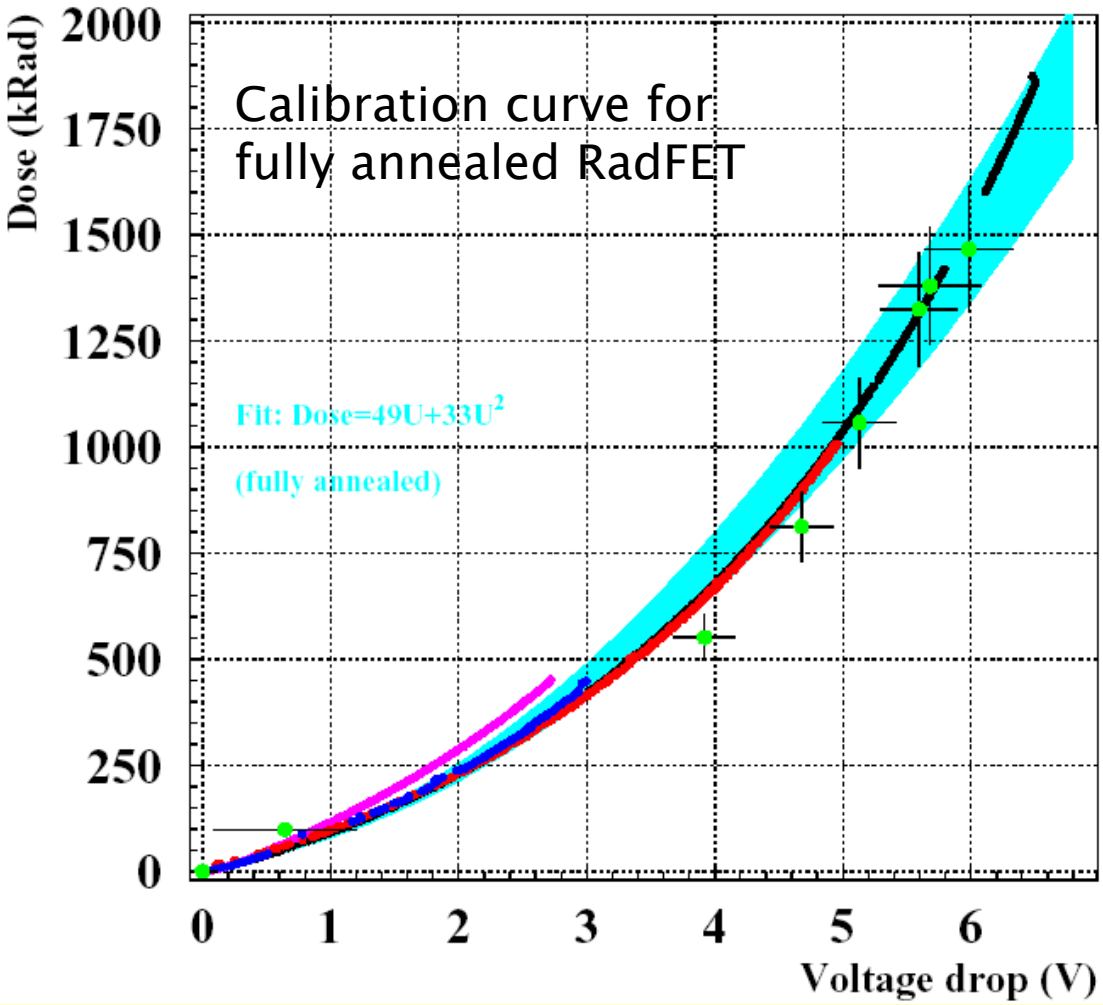
There was no observable difference in RadFET response with and without 2mm thick Al board (Compton scattering) in front of the sensors



RadFET calibration results

- In 5 irradiations we confirmed that K range RadFET can be used up to at least 2MRad
- good reproducibility of the sensor response





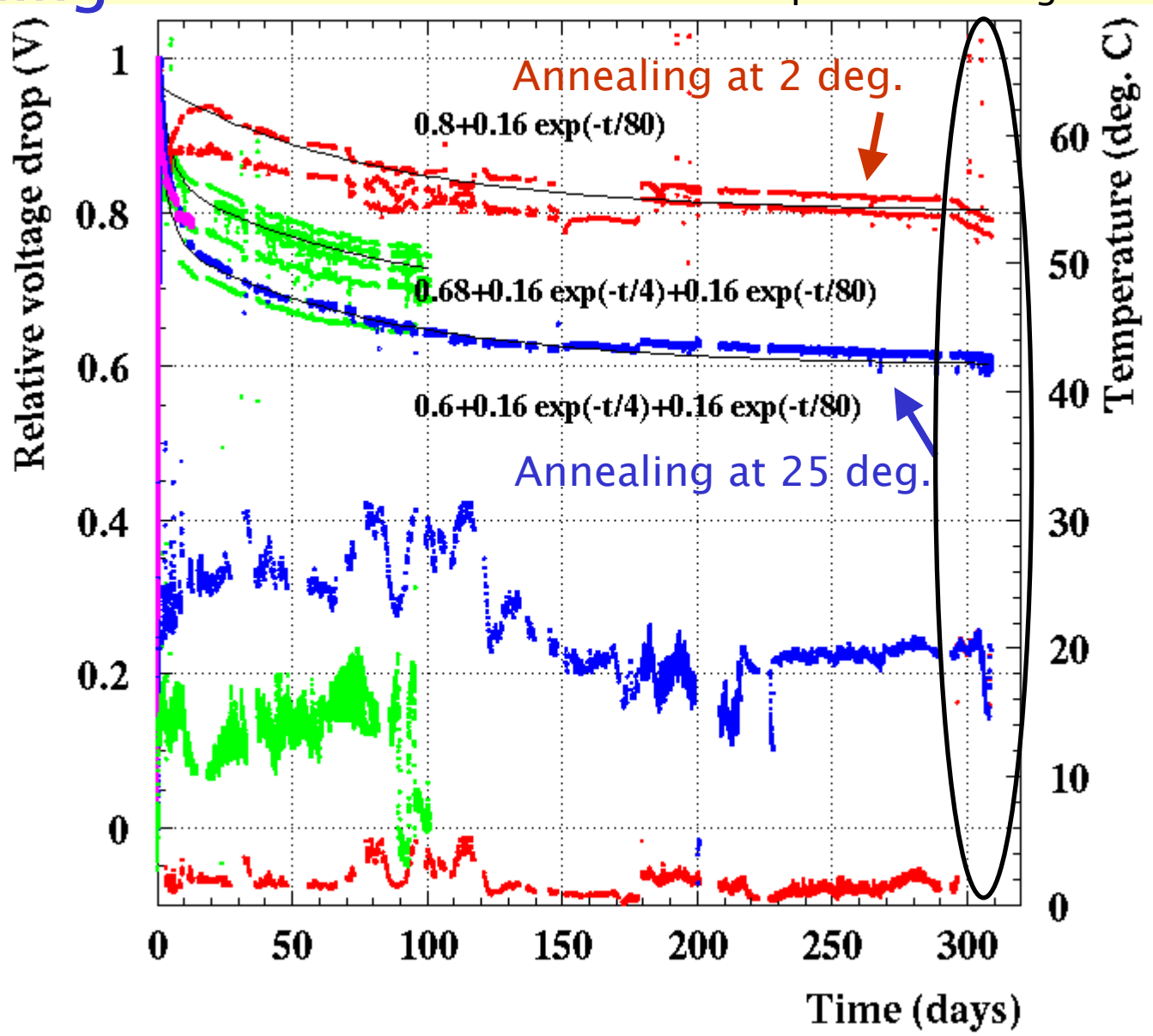
- Low dose rate (1.6kRad/h) irradiation results agree with high dose rate (80kRad/h) ones

RadFET Annealing

Increase temp. 2 -> 20 deg.

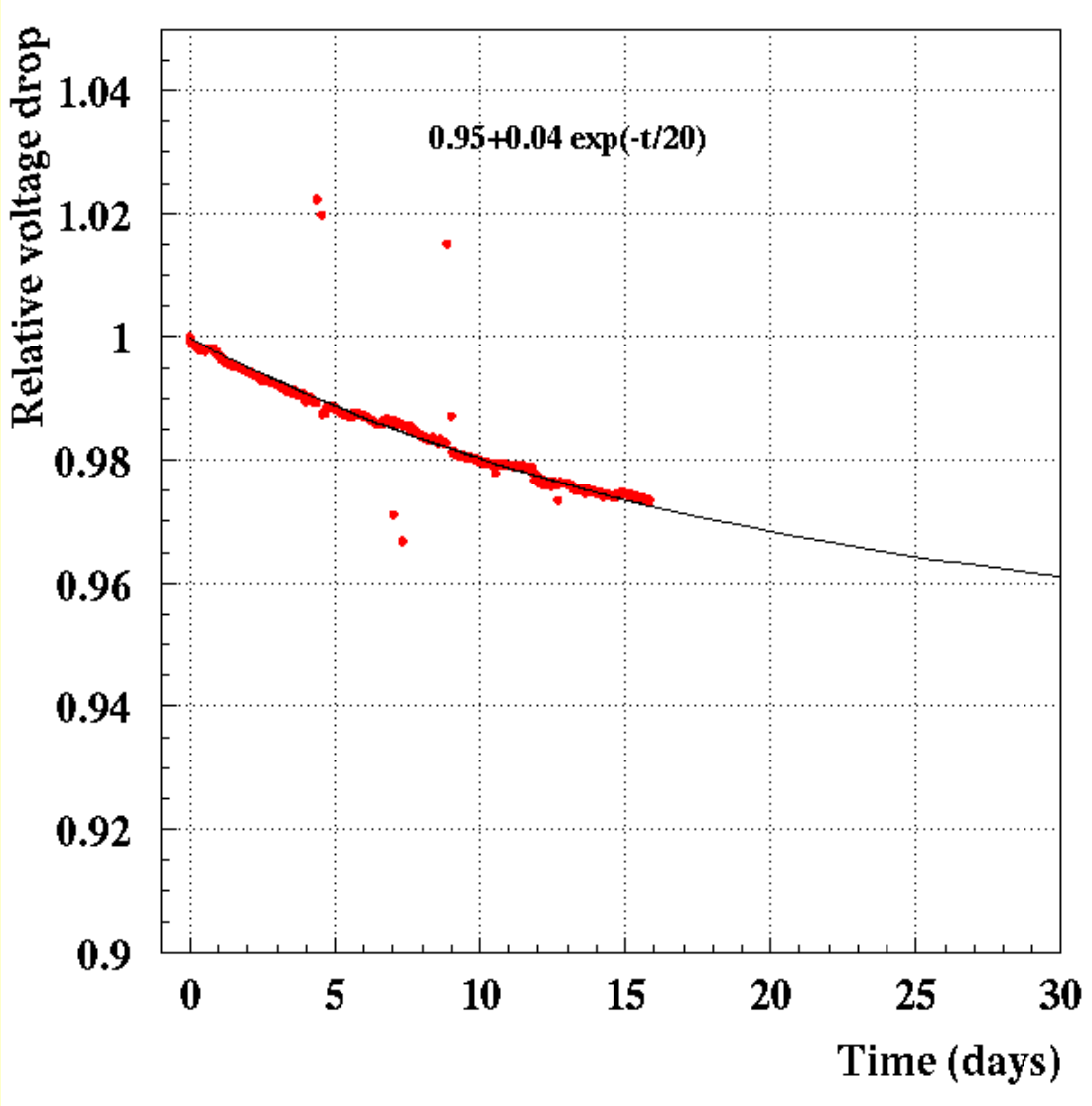
- We found that both, the annealing rate and the total amount of annealing strongly depend on env. temp.

- There are at least 2 annealing components, a fast one with ~4 days time constant and a slow one with ~80 days constant



Temperature dependence of RadFET Annealing

- After “unfreezing” RadFET sensors annealing at 2 deg. For a year, annealing accelerated with a time constant of ~20 days
- Measurements require a lot of time, more data needed



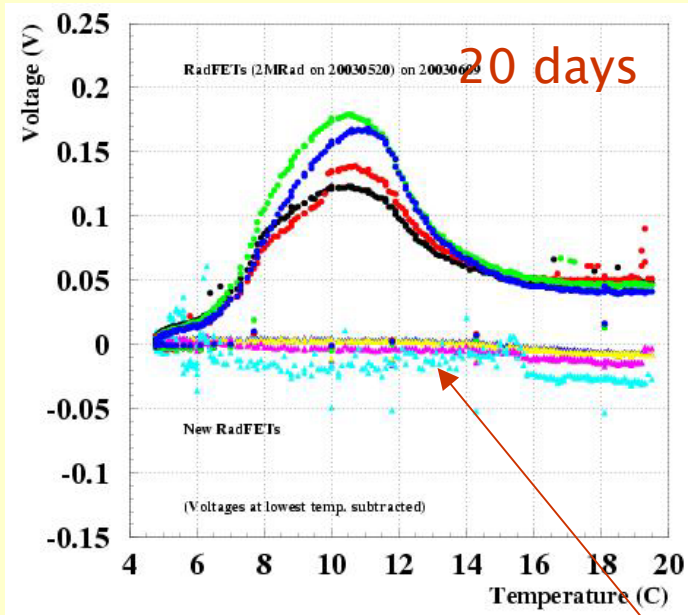
Temperature dependence of gate voltage

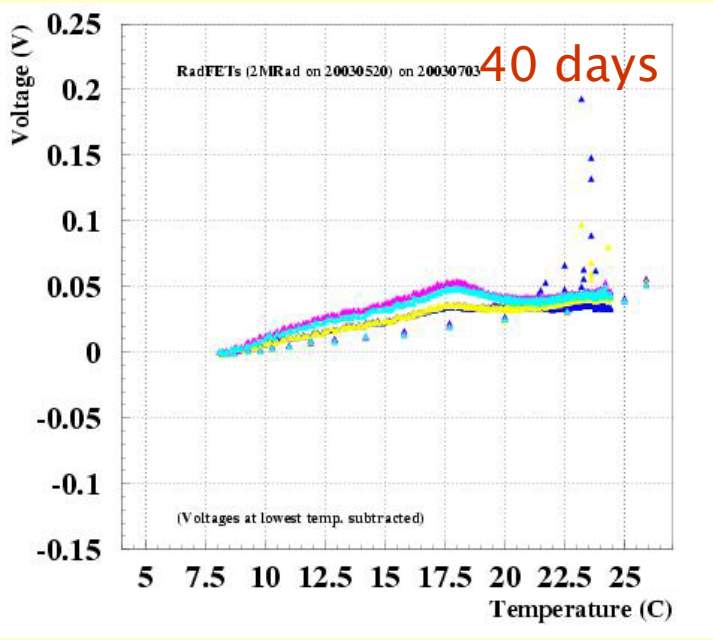
At any particular moment during annealing, gate voltage of irradiated RadFET changes with temperature!

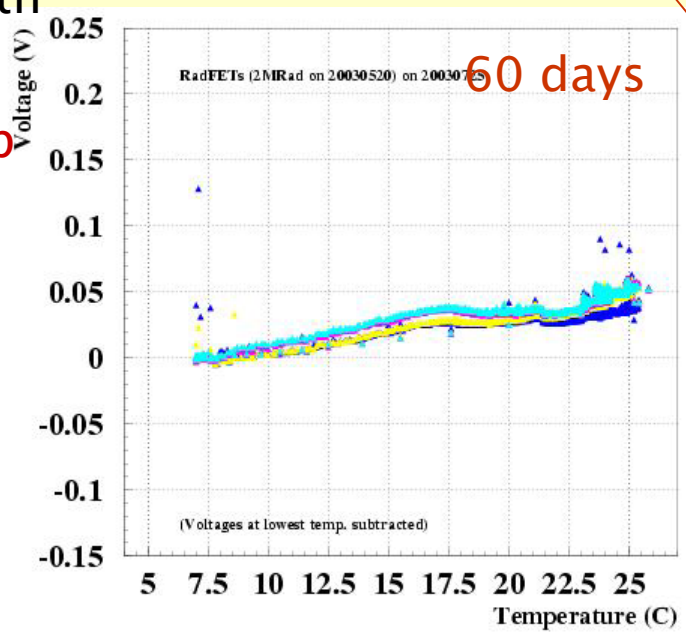
Maybe this can help determine temp. thresholds?

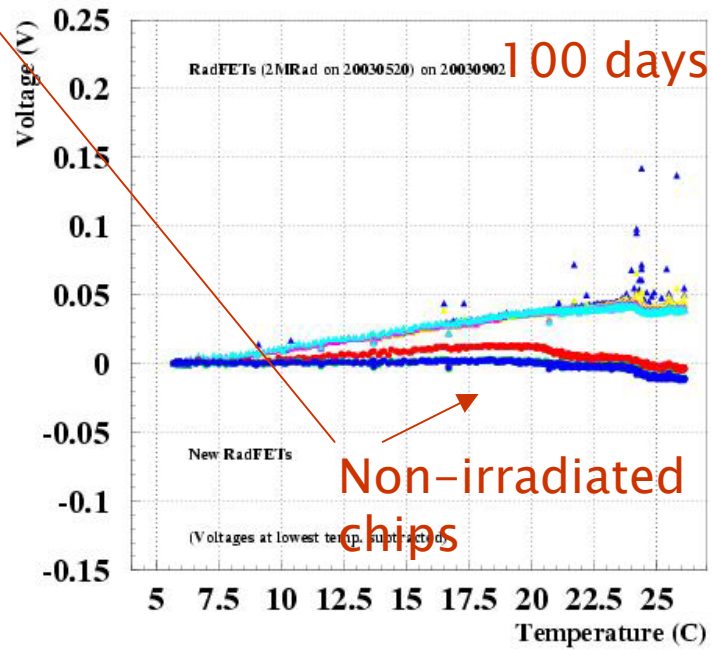
Irradiated RadFET were exposed to 1.85MRad

Annealing was at room temperature

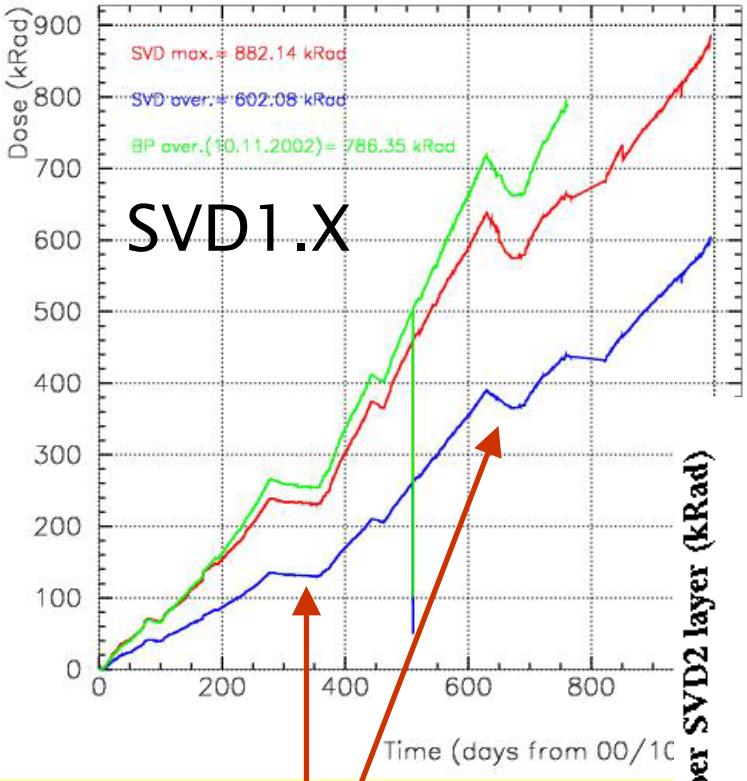




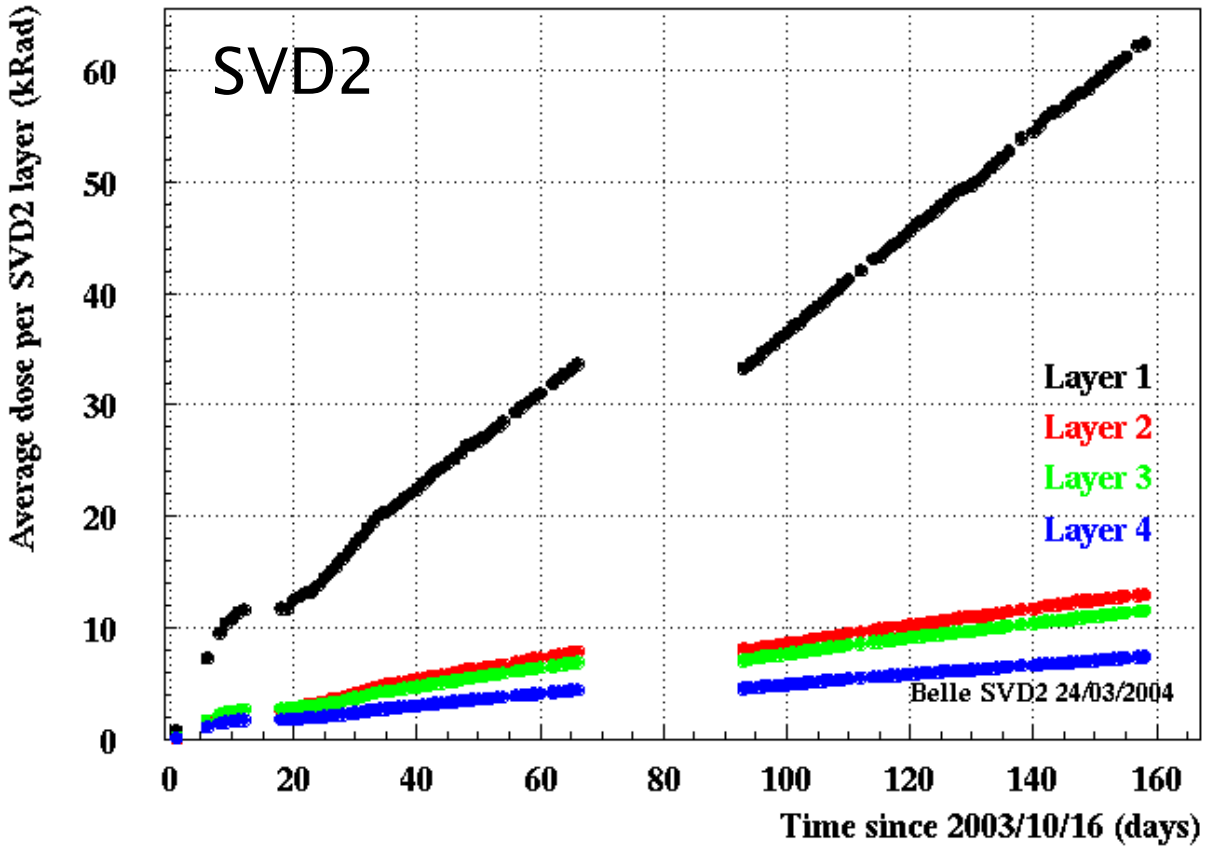




RadFET monitoring results in Belle

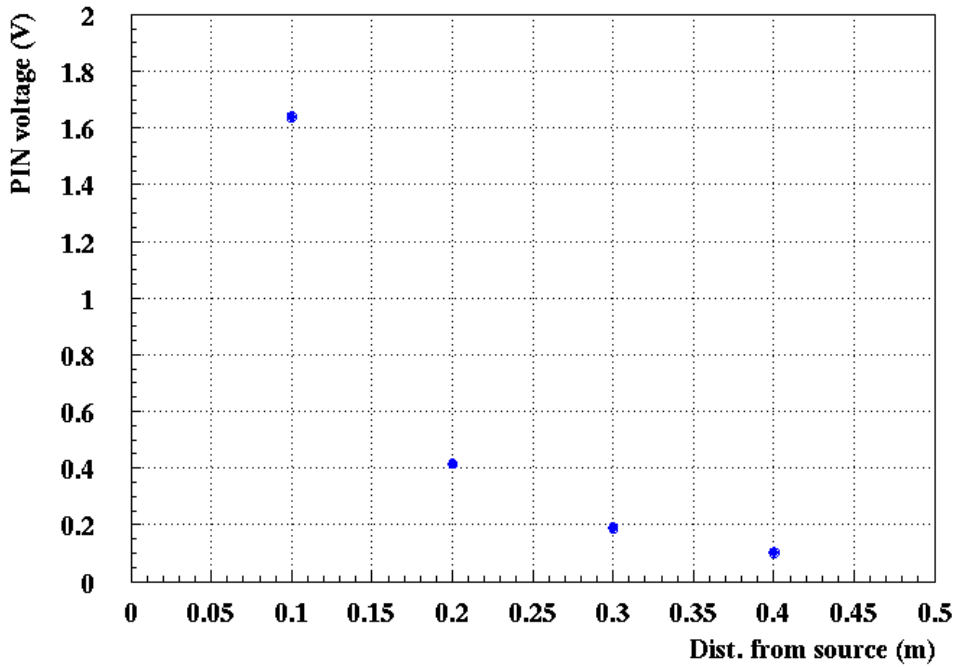


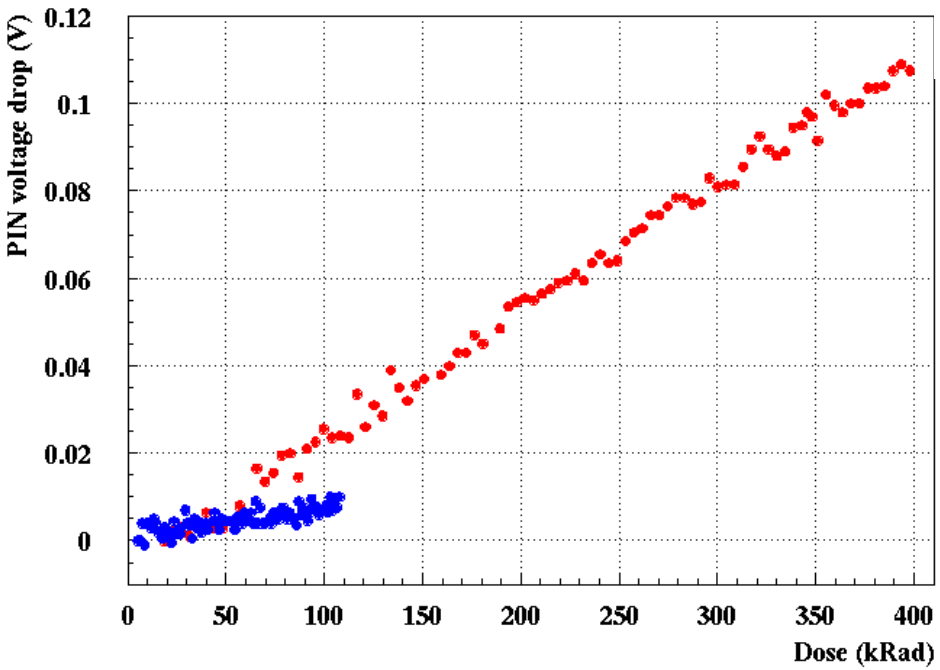
Annealing during summer shutdown



PIN irradiation (^{60}Co)

- For now irradiated up to 400kRad
- confirmed linearity of PIN response with dose rate (quadratic response with distance from point source) in this range

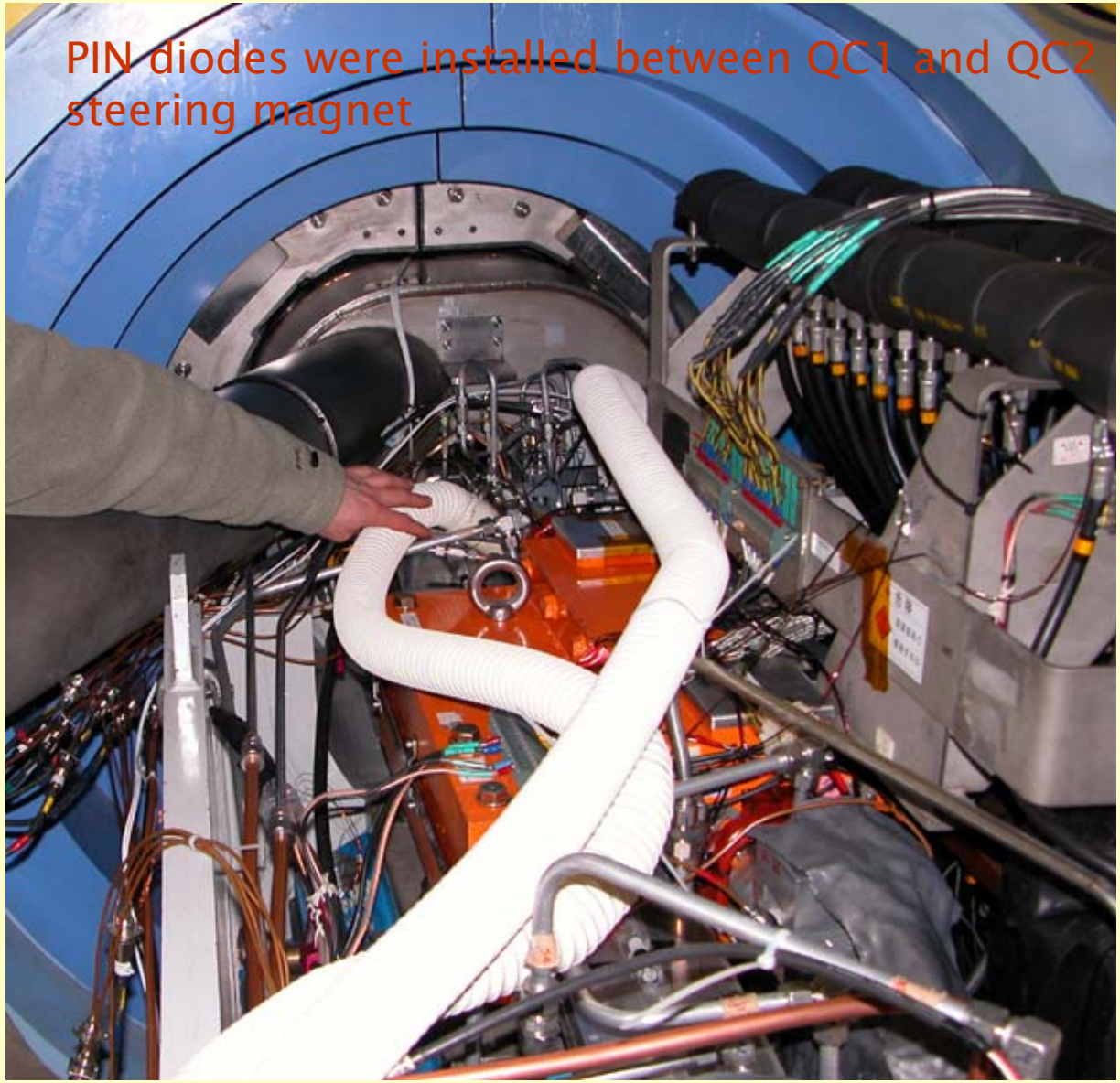




- studied the dependence of the PIN gain drop with the dose
- Different slope for the 2 investigated rates with Co-60
- Smaller gain drop than in Belle (different types/energies of ionizing particles?)

PIN irradiation (KEKB HER and LER rings)

- Irradiated up to 100kRad in a specific setup configuration (dose rate, amplification gain)
- Doses measured by aniline dosimeters, rates much smaller
- 0.3kRad/h for LER, 100x less than TIT
- 0.03kRad/h for HER, 1000x less than TIT

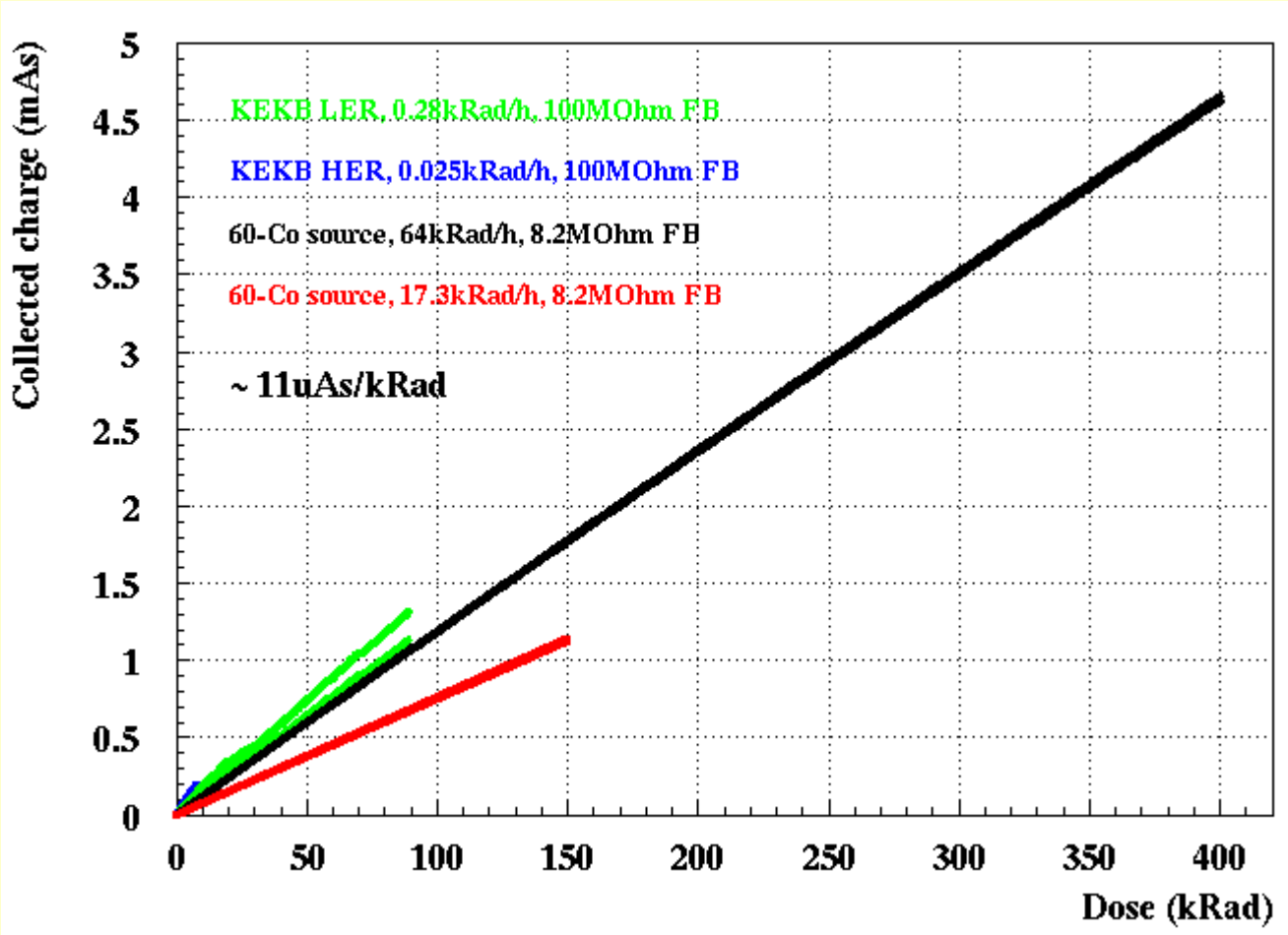


PIN calibration results

Taking into account different amplification gains and converting integrated PIN outputs into collected charge gives

~ 11μAs/kRad

Independently of the dose rate.



2MRad PIN calibration will be done in April 2004.

Conclusions

- We can successfully monitor radiation dose up to 2MRad with about 15% precision with RadFET.

- After irradiation, voltage drop in RadFET gradually decreases for about 40% and we suspect at least two temperature dependant components of the annealing with time constants of about 4 and 80 days.

- Relation between gate voltage and temperature differs for RadFET in different stages of annealing. Its behavior suggest correlation with fast annealing component.

- Experiments with PIN diodes at different dose rates suggest linear correlation of collected charge with the dose both for ^{60}Co and electron-positron collider generated background. With continuous read-out they can measure both dose rate and integrated dose.