Radiation monitoring and beam aborts at Belle and R&D for SuperKEKB

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For Belle Monitoring Group

SuperB Workshop in Hawaii
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The Past

Radiation monitoring system evolved together with SVD:

SVD 1.0 (1999/01–1999/07)
1.4 mm VA1 readout chip (resistant to 200kRad), unsatisfactory protection against radiation – fatally damaged by SR light and had to be replaced.

SVD 1.2 (1999/08–2000/05)
Identical to SVD 1.0 except for 10μm-thick gold foil wrapping of IR against SR and radiation monitoring. Accumulated 80kRad/year, 10% gain drop – replaced.

Monitors providing abort signal, some background studies possible

SVD 1.4 (2000/08–2002/11)
0.85 μm VA1 readout chip (res. to 1MRad), IR chamber gold-coated containing saw-tooth shaped SR stopper for HER beam. Improved radiation monitoring, tested to 500kRad, provided some feedback to accelerator operation. Replaced because of beam-pipe vacuum leak.

SVD 1.6 (2003/01–2003/05)
Basically same as SVD 1.4 – no problems, replaced in regular upgrade.

Modular monitor design, better abort logic, detailed studies of rad. field around SVD1.x

The Present and the Future

SVD 2.0 (2003/08-)

0.35 μm VA1TA readout chip (rad. hard to 2MRad), IR designed to provide supreme protection against SR and particle backgrounds, new monitoring system tested to 2MRad with better r and Phi resolution, new analysis possibilities

New sensor design adapted to new IR geometry,
New monitoring features,
Better spatial resolution,
Larger applicable range (>2Mrad)…

SVD 3.0?

Studies are under way:

- Test of RadFET and PIN sensors up to >10Mrad
- New RadFET readout electronics with larger read-out range
- Study of annealing effects
- Test of CVD diamond sensors
- …

Radiation background and its effects

SVD is closest to IR and is exposed to high radiation background from

- Charged particles, scattered on gas in the accelerator rings
- Direct SR Photons (synchrotron radiation)
- Back-scattered SR light
- Tauschek effect (inter-bunch scattering)

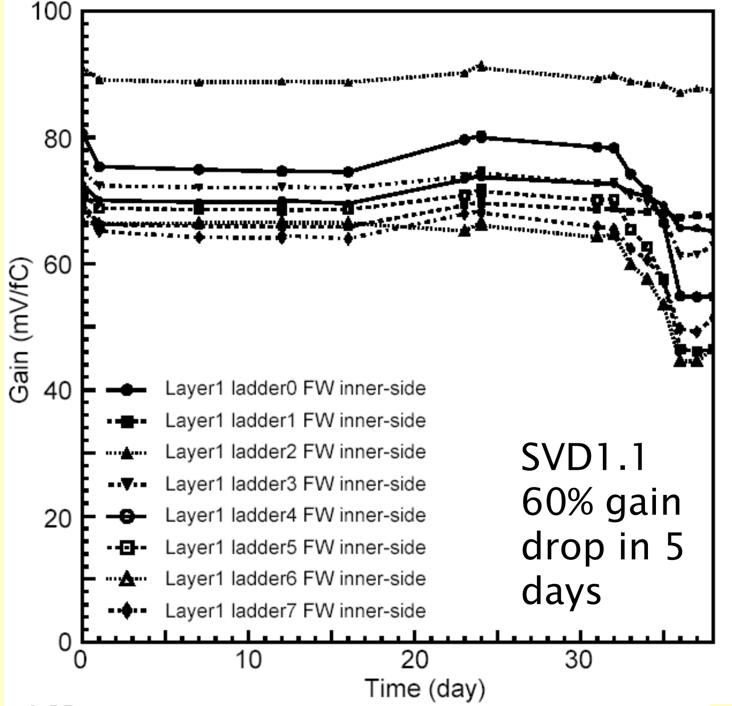
Background affects SVD performance

- Increase in SVD occupancy
- Damage to modules and read-out electronics
  (decrease in gain with accumulated ionizing dose)

… and how to minimize them

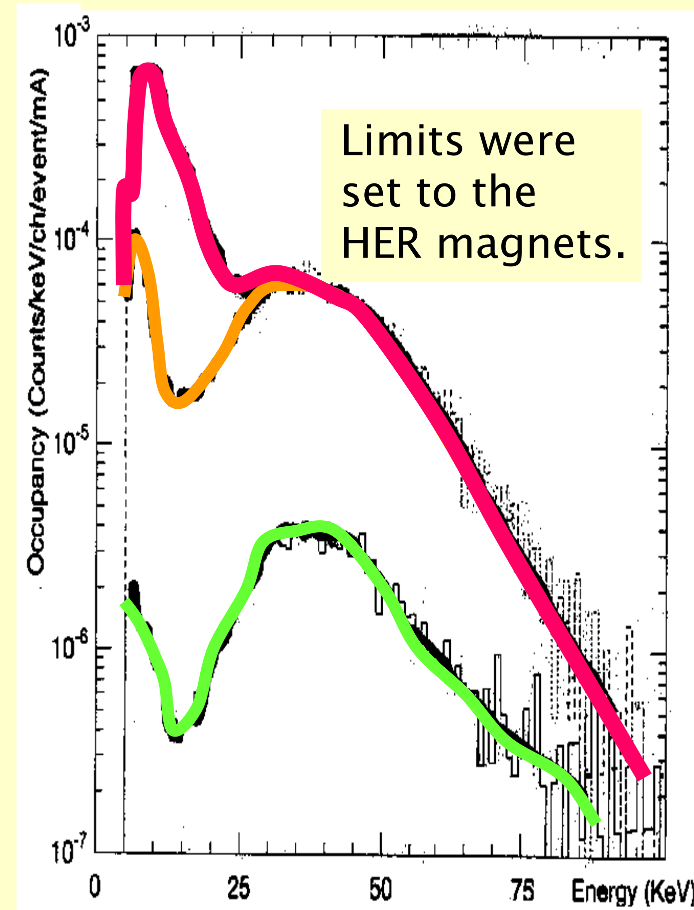
These dangers were minimized through effort of many people from both KEKB and Belle in an interplay of

- Smart IR region design (including a thin layer of gold inside it), preventing the radiation to directly hit SVD
- Better understanding of the beam background sources and limitation of steering magnet parameters
- Aborting the beams in the case of instabilities before the radiation at SVD increases – beam phase abort, KEKB SR abort
- A reliable monitoring system around IR that can be used for beam abort in the case of high radiation – should provide as much feedback as possible for tuning of relevant accelerator parameters

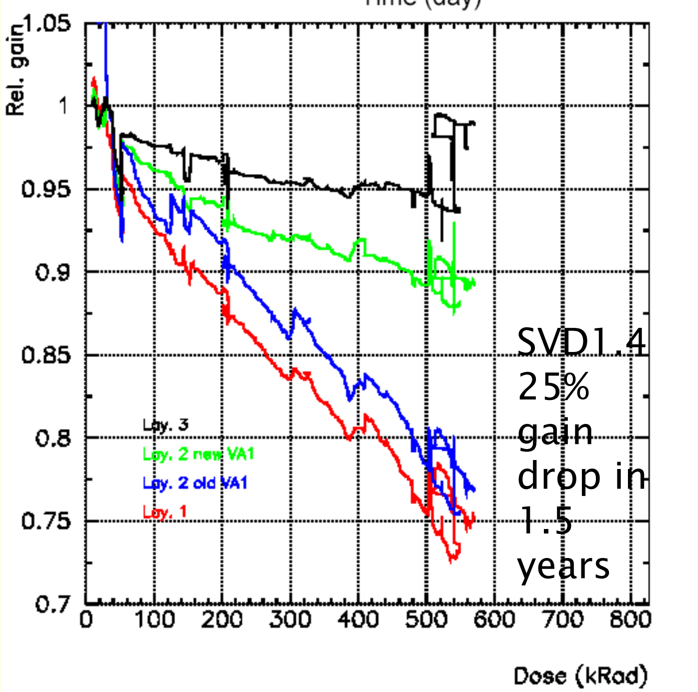


Synchrotron radiation from HER upstream magnets.
This killed SVD 1.0

SVD 1.1



SVD 1.4



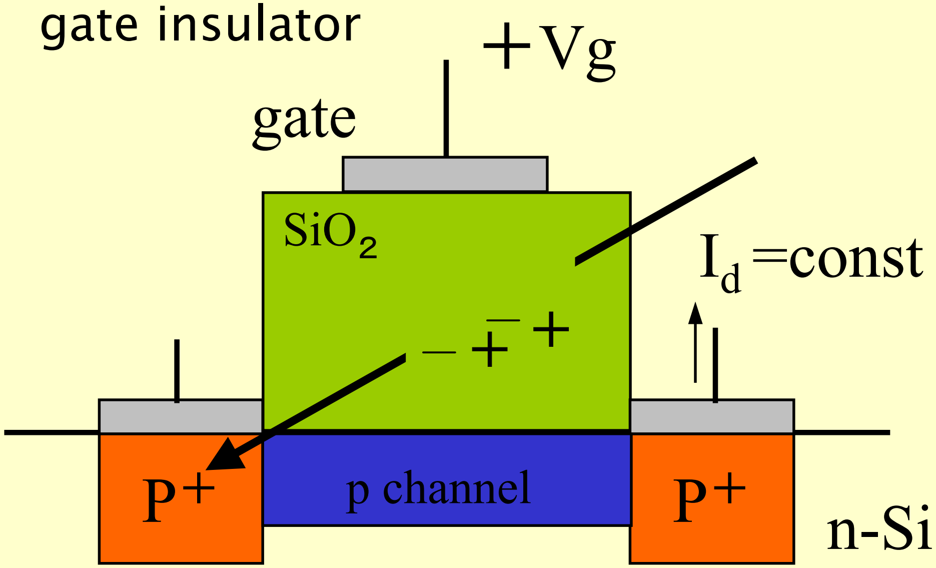
The downstream chamber was replaced with a Cu chamber

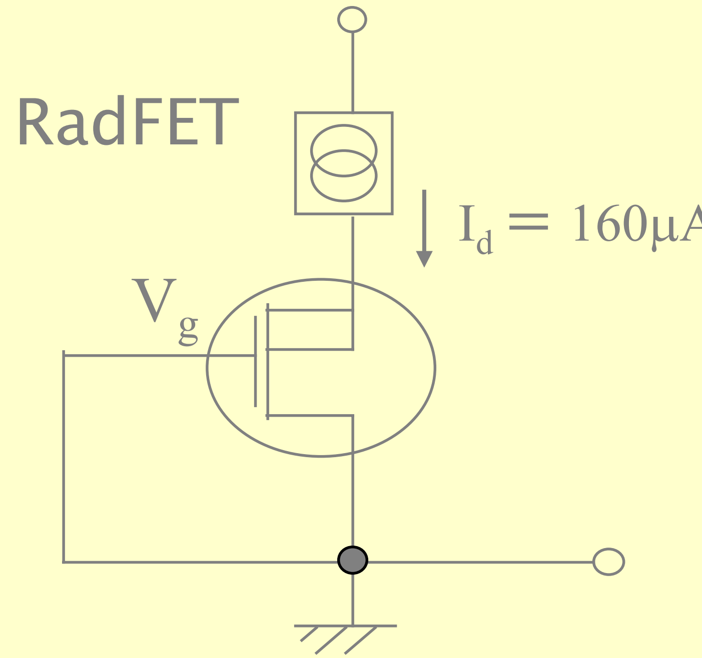
Design goals of the radiation monitoring system

- Detect increased radiation background and to perform necessary actions (abort beam or warn shift crew) to protect the SVD
- Monitor the accumulated dose to compare the expected decrease of the SVD performance to the actual situation
- Provide as detailed information as possible about the radiation field around the IP to make possible to tune various KEKB parameters
    - Apertures of the movable particle masks
    - Beam injection parameters
    - Orbit parameters
    - Bunch pattern…

Choice of 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





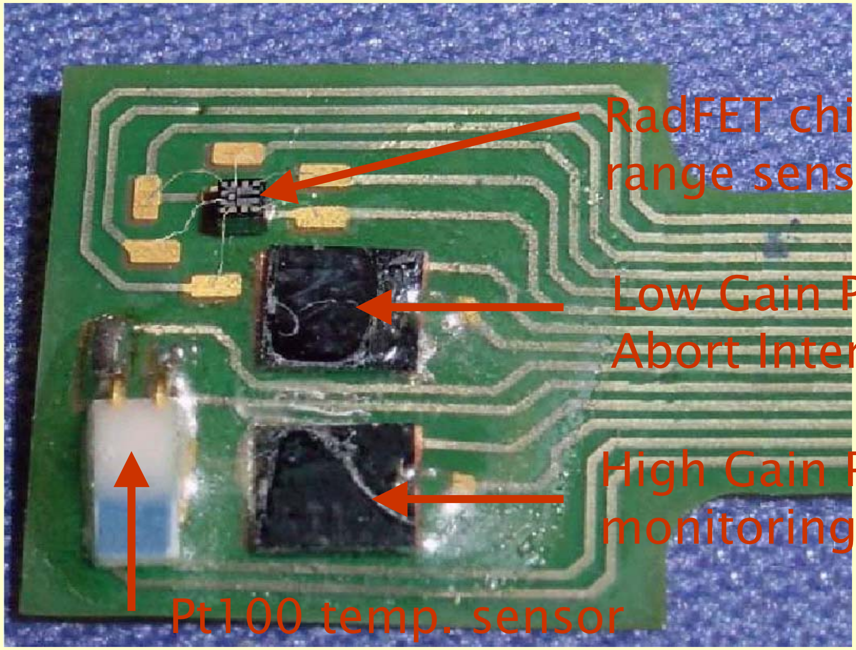
- Unbiased PIN diodes for measuring the instantaneous dose rate –

The radiation induced signal is amplified by a pre-amplifier close to the PIN
(Both types of sensors have to be calibrated)

Monitoring system for SVD1.4

We integrated both types of radiation monitors (RadFET and PIN) together with temperature monitors (Pt100) into hybrid, multi-purpose units

Sensor part

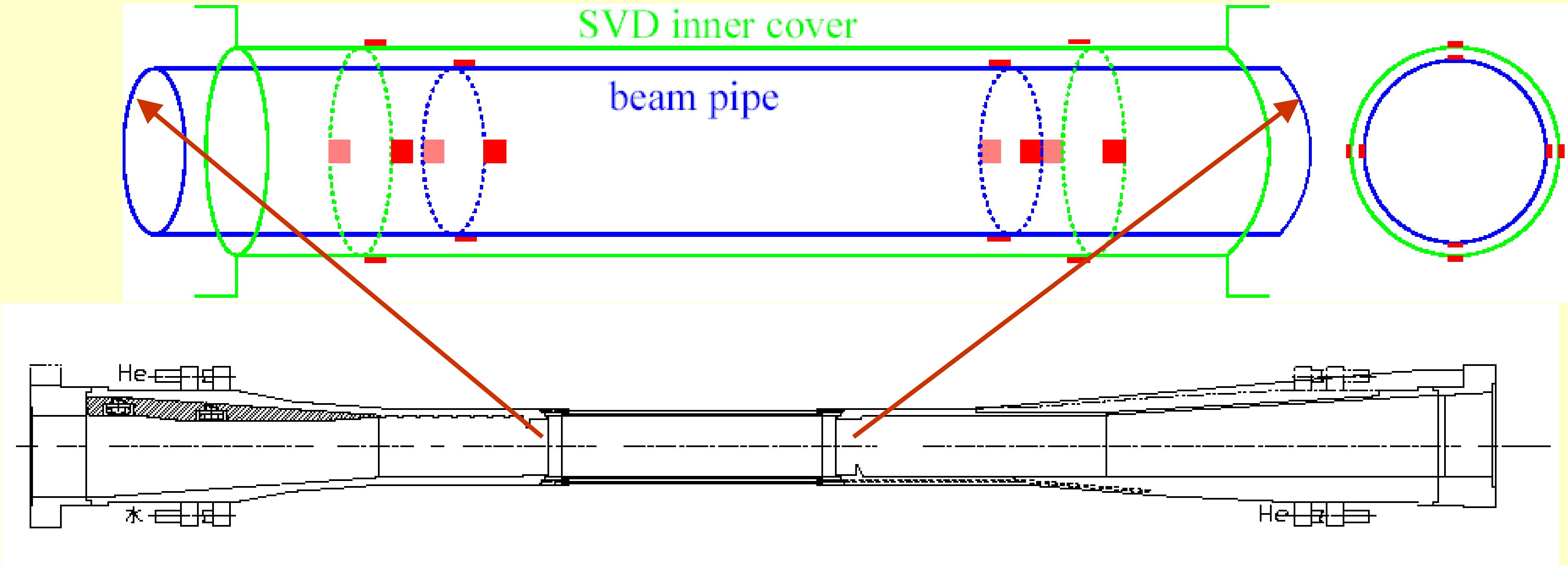


Electronics and readout part

- pre-amplifiers for PIN diodes with 2 different amplification gains differing for a factor of 100 (20cm away from sensors due to constraint space between beam-pipe and SVD)
- RadFET read-out modules
- IOTECH data logger

SVD1.4 monitor layout scheme

- Both PIN and RadFET provided radiation information at 2 different radii (on beam-pipe and SVD inner cover) for 4 different Phi left and right from the IP

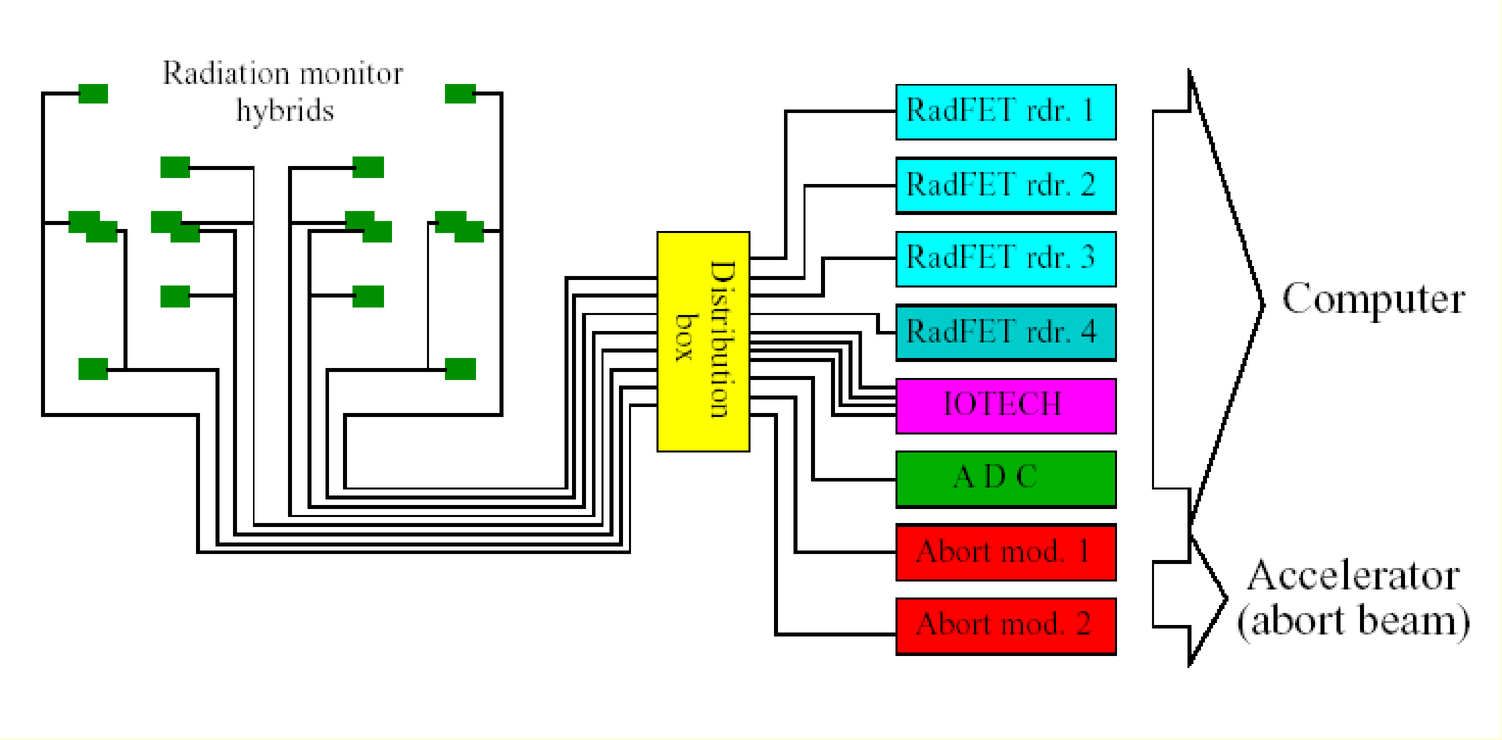


We had 16 monitor hybrids installed, meaning:

- 16 low gain + 16 high gain PIN diodes
- 16 RadFET chips containing 2 K range sensors each
- A temperature sensor on each hybrid

SVD1.4 monitor connection scheme

- All components are electrically isolated on hybrids and cables. Wires are regrouped according to their logical functions in a distribution box in the electronics hut and connected to appropriate read-out units.
- Such system proved to assure few interferences between low level signals and problems with a certain sensor did not affect operation of the others.



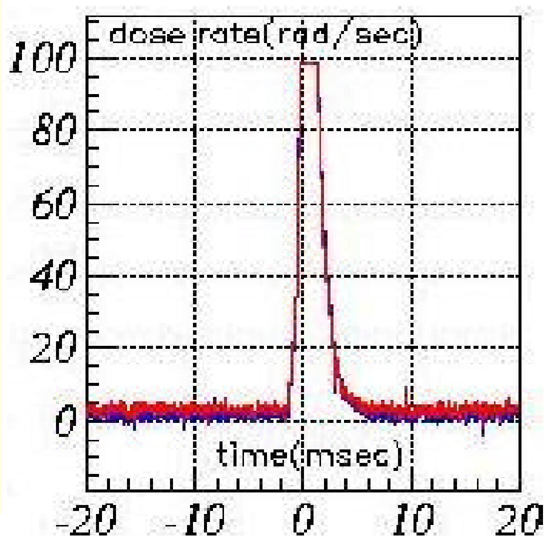
SVD1.4 beam aborts

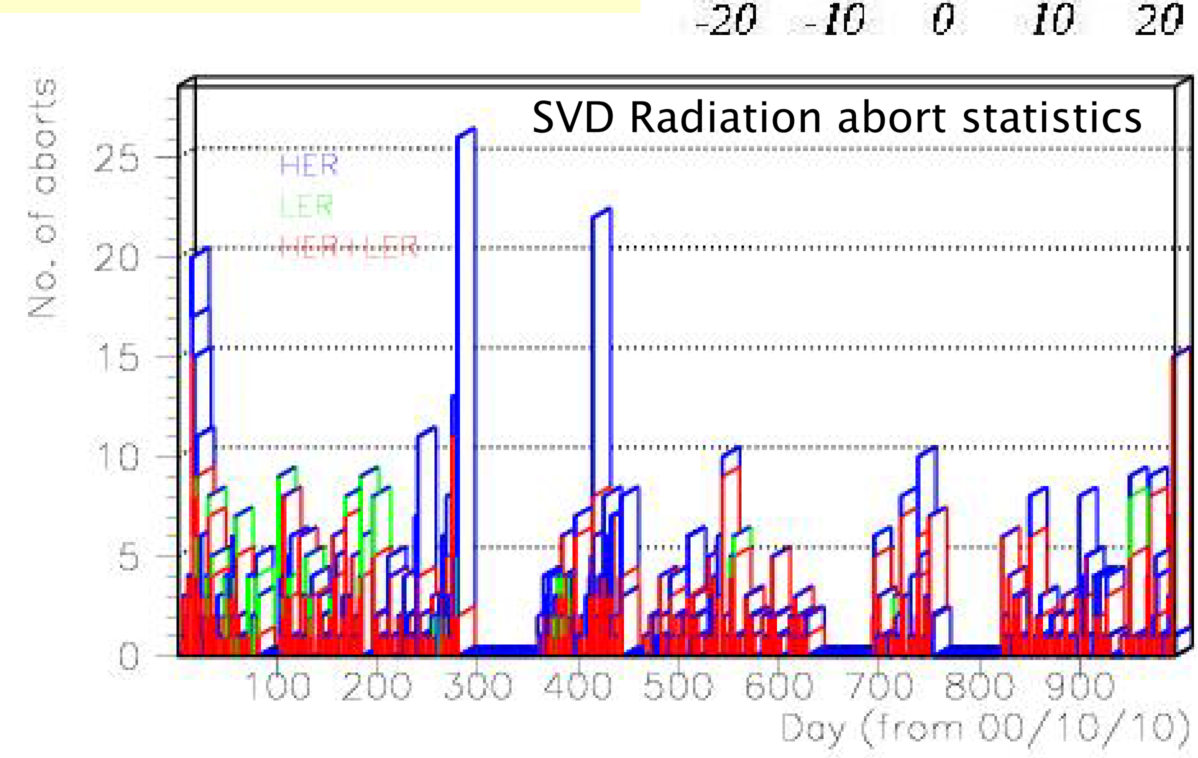
PIN diodes triggered beam abort in case of high instantaneous dose rates.

- For rates > 100Rad/s hardware abort (decision time was about 1ms). A low pass filter is used to eliminate fake “noise” aborts.

- For rates > 100mRad/s for more than 2s a software beam abort.

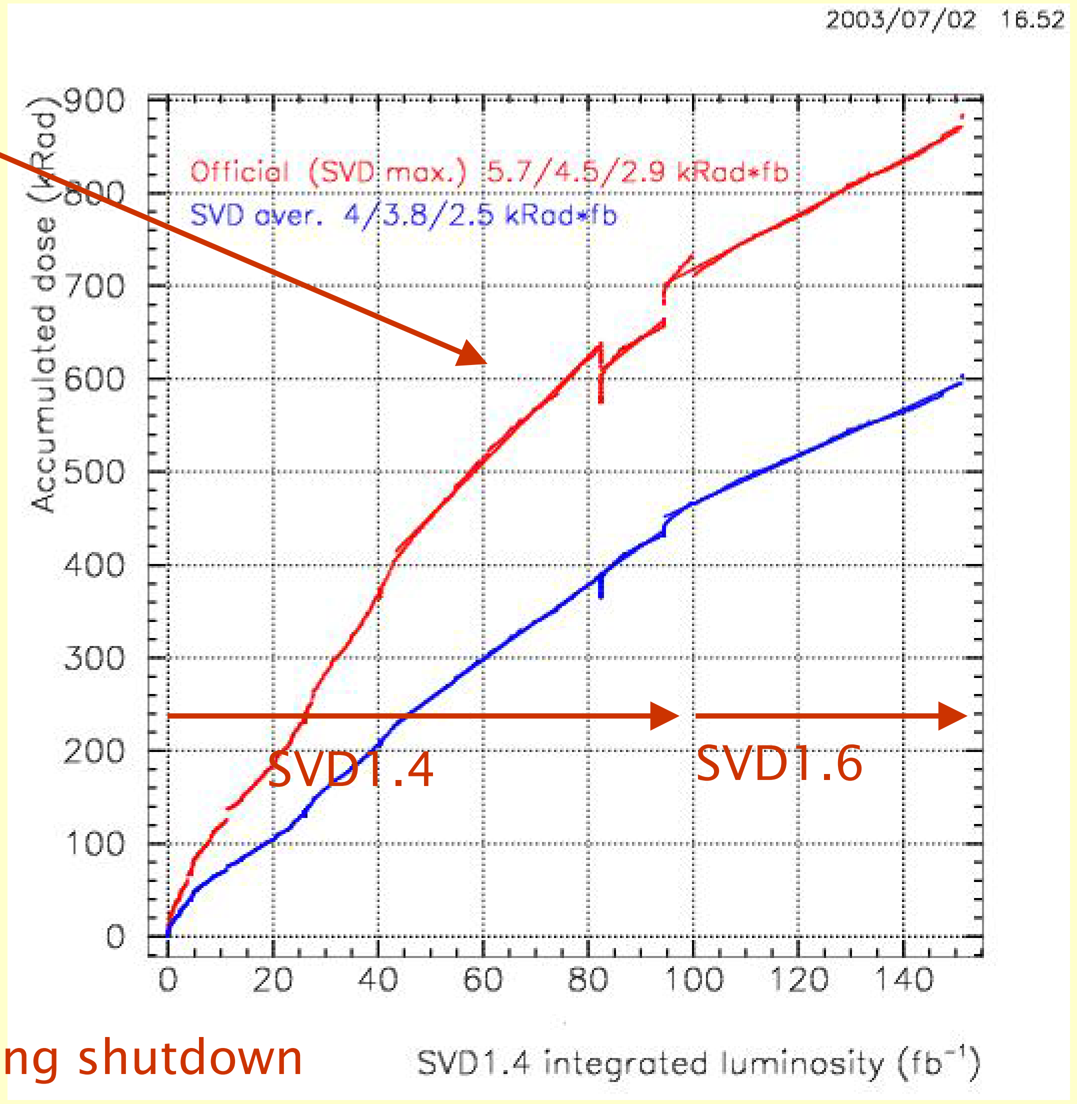
- During injection, abort the injected beam first, the other after 50ms if background doesn’t decrease (shorter injection time)

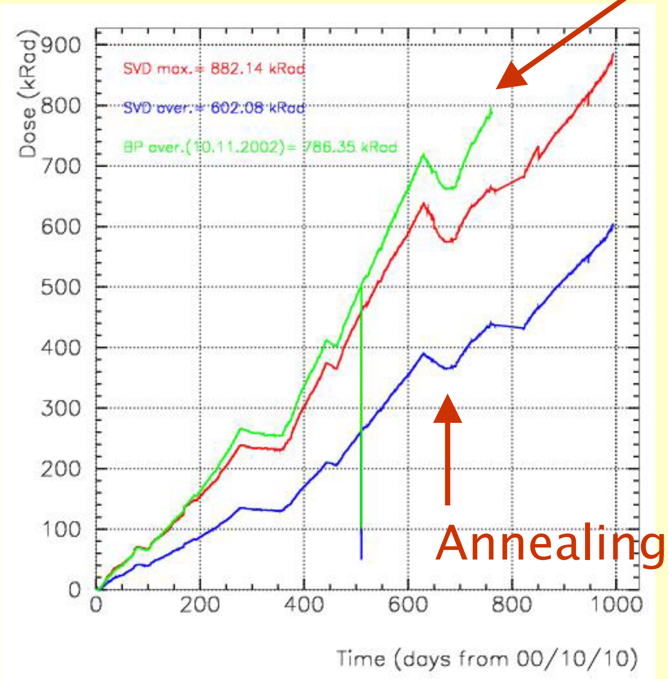




SVD1.4 Monitoring results

- Ratio between accumulated dose and integrated luminosity kept improving for SVD1.4 and 1.6
- In SVD 1.6 we had no rad. Sensors on the beam-pipe, we ran with SVD sensors only





Annealing during shutdown

Spatial distribution of the dose

RadFET responses, parametrized according to the orientation with respect to the KEKB ring

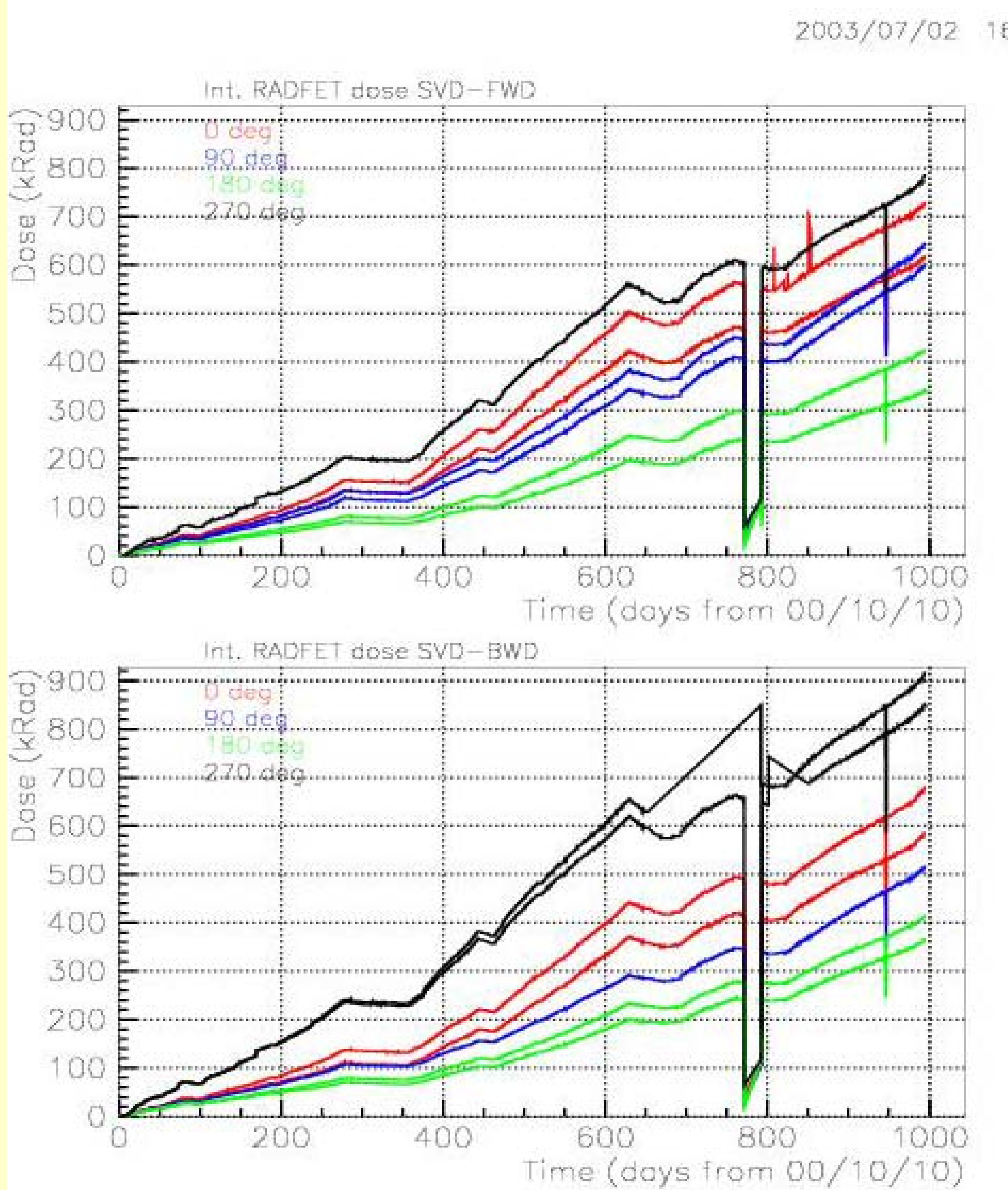
Black – down

Green – in

Blue – up

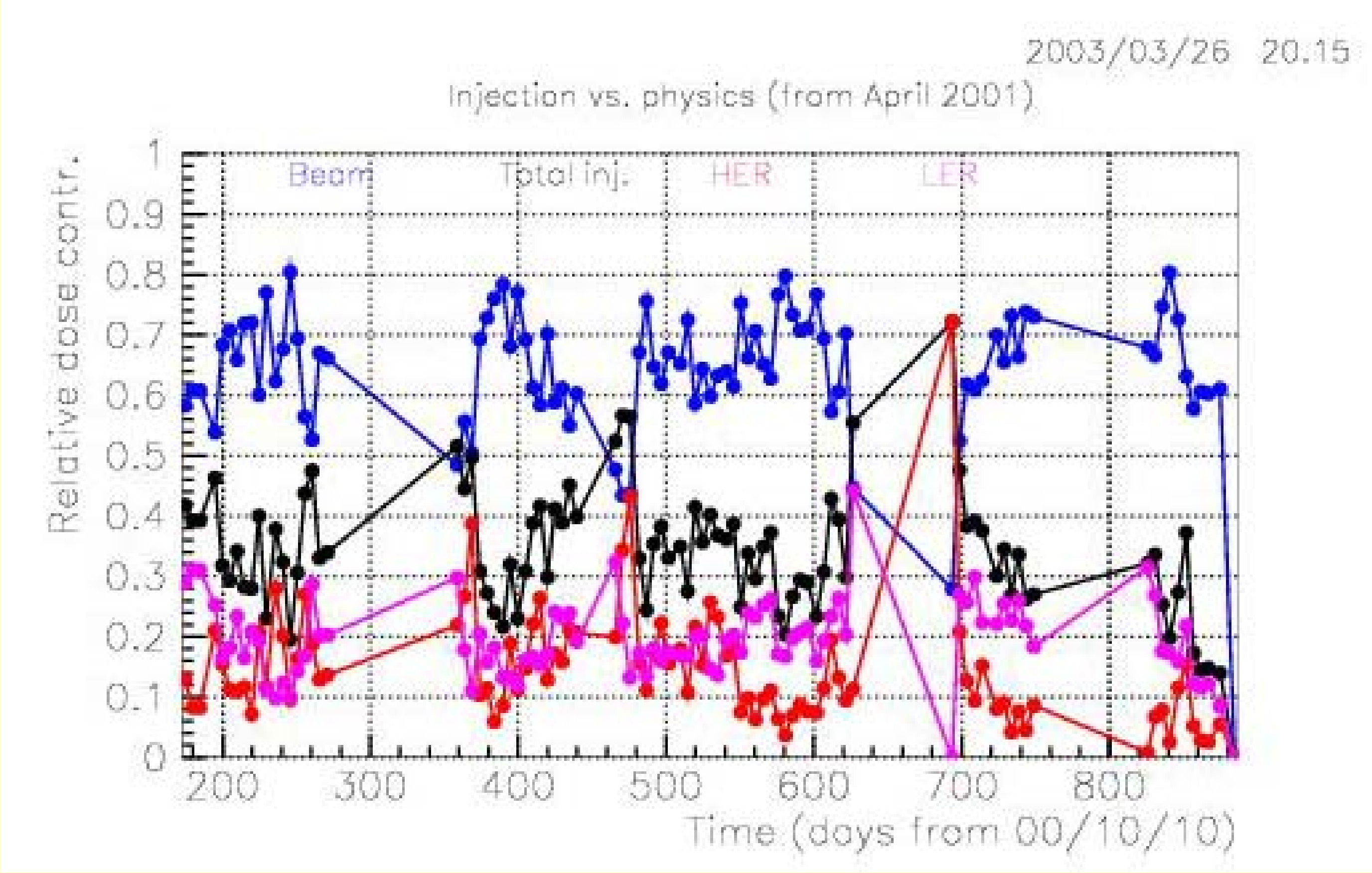
Red – out

For SVD1.4–SVD1.6 there was a large background in the downward direction due to the choice of the beam orbit



Contributions to the total dose

- Beam injection contributed about 1/3 of the total dose
- Contributions of the HER/LER varied

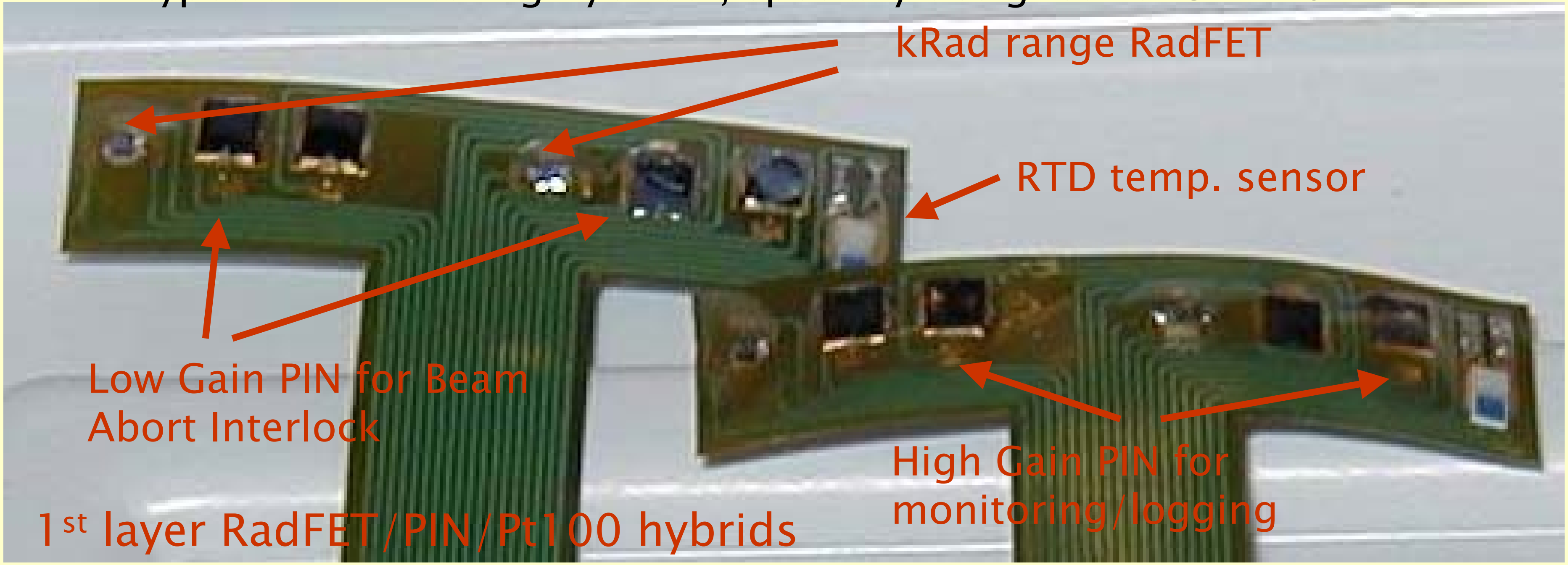


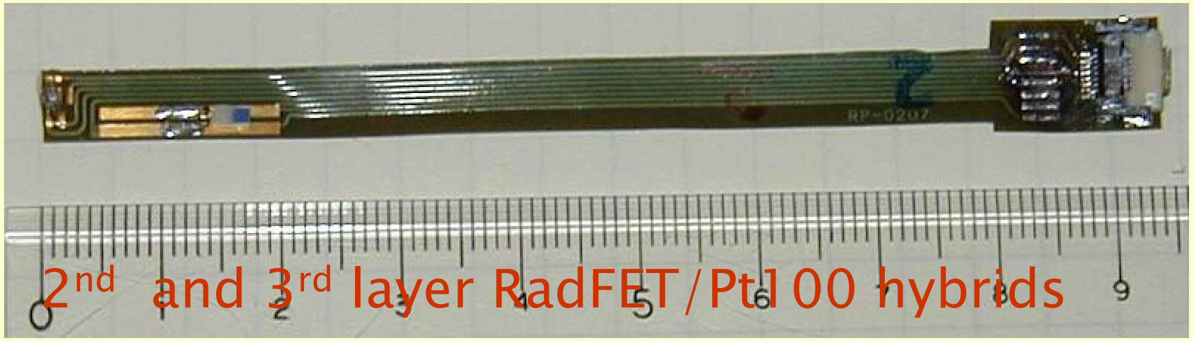
We succeeded to make a systematic and easy to handle monitoring system that helped preserve SVD1.x detectors! We used the experience we gained to get even better results for SVD2.0…

Monitoring system for SVD2

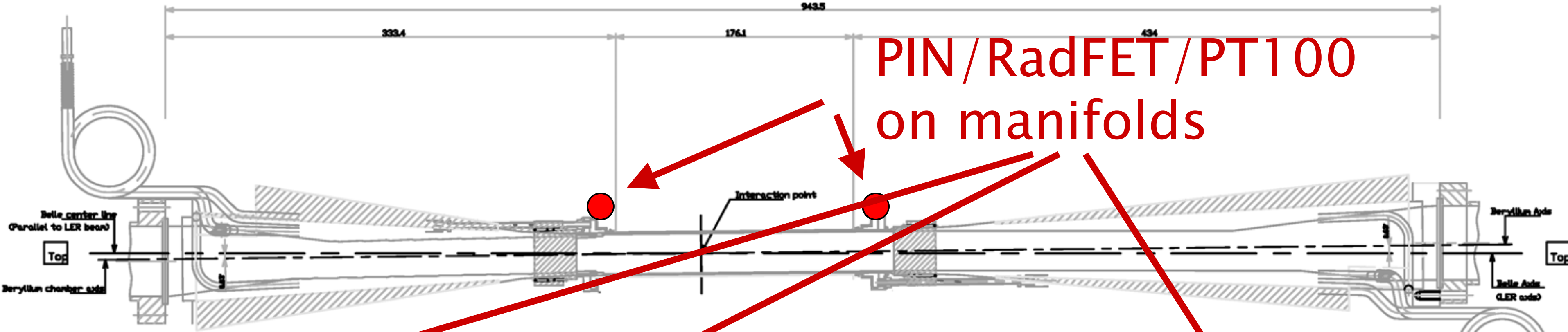
The conceptual design remained the same as for SVD1.4, however, we changed many things:

- New types of “monitoring hybrids”, specially designed for SVD2.0 IR





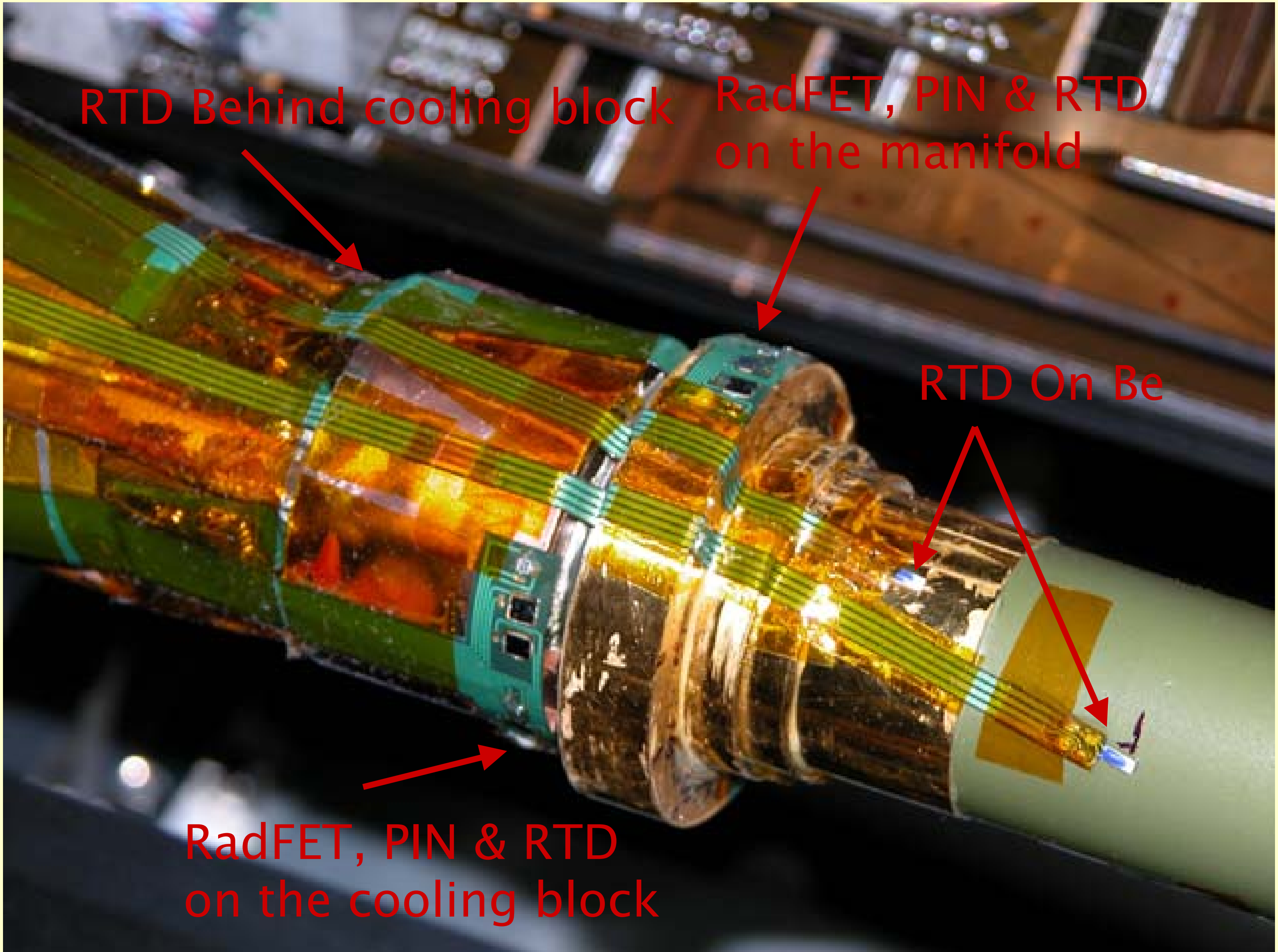
Positioning of SVD2.0 monitors

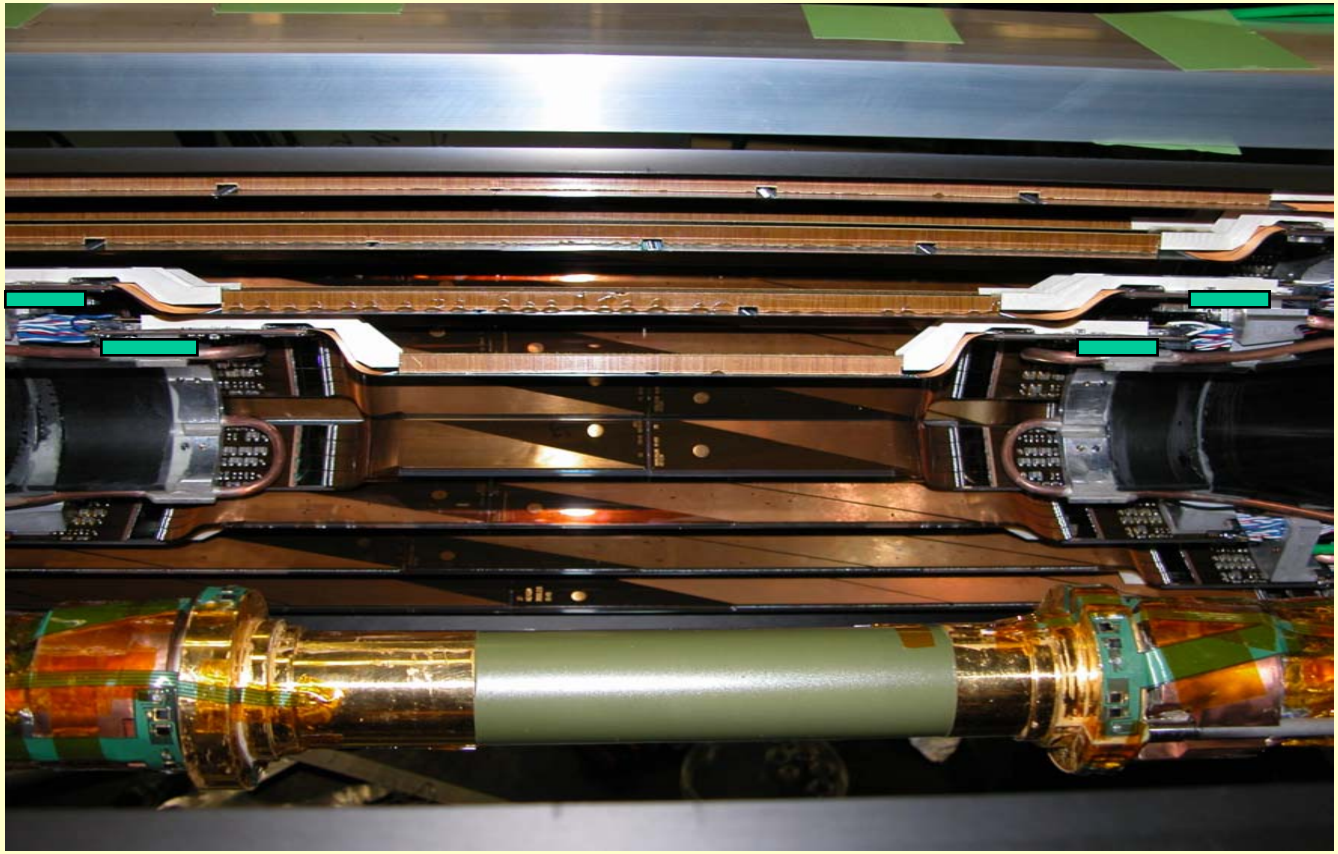


PIN/RadFET/PT100
on manifolds

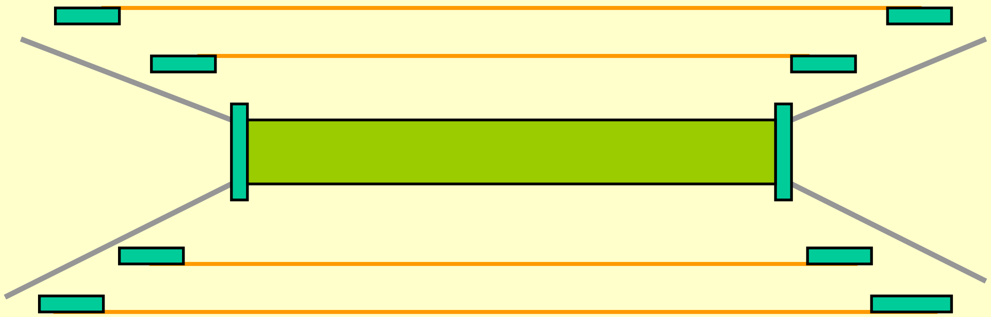
PIN signal amplifier

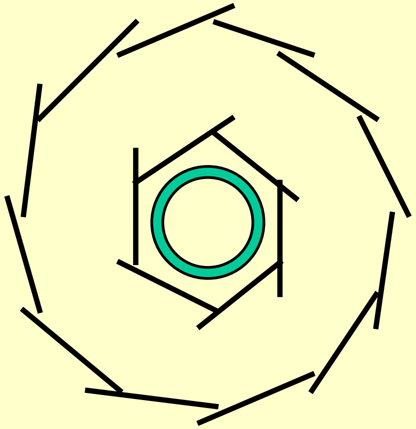
Radiation and temp. sensors on the IR beam-pipe





2^{nd} and 3^{rd} layer hybrids





New layout

We have

- 6 x layer 1 “large” hybrids, containing 4 K range RadFET sensors, 2 High gain PIN, two Low gain PIN and a Pt100 temp. sensor each. They provide 60 deg. resolution of rad. field measurement. 12 PIN are used for beam abort.
- 12 x layer 2 + 12 x layer 3 “small” hybrids, containing 2 K range RadFET sensors and a Pt100 temp. sensor each. They provide radial dependence of the rad. field.

New read-out electronics provides, apart from all abort/monitoring options available for SVD1.x, also:

- Read-out for the PIN diode abort pattern (which PIN fired abort request)
- Logging of the development of individual PIN signals from -4 to +2ms from the beam abort request

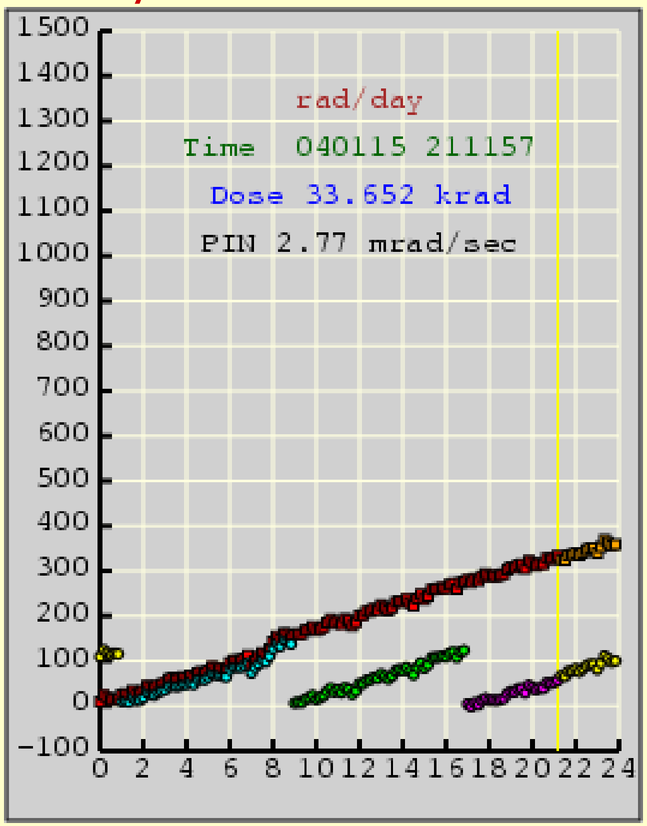
Which is/will be useful to improve the abort logic efficiency.

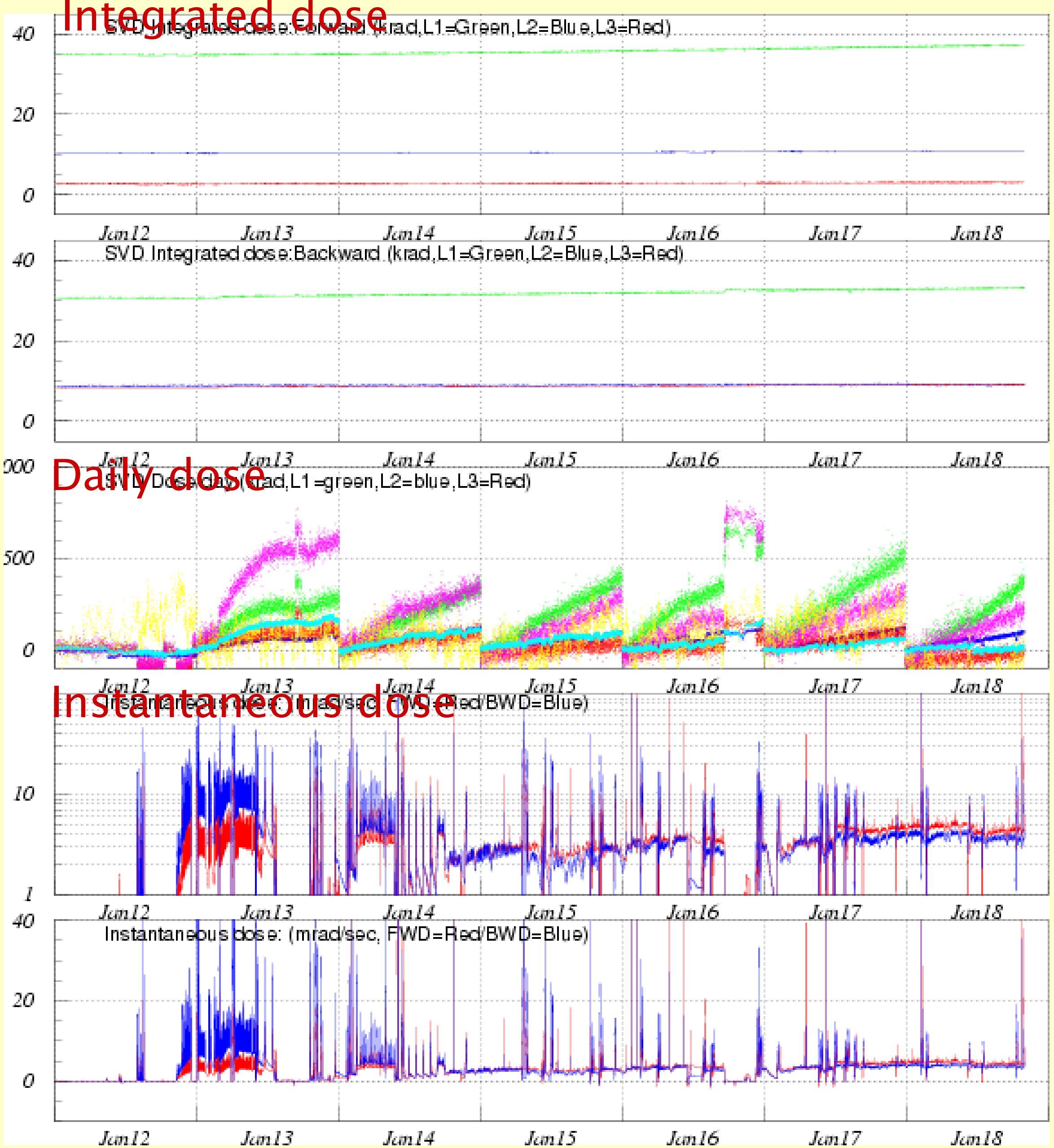
SVD2.0 Radiation Monitoring Online

maintained by T.Tsuboyama

at belle.kek.jp/~tsuboy/svdmonitor

Daily dose for shift crew

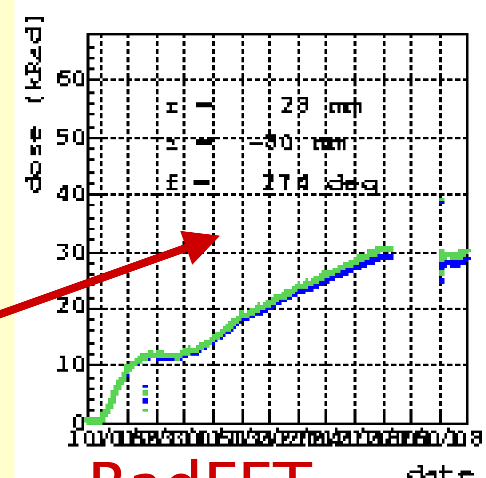




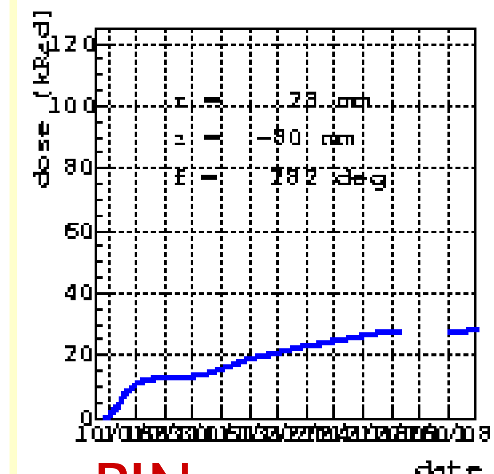
More SVD2.0 Monitoring

Online, maintained by O.Tajima at
belle.kek.jp/~tajimao/public/background

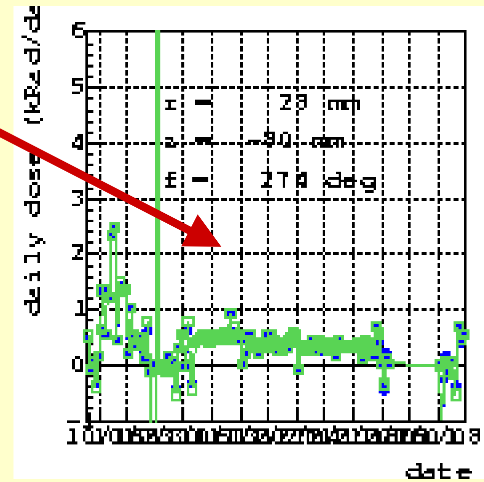
- Integrated dose vs. time
- Daily dose vs. time
- A week of instantaneous dose history

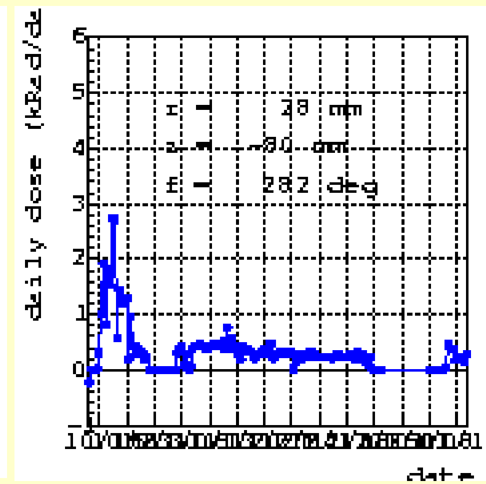


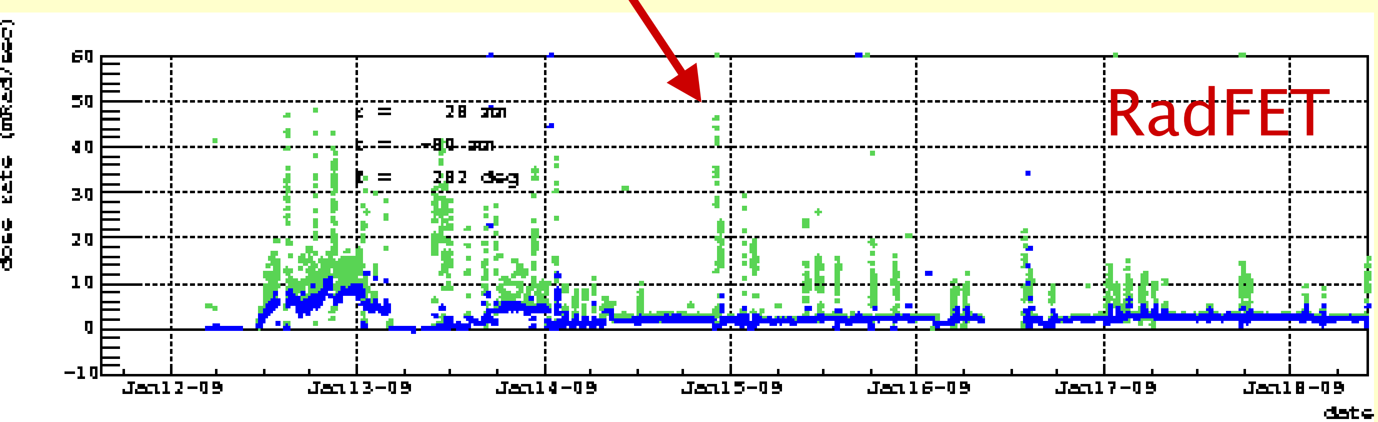
RadFET



PIN







RadFET

(example for a single angle at single radius)

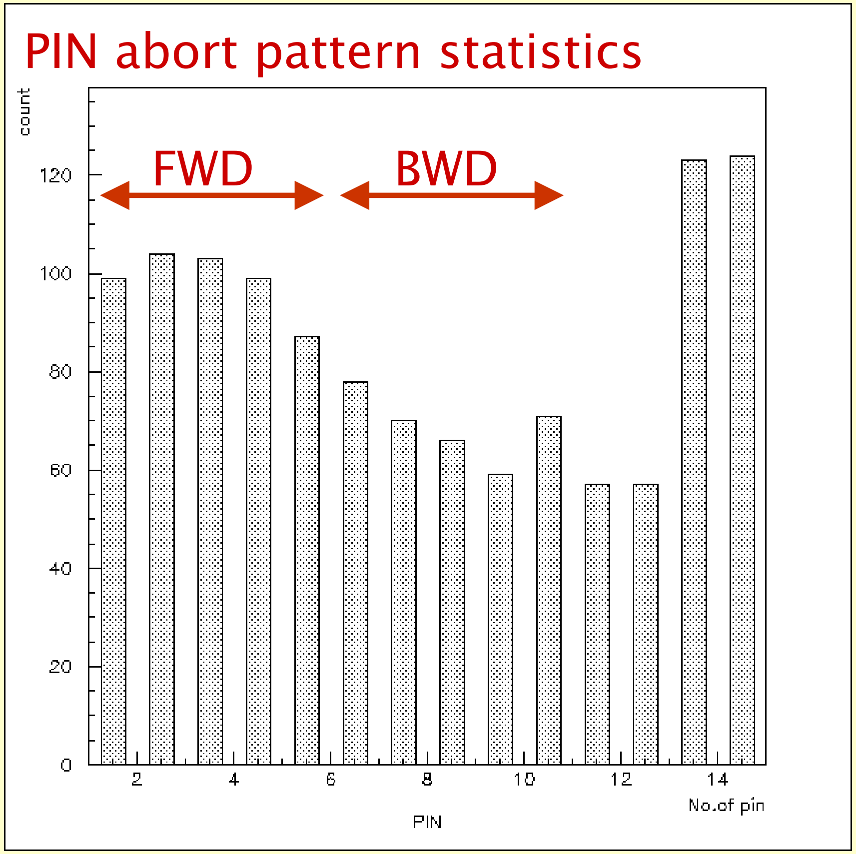
Abort Logic for SVD2.0

- Signals from 12 low gain PIN diodes from large monitor hybrids, placed on the beam-pipe manifolds are used as beam abort triggers.

- Trigger level can be tuned in the electronics hut, separately for each PIN. At present, a PIN “fires” if its signal exceeds 6V (about 120 Rad/s)

- 6 FWD and 6 BWD diodes are grouped together, and FWD or BWD abort signal is issued if more than 3 PIN from a certain region “fire”. The multiplicity threshold can also be changed at elec. hut.

- The SVD abort request to KEKB is at present OR of FWD and BWD abort signals.



SVD2.0 Abort PIN pattern

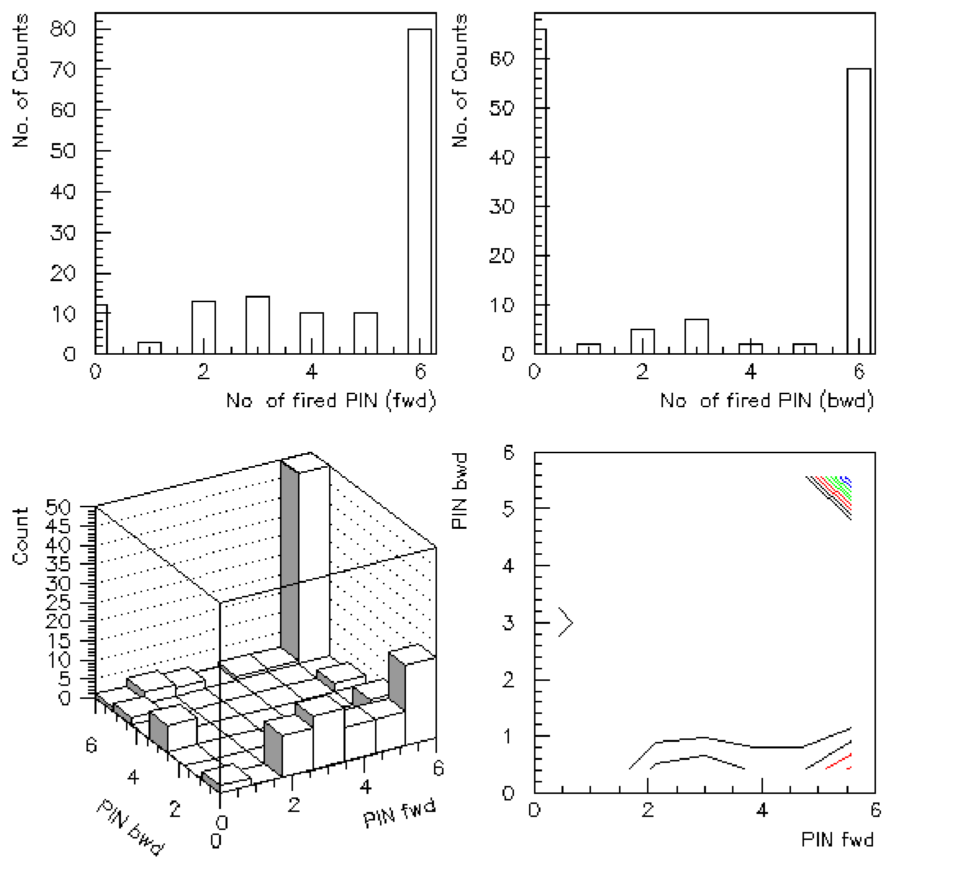
maintained by T.Tsuboyama

at belle.kek.jp/~tsuboy/beamabort

PIN hit pattern at 03/12/26 01:05:53.

DATE	TIME	FFFFFFBBBBBBCA 123456123456HB
03/12/24	12:29:16	00000000000001
03/12/23	23:09:26	11111111111111
03/12/23	20:10:37	11111111111111
03/12/23	19:33:49	11111111111111
03/12/23	18:57:45	11111111111111
03/12/23	18:49:06	11111111111111
03/12/23	18:38:13	00000011011111
03/12/23	16:56:02	11111111111111
03/12/23	13:22:58	11111100000011
03/12/22	19:55:14	11111111111111
03/12/21	03:50:30	11111100000011
03/12/18	19:45:54	11111100000011
03/12/15	13:22:58	11110011111111
03/12/15	13:00:01	11000000000010
03/12/15	08:13:28	01110000000011
03/12/15	07:57:21	11111100000011

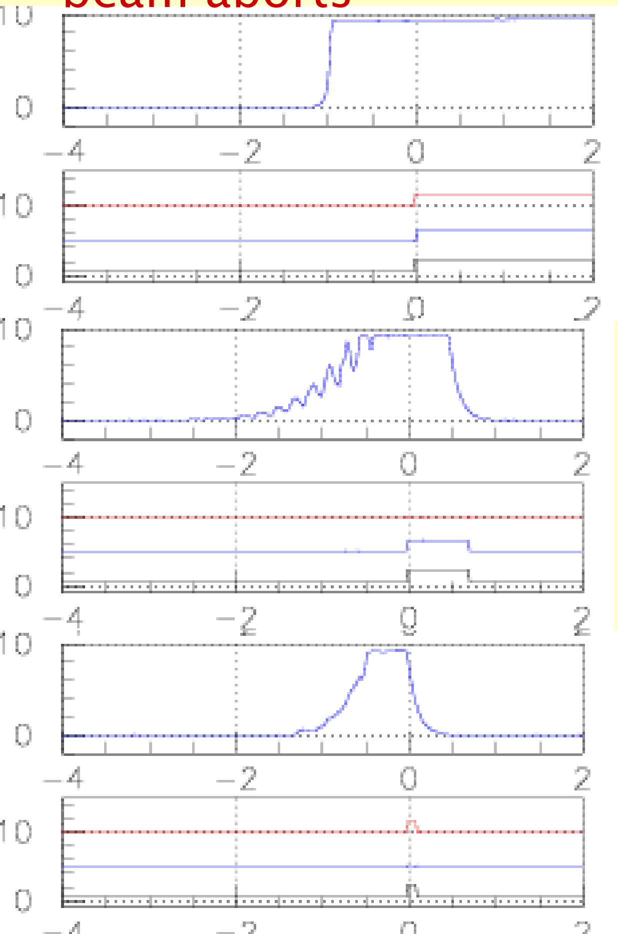
PIN abort pattern statistics



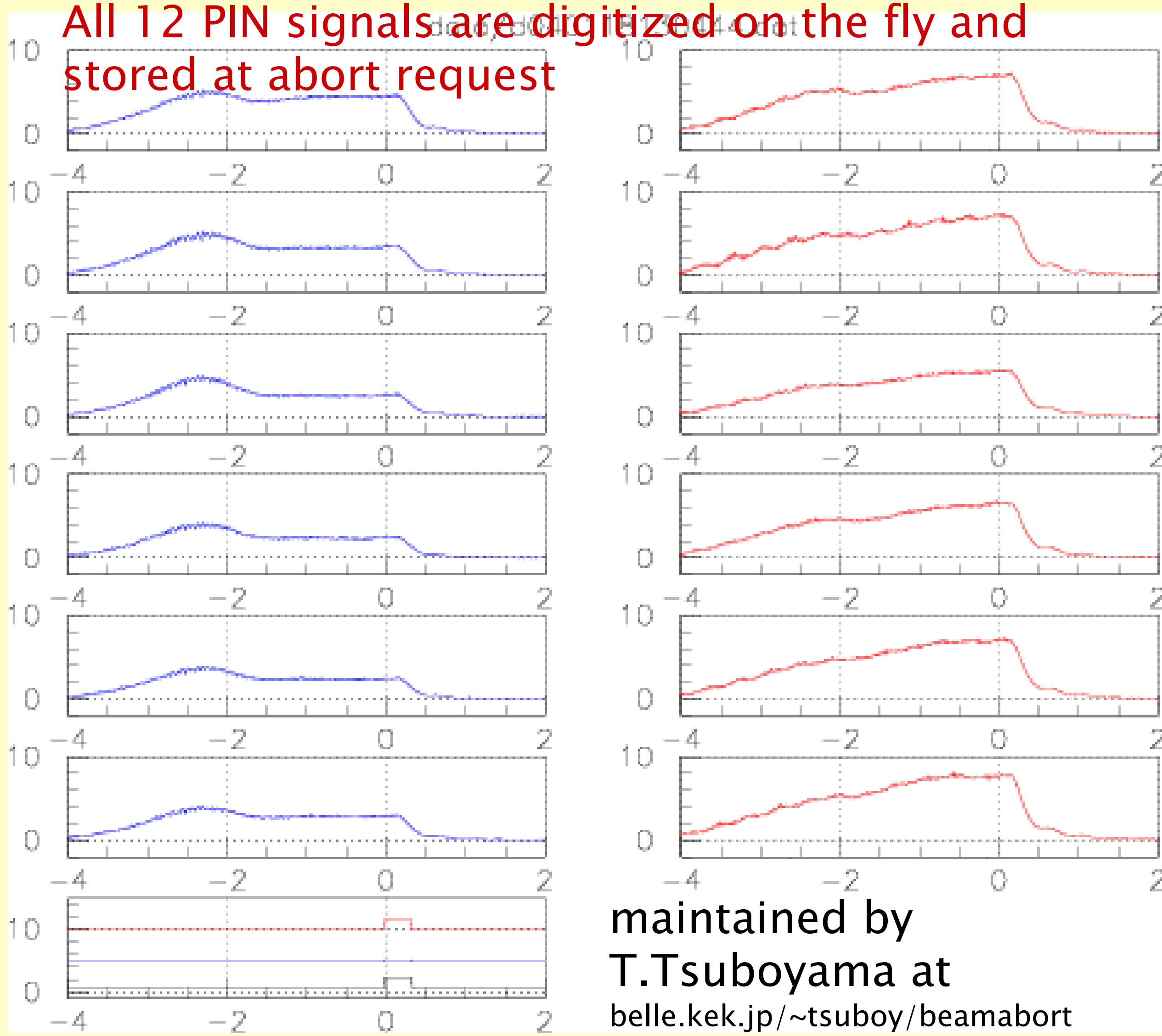
We log which PIN required the abort (red). In case that the multiplicity threshold is not reached, abort is not issued (orange). Blue is abort due to cooling system interlock.

SVD2.0 Abort – PIN signal development

Examples of different beam aborts



All 12 PIN signals are digitized on the fly and stored at abort request



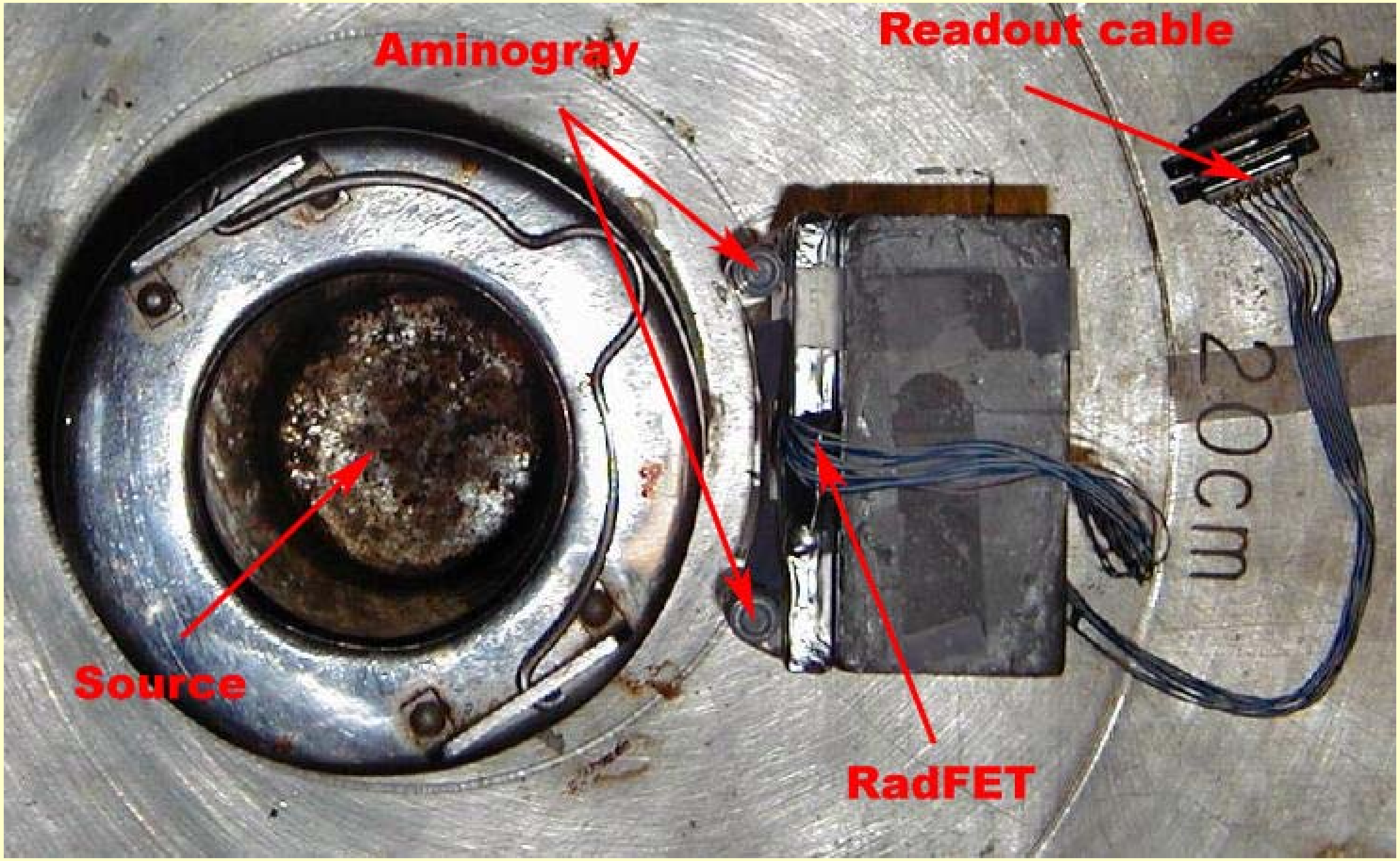
maintained by T.Tsuboyama at belle.kek.jp/~tsuboy/beamabort

Monitoring R&D

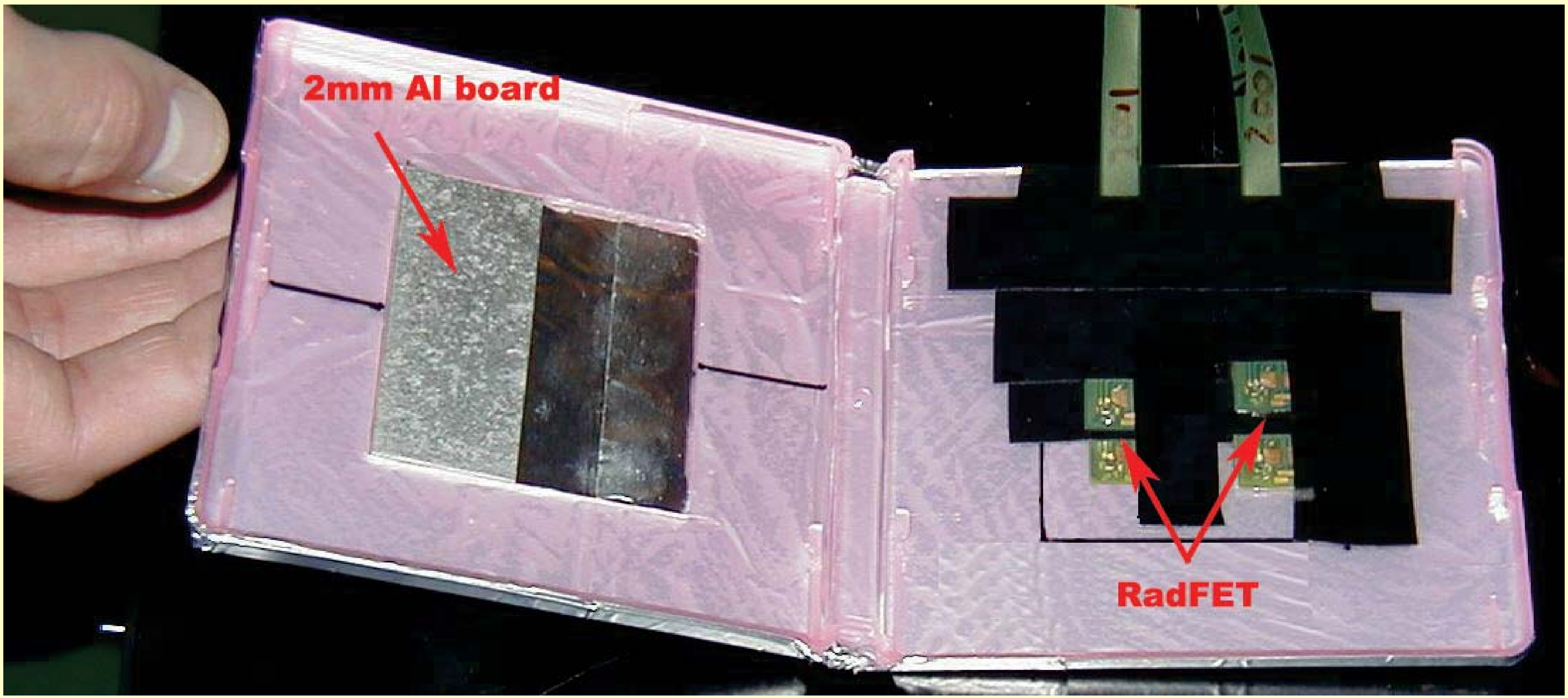
1. Calibration of PIN/RadFET
   - RadFET response is not linear with the dose. To correctly estimate radiation damage, we calibrated the RadFET with 15% error.
   - PIN gain decreases with accumulated dose. Now they are calibrated by the RadFET, however, independent calibration is desired.
   - For survival and calibration reasons both PIN and RadFET have to be tested up to the expected doses in Belle.
2. Testing of new types of radiation monitors
   - Need sensors that will be able to survive SuperKEKB environment – candidates are CVD diamond sensors
   - Studies will begin in Feb./March 2004
3. Design of new detector geometries and new monitoring tools
   - Will proceed with other SuperB related work

Calibration

A series of RadFET calibration experiments was performed with Co-60 source at TIT in Tokyo. All the rates were confirmed by our own dosimetry (using commercial aniline dosimeters).

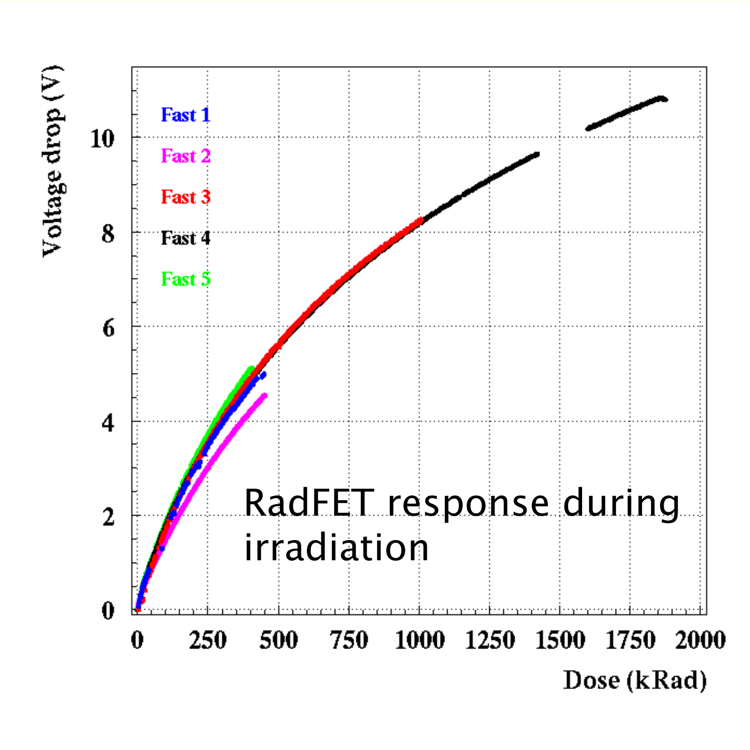


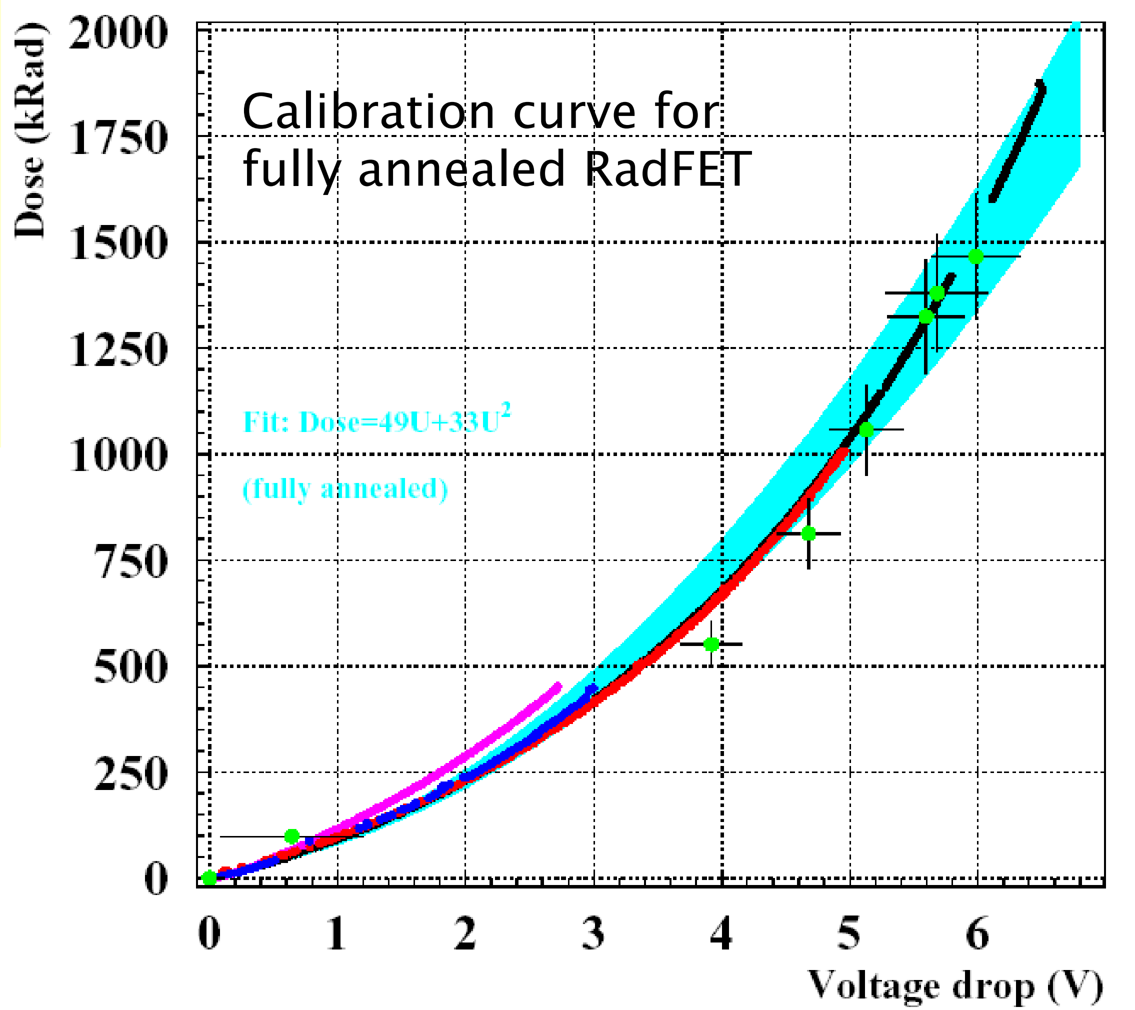
There was no observable difference in RadFET response with and without 2mm thick Al board (Compton scattering) in front of the sensors



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

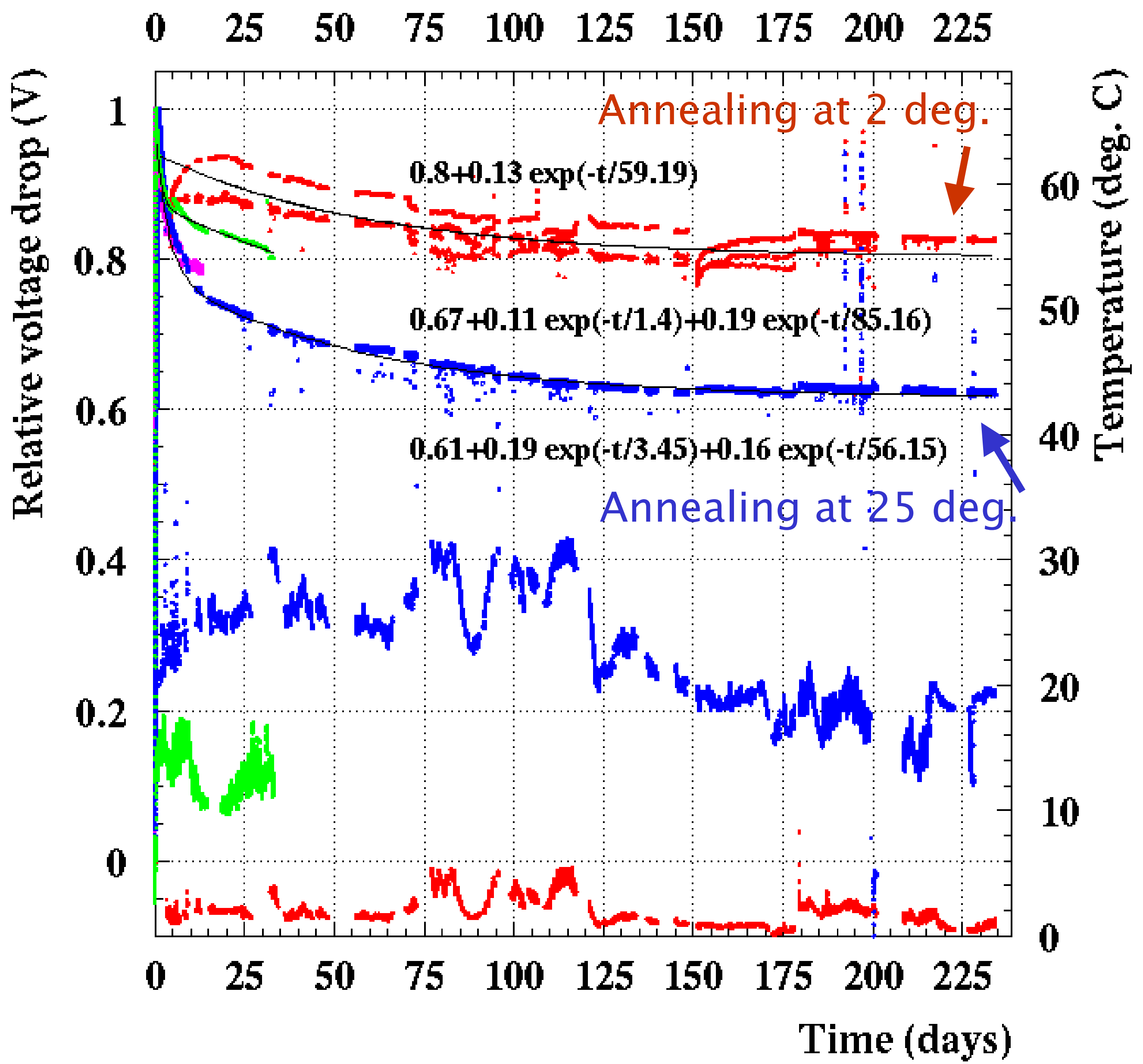




- Low dose rate (1.6kRad/h) irradiation results agree with high dose rate (80kRad/h) ones

Annealing

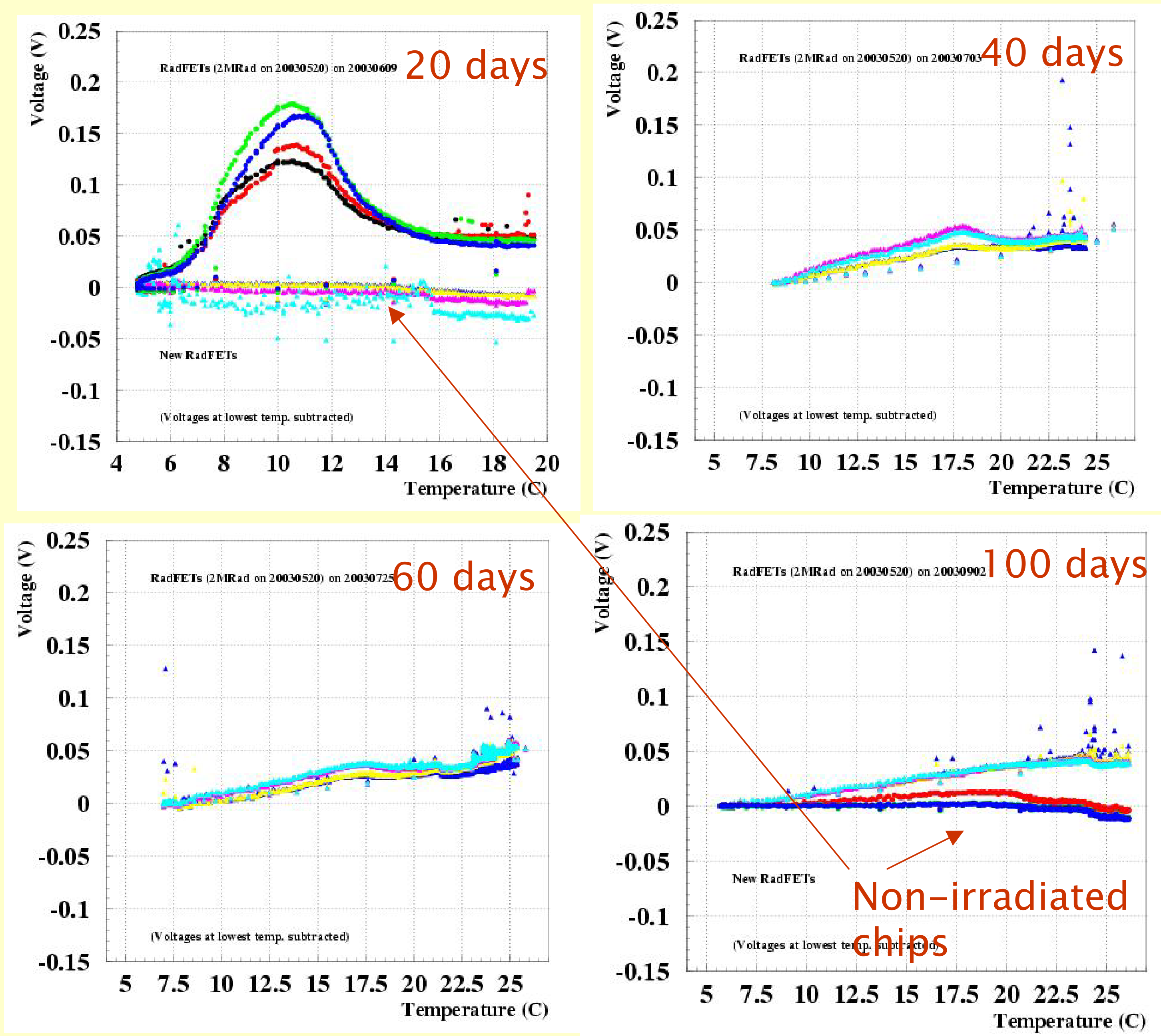
- We found that both, the annealing rate and the total amount of annealing strongly depend on env. temp.
- There are at least 2 annealing components, a fast one with 4 days time constant and a slow one with 80 days constant
- Measurements require a lot of time, more data needed



Temperature dependence of the gate voltage

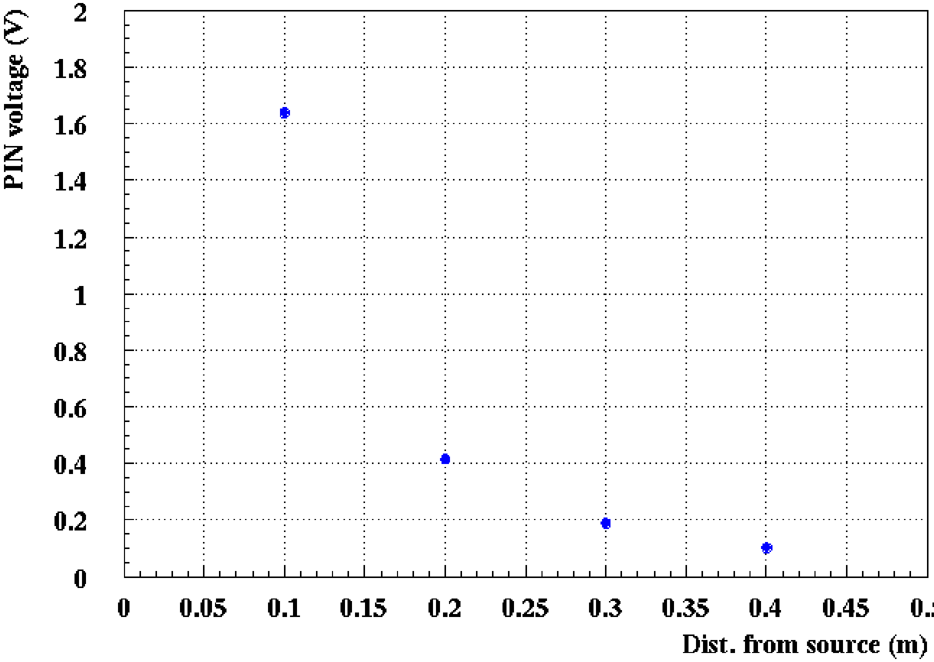
Irradiated RadFET were exposed to 1.85MRad

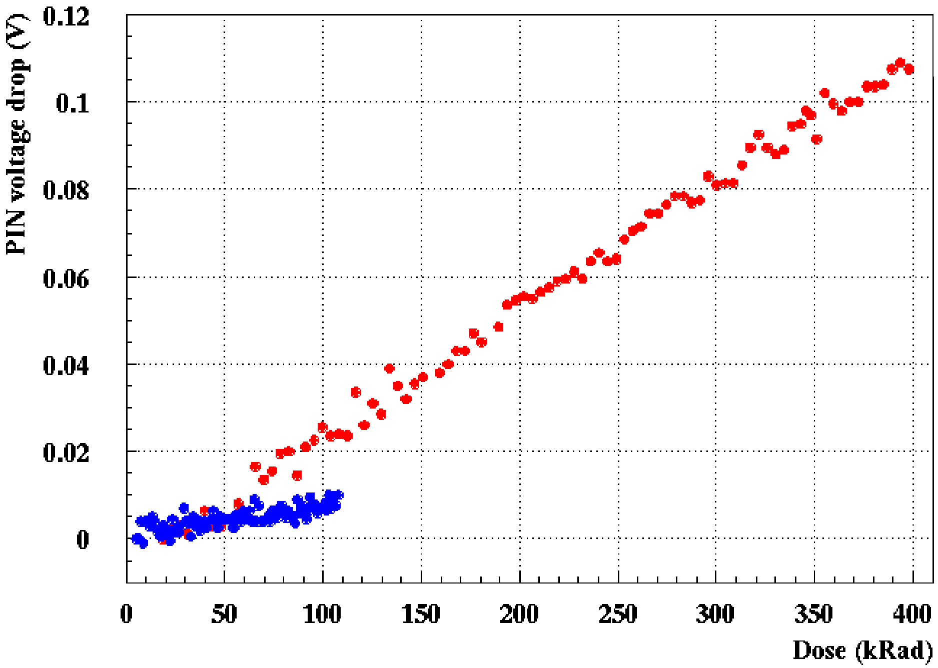
Annealing was at room temperature



PIN calibration

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





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

Preparing for irradiations around QC1 magnet in KEKB tunnel

Calibration

- Same background sources as Belle
- Close at hand

Physics

- Useful to know about radiation background around steering magnets

In the near future…

- We will start testing CVD diamond sensors as soon as possible
- Push the RadFET/PIN usage limit as high as it goes
- Reach better understanding of annealing effects
- Prepare new generation of readout electronics needed for that
- And learn as much as we can from the present system!