Radiation Monitoring with CVD Diamonds in BaBar

Brian Aagaard Petersen
Stanford University

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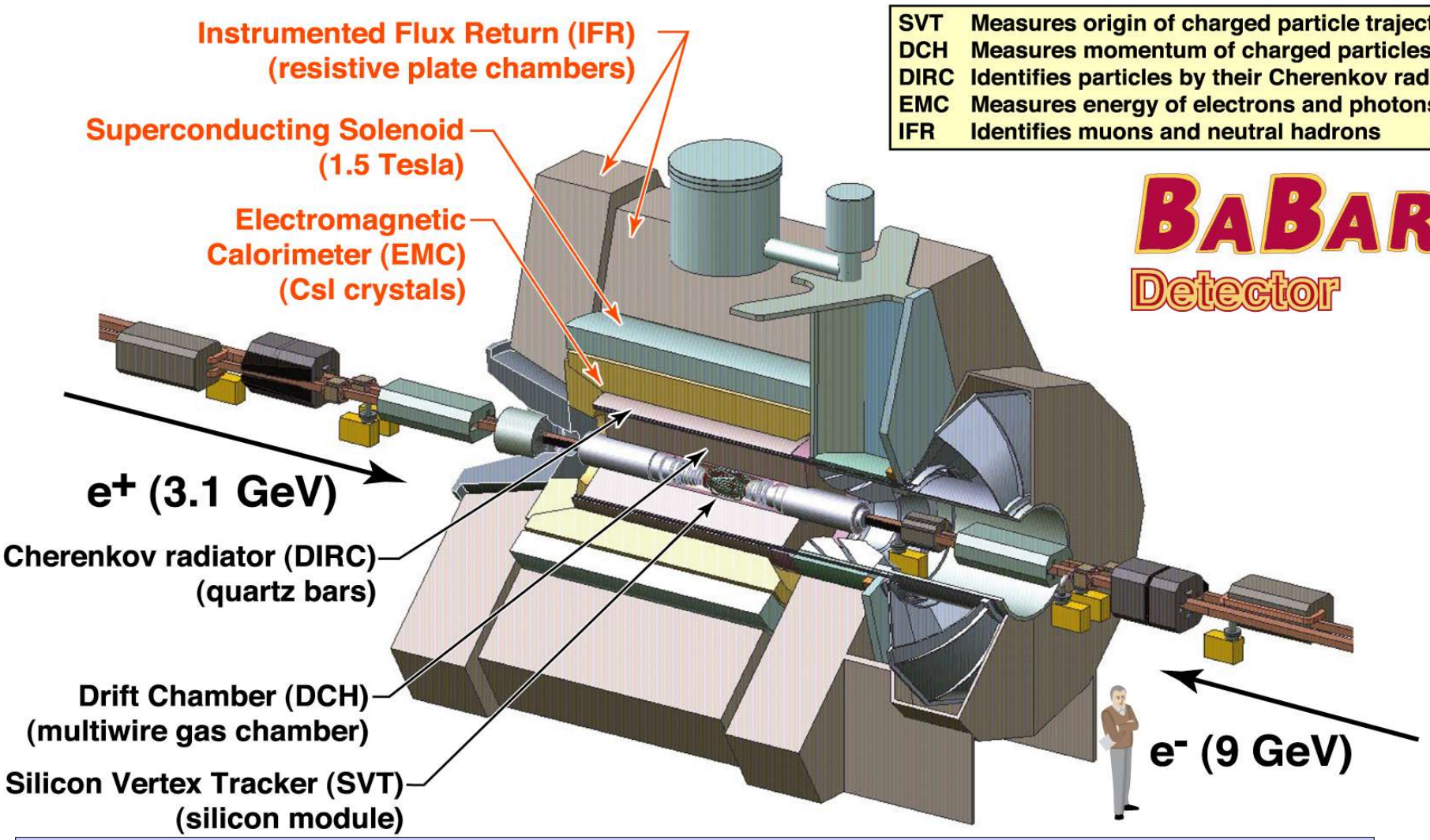
Institutes:

- Ohio State University: *Harris Kagan, Richard Kass, Teela Pulliam*
- Stanford University: *Pat Burchat, Adam Edwards, Brian Petersen*
- UC Irvine: *Maarten Bruinsma, David Kirkby*

The BaBar Experiment

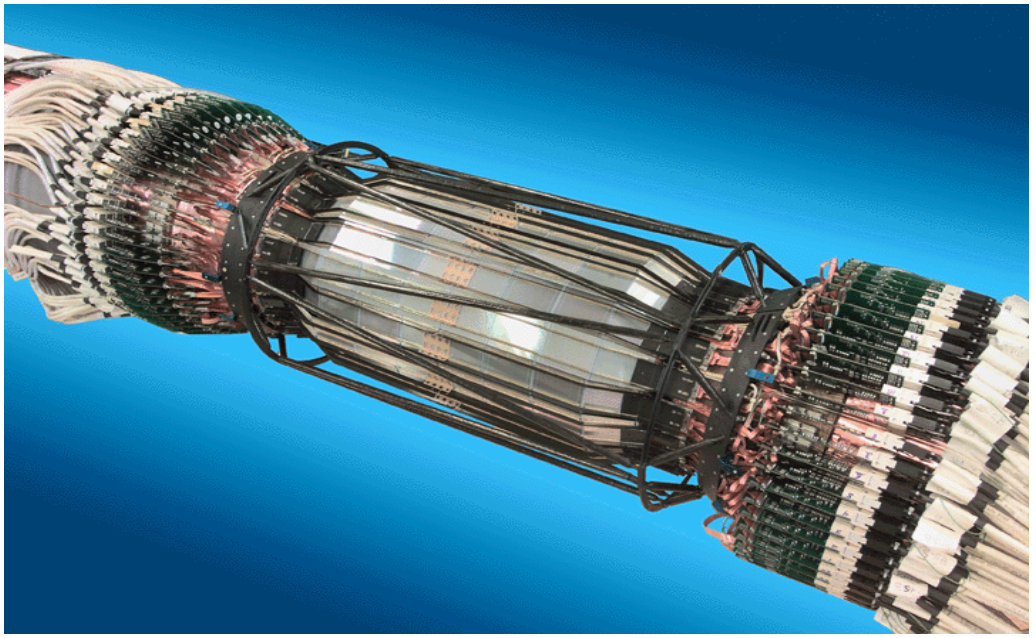


B-Factory:

High luminosity, $O(10^{34}\ cm^{-2}s^{-1})$, e^+e^- experiment at $\Upsilon(4S)$ energy

Designed to reconstruct beauty, charm and tau decays

Silicon Vertex Tracker



Silicon Vertex Tracker (SVT):

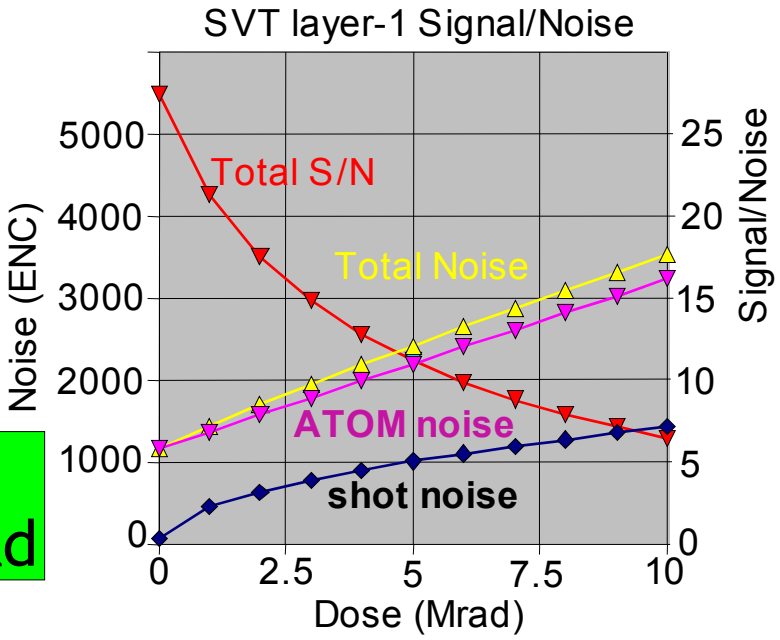
- 5 layers of double sided Silicon
- 300 μm thick n-type Si
- Operated at room temperature
- AC-coupled readout
- 150000 readout channels
- Track eff. >70% for p_T>80 MeV/c
- Vertex z resolution ~80 μm

Potential Radiation Damage:

- P-stop shorts at >1 rad/ms
- Increasing dark current ($2\mu A/cm^2$/Mrad)
- Increasing noise and reduced gain in readout chips (16%/Mrad)

SVT was designed for 2 Mrad
Has been successfully tested to 5 Mrad

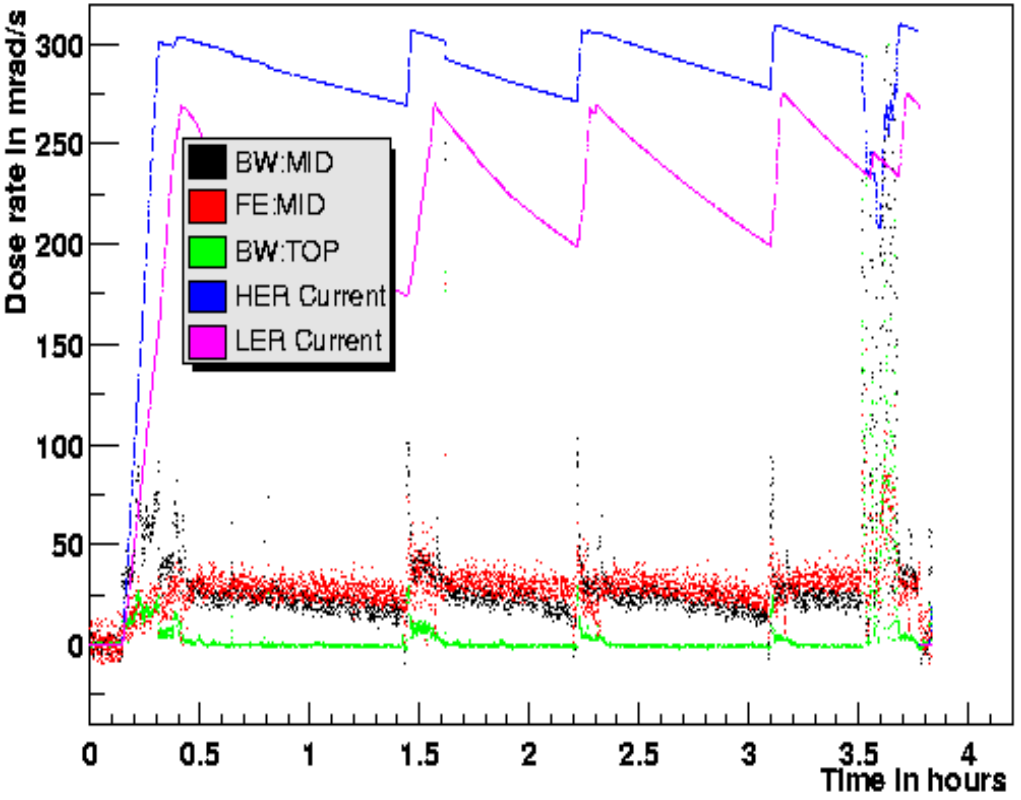
- **SVT L1-Signal/Noise vs dose**

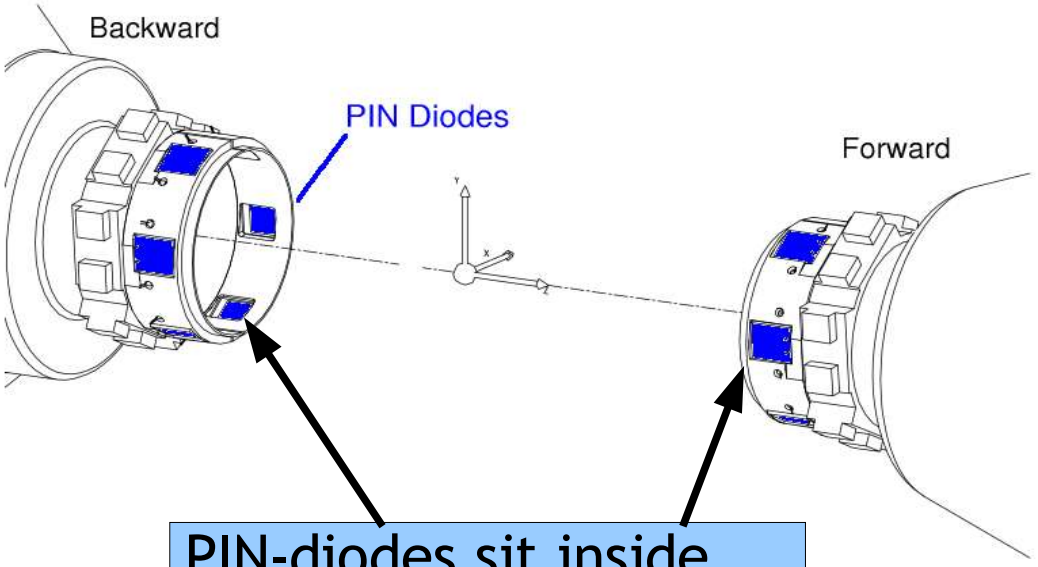


Radiation Protection & Monitoring

Radiation Monitoring System:

- 12 Hamamatsu Si PIN-diodes
- 1x1 cm^2 active area
- Reversed biased at 50 V
- Radiation measured from DC current: 1nA~5mrad/s





PIN-diodes sit inside layer 1 readout

Radiation environment:

- Typical dose rates: 1-50 mrad/s
- Operator alarms at ~100 mrad/s
- Beam aborts >1 rad/s

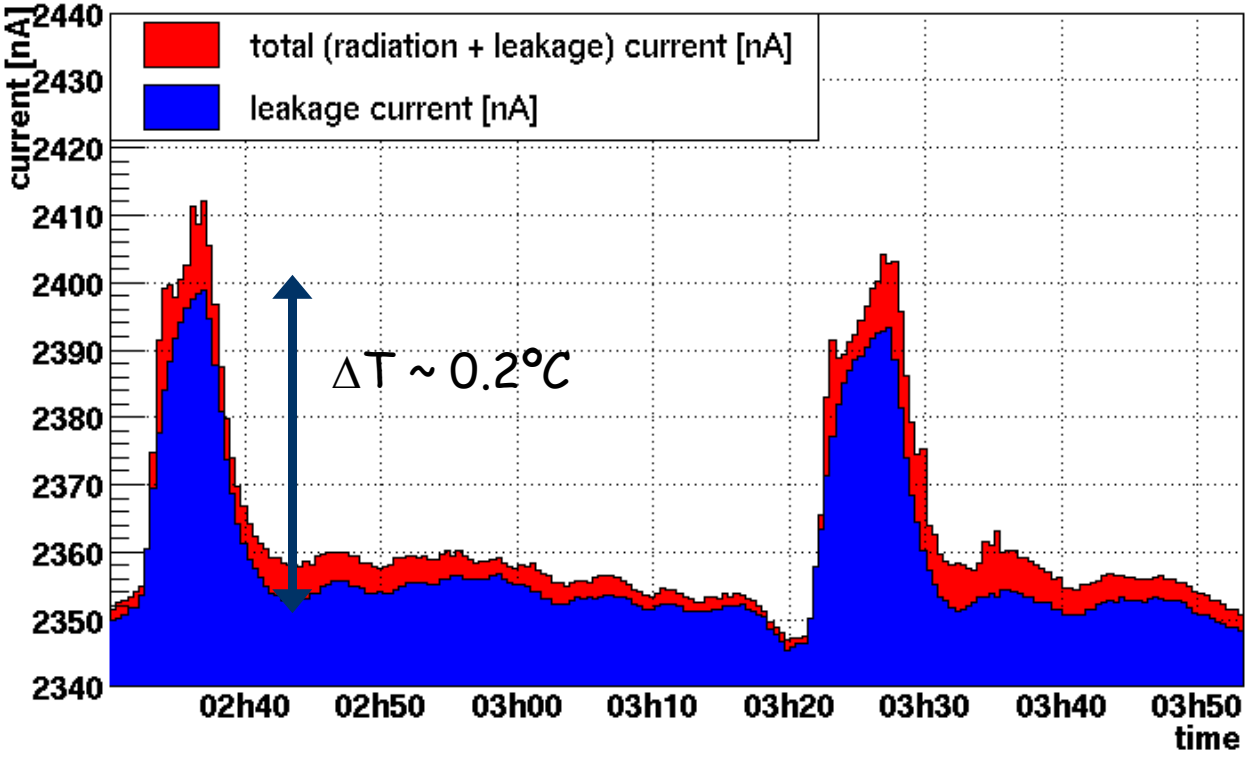
Silicon PIN-diodes

PIN-diode dark current:

- Dark current in Si grows with radiation dose (1-2 nA per krad)
- Dark current depends strongly on temperature (~10% per °C)
- Needs to be continuesly monitored and predicted in order to estimate radiation induced current

Signal currents are now below 1‰ of the dark currents in many of the PIN-diodes

The dose rate can no longer be accurately measured



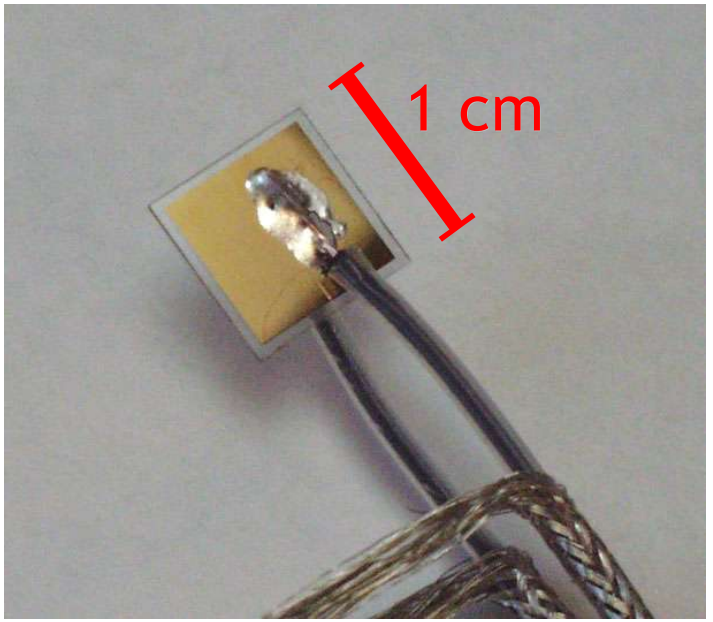
Can we replace Si PIN-diodes with CVD diamonds?

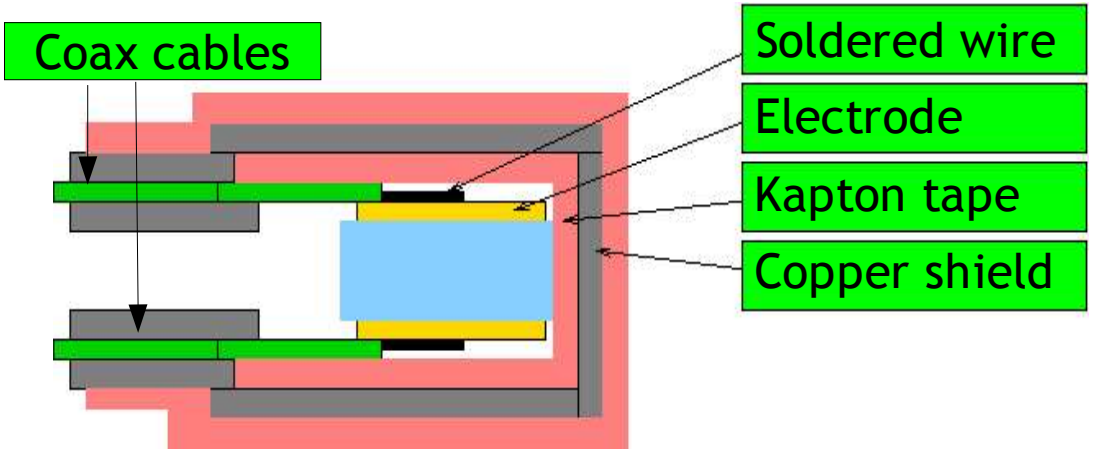
CVD Diamonds In BaBar

Two polycrystalline CVD diamonds installed in 2002

(In collaboration with RD42 and Element Six)

- Both 1cm x 1cm x 500 μm with 0.9 cm x 0.9 cm gold pads
- Charge collection distance of ~200 μm
- HV coax cables soldered directly on gold pads
- Wrapped in kapton and copper tape for noise and HV shielding
- Radiation measured by total DC current at 500 V

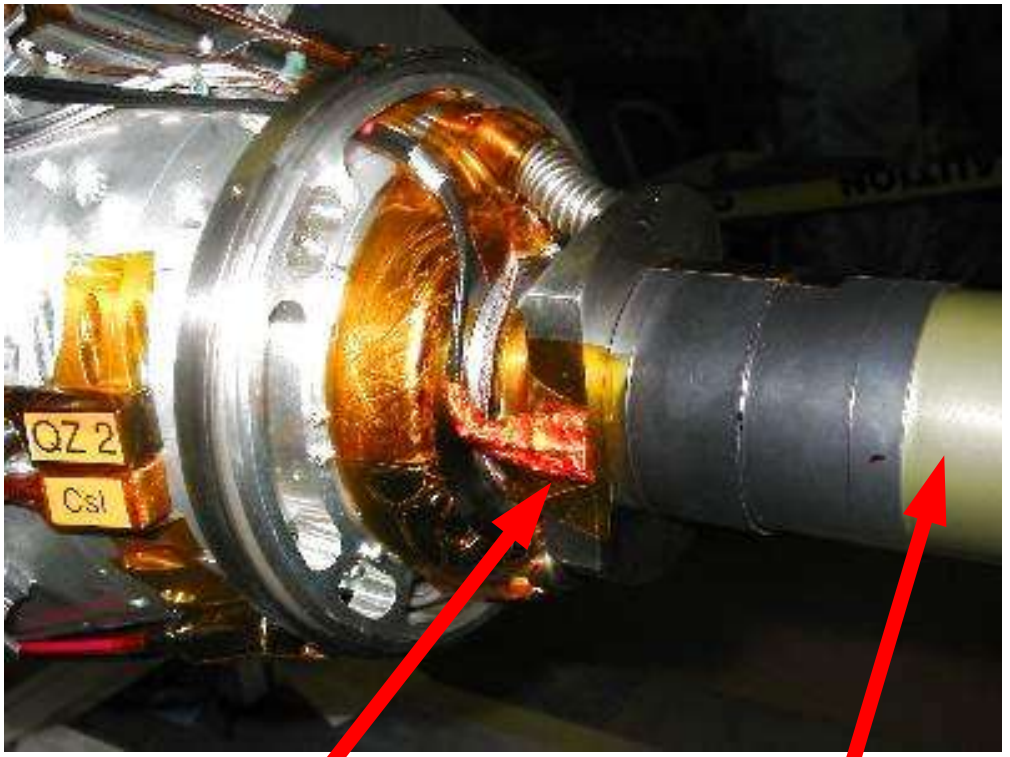




Diamond Installation

- The two diamonds added to existing system of PIN-diodes
- Placed in horizontal plane, 15 cm from interaction point (PIN-diodes are 10 cm from interaction point)
- Integrated into existing PIN-diode readout system
- Diamonds have been biased at 500 V and read out for last 15 months

Packaged Diamond:



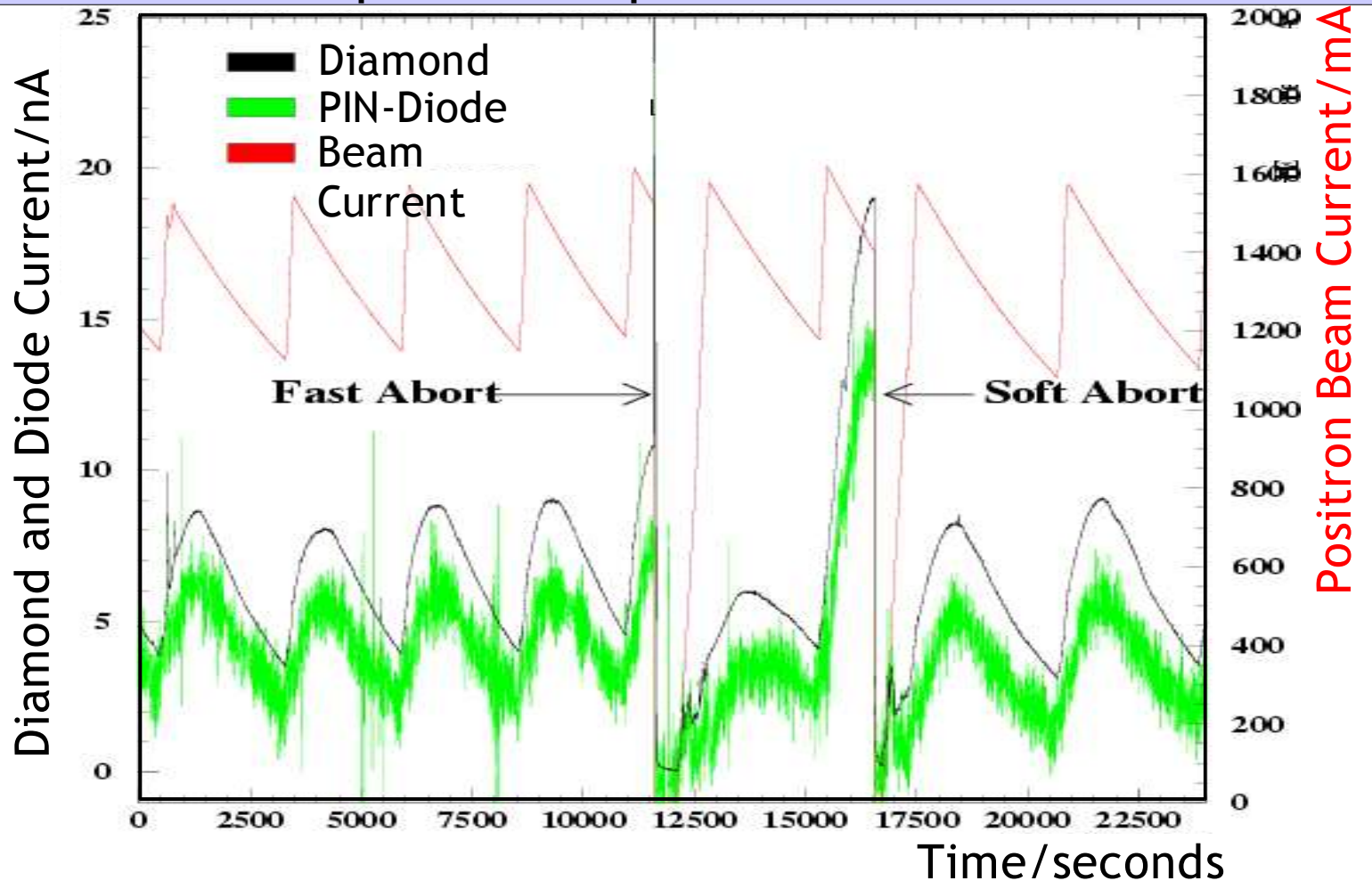
Diamond sensor

Be beam pipe

Diamond Results

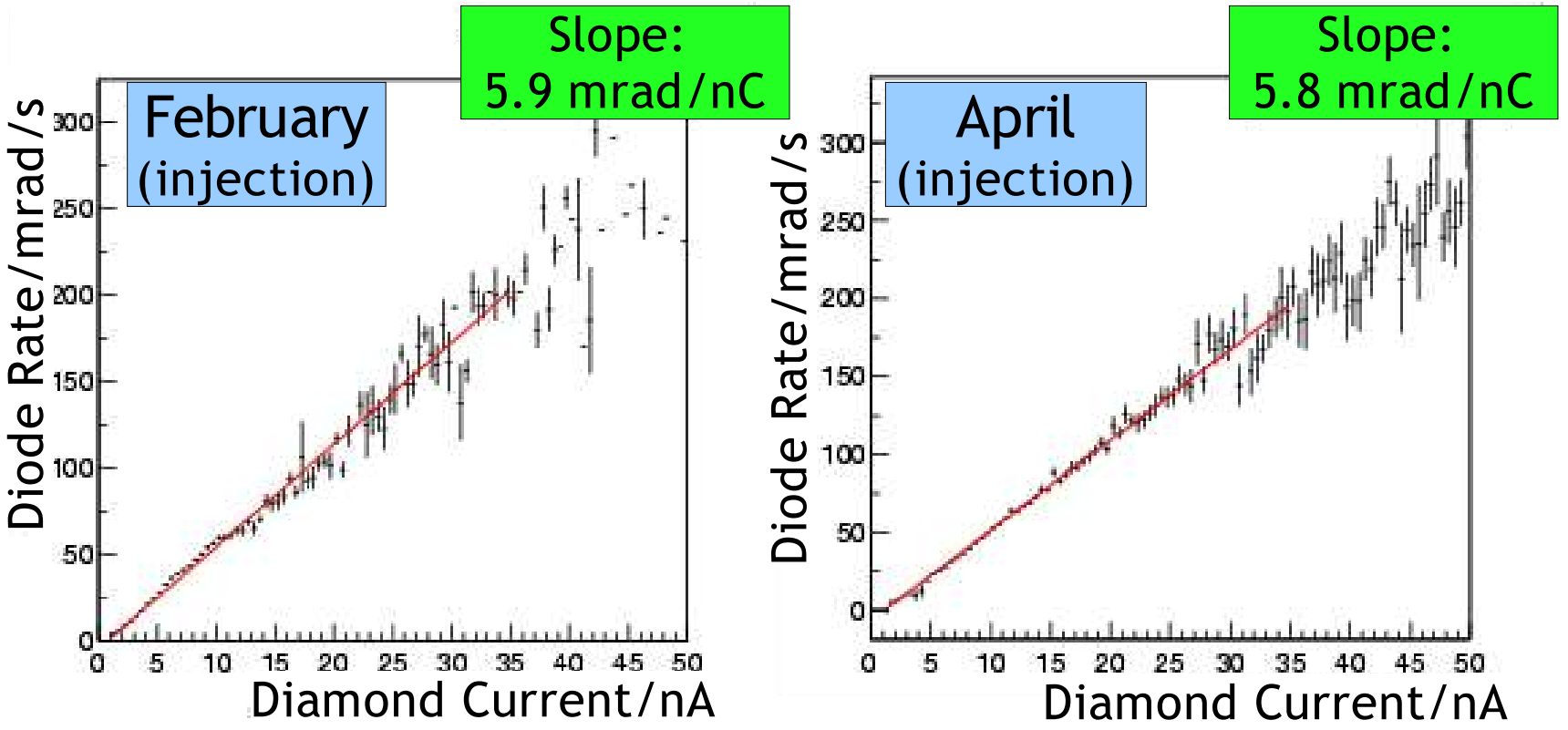
Excellent results from the two diamonds:

- Diamond signals are fully correlated with nearby PIN-diodes
- Provide very clean signal due to their tiny dark currents
- Have had no operational problems



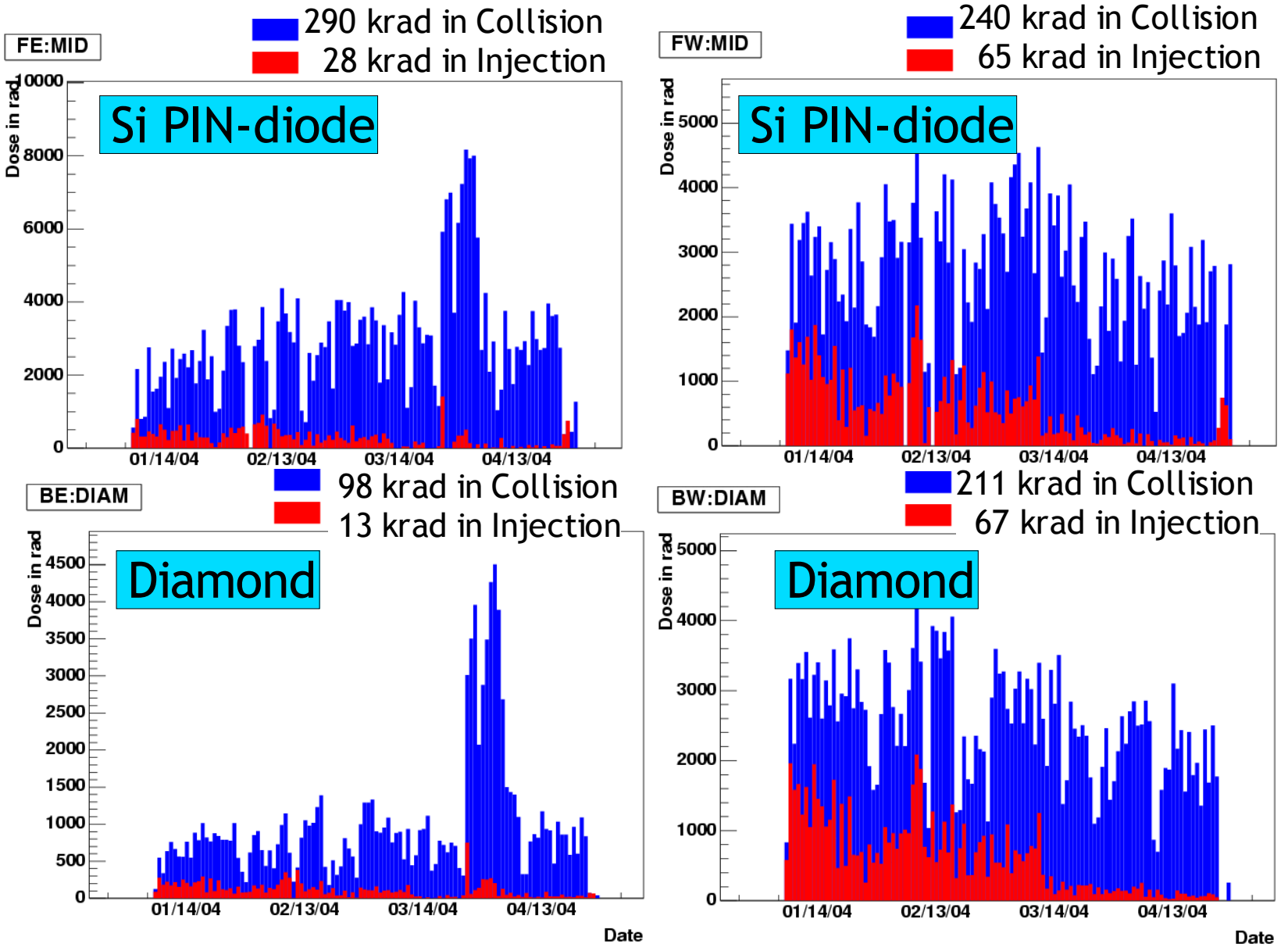
Diamond & Si PIN-diode Correlation

Diamonds have received ~500-800 krad while installed
- No increase in leakage current observed
- Diode-diamond correlation almost unchanged over many months



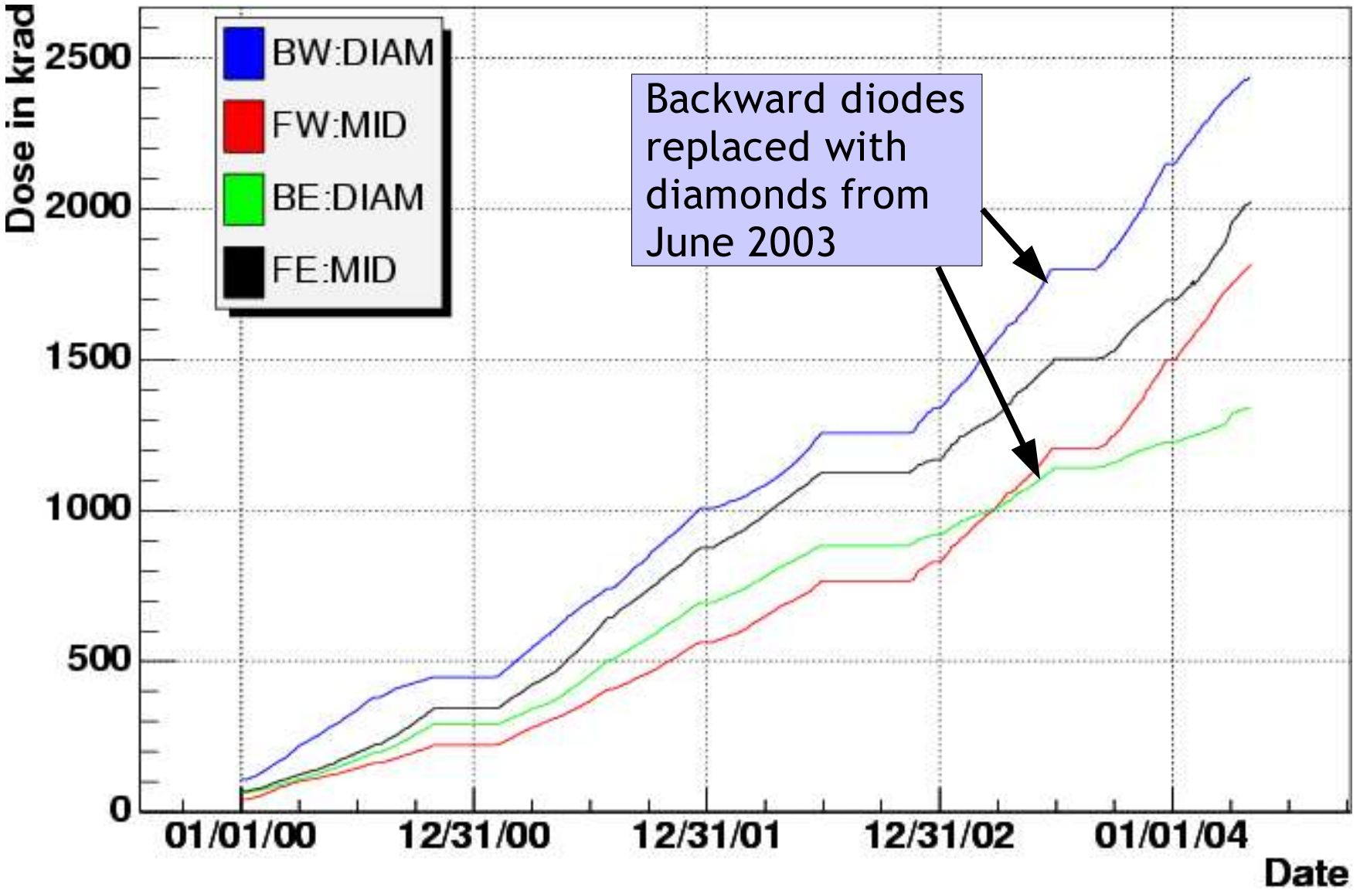
Daily Dose Monitoring

The two diamonds are now part of the daily dose monitoring:



Dose Monitoring

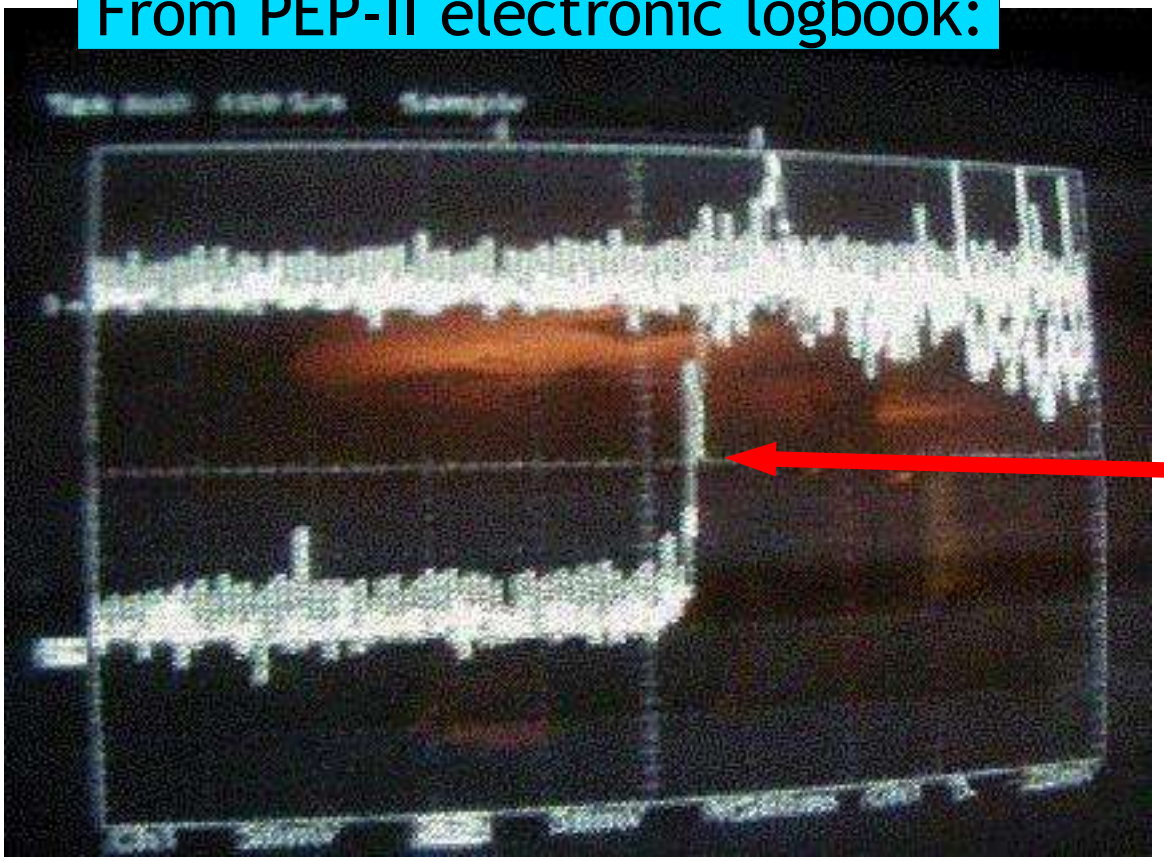
Similarly the diamonds help keep track of the total SVT dose:



Feedback to Storage Ring

Dose rates from PIN-diodes and diamonds send to PEP-II at 0.5 Hz
An analog signal from diamonds to PEP-II provides faster feedback on background levels for operators

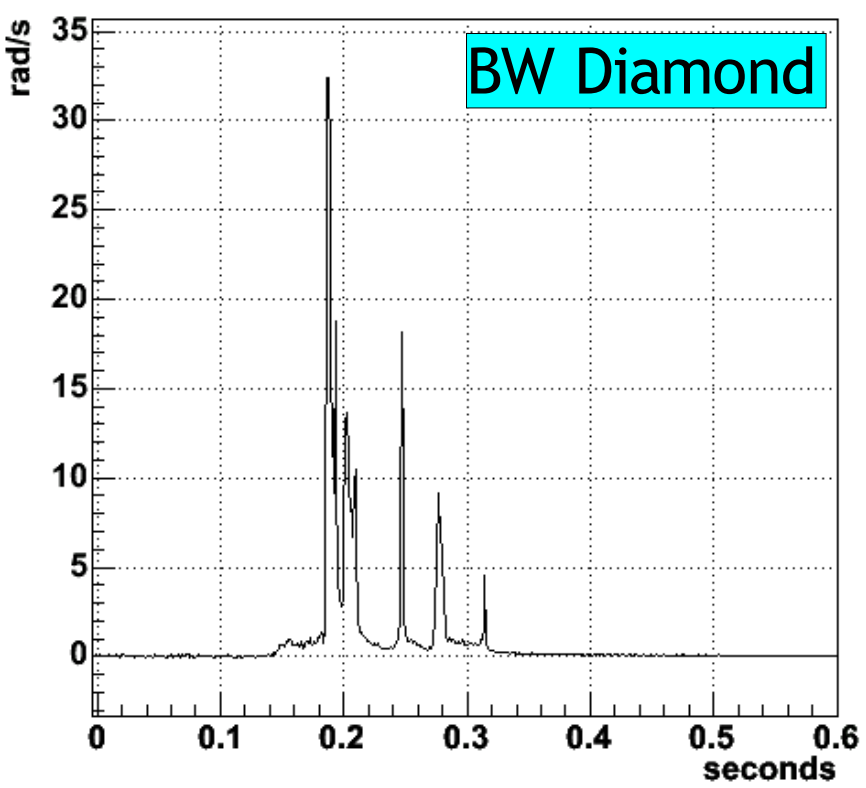
From PEP-II electronic logbook:

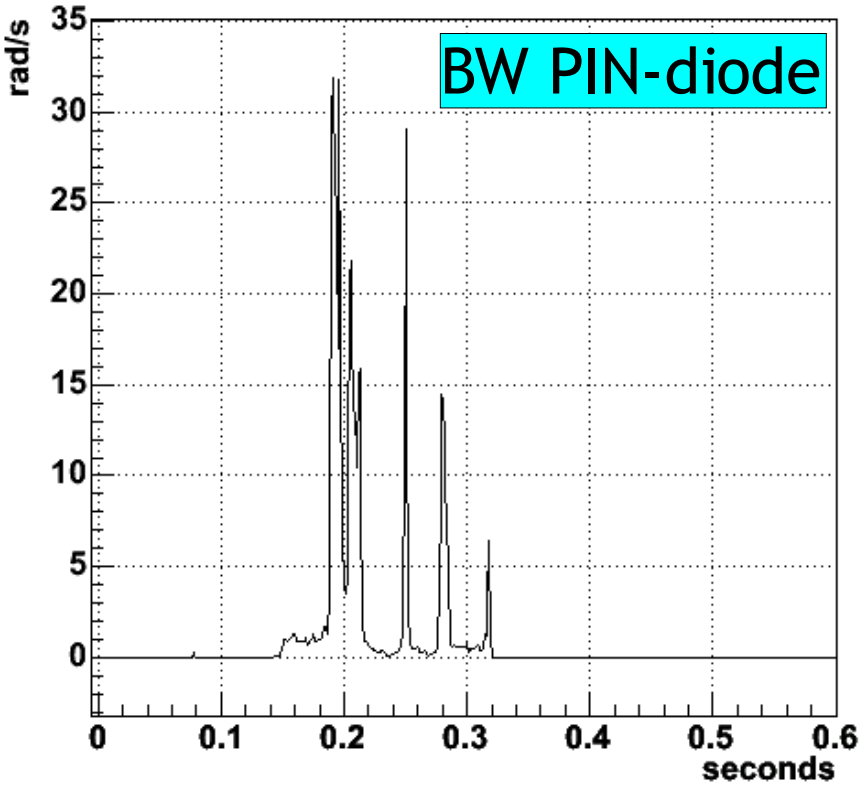


Diamond Response Time

Beam abort system requires fast response to radiation spikes

- Signals during radiation aborts show same pattern in diamonds and PIN-diodes and, within precision, the same response time



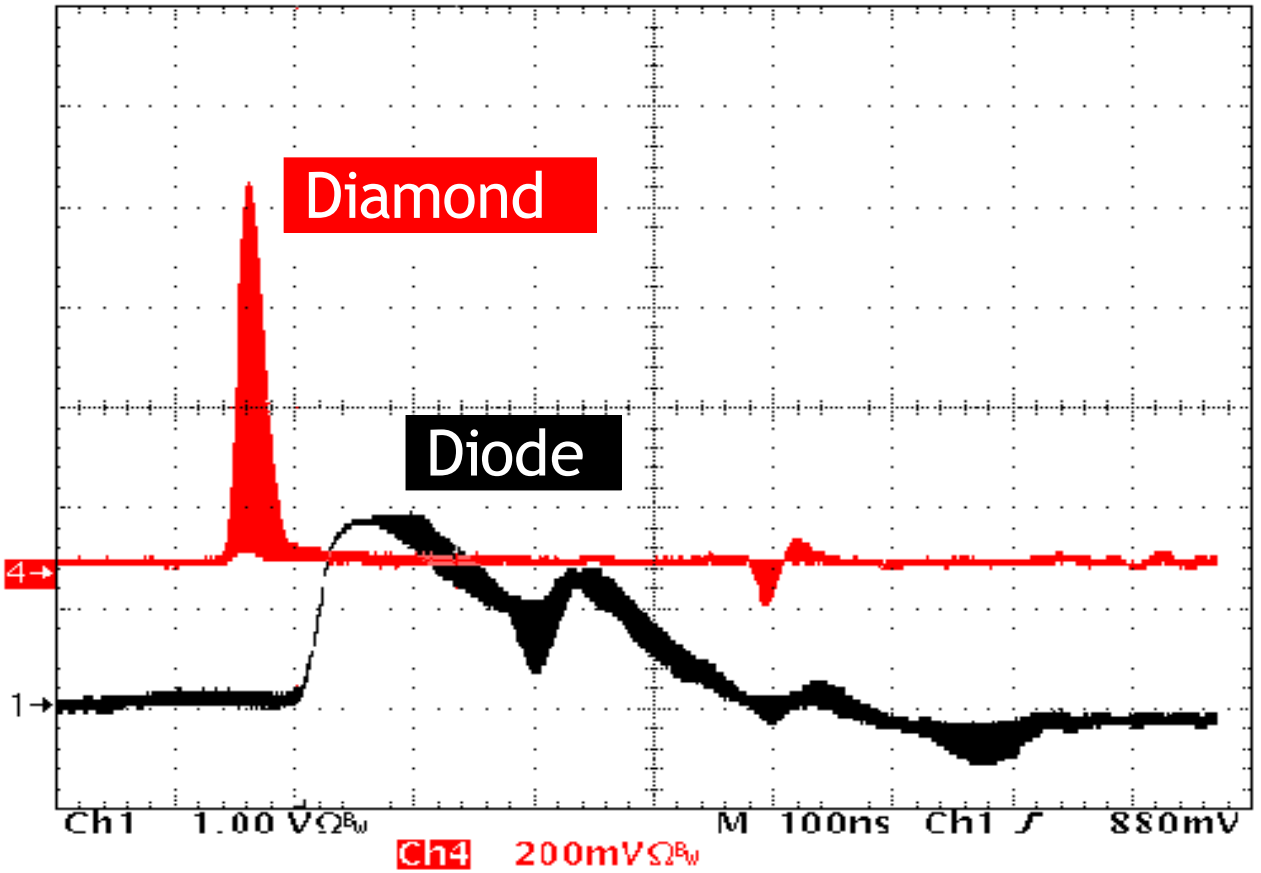


Time resolution is 1 ms

Diamond Response Time, cont'd

Checking response time with better resolution:

- Diamond connected to a fast amplifier
- Scope triggered by Si PIN-diode

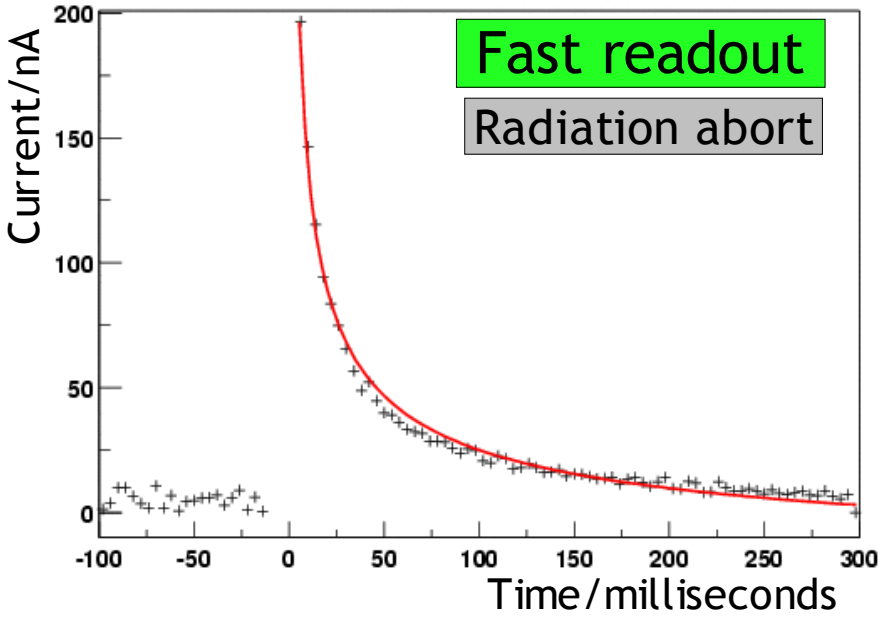


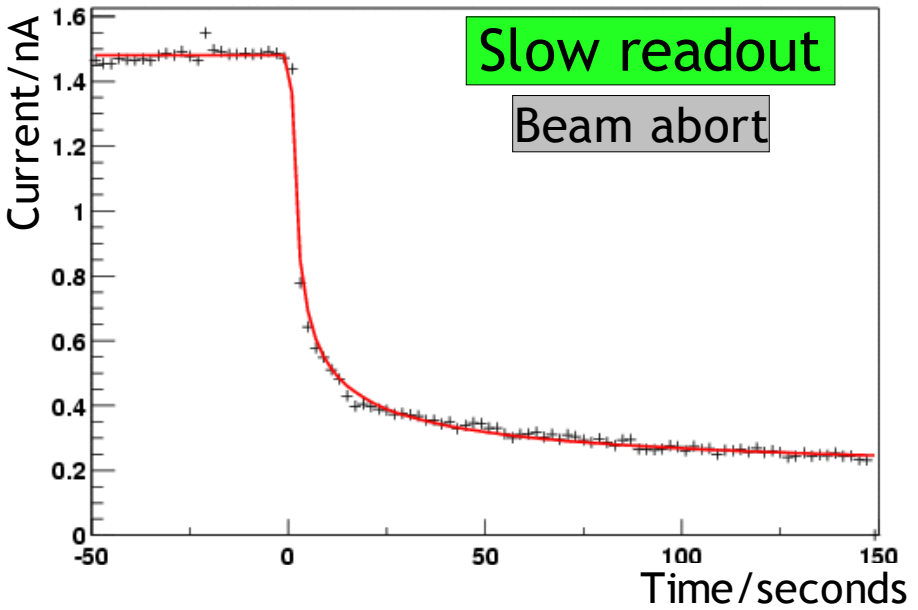
Better than 20ns – we only need ~10μs

Delayed Signal Component

Diamond signal has a slow component:

- See remnant current after radiation goes away
- Lasts for many seconds – not an exponential decay



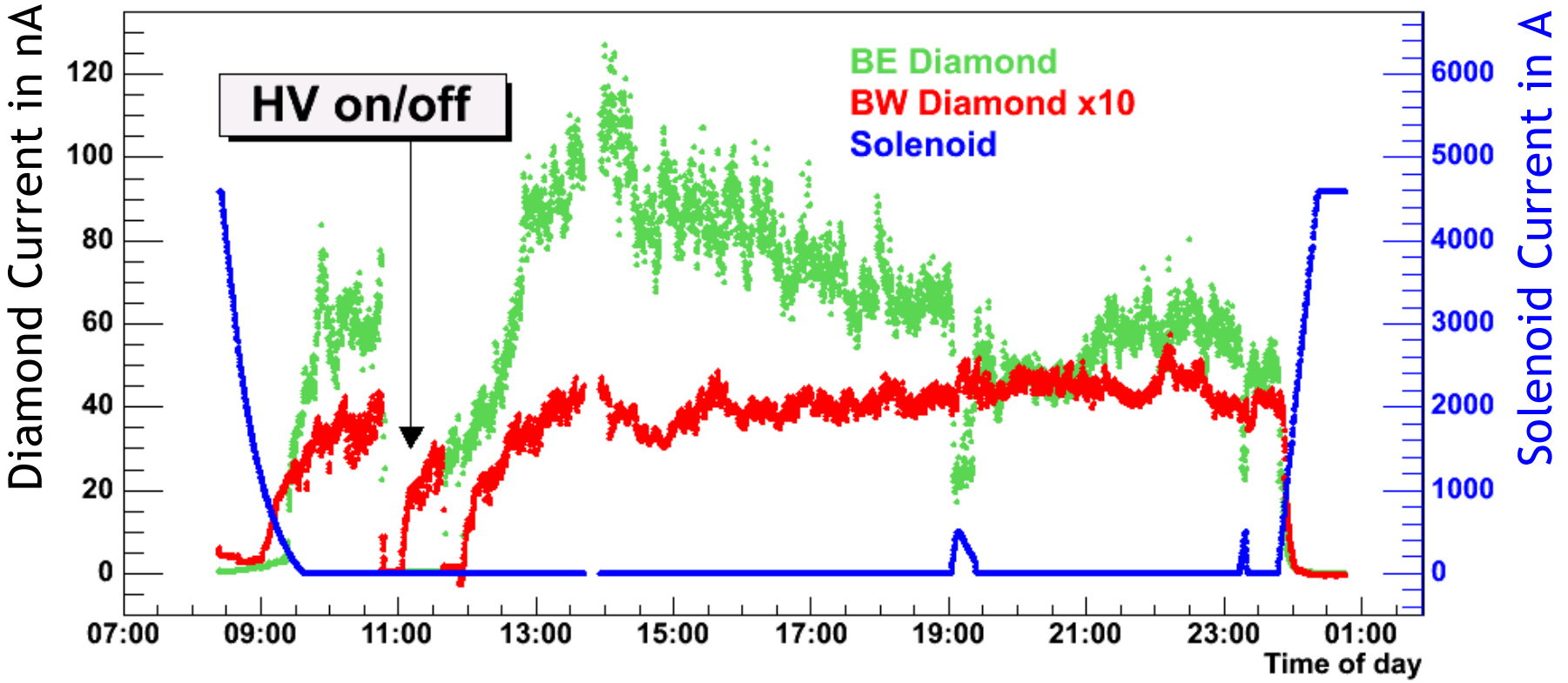


Believe current is associated with charge traps, presumably mainly in polycrystalline grain boundaries?

Not an issue for protection system
Major part of radiation signal is fast enough

Erratic Dark Currents at B=0

- During operations both diamonds located in 1.5 T magnetic field
- In this field, diamond dark current is below readout noise (<0.2 nA)
- Without magnetic field, it increases to 2-100 nA and is erratic
- Turning magnet back on at 1.5 T removes all erratic dark currents



More details in Adams presentation

Summary and Outlook

- Diamonds are being investigated as radiation sensors in BaBar
- Successfully installed two diamonds in 2002
- Have had no operational problems
- Provides a better signal than old silicon PIN-diodes
- The two diamonds went from being a test setup to an integral part of the standard radiation monitoring system
- Some effects still to be fully understood
  - None of them prevents us from using diamonds as radiation sensors

- Plan to add diamonds to all 12 PIN-diodes in 2005 shutdown
- Trying to get single-crystal instead of poly-crystal diamonds
  - Not clear that we will get them in large enough size in time for the upgrade
  - Main advantages of single-crystal diamonds would be lower bias voltage (can use existing cables) and larger signal