Diamond detectors for radiation monitoring and beam abort at Belle II

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for the Belle II collaboration

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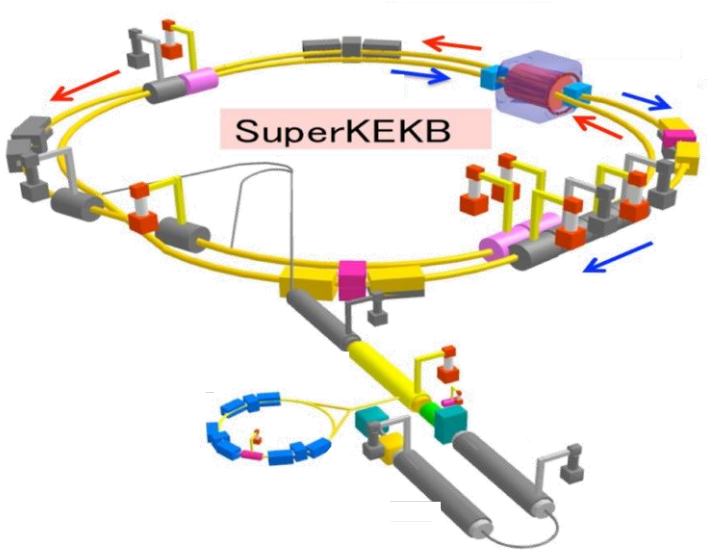
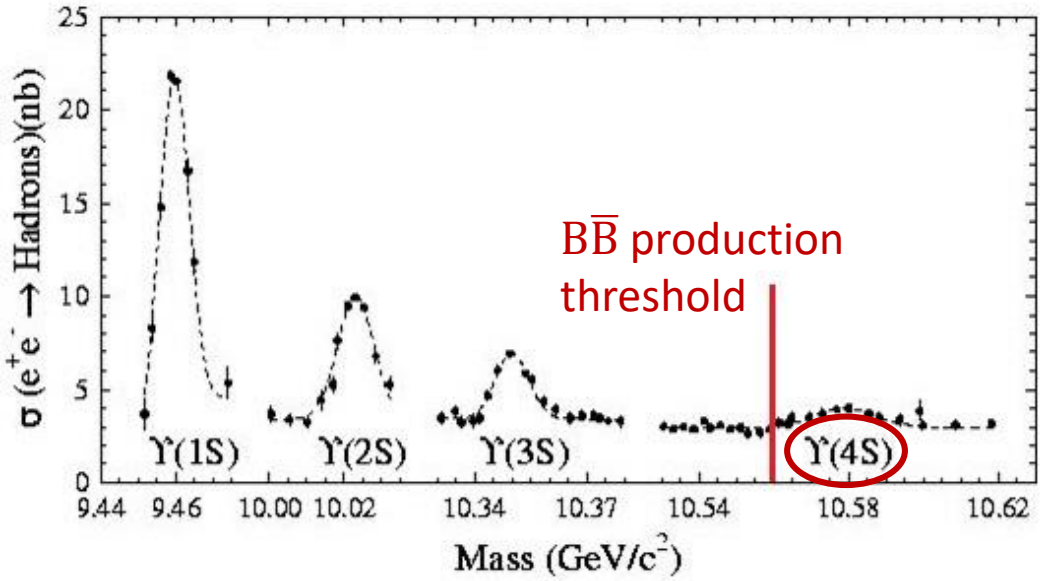
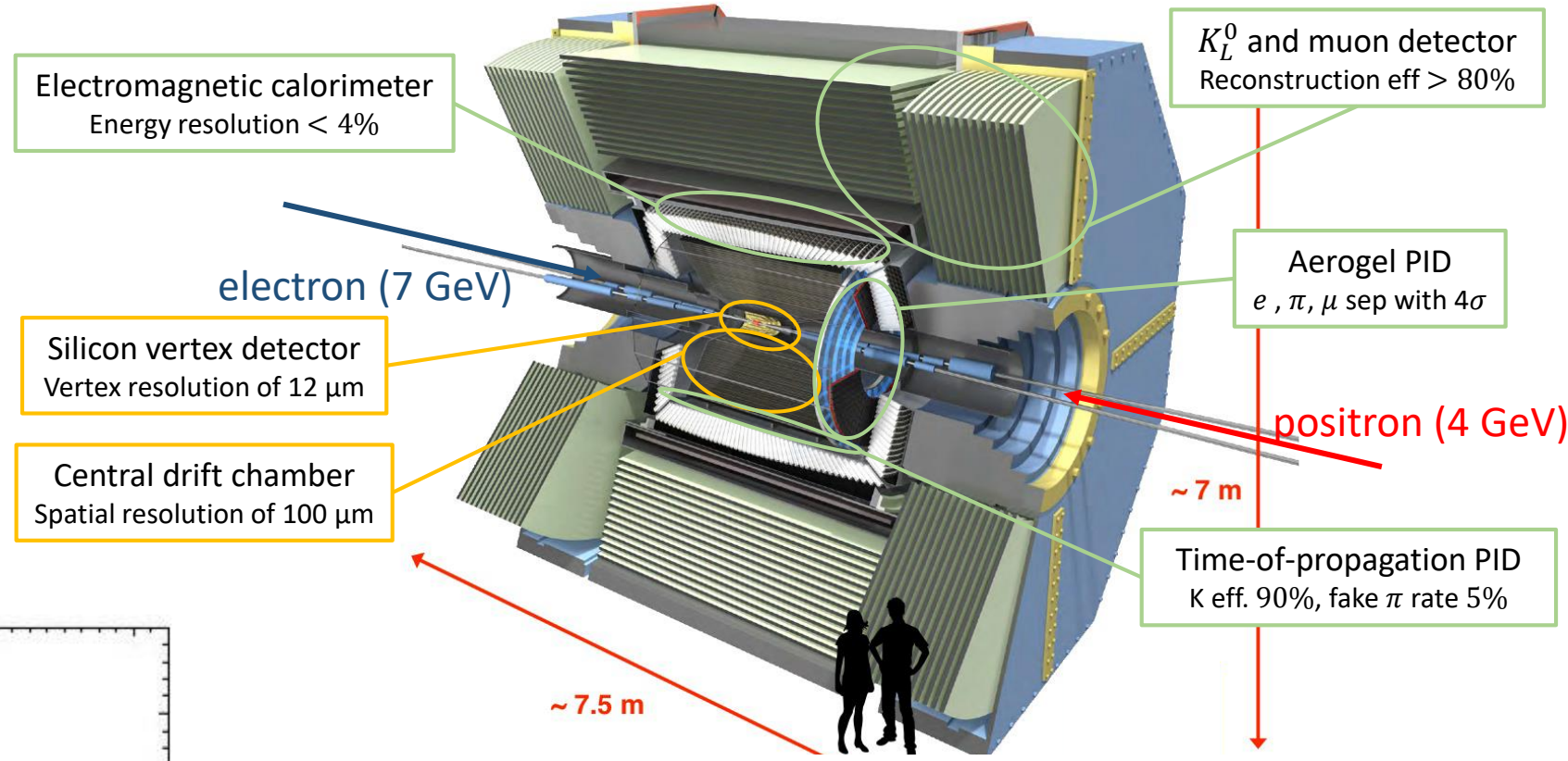
The Belle II detector at the SuperKEKB collider





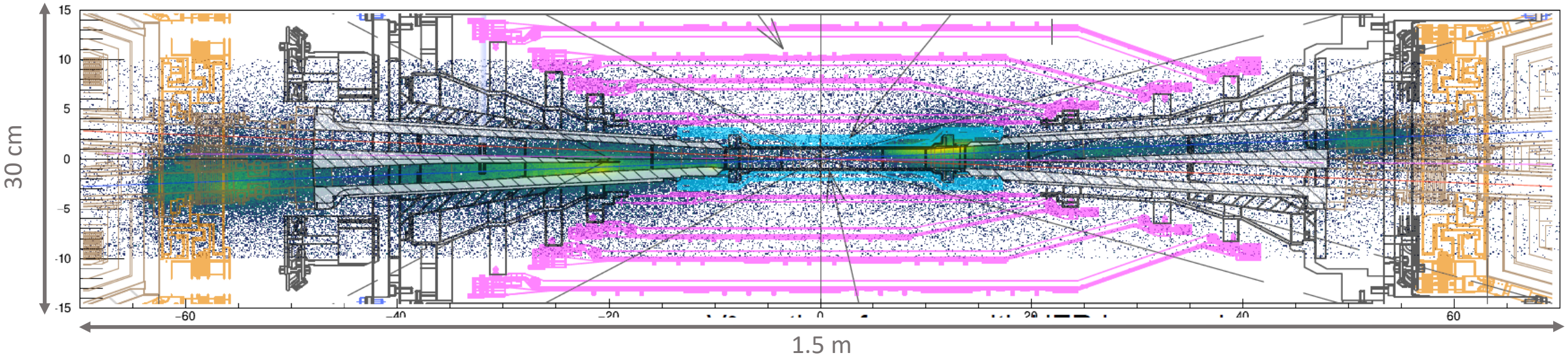


900 $B\bar{B}$ pairs/second in a low-bkg enviroment for 10 years
Aim: study precisely B decays to probe deviations from SM

Need 8×10^{35}cm^{-2} s^{-1} luminosity, 40x higher than predecessor beam currents 2x more intense, interaction region 20x smaller

Beam-background

High luminosity ⇒ high radiation from beam losses



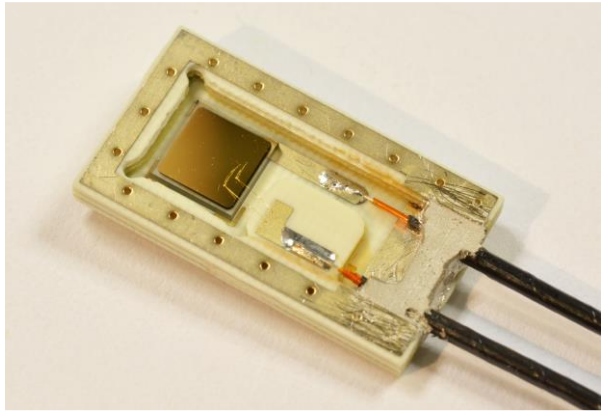
Vertex detector, 6 layers of silicon at 14 to 135 mm radii – the heart of Belle II
- maximum tolerable dose $\approx 10 - 20$ Mrad in 10 years
- localized damage with high radiation spikes: $\gtrsim 1$ rad in < 1 ms

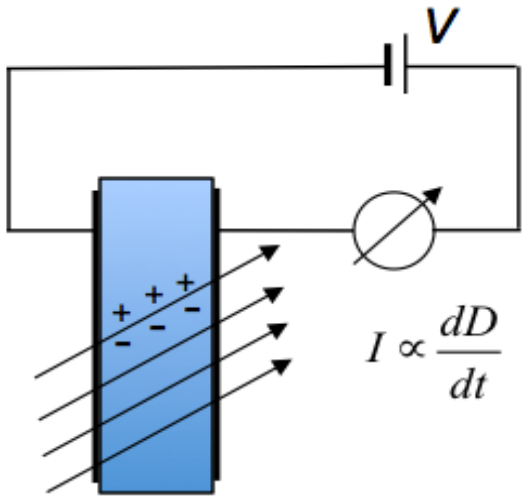
Final-focus superconducting-magnets quench if hit by large losses

Need precise dose monitor and protection: radiation monitoring and beam abort

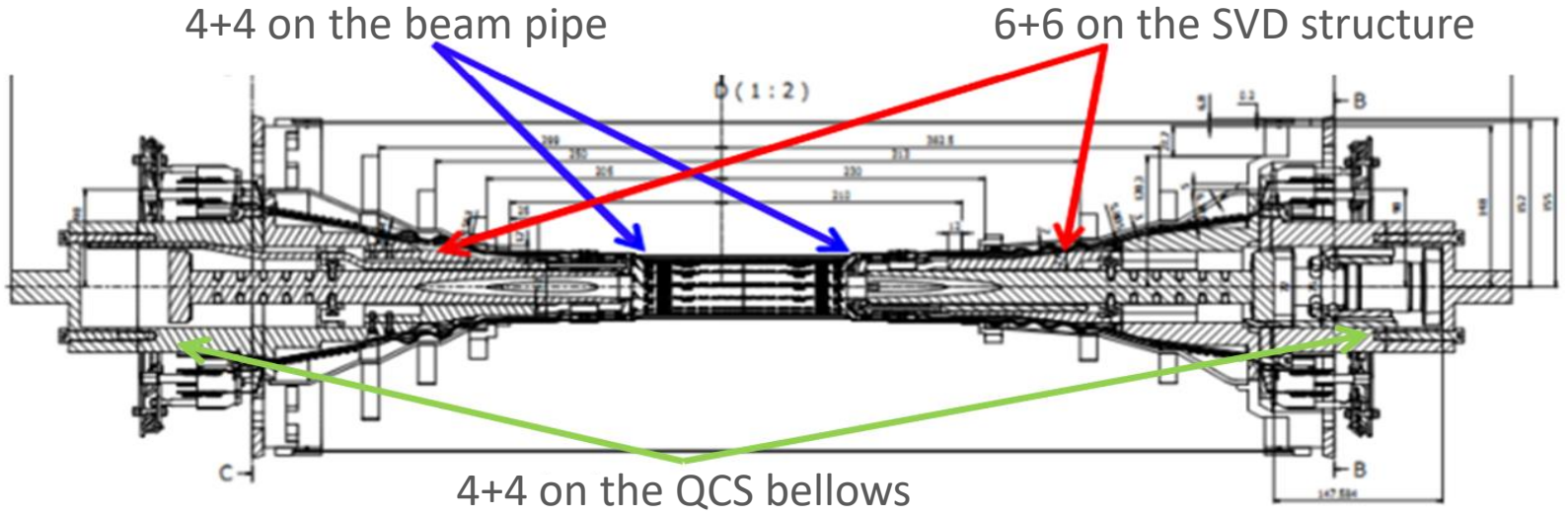
Diamond sensors

28 synthetic diamond $5 \times 5 \times 0.5$ mm^3 sensors at 5 to 30 cm from interaction region



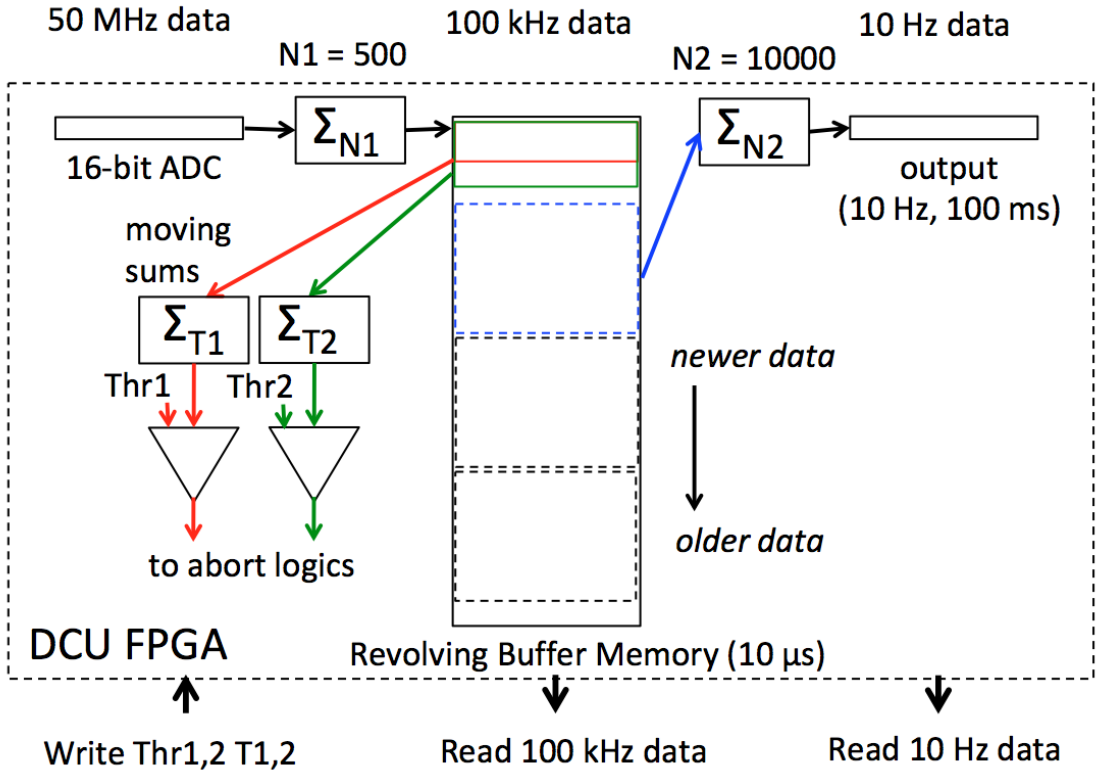


- Radiation resistant
- Rapid response (sensitivity to sudden intense radiation bursts)
- Miniaturizable to fit the tight space constraints
- Broad dynamic range: handle µrad/s to >10 krad/s signals
- Reliable and stable for long-term dose measurement



Readout and functionalities

Signals amplified and digitized by ADCs, in one of 3 configurable ranges.
FPGAs control groups of 4 diamonds, providing monitoring data (10 Hz) and abort signals (100 kHz)
Pedestal (signal baseline values, without beams) calibrated regularly for achieving two main purposes:



Monitoring: most sensitive measurement range
(typical noise 0,008 mrad/s)

Abort logic: coarser range

- Threshold on integrated dose (10 – 70 mrad)
- Integrated in moving time-windows (1 ms or 40 µs)
- Update and compare with threshold every 10 µs

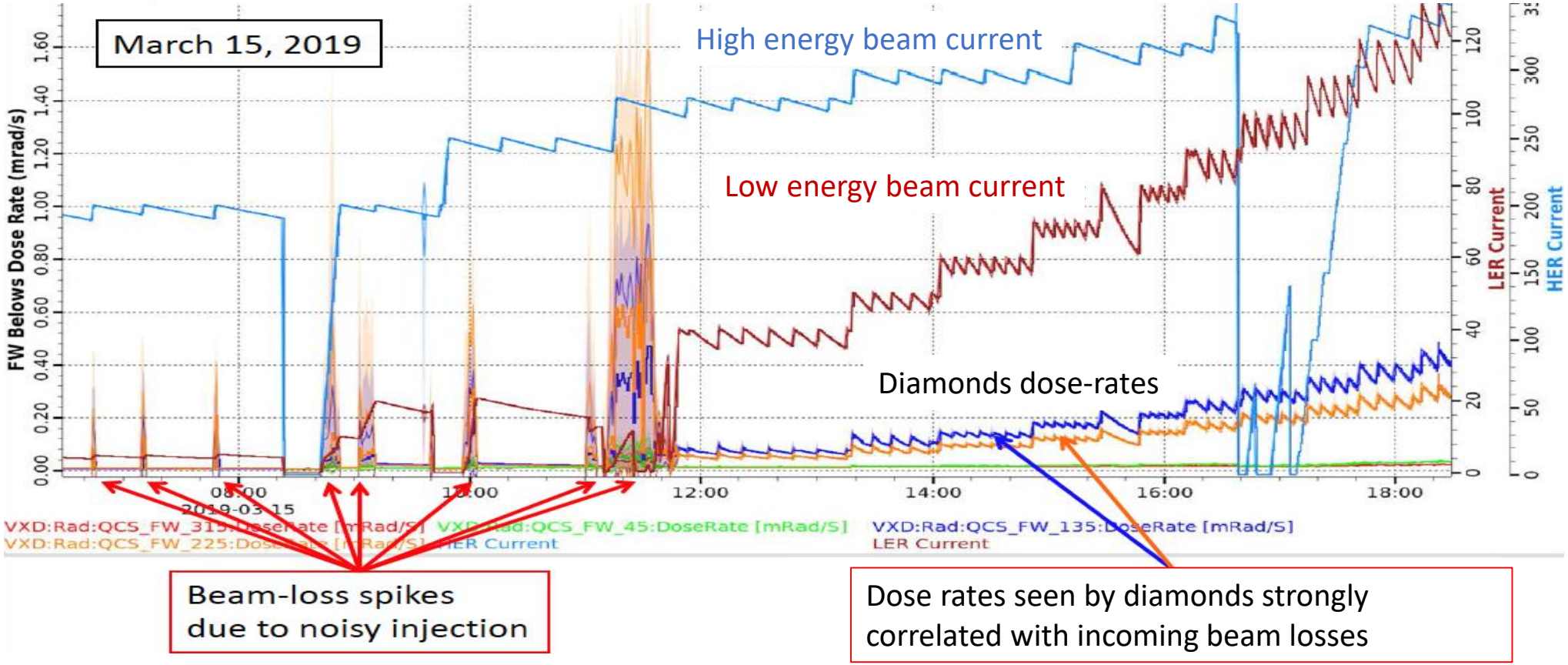
Beam-aborts issued: 179 in spring 2019 run, 126 in fall 2019 run

Operations

Tradeoff between

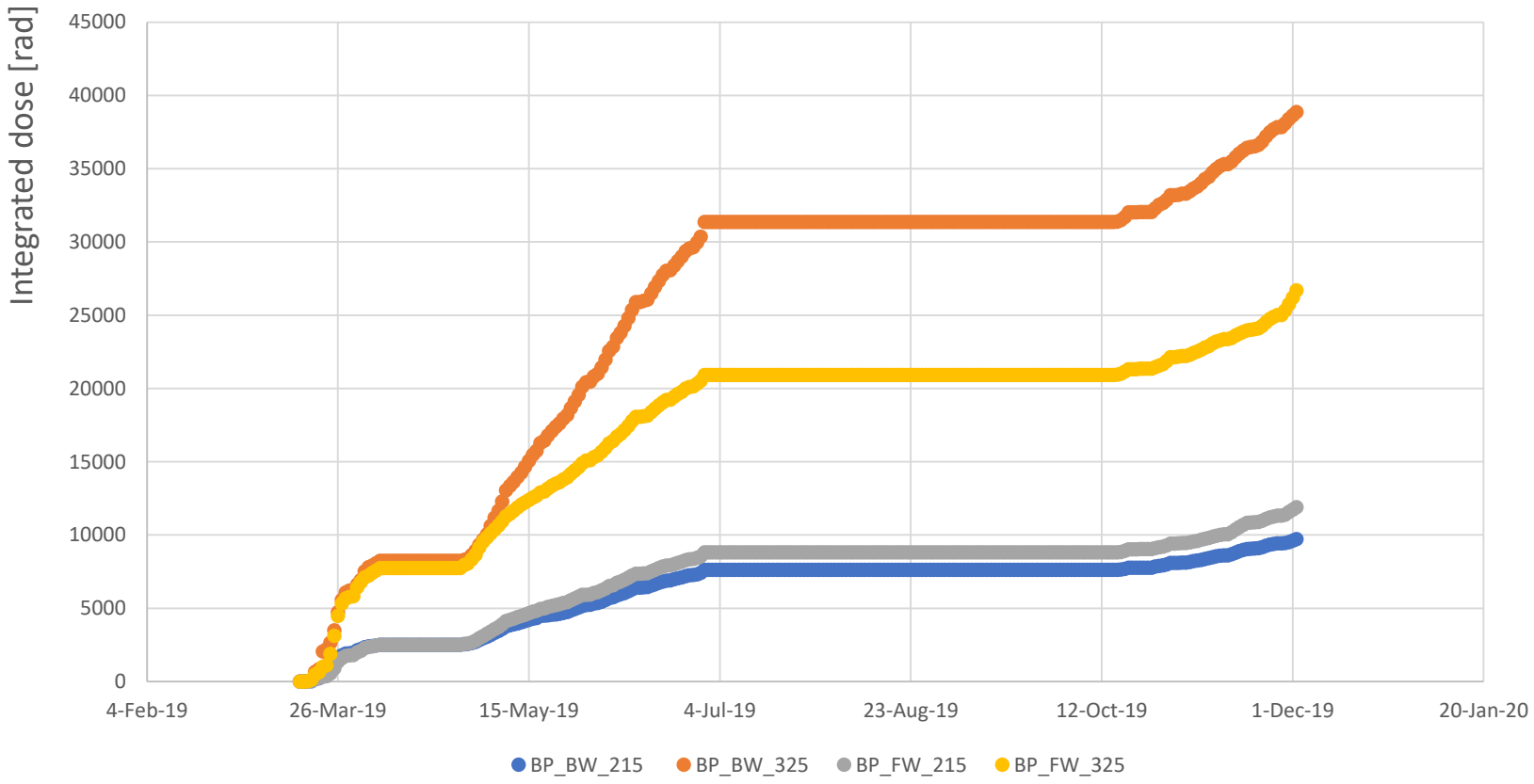
- Efficient data-taking (no false aborts)
- Safe conditions (avoid high radiation)

through continuous monitoring and consistent setting of **pedestal**, **thresholds** and **integrating ranges**



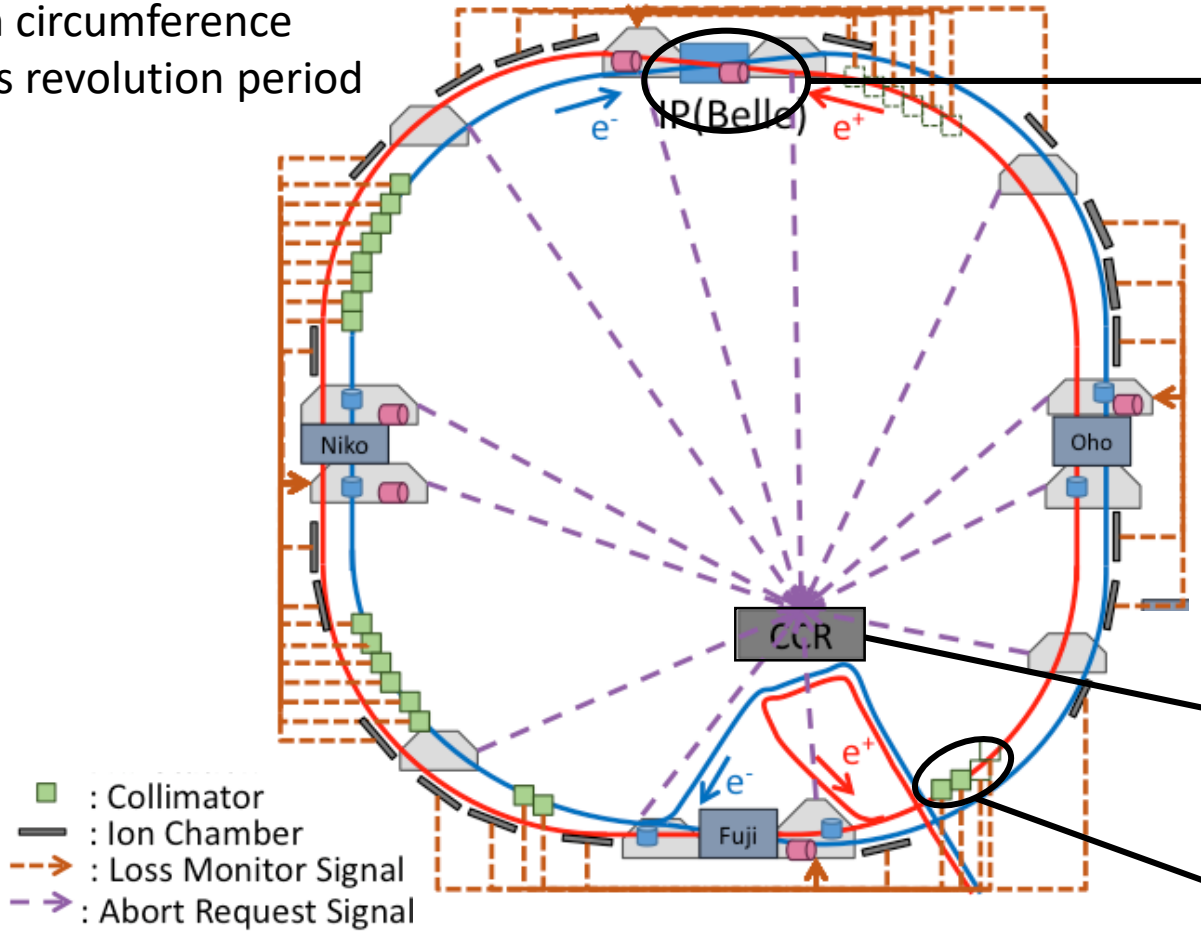
Radiation monitoring

Preliminary plot of integrated dose in the diamonds installed on the beam pipe



SuperKEKB abort

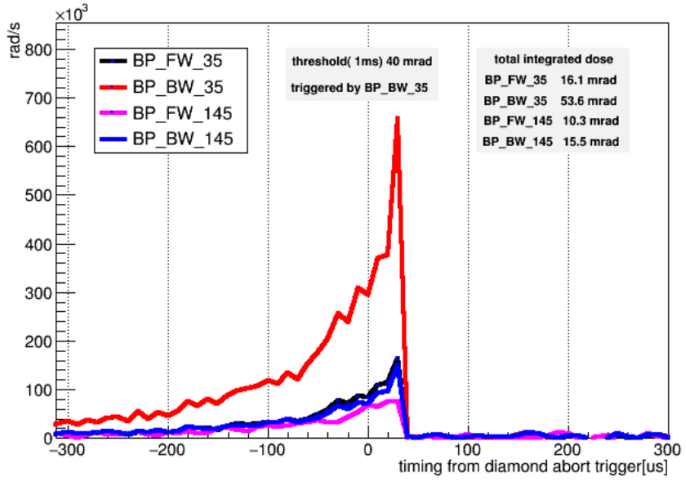
3 km circumference
10 μs revolution period



Diamonds (Belle II interaction point)

send abort signal to

Example: diamond dose rates triggering abort



SKB control room: collect all abort signals

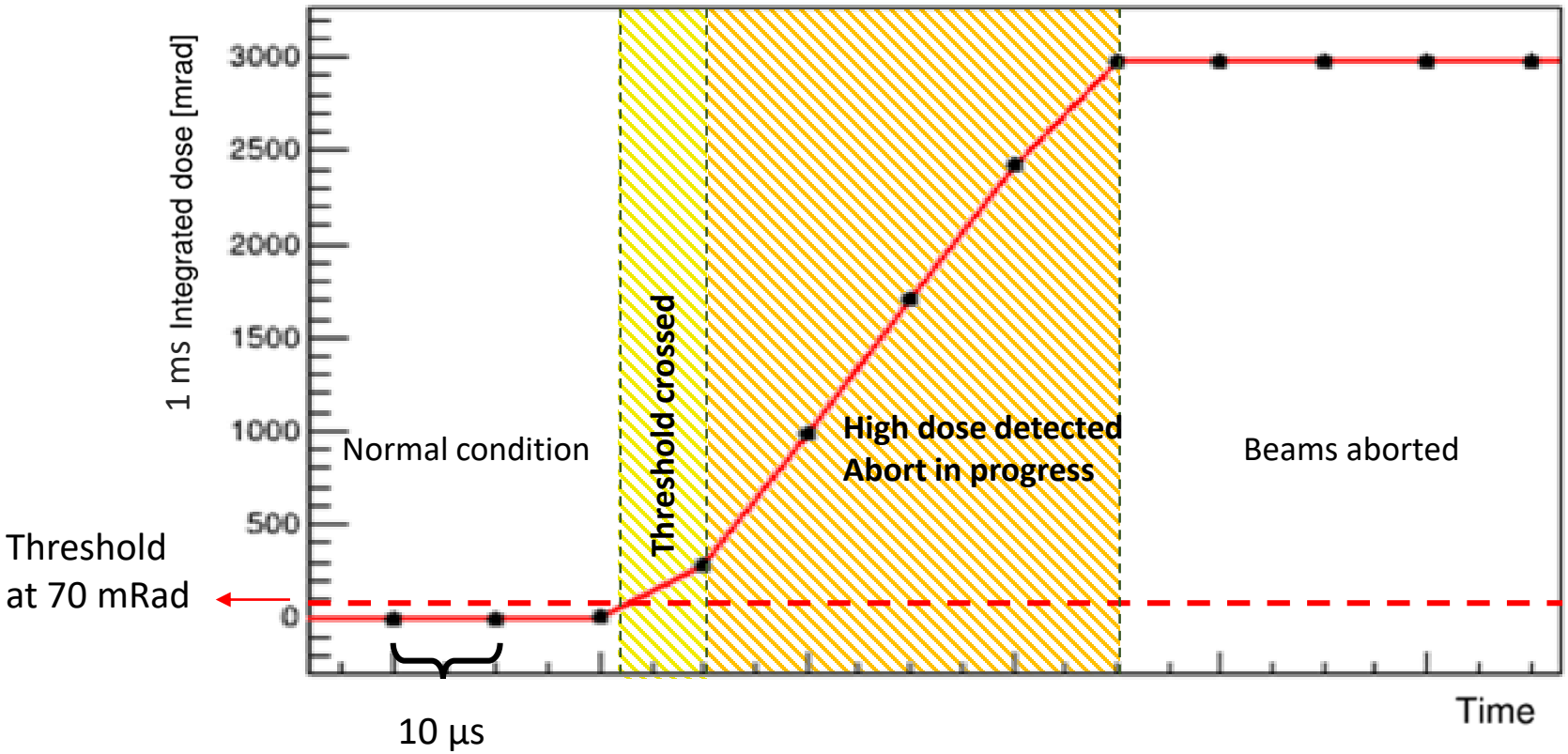
Kickers

activates

Severe beam losses: an example

Unexpected issues need prompt care and control to implement countermeasures

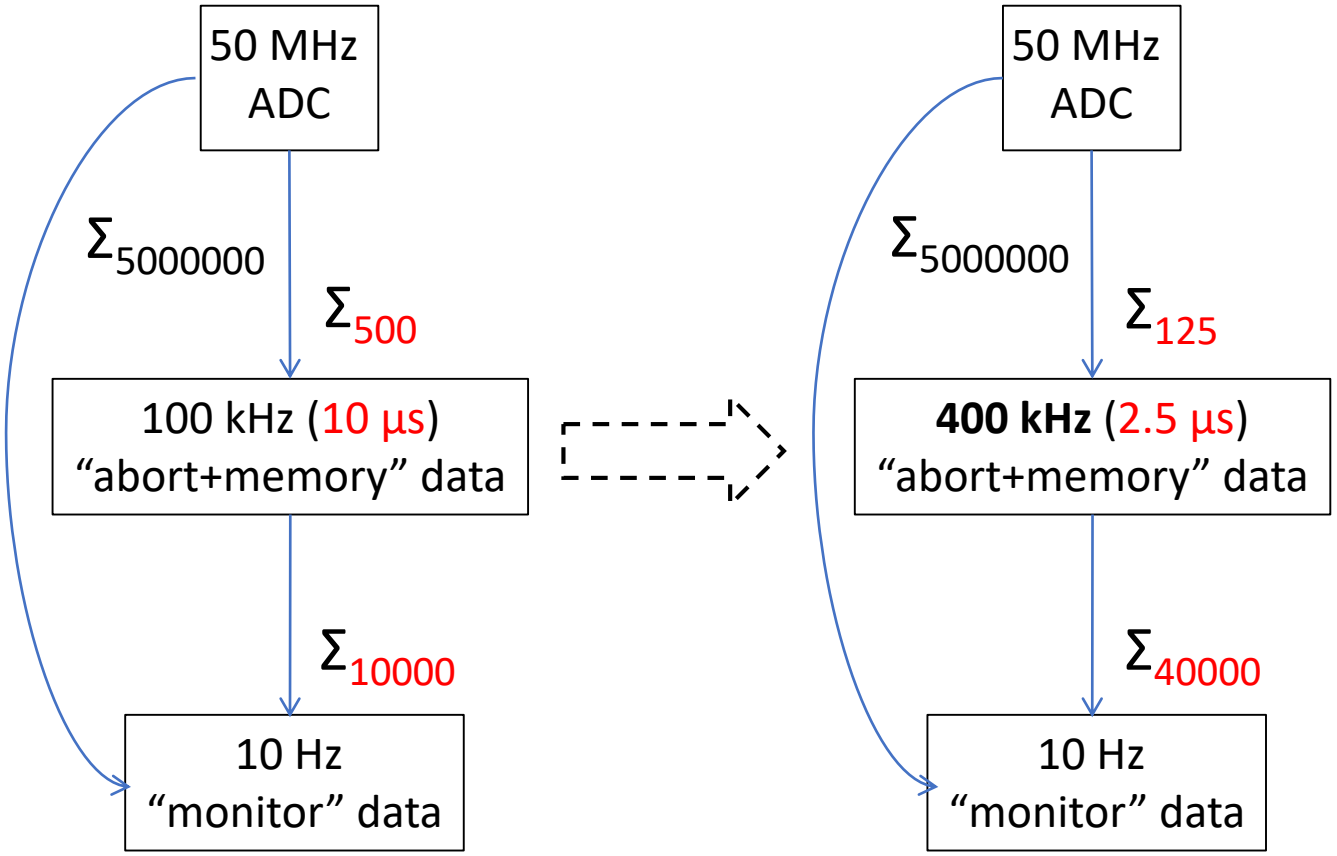
June 9, 2019 beam-dust event



Nearly the whole dose (~3 rad) integrated in the transient btw abort issuing and completion due to intrinsic delays

Timing improvements implemented by SuperKEKB and diamonds.

Firmware upgrade



- Reduces delay between diamond input and threshold crossing
- Allows for shorter time-integration in abort logic
- 4x improvement in time resolution of post-abort memory data (at the cost of an acceptable noise increase)

Summary

A state-of-the-art detector and unprecedented luminosity -- Belle II: a leading flavor experiment for the next decade. Success critically depends on controlling beam backgrounds and protecting the detector from them.

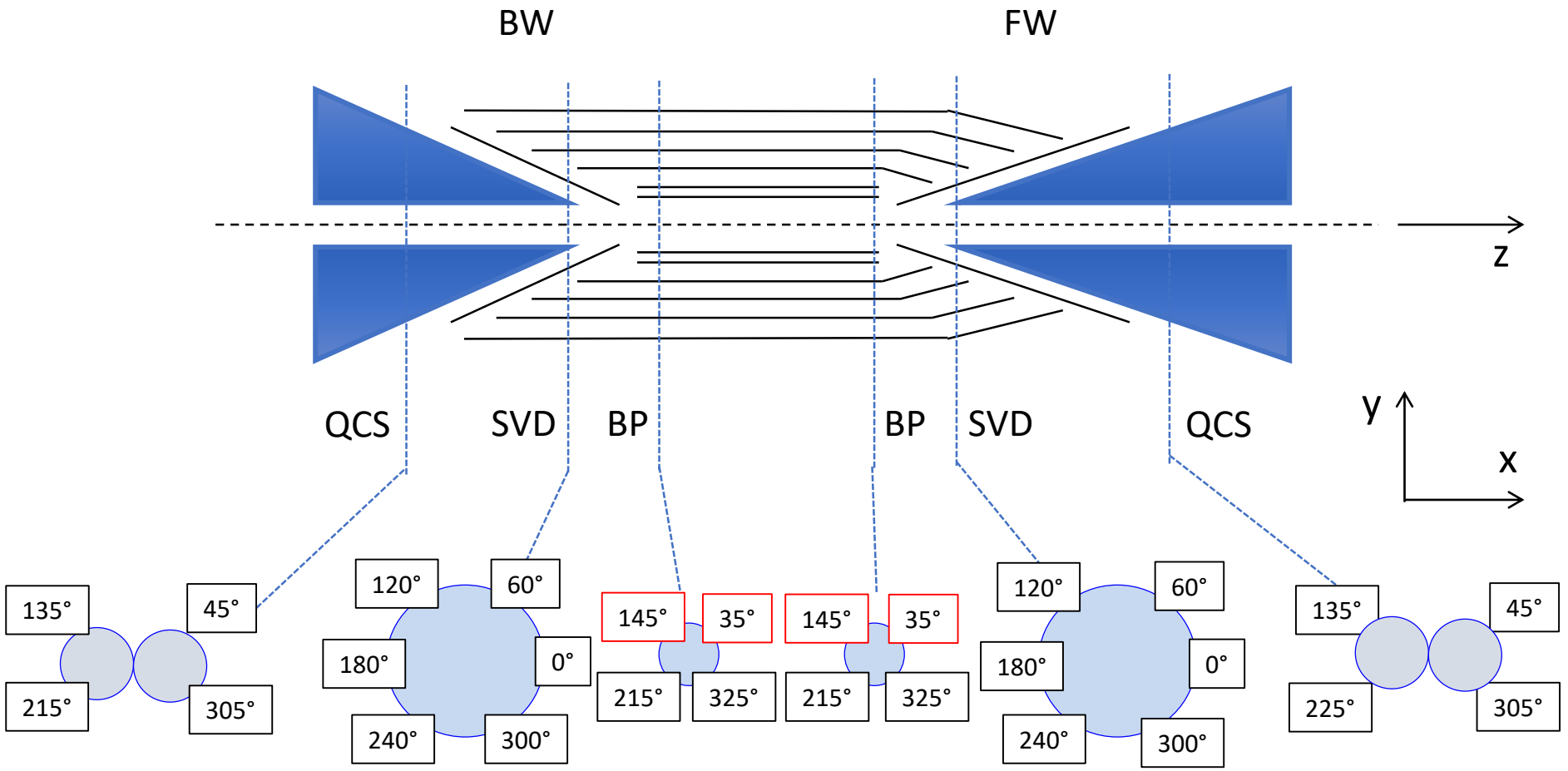
28 diamond sensors around the interaction region: excellent radiation-monitoring and beam-abort capabilities. System performed well in 2019 runs.

System upgraded for 2020 data: finer dose sampling, reduced abort delays, generally optimized configuration.

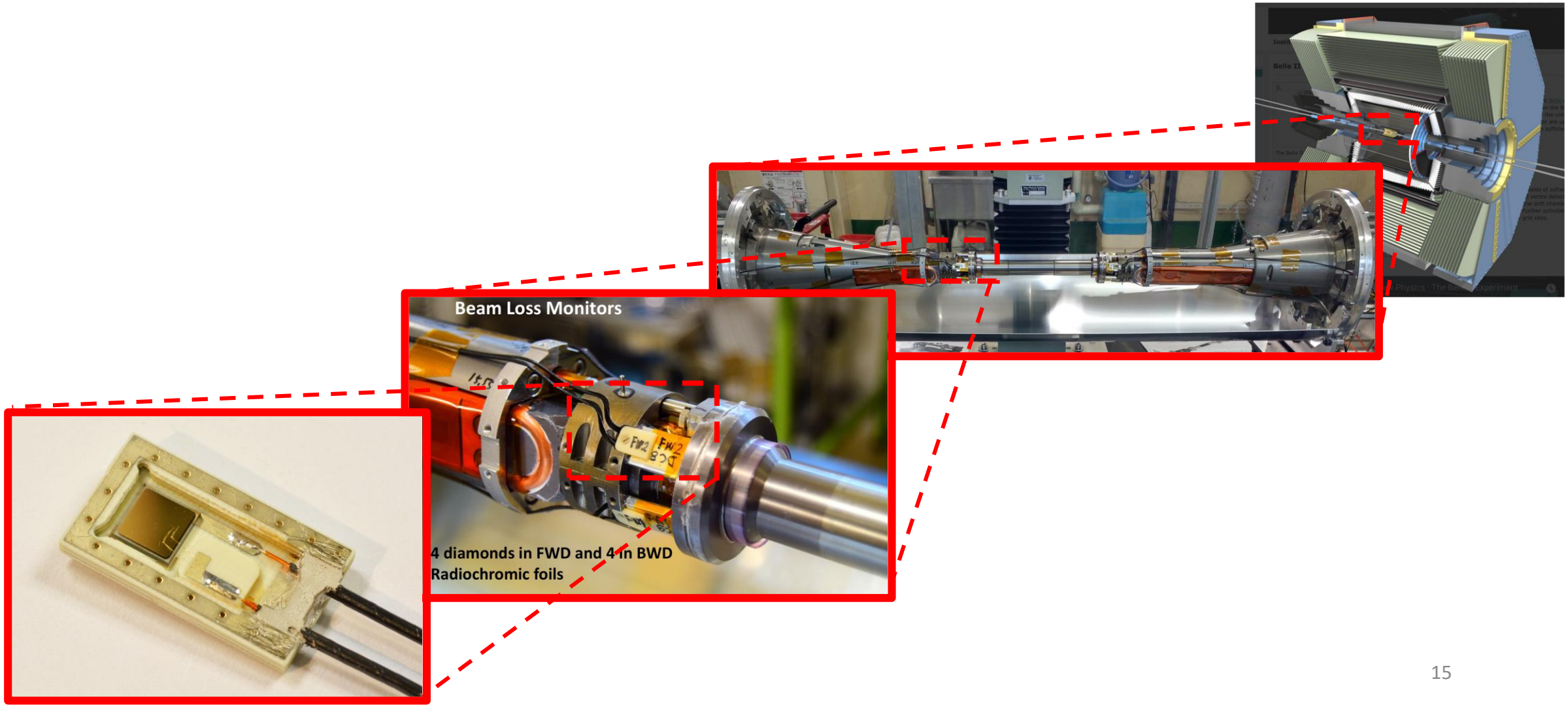
Enjoy safe and smooth data taking while offering useful feedback to the accelerator, which results in more efficient operations.

backup

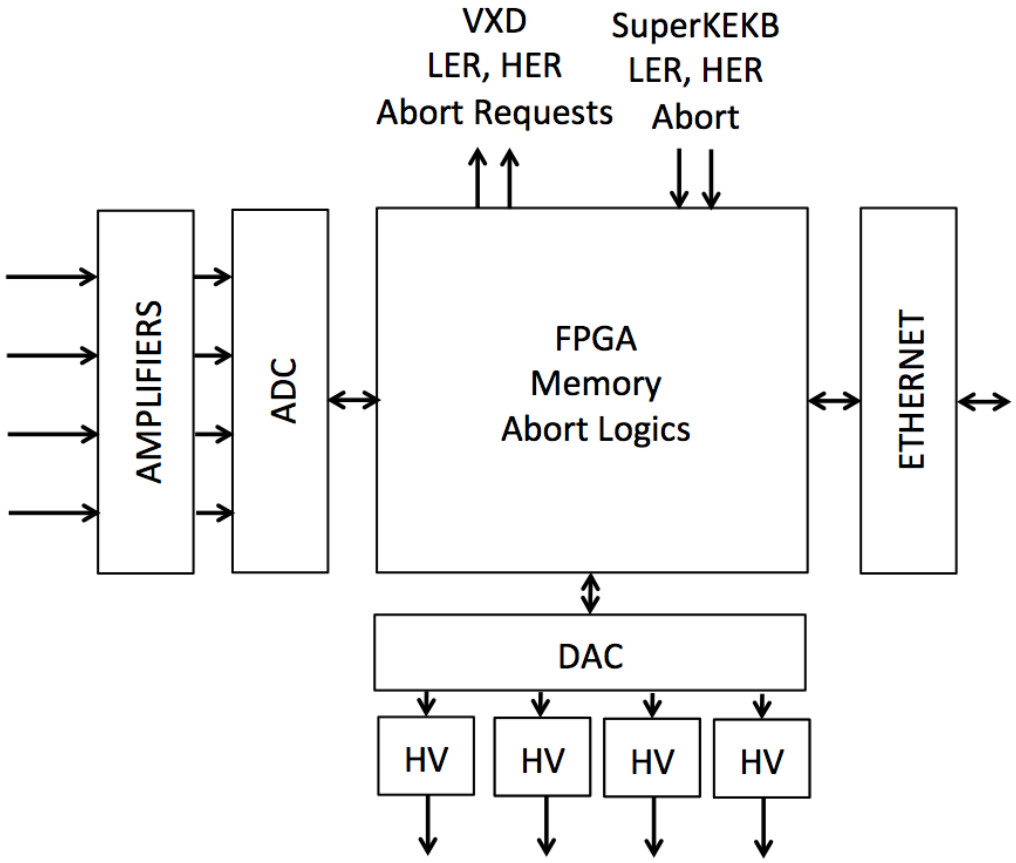
Diamond setup Phase3

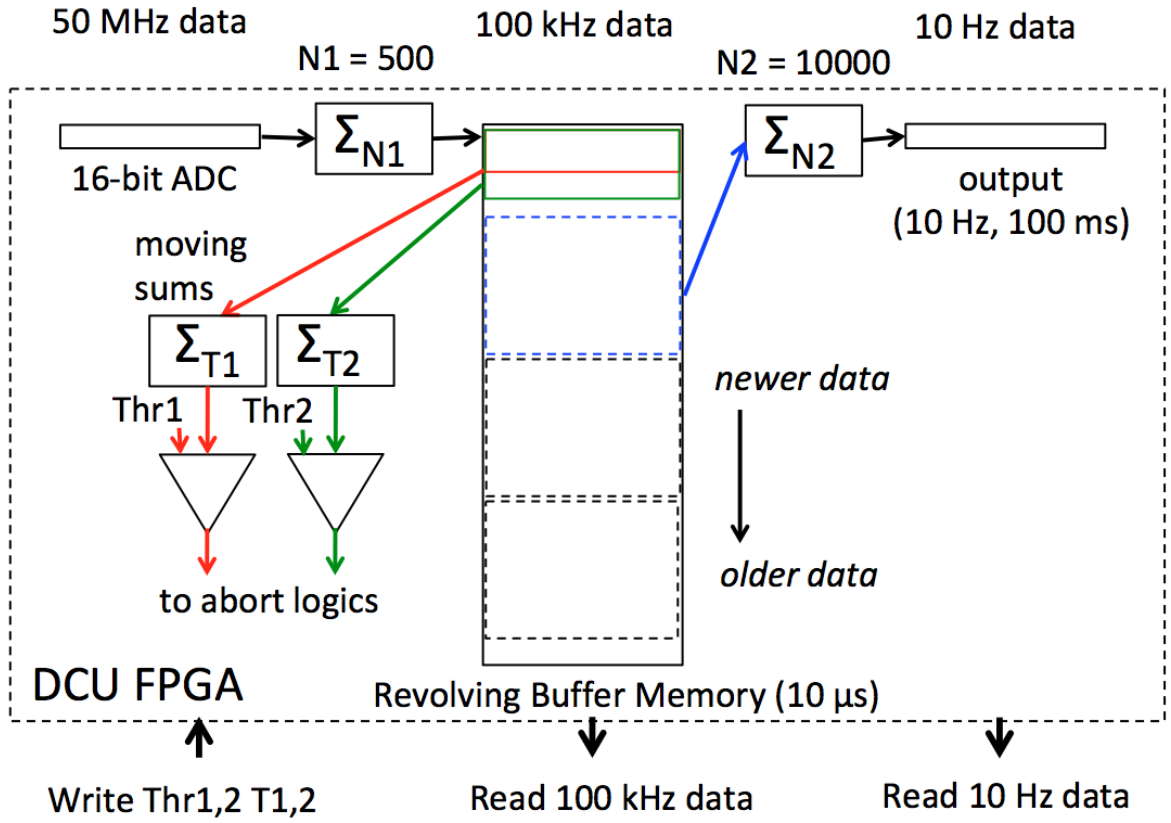


Diamond layout



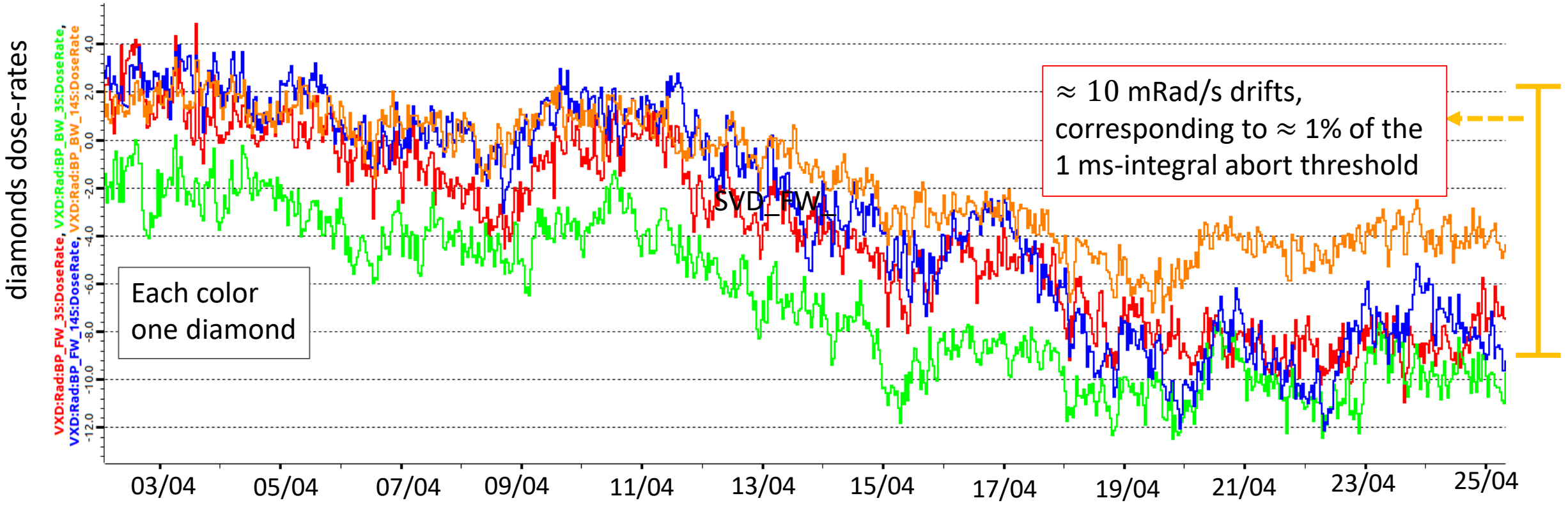
DCU scheme


VXD
LER, HER
Abort Requests
SuperKEKB
LER, HER
Abort
AMPLIFIERS
ADC
FPGA
Memory
Abort Logics
ETHERNET
DAC
HV
HV
HV
HV


50 MHz data
N1 = 500
100 kHz data
N2 = 10000
10 Hz data
16-bit ADC
output
(10 Hz, 100 ms)
moving
sums
Thr1
Thr2
to abort logics
newer data
older data
DCU FPGA
Revolving Buffer Memory (10 µs)
Write Thr1,2 T1,2
Read 100 kHz data
Read 10 Hz data

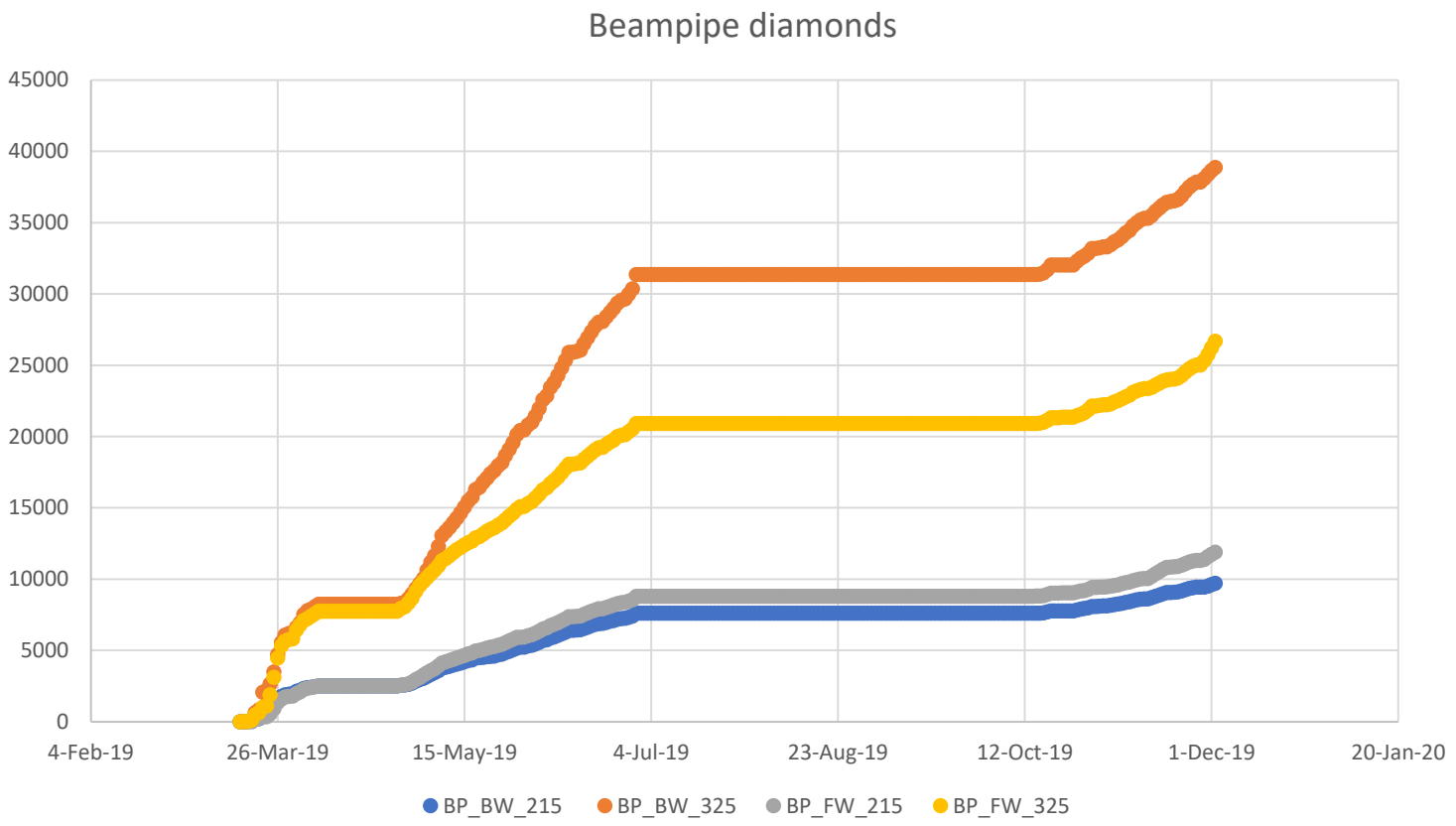
Diamond pedestals

Coarser measurement range for aborts: observed pedestal shifts that change the effective threshold

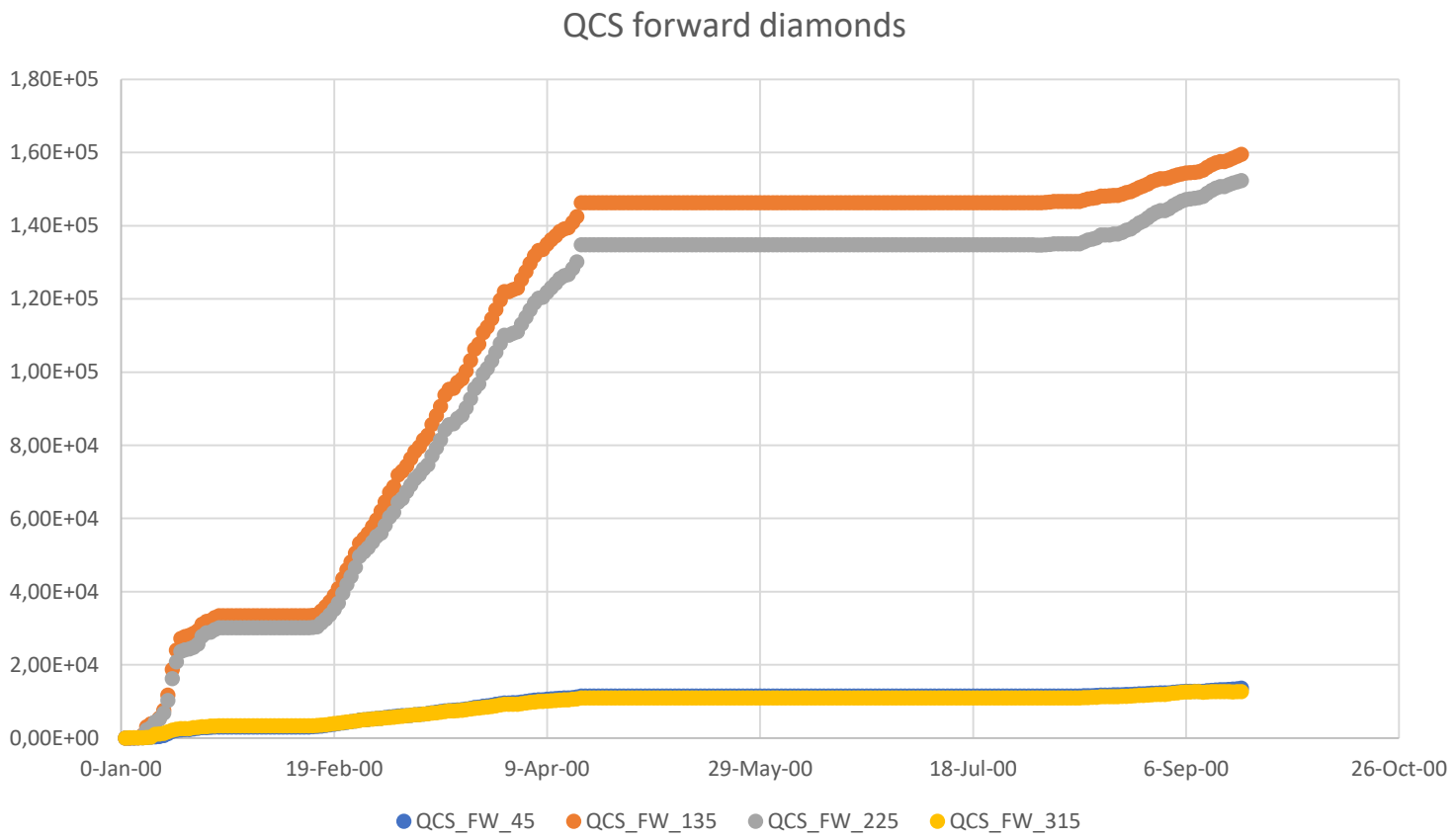


It is fundamental to measure pedestals and update their values every 1 to 5 days

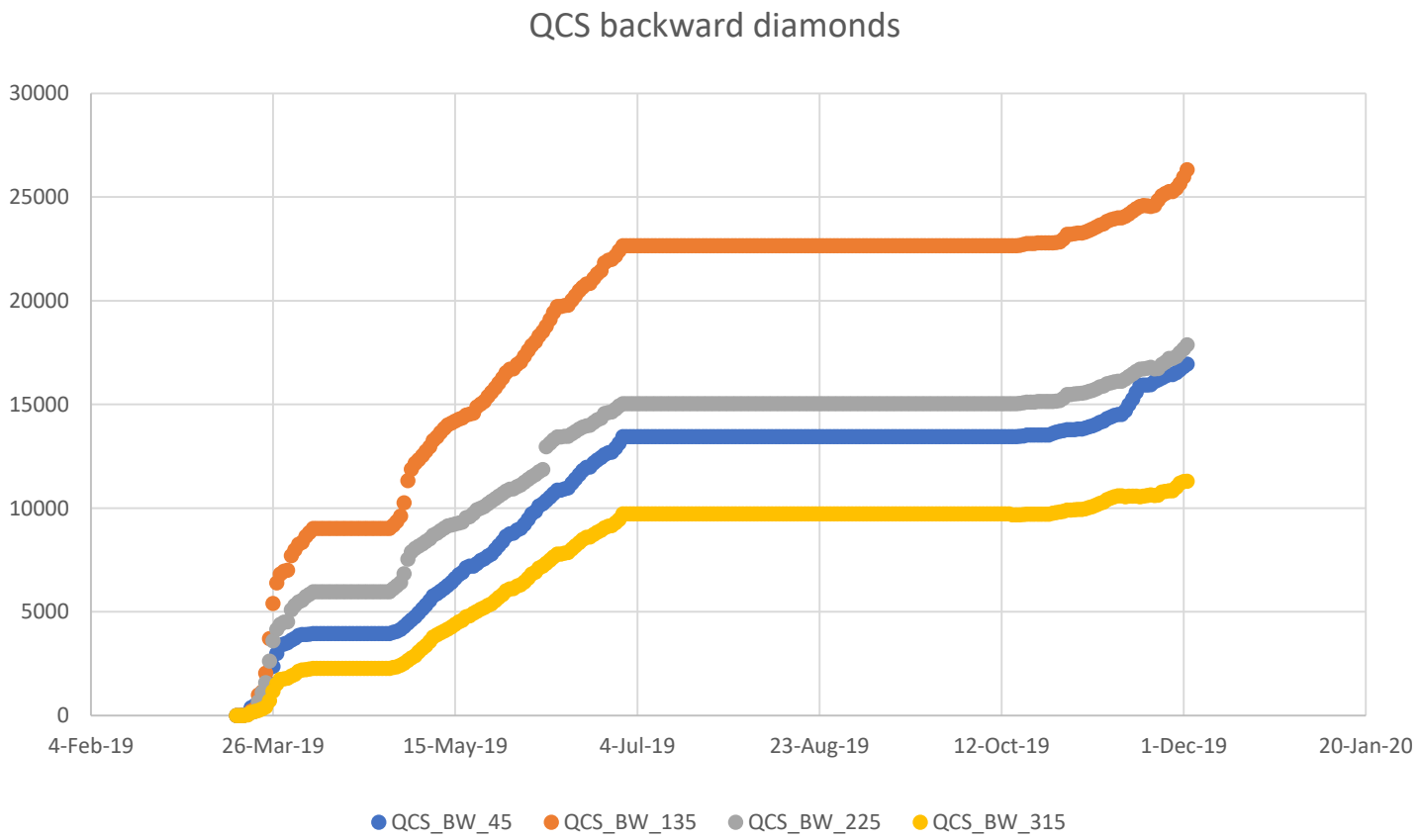
Integrated dose



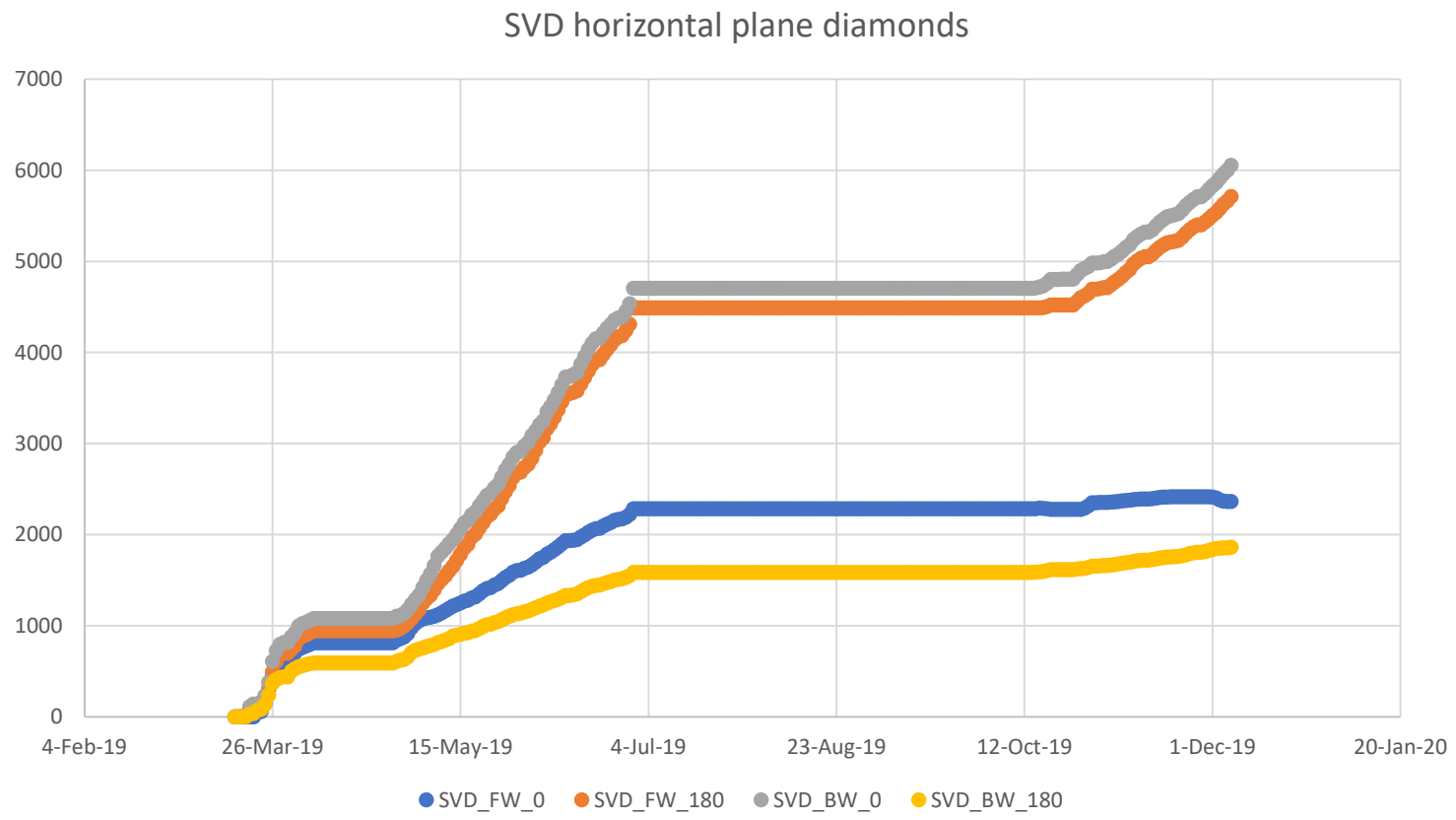
Integrated dose



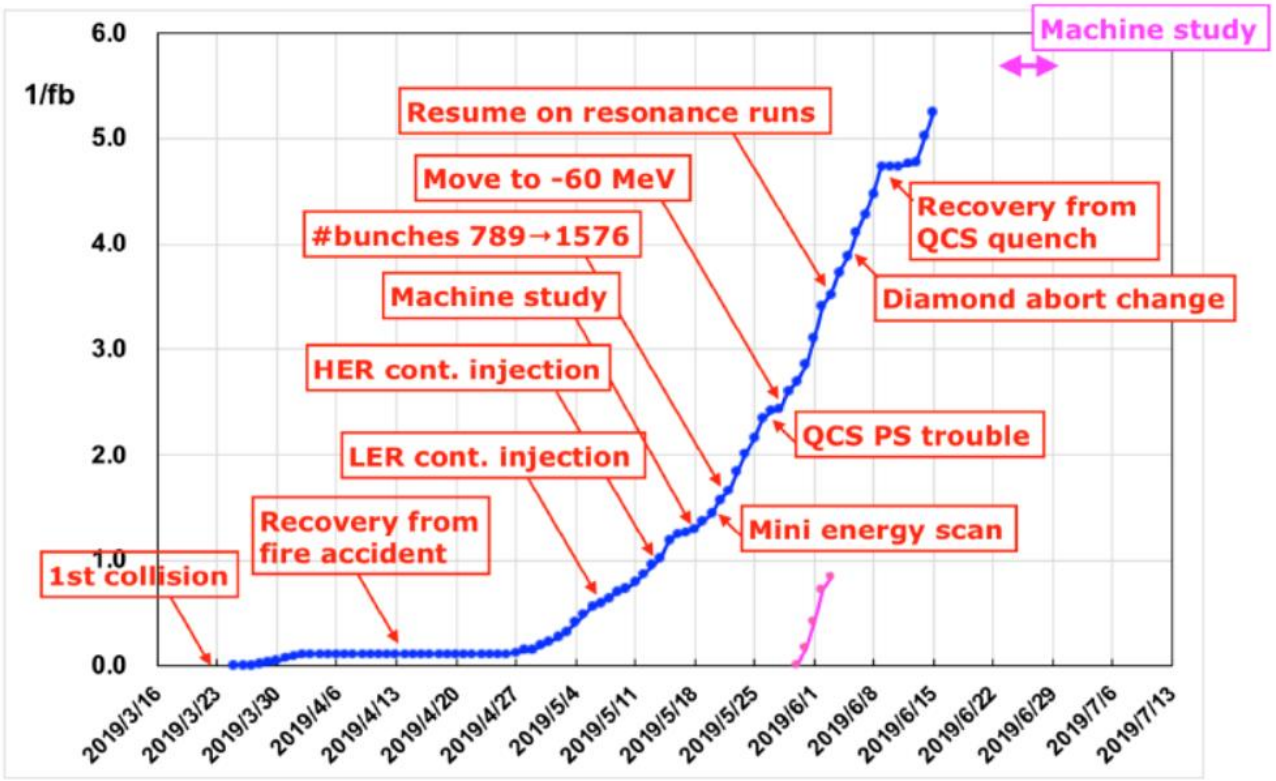
Integrated dose



Integrated dose



SKB configuration changes



Configuration changes during operations

Initial configuration in spring 2019: *fast* (1 ms) and *slow* (1 s) thresholds

- Value changed during operations

	until 27/03	until 05/06	until 26/06	until run end
FAST :	10 mRad	50 mRad	70 mRad	70 mRad
SLOW:	200 mRad	1000 mRad	2200 mRad	10000 mRad

- Total of 179 beam-aborts issued

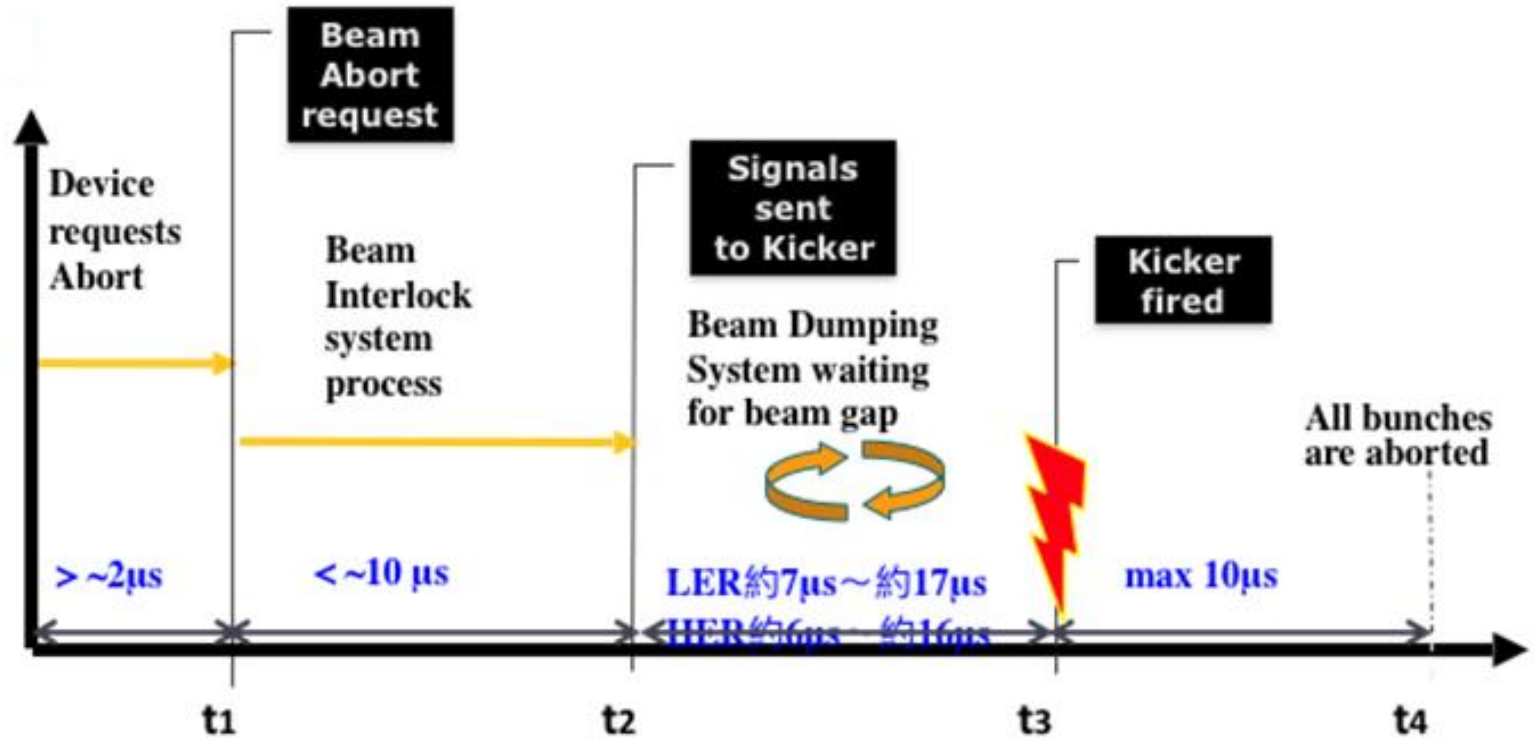
Change in winter 2019: *fast* (1 ms) and *very fast* (40 µs) thresholds

- Values changed during operations

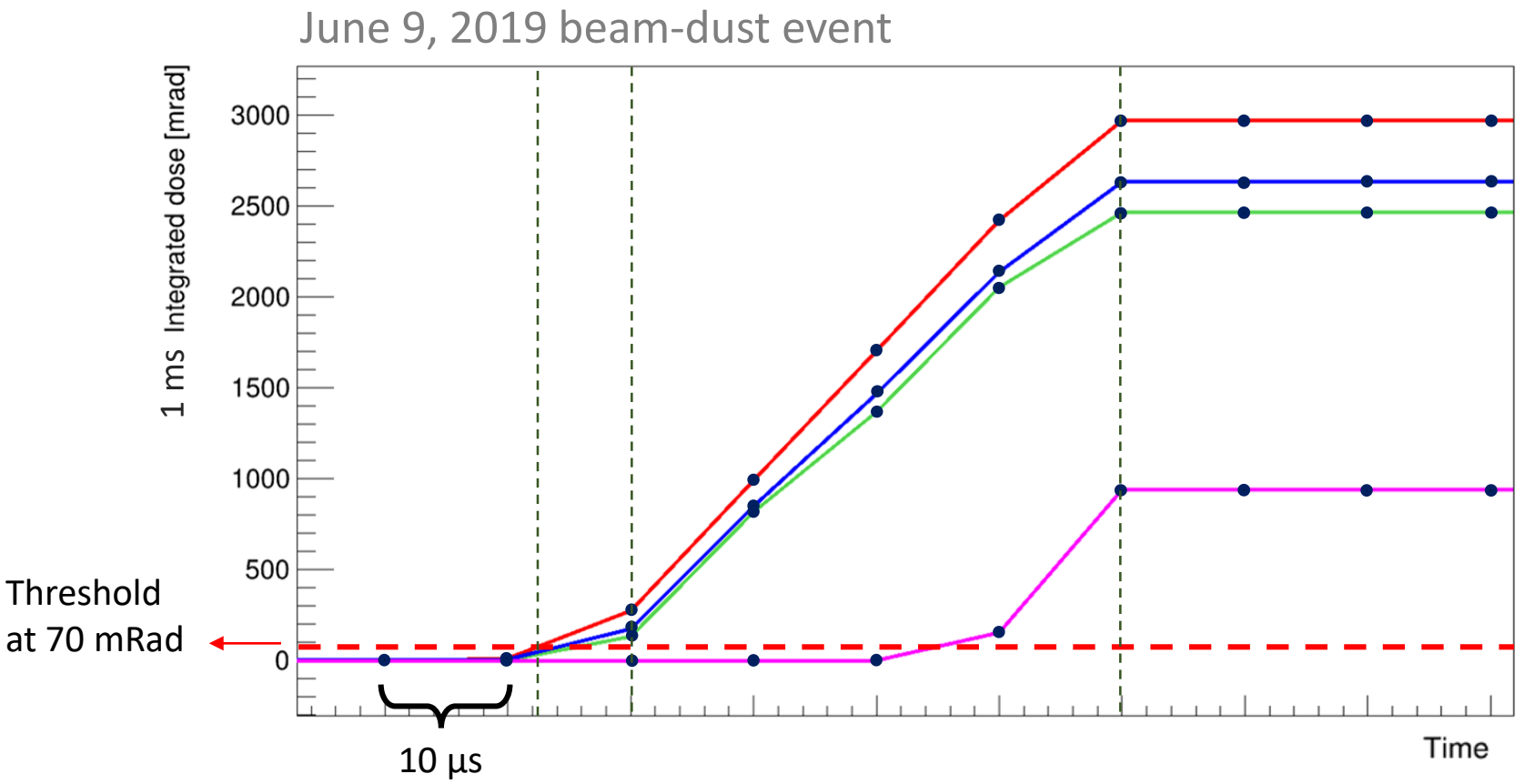
	until 28/10	current setting
FAST :	30 mRad	40 mRad
VERY FAST:	4 mRad	40 mRad

- Total of 125 beam-aborts issued

Abort delays



Severe beam losses: an example



Beam-background sources:

- *Touschek effect*: scattering between particles in the same bunch
- *Beam-gas scattering*: interaction with residual gas particles in the beam-pipe
- *Radiative Bhabha scattering*: $e^+e^- \rightarrow e^+e^-\gamma$
- *Synchrotron radiation*: radiation emitted by accelerated charged particles
- *Injection background*: radiation associated to new injected particles into circulating bunches