Commissioning and Results of a Scintillator Based Beam Abort and Machine Protection System at SuperKEKB

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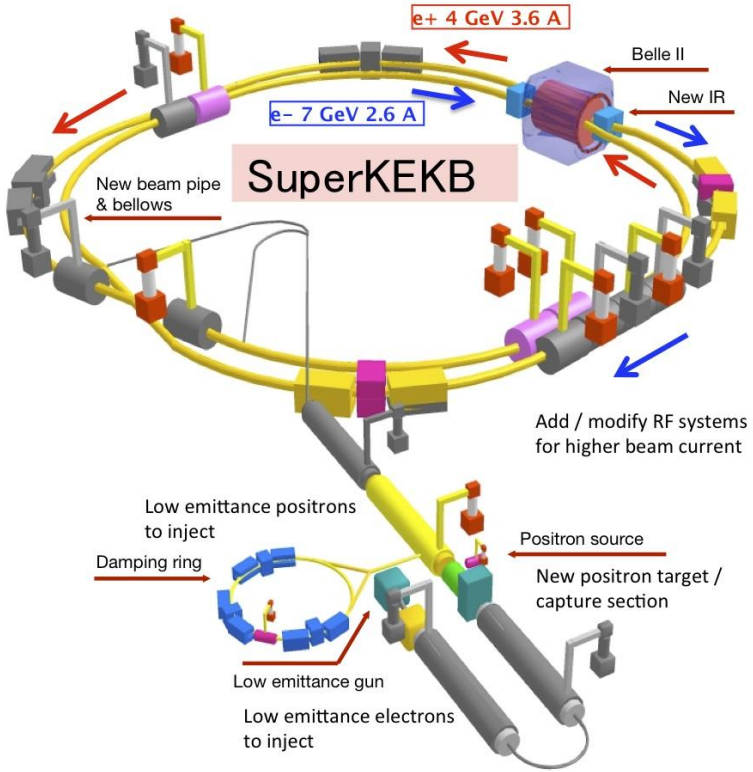
Outline:

1. SuperKEKB & Belle II
2. The CLAWS System
3. Abort Trigger Performance
4. Outlook

SuperKEKB and Belle II

- Asymmetric e^+e^- collider at the Y(4S) resonance (10.58 GeV)
  - December 2021 - world record for highest instantaneous luminosity at $3.8 \times 10^{34} cm^{-2} s^{-1}$
- Extensive upgrade of KEKB and Belle
  - Increase of a factor 40 in luminosity through **increasing of beam currents** and implementation of **nano beam scheme**
  - Design luminosity will be reached in 2025



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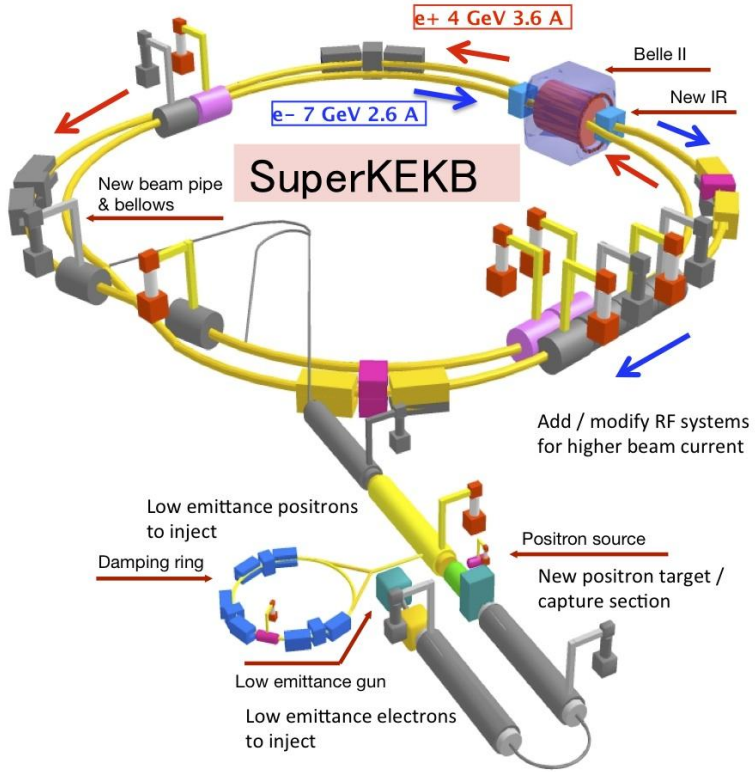
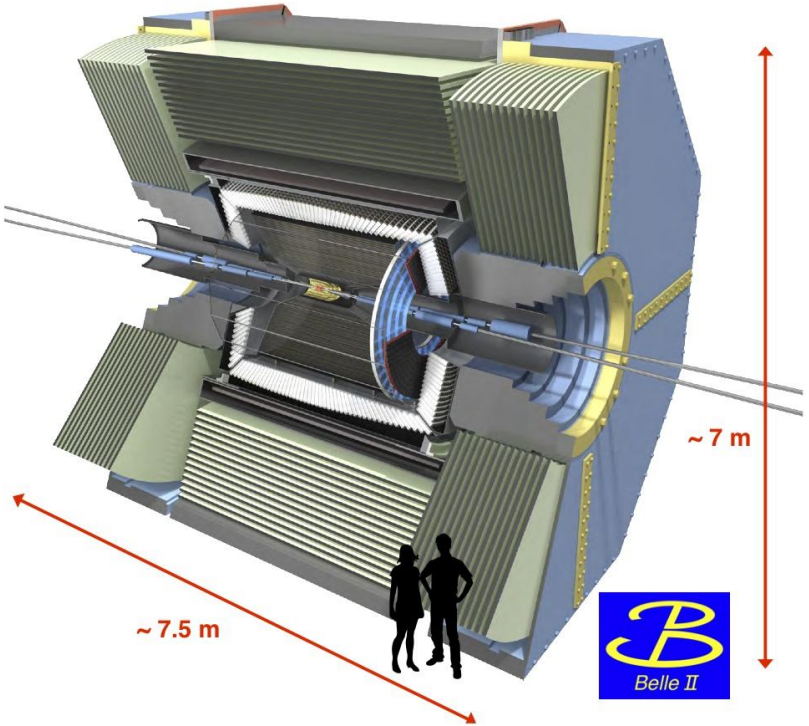
Until then persistent tuning of beam can often lead to problems.



SuperKEKB and Belle II

Consequences of high beam backgrounds:

- Inner layers of Belle II Vertex Detector close to beam
  - PXD and SVD readout system not efficient when particle rates are high
  - Direct beam hitting any detector would render it inoperational
- Beam hitting a superconducting magnet can cause a “quench”



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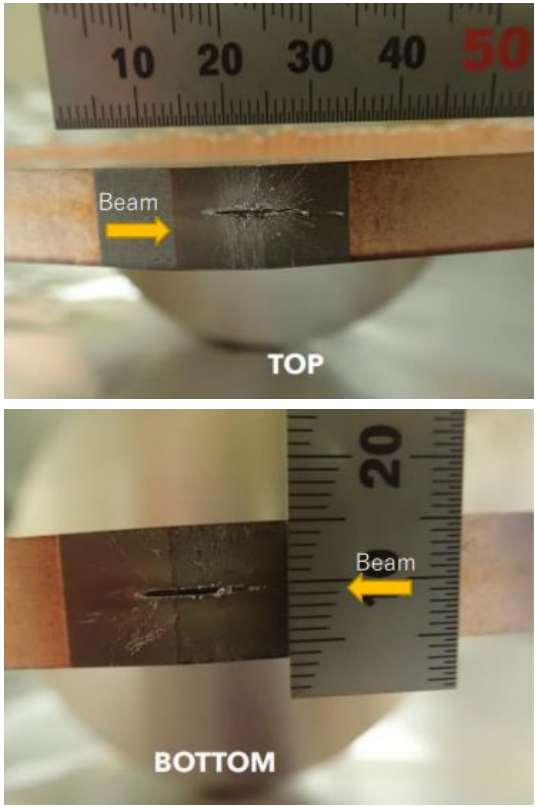
Dedicated background monitoring and beam abort systems are a necessity!

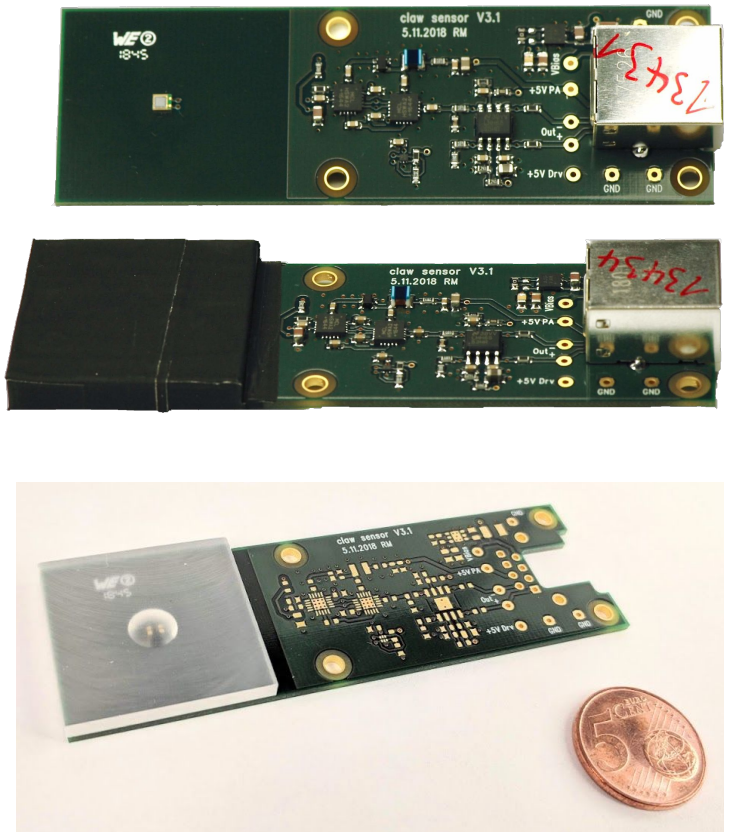


Severe damage on a collimator head after QCS quench on 06.06.2021

The CLAWS System

Scintillator **L**ight **a**nd **W**aveform **S**ensors:

- Hamamatsu silicon photomultipliers mounted on 3x3 cm^2 plastic scintillators, primarily sensitive to penetrating charged particles (“MIP”s)



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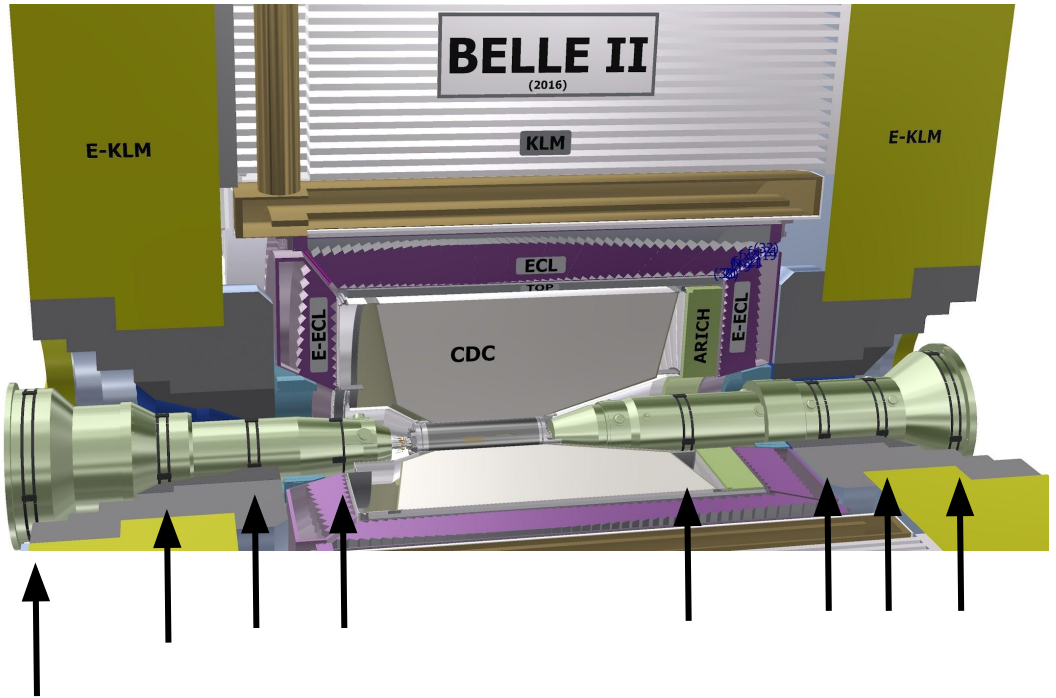

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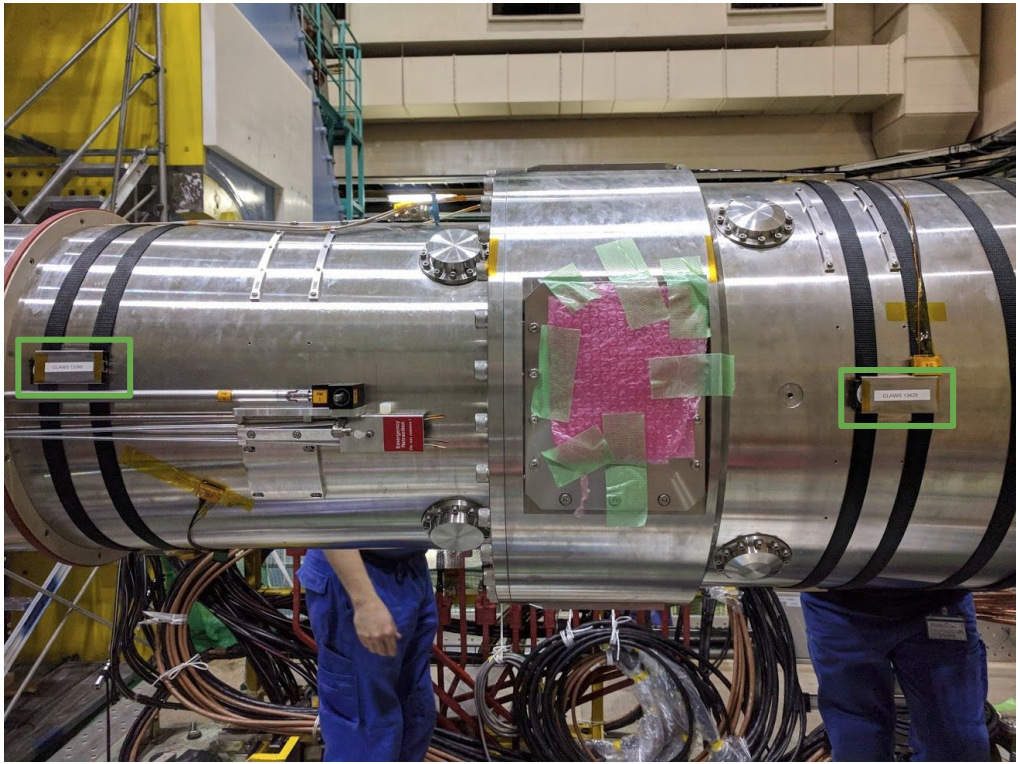
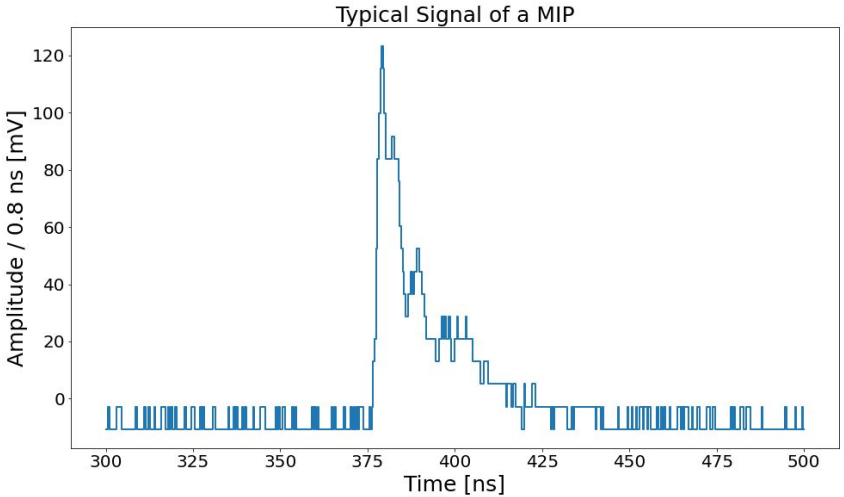


CLAWS Abort Trigger Scheme



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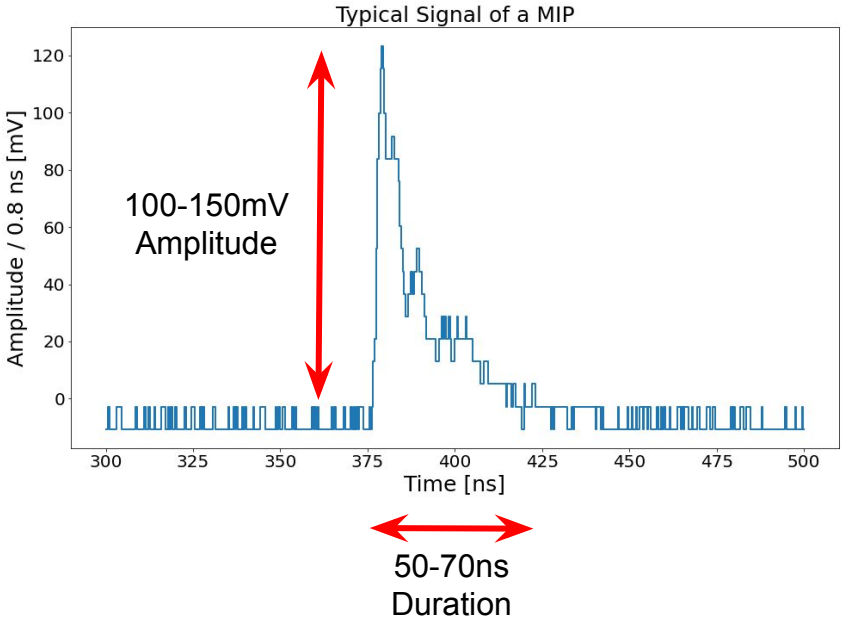

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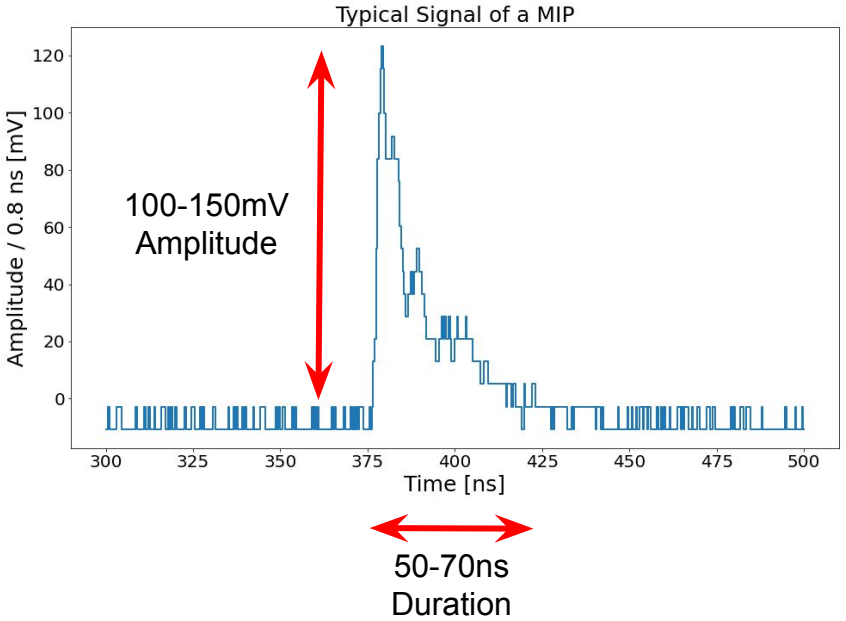

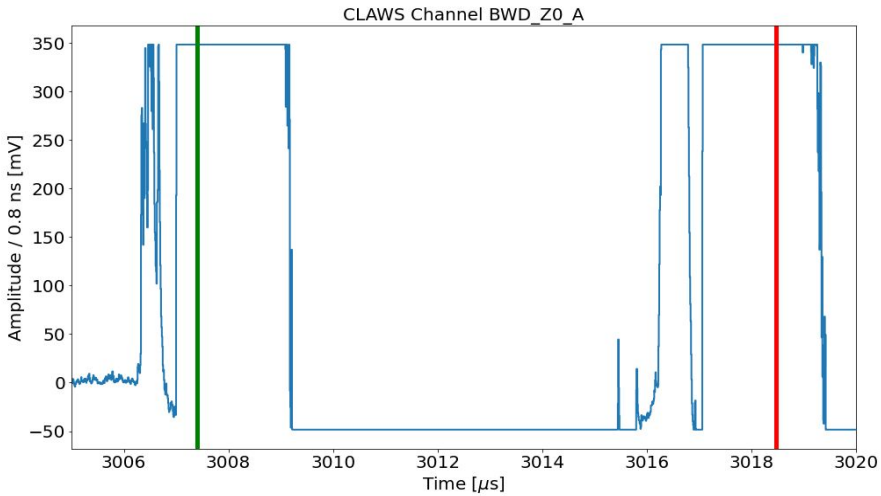

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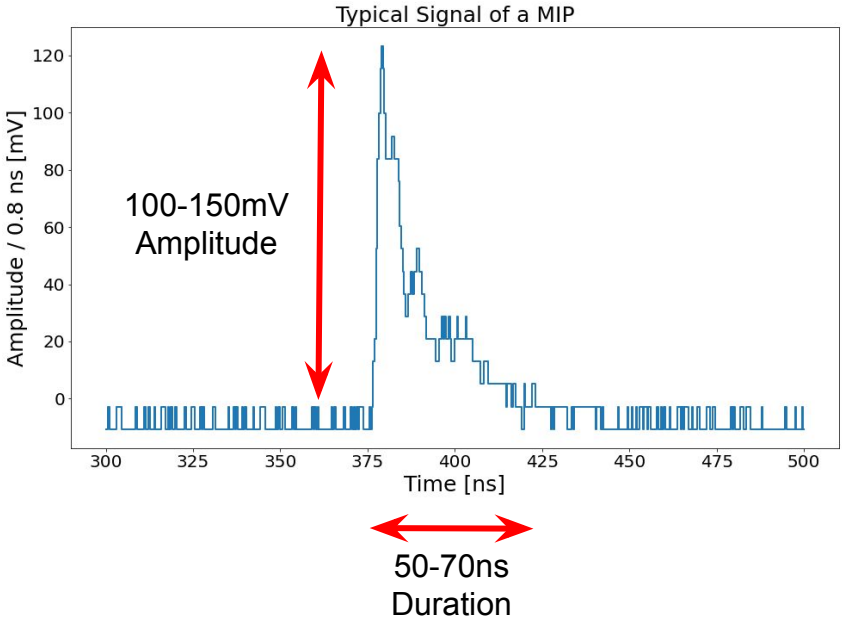
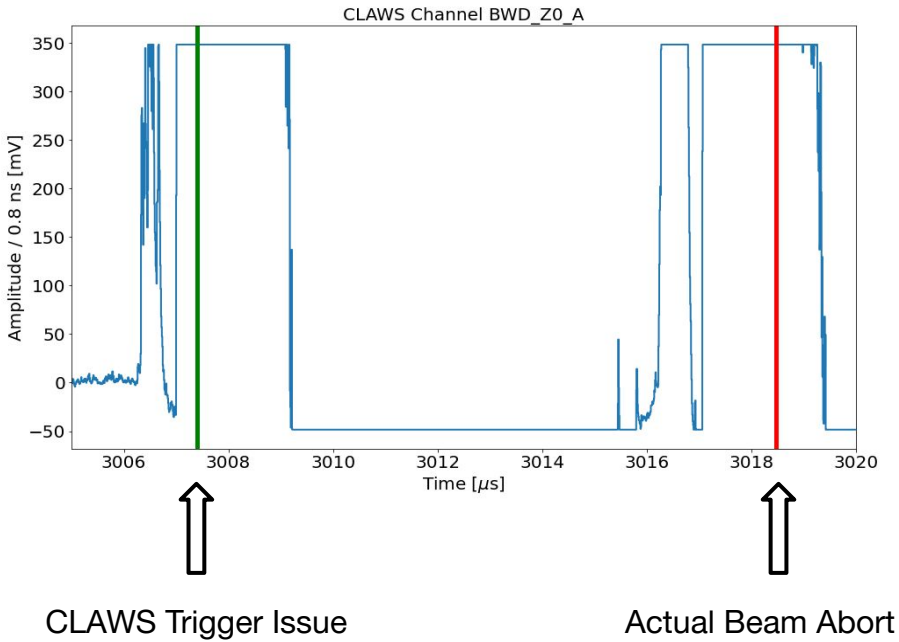
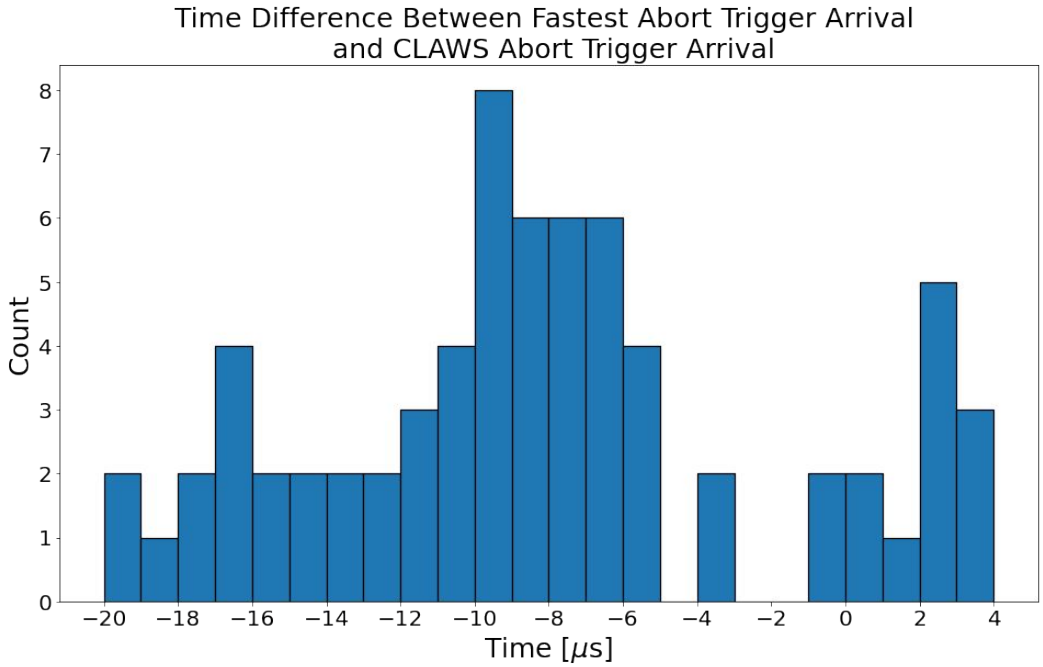




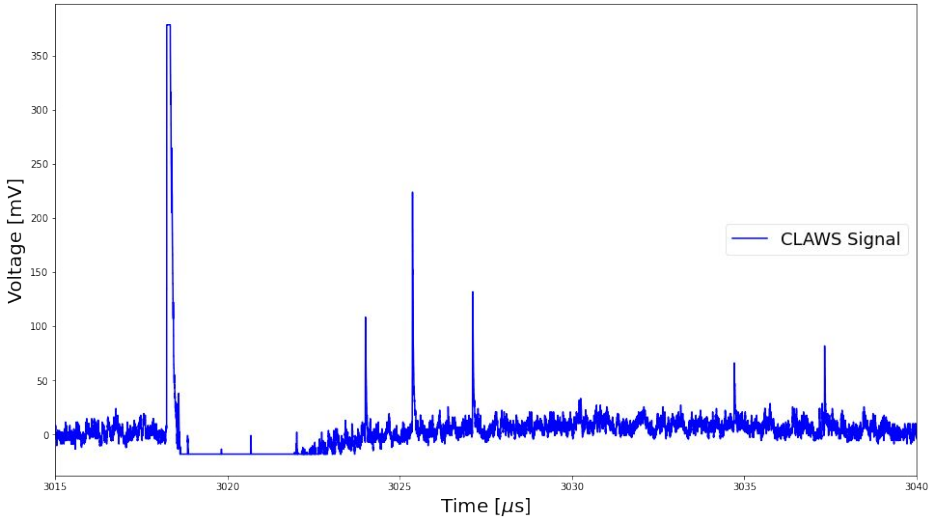
Commissioning Phase

- Run Time: 30.04 - 25.05.2021
- System hardware and cabling fully functional
- CLAWS triggered on **75** aborts
  - First abort system to issue a trigger for **64**
  - On average **8.8us** faster than next fastest abort system

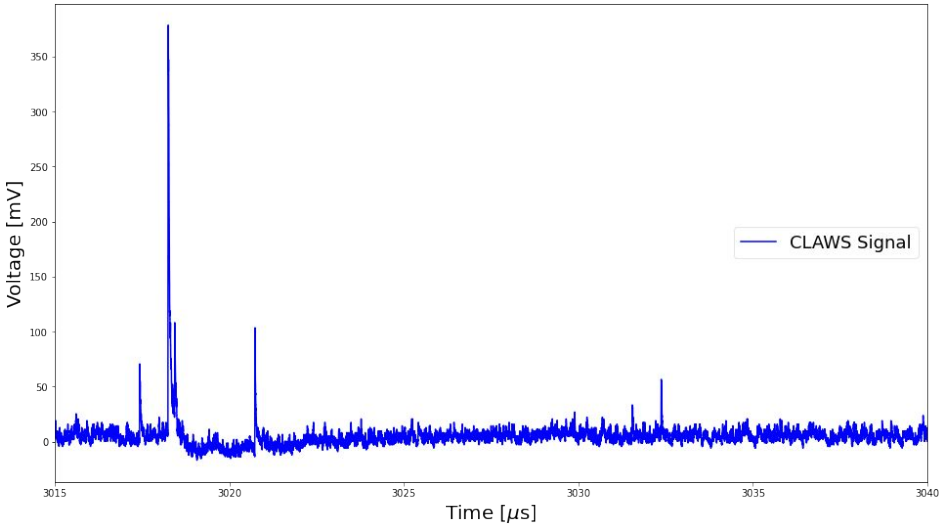


Commissioning Phase

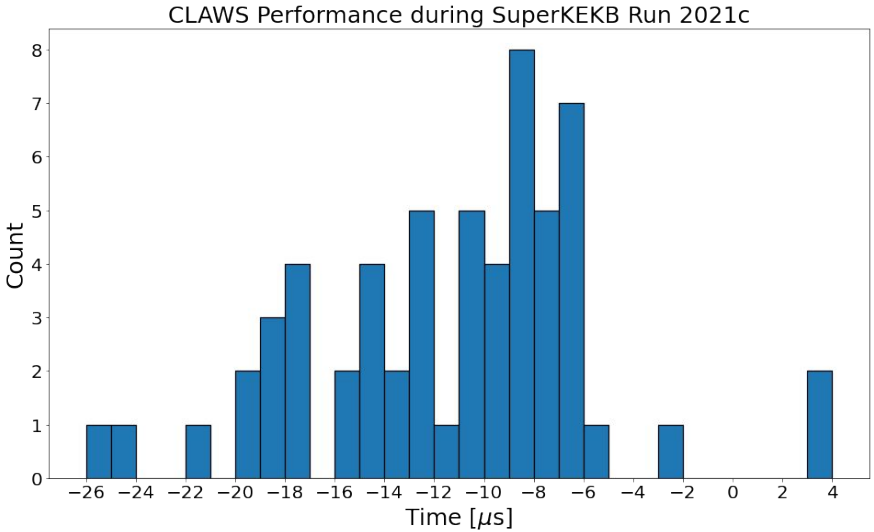
Additional CLAWS trigger without corresponding beam abort, 05.05 06:50



Normal beam abort event, 29.04 04:45



Performance



- May 29th - July 5th
- CLAWS aborts on average **6.8us** faster

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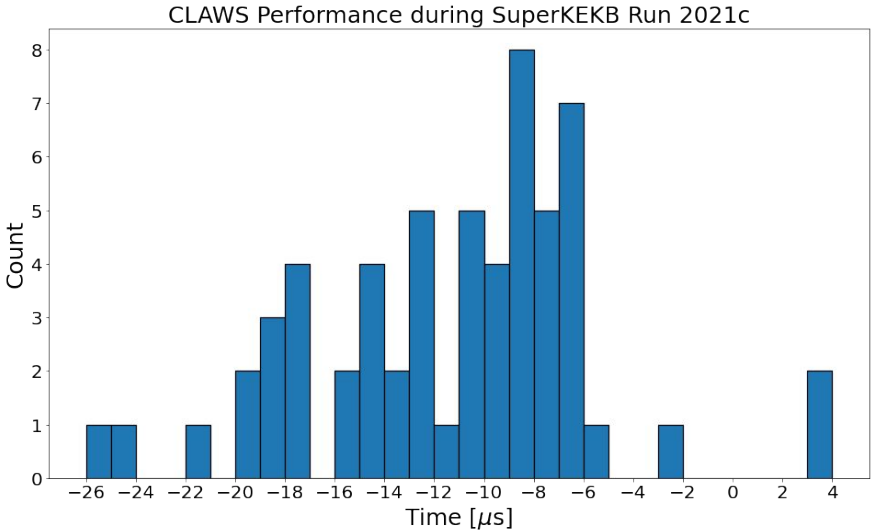

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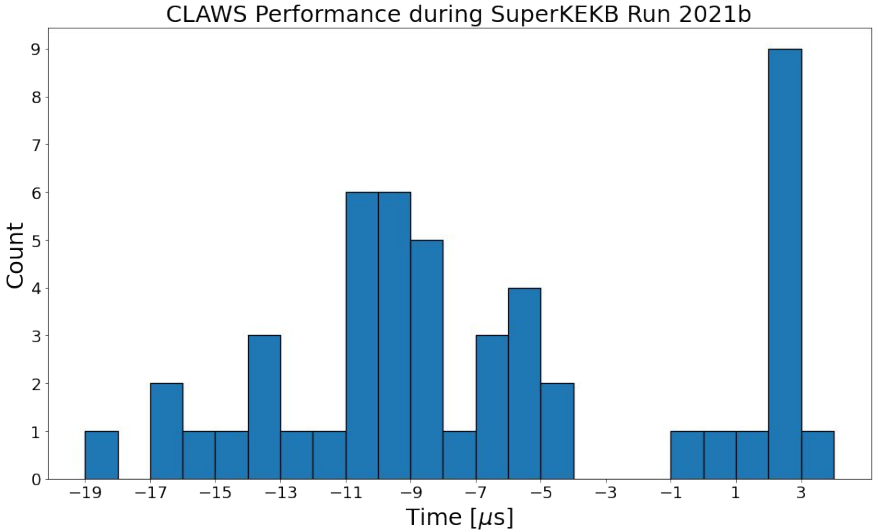


- October 19th - December 24th
- CLAWS aborts on average **11.4us** faster

Summary & Outlook

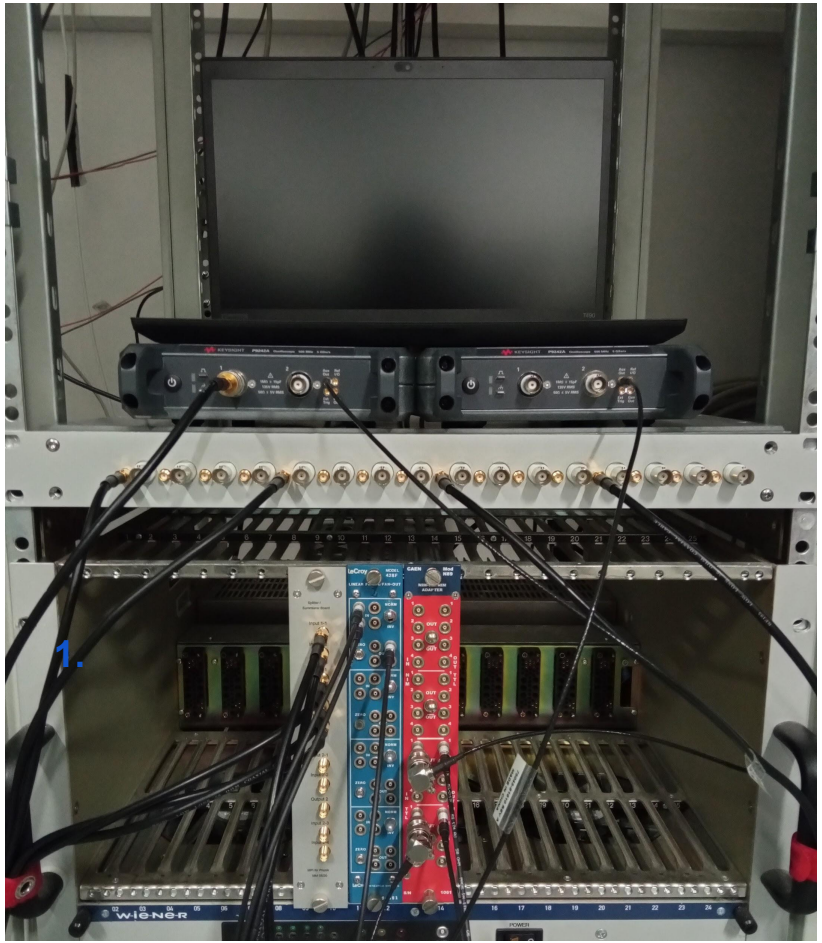
- The SuperKEKB collider achieved a world record in instantaneous luminosity in December 2021 and is set to further increase its luminosity
- Persistent tuning of its beams can lead to dangerously high beam backgrounds, which often lead to hardware damages if not properly monitored and mitigated
- The CLAWS has been active since end of May 2021 and is issuing beam aborts one beam revolution (or more) earlier than currently existing systems
- Since the enabling of CLAWS abort system detectors and hardware near the interaction point haven’t suffered significant beam-related damage
- Development of mobile CLAWS stations is currently ongoing to extend monitoring and abort capabilities outside of IP

Backup Slides

The CLAWS System

Electronics:

- 2 types of boards manufactured by the MPP (signal splitter and signal combiner boards)
- NIM Modules



The CLAWS System

Electronics:

- 2 types of boards manufactured by the MPP (signal splitter and signal combiner boards)
- NIM Modules
- Keysight P9242A USB Oscilloscope
  - 500 MHz bandwidth, 5 GSa/s sample rate
  - 200ps time resolution
  - Allows for complex trigger settings
  - 4us recuperation time after triggering
  - Ideal for fast reaction to beam disturbances

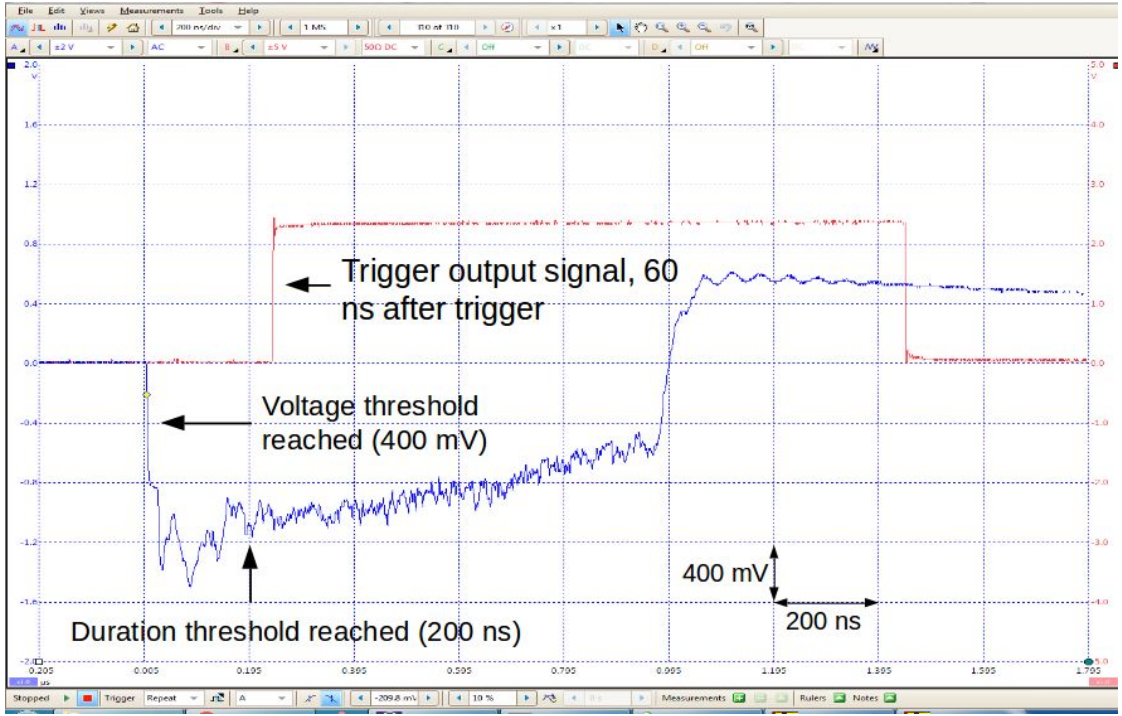
Hardware Test

Trigger test setup:

- A UV-LED diode was powered with very short pulses from an Agilent 81110A Pulse Pattern Generator
- The diode and an unwrapped CLAWS sensor were placed in a light tight box with a thin barrier between the sensor and the diode
- Scope set to trigger on negative signals which stay above 400 mV for at least 200 ns
- The CLAWS sensor signal (in blue) and the USB Oscilloscope output signal (in red) were fed into a Picoscope in order to observe trigger delay

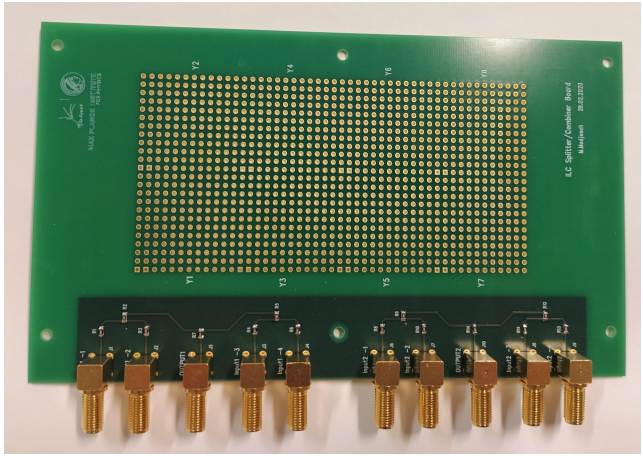
Hardware Test

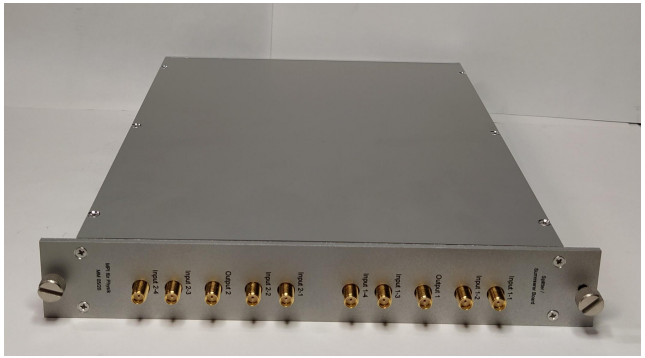
- Simulated unstable beam behavior by shining UV light in an unwrapped CLAWS sensor
- Connected Keysight P9242A and set duration and voltage thresholds
- The USB Oscilloscope outputs a signal **60ns** after fulfilment of trigger conditions, or a total of **260ns** after start of beam disturbance
- Current beam abort system outputs a signal **10us** after begin of beam disturbance



CLAWS Sensor Signal Addition

- ➔ To optimize reliability, at least four sensors per side should be considered for the trigger
- ➔ Due to high cost of scope modules a custom-designed combiner board will be used to add signals from up to four sensors
- ➔ Board was put in a metal casing, fit to be mounted on a NIM rack
- ➔ Same test as described in the previous slides was repeated successfully with the combiner board





Full Beam Abort Setup

- Two passive signal splitter board for the FWD and BWD CLAWS modules to enable the installation of this second DAQ
- A passive combiner board to combine the signals from the four innermost sensors of the FWD and BWD CLAWS modules for additional reliability
- Two Keysight P9242A USB Oscilloscopes to monitor combined signals from FWD and BWD CLAWS modules and send out trigger signal if background rate conditions are not acceptable
- A Lenovo ThinkPad T490 notebook to steer the oscilloscopes
- CAEN N89 NIM-TTL-NIM Adapter to convert trigger signal from scopes to NIM
- LeCroy Model 428F Linear Fan-In/Fan-Out to form logical OR of FWD and BWD trigger signal

Setup Reliability

Keysight P9242A:

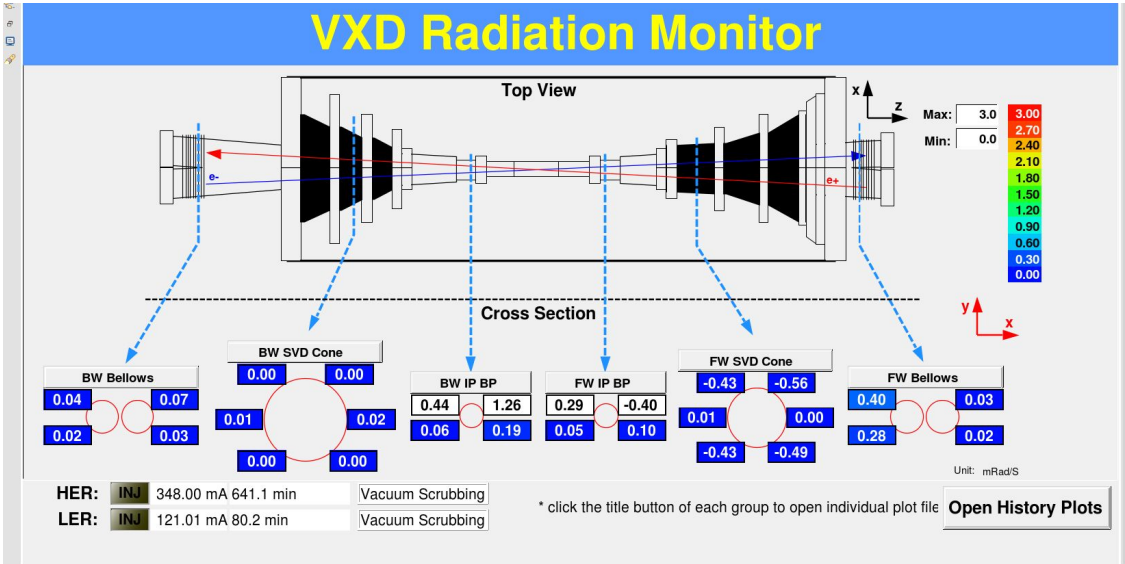
- P9242A continues to trigger indefinitely after loss of PC connection
- Even in case of a PC issue, the setup will continue to function

CLAWS System:

- Regardless of abort source (LER or HER spike), all CLAWS sensors observe the abort at roughly the same timing (+/- couple of ns)
- CLAWS system equally sensitive to background spikes in both HER and LER

The system was installed in SuperKEKB on 26.02.2021 and is currently tested for speed and efficiency. Once the test is completed the trigger signal from CLAWS for Beam Abort will be directed towards the Belle 2 PXD sensors.

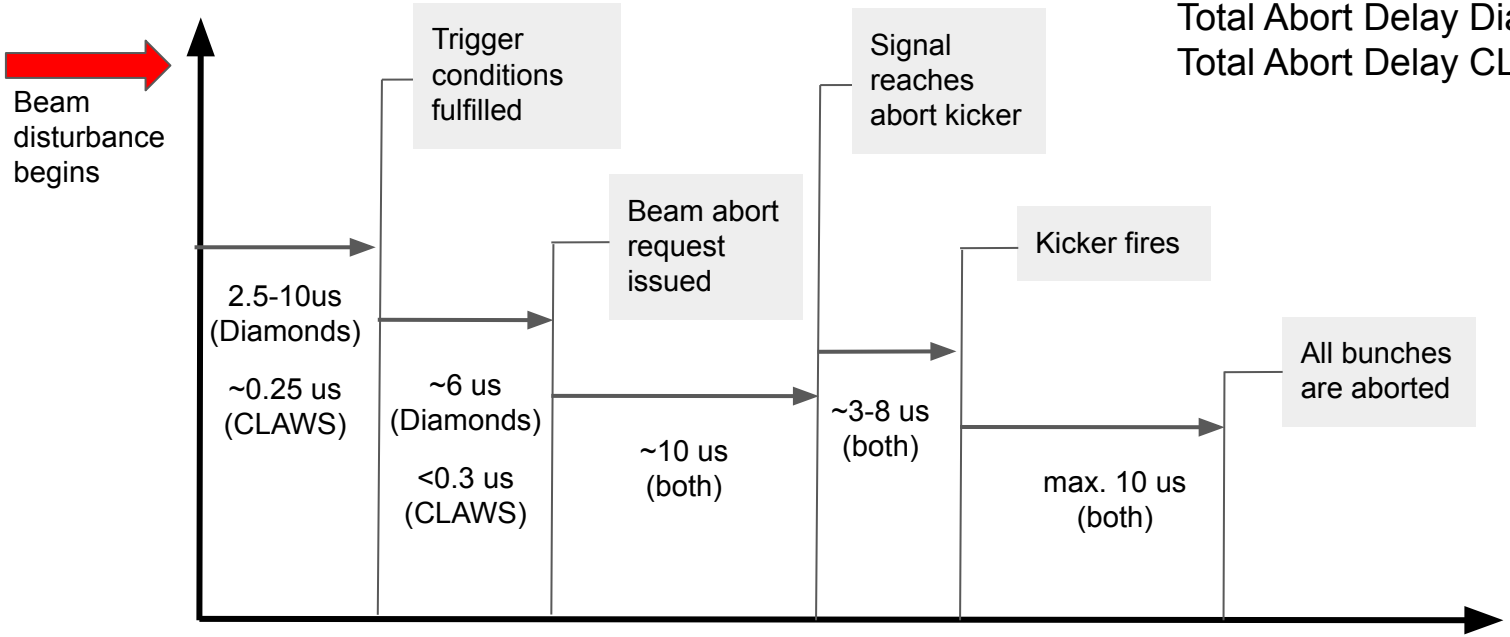
Radiation Monitoring and Beam Abort



Most prominent current system - the **Diamonds:**

- Integrated radiation dose monitoring
- “Slow” aborts with 1ms signal integration time
- “Fast” aborts with 10us signal integration time
  - Beam revolution time - 10us
  - Faster aborts necessary to minimize damage

Overall Abort Timing Comparison



Total Abort Delay Diamonds: **31.5-44us**
Total Abort Delay CLAWS: **23.5-28.5us**

CLAWS for Beam Abort speeds up abort process by **22-35%**

Typical Abort Events