A Scintillator Based Background and Beam Abort System for SuperKEKB

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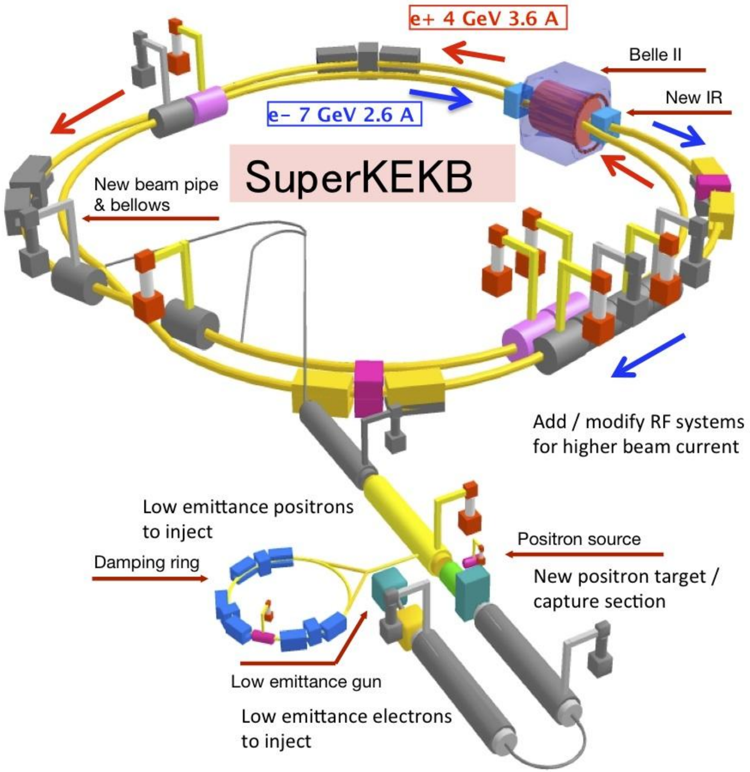
Outline:

1. SuperKEKB & Belle II
2. Current Radiation Monitoring System
3. The CLAWS System
4. Abort Trigger Scheme

MAX-PLANCK-INSTITUT FÜR PHYSIK

SuperKEKB and Belle 2

- Asymmetric e^+e^- collider at the Y(4S) resonance (10.57 GeV)
  - High energy ring for 7 GeV e^-
  - Low energy ring for 4 GeV e^+
- Extensive upgrade to KEKB and Belle
  - Increase in factor 40 to luminosity
  - June 2020 - world record for highest instantaneous luminosity at $2.4 \times 10^{34} cm^{-2} s^{-1}$
  - Design luminosity will be reached in 2025



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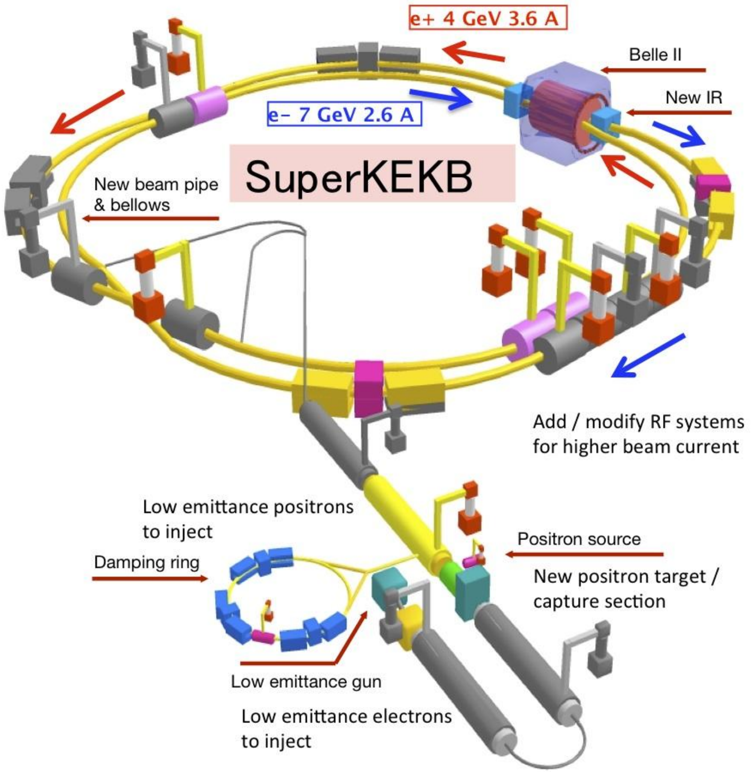
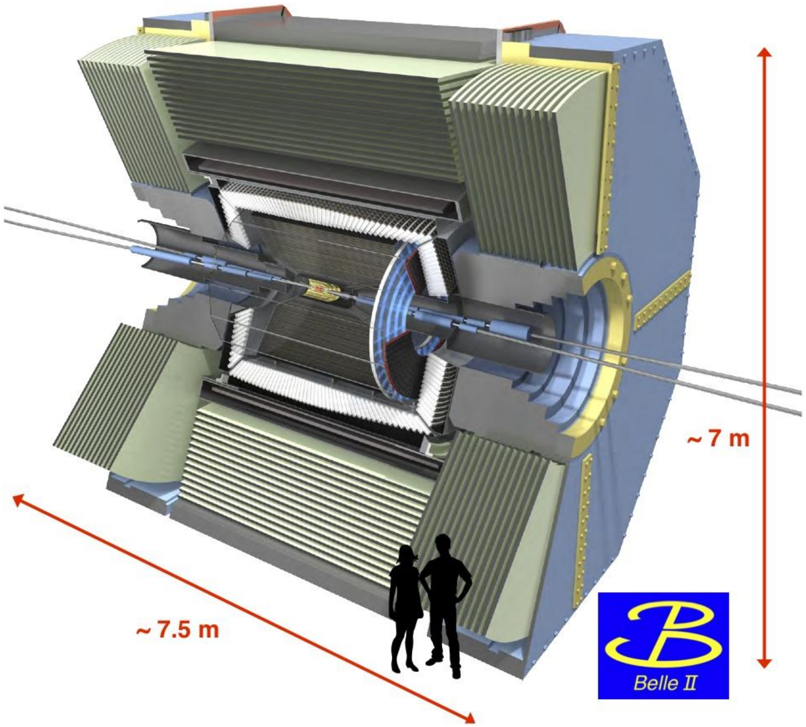
Until then persistent tuning of beam can often lead to problems.



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 very destructive “quench”



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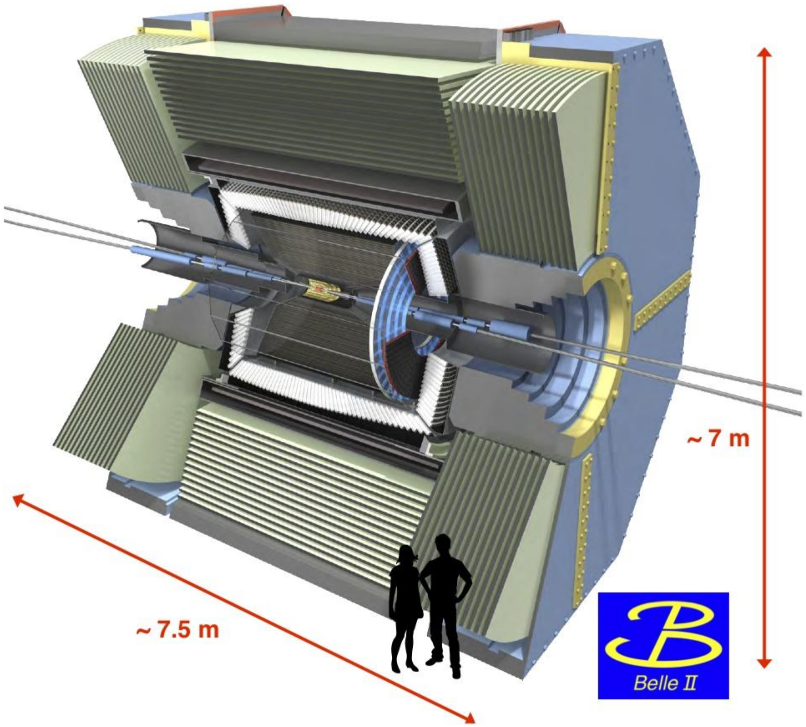
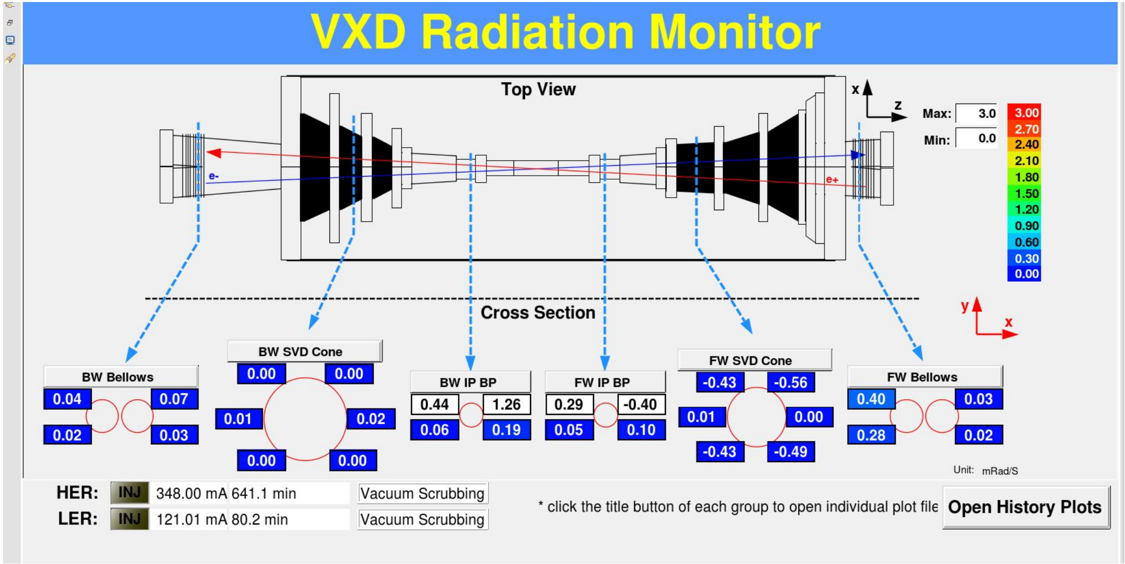
Dedicated background monitoring and beam abort systems are a necessity!



Radiation Monitoring and Beam Abort



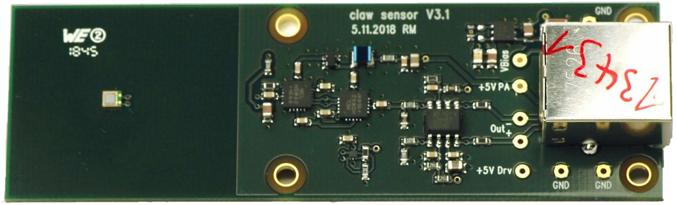
Most prominent current system - the **Diamonds:**

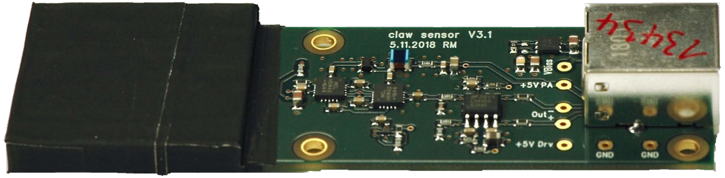
- Integrated radiation dose monitoring
- "Slow" aborts with 1ms signal integration time
- "Fast" aborts with 10us signal integration time
    - Beam revolution time - 10us
    - Faster aborts necessary to minimize damage

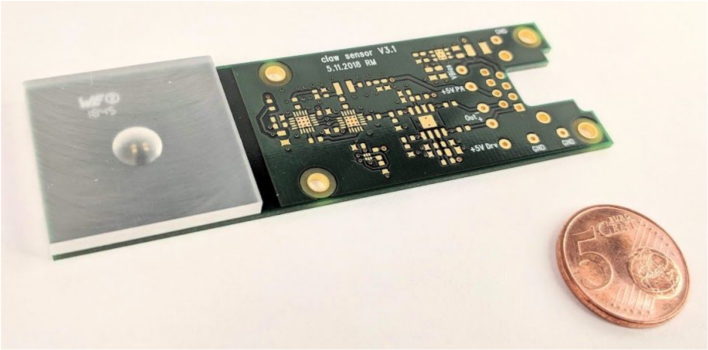
The CLAWS System

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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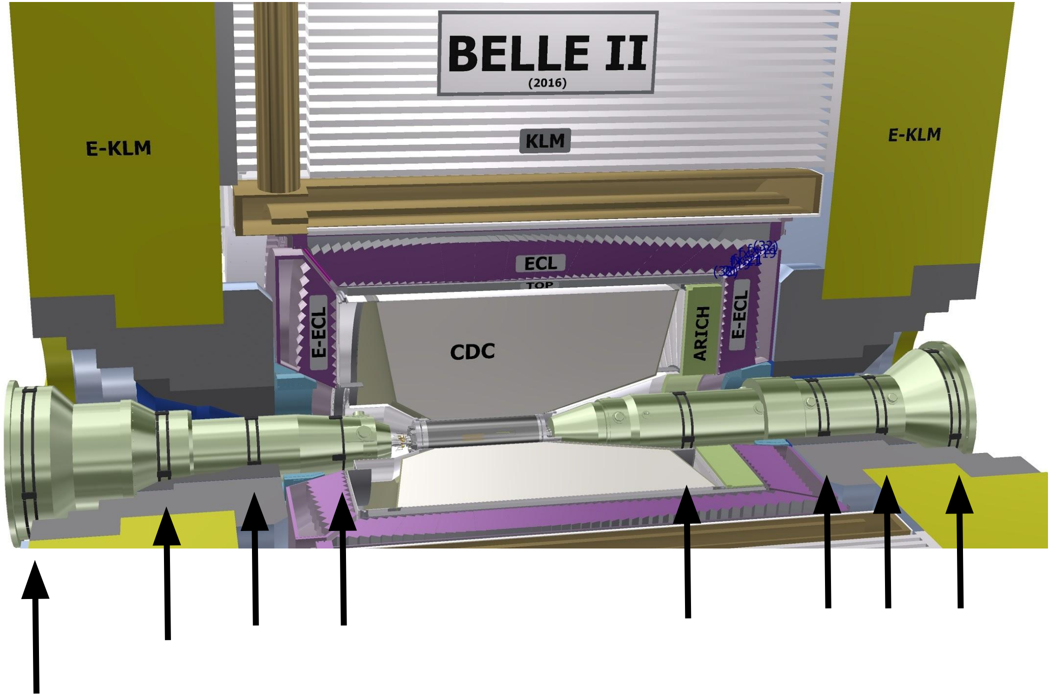

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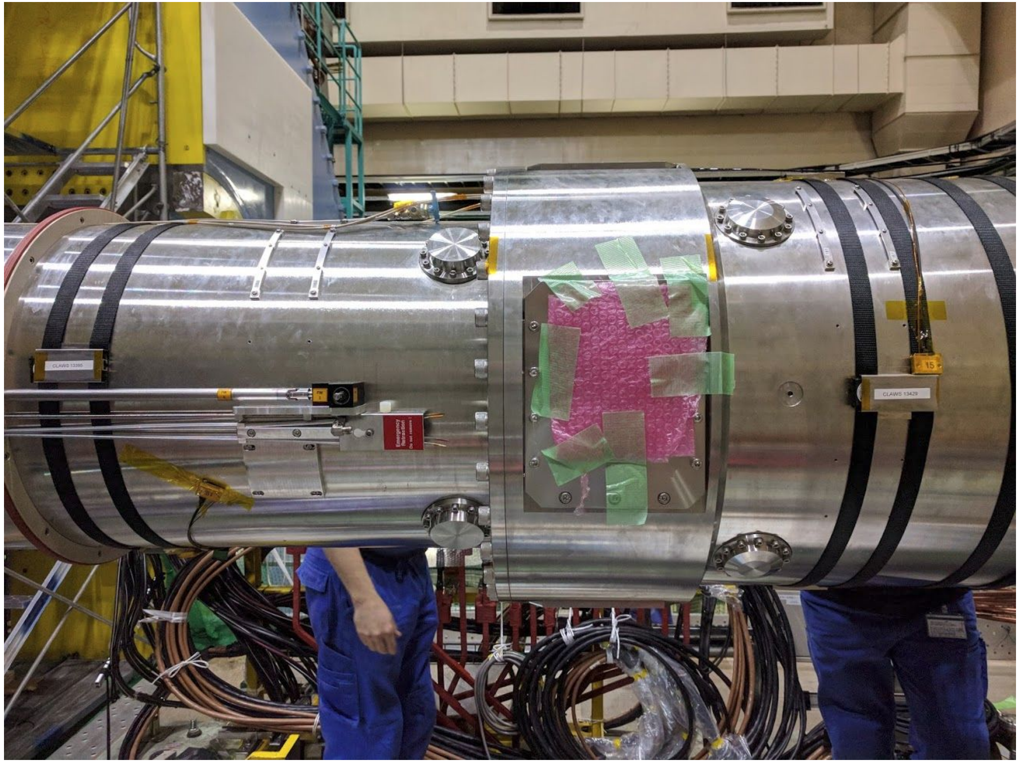
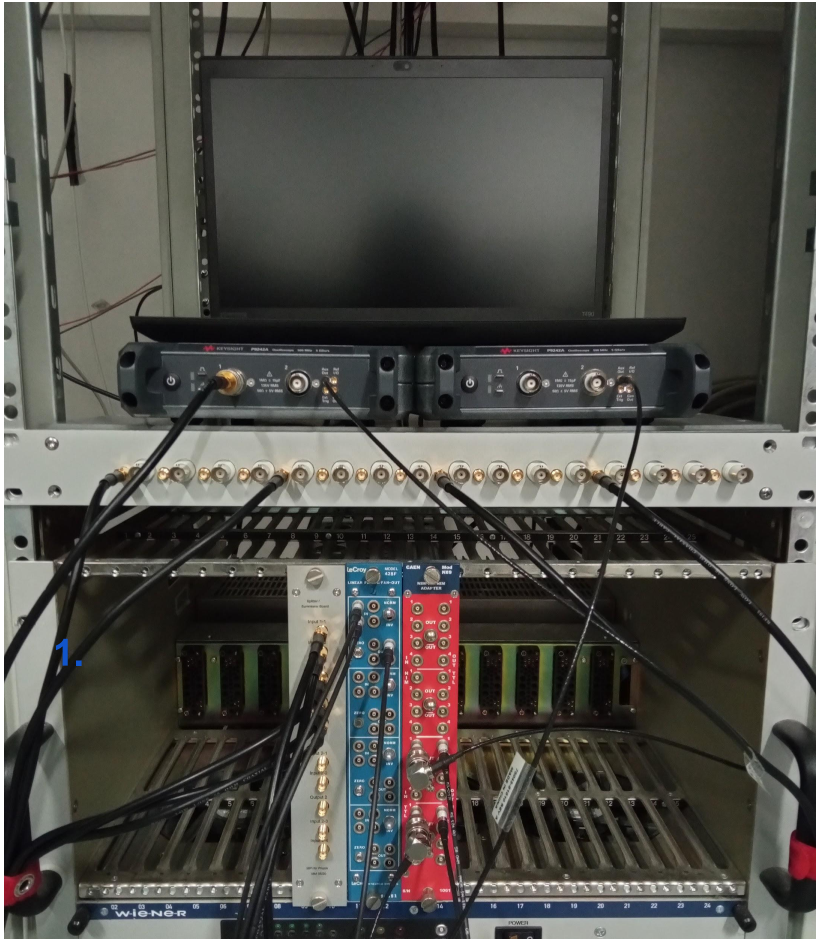


The CLAWS System

Electronics:

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



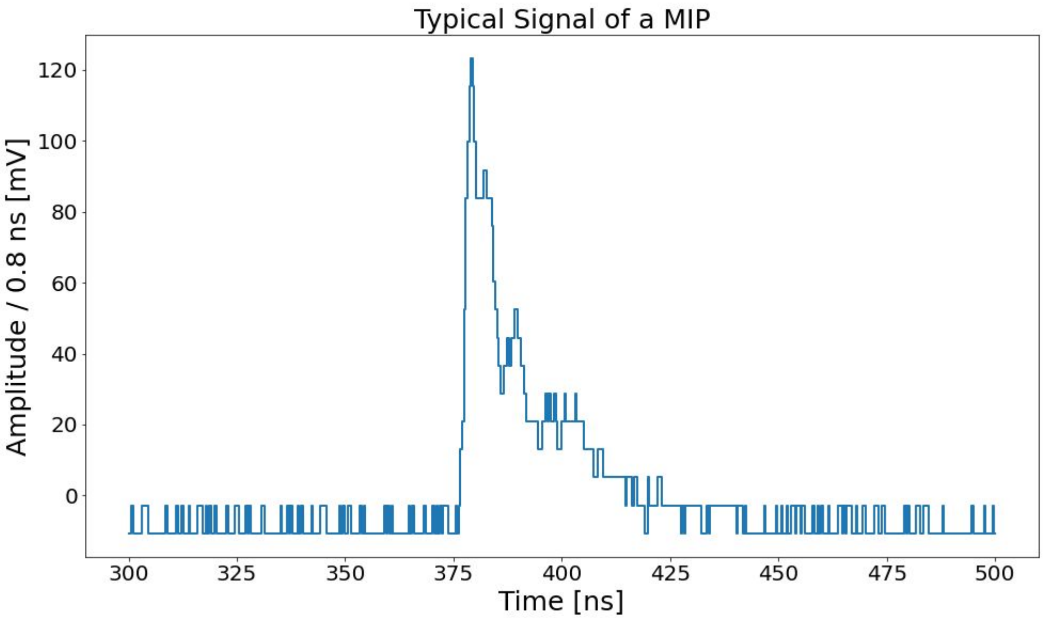
The CLAWS System

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

CLAWS Abort Trigger Scheme

- Typical MIP signals observed by CLAWS sensors have **100-150mV** amplitude and decay over **50-70ns**



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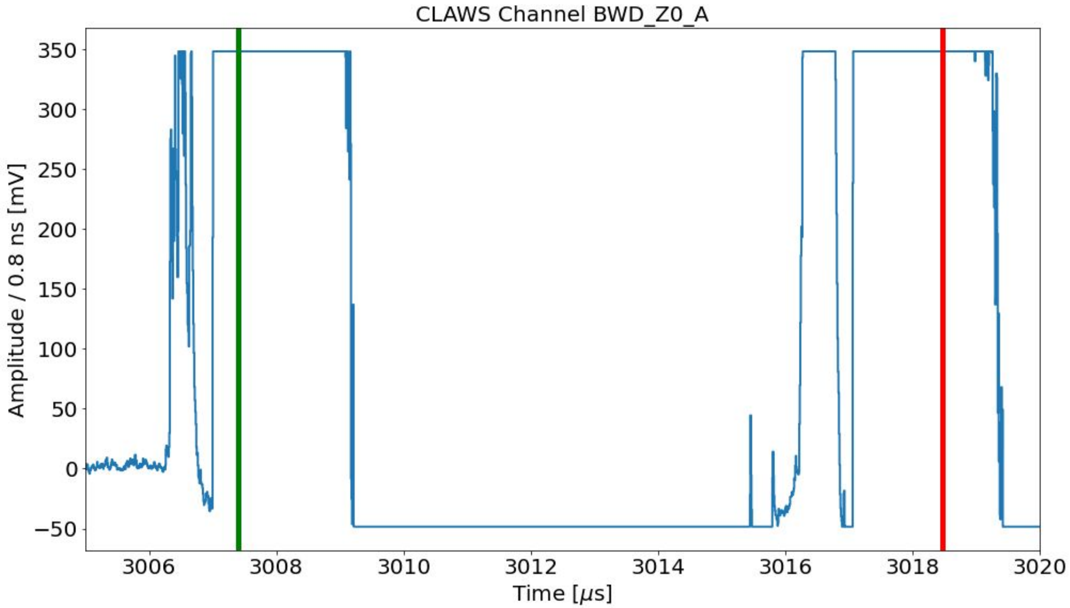
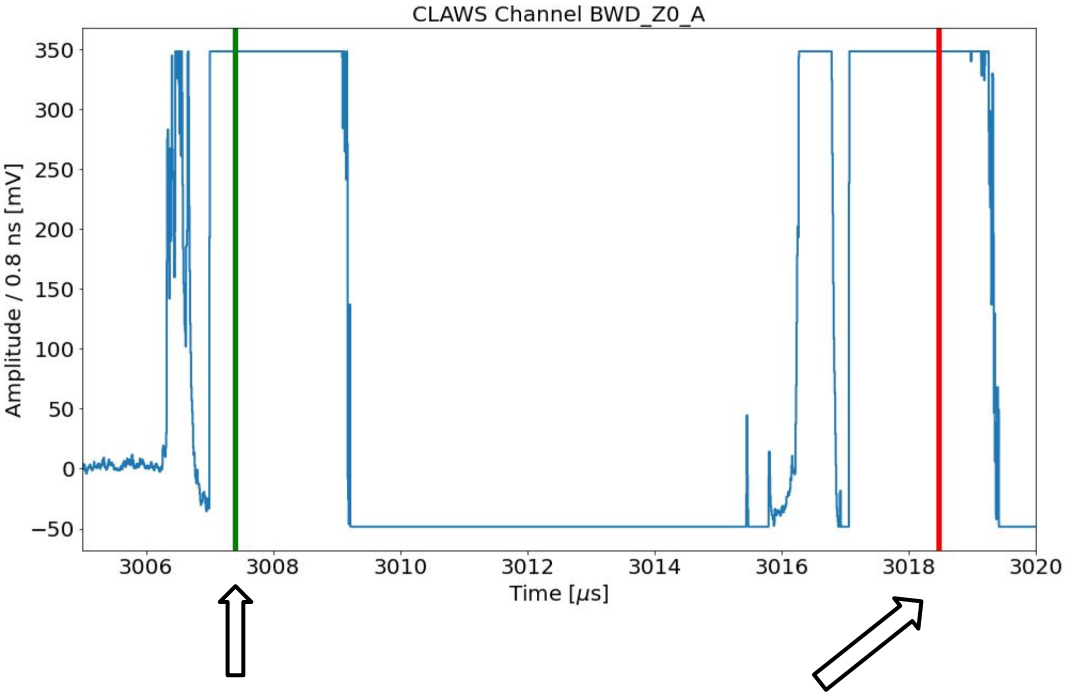


CLAWS Abort Trigger Scheme

- Typical MIP signals observed by CLAWS sensors have **100-150mV** amplitude and decay over **50-70ns**
- In beam abort events amplitude stays above **300mV** for at least **200ns** (normally a couple of us)
- By setting an amplitude and a duration threshold the CLAWS system can react to beam abort events **substantially earlier** than currently existing systems

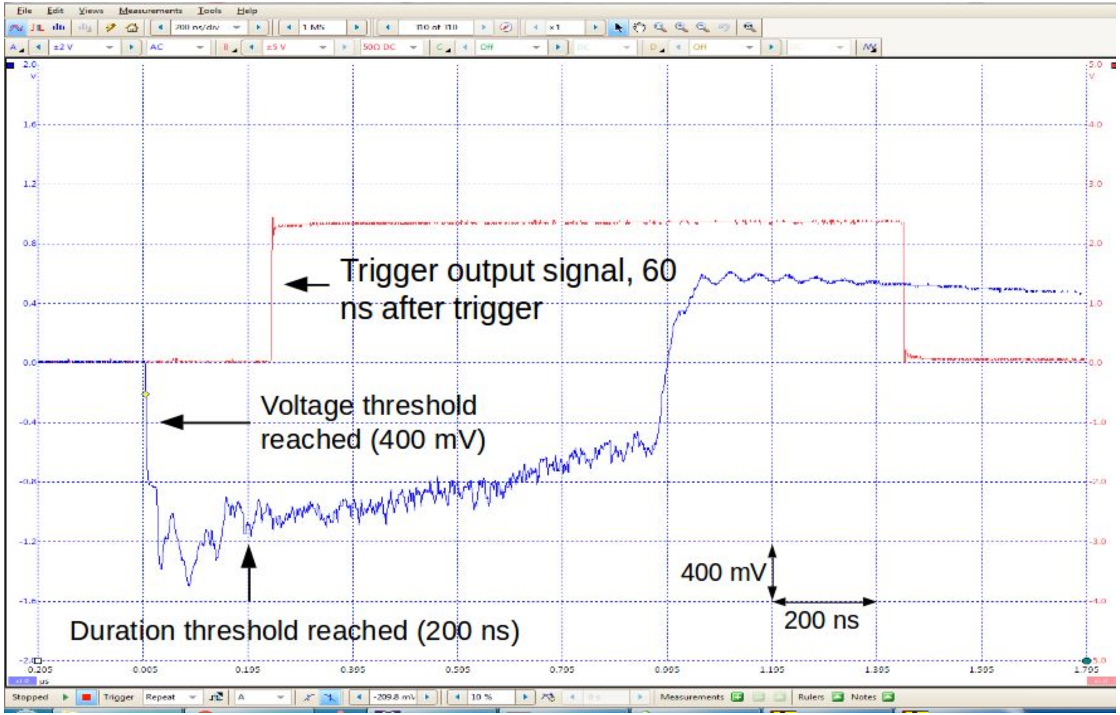


CLAWS Beam Abort Trigger Issue

Diamonds Beam Abort Trigger Issue

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

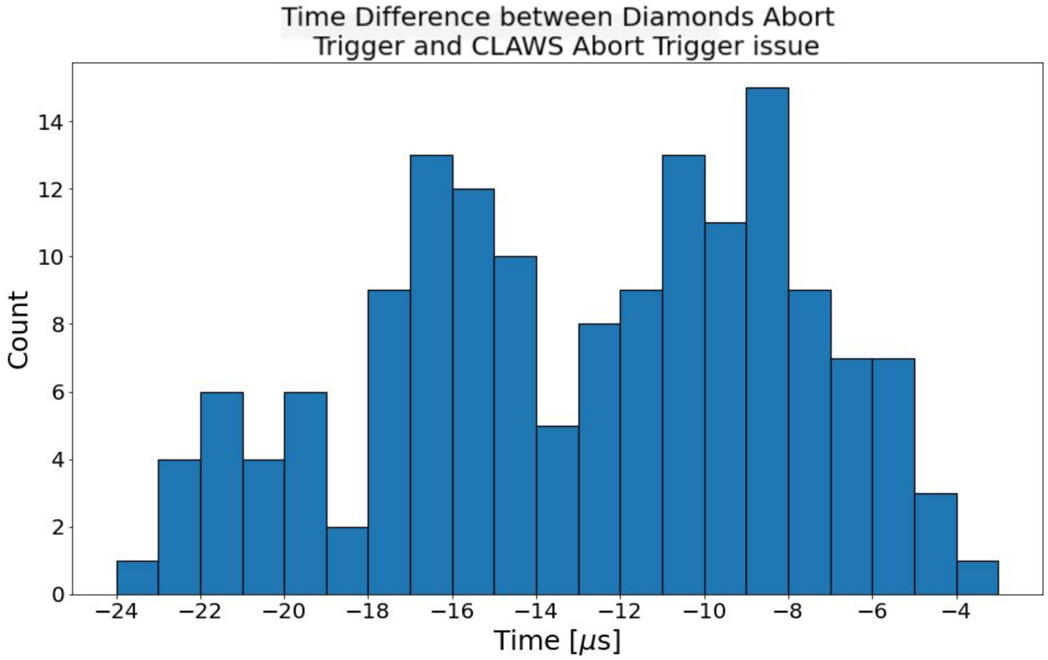


Trigger Performance

In 2020 Run C of SuperKEKB (October - December) CLAWS observed **177** beam abort events

Summary:

- Triggered on **175** events (98.87%)
- Faster reaction than current system for **170** events (96%)
- On average CLAWS would issue an abort **more than 1 beam revolution earlier** (13us) than current system



Summary

- The SuperKEKB collider achieved a world record in instantaneous luminosity in June 2020 and is set to further increase its luminosity
- Persistent tuning of its beams can lead to dangerously high beam backgrounds, which can lead to hardware damages if not properly monitored and mitigated
- The CLAWS system can conceptually issue beam aborts one beam revolution (or more) earlier than currently existing systems
- Currently in commissioning with final electronics and colliding beams
- After the commissioning phase is over, CLAWS will serve initially to power down PXD sensors during high beam backgrounds, at a later point it will also abort the beam

Backup Slides

Keysight P9242A

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

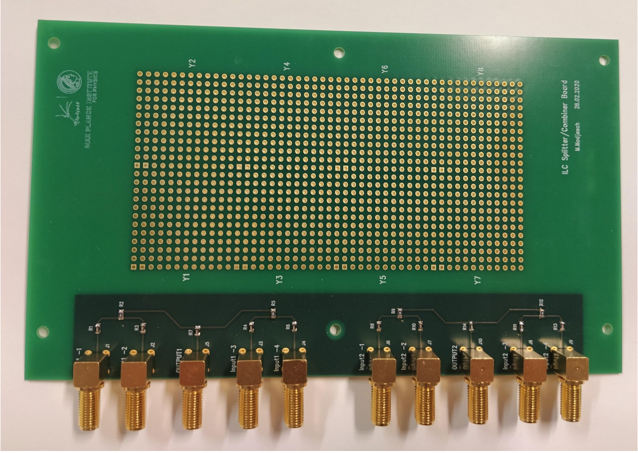
CLAWS Sensor Signal Addition

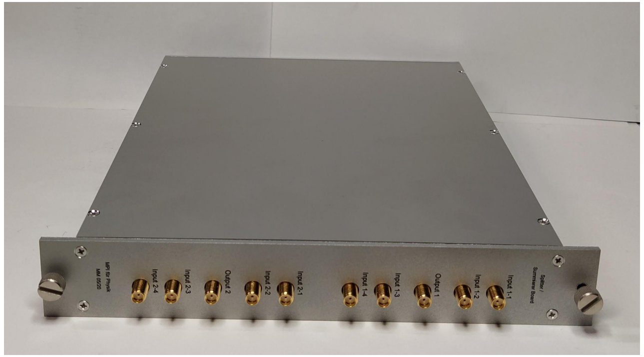
➔ To optimize reliability, at least four sensors per side should be considered for the trigger

➔ 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.

Typical Abort Events