CLAWS for Beam Abort Performance and Prospects

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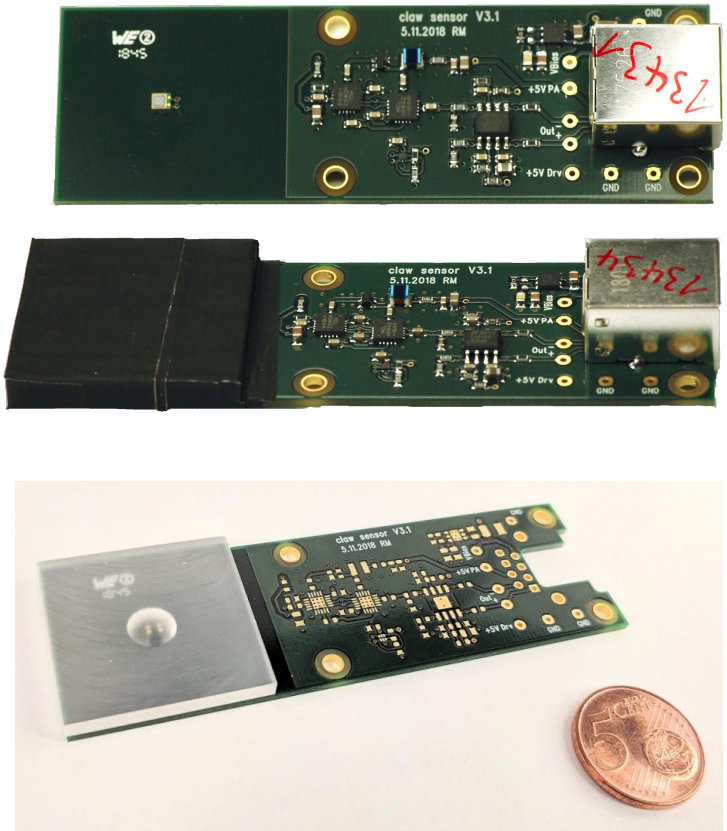
Outline:

1. The CLAWS System
2. Abort Trigger Performance
3. Outlook and Future Prospects

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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The CLAWS System

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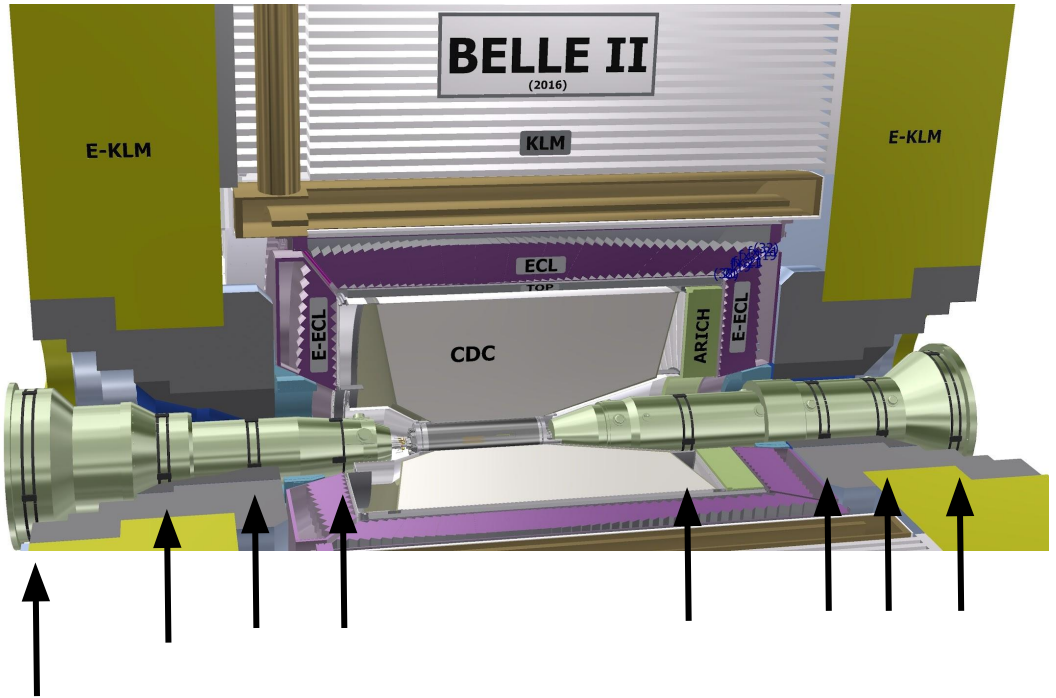
- Hamamatsu silicon photomultipliers mounted on 3x3 cm^2 plastic scintillators, primarily sensitive to penetrating charged particles (“MIP”s)
- 32 sensors, 16 on forward and backward side of the Belle 2 detector, mounted on the QCS with varying z and ϕ positions



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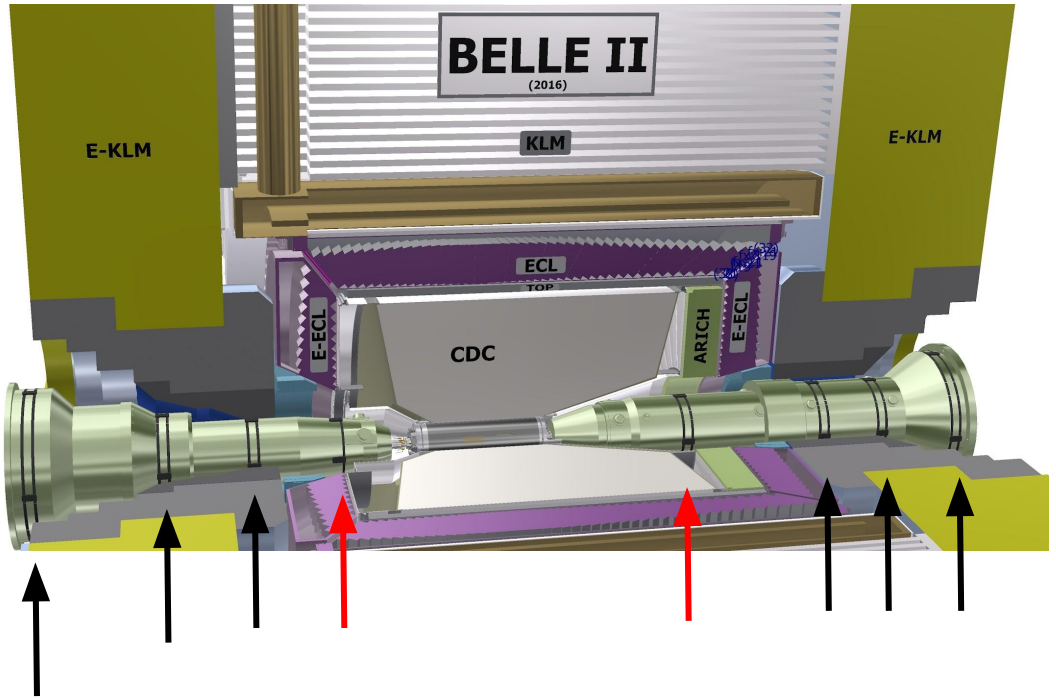

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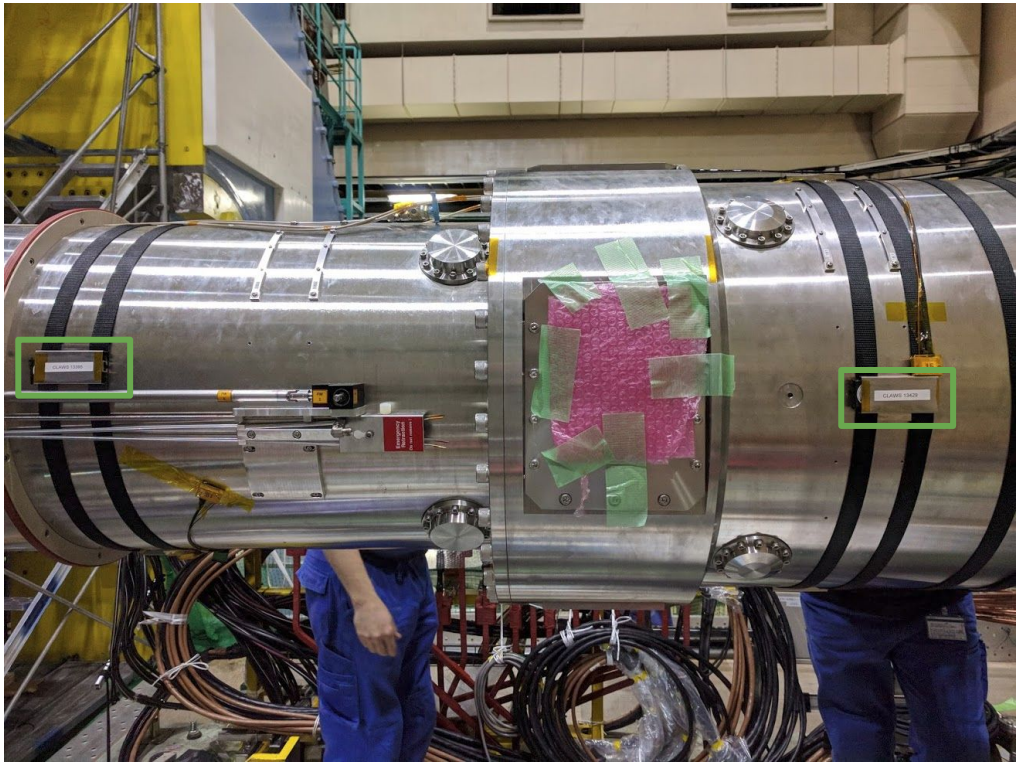

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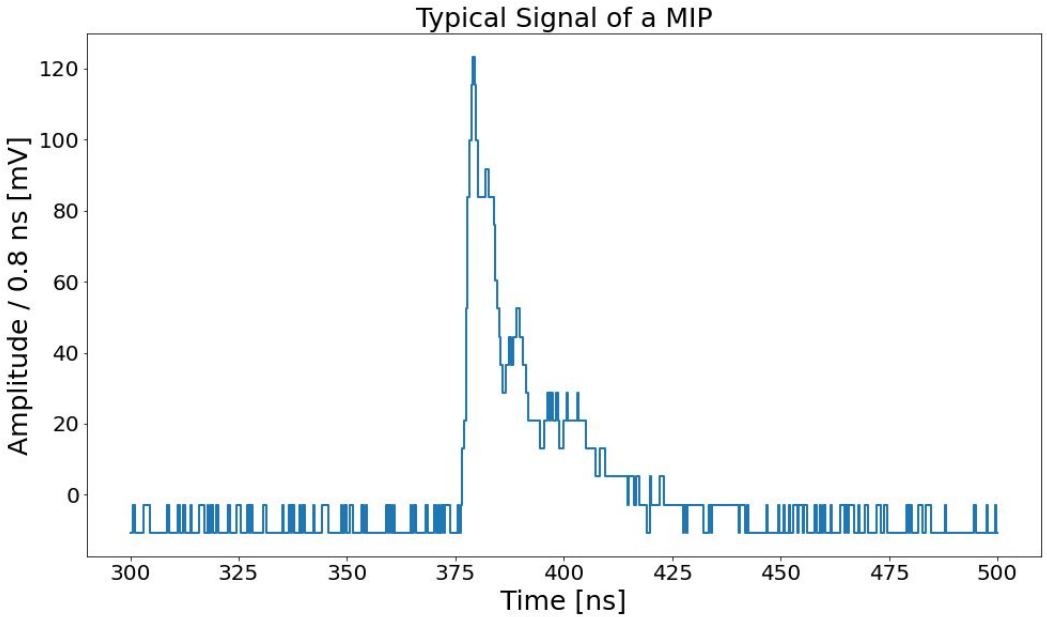
CLAWS Abort Trigger Scheme

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



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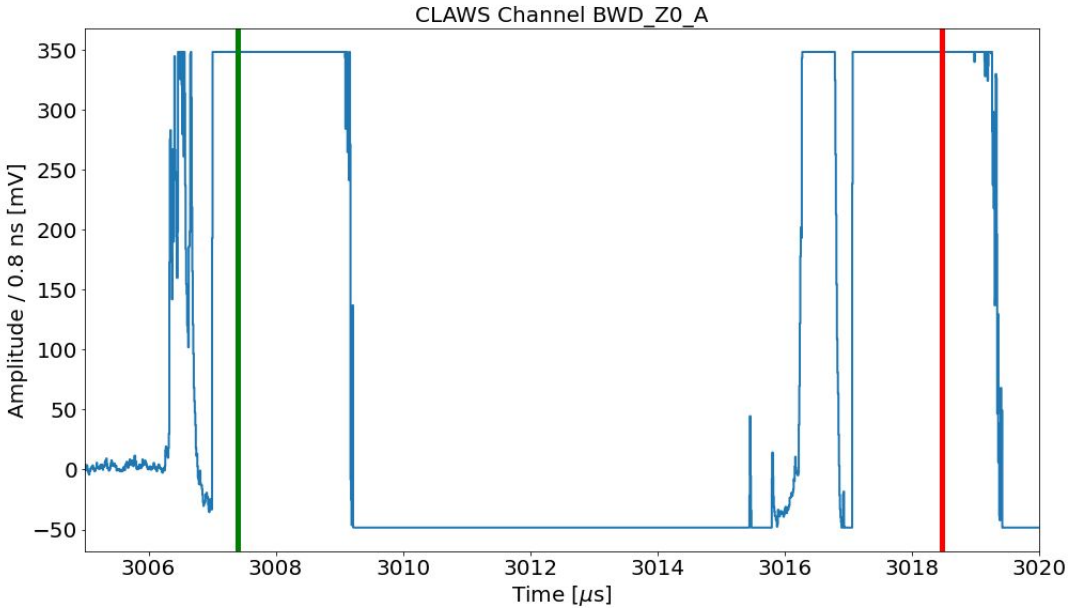
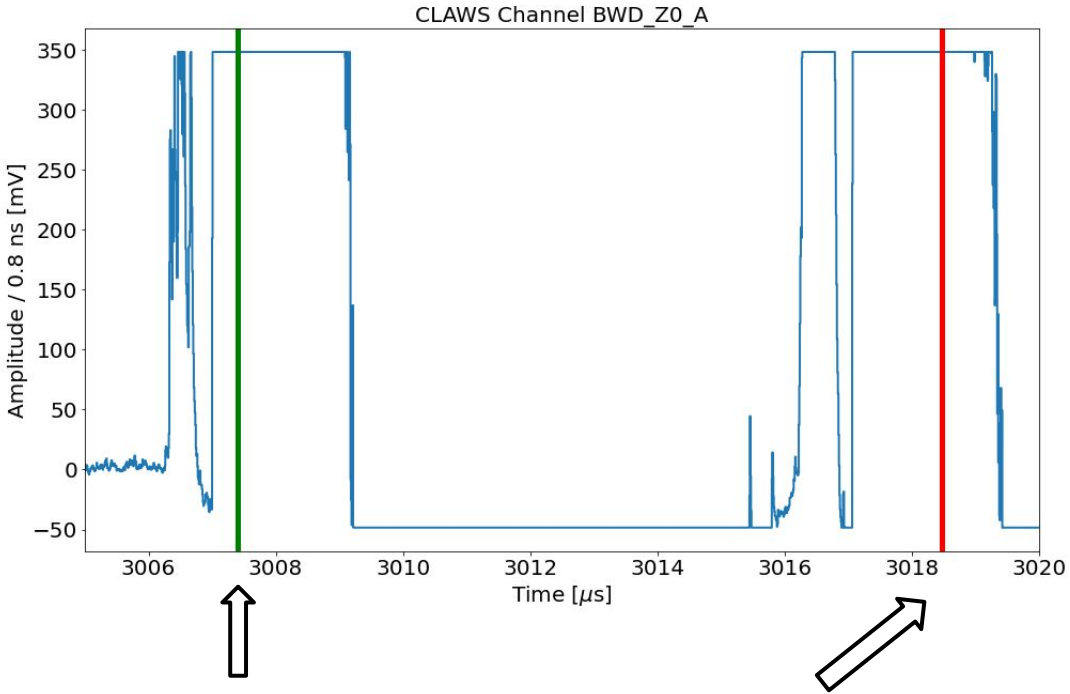


CLAWS Abort Trigger Scheme

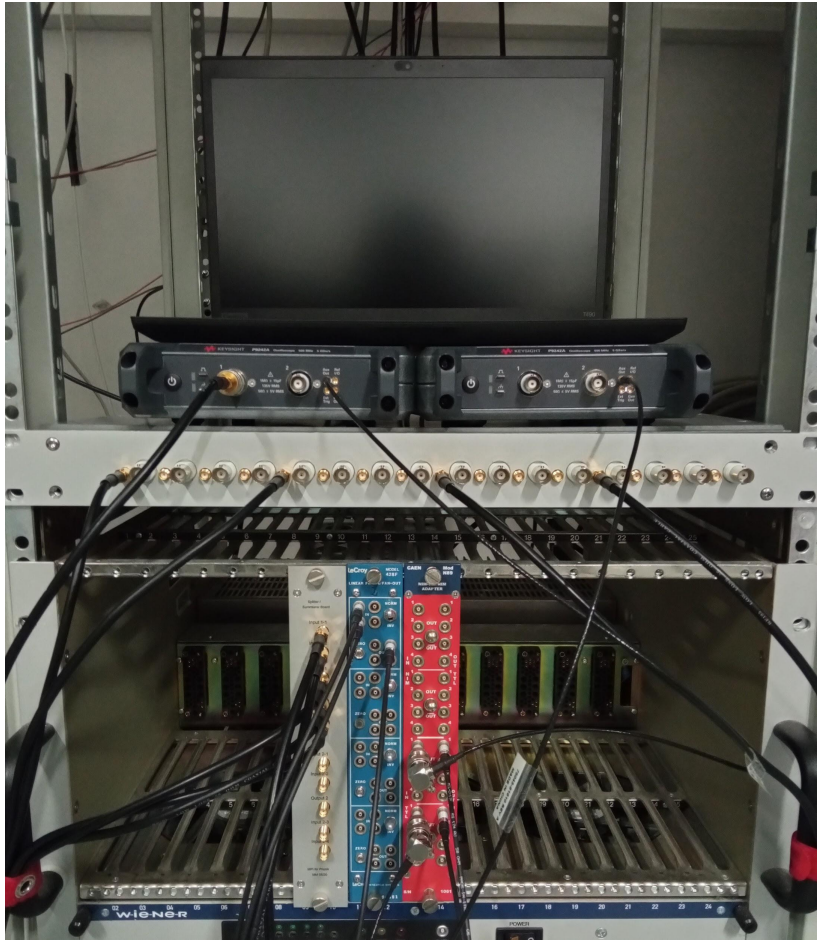
- Typical MIP signals observed by CLAWS sensors have **100-150mV** amplitude and decay over **50-70ns**
- In typical beam abort events the amplitude stays above **250mV** for **a couple of us**
- An amplitude and duration based threshold exceeding 250 mV for at least 200 ns reacts **substantially earlier** than current existing systems



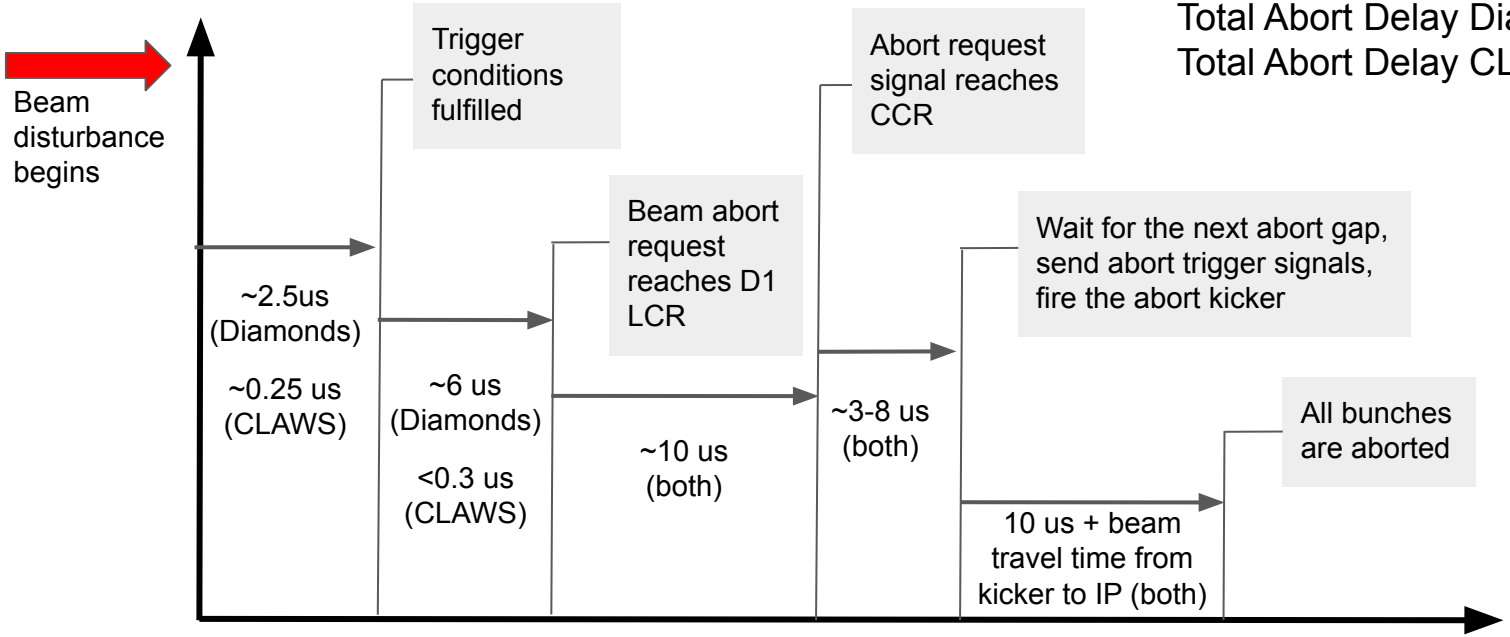
The CLAWS System

Electronics:

- 2x Keysight P9242A USB Oscilloscope
  - Provides trigger logic
  - Sends abort signal <0.5us after beginning of beam disturbance
- 8x PicoScope 6404D
  - Data acquisition from all 32 CLAWS sensors
  - Records 300 turns before and 300 turns after trigger with timing resolution of 800ps
- Assorted NIM modules and custom built boards



SuperKEKB Abort Timing



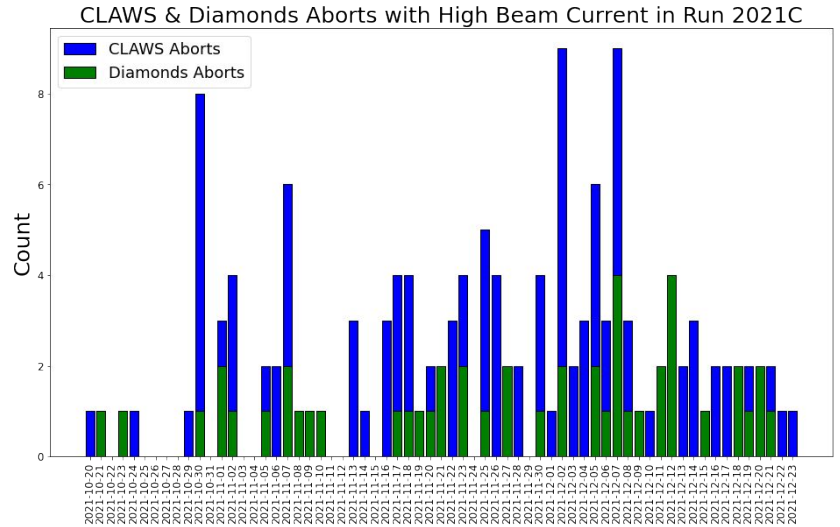
Total Abort Delay Diamonds: **31.5-35.5us**
Total Abort Delay CLAWS: **23.5-28.5us**

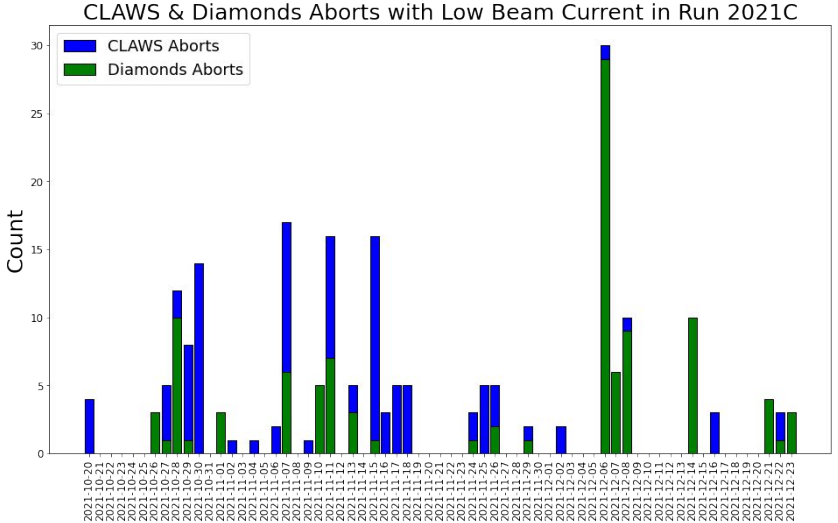
CLAWS for Beam Abort speeds up abort process by **10-34%**

Performance in Run 2021c

Time Frame: 2021/10/19 - 2021/12/23:

- **133** Aborts with High Beam Current (i.e both rings >60mA), ~**200** Aborts during MR operation start-up
  - ~80 synced with **HER injection**, about ~180 synced with **LER injection**
  - Solution: **injection veto**
    - CLAWS abort signal is masked before and after injections
    - Veto window: **[-16us : +120us]** with regard to arrival time of injected bunch
    - Total downtime of CLAWS abort signal - 0.272ms out of every 40ms, i.e **0.68% of total runtime**

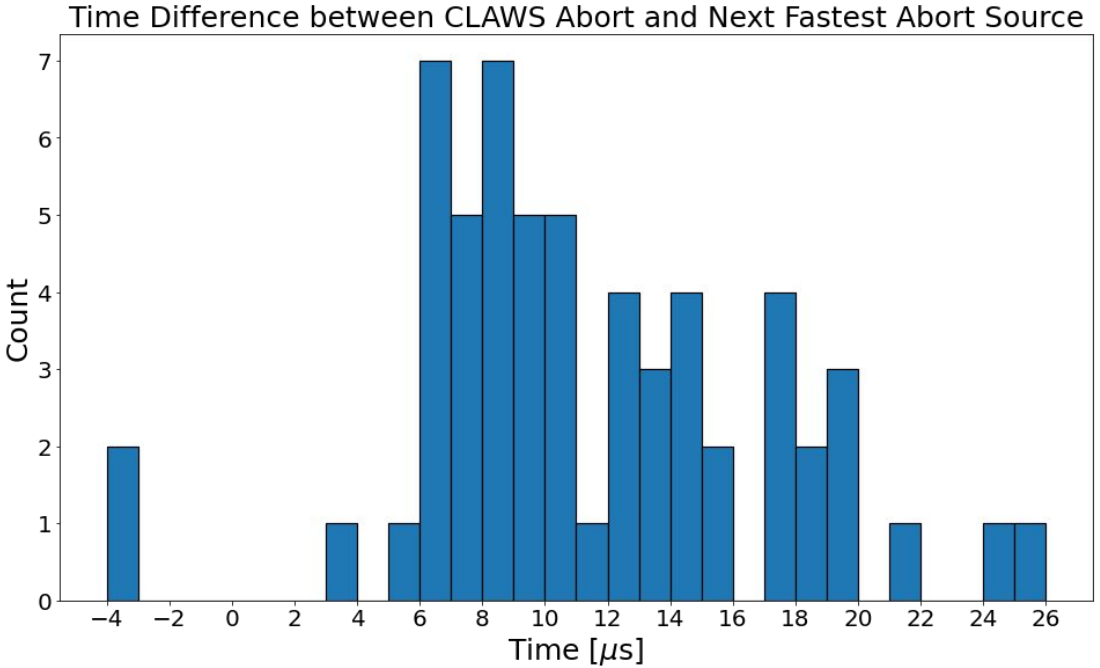




Performance in Run 2021c

Time Frame: 2021/10/19 - 2021/12/23:

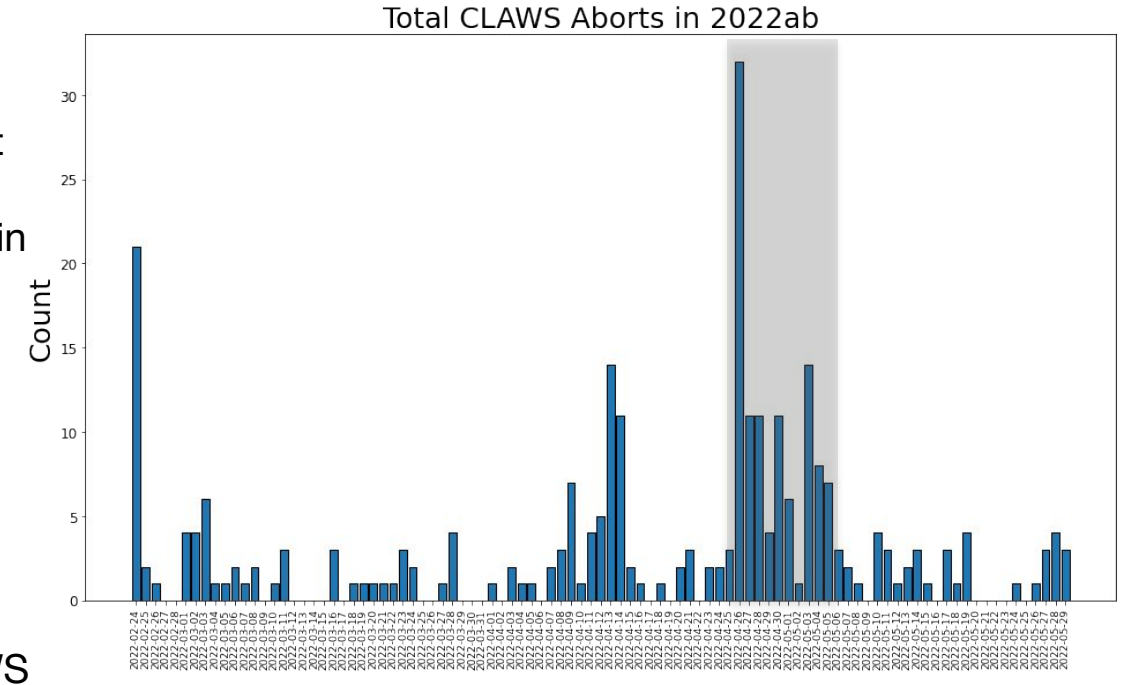
- **60** CLAWS aborts with more than 1 abort source and >1mA stored in both rings
  - CLAWS was the first system to issue abort for **58** of those
  - On average **11.4us** faster than next fastest abort source
  - Outperformed by RF D5-F for 2 LER aborts



Performance in Run 2022ab

Time Frame: 2022/02/24 - 2022/06/22:

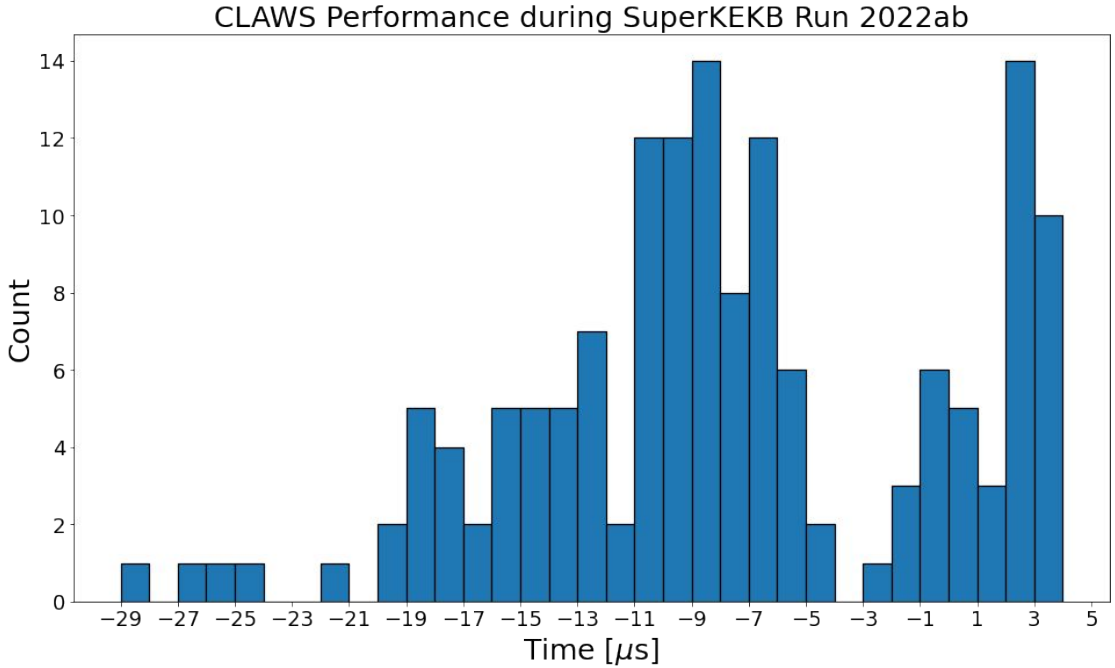
- **126** Aborts with High Beam Current
  - On average 30% less High Beam Current aborts per day in comparison to Run 2021c
- **154** Aborts during MR operation start-up
  - All in sync with injections
  - Solution: **increase veto duration**
    - New Veto Window: **[-16us : +300us]**
    - Total downtime of CLAWS abort signal - **1.58% of total runtime**



Performance in Run 2022ab

Time Frame: 2022/02/24 - 2022/06/22:

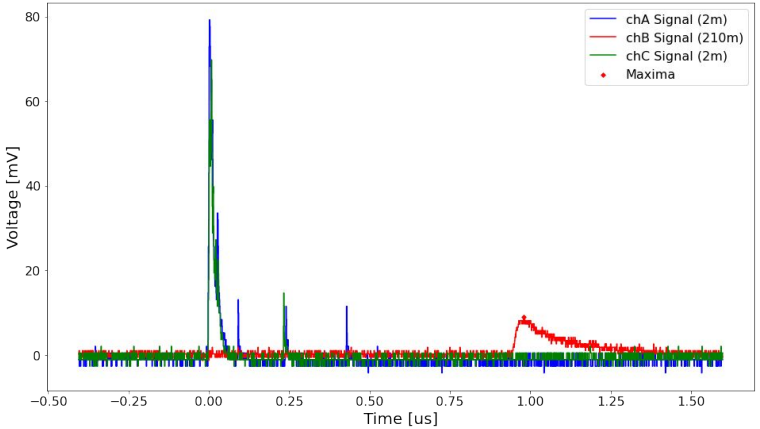
- **151** CLAWS aborts with more than 1 abort source and >1mA stored in both rings
  - CLAWS was the first system to issue abort for **119**
  - Newly installed beam loss monitors are able to provide better abort timing than CLAWS for events with beam loss originating in certain collimator heads
  - On average **7.6us** faster than next fastest abort source

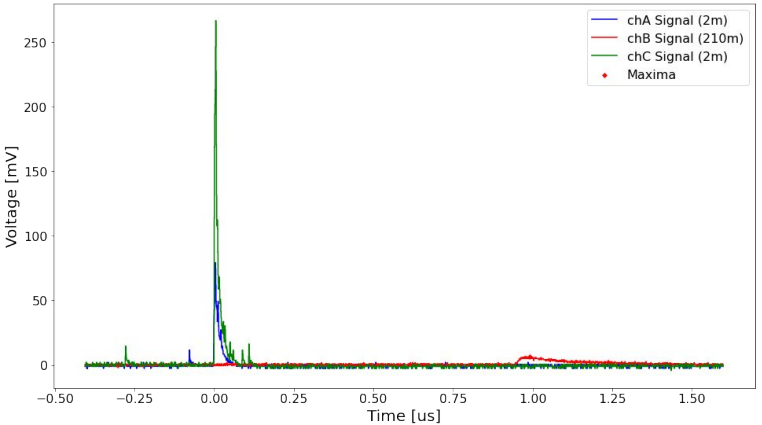


CLAWS Expansion

- Due to large beam loss consistently observed at a number of collimator heads an expansion of the CLAWS abort system is proposed
- Streamlined CLAWS setups will be installed at critical upstream locations, enabling issue of beam abort signal up to **8us** faster than IR CLAWS
    - Currently chosen locations - **D06 collimator** and **NLC** for LER, **D09 collimator** for HER
    - Each setup would consist of 4 CLAWS sensors, CAT7 cables from sensors to electronics, a Picoscope for DAQ + assorted NIM electronics
    - If a location is deemed advantageous, trigger logic will be added to the station to enable abort capabilities (a Keysight USB oscilloscope)
- Main difference to current CLAWS for beam abort setup - distance from sensor to read-out electronics!
    - Current CLAWS sensor to electronics distance - 50m
    - Proposed setups sensor to electronics distance - 100m to 250m

CLAWS Expansion





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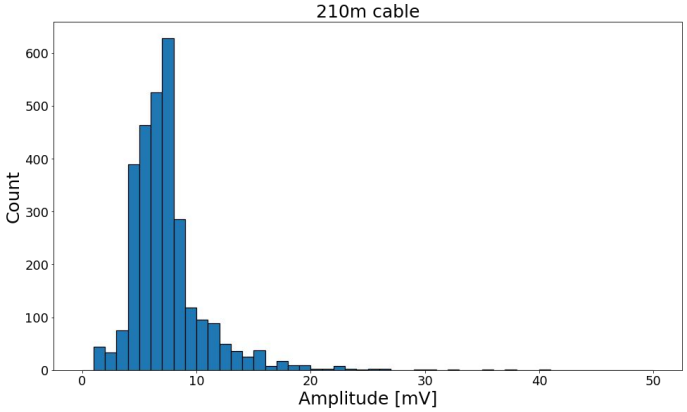
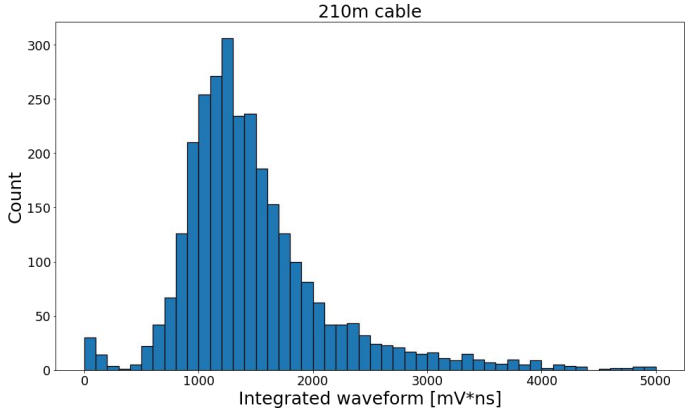
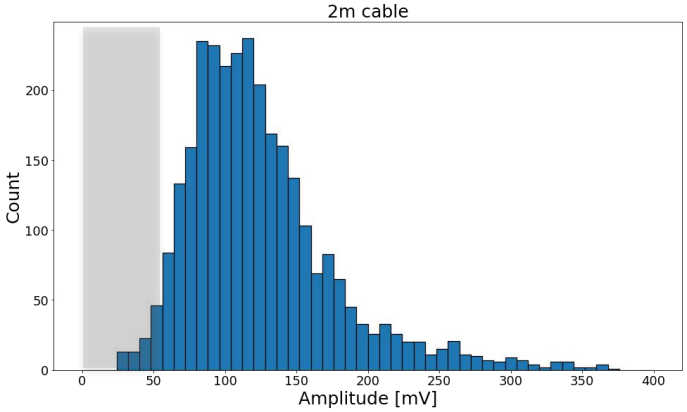
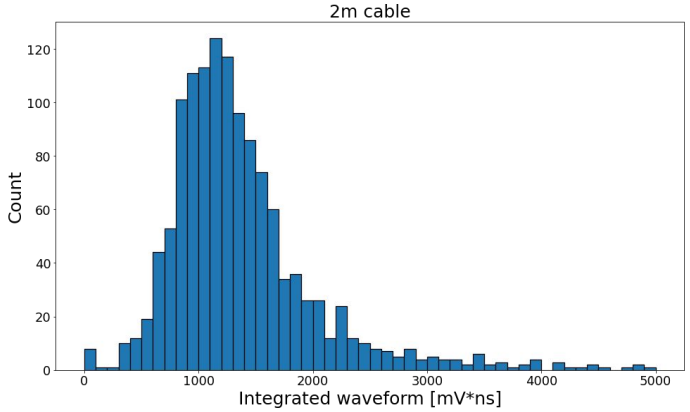








Summary

- The CLAWS system has been functional as a beam abort system since 28.05.2021 and has substantially reduced beam-related damage

- During Run 2021c the CLAWS issued aborts **11.4us** faster than next fastest abort system. Due to system's sensitivity to particle injections, an injection veto was implemented for the CLAWS system leading to **0.68%** system downtime.

- During Runs 2022ab CLAWS issued aborts on average **7.6us** faster than next fastest system. Reason for worse performance are the newly installed Loss Monitors, which provide superior abort timing for certain events due to their location. Injection veto downtime was increased **1.58%**

- Streamlined CLAWS stations to be installed in 2023 at locations with known beam loss occurrence to provide better understanding of said beam loss and superior abort timing.

Backup Slides

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

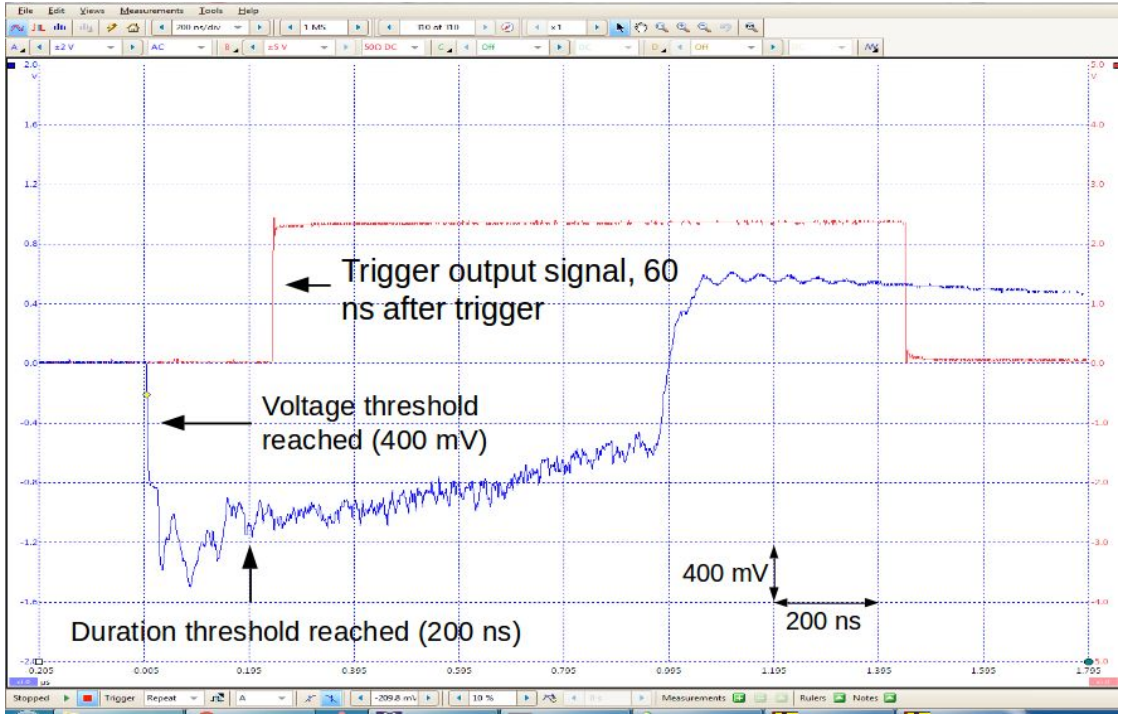
Hardware Test

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

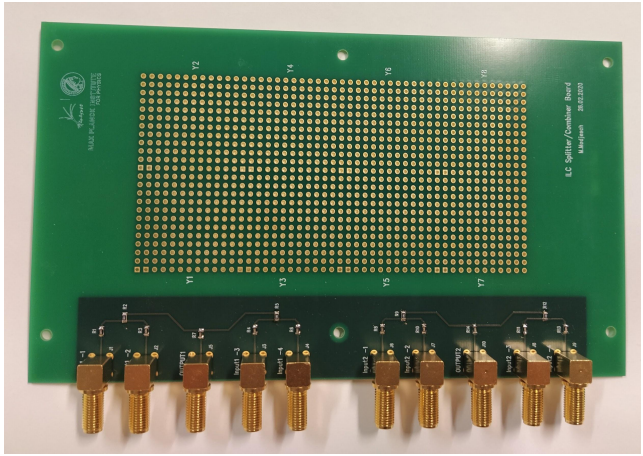
Hardware Test

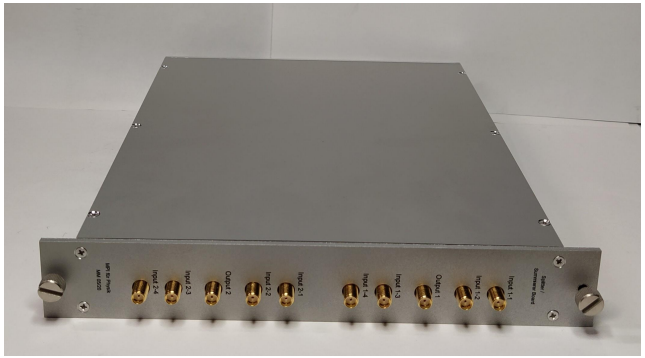
- Simulated unstable beam behavior by shining UV light in an unwrapped CLAWS sensor
- Connected Keysight P9242A and set duration and voltage thresholds
- The USB Oscilloscope outputs a signal **60ns** after fulfilment of trigger conditions, or a total of **260ns** after start of beam disturbance
- Current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



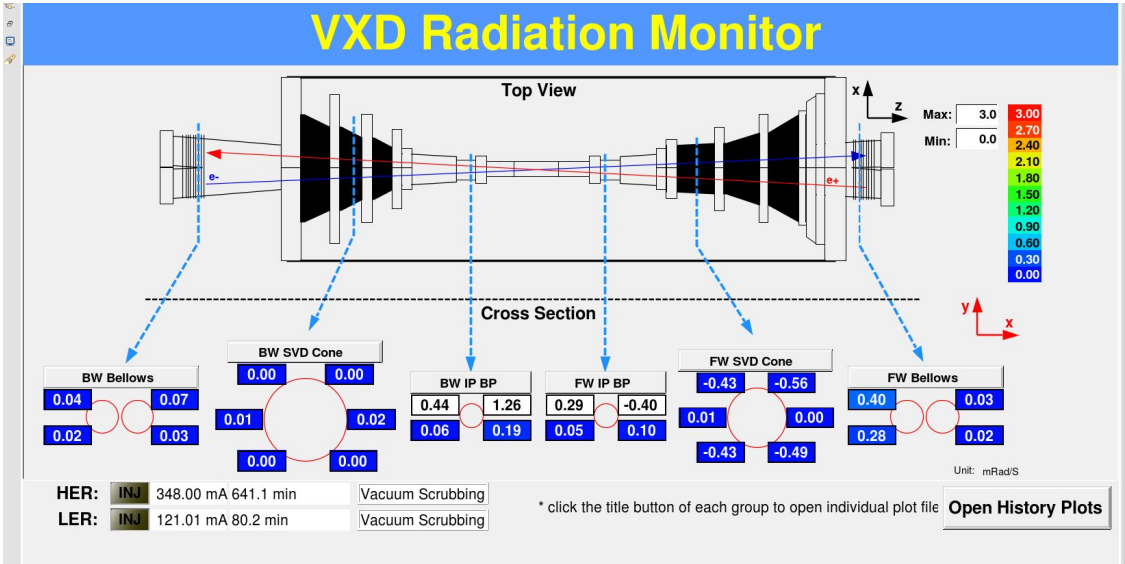
CLAWS Sensor Signal Addition

- ➔ 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





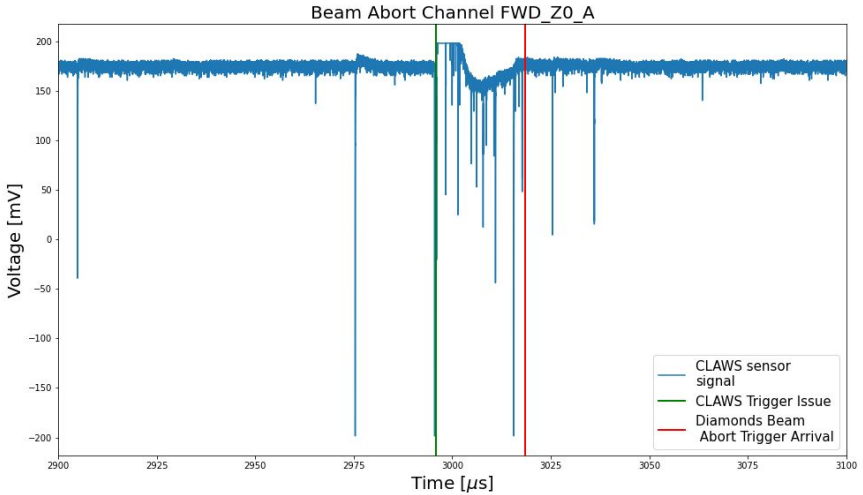
Radiation Monitoring and Beam Abort

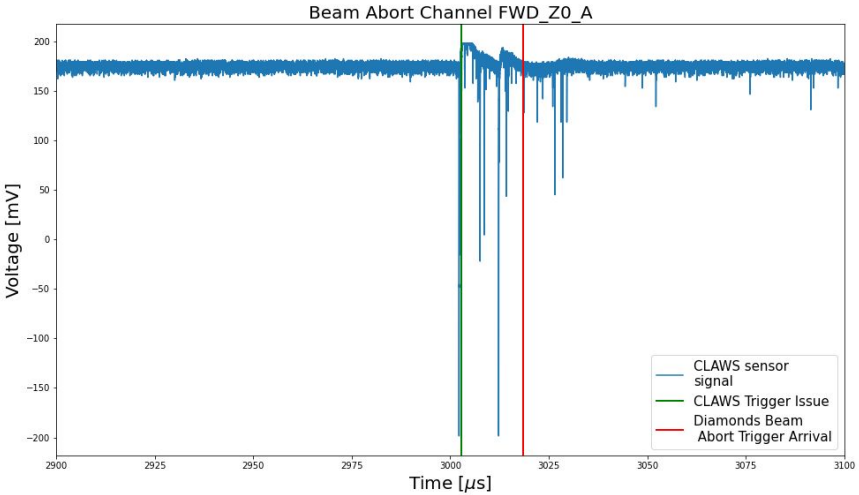


Most prominent current system - the **Diamonds:**

- 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

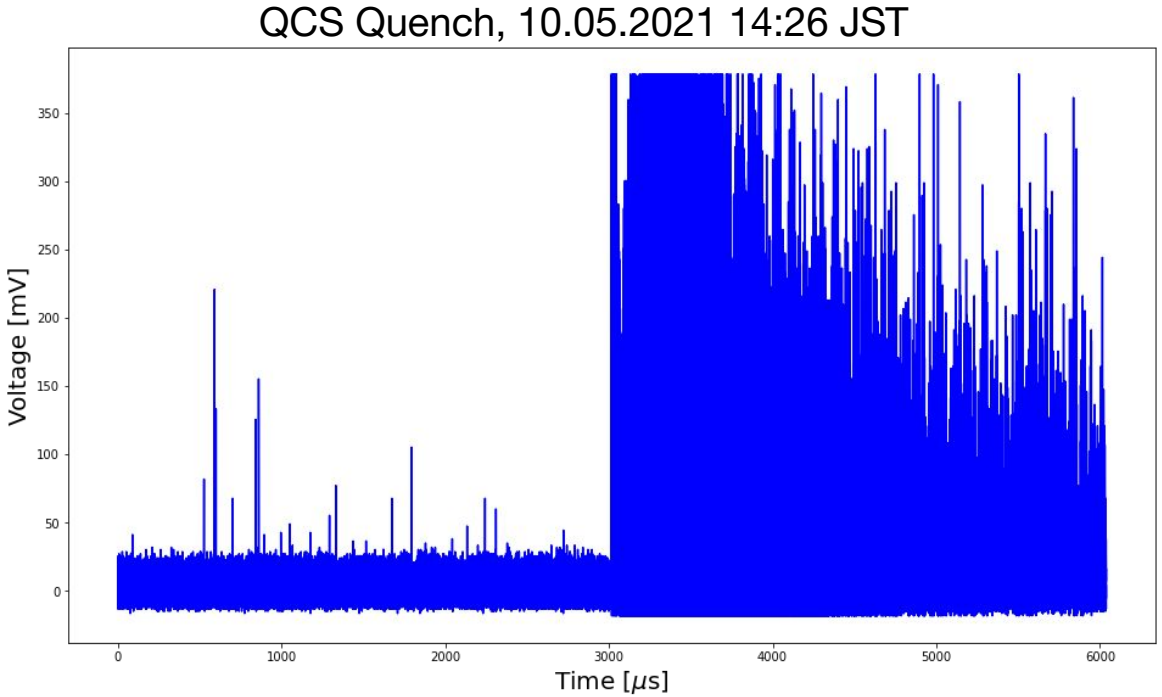
Typical Abort Events





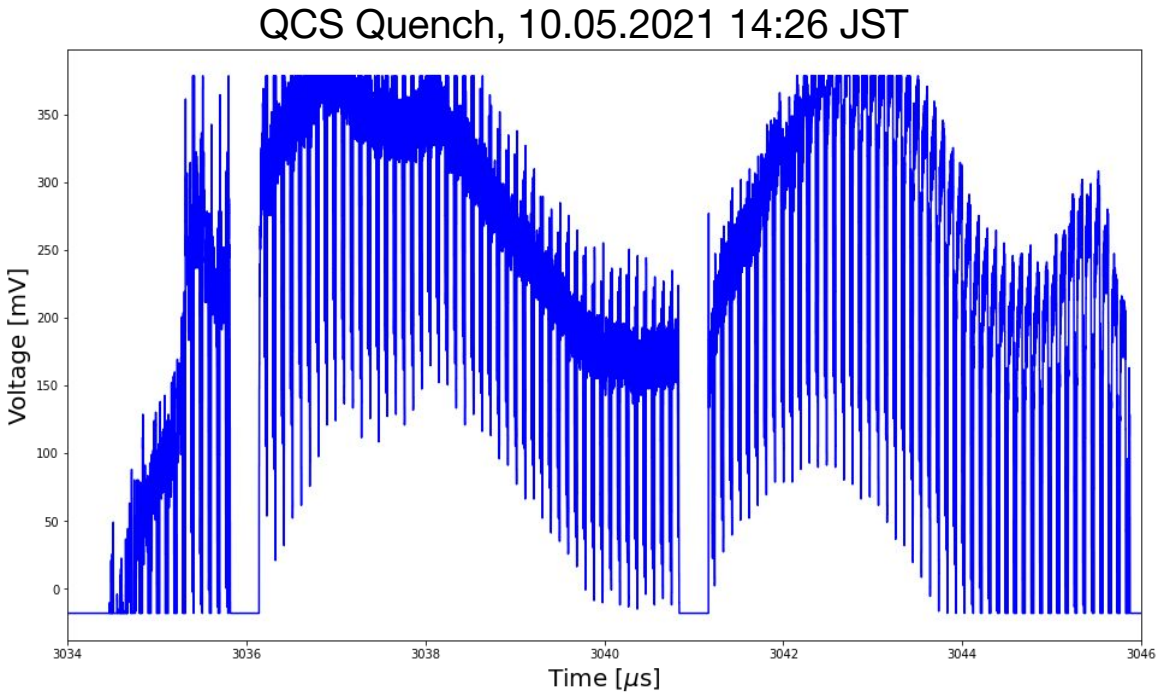
CLAWS Offline Analysis Capabilities

- Waveforms recorded from all 32 sensors are saved for each abort event, allowing for location-based analysis of the abort event
- Waveform length of ~6ms (~600 beam revolutions) with 50% pre-trigger and 50% post-trigger



CLAWS Offline Analysis Capabilities

- Waveforms recorded from all 32 sensors are saved for each abort event, allowing for location-based analysis of the abort event
- Waveform length of ~6ms (~600 beam revolutions) with 50% pre-trigger and 50% post-trigger
- Sampling time of 800ps, allowing for precise analysis in areas of interest



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