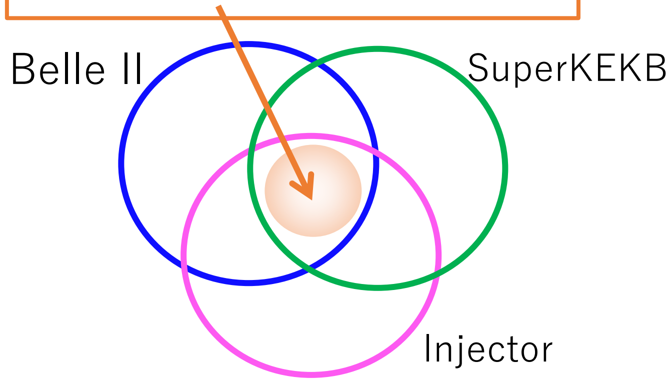
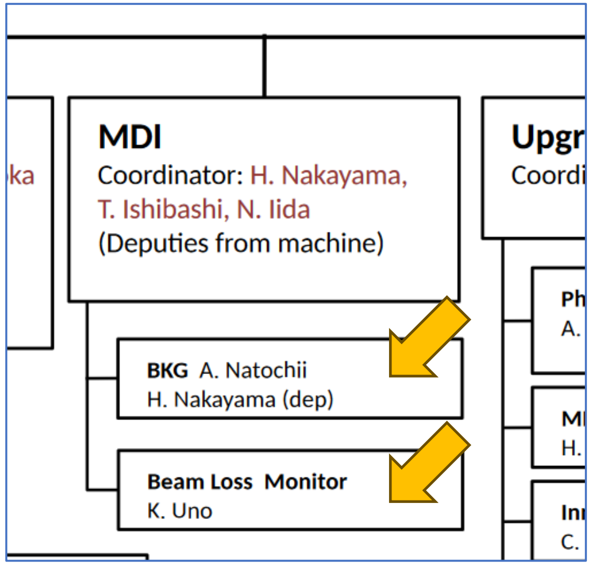
MDI status

MDI group
(MDI= Machine-Detector Interface)



Hiro Nakayama (KEK)

Belle II organization chart



Since June 2023, two subgroups
(Beam background, Loss monitor)
are officially added under the “MDI” tree
In the Organization Chart

Our ultimate goal:

More integrated luminosity

Key Objectives

- Higher instantaneous luminosity
- Increase effective beam time

Major strategies

- Squeeze beam size at IP
- Increase beam currents
- Reduce downtime due to troubles
- Minimize DAQ deadtime (injection veto)

Challenges

- Short beam life due to narrow dynamic/physical aperture at small beta*y optics
- Beam blowup at higher beam currents
- Poor **injection efficiency** due to instability of injection beam charge and quality (emittance blowup in BT)
- Non-optimal **collimator settings** due to poor injection quality, TMC instability (beam size blow up), and head surface damage caused by severe beam loss
- **Beam background** impact on sensor lifetime and data quality for physics analysis
- Beam current limit due to RF power
- **Sudden Beam Loss** (SBL) events causing QCS quenches and severe collimator/sensor damage
- **Long injection BG duration** and large DAQ deadtime
- and so on…

topics covered by MDI activities

1-page summary of

MDI-related major improvements during LS1

Collimator/Injection

- Installed a **Non-Linear Collimator** (NLC, or LER D5V1) to reduce impedance
- Damaged collimator jaws were replaced. Copper coating were added on jaws for fireball suppression.
- Many improvements in **injection chain** (LINAC+BT)

Sudden beam loss

- Added more loss monitors and acoustic sensors to investigate Sudden Beam Loss (SBL) events
- Also added Beam Orbit Recorders (BORs) to observe initial beam instability in SBL events

Beam background

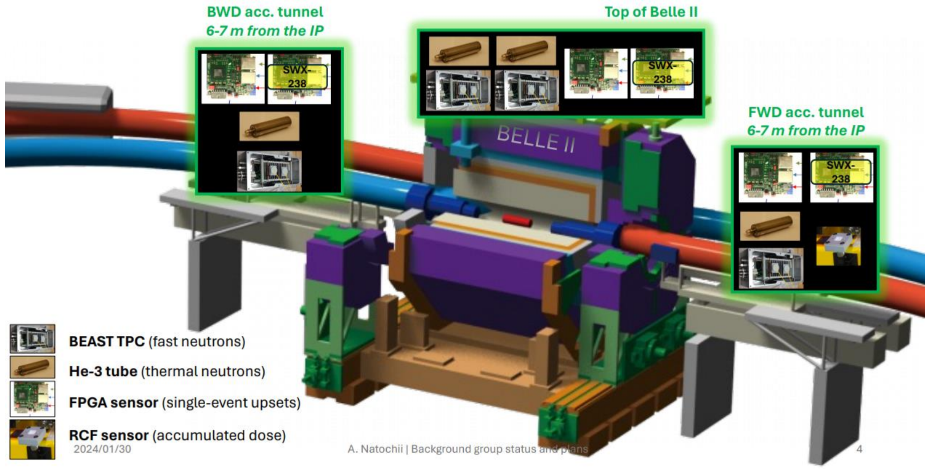
- Installed **additional BG shields** (bellows shield, QCS neutron shield)
- Reinforced neutron measurements on top of Belle II (to understand PXD power supply trips)

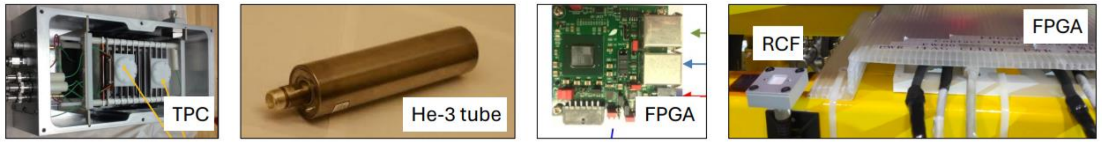
Others

- Developed real-time BG monitors (NN-based, ECL-based) to support machine/collimator tuning
- Apply **Machine-Learning technique** for machine tuning

Beam background group activities

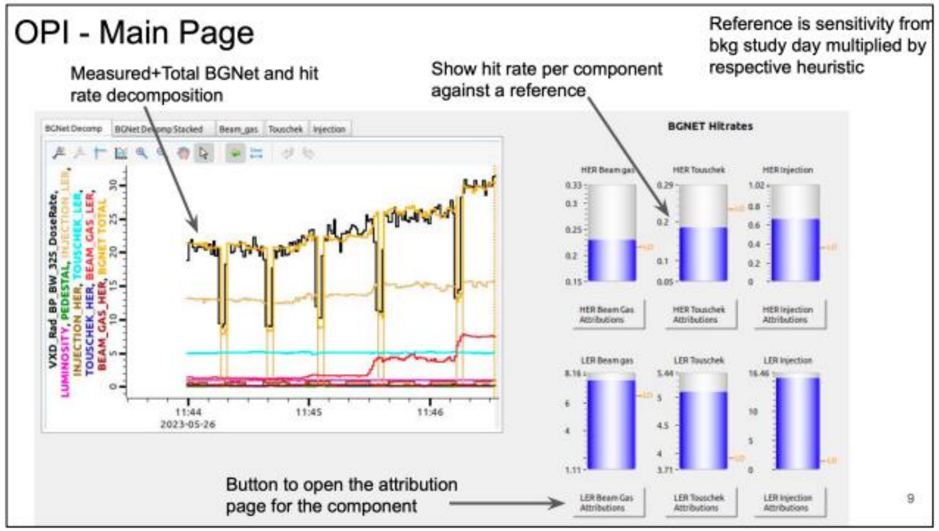
- Neutron sensors installed around Belle II





More neutron sensors on top of Belle II
to understand PXD power supply trips

- Real-time BG composition monitors (NN-based, ECL-based)



・Capable of segregating each BG component based on neural-network training using hundred of EPICS PVs, or MC-template fitting using hit distribution in ECL trigger cells
・Powerful tools for machine/collimator tuning

Proposed machine studies for the Run 2

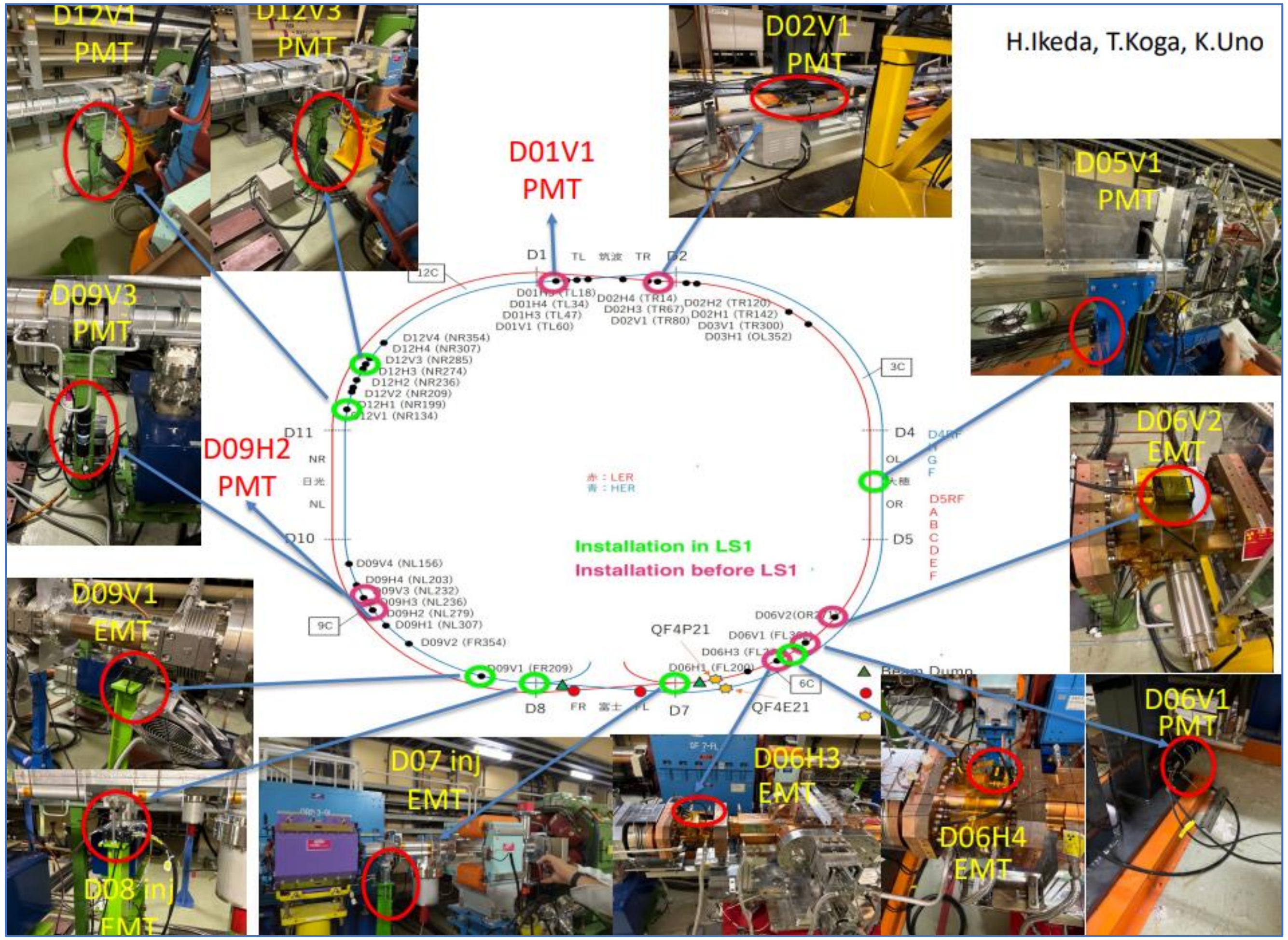
- NLC commissioning study
- Non-linear optics tuning (vary NLC K-value)
- Collimator jaw position offset measurements
- IP beam orbit angle optimization (BG, SR, luminosity)

Studies to be done in early stage of beam commissioning

- **Usual BG studies to separate each BG component**
  - Single-beam measurements followed by the luminosity study
- **Comprehensive injection BG duration study**
  - Varying injection beam size/amplitude, collimators, FB ON/OFF, tune resonance line, chromaticity, etc.
- Horizontal collimator scan for dynamic aperture check
- New real-time BG monitor commissioning
- Pressure bump study

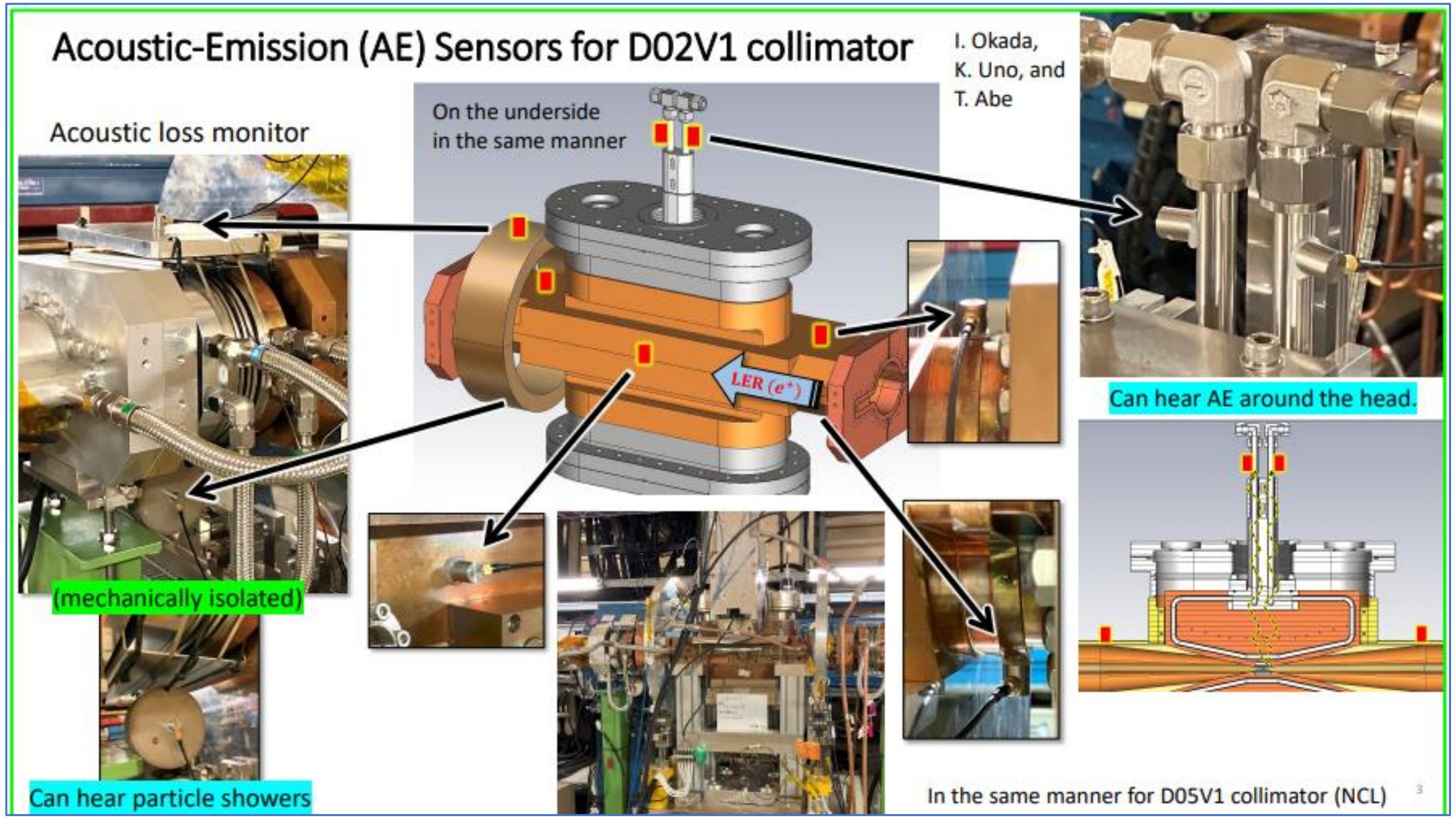
Important studies to be done once stable beam operation is achieved

More loss monitors installed during LS1



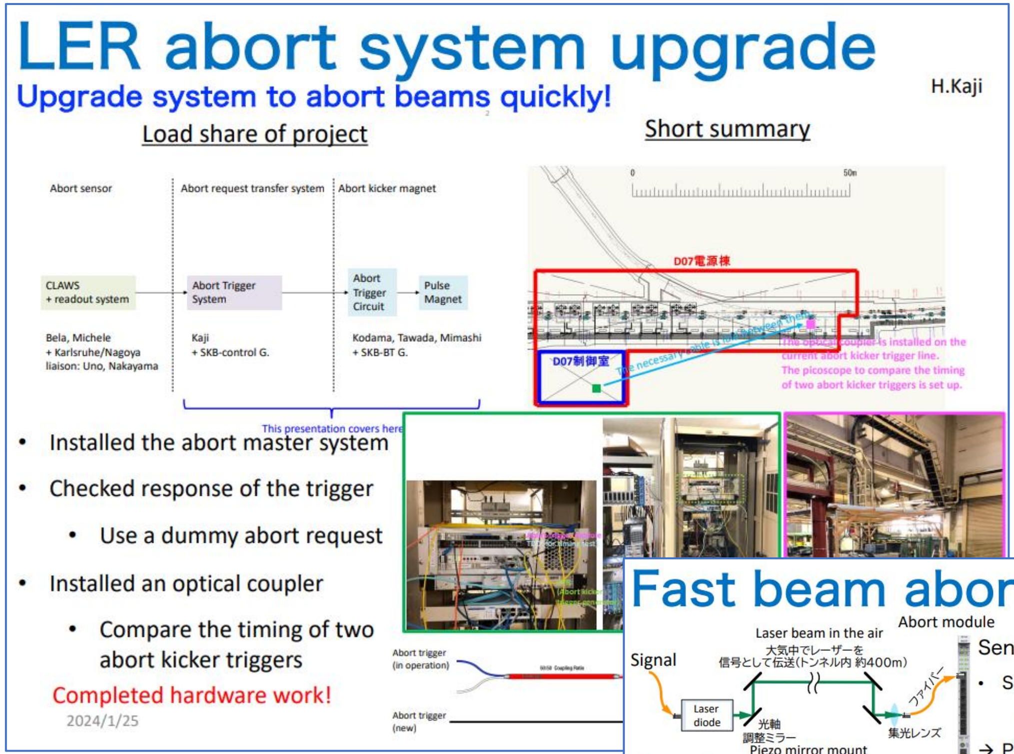
- **Beam loss monitors** equipped with GPS-synchronized fast readout are installed along the main ring
- We can track the **chronological sequence of beam loss** at loss monitors and identify the ring location where initial beam loss occurred during SBL events
- During LS1, we installed **more loss monitors** at HER/LER collimators, which provides more precise position analysis and better understanding of SBL events
- We also installed loss monitors at **HER/LER injection points**, which allows injection loss timing analysis and useful for **injection /collimator tuning to minimize injection BG.**
- **GUI panel** is in preparation to provide read-time feedback to machine operator

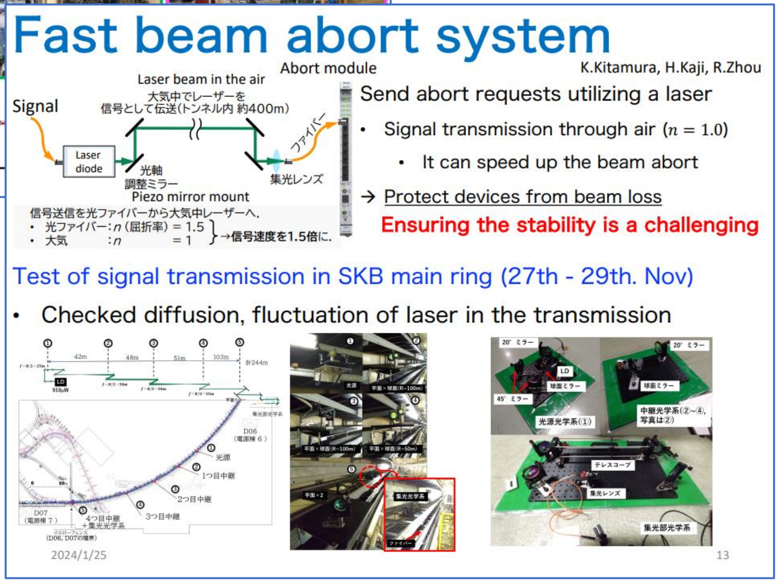
Acoustic sensors for “fireball” hypothesis



- Acoustic sensors can detect the **sound produced by electric discharge,** which is expected in the “fireball” hypothesis proposed for SBL events.
- During LS1, we installed many acoustic sensors at **LER collimators (D2V1/D5V1)** and **QCS beam pipes**.
- Ready for data taking, waiting for the SBL events in this run
- More details can be found here

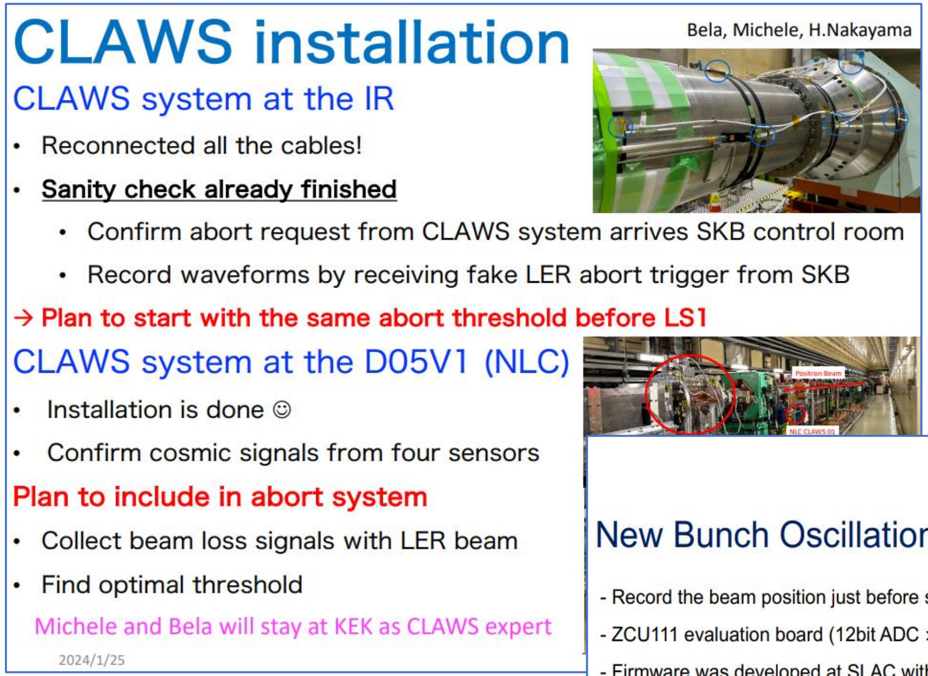
Faster beam abort delivery

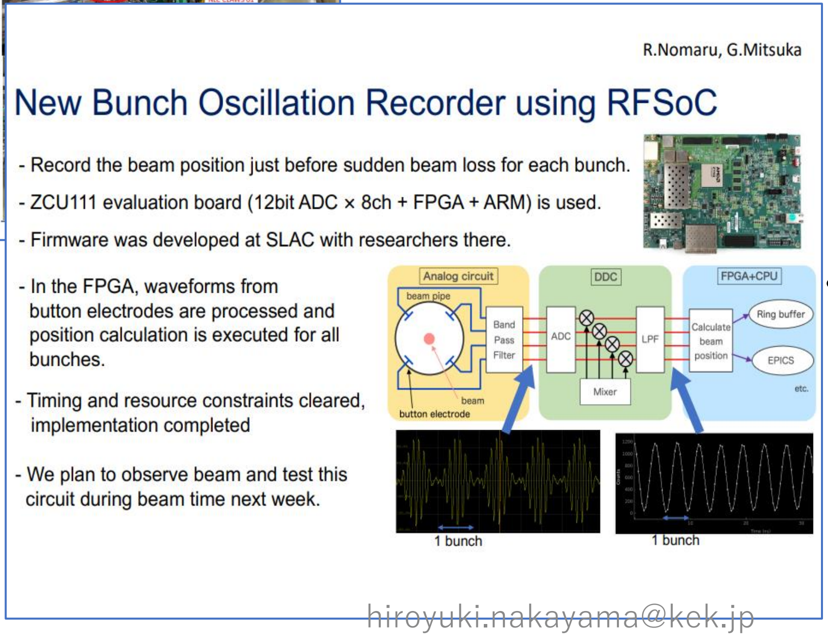




- **Shorter abort request path**
  - In the new path prepared during LS1, abort requests can be directly delivered to the abort kicker, not passing the SKB control building
  - It can gain **1~2 us** (20-40% chance for 5 us gain, depending on the timing from abort gaps)
  - **Damage on Belle II sensor / collimator damage can be mitigated**
  - Further improvement planned in the next FY, by installing new racks and cables
- For longer-term R&D, we investigate the possibility to utilize a new technology, such as **laser transmission in air**
  - Feasibility tests in the main ring tunnel conducted during LS1

Other loss monitor group activities

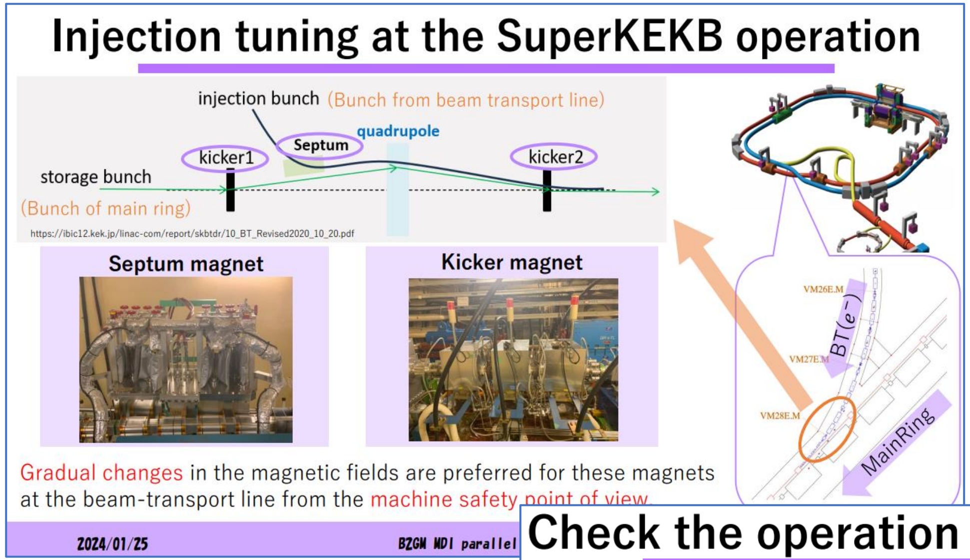


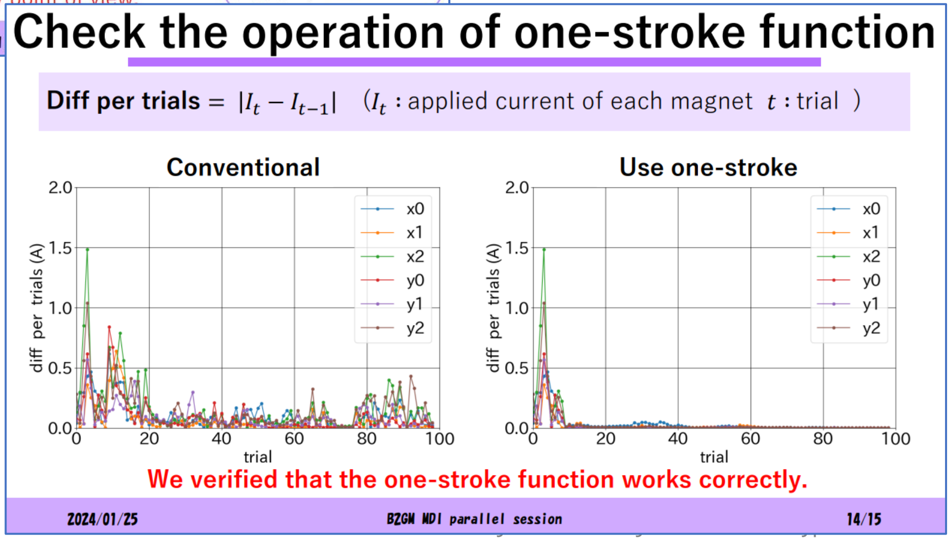


- **CLAWS scintillators**
  - CLAWS installed around QCS has been very effective to issue fast beam aborts
  - We also installed similar setup around LER NLC, aiming to issue earliest beam aborts upon beam loss on the new collimator
- **Bunch Oscillation Recorder (BOR)**
  - In addition to loss monitors, BORs can provide important insights for SBL events.
  - BORs can detect initial **beam instability** inside beam pipe, **which should happen before we observe beam loss**
  - We installed more BORs during LS1. We also developed a new module (called RFSoC) which can be used for new BORs.
- **and so on..**

We offer distinctive opportunities for collaboration with SKB members and participation in machine operations.
We welcome new students and postdocs, Come and join us!

Machine-Learning assisted accelerator tuning





Since MR injection septum/kicker magnets prefer gradual change on its parameters, we implemented "one-stroke function" in our optimization algorithm

- Currently, accelerator tuning depends on a limited number of experts, making it unrealistic to maintain 24-hour coverage
- Therefore, we aim to develop a **ML-based machine tuning algorithm** which can support non-expert operators
- In the past several months, **machine studies using LINAC e+ beam** demonstrated that our **Bayesian optimization approach** seem promising
- Now we plan to apply a similar method for **injection tuning to the MR.** Machine studies to be conducted during Run2

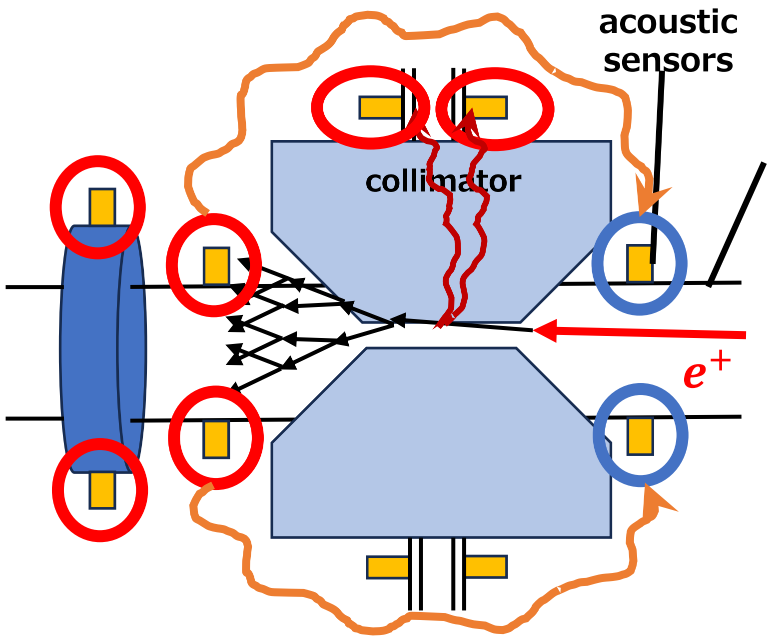
“hot from the oven”

Some initial observations from Run2

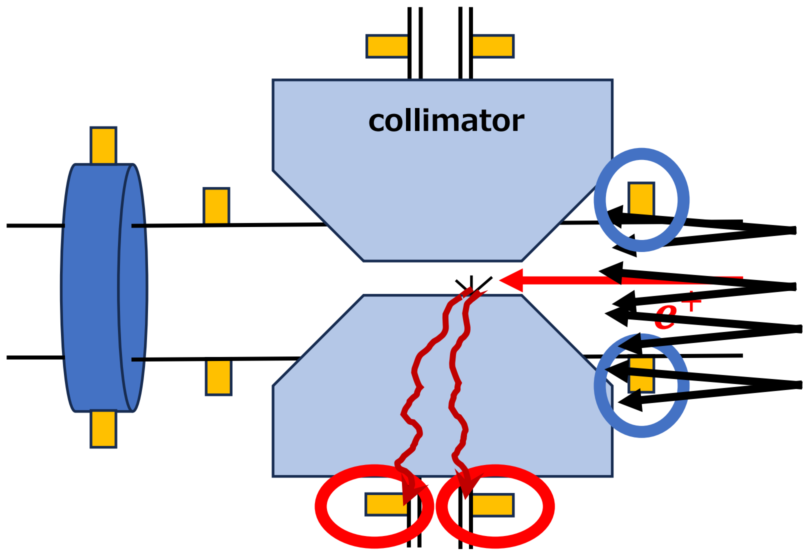
- Acoustic sensors
- Beam orbit during SBL event measured by “RFSoC”

Okada, Abe, Uno

Can acoustic sensors distinguish beam loss shower and vacuum arching event?



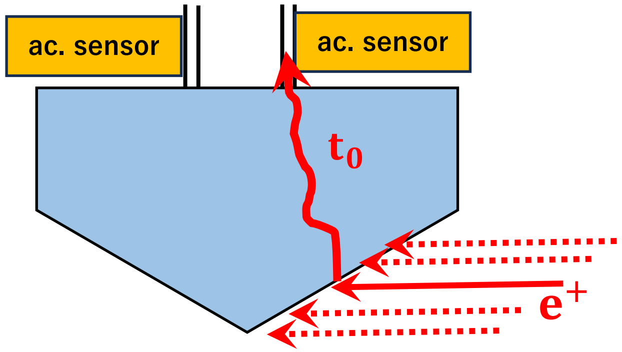
In case of beam loss at the collimator, generated showers first interact with the **downstream acoustic sensors** and then the sound wave propagates to the **upstream acoustic sensors AFTER O(~100us).**



If vacuum arching occurs (as expected in the fireball hypothesis) at the collimator, it triggers the **acoustic sensors on the collimator** but **not the sensors on downstream beam pipes,** which are mechanically disconnected with the collimator. The **upstream acoustic sensors** may be triggered **AFTER ~10us** (=1 turn), by the showers generated further upstream.

Can acoustic sensors determine the timing precisely enough?

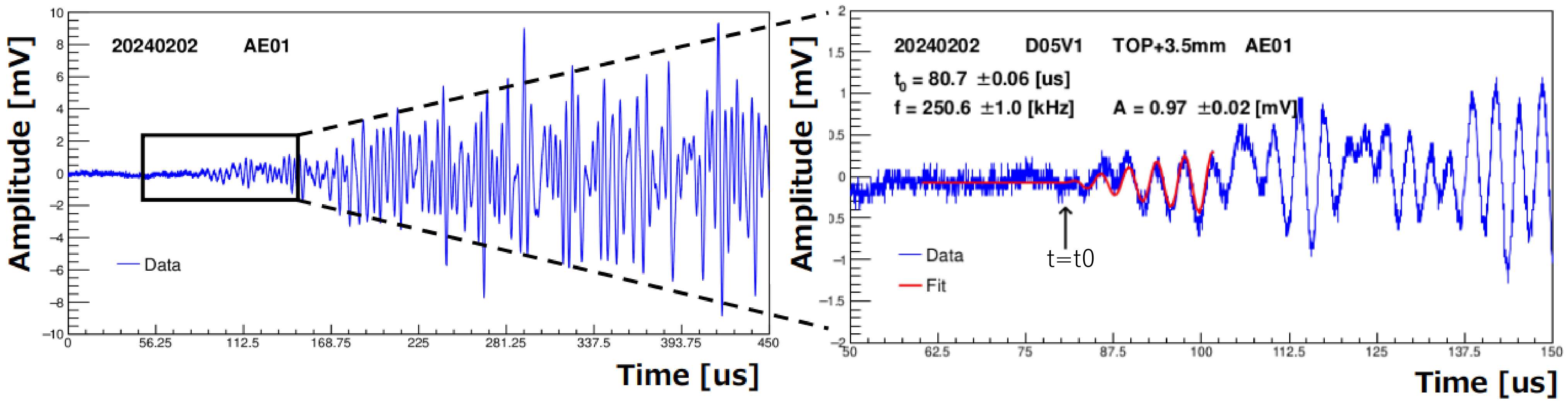
Machine study to check time resolution of acoustic sensor measurement



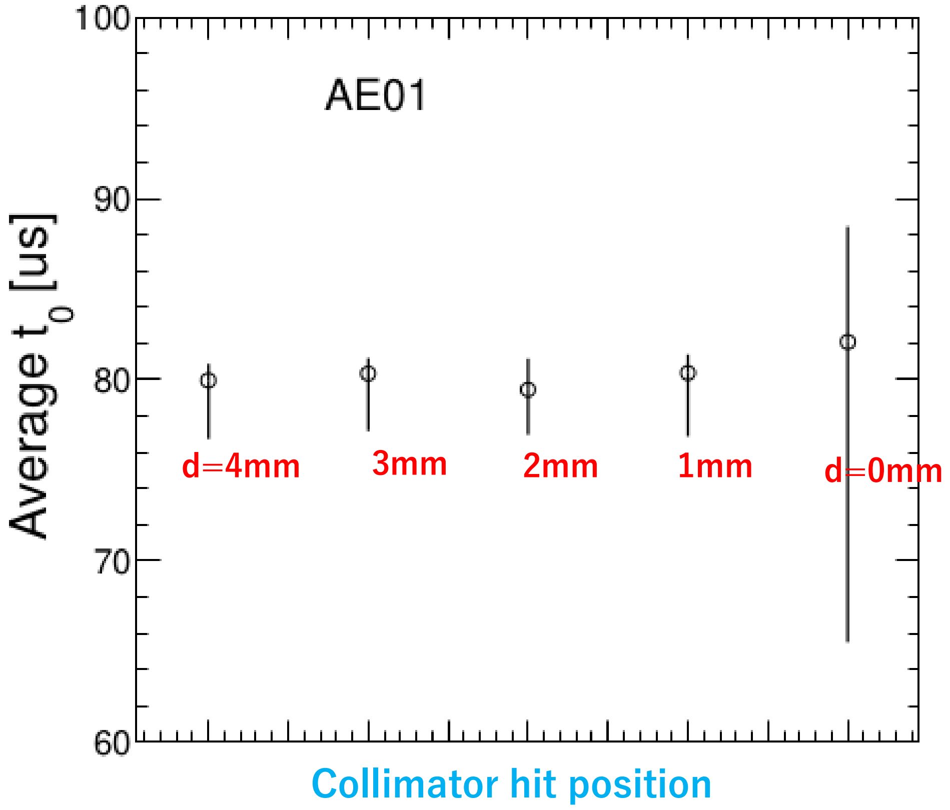
Machine study:

- Shoot the LER single bunch (0.5nC) to the collimator
- Observed acoustic sensor signal waveforms are fitted with the model function(*) to obtain the signal timing (t=t0)
- Shoot five times and check the reproducibility of timing measurement
- Vary the hit position from the tip of collimator head (0~4mm)

(*) $f(t) = A\left(1 - e^{-\frac{\omega}{2Q_L}(t-t_0)}\right)\sin(\omega(t-t_0))\,U(t-t_0) + \text{offset}$ $U(x) = \begin{cases} 0 & (x \le 0) \\ 1 & (x > 0) \end{cases}$



Machine study to check
time resolution of acoustic sensor measurement (contd.)

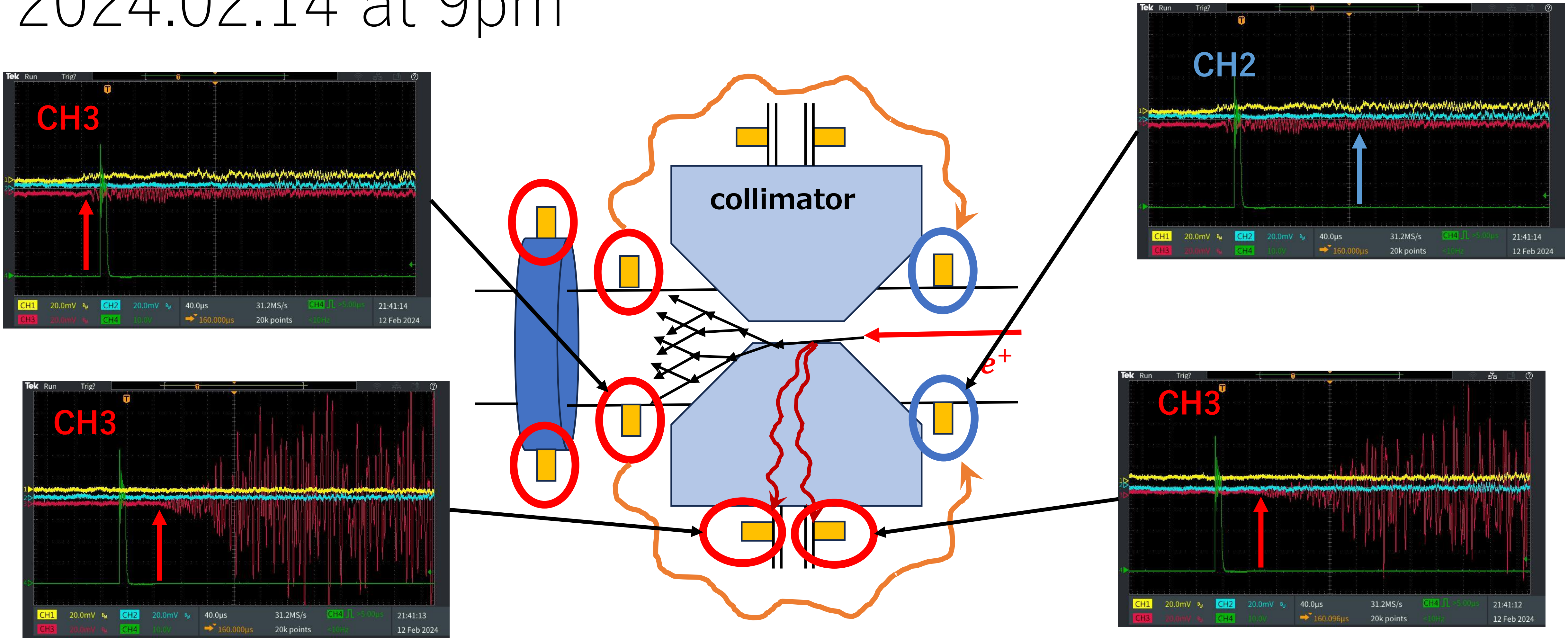


<u>How to interpret the plot:</u>

The machine study demonstrate that we can determine the timing of acoustic senor signal at the resolution of < 10us (except d=0mm). Similar result for other acoustic sensors.

→ Measurement based on acoustic sensors is promising to distinguish beam loss showers and vacuum arching events!!

Acoustic sensor signals at the event on 2024.02.14 at 9pm

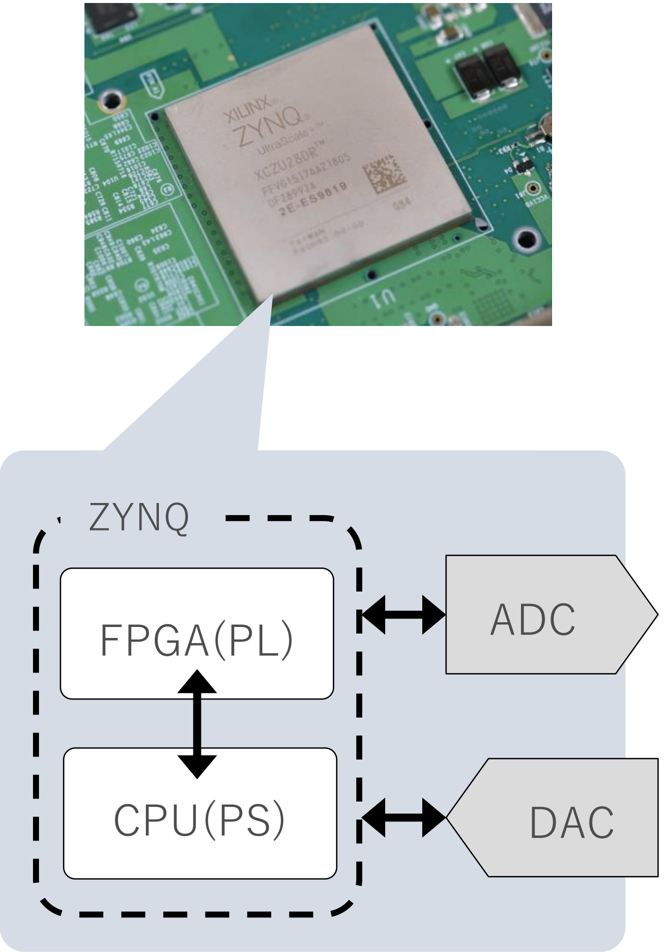


Downstream sensors triggered first
& upstream sensors triggered O(~100us) later
➔ Seems to be the beam loss event, not vacuum arching

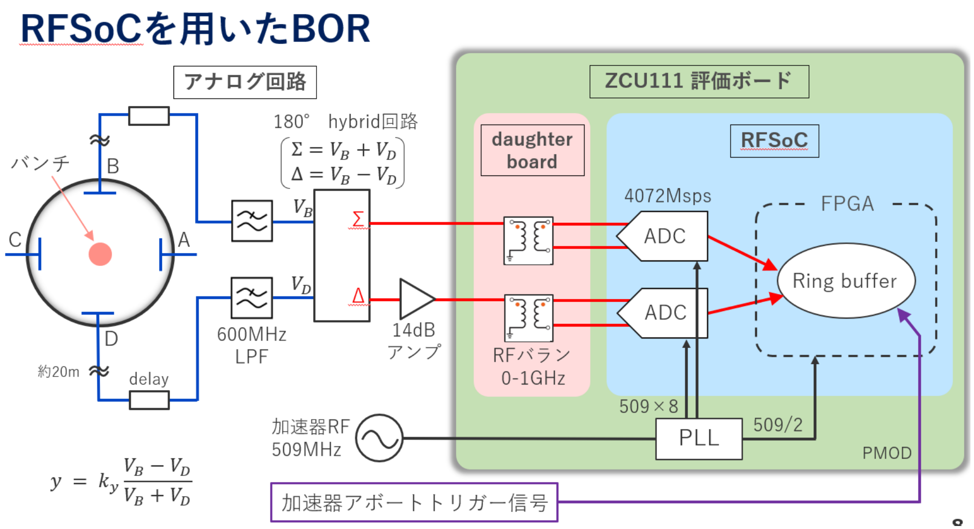
Nomaru, Mitsuka

New BOR using “RFSoC” by AMD/Xilinx

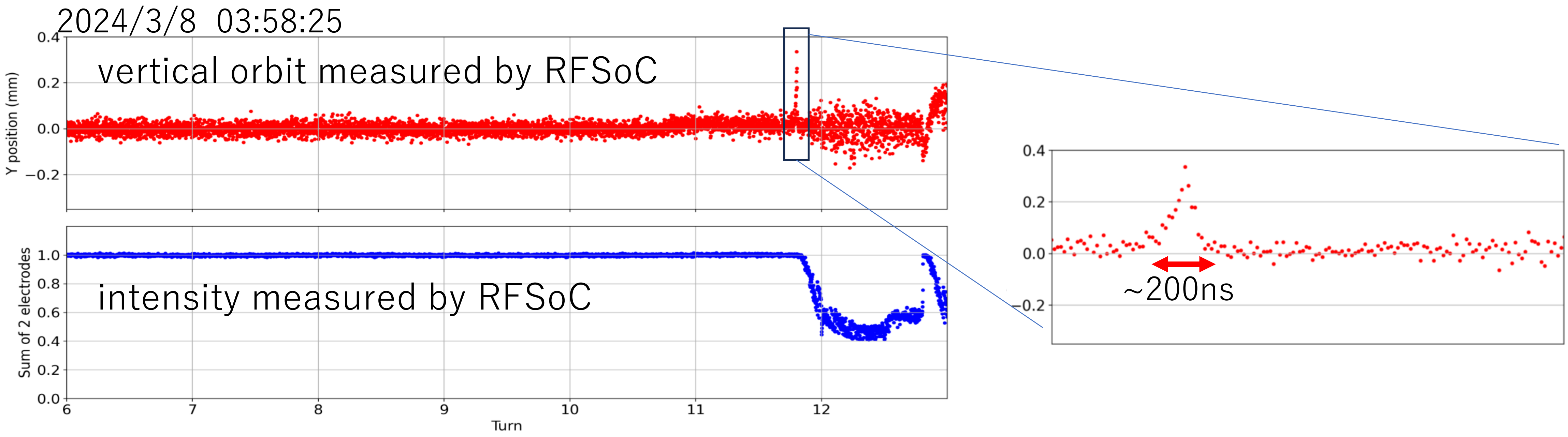
Beam Orbit Recorder RF System on Chip

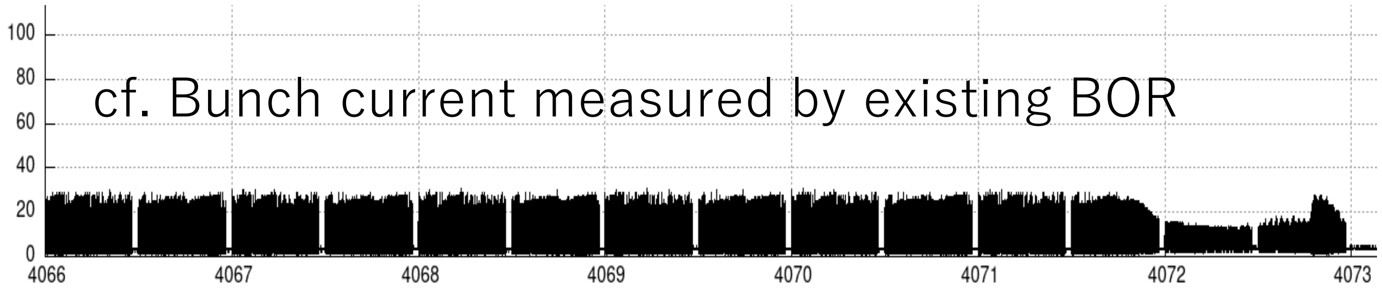


- BOR could detect the initial beam instability **inside the beam pipe** for SBL events (loss monitor can see beam showers coming **out of the beam pipe**)
- Need more BORs in the ring to pin down the location of the origin of SBL
- RFSoC is a good candidate for a new BOR, with larger ADC resolution (8bit→12bit) and more portability (VME rack not needed)



RFSoC already sees recent LER SBL aborts





RFSoC is already installed to LER and provides interesting measurements for SBLs

Summary

- Many improvements implemented during LS1
- Newly installed loss monitors and acoustic sensors should provide more insights on SBL events
- Several ongoing efforts to make beam abort even faster
- Machine Learning looks promising for effective accelerator tuning

- Interesting observations from Run2 are already coming out and detailed analysis is ongoing.

- **MDI efforts are crucial to cope with upcoming challenges in achieving higher luminosity. Close collaboration between Belle II, SuperKEKB and LINAC colleagues are required**.

backup

Nov. 2023 BPAC recommendations

Full Report for BPAC Nov. 2023, Section 2 (Accelerator and MDI)

2.2 Concern

- Cause for the sudden beam loss events is still not understood. With increased beam currents, these events will most likely happen more frequently.
- There are still mysteries concerning beam emittance blowup in the beam-transport lines.

2.3 Recommendation

- Continue to improve recovery time from a sudden beam abort. If the sudden beam losses happen without damaging equipment, it is important to shorten the recovery time in order to maximise integrated luminosity.
- Continue to try understanding the emittance issues with the beam-transport lines.

If equipment is not damaged, we can swiftly restart the beam operation. However, if collimator is heavily damaged, it takes at least several days for replacement work and following vacuum baking. We use low-Z material for the "spoiler" collimator to avoid severe damage on it.

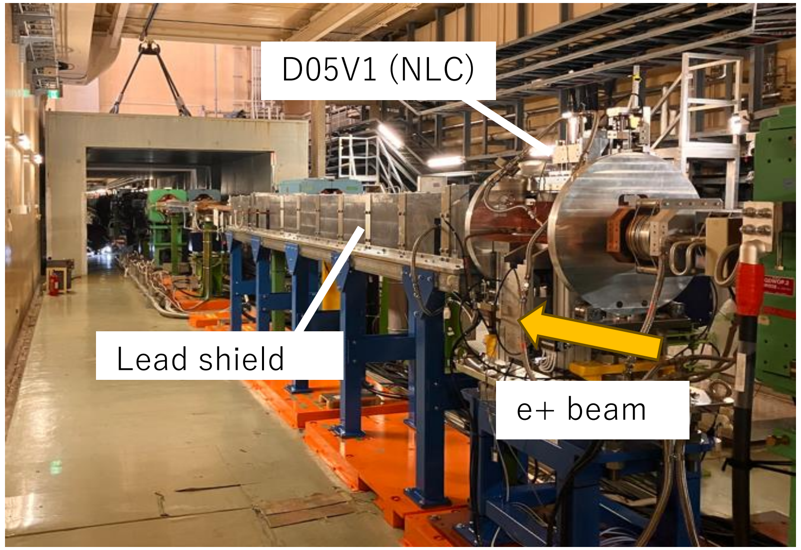
During LS1, we have implemented a series of improvements on beam injection:

- New pulse magnets to improve e- injection beam (J-arc, sector-1,2)
- New fast kickers to cure e- 2nd-bunch quality (J-arc, LINAC end, HER BT)
- Renewal of LINAC accelerating structures
- New HER chamber with larger aperture at injection point & improved septum magnet field
- Install OTR (Optical Transition Radiation) monitors for more precise measurement of emittance & energy spread
- etc..

Also, intensive injection studies has been conducted in the past few months, before resuming MR operation. Analysis of those studies is currently ongoing and will be reported soon.

Takuya Ishibashi

Collimators

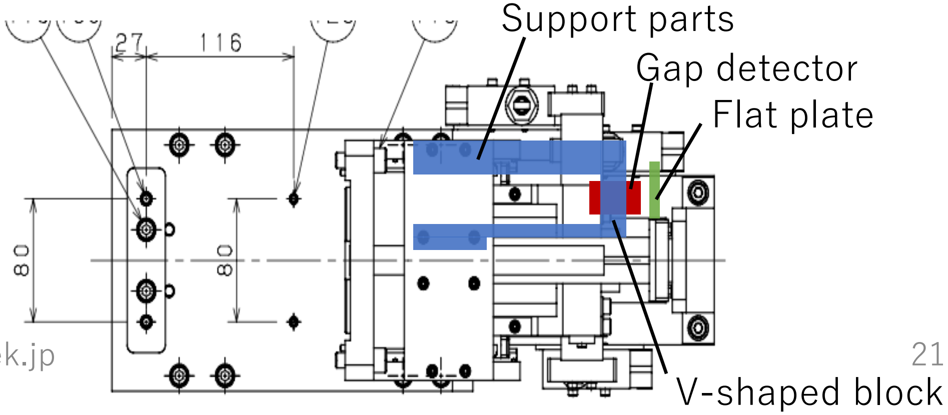


- **D05V1(NLC) installation work complete**
  - 5m-long lead radiation shield downstream
- **All damaged jaws replaced with spare jaws**
  - Except HER D9V1, will finish before HER start
  - Coated with cupper to mitigate "fireball" phenomena
- **Three spare jaws produced within this fiscal year**
  - Including "hybrid" type jaws (Carbon/Ta)
- **Additional displacement sensor will arrive next year**
  - Provides precise head-position measurement (<0.2um)

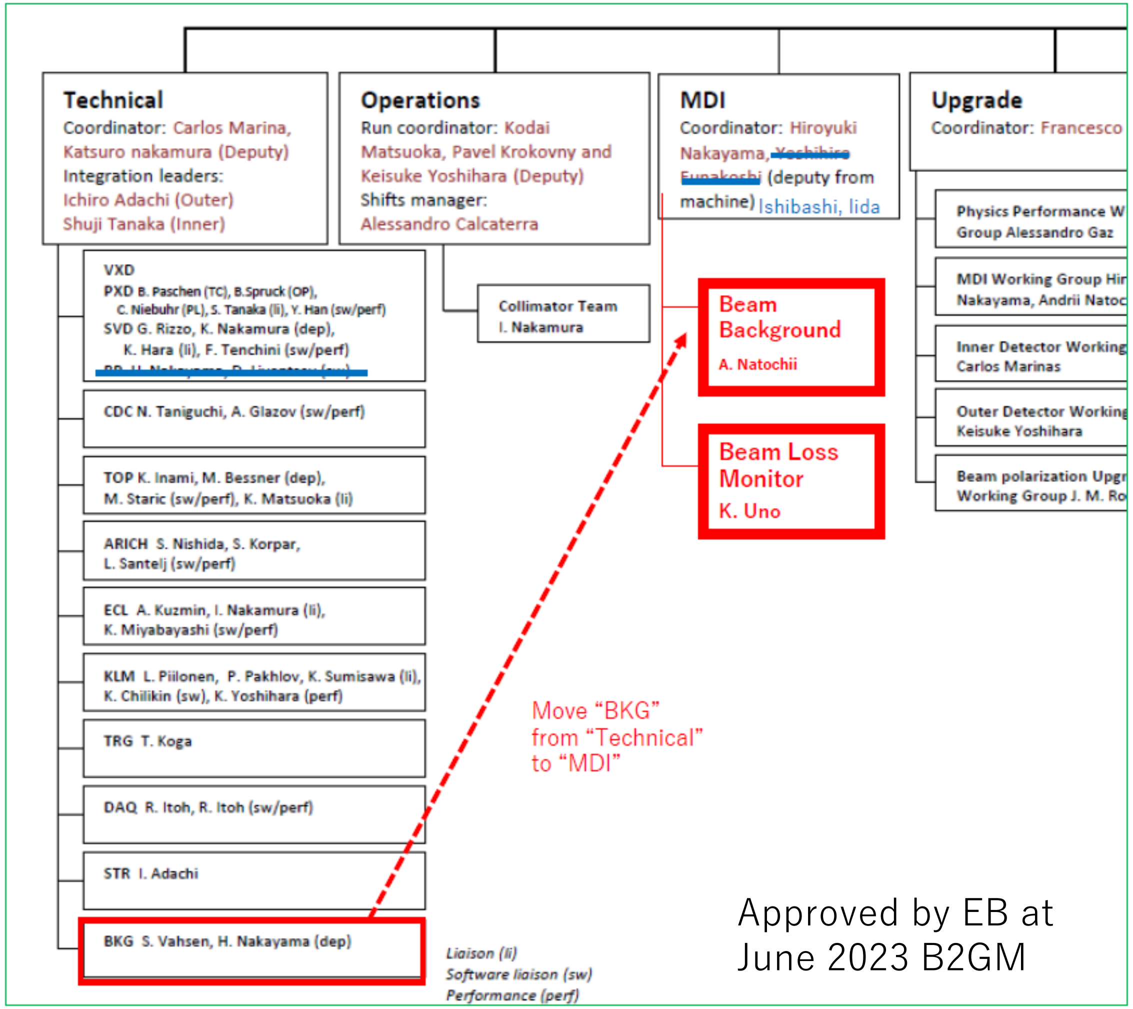
List of spare jaws

Tip Material (): longitudinal length in mm	Collimator to be installed (assumed)	Remarks
HER vertical: Cu coated Ta (10)	D01V1	Plan to deliver in this fiscal year.
HER vertical: Cu coated Ta (10)	D01V1	Plan to deliver in this fiscal year.
HER vertical: Cu coated Ti (40)	D09V1-V4, D12V1-V4	
HER vertical: Cu coated Ti (40)	D09V1-V4, D12V1-V4	
LER vertical: Cu coated Ta (10)	D02V1	
LER vertical: Cu coated Ta (10)	D02V1	
LER vertical: hybrid (3)	D05V1, D06V1-V2	Delivered this Sep.
LER vertical: hybrid (3)	D05V1, D06V1-V2	Delivered this Sep.
LER vertical: Cu coated Ta (10)	D02V1, D05V1, D06V1-V2	Plan to deliver in this fiscal year.
LER vertical: Cu coated Ta (10)	D02V1, D05V1, D06V1-V2	Plan to deliver in this fiscal year.
LER horizontal: Ta (10)	D06H4	

New displacement sensor



MDI structure in the Organization Chart



Two subgroups under the MDI tree

- **Beam background group**
  - Leader: **Andrii Natochii**
  - Moved from TB tree for close communication with machine folks
  - Keep reporting at TB meeting to ensure information flow to Belle II
- **Loss monitor group**
  - Leader: **Keta Uno**
  - ~10 staff members from both Belle II and SuperKEKB, and 8 Msc/PhD students
- **Other important MDI-related activities directly reported to MDI meetings**
  - Collimator, Injection, Abort sensors, etc···

Possible causes of low injection efficiency

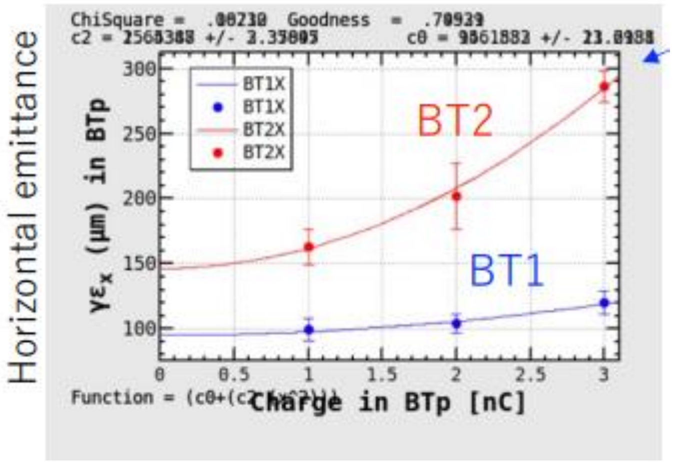
- HER
  - **Emittance blowup in the beam transport line (BT)**
  - Drift of the emittance of injection beam
  - The orbit and emittance drift of 2nd bunch of the injection beam
  - We could not put the injection beam close to the septum plate because of the magnetic field drop → The horizonal oscillation becomes larger.
  - Misalignment in the injection region
  - Shorter lifetime of HER than the design

Done in LS1

- LER
  - **Emittance blowup in the beam transport line (BT)**
  - We could not put the injection beam close to the septum plate because of the magnetic field drop → The horizonal oscillation becomes larger.
  - Misalignment in the injection region
  - Short lifetime of LER

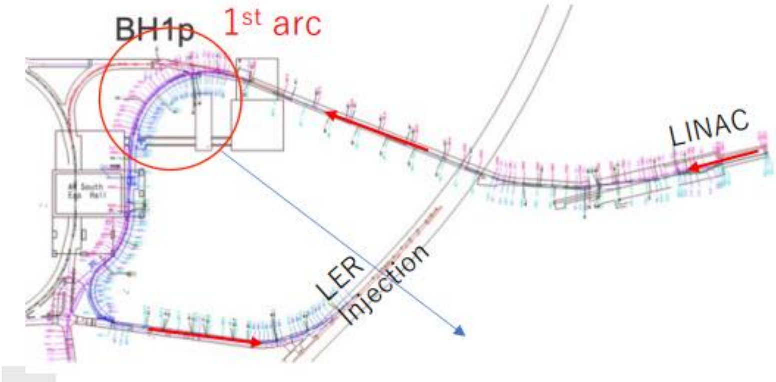
Naoko Iida

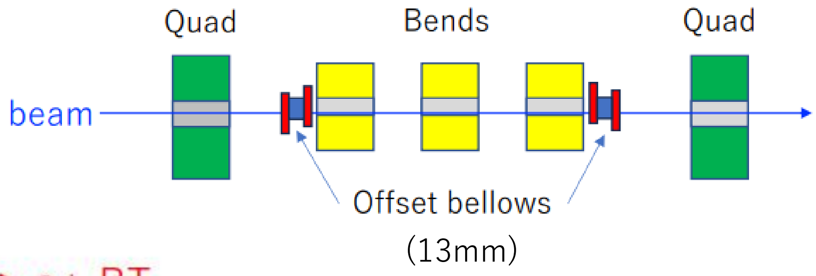
LINAC/BT
Positron BT modification



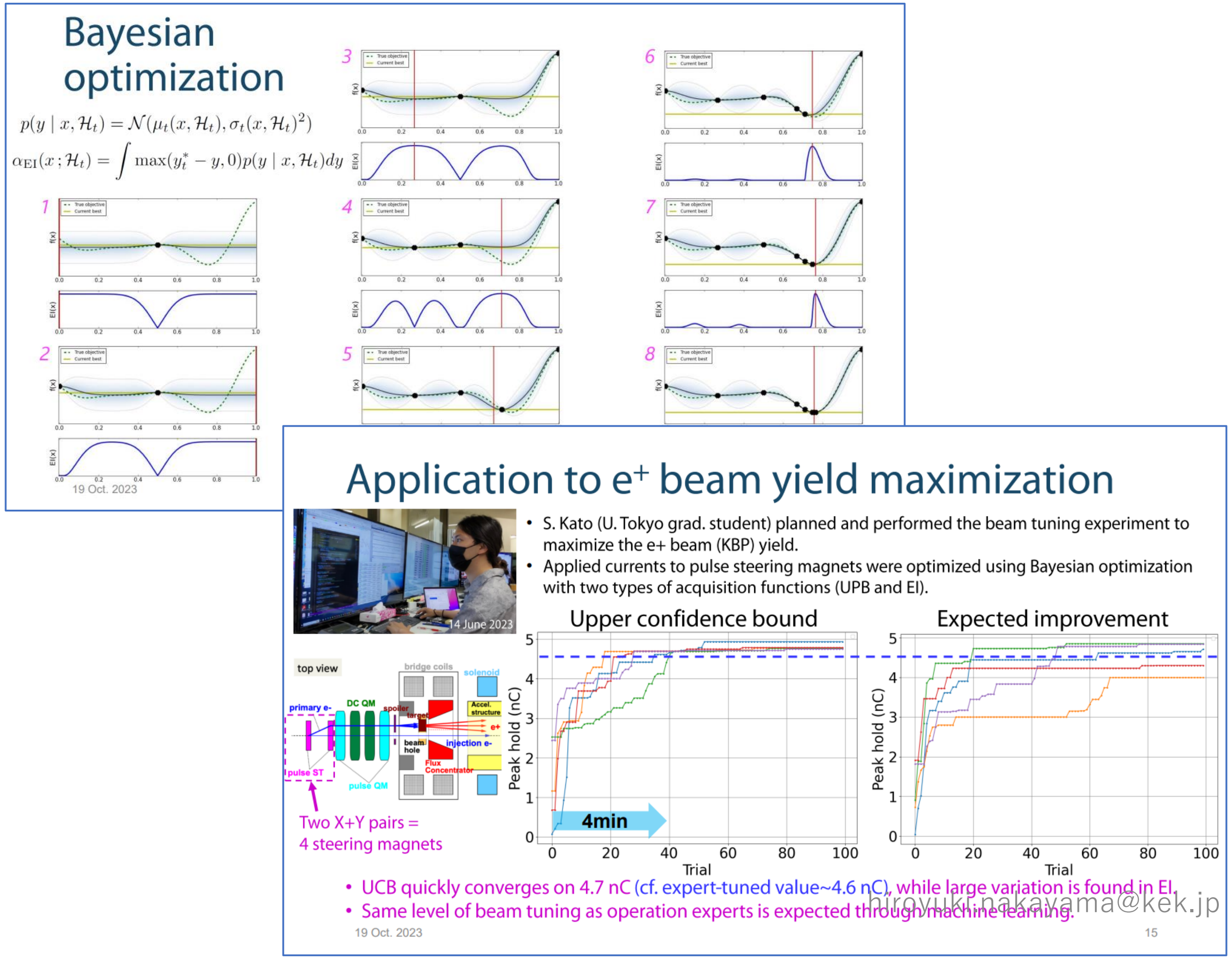
- Positron horizontal emittance in BT significantly increases at large charge → **caused by CSR effect?**
- If yes, the blowup should be reduced by moving the beam orbit closer to the beam pipe inner wall
- Bending magnets and chambers in positron BT 1st arc are shifted upwards by 13mm(!)

- LINAC operation already started on Oct. 16th
- BT operation (with BT-dump mode) will start from Nov. 27th
  - BT tuning could be challenging due to the 13mm offset





Machine learning-assisted beam tuning



- To achieve target luminosity, improving the efficiency of beam tuning is essential
- We conducted a machine study using LINAC e- beam, to optimize beam quality by parameter search based on Bayesian optimization approach
- The study demonstrated that charge maximization and/or dispersion minimization by adjusting LINAC pulse magnet parameters was successful
- We plan to conduct a similar study at SuperKEKB MR in January

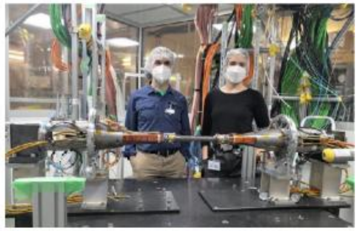
L. Vitale

Diamond abort

Diamonds activities during LS1

During the LS1 several hardware changes:

- **Beam Pipe: 8 new** diamonds on the new BP (Feb 2023),
- **QCS bellows** diamonds all changed their locations due to new shielding (Jul 2023)
- **All connectors** at DOCKs replaced halogen free ones
- Diamond characterization



Oct 19, 2023 L.Vitale - MDI meeting 2

Status of relaxed threshold during injection

There was a long discussion last winter/spring to modify the DCU firmware to allow a relaxed diamond threshold during injection.

My summary in SVD & MDI meetings in Mar-Apr 2023 :

1. Change the assignment of DCUs input and output signals
   - One of the two inputs: “INJECTION gate”
   - Outputs: gated (complementary) low and high threshold abort requests
2. Change the DCUs configuration parameters
   - Re-program the two outputs to “low-threshold” and “high-threshold” abort requests
3. Modify the DCUs firmware
   - Use the “INJECTION gate” input to enable “high-threshold” signals during the injection time interval and “low-threshold” signals otherwise

Pros:

- minimal modifications to external cabling
- No change in EPICS handshake, memory read and timeout

NB: SuperKEKB should insert a circuit to abort both HER and LER beams for each of our two abort requests

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