

Belle II beam background

KEKB Review

2026.10.26

Hiro Nakayama (KEK)

Quick recap of

Beam Background at SuperKEKB

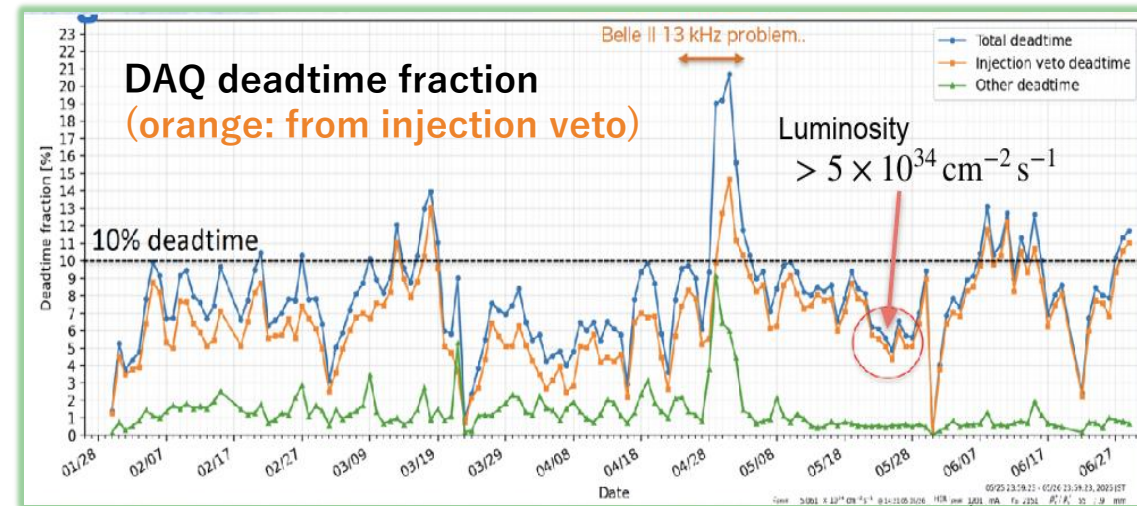
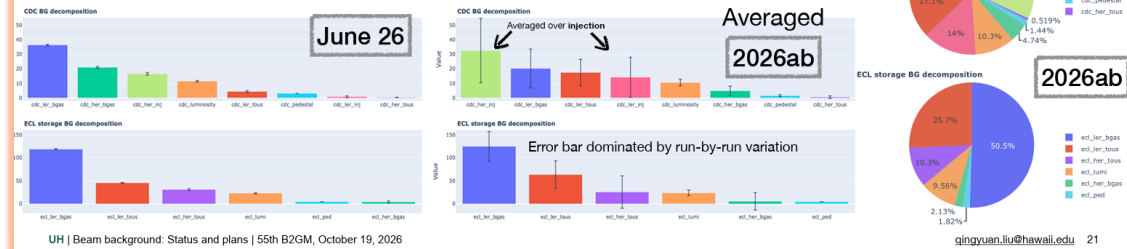
- **Major BG sources**
 - Single-beam: Touschek, Beam–gas scattering, SR, Injection background
 - Luminosity-related: Radiative Bhabha, two-photon process
- **BG impact**
 - Increased detector occupancy and hit rates
 - Radiation damage from accumulated dose and sudden beam losses
 - Reduced data-taking efficiency due to injection vetoes
 - Limits on achievable beam currents and luminosity
- **Countermeasures**
 - **Movable collimators:** intercept stray beam particles before they reach IR, protect Belle II against severe beam loss. Need to avoid damaging collimators in case of SBLs.
 - IR shielding: absorb secondary showers before they reach Belle II sensor components
 - Vacuum baking: gradually reduce Beam-gas BG
 - **Injection optimization:** improve injection efficiency to reach higher currents, suppress injection BG and DAQ deadtime, allow tighter collimator settings to further reduce storage BG

2026ab Beam BG status

- Both storage and injection BG increased as beam currents increased in 2026ab.
- Injection BG fluctuated significantly, occasionally exceeding storage BG.
- BG rates were mostly within detector limits, but **CDC inner-layer BG limit constrained beam currents** in late 2026ab.
- DAQ deadtime dominated by injection veto, reaching $\sim 10\%$, causing sizable loss of integrated luminosity
- Key priority: reduce injection BG and maintain good conditions for longer periods.**
 - Note: better injection performance can reduce injection BG and also enable tighter collimator settings to suppress storage BG further

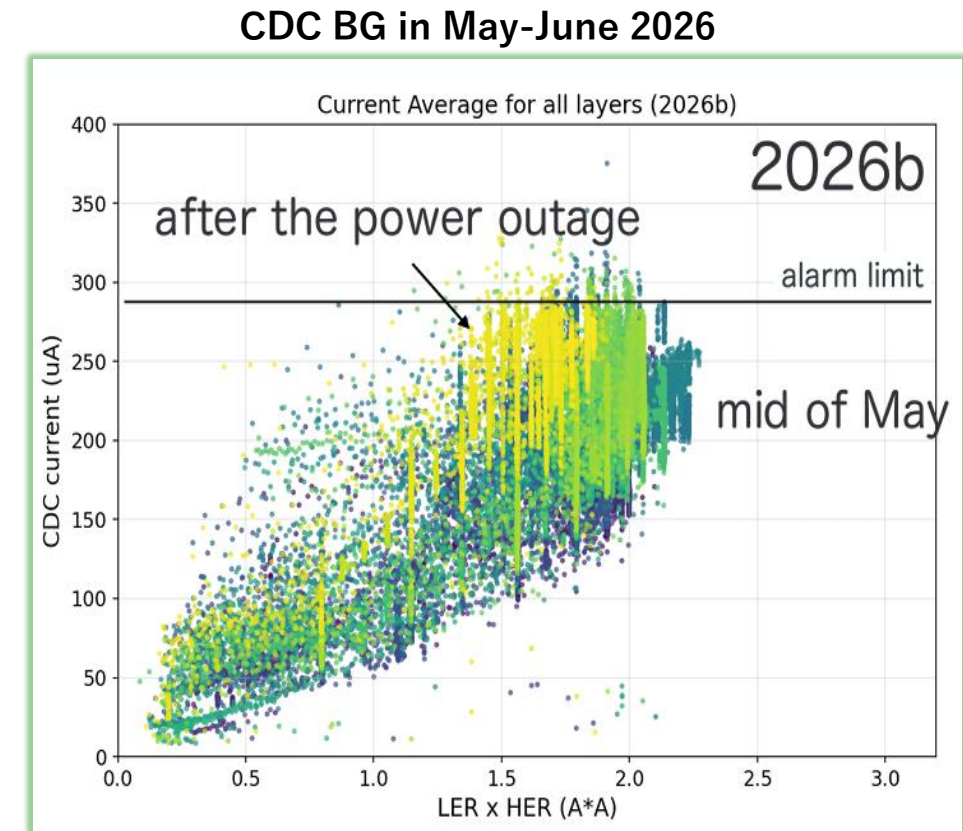
What were the main sources of the background?

- Summary for high beam currents with injection: **Injection BG > LER > others**
 - BG spikes during injection:
 - ECL injection-induced hit rates can be **> 10 x higher** than storage rates
 - CDC injection BG can exceed storage BG
 - The averaged BG **over the run**:
 - CDC storage BG (dominated by LER beam-gas) > injection BG
- BG Decomposition (BGNet and ECL online) using data at LER/HER=1000/800 mA
http://kekb-co-web.kek.jp/doc/Image/BELLE/beam/bg_summary/bg_runs_ana.html (access via KEK VPN)

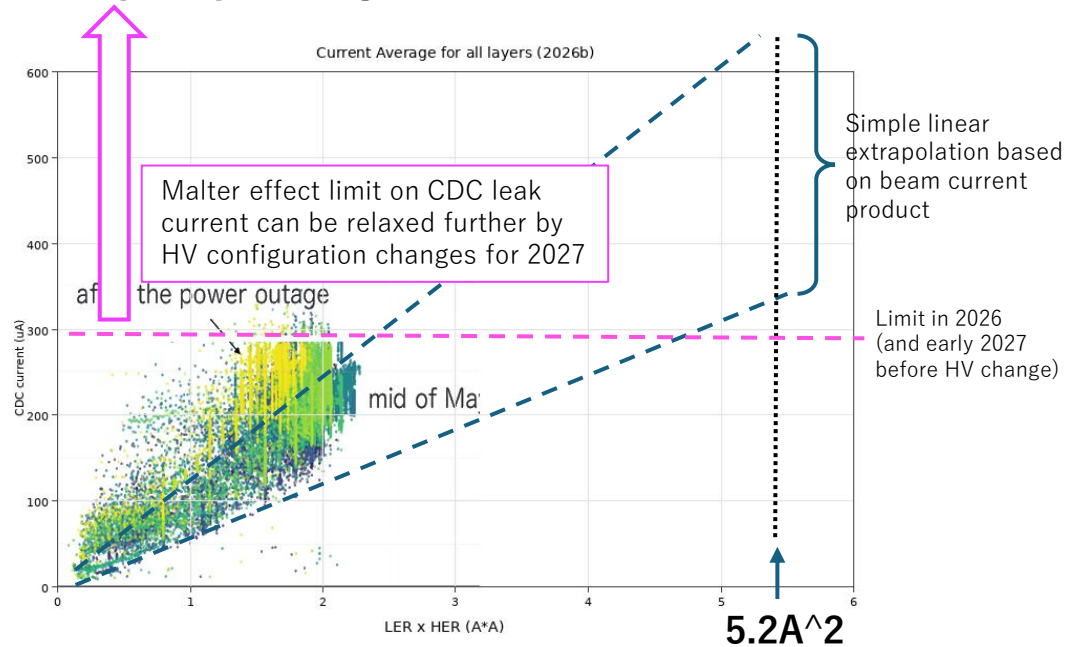


Belle II CDC: 2026 situation and 2027 plans

- **Belle II CDC imposes the most stringent BG limit**
- **Malter effect** triggered by high instantaneous BG could cause serious irreversible wire aging
 - In March 2026, the HV/gain of the inner CDC layers reduced to increase BG tolerance
 - In late 2026ab, CDC BG had reached its threshold as beam currents increased, **limiting further increases in operating beam currents**
 - Toward 2027ab, we plan to adjust **HV current-limiter** thresholds for the inner layers **to suppress injection BG spikes** and further increase BG tolerance (maybe not from the very beginning)
- **Tracking performance** may degrade due to increased wire hit rate, potentially reducing effective luminosity available for analysis, even before the Malter-effect limit is reached.
 - The detailed evaluation of this impact is currently ongoing.
- Other issues should also be addressed
 - Gas gain reduction due to contaminants, DAQ instabilities, electronics cross talk at higher rate, etc..



CDC BG extrapolation toward 2027



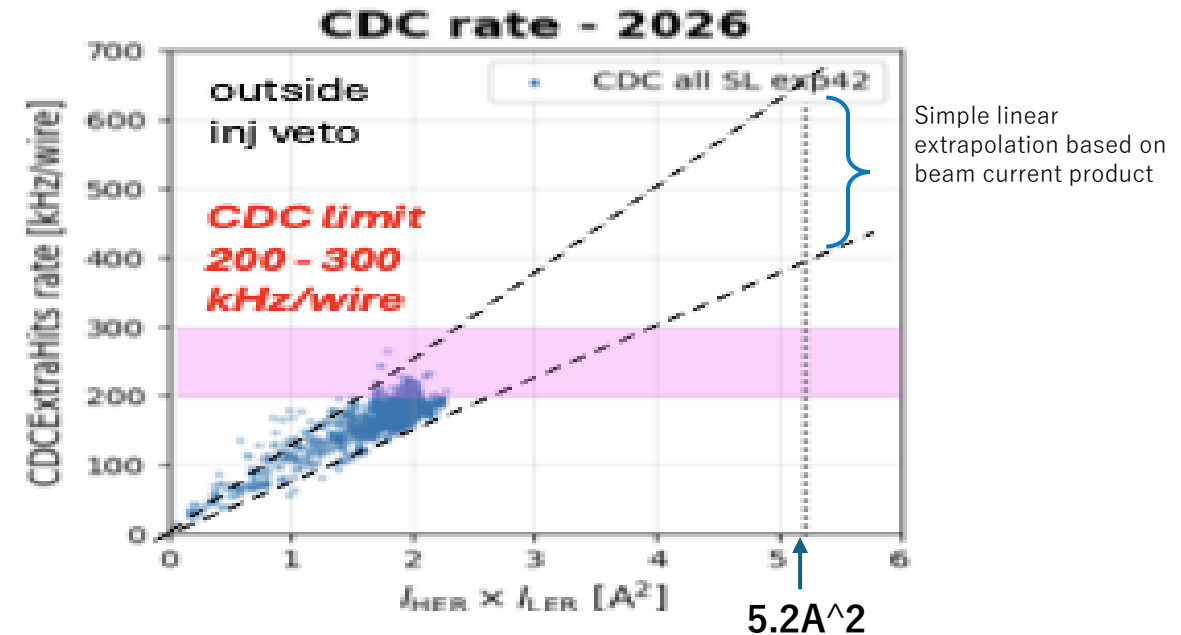
Malter effect:

- **HV configuration changes for 2027**, including current limiters on inner layers, are expected to relax the Malter effect, while a careful check for possible impact on tracking performance is required.
- Thank to HV changes, simple (I^2) extrapolation suggests that CDC leak currents can remain within the limit, provided that injection BG are kept under control.
- **Operational caution:** The HV changes will be introduced only after careful evaluation with beam in early 2027, not from the very beginning. Until then, the Malter effect limit will still remains an important operational constraint.

Achieve and maintain a good injection condition is a key challenge for 2027ab operation. Close collaboration among LINAC/BT/Belle II team is crucial.

Target for 2027

- $\beta^*y = 0.9\text{mm}$, $\beta^*x = 55\text{mm}$ (same as 2026)
- $I_{\text{LER}} = 2.6\text{A}$, $I_{\text{HER}} = 2.0\text{A}$ (**5.2A²**), $N_b \sim 2500$
- **$L \sim 1\text{E}+35$**



Tracking performance

- **Some degradation in tracking performance is expected in 2027**, even before the Malter effect limit is reached. Detailed evaluation is ongoing.
- **While not expected to immediately constrain beam operation, this could reduce the effective luminosity available for physics analysis.**
- **Improved injection performance could help mitigate this impact:**
 - Injection BG is reduced by injection veto, although residual spikes may persist beyond the veto window and affect tracking performance.
 - Improving injection efficiency could allow tighter collimator settings to suppress storage BG further.

How about other subdetectors?

G. Rizzo

Background vs detector limits: near term extrapolation

Preliminary

Detector instantaneous limits, performance driven, (ECL, CDC, SVD) could be raised with SW improvements

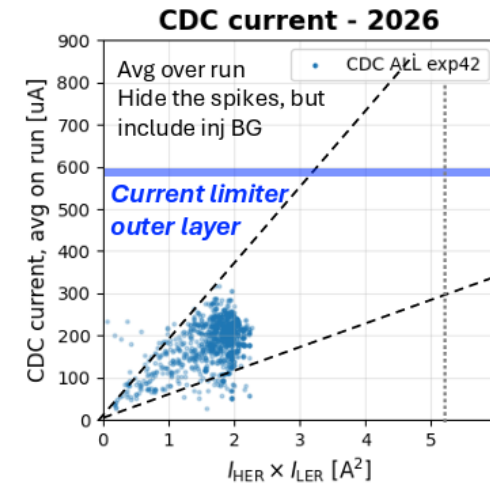
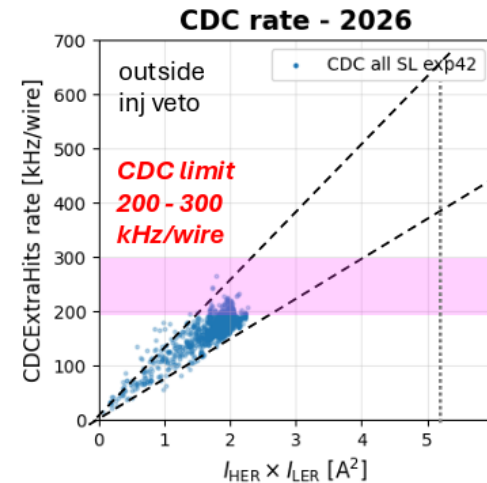
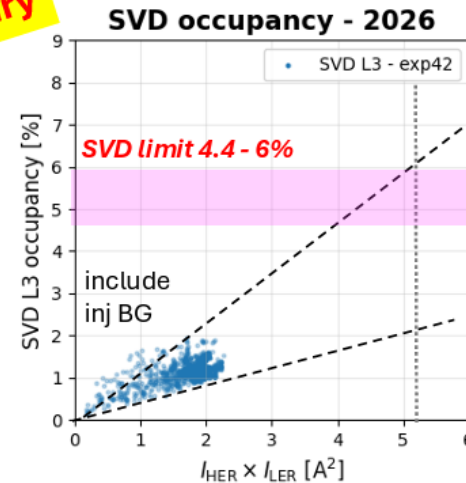
- ECL in rel 11- 2027, more in future releases (?)
- SVD (?)
- CDC in future releases (GNN ?)

CDC limit will be higher with reduced cross talk → FE elec. upgrade in 2028

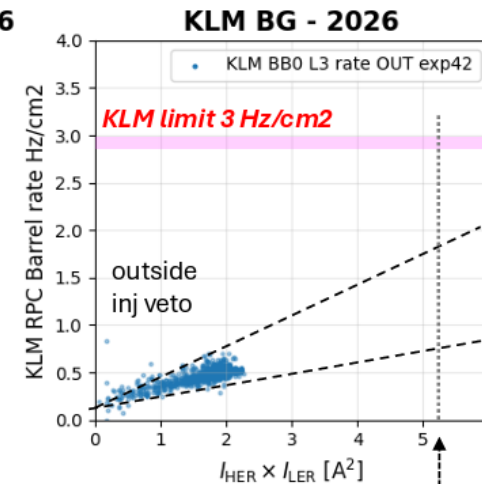
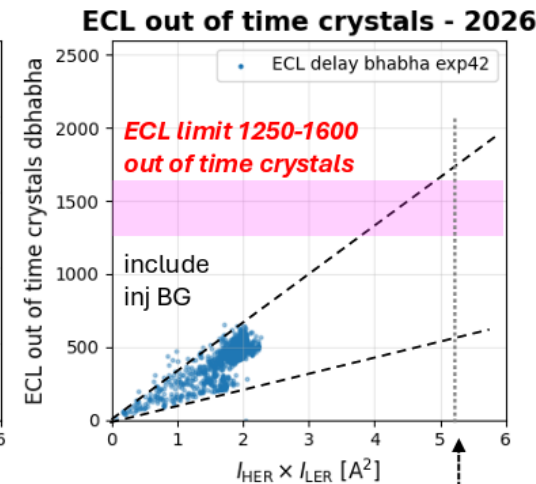
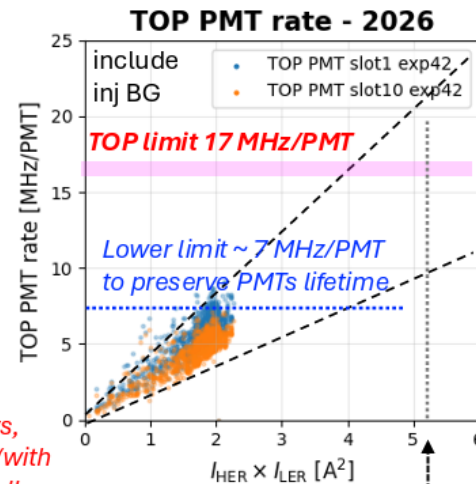
- impact on performance limit to be evaluated

More details on detector limits, instantaneous & aging related (with recent revision) in Katsuro's talk

25/10/2026



Above ~ 600 uA CDC outer layers will also start to have lower HV/gain (reduced by current limiter)



Simple linear extrapolation based on product of beam currents

reasonable assumption with pressure and β_y^* similar to 2026

**L=1e35
5.2 A²**

G. Rizzo

**L=1e35
5.2 A²**

**L=1e35
5.2 A²**

BG Prospect for Pre-LS2

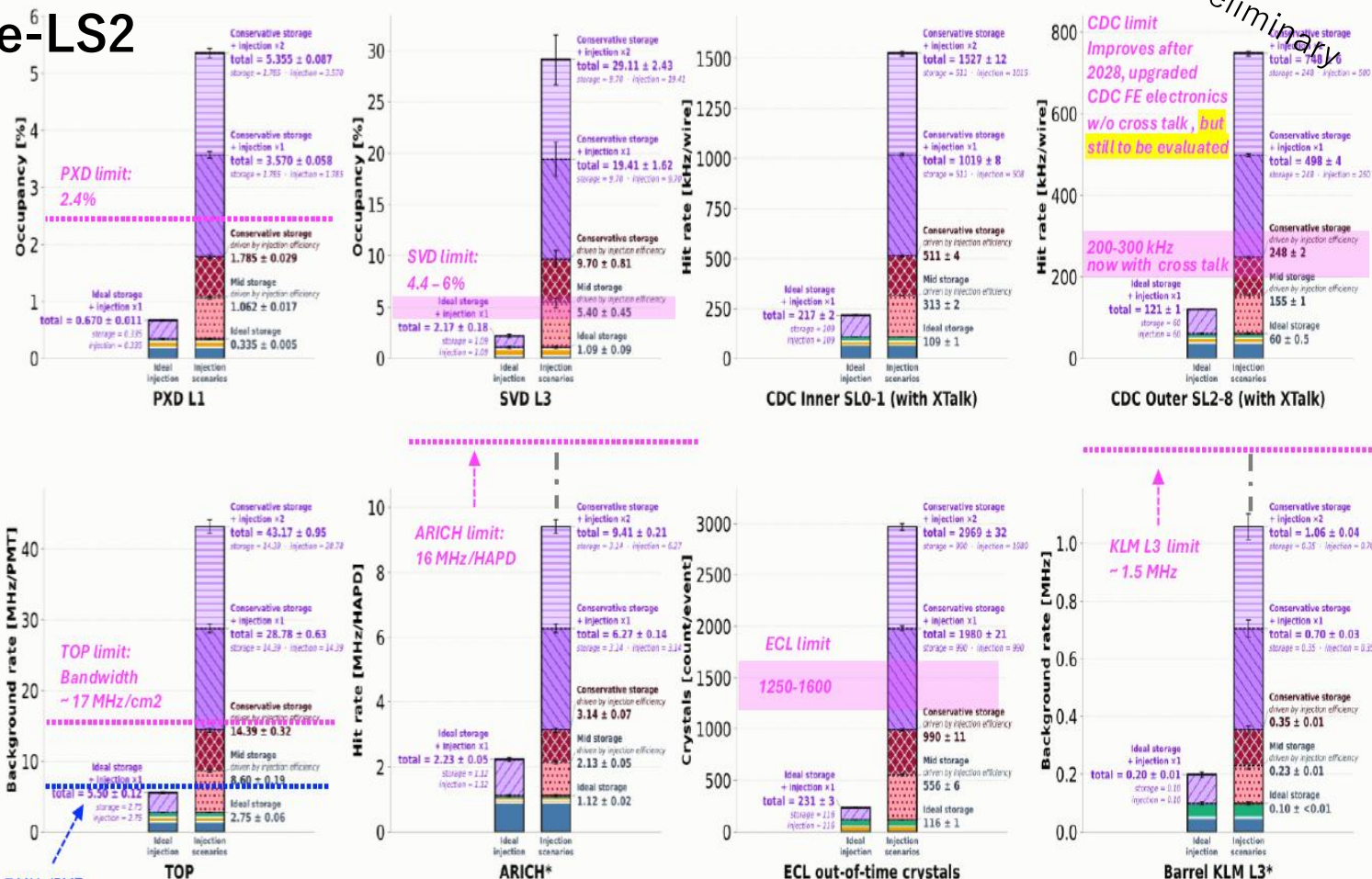
Machine Parameters for Pre-LS2 (assumed in CDR)

- $\beta^*y = 0.6\text{mm}$, $\beta^*x = 100\text{mm}$
- $I_{\text{LER}} = 2.52\text{A}$, $I_{\text{HER}} = 1.82\text{A}$ (4.6A^2), $N_b = 1576$
- $L \sim 2.8\text{E}+35$

These numbers will be updated following ongoing discussion on operation plan.

■ Luminosity BG
 ■ Touschek LER
 ■ Beam-gas LER
 Ideal storage single-beam BG
 ■ + Mid storage
 ■ + Injection x1 = 1 x Conservative storage
 ■ + Injection x1 = 1 x Ideal storage
 * Data/MC ratio taken per subdetector, not averaged
■ Touschek HER
■ Beam-gas HER
 no safety factor
■ + Conservative storage
■ + Injection x2 = 2 x Conservative storage
■ + Injection x2 = 2 x Ideal storage

Pre-LS2



- After squeezing β^*y to 0.6mm, IR loss mitigation by collimators becomes more challenging
 - Reduced IR aperture requires tighter collimators, while TMCI limit does not allow too tight settings
 - Linear extrapolation based on beam current product may underestimate pre-LS2 BG → SAD simulation!
- Actual collimator settings are subject to operational constraints which results in higher storage BG
 - Constraints such as poor injection efficiency, SBL risk, or other factors may require wider collimators. **This uncertainties on storage BG** shown separately in the plots as “Ideal” – “Mid- “Conservative” for storage BG
- Large uncertainty on injection BG for pre-LS2, not simulated yet
 - The plot only include rough estimates, assuming x1, x2 ... of storage BG. The sensitivity to injection BG differs among subdetectors, but the same factor is assumed here.
- Detector limits
 - Showing instantaneous, performance driven limits
 - ECL/SVD/CDC limits could be relaxed further with future software improvements
 - Applying a full injection BG veto for a few msec would relax the limit, at the price of a reduced data taking efficiency
- **Injection improvement is crucial** for reaching target currents for pre-LS2, requiring close collaboration with SKB & Belle II.

Lower limit ~ 7 MHz/PMT to preserve PMTs lifetime

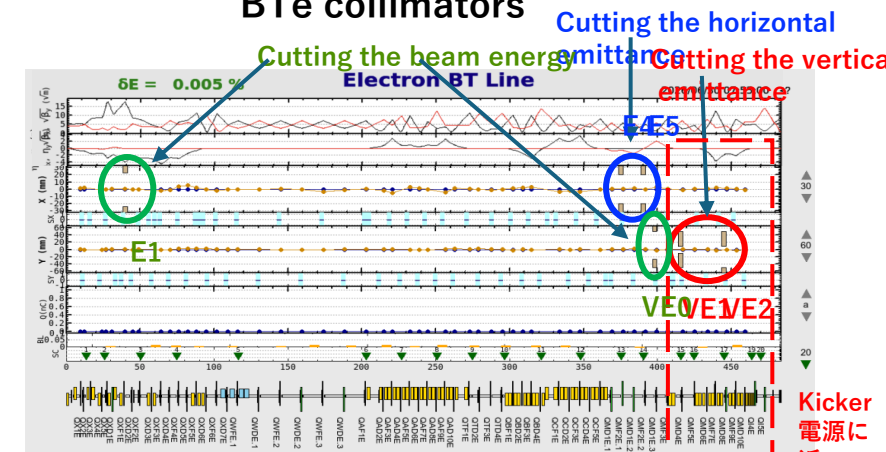
Injection improvement efforts

- Plans for 2027 operation:
 - Electron RF gun replacement** for better emittance and more charge
 - Improve performance of 2-bunch injection mode**
 - Auto-tuning/feedback systems for emittance and beam orbit,
 - Beam control using fast kickers
 - Update of beam diagnostic system, etc..
 - Chamber replacement at LER injection point** for improvement in injection efficiency
- Other recent initiatives
 - Time-resolved injection loss information:** CLAWS loss monitor waveforms provide unique timing/frequency information to support effective injection tuning
 - Injection background simulation:** Simulation studies using SAD/Xsuite are ongoing to understand injection loss mechanism and suggest effective tuning procedures
 - BT collimator optimization:** Cut beam tails to improve injection bunch quality delivered to MR. Team is being formed including contribution from Belle II members. Dedicated machine studies are planned in early 2027.

LER chamber at injection point



BTe collimators



SBL precursor signals

Turning PXD ON would be possible:

I. if **sufficient suppression of SBL** under high current is confirmed

OR

II. when reliable **SBL precursor signals** are available together with the PXD fast shutdown reliably in place

- Precursor signals could also be used to trigger an earlier beam abort to mitigate SBL damage,
- But the fake rate requirement is more stringent for beam-abort triggers than for PXD shutdown.
- For HER SBLs, enabling the HER D8 abort master will make abort faster and help mitigate damage

SBL precursor signal candidates:

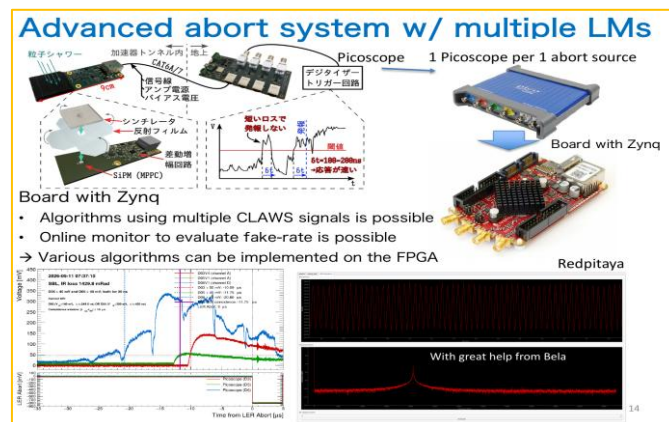
Precursor signal which arrives -18us earlier than beam loss can safely shutdown PXD HV.

a) Loss Monitors

Combining multiple Loss Monitor (CLAWS) waveforms could find anomaly prior to SBL beam loss

Readout board (RedPitaya) to issue the trigger has been developed and will be ready for next run

Anomaly finding algorithms on FPGA should be optimized to reduce fake trigger rate



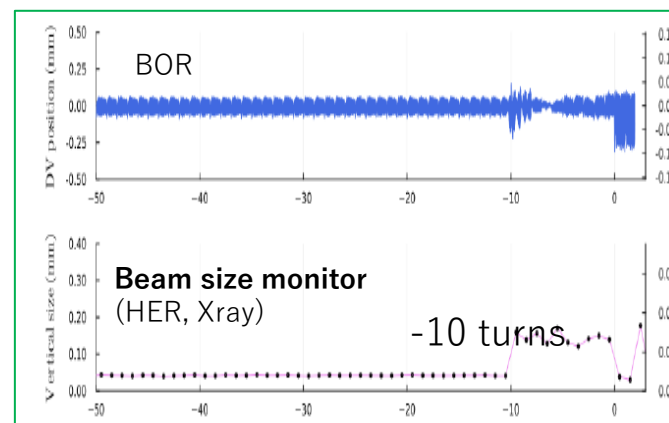
Details in backup (p.38-39)

b) Beam size monitors

Fast beam size blowup observed much earlier than SBL beam loss could also be a good candidate

SiXRM demonstrates capability of bunch-by-bunch beam size measurement

Realtime triggering requires online software implementation on FPGA



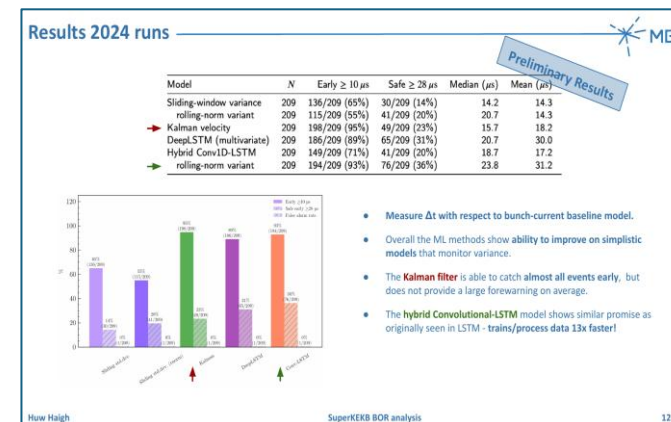
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c) BORs (Bunch Oscillation Recorder)

Beam-orbit instability earlier than SBL beam loss could be a promising candidate as SBL precursor

Quantitative study on offline data using ML is performed intensively.

Multi-BOR system based on IDROGEN+VERSAL board is under development



Details in backup (p.44)

Prospects for SBL precursor candidates

	a) Loss Monitors	b) Fast beam size monitor	c) BORs
SBL precursor detection efficiency (-18us before loss)	• ~10% triggering efficiency with single CLAWS waveform • Advanced algorithm and combined waveforms from multiple loss monitors could improve efficiency	• Not yet been quantitatively evaluated due to limited measurement statistics. • Limited bunch coverage with existing beam size monitors	• ~40% triggering efficiency demonstrated in ML-based offline analysis (preliminary) • Combining more BORs could improve efficiency with acceptable fake rates
Hardware readiness	• Loss monitors have been installed and operating successfully • New readout board to be installed in E-hut	• SiXRM with RFSoc-readout to be tested on <u>HER</u> X-ray beam line • Beam-size reconstruction and anomaly detection to be implemented on FPGA	• Multi-BOR system based on IDROGEN modules + Versal board to be developed • PCIe readout and firmware integration in progress
Implementation Timeline	• Integration with PXD HV system technically feasible for 2027 runs • Further algorithm optimization is needed to balance detection efficiency and fake rate	• SiXRM shadow-mode operation planned for 2027 runs • If successful, integration with PXD HV system and/or abort system during 2027 runs	• Commissioning with single-BOR planned for 2027 runs • Further development needed before multi-BOR online triggering can be deployed

Close to operational, but detection efficiency still needs improvement

Validation tests before integration with PXD and/or abort system

Commissioning with single-BOR

Summary

- **Beam background limits operating beam currents**
 - Further increases in beam currents were constrained by the Belle II beam background upper limits in late 2026
- **Belle II CDC is the most critical detector constraint**
 - To mitigate Malter-effect risks and increase BG tolerance, further CDC HV configuration adjustments are being prepared for 2027,
 - Degradation in tracking performance caused by high occupancy due to BG hits may impose an additional operation limit, even before Malter-effect limit is reached
- **Injection performance improvements are essential for 2027.**
 - To reach the target beam currents and $L = 1\text{E}+35$, reduction of injection BG spikes and improvements of injection efficiency are required.
- **SBL precursor signal for PXD HV shutdown: investigation ongoing**
 - Required for safely turning on PXD again
- **Accelerator–detector collaboration is further strengthened.**
 - Close coordination among both teams is a key to maximize luminosity while maintaining stable operation.

backup

Response to the last KEKB review (2025 Feb)

Recommendations in the MDI section

R16.1: Continue to improve, and devise new, diagnostics and detectors in the two main rings (HER and LER) in the hunt for SBL sources.

R16.2: Continue to work with the LINAC team to improve injection capture efficiency.

R16.3: For backgrounds associated with long injection durations, it is essential to identify which injected particles are lost in phase space and, if feasible, design specific collimators for the BT to address this issue.

R16.4: The ARC recommends that the MDI group not only focuses on mitigating beam background, but also provides potentially useful beam information to the accelerator team.

R16.5: The ARC suggests extending the machine learning (ML)-based injection tuning approach by incorporating the objective of reducing detector backgrounds. This effort should involve optimizing not only the linac and transport line, but also explore the inclusion of additional tuning knobs in the ring.

SBL diagnosis using various sensors shows a good progress. Fast beam size monitors sees blowup on some SBLs, and novel Bunch-by-bunch SiXRM will be installed. BOR phase analysis indicates SBL origin locations which matches the oscillation pattern. Details in SBL talk by Kenta Uno.

LINAC/BT Efforts to improve injection performance are ongoing, including replacement of electron RF gun, 2-bunch injection mode improvements LER chamber replacement at the injection point, etc.

First trial to utilize BT collimators to suppress injection beam tails are planned in early 2027, with contributions from Belle II team.

The Belle II MDI team has been and will continue to provide useful insights to the accelerator team, through loss monitors installed by the Belle II team, detailed analyses of SuperKEKB sensor data, and other activities.

ML/AI activities are now in full swing. For example, Bayesian optimization for beam collision tuning is being extensively tested in 2026. Big-data analysis of SuperKEKB EPICS PVs has revealed a correlation between luminosity fluctuations and the temperature in the DAQ room, particularly around the feedback modules. Details in ML/AI talk by Taichiro Koga.

MDI subgroup

Simulation and Modeling



Leaders:

[John Patrick Salvesen](#), [Giacomo Broggi](#)

Regular meetings: [indico](#) (monthly)

Recent summary report at MDI

- [link](#) to Jack's presentation on May 28th

Ongoing activities

- Xsuite: accelerator simulation framework developed at CERN, capable of various topics
 - beam background prediction, IP feedback, optics study, beam-based alignment, beam-beam simulation, etc..
- Implement SKB MR + LINAC/BT elements in Xsuite
- **Beam background simulation for storage/injection**
- Benchmarking Xsuite prediction against SAD simulation and machine study results
- Modelling luminosity performance with different beam conditions
- etc..

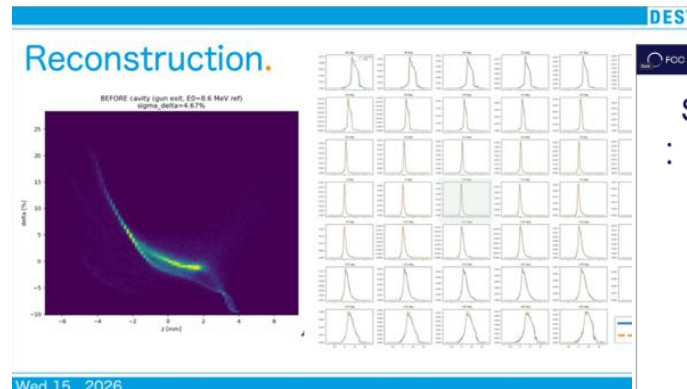
Open tasks

- **Xsuite activity officially approved as an MDI subgroup → ready to host Belle II students and postdocs for qualification-task projects**
- A Belle II Msc student (Nemoto-san) will visit CERN this summer to receive training from Xsuite team on **injection BKG simulation**
- Wide variety of further collaboration possibilities through already established strong links with:
 - Belle II Beam Background Group
 - SuperKEKB Optics Group
 - SuperKEKB Beam-Beam TF

Recent Highlights from Xsuite simulations

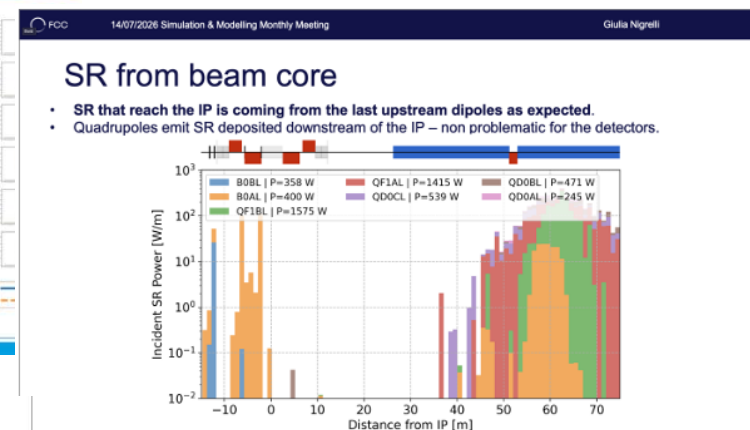
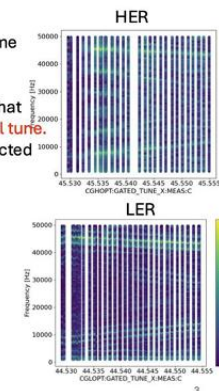
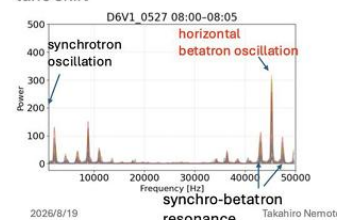
Initiatives within the Belle II MDI group, led by J. Salvesen and G. Broggi

- **Beam dynamic studies in LINAC/BT**
 - A. Polo
 - **BT Emittance Growth**
 - T. Mori (KEKB)
 - **Beam Injection Loss Frequency**
 - T. Nemoto
 - **Synchrotron radiation studies**
 - G. Nigrelli, G. Broggi
 - **Beam-Beam Simulations**
 - H. Sugimoto (KEKB)
 - **SAD2XS conversion**
 - J. Salvesen
 - **etc...**
- 
- A blue square logo with a white stylized 'X' shape and the word 'xray' in white lowercase letters below it.



FFT Analysis of Injection Beam Loss

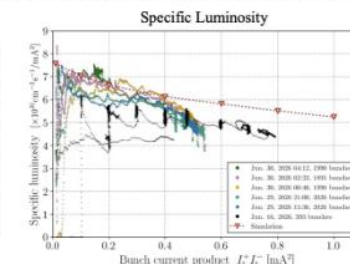
- From FFT for Injection beam loss after 1ms, some peaks are observed that match the calculation results
- Horizontal tune scan (2026/06/16) confirmed that the spectral peak originates from the horizontal tune shift
- The observed slope is consistent with the expected tune shift



Comparison with Measurements in 2026b

- The actual lattice and wakefields are included; lattice errors are excluded. W_x and W_y are scaled to match the measured tune shifts.
- No sudden luminosity drop is observed in either the 393-bunch data or the simulation.
- In the 2026-bunch data, luminosity drops sharply above $I^* I^b \approx 0.4 \text{ mA}^2$.
- Total-current-dependent effects, such as beam-line deformation and resistive-wall wakefields, may limit performance.

Parameters	LER (e^+)	HER (e^-)	U
I_b	I_b^* (variable)	$I_b^- = 0.75 \times I_b^*$	
ε_x	4.05	4.43	
ε_y	40	40	
(β_x^*, β_y^*)	(55, 0.9)	(55, 0.9)	
(ν_x, ν_y)	(44.537, 46.584)	(45.531, 43.607)	
ν_z	0.0237	0.0272	
σ_z	4.6	5.8	
(τ_x, τ_y, τ_z)	(53.0, 53.0, 26.5)	(56.0, 56.0, 29.0)	
CW ratio	80	60	



Strong and productive collaborations are growing between the Xsuite and SuperKEKB team!

Belle II backgrounds

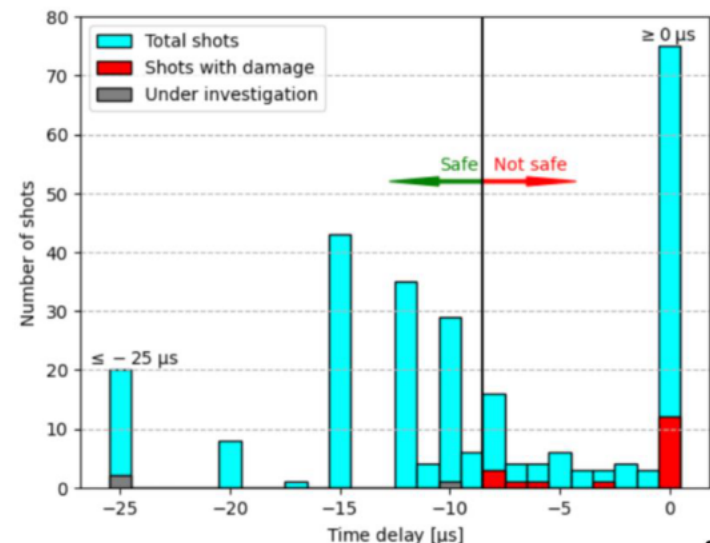
Strategy for PXD, CDC, TOP near & mid term operation

more details about TOP and CDC will be given in next talks

Strategy to turn PXD ON

- PXD is kept OFF to prevent damage from high BG spikes from SBL
- New fast PXD PS shutdown developed to bring it quickly in safe state
 - First tests in Bonn: realistic set up + two real modules :11k + 2K fast shutdown w/o any damage
 - Final test with beams, high intensity fast irradiation in MAMI: confirmed **fast shutdown safe, no damage to PXD modules, if shutdown signal arrived at PXD PS ~18 μ s before radiation spike**
→ in Belle II: need SBL precursor signals arriving at PXD PS ~ 18 us earlier than radiation at the IP!
- PXD PS shutdown installed in Belle II in June 2026: some unexpected observations (next slide)
- For full protection of the PXD against SBL, needs two conditions:
 1. fast hardware shutdown system in placeAND
 2. reliable precursor signals of SBL arriving 18 μ s before a high-radiation event at the IP
- At present, the PXD cannot be fully protected: **still no reliable precursor signals available** (under development, MDI's talk)
- If full protection not ready, turning PXD ON can only be considered under reasonably low-risk conditions:
 - Need a period of stable machine operation (2–3 months), with high-current operation & w/o SBL with large loss at the IP
- So far in 2026 such stable operation has not yet been achieved
- Turning PXD ON would be possible:
 - I. if sufficient suppression of SBL under high current is confirmed (see MDI's talk on SBL mitigation perspectives)OR
 - II. when reliable precursor signals are available (MDI's talk) together with the PXD fast shutdown reliably in place
- Different approaches, with higher risk of damaging PXD, could be considered in case I or II are not available

PXD FastShutdown irradiation test @MAMI



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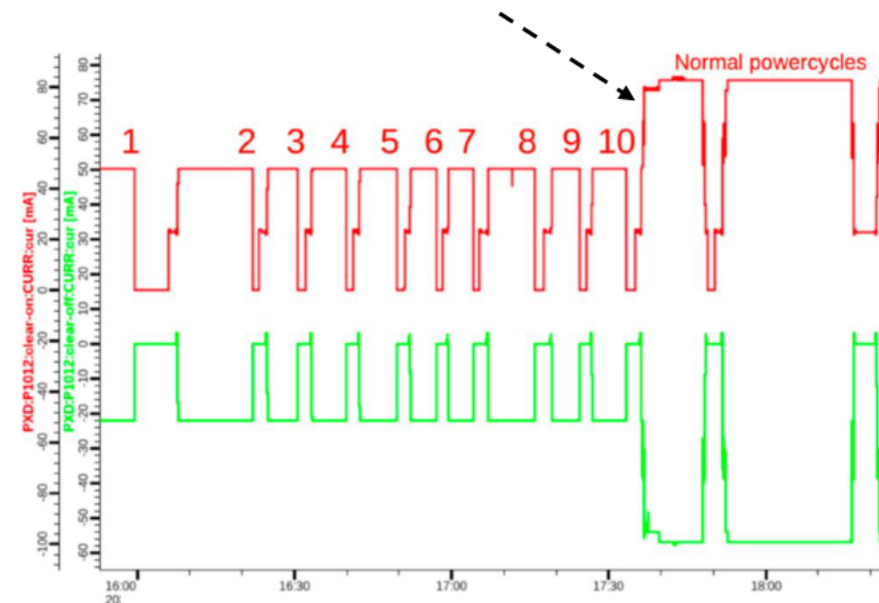
PXD fast shutdown installed in KEK

- New front PCB of PXD power supply produced and tested in Bonn
- Additional modification of the power supply in KEK:
 - reduced the PS reaction time by 2.7us → **precursor signal required ~ 15 us before radiation spike at IP**
- Power Supply in KEK modified with new fast shutdown PCB & tested
- **Fast shutdown tested with full PXD system:**
 - fast shutdown triggered 10 times on 29 modules with interlock signal
 - **9 iterations w/o any issue**
 - **after 10th iteration one module increased current -> damaged switcher**
- **Damaged module is L1 BWD type**
 - increase current & temperature in the damage switcher
 - → **higher noise but the module can still provide good data**

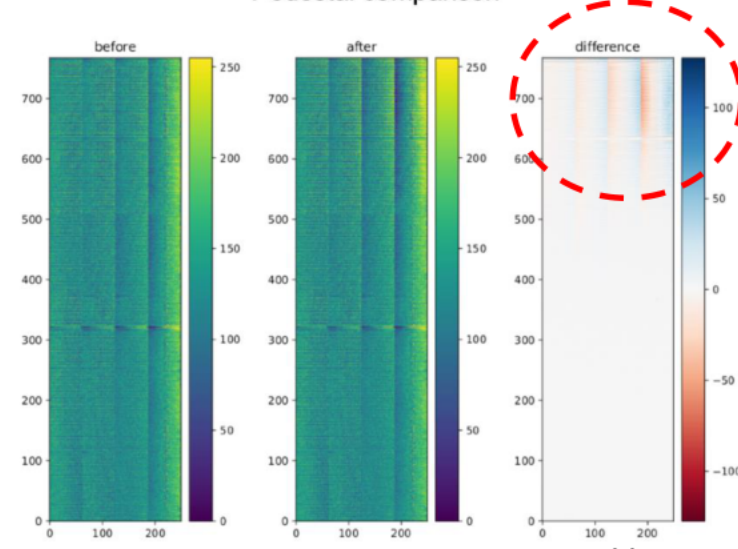
Planned test to understand the issue and current status

- No specific fast shutdown tests done on this module type in Bonn
 - 11k + 2K fast shutdown w/o any damage on 2 other module types
 - perform more shutdown tests on this module type in Bonn in next weeks
- PS connected to damaged modules also transported to Bonn for further tests
- Investigate more in details past history of this damaged module & MAMI data

High Clear ON current on L1 BWD module after 10th fastshutdown → damaged by the 10th trial



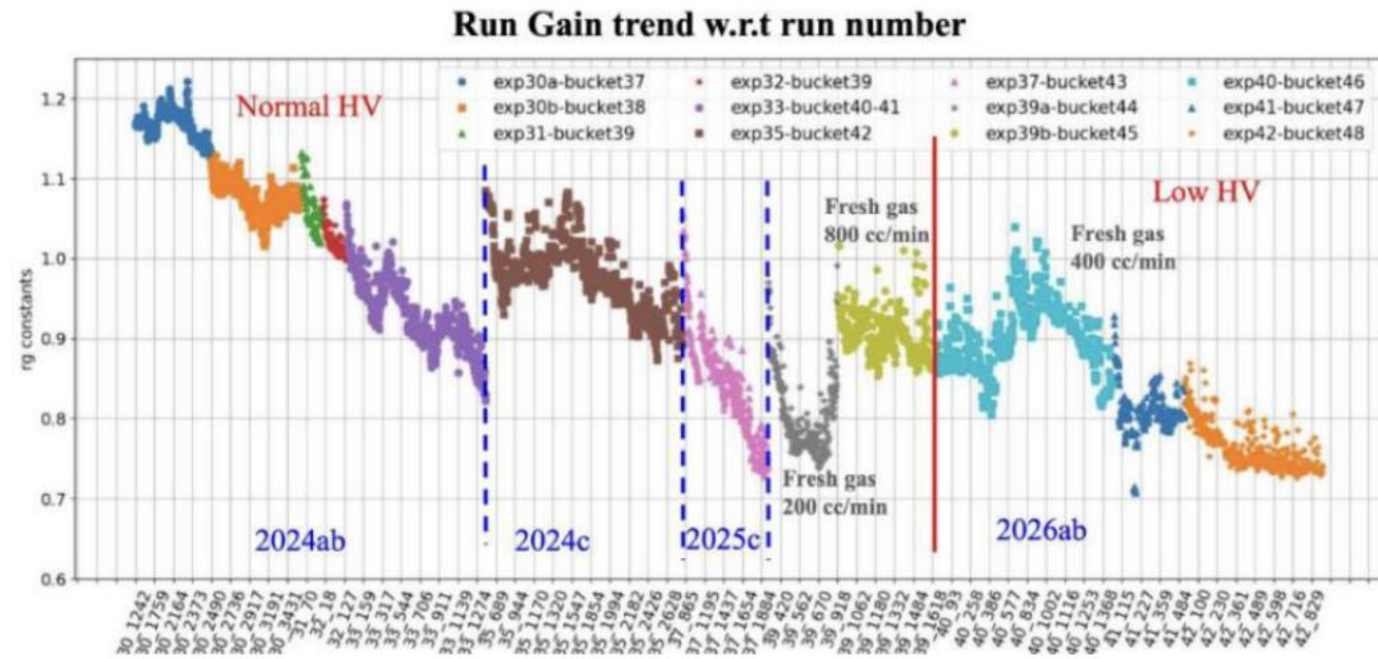
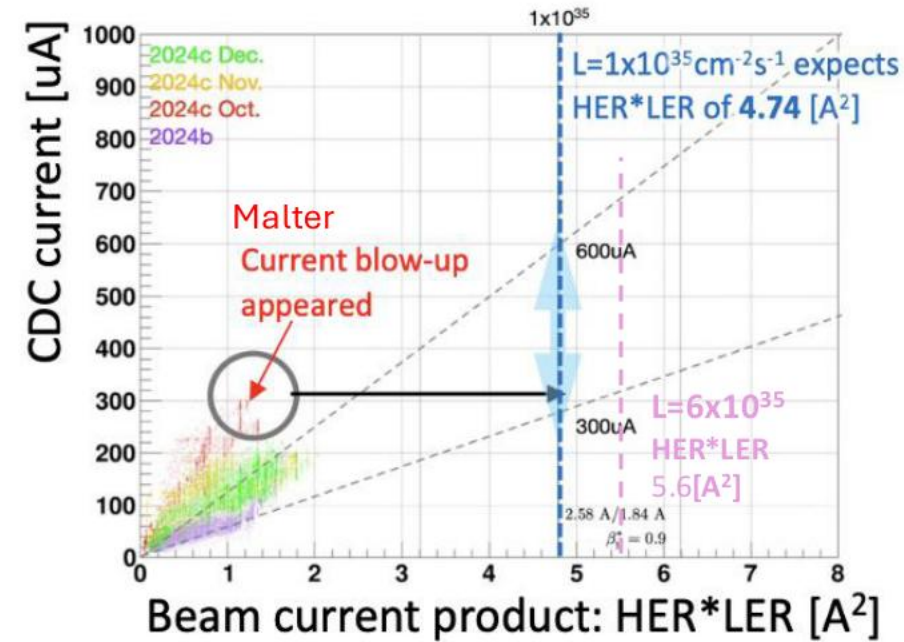
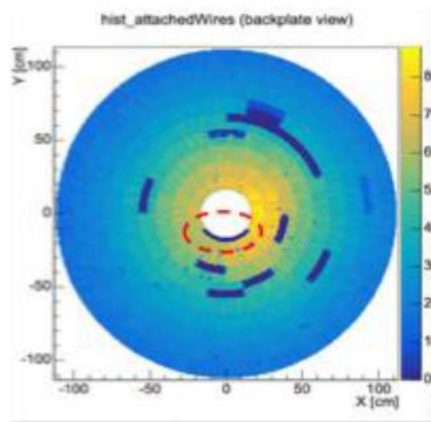
Pedestal comparison



CDC recap

Main issues:

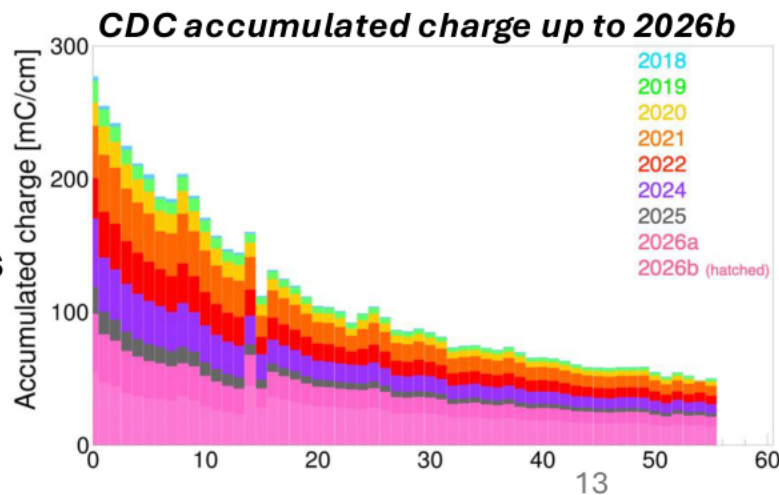
- **Malter effect:** can be triggered by high "instantaneous" BG, accumulated charge from positive ions on cathode wire, after insulator deposit, cause e- emission → **very serious irreversible aging**
 - seen in L0-1-2 in 2024c turned OFF ¼ of L0-1-2
 - want to keep CDC current below 20nA/cm/wire (~300 uA/layer in inner layers)
- Gas gain reduction due to gas contaminants, from avalanche, **reversible & reducible "aging"** with higher fresh gas flow
- **DAQ instabilities:** FE boards with unstable links, several are OFF in some runs
- **Performance degradation with high rate from BG & electronics cross talk**
- Gas gain reduction from long term aging, from accumulated charge on sense wire



CDC operation strategy in near/mid term

Mitigation: of Malter effect, gas gain reduction from contaminants, cross talk & high BG, DAQ errors & **continue aging studies**

- **Gas system improvements in 2025c/2026: stably higher O₂ and H₂O content to prevent Malter & increased fresh gas flow rate** to reduce contaminant and keep stable gain
 - In 2026 fresh gas flow increased x4, with clear beneficial effects, then was reduced (low availability of highly pure He).
 - In 2027 could probably increase it again up to x10 (TBC) & explore additional filters for contaminants, for future runs
- **Malter effect mitigation: lower HV in inner layers to reduce current & explore more additives**
 - **2026: inner layers (SL0-1) set to lower HV/gain (50% current) to mitigate risks of Malter & reduce aging in long term:** trigger, tracking and dE/dX calib adjusted to partially recover performance. No dramatic effects so far, see performance's talk
 - **2027: explore further HV/gain reduction in SL0-1**, static or dynamic, or even to operate w/o SL0-1, **for safe operation with higher BG**. Now prepare (HW & SW)
 - **Additives plan:** increase O₂ in 2027, study alcohol effects in test chamber to possibly deploy it in future runs
- **Mitigation of performance degradation due to cross-talk & high BG**
 - **FE electronics upgrade:** prototypes **effective to suppress present FE cross-talk**
Tests are ongoing → **earliest possible installation in 2028**
 - Improve software robustness against background for future releases (GNN ?)
- **FE instabilities mitigation:** related to low PS voltage, **evaluate other PS boards**
- **Continue aging tests to understand impact in future operation:**
 - reached 1 C/cm @Tohoku Univ. test: no significant gain degradation seen
 - So far no evidence of larger gain loss w.r.t Belle aging test results: 6%/C/cm



CDC FE Upgrade: Path Towards a 2028 Installation

Validation (2026 - Early 2027)

- New ASIC demonstrates ~10x reduction of dominant analog crosstalk
- Complete validation of:
 - digital crosstalk /multiple-hit effect (newly observed) to be cured with new ASICS settings w/o chip redesign
 - Analog cross talk with new ASICS settings
 - tracking performance with nominal HV & low HV (outer/inner layers)
- Lab tests ongoing & new test beam planned in Nov/Dec 2026
- **Milestone Jan 2027:** internal CDC review on performance validation

Production (2027)

- Finalize FE board design
- **Define FE cooling reinforcement*** and new LV power supplies
- Complete second FE prototype & verification
- Launch FE board mass production
- **Define QA and commissioning plan***
- **CDCTRG preparation related to the CDC FE electronics upgrade***
- **Milestone Sept 2027:** production readiness & start FE mass production
- **Milestone March 2028:** FE mass production validated

Installation: 2028 shutdown

- **~ 9-10 months (TBC)**
- **CDC** new FE installation with new cooling & new low voltage PS
- **TOP** interventions
- **VXD** cable disconnection & related activity needed to access CDC FE / TOP

*Criticalities:

- Eng. for cooling reinforcement evaluation not yet assigned/available
- Person power for QA & commissioning & CDCTRG preparation

TOP PMTs recap

- **In Run1:** installed modules showed **significant lower PMTs lifetime than expected** from lab test
 - Qlife gives 80% QE reduction
- **During LS1:** replaced most of the **Conventional** PMTs with **new Life Extended ALD**, and **ALD** relocated
- **In Run2:** significant QE relative loss, 30% in 25% of the PMTs, not due to aging & confirmed to be due to **delamination** (see Martin's talk). It could extend up to 50% of the PMTs. **Could be fixed accessing the PMTs during a shutdown**
 - After delamination effect is removed in Run2 data analysis, the QE loss has not the expected quadratic decrease with accumulated charge? New effect present? TOP Martin's talk

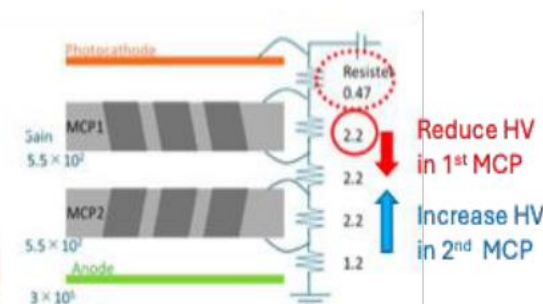
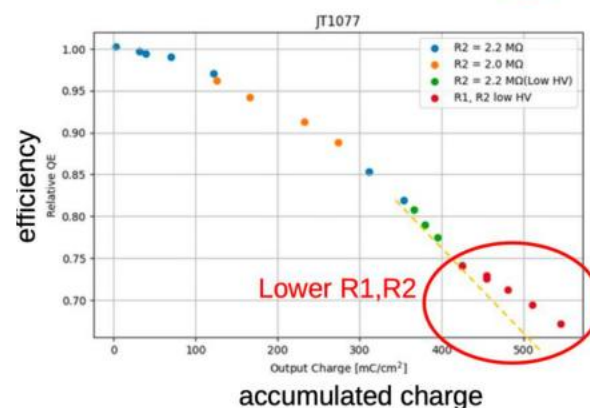
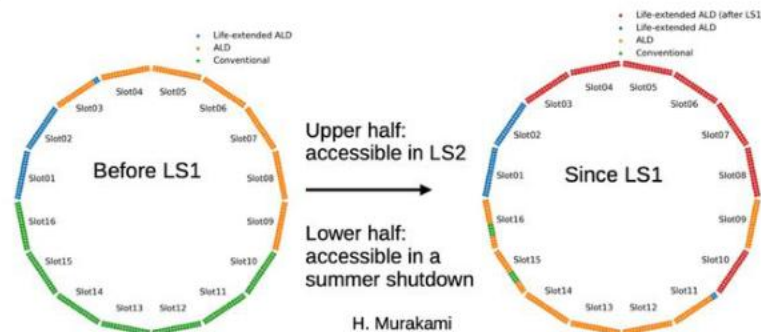
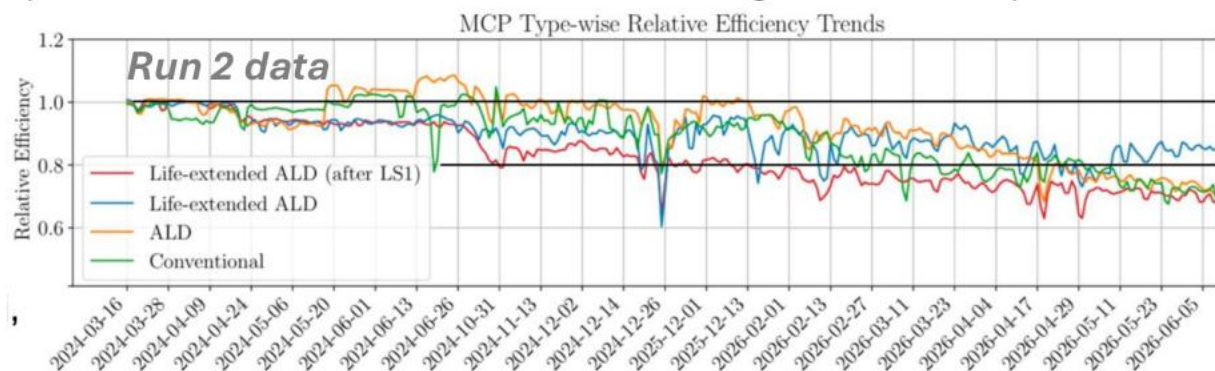
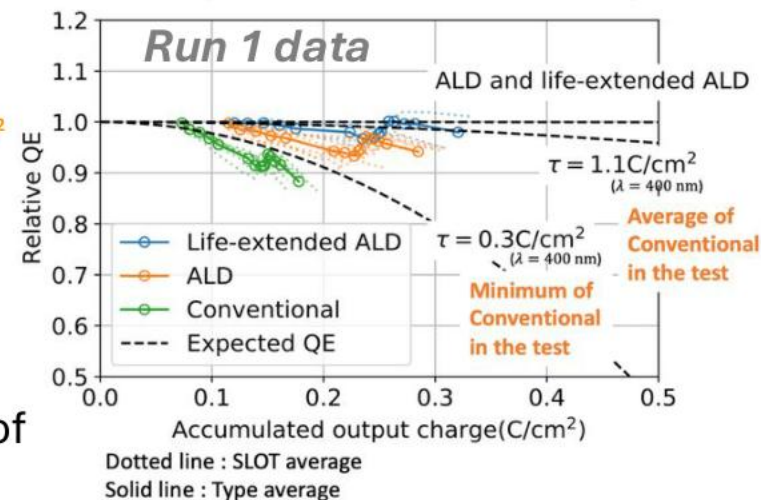
$$\text{Relative QE} = 1 - 0.2x(Q/Q_{\text{life}})^2$$

Lab results

Conventional Qlife = 1.1 C/cm²

Atomic Layer Deposition (ALD) Qlife = 10 C/cm²

Life Extended ALD Qlife > 13.6 C/cm²



- **PMT QE tests continue:**
 - **investigate origin of larger degradation:** combination of B-field + high temperature → to be completed in autumn
 - **improve lifetime with new HV divider optimization** (keep gain constant, but reduce 1st MCP gain, reducing photocathode aging from back scattered ions) → **promising results, to be validated & tested on Life Extended ALD PMTs (relevant in next years)**

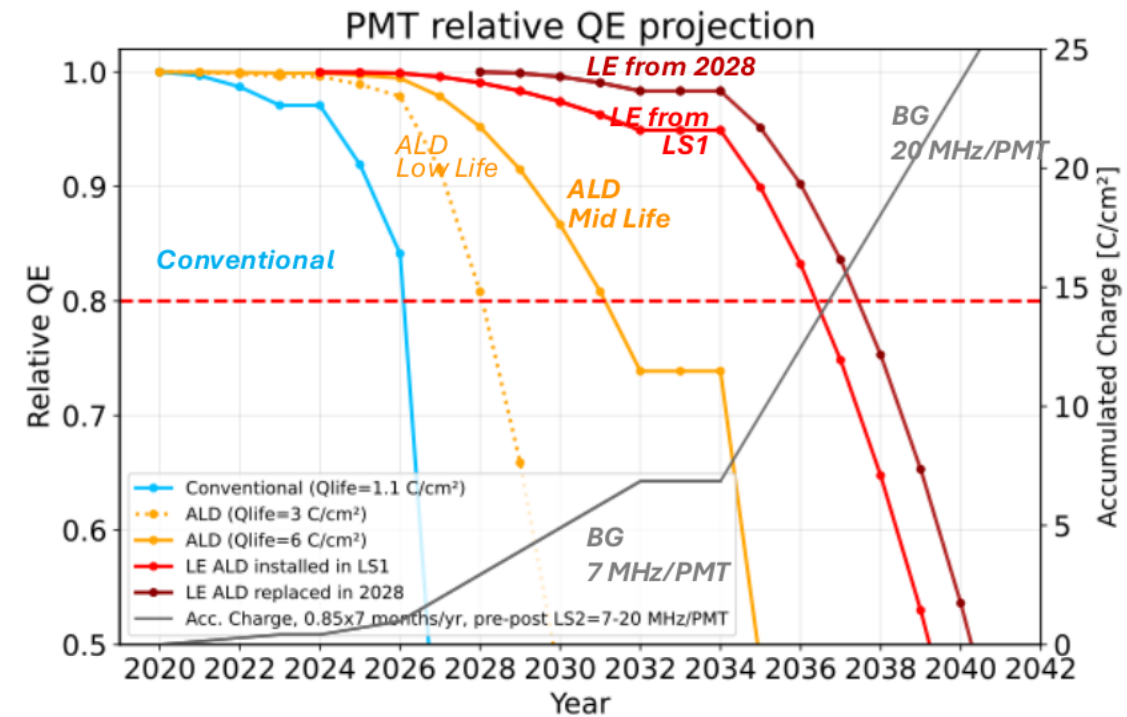
G. Rizzo

TOP PMT strategy

- With the current BG extrapolation rates (pre-LS2 ~ 7 MHz/PMT, post LS2 ~ 20 MHz/PMT) & the relative QE evolution:
 - ALD will need to be replaced before LS2
 - ALD lifetime in installed modules smaller than in lab, from Run1 seems more similar to Conventional PMTs (blue in the plot)
 - Life extended ALD could survive only a few years after LS2 with high BG level ~20 MHz/PMT, with still large uncertainty on BG prediction
 - New batch of Life extended PMTs, or even more resilient technology, would be needed for post-LS2.

Strategy under discussion:

1. Fix the delamination & install the new HV divider during access to upgrade the CDC FE electronics, shutdown in 2028, need to disconned VXD cables & remove Dock-box.
 2. During the same shutdown replace ALD, the ones with low lifetime, with new LifeExtended ALD
- Postponing after 2028 & before LS2 the replacement #2 of ALD, w.r.t intervention #1, is not effective
 - Lab test of dismounted PMTs in 2028 could help to understand better the mechanism of additional QE degradation seen in Belle II



Topic	What do we know?	Open Questions	Decision deadline
Delamination	Confirmed, 30% QE loss in PMTs affected. Now 25% of PMTs, could extend to 50% of PMTs (shim applied)	Which repair fix should be adopted?	2027
HV divider	Results encouraging	Final validation Quantify impact on lifetime also for LifeExtended PMTs	2027
LE-ALD replacement for ALD	spares available	optimal installation time	2027
Post-LS2 BG	new estimate 20 MHz/PMT	Is 20 MHz/PMT rate sustainable from HW & Performance?	Asap (before BPAC)
2028 shutdown	CDC FE & TOP interventions should be combined. Both need VXD cables disconnection and Dock-box removal. Previous experience suggests shutdown ~ 6-8 months (TBC).	scope of intervention: • CDC FE • HV divider • fix of the delamination LE - ALD (bottom) replacement?	1.5 years before the intervention → beg of 2027 if shutdown in summer 2028

Detector BG Inputs: 2026 data extrapolation & detector limits VS BG prediction

Many thanks to all background,
detector & performance
experts for providing inputs
and very useful discussion

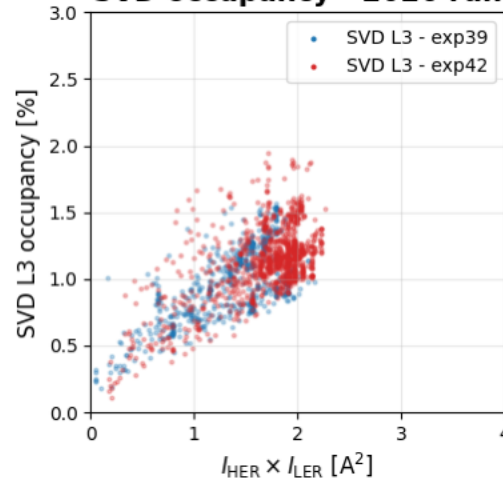
G. Rizzo, Oct, 24 - 2026 – BPAC preparation

1. Extrapolation of BG from 2026 data to 2027 conditions & comparison with detector limits
2. Comparisong of new pre-LS2 and post-LS2 BG simulation prediction with BG in 2026 data, assuming a linear scaling with the product of beam currents
 - **Caveats:**
 - future pressure will be lower than in 2026 data → linear extrapolation from data overestimate future BG
 - future β_y^* will be lower → linear extrapolation from 2026 data underestimare future BG
 - Injection BG is not simulated, but estimated using re-scaled xN from storage component

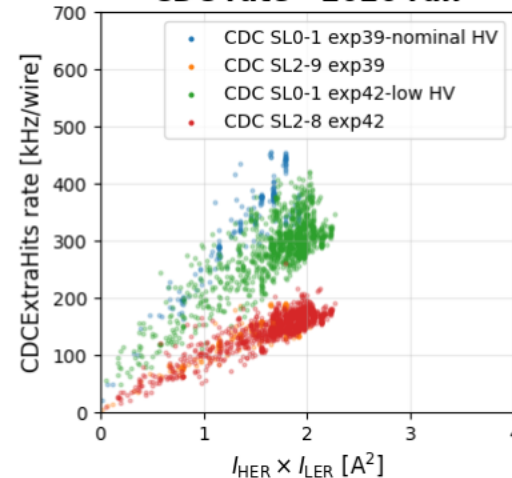
Background in 2026 run

- More **challenging operation conditions** due to higher beam currents & BG, with injection spikes
- In all systems **linear correlation of BG levels with beam current product**
- **Quite large BG variations due to variable machine conditions & injection BG**
 - Since 2026, many more BG related variables included in Mirabelle: easier access to monitor BG and correlation studies
- **In general we are operating below sub-detector limits**
 - **CDC inner layers exception:** high current & increased risks of Malter, very high BG occupancy
 - CDC inj BG is ~ 50-80% of storage BG
 - Trigger injection veto needed frequent optimizations & **high injection BG** caused large deadtime
- **Injection BG mitigation is critical**

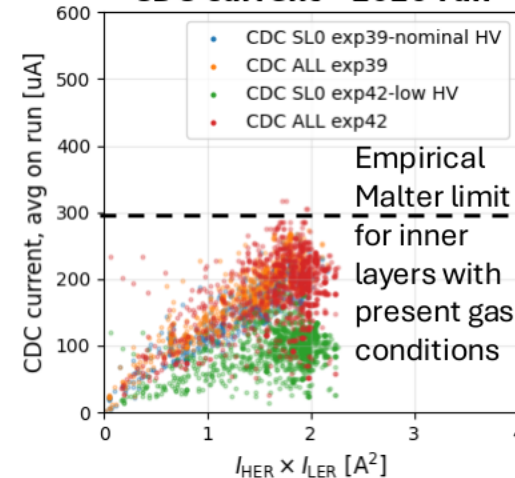
SVD occupancy - 2026 run



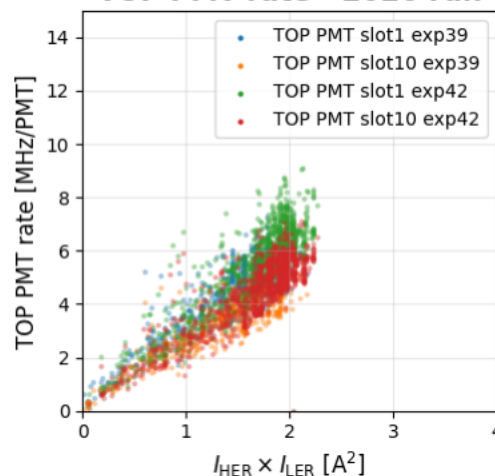
CDC rate - 2026 run



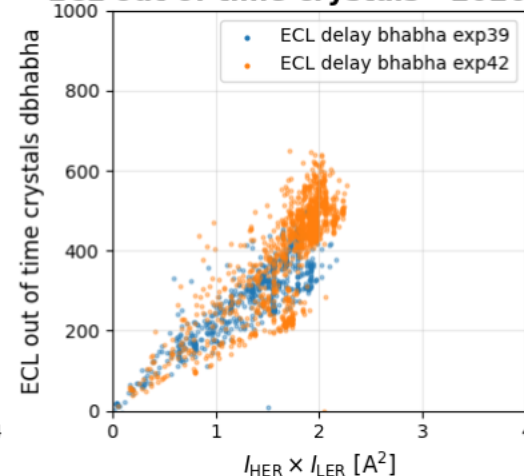
CDC current - 2026 run



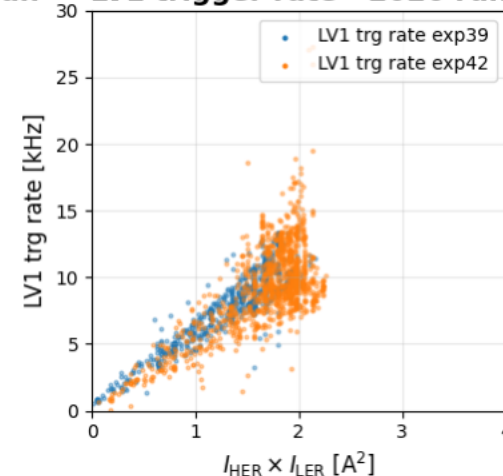
TOP PMT rate - 2026 run



ECL out of time crystals - 2026 run



LV1 trigger rate - 2026 run



Background vs detector limits: near term extrapolation

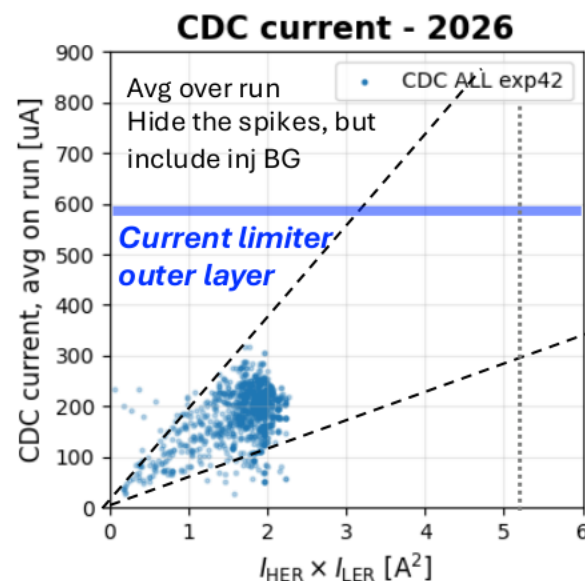
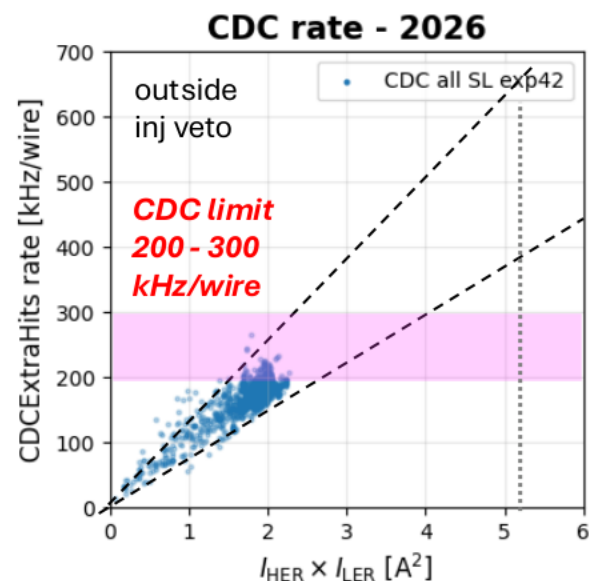
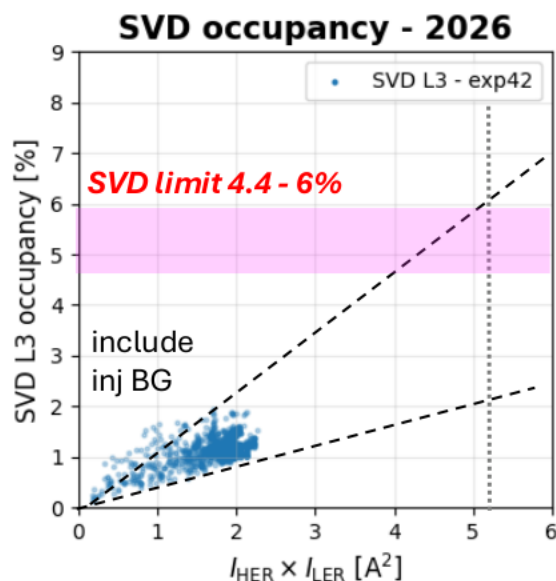
Preliminary

Detector instantaneous limits, performance driven, (ECL, CDC, SVD) could be raised with SW improvements

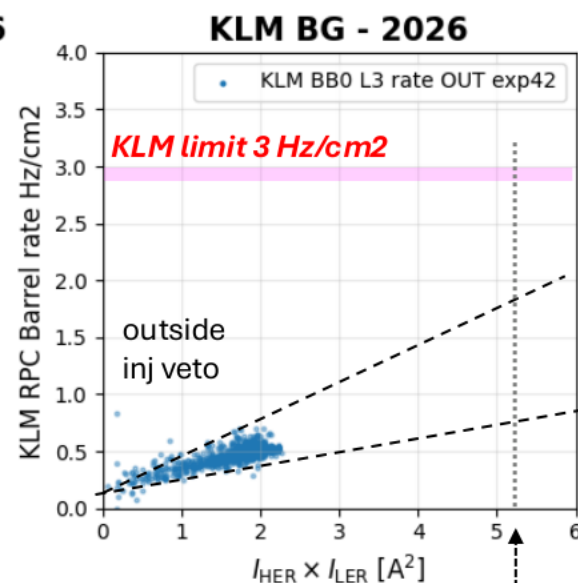
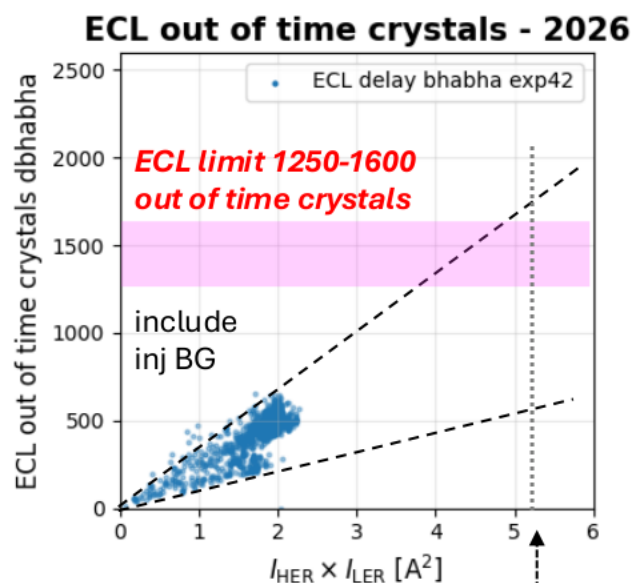
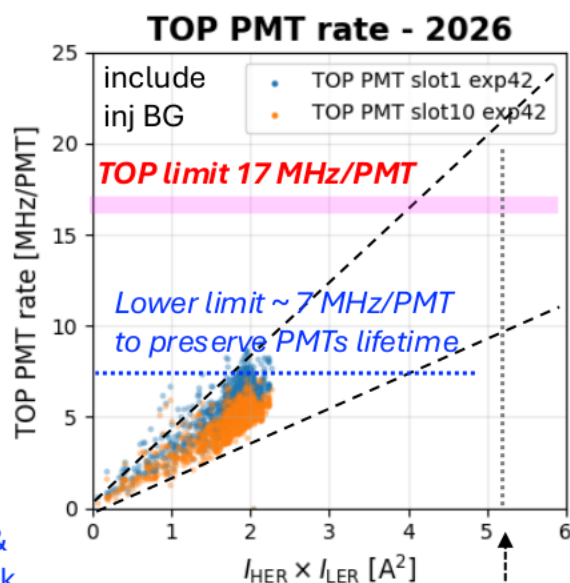
- ECL, in 2027
- SVD (?)
- CDC in future releases (GNN ?)

CDC limit is higher with reduced cross talk $\rightarrow$ FE elec. upgrade in 2028, still impact on performance limit to be evaluated

Complete description of detector limits, with recent revision (both instantaneous & aging related) in Katsuro's talk



Above $\sim 600 \mu\text{A}$ CDC outer layers will also start to have lower HV/gain (reduced by current limiter)



Simple linear extrapolation based on product of beam currents

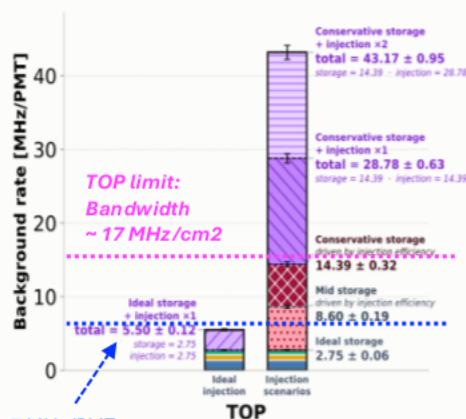
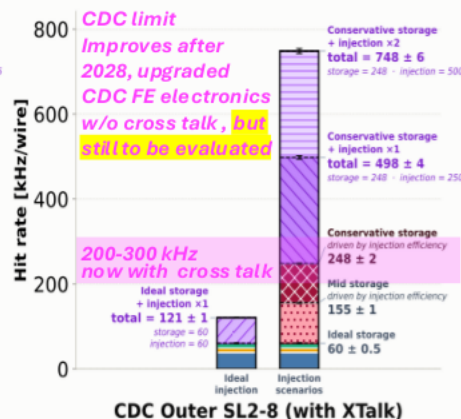
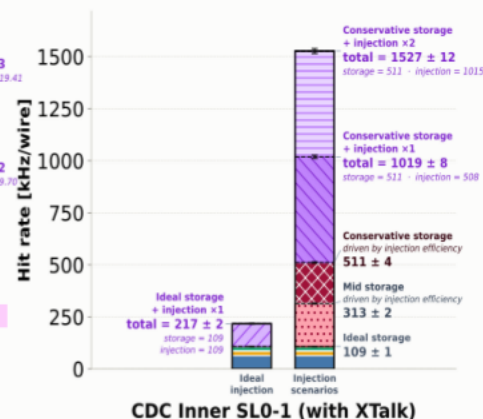
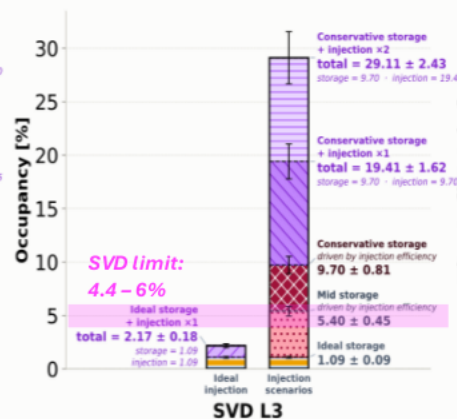
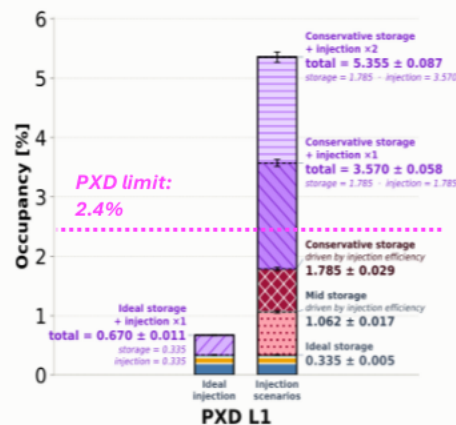
reasonable assumption with pressure and β_y^* similar to 2026

Background vs detector limits: pre-LS2

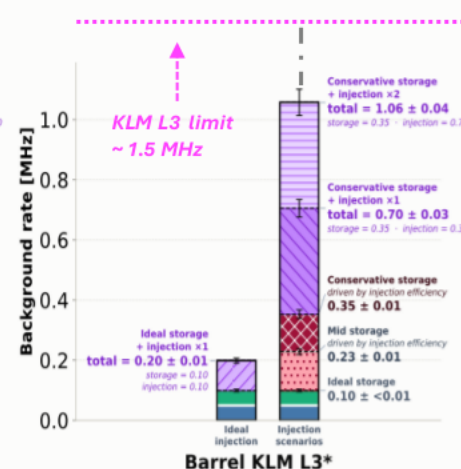
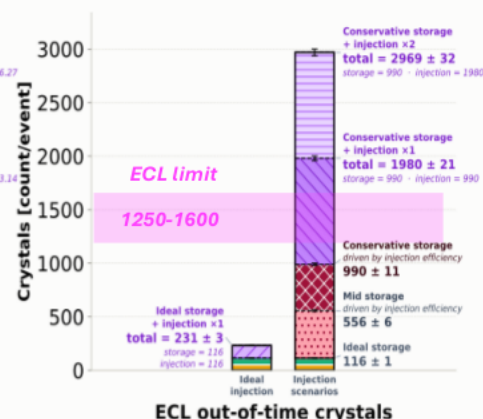
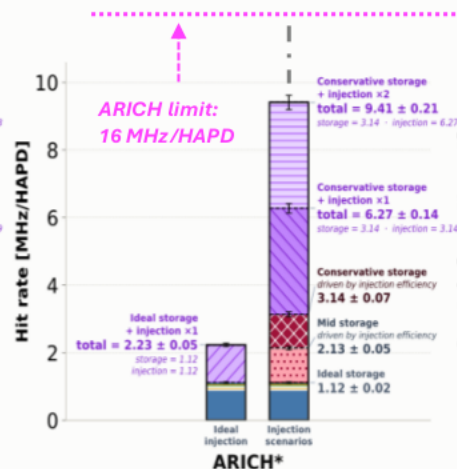
Preliminary

■ Luminosity BG
 ■ Touschek LER
 ■ Beam-gas LER
 ■ Ideal storage single-beam BG no safety factor
 ■ + Mid storage
 ■ + Injection $\times 1 = 1 \times$ Conservative storage
 ■ + Injection $\times 1 = 1 \times$ Ideal storage
 * Data/MC ratio taken per subdetector, not averaged
■ Touschek HER
■ Beam-gas HER
■ + Conservative storage
■ + Injection $\times 2 = 2 \times$ Conservative storage
■ + Injection $\times 2 = 2 \times$ Ideal storage

- Large uncertainty on prediction from injection contribution
- Duration of largest Injection BG spikes confined to first 1-2 ns from injection
- In case large injection is present can still operate the detector applying a **full injection veto** for a few ms, at the price of a **reduced taking efficiency**.



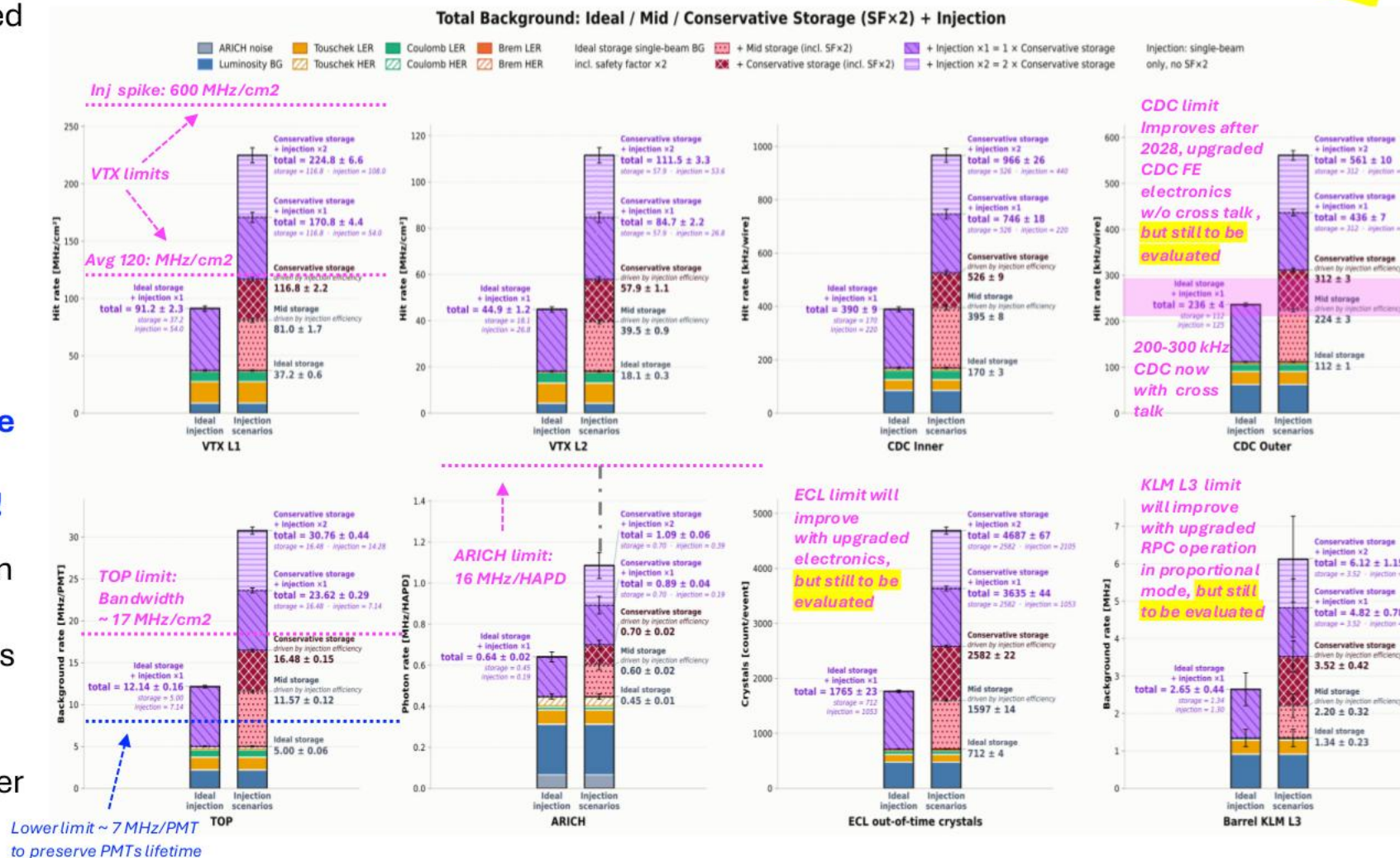
Lower limit ~ 7 MHz/PMT to preserve PMTs lifetime



Background vs detector limits: post-LS2 (machine parameters still not frozen)

Preliminary

- Limits for upgraded detectors still need to be carefully evaluated
- Background prediction is very uncertain with machine parameters still not frozen.
- Further improvements in detector limit could be partly possible in an early stage of the design
- important to define asap machine configuration to understand future BG constraints on detectors design!
- Example: VTX OBELIX-2 chip in design phase now, is implementing an injection veto feature. Further changes to accommodate higher storage BG could be maybe still possible at the expense of area in the periphery, power → cooling, material ??



enko

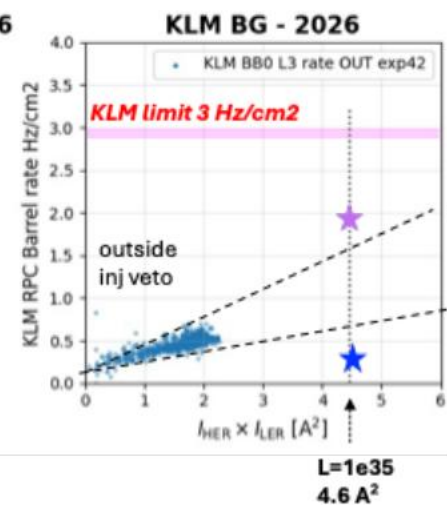
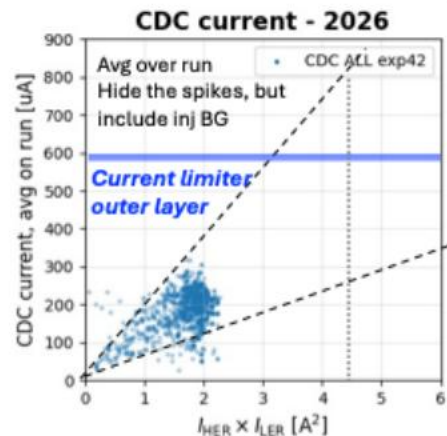
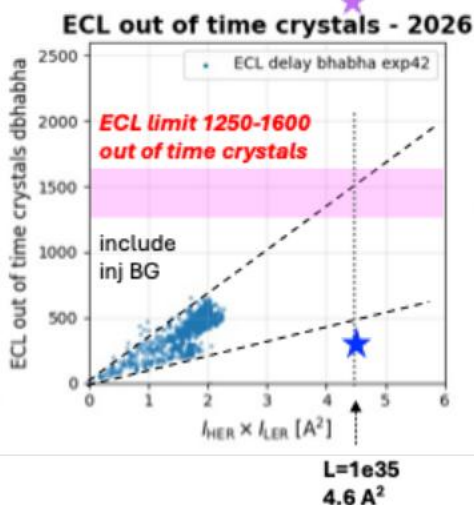
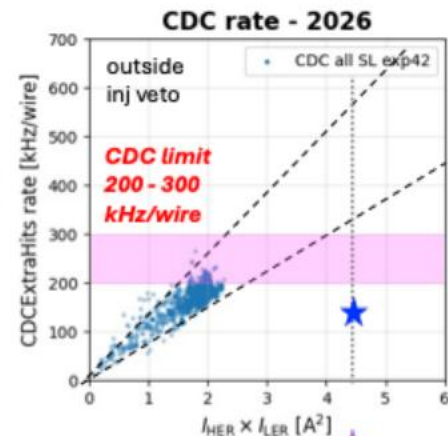
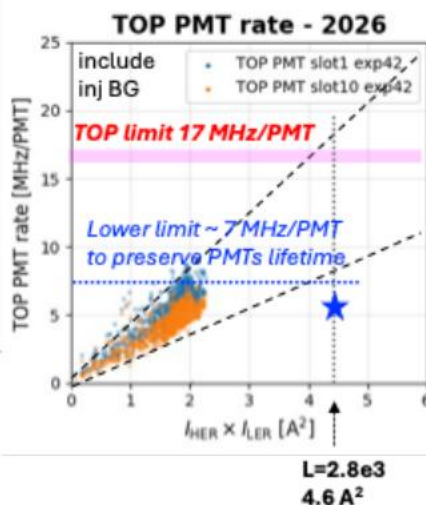
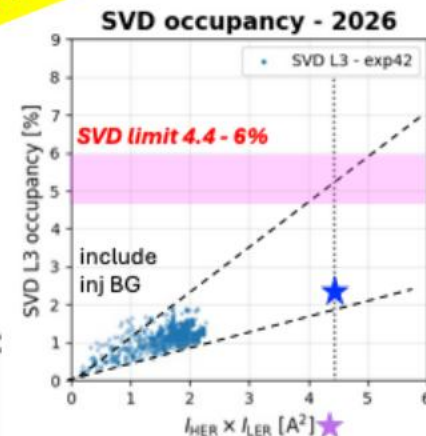
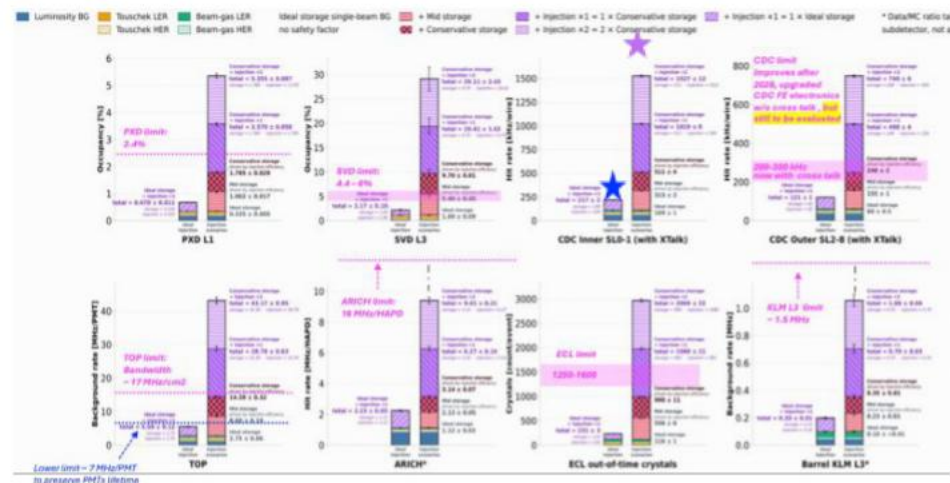
Background in 2026 vs new pre LS2 BG prediction

$$\beta_y^* = 1 - 0.9 \text{ mm in 2026 data}$$

Pre-LS2 from CDR: $\rightarrow I_{\text{ler}} \times I_{\text{her}}$
 $2.52 \times 1.82 = 4.6 \text{ A}^2, \beta_y^* = 0.6 \text{ mm}$

- Interesting to compare **new pre-LS2 prediction** with BG in data, using simple linear scaling with the product of beam currents
- Caveats:** slope could be higher/lower due to smaller β_y^* smaller pressure
- Ideal collimator settings and small inj BG blue star ★
- Large injection BG purple star ★

Preliminary



Above ~ 600 uA CDC outer layers will also start to have lower HV/gain (reduced by current limiter)

Simple linear extrapolation based on product of beam currents
 reasonable assumption with pressure and β_y^* similar to 2026

Bogdan Kutsenko
 Qingyuan Liu

24/10/2026

G. Rizzo

KLM rates
 $0.2 \text{ MHz}/50 \text{ m}^2 = 0.4 \text{ Hz}/\text{cm}^2$
 $1 \text{ MHz}/50 \text{ m}^2 = 2 \text{ Hz}/\text{cm}^2$

Background in 2026 vs new post LS2 BG prediction

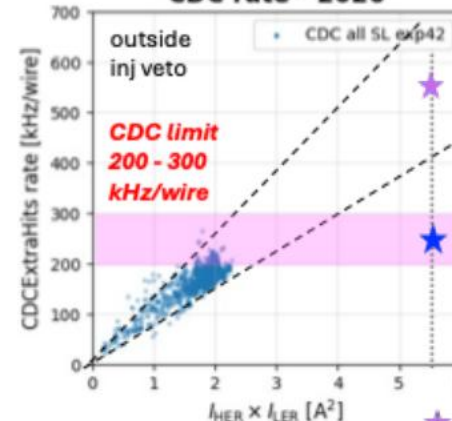
$$\beta_y^* = 1 - 0.9 \text{ mm in 2026 data}$$

$$\text{New Post-LS2} \rightarrow I_{\text{ler}} \times I_{\text{her}} \\ 2.8 \times 2.0 = 5.6 \text{ A}^2, \beta_y^* = 0.3 \text{ mm}$$

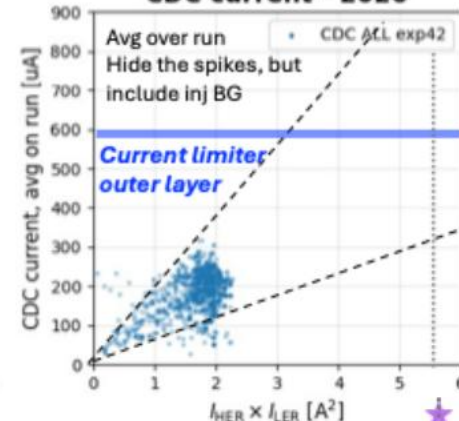
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- Caveats:** slope could be higher/lower due to smaller β_y^* smaller pressure
- Ideal collimator settings and small inj BG blue star ★
- Large injection BG purple star ★

Preliminary

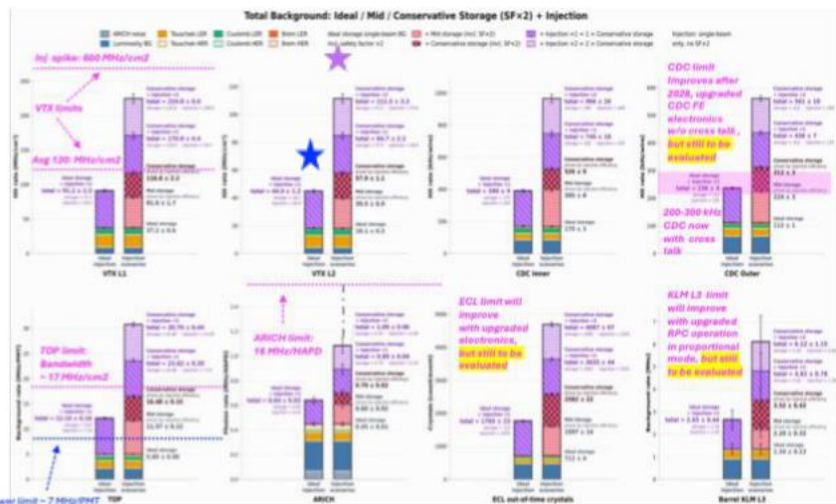
CDC rate - 2026



CDC current - 2026

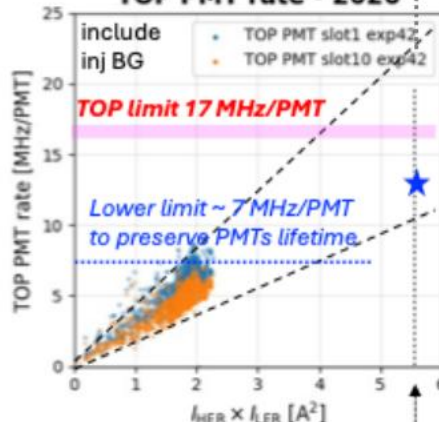


Above ~ 600 uA CDC outer layers will also start to have lower HV/gain (reduced by current limiter)



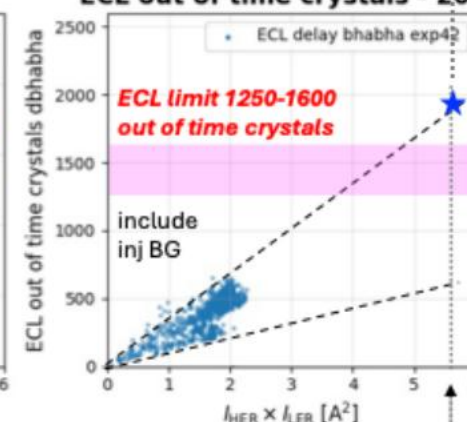
$I_{\text{HER}} \times I_{\text{LER}} [\text{A}^2]$

TOP PMT rate - 2026



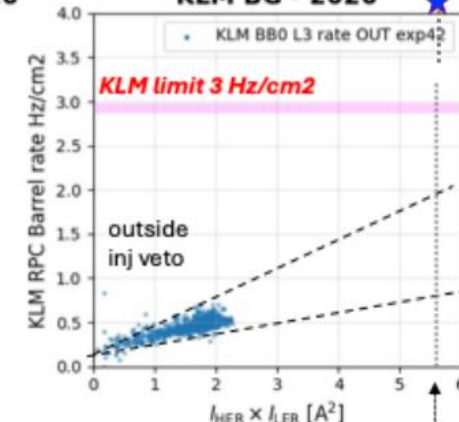
L=6e35
5.6 A²

ECL out of time crystals - 2026



L=6e35
5.6 A²

KLM BG - 2026



L=6e35
5.6 A²

Simple linear extrapolation based on product of beam currents
reasonable assumption with pressure and β_y^* similar to 2026

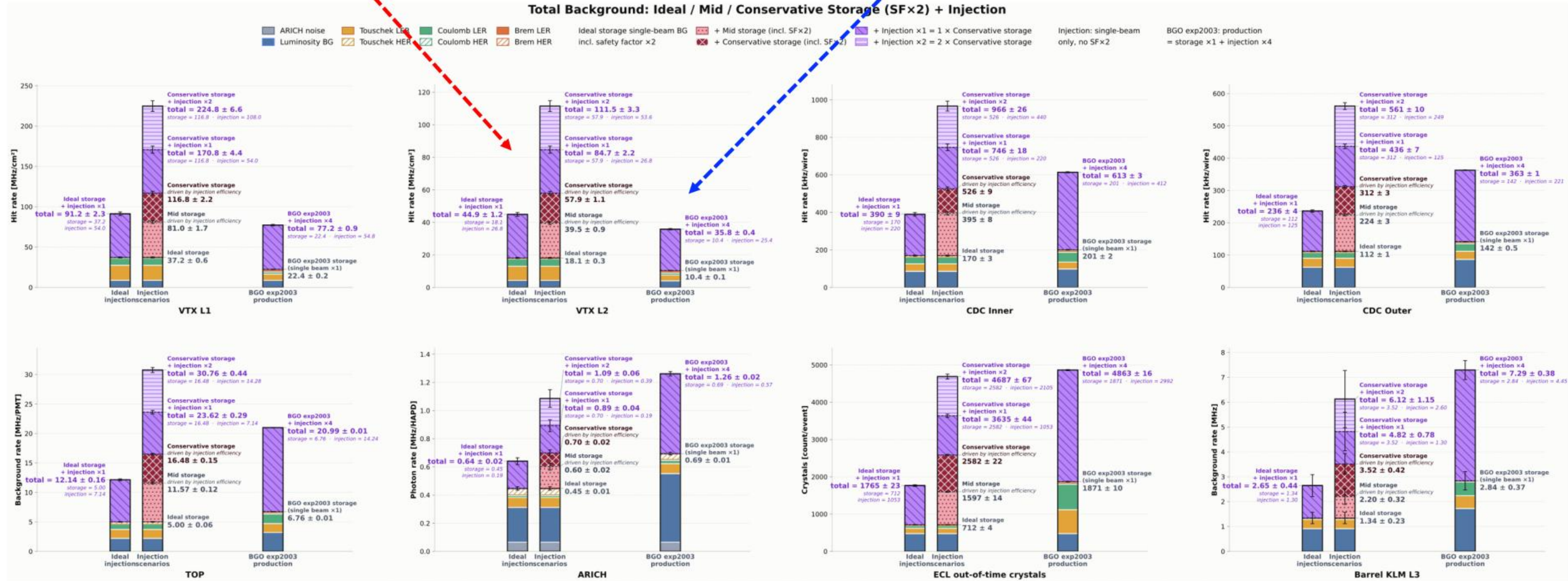
Bogdan Kutsenko
Qingyuan Liu

New post LS2 BG prediction vs BG Overlay 2003

2 scenarios

- ideal collimators & good injection
- conservative with higher injection

Produced with a previous version of the post-LS2 BG → will be redone



SKB parameters used in BG simulation

Setup	<i>Pre-LS2</i>	<i>Post-LS2</i>
$\beta_y^*(\text{LER/HER})$ [mm]	0.6/0.6	0.27/0.3
$\beta_x^*(\text{LER/HER})$ [mm]	60/60	32/25
$\mathcal{L}$ [$\times 10^{35}$ cm $^{-2}$ s $^{-1}$]	2.8	6.0
$I(\text{LER/HER})$ [A]	2.52/1.82	2.80/2.00
$\bar{P}_{\text{eff.}}(\text{LER/HER})$ [nPa]	48/17	52/18
n_b [bunches]	1576	1761
$\varepsilon_x(\text{LER/HER})$ [nm]	4.6/4.5	3.2/4.6
$\varepsilon_y/\varepsilon_x(\text{LER/HER})$ [%]	1/1	0.27/0.28
$\sigma_z(\text{LER/HER})$ [mm]	8.27/7.60	8.25/7.58
CW	ON	OFF

Setup	<i>Pre-LS2</i>	<i>Post-LS2</i>
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$\sigma_z(\text{LER/HER})$ [mm]	8.27/7.60	8.25/7.58
CW	ON	OFF

Post-LS2 Beam Background

BG Prospect for Post-LS2

(machine parameters not frozen)

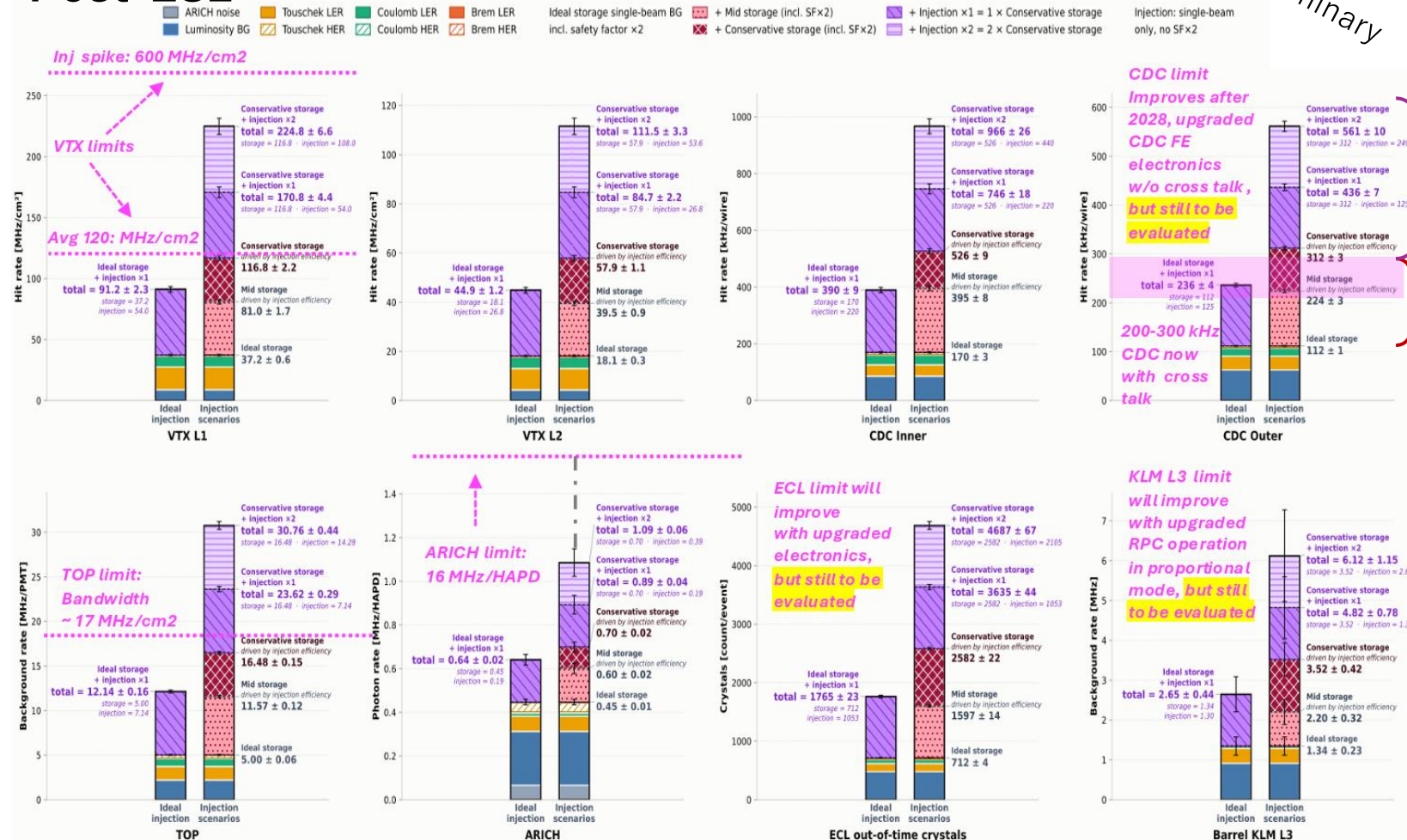
Machine Parameters for Post-LS2(assumed in CDR)

- $\beta^*y = 0.27/0.30\text{mm}$ (LER/HER), $\beta^*x = 32/35\text{mm}$
- $I_{\text{LER}} = 2.8\text{A}$, $I_{\text{HER}} = 2.0\text{A}$ (5.6A^2), $N_b = 1761$
- $L \sim 6\text{E}+35$

Post-LS2 machine parameters are still not frozen, making background prediction very uncertain

Post-LS2

Total Background: Ideal / Mid / Conservative Storage (SFx2) + Injection



- Left plots: SAD simulation of storage BGs using the latest post-LS2 SuperKEKB optics
- BG collimation becomes even more challenging with further squeezed β^*y**
 - Only a few vertical collimators can be closed due to TMCI limits at $\beta^*y \sim 0.3\text{mm}$
- Actual collimator settings are subject to operational constraints which results in higher storage BG**
 - Constraints such as poor injection efficiency, SBL risk, or other factors may require wider collimators. **This uncertainties on storage BG** shown separately in the plots as “Ideal” – “Mid-“Conservative” for storage BG
- Large uncertainty on injection BG**, not simulated yet
 - The plot only include rough estimates, assuming x1, x2 ... of storage BG. The sensitivity to injection BG differs among subdetectors, but the same factor is assumed here.
- SR impact is also under careful study
 - Significant impact on the ongoing effort of post-LS2 IR beam pipe design
- Detector limits** for upgraded detectors still need to be carefully evaluated
 - Further improvements in the limit could be partly possible in an early stage of the design

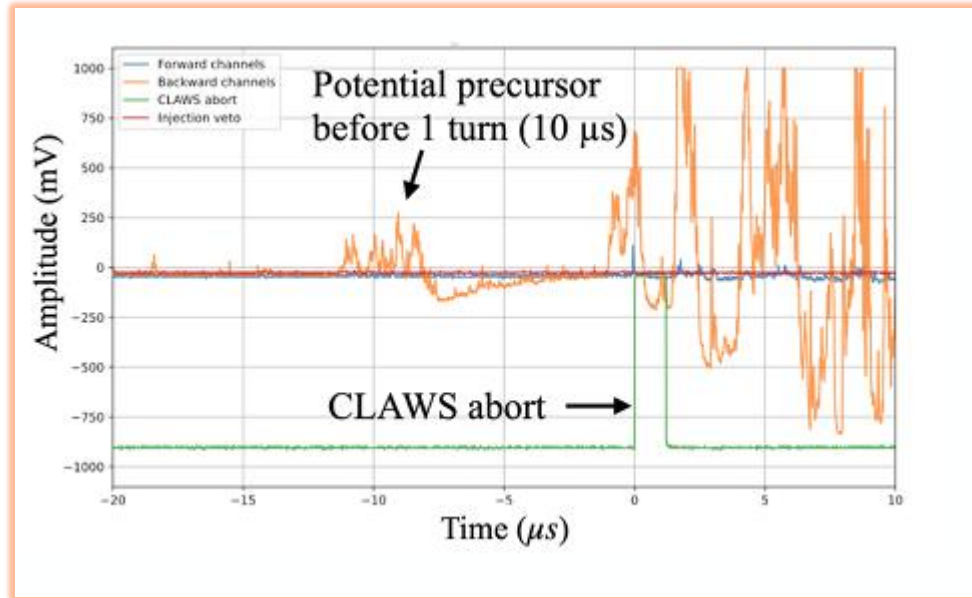
Bogdan Kutsenko

We need to define machine configuration asap, to understand future BG constraints on detectors design!

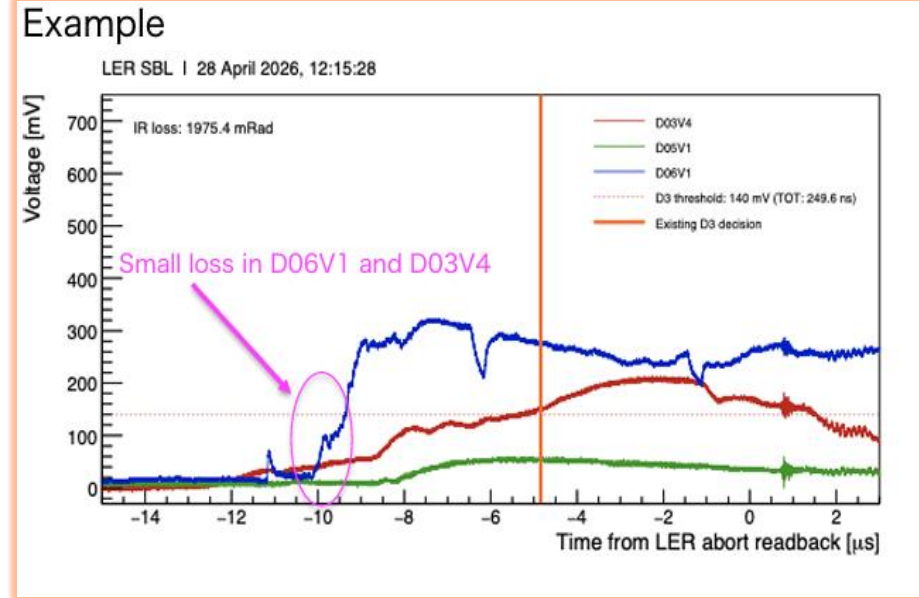
SBL precursor signals

a) Loss Monitors as SBL precursor?

[MDI report](#) by D. Ghosh

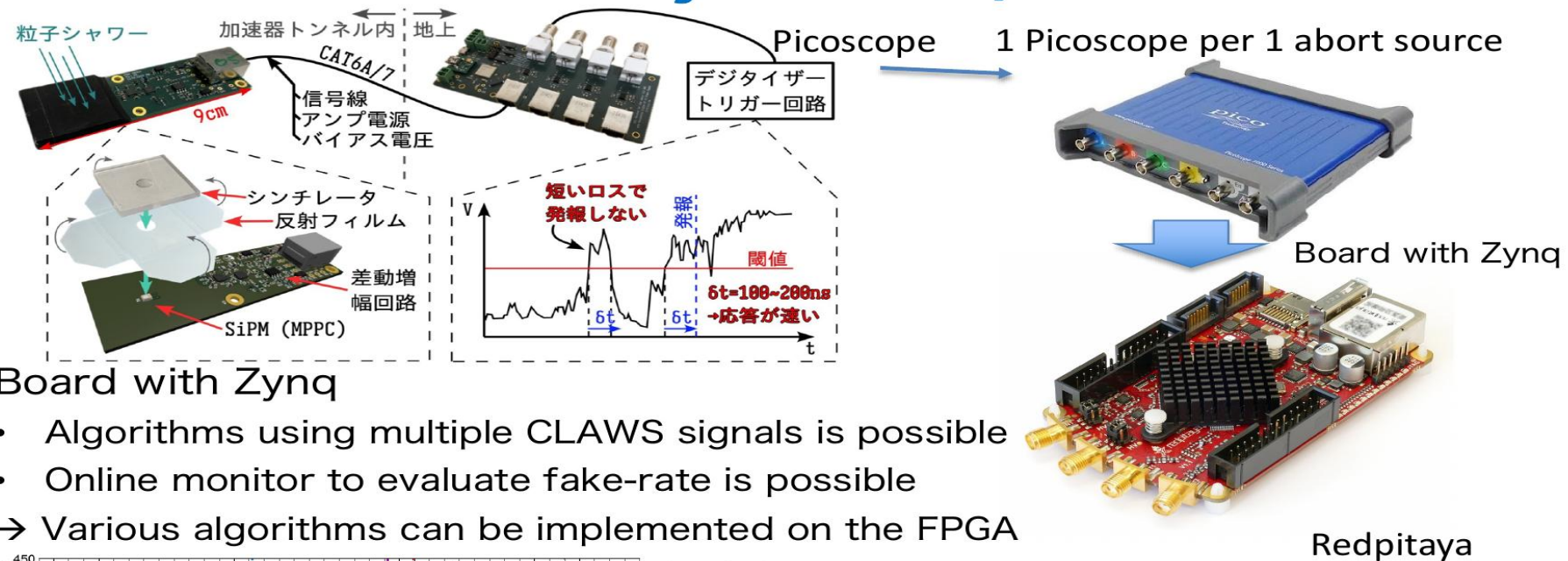


[MDI report](#) by K. Uno



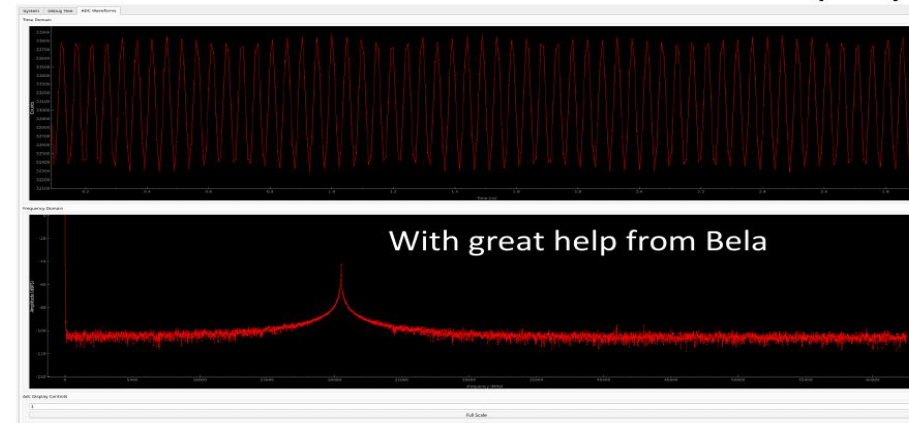
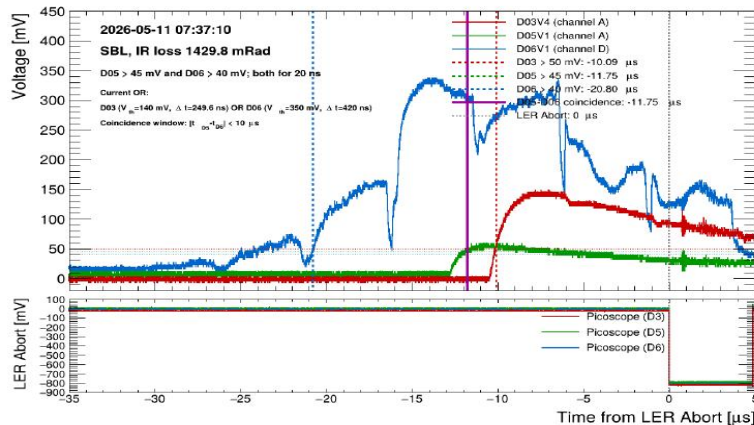
- Using a **single CLAWS sensors** at IR, we can issue a trigger at -18μs for 10% of SBLs (with fake trigger rate of <0.1mHz = several times per day)
- Lowering the threshold can trigger more SBL events but increases fake trigger rate.
- Using **multiple CLAWS sensors** may allow earlier triggering of SBLs with much reduced fake rate

Advanced abort system w/ multiple LMs



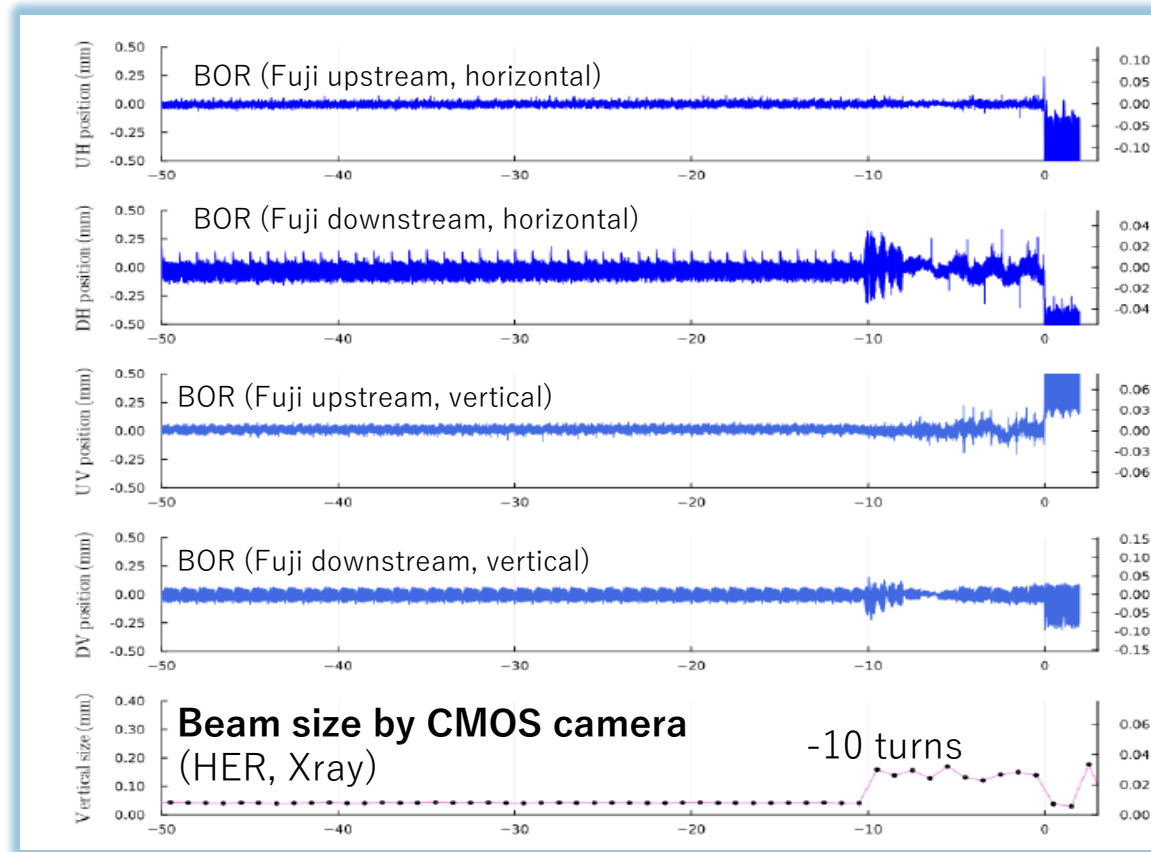
Board with Zynq

- Algorithms using multiple CLAWS signals is possible
 - Online monitor to evaluate fake-rate is possible
- Various algorithms can be implemented on the FPGA



- Readout board is prepared to combine multiple waveforms and issue a trigger
- Need to optimize anomaly-finding thresholds to minimize fake trigger rate

b) Beam size blowup as SBL precursor?



- In some SBL events, beam-size blow-up appears to start much earlier than the beam loss. Observed for both LER and HER.
 - Measurement available for limited bunches
- SuperKEKB beam size monitors: CMOS camera/gate-camera/Si-sensor on visible/X-ray beam lines for LER/HER
- Fast beam size measurement based on SiXRM (see next page) could be a promising candidate of SBL precursor signal.
- Remaining questions
 - Is beam-size blow-up significantly correlated with SBLs across events?
 - What are the achievable detection efficiency and warning time?

高速ビームサイズモニターの2027ab予定

	モニター種類	担当者	露光時間	トリガー	連続測定	オンライン解析
HER 可視光	高速ゲートカメラ	池田	100 ns	アボートトリガー	無	無
	高速CMOSカメラ	三塚	1 μ s (実効的に2 μ s)	Revolution x 0.5	~1000ターン	有
HER X線	高速CMOSカメラ	三塚	1 μ s (実効的に2 μ s)	Revolution	~1000ターン	有
	Siセンサーモニター	能丸、三塚	バンチバイバンチ	ソフトトリガー	1ターン	無
LER 可視光	高速ゲートカメラ	池田	100 ns	アボートトリガー	無	無
	高速CMOSカメラ	三塚	1 μ s (実効的に2 μ s)	Revolution x 0.5	~1000ターン	有
LER X線	高速CMOSカメラ	三塚	1 μ s (実効的に2 μ s)	Revolution	~1000ターン	有

- ゲートカメラデータ吸い取りのオンライン化が進行中(少なくとも予定)と聞いている。
- LER X線のCMOSカメラは周囲からの放射線被ばくが大きい、結構難しい。故障覚悟ならば検討。
- LER 可視光CMOSカメラとHER SiXRMは再開させる予定。ただし、SiXRMはセンサー基板の再製作が必要。
- 私見
 - データ解析面に注力していくのが良いと思う。
 - サイズ変化とSBLの相関は有意か？物理モデルに制限を加えられるか？SBL解決に貢献できるのか？
 - データ解析からmissing partを洗い出し、サイズモニター改良へつなげる。

Fast Beam Size monitor (SiXRM)

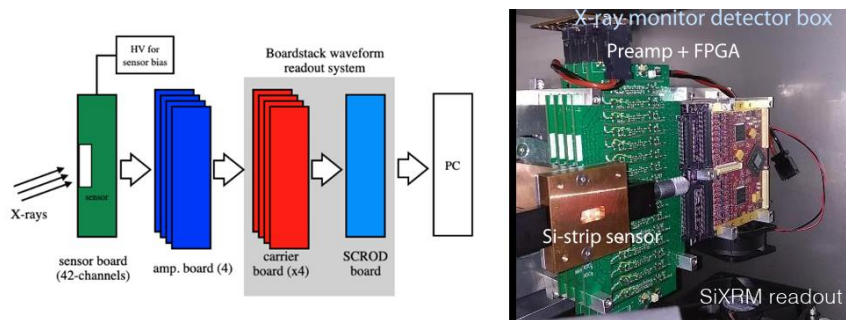
[MDI report by K. Yoshihara](#)

Motivation

- **Bunch-by-bunch beam size measurement is critical for understanding SBL mechanism.**
- In some SBL events, beam-size blow-up appears to start much earlier than beam oscillation seen in BOR.
- Fast beam size measurement could be a candidate of SBL precursor signal required for turning PXD back on.

Current SiXRM setup and its readout

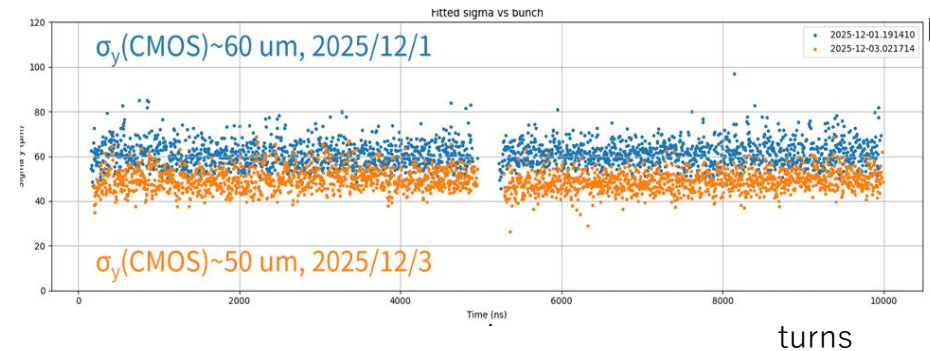
K.Yoshihara



SiXRM employs Belle II TOP boardstack to enable bunch-by-bunch measurement

Riku Nomaru, Bela Urbschat, Cody Driver, Gaku Mitsuka, Matt Andrew, Keisuke Yoshihara

Successful bunch-by-bunch beam size measurement

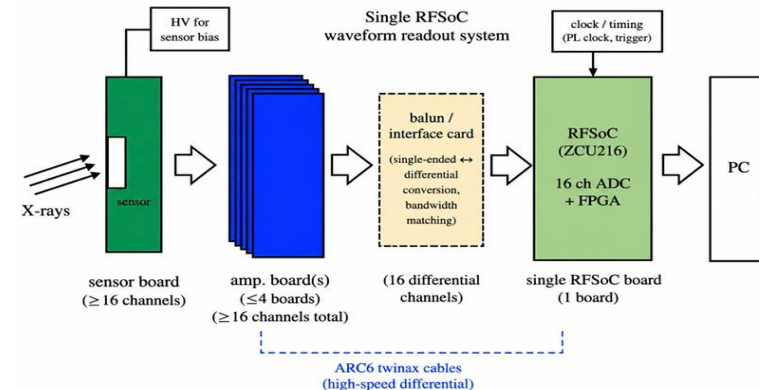


Riku Nomaru

Consistent with turn-by-turn measurement by CMOS sensor

RFSoc-based readout and NN-based beam-size estimation on FPGA are getting ready

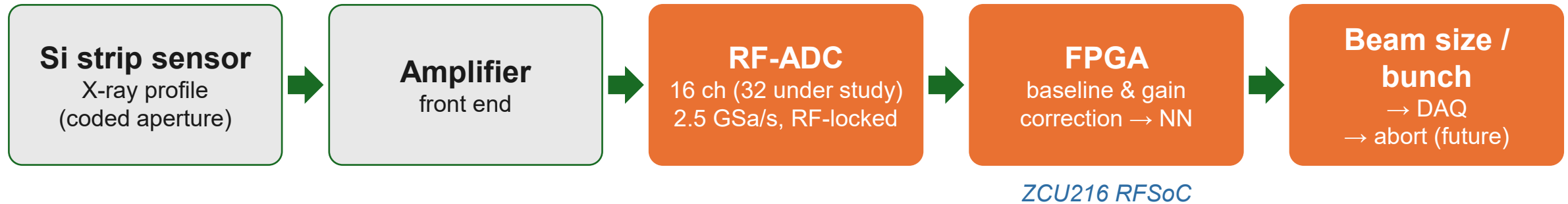
Yoshihara



SiXRM: toward real-time SBL precursor detection

Silicon-strip X-ray beam size monitor, HER X-ray line — Univ. of Hawaii / KEK

Readout upgrade: TOP boardstack (triggered) → AMD RFSoc ZCU216 (continuous)



Online algorithm (UH, 2025 beam data)

- Small neural network (hls4ml, quantized) estimates σ_y from the 16-strip profile; 16 vs 32 channels being compared
- FPGA-friendly baseline correction reproduces the offline analysis within a few μm
- Pseudo-data generator from 2025 data for training and firmware tests

Plan

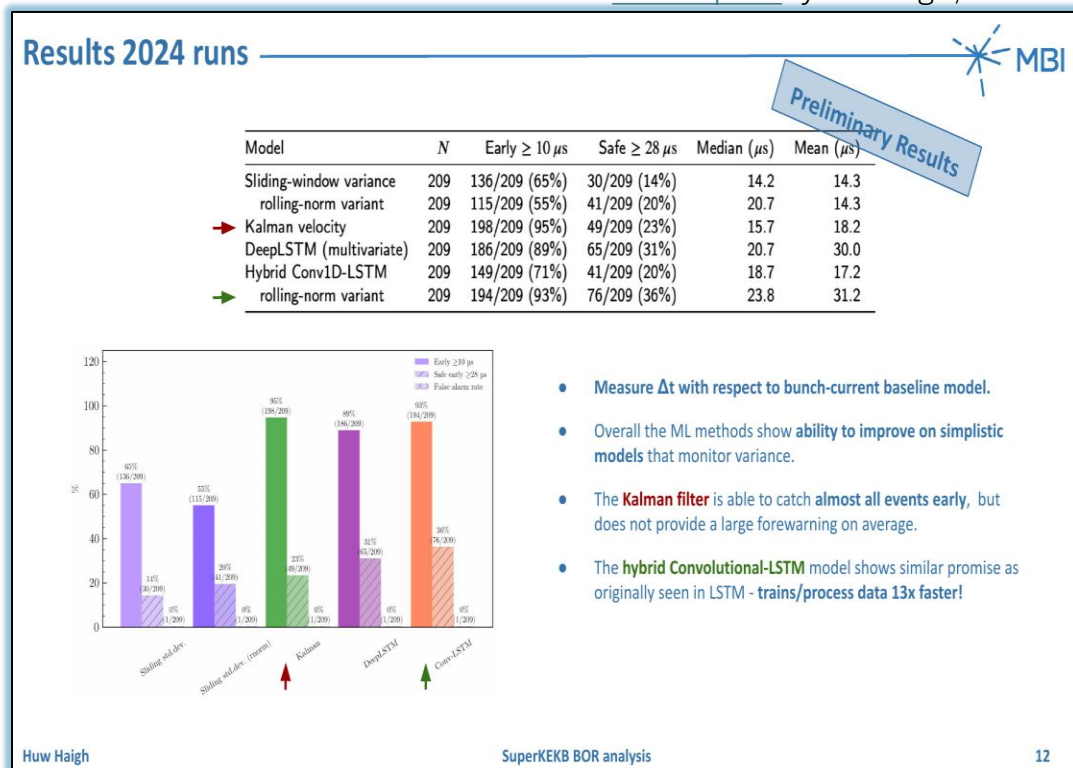
- **Oct 2026** RFSoc readout test at KEK, then sensor + amplifier test
- **2027ab** "Shadow mode": continuous monitoring, not connected to abort; study σ_y around SBL events
- **Later** Set threshold from shadow-mode data, connect to abort system

Bunch-by-bunch σ_y with the present readout agrees with the CMOS monitor, precision $< 6.4 \mu\text{m}$ (arXiv:2607.08205)

c) BOR waveforms

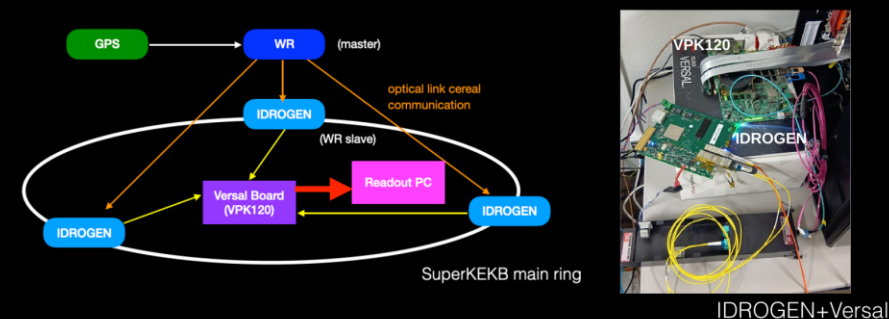
MDI report by H. Haigh, P. Horak

K. Yoshihara



- Offline analysis on 209 SBLs in 2024
- Various anomaly-detection methods are compared
- 71–90% can be flagged $\geq 10 \mu\text{s}$ before loss, depending on the method. Up to 36% have a $\geq 28 \mu\text{s}$ warning margin in the preliminary study.
- Fake rate looks acceptable but should be further checked by taking random-trigger data
- Paper draft on [arxiv](https://arxiv.org/abs/2406.12345)

Bunch Oscillation Recorder (BOR)



- A multi-BOR system with unified hardware is being developed:
 - ▶ Beam oscillation may also be useful for SBL precursor detection.
 - ▶ Timestamp sharing enables synchronized analysis.
- Readout R&D at KEK: IDROGEN + Versal Board (VPK120)
- Collaboration with KEK, UH, Giessen, and IJCLab

June 11, 2026 Kelsuke Yoshihara

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- Install multiple BORs and synchronized readout to conduct online analysis for anomaly triggering
- Hardware R&D for IDROGEN modules and Versal Board is currently ongoing

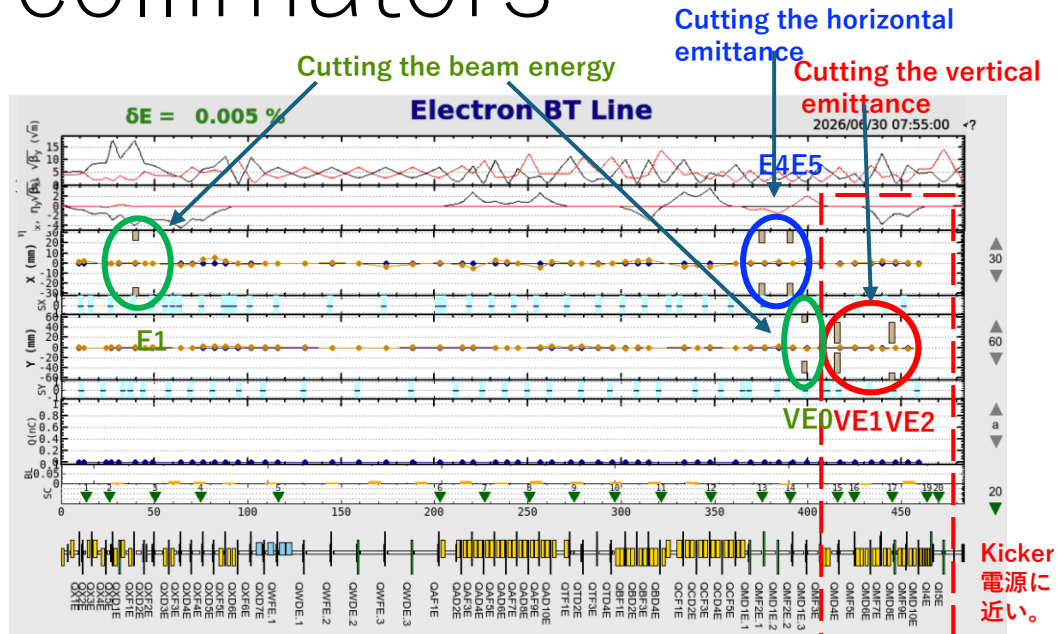
BT collimator study

Injection improvement with BT collimators

- Closing BT collimators could improve injection beam quality
 - 6 collimators in electron line, 7 collimators in positron line
- Dedicated study planned for 2027 runs
 - Jan: BT collimator width vs. local beam loss at the collimators
 - After MR start: BT collimator width vs. various injection BG variables (efficiency, loss, duration, frequency, etc)
- Limitation: radiation dose on the kicker PS should be kept in acceptable level
 - Dedicated sensors for dose monitoring will be installed (neutron/gamma)
- Team building:
 - SKB Beam injection TF (management)
 - SKB BT group (conduct machine study, hardware preparation)
 - Belle II loss monitor group (conduct machine study, sensor preparation)
 - Xsuite group (beam line simulation)

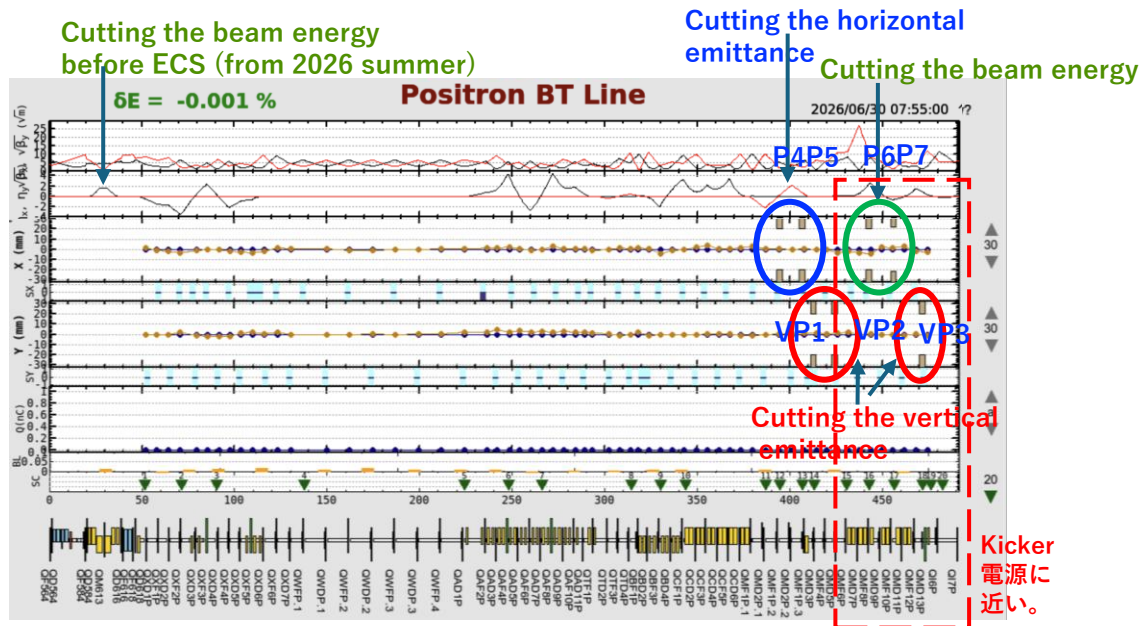
BT collimators

e^-



Collimator BTe	BPM
E1	BTeBPM:QXF1E_M_1:XPOS_1Hz
E4	BTeBPM:QMF2E_1M_1:XPOS_1Hz
E5	BTeBPM:QMF2E_2M_1:XPOS_1Hz
VE0	BTeBPM:QMD1E_3M_1:YPOS_1Hz
VE1	BTeBPM:QMD4E_M_1:YPOS_1Hz
VE2	BTeBPM:QMD8E_M_1:YPOS_1Hz

e^+



Collimator BTp	BPM
P4	BTpBPM:QMF1P_2K_1:XPOS_1Hz
P5	BTpBPM:QMF1P_3K_1:XPOS_1Hz
P6	BTpBPM:QMF8P_K_1:XPOS_1Hz
P7	BTpBPM:QMF10P_K_1:XPOS_1Hz
VP1	BTpBPM:QMD3P_K_1:YPOS_1Hz
VP2	BTpBPM:QMD5P_K_1:YPOS_1Hz
VP3	BTpBPM:QMD13P_KL_1:YPOS_1Hz