

Dark Matter Search with $e^+ e^-$ collider: B05 Update

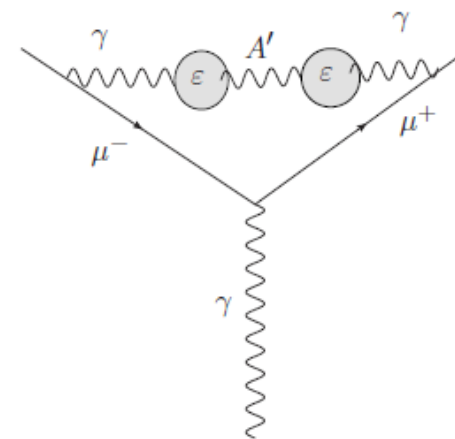
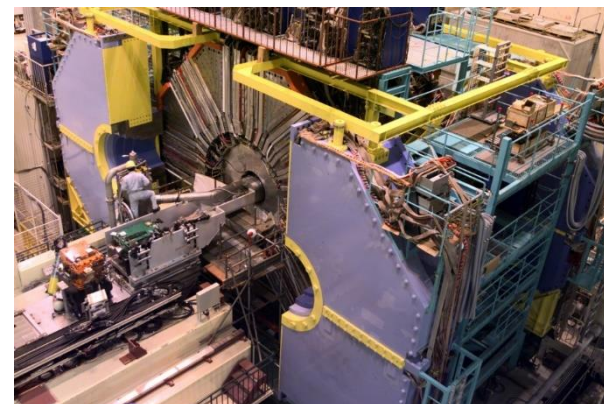
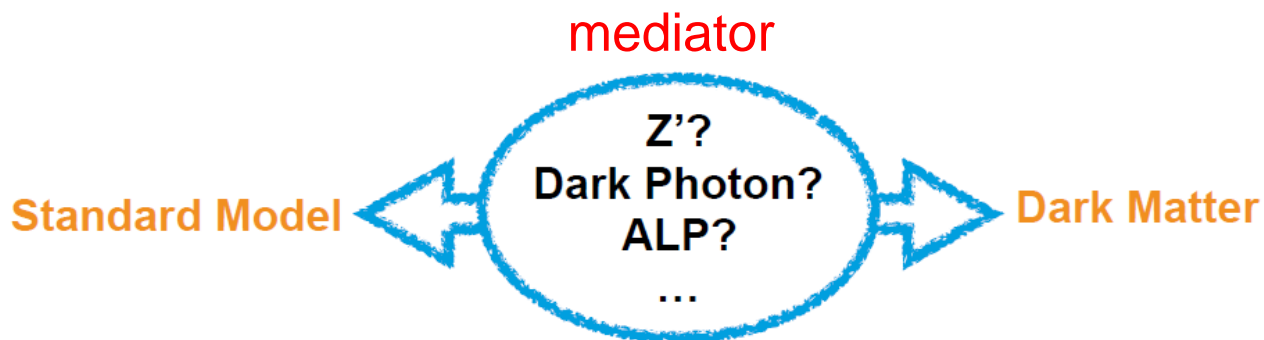
Shohei Nishida

KEK

Dark Matter Symposium

Mar. 7, 2024

- Search for Dark Matter (DM) at Belle, Belle II.
 - ✓ CM energy is $\sim 10\text{GeV}$
 - mass region up to $O(1)\text{ GeV}$ (“light DM”)



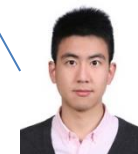
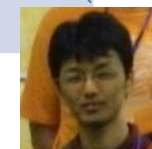
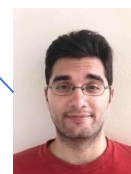
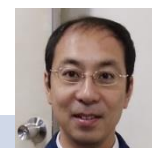
Bonus

- A', Z' may explain the discrepancy of $(g-2)_\mu$ between theory and experiment.
- Typical process
 - ✓ $e^+ + e^- \rightarrow \text{SM-particles} + \text{Mediator}$
 - ✓ $B \text{ (or other hadron)} \rightarrow \text{SM-particles} + \text{Mediator}$
- Some of these processes have not been searched in BaBar or Belle experiment (due to trigger setting etc.), and may be searched with initial Belle II data.

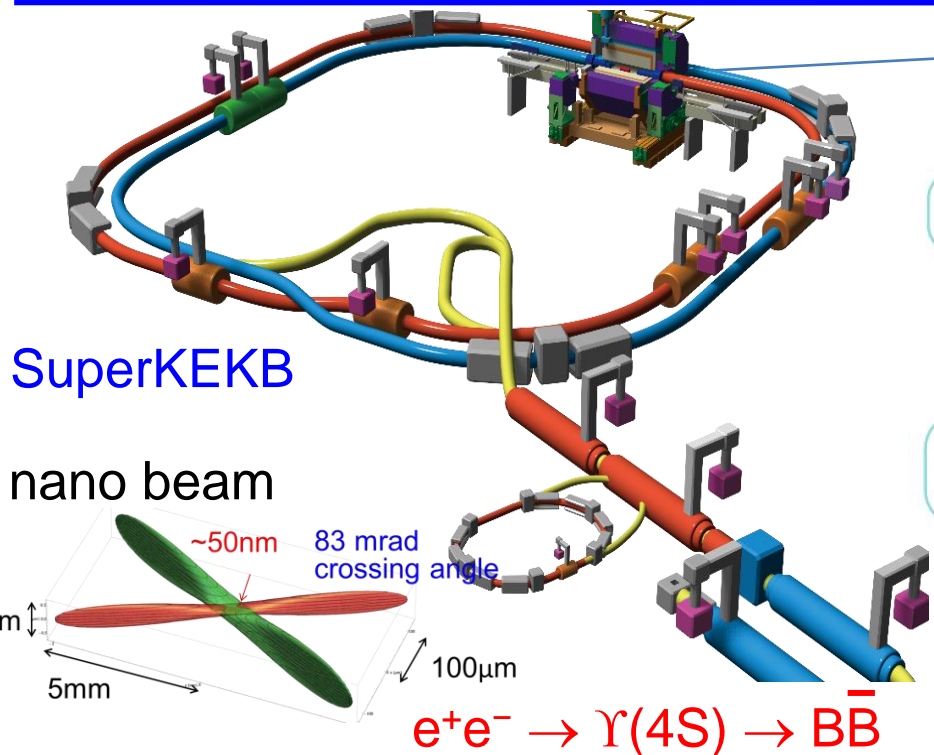
B05「電子陽電子加速器によるダークマター探索」

B05 “Dark Matter Search with Electron-Positron Collider”

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旧メンバー 伊藤 慎太郎 (Shintaro Ito) → 北九州工業高専
Eiasha Waheed



Belle II

EM Calorimeter

CsI(Tl), waveform sampling electronics

electrons (7 GeV)

Vertex Detector

2 layers Si Pixels (DEPFET) +
4 layers Si double sided strip DSSD

Central Drift Chamber

Smaller cell size, long lever arm

KL and muon detector

Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC
(end-caps, inner 2 barrel layers)

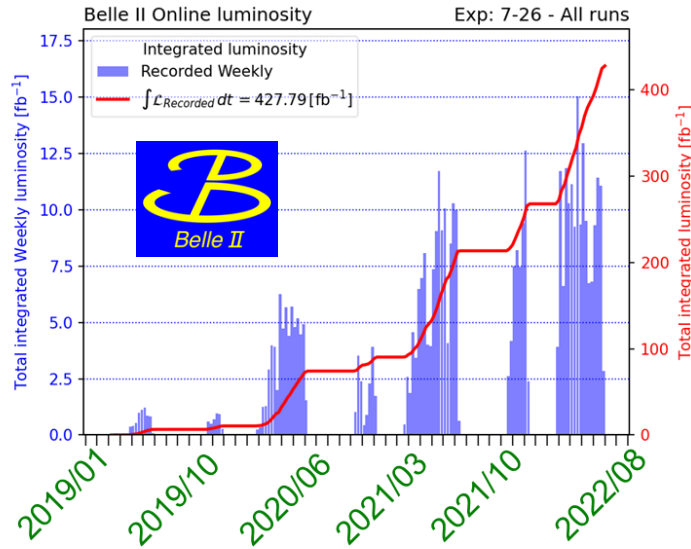
Particle Identification

Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (forward)

positrons (4 GeV)

Belle II TDR, arXiv:1011.0352

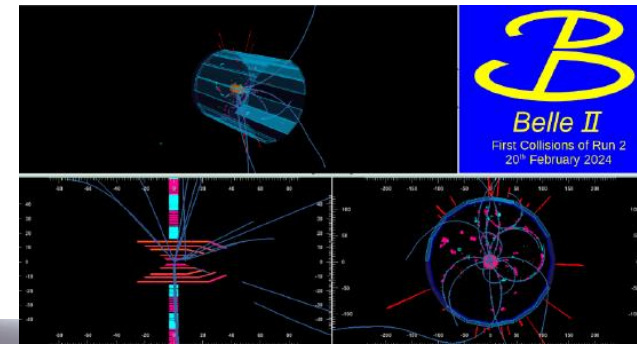
- Belle II experiment at KEK: flavor physics experiment, successor of Belle.
- SuperKEKB asymmetric electron-positron collider: 4 GeV e^+ + 7 GeV e^- .
- Nano beam scheme to achieve high luminosity.
- Run1 Operation 2019-2022 \rightarrow Long Shutdown (LS1) \rightarrow Run2 2024-



- Long shutdown (LS) 1 from summer 2022 to fully install the pixel detector (PXD) has been successfully finished.
- Improvement in SuperKEKB

- Luminosity $4.7 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ achieved (Jun. 2022):
 - ✓ World record ($\sim \times 2$ of KEKB)
 - ✓ Aiming one order higher.
- 424 fb^{-1} of data accumulated so far.
 - ✓ Belle: 1 ab^{-1} in 11 years.
 - ✓ Belle II target: 50 ab^{-1} .

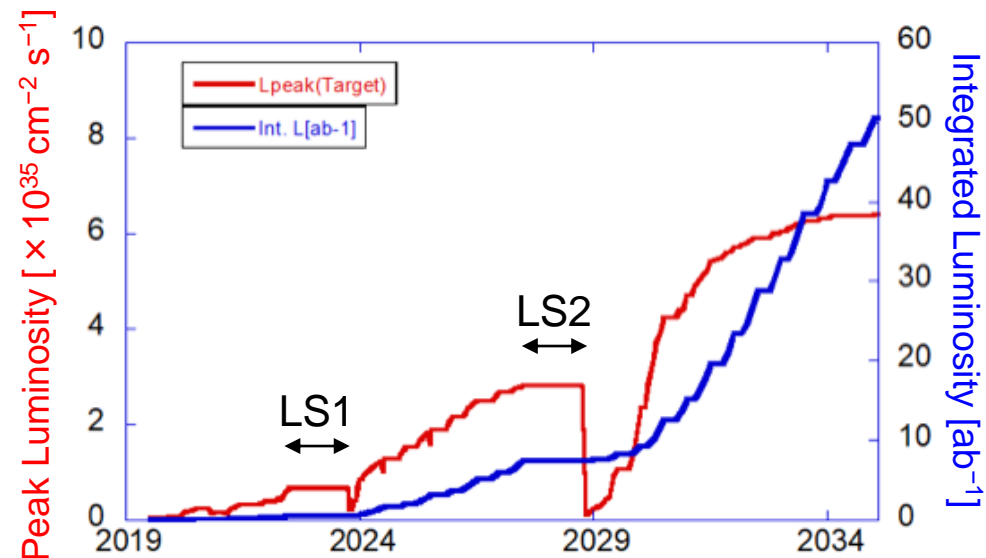
First collision in Run2 (2024/2/20)



- Run 2 just started.
 - ✓ We will also see the situation of the beam background and trigger rate (presented last year).
- In parallel, data analysis using Run 1 data (362 fb^{-1}) is going on.
- Analyses using run 2 data should show up in the end of JFY2024.
- Many results will come.
- $e^+e^- \rightarrow \gamma A' (\rightarrow \text{invisible})$ analysis is waiting for reprocessing of the data, which is necessary for background suppression. This will come this year (?).

Target for 2024 run

- Run stably at $10^{35} \text{ cm}^{-2} \text{ s}^{-1}$
- Reach 150 fb^{-1} per month
- Exceed 1 ab^{-1}



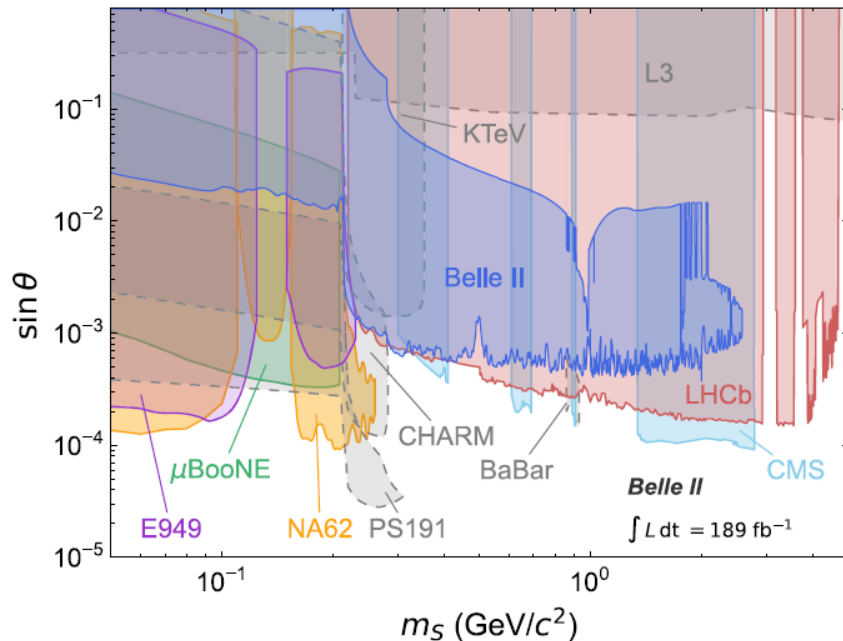
Recent or on-going searches at Belle (II)

- $e^+e^- \rightarrow \gamma A' (\rightarrow \text{invisible})$ [on-going at Belle II] → T. Czank's talk
- $Z' \rightarrow \text{invisible}$ [PRL 130, 231801] : on-going at Belle, Belle II
- $Z' \rightarrow \mu^+\mu^-$ [PRD 106, 012003 (Belle), new result coming (Belle II)]
- $Z' \rightarrow \tau^+\tau^-$ [Phys.Rev.Lett 131, 121802 (Belle II)] new
- ALP (Axion Like Particle) $e^+e^- \rightarrow a (\rightarrow \gamma\gamma) \gamma$ [PRL125 (2020), 161806]
- Dark Higgsstrahlung $e^+e^- \rightarrow A' (\rightarrow \mu^+\mu^-) h' (\rightarrow \text{invisible})$ [PRL 130, 071804 (2023)]
- Heavy neutral lepton (S.Dey) → S.Dey's talk
- Dark Matter etc. from B (Υ, τ, \dots) decays.
 - ✓ $B \rightarrow K S (\rightarrow \text{leptons})$: dark scalar
 - ✓ $B \rightarrow K S (\text{long-lived})$: long-lived dark scalar [Phys.Rev.D 108, 111104 (Belle II)] new
 - ✓ $B \rightarrow K a (\rightarrow \gamma\gamma)$: ALP search
 - ✓ $B \rightarrow K a (\rightarrow \text{hadrons})$: heavy QCD axion (S.Ito, E.Waheed → S.Dey)
 - ✓ $\Upsilon(1S) \rightarrow \gamma + \text{invisible}$: light Higgs [PRL 128, 081804 (2022) (Belle)]
 - ✓ $\tau \rightarrow l \alpha$ [Phys.Rev.Lett. 130 (2023) 181803] → update with Belle (K.Uno)
 - ✓ $D^{*0} \rightarrow D^0 A' (\rightarrow e^+e^-)$ (H.Kindo) : a little stalled

Long-lived dark scalar

[Phys.Rev.D 108, 111104 (Belle II)]

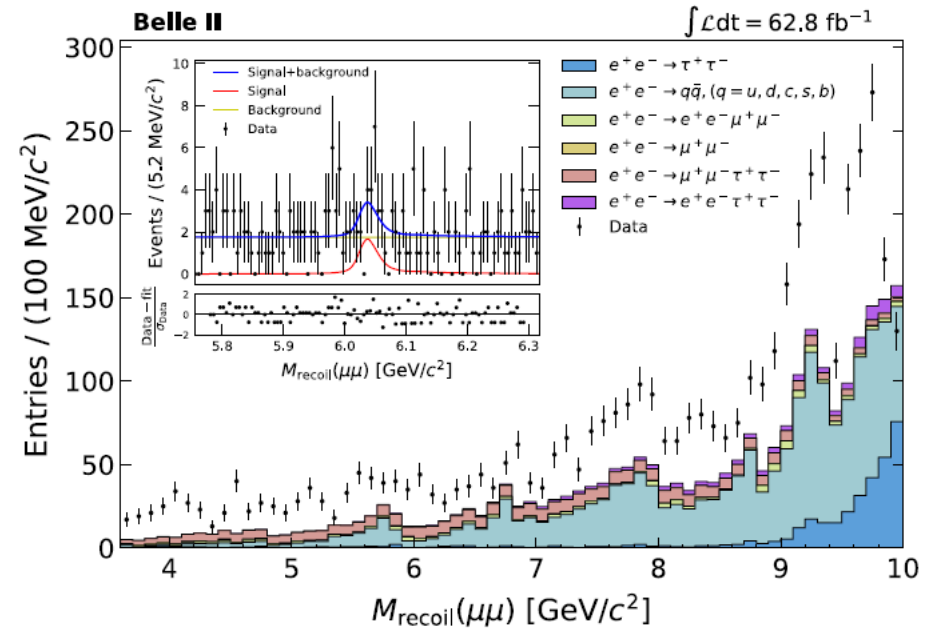
- Long lived spin-0 mediator in $b \rightarrow s$
- $B \rightarrow K(*) S (\rightarrow x^+x^-)$
- 189 fb^{-1}



$e^+e^- \rightarrow X(\tau^+\tau^-) \mu^+\mu^-$

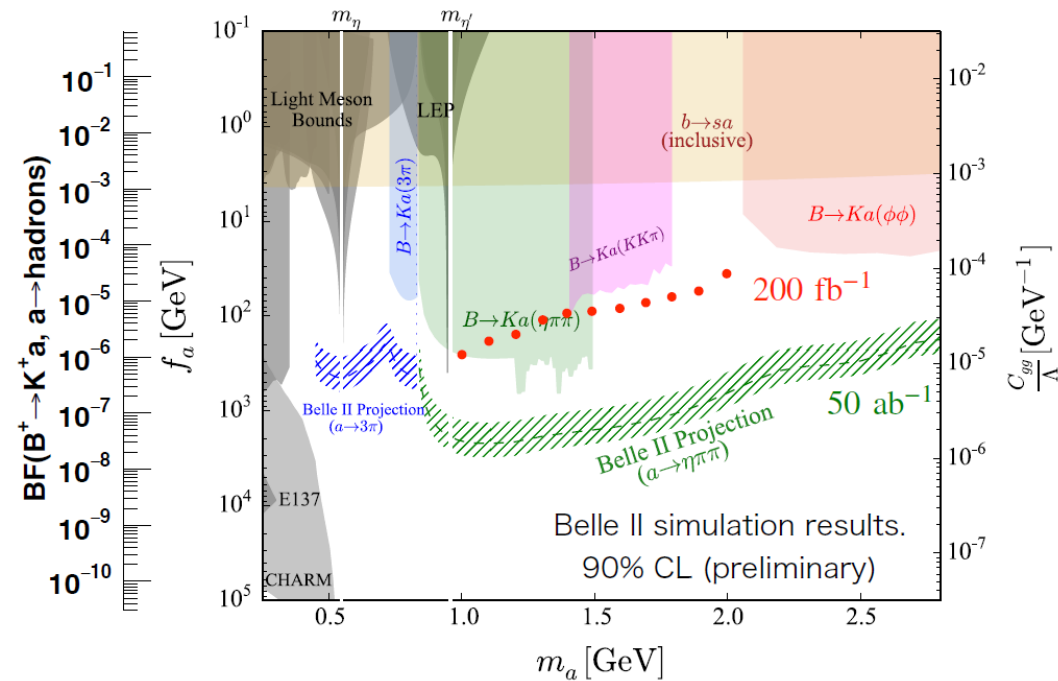
[Phys.Rev.Lett 131, 121802 (Belle II)]

- $X = Z', S, \text{ALP}$
- 63 fb^{-1}



- Discrepancy are due to ISR in 4 lepton process ($<6\text{GeV}$) and 2-photon processes not well estimated in MC.

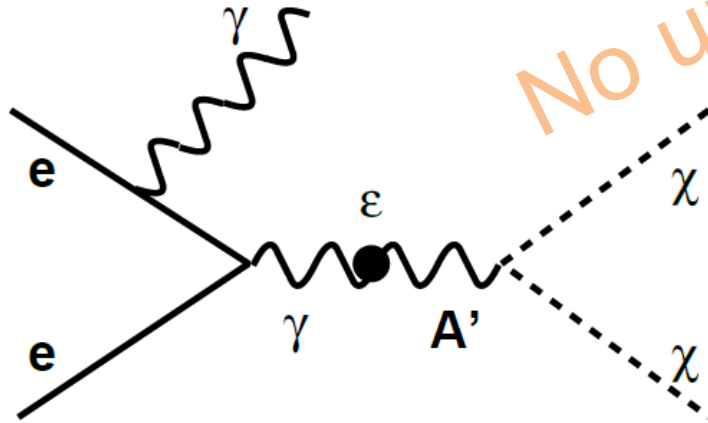
- Heavy QCD axion $m_a \gg m_\pi f_\pi / f_a$
 - ✓ Solve strong CP problem.
 - ✓ May provide some hints in dark matter search.
- Can be searched through $B^+ \rightarrow K^+ a$, $a \rightarrow \text{hadrons}$
 - ✓ B.F. of $a \rightarrow \text{hadrons}$ can be predicted assuming axion-gluon coupling is dominant over axion-SM coupling



- S. Ito was working on this analysis with 189 fb^{-1} data, left B05 and Belle II.
- Taken over by S.Dey (joined 2023 Sep). Aiming this year with 362 fb^{-1} data.

Backup

$$e^+e^- \rightarrow \gamma + \text{invisible}$$

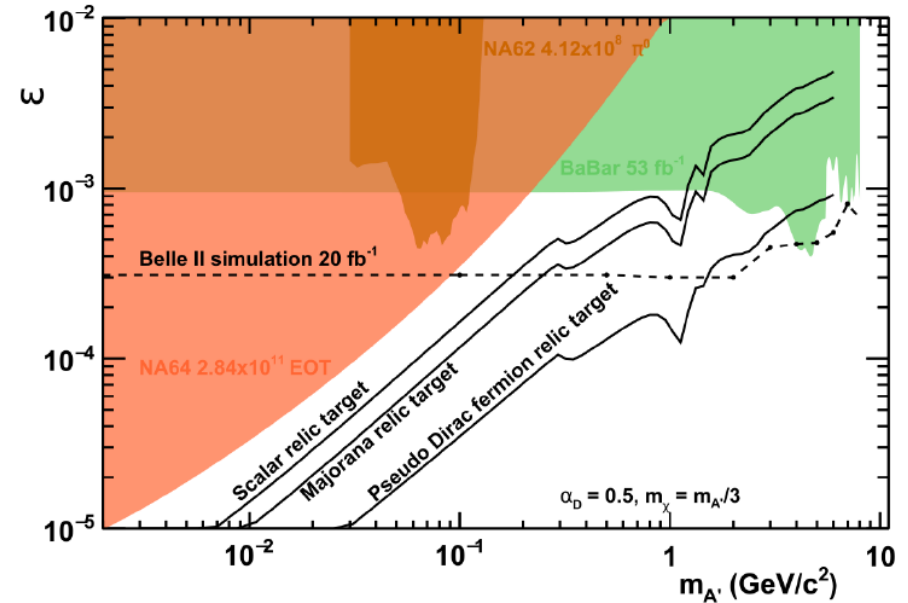


No update

On-going analysis at Belle II

Dark Photon A' , SIMP (Strongly Interacting Massive Particle)...

- Final state: a single photon only.
- Bump in a recoil mass or photon energy.
- Need special “single photon trigger” to collect such events.
 - ✓ Belle didn't have this trigger.
 - ✓ BaBar had it (for some period).
- Main background $e^+e^- \rightarrow \gamma\gamma(\gamma)$
 - ✓ Need understanding the detector.

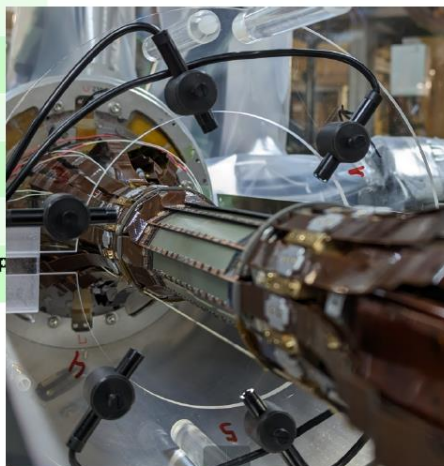


Still need more time to study.
Waiting the update of the analysis library + process...

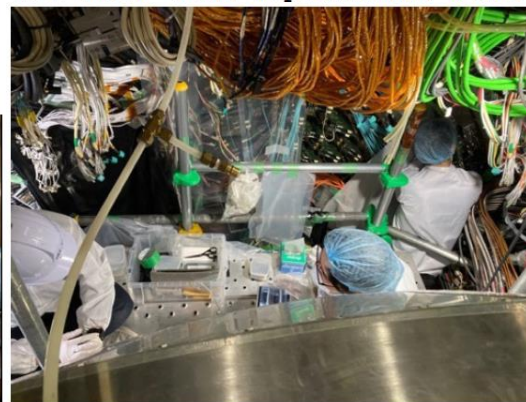
PXD/SVD	PXD commissioning plan in KEK, and VXD reinstallation. SVD 3/6-mixed mode.
CDC	Improvement in gas circulation and monitoring
TOP	TOP MCP-PMT replacement
ECL	Improvement in pedestal correction Gain adjustment on ShaperDSP
KLM	BB2 efficiency recovery Reinforcement of monitoring system
TRG	Optimization of trigger veto. TOPTRG
DAQ	PCIe40 long-term stability test with realistic high-occupancy data
Background	Additional neutron shields
MDI	Installation of additional loss monitors and speed-up abort signal

2022-2023

PXD2 at KEK since March



TOP MCP-PMT replacement work



CDC FE reinstallation work



VXD extraction in May



SVD standalone commissioning



but also DAQ upgrade, KLM work,



Belle and Belle II experiment:

- KEK (High Energy Accelerator Research Organization) in Tsukuba, Japan.
- Accelerator: KEKB / SuperKEKB
 - ✓ Linac + 3km ring
 - ✓ Asymmetric e^+e^- collider
- “B factory experiments” (produce large amount of B mesons).

Accelerator	KEKB	SuperKEKB
Experiment (Detector)	Belle	Belle II
Operation (Year)	1999-2010	2019-
Beam Energy	3.5 GeV e^+ + 8 GeV e^-	4 GeV e^+ + 7 GeV e^-
Luminosity [$\text{cm}^{-2} \text{s}^{-1}$]	2.1×10^{34}	$3.8 \times 10^{34} / 6 \times 10^{35}$ (target)