B05: Electron-Positron Accelerator

Shohei Nishida

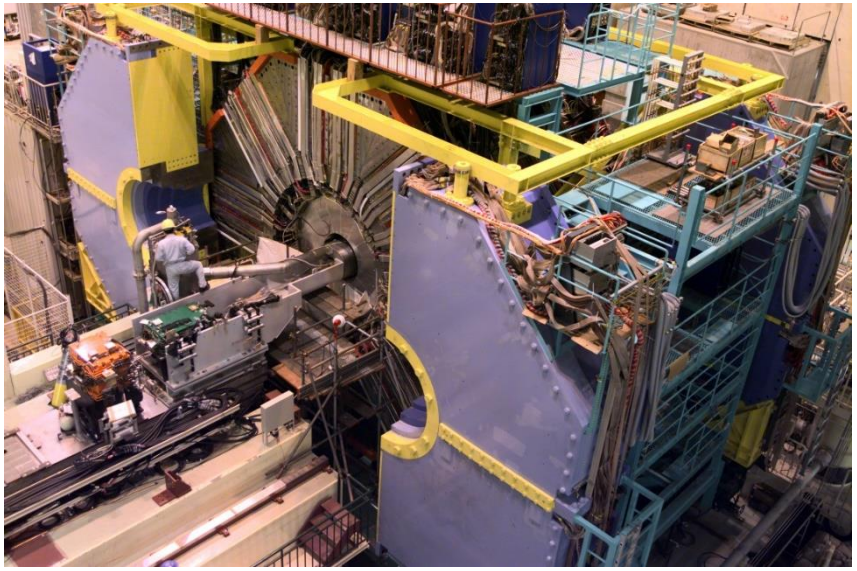
KEK

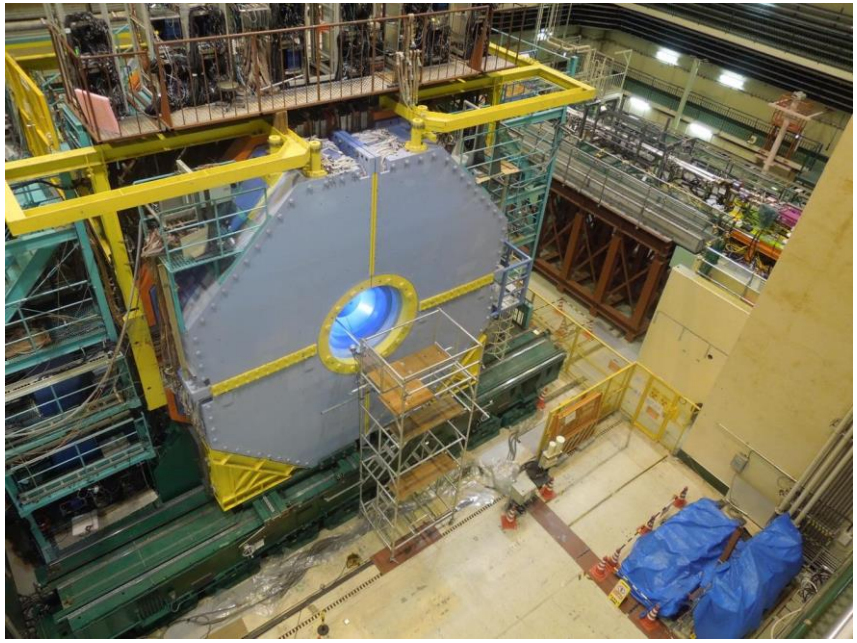
Dark Matter Symposium

Feb. 6, 2021

Contents

- Introduction
- Belle II experiment
- Dark Matter Search at Belle II.





B05 Members

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”

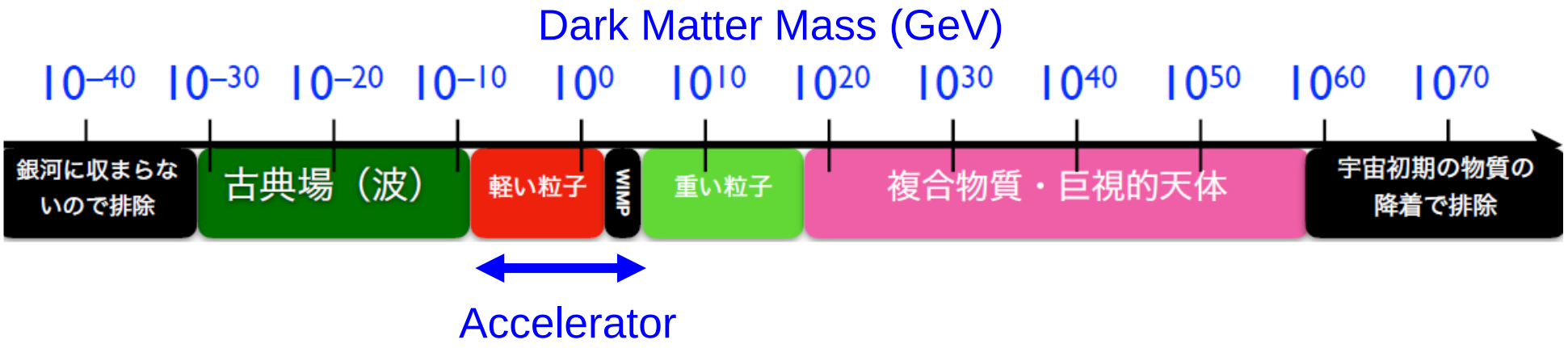
研究代表者 (Principal Investigator)	西田昌平(Shohei Nishida)	KEK
研究分担者 (Co-investigator)	原康二 (Koji Hara)	KEK
研究分担者 (Co-investigator)	角野秀一 (Hidekazu Kakuno)	首都大(TMU)
研究分担者 (Co-investigator)	Thomas Czank	IPMU
研究分担者 (Co-investigator)	Yun-tsung Lai	IPMU
研究協力者 (Collaborative Researcher)	松本重貴 (Shigeki Matsumoto)	IPMU






+ one new PostDoc researcher at KEK from JFY2022 (now under selection)

Dark Matter Search @Accelerator



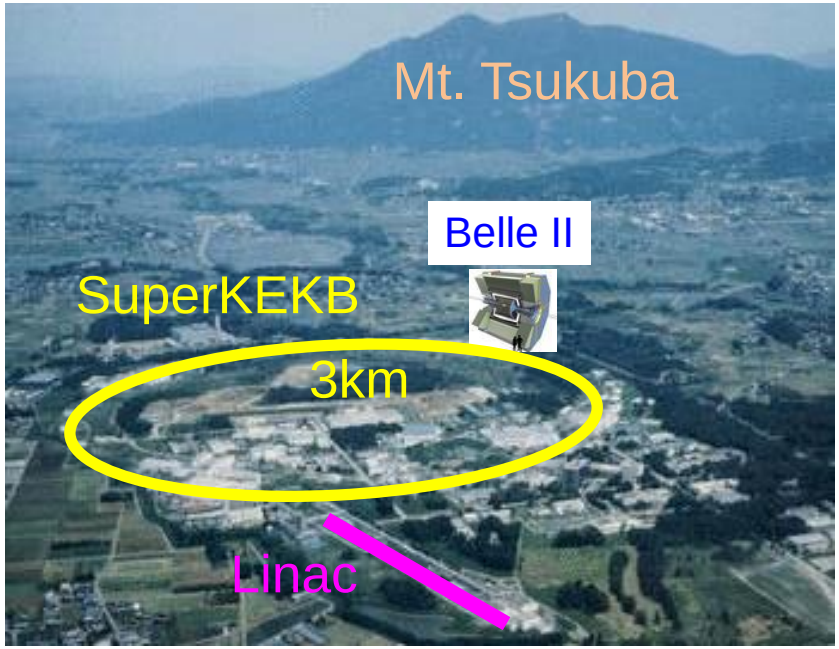
e^+e^- collider

- KLOE, BaBar, Belle, Belle II
- ~ 10 GeV : sub GeV region
- Clean environment
  - ✓ missing energy → invisible channels.
- (ILC 250 GeV … future)

hadron collider

- LHC (ATLAS, CMS, LHCb)
- ~ 10 TeV : WIMP search
- Also search to sub GeV region (competitive)
  - ✓ large cross section.

Belle II Experiment

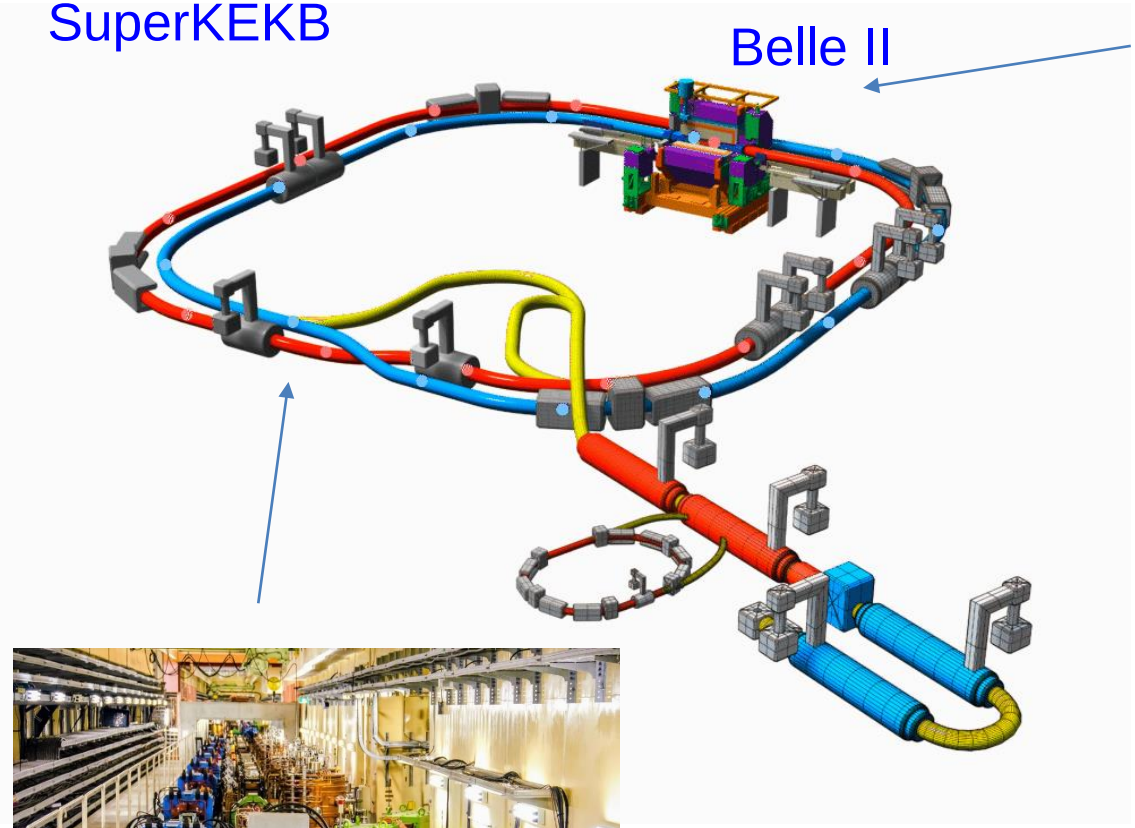


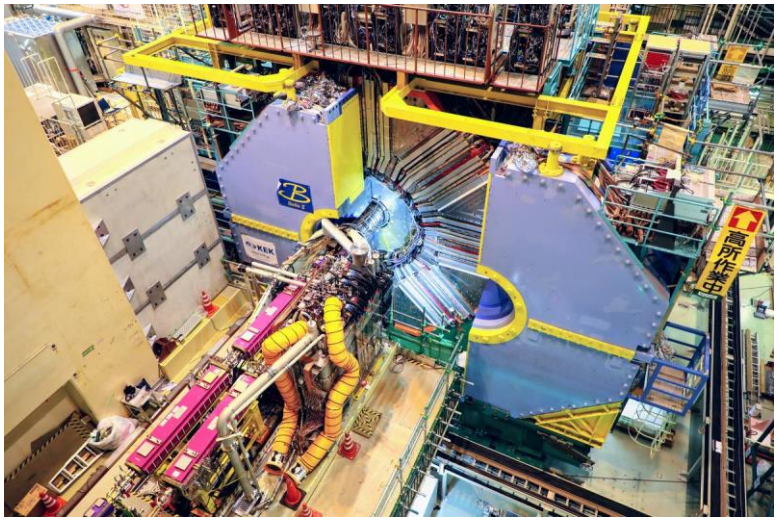
Belle and Belle II experiment:

- 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 [$cm^{-2}\ s^{-1}$]	2.1×10^{34}	2.4×10^{34} / 8×10^{35} (target)

Belle II Experiment





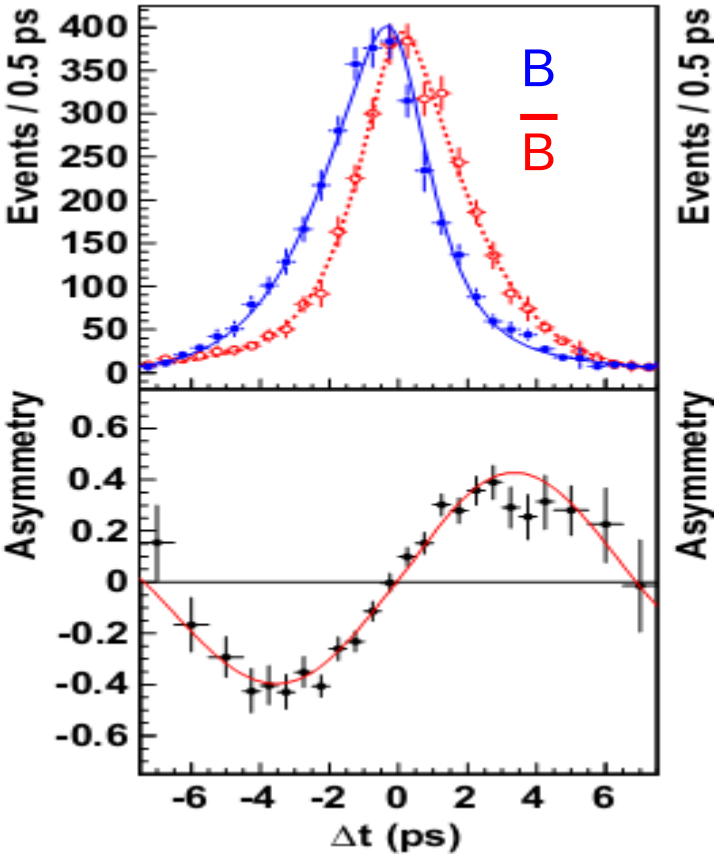
main target process

$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\overline{B}$ (σ=1.1nb)

- “B factory”.
- large amount of charm and τ are also produced.

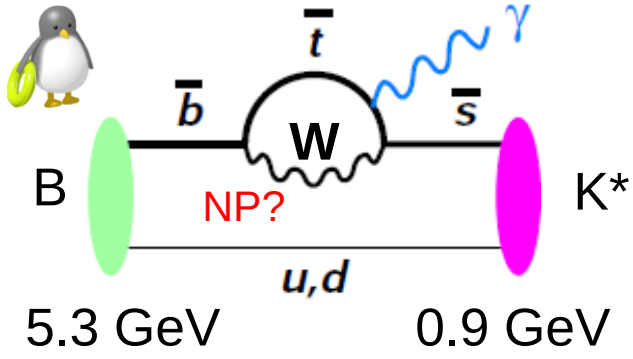
Belle, Belle II

[PRL 108, 171802 (2012)]

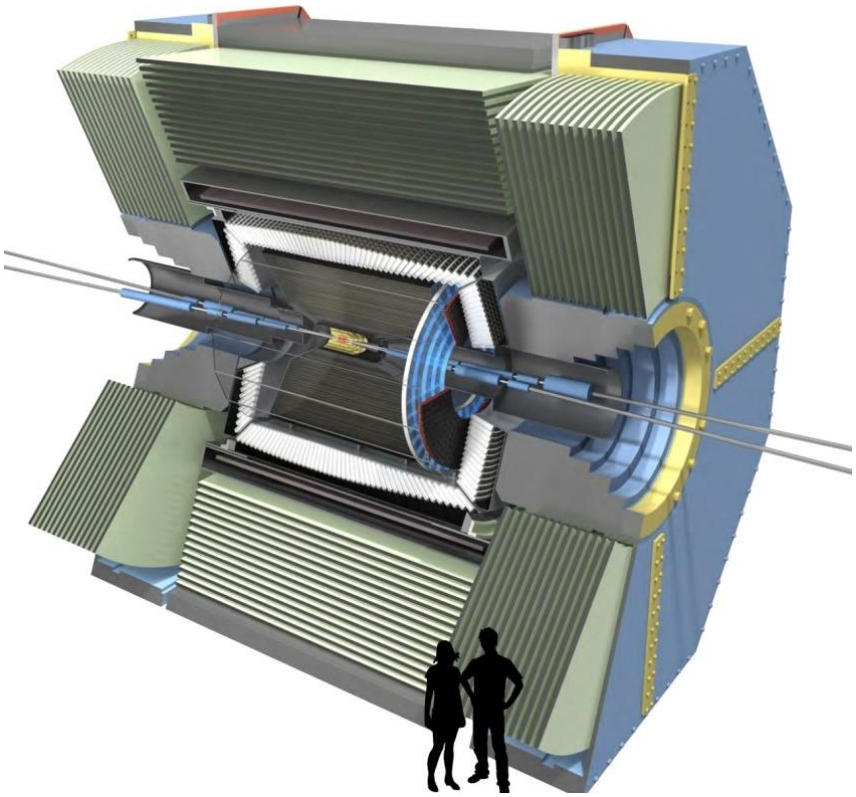


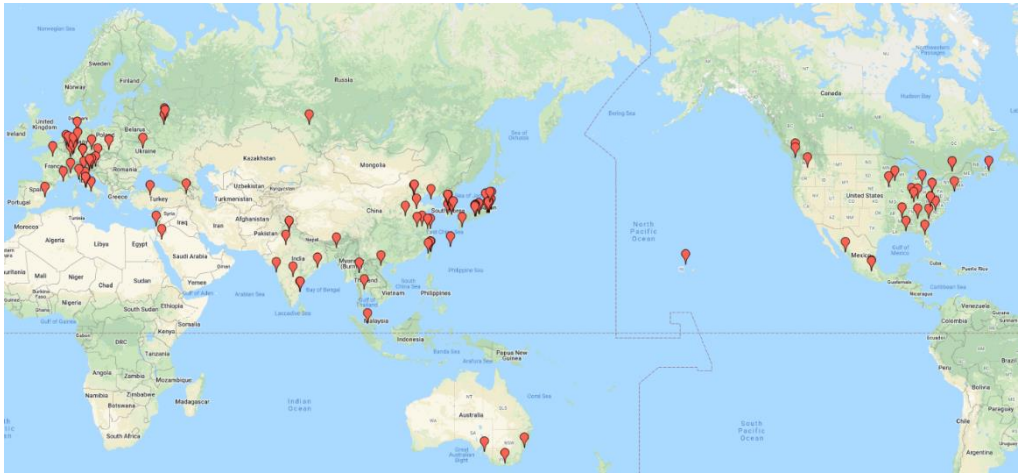
- In 2001, Belle and BaBar (experiment at SLAC) discovered the CP Violation in B mesons.
- Verification of Kobayashi-Maskawa Theory
  - ✓ Nobel Prize to Kobayashi and Maskawa (2008)

- Search for New Physics using “loop effect”
  - ✓ Virtual heavy particles (maybe non-SM) appear in a loop
- Precise measurement and comparison with the SM prediction.
  → Need very large dataset (B mesons).



Belle II



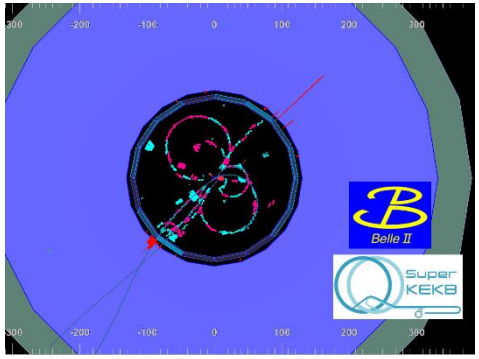


- Belle II Collaboration
  - ✓ 26 countries and regions
  - ✓ ~120 institutes
  - ✓ ~1000 collaborators
- International collaboration.

- General purpose detector.
- Asymmetric beam energy → study of CP violation by measuring the decay vertex

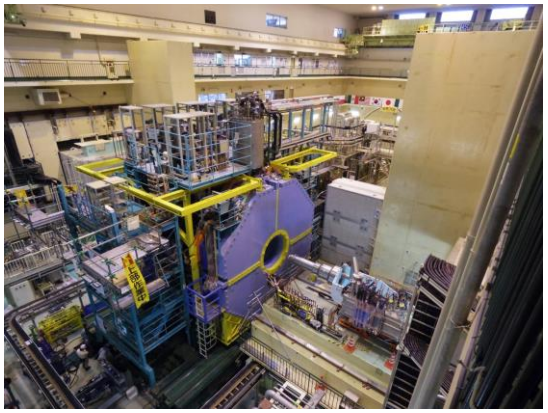
Belle II

- 2016 Feb-Jun : Phase 1
  - ✓ SuperKEKB operation without Belle II
- 2018 Feb-Jul : Phase 2
  - ✓ Belle II without inner vertex detector.
  - ✓ Commissioning of SuperKEKB.
  - ✓ First collision.



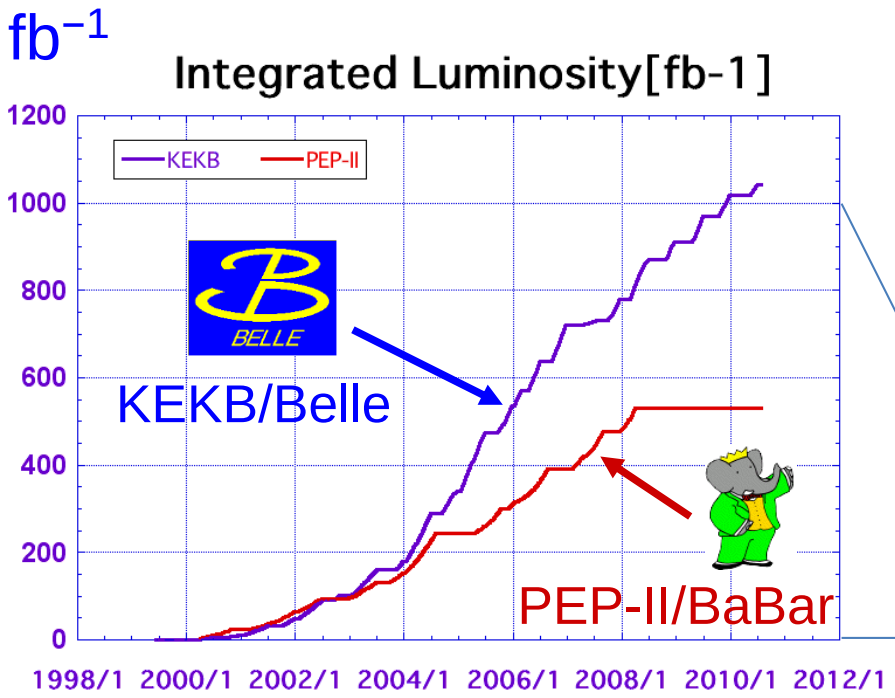
- 2019 Feb- :
  - ✓ Physics run with full Belle II detector.

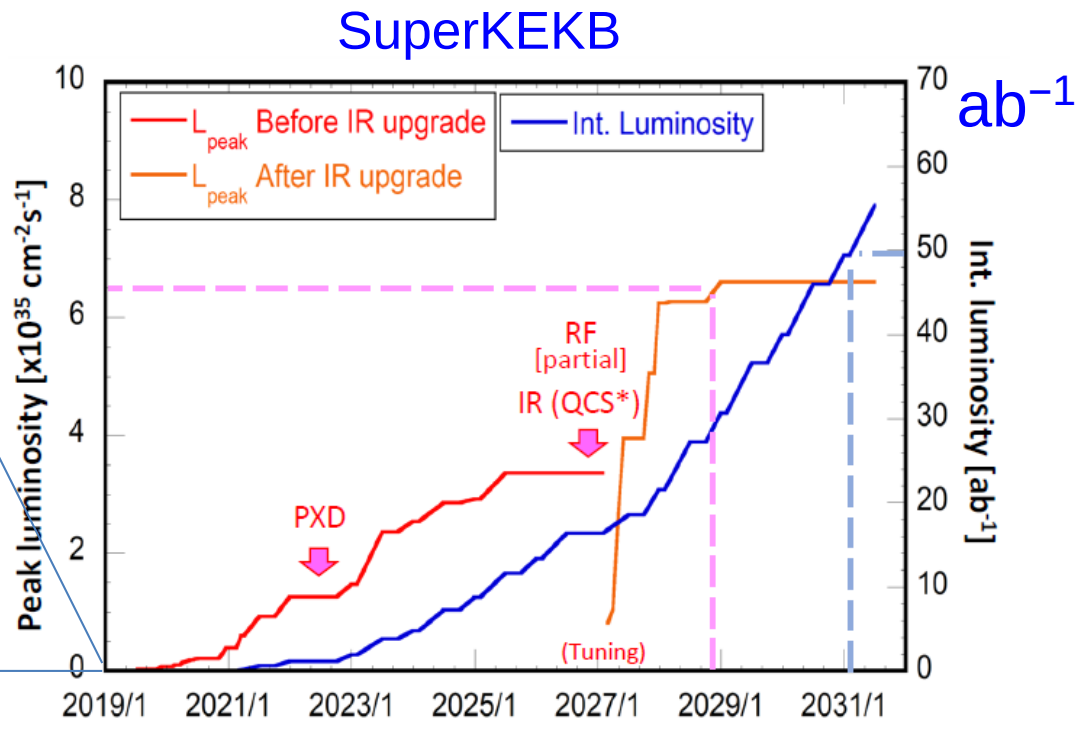
2017/4/11 Belle II roll-in



Belle II

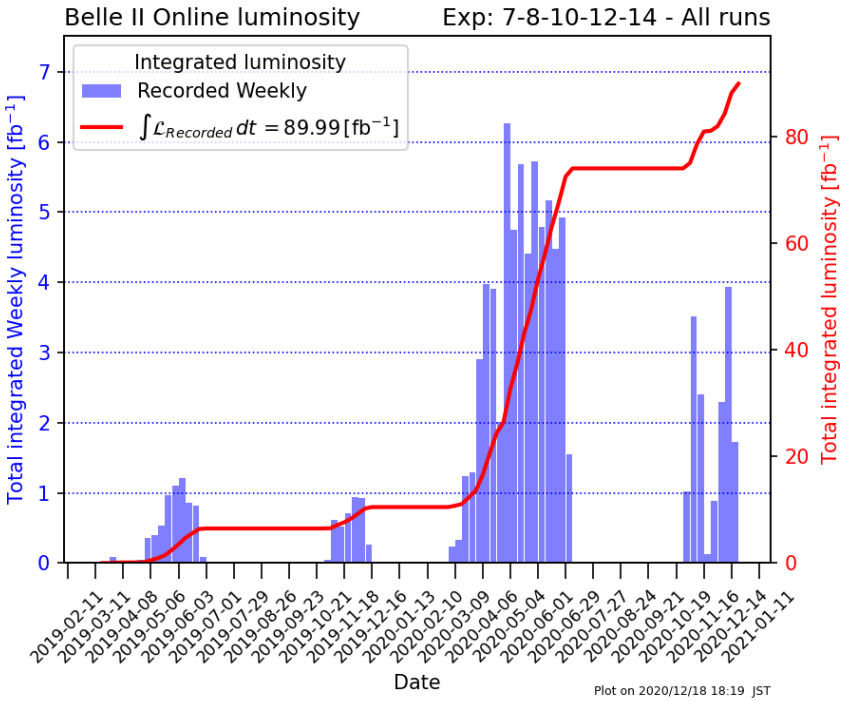
- Luminosity [$cm^{-2}\,s^{-1}$] = (event rate [s^{-1}]) / (cross-section [cm^{-2}])
  - ✓ performance of accelerator (~ ability of collision). $10^{34}\ cm^{-2}\,s^{-1} = 10\ nb^{-1}s^{-1}$
- Integrated luminosity = Luminosity × (operation time) = Data Size
  - ✓ 1 ab^{-1} = 1000 fb^{-1} : total amount of Belle data in 10 year's operation
  - ✓ Belle II aims to collect 50 ab^{-1}.





Belle II

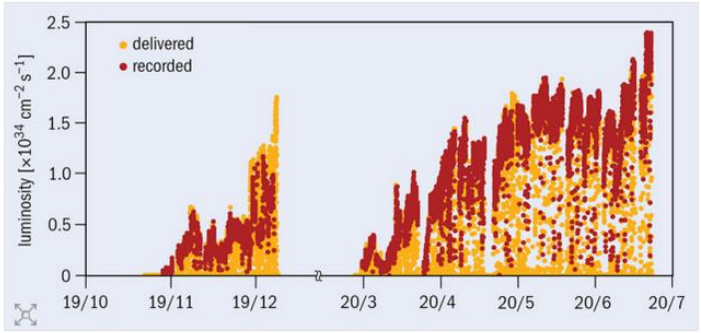
- In 2020, SuperKEKB achieved the luminosity 2.4×10^{34} cm^{-2}s^{-1} , which is higher than KEKB record (and is also world record).
- But the goal is more than 10 times higher.



ACCELERATORS | NEWS

KEK reclaims luminosity record

30 June 2020



Record breaker The instantaneous luminosity of SuperKEKB measured at 5-minute intervals from late 2019 to 22 June 2020. Values are online measurements and contain an approximate 1% error. Credit: KEK

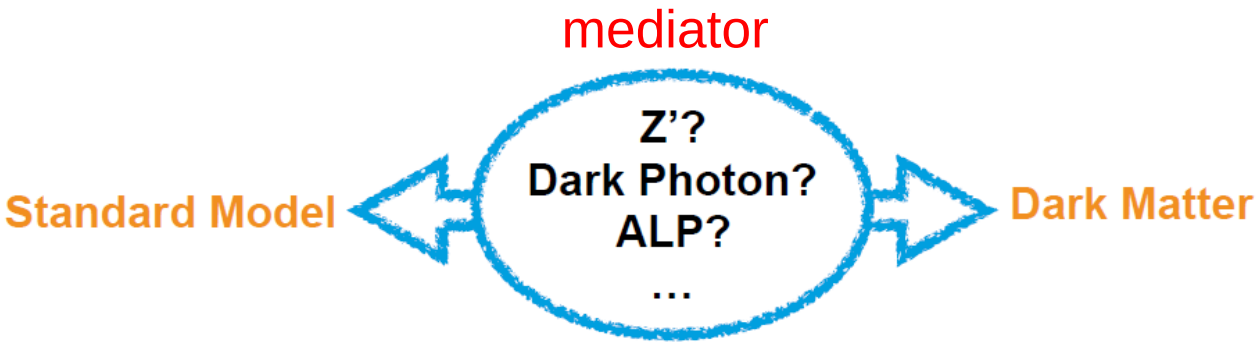
A new record for the highest luminosity at a particle collider has been set by SuperKEKB at the KEK laboratory in Tsukuba, Japan. On 15 June, electron–positron collisions at the 3 km-circumference double-ring collider reached an instantaneous luminosity of 2.22×10^{34} cm^{-2} s^{-1} — surpassing the LHC's record of 2.14×10^{34} cm^{-2}s^{-1} set with proton–proton collisions in 2018. A few days later, SuperKEKB pushed the luminosity record to 2.4×10^{34} cm^{-2}s^{-1}. This milestone follows more than two years of

https://cerncourier.com/a/kek-reclaims-luminosity-record/

- Belle II accumulated 90 fb^{-1} (in 2019, 2020)
- Still 1/10 of Belle (= 1040 fb^{-1} ~ 1 ab^{-1}) and
- 1/500 of Belle II goal (50 ab^{-1})
- 1-3 ab^{-1} in 4 years (?)

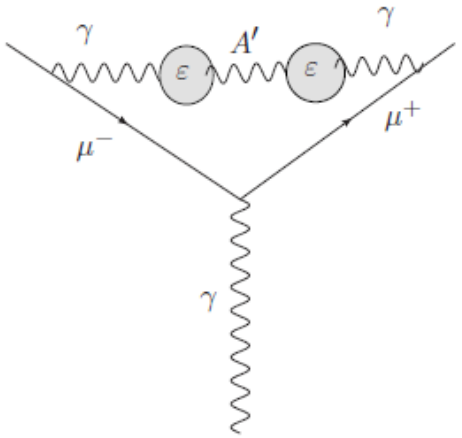
Dark Matter Search at Belle II

- Search for Dark Matter (DM) at Belle, Belle II.
  - ✓ CM energy is ~10GeV → mass region up to O(1) GeV (“light DM”)



Bonus

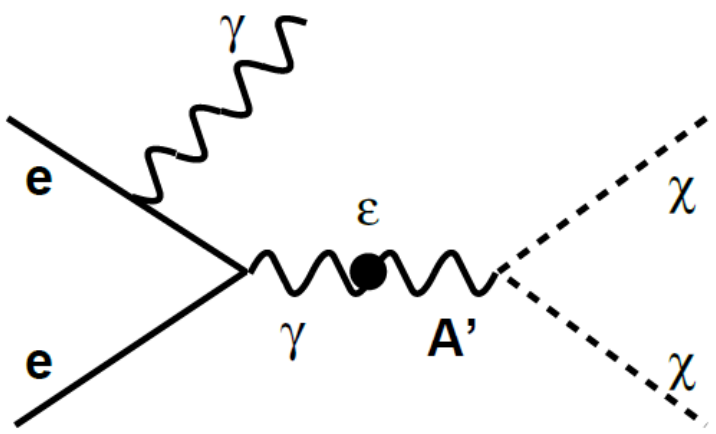
- ➢ A’, Z’ may explain the discrepancy of $(g-2)_\mu$ between theory and experiment.



- Typical process
  - ✓ $e^+ + e^- \rightarrow$ SM-particles + Mediator
  - ✓ B (or other hadron) $\rightarrow$ SM-particles + Mediator

Invisible Mode

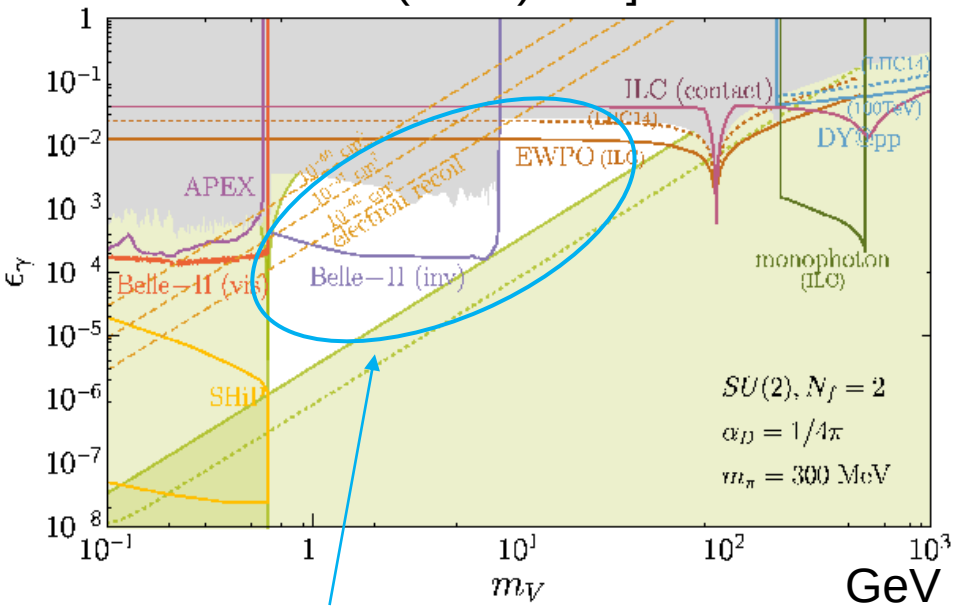
$e^+e^- \to \gamma$ + invisible



- Final state: a single photon only.
- Bump in a recoil mass or photon energy.
- Need special "single photon trigger" to collect such events.
- Not many previous measurements → possible with initial Belle II data.

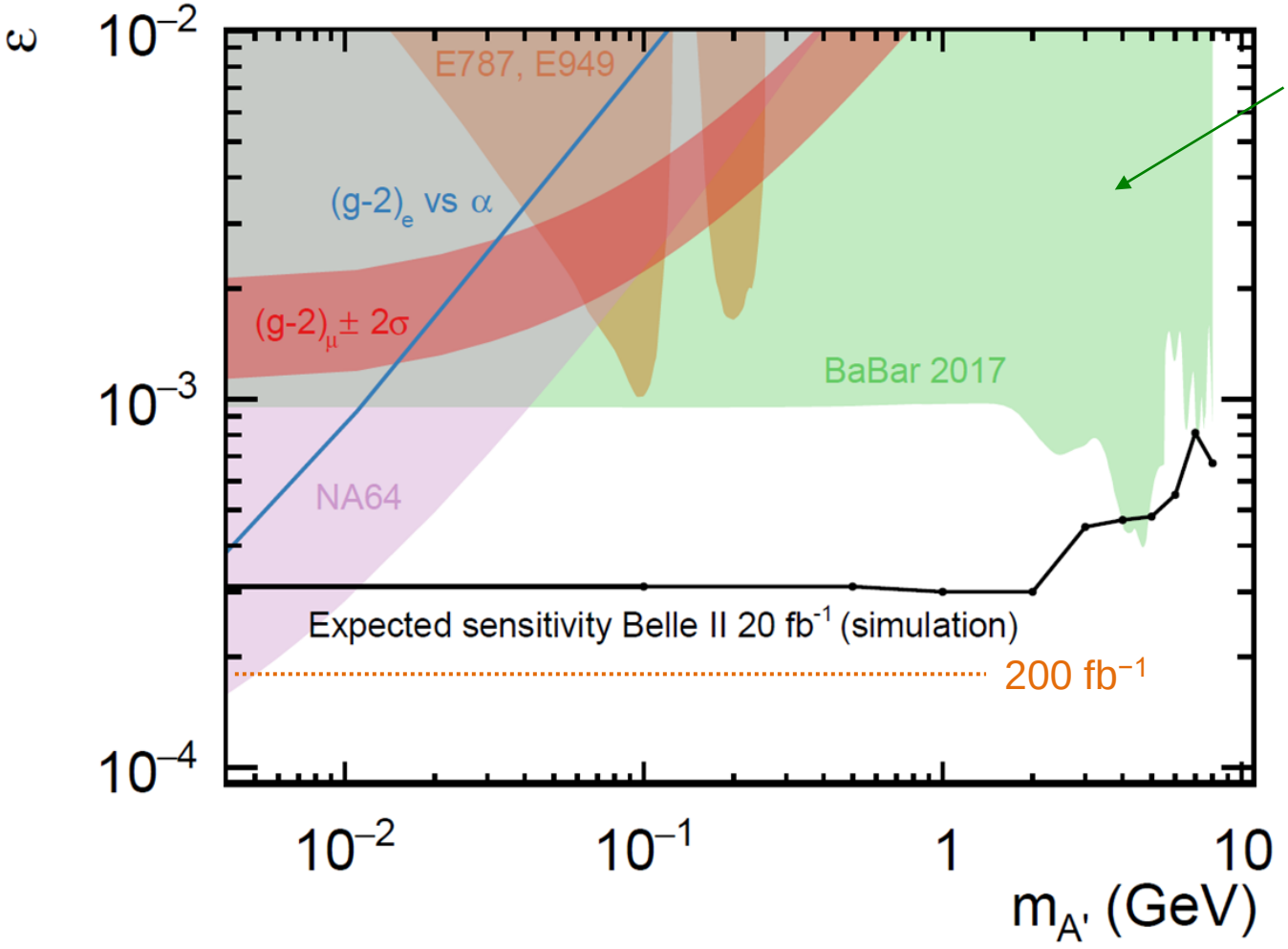
Dark Photon A', SIMP (Strongly Interacting Massive Particle)…

[Y. Hochberg, E. Kuflik, H. Murayama JHEP05 (2016) 090]



Wide discovery space around 0.5 – 50 GeV can be explored by Belle II (<10GeV)

Invisible Mode



BaBar experiment (53 fb^{-1}) [PRL 119 131804 (2017)]

- ✓ Single photon trigger is available for 53 out of 550 fb^{-1}

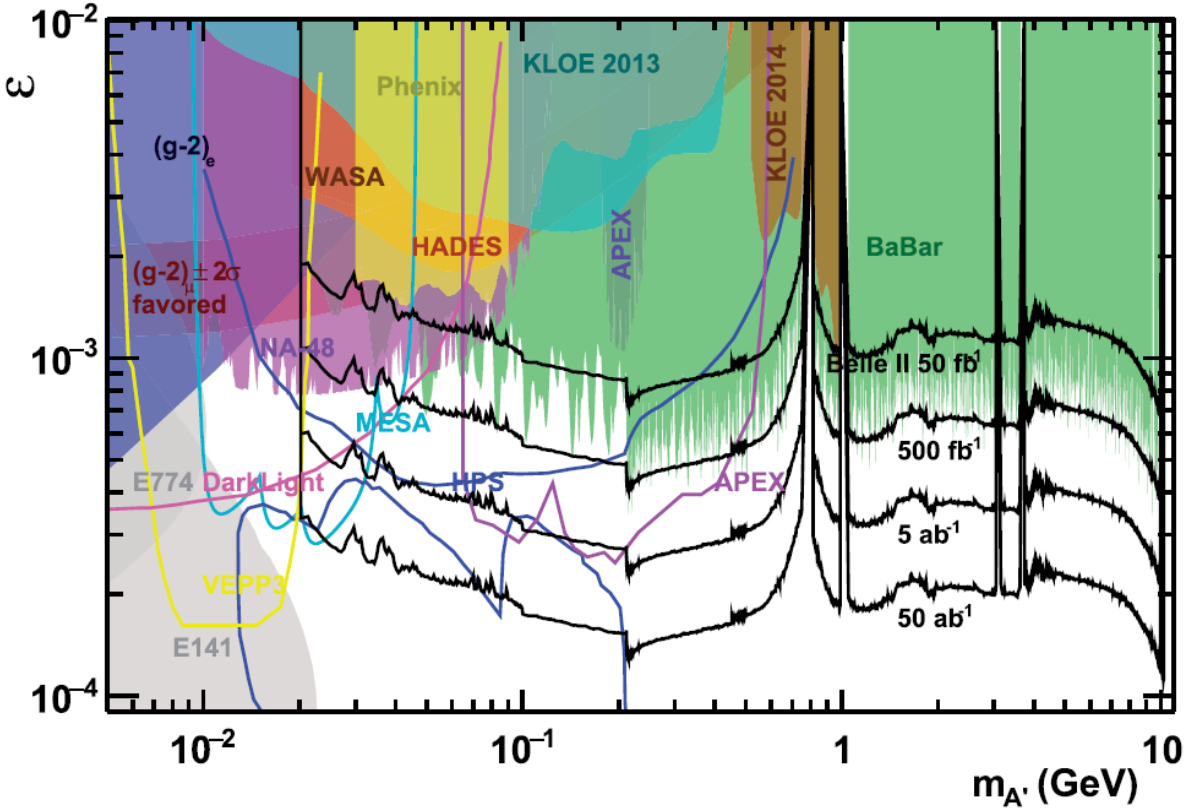
- Belle didn't have a single photon trigger.

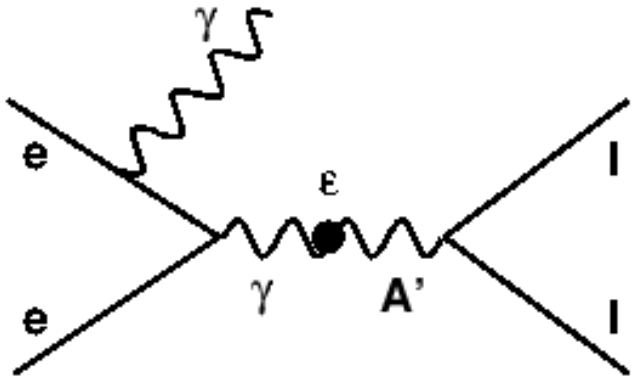
- Better limit is expected at Belle II with 20 fb^{-1} (due to detector configuration).
- Need good understanding of the detector.

Leptonic Mode

If m(A') < 2m(χ), A' decays to SM particles.

- e.g. $e^+e^- \to \gamma A'$, $A' \to l^+l^-$ (l = e, μ, τ)

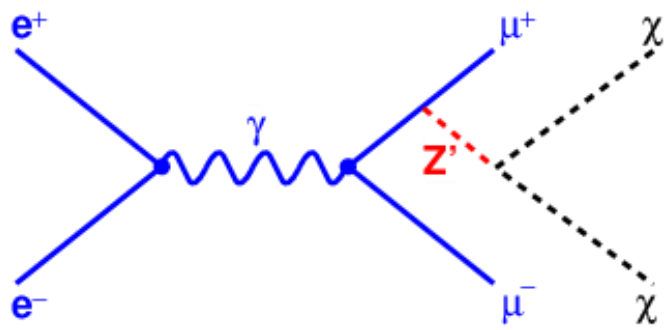


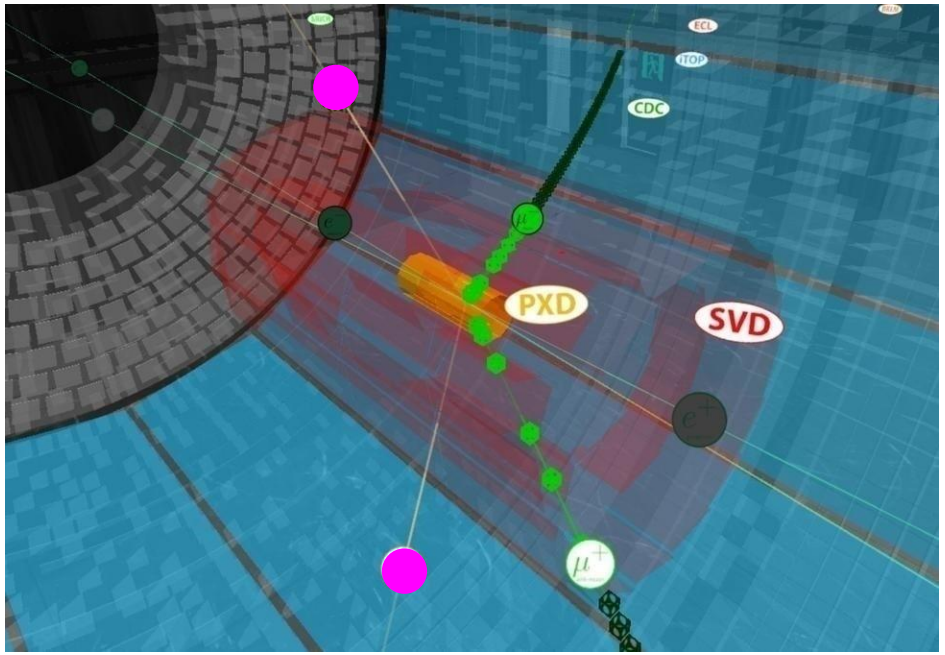


- Best limit in 0.1 – 10 GeV by BaBar [PRL 113, 201801 (2014)]
- Some analyses are going on at Belle II, but need more data.
  - ✓ Best sensitivity by Belle II within a few years.
- Competition with LHCb.

$L_\mu - L_\tau$ Model

- Gauging $L_\mu - L_\tau$, difference of the μ and τ lepton number, allows additional neutral Z' b0son.
- Can solve deviation of $(g-2)_\mu$, and other anomalies seen in flavor physics ($B \to K^{(*)}\mu\mu$).
- Production with the final state radiation from a muon.





Z' may decay to

- Invisibly: $e^+e^- \to \mu^+\mu^- Z'$, $Z' \to \chi\chi$
- SM particles:
  $e^+e^- \to \mu^+\mu^- Z'$, $Z' \to \mu^+\mu^-$

event display (simulation)
for $e^+e^- \to \mu^+\mu^- Z'$, $Z' \to \chi\chi$

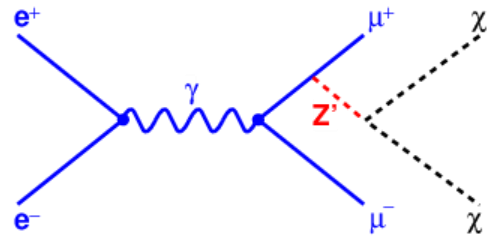
Again, Z' may decay to

Z'→ invisible

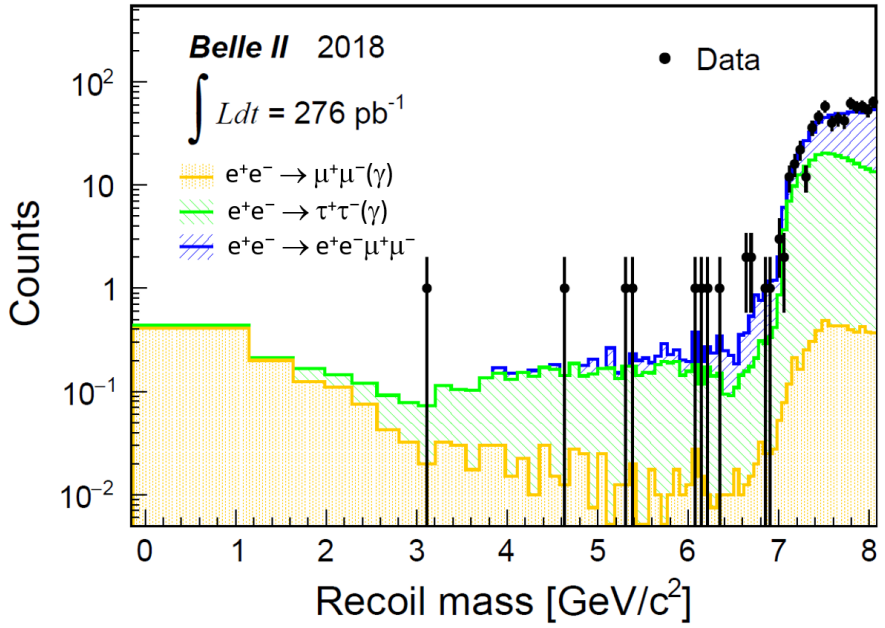
Z'→ invisible : First physics result from Belle II !!

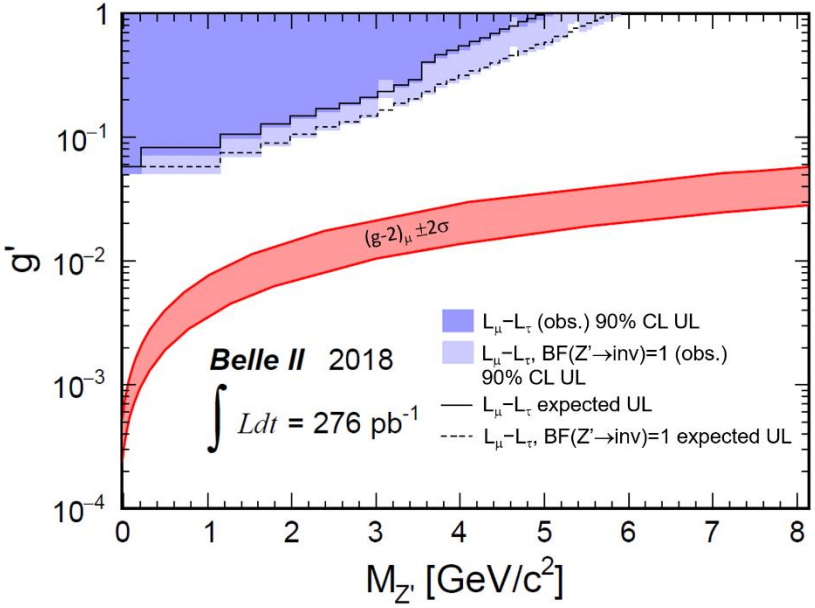
[PRL124 (2020), 141801]

- 0.276 fb^{-1} data from Belle II Phase II run.
  - ➢ Phase II: commissioning run in 2018 taken without inner vertex detector.
- $e^+e^- \to \mu^+\mu^-$ + missing energy and search for a bump in recoil mass.



$e^+e^- \to \mu^+\mu^- Z'$, $Z' \to \chi\chi$



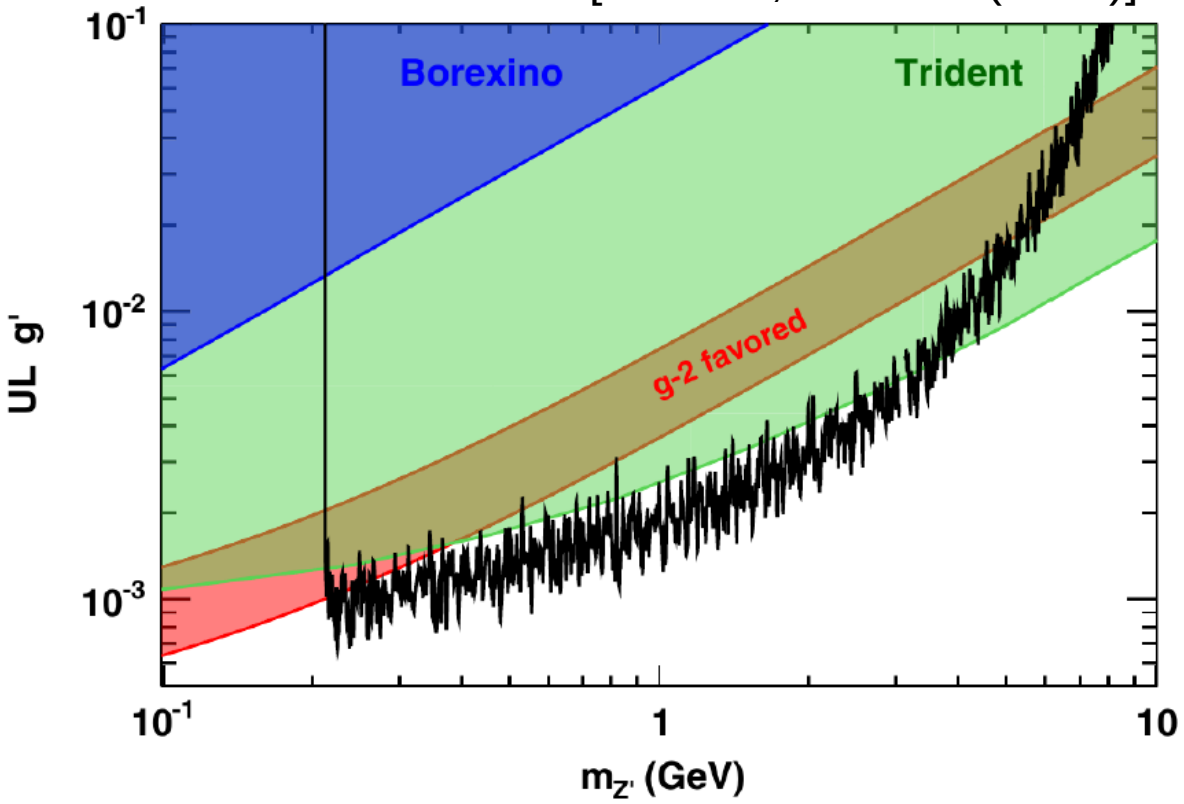


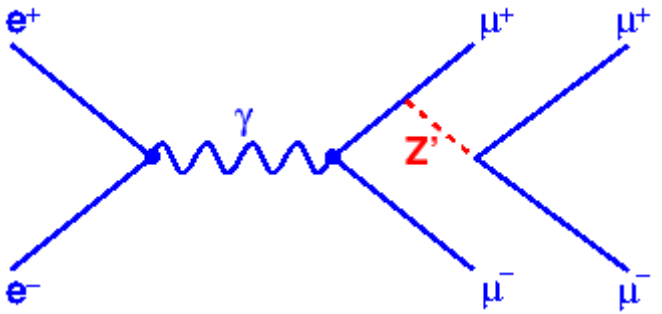
$Z' \rightarrow \mu^+\mu^-$

$Z' \rightarrow \mu^+\mu^-$

- 4 lepton final states
- Past search by BaBar

[PRD 94, 0111102 (2016)]





$e^+e^- \rightarrow \mu^+\mu^- Z'$, $Z' \rightarrow \mu^+\mu^-$

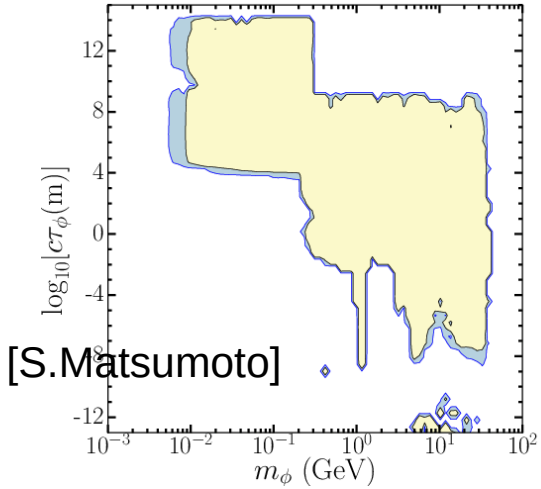
- g-2 favored region is almost excluded by BaBar.
- Analysis with Belle full data set is going on by Thomas Czank. Result will appear soon!

Dark Matter Search at Belle II

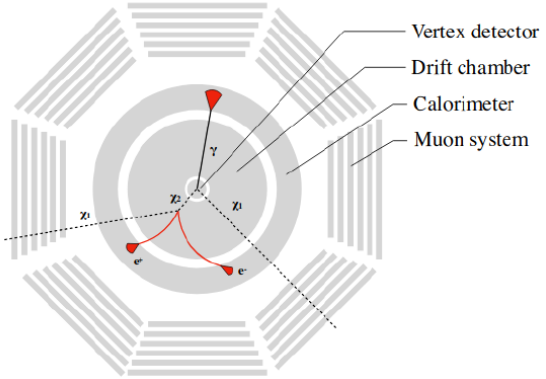
Target	Process	Mass Range (GeV)
SIMP / Dark Photon (A')	$e^+e^- \to A'\gamma,\ A' \to$ invisible	$m_{A'} < 10$
SIMP / Dark Photon (A')	$e^+e^- \to A'\gamma,\ A' \to \ell^+\ell^-, h^+h^-$	$0.1 < m_{A'} < 10$
Dark gauge boson (Z')	$e^+e^- \to Z'\mu^+\mu^-,\ Z' \to \mu^+\mu^-$	$0.2 < m_{Z'} < 10$
Dark gauge boson (Z')	$e^+e^- \to Z'\mu^+\mu^-,\ Z' \to$ invisible	$m_{Z'} < 10$
Axion (a)	$e^+e^- \to \gamma a,\ a \to \gamma\gamma$	$m_a < 10$
A' and Dark Higgs (h')	$e^+e^- \to A'h',\ A' \to \ell\ell,\ h' \to$ invisible	$m_{A'} + m_{h'} < 10$
Dark Scaler (S)	$B \to KS,\ S \to \gamma\gamma$	$m_a < 10$
Light WIMP (ϕ)	$B \to K\phi$ (ϕ は long-lived)	$m_a < 3$
Dark Photon (A')	$D^{*0} \to D^0 A',\ A' \to e^+e^-$	$0.01 < m_{A'} < 0.1$
Dark Photon (A')	$\Upsilon(2S,3S) \to \Upsilon(1S)\pi^+\pi^-$, $\Upsilon(1S) \to A'\gamma,\ A' \to$ invisible	$m_{A'} < 10$

- Production at e^+e^- collision.
- Decay of B, D*, Υ mesons, which are largely produced at Belle II.
- Displaced vertex (long lived particles)

- Many search processes.
- Close discussion with theorists.



[S.Matsumoto]



Summary

- Belle II experiment started in 2019 is running.
- So far, (only) 90 fb^{-1} of data is accumulated
  - ✓ Nevertheless, Belle II already got physics results for Dark Matter Search.
- Within a few years, Belle II will have the largest data sample.
  - ✓ High sensitivity to MeV-GeV scale DM in many models.
- Broad programs to search for DM.