Dark Sector Physics with Belle II

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For the Belle II Collaboration

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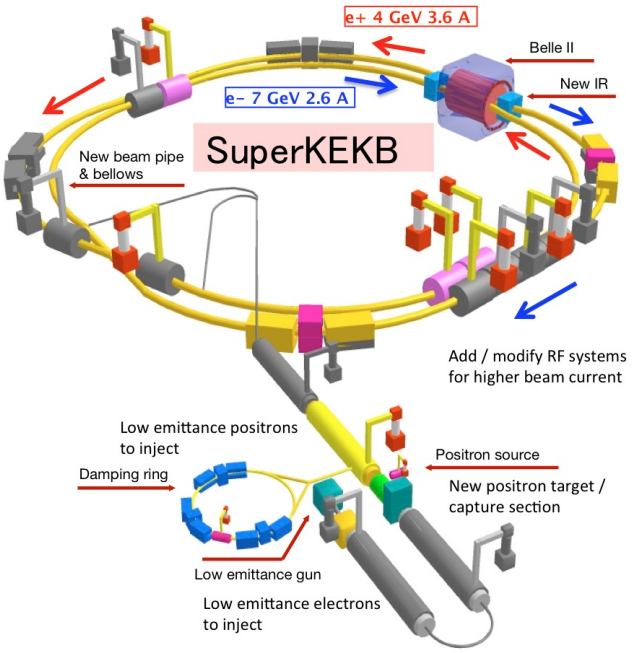
Outline of this talk

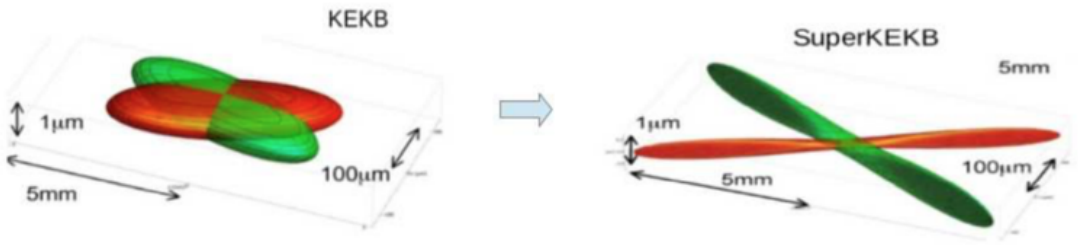
- **The experiment: Belle II@SuperKEKB**
- **Search for the dark photon and the light dark matter**
- **Search for the Axion-Like Particles**

The collider: SuperKEKB

- Located in Tsukuba, Japan
- KEKB started in 1998 and has been upgraded to SuperKEKB
- Asymmetric-energy 10.57 GeV (c.o.m.) e^+–e^- collider
- 40-fold increase in luminosity over KEKB :

  (target: 8×10^{35} $cm^{-2}s^{-1}$ instantaneous, $50ab^{-1}$ integrated), due to:
  - "Nano-beam" scheme
  - Doubled beam currents
  - First turns Feb. 10, 2016
  - First collisions Apr. 26, 2018





~x2 in beam current

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \zeta_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right) = 8\times10^{35}\,cm^2s^{-1}$$

Vertical beta function reduction (5.9→0.3 mm) gives x20

Beam Energies 8.0/3.5→7.0/4.0

The Belle II detector

Belle II TDR, arXiv:1011.0352

Central beam pipe: 2cm diameter, Beryllium with gold coating on inside

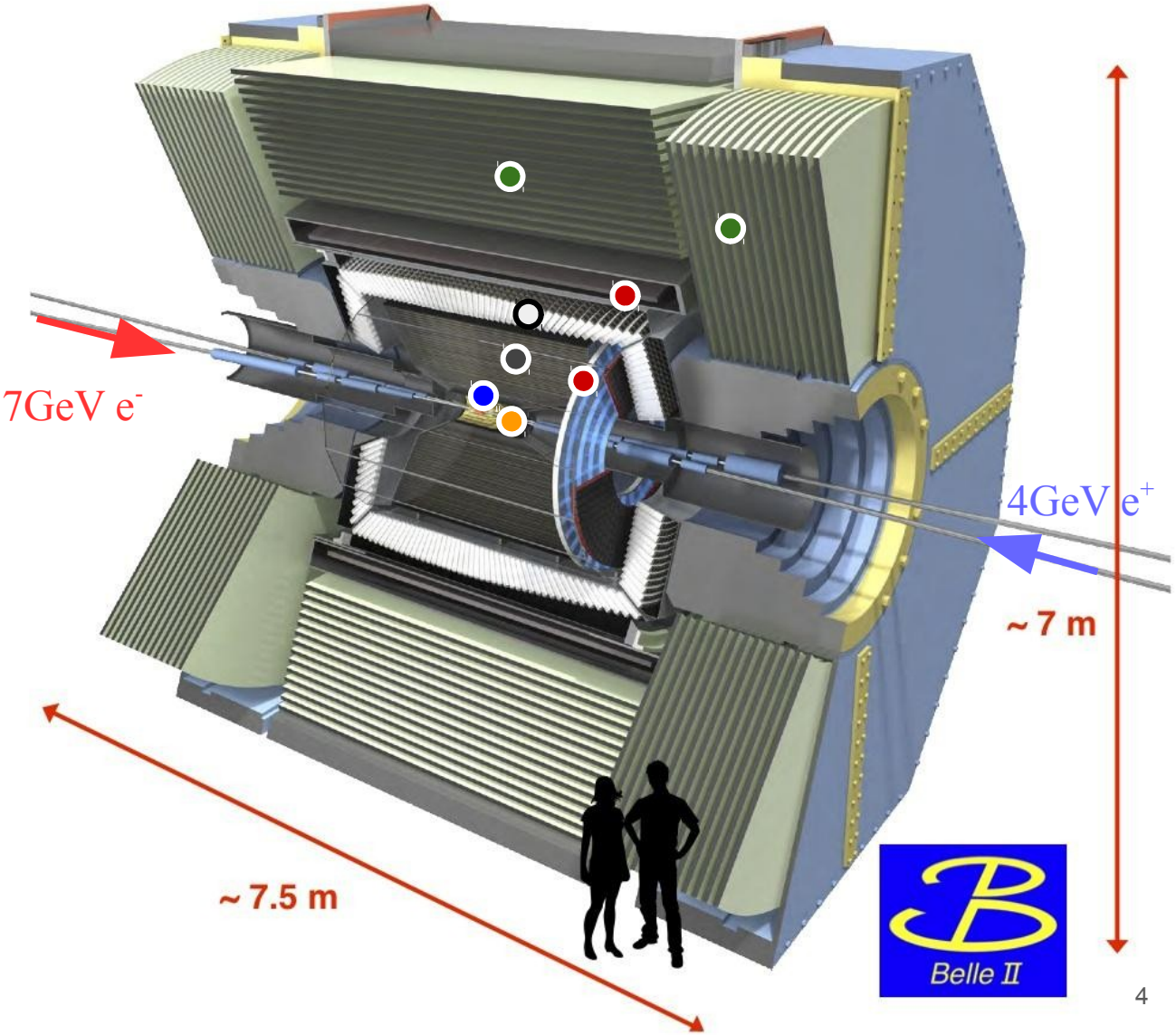
Vertexing: new 2 layers of pixels, 4 double-sided layers of silicon strips

Tracking: 14336-wire drift chamber

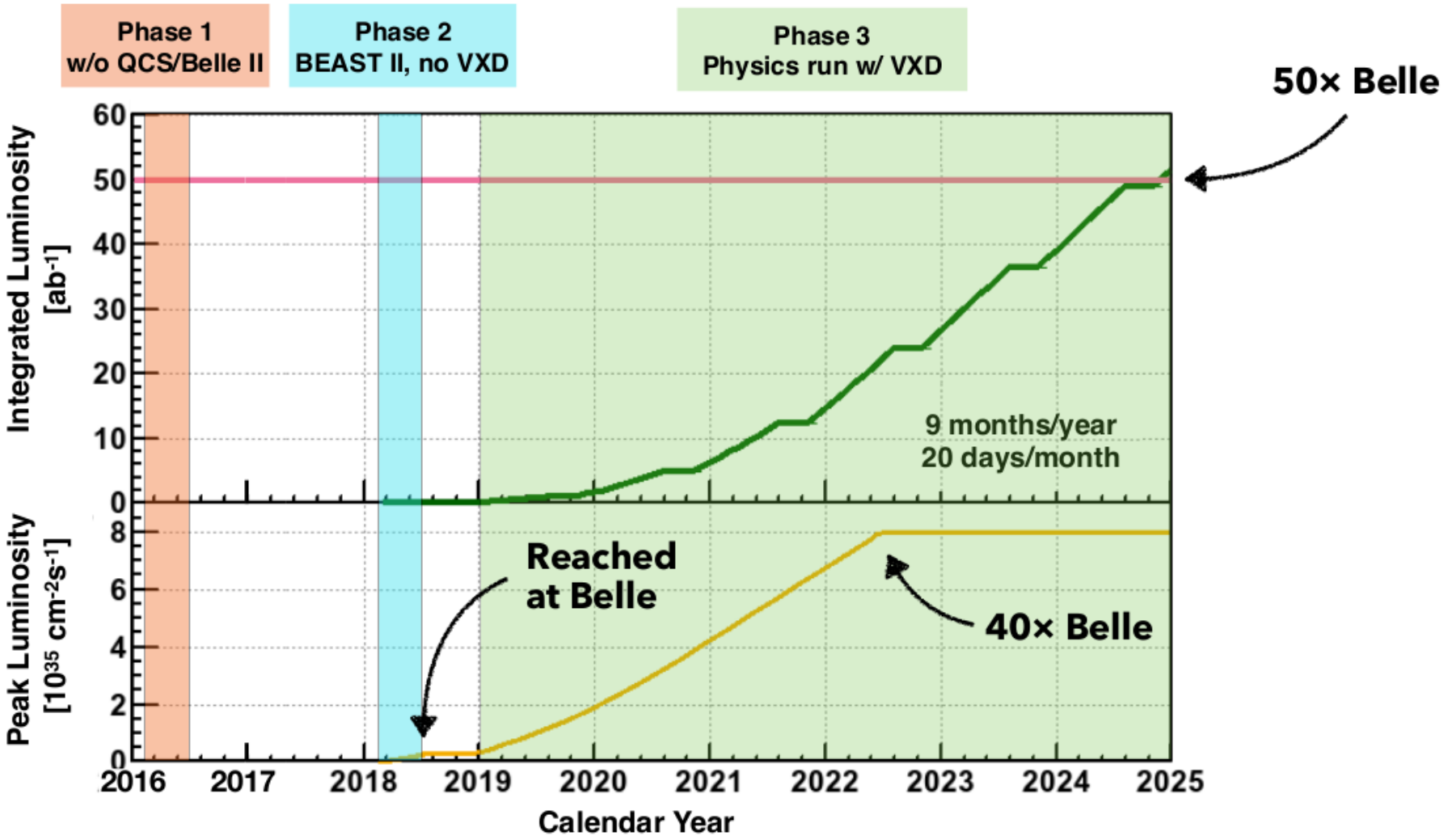
PID: time-of-flight (barrel) and proximity focusing aerogel (endcap) Cherenkov detectors

EM calorimetry: CsI(Tl) crystals

K_L and μ scintillators (endcap and inner two layers of barrel) and RPCs (remainder of barrel)

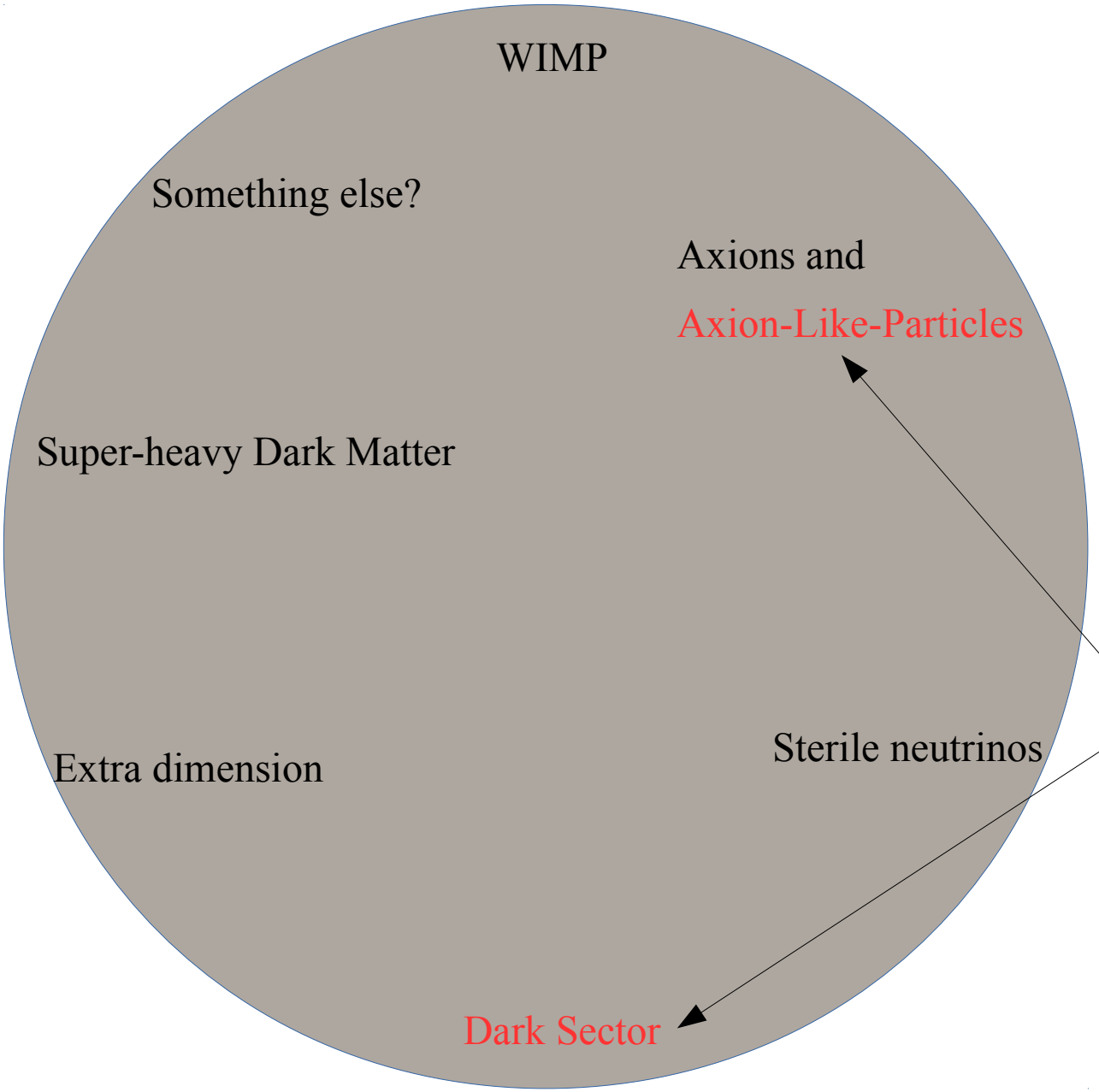


Projected luminosity



- During Phase 2, i.e. between Apr. 26 2018 and Jul. 15 2018, we will collect 20 to 40 fb^{-1}
- During Phase 3, i.e. between ~Feb. 2019 and ~Dec. 2024, we will collect 50 ab^{-1}

List of dark matter candidates



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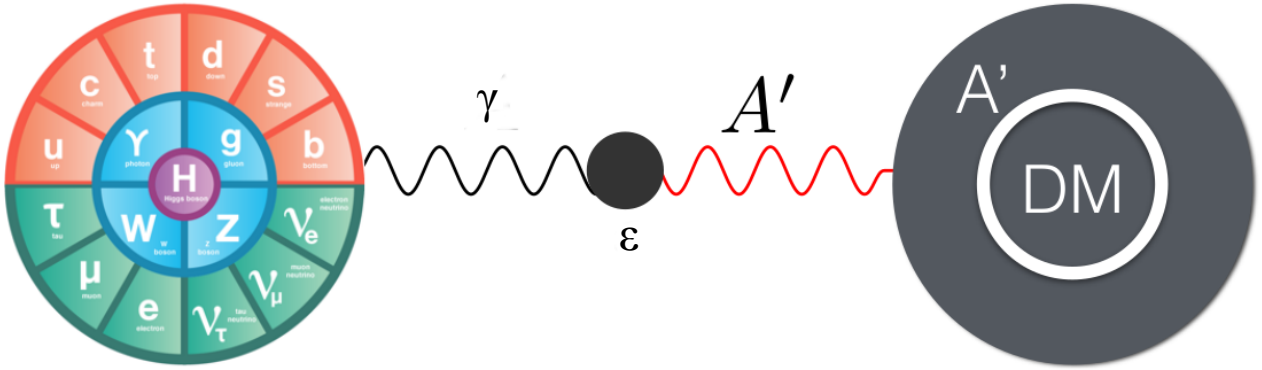
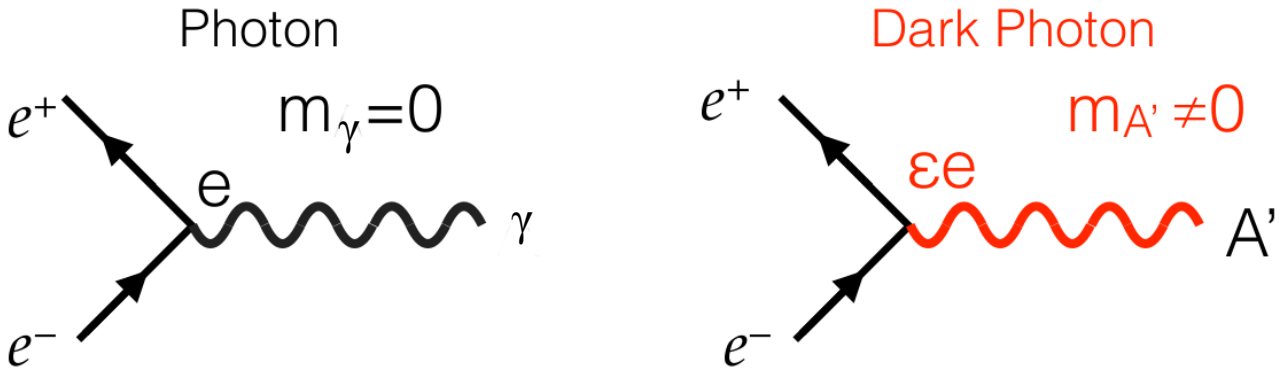
C. Boehm and P. Fayet, Nucl. Phys. B **683**, 219 (2004).
P. Fayet, Phys. Rev. D **70**, 023514 (2004).
N. Arkani-Hamed, D.P. Finkbeiner, T.R. Slatyer and N. Weiner, Phys. Rev. D **79**, 015014 (2009).
M. Pospelov, A. Ritz and M. Voloshin, Phys. Lett. B **662**, 53 61b (2008).

Dark Sector Models

R. Essig, P. Schuster, and N. Toro, Phys. Rev. D **80**, 015003 (2009).

- Attempt to simultaneously explain all recent results of direct and indirect dark matter detection experiments
- Models include WIMP dark matter candidates, and a new force, mediated by "Dark Gauge Boson"
- Dark photon A' mixes with SM photon with kinetic mixing ε



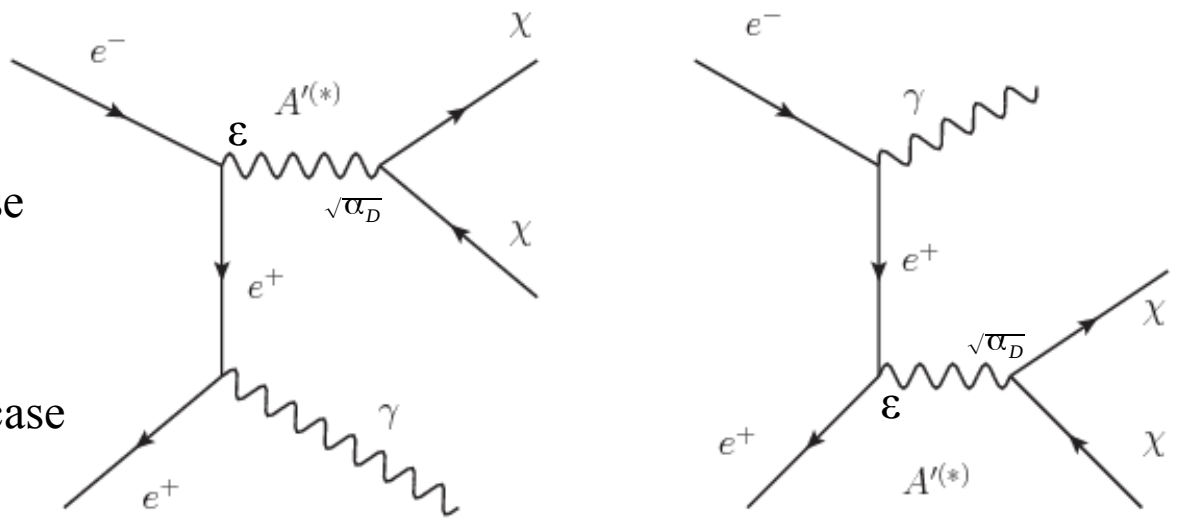


(Dark) radiative process

Search for the dark photon, A', and the light dark matter, χ, in the radiative process: $e^+e^- \rightarrow \gamma A'^{(*)}$

- On-shell case: $A' \rightarrow \chi\chi$ if $m_{A'} \geq 2m_\chi$
- (Off-shell case: $\chi\chi$ and $m_{A'} / 2 < m_\chi$)
- Branching Ratio (BR) = 1
  - Independent of α_D for the on-shell case
- Cross-section: $\sigma \propto \alpha^2\varepsilon^2 / E_{cm} = 2ab$

  for $\varepsilon = 10^{-4}$ and $E_{cm} = 10$ GeV/c^2
  - Independent of m_χ for the on-shell case
- For the mass ranges of:
  - 1 MeV $\leq m_{A'} \leq$ 10 GeV, and
  - 500 keV $\leq m_\chi \leq$ 5 GeV



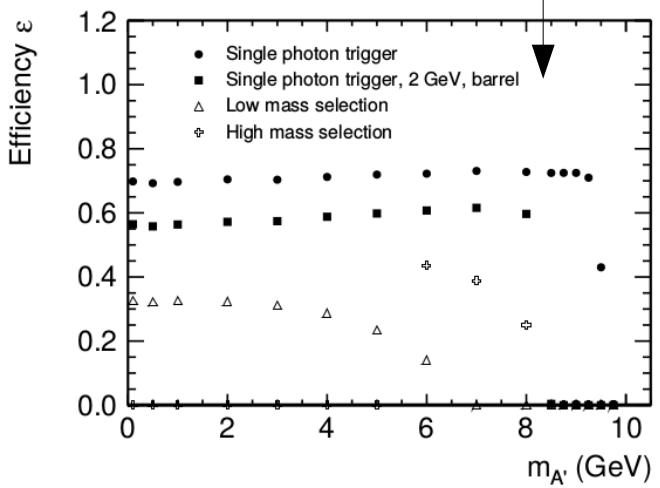
- $\varepsilon^2 = \alpha' / \alpha$ is the kinetic mixing between A' and γ
  - α' electromagnetic coupling of A' to γ
  - $\alpha = 1 / 137$ (SM electromagnetic coupling)
- $\alpha_D = g_D^{\,2} / 4\pi$ is the dark sector constant
  - g_D is the dark sector gauge coupling of A' to χ

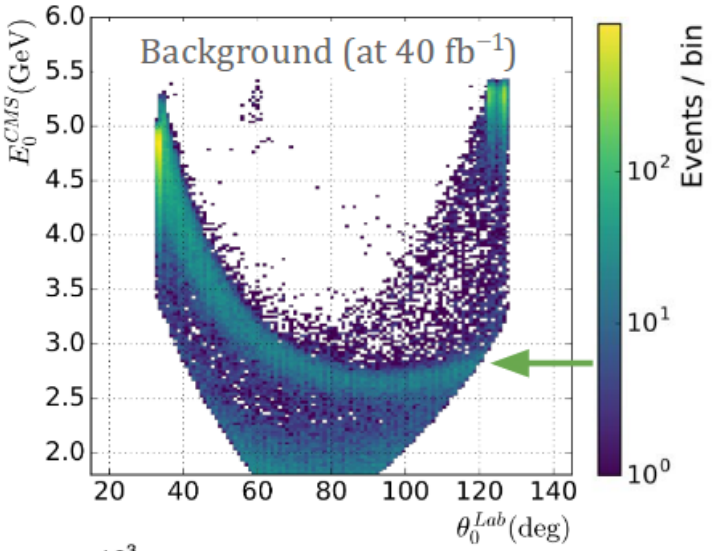
The signals observed should be a single photon and missing energy

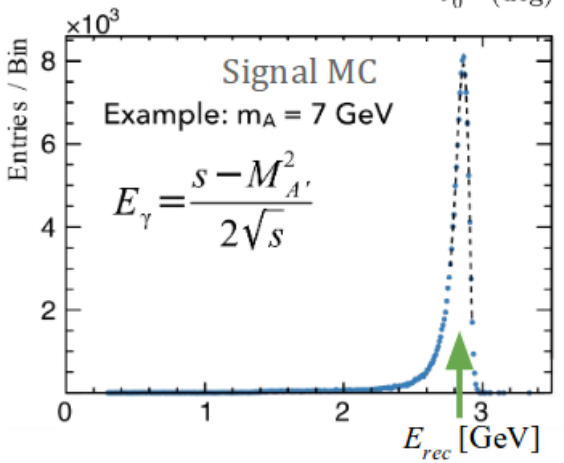
Expected background and signal signatures

arXiv:1702.0332 B2TIP

- Expected background channels:
  - $e^+e^- \rightarrow (\gamma)\gamma\gamma$ at low photon energies
  - $e^+e^- \rightarrow (\gamma)e^+e^-$ at high photon energies
- Signal signatures:
  - Mono-energetic photon in CMS
  - Resonance in the dark photon missing mass
- Optimized single photon trigger
  - An ECL cluster with $E^{CMS} > 1$GeV
  - No ECL cluster with $E^{CMS} > 0.1$GeV
  - ddNo tracks with $p_T^{CMS} > 0.2$GeV

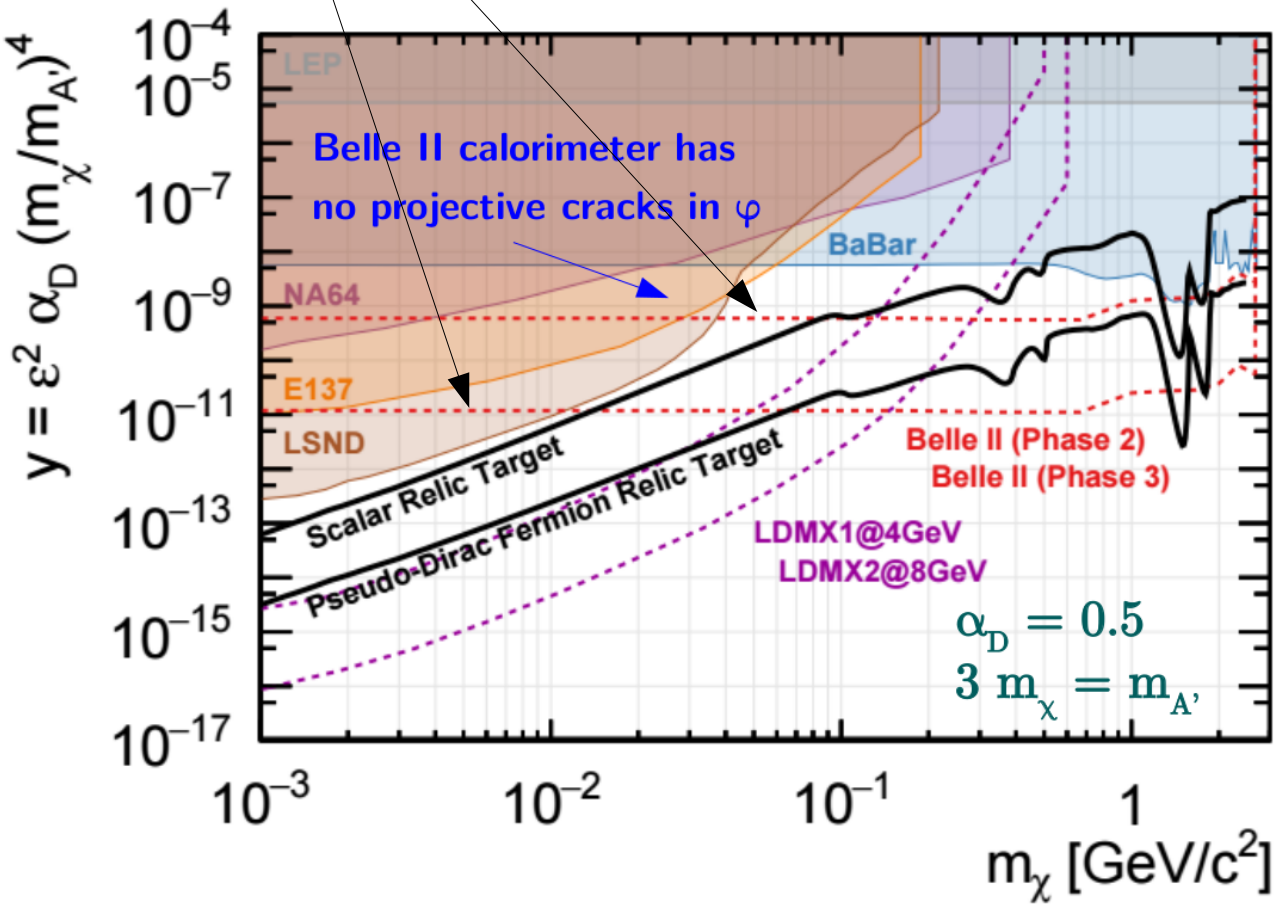






Belle II expected sensitivity

- Compared to BABAR (170203327 PRL), Belle II trigger efficiency increased by an order of magnitude
- With 20fb^{-1}, sensibility increased by a factor 3-4
- With 50ab^{-1}, sensibility increased by two order of magnitude

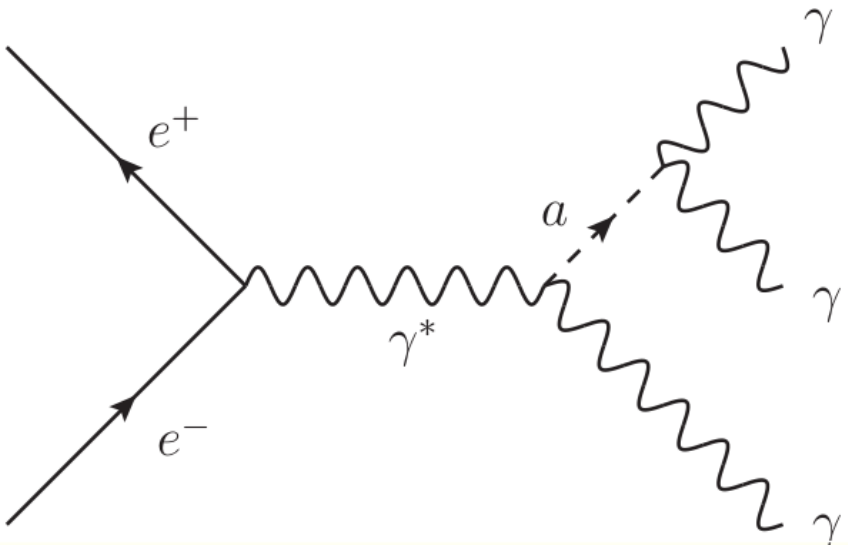


Axion-Like Particles (ALPs)

JHEP 12 (2017) 094

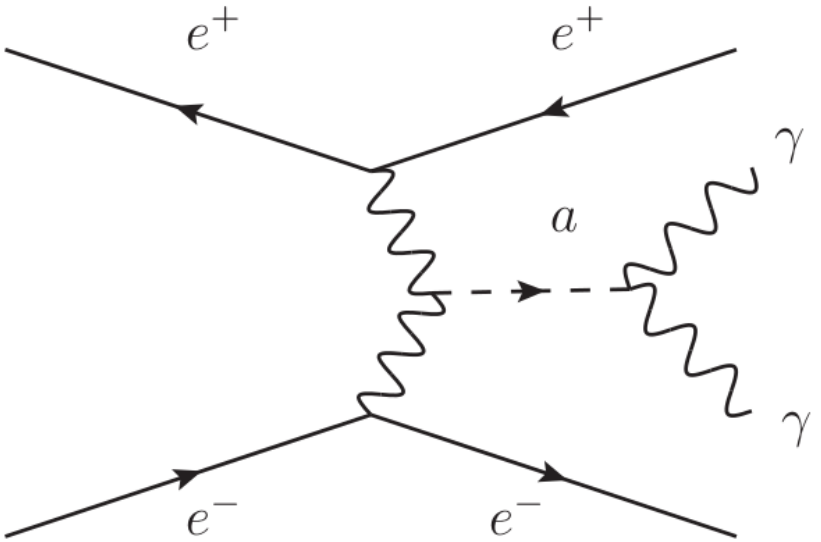
- ALPs are pseudo-scalars and couple to bosons.
- ALP(a)γγ coupling with ALP-strahlung

- ALP-strahlung: $e^+e^- \rightarrow \gamma a$, $a \rightarrow \gamma\gamma$



- Photon fusion (low mass ALP):

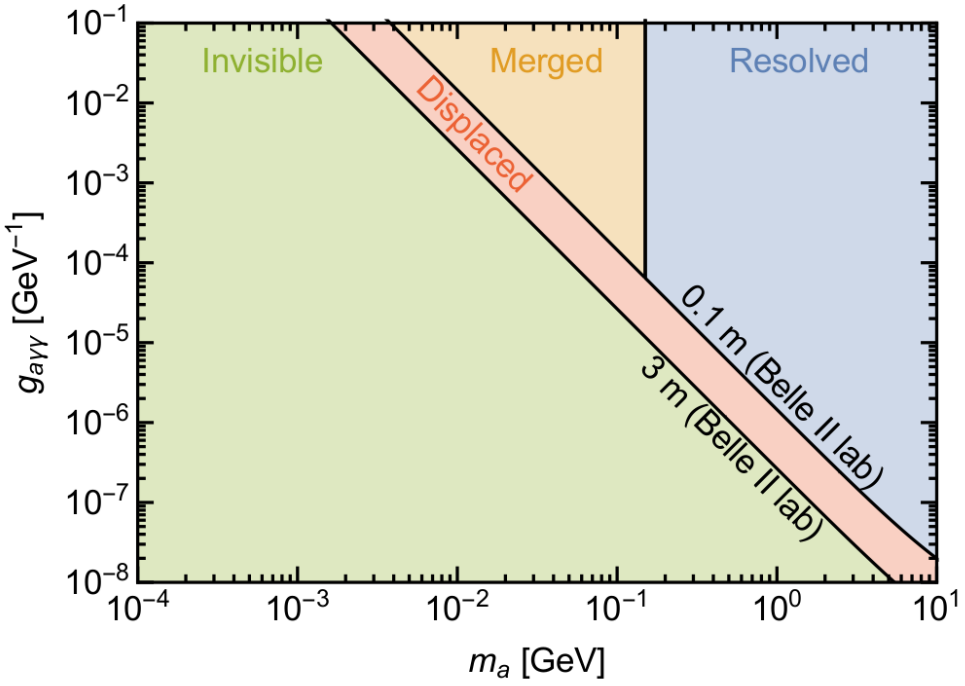
  $e^+e^- \rightarrow a$, $a \rightarrow \gamma\gamma$

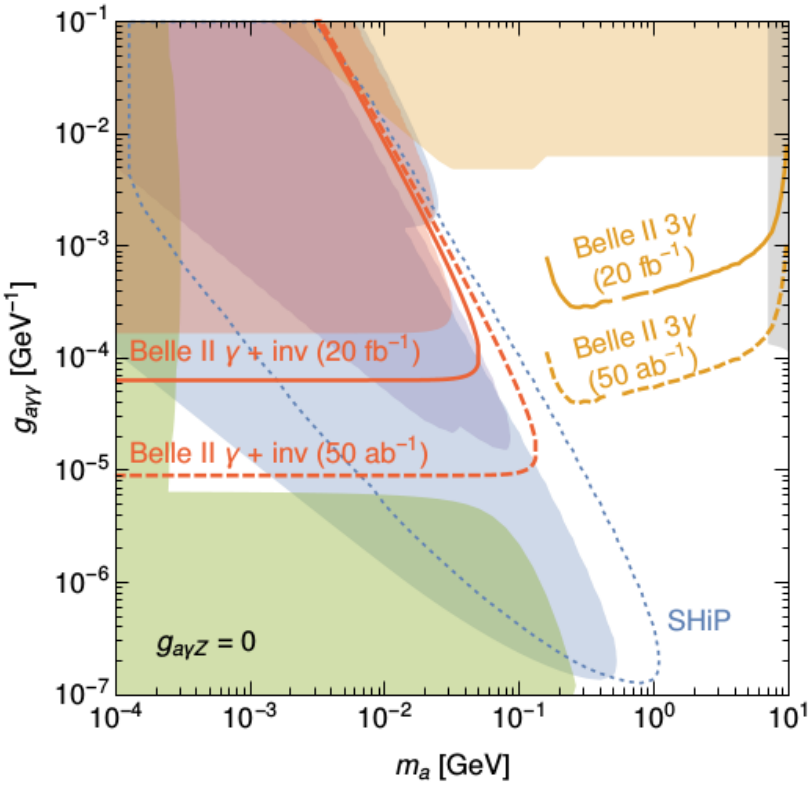


Belle II projected sensitivity

Signature in Belle II

- Three photons (Resolved): High m_a
- Two photons (Merged): $m_a < 150$MeV → hard to analyze
- Single photon (Invisible): do not decay in the detector.





Conclusion

- SuperKEKB produced the first collisions last April
- Belle II detector is currently taking data (w/o SVD)
- We expect to collect between 20 to 40fb^{-1} this year
- In 2019, Belle II w/ SVD will take data again
- With only 20fb^{-1} and optimized single photon trigger, we can search for
  - The dark photon and the light dark matter
  - The Axion-Like Particles

Thank you