Dark sector physics with Belle II

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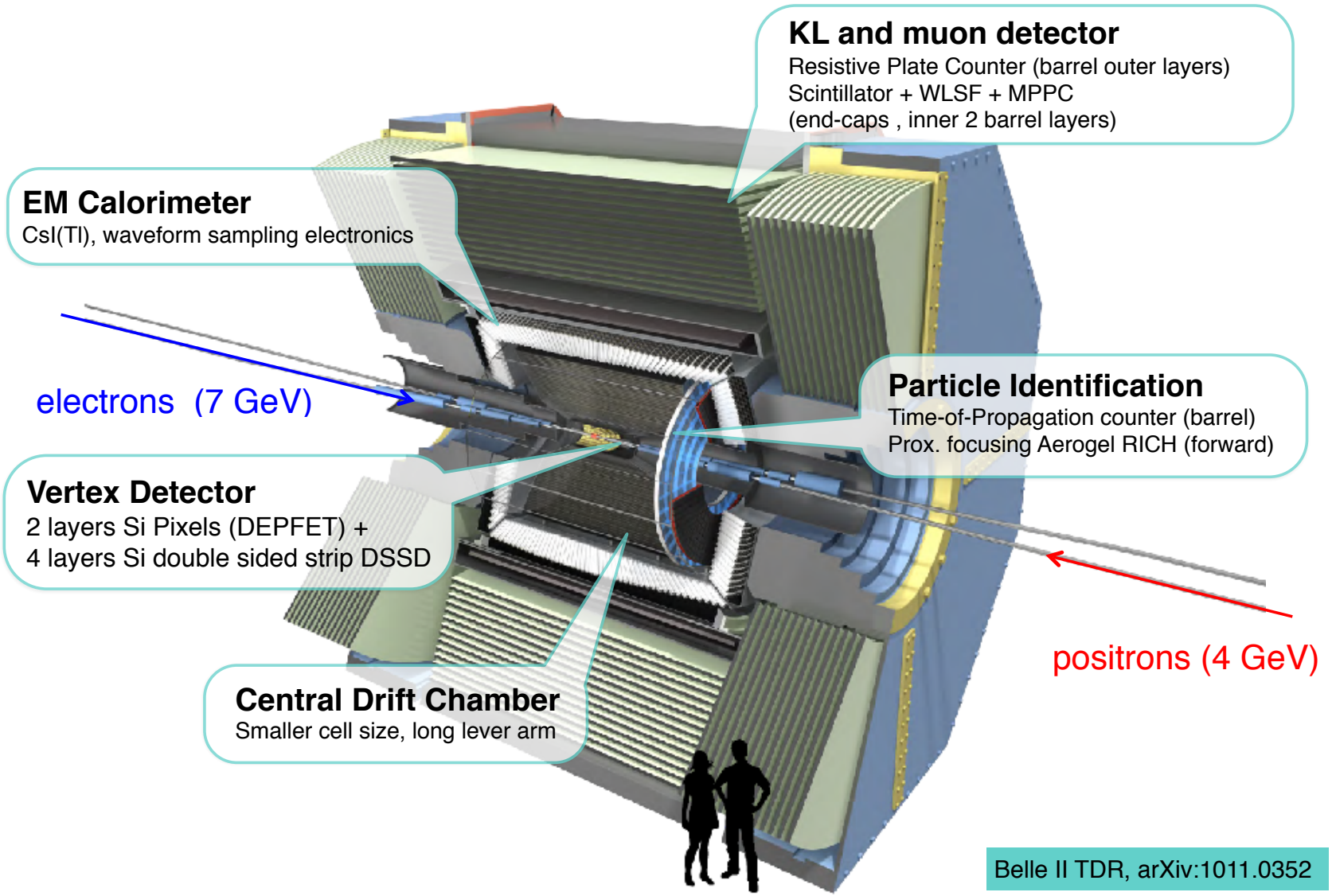
Belle II Detector

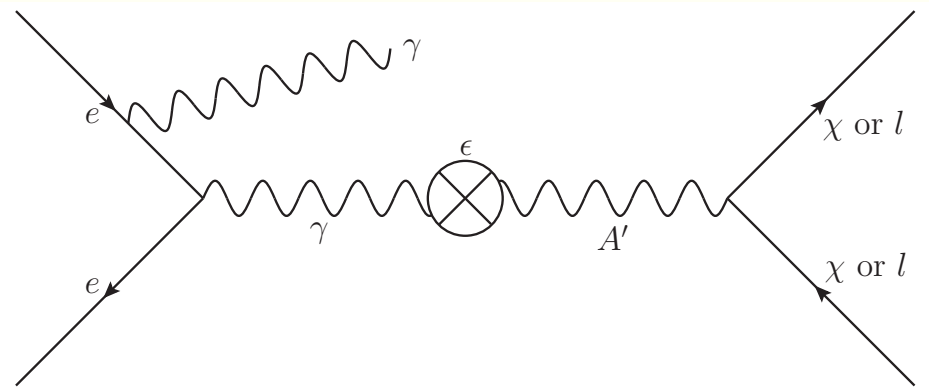


Belle II TDR, arXiv:1011.0352

Introduction: Dark Photon

- Dark photon can mix with SM photon with the small coupling strength ϵ. [HOLDOM, Phys. Lett B166 (1986)]
- Dark photon can decay into lepton or hadron pair (visible), or dark matter pair (invisible).
  - **Invisible: single ISR recoil mass**
  - Visible: invariant mass of lepton pair
- BaBar published the result

  [PRL 119.131804 (2017)], [PRL 113.201801 (2014)]

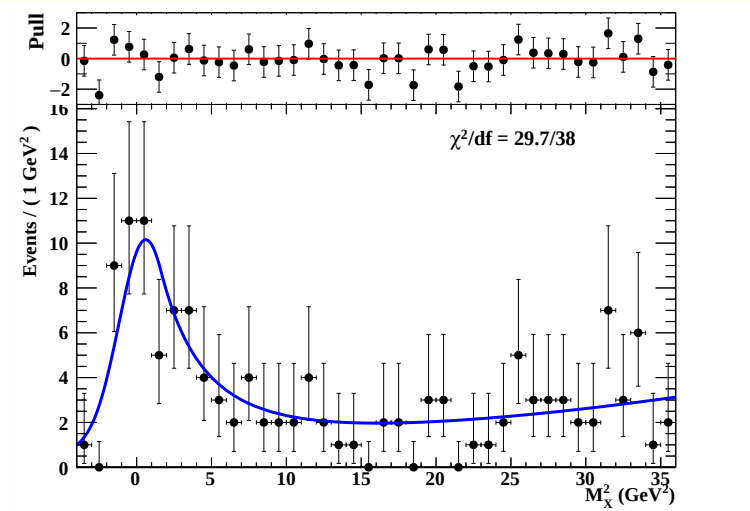


Dark photon - SM photon mixing with ISR

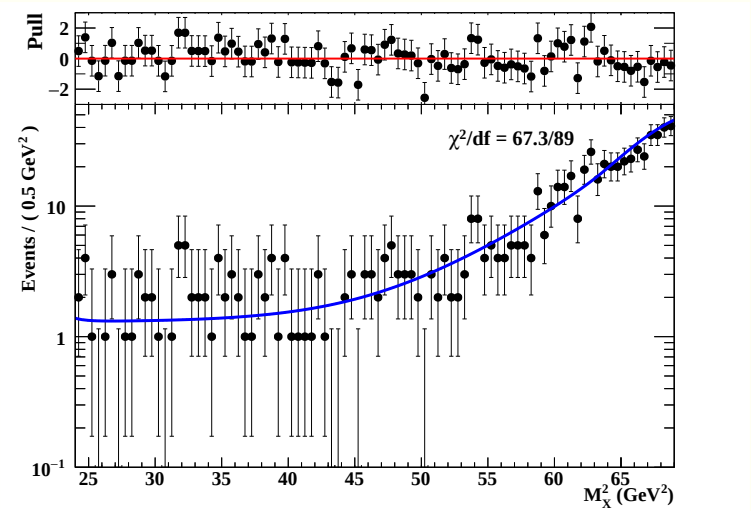
Dark photon search at BaBar (invisible)

- Invisible dark photon search
- Energy region: $E_\gamma > 1.5\ \mathrm{GeV}$ (due to the triger threshold)
- Dominant two background sources
  - Low $m_{A'}$: $e^+e^- \to \gamma\gamma$
  - High $m_{A'}$: $e^+e^- \to e^+e^-\gamma$

$<\Upsilon(3S)$ result with background only fitting$>$ [PRL 119.131804 (2017)]



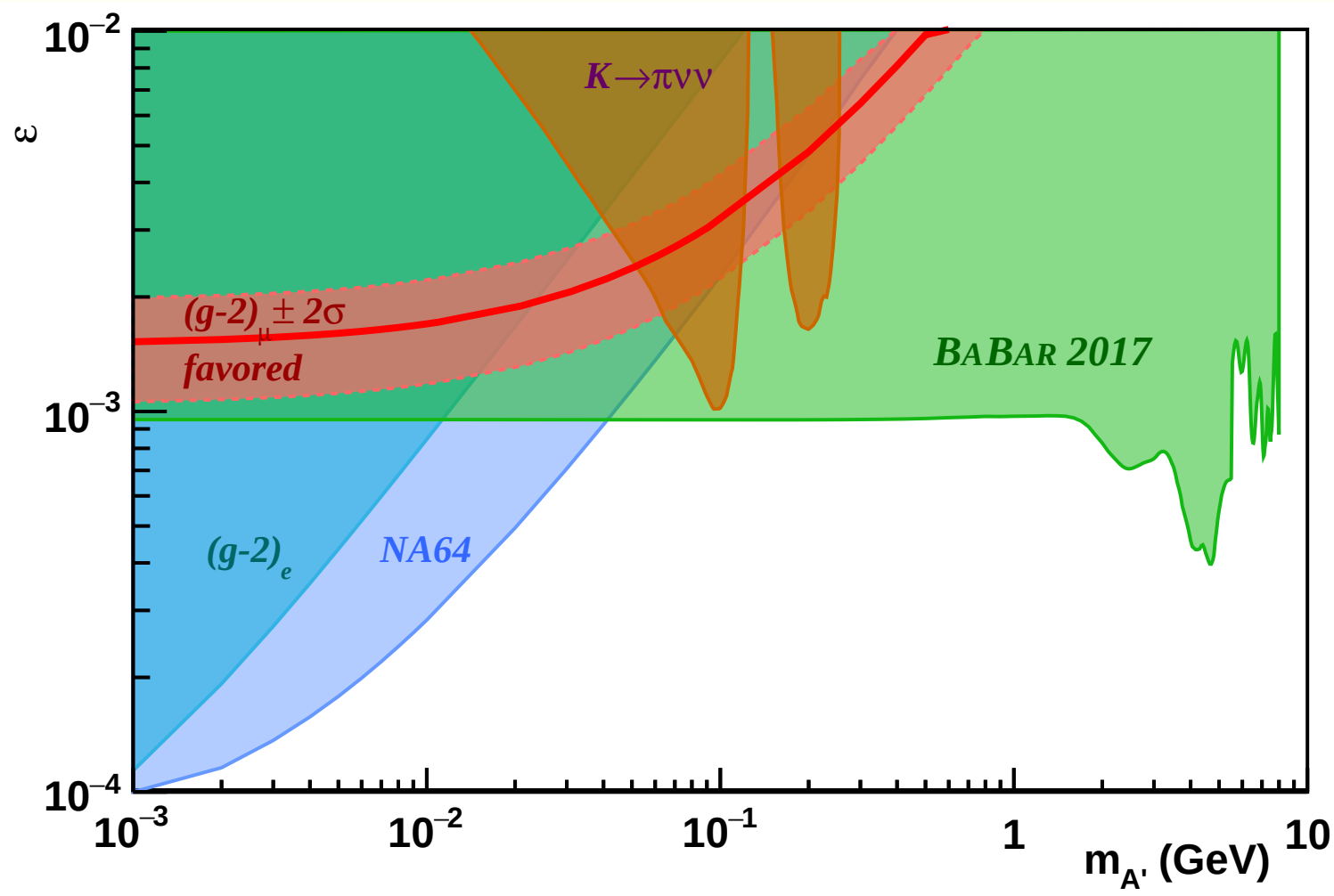
Low $m_{A'}$ region



High $m_{A'}$ region

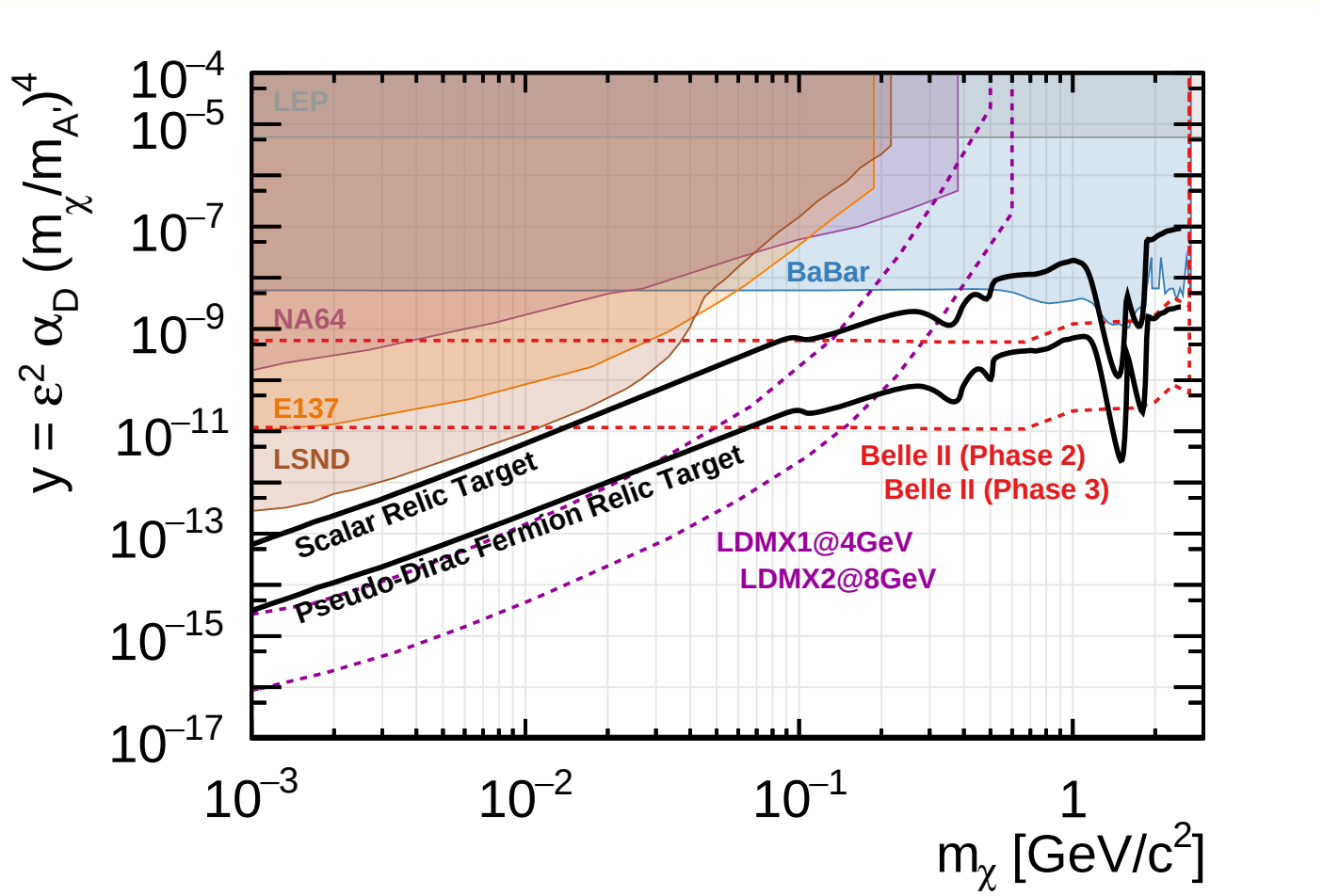
Dark photon search at BaBar (invisible)

- Constraints of coupling strength ϵ [PRL 119.131804 (2017)]



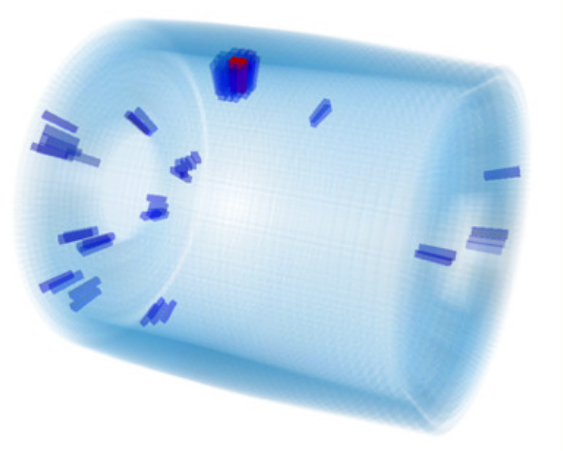
Dark photon search at Belle II (invisible)

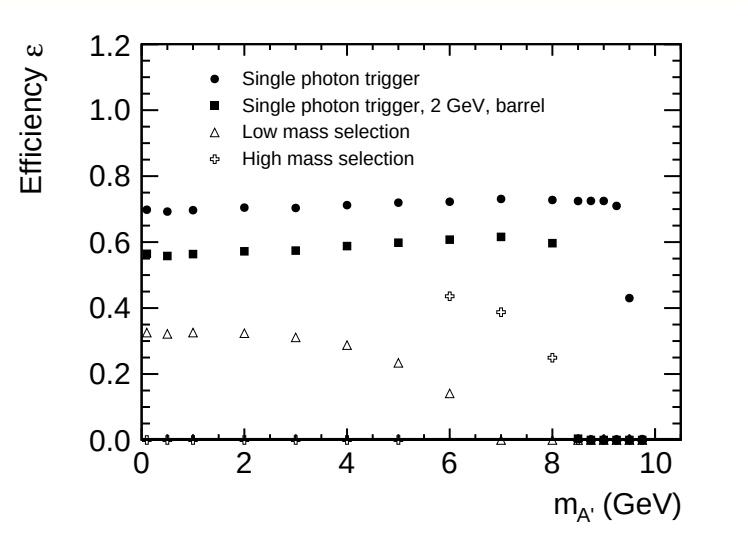
- Expected sensitivity [PRL 119.131804 (2017), arXiv:1608.08632]
  - Phase 2 $= 20\mathrm{fb}^{-1}$, Phase 3 $= 50\mathrm{ab}^{-1}$



Dark photon search at Belle II (invisible)

- Basic event selection
  - An ECL cluster with $E^{CM} > 1.0\mathrm{GeV}$
  - No other cluster with $E^{CM} > 0.1\mathrm{GeV}$
  - No tracks with $p_T^{CM} > 0.2\mathrm{GeV}$



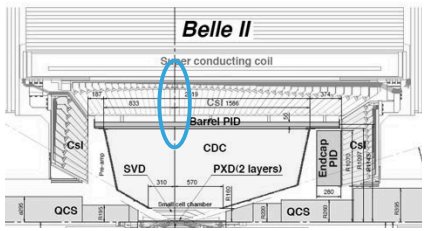


- Trigger efficiency for signal MC as a function of A' mass (filled circles)
- $E^{CM} > 2\mathrm{GeV}$ selection give more relevant for the subsequent event selection (filled squares)

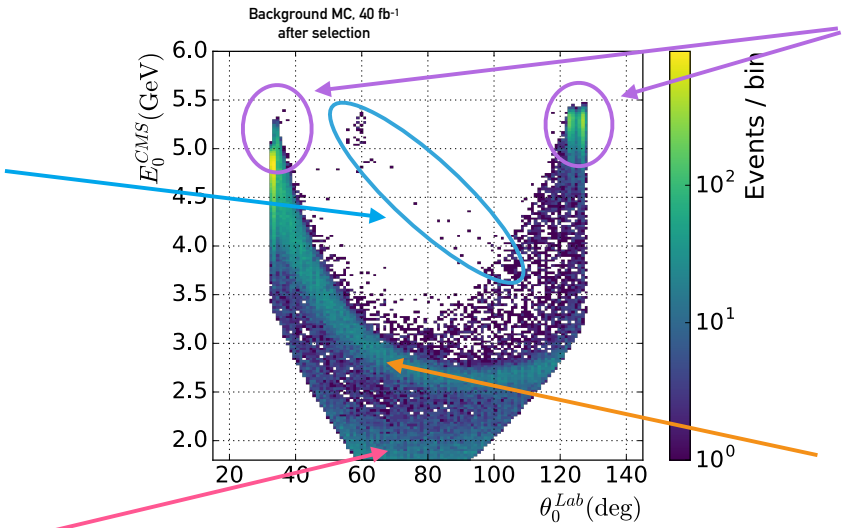
[arXiv:1702.0332 B2TIP, to be submitted in PTEP (2018)]

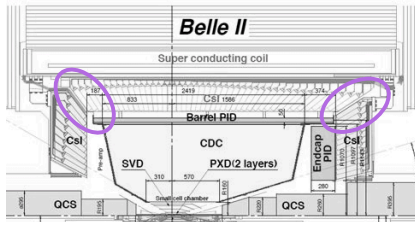
Dark photon search at Belle II (invisible)

- Background Analysis
  - Various kinds of backgrounds are indentified in E^{CM} vs. θ^{Lab}.

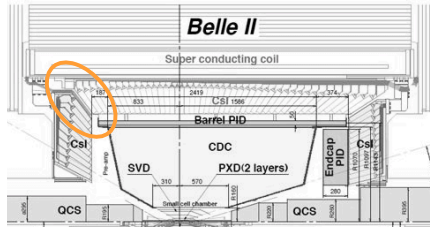


ee→2γ and 3γ
1γ in ECL 90° gap
1γ out of ECL acceptance





ee→2γ
1γ in ECL BWD or FWD gap



ee→3γ
1γ in ECL BWD gap
1γ out of ECL acceptance

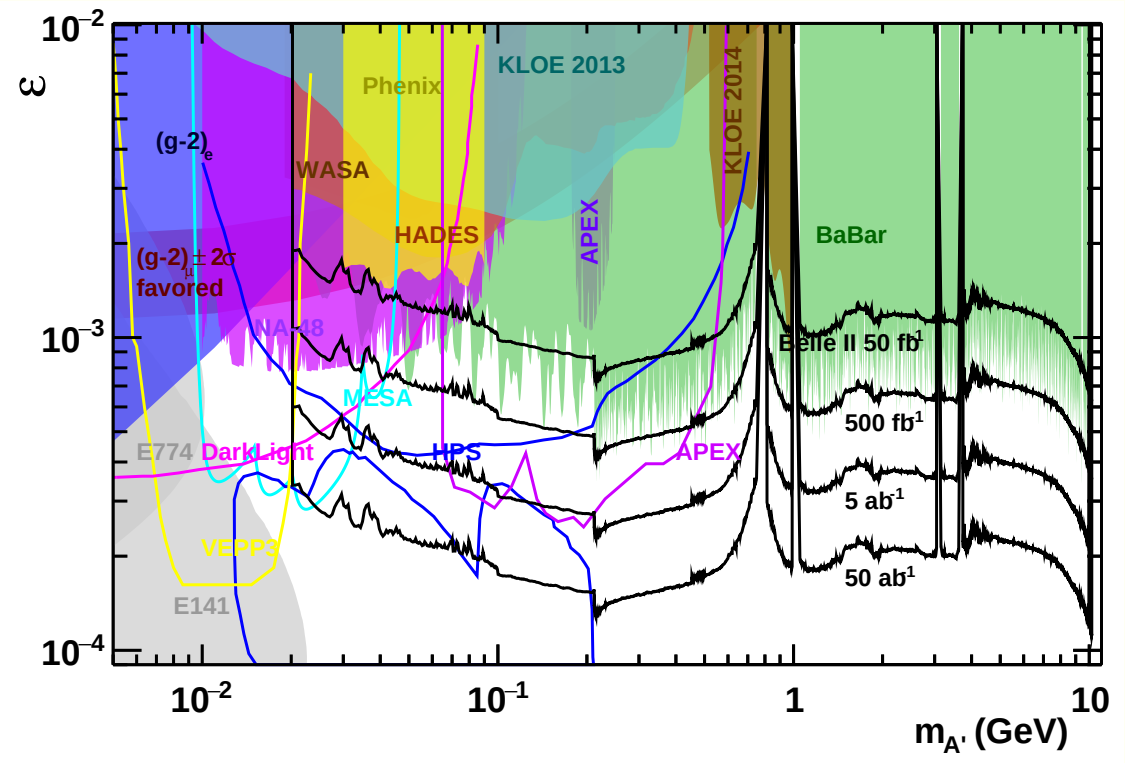
ee→eeγ
both electrons
out of tracking acceptance

Dark photon search at Belle II (visible)

- Expected sensitivity

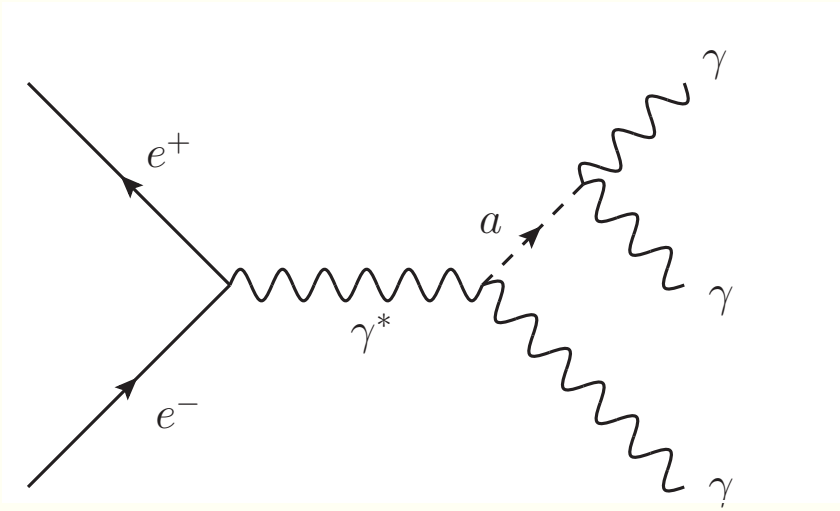
  [arXiv:1702.0332 B2TIP, to be submitted in PTEP (2018)]

  - Belle II can perform the analysis with improved low multiplicity trigger compared to Belle.

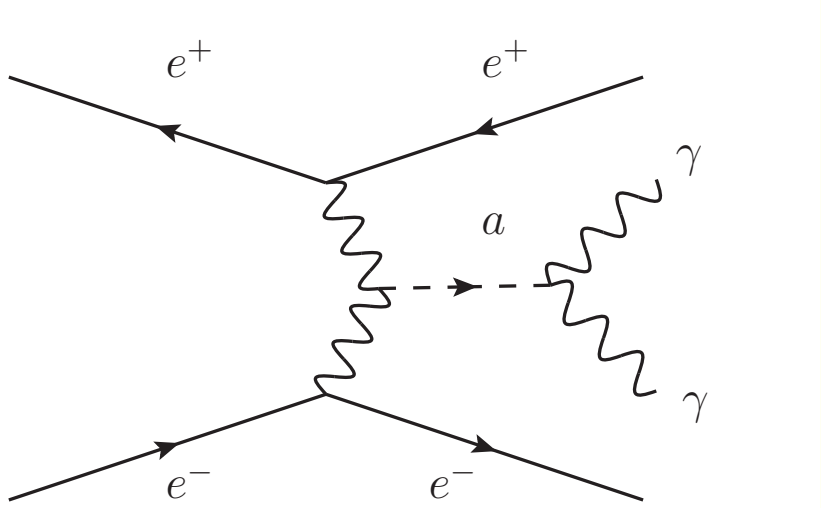


Introduction: Axion-Like Particles (ALPs)

- ALPs are pseudo-scalars and couple to bosons.
- They are also one of the DM candidate with many BSM scenarios.
- ⋆ **Focusing**: ALP(a)$\gamma\gamma$ coupling with ALP-strahlung



ALP-strahlung



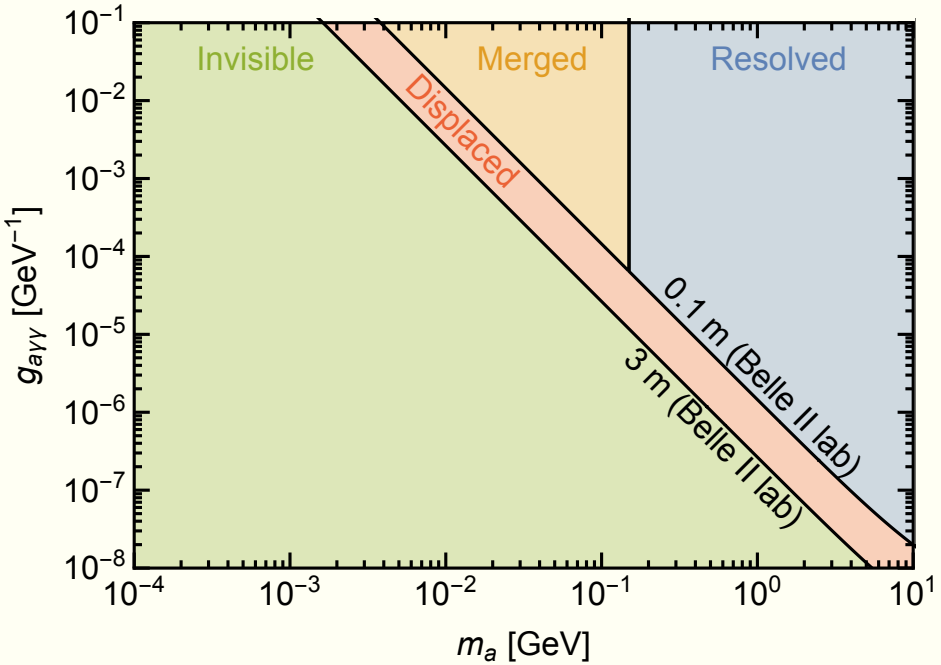
Photon fusion (low mass ALP)

[JHEP 12 (2017) 094]

- No Belle and BaBar analysis

ALP $\to \gamma\gamma$ search at Belle II

- Signature in the detector
  - Three photons (Resolved): High m_a
  - Two photons (Merged): $m_a \lesssim 150\mathrm{MeV} \to$ hard to analyze
  - Single photon (Invisible): a doesn't decay in the detector.



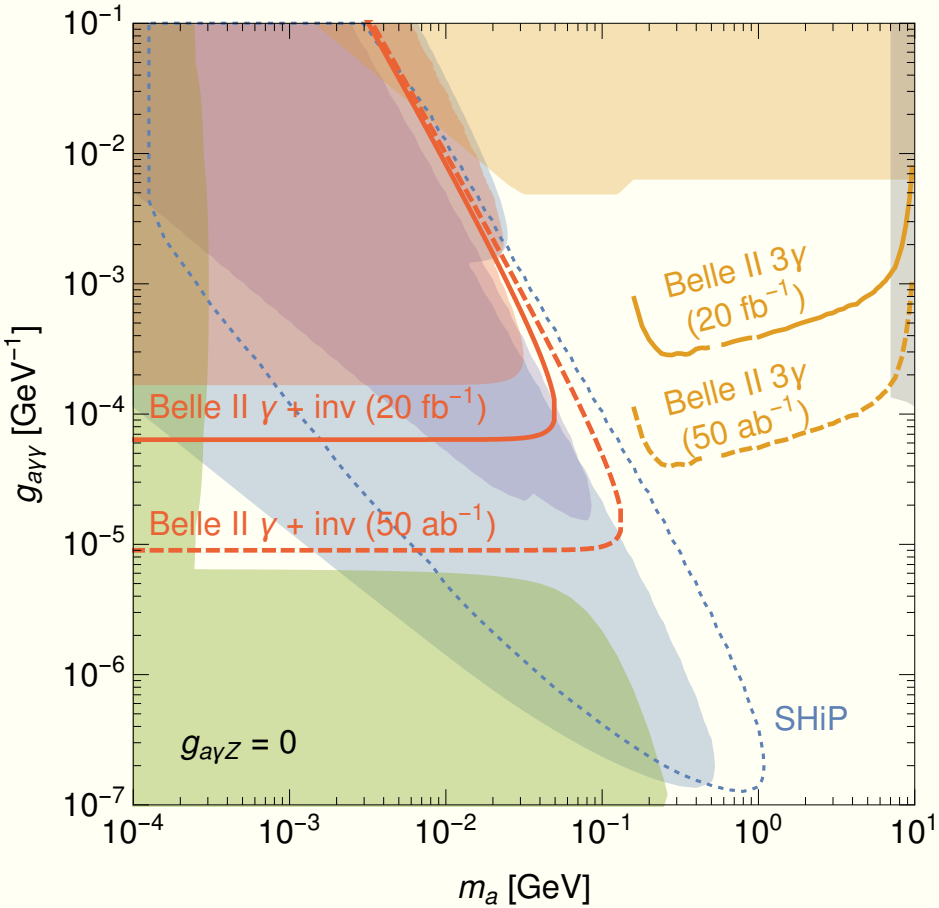
[JHEP 12 (2017) 094]

ALP $\to \gamma\gamma$ search at Belle II

- Event selection (Resolved ALP decay)
  - Three photons with a CM energy $E > 0.25\mathrm{GeV}$
  - After selection, scan for the $m_{\gamma\gamma}$ bump
- Possible background (Resolved ALP decay)
  - $e^+e^- \to \gamma\gamma\gamma$: dominant
  - $e^+e^- \to \gamma\gamma + \gamma$ from beam-induced background
    - Reduced using timing information of ECL
  - $e^+e^- \to \gamma\gamma$, $\gamma \to e^+e^-$ outside of tracking
    - Reduced using angular structure between γ, e^+, and e^-
  - $e^+e^- \to \pi^0\gamma$, $\eta\gamma$, and $\eta'\gamma$ ($m_a = m_{\pi^0}$ region is not sensitive)
    - Exclude $^{50\mathrm{MeV}}_{-75\mathrm{MeV}}$ region arround the η and η'

ALP $\rightarrow \gamma\gamma$ search at Belle II

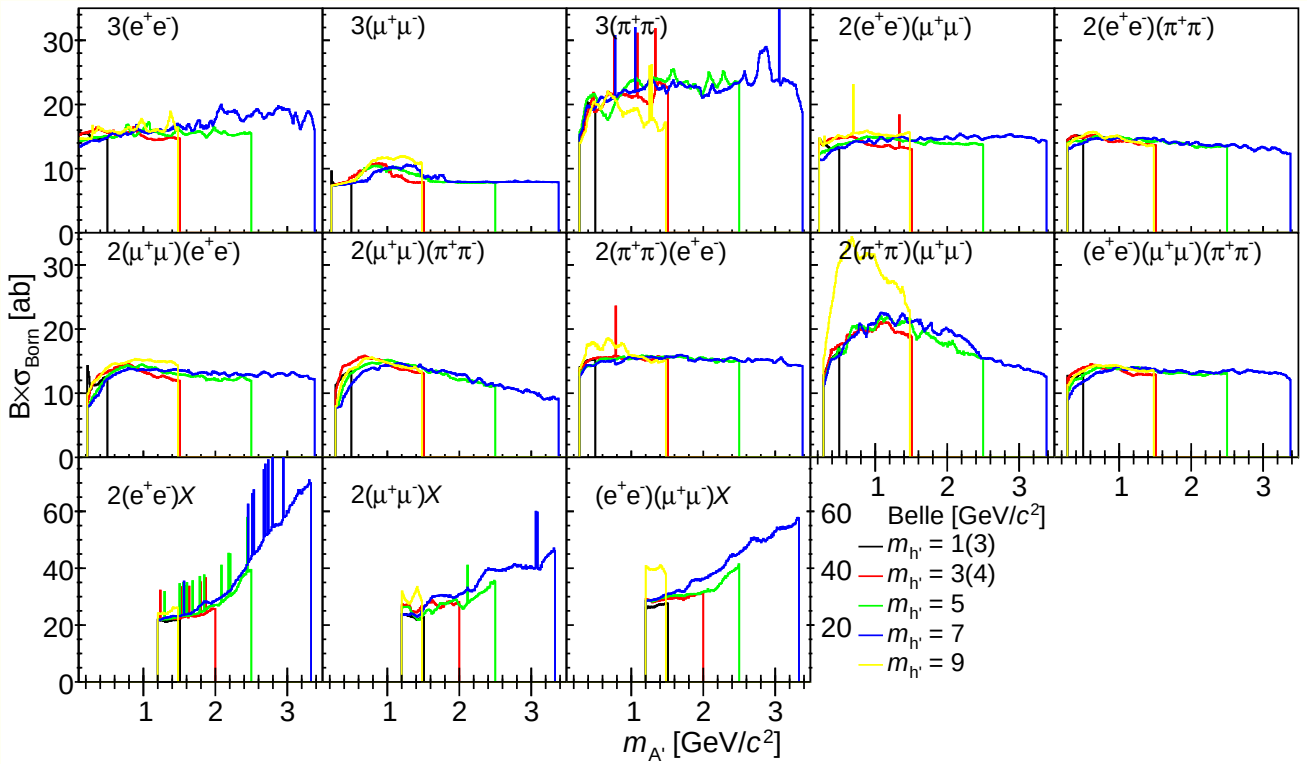
- Requirement for other ALP decay
  - Single photon trigger for invisible ALP
  - Cluster seperation improvement for low mass ALP



Expected sensitivity projection for $a\gamma\gamma$ coupling

Other Belle Result [PRL 114.211801 (2015)]

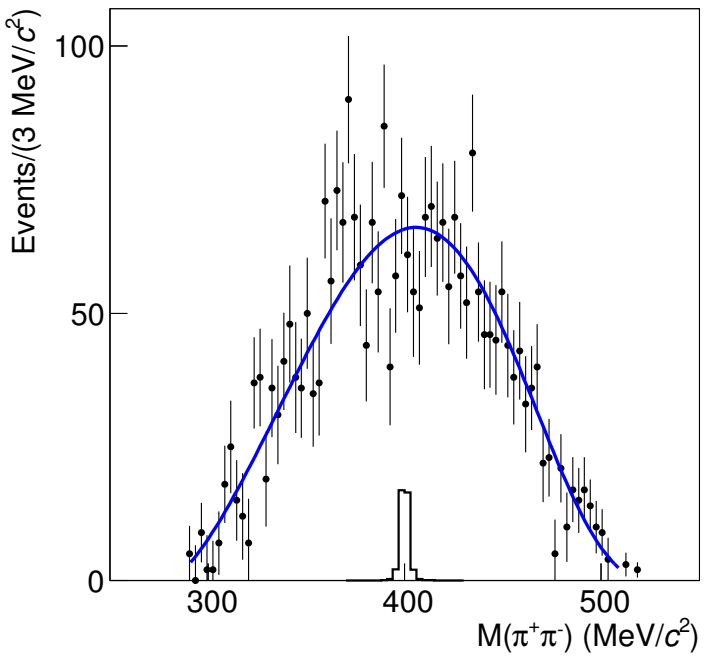
- Dark photon and Higgs search with Higgs-strahlung channel
  - $e^+e^- \to A'h'$, with $h' \to A'A'$
  - 10 exclusive channels and 3 inclusive channels are studied.



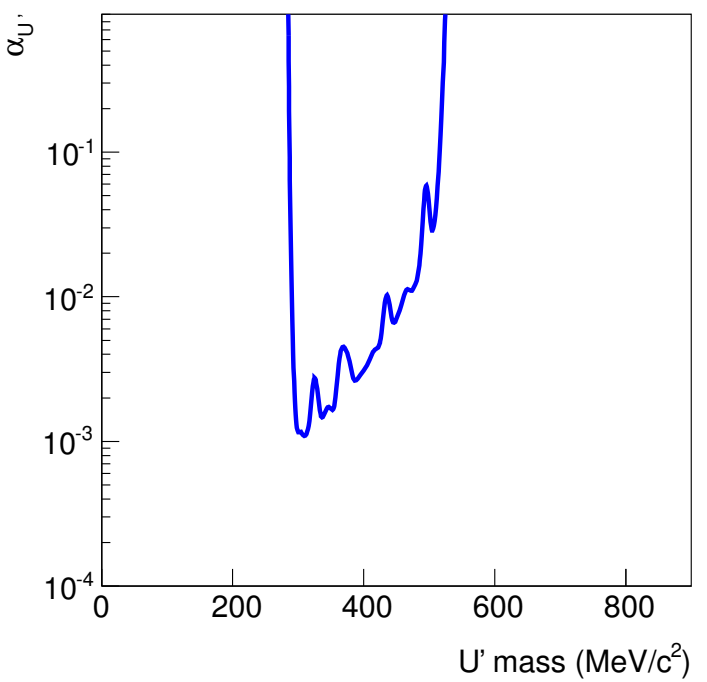
90% CL upper limit on the combined born cross section for 13 final states

Other Belle Result [PRD 94.092006 (2016)]

- Dark photon - quark coupling search with D^* decay chain
  - $D^{*+} \to D^0\pi^+$, $D^0 \to K^0_S\eta$, $\eta \to U'\gamma$, $U' \to \pi^+\pi^-$



$m_{\pi^+\pi^-}$ after background subtraction (below line: signal MC)



95% CL limit on the baryonic fine structure constant

Summary

- Dark sector was successfully studied with Belle and BaBar.
  - Belle cannot search $e^+e^- \to \gamma X$ events since lack of trigger.
  - BaBar searched single photon events with high luminosity, but we need much higher luminosity.
- Belle II is now preparing dark photon and ALPs search with enhancement of single photon and low multiplicity trigger.
- Not only ISR related events, but also there are many topics related dark sector not covered in this presentation.

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Thank you for listening!

Backup

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