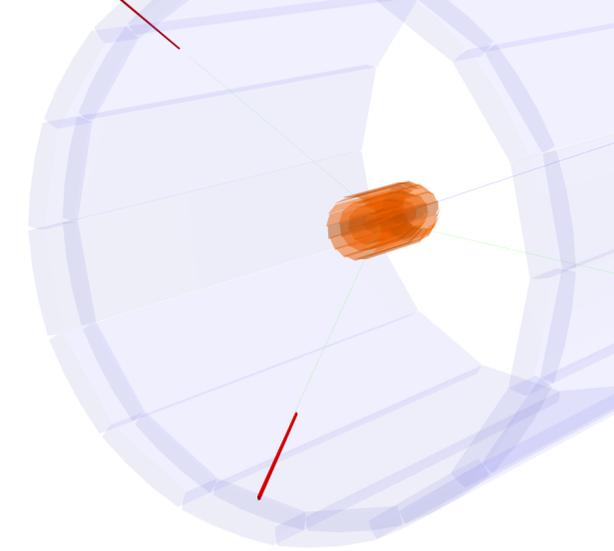


First results on Dark Matter searches at Belle II.



13th February 2020

Lake Louise Winter Institute 2020

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HELMHOLTZ RESEARCH FOR
GRAND CHALLENGES

UH
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG



Outline

1. SuperKEKB & Belle II

See also talks from *Andreas Warburton* (Tuesday), *Tadeas Bilka* and *Ming-Chuan Chang* (tomorrow)

Not just a B-factory: also a “Dark Searcher”

2. Dark photon

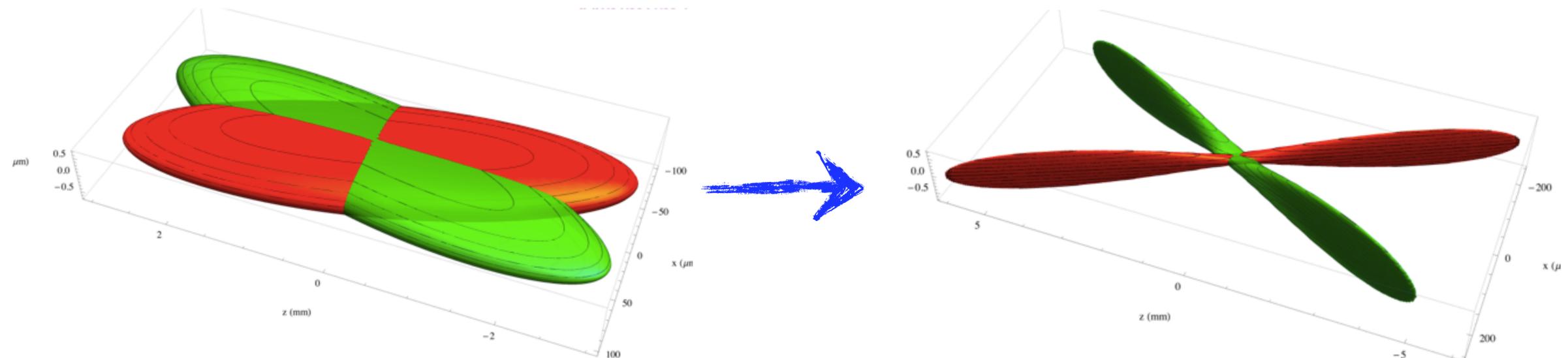
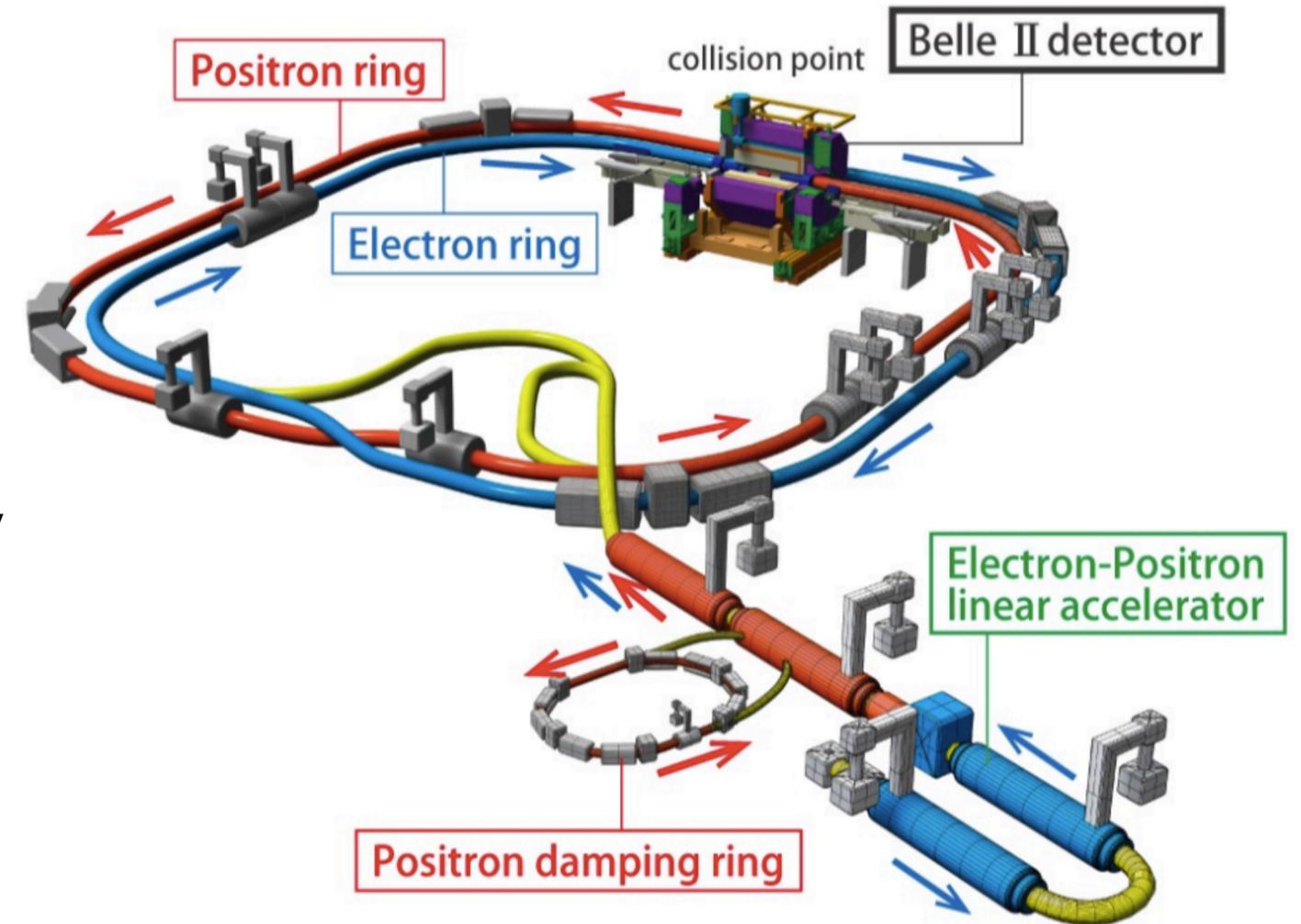
3. Axion-Like Particles (ALPs)

4. Z'

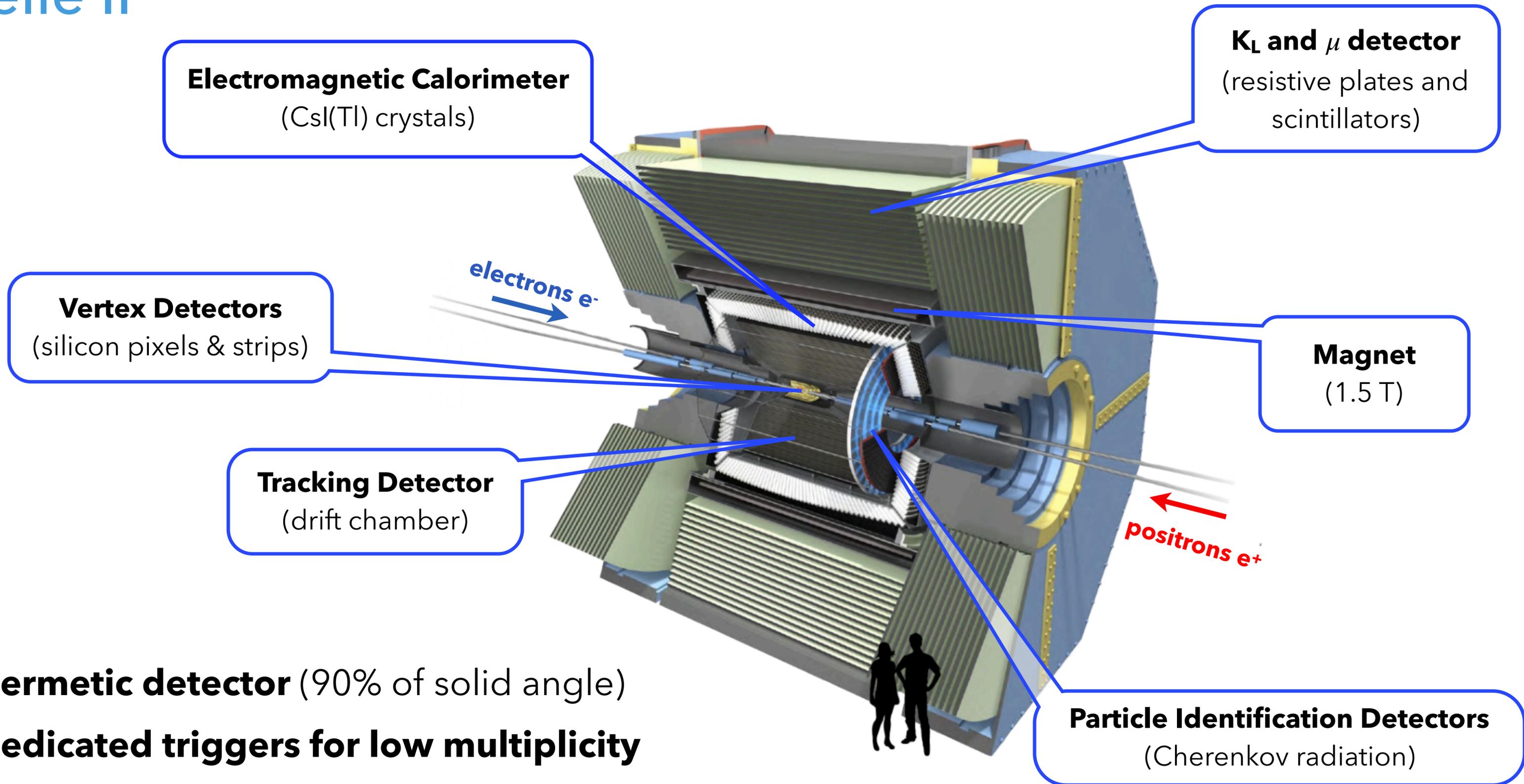
SuperKEKB and Belle II.

SuperKEKB

- **Asymmetric e^+e^- collider**
@ $\Upsilon(4S)$ energy = 10.58 GeV
- Second generation **B-factory**
(optimized to produce a lot of B mesons)
- **40 times** increase in instantaneous luminosity with respect to predecessor KEKB:
 $\approx 8 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$, highest in the world
 - 2x from higher beam current
 - 20x from final focus magnets

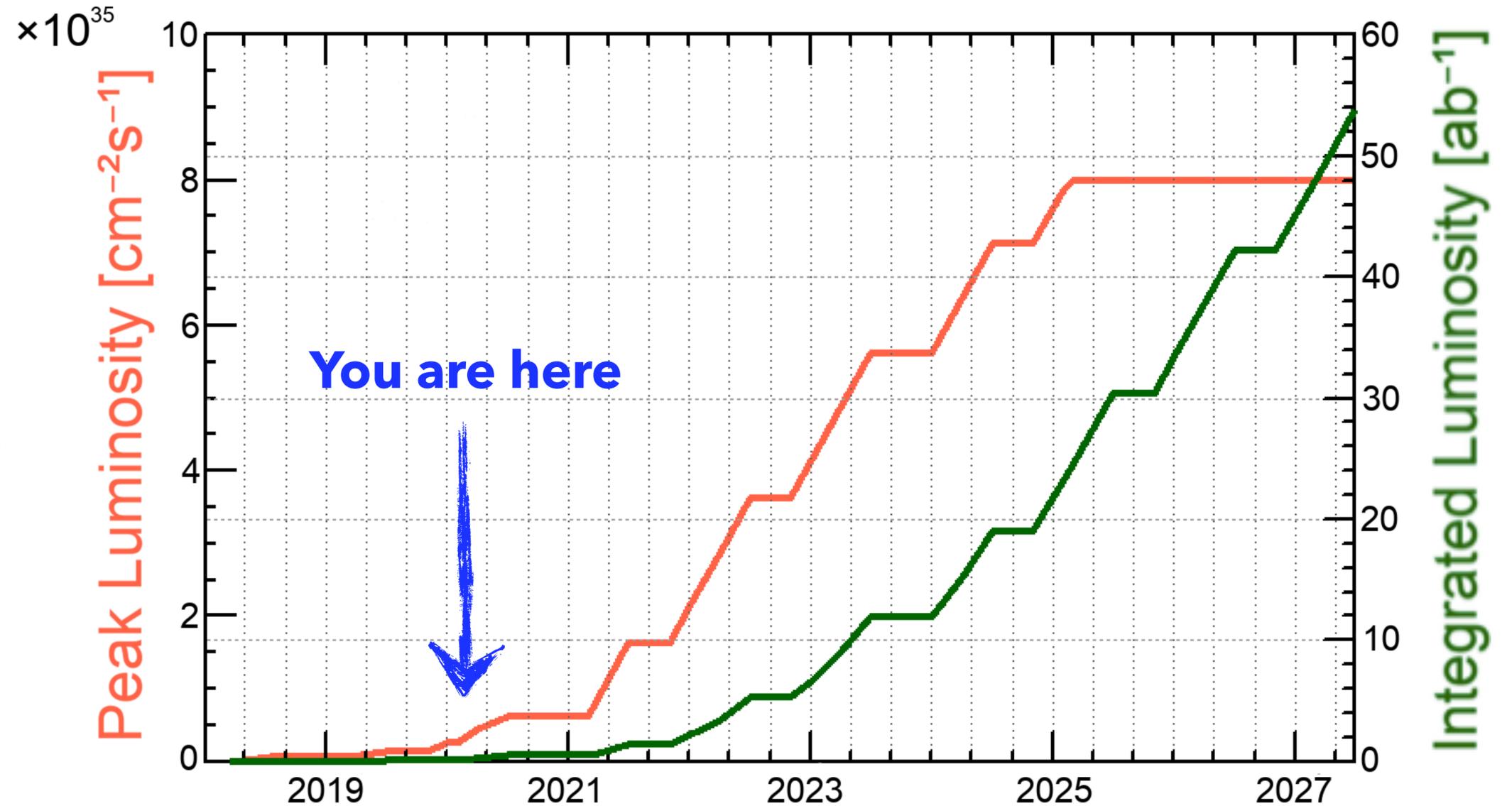


Belle II



Data collection schedule

- 2018: 500 pb⁻¹
- Commissioning run
- But still, physics results **can** be extracted (and are being extracted)
- 2019: 10.5 fb⁻¹
- Schedule lifetime dataset: **50 ab⁻¹**



Adapted from [SuperKEKB Page](#)

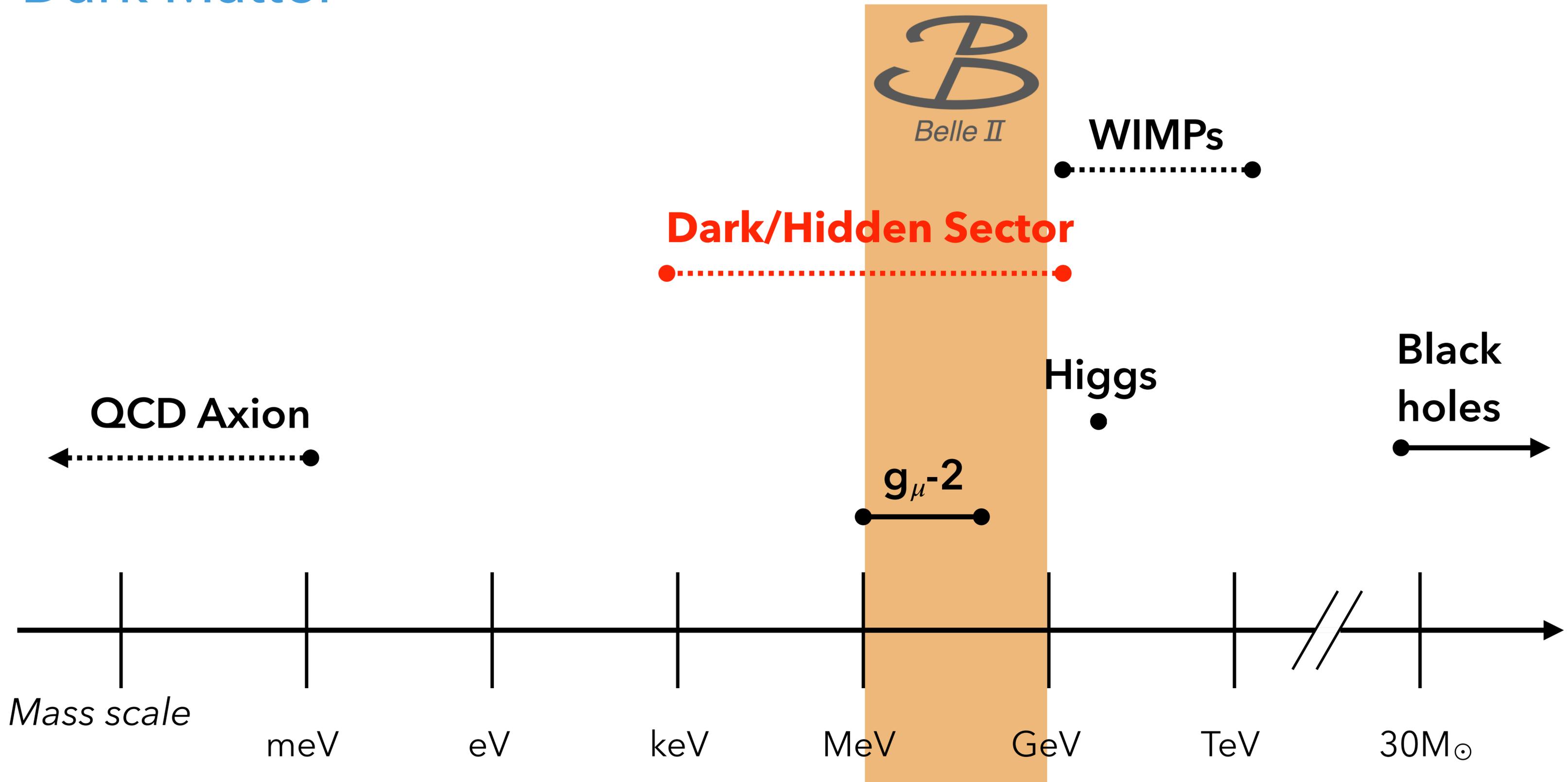
Dark Sector perspective

- Hermetic detector
- Specialized triggers for low multiplicity events (e.g. *single* photon trigger)
- High luminosity
- Clean environment (e^+e^- collider)

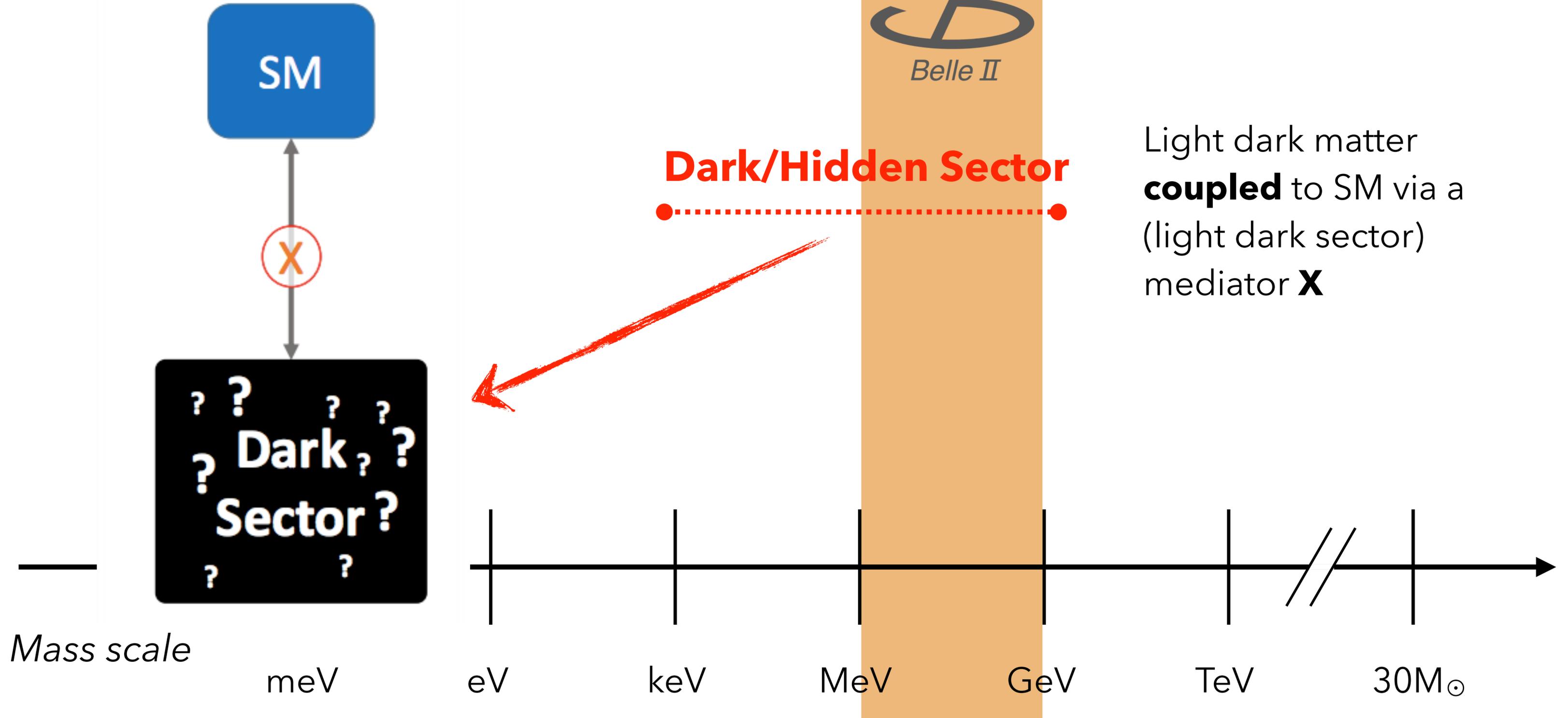
- Excellent place where to **search for dark matter** candidates!
 - That's what we are doing (amongst other things)

Dark Matter.

Dark Matter



Dark Matter

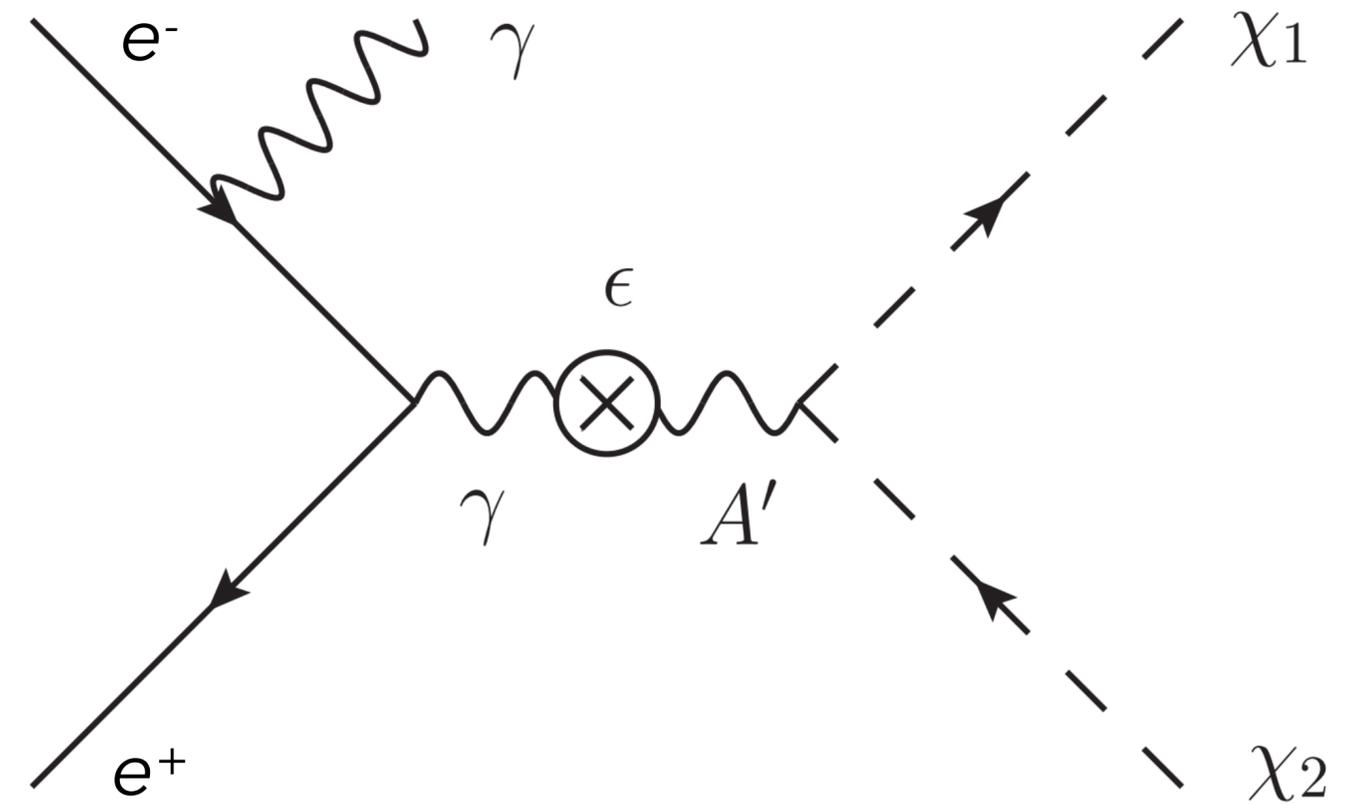


Dark Photon.

Dark Photon - theory

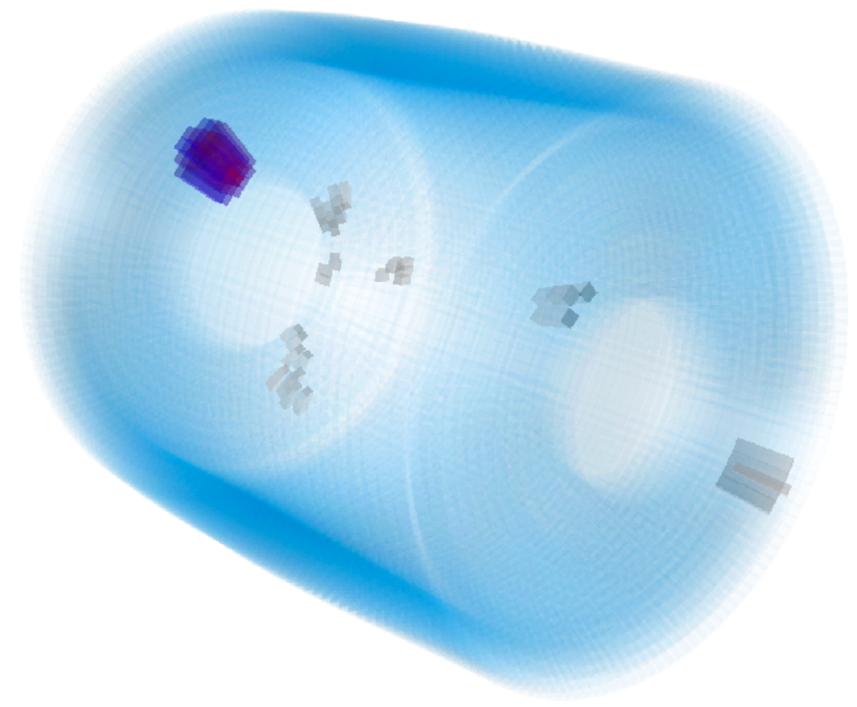
- Massive vector mediator A' **mixes with SM photon** (via kinetic mixing ϵ)
- Possible decays:
 - into DM final state: **invisible** $A' \rightarrow \chi_1 \chi_2$
 - into two leptons: visible $A' \rightarrow f^+ f^-$
- Experimental trick: requiring **ISR photon** (on-shell production & visible final state)

$$E_{\gamma\text{ISR}} = \frac{s - m_{A'}^2}{2\sqrt{s}}$$

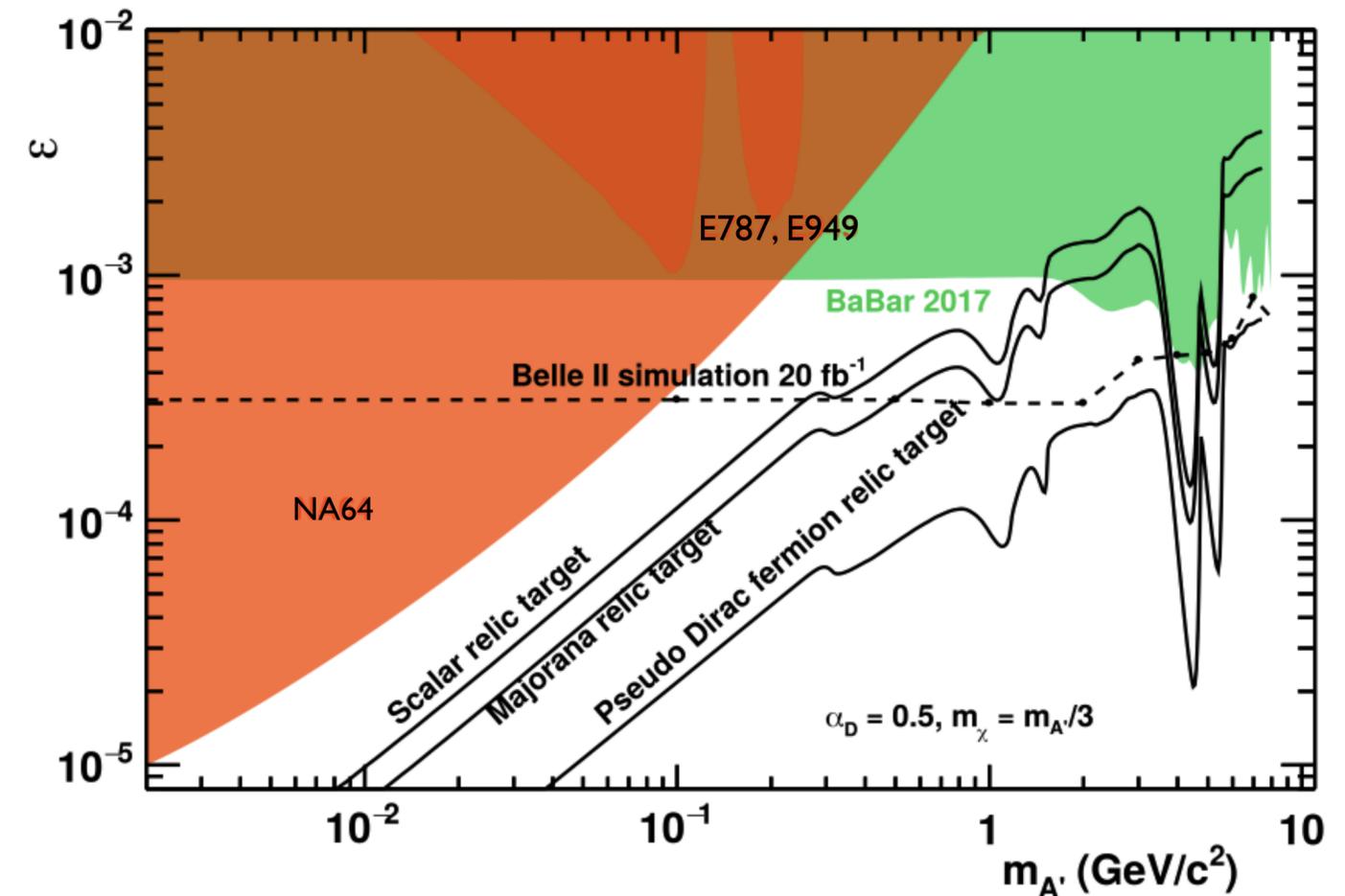


Dark Photon - analysis & sensitivity

- Current approach: **invisible: $A' \rightarrow \chi_1 \chi_2$, single photon**
 - Needs a **special single-photon trigger**: not available* in previous generation B-factories
- One photon and nothing else in the whole event
 - E_{cms} vs θ of the photon
 - Bump search in recoil mass spectrum
- Backgrounds:
 - Cosmic rays
 - $e^+e^- \rightarrow e^+e^-\gamma(\gamma)$
 - $e^+e^- \rightarrow \gamma\gamma(\gamma)$



Belle II simulation, signal only

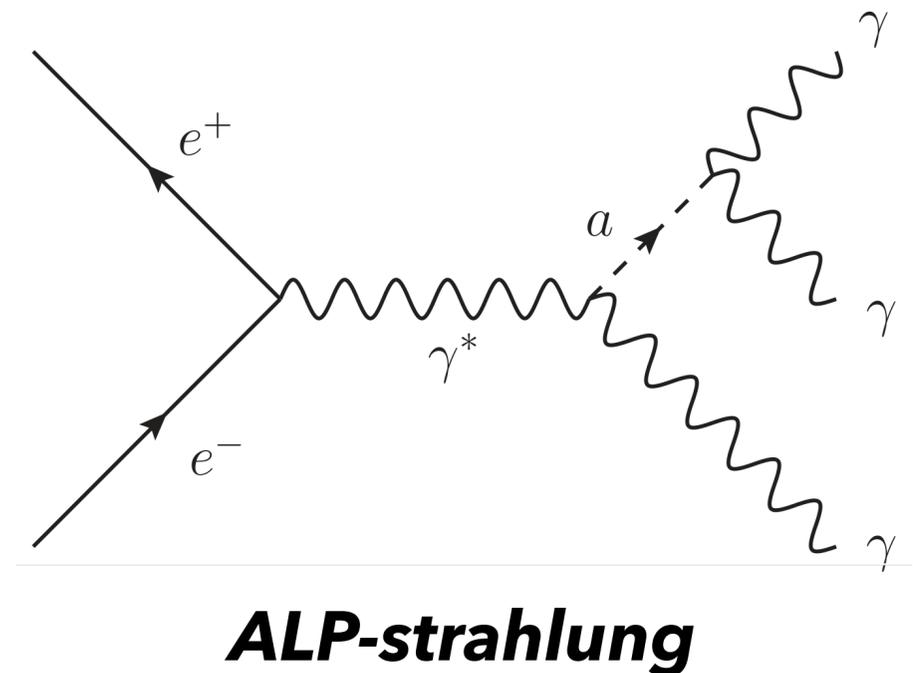
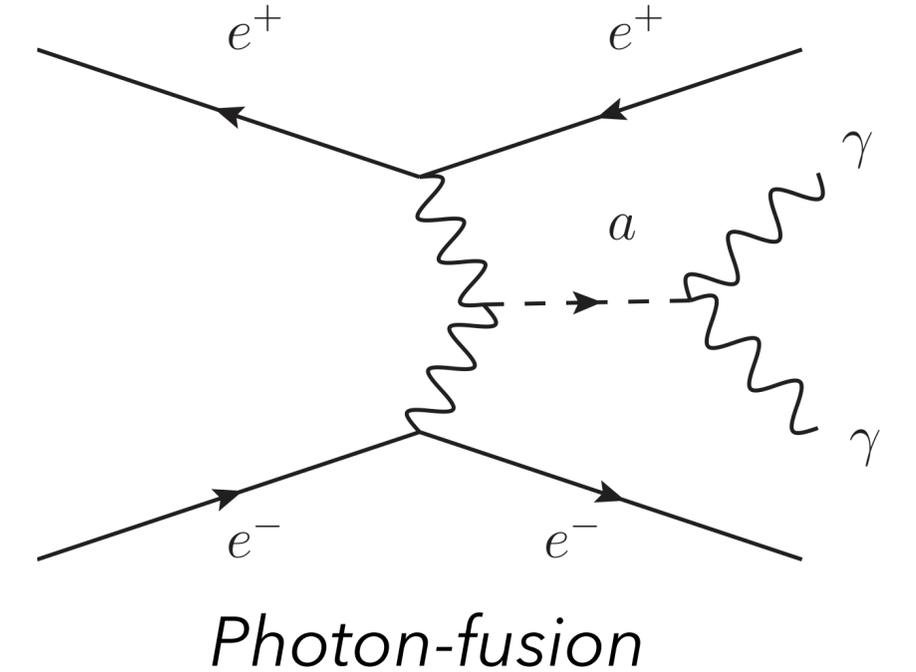


*not at all in Belle, ~10% of data in BaBar

Axion-Like Particles.

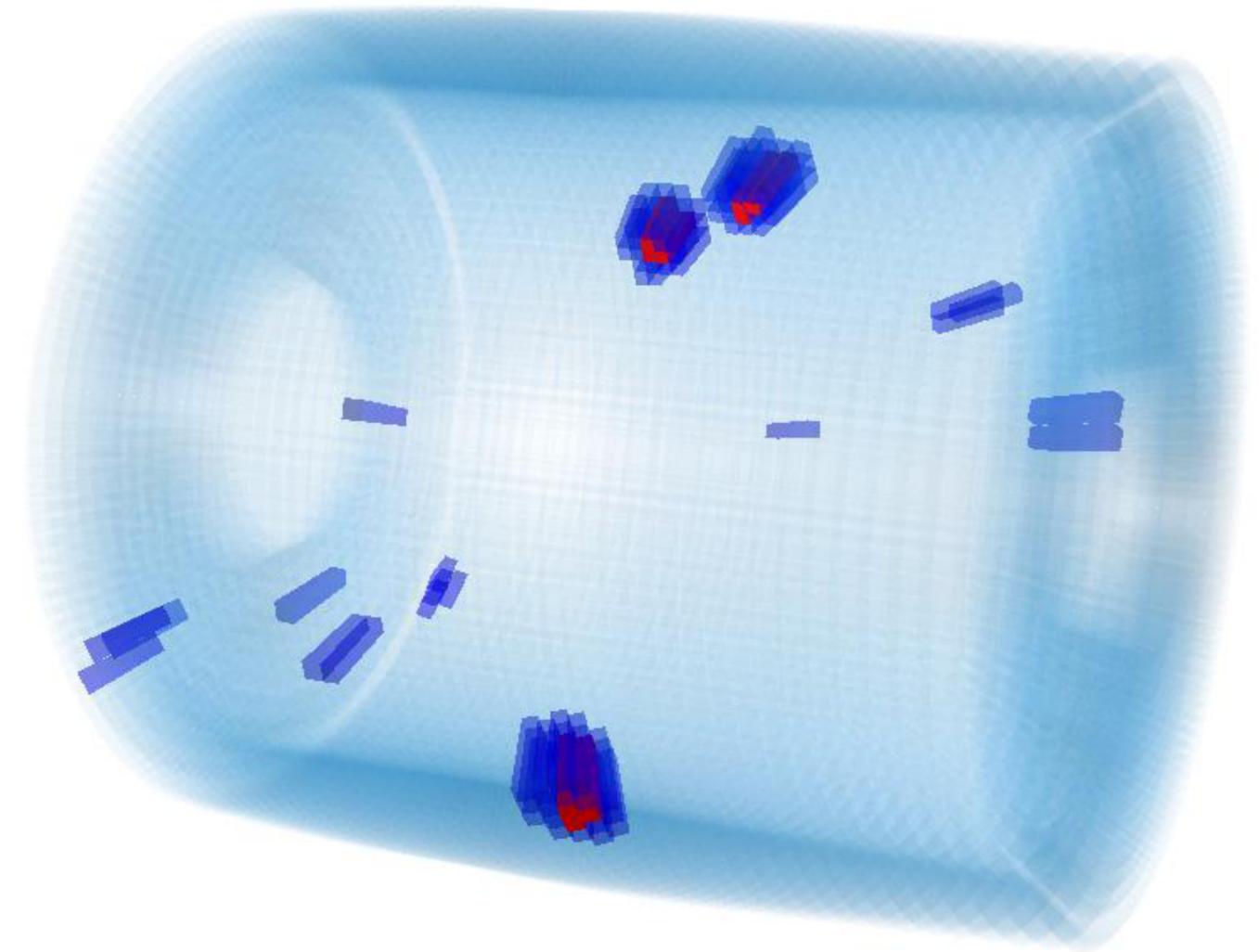
ALPs - theory

- Original axions: solution to the strong CP problem
- ALPs (***a***) are just relatives of the axions
 - Neutral massive pseudoscalar
 - No mass-coupling constraints
- We focus on their coupling with photons
 - Assume they couple **only** to photons
- Two possible processes at e^+e^- colliders:
 - Photon fusion
 - **ALP-strahlung**



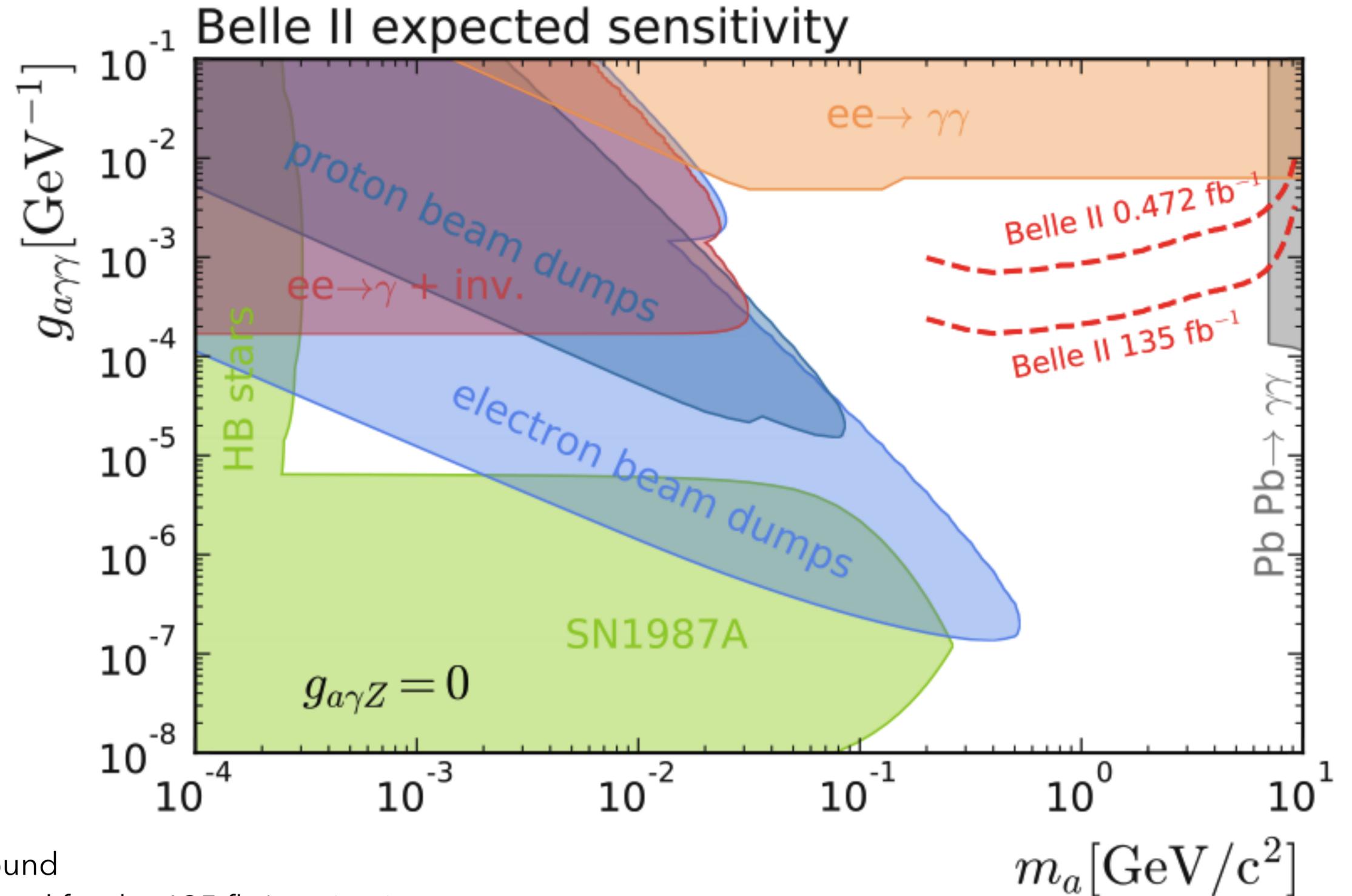
ALPs - analysis

- Experimentally **ALP-strahlung** is easier: start with this
- **Three photons** summing up to beam energy, no other particles
 - Bump search in di-photon and recoil mass
- Backgrounds:
 - $e^+e^- \rightarrow \gamma\gamma(\gamma)$
 - $e^+e^- \rightarrow e^+e^-(\gamma)$
 - $e^+e^- \rightarrow P\gamma, P=\pi^0/\eta/\eta', P \rightarrow \gamma\gamma$
peaking but negligible background



Belle II simulation, signal only

ALPs - sensitivity



[JHEP12\(2017\)094](#)

No systematics

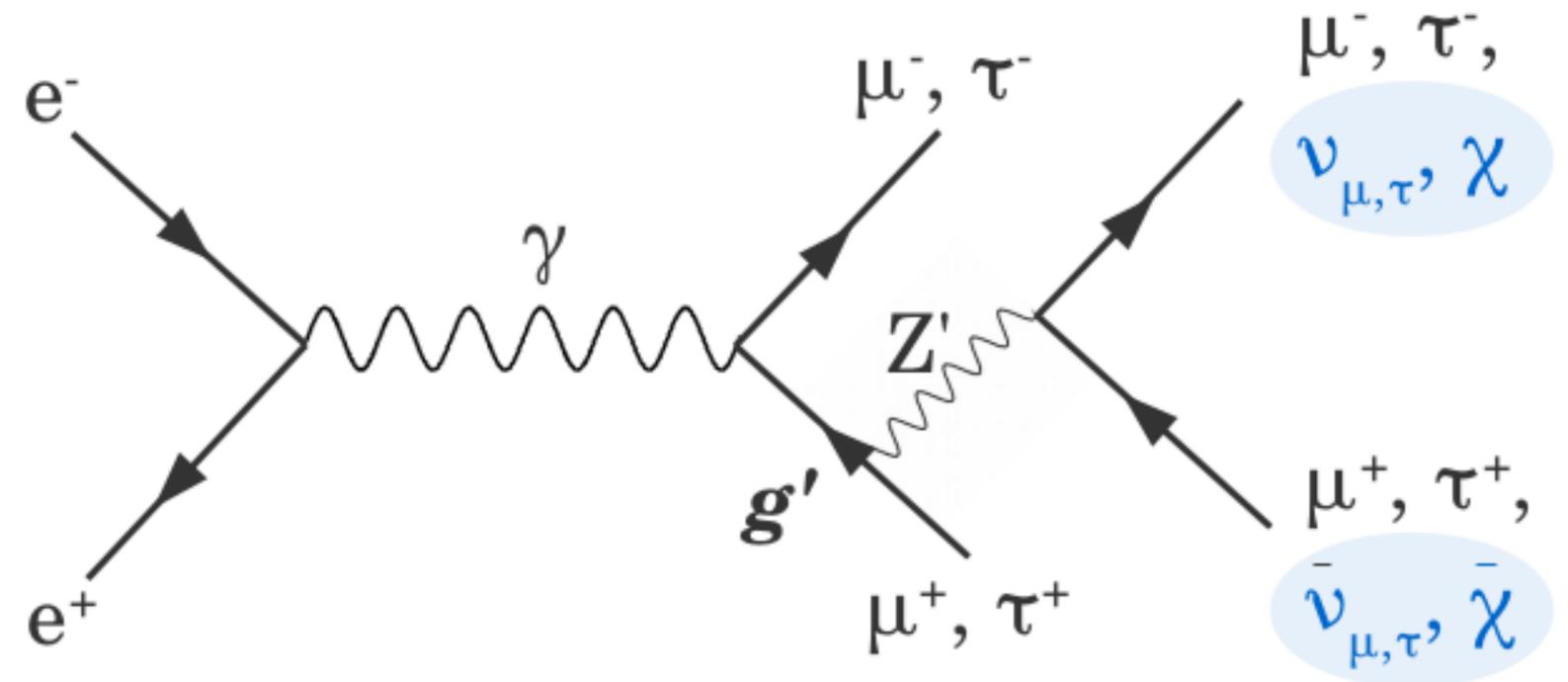
Only dominant $e^+e^- \rightarrow \gamma\gamma(\gamma)$ background

Assumes no $\gamma\gamma$ trigger veto in the barrel for the 135 fb⁻¹ projection

Z'

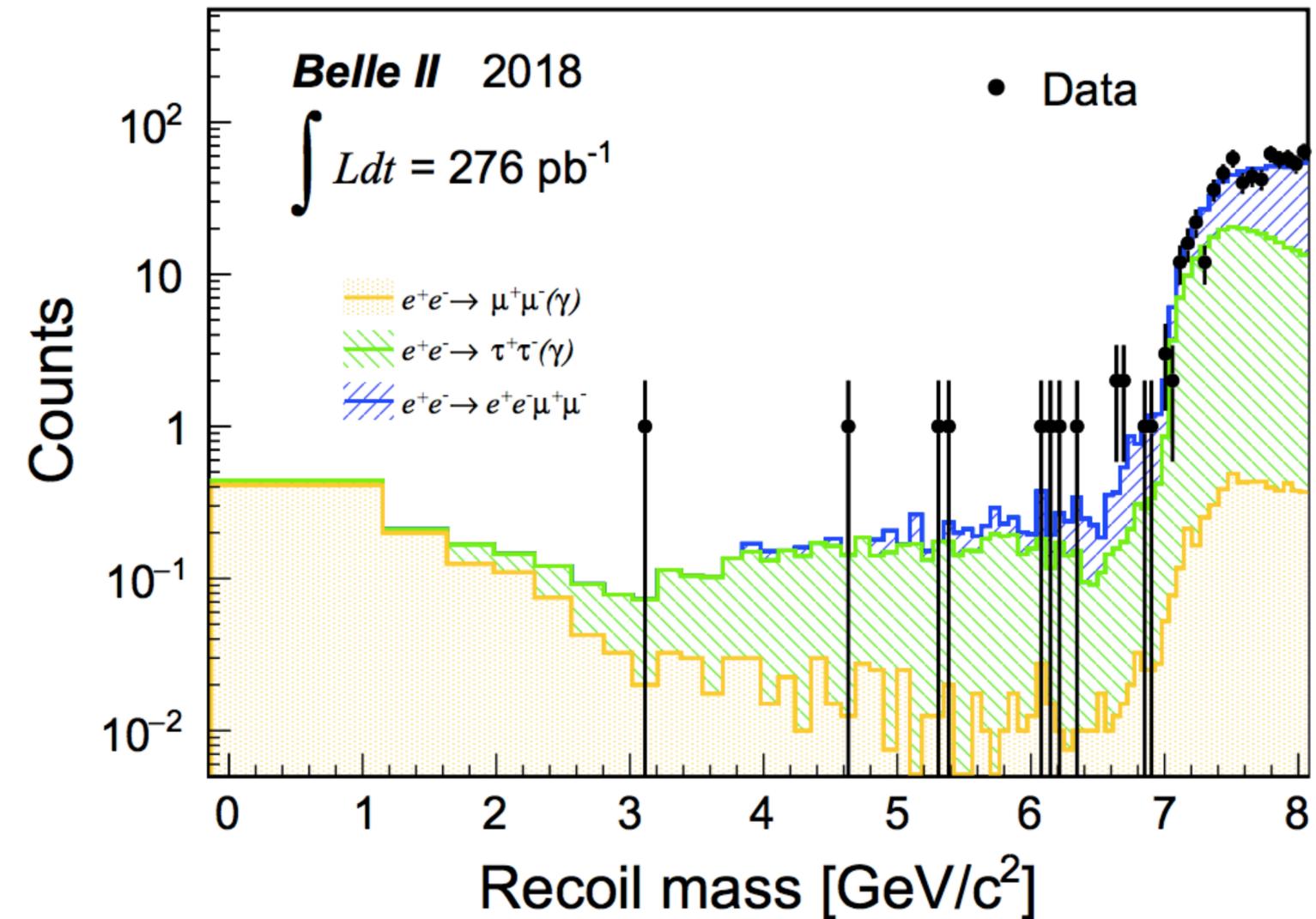
Z' - theory

- **New gauge boson Z'** coupling only with 2nd and 3rd generations of leptons ($L_\mu - L_\tau$)
 - Could come either from μ or τ
 - Possible solution for $g_\mu - 2$
- If it is lighter than 2 muons:
decays only into neutrinos and/or DM
 - **Invisible decay**



Z' - analysis

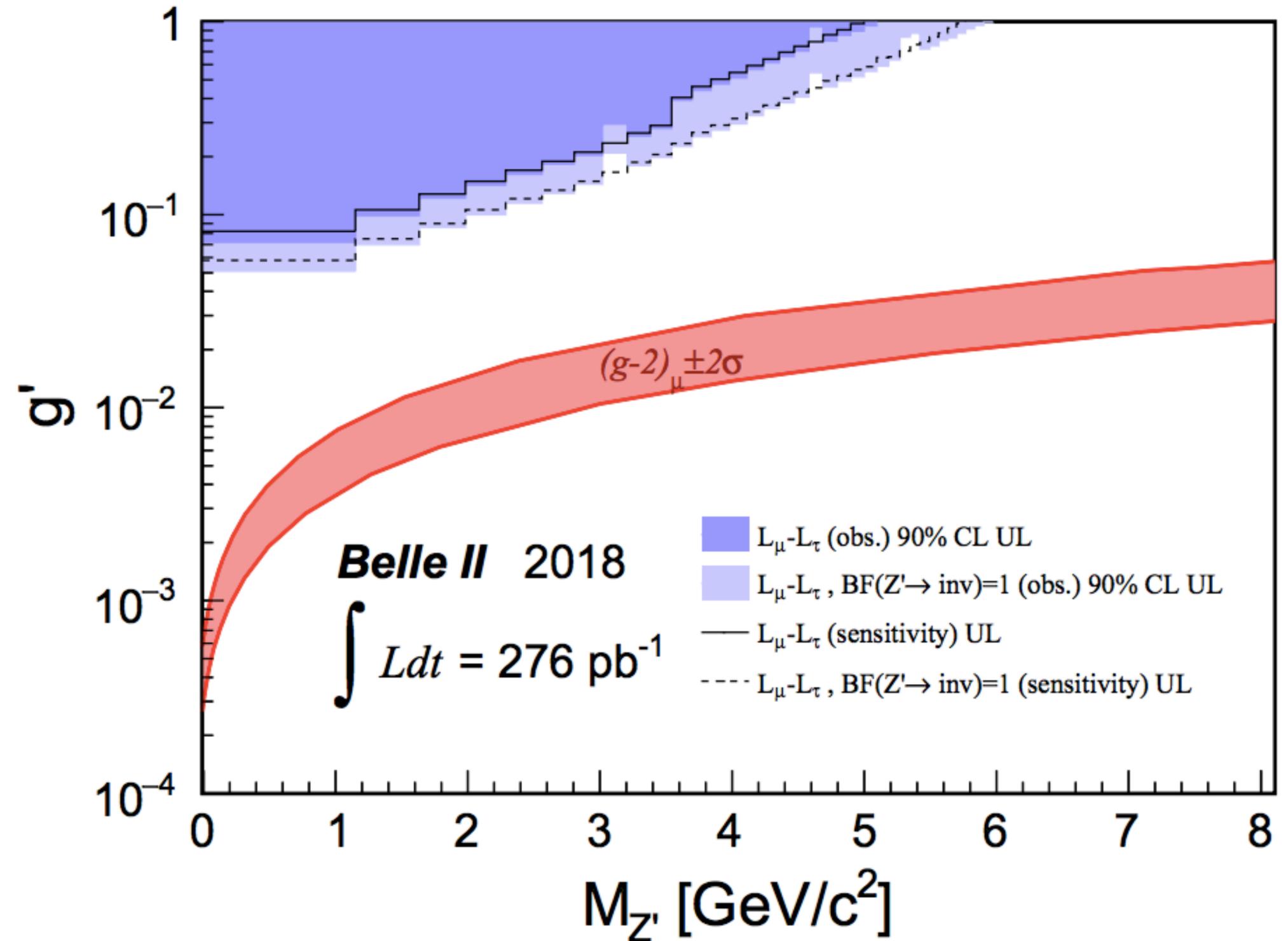
- Investigate $e^+e^- \rightarrow \mu^+\mu^- + \text{missing energy}$
 - Nothing else in the event
 - Bump search in recoil mass against $\mu^+\mu^-$
- Backgrounds:
 - $e^+e^- \rightarrow \mu^+\mu^- (\gamma)$
 - $e^+e^- \rightarrow \tau^+\tau^- (\gamma), \tau \rightarrow \mu \nu_\mu \nu_\tau$
 - $e^+e^- \rightarrow \mu^+\mu^- e^+e^-$
- Only ~50% of 2018 commissioning data available due to trigger conditions



[arXiv:1912.11276](https://arxiv.org/abs/1912.11276)

Z' - limits

- **First** result ever for the Z' to invisible decay
- **First** physics paper submitted by Belle II



[arXiv:1912.11276](https://arxiv.org/abs/1912.11276)

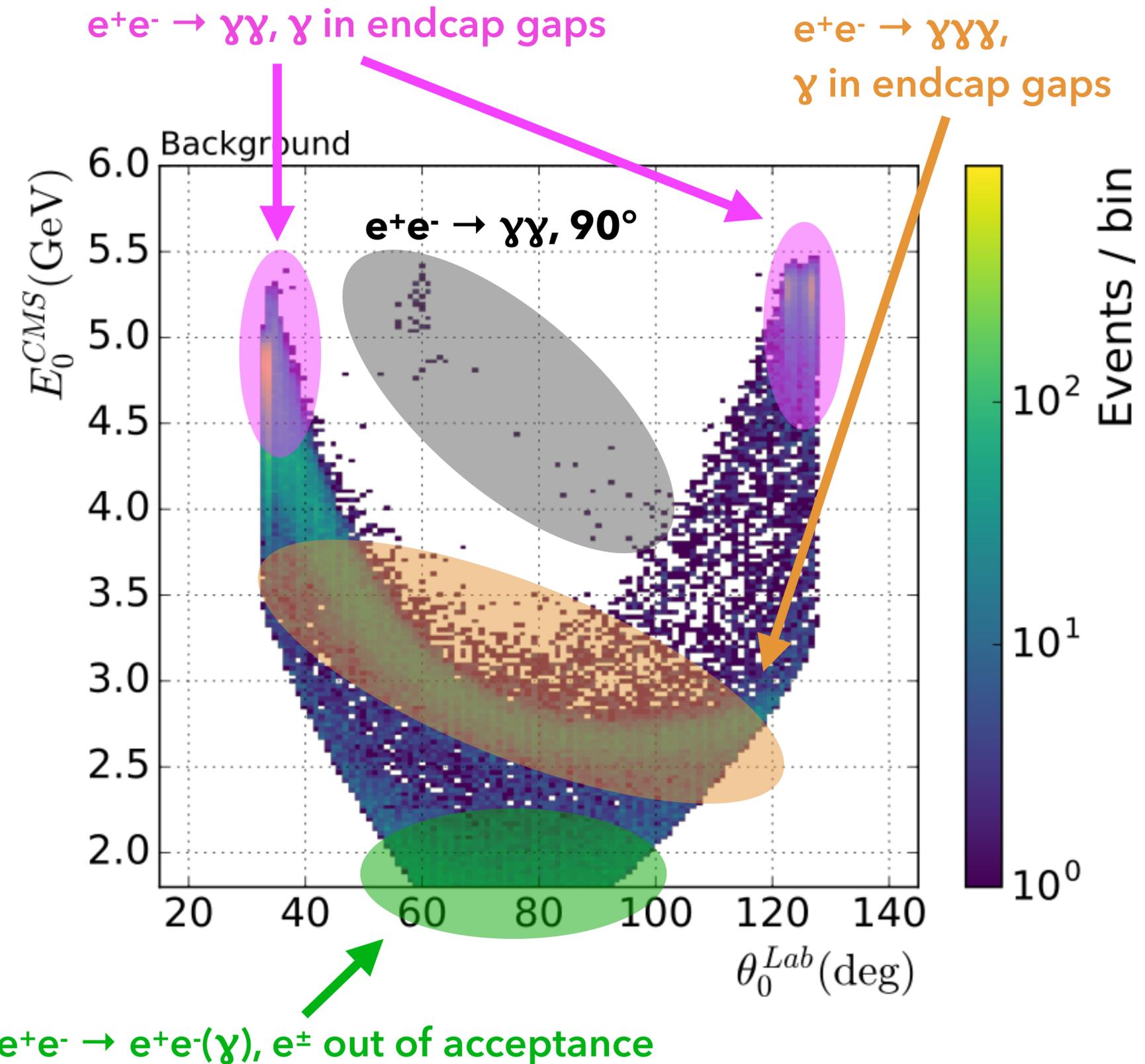
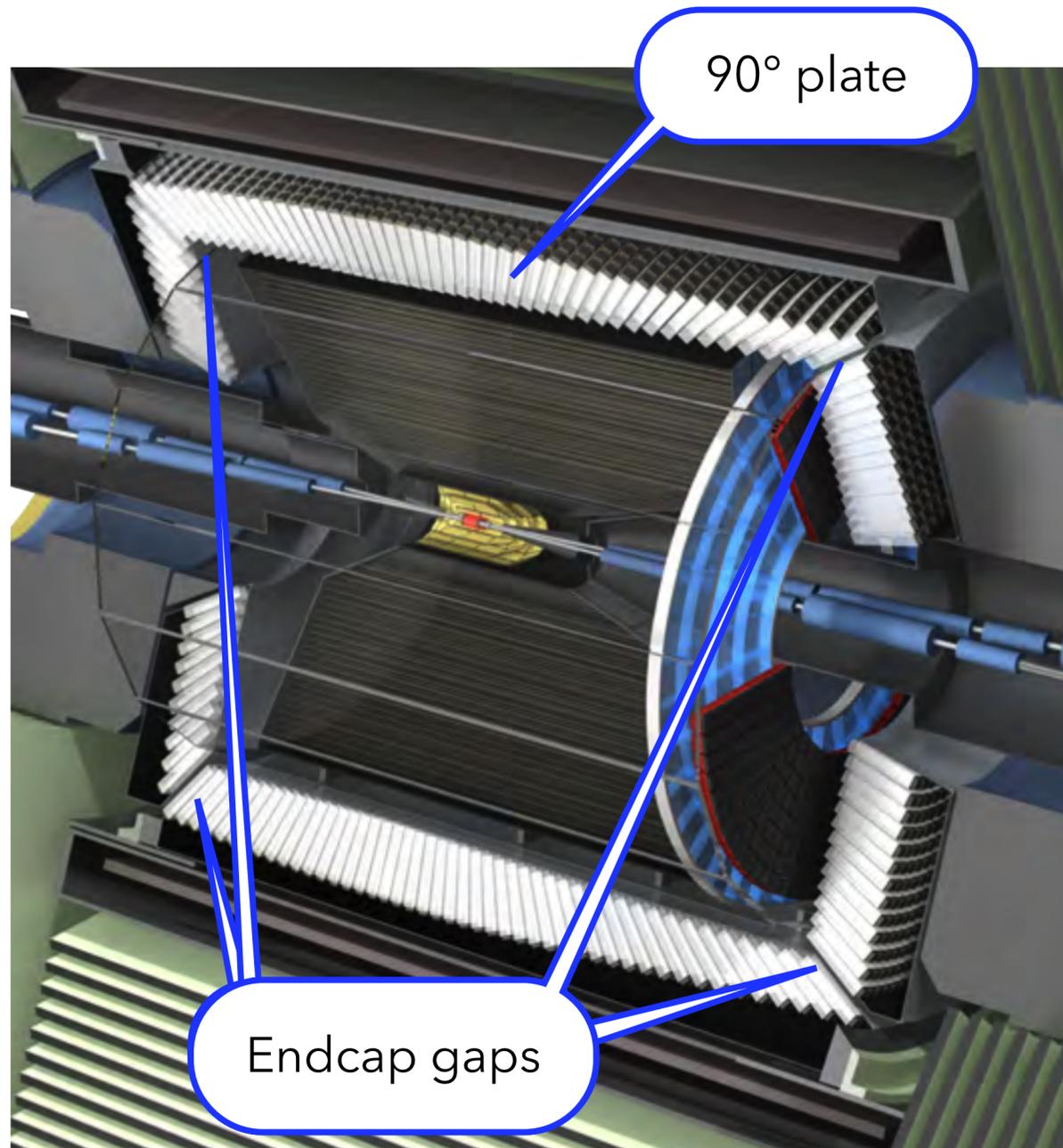
Summary.

Summary

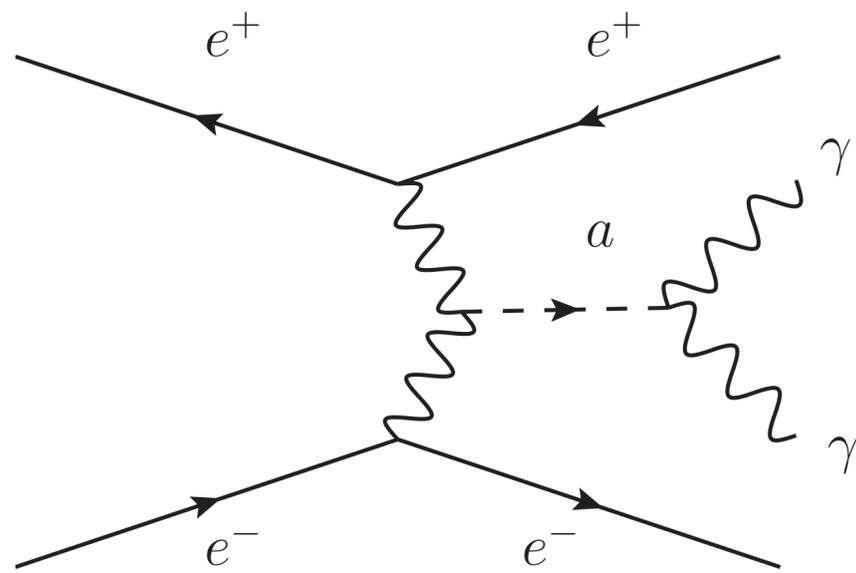
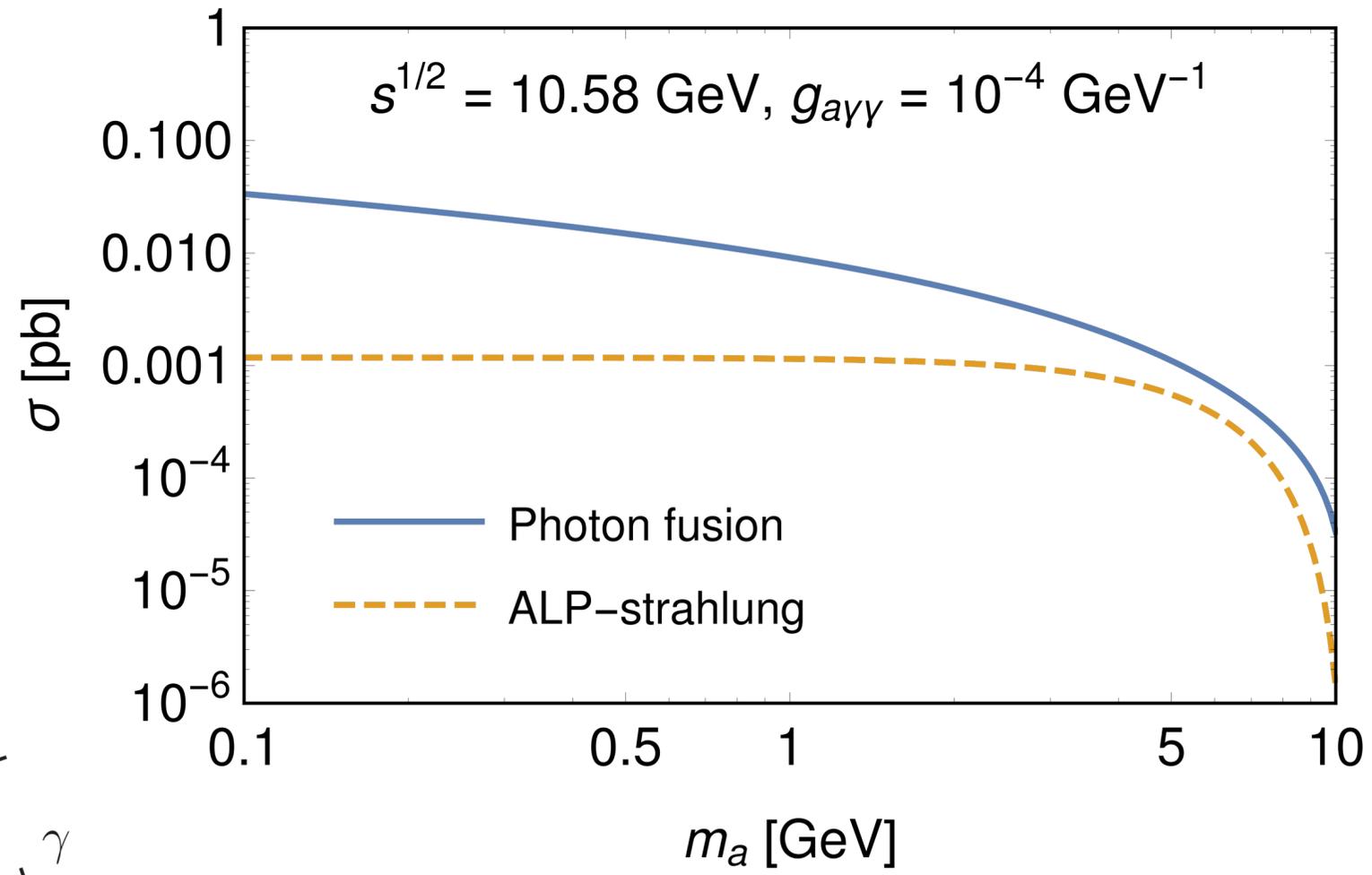
- **Belle II** is a B-factory but can do **more than just B-physics**
- **Dark photon**: decaying to stable DM: we can improve limits with just 20 fb^{-1}
- **ALP**: we are performing competitive analysis with early commissioning data
- **Z'**: first Belle II physics paper, with early commissioning data
- Other searches are going to start, like **long-lived particles (LLP)**:
[arXiv:1911.03490](https://arxiv.org/abs/1911.03490), [arXiv:1911.03176](https://arxiv.org/abs/1911.03176)
- Belle II can access parameter spaces for **multiple DM models never investigated before** - and it's doing it!

Backup.

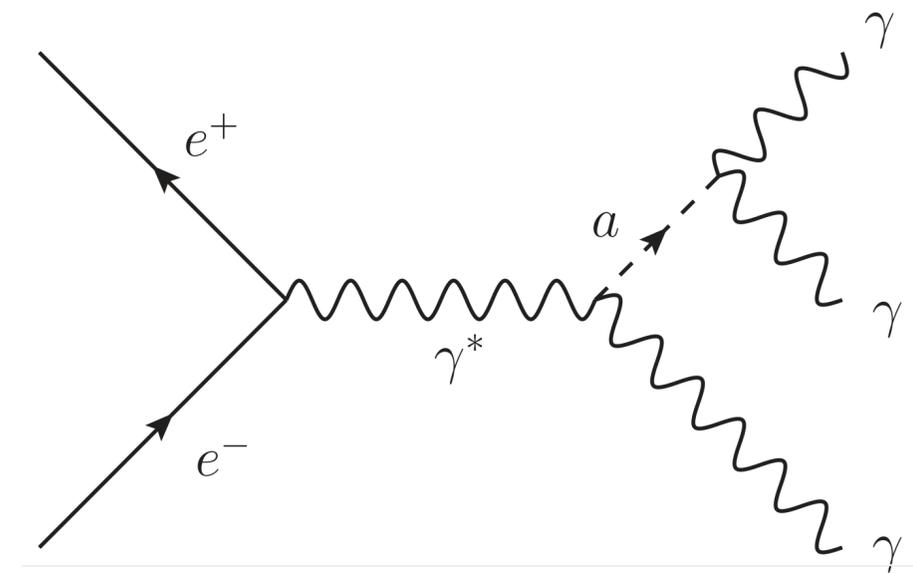
Dark Photon - analysis



ALPs - theory



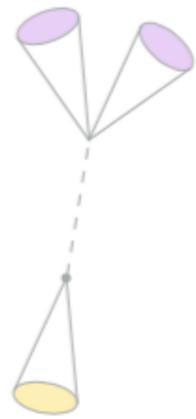
Photon-fusion



ALP-strahlung

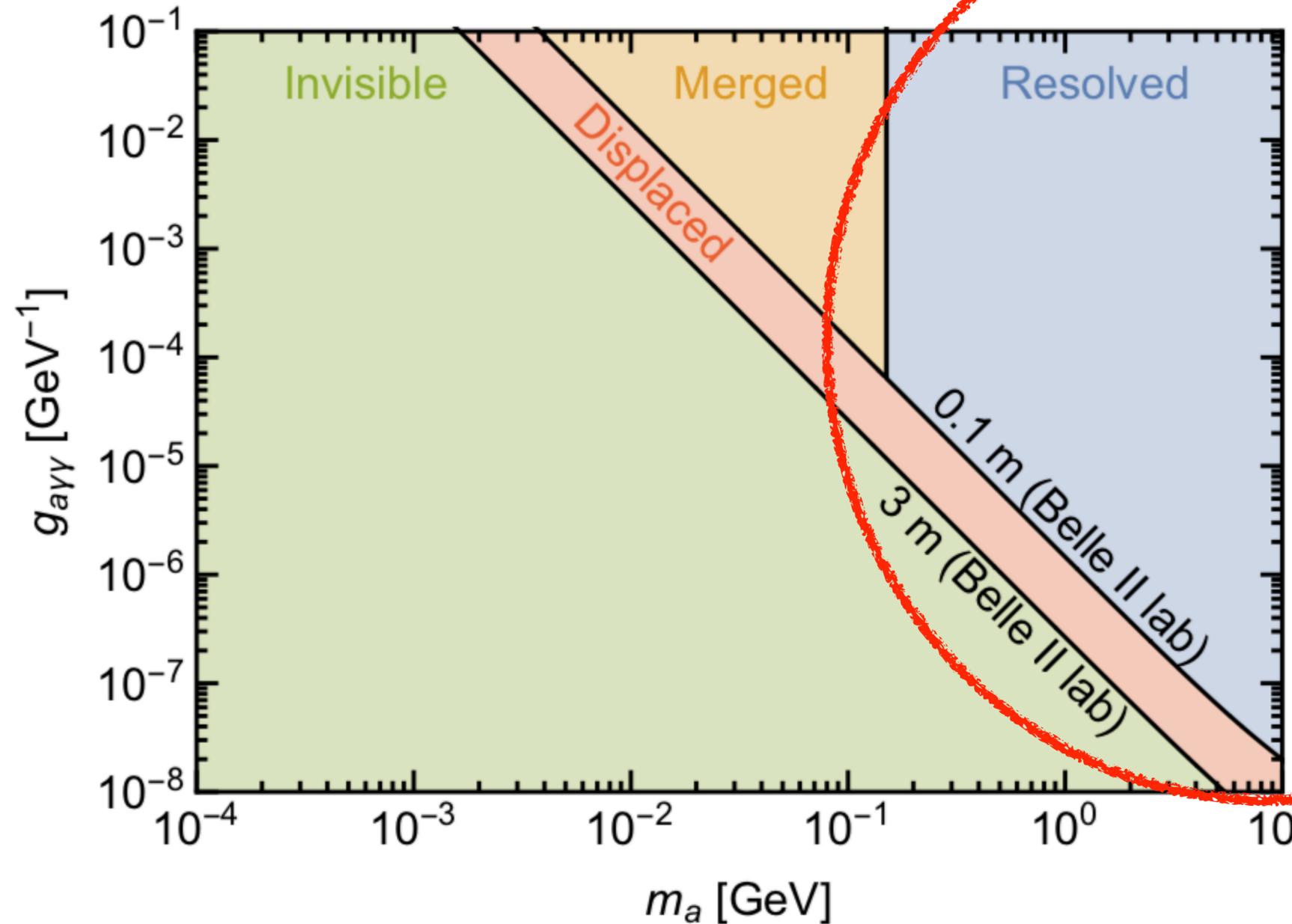
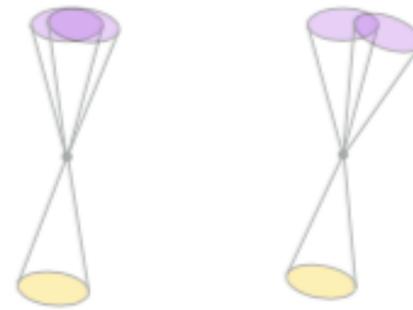
[JHEP12\(2017\)094](#)

ALPs - analysis



ALP decays outside of the detector or decays into **invisible** particles: single photon final state

Two of the photons overlap or **merge**



Current focus

Three **resolved**, high energetic photons