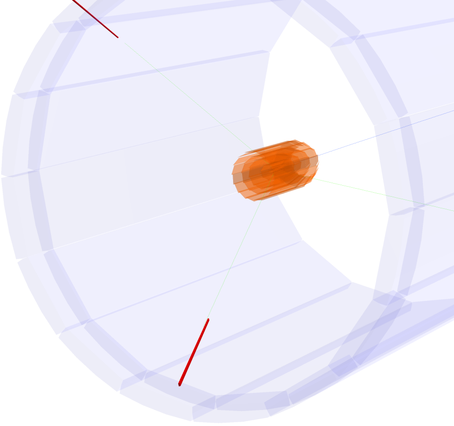


First results on Dark Matter searches at Belle II.

13th February 2020

Lake Louise Winter Institute 2020

Michael De Nuccio (michael.de.nuccio@desy.de)

Belle II

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

DESY.

Outline

1. SuperKEKB & Belle II
   Not just a B-factory: also a “Dark Searcher”

2. Dark photon

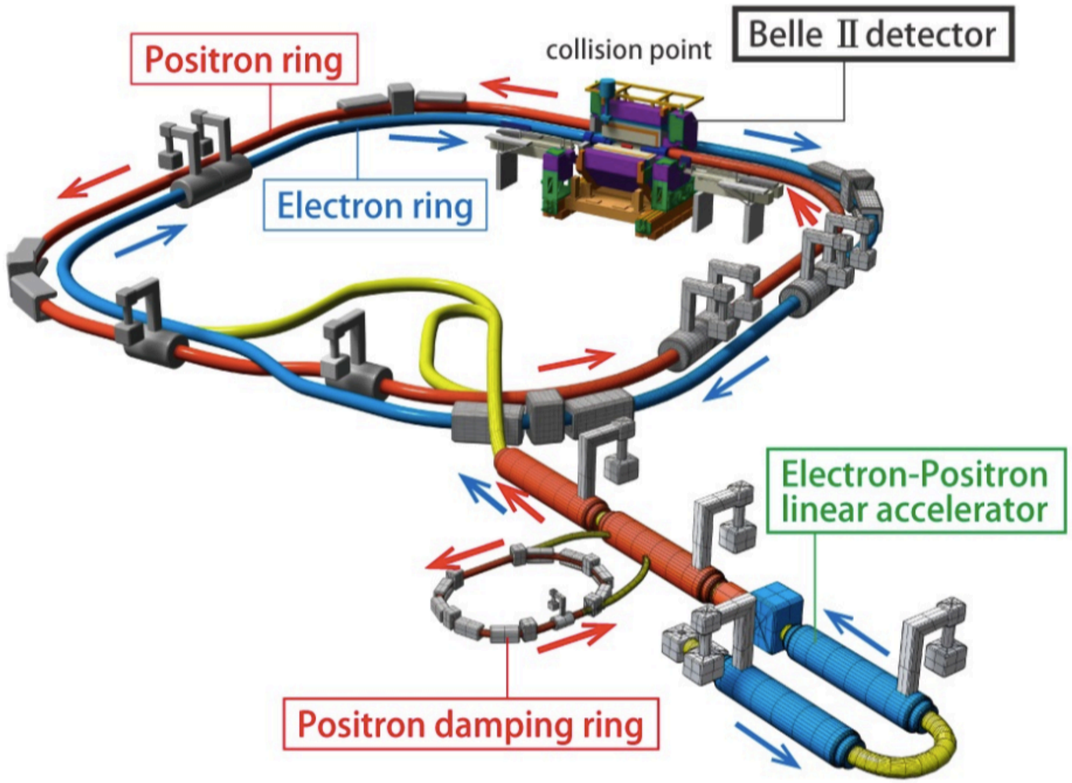
3. Axion-Like Particles (ALPs)

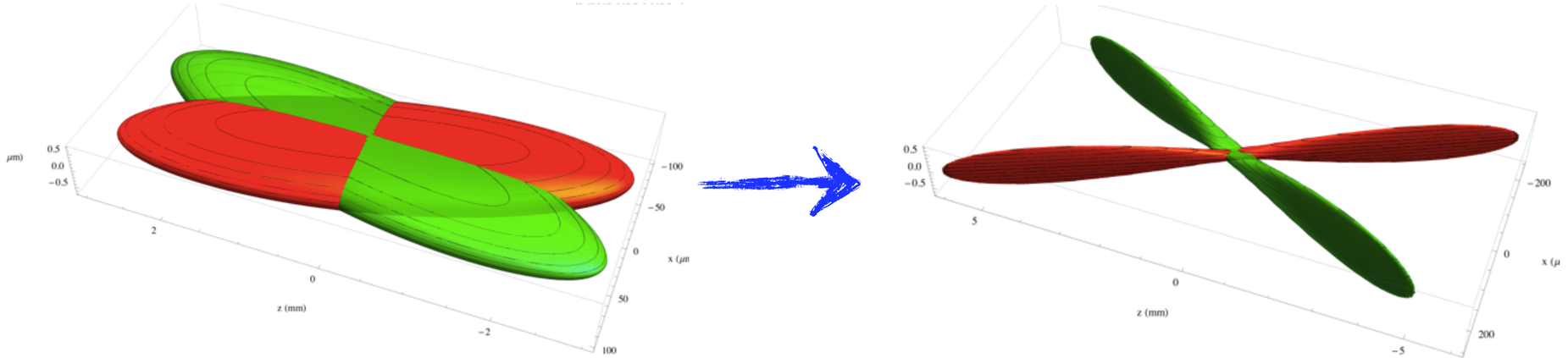
4. Z’

SuperKEKB and Belle II.

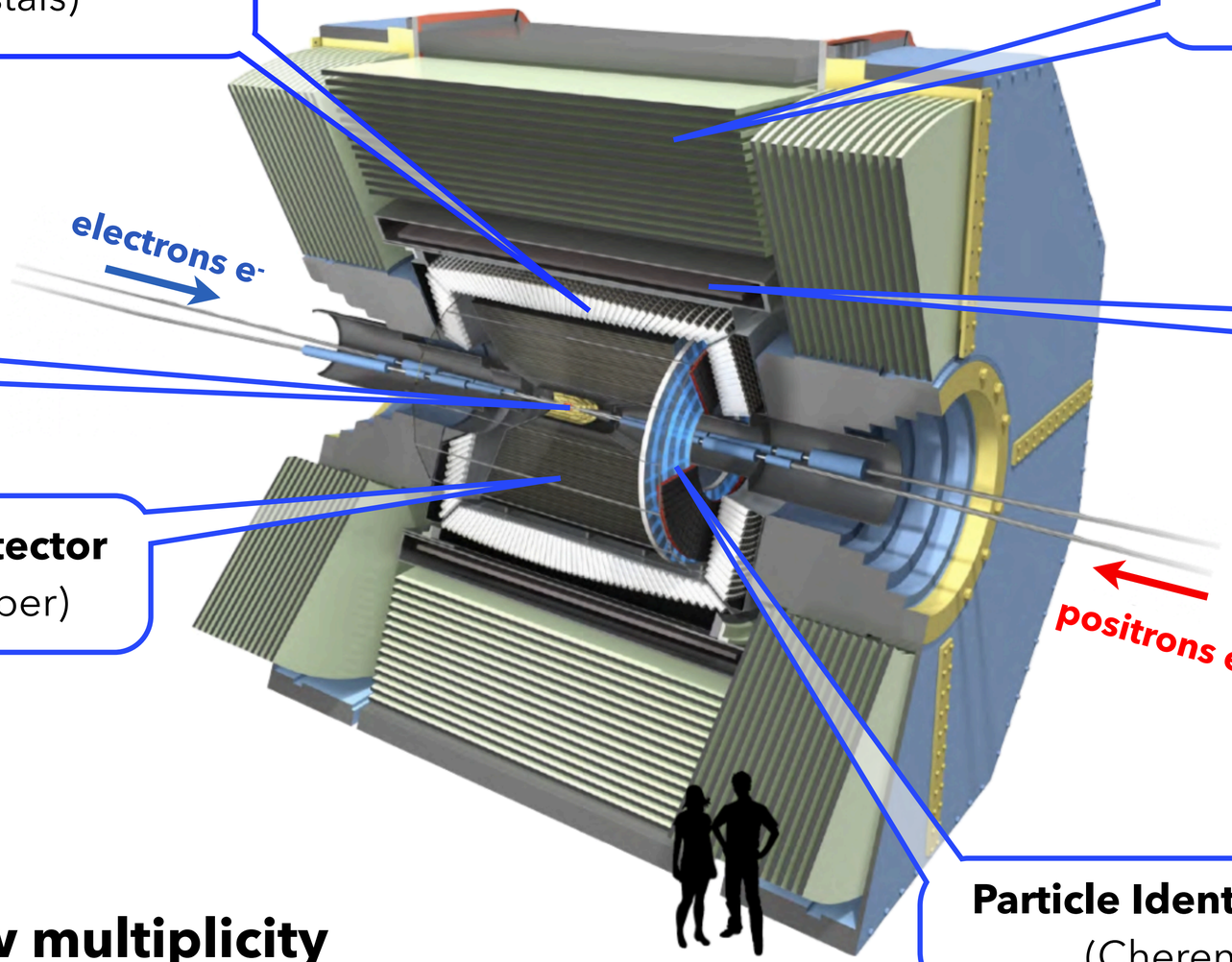
SuperKEKB

- **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:
  $\approx 8 \times 10^{35}$ cm^{-2} s^{-1}, highest in the world
  - 2x from higher beam current
  - 20x from final focus magnets





Belle II



Electromagnetic Calorimeter
(CsI(Tl) crystals)

K_L and μ detector
(resistive plates and scintillators)

Vertex Detectors
(silicon pixels & strips)

Magnet
(1.5 T)

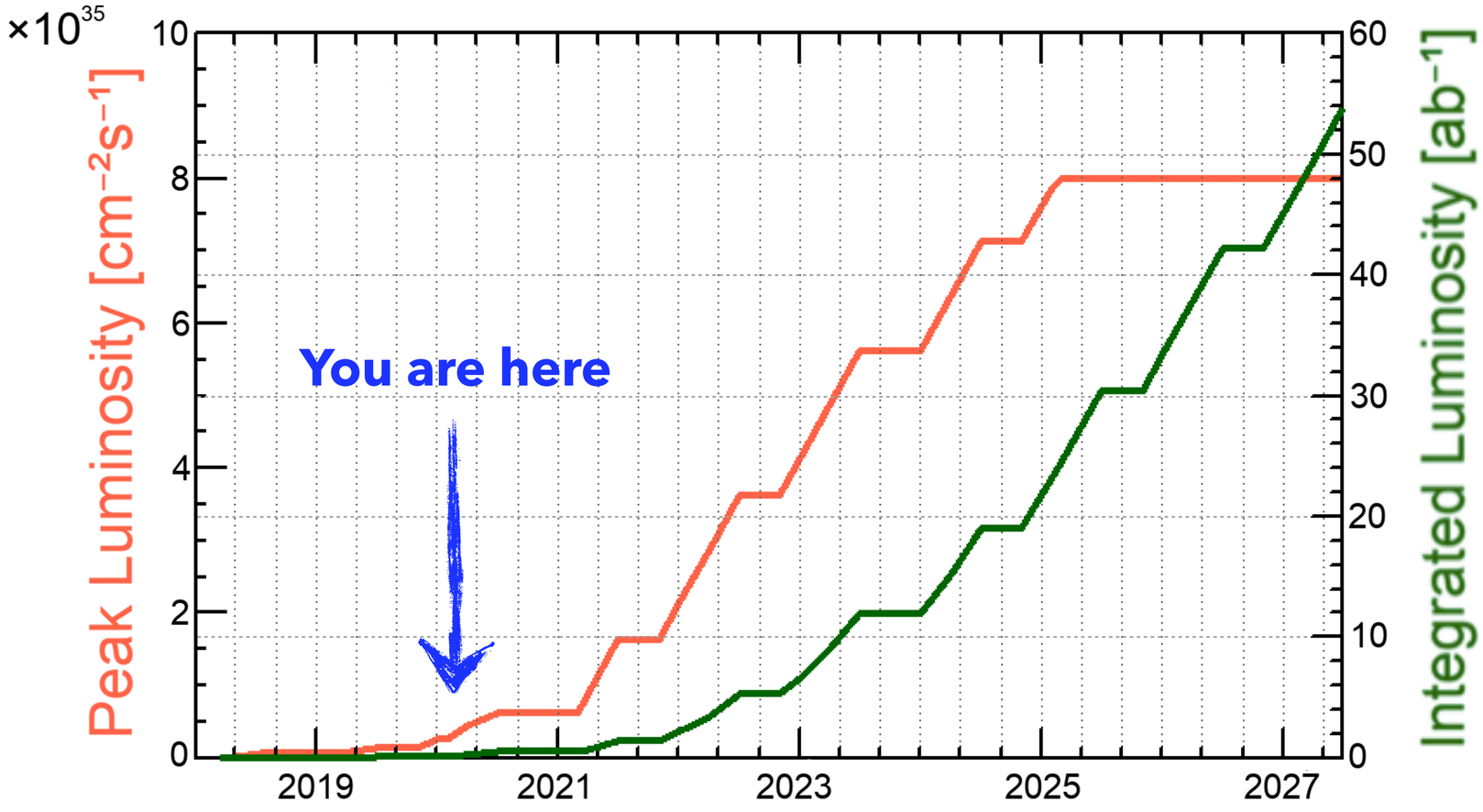
Tracking Detector
(drift chamber)

Particle Identification Detectors
(Cherenkov radiation)

- **Hermetic detector**
- **Dedicated triggers for low multiplicity**

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

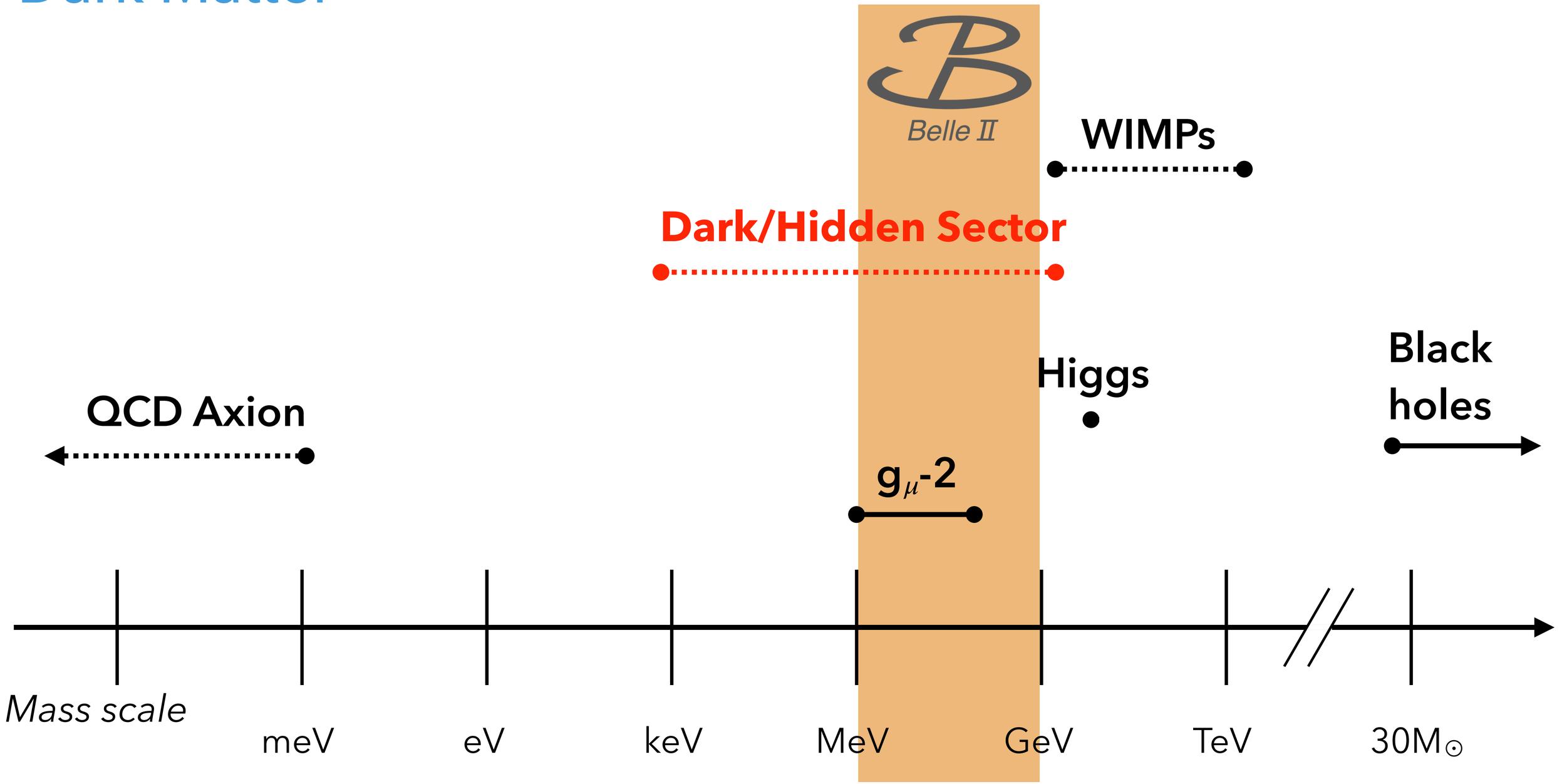
Dark Sector perspective

- High luminosity
- Hermetic detector
- Specialized triggers for low multiplicity events
- Clean environment (e^+e^- collider)

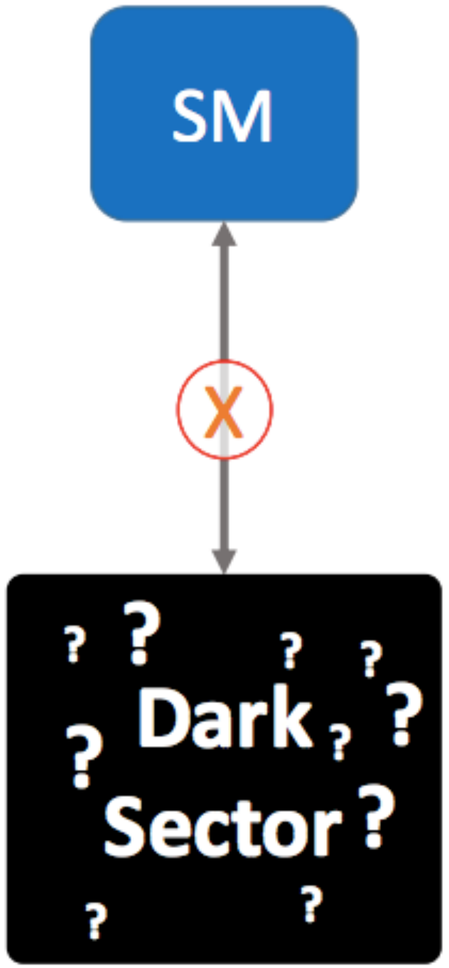
- Excellent place where to **search for dark matter** candidates!
  - That's what we are doing (amongst other things)

Dark Matter.

Dark Matter


Belle II
WIMPs
Dark/Hidden Sector
Higgs
Black holes
QCD Axion
g_μ-2
Mass scale
meV
eV
keV
MeV
GeV
TeV
30M⊙

Dark Matter

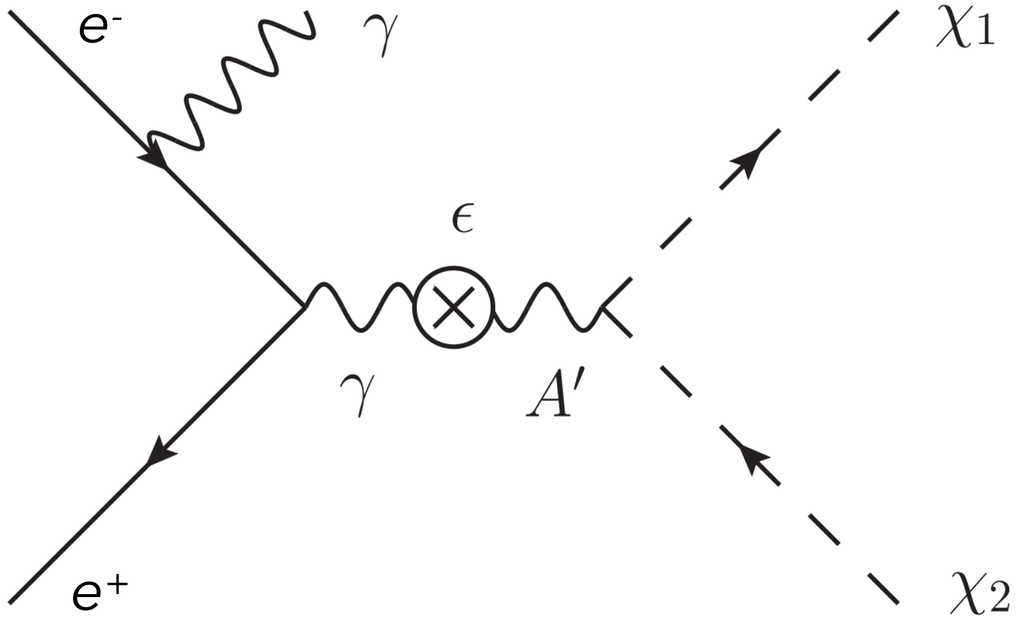

SM
X
Dark
Sector

Belle II
Dark/Hidden Sector
Light dark matter **coupled** to SM via a (light dark sector) mediator **X**
Mass scale
meV
eV
keV
MeV
GeV
TeV
30M⊙

Dark Photon.

Dark Photon - theory

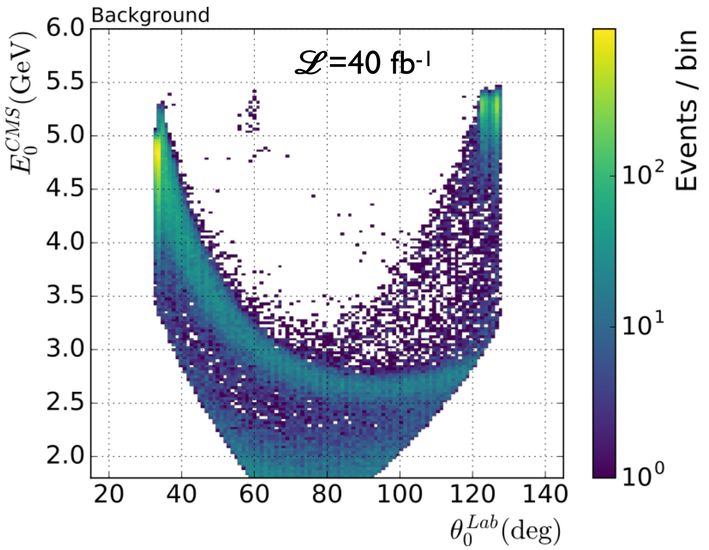
- Massive vector mediator A′
  mixes with SM photon (via kinetic mixing ε)
- Possible decays:
  - into DM final state: **invisible** A′ → $\chi_1\chi_2$
  - into two leptons: visible A′ → f^+f^-
- Experimental trick: requiring **ISR photon**
  (on-shell production & visible final state)

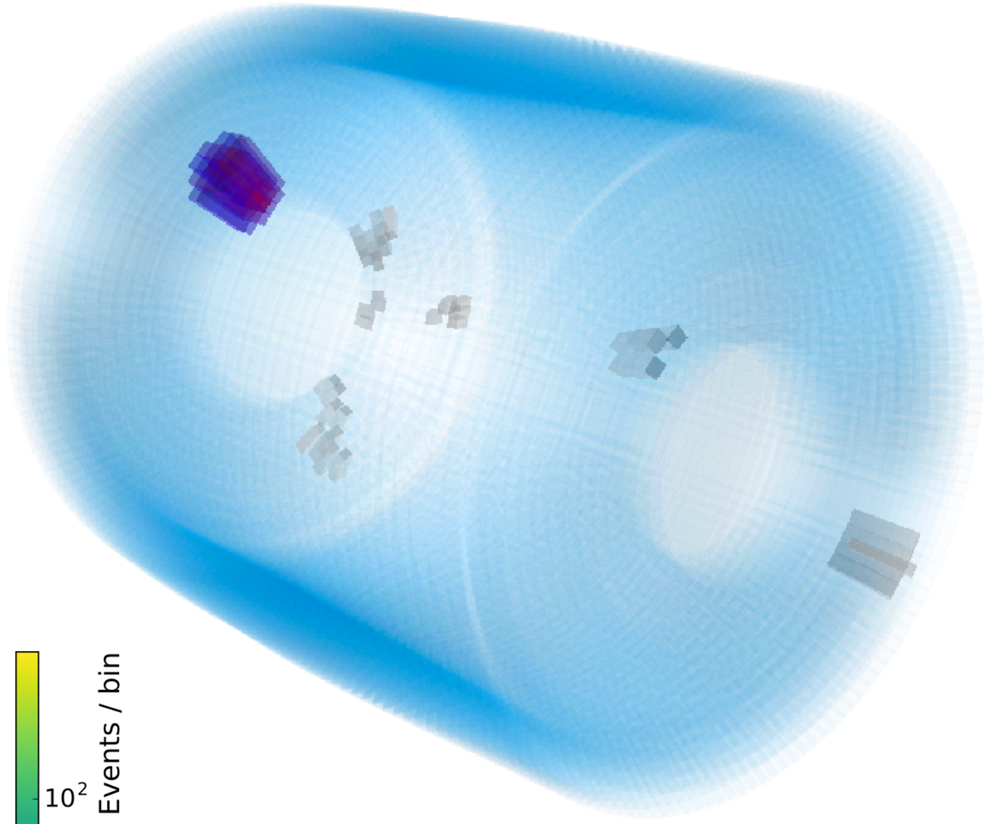


$$E_{\gamma_{\mathrm{ISR}}} = \frac{s - m^2_{A'}}{2\sqrt{s}}$$

Dark Photon - analysis

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

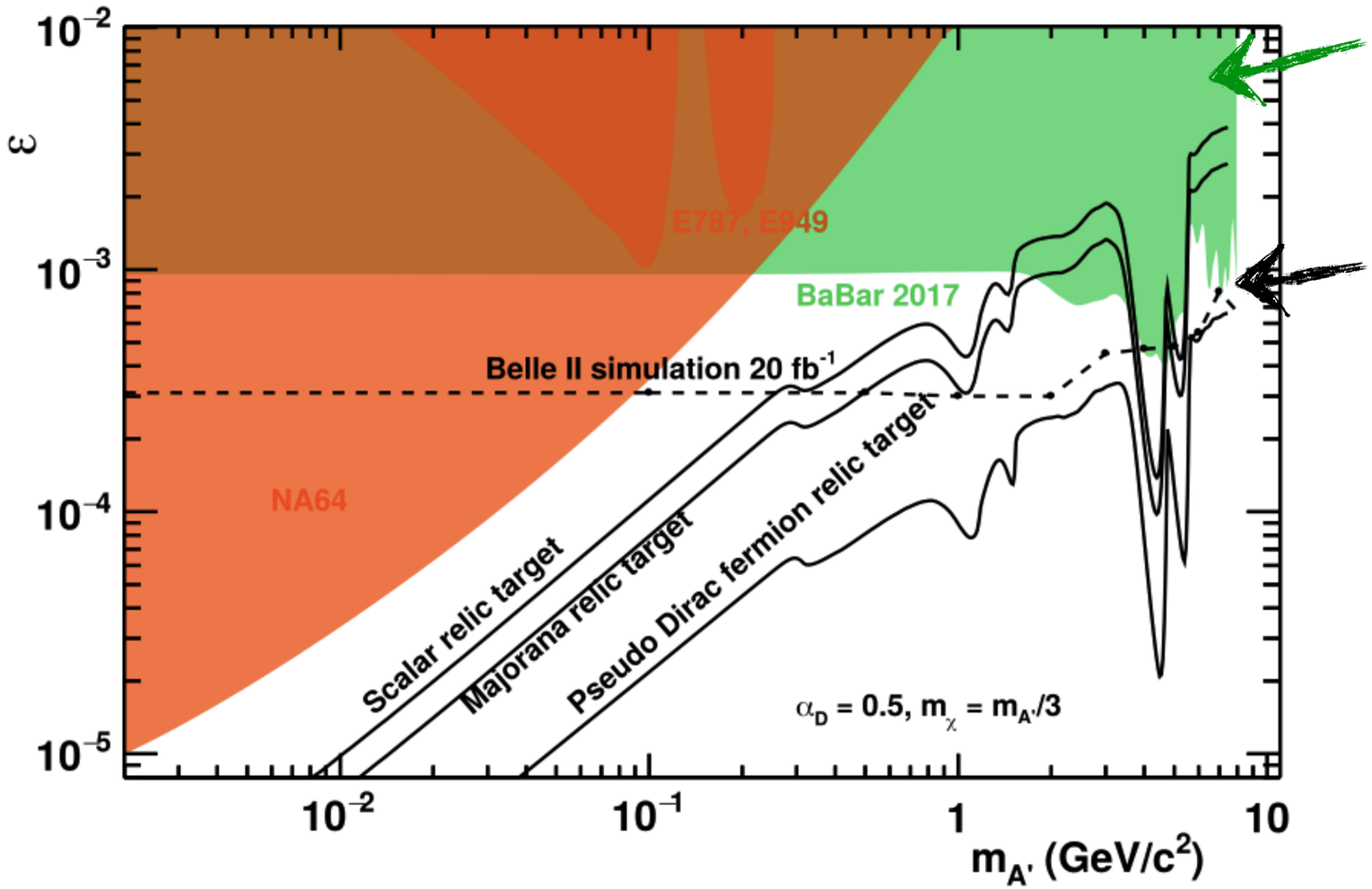




Belle II simulation, signal only

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

Dark Photon - sensitivity



BaBar with 50 fb^{-1}

Belle 2 projection with 20 fb^{-1}

Less data but we do better because:

- Non-projective geometry of calorimeter
- Smaller boost and larger calorimeter $\Longrightarrow$ larger acceptance

arXiv:1808.10567

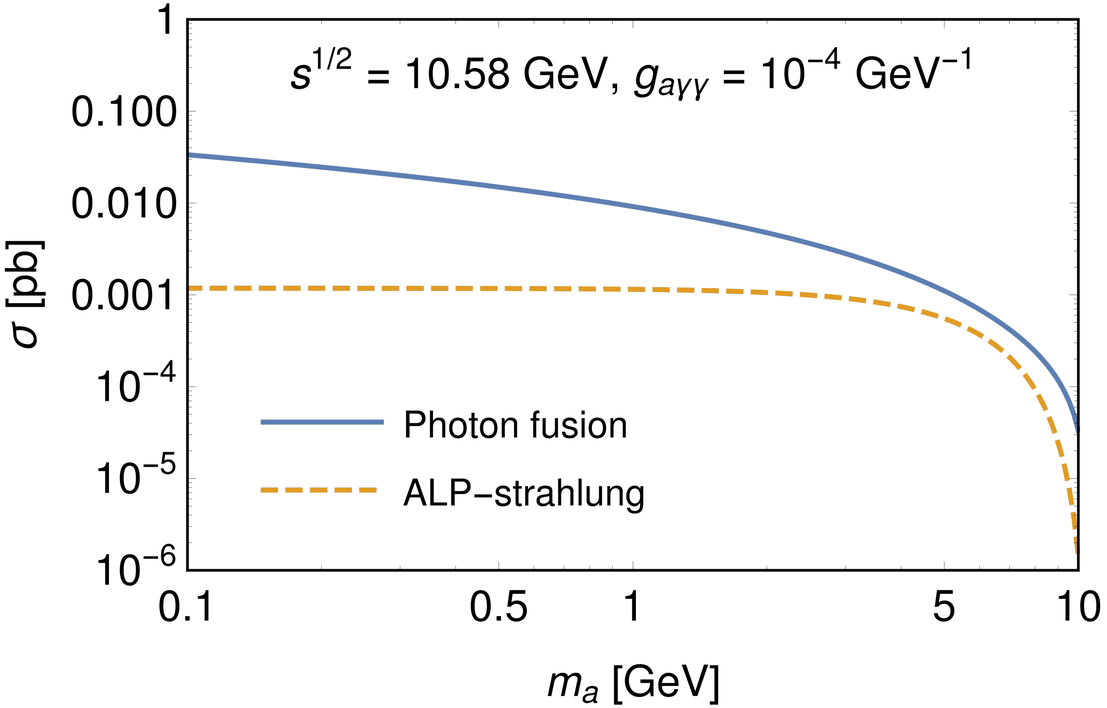
PRL.119.131804

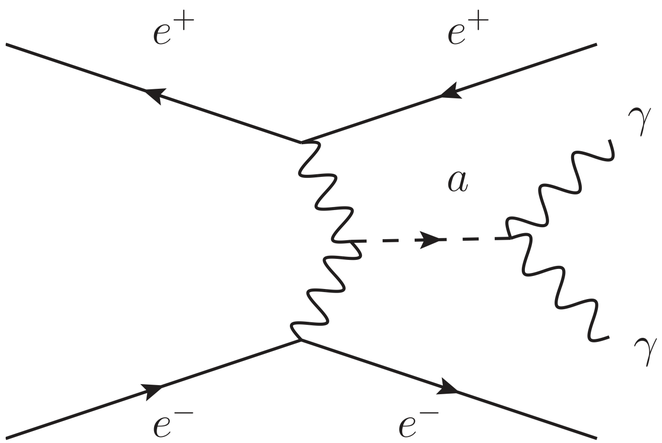
arXiv:1906.00176

Axion-Like Particles.

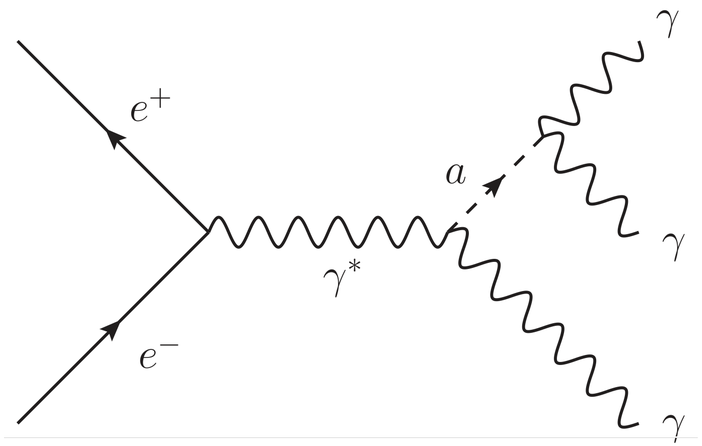
ALPs - theory

- Axions as solution to the strong CP problem
- ALPs (***a***) have 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**





Photon-fusion

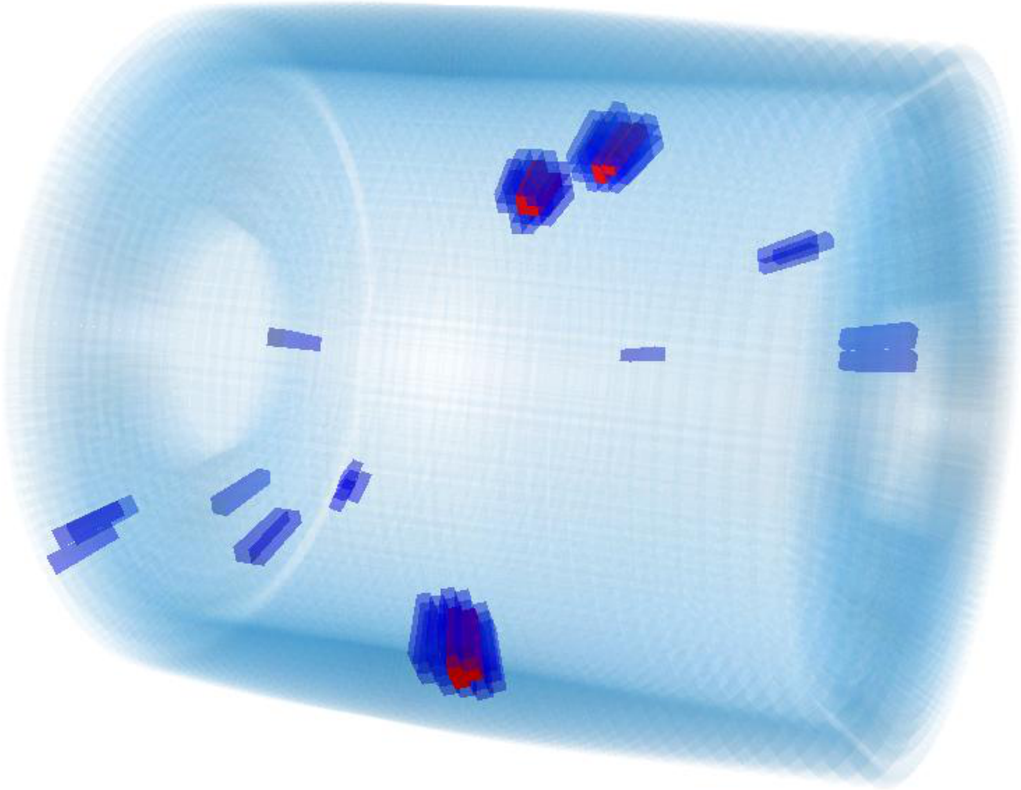


ALP-strahlung

[JHEP12(2017)094]

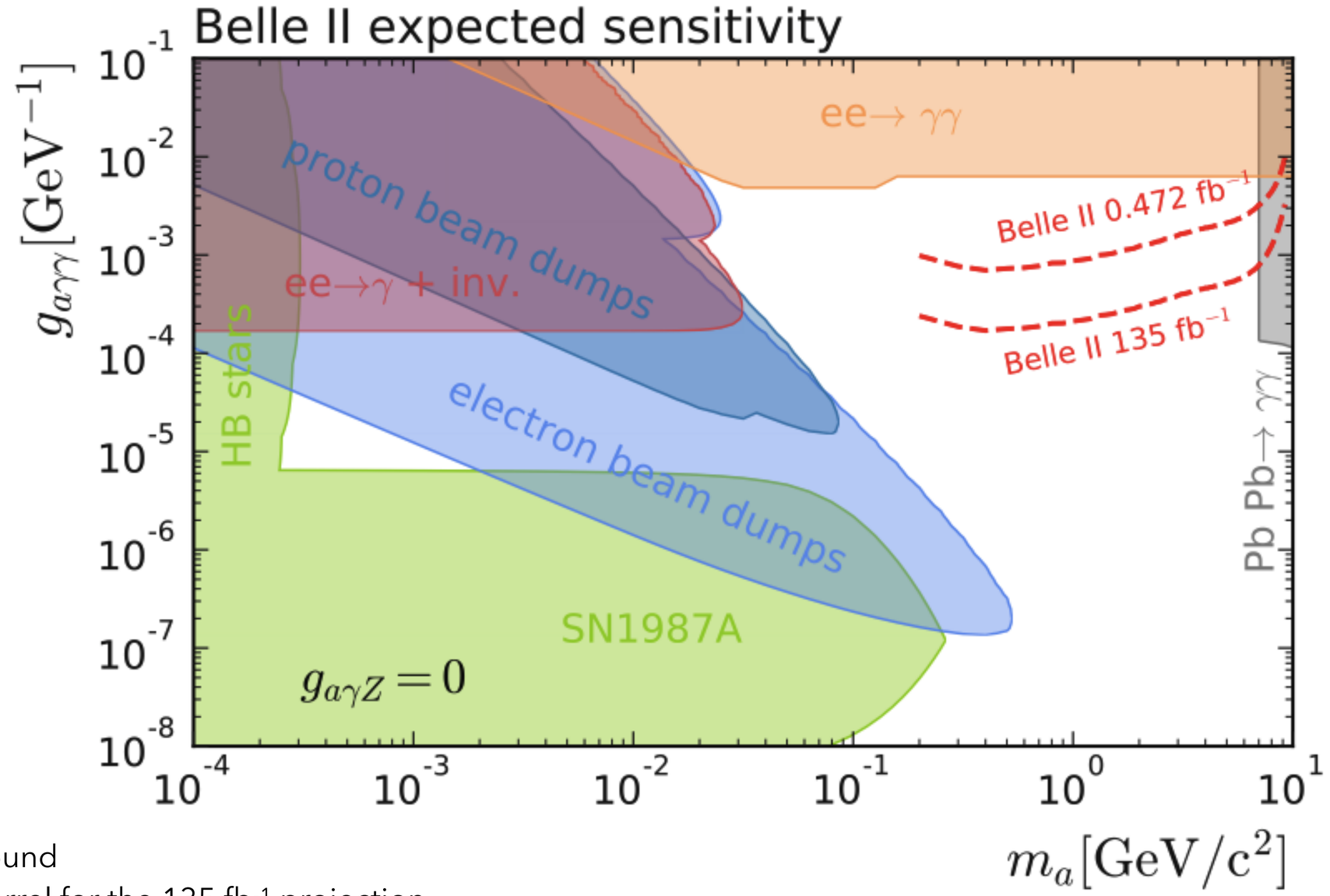
ALPs - analysis

- 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:
  - $e^+e^- \to \gamma\gamma(\gamma)$
  - $e^+e^- \to e^+e^-(\gamma)$
  - $e^+e^- \to P\gamma$, $P=\pi^0/\eta/\eta'$, $P \to \gamma\gamma$
    peaking but negligible background



Belle II simulation, signal only

ALPs - sensitivity



JHEP12(2017)094

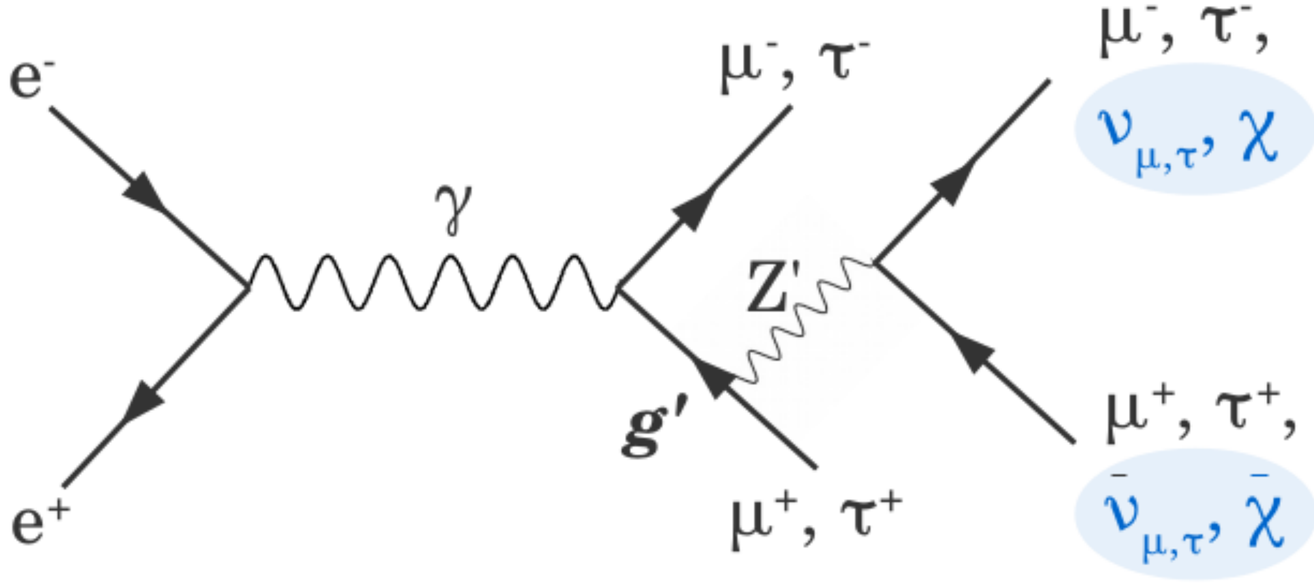
No systematics

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

Assumes no $\gamma\gamma$ trigger veto in the barrel for the 135 fb^{-1} projection

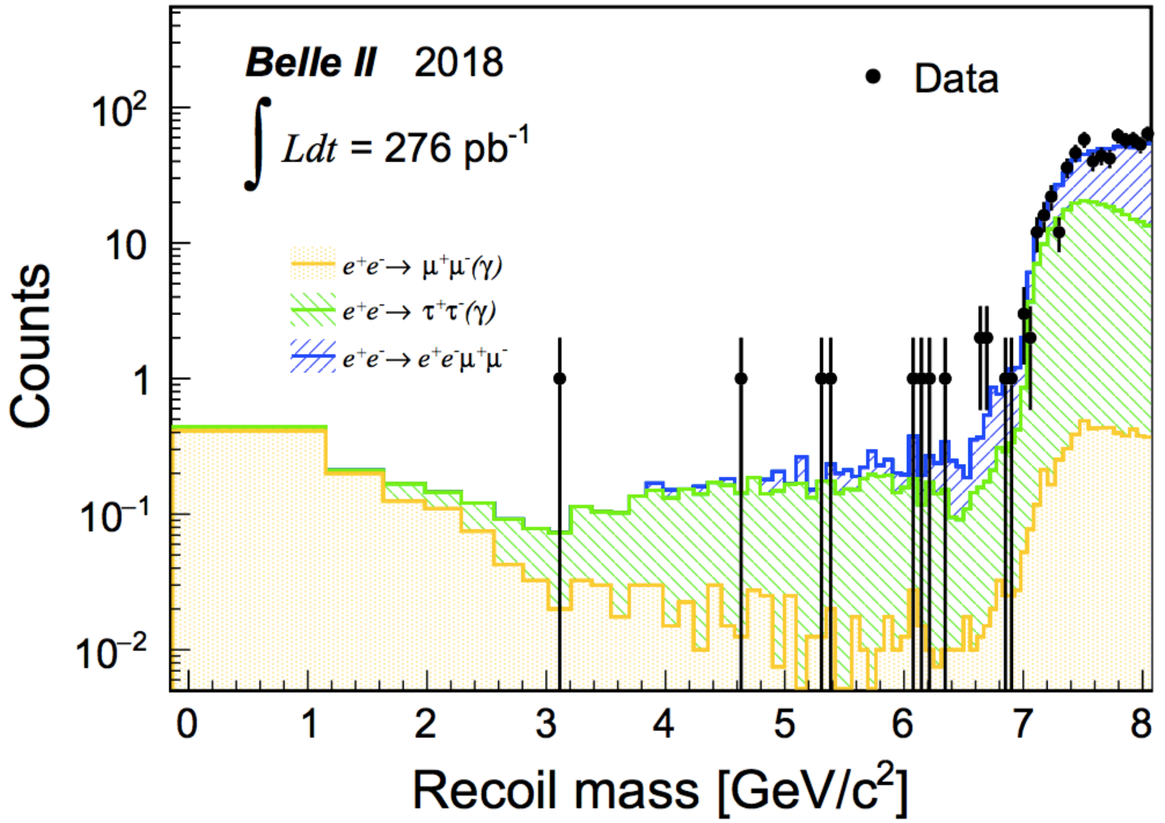
Z’ - theory

- **New gauge boson Z’** coupling only with 2nd and 3rd generations of leptons (Lμ - Lτ)
  - Could come either from μ or τ
- If it is lighter than 2 muons: decays only into neutrinos and/or DM
  - **Invisible decay**



Z′ - analysis

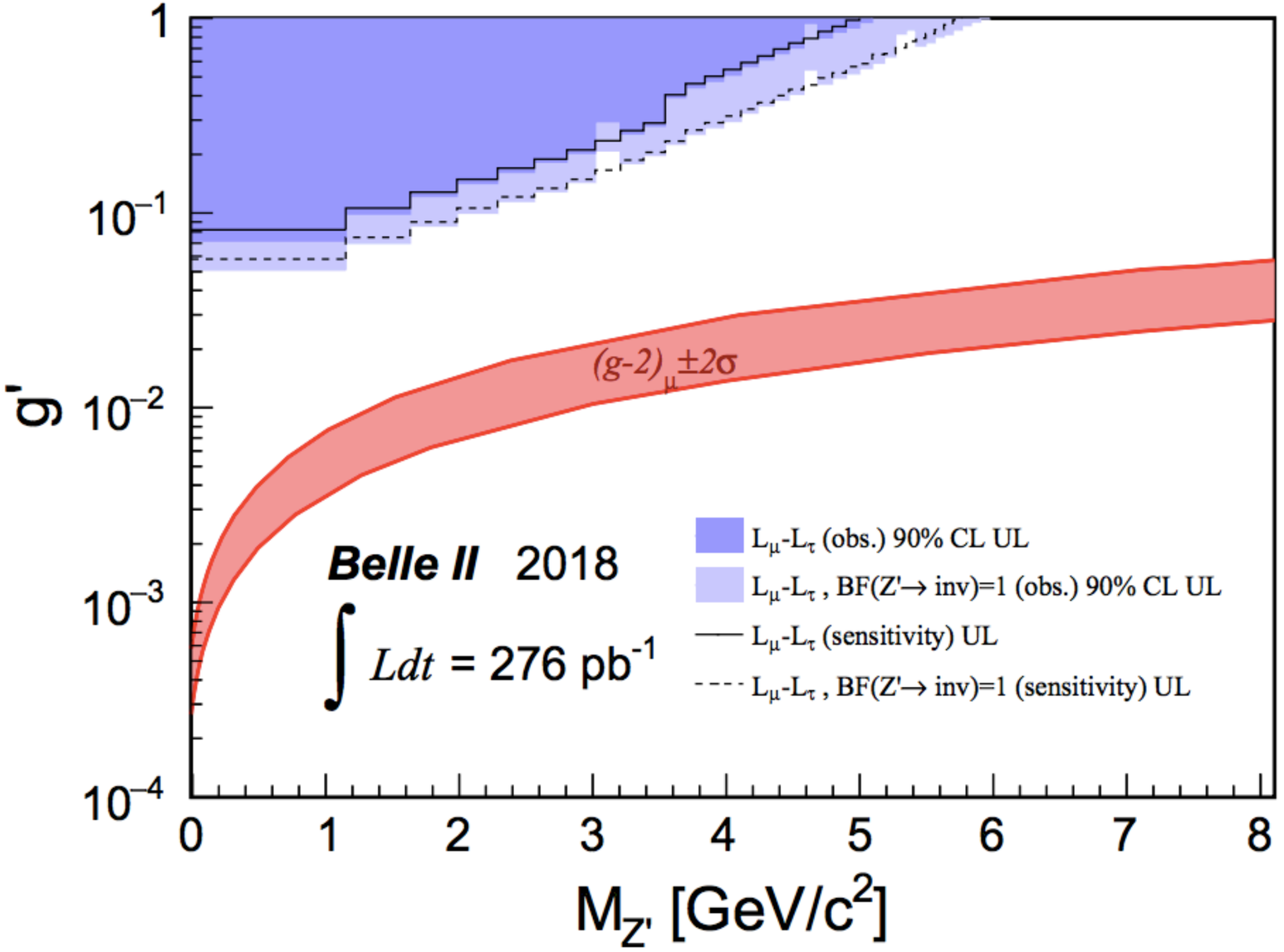
- Investigate **$e^+e^- \to \mu^+\mu^-$ + missing energy**
  - Nothing else in the event
  - Bump search in recoil mass against $\mu^+\mu^-$
- Backgrounds:
  - $e^+e^- \to \mu^+\mu^- (\gamma)$
  - $e^+e^- \to \tau^+\tau^- (\gamma)$, $\tau \to \mu\, \nu_\mu\, \nu_\tau$
  - $e^+e^- \to \mu^+\mu^-\, e^+e^-$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



arXiv:1912.11276

Z′ - sensitivity

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



arXiv:1912.11276

Summary.

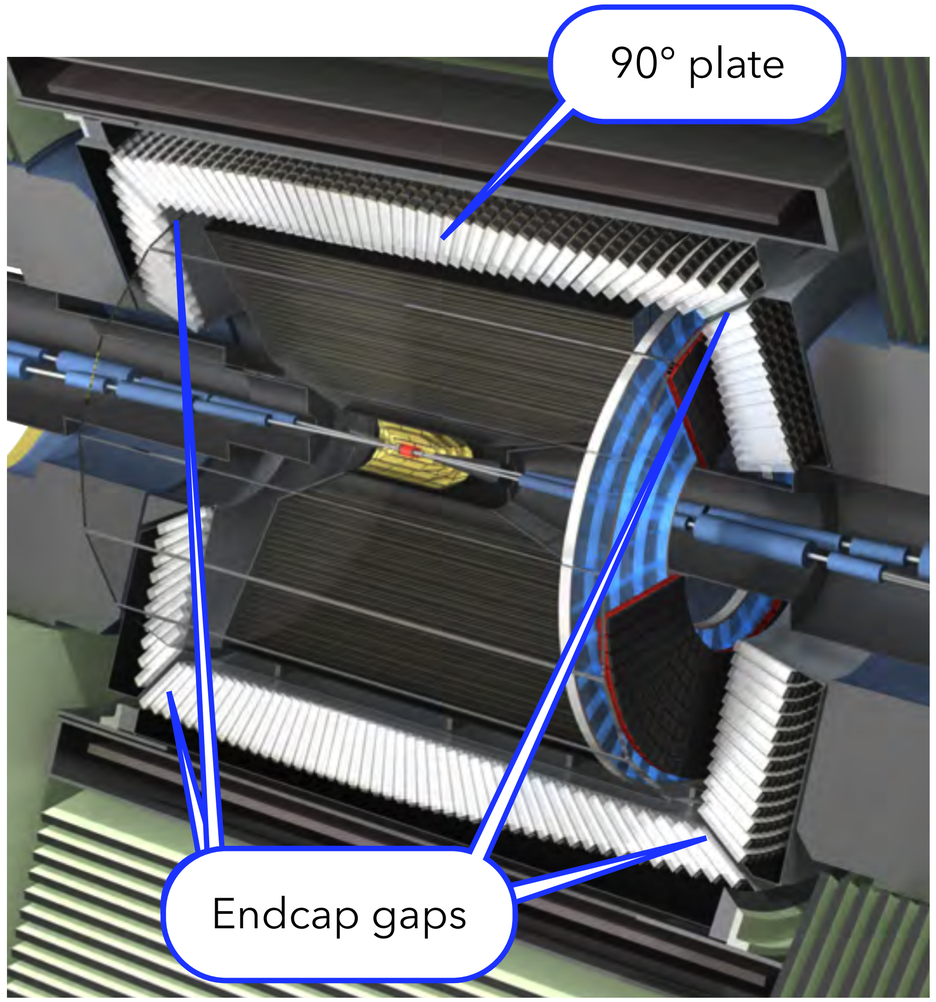
Summary

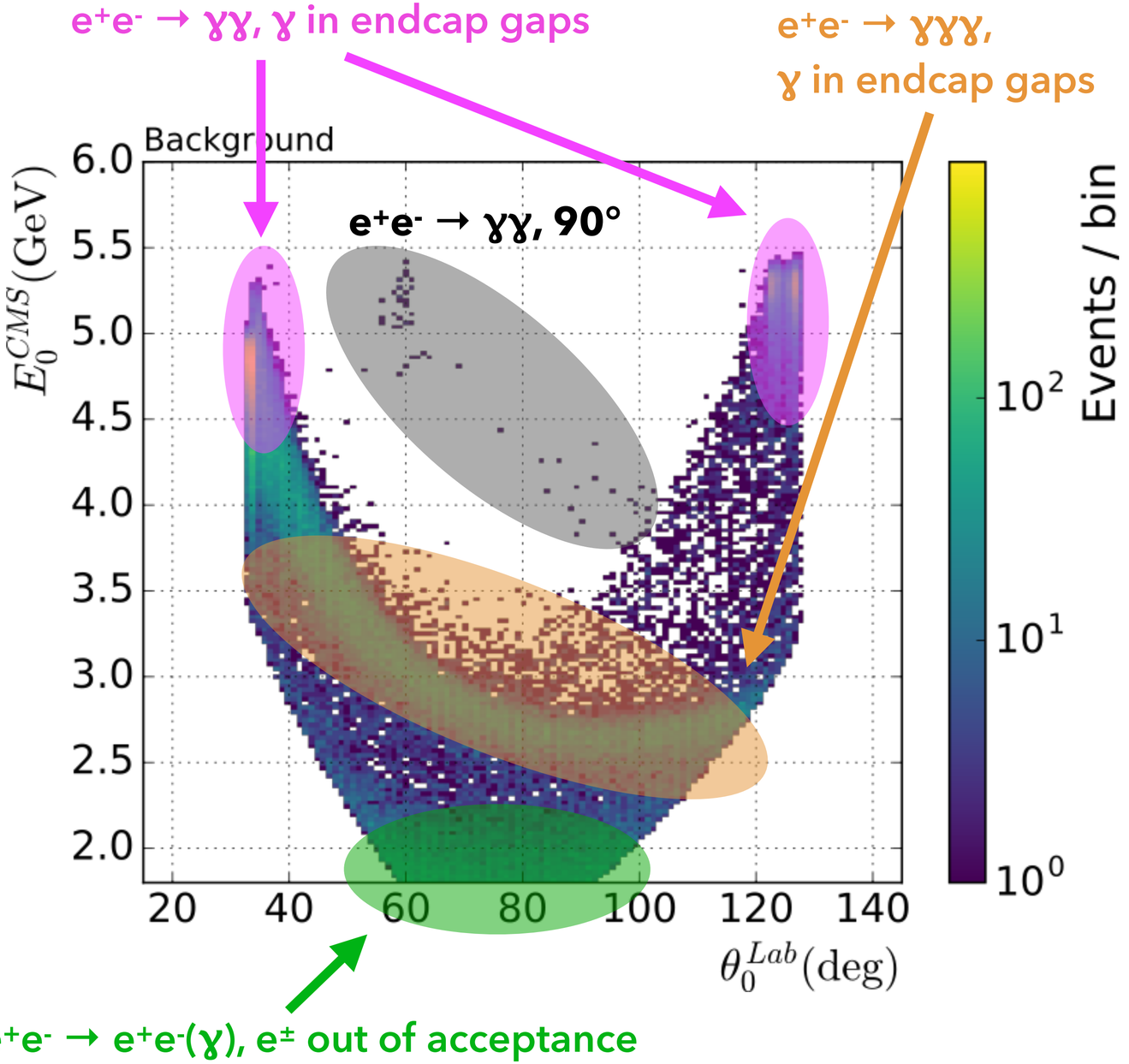
- **Belle II** is a B-factory but can do **more than just B-physics**
- **Dark photon**: decaying to stable DM: we can improve limits with little data
- **ALP**: we are performing competitive analysis with early calibration data
- **Z'**: first Belle II physics paper, with early calibration data
- Other searches are going to start, like **long-lived particles** (LLP):

  arXiv:1911.03490, arXiv:1911.03176
- Belle II can access parameter spaces for
  multiple DM models never investigated before - and it's doing it!

Backup.

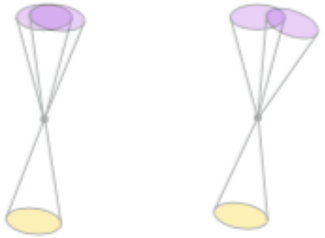
Dark Photon - analysis





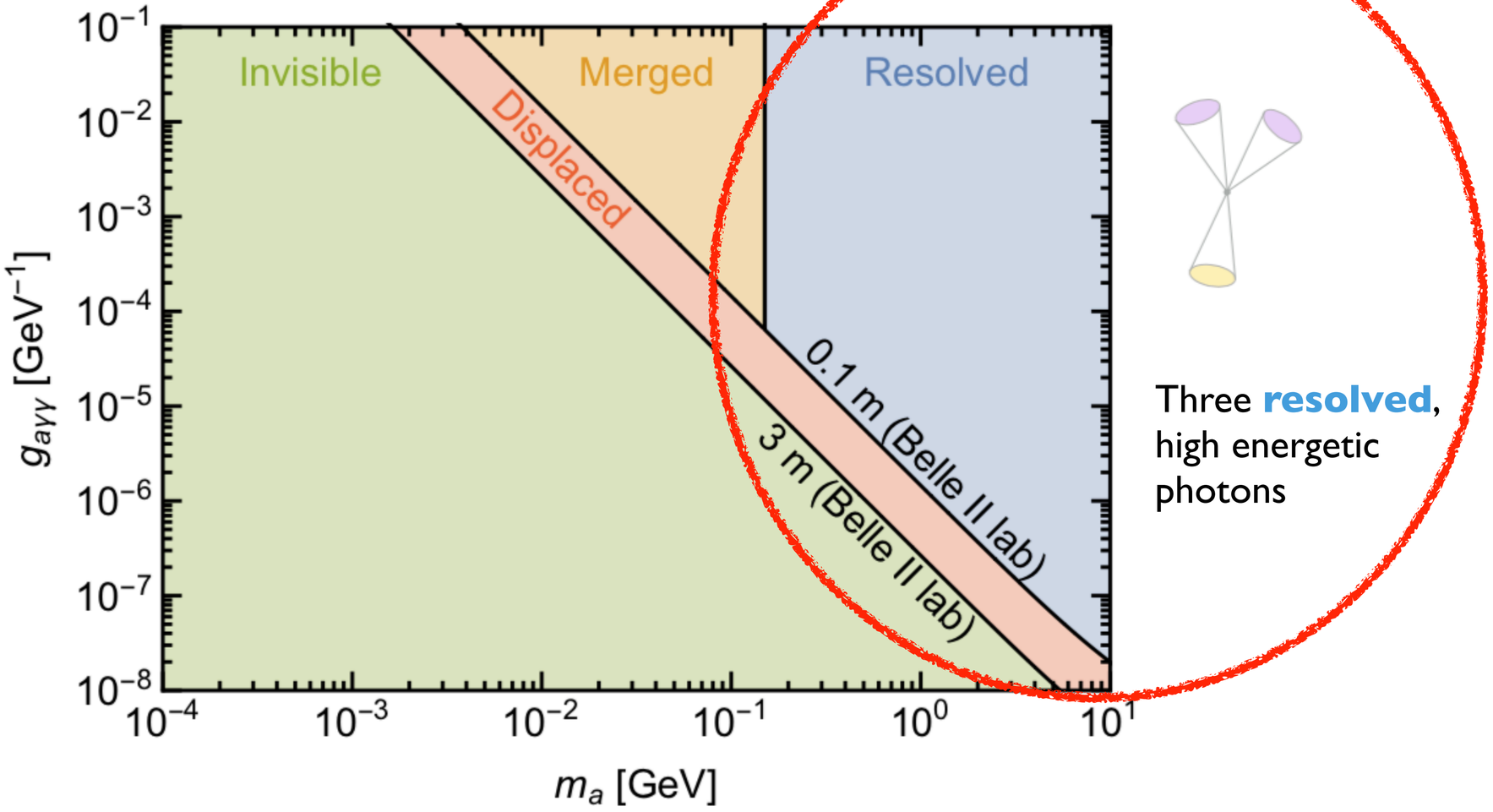
ALPs - analysis

Two of the photons overlap or **merge**



Current focus

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



Three **resolved**, high energetic photons

[JHEP12(2017)094]