

LESS TRAVELLED PATH OF DARK MATTER: AXIONS AND PRIMORDIAL BLACKHOLES

Due to the ongoing COVID-19 pandemic, the original program has been canceled. However, the program will be conducted through online lectures.

The existence of dark matter (DM) has been inferred from its gravitational interactions, yet the identity of the dark matter particles remains completely unknown. The dominant candidate for DM over the last 30 years has been Weakly Interacting Massive Particles (WIMPs). However, despite extensive underground (direct), telescope (indirect), and collider searches, dedicated experiments have not found any evidence of WIMPs. Meanwhile, several astrophysical small-scale structure and cosmological hints might be an indication that DM has non-gravitational interactions that cannot easily be explained with vanilla WIMPs.

This online workshop on the Less Travelled Path of Dark Matter (LTPDM) will bring together particle physicists and cosmologists from all over the world to address current trends in DM searches, focused on axions and primordial black holes, and map the way forward. The program will also include a school, with lectures addressed to students and postdocs, familiarizing them with new and advanced concepts.

We plan to have a longer physical workshop on dark matter, with a larger perspective, in the near future once the current global pandemic crisis has subsided.

9 – 13 NOV, 2020
Online Program

Application Deadline
15 October, 2020

Organisers

Subinoy Das, Koushik Dutta,
Raghavan Rangarajan, Vikram Rantala

icts.res.in/program/LTPDM2020

ltpdm2020@icts.res.in



Hunting for LDM candidates at flavor factories

Gagan Mohanty



- Overview
- Key aspects
- Minimal dark photons
- Non-minimal dark photons
- Axion-like particles
- Future prospects

What is a flavor factory?

☞ Relatively low-energy e^+e^- machine operating mostly at the $\Upsilon(4S)$ peak

☐ Luminosity is key strength → also called “intensity-frontier” experiment

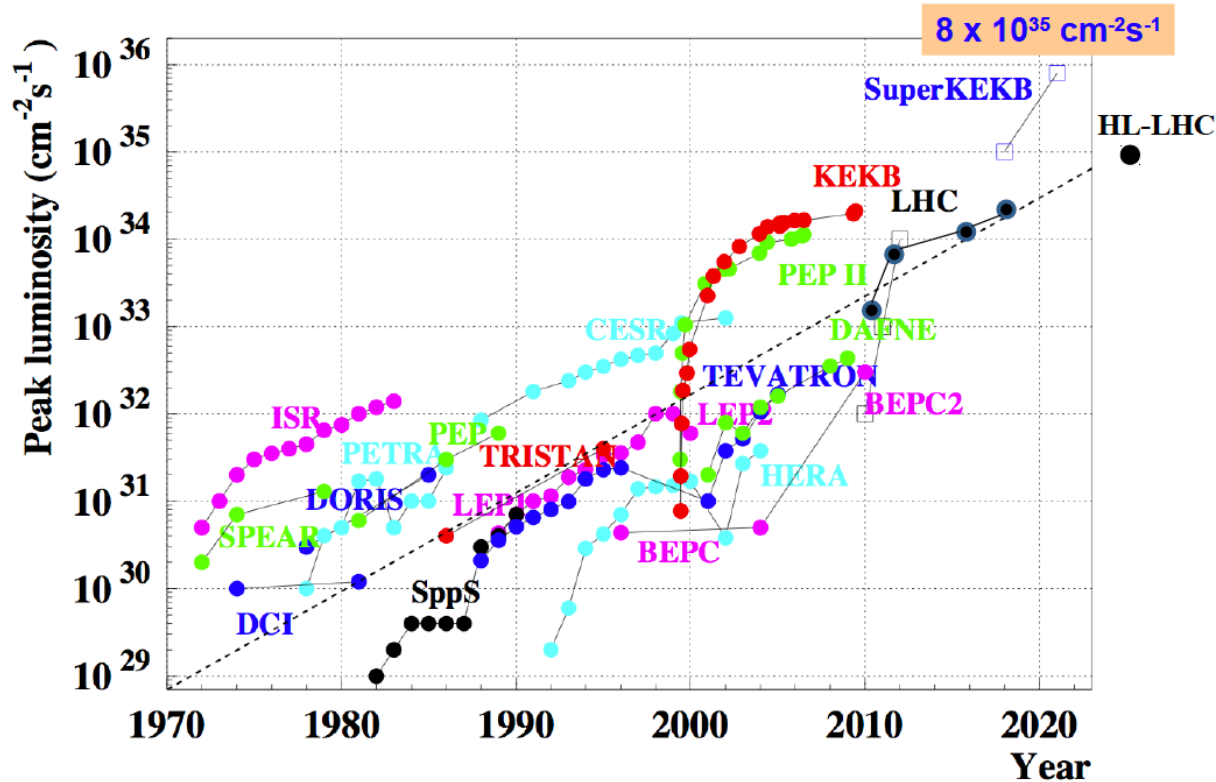
☞ Broad physics program

☐ Flavor physics → CKM matrix and CP violation in beauty and charm decays

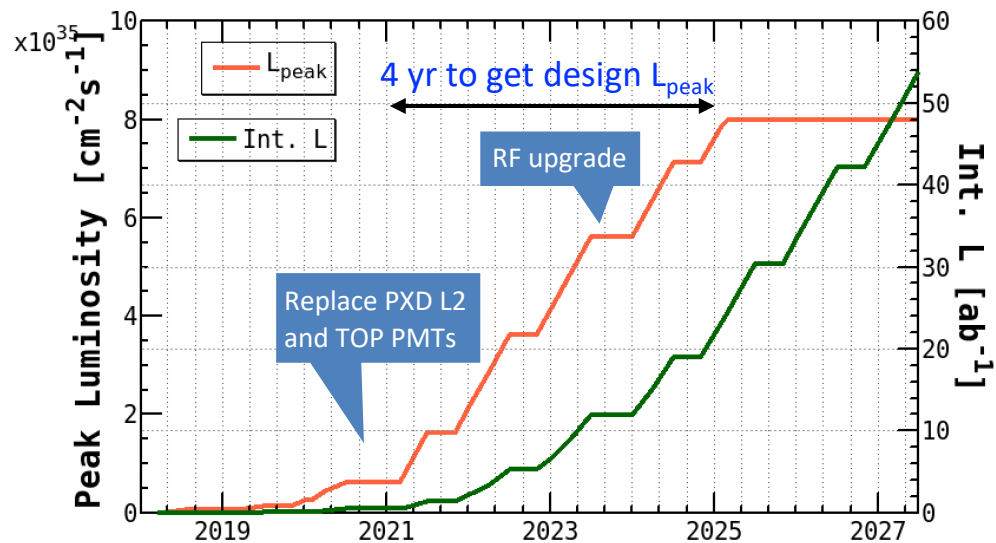
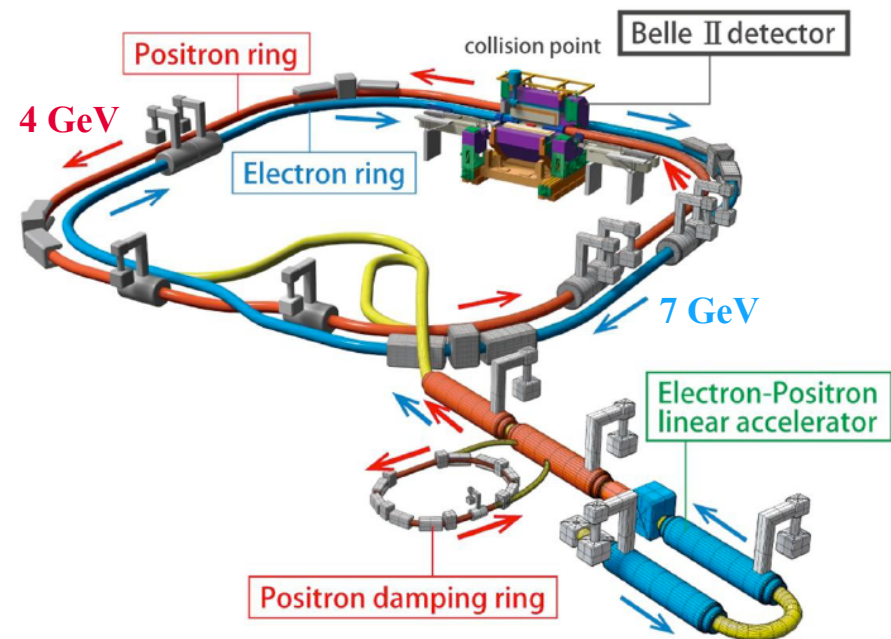
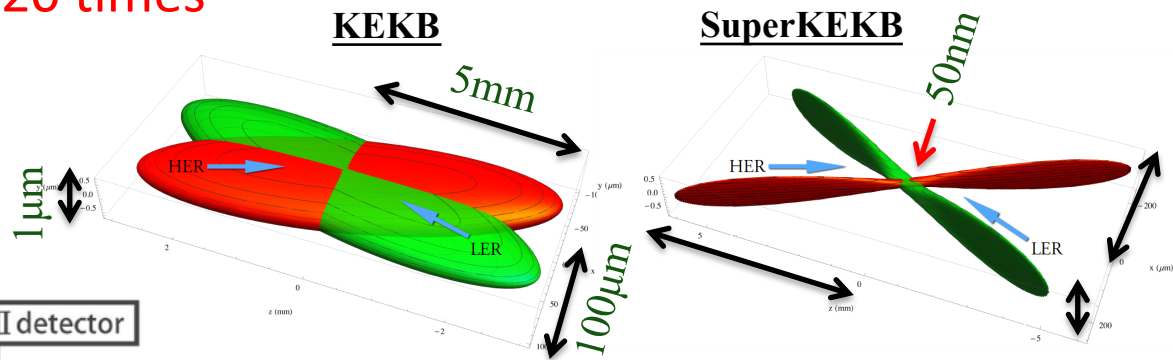
☐ Indirect search for new physics → Super-rare decays especially mediated by the loops and forbidden decays e.g. LFV in τ decay

☐ Test of QCD → exotic quarkonium-like particles

☐ Dark sector → agenda for today



- ❑ Targets to deliver e^+e^- collisions at a peak luminosity of $8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$, 40 times that of its predecessor (KEKB)
 - ✧ Increase beam currents **twice**
 - ✧ Reduce beam size by **20 times**



: A 21st century HEP experiment

☞ Designed to operate with a performance similar or better than Belle, but in a harsh beam background condition

EM Calorimeter (ECL):
CsI(Tl) crystals, waveform sampling readout

K_L and muon detector (KLM):
Resistive plate counter (barrel outer); plastic scintillator + WLS fiber + SiPM (barrel inner two layers and endcap)

Particle identification:
Time-of-Propagation counter (barrel); Proximity focusing Aerogel RICH (forward)

Trigger:
L1 < 30 kHz, HLT < 10 kHz
dedicated low-multiplicity lines

e^- (7 GeV)

Beryllium beam-pipe (10 mm radius)

Central Drift Chamber (CDC):
He(50%)+C₂H₆(50%), small cells, long lever arm, fast electronics

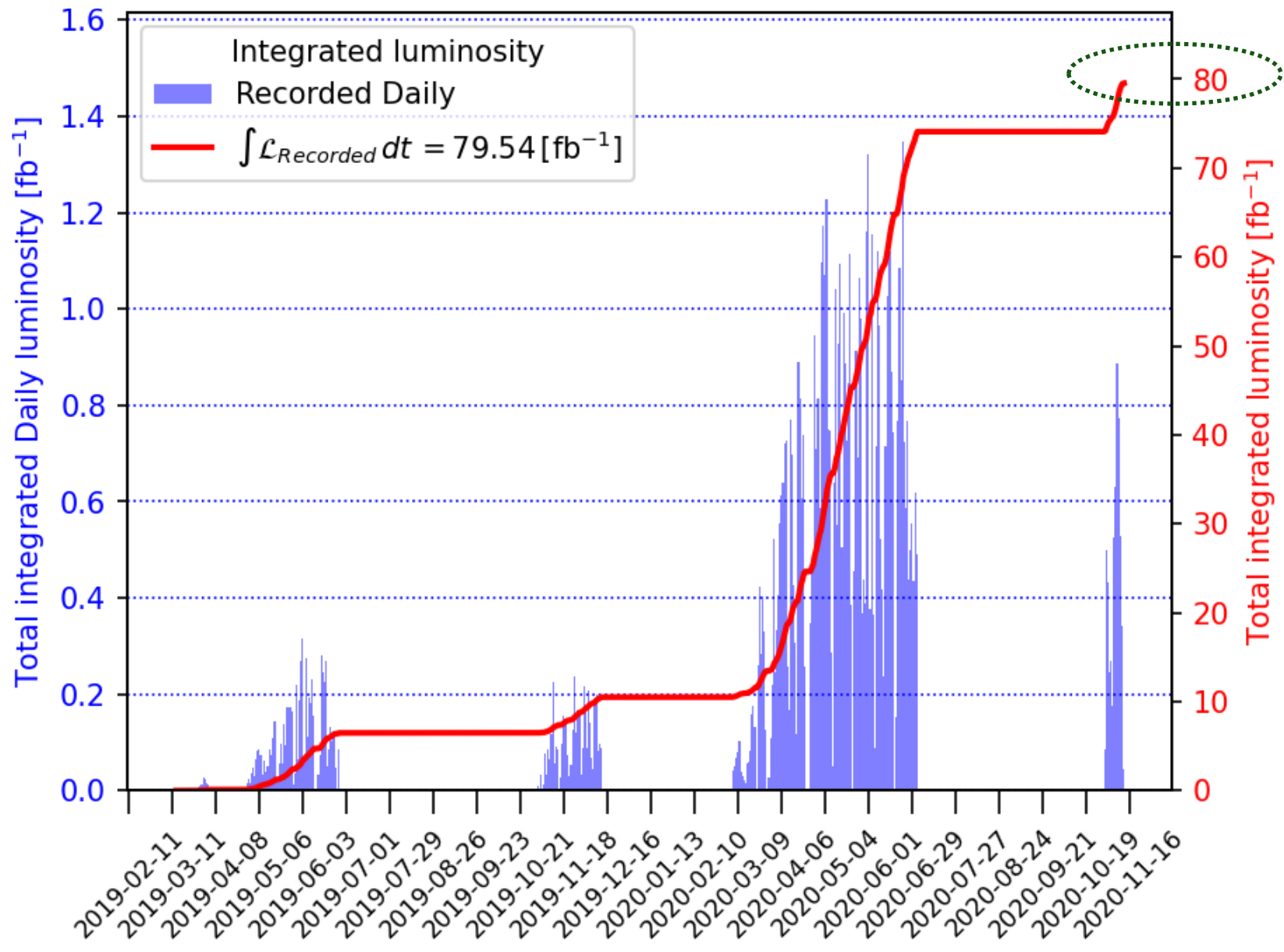
e^+ (4 GeV)

Vertex Detector (VXD): 2-layer pixel (PXD) + 4-layer microstrip (SVD)



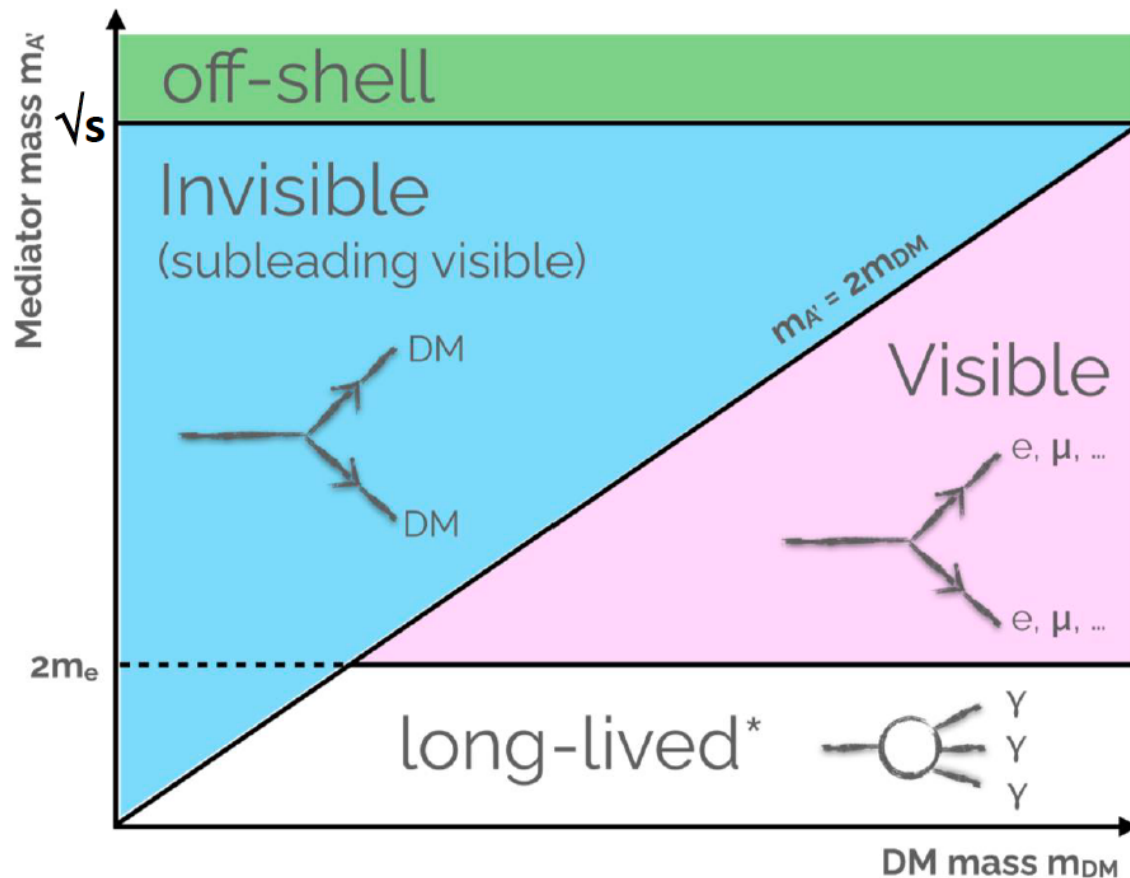
How far has it come?

👉 Pilot run (2018): 0.5 fb^{-1} and typical data-taking efficiency: 90%



What is the agenda for today?

- Hunt for light dark matter (LDM)
 - Probability of interaction with detector is negligible $\Rightarrow$ look for mediators, missing energy signatures, or both
- Different signature depending on DM $\leftrightarrow$ mediator mass relation



Why flavor factory when LHC is rocking?

- Low energy $\Rightarrow$ in the vicinity of the light region
 - Clean e^+e^- vs. murky hadronic environment
 - Energy-momentum conservation as opposed to p_T alone
 - Full event interpretation
-
- ☐ Low-multiplicity signatures
 - ☐ Missing energy channels
 - ☐ Invisible particles, often in closed kinematic range
 - ☐ Accessibility to fully neutral final states
 - ☐ Often cleanliness and luminosity compensate for cross section $\Rightarrow$ competition

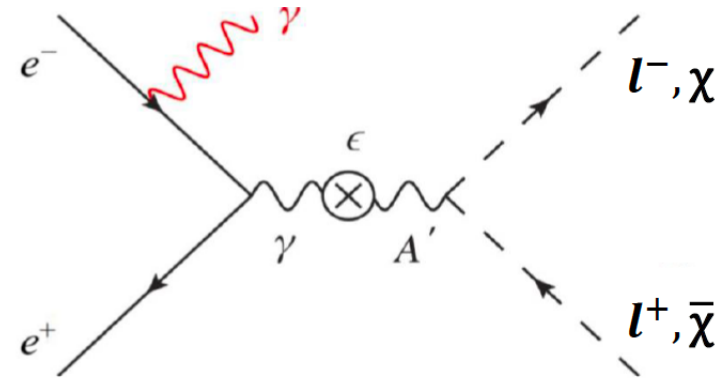
 More details in Belle II physics book

arXiv:1808.10567
(10.1093/ptep/ptz106)

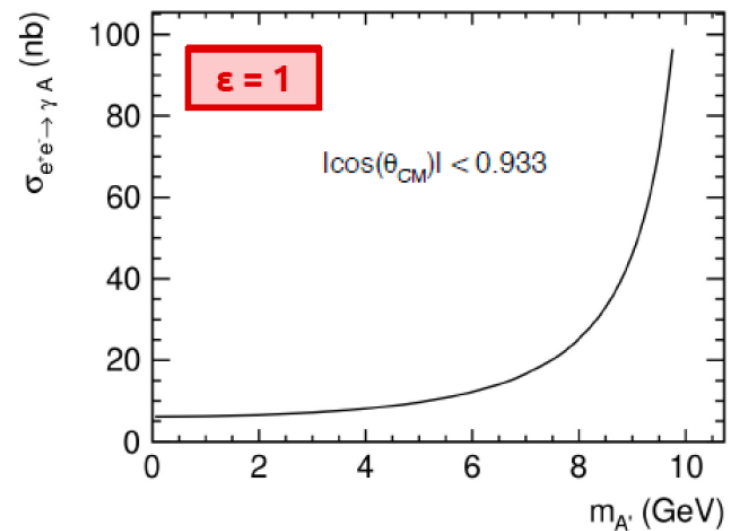
Enter dark photons

- Paradigm of the vector portal extension of the standard model (SM)
- QED inspired $U(1)' \rightarrow$ new spin-1 gauge boson A'
- Couples to SM hypercharge via kinematic mixing ϵ and to DM with a strength α_D
- Mass through the Higgs mechanism

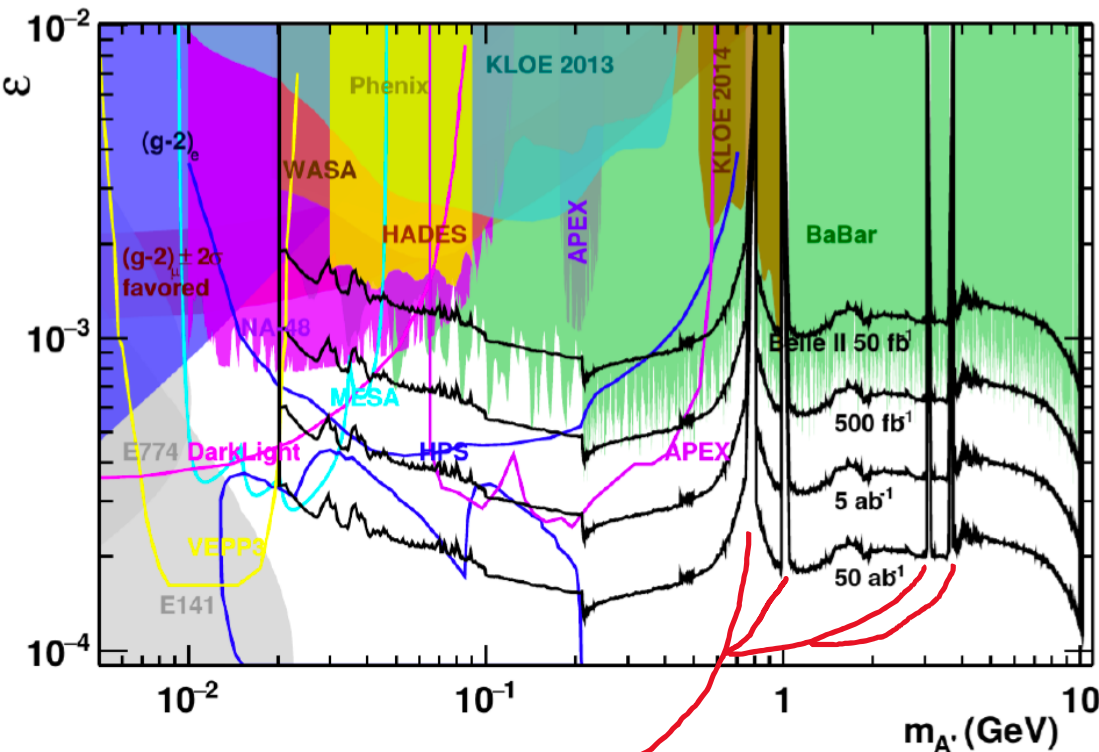
P. Fayet, PLB 95, 285 (1980)
P. Fayet, NPB 187, 184 (1981)



- Two decay scenarios for A' :
- SM particles (ℓ, h): $m_{A'} < 2m_\chi$
 - Invisible decay: $m_{A'} > 2m_\chi$



Visible dark photons

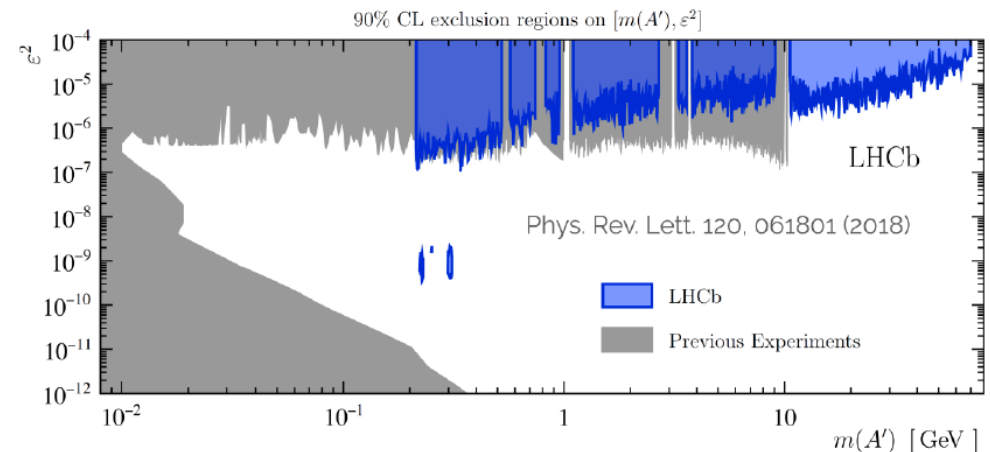


Veto to reject ω , ϕ , J/ψ , $\psi(2S)$ and $\Upsilon(1S, 2S)$

Competition with LHCb

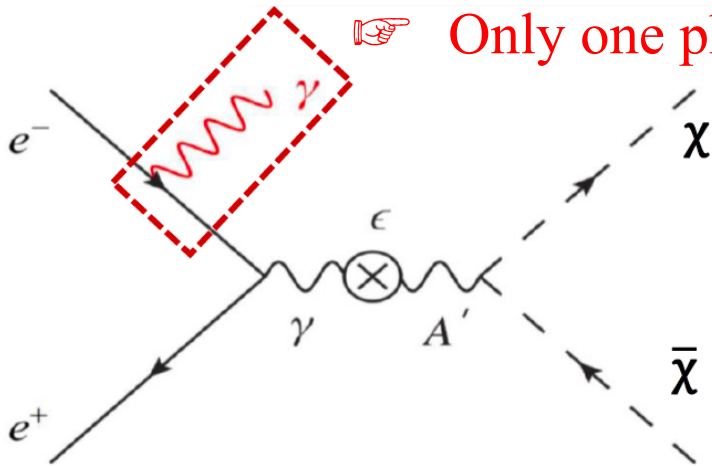
Best limits in the GeV range from BaBar PRL 113, 201801 (2014)

- Belle did not have suitable low-multiplicity triggers in order to be able to perform this kind of search
- Belle II needs few years of data for improving over the current limits $\Rightarrow$ search strategy is in development



Invisible dark photons

☞ Only one photon and nothing else in the detector

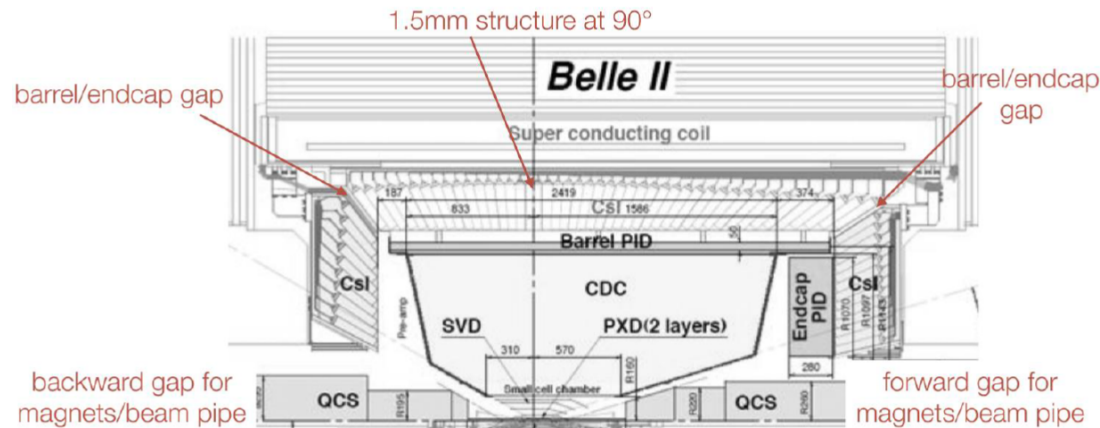


- ☐ Need single photon trigger (Belle did not have whereas $\sim 10\%$ BaBar data had; of course Belle II has it)
- ☐ Also need an excellent knowledge of the detector coverage

☞ One is looking for a bump in the recoil mass of photon:

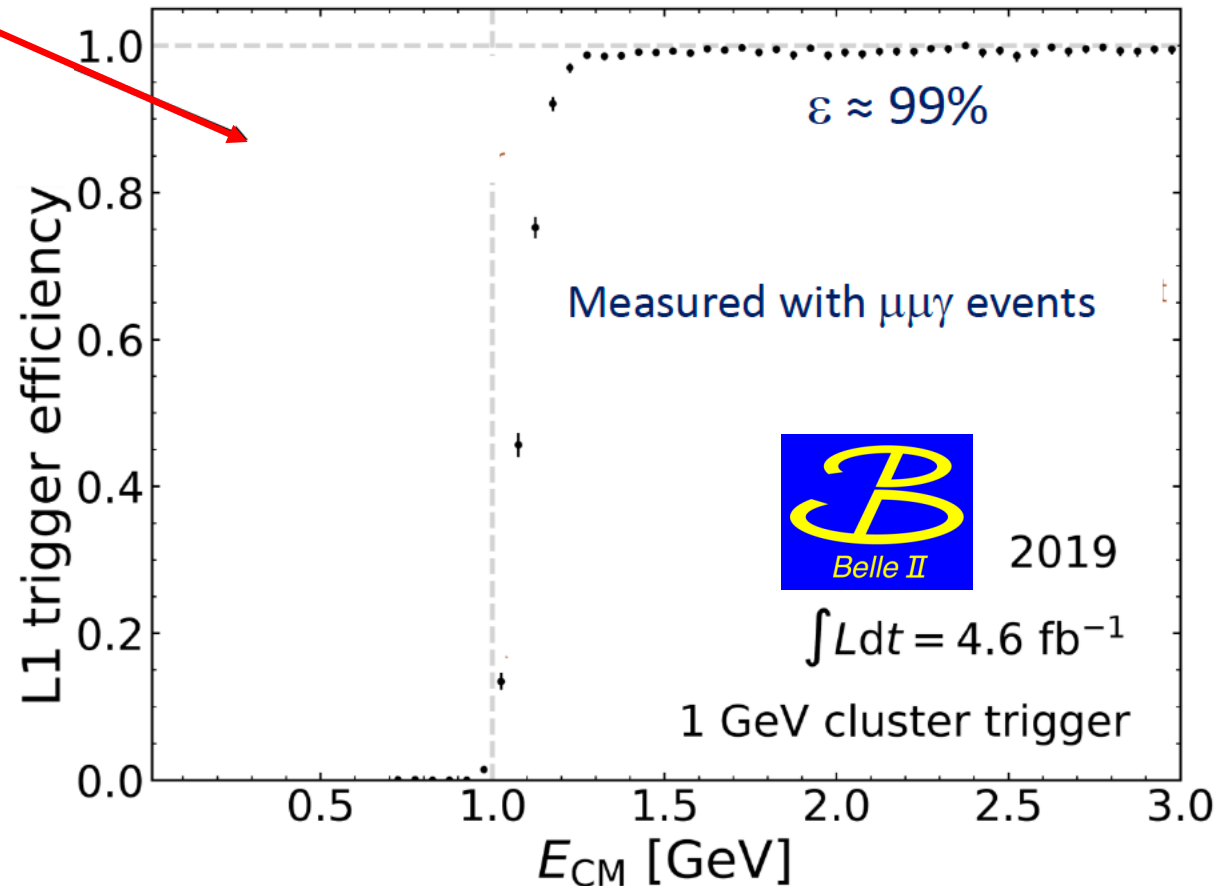
$$E_\gamma = \frac{s - M_{A'}^2}{2\sqrt{s}}$$

- ☐ Possible QED background:
 $e^+e^- \rightarrow e^+e^-\gamma(\gamma)$ at high $m_{A'}$ and $e^+e^- \rightarrow \gamma\gamma(\gamma)$ at low $m_{A'}$ region, cosmic, and $e^+e^- \rightarrow \nu\bar{\nu}\gamma$



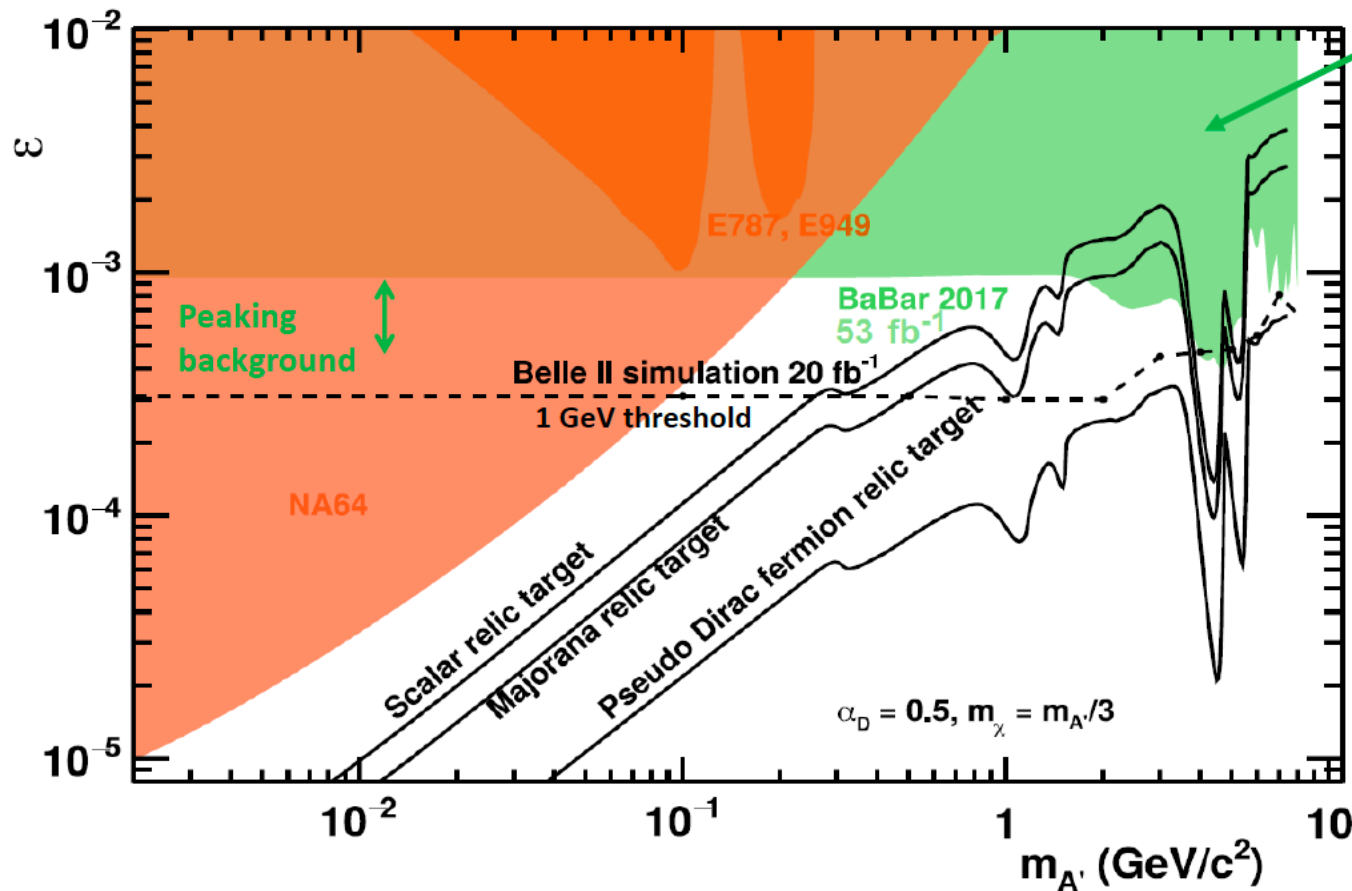
Single photon trigger holds the key

- a) $E_{\text{CM}} > 2 \text{ GeV}$
- b) $E_{\text{CM}} > 1 \text{ GeV} + \text{no other cluster}$
- c) $E_{\text{CM}} > 0.5 \text{ GeV}$ in barrel + no other cluster



- Much more aggressive than originally expected
- Provides excellent condition to perform the measurement asap

Invisible dark photon: sensitivity



BABAR

PRL 119, 131804 (2017)

☞ Compared to BaBar, Belle II profits from a calorimeter with no projective cracks in ϕ , larger size + smaller boost $\Rightarrow$ larger coverage

Dark Z boson: $L_\mu - L_\tau$ model

- Gauging the difference of muon and tau lepton number, $L_\mu - L_\tau$
- A new gauge boson that couples to only second and third lepton families
- Helps to solve
 - DM puzzle (light Dirac fermions, sterile neutrinos)
 - Muon (g-2)
 - Flavor anomalies: R_K and R_{K^*}

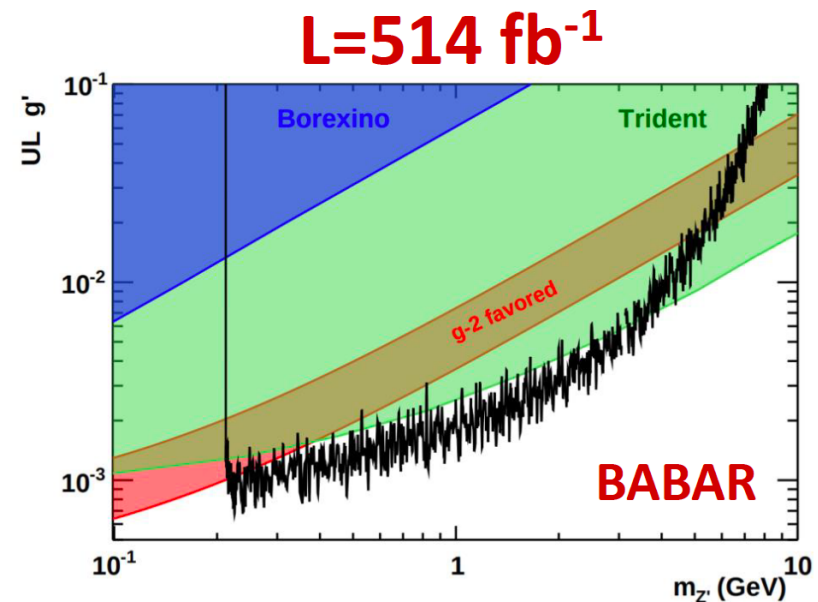
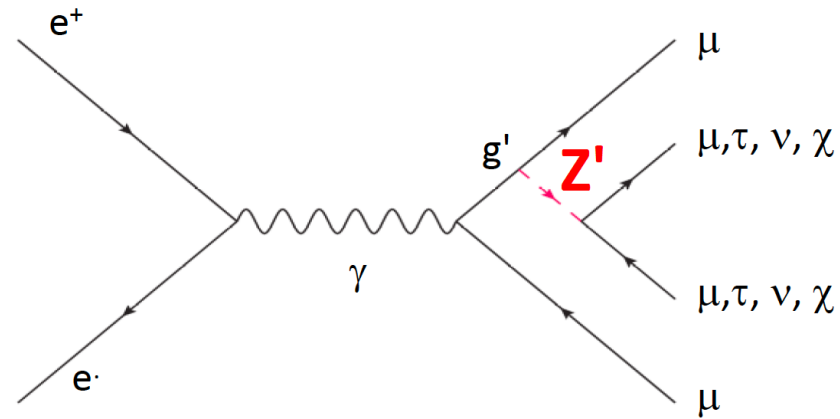
- BaBar has results for $Z' \rightarrow \mu\mu$

PRD 94, 011102 (2016)

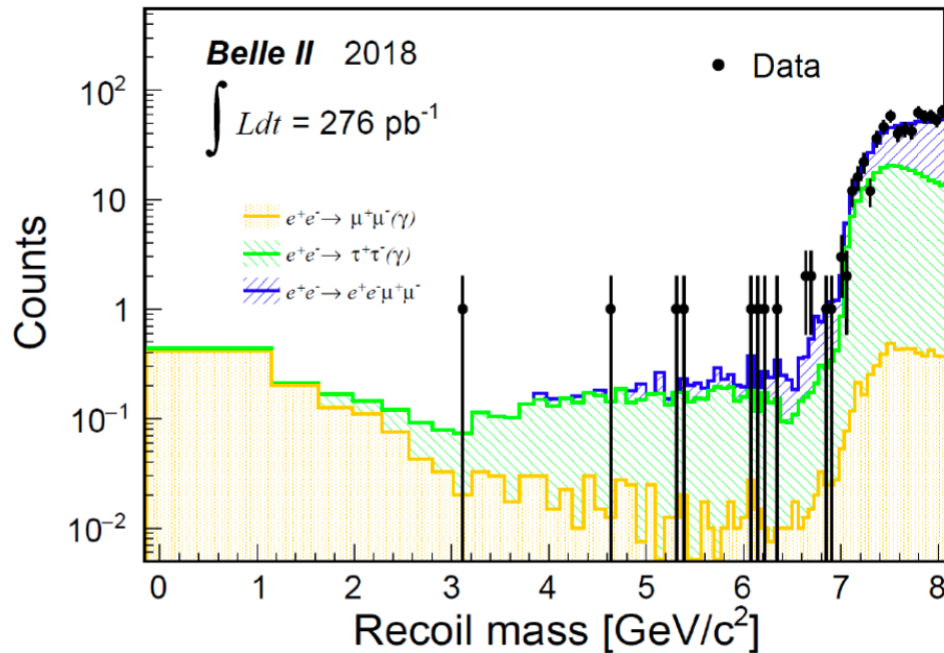
- Work is underway with full data in Belle

- ☞ Belle II can compete with 100 fb^{-1} , thanks to an aggressive background fighting strategy

Shuve and Yavin, PRD 89, 113004 (2014)
Altamannshofer et al. JHEP 1612, 106 (2016)



$Z' \rightarrow \text{invisible}$



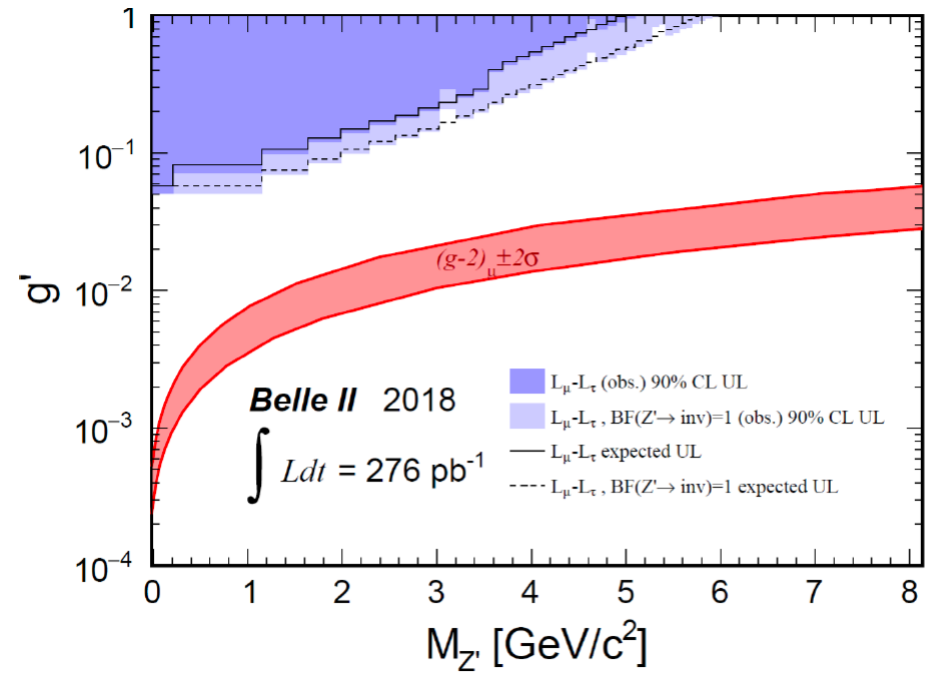
Systematics

Source	Uncertainty
Trigger efficiency	6%
Tracking efficiency	4%
PID	4%
Luminosity	1.5%
Background before τ suppression	2%
τ suppression (background)	22%
Discrepancy in $\mu\mu$ yield (signal)	12.5%

will decrease with new data

👉 First physics paper of Belle II
 PRL 124, 141801 (2020)

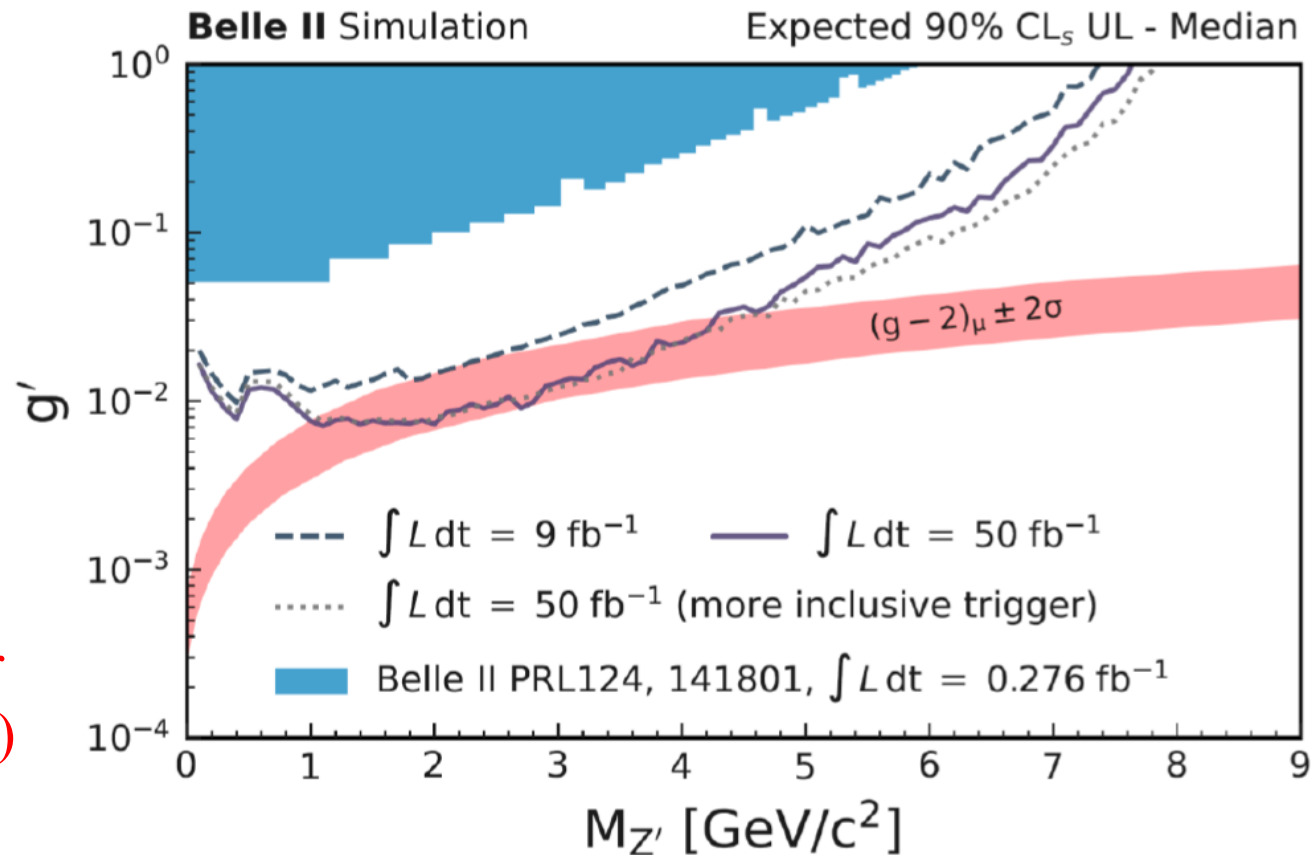
❑ Used a small dataset recorded during the pilot run



$Z' \rightarrow$ invisible: where we can go?

- Improvement in muon ID
- Deployment of new triggers
- Machine learning based selection

☞ Very low expected background (upper limit scales as $1/L$)

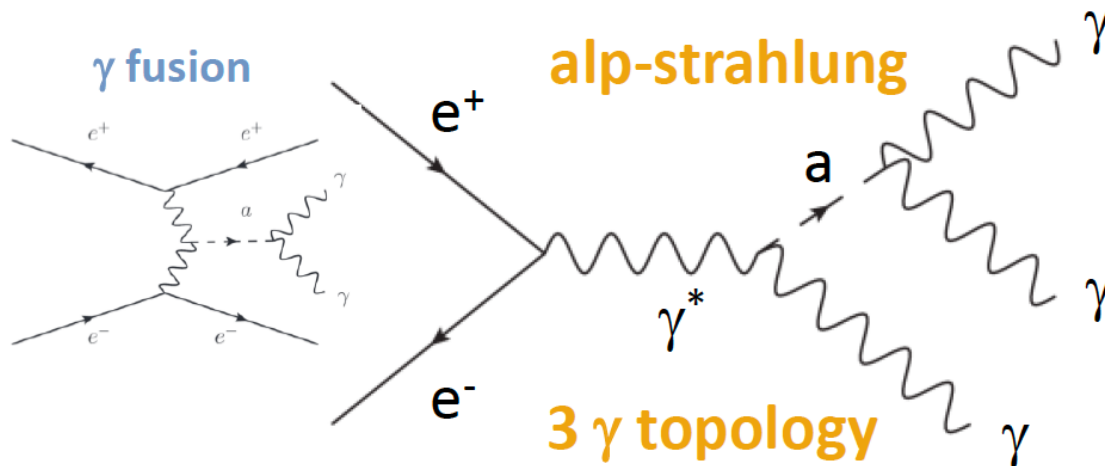


Axion-Like Particles (ALPs)

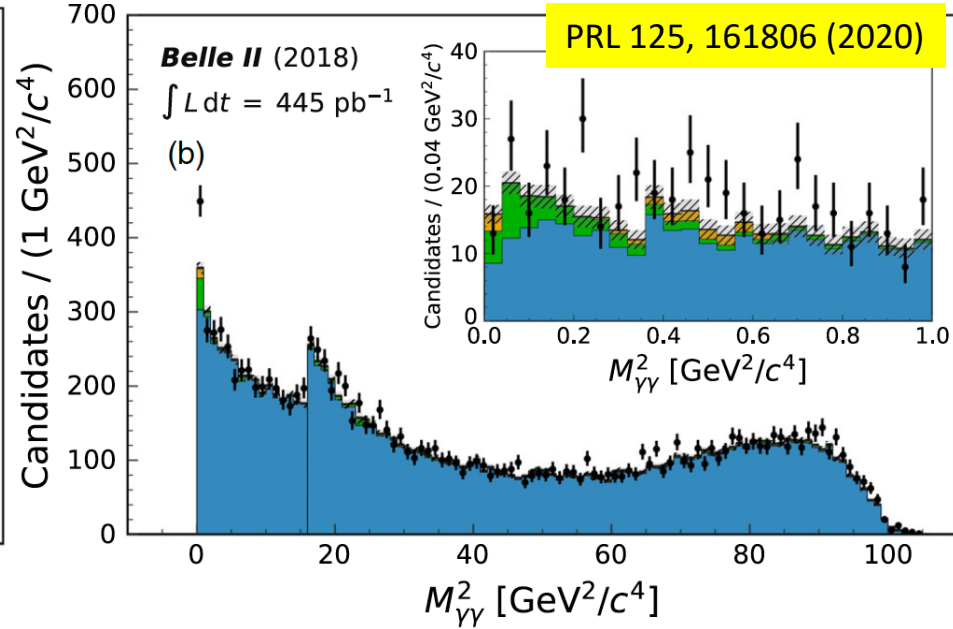
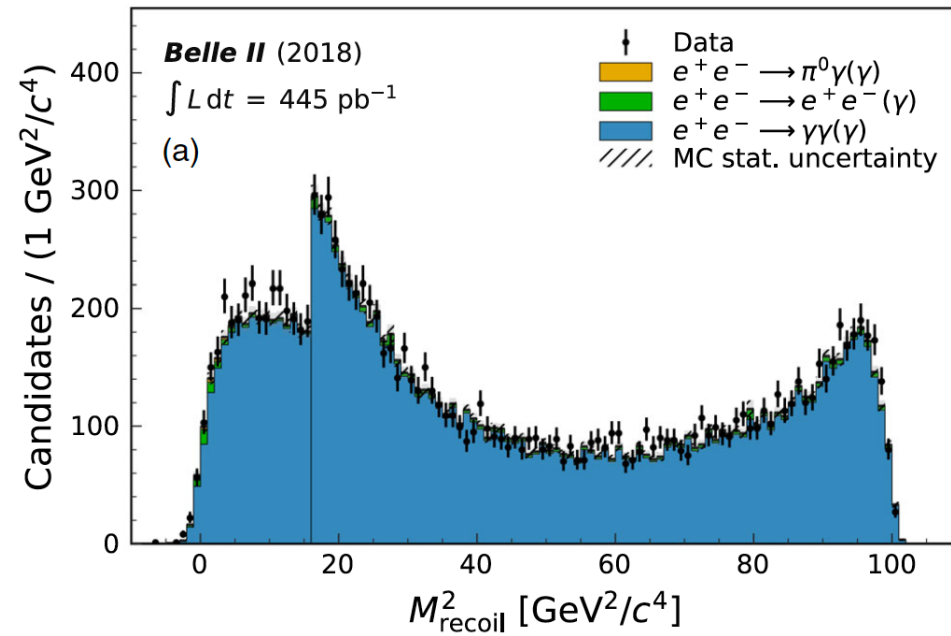
- Appear in various extensions to the SM after some global symmetry breaking
- Pseudo-Goldstone bosons $\Rightarrow$ naturally light
- Cold DM candidates, if m_a is in sub-MeV range
- Couple naturally to photons
- No mass $\leftrightarrow$ coupling relationship (as for QCD)

□ Focus on the coupling to photons: $g_{a\gamma\gamma}$

□ ALP-strahlung + photon fusion production mechanism

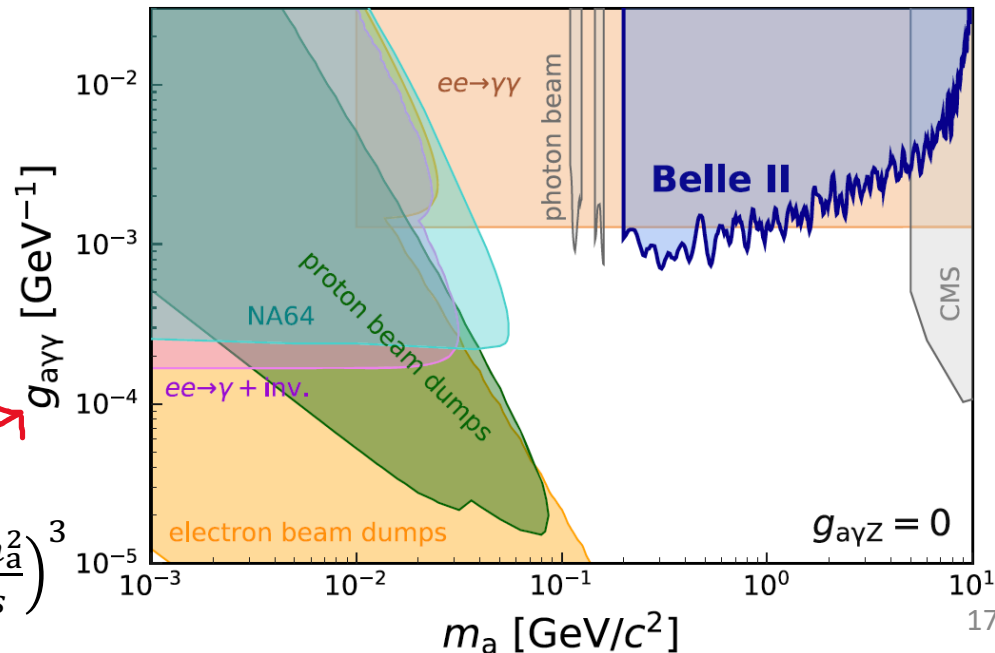


ALPs: Hots off press...



- Look for bumps in the recoil mass (at high m_a) or in the diphoton mass (at low m_a)
- Expect no peaking background
- About 500 fits in sliding ranges with steps of half resolution for $0.2 < m_a < 9.7 \text{ GeV}/c^2$

$$\sigma_a = \frac{g_{a\gamma\gamma}^2 \alpha_{\text{em}}}{24} \left(1 - \frac{m_a^2}{s}\right)^3$$



Closing words

- ❑ Persistent null results from NP searches, especially DM candidates, at the LHC and else where make LDM an attractive avenue to probe
- ❑ Flavor factories provide an excellent prospect for such searches: already a good part of parameter space excluded by Belle and BaBar
- ❑ Belle II has a broad-based search program for LDM candidates, which is quite complementary to that at the LHC
- ❑ Let's continue to dig...

