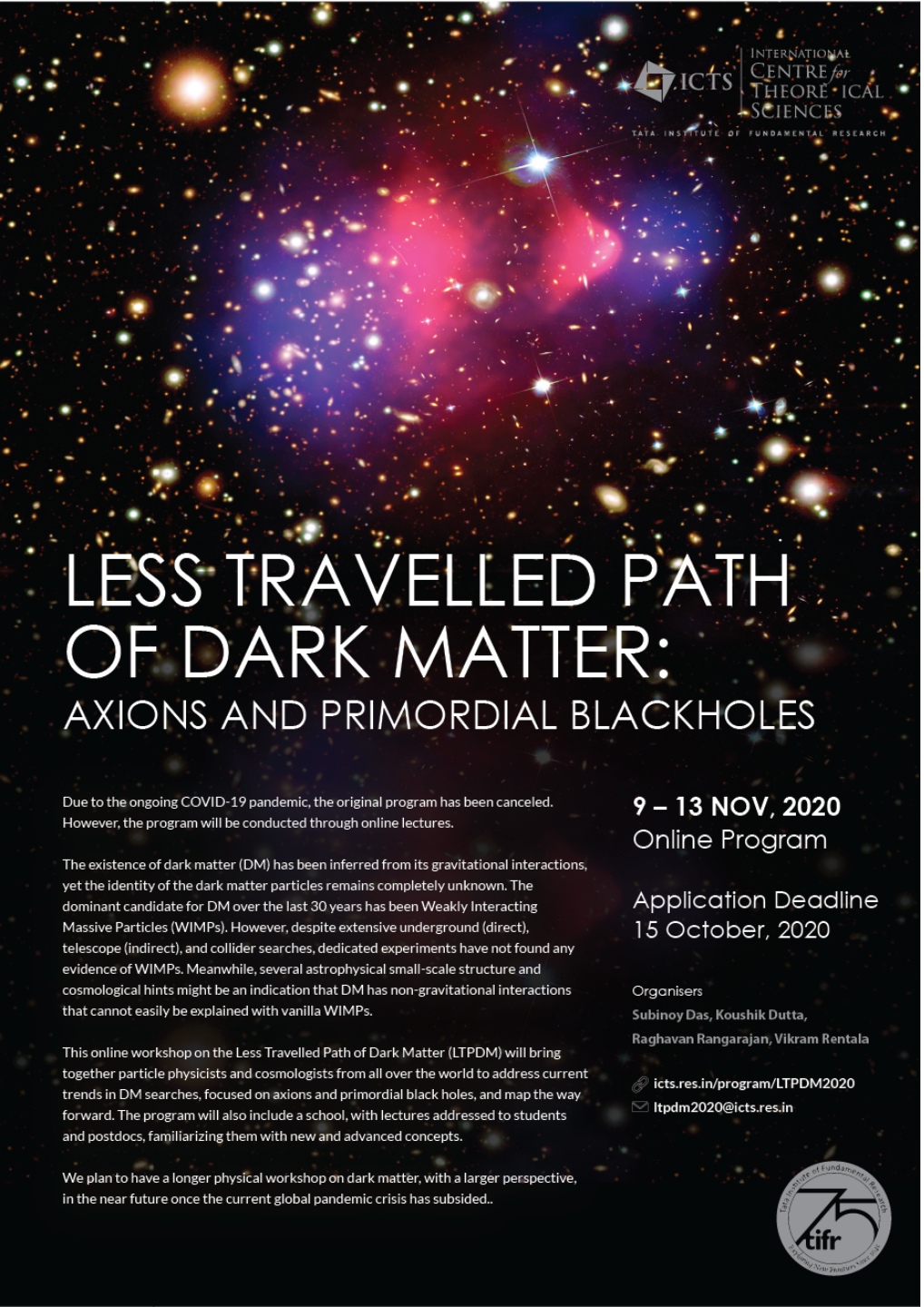


Hunting for LDM candidates at flavor factories

Gagan Mohanty

tifr

BELLE BABAR Belle II

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

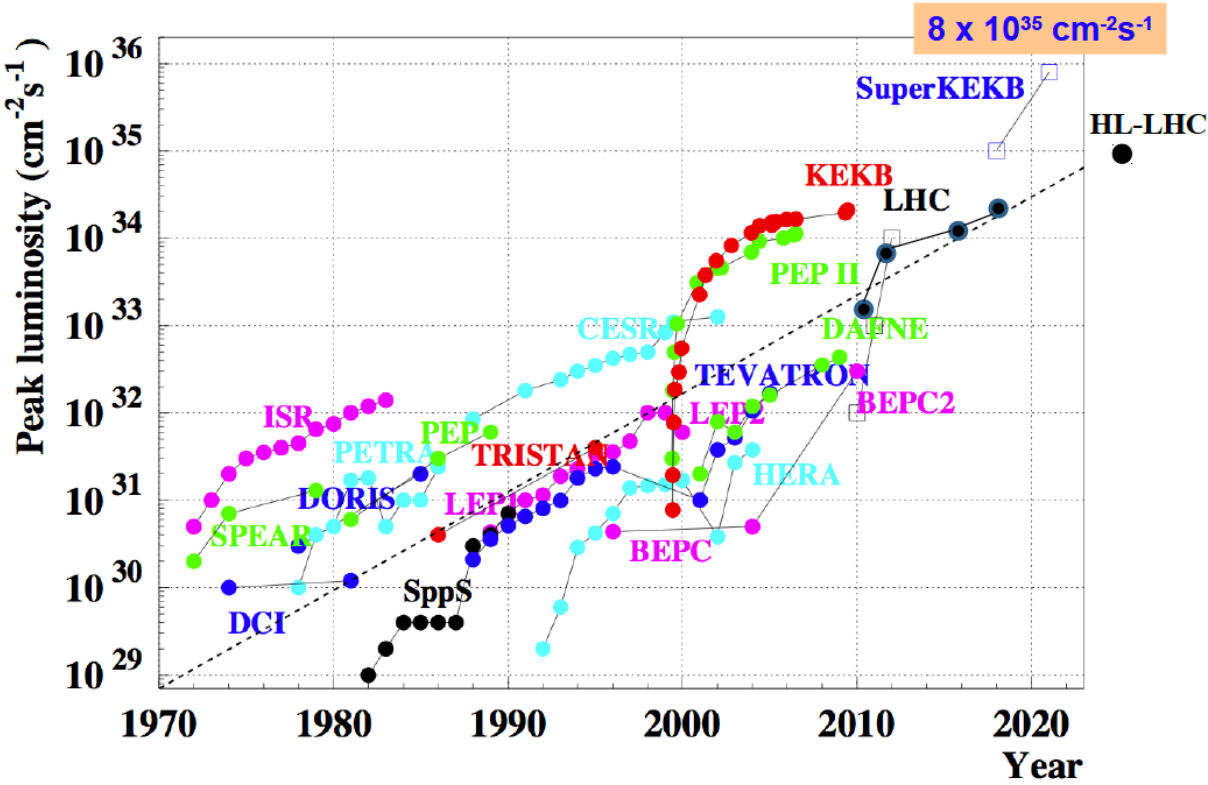
What is a flavor factory?

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

- ❑ Luminosity is key strength ➔ also called "intensity-frontier" experiment

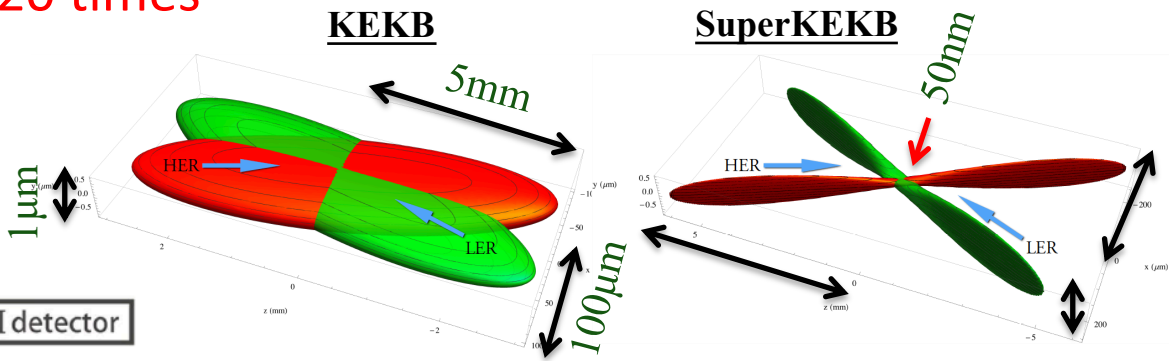
☞ Broad physics program

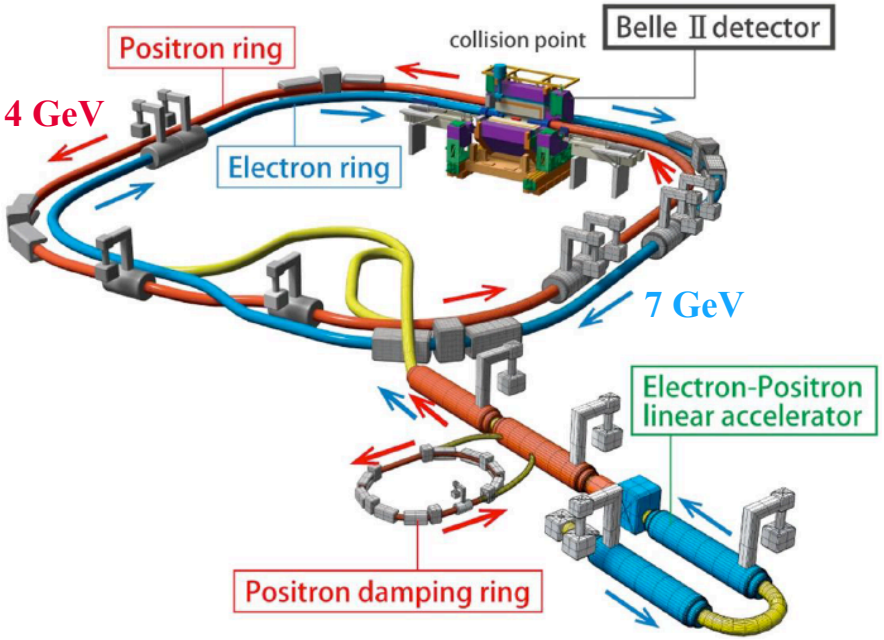
- ❑ Flavor physics ➔ CKM matrix and CP violation in beauty and charm decays
- ❑ Indirect search for new physics ➔ Super-rare decays especially mediated by the loops and forbidden decays e.g. LFV in τ decay
- ❑ Tests of QCD ➔ exotic quarkonium-like particles
- ❑ Dark sector ➔ agenda for today

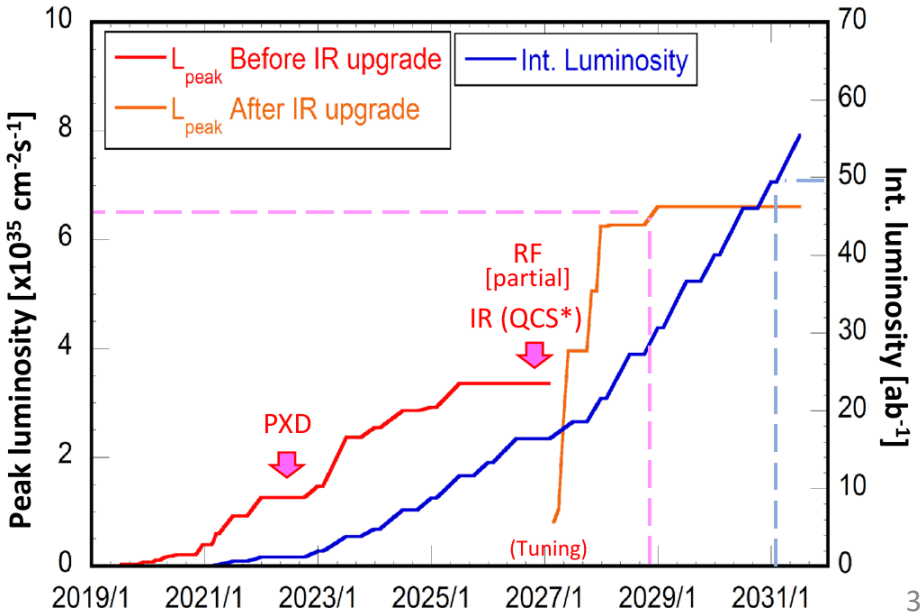


SuperKEKB : Current flag bearer

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







Belle II: 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)

e^- (7 GeV)

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

Beryllium beam-pipe (10 mm radius)

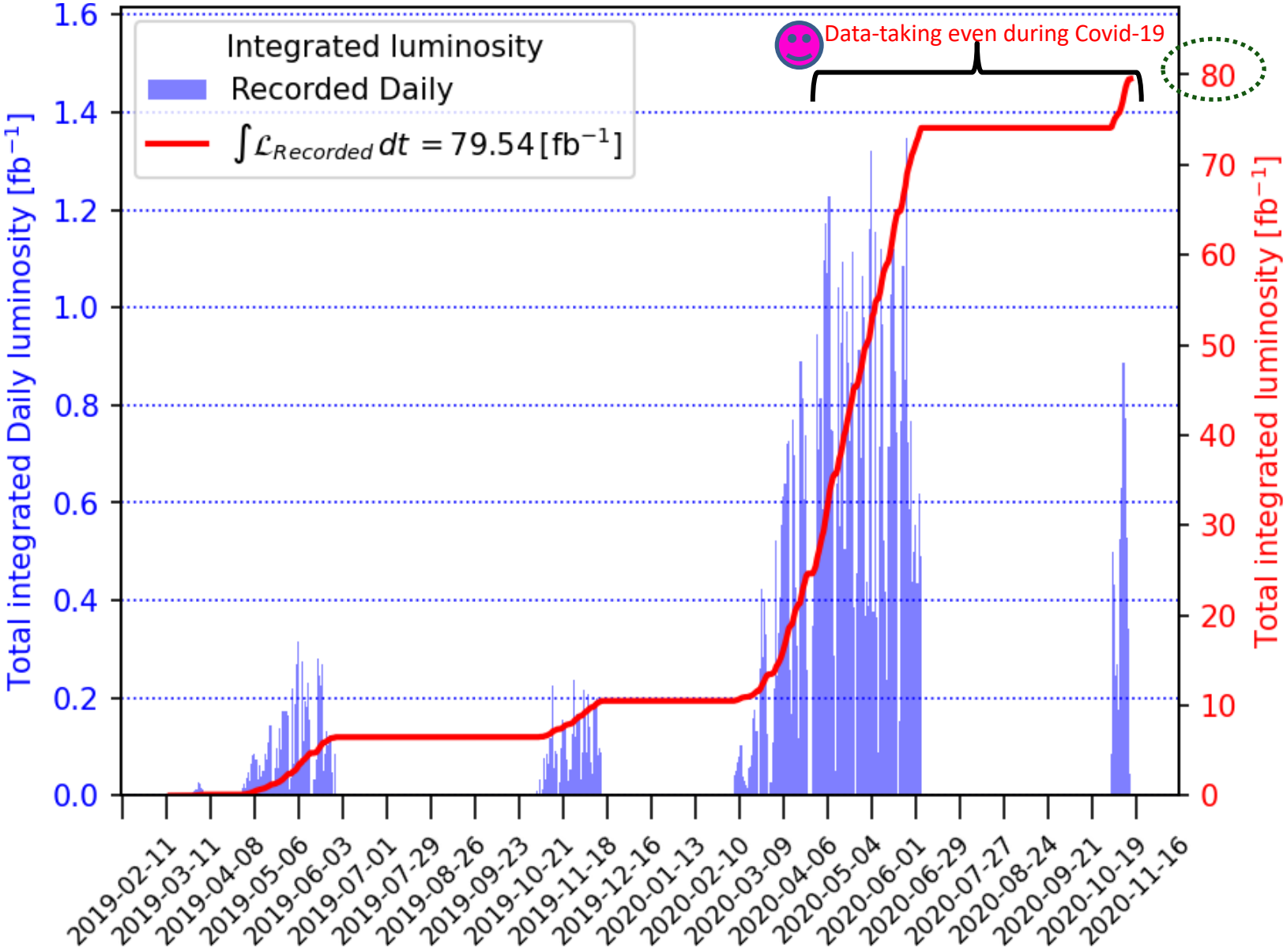
e^+ (4 GeV)

Central Drift Chamber (CDC): He(50%)+C_2H_6(50%), small cells, long lever arm, fast electronics

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

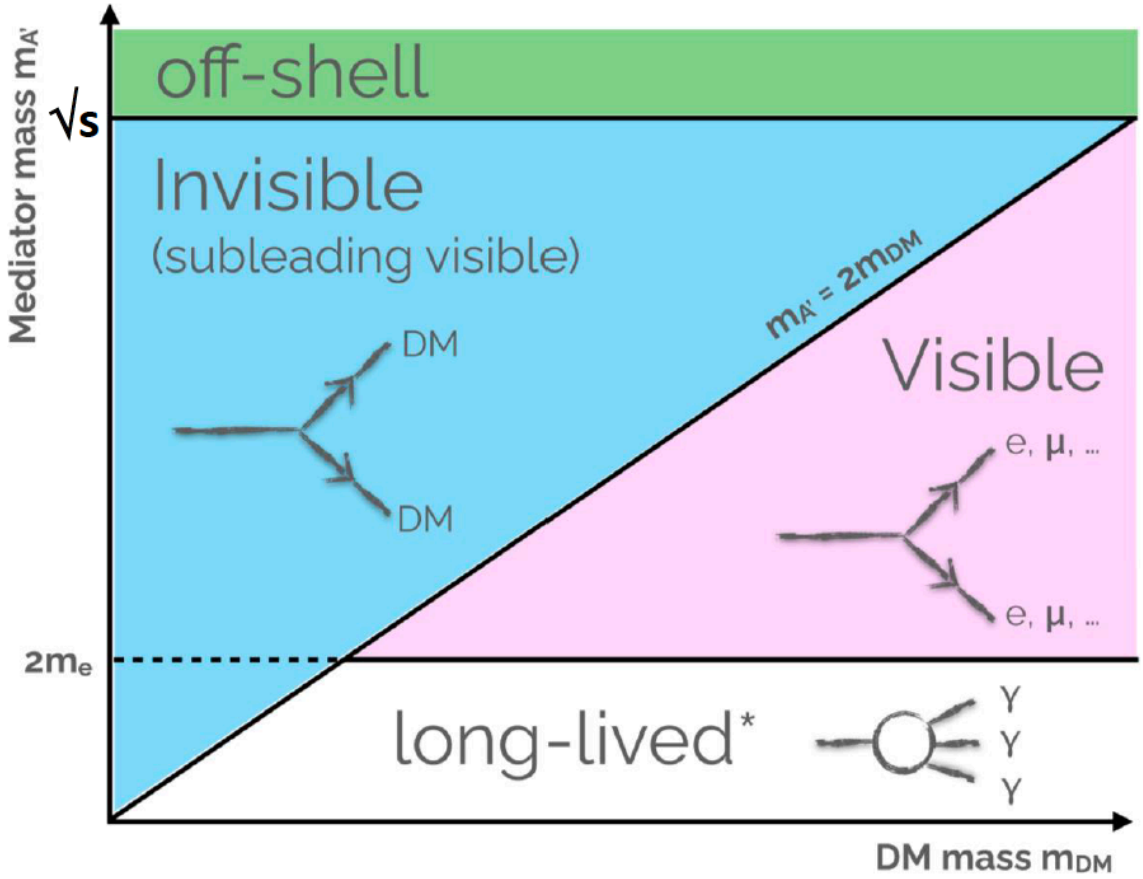
How far have we come?

☞ 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 ⇒ look for mediators, missing energy signatures, or both
- Different signatures depending on DM↔mediator mass relation



Why flavor factory when LHC is rocking?

- Low energy ⇒ 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 ⇒ competition

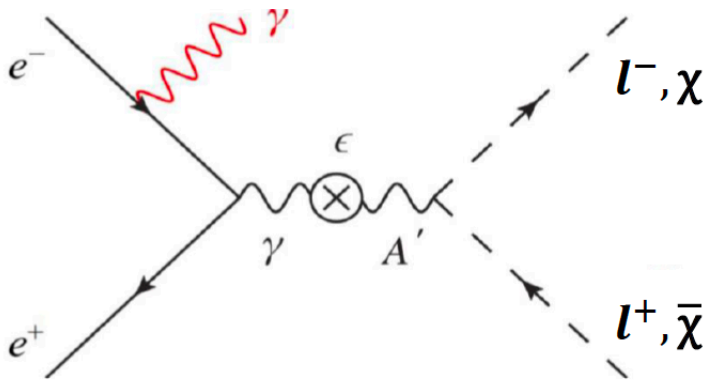
☞ More details in Belle II physics book

arXiv:1808.10567
(10.1093/ptep/ptz106)

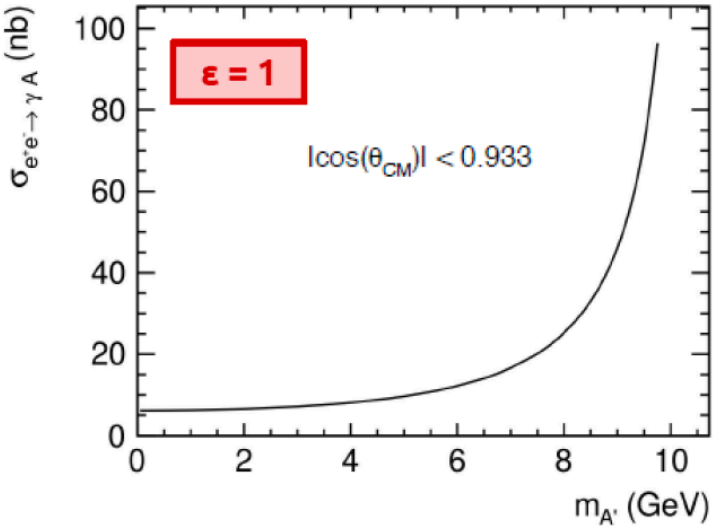
Enter dark photons

- 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

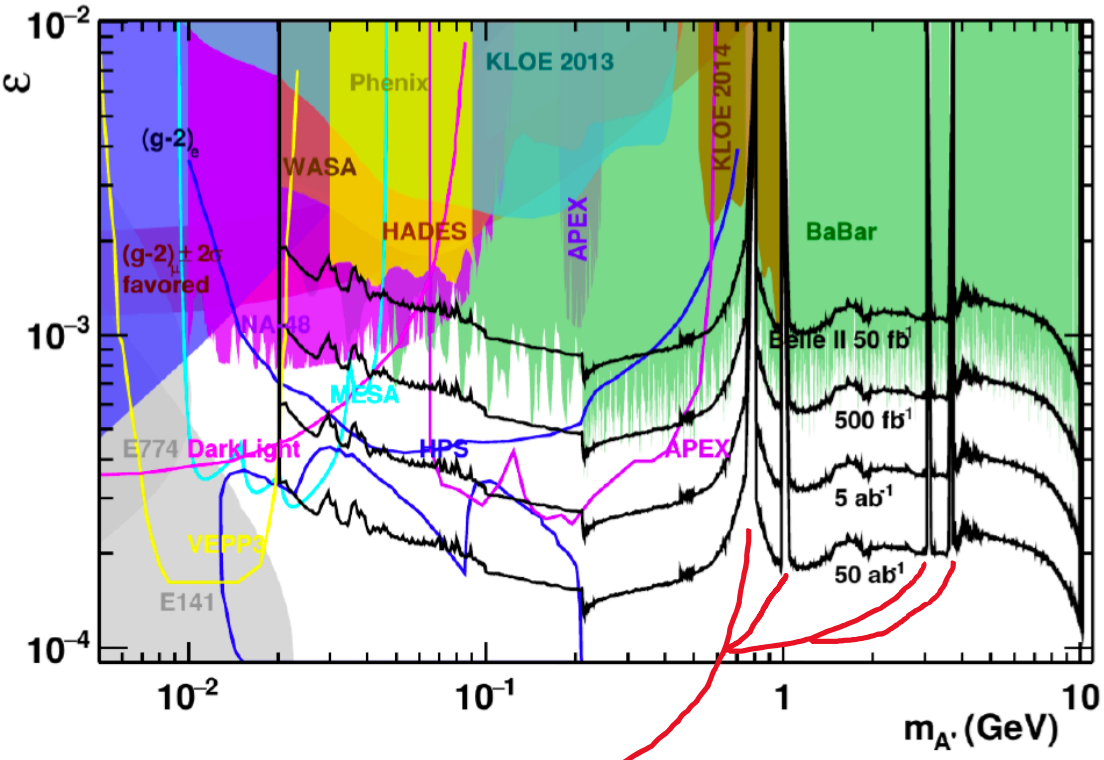
P. Fayet, PLB 95, 285 (1980)
P. Fayet, NPB 187, 184 (1981)



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



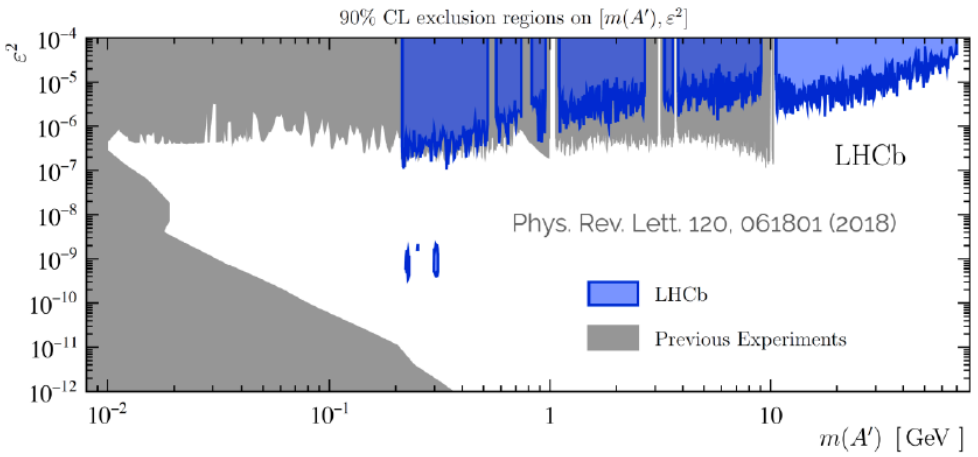
Visible dark photons



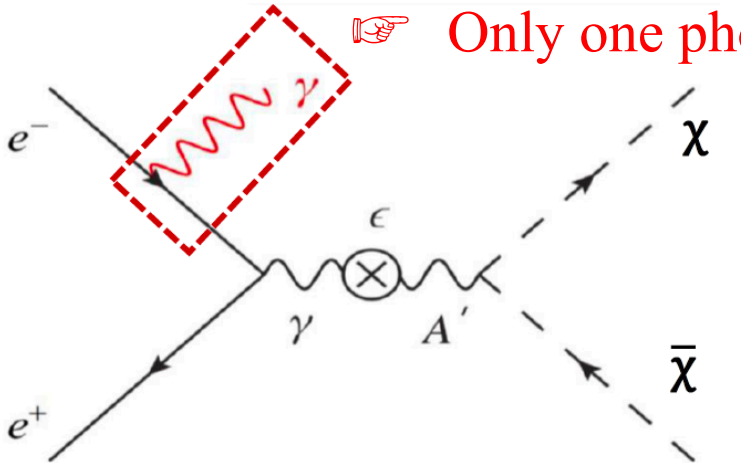
- Best limits in the GeV range from BaBar PRL 113, 201801 (2014)
- Belle did not have suitable low-multiplicity triggers in order to be able to perform this kind of search
- Belle II needs few years of data for improving over the current limits ⇒ search strategy is in development

Vetoes to reject ω, $\phi, J/\psi, \psi(2S)$ and $\Upsilon(1S, 2S)$

Competition with LHCb



Invisible dark photons



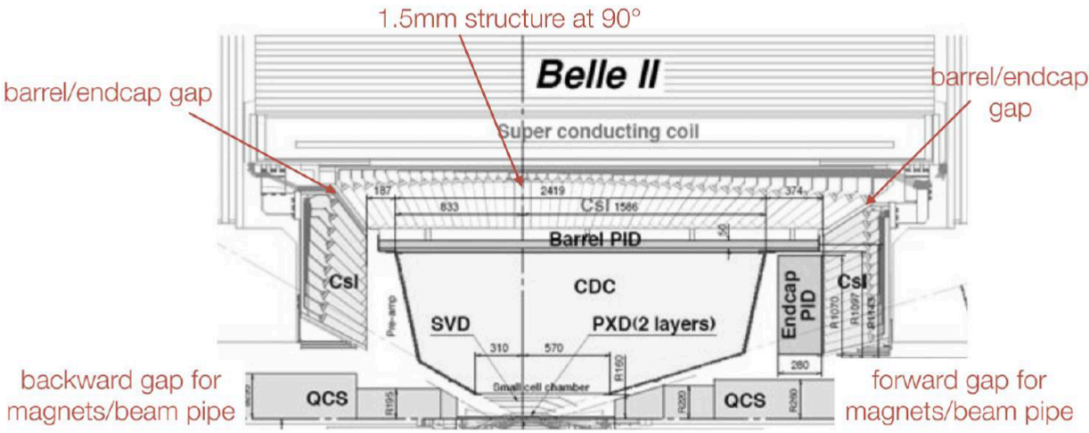
☞ Only one photon and nothing else in the detector

- Need single photon trigger (Belle did not have whereas ~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:

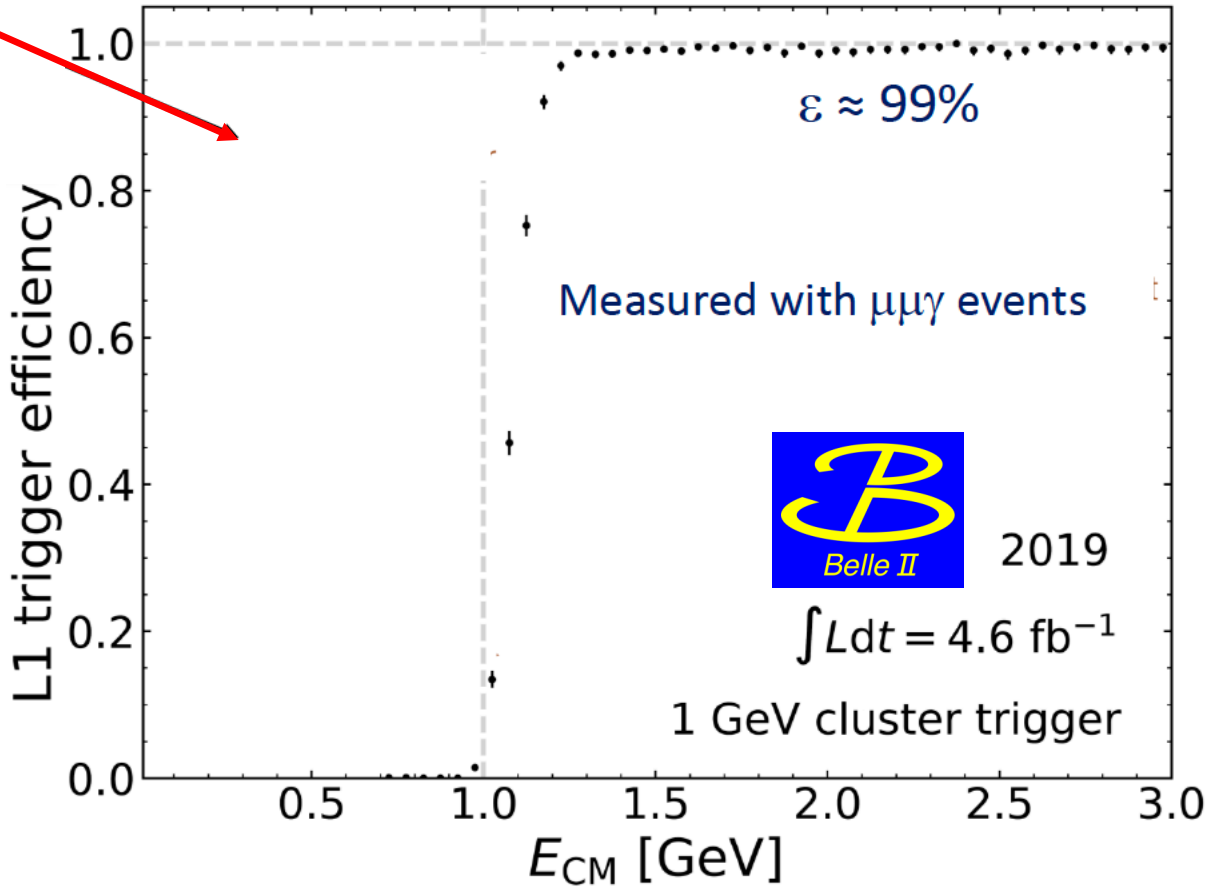
$$E_\gamma = \frac{s - M_A^2}{2\sqrt{s}}$$

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



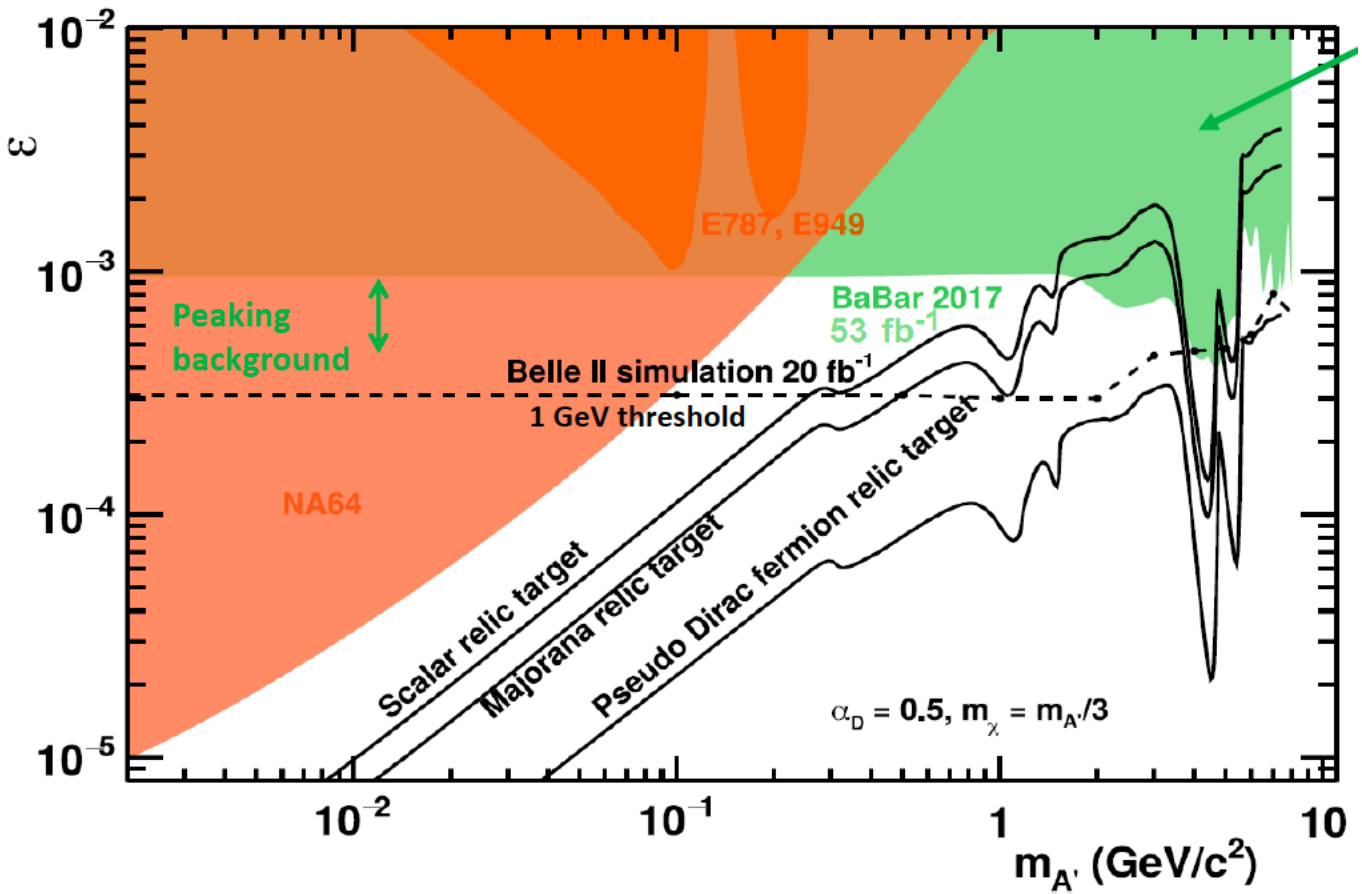
Single photon trigger holds the key

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



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

Invisible dark photon: sensitivity



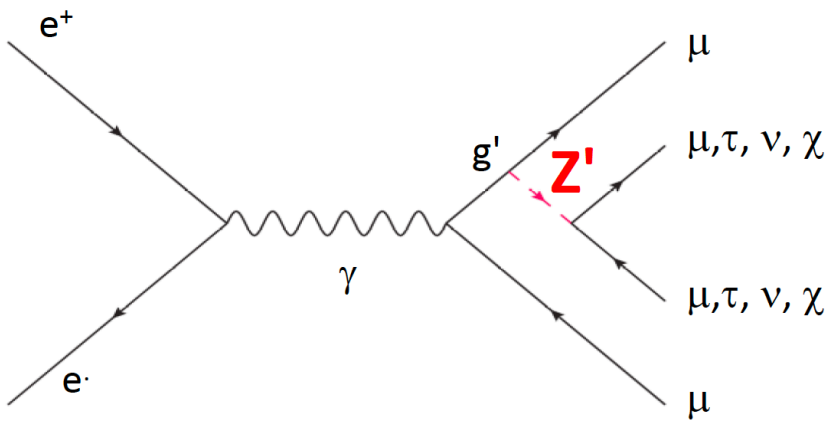
PRL 119, 131804 (2017)

☞ Compared to BaBar, Belle II profits from a calorimeter with no projective cracks in ϕ, larger size + smaller boost ⇒ 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
  a) DM puzzle (light Dirac fermions, sterile neutrinos)
  b) Muon (g-2)
  c) Flavor anomalies: R_K and R_{K^*}

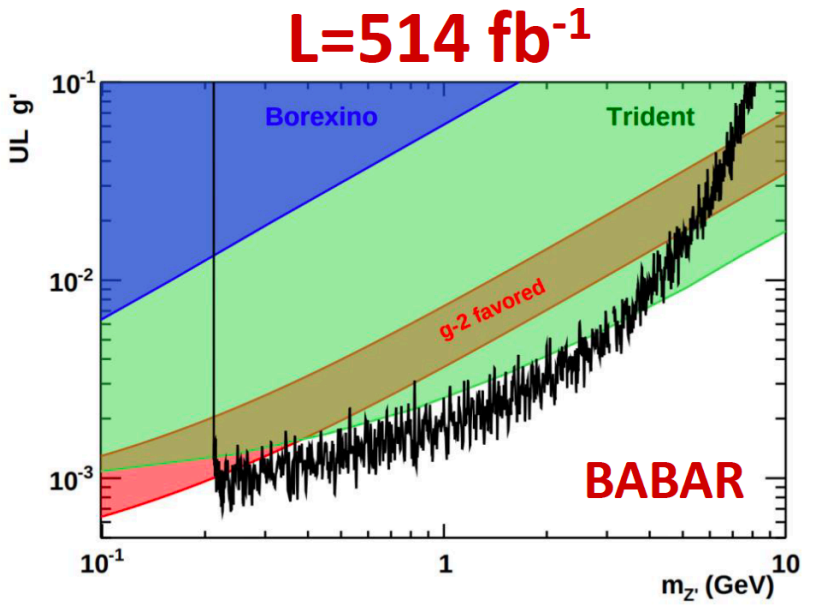
Shuve and Yavin, PRD 89, 113004 (2014)
Altamannshofer et al. JHEP 1612, 106 (2016)



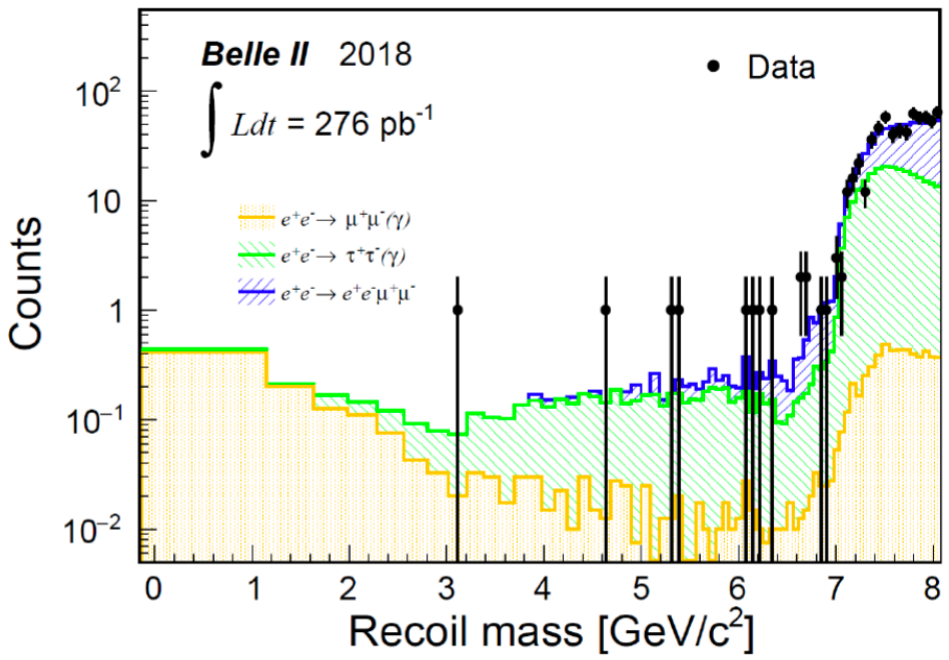
- BaBar has results for $Z' \to \mu\mu$

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



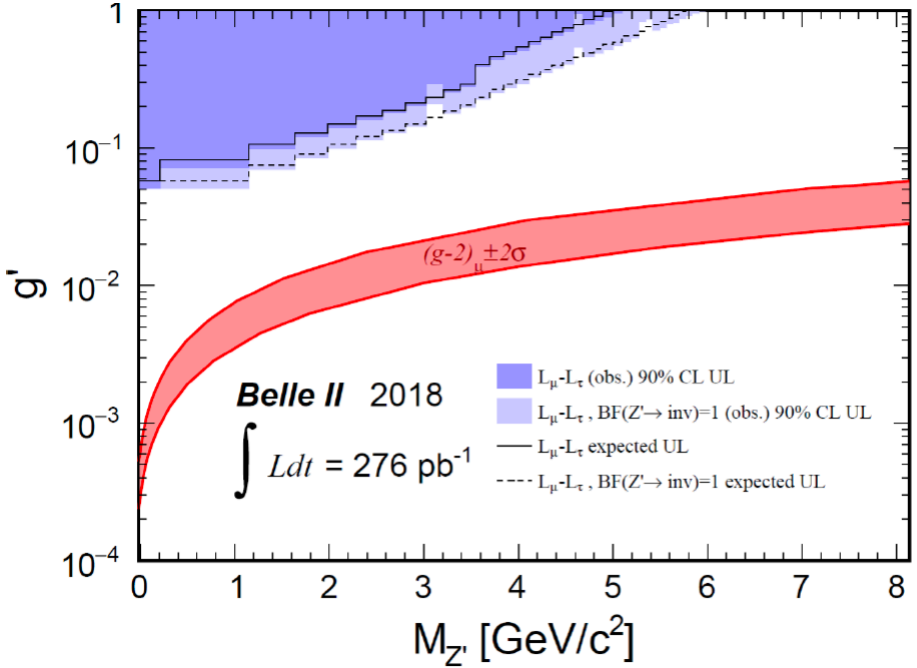
$Z' \rightarrow$ invisible



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 μμ yield (signal)	12.5%

will decrease with new data



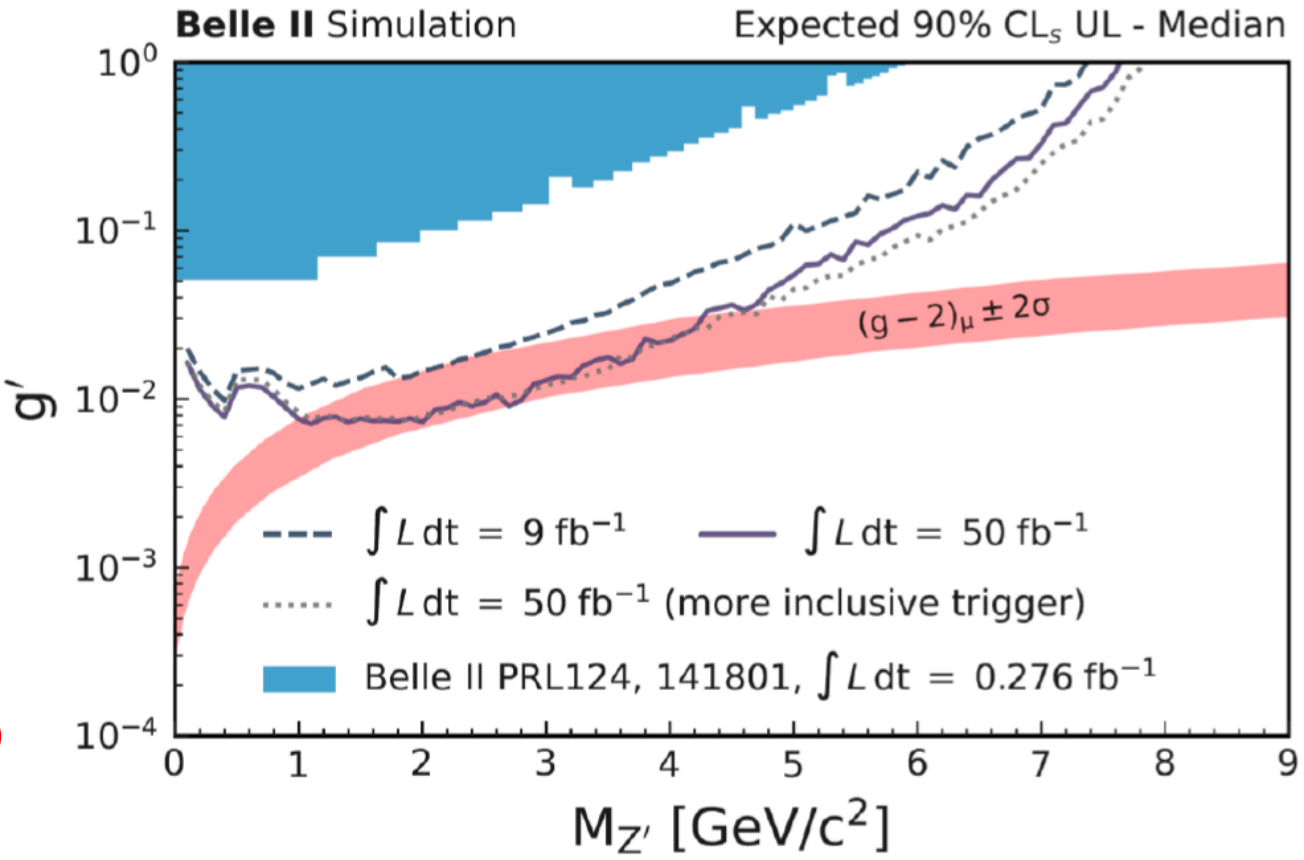
☞ First physics paper of Belle II

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

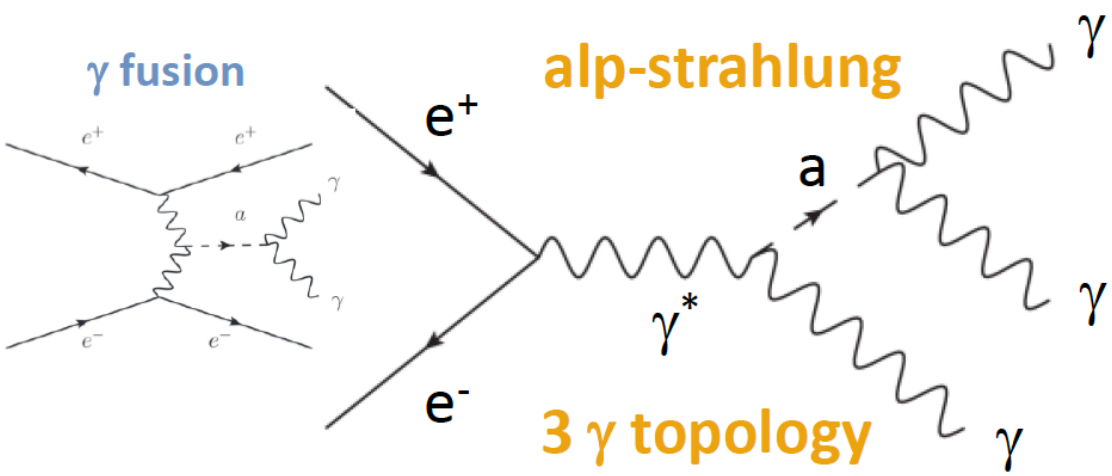


☞ Very low expected background (upper limit scales as $1/L$)

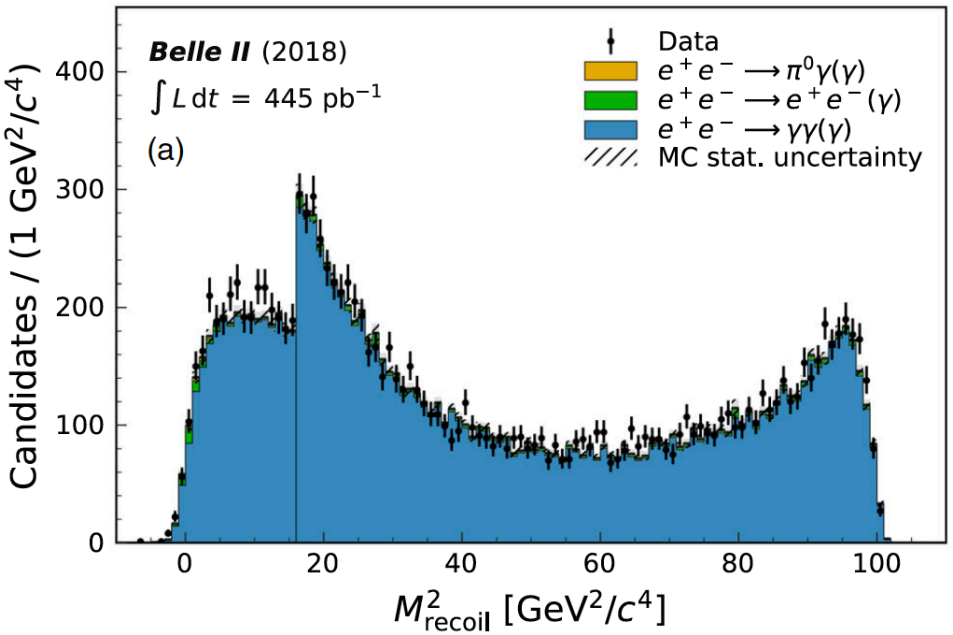
Axion-Like Particles (ALPs)

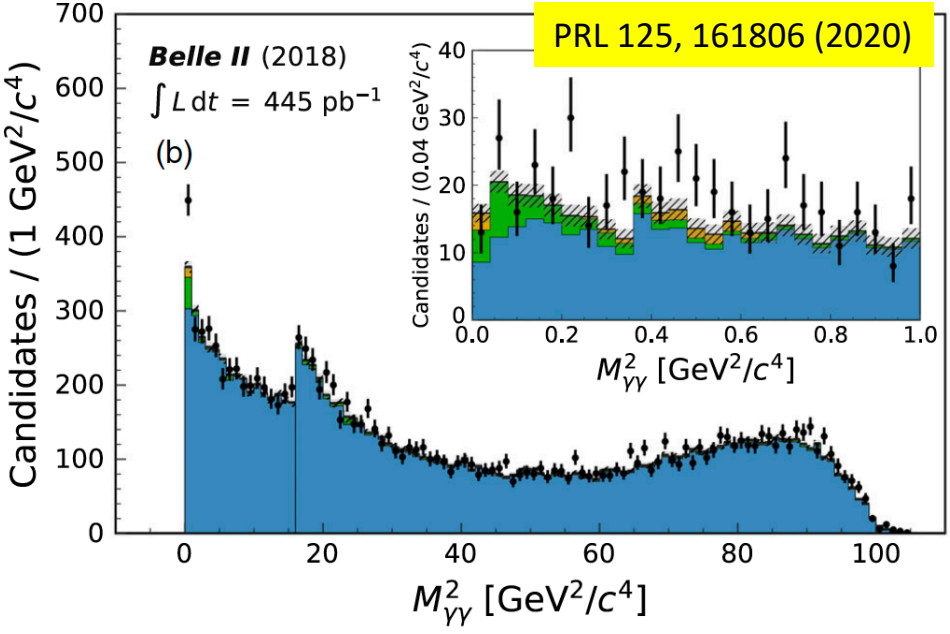
- Appear in various extensions to the SM after some global symmetry breaking
- Pseudo-Goldstone bosons ⇒ naturally light
- Cold DM candidates, if m_a is in sub-MeV range
- Couple naturally to photons
- No mass↔coupling relationship (as for QCD)

  - ❑ Focus on the coupling to photons: $g_{a\gamma\gamma}$
  - ❑ ALP-strahlung + photon fusion production mechanism



ALPs: Hots off press…

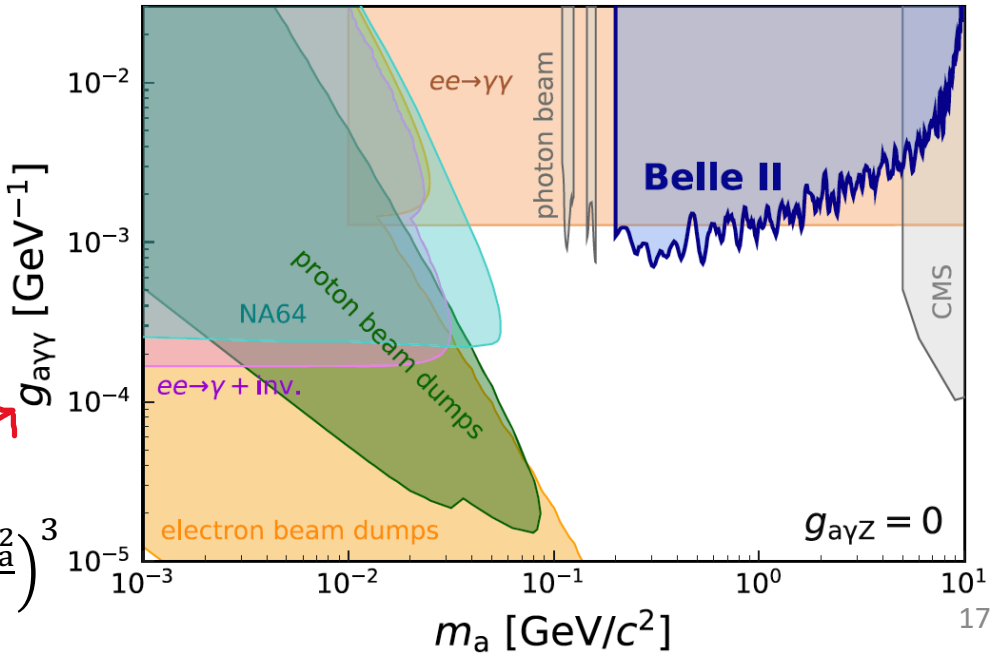




PRL 125, 161806 (2020)

- 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 $0.2 < m_a < 9.7$ GeV/c^2

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



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…