


Dark Sector Searches at Belle II

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MOCa 2021: Materia Oscura en Colombia
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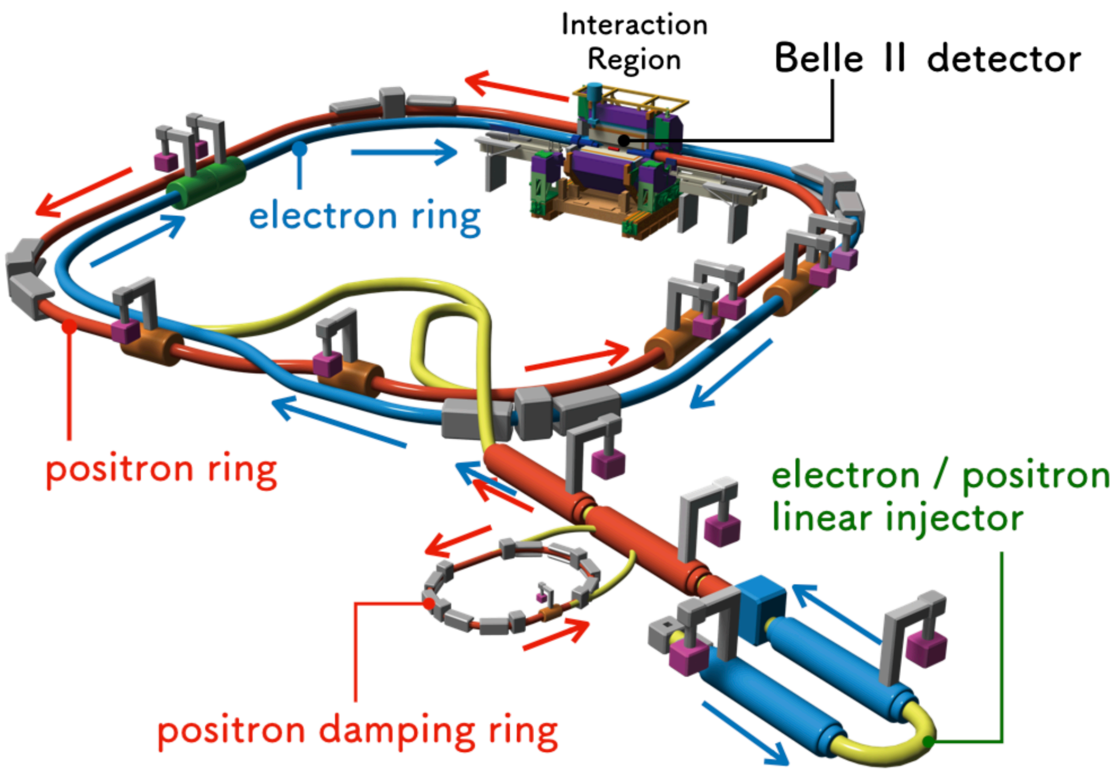
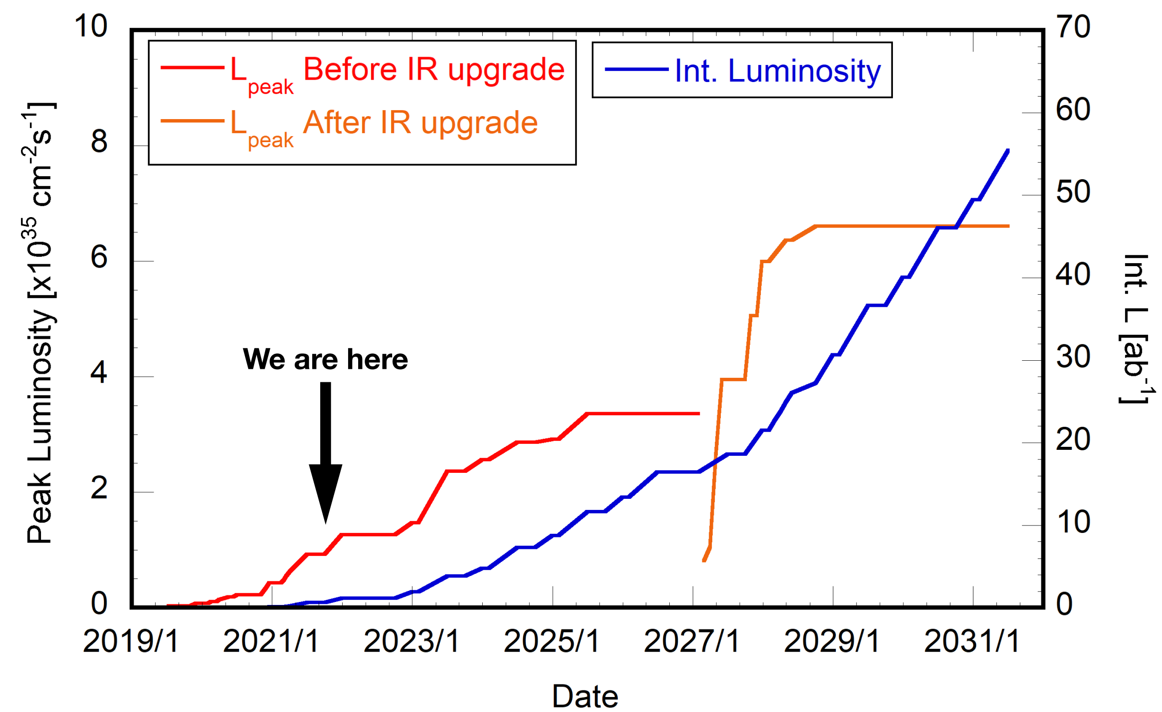
Belle II and SuperKEKB

SuperKEKB

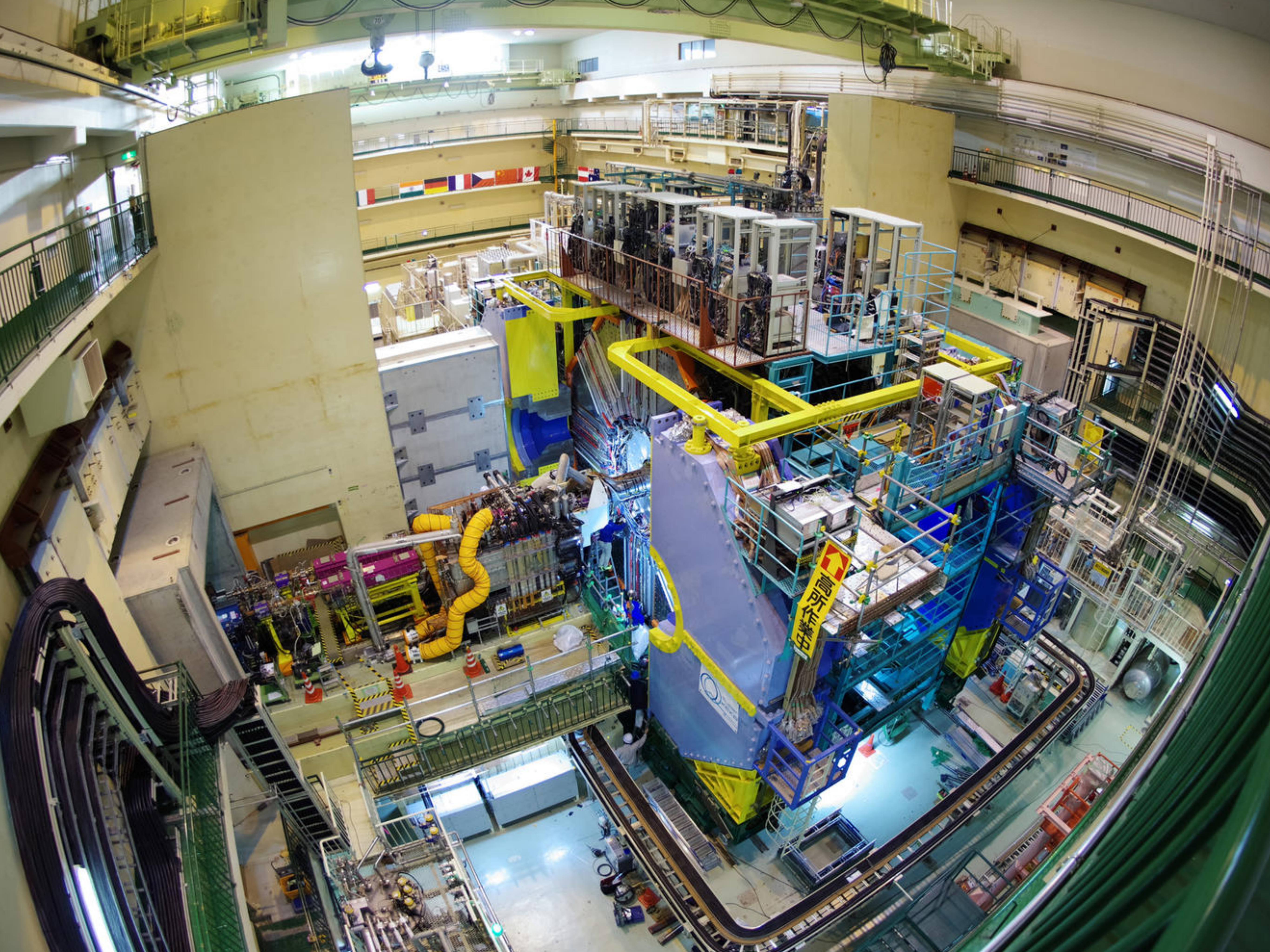




- super *B*-factory, located in Tsukuba, Japan
- asymmetric e^+e^- collider (e^- at 7 GeV, e^+ at 4 GeV, $\langle\beta\gamma\rangle \approx 0.284$)
- commissioning run from Feb to Jul 2018
- regular operations started in Mar 2019
- operated around 10.58 GeV ($= m_{\Upsilon(4S)}$)
- design luminosity 6×10^{35} cm^{-2} s^{-1}

→ 30 times higher luminosity

1.5x higher beam currents
20x smaller beam spot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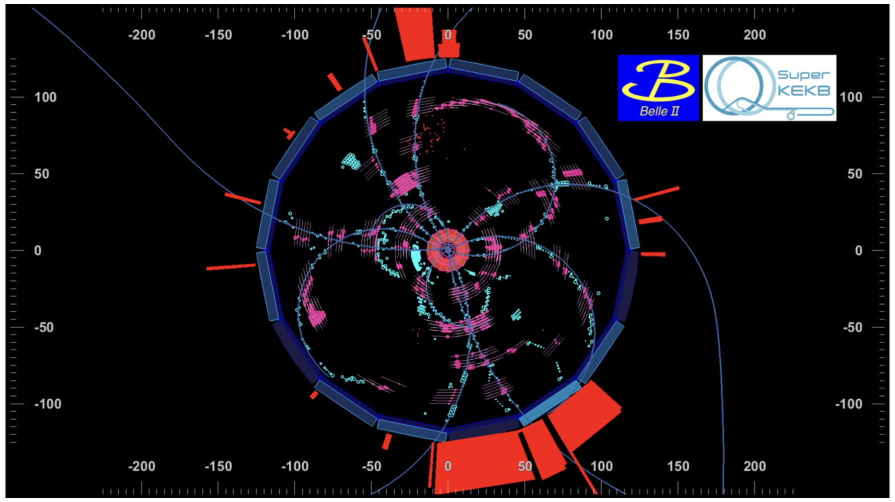
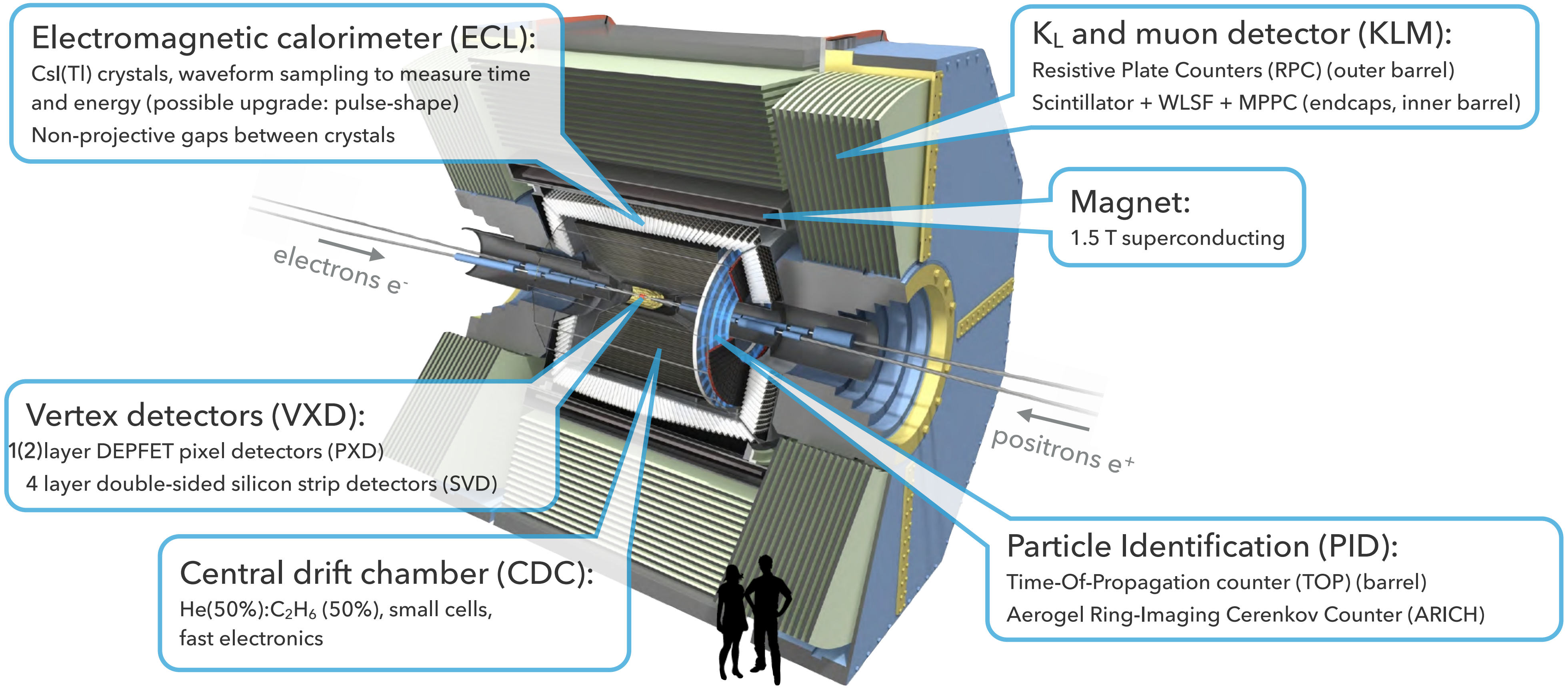
Belle II

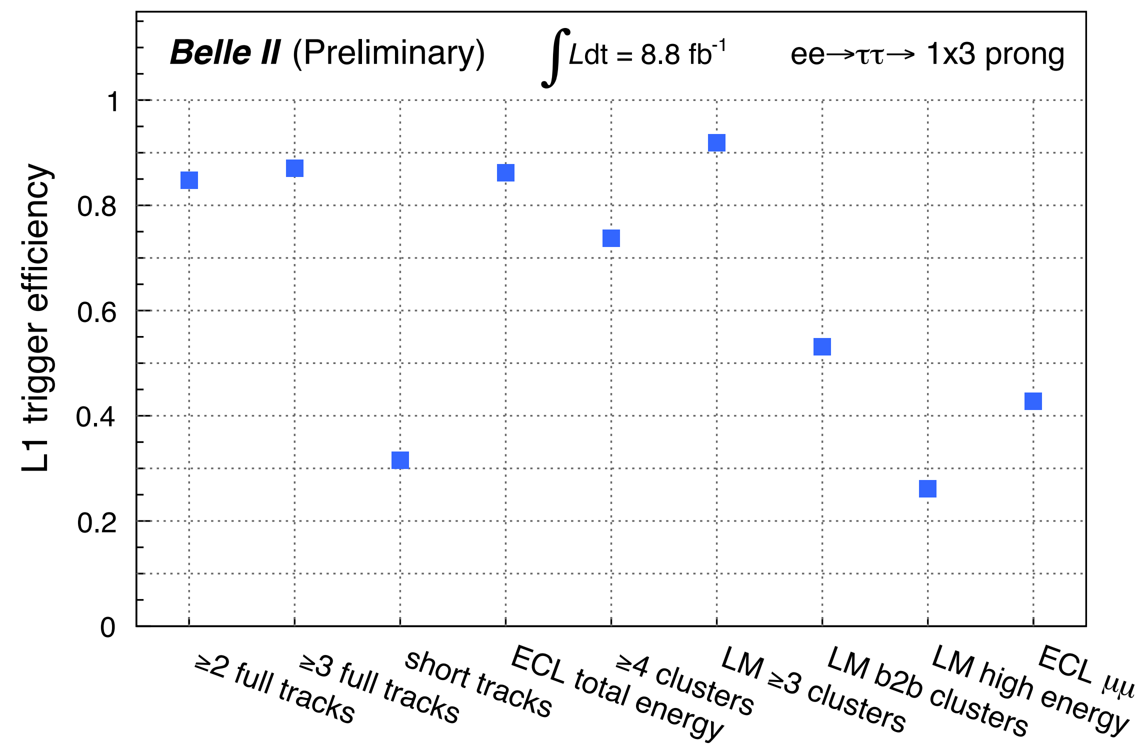
- 1102 members and 123 institutes
- 0.5 fb^{-1} collected during commissioning run in 2018
- 180 fb^{-1} collected up to now
- plan to collect 50 times more data than Belle
- rich physics program: *B* and *D* physics, quarkonium, τ, low mass dark sector,…

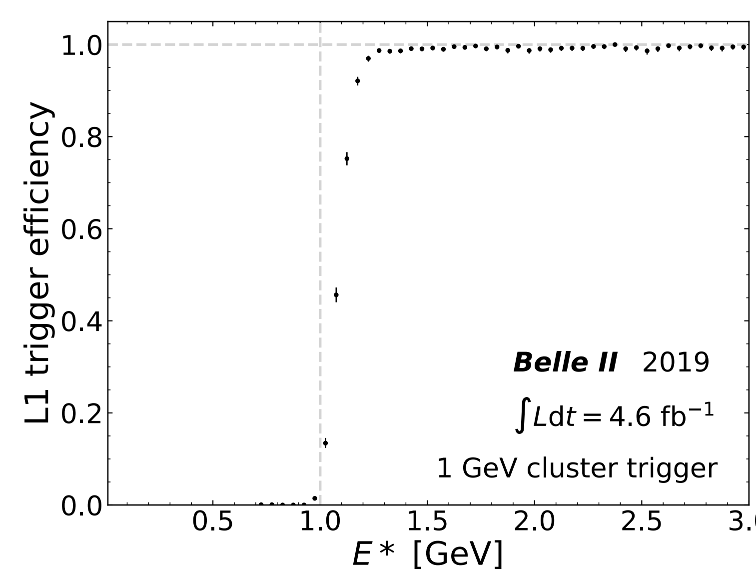




Belle II L1 Trigger

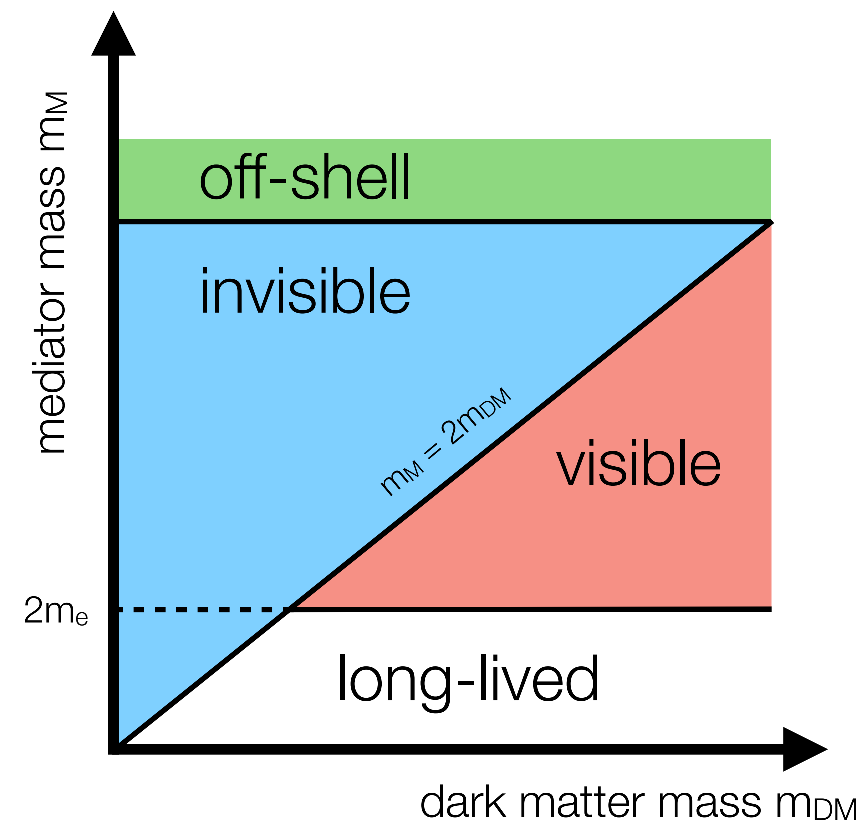
- Belle II trigger system consists of two levels
    - low level trigger implemented in hardware (L1)
    - software-based high level trigger (HLT)
- identify and select events over beam backgrounds (Touschek effect, beam-gas scattering)
- L1 trigger
    - maximum average trigger rate of 30kHz
    - 4 sub-detector triggers: CDC, ECL, TOP, KLM
    - trigger menu designed for different physics targets
- dedicated dark sector/low-multiplicity trigger lines
    - single photon trigger
    - single track trigger
    - 3D tracks are reconstructed with a neural network approach
    - combination of full/short/neuro tracks
    - ECL clusters with various energy levels and angular separation

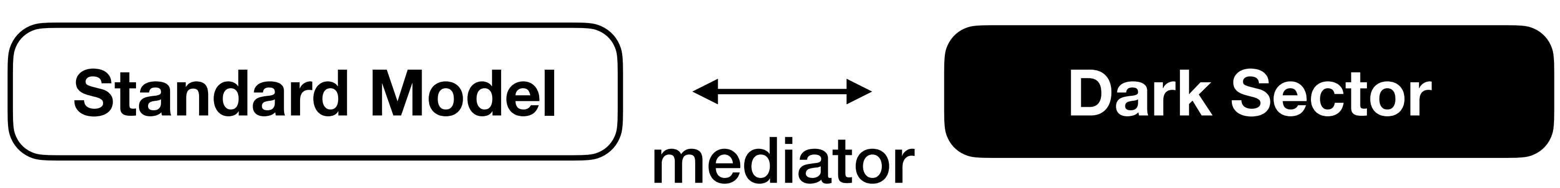




Dark Sector Searches

- probe light dark sectors with low-mass mediators O(GeV)
- possible portals between SM and DM include
  - vector portal (dark photon A', dark Z')
  - pseudo-scalar portal (axion-like particle)
  - scalar portal
  - neutrino portal
- searches at Belle II profit from
  - hermetic detector
  - clean collision environment
  - excellent PID
  - dedicated low-multiplicity triggers (single photon/track trigger)





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Search for an Invisibly Decaying Z' Boson at Belle II in $e^+e^- \to \mu^+\mu^-(e^\pm\mu^\mp)$ Plus Missing Energy Final States

I. Adachi *et al.* (Belle II Collaboration)
Phys. Rev. Lett. **124**, 141801 – Published

Physics See synopsis: Closing in on the Z'

Article | References | Citing Article

ABSTRACT

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violating Z' in $e^+e^- \to e^\pm\mu$
upper limits on the cross s
$L_\mu - L_\tau$ theory, into upper
$M_{Z'} \leq 6\ \mathrm{GeV}/c^2$.

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Search for Axionlike Particles Produced in e^+e^- Collisions at Belle II

F. Abudinén *et al.* (Belle II Collaboration)
Phys. Rev. Lett. **125**, 161806 – Published 14 October 2020

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More

Article | References | No Citing Articles | Supplemental Material | PDF | HTML | Export Citation

ABSTRACT

We present a search for the direct production of a light pseudoscalar a decaying into two photons with the Belle II detector at the SuperKEKB collider. We search for the process $e^+e^- \to \gamma a$, $a \to \gamma\gamma$ in the mass range $0.2 < m_a < 9.7\ \mathrm{GeV}/c^2$ using data corresponding to an integrated luminosity of $(445 \pm 3)\,\mathrm{pb}^{-1}$. Light pseudoscalars interacting predominantly with standard model gauge bosons (so-called axionlike particles or ALPs) are frequently postulated in extensions of the standard model. We find no evidence for ALPs and set 95% confidence level upper limits on the coupling strength $g_{a\gamma\gamma}$ of ALPs to photons at the level of $10^{-3}\,\mathrm{GeV}^{-1}$. The limits are the most restrictive to date for $0.2 < m_a < 1\ \mathrm{GeV}/c^2$.

Issue
Vol. 125, Iss. 16 — 16 October 2020

Check for updates

→ first physics papers!

Invisible Z′

Invisible Z′

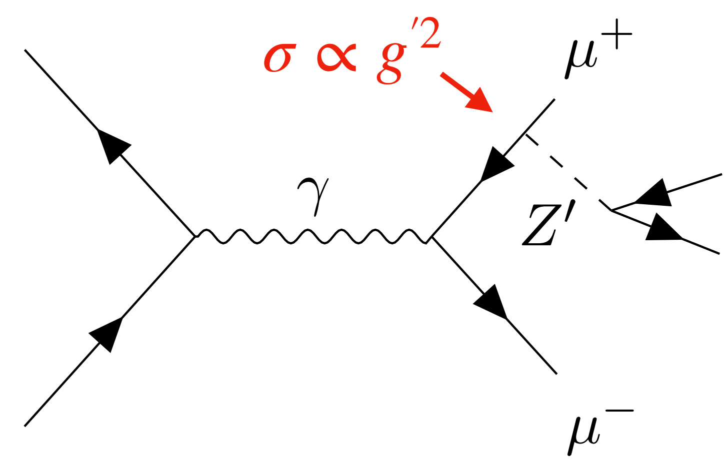
- extend SM by adding a *U(1)′* group
- new massive gauge boson *Z′* couples only to leptons of 2nd and 3rd generation
- *Z′* coupled to L_μ-L_τ via *g′*
- focus on invisible *Z′* decay produced with a pair of muons
- invisible decay channel explored for the first time

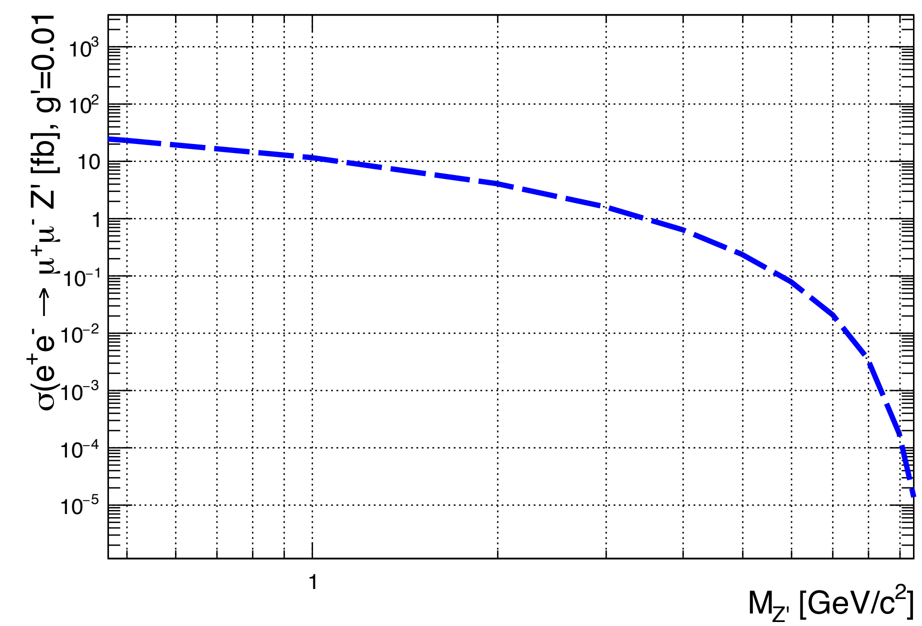
JHEP 1612 (2016) 106
PRD 89, 113004 (2014)

$$
\begin{aligned}
M_{Z'} < 2M_\mu &\implies BF[Z' \to \text{invisible}] = 1,\\
2M_\mu < M_{Z'} < 2M_\tau &\implies BF[Z' \to \text{invisible}] \simeq 1/2,\\
M_{Z'} > 2M_\tau &\implies BF[Z' \to \text{invisible}] \simeq 1/3.
\end{aligned}
$$

$$\text{if } M_{Z'} > 2M_\chi$$
$$BF(Z' \to \chi\bar{\chi}) = 1$$

$$\mathcal{L} = \sum_\ell \theta g' \bar{\ell}\gamma^\mu Z'_\mu \ell$$

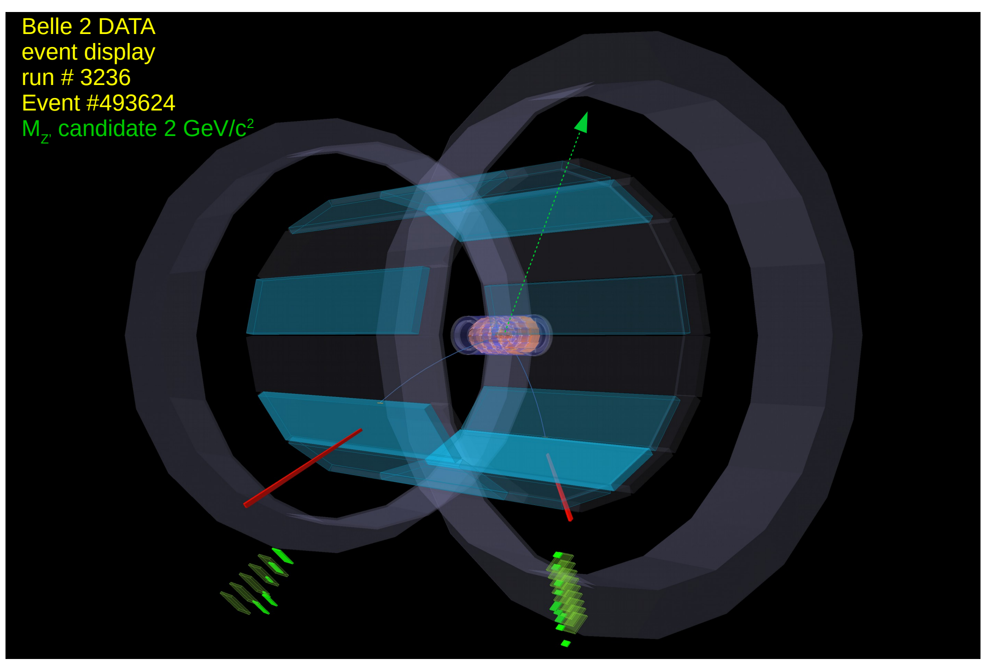


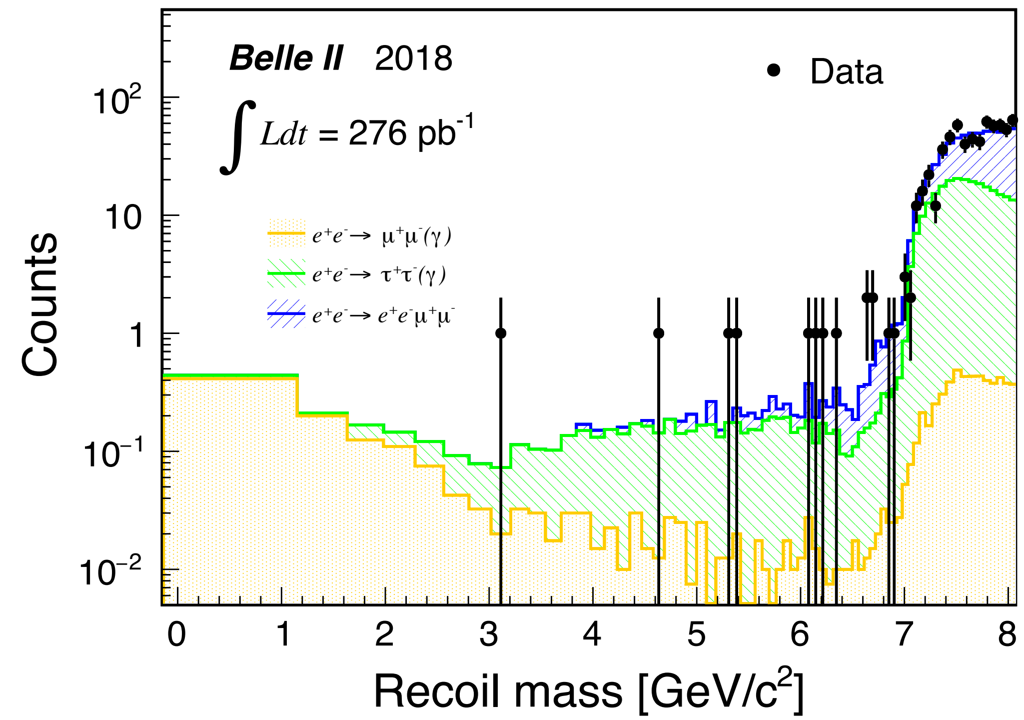


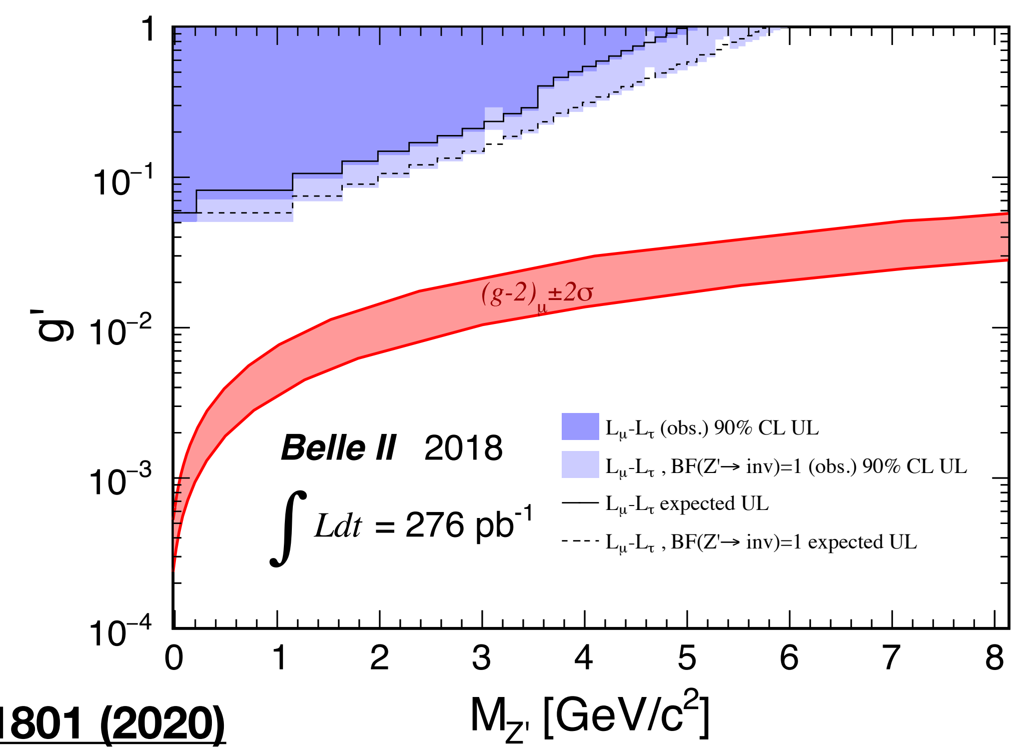
★ **may serve as mediator between SM and DS**
★ **may explain *(g-2)*$_\mu$**
★ **may address anomalies in *b→sμ⁺μ⁻***

Invisible Z′

- reconstruct recoiling mass against $\mu\mu$-pair, require nothing else to be in rest of event
- look for a peak in recoil mass distribution
- main bkgs arise from QED processes:
  - $\mu^+\mu^-(\gamma)$
  - $\tau^+\tau^-(\gamma)$, $\tau \to \mu\nu\nu$
  - $\mu^+\mu^-e^+e^-$



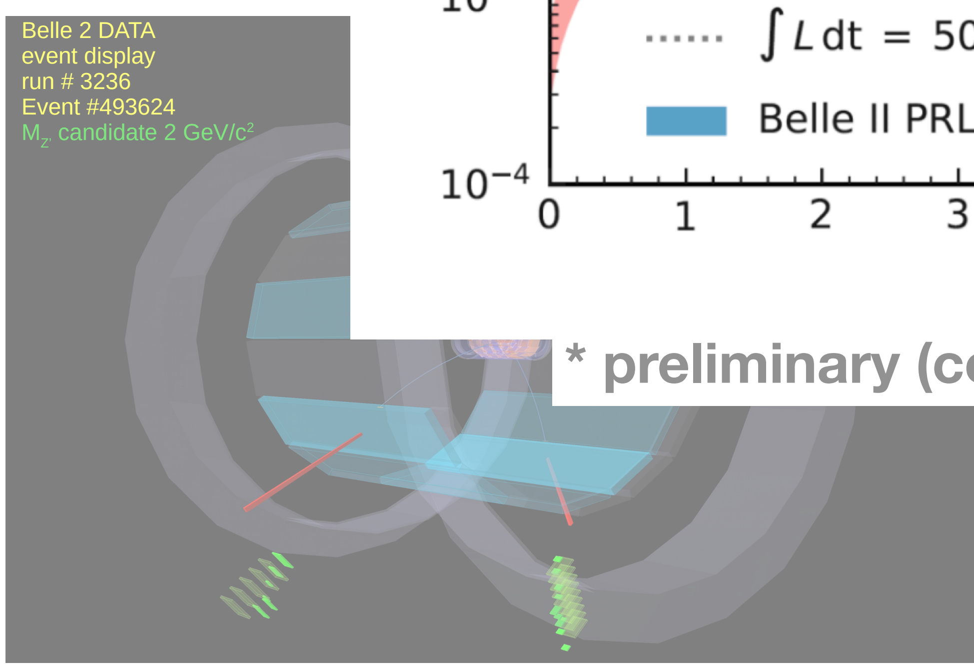


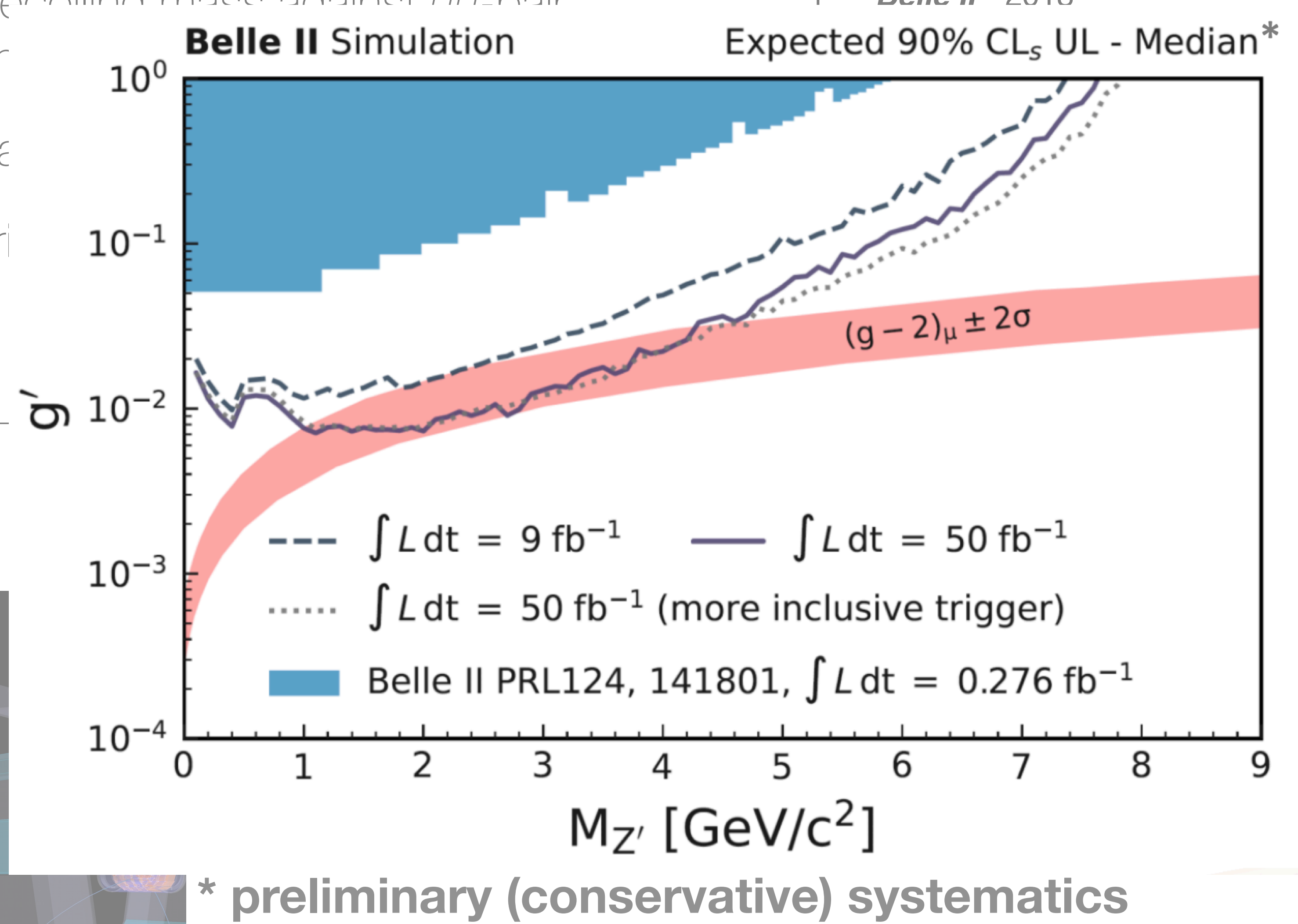


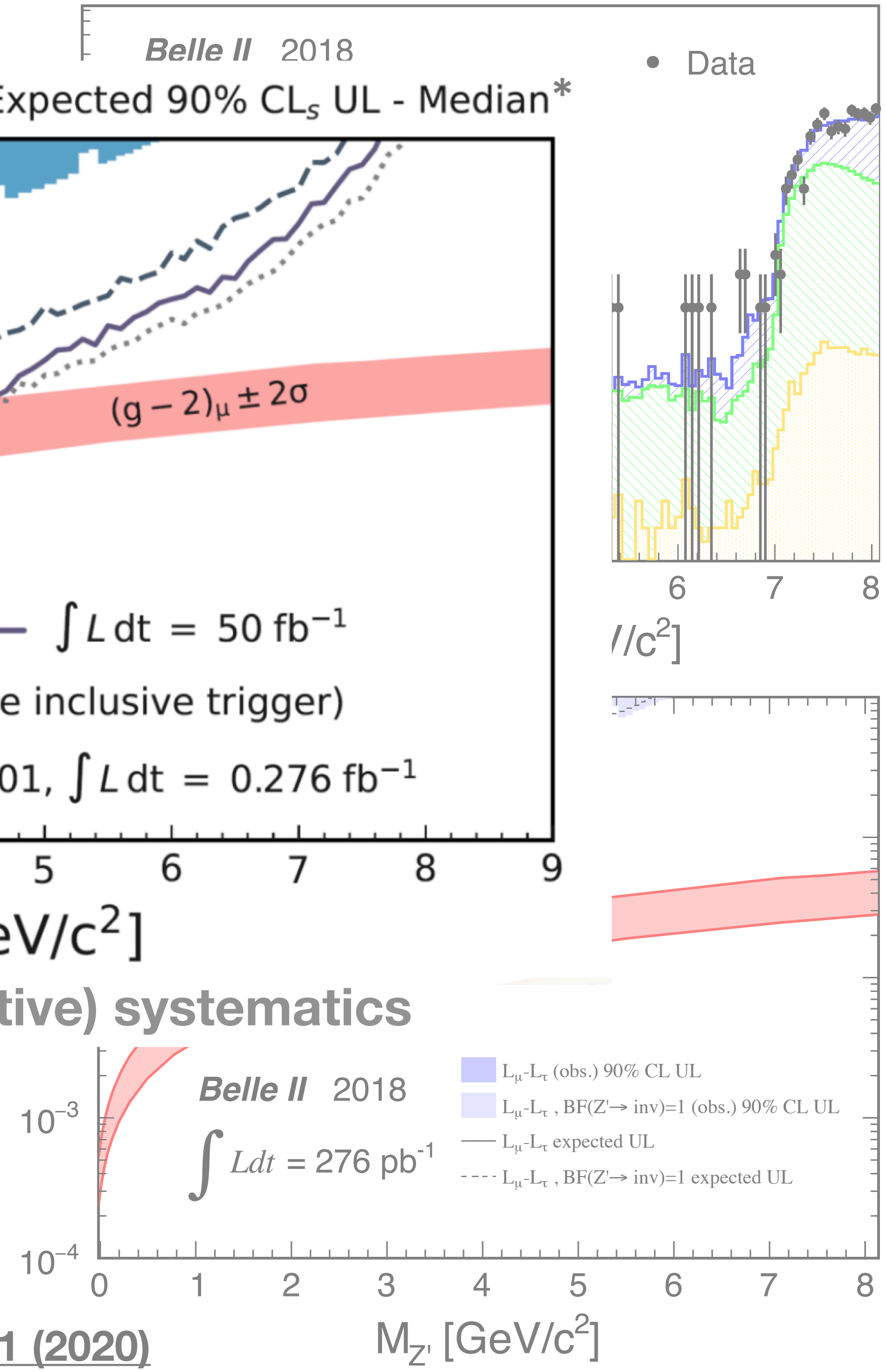
PRL 124, 141801 (2020)

Invisible Z′

- reconstruct recoiling mass against $\mu\mu$-pair
  require nothir
- look for a pea
- main bkgs ar
  - $\mu^+\mu^-(\gamma)$
  - $\tau^+\tau^-(\gamma)$, τ-
  - $\mu^+\mu^-e^+e^-$

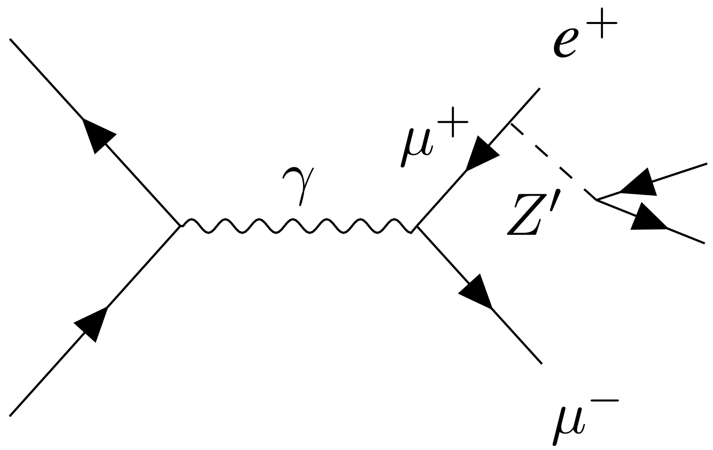




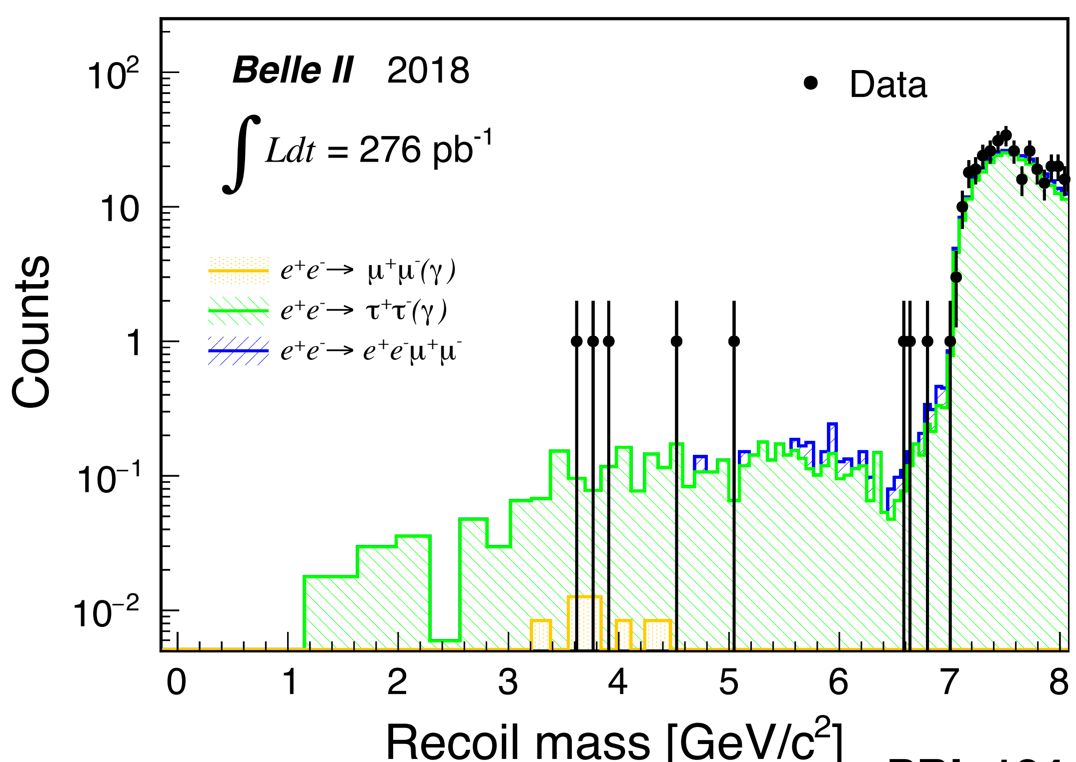


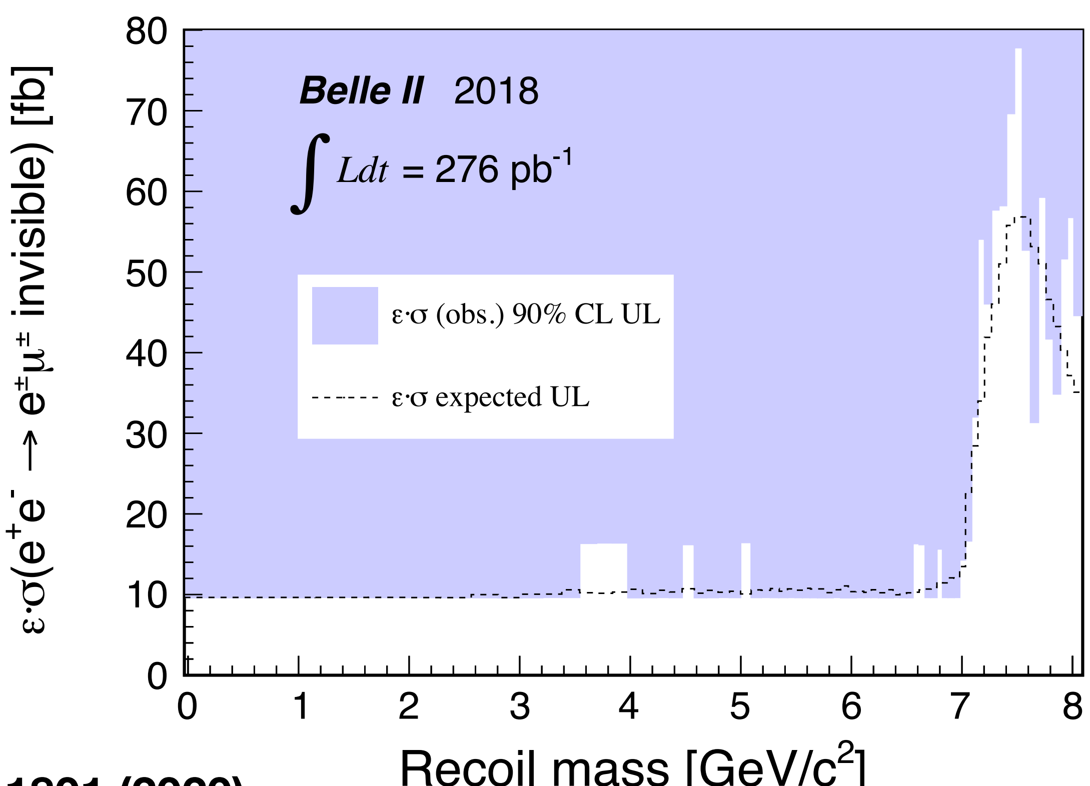
PRL 124, 141801 (2020)

Invisible Z' - LFV



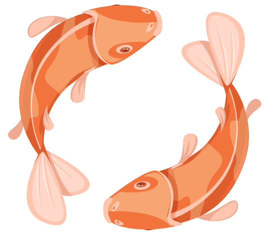
- look for LFV *Z'* that couples to *eμ*
- model-independent search with same selection criteria
- included in same publication





PRL 124, 141801 (2020)

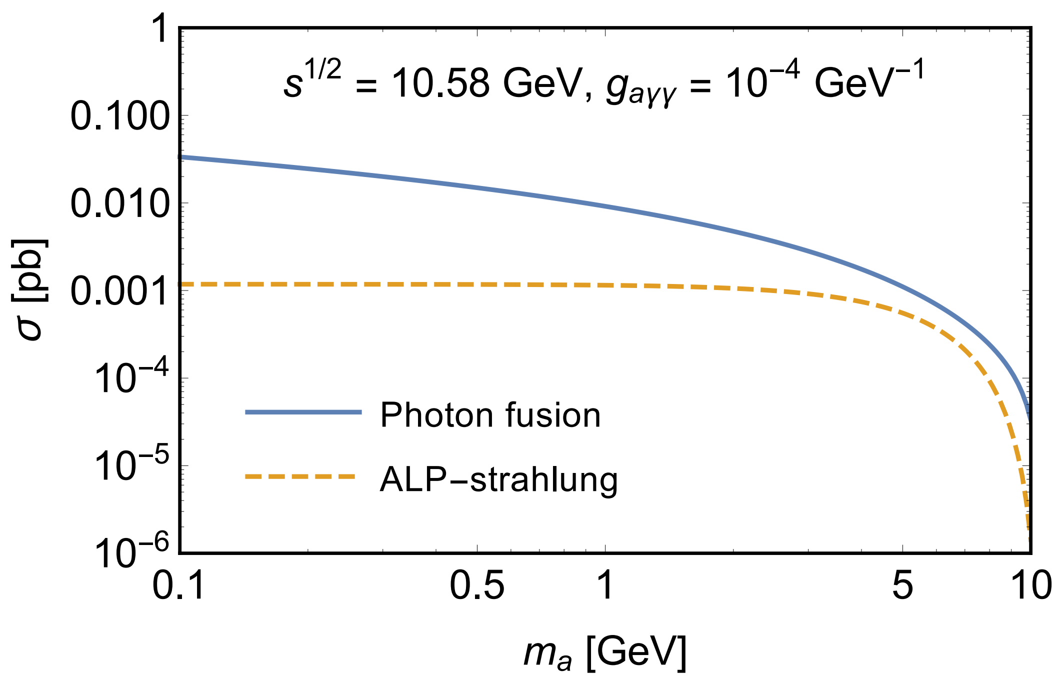
ALPs

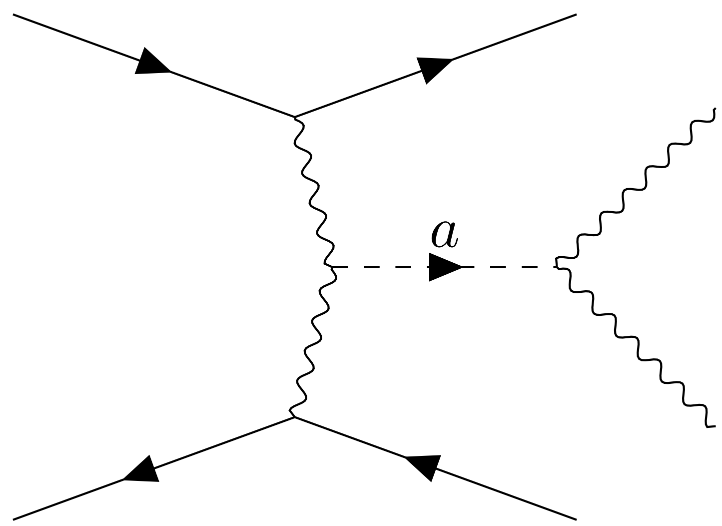


ALPs

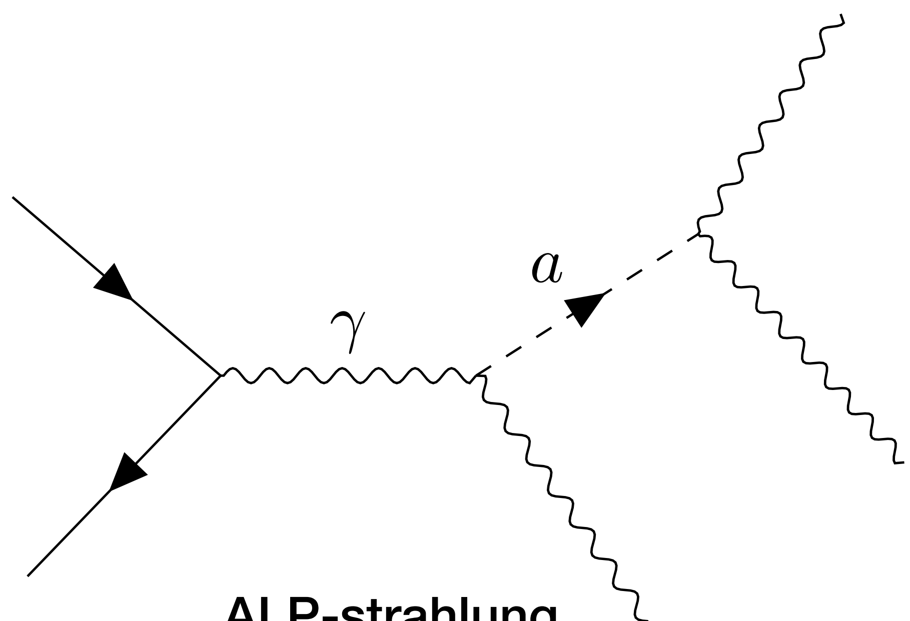
- axion-like particles are pseudoscalar particles that couple to bosons and appear in different extensions to the SM
- coupling and mass of ALPs are taken to be independent
- simplest approach at Belle II is via two photon coupling
    - photon-fusion, high QED background
    - ALP-strahlung, most promising channel

JHEP 1712 (2017) 094





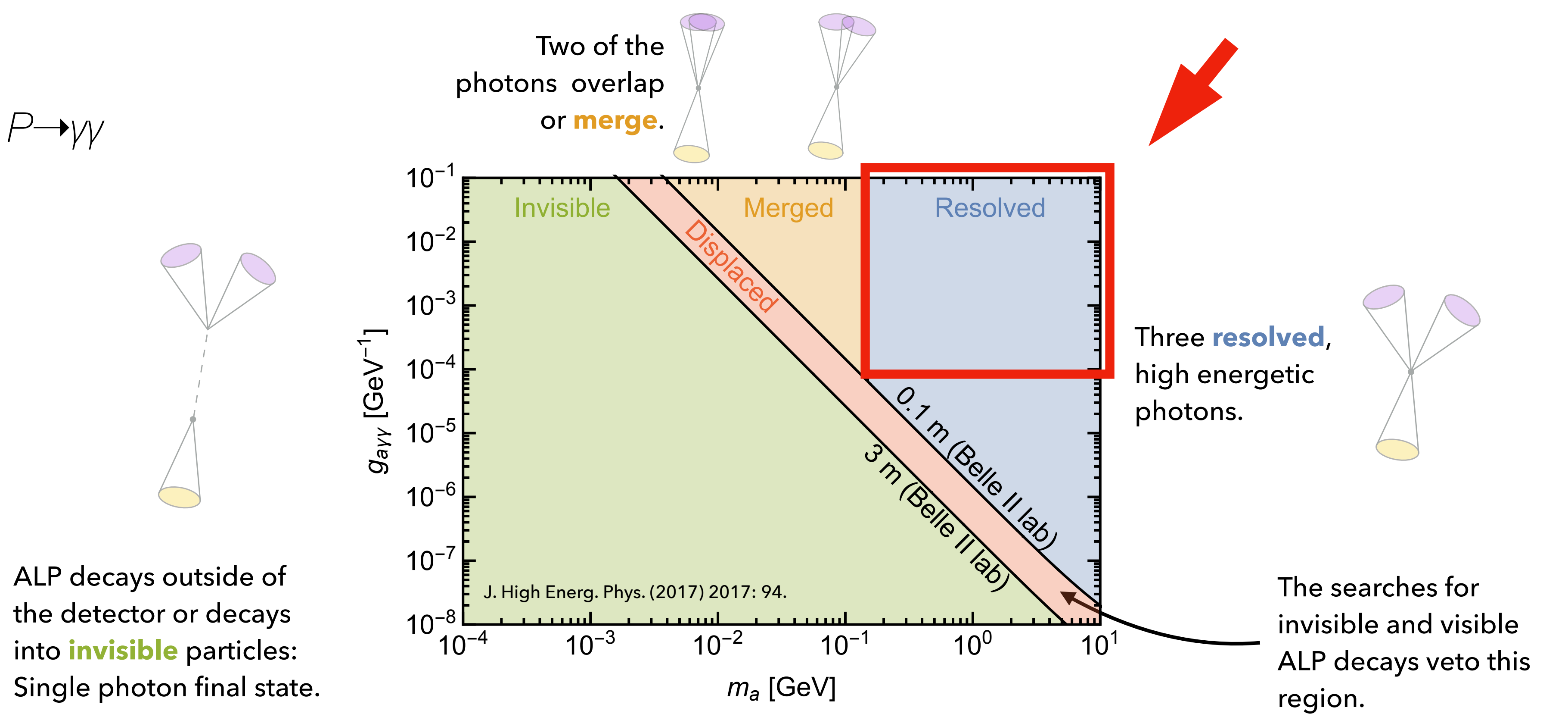
Photon fusion



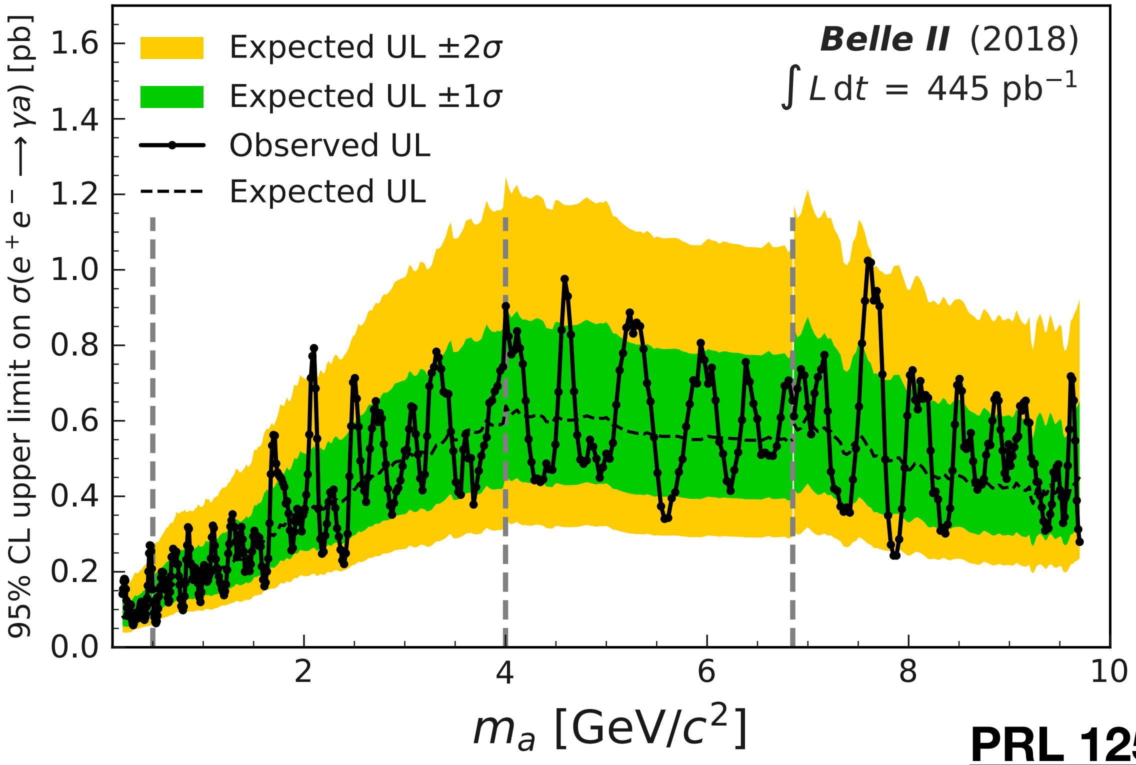
ALP-strahlung

ALPs

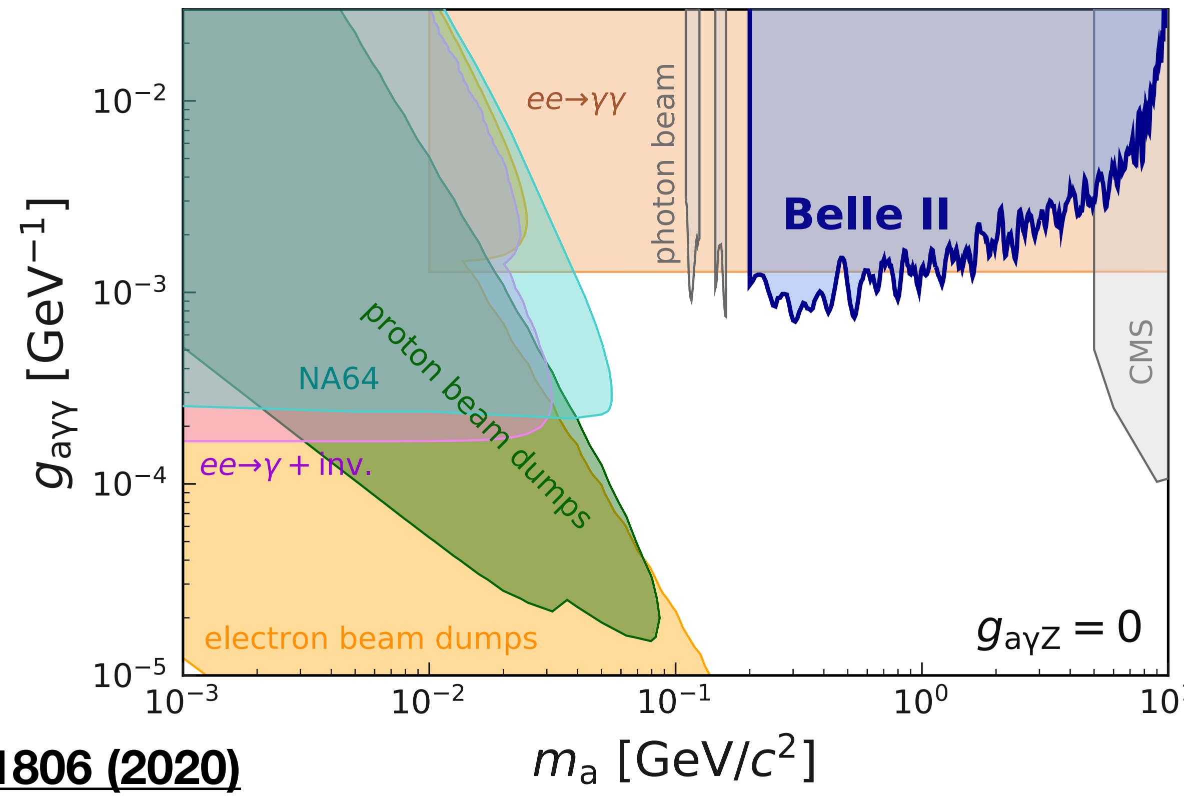
- different topologies according to ALP mass and coupling
- search for 3 photons with energies summing up to beam energy and no tracks in event
- look for peak in di-photon and recoil mass
- bkgs:
    - $\gamma\gamma(\gamma)$
    - $e^+e^-(\gamma)$
    - $P\gamma$, $P=\pi^0/\eta/\eta'$, $P\to\gamma\gamma$



ALPs

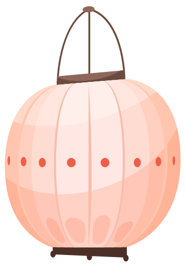


PRL 125, 161806 (2020)

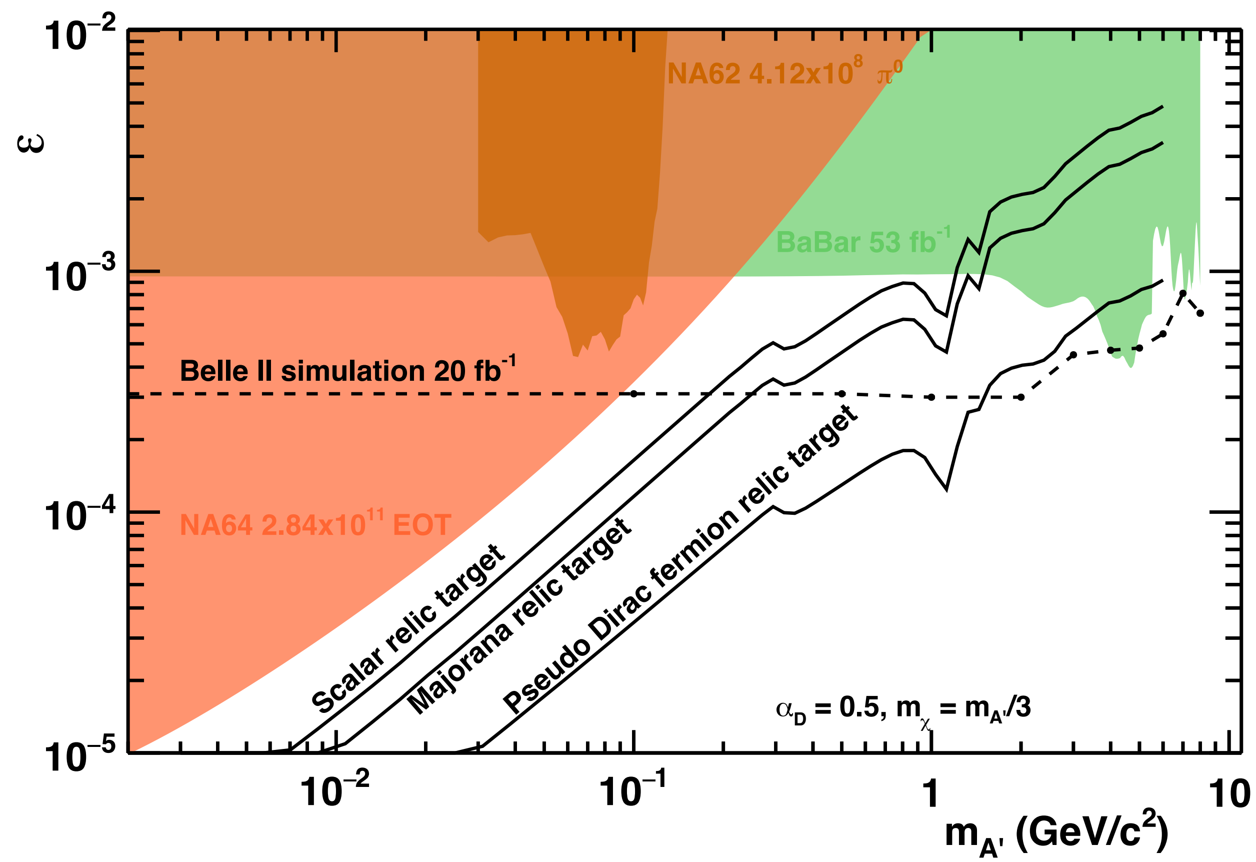


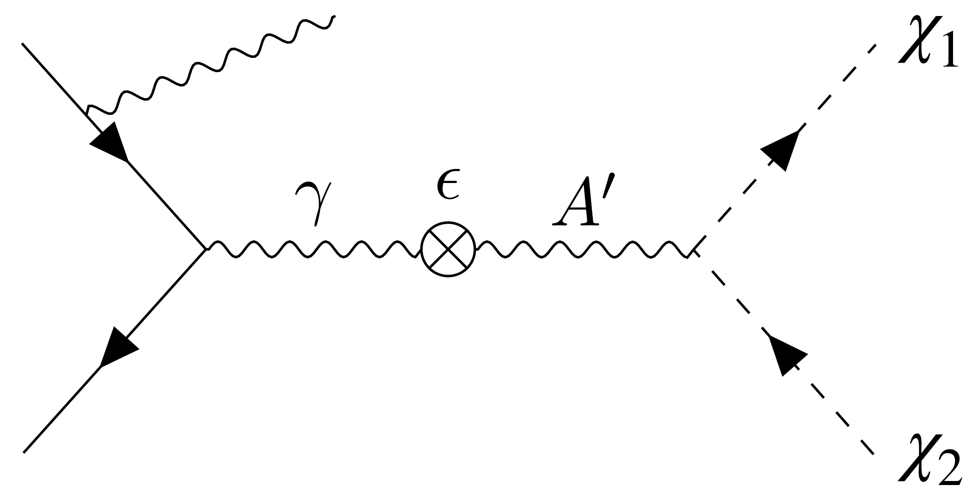
- performed search in mass range from 0.2 to 9.7 GeV/c²
- no excess was found
- upper limits on cross section translated to coupling constant
- to be repeated with more data

Dark Photon

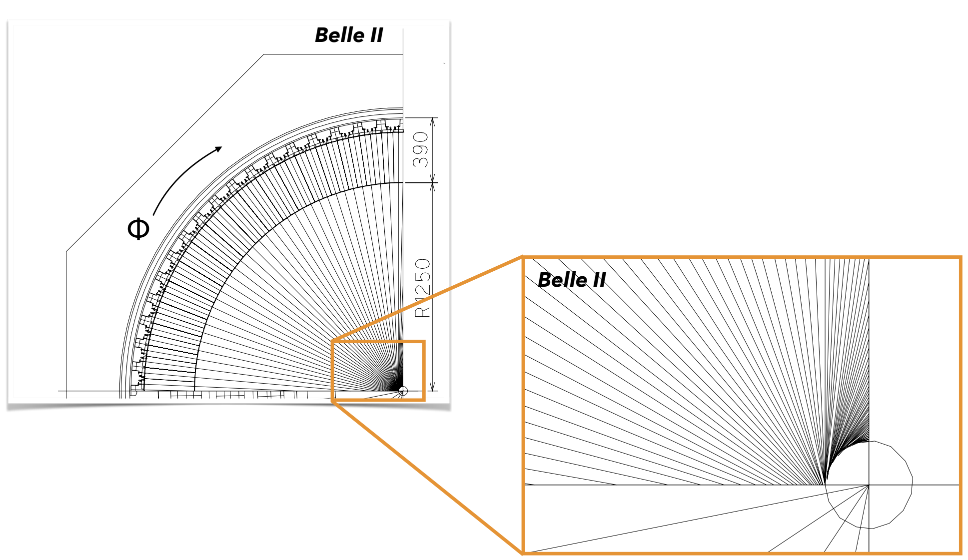


Dark Photon



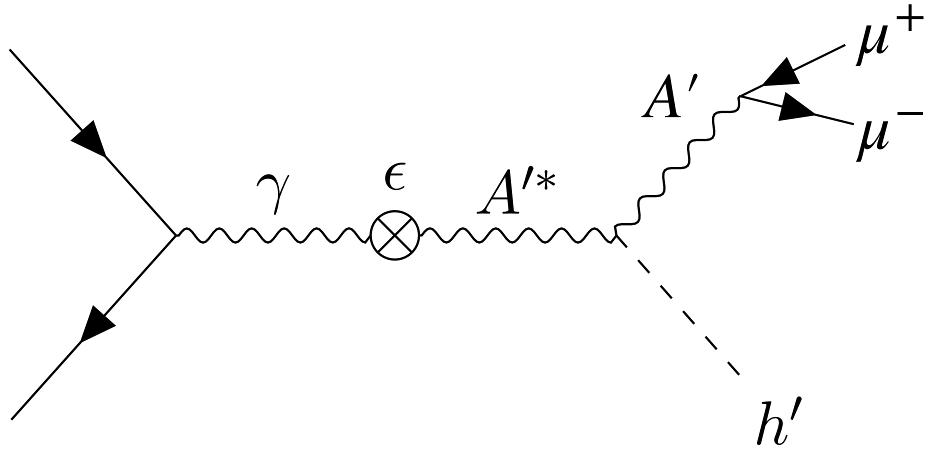


- explore invisible decay first, $A' \rightarrow \chi_1 \chi_2$
- require one ISR photon and nothing else in the event
- needs a single photon trigger (not available in Belle, 10% of data in BaBar)
- bkgs include γγ(γ), e+e-γ(γ) and cosmics
- advantages over BaBar
  - no projective cracks in ECL
  - more hermetic calorimeter
  - KLM veto

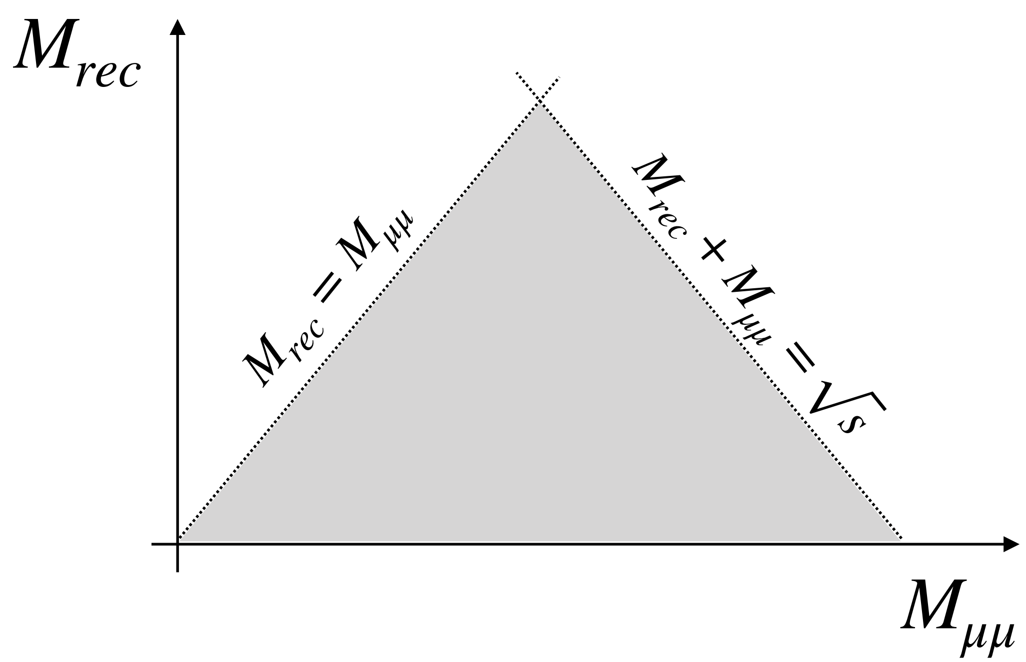


What about a Dark Higgs?

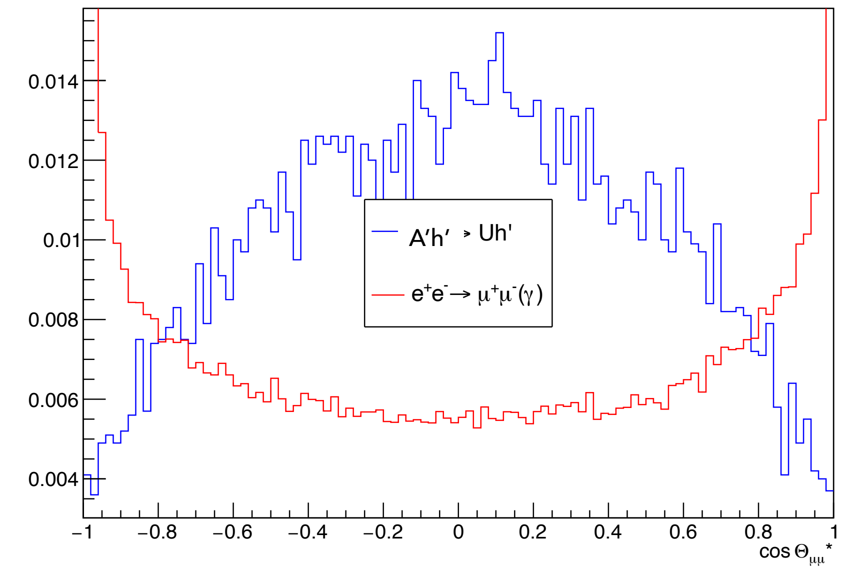
- introduce in analogy to SM a spontaneous symmetry breaking mechanism of *U(1)* with new particle, dark Higgs *h'*
- $e^+e^- \rightarrow A'h'$ (Higgsstrahlung)
    - focus on $m_{h'} < m_{A'}$,
    - *h'* has large lifetime to escape detection, *A'* decays into SM particles
    - 2 charged particle final state plus missing energy
    - find a peak in two dimensional distribution of recoiling mass vs dimuon mass
    - previously only investigated by KLOE



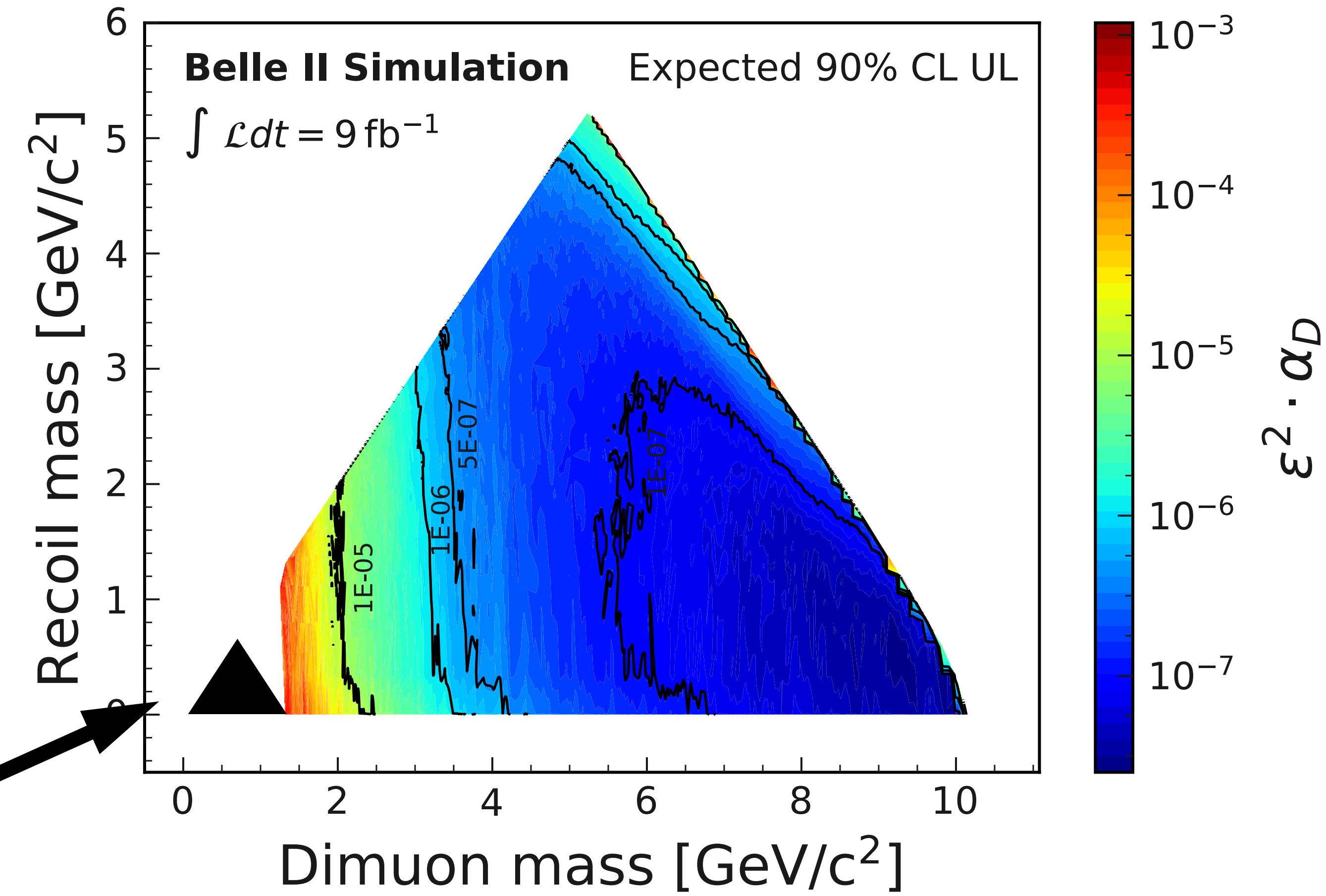
$\sigma \propto \epsilon^2 \times \alpha_D$



What about a Dark Higgs?



- main SM background contributions arise from
  - $\mu^+\mu^-(\gamma)$
  - $\tau^+\tau^-(\gamma)$
  - $e^+e^-\mu^+\mu^-$
- background suppression based on kinematic features
- improvements w.r.t KLOE result
  - probing unconstrained regions in 2D mass plane
  - probing non trivial regions of $\varepsilon^2\alpha_D$
- ongoing analysis, recently started unblinding
- expect results soon

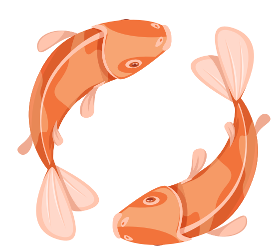


KLOE result

[Phys.Lett.B 747 (2015) 365-372]

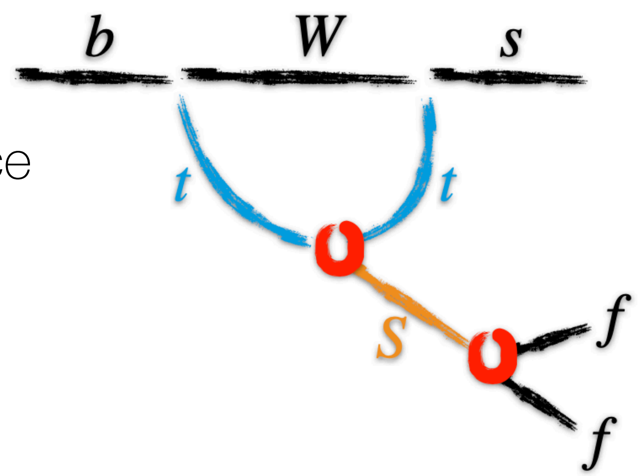
Conclusion

- broad and active program of DS physics at Belle II
- available phase-space is probed with many different models
- further analysis include Inelastic Dark Matter, Z' to visible, DM searches in B decays…
- first results published
- much more to come

Backup

Additional searches



- Search for inelastic Dark Matter
    - long-lived particle detector signature and unconstrained parameter space
    - displaced pair of electrons, muons or hadrons
- Search for long-lived scalar in rare *B* meson decays
    - $B \to KS$, $S \to \mu\mu, \pi\pi, KK$
    - generic scalar that mixes with the Higgs sector
    - small mixing leads to large lifetime and small production cross section