Dark sector searches at *Belle II*: recent results and future prospects

Light Dark World International Forum 2021 - December 13th – 15th
Online Conference

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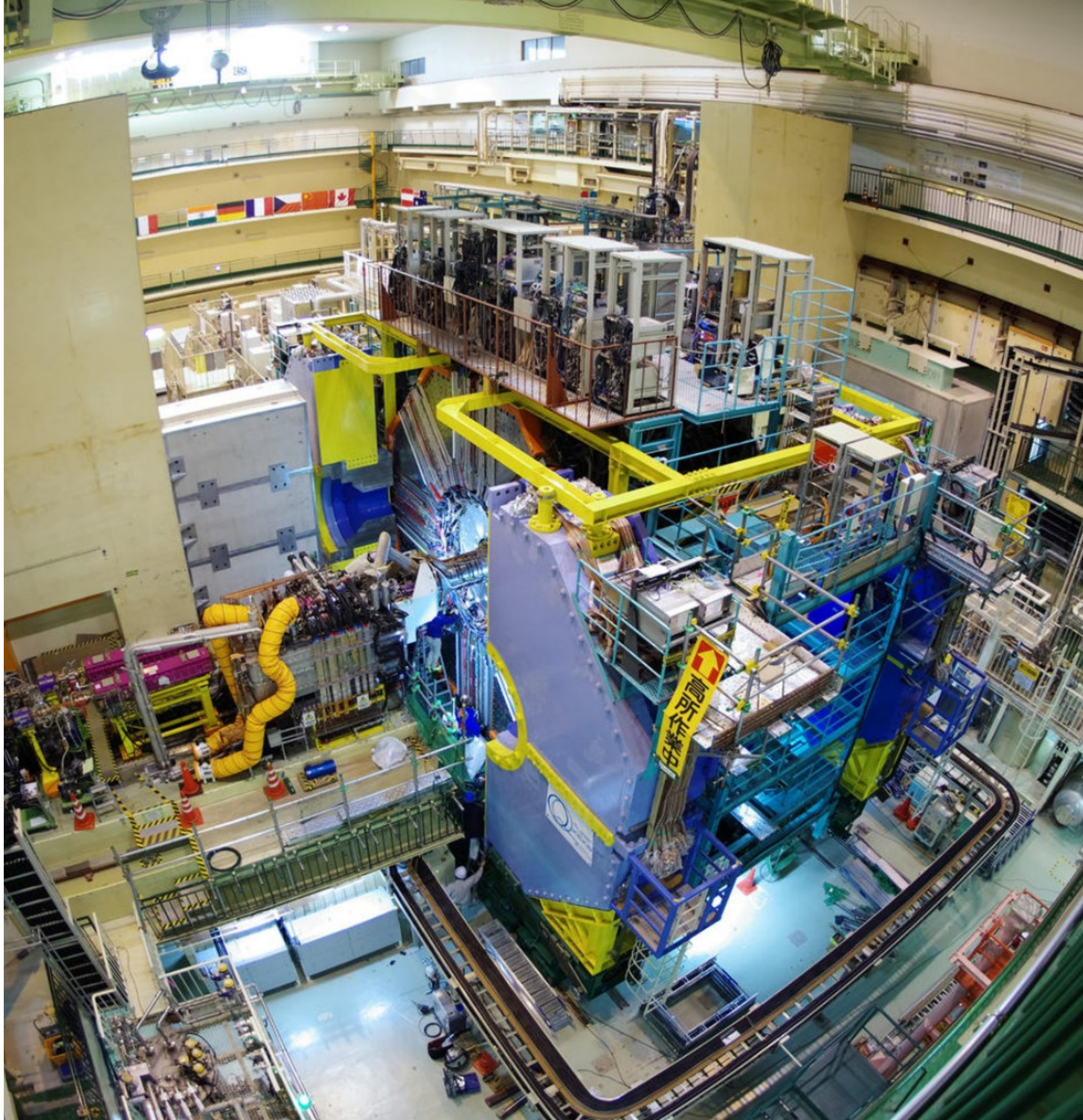
on behalf of the *Belle II* collaboration

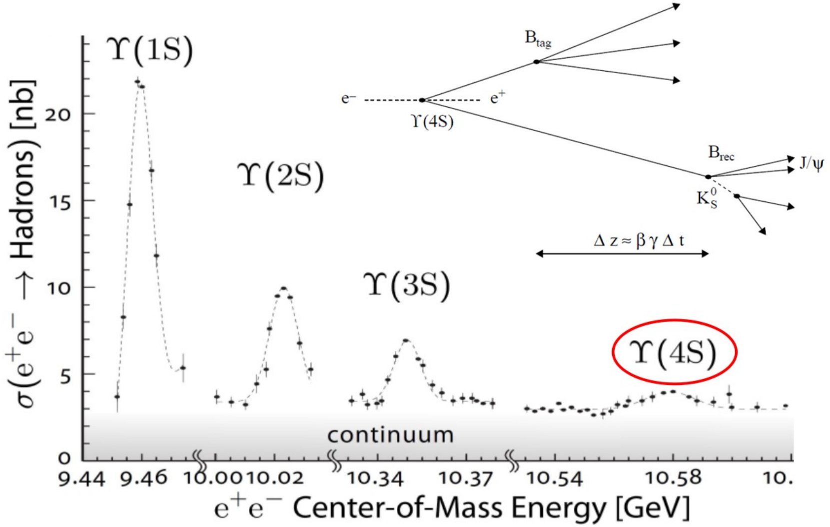
Outline

- **Introduction to SuperKEKB and the *Belle II* experiment**
- **Overview on dark sector analysis @ *Belle II***
- **Conclusions**

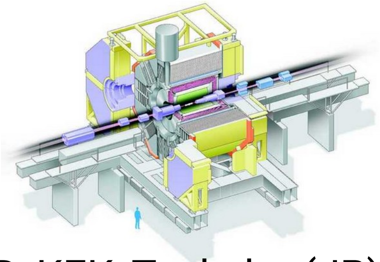


B-factories

- Asymmetric e^+e^- colliders optimized for the production of *B* meson pairs, but also *D* mesons, τ leptons, ...
- Collisions occur at Υ(nS) resonances
  - ➔ Mainly at Υ(4S): √s = 10.58 GeV
    just above the production threshold of $B\bar{B}$
    $BR(\Upsilon(4S) \to B\bar{B}) > 96\%$
- Beam asymmetric energies: boosted $B\bar{B}$ pairs, for CP-violation time-dependent measurements
- High peak luminosity $L > 10^{34}$ cm^{-2}s^{-1}

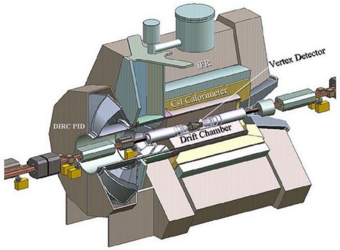


First generation of *B*-factories



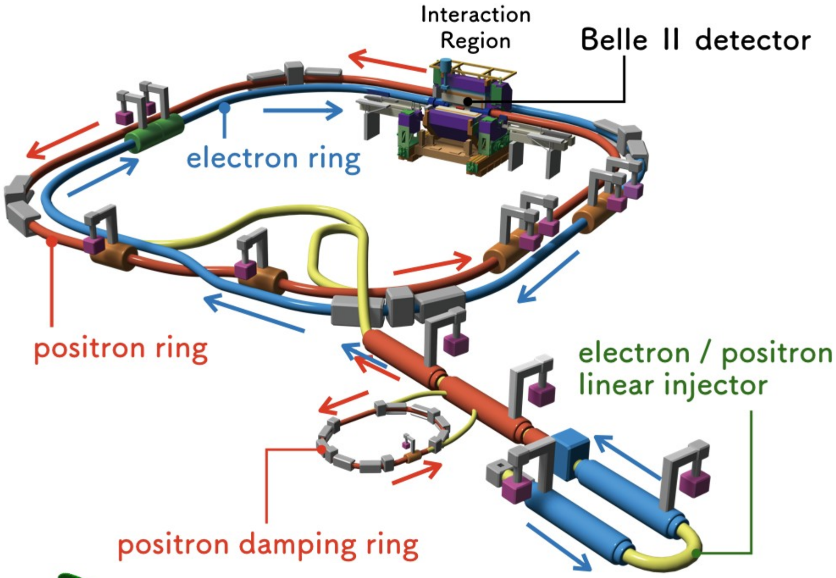
Belle@KEKB, KEK, Tsukuba (JP)
1999–2010, $\int L\,dt$ = 1 ab^{-1}

Tot: 1.5 ab^{-1}

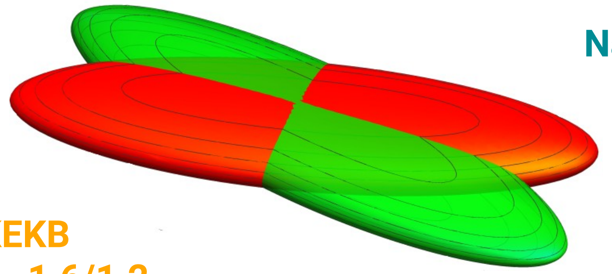


BaBar@PEP-II, SLAC (USA)
1999–2008, $\int L\,dt$ = 0.5 ab^{-1}

The SuperKEKB collider



- SuperKEKB: new generation of *B*-factory that provides luminosity to the *Belle II* experiment
  - ➔ Asymmetric beam energies: e^- (7 GeV)/e^+ (4 GeV) Operating mainly at Υ(4S), but foreseen runs from Υ(2S) to Υ(6S)
  - ➔ Highest world peak luminosity with the nano-beam scheme

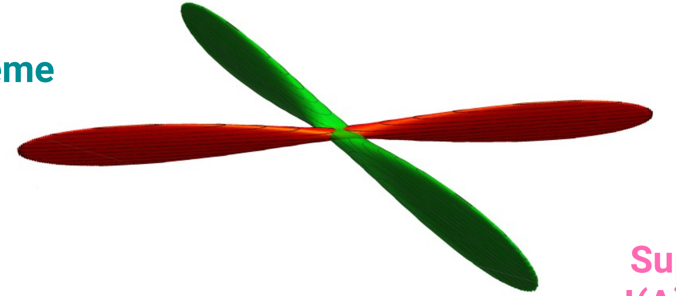


KEKB
- I(A) ~ 1.6/1.2
- β_y*(mm) ~ 5.9/5,9

Nano-beam scheme

β_y* ~ 1/20x
I ~ 1.5x

30x peak luminosity:
$6.5 \cdot 10^{35}$ cm^{-2}s^{-1}



SuperKEKB
- I(A) ~ 2.8/2.0
- β_y*(mm) ~ 0.27/0.3

SuperKEKB: a new intensity frontier machine

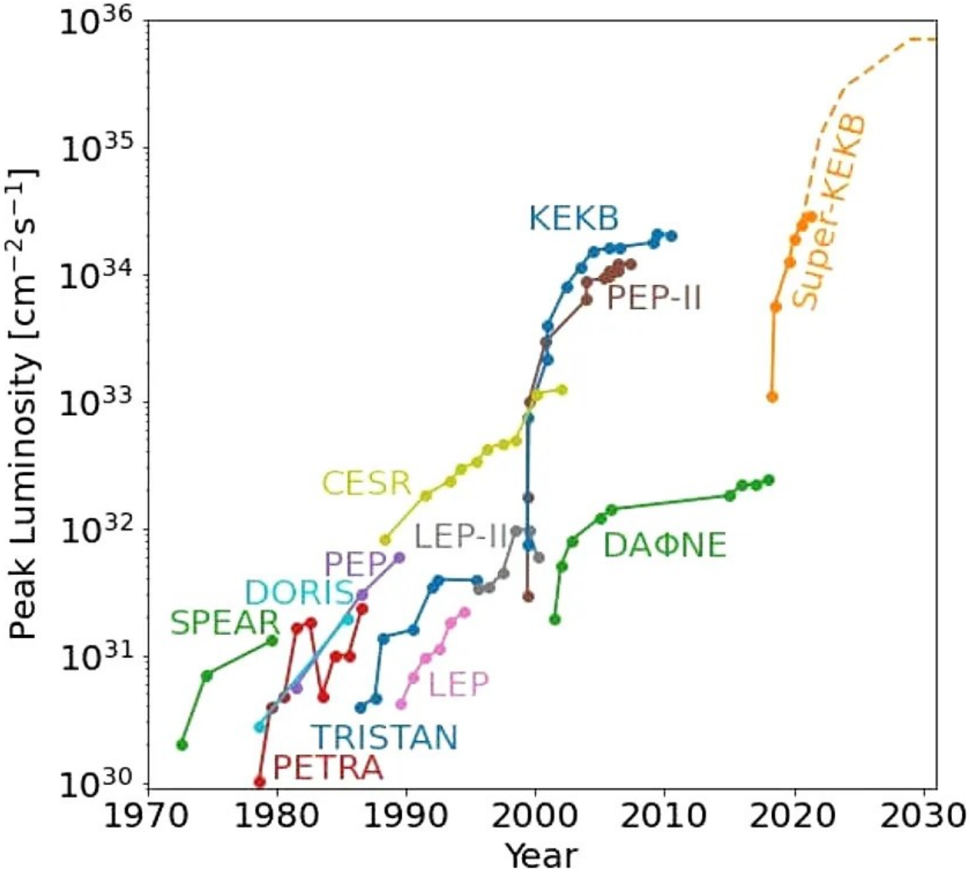
- Set a new luminosity world record on June 22nd, 2021:
  3.12×10^{34} cm^{-2}s^{-1}

- SuperKEKB peak performance:

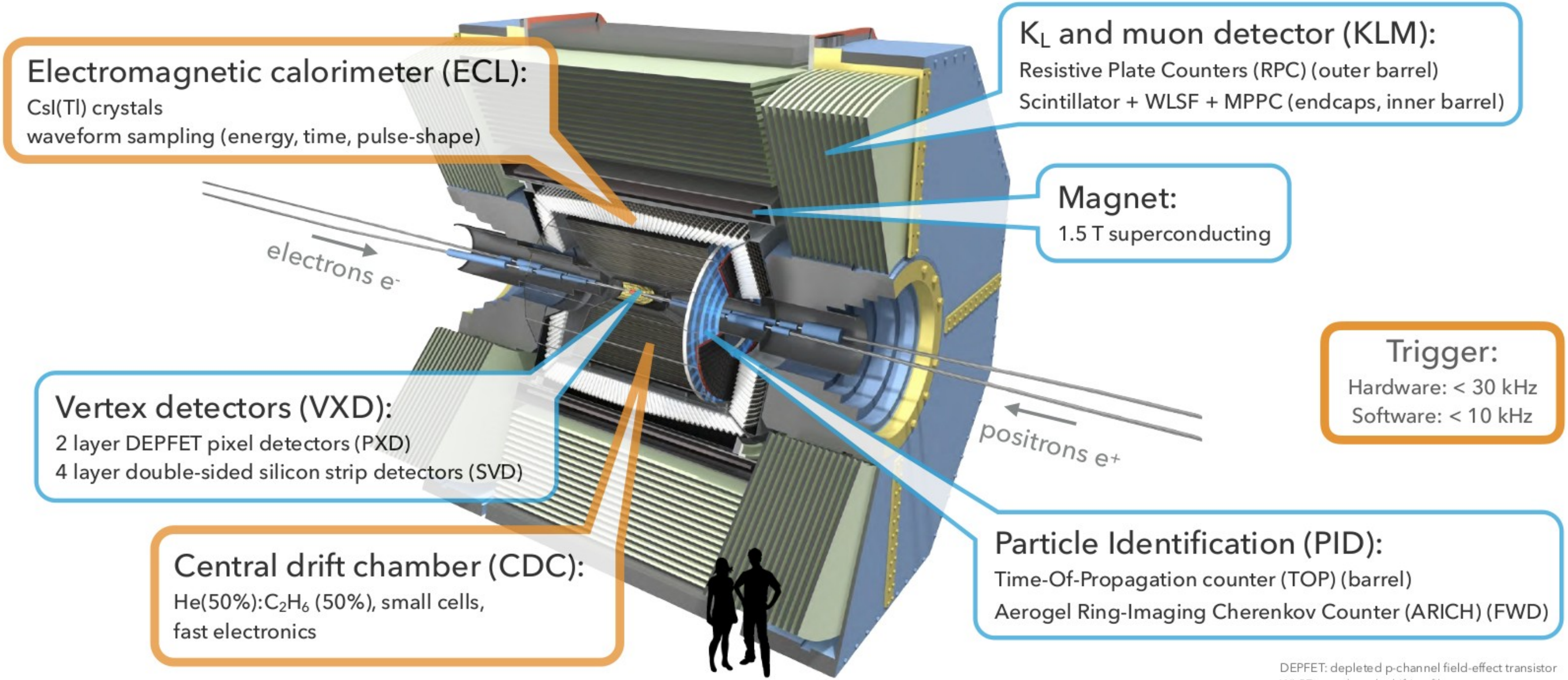
  ➔ $I(e^-/e^+)$ = 830/690 mA (target: ~ 2.9/2.0 A)

  ➔ β_y^* = 1 mm (target: ~ 0.3 mm)

- Target peak luminosity: **$6.5 \cdot 10^{35}$ cm^{-2}s^{-1}**



Belle II detector @ SuperKEKB



DEPFET: depleted p-channel field-effect transistor
WLSF: wavelength-shifting fiber
MPPC: multi-pixel photon counter

- Major upgrade of Belle@KEKB
- Covers more than 90% of the total solid angle

Belle II operations

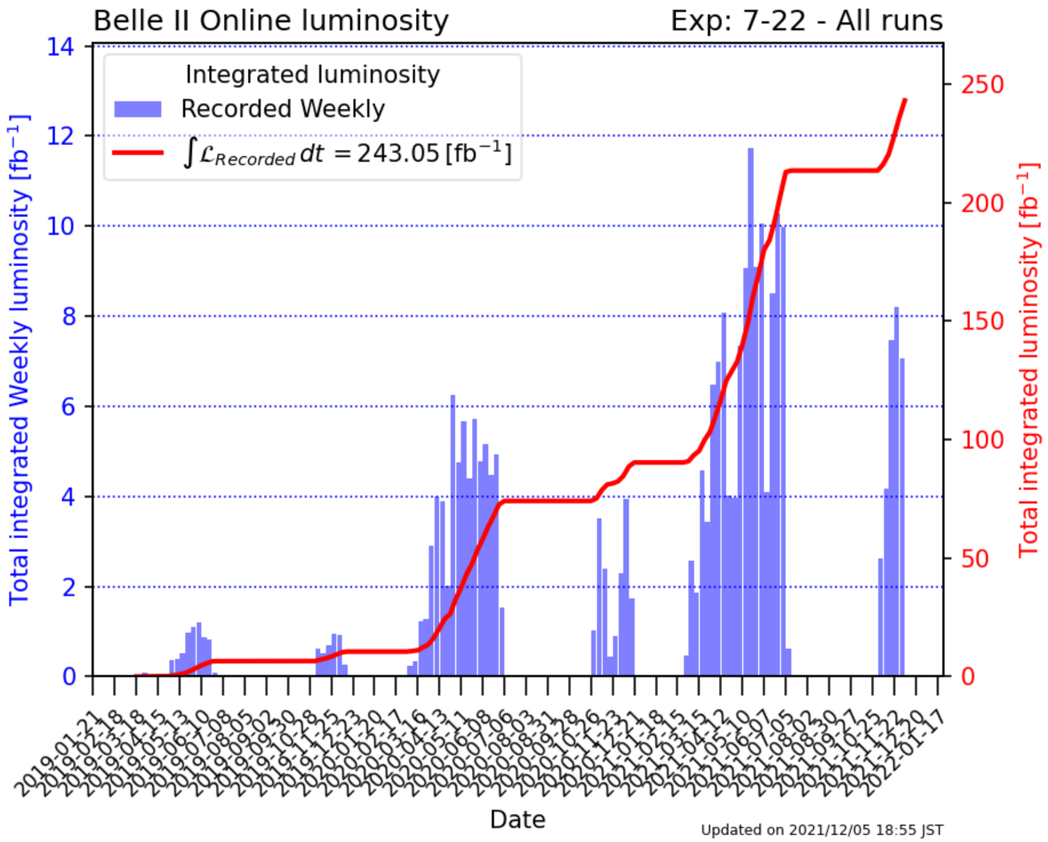
- First collisions during commissioning run on April 26th 2018

  ➔ 0.5 fb^{-1} collected in 2018

- First collisions with full detector on March 2019

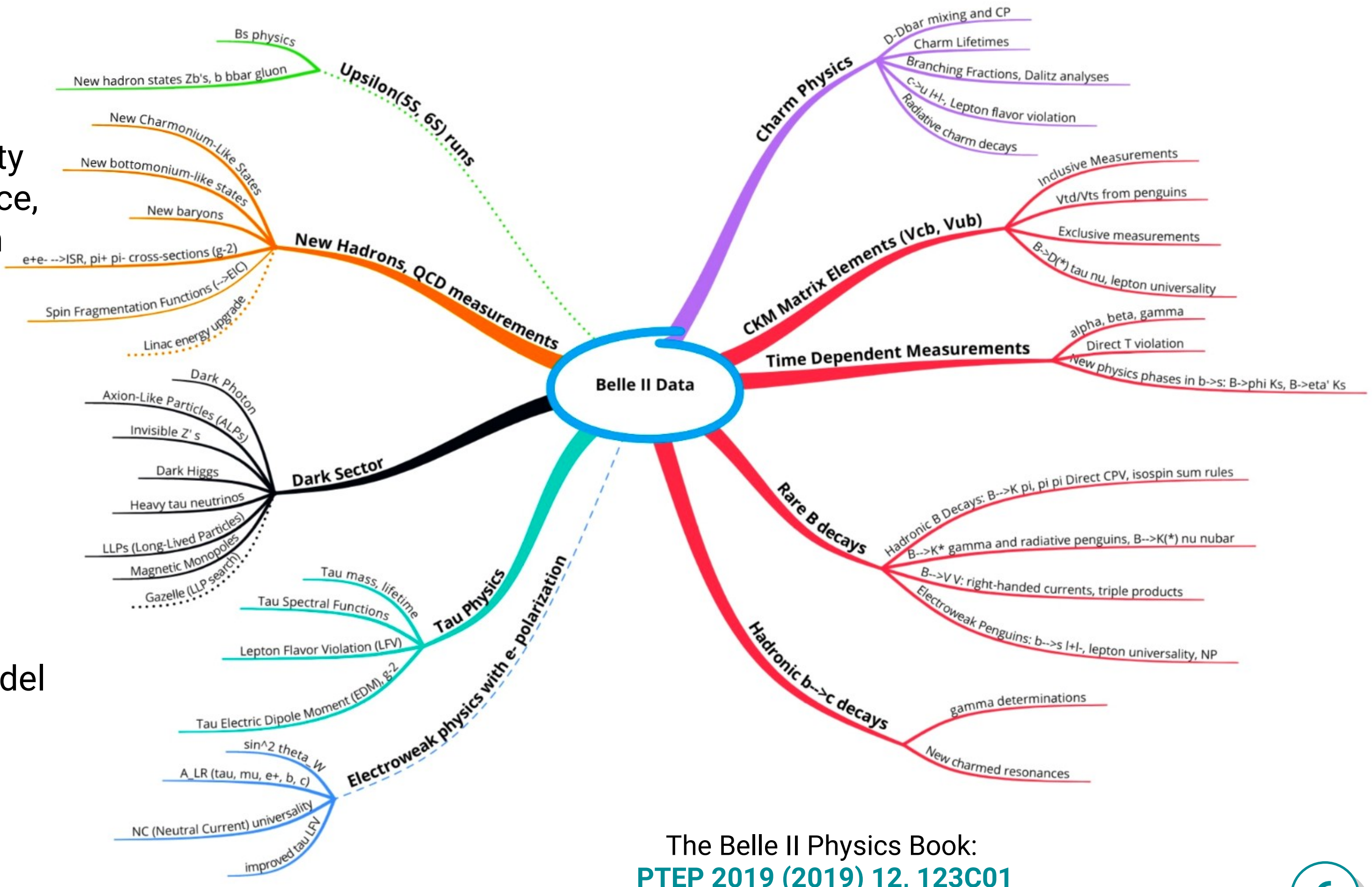
  ➔ > 240/fb collected in almost 3 years of data taking

- Target integrated luminosity of the *Belle II* experiment:
  50/ab (x30 Belle + BaBar)



Belle II physics program

- Thanks to the high luminosity and the detector performance, *Belle II* will be competitive in many physics researches
  - ➔ Flavor physics
  - ➔ Standard Model tests
  - ➔ Search for rare or suppressed processes in Standard Model
  - ➔ **Dark Sector physics**



The Belle II Physics Book:
PTEP 2019 (2019) 12, 123C01

Belle II physics program

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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 Collaborati

Phys. Rev. Lett. **124**, 141801 – Publ

Physics See synopsis: Closing in on

First *Belle II* physics publications

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

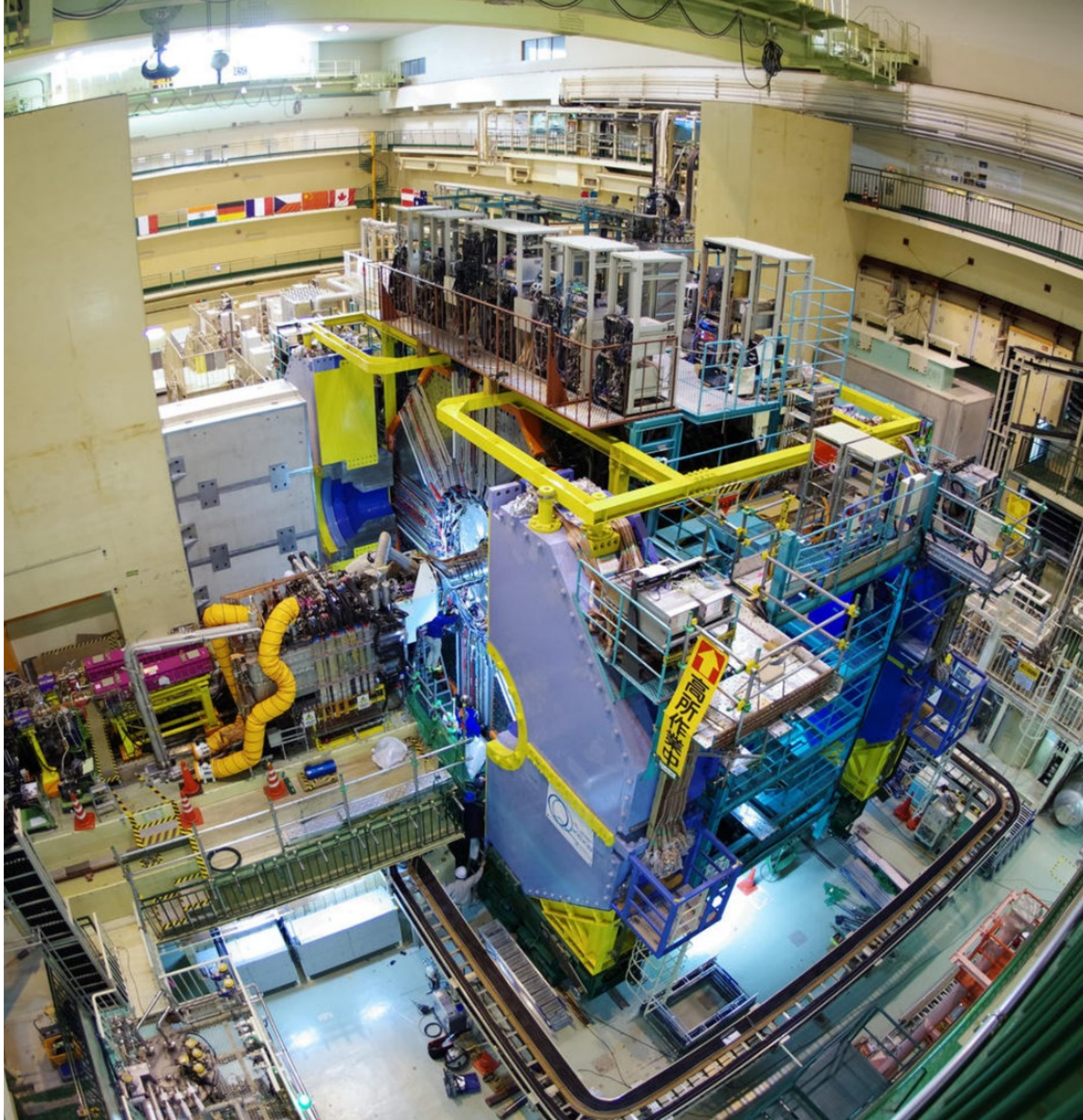
F. Abudinén *et al.* (Belle II Collaboration)

Phys. Rev. Lett. **125**, 161806 – Published 14 October 2020

→ Search for rare or suppressed processes in Standa

→ **Dark Sector physics**

General introduction to dark sector @ *Belle II*



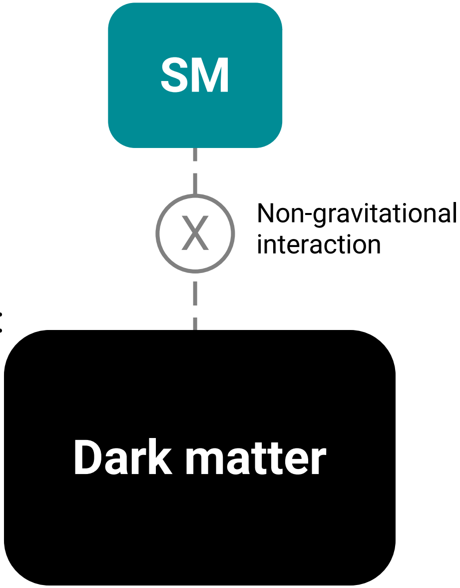
Dark sector

- **Main motivation:** the absence of dark matter discoveries at the electroweak scale by the LHC or direct detection experiments motivates the interest for models with low-mass dark matter candidates

- **Theoretical scenarios introducing light dark matter with M ~ O(MeV-GeV) need light mediators too**

➔ Dark matter not charged directly under the Standard Model

➔ Dark matter may interact to Standard Model through several "**portal**" interactions [1,2]:
- vector portal (dark photon, Z',...)
- scalar portal (dark Higgs,...)
- pseudo-scalar portal (axions, axion-like particles),
- neutrino portal (heavy neutrinos)



➔ Not just solving the dark matter puzzle. Could explain:
- some astrophysics anomalies: positron excess, ..., (PAMELA, Fermi, ...)
- some anomalies in *B* meson decays: R_K, R_{K^*},... (Belle, LHCb, ...)
- the $(g-2)_\mu$ anomaly, recently confirmed at Fermilab [3]

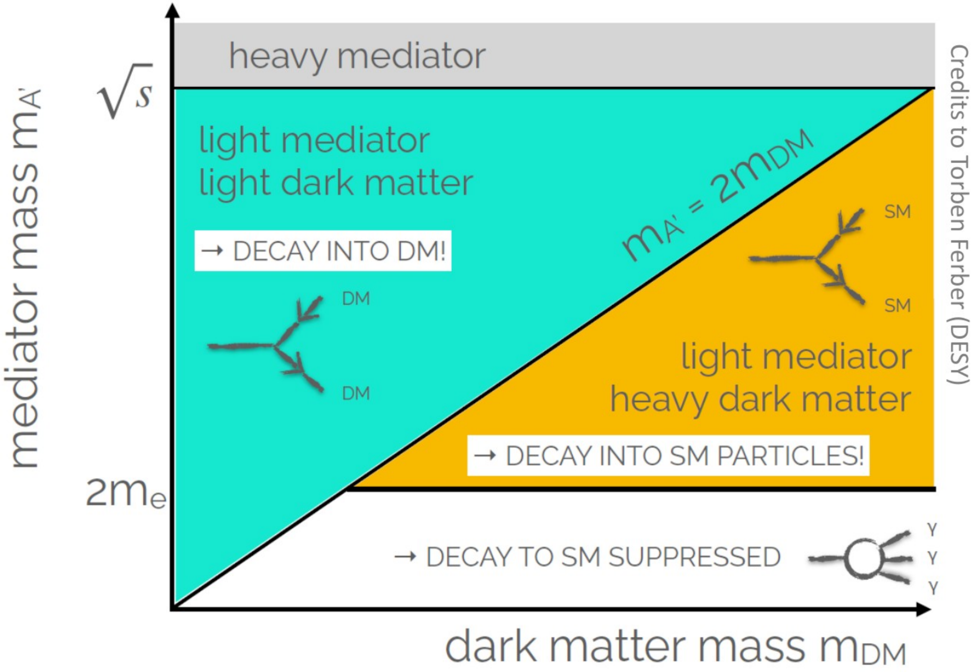
[1] Batell et al., Phys. ReV. D 80, 095024 (2009)
[2] Essig et al., arXiv:1311.0029 (2013)
[3] Abi et al., Phys. Rev. Lett. 126, 141801 (2021)

Dark sector searches @ *B*-factories

- **Negligible interaction probability of dark matter with the detector**
  - → Search for mediators (visibles or invisibles)
  - → Search for final states with missing mass
  - → Search for both

- **Advantages of *B*-factories**
  - → High luminosity
  - → Well known initial state
  - → Clean environment with low background
  - → Hermetic detector with good PID performance

The relationship between mass of the mediators and DM candidates leads to different topologies.



- **Excellent capabilities for low multiplicities and missing energy signatures at *B*-factories**

Dark sector searches @ *Belle II*

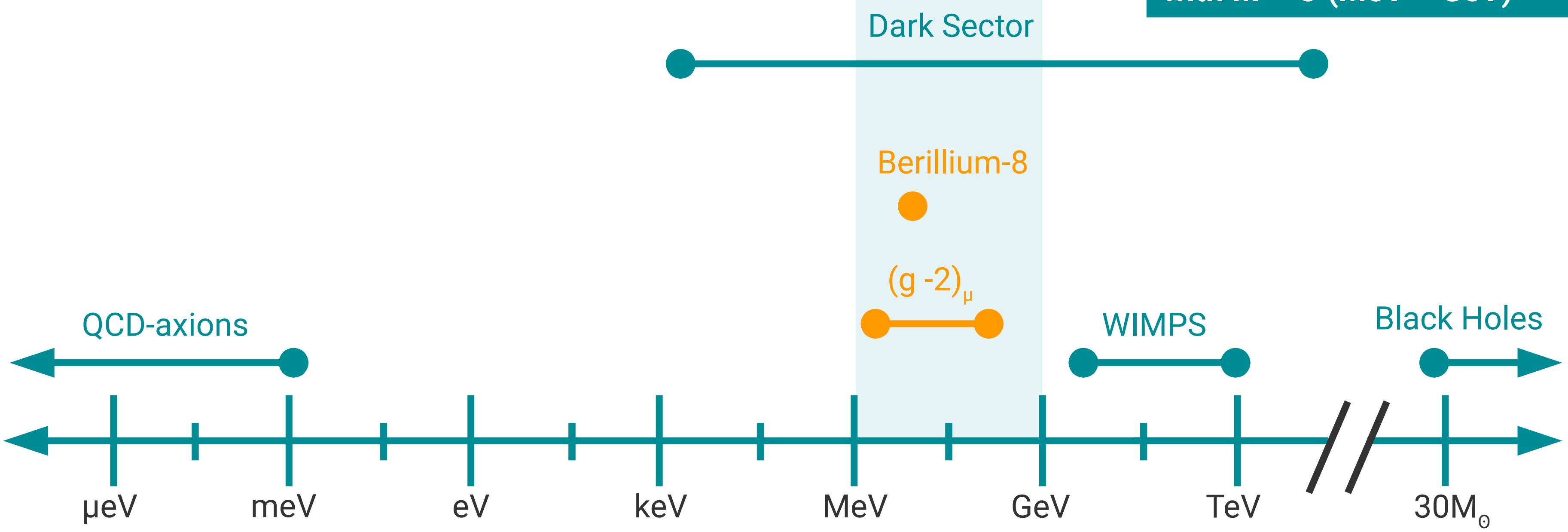
[1] Battaglieri et al., arXiv:1707.04591

- **High luminosity provided by SuperKEKB**
- **All advantages of the *B*-factories**
- **High performance detector with dedicated triggers**

Belle II

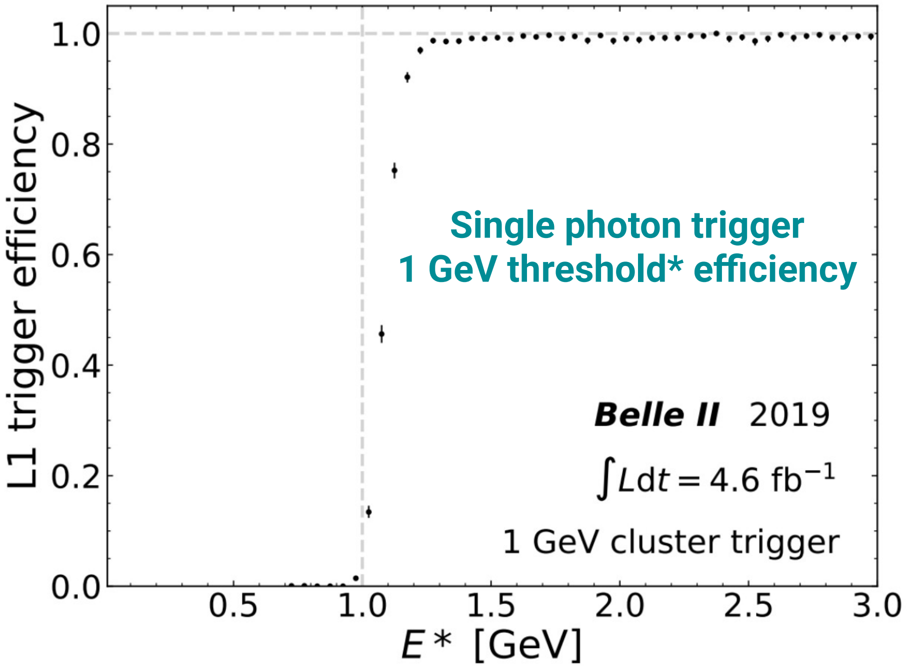
- Dark matter candidates
- Observed anomalies

***Belle II* will provide an important contribution in the search for dark sector physics with M ~ O (MeV – GeV)**



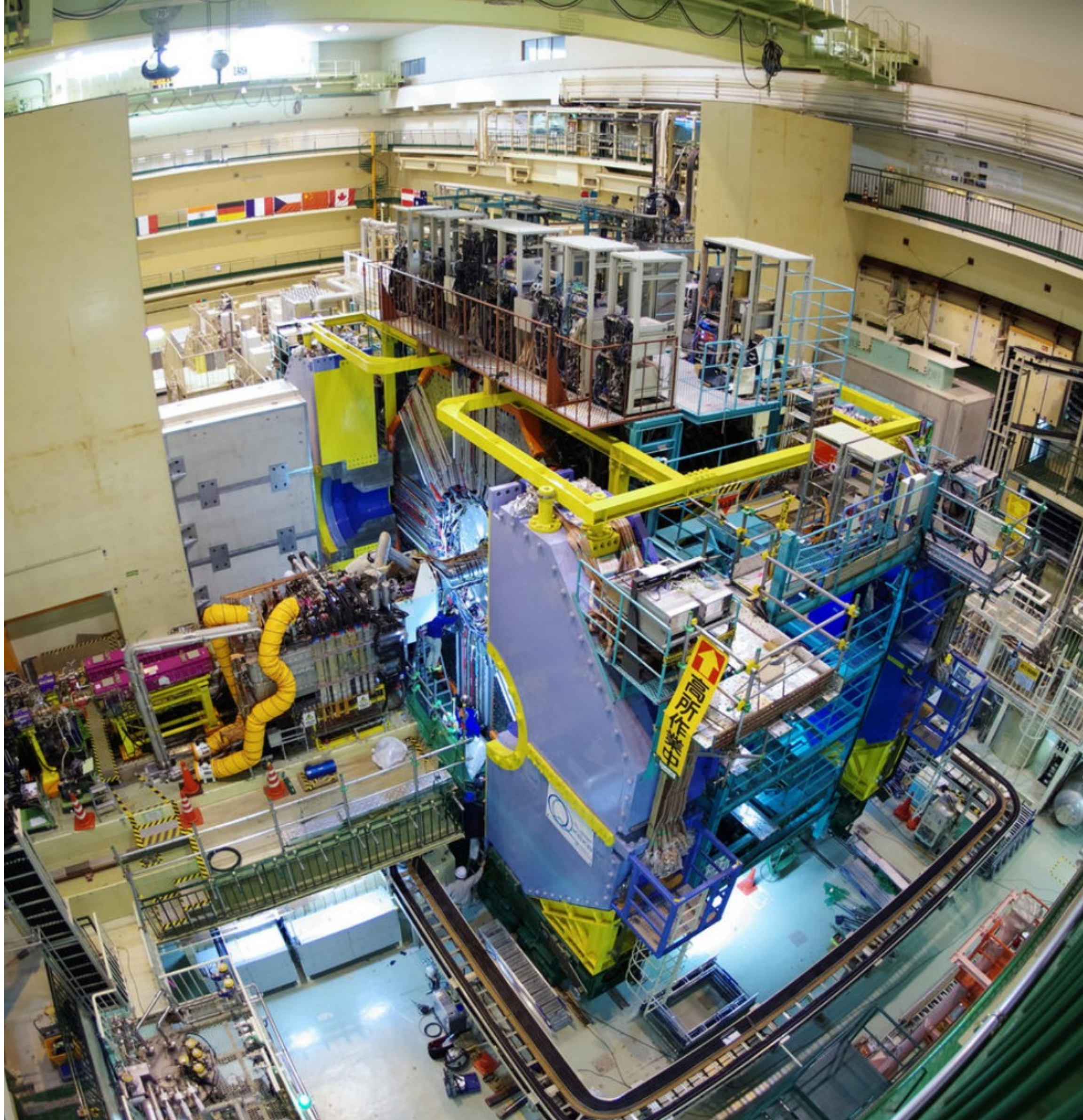
Belle II dark sector trigger

- 2-level trigger:
  - ➔ Hardware-based Level1 Trigger (L1): < 30 kHz
  - ➔ Software-based High Level Trigger (HLT): < 10 kHz
- New “dark sector” triggers make the dataset collected up to now world-unique
  - ➔ **Single photon trigger** operational for entire dataset
    - not present in Belle
    - 53/fb in BaBar recorded with single photon trigger
  - ➔ **Single muon trigger** using KLM recently introduced, efficiency ~ 90%
  - ➔ **3D track reconstruction at L1 level** using neural networks



*Actually, newly designed trigger allows sensitivity down to 0.5 GeV of single photon

Overview on dark sector searches @ *Belle II*

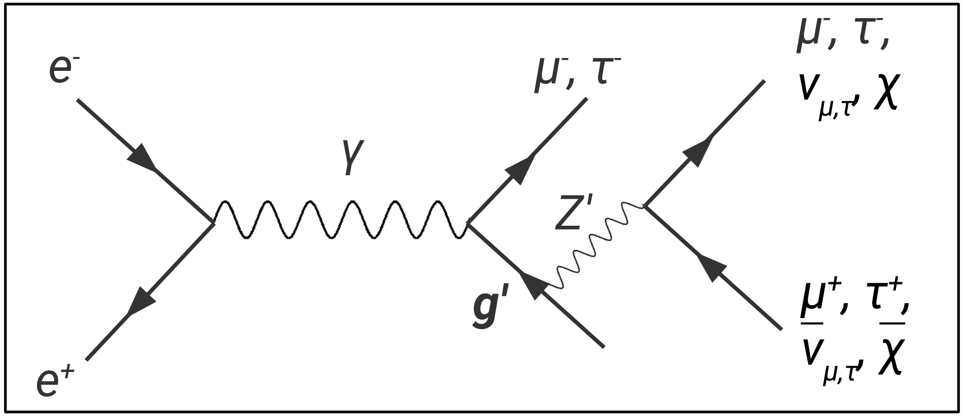


Search for a Z' boson

- Vector boson Z' with a coupling $\boldsymbol{g'}$ only to the 2nd and 3rd generations of leptons, introduced by the $L_\mu - L_\tau$ model [1,2,3]:

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

  θ =+1 se $l = \mu$
  θ =-1 se $l = \tau$



- Possible final states:

  ➔ Invisible decays:
  - $Z' \to \nu\bar{\nu}$ (μ or τ neutrinos)
  - primarily $Z' \to \chi\bar{\chi}$ (light dark matter) if kinematically accessible

  ➔ Visible decays:
  - $Z' \to \mu\mu$
  - $Z' \to \tau\tau$

[1] Shuve et al., Phys. Rev. D 89 , 113004 (2014)
[2] Altmannshofer et al., JHEP 106 (2016)
[3] D. Curtin et al., JHEP 02 (2015) 157

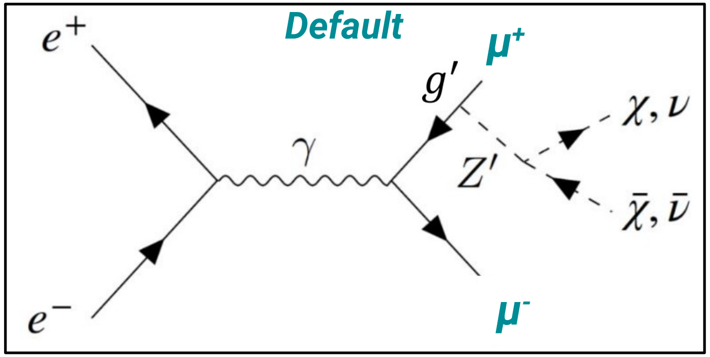
$Z' \to$ Invisible

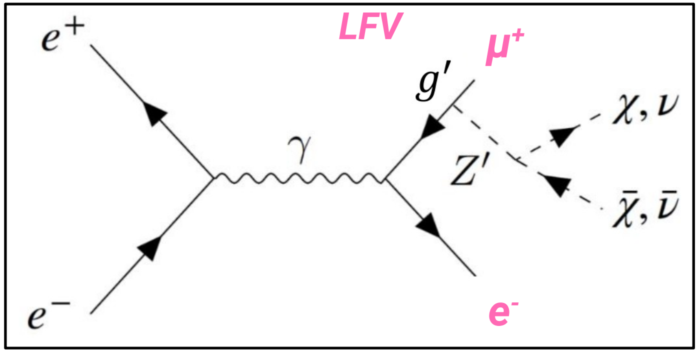
Analysis on data, published on PRL

- Searching for an invisible *Z'* for the first time, with 0.276/fb collected by *Belle II* in 2018
  - ➔ If dark matter particles kinematically accessible exist, than *BR*($Z' \to$ invisible) = 1
  - ➔ *BR*($Z' \to$ invisible) = 1 for $M_{Z'} < 2m_\mu$ whatever the dark matter is
- Hermetic *Belle II* detector and clean e^+e^- collisions allow precision determination of missing energy
- Two cases:
  - ➔ ***$e^+e^- \to \mu^+\mu^-$ + Missing Energy***
  - ➔ ***$e^+e^- \to \mu^\pm e^\mp$ + Missing Energy*** (Lepton-Flavor Violation)

$$\boxed{M^2_{recoil} = s + M^2_{\mu\mu} - 2\sqrt{s}(E^{CMS}_{\mu^+} + E^{CMS}_{\mu^-})}$$

- Search for a narrow peak in the recoil mass distribution against $\mu^+\mu^-$ (*LFV: $\mu^\pm e^\mp$*)

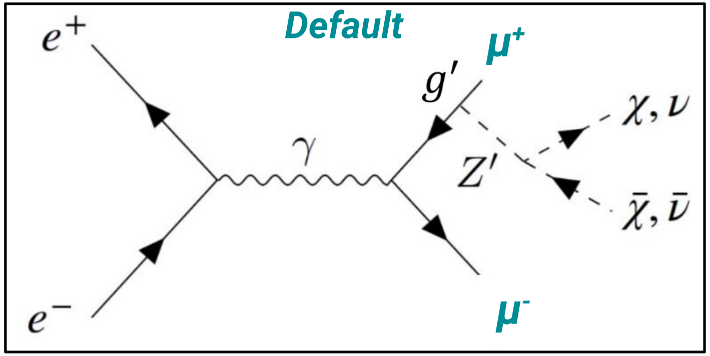




$Z' \rightarrow$ Invisible ($\mu^+\mu^-$)

- ***$e^+e^- \rightarrow \mu^+\mu^-$ + Missing Energy***

- Main background components:
  - $e^+e^- \rightarrow \tau^+\tau^-(\gamma)$: missing energy due to neutrinos
  - $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$: missing energy due to undetected photons
  - $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$: missing energy due to undetected electrons



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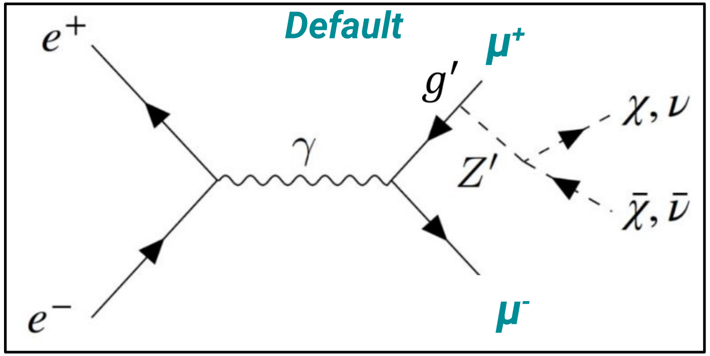
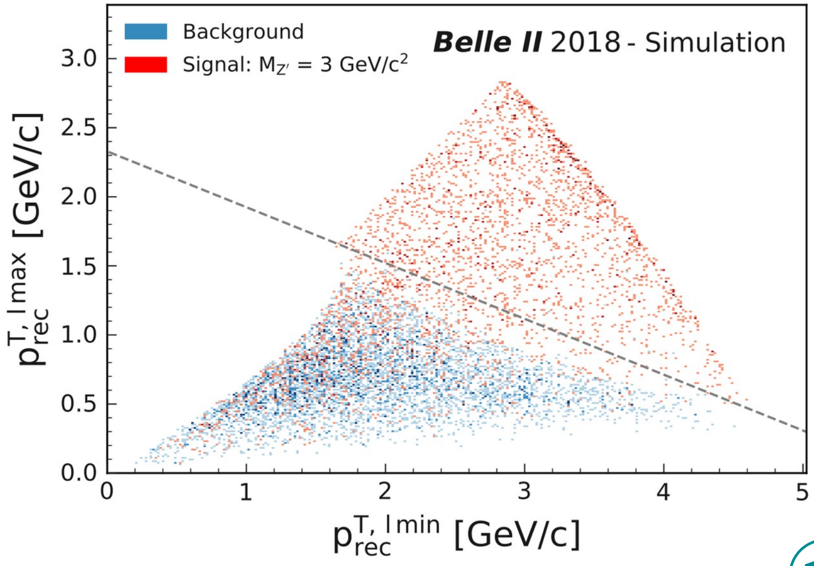
- Dedicated background suppression based on the different origin of missing momentum in background (neutrinos for $\tau\tau$ and ISR for $\mu\mu(\gamma)$) and signal (FSR)

➔ Exploits lepton kinematics





$Z' \to$ Invisible ($\mu^+\mu^-$)

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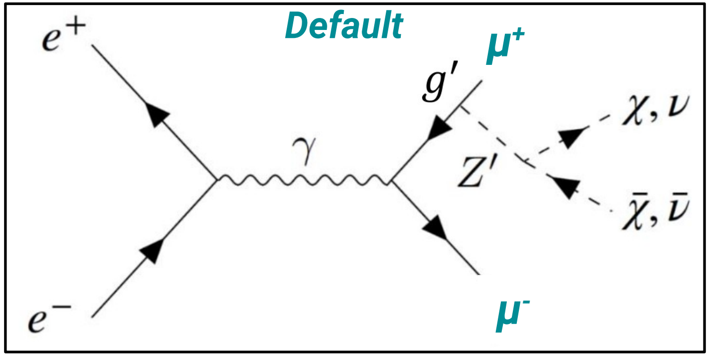
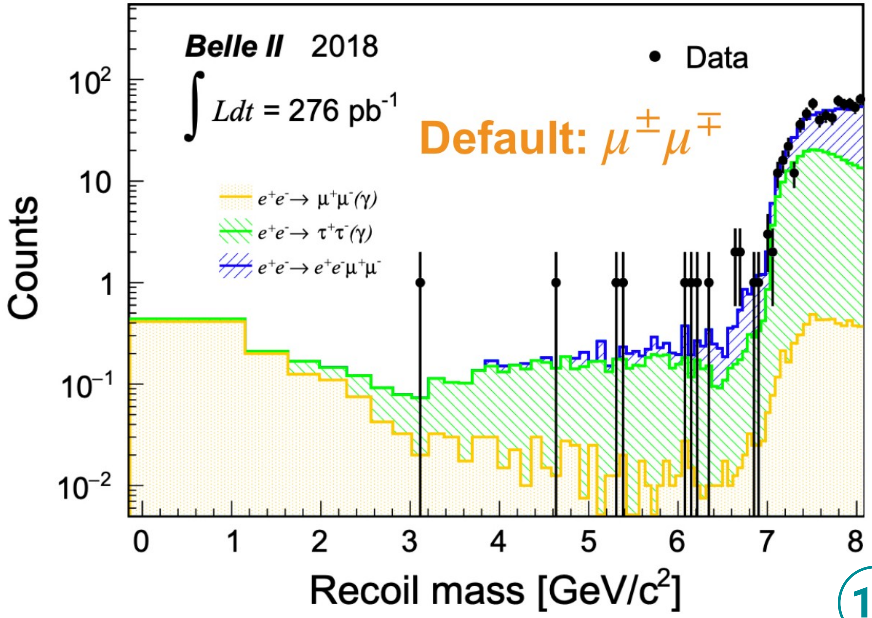
- Dedicated background suppression based on the different origin of missing momentum in background (neutrinos for $\tau\tau$ and ISR for $\mu\mu(\gamma)$) and signal (FSR)

  ➔ Exploits lepton kinematics

- **No significant excess observed in data**

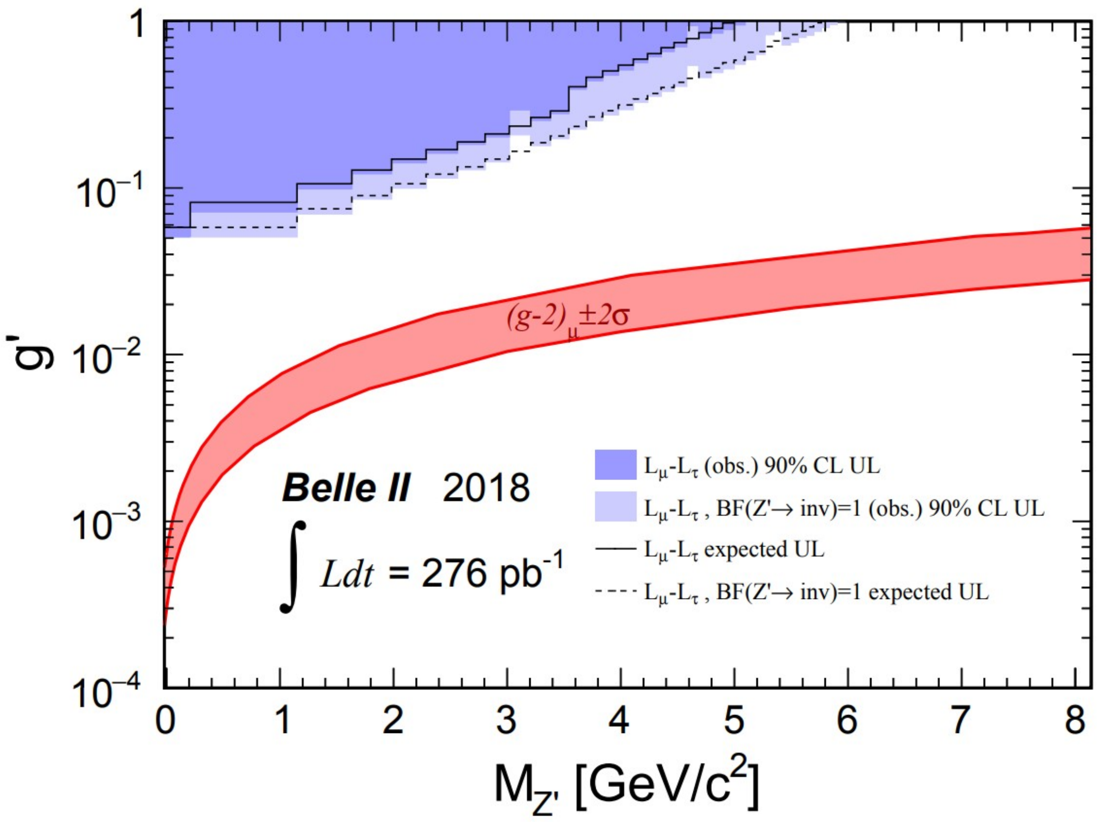




$Z' \rightarrow$ Invisible. 90% CL UL on g'

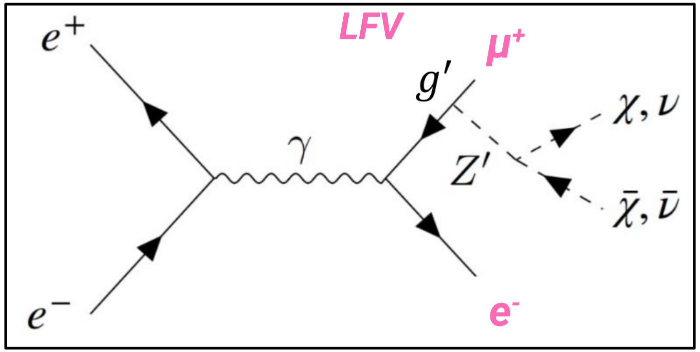
- 90% CL upper limits on the coupling constant *g'* as a function of the *Z'* mass
  - *g'* below $5 \cdot 10^{-2}$

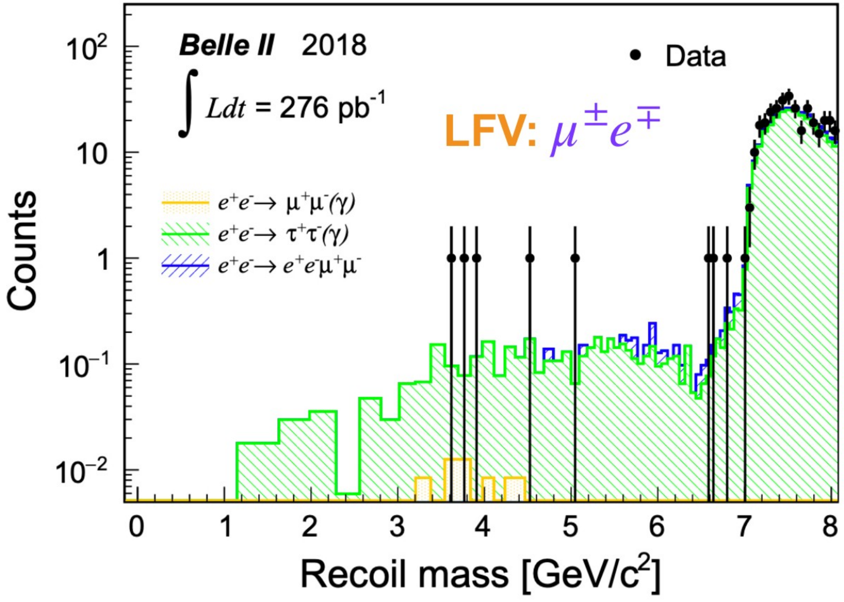
- First *Belle II* physics publication:
  [Phys. Rev. Lett. 124 (2020) 141801]()

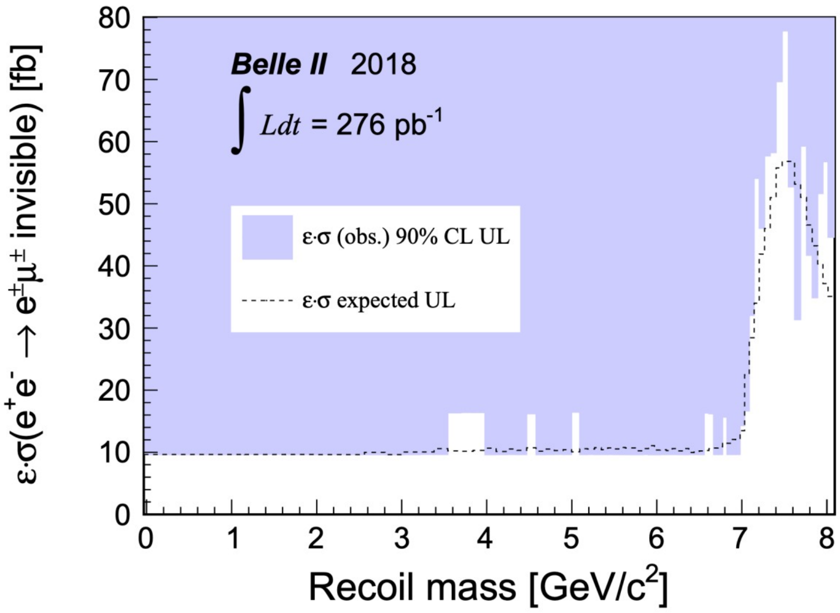


$Z' \rightarrow$ Invisible (*LFV*)

- No excess observed in data
- First model independent limits on
  $\epsilon \cdot \sigma(e^+e^- \rightarrow e^\pm\mu^\mp + \text{invisible})$ down to 10 fb
- First *Belle II* physics publication:
  [Phys. Rev. Lett. 124 (2020) 141801]

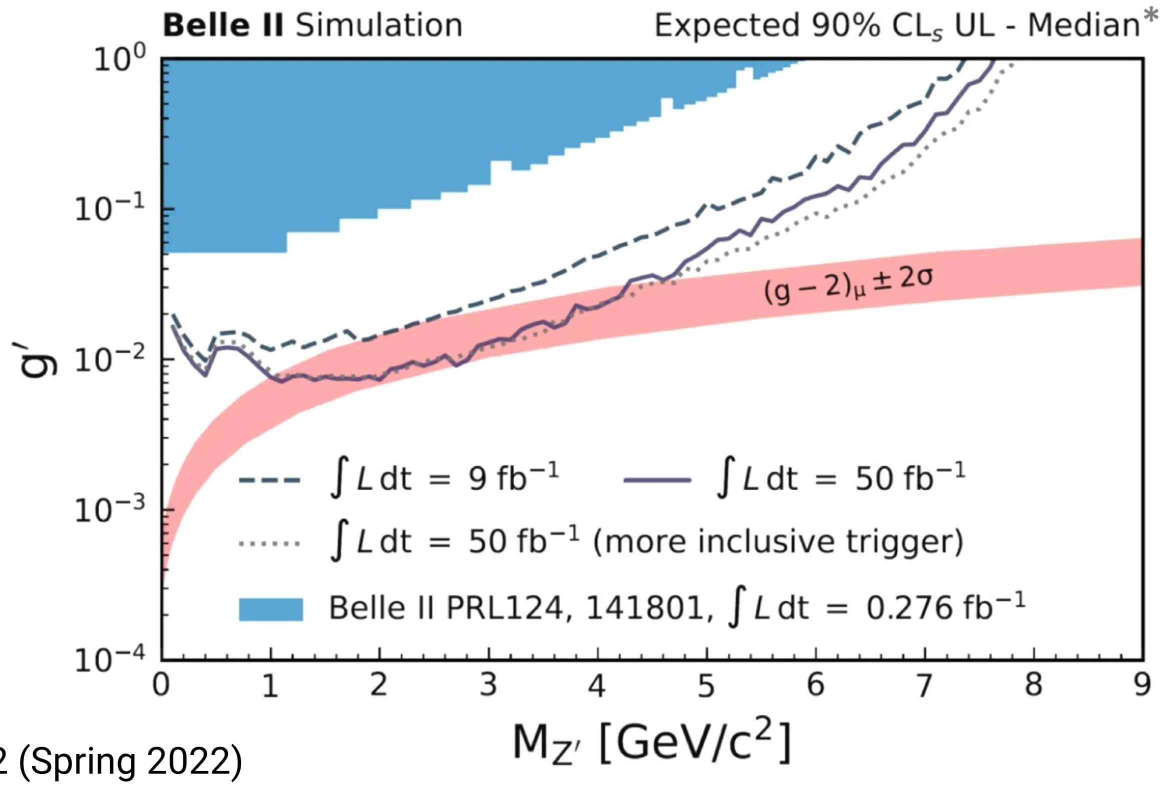






$Z' \rightarrow$ Invisibile, future prospects

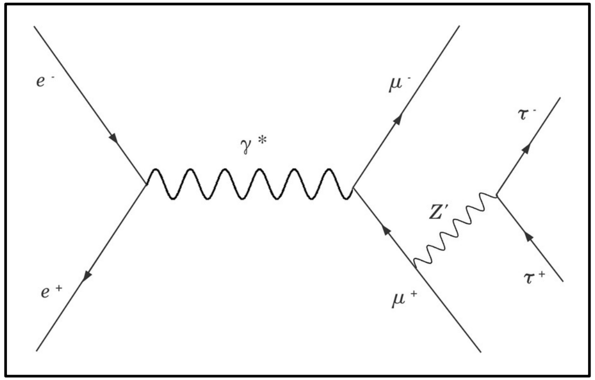
- **Short-term program**
  - → Much more integrated luminosity (already available)
  - → Analysis improvements (MVA based background suppression)
  - → New trigger lines
- **Preliminary sensitivity**
  - → Starting to investigate the model parameters that can explain the $(g-2)_\mu$



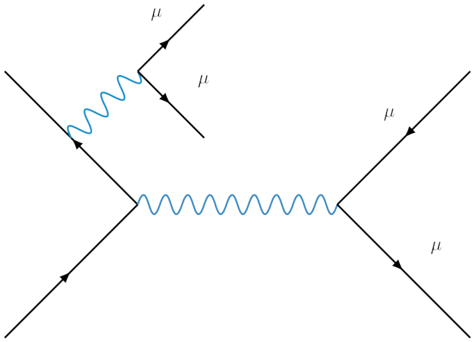
- Analysis will be finalized by Moriond 2022 (Spring 2022)

Highlights on $Z' \to \mu\mu$ @ *Belle II*

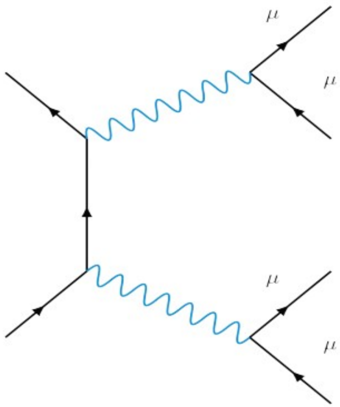
- $e^+e^- \to \mu^+\mu^- Z', Z' \to \mu^+\mu^-$
- Existing results by **BaBar** with 514/fb and **Belle** with 643/fb
- Competitive with early dataset (100/fb) due to **aggressive background suppression**
  - ➔ MLP (Multi-Layer Perceptron (NN)) based background suppression
- Main background: QED *μμμμ* processes
  - ISR
  - Double-photon conversion
- Analysis will be finalized by Summer 2022



ISR

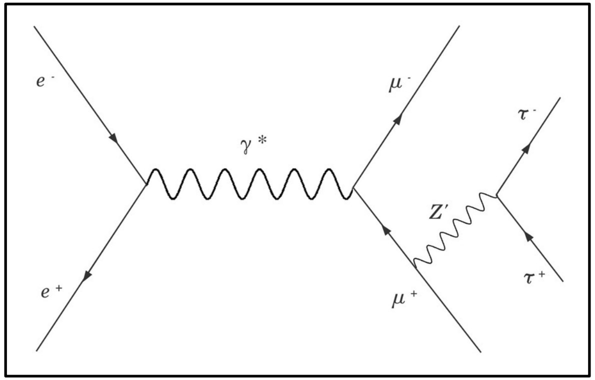


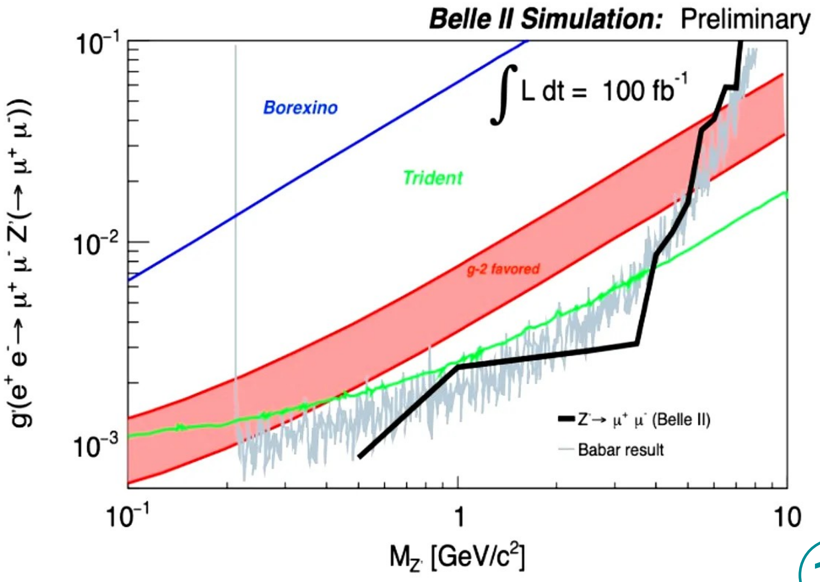
Double-photon conversion



Highlights on *Z' → μμ @ Belle II*

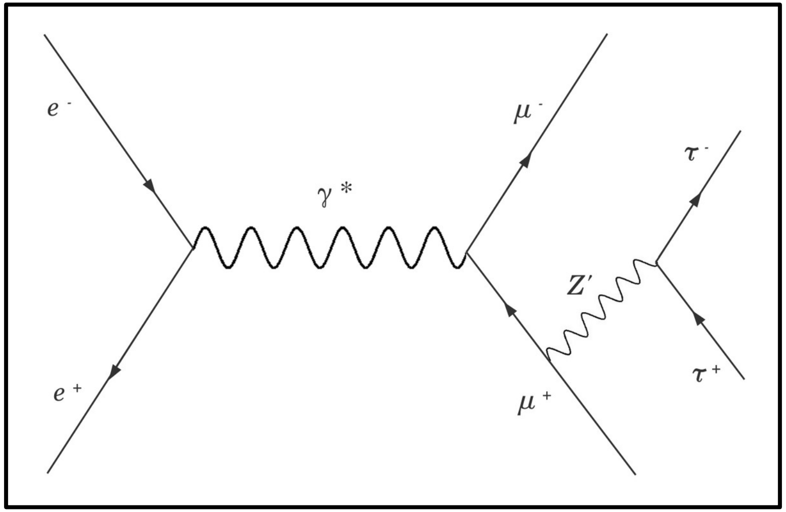
- ***$e^+e^- \to \mu^+\mu^- Z'$, $Z' \to \mu^+\mu^-$***
- Existing results by **BaBar** with 514/fb and **Belle** with 643/fb
- Competitive with early dataset (100/fb) due to **aggressive background suppression**
  - ➔ MLP (Multi-Layer Perceptron (NN)) based background suppression
- Main background: QED *μμμμ* processes
  - ISR
  - Double-photon conversion
- Analysis will be finalized by Summer 2022
- **Preliminary sensitivity at 90% CL w/o systematics included, using fit scan strategy on dimuon invariant mass**





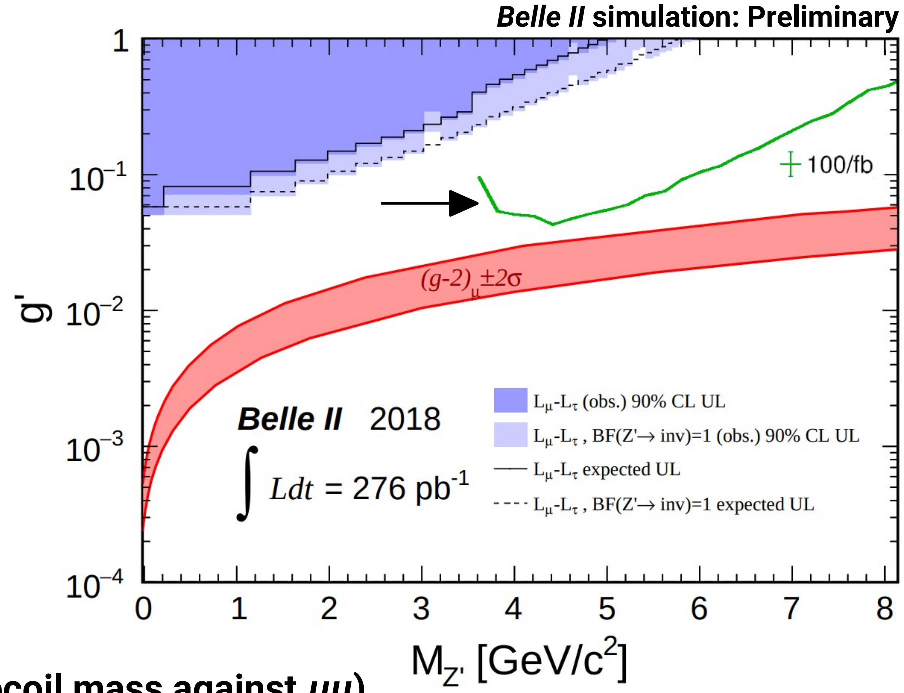
Highlights on *Z'* → *ττ* @ *Belle II*

- $e^+e^- \to \mu^+\mu^- Z'$, $Z' \to \tau^+\tau^-$: **First time search!**
- Benchmark model: possibility to reinterpret the results found for the *Z'* boson of the L_μ - L_τ in other models, and in particular those with $\tau\tau$ resonance in a $\mu\mu\tau\tau$ final state
- The analysis is challenging:
  - ➔ The presence of neutrinos in the final state makes it impossible to exploit the Υ(4S) kinematic costraint
- Main background components expected: $q\bar{q}$, $\tau\tau$, $\mu\mu$, $ee\mu\mu$
- Background suppression:
  - ➔ MLP (Multi-Layer Perceptron (NN)) based
- Profit of *B*-factory clean environment
- Analysis will be finalized by Summer 2022



Highlights on $Z' \to \tau\tau$ @ *Belle II*

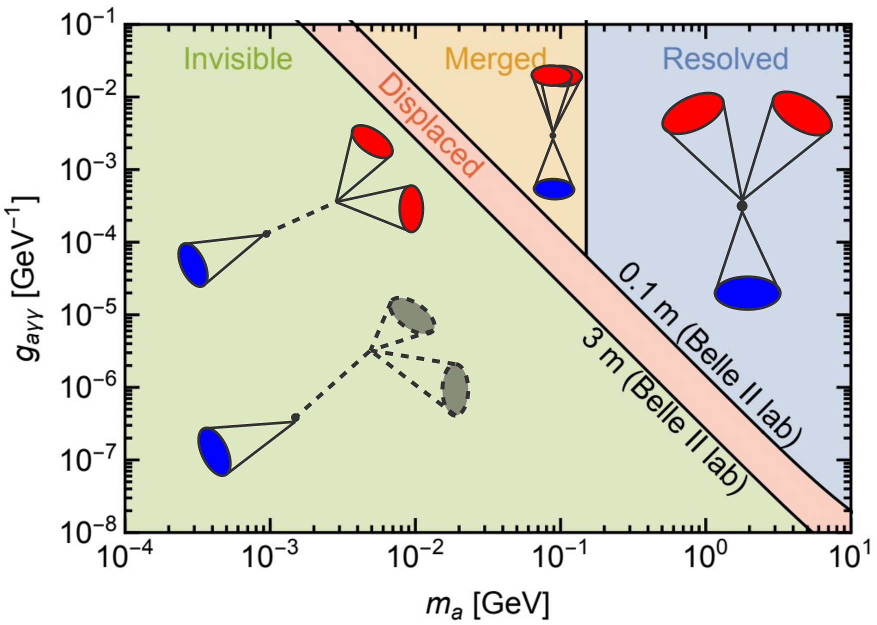
- *$e^+e^- \to \mu^+\mu^- Z'$, $Z' \to \tau^+\tau^-$*: **First time search!**
- Benchmark model: possibility to reinterpret the results found for the *Z'* boson of the L_μ - L_τ in other models, and in particular those with *ττ* resonance in a *μμττ* final state
- The analysis is challenging:
  - ➔ The presence of neutrinos in the final state makes it impossible to exploit the Y(4S) kinematic costraint
- Main background components expected: *$q\bar{q}$*, *ττ*, *μμ*, *eeμμ*
- Background suppression:
  - ➔ MLP (Multi-Layer Perceptron (NN)) based
- Profit of *B*-factory clean environment
- Analysis will be finalized by Summer 2022
- **Preliminary 90% CL sensitivity w/o systematics on MC, using cut and count strategy (final strategy: fit scan on recoil mass against *μμ*)**

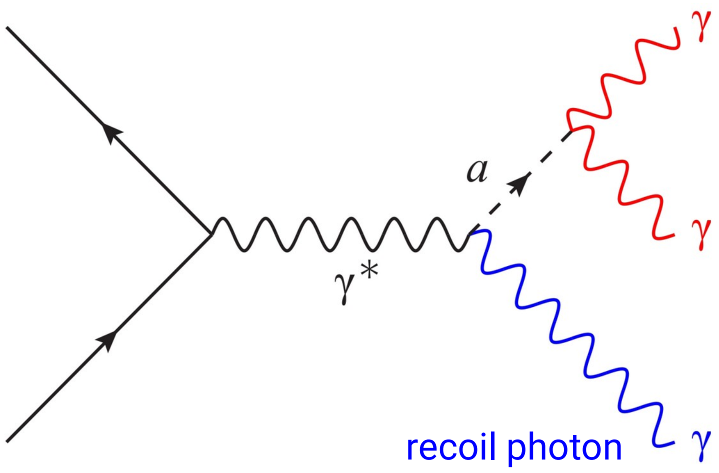


Axion-like particle (ALP)

Analysis on data, published on PRL

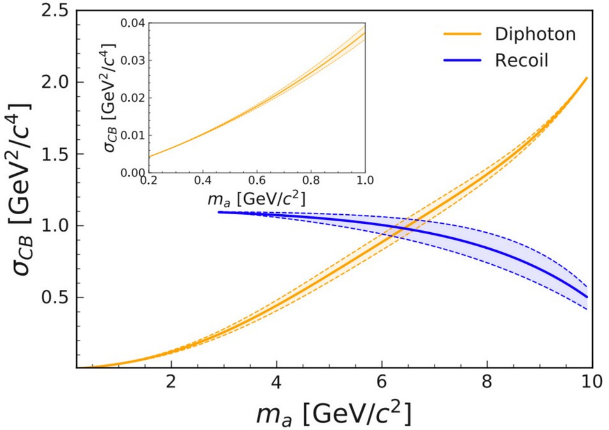
- GeV-scale ALPs: pseudo-scalar portal mediator between dark sector and Standard Model
- If ALP-photon coupling ($g_{a\gamma\gamma}$) dominates, than $BR(a \to \gamma\gamma) \sim 100\%$
- Different topologies depending on model parameters (m_a, $g_{a\gamma\gamma}$): focus on mass region where ALP decay is prompt and photons can be well resolved by *Belle II*



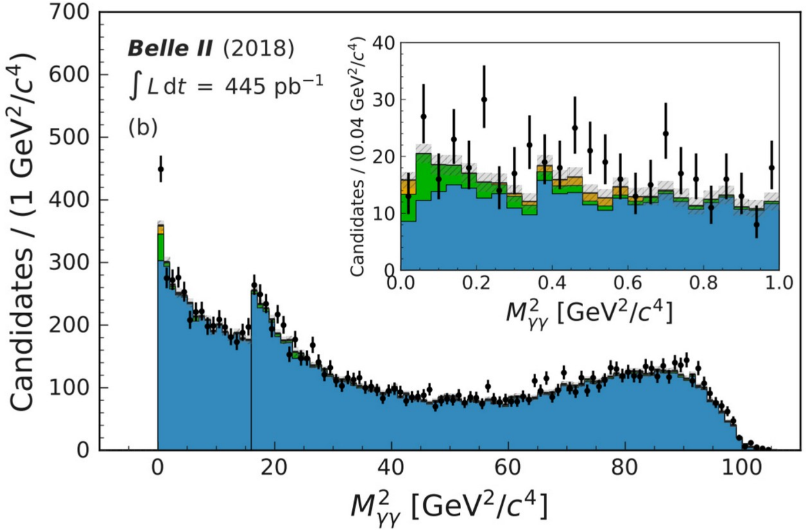


Search for an ALP

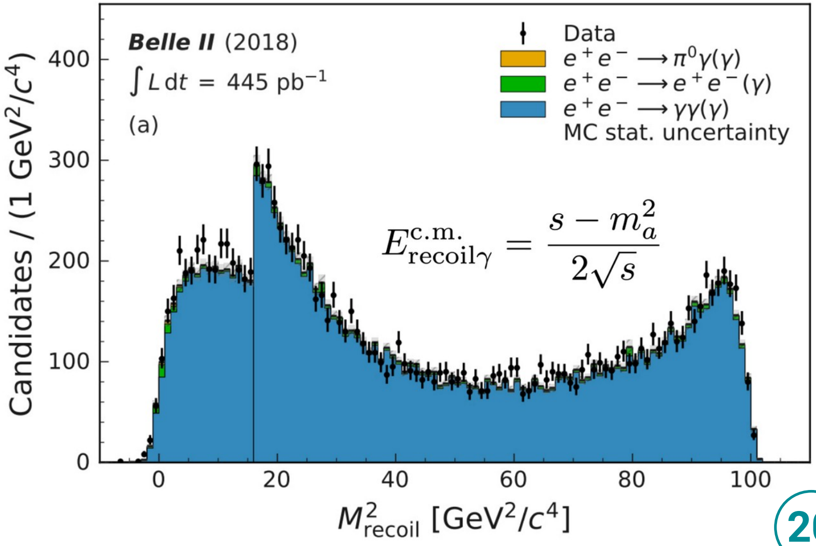
- Select events with three photon invariant mass compatible with collision √s
- Search for a narrow peak in $M^2_{\gamma\gamma}$ or M^2_{recoil}, depending on best resolution of signal peak
- Largest background from $e^+e^- \to \gamma\gamma(\gamma)$



$M^2_{\gamma\gamma}$: m_a < 6.85 GeV/c²

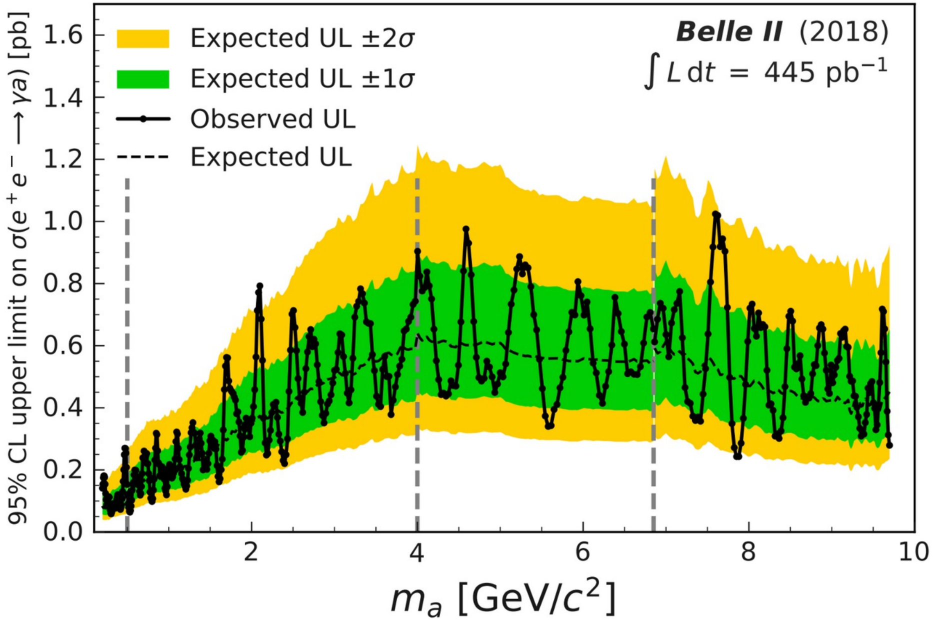


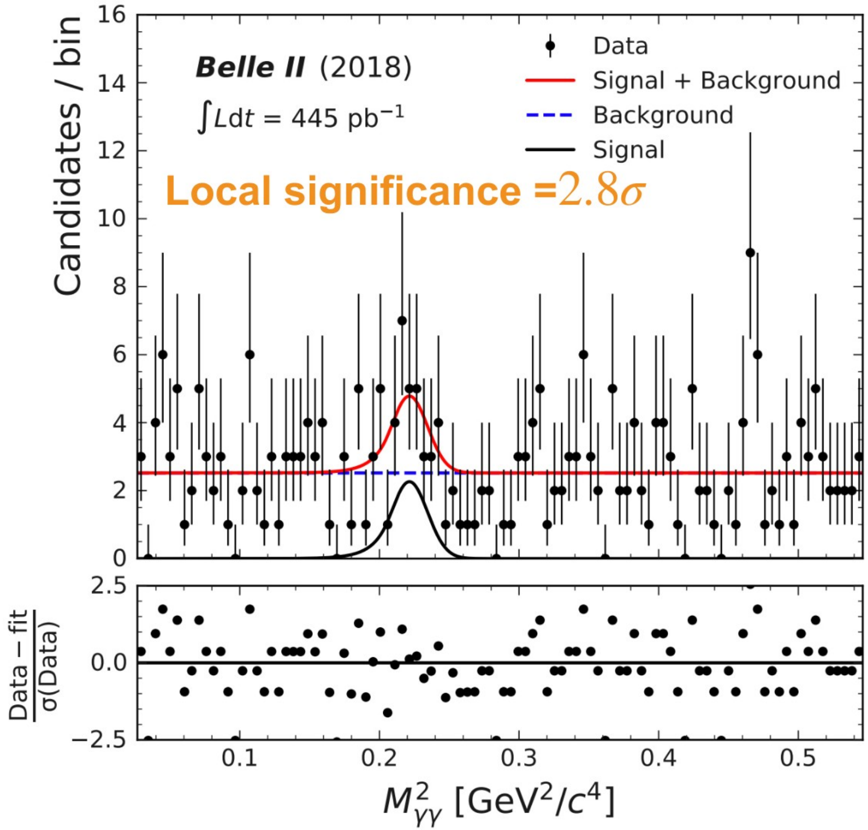
M^2_{recoil}: m_a > 6.85 GeV/c²



Search for an ALP: results

- Search ranges from $0.2 < m_a < 9.7$ GeV/c^2, with the 0.445/fb collected in 2018 with *Belle II*
  - ➔ 500 fits with steps of half mass resolution
- No excess in data observed
  - ➔ Highest local significance 2.8σ, observed at $m_a = 0.477$ GeV/c^2

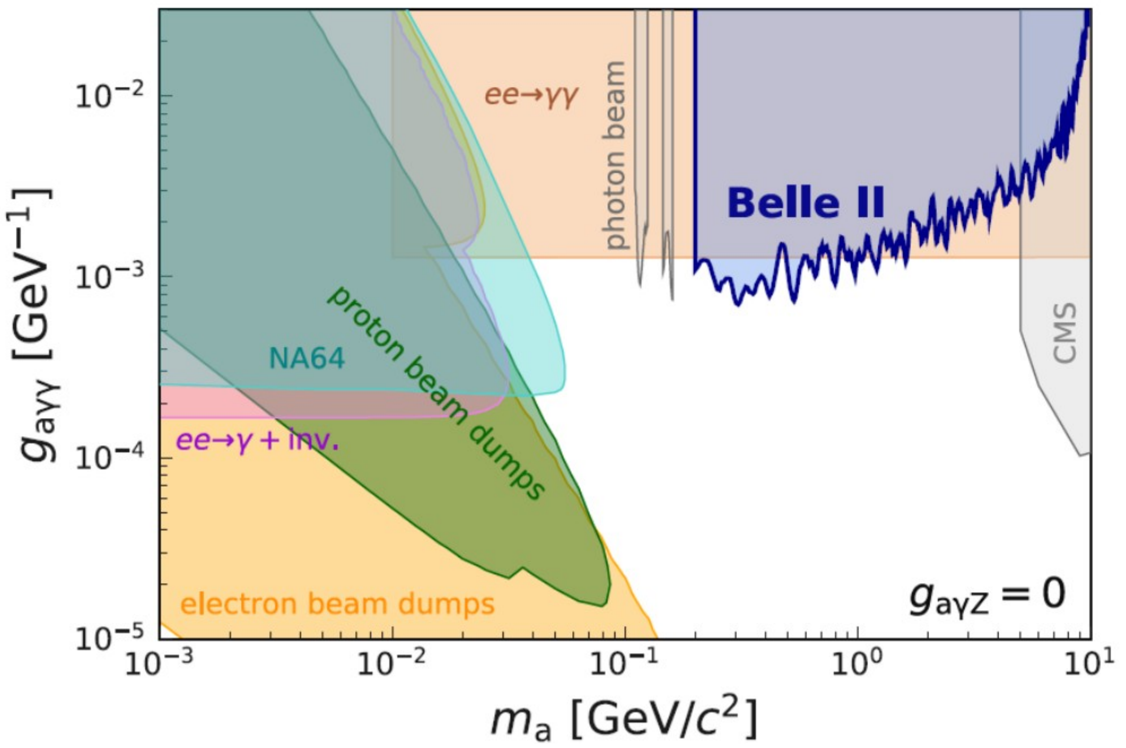




Exclusion on $g_{a\gamma\gamma}$

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

- 95% CL upper limits on the coupling constant $g_{a\gamma\gamma}$
  - $g_{a\gamma\gamma}$ below 10^{-3}
- Limits improve over recast from $e^+e^- \to \gamma\gamma$ analysis by LEP-II
- First result for ALP at *B*-factories and second physics publication of *Belle II*
  [Phys. Rev. Lett. 125, 161806 (2020)]



Search for a dark photon *A'*

- New massive vector gauge boson, *A'* , with a coupling to the Standard Model photon through the kinetic mixing mechanism, with strenght **ε** [1,2]

[1] P. Fayet, Phys. Lett. B 95, 285 (1980)
[2] P. Fayet, Nucl. Phys. B 187, 184 (1981)

Dark photon field

➔ $\mathcal{L}_{int} = \underbrace{e\varepsilon}_{\text{Interation stenght}} \underbrace{A'_{\mu}}_{\text{Dark photon field}} \underbrace{J^{\mu}_{em}}_{\text{Electromagnetic current}}$

Interation stenght

Electromagnetic current

- This gauge boson can be produced at e^+e^- colliders through different processes:
  - direct production: $e^+e^- \to \gamma_{ISR}A'$
  - meson decays: $\pi^0 \to A'\gamma$
  - dark higgsstrahlung: $e+e- \to A'^* \to A'h'$

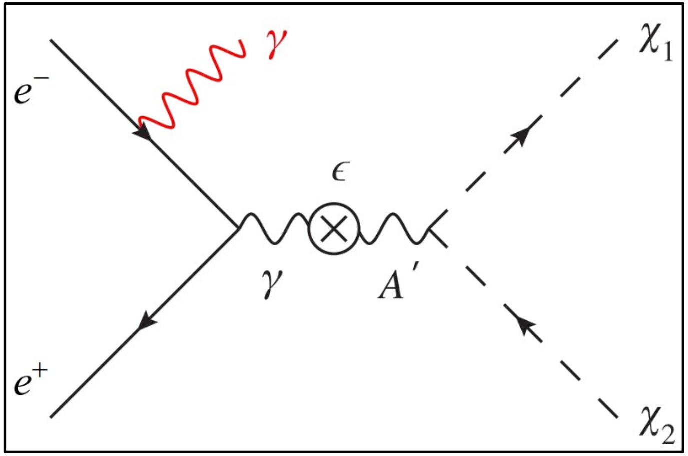
- **Direct production with ISR particularly interesting:** $e^+e^- \to \gamma_{ISR}A'$

- Two basic scenarios depending on dark photon mass:

➔ $M_{A'} > 2m_\chi$: invisible decay $A' \to \chi\bar{\chi}$

➔ $M_{A'} < 2m_\chi$: visible decay in Standard Model particles

$e^+e^- \to \gamma_{ISR}A'\ (A' \to \chi\bar{\chi})$



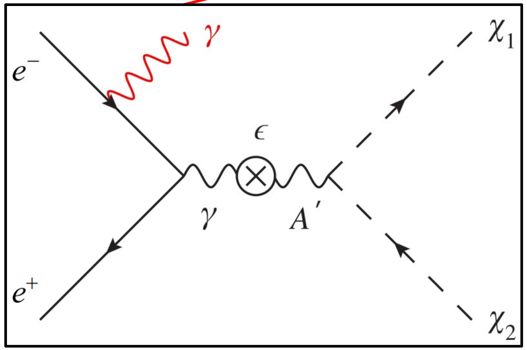
$A' \rightarrow$ invisible

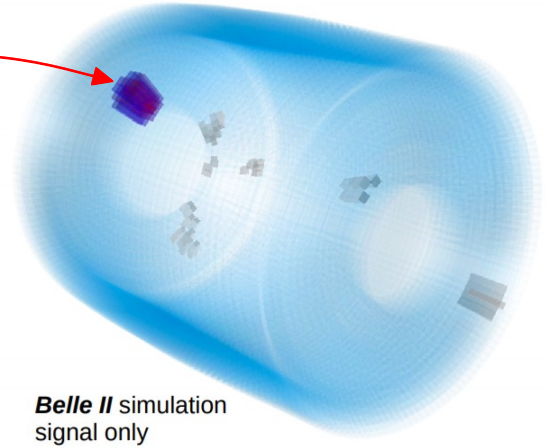
- Single photon in the final state needs a single photon trigger, present in the full *Belle II* dataset

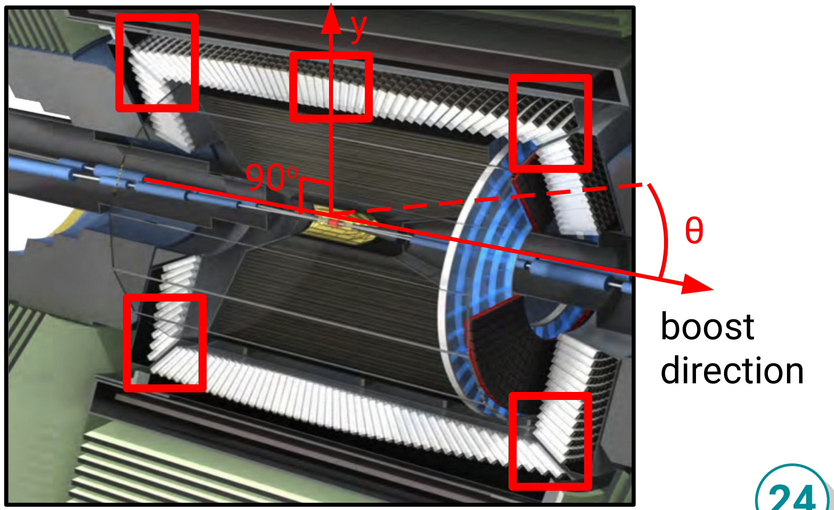
- For signal events: peak in the energy of the photon depending on the $M_{A'}$

$$\rightarrow \quad E_\gamma = \frac{s - M^2_{A'}}{2\sqrt{s}}$$

- Main background components:
  - $e^+e^- \rightarrow e^+e^-(\gamma)$: electrons out of acceptance
  - $e^+e^- \rightarrow \gamma\gamma(\gamma)$: photons lost in e.m. calorimeter (ECL) inefficient regions (gaps)
  - cosmic rays







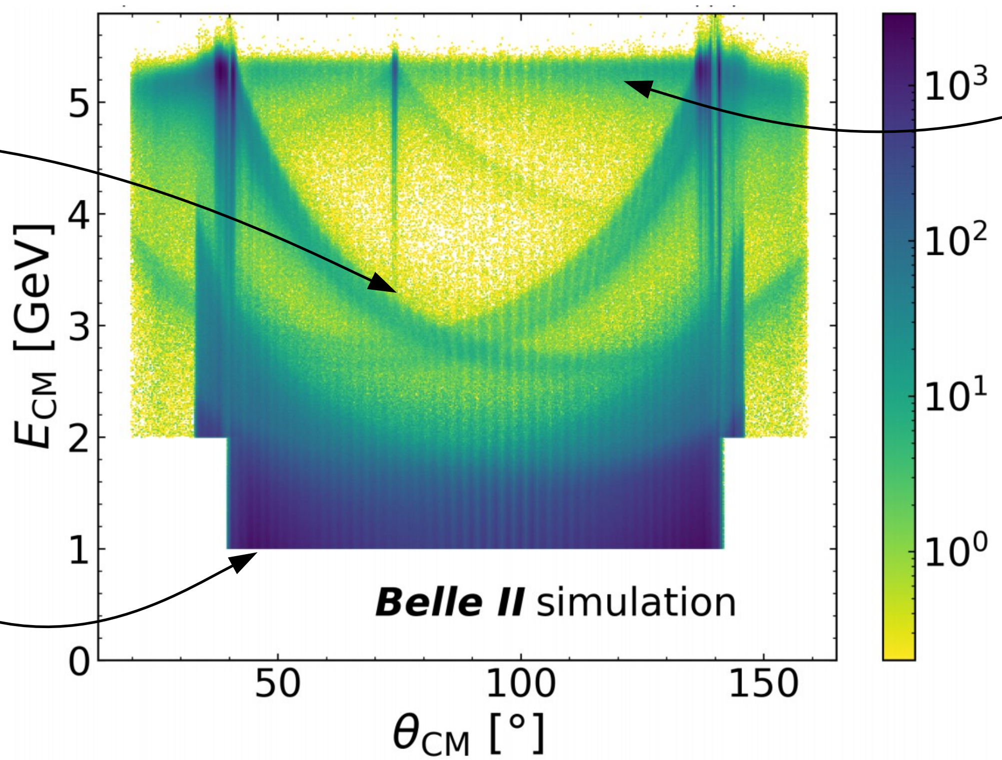
$A' \to$ invisible, background

- Event selection criteria based on E_γ vs θ_γ distribution

Background simulation, assuming 20/fb

$\gamma\gamma\gamma$, with two undetected photons

$e^+e^-\gamma$, with both e^+e^- out of detector acceptance

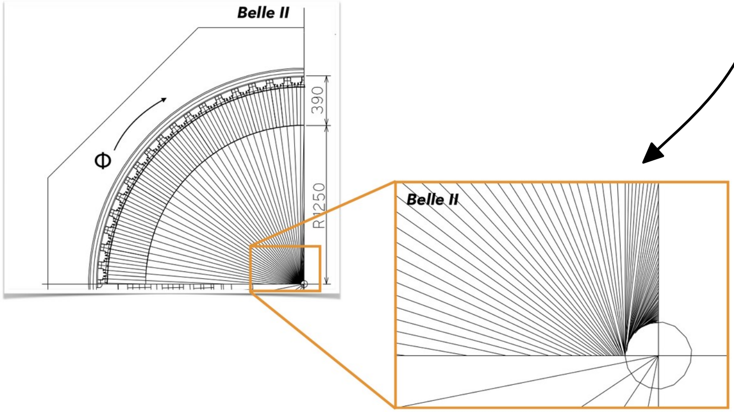


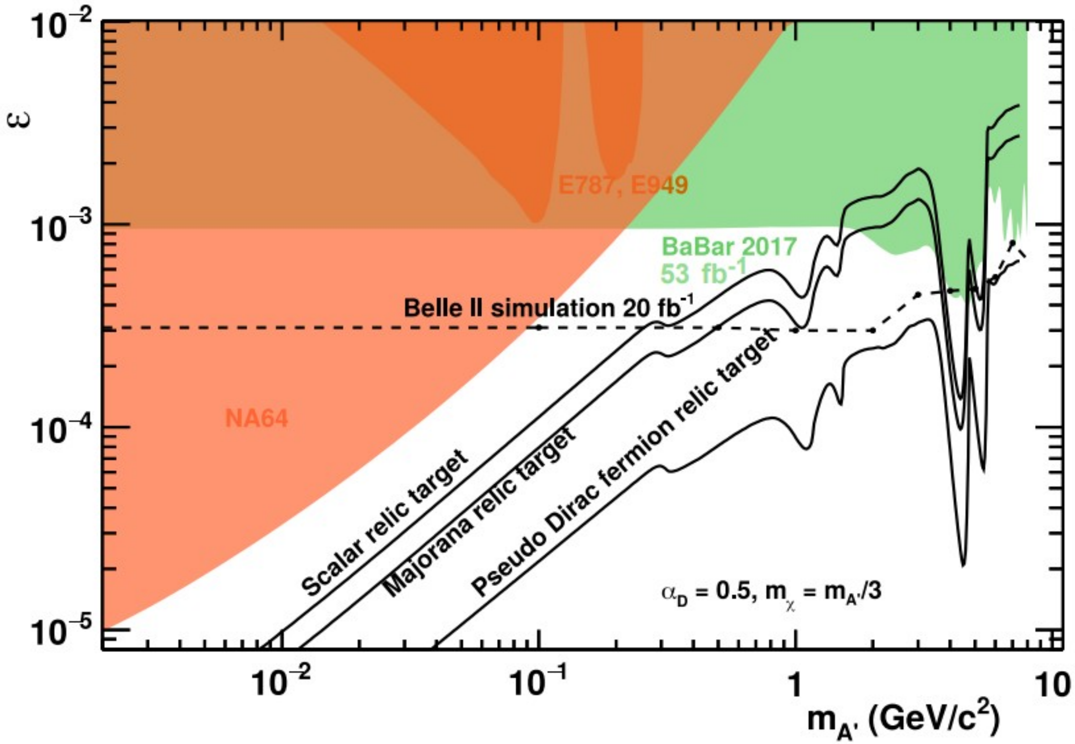
$\gamma\gamma$, with an undetected photon

90% CL Exclusion on ε

[1] Belle II Physics Book, PTEP 2019 12 (2019)
[2] Less et al., Phys. Rev. Lett. 119, 131804 (2017)

- ***$e^+e^- \rightarrow \gamma_{ISR} A'$ ($A' \rightarrow$ inv.)***: very promising @ *Belle II*, even with low statistics [1]
- Expected to perform better than BaBar [2]:
  - smaller boost and bigger calorimeter:
    larger acceptance
  - **KLM veto**:
    reject events with a photon undetected in the calorimeter
  - no ECL cracks in pointing to the interaction region: **better calorimeter hermeticity**

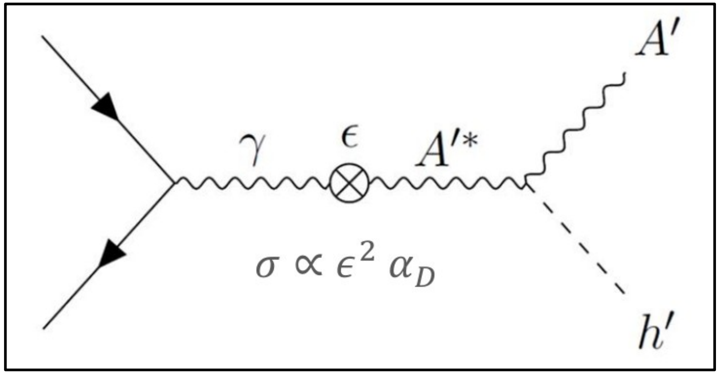




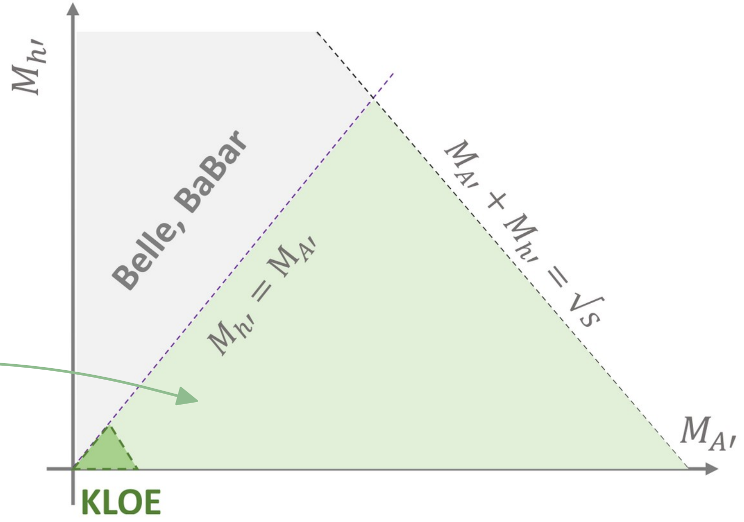
- Analysis timescale ~ end of 2022

Search for a dark Higgs

[1] Batell et al., Phys. Rev. D 79, 115008 (2009)

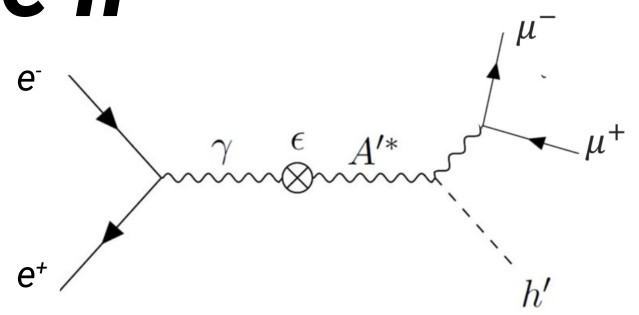


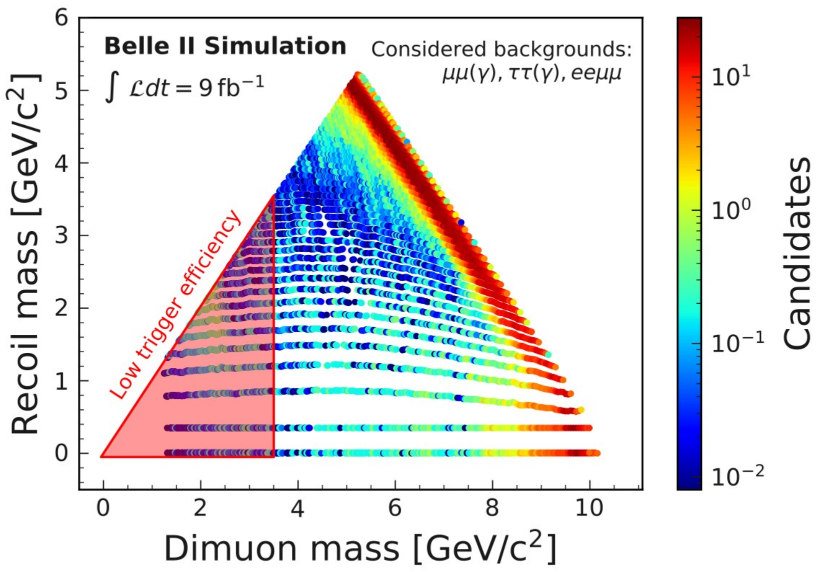
- Dark photon mass produced by the Higgs mechanism involving a dark Higgs boson [1]
- Both *A'* and *h'* can be produced at e^+e^- colliders through the dark higgsstrahlung process
- Different signatures depending on *h'* mass
  - ➔ $M_{h'} > M_{A'}$: prompt decay $h' \to A'A'$, up to 6 tracks in the final state. Investigated by BaBar(2012) and Belle(2015)
  - ➔ $M_{h'} < M_{A'}$: *h'* is long-lived, thus invisible. Investigated by KLOE(2015)
- ***Belle II* focuses on the invisible *h'***



Dark higgstrahlung @ *Belle II*

- ***$e^+e^- \rightarrow A'h'$, $A' \rightarrow \mu\mu$, $h' \rightarrow$ invisible***
  - ➔ Signature: 2D peak in recoil vs dimuon mass
- Analysis strategy:
  - ➔ scan+count in elliptical mass windows (9k overlapping ellipses)
- Background from QED:
  - $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$
  - $e^+e^- \rightarrow \tau^+\tau^-(\gamma)$
  - $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$





Dark higgstrahlung @ *Belle II*

- *$e^+e^- \to A'h'$, $A' \to \mu\mu$, $h' \to$ invisible*
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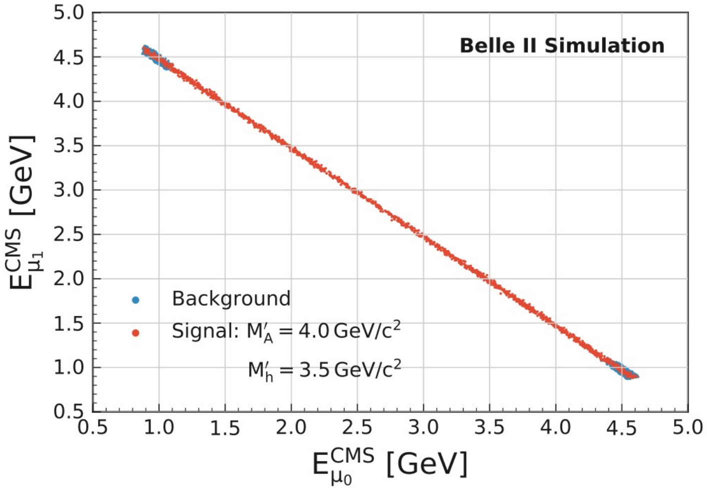
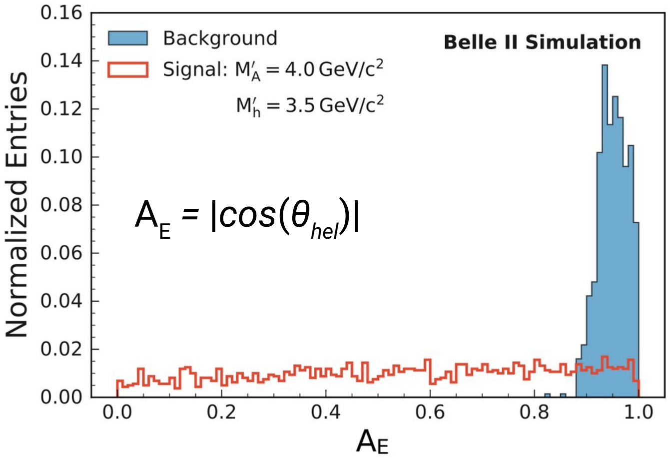
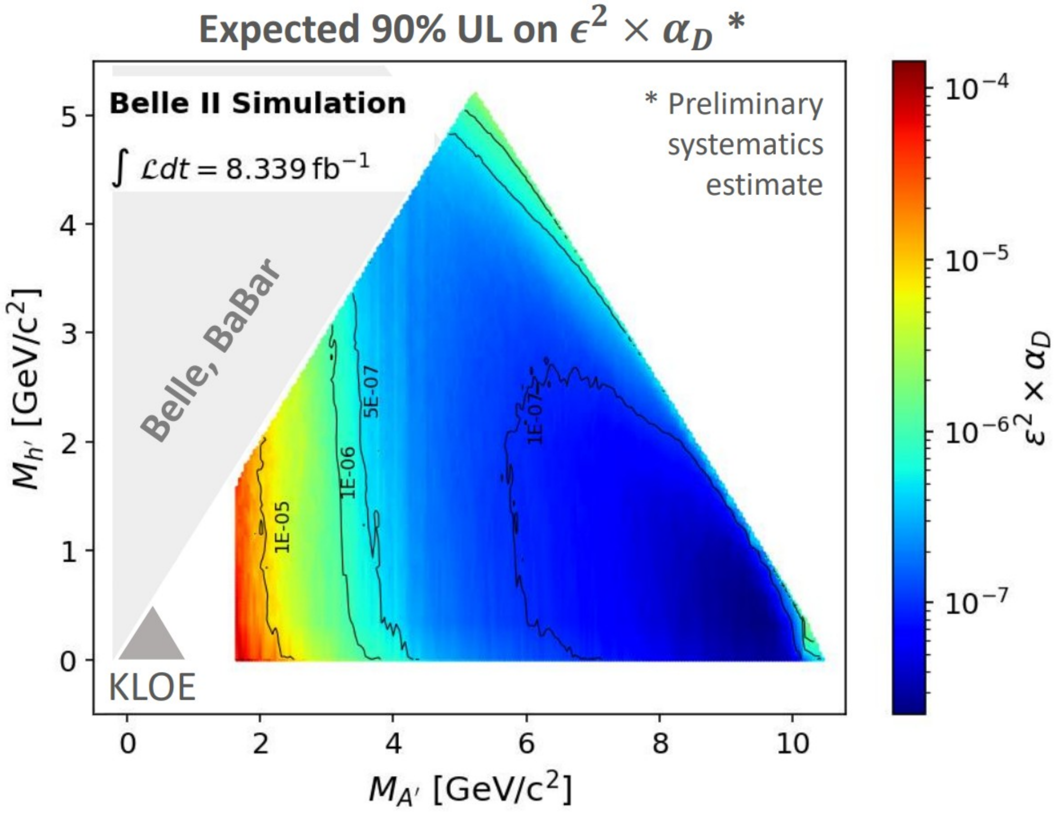
- Analysis strategy:
  - ➔ scan+count in elliptical mass windows (9k overlapping ellipses)
- Background from QED:
  - $e^+e^- \to \mu^+\mu^-(\gamma)$
  - $e^+e^- \to \tau^+\tau^-(\gamma)$
  - $e^+e^- \to e^+e^-\mu^+\mu^-$
- Background suppression based on helicity angle (muon energy asymmetry)



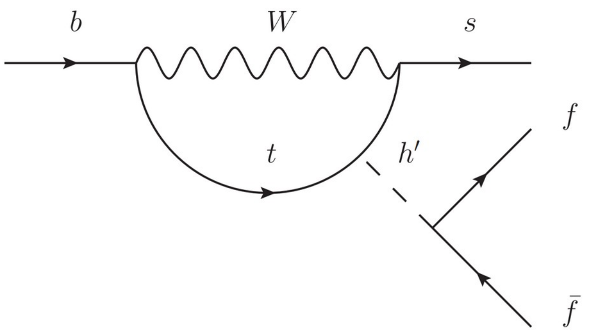


Dark higgstrahlung @ *Belle II*

- Very promising expectations even with the 2019-only dataset (less than 9/fb)
  - ➔ Complementary to BaBar and Belle
  - ➔ Probing the region left unexplored by KLOE
  - ➔ Probing non-trivial $\varepsilon^2\alpha_D$ couplings (below $5 \cdot 10^{-7}$)
- Analysis is going to be published soon!

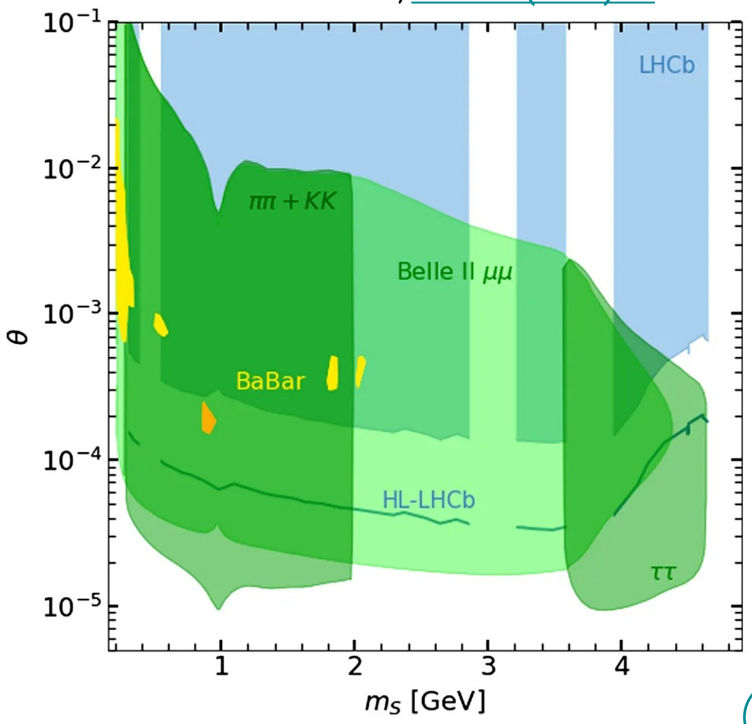


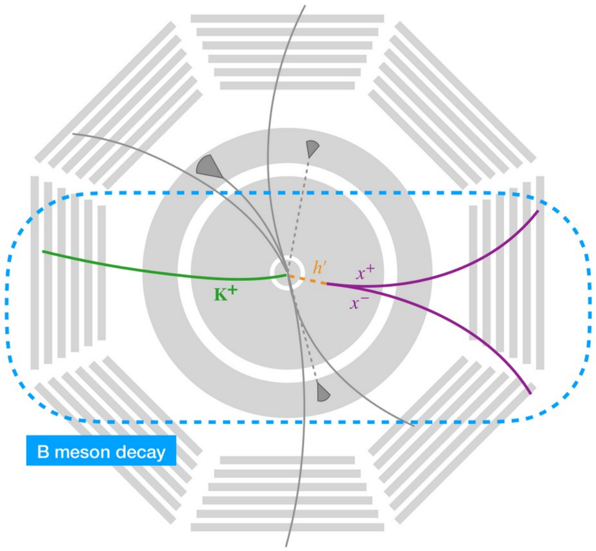
Highlights on *B* → *Kh'*



- Long-lived *h'* produced in $b \to s$ transition
- *h'* mixes with the Standard Model Higgs boson with angle θ
- Search for a bump in the invariant mass of tracks coming from a displaced vertex
- LHCb and *Belle II* complementary

Filimonova et al., [JHEP04 (2021) 39]

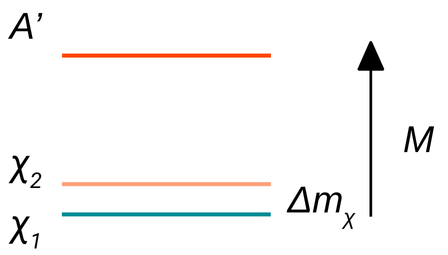


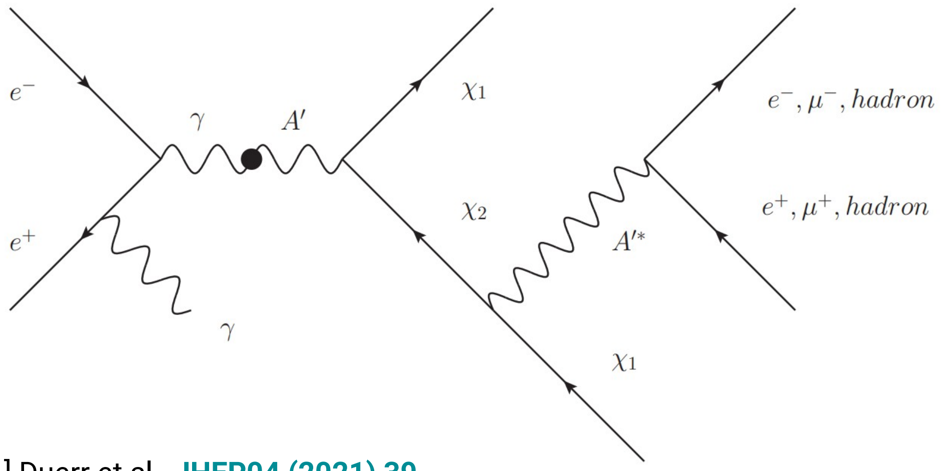


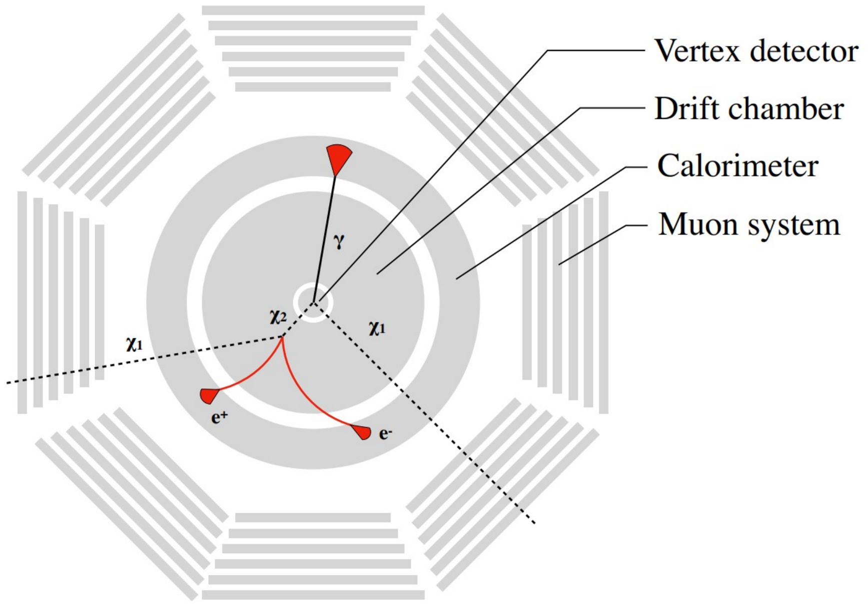
- Exclusion regions expected with 50/ab at *Belle II* in green
- Analysis timescale ~ end of 2022

Inelastic Dark Matter (iDM) @ *Belle II*

- Expanded dark sector with two dark matter states with a small mass splitting and a dark photon
  - ➔ χ_1 is stable (relic candidate)
  - ➔ χ_2 is long-lived
- Focus on $M_{A'} > m_{\chi 1} + m_{\chi 2}$: the decay $A' \rightarrow \chi_1\chi_2$ is favored







[1] Duerr et al., JHEP04 (2021) 39
[2] Duerr et al., JHEP04 (2021) 146

iDM @ *Belle II*

- Expanded dark sector with two dark matter states with a small mass splitting and a dark photon
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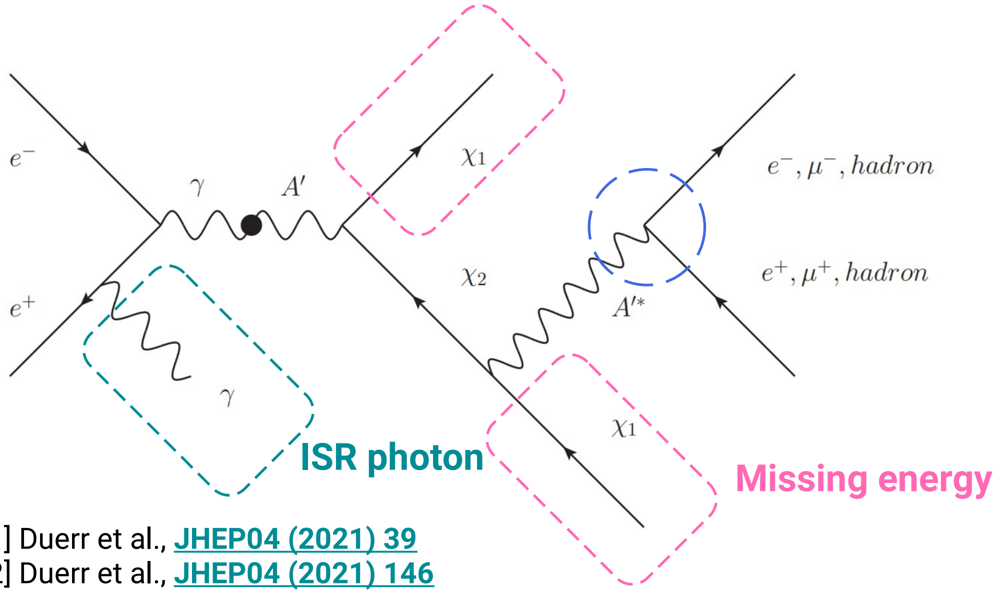
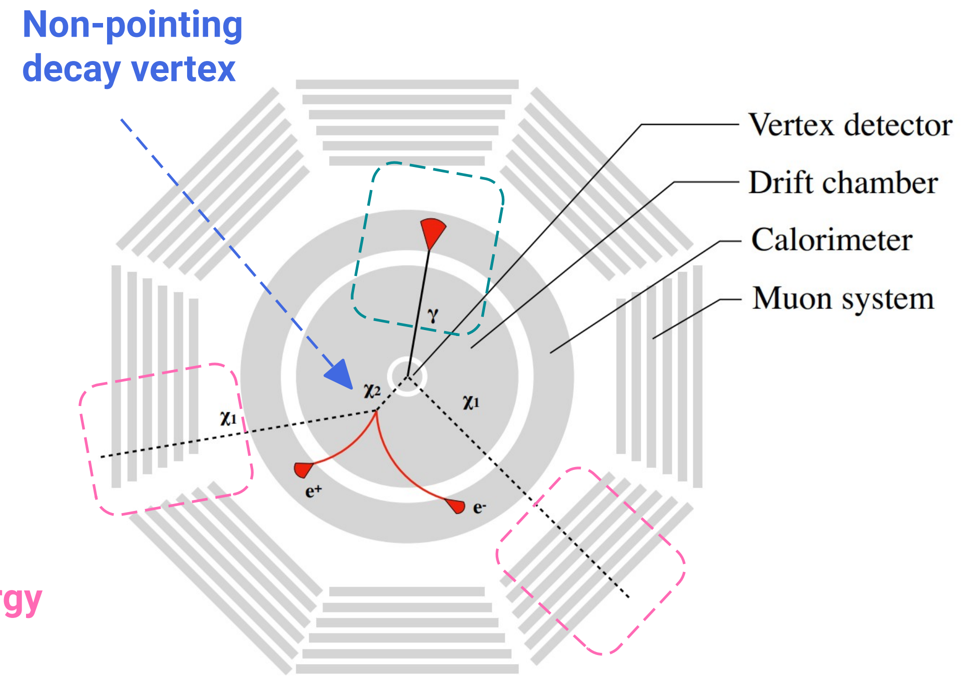
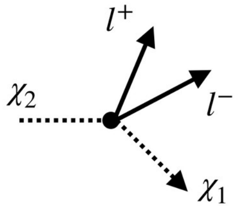




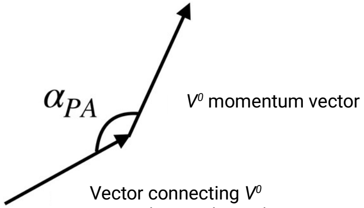
[1] Duerr et al., JHEP04 (2021) 39
[2] Duerr et al., JHEP04 (2021) 146

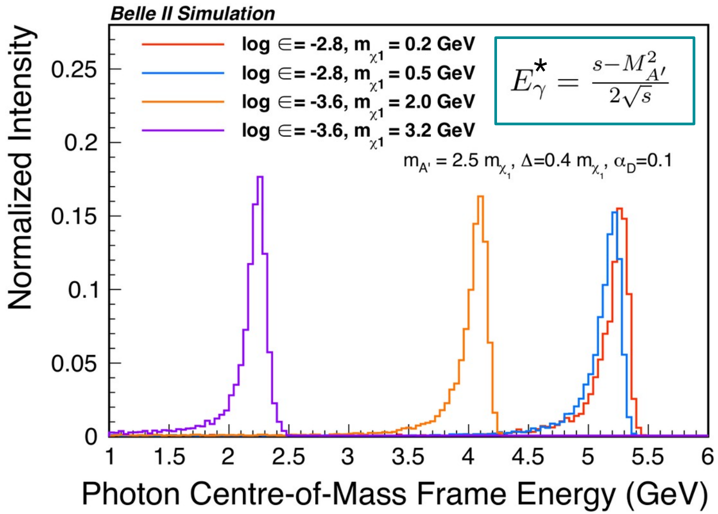
Search for iDM

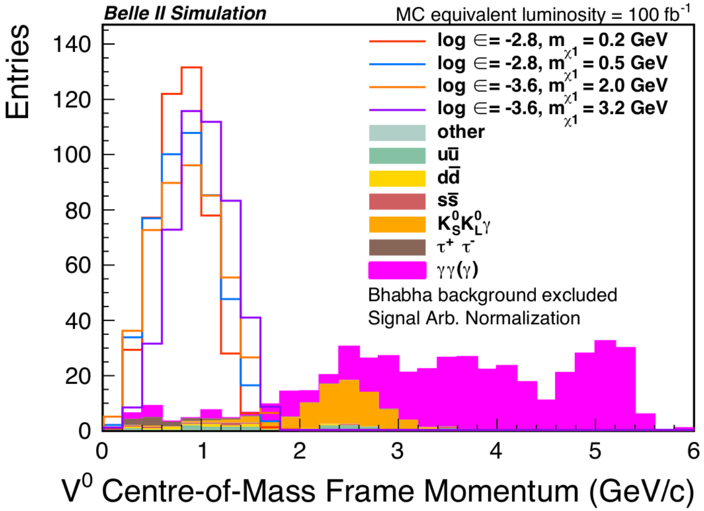
- Search for a peak in the center-of-mass frame energy of the ISR photon plus a displaced vertex V^0
- Background:
  - photon conversion, $e^+e^- \rightarrow \gamma\gamma(\gamma)$, $\gamma \rightarrow e^+e^-$
  - meson decays, $e^+e^- \rightarrow K_S^0 K_L^0(\gamma)$, K_S^0 decays
- Background suppression:
  - ➔ V^0 momentum

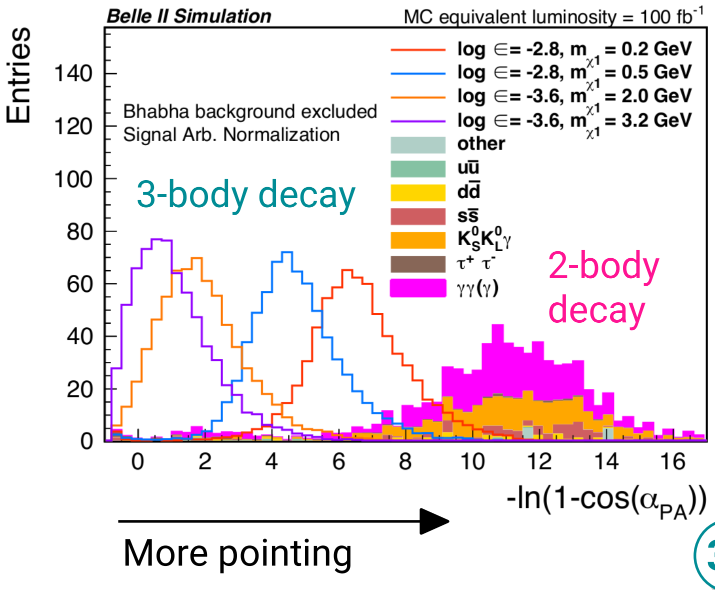


  - ➔ Pointing angle α_{PA}



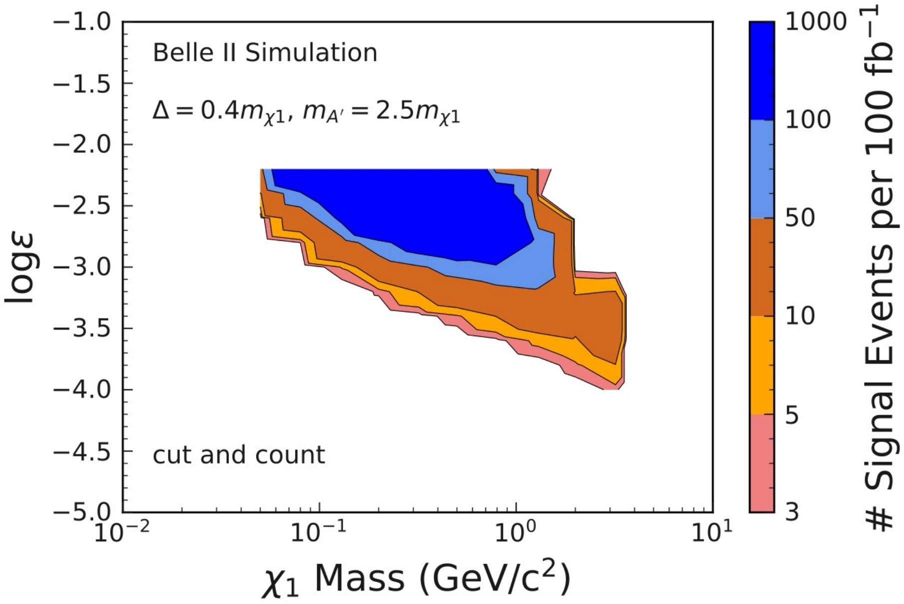




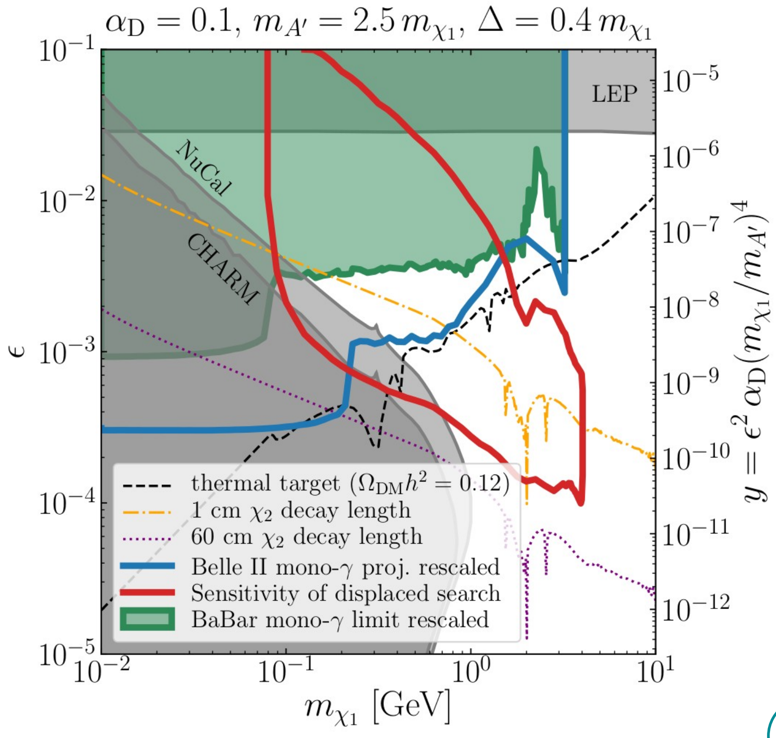


iDM prospects

- Estimate signal yield by counting events in ISR photon energy window (final analysis will use a template fit)
- With early *Belle II* dataset expect to probe dark sector-Standard Model couplings down to 10^{-3} – 10^{-4}
- New displaced vertex trigger under consideration
- Analysis timescale ~ end of 2022



Duerr et al., JHEP04 (2021) 39



Conclusions

- The Belle II experiment is exploring Dark Sectors at the luminosity frontier

  → Will lead in the MeV-GeV mass range in the coming years

- > 240/fb collected up to now

- World-leading results with early data:

  → $Z' \to$ invisible: [Phys. Rev. Lett. 124 (2020) 141801]

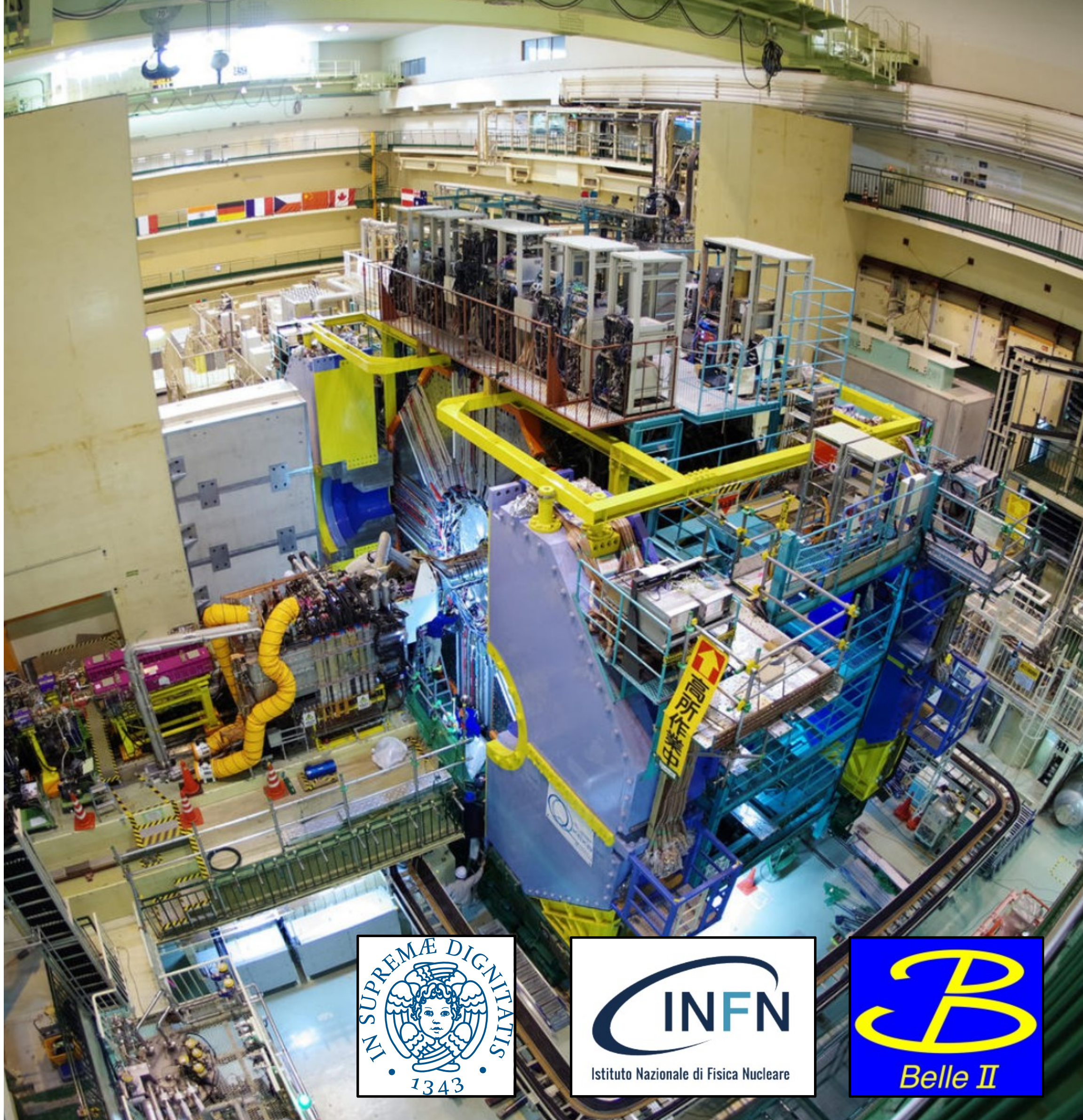
  → $a \to \gamma\gamma$: [Phys. Rev. Lett. 125, 161806 (2020)]

- Many new searches ongoing: dark Higgs, dark photon, visible Z', Long-lived dark particles …

Control room during first phase3 collisions on March 2019

Thank you for the attention!

Luigi Corona - INFN and University of Pisa
luigi.corona@pi.infn.it
on behalf of the *Belle II* collaboration

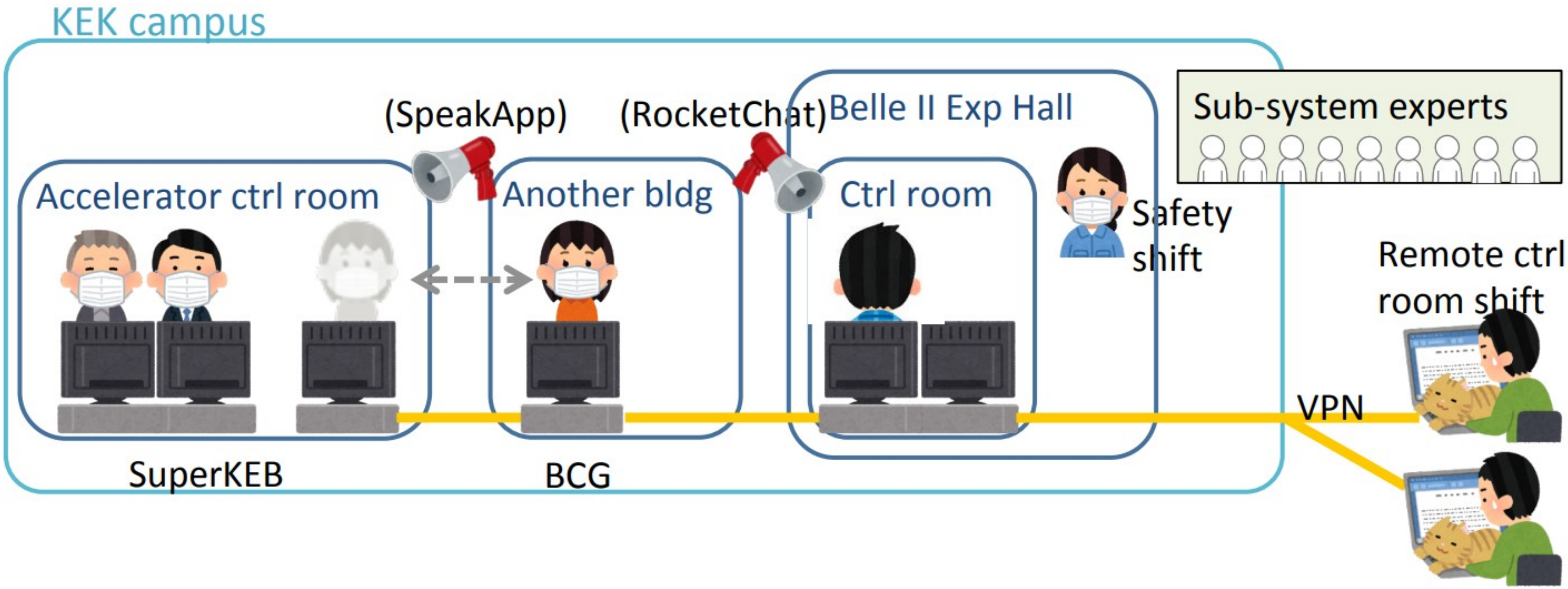


Backup Slides

Taking data during the pandemic

- Non-stop operations with COVID-19 pandemic
  - ➔ Social distancing requirements
  - ➔ Strong developments for close to or fully remote sub-system operations
  - ➔ Huge commitments from japanese colleagues and residents in Japan

Data-taking efficiency: 89.5%



Luminosity

Beam currents

Beam-beam parameter

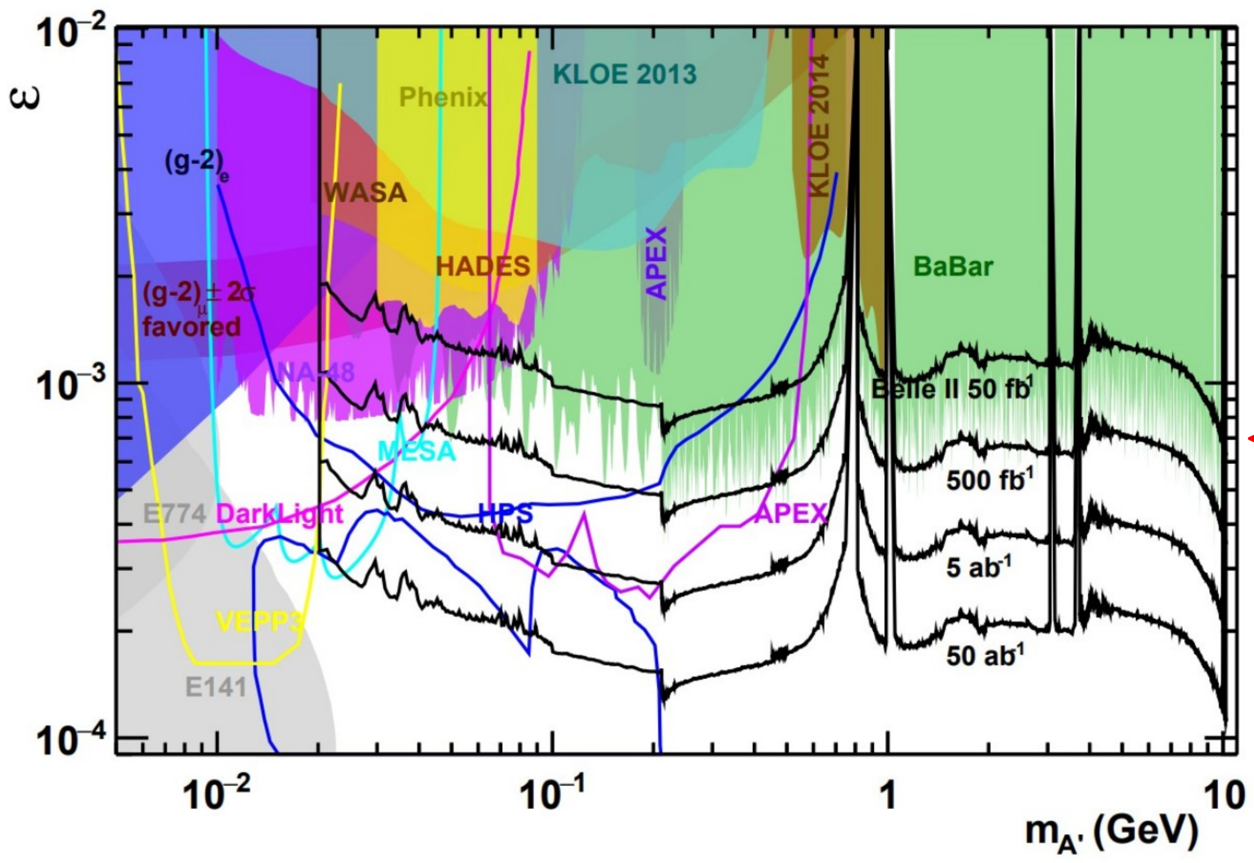
$$\mathcal{L} = \frac{\gamma_{\pm}}{2er_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_{\pm}\xi_{y\pm}}{\beta_{y\pm}^*}\frac{R_L}{R_{\xi_y}}$$

Geometrical reduction parameter (~0.8 – 1)

Ratio between the y and x dimension of the beam (0.01 – 0.02)

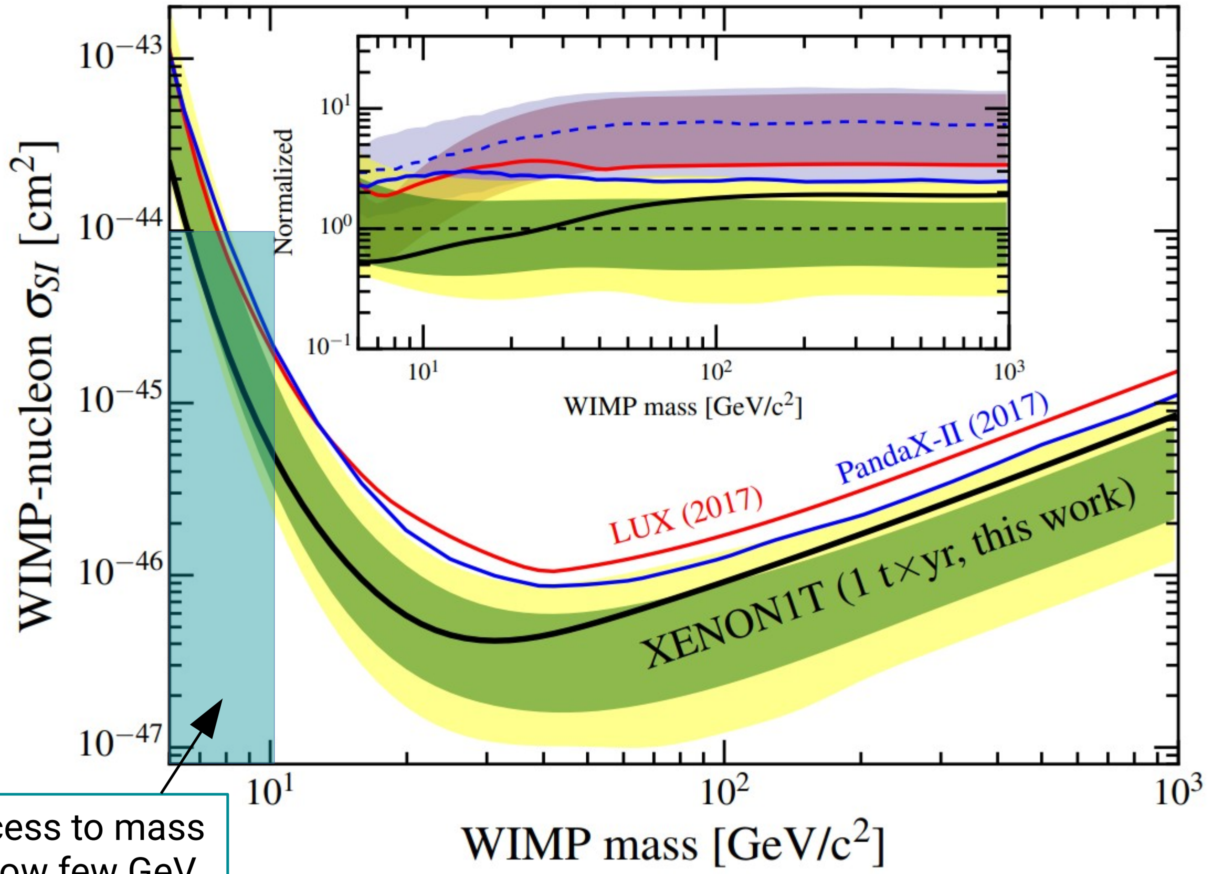
Vertical beta function at IP

UL on visible *A'* searches



BaBar limit on ε ~ $7 \cdot 10^{-4}$

Weak direct detection bounds



Access to mass below few GeV

- Large detectors search for DM scattering against nuclei/electrons