Dark sector searches at Belle II

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Belle II

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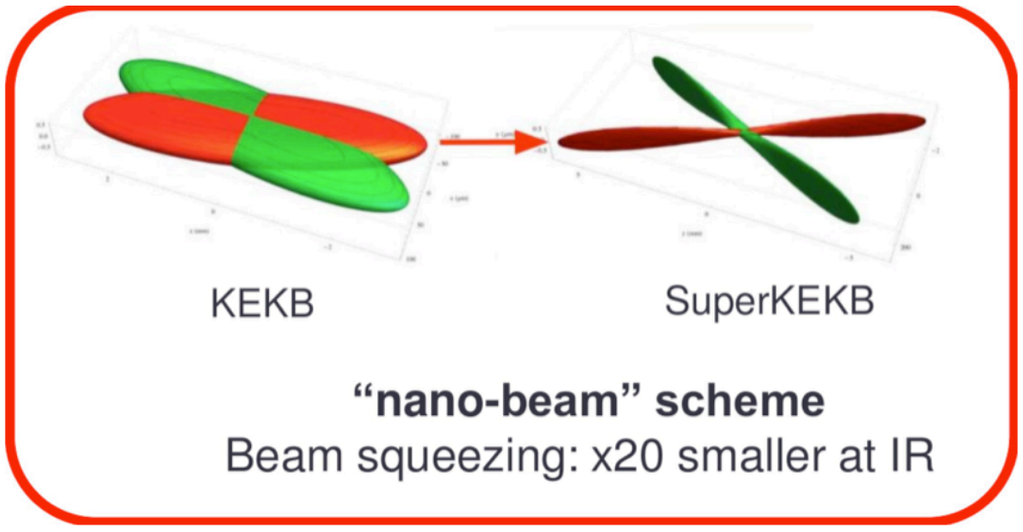
JENNIFER 2
EU grant n.822070

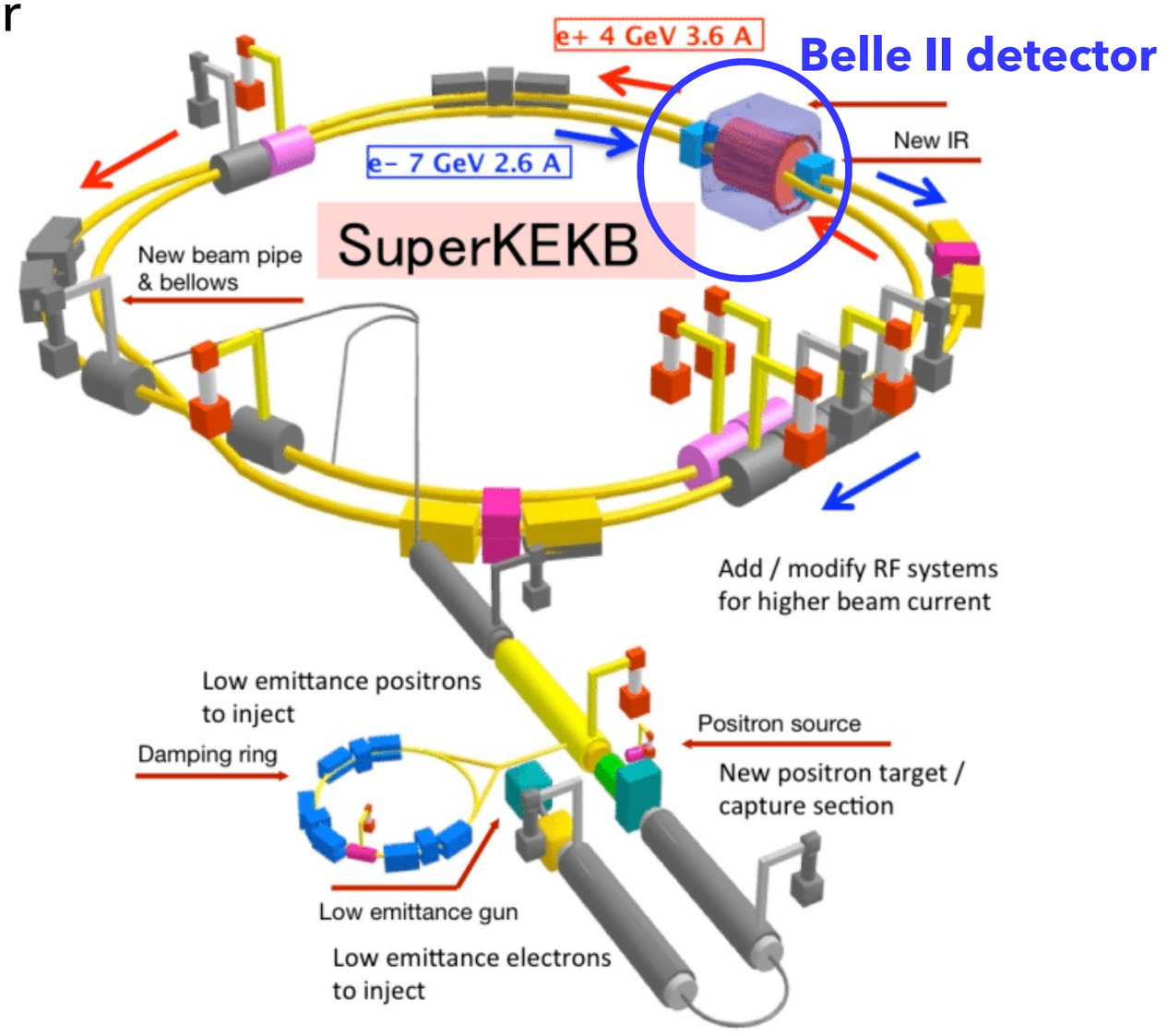
The SuperKEKB e^+e^- - collider

- SuperKEKB is an asymmetric e^+e^- - collider located in Tsukuba, Japan

- CM energy: 10.58 GeV ($\Upsilon(4S)$ resonance)

Tuneable between $\Upsilon(2S)$ and $\Upsilon(6S)$ resonance as well

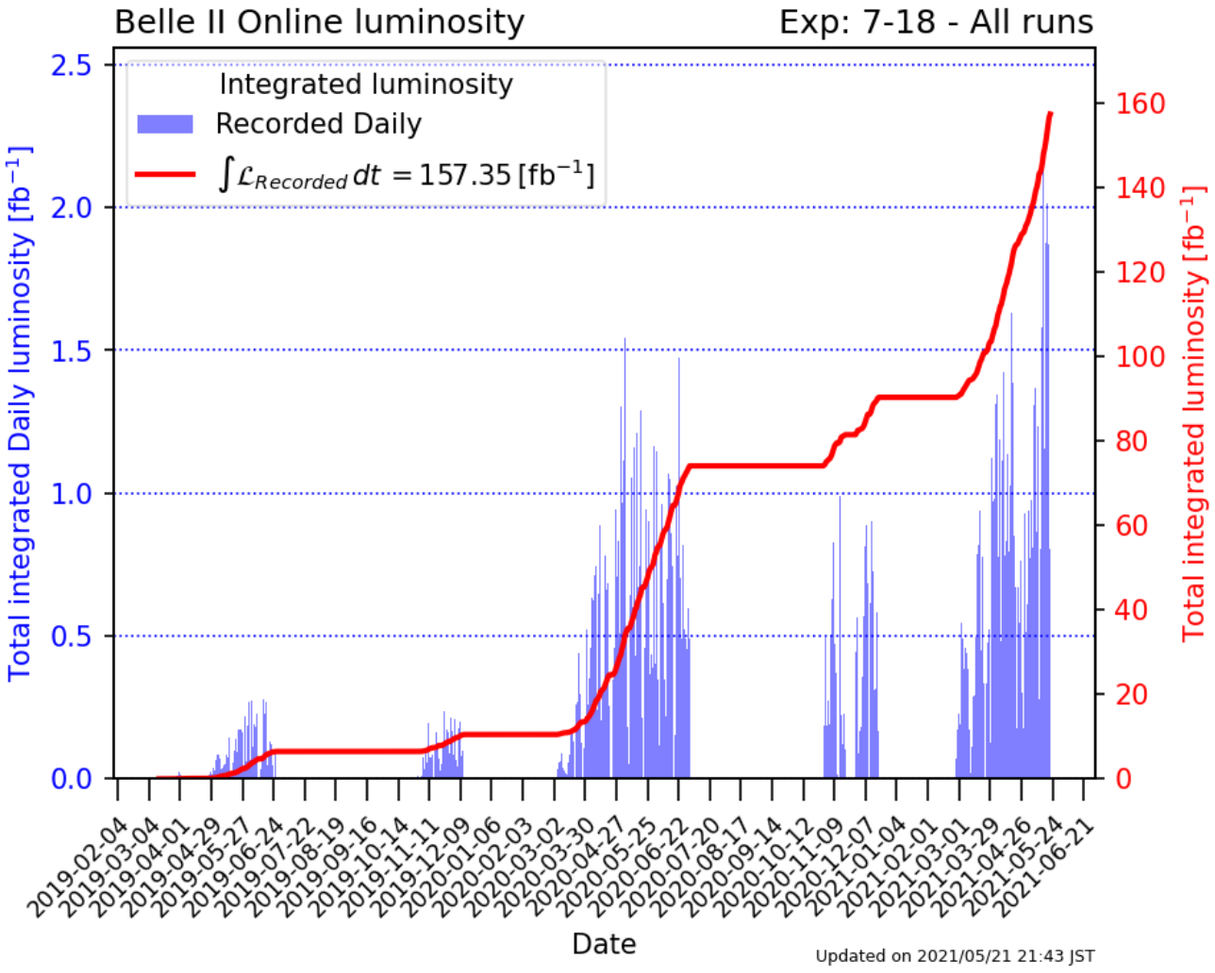


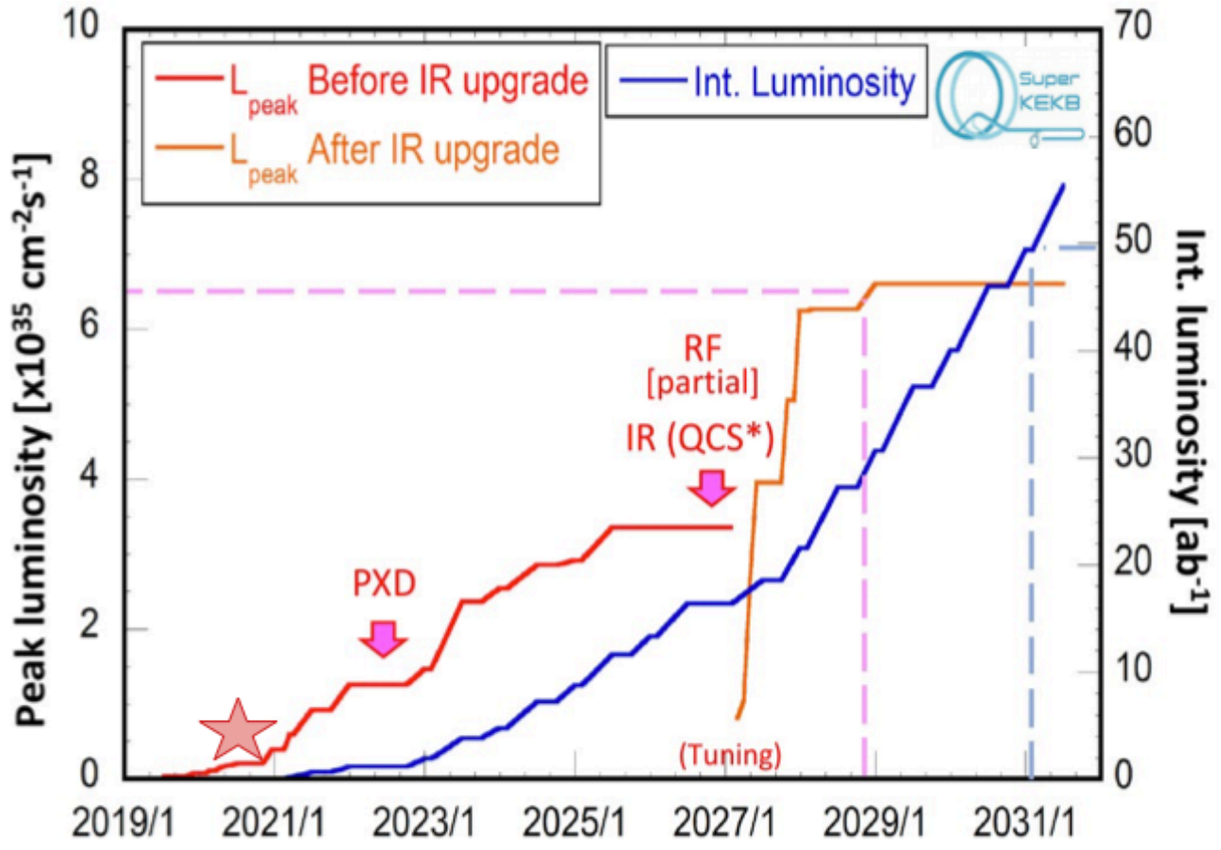


Target peak luminosity : $6 \times 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Achieved (May 2021) : $2.8 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

B-factories at the intensity frontier





- Pilot run in 2018: 500 pb^{-1} recorded
- Integrated luminosity (May 2021) : > 150 fb^{-1}

Objective: 50 ab^{-1} by 2030

The Belle II detector

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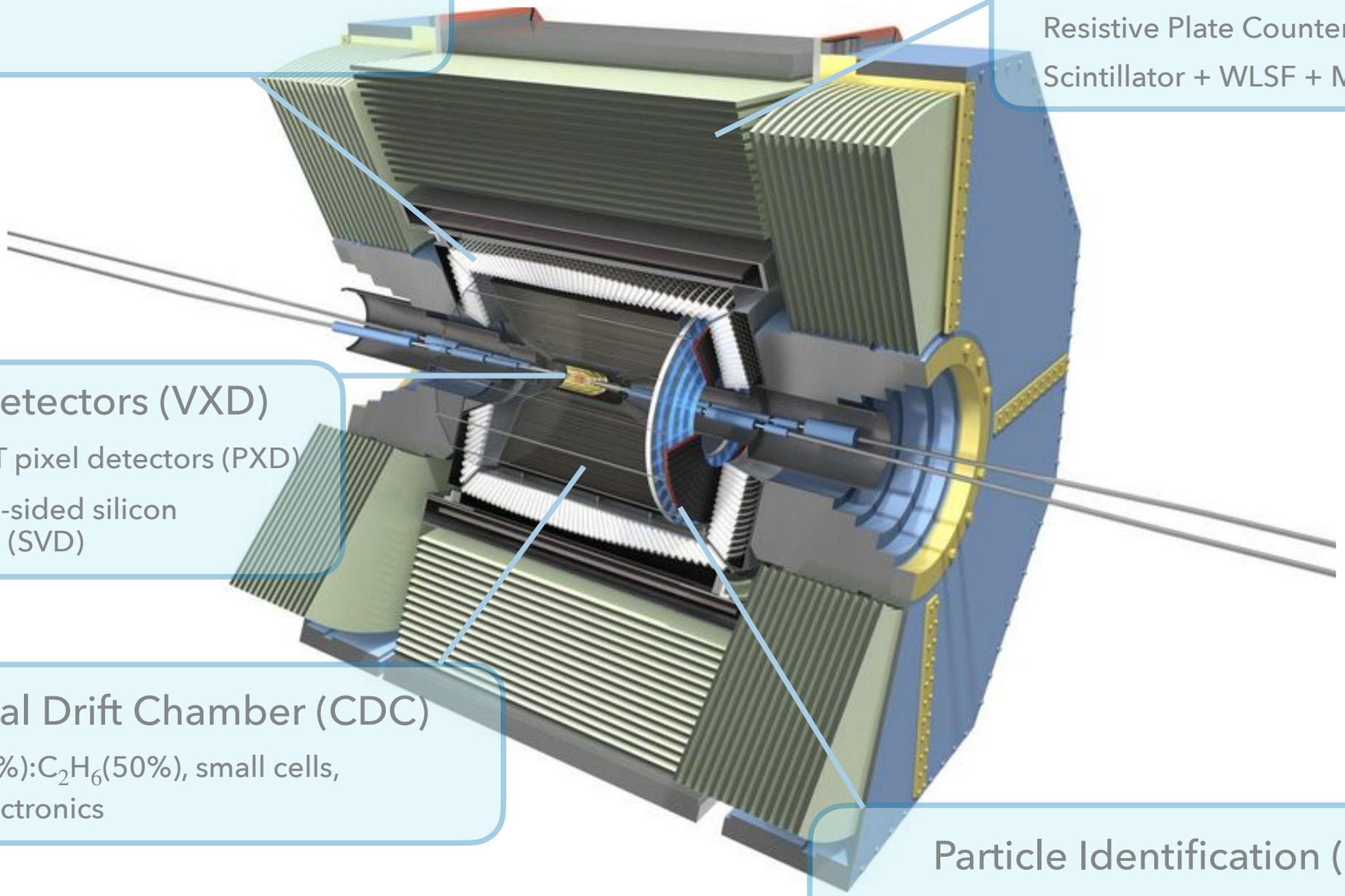
Electromagnetic calorimeter (ECL)

CsI(TI) crystals

K_L and muon detector (KLM)

Resistive Plate Counter (RPC) (barrel)

Scintillator + WLSF + MPPS (end-caps)



Vertex Detectors (VXD)

1 layer DEPFET pixel detectors (PXD)

4 layer double-sided silicon strip detectors (SVD)

Central Drift Chamber (CDC)

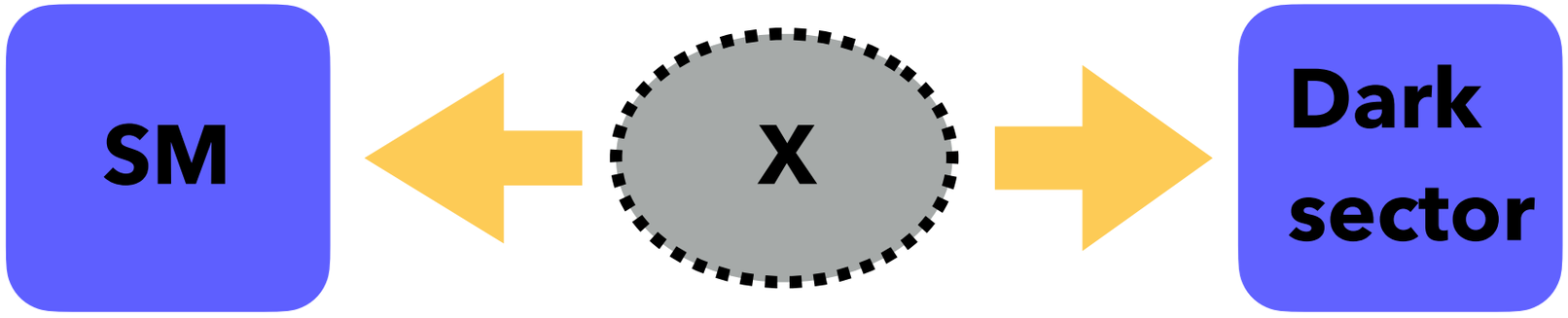
He (50%):C_2H_6(50%), small cells, fast electronics

Particle Identification (PID)

Time-of-Propagation counter (TOP) (barrel)

Aerogel Ring-Imaging Cerenkov Counter (ARICH)

Dark matter (DM) searches

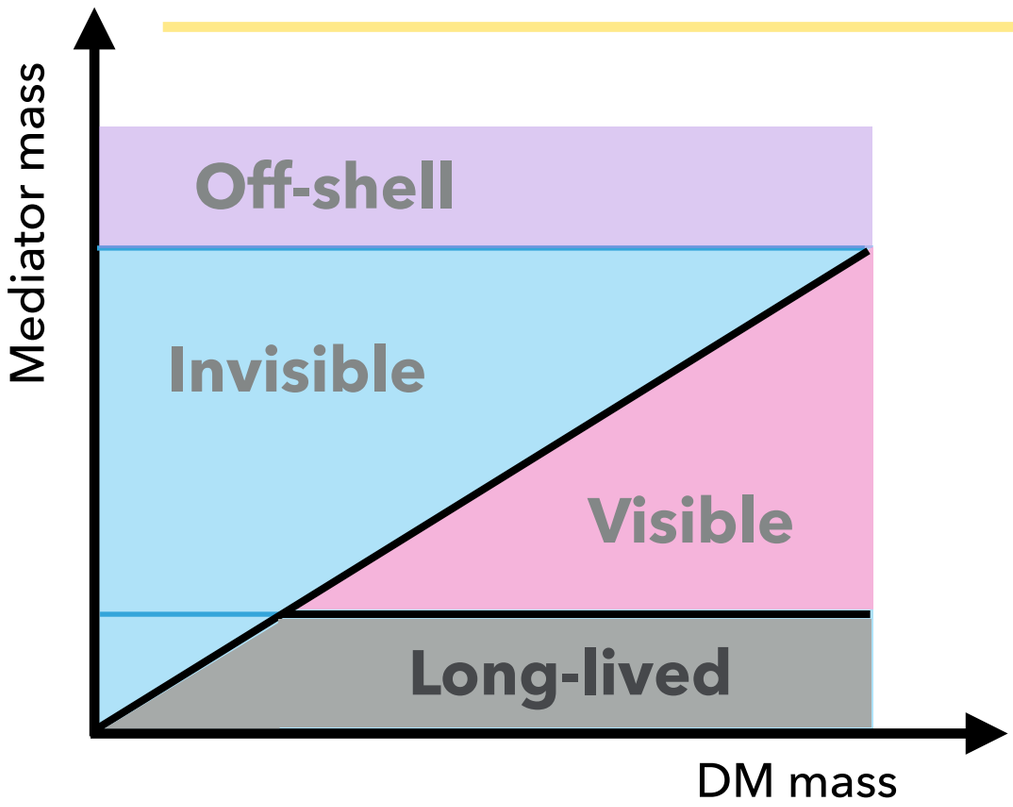


Models for low-mass (sub-)GeV DM with light dark mediator between Standard Model (SM) and DM

Possible portals between DM and SM

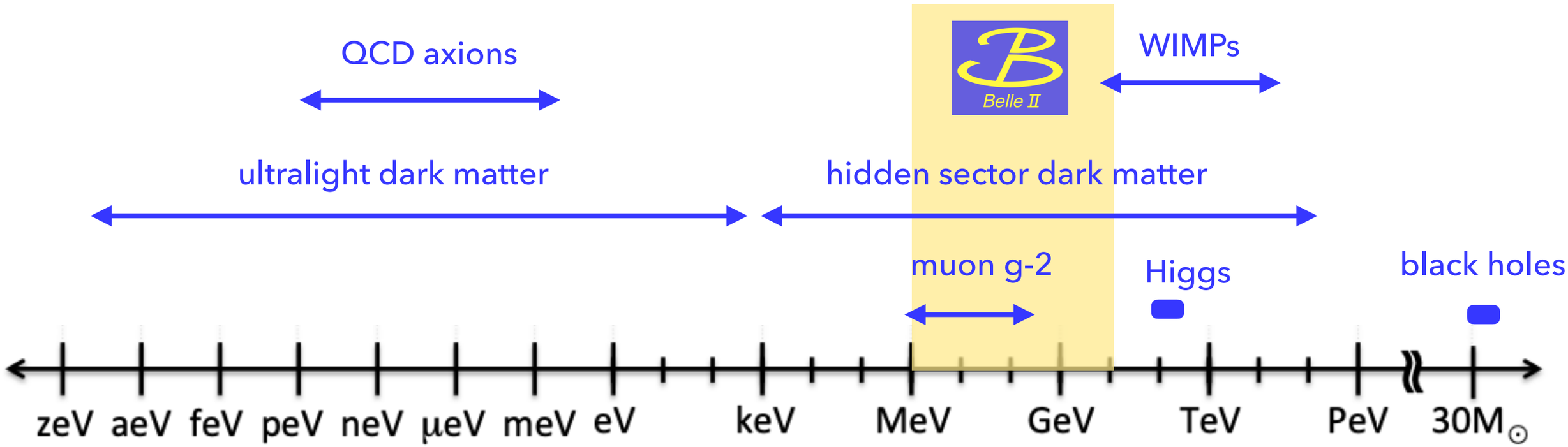
- Vector portal (dark photon A′, dark Z′)
- Pseudo-scalar portal (axion-like particle)
- Scalar portal (dark scalars)
- Neutrino portal (sterile neutrino)

Search for Dark Matter



Dark matter searches at Belle II profit from:

- Well-defined initial conditions
- Hermetic detector
- Clean collision environment
- Excellent PID
- Dedicated low-multiplicity triggers



arXiv:1707.04591

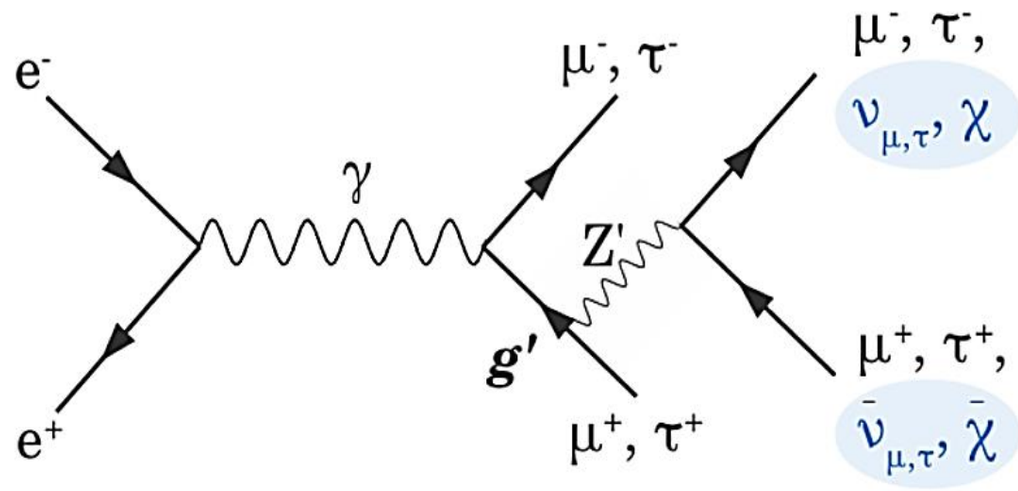
Invisibly decaying Z′ boson

Shuve et al. (2014) Phys. Rev. D 89, 113004

Altmannshofer et al. (2016) JHEP 1612 106

- $L_\mu - L_\tau$ model: new light gauge boson Z′ arises that only couples to 2nd and 3rd lepton family

- Model might explain:
  - Dark matter puzzle
  - $(g - 2)_\mu$ anomaly
  - $B \to K^{(*)}\mu\mu$, $R_{K^{(*)}}$ anomalies



$$e^+e^- \to \mu^+\mu^- Z'$$

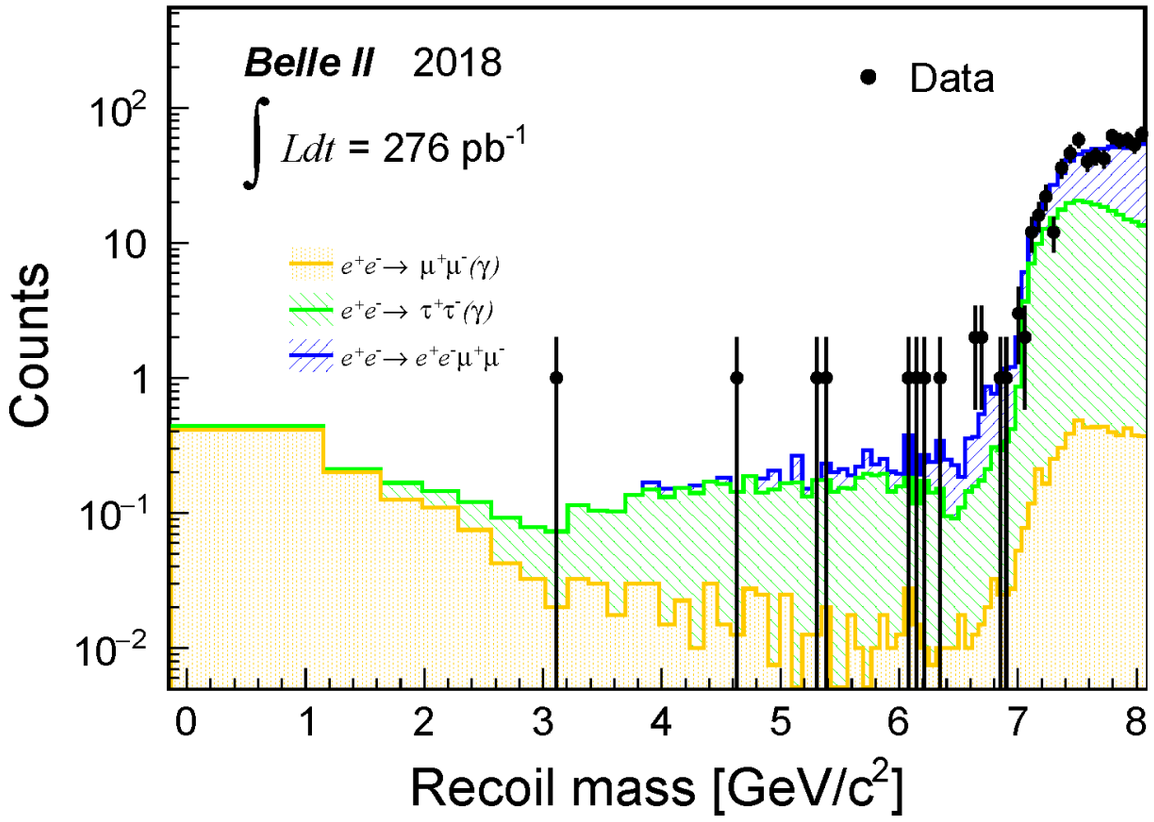
$$Z' \to \text{invisble}$$

- Experimental search for Z′ decaying invisibly
  - Searching for peak in the recoil system against $\mu\mu$

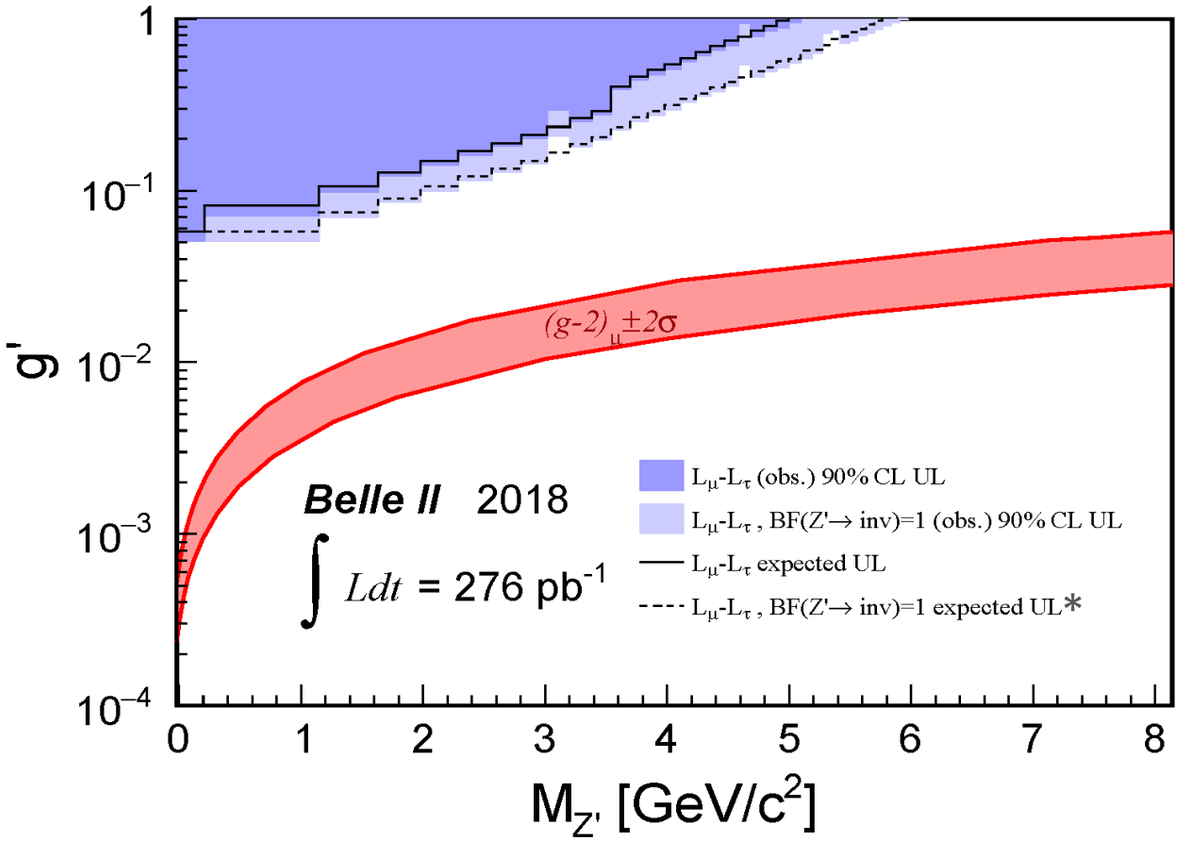
Invisibly decaying Z' boson

- Search performed with only 276 pb^{-1} that was taken during the 2018 pilot run of Belle II
- Improvements :
  - New triggers
  - PID system
  - Analysis techniques based on machine learning

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



90% CL upper limits

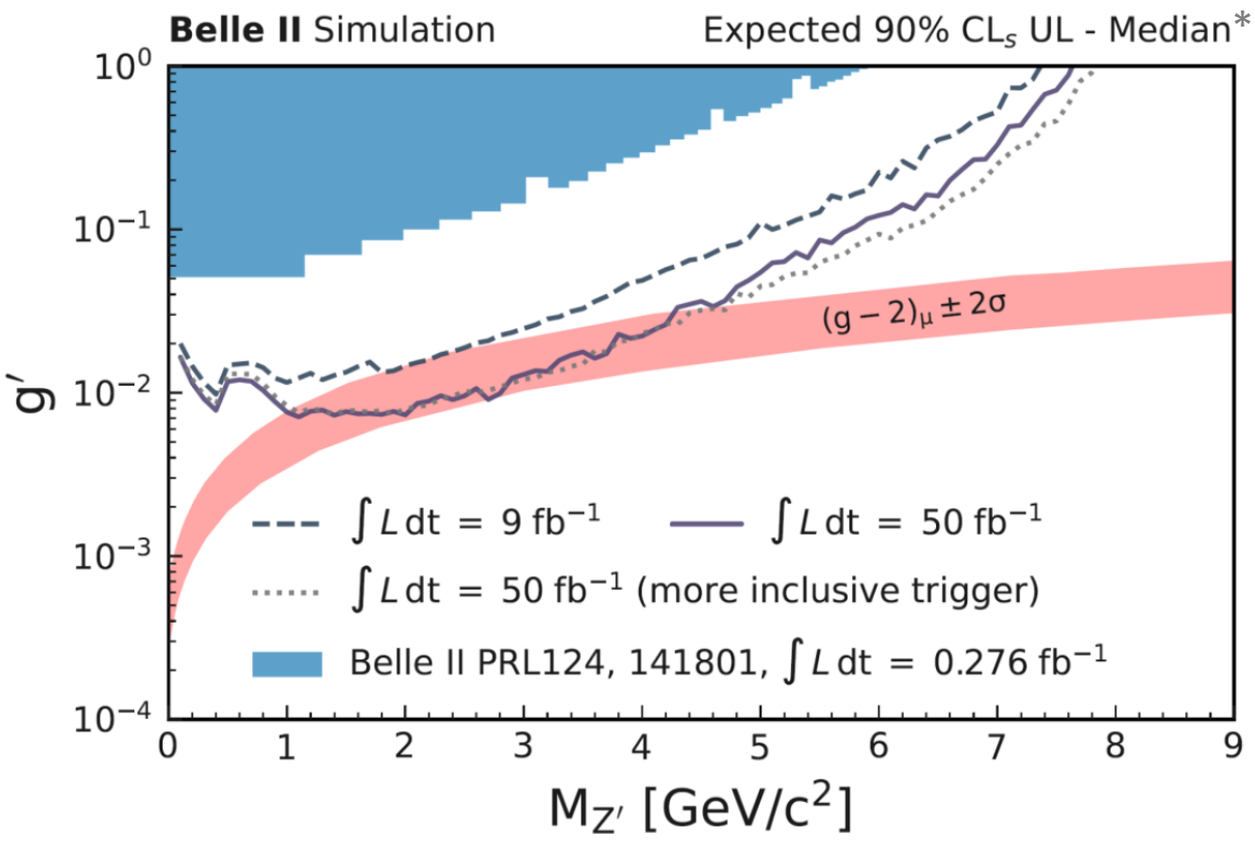


Invisibly decaying Z' boson

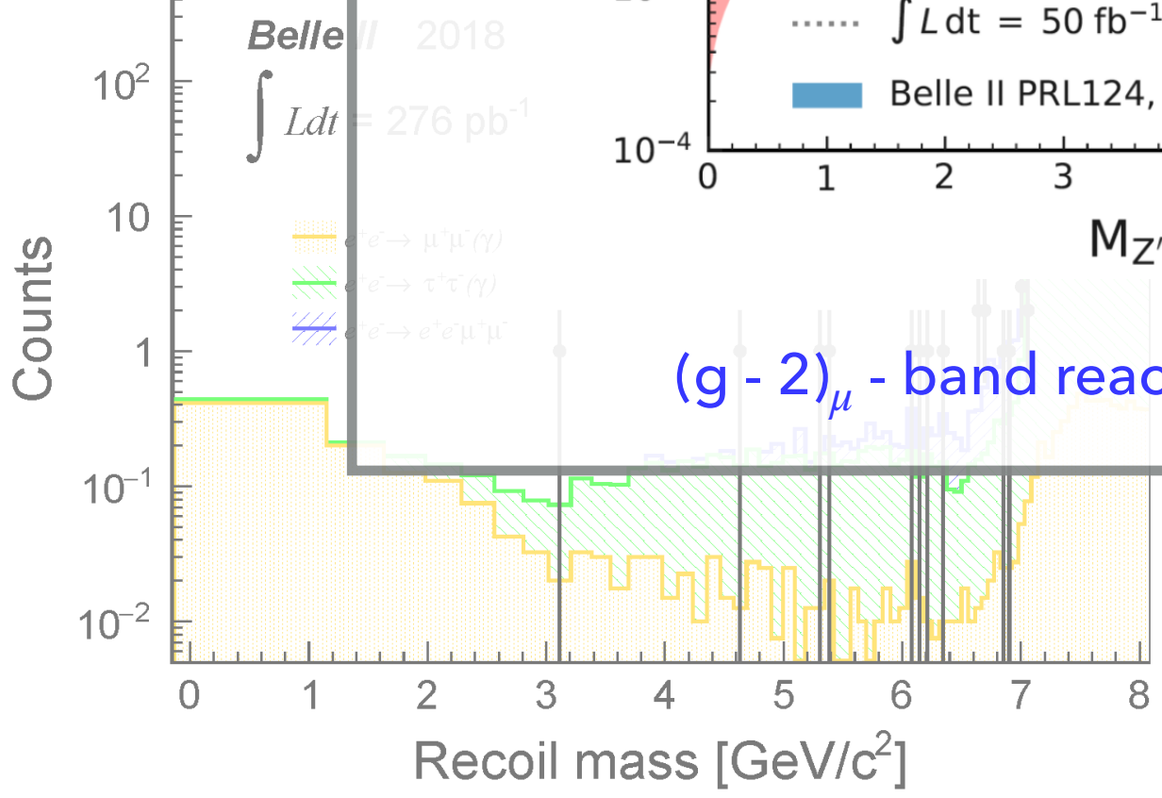
- Search performed with only 276 pb^{-1} that was taken during the 2018 pilot run of Belle II
- Improvements:
  - New trig
  - PID syste
  - Analysis on mach

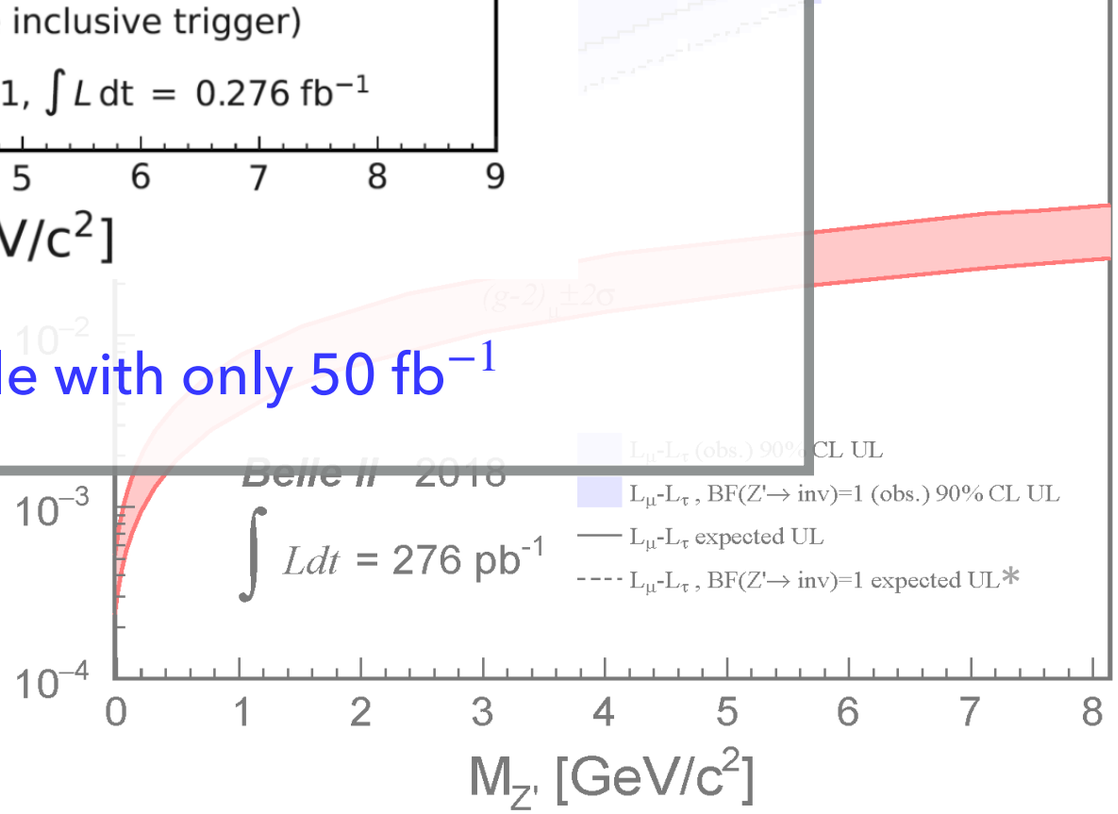
II physics paper: 41801 (2020)

preliminary (conservative) systematics



$(g - 2)_\mu$ - band reachable with only 50 fb^{-1}

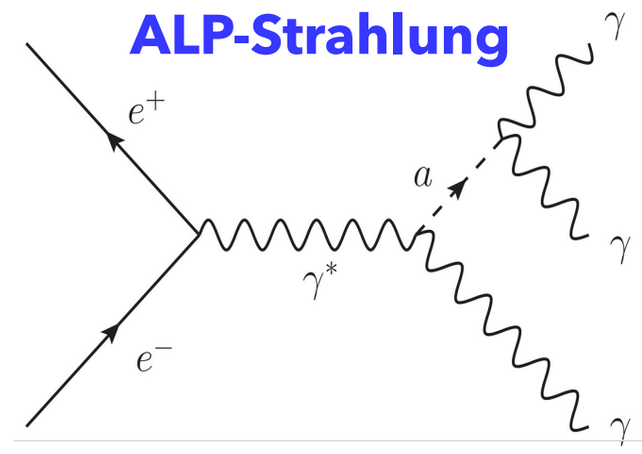




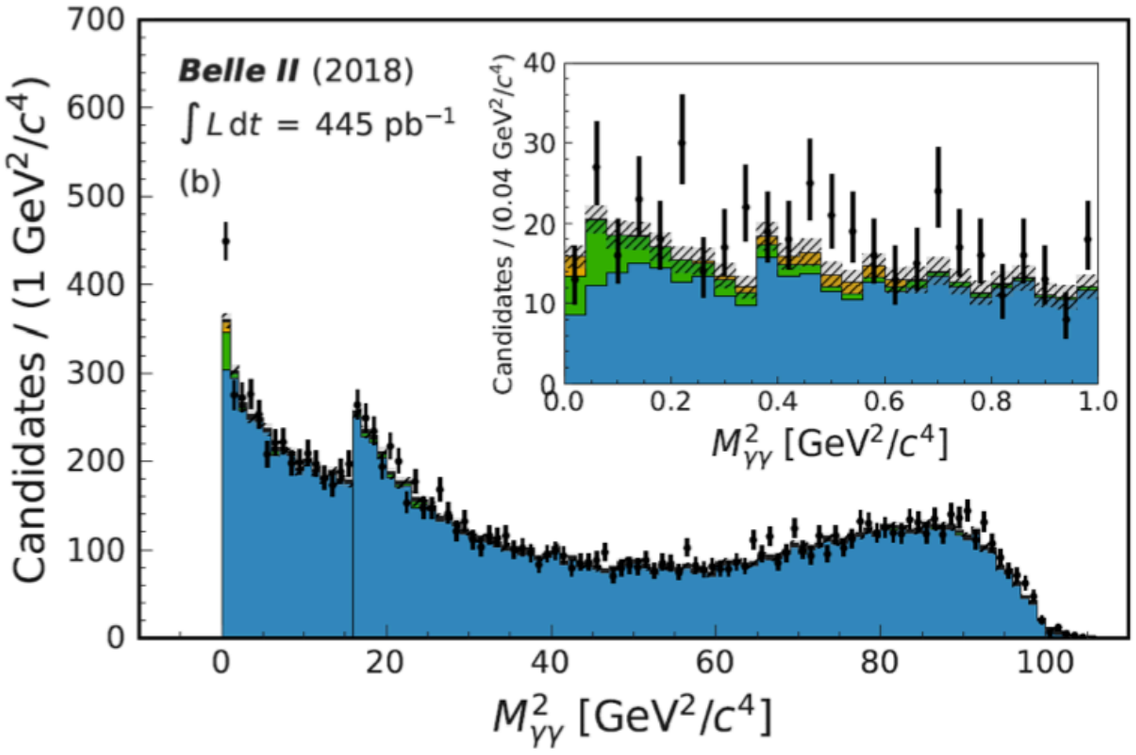
Axion Like Particles (ALPs)

- Axion Like Particles (ALPs) are pseudo-scalars coupling to bosons which appear in several BSM models
- Analysis performed with 445 pb^{-1} recorded during 2018 pilot run
- Search for peak in :

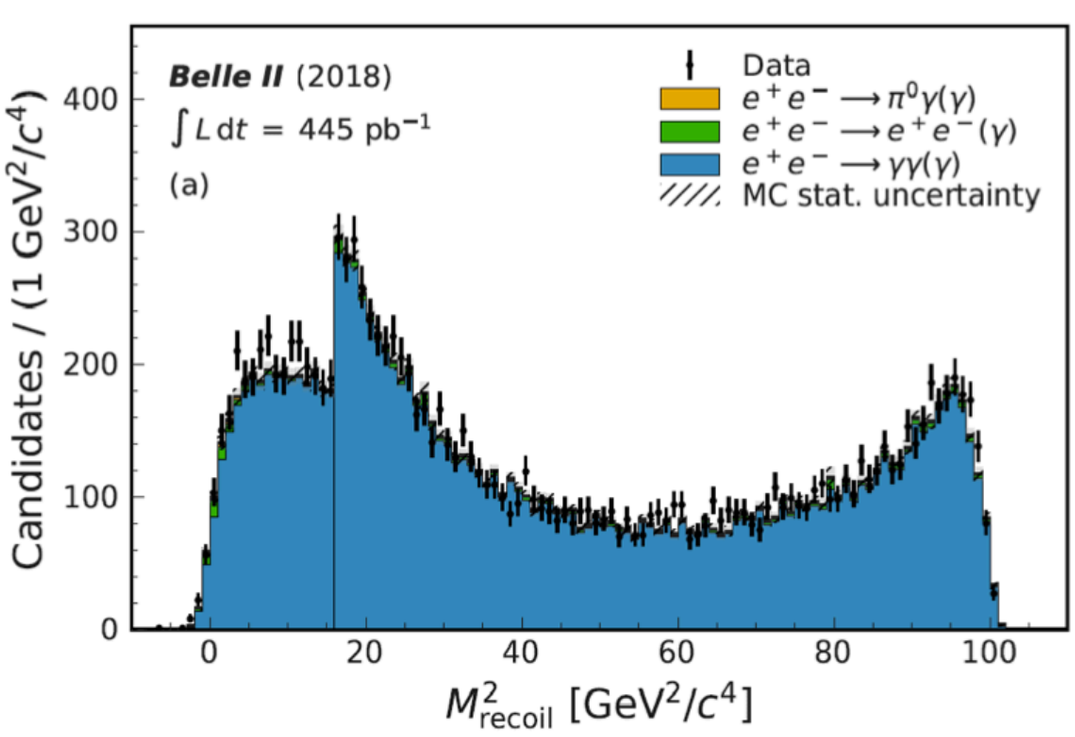
Belle II focusing on ALPs coupling to photons



Diphoton invariant mass (low m_a)



Recoil invariant mass (high ALP mass m_a)



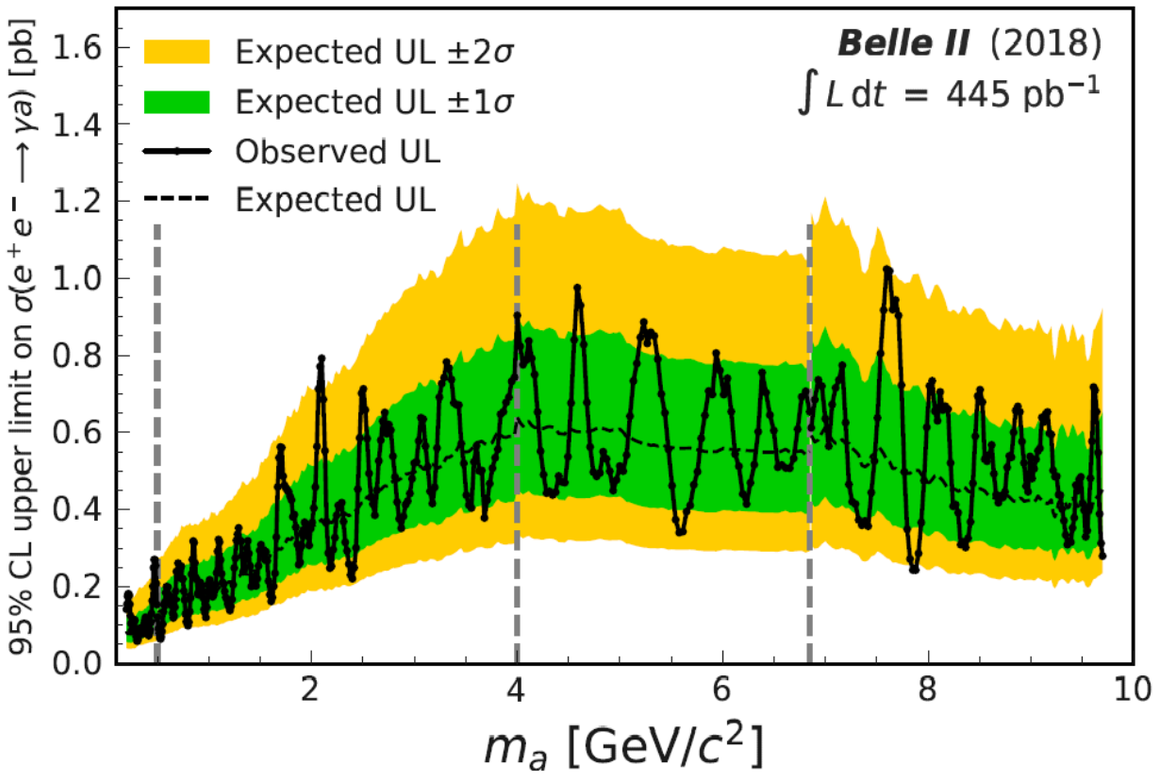
Axion Like Particles (ALPs)

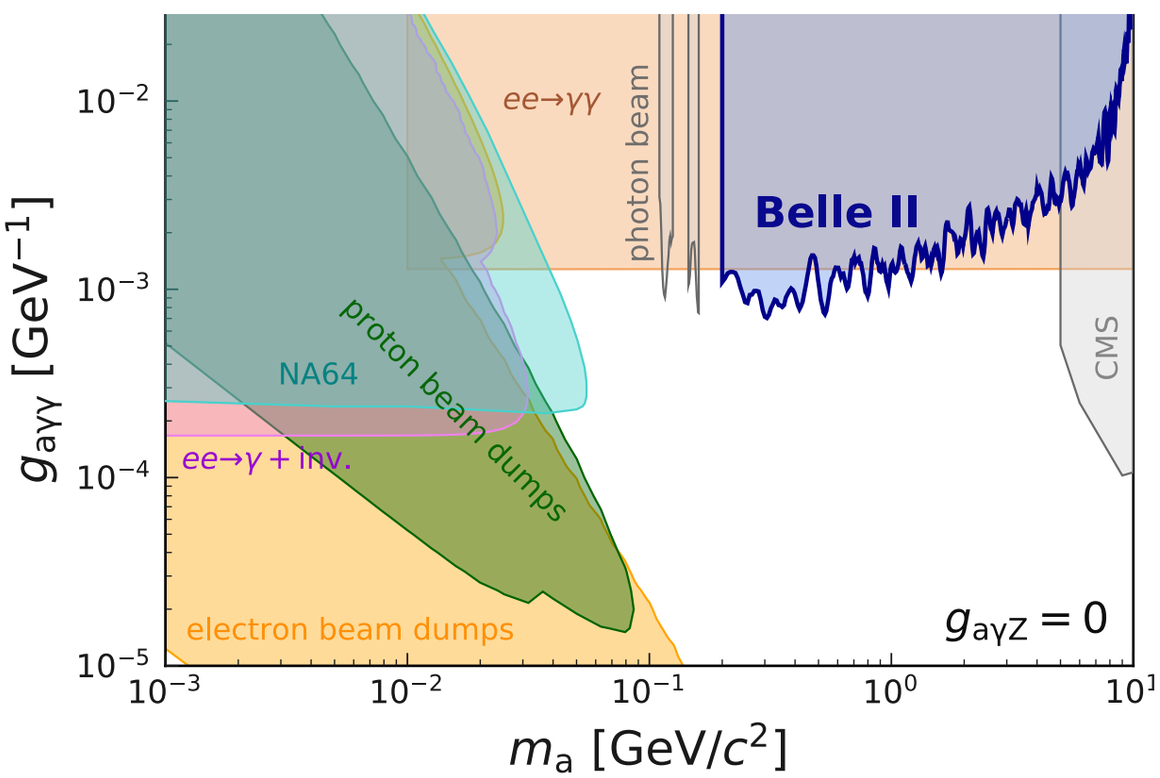
- Mass range between 0.2 to 9.7 GeV/c^2 studied
- No excess was found
- Upper limits on cross section translated to coupling constant

Belle II physics paper:
PRL 125, 161806 (2020)

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

90% CL upper limits on the cross section





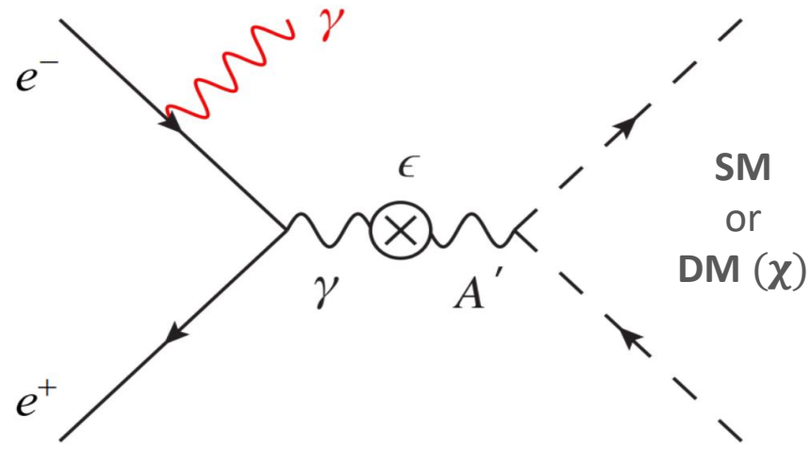
Dark Photon to Invisible

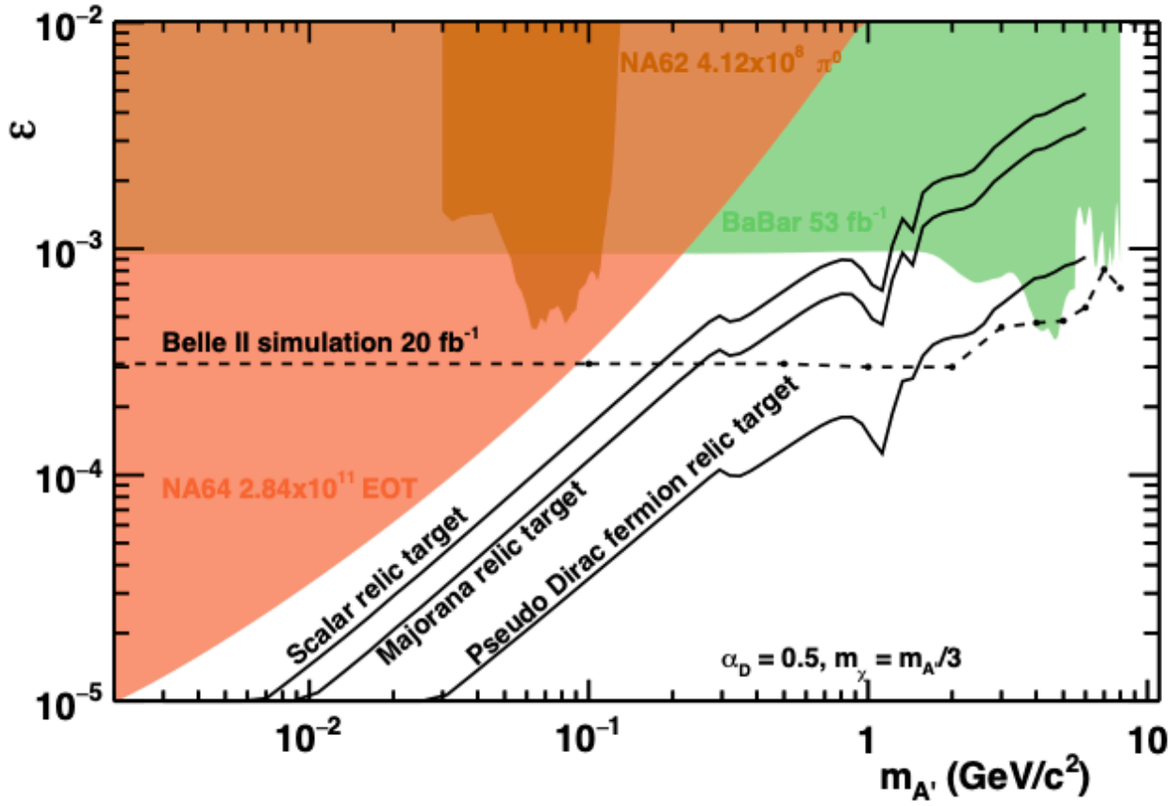
- Dark photon A′ : new massive gauge boson coupling to SM photon by kinetic mixing with mixing strength ε

- Invisible decay: $e^+e^- \to \gamma_{ISR}A' \to \gamma_{ISR}\chi\bar{\chi}$

  - Search for single photon in the detector
    - Requires single photon trigger and precise knowledge of detector acceptance to reject background

- Background sources:
  - $e^+e^- \to e^+e^-\gamma(\gamma)$
  - $e^+e^- \to \gamma\gamma(\gamma)$
  - Cosmics





Summary and Outlook

- Belle II has an extensive program of dark sector searches

- First results published:
  - Z′ to invisible PRL 124, 141801 (2020)
  - Search for ALPs PRL 125, 161806 (2020)

Other ongoing studies:

- Dark Higgs-Strahlung
- Dark Scalar
- Other Z′ decays
- Inelastic dark matter
- And many more

- Many more results expected in the near future

- More details : The Belle II Physics Book, December 2019, arXiv:1808.10567

BACK-UP

Unsupervised anomaly detection

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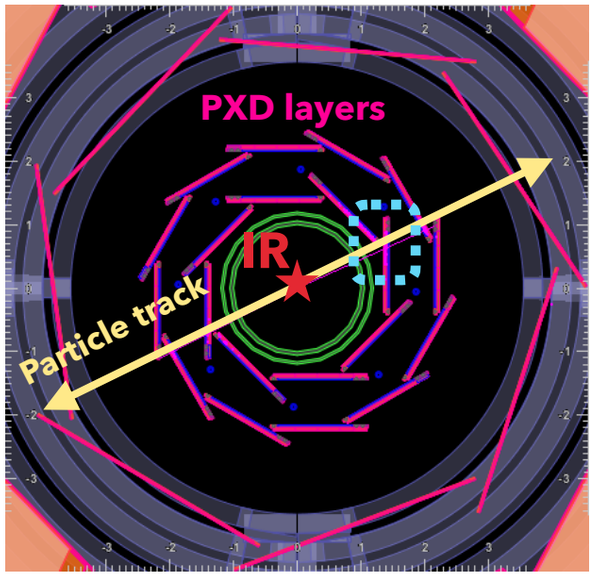
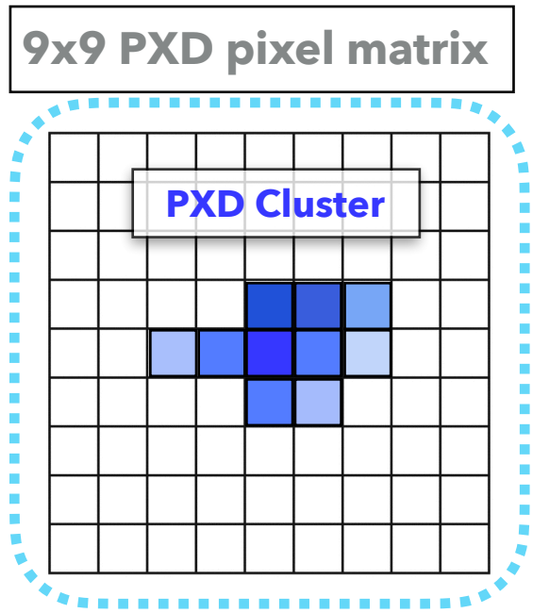
Search for rare events (anomalies) in background

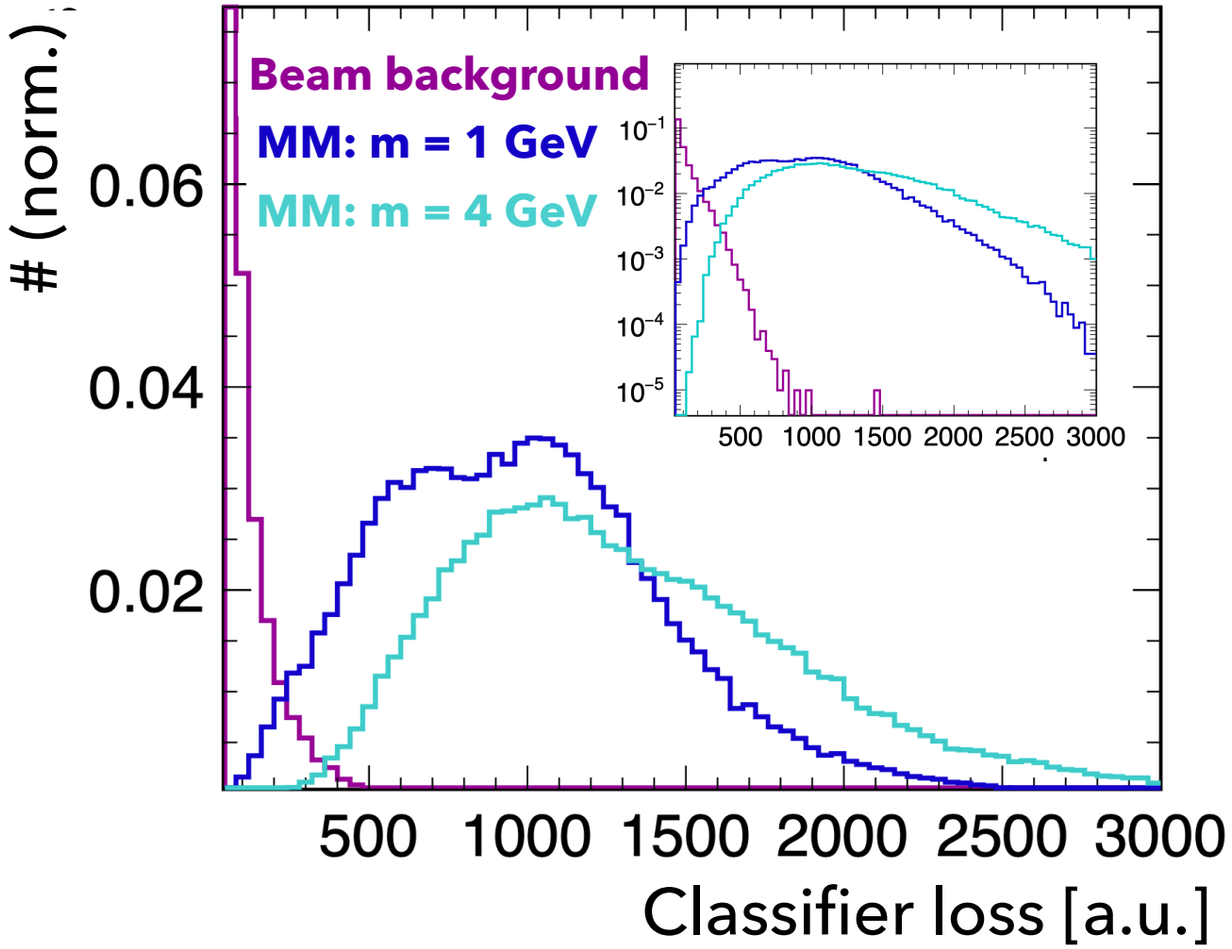
Pixel Detector (PXD)





- Classifier is trained on background only (either simulated or data) and later presented to a dataset that potentially contains signal

Example: Simulation of magnetic monopoles (MM)

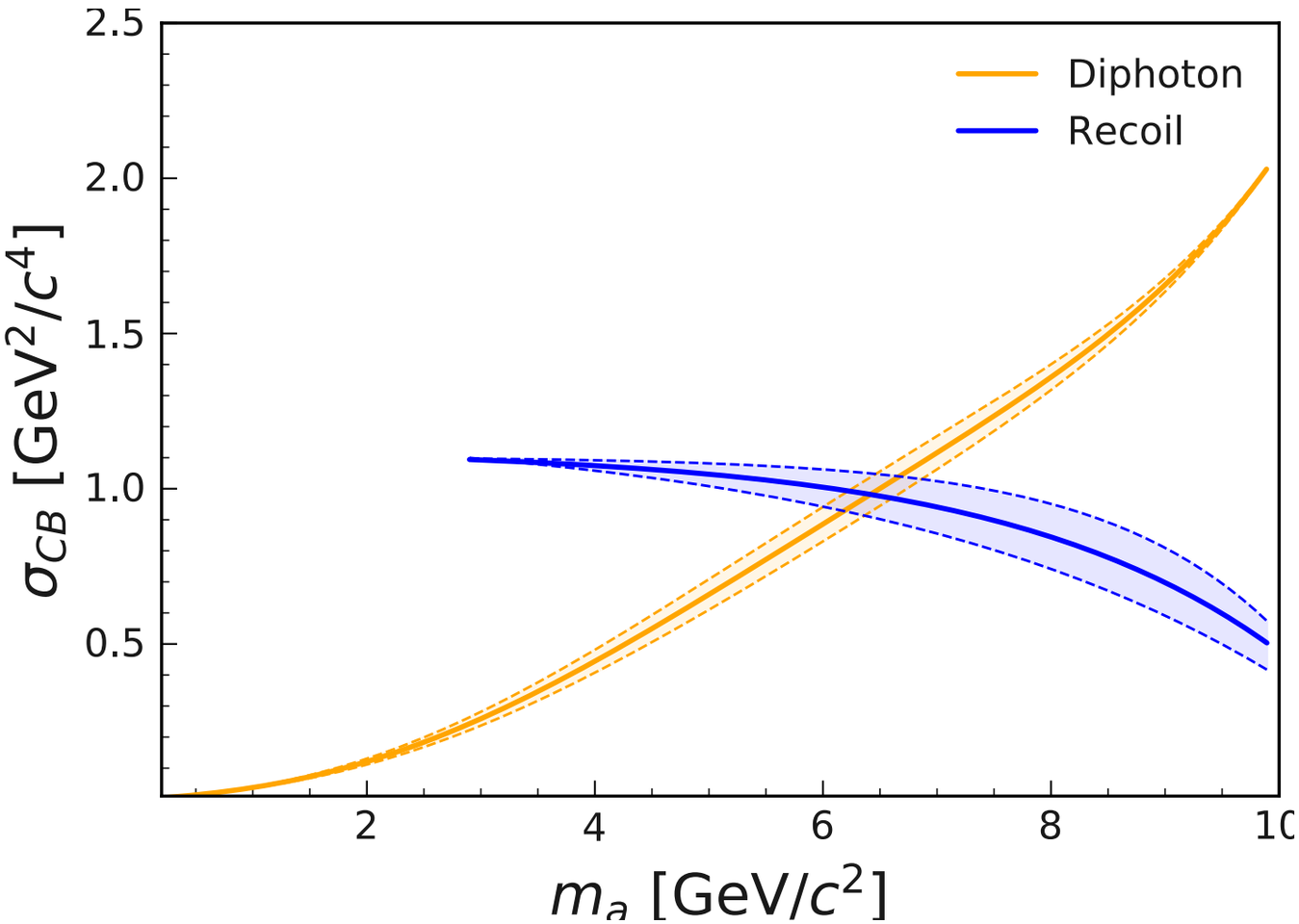


- Classifier tags anomalous data (high classifier loss) that is worth undergoing a detailed study

- Model independent search

➡ No models for background and new physics scenario

Back-up


Diphoton
Recoil
2.5
2.0
1.5
1.0
0.5
σ_{CB} [GeV$^2/c^4$]
2
4
6
8
10
m_a [GeV/c^2]