Dark sector searches at Belle II

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Belle II

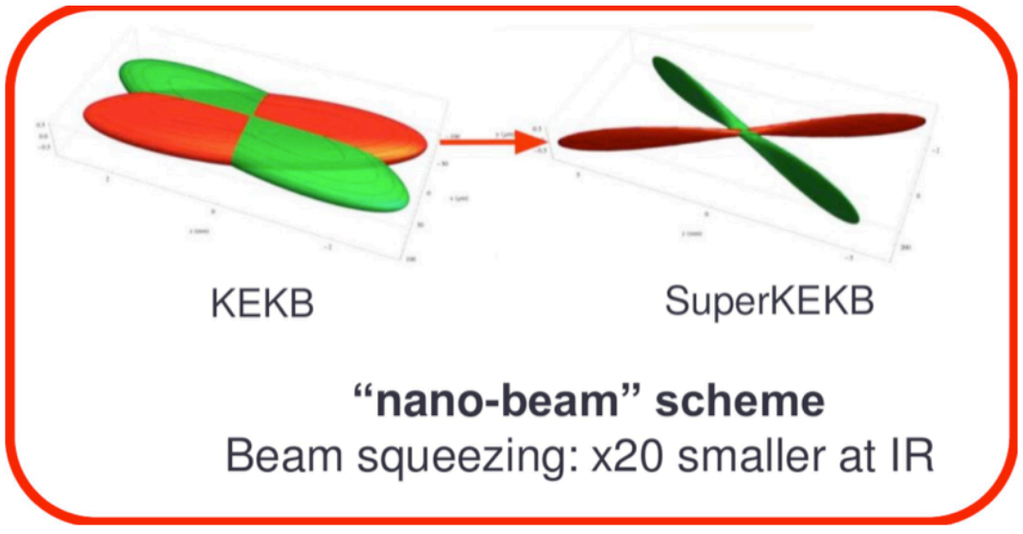
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

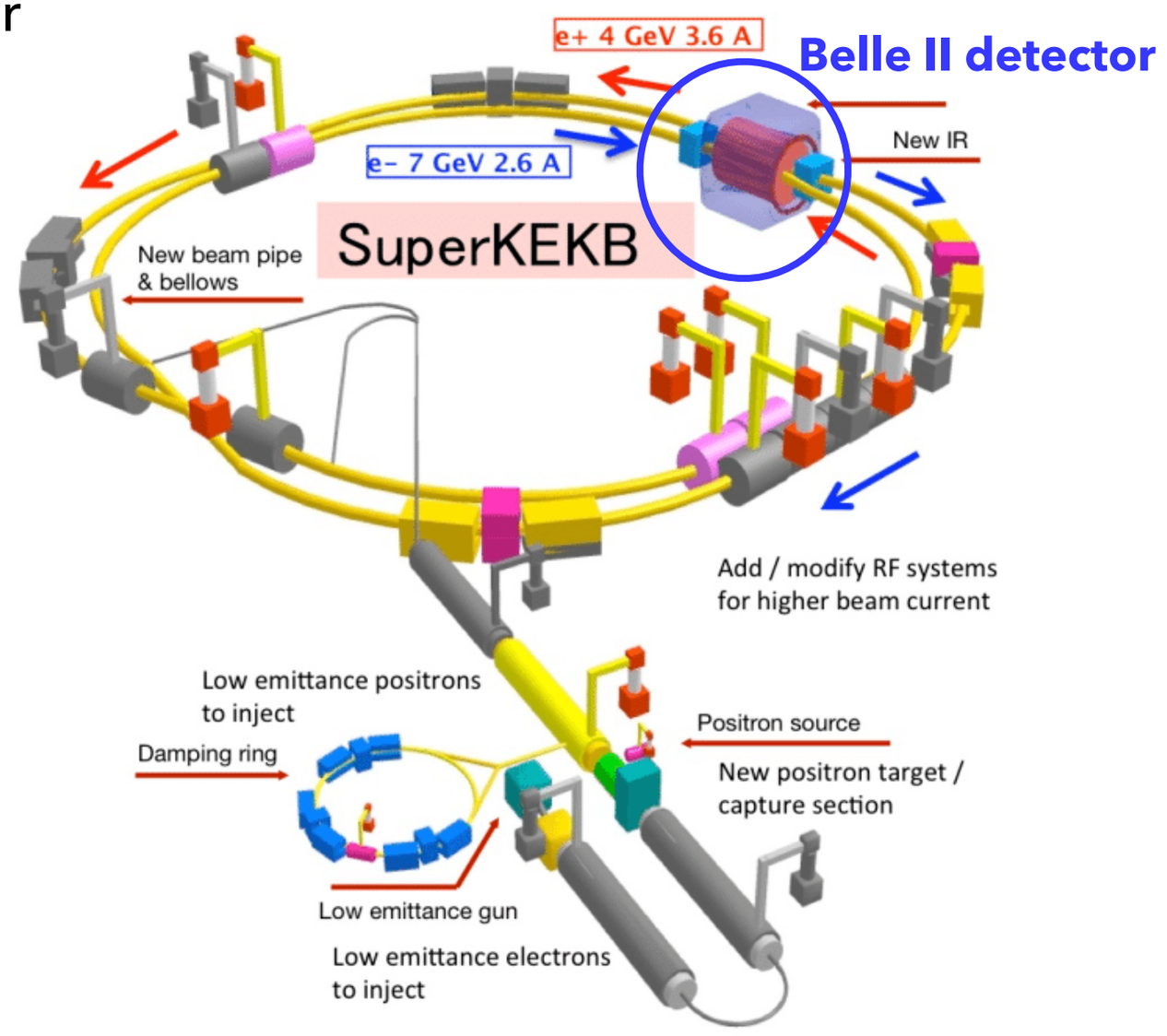
JENNIFER 2
EU grant n.822070

The SuperKEKB e+e- collider

- SuperKEKB is an asymmetric e^+e^- - collider located in Tsukuba, Japan
- CM energy: 10.58 GeV ($\Upsilon(4S)$ resonance)

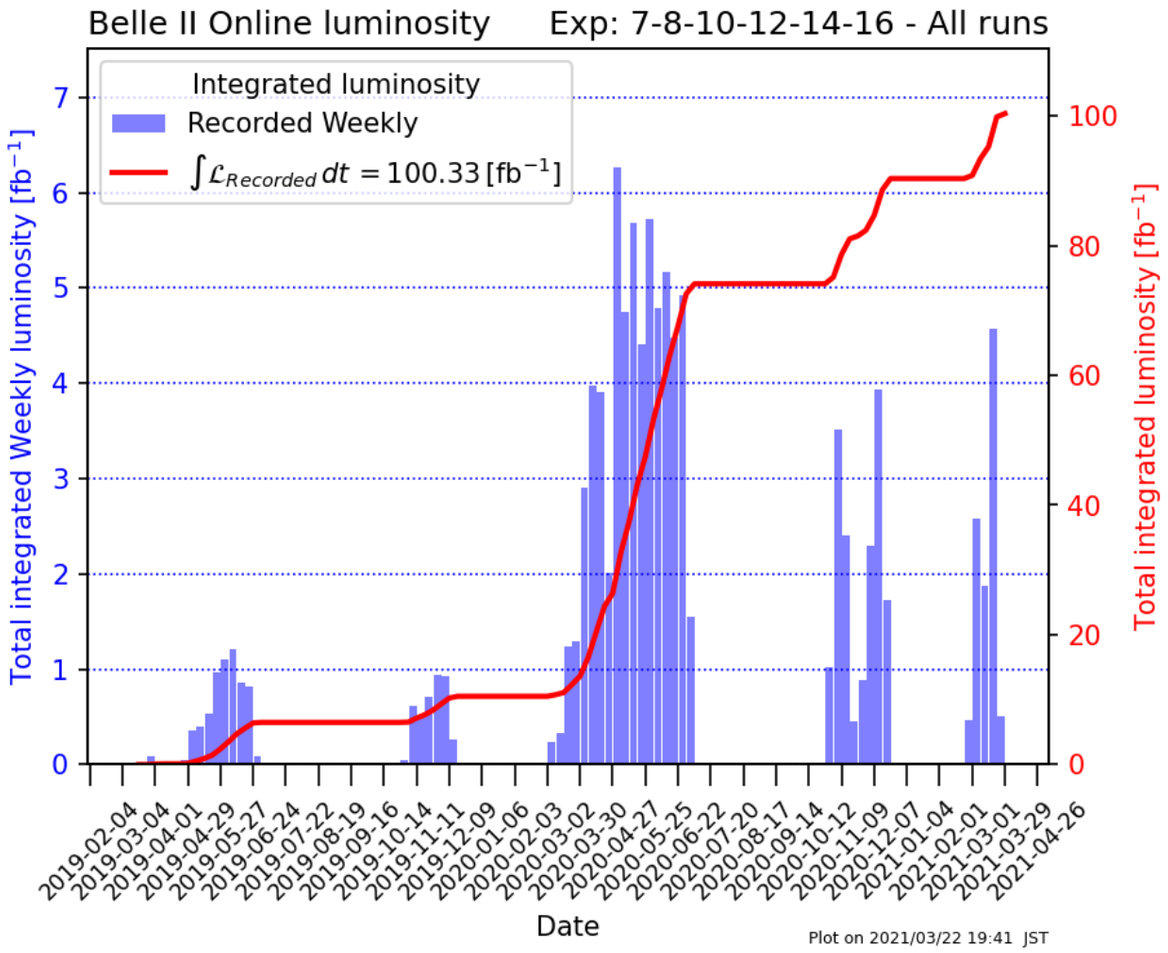
  Tuneable to $\Upsilon(2S)$ and $\Upsilon(6S)$ resonance as well

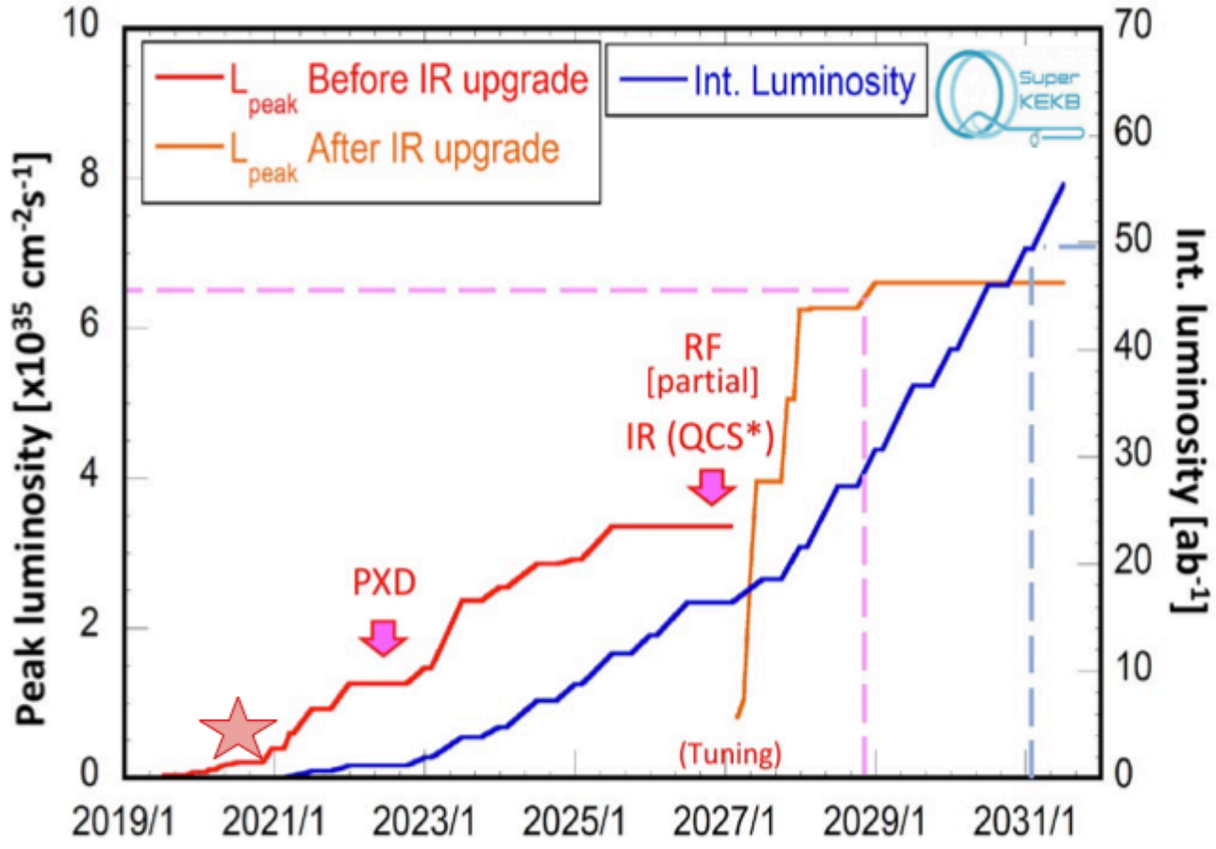




Peak luminosity : $6 \times 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

B-factories at the intensity frontier

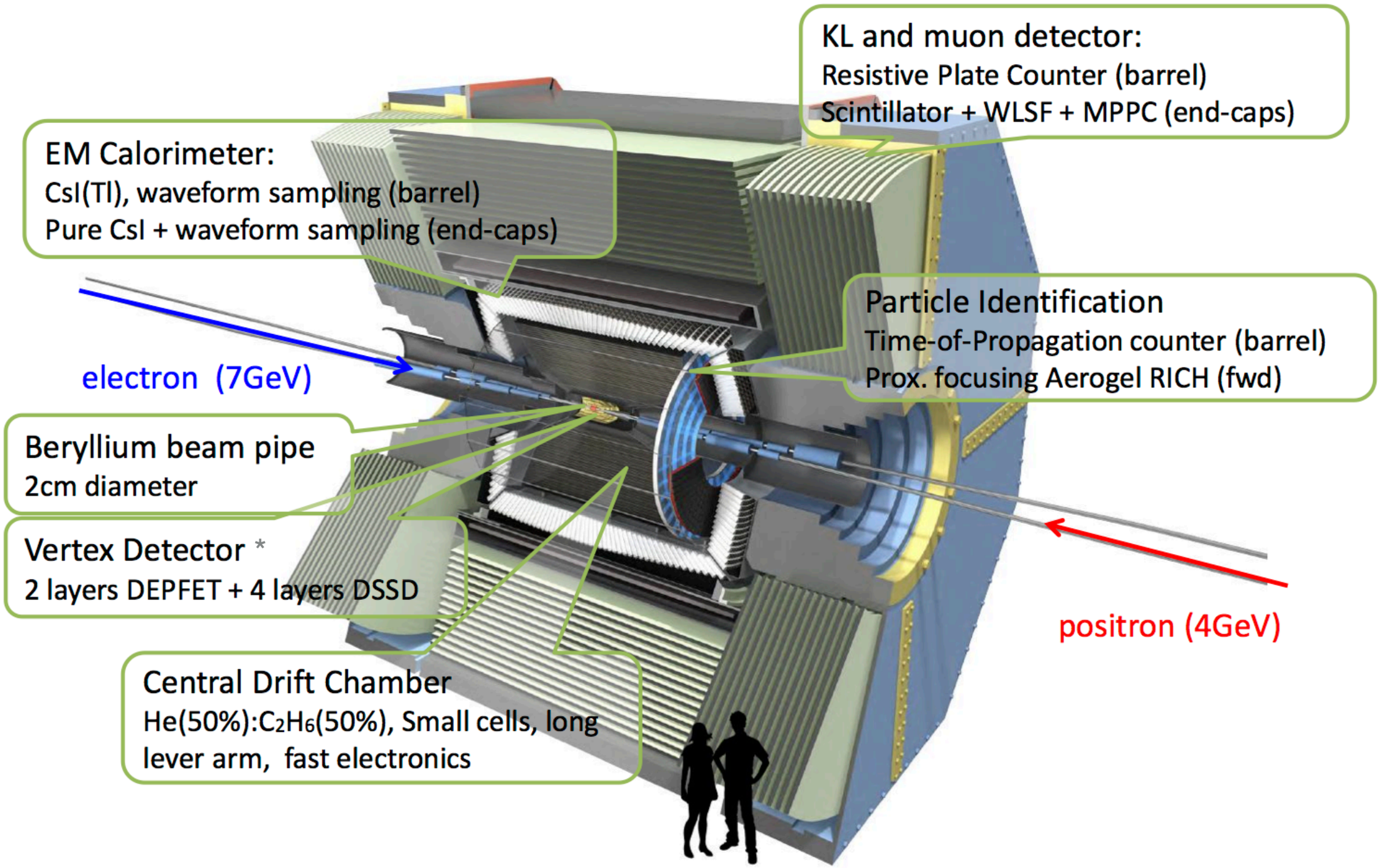




- Pilot run in 2018: 500 pb^{-1} recorded
- Integrated luminosity (May 2021) : > 100 fb^{-1}

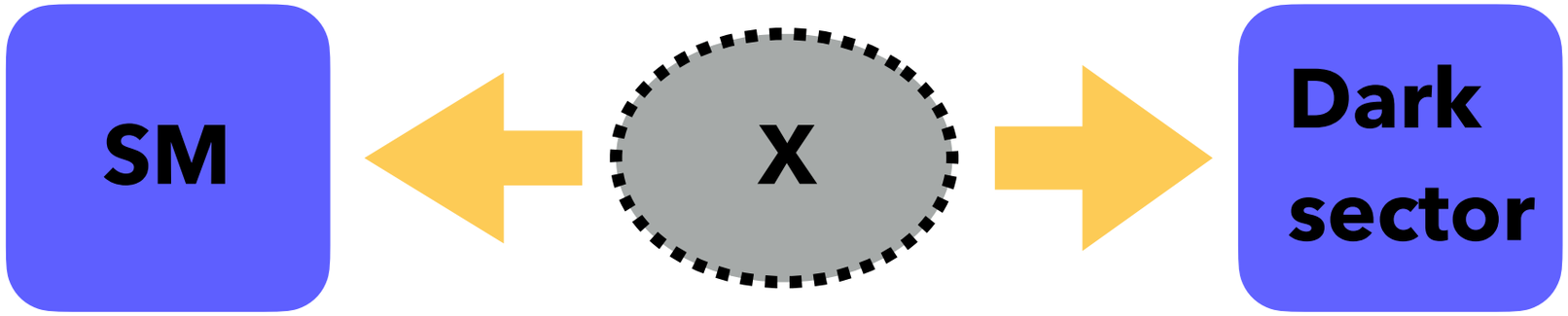
Objective: 50 ab^{-1} by 2030

The Belle II detector



*(*) 1 layer of DEPFET sensors not completely installed yet*

Dark matter (DM) searches

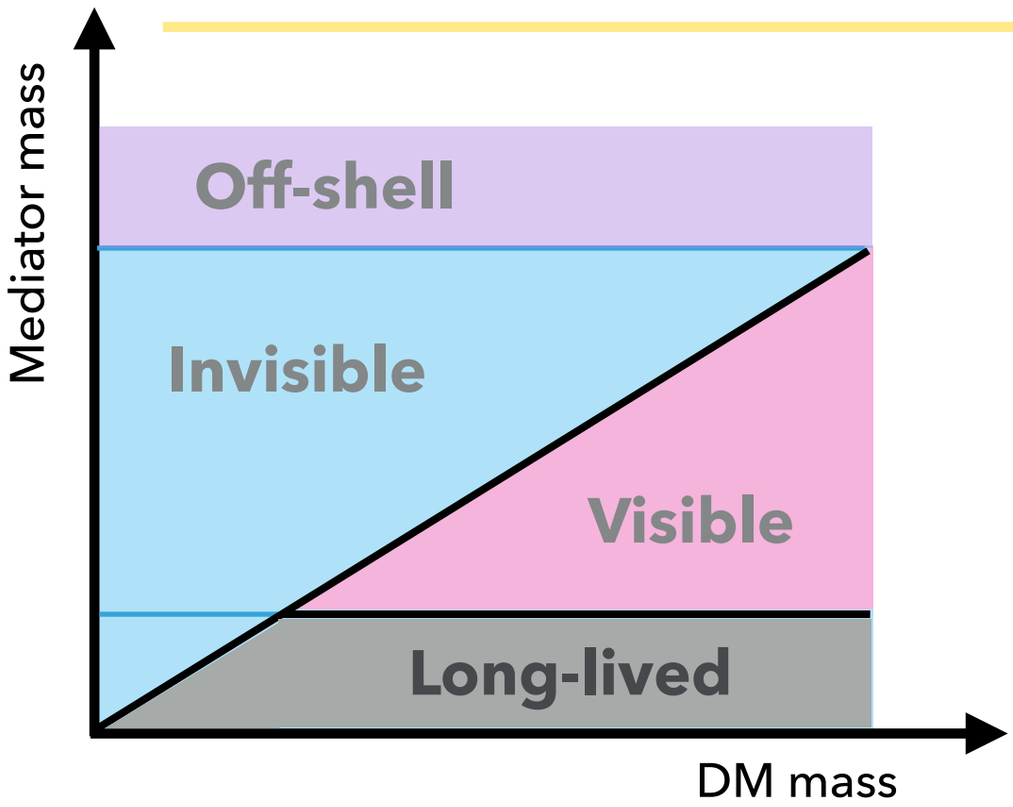


Models for low-mass (sub-)GeV DM with light dark mediator between Standard Model (SM) and DM

Possible portals between DM and SM

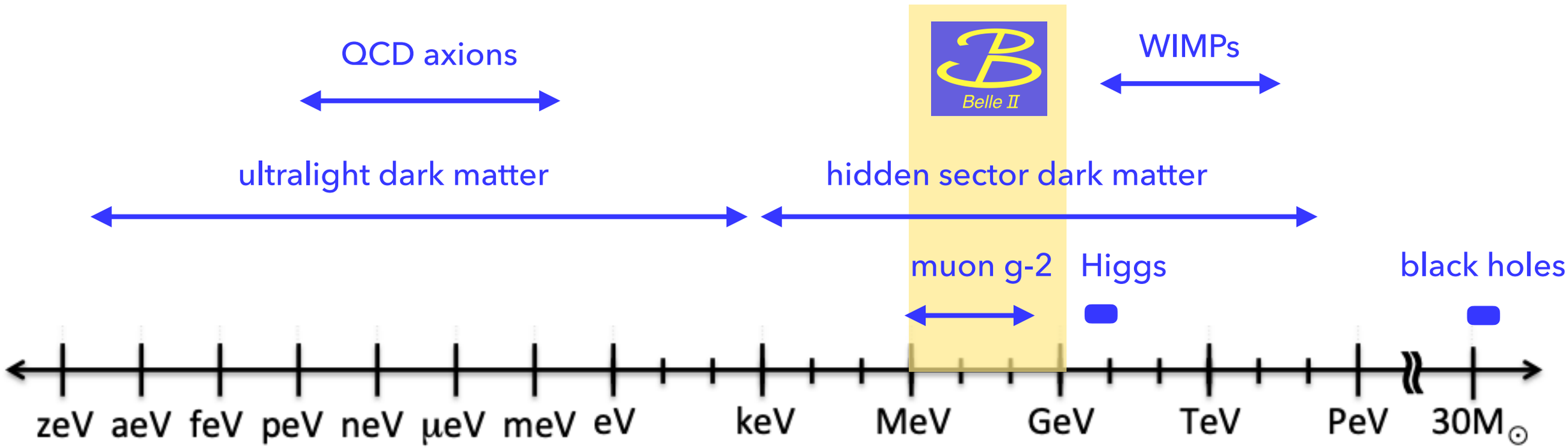
- Vector portal (dark photon A′, dark Z′)
- Pseudo-scalar portal (axion-like particle)
- Scalar portal (dark scalars)
- Neutrino portal (sterile neutrino)

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



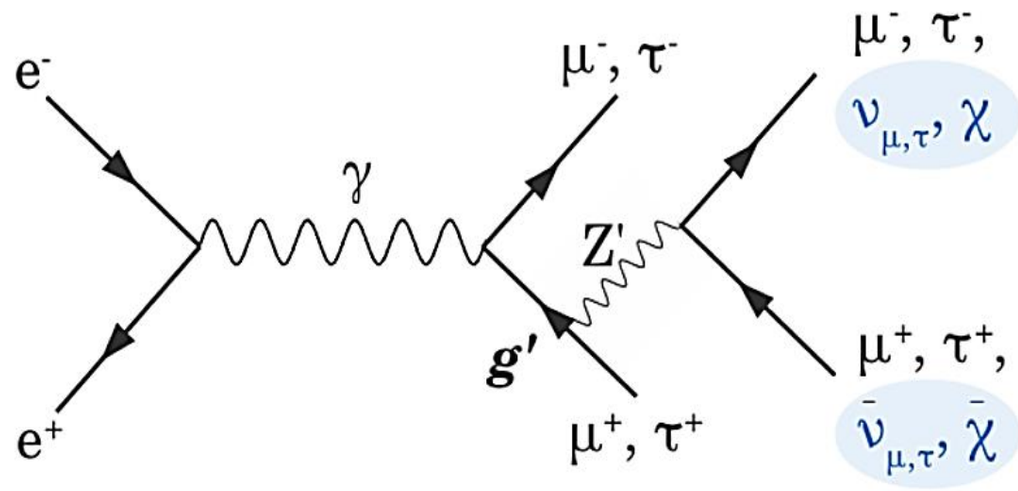
arXiv:1707.04591

Invisibly decaying Z′ boson

arXiv:1609.04026
arXiv:1403:2727

- $L_\mu - L_\tau$ 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



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

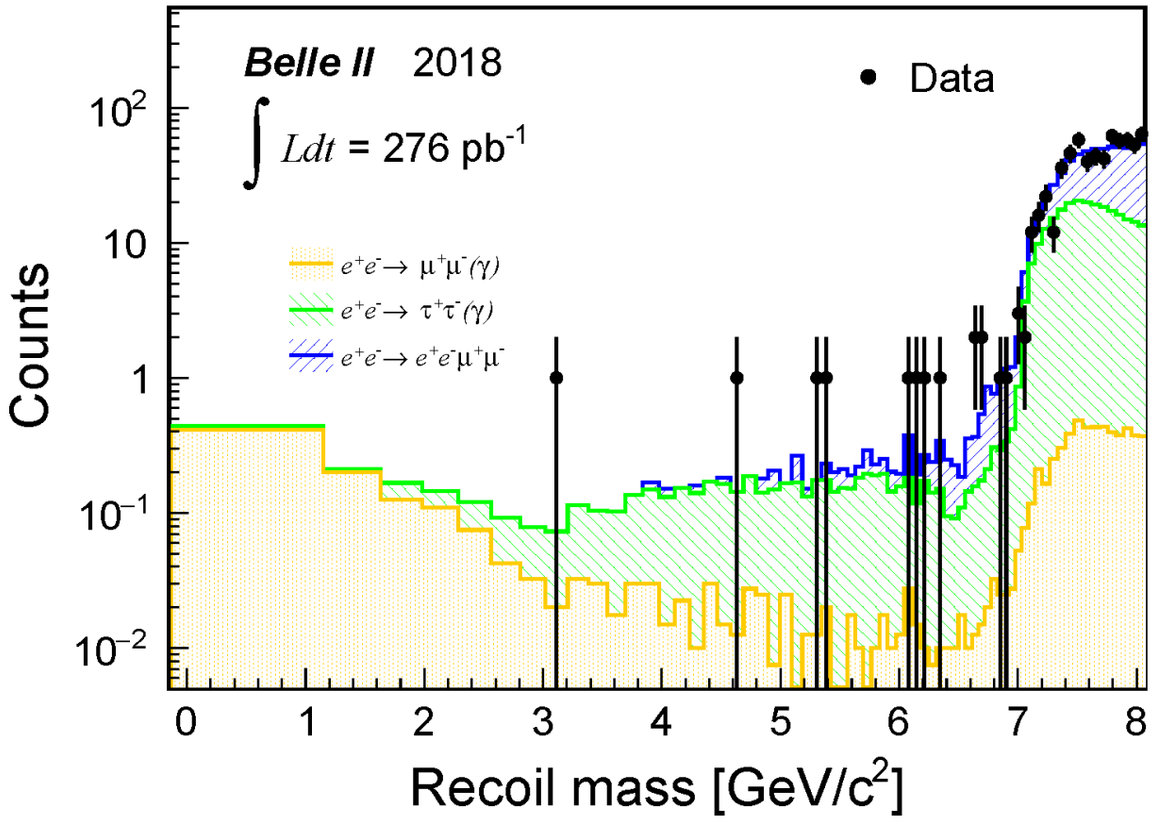
$$Z' \to \text{invisble}$$

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

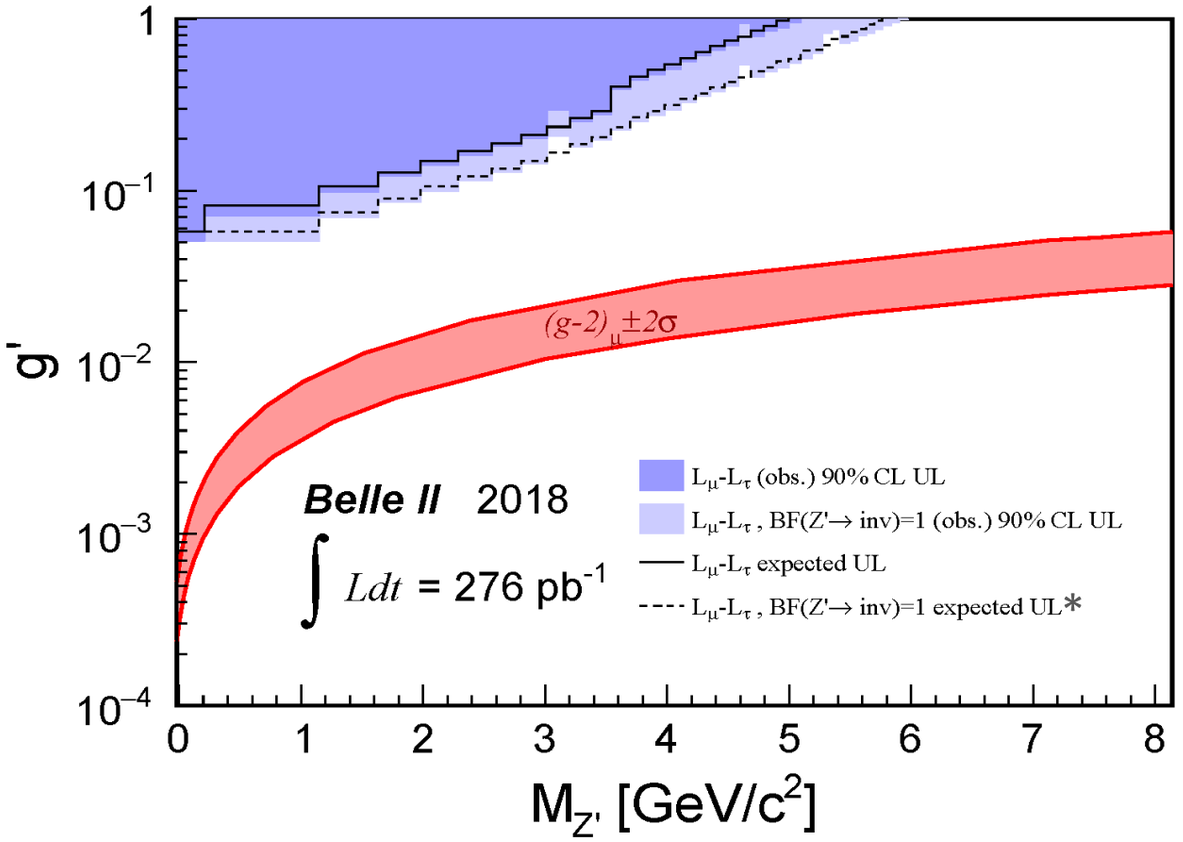
Invisibly decaying Z' boson

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

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



90% CL upper limits



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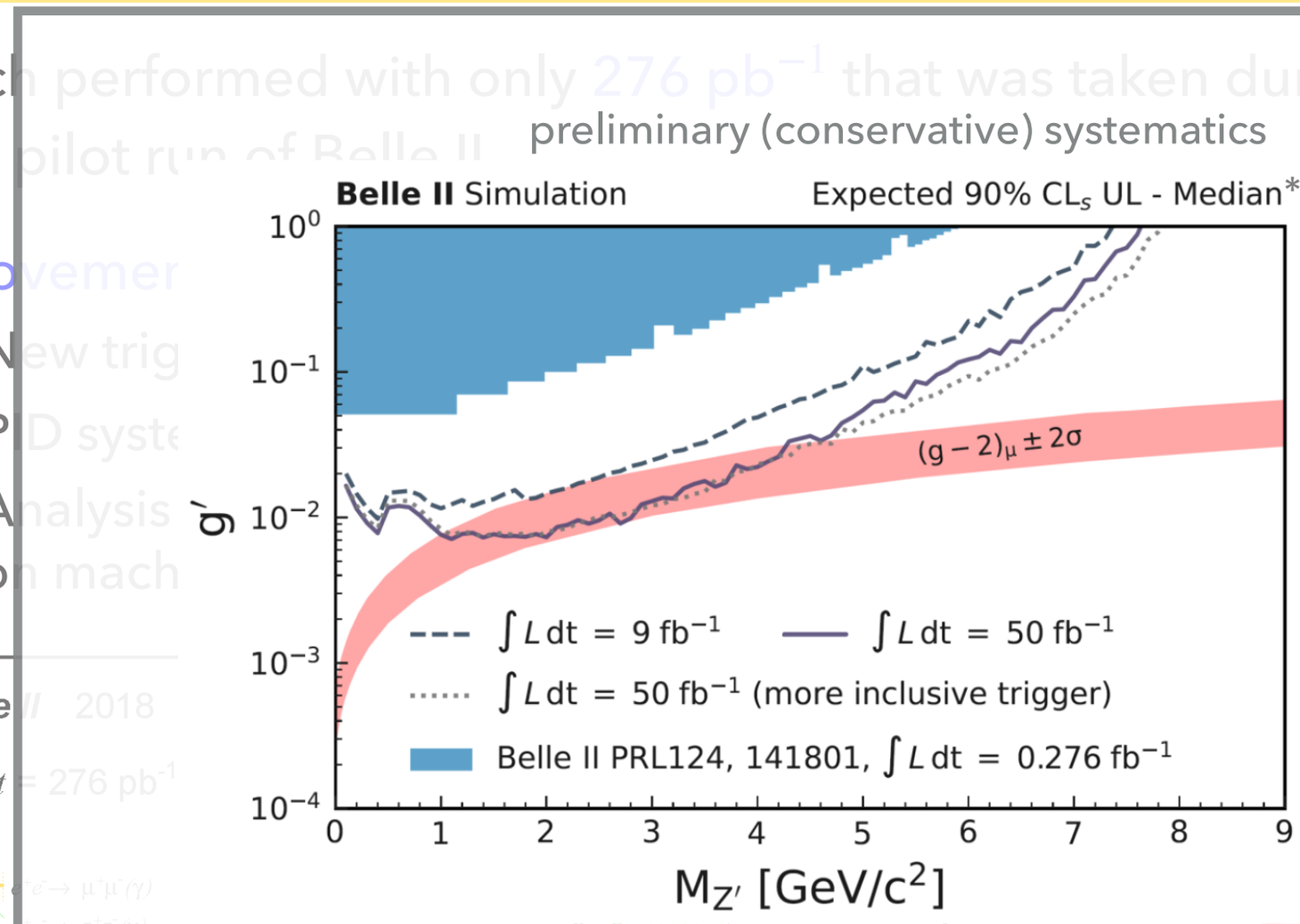
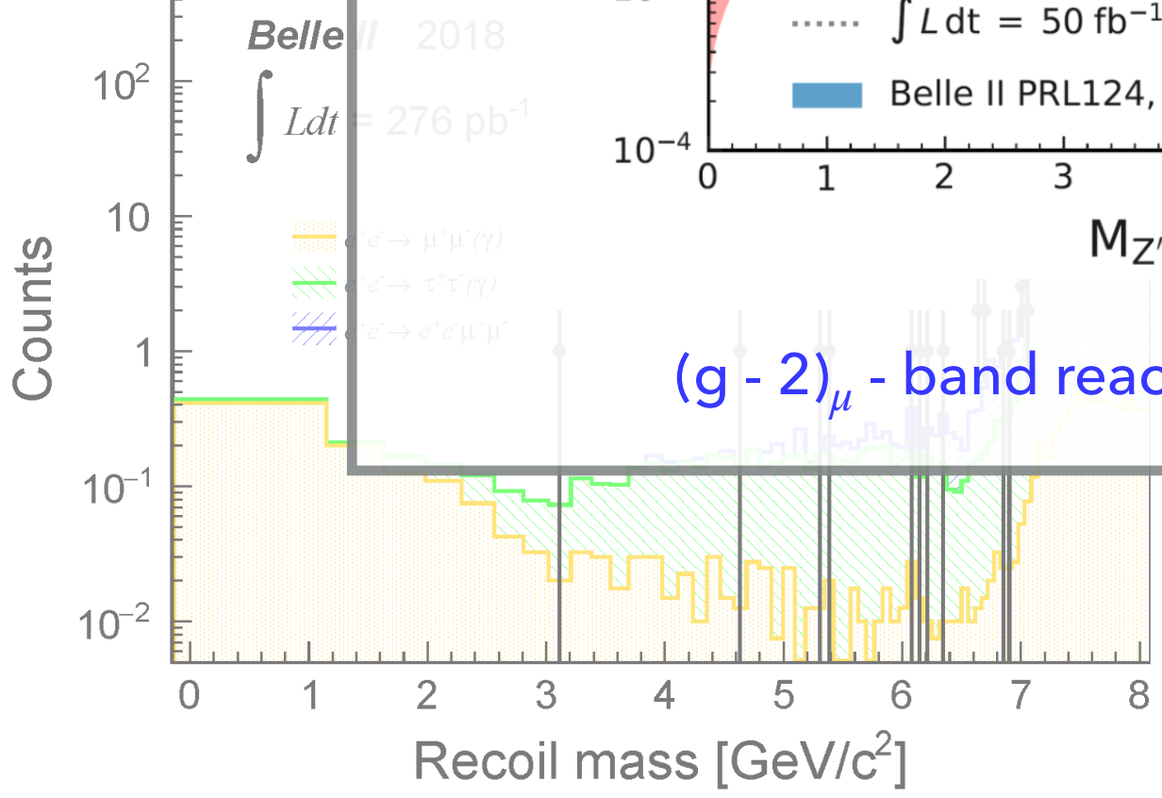
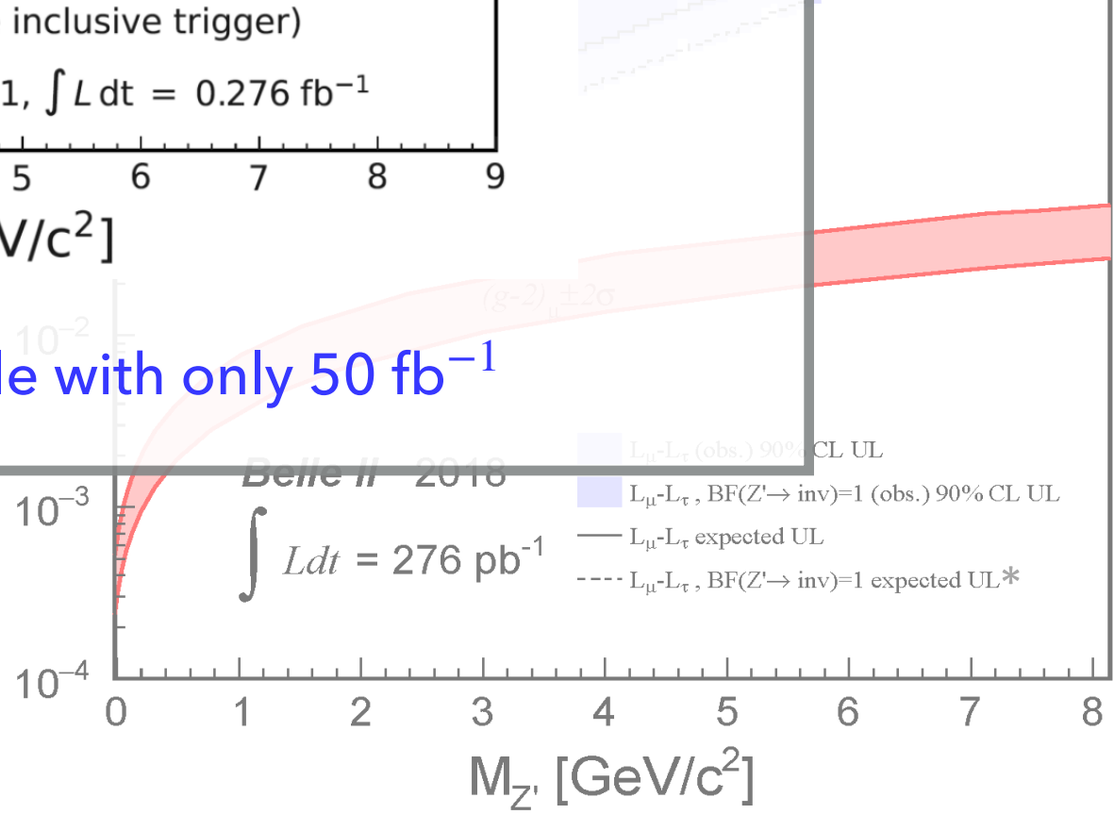
II physics paper: 41801 (2020)



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

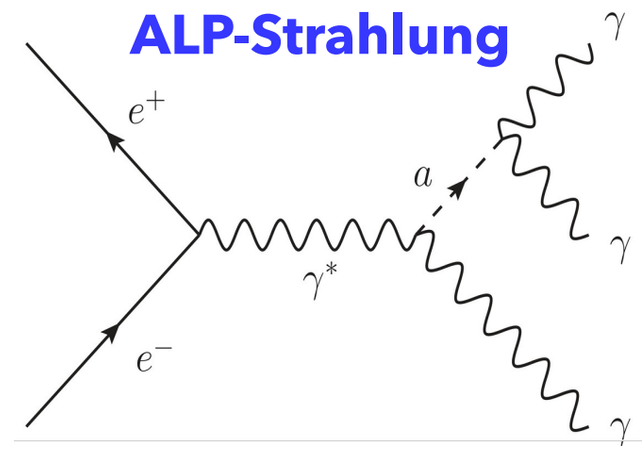




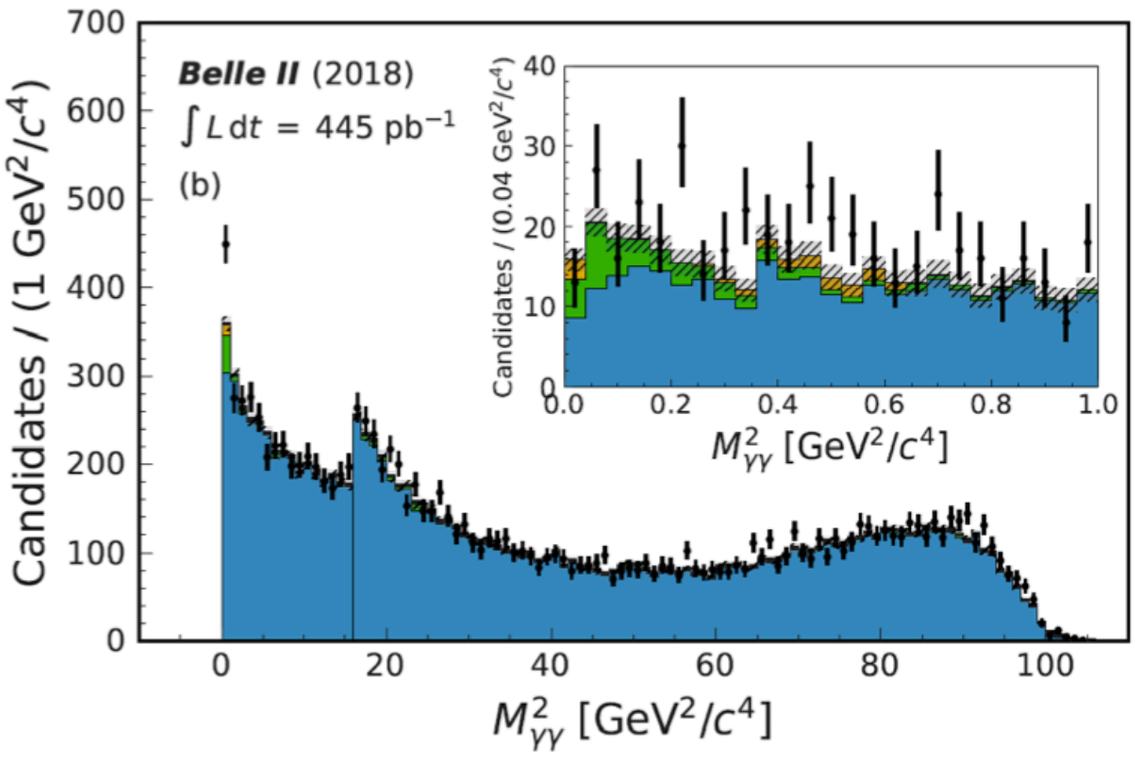
Axion Like Particles (ALPs)

- 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 :

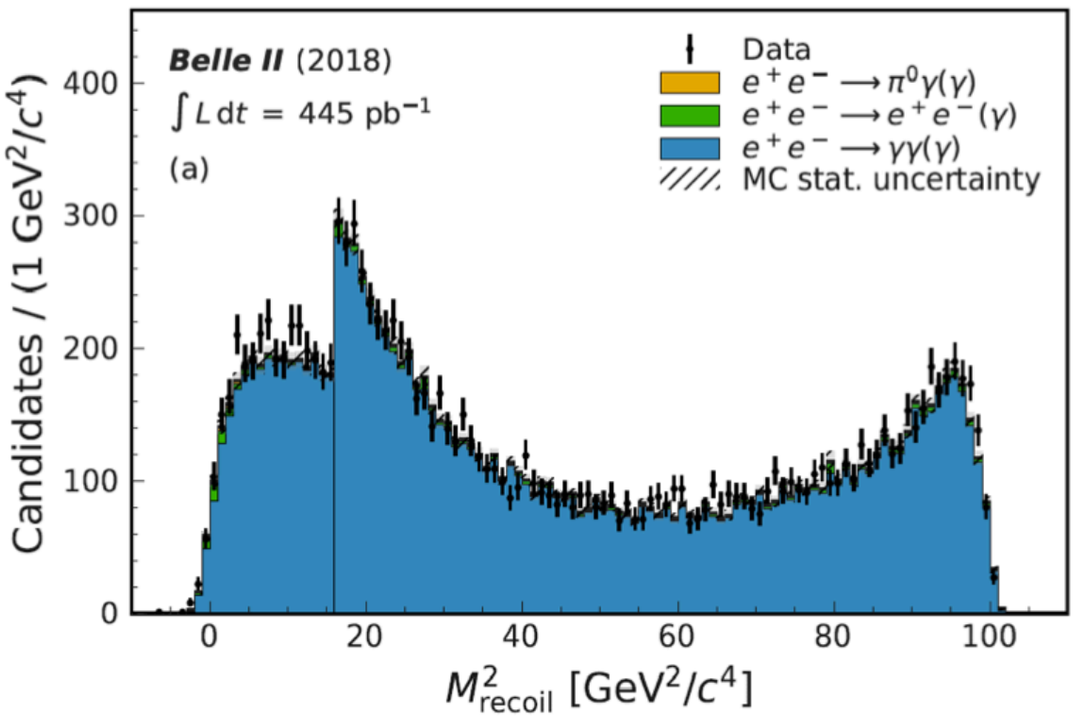
Belle II focusing on ALPs coupling to photons



Diphoton invariant mass (low m_a)



Recoil invariant mass (high ALP mass m_a)



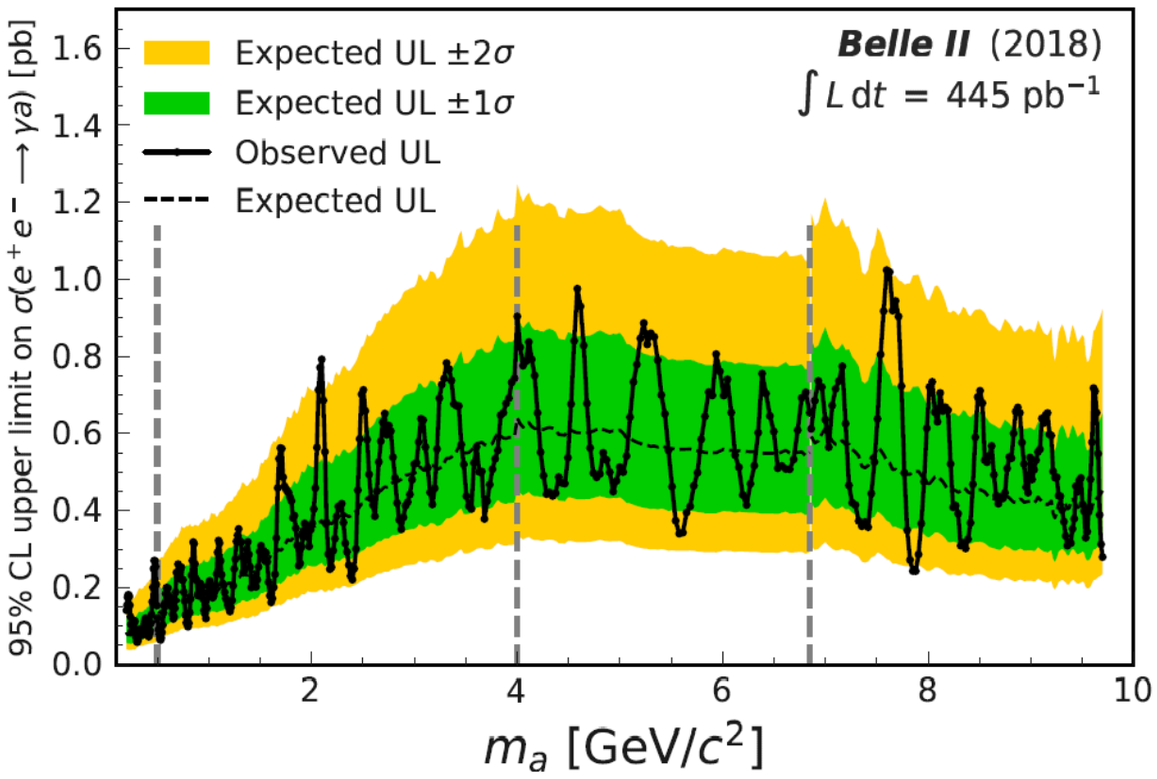
Axion Like Particles (ALPs)

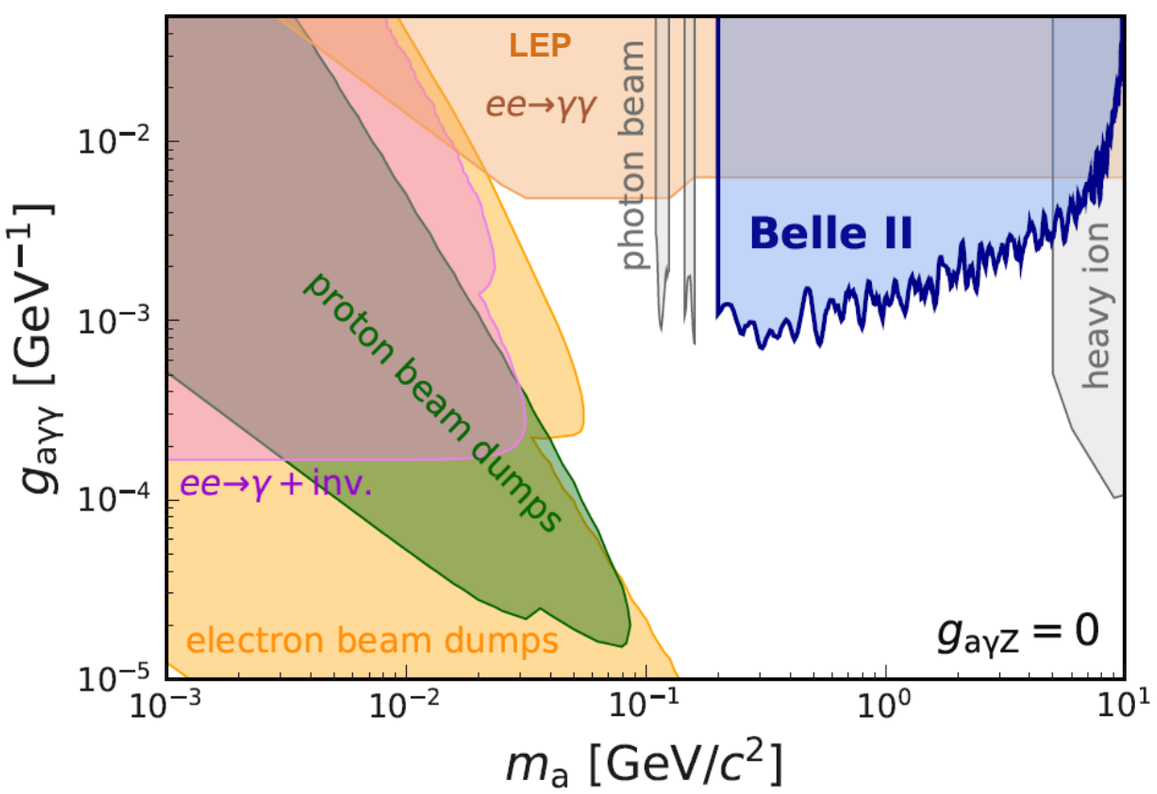
- Mass range between 0.2 to 9.7 GeV/c^2 studied
- No excess was found
- Upper limits on cross section translated to coupling constant

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

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

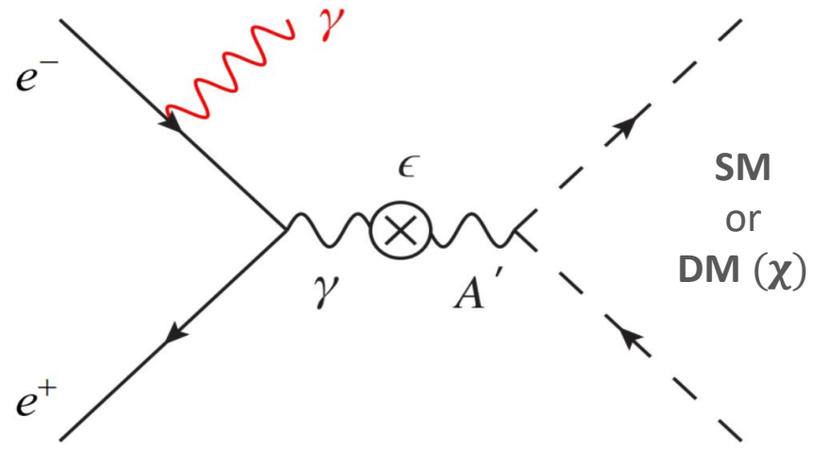
90% CL upper limits on the cross section





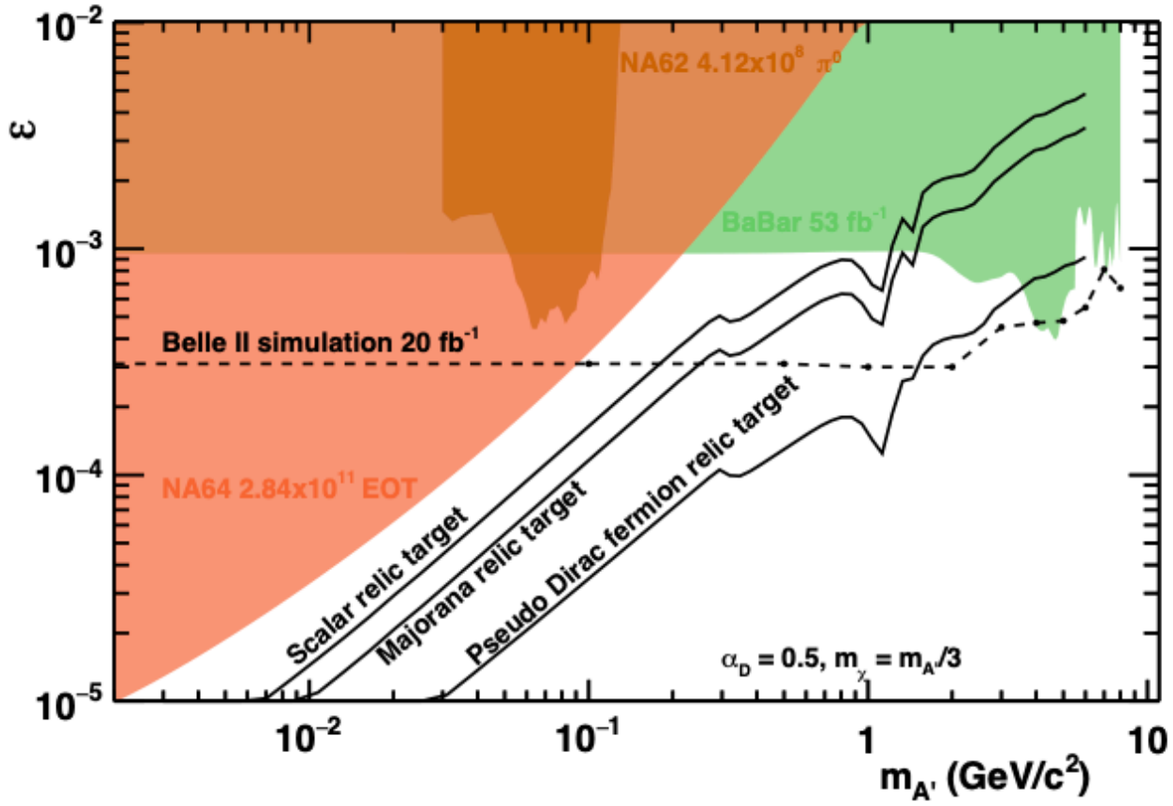
Dark Photon to Invisible

- 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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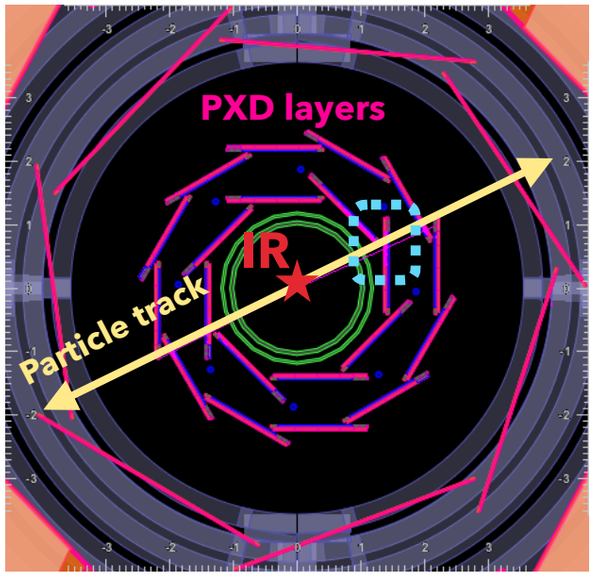
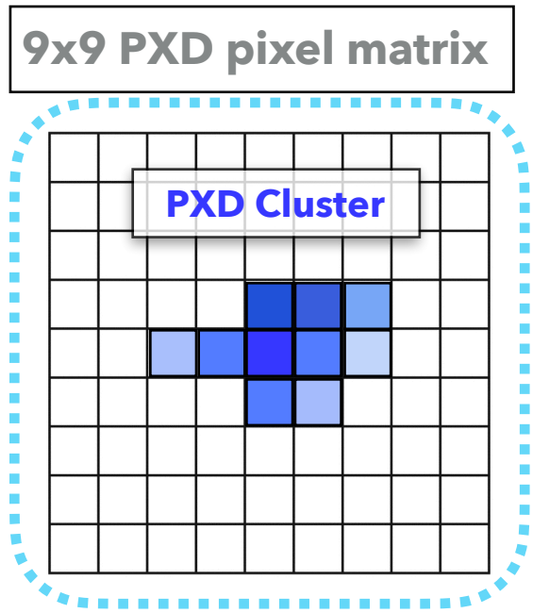
Search for rare events (anomalies) in background

Pixel Detector (PXD)





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

- Model independent search

➡ No models for background and new physics scenario

- 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)