Istituto Nazionale di Fisica Nucleare
Sezione di Roma Tre

ROMA TRE
UNIVERSITÀ DEGLI STUDI

Dark Sector Physics with Belle II

Alberto Martini

Belle II group, University & INFN Roma Tre

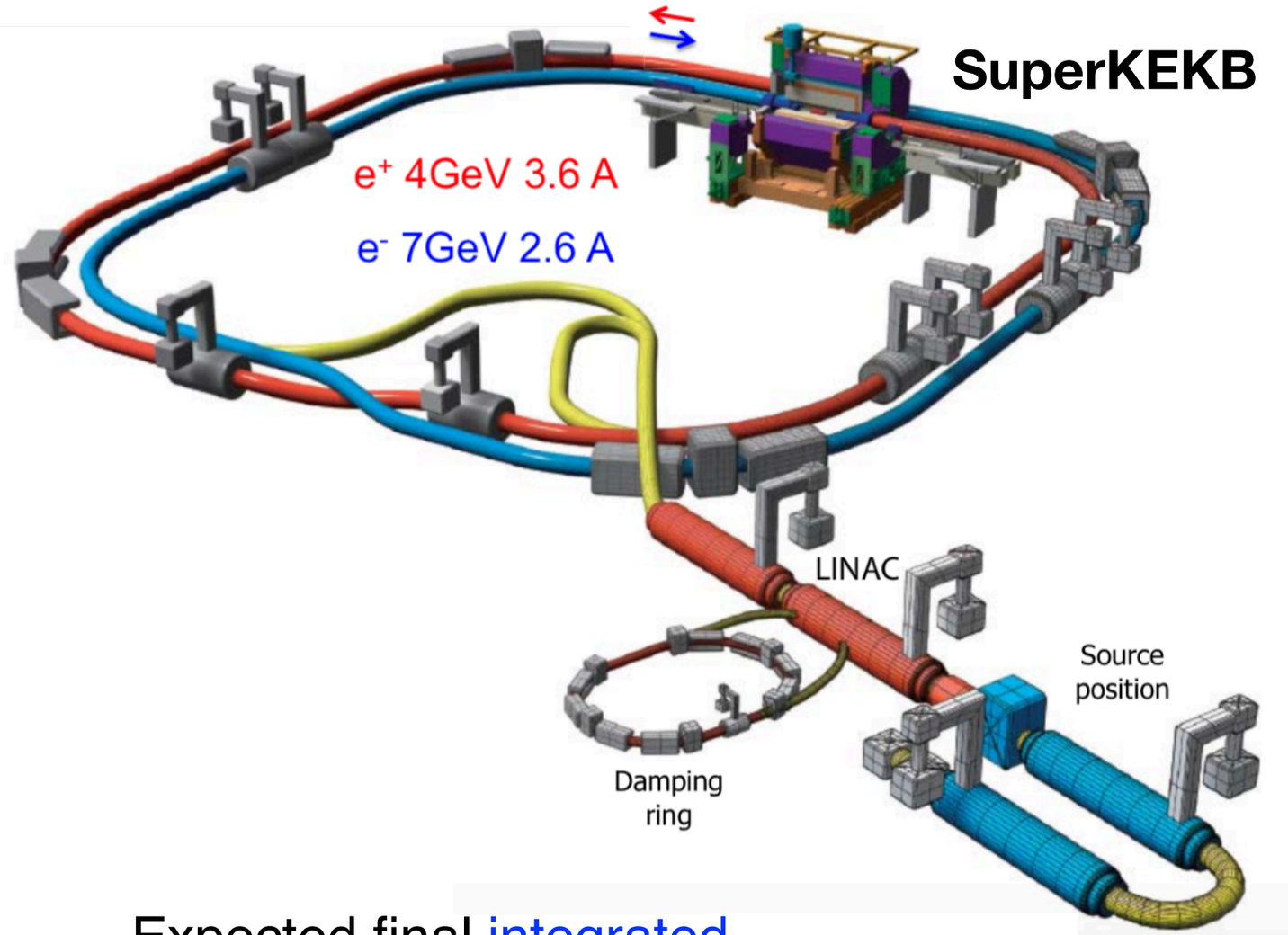
XXV International Symposium PASCOS, Particle physics String theory and Cosmology

Manchester (UK), 1 July 2019

Belle II

Belle II: second generation B-factory

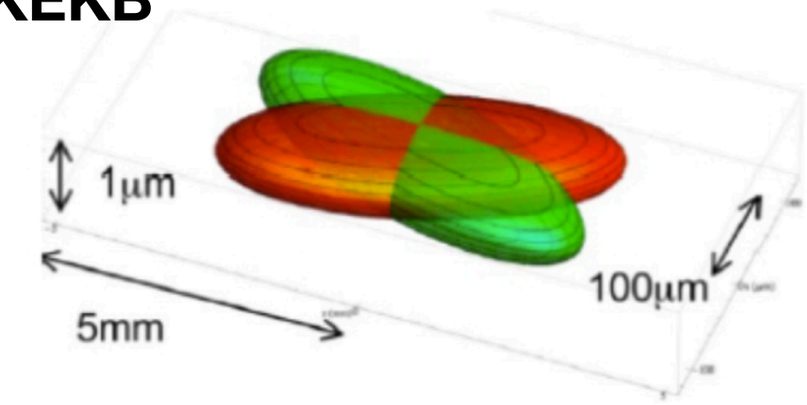
B-factories: e^+e^- asymmetric-energy colliders → production of quantum coherent $B\bar{B}$ pairs



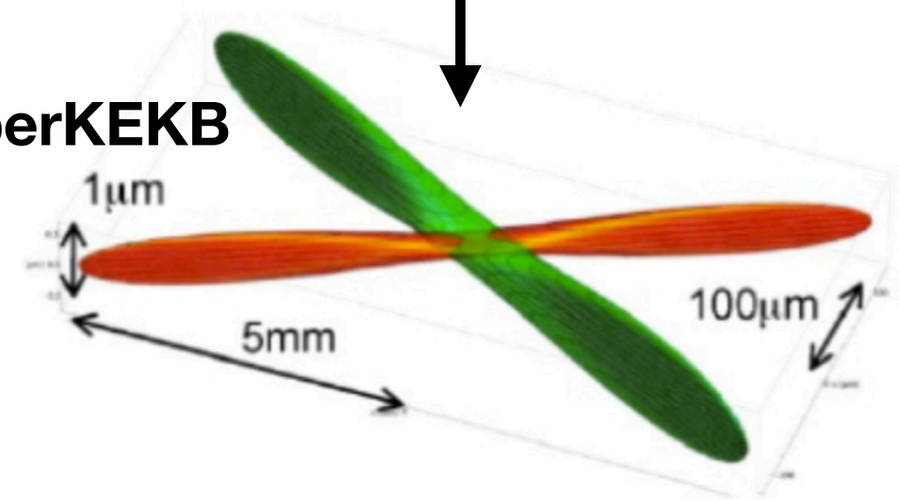
SuperKEKB

Nano-beam scheme

KEKB

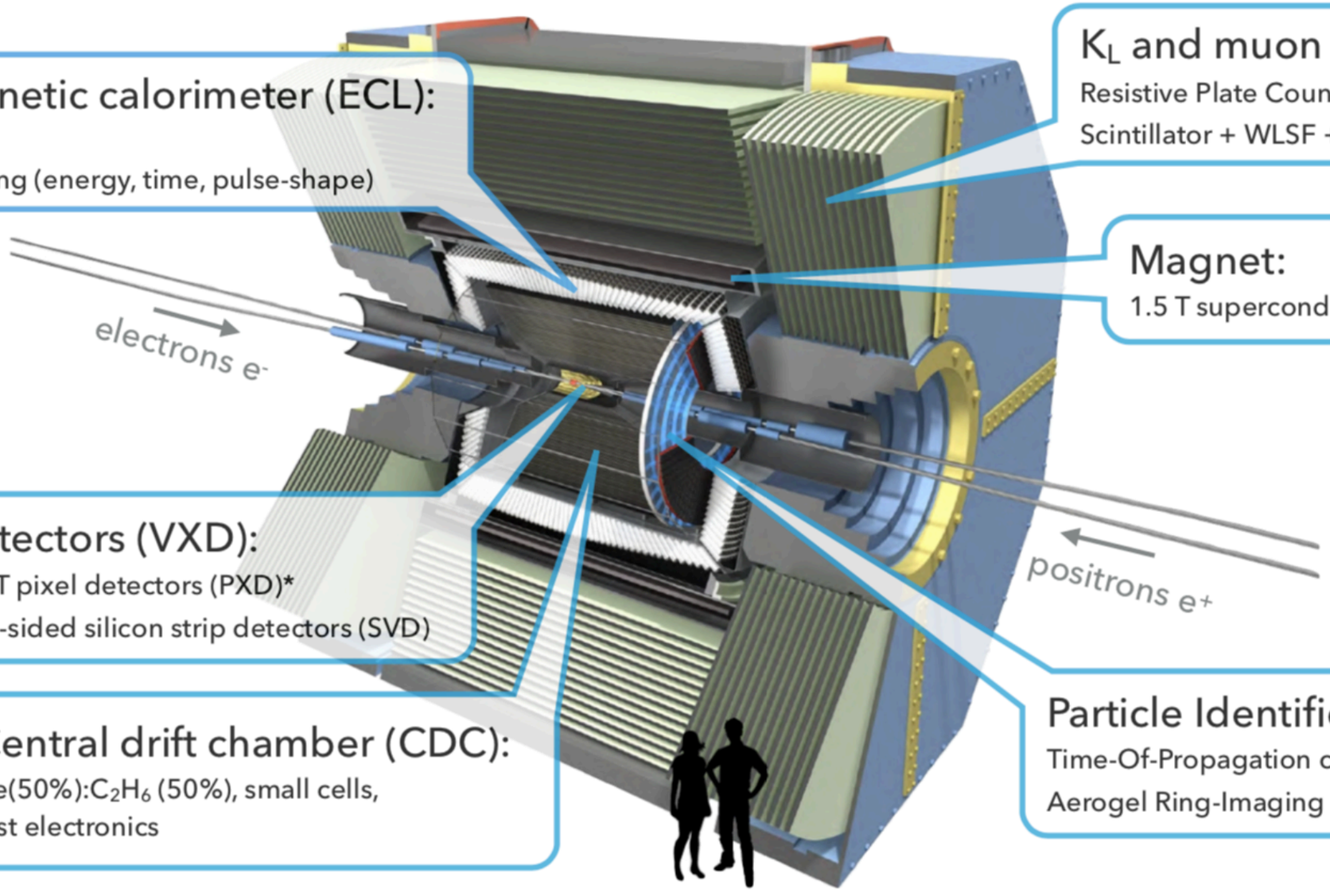


SuperKEKB



Expected final integrated luminosity of **50 ab^{-1}**

Belle II detector



Electromagnetic calorimeter (ECL):
CsI(Tl) crystals
waveform sampling (energy, time, pulse-shape)

K_L and muon detector (KLM):
Resistive Plate Counters (RPC) (outer barrel)
Scintillator + WLSF + MPPC (endcaps, inner barrel)

Magnet:
1.5 T superconducting

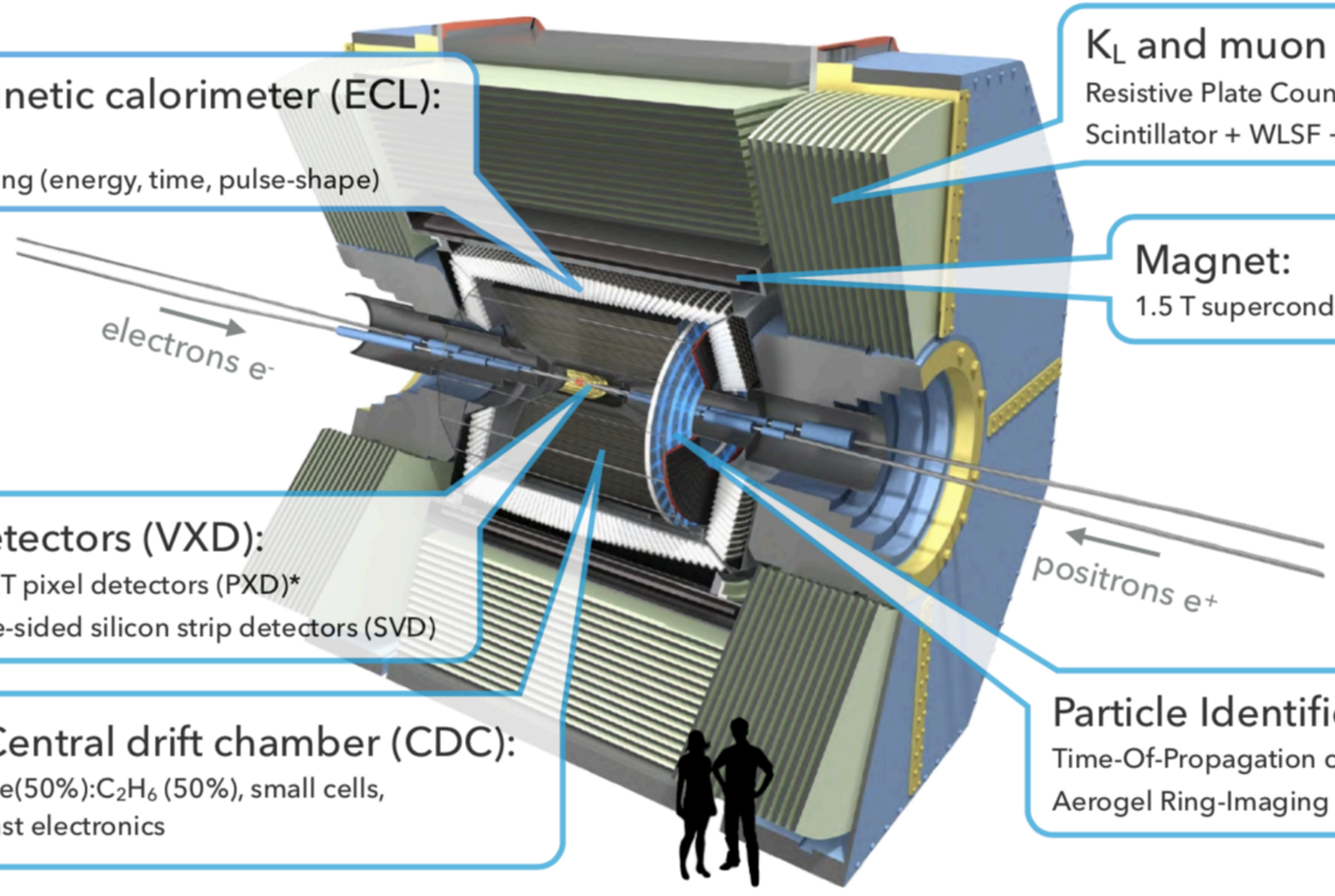
Trigger*:
Hardware: < 30 kHz
Software: < 10 kHz

Vertex detectors (VXD):
2 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 Cherenkov Counter (ARICH) (FWD)

Belle II detector



Electromagnetic calorimeter (ECL):
CsI(Tl) crystals
waveform sampling (energy, time, pulse-shape)

K_L and muon detector (KLM):
Resistive Plate Counters (RPC) (outer barrel)
Scintillator + WLSF + MPPC (endcaps, inner barrel)

Magnet:
1.5 T superconducting

Trigger*:
Hardware: < 30 kHz
Software: < 10 kHz

Vertex detectors (VXD):
2 layer DEPFET pixel detectors (PXD)*
4 layer double-sided silicon strip detectors (SVD)

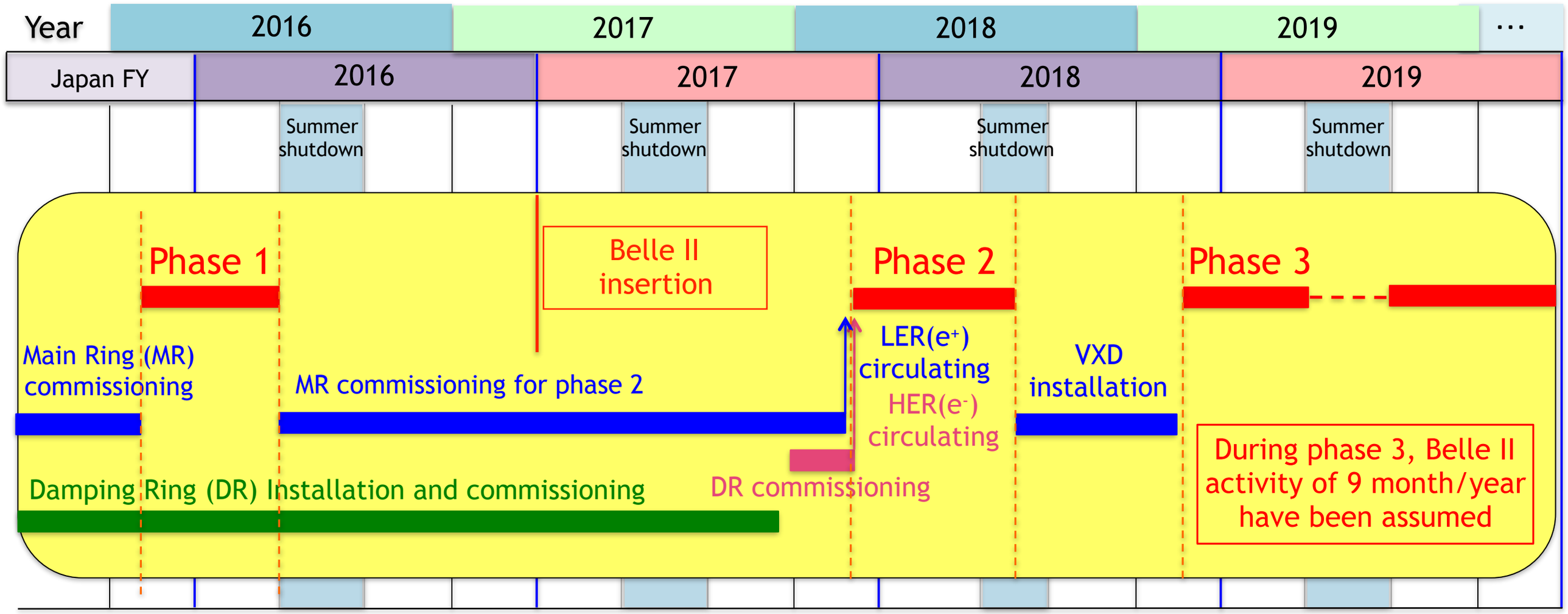
Central drift chamber (CDC):
He(50%):C_2H_6 (50%), small cells,
fast electronics

Particle Identification (PID):
Time-Of-Propagation counter (TOP) (barrel)
Aerogel Ring-Imaging Cherenkov Counter (ARICH) (FWD)

Improved detector performances → **Possible New Physics discoveries!** ← Improved collider SuperKEKB

Belle II

Belle II operation status

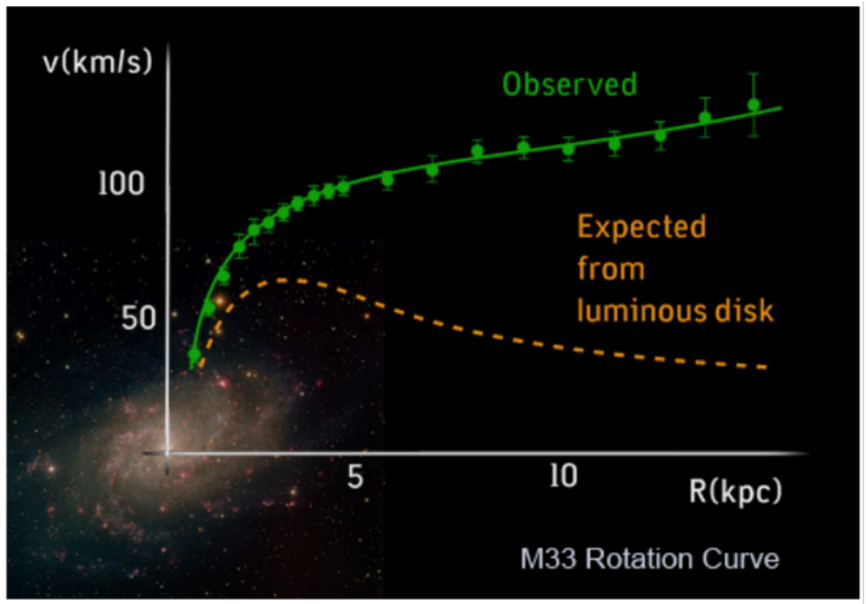


Phase 1: SuperKEKB commissioning & background estimation — **Completed**

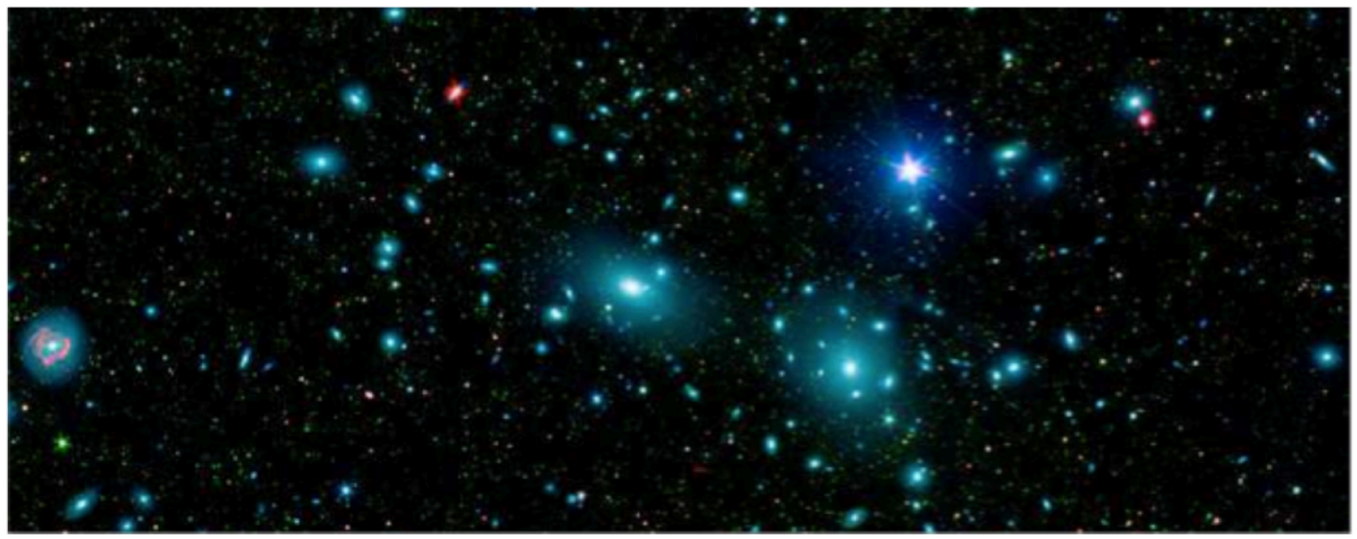
Phase 2: Collision runs with the detector installed partially, without the vertex detector → first physics data and results! — **Completed**

Phase 3: Data taken with the whole detector installed, **ongoing**! — **March 2019**

Dark matter knowledge

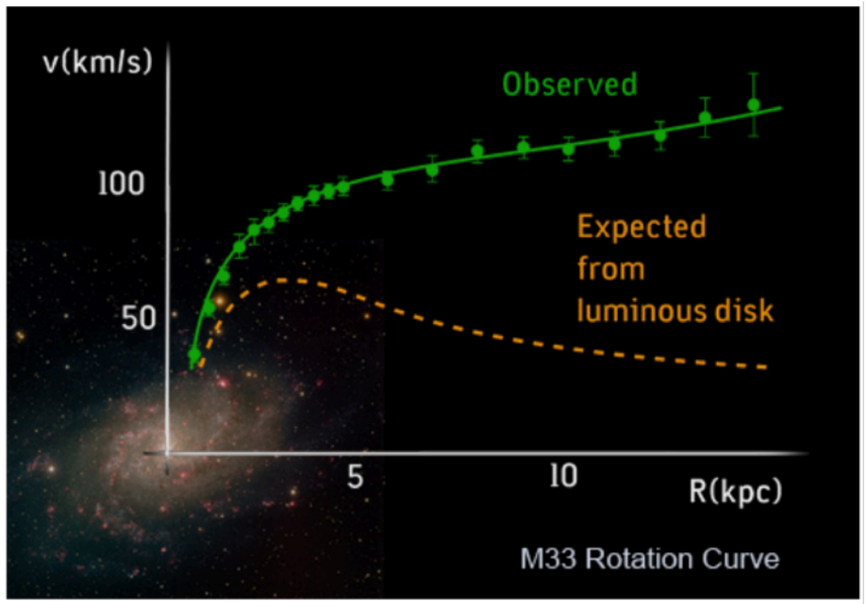


*Large **halos** around Galaxies*
Rotation Curves

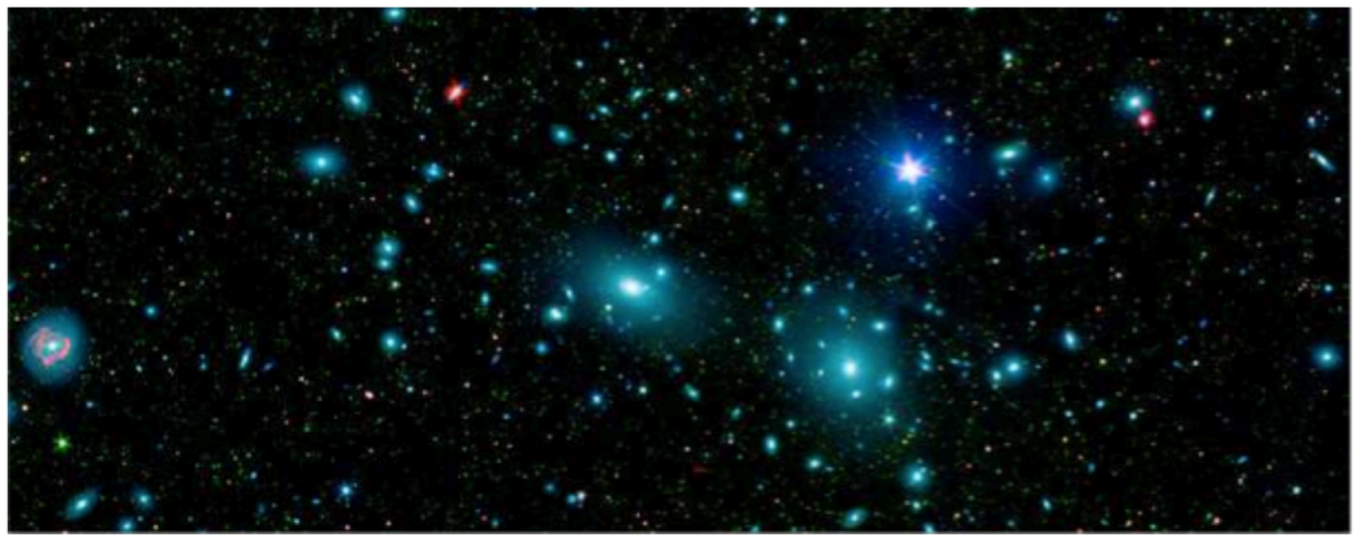


*Comprises **majority** of **mass** in Galaxies*
Missing mass on Galaxy Cluster scale

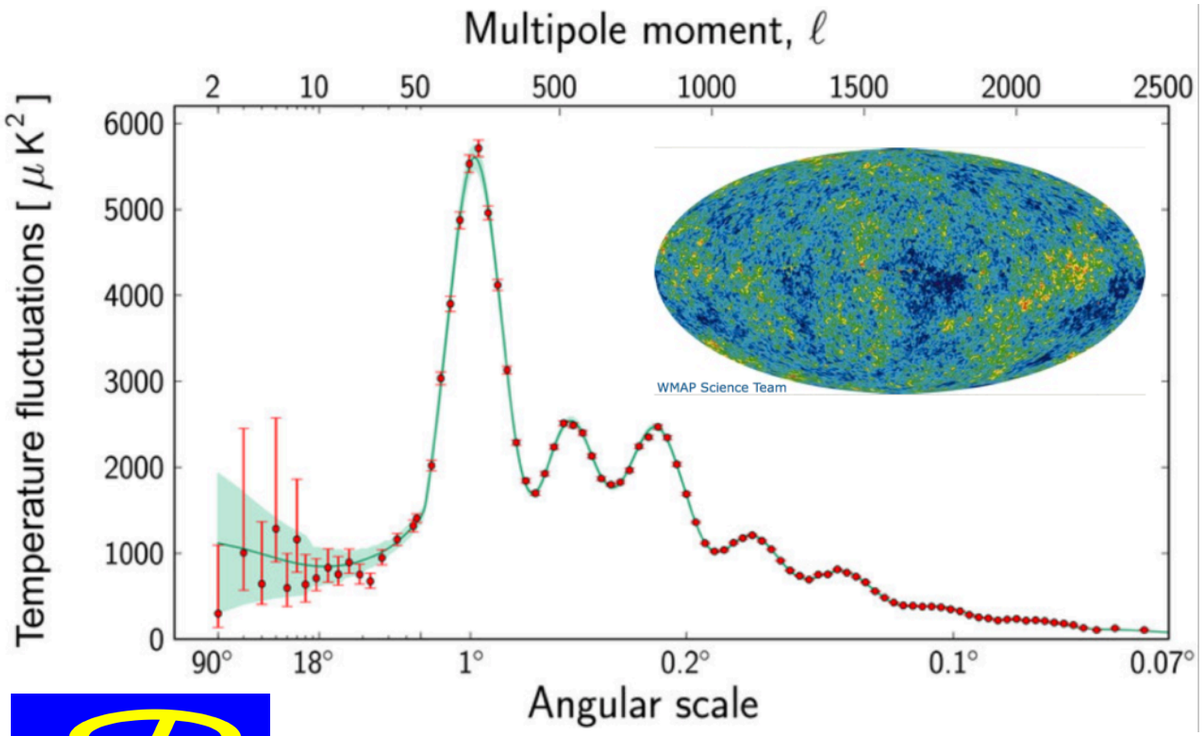
Dark matter knowledge



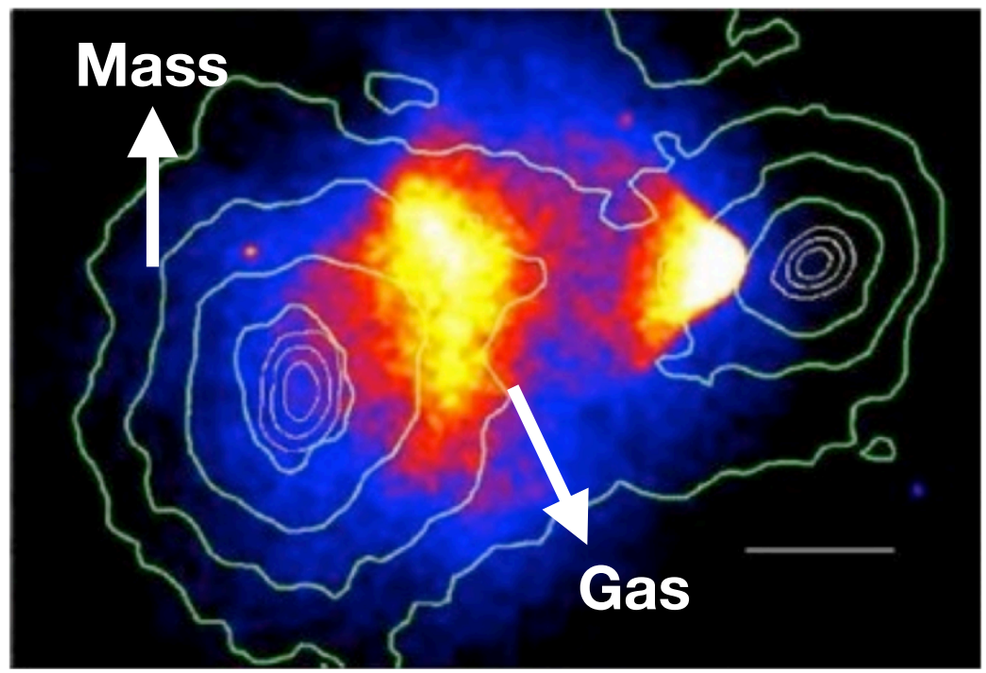
*Large **halos** around Galaxies*
Rotation Curves



*Comprises **majority** of **mass** in Galaxies*
Missing mass on Galaxy Cluster scale

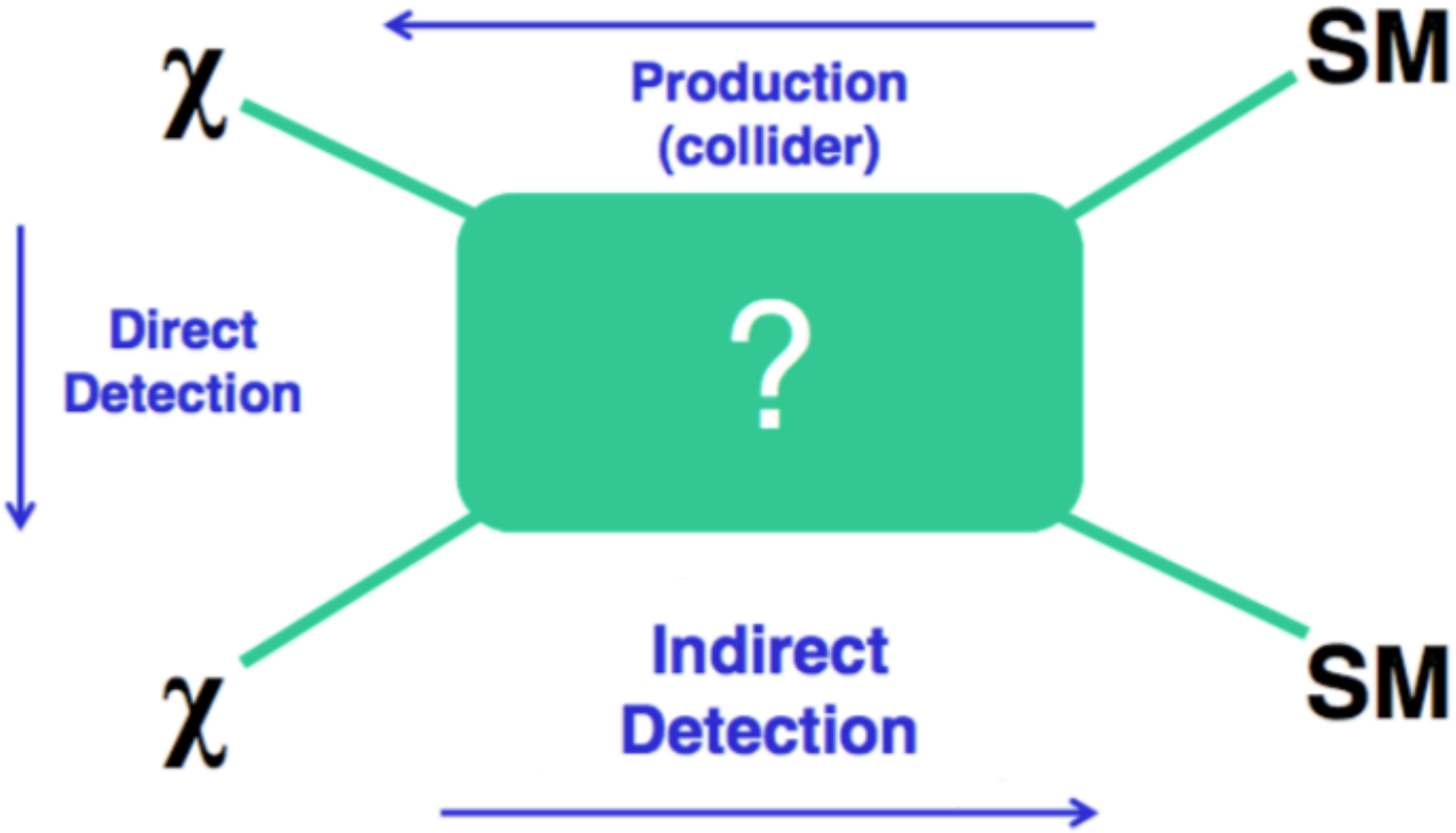


Non-Baryonic

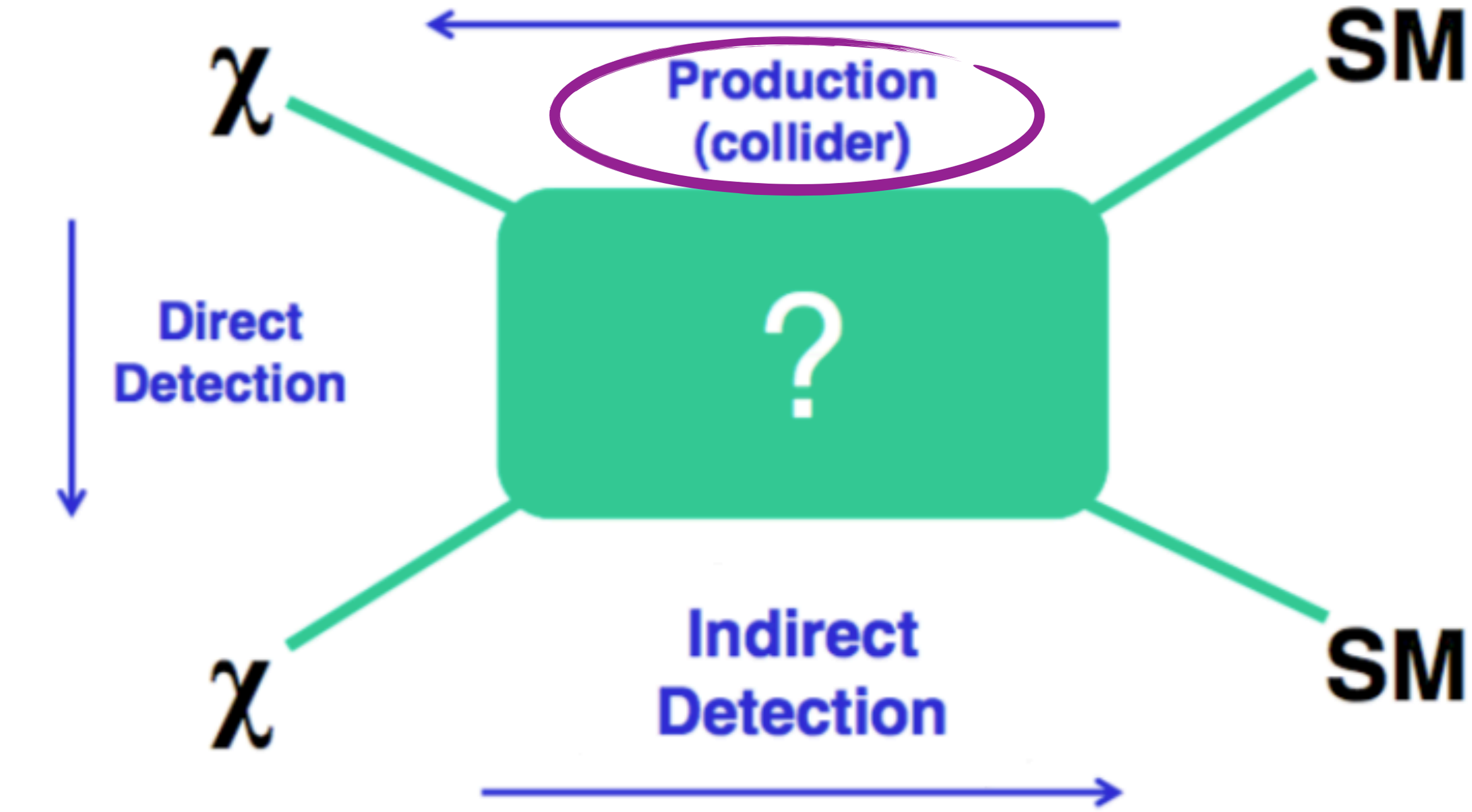


*Almost **collisionless***

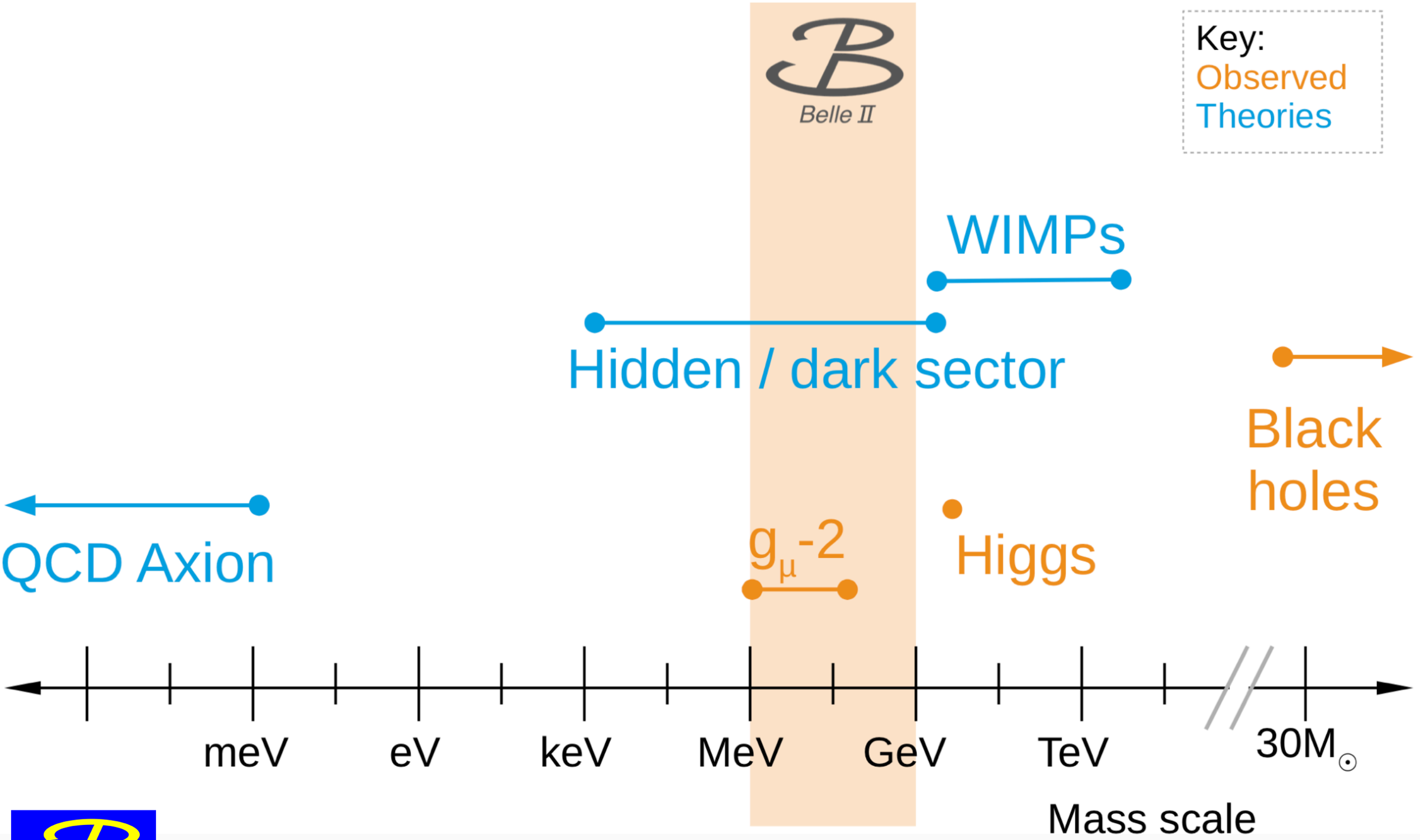
Dark matter detection



Dark matter detection

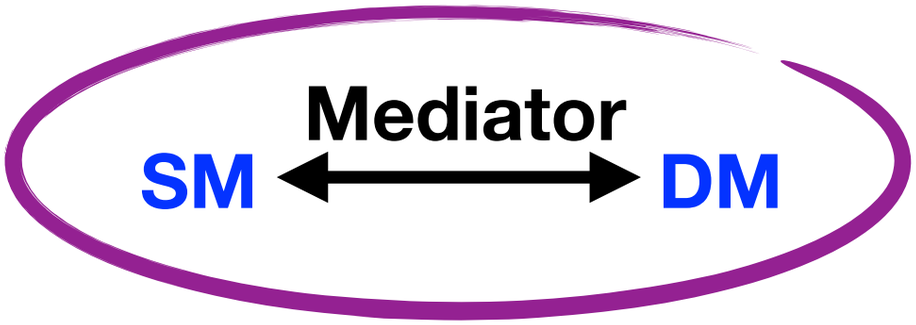


Dark matter searches @Belle II (I)



Dark matter searches @Belle II (I)

Dark sector:



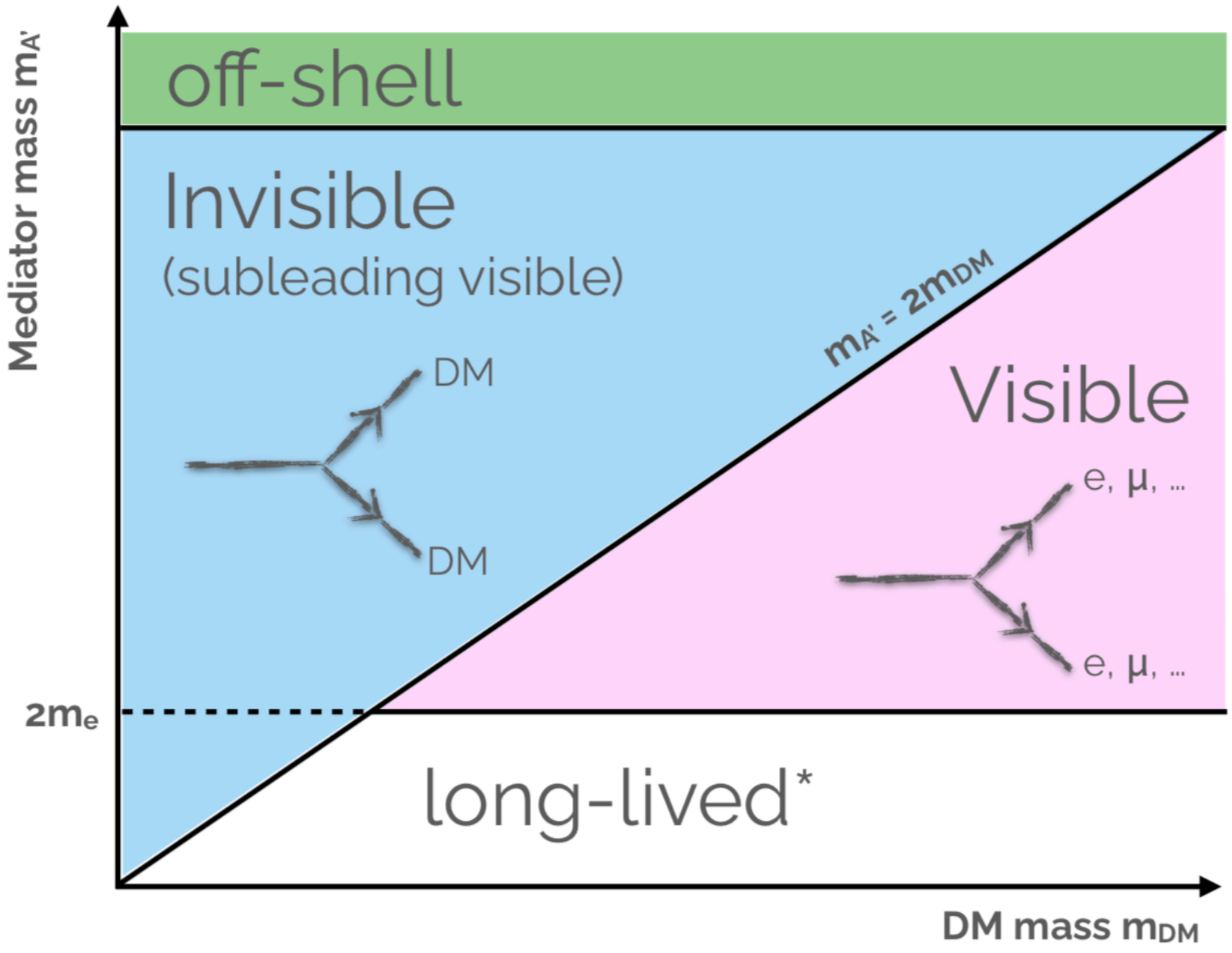
Dark matter searches @Belle II (II)

Mediators studied at Belle II:

- Dark photon
  (vector-like portal)

- Z' mediator
  (vector-like portal)

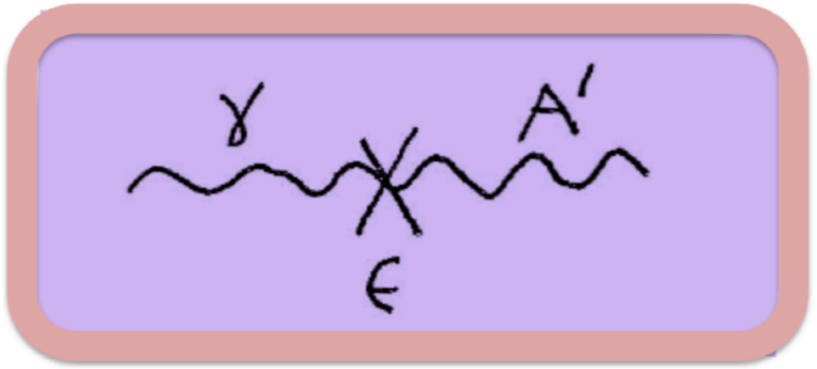
- Axion Like Particle, ALP
  (pseudo-scalar portal)



Dark photon

Minimal model introducing the dark interaction comprises:

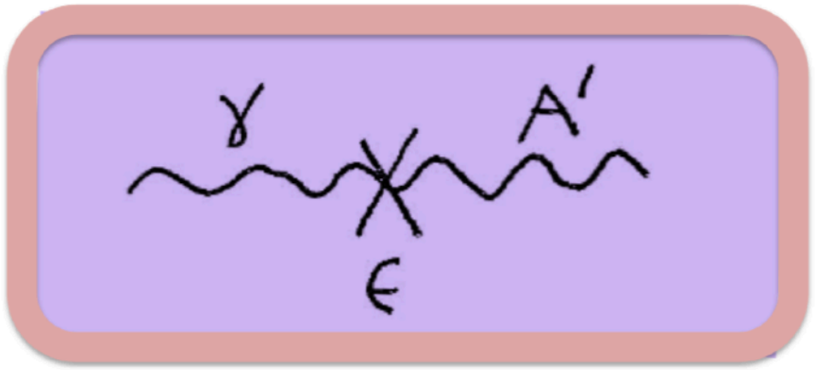
- A': dark photon. Boson mediator of the dark interaction with mass $m_{A'}$ and spin 1
- ε: coupling parameter. It indicates the coupling intensity between the dark photon and the SM photon



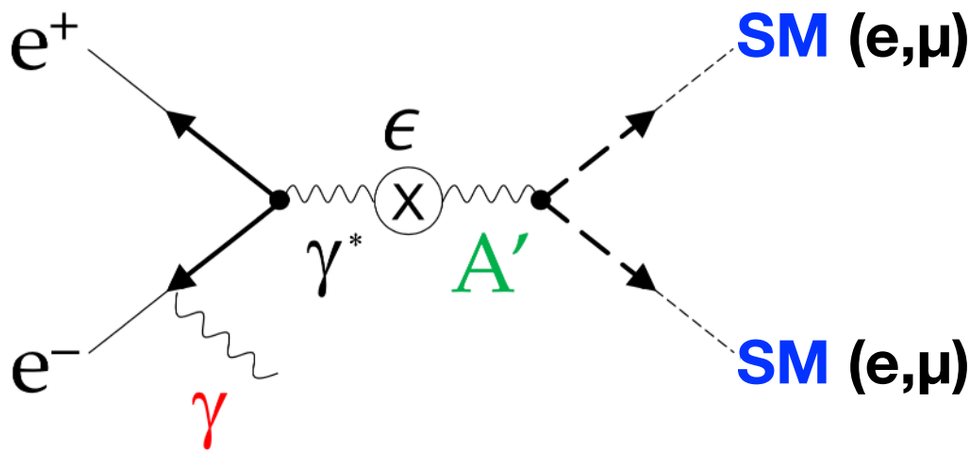
Dark photon: visible final state

Minimal model introducing the dark interaction comprises:

- **A'**: dark photon. Boson mediator of the dark interaction with mass $m_{A'}$ and spin 1
- ε: coupling parameter. It indicates the coupling intensity between the dark photon and the SM photon
- **SM**: standard model particles

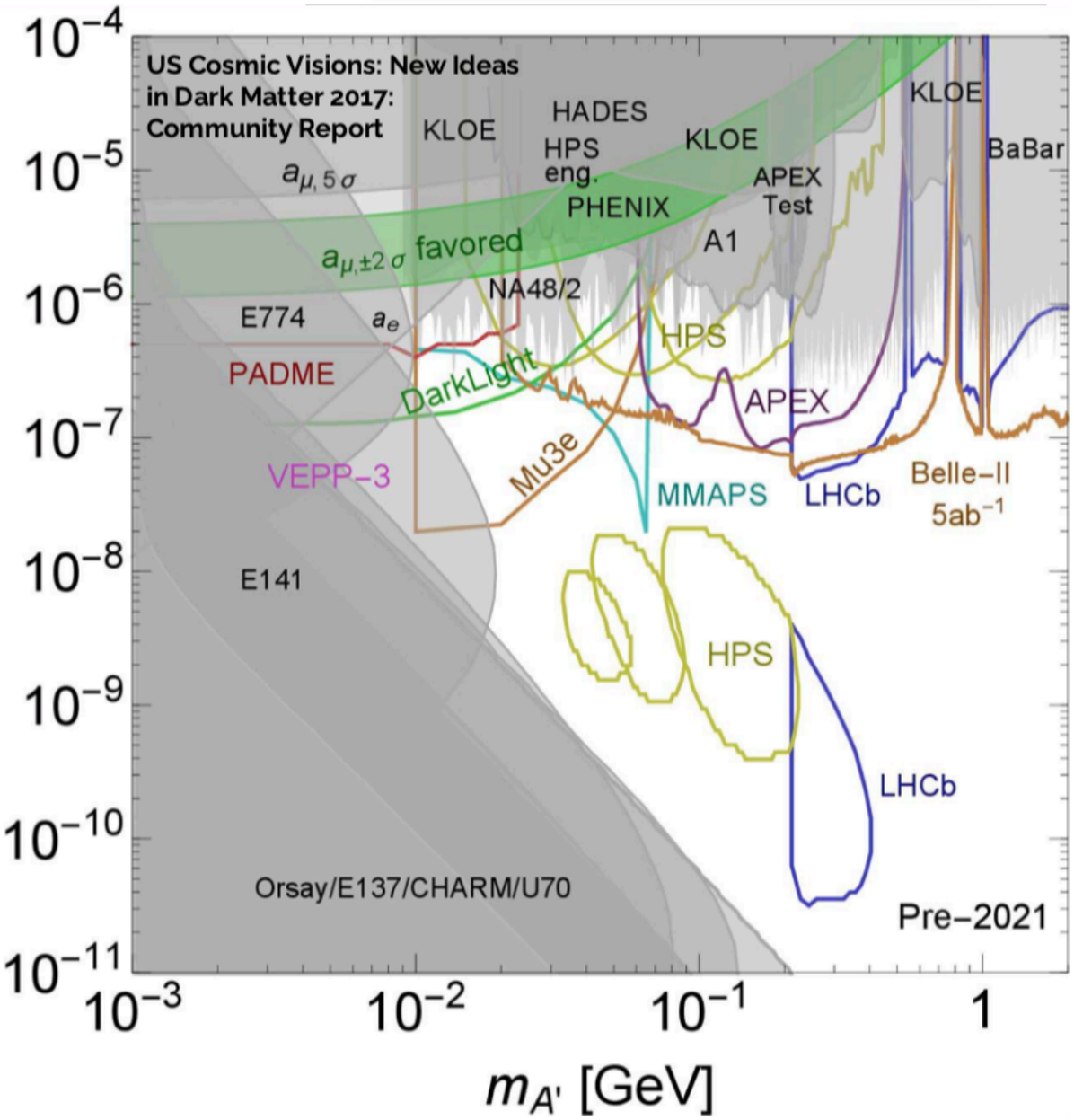


A' decay into visible states



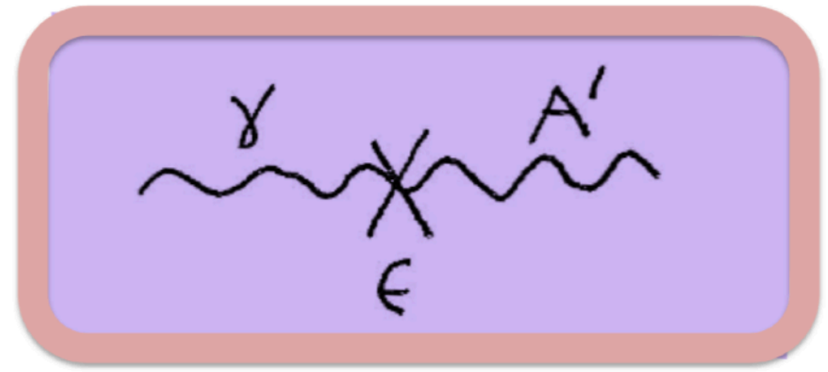
e, μ channels are the most promising
(no neutrinos, no other peaking signals)

$\mathscr{L}^{int}$=5 ab^{-1} needed to improve current limits



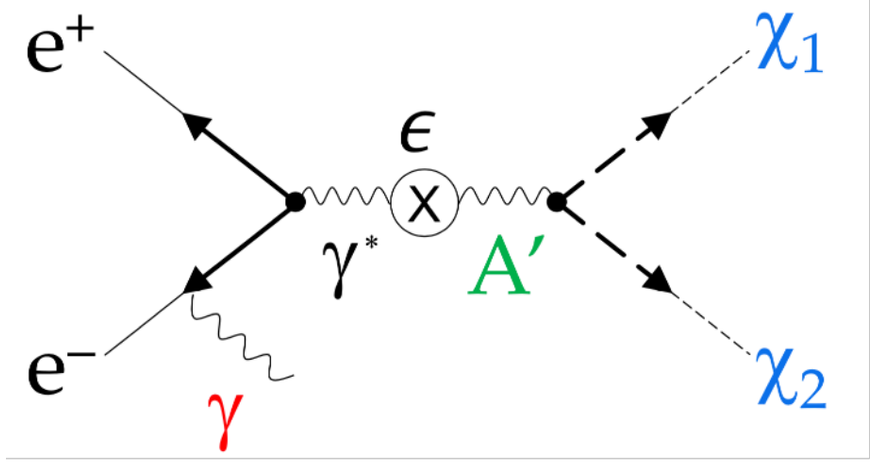
Dark photon: invisible final state (I)

Minimal model introducing the dark interaction comprises:

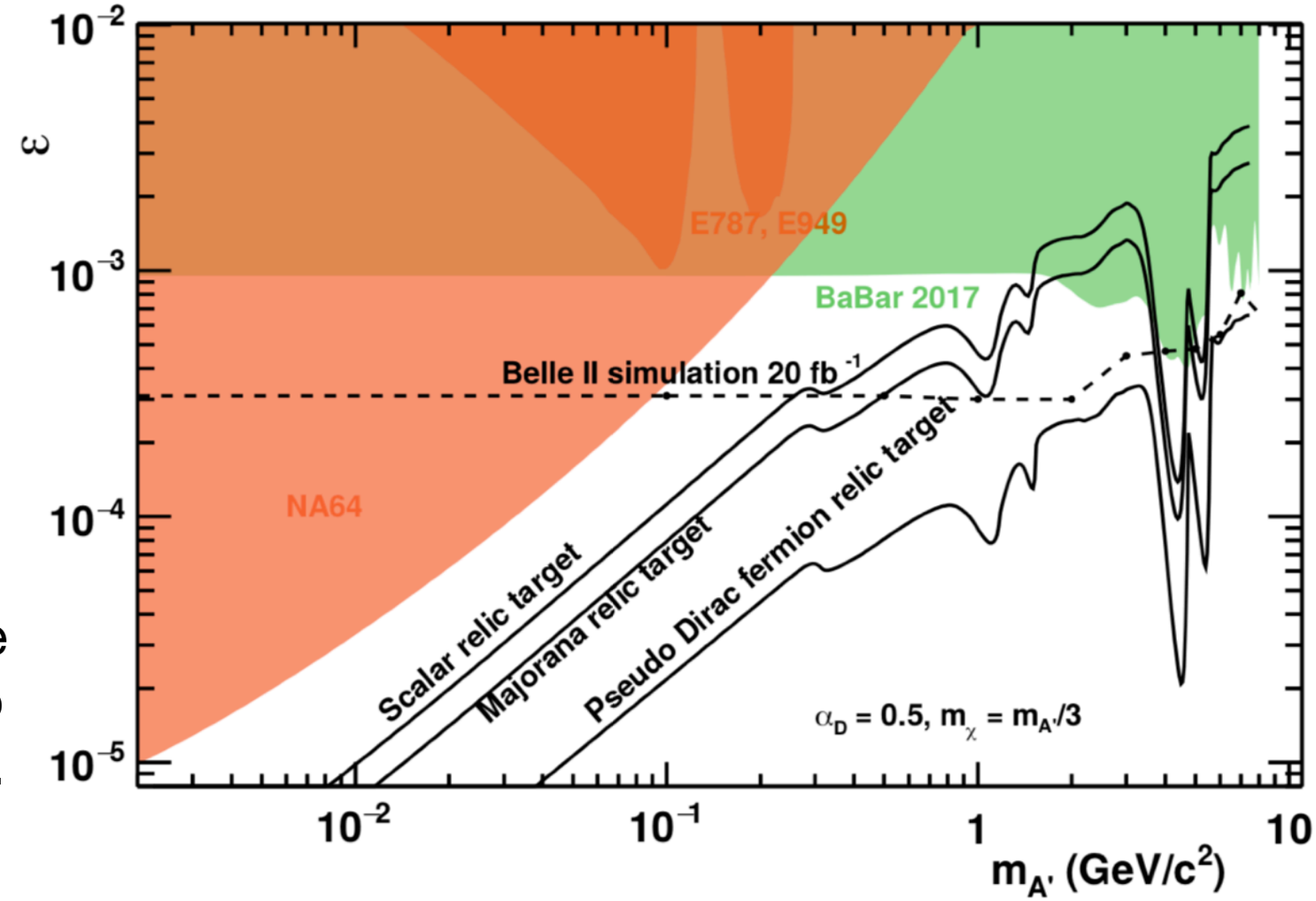


- **A'**: dark photon. Boson mediator of the dark interaction with mass $m_{A'}$ and spin 1
- ε: coupling parameter. It indicates the coupling intensity between the dark photon and the SM photon
- $\chi_{1,2}$: dark matter particles

A' decay into invisible states



At the moment, this analysis can be performed only by Belle II thanks to the single photon dedicated trigger.



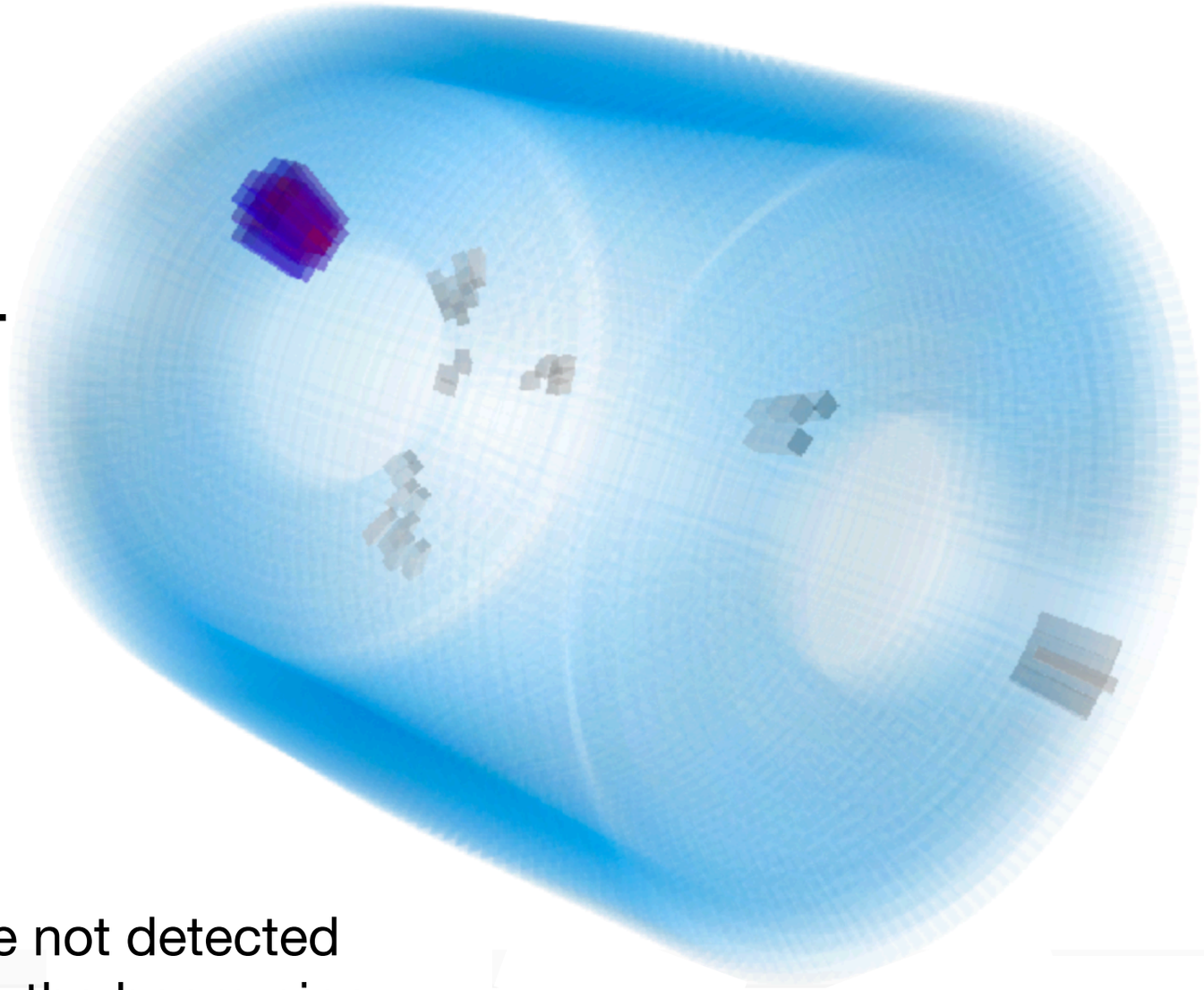
Possible improvement of the limits with 2019 dataset $\mathscr{L}^{int}$=20 fb^{-1}

Dark photon into invisible final state (II)

Experimental signature of the event:

ONLY 1 high energetic photon in the event.
Search for a peak around:

$$E_\gamma = \frac{s - m_{A'}}{2\sqrt{s}}$$

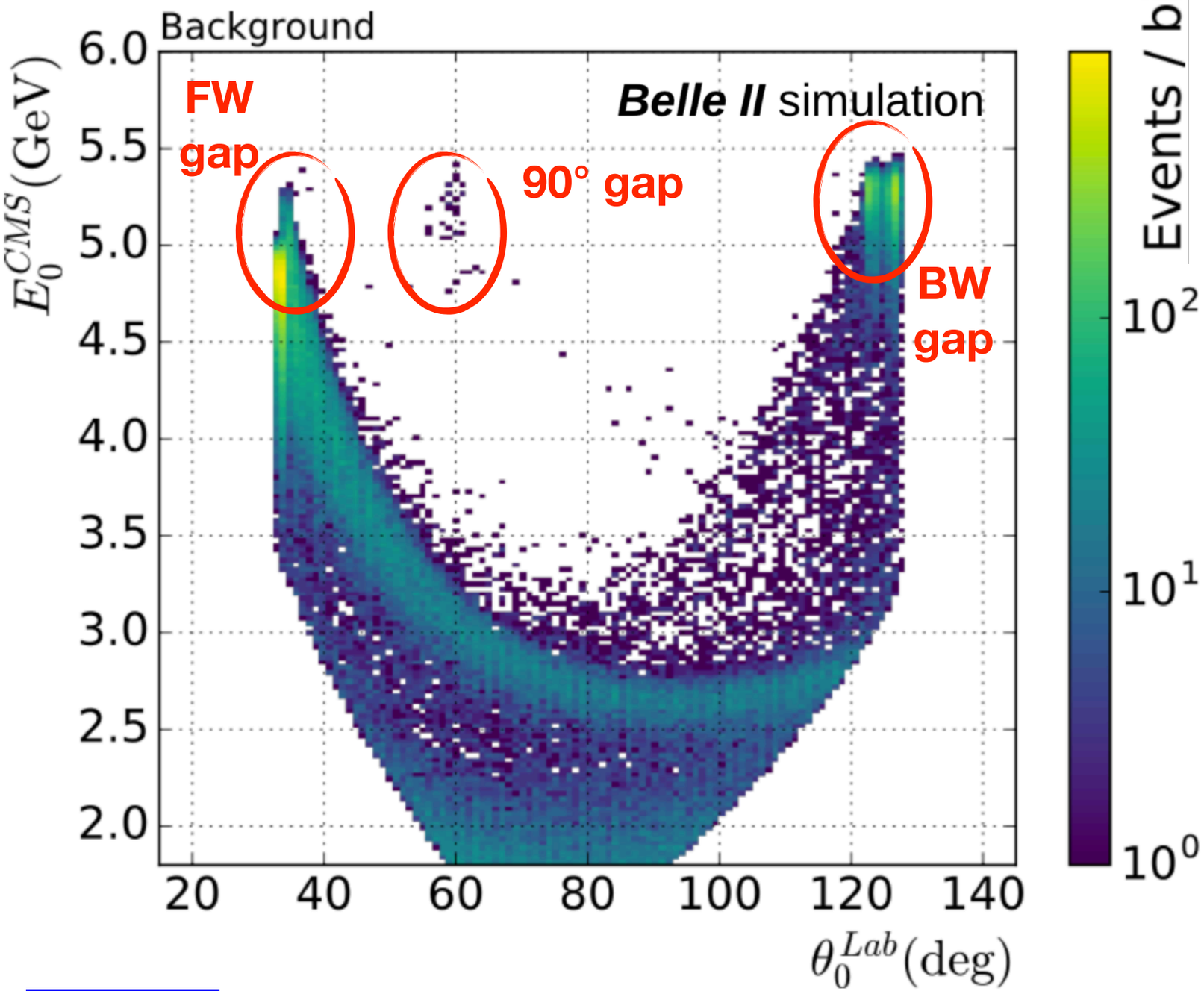


Physical background:

- $e^+e^- \longrightarrow \gamma\gamma(\gamma)$ where 1 or 2 photon are not detected
- $e^+e^- \longrightarrow e^+e^-\gamma$ where $e^\pm$ usually go in the beam pipe
- Cosmic rays

Belle II has better sensitivity wrt BaBar due to the more hermetic detector (both ECL and KLM).

Dark photon into invisible final state (III)



Experimental limitations:
Detector acceptance and dead regions.

3 main gaps in the calorimeter: backward (BW) and forward (FW) regions and at 90°.

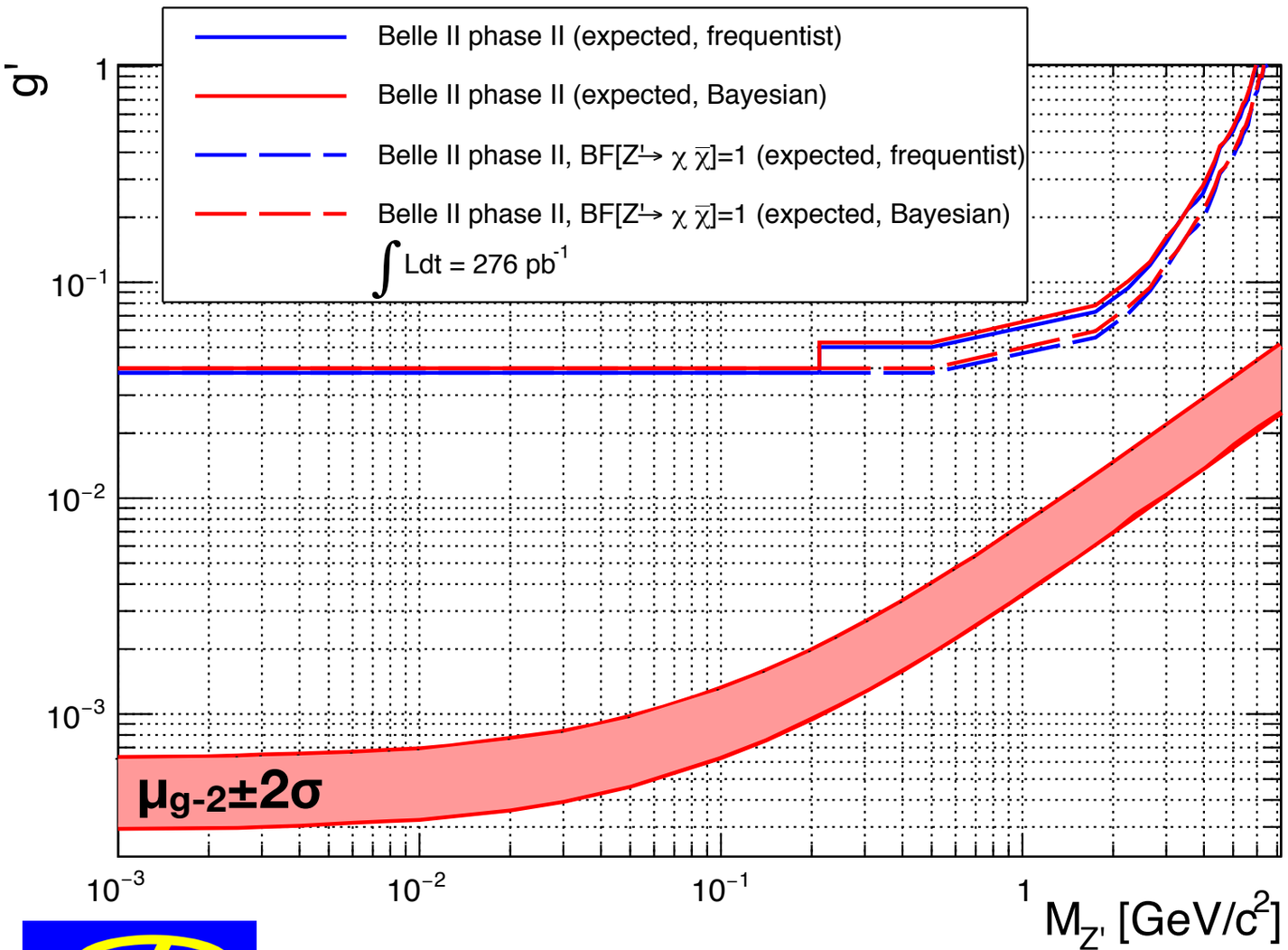
Usage of the outermost detector (KLM) to veto events with multiple photons

Z' mediator: $L_\mu - L_\tau$ model (I)

Vector massive mediator **Z'** → *non* minimal model

Z' couples with μ and τ only → $\mathbf{L_\mu - L_\tau}$ model

Possibility to also explain the g-2 and B anomalies w/ full statistics



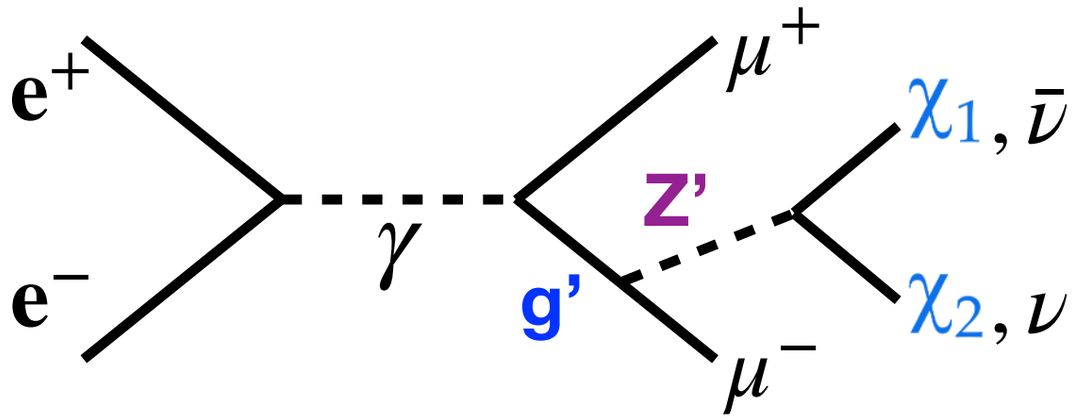
Z'→ visible final state already **studied in BaBar**

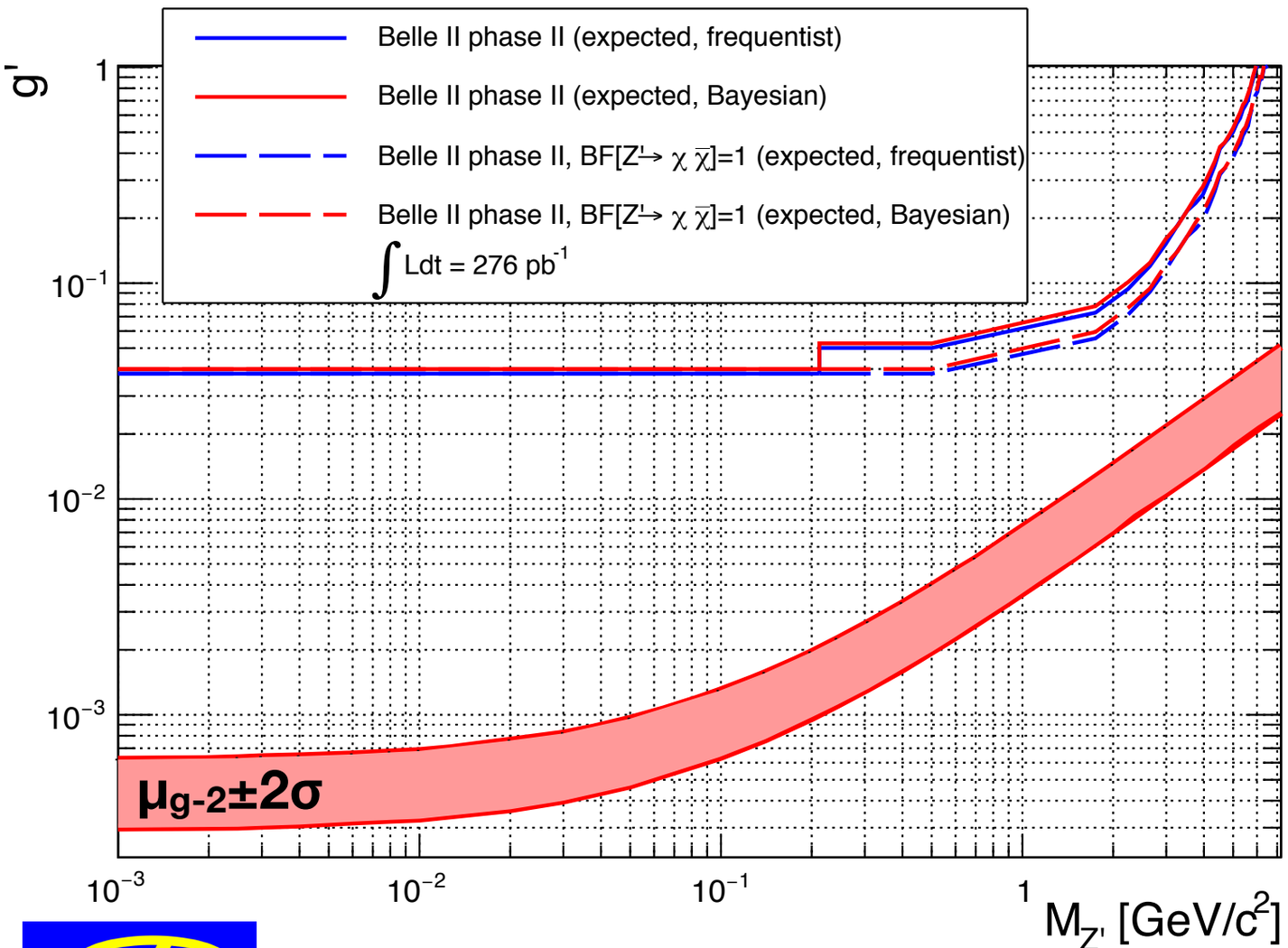
Z' mediator: $L_\mu - L_\tau$ model (I)

Vector massive mediator **Z'** → *non* minimal model

Z' couples with μ and τ only → $\mathbf{L_\mu - L_\tau}$ model

Possibility to also explain the g-2 and B anomalies w/ full statistics





Z'→ visible final state already **studied in BaBar**

Z'→ invisible final state has **not been measured** yet

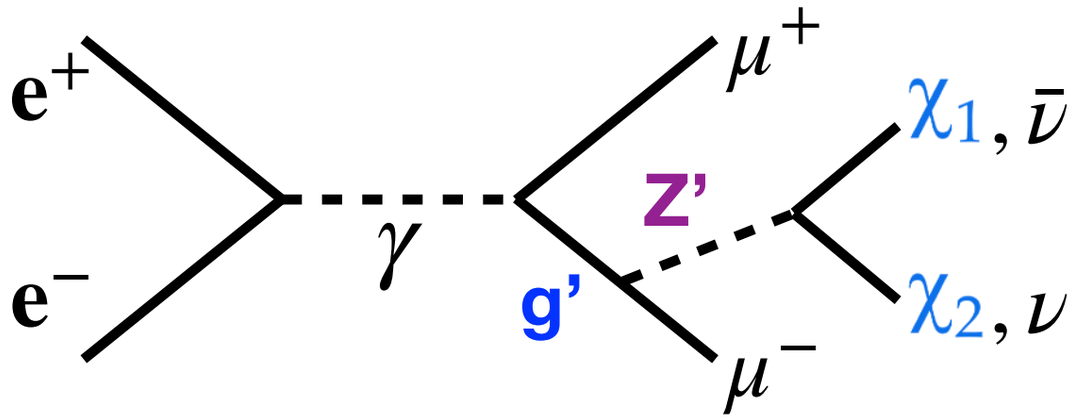
Belle II analysis ongoing → aims to publish with dataset from 2018.

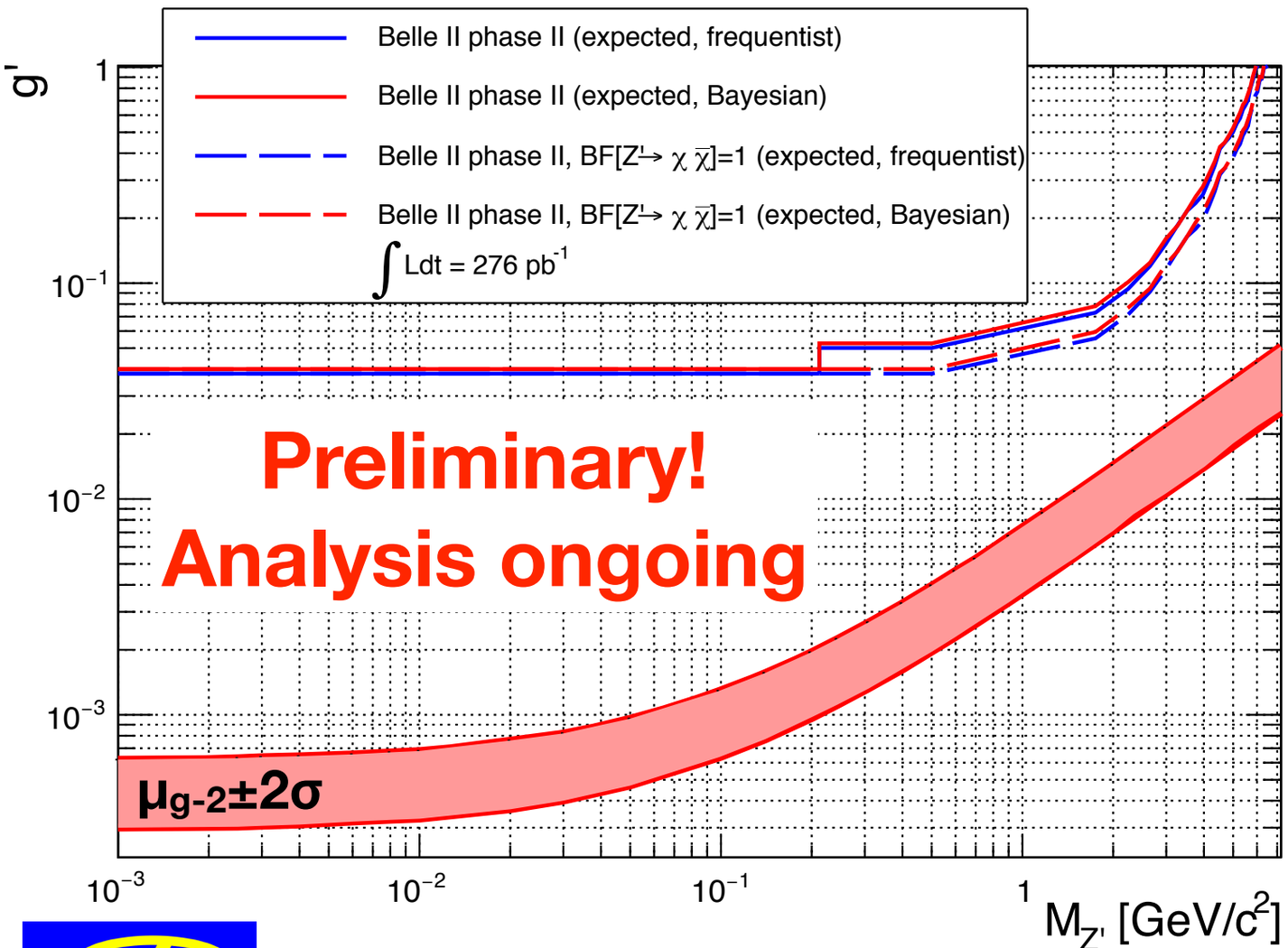
Z' mediator: $L_\mu - L_\tau$ model (I)

Vector massive mediator **Z'** → *non* minimal model

Z' couples with μ and τ only → $\mathbf{L_\mu - L_\tau}$ model

Possibility to also explain the g-2 and B anomalies w/ full statistics





Z'→ visible final state already **studied in BaBar**

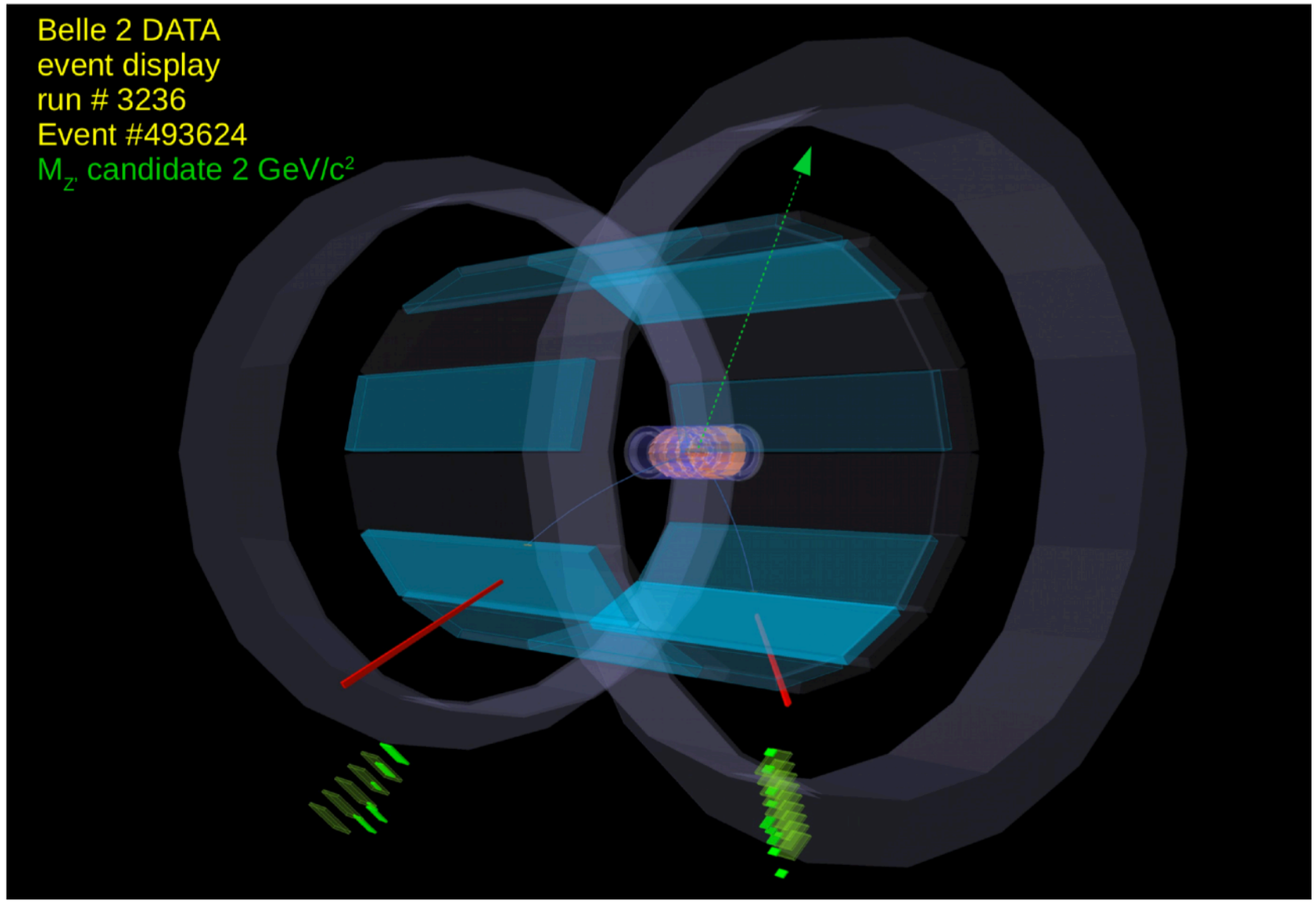
Z'→ invisible final state has **not been measured** yet

Belle II analysis ongoing → aims to publish with dataset from 2018.

Z’ mediator: $L_\mu - L_\tau$ model (II)

Experimental signature:

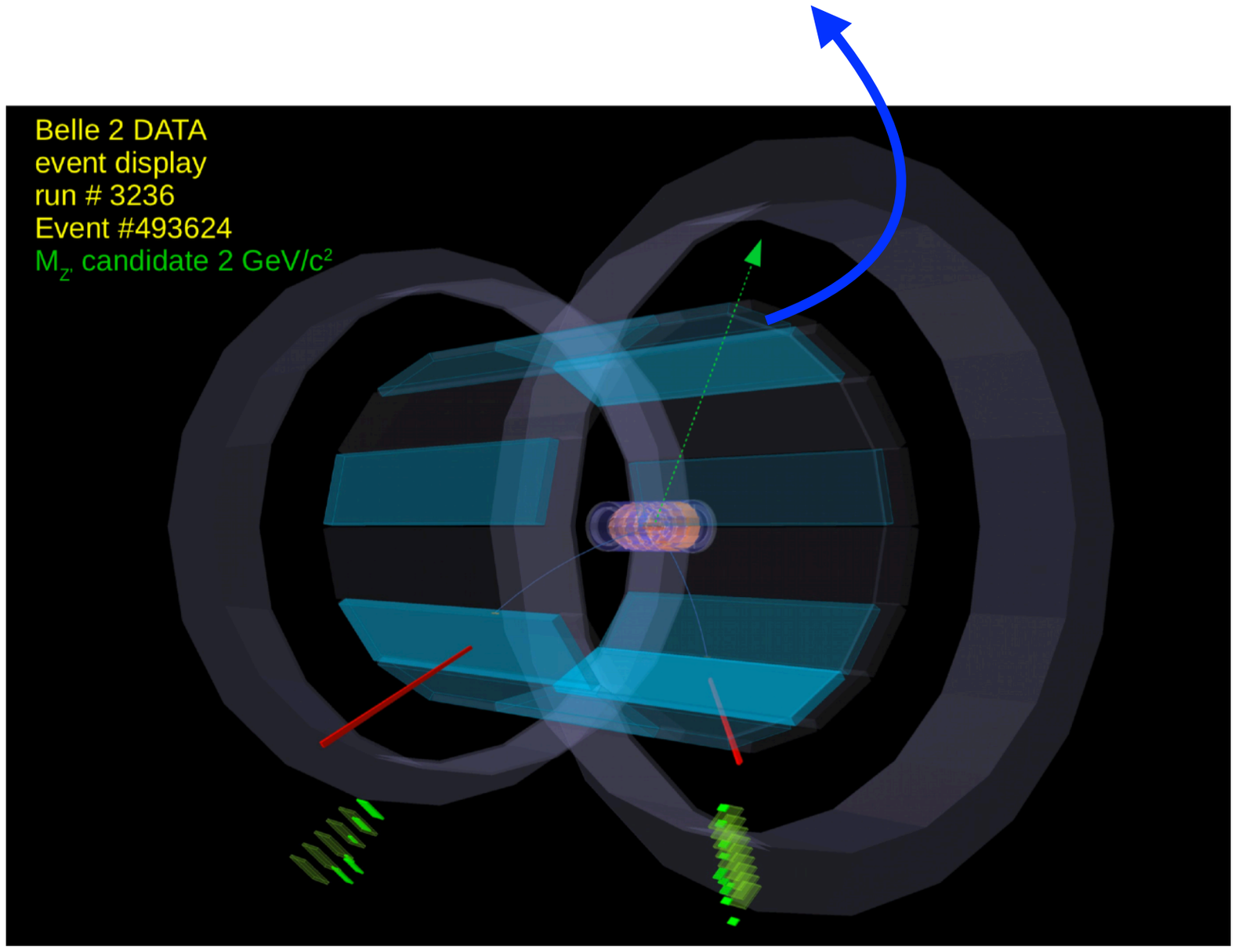
Z’ mass hypothesis → search for a **peak at $\mu^+\mu^-$ recoil mass** distribution



Z’ mediator: $L_\mu - L_\tau$ model (II)

Experimental signature:

Z’ mass hypothesis → search for a **peak at $\mu^+\mu^-$ recoil mass** distribution
Z’ momentum (missing momentum) pointing to active part of the detector.



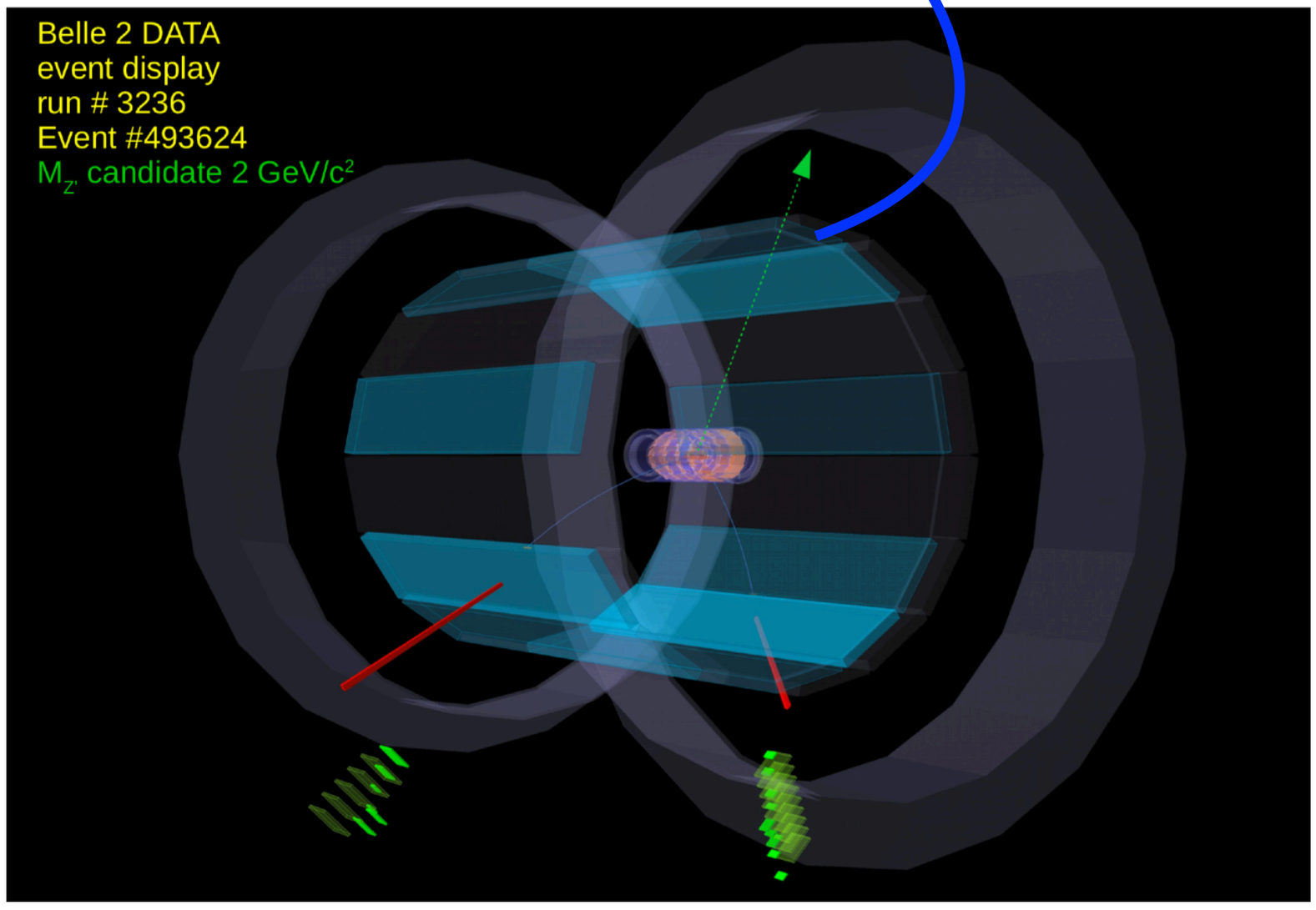
Z' mediator: $L_\mu - L_\tau$ model (II)

Experimental signature:

Z' mass hypothesis → search for a **peak at $\mu^+\mu^-$ recoil mass** distribution
Z' momentum (missing momentum) pointing to active part of the detector.

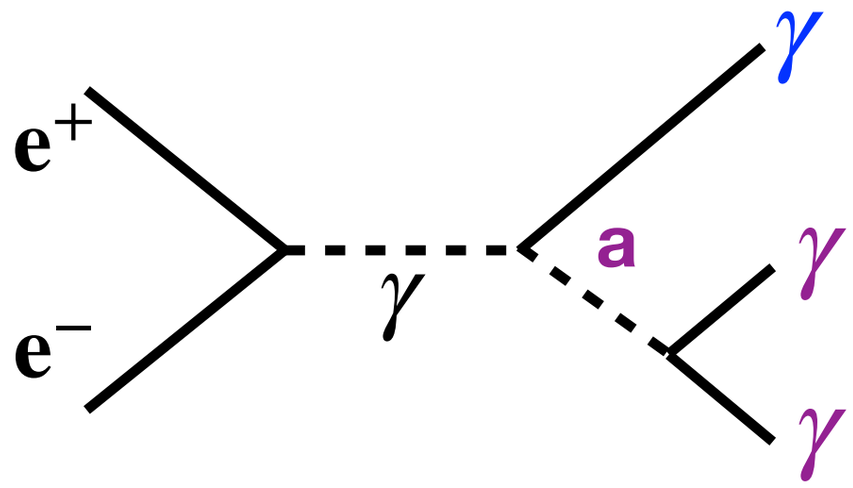
Physical background:

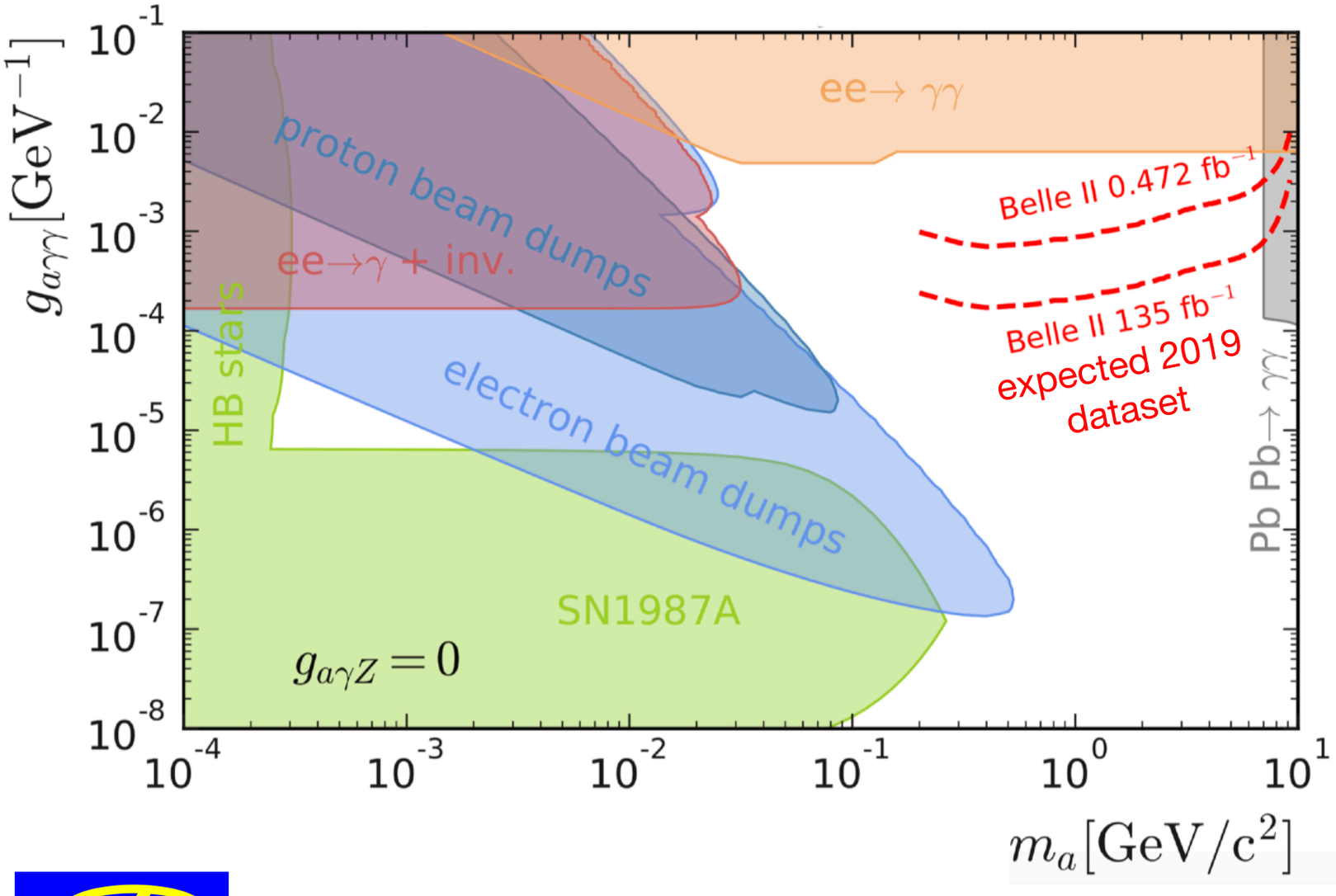
- $e^+e^- \longrightarrow \mu^+\mu^-\gamma(\gamma)$ for low $m_{Z'}$
- **Tau decays**: important effort on background rejection using kinematic variables. **Dominant contribution** in the studied mass range.
- $e^+e^- \longrightarrow e^+e^-\mu^+\mu^-$



Axion Like Particles searches (I)

Axion-Like Particles (ALPs) **a:** pseudo-scalar mediator.
Coupling with bosons → Belle II investigates $a \longrightarrow \gamma\gamma$
No relation between mass and coupling.

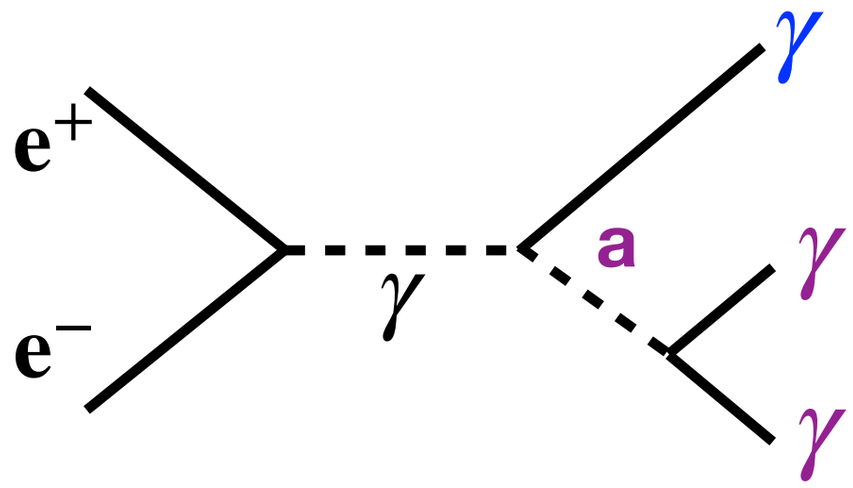


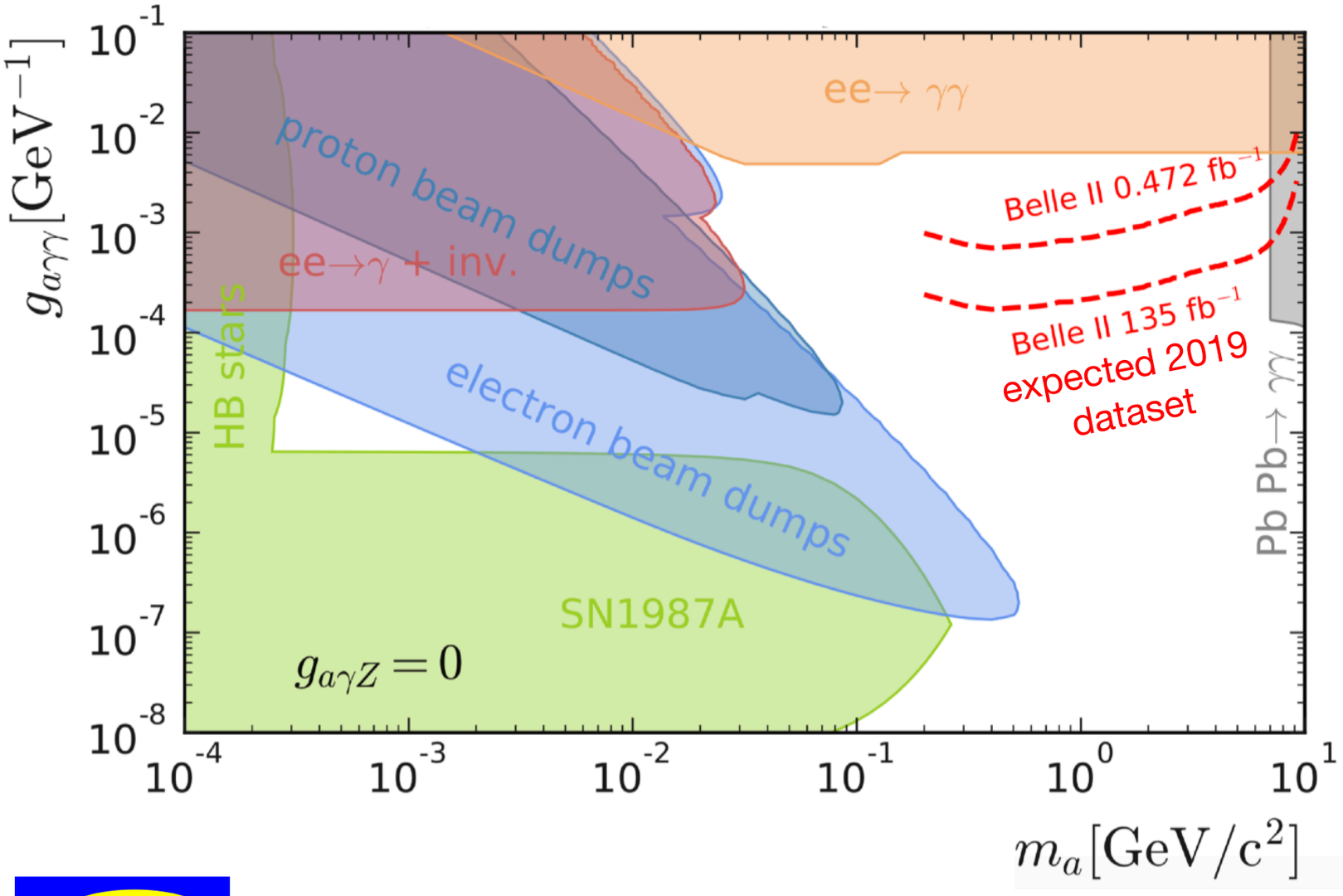


No previous results → Belle II will provide first measurement with data from 2018

Axion Like Particles searches (I)

Axion-Like Particles (ALPs) **a:** pseudo-scalar mediator.
Coupling with bosons → Belle II investigates $a \longrightarrow \gamma\gamma$
No relation between mass and coupling.





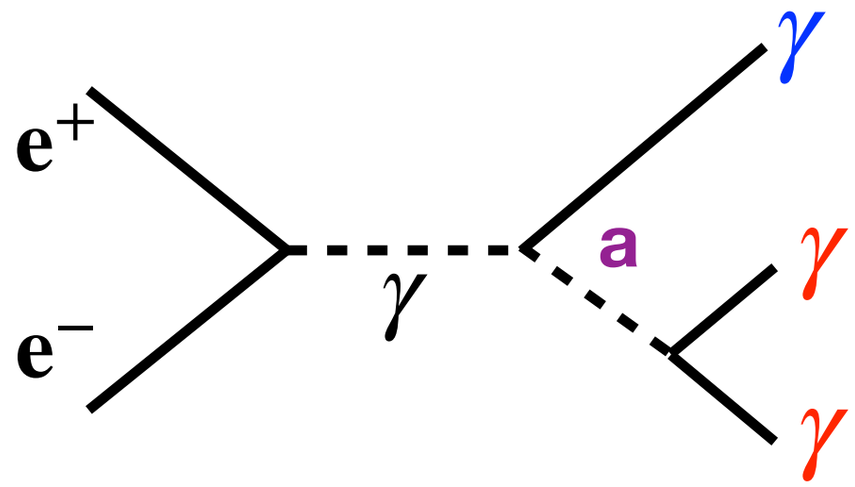
No previous results → Belle II will provide first measurement with data from 2018

B decays physics allow to investigate charged couplings

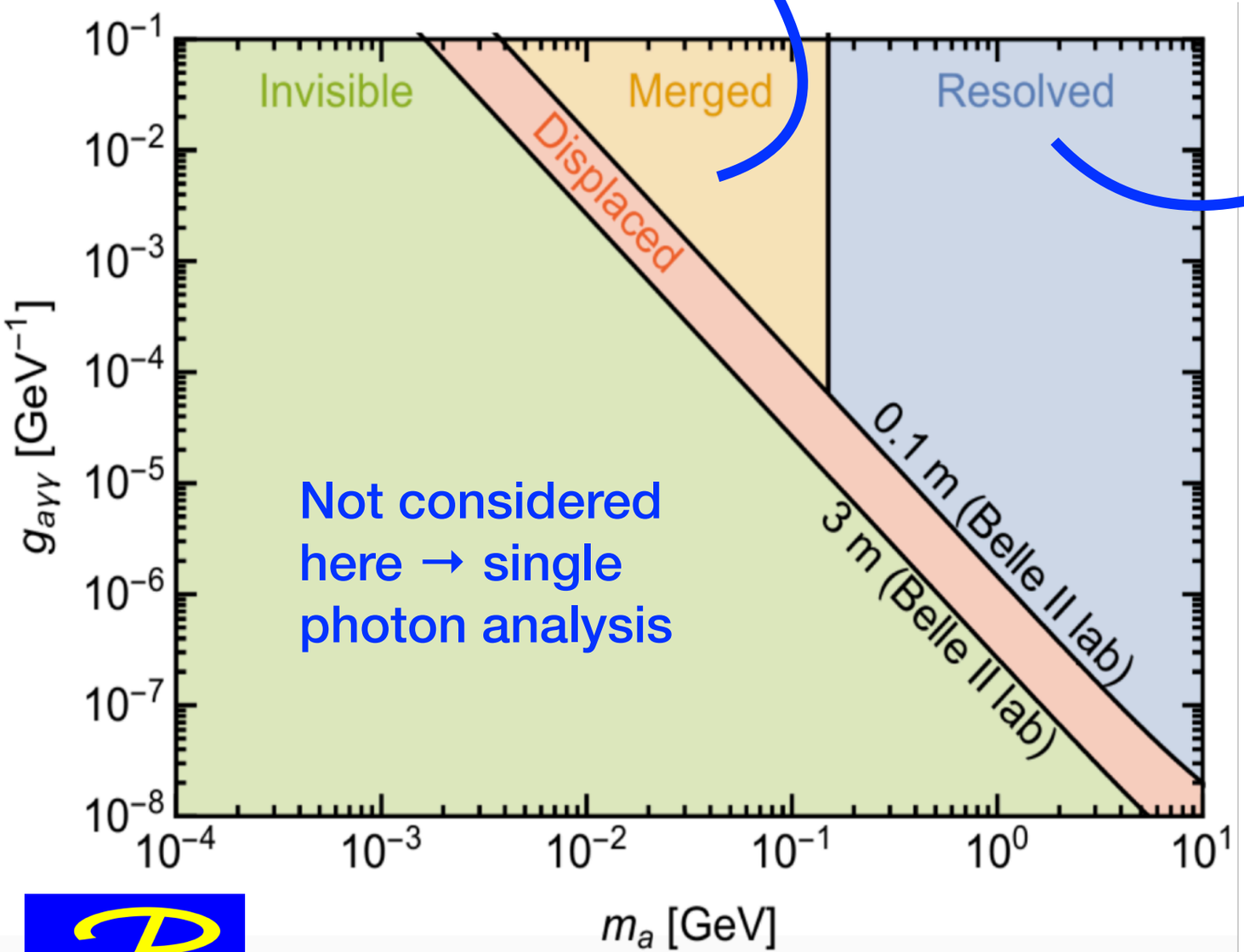
Belle II $\mathscr{L}^{int} > 1 ab^{-1}$ → possibility to get new results also in decays into charged bosons.

Axion Like Particles searches (II)

Experimental signature: 2 **photons** peaking at m_a



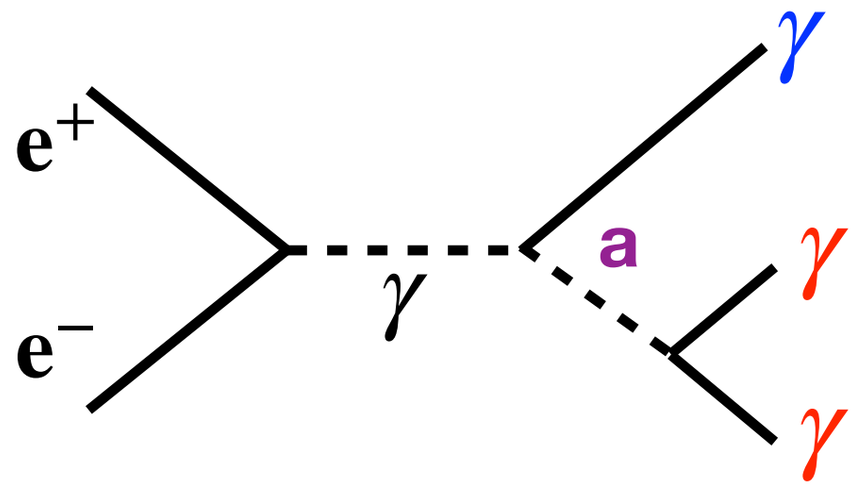
2 close photons → 1 calorimetric cluster



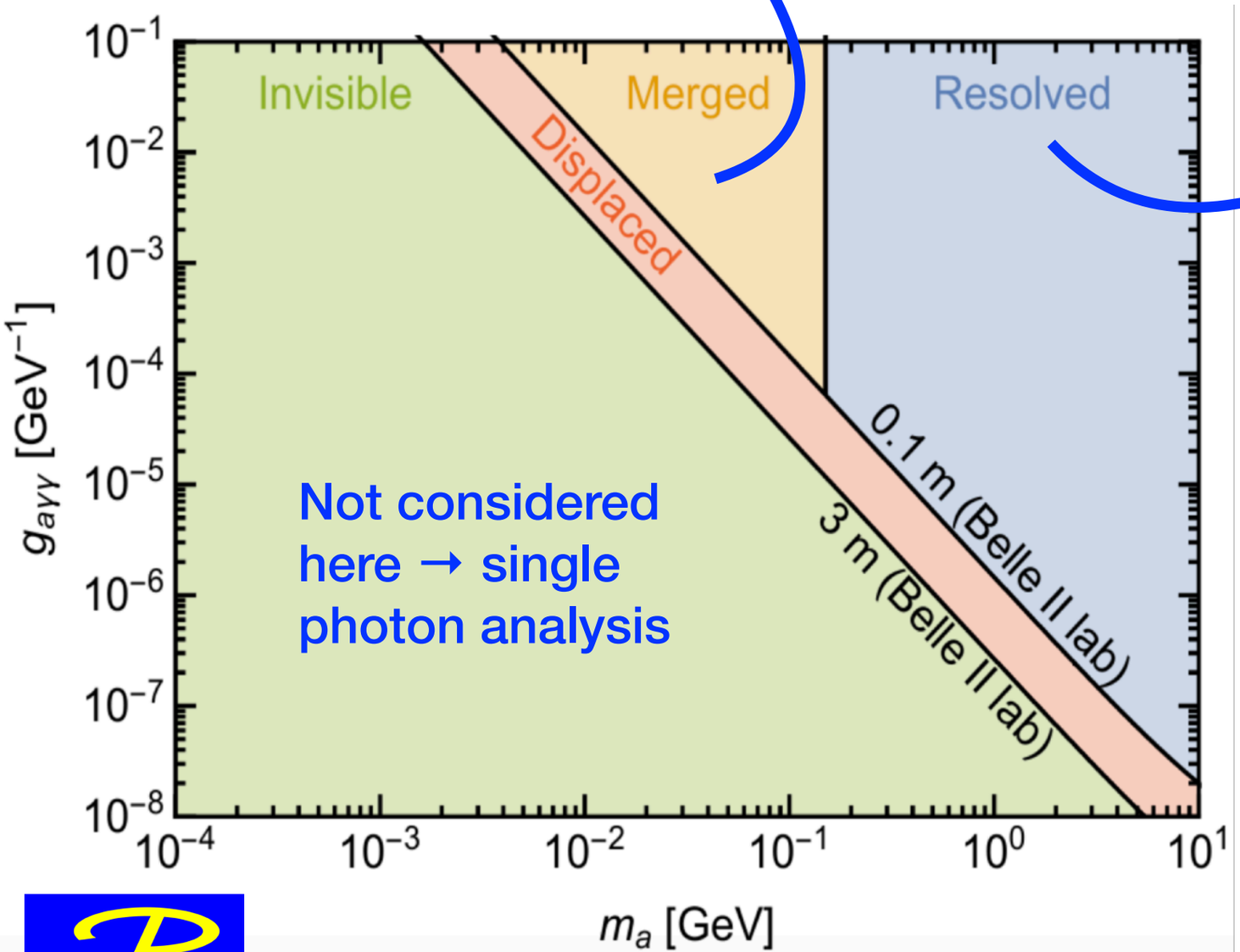
3 different calorimetric cluster, best situation

Axion Like Particles searches (II)

Experimental signature: 2 **photons** peaking at m_a



2 close photons → 1 calorimetric cluster



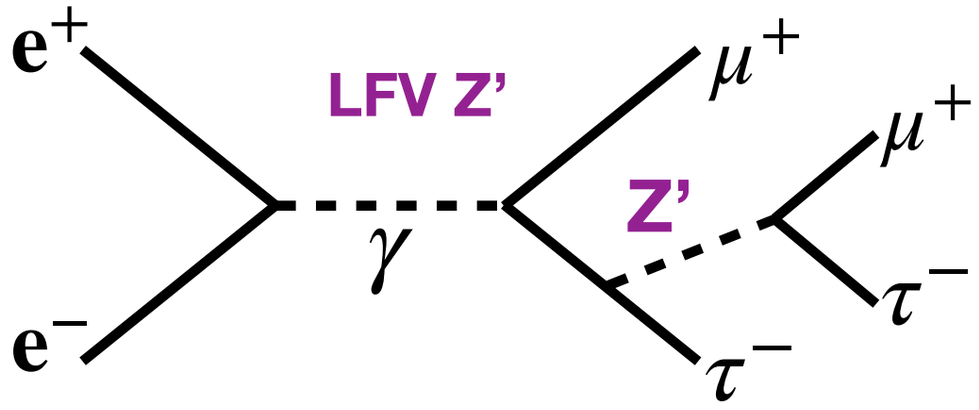
3 different calorimetric cluster, best situation

Physical background:

- $e^+e^- \longrightarrow \gamma\gamma\gamma$ largest contribution but not peaking
- $e^+e^- \longrightarrow \pi^0\gamma$, $\eta\gamma$, $\eta'\gamma$ use of form factor informations to suppress
- $e^+e^- \longrightarrow \omega\gamma(\omega \rightarrow \pi^0\gamma)$

Other dark sector studies @Belle II

- Z' with Lepton Flavor Violation



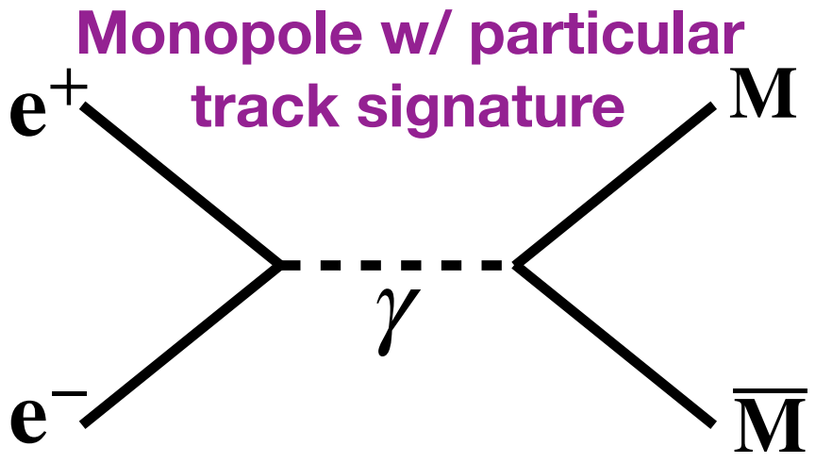
- Dark scalar mediator: $e^+e^- \to \tau^+\tau^- S, S \to l^+l^-$

- Magnetic monopoles with small magnetic charges

- Invisible $\Upsilon(1S)$ decays via $\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$

- Dark Higgs - Higgstrahlung

- **and many others!!**



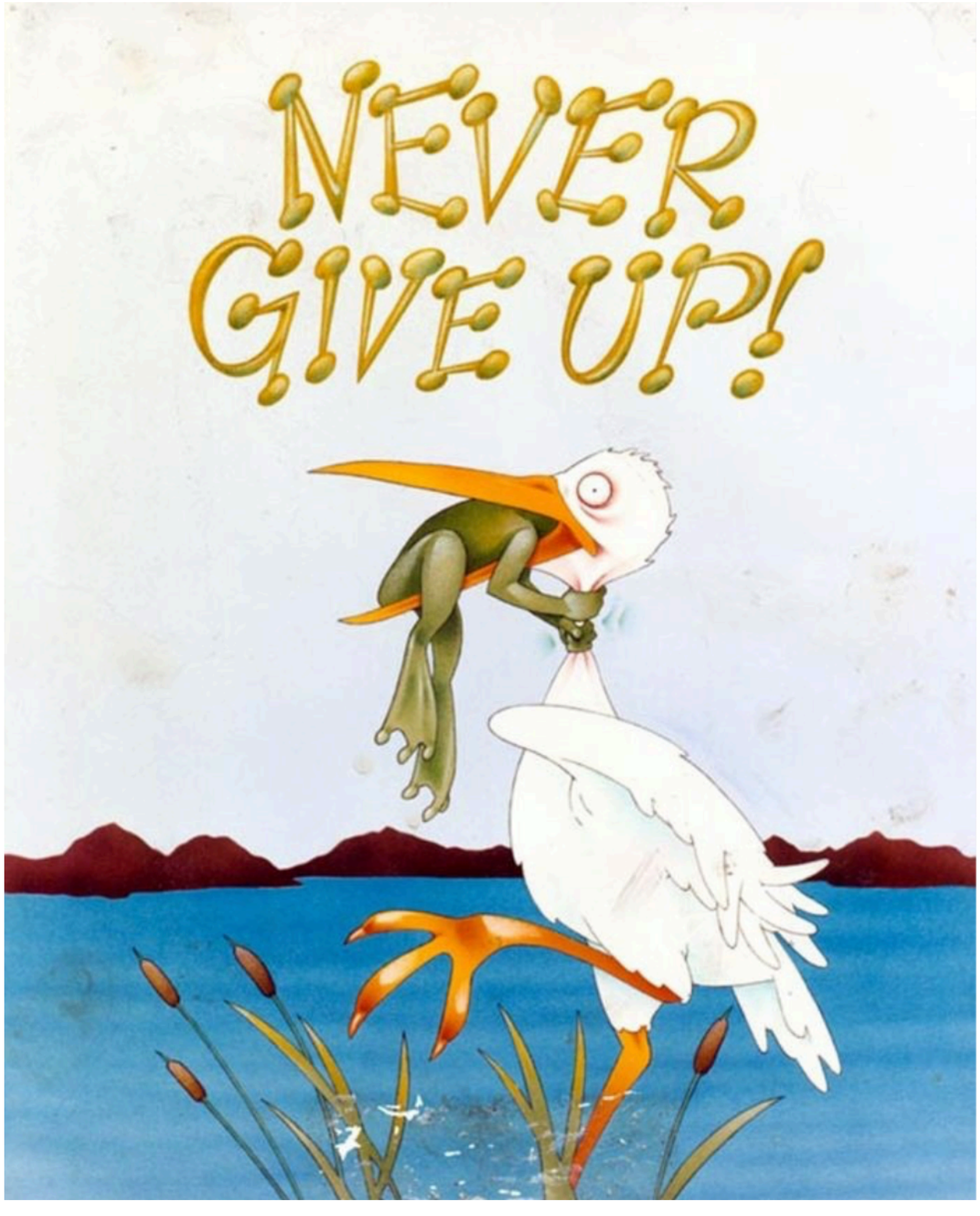
Conclusions

- Belle II started to collect data and investigate light Dark Sector models.

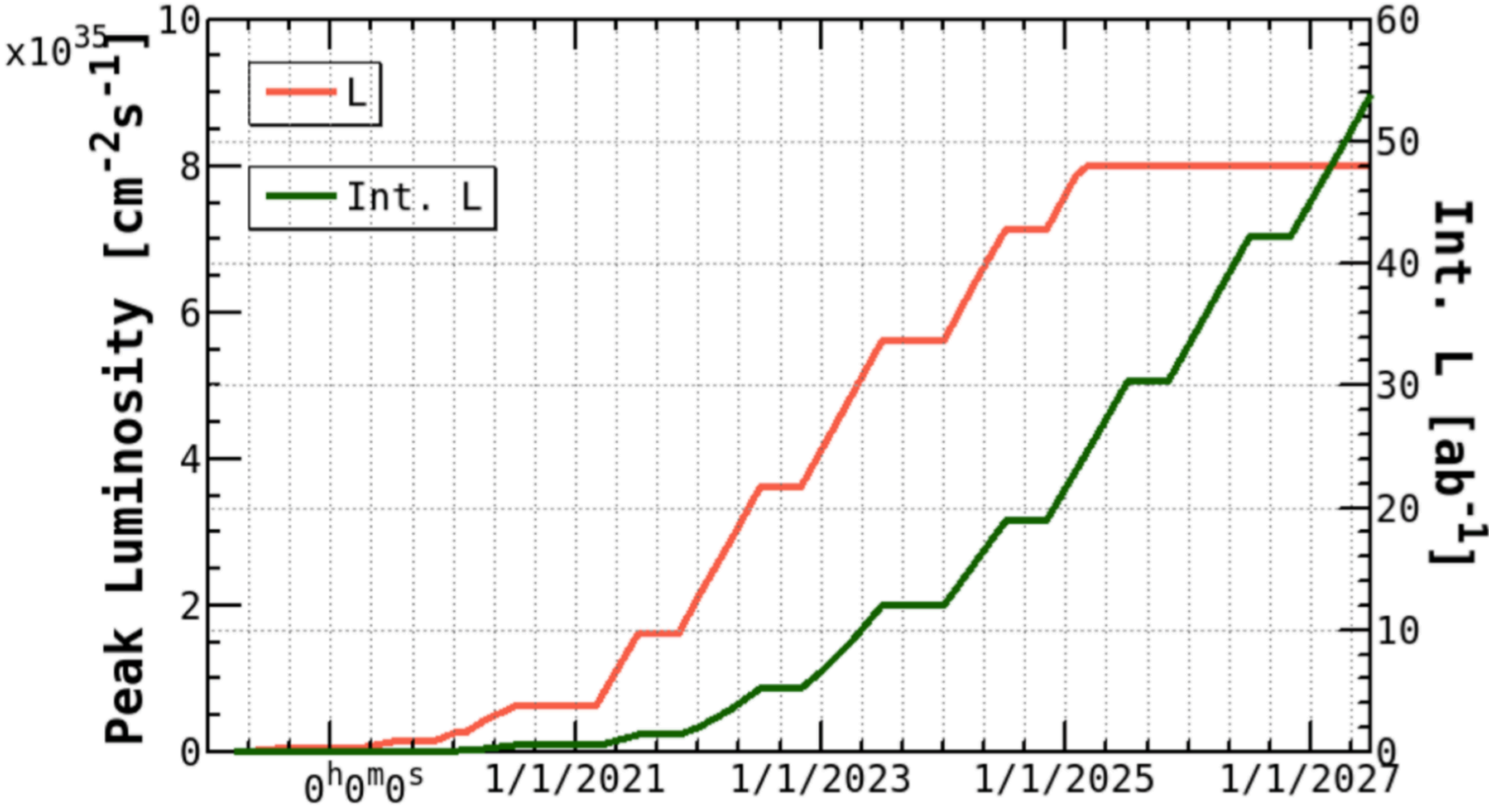
- Invisible dark photon search: first Belle II results from 20 fb^{-1}
- Vector boson Z' $\longrightarrow$ invisible: non minimal model which will provide the first measurement ever with data from 2018.
- ALPs measurements: visible channel a$\rightarrow\gamma\gamma$ will be published with data from 2018

- It is early (statistical reasons) for plenty of other dark searches!

Emergency slides!!



Belle II: second generation B-factory



Belle II