Dark Sector searches at Belle II

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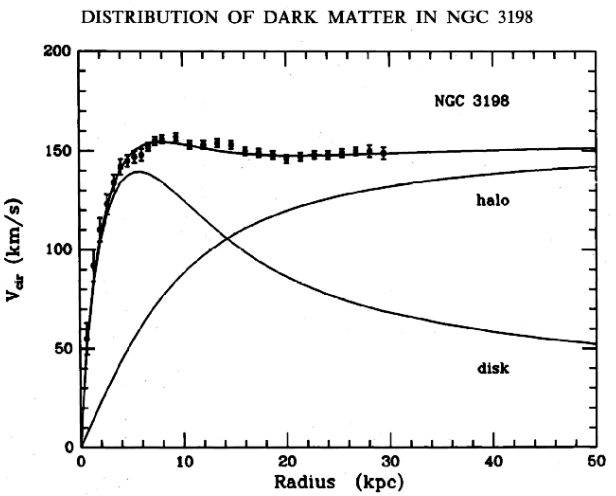
Dark Matter (DM)

What do we know about dark matter:

1. It exists
2. It is dark

Existence of dark matter has been established in astrophysics:

- Rotation curve of a disk galaxy
- Spatial distributions of luminous baryonic total matter in a collision of galaxy clusters
- CMB



The X-ray observations of the Bullet Cluster, as taken by the Chandra X-ray observatory. Note the... [+] NASA/CXC/CFA/M.MARKEVITCH ET AL., FROM MAXIM MARKEVITCH (SAO)

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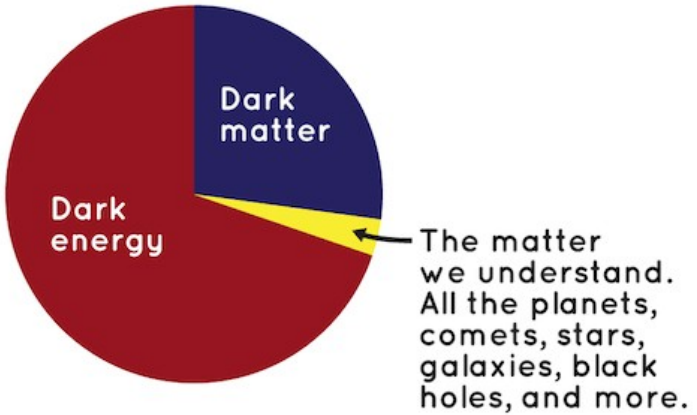

Dark matter does not interact with the electromagnetic force:

- No absorption
- No reflection
- No emission

→Most of the matter in the universe is in the form of an unknown non-baryonic component which does not interact with photons (dark)

→DM is one of the most compelling reasons for new physics

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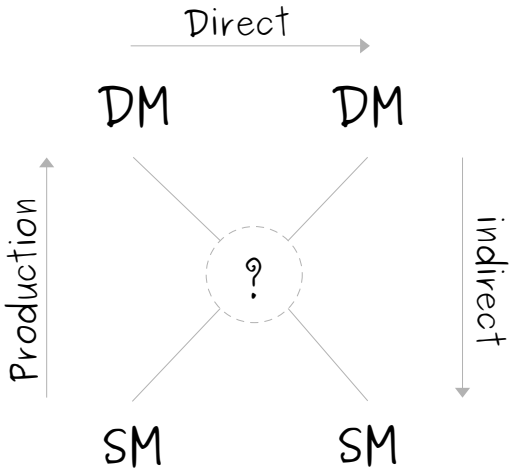
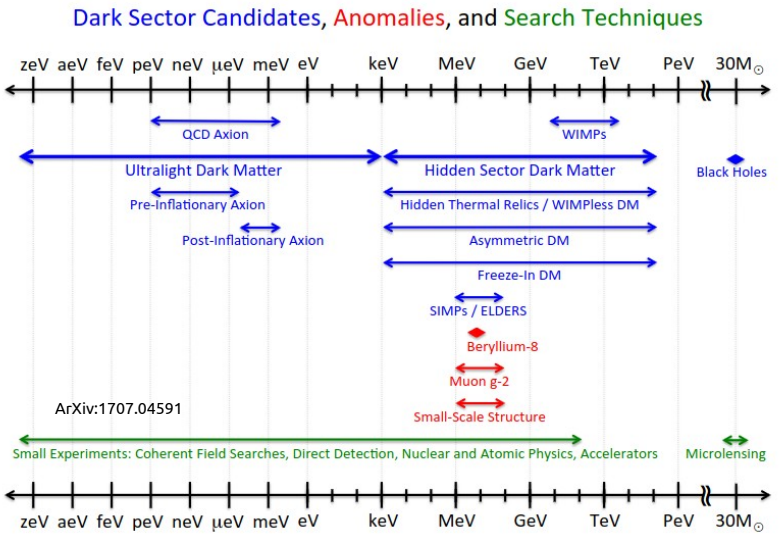
How to detect Dark Matter

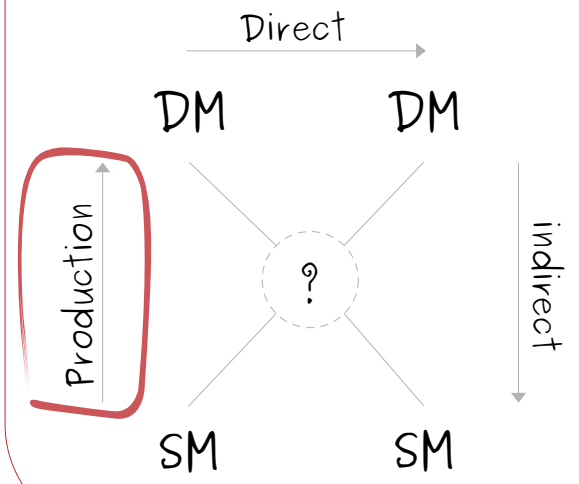
Three ways of detecting DM

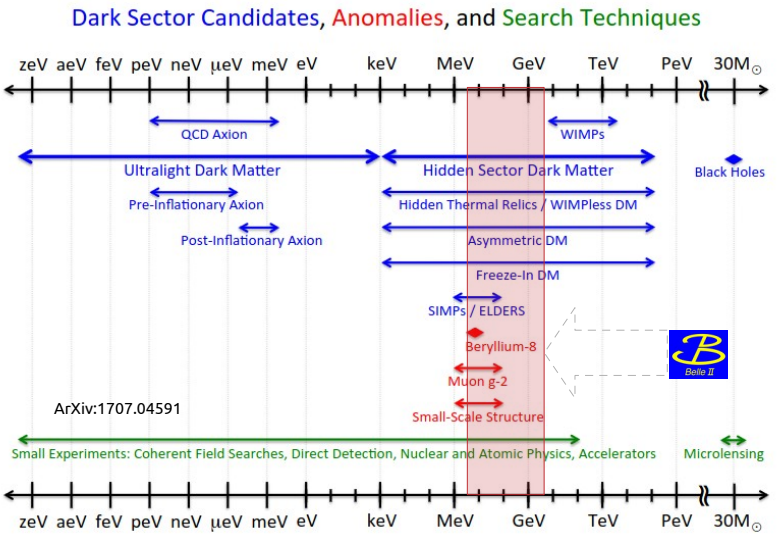




How to detect Dark Matter (DM) at B-factories

Three ways of detecting DM

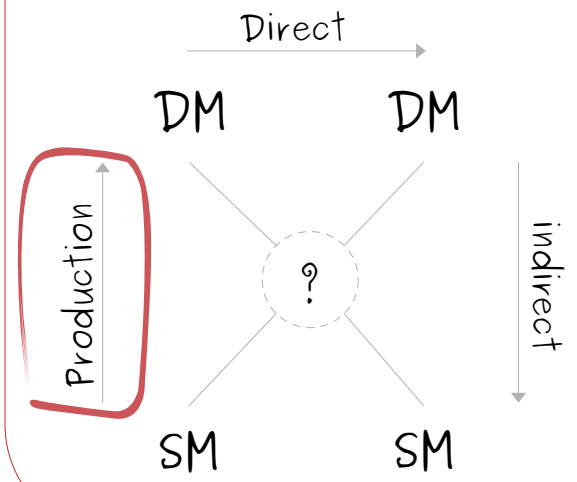




B-factories at e^+e^- collider can access the mass range favored by **light dark sectors**

How to detect Light Dark Matter (LDM) at B-factories

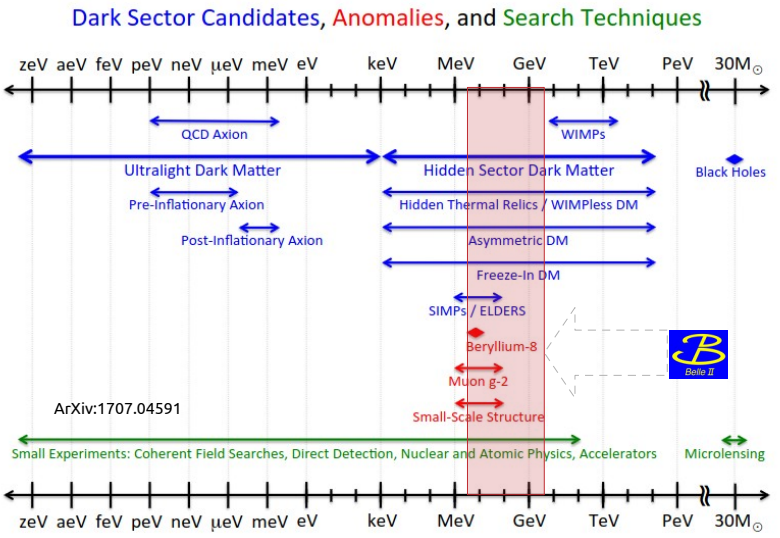
Three ways of detecting DM



Possible sub-GeV scale scenario:

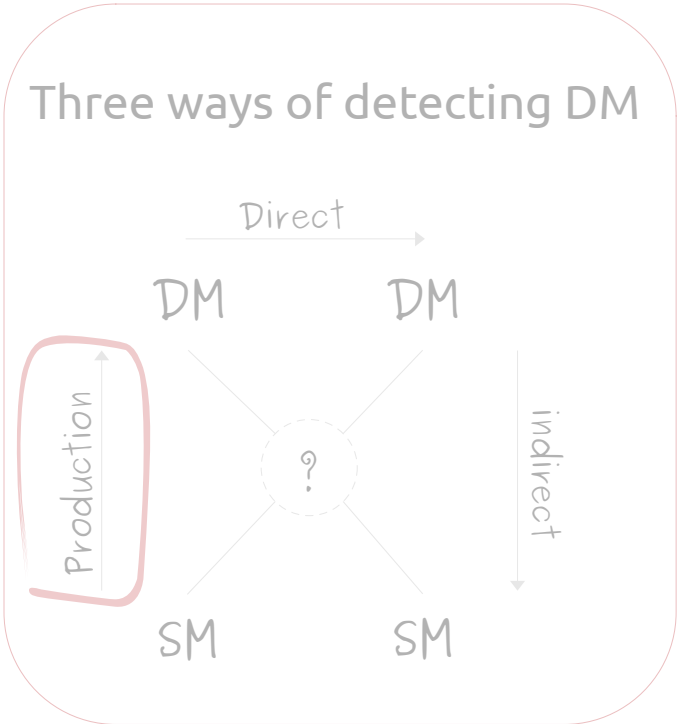
DM weakly coupled to SM through a **light mediator X**:

1. Vector portal
   Dark Photons, Z' bosons
2. Pseudo-scalar portal
   Axion Like Particles (ALPs)
3. Scalar portal
   Dark higgs/Scalars
4. Neutrino portal
   Sterile Neutrinos



B-factories at e^+e^- collider can access the mass range favored by **light dark sectors**

How to detect Light Dark Matter (LDM) at Belle II



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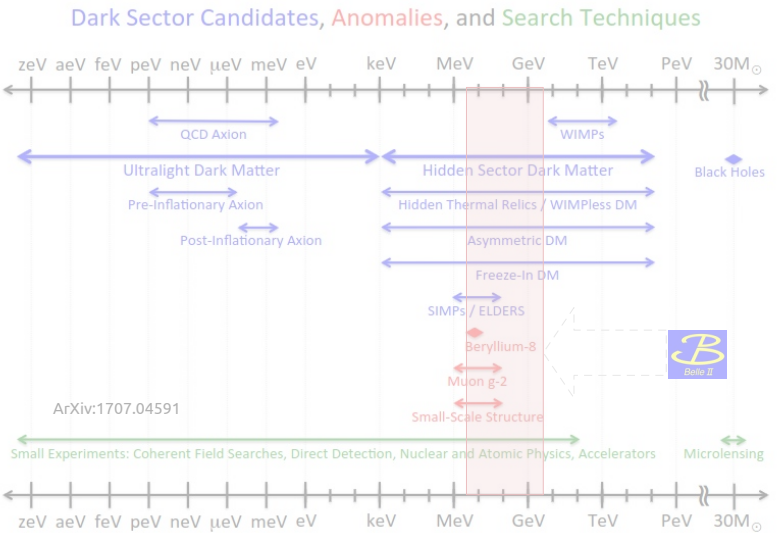

B-factories at e^+e^- collider can access the mass range favored by **light dark sectors**

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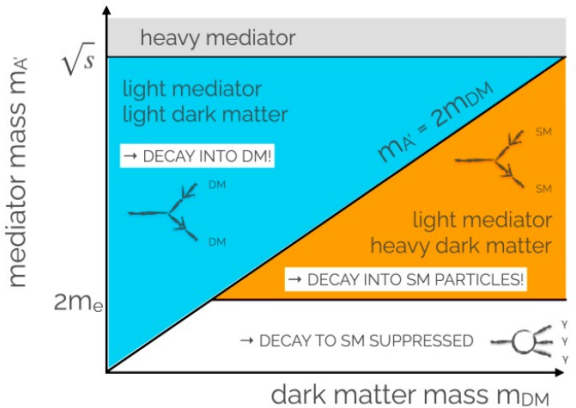
Dark Sector @ Belle II

- Signature-based



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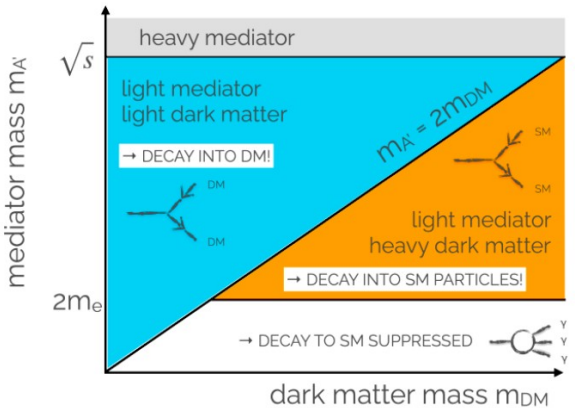
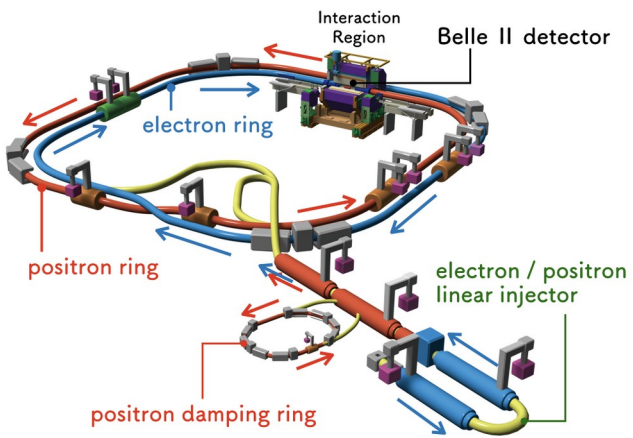
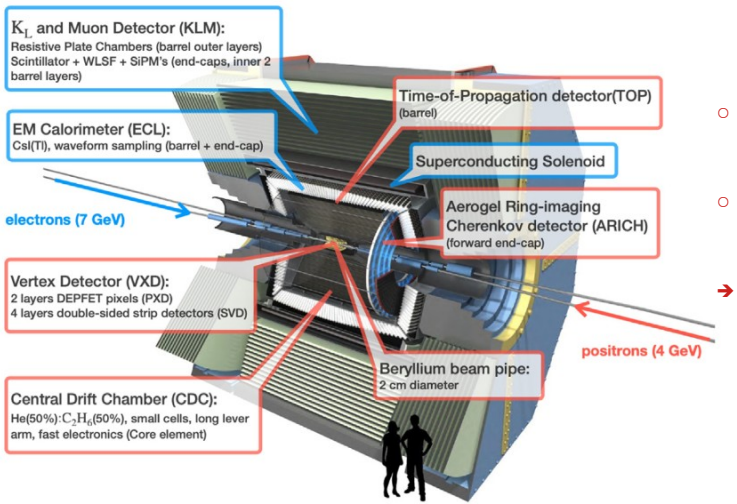
Dark Sector @ Belle II

- Signature-based
- Advantages from the **clean environment** at lepton colliders + **hermetic detector**:
  → Belle II at SuperKEKB asymmetric e^+e^- collider
  - running at 10.58 GeV, very well-known **initial condition**
  - efficient reconstruction of **neutrals**
  - specific low-multiplicity **triggers**
  - excellent Particle IDentification **(PID)** capabilities

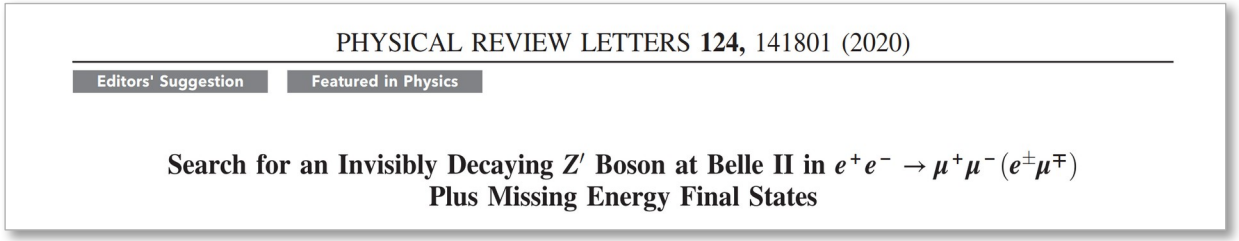


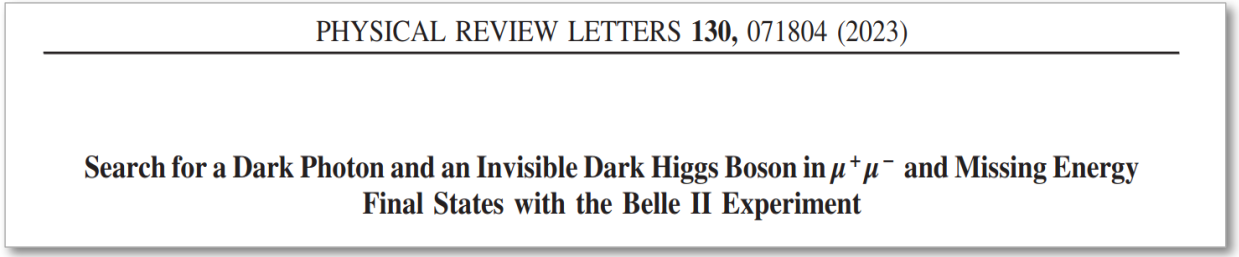


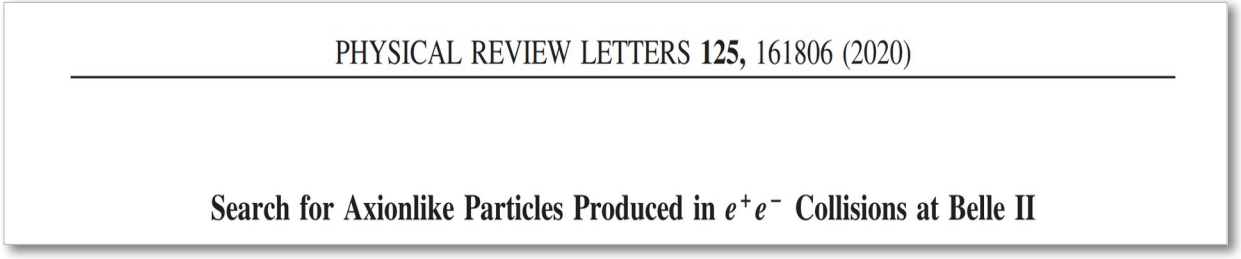


- Unprecedented instantaneous luminosity: **4.7 x 10^{34} cm^{-2} s^{-1}**
- So far **424 fb^{-1}** collected (currently in LS1)
- → **See yesterday B. Scavino's contribution for further details about SuperKEKB@BelleII**

Dark Sector @ Belle II: Published results







World leading results also with limited luminosity!

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Recent DS results at Belle II: Z' to invisible

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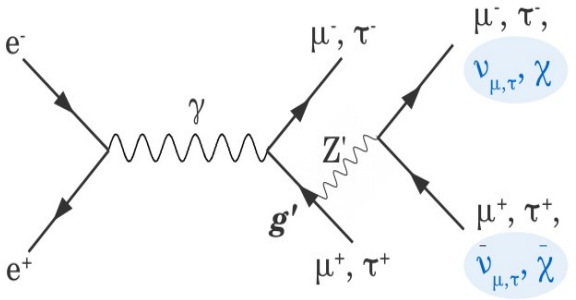
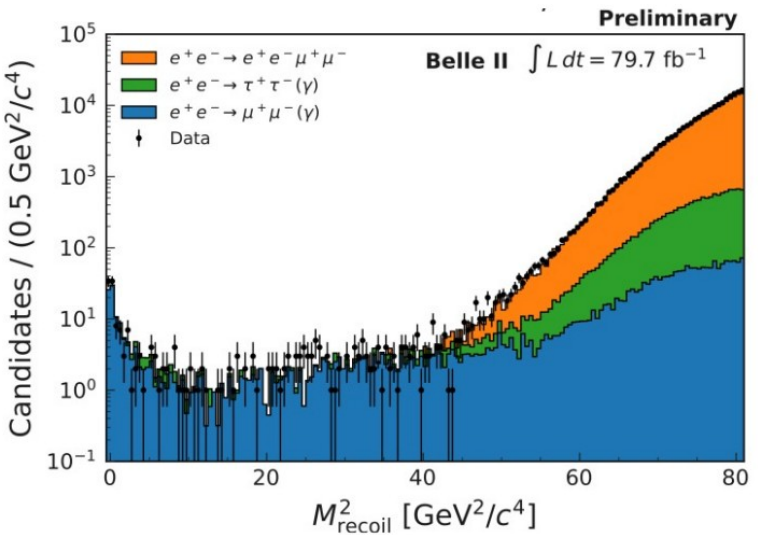
Recent DS results at Belle II: Z' to invisible

- New gauge boson Z' coupling only to the **2nd** and **3rd** generation of leptons (L_μ-L_τ) may explain: long-standing **$(g-2)_\mu$ anomaly**, **dark matter abundance**...
- Search for the process: **$e^+e^- \to \mu^+\mu^- Z'$** where:
  - BF($Z' \to \nu\bar{\nu}$) ~ 33-100% (*"Vanilla"*)
  - BF($Z' \to \chi\chi$) ~ 100%, if DM kinematically accessible (*"Fully invisible"*)
- Look for a narrow peak **in the recoil mass against a $\mu^+\mu^-$ pair** in events where nothing else is detected
- Dominant background radiative QED processes:
  1) $e^+e^- \to e^+e^- \mu^+\mu^-$
  2) $e^+e^- \to \tau^+\tau^- (\gamma)$
  3) $e^+e^- \to \mu^+\mu^- (\gamma)$

ⓘ FSR properties of the emitted Z' feeded in a neural network trained for all Z' masses simultaneously



$e^+e^- \to \mu^+\mu^- Z'$; $Z' \to$ *invisible*



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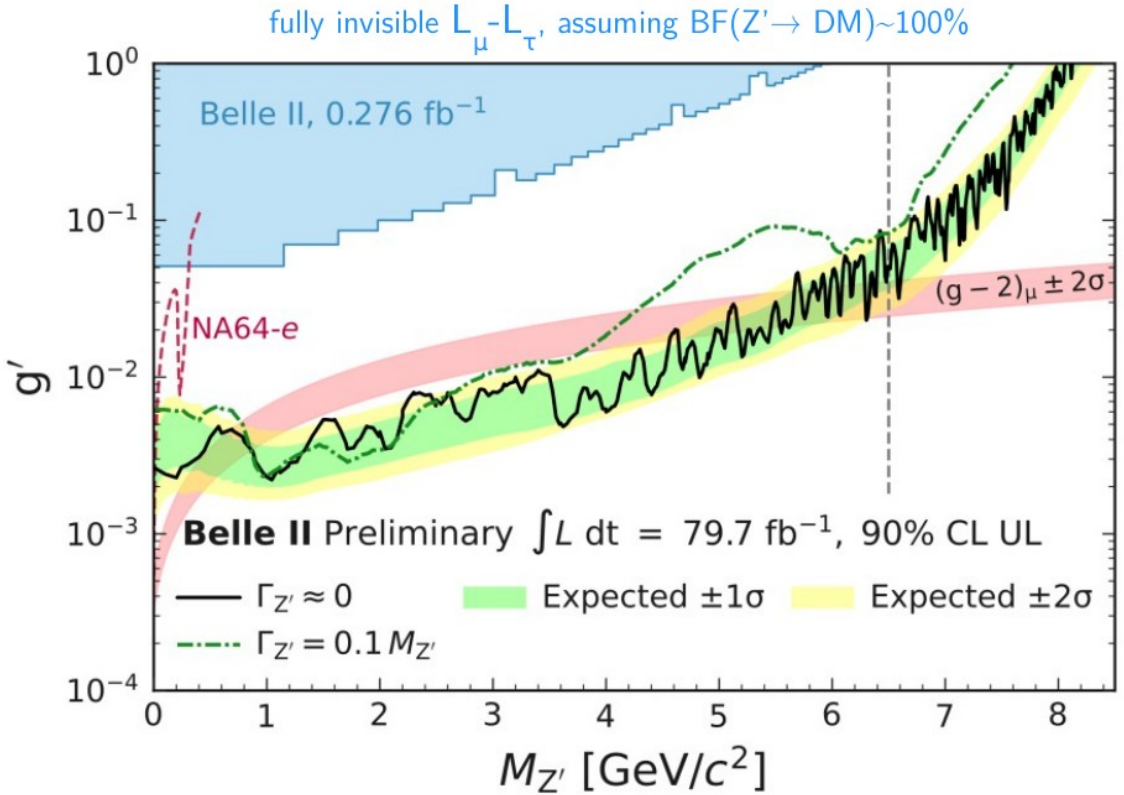
Recent DS results at Belle II: Z' to invisible

90% CL upper limits on σ(e⁺e⁻→μ⁺μ⁻Z', Z'→ inv.) and on the g'



→no excess found in 79.7 fb^{-1}
→$(g\text{-}2)_\mu$ favored region excluded for 0.8 < M(Z') < 5 GeV

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Recent DS results at Belle II:
Search for a long-lived (pseudo-)scalar particle in $b \to s$

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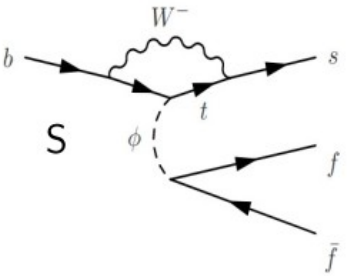
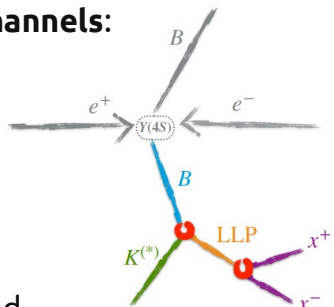
Recent DS results at Belle II:
Search for a long-lived (pseudo-)scalar particle in $b \to s$

- **Model-independent** search for **dark scalar** particles S from B decays in **rare b→s transitions**
  - S could mix with SM Higgs with mixing angle θ_s (naturally long-lived for $\theta_S << 1$)
  - $M_S < M_B$ decay to dark matter kinematically forbidden by relic density constraint

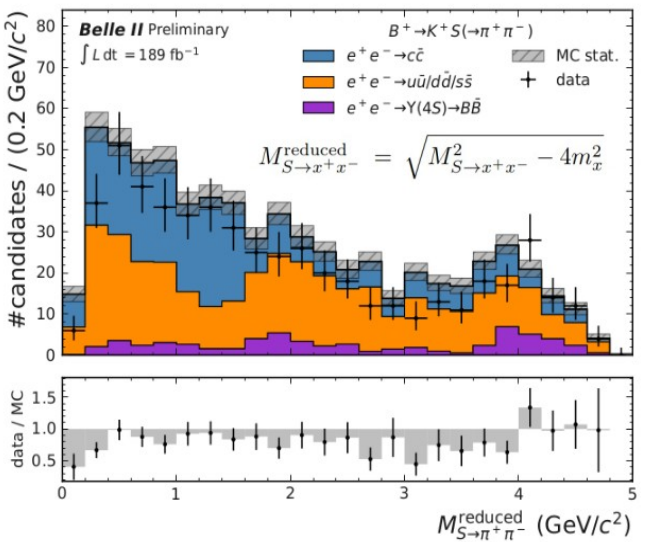


- Look for S decays into SM final states in **8 exclusive channels**:
  - $B^+ \to K^+ S$
  - $B^0 \to K^{*0}$ ($\to K^+\pi^-$)S

→ **S → ee/μμ/ττ/KK**



- B-meson kinematics to reject combinatorial background
- SM long-lived K_S mass region vetoed → excellent control sample in data
- **Signature**: bump hunt with extended max likelihood unbinned fits to the reduced mass spectrum subtracted by twice the mass of the final state particles (easier to model at threshold), separately for each channel and lifetime



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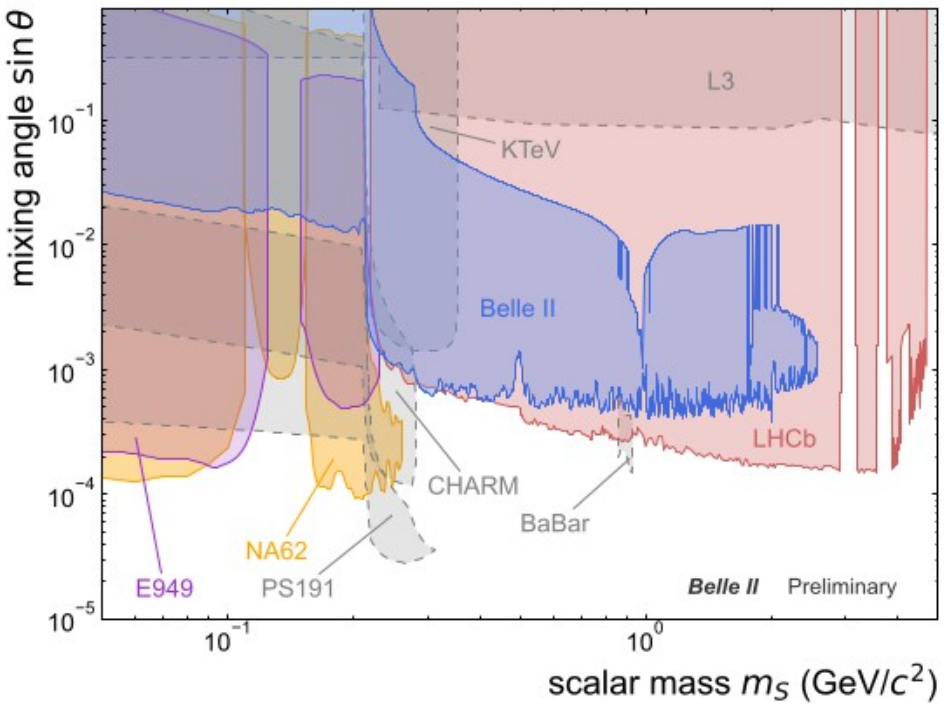
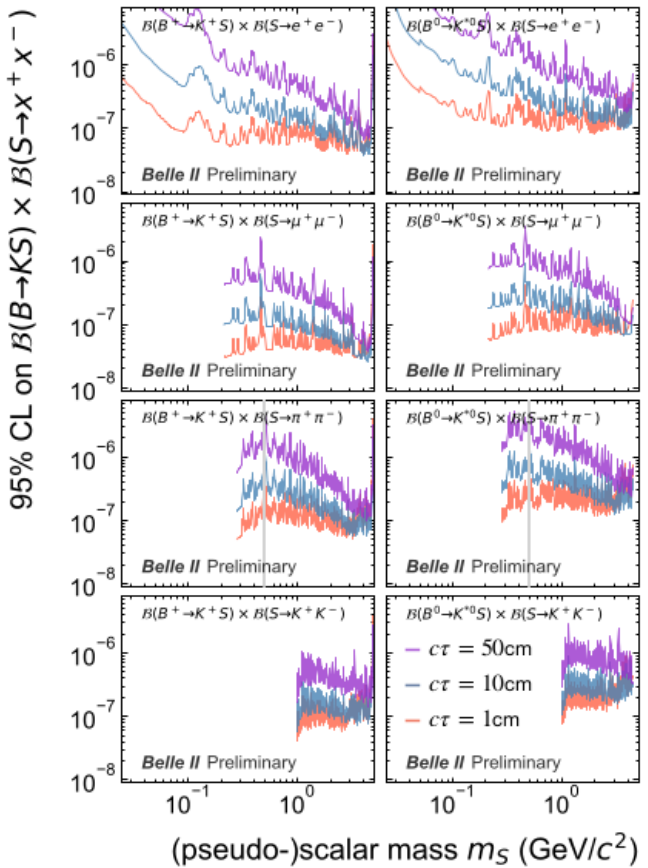
Recent DS results at Belle II:
Search for a long-lived (pseudo-)scalar particle in $b \to s$

- **No significant excess found in 189 fb^{-1}**
  - first model-independent 95% CL upper limits on BF(B→KS)×BF(S→x^+x^-)
  - first limits on decays to hadrons





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Conclusion

- Belle II has unique sensitivity for light dark sectors searches
- World's leading results also with limited statistics
- 424 fb^{-1} already on tape, more results on larger statistics and with improved analyses in the pipeline

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