Dark sector searches at Belle II.

Sascha Dreyer on behalf of the Belle II collaboration

32nd Rencontres de Blois — Beyond the Standard Model & Dark Matter parallel session
19.10.2021

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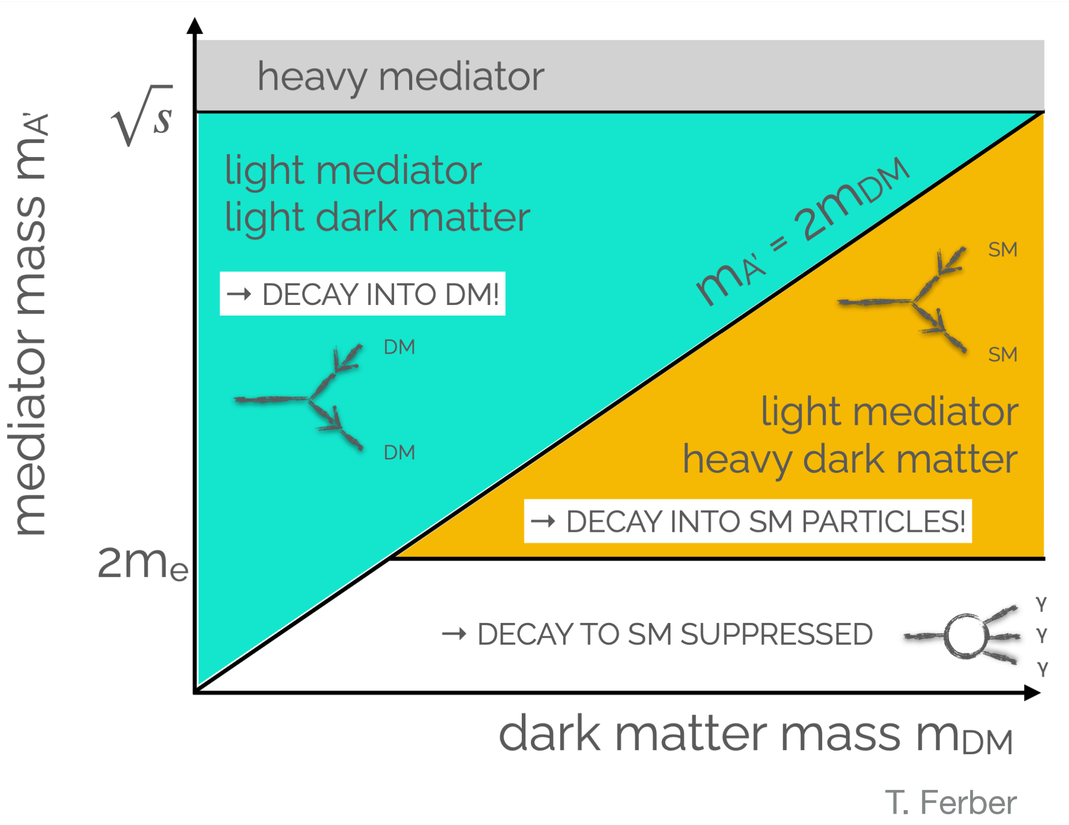
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Dark Sectors.

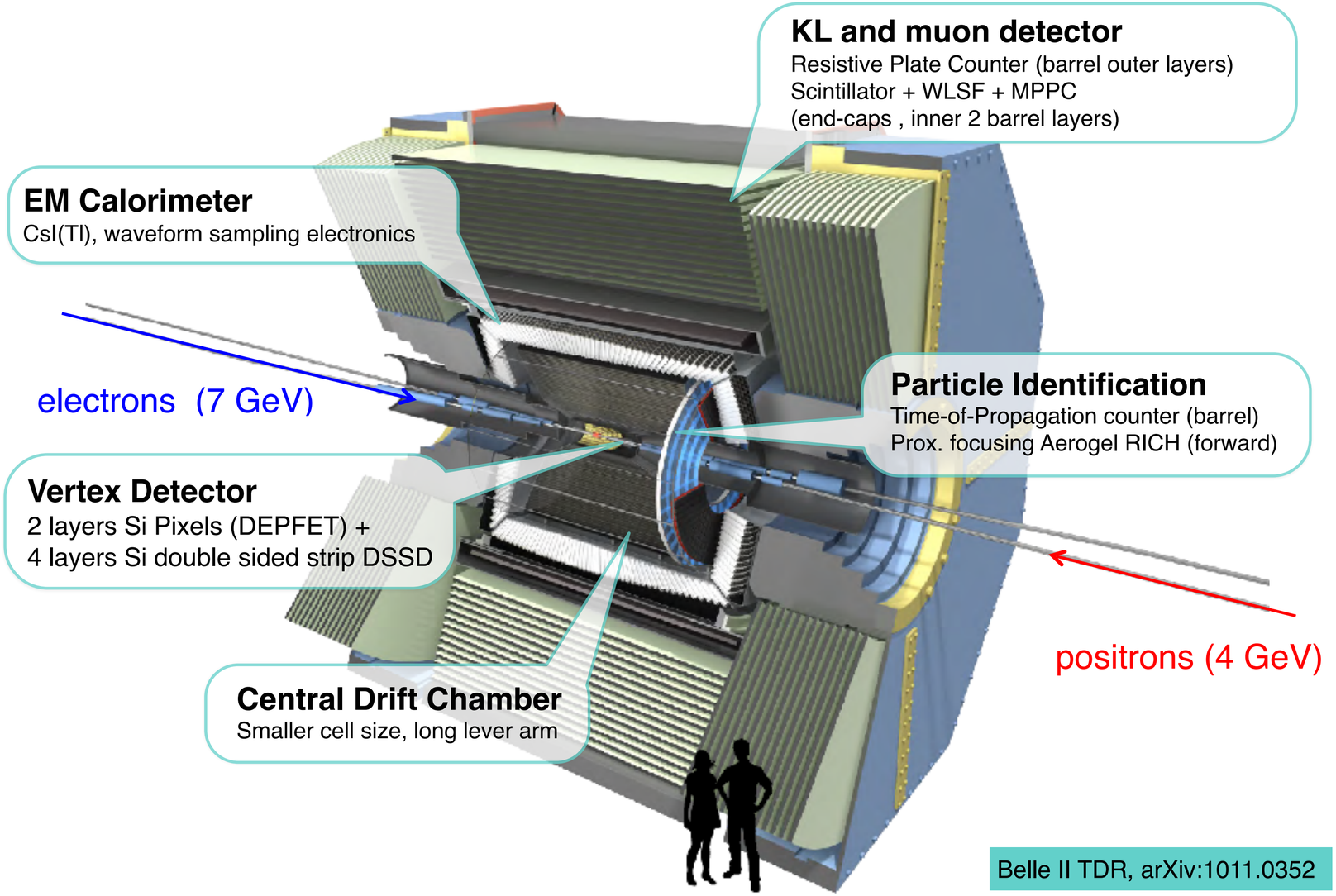
Standard Model ⟷ Mediator ⟷ Dark Sector

- Light dark sector coupled to Standard Model
- Possible portal interactions:
  - Vector → Dark Photons A', Z'
  - Pseudo-scalar → ALPs
  - Scalar → Dark Higgs
  - Neutrino → Sterile Neutrinos



SuperKEKB collider & Belle II experiment.

- Accelerator: SuperKEKB
- Running at the $\Upsilon(4S)$ resonance
- Target 50 ab^{-1} (50× Belle)
  - Higher beam currents
  - Smaller beam spot
- Collected 213 fb^{-1} up to now
- Updated detector: Belle II



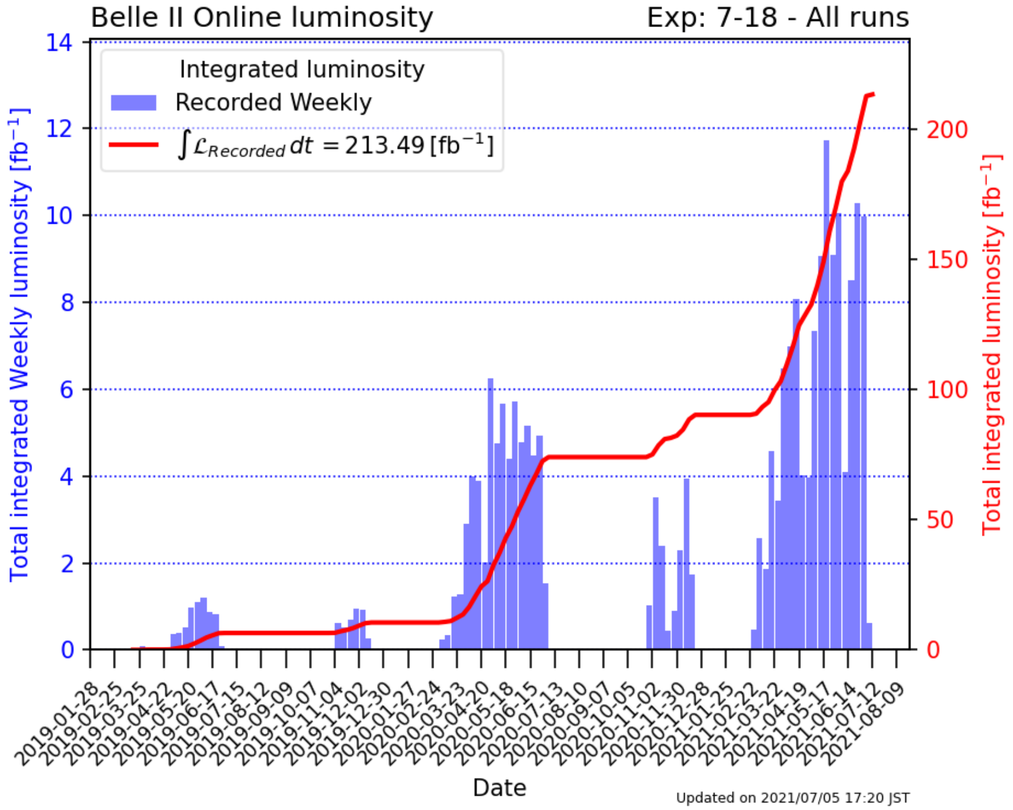
Belle II TDR, arXiv:1011.0352

Dark Sectors with Belle II.

$$e^+e^- \to X \to \chi\chi \text{ or SM}$$

$$e^+e^- \to \Upsilon(4S) \to B[\bar{B} \to KX]$$

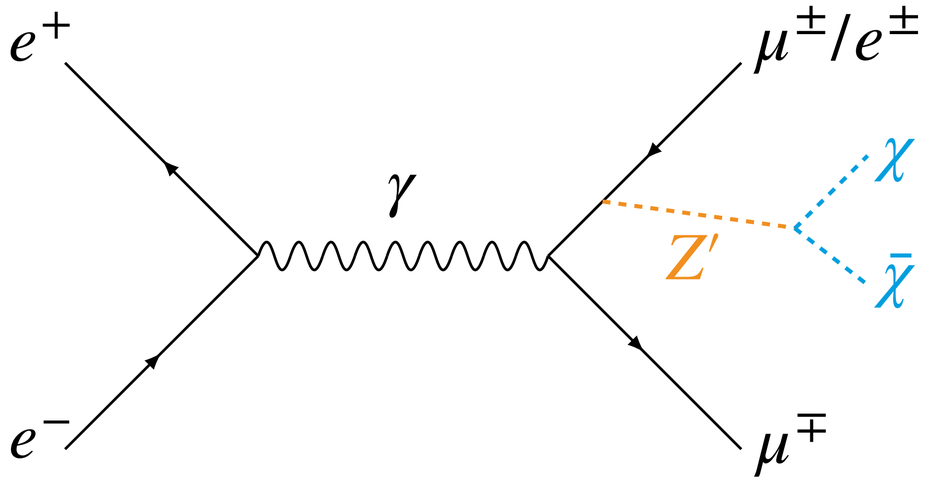
- Design focus as B & τ factory
- And: Light dark sectors
- Well known initial conditions and less/no pile-up
- Special low multiplicity triggers
  - Single photon trigger (not available at Belle)
  - Single muon trigger
  - 3D track reconstruction at L1 using NN
  - Single track trigger using NN

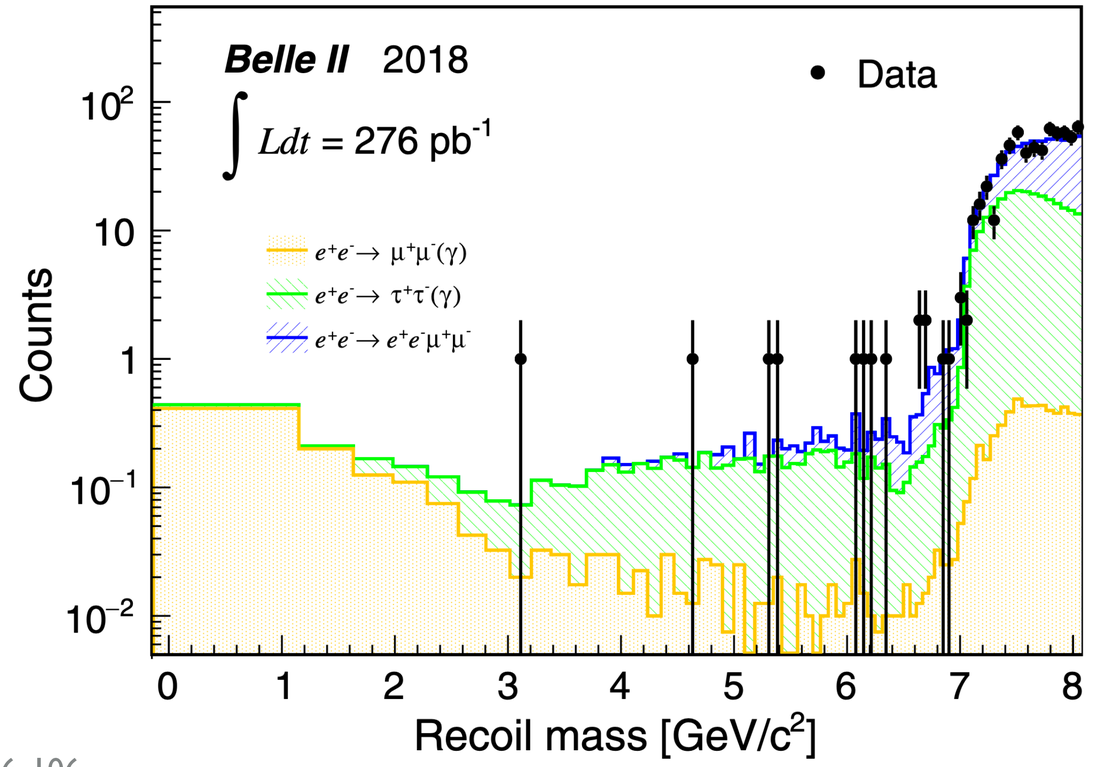


Published searches

Search for an invisibly decaying Z' boson.

- Additional massive gauge boson Z'
- Could explain discrepancies [1] & [2]
  - $(g-2)_\mu$
  - $b \to s\mu\mu$
- Study mass recoiling against $\mu\mu$ system
- Backgrounds:
  - $e^+e^- \to \tau^+\tau^-$
  - $e^+e^- \to \mu^+\mu^-(\gamma)$
  - $e^+e^- \to e^+e^-\mu^+\mu^-$



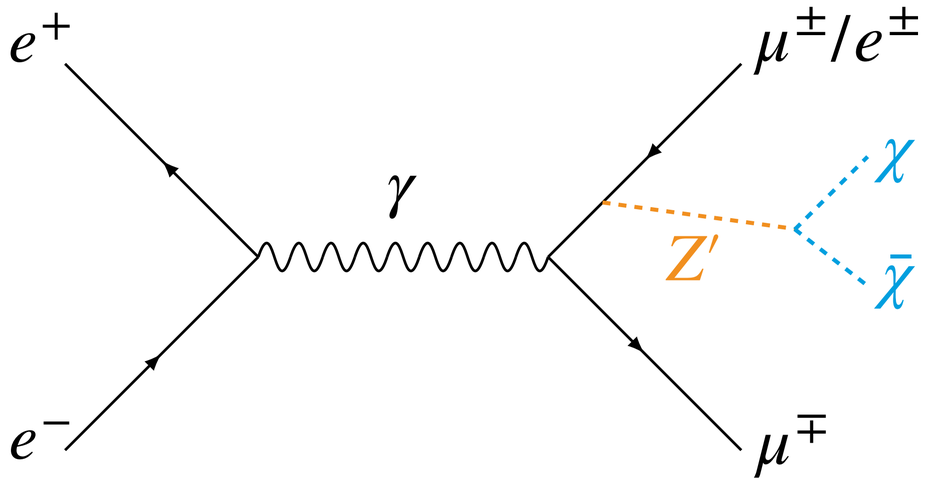


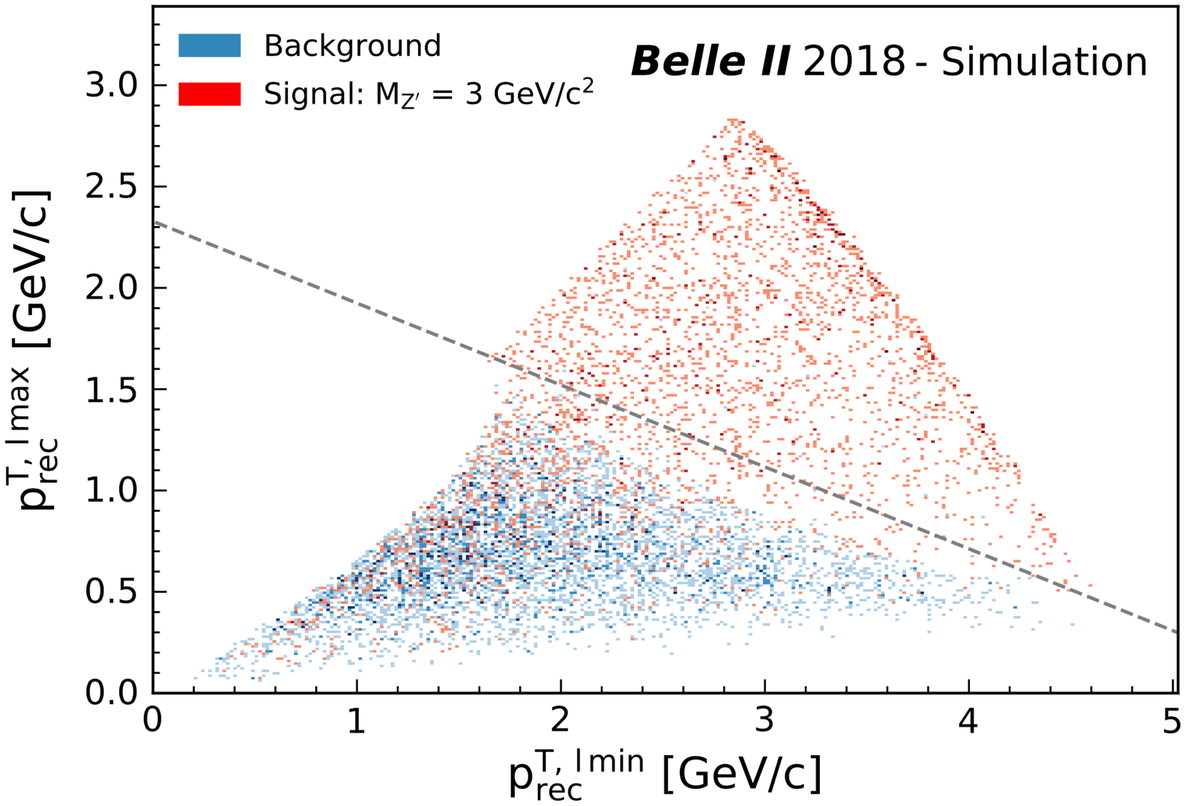
Published!
Phys. Rev. Lett. 124, 141801

[1] B. Shuve et al., Phys. Rev. D 89, 113004
[2] W. Altmannshofer et al., J. High Energ. Phys. 2016, 106

Search for an invisibly decaying Z' boson.

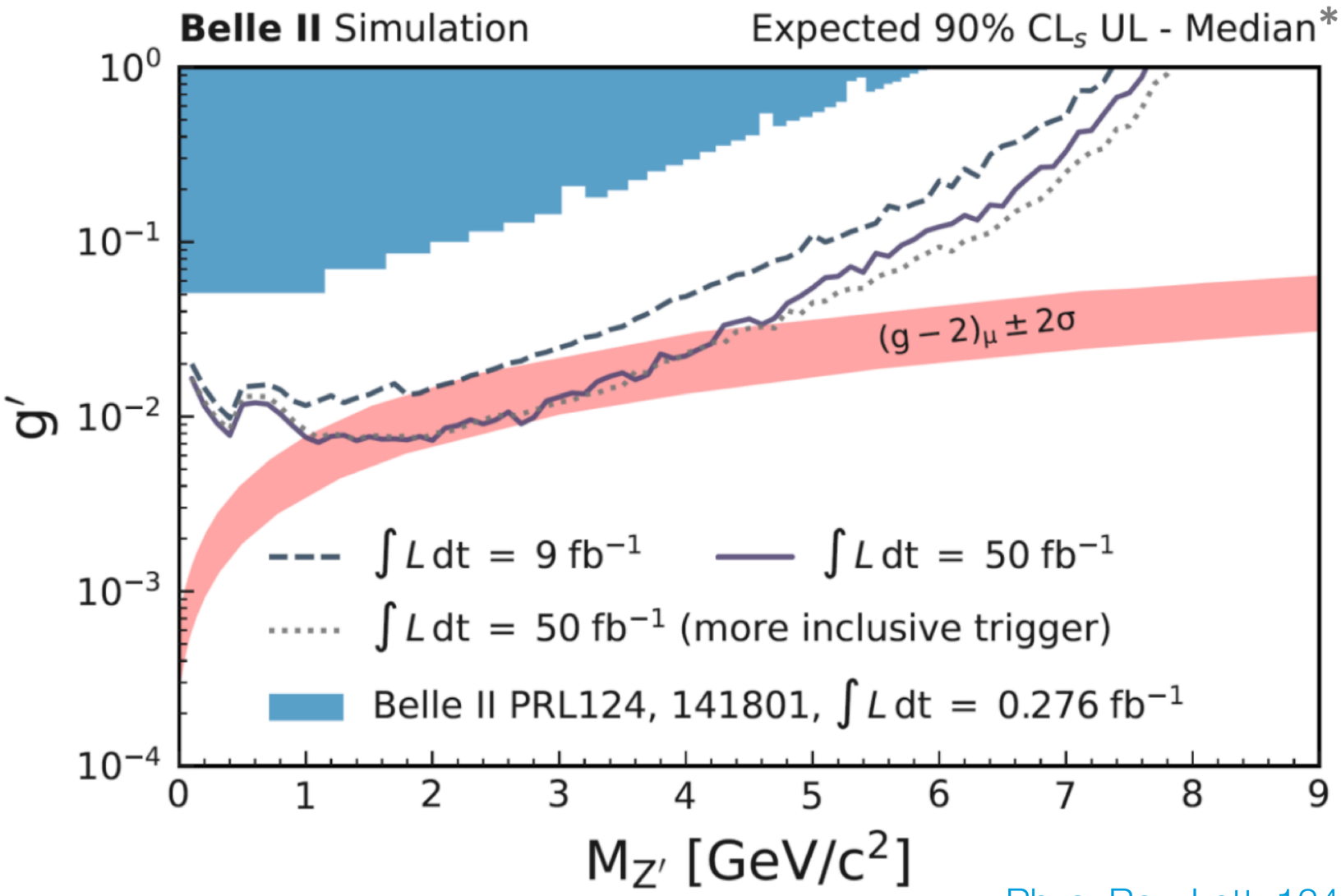
- Two tracks in barrel calorimeter
  - Azim. opening angle > 90 deg
- Particle identification via E and E/p
- Recoil momentum isolated & within barrel
- τ pair background suppression
  - Z' is radiated from one muon leg
  - Neutrinos in τ decay from both legs
- LFV mode studied as well





Published!
Phys. Rev. Lett. 124, 141801

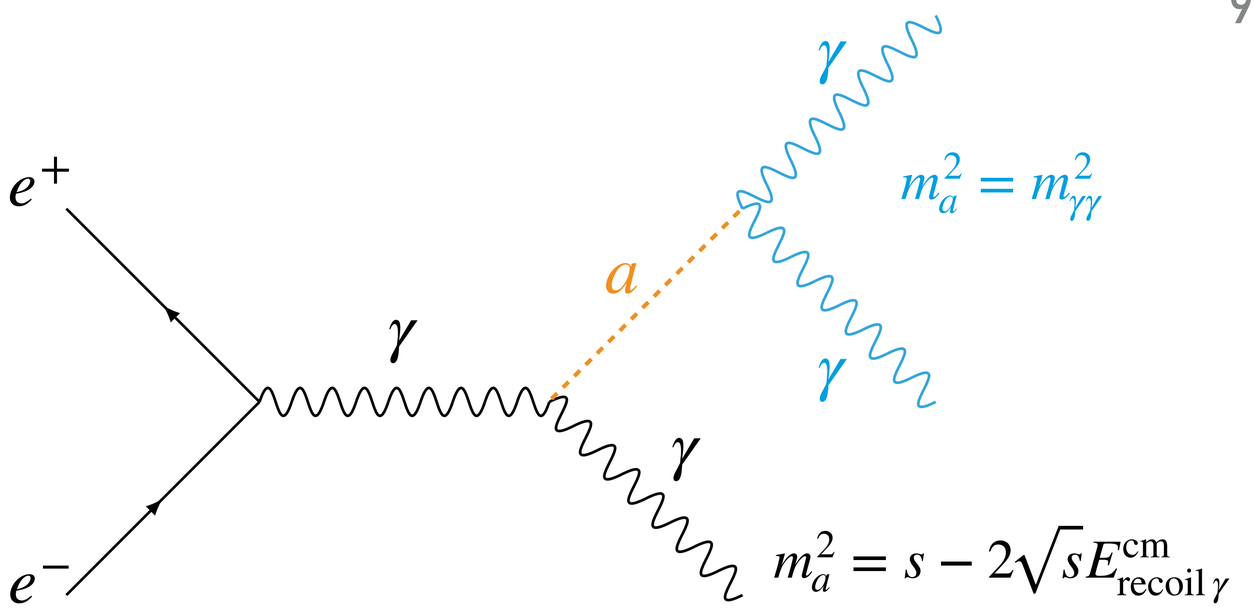
Search for an invisibly decaying Z' boson.

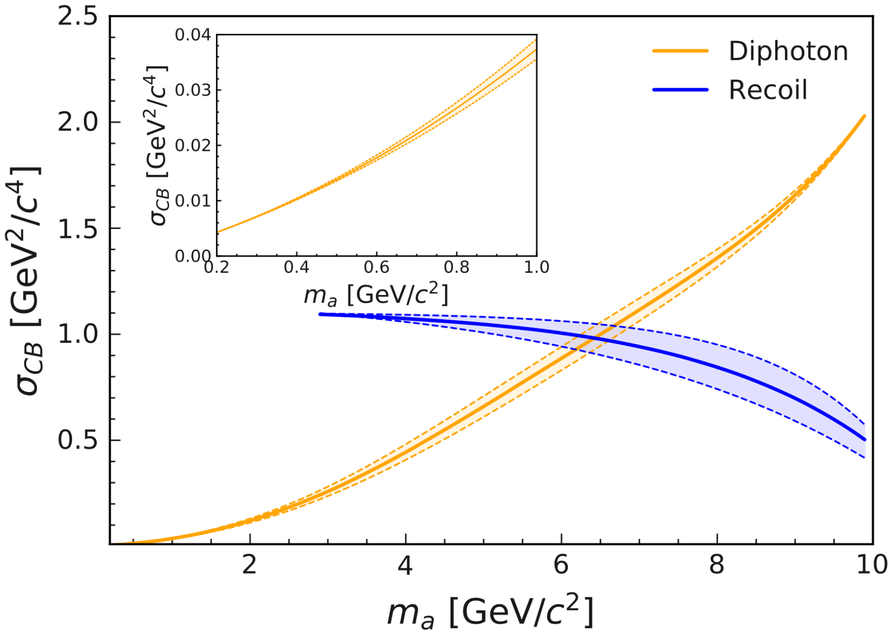


Phys. Rev. Lett. 124, 141801

Search for Axion Like Particles (ALP).

- Pseudoscalar ALP a
- Events with three γ consistent with $\sqrt{s}$
- Search for a peak in reconstructed ALP mass distribution
- Using two different ways to reconstruct ALP mass



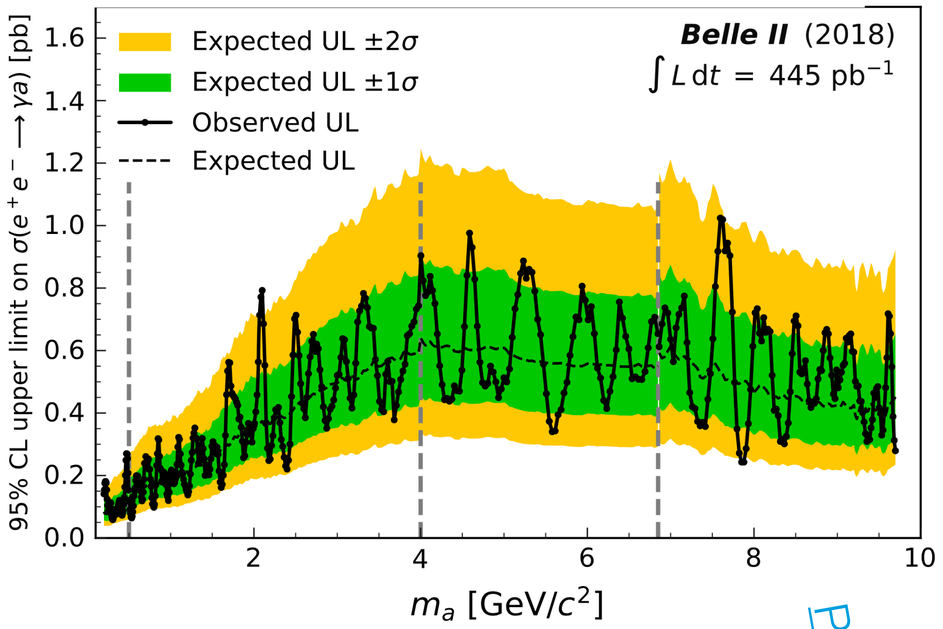


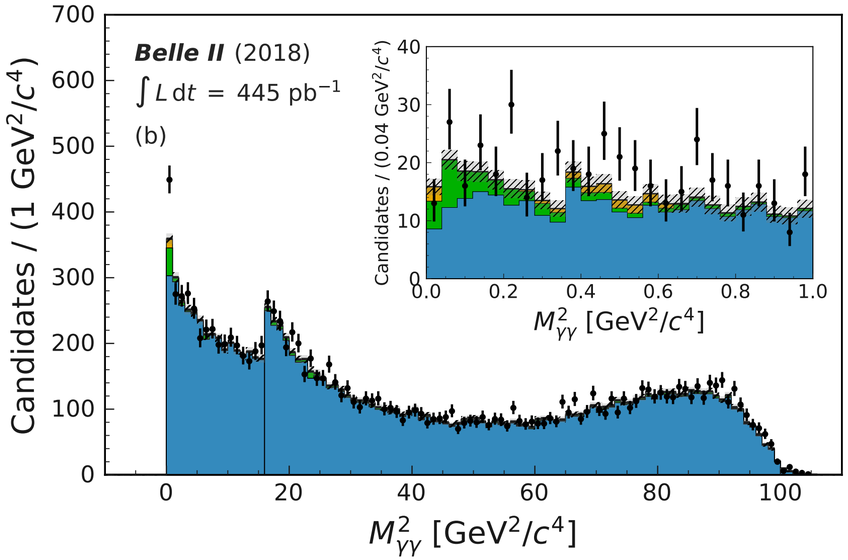
Published!

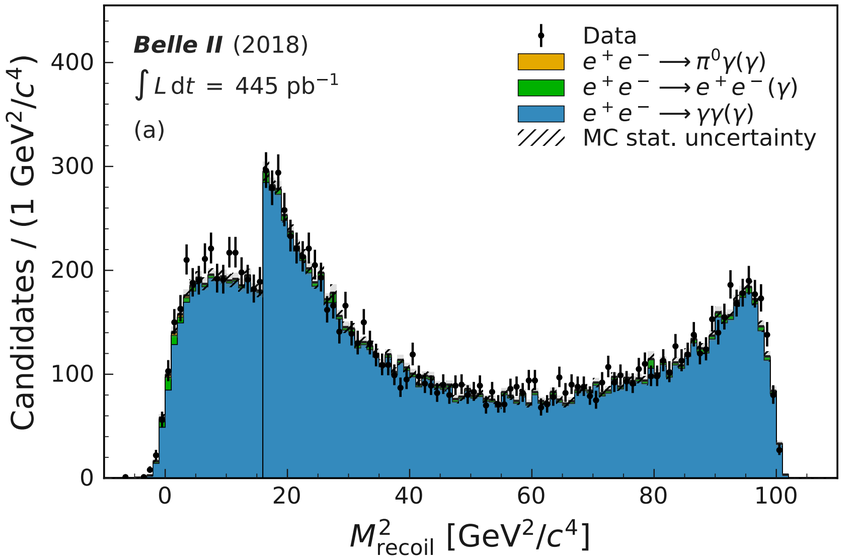
Phys. Rev. Lett. 125, 161806

Search for Axion Like Particles (ALP).

- Backgrounds mainly $e^+e^- \to \gamma\,\gamma\,(\gamma)$
- Determine background normalisation directly in data by fitting mass sidebands

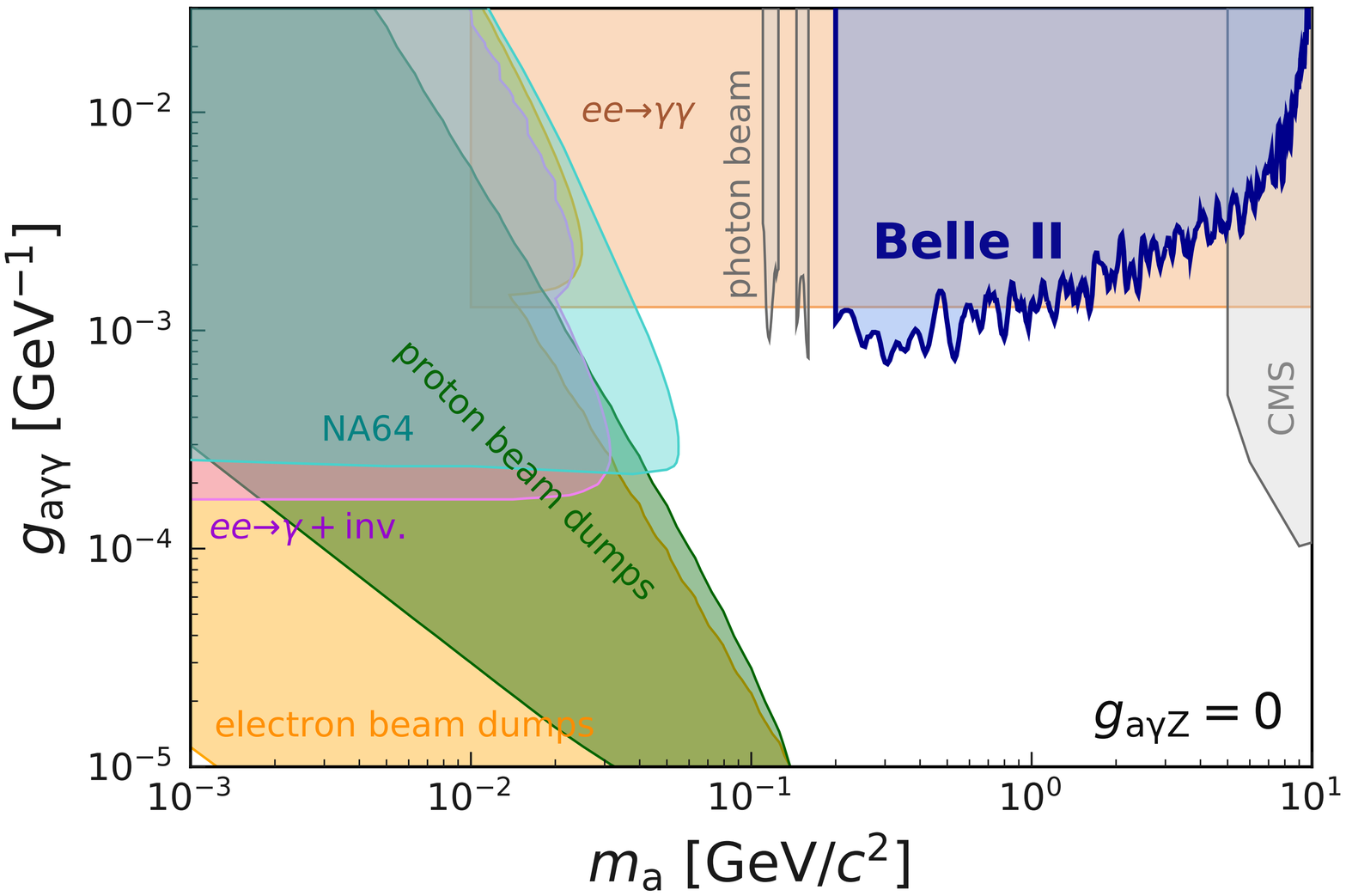






Published!
Phys. Rev. Lett. 125, 161806

Search for Axion Like Particles (ALP).



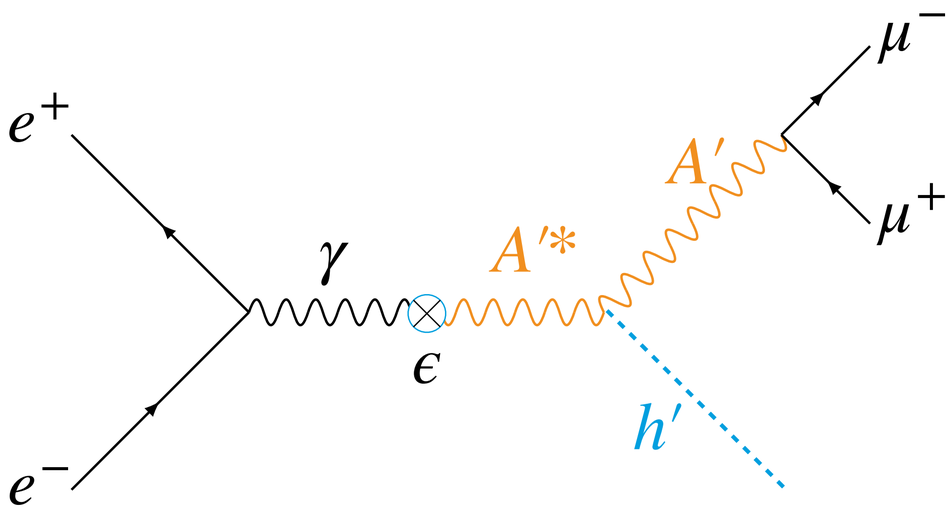
Phys. Rev. Lett. 125, 161806

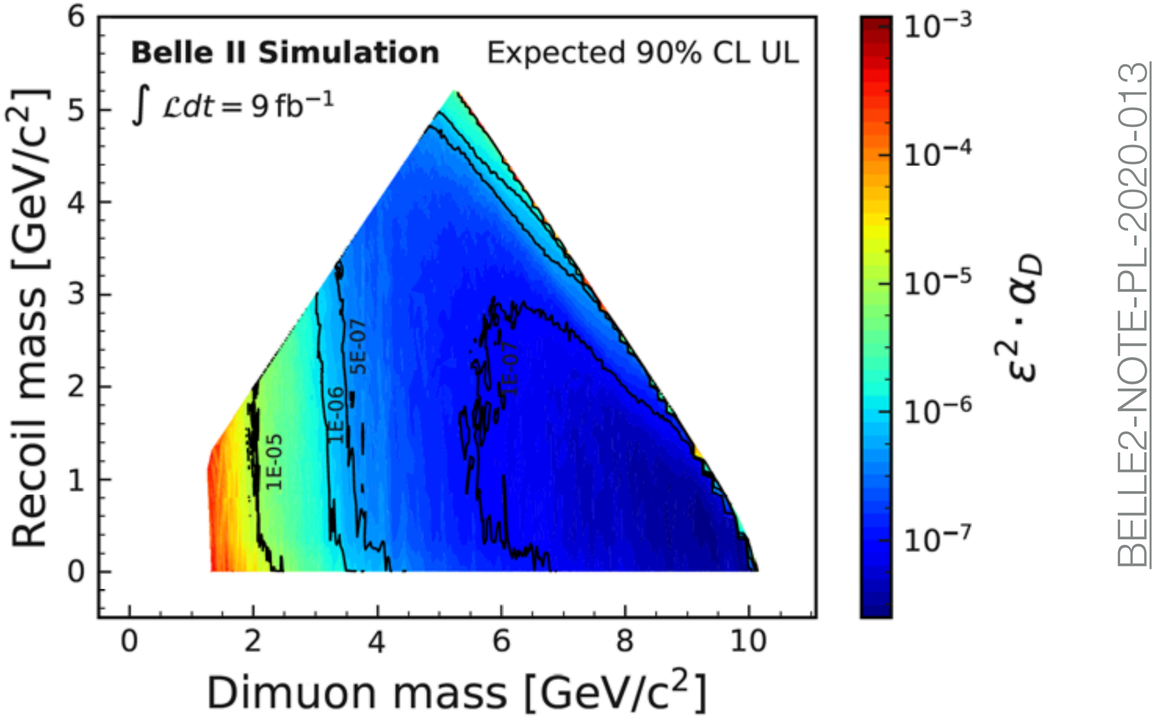
Ongoing searches

Search for a Dark Higgs.

Ongoing!

- Dark photon A' with a Dark Higgs h'
- h' Invisible (very long-lived, $m_{h'} < m_{A'}$)
- Dark photon decay into $\mu\mu$
- Search for a 2D peak in $M_{\mu\mu}$ vs. M_{recoil}
  - Scan using elliptical, tilted windows of varying size
- Main backgrounds:
  - $e^+e^- \to \mu^+\mu^-(\gamma)$
  - $e^+e^- \to \tau^+\tau^-(\gamma)$
- Submitting soon!

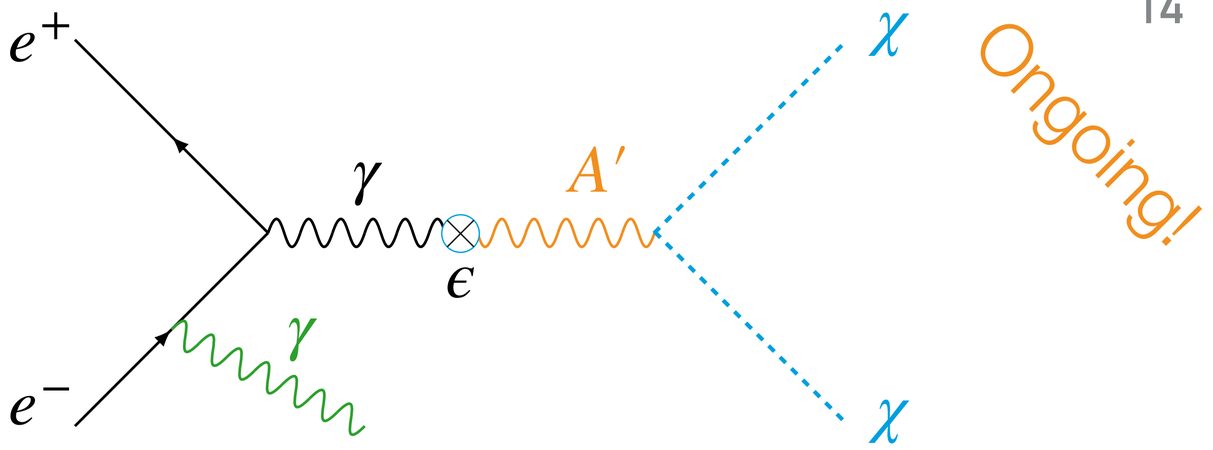




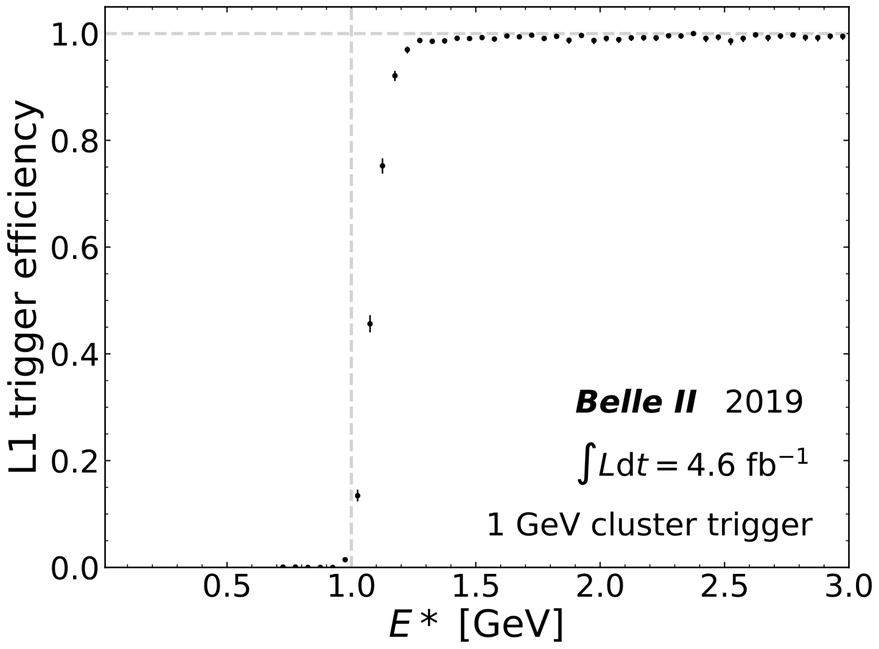
BELLE2-NOTE-PL-2020-013

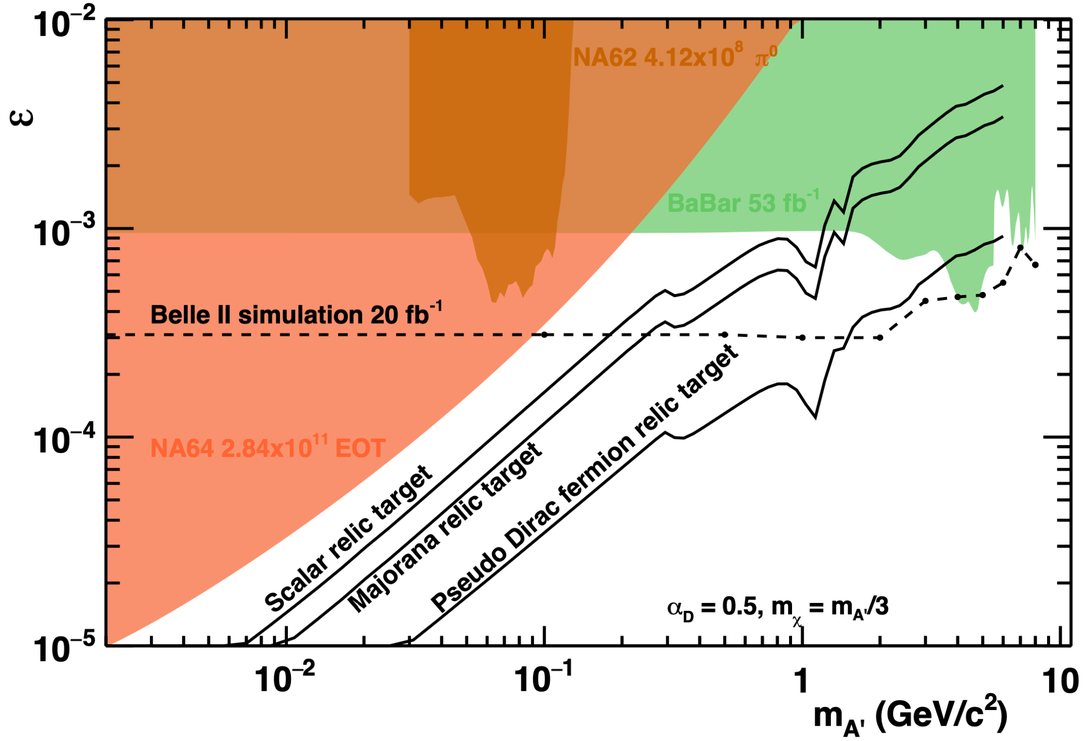
Search for a Dark Photon.

- Dark photon A' with kinematic mixing parameter ϵ
- Vanilla benchmark-model
- Invisible decay to Dark Matter χ (or very long-lived)
- Search for a bump in ISR γ energy

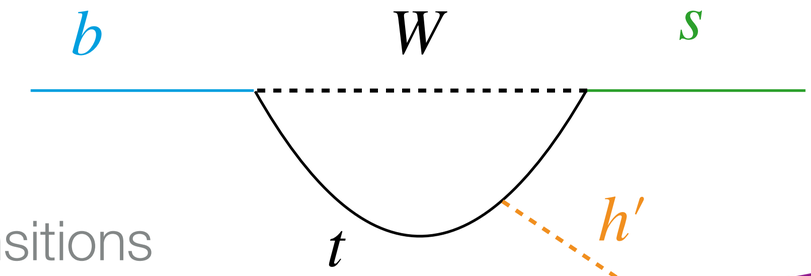


Ongoing!



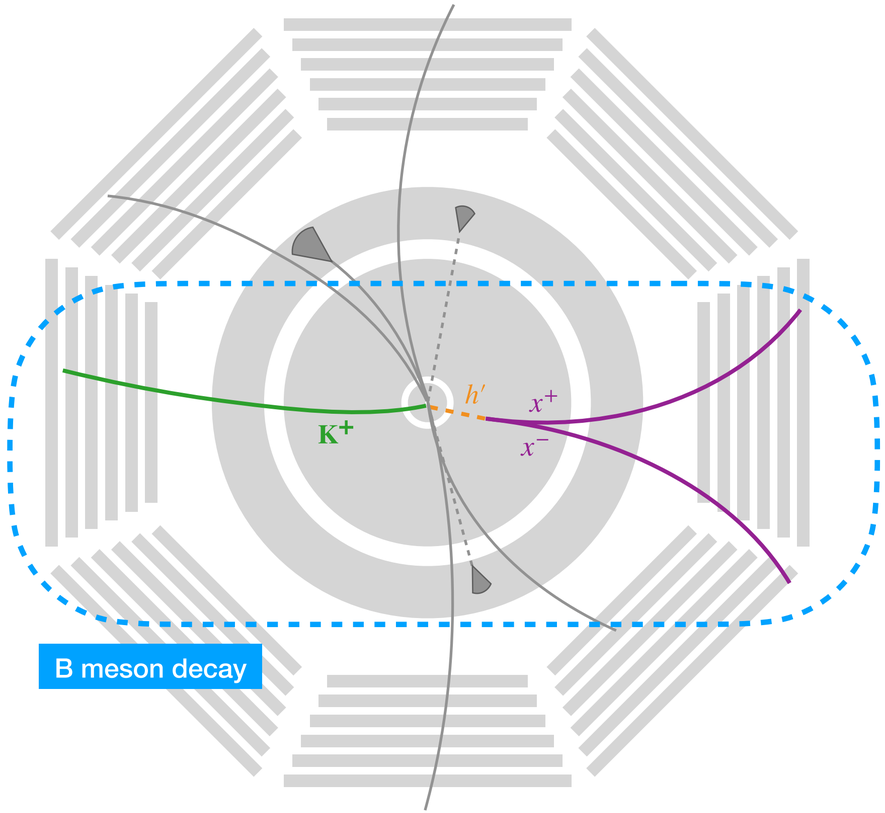


Search for B→Kh'.

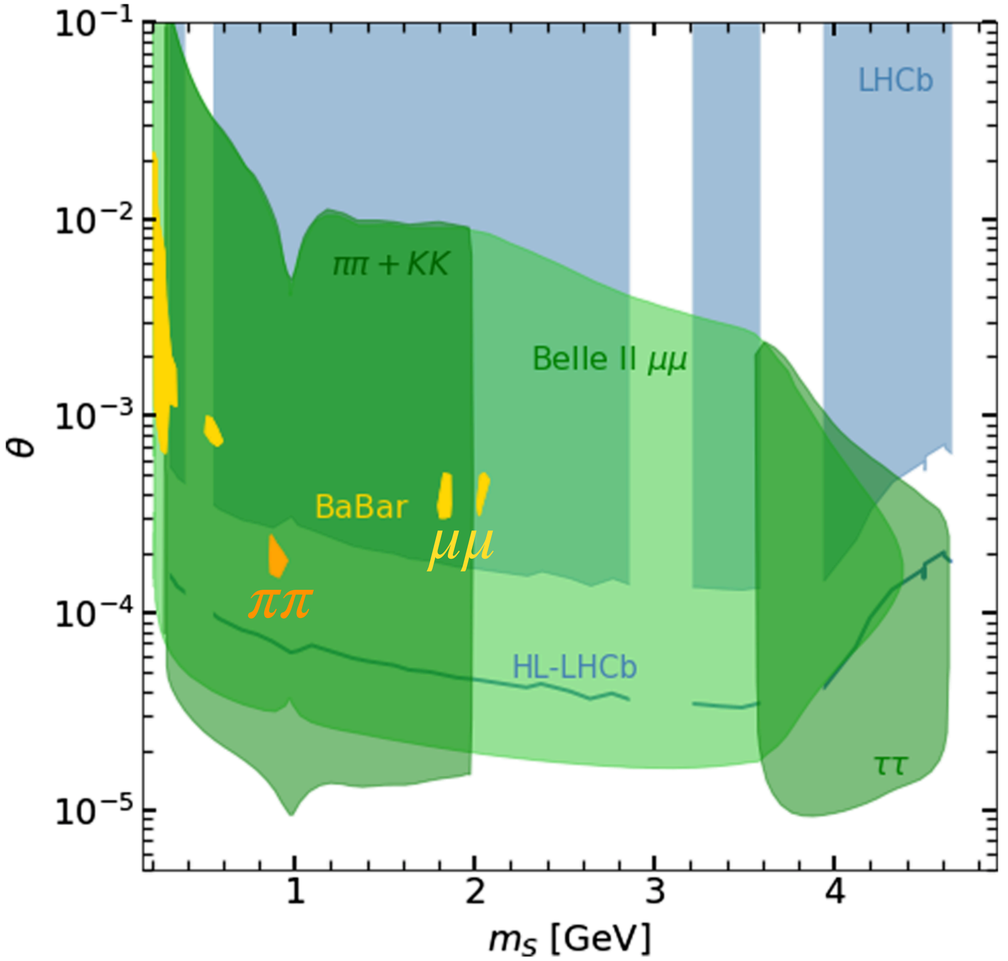


Ongoing!

- Long-lived Dark Higgs h' in $b \to s$ transitions
- Form signal B meson candidate



adapted from T. Ferber



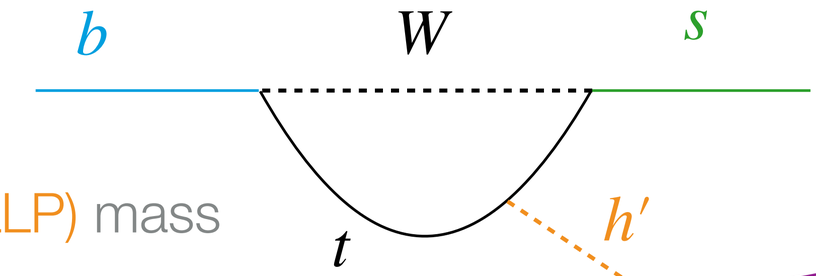
production rate

lifetime

A. Filimonova, R. Schäfer, S. Westhoff

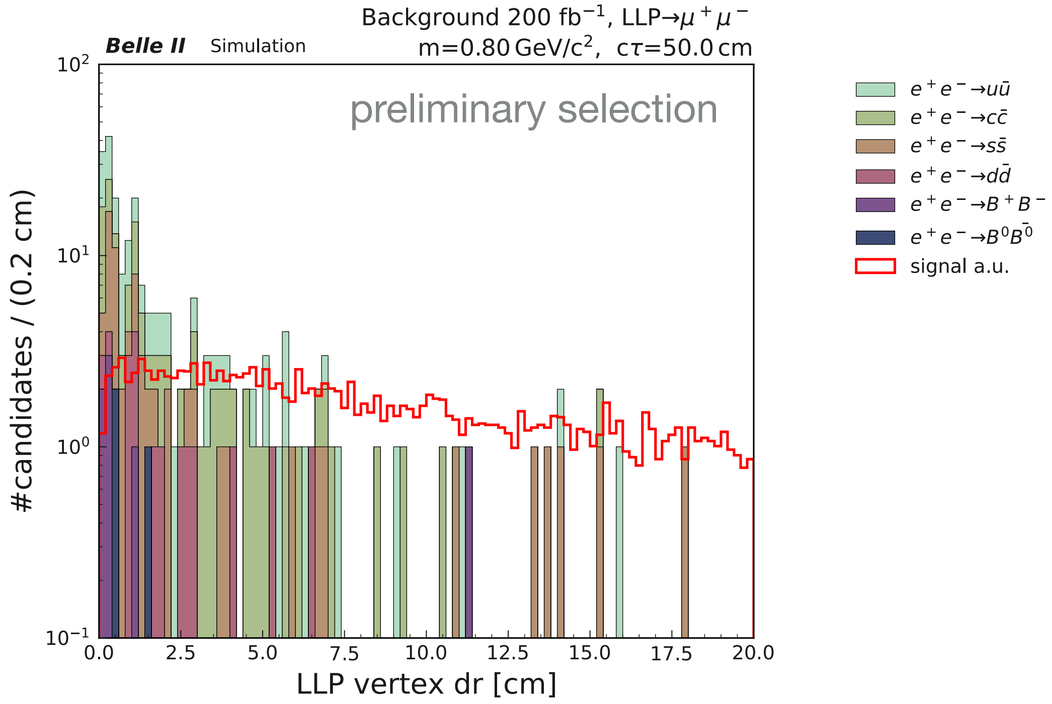
Phys. Rev. D 101, 095006 (2020)

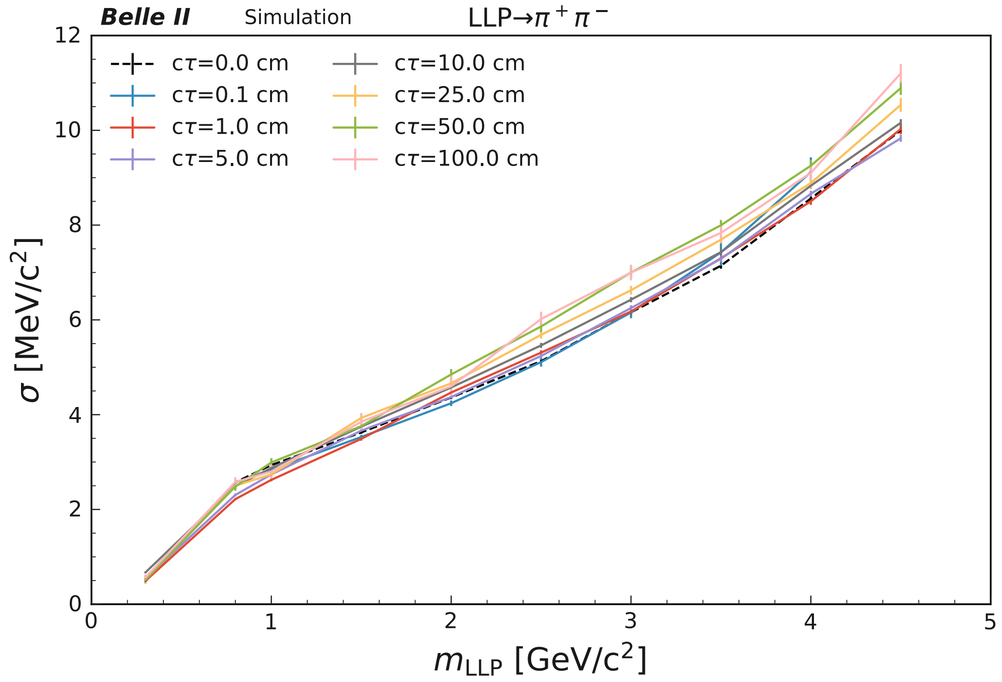
Search for B→Kh'.



Ongoing!

- Search for bump in reconstructed h' (LLP) mass
- Mostly backgrounds at low displacements





Summary.

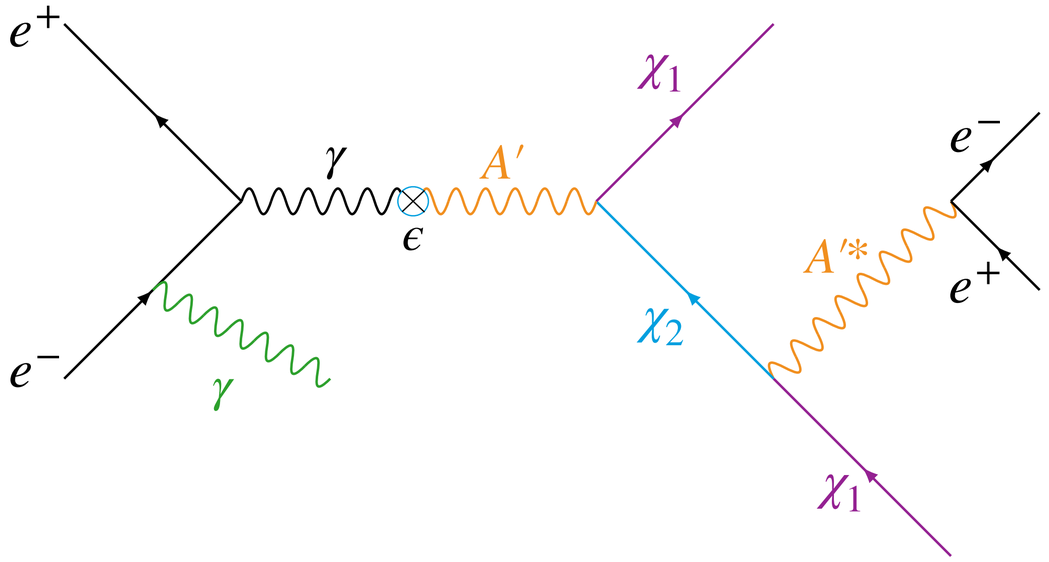
- Results published with early datasets:
  - Invisible Z' Phys. Rev. Lett. 124, 141801
  - ALPs search Phys. Rev. Lett. 125, 161806
- Ongoing searches:
  - Dark Photon, Dark Higgs
  - Inelastic Dark Matter, Long-lived Dark Higgs
  - … many more!
- Belle II will be leading the field of light dark matter in the coming years

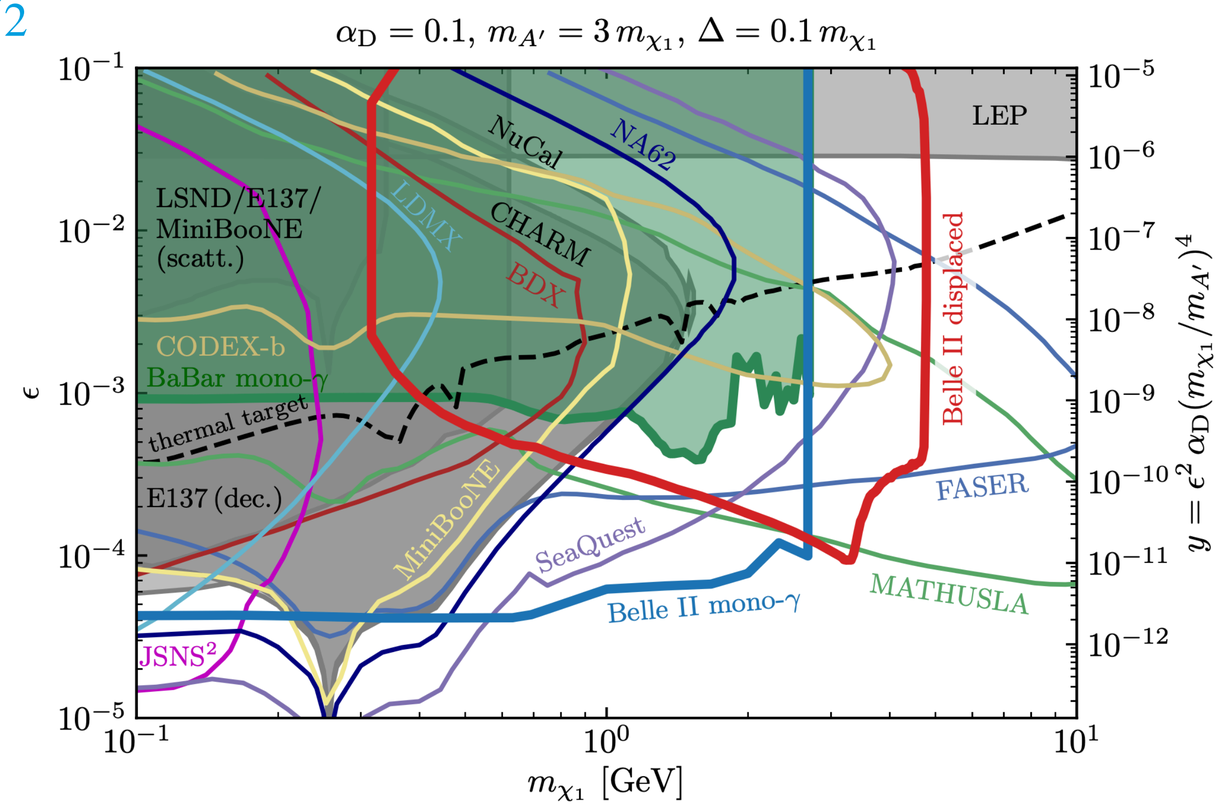
Backup.

Search for Inelastic Dark Matter.

Ongoing!

- Dark photon A' and two Dark Matter states χ_1, χ_2
- Long-lived χ_2, relic candidate χ_1 with $m_{\chi_2} > m_{\chi_1}$
- Initial state radiation γ for triggering





M. Duerr, T. Ferber, C. Hearty,
F. Kahlhoefer, K. Schmidt-Hoberg, P. Tunney

J. High Energ. Phys.
2020, 39 (2020)

Search for Inelastic Dark Matter.

Ongoing!

- Reconstruct displaced χ_2 vertex
- Search in recoil mass of the ISR γ
- Background suppression:
  - Non-pointing vertex
  - Missing energy: K_S^0 and γ conversion