

Dark sector searches at Belle II.

Sascha Dreyer on behalf of the Belle II collaboration

XXVIII International Conference on Supersymmetry and Unification of Fundamental Interactions (SUSY)
23.08.2021

sascha.dreyer@desy.de

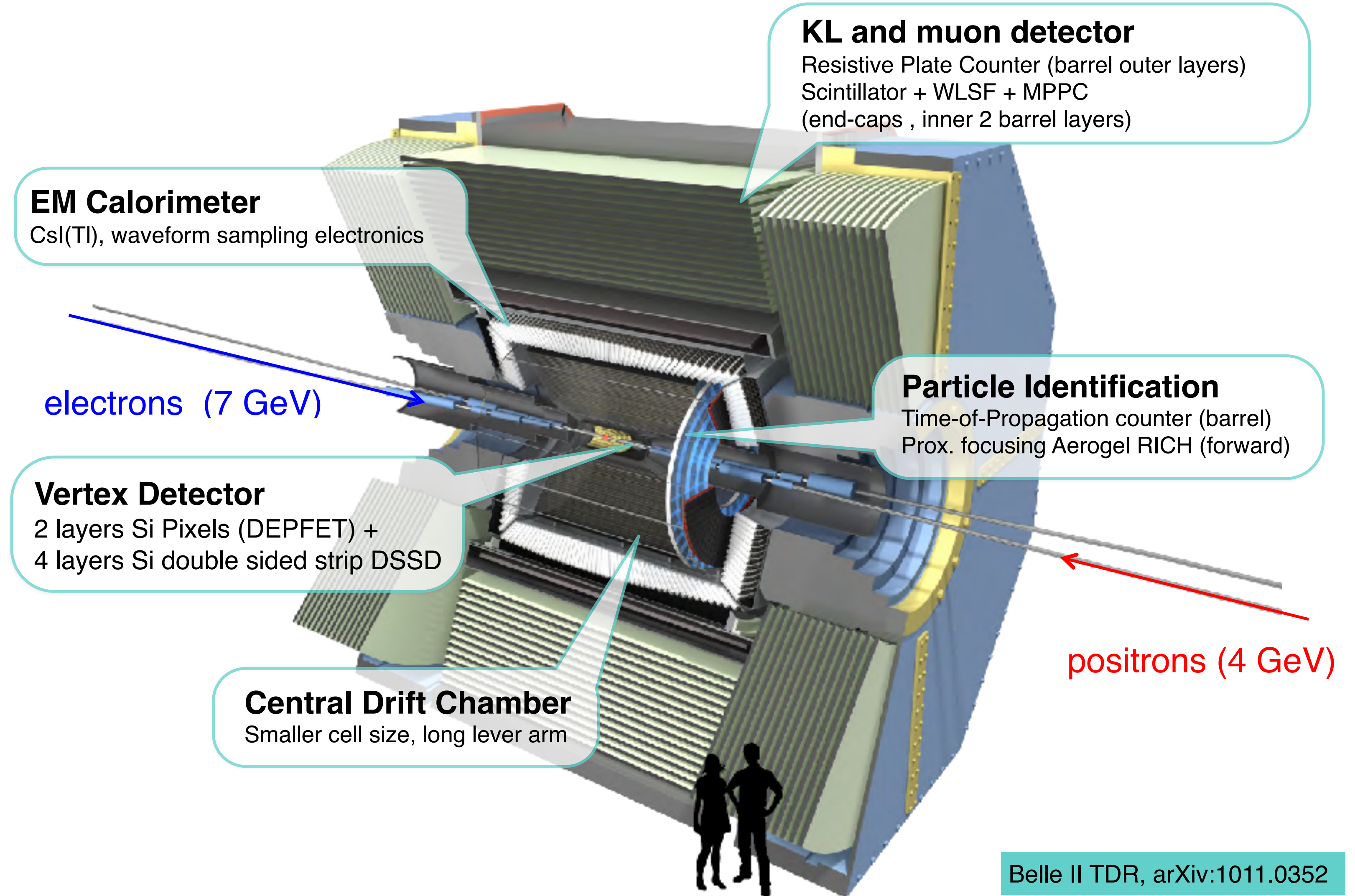


HELMHOLTZ RESEARCH FOR
GRAND CHALLENGES

UH
 Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG



- ▶ 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

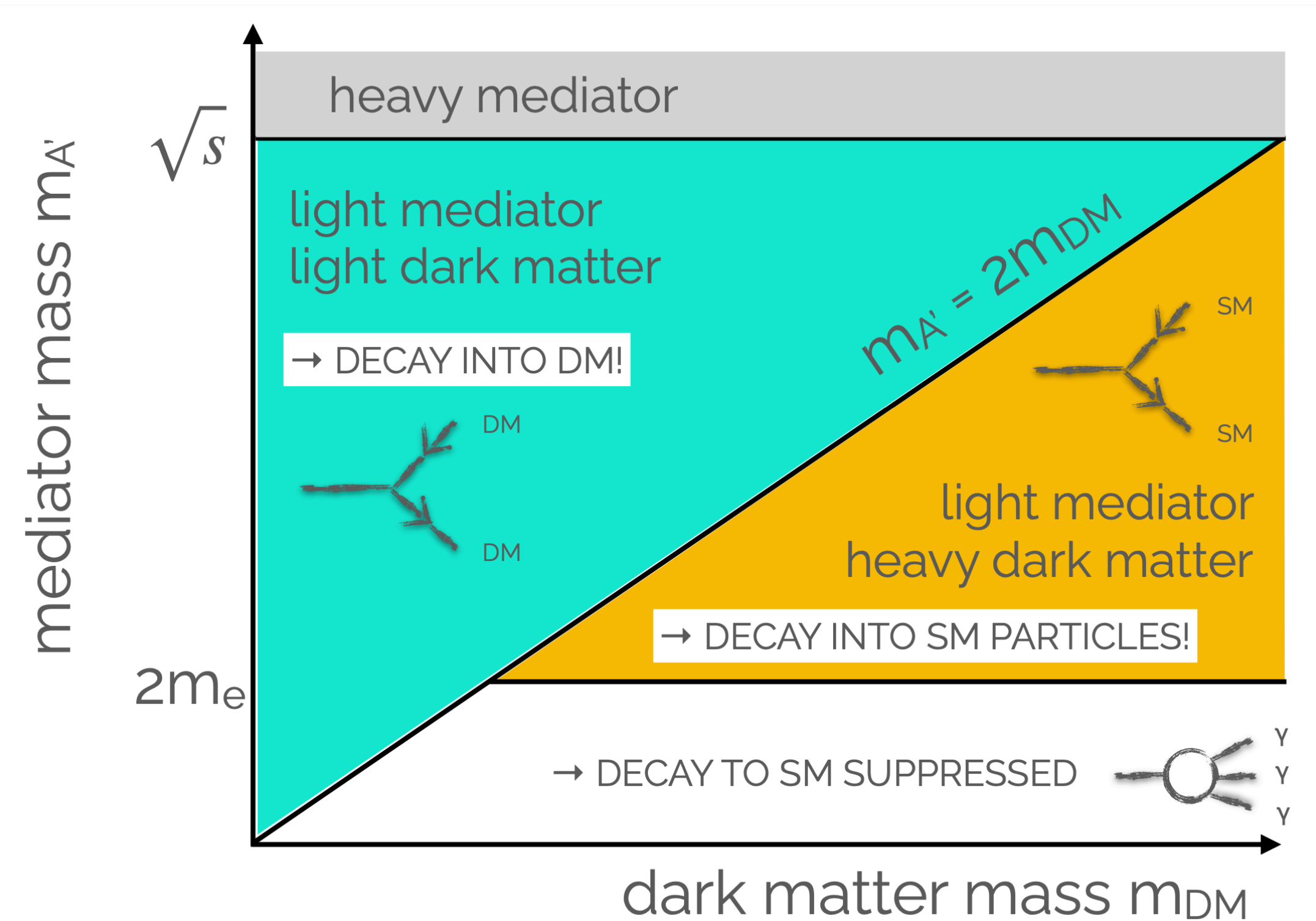


Standard Model



Dark Sector

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

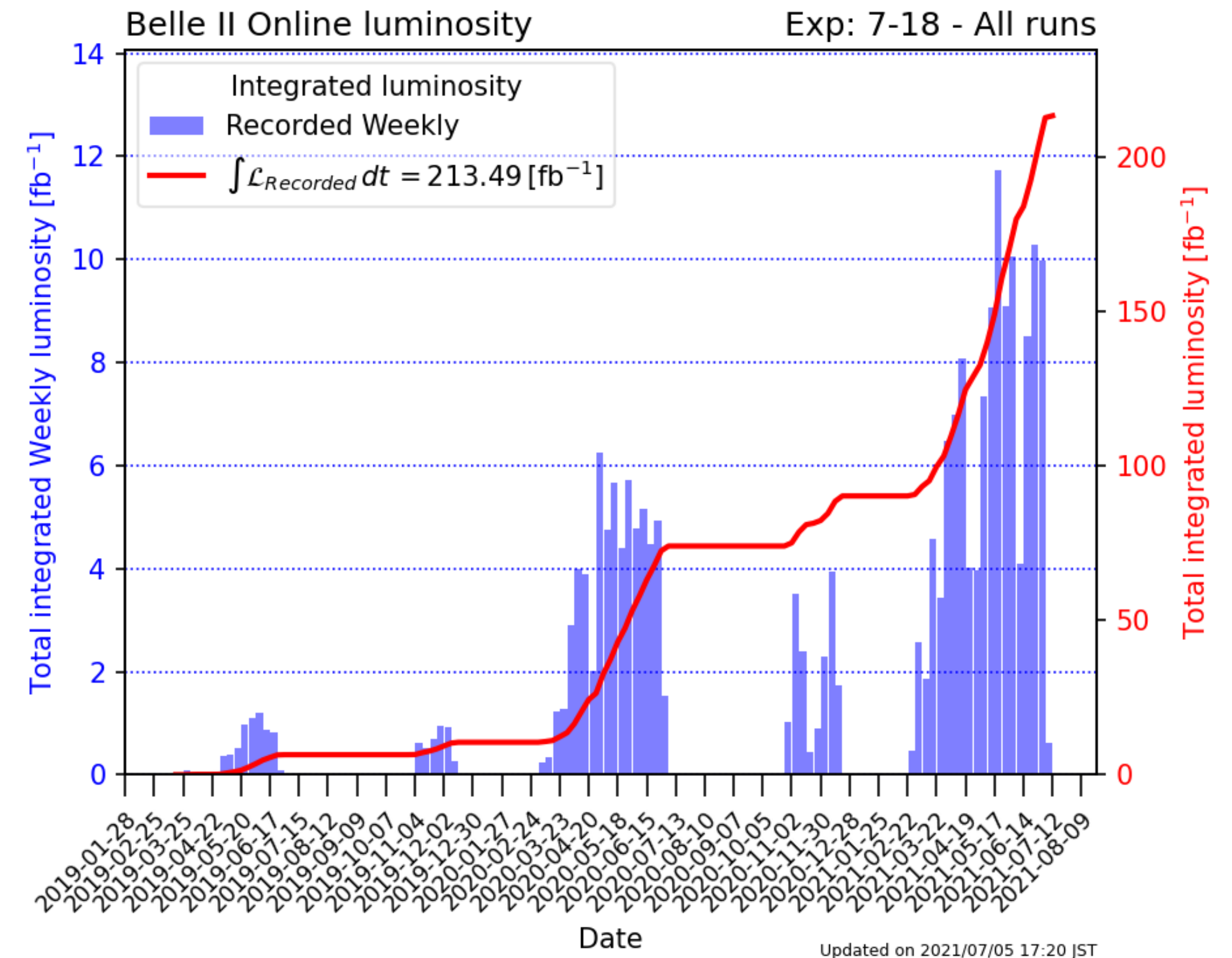


T. Ferber

- ▶ 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

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

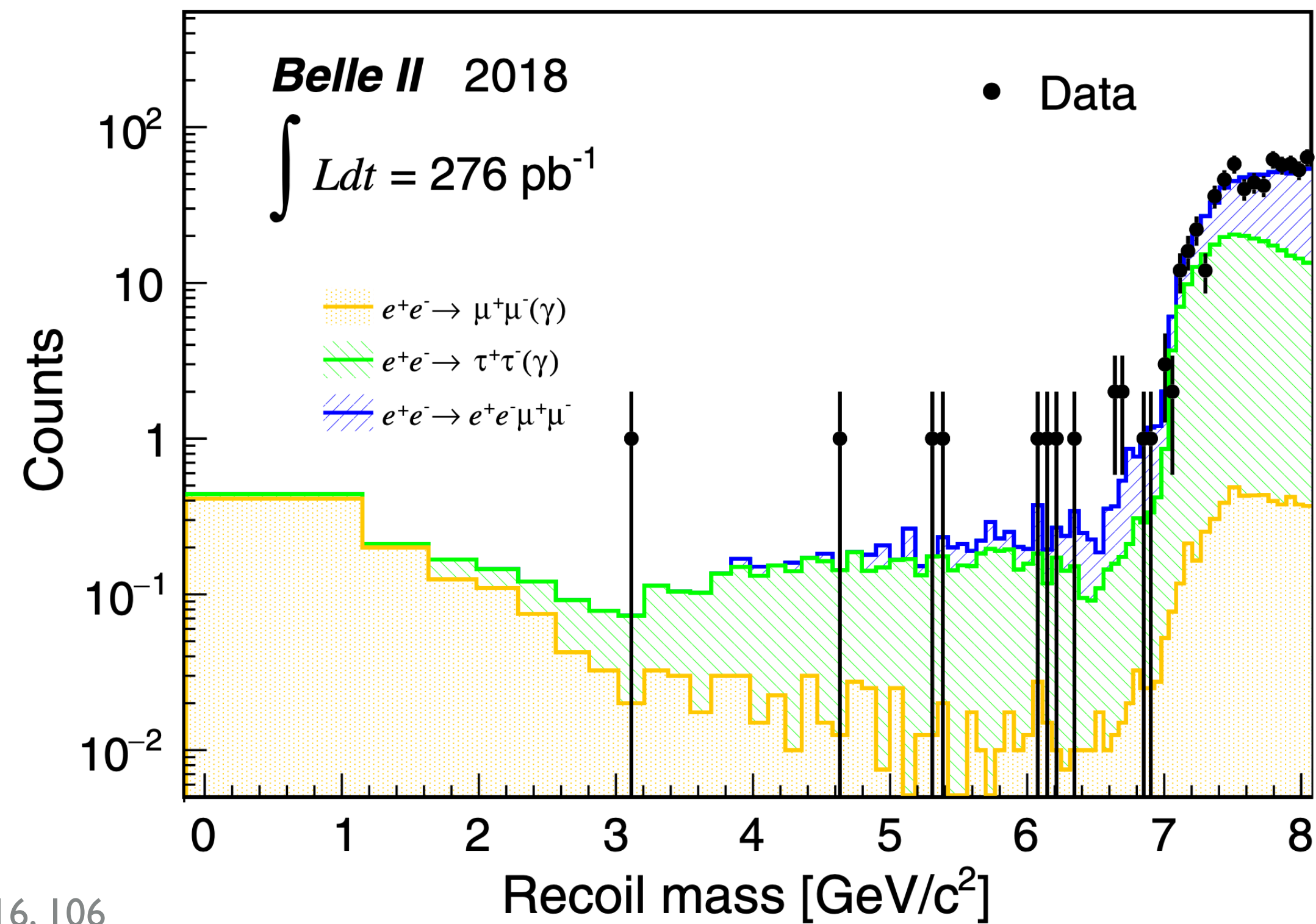
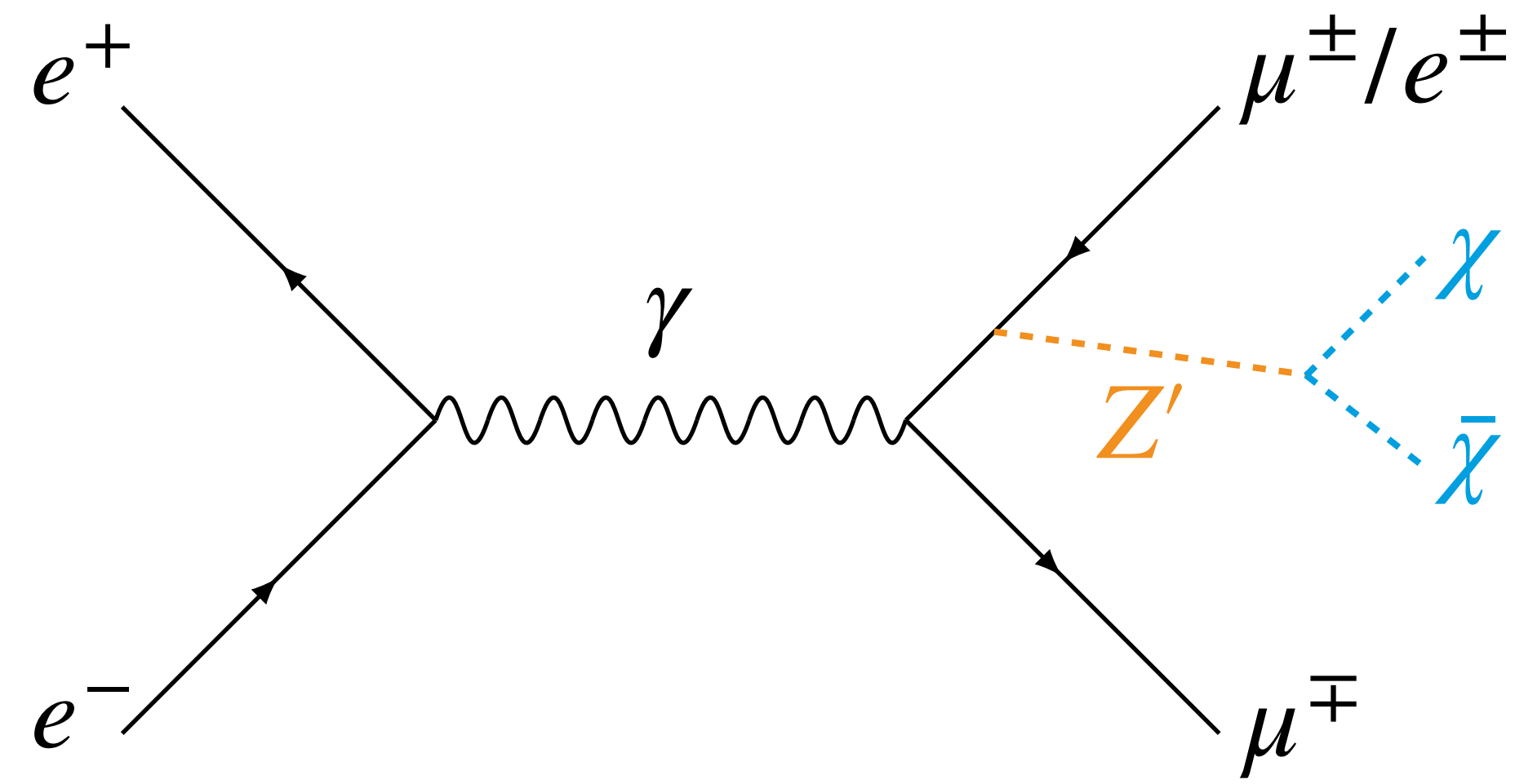
$$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B[\bar{B} \rightarrow KX]$$



Published searches

Search for an invisibly decaying Z' boson.

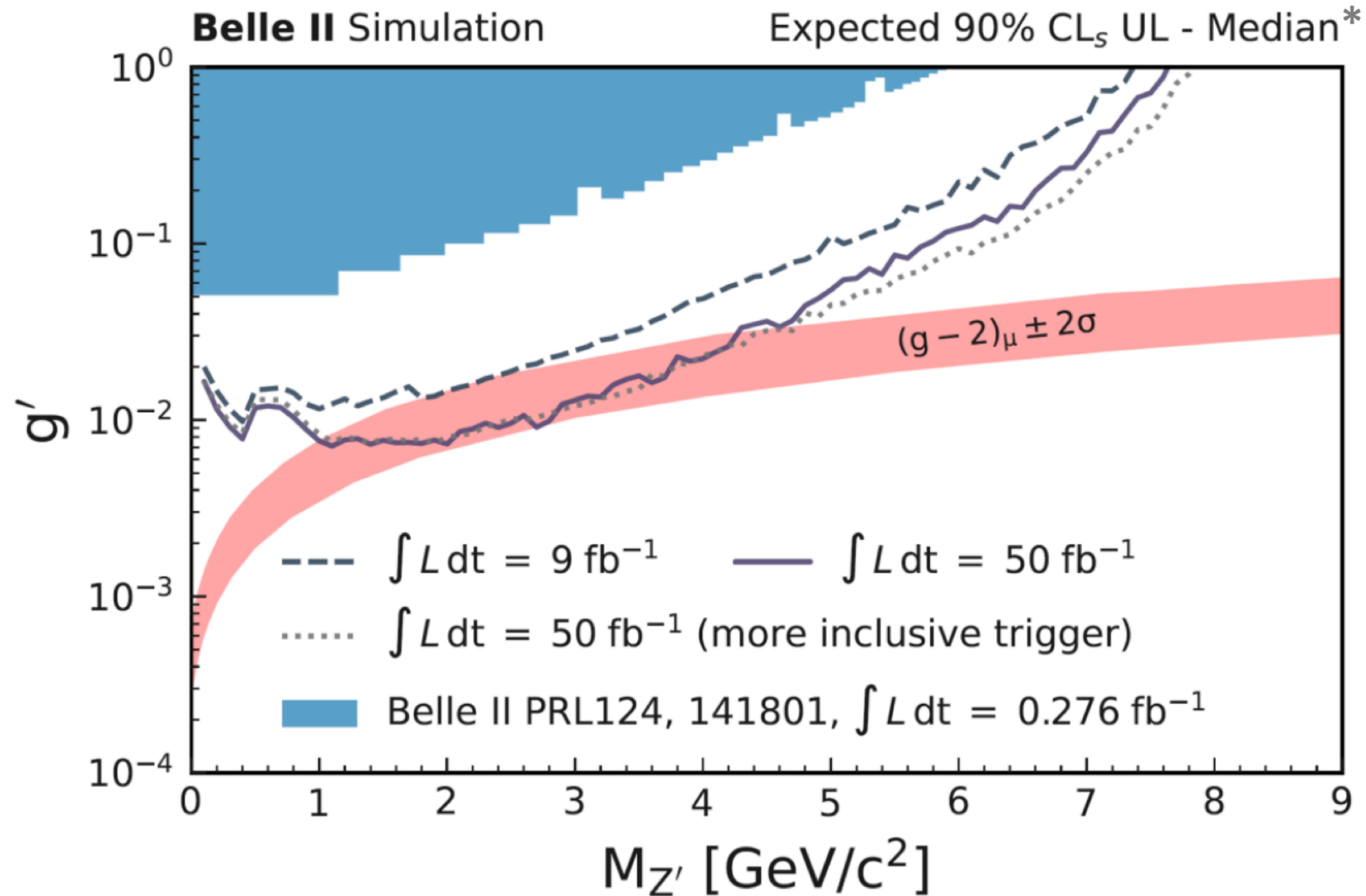
- ▶ Additional massive gauge boson Z'
- ▶ Could explain discrepancies [1] & [2]
 - ▶ $(g - 2)_\mu$
 - ▶ $b \rightarrow s\mu\mu$
- ▶ Study mass recoiling against $\mu\mu$ system
- ▶ Backgrounds:
 - ▶ $e^+e^- \rightarrow \tau^+\tau^-$
 - ▶ $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$
- ▶ LFV mode studied as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



Phys. Rev. Lett. 124, 141801
 Published!

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

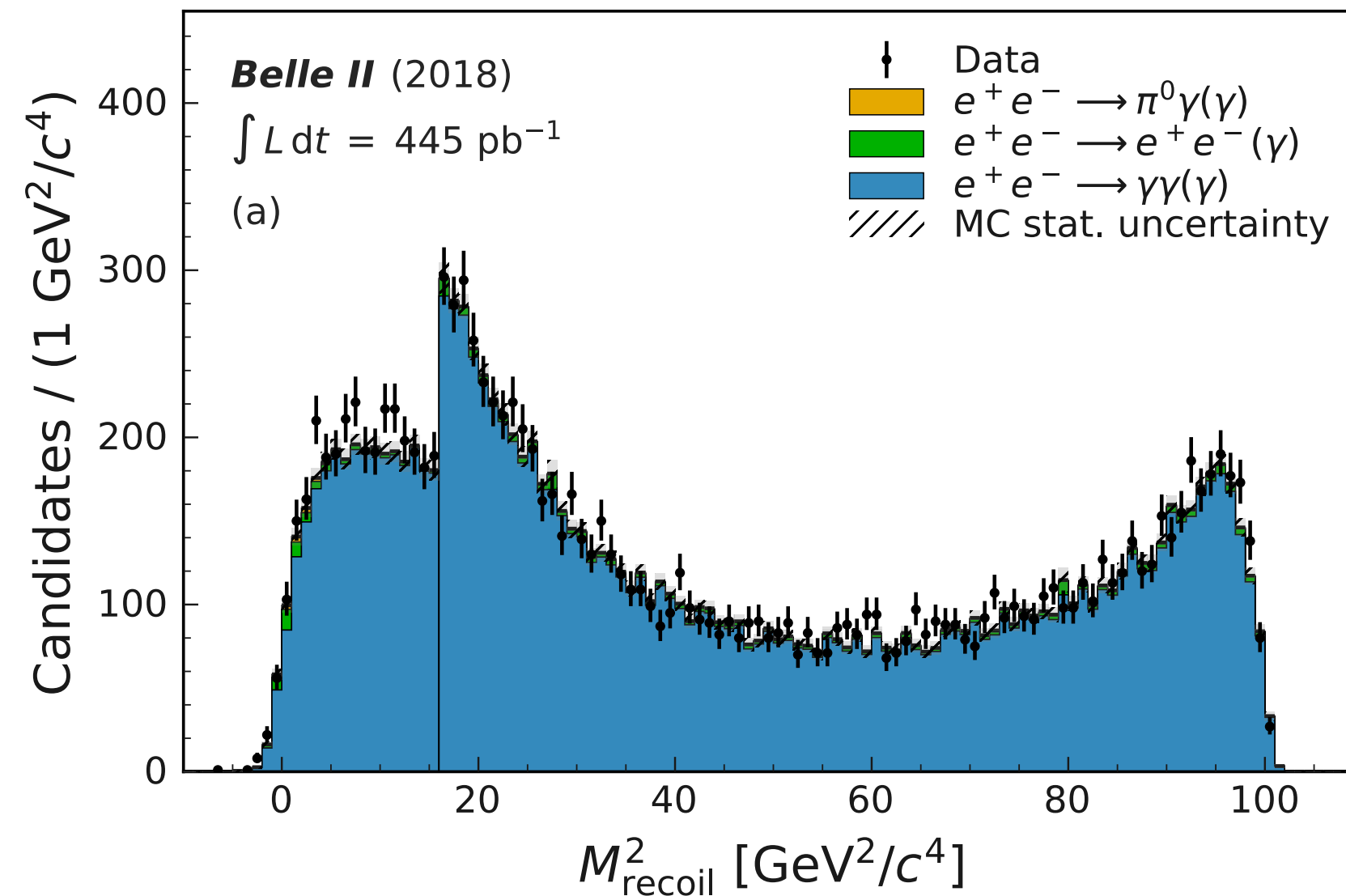
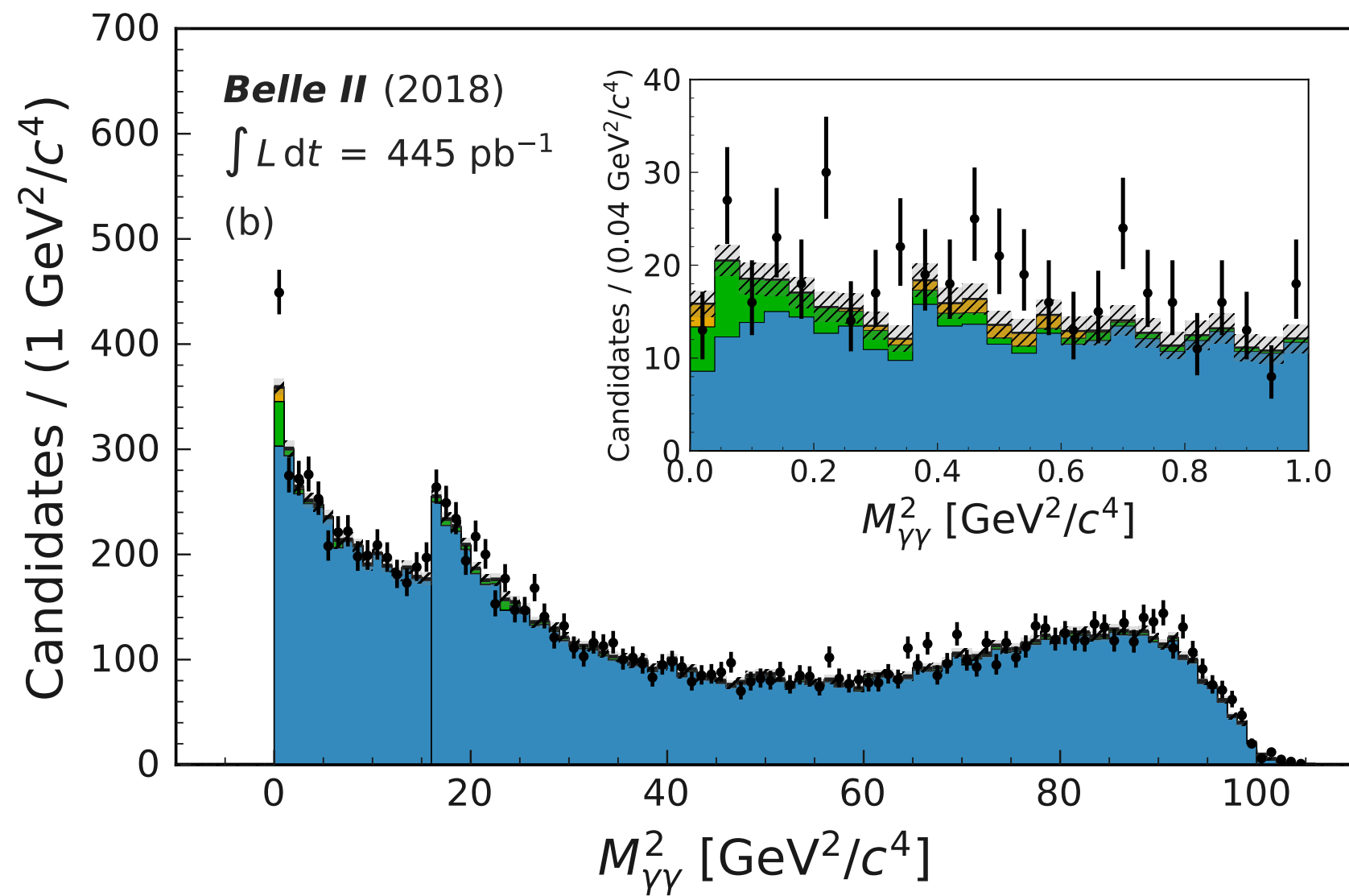
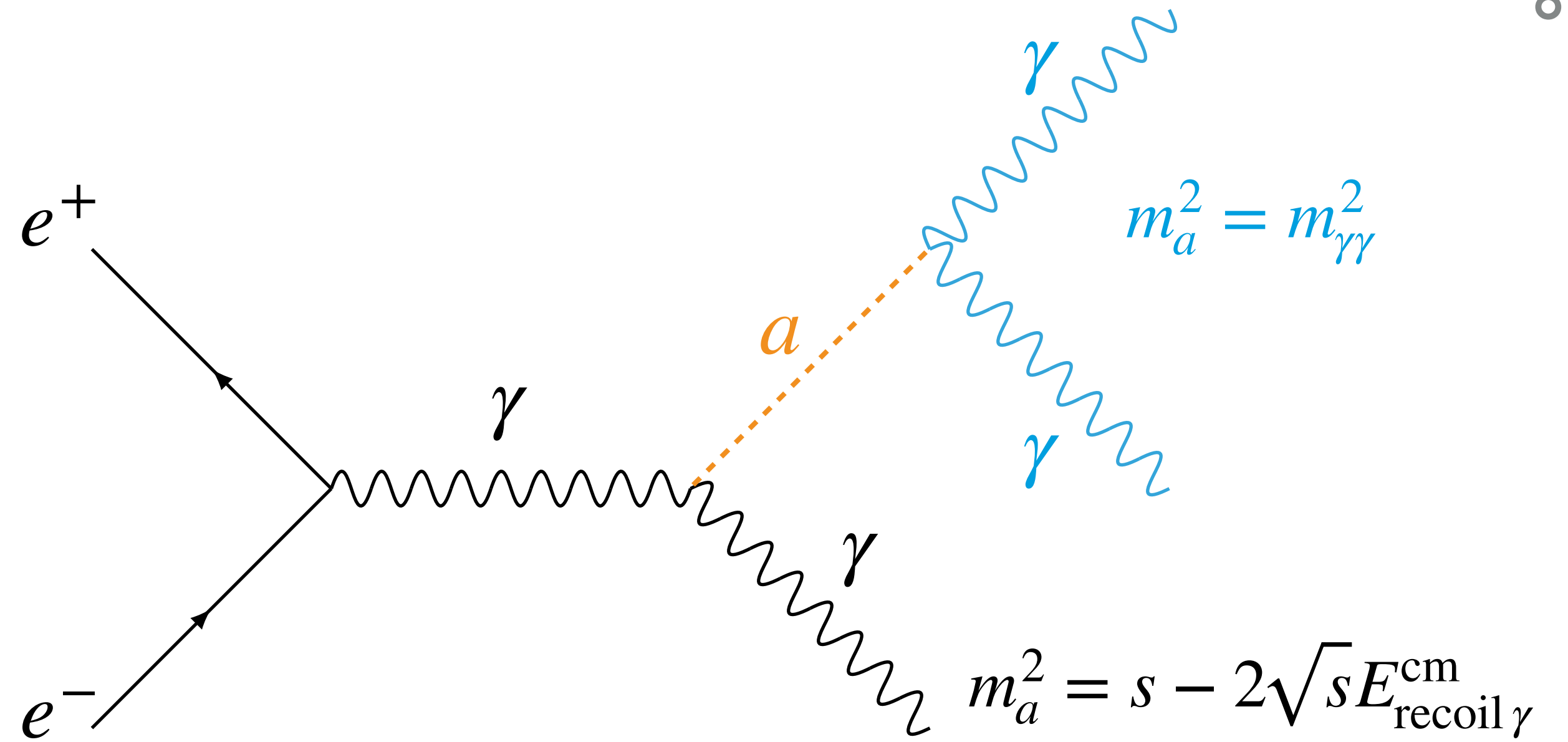
Search for an invisibly decaying Z' boson.



[Phys. Rev. Lett. 124, 141801](#)

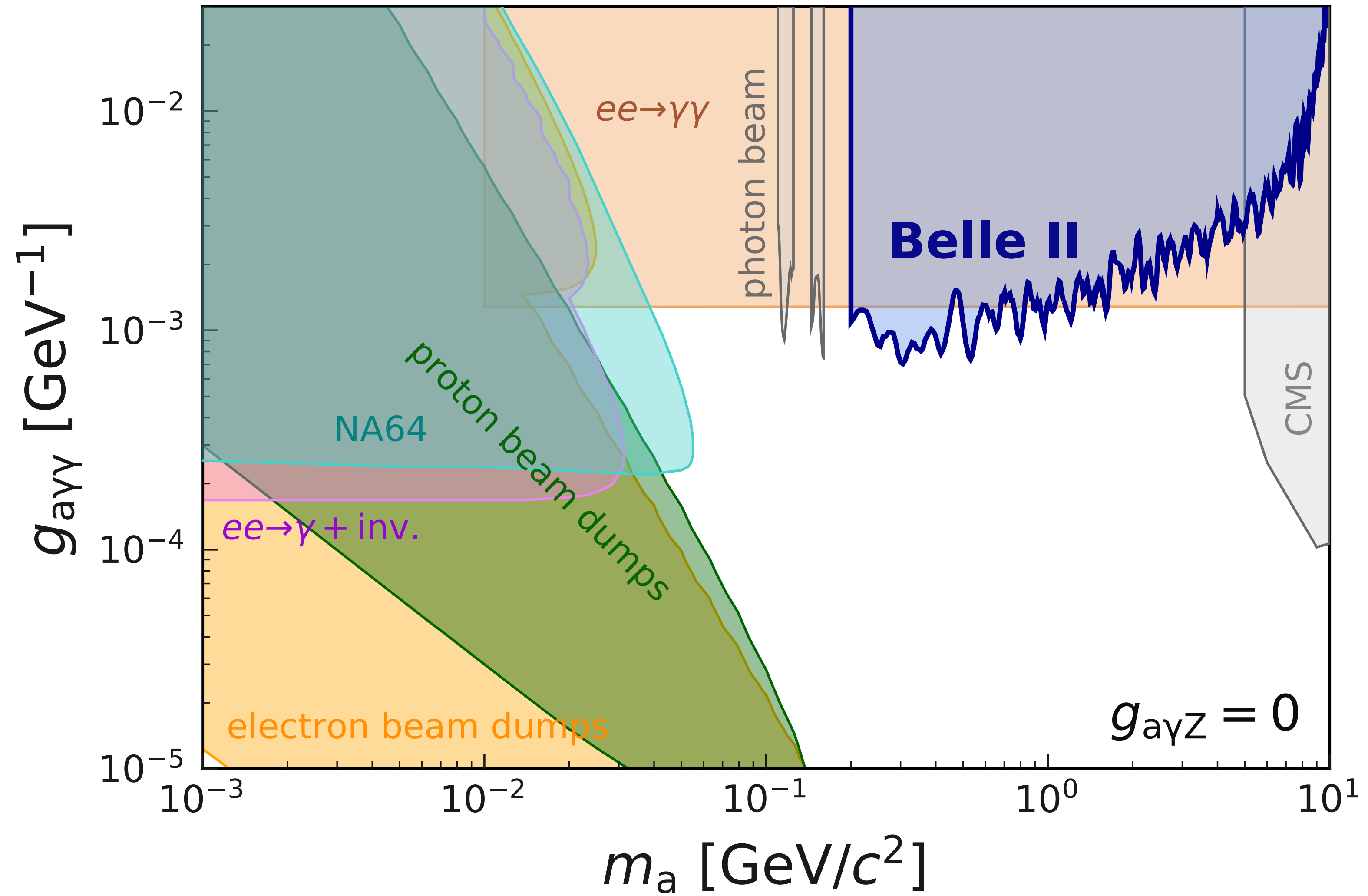
Search for Axion Like Particles (ALP).

- ▶ Pseudoscalar ALP a
- ▶ Events with three γ consistent with \sqrt{s}
- ▶ Search for a peak in reconstructed ALP mass distribution
- ▶ Backgrounds mainly $e^+e^- \rightarrow \gamma\gamma(\gamma)$



Phys. Rev. Lett. 125, 161806
 Published!

Search for Axion Like Particles (ALP).

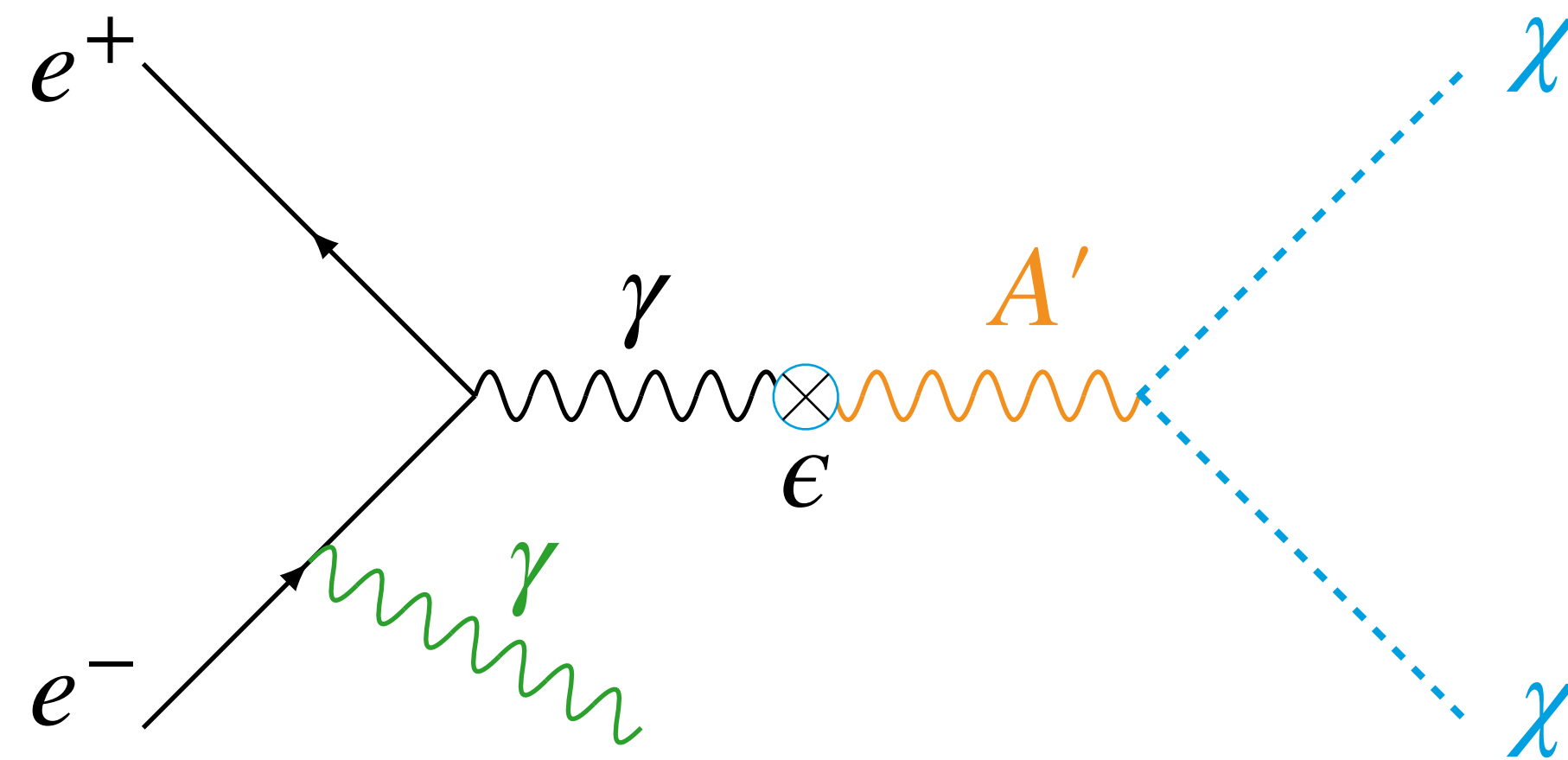


[Phys. Rev. Lett. 125, 161806](https://arxiv.org/abs/1608.05937)

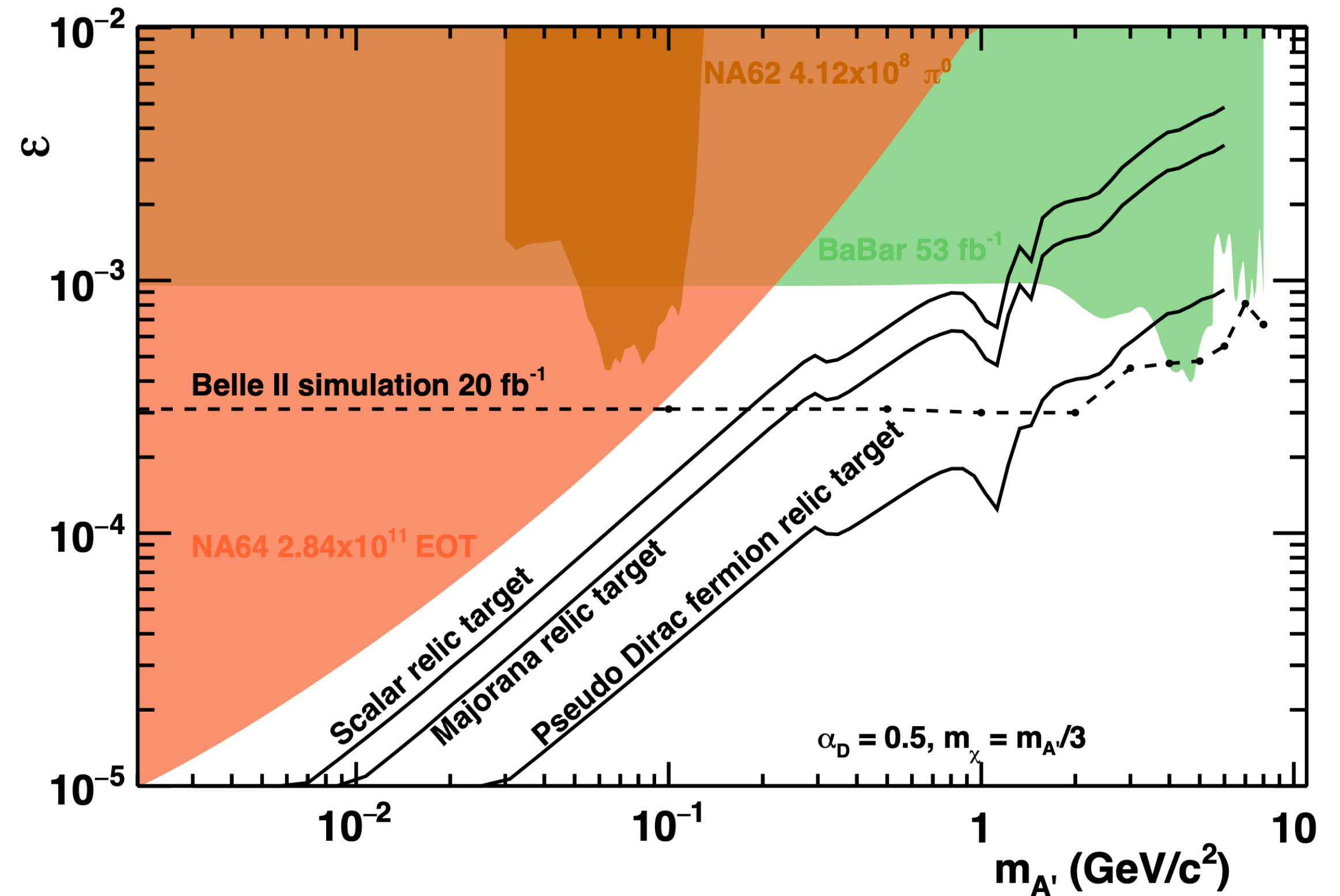
Ongoing searches

Search for a Dark Photon.

- ▶ Dark photon A'
- ▶ Vanilla benchmark-model
- ▶ Invisible decay to Dark Matter χ (or very long-lived)
- ▶ ISR photon γ
- ▶ Search for a bump in E_γ
- ▶ Main background: $e^+e^- \rightarrow \gamma\gamma(\gamma)$
 - ▶ Understanding the detector is crucial



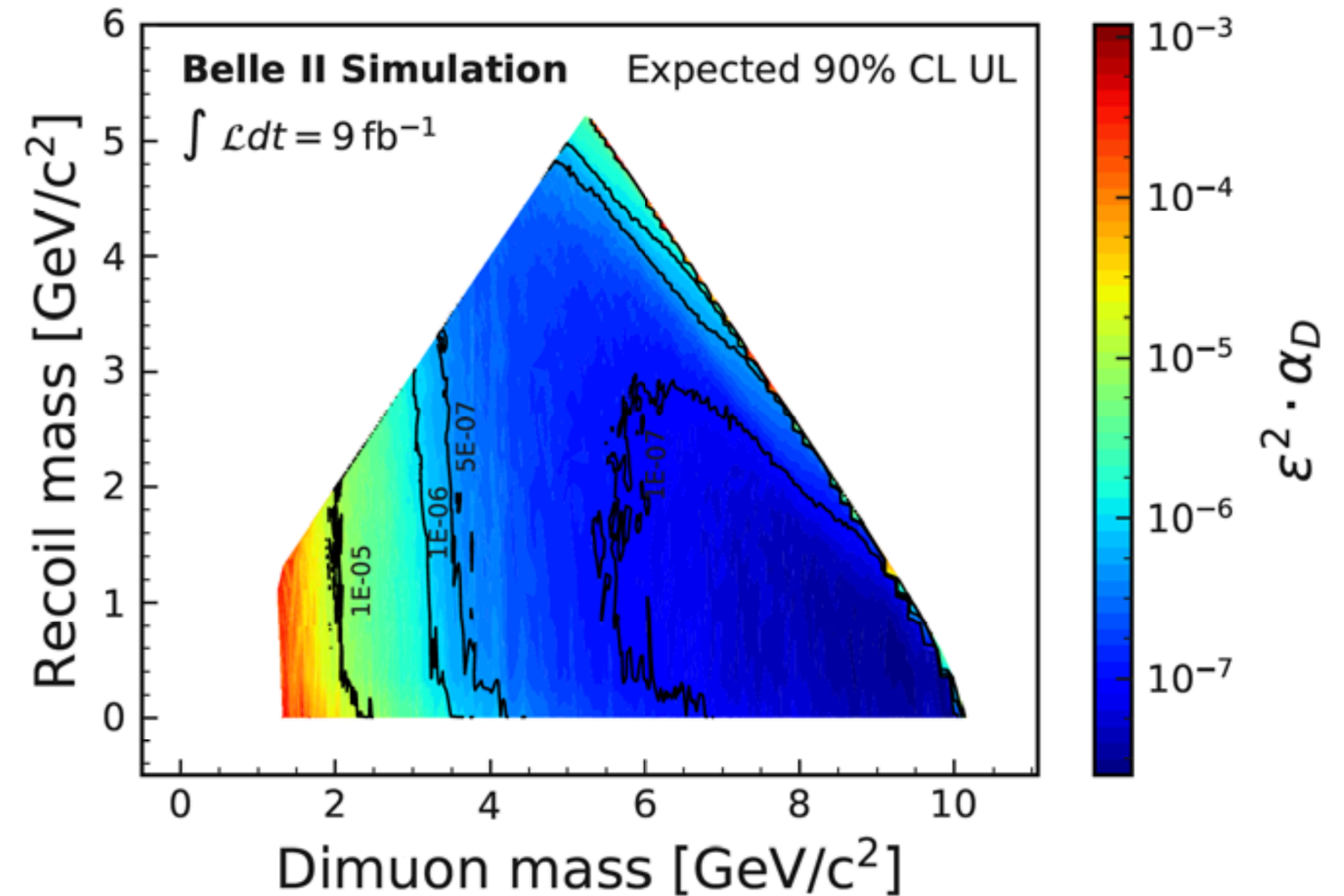
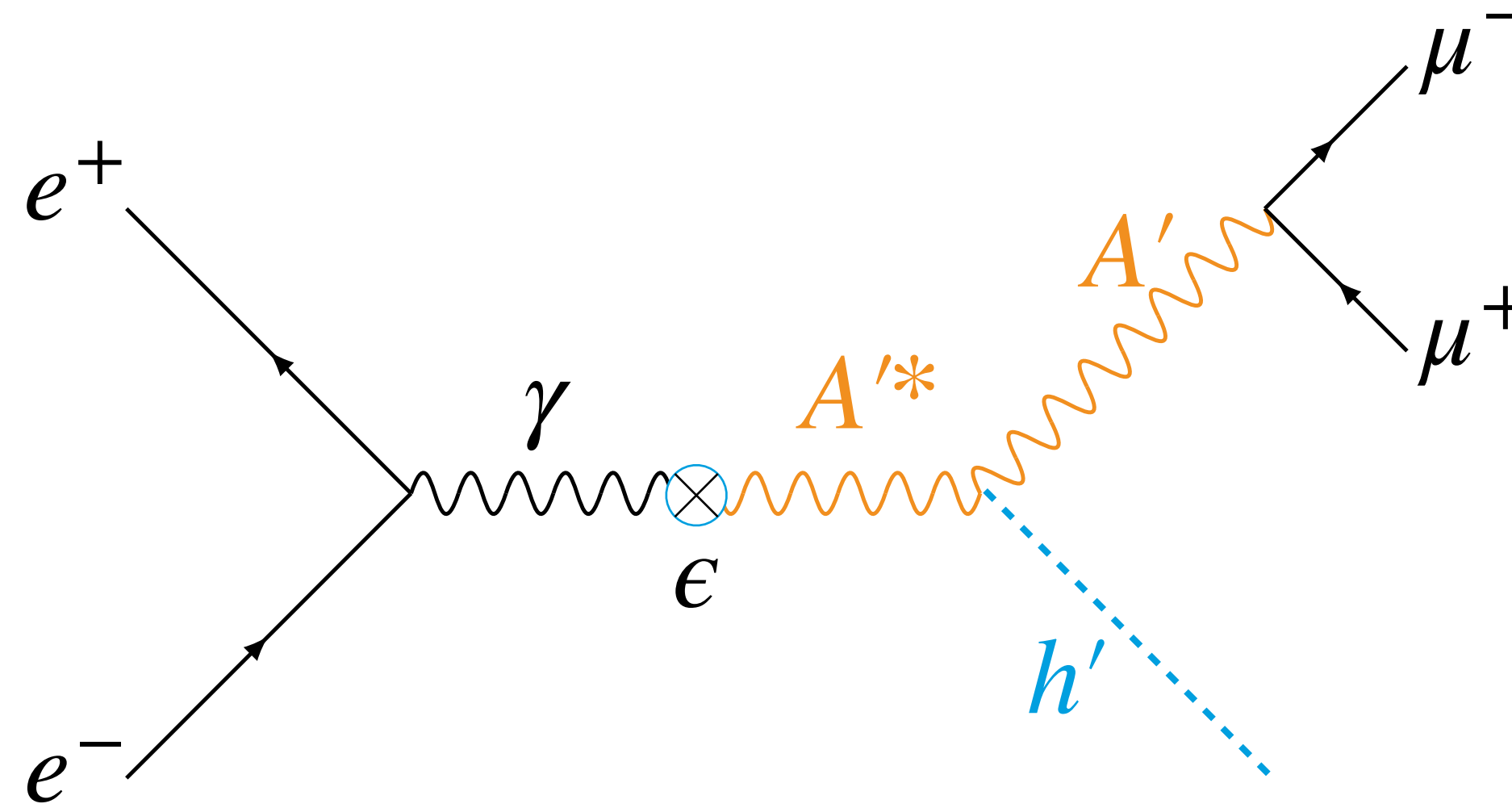
11
Ongoing!



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}
- ▶ Main backgrounds:
 - ▶ $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$
 - ▶ $e^+e^- \rightarrow \tau^+\tau^-(\gamma)$

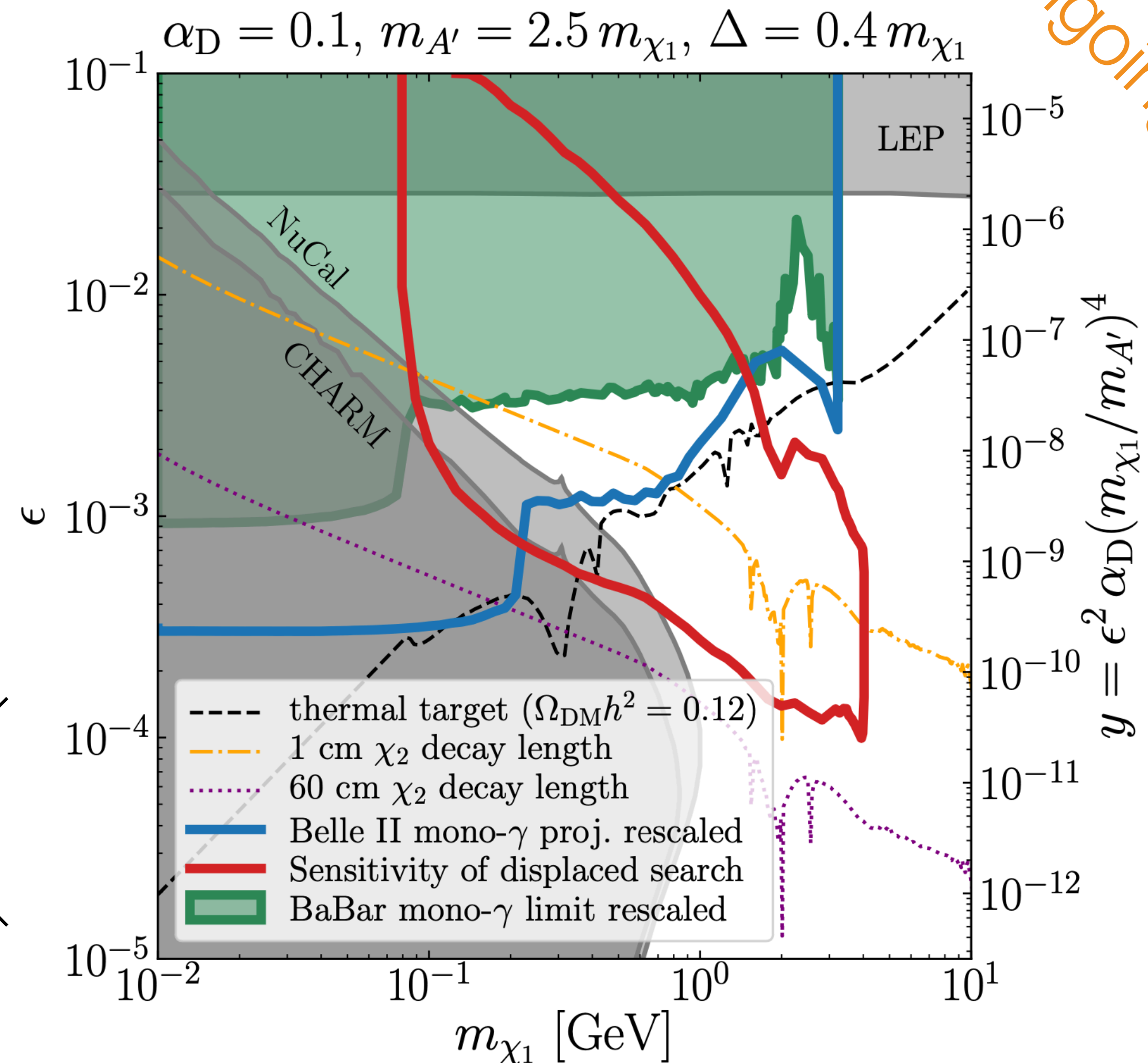
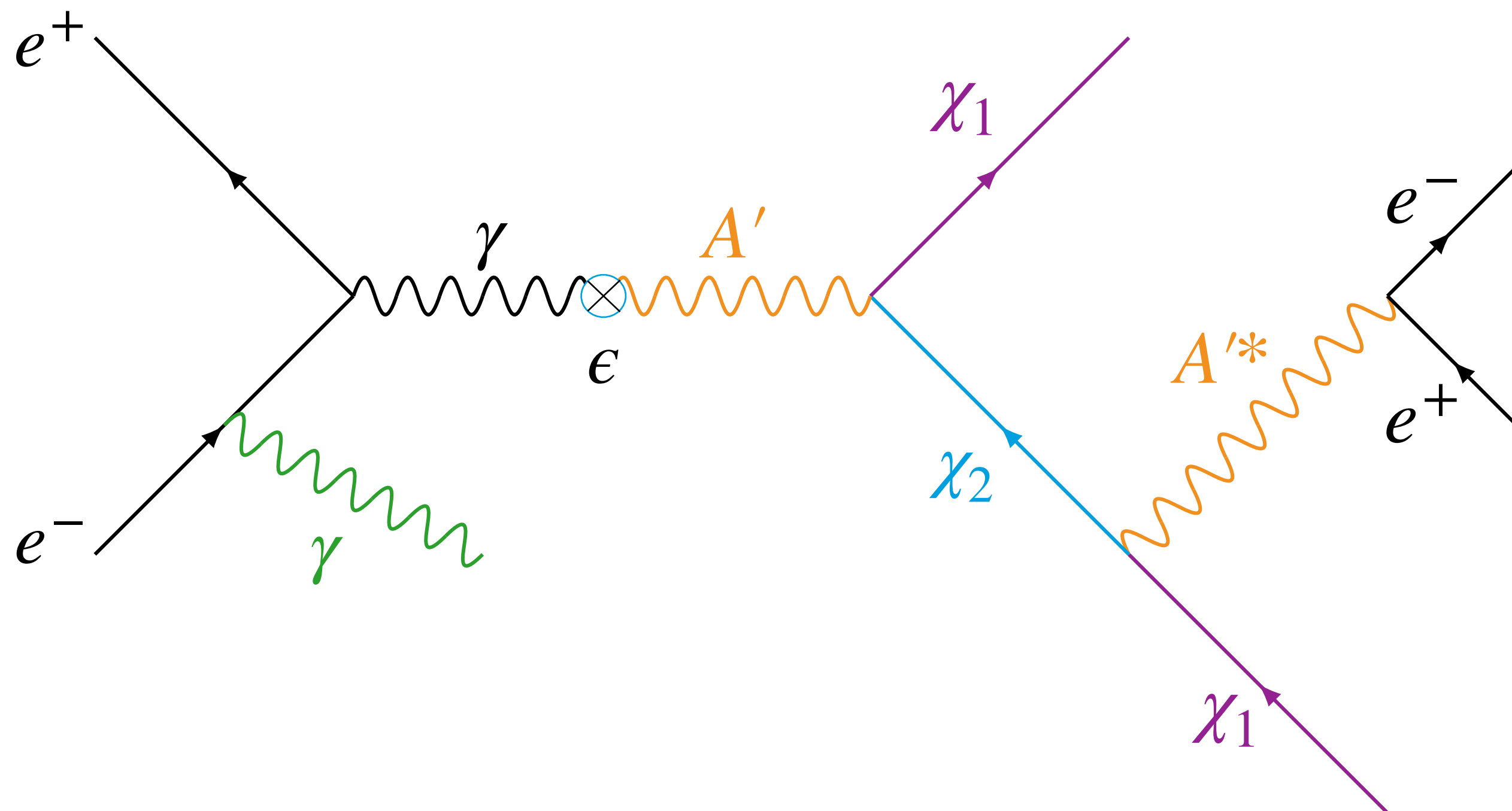


BELLE2-NOTE-PL-2020-013

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

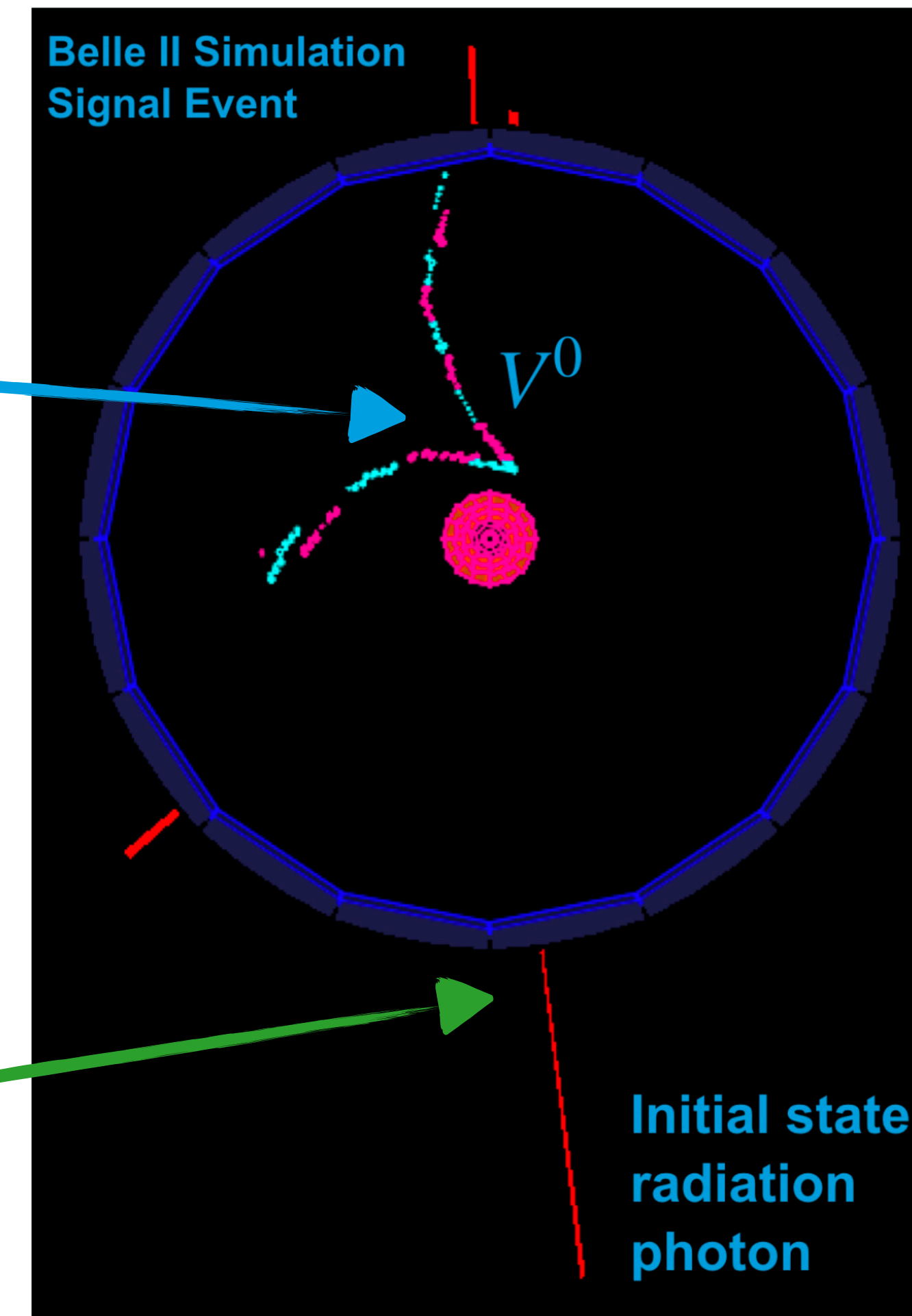
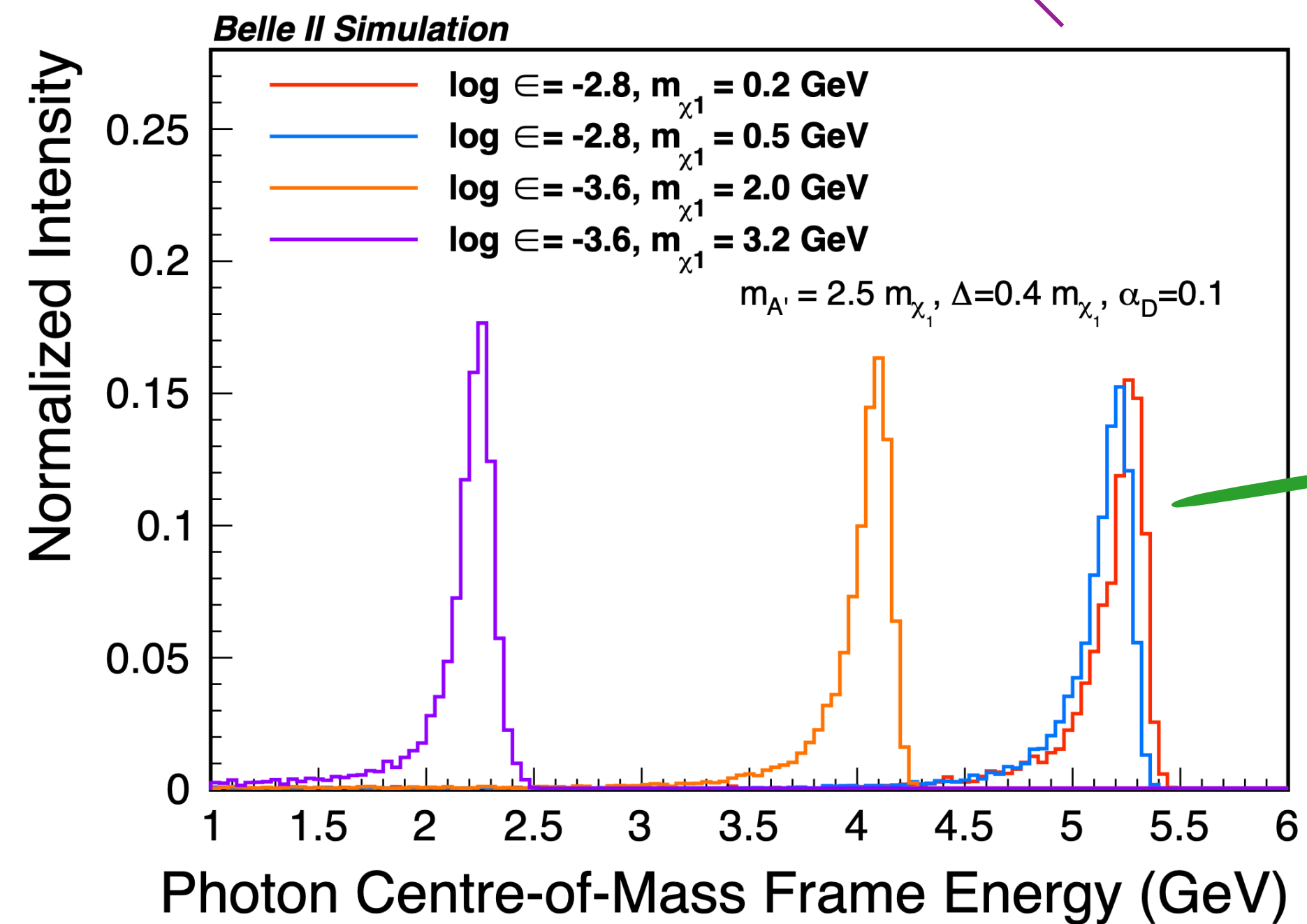
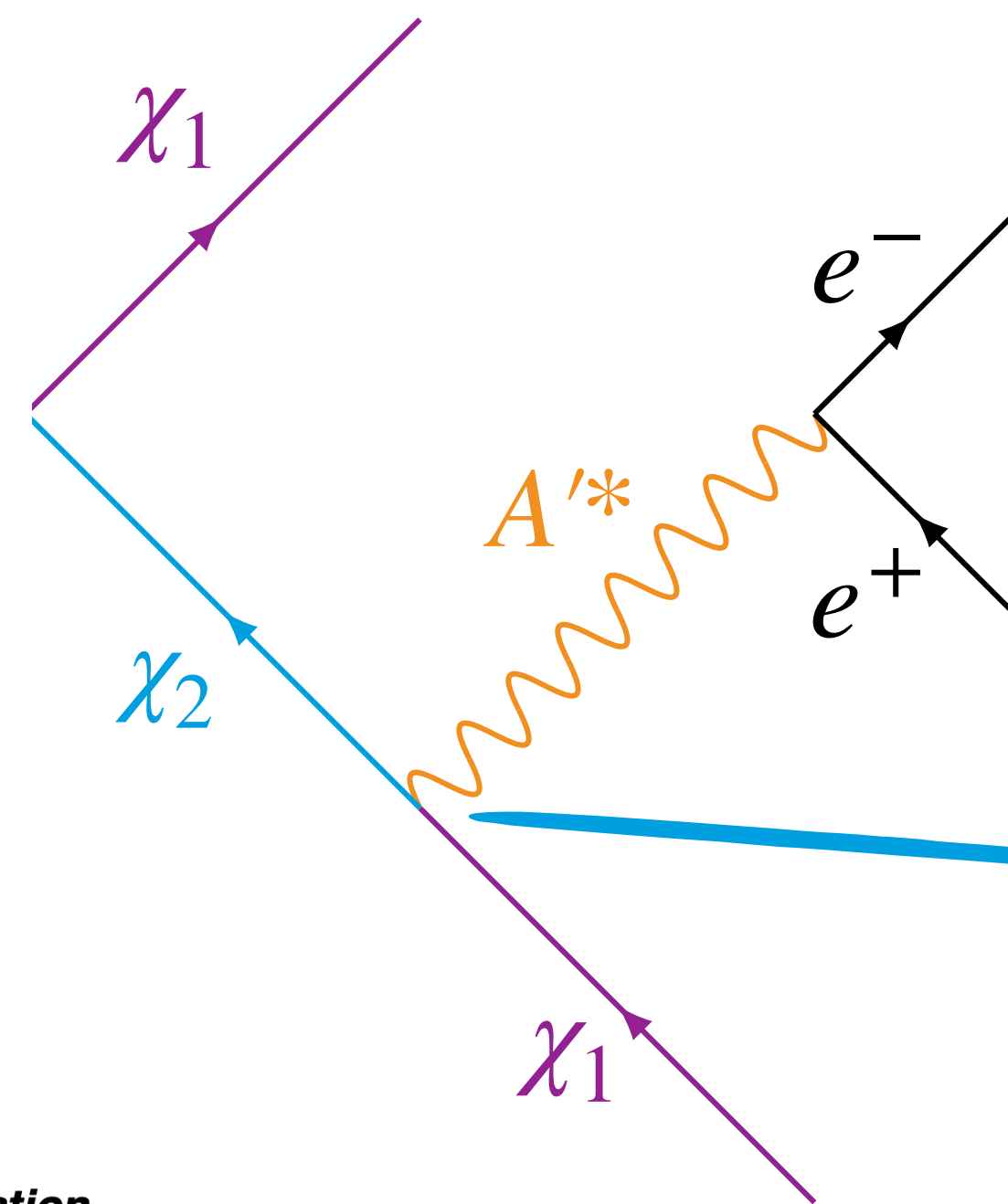


M. Duerr, T. Ferber, C. Hearty,
 F. Kahlhoefer, K. Schmidt-Hoberg, P. Tunney
 J. High Energy. Phys.
 2020, 39 (2020)

Search for Inelastic Dark Matter.

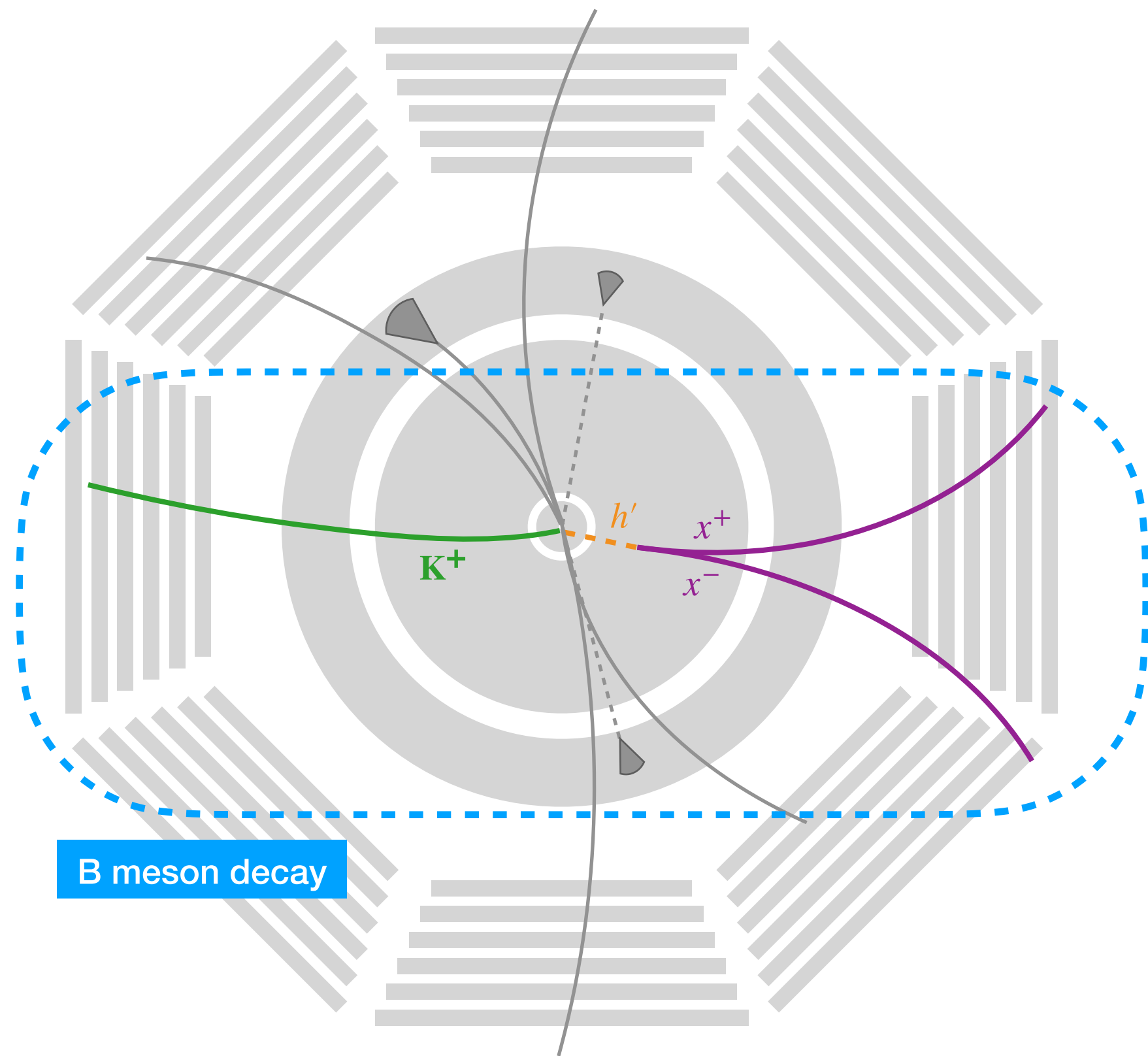
Ongoing!

- ▶ 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

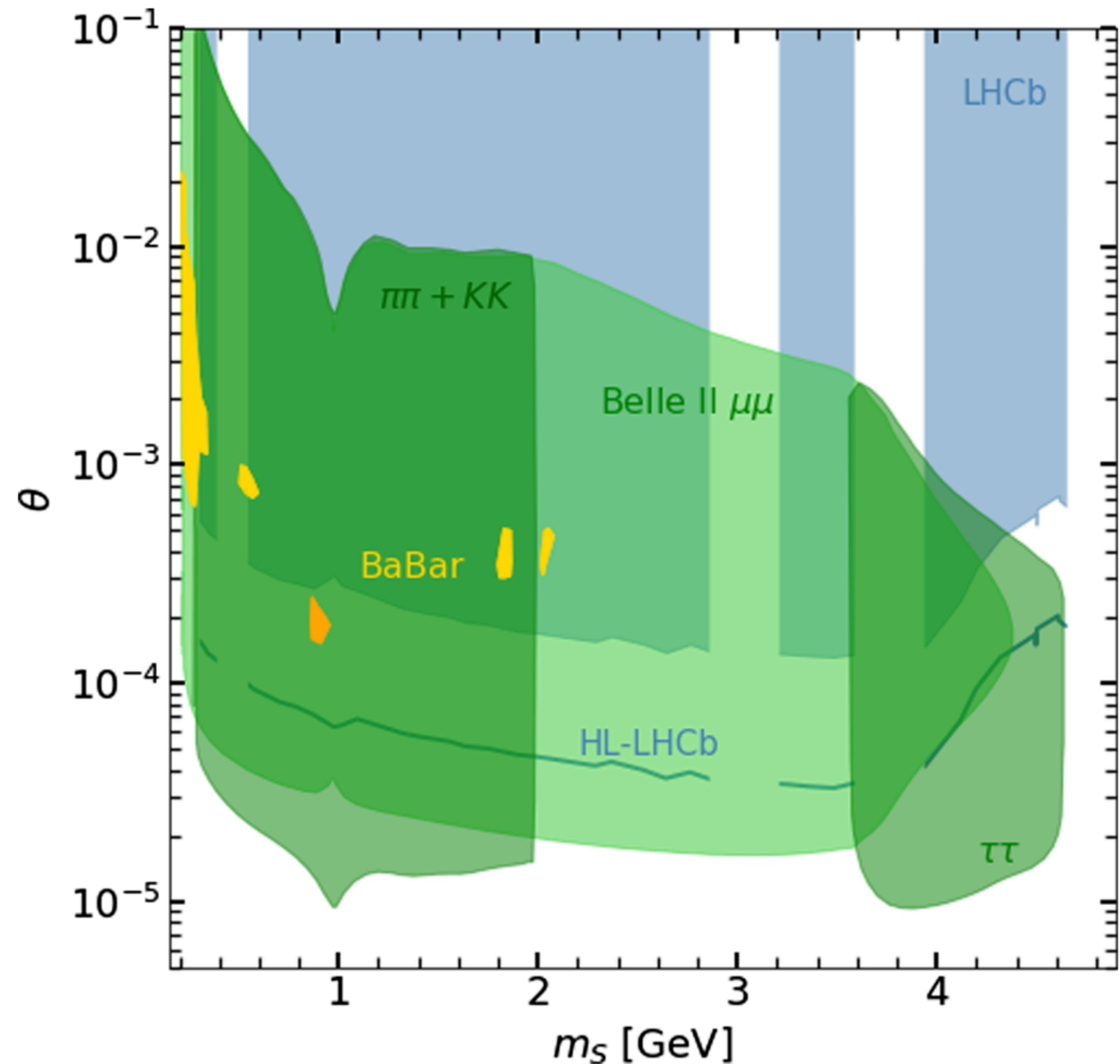
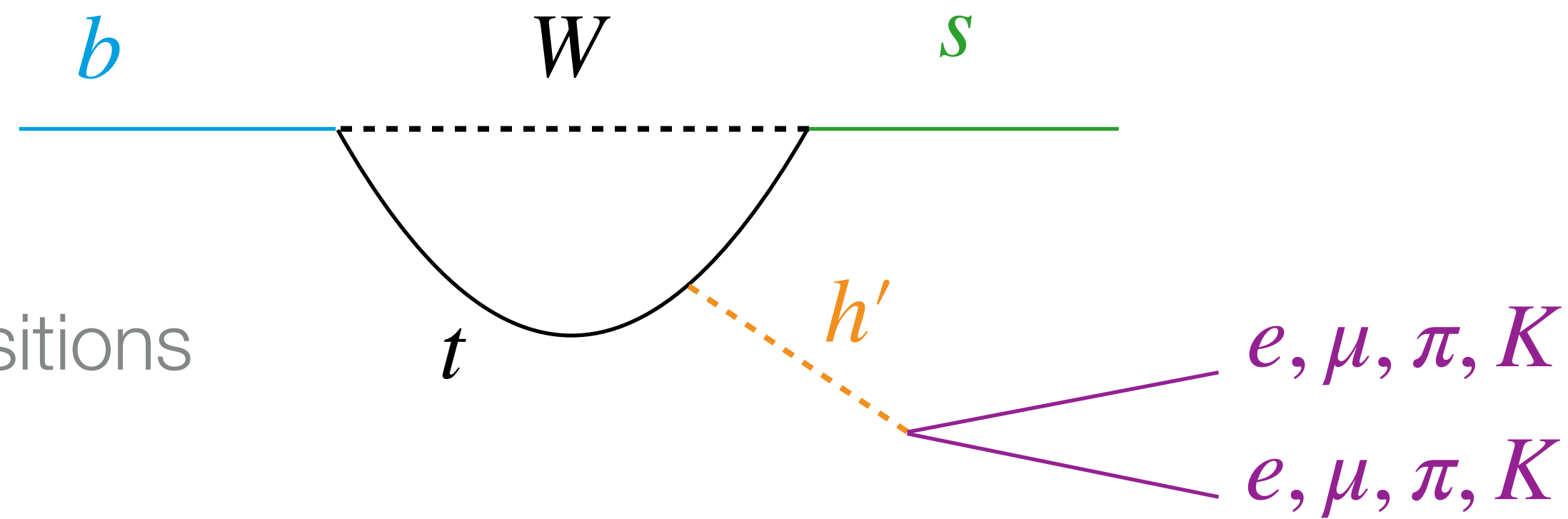


Search for $B \rightarrow Kh'$.

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



adapted from T. Ferber



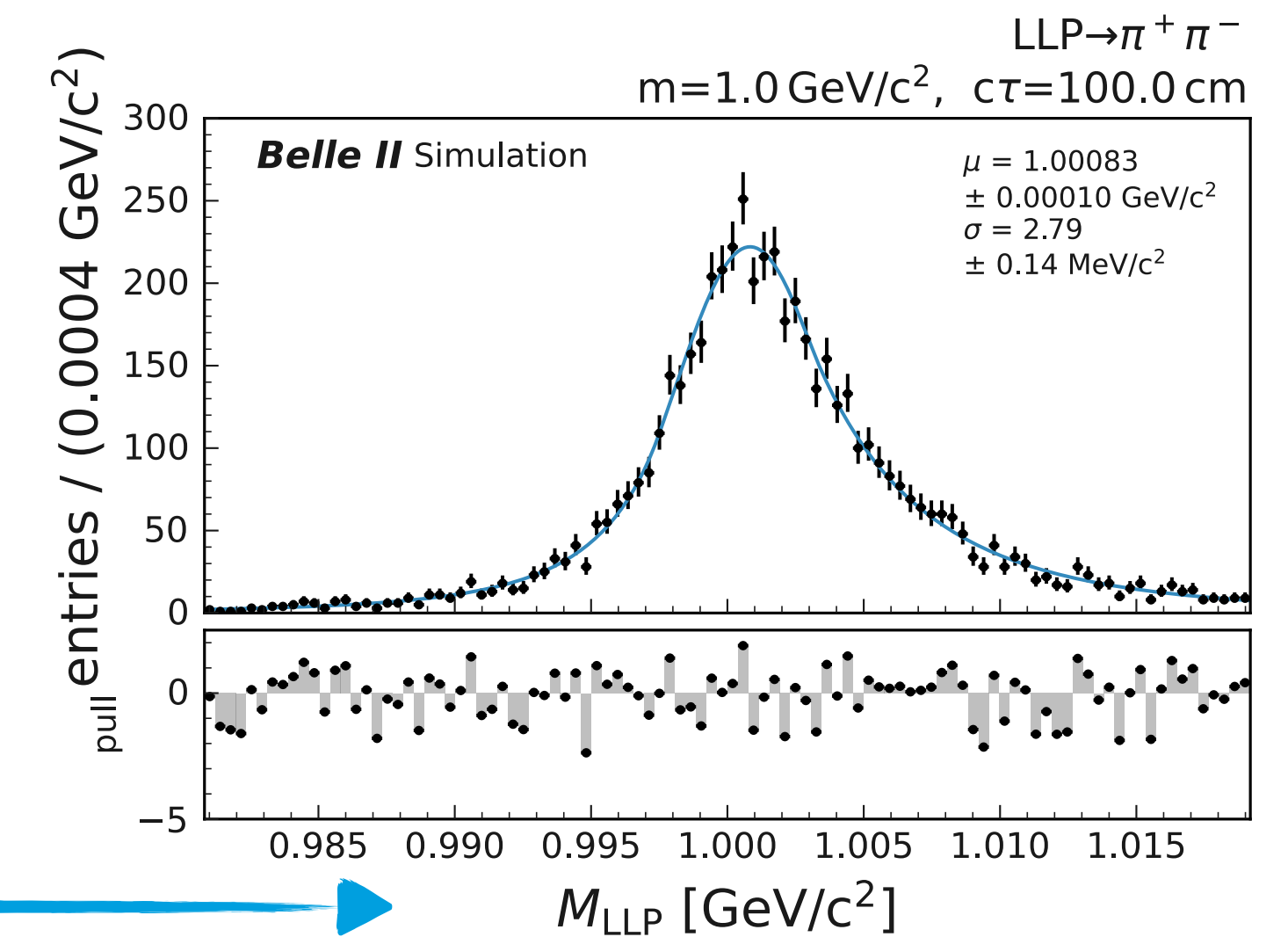
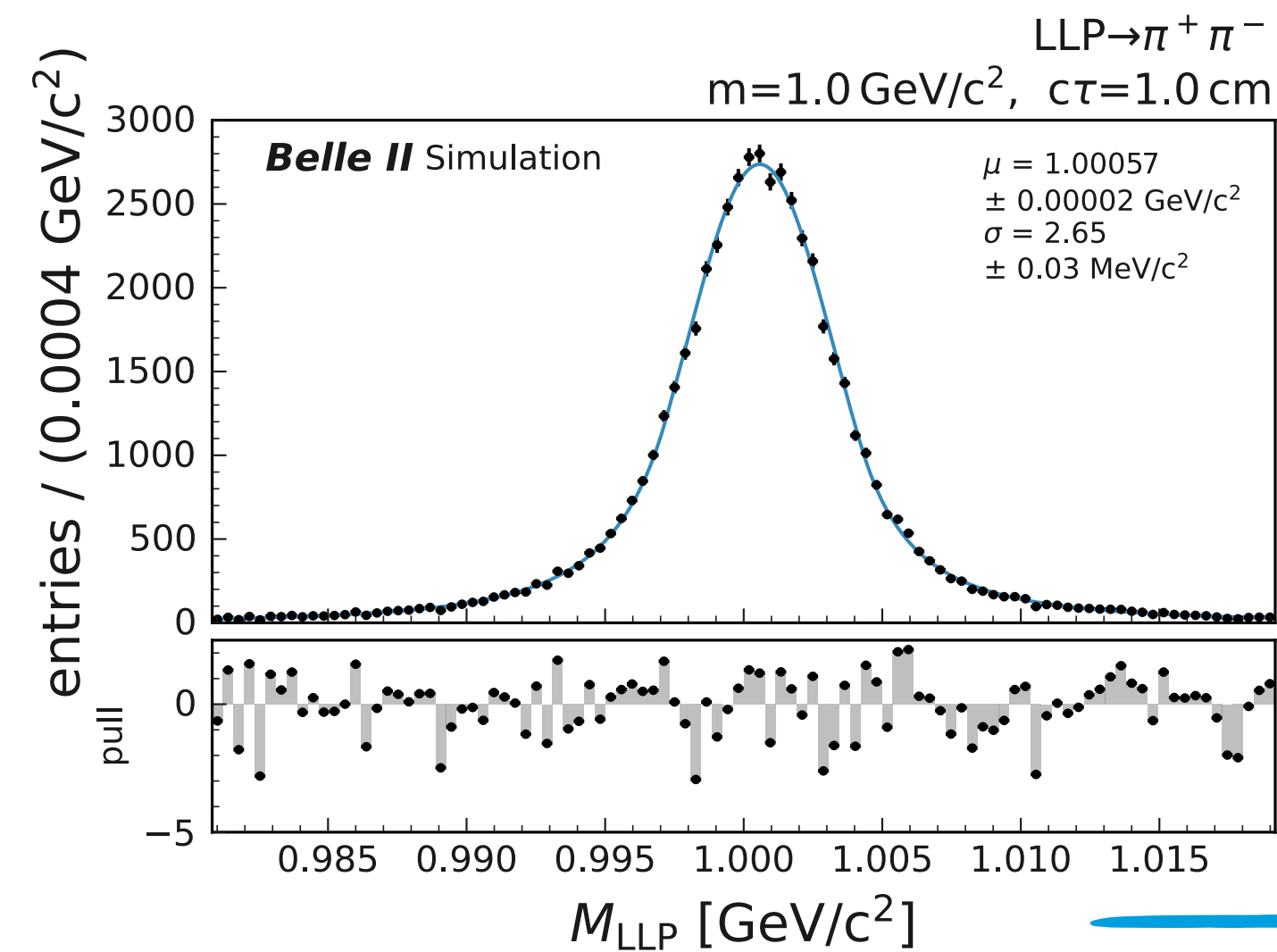
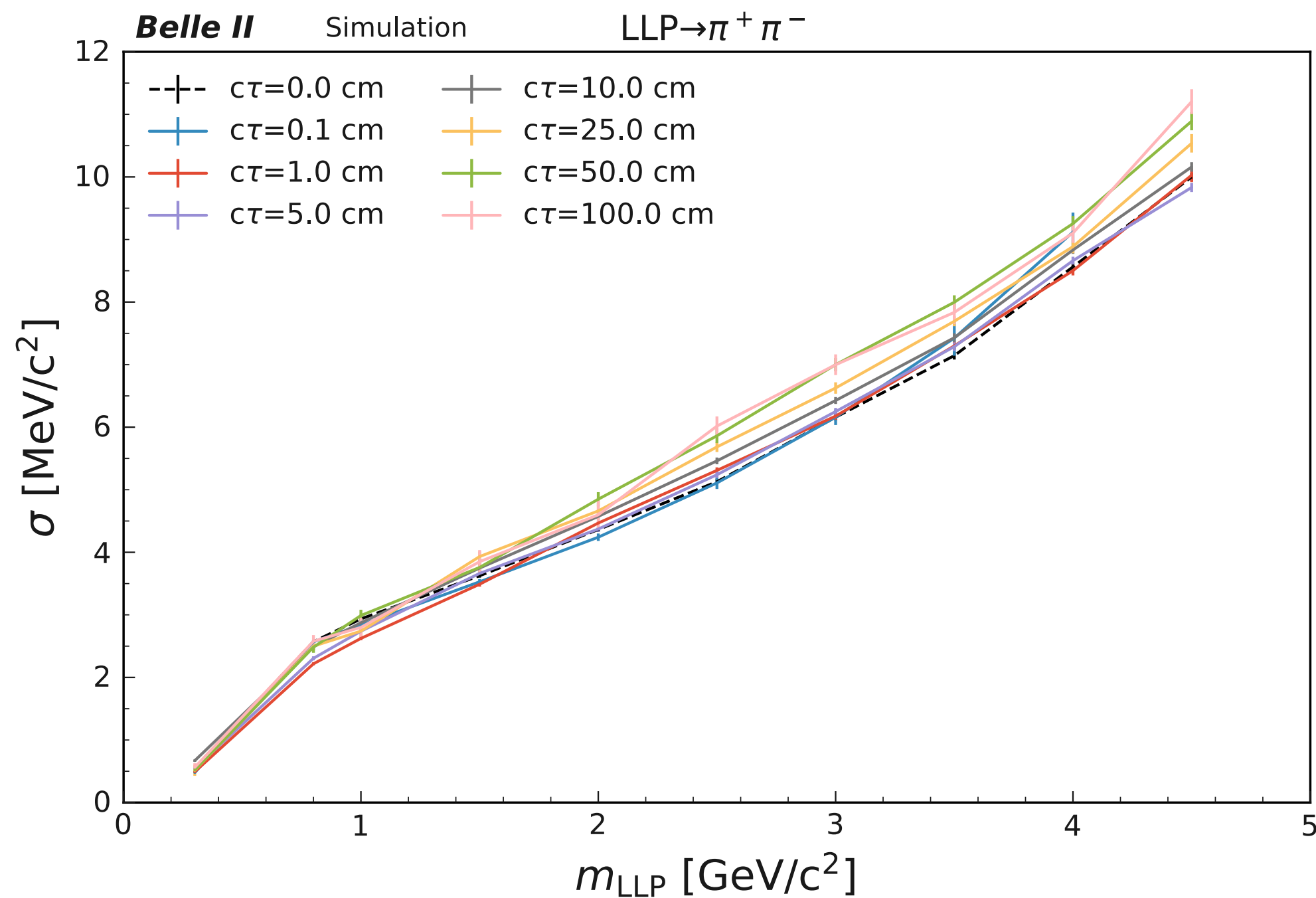
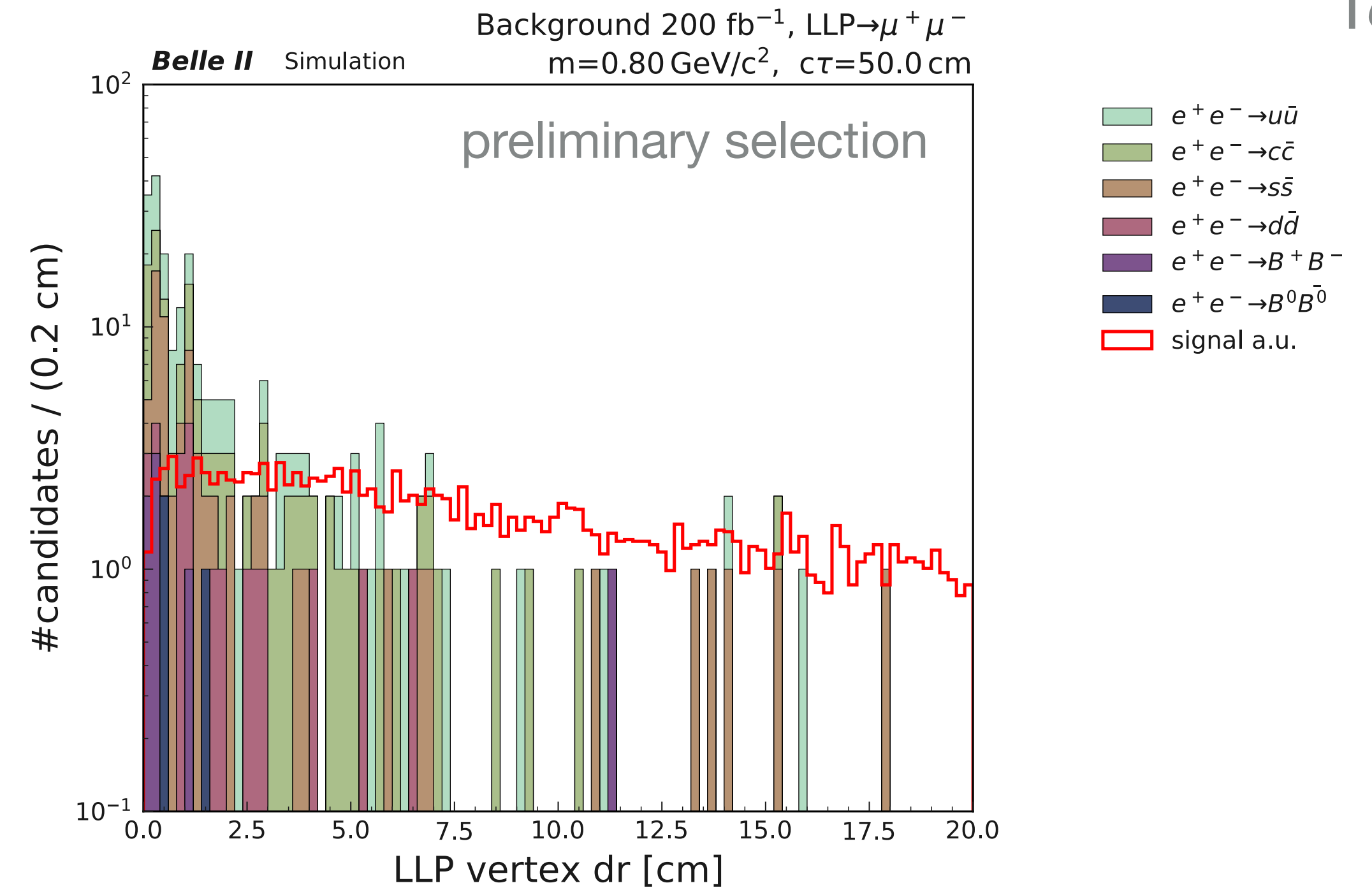
production rate ↑
lifetime ↓

A. Filimonova,
R. Schäfer, S. Westhoff
Phys. Rev. D 101,
095006 (2020)

Ongoing!

Search for $B \rightarrow Kh'$.

- ▶ Search for bump in reconstructed h' (LLP) mass
- ▶ Mostly backgrounds at low displacements
- ▶ Reconstructed mass slightly asymmetric for large lifetimes



lifetime

- 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.