

Recent Dark-Sector and τ results from Belle II.

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Lake Louise Winter Institute 2023

21.02.2023

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HELMHOLTZ RESEARCH FOR
GRAND CHALLENGES





Today's menu:

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

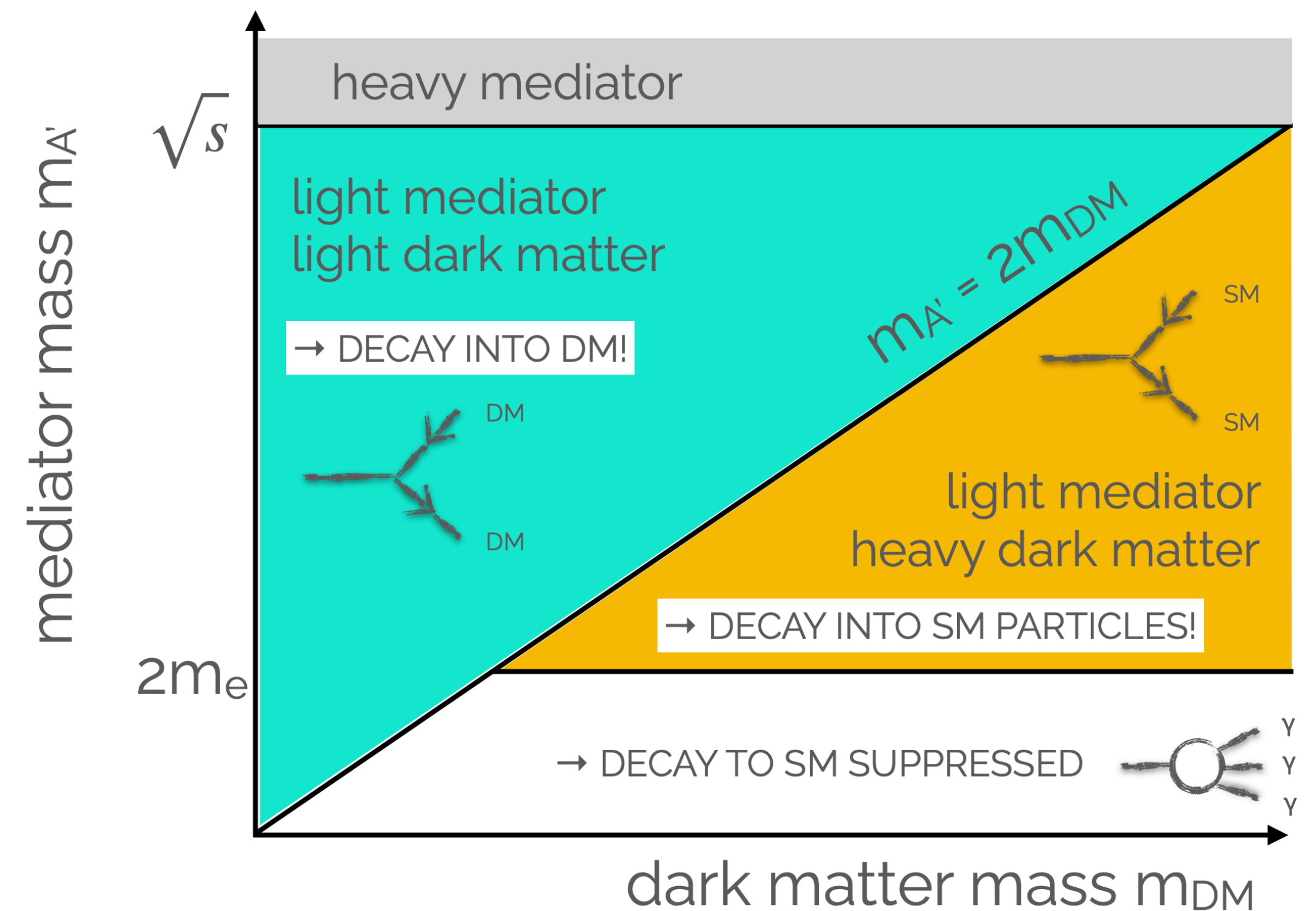
$$e^+e^- \rightarrow \text{SM} [X \rightarrow \text{SM}]$$

$$e^+e^- \rightarrow \tau [\tau \rightarrow \text{SM} X]$$

▶ Light Dark-Sector coupled to **Standard Model**

▶ Possible **Portal Interactions**:

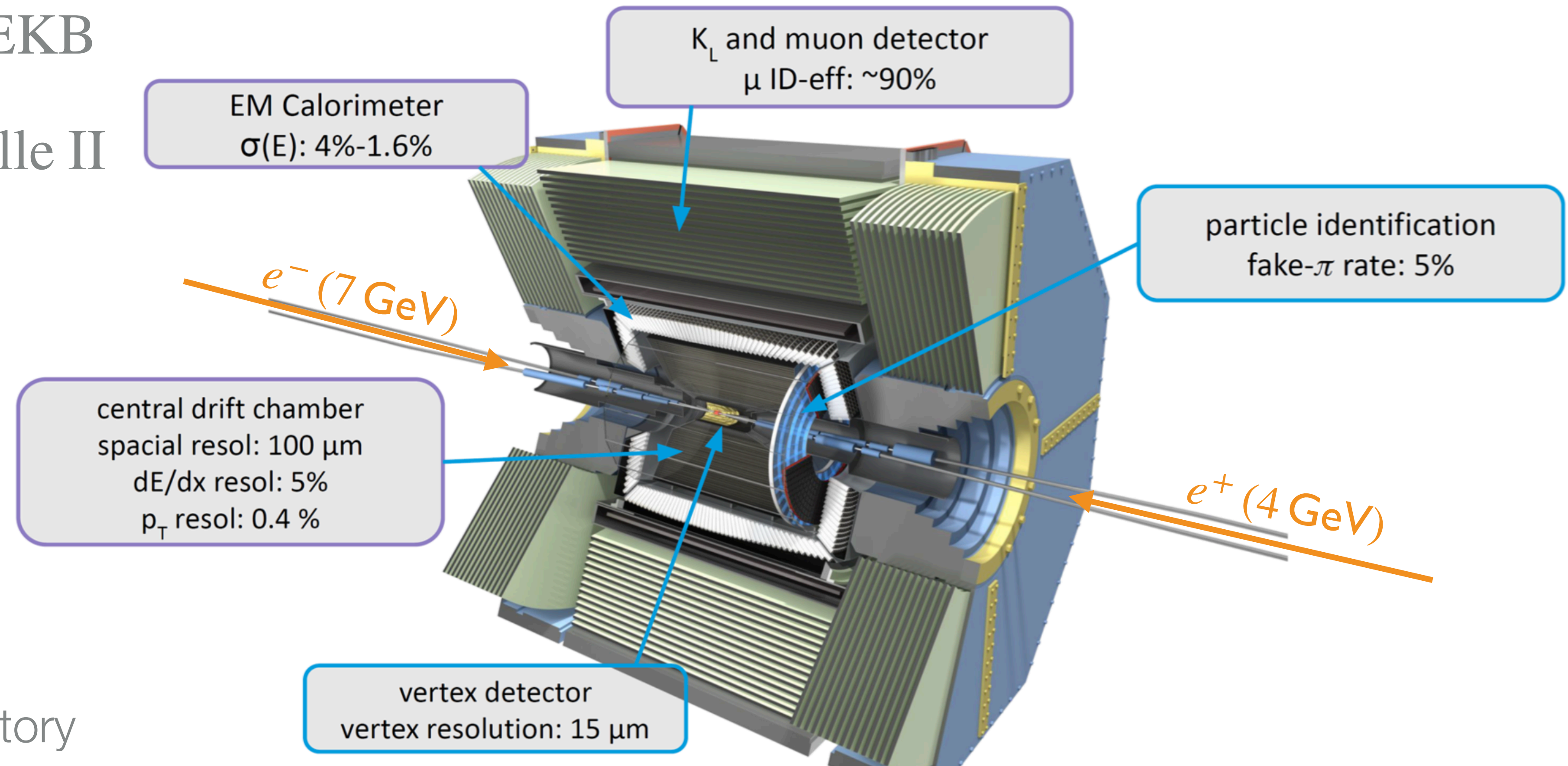
- ▶ Vector \rightarrow Dark Photons A', Z'
- ▶ Pseudo-scalar \rightarrow ALPs
- ▶ Scalar \rightarrow Dark Higgs
- ▶ Neutrino \rightarrow Sterile Neutrinos



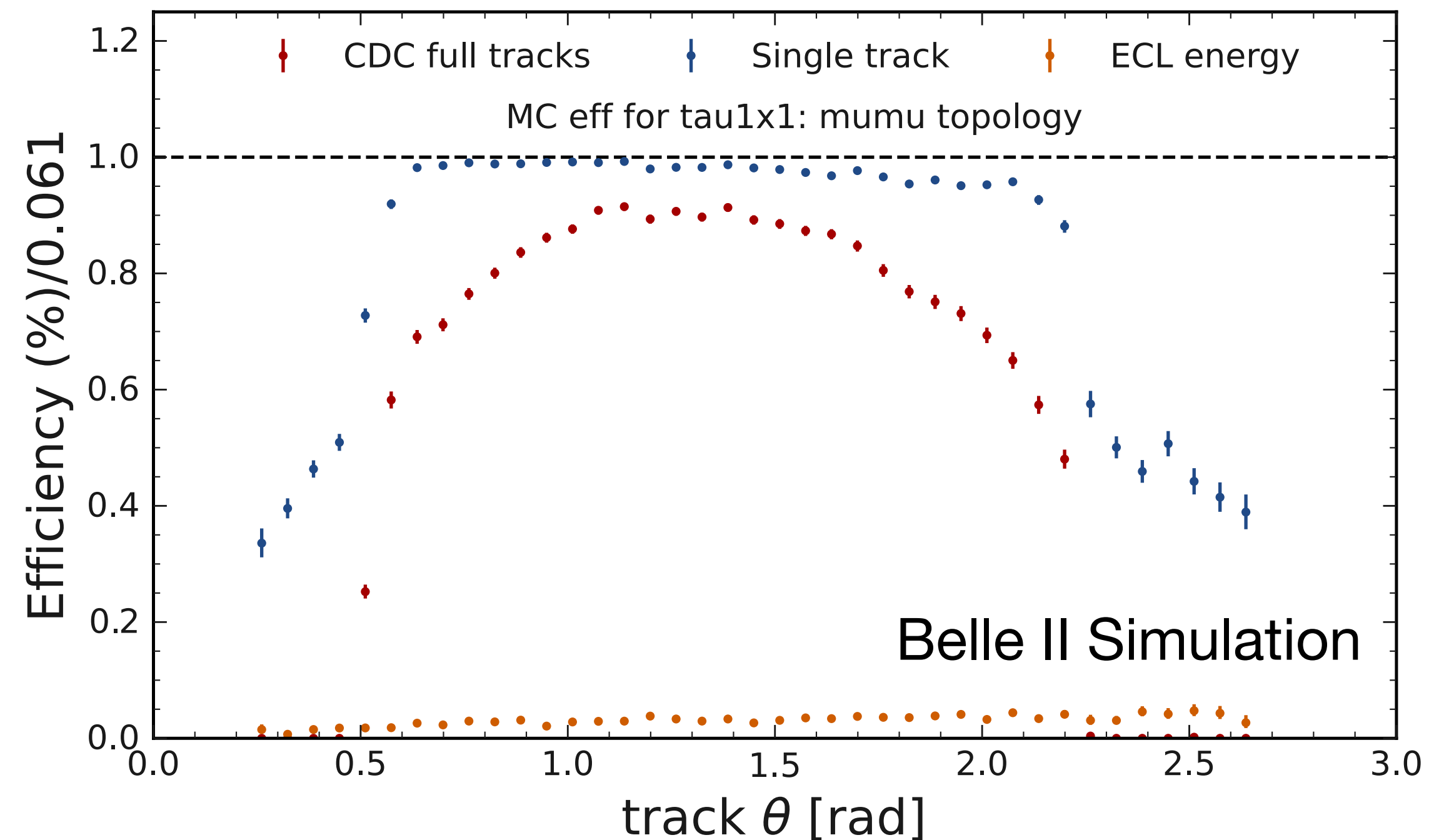
T. Ferber

SuperKEKB collider & Belle II experiment.

- ▶ Accelerator: SuperKEKB
- ▶ Updated detector: Belle II
- ▶ Running at the $\Upsilon(4S)$
- ▶ Collected 428 fb^{-1}
- ▶ Target 50 ab^{-1}
- ▶ Currently in LS 1
- ▶ Design focus as B -factory

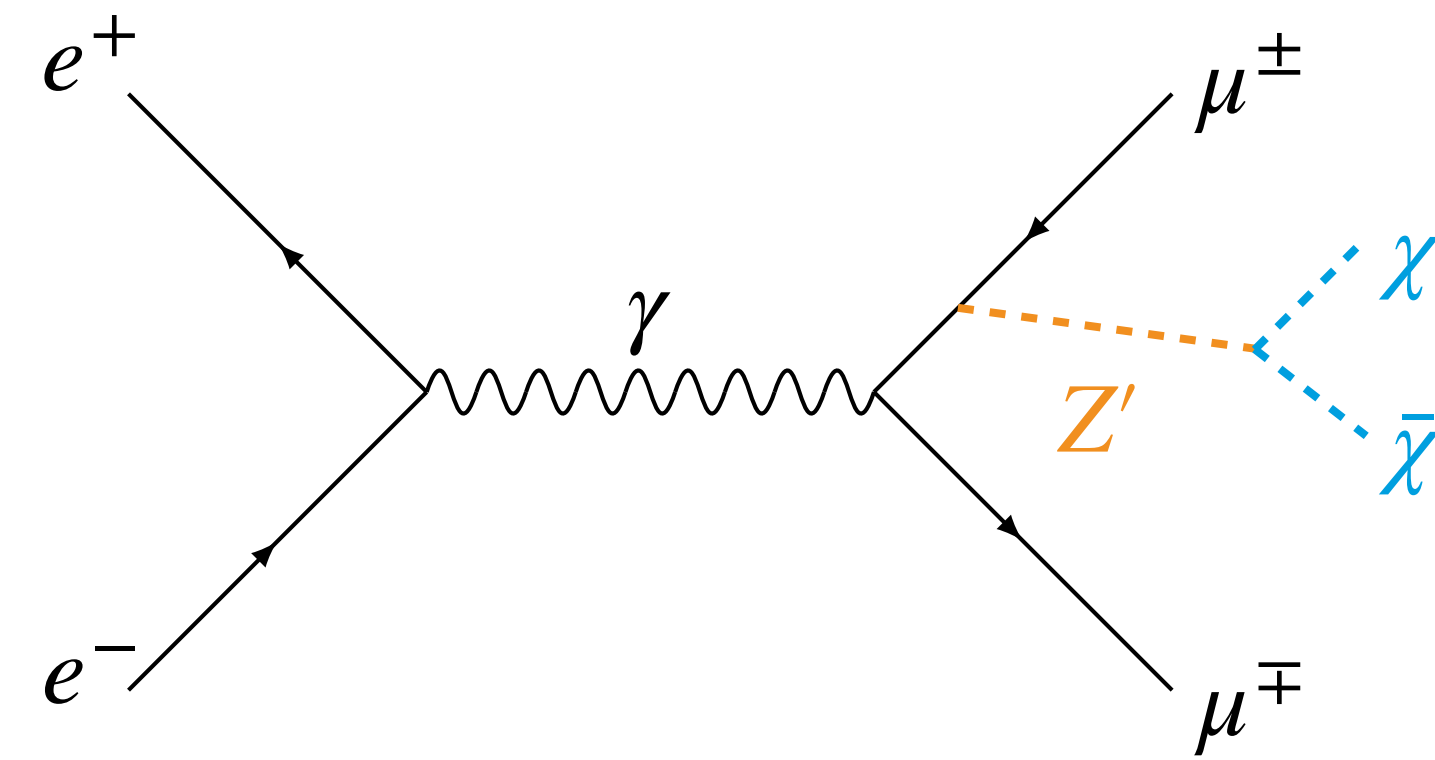


- ▶ Well known initial conditions and little/no pile-up
- ▶ Special triggers for low multiplicity
 - ▶ Single photon trigger (not available at Belle)
 - ▶ Single muon trigger
 - ▶ Single track trigger using NN
 - ▶ NN-based trigger at L1 under development e.g.
 - ▶ *3d* track reconstruction
 - ▶ Displaced vertex trigger
- ▶ τ -samples have a major role in performance inputs
 - ▶ Tracking efficiencies
 - ▶ Trigger efficiencies
 - ▶ Particle identification efficiencies



Search for an invisibly decaying Z' boson.

- ▶ Additional massive gauge boson Z' with $L_\mu - L_\tau$ model
 - ▶ Coupling only to second and third generation leptons
- ▶ Could explain discrepancies in $(g - 2)_\mu$ [1]



- ▶ Study system recoiling against $\mu\mu$

- ▶ M_{recoil}^2 and $\theta_{\text{recoil}}^{\text{CMS}}$

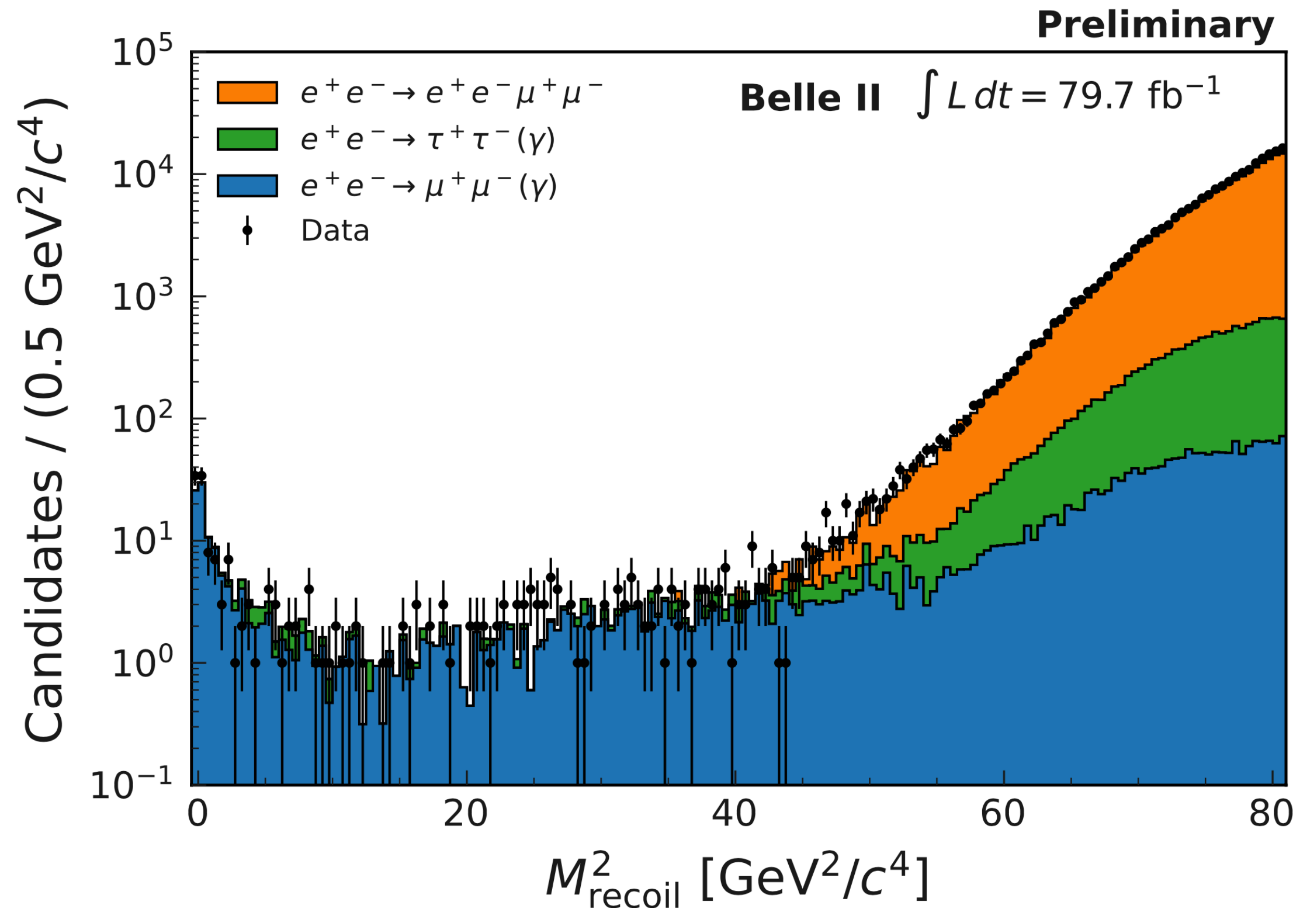
- ▶ Using partial dataset of 79.7 fb^{-1}

- ▶ Backgrounds:

- ▶ $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$

- ▶ $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$

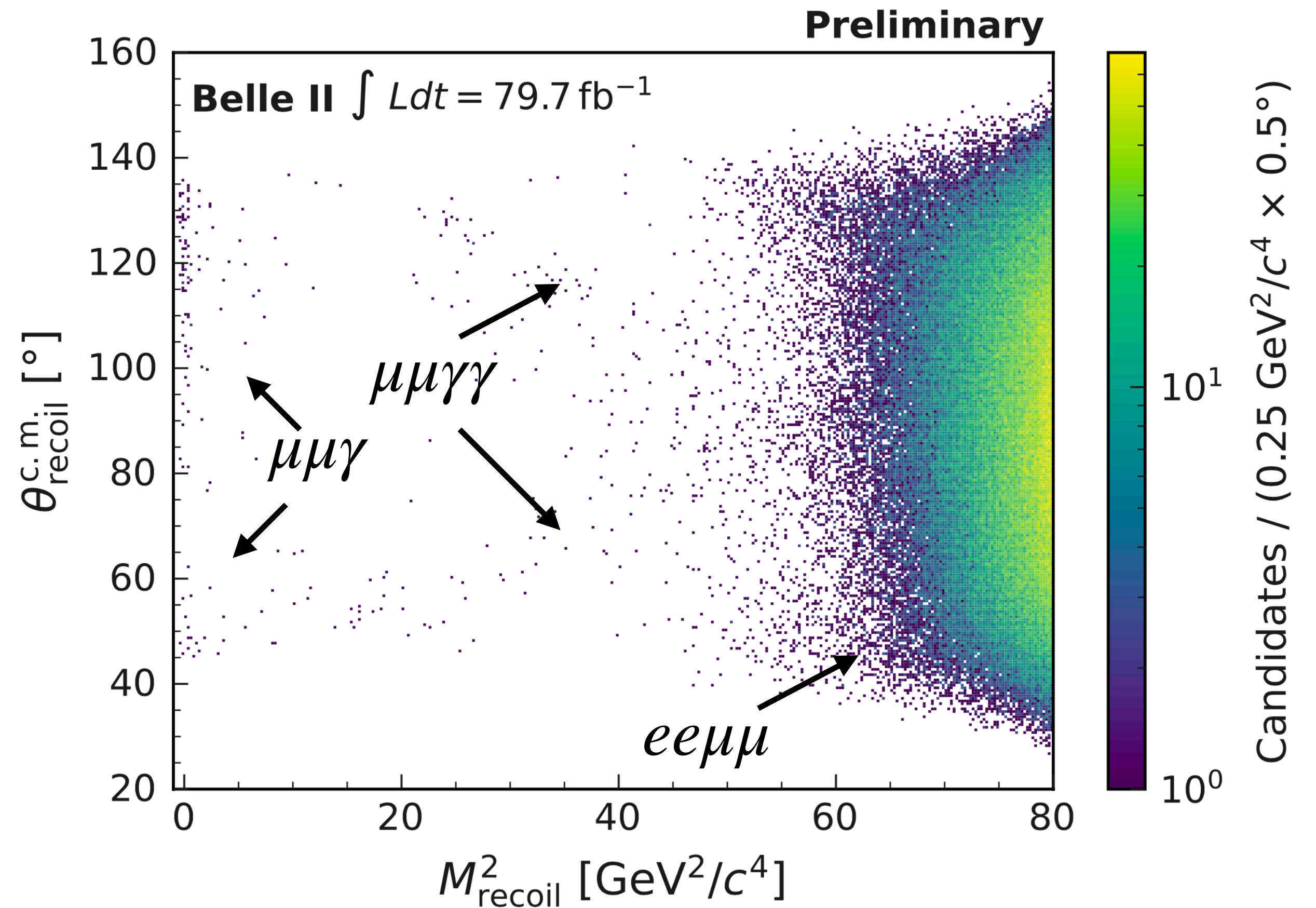
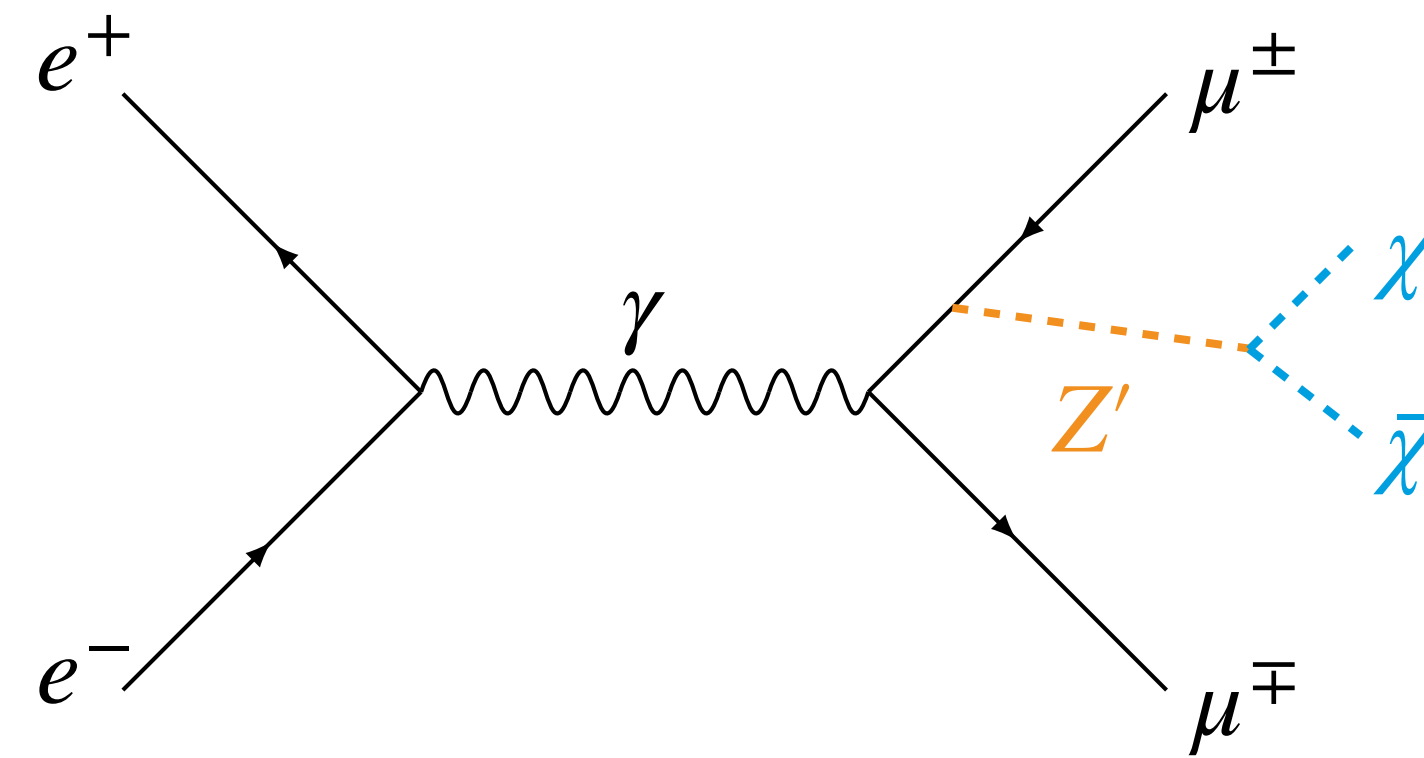
- ▶ $e^+e^- \rightarrow \tau^+\tau^-(\gamma), \tau \rightarrow \mu\nu\bar{\nu}$



[1] B. Shuve et al., *Phys. Rev. D* 89, 113004

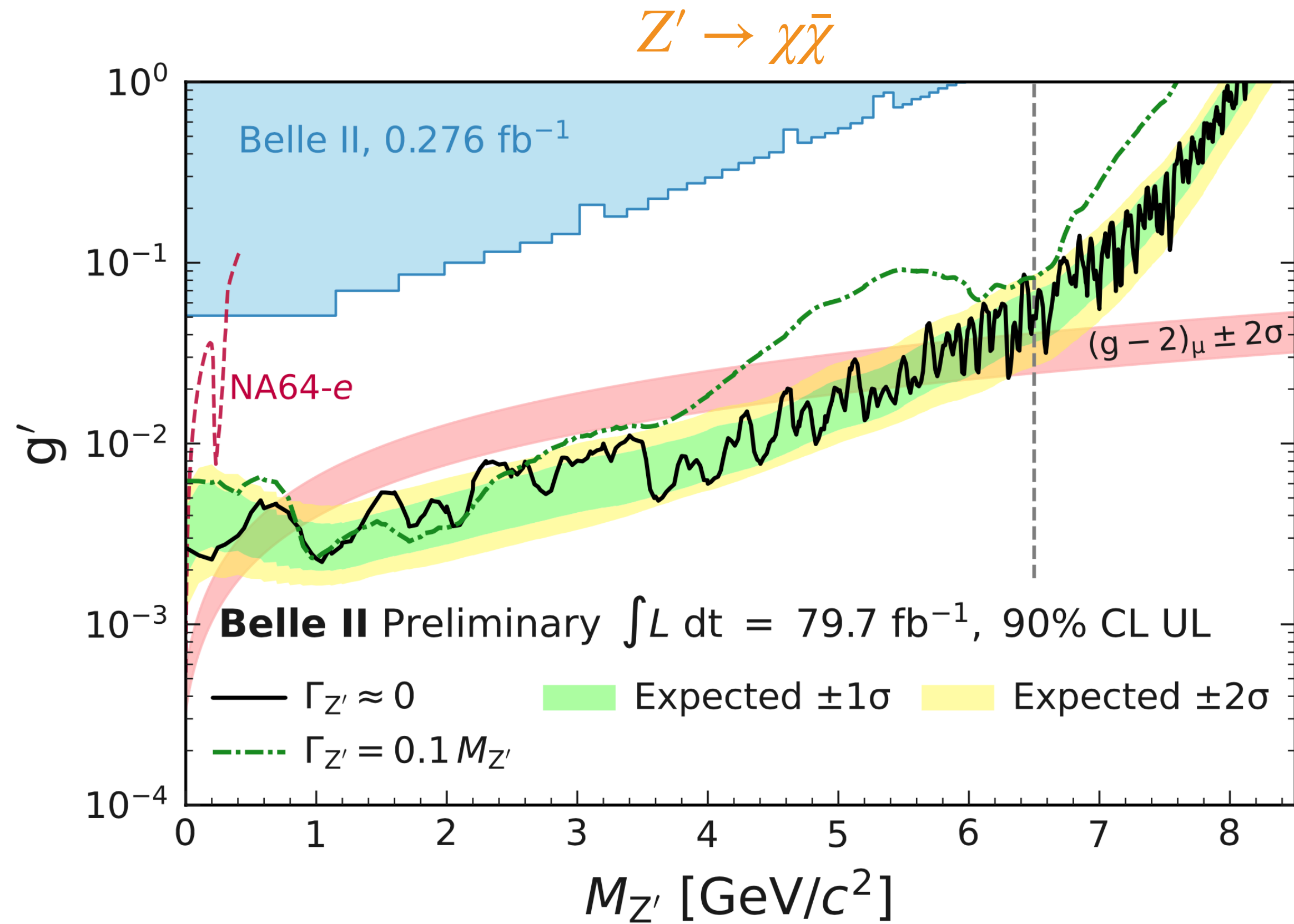
Search for an invisibly decaying Z' boson.

- ▶ Particle identification of μ with
 - ▶ 93 – 99 % efficiency
 - ▶ 80 – 97 % π rejection
- ▶ Sum of all photon energies < 0.5 GeV
- ▶ Neural network with Punzi-loss trained for background suppression for all Z' masses simultaneously [1]
- ▶ 2d fit in M_{recoil}^2 and $\theta_{\text{recoil}}^{\text{c.m.}}$
- ▶ Systematics and corrections from ee , $e\mu$ and $\mu\mu\gamma$ control samples
- ▶ Update of previous search [2] with 300x dataset



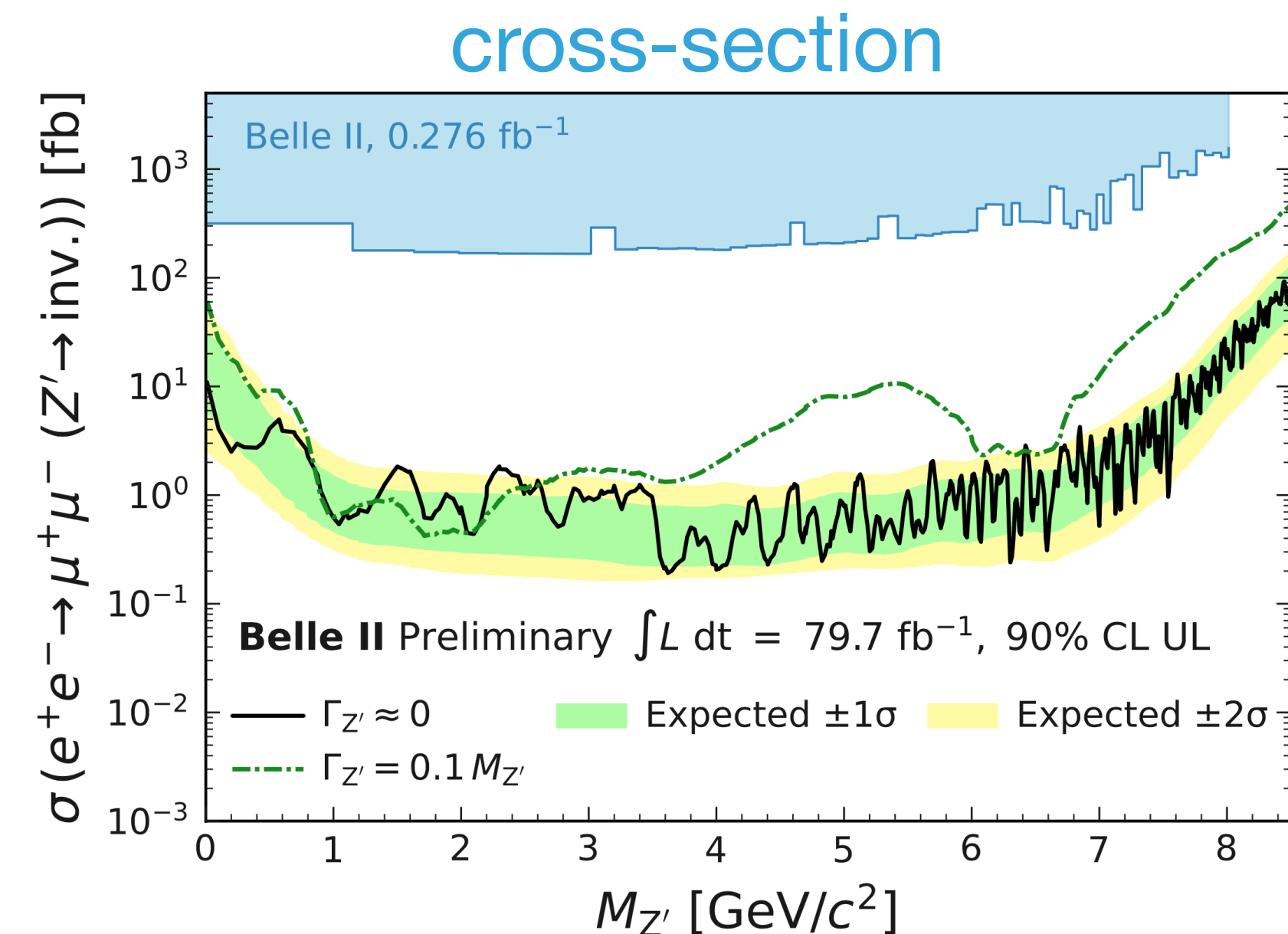
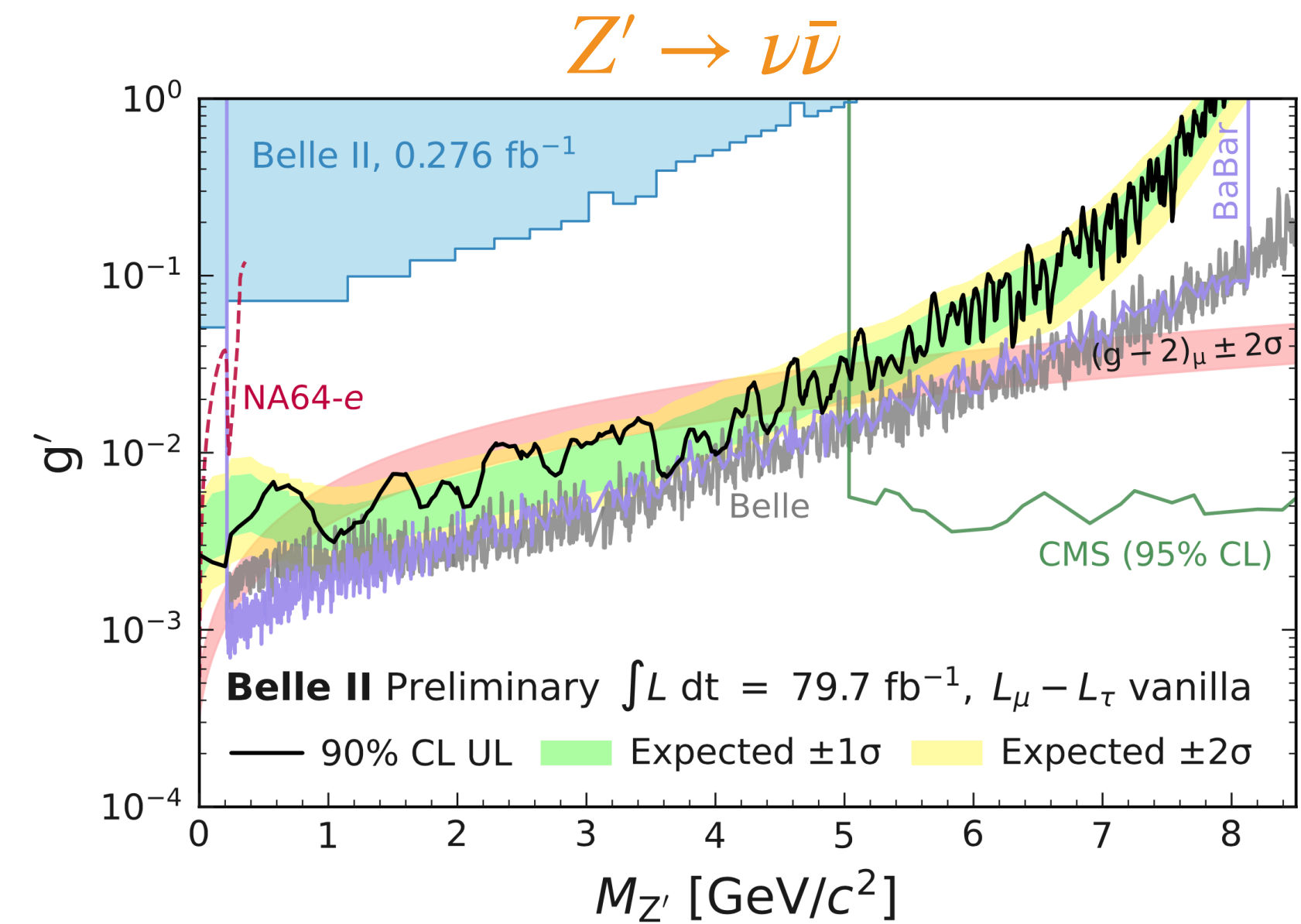
[1] F. Abudinén et al., *Eur.Phys.J.C* 82 (2022) 2, 121
 [2] Belle II Collaboration, *Phys. Rev. Lett.* 124, 141801 (2020)

Search for an invisibly decaying Z' boson.



$(g-2)_\mu$ preferred region excluded
between $0.8 < m_{Z'} < 4 \text{ GeV}/c^2$

[arXiv:2212.03066](https://arxiv.org/abs/2212.03066) to be submitted to PRL

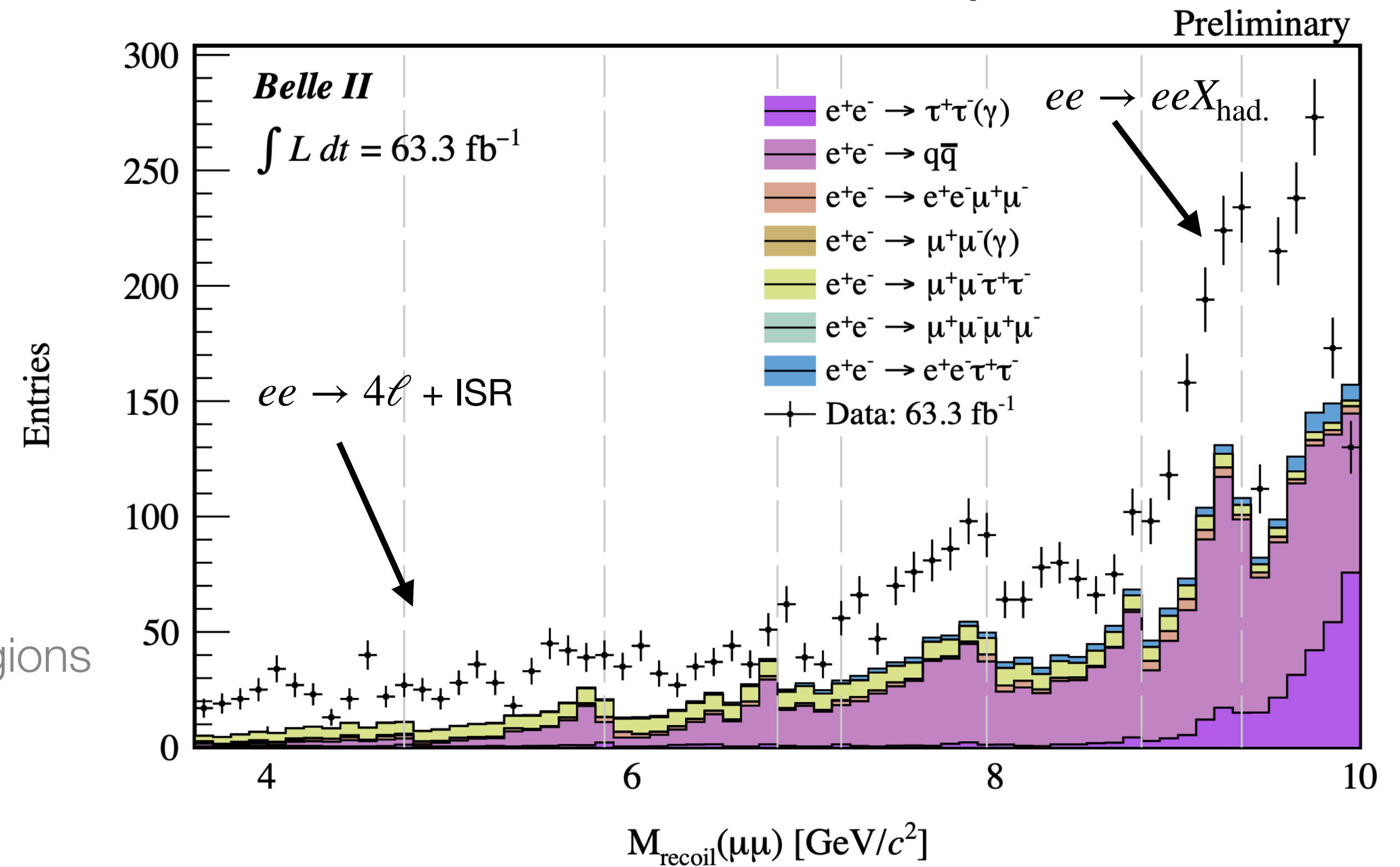
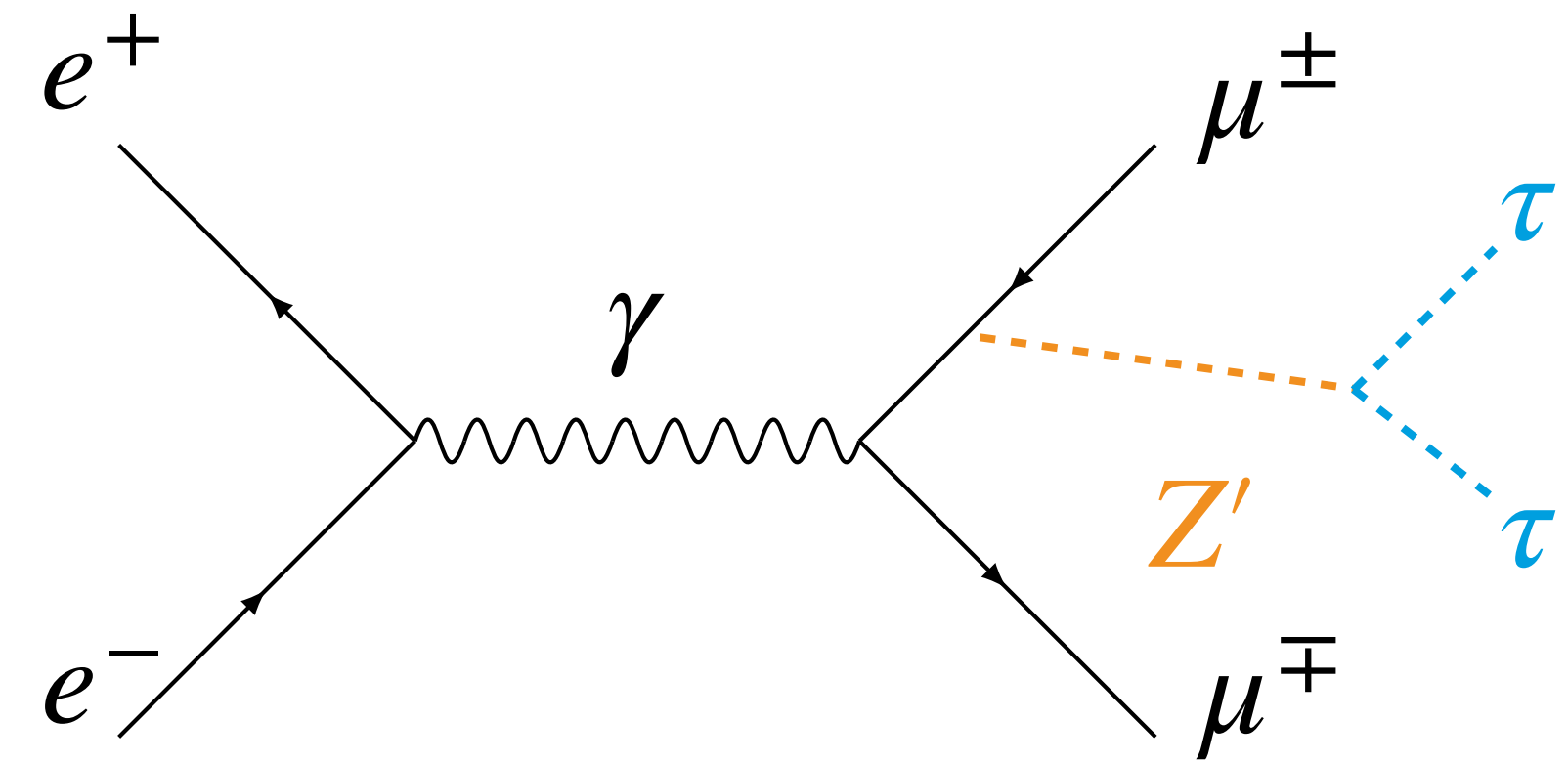


Search for a $\tau\tau$ resonance in $ee \rightarrow \mu\mu\tau\tau$.

- ▶ Probe three different mediator models:
 - ▶ Z' with $L_\mu - L_\tau$ [1], leptophilic S [2] and ALP [3]
- ▶ τ decays to one charged plus any number of neutral particles
→ four tracks in the event (at least two μ)
- ▶ Require missing energy by $M_{4 \text{ tracks}} < 9.5 \text{ GeV}/c^2$

Modelled	Un-modelled
$ee \rightarrow \tau\tau$	$ee \rightarrow eeX_{\text{had.}}$
$ee \rightarrow qq$	$ee \rightarrow ee\pi\pi$
$ee \rightarrow 4\ell$	$ee \rightarrow 4\ell + \text{ISR}$

- ▶ Eight different classifiers (MLP) in different $M_{\text{recoil}}(\mu\mu)$ regions
- ▶ Signal extracted by fits to $M_{\text{recoil}}(\mu\mu)$
- ▶ Background determined directly in data → un-modelled non-peaking background are not a problem

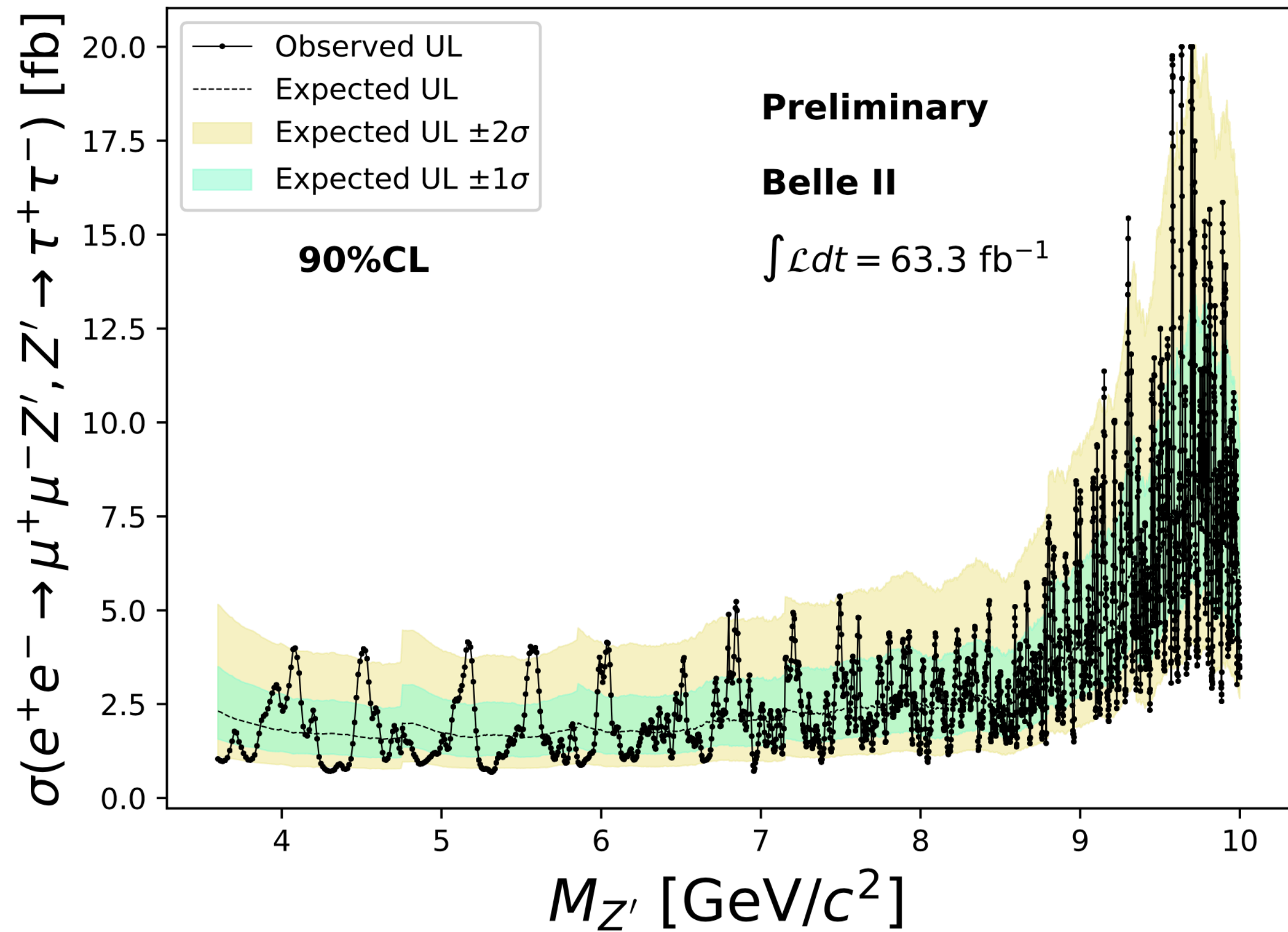


[1] W. Altmannshofer et. al. *JHEP* 12 (2016) 106
 [2] B. Batell et. al. *PRD* 95 (2017) 075003
 [3] M. Bauer et. al. *arXiv:2110.10698*

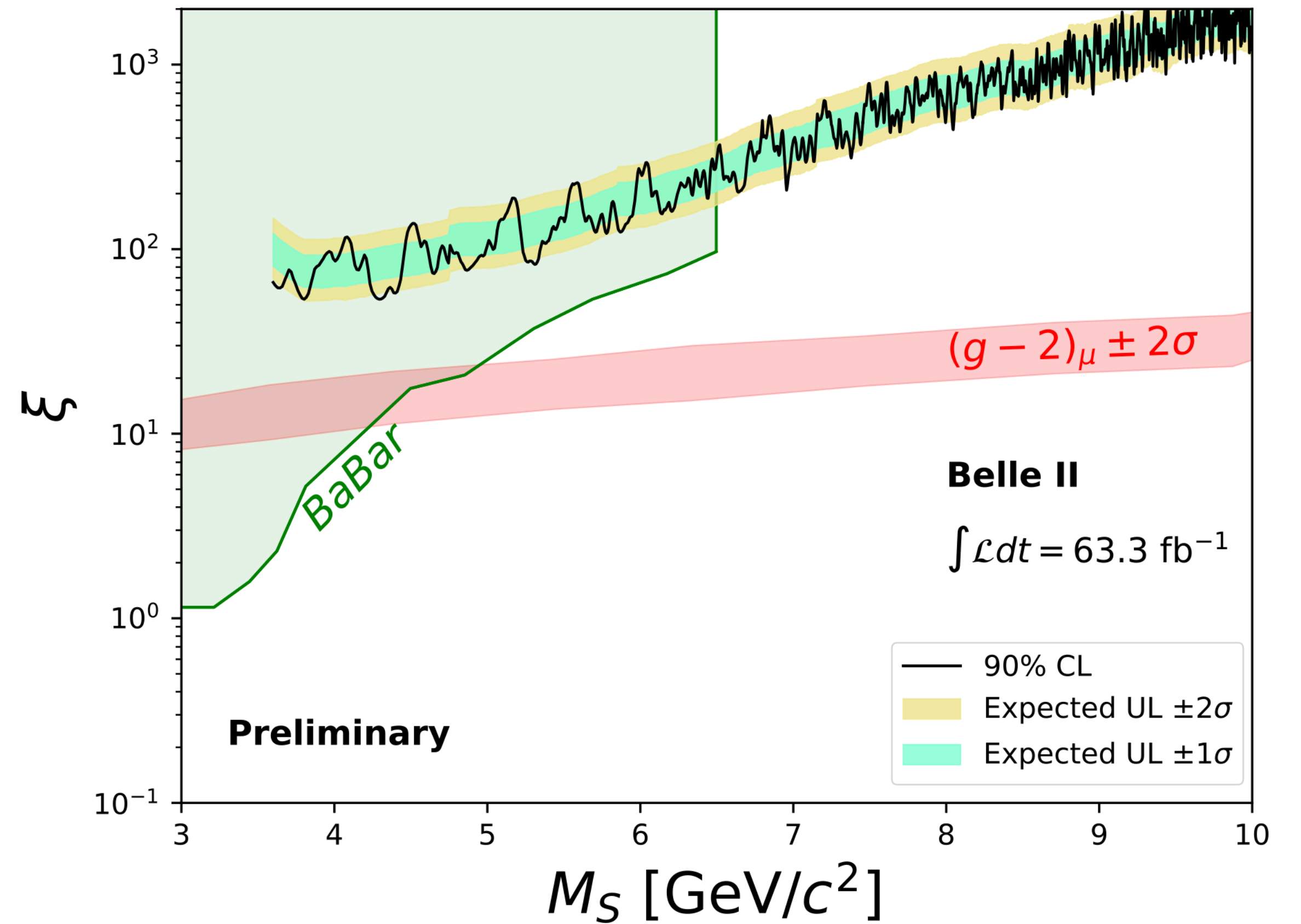
Search for a $\tau\tau$ resonance in $ee \rightarrow \mu\mu\tau\tau$.

to be submitted soon!

cross-section



leptophilic scalar model



Strongest constraints for $M_S > 6.5 \text{ GeV}/c^2$

Search for an invisible scalar in lepton-flavour violating τ decays.

▶ Search for $\tau_{\text{sig}} \rightarrow \ell \alpha$ with invisible scalar α

▶ Reconstruct $\tau_{\text{tag}} \rightarrow 3\pi$ in $ee \rightarrow \tau_{\text{tag}} \tau_{\text{sig}}$

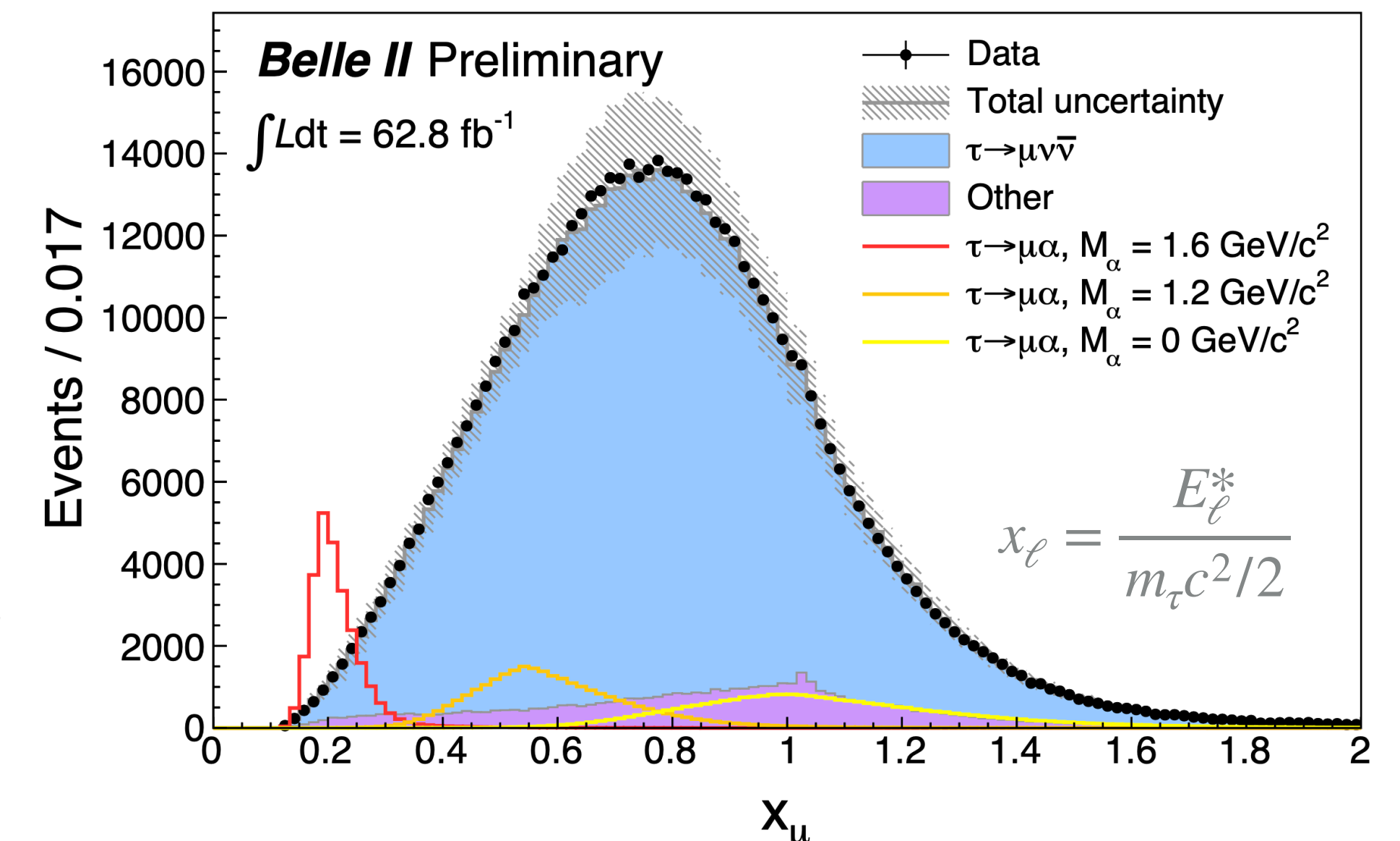
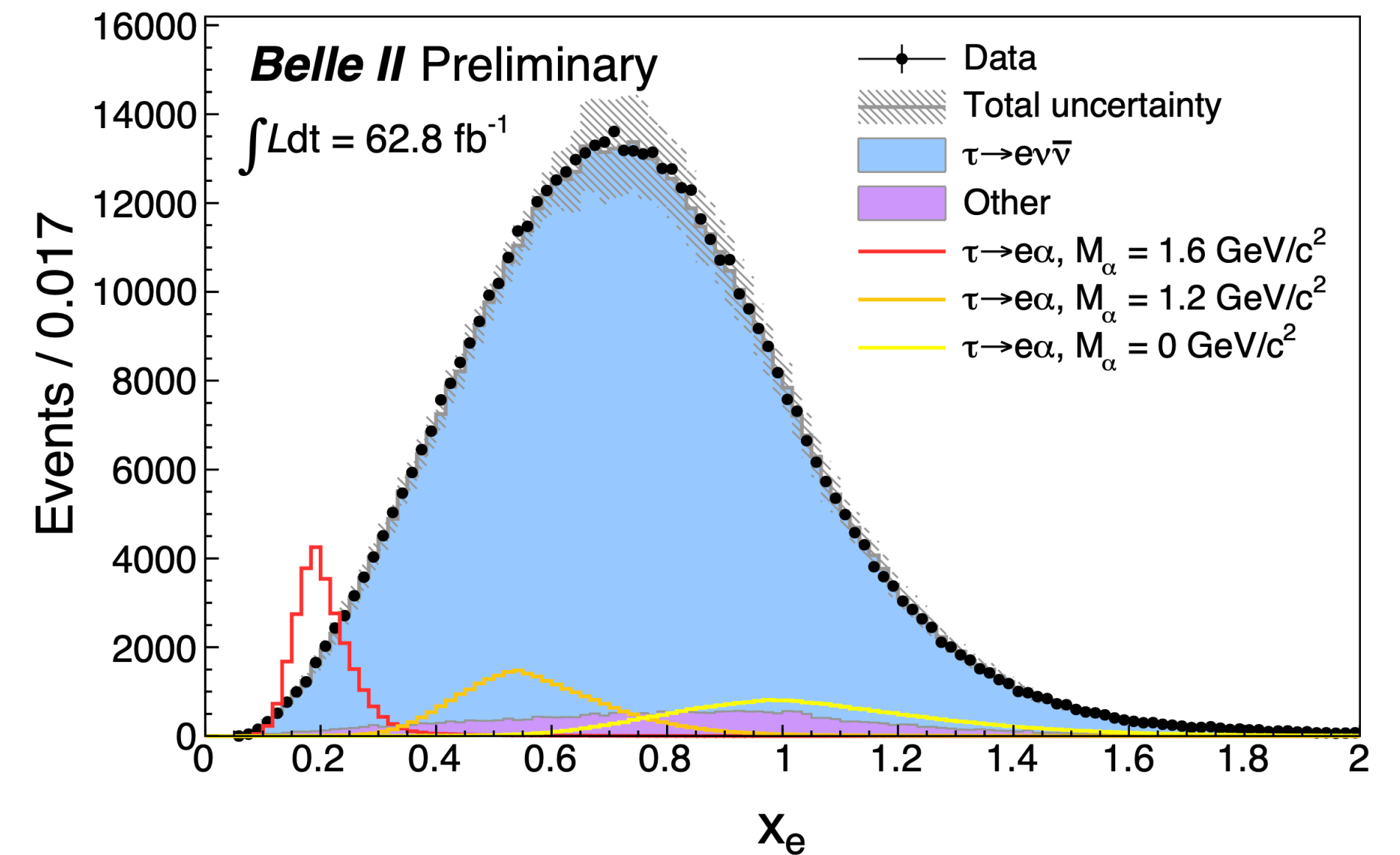
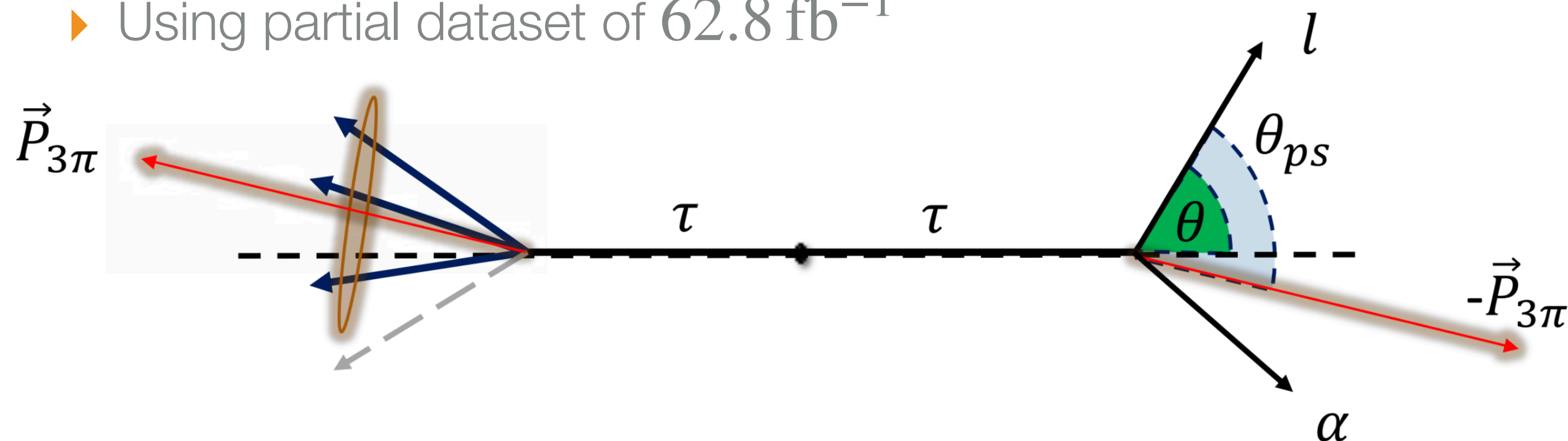
▶ Approximate τ_{sig} rest-frame by

$$\text{▶ } E_{\tau_{\text{sig}}} \approx E_{\text{cms}}/2 \text{ and } \hat{p}_{\text{sig}} \approx -\vec{p}_{\tau_{\text{tag}}} / |\vec{p}_{\tau_{\text{tag}}}|$$

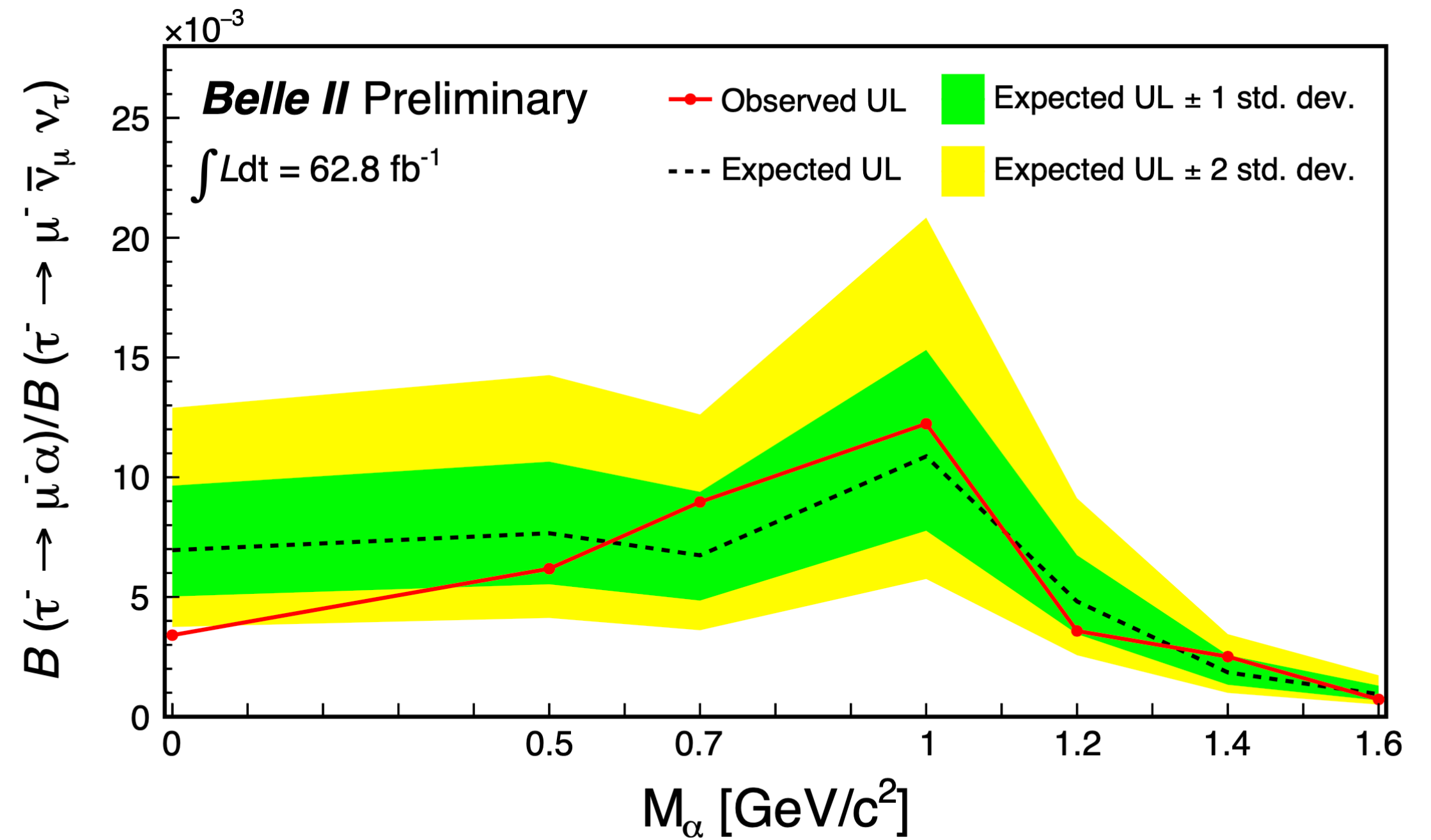
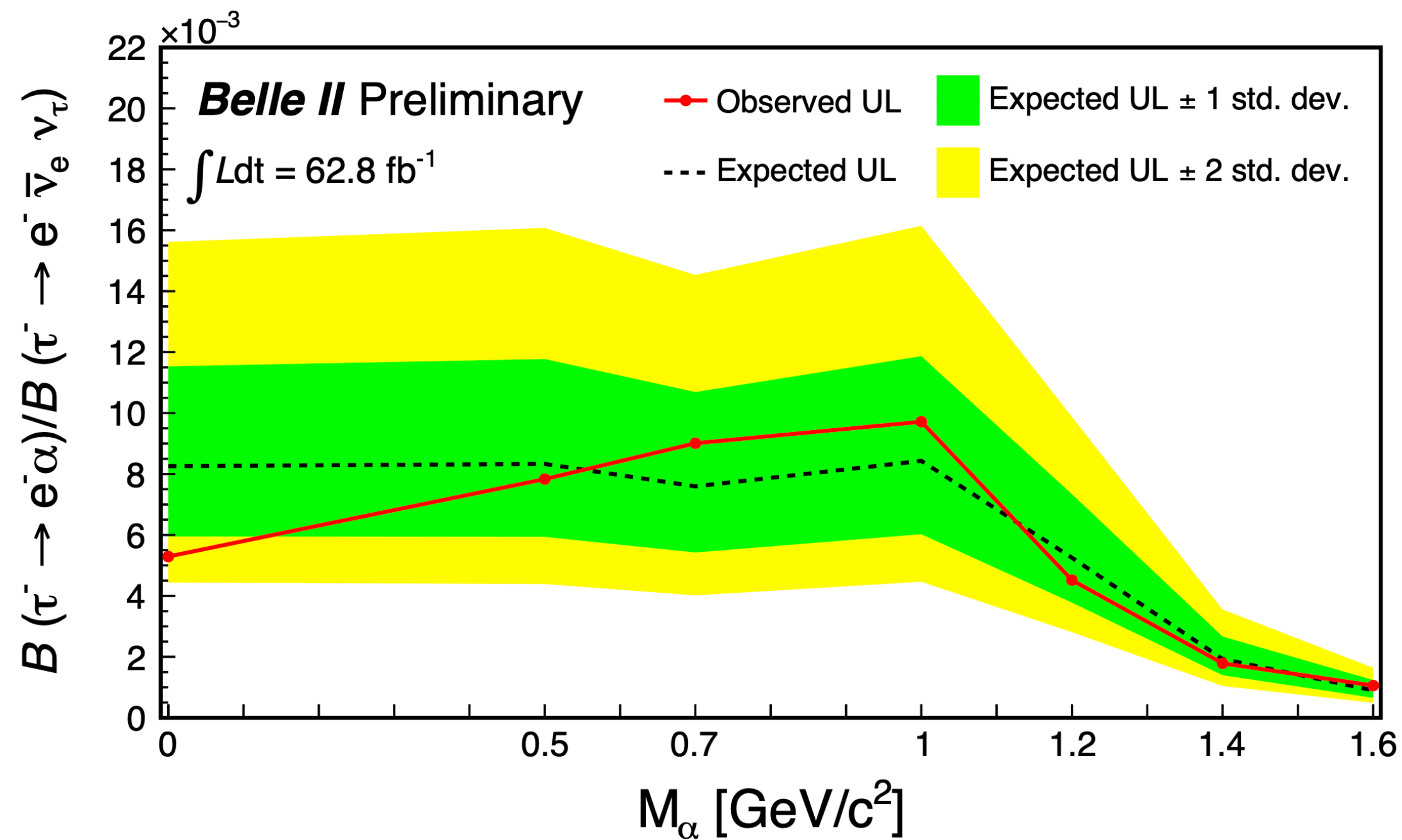
▶ Two body signal decay peaks in lepton momentum

▶ Search for bump on top of $\tau_{\text{sig}} \rightarrow \ell \nu \bar{\nu}$

▶ Using partial dataset of 62.8 fb^{-1}



Search for an invisible scalar in lepton-flavour violating τ decays.

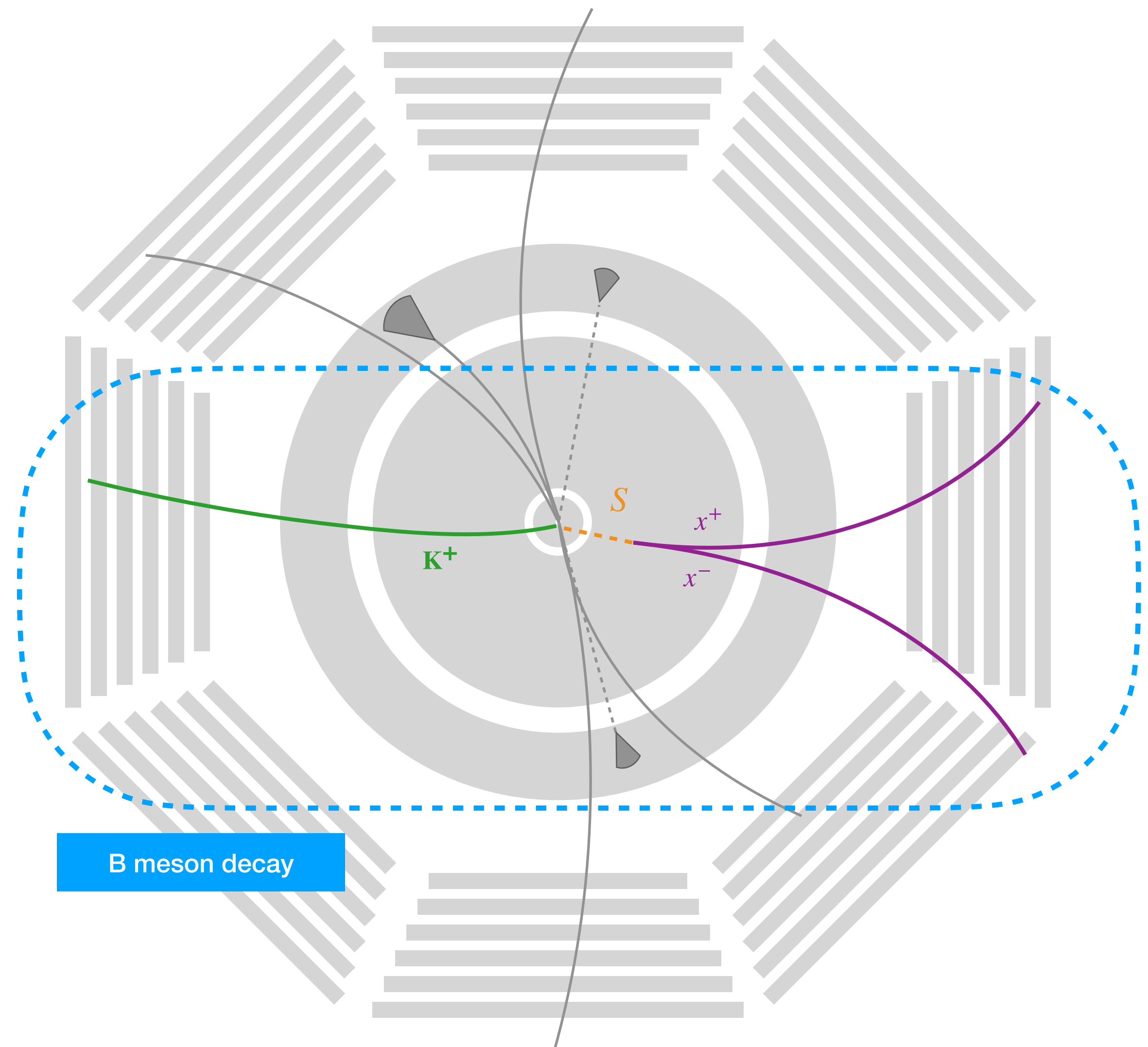


Observed limits are 2.2 to 14 times as strong as previous limits set by ARGUS [1] depending on M_α

[arXiv:2212.03634v1](https://arxiv.org/abs/2212.03634v1) to be submitted to PRL

[1]: ARGUS Collaboration, *Z. Phys. C* 68, 25 (1995)

- ▶ Dark long-lived scalar S in $b \rightarrow s$ transitions [1]
- ▶ First long-lived particle search from Belle II
- ▶ No direct mediator production: B -meson decays
- ▶ Tackling eight different fully visible channels:
 - ▶ $B^+ \rightarrow K^+ S$ and $B^0 \rightarrow K^{*0} S$
 - ▶ $S \rightarrow ee/\mu\mu/\pi\pi/KK$
- ▶ Bump hunt in M_S
- ▶ Dedicated study of displaced vertex performance, verified with K_S^0 control sample
 - ▶ Reconstruction efficiency & M_S shape
 - ▶ Particle identification
- ▶ Results **expected very soon!**



[1]: A. Filimonova, R. Schäfer, S. Westhoff [Phys. Rev. D 101, 095006 \(2020\)](#)

- Recent **Dark-Sector** and τ results from Belle II:
 - Search for **invisible Z'** in $ee \rightarrow \mu\mu Z'$ [arXiv:2212.03066](#)
 - Search for **$\tau\tau$ resonance** in $ee \rightarrow \mu\mu\tau\tau$ to be published soon
 - Search for **invisible LF-violating scalar** in $\tau \rightarrow \ell\alpha$ [arXiv:2212.03634](#)
- Belle II has a unique sensitivity to light Dark-Sectors
- Results are complimentary to higher-energy collider and beam-dump experiments

Backup.

