

Recent dark sector and τ results from Belle II.

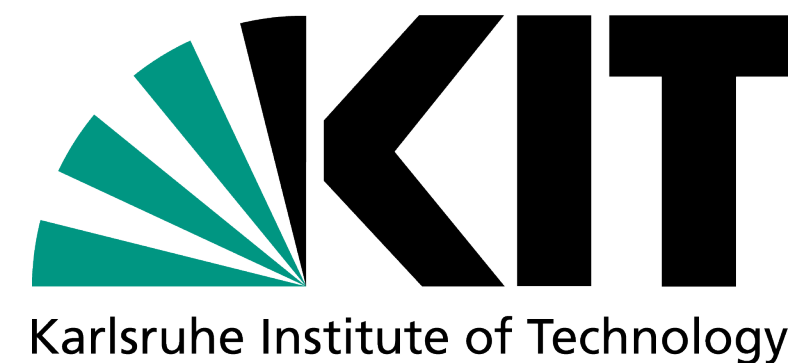
Sascha Dreyer on behalf of the Belle II collaboration

Rencontres de Moriond 2023 — Electroweak edition
21.03.2023

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HELMHOLTZ RESEARCH FOR
GRAND CHALLENGES

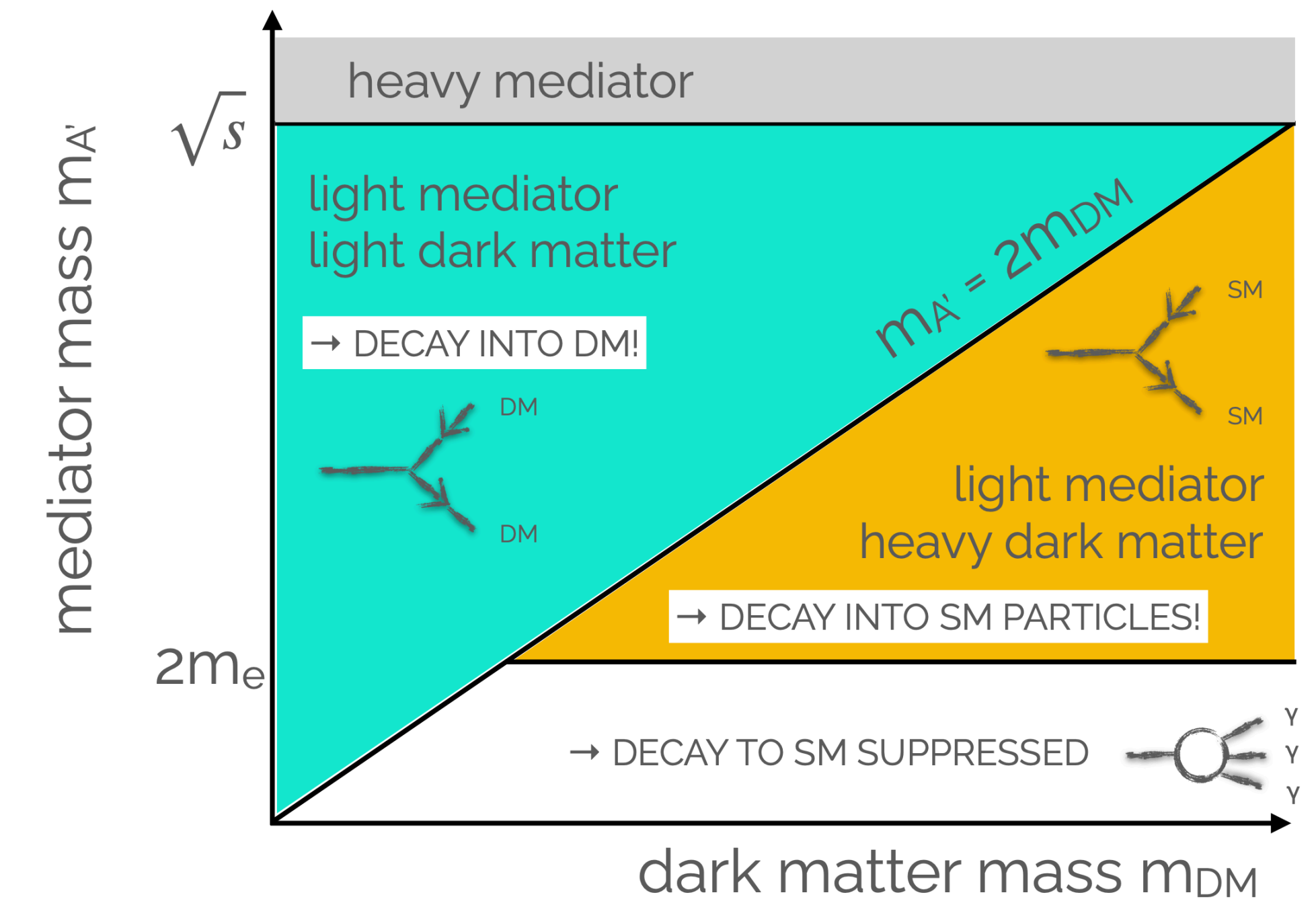


1. Direct searches for BSM physics:

- ▶ No signs in searches for SUSY and extra dimensions
- ▶ Light dark sectors not yet well tested
- ▶ Target **mediators** that couple dark sectors to **SM**
- ▶ Theoretical description via portal interactions

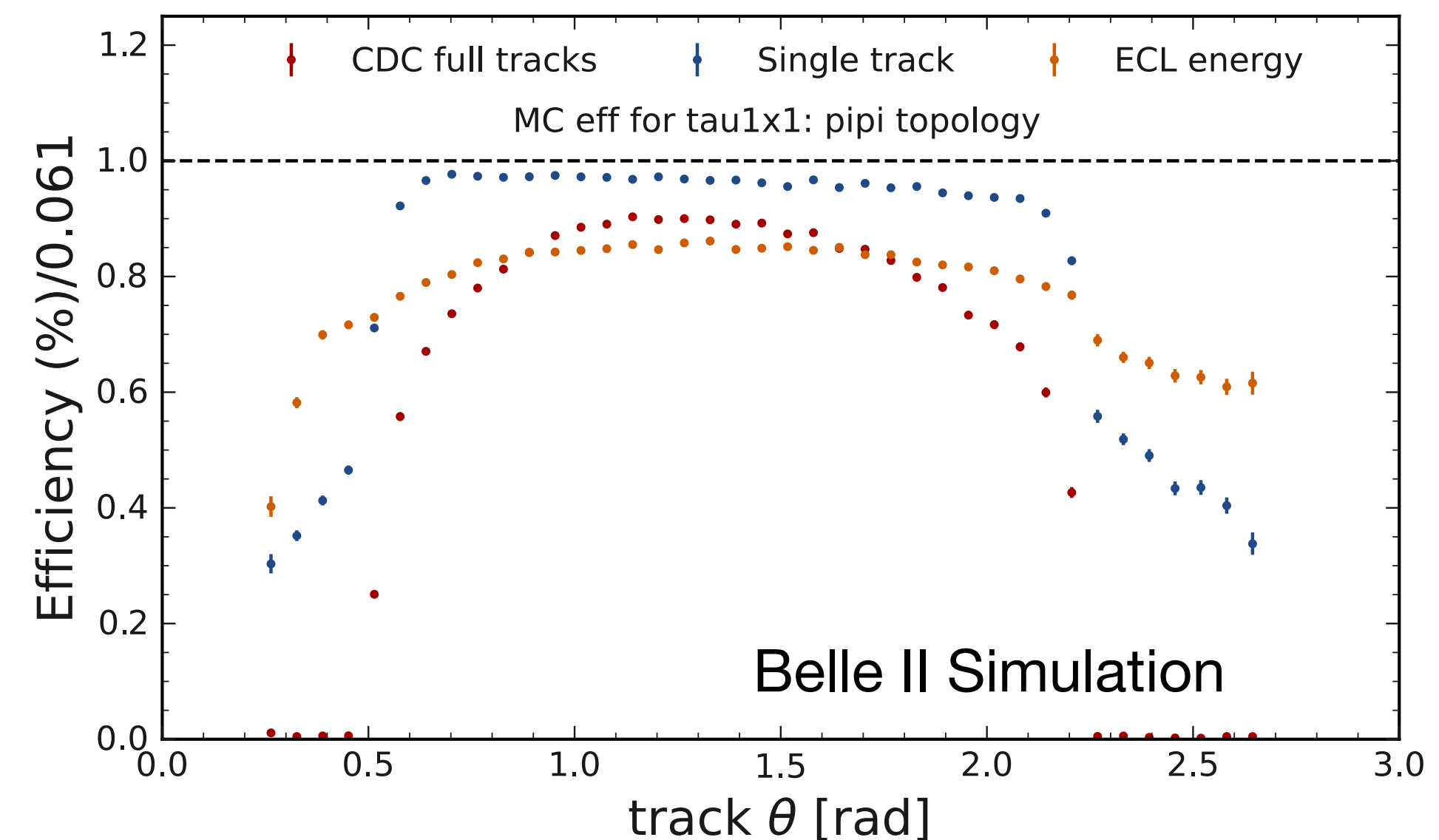
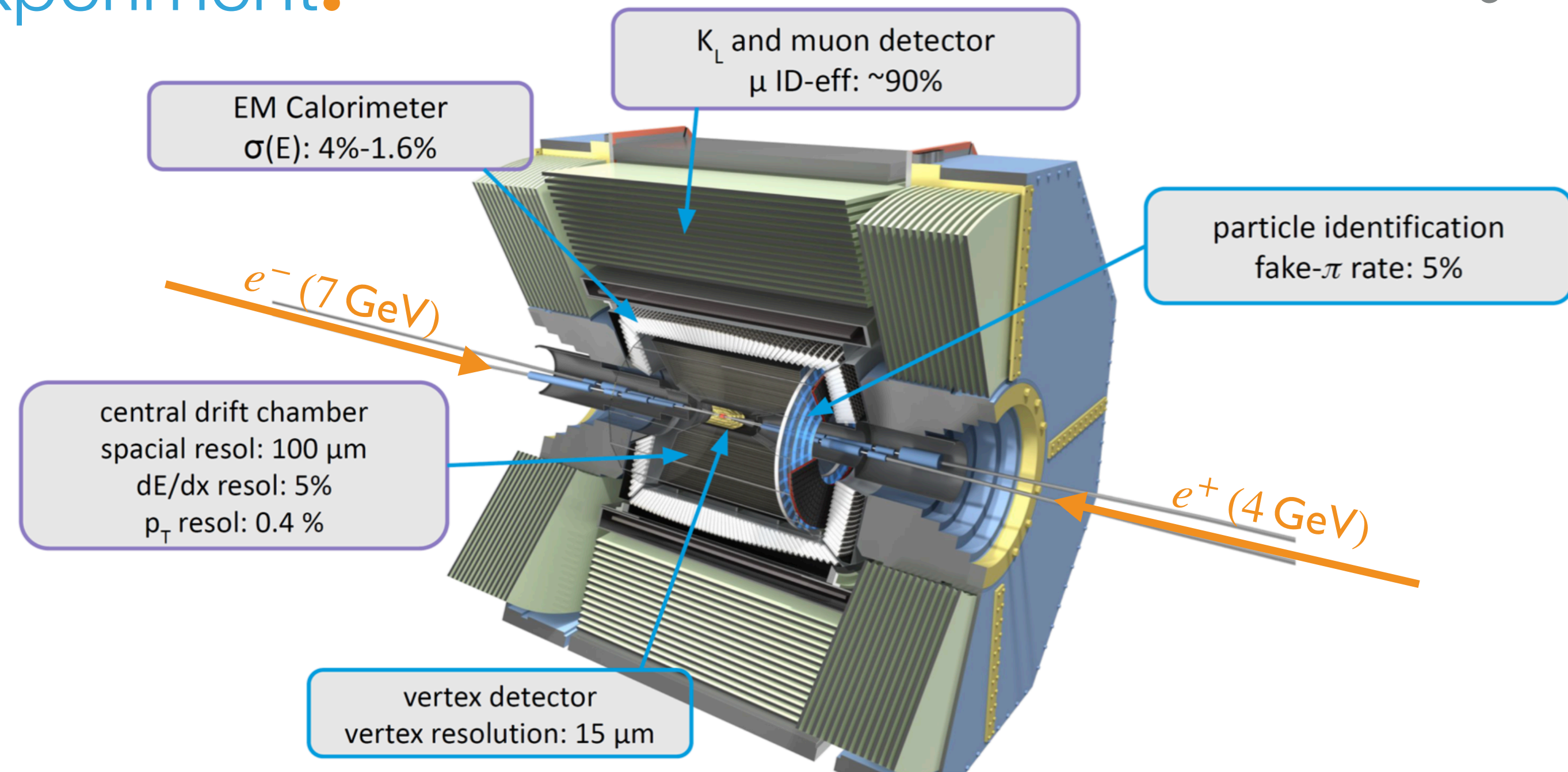
2. Precision measurements of **SM** parameters

- ▶ Direct test of **SM** and indirectly constrain physics beyond **SM**
- ▶ τ -lepton mass: related to LUV tests, BF predictions and α_s



SuperKEKB accelerator & Belle II experiment.

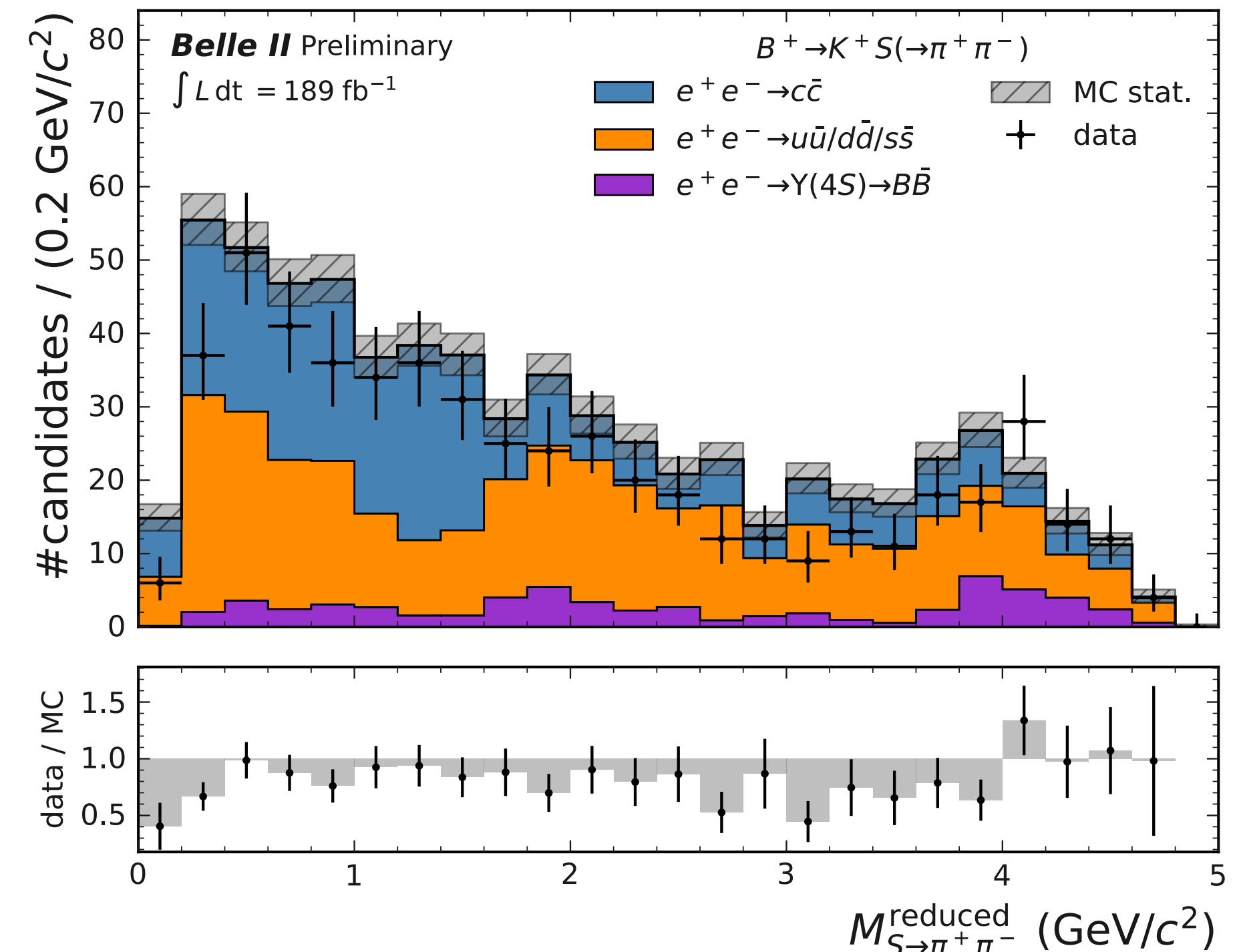
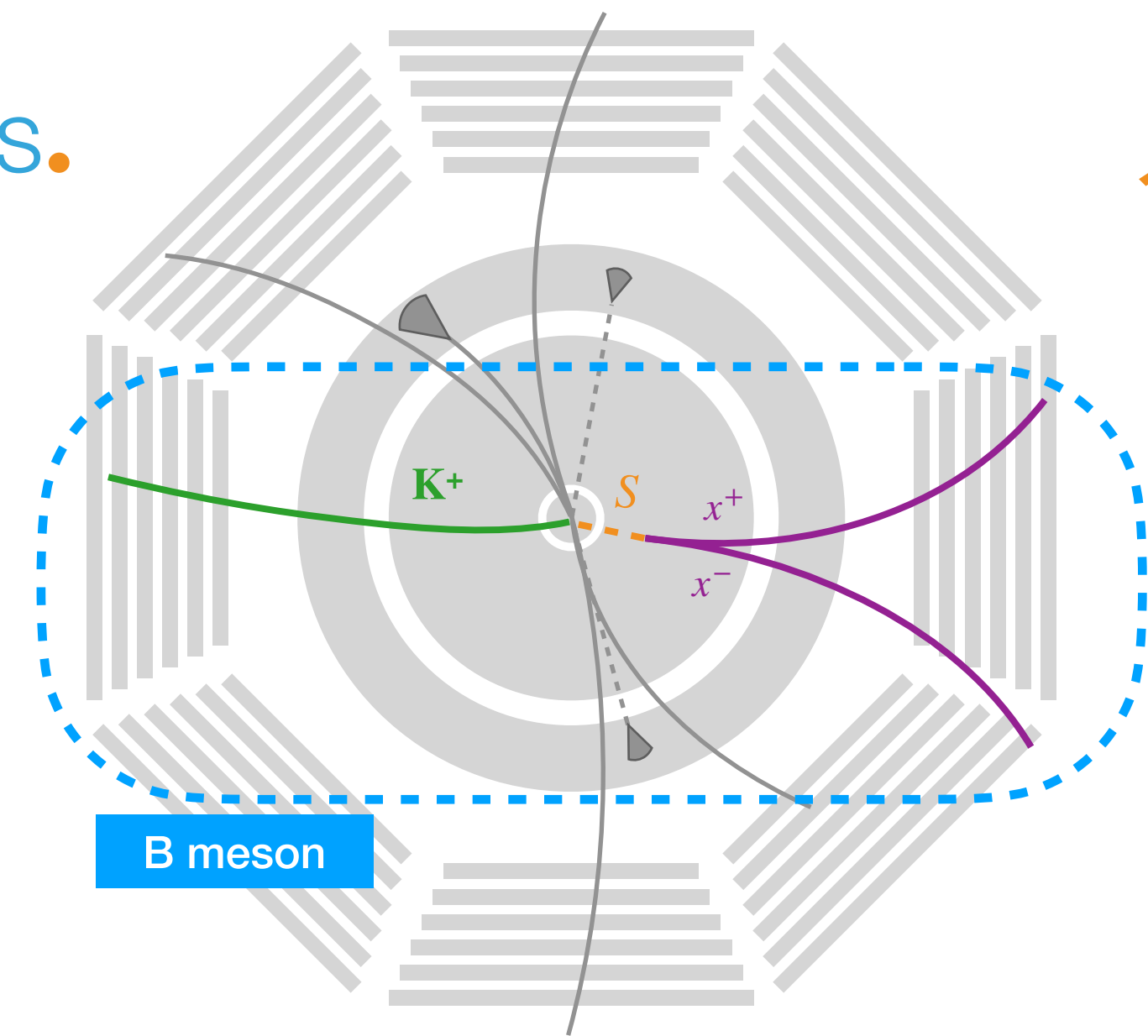
- ▶ SuperKEKB accelerator
- ▶ Upgraded Belle II detector
- ▶ Running at the $\Upsilon(4S)$
- ▶ Collected 428 fb^{-1} , currently in LS1
- ▶ Well known initial conditions
- ▶ Little/no pile-up — clean environment
- ▶ **Special triggers** for low multiplicity
 - ▶ Single photon trigger (not available at Belle)
 - ▶ Single muon trigger
 - ▶ Single track trigger using NN



Search for a long-lived (pseudo-)scalar in $b \rightarrow s$ transitions.

New!

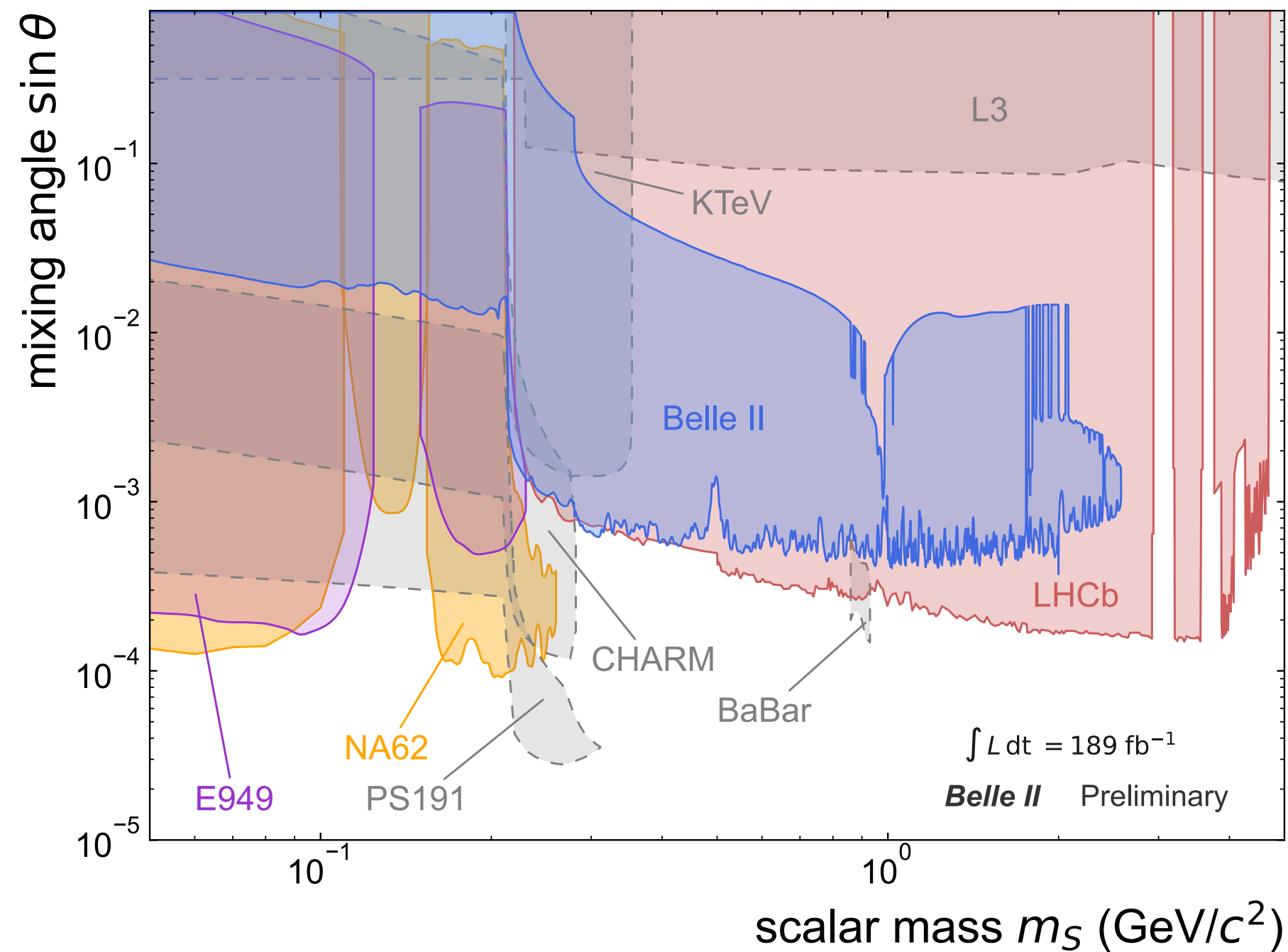
- ▶ First Belle II long-lived particle (LLP) search!
- ▶ Search in eight exclusive fully visible channels:
 - ▶ $B^+ \rightarrow K^+ S$ and $B^0 \rightarrow [K^{*0} \rightarrow K^+ \pi^-] S$
 - ▶ $S \rightarrow ee/\mu\mu/\pi\pi/KK$
- ▶ Challenge: LLP performance
 - ▶ Corrections using K_S^0 control sample
 - ▶ Reconstruction efficiency
 - ▶ M_S shape
 - ▶ Particle identification
- ▶ Bump hunt in LLP mass distribution M_S



Search for a long-lived (pseudo-)scalar in $b \rightarrow s$ transitions.

New! 5

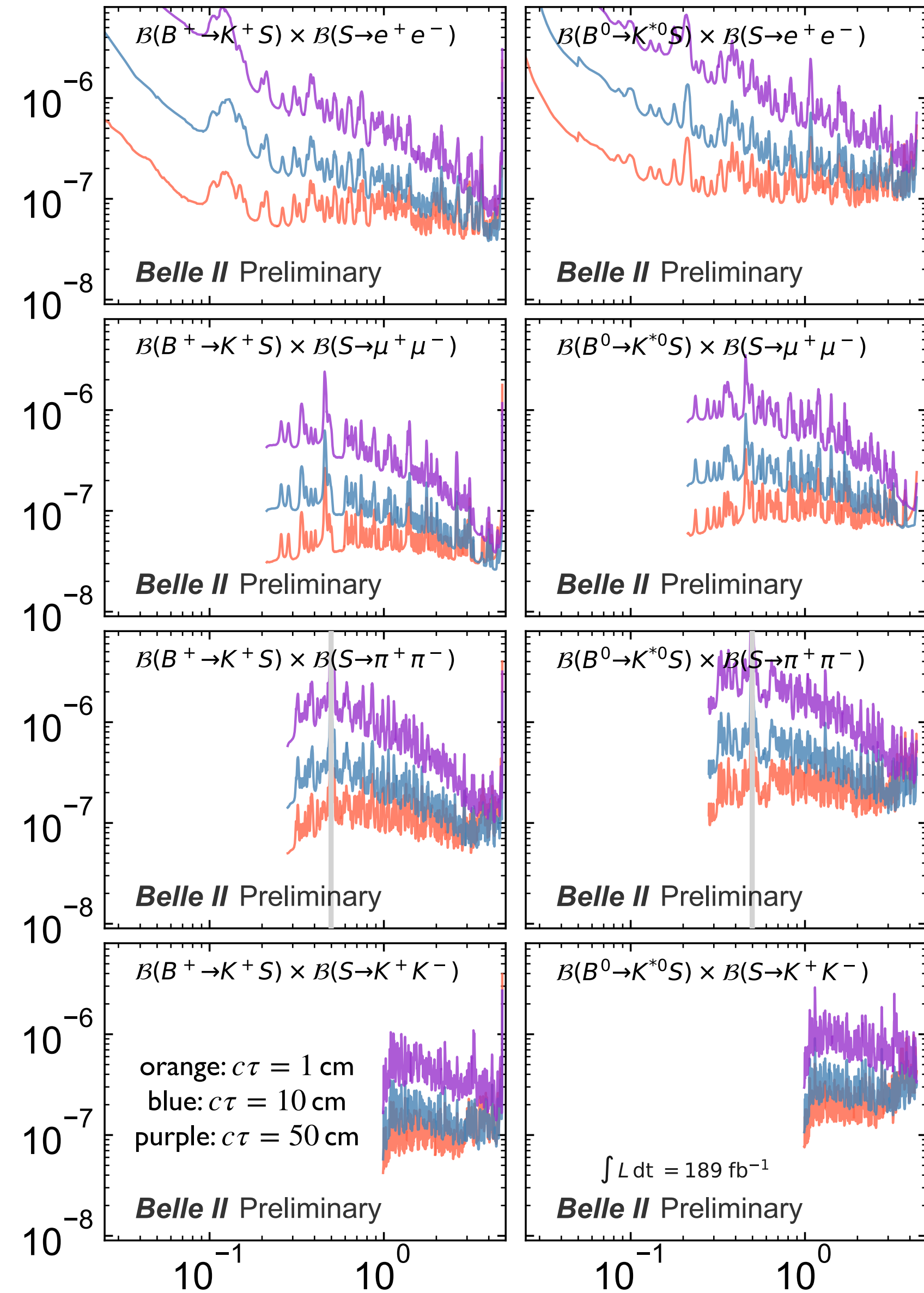
- Model independent limits on (pseudo-)scalar LLP branching fraction
- First limits for LLP decays into hadrons
- Interpretation as dark scalar S [1] (PBC BC4 [2])



[1]: Phys. Rev. D 101, 095006 (2020)

[2]: J. Phys. G: Nucl. Part. Phys. 47 010501

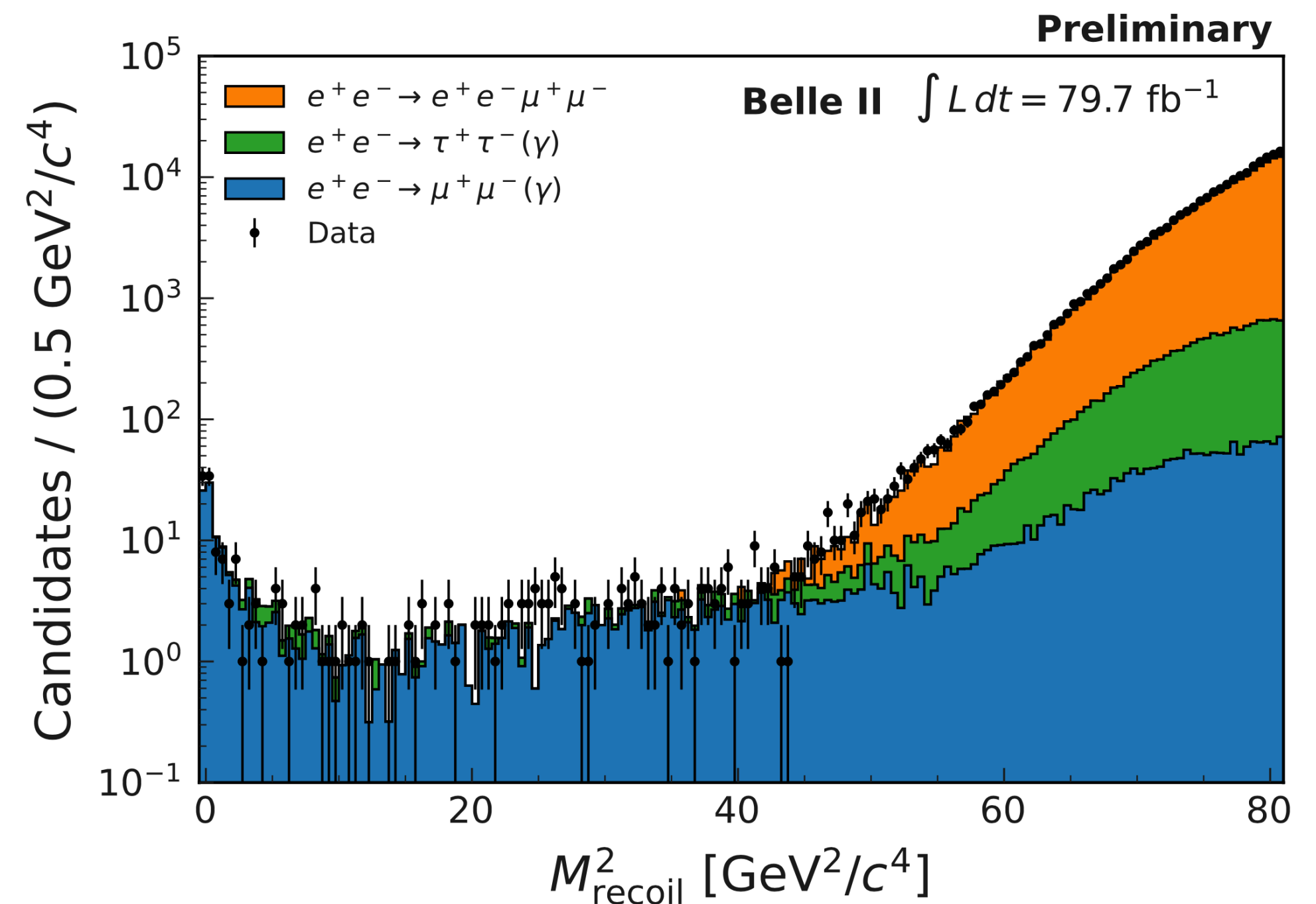
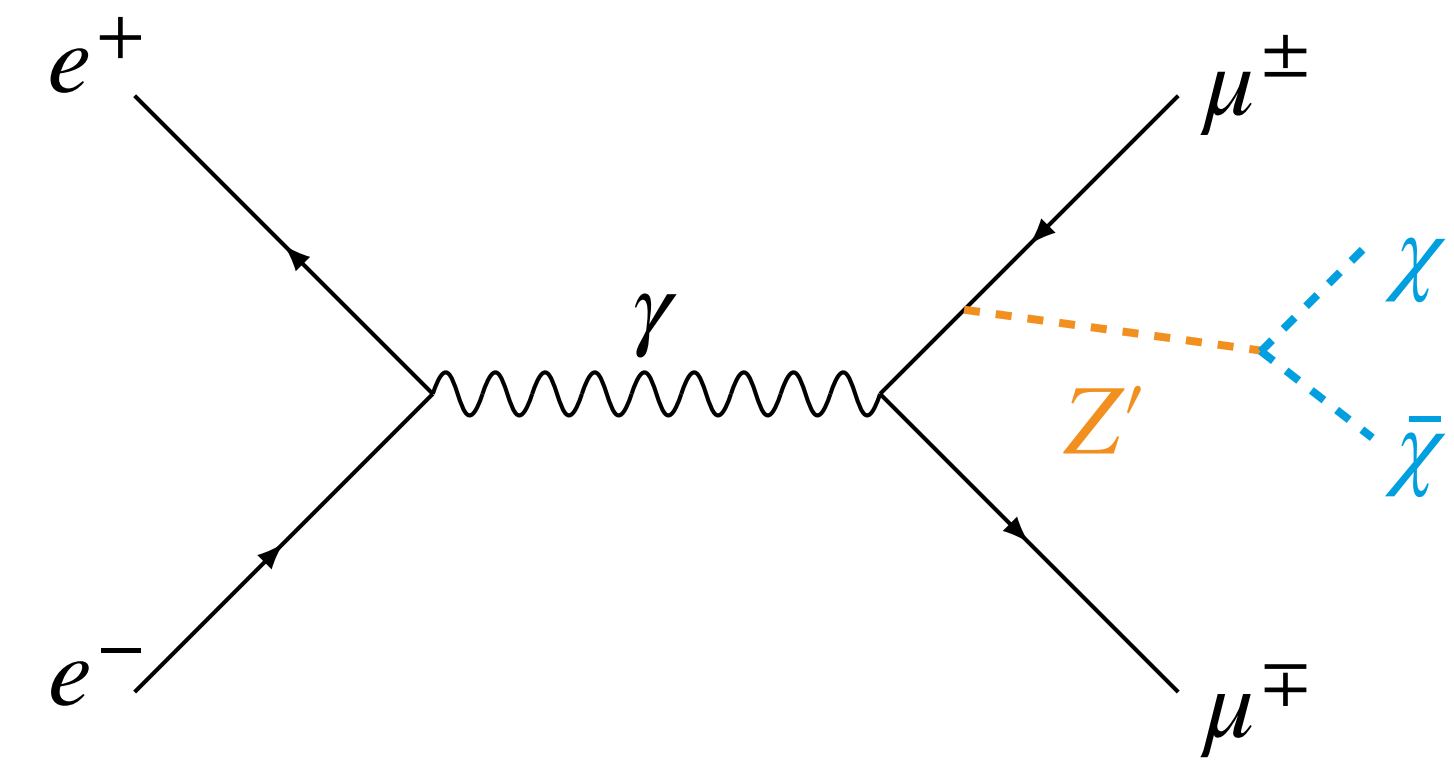
95% CL on $B(B \rightarrow KS) \times B(S \rightarrow X^+ X^-)$



(pseudo-)scalar mass m_S (GeV/c^2)

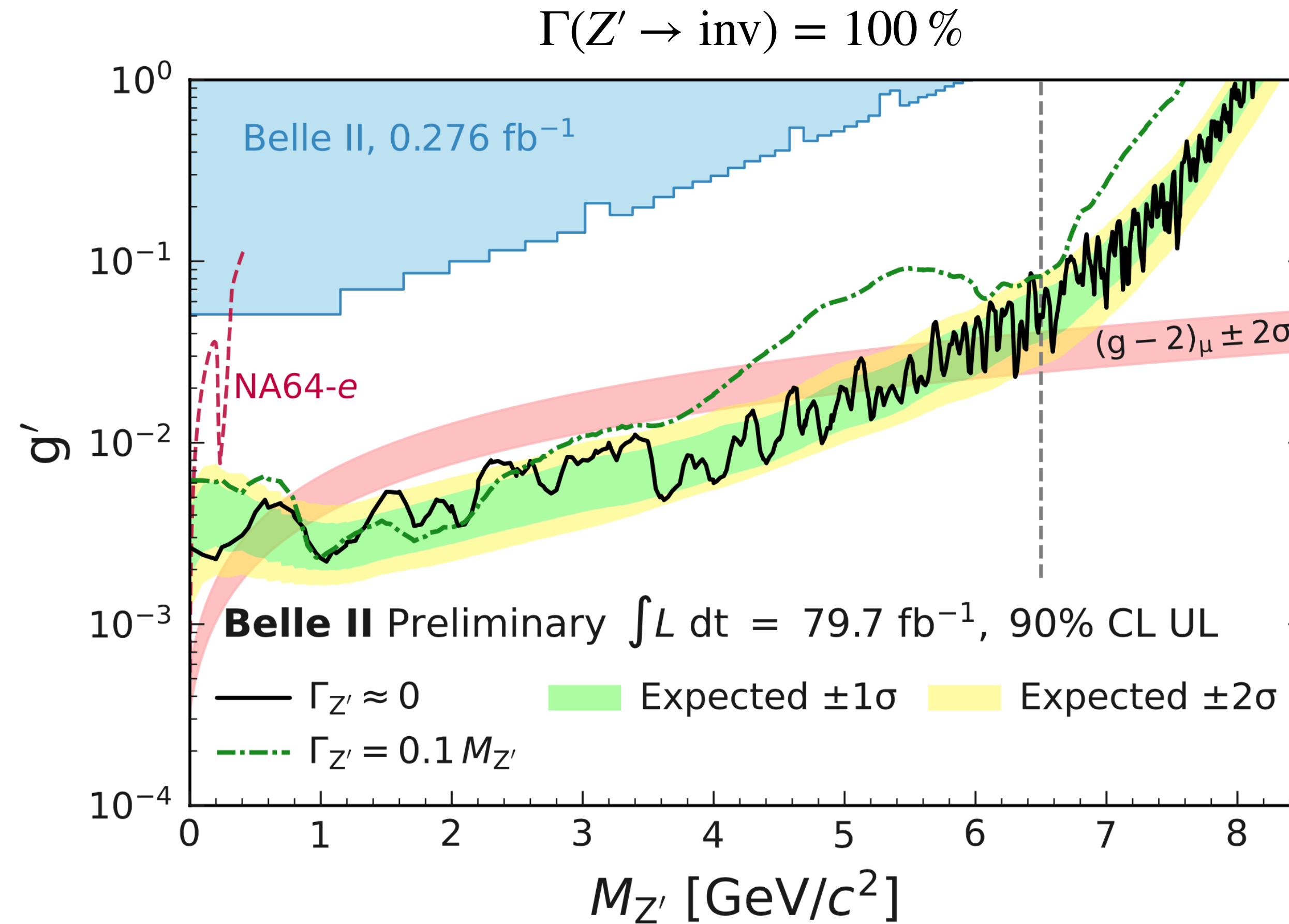
Search for an invisibly decaying Z' boson.

- ▶ 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 $\mu\mu$
 - ▶ $2d$ fit in M_{recoil}^2 and $\theta_{\text{recoil}}^{\text{CMS}}$
- ▶ Challenging $\tau\tau$ background tackled with neural network simultaneously trained for all Z' masses [2]
- ▶ Systematics and corrections from ee , $e\mu$ and $\mu\mu\gamma$ control samples
- ▶ Using 79.7 fb^{-1} , update of [3] with 300x dataset



[1] B. Shuve et al., [Phys. Rev. D 89, 113004](#)
 [2] F. Abudinén et al., [Eur.Phys.J.C 82 \(2022\) 2, 121](#)
 [3] Belle II Collaboration, [Phys. Rev. Lett. 124, 141801 \(2020\)](#)

Search for an invisibly decaying Z' boson.



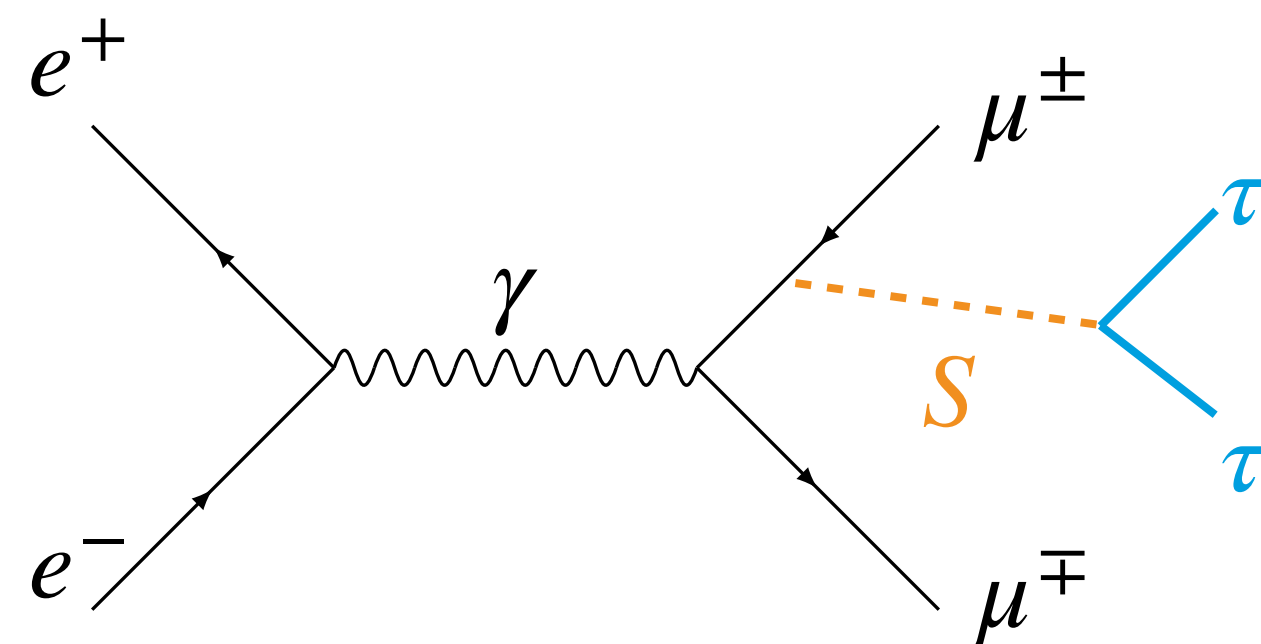
$(g-2)_\mu$ preferred region excluded between $0.8 < m_Z < 4 \text{ GeV}/c^2$

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

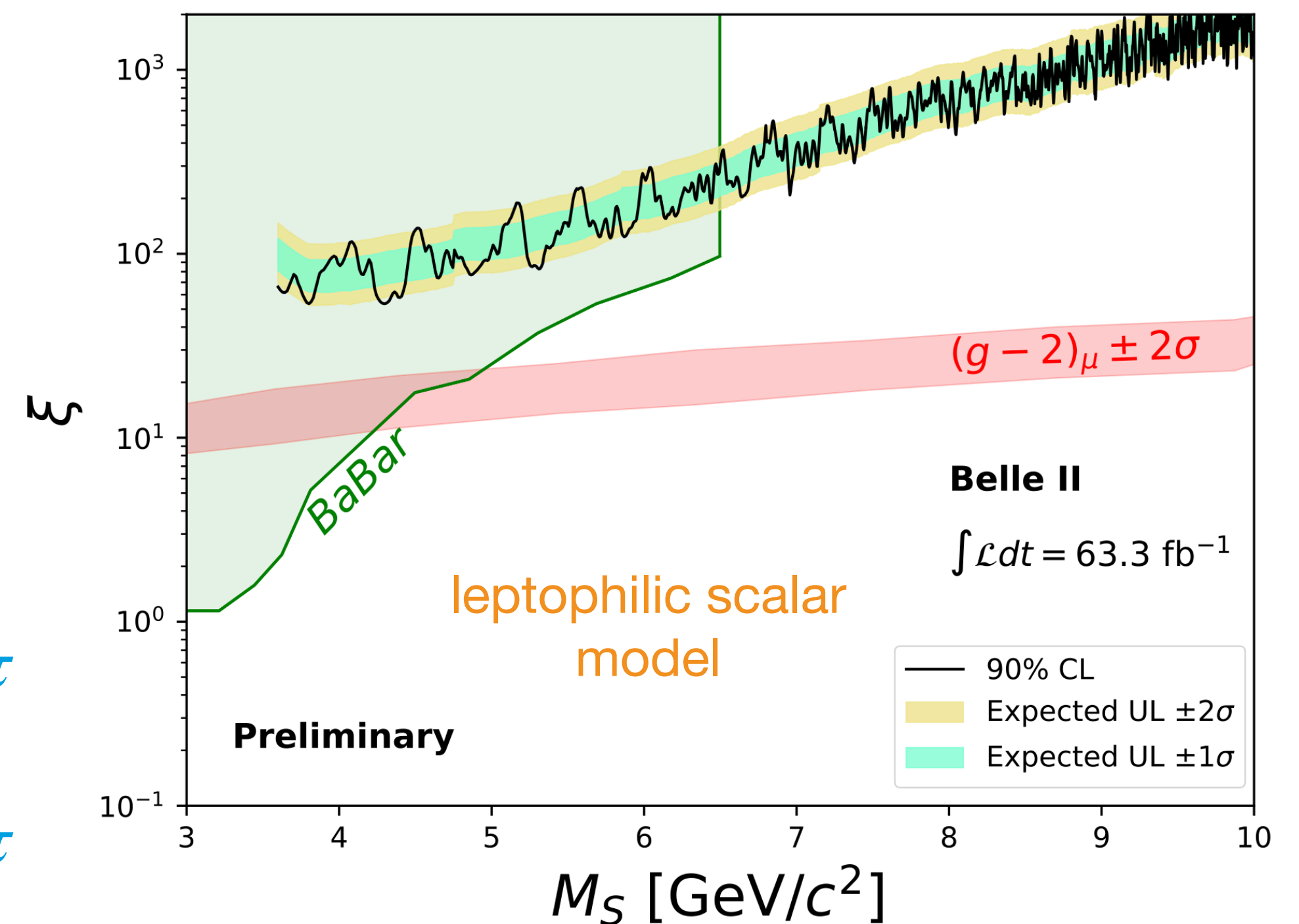
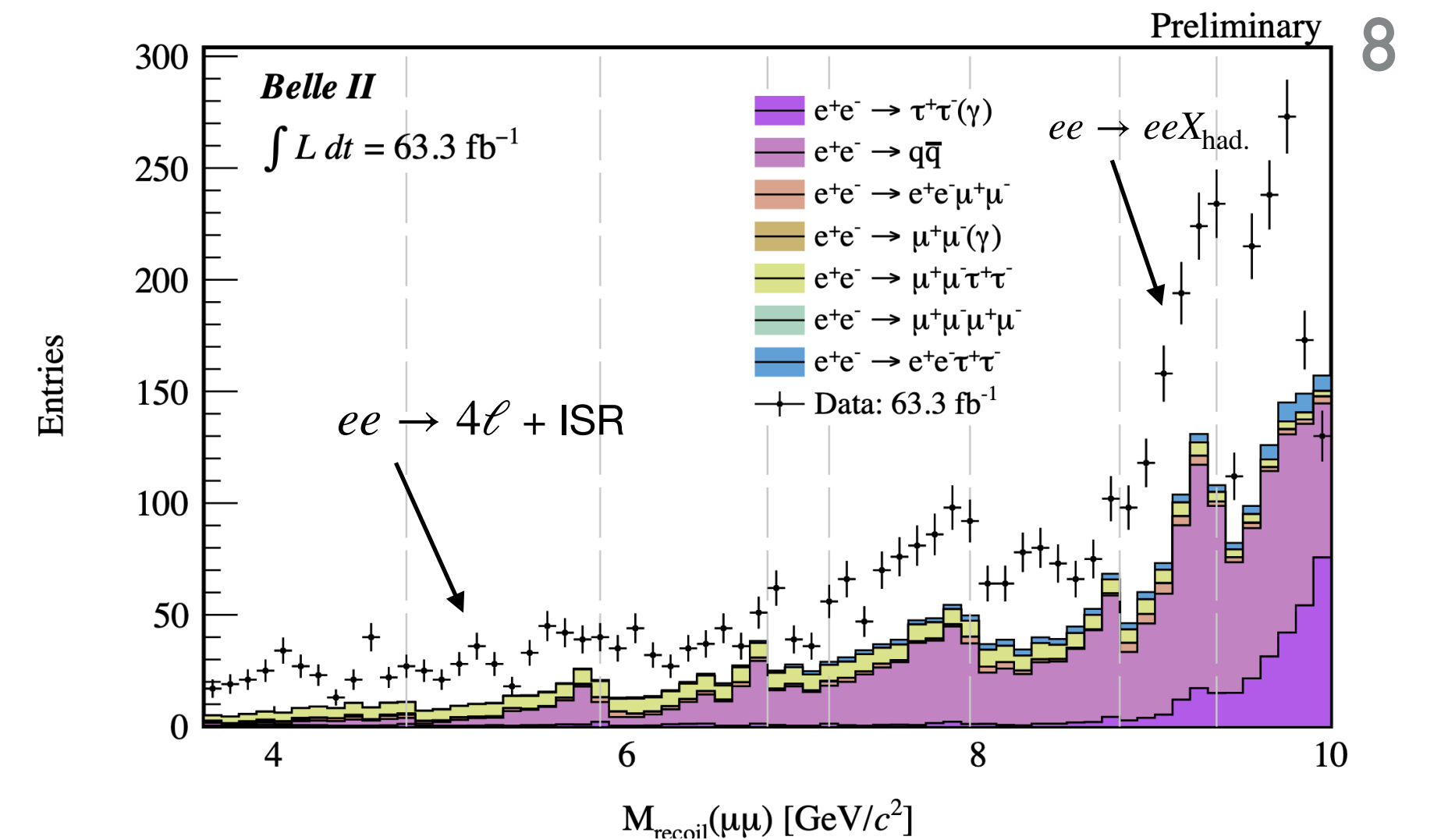
Search for a $\tau\tau$ resonance in $ee \rightarrow \mu\mu\tau\tau$.

- ▶ Four track final-state: $\tau^\pm \rightarrow \pi^\pm(\pi^0)$
- ▶ Challenging backgrounds in final-state with neutrinos
 - ▶ Require missing energy by $M_{4 \text{ tracks}} < 9.5 \text{ GeV}/c^2$
 - ▶ Eight classifiers in different mass regions
- ▶ Signal extracted in fits to $M_{\text{recoil}}(\mu\mu)$
- ▶ Background determined directly in data \rightarrow un-modelled non-peaking background are not problematic
- ▶ Strongest constraints for $M_S > 6.5 \text{ GeV}/c^2$ in leptophilic S model [1]

[1] B. Batell et. al. PRD 95 (2017) 075003



Dark sector and τ results from Belle II



to be submitted soon!

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

▶ Search for $\tau_{\text{sig}} \rightarrow \ell \alpha$ with invisible scalar α and $\ell = e, \mu$

▶ Reconstruct $\tau_{\text{tag}} \rightarrow 3\pi\nu$ (ν missing) in $ee \rightarrow \tau_{\text{tag}}\tau_{\text{sig}}$

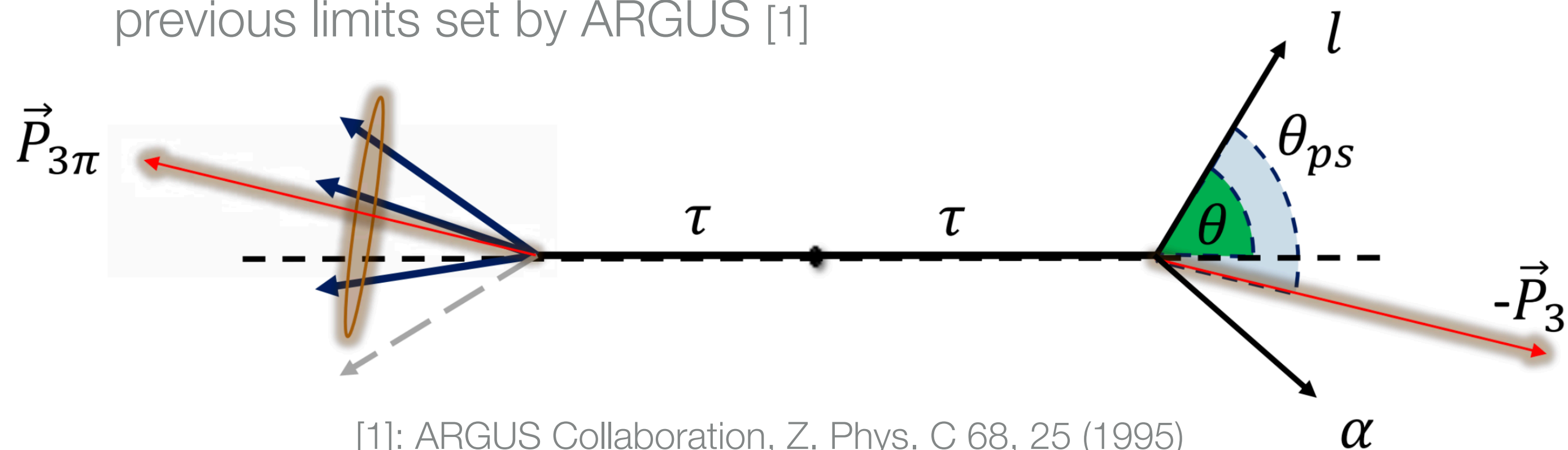
▶ Approximate τ_{sig} rest-frame by:

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

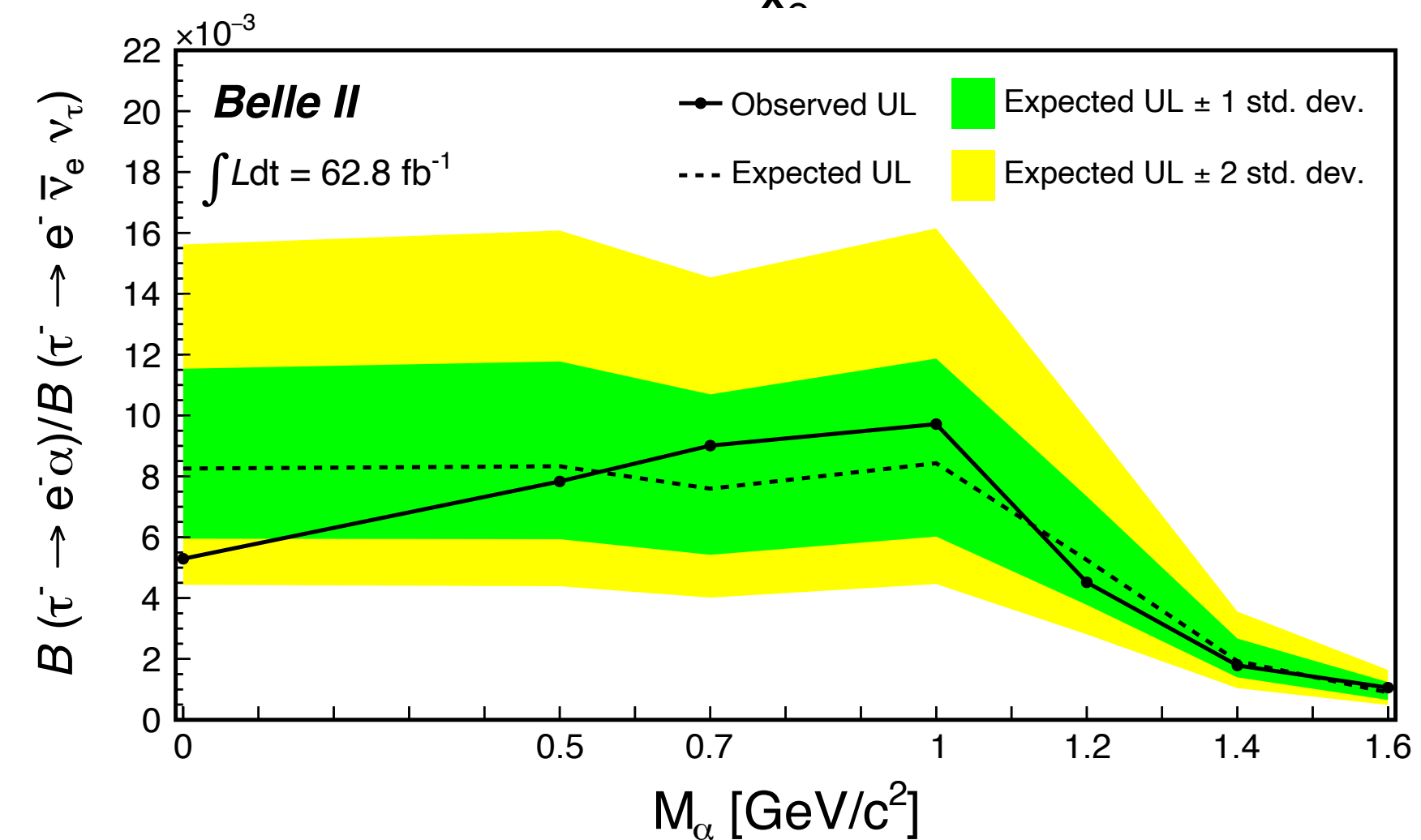
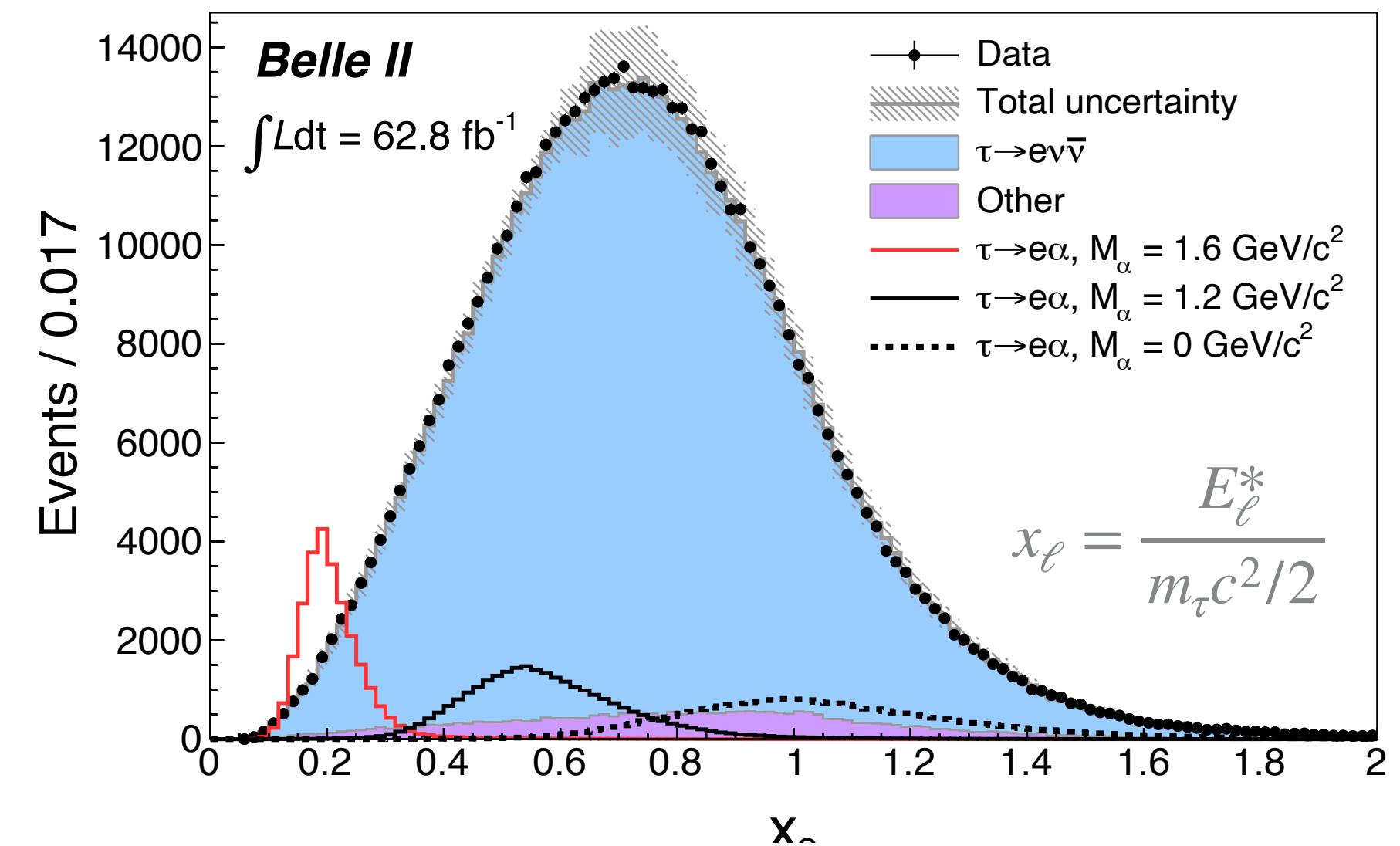
▶ Two body signal decay topology

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

▶ Observed limits using 62.8 fb^{-1} are 2.2 to 14 stronger than previous limits set by ARGUS [1]

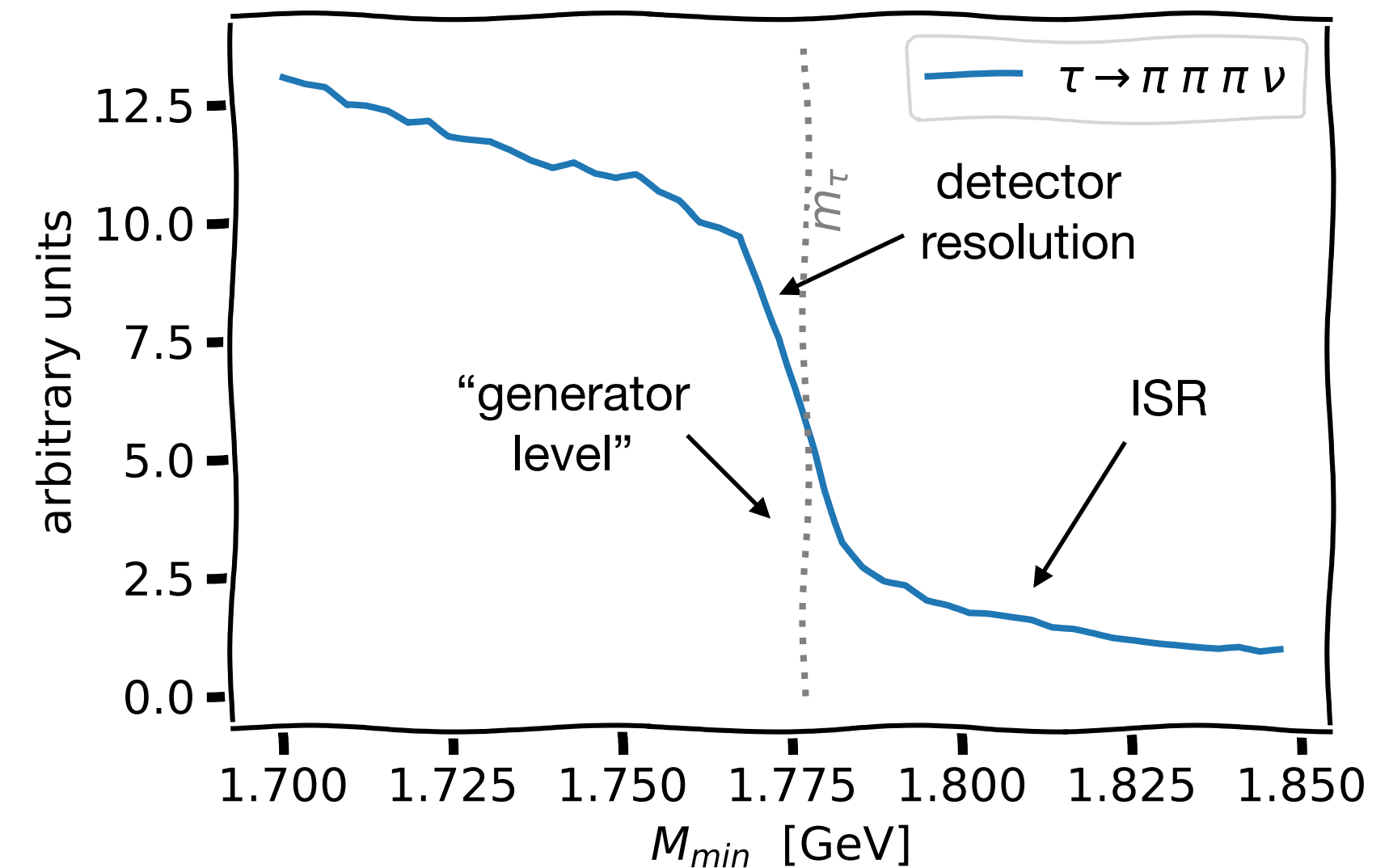
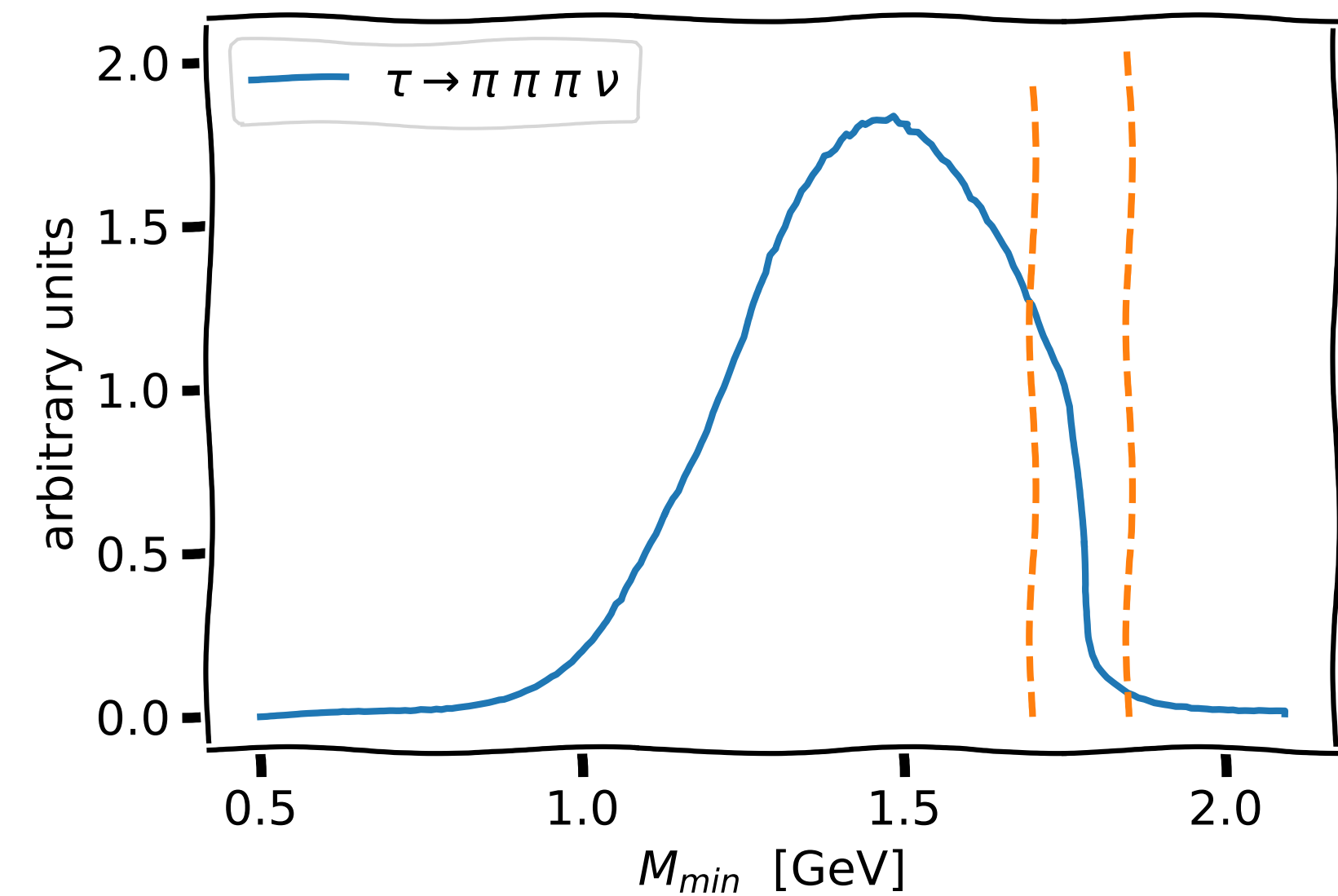


arXiv:2212.03634v1 accepted by PRL



Measurement of the τ -lepton mass.

- ▶ Large $e^+e^- \rightarrow \tau\tau$ cross-section and clean environment allow high precision τ measurements
- ▶ Reconstruct $\tau_{\text{tag}}^\pm \rightarrow \pi^\pm(\pi^0)\nu$ and $\tau_{\text{sig}} \rightarrow 3\pi\nu$ (ν missing)
- ▶ Four tracks and no additional high energy photons
- ▶ Study M_{min} variable to access mass:
 - ▶ Sharp step at m_τ
 - ▶ Candidates at larger M_{min} due to ISR
 - ▶ Smearing of the edge due to detector resolution
 - ▶ Use empirical fit function



$$M_{\text{min}} = \sqrt{M_{3\pi}^2 + 2(\sqrt{s}/2 - E_{3\pi}^*)(E_{3\pi}^* - P_{3\pi}^*)} \leq m_\tau$$

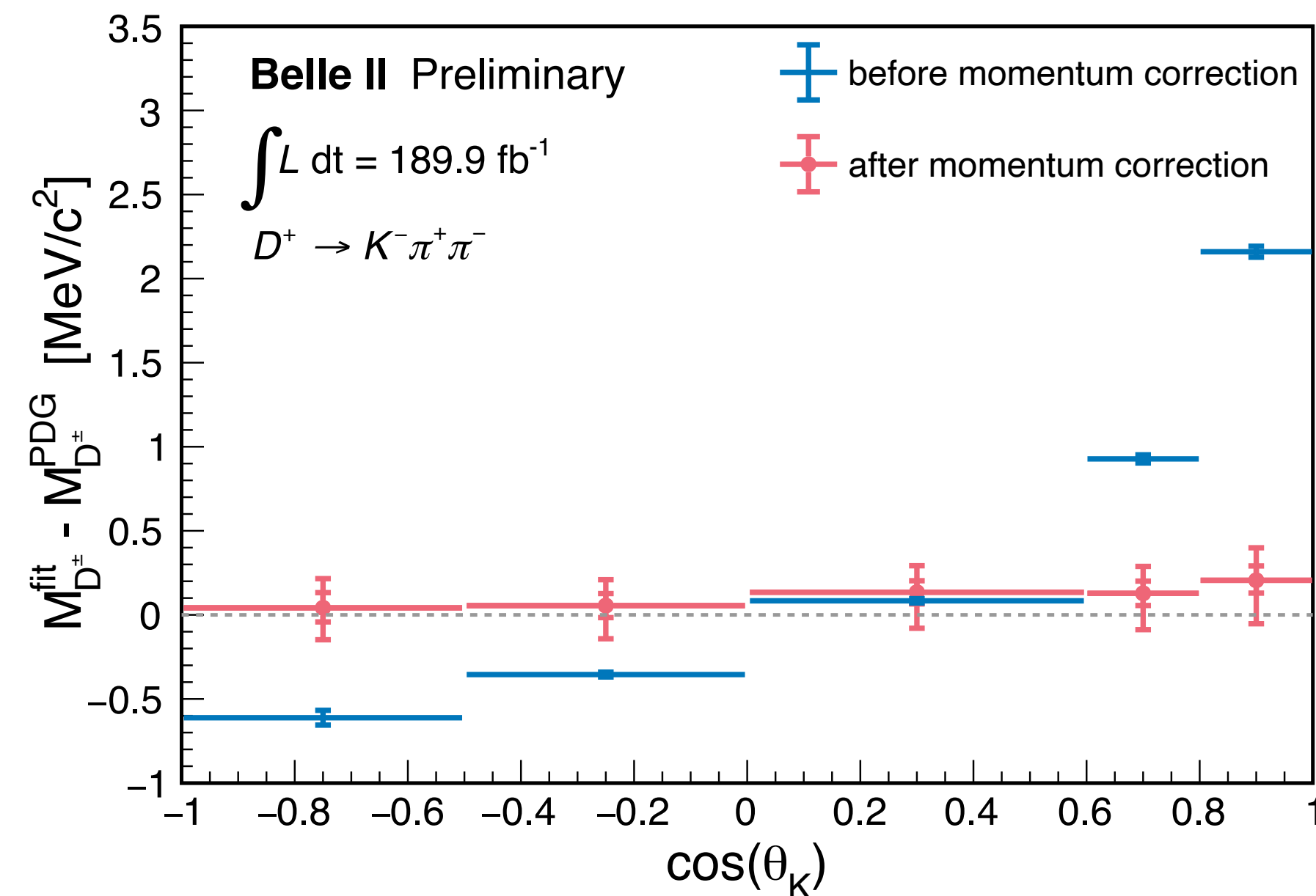
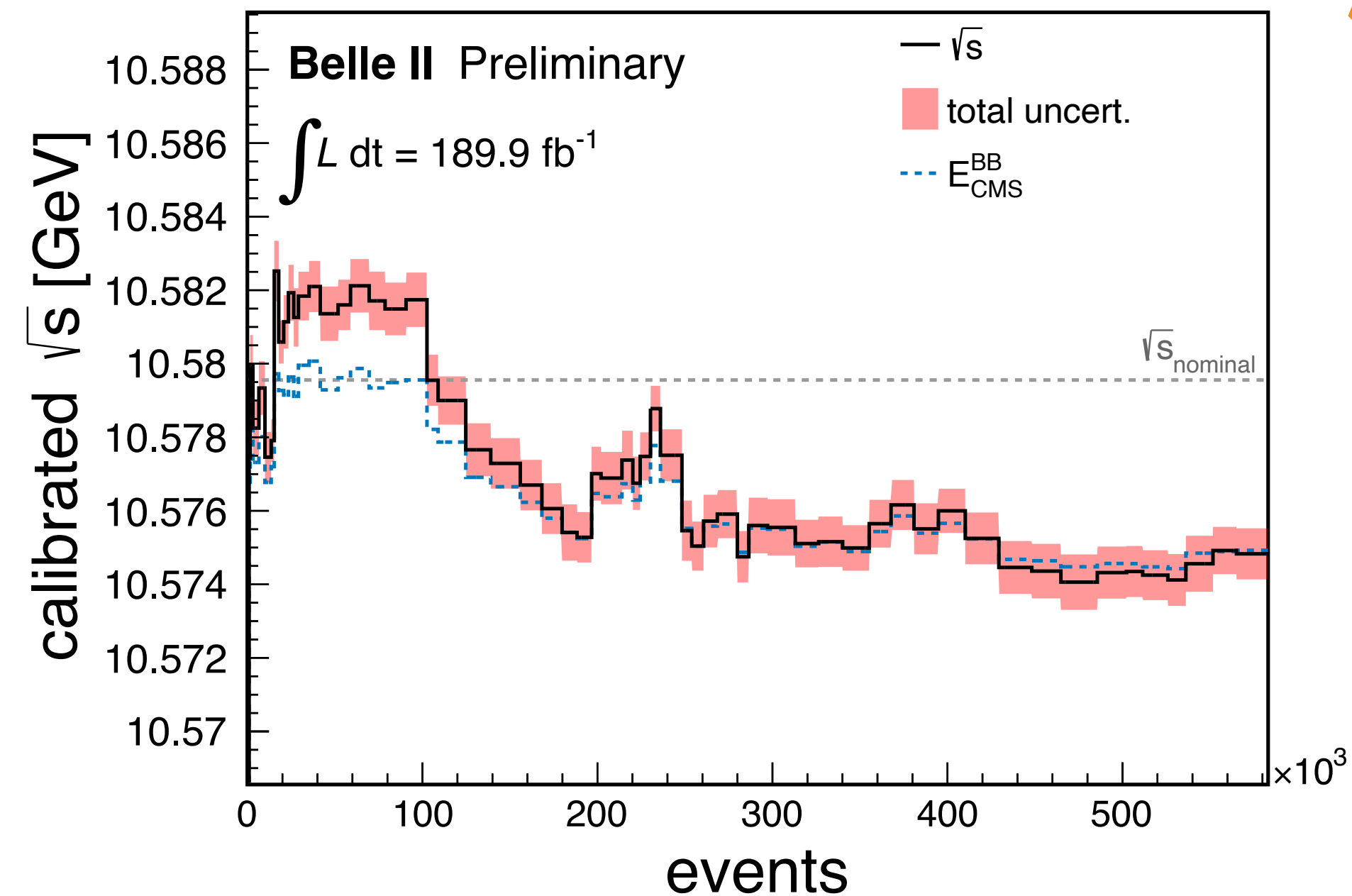
New! 10

Measurement of the τ -lepton mass.

- ▶ Benchmark for precision capabilities of Belle II
- ▶ Control of systematic uncertainties is key:

$$M_{\min} = \sqrt{M_{3\pi}^2 + 2\left(\sqrt{s}/2 - E_{3\pi}^*\right)\left(E_{3\pi}^* - P_{3\pi}^*\right)} \leq m_{\tau}$$

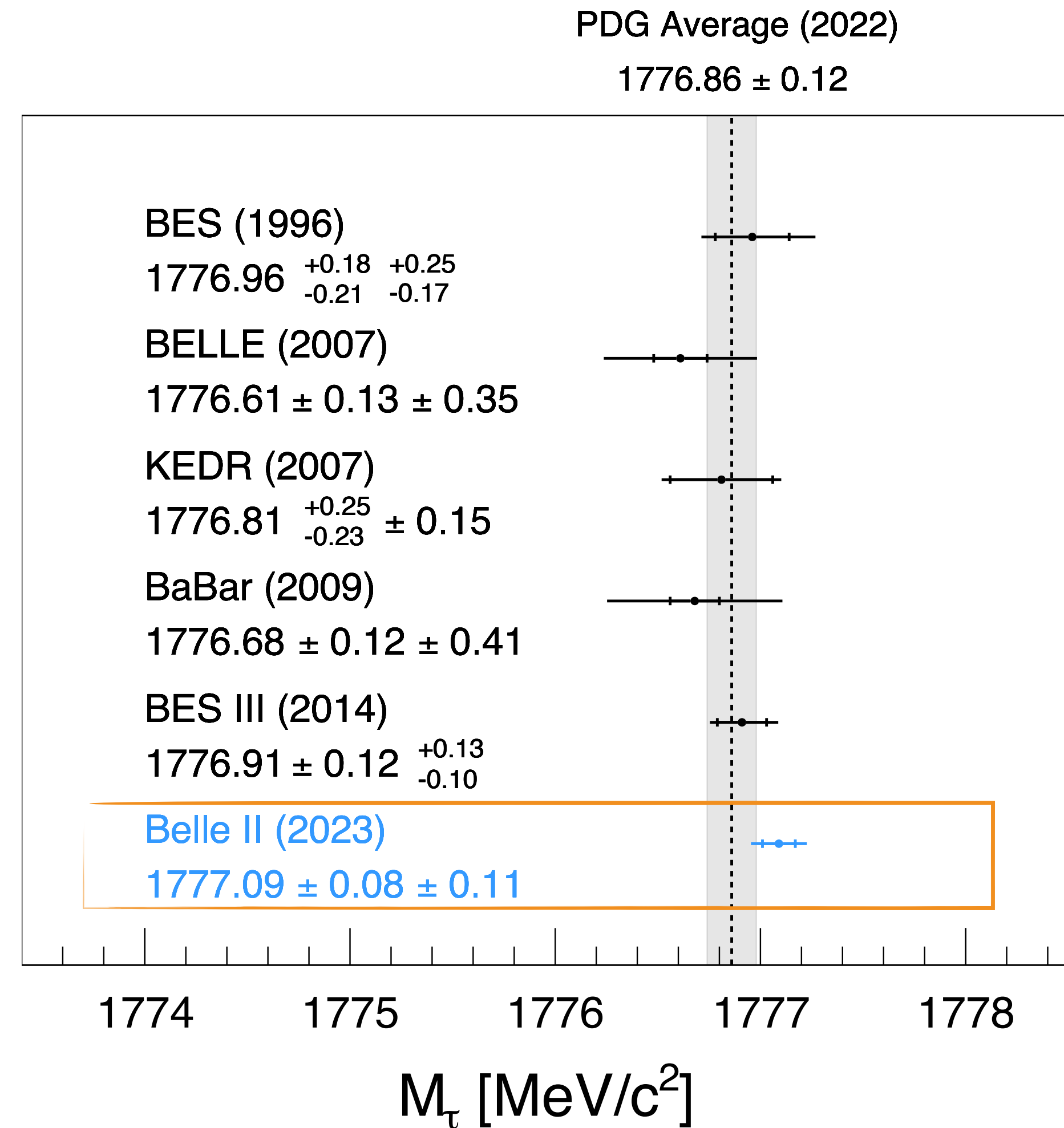
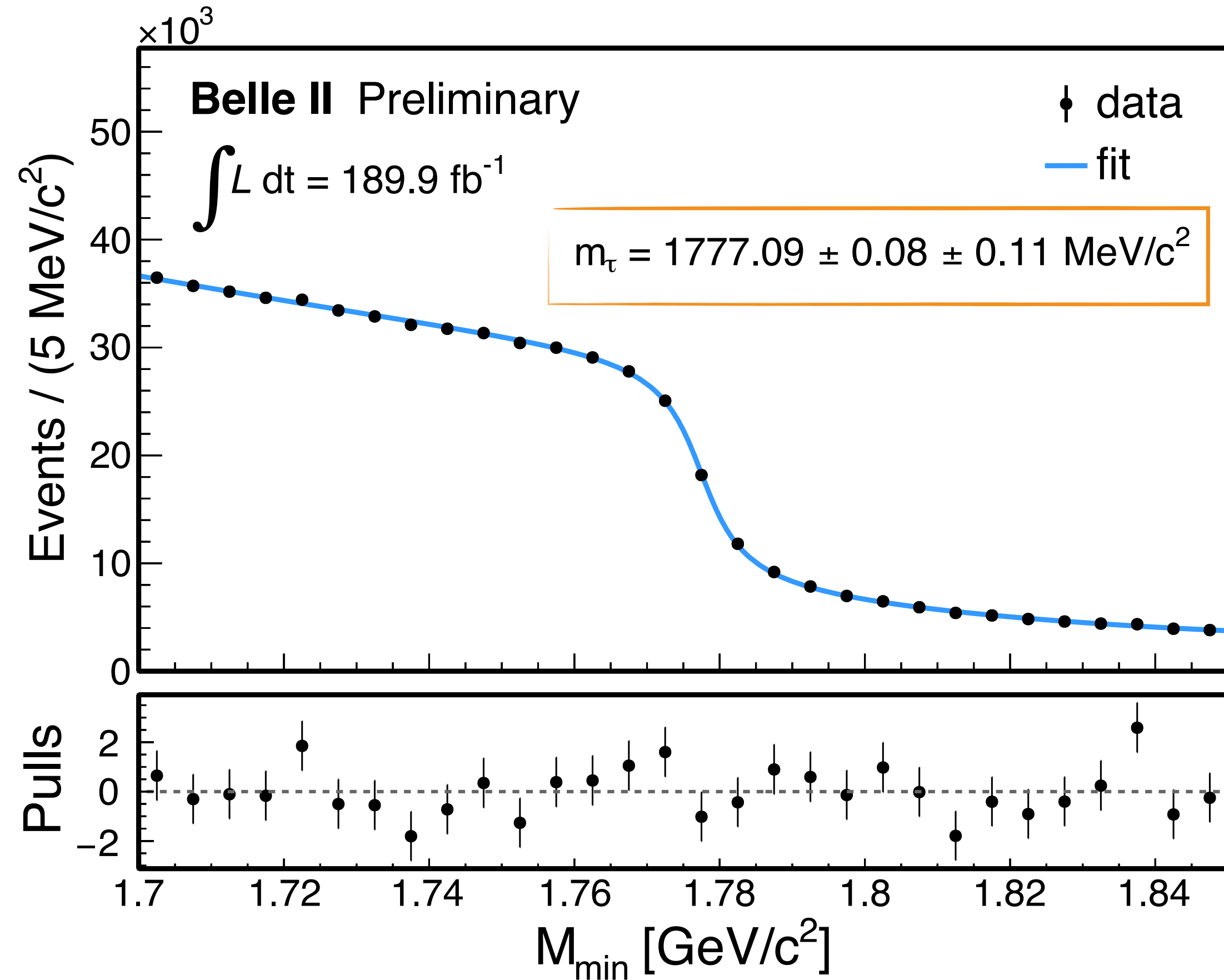
Source	Uncertainty [MeV/c ²]
Knowledge of the colliding beams:	
Beam energy correction	0.07
Boost vector	≤ 0.01
Reconstruction of charged particles:	
Charged particle momentum correction	0.06
Detector misalignment	0.03
Fitting procedure:	
Estimator bias	0.03
Choice of the fit function	0.02
Mass dependence of the bias	≤ 0.01
Imperfections of the simulation:	
Detector material budget	0.03
Modeling of ISR and FSR	0.02
Momentum resolution	≤ 0.01
Neutral particle reconstruction efficiency	≤ 0.01
Tracking efficiency correction	≤ 0.01
Trigger efficiency	≤ 0.01
Background processes	≤ 0.01
Total	0.11



New! 11

Measurement of the τ -lepton mass.

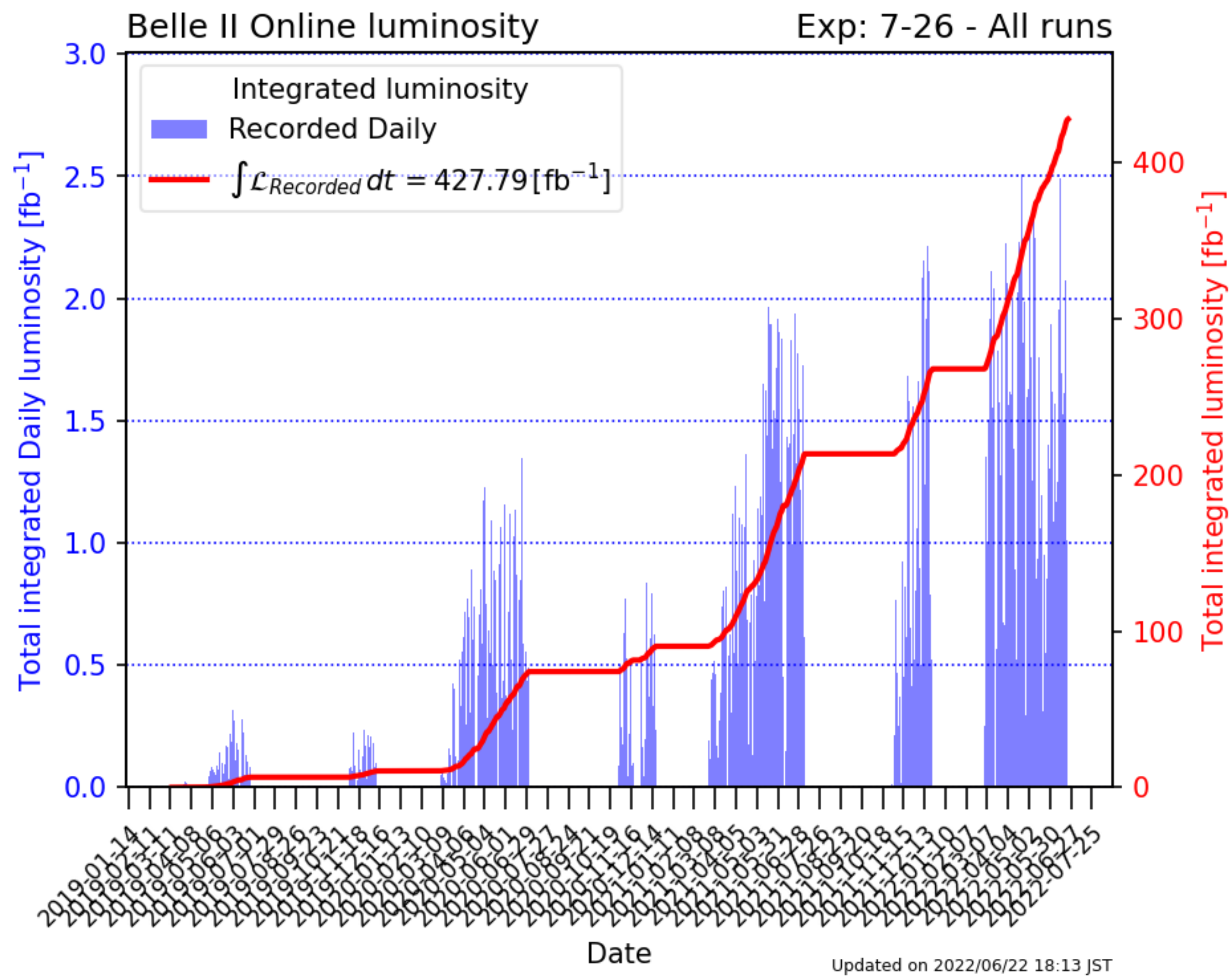
New!



- ▶ Worlds most precise τ mass measurement!

- Recent **dark sector** and τ results from Belle II:
 - **New!** Search for a **long-lived (pseudo-)scalar** in $b \rightarrow s$ transitions (paper in preparation)
 - Search for **invisible Z'** in $ee \rightarrow \mu\mu Z'$ [arXiv:2212.03066](https://arxiv.org/abs/2212.03066)
 - Search for **$\tau\tau$ resonance** in $ee \rightarrow \mu\mu\tau\tau$ (paper in preparation)
 - Search for **invisible LF-violating scalar** in $\tau \rightarrow \ell\alpha$ [arXiv:2212.03634](https://arxiv.org/abs/2212.03634)
 - **New!** Measurement of the **τ -lepton mass** (paper in preparation)
- Belle II has a unique sensitivity to light Dark-Sectors and is able to perform world-leading precision measurements
- Results are complementary to higher-energy collider and beam-dump experiments

Backup.



Long-shutdown activity and plans

Belle II stopped taking data in Summer 2022 for a long shutdown

- replacement of beam-pipe
- replacement of photomultipliers of the central PID detector (TOP)
- installation of 2-layered pixel vertex detector
- improved data-quality monitoring and alarm system
- complete transition to new DAQ boards (PCIe40)
- replacement of aging components
- additional shielding and increased resilience against beam backgrounds

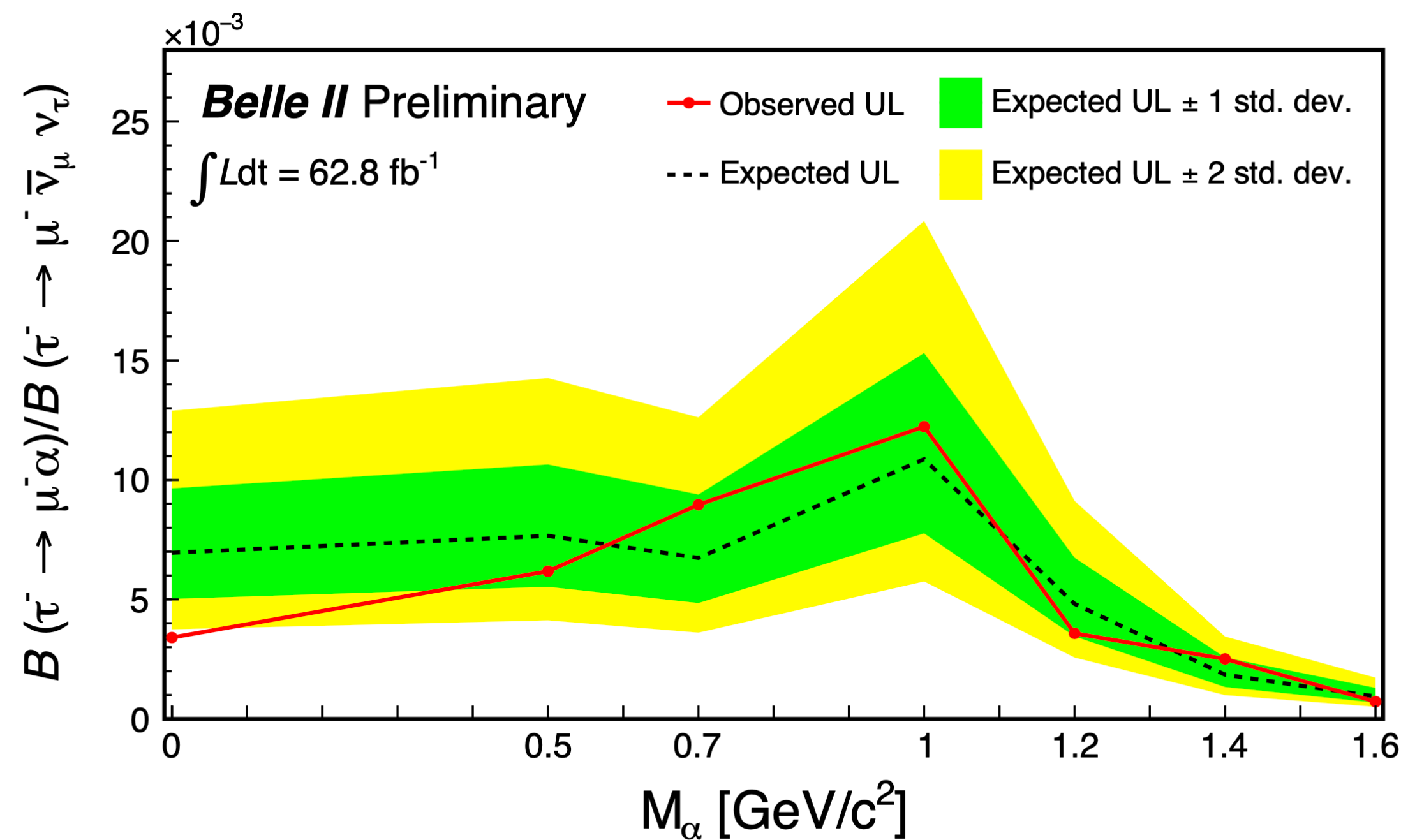
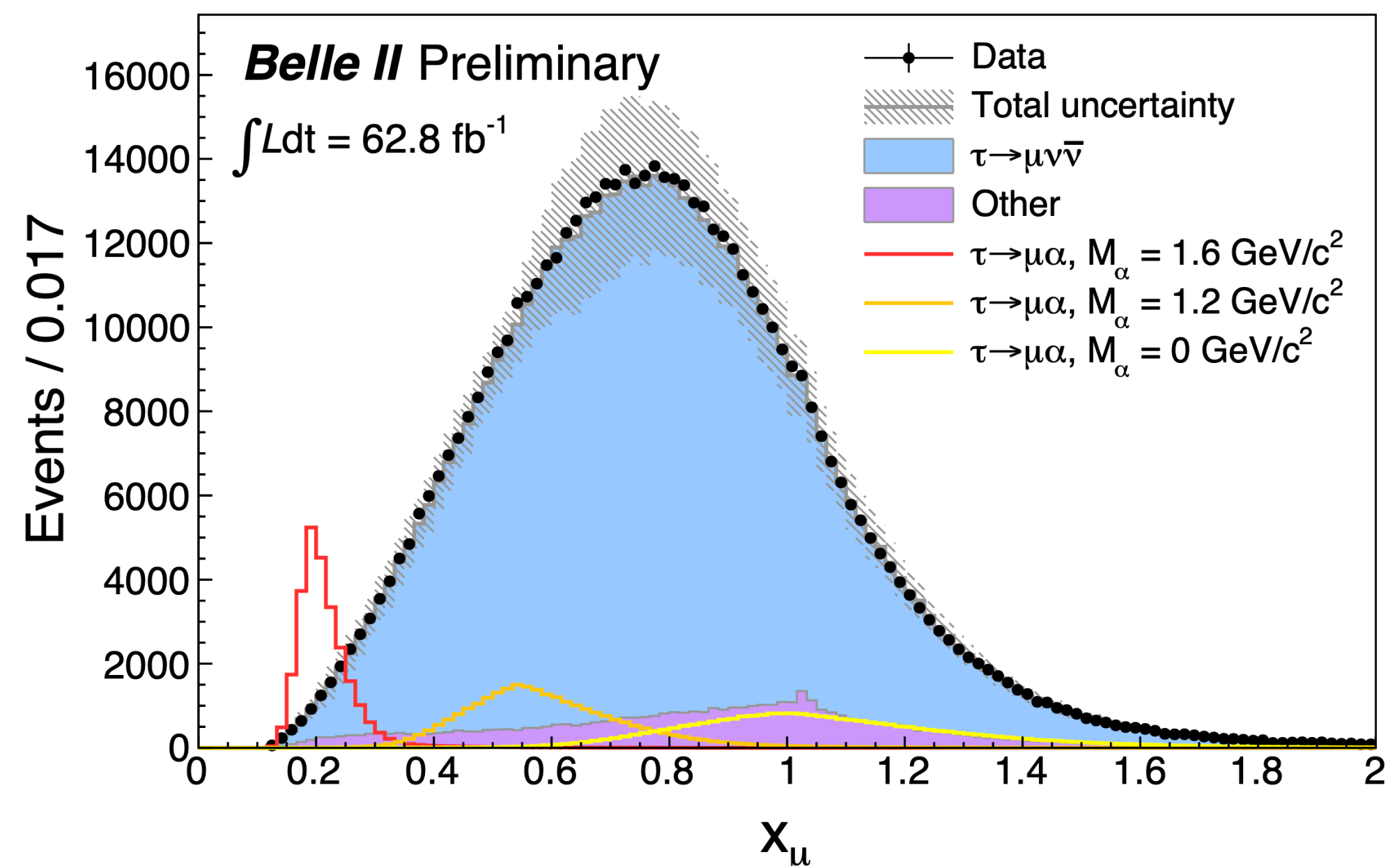
Currently working on pixel detector installation:

- > shipping to KEK in mid March
- > final test at KEK scheduled in April

On track to resume data taking next winter with new pixel detector

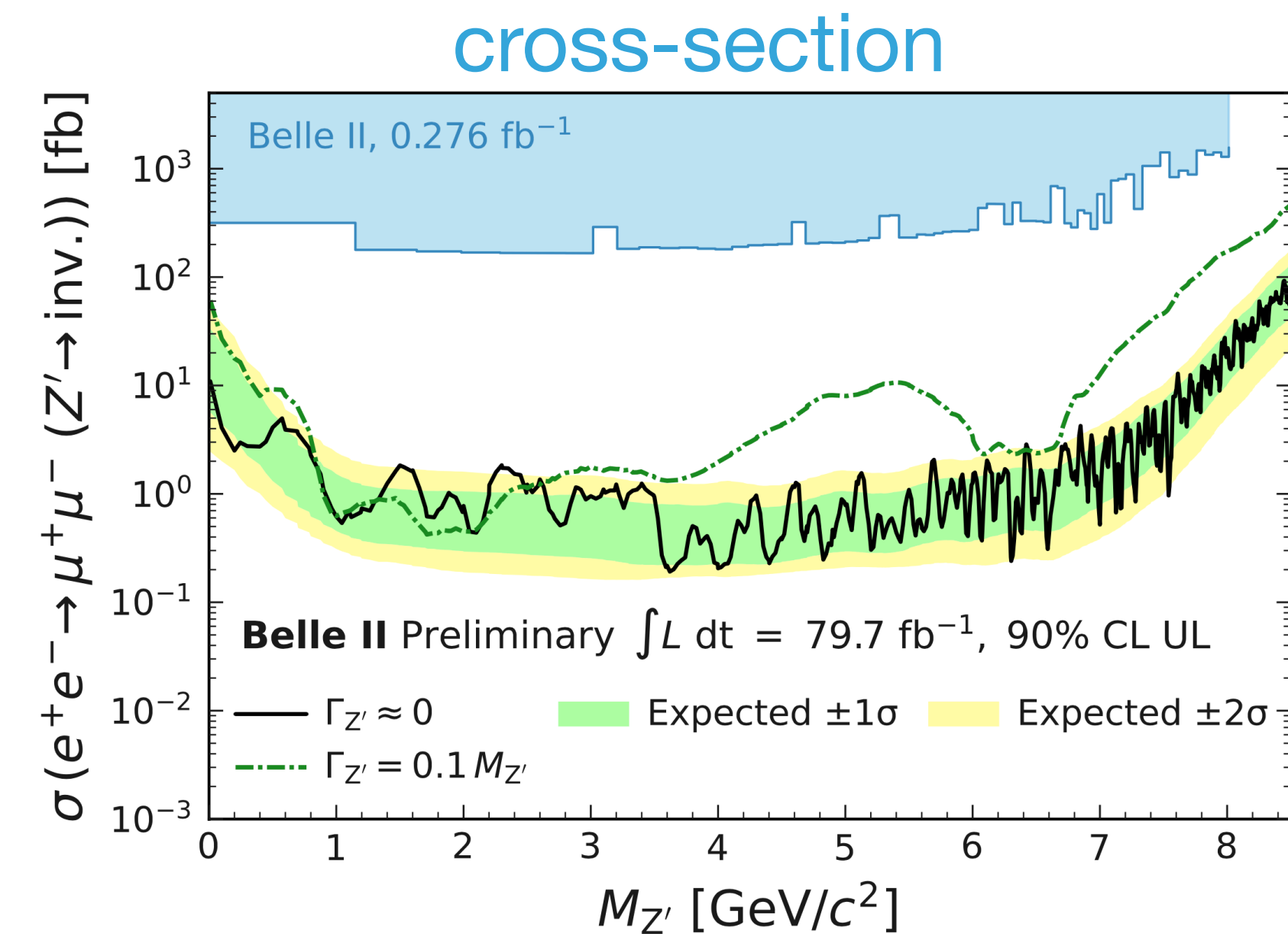
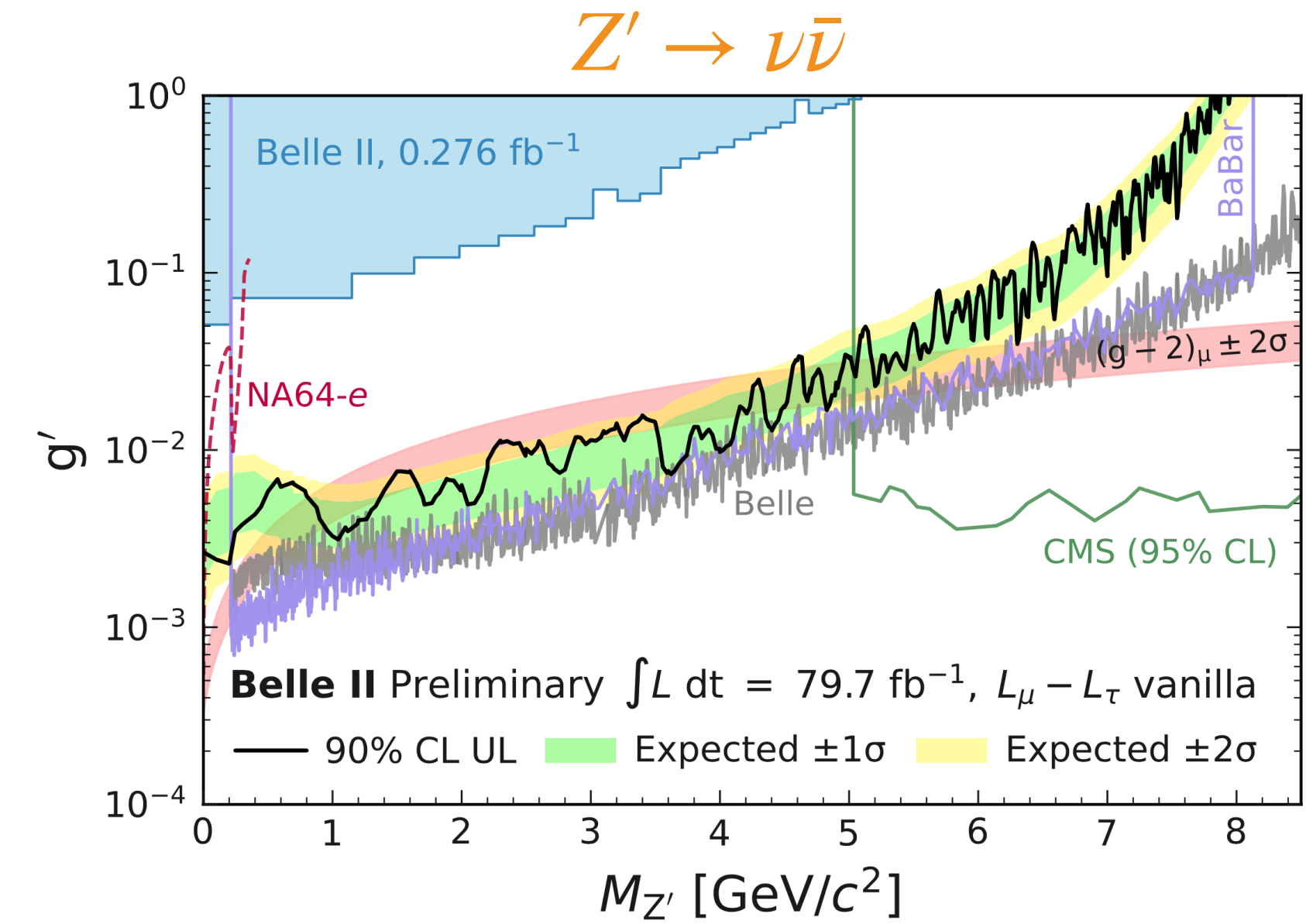
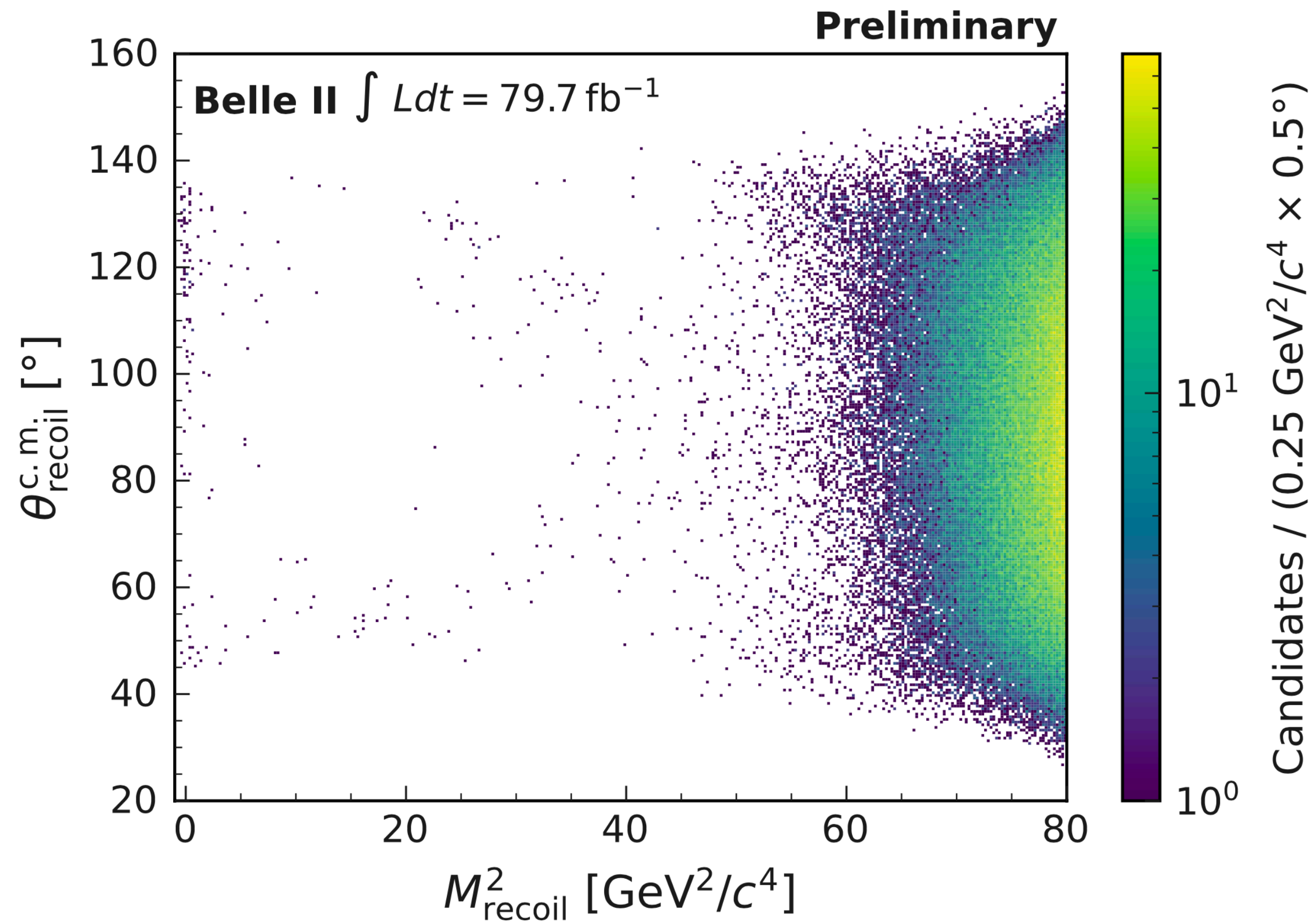
1

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



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

Search for an invisibly decaying Z' boson.



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

