Recent Dark-Sector and τ results from Belle II.

Sascha Dreyer on behalf of the Belle II collaboration

Rencontres de Moriond 2023 — Electroweak edition
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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

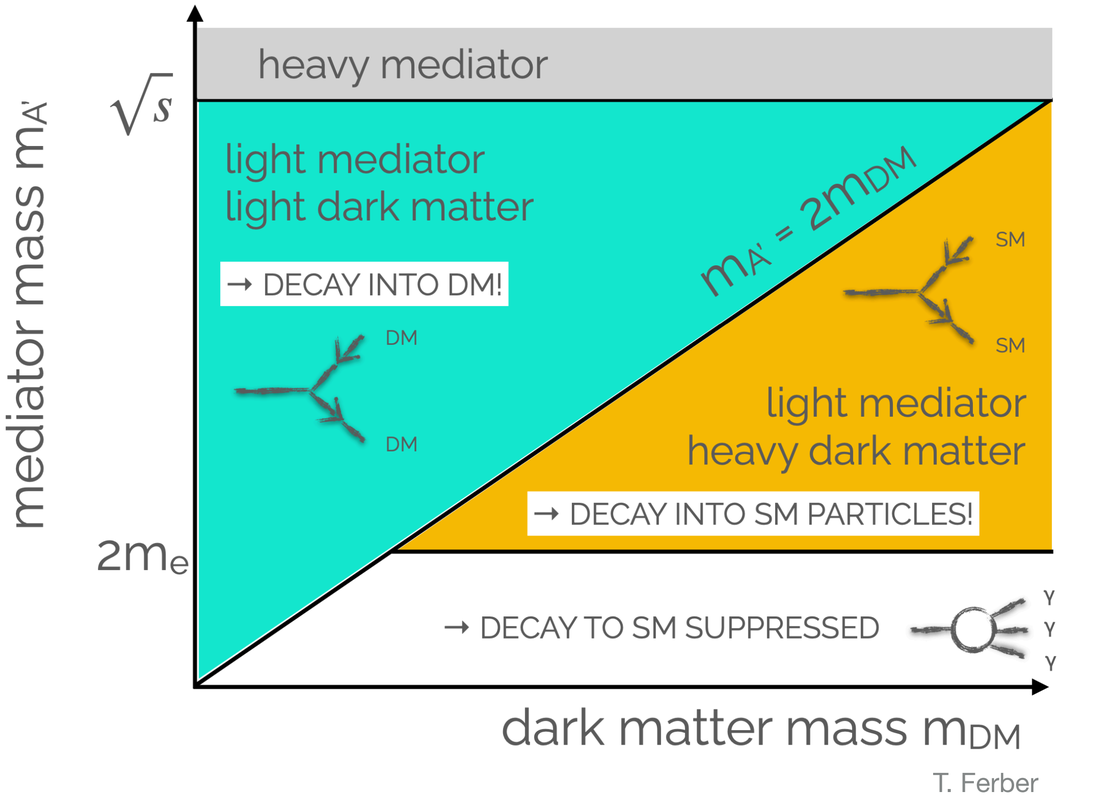
Light Dark-Sectors.

Standard Model ⟷ Mediator ⟷ Dark-Sector

Todays menu:

$$e^+e^- \to \mathrm{SM}[X \to \chi\chi]$$
$$e^+e^- \to \mathrm{SM}[X \to \mathrm{SM}]$$
$$e^+e^- \to \tau[\tau \to \mathrm{SM}\, X]$$
$$e^+e^- \to \Upsilon(4s) \to B[B \to [K\, X \to \mathrm{SM}]]$$

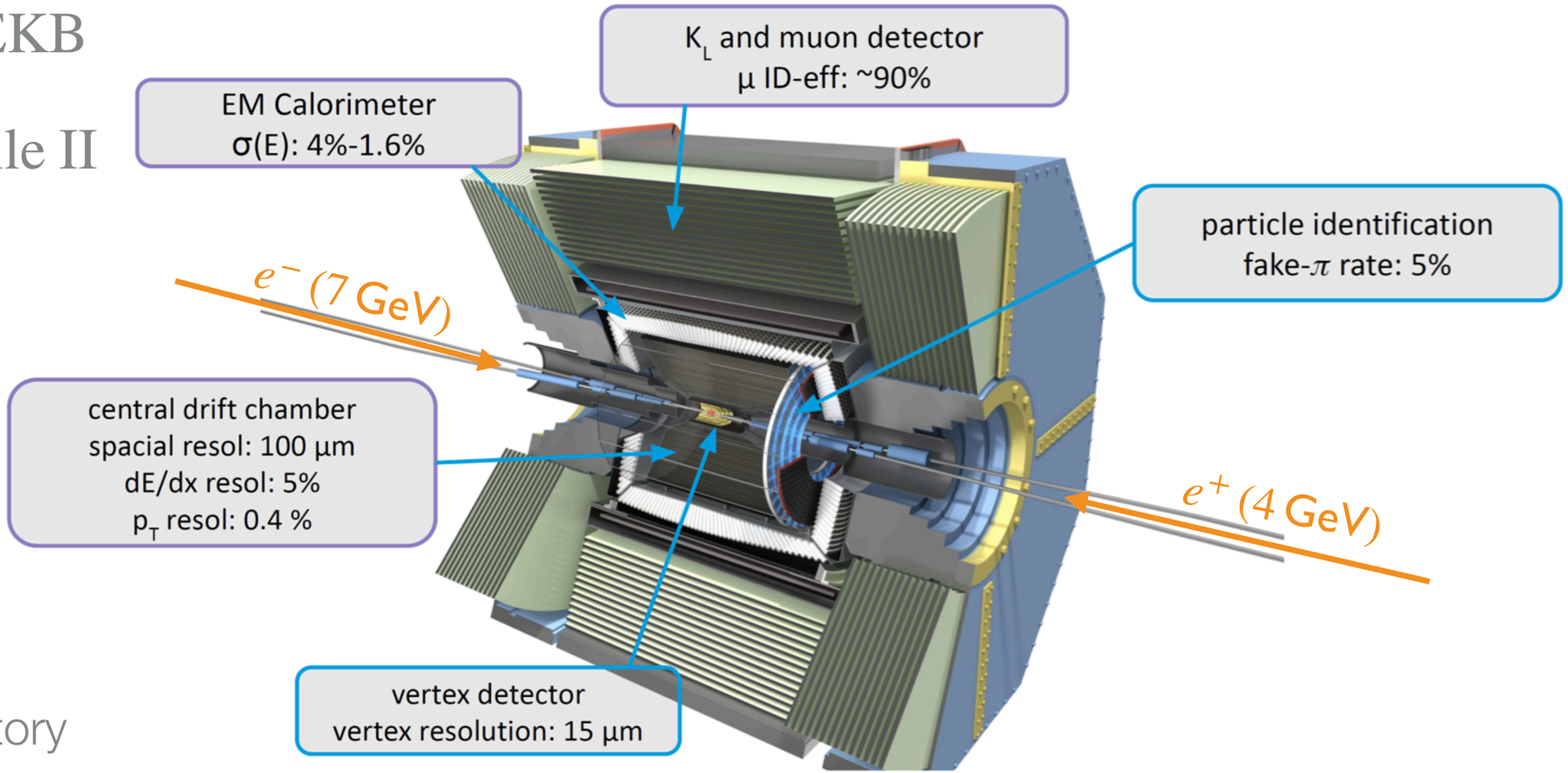
- Light **Dark-Sector** coupled to **Standard Model**
- Possible **Portal Interactions**:
  - Vector → Dark Photons A', Z'
  - Pseudo-scalar → ALPs
  - Scalar → Dark Higgs
  - Neutrino → Sterile Neutrinos



T. Ferber

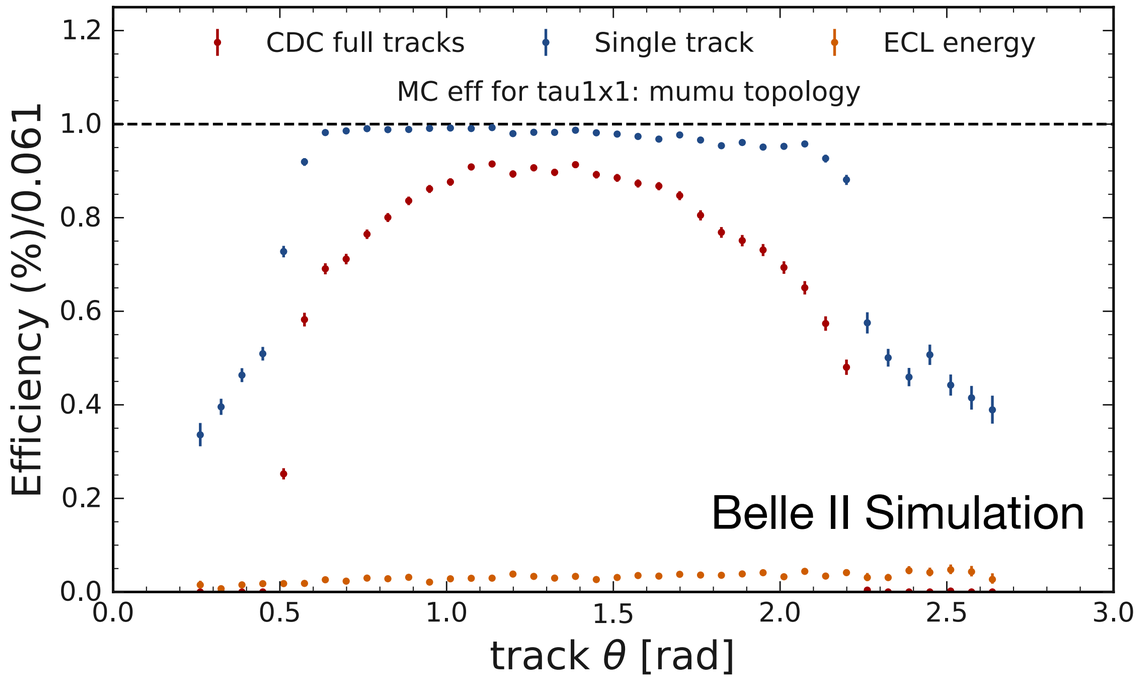
SuperKEKB collider & Belle II experiment.

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



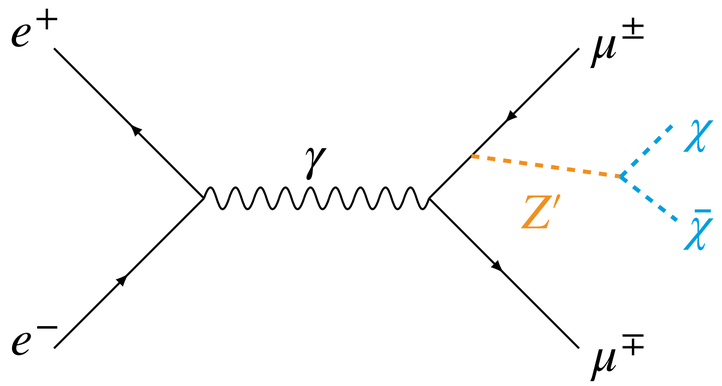
Searches for light Dark-Sectors with Belle II.

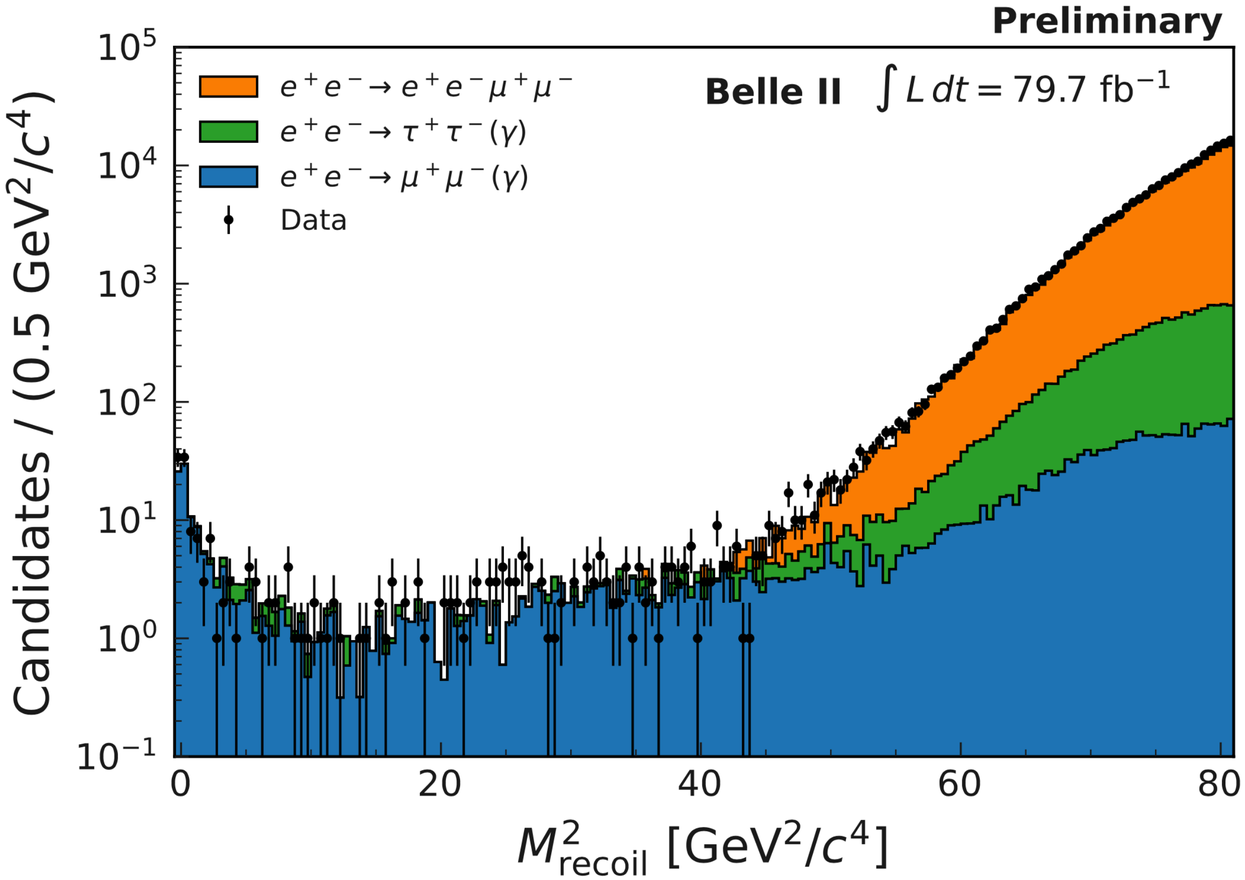
- Well known initial conditions and little/no pile-up
- Special triggers for low multiplicity
  - Single photon trigger (not available at Belle)
  - Single muon trigger
  - Single track trigger using NN
  - NN-based trigger at L1 under development e.g.
    - $3d$ track reconstruction
    - Displaced 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^2_{recoil} and $\theta^{\text{CMS}}_{\text{recoil}}$
- Backgrounds:
  - $e^+e^- \to \mu^+\mu^-(\gamma)$
  - $e^+e^- \to e^+e^-\mu^+\mu^-$
  - $e^+e^- \to \tau^+\tau^-(\gamma)\,,\, \tau \to \mu\nu\bar{\nu}$

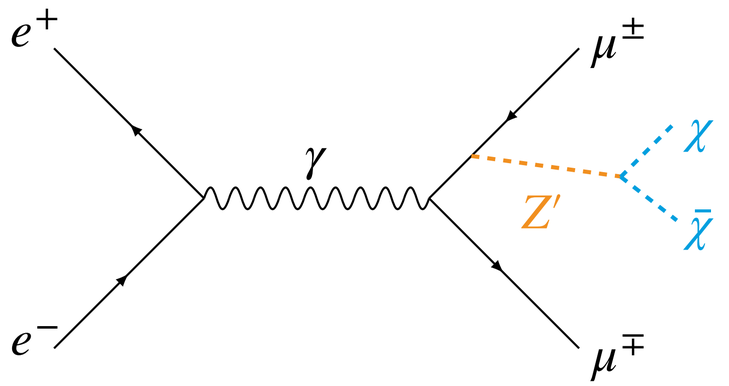




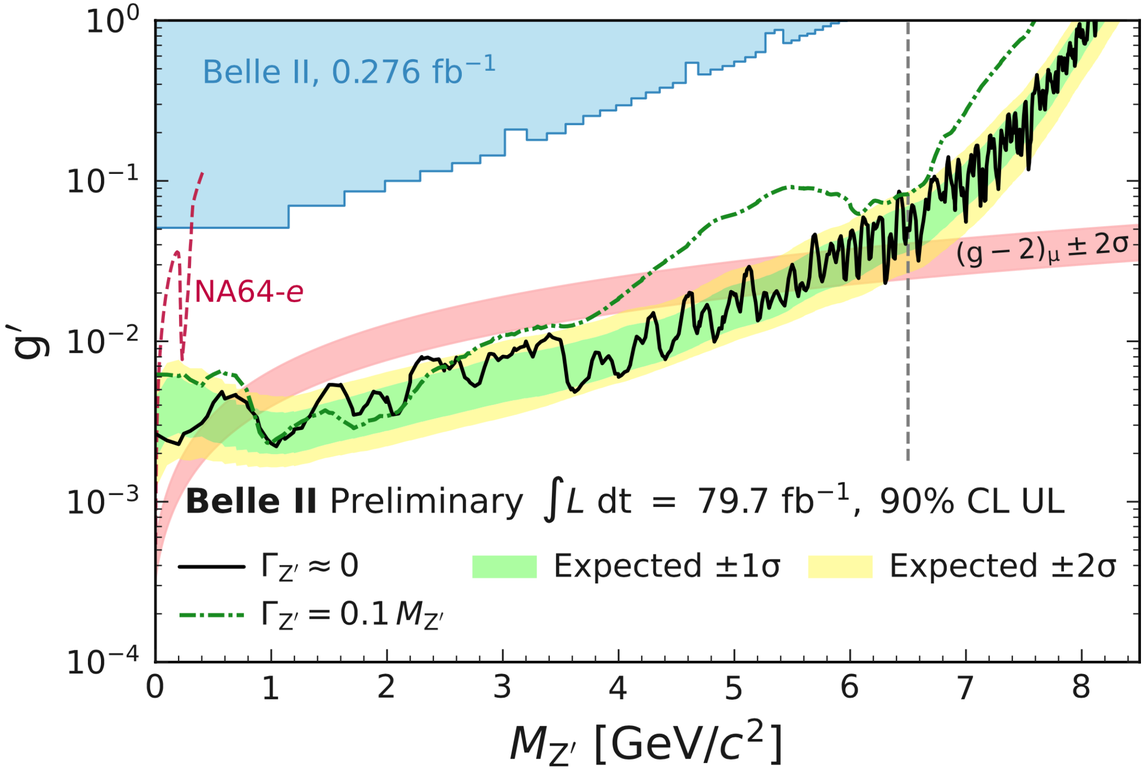
[1] B. Shuve et al., Phys. Rev. D 89, 113004

Search for an invisibly decaying Z' boson.

- Neural network with Punzi-loss trained for background suppression for all Z' masses simultaneously [1]
- $2d$ fit in M^2_{recoil} and $\theta^{\text{c.m.}}_{\text{recoil}}$
- Systematics and corrections from ee, $e\mu$ and $\mu\mu\gamma$ control samples
- Using partial dataset of $79.7\,\text{fb}^{-1}$, update of previous search [2] with 300x dataset
- $(g-2)_\mu$ preferred region excluded between $0.8 < m_Z < 4\,\text{GeV}/c^2$



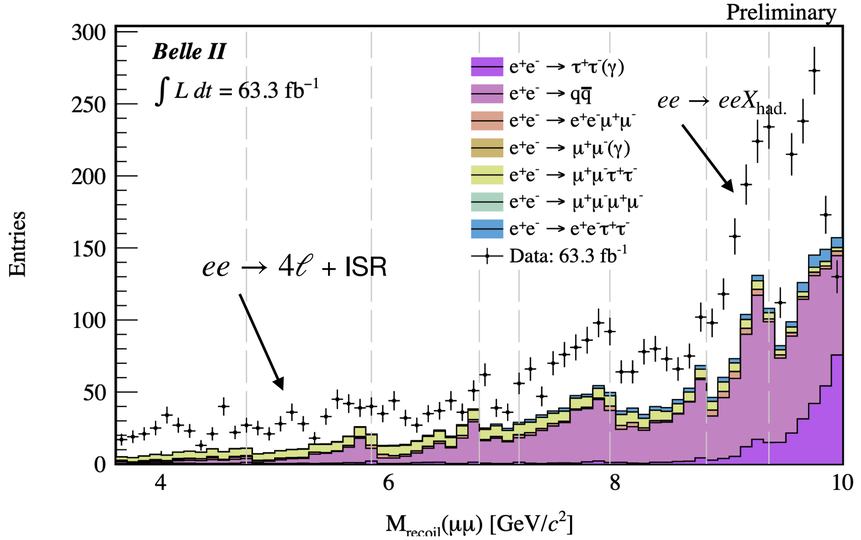
arXiv:2212.03066 to be submitted to PRL

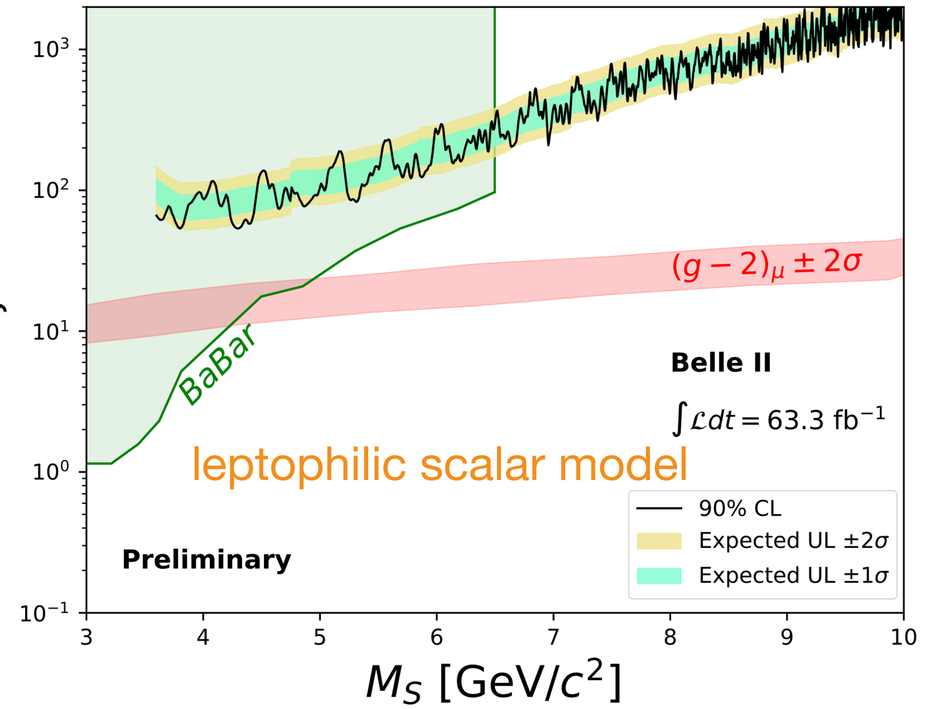


[1] F. Abudinén et al., Eur.Phys.J.C 82 (2022) 2, 121
[2] Belle II Collaboration, Phys. Rev. Lett. 124, 141801 (2020)

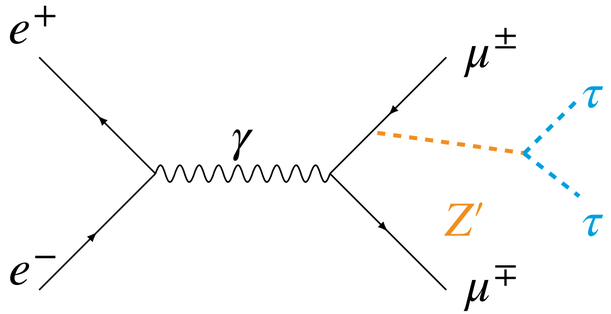
Search for a $\tau\tau$ resonance in $ee \to \mu\mu\tau\tau$.

- Probe **three different** models: Z' [1], leptophilic S [2] and ALP [3]
- τ decays to one charged plus any number of neutral particles
- Require missing energy by $M_{4\,\text{tracks}} < 9.5\ \text{GeV}/c^2$
- Eight **different classifiers** (MLP) in different $M_{\text{recoil}}(\mu\mu)$ regions
- Background determined directly in data → un-modelled non-peaking background are not problematic
- Strongest constraints for $M_S > 6.5\ \text{GeV}/c^2$ in leptophilic S model





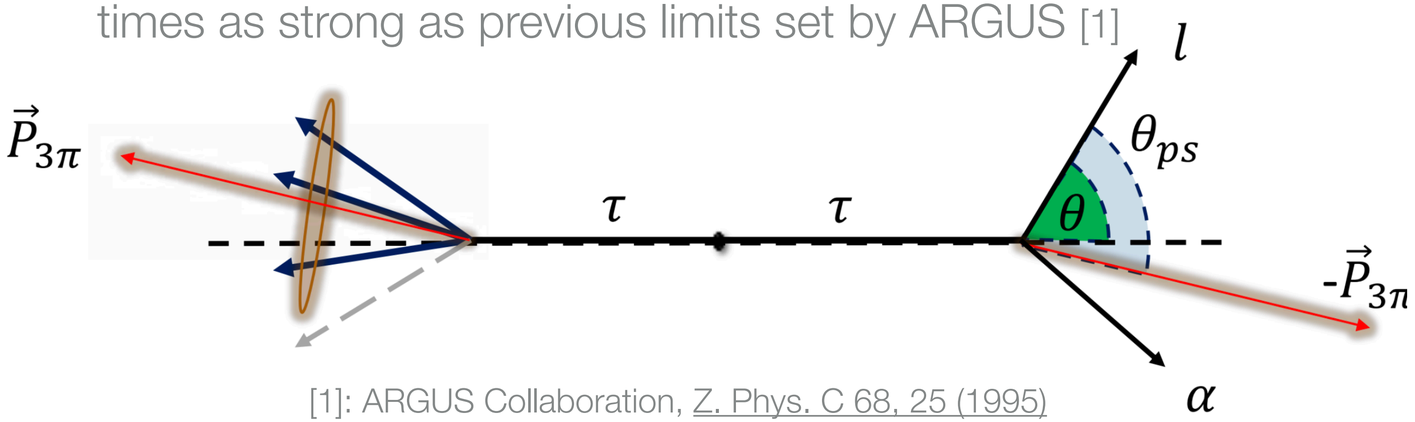
to be submitted soon!



[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

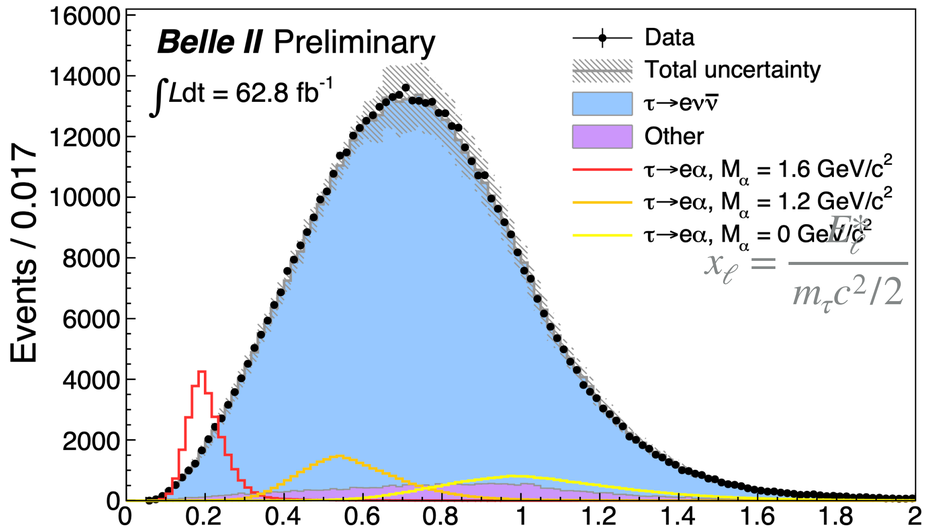
Search for an invisible scalar in lepton-flavour violating τ decays.

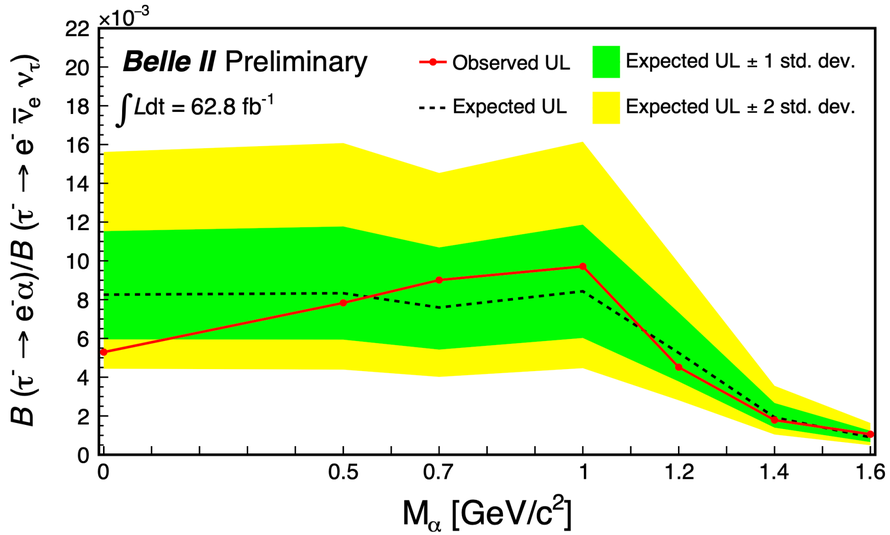
- Search for $\tau_{\mathrm{sig}} \to \ell\alpha$ with invisible scalar α
- Reconstruct $\tau_{\mathrm{tag}} \to 3\pi$ in $ee \to \tau_{\mathrm{tag}}\tau_{\mathrm{sig}}$
- Approx. τ_{sig} rest-frame by $E_{\tau_{\mathrm{sig}}} \approx E_{\mathrm{cms}}/2$ and $\hat{p}_{\mathrm{sig}} \approx -\vec{p}_{\tau_{\mathrm{tag}}}/|\vec{p}_{\tau_{\mathrm{tag}}}|$
- Two body signal decay topology
- Search for bump on top of $\tau_{\mathrm{sig}} \to \ell\nu\bar{\nu}$
- Observed limits using partial dataset of $62.8\,\mathrm{fb}^{-1}$ are 2.2 to 14 times as strong as previous limits set by ARGUS [1]



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

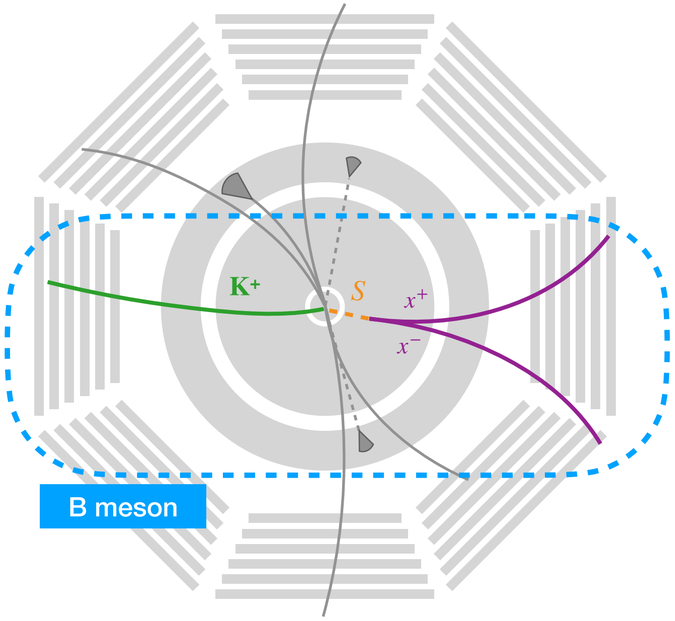
arXiv:2212.03634v1 to be submitted to PRL

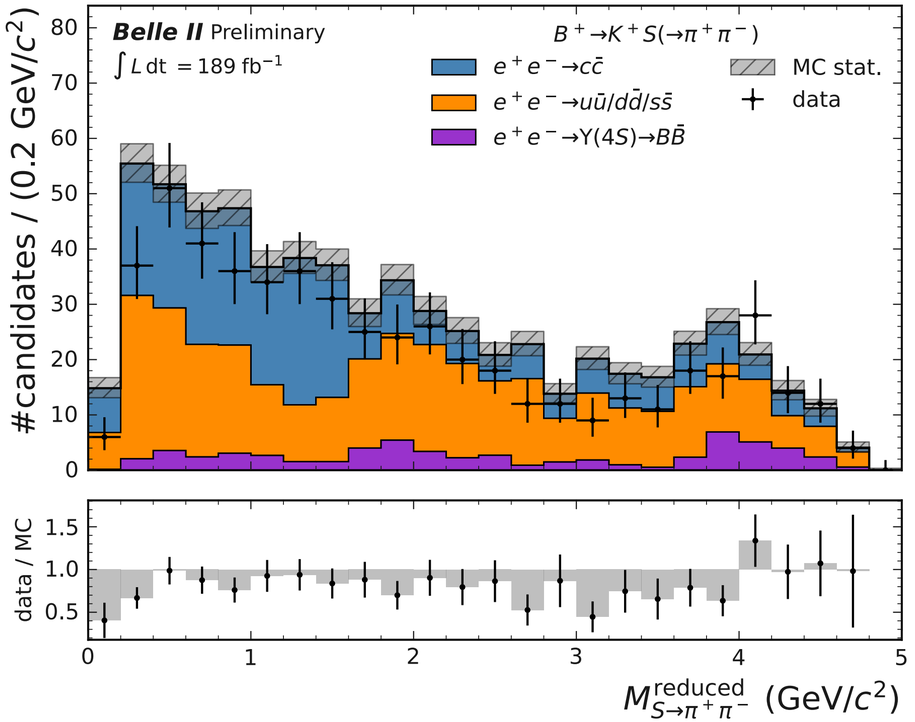




Search for a long-lived (pseudo-)scalar in $b \to s$ transitions.

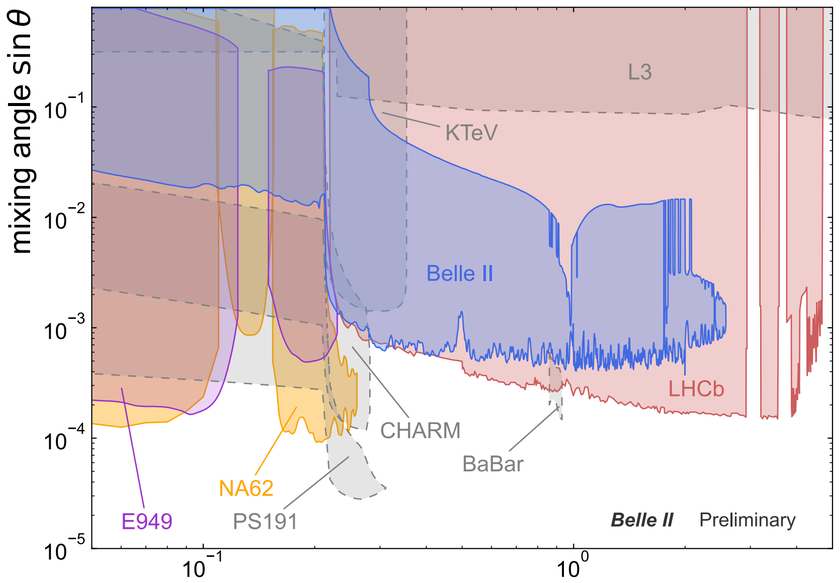
- Dark **long-lived (pseudo-)scalar** in $b \to s$ transitions
- First long-lived particle search from Belle II
- No direct mediator production: $B-$meson decays
- Search in eight exclusive fully visible channels:
  - $B^+ \to K^+ S$ and $B^0 \to K^{*0} S$ with $K^{*0} \to K^+ \pi^-$
  - $S \to ee/\mu\mu/\pi\pi/KK$
- Bump hunt in LLP mass distribution M_S using unbinned maximum likelihood fits
- Dedicated study of displaced vertex performance, corrections determined with K^0_S control sample
  - Reconstruction efficiency & M_S shape
  - Particle identification

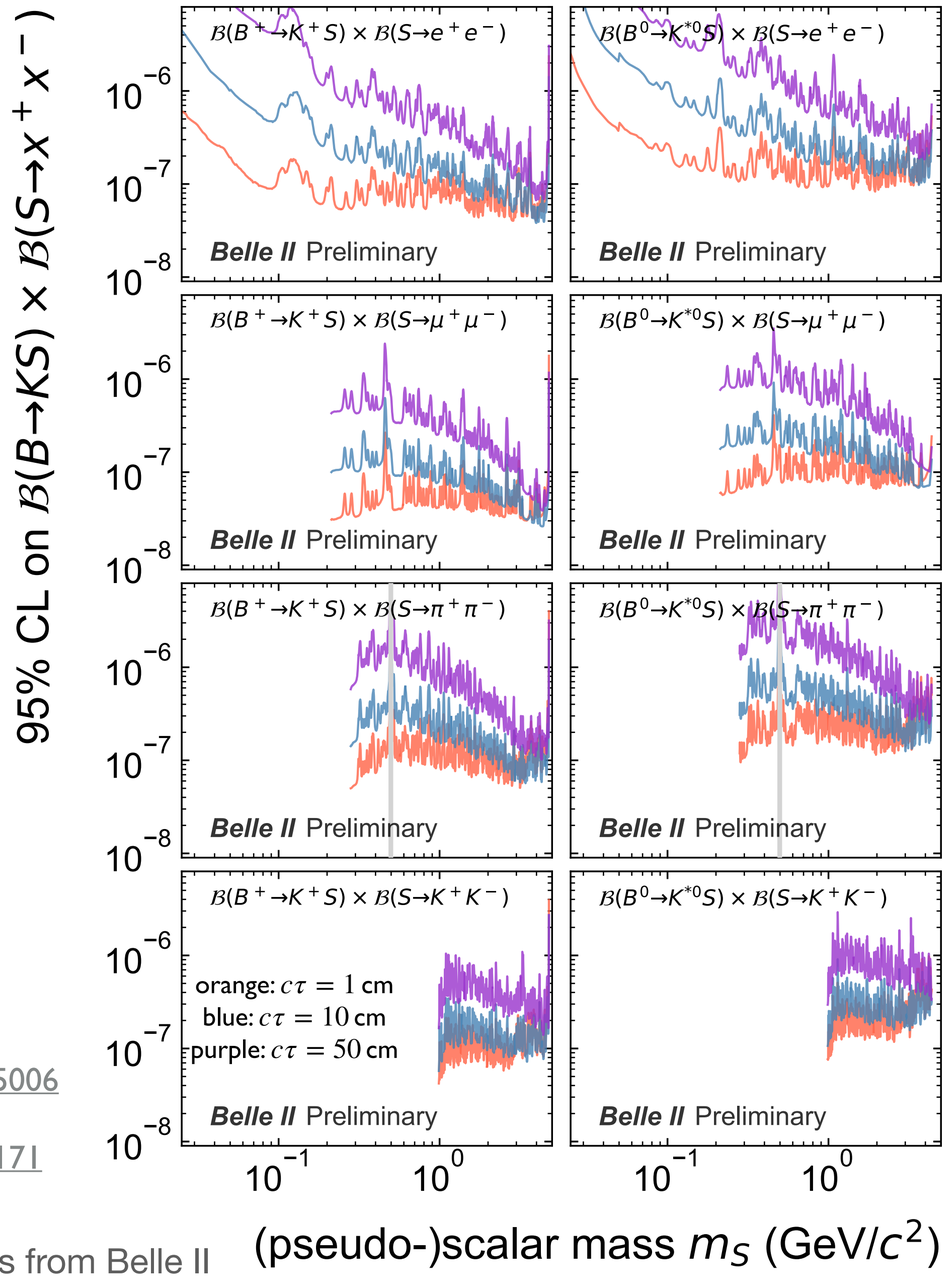




Search for a long-lived (pseudo-)scalar in $b \to s$ transitions.

- Setting model independent limits on (pseudo-)scalar LLP branching fraction
- First limits for LLP decays into hadrons
- Model interpretations
  - Dark Higgs-like scalar S [1] (FPC BC4)
  - Pseudo-scalar ALP a [2] (FPC BC10)



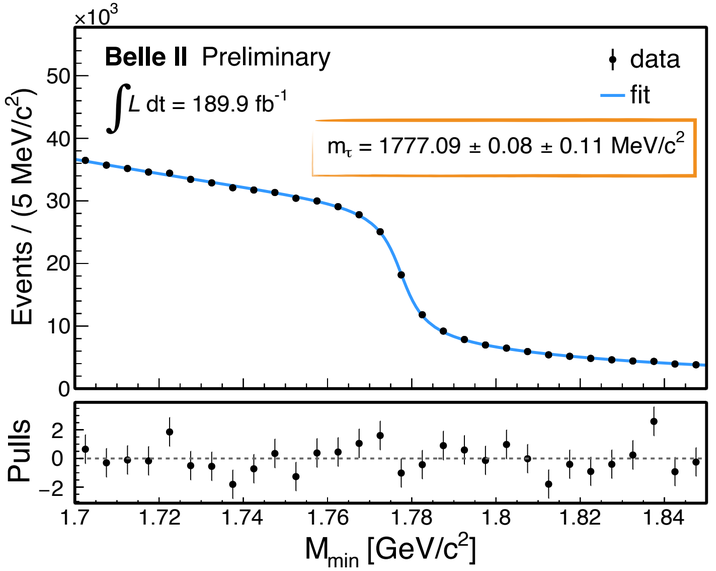


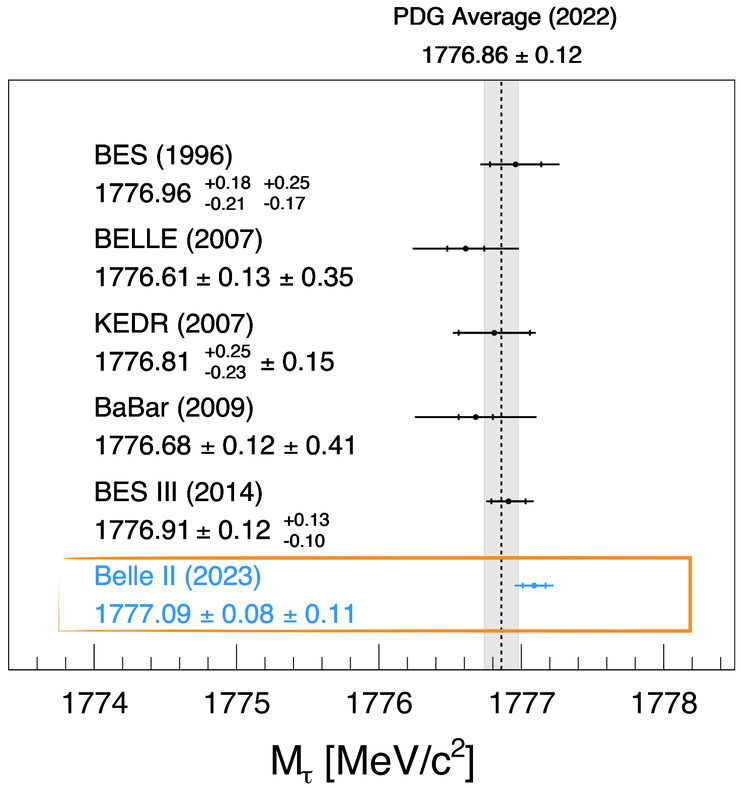
[1]: Phys. Rev. D 101, 095006 (2020)
[2]: JHEP 1503 (2015) 171

Measurement of the τ-lepton mass.

- Large for $e^+e^- \to \tau\tau$ cross-section and clean environment allow high precision measurements of τ-lepton properties
- Reconstruct $\tau^{\pm}_{\text{tag}} \to \pi^{\pm}(\pi^0)$ and $\tau_{\text{sig}} \to 3\pi$
- Four tracks and no additional high energy photons in the event
- Pseudo-mass technique to access mass:
  - Sharp edge at m_τ
  - Use empirical fit function

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

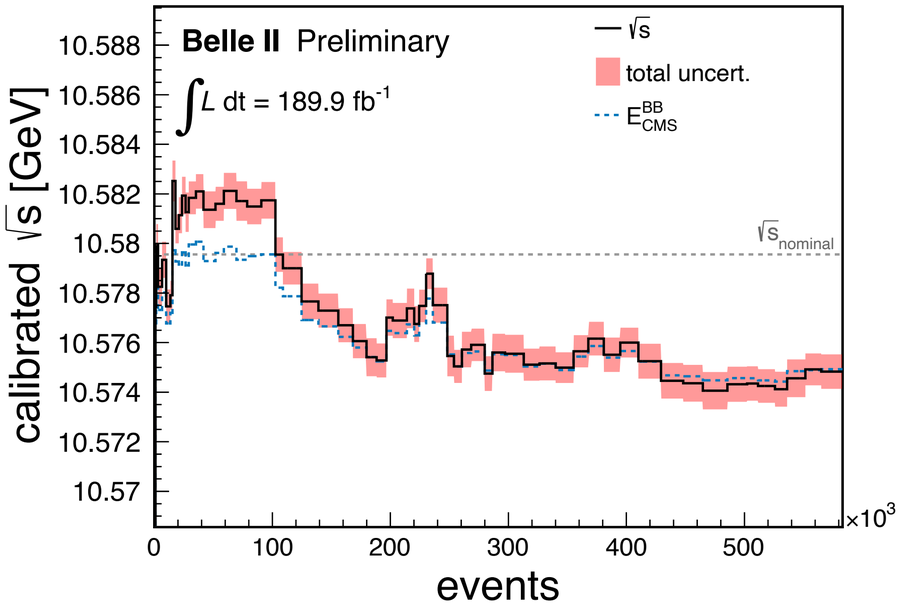


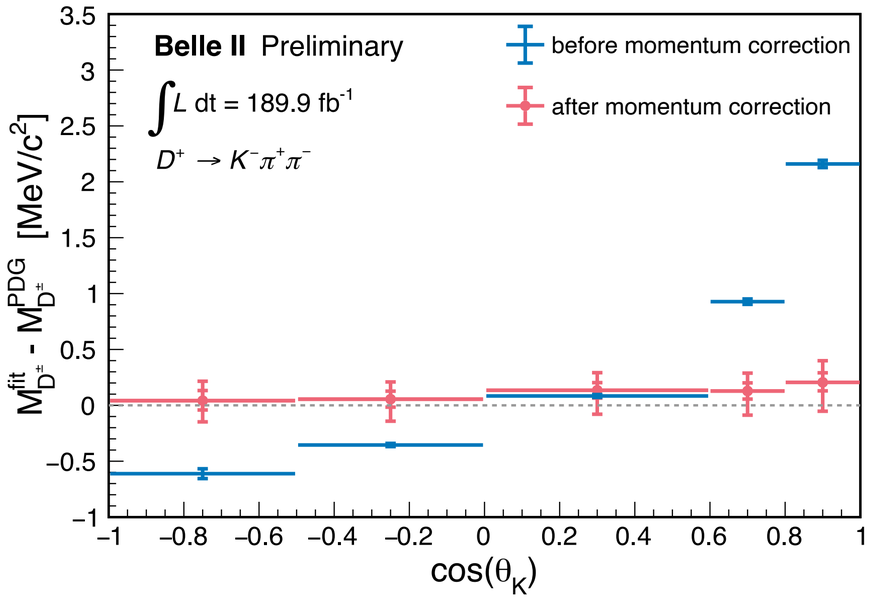


Measurement of the τ-lepton mass.

- Worlds most precise τ mass measurement!
- Benchmark for precision capabilities and collaborative work for the Belle II experiment
- Control of systematic uncertainties is key:

Source	Uncertainty [MeV/c^2]
Knowledge of the colliding beams:	
Beam energy correction	0.07
Boost vector	$\leq$ 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	$\leq$ 0.01
Imperfections of the simulation:	
Detector material budget	0.03
Modeling of ISR and FSR	0.02
Momentum resolution	$\leq$ 0.01
Neutral particle reconstruction efficiency	$\leq$ 0.01
Tracking efficiency correction	$\leq$ 0.01
Trigger efficiency	$\leq$ 0.01
Background processes	$\leq$ 0.01
Total	0.11

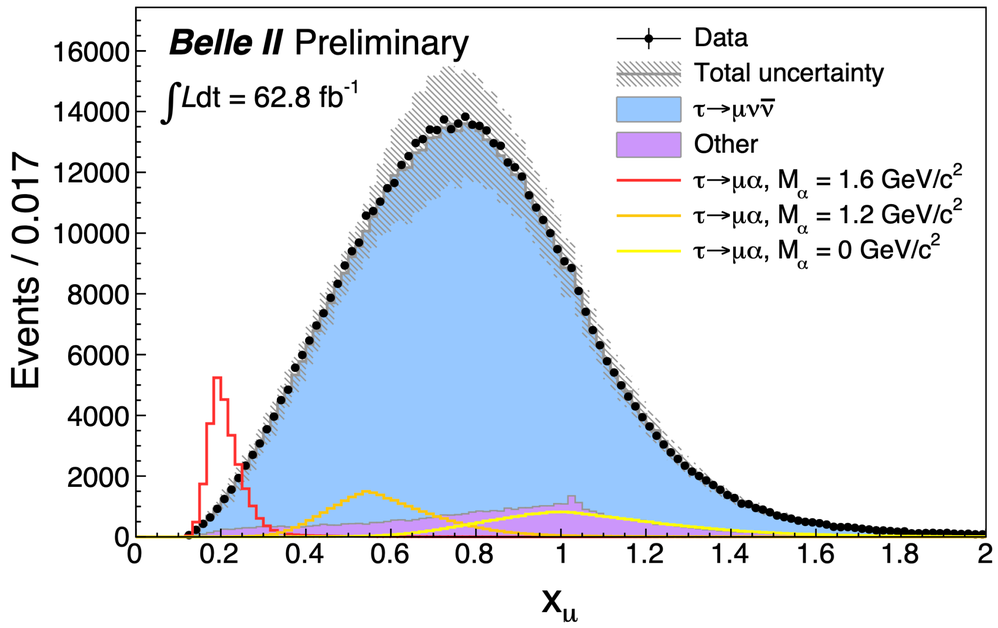


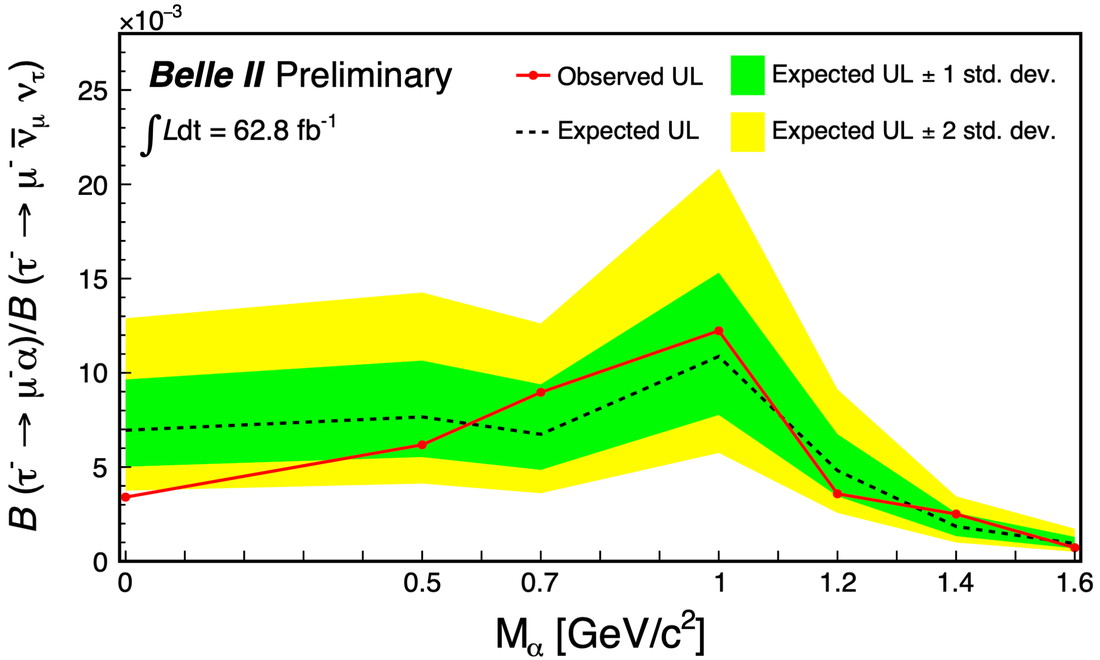


Summary.

- Recent Dark-Sector and τ results from Belle II:
  - Search for invisible Z' in $ee \to \mu\mu Z'$ arXiv:2212.03066
  - Search for $\tau\tau$ resonance in $ee \to \mu\mu\tau\tau$ (to be published soon)
  - Search for invisible LF-violating scalar in $\tau \to \ell\alpha$ arXiv:2212.03634
  - Search for a long-lived (pseudo-)scalar in $b \to s$ transitions (to be published soon)
  - Measurement of the τ-lepton mass (to be published soon)
- Belle II has a unique sensitivity to light Dark-Sectors and can perform precision measurements
- Results are complimentary to higher-energy collider and beam-dump experiments

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

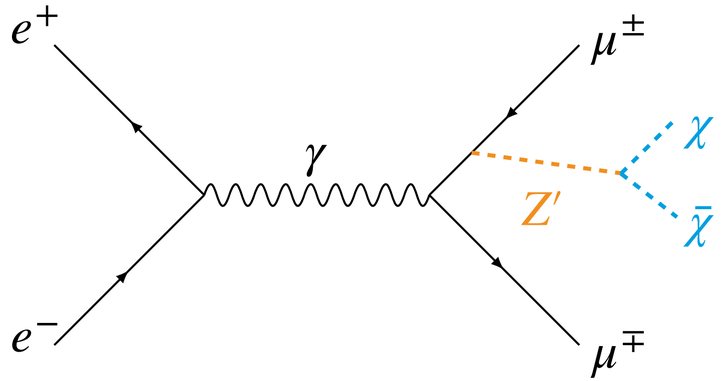


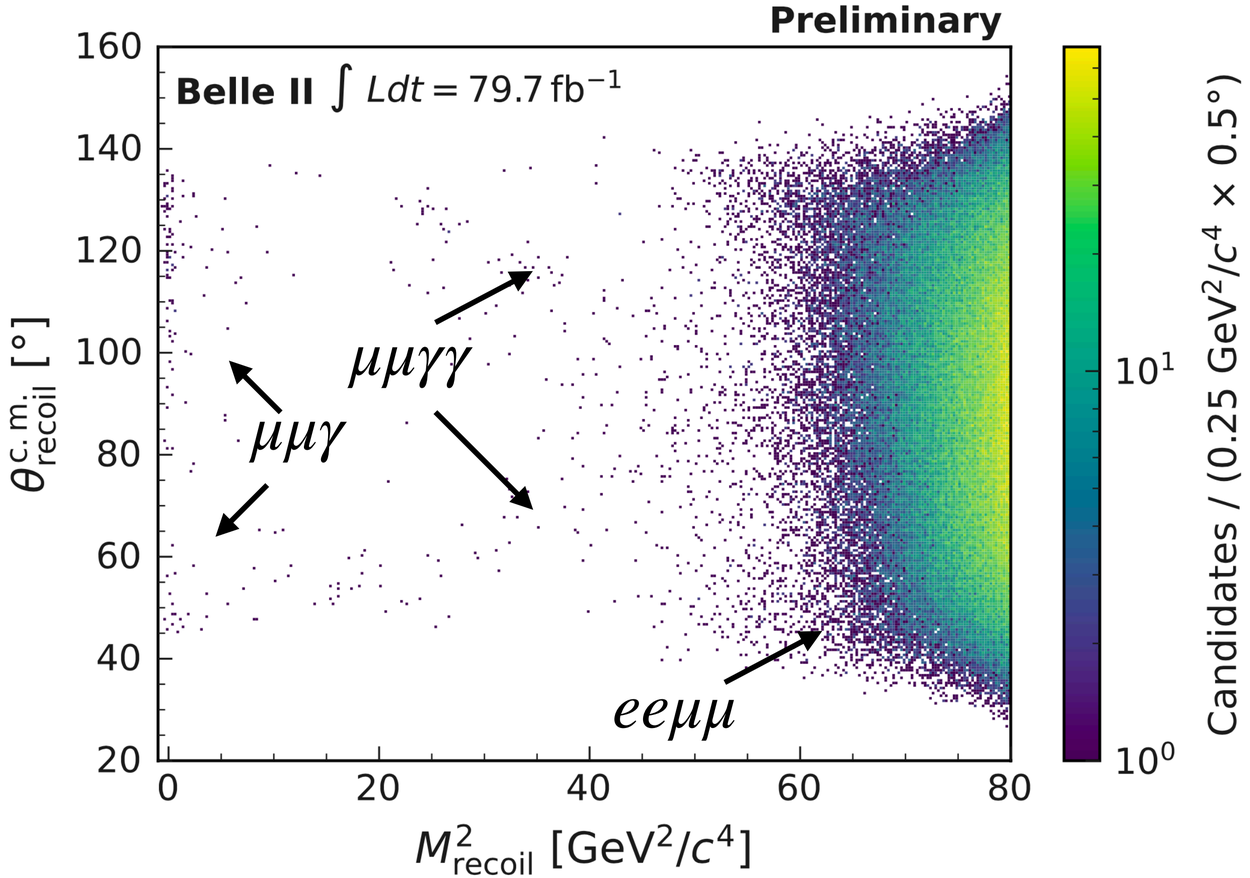


[1]: ARGUS Collaboration, Z. Phys. C 68, 25 (1995)

Search for an invisibly decaying Z' boson.

- 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^2_{recoil} and $\theta^{\text{c.m.}}_{\text{recoil}}$
- 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
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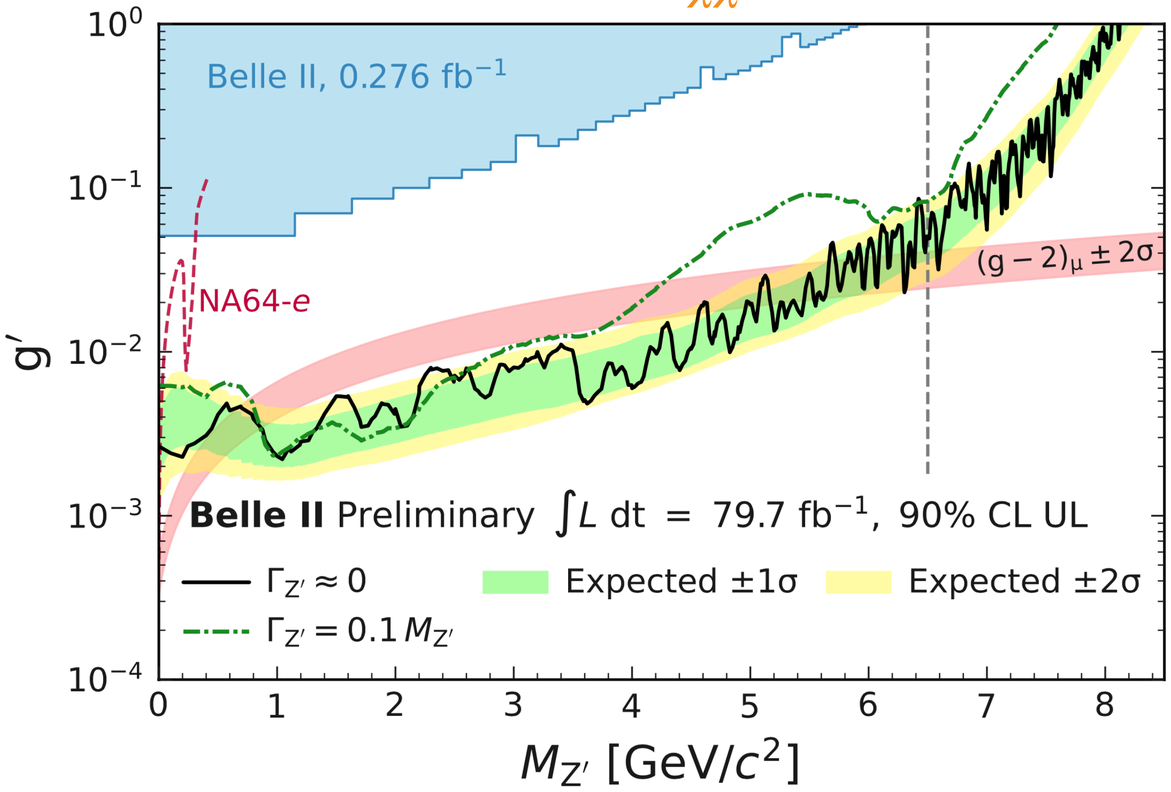
Search for an invisibly decaying Z' boson.

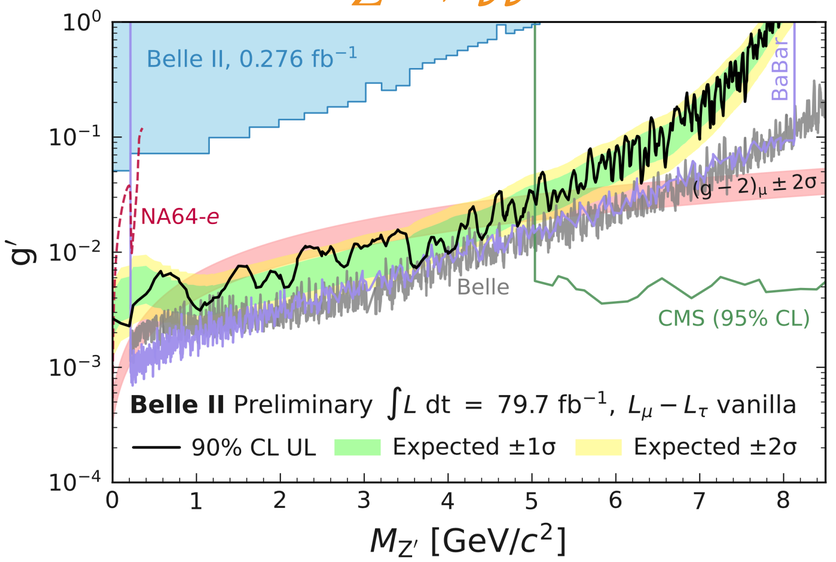
$Z' \to \chi\bar{\chi}$



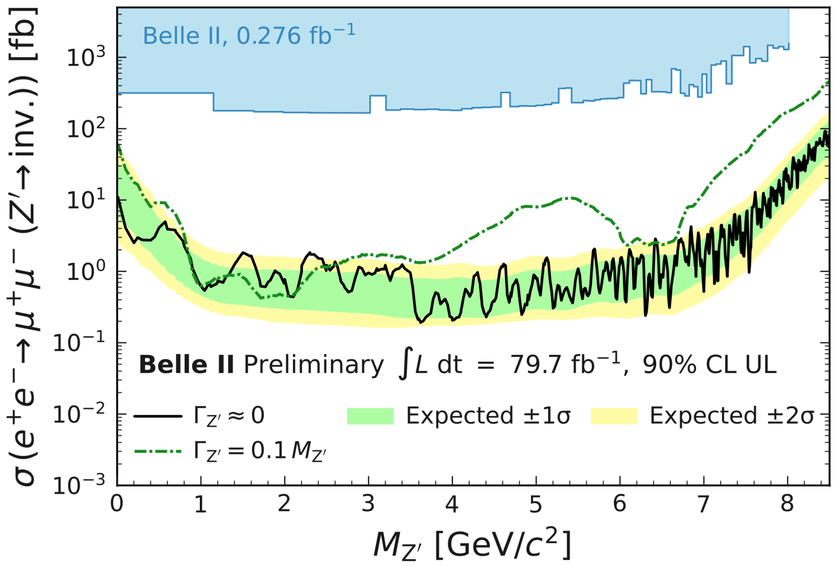
$(g-2)_\mu$ preferred region excluded between $0.8 < m_Z < 4\,\mathrm{GeV}/c^2$

arXiv:2212.03066 to be submitted to PRL

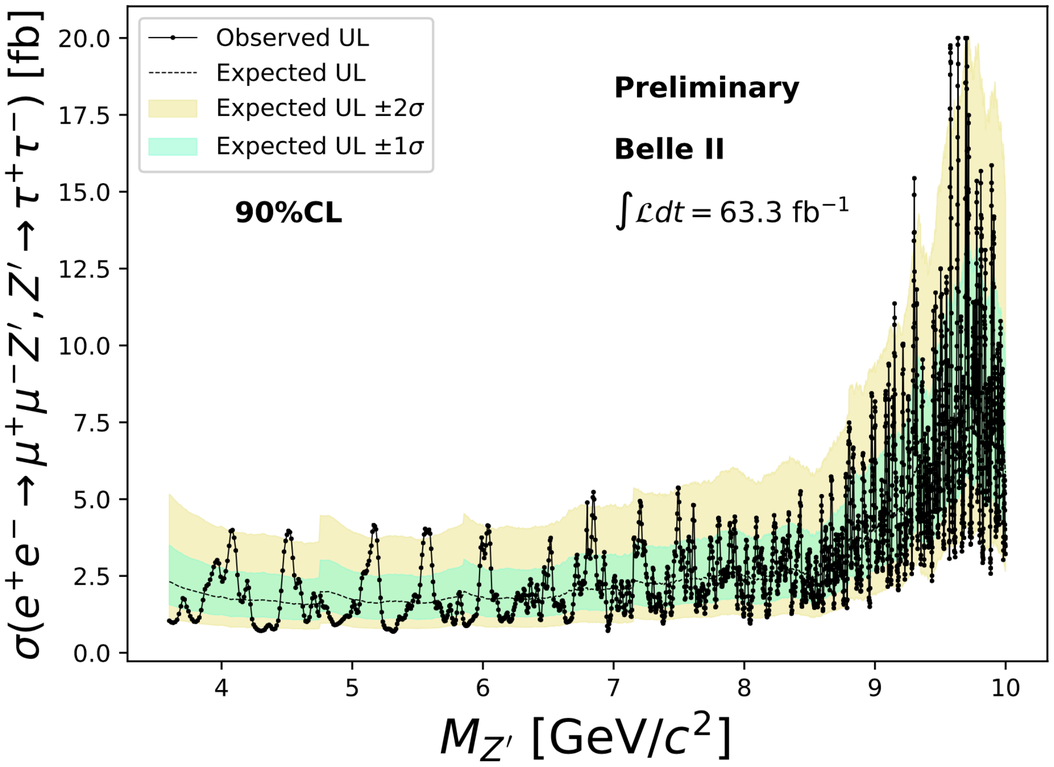
$Z' \to \nu\bar{\nu}$



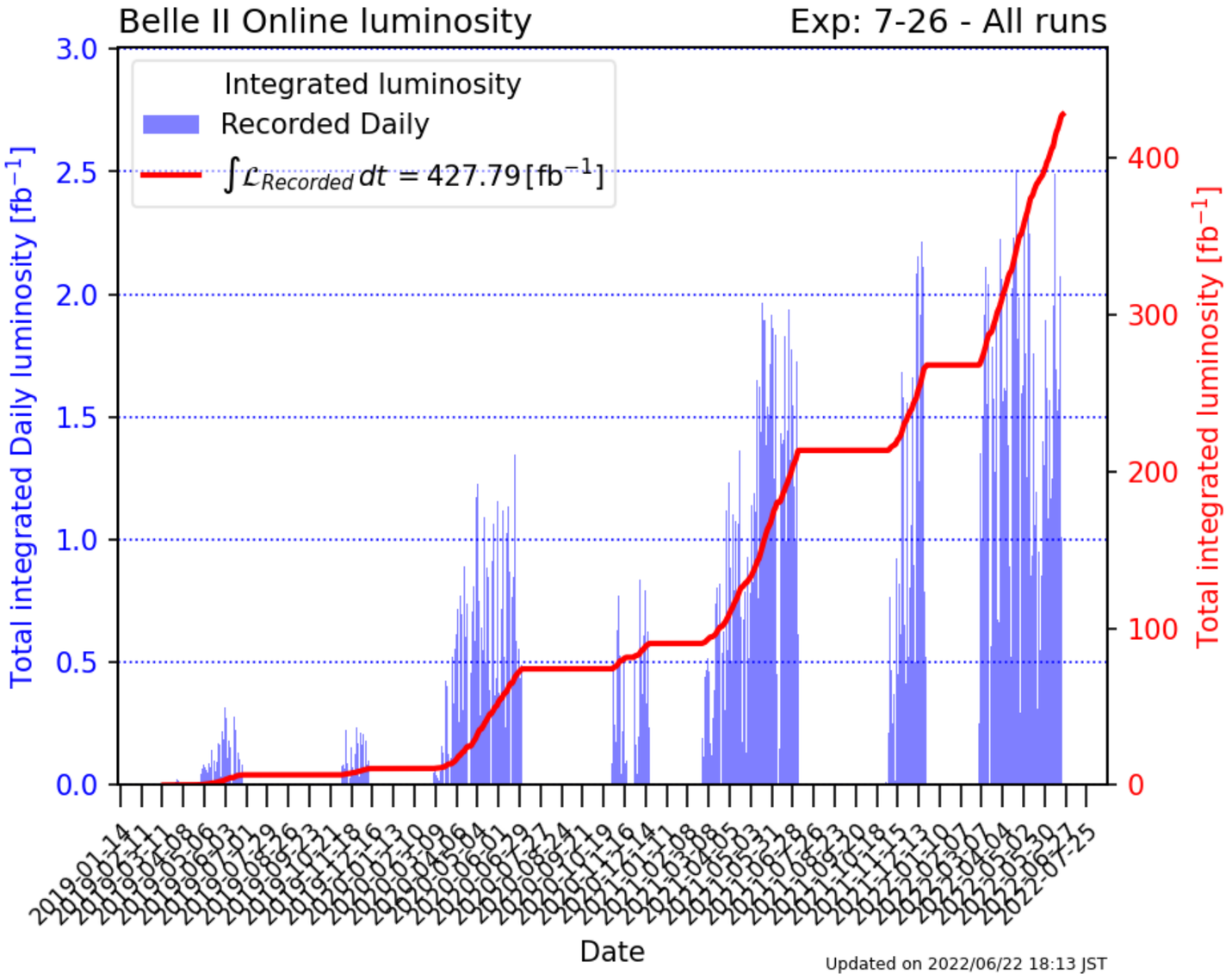
cross-section



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



Backup.


Belle II Online luminosity
Exp: 7-26 - All runs
Integrated luminosity
Recorded Daily
$\int \mathcal{L}_{Recorded}\, dt = 427.79\,[\mathrm{fb}^{-1}]$
Total integrated Daily luminosity [fb^{-1}]
Total integrated luminosity [fb^{-1}]
3.0
2.5
2.0
1.5
1.0
0.5
0.0
400
300
200
100
0
Date
Updated on 2022/06/22 18:13 JST