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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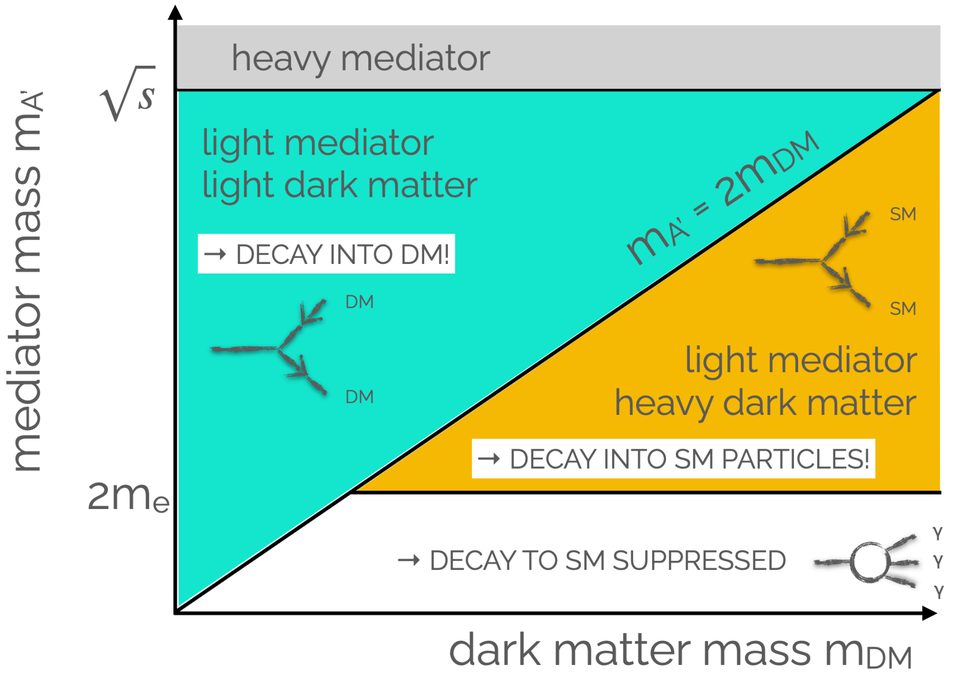
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

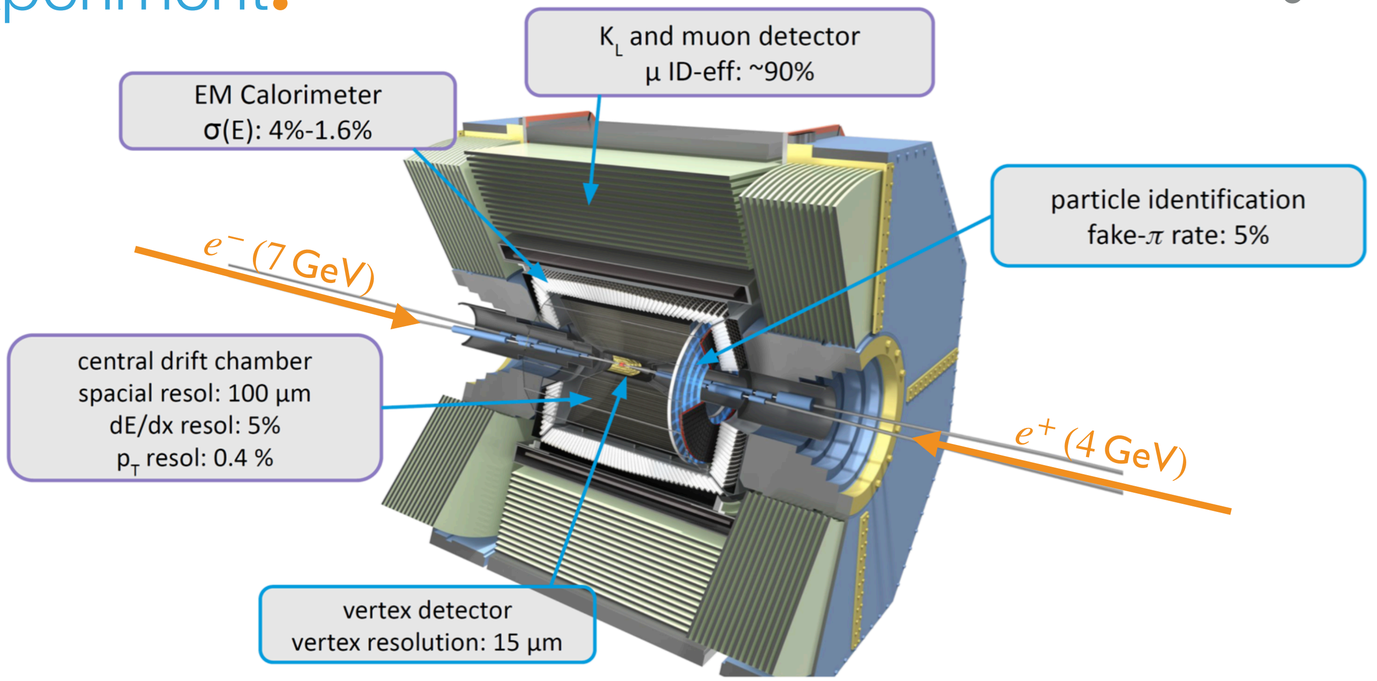
Light dark sectors and precision measurements.

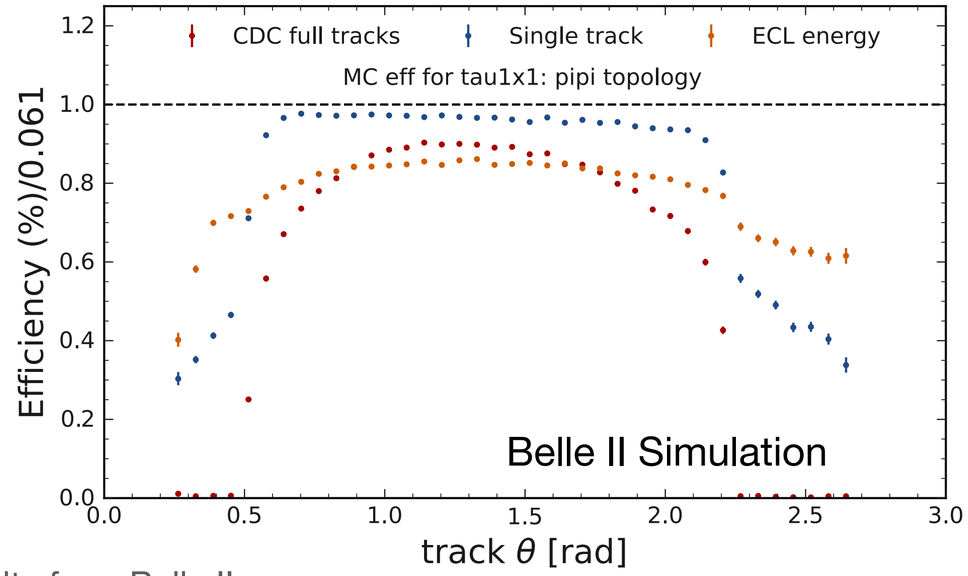
1. Direct searches for BSM physics:
   - No signs in searches for SUSY and extra dimensions
   - Light dark sectors not yet well tested
   - Target mediators that couple dark sectors to SM
   - Theoretical description via portal interactions
2. Precision measurements of SM parameters
   - Direct test 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.

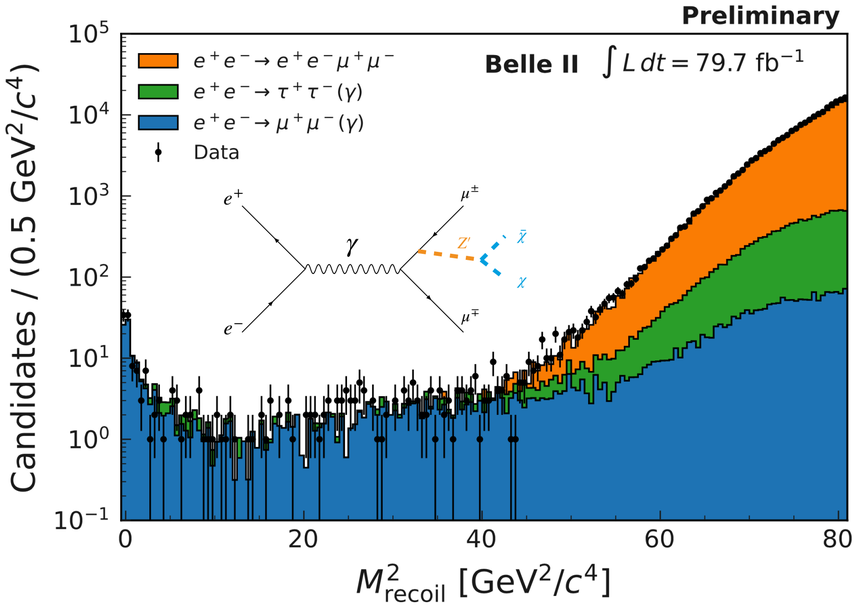
- SuperKEKB accelerator
- Upgraded Belle II detector
- Running at the $\Upsilon(4S)$
- Collected 428 fb^{-1}, currently in LS1
- Well **known initial conditions**
- Little/no pile-up — **clean environment**
- **Special triggers** for low multiplicity
  - Single photon trigger (not available at Belle)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

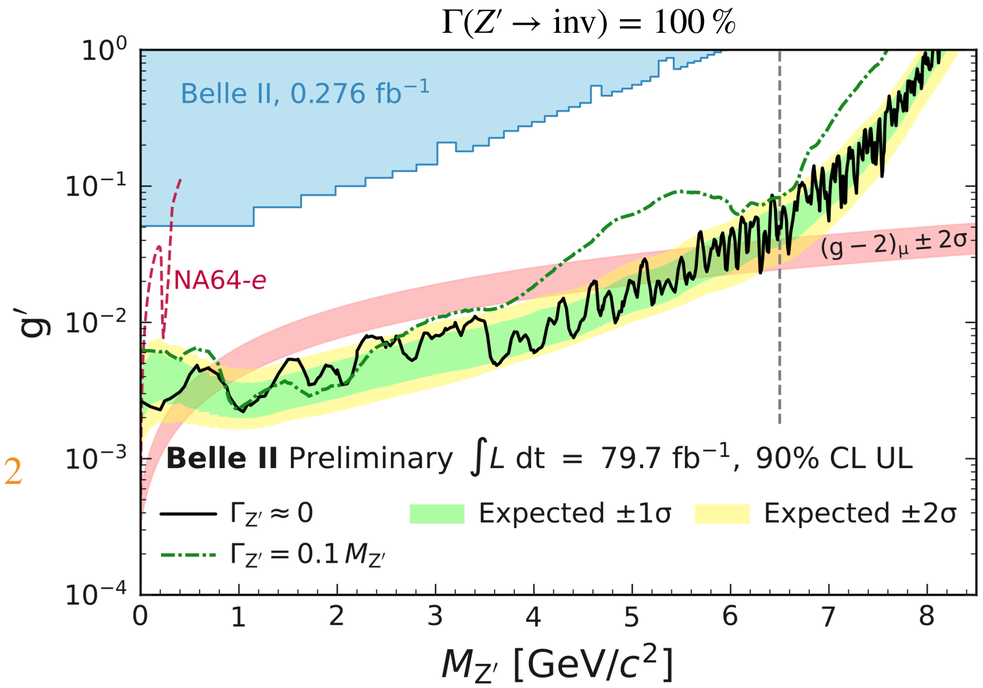




Search for an invisibly decaying Z' boson.

- 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^2_{recoil} and $\theta^{\text{CMS}}_{\text{recoil}}$
- 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
- Update of [3] with 300x dataset
- **$(g-2)_\mu$ preferred region excluded for $m_Z \in (0.8, 4.0)$ GeV/c^2**

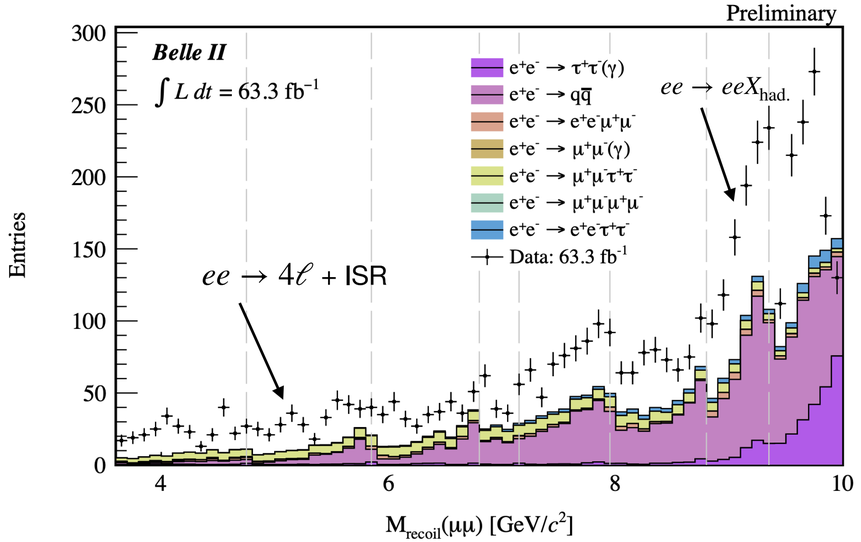


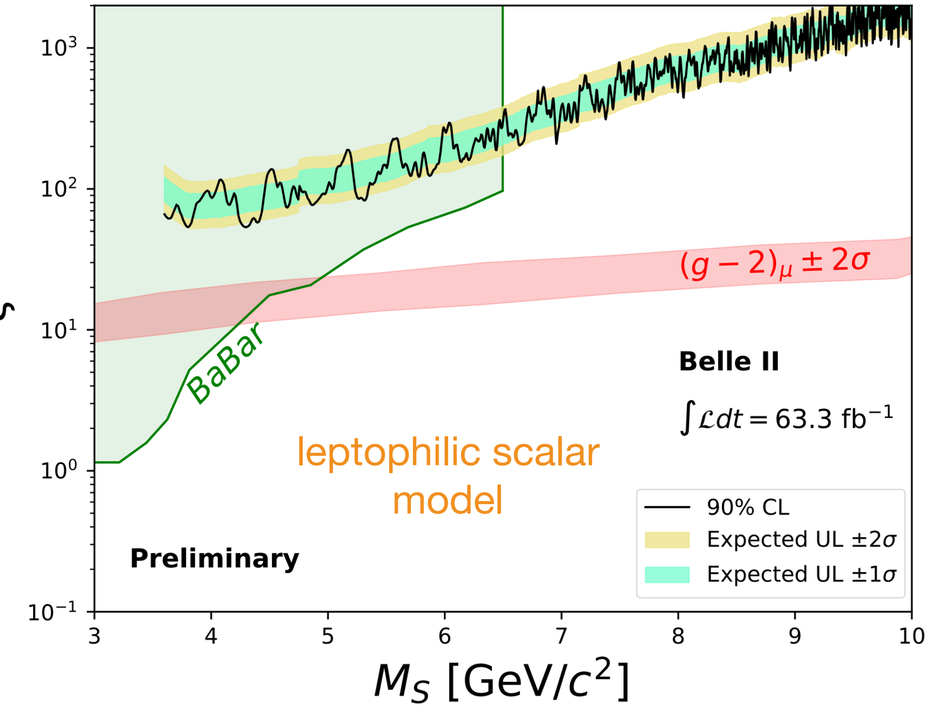


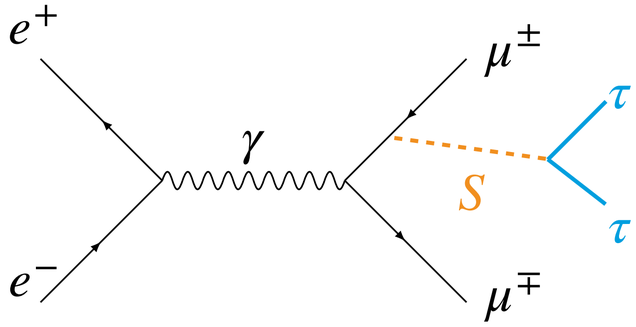
[1] B. Shuve et al., Phys. Rev. D 89, 113004
[2] F. Abudinén et al., Eur.Phys.J.C 82 (2022) 2, 121
[3] Belle II Collaboration, Phys. Rev. Lett. 124, 141801 (2020)

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

- Four track final-state: $\tau^{\pm} \to \pi^{\pm}(\pi^0)\nu, \ell\nu\nu$ with $\ell = e, \mu$
- 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 → un-modelled non-peaking background are not problematic
- **Strongest constraints** for $M_S > 6.5\ \text{GeV}/c^2$ in leptophilic S model [1]



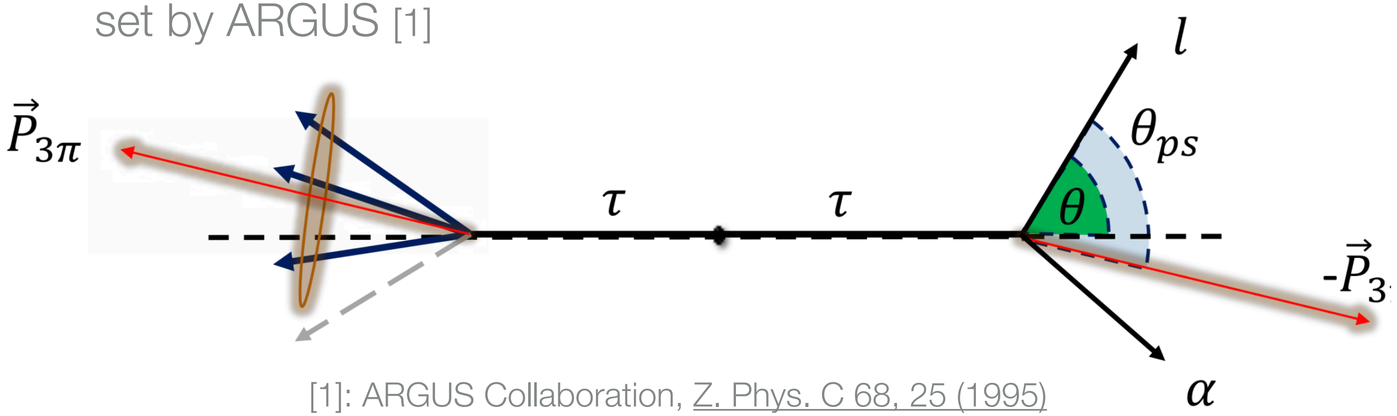




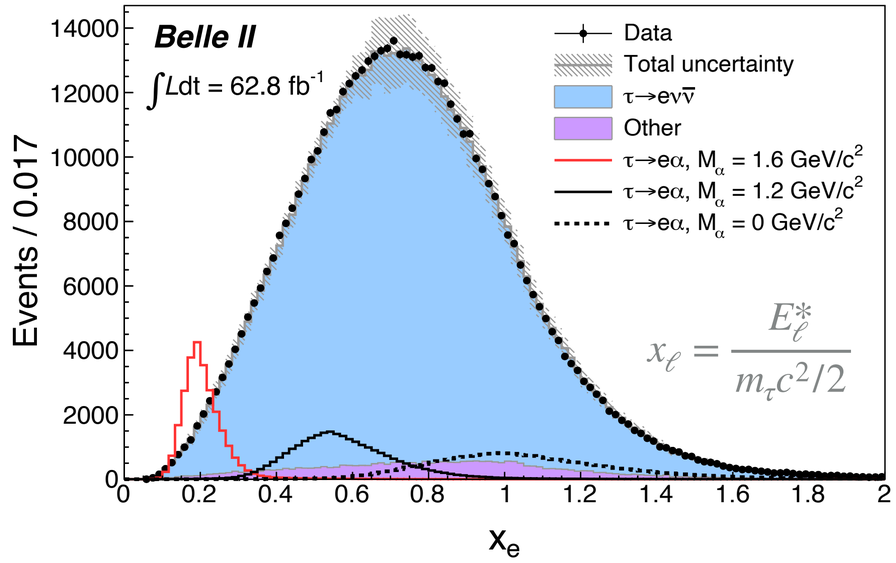
[1] B. Batell et. al. PRD 95 (2017) 075003

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

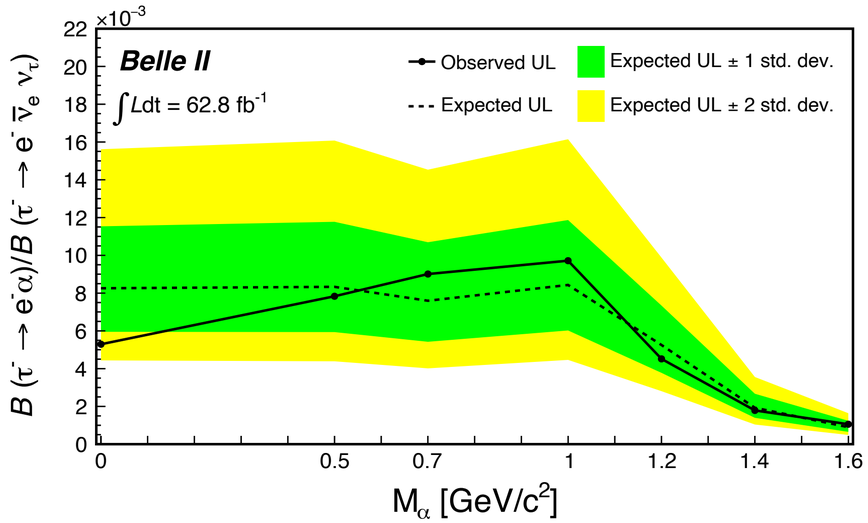
- Search for $\tau_{\text{sig}} \to \ell\alpha$ with invisible scalar α and $\ell = e, \mu$
- Reconstruct $\tau_{\text{tag}} \to 3\pi\nu$ (ν missing) in $ee \to \tau_{\text{tag}}\tau_{\text{sig}}$
- Approximate τ_{sig} rest-frame by:
  - $E_{\tau_{\text{sig}}} \approx E_{\text{cms}}/2$ and $\hat{p}_{\text{sig}} \approx -\vec{p}_{\tau_{\text{tag}}}/|\vec{p}_{\tau_{\text{tag}}}|$
- Two body signal decay topology
- Search for bump on top of $\tau_{\text{sig}} \to \ell\nu\bar{\nu}$
- Observed limits are **2.2 to 14x stronger than previous limits** set by ARGUS [1]



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

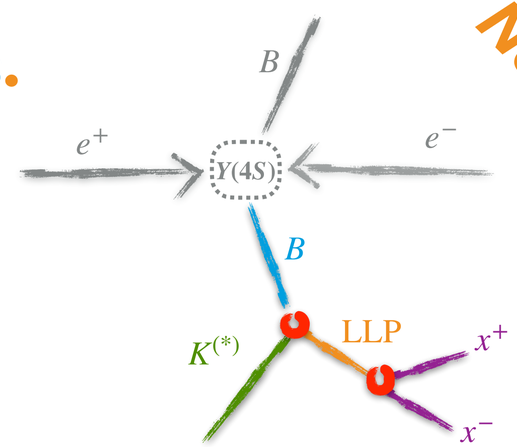


arXiv:2212.03634v1 accepted by PRL

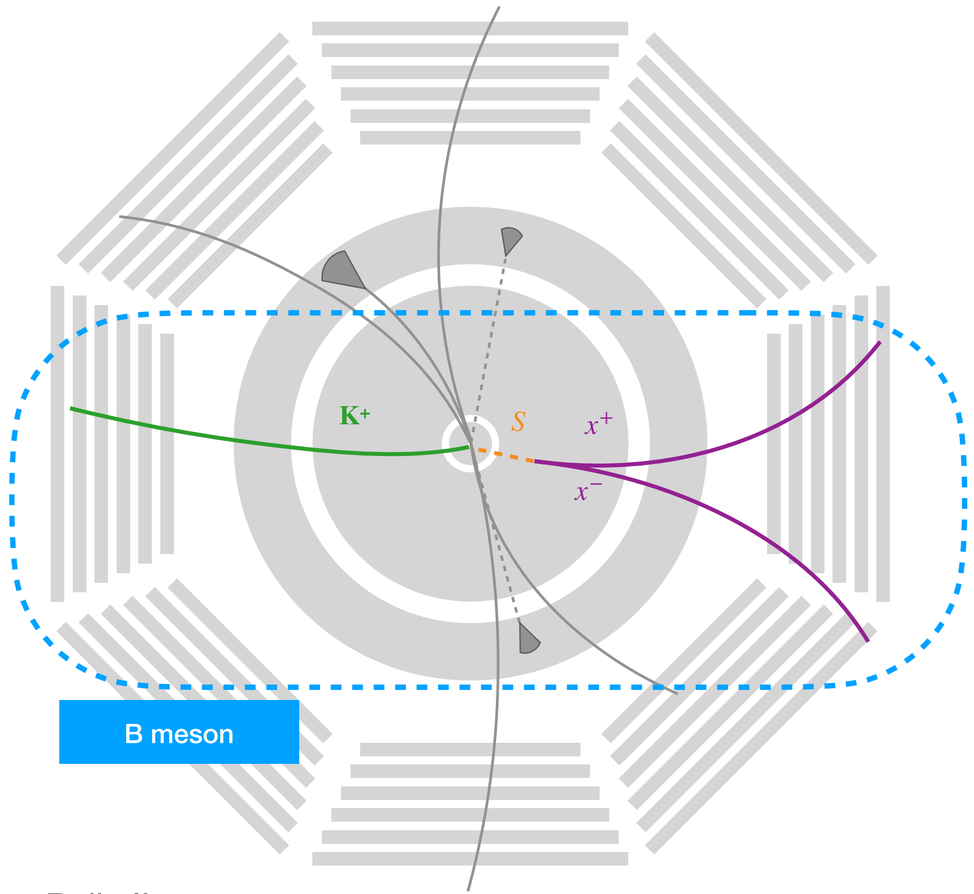


Search for a long-lived (pseudo-)scalar in $b \to s$ transitions.

New for Moriond!



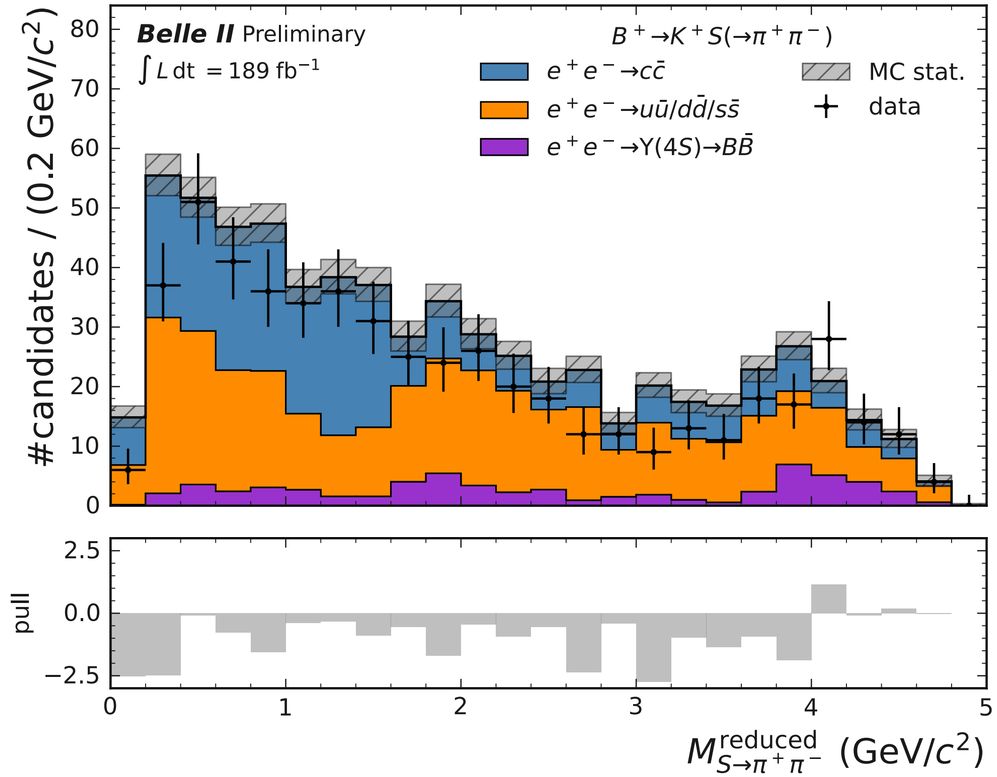
- First Belle II long-lived particle (LLP) search!
- Search in eight exclusive visible channels:
  - $B^+ \to K^+ S$ and $B^0 \to [K^{*0} \to K^+\pi^-]S$
  - $S \to ee/\mu\mu/\pi\pi/KK$
- Signal B-meson fully reconstructed
- Backgrounds:
  - Combinatorial $ee \to q\bar{q}$ reduced by requiring kinematics similar to B-meson expectations
  - K^0_S window vetoed in $M_{\pi\pi}$
  - Further peaking backgrounds suppressed by tighter displacement selection



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

New for Moriond!

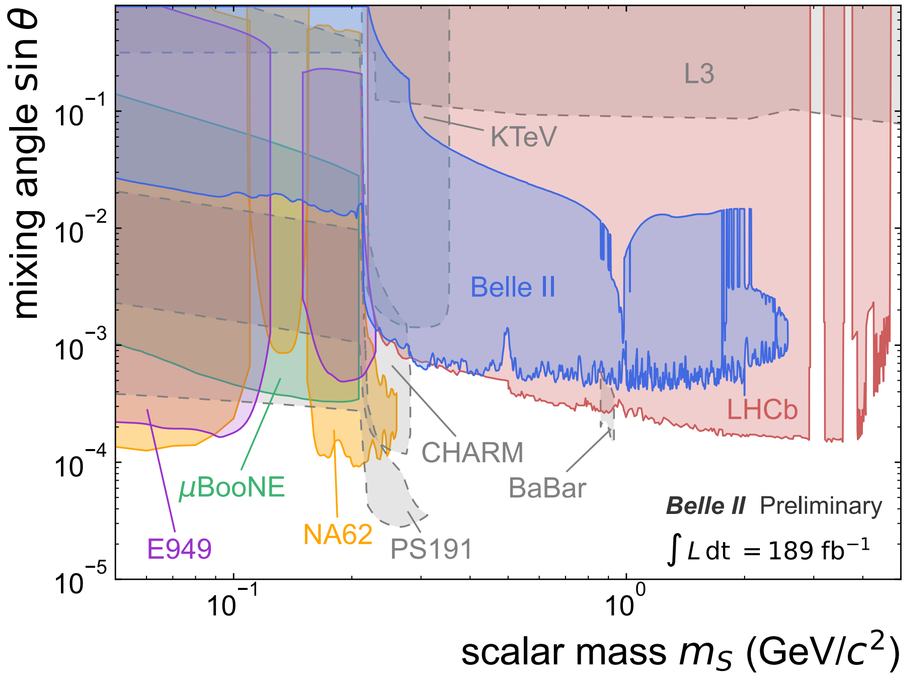
- Bump hunt in LLP mass distribution M_S using unbinned maximum likelihood fits
- Challenge: LLP performance
  - Study K_S^0 control sample and derive corrections
    - Reconstruction efficiency
    - M_S shape
    - Particle identification
- Probe lifetimes between $0.001 < c\tau < 400\,\text{cm}$

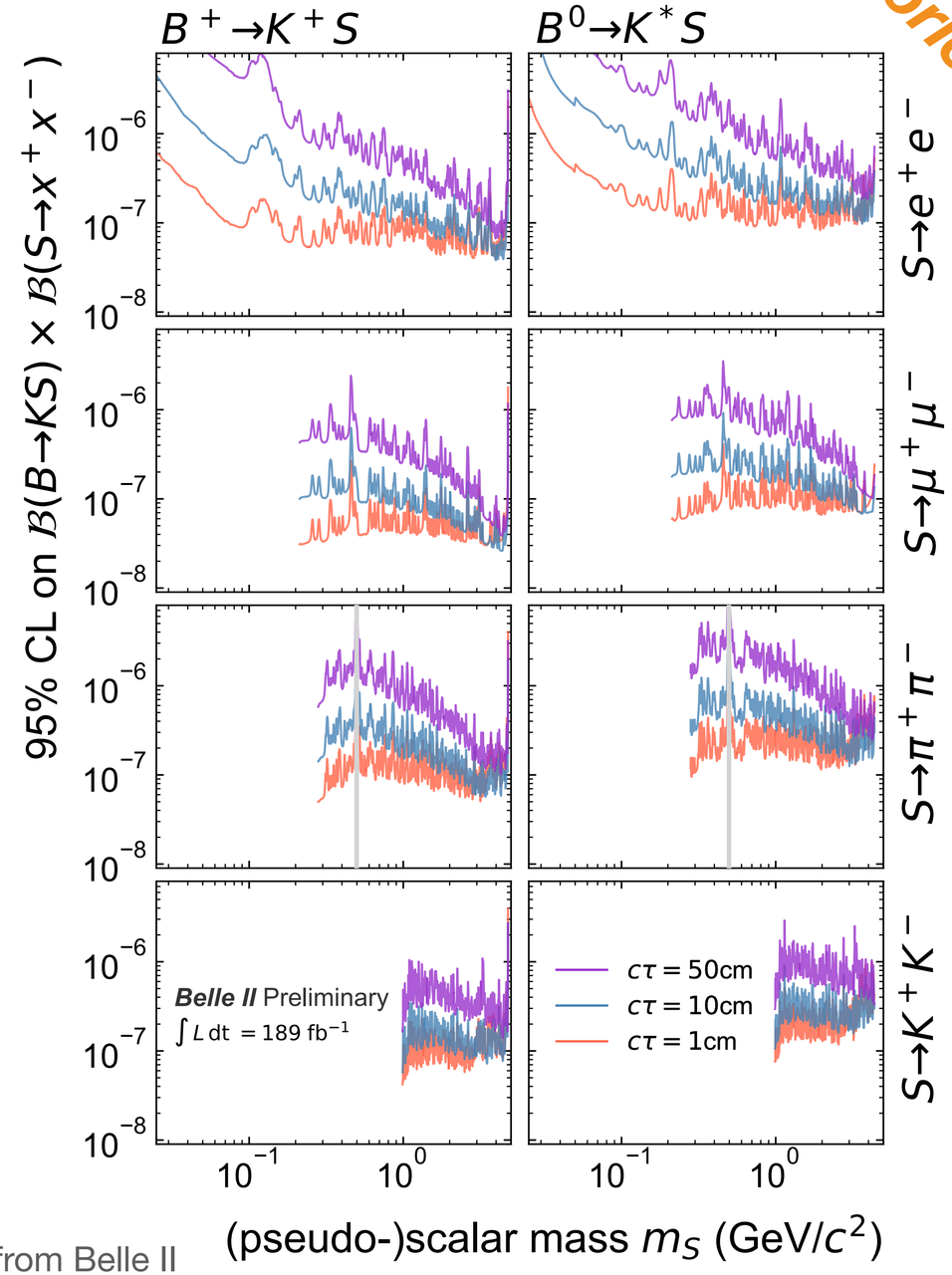


Search for a long-lived (pseudo-)scalar in $b \to s$ transitions.

New for Moriond!

- **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])



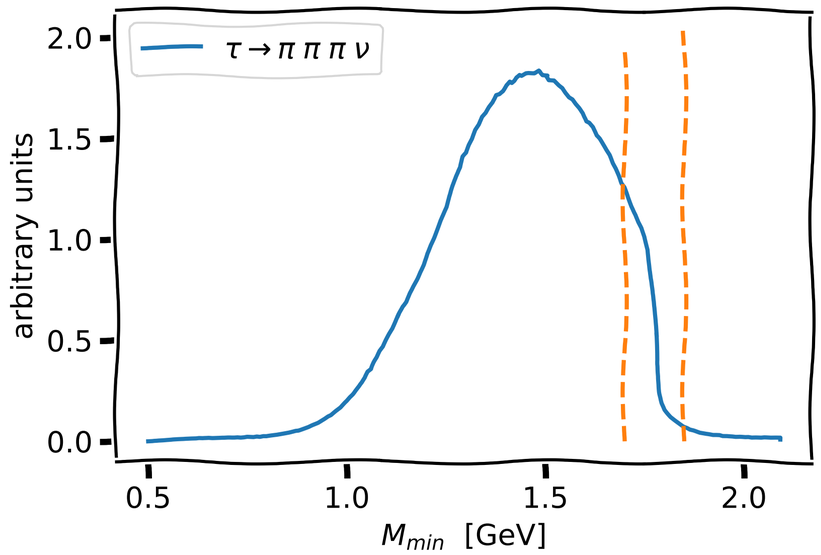


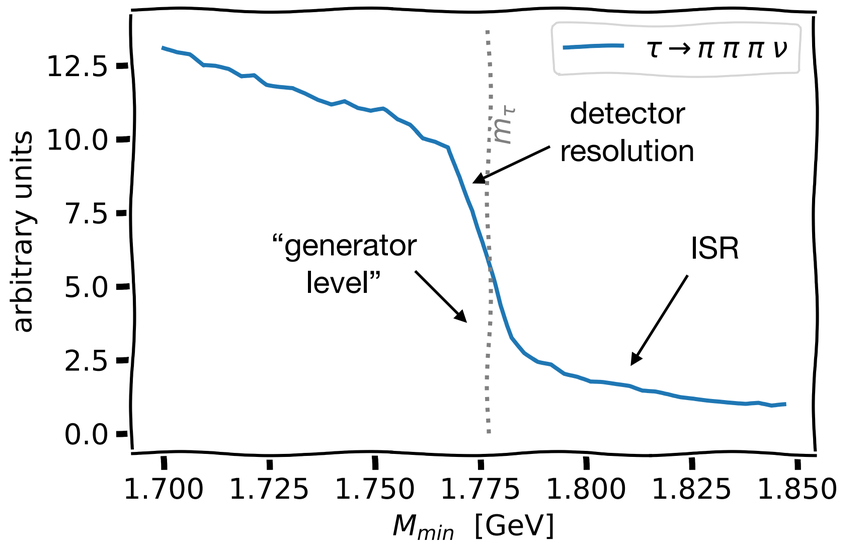
[1]: Phys. Rev. D 101, 095006 (2020)
[2]: J. Phys. G: Nucl. Part. Phys. 47 010501

Measurement of the τ-lepton mass.

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

New for Moriond!



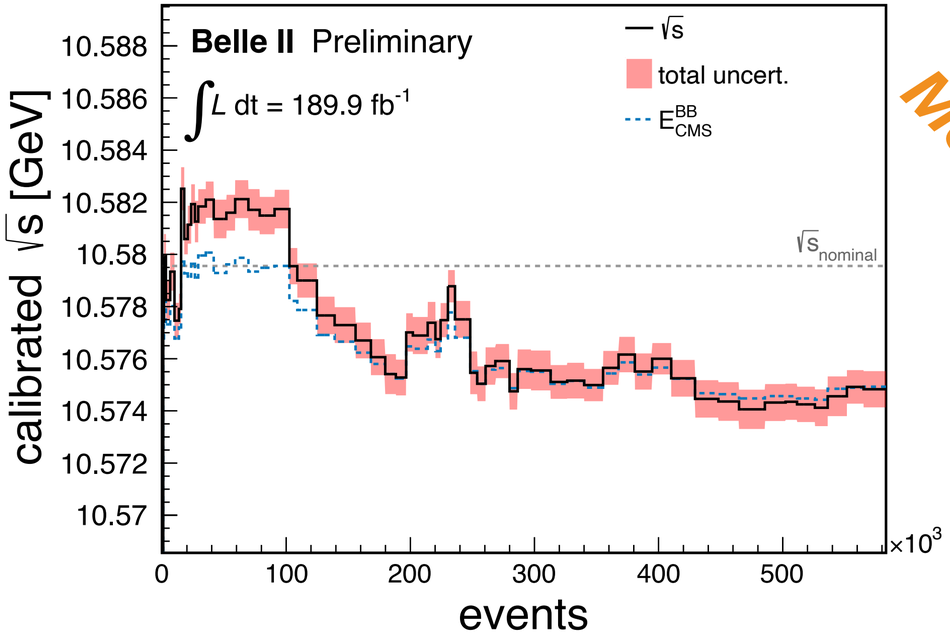


$$M_{\text{min}} = \sqrt{M_{3\pi}^2 + 2(\sqrt{s}/2 - E_{3\pi}^*)(E_{3\pi}^* - P_{3\pi}^*)} \leq m_\tau$$

Measurement of the τ-lepton mass.

- Benchmark for precision capabilities of Belle II
- Control of **systematic uncertainties** is key:
- $$M_{\min} = \sqrt{M_{3\pi}^2 + 2(\sqrt{s}/2 - E_{3\pi}^*)(E_{3\pi}^* - P_{3\pi}^*)} \leq m_\tau$$

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



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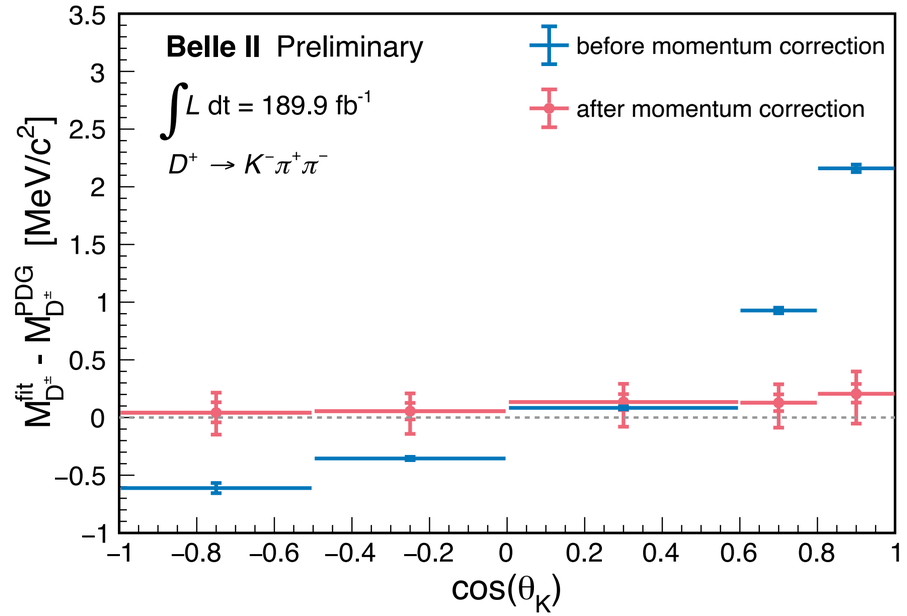
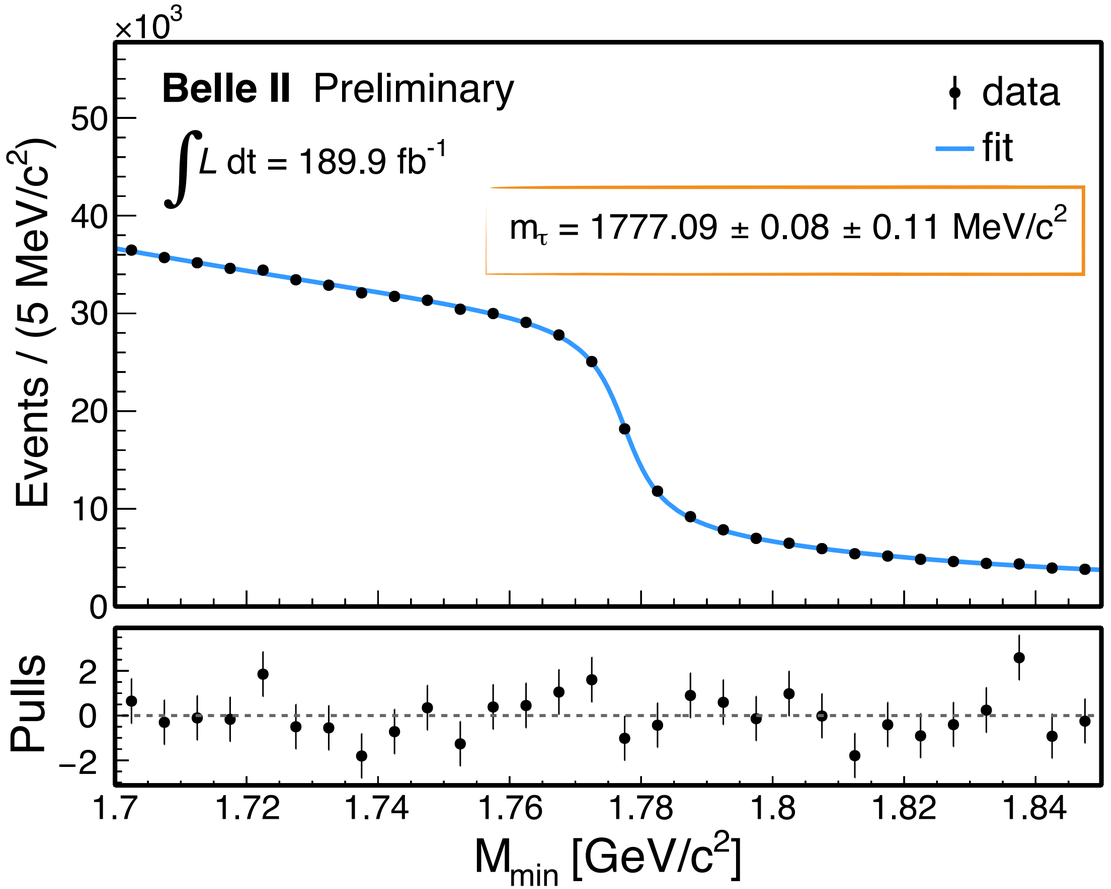
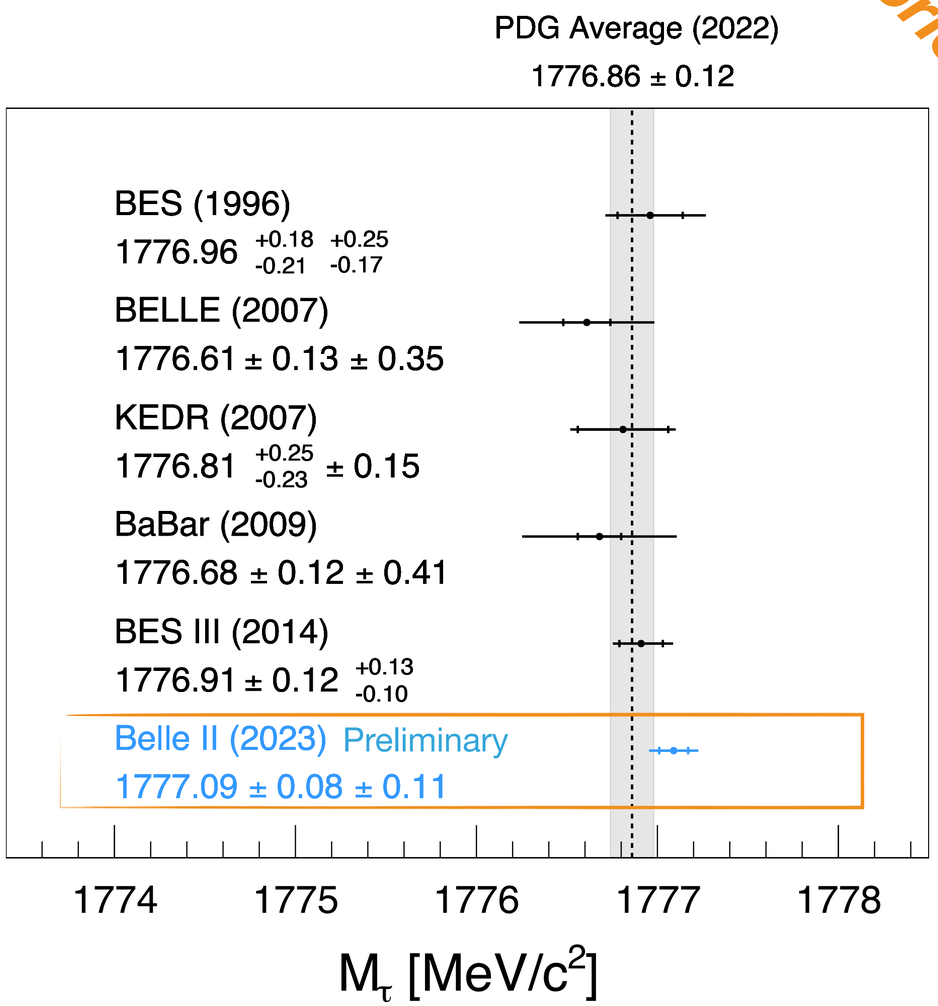


Measurement of the τ-lepton mass.

New for Moriond!





- Worlds **most precise τ mass** measurement!

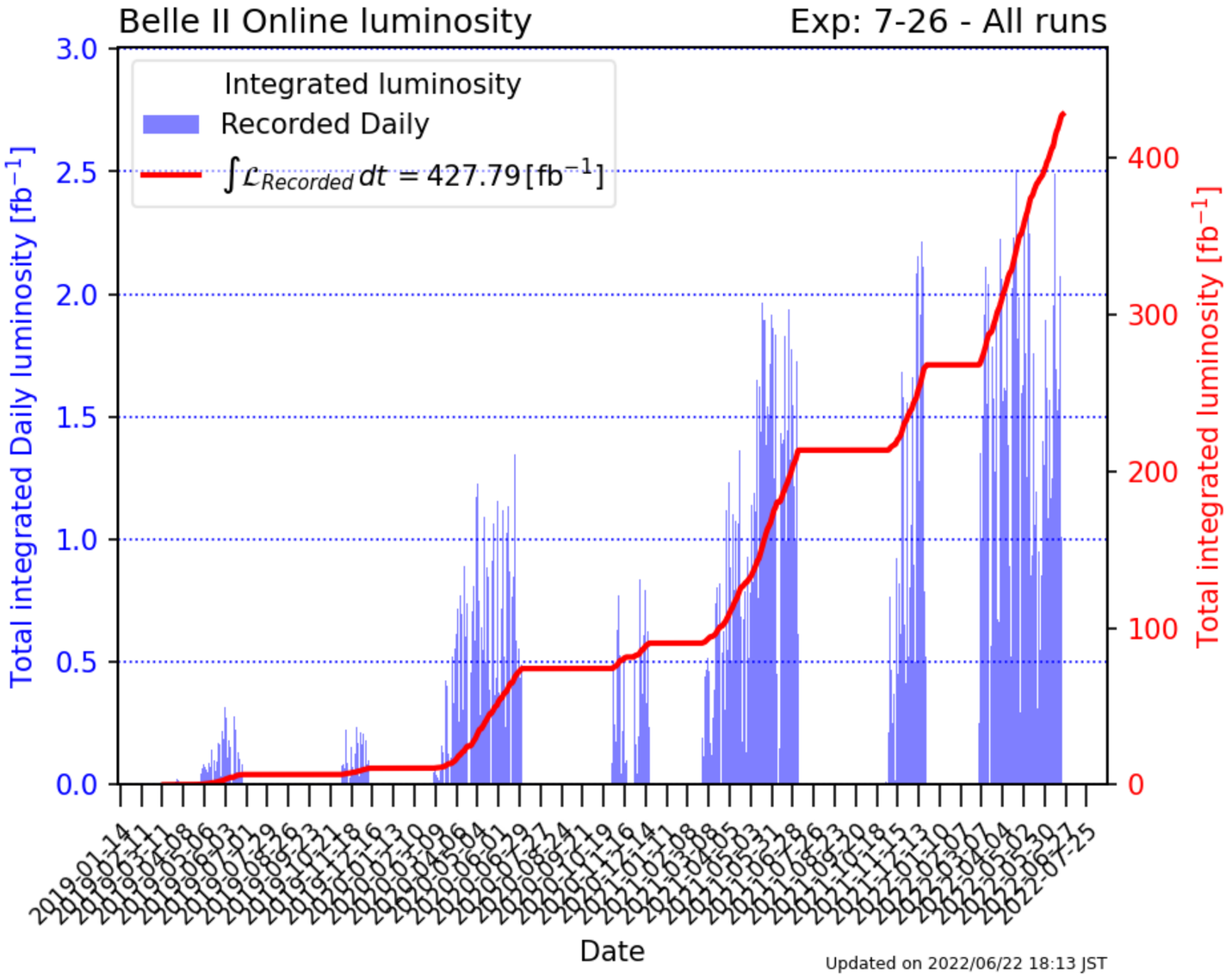
Summary.

Belle II has a unique sensitivity to light dark sectors and is able to perform world-leading precision measurements

- Search for invisible Z' in $ee \to \mu\mu Z'$ arXiv:2212.03066
- Search for $\tau\tau$ resonance in $ee \to \mu\mu\tau\tau$
- Search for invisible LF-violating scalar in $\tau \to \ell\alpha$ arXiv:2212.03634
- ***New!*** Search for a long-lived (pseudo-)scalar in $b \to s$ transitions
- ***New!*** Measurement of the τ-lepton mass

Results are complementary to higher-energy collider and beam-dump experiments

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}]
Date
Updated on 2022/06/22 18:13 JST

Long-shutdown activity and plans.

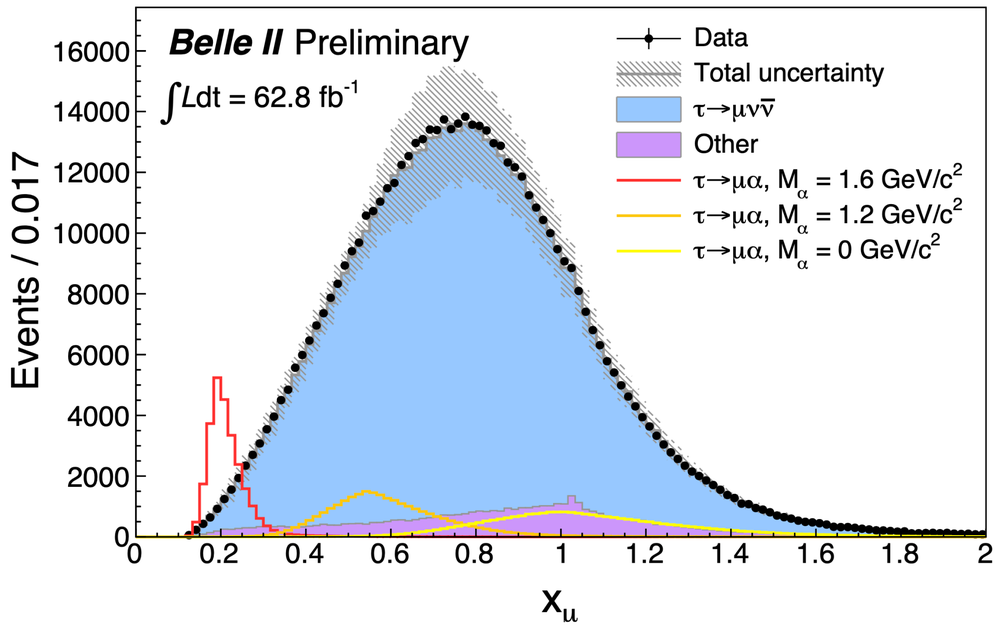
Belle II stopped taking data in Summer 2022 for a long shutdown

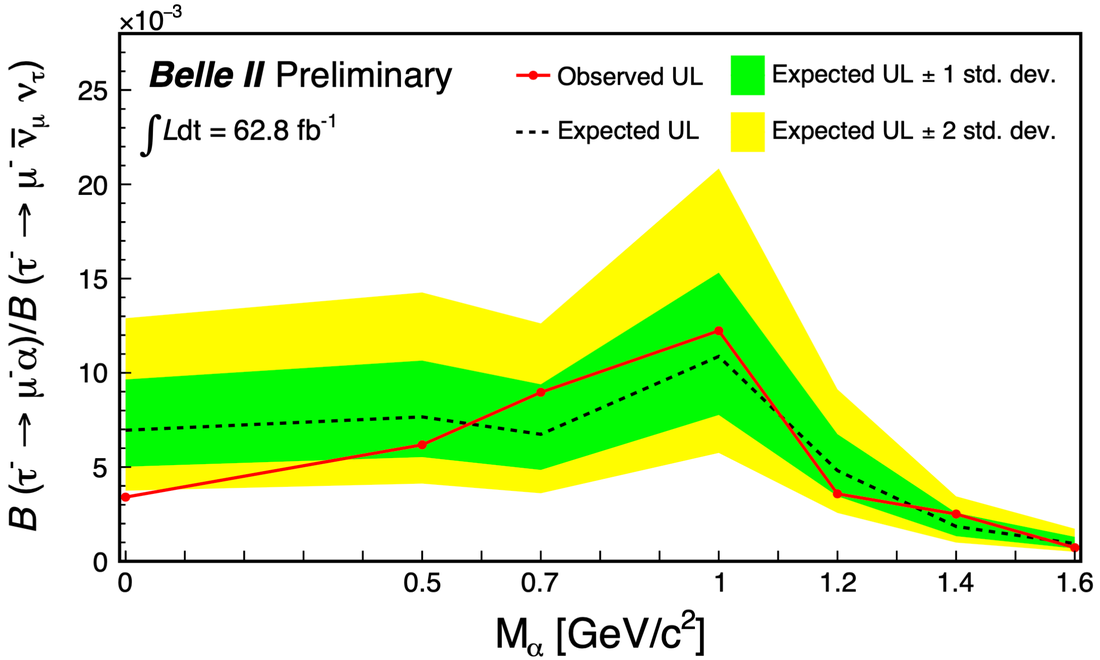
- replacement of beam-pipe
- replacement of photomultipliers of the central PID detector (TOP)
- installation of 2-layered pixel vertex detector
- improved data-quality monitoring and alarm system
- completed transition to new DAQ boards (PCIe40)
- accelerator improvements: injection, non-linear collimators, monitoring
- replacement of aging components
- additional shielding and increased resilience against beam background

Currently working on pixel detector installation:
==> shipped to KEK in last week
==> final tests at KEK scheduled in April

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

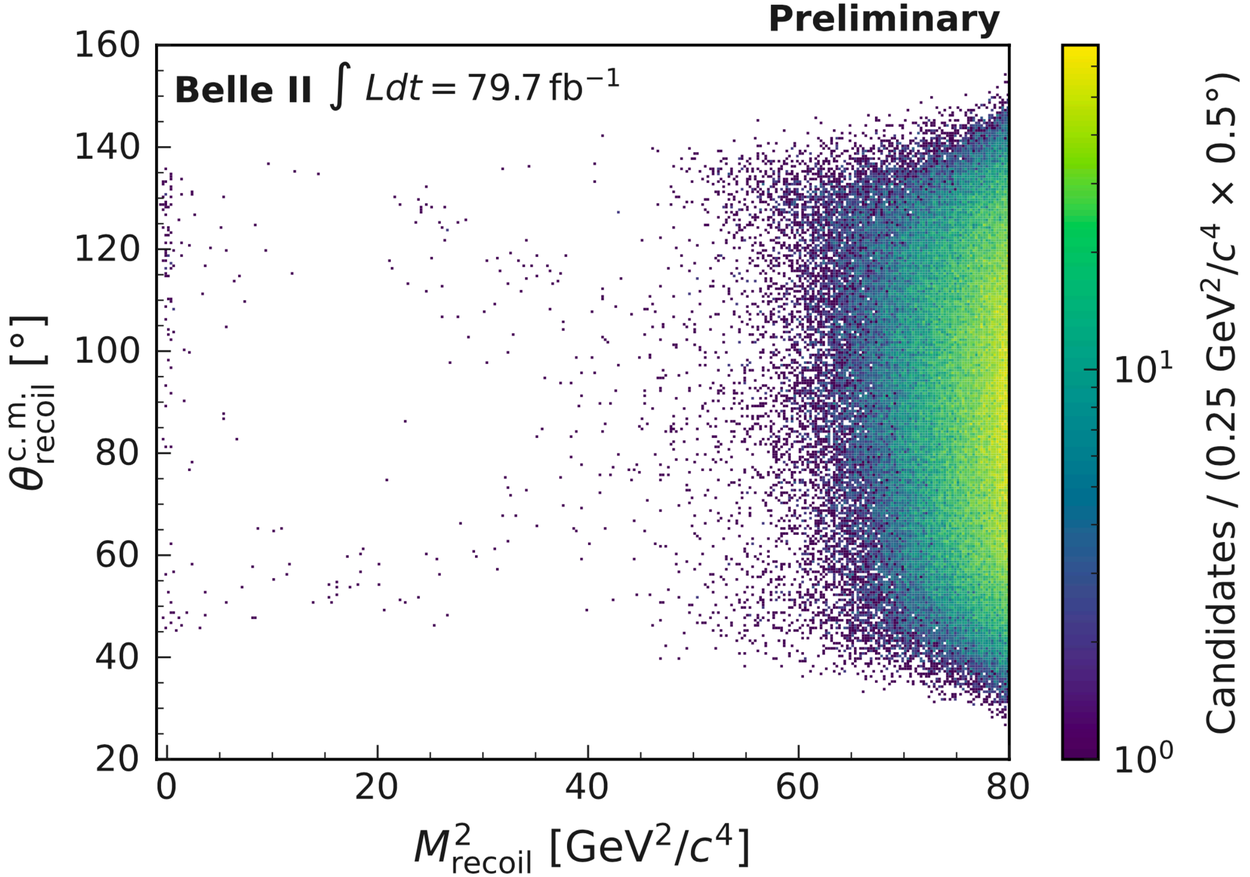
Search for an invisible scalar in lepton-flavour violating τ decays.



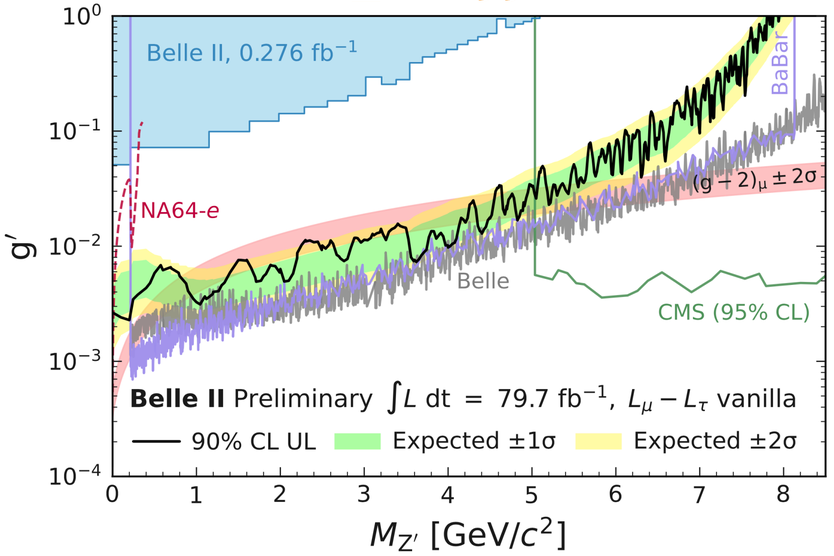


[1]: ARGUS Collaboration, Z. Phys. C 68, 25 (1995)

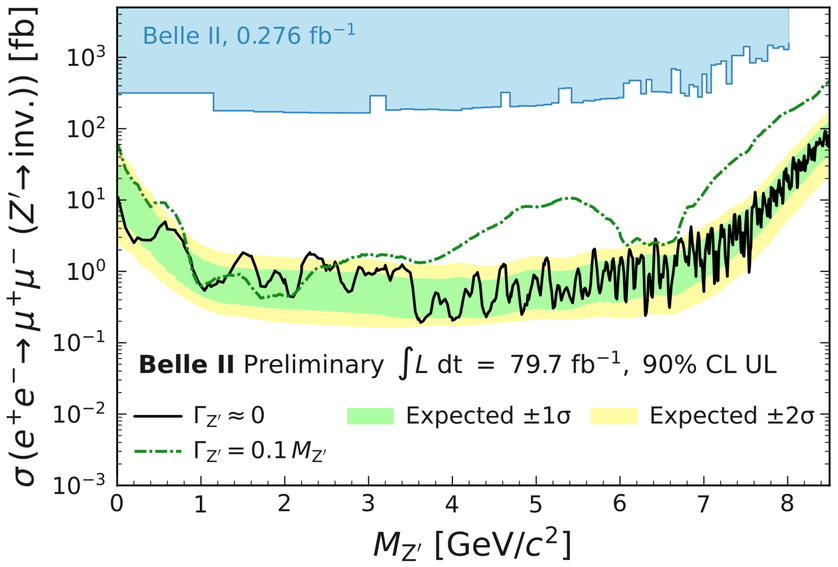
Search for an invisibly decaying Z' boson.



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



cross-section



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