RECENT QUARKONIA, TAU AND LOW MULTIPLICITY MEASUREMENTS FROM BELLE AND BELLE II

La Thuile 2024 - Les Rencontres de Physique de la Vallée d'Aoste
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on behalf of the Belle and Belle II collaborations

THE UNIVERSITY OF BRITISH COLUMBIA

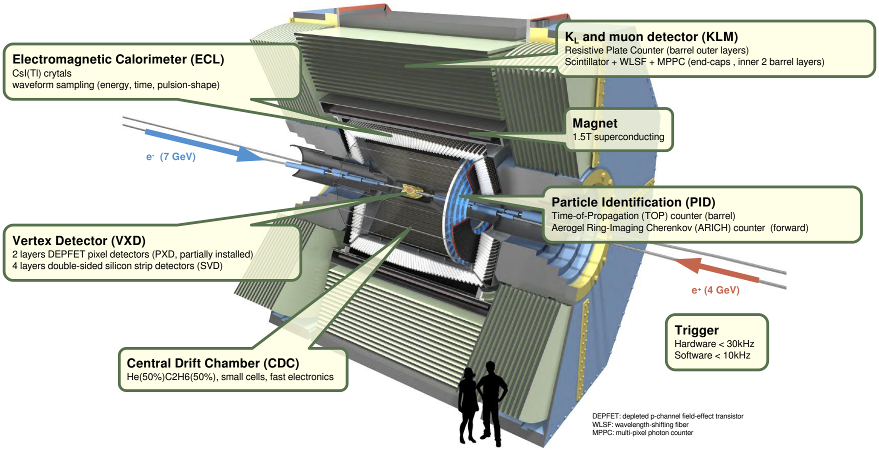
BELLE

Belle II

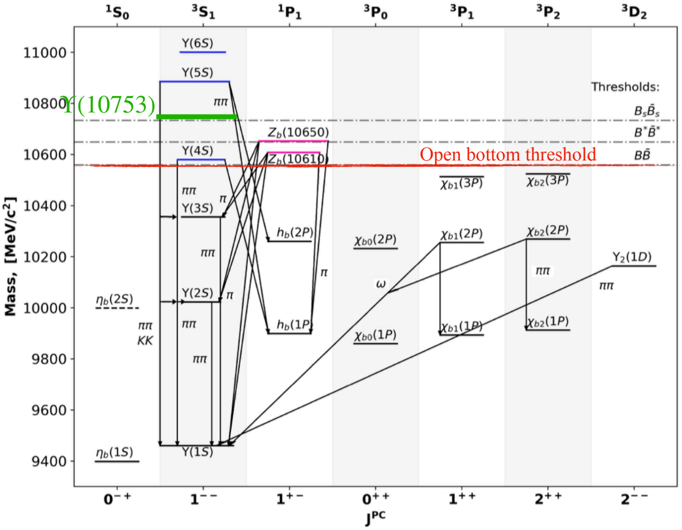
Belle and Belle II experiments

Belle II strength for τ^- and low multiplicity physics:

- Hermetic detector: good missing energy and neutral reconstruction
- Special triggers dedicated to low-multiplicity events
- Excellent vertexing and tracking capabilities



Hadron spectroscopy at Belle and Belle II



- **Below $B\bar{B}$ threshold:** well described by potential models
- **Above the $B\bar{B}$ threshold** ($\Upsilon(4S)$, $\Upsilon(5S)$ and $\Upsilon(6S)$): show unexpected properties
  - Hadronic transitions to lower bottomonia are strongly enhanced
  - Strong violation of Heavy Quark Spin Symmetry

$\Rightarrow$ **Exotic admixtures**: molecule, compact tetraquark, hybrid

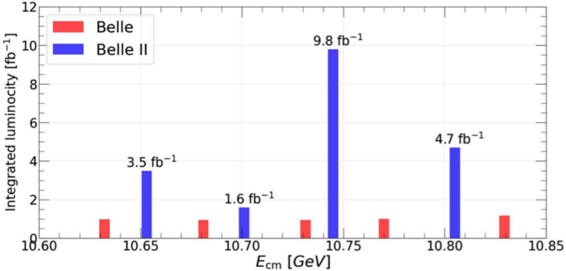
Progress of Theoretical and Experimental Physics. 2020 (2020) p. 083C01

Hadron spectroscopy at Belle and Belle II

New Belle II energy scan

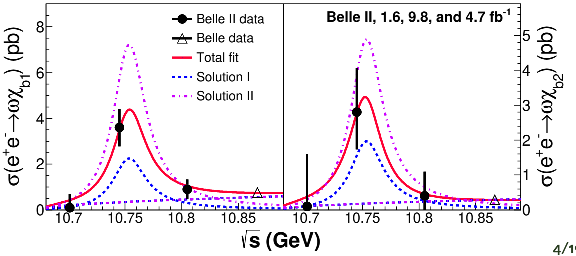
To study the $\Upsilon(10753)$, a new energy scan data taking was performed by Belle II:

- Fill Belle energy gaps
- Total integrated luminosity of 19 fb^{-1} with 9.8 fb^{-1} at the $\Upsilon(10753)$ energy



Already proves its efficiency by the rediscovery of $\Upsilon(10753)$ in a new decay $e^+e^- \to \omega(\to \pi^+\pi^-\pi^0)\chi_{bJ}(\to \gamma\Upsilon(1S))$

Phys. Rev. Lett. 130 (2023) p. 091902

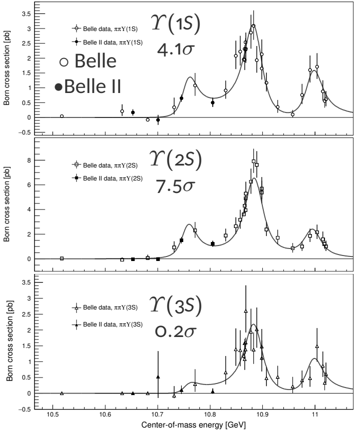


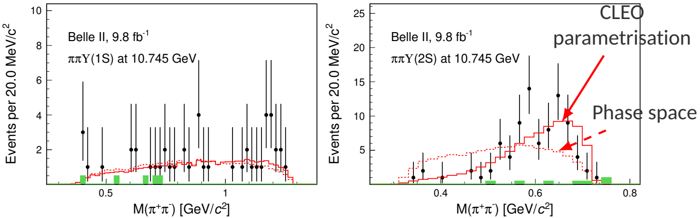
Belle II – *Study of* $e^+e^- \to \Upsilon(nS)\pi^-\pi^+$

arXiv:2401.12021

Confirm the existence of $\Upsilon(10753)$ in its discovery mode
- Measure the di-pion spectrum
- Looks for any Z_b contributions

- **Reconstruct $e^+e^- \to \pi^+\pi^-\Upsilon(nS)(\to \mu^-\mu^+)$**





- **Observation of the $\Upsilon(10753)$ in agreement with the Belle** measurement

$$M(\Upsilon(10753)) = 10756.3 \pm 2.7 \pm 0.6\,\mathrm{MeV}/c^2$$
$$\Gamma(\Upsilon(10753)) = 29.7 \pm 8.5 \pm 1.1\,\mathrm{MeV}$$

- $\Upsilon(1S)$: $M(\pi^+\pi^-)$ distribution is consistent with phase space
- $\Upsilon(2S)$: $M(\pi^+\pi^-)$ large values are enhanced (similarly to $\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$)
- **No signals** of intermediate Z_b^+ **(10610/10650)** resonances are observed

Belle II – *Search for* $\Upsilon(10753) \to \omega\eta_b(1S)/\chi_{b0}(1P)$

arXiv:2312.13043

Test the tetraquark interpretation for the $\Upsilon(10753)$:

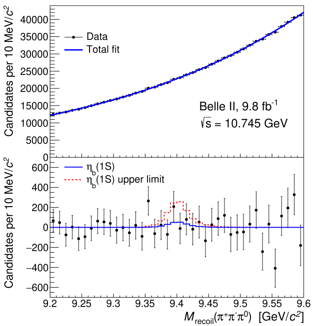
- Predicts a **strong transition** of $\omega\eta_b(1S)$ compared to $\Upsilon\pi^+\pi^-$
- There is no convenient way to reconstruct η_b

- **Only reconstruct** $\omega \to \pi^+\pi^-\pi^0$
- **Search for a signal bump in the recoil mass** $M_{recoil}(\pi^+\pi^-\pi^0)$ distribution

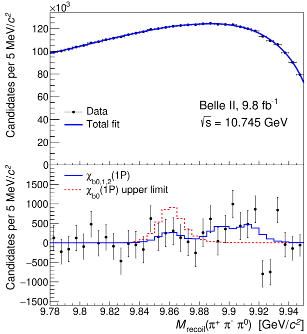
$$M_{recoil}(\pi^+\pi^-\pi^0)=\sqrt{\left(\frac{E_{c.m.}-E^*}{c^2}\right)^2-\left(\frac{p^*}{c}\right)^2}$$

where $E_{c.m.}$: total energy of the e^+e^- in the centre of mass
E^*, p^*: energy and momentum of $\pi^+\pi^-\pi^0$ in the centre of mass

$\omega\eta_b(1S)$



$\omega\chi_{b0}(1P)$



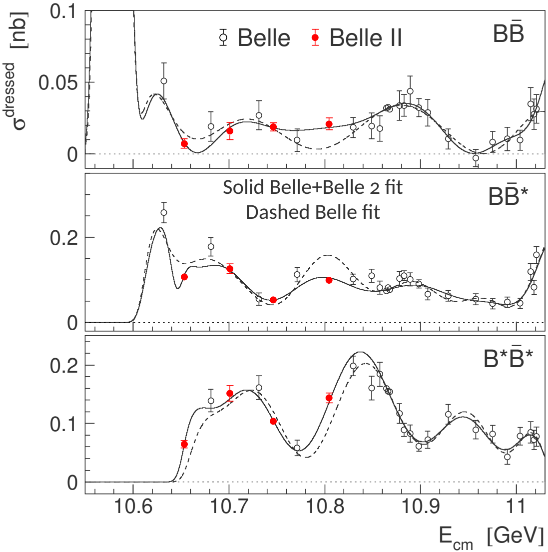
- **No significant χ_{b0} and $\eta_b(1S)$ signals are observed**
  $\sigma(e^+e^- \to \omega\chi_{b0}(1S)) < 8.7\,pb$
  $\sigma(e^+e^- \to \omega\eta_b(1S)) < 2.5\,pb$
- **This result does not support the prediction of the tetraquark model**

Belle II – *Energy dependence of* $e^+e^- \rightarrow B^{(*)}\bar{B}^{(*)}$

Preliminary

The open flavour final states $B^{(*)}\bar{B}^{(*)}$ make dominant contribution to $b\bar{b}$ cross-section

- Their measurements are critical for understanding the structure of $b\bar{b}$ states
- Can be used to extract Υ states parameters

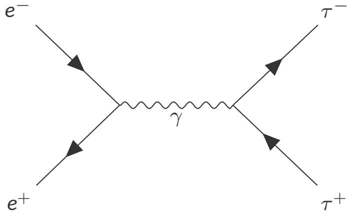


- **Cross sections at the four energies are consistent with Belle's results.**
- $\sigma(e^+e^- \rightarrow B^*\bar{B}^*)$ increase rapidly above $B^*\bar{B}^*$ threshold similar to $D^*\bar{D}^*$ $\Rightarrow$resonance or bound state?

τ lepton physics

SuperKEKB as a **τ factory**:

- **e^+e^- collider produce τ leptons pairs at high rate**



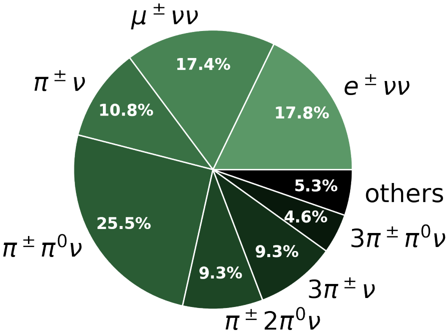
$$\sigma(e^+e^- \to \tau^+\tau^-) = 0.92\ nb$$

$$\sigma(e^+e^- \to B\bar{B}) = 1.05\ nb$$

- cross section equivalent to $B\bar{B}$ process

τ decays:

- Massive enough to decay into **lighter lepton & hadrons**
- Mostly **one or three charged particles** in final states
- Challenging reconstruction with neutrinos in the final state

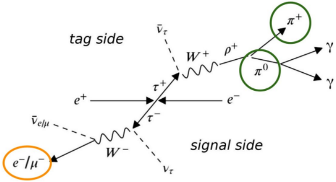


Belle II – *Lepton Flavour Universality measurement*

Preliminary

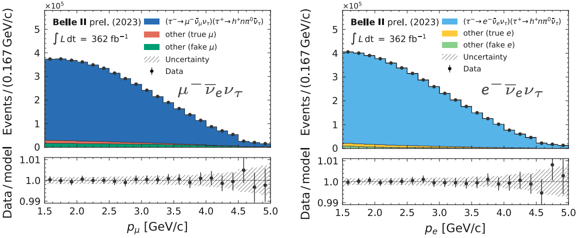
- Test if the W gauge bosons have the same couplings g as the three generations of leptons $g_e = g_\mu = g_\tau$ as predicted in the SM

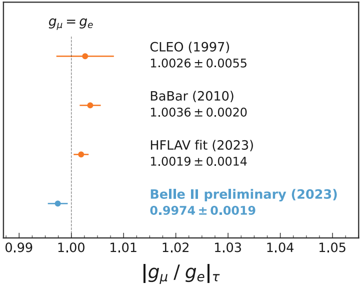
$$\left(\frac{g_\mu}{g_e}\right)^2_\tau \sim R_\mu = \frac{\mathcal{B}(\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau)}{\mathcal{B}(\tau^- \to e^- \overline{\nu}_e \nu_\tau)}$$



- Event selection is performed with rectangular cuts and neural network
- **94% purity with 9.6% signal efficiency for the combined sample**
- Mains systematics coming from PID (0.32%) and trigger (0.1%)

Extract R_μ by fitting the lepton momentum $[1.5, 5]$ GeV/c





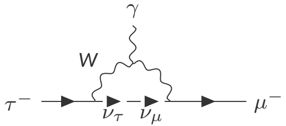
- Most precise e/μ universality from τ^- decays in a single measurement with 362 fb^{-1}

$$R_\mu = 0.9675 \pm 0.0007(stat) \pm 0.0036(sys)$$

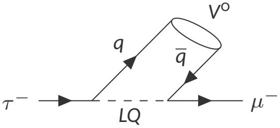
Lepton Flavour Violation (LFV) searches

The lepton flavour is accidentally conserved in the SM
Lepton flavour violation is only allowed by:

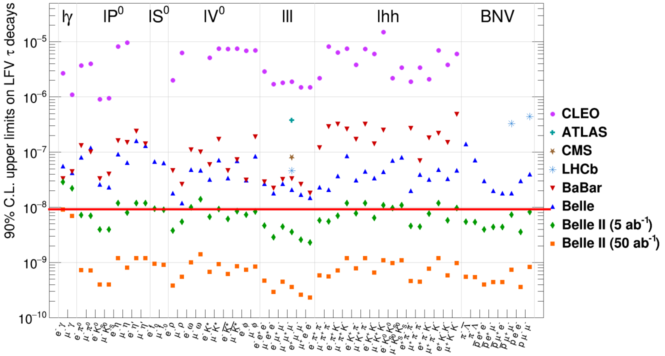
- **Neutrino oscillations** $\mathcal{O}(10^{-55})$
far beyond current experimental sensitivities
- **New Physics models** $\mathcal{O}(10^{-8})$
e.g. Leptoquarks for $\tau^- \to \ell^- V^0$ deals with $R(K^{*0})$ anomalies



(a) $\tau^- \to \mu^- \gamma$ via Standard Model with neutrino oscillation



(b) $\tau^- \to \ell^- V^0$ via leptoquark interaction



Progress of Theoretical and Experimental Physics. 2019 (2019) p. 123C01; arXiv:2203.14919

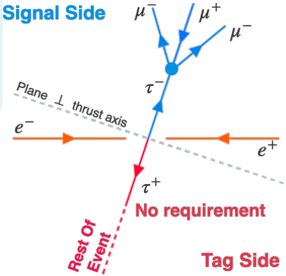
Observation of such decays will be a clear signature of New Physics

Belle II – $\tau \to 3\mu$ *Lepton Flavour Violation decay*

Preliminary

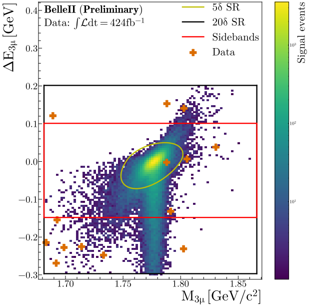
Flagged as Belle II golden channel

- Accessible:
  - good reconstruction of τ^- mass and energy
  - low SM background
- Also probed by LHC experiments



Signal efficiency challenge:

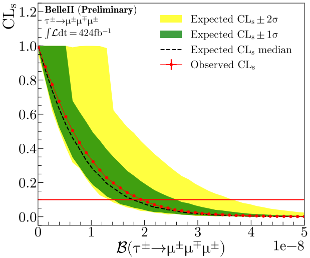
- BDT classifier: reject main backgrounds $e^+e^- \to q\bar{q}$ using signal, "Rest of Event" and kinematic features
- $\varepsilon_{sig} \simeq 20.41\%$ (3× **Belle Physics Letters B. 687 (2010) pp. 139–143)**



- Observed 1 event in 424 fb^{-1} of data
- Set 90% CL upper-limit on the BF

$$\mathcal{B}(\tau \to \mu\mu\mu) \quad < 1.9 \times 10^{-8}$$

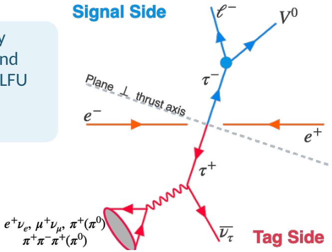
- New most stringent results compared to Belle 2.1 and CMS 2.9 $\times 10^{-8}$
- Performances confirmed by a conventional 3 × 1 tagging approach



Belle – $\tau \to \ell V^0$ *Lepton Flavour Violation decay*

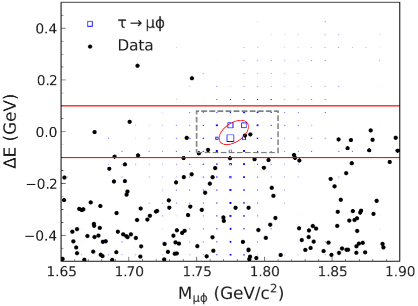
J. High Energ. Phys. 2023 (2023) p. 118

New mediators (vector leptoquark) may enhance such decay, up to $\mathcal{O}(10^{-10})$ and accommodate for flavour anomalies in LFU tests
Phys. Rev. D. 104 (2021) p. 055017



Signal efficiency challenge:

- Use more tag τ^+ final state channels
- BDT classifier: reject main backgrounds $e^+e^- \to q\bar{q}$



Belle has no significant excess in 980 fb^{-1}

$$\mathcal{B}(\tau \to eV^0) < (1.7 - 2.4) \times 10^{-8}$$
$$\mathcal{B}(\tau \to \mu V^0) < (1.7 - 4.3) \times 10^{-8}$$

- The limit is improved by 30% *wrt* the previous Belle results

Belle II results on $\tau^- \to \ell^-\phi$ channel using an untagged approach with 189 fb^{-1} (2023):

$$\mathcal{B}(\tau \to e\phi) < 23 \times 10^{-8}$$
$$\mathcal{B}(\tau \to \mu\phi) < 9.7 \times 10^{-8}$$

Mode	ε(%)	N_{BG}	σ_{syst} (%)	N_{obs}	$\mathcal{B}_{obs}$ ($\times 10^{-8}$)
$\tau^\pm \to \mu^\pm\rho^0$	7.78	0.95 ± 0.20 (stat.) ±0.15 (syst.)	4.6	0	< 1.7
$\tau^\pm \to e^\pm\rho^0$	8.49	0.80 ± 0.27 (stat.) ±0.04 (syst.)	4.4	1	< 2.2
$\tau^\pm \to \mu^\pm\phi$	5.59	0.47 ± 0.15 (stat.) ±0.05 (syst.)	4.8	0	< 2.3
$\tau^\pm \to e^\pm\phi$	6.45	0.38 ± 0.21 (stat.) ±0.00 (syst.)	4.5	0	< 2.0
$\tau^\pm \to \mu^\pm\omega$	3.27	0.32 ± 0.23 (stat.) ±0.19 (syst.)	4.8	0	< 3.9
$\tau^\pm \to e^\pm\omega$	5.41	0.74 ± 0.43 (stat.) ±0.06(syst.)	4.5	0	< 2.4
$\tau^\pm \to \mu^\pm K^{*0}$	4.52	0.84 ± 0.25 (stat.) ±0.31 (syst.)	4.3	0	< 2.9
$\tau^\pm \to e^\pm K^{*0}$	6.94	0.54 ± 0.21 (stat.) ±0.16 (syst.)	4.1	0	< 1.9
$\tau^\pm \to \mu^\pm\bar{K}^{*0}$	4.58	0.58 ± 0.17 (stat.) ±0.12 (syst.)	4.3	1	< 4.3
$\tau^\pm \to e^\pm\bar{K}^{*0}$	7.45	0.25 ± 0.11 (stat.) ±0.02 (syst.)	4.1	0	< 1.7

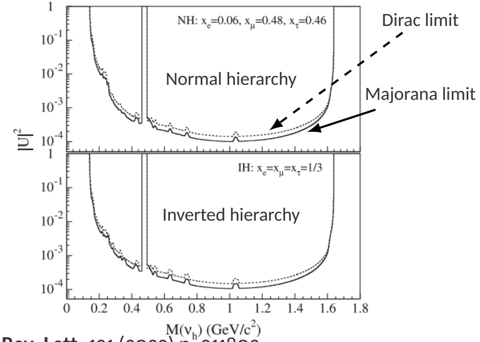
New world-leading results

Belle – *BSM heavy neutrino searches*

Experimental neutrino oscillation evidence has demonstrated that neutrinos are massive
$\longrightarrow$ can be introduced by several candidates like heavy, right-handed or sterile neutrinos

Search for a heavy neutrino in $\tau^- \to \pi^- \nu_h (\to \pi^\pm \ell^\mp)$ with 988 fb^{-1}

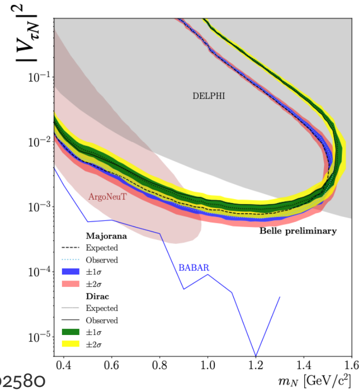
- **No narrow peak found** in the $0.2 < M(\nu_h) < 1.6$ GeV/c^2 while excluding the K_S^0 region
- Establish 95% CL on the heavy neutrino mixing



Phys. Rev. Lett. 131 (2023) p. 211802

Search for a sterile neutrino in $\tau^- \to \pi^- N(\to \mu^+ \mu^- \nu_\tau)$ with 915 fb^{-1}

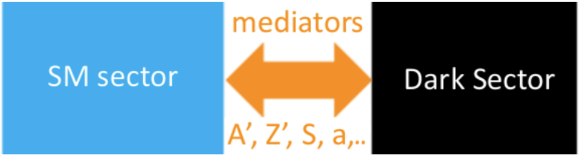
- **No significant observed signal** found while excluding the K_S^0
- Establish a limit on the mixing coefficient $|V_{\tau N}|^2$ between ν_τ and N



arXiv:2402.02580

Dark matter searches

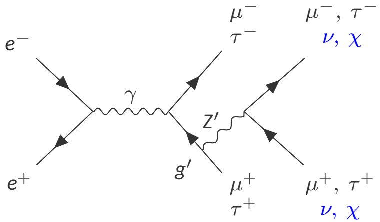
B factories at e^+e^- collider can access the mass range favoured by light-dark sectors



Light dark sector weakly couples to SM through various light mediators

Belle II – *Search for Z' boson*

New gauge boson Z' coupling only to the 2nd and 3rd generation of leptons ($L_\mu - L_\tau$) via g':
- dark matter puzzle
- long-standing $(g-2)_\mu$ anomaly

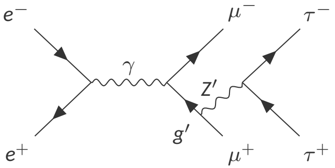


Depending on the Z' candidate mass the final state can be:

- $\nu\nu$
- χ, χ
- $\mu^-\mu^+$
- $\tau^-\tau^+$

($\nu\nu$ and χ, χ:) Fully invisible **Phys. Rev. Lett.** 130 (2023) p. 231801

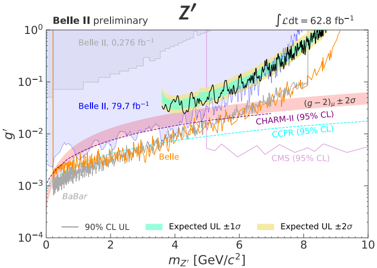
Belle II – *Search for $\tau^+\tau^-$ resonance in $e^+e^- \to \mu^+\mu^-\tau^+\tau^-$* Phys. Rev. Lett. 131 (2023) p. 121802

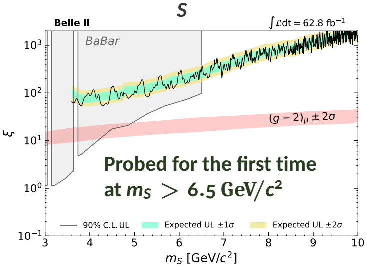


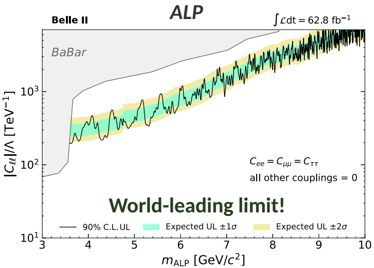
No significant excess was observed in 62.8 fb^{-1}

- 90% CL upper limits on the cross-section $\sigma(e^+e^- \to X\mu^+\mu^-)\, B(X \to \tau^+\tau^-)$, with $X = Z',\ S,\ ALP$ and on the coupling constant

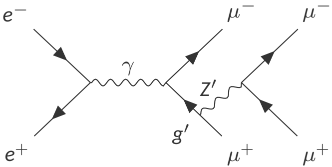
- Search for **$\tau^+\tau^-$ resonance** in recoil mass (against dimuons)
  $\Rightarrow$ also sensitive to leptophilic scalar S and ALPs







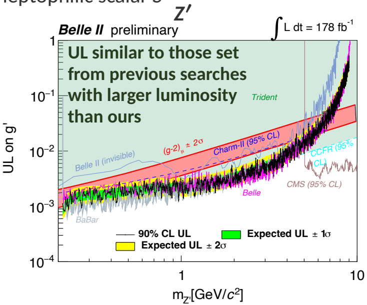
Belle II – *Search for $\mu^+\mu^-$ resonance in $e^+e^- \to \mu^-\mu^+\mu^-\mu^+$* Preliminary

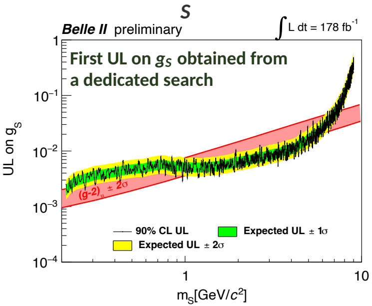


No significant excess was observed in 178 fb^{-1}

- 90% CL upper limits on the cross-section $\sigma\left(e^+e^- \to X\mu^+\mu^-\right) B\left(X \to \mu^+\mu^-\right)$, with $X = S, Z'$ and on the coupling constant

- Search for $\mu^+\mu^-$ **resonance** in the reduced dimuon mass $M_R \equiv \sqrt{M^2(\mu\mu) - 4m_\mu^2}$
  $\Rightarrow$ also sensitive to leptophilic scalar S

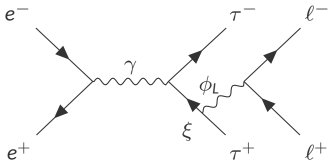




Belle – *Search for dark leptophilic scalar*

Phys. Rev. D. 109 (2024) p. 032002

The **dark leptophilic scalar ϕ_L can only couple to leptons**:
- long-standing $(g-2)_\mu$ anomaly
- dark matter abundance
- lepton flavour universality violations
- leptophilic scalar constraints are still loose

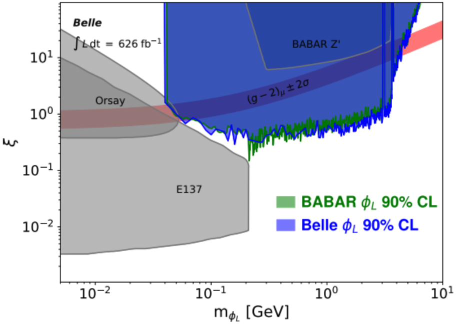


- Search process $e^+e^- \to \tau^-\tau^+\phi_L(\to \ell^-\ell^+)$ where $\ell = e, \mu$
- Reject the main backgrounds with BDT

Results

No significant excess was observed in 626 fb^{-1}

- 90% CL upper limits on the cross-section $\sigma\left(e^+e^- \to \phi_L\tau^-\tau^+\right) B\left(\phi_L \to \ell\ell\right)$, with $\ell = e, \mu$ and on the coupling constant
- no ϕ_L with mass $M(\phi_L) < 4$ GeV that can explain the observed excess in $(g-2)_\mu$



Outlook and conclusion

The **observation of the $\Upsilon(10753)$ is confirmed, its nature remains unclear**
$\Rightarrow$ but several studies are ongoing to push forward

Several new world best limit on high-profile τ LFU/LFV searches ($\tau \to \ell V^0$ and $\tau \to 3\mu$)
Proving that Belle and Belle II are also τ-factories

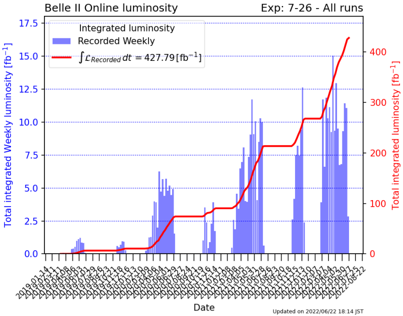
Belle II has unique sensitivity for light dark sectors searches and is complementary to other experiments
Excellent performance with displaced vertices and missing energy allows the world's leading results

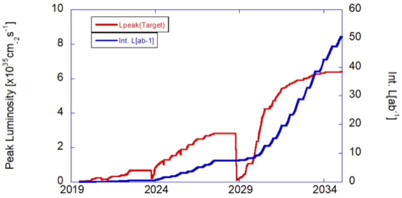
Belle II has successfully concluded Run1 with 424 fb^{-1}, and the first results show excellent performances
Now, after 18 months of shutdown, we aim to collect data at $10^{35}\ cm^{-2}s^{-1}$ and reach the 1 ab^{-1} by the end of the year!

Thank you!

Backups

Belle II Luminosity and LS1 plans





LS1 plans:

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

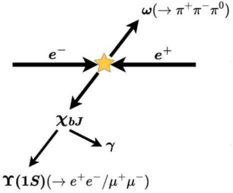
- replacement of beam-pipe
- replacement of photomultipliers of the central PID detector (TOP)
- installation of 2-layered pixel vertex detector
- improved data-quality monitoring and alarm system
- complete transition to new DAQ boards (PCIe40)
- replacement of aging components
- additional shielding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

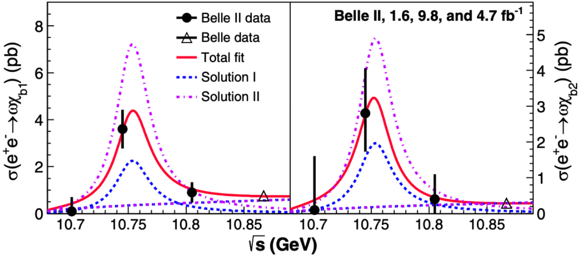
Currently working on pixel detector installation:

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

Belle II – *Observation of* $\Upsilon(10753) \to \omega\chi_{bJ}(1P)$

Search for $e^+e^- \to \omega(\to \pi^+\pi^-\pi^0)\chi_{bJ}(\to \gamma\Upsilon(1S))$:





- **Visible $\Upsilon(10753)$ peak in collision energy**

$\Rightarrow$ Confirm the $\Upsilon(10753)$

$\Rightarrow$ Observation of a new decay channels

- $\frac{\sigma\left(e^+e^- \to \chi_{bJ}(1P)\omega\right)}{\sigma\left(e^+e^- \to \Upsilon(nS)\pi^+\pi^-\right)} \sim \begin{matrix} 1.5 \text{ at } \Upsilon(10753) \\ 0.15 \text{ at } \Upsilon(5S) \end{matrix} \Rightarrow$ $\Upsilon(10753)$ and $\Upsilon(5S)$ have **different structures**

Belle II – τ mass measurement

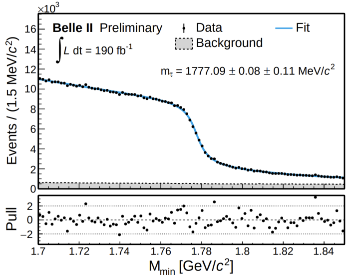
Phys. Rev. D. 108 (2023) p. 032006

Reconstruct:

$$e^+e^- \rightarrow [\tau_{sig} \rightarrow \pi\pi\pi\nu_\tau]$$
$$[\tau_{tag} \rightarrow \ell\nu\nu / \pi(\pi^0)\nu]$$

And then exploit the **Pseudomass technique** developed by ARGUS:
unbinned maximum likelihood fit of the pseudo mass:

$$M_{min} = \sqrt{M^2_{3\pi} + 2\left(\sqrt{s}/2 - E^*_{3\pi}\right)\left(E^*_{3\pi} - P^*_{3\pi}\right)} < M_\tau$$



Dominated by systematics uncertainties

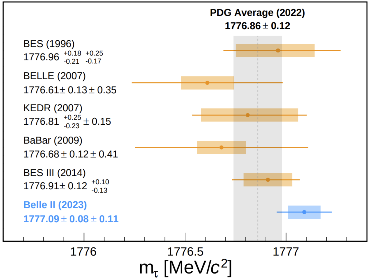
Source	Uncertainty MeV/c^2
Knowledge of the colliding beams:	
Beam energy correction	**0.07**
Boost vector	$\leq$ 0.01
Reconstruction of charged particles:	
Charged particle momentum correction	**0.06**
Detector misalignment	0.03
Fitting procedure:	
Estimator bias	0.03
Choice of the fit function	0.02
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**

World's most precise M_τ measurement:

$$M_\tau = 1777.09 \pm 0.08_{stat} \pm 0.11_{sys}\ \mathrm{MeV}/c^2$$

Using

Demonstration of Belle II capability to provide high precision measurement



Progress of Theoretical and Experimental Physics. 2020 (2020) p. 083C01

τ mass measurement

Phys. Rev. D. 108 (2023) p. 032006

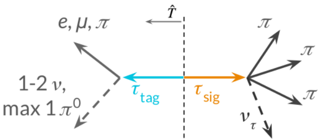
Motivations:

- Lepton masses are fundamental parameters of the SM
- Current precision on τ mass is 10^3 worse than muon mass
- Its precision impacts LFU test analysis

$$e^+e^- \to [\tau_{sig} \to \pi\pi\pi\nu_\tau][\tau_{tag} \to \ell\nu\nu/\pi(\pi^0)\nu]$$

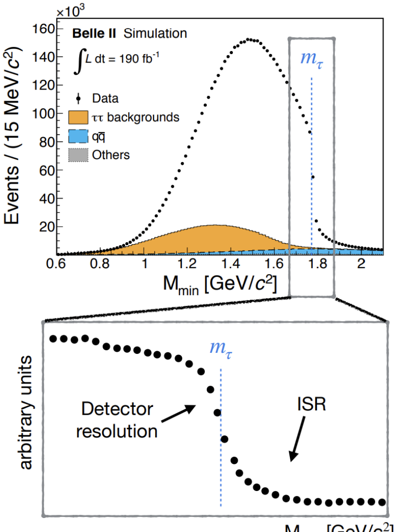
Pseudomass technique
developed by ARGUS

- Exploit the kinematics of the 3π system with only four tracks and no additional high-energy photons
- Pseudomass M_{min}:



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

- Cutoff position at the τ mass is extracted from a fit with an empirical function fit
  - Detector resolution $\Rightarrow$ smeared edges
  - ISR $\Rightarrow$ tail at $M_{min} > M_\tau$



[1]Physics Letters B. 292 (1992) pp. 221–228

τ mass measurement

Phys. Rev. D. 108 (2023) p. 032006

- Measurement dominated by systematics uncertainties: $M_{min} = \sqrt{M_{3\pi}^2 + 2(\sqrt{s}/2 - E_{3\pi}^*)(E_{3\pi}^* - P_{3\pi}^*)}$

Source	Uncertainty MeV/c^2
Knowledge of the colliding beams:	
Beam energy correction	**0.07**
Boost vector	$\lesssim$ 0.01
Reconstruction of charged particles:	
Charged particle momentum correction	**0.06**
Detector misalignment	0.03
Fitting procedure:	
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Mass dependence of the bias	$\lesssim$ 0.01
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Momentum resolution	$\lesssim$ 0.01
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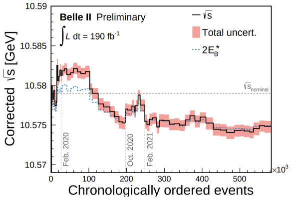
Tracking efficiency correction	$\lesssim$ 0.01
Trigger efficiency	$\lesssim$ 0.01
Background processes	$\lesssim$ 0.01
Total	**0.11**

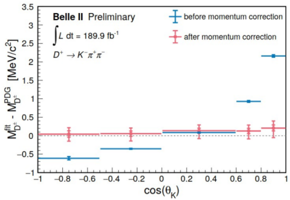
Beam energy callibration

Use B meson hadronic decays method and $\Upsilon(4S)$ lineshape measurement to get $\sqrt{s}$

Momentum scale factor

- Cure bias due to imperfect magnetic field
- Extract polar angle $cos\theta_{track}$ dependant correction: comparing $D^0 \longrightarrow K\pi$ mass peak w.r.t PDG mass





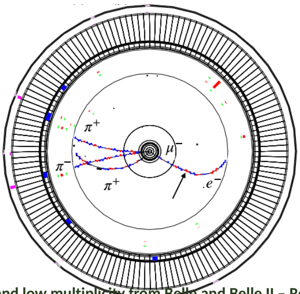
Belle – *Michel parameters measurement*

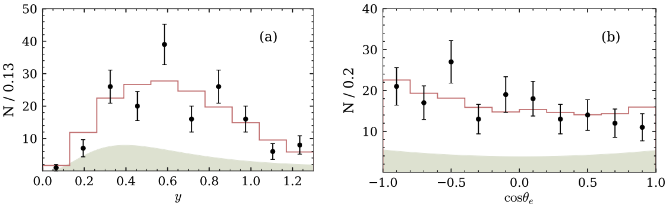
Phys. Rev. Lett. 131 (2023) p. 021801

Michel parameters arise from bilinear combinations of **coupling constants between the τ^- and the W boson**
Any deviations on them are prints of BSM physics: new gauge bosons, the presence of massive neutrinos

The ξ' defines the longitudinal polarization of the daughter μ^- when τ^- is unpolarized

- **Use μ^- decays in flight**
  $\tau^- \to \mu^-(\to e^-\overline{\nu}_e\nu_\mu)\overline{\nu}_\mu\nu_\tau$
- Require two tracks on the signal side:
  - One μ^- from the IP and ending in the CDC
  - One e^- not from the IP and close to the muon ⇒ **kink J. High Energ. Phys.** 2022 (2022) p. 35





E_{e^-} in the μ^- rest frame (GeV)

Emission angle in the μ^- rest frame

- **First direct measurement of the Michel parameter ξ' in the $\tau^- \to \mu^-\overline{\nu}_\mu\nu_\tau$ decay** with 988 fb^{-1} of Belle

$$\xi' = 0.22 \pm 0.94 \text{ (stat)} \pm 0.42 \text{ (syst)}$$

Belle II – $\tau \to \ell\alpha$ LFV decay

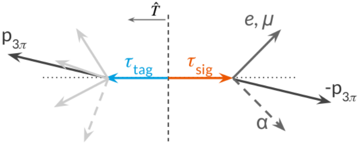
Phys. Rev. Lett. 130 (2023) p. 181803

Motivations:

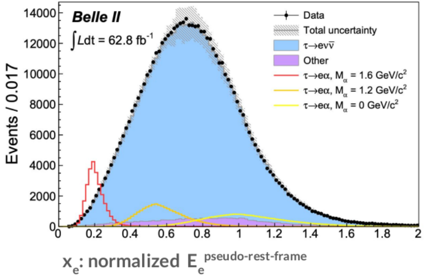
- Decays with **new LFV α bosons** (ALPs) are predicted in many models

Strategy:

- Approximate τ_{sig} pseudo-rest frame as: $E_{sig} \approx \sqrt{s}/2$ & $\hat{p}_{sig} \approx -\vec{p}_{\tau_{tag}} / |\vec{p}_{\tau_{tag}}|$



- Two body decay: search for a bump in normalized lepton energy spectrum over $\tau_{SM} \to \ell\nu\nu$ irreducible background

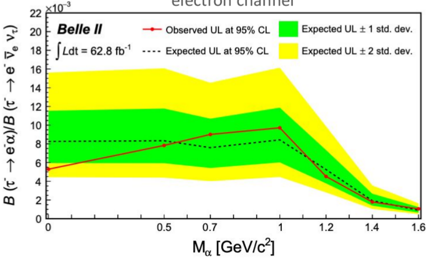


Results:

- No signal found in 62.8 fb^{-1}
- Set 95% CL upper-limit on BF ratio:

$$\mathcal{B}(\tau \to \ell\alpha)/\mathcal{B}(\tau_{SM} \to \ell\nu\nu)$$

- Between 2 to 14 times more stringent than previous limits, ARGUS



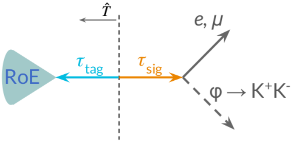
[1] Phys. Rev. Lett. 124 (2020) p. 211803 [2] Z. Phys. C - Particles and Fields. 68 (1995) pp. 25–28

Belle II – $\tau \to \ell\phi$ LFV decay (2023)

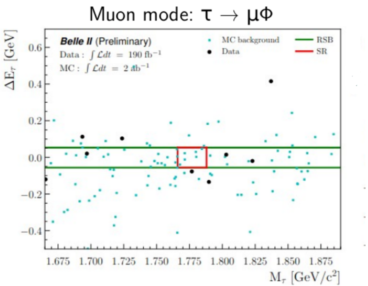
Signal efficiency challenge:

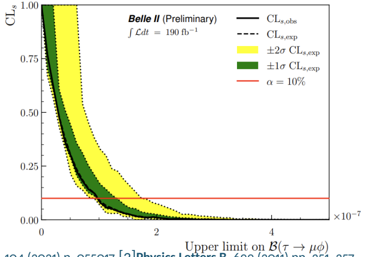
- Untagged reconstruction: drop any requirements on the tag side
- Cut-based preselections on missing momentum to reject $e^+e^- \to \ell^-\ell^+(XX)$ backgrounds
- BDT classifier: reject main backgrounds ($e^+e^- \to q\bar{q}$, $\tau^- \to 3\pi\nu_\tau$) using signal and kinematic features
- Expected background evaluated from data **reduced sidebands** with scaling from simulation: Poisson counting in **signal peaking region**:

$$M_\tau \text{ and } \Delta E_\tau = E_{sig} - \sqrt{s}/2$$



$\varepsilon_{sig} \simeq 6.1\%(6.5\%)$ for $e(\mu)$ modes, $2\times$ Belle





- No significant excess in 189 fb^{-1}
- Set 90% CL upper-limit on the BF with CL_s method

$$\mathcal{B}_{UL}(\tau \to e\phi) = 23 \times 10^{-8}$$
$$\mathcal{B}_{UL}(\tau \to \mu\phi) = 9.7 \times 10^{-8}$$

- First successful application of the untagged approach in τ-pair analysis at Belle II

[1]Phys. Rev. D. 104 (2021) p. 055017 [2]Physics Letters B. 699 (2011) pp. 251–257

Belle II – *Search for long-lived (pseudo)scalar in $b \to s$ transitions* Phys. Rev. D. 108 (2023) p. L111104

S could mix with SM Higgs with mixing angle θ_S (naturally long-lived for $\theta_S << 1$). For $M_S < M_B$, decay to dark matter kinematically forbidden by relic density constraint

First model-independent search for dark scalar S from B decays in rare $b \to s$ transition

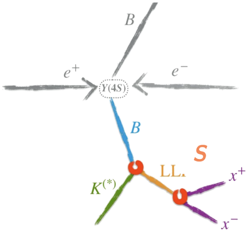
- 8 exclusive channels probed

  $B^+ \to K^+ S$

  $B^0 \to K^{*0} S$ with $S \to ee, \mu\mu, \pi\pi, KK$

- Bump hunt in the reduced mass spectrum

$$M^{reduced}_{S \to x^+x^-} = \sqrt{M^2_{S \to x^+x^-} - 4m_x^2}$$



- No significant excess was found in 189 fb^{-1}
- First model-independent 95% CL upper-limit on $\mathcal{B}(B \to KS) \times \mathcal{B}(S \to x^+x^-)$