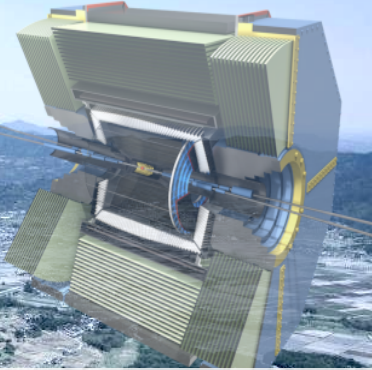


Belle II

Zuzana Gruberová (Charles University in Prague)

University of Warwick Elementary Particle Physics Seminar, May 26, 2022

Outline

» **Introduction**
- Physics motivation
- B-factories

» **Experiment**
- SuperKEKB
- Belle II

» **Status and Prospects**
- Luminosity and data taking
- Selected physics results

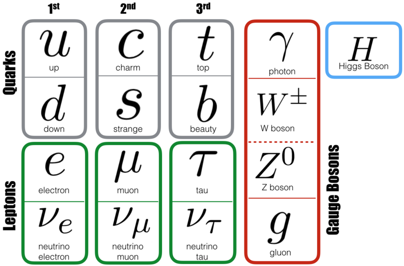
» **Summary**

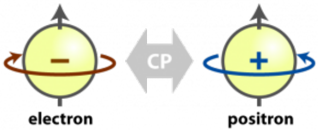
Exploring our universe

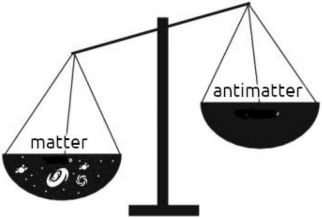
» **Big questions**

- origin of particles generations and the role of flavour
- CP violation and matter-antimatter asymmetry

  → not addressed by the Standard Model
  → we need New Physics







Physics motivation

Exploring our universe

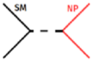
» **Big questions**

- origin of particles generations and the role of flavor
- CP violation and matter-antimatter asymmetry

  → not addressed by the Standard Model
  → we need New Physics

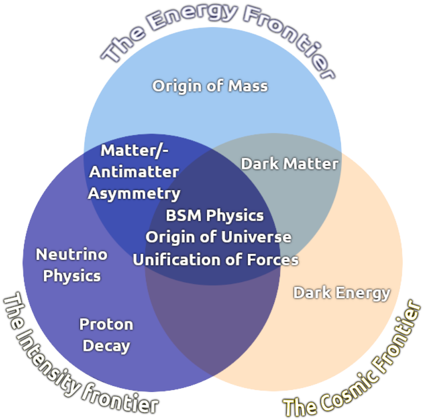
» **Where to look for NP at colliders?**

- direct searches at the Energy Frontier → direct production of new particles, limited by the collision energy



- indirect searches at the Intensity Frontier → new virtual particles, even if no new particles are found, the NP effects can still appear in high precision measurements as deviation from SM predictions

» Belle II is a leading Flavour Physics experiment at the Intensity Frontier



B-factories

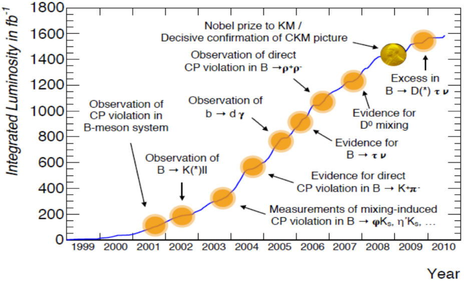
First generation B-factories

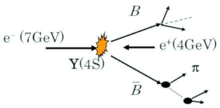
» **Asymmetric beam energies**

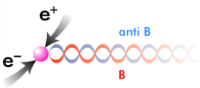
- boosted collision products

» **Collision energy at $\Upsilon(4S)$ resonance 10.6 GeV**

- $\sigma(e^+e^- \to B\bar{B}) = 1.05$ nb
  $\to$ 50% decays: coherent production of $B^0\bar{B}^0$
- full reconstruction of one of the B's, taging the flavor of the other B







» **Assets of B-factories**

- well-defined kinematics of initial state
- high vertex resolution and excellent calorimetry
- sophisticated particle ID

» **Belle@KEKB and BaBar@PEP-II**

- past B-factory experiments
- high luminosities:
  711 fb^{-1} @Belle, 424 fb^{-1} @BaBar

» **Wide physics program**

$\to$ success culminated in 2008 Nobel prize in Physics

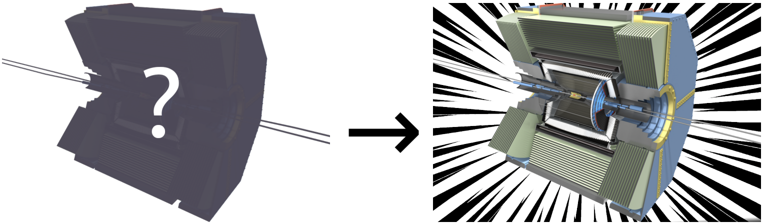
$\to$ rich legacy left for next generation experiments

B-factories

Motivation for another e^+e^- flavour factory

- probing the Standard Model? $\rightarrow$ high precision measurements of CKM matrix element
- looking for new CP violating phases? $\rightarrow$ study CP violation in B and D decays
- imprint of new physics in FCNC transitions? $\rightarrow$ examine radiative and electroweak penguin decays
- charged Higgs boson? $\rightarrow$ study tree-level decay $B \rightarrow \tau\nu$ or $B \rightarrow D^*\tau\nu$
- new physics in τ sector $\rightarrow$ search for lepton flavor violating τ decays
- dark matter? $\rightarrow$ search for hidden dark sector, invisible decays

$\rightarrow$ Belle II @ SuperKEKB will address these and other questions with almost two orders of magnitude larger dataset than Belle+BABAR



SuperKEKB

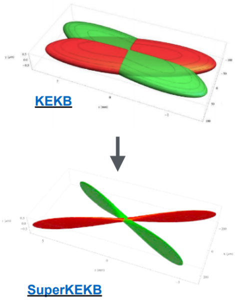
@ KEK, Tsukuba, Japan

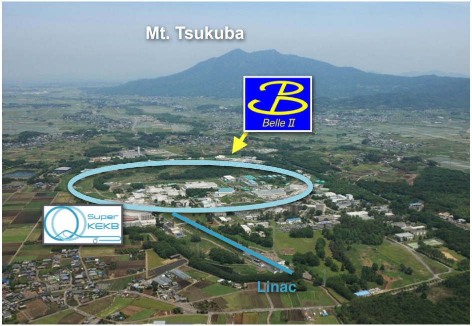
» **major upgrade of KEKB, first collision in 2018**
- 3 km long circular e^+e^- collider + linac
- asymetric beam energies of 7.0 GeV (e^-) and 4.0 GeV (e^+)
- nano-beam focusing, small interaction point, increased currents

» **Design luminosity of** $6 \times 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

→ higher background

→ higher trigger rates



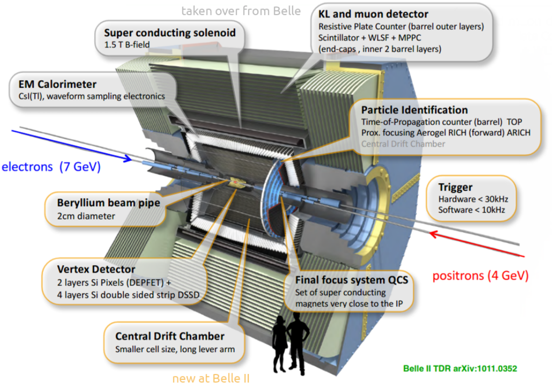


Belle II

B-factory of the next generation

» **Belle II**

- successor of the Belle experiment
- upgraded trigger system
  → allows for the selection of signals that were not possible to trigger at Belle
- excellent tracking efficiency and improved vertex resolution
  → enables for new measurement approaches



Belle II

Luminosity status and plans

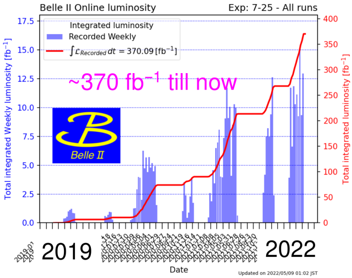
- **Despite the global pandemic, SuperKEKB managed to set new peak luminosity records in the past year**

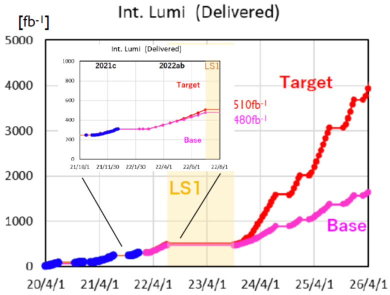
  https://cerncourier.com/a/superkekb-raises-the-bar/

→ luminosity above the B-factories and LHC, with a product of beam currents 3.5 times lower than KEKB

→ new record $4.14 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ reached just a week!

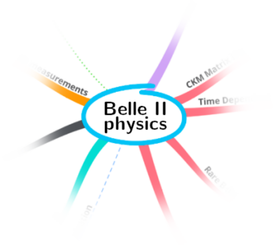
- **Operation plans**
  - long shutdown (LS1) starts from summer 2022 for 15 months to replace the vertex detector (VXD)
  - additional improvements are being discussed
  - long shutdown for machine improvements could happen on the time frame of 2026-2027





Belle II physics results

Only a small fraction of recent Belle II results will be presented!



...and the selection of the presented analyses is also sligthly biased

The Belle II Physics Book

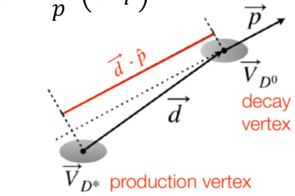
D^0, D^+ and Λ_c^+ lifetime measurements

» **Motivation**

- test of non-perturbative QCD
- large number of charm mesons are produced at B-factories
- no D^0, D^+ lifetime measurement from Belle/BaBar/LHCb
- no Λ_c^+ measurement from Belle/BaBar

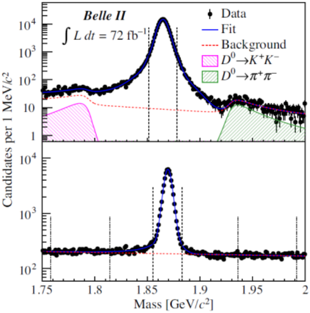
→ Belle II has better vertex resolution compared to Belle and BaBar thanks to new vertex detectors located at a closer position to the IP

$$t = \frac{m_D}{p}\left(\vec{d} \cdot \hat{\vec{p}}\right)$$



Decay vertex displaced by $\sim 200/500$ μm for D^0/D^+

72 fb^{-1}



$D^0 \to K^-\pi^+$

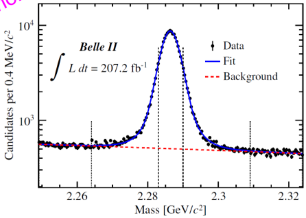
$D^+ \to K^-\pi^+\pi^+$

D from D* are selected ($D^* \to D$ + slow pion)

Preliminary (Moriond)

$\Lambda_c^+ \to pK^-\pi^+$

207 fb^{-1}

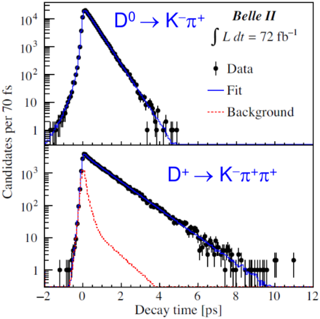


D^0, D^+ and Λ_c^+ lifetime measurements

» **Motivation**

- test of non-perturbative QCD
- large number of charms are produced at B-factories
- no D^0, D^+ lifetime measurement from Belle/BaBar/LHCb
- no Λ_c^+ measurement from Belle/BaBar

→ Belle II has better vertex resolution compared to Belle and BaBar thanks to new vertex detectors located at a closer position to the IP

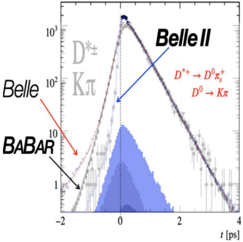


[PRL 127, 211801]

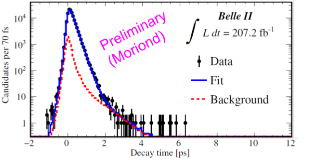
» **Strategy**

- 2D fit of decay time and its uncertainty
- all PDF parameters extracted directly from the data without simulation input

→ the time resolution at Belle II is nearly 2× better than at Belle or BaBar



$\Lambda_c^+ \rightarrow pK^-\pi^+$ [paper in preparation]



PRL 127, 211801

D^0, D^+ and Λ_c^+ lifetime measurements

» **Results**

- consistent with and the world average
- still statistically limited, dominant syst. uncertainties come from detector alignment and modelling of background (for D^+)

→ first and most precise measurement in last 20 years

→ demonstration of Belle II vertexing capabilities compared to its predecessors

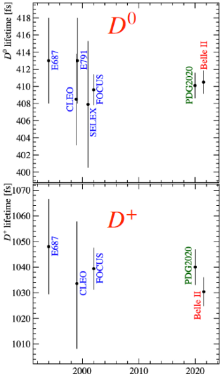
Belle II	World average
$\tau(D^0)$ = **(410.5 ± 1.1 ± 0.8) fs**	(410.1 ± 1.5) fs
$\tau(D^+)$ = **(1030.4 ± 4.7 ± 3.1) fs**	(1040 ± 7) fs
$\tau(\Lambda_c^+)$ = **(204.1 ± 0.8 ± 0.7 - 1.4) fs**	(202.4 ± 3.1) fs

	$D^0 \to K^-\pi^+$	$D^+ \to K^-\pi^+\pi^+$
Source	$\tau(D^0)$ [fs]	$\tau(D^+)$ [fs]
Resolution model	0.16	0.39
Backgrounds	0.24	2.52
Detector alignment	0.72	1.70
Momentum scale	0.19	0.48
Total	0.80	3.10

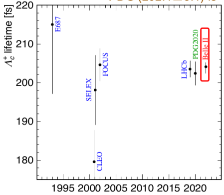
$\Lambda_c^+ \to pK^-\pi^+$

Source	Uncertainty [fs]
Resolution model	0.46
Backgrounds	0.20
Detector alignment	0.46
Momentum scale	0.09
Ξ_c contamination	1.39
Total	$0.69_{-1.39}$

systematic uncertainties



PDG (202.4±3.1) fs



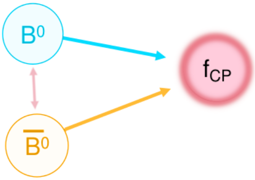
B^0 lifetime and mixing frequency

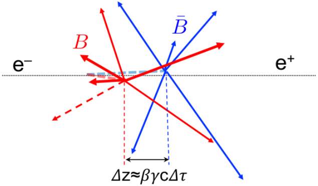
» **Goal**

- one of the main targets of Belle II – mixing-induced CP asymmetry
- B^0 and $\bar{B}^0$ decay to a common CP eigenstate f_{CP}
- CP violation appears as a decay time difference

$$A_{CP}(\Delta t) = \frac{\Gamma(\overline{B}^0(\Delta t) \to f_{CP}) - \Gamma(B^0(\Delta t) \to f_{CP})}{\Gamma(\overline{B}^0(\Delta t) \to f_{CP}) + \Gamma(B^0(\Delta t) \to f_{CP})}$$
$$= S \sin(\Delta m \Delta t) + A \cos(\Delta m \Delta t)$$
$$S = -\xi \sin(2\phi_1) \text{ for } B \to J/\psi K_S \qquad (\phi_1 = \beta)$$

S – mixing induced CPV, A – direct CPV





$\beta\gamma \approx$ **0.27**

$\to$ **mean vertex separation** $\Delta z \approx 130\mu m$

» **Current analysis**

- measuring decays to final state $D^{(*)-}K^+/\pi^+$ (instead of f_{CP})
  $\to$ fully reconstructed hadronic decay vertex

$\to$ measurement of mixing frequency (Δm) and lifetime

B^0 lifetime and mixing frequency

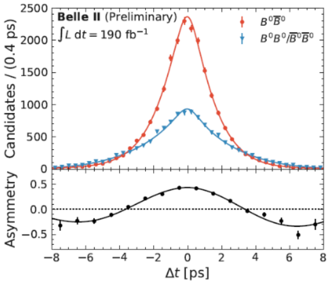
» **Results**

$$\tau_{B^0} = 1.499 \pm 0.013\,(\text{stat.}) \pm 0.008\,(\text{syst.})\ \text{ps},$$
$$\Delta m_d = 0.516 \pm 0.008\,(\text{stat.}) \pm 0.005\,(\text{syst.})\ \text{ps}^{-1}$$

- similar uncertainty as Belle and BaBar

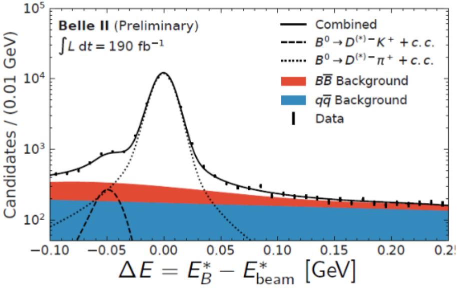
» **Next steps**

- include semileptonic mode $D^*\ell\nu$
- measure $\sin(2\phi_1)$ ($=\sin(2\beta)$)



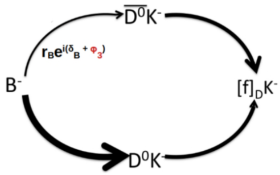
190 fb⁻¹

Preliminary
(Moriond)

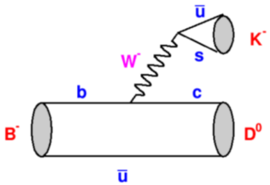


Measurement of ϕ_3

- **ϕ_3 (γ) is a weak phase between $b \to u$ and $b \to c$ transition**
  - proceeding only through tree-level $B^- \to D^0 K^-$ decays
  - SM benchmark, no theory uncertainties
  - the phase can be accesed through the interference between two possible paths to the common final state
  - interference depends on B and D physics



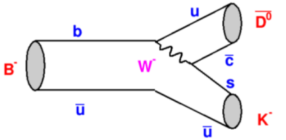
$$\frac{\mathcal{A}^{\text{suppr.}}(B^- \to \overline{D}{}^0 K^-)}{\mathcal{A}^{\text{favor.}}(B^- \to D^0 K^-)} = r_B e^{i(\delta_B + \phi_3)}$$



color favored

$B^- \to D^0 K^- \approx V_{cb} V_{us}^*$

$\mathbf{A_1}$



color suppressed

$B^- \to \bar{D}^0 K^- \approx V_{ub} V_{cs}^*$

$\mathbf{A_1 r_B e^{i(\delta_B + \phi_3)}}$

Measurement of ϕ_3

» **ϕ_3 (γ) is a weak phase between $b \to u$ and $b \to c$ transition**

- proceeding only through tree-level $B^- \to D^0 K^-$ decays
- SM benchmark, no theory uncertainties
- the phase can be accesed through the interference between two possible paths to the common final state
- interference depends on B and D physics

» **Analytical approach**

- experimentally challenging due to small branching fractions

→ Binned Dalitz plot analysis using $B^- \to D^0 h^-$ with $D^0 \to K_S^0 h^+ h^-$ (GGSZ method [PRD 68. 054018 (2003)])

→ this method is model-independent

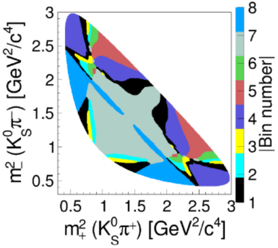
yields in each bin

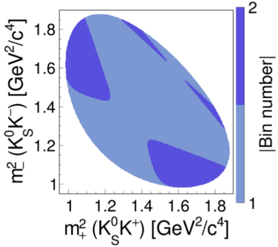
$$N_i^\pm = h_B^\pm \left[F_i + r_B{}^2 \bar{F}_i + 2\sqrt{F_i \bar{F}_i}(c_i x_\pm + s_i y_\pm) \right]$$

$(x_\pm, y_\pm) = r_B \left(\cos(\gamma + \delta_B), \ \sin(\gamma + \delta_B)\right)$

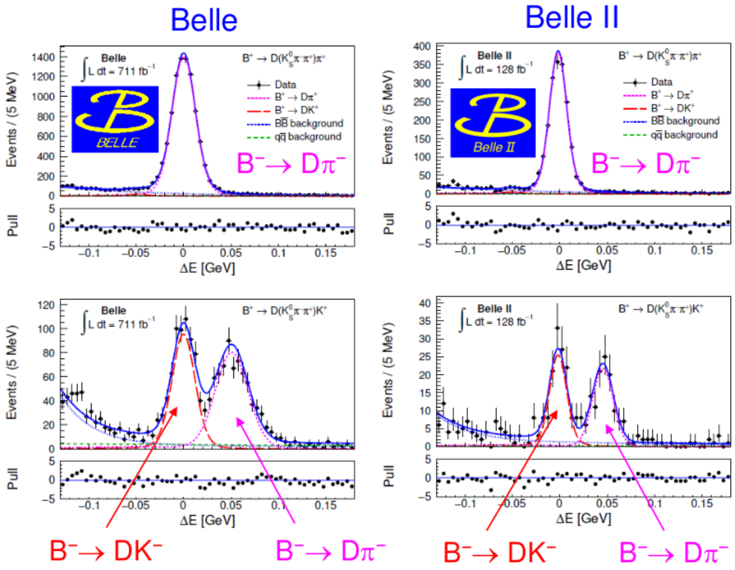
c_i, s_i: D^0-$\bar{D}^0$ strong phase differences (inputs from BES III/CLEO)

F_i: fraction of D decays to i-th bin





» combined Belle (711 fb^{-1}) and Belle II (128 fb^{-1}) analysis [JHEP 02 (2022) 063]



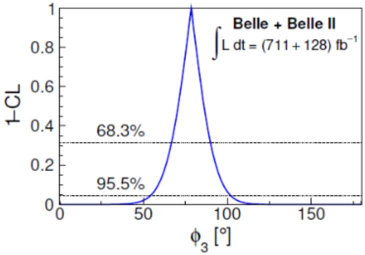
Belle:
$K_S{}^0\pi\pi$: 1467 ± 53
$K_S{}^0KK$: 194 ± 17

Belle II :
$K_S{}^0\pi\pi$: 280 ± 21
$K_S{}^0KK$: 34 ± 7

Measurement of ϕ_3

» **Results**

$$\delta_B[^\circ] = 124.8 \pm 12.9\ (\text{stat})\ \pm 0.5\ (\text{syst})\ \pm 1.7\ (\text{ext})$$
$$r_B^{DK} = 0.129 \pm 0.024\ (\text{stat})\ \pm 0.001\ (\text{syst})\ \pm 0.002\ (\text{ext})$$
$$\gamma[^\circ] = 78.4 \pm 11.4\ (\text{stat})\ \pm 0.5\ (\text{syst})\ \pm 1.0\ (\text{ext})$$



» **Many improvements with respect to the previous result from Belle**

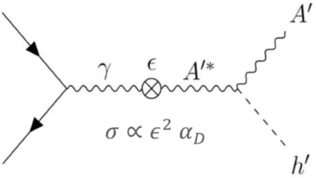
- use of $D(K_S^0 K^- K^+)$ channel
- improved suppression of continuum background
  $\rightarrow$ improvevent equivalent to doubling the statistics
- reduction of systematics thanks to latest inputs on strong phase from BESIII
- fractions F_i obtained directly from simultaneous fit to data (LHCb strategy)
- expected reduction of statistical uncertainty to $< 3^\circ$ with 10 ab^{-1} and using more D final states (but still will be statistically dominated)

Dark Higgsstrahlung

» **Next-to-minimal dark photon model**

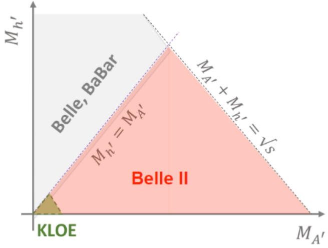
- dark photon (A') couples to the SM photon via kinetic mixing parameter ϵ
- A' mass can be generated via spontaneous symmetry breaking mechanism

  → a dark Higgs boson (h') is added to the theory [PRD 79, 115008 (2009)]
- h' does not mix with the SM Higgs
- both particles A' and h' can be produced via dark Higgsstrahlung process



» **Mass hierarchy scenarios**

- $m_{h'} > m_{A'}$: $h' \to A'A' \to 4\ell$, 4had, 2ℓ + 2had ⇒ 6 charged tracks
  Investigated by BaBar (2012) and Belle (2015).
- $m_{h'} < m_{A'}$: h' is long-lived and thus invisible ⇒ 2 charged tracks
  Partially constrained by KLOE (2015).



→ exploring unconstrained territories at Belle II

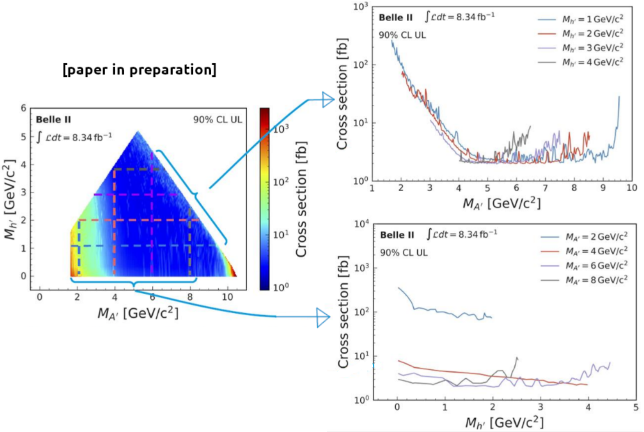
Dark Higgsstrahlung

- **New result from Belle II using 8.34 fb^{-1}**
  - upper limits are set on σ and $\epsilon^2 \alpha_D$
  - covered region of masses $1.65 < M_{A'} < 10.51$ GeV and $M_{h'} < M_{A'}$

→ 90% CL UL on σ ranges from 1.7 to 5 fb

- **Sensitivity**
  - $4 < M_{A'} < 9.7$ GeV the most sensitive region
  - $M_{A'} < 4$ GeV low sesitivity due to trigger efficiency
  - $M_{A'} > 9$ GeV large dimuon background

[paper in preparation]



→ unique results in previously unexplored regions

» **Lepton masses are fundamental parameters of the SM**

$$m_e = (0.5109989461 \pm 0.0000000031)\ \text{MeV}$$
$$m_\mu = (105.6583745 \pm 0.0000024)\ \text{MeV}$$
$$m_\tau = (1776.86 \pm 0.12)\ \text{MeV}$$

→ the m_τ precision impacts LFU tests!

» **Pseudomass measurement at Belle II**

- method developed by ARGUS collaboration
- measured in $\tau \to 3\pi\nu$ decay channel
- τ mass can be calculated as $(h \leftrightarrow 3\pi)$

$$m_\tau^2 = (P_h + P_\nu)^2 = $$
$$= 2E_h(E_\tau - E_h) + m_h^2 - 2|\vec{p_h}|(E_\tau - E_h)\cos(\vec{p_h}, \vec{p_\nu})$$

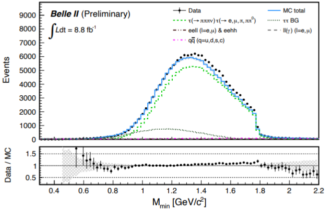
- since the direction of the neutrino is unknown, $\cos(\vec{p_h}, \vec{p_\nu}) = 1$ is taken and M_{min} is defined as

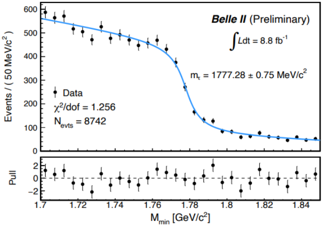
$$M_{min}^2 = 2E_h(E_\tau - E_h) + m_h^2 - 2|\vec{p_h}|(E_\tau - E_h) < m_\tau^2$$

- the M_{min} distribution is then fitted to an empirical edge function, and the position of the cutoff indicates the value of the τ mass

» **Challenges of the measurement**

- find the most accurate empirical fitting function
- properly evaluate the estimator bias





Belle II measurement from 2020

arXiv:2008.04665

The τ mass measurement

» **The goal is to achieve best precision among pseudomass measurements**

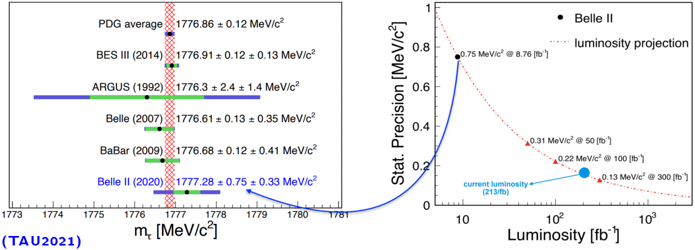
- best measurement from pseudomass technique by Belle
- world-leading result by BES III using a different method (measurement in the production threshold)

» **Belle II measurement from 2020**

- statistically dominated and in agreement with the world average
  $\rightarrow$ we will match the statistical precision of Belle/BaBar with 300 fb^{-1}
- systematic uncertainty at the level of Belle
  $\rightarrow$ we expect significant reduction in the main systematic uncertainties and further improvements of reconstruction efficiency

» **Improvements in progress**

- using more data, detailed studies of systematic corrections and uncertainties
- intense work towards a publication



Tau mass poster (TAU2021)

The τ lifetime measurement

» **Important SM parameter**

- its precision affects LFU measurements, $\alpha_s(m_\tau)$, etc.

» **World-leading measurement by Belle**

- uses a 3×3 topology, with both tau leptons decaying to $3\pi\nu$

$$\tau_\tau = 290.17 \pm 0.53(\text{stat}) \pm 0.33(\text{syst}) \text{ fs}$$

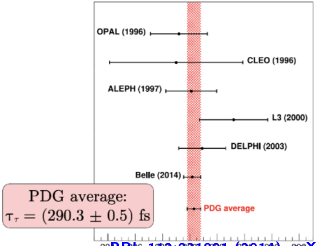
» **Belle II approach**

1. reconstruct vertex for 3-prong τ
   - only one 3-prong $\tau \to$ higher statistics
2. estimate the τ momentum
   - hadronic decays in both sides
3. find the production vertex
   - intersection of τ momentum with the plane IPy

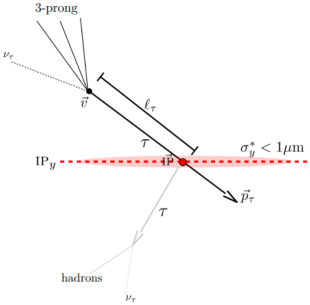
→ possible due to the tiny beamspot size at the IP at Belle II

» **Greatest challenge of this method**

- the τ momentum estimation and reconstruction of the production vertex



PRL 112:031801 (2014), arXiv:1310.8503



The τ lifetime measurement

» **Belle II MC measurement**

$$\tau_\tau = 287.2 \pm 0.5(\text{stat})\ \text{fs}$$

→ competitive statistical precision was reached already with 200 fb^{-1} (compared to 711 fb^{-1} used at Belle)

→ the resolution at Belle II is nearly 2× narrower than at Belle

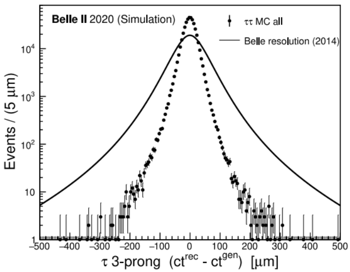
» **The measured lifetime presents $\simeq$ 3 fs bias** (generated value: 290.57 fs)

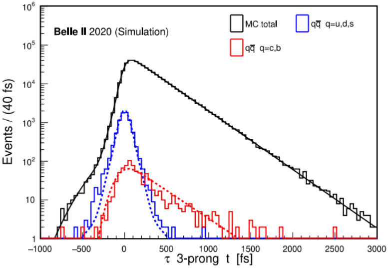
- ISR/FSR losses → underestimation of the proper time
- an intrinsic bias in the measurement

» **Further studies to estimate systematics**

- test dependence on the resolution function in the fit
- beam-spot position
- ISR/FSR simulation
- vertex detector alignment (dominant systematic uncertainty at Belle)

Tau lifetime poster (TAU2021)





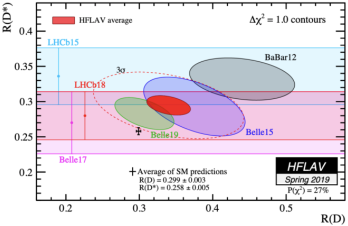
Lepton flavour universality in τ decays

» **Three lepton generations:** e, μ, τ
- different masses
- different and separately conserved lepton numbers
- the coupling of leptons to W bosons is flavour-independent, $g_e = g_\mu = g_\tau$

→ This is the SM picture of leptons, however various experimental results presented in the past years suggest LFU violation!

» **Anomalies in quark sector**
- $R(D) - R(D^*)$ plane (3.1σ),
- $R(K)$ (3.1σ), also P_5' in $B \to K^* \mu^+ \mu^-$ (3.4σ)
- and more..!

» **Significant tensions in lepton sector**
- anomalous magnetic moment of μ (4.5σ) and e (2.5σ)



» **LFU tests with τ decays**
- $e - \mu$ universality

$$\left(\frac{g_\mu}{g_e}\right)^2_\tau \propto \frac{BR(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)}{BR(\tau^- \to e^- \bar{\nu}_e \nu_\tau)}$$

- $\tau - \mu$ universality

$$\left(\frac{g_\tau}{g_\mu}\right)^2_h \propto \frac{BR(\tau \to h \nu_\tau)}{BR(h \to \mu \nu_\tau)}$$

» **Most precise measurements (BaBar)**

$$\left(\frac{g_\mu}{g_e}\right)_\tau = 1.0036 \pm 0.0020$$

→ in agreement with the SM

$$\left(\frac{g_\tau}{g_\mu}\right)_h = 0.9850 \pm 0.0054$$

→ 2.8 σ below the SM prediction

PRL 105:051602 (2010)

Lepton flavour universality in τ decays

» **Test of $e - \mu$ universality**

- the most stringent test of $e - \mu$ universality in the τ sector comes from measurement of the ratio R_μ

$$R_\mu = \frac{\mathcal{B}(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)}{\mathcal{B}(\tau^- \to e^- \bar{\nu}_e \nu_\tau)} \quad \Rightarrow \quad \left(\frac{g_\mu}{g_e}\right)^2_\tau = R_\mu \cdot \frac{f(m_e^2/m_\tau^2)}{f(m_\mu^2/m_\tau^2)}$$

, where: $f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \log x$

- world-leading measurement from BaBar [PRL 105:051602 (2010)]
  $R_\mu = 0.9796 \pm 0.0016(\mathrm{stat}) \pm 0.0036(\mathrm{sys})$
- high purity of $\tau^\pm \to \ell^\pm \nu \bar{\nu}$ samples were achieved (**99.7%** for $\tau \to e\nu\bar{\nu}$ and **97.3%** for $\tau \to \mu\nu\bar{\nu}$)

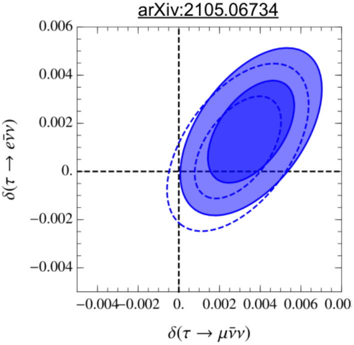
» **Search for LFUV in $\tau \to \ell \nu \bar{\nu}$**

- global fit to $\tau \to \ell\nu\bar{\nu}$ and $\mu \to e\nu\bar{\nu}$ ratios (latter well constrained by EW data)

→ 2σ tension with the SM [arXiv:2105.06734]

- will this tension become more significant with better precision on R_μ?

→ Belle II is the only experiment in the coming 10-20 years that can provide answers!



» **Strategy at Belle II**

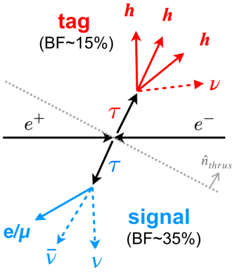
» search for LFUV 3×1-prong and 1×1-prong τ-pair events

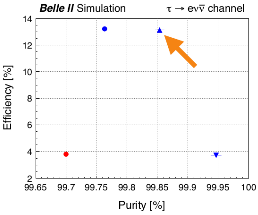
» employ MVA techniques to achieve even better purity

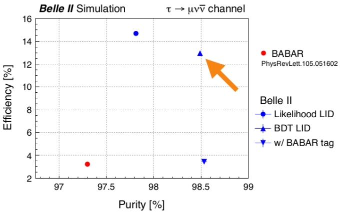
» current studies are done on MC only → blinded data analysis is the next step

Lepton flavour universality in τ decays

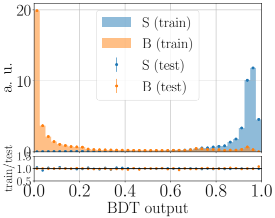
» **3×1-prong τ-pair topology**







$$FOM = \frac{N_{sig}}{\sqrt{N_{sig} + 100 \cdot N_{bkg}}}$$



» **Cut-based analysis**

- optimisation of rectangular cuts with FOM, factor 100 penalty to background to favour purity over efficiency

→ Compared to BaBar, Belle II has $\sim 4\times$ higher efficiency with better purity

» **BDT analysis**

- combined signal in training ($\tau \to \ell\nu\bar{\nu}$) → maximize cancellation of tag-side systematics

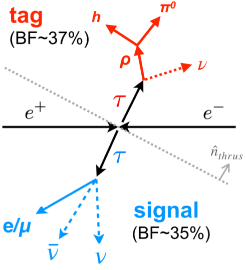
→ for the purity of 98% the efficiency is 23%
$\sim 1.7\times$ improvement wrt cut-based analysis and $\sim 7\times$ improvement wrt BaBar (averaging the e and μ channels)

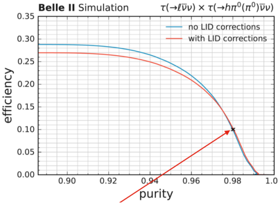
Lepton flavour universality in τ decays

» **1×1-prong τ-pair topology**

- not used at BaBar but possible at Belle II thanks to the trigger performance
- most recent result comes from CLEO [SLAC-PUB-9839]

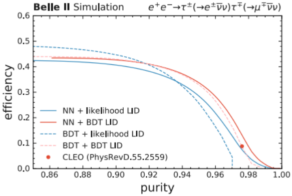
- tag $\mathcal{BR}$ is $\sim 2.5\times$ larger wrt 3×1
- more challenging backgrounds $\rightarrow$ multivariate analysis is a necessity

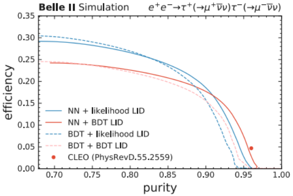




» **Earlier Neural Network analysis**

- studying e and μ channels individually — BELLE2-NOTE-PL-2021-009
- better performance for $e-\mu$ and very close for $\mu-\mu$ compared to CLEO





» **Updated NN analysis**

- optimized preselections $\rightarrow$ 88% purity at 29% signal efficiency
- combined signal in training ($\tau \rightarrow \ell\nu\bar{\nu}$) $\rightarrow$ maximize cancellation of tag-side systematics

$\rightarrow$ for the purity of 98% the efficiency is 10%

$B \to$ charm, weak phases, forbidden decays, dark sector...

» $B \to X_c \ell \nu$ [paper in preparation]

- new measurement of the inclusive $B \to X_c \ell \nu$ with tagged method at Belle II
- novel idea: reduction of HQE parameters ($13 \to 8$) by reparametrization $\to$ [arXiv:1812.00747]

» ϕ_2 [arXiv:2107.02373]

- unique capability of Belle II to study all the $B \to \pi\pi, \rho\rho$ decays to determine phase ϕ_2 (α)
- 20% precision improvement with respect to Belle at the same luminosity

» $B^+ \to K^+ \nu \bar{\nu}$ [arXiv:2104.12624]

- probing of a FCNC decay
- novel inclusive tagging technique at Belle II $\to$ signal efficiency 4.3% (compared to at best 0.2% efficiency of the previous measurements by Belle and BaBar)

» Dark sector studies

- $e^+e^- \to \mu^+\mu^- Z', Z' \to$ invisible (0.28 fb^{-1}) $\to$ [PRL124 (2020), 141801]
- Axion-like Particle (ALP) search in $e^+e^- \to a(\to \gamma\gamma)\gamma$ (0.44 fb^{-1}) $\to$ [PRL125 (2020), 161806]

» $A_{CP}(B^0 \to K_S^0 \pi^0), B^+ \to \rho^+\rho^-$ angular analysis

» electroweak penguin B decays $B \to K^* \ell^+ \ell^-$

» hadron spectroscopy (Belle II took energy scan data above $\Upsilon(4S)$ in 2021)

...and more analyses published and in progress!

Summary

» **Belle II is a B-factory of the next generation**

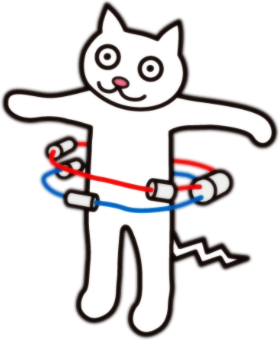
- setting peak luminosity records thanks to nano-beam scheme
- opening new possibilities for measurements thanks to upgraded trigger, vertex resolution and tracking efficiency

→ since its first collision in 2018, Belle II has collected almost 400 fb^{-1} of data

» **Belle II contributes to wide range of physics topics**

- D^0, D^+ and Λ_c^+ lifetime measurements
- B^0 lifetime and mixing frequency
- measurement of ϕ_3
- dark Higgsstrahlung
- the τ mass measurement
- the τ lifetime measurement
- lepton flavour universality in τ decays
- ...and various other topics

Stay tuned for more exciting results!



Thank you for your attention