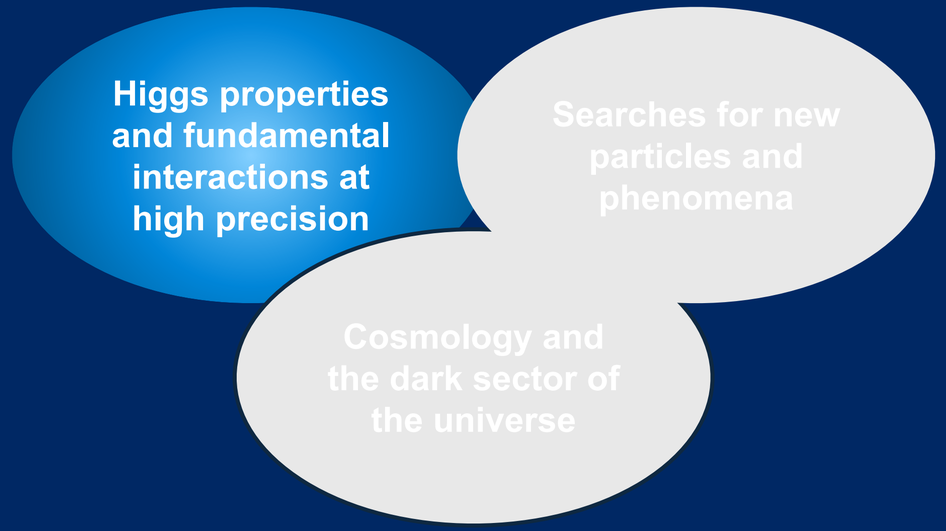
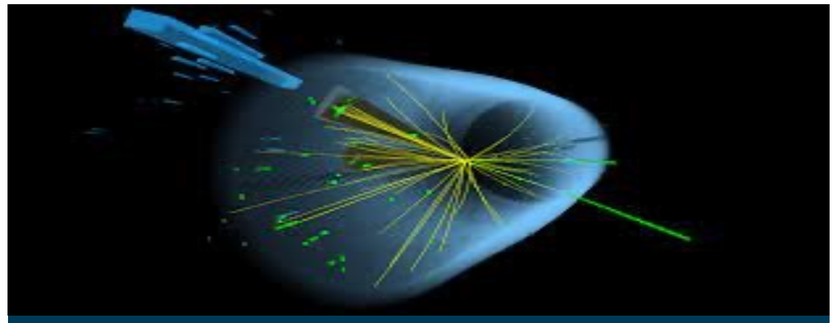


MATTER AND THE UNIVERSE

POF V

Belle II

Ami Rostomyan
Hamburg, 12 February 2025



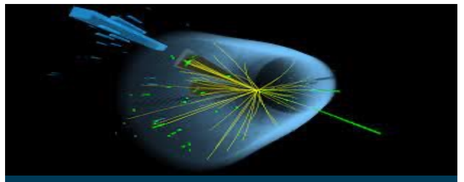
The origin of mass, the flavour puzzle, and the imbalance between matter and anti-matter

- Higgs boson
- Top and B physics
- Charge-parity violation
- Lepton flavour universality

DESY.

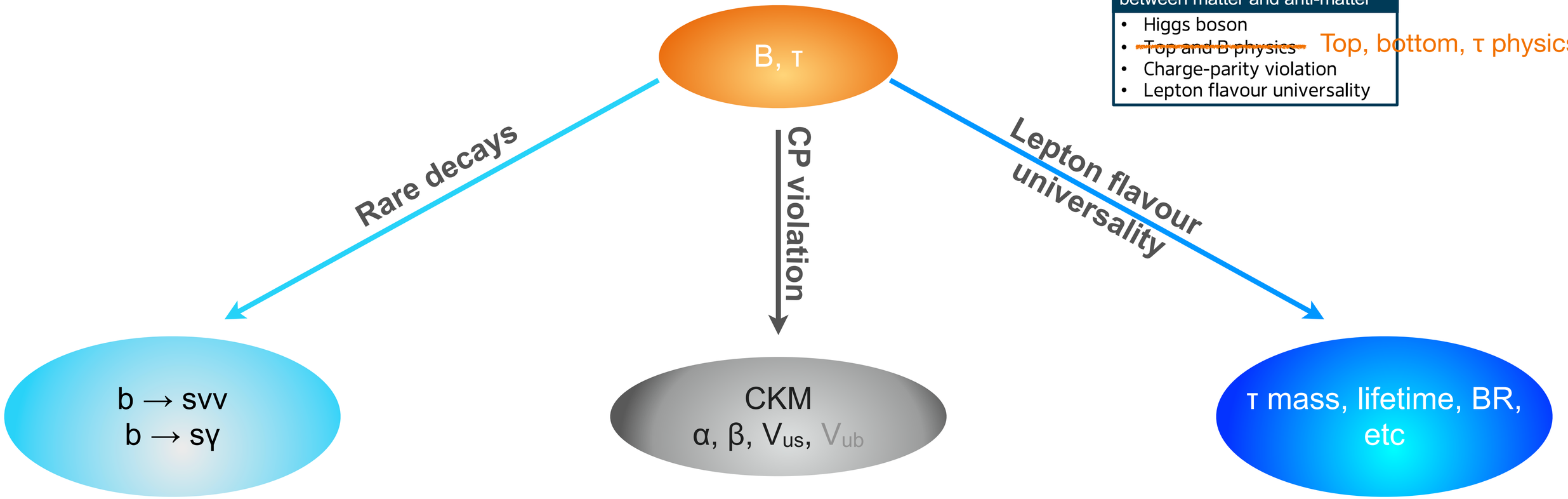
Targeting unique to Belle II measurements

Belle II provides unique sensitivity to NP couplings to the 3rd generation



The origin of mass, the flavour puzzle, and the imbalance between matter and anti-matter

- Higgs boson
- ~~Top and B physics~~ Top, bottom, τ physics
- Charge-parity violation
- Lepton flavour universality



Except β, all other measurements cannot be done at LHCb

Belle II

Belle II collected $575\ \mathrm{fb}^{-1}$ data, as much as the first generation B-factories

- Slower than expected data accumulation at SuperKEKB

Achieved a new world record peak luminosity

$5.1 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ on December 27, 2024

- Target luminosity: $6 \times 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

To achieve the ambitious Belle II program higher luminosity is required

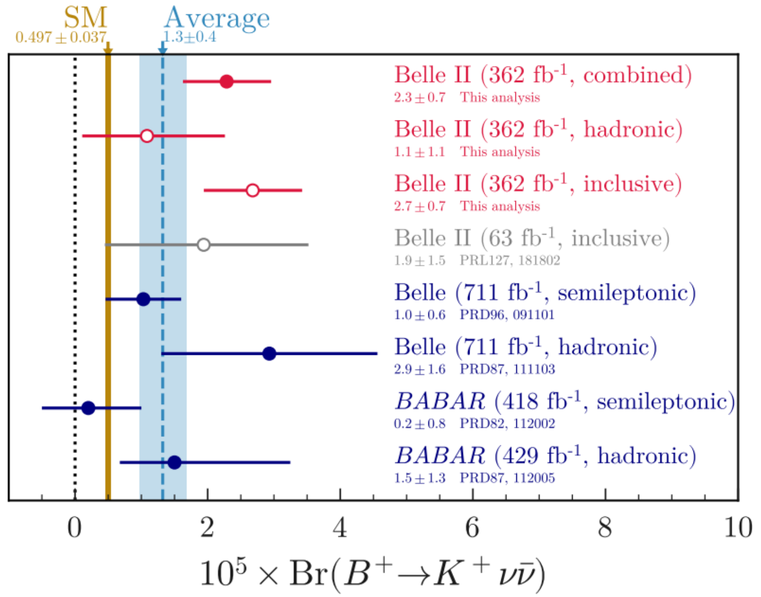
- To reach instantaneous luminosities beyond $2 \times 10^{35} cm^{-2} s^{-1}$ a redesign of IP and new vertex detector is planned
- For next POF period projections: $5 - 10\mathrm{ab}^{-1}$

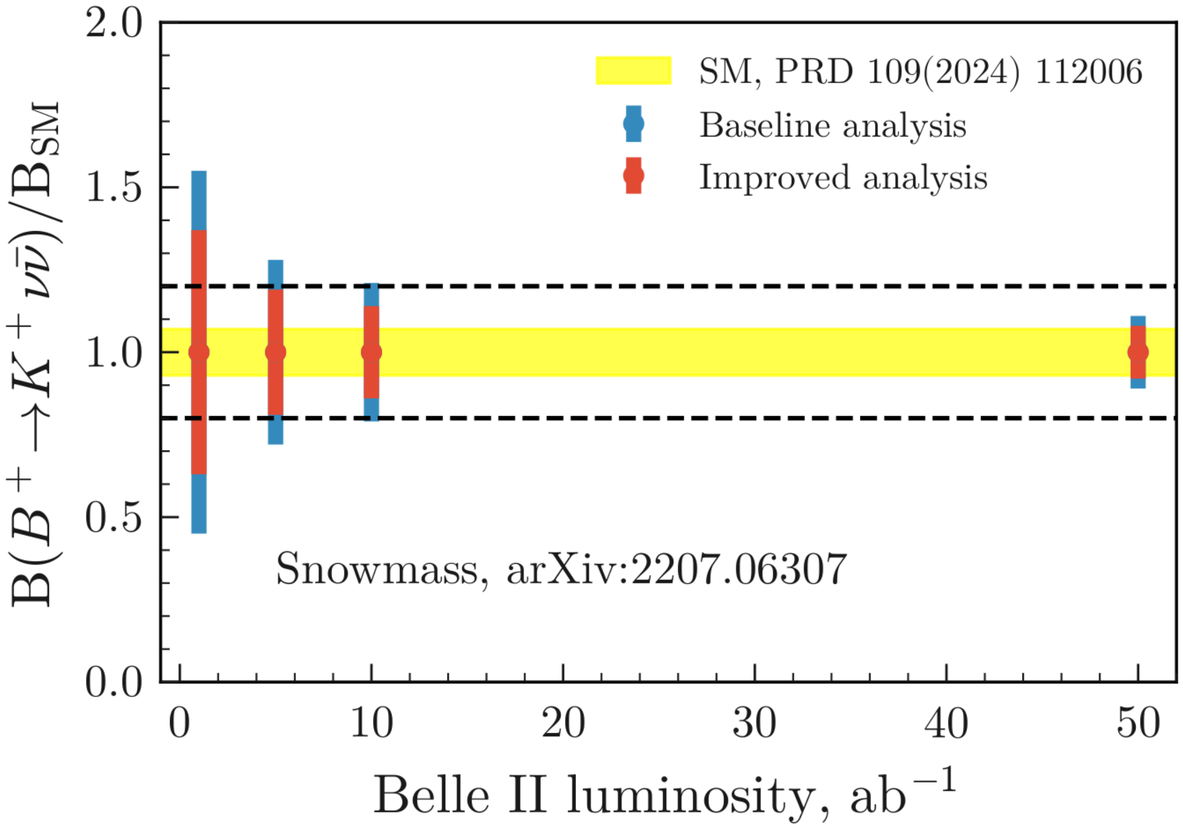
Rare decays: $b -> s\nu\nu$

Based on Snowmass studies for $B^+ \to K^+\nu\nu$:

- 5ab^{-1} is sufficient to establish the process (assuming SM)
- 50ab^{-1} is needed to match SM theory accuracy

- Complement $B^+ \to K^+\nu\nu$ with $B \to K^0_S\nu\nu, K^{*0}\nu\nu, K^{*+}\nu\nu$





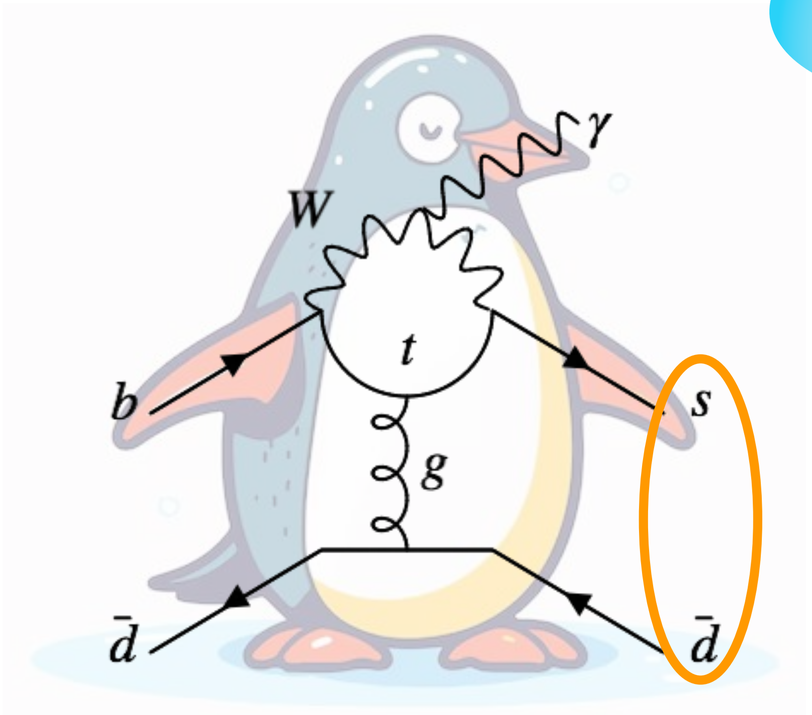
b → svv

Inclusive B → $X_s\gamma$ Decays

b → sγ

Rare decay: $\mathcal{B}(B \to X_s\gamma) = (3.49 \pm 0.19) \times 10^{-4}$

- Flavour changing neutral current (FCNC)
  - Suppressed in the SM ⇒ Enhanced sensitivity to new physics
- In addition to the branching fraction, what is interesting to measure?
  - Decay rate and *CP* asymmetries sensitive probes of BSM physics via electroweak penguin loop
  - Shape of photon energy spectrum sensitive to m_b
    - Relates to inclusive measurements of $|V_{ub}|$



For hadronic tag

Lower E_γ^B threshold	Statistical uncertainty				Baseline (improved)
	1 ab^{-1}	5 ab^{-1}	10 ab^{-1}	50 ab^{-1}	syst. uncertainty
1.4 GeV	10.7%	6.4%	4.7%	2.2%	10.3% (5.2%)
1.6 GeV	9.9%	6.1%	4.5%	2.1%	8.5% (4.2%)
1.8 GeV	9.3%	5.7%	4.2%	2.0%	6.5% (3.2%)
2.0 GeV	8.3%	5.1%	3.8%	1.7%	3.7% (1.8%)

CKM precision measurement

CKM
α, β, V_{us}

β: from decay-time-dependent *CP* analyses of $B \to J/\psi K^0$ decays

- With 5/ab of data, statistical precision on beta is expected to be competitive with LHCb with 50/fb of data
- Both LHCb and Belle II analyses will be systematics-limited and will require improvement
  - PXD fundamental in controlling resolution function systematics

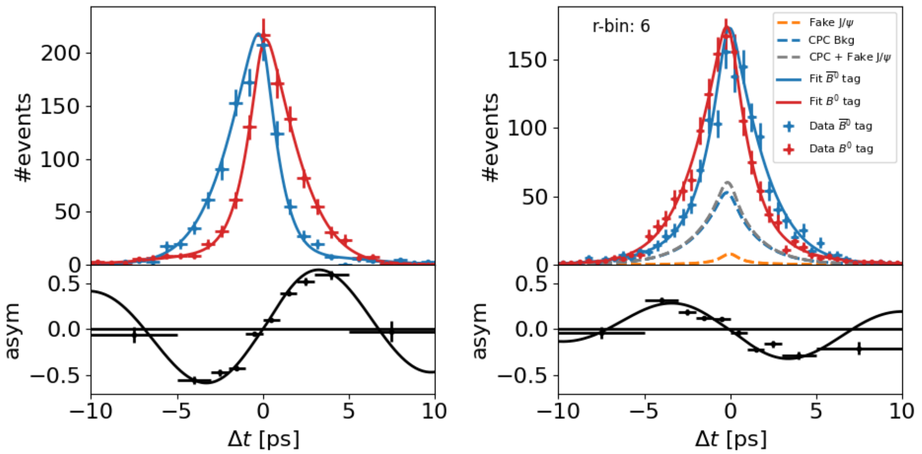
α: from analysis of $B \to \rho\rho$, $B \to \pi\pi$, $B \to \rho\pi$ decays

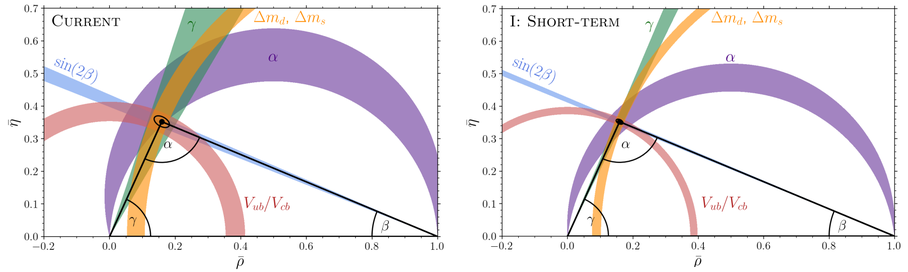
- α is the least well known CKM angle so far
- Belle II will lead the precision

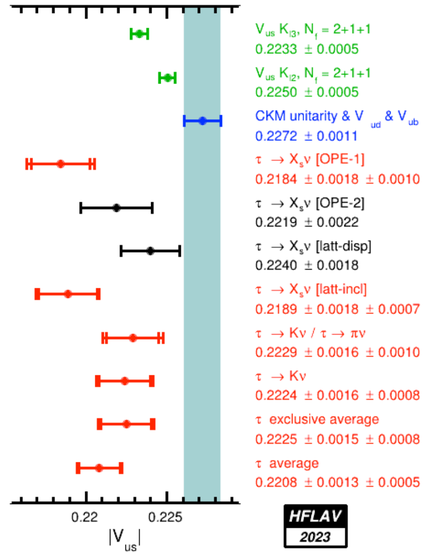
V_{us}: exclusive and inclusive from τ decays

- The value of V_{us} from τ decays high (Cabibbo angle anomaly)
- As a τ factory, Belle II is uniquely placed to address this issue

$B \to J/\psi K_S^0$ $B \to J/\psi K_L^0$







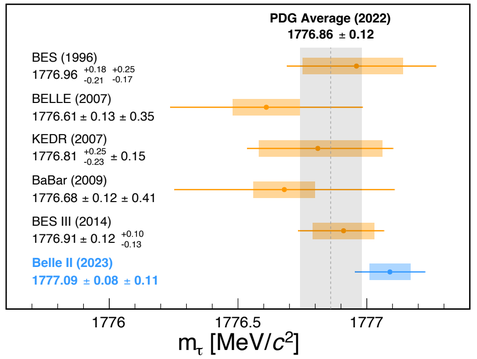
Lepton flavour universality with τ-lepton decays

τ mass, lifetime, BR

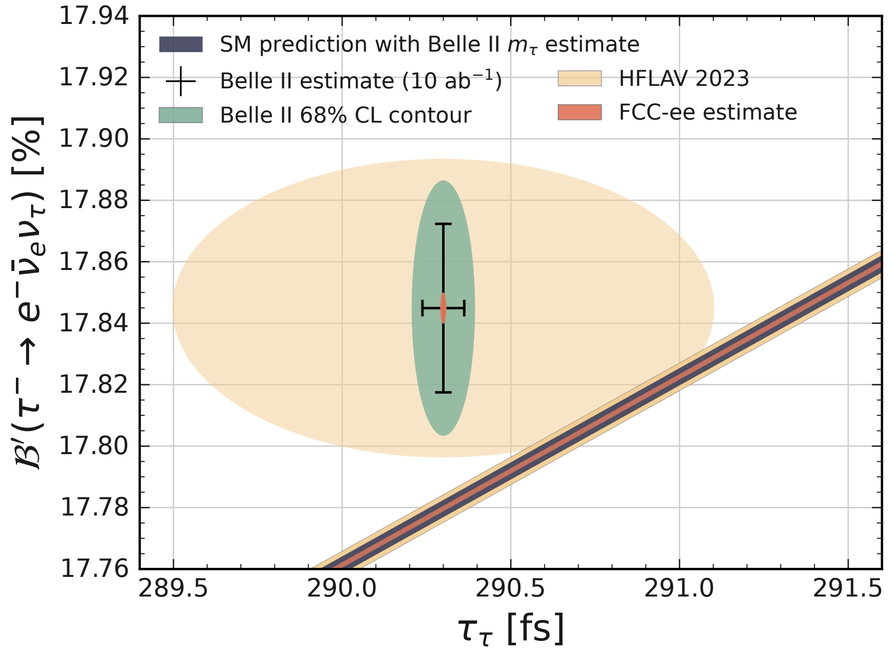
The τ mass, lifetime and $\mathcal{B}(\tau \to \ell \nu_\ell \nu_\tau)$

- The most precise τ mass measurement so far from Belle II

$$m_\tau = 1777.09 \pm 0.14\ \mathrm{MeV/c^2}$$



- Ongoing studies show that further reduction of systematic uncertainty is possible
- Ongoing studies show a significant improvement in the τ lifetime and leptonic branching fraction precisions
  - PXD is pivotal for the lifetime measurement
  - The absolute branching fractions $\mathcal{B}(\tau \to e\nu_e\nu_\tau)$ and $\mathcal{B}(\tau \to \mu\nu_\mu\nu_\tau)$ have not been measured at B-factories



Test of lepton flavour universality in τ decays

τ mass, lifetime, BR

The coupling of leptons to W bosons is flavour-independent

$$g_e = g_\mu = g_\tau$$

$\mu - e$ universality

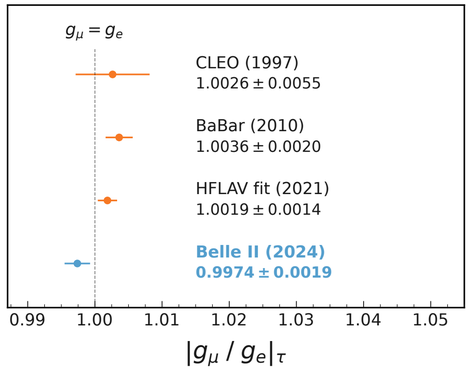
- Most precise test from π decays
- Followed by τ decays
  - Belle II has the most precise single measurement in τ decays

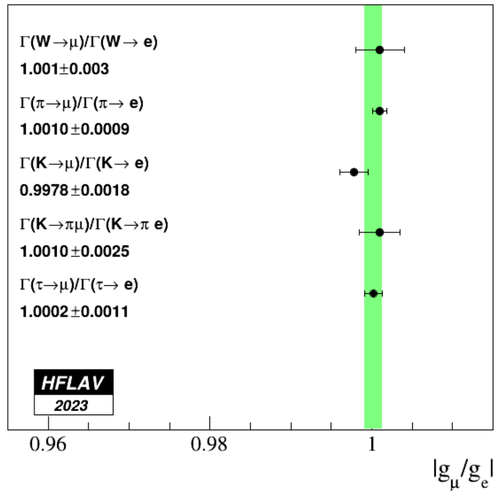
$\tau - e$ universality

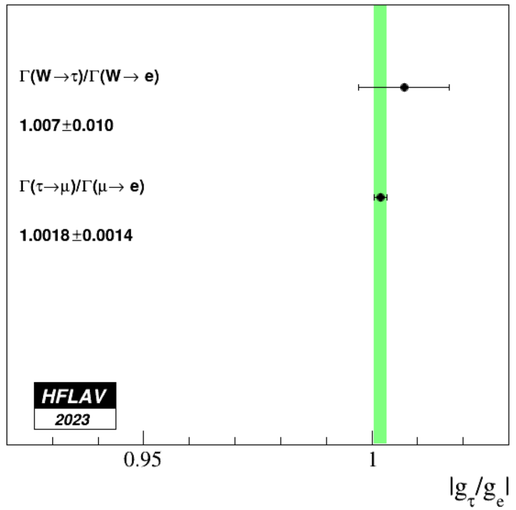
- An order of magnitude more precise measurements from τ decays (BaBar) than from W decays

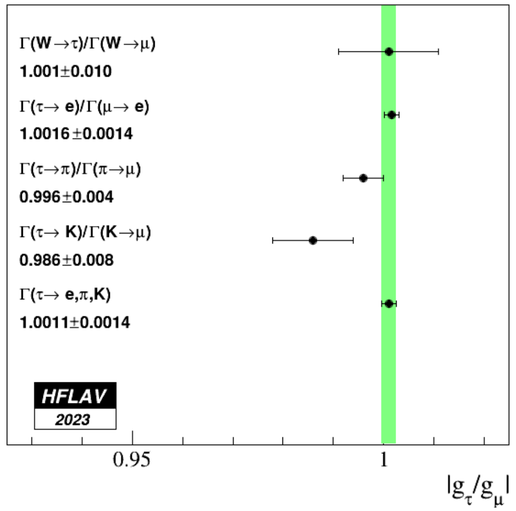
$\tau - \mu$ universality

- τ/μ decays have the best precision







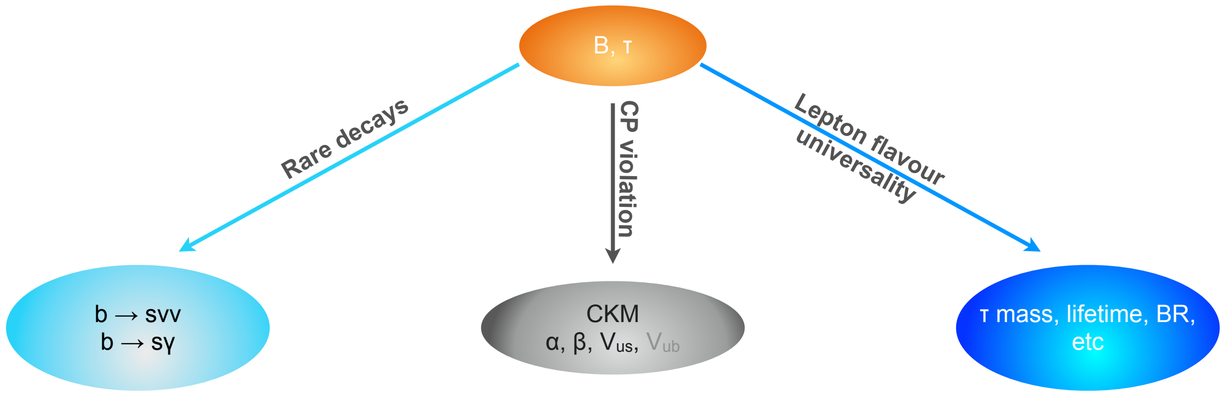


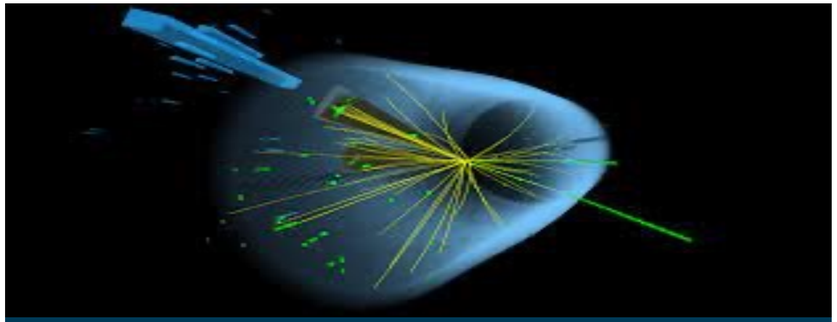
Belle II prospects:

- Require measurements of absolute branching fractions: $\tau \to e, \mu, \pi, K$
- Initial studies show promising results for hadronic and leptonic branching fraction measurements

Summary

Belle II provides unique sensitivity to NP couplings to the 3rd generation





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- Charge-parity violation ✓
- Lepton flavour universality ✓