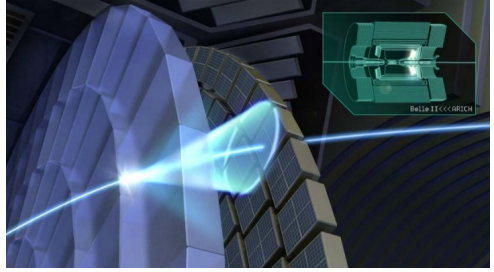
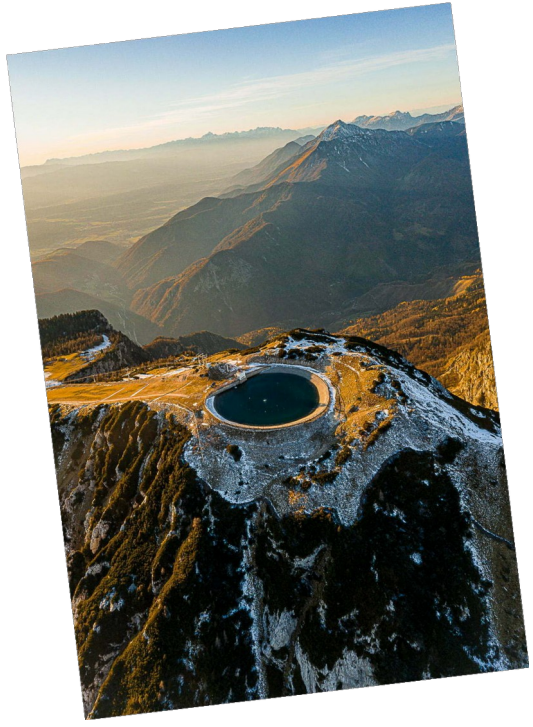
Institut
"Jožef Stefan"
Ljubljana, Slovenija



Belle II

Luka Šantelj



F9 – Stratesko srecanje, Krvavec, 29.9.2026

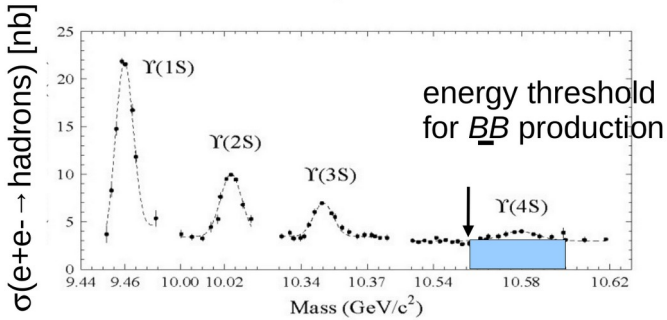
Belle II @ SuperKEKB – B factory of 2nd generation

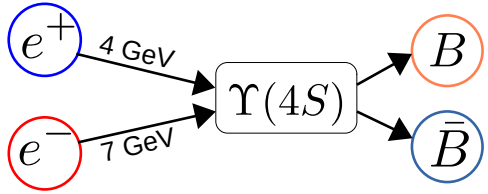
- Experiment on the **intensity frontier;** Successor of the very successful Belle@KEKB, in Tsukuba, Japan.

  → search for New Physics via precise measurement of rare decays of B, D mesons and τ leptons

- Aim to collect $50\ \mathrm{ab}^{-1}$ of e^+e^- collisions, nominally at the energy of the $\Upsilon(4S)$ (10.58 GeV), this gives:

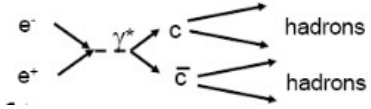
  → a (Super) B factory: $\sim 1.1 \times 10^9\ B\bar{B}$ pairs per ab^{-1}





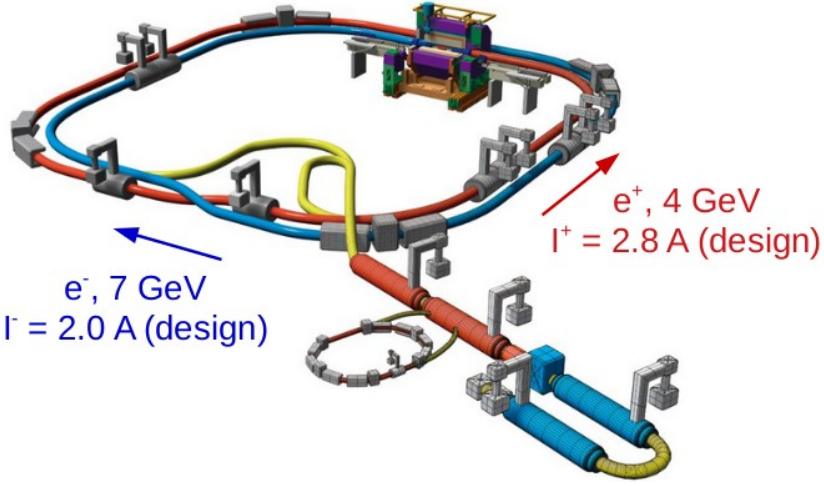
→ 2 B's and nothing else
→ in a quantum coherent state

  → a (Super) charm factory: $\sim 1.3 \times 10^9\ c\bar{c}$ pairs per ab^{-1}

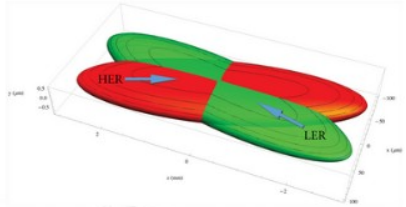


  → a (Super) τ factory: $\sim 1.3 \times 10^9\ \tau^+\tau^-$ pairs per ab^{-1}

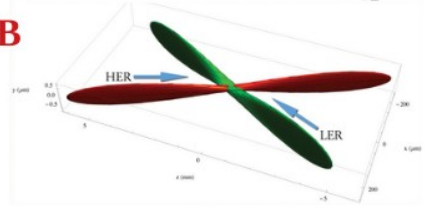
The SuperKEKB collider



KEKB



SuperKEKB



$$L = \frac{N_+ N_- n_b f_0}{4\pi \sigma^*_{x,\mathrm{eff}} \sqrt{\varepsilon_y \beta^*_y}}$$

Improvements over KEKB:

x20 by ‘nanobeam scheme’;

x1.5 by increasing beam currents.

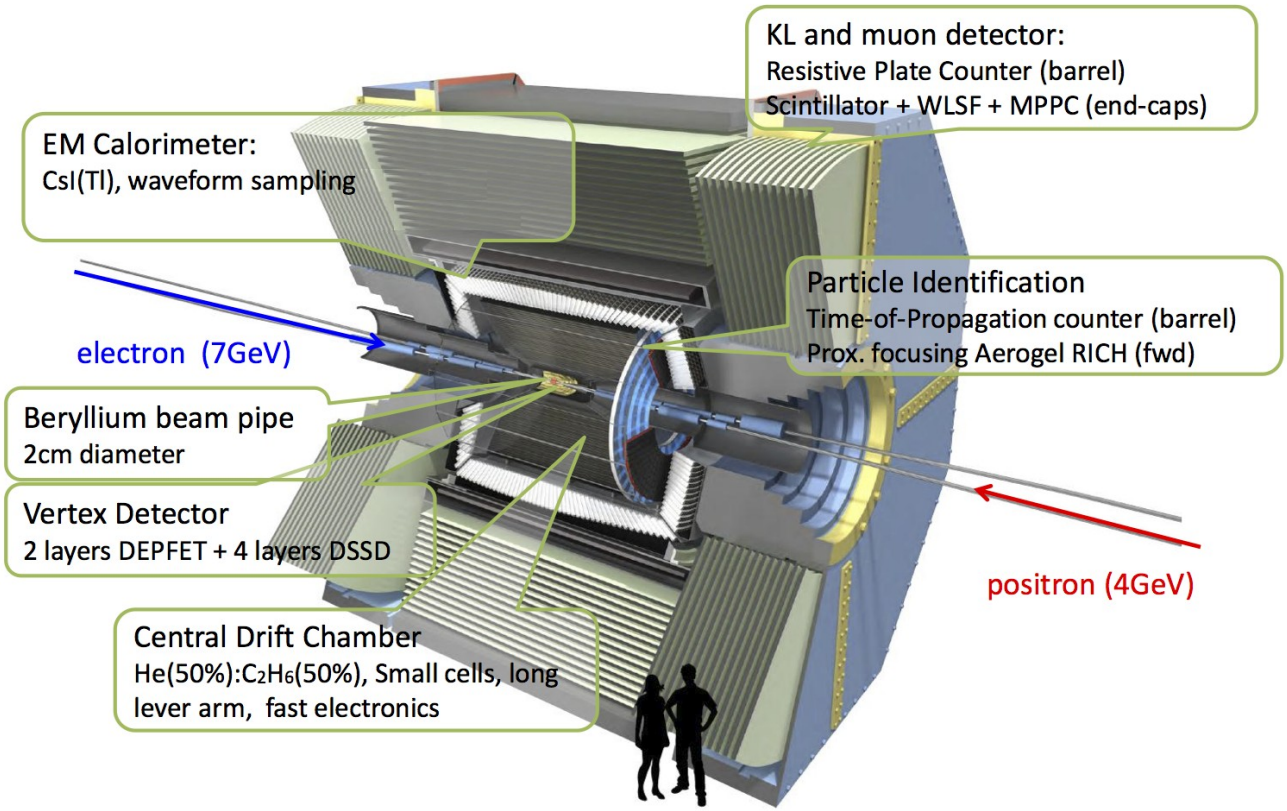
Goals:

Instantaneous lumi: ~6 x 10^{35} $cm^{-2}s^{-1}$ 30 x higher than KEKB!

Integrated lumi: 50 ab^{-1}

Belle II @ SuperKEKB – B factory of 2nd generation

The Belle II detector



- General purpose spectrometer (B=1.5 T)
- Excellent decay vertex resolution

  ($\sigma \sim 60\ \mu$m for B,D)

- **Particle identification is a key issue**

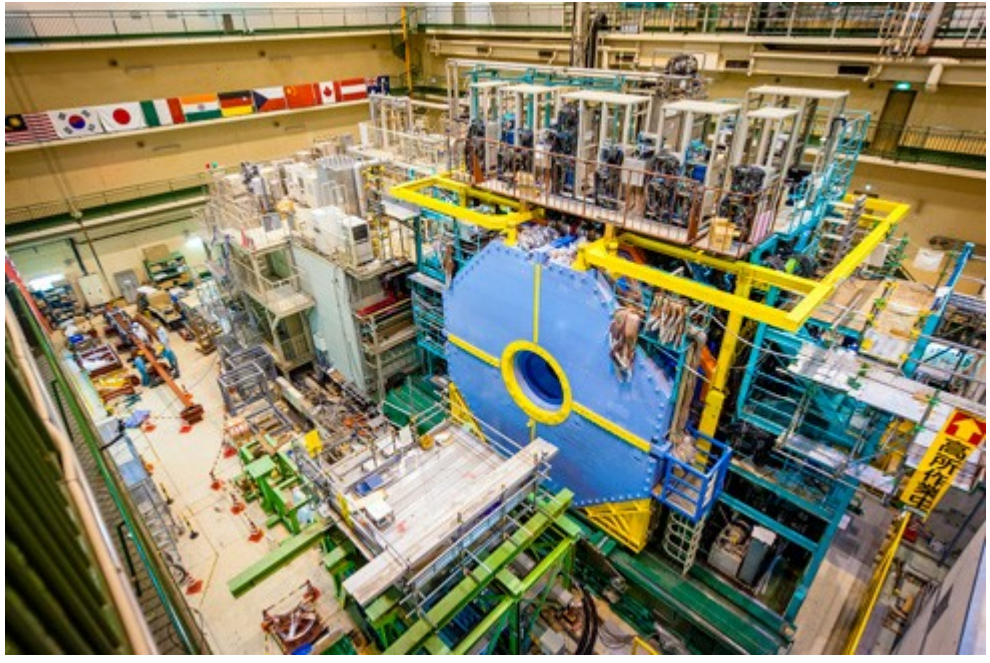
  → background reduction

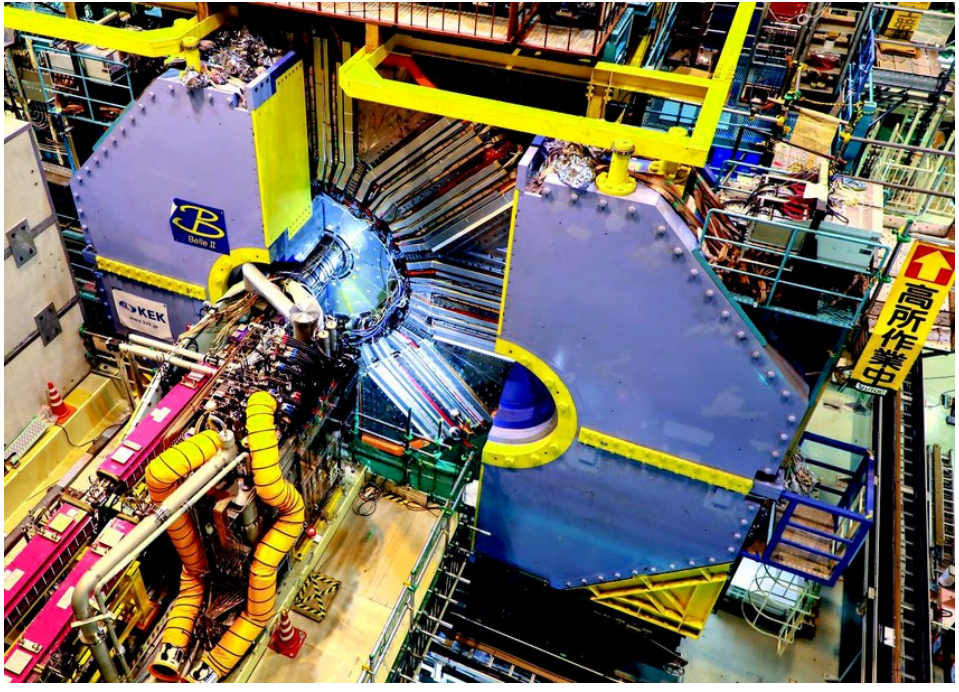
  e.g. $B \to \rho\gamma, B \to K^\star\gamma$

  → efficient flavor tagging (B^0 or $\bar{B}^0$)
- **two novel PID detectors**

  → Time-of-propagation counter

  → Aerogel RICH




Belle II
KEK
高所作業中

Flavor physics at e^+e^- vs. at LHCb

Belle (II)

$e^+e^- \to \Upsilon(4S) \to b\bar{b}$

at $\Upsilon(4S)$: 2 B's (B^0 or B^+) and nothing else ⇒ clean events

$\sigma_{b\bar{b}} \sim 1\,\text{nb} \Rightarrow 1\ \text{fb}^{-1}$ produces $10^6\ B\bar{B}$

$\sigma_{b\bar{b}}/\sigma_{\text{total}} \sim 1/4$

mean decay length $\beta\gamma c\tau \sim 200\ \mu\text{m}$

LHCb

$pp \to b\bar{b}X$

production of B^+, B^0, B_s, B_c, Λ_b...

but also a lot of other particles in the event

⇒ lower reconstruction efficiencies

$\sigma_{b\bar{b}}$ much higher than at the $\Upsilon(4S)$

	$\sqrt{s}$ [GeV]	$\sigma_{b\bar{b}}$ [nb]	$\sigma_{b\bar{b}}/\sigma_{\text{tot}}$
HERA pA	42 GeV	~30	$\sim 10^{-6}$
Tevatron	2 TeV	5000	$\sim 10^{-3}$
LHC	8 TeV	$\sim 3\times10^5$	$\sim 5\times10^{-3}$
	14 TeV	$\sim 6\times10^5$	$\sim 10^{-2}$

$\sigma_{b\bar{b}}/\sigma_{\text{total}}$ much lower than at the $\Upsilon(4S)$

⇒ lower trigger efficiencies

mean decay length $\beta\gamma c\tau \sim 7$ mm

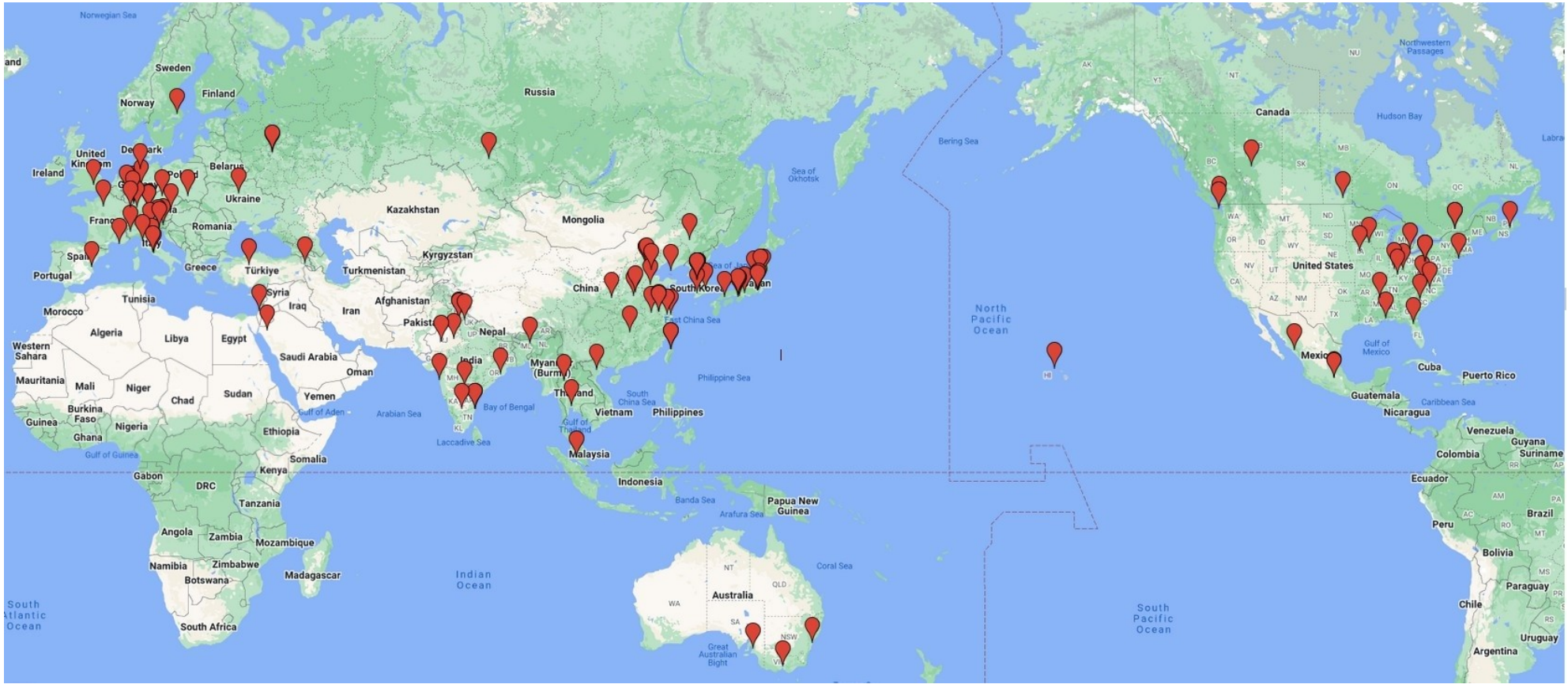
→ **many of the interesting modes are unique to B factories:**

- channels with π^0, K_L, $\eta^{(')}$, … ;
- final states with one or more ν's;
- modes affected by "difficult" backgrounds, where the full knowledge of the kinematics in the event is the only way to control them;
- a variety of inclusive measurements can be performed;

+ extraordinary claims require extraordinary evidence

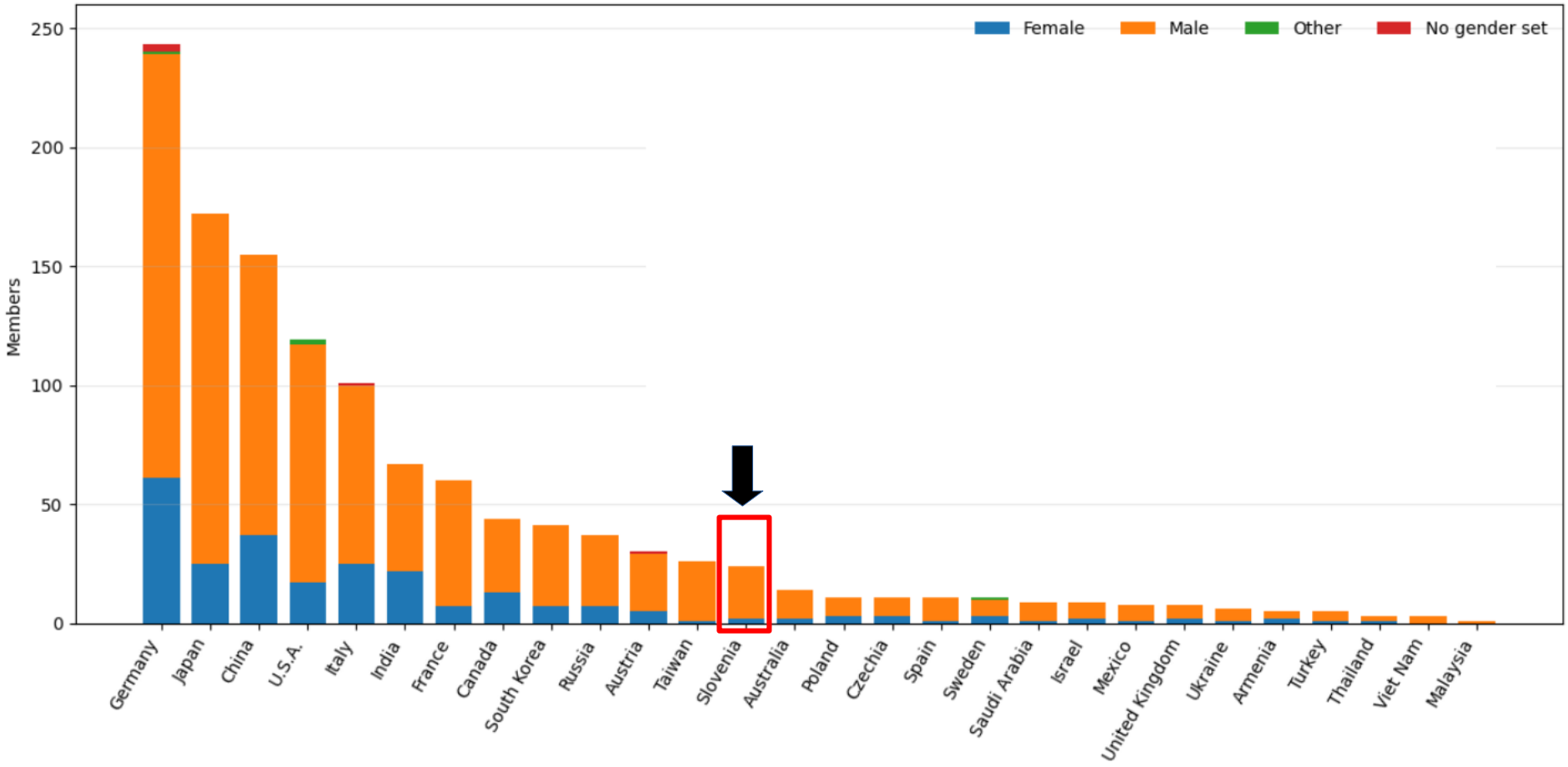
→ independent confirmation of as many modes as possible

The Belle II collaboration



1243 active members, 125 institutes, 28 countries (as of Jun. 2026)

The Belle II collaboration



So far collected data

- physics runs started in **2019**

- **SuperKEKB** recently achieved world record instantaneous luminosity of

$$5.3 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

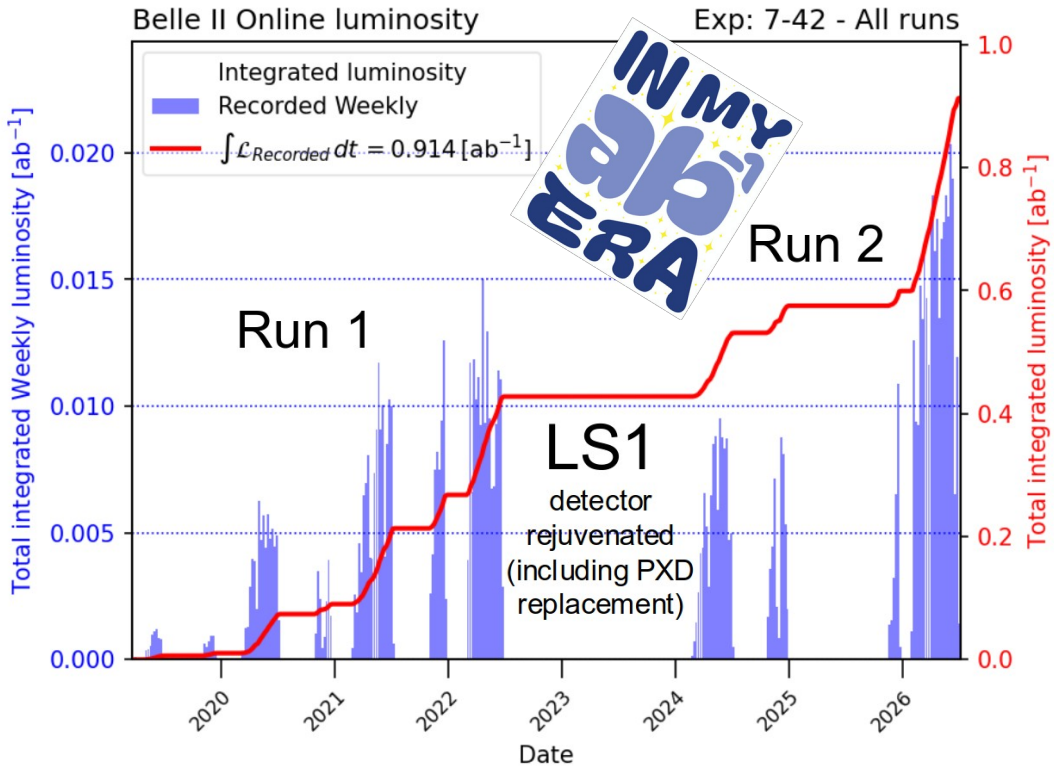
$2.1 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ @ KEKB
$1.2 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ @ PEP-II
(but still order of magnitude below design value)

- **Belle II** data taking efficiency ~ 90%

- Recorded luminosity @ Belle II

$$\sim 914\ \mathrm{fb}^{-1}$$

$988\ \mathrm{fb}^{-1}$ @ Belle (exceeding Belle BB sample size!)
$513\ \mathrm{fb}^{-1}$ @ BaBar



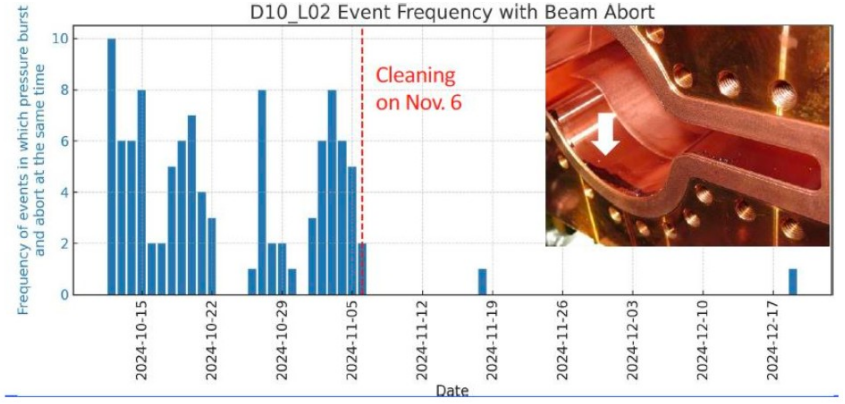
- After LS1 still slow progress in increasing instant. luminosity…

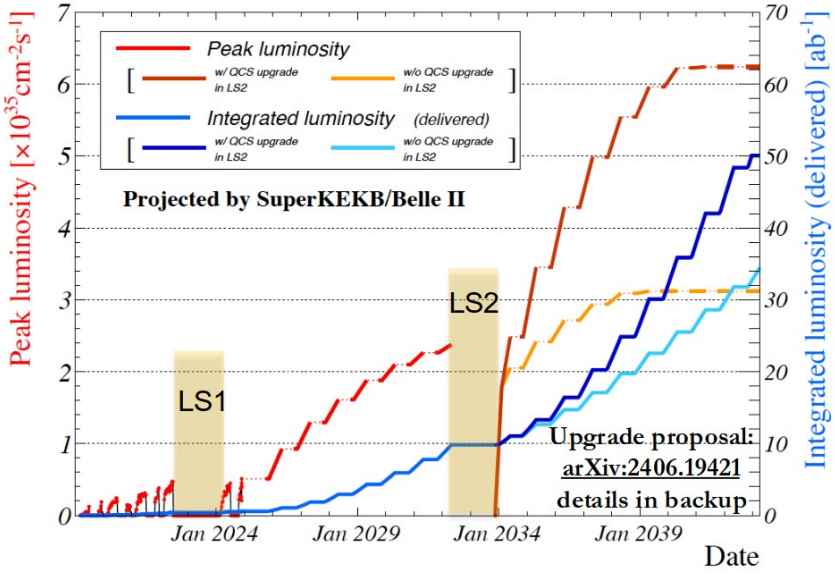
Run 2 (2024 – ~2032)

- After LS1, back to operations at $4 \times 10^{34}\ \mathrm{cm^{-2}s^{-1}}$, but... sudden beam loss happened with very large dose in the detector damaging 2% of PXD gates → turned off PXD as a precautionary measure until beam losses mitigated

- Black stains found inside beam pipe flanges, caused by vacseal residual (high vacuum sealant)

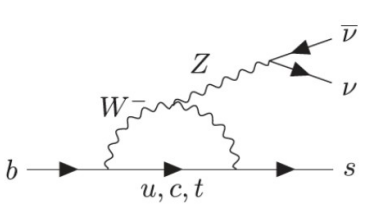
- Collisions resumed in Nov 2025 (PXD off) and plan to accumulate ~10 $\mathrm{ab^{-1}}$ by LS2

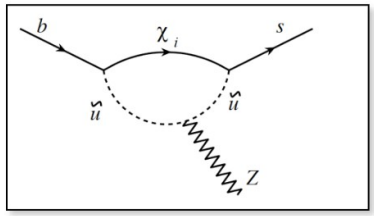




Physics – Hot Topics

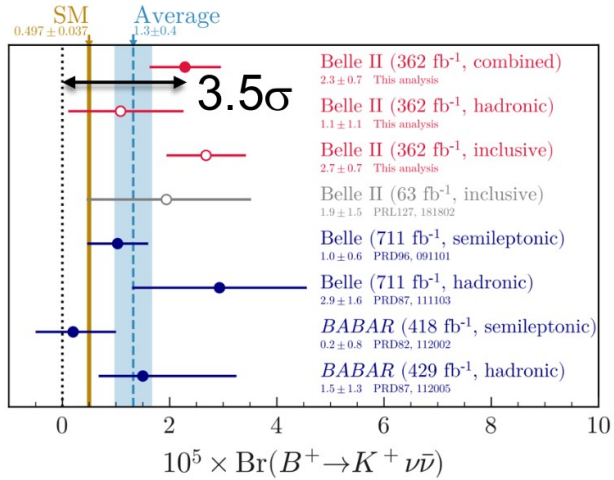
Observation of $B^+ \to K^+ \nu\nu$



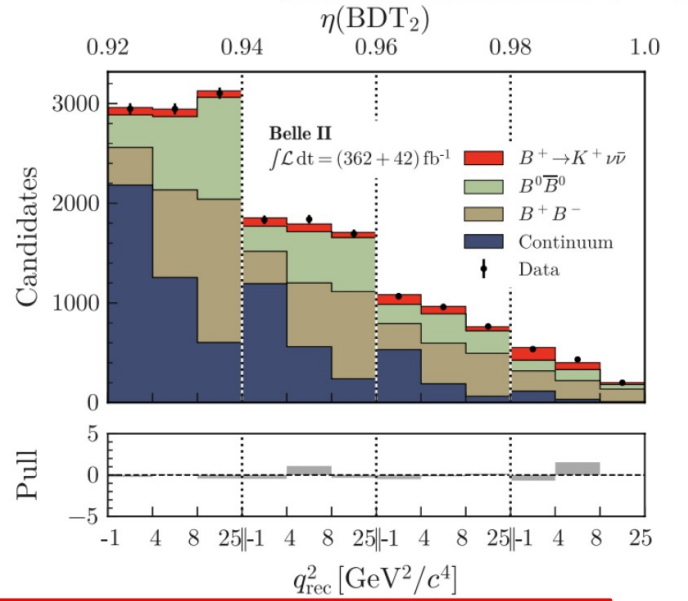


Novel approach at Belle II: inclusive tagging (total eff. ~8%)

Fit to invariant masses of neutrinos (q^2) and classifier exploiting topology of the signal



PhysRevD.109.112006 (2024)



$$B(B^+ \to K^+ \nu\bar{\nu}) = [2.3 \pm 0.5(\text{stat})^{+0.5}_{-0.4}(\text{syst})] \times 10^{-5}$$

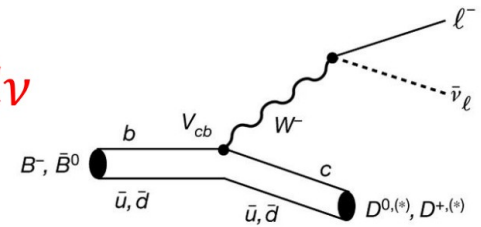
Tension with SM at 2.7σ

Checked with hadronic tag and combined with 10% increase in precision

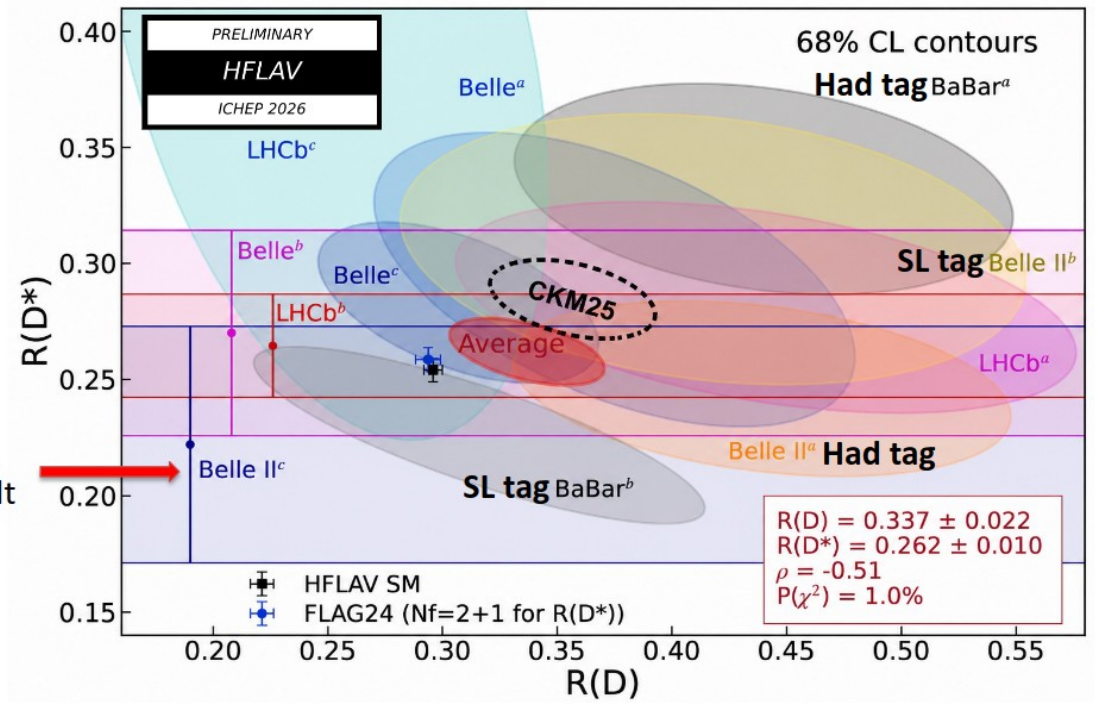
LFU tests in SL B decays

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)}$$

$b \to c\ell\nu$



R(D)&R(D*) today



Belle II's new result

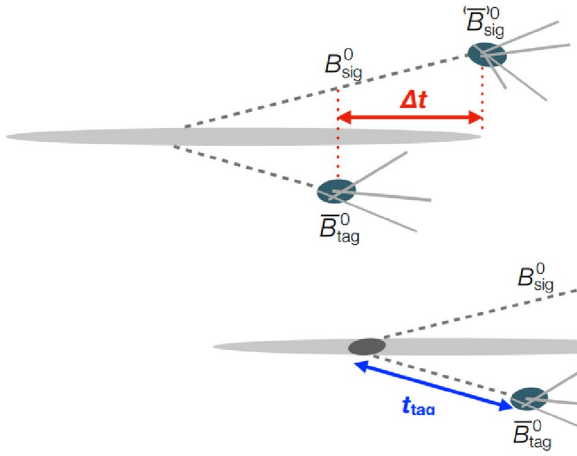
Tension with SM ~ 2σ (was 3σ). Note: P-value is 1% (was 27%).

R(D)&R(D) is (will keep) evolving as new measurements (will) arrive.*

Time-dependent CP violation in $B^0 \to \pi^0\pi^0$

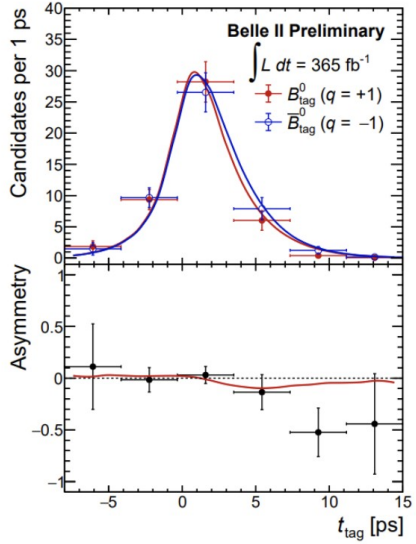
arxiv:2606.20797

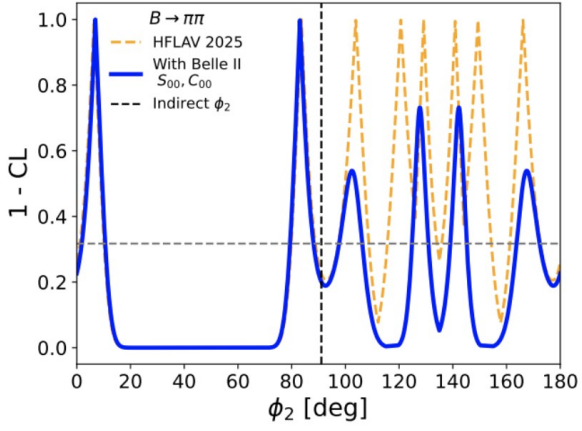
- α/ϕ_2 is the least precise angle in CKM unitarity triangle
- Δt time dependent measurement of CP violation only possible reconstructing $\pi^0 \to e^+e^-\gamma$: very small BR, tens of ab^{-1} needed for competitive measurement



Novel approach:

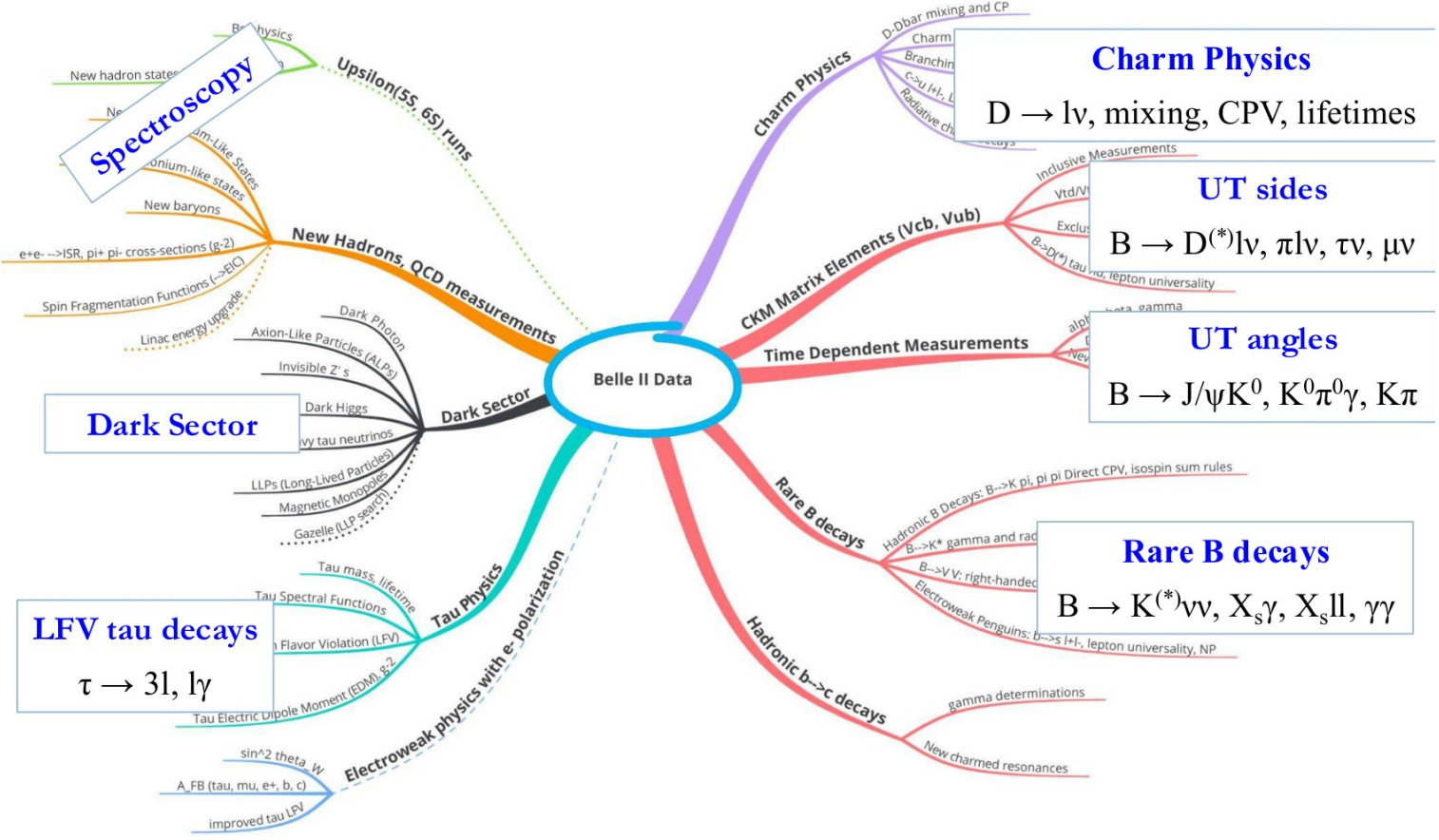
- exploit small interaction region (SuperKEKB) and improved vertex resolution (PXD) to measure t_{tag}
- Quantum correlation of neutral B mesons allows to link CP asymmetry to t_{tag} distribution*





1σ interval reduced by 40%. Expected to remove solution degeneracy with 5 ab^{-1}

Belle II physics program



Charm Physics

$D \to l\nu$, mixing, CPV, lifetimes

UT sides

$B \to D^{(*)}l\nu$, $\pi l\nu$, $\tau\nu$, $\mu\nu$

UT angles

$B \to J/\psi K^0$, $K^0\pi^0\gamma$, $K\pi$

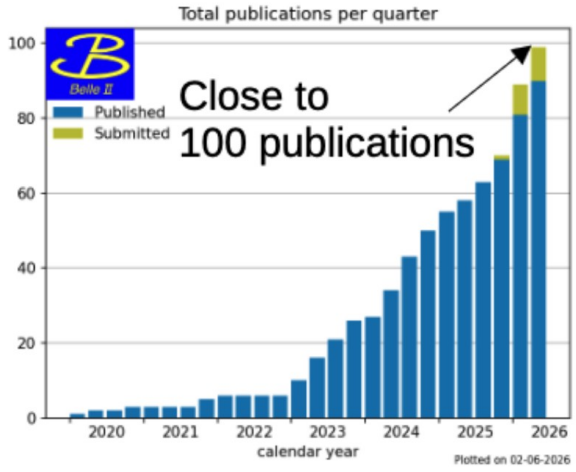
Rare B decays

$B \to K^{(*)}\nu\nu$, $X_s\gamma$, $X_s ll$, $\gamma\gamma$

Dark Sector

LFV tau decays

$\tau \to 3l$, $l\gamma$



→ physics program of Belle II is incredibly rich

→ despite still relatively small amount of data, close to 100 published results!

(improved detector wrt B factories, novel approaches, ...)

Our group activities

- Ongoing physics analyses

→ first search for $B \to K_s \tau\tau$ (almost published)

→ search for $D^+ \to \pi^+ e^+ e^-$ (almost published)

→ measurement of inclusive Br of $B \to \Lambda_c X$

→ $B \to K^{(*)} \nu\nu$ inclusive tag (also starting involvement in SL tag)

→ search for $B \to (\pi, \rho)\tau\nu$

→ search for $\Lambda_c^+ \to p\nu\nu$

→ measurement of Br and Acp in $B \to h\eta$ $(h = \pi^+, K^+, K^0)$

→ search for $B \to J/\psi\gamma$

Our group activities

- Particle ID (ARICH + TOP) detectors (leading efforts for >~15 years)

  → detector design, construction, operation, upgrade
  → software development, detector calibrations

- + many other contributions (analysis framework development, data quality monitoring, etc.)

- Several important roles by our group members

  (Peter – deputy spokeperson (ended), Samo – ARICH leader, Gaetano – convener of EW penguins WG, Paul – Analysis tools WG coordinator, Eldar – neutrals rec. and perf. (ended), Marko – TOP software, LS – hadronic B decays WG convener (ended), DQM WG coordinator)

How do we **compare**?

~4-7 faster

Experiment	Integrated luminosity	Effective operating days	Average recorded / operating day
Belle	**1.04 ab^{-1}**	**~2200**	**~0.47 fb^{-1}/day**
BaBar	**0.53 ab^{-1}**	**~1900**	**~0.28 fb^{-1}/day**
Belle II (2026ab only)	**314 fb^{-1}**	**157**	**~2.00 fb^{-1}/day**
Belle II (all running to date)	**914 fb^{-1}**	**~1000**	**~0.91 fb^{-1}/day**