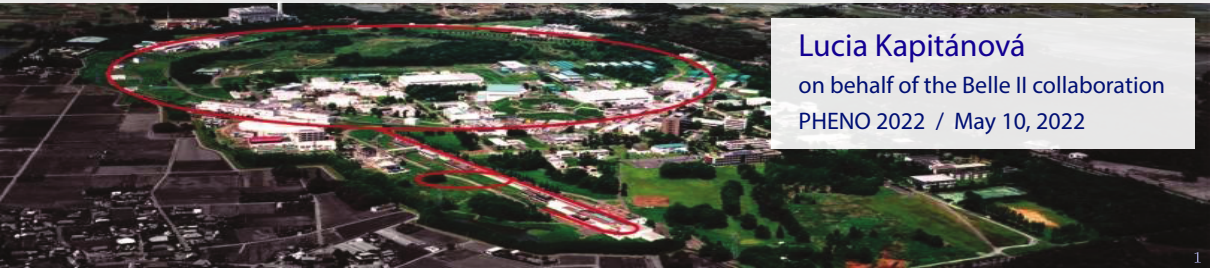
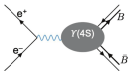
Recent Results from Belle II

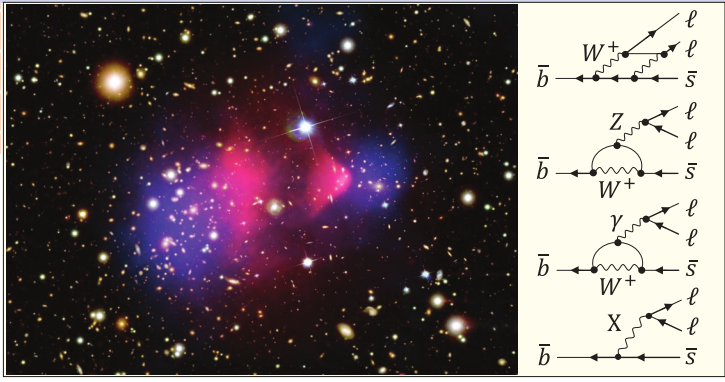


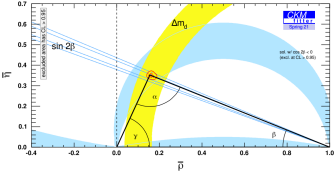
Lucia Kapitánová
on behalf of the Belle II collaboration
PHENO 2022 / May 10, 2022

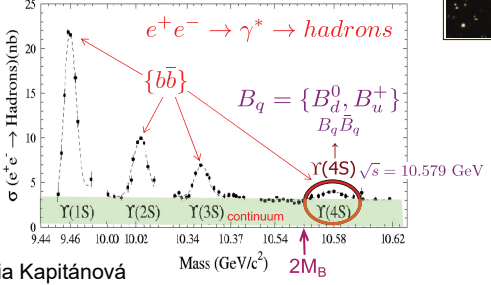
Big questions and complementarity

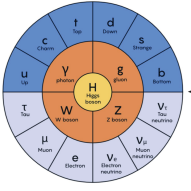
- Physics Beyond the Standard Model
  - Search at the energy frontier - limited
  - B physics - hints of SM anomalies
  - CP asymmetry
  - Rare decay channels uniquely probed by Belle II
  - Lepton flavor universality





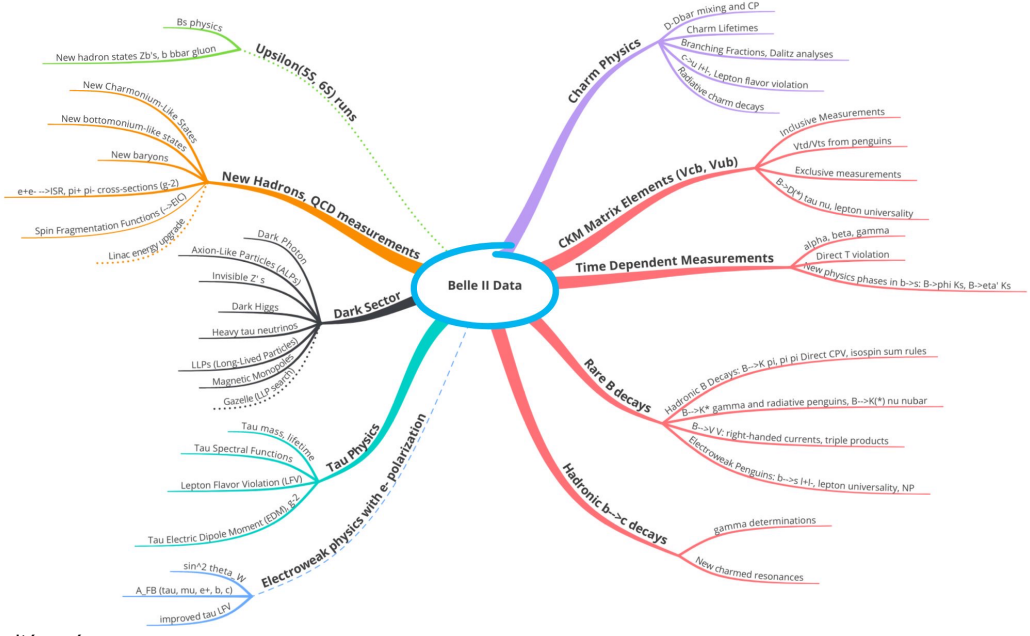






dark portals

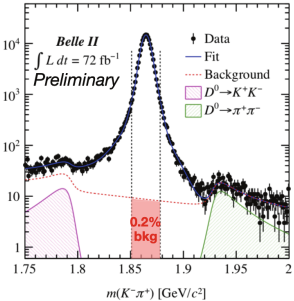
A', Z', H, ..


Belle II Data
Charm Physics
D:Dbar mixing and CP
Charm Lifetimes
Branching Fractions, Dalitz analyses
c->u l+l-, Lepton flavor violation
Radiative charm decays
CKM Matrix Elements (Vcb, Vub)
Inclusive Measurements
Vtd/Vts from penguins
Exclusive measurements
B->D(*) tau nu, lepton universality
Time Dependent Measurements
alpha, beta, gamma
Direct T violation
New physics phases in b->s: B->phi Ks, B->eta' Ks
Rare B decays
Hadronic B Decays: B-->K pi, pi pi Direct CPV, isospin sum rules
B-->K* gamma and radiative penguins, B-->K(*) nu nubar
B-->V V: right-handed currents, triple products
Electroweak Penguins: b-->s l+l-, lepton universality, NP
Hadronic b->c decays
gamma determinations
New charmed resonances
Electroweak physics with e- polarization
sin^2 theta_W
A_FB (tau, mu, e+, b, c)
improved tau LFV
Tau Physics
Tau mass, lifetime
Tau Spectral Functions
Lepton Flavor Violation (LFV)
Tau Electric Dipole Moment (EDM), g-2
Dark Sector
Dark Photon
Axion-Like Particles (ALPs)
Invisible Z' s
Dark Higgs
Heavy tau neutrinos
LLPs (Long-Lived Particles)
Magnetic Monopoles
Gazelle (LLP search)
New Hadrons, QCD measurements
New Charmonium-Like States
New bottomonium-like states
New baryons
e+e- -->ISR, pi+ pi- cross-sections (g-2)
Spin Fragmentation Functions (-->FFC)
Linac energy upgrade
Upsilon(5S, 6S) runs
Bs physics
New hadron states Zb's, b bbar gluon

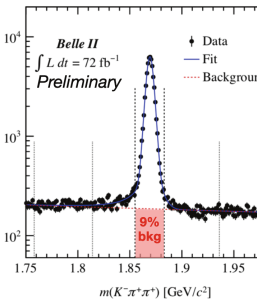
PRL 127, 211801 (2021)

- Provide important inputs to tune *flavor dynamics phenomenological models*
- *Experimental challenge*: <% control of systematic uncertainties (especially alignment)

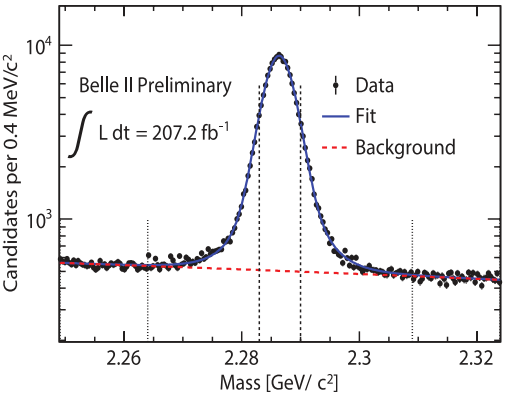
~171k $D^{*+} \to (D^0 \to K^-\pi^+)\pi^+$



~59k $D^{*+} \to (D^+ \to K^-\pi^+\pi^+)\pi^0$



~152k $\Lambda_c^+ \to pK^-\pi^+$

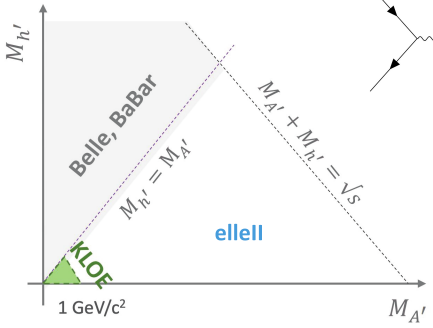


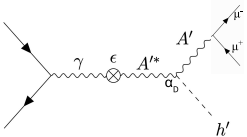
Belle II - dataset of 72 fb^{-1}:	PDG value
$\tau(D^0) = 410.5 \pm 1.1_{(stat)} \pm 0.8_{(sys)}$ fs	410.1 ± 1.5 fs
$\tau(D^+) = 1030.4 \pm 4.7_{(stat)} \pm 3.1_{(sys)}$ fs	1040 ± 7 fs
NEW : dataset of 297 fb^{-1}:	
$\tau(\Lambda_c) = 204.12 \pm 0.84_{(stat)} \pm 0.69_{(sys)}$ fs	202.4 ± 3.1 fs

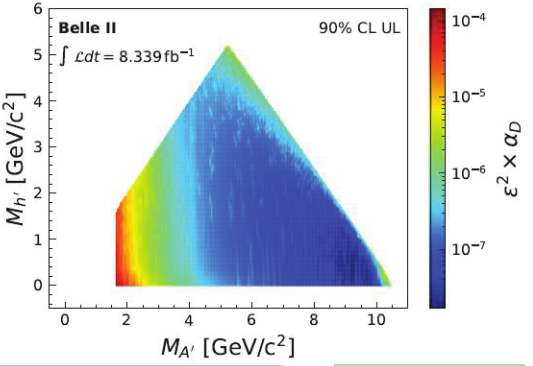
World best results - establish excellent understanding of Belle II vertexing and tracking

- Lack of evidence of wimp-like DM motivates searches for low-mass DM
- Experimental challenge: control of trigger/backgrounds in very early data

- $\sigma \propto \varepsilon^2 \alpha_D$
- U(1)′ extension to SM
- Belle II : focus on $M_h^{'} < M_A^{'}$ region
- α_D - dark coupling constant
- $e^+e^- \to h'A'(\to \mu^+\mu^-)$







→ Probing previously unexplored regions → No significant deviation from SM bkg expectation measured → World best results!

Unique access to: $B^+ \to K^+ \nu\overline{\nu}$

- Channel unique to Belle II
- Experimental challenge: detailed understanding and tuning of simulation

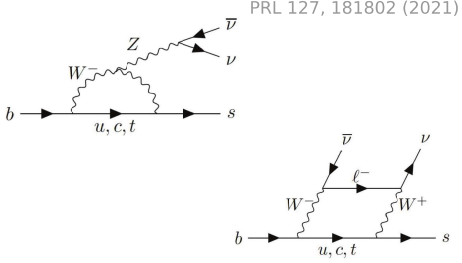
SM

- FCNC heavily suppressed
- Expectation based on SM $(4.6 \pm 0.5) x 10^{-6}$

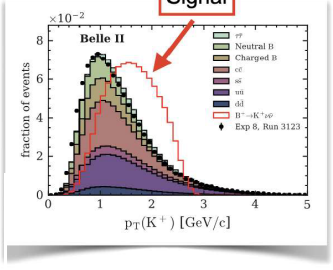
Experiment

- Validated using $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$
- Inclusive tag approach giving best performance

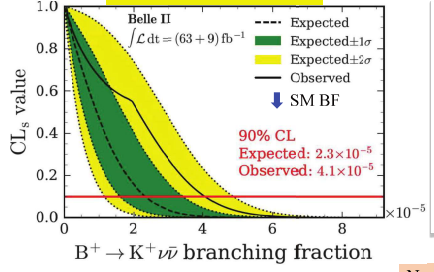
PRL 127, 181802 (2021)

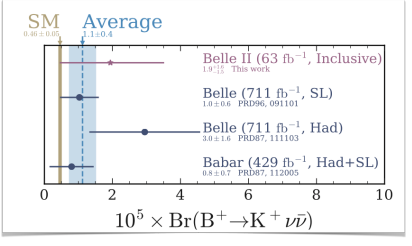


Signal



PRL 127, 181802 (2021)



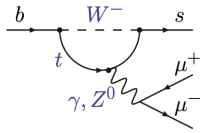


→ set upper limit @ 90% CL $\mathbf{B}(B \to K\nu\overline{\nu}) < 4.1 x 10^{-5}$

→ corresponding BF $\mathcal{B}(B \to K\nu\overline{\nu}) = 1.9^{+1.6}_{-1.5} x 10^{-5}$

→ No significant signal observed -up to a factor of two more sensitivity at given luminosity wrt previous approaches!

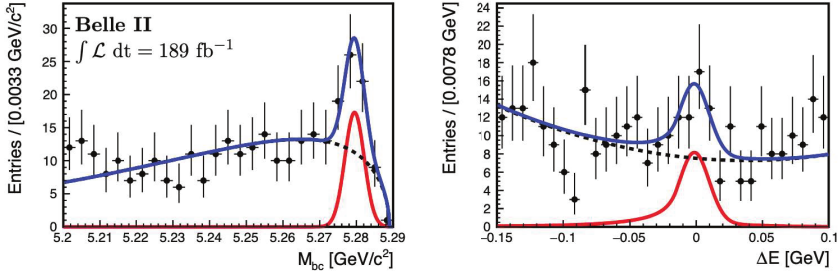
- Suppressed SM transition $b \to s$
- Similar reconstruction precision for e and μ channels
  - → Check of $R(K^{(*)})$ possible NP anomalies
  - → $\sim 3\sigma$ evidence for an anomalous ratio of $\mu^-\mu^+/e^+e^-$ from other experiments
  - → Provide constraint on Wilson Coefficient C_9 for both modes by BF measurement
- Searching using 189.26 fb^{-1}
- Validated using $B^+ \to J/\psi(\to l^+l^-)\, K^{(*)}$



		PDG$\mathcal{B}$x10^6
$\mathcal{B}(B \to K^*\mu^+\mu^-)$	$= (1.19 \pm 0.31^{+0.08}_{-0.07}) x10^{-6}$	0.94 ± 0.05
$\mathcal{B}(B \to K^*e^+e^-)$	$= (1.49 \pm 0.48 \pm 0.09) x10^{-6}$	1.03 ± 0.19
$\mathcal{B}(B \to K^*l^+l^-)$	$= (1.25 \pm 0.30^{+0.08}_{-0.07}) x10^{-6}$	0.99 ± 0.12

B→K*ℓℓ fit projections

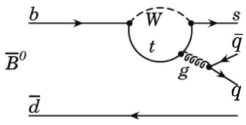
Belle II preliminary



Outlook:with few ab^{-1} Belle II will provide important independent information on the existence of the anomalies

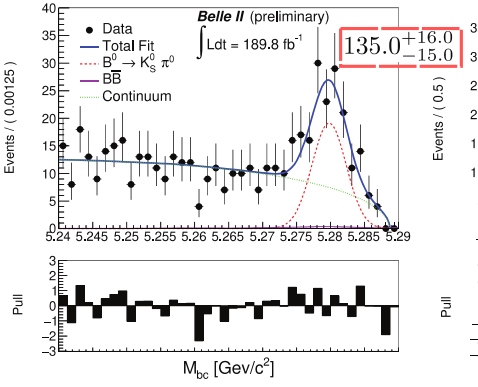
$B^0 \to K^0\pi^0/K^0_S\pi^0$

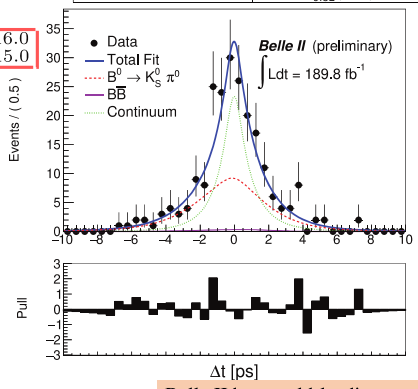
- Rare decays - sensitive to New Physics
- Unique high precision probe of theoretically accurate relationships between rates of $B \to K\pi$ decays
- Experimental challenge: vertex reconstruction with a $K_s\pi^0$ final state
- S_{CP} fixed to the average of previous measurements previous measurements - measure A_{CP}



$$2A_{CP}(B^0 \to K^+\pi^-) + 1.3A_{CP}(B^+ \to K_S\pi^+) - 1.2A_{CP}(B^+ \to K^+\pi^0) - A_{CP}(B^0 \to K_S\pi^0) \approx 0$$

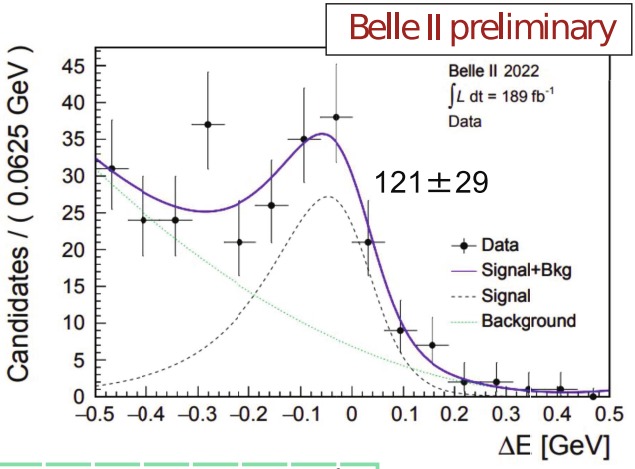
Observable	Fitted value	WA[1] value
$\mathscr{B}(B^0 \to K^0\pi^0) \times 10^{-6}$	$11.0 \pm 1.2(stat) \pm 1.0(syst)$	9.9 ± 0.5
$\mathcal{A}_{CP}$	$-0.41^{+0.30}_{-0.32}(stat) \pm 0.09(syst)$	-0.01 ± 0.10





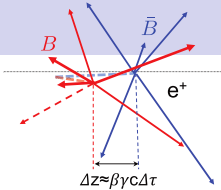
→ Belle II has world-leading access to these modes

- Channel unique to Belle II
- *SM* Flavor-specific γ polarization due to V-A
  - $\to$ $B^0 \to K_S^0 \pi^0 \gamma$ - RH γ
  - $\to$ $\overline{B}^0 \to K_S^0 \pi^0 \gamma$ - LH γ
- NP search : may appear as TDCP asymmetry

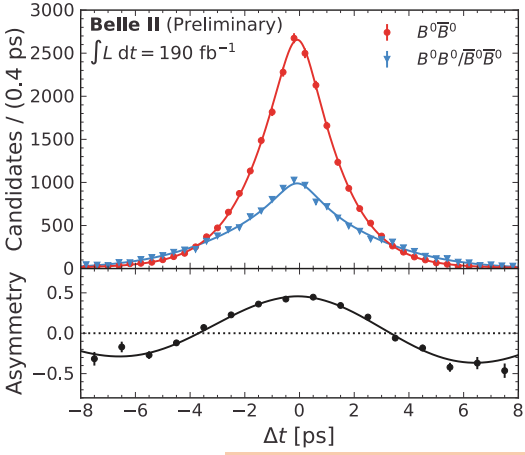


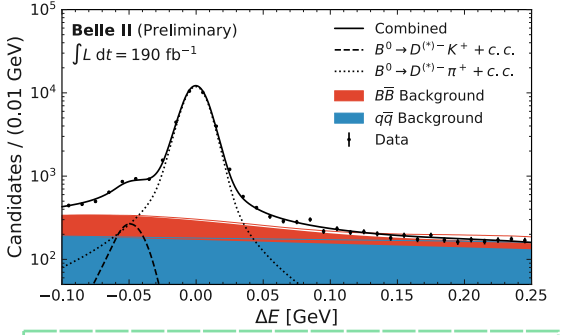
$$\mathscr{B}(B^0 \to K_S^0 \pi^0 \gamma) = (7.3 \pm 1.8(\text{stat}) \pm 1.0(\text{syst}))\text{x}10^{-6}$$

$$\mathscr{B}(B^0 \to K_S^0 \pi^0 \gamma) = (7.0 \pm 0.4)\text{x}10^{-6} \qquad PDG$$



- Experimental challenge: vertex resolution model
- 2 backgrounds: $e^+e \to q\bar{q}$ and misreconstructed and $e^+e \to B\overline{B}$





$$\tau_{B^0} = 1.499 \pm 0.013\,(\text{stat.}) \pm 0.008\,(\text{syst.})\ \text{ps}$$

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

→ Keystone achievement in establishing Belle II readiness for time-dependent measurements

SUMMARY

- e^+e^- asymmetric collisions @ $\Upsilon(4S)$ - intensity frontier experiment
- Belle II detector at a B-factory - ideal environment for probing New Physics
- Current results obtained with $\int dt\mathscr{L} = 189.3$ fb^{-1}
- Both time-dependent ($\tau(c)$, $\tau(B^0)$, Δm_D, A_{CP},...) and time-independent (dark sector probing, $|V_{cb}|$,$|V_{ub}|$..) measurements

  More results available:
  - Belle II Publication page
  - Integrated luminosity [Chinese Physics C 44, 021001 (2020)]
  - search for invisible Z$'$ [PRL 124, 141801 (2020)]
  - search for axion-like particles [PRL 125, 161806 (2020)]
  - search for $K\nu\bar{\nu}$ [PRL 127, 181802 (2021)]
  - D^0 and D^+ lifetime measurement [PRL 127, 211801 (2021)]
  - Belle + Belle II, CKM angle ϕ_3/γ [JHEP 02 2022, 063 (2022)]

World best results - Charm meson lifetimes

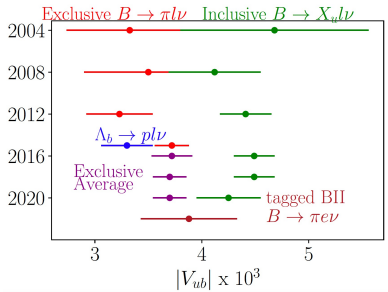
World's first upper limits on cross section and couplings for 4 GeV $< M_{A'} <$ 9.7 GeV

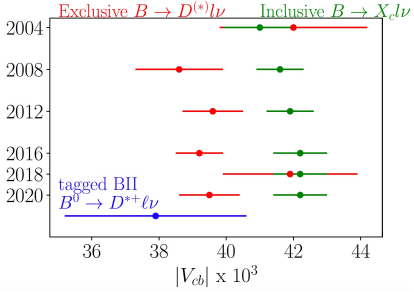
Belle II ready for time-dependent CPV measurements

More exciting measurements and results to come with bigger datasets and further analyses!

BACK-UP SLIDES

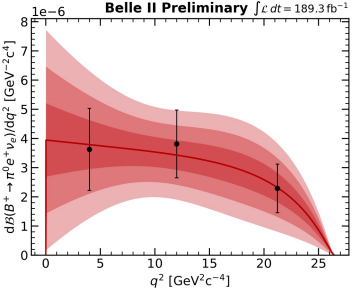
Putting them together

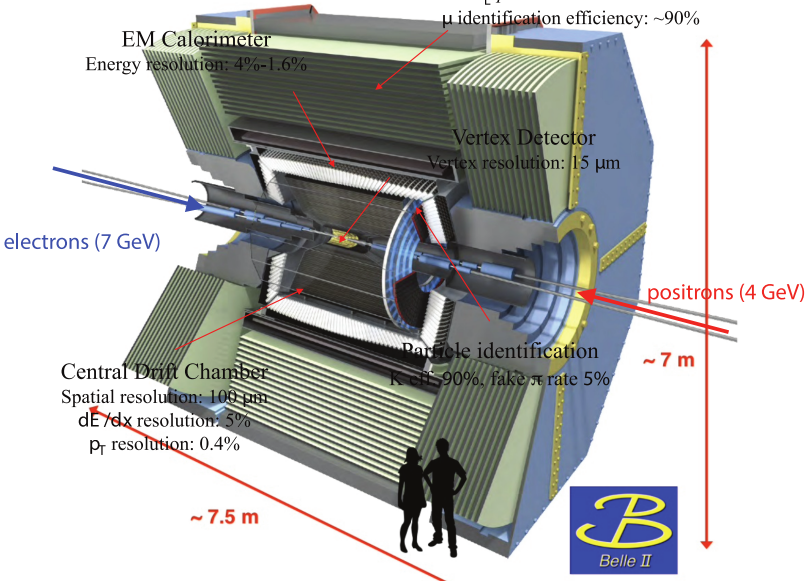


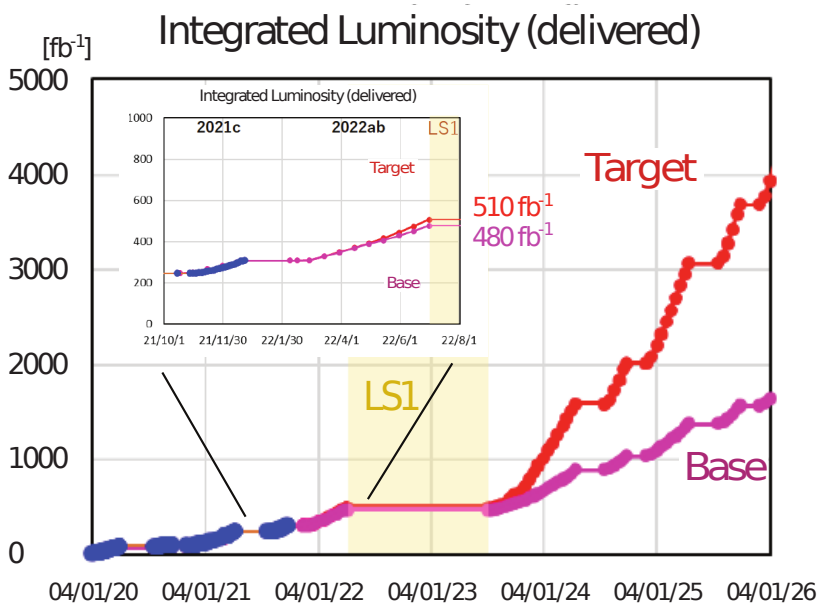


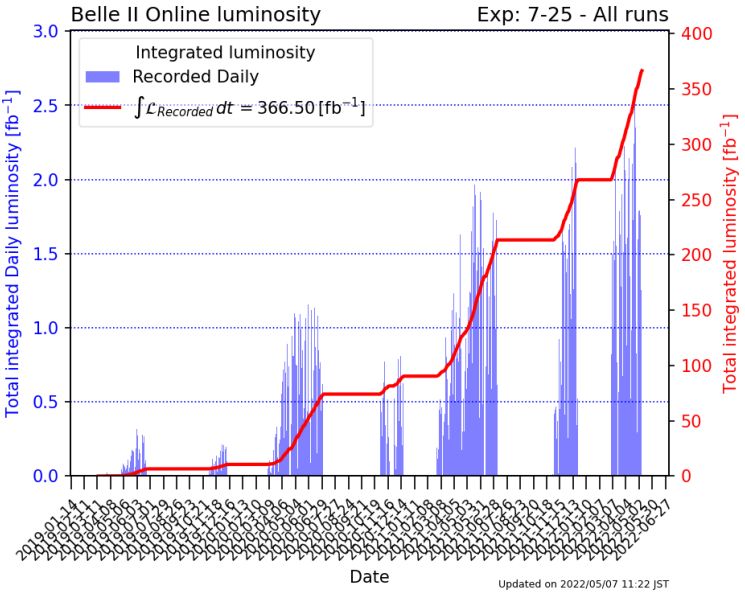
Decay mode	Fitted $\lvert V_{\rm ub}\rvert$
$B^0 \to \pi^- e^+ \nu_e$	$(3.71 \pm 0.55) \times 10^{-3}$
$B^+ \to \pi^0 e^+ \nu_e$	$(4.21 \pm 0.63) \times 10^{-3}$
Combined fit	$(3.88 \pm 0.45) \times 10^{-3}$

- These first tagged determinations of $|V_{ub}|$ and $|V_{cb}|$ from Belle II are statistically limited
- We expect a higher precision with untagged measurement as the corresponding efficiency is 20–30%




K_L and μ detection
K_L^0 *p*-resolution: 15 MeV
μ identification efficiency: ~90%
EM Calorimeter
Energy resolution: 4%-1.6%
Vertex Detector
Vertex resolution: 15 μm
electrons (7 GeV)
positrons (4 GeV)
Particle identification
Central Drift Chamber
Spatial resolution: 100 μm
dE/dx resolution: 5%
p_T resolution: 0.4%
~ 7 m
~ 7.5 m
Belle II


Integrated Luminosity (delivered)
[fb-1]
5000
4000
3000
2000
1000
0
04/01/20
04/01/21
04/01/22
04/01/23
04/01/24
04/01/25
04/01/26
Target
510 fb-1
480 fb-1
LS1
Base
Integrated Luminosity (delivered)
2021c
2022ab
LS1
Target
Base
1000
800
600
400
200
0
21/10/1
21/11/30
22/1/30
22/4/1
22/6/1
22/8/1


Belle II Online luminosity
Exp: 7-25 - All runs
Integrated luminosity
Recorded Daily
$\int \mathcal{L}_{Recorded}\, dt = 366.50\,[\mathrm{fb}^{-1}]$
Total integrated Daily luminosity [fb^{-1}]
Total integrated luminosity [fb^{-1}]
Date
Updated on 2022/05/07 11:22 JST

Belle II - LHCb Comparison

+ Important contributions on B and D flavour physics from ATLAS, CMS, BESIII.

Belle II
Higher sensitivity to decays with photons and neutrinos (e.g. B→Kνν, μν), inclusive decays, time dependent CPV in B_d, τ physics.

LHCb
Higher production rates for ultra rare B, D, & K decays, access to all b-hadron flavours (e.g. Λ_b), high boost for fast B_s oscillations.

Overlap in various key areas to verify discoveries.

Upgrades
Most key channels will be stats. limited (not theory or syst.).
LHCb scheduled major upgrades during LS3 and LS4.
Belle II formulating a 250 ab^{-1} upgrade program post 2028.

Observable	Current Belle/ Babar	2019 LHCb	Belle II (5 ab^{-1})	Belle II (50 ab^{-1})	LHCb (23 fb^{-1})	Belle II Upgrade (250 ab^{-1})	LHCb upgrade II (300 fb^{-1})
CKM precision, new physics in CP Violation							
✸ $\sin 2\beta/\varphi_1$ ($B\to J/\psi K_S$)	0.03	0.04	0.012	0.005	0.011	0.002	0.003
✸ γ/φ_3	13°	5.4°	4.7°	1.5°	1.5°	0.4°	0.4°
✸ α/φ_2	4°	–	2	0.6°	–	0.3°	–
✸ $\lvert V_{ub}\rvert$ (Belle) or $\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$ (LHCb)	4.5%	6%	2%	1%	3%	<1%	1%
φ_s	–	49 mrad	–	–	14 mrad	–	4 mrad
✸ S_{CP}($B\to\eta' K_S$, gluonic penguin)	0.08	○	0.03	0.015	○	0.007	○
✸ A_{CP}($B\to K_S\pi^0$)	0.15	–	0.07	0.04	–	0.02	–
New physics in radiative & EW Penguins, LFUV							
✸ S_{CP}($B_d\to K^*\gamma$)	0.32	○	0.11	0.035	○	0.015	○
✸ R($B\to K^*l^+l^-$) ($1<q^2<6$ GeV$^2/c^2$)	0.24	0.1	0.09	0.03	0.03	0.01	0.01
✸ R($B\to D^*\tau\nu$)	6%	10%	3%	1.5%	3%	<1%	1%
Br($B\to\tau\nu$), Br($B\to K^*\nu\nu$)	24%, –	–	9%, 25%	4%, 9%	–	1.7%, 4%	–
Br($B_d\to\mu\mu$)	–	90%	–	–	34%	–	10%
Charm and τ							
✸ ΔA_{CP}(KK-ππ)	–	8.5×10^{-4}	–	5.4×10^{-4}	1.7×10^{-4}	2×10^{-4}	0.3×10^{-4}
✸ A_{CP}($D\to\pi^+\pi^0$)	1.2%	–	0.5%	0.2%	–	0.1%	–
Br($\tau\to e\gamma$)	$<120\times10^{-9}$	–	$<40\times10^{-9}$	$<12\times10^{-9}$	–	$<5\times10^{-9}$	–
Br($\tau\to\mu\mu\mu$)	$<21\times10^{-9}$	$<46\times10^{-9}$	$<3\times10^{-9}$	$<3\times10^{-9}$	$<16\times10^{-9}$	$<0.3\times10^{-9}$	$<5\times10^{-9}$

Results on other D & τ modes expected

arXiv: 1808.08865 (Physics case for LHCb upgrade II), PTEP 2019 (2019) 12, 123C01 (Belle II Physics Book)

○ *Possible in similar channels, lower precision*
– *Not competitive.*