Recent Results from Belle & Belle II

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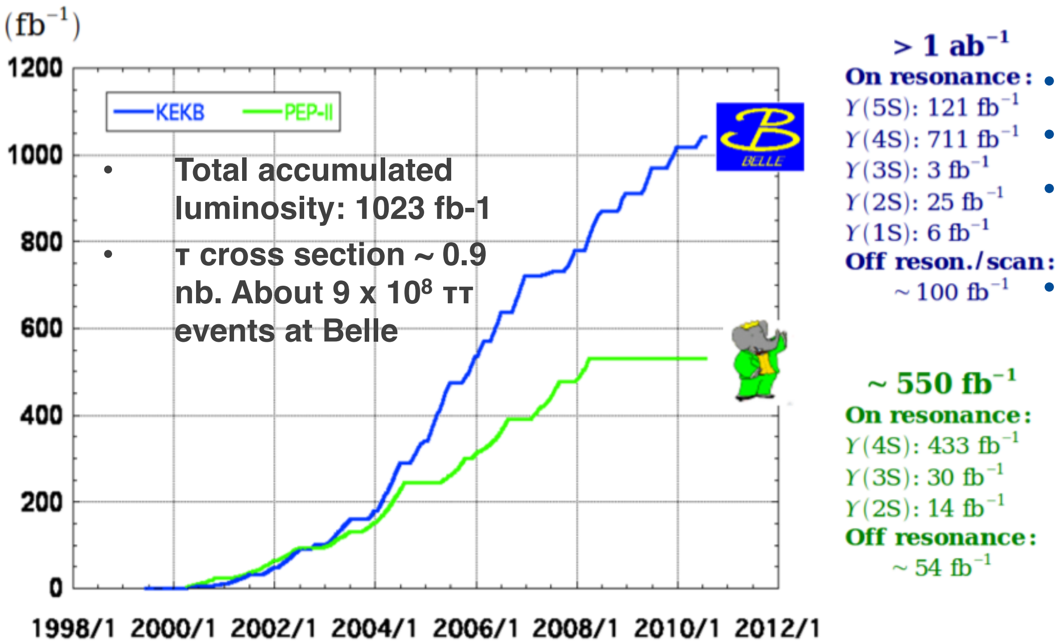
(On behalf of the Belle and Belle II Collaborations)

XXVIII International Conference on SUSY 2021
Institute of Theoretical Physics, CAS, Beijing
August 23 - 28, 2021

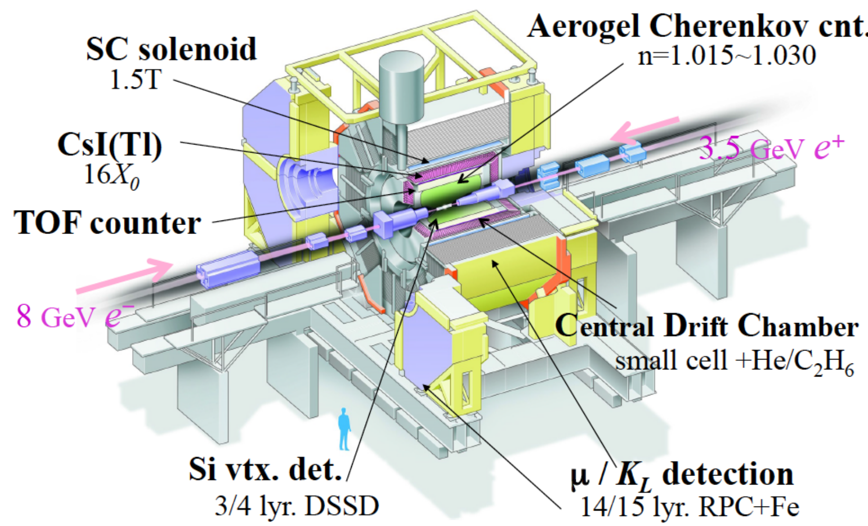
1st generation *B*-factory experiments



- Total accumulated luminosity: 1023 fb-1
- τ cross section ~ 0.9 nb. About 9 x 10^8 ττ events at Belle

- $e^+ e^-$ collider (operated during 1999 – 2010)
- Asymmetric E: 8 GeV (e^-) and 3.5 GeV (e^+)
- Mostly operated at the Y(4S) resonance (10.58 GeV)
- Continue to publish important physics results.
  - 2 PRL, 4 JHEP, 15 PRD in the last one year.

Lepton ID efficiency ~ 90%
Fake rate ~0.1% (electrons), ~1% (muons)



- Shall discuss results which are relevant for BSM physics including SUSY.

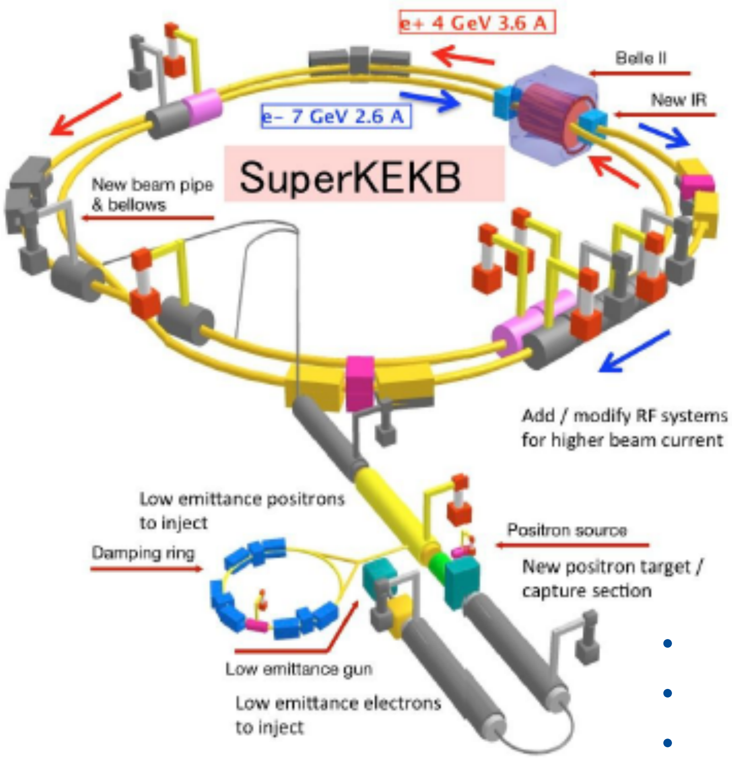
KEKB to SuperKEKB nanobeams

At SuperKEKB, we increase the luminosity based on "Nano-Beam" scheme (originally proposed for SuperB by P. Raimondi)

beam current x1.5
beam-beam param. x1

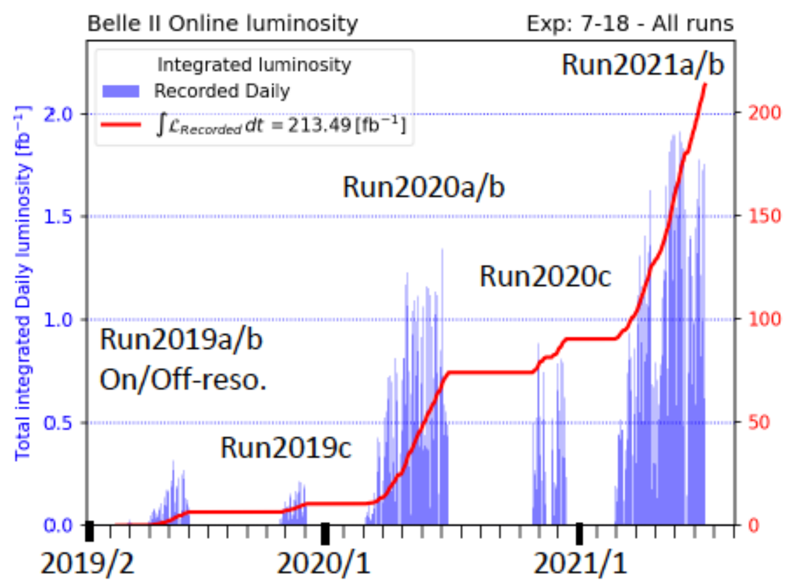
$$L = \frac{\gamma_\pm}{2 e r_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\frac{R_L}{R_\xi}\frac{I_\pm \xi_{y\pm}}{\beta_{y\pm}^*}$$

vertical beta function x 1/20



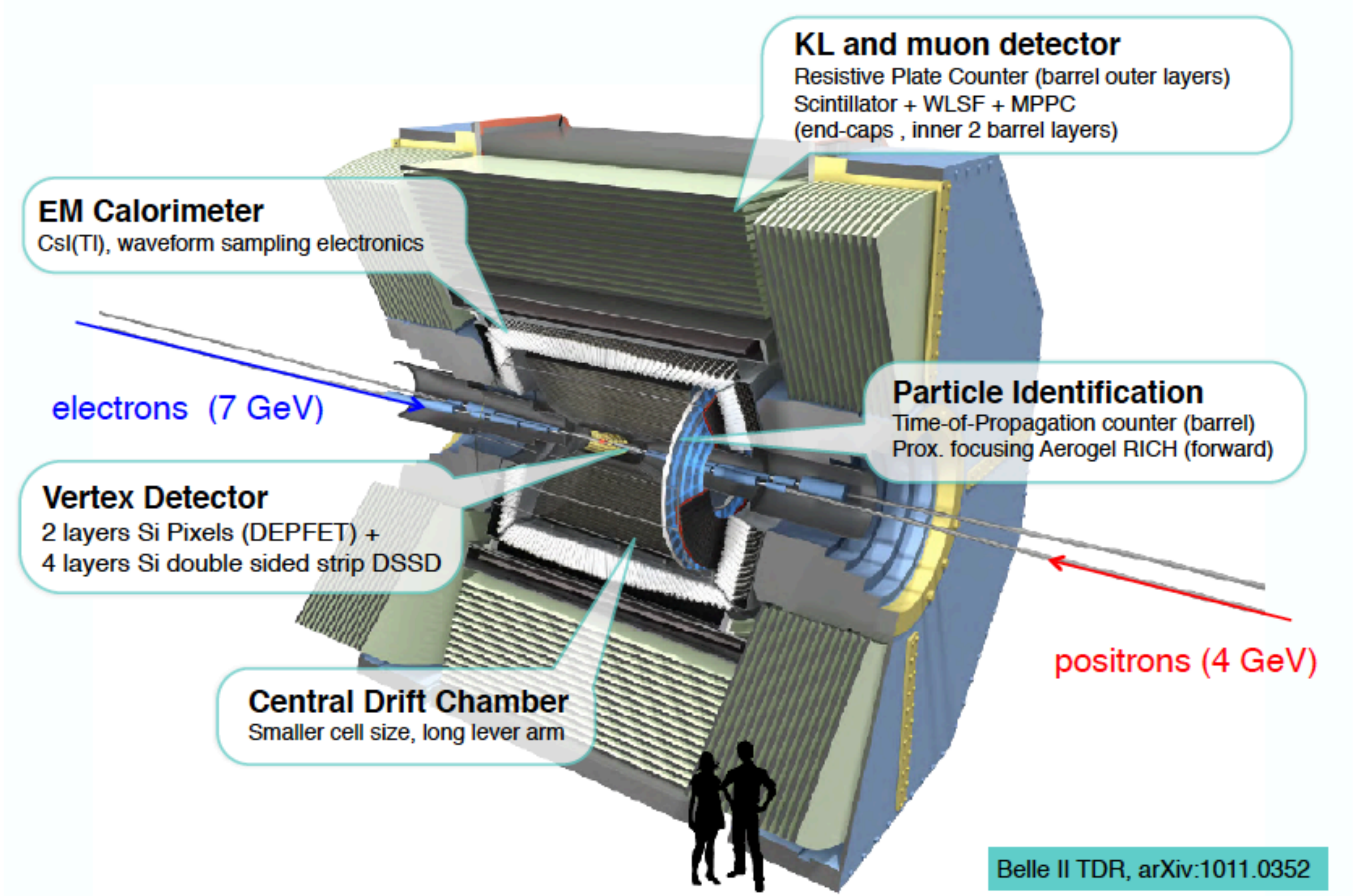
parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7	GeV
bg		0.425		0.28		
Half crossing angle	ϕ	11		41.5		mrad
Beta functions at IP	β_x^*/β_y^*	1200/5.9		60/0.3		mm
Beam currents	I_b	1.64	1.19	2.5	1.8	A
Luminosity	L	2.1 x 10^{34}		6.5 x 10^{35}		$cm^{-2}s^{-1}$

x20
x1.5



- 2021b run ended on July 5.
- Achieved new luminosity world record of $3.1 \times 10^{34}/cm^2/s$ on 22nd June
- Total integrated luminosity of 213 fb^{-1} so far.

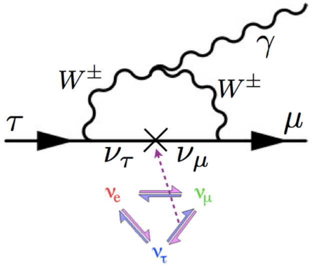
Belle II Detector



Lepton Flavor Violation

- Observed neutrino oscillations signal violation of lepton flavor in the neutral leptonic sector.
  - What about LFV in the charged leptons?
- LFV violation in the charged leptons is highly suppressed in the SM even after the inclusion of neutrino masses:
  - Neutrino masses are expected to be much smaller compared to the electroweak scale, $M_W \approx 80.4$ GeV.
  - Searches of LFV in the SM is beyond experimental reach:

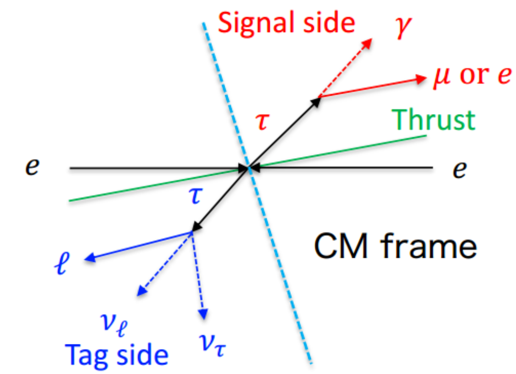
$$\mathcal{B}(\tau \to \ell\gamma) \propto \left(\frac{M_{\nu_\tau}^2 - M_{\nu_\ell}^2}{M_W^2}\right)^2 \approx 10^{-50} \sim 10^{-54}$$



- Observation of LFV in the charged lepton is a clear signal for NP beyond SM:
  - Many extensions of the SM such as SUSY, little Higgs models, extra dimensions predict enhanced LFV.
  - LFV in τ decays can be as high as $O(10^{-8})$
    - Within the reach of Belle II
- Searches for charged LFV is currently dominated by BaBar and Belle experiments. Most of the results are in τ decays
  - Heaviest lepton: less GIM suppression compared to muon
  - Strong coupling to NP contributions
  - many possible LFV decays

Lepton flavor violation in tau decays

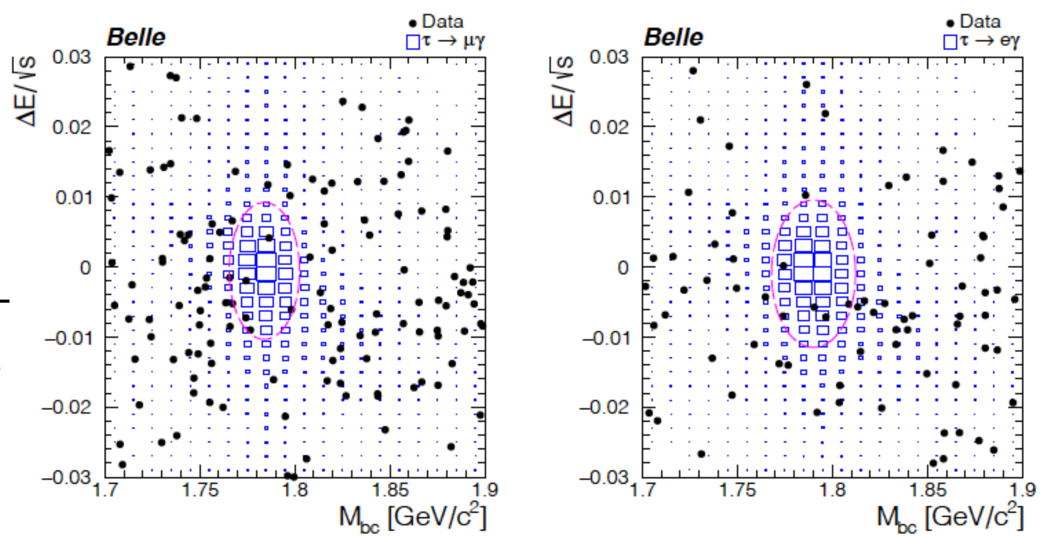
- Search for LFV decays $\tau \to l\,\gamma$ $(l = e, \mu)$ using total integrated luminosity of 988 fb^{-1}. Largest number of tau pairs recorded by a single e^+e^- experiment so far.
- Require $N_l = 1, N_\gamma = 1$ on the signal side, Tag side: 1-prong decay (Eg. $\tau \to l\nu\nu, \pi\nu, \rho\nu$)
- Improved analysis techniques, including additional variables to improve the signal to noise ratio. Blind analysis techniques.
- Un-binned maximum likelihood fit to:
  - $M_{bc} = \sqrt{[(E_{beam}^{CM})^2 - (\vec{p}_{l\gamma}^{CM})^2]}$
  - $\frac{\Delta E}{\sqrt{s}} = (E_{l\gamma}^{CM} - \sqrt{s}/2)/\sqrt{s}$
- Major backgrounds:
  - $\tau \to l\,\nu\nu$ + ISR or beam background
  - $ee \to ll$ + ISR or beam background



Submitted to JHEP

Channel	$\tau \to \mu\gamma$	$\tau \to e\gamma$
Signal efficiency	3.7%	2.9 %
Exp. # bkgs.	5.8 ± 0.4	5.1 ± 0.4
Obs. event	5	5
$N_{\rm sig}^{\rm UL}$	2.8	3.0
UL (90% CL)	$< 4.2 \times 10^{-8}$	$< 5.6 \times 10^{-8}$

Most stringent limit on the muon channel so far.



(a) $\tau^\pm \to \mu^\pm\gamma$ (b) $\tau^\pm \to e^\pm\gamma$

arXiv:2103.12994

See **Hulya Atmacan's** talk LFV and LFU at Belle

Lepton flavor violation in $B^0 \to \tau^{\pm} l^{\mp}$

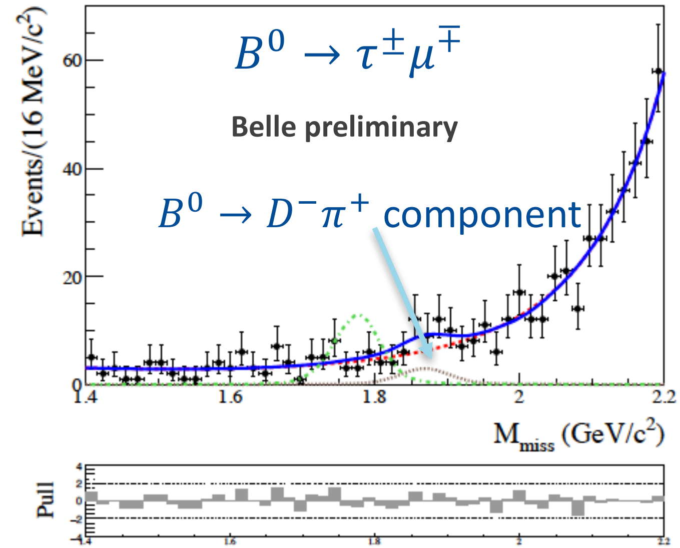
- $B^0 \to \tau^{\pm} l^{\mp}$ can occur in principle via neutrino mixing.
  - Rate is ~ 10^{-54}. Beyond experimental reach
- NP models such as Pati-Salam vector leptoquarks of mass 86 TeV/c^2 give rise to BF ~10^{-9}.
- Full Belle data set is used: ~711 fb^{-1}.
- No exclusive reconstruction of the signal side τ.
  - $\boldsymbol{B_{tag}}$ is reconstructed via hadronic decays. Use the reconstructed B_{tag} momentum and the e^+e^- initial momentum to determine the B_{sig} momentum.
  - Calculate "missing mass" as,

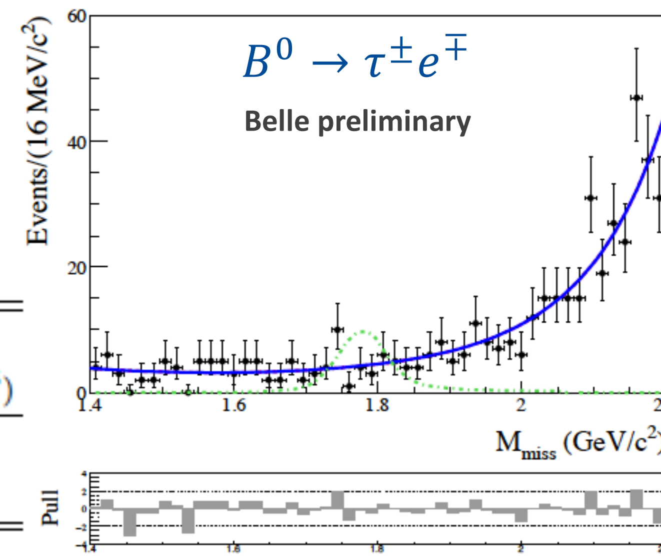
$$M_{miss} = \sqrt{[(E_{sig} - E_l)^2 - (\vec{p}_{B_{sig}} - \vec{p}_l)^2]}$$

M_{miss} should peak at τ mass.

- Background mostly from $b \to c$ and $b \to ul\nu$ decays.
- Signal yields are extracted by performing an unbinned maximum likelihood fit to the M_{miss} distributions

Mode	ε $(\times 10^{-4})$	N_{sig}	N_{sig}^{UL}	$\mathcal{B}^{UL}$ $(\times 10^{-5})$
$B^0 \to \tau^{\pm}\mu^{\mp}$	11.0	$1.8^{+8.2}_{-7.6}$	12.4	1.5
$B^0 \to \tau^{\pm}e^{\mp}$	9.8	$0.3^{+8.8}_{-8.2}$	11.6	1.6

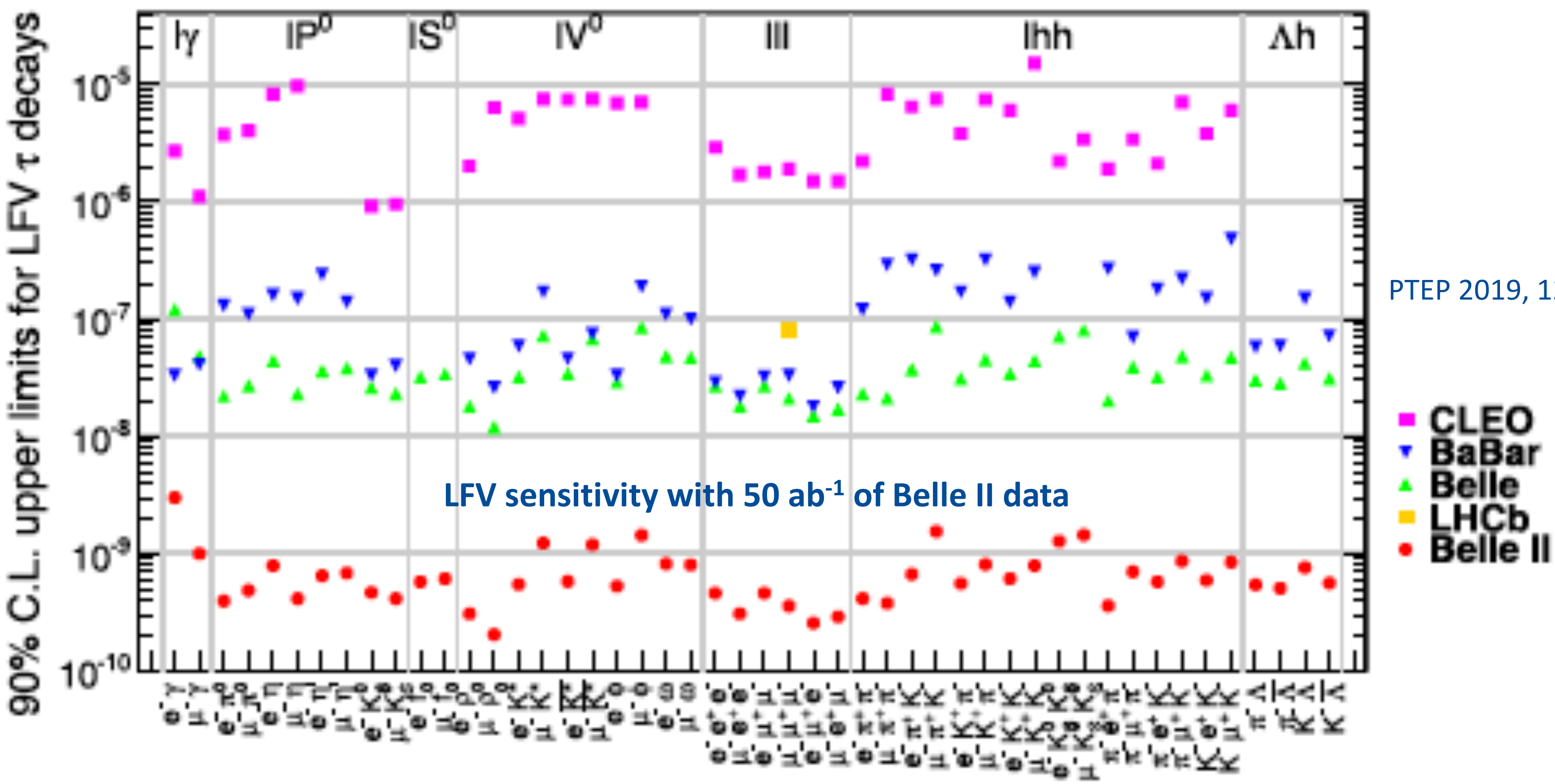




See **Hulya Atmacan's** talk LFV and LFU at Belle

Prospects of LFV at Belle II

- Belle II will collect about 10^{11} τ leptons compared to 10^{9} presently available.
- Sensitivity depends on the background
  - $\tau \rightarrow 3$ leptons mode is still very clean at Belle II
  - For $\tau \rightarrow \mu\gamma$ better understanding and control of the background will be necessary.



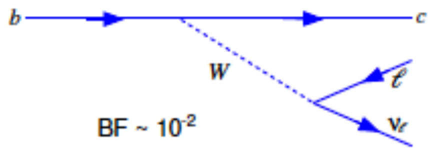
PTEP 2019, 123C01

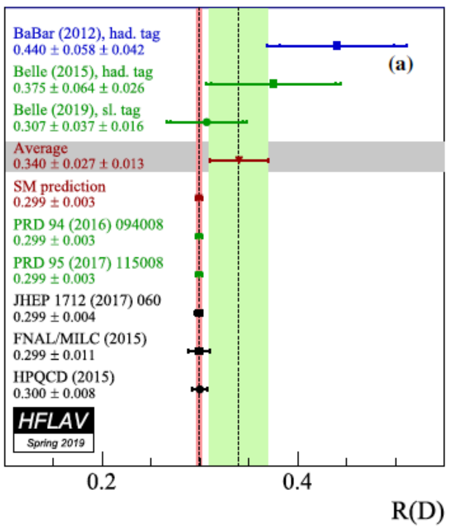
See **Marcela Garcia Hernandez's** talk

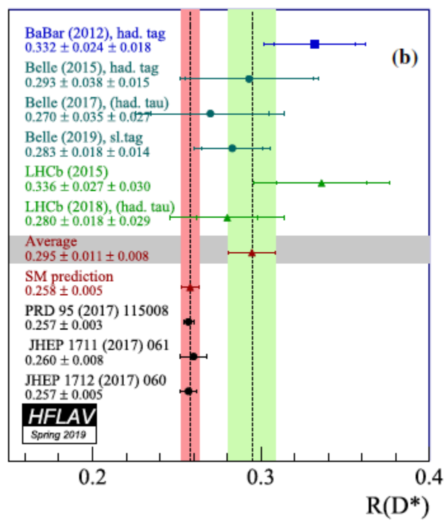
Lepton Flavor Universality

- In the SM, gauge bosons couplings to the three generations of leptons are independent of flavor ☞ LFU
- Several discrepancies are already observed in the *B*-decays related to LFU.

Decays: $B \to D^{(*)} l\nu_l$
Variables: $R(D), R(D^*)$







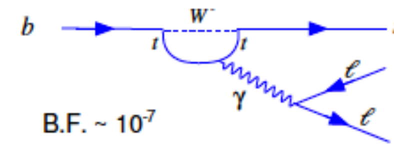
Global Average: 3.1 σ discrepancy with SM for $R(D^*)$

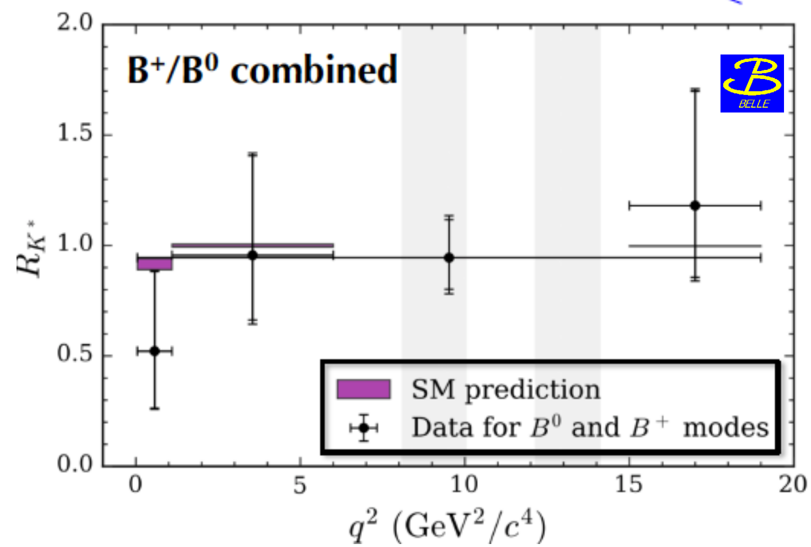
Latest Belle Results: PRL 124, 161803 (2020) with SL tagging

$\boldsymbol{R(D^*) = 0.283 \pm 0.018 \pm 0.014}$: agrees with SM within 1.1σ

$\boldsymbol{R(D) = 0.307 \pm 0.037 \pm 0.016}$: agrees with SM within 0.2σ

Decays: $B \to K^{(*)} ll$
Variables: $R(K), R(K^*)$





q^2 (GeV²/c⁴)	Comb. (B^0/B^+)
[0.045, 1.1]	$0.52^{+0.36}_{-0.26} \pm 0.05$
[1.1, 6]	$0.96^{+0.45}_{-0.29} \pm 0.11$
[0.045, 19]	$\mathbf{0.94}^{+0.17}_{-0.14} \pm 0.08$

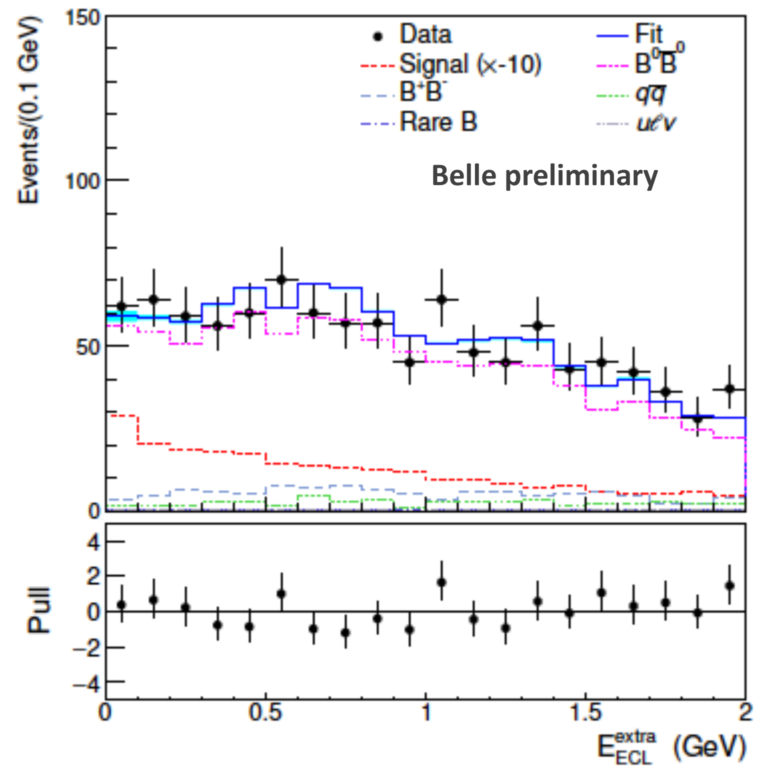
Largest deviation is in the lowest q^2bin. Same as LHCb

$R_{K^+} = 0.846^{+0.042+0.013}_{-0.039-0.012}$ ☞ LHCb

Evidence of LFUV at 3.1 σ level. arXiv:2103.11769

Lepton Flavor Universality: $B^0 \to K^{*0}\tau^+\tau^-$

- LFU can be further explored by studying $B^0 \to K^{*0}\tau^+\tau^-$.
- Highly suppressed in the SM, FCNC process, BF $\mathcal{O}(10^{-7})$.
  - Sensitive to BSM models in which coupling is proportional to mass or only couples to the third generation.
- Full data set (~711 fb^{-1}) from the Belle experiment is used.
  - Experimentally difficult. Presence of the neutrinos in the final state makes the full reconstruction of the decay difficult.
  - $\boldsymbol{B_{tag}}$ is reconstructed completely from hadronic decay modes. Tagging efficiency ~0.24%.
  - Signal τ is reconstructed from: $\tau^- \to e^-\overline{\nu_e}\,\nu_\tau$, $\tau^- \to \mu^-\overline{\nu_\mu}\,\nu_\tau$ and $\tau^- \to \pi^-\,\nu_\tau$. Signal selection efficiency: 1.2×10^{-5}
  - $\boldsymbol{N_{sig}}$ is determined from a fit to the extra energy in the ECL, not associated either with B_{tag} or B_{sig}. Signal region is defined by $E_{ECL}^{extra} < 0.2\ GeV$.



Observation:
$$N_{sig} = -4.9 \pm 6.0$$
$$N_{bkg} = 122.4 \pm 4.9$$

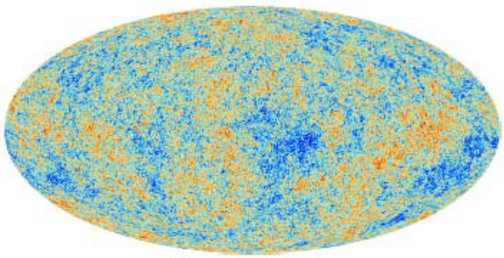
90% CL upper limit on BF at 2×10^{-3}
First experimental limit on this decay.

See **Hulya Atmacan's** talk LFV and LFU at Belle

Dark Sector Physics

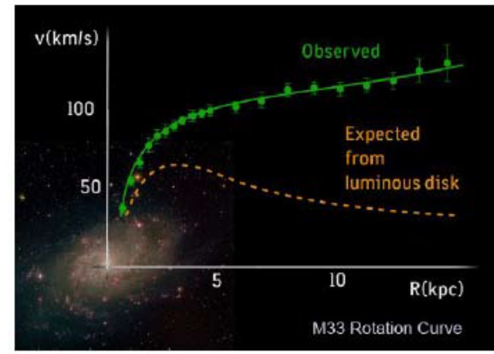
- Zwicky, 1933: first suggestion for the existence of unseen “dark” matter after the analysis of the velocity dispersion of galaxies in the Coma cluster.
- Since then: numerous astrophysical evidences for its existence – all based on gravity

Structure of Cosmic Microwave Background



Gravitational Lensing

Galactic Rotation Curves



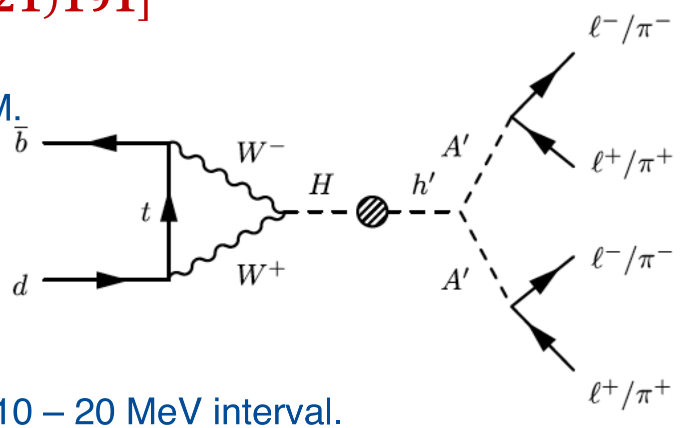
- But its nature is still a mystery.
  - Most favorable candidate so far: Weakly Interacting Massive Particles (WIMP)
- So far null results from direct detection experiments and LHC
  - New ideas needed to go beyond the standard WIMP paradigm.
- Dark sectors can include one or more mediator particles coupled to the SM via *portal*:

$$\mathcal{L} \supset \begin{cases} -\frac{\epsilon}{2\cos\theta_W} B_{\mu\nu} F'^{\mu\nu}\,, & \text{Vector portal, mediated by } A' \text{ with Spin 1 and odd-parity} \\ (\mu\phi + \lambda\phi^2) H^\dagger H\,, & \text{Higgs portal, mediated by a scalar} \\ y_n L H N\,, & \text{Neutrino portal, mediated by a fermion } N \\ \frac{a}{f_a} F_{\mu\nu}\widetilde{F}^{\mu\nu}\,, & \text{Axion portal, with a pseudoscalar } a \end{cases}$$

Recent Dark Sector Physics Results at Belle

- Several results are already published on the vector *portal* as it is the most viable for thermal models of light DM.
  - Introduce a new symmetry group $U(1)_D$ for the dark sector if the mediator is a vector boson, A'.
  - The "kinetic mixing" interaction $(\varepsilon / 2\cos\theta_W)B^{\mu\nu}F'_{\mu\nu}$ is invariant under gauge transformations of both $U(1)_D$ and $U(1)_Y$.

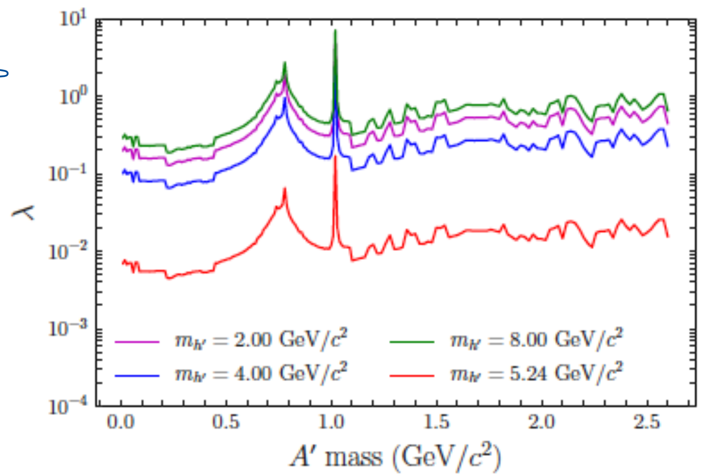
- New results on the Higgs portal: $B^0 \to A'A'$ **[*JHEP* 04 (2021)191]**
  - SM: BF for the 4*l* channel is $O(10^{-12})$
    - Low SM signal and background. Ideal to search for BSM.
  - Assume that A' decays promptly and all dark sector particles coupling to A' are heavier than A'
    - ☞ **A' can decay only to SM particles.**
  - 5 decay modes ($4e, 2e\ 2\mu, 4\mu, 2e\ 2\pi$, and $2\mu\ 2\pi$) for the reconstruction of A'.
  - Search for A' in the mass range of (10 MeV – 2.6 GeV) with 10 – 20 MeV interval.
  - Major backgrounds:
    - SM resonances mis-identified as A' : J/ψ, $\psi(2S)$, D^0, light mesons ($K_S, \rho^0, \phi, etc.$)
    - $e^+e^- \to q\bar{q}$, especially for $l^+l^-l^+l^-$ modes
      - Suppressed by the Fisher discriminant
    - Combinatorial, leptons mostly from semi-leptonic decays of quarks.

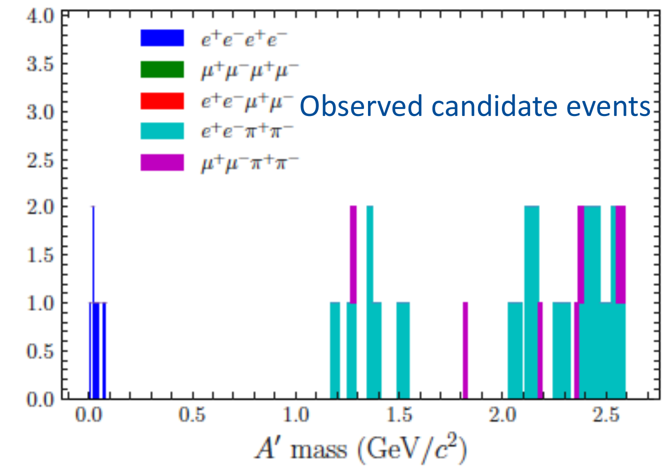


$B^0 \to A'A'$ Results

- No significant signal yield observed.
- Calculate 90% CL upper limits using Feldman-Cousins unified approach (clean background)
  - UL mostly $\mathcal{O}(10^{-8} - 10^{-7})$. Up to $\mathcal{O}(10^{-5})$ near the light meson rejection region.

90% CL UL on the Higgs portal coupling (λ) as a function of dark photon mass for different masses of dark Higgs.





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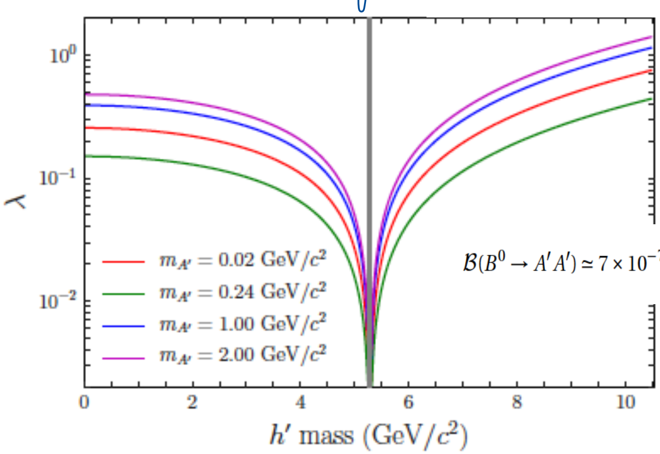
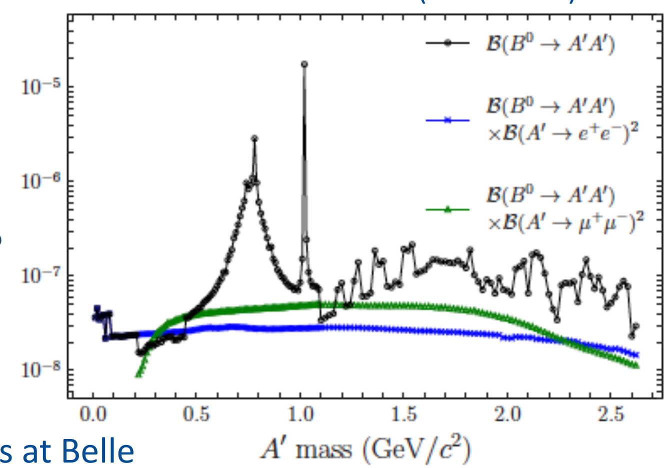


Higgs portal coupling (λ) derived from the following equation:

$$\mathcal{B}(B^0 \to A'A') \simeq 7 \times 10^{-7} \times \lambda^2 \times V_{A'A'}^{1/2} \times \frac{V_{A'A'} + 12 m_{A'}^4 / m_{B^0}^4}{(1 - m_{h'}^2 / m_{B^0}^2)^2}, \quad V_{A'A'} = 1 - 4 m_{A'}^2 / m_{B^0}^2$$

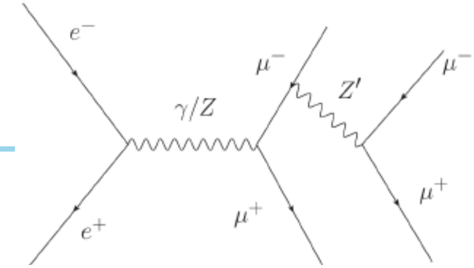
[PRD 83 054005]

90% CL UL on BF($B^0 \to A'A'$)



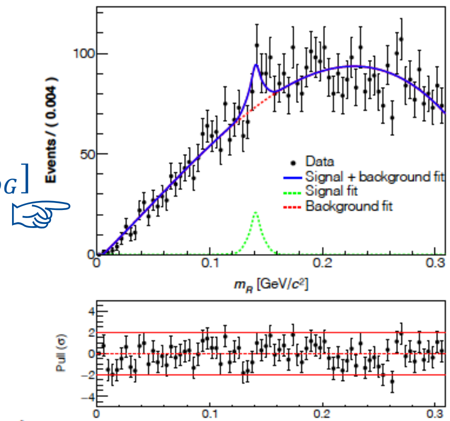
See **Giacomo De Pietro's** talk on Dark Sector searches at Belle

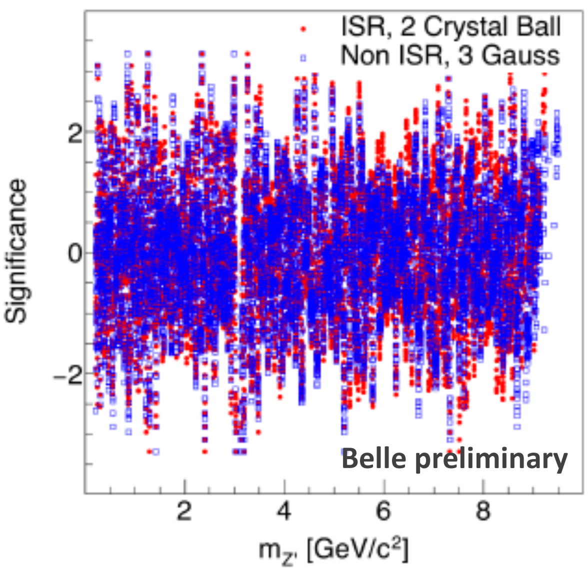
Search for $e^+e^- \to \mu^+\mu^- Z'_{L_\mu - L_\tau}$



- Dark sector U(1) gauge boson (Z').
- Search for the Z' in gauged $L_\mu - L_\tau$ model through $Z' \to \mu^+\mu^-$.
  - Z' only couples to heavy leptons (μ, τ) and their neutrinos.
- $Z'_{L_\mu - L_\tau}$ can be solutions of $(g-2)_\mu$ anomaly, but almost rejected in our energy range.
- ~679 fb^{-1} data is used from Belle, collected at all the $\Upsilon(nS)$ resonances.
- Signal extraction: binned maximum likelihood fit, total 9788 fits for different Z' masses, in steps of 1 MeV/c^2

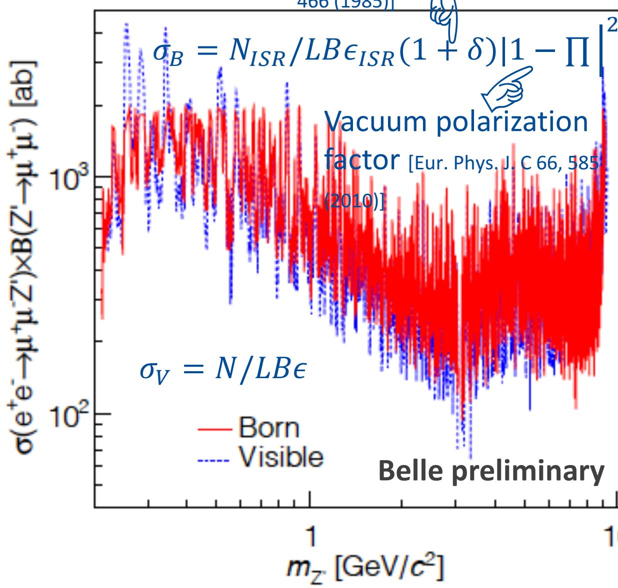
$m_R = \sqrt{[m^2_{\mu^+\mu^-} - 4m^2_{\mu PDG}]}$



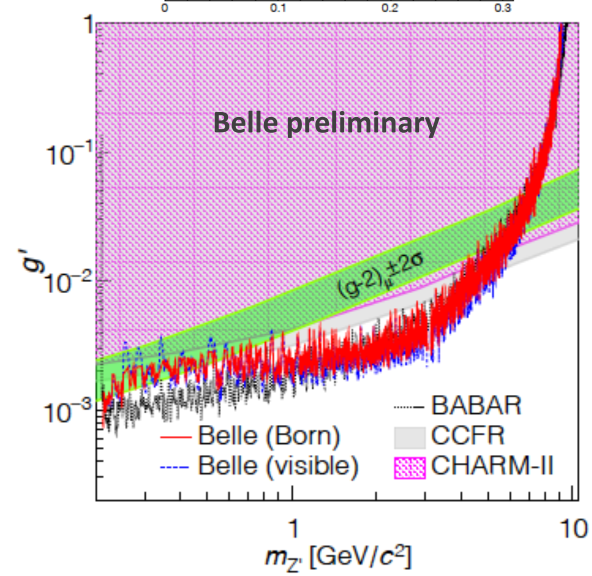


Significance of N_{obs}

ISR Correction factor [J. Nucl. Phys. 41, 466 (1985)]



90% CL UL on the cross-section

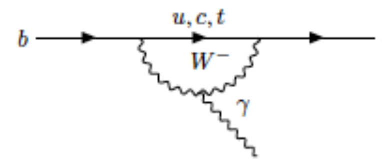


90% CL UL on g'

See **Sascha Dreyer's** talk for Belle II prospects

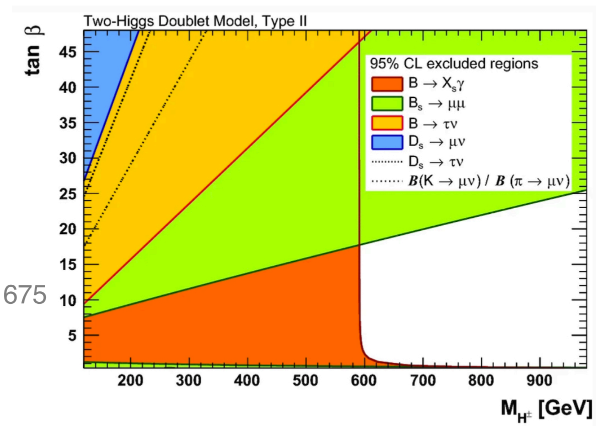
Radiative Penguin Decay: B→ $K^*\gamma$

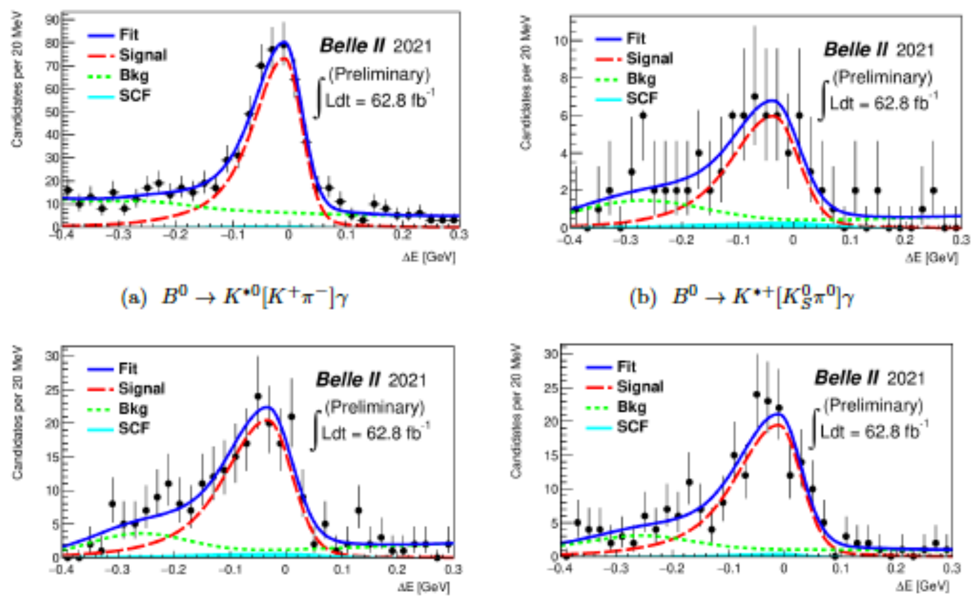
- $b \to s\gamma$ are FCNC processes, allowed only through loop diagrams in the SM.
  - BSM particles can enter the loop to alter the BF and other observables such as CP asymmetry, isospin asymmetry etc.



Strong constraint already on the 2HDM Type II from $B \to X_s\gamma$

Eur.Phys.J.C 78 (2018) 8, 675





(a) $B^0 \to K^{*0}[K^+\pi^-]\gamma$ (b) $B^0 \to K^{*+}[K^0_S\pi^0]\gamma$

(c) $B^+ \to K^{*+}[K^+\pi^0]\gamma$ (d) $B^+ \to K^{*+}[K^0_S\pi^+]\gamma$

- $B \to K^*\gamma$ suffers from large uncertainties due to form factors.
  - Important observables are CP and isospin asymmetries. Most uncertainties cancel in the ratio.
  - Belle has already reported a 3.1 σ discrepancy in the isospin asymmetry. (PRL 119, 191802 (2017))

Mode	Signal yield	Signal efficiency (%)	B.F (Fit) $\times 10^{-5}$	B.F (PDG) $\times 10^{-5}$
$B^0 \to K^{*0}[K^+\pi^-]\gamma$	454 ± 28	14.9	$4.6 \pm 0.3 \pm 0.3$	4.18 ± 0.25
$B^0 \to K^{*0}[K^0_S\pi^0]\gamma$	50 ± 10	1.7	$4.4 \pm 0.9 \pm 0.6$	4.18 ± 0.25
$B^+ \to K^{*+}[K^+\pi^0]\gamma$	169 ± 18	4.7	$5.1 \pm 0.5 \pm 0.5$	3.92 ± 0.22
$B^+ \to K^{*+}[K^0_S\pi^+]\gamma$	160 ± 17	4.1	$5.5 \pm 0.6 \pm 0.4$	3.92 ± 0.22

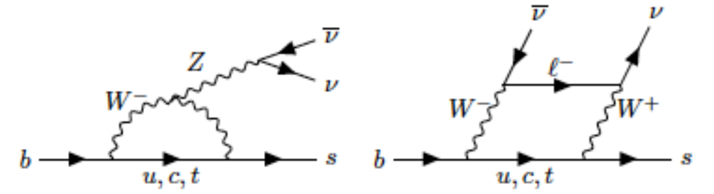
Results from Belle II on $B \to K^*\gamma$ are consistent with SM

$$CP\ asymmetry\ A_{CP} = \frac{\Gamma(\bar{B} \to \bar{K}^*\gamma) - \Gamma(B \to K^*\gamma)}{\Gamma(\bar{B} \to \bar{K}^*\gamma) + \Gamma(B \to K^*\gamma)}$$

$$\text{Isospin}\ asymmetry\ \Delta_{+0} = \frac{\Gamma(B^0 \to K^{*0}\gamma) - \Gamma(B^+ \to K^{*+}\gamma)}{\Gamma(B^0 \to K^{*0}\gamma) + \Gamma(B^+ \to K^{*+}\gamma)}$$

See **Yo Sato's** talk

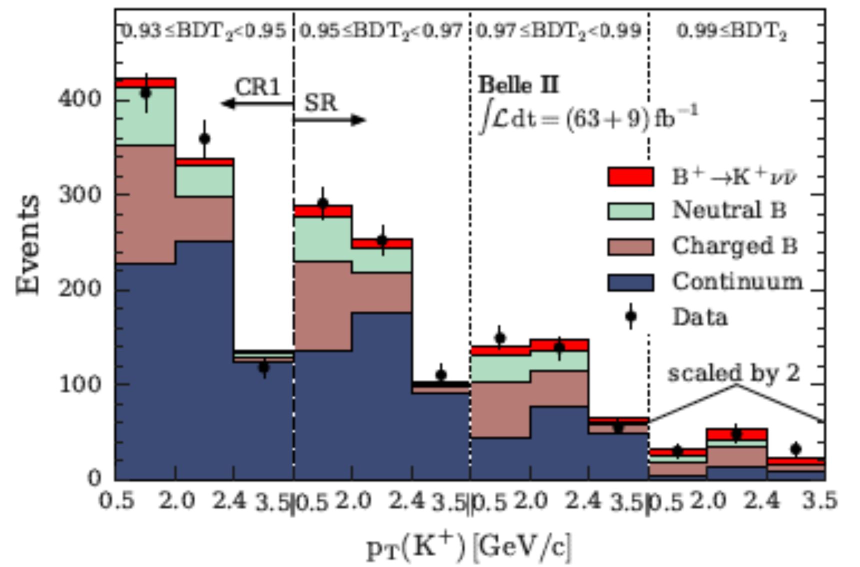
EW Penguin: $B^{\pm} \to K^{\pm}\nu\,\bar{\nu}$

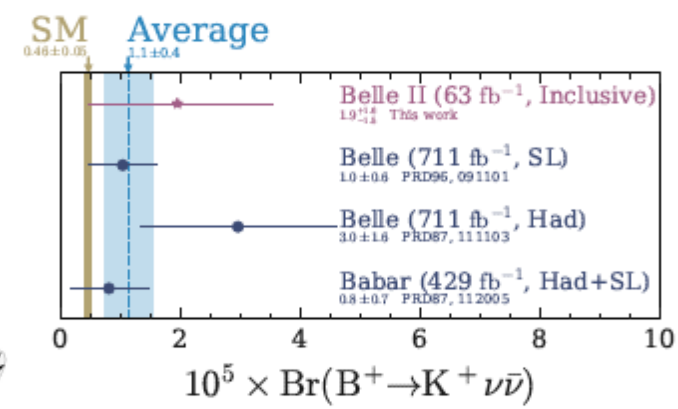


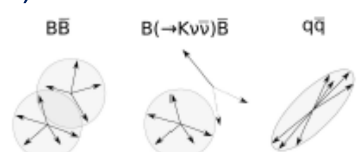
(a) Penguin diagram (b) Box diagram

- FCNC process, yet to be observed experimentally.
  - No photon contribution, much cleaner theoretical prediction: $BF(B^{\pm} \to K^{\pm}\nu\bar{\nu}) = (4.6 \pm 0.5)\times 10^{-6}$
  - Observation of this decay can help constrain BSM models: leptoquarks, axions, dark matter particles
- Previous searches are based on tagged analyses
  - B_{tag} is reconstructed completely from semi-leptonic decay modes. Signal efficiency ~0.2%.
  - B_{tag} is reconstructed completely from hadronic decay modes. Signal efficiency ~0.04%.
- Belle II use a new approach based on inclusive tag
  - No explicit reconstruction of the second B-meson
  - Use BDTs to exploit the topological features of the signal vs background
  - Much higher signal selection efficiency: ~4.3%
- Further improvements are expected
  - Additional data (already 3x more on tape)
  - Additional channels such as the $K^{*0}\bar{\nu}\nu$, $K_s^0\bar{\nu}\nu$ etc.

arXiv:2104.06224 (submitted to PRL)





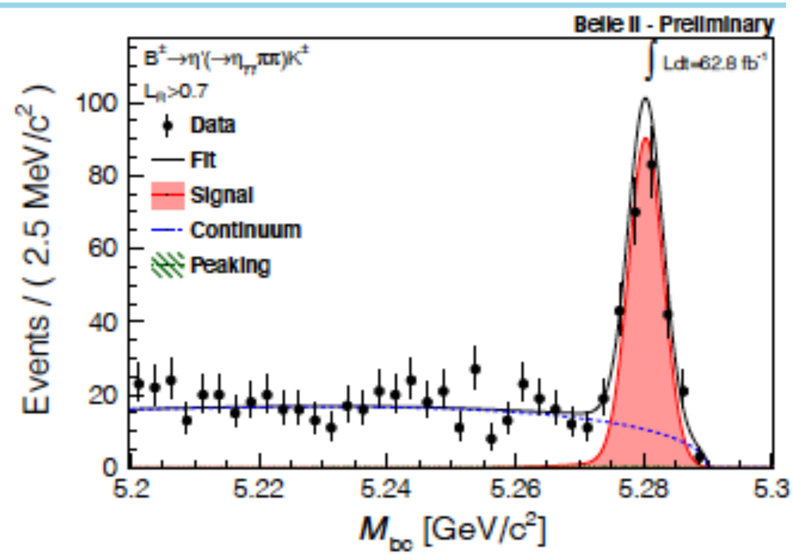


See **Yo Sato's** talk

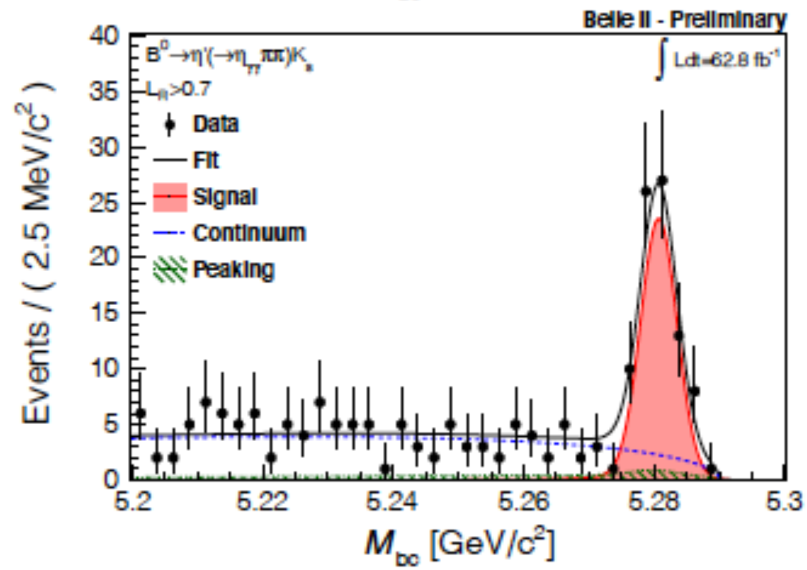
Rediscovery of B→ $\eta' K$

arXiv:2104.06224

- First Belle II measurement of a rare charmless hadronic *B* decay, mediated via hadronic penguin diagram.
  - Sensitive to new physics in the hadronic loop.
- Both charged and neutral modes, $B^0 \to \eta' K_S^0$ *and* $B^\pm \to \eta' K^\pm$ are studied.
  - η' is reconstructed from $\eta' \to \eta\pi^+\pi^-$ with $\eta \to \gamma\gamma$ and $\eta' \to \rho\gamma$.
  - 62.8 fb^{-1} data collected in 2019 and 2020 are used.



Mode	N_{sig}	*sig.*	$\varepsilon(\%)$	$\varepsilon\mathcal{B}(\%)$	$\mathcal{B}\ (10^{-6})$
$B^\pm \to \eta'(\to \eta(\to \gamma\gamma)\pi^+\pi^-)K^\pm$	$263\ ^{+18}_{-19}$	25.7	31.7 ± 0.03	5.45	$63.9\ ^{+4.6}_{-4.4} \pm 4.0$
$B^\pm \to \eta'(\rho(\to \pi^+\pi^-)\gamma)K^\pm$	$335\ ^{+26}_{-25}$	22.2	24.2 ± 0.04	7.05	$62.9\ ^{+4.8}_{-4.8} \pm 5.5$
$B^0 \to \eta'(\to \eta(\to \gamma\gamma)\pi^+\pi^-)K_S^0$	$80.0\ ^{+11.2}_{-10.4}$	13.8	31.0 ± 0.03	1.80	$61.6\ ^{+8.6}_{-8.0} \pm 3.9$
$B^0 \to \eta'(\rho(\to \pi^+\pi^-)\gamma)K_S^0$	$99.7\ ^{+14.2}_{-12.7}$	14.2	23.6 ± 0.04	2.35	$58.5\ ^{+7.9}_{-7.4} \pm 4.4$



	This analysis	World average
Channel	$\mathcal{B}\ (\times 10^6)$	
$B^\pm \to \eta' K$	$63.4\ ^{+3.4}_{-3.3}$(stat) $\pm$ 3.4(syst)	70.4 ± 2.5
$B^0 \to \eta' K^0$	$59.9\ ^{+5.8}_{-5.5}$(stat) $\pm$ 2.7(syst)	66 ± 4

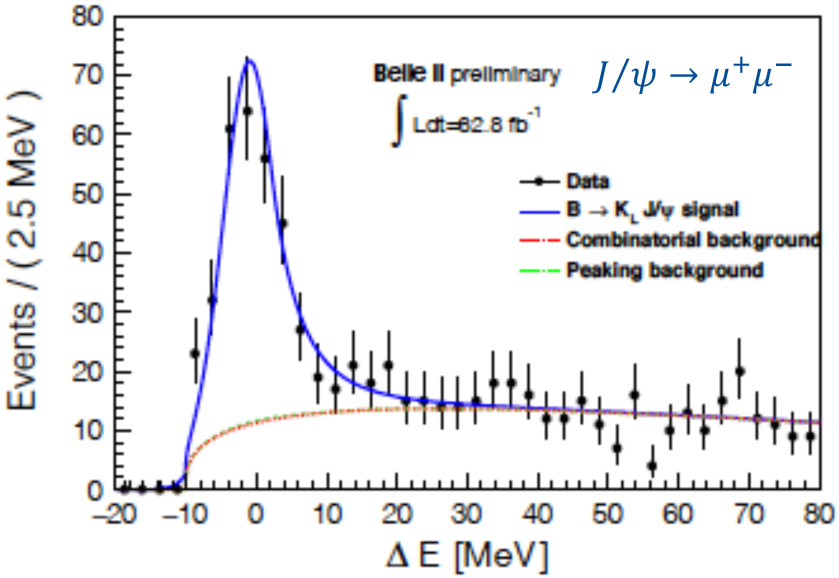
Results are compatible with the world average.

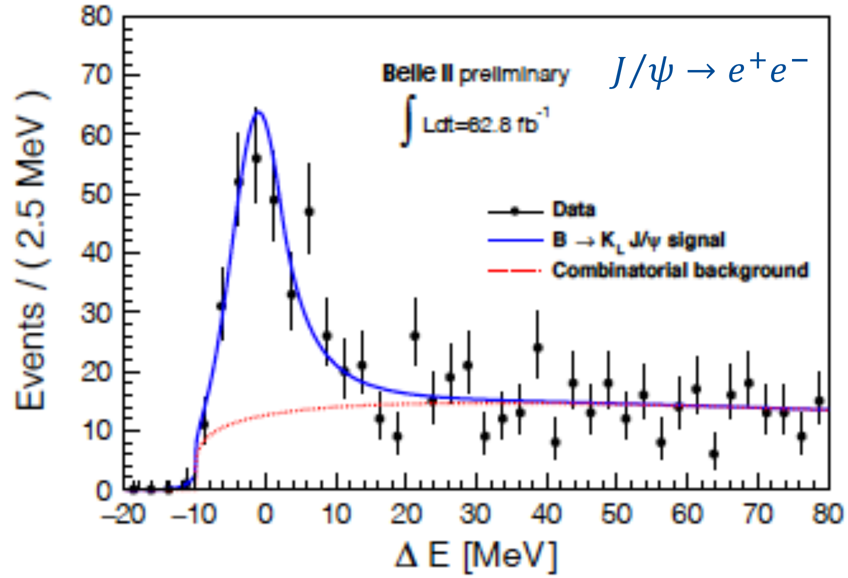
Rediscovery of B→ $J/\psi K_L$

arXiv:2106.13547

- Mesurement of $\sin(2\phi_1/\beta)$ using $B^0 \to J/\psi K_L^0$ decay complements the one from $B^0 \to J/\psi K_S$.
  - Observed signal yield is consistent with the Belle measurement with similar purity
  - More to come: time-dependent CP violation and precise measurement of $\sin(2\phi_1)$.

$$N_{\text{sig}}\ (\mu^+\mu^-) = 267 \pm 21(\text{stat}) \pm 28(\text{peaking})$$
$$N_{\text{sig}}\ (e^+e^-) = 226 \pm 20(\text{stat}) \pm 31(\text{peaking})$$

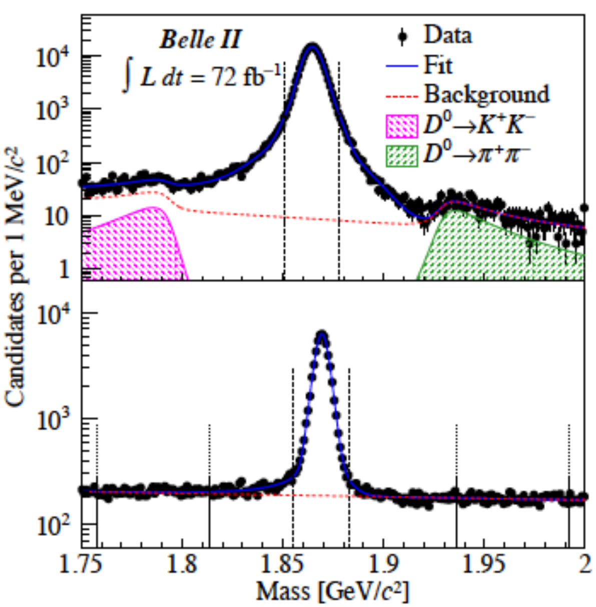




D^0 and D^+ Lifetime Measurements

arXiv:2108.03216

- Select high purity samples of $D^{*+} \to D^0(\to K^- \pi^+)\pi^+$ and $D^{*+} \to D^+(\to K^-\pi^+\pi^+)\pi^0$ decays.
  - 72 fb^{-1} of data collected during 2019 and first half 2020 is used in the analysis.
- Fit the distribution of the decay time with accurate modelling of the resolution.
- Dominant systematic uncertainties come from residual detector mis-alignment (D^0) and from background modelling (D^+).
- Preliminary results are consistent with, and more precise than, respective world averages.
- Demonstration of excellent vertexing capabilities of the Belle II detector.
  - Combined PXD+SVD system provides average decay-time resolutions of about 70 fs and 60 fs, respectively for D^0 and D^+ decays.



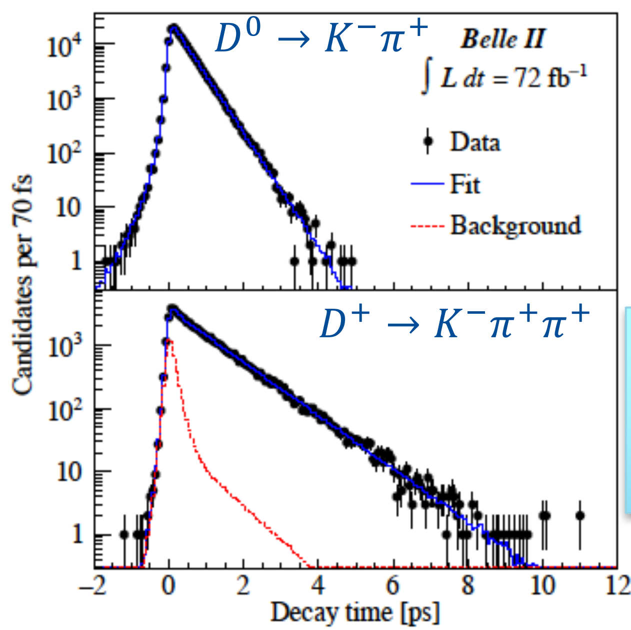


Table I: Systematic uncertainties.

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

	Belle II	World Average
	$\tau(D^0) = (410.5 \pm 1.1 \pm 0.8)$fs	(410.1 ± 1.5)fs
	$\tau(D^*) = (1030.4 \pm 4.7 \pm 3.1)$fs	(1040 ± 7) fs

$B \to D^{(*)}K/\pi$ towards ϕ_3/γ measurement

arXiv:2104.03628

Belle II

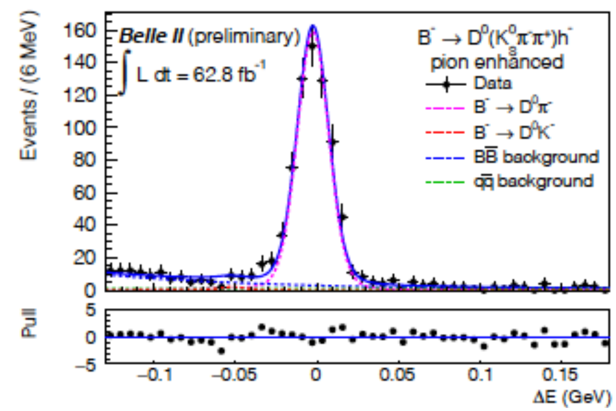
- The decays $B^- \to D^{(*)0}\pi^-$ *and* $\bar{B}^0 \to D^{(*)+}\pi^-$ arise from the favored $b \to c$ transition.
  - Some of the most abundant hadronic *B* decays with BF between 0.25% and 0.5%.
- $B^- \to D^{(*)0}K^-$ are sensitive to CKM unitarity-triangle angle ϕ_3 *or* γ.
  - “golden” mode: $B^- \to D^0(K_S\pi^+\pi^-)K^-$
- Ratio between decay rates are important observables:
  - Many systematics cancel in the ratio calculation.
  - Can test theoretical predictions: factorization, SU(3) symmetry breaking in QCD.
- Analysis is based on 62.8 fb^{-1} of data.
  - Results are consistent with the world average.

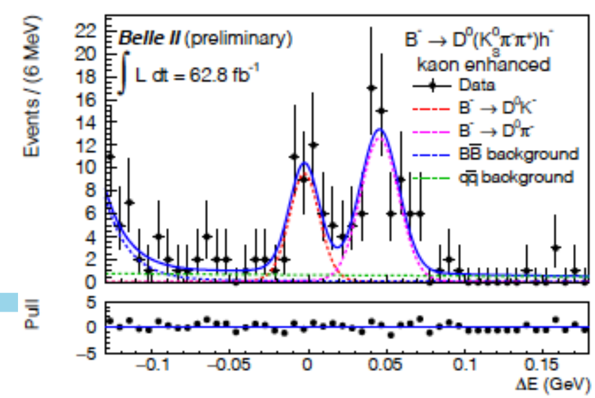
$$R^{(*)0} = \frac{\Gamma(B^- \to D^{(*)0}K^-)}{\Gamma(B^- \to D^{(*)0}\pi^-)}$$

$$R^{(*)+} = \frac{\Gamma(\overline{B^0} \to D^{(*)+}K^-)}{\Gamma(\overline{B^0} \to D^{(*)+}\pi^-)}$$

Re-optimization of the Belle ϕ_3 analysis on-going

Aiming for first Belle + Belle II combined result shortly.



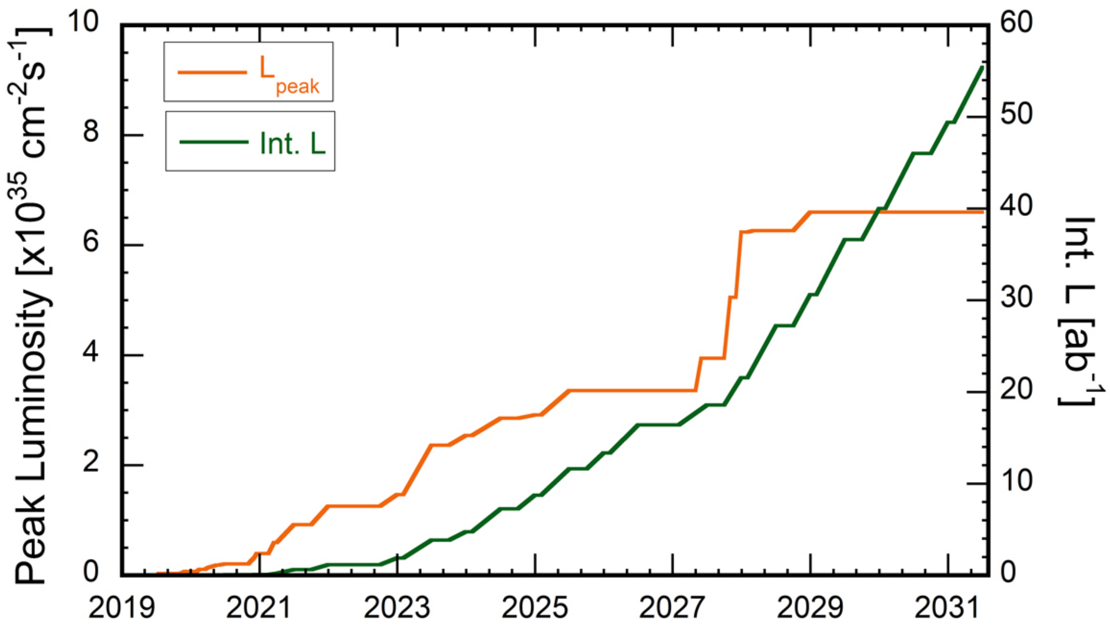


	$B^- \to D^0(K^-\pi^+)h^-$	$B^- \to D^0(K^0_S\pi^+\pi^-)h^-$	$\bar{B}^0 \to D^+h^-$
Belle II $R^{+/0}$ $(\times 10^{-2})$	$7.66 \pm 0.55\ ^{+0.11}_{-0.08}$	$6.32 \pm 0.81\ ^{+0.09}_{-0.11}$	$9.22 \pm 0.58 \pm 0.09$
LHCb $R^{+/0}$ $(\times 10^{-2})$	$7.77 \pm 0.04 \pm 0.07$ [24]	$7.77 \pm 0.04 \pm 0.07$ [24]	$8.22 \pm 0.11 \pm 0.25$ [25]

Belle II Run Plan

- 2021: Already collected about 213 fb^{-1}
- 2021: Autumn run.
  - $\Upsilon(4S)$: ~ 400 fb^{-1}
  - 10.75 GeV + Scan for 10 fb^{-1} is planned.
- 2022 Summer: ~ 700 fb^{-1} (equivalent to total Belle data)
- 2022 Long shutdown1 (LS1)
  - Full pixel in the 2nd inner most layer.
  - TOP PMT replacement
- 2026: ~15 ab^{-1}
- 2031: ~50 ab^{-1}

Belle II Luminosity Projection



Summary

- Flavor physics at the electron-positron collider offers an extremely rich physics program with many opportunities to probe new physics beyond the SM.
  - Much cleaner environment: great for physics studies with π^0, γ and ν. Inclusive analysis possible with full control on the event kinematics.

- Belle continues to produce interesting physics results which are sensitive to the BSM searches.
  - Will continue to do so for few more years before Belle II takes over.

- Belle II has already collected about 213 fb^{-1} of data. Complimentary physics program to LHCb.
  - Started to publish competitive physics results. Several new ideas to increase the sensitivity per fb^{-1} of data.
  - Planning to collect 50 ab^{-1} of data by 2031.
  - Exciting time ahead in flavor physics.

Backup Slides

Precision Measurements at Belle II vs LHCb

Table 16. Expected errors on several selected flavor observables with an integrated luminosity of 50 ab^{-1} of Belle II data. Errors given in % represent relative errors. In the final column we denote where LHCb is expected to reach a highly competitive level of precision: if one experiment is expected to be slightly more accurate we list it first.

Observables	Exp. theor. accuracy	Exp. experim. uncertainty	Facility (2025)
UT angles and sides			
ϕ_1 [°]	***	0.4	Belle II
ϕ_2 [°]	**	1.0	Belle II
ϕ_3 [°]	***	1.0	LHCb/Belle II
$\|V_{cb}\|$ incl.	***	1%	Belle II
$\|V_{cb}\|$ excl.	***	1.5%	Belle II
$\|V_{ub}\|$ incl.	**	3%	Belle II
$\|V_{ub}\|$ excl.	**	2%	Belle II/LHCb
CP violation			
$S(B \to \phi K^0)$	***	0.02	Belle II
$S(B \to \eta' K^0)$	***	0.01	Belle II
$\mathcal{A}(B \to K^0 \pi^0)$ $[10^{-2}]$	***	4	Belle II
$\mathcal{A}(B \to K^+ \pi^-)$ $[10^{-2}]$	***	0.20	LHCb/Belle II
(Semi-)leptonic			
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	**	3%	Belle II
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	**	7%	Belle II
$R(B \to D\tau\nu)$	***	3%	Belle II
$R(B \to D^*\tau\nu)$	***	2%	Belle II/LHCb
Radiative and EW penguins			
$\mathcal{B}(B \to X_s\gamma)$	**	4%	Belle II
$A_{CP}(B \to X_{s,d}\gamma)$ $[10^{-2}]$	***	0.005	Belle II
$S(B \to K_S^0 \pi^0 \gamma)$	***	0.03	Belle II
$S(B \to \rho\gamma)$	**	0.07	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	**	0.3	Belle II
$\mathcal{B}(B \to K^*\nu\bar{\nu})$ $[10^{-6}]$	***	15%	Belle II
$R(B \to K^*\ell\ell)$	***	0.03	Belle II/LHCb
Charm			
$\mathcal{B}(D_s \to \mu\nu)$	***	0.9%	Belle II
$\mathcal{B}(D_s \to \tau\nu)$	***	2%	Belle II
$A_{CP}(D^0 \to K_S^0 \pi^0)$ $[10^{-2}]$	**	0.03	Belle II
$\|q/p\|(D^0 \to K_S^0 \pi^+ \pi^-)$	***	0.03	Belle II
$A_{CP}(D^+ \to \pi^+ \pi^0)$ $[10^{-2}]$	**	0.17	Belle II
Tau			
$\tau \to \mu\gamma$ $[10^{-10}]$	***	< 50	Belle II
$\tau \to e\gamma$ $[10^{-10}]$	***	< 100	Belle II
$\tau \to \mu\mu\mu$ $[10^{-10}]$	***	< 3	Belle II/LHCb

- Details in "The Belle II Physics Book", Prog. Theor. Exp. Phys. 2019, 123C01.
- e^+e^- collider: much cleaner environment, good for final states with γ, π^0 *and* ν
- Possible to do inclusive analysis by exploiting event kinematics.