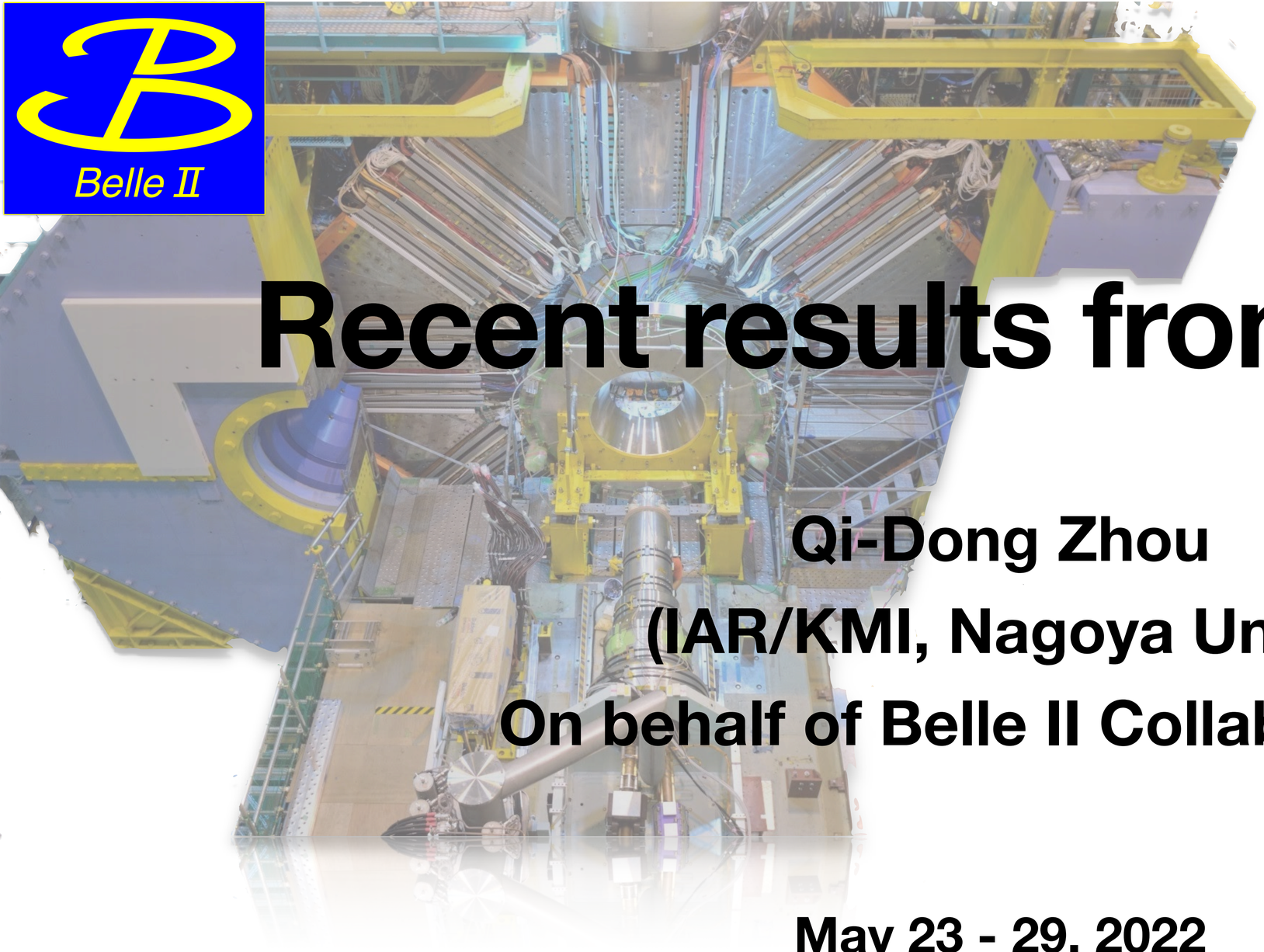


Recent results from Belle II

Qi-Dong Zhou

(IAR/KMI, Nagoya Univ.)

On behalf of Belle II Collaboration

May 23 - 29, 2022

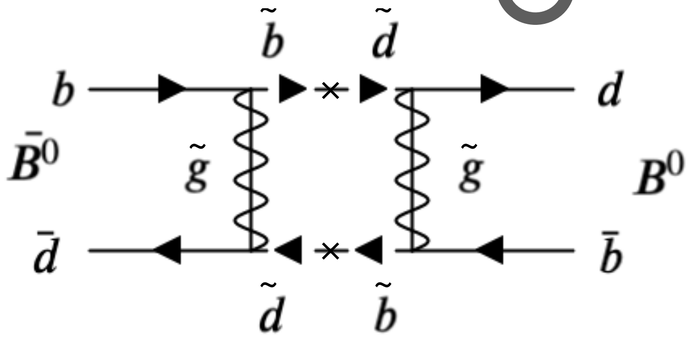
21st International Symposium on Very High Energy Cosmic Ray Interactions

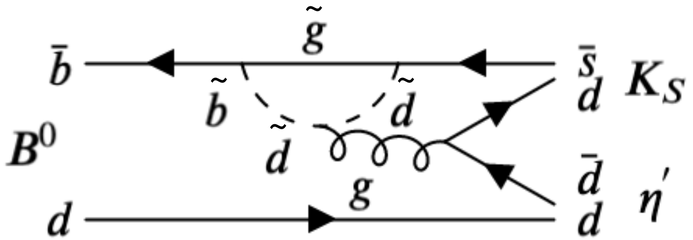
ISVHECRI 2022 (Virtual)

New physics search at Belle II

Energy frontier : direct search

Luminosity frontier : indirect search





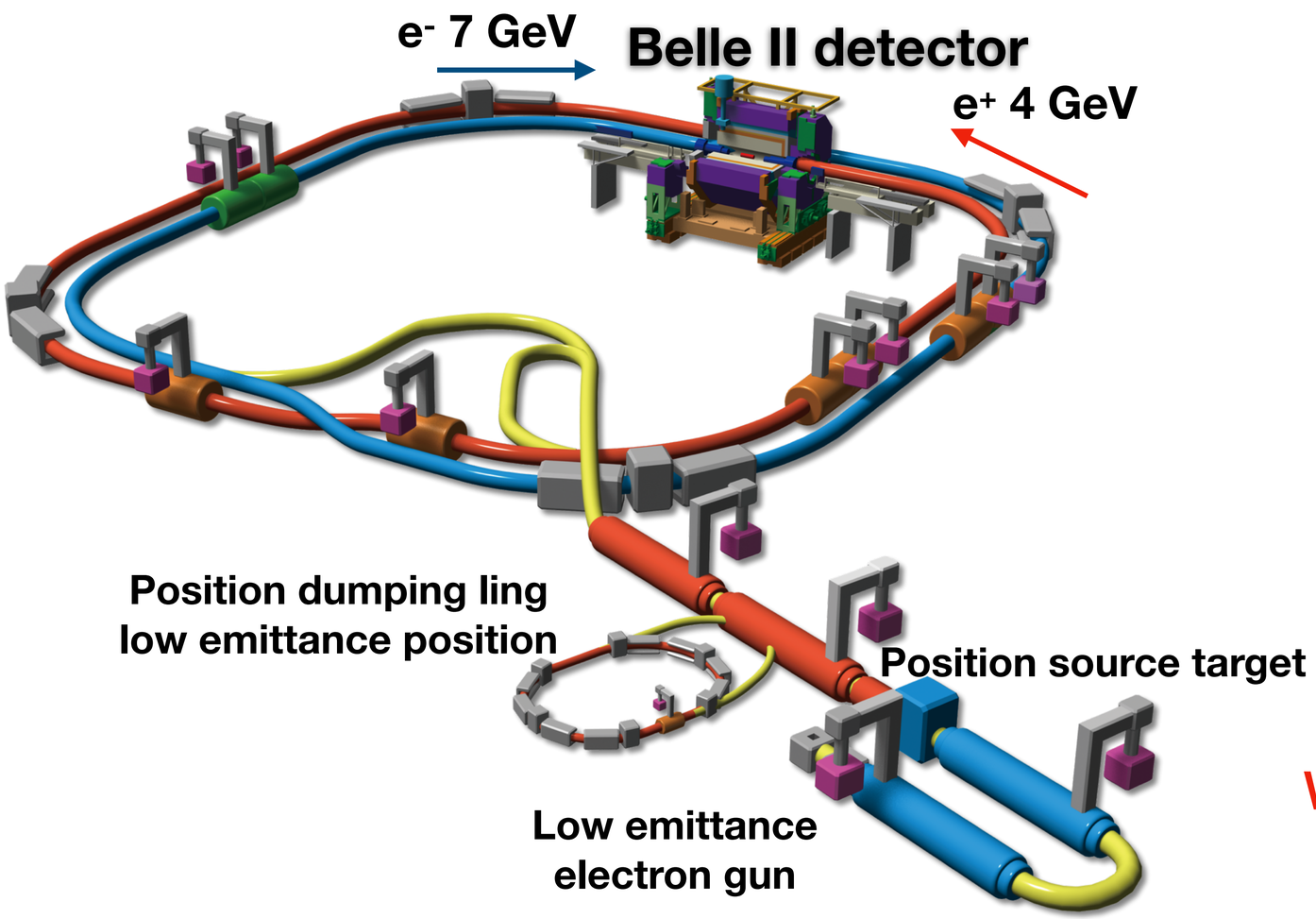
- Indirect search for New Physics (NP) in quantum effect
  - Sensitivity of NP detection up to **200 TeV** for loop diagram (depending on the NP coupling constant)

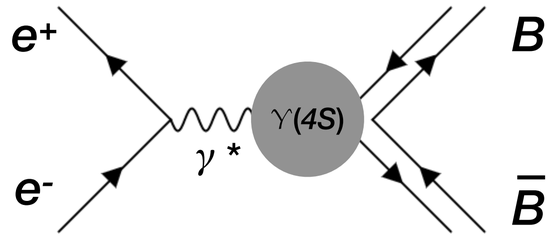
arXiv:1309.2293

- Standard Model suppressed or forbidden decays
- Test lepton flavor universality and the lepton flavor violations
- Dark sector search, τ physics, etc..

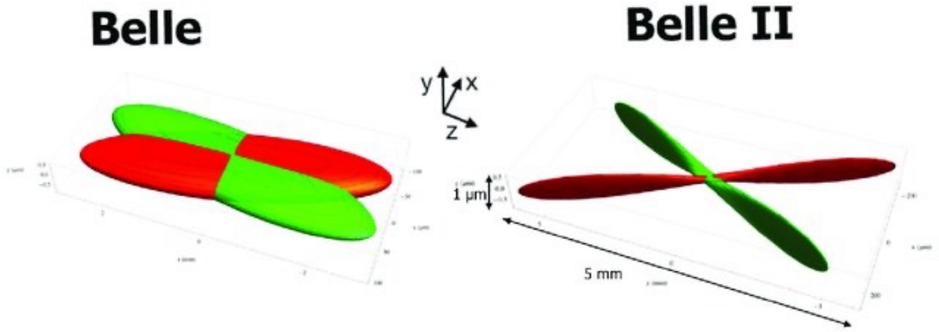
Luminosity frontier: SuperKEKB/Belle II

Asymmetric e^+e^- collider operating at a center of mass energy of the $\Upsilon(4S)$ resonance





Nano beam scheme



- Squeeze the beam σ_y^*~50 nm
- Large crossing angle

World's highest instantaneous luminosity:

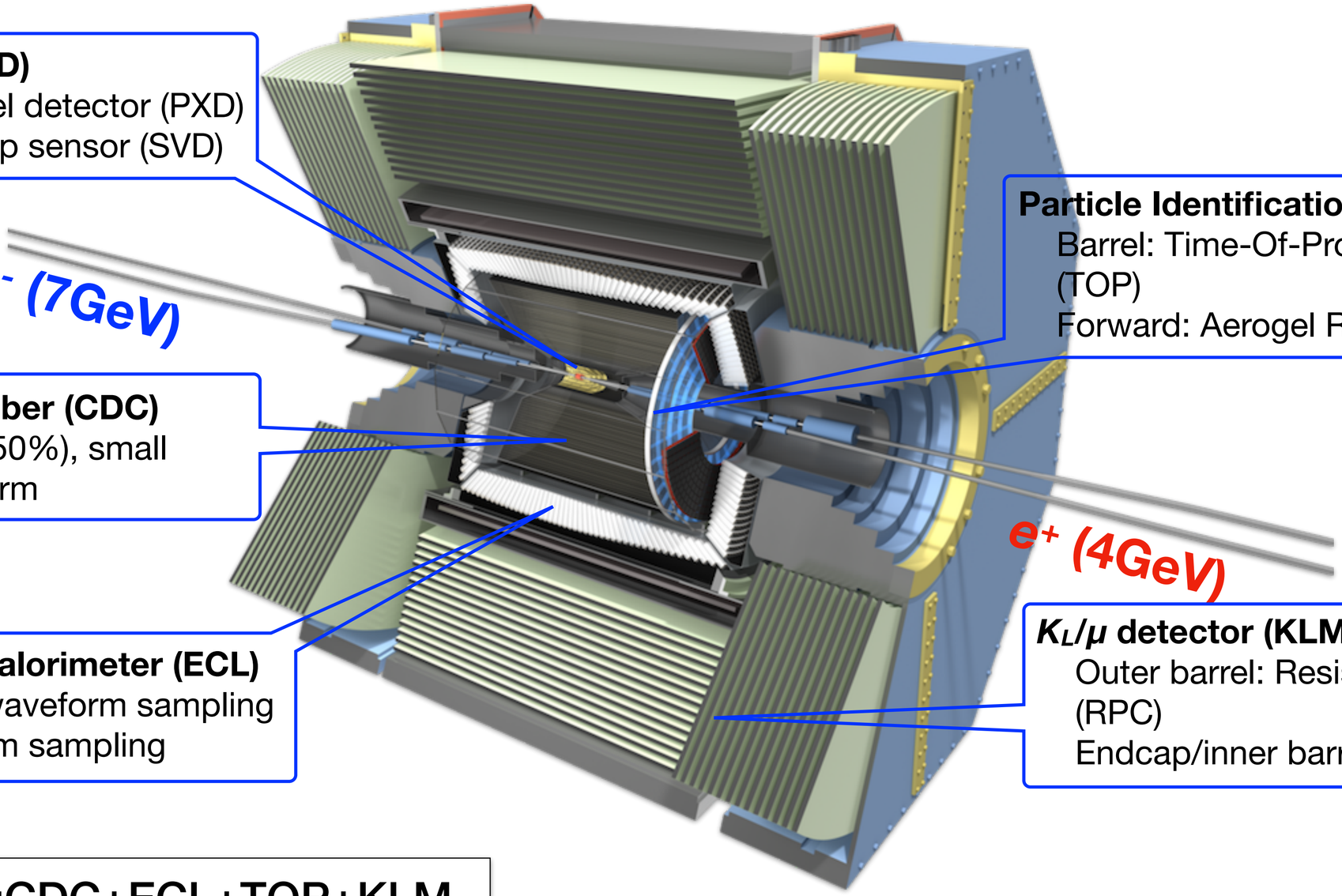
$\mathcal{L} = 4.14 \times 10^{34}\ \mathrm{cm^{-2}\ s^{-1}}$

KEKB record: $2.1 \times 10^{34}\ \mathrm{cm^{-2}\ s^{-1}}$

The Belle II detector

Vertex detector (VXD)
Inner 2 layers: pixel detector (PXD)
Outer 4 layers: strip sensor (SVD)

Particle Identification
Barrel: Time-Of-Propagation counters (TOP)
Forward: Aerogel RICH (ARICH)



Central Drift Chamber (CDC)
He (50%), C_2H_6 (50%), small cells, long lever arm

ElectroMagnetic Calorimeter (ECL)
Barrel: CsI(Tl) + waveform sampling
Endcap: waveform sampling

***K_L/μ* detector (KLM)**
Outer barrel: Resistive Plate Counter (RPC)
Endcap/inner barrel: Scintillator

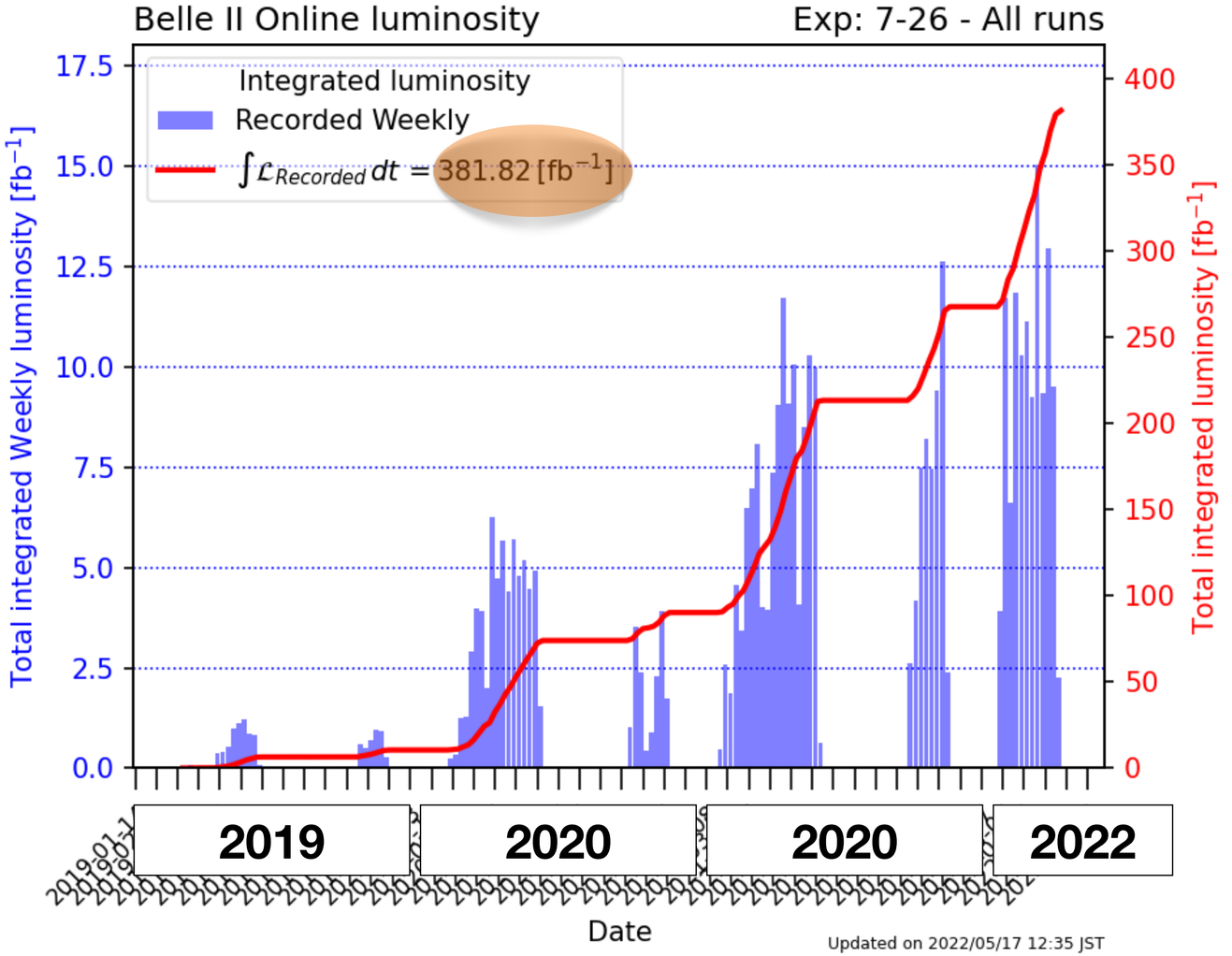
Level-1 trigger :CDC+ECL+TOP+KLM
DAQ: Maximum 30 kHz L1 trigger

Operation status and integrated luminosity

- Belle II operation under COVID-19

Belle II data taking efficiency ~90%

- ~380 fb^{-1} till now, expect ~500 fb^{-1} till LS1
  - Belle: 1 ab^{-1}
- Long shutdown (LS) 1 starts from summer 2022 to autumn 2023 to replace PXD
- LS2 is under discussion for machine improvements on the time frame of 2026-27

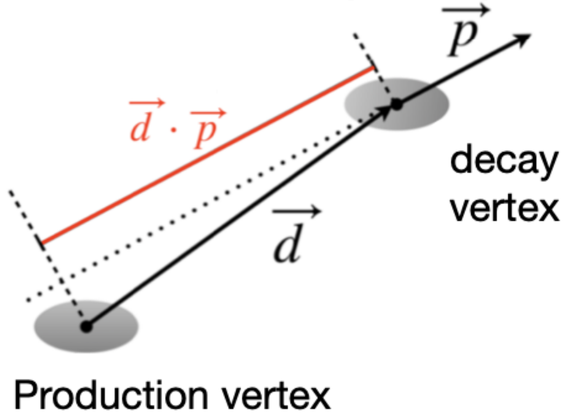


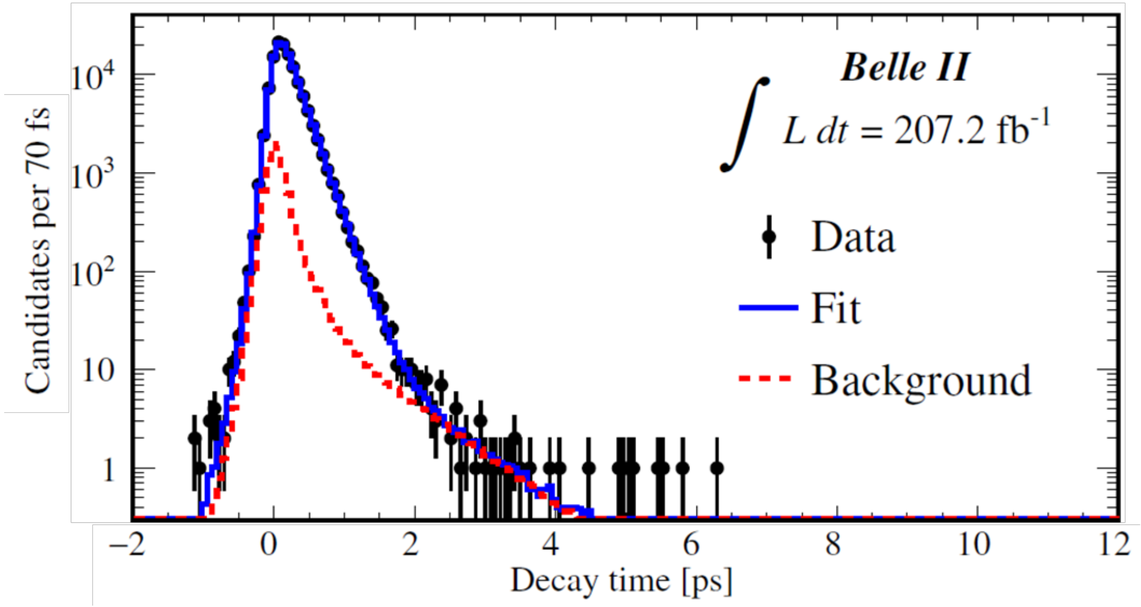
Charm lifetimes

Charm lifetime measurements at Belle II

- World's most precise measurement of D^0/D^+ lifetime by Belle II, PRL 127, 211801 (2021)
  - Small interaction region
  - New vertex detector

Belle II	World average
$\tau(D^0) = 410.5 \pm 1.1$ (stat.) ± 0.8 (syst.) fs	410.1 ± 1.5 fs
$\tau(D^+) = 1030.4 \pm 4.7$ (stat.) ± 3.1 (syst.) fs	1040 ± 7 fs

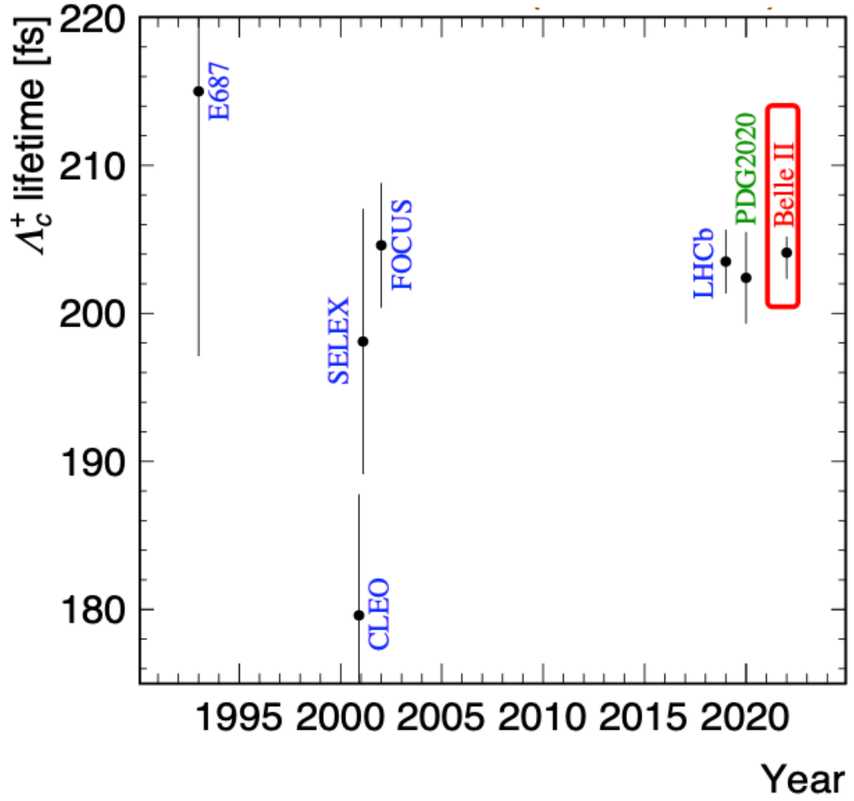




$\tau(\Lambda_c^+) = 204.1 \pm 0.8$ (stat.) ± 1.4 (syst.) fs

(202.4 ± 3.1 fs PDG)

World's most precise measurement



B physics

CKM matrix and unitarity triangle (UT)

$$V=\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}=\begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A^2\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}+O(\lambda^4)$$

Complex phase cause CP violation

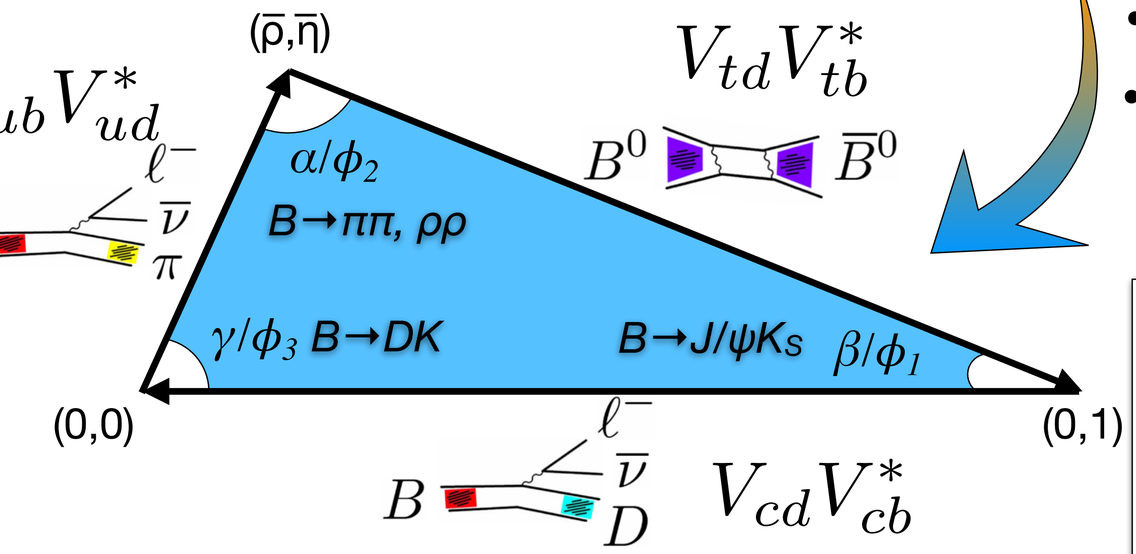
$V^\dagger V = 1$ → ***b*** row ***d*** column →

$$\underset{\lambda^3\cdot 1}{V_{ub}^* V_{ud}}+\underset{\lambda^2\cdot\lambda}{V_{cb}^* V_{cd}}+\underset{1\cdot\lambda^3}{V_{tb}^* V_{td}}=0$$

$$\phi_1=\arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right) \quad V_{ub}V_{ud}^*$$

$$\phi_2=\arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right) \quad B \to \ell^- \bar{\nu} \pi$$

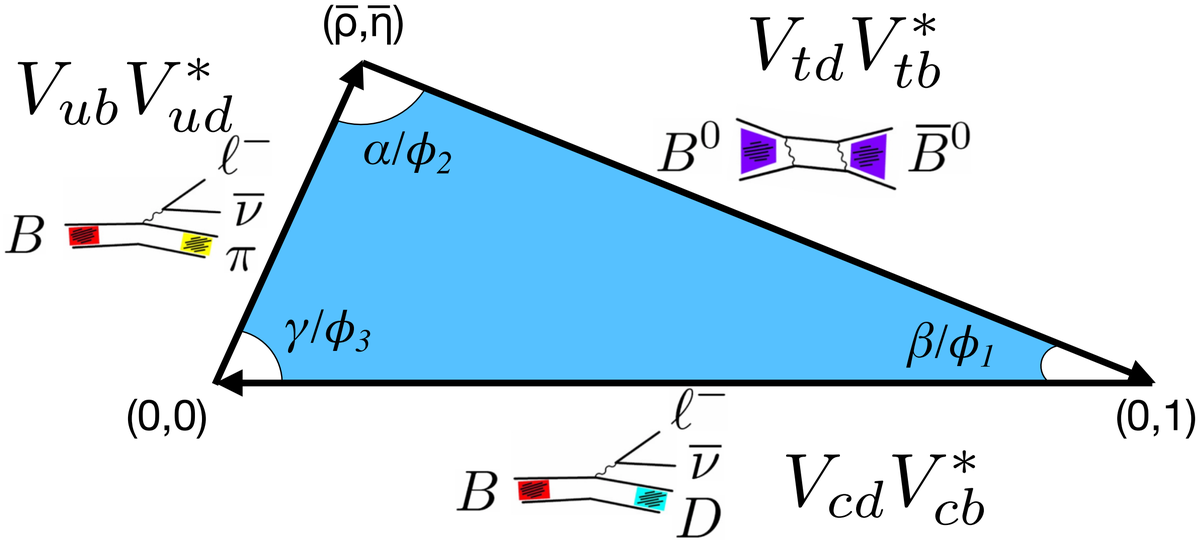
$$\phi_3=\arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$



- A triangle on the complex plane
- Normalization by $\bar{\rho}=\rho(1-\frac{\lambda^2}{2})$ $\bar{\eta}=\eta(1-\frac{\lambda^2}{2})$

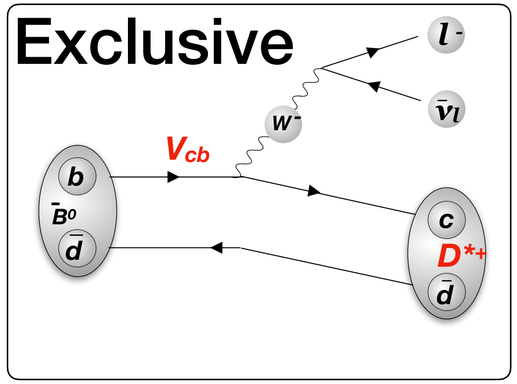
- Comprehensive test by Belle II
  - Measure **all sides and angles**
- Search NP in mixing (**tree**, **loop**) by precise measurement of UT

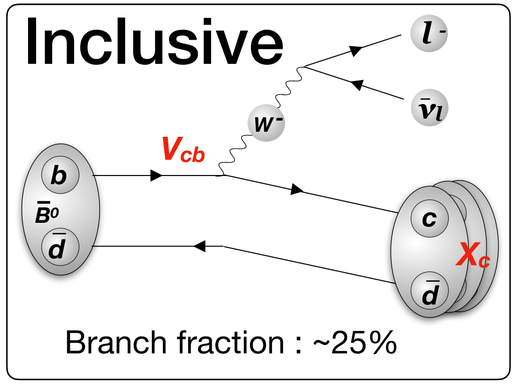
$|V_{cb}|$, $|V_{ub}|$ measurement through semileptonic B decays

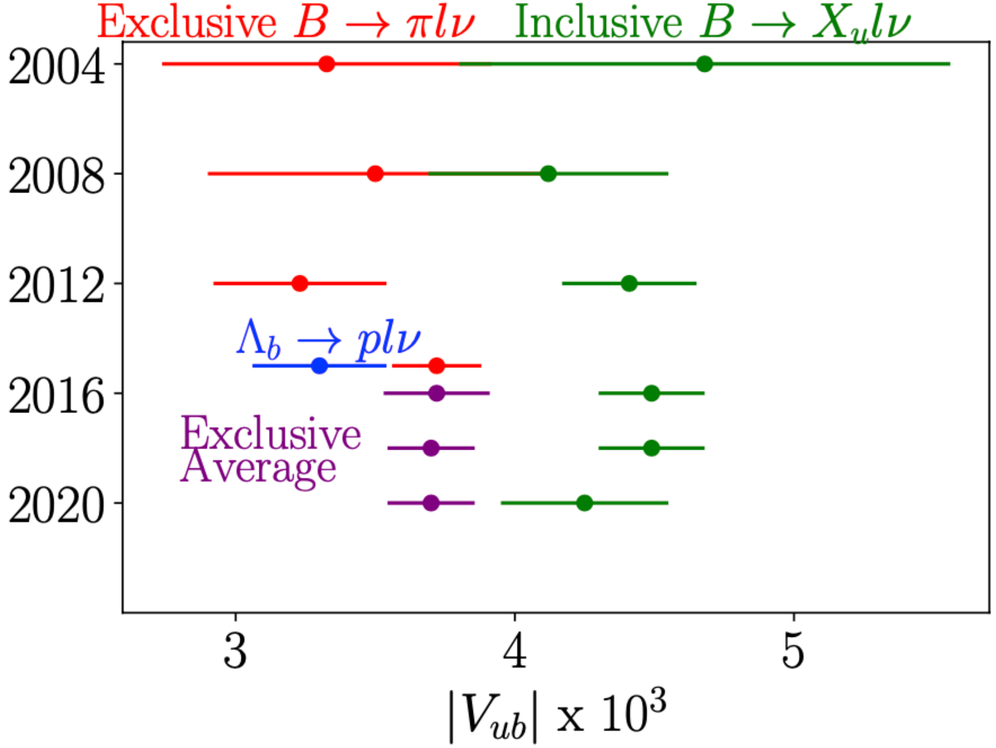


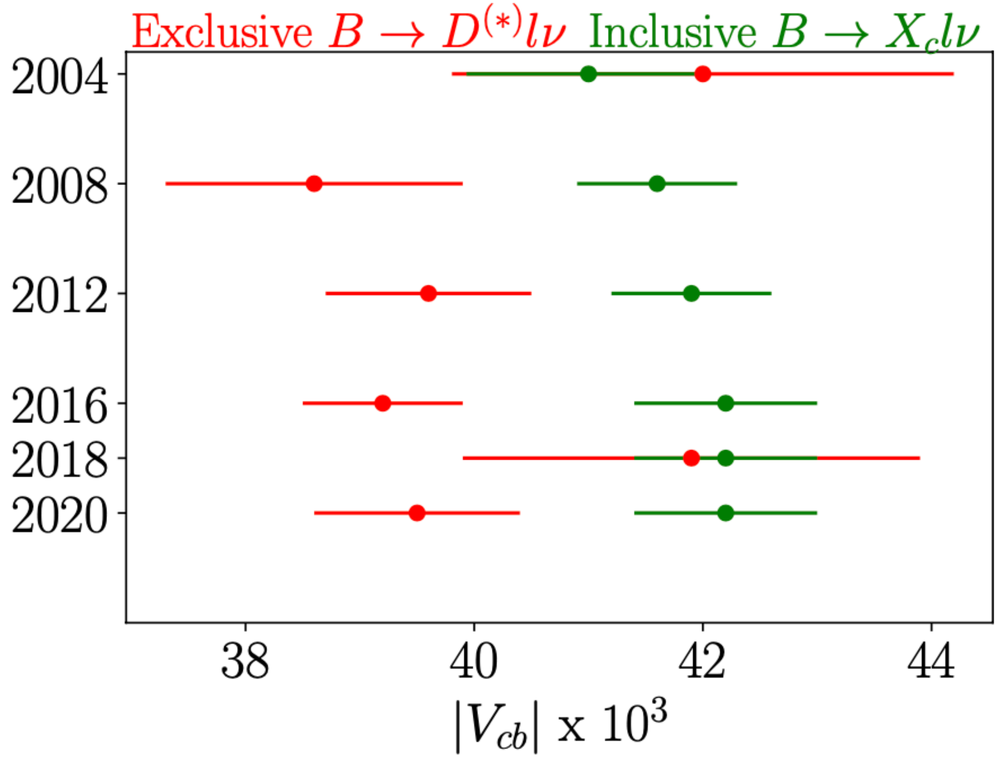
Status of $|V_{ub}|$ and $|V_{cb}|$ determinations

Semi-leptonic decay:





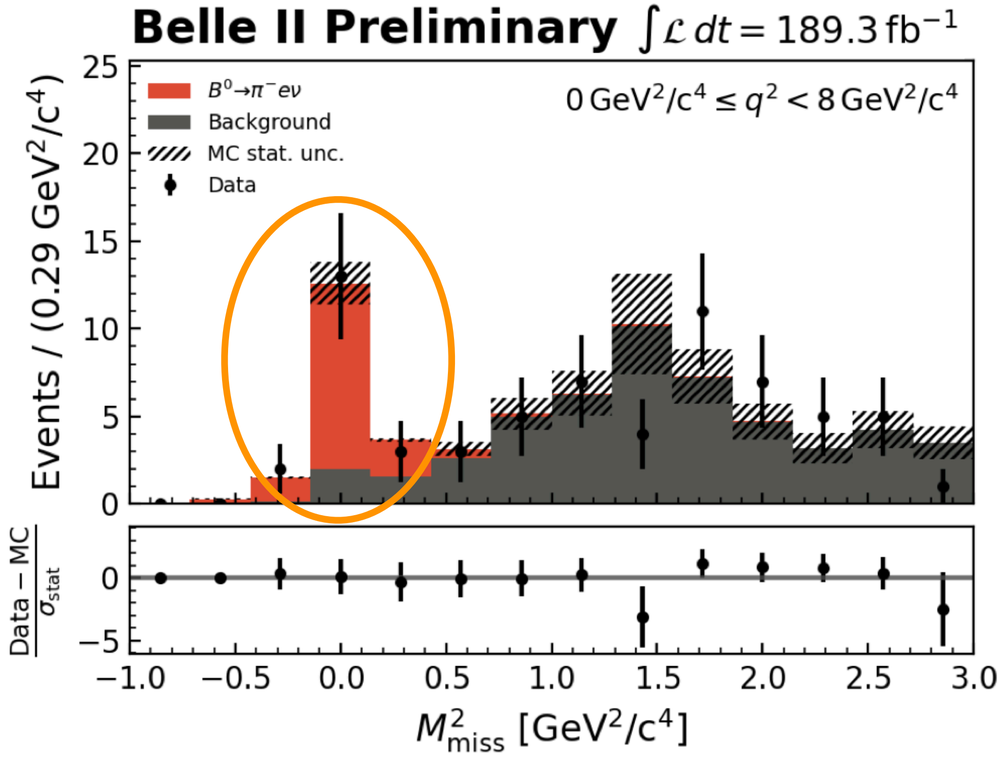


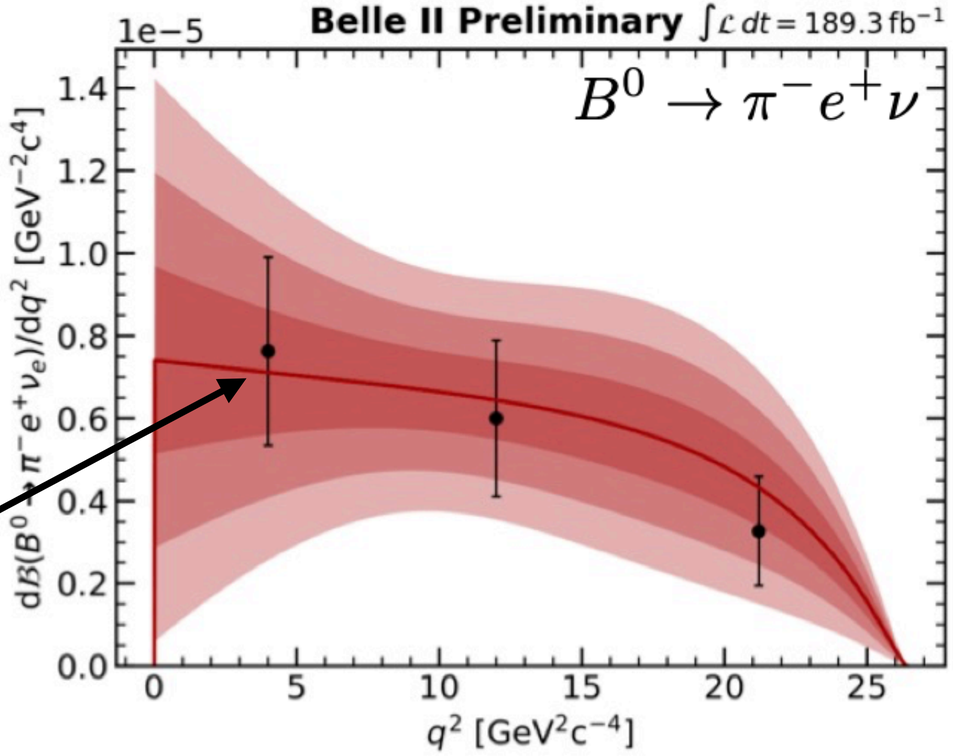


$|V_{ub}|$ and $|V_{cb}|$ results from Belle, BaBar, etc., has longstanding discrepancy btw inclusive and exclusive measurements

Measuring $|V_{ub}|$ from $B^0 \to \pi^- e \nu$

$$\frac{d\mathcal{B}}{dq^2}(B \to \pi \ell \nu) \propto |V_{ub}|^2 f_+^2(q^2)$$





$$M^2_{\text{miss}} = (p_{e^+e^-} - p_{B_{\text{tag}}} - p_e - p_\pi)^2$$

$$q^2 = m^2_{\ell\nu} = (p_{e^+e^-} - p_{B_{\text{tag}}} - p_\pi)^2$$

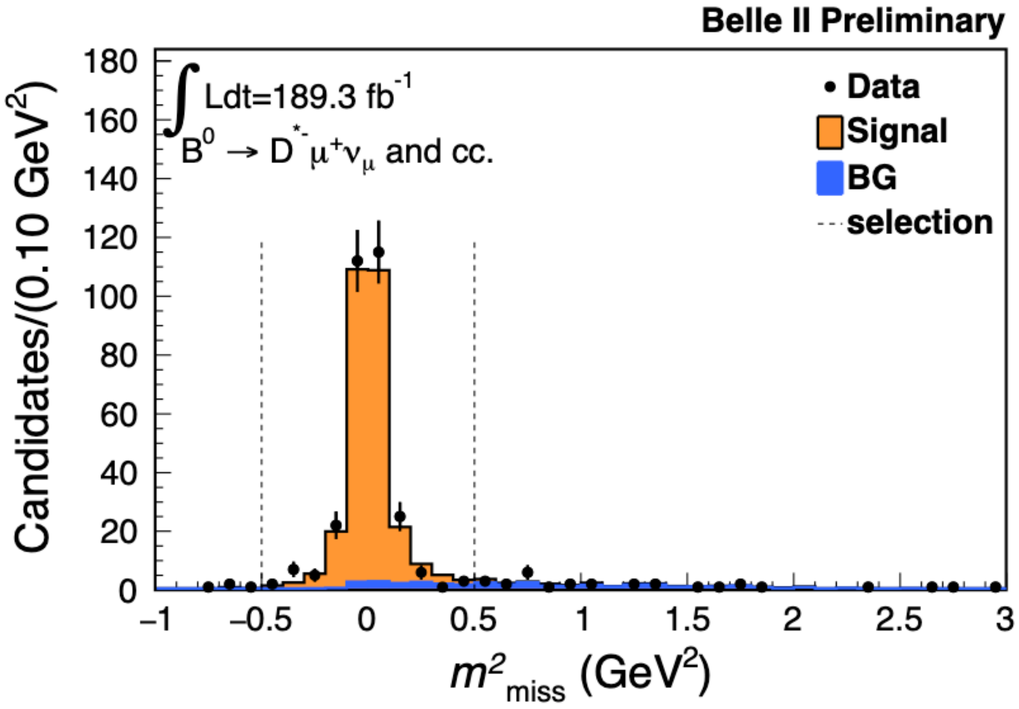
Combined fit of $B^0 \to \pi^- e^+ \nu$ and $B^+ \to \pi^0 e^+ \nu$

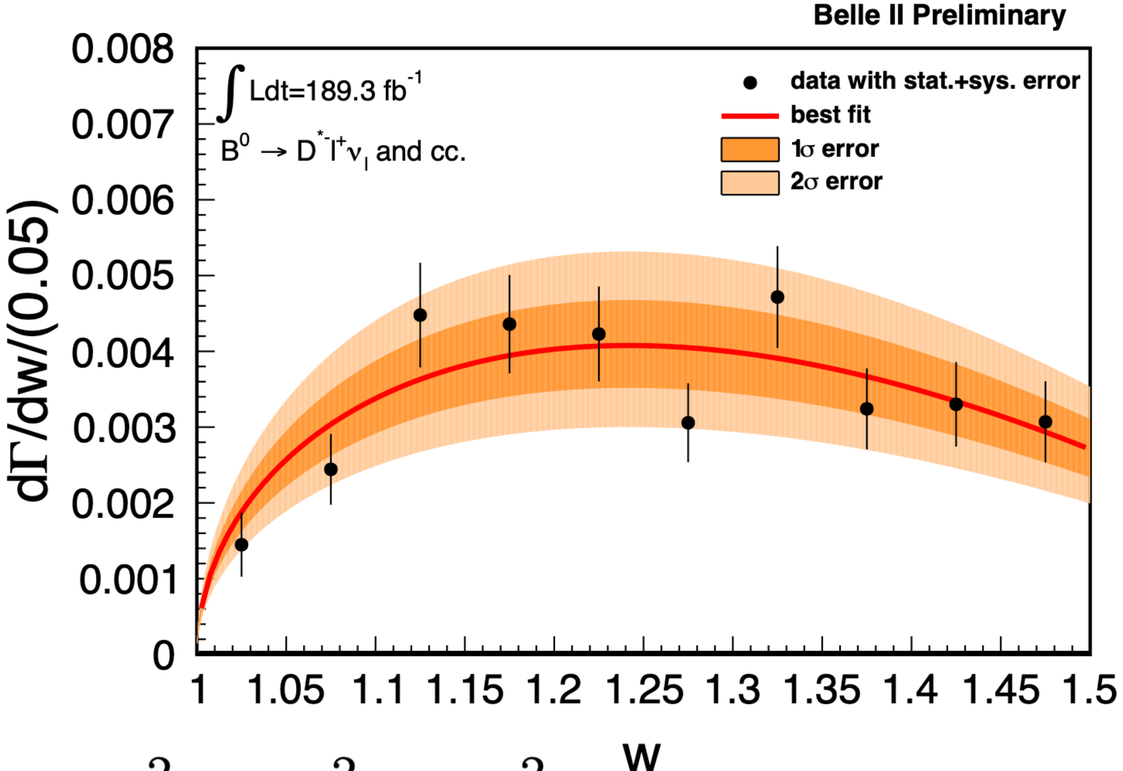
- Hadronic B tag : Full Event Interpretation trained 200 BDTs to reconstruct ~100 decays channels, ~10000 B decay chains

$|V_{ub}| = (3.88 \pm 0.45) \times 10^{-3}$

$|V_{ub}| = (3.67 \pm 0.15) \times 10^{-3}$ (PDG)

Measurement of $B \to D^* l \nu$ for $|V_{cb}|$



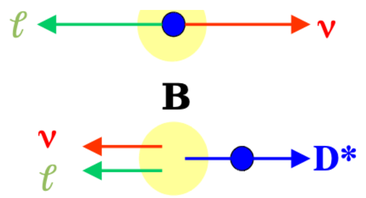


$$M^2_{\text{miss}} = (p_{e^+e^-} - p_{B_{\text{tag}}} - p_\ell - p_{D^*})^2$$

$$\frac{d\Gamma}{d\omega} \propto |Vcb|^2 |\mathcal{F}(\omega)|^2$$

$$w = \frac{m_B^2 - m_{D^*}^2 - q^2}{2 m_B m_{D^*}}$$

$$q^2 = (p_{e^+e^-} - p_{B_{\text{tag}}} - p_{D^*})^2$$



w = 1

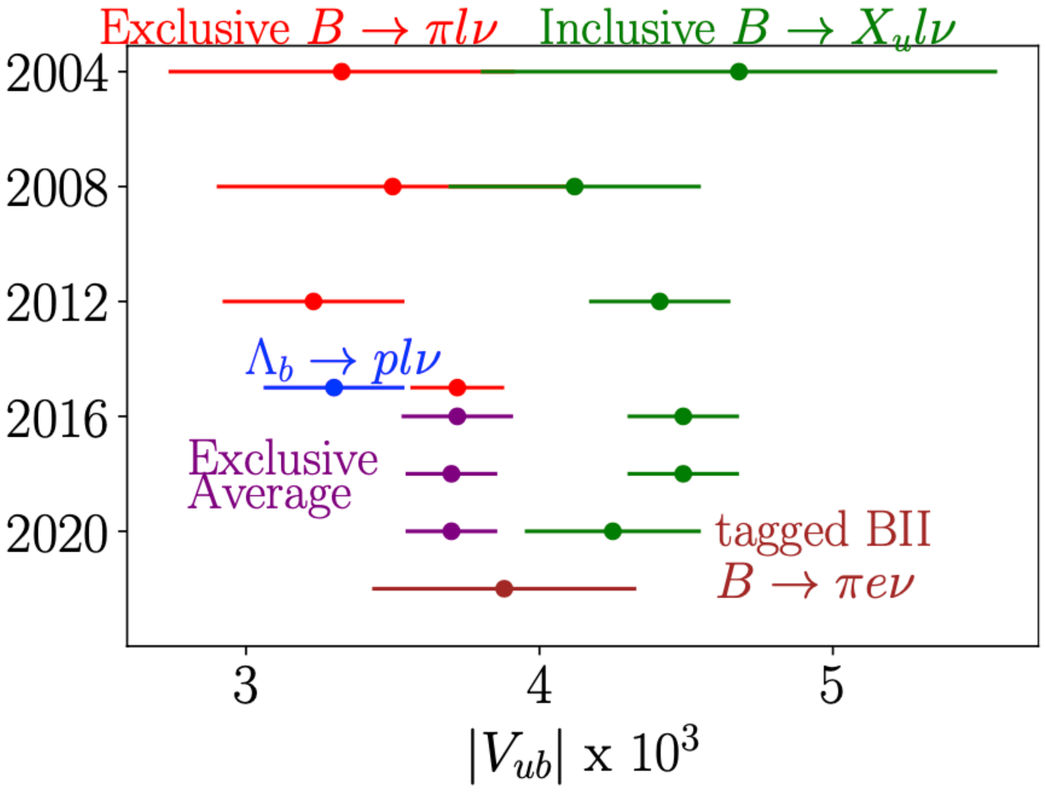
w = 1.5

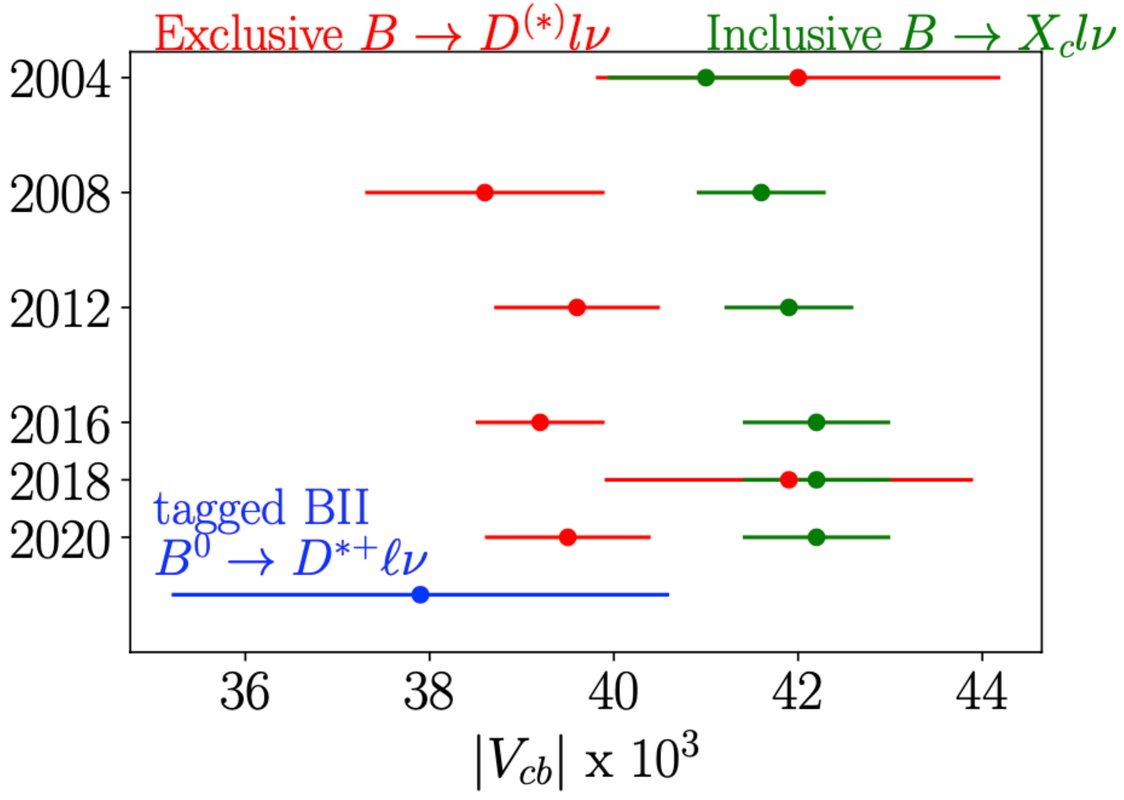
$\mathcal{F}^2(w)$: Form factor determination rely heavily on $w = 1$ (zero recoil), using CLN parameterization, NP B530, 153 (1998)

$|V_{cb}| = (37.9 \pm 2.7) \times 10^{-3}$

$|V_{cb}| = (39.5 \pm 0.9) \times 10^{-3}$ (PDG)

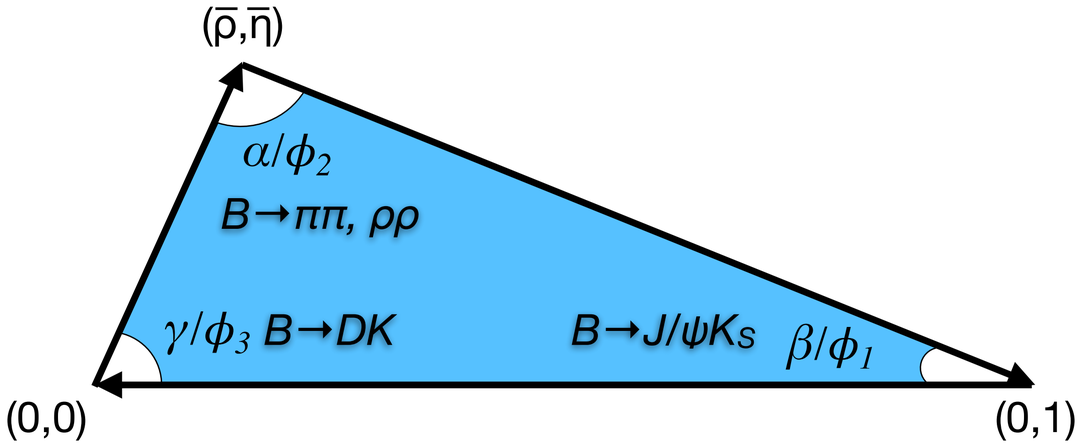
First Belle II $|V_{ub}|$ and $|V_{cb}|$ results





- These are the first Belle II tagged measurements of $|V_{ub}|$ and $|V_{cb}|$ are still statistically limited
  - More precise measurements with larger dataset
  - Higher precision with untagged measurement as the efficiency is 20-30%

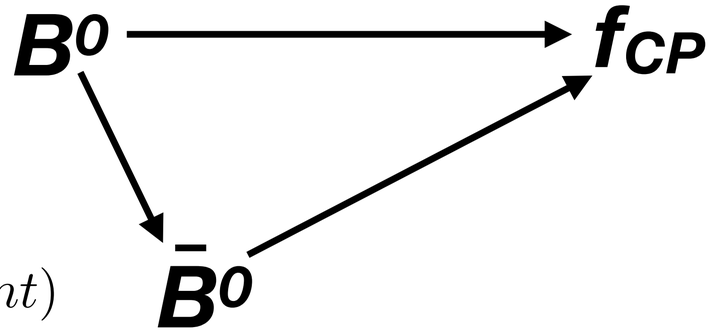
ϕ_1/β, ϕ_2/α, ϕ_3/γ measurements



Time dependent CPV - Flavor tagging

Time dependent CP-Violation measurement:

- **Precise measurement of Δt**
- **B flavor tagger**



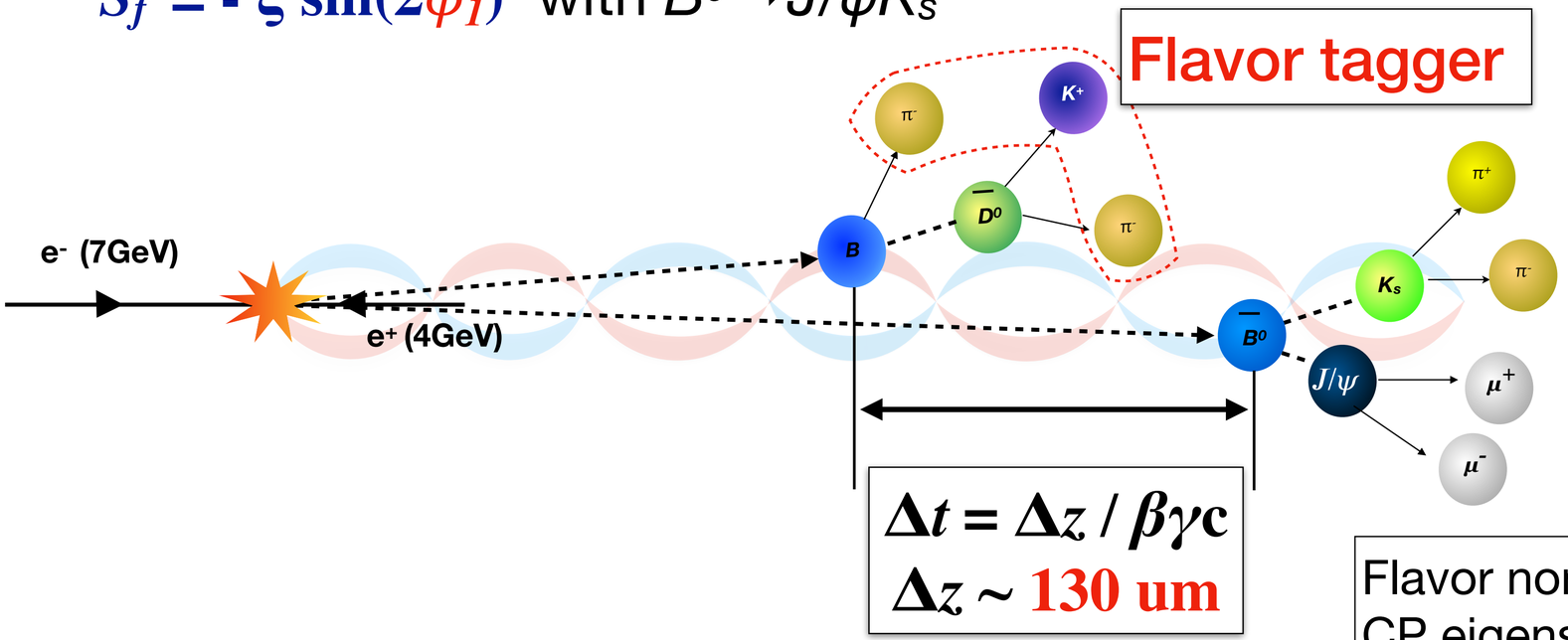
$$A_{CP} = \frac{\Gamma(\bar{B}^0(t) \to f_{CP}) - \Gamma(B^0(t) \to f_{CP})}{\Gamma(\bar{B}^0(t) \to f_{CP}) + \Gamma(B^0(t) \to f_{CP})} = S_f sin(\Delta mt) + A_f cos(\Delta mt)$$

S_f : indirect (Time dependent) CPV parameter

A_f : direct CP violation parameter

Δm : the oscillation frequency

$S_f = -\xi \sin(2\phi_1)$ with $B^0 \to J/\psi K_s$



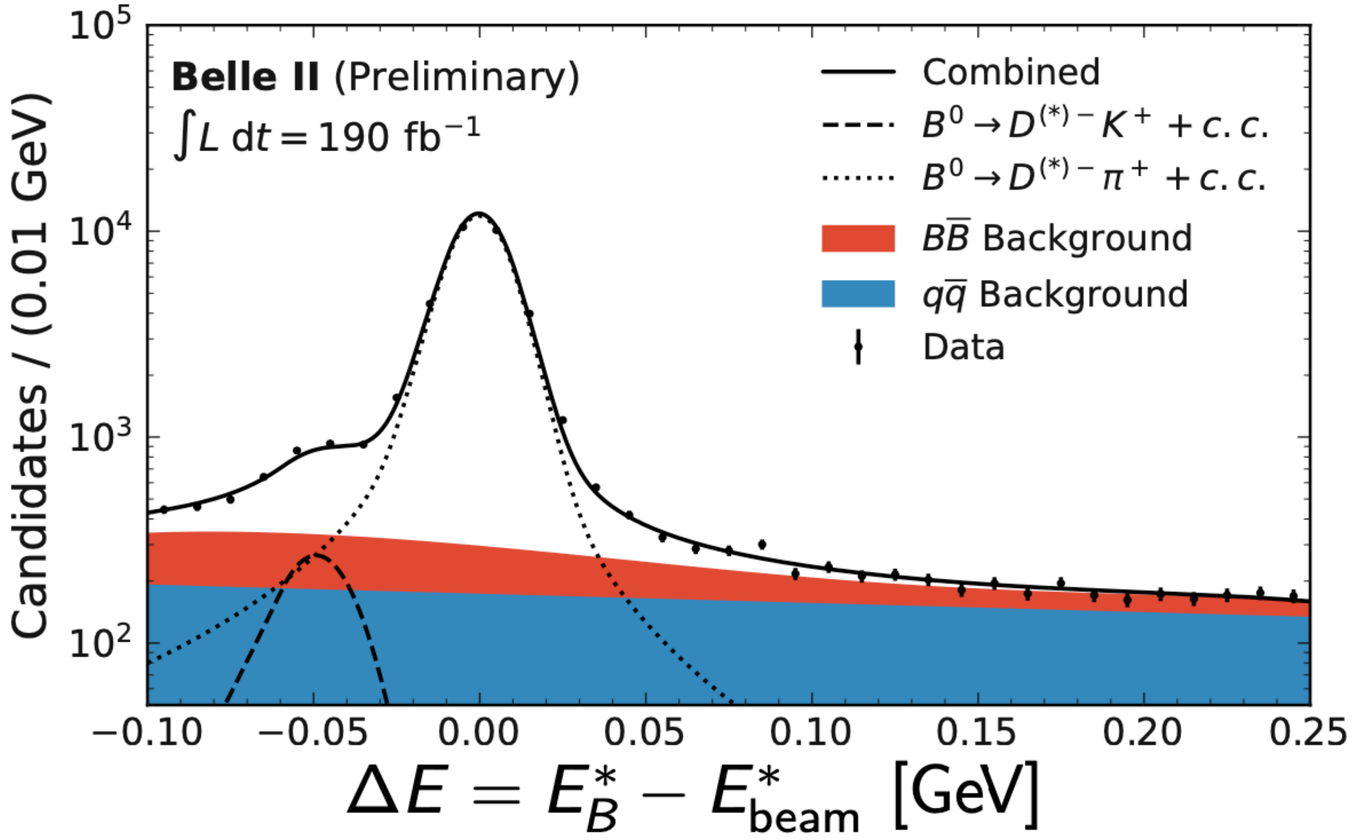
Effective flavor tagging efficiency:

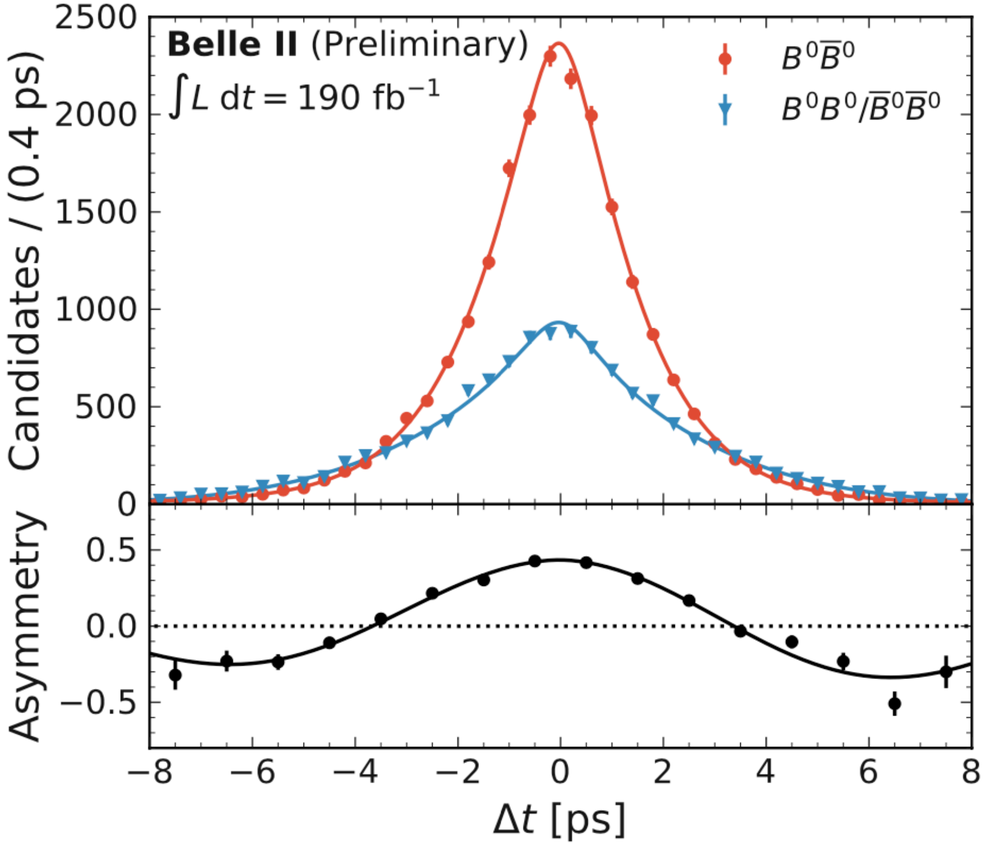
- **Belle II : (30.0 ± 1.3)%**
- Belle : (30.1 ± 0.4)%

EPJ C(2022) 82, 283

Flavor non-specific CP eigenstate

B^0 Lifetime and mixing frequency





τ_{B0} = 1.499 ± 0.013 (stat.) ± 0.008 (syst.) ps

τ_{B0} = 1.519 ± 0.004 ps (PDG)

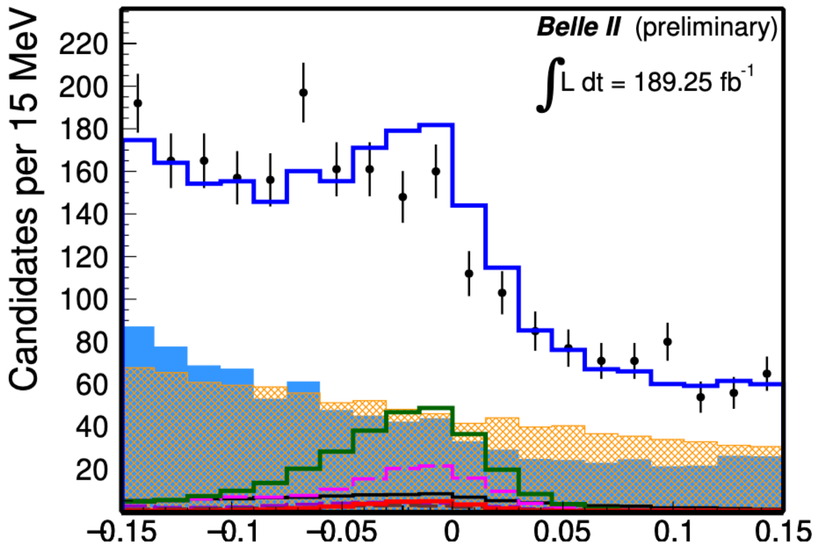
Δm = 0.516 ± 0.008 (stat.) ± 0.005 (syst.) ps^{-1}

- Result compatible with world average
- Similar uncertainty as Belle, BaBar results
  - $B \to D^* l \nu$ to be included
- Belle II ready for time dependent analysis
- Next step $\sin(2\phi_1)$ measurement

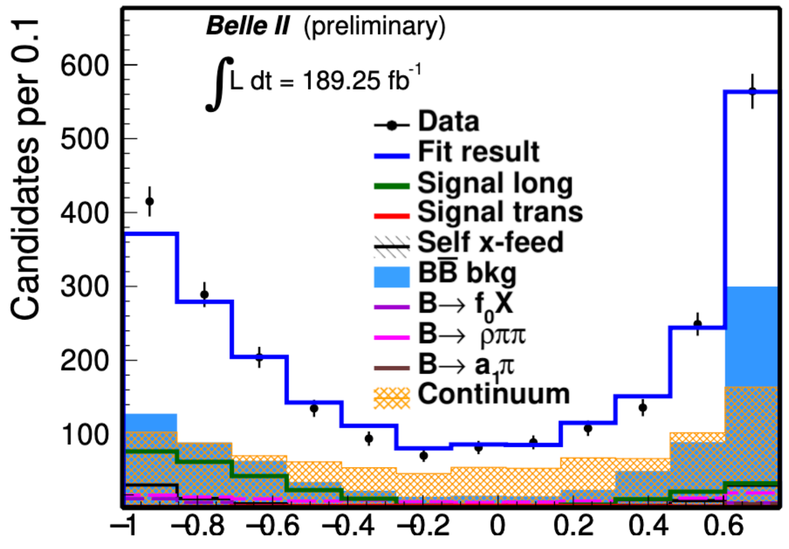
ϕ_2/α measurement ($B^+ \to \rho^+\rho^0$)

Constraint for ϕ_2 using combination of $B \to \rho\rho$ ($\rho^+\rho^-$, $\rho^\pm\rho^0$, $\rho^0\rho^0$) decays

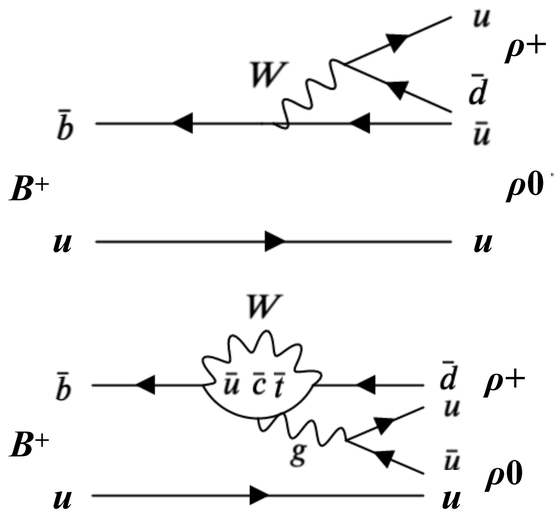
- Longitudinal polarization fraction f_L
- Asymmetry in rate $B^+ \to \rho^+\rho^0$ ***vs*** $B^- \to \rho^-\rho^0$
  - Direct CP-violation from interference between tree and penguin diagram



$$\Delta E = E_B^* - E_{\text{beam}}^* \ [\text{GeV}]$$



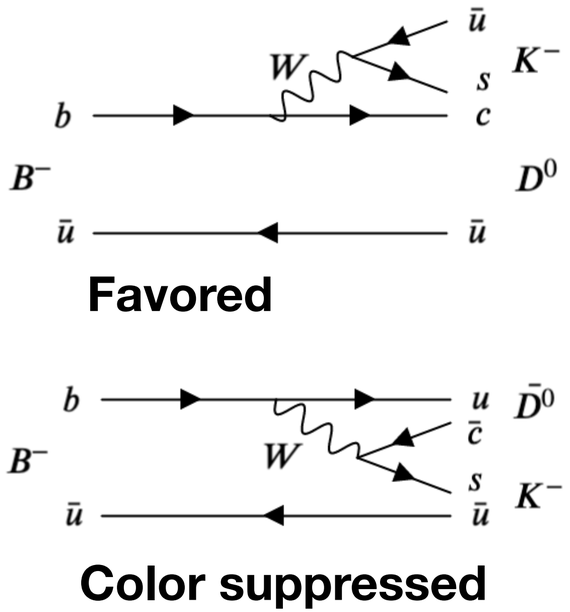
$$\cos\theta_{\rho^+}$$

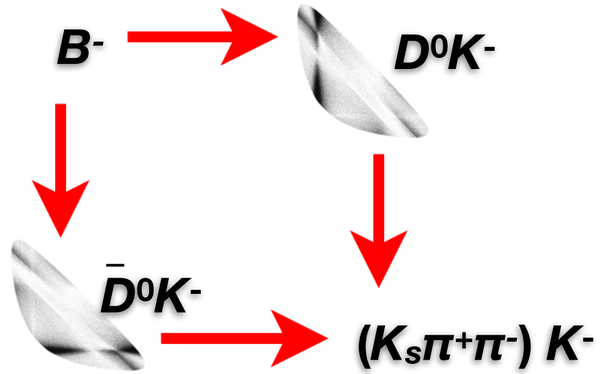


$$A_{CP} = -0.069 \pm 0.068\ (\text{stat.}) \pm 0.060\ (\text{syst.})$$
$$\mathcal{B}(B^+ \to \rho^+\rho^0) = \left(23.2^{+2.2}_{-2.1}\ (\text{stat.}) \pm 2.7\ (\text{syst.})\right) \times 10^{-6}$$
$$f_L = 0.943^{+0.035}_{-0.033}\ (\text{stat.}) \pm 0.027\ (\text{syst.})$$

World average: $A_{CP} = -0.05 \pm 0.05$

ϕ_3/γ measurement





- Interference between $b \to c$ and $b \to u$ (tree level)

$$\frac{A^{suppr.}(B^- \to \bar{D}_0 K^-)}{A^{favor.}(B^- \to D_0 K^-)} = r_B e^{i(\delta_B - \phi_3)}$$

r_B : ratio of amplitude

δ_B : strong phase difference

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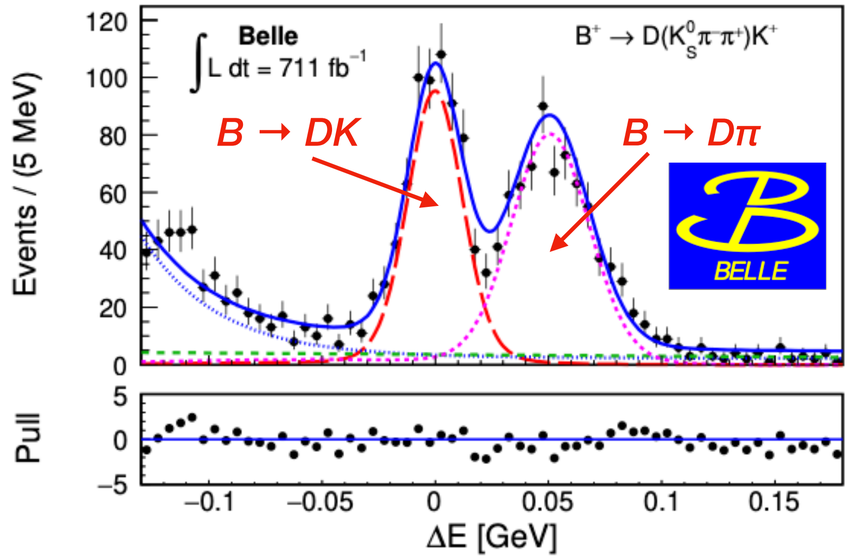
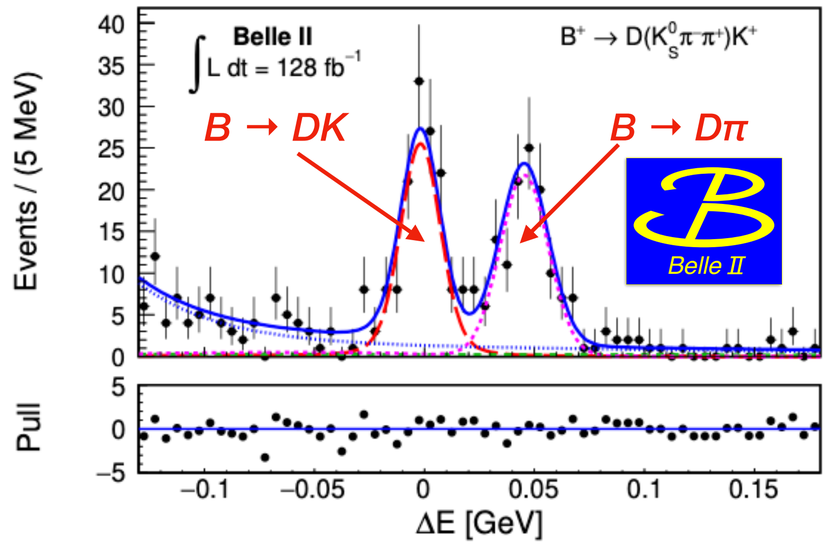




First combined Belle (711 fb^{-1}) and Belle II (128 fb^{-1}) analysis

δ_B[°]	124.8 ± 12.9 (stat.) ± 0.5 (syst.) ± 1.7 (ext.)
r_B	0.123 ± 0.024 (stat.) ± 0.001 (syst.) ± 0.002 (ext.)
γ[°]	78.4 ± 11.4 (stat.) ± 0.5 (syst.) ± 1.0 (ext.)

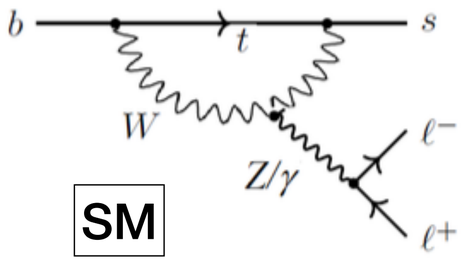
- Expect < 3° uncertainty with 10 ab^{-1}
- Will still statistically limited

B anomaly

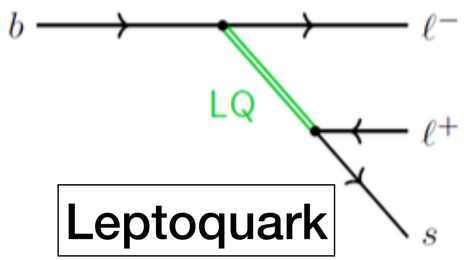
LFU violation in $b \to s\ell\ell$

- LHCb finds 3.1σ evidence for LFU violation

$$R(K^{(*)}) = \frac{Br(B \to K^{(*)}\mu^+\mu^-)}{Br(B \to K^{(*)}e^+e^-)}$$

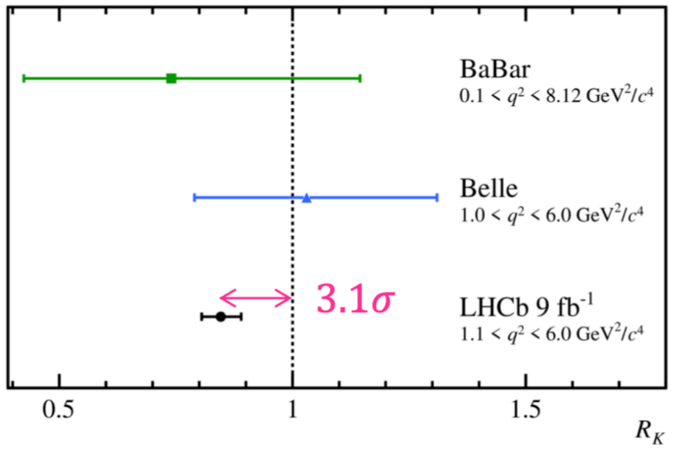


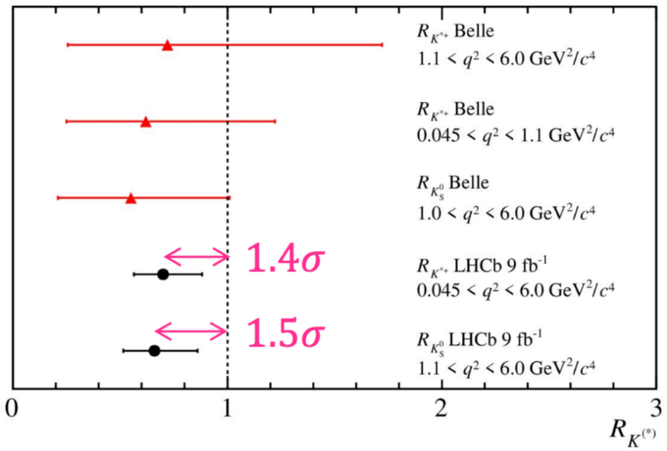
SM



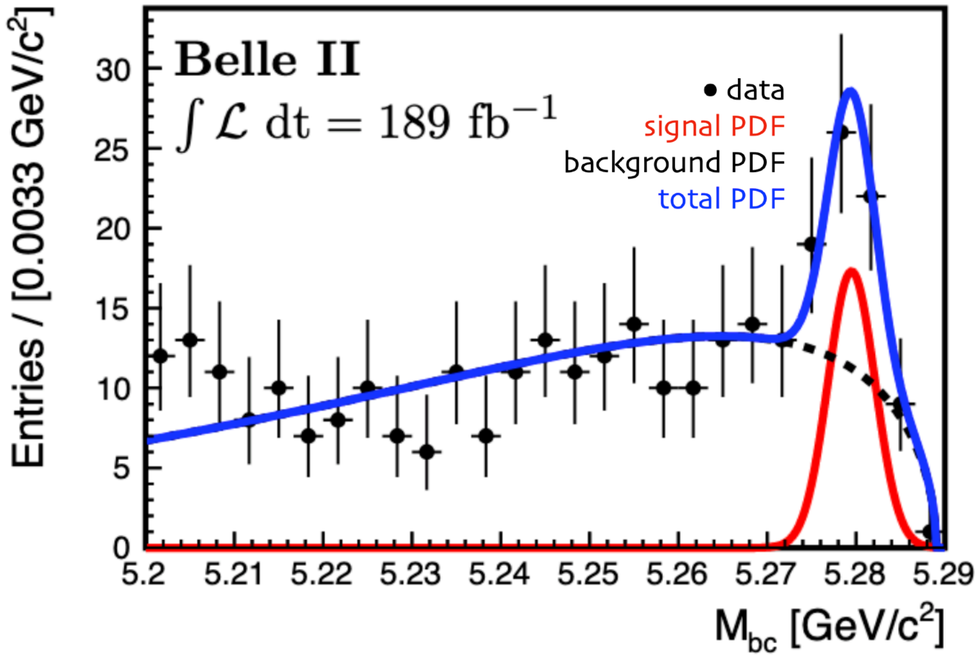
Leptoquark

arXiv:2103.11769 arXiv:2110.09501





$B \to K^*l^+l^-$



- Similar precision for electron and muon channels
- Limited by sample size
- Expected to became competitive with 1 ab^{-1}

$$\mathcal{B}(B \to K^*\mu\mu) = (1.19 \pm 0.31 \pm^{+0.08}_{-0.07}) \times 10^{-6},$$
$$\mathcal{B}(B \to K^*ee) = (1.42 \pm 0.48 \pm 0.09) \times 10^{-6},$$
$$\mathcal{B}(B \to K^*\ell\ell) = (1.25 \pm 0.30 \pm^{+0.08}_{-0.07}) \times 10^{-6},$$

PDG averages

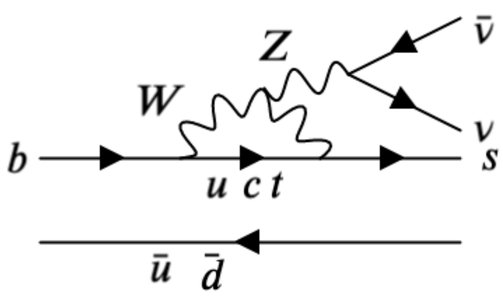
(1.06 ± 0.09) x 10^{-6}

(1.19 ± 0.20) x 10^{-6}

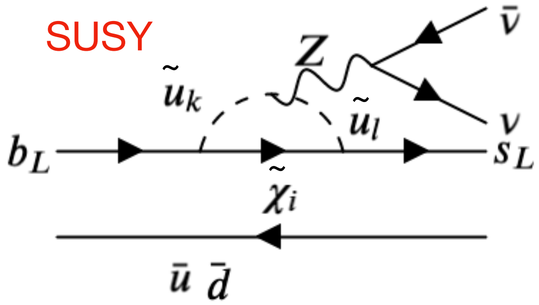
(1.05 ± 0.10) x 10^{-6}

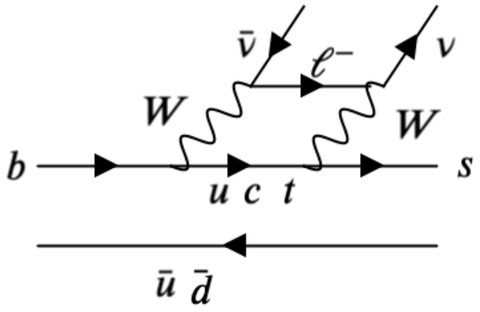
Inclusive search of $B^{\pm} \to K^{\pm} \nu\nu$

- Search for flavor-changing neutral current
- A channel unique to Belle II
- $b \to \bar{s}\nu\nu$ contain the same new physics of $b \to s l^+ l^-$
- $b \to \bar{s}\nu\nu$ is theoretically clean than $b \to s l^+ l^-$

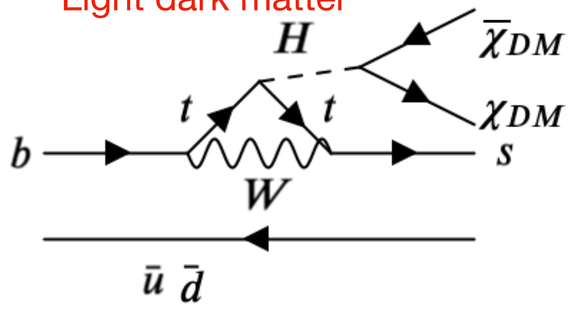


SUSY





Light dark matter



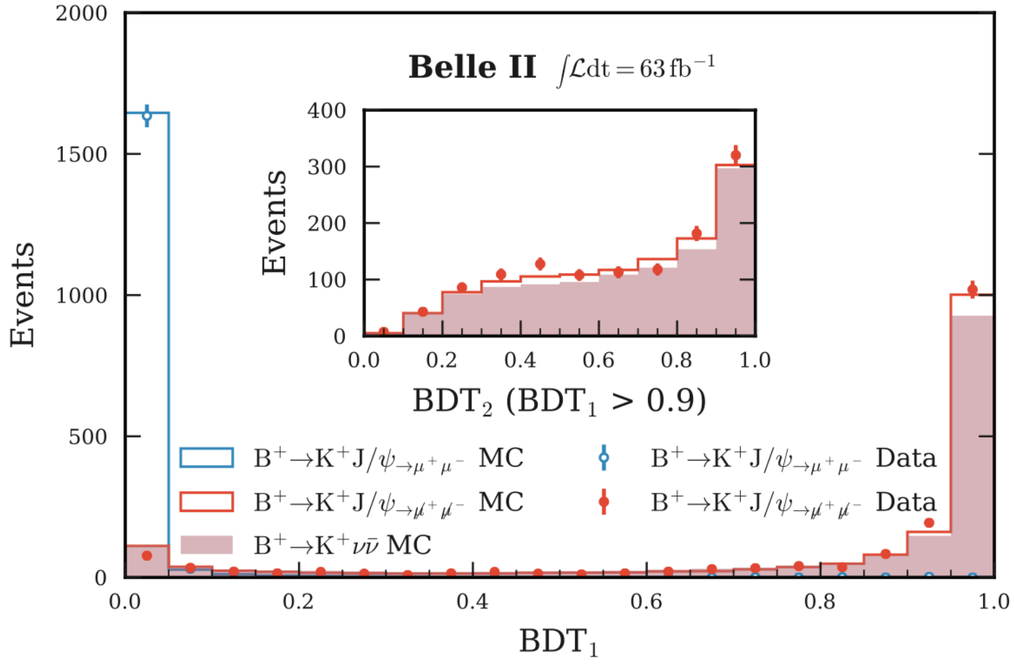
This method only sensitive to high p_T region of K^+

SM prediction:

$$Br(B^+ \to K^+ \nu\bar{\nu})_{SM} = (4.6 \pm 0.5) \times 10^{-6}$$

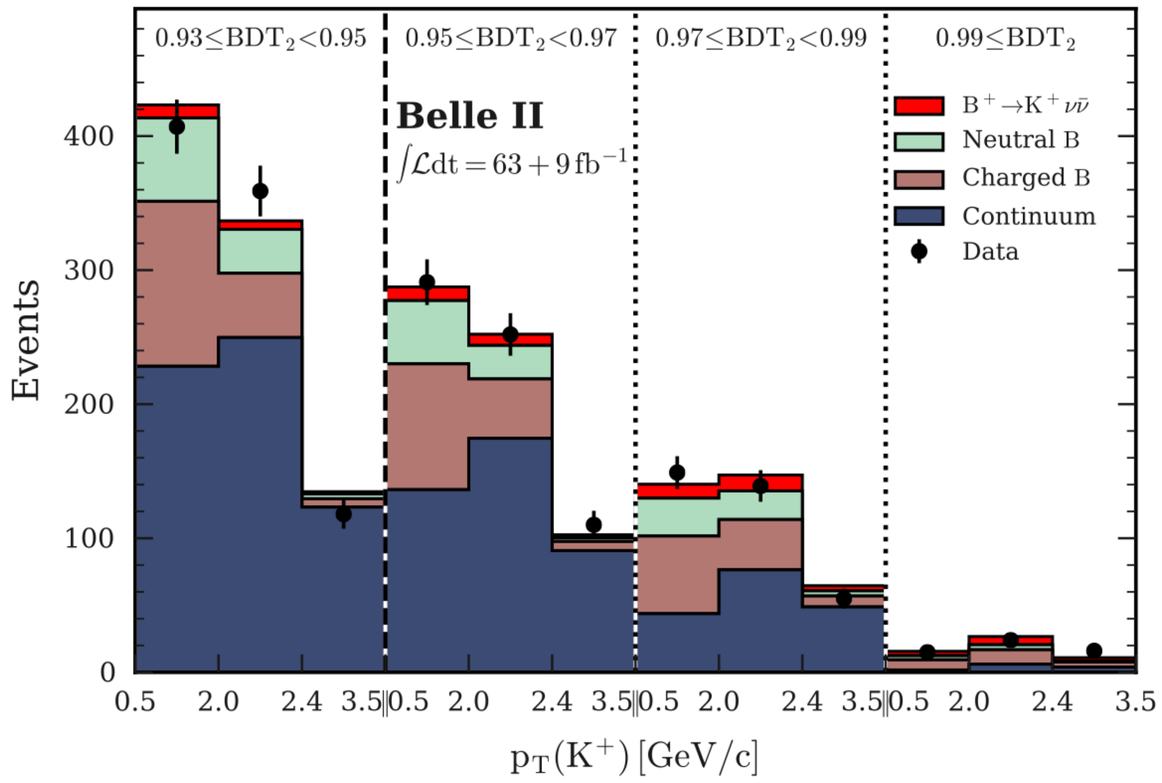
High Energy Phys. 02, 184 (2015)

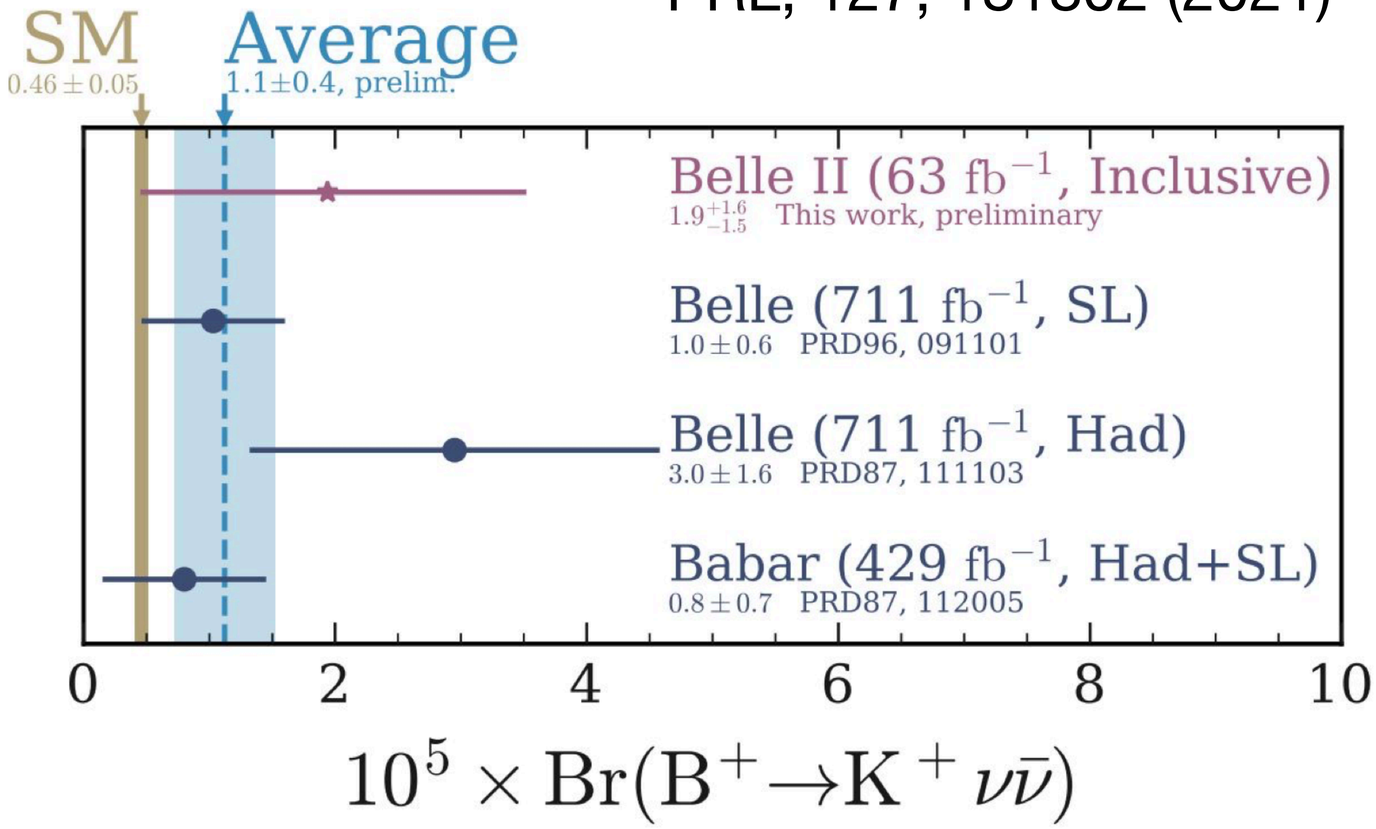
- Belle, Babar: B tag
  - **ε ~0.04%** (hadronic)
  - **ε ~0.2%** (semileptonic)
- Belle II : **untag**
  - **ε ~4%** (2 step Fast BDT)



Result of inclusive search of $B^{\pm} \to K^{\pm} \nu\nu$

PRL, 127, 181802 (2021)



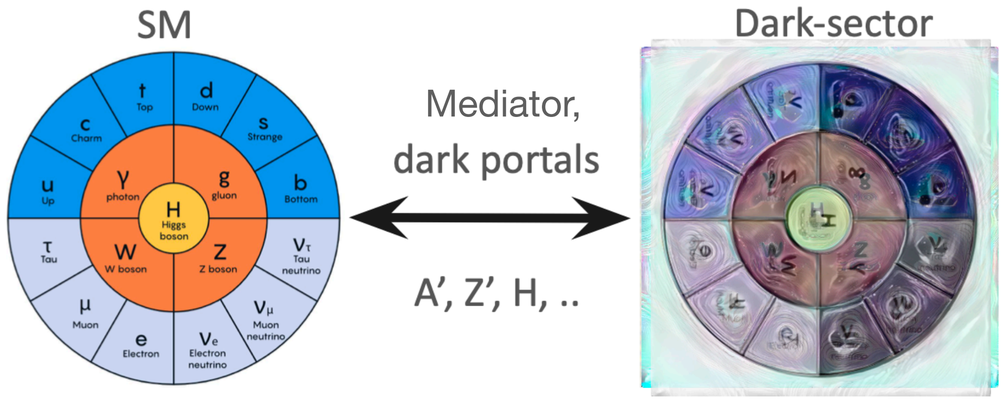


- 2~3 times limit compare to Belle and BaBar with only 63 fb^{-1}
- Expect 2 times limit compare SM prediction with 500 fb^{-1} (towards discovery)

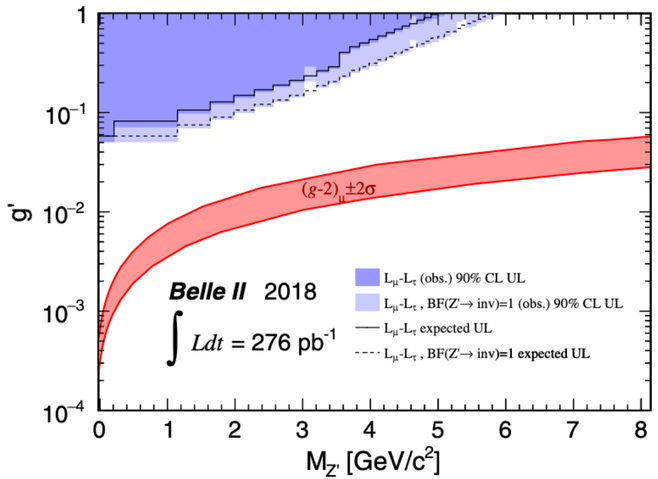
Dark Sector

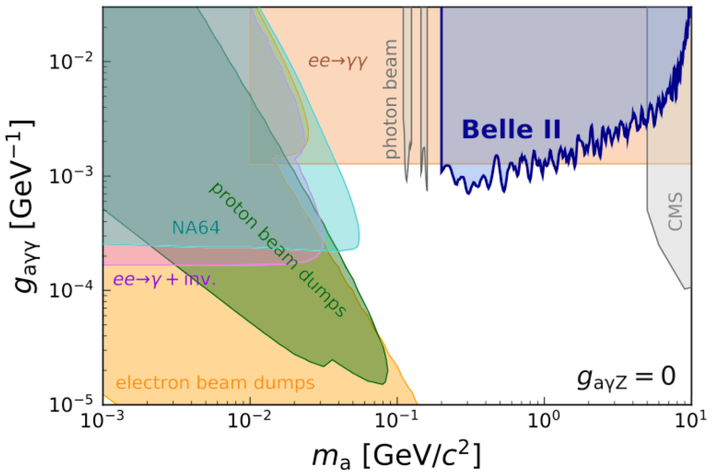
Dark Sector Search at Belle II

- Light dark matter search, low background, 3D momentum conservation at Belle II
  - Sensitivity for MeV-GeV scenarios
  - Typical processes
    - $e^+ + e^- \rightarrow$ SM particle + mediator
    - $B \rightarrow$ SM particle + mediator



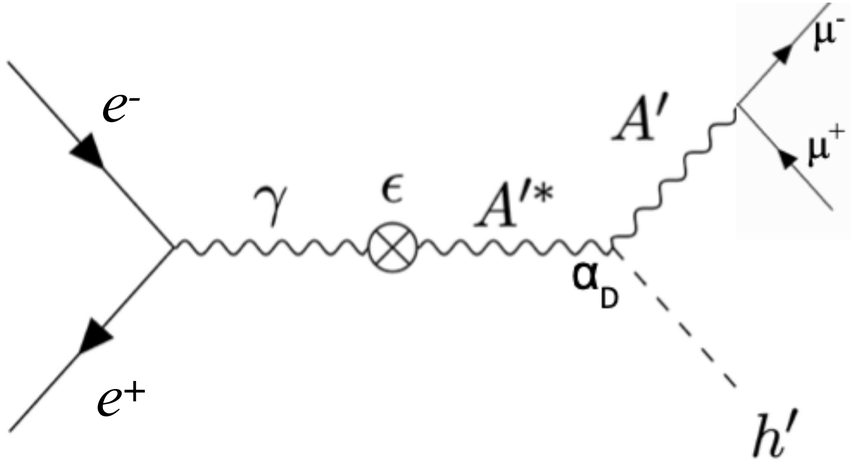
- Belle or BaBar not able for DM search for low multiplicity processes (trigger setting, etc.), Belle II have the capability, already published 2 results with initial data
  - $e^+e^- \rightarrow \mu^+\mu^- Z'$, $Z' \rightarrow$ invisible (0.28 fb^{-1}) PRL 124 (2020), 141801
  - $e^+e^- \rightarrow a(\rightarrow\gamma\gamma)\gamma$ (Axion-Like Particle) (0.44 fb^{-1}) PRL 125 (2020), 161806



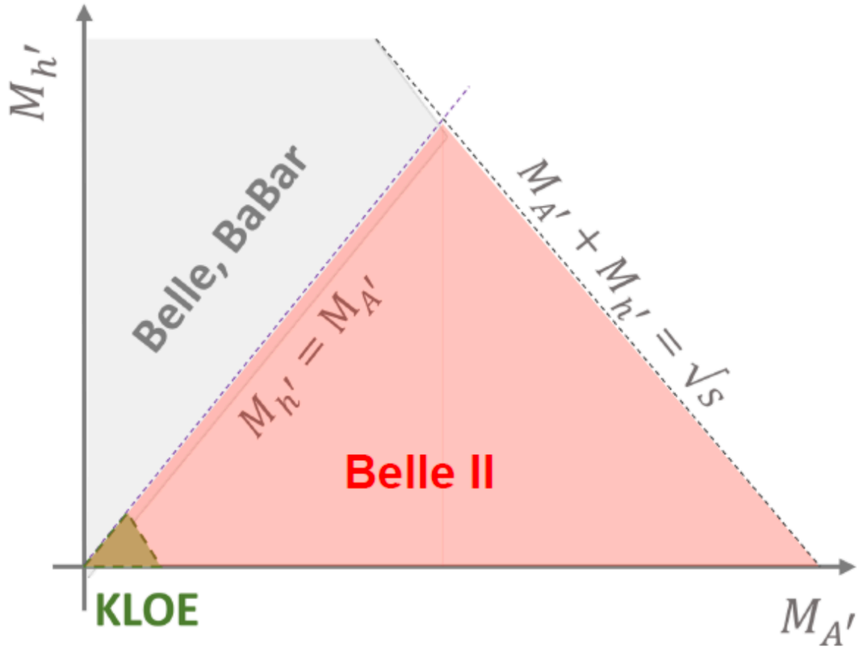


Dark Higgsstrahlung

- U(1)' extension of the standard model
  - Massive dark photon (*A'*) as the mediator
  - Spontaneous symmetry breaking introduce a dark Higgs (*h'*)
  - Phys.Rev. D 79, 115008 (2009)
  - *A'* couples to SM only via kinetic mixing (*ε*)
  - α_D dark coupling constant



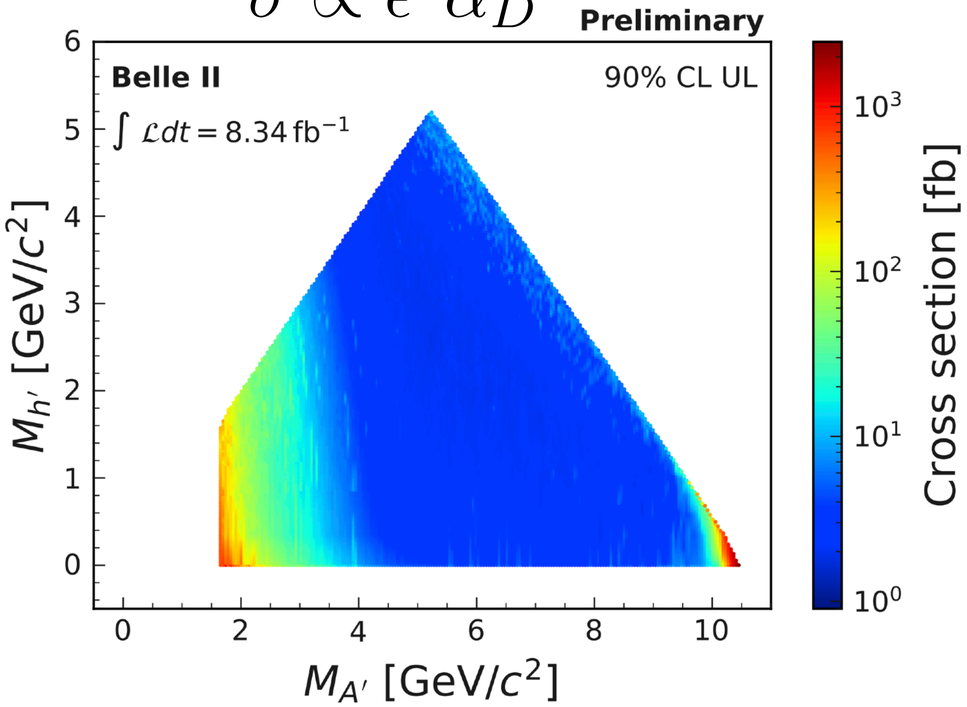
- Mass hierarchy scenarios
  - $m_{h'} > m_{A'}$: $h' \rightarrow A'A'^{(*)}$, 4had., 2ℓ + 2 had. (final state: 6 tracks), probed by BaBar (2012), Belle (2015)
  - $m_{h'} < m_{A'}$: *h'* "long lived thus invisible" (2 tracks), partly probed by KLOE (2015)

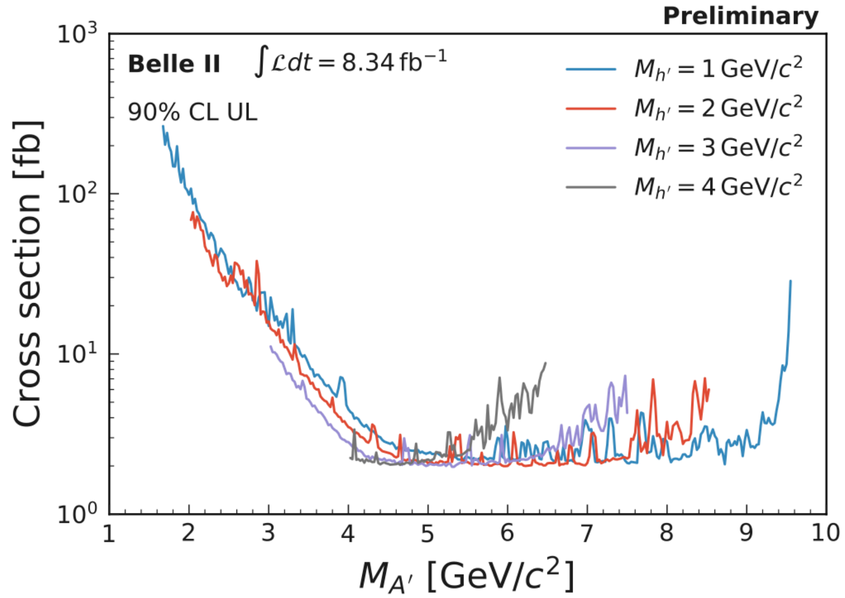


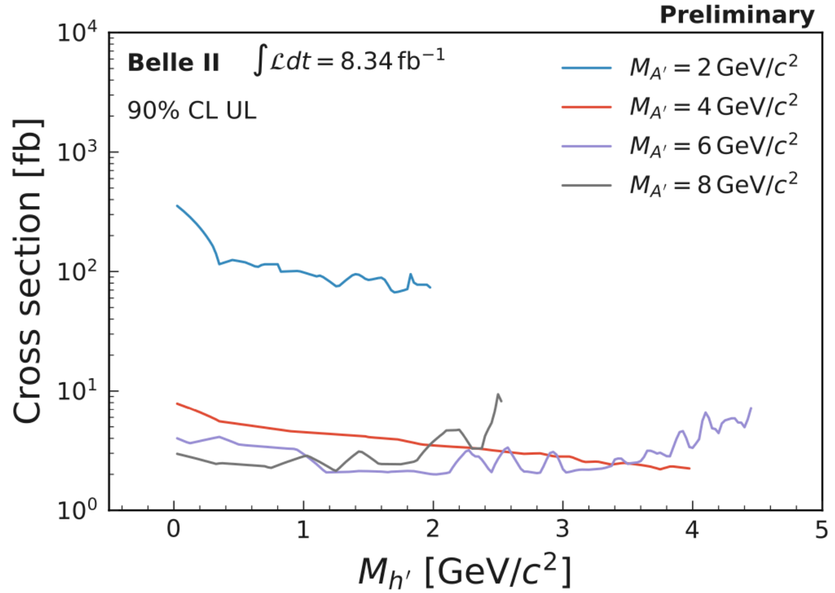
Dark Higgstrahlung results

- No significant deviation from SM background expectation is observed (8.34 fb^{-1})
- Upper limits are set on σ and $\varepsilon^2\alpha_D$:
  - Covered region: 1.65 < $M_{A'}$< 10.51 GeV and $M_{h'}$< $M_{A'}$
  - 90% CL UL on σ from 1.7 to 5 fb @ 4<$M_{A'}$< 9 GeV
  - For $M_{A'}$< 4 GeV: low sensitivity due to trigger eff.
  - For $M_{A'}$> 9 GeV: large dimuon background

$$\sigma \propto \epsilon^2 \alpha_D$$







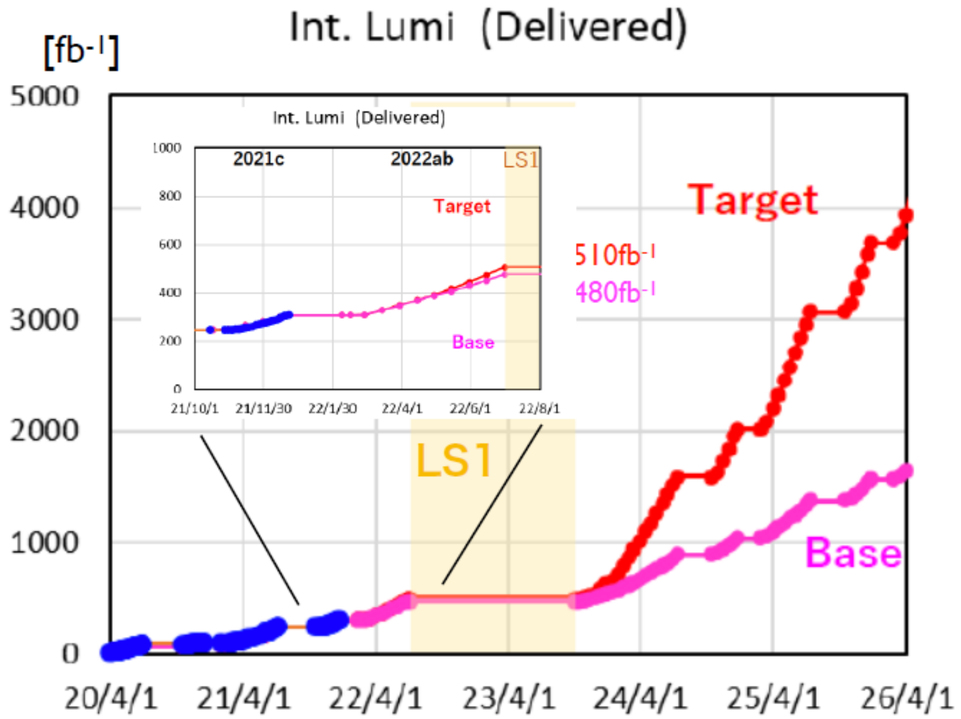
Summary and prospects

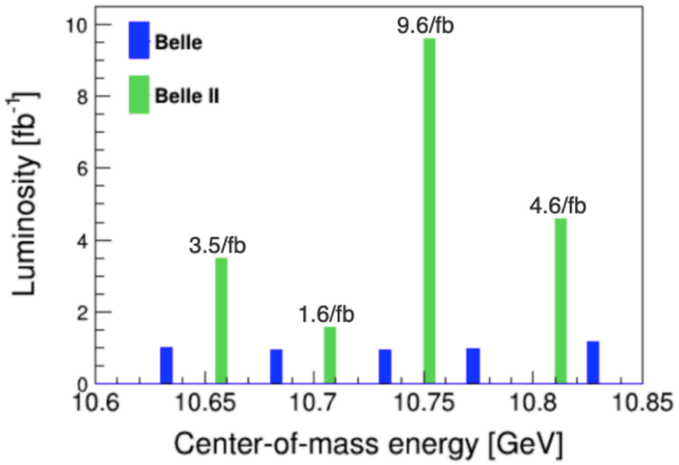
- Belle II already accumulated 380 fb^{-1} data, aim to take ~500 fb^{-1} till LS1 (Belle 1 ab^{-1})

- Recent results presented in today's talk
  - Lifetime of D^0, D^+ and Λ_c^+: world most precise
  - Semileptonic B decays
    - First $|V_{ub}|$ and $|V_{cb}|$ measurement
  - B^0 lifetime and mixing frequency: next step $\sin(2\phi_1)$
  - $B^+ \to \rho^+\rho^0$ measurement for ϕ_2/α
  - Measurement of ϕ_3/γ : first Belle + Belle II analysis
  - Search for Dark sector

- Still other results can not covered in this talk
- Belle II took unique data with collision energy above Υ(4S), around 10.751 GeV, for new structure studies

- More results are expected with competitive intergraded luminosity of BaBar experiment plan to be taken until summer 2022



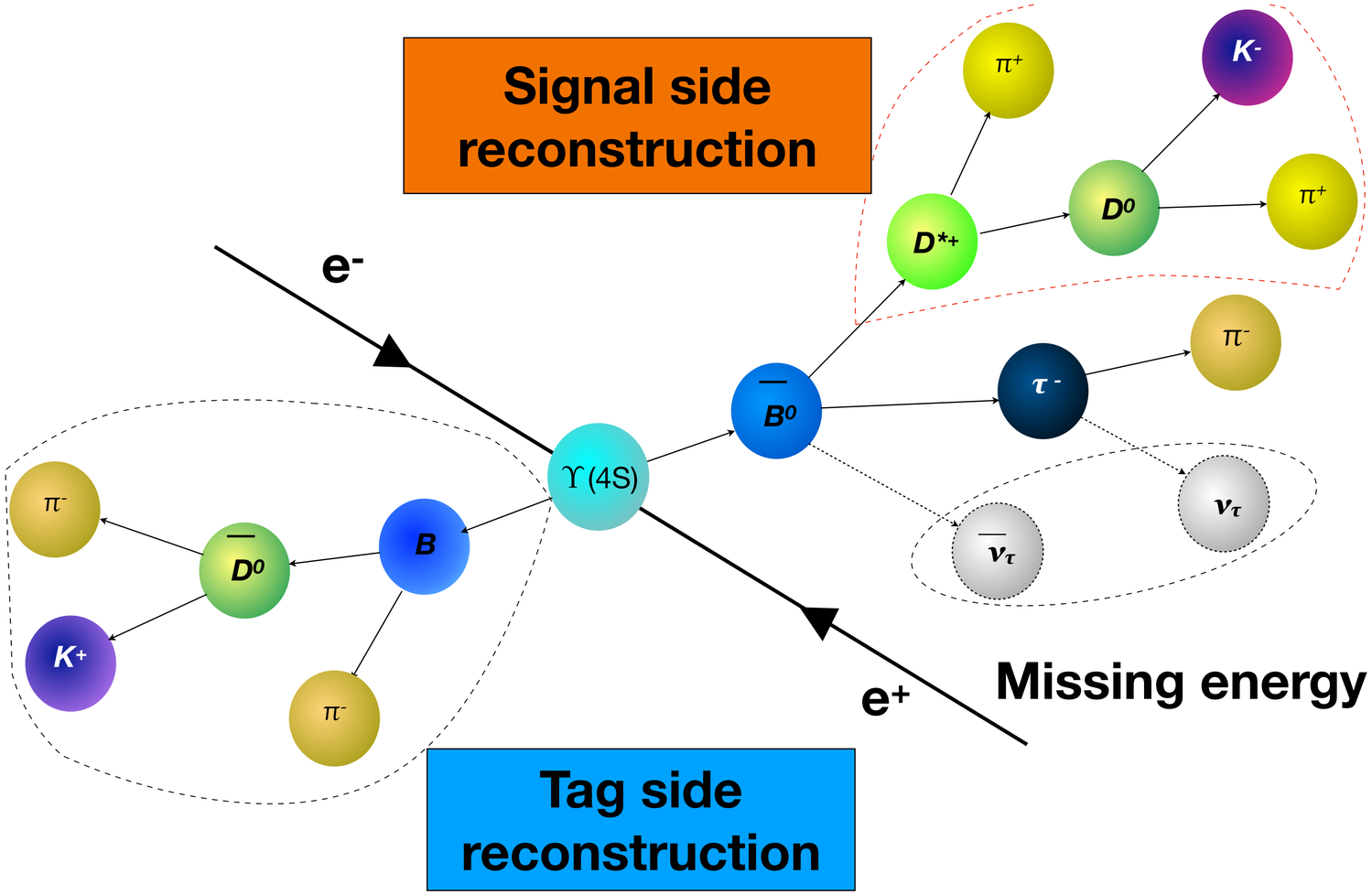


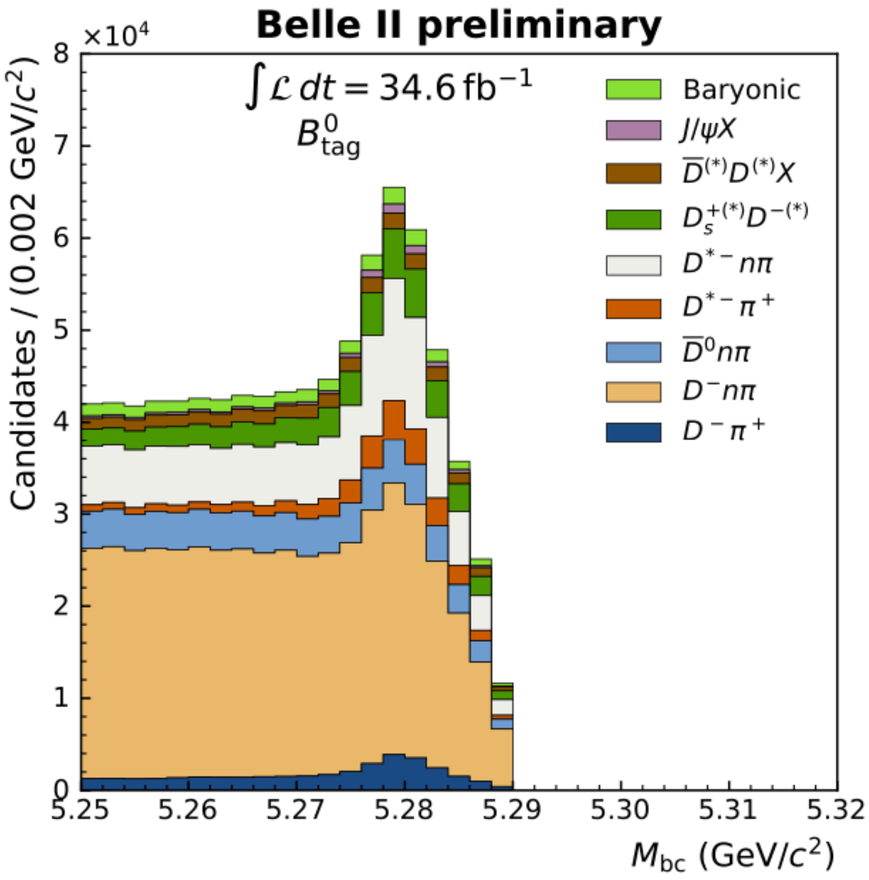
Backup

Tag side reconstruction at Belle II

- Hadronic tag : Full Event Interpretation trained 200 BDTs to reconstruct ~100 decays channels, ~10000 *B* decay chains
  - ε=0.47% for $B^{\pm}$
  - ε=0.29% for B^{0}

arXiv:2008.06096



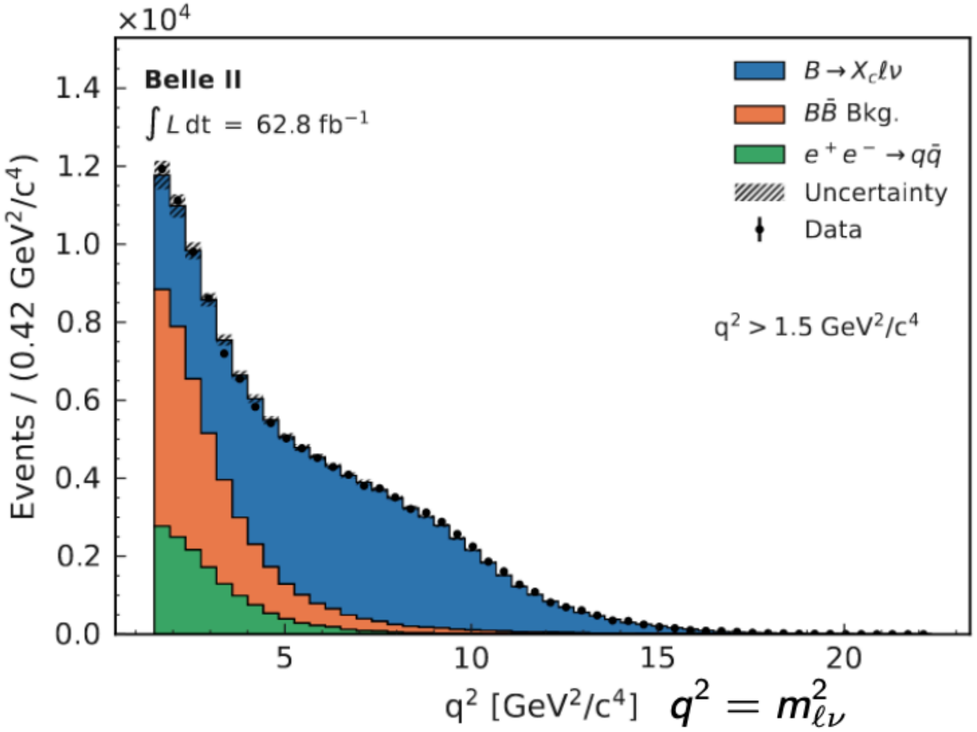


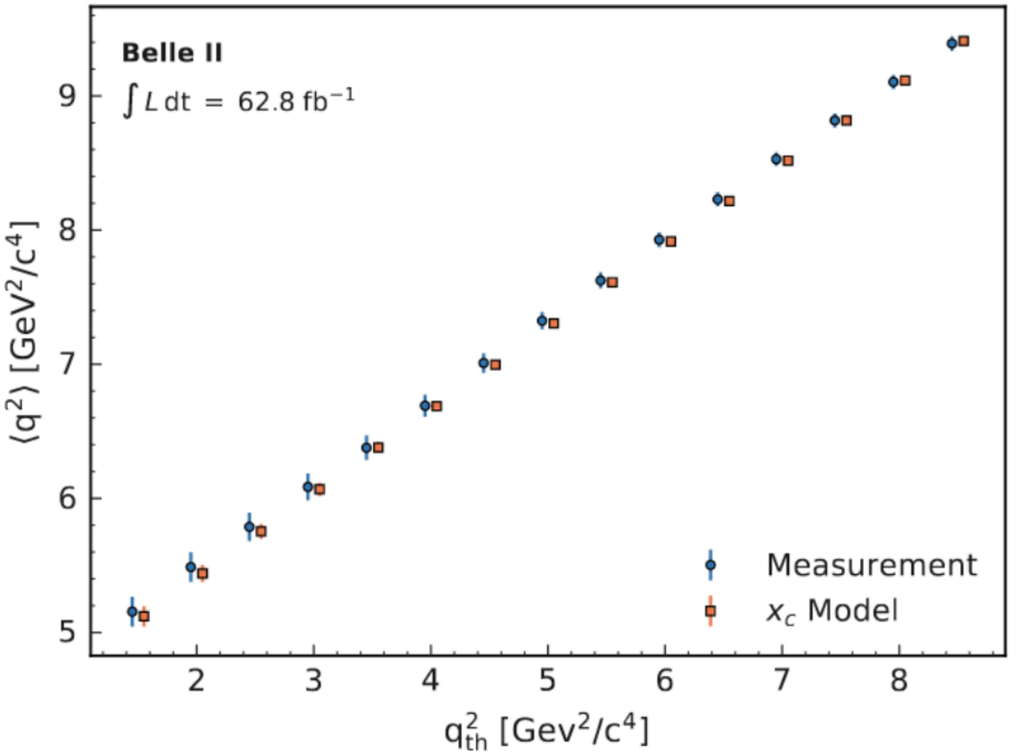
$$m_{\mathrm{bc}} = \sqrt{(E^*_{\mathrm{beam}})^2 - (p^*_B)^2}$$

Measurement of $B \to X_c l \nu$ for $|V_{cb}|$

Hadronic mass moments of
inclusive $B \to X_c l \nu$ with hadronic tag

https://inspirehep.net/literature/2081808



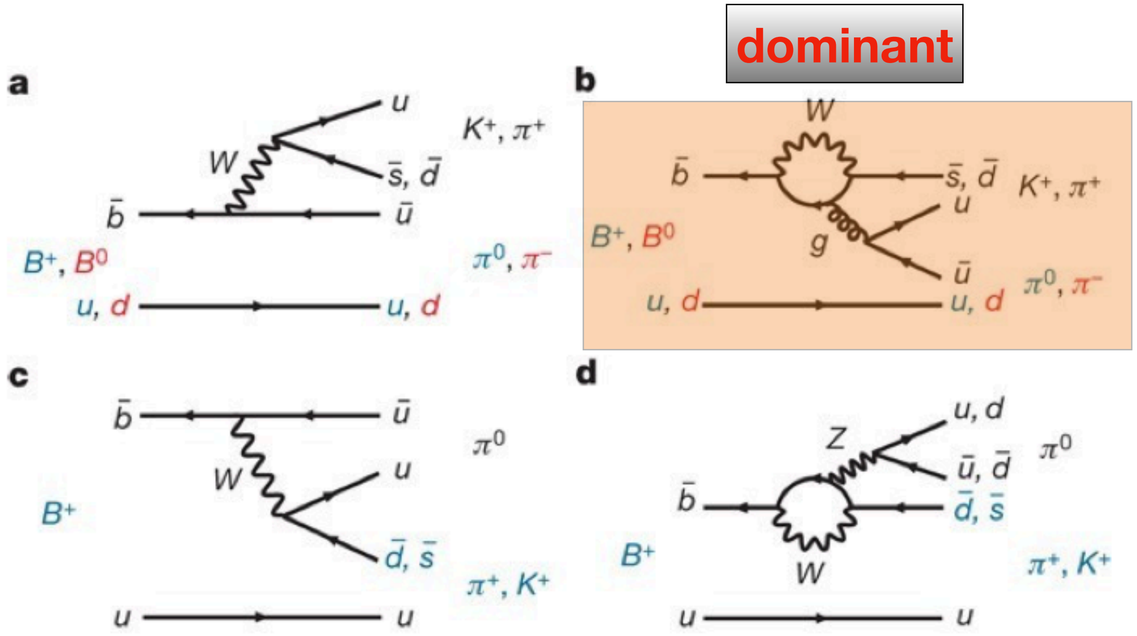


q^2 moments as a function of q^2 momentum threshold

- A new method proposed in JHEP02 (2019)177 to extract $|V_{cb}|$ from q^2 moments
  - $B \to X_c l \nu$ decay width is expressed with HQE (heavy-quark expansion) parameters
  - This method reduce HQE parameters from 13 to 8
  - Global fit for inclusive $|V_{cb}|$ in the future

B rare decay

$B \to K\pi$ puzzle



- Assume penguin + tree diagrams are dominant

$$A_{CP}(K^+\pi^-) + \underbrace{A_{CP}(K^0\pi^+)}_{\text{small}} \approx A_{CP}(K^+\pi^0) + \underbrace{A_{CP}(K^0\pi^0)}_{\text{small}}$$

$$\boxed{A_{CP}^{K^+\pi^0} \sim A_{CP}^{K^+\pi^-}}$$

- Current results obtained from the experiment

$$\Delta A_{K\pi} = A_{CP}^{K^+\pi^0} - A_{CP}^{K^+\pi^-} = (12.4 \pm 2.1)\% \quad \text{PDG}$$

- Another approach (isospin sum rule) to pin down the $B \to K\pi$ puzzle (less theoretical uncer.)
  - QCD color suppression effect cannel out

$$I_{K\pi} \equiv A_{CP}^{K^+\pi^+} + A_{CP}^{K^0\pi^+}\frac{\mathcal{B}_{K^0\pi^+}}{\mathcal{B}_{K^+\pi^-}}\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{CP}^{K^+\pi^0}\frac{\mathcal{B}_{K^+\pi^0}}{\mathcal{B}_{K^+\pi^-}}\frac{\tau_{B^0}}{\tau_{B^+}} - A_{CP}^{K^0\pi^0}\frac{\mathcal{B}_{K^0\pi^0}}{\mathcal{B}_{K^+\pi^-}} = 0(?)$$

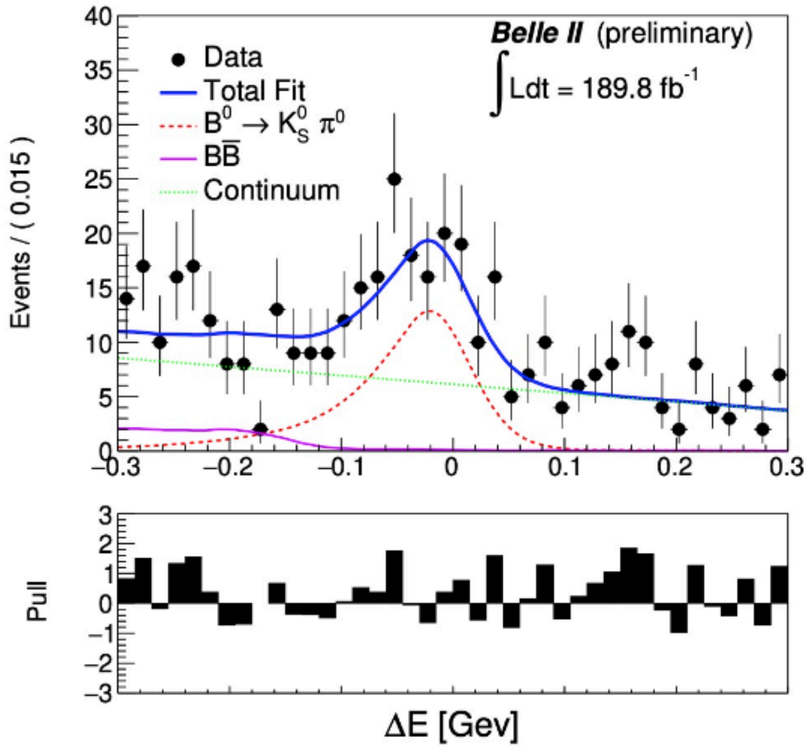
World average: $I_{K\pi}$ = (-14 ± 11)%

Neutral final states are crucial !

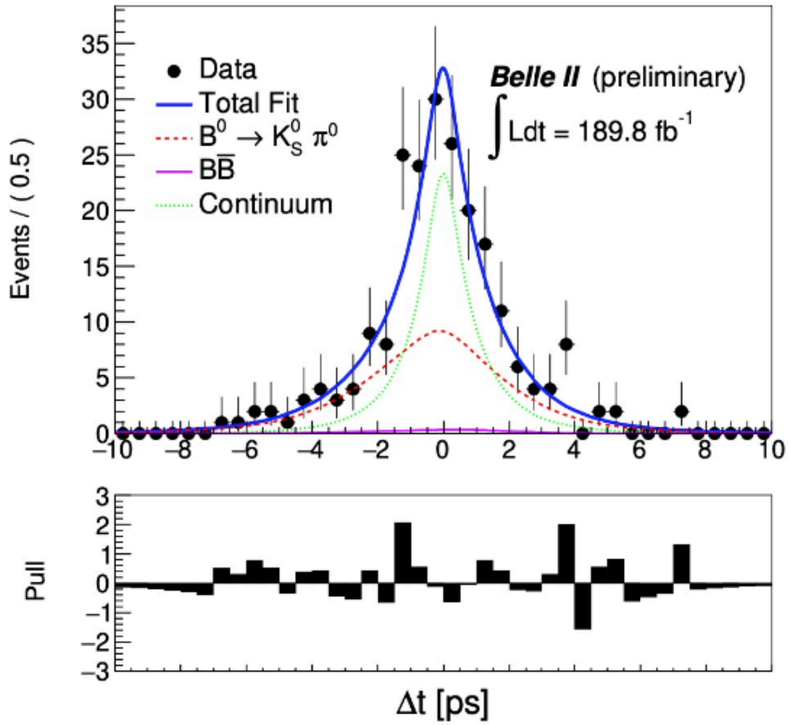
Measurement of $B \to K\pi$ decays

- Perform 4D fit (ΔE, Δt, M_{bc}, continuum suppression output)
- Constrain S_{CP} using previous measurements to maximize precision on A_{CP}

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



$$\Delta E = E^*_B - E^*_{beam}$$



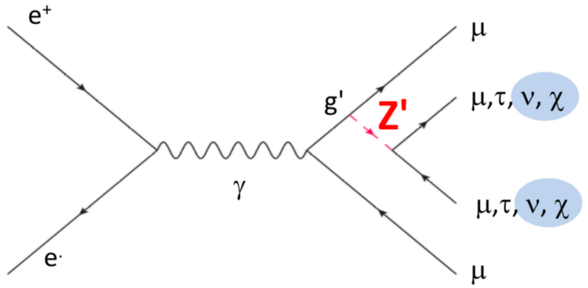
	$B \to K^0\pi^0$ (189.8 fb^{-})
Br(10^{-6})	11.0 ± 1.2 (stat.) ± 1.0 (syst.)
PDG(10^{-6})	9.9 ± 0.5
A_{CP}	$-0.41\ ^{+0.30}_{-0.32} \pm 0.09$
A_{CP}(PDG)	0.00 ± 0.13

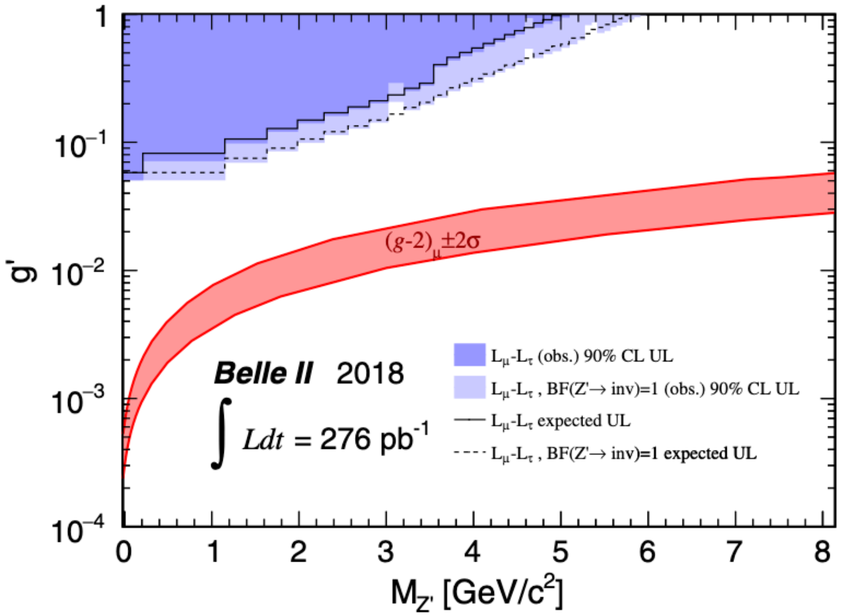
The Belle II Physics Book, PTEP 2019, 123C01

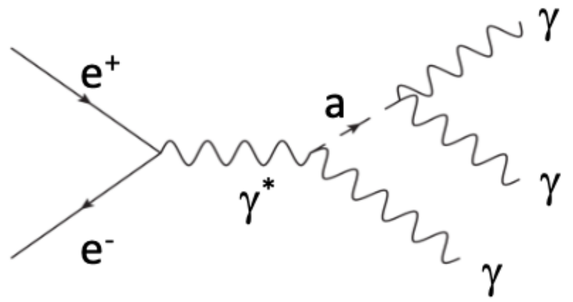
Uncertainty **~4%** at Belle II, able to **answer $I_{k\pi}$**

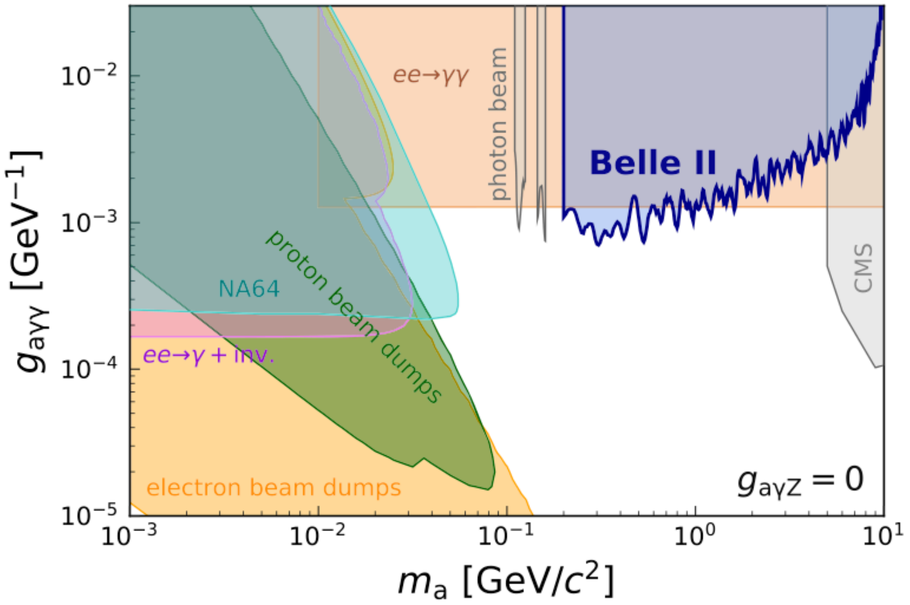
Dark Sector Search at Belle II

- Belle or BaBar did not search for some of the processes (trigger setting, etc.), Belle II initial data enable two searches
  - $e^+e^- \to \mu^+\mu^- Z'$, $Z' \to$ invisible (0.28 fb^{-1}) PRL 124 (2020), 141801
  - $e^+e^- \to a(\to\gamma\gamma)\gamma$ (Axion-Like Particle) (0.44 fb^{-1}) PRL 125 (2020), 161806



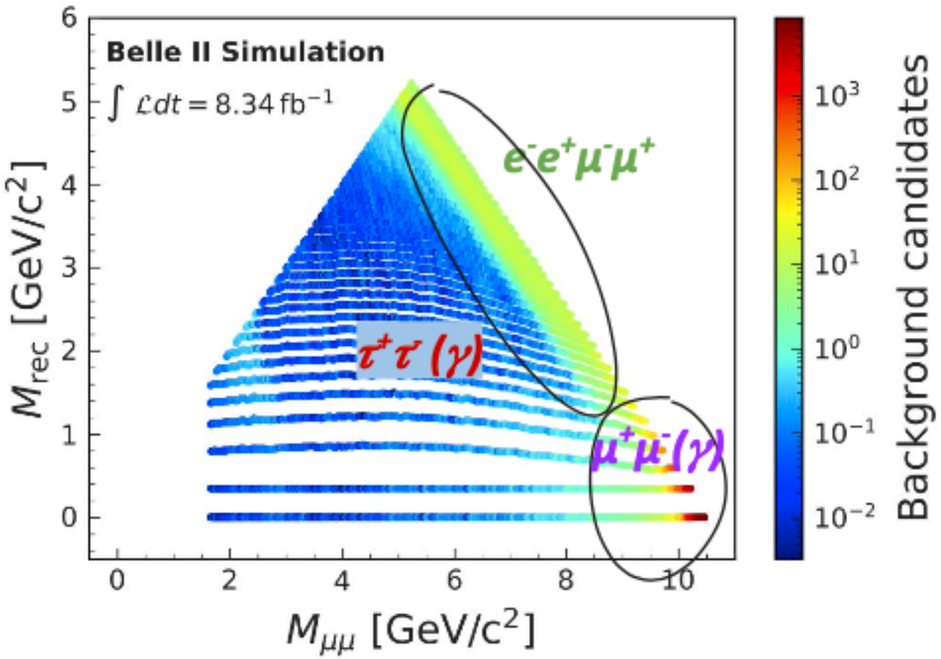






Dark Higgstrahlung background and systemtatics

- Backgrounds
  - dominant backgrounds:
    - $\mu^+\mu^-(\gamma)$ **(79%)**
    - $\tau^-\tau^+(\gamma)$ **(18%)**
    - $e^-e^+\mu^-\mu^+$ **(3%)**
  - different contributions in different regions

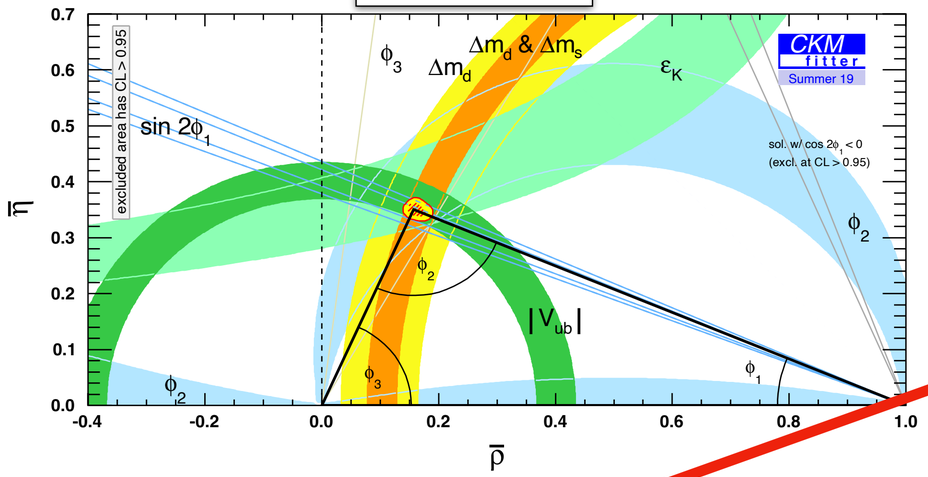


- Systematics:
  - impacting both signal and background: 2.2%-12.7%
  - impacting signal only:
    - differences in M resolution in data/MC (1-5%), BR theory uncert. 4%

Unitarity Triangle fit extrapolation

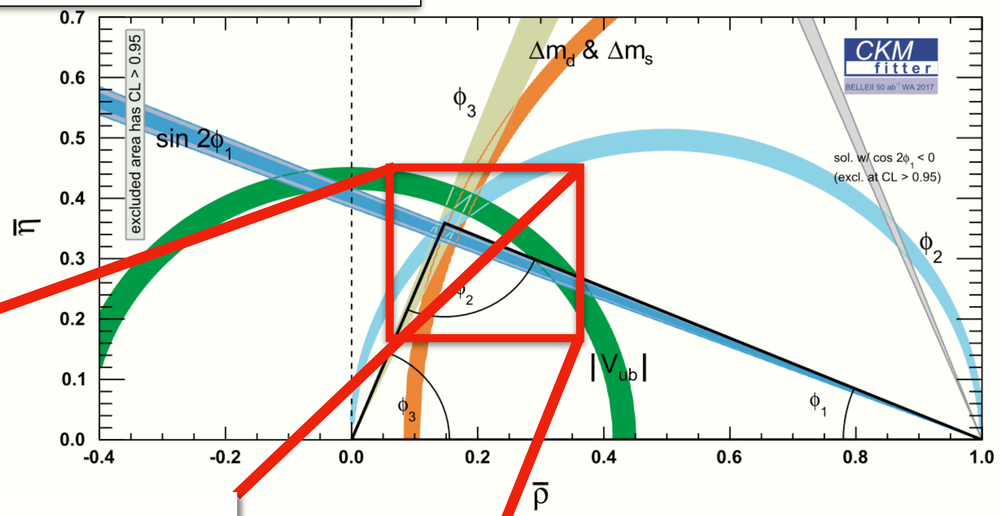
The Belle II Physics Book, PTEP 2019, 123C01

Current

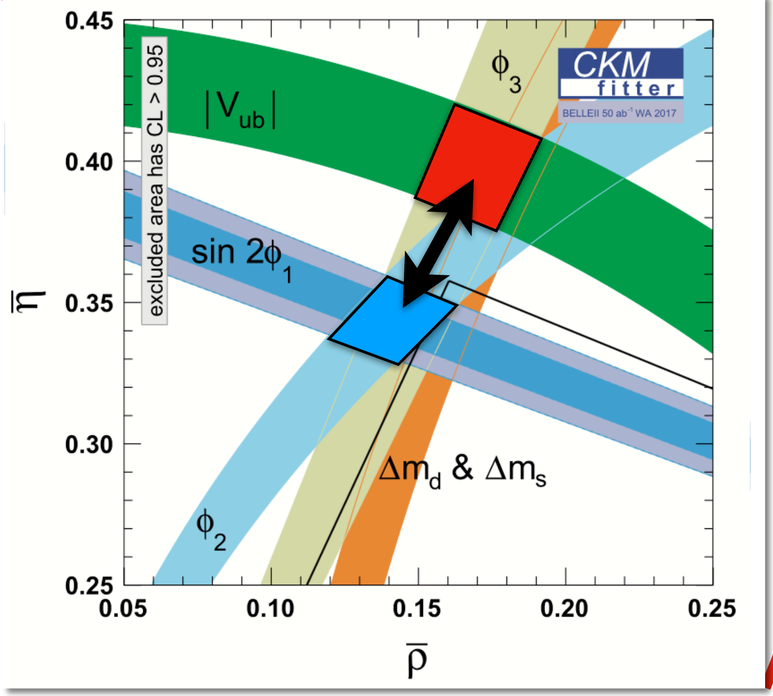


Belle II 50 ab^{-1}

If the current World Average hold

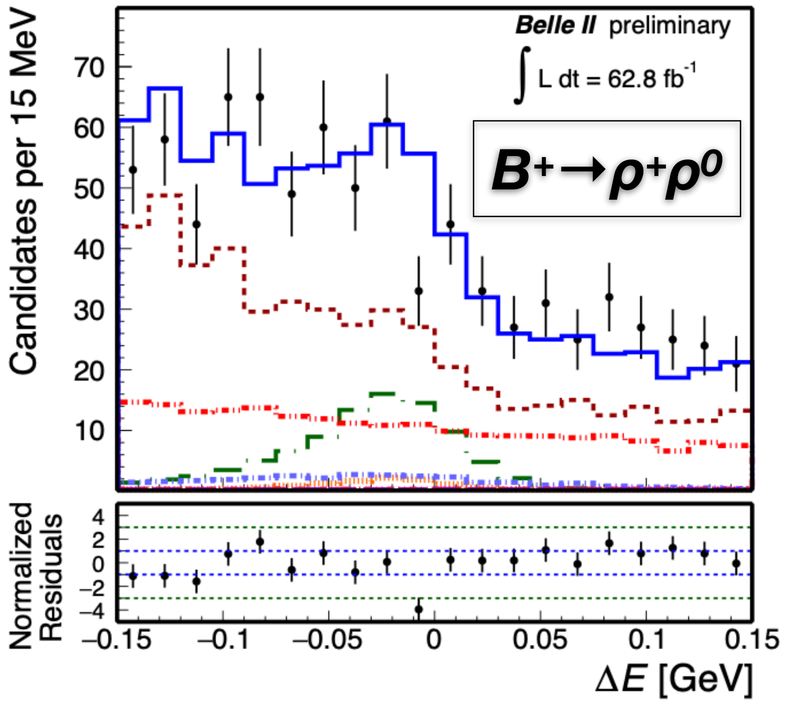


Zoom



- Tensions existed on V_{ub} and ϕ_1
  - UT can not close if keeping the central value for 50 ab^{-1}
- Differences between UT determined by **tree** (V_{ub}, ϕ_3) and **loop** (ϕ_1, ϕ_2) can be discriminated with 50 ab^{-1} data-set

ϕ_2 measurement ($B \to \rho\rho$)



BELLE2-CONF-DRAFT-2021-005

$\int L\,dt = 62.8\ fb^{-1}$

Data
Fit result
Signal long
Signal trans
SxF
$B\bar{B}$ bkg
$B \to f_0 X$
$B \to \rho\pi\pi$
Continuum

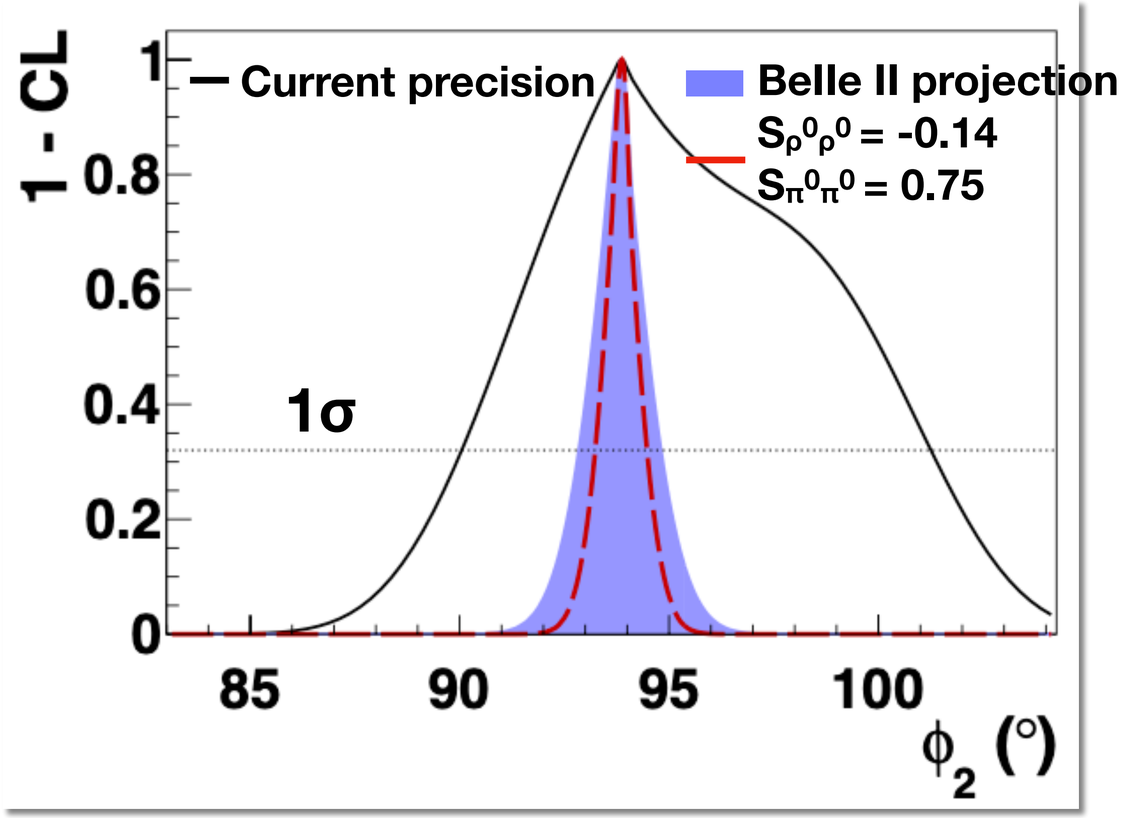
$$\Delta E = E_B^* - E_{beam}^*$$

	$B^+ \to \rho^+\rho^0$
Yeild	104 ± 16
$Br(10^{-6})$	$20.6 \pm 3.2 \pm 3.1$
PDG	24.0 ± 1.9
f_L	$0.936^{+0.049}_{-0.041} \pm 0.021$
f_L(PDG)	0.950 ± 0.016

f_L = fraction of longitudinally polarized events

- Compatible with PDG value
- Performance superior to early Belle results

The Belle II Physics Book, PTEP 2019, 123C01



- $\Delta\phi_2 \sim 0.6°$ (current 4.2°) with 50 fb^{-1} data
  - $B \to \pi\pi$, $B \to \rho\rho$ isospin analysis and $B \to \rho(\pi\pi)\pi$ Dalitz analysis of 3 body decays
  - **LHCb can not measure ϕ_2**

Belle II - LHCb comparison

P. URQUIJO @ Beauty 2020

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 2β/φ_1 (B→ J/ψ 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°	–
✸ $\|V_{ub}\|$ (Belle) or $\|V_{ub}\|/\|V_{cb}\|$ (LHCb)	4.5%	6%	2%	1%	3%	<1%	1%
φ_s	–	49 mrad	–	–	14 mrad	–	4 mrad
✸ S_{CP}(B→η' K_S, gluonic penguin)	0.08	○	0.03	0.015	○	0.007	○
✸ A_{CP}(B→$K_S\pi^0$)	0.15	–	0.07	0.04	–	0.02	–
New physics in radiative & EW Penguins, LFUV							
✸ S_{CP}(B_d→K^* γ)	0.32	○	0.11	0.035	○	0.015	○
✸ R(B→$K^* l^+l^-$) ($1<q^2<6$ GeV$^2/c^2$)	0.24	0.1	0.09	0.03	0.03	0.01	0.01
✸ R(B→$D^*\tau\nu$)	6%	10%	3%	1.5%	3%	<1%	1%
Br(B→τν), Br(B→$K^*\nu\nu$)	24%, –	–	9%, 25%	4%, 9%	–	1.7%, 4%	–
Br(B_d→μμ)	–	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→$\pi^+\pi^0$)	1.2%	–	0.5%	0.2%	–	0.1%	–
Br(τ→e γ)	$<120\times10^{-9}$	–	$<40\times10^{-9}$	$<12\times10^{-9}$	–	$<5\times10^{-9}$	–
Br(τ→μμμ)	$<21\times10^{-9}$	$<46\times10^{-9}$	$<3\times10^{-9}$	$<3\times10^{-9}$	$<16\times10^{-9}$	$<0.3\times10^{-9}$	$<5\times10^{-9}$

Results on other D & τ modes expected

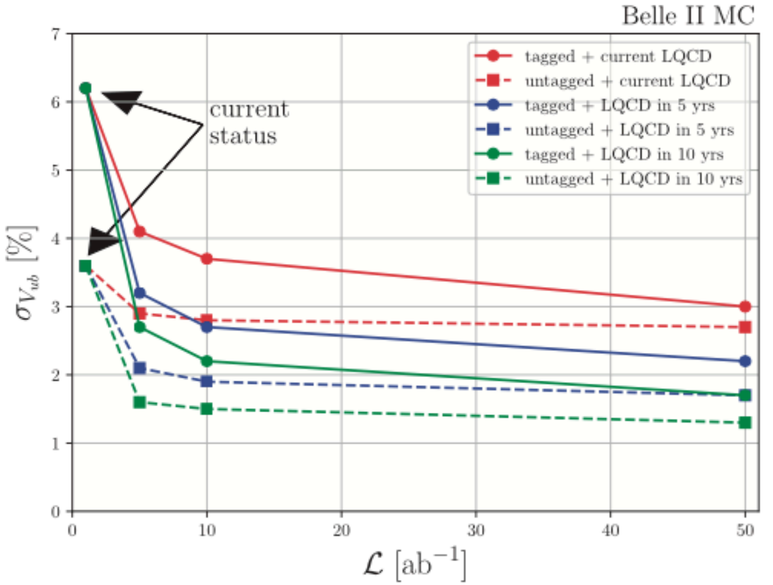
arXiv: 1808.08865 (Physics case for LHCb upgrade II), PTEP 2019 (2019) 12, 123C01 (Belle II Physics Book)

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

Prospects of $|V_{ub}|$ and $|V_{cb}|$

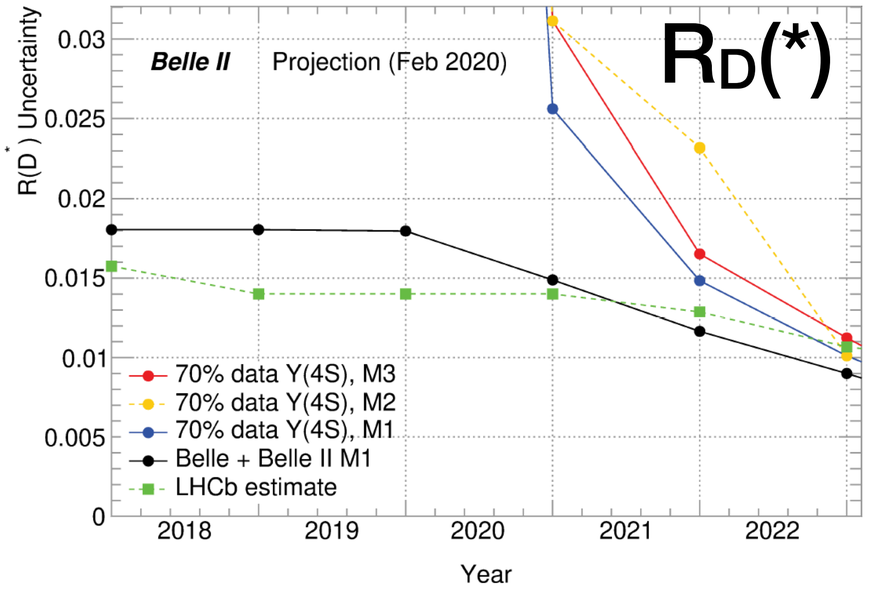
The Belle II Physics Book, PTEP 2019, 123C01

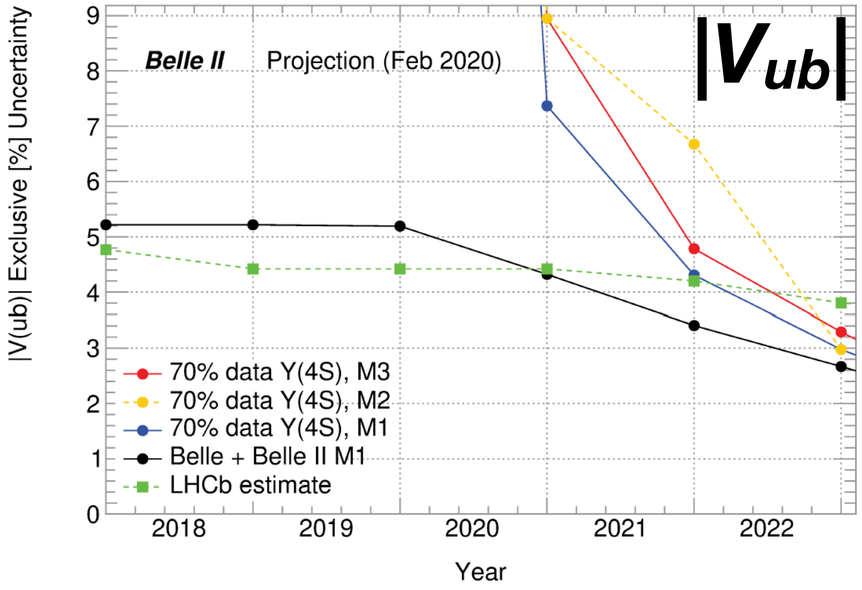
Side	Observable	Dominant uncertainties
$\|V_{td}\|$	Δm_d: $B\bar{B}$ mixing frequency	Lattice QCD ($\|V_{td}\|$ now is mainly limited by LQCD)
$\|V_{cb}\|$	$Br(b\to c l\nu)$	Exclusive: Lattice QCD Inclusive: experiment vs. phenomenology
$\|V_{ub}\|$	$Br(b\to u l\nu)$	

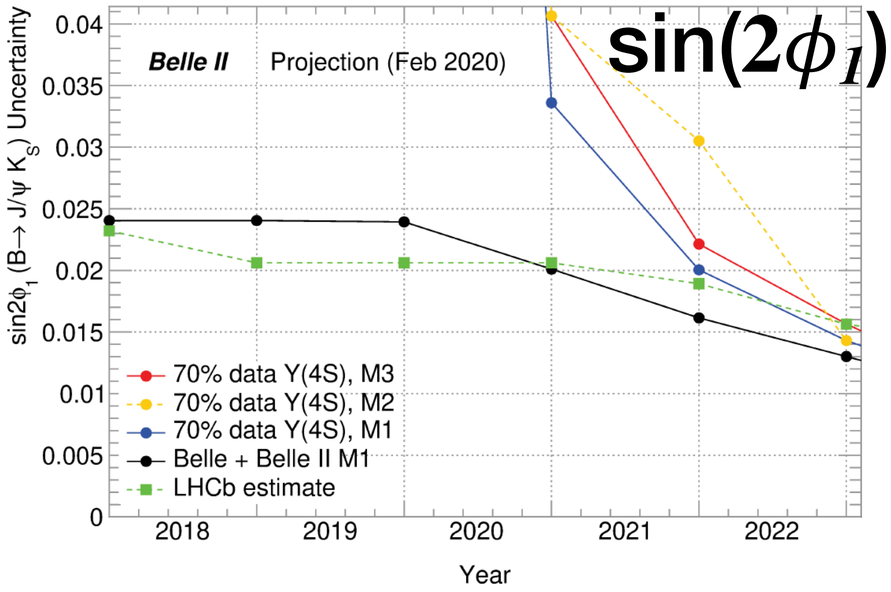


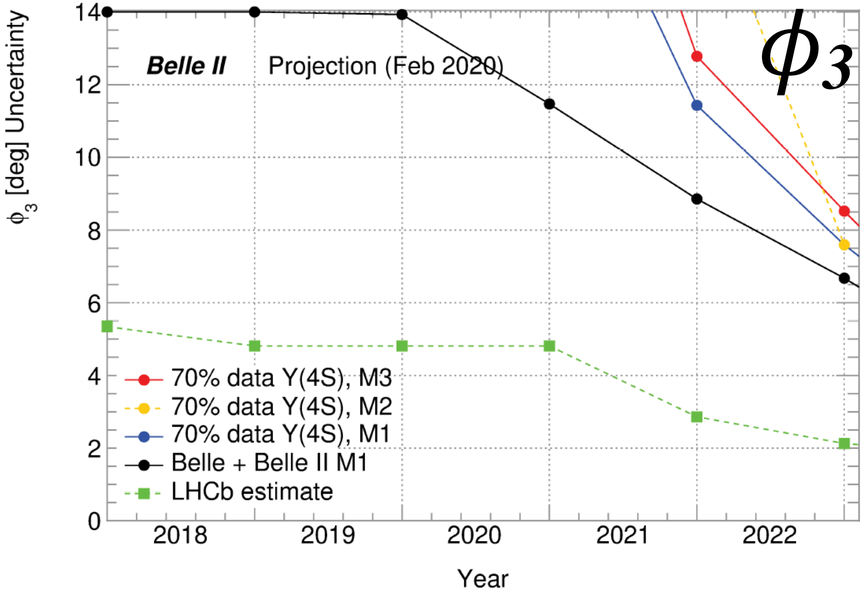
Observables	Belle	Belle II	
	(2017)	5 ab^{-1}	50 ab^{-1}
$\|V_{cb}\|$ incl.	$42.2 \cdot 10^{-3} \cdot (1 \pm 1.8\%)$	1.2%	–
$\|V_{cb}\|$ excl.	$39.0 \cdot 10^{-3} \cdot (1 \pm 3.0\%_{\text{ex.}} \pm 1.4\%_{\text{th.}})$	1.8%	1.4%
$\|V_{ub}\|$ incl.	$4.47 \cdot 10^{-3} \cdot (1 \pm 6.0\%_{\text{ex.}} \pm 2.5\%_{\text{th.}})$	3.4%	3.0%
$\|V_{ub}\|$ excl. (WA)	$3.65 \cdot 10^{-3} \cdot (1 \pm 2.5\%_{\text{ex.}} \pm 3.0\%_{\text{th.}})$	2.4%	1.2%
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	$91 \cdot (1 \pm 24\%)$	9%	4%
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	< 1.7	20%	7%
$R(B \to D\tau\nu)$ (Had. tag)	$0.374 \cdot (1 \pm 16.5\%)$	6%	3%
$R(B \to D^*\tau\nu)$ (Had. tag)	$0.296 \cdot (1 \pm 7.4\%)$	3%	2%

Belle II - LHCb comparison



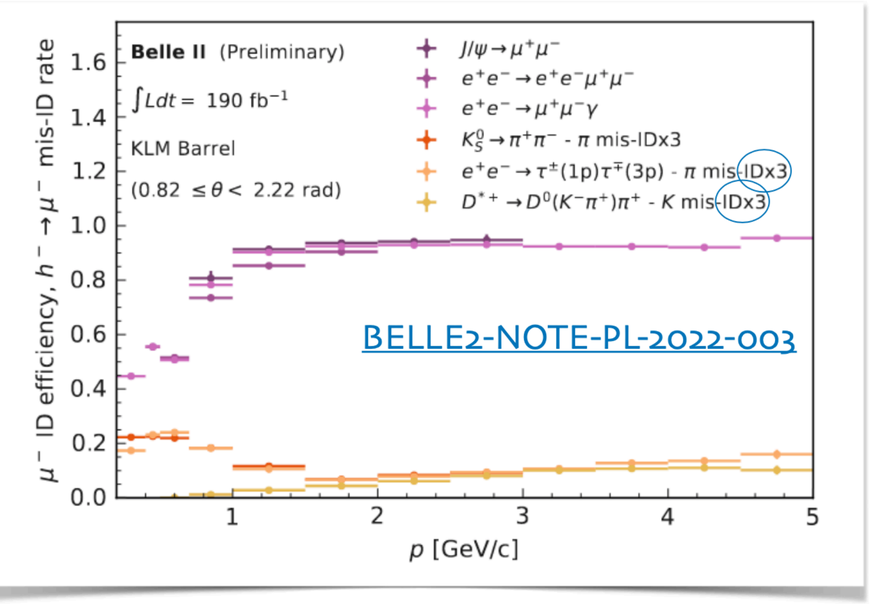




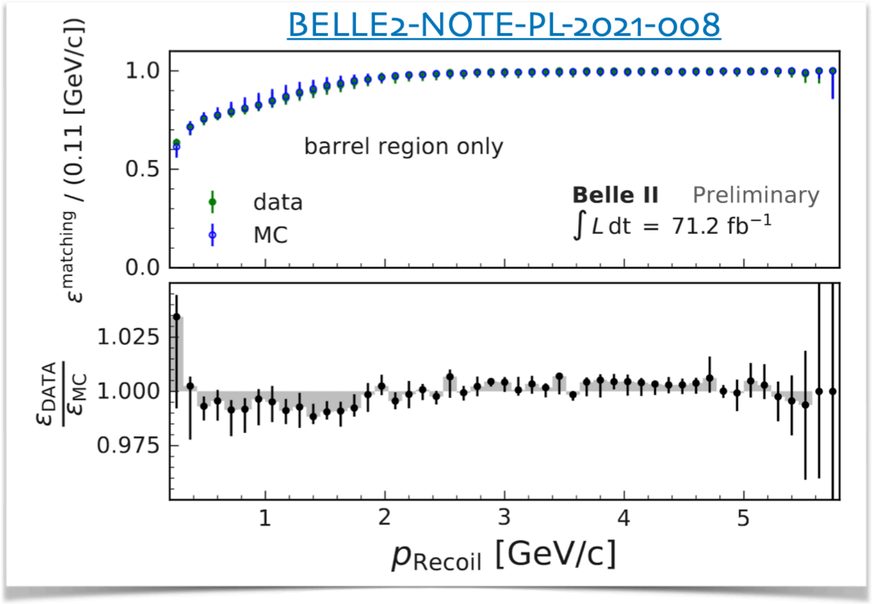


Belle II detector performance

Good Lepton ID, Muon/ Electron-ID over/under performing wrt Belle, improvements in progress



High photon detection efficiency,
Belle-like resolution π⁰ mass



Good kaon identification, underperforming wrt Belle, improvements in progress