Prospects of semi-leptonic B decays and CKM parameters from B decays with the Belle II experiment

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On behalf of the Belle II Collaboration

SUSY 2017

TIFR INDIA

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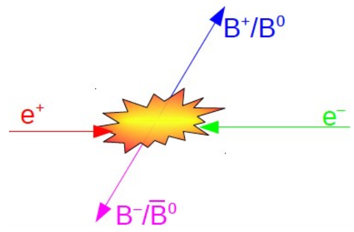
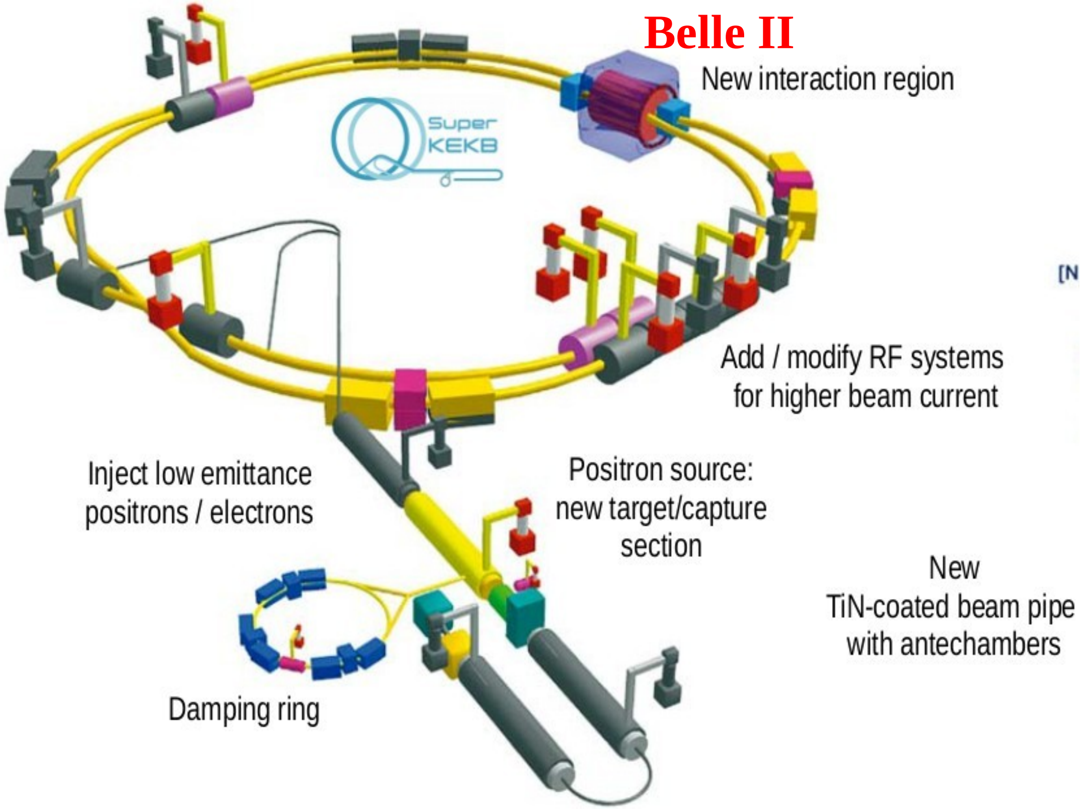
SuperKEKB (High luminosity frontier machine!)

- SuperKEKB – major upgrade of the KEKB B factory at KEK
- e^+e^- (**4 GeV** + **7 GeV**) → BB mainly at $\sqrt{s_{cm}}$=10.58 GeV (peak of Y(4S) resonance)



10^{10} BB pairs per year



Belle II

New interaction region

Add / modify RF systems for higher beam current

Inject low emittance positrons / electrons

Positron source: new target/capture section

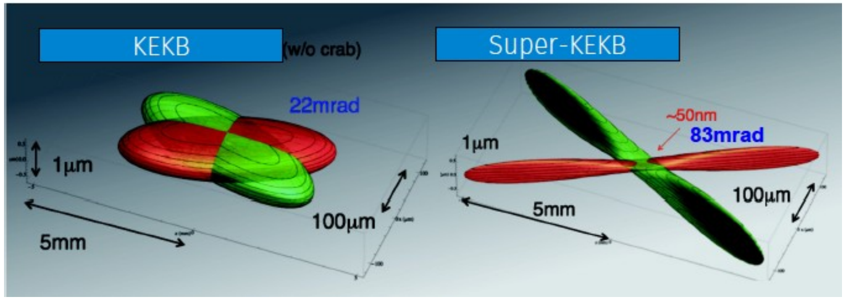
New TiN-coated beam pipe with antechambers

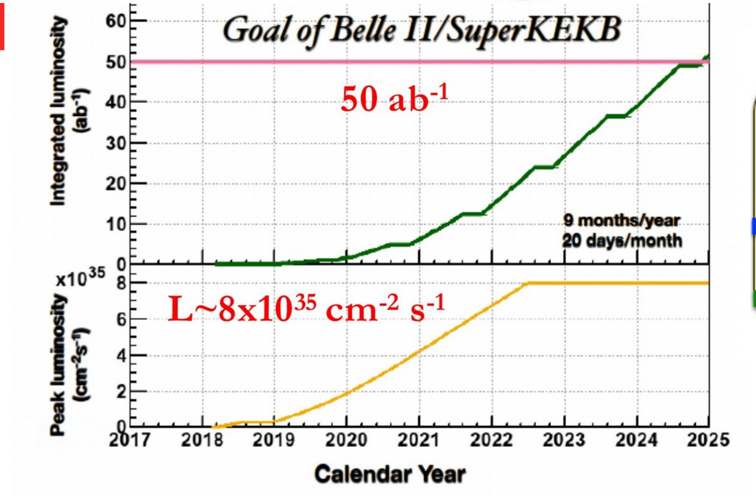
Damping ring

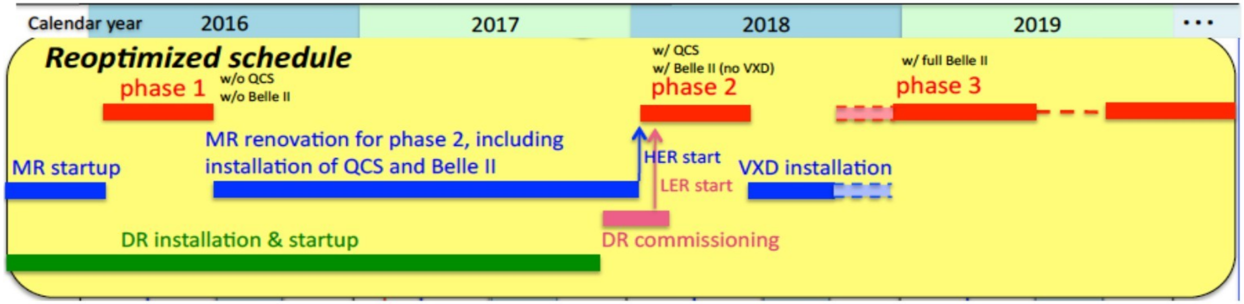
To obtain x40 higher instantaneous luminosity:

- Double beam current
- Major increase by small beam size "nano-beam" (vertical spot size ~50nm !!)

New technologies: nano beam scheme



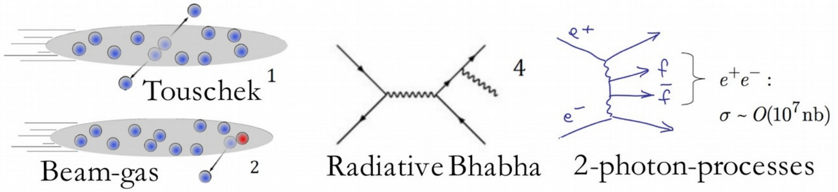




Belle ➡ Belle II

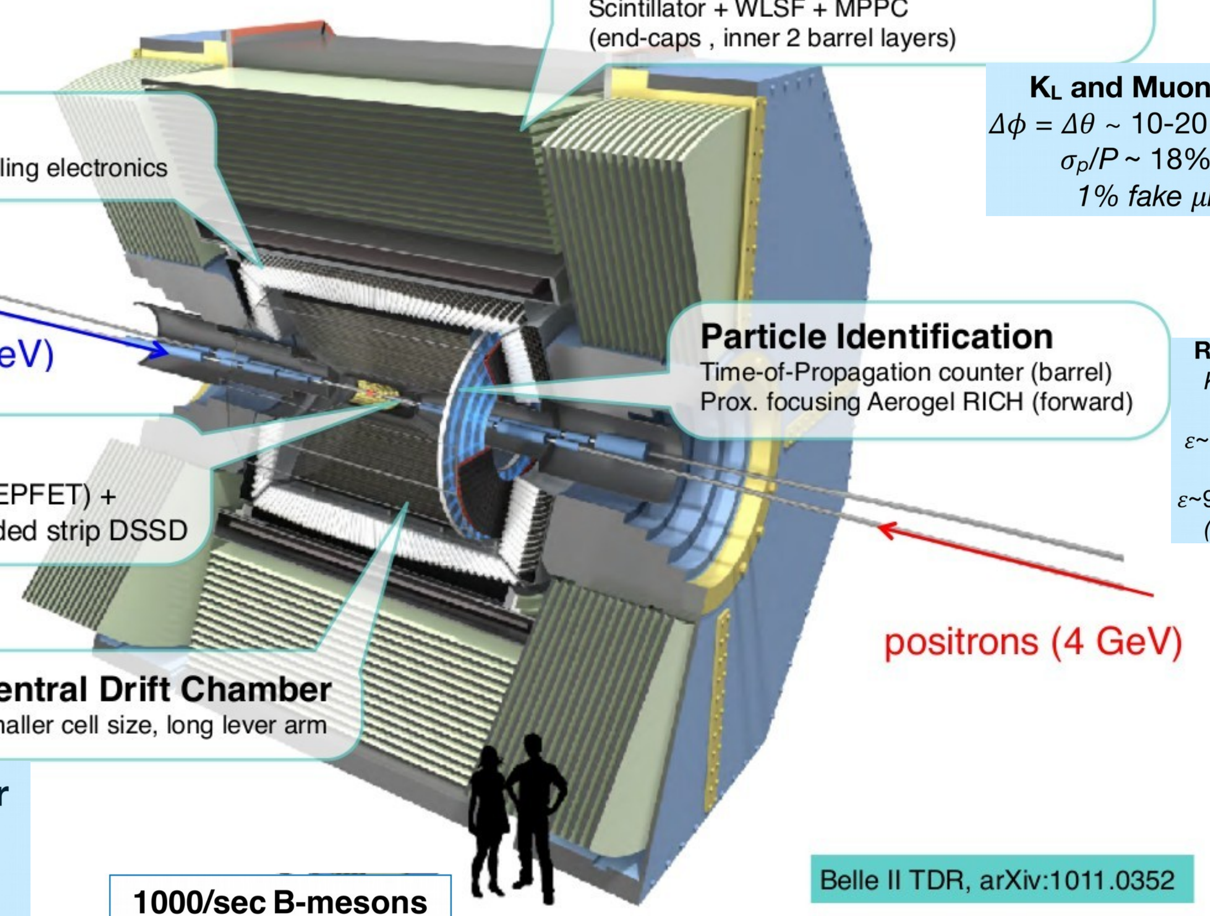
- High luminosity ➡ higher event rate and radiation damage to detectors from **machine background processes**
- Upgrade Belle to have better performances in higher radiation environment

Higher backgrounds



- Radiation damage
- Occupancy in inner detectors
- Fake hits and pile-up

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



KL and muon detector
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC
(end-caps , inner 2 barrel layers)

K_L and Muon detector
$\Delta\phi = \Delta\theta \sim$ 10-20 mrad (for K_L)
$\sigma_p/P \sim$ 18% (for K_L)
1% fake μID rate

EM Calorimeter
CsI(Tl), waveform sampling electronics

EM Calorimeter
σ_E/E = 2%
(for E=1GeV)

electrons (7 GeV)

Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (forward)

RICH detectors
K/π separation
Barrel:
ε~94% @ 5% fake
End-caps:
ε~96% @ 15% fake
(for p=1GeV/c)

Vertex Detector
2 layers Si Pixels (DEPFET) +
4 layers Si double sided strip DSSD

Vertex detector
$\sigma_{z0} \sim 20\ \mu$m
(4x better than Belle)

positrons (4 GeV)

Central Drift Chamber
Smaller cell size, long lever arm

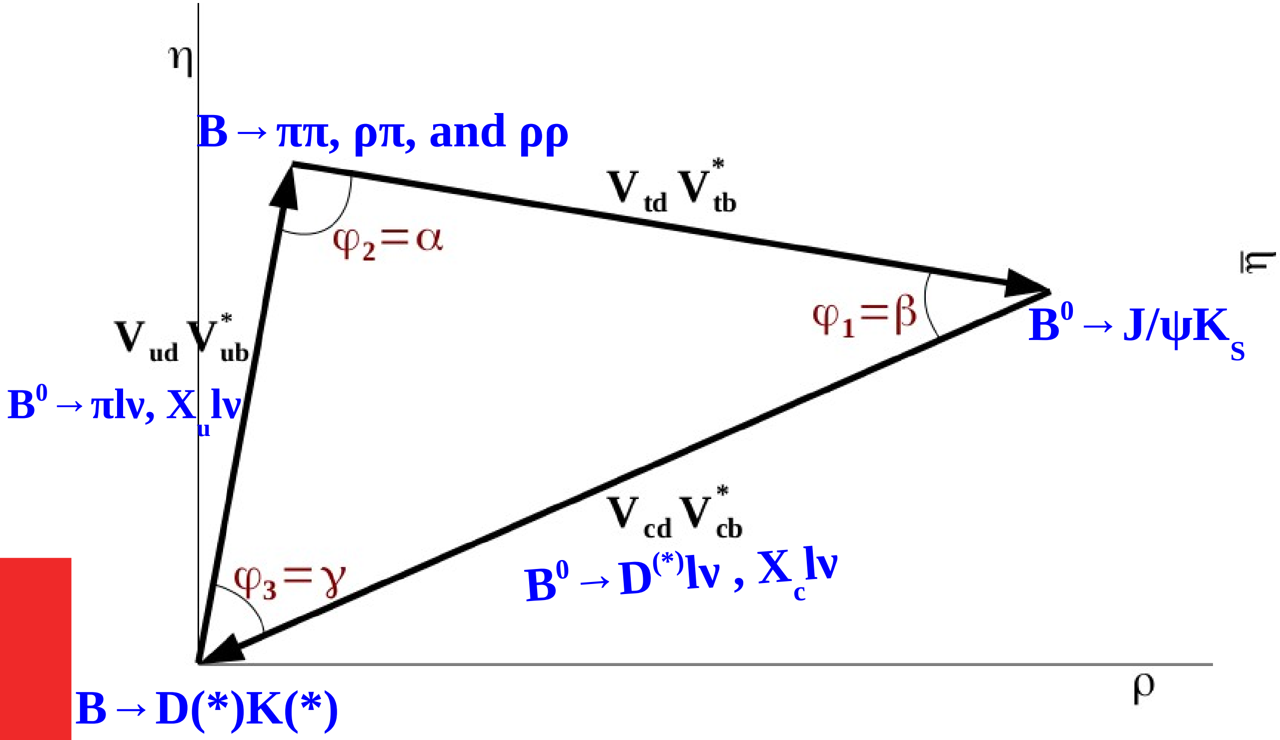
Drift chamber
$\sigma_{r\phi} \sim 100\ \mu$m
$\sigma_{dE/dx} \sim 5\%$

1000/sec B-mesons stored on disk

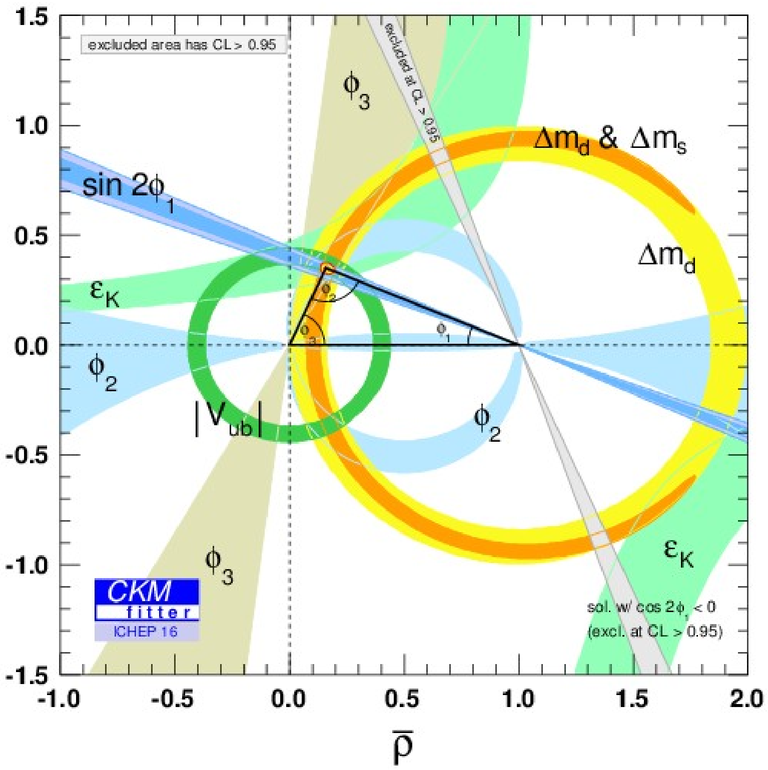
Belle II TDR, arXiv:1011.0352

CKM UT triangle and tree level measurements

$$V_{ud}V_{ub}^{*} + V_{cd}V_{cb}^{*} + V_{td}V_{tb}^{*} = 0$$



Current status



UT angle	Current status	Prediction
φ_1	$(21.85^{+0.68}_{-0.67})^{o}$	$(23.7^{+1.1}_{-1.0})^{o}$
φ_2	$(88.8 \pm 2.3)°$	$(92.1^{+1.5}_{-1.1})°$
φ_3	**$(72.1^{+5.4}_{-5.8})°$**	**$(65.3^{+1.0}_{-2.5})°$**

Dominated by experimental uncertainties. A lot more room for improvement

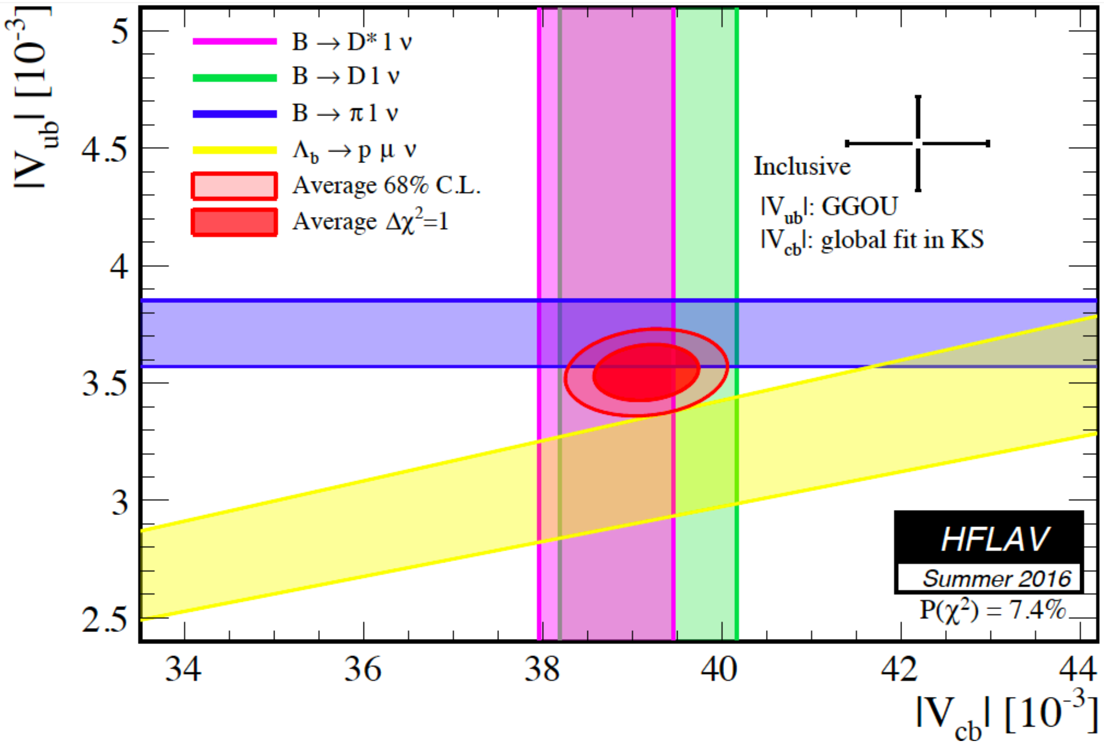
Current status of V_{ub} and V_{cb}

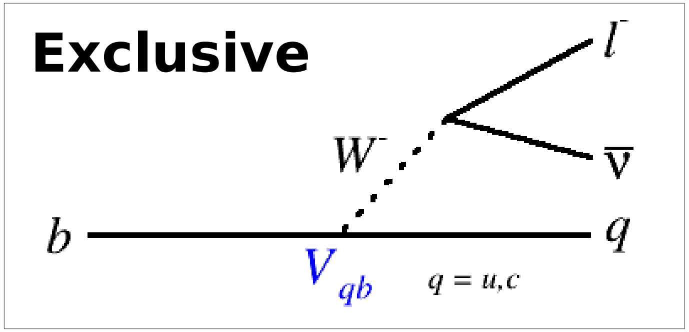
$|Vub|^{incl}=(4.52\ ^{+0.19}_{-0.21})\times10^{-3}$ $|Vcb|^{incl}=(42.19 \pm 0.78)\times10^{-3}$

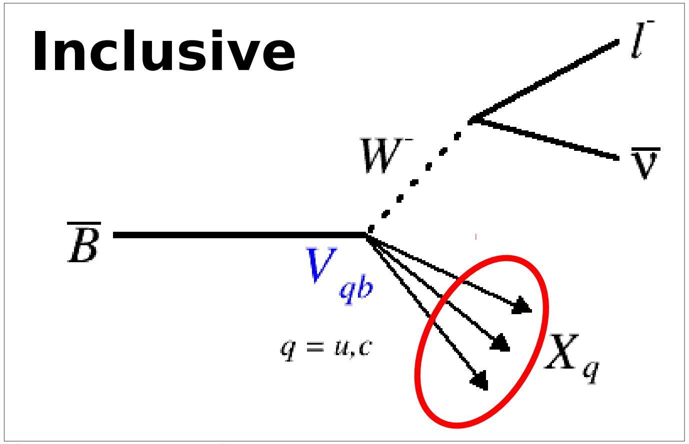
$|Vub|^{excl}=(3.55 \pm 0.12)\times10^{-3}$ $|Vcb|^{excl}=(39.16 \pm 0.58)\times10^{-3}$

I. Komarov, EPS 2017

Current world average







- Longstanding discrepancy between inclusive and exclusive measurements
- Measurement of V_{ub}/V_{cb} is important as it constrains the length of the unitarity triangle opposite the angle φ_1

How to extract Exclusive V_{ub}?

Pseudoscalar

$$\frac{d\mathcal{B}(B\to\pi l\nu)}{dq^2}=\frac{G_F^2\tau_B}{24\pi^3}p_\pi^3|V_{ub}|^2|f_+^{B\pi}(q^2)|^2$$

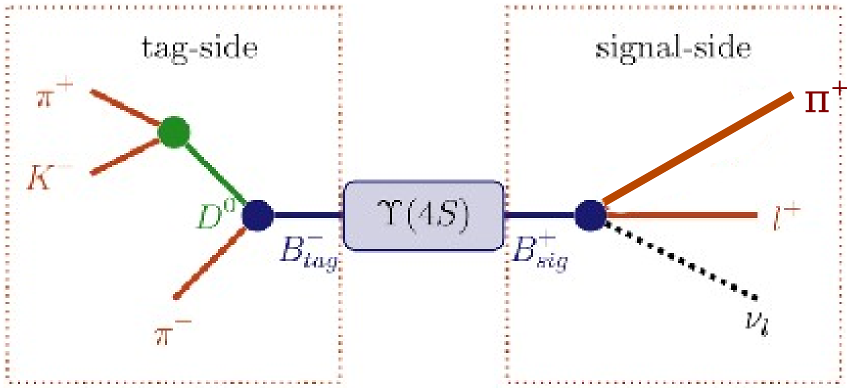
Vector

$$\frac{d\mathcal{B}(B\to V l\nu)}{dq^2}=\frac{G_F^2 p_V q^2\tau_B}{96\pi^3 m_B^2}|V_{ub}|^2[|H_0(q^2)|^2+|H_+(q^2)|^2+|H_-(q^2)|^2]$$

- Measure differential branching fractions in bins of q^2 (**Experimental measurement**)
- Form factor through QCD based calculation (**theoretical input**)
- Extract **V_{ub}**
- Inclusive and exclusive vary depending upon the composition and theoretical input
- Measure branching fractions through tagged (hadronic, semileptonic) and untagged measurements

Methods to do measurement

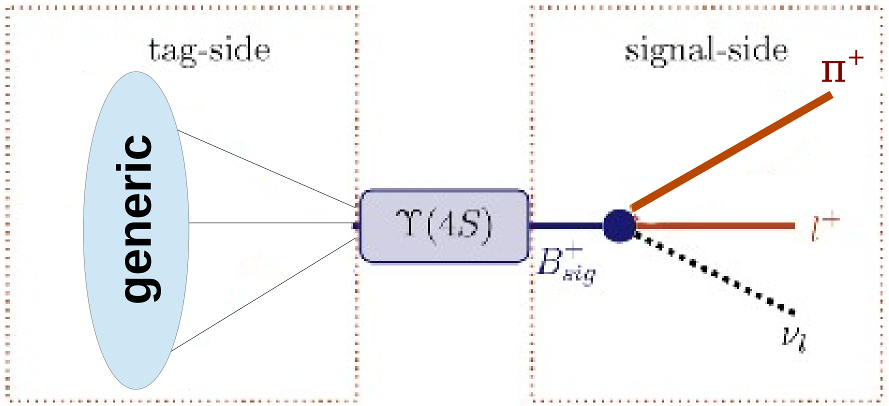
“Hadronic Tagged” measurement



Advantage

- Exact momentum of companion B gives good q^2 resolution.
- ε = 0.55% (0.3%@Belle)
- Improvement w.r.t. Belle is due to the better tagging algorithms

“Untagged” measurement



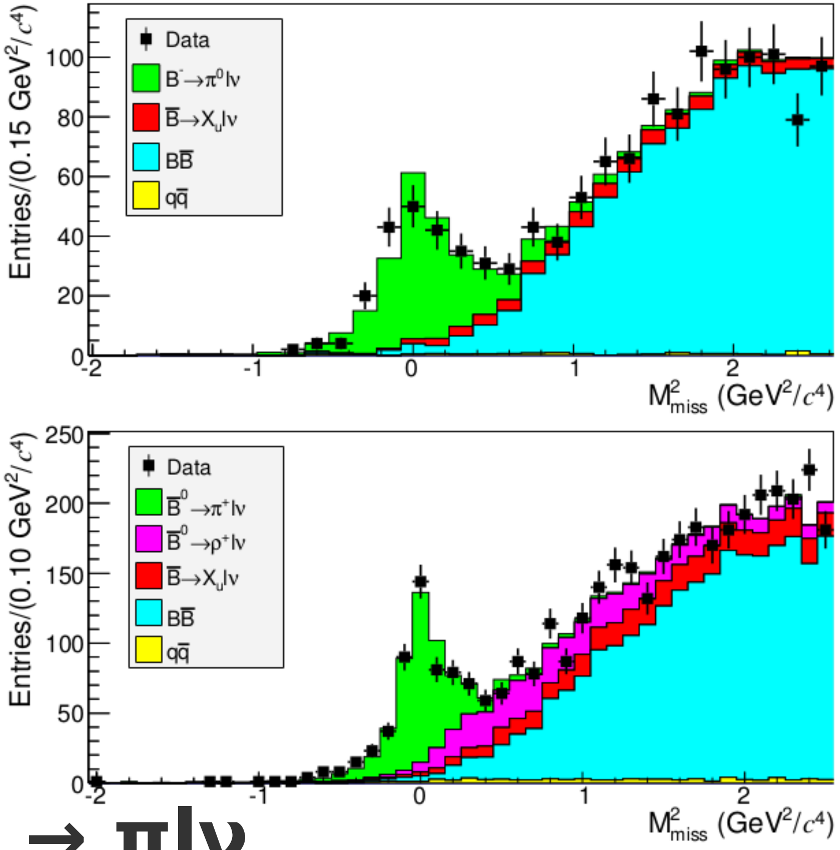
Advantage

- Indirect determination of companion B momentum spoils q^2 resolution.
- ε = 20% (11%@Belle)
- Improvement w.r.t. Belle is due to the better ROE handling

Belle Exclusive: B → πlν

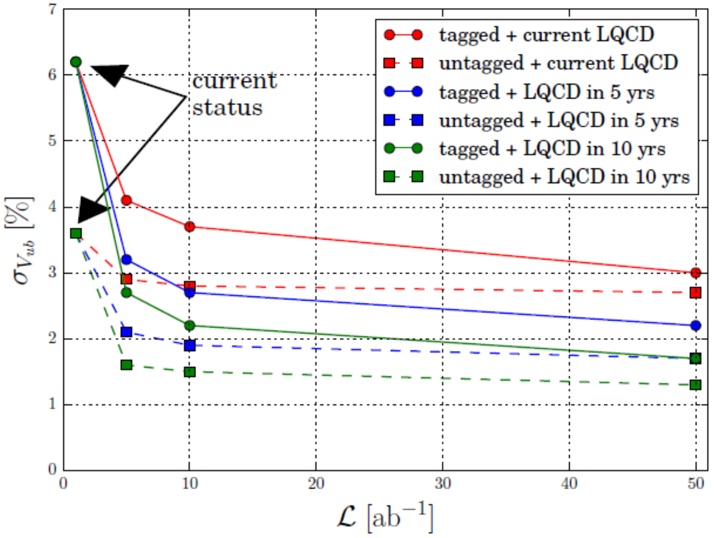
Phys. Rev. D **88**, 032005 (2013)

- Data sample = 711 fb^{-1}
- Clean signal in missing mass ~ 0
- Signal yield: B^+ = 232 ± 23, B^0 = 463 ± 28
- Exclusive $|V_{ub}|$ = (3.52 ± 0.29) x 10^{-3}



Belle II Projection to B → πlν

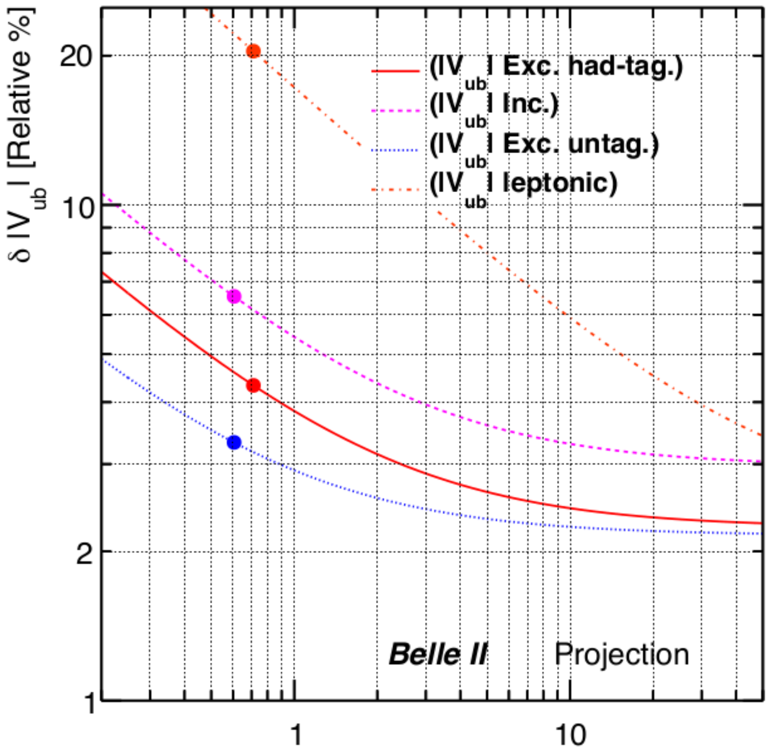
Expected precision at 50 ab^{-1} from B→πlν (Untagged) $\delta_{|Vub|}$ = 1.3%



Forecasts of V_{ub} sensitivity to various luminosity values for tagged and untagged modes.

V_{ub} extrapolation to Belle II

Belle II will provide more precise measurements **(B2TIP)**



	Statistical	Systematic (reducible, irreducible)	Total Exp	Theory	Total
$\|V_{ub}\|$ exclusive (had. tagged)					
711 fb^{-1}	3.0	(2.3, 1.0)	3.8	8.7 (2.0)	9.5 (4.3)
5 ab^{-1}	1.1	(0.9, 1.0)	1.7	4.0 (2.0)	4.4 (2.6)
50 ab^{-1}	0.4	(0.3, 1.0)	1.1	2.0	2.3
$\|V_{ub}\|$ exclusive (untagged)					
605 fb^{-1}	1.4	(2.1, 0.8)	2.9	8.7 (2.0)	9.1 (4.0)
5 ab^{-1}	0.5	(0.8, 0.8)	1.2	4.0 (2.0)	4.2 (2.4)
50 ab^{-1}	0.2	(0.3, 0.8)	0.9	2.0	2.2
$\|V_{ub}\|$ inclusive					
605 fb^{-1} (old B tag)	4.5	(3.7, 1.6)	6.0	2.5–4.5	6.5–7.5
5 ab^{-1}	1.1	(1.3, 1.6)	2.3	2.5–4.5	3.4–5.1
50 ab^{-1}	0.4	(0.4, 1.6)	1.7	2.5–4.5	3.0–4.8

Expected errors in $|V_{ub}|$ measurements with the Belle full data sample, 5 ab^{-1} and 50 ab^{-1} Belle II data.

- Expected: theory error down to 2% for exclusive and 2–4 % for inclusive modes
- Most promising are exclusive analysis with hadronic tags: clean and detailed exploration of exclusive b → u
- Untagged analyses is competitive too

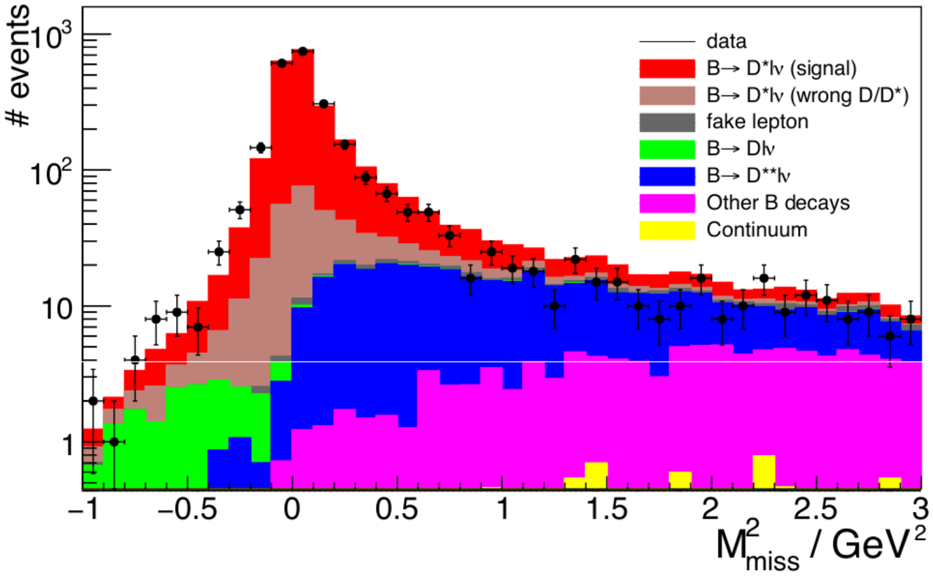
New V_{cb} exclusive results from Belle

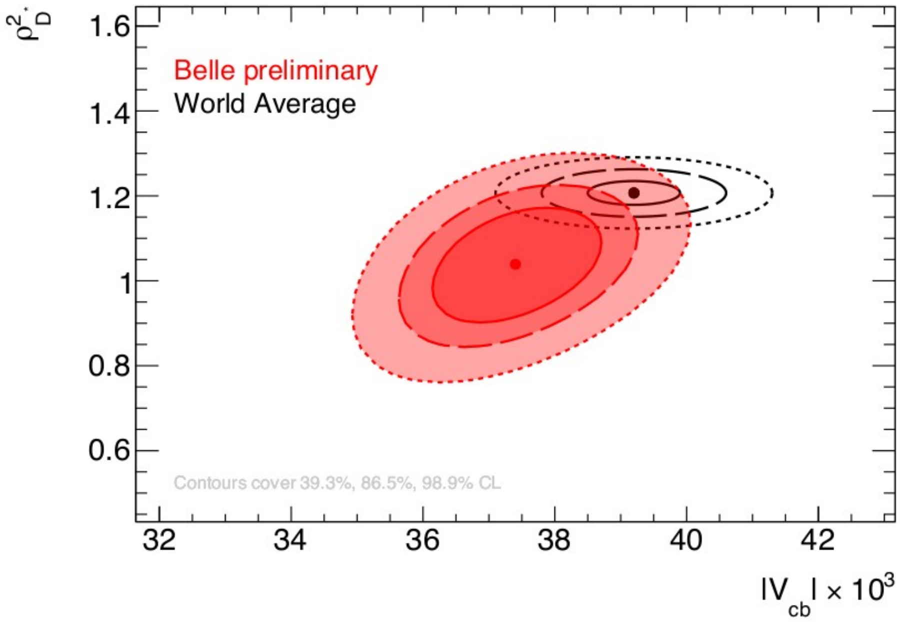
arXiv:1702.01521

V_{cb} determined by inclusive and exclusive measurements show **2-3σ** discrepancy

- Signal identified using Hadronic tag
- Signal extracted by missing mass square:

$$M^2_{\text{miss}} = \left(p_{\text{beam}} - p_{B_{\text{tag}}} - p_D - p_l\right)^2 \quad (l = e, \mu)$$

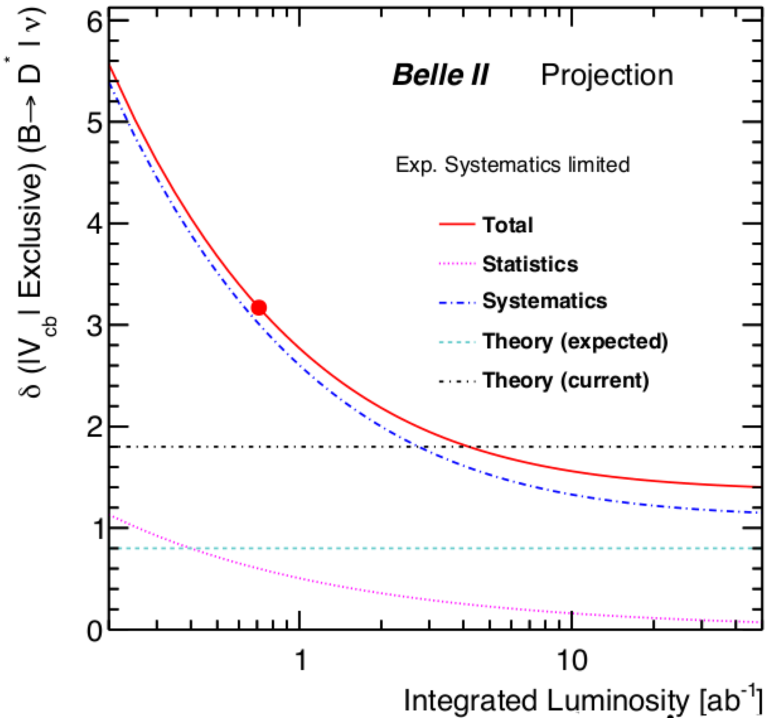




$|V_{cb}| = (37.4 \pm 1.3) \times 10^{-3}$

V_{cb} extrapolation to Belle II

Belle II will provide more precise measurements **(B2TIP)**



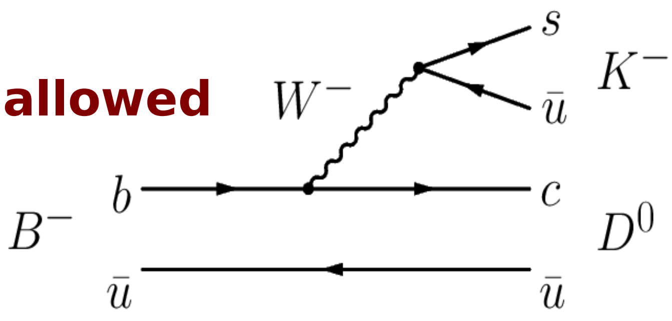
	Statistical	Systematic (reducible, irreducible)	Total Exp	Theory	Total
$\lvert V_{cb}\rvert$ exclusive : F(1)					
711 fb^{-1}	0.6	(2.8, 1.1)	3.1	1.8	3.6
5 ab^{-1}	0.2	(1.1, 1.1)	1.5	1.0	1.8
50 ab^{-1}	0.1	(0.3, 1.1)	1.2	0.8*	1.4
$\lvert V_{cb}\rvert$ exclusive : G(1)					
423 fb^{-1}	4.5	(3.1, 1.2)	5.6	2.2	3.6
5 ab^{-1}	1.3	(0.9, 1.2)	2.0	1.5*	2.7
50 ab^{-1}	0.6	(0.4, 1.2)	1.4	1.0*	1.7

Expected errors in |V_{cb}| exclusive measurements with the Belle full data sample, 5 ab^{-1} and 50 ab^{-1} Belle II data.

φ_3

Φ_3 from interference between $B^- \to D^0K^-$ and $B^- \to \bar{D}^0K^-$ using tree level B decay

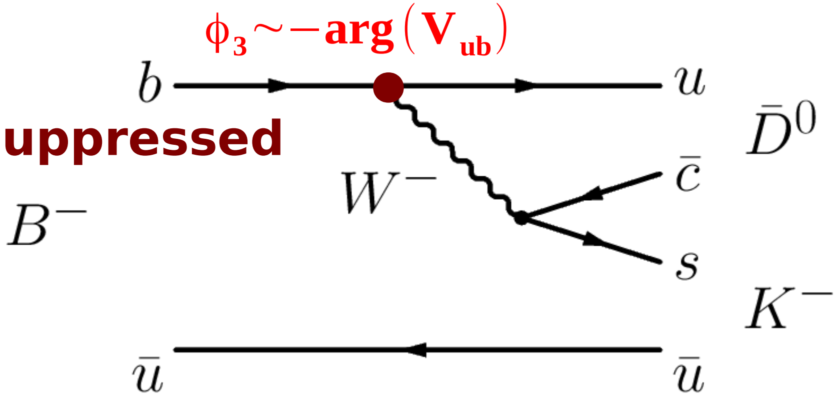
Color allowed



$B^- \to D^0K^- \sim V_{cb}V^*_{us}$

$\sim A\lambda^3$

Color suppressed



$B^- \to D^0K^- \sim V_{ub}V^*_{cs}$

$\sim A\lambda^3 (\rho + i\eta)$

$$\frac{A_S(B^- \to \overline{D^0}K^-)}{A_F(B^- \to D^0K^-)} = r_B e^{i(\delta_B - \phi_3)}$$

Combine results from various B and D decays.

Extraction of Φ_3 by combining information from all measurements

Using different B decays: DK , D*K, DK* . . .

Different hadronic factors (r_B, δ_B) for each B decay mode

Three main methods for various D decays:

- **CP eigenstates : GLW method**

PLB 253, 483 (1991),
PLB 265, 172 (1991)

- **Doubly - Cabbibo suppressed decays : ADS method**

PRD 63, 036005 (2001)

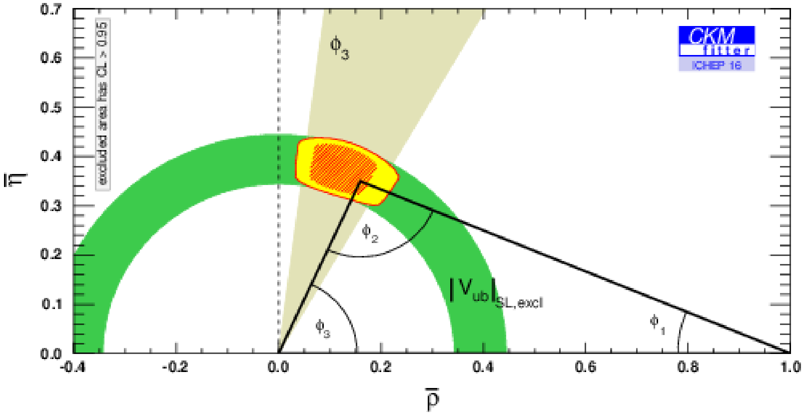
- **Three- body decays : GGSZ (Dalitz) method**

PRD 68, 054018 (2003)

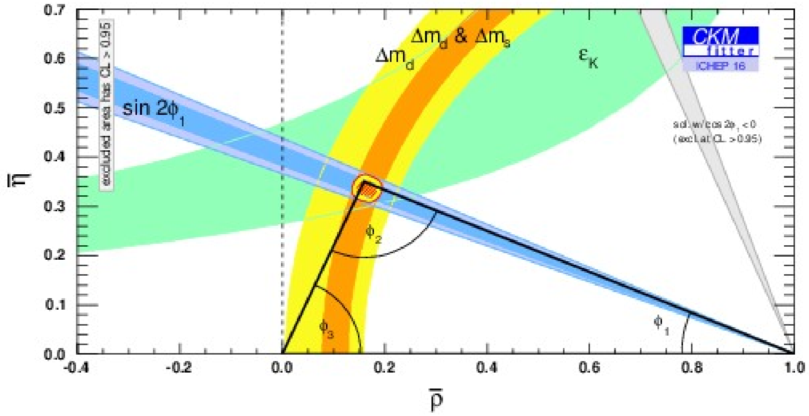
Current Direct / Indirect sensitivity:

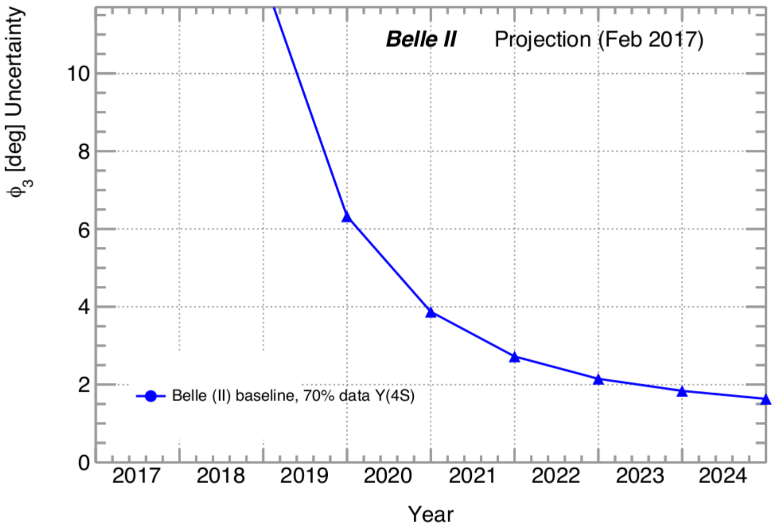
Measure ϕ_3 direct(tree) and indirect way (loop) and compare to see effect of new physics

Current direct sensitivity : $\phi_3 = (72.1^{+5.4}_{-5.8})^o$



Current indirect sensitivity : $\phi_3 = (65.3^{+1.0}_{-2.5})^o$





Why best ϕ_3 sensitivity is from Belle II ?

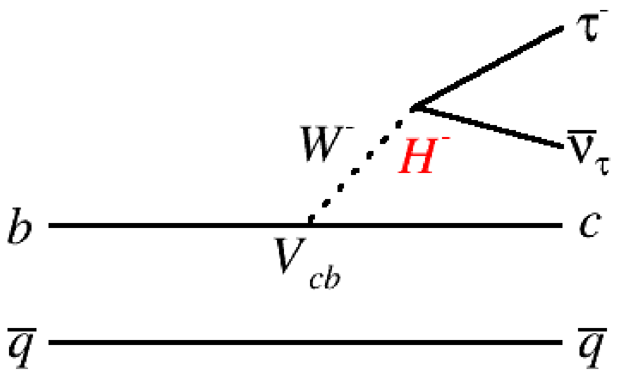
Along with leading modes $K^+\pi^-$, K^+K^-, $\pi^+\pi^-$, $K_s\pi^0$, $K_s\pi^+\pi^-$, $K_sK^+K^-$, Any final state can be reconstructed including those with γ.

With 50 ab^{-1} data: Forseen ϕ_3 precision of 1.5°

B→D*τν a powerful probe for new physics

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}l\nu)} \quad (l = e, \mu)$$

$$P_\tau(D^{(*)}) = \frac{\Gamma^+ - \Gamma^-}{\Gamma^+ + \Gamma^-}$$



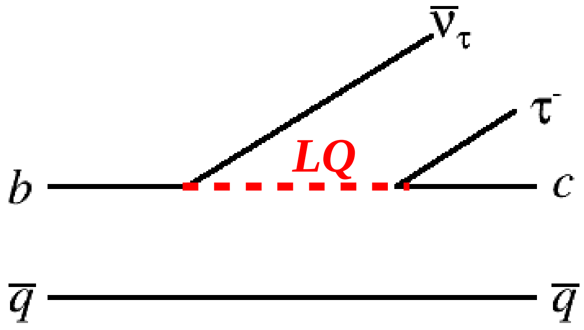
SM predictions

$R_D = 0.299 \pm 0.003$

$R_{D^*} = 0.257 \pm 0.003$

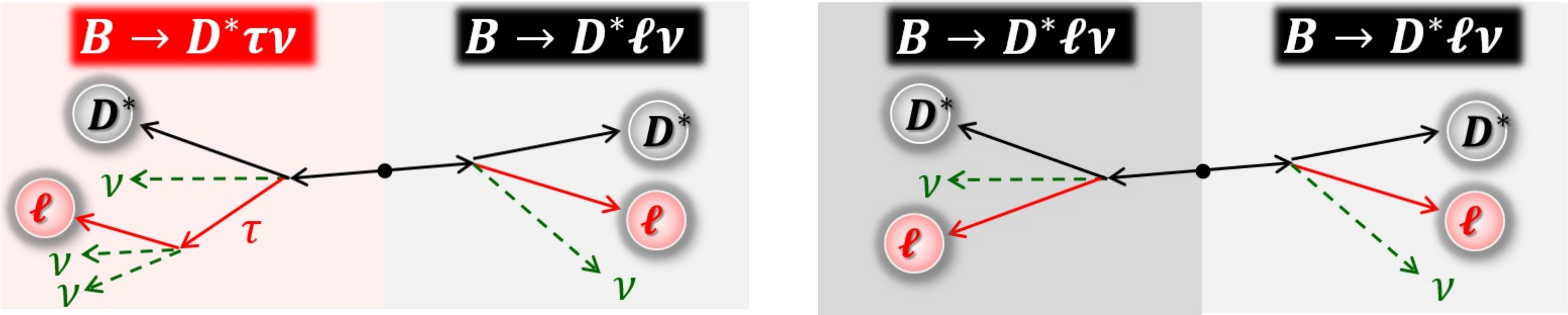
$P_\tau(D) = 0.325 \pm 0.009$

$P_\tau(D^*) = -0.497 \pm 0.013$



- Sensitive to new physics models through charged Higgs and leptoquarks at tree level diagram
- Ratio of Branching fractions cancel several uncertainties
- Measured by Belle, BaBar, LHCb show a large discrepancy from SM

Belle Results summary



Tag method	τ^- decays	Observables	Fit Variables	Result
Hadronic	$l^-\nu_\tau\bar{\nu}_l$	R_D	M^2_{miss}, O_{NB}	0.375±0.064(stat)±0.026(syst) Phys. Rev. D 92(7), 072014 (2015)
Hadronic	$l^-\nu_\tau\bar{\nu}_l$	R_{D^*}	M^2_{miss}, O_{NB}	0.293±0.038(stat)±0.015(syst) Phys. Rev. D 92(7), 072014 (2015)
Semileptonic	$l^-\nu_\tau\bar{\nu}_l$	R_{D^*}	E_{ECL}, O'_{NB}	0.302±0.030(stat)±0.011(syst) Phys. Rev. D 94(7), 072007 (2016)
Hadronic	$h^-\nu_\tau$	R_{D^*}	$E_{ECL}, \cos\theta_{hel}$	$0.270\pm0.035(\text{stat})^{+0.028}_{-0.025}(\text{syst})$ Phys. Rev. Lett. 118, 211801 (2017)
Hadronic	$h^-\nu_\tau$	$P_\tau(D^*)$	$E_{ECL}, \cos\theta_{hel}$	$-0.38\pm0.51(\text{stat})^{+0.21}_{-0.16}(\text{syst})$ Phys. Rev. Lett. 118, 211801 (2017)

Advantage of different tag methods

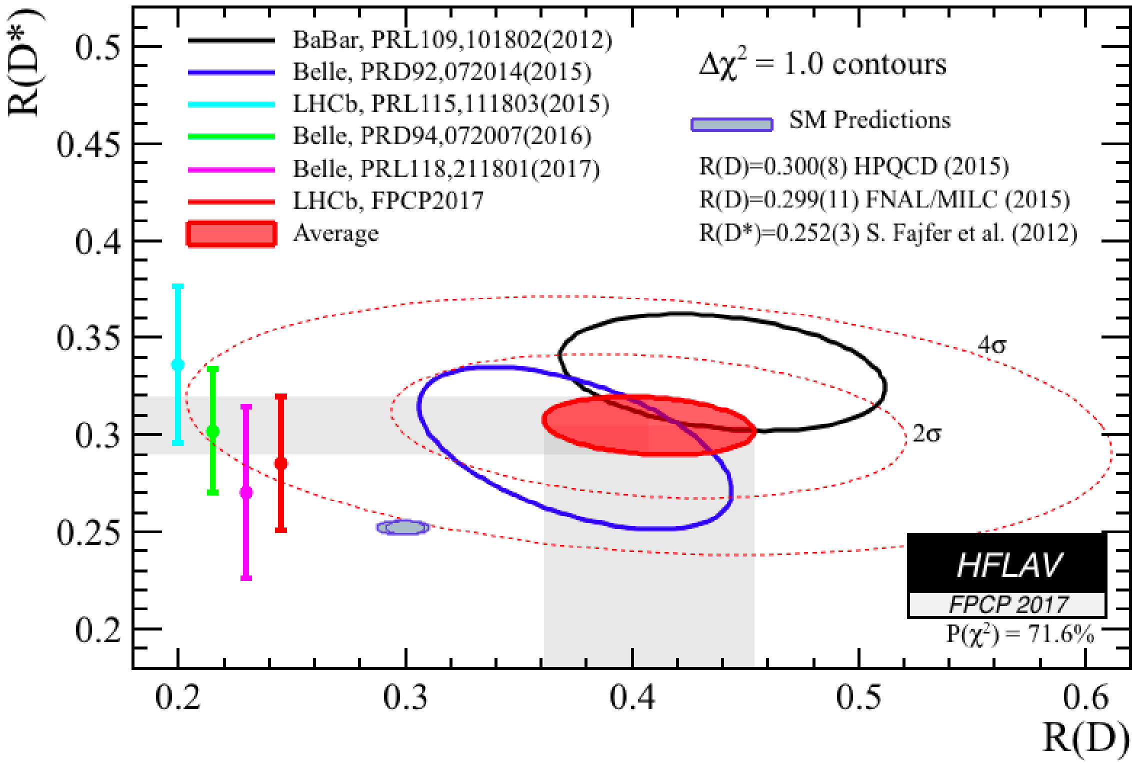
Hadronic: low background, Efficiency = O(0.1%)

Semileptonic: Efficiency O(0.2%)

Inclusive: High background, Efficiency: O(2%)

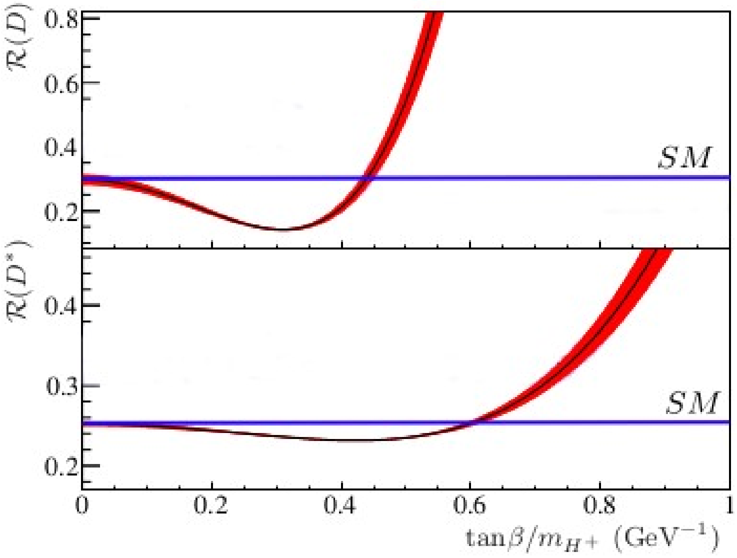
Status of B → $D^*\tau\nu$

Current measurement of $R(D^*)$ and $R(D)$ from world average



4.1σ deviation from SM

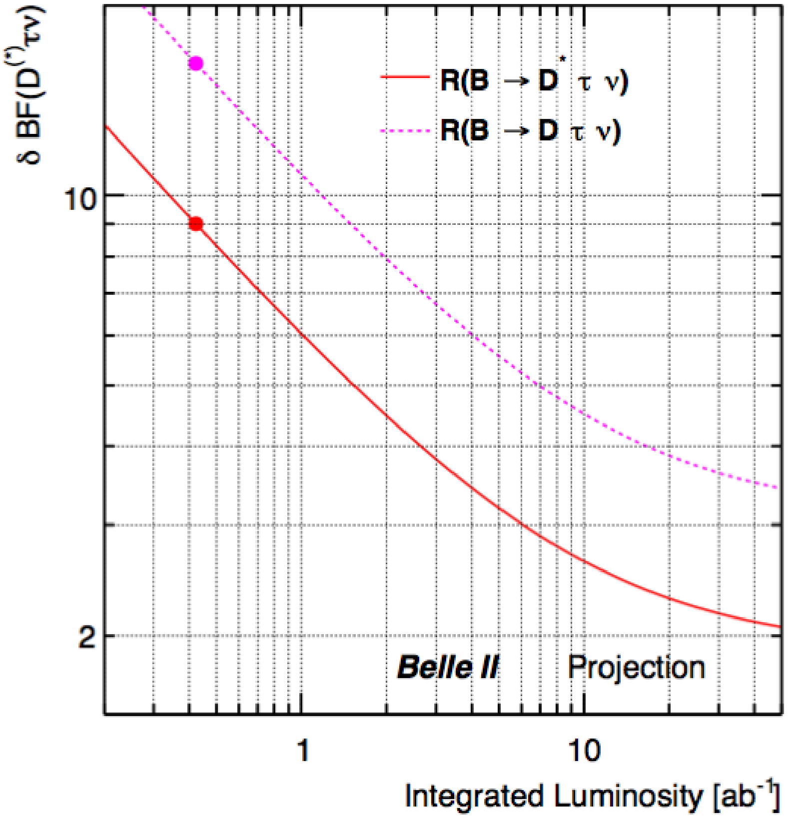
Constraint on NP models

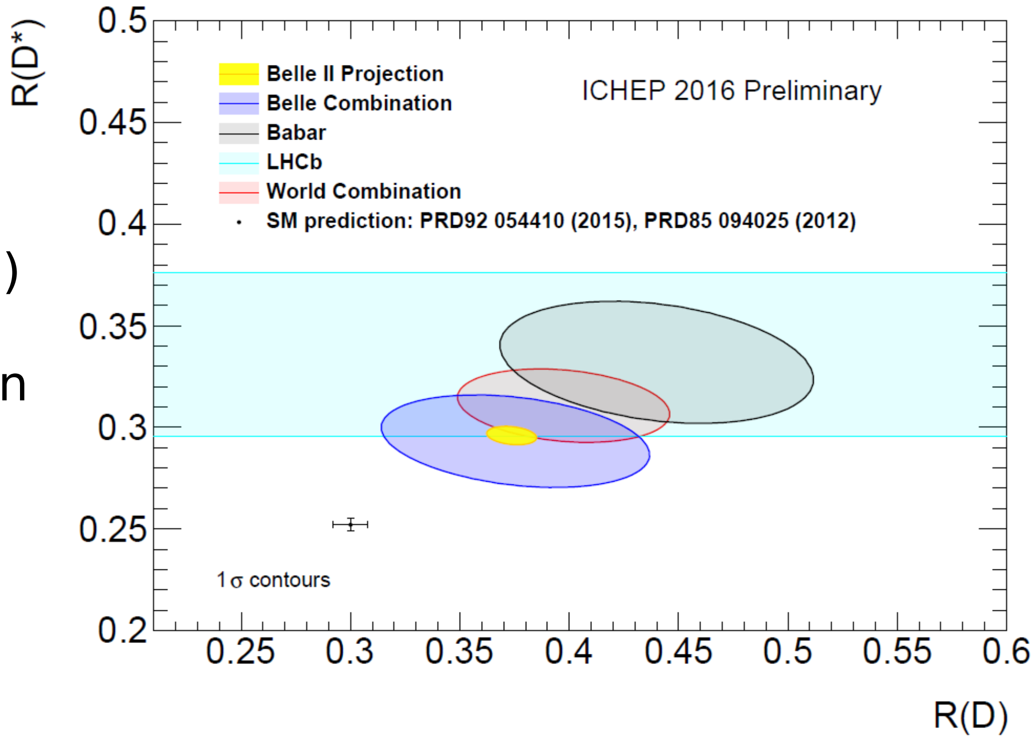


prediction of $R(D^{(*)})$ from 2HDM model as function of $\tan\beta/m_{Higgs}$

Extrapolation to Belle II

- Confirm the excess with better sensitivity
- Better understanding of backgrounds specifically B → D** l ν (most delicate BG)
- Belle II will provide tau and D* polarization with better sensitivity





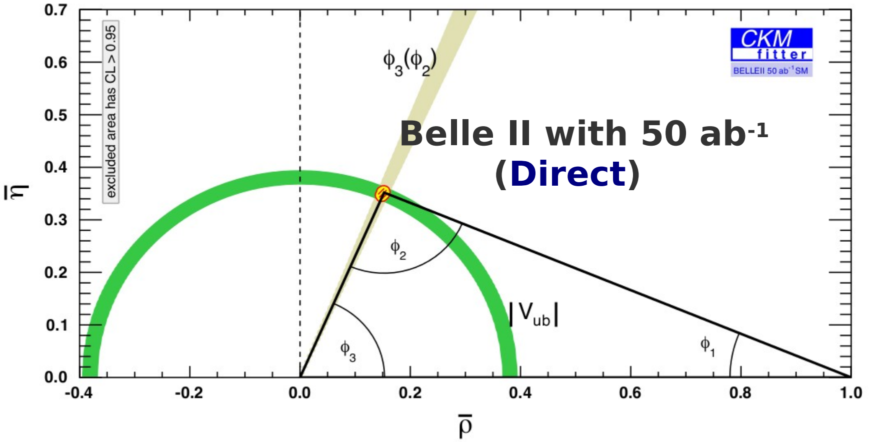
Belle II sensitivity

	5 ab^{-1}	50 ab^{-1}
R_D	(6.0 ± 3.9)%	(2.0 ± 2.5)%
R_{D*}	(3.0 ± 2.5)%	(1.0 ± 2.0)%
$P_\tau(D*)$	(0.18 ± 0.08)	(0.06 ± 0.04)

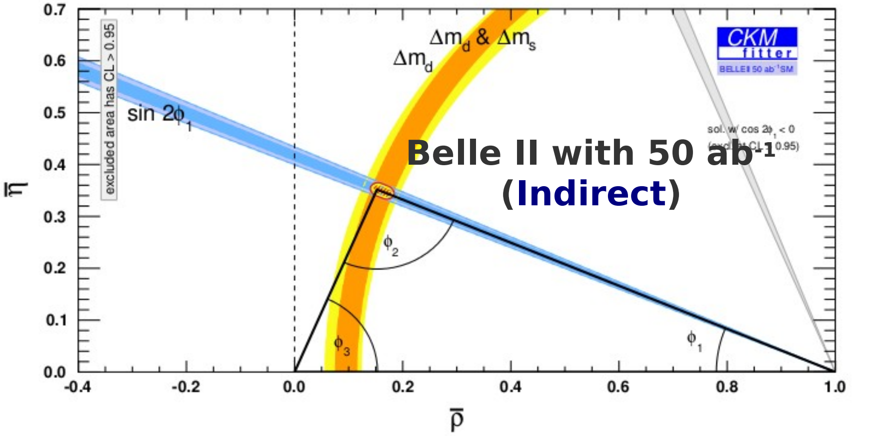
First uncertainty is statistical and second is systematic

Summary

- Belle II aims to provide 50 ab^{-1} at Y(4S) within its runtime (Belle: one ab^{-1})
- Measurements of the Belle II will test CKM unitarity with 1% precision.
- Most relevant contribution to using CKM physics to probe new physics is significant improvent of V_{ub} and Φ_3 at Belle II
- ~4σ discrepancy from the SM remains for the world average of R(D(*))
- The precision of all these measurements will be improved by the Belle II experiment
  (May point to new physics?)



Belle II with 50 ab^{-1}
(Direct)



Belle II with 50 ab^{-1}
(Indirect)

More Belle and Belle II Flavor talks

FP parallel session

- N. Dash: Recent results on FCNC B meson decays at Belle
- S. Sandilya: Radiative and Electroweak Penguin B Decays at Belle II
- Giacomo Caria: Recent results and prospects for $B \to D^{*}\tau\nu$, $B \to \tau\nu$, $B \to \mu\nu$ (already covered)

Plenary talk

- Phillip Urquijo: B physics recent results and future prospects at Belle II

Thank you!