Hot Topics at Belle and Belle II

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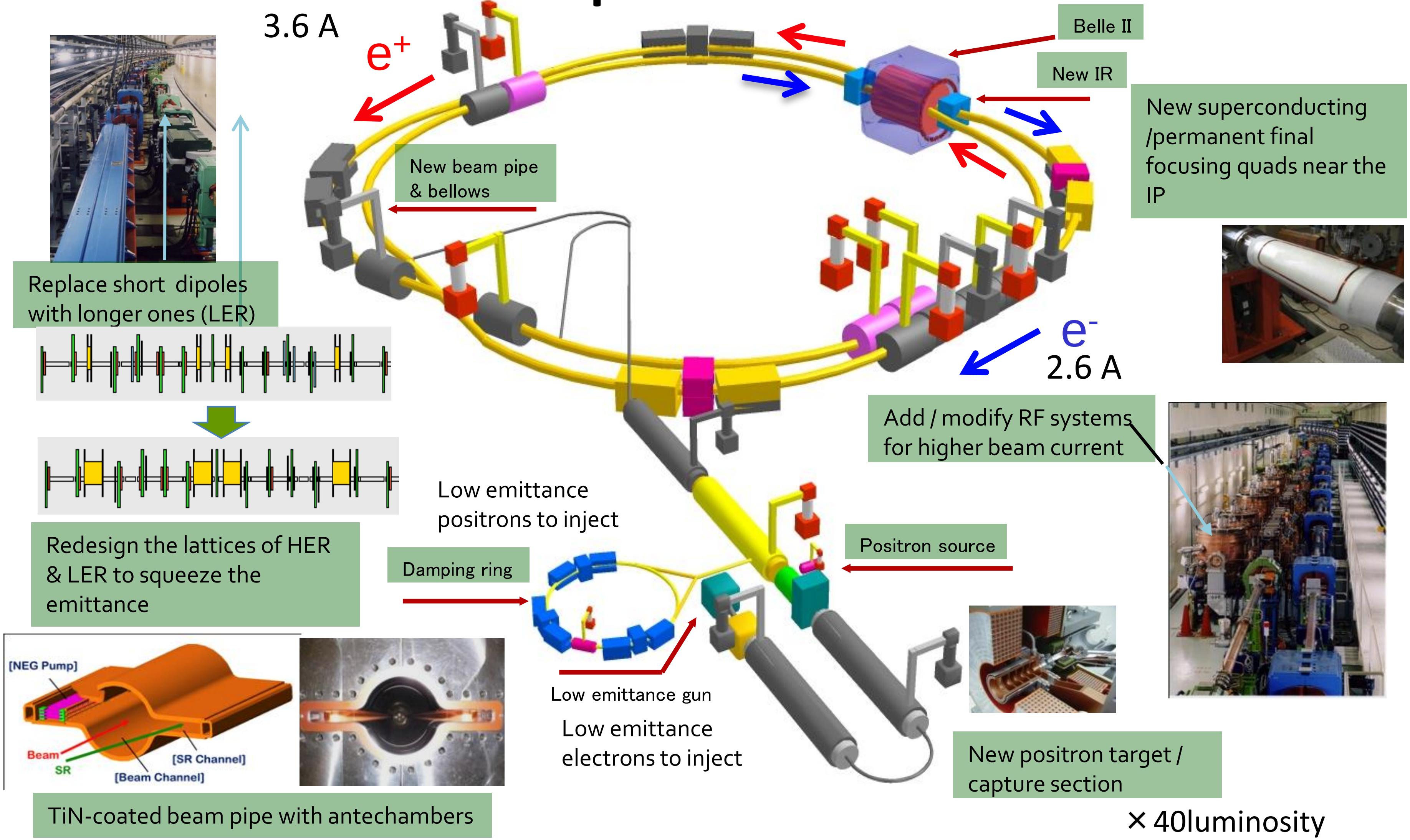
KEK Theory Meeting on Particle Physics Phenomenology (KEK-PH2018 winter)
and 3rd KIAS-NCTS-KEK workshop on Particle Physics Phenomenology

Outline

- SuperKEKB and BelleII detector
- Phase-2 and toward Phase-3
- Physics program
- Pick up topics
  - $B \to \ell\nu$
  - $B \to D^{(*)}\tau\nu$
  - $B \to K^{(*)}\ell\ell$
  - $B \to K^{(*)}\nu\nu$
  - τ LFV
- Summary

SuperKEKB



× 40luminosity

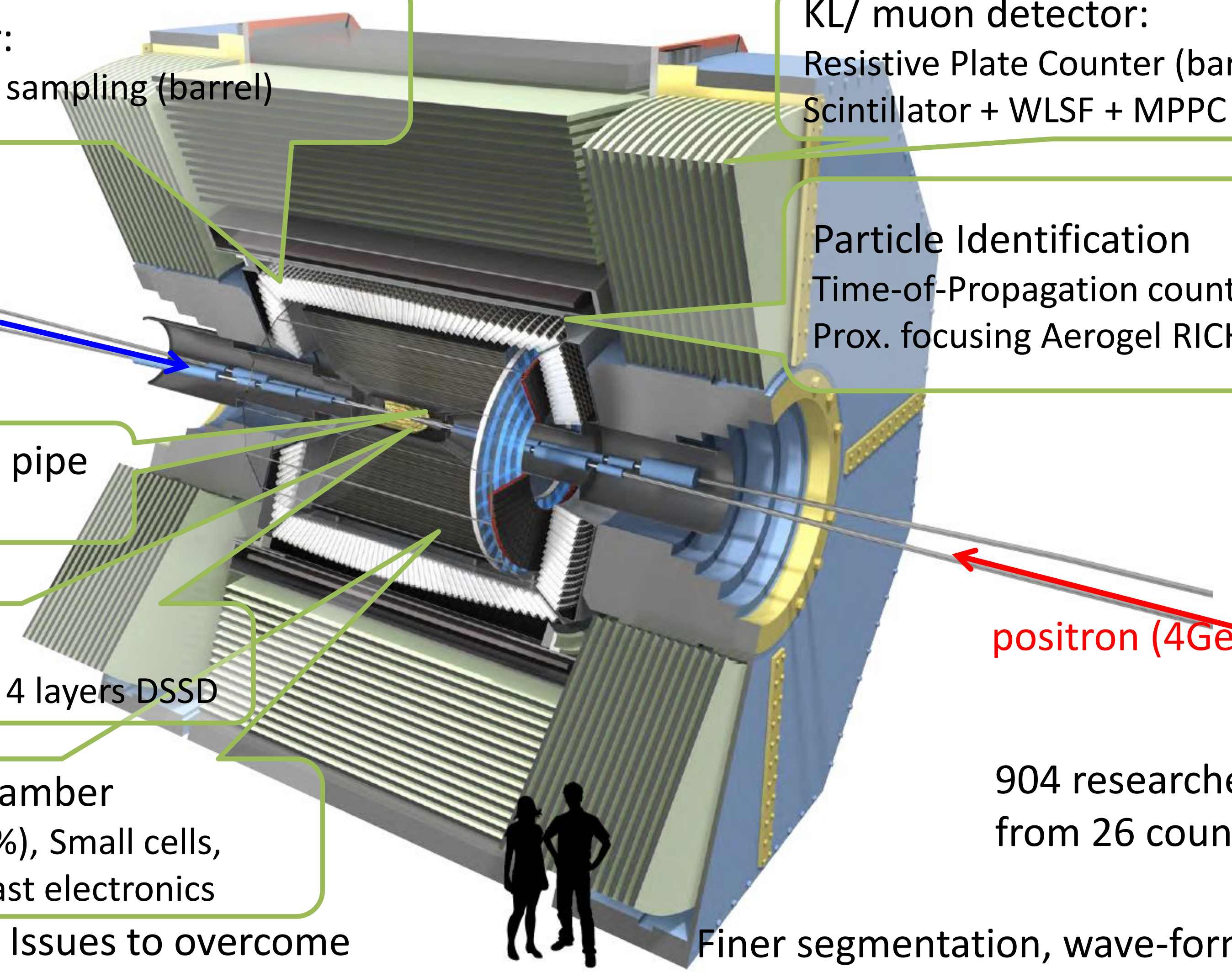
- Nano-beam
- Increases current

Peak luminosity: $2 \times 10^{34}\ cm^{-1}s^{-1} \rightarrow 8 \times 10^{35} cm^{-1}s^{-1}$

Increases current: 3.5/8.0 GeV→4.0/7.0 GeV

Boost factor~2/3

Belle II Detector



904 researchers
from 26 countries

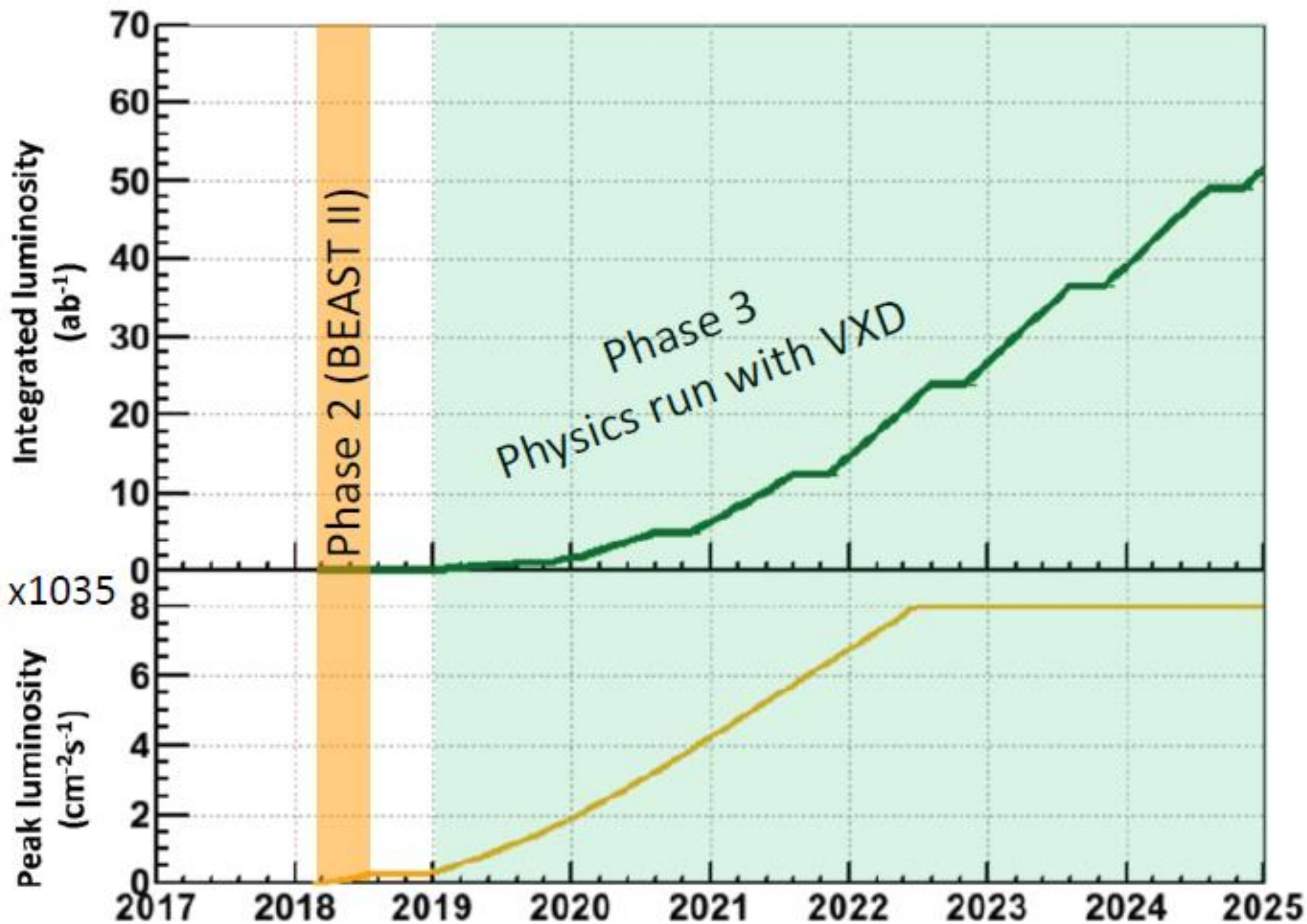
Issues to overcome
- Beam background
- High rate capability
- Boost ~2/3

Finer segmentation, wave-form sampling
Large angular coverage
Closer to the IP(3cm→2cm) Vertex det.
Particle ID improve(K/π)

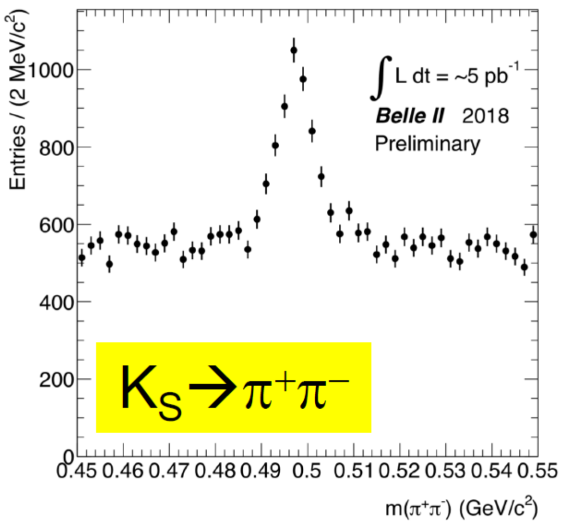
Luminosity prospect

Phase 2: Belle Ⅱ with BEAST(Partial vertex detector)

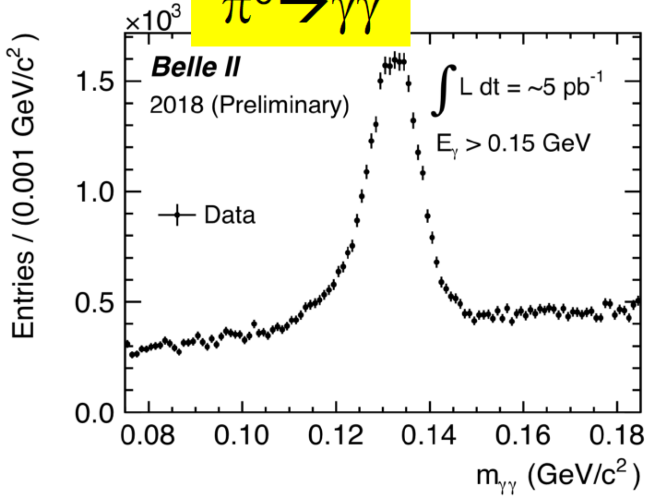
Phase 3: Belle Ⅱ detector with vertex detector



Rediscoveries in Phase-2

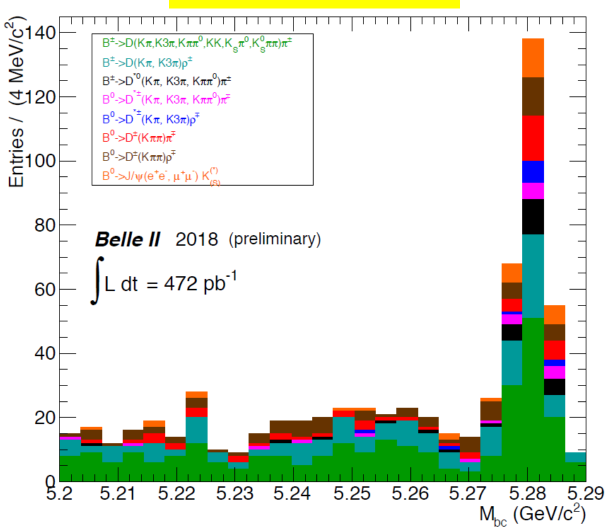


$\pi^0 \rightarrow \gamma\gamma$

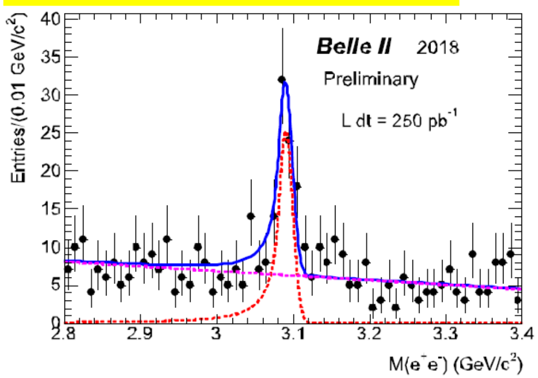


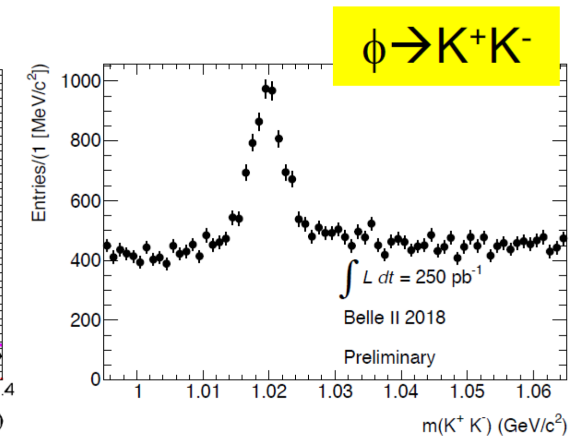
K_S,π^0 are confirmed in early ~5pb^{-1}.
Fully reconstructed B mesons are seen with ~250pb^{-1}.
Totally, 500pb^{-1} collected.

B mesons



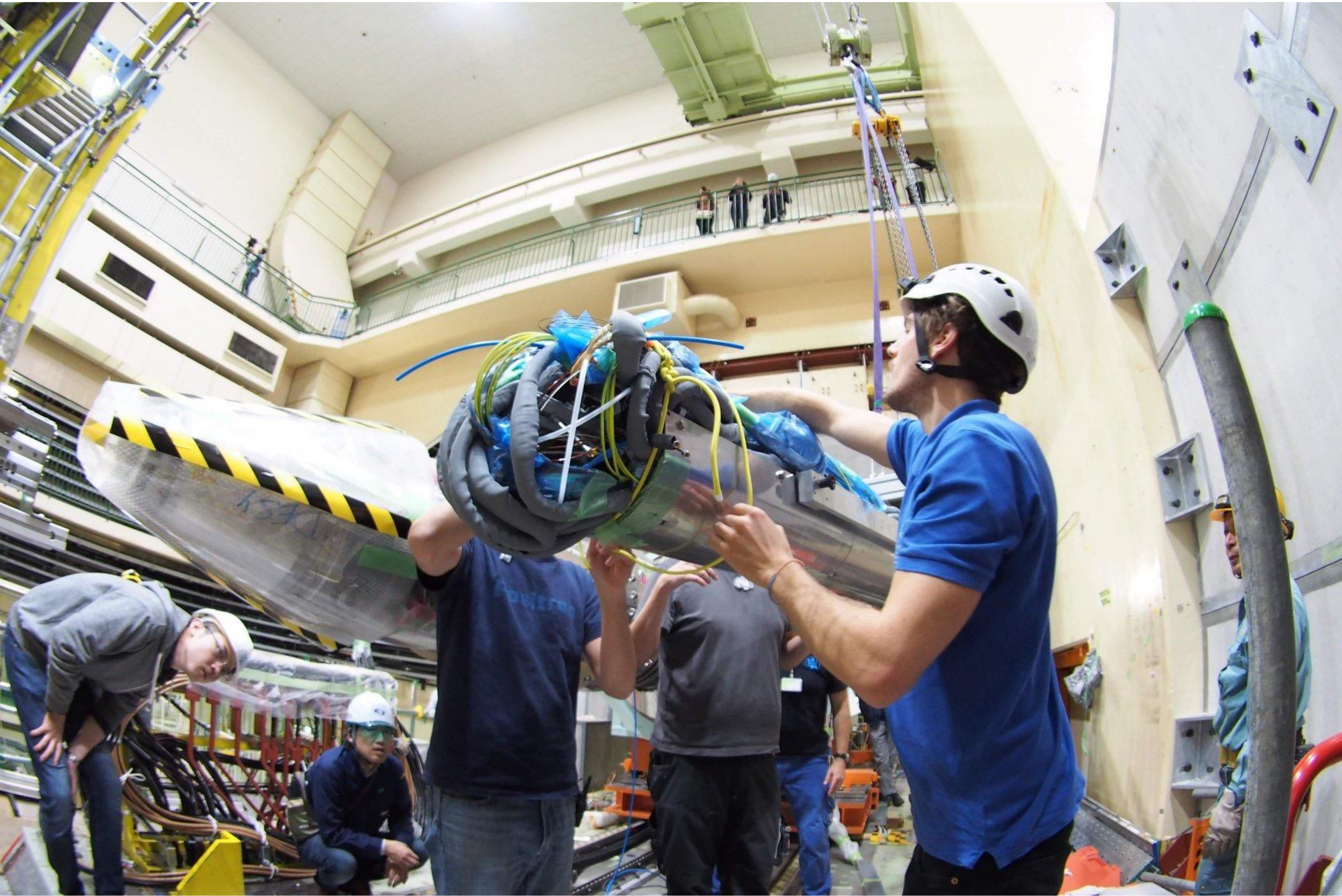
$J/\psi \rightarrow e^+e^-$



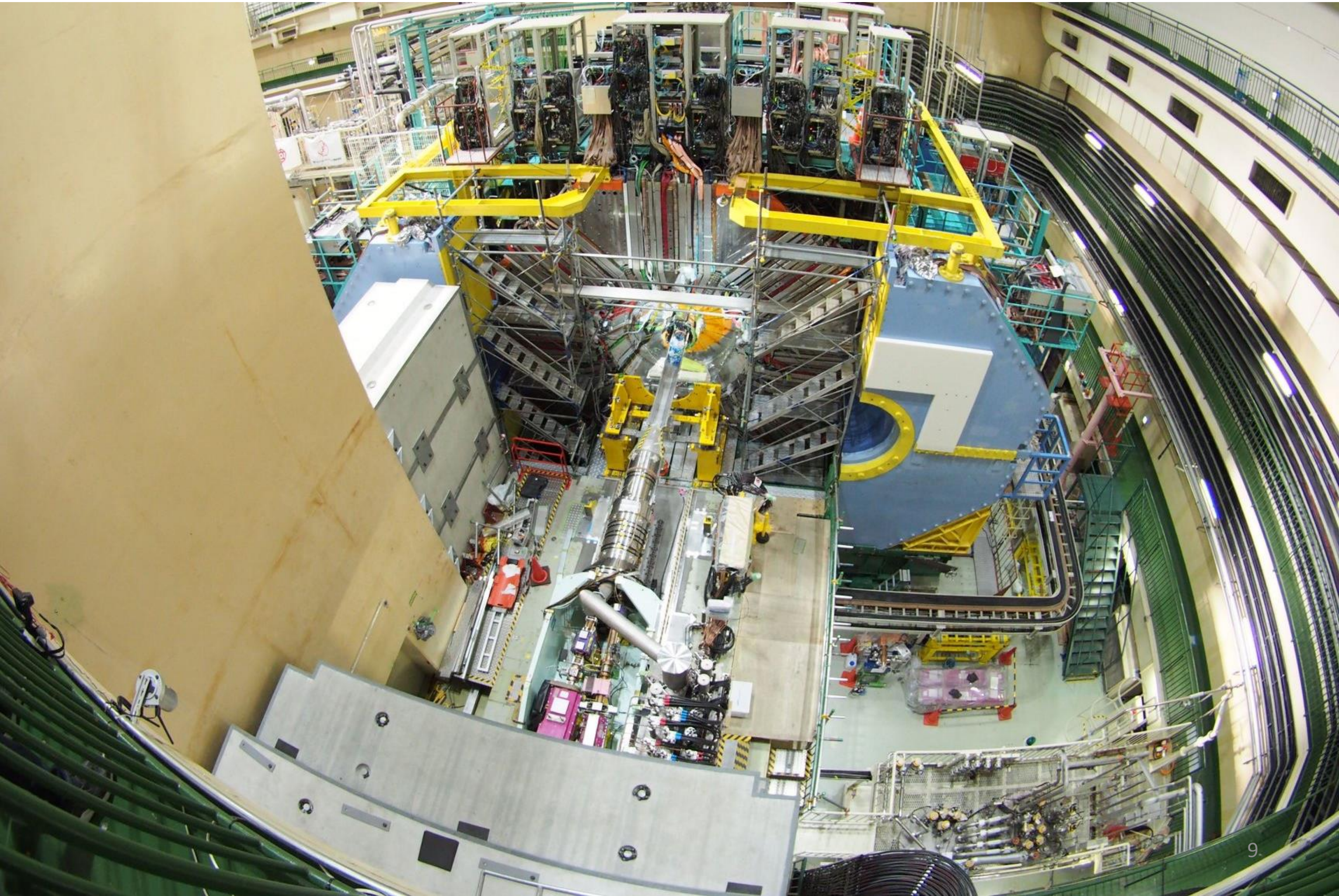


To Phase 3

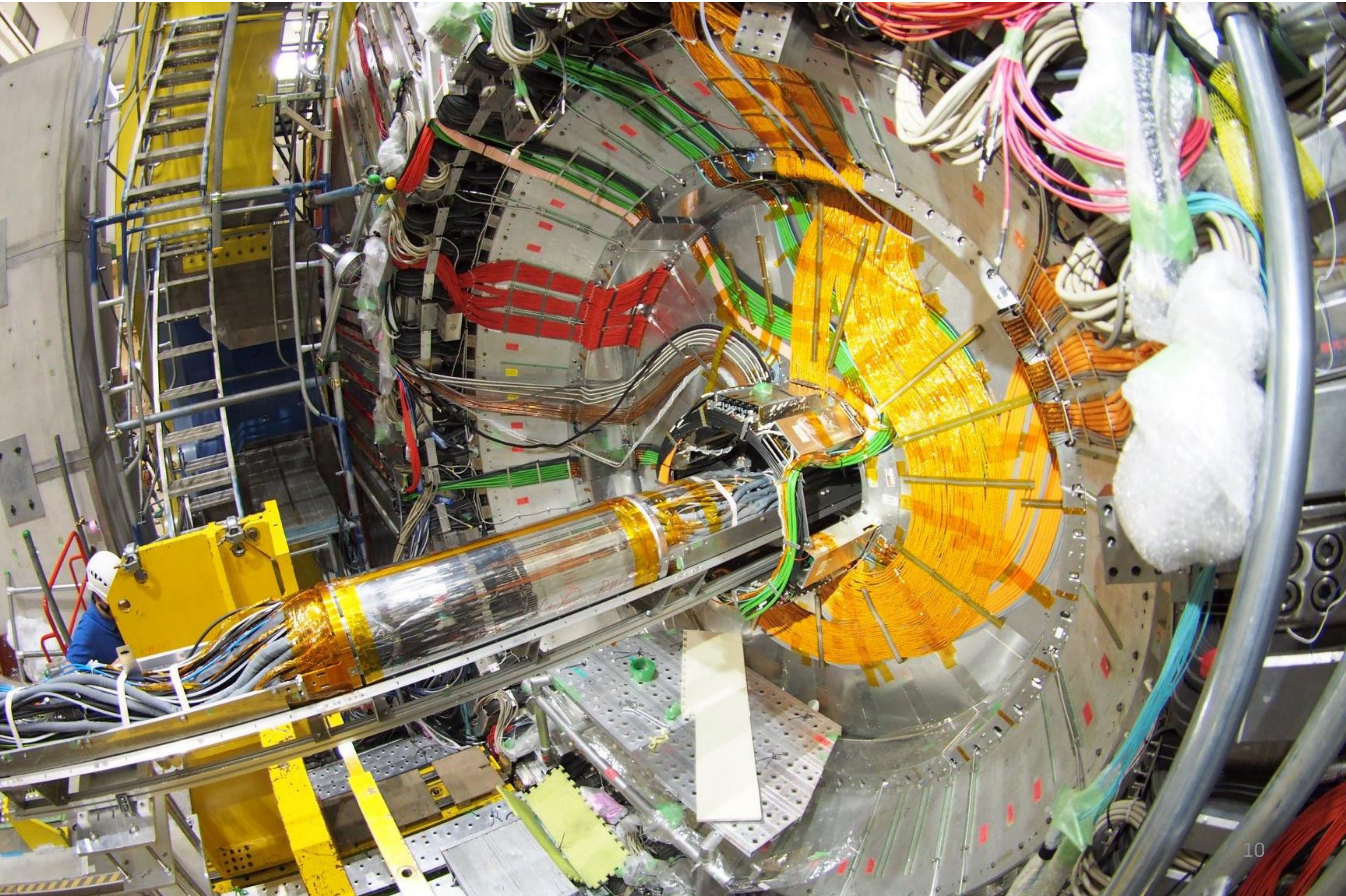
To Phase 3



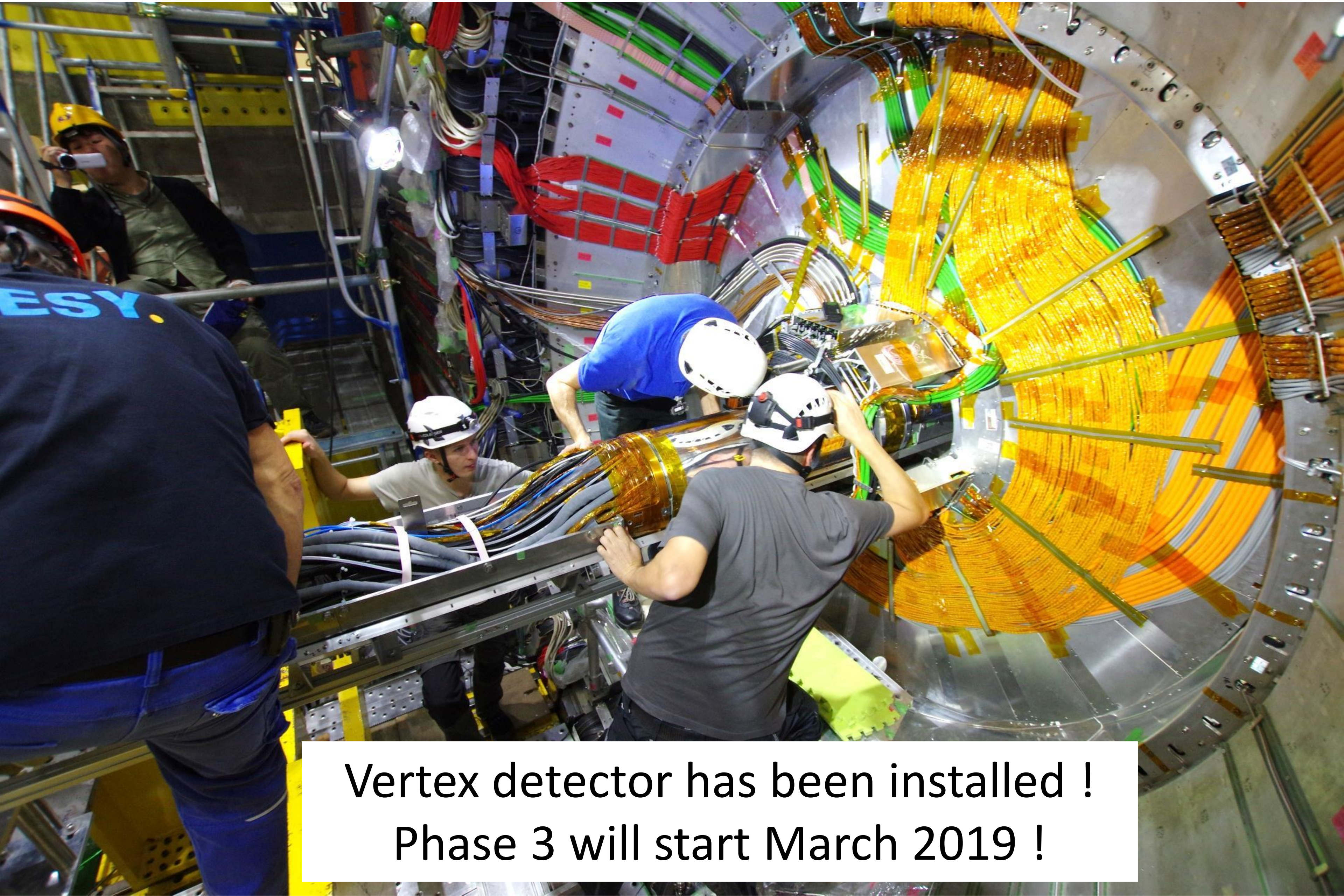
To Phase 3



To Phase 3



To Phase 3



Vertex detector has been installed !
Phase 3 will start March 2019 !

Belle Ⅱ physics program

“The Belle II Physics Book” arXiv.1808.10567

$\sigma(b\bar{b})$ = 1.1 nb

$\sigma(c\bar{c})$ = 1.6 nb

$\sigma(\tau^+\tau^-)$ = 0.9 nb

Category	Process	Observable	Theory	Sys. limit (Discovery) [ab^{-1}]	vs LHCb	vs Belle	Anomaly	NP
(Semi)leptonic	$B \to \pi \ell \nu_l$	$\|V_{ub}\|$	★★★	10-20	★★★	★★★	★★	★
	$B \to X_u \ell \nu_\ell$	$\|V_{ub}\|$	★★	2-10	★★★	★★	★★★	★
	$B \to \tau\nu$	$Br.$	★★★	>50 (2)	★★★	★★★	★	★★★
	$B \to \mu\nu$	$Br.$	★★★	>50 (5)	★★★	★★★	★	★★★
	$B \to D^{(*)} \ell \nu_\ell$	$\|V_{cb}\|$	★★★	1-10	★★★	★★	★★	★
	$B \to X_c \ell \nu_\ell$	$\|V_{cb}\|$	★★★	1-5	★★★	★★	★★	★★
	$B \to D^{(*)} \tau \nu_\tau$	$R(D^{(*)})$	★★★	5-10	★★	★★★	★★★	★★★
EW Penguin	$B \to K^{(*)} \nu\nu$	$Br., F_L$	★★★	>50	★★★	★★★	★	★★
	$B \to X_{s+d}\gamma$	A_{CP}	★★★	>50	★★★	★★★	★	★★
	$B \to X_d\gamma$	A_{CP}	★★	>50	★★★	★★★	-	★★
	$B \to K_S^0 \pi^0 \gamma$	$S_{K_S^0 \pi^0 \gamma}$	★★	>50	★★	★★★	★	★★★
	$B \to \rho\gamma$	$S_{\rho\gamma}$	★★	>50	★★★	★★★	-	★★★
	$B \to X_s l^+ l^-$	$Br.$	★★★	>50	★★★	★★	★★	★★★
	$B \to X_s l^+ l^-$	R_{X_s}	★★★	>50	★★★	★★★	★★	★★★
	$B \to K^{(*)} e^+ e^-$	$R(K^{(*)})$	★★★	>50	★★	★★★	★★★	★★★
ϕ_1,ϕ_2 tree, penguin	$B \to J/\psi K_S^0$	ϕ_1	★★★	5-10	★★	★★	★	★
	$B \to \phi K_S^0$	ϕ_1	★★	>50	★★	★★★	★	★★★
	$B \to \eta' K_S^0$	ϕ_1	★★	>50	★★	★★★	★	★★★
	$B \to \rho^\pm \rho^0$	ϕ_2	★★★	-	★	★★★	★	★
ϕ_3	GGSZ	ϕ_3	★★★	>50	★★	★★★	★	★★
	GLW	ϕ_3	★★★	>50	★★	★★★	★	★★
	ADS	ϕ_3	★★	>50	★★	★★★	★	★★★
charmless	$B \to \pi^0 K^0$	$A_{CP}, I_{K\pi}$	★★	-	★★★	★★★	★★★	★★
	$B \to \rho K$	$A_{CP}, I_{K\rho}$	★	-	★★	★★★	-	★★
	$B \to \ell\nu\gamma$	λ_B	★★	-	★★★	★★★	★	★★
	$B \to \rho K^*$	γ polari.	★★	-	★★	★★	-	★★★
	$B \to K^+K^-/\pi^+\pi^-$	$Br., A_{CP}$	★★	-	★	★★★	★★	★★
charm	$D^0 \to K_S^0 K_S^0$	A_{CP}	★★★	-	★★★	★★	★	★
	$D^+ \to \pi^+ \pi^0$	A_{CP}	★★★	-	★★★	★★	★	★★
	$D_s \to \ell^+ \nu$	f_{D_s}	★★★	-	★★★	★	-	★★
τ and low multiplicity	$\tau \to \mu\gamma$	$Br.$	★★★	>50	★★★	★★★	★	★★★
	$\tau \to lll$	$Br.$	★★★	>50	★★★	★★★	★	★★★
	$\tau \to K\pi\nu$	A_{CP}	★★★	-	★★★	★★★	★★	★★
	$e^+e^- \to \gamma A'(\to$invisible$)$	σ	★★★	-	★★★	★★★	★	★★★
	$e^+e^- \to \gamma A'(\to \ell^+\ell^-)$	σ	★★★	-	★★★	★★★	★	★★★

Belle Ⅱ as a super B, τ, Charm factory. The Golden/Silver observables well defined.

CKM matrix V_{CKM}

N. Cabibbo, PRL.10, 531 (1963);M. Kobayashi and T. Maskawa, Prog. Theor. Phys. 49, 652 (1973).
I. I. Bigi and A. I. Sanda, Phys. Lett. B 211, 213 (1988).

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

#of complex phase
=(n-1)(n-2)/2

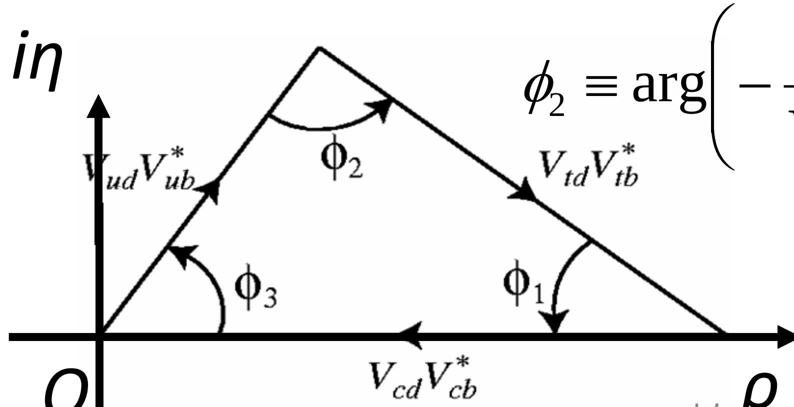
$$V_{CKM} \equiv \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

λ ~ 0.22, A ~ 0.80

diagonal→Favored
Off-diagonal→Suppressed

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

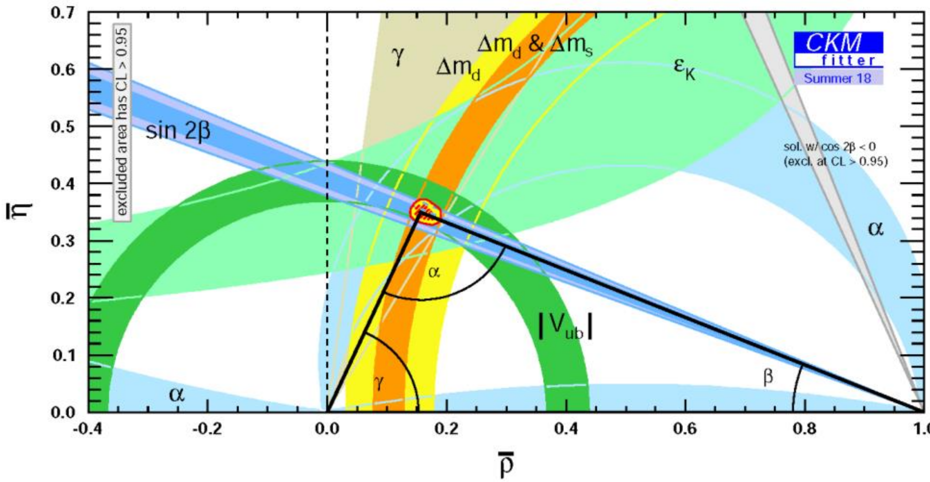
$$\phi_2 \equiv \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*} \right)$$

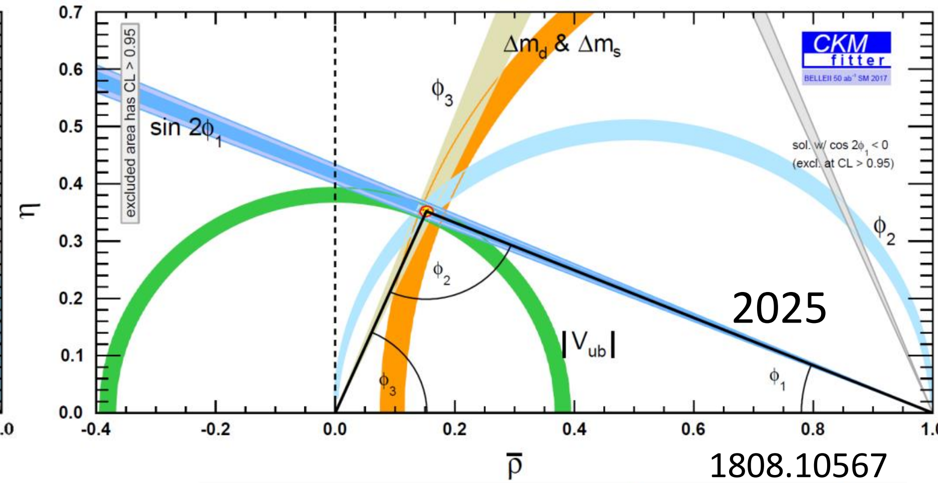


$$\phi_3 \equiv \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} \right)$$

$$\phi_1 \equiv \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*} \right)$$

CKM UT triangle



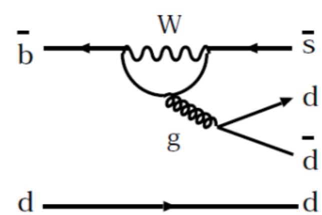


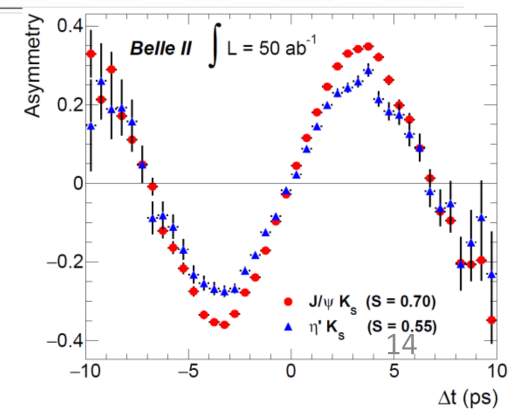
1808.10567

Input	World average 2016	Belle II (+LHCb) 2025	SM-like Belle II (+LHCb) 2025
$\lvert V_{ub}\rvert$(semileptonic)$[10^{-3}]$	$4.01 \pm 0.08 \pm 0.22$	± 0.10	3.71 ± 0.09
$\lvert V_{cb}\rvert$(semileptonic)$[10^{-3}]$	$41.00 \pm 0.33 \pm 0.74$	± 0.57	41.80 ± 0.60
$\mathcal{B}(B \to \tau\nu)$	1.08 ± 0.21	± 0.04	0.817 ± 0.03
$\sin 2\phi_1$	0.691 ± 0.017	± 0.008	0.710 ± 0.008
$\phi_3[^\circ]$	$73.2^{+6.3}_{-7.0}$	± 1.5 (± 1.0)	67 ± 1.5 (± 1.0)
$\phi_2[^\circ]$	$87.6^{+3.5}_{-3.3}$	± 1.0	90.4 ± 1.0

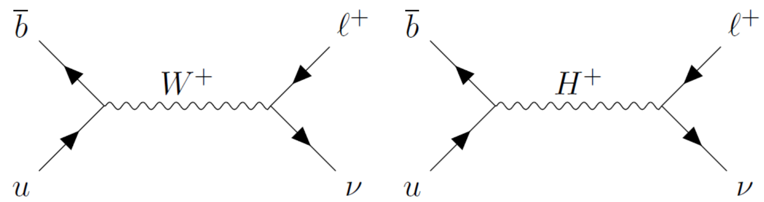
	WA (2017)		5 ab^{-1}		50 ab^{-1}	
Channel	$\sigma(S)$	$\sigma(A)$	$\sigma(S)$	$\sigma(A)$	$\sigma(S)$	$\sigma(A)$
$J/\psi K^0$	0.022	0.021	0.012	0.011	0.0052	0.0090
ϕK^0	0.12	0.14	0.048	0.035	0.020	0.011
$\eta' K^0$	0.06	0.04	0.032	0.020	0.015	0.008
ωK^0_S	0.21	0.14	0.08	0.06	0.024	0.020
$K^0_S \pi^0 \gamma$	0.20	0.12	0.10	0.07	0.031	0.021
$K^0_S \pi^0$	0.17	0.10	0.09	0.06	0.028	0.018

UT measured by tree decay →SM anchor point.
Additional new phase from NP can shift the angle.





B→τν and B→μν



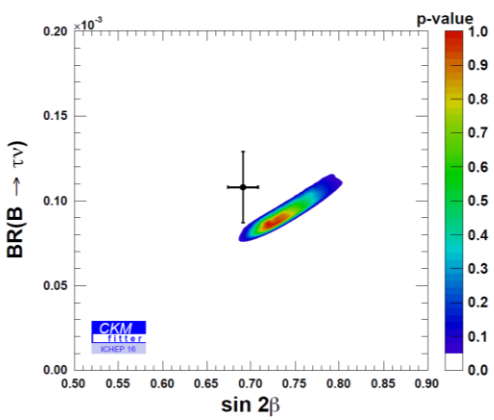
$$\mathcal{B}(B \to \tau \bar{\nu}_\tau) = \frac{\tau_{B^-} G_F^2 |V_{ub}|^2 f_B^2}{8\pi} m_B m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 |1 + r_{\rm NP}|^2 ,$$

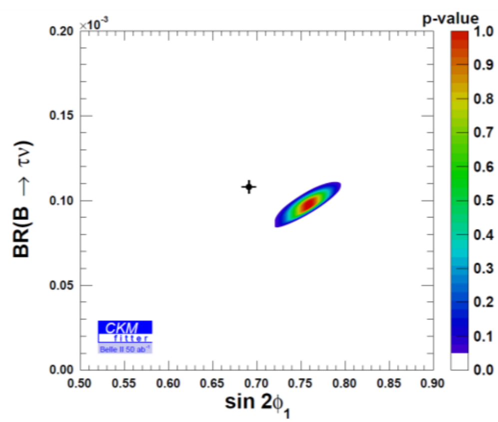
$$r_{\rm NP} = C_{V_1} - C_{V_2} + \frac{m_B^2}{m_b m_\tau} (C_{S_1} - C_{S_2}) .$$

PTEP. **2017**, 013B05
Model indep. approach

- $B_{SM}(B\to\tau\nu)$ =$(7.71\pm0.62)\times10^{-5}$ 1808.10567
- $B_{meas}(B\to\tau\nu)$ =$(10.6\pm1.9)\times10^{-5}$ 1612.07233
- $B_{SM}(B\to\mu\nu)$ =$(3.46\pm0.28)\times10^{-7}$ 1808.10567
- $B_{meas}(B\to\mu\nu)$ =$(6.46\pm2.22\pm1.60)\times10^{-7}$ 2.4 σ excess(Belle) PRL121.031801

→5 σ@BelleII ~6 ab^{-1}





	Integrated Luminosity (ab^{-1})	1	5	50
hadronic tag	statistical uncertainty (%)	29	13	4
	systematic uncertainty (%)	13	7	5
	total uncertainty (%)	32	15	6
semileptonic tag	statistical uncertainty (%)	19	8	3
	systematic uncertainty (%)	18	9	5
	total uncertainty (%)	26	12	5

ΔBR ~ 5 % level@ 50 ab^{-1}

Ratio of B→τν to B→μν

$$R_{\rm ps} = \frac{\tau_{B^0}}{\tau_{B^-}} \frac{\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \to \pi^+ \ell^- \bar{\nu}_\ell)} = (0.539 \pm 0.043) \left|1 + r^\tau_{\rm NP}\right|^2$$

$$R_{\rm pl} = \frac{\mathcal{B}(B \to \tau \bar{\nu}_\tau)}{\mathcal{B}(B \to \mu \bar{\nu}_\mu)} = \frac{m_\tau^2}{m_\mu^2} \frac{(1 - m_\tau^2/m_B^2)^2}{(1 - m_\mu^2/m_B^2)^2} |1 + r_{\rm NP}|^2 \simeq 222\,|1 + r_{\rm NP}|^2.$$

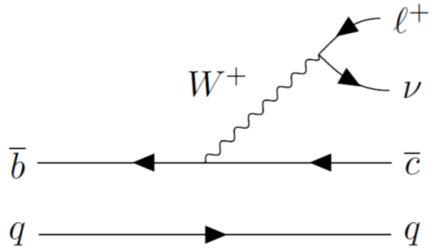
Current measurement $R_{\rm ps} =$ 0.73 ± 0.14, $R_{\rm pl}$ Not yet

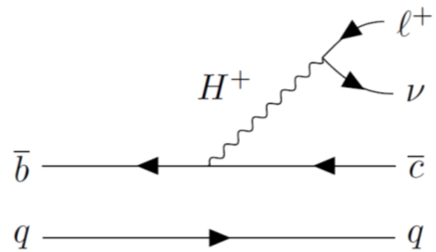
Luminosity	$R_{\rm ps}$ $r^\tau_{\rm NP}$	$R_{\rm pl}$ $r^\tau_{\rm NP}$
$5\,{\rm ab}^{-1}$	$[-0.22, 0.20]$	$[-0.42, 0.29]$
$50\,{\rm ab}^{-1}$	$[-0.11, 0.12]$	$[-0.12, 0.11]$

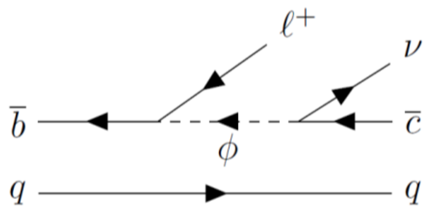
95 % C.L.
1808.10567

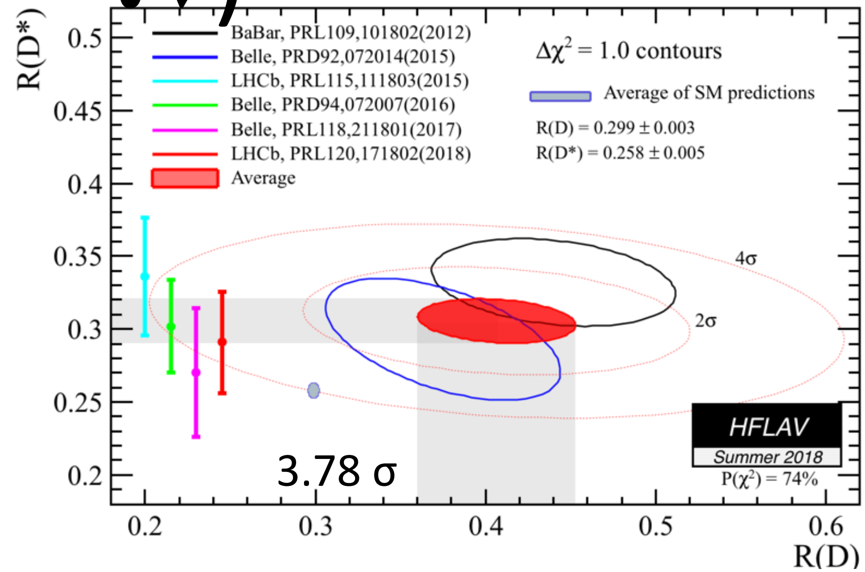
$r_{NP}{}^{\tau} < O(0.1)$ can be tested.
Further sensitivity can be achieved for direct ratio measurement to cancel some experimental systematic uncertainty

Br(B→D$^{(*)}$τν)









$$R_{D^{(*)}} = \frac{\mathrm{Br}(B \to D^{(*)}\tau\nu_\tau)}{\mathrm{Br}(B \to D^{(*)}\ell\nu_\ell)},$$

$R_{D(*)}{}^{SM}$ = 0.258 ± 0.005, $R_D{}^{SM}$ = 0.299 ± 0.003

	5 ab^{-1}	50 ab^{-1}
R_D	$(\pm 6.0 \pm 3.9)\%$	$(\pm 2.0 \pm 2.5)\%$
R_{D^*}	$(\pm 3.0 \pm 2.5)\%$	$(\pm 1.0 \pm 2.0)\%$

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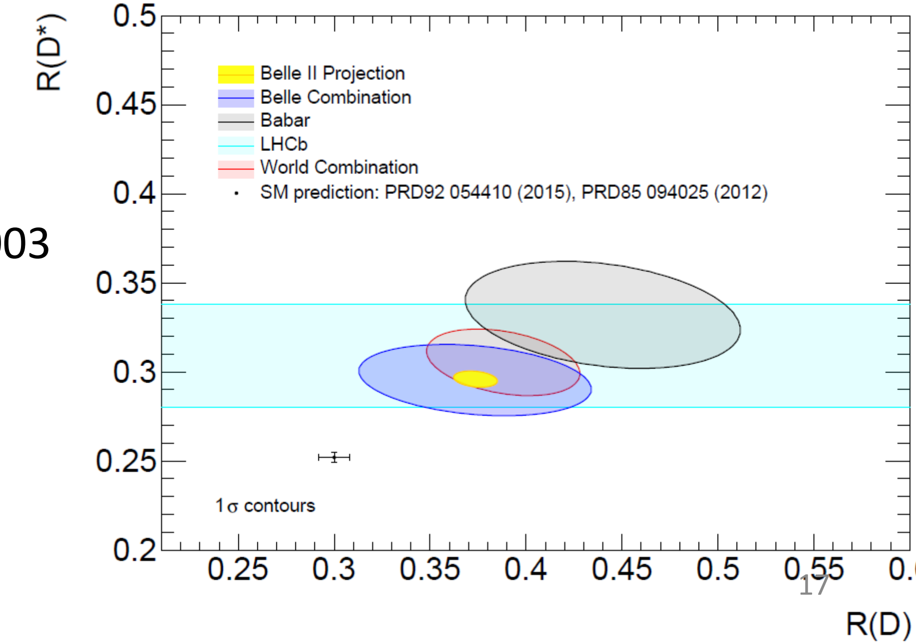
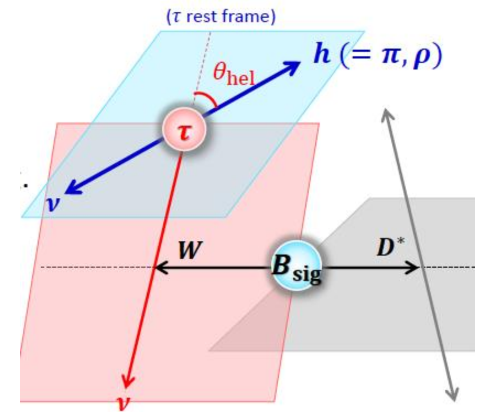


τ polarization in B→D$^{(*)}$τν



$$\frac{1}{\Gamma(D^{(*)})}\frac{d\Gamma(D^{(*)})}{d\cos\theta_{\rm hel}} = \frac{1}{2}[1+\alpha P_\tau(D^{(*)})\cos\theta_{\rm hel}],$$

$\alpha = 1$ for $\tau^- \to \pi^- \nu_\tau$

$\alpha = 0.45$ for $\tau^- \to \rho^- \nu_\tau$

$$P_\tau(D^*) = \frac{2}{\alpha_i}\frac{N^{Fij}_{\rm sig} - N^{Bij}_{\rm sig}}{N^{Fij}_{\rm sig} + N^{Bij}_{\rm sig}},$$

FW-BW asymmetry

where

$$N^{Fij}_{\rm sig} = N^{ij}_{\rm sig}\int_0^1 \frac{d\Gamma^{ij}(D^{(*)})}{d\cos\theta_{\rm hel}}\,d\cos\theta_{\rm hel}, \quad \text{FW}$$

$$N^{Bij}_{\rm sig} = N^{ij}_{\rm sig}\int_{-1}^0 \frac{d\Gamma^{ij}(D^{(*)})}{d\cos\theta_{\rm hel}}\,d\cos\theta_{\rm hel}. \quad \text{BW}$$

- Measurement(Belle) PRL118.211801(2017), PRD97.012004(2018)

$$P_\tau(D^*) = -0.38 \pm 0.51({\rm stat})^{+0.21}_{-0.16}({\rm syst}),$$

- SM expectation PRD82,034027(2010), PRD87,034028(2013)

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

	5 ab^{-1}	50 ab^{-1}
$P_\tau(D^*)$	$\pm 0.18 \pm 0.08$	$\pm 0.06 \pm 0.04$

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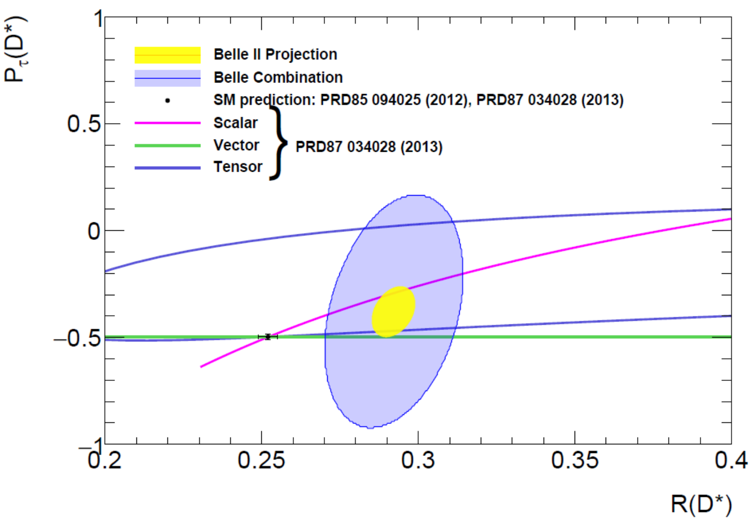


τ polarization is sensitive for NP structure with R(D*).
The q^2 information also has the sensitivity. Full angular analysis will be the challenge at BelleII.

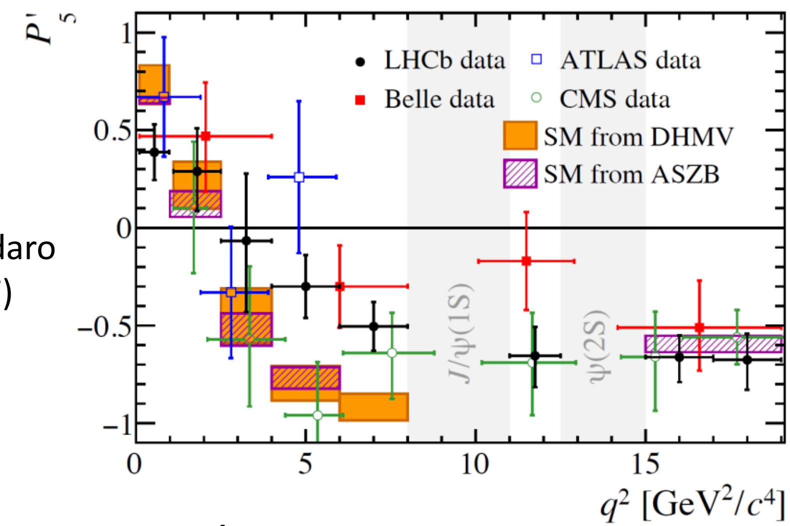
Angular analysis of $B^0 \to K^{*0}\ell^+\ell^-$

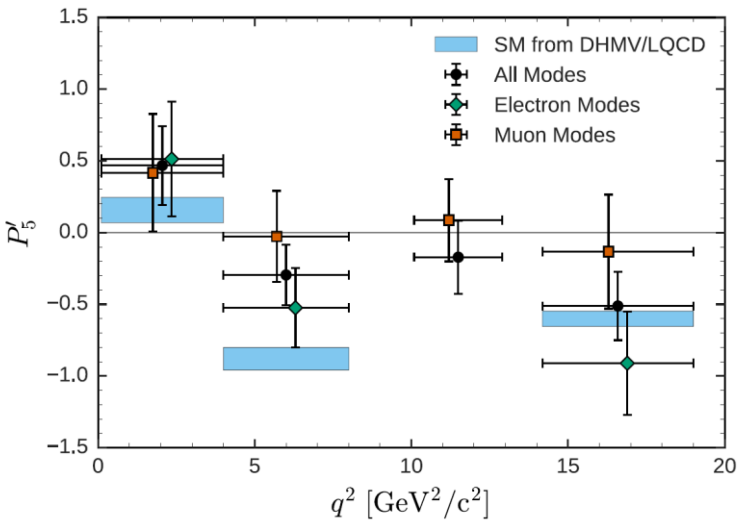
- Transversity basis $A_{\perp,\parallel,0}$ and lepton chirality L,R
  $\to$ 6 amplitudes $A_{\perp,\parallel,0}^{L,R}$

JHEP01(2009)019
JHEP02(2016)104
PRL118,111801(2017)

- $P_5' \propto \mathrm{Re}(A_0^L A_\perp^{L*} - A_0^R A_\perp^{R*})$ approximately expressed by $C_7^{(\prime)}$, $C_9^{(\prime)}$, $C_{10}^{(\prime)}$
- LHCb: 2.8 σ and 3.0 σ deviation in P_5' in muon mode.
- Belle : 2.6 σ(1.3 σ) deviation in P_5' in the muon(electron) mode.

J. Prisciandaro (FPCP2017)

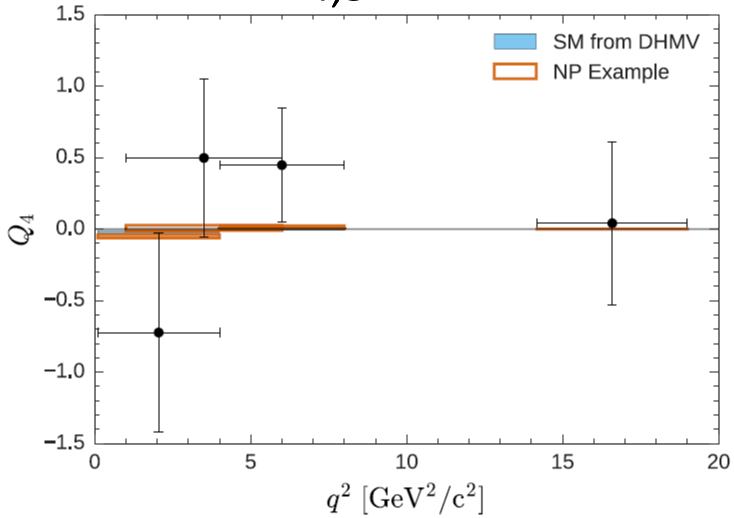


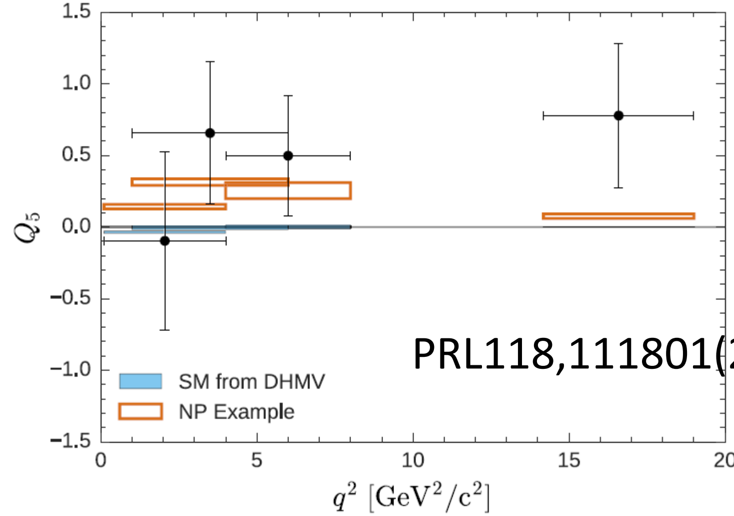


Naïve extrapolation:
2.8 ab^{-1} of BelleII data(~2020)→ Comparable uncertainty to LHCb 3 fb^{-1} at q^2[4,6].
50 ab^{-1} of BelleII data(~2025) → Slightly 20 % larger uncertainty of LHCb 50 fb^{-1}.
With the muon mode, Belle II has an unique measurement for electron mode.

LFU in $B^0 \to K^{(*)0} \ell^+ \ell^-$ angular analysis

- LFUV observable $Q_{4,5}$ ($=P_{4,5}^{\mu'} - P_{4,5}^{e'}$) meas. by Belle
- Non-zero $Q_{4,5}$ would point to NP JHEP10(2016)075





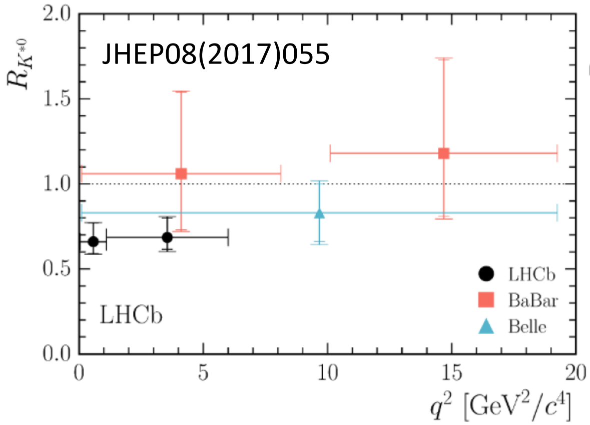
PRL118,111801(2017)

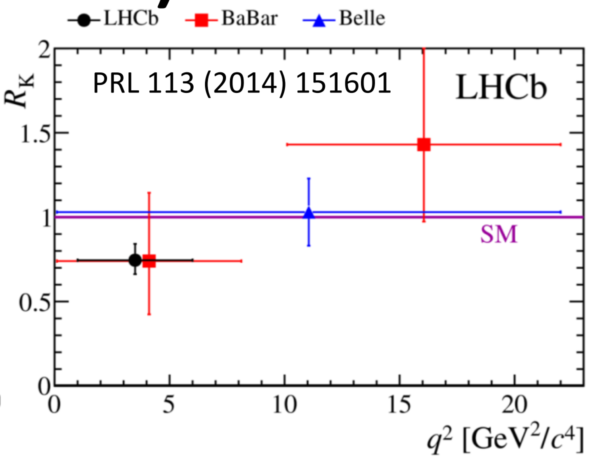
- Belle II

Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
Q_4 ([1.0, 2.5] GeV^2)	0.50	0.18	0.056
Q_4 ([2.5, 4.0] GeV^2)	0.45	0.15	0.049
Q_4 ([4.0, 6.0] GeV^2)	0.34	0.12	0.040
Q_5 ([1.0, 2.5] GeV^2)	0.47	0.17	0.054
Q_5 ([2.5, 4.0] GeV^2)	0.42	0.15	0.049
Q_5 ([4.0, 6.0] GeV^2)	0.34	0.12	0.040

$\Delta Q_{4,5}$~ 5 % level@ 50 ab^{-1}
1808.10567

LFU in $R(K^{(*)})$ and the double ratio





$$\mathcal{R}_{K^{(*)}} \equiv \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)}.$$

Observables	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
R_K ([1.0, 6.0] GeV^2)	11%	3.6%
R_K (> 14.4 GeV^2)	12%	3.6%
R_{K^*} ([1.0, 6.0] GeV^2)	10%	3.2%
R_{K^*} (> 14.4 GeV^2)	9.2%	2.8%
R_{X_s} ([1.0, 6.0] GeV^2)	12%	4.0%
R_{X_s} (> 14.4 GeV^2)	11%	3.4%

JHEP02(2015)055

$$R_K \simeq 1 + \Delta_+ ,$$
$$R_{K_0(1430)} \simeq 1 + \Delta_- ,$$
$$R_{K^*} \simeq 1 + p\,(\Delta_- - \Delta_+) + \Delta_+ ,$$
$$R_{X_s} \simeq 1 + (\Delta_+ + \Delta_-)/2 ,$$

where

$$\Delta_\pm = \frac{2}{|C_9^{\rm SM}|^2 + |C_{10}^{\rm SM}|^2}\left[{\rm Re}\left(C_9^{\rm SM}(C_9^{{\rm NP}\mu} \pm C_9'^{\mu})^*\right) + {\rm Re}\left(C_{10}^{\rm SM}(C_{10}^{{\rm NP}\mu} \pm C_{10}'^{\mu})^*\right) - (\mu \to e)\right].$$

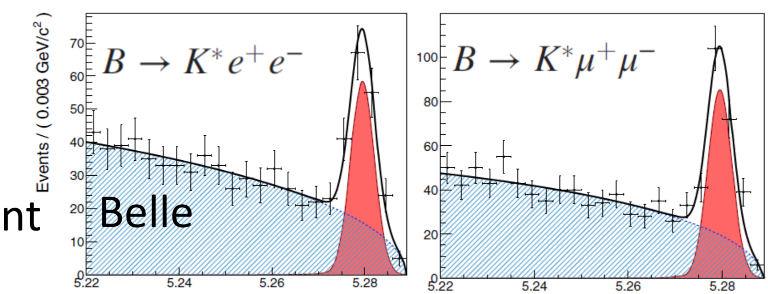
$p \simeq 0.86$, $C_{10}^{SM} = -4.2$, $C_9^{SM} = 4.2$ (at m_b scale)

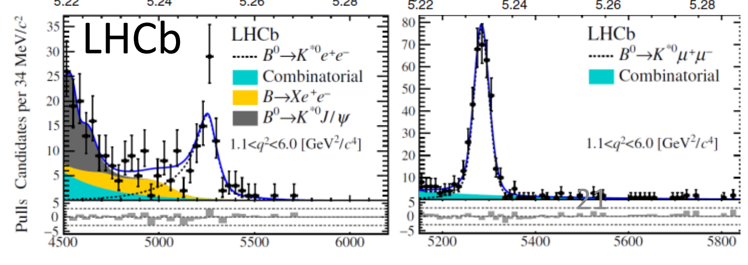
R_H can constrain $C_9^{(')NP\ell}$, $C_{10}^{(')NP\ell}$

Double ratio $X_H \equiv R_H/R_K$

$$X_{K_0(1430)} \simeq 1 + \Delta_- - \Delta_+ ,$$
$$X_{K^*} \simeq 1 + p\,(\Delta_- - \Delta_+) ,$$
$$X_{X_s} \simeq 1 + \frac{1}{2}(\Delta_- - \Delta_+) .$$

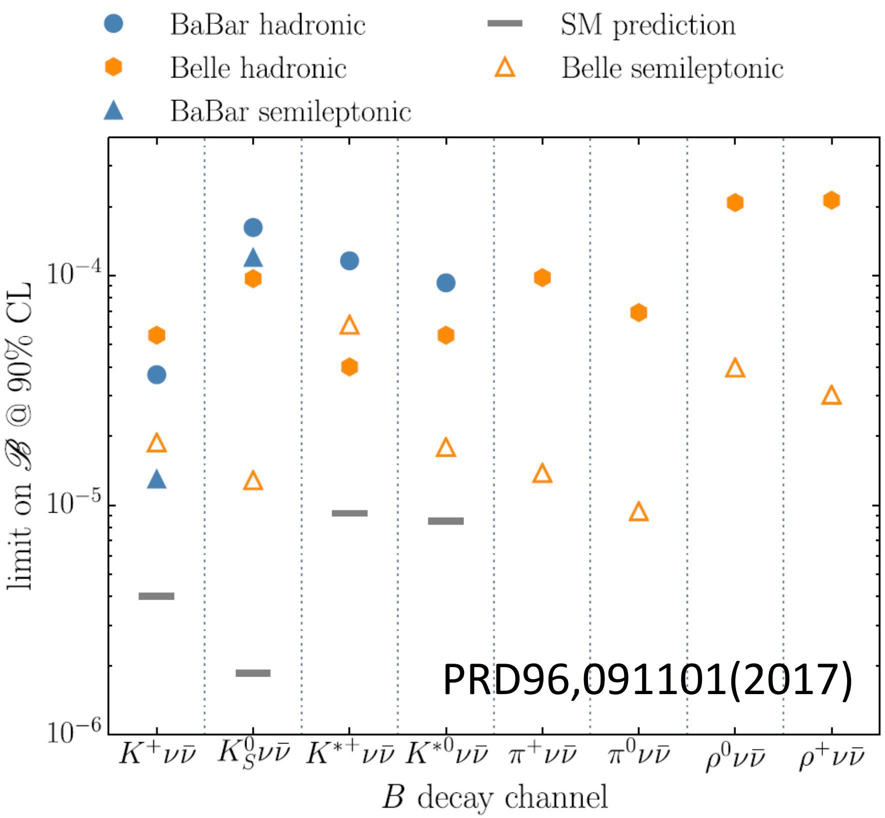
$\Delta_- - \Delta_+$ cancels left-handed current
double ratio X_H can only probe right-handed current $C_i'O_i'$

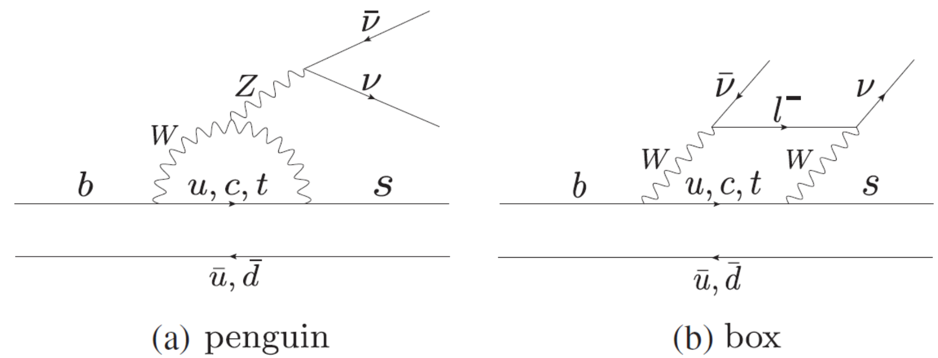




Belle(II) has a symmetric detection eff. for electron/muon
May be easier to control the systematic uncertainties.

B→K(*)νν





Observables	Belle 0.71 ab^{-1} (0.12 ab^{-1})	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathrm{Br}(B^+ \to K^+\nu\bar{\nu})$	$< 450\%$	30%	11%
$\mathrm{Br}(B^0 \to K^{*0}\nu\bar{\nu})$	$< 180\%$	26%	9.6%
$\mathrm{Br}(B^+ \to K^{*+}\nu\bar{\nu})$	$< 420\%$	25%	9.3%
$F_L(B^0 \to K^{*0}\nu\bar{\nu})$	–	–	0.079
$F_L(B^+ \to K^{*+}\nu\bar{\nu})$	–	–	0.077
$\mathrm{Br}(B^0 \to \nu\bar{\nu}) \times 10^6$	< 14	< 5.0	< 1.5

1808.10567

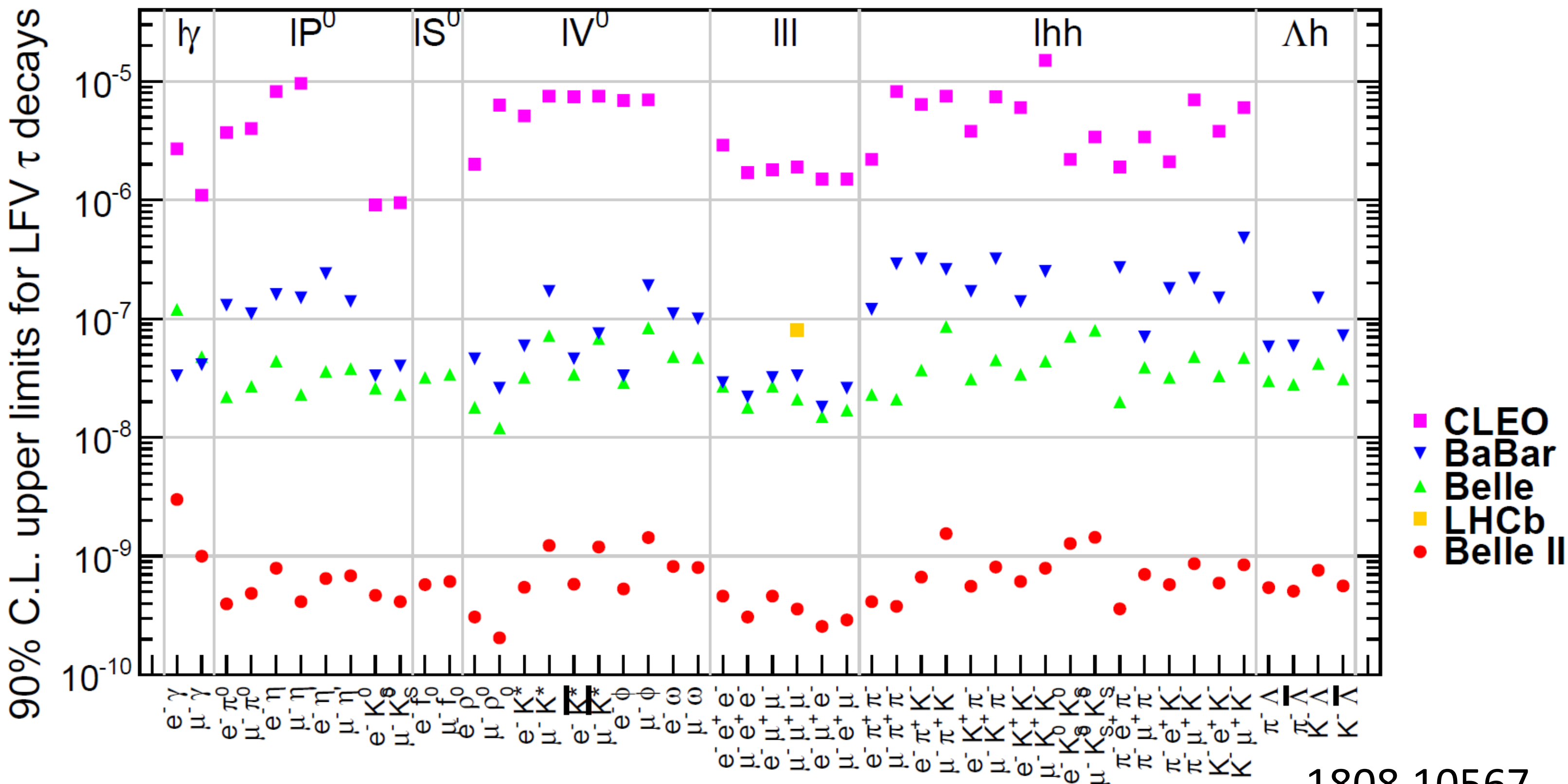
2.3 σ excess@K*νν by Belle
Will be observed at 10 ab^{-1} (~2021)

Unknown flavor of ν.
If NP couples mostly to the third generation lepton, anomaly may be in this mode?
This mode may enhance from SM expectation.

τ LFV

$\tau \to \ell\ell\ell$, $\tau \to \mu\gamma$,... (ℓ=e,μ)

BR can be enhanced by some NP scenarios to be detectable~$O(10^{-8})$



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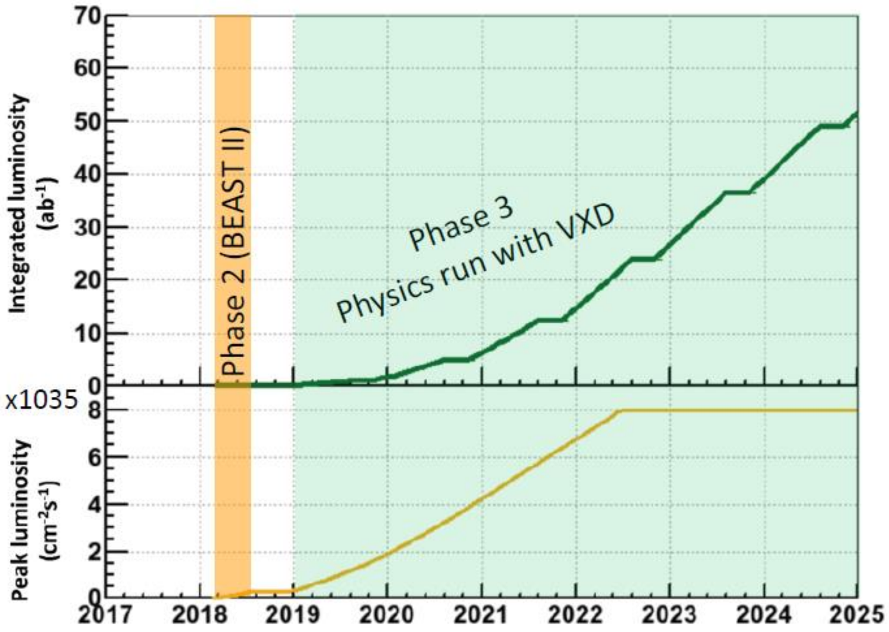
Summary

- Belle Ⅱ @SuperKEKB successor to Belle@KEKB
- Phase2 achieved 1st collision and rediscovery of particles.
- Phase3 preparation on going and will start March 2019.
- Interesting physics modes, Golden modes, are predefined well and the details are gathered in “The Belle Ⅱ Physics Book ” arXiv.1808.10567
- Many physics programs; NP through the CPV, FUV, FLV in B-meson and τ–lepton.
- Large part of current flavor anomalies will be clarified after a couple of years.



backup

$B^0 \to K^{*0} \ell^+ \ell^-$ Wilson coefficient

JHEP11(2011)121/122

Within the SM, the effective Hamiltonian for the quark-level transition $b \to s\mu^+\mu^-$ is

$$\mathcal{H}_{\rm eff}^{\rm SM} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \left\{ \sum_{i=1}^{6} C_i(\mu)\mathcal{O}_i(\mu) + C_7 \frac{e}{16\pi^2} [\bar{s}\sigma_{\mu\nu}(m_s P_L + m_b P_R) b] F^{\mu\nu} + C_9 \frac{\alpha_{em}}{4\pi} (\bar{s}\gamma^\mu P_L b)\, \bar{\mu}\gamma_\mu \mu + C_{10} \frac{\alpha_{em}}{4\pi} (\bar{s}\gamma^\mu P_L b)\, \bar{\mu}\gamma_\mu\gamma_5 \mu \right\}, \quad (2.1)$$

where $P_{L,R} = (1 \mp \gamma_5)/2$. The operators $\mathcal{O}_i$ $(i = 1, \ldots 6)$ correspond to the P_i in ref. [31], and $m_b = m_b(\mu)$ is the running b-quark mass in the $\overline{\rm MS}$ scheme. We use the SM Wilson coefficients as given in ref. [61]. In the magnetic dipole operator with the coefficient C_7, we neglect the term proportional to m_s.

We now add new physics to the effective Hamiltonian for $b \to s\mu^+\mu^-$, so that it becomes

$$\mathcal{H}_{\rm eff}(b \to s\mu^+\mu^-) = \mathcal{H}_{\rm eff}^{\rm SM} + \mathcal{H}_{\rm eff}^{VA} + \mathcal{H}_{\rm eff}^{SP} + \mathcal{H}_{\rm eff}^{T}, \quad (2.4)$$

where $\mathcal{H}_{\rm eff}^{\rm SM}$ is given by eq. (2.1), while

$$\mathcal{H}_{\rm eff}^{VA} = -\frac{4G_F}{\sqrt{2}} \frac{\alpha_{em}}{4\pi} V_{ts}^* V_{tb} \left\{ R_V (\bar{s}\gamma^\mu P_L b)\, \bar{\mu}\gamma_\mu \mu + R_A (\bar{s}\gamma^\mu P_L b)\, \bar{\mu}\gamma_\mu\gamma_5 \mu + R'_V (\bar{s}\gamma^\mu P_R b)\, \bar{\mu}\gamma_\mu \mu + R'_A (\bar{s}\gamma^\mu P_R b)\, \bar{\mu}\gamma_\mu\gamma_5 \mu \right\}, \quad (2.5)$$

$$\mathcal{H}_{\rm eff}^{SP} = -\frac{4G_F}{\sqrt{2}} \frac{\alpha_{em}}{4\pi} V_{ts}^* V_{tb} \left\{ R_S (\bar{s}P_R b)\, \bar{\mu}\mu + R_P (\bar{s}P_R b)\, \bar{\mu}\gamma_5\mu + R'_S (\bar{s}P_L b)\, \bar{\mu}\mu + R'_P (\bar{s}P_L b)\, \bar{\mu}\gamma_5\mu \right\}, \quad (2.6)$$

$$\mathcal{H}_{\rm eff}^{T} = -\frac{4G_F}{\sqrt{2}} \frac{\alpha_{em}}{4\pi} V_{ts}^* V_{tb} \left\{ C_T (\bar{s}\sigma_{\mu\nu} b) \bar{\mu}\sigma^{\mu\nu}\mu + i C_{TE} (\bar{s}\sigma_{\mu\nu} b) \bar{\mu}\sigma_{\alpha\beta}\mu\ \epsilon^{\mu\nu\alpha\beta} \right\} \quad (2.7)$$

are the new contributions. Here, $R_V, R_A, R'_V, R'_A, R_S, R_P, R'_S, R'_P, C_T$ and C_{TE} are the NP effective couplings. We do not consider NP in the form of the $O_7 = \bar{s}\sigma^{\alpha\beta} P_R b\, F_{\alpha\beta}$ operator or its chirally-flipped counterpart $O'_7 = \bar{s}\sigma^{\alpha\beta} P_L b\, F_{\alpha\beta}$. This is because there has been no hint of NP in the radiative decays $\bar{B} \to X_s\gamma, \bar{K}^{(*)}\gamma$ [45], which imposes strong constraints

NP couplings

$R_V, R_A, R'_V, R'_A, R_S, R_P, R'_S, R'_P, C_T$ and C_{TE} are

Real...CP conserving

Complex...CP violating

B→K$^{(*)}\ell\ell$ angular analysis

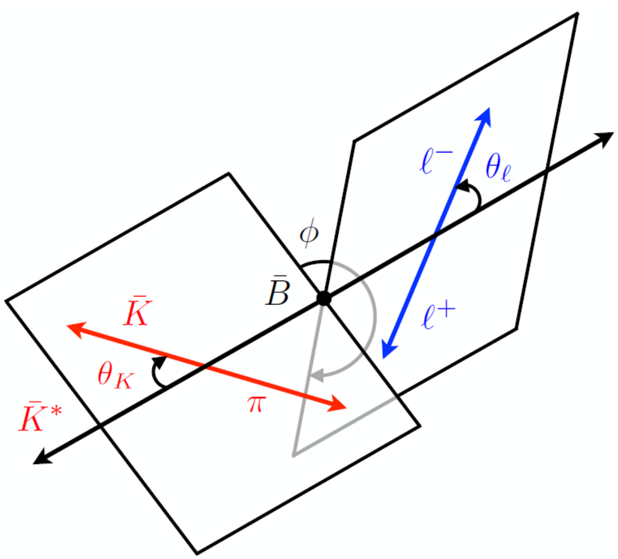
JHEP11(2011)121, 122

$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{d\cos\theta_\ell\, d\cos\theta_K\, d\phi\, dq^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi$$
$$+ S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + S_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi$$
$$+ S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big],$$

$A_{FB}=3/4S_6$

$$F_L = S_{1c} = \frac{|\mathcal{A}_0^L|^2 + |\mathcal{A}_0^R|^2}{|\mathcal{A}_0^L|^2 + |\mathcal{A}_0^R|^2 + |\mathcal{A}_\parallel^L|^2 + |\mathcal{A}_\parallel^R|^2 + |\mathcal{A}_\perp^L|^2 + |\mathcal{A}_\perp^R|^2}.$$

i	I_i	f_i
1s	$\frac{3}{4}\left[|\mathcal{A}_\parallel^L|^2 + |\mathcal{A}_\perp^L|^2 + |\mathcal{A}_\parallel^R|^2 + |\mathcal{A}_\perp^R|^2\right]$	$\sin^2\theta_K$
1c	$|\mathcal{A}_0^L|^2 + |\mathcal{A}_0^R|^2$	$\cos^2\theta_K$
2s	$\frac{1}{4}\left[|\mathcal{A}_\parallel^L|^2 + |\mathcal{A}_\perp^L|^2 + |\mathcal{A}_\parallel^R|^2 + |\mathcal{A}_\perp^R|^2\right]$	$\sin^2\theta_K\cos 2\theta_l$
2c	$-|\mathcal{A}_0^L|^2 - |\mathcal{A}_0^R|^2$	$\cos^2\theta_K\cos 2\theta_l$
3	$\frac{1}{2}\left[|\mathcal{A}_\perp^L|^2 - |\mathcal{A}_\parallel^L|^2 + |\mathcal{A}_\perp^R|^2 - |\mathcal{A}_\parallel^R|^2\right]$	$\sin^2\theta_K\sin^2\theta_l\cos 2\phi$
4	$\sqrt{\frac{1}{2}}\mathrm{Re}(\mathcal{A}_0^L\mathcal{A}_\parallel^{L*} + \mathcal{A}_0^R\mathcal{A}_\parallel^{R*})$	$\sin 2\theta_K\sin 2\theta_l\cos\phi$
5	$\sqrt{2}\mathrm{Re}(\mathcal{A}_0^L\mathcal{A}_\perp^{L*} - \mathcal{A}_0^R\mathcal{A}_\perp^{R*})$	$\sin 2\theta_K\sin\theta_l\cos\phi$
6s	$2\mathrm{Re}(\mathcal{A}_\parallel^L\mathcal{A}_\perp^{L*} - \mathcal{A}_\parallel^R\mathcal{A}_\perp^{R*})$	$\sin^2\theta_K\cos\theta_l$
7	$\sqrt{2}\mathrm{Im}(\mathcal{A}_0^L\mathcal{A}_\parallel^{L*} - \mathcal{A}_0^R\mathcal{A}_\parallel^{R*})$	$\sin 2\theta_K\sin\theta_l\sin\phi$
8	$\sqrt{\frac{1}{2}}\mathrm{Im}(\mathcal{A}_0^L\mathcal{A}_\perp^{L*} + \mathcal{A}_0^R\mathcal{A}_\perp^{R*})$	$\sin 2\theta_K\sin 2\theta_l\sin\phi$
9	$\mathrm{Im}(\mathcal{A}_\parallel^{L*}\mathcal{A}_\perp^L + \mathcal{A}_\parallel^{R*}\mathcal{A}_\perp^R)$	$\sin^2\theta_K\sin^2\theta_l\sin 2\phi$



CP-averaged observables
insensitive to form-factor uncertainty

$$P_1 = \frac{2S_3}{(1-F_L)} = A_T^{(2)},$$
$$P_2 = \frac{2}{3}\frac{A_{FB}}{(1-F_L)} = (1/2)A_T^{(re)}$$
$$P_3 = \frac{-S_9}{(1-F_L)} = (-1/2)A_T^{(im)}$$
$$P'_{4,5,8} = \frac{S_{4,5,8}}{\sqrt{F_L(1-F_L)}},$$
$$P'_6 = \frac{S_7}{\sqrt{F_L(1-F_L)}}.$$

$B \to K^{(*)}\ell\ell$

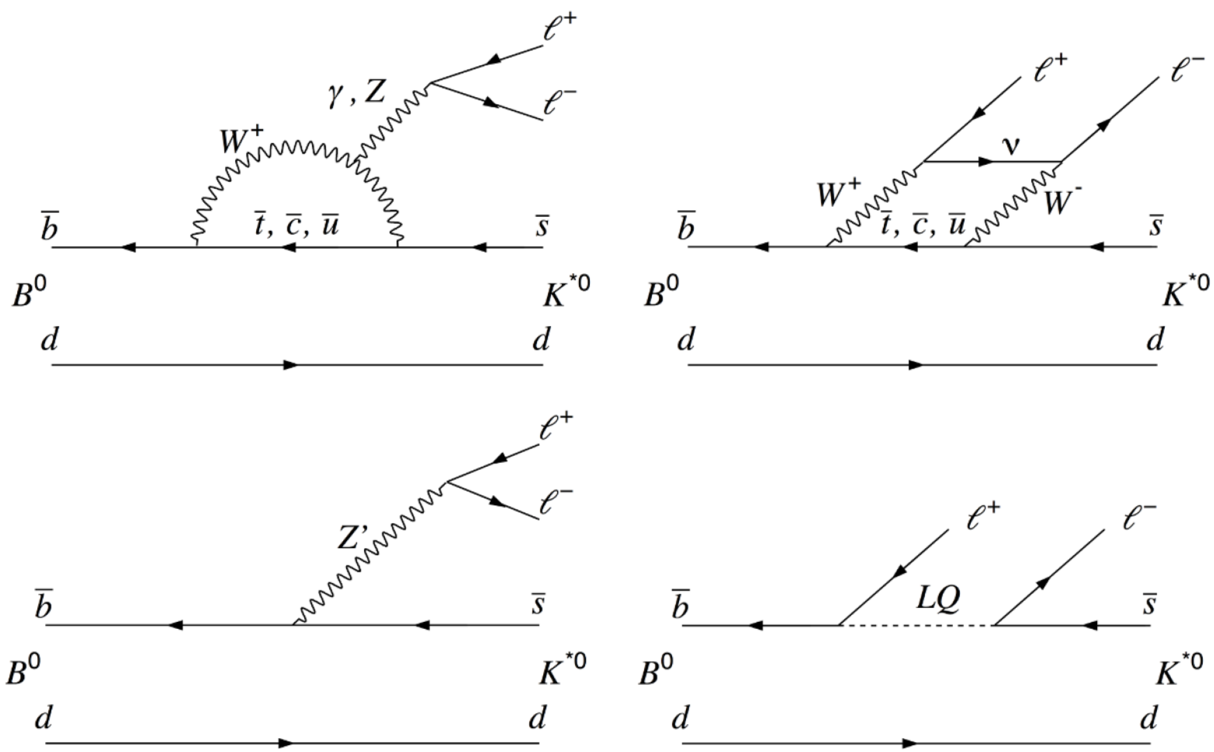


Figure 1. Feynman diagrams in the SM of the $B^0 \to K^{*0}\ell^+\ell^-$ decay for the (top left) electroweak penguin and (top right) box diagram. Possible NP contributions violating LU: (bottom left) a tree-level diagram mediated by a new gauge boson Z' and (bottom right) a tree-level diagram involving a leptoquark LQ.

$B^0 \to K^{*0}\ell^+\ell^-$ CP-conserving/violating observables

JHEP11(2011)121 (CP Conserving)

Observable	SM	Only new VA	Only new SP	Only new T
$B_d^0 \to K^* \mu^+\mu^-$				
DBR		• E (×2) • S (÷2)	No effect	• E (×2)
A_{FB}	ZC≈ 3.9 GeV^2	• E at low q^2 • ZC shift / disappearence	No effect	• Significant S • ZC shift
f_L	• 0.9 → 0.3 (low→high q^2)	• Large S	No effect	• Significant S
$A_T^{(2)}$	• ↑ with q^2 • No ZC	• E (×2) • ZC possible	No effect	• Significant S
A_{LT}	• ZC at low q^2 • more -ve at large q^2	• Significant S • ZC shift / disappearence	No effect	• Significant S

Table 1. The effect of NP couplings on observables. E(×n): enhancement by up to a factor of n, S(÷n): suppression by up to a factor of n, ZC: zero crossing.

JHEP11(2011)122(CP violating)

Observable	SM	Only new VA	Only new SP	Only new T
$B_d^0 \to K^* \mu^+\mu^-$				
A_{CP}	• $10^{-3} \to 10^{-4}$ (low→high q^2)	• (9 → 14)% (low→high q^2)	No effect	• < 1%
ΔA_{FB}	• $10^{-4} \to 10^{-6}$ (low→high q^2)	• (6 → 19)% (low→high q^2)	No effect	• < 1%
Δf_L	• $10^{-4} \to 10^{-7}$ (low→high q^2)	• (9 → 16)% (low→high q^2)	No effect	• < 1%
$\Delta A_T^{(2)}$	Zero	• ∼ 12%	No effect	No effect
ΔA_{LT}	Zero	• < 3%	No effect	No effect
$A_T^{(im)}$	Zero	• ∼ 50%	No effect	No effect
$A_{LT}^{(im)}$	Zero	• ∼ 10%	No effect	No effect

Table 1. The effect of NP couplings on observables. E: enhancement, S: suppression. The numbers given are optimistic estimates.

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Observables	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$A_T^{(2)}$ ([0.002, 1.12] GeV^2)	0.21	0.066
A_T^{Im} ([0.002, 1.12] GeV^2)	0.20	0.064

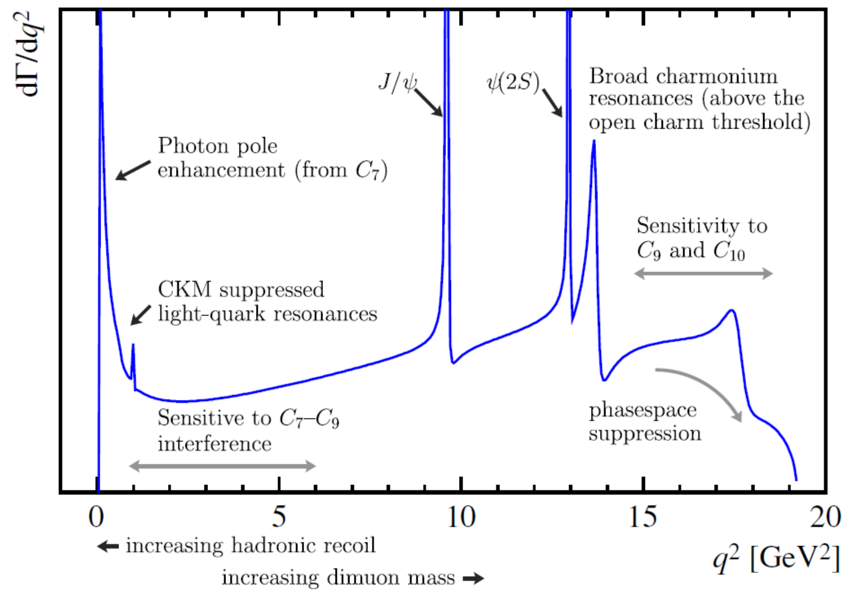
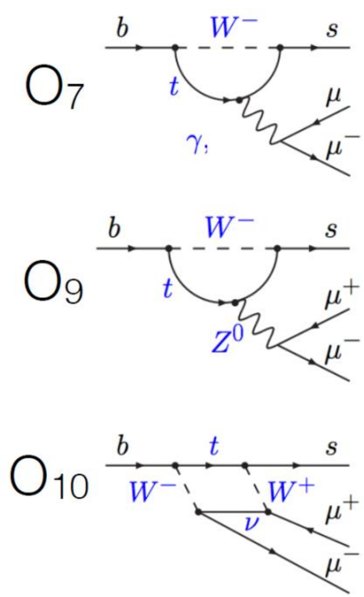
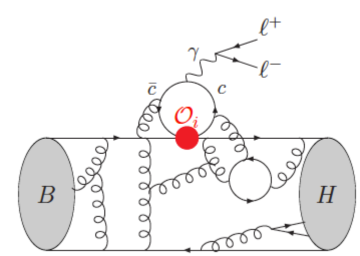


Fig. 7. Cartoon illustrating the dimuon mass squared, q^2, dependence of the differential decay rate of $B \to K^*\ell^+\ell^-$ decays. The different contributions to the decay rate are also illustrated. For $B \to K\ell^+\ell^-$ decays there is no photon pole enhancement due to angular momentum conservation.

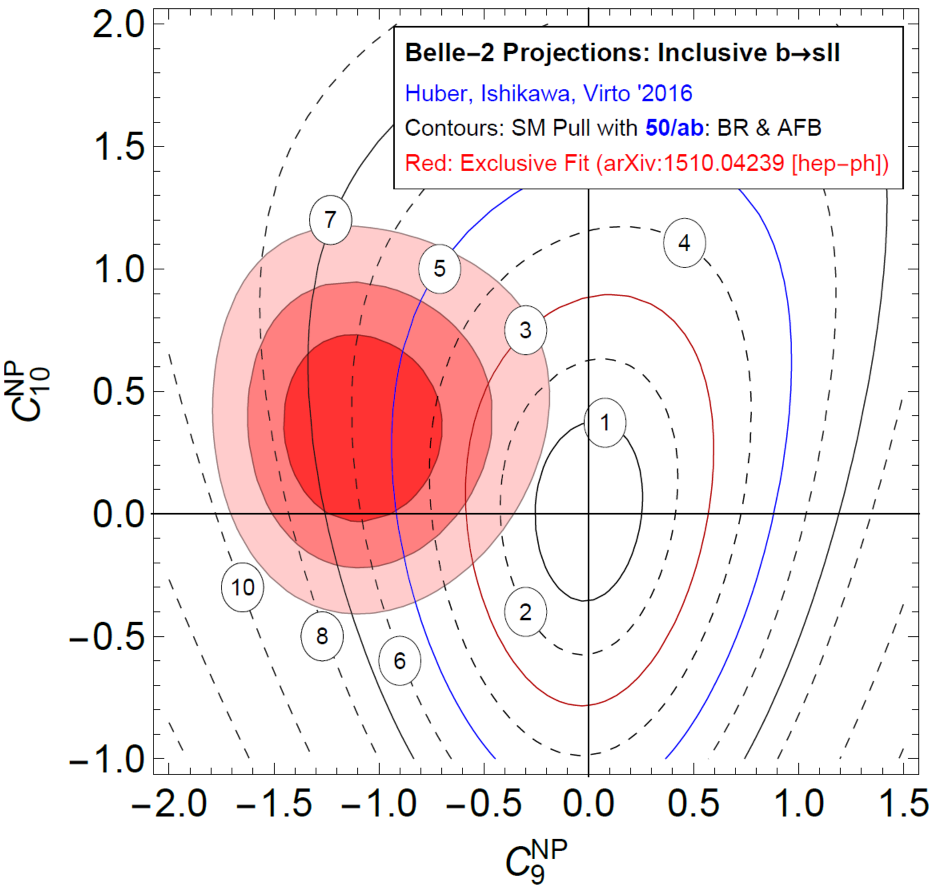
Slide from
Jessica Prisciandaro FPCP2017





Long distance charm loop effect ?

Inclusive $B \to X_s \ell^+ \ell^-$



Exclusive Fit:
- $B^0 \to K^{(*)0} \ell^+ \ell^-$
- $B_s^0 \to \phi\mu\mu$
- $B^0 \to X_s \gamma$
- $B_s \to \mu\mu$

Input from mainly LHCb

Inclusive b→sll

Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$Br(B \to X_s \ell^+ \ell^-)$ ([1.0, 3.5] GeV^2)	29%	13%	6.6%
$Br(B \to X_s \ell^+ \ell^-)$ ([3.5, 6.0] GeV^2)	24%	11%	6.4%
$Br(B \to X_s \ell^+ \ell^-)$ (> 14.4 GeV^2)	23%	10%	4.7%
$A_{CP}(B \to X_s \ell^+ \ell^-)$ ([1.0, 3.5] GeV^2)	26%	9.7 %	3.1 %
$A_{CP}(B \to X_s \ell^+ \ell^-)$ ([3.5, 6.0] GeV^2)	21%	7.9 %	2.6 %
$A_{CP}(B \to X_s \ell^+ \ell^-)$ (> 14.4 GeV^2)	21%	8.1 %	2.6 %
$A_{FB}(B \to X_s \ell^+ \ell^-)$ ([1.0, 3.5] GeV^2)	26%	9.7%	3.1%
$A_{FB}(B \to X_s \ell^+ \ell^-)$ ([3.5, 6.0] GeV^2)	21%	7.9%	2.6%
$A_{FB}(B \to X_s \ell^+ \ell^-)$ (> 14.4 GeV^2)	19%	7.3%	2.4%
$\Delta_{CP}(A_{FB})$ ([1.0, 3.5] GeV^2)	52%	19%	6.1%
$\Delta_{CP}(A_{FB})$ ([3.5, 6.0] GeV^2)	42%	16%	5.2%
$\Delta_{CP}(A_{FB})$ (> 14.4 GeV^2)	38%	15%	4.8%

1808.10567

If $C_9^{NP} = -1$, BelleII@ 50 ab^{-1} has a 5 σ determination.

$B \to K^{(*)}\tau\tau$

$$\mathrm{Br}(B \to K\tau^+\tau^-)^{[15,22]}_{\mathrm{SM}} = (1.20 \pm 0.12) \times 10^{-7},$$

$$\mathrm{Br}(B \to K^*\tau^+\tau^-)^{[15,19]}_{\mathrm{SM}} = (0.98 \pm 0.10) \times 10^{-7},$$

Phys.Rev.Lett.120.181802

$\mathcal{B}(B^+ \to K^+\tau^+\tau^-) < 2.25 \times 10^{-3}$. BaBar Phys.Rev.Lett.118.031802

Primary BG: $B_{sig} \to D^{(*)}\ell\bar{\nu}_\ell$ with $D^{(*)} \to K\ell'\nu_{\ell'}$

Observables	Belle 0.71 ab^{-1} (0.12 ab^{-1})	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathrm{Br}(B^+ \to K^+\tau^+\tau^-) \cdot 10^5$	< 32	< 6.5	< 2.0
$\mathrm{Br}(B^0 \to \tau^+\tau^-) \cdot 10^5$	< 140	< 30	< 9.6
$\mathrm{Br}(B^0_s \to \tau^+\tau^-) \cdot 10^4$	< 70	< 8.1	–
$\mathrm{Br}(B^+ \to K^+\tau^\pm e^\mp) \cdot 10^6$	–	–	< 2.1
$\mathrm{Br}(B^+ \to K^+\tau^\pm \mu^\mp) \cdot 10^6$	–	–	< 3.3
$\mathrm{Br}(B^0 \to \tau^\pm e^\mp) \cdot 10^5$	–	–	< 1.6
$\mathrm{Br}(B^0 \to \tau^\pm \mu^\mp) \cdot 10^5$	–	–	< 1.3

arXiv.1808.10567

May enhance x100 in Gino Ishidori's talk yesterday

Belle II may have a chance for $B \to K^{(*)}\tau\tau$ and $B \to K^{(*)}\tau\mu$ if the BR enhance to ~10^{-5}

$B \to \tau\nu$ vs $\sin 2\phi_1$

$$\frac{BR(B\to\tau\nu)}{\Delta m_d}=\frac{3\pi}{4}\frac{m_\tau^2\tau_B}{m_W^2\eta_B S(x_t)|V_{ud}|^2}\left(1-\frac{m_\tau^2}{m_B^2}\right)^2\frac{\sin^2(\beta)}{\sin^2(\gamma)}\frac{1}{\boldsymbol{B}_{\boldsymbol{B}_d}}$$

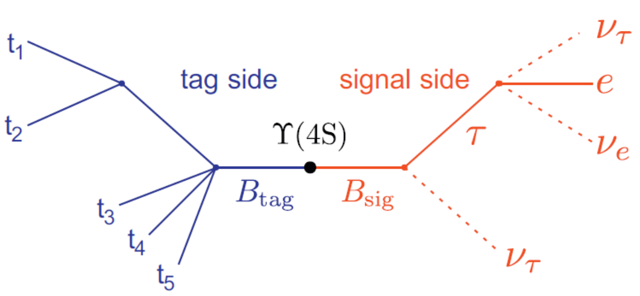
QCD parameter {

- B_{Bd}…bag parameter
- η_B…QCD correction factor
- $S(x_t)$…Inami-Lin function $x_t=m_t^2/m_w^2$

$B \to \mu\nu$

- $B_{SM}(B \to \mu\nu) = (3.46 \pm 0.28) \times 10^{-7}$
- The presence of NP with different chiral structure would be observed through the modifications $B(B \to \mu\nu)$.
  - Naively just scaling statistics,
  - Next: High efficiency Hadronic tag using the Full Event Interpretation(FEI)

    …Neural Network based tag side reconstruction



Tag	FR[10] @ Belle	FEI @ Belle MC	FEI @ Belle II MC
Hadronic B^+	0.28 %	0.49 %	0.61 %
Semileptonic B^+	0.67 %	1.42 %	1.45 %
Hadronic B^0	0.18 %	0.33%	0.34 %
Semileptonic B^0	0.63 %	1.33%	1.25 %

B→(D)τν Wilson coefficient

The effective Lagrangian that contains all conceivable four-Fermi operators is written as

$$-\mathcal{L}_{\text{eff}} = 2\sqrt{2}G_F V_{cb} \sum_{l=e,\mu,\tau} \left[(\delta_{l\tau} + C^l_{V_1})\mathcal{O}^l_{V_1} + C^l_{V_2}\mathcal{O}^l_{V_2} + C^l_{S_1}\mathcal{O}^l_{S_1} + C^l_{S_2}\mathcal{O}^l_{S_2} + C^l_T\mathcal{O}^l_T\right], \quad (4)$$

where the four-Fermi operators are defined by

$$\mathcal{O}^l_{V_1} = \bar{c}_L\gamma^\mu b_L\,\bar{\tau}_L\gamma_\mu\nu_{Ll}\,, \quad (5)$$

$$\mathcal{O}^l_{V_2} = \bar{c}_R\gamma^\mu b_R\,\bar{\tau}_L\gamma_\mu\nu_{Ll}\,, \quad (6)$$

$$\mathcal{O}^l_{S_1} = \bar{c}_L b_R\,\bar{\tau}_R\nu_{Ll}\,, \quad (7)$$

$$\mathcal{O}^l_{S_2} = \bar{c}_R b_L\,\bar{\tau}_R\nu_{Ll}\,, \quad (8)$$

$$\mathcal{O}^l_T = \bar{c}_R\sigma^{\mu\nu} b_L\,\bar{\tau}_R\sigma_{\mu\nu}\nu_{Ll}\,, \quad (9)$$

and C^l_X $(X = V_{1,2}, S_{1,2}, T)$ denotes the Wilson coefficient of $\mathcal{O}^l_X$. Here we assume that the light neutrinos are left-handed.[1] The neutrino flavor is specified by l, and we take all cases of $l = e$, μ and τ into account in the contributions of new physics. Since the neutrino flavor is not observed in the experiments of bottom decays, the neutrino mixing does not affect the following argument provided that the Pontecorvo-Maki-Nakagawa-Sakata matrix is unitary. The SM contribution is expressed by the term of $\delta_{l\tau}$ in Eq. (4). We note that the tensor

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We note that the tensor operator $\mathcal{O}_T$ does not contribute to this $B^- \to \tau^-\bar{\nu}_\tau$

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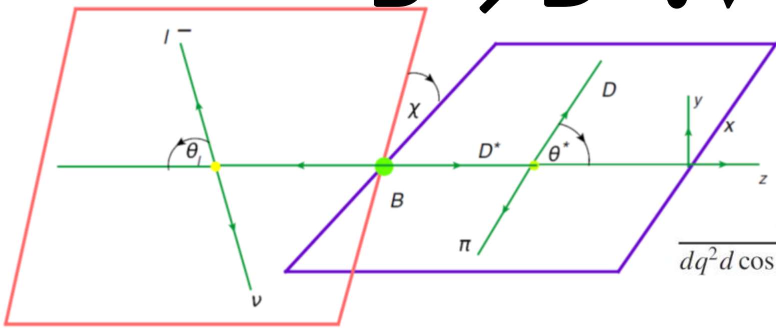
The SM condition requires that C_X = 0 for all type X

B→D*τν angular analysis



PRD90, 074013(2014)

$$\frac{d^4\Gamma}{dq^2\, d\cos\theta_l\, d\cos\theta_{D^*}\, d\chi} = \frac{9}{32\pi} NF\{\cos^2\theta_{D^*}(V_1^0 + V_2^0\cos 2\theta_l + V_3^0\cos\theta_l) + \sin^2\theta_{D^*}(V_1^T + V_2^T\cos 2\theta_l + V_3^T\cos\theta_l)$$
$$+ V_4^T\sin^2\theta_{D^*}\sin^2\theta_l\cos 2\chi + V_1^{0T}\sin 2\theta_{D^*}\sin 2\theta_l\cos\chi + V_2^{0T}\sin 2\theta_{D^*}\sin\theta_l\cos\chi$$
$$+ V_5^T\sin^2\theta_{D^*}\sin^2\theta_l\sin 2\chi + V_3^{0T}\sin 2\theta_{D^*}\sin\theta_l\sin\chi + V_4^{0T}\sin 2\theta_{D^*}\sin 2\theta_l\sin\chi\},$$

The longitudinal V^0's ($\lambda_1\lambda_2 = 00$) are given by

$$V_1^0 = 2\left[\left(1 + \frac{m_l^2}{q^2}\right)(|\mathcal{A}_0|^2 + 16|\mathcal{A}_{0T}|^2) + \frac{2m_l^2}{q^2}|\mathcal{A}_{tP}|^2 - \frac{16m_l}{\sqrt{q^2}}\mathrm{Re}[\mathcal{A}_{0T}\mathcal{A}_0^*]\right],$$

$$V_2^0 = 2\left(1 - \frac{m_l^2}{q^2}\right)[-|\mathcal{A}_0|^2 + 16|\mathcal{A}_{0T}|^2],$$

$$V_3^0 = -8\mathrm{Re}\left[\frac{m_l^2}{q^2}\mathcal{A}_{tP}\mathcal{A}_0^* - \frac{4m_l}{\sqrt{q^2}}\mathcal{A}_{tP}\mathcal{A}_{0T}^*\right].$$

The transverse V^T's ($\lambda_1\lambda_2 = ++, --, +-, -+$) are given by

$$V_1^T = \left[\frac{1}{2}\left(3 + \frac{m_l^2}{q^2}\right)(|\mathcal{A}_\parallel|^2 + |\mathcal{A}_\perp|^2) + 8\left(1 + \frac{3m_l^2}{q^2}\right)(|\mathcal{A}_{\parallel T}|^2 + |\mathcal{A}_{\perp T}|^2) - \frac{16m_l}{\sqrt{q^2}}\mathrm{Re}[\mathcal{A}_{\parallel T}\mathcal{A}_\parallel^* + \mathcal{A}_{\perp T}\mathcal{A}_\perp^*]\right],$$

$$V_2^T = \left(1 - \frac{m_l^2}{q^2}\right)\left[\frac{1}{2}(|\mathcal{A}_\parallel|^2 + |\mathcal{A}_\perp|^2) - 8(|\mathcal{A}_{\parallel T}|^2 + |\mathcal{A}_{\perp T}|^2)\right],$$

$$V_3^T = 4\mathrm{Re}\left[-\mathcal{A}_\parallel\mathcal{A}_\perp^* - \frac{16m_l^2}{q^2}\mathcal{A}_{\parallel T}\mathcal{A}_{\perp T}^* + \frac{4m_l}{\sqrt{q^2}}(\mathcal{A}_{\perp T}\mathcal{A}_\parallel^* + \mathcal{A}_{\parallel T}\mathcal{A}_\perp^*)\right],$$

$$V_4^T = \left(1 - \frac{m_l^2}{q^2}\right)[-(|\mathcal{A}_\parallel|^2 - |\mathcal{A}_\perp|^2) + 16(|\mathcal{A}_{\parallel T}|^2 - |\mathcal{A}_{\perp T}|^2)],$$

$$V_5^T = 2\left(1 - \frac{m_l^2}{q^2}\right)\mathrm{Im}[\mathcal{A}_\parallel\mathcal{A}_\perp^*].$$

The mixed V^{0T}'s ($\lambda_1\lambda_2 = 0\pm, \pm 0$) are given by

$$V_1^{0T} = \sqrt{2}\left(1 - \frac{m_l^2}{q^2}\right)\mathrm{Re}[\mathcal{A}_\parallel\mathcal{A}_0^* - 16\mathcal{A}_{\parallel T}\mathcal{A}_{0T}^*],$$

$$V_2^{0T} = 2\sqrt{2}\mathrm{Re}\left[-\mathcal{A}_\perp\mathcal{A}_0^* + \frac{m_l^2}{q^2}(\mathcal{A}_\parallel\mathcal{A}_{tP}^* - 16\mathcal{A}_{\perp T}\mathcal{A}_{0T}^*) + \frac{4m_l}{\sqrt{q^2}}(\mathcal{A}_{0T}\mathcal{A}_\perp^* + \mathcal{A}_{\perp T}\mathcal{A}_0^* - \mathcal{A}_{\parallel T}\mathcal{A}_{tP}^*)\right],$$

$$V_3^{0T} = 2\sqrt{2}\mathrm{Im}\left[-\mathcal{A}_\parallel\mathcal{A}_0^* + \frac{m_l^2}{q^2}\mathcal{A}_\perp\mathcal{A}_{tP}^* + \frac{4m_l}{\sqrt{q^2}}(\mathcal{A}_{0T}\mathcal{A}_\parallel^* - \mathcal{A}_{\parallel T}\mathcal{A}_0^* + \mathcal{A}_{\perp T}\mathcal{A}_{tP}^*)\right],$$

$$V_4^{0T} = \sqrt{2}\left(1 - \frac{m_l^2}{q^2}\right)\mathrm{Im}[\mathcal{A}_\perp\mathcal{A}_0^*].$$

B→D*τν CP-violating observables

the D^* longitudinal and transverse polarization amplitudes A_L and A_T are

$$A_L = \left(V_1^0 - \frac{1}{3}V_2^0\right), \quad A_T = 2\left(V_1^T - \frac{1}{3}V_2^T\right) . \tag{3.7}$$

JHEP09(2013)059

The first TP is $A_T^{(1)}$, introduced above in eq. (3.17). One can find $A_T^{(1)}$ and $\bar{A}_T^{(1)}$ as

$$A_T^{(1)}(q^2) = \frac{4V_5^T}{3(A_L + A_T)}, \quad \bar{A}_T^{(1)}(q^2) = -\frac{4\bar{V}_5^T}{3(\bar{A}_L + \bar{A}_T)} . \tag{3.33}$$

In the absence of direct CP violation $\bar{A}_T^{(1)} = A_T^{(1)}$. We observe that $A_T^{(1)}$ depends on both the g_A and the g_V couplings and not on the g_P coupling. The CP-violating triple-product asymmetry is

$$\langle A_T^{(1)}(q^2)\rangle = \frac{1}{2}\left(A_T^{(1)}(q^2) + \bar{A}_T^{(1)}(q^2)\right) . \tag{3.34}$$

The second TP is $A_T^{(2)}$, introduced above in eq. (3.22). $A_T^{(2)}$ and $\bar{A}_T^{(2)}$ are given by

$$A_T^{(2)}(q^2) = \frac{V_3^{0T}}{(A_L + A_T)}, \quad \bar{A}_T^{(2)} = \frac{\bar{V}_3^{0T}}{(\bar{A}_L + \bar{A}_T)} . \tag{3.35}$$

We observe that $A_T^{(2)}(q^2)$ depends on all the three new couplings g_A, g_V, and g_P. This TP is proportional to the lepton mass and so is very small when the lepton is the electron or the muon. The CP-violating triple-product asymmetry is

$$\langle A_T^{(2)}(q^2)\rangle = \frac{1}{2}\left(A_T^{(2)}(q^2) - \bar{A}_T^{(2)}(q^2)\right) . \tag{3.36}$$

The third TP is $A_T^{(3)}$, introduced above in eq. (3.27). $A_T^{(3)}$ and $\bar{A}_T^{(3)}$ are given by

$$A_T^{(3)}(q^2) = \frac{V_4^{0T}}{(A_L + A_T)}, \quad \bar{A}_T^{(3)} = -\frac{\bar{V}_4^{0T}}{(\bar{A}_L + \bar{A}_T)} . \tag{3.37}$$

We observe that $A_T^{(3)}$ depends on both the new couplings g_A and g_V but does not depend on g_P. The CP-violating triple-product asymmetry is

$$\langle A_T^{(3)}(q^2)\rangle = \frac{1}{2}\left(A_T^{(3)}(q^2) + \bar{A}_T^{(3)}(q^2)\right) . \tag{3.38}$$

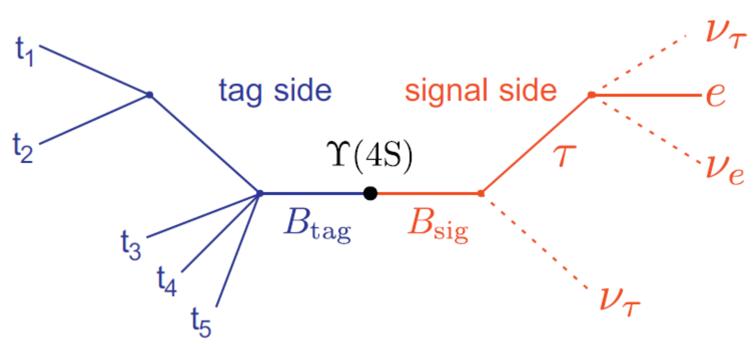
CP-violating: Triple product correlations

Non-zero TP's =>NP

q^2 distribution of TP's differs NP scenarios

Hierarchical hadronic full reconstruction algorithm

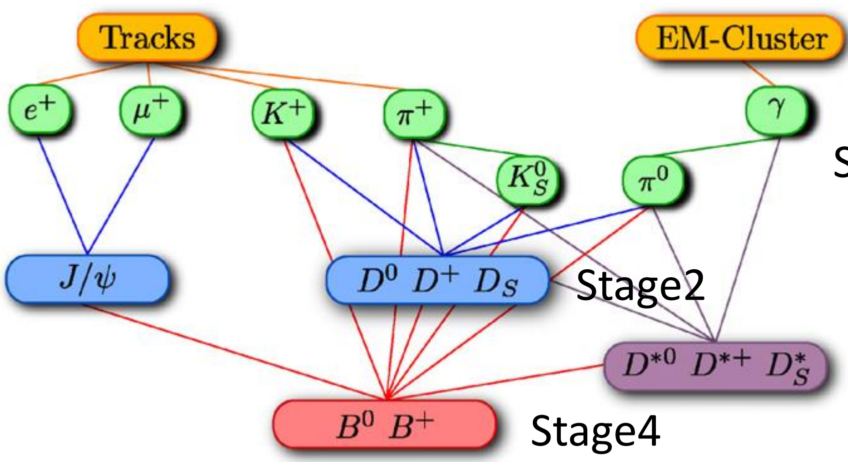
NIM A654, 432(2011)

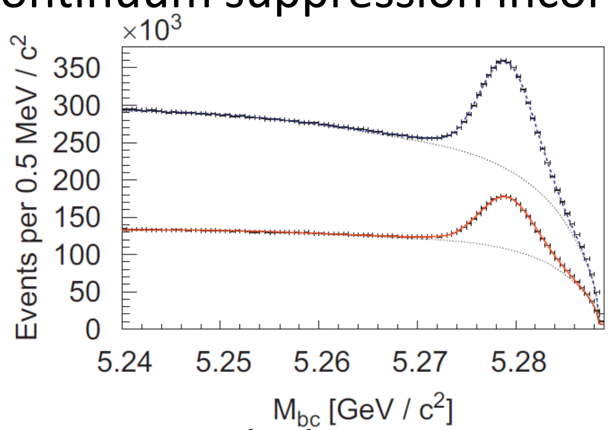


- B meson decay including neutrinos
- B_{tag} side reconstruction
  - Full reconstruction as a sum of exclusive(~100)
  - Hierarchical hadronic full recon

  → Hierarchical hadronic full recon developed for Belle

  → Continuum suppression incorporated

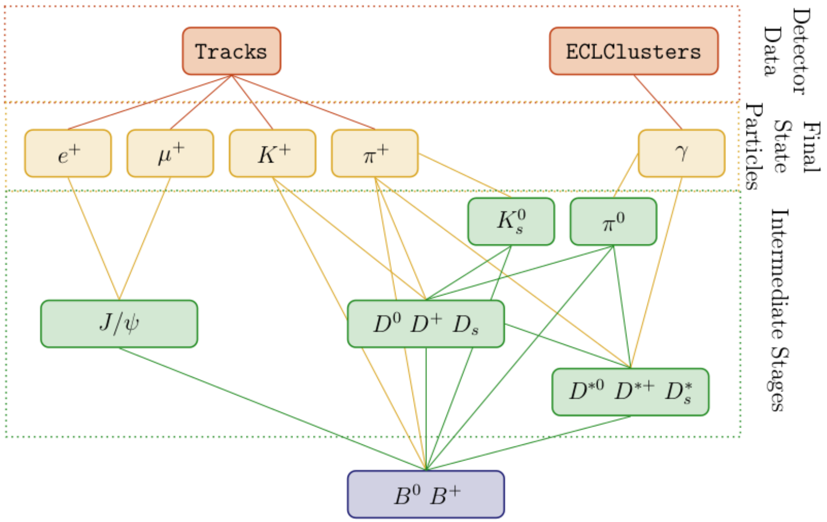




Effective luminosity factor 2 improvement comparing with the previous.

Full Event Interpretation(FEI)

- Developing for Belle II
- Full reconstruction: training MVC was done independently from signal-side B decay tag reconstruction independent
- FEI: can take into account signal-side. Signal specific training is possible.



$Br(B \to D^{(*)} \tau \nu)$ tagging

Tagging method for (semi)leptonic decay

- Hadronic tagging
  - Hadronic decay channels.
  - Good purity
- Semileptonic tagging
  - Semileptonic decay channels
  - Good efficiency
- Inclusive tagging
  - Combines the four-momenta of all particle in the rest of B_{sig}
  - bad purity, best efficiency
- Full event interpretation
  - Combines hadronic tagging and semileptonic tagging into single algorithm

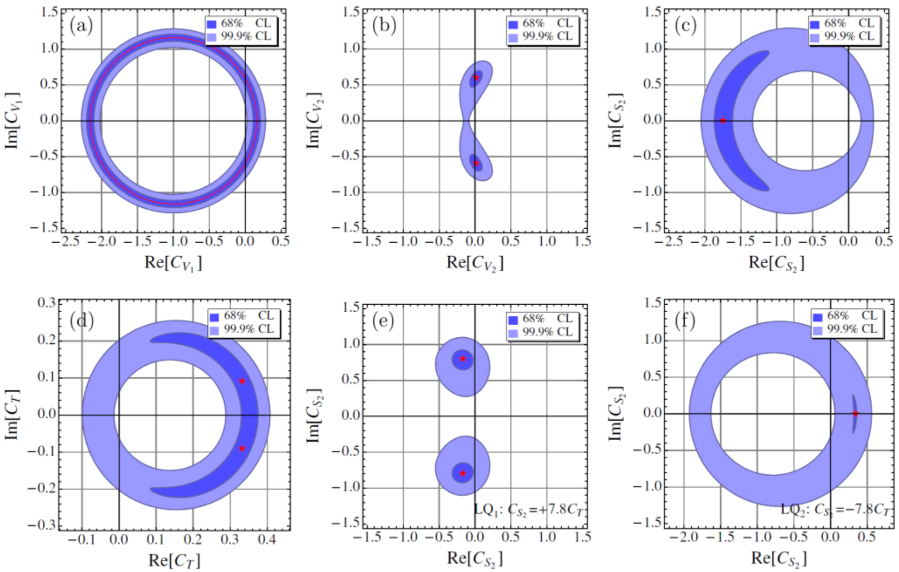
$D^{(*)}\tau\nu$,τ->hν, hadronic tag measurement

	D^0 mode	
High-SNR	$K_S\pi^0$	$(1.2\pm0.04)\%$
	$\pi^+\pi^-$	$(1.420\pm0.025)\times10^{-3}$
High-SNR	$K^-\pi^+$	$(3.93\pm0.04)\%$
High-SNR	K^+K^-	$(4.01\pm0.07)\times10^{-3}$
	$K^-\pi^+\pi^0$	$(14.3\pm0.8)\%$
High-SNR	$K_S\pi^+\pi^-$	$(2.85\pm0.20)\%$
	$K_S\pi^+\pi^-\pi^0$	$(5.2\pm0.6)\%$
High-SNR	$K^-\pi^+\pi^-\pi^+$	$(8.06\pm0.23)\%$
	$K_SK^-\pi^+$	$(3.6\pm0.5)\times10^{-3}$
	$K_SK^-K^+$	$(4.51\pm0.34)\times10^{-3}$
	$\pi^+\pi^-\pi^0$	$(1.47\pm0.09)\%$
	$\pi^+\pi^-\pi^+\pi^-$	$(7.45\pm0.22)\times10^{-3}$

	D^+ mode	
High-SNR	$K_S\pi^+$	$(1.53\pm0.06)\%$
High-SNR	K_SK^+	$(2.95\pm0.15)\times10^{-3}$
	$K_S\pi^+\pi^0$	$(7.24\pm0.17)\%$
High-SNR	$K^-\pi^+\pi^+$	$(9.46\pm0.24)\%$
	$K^+K^-\pi^+$	$(9.96\pm0.26)\times10^{-3}$
	$K^-\pi^+\pi^+\pi^0$	$(6.14\pm0.16)\%$
	$K_S\pi^+\pi^-\pi^+$	$(3.05\pm0.09)\%$
	$K^-\pi^+\pi^-\pi^+\pi^+$	$(5.8\pm0.5)\times10^{-3}$
	$\pi^+\pi^+\pi^-$	$(3.29\pm0.20)\times10^{-3}$
	$\pi^+\pi^+\pi^-\pi^0$	$(1.17\pm0.08)\%$

Can be added

q$^2 \equiv (p_B - p_{D^{(*)}})^2$ sensitivity to NP

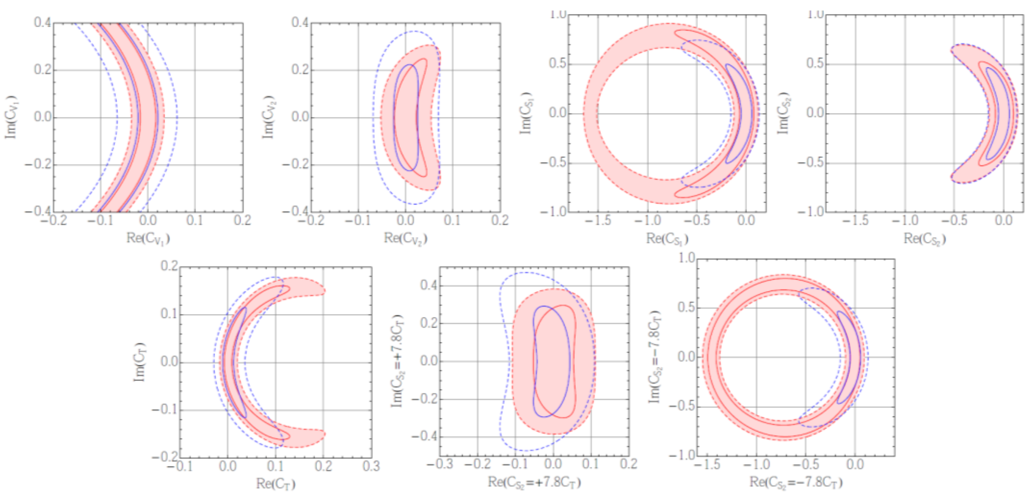


←R(D$^{(*)}$) measurement constrained

$R(D) = 0.421 \pm 0.058$, $R(D^*) = 0.337 \pm 0.025$, BaBar+Belle(by 2013)

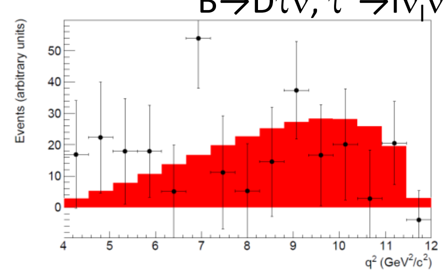
$$\mathcal{H}_{\rm eff} = \frac{4G_F}{\sqrt{2}} V_{cb}[(1 + C_{V_1})\mathcal{O}_{V_1} + C_{V_2}\mathcal{O}_{V_2} + C_{S_1}\mathcal{O}_{S_1} + C_{S_2}\mathcal{O}_{S_2} + C_T\mathcal{O}_T],$$

$$\mathcal{O}_{V_1} = (\bar{c}_L\gamma^\mu b_L)(\bar{\tau}_L\gamma_\mu\nu_L),$$
$$\mathcal{O}_{V_2} = (\bar{c}_R\gamma^\mu b_R)(\bar{\tau}_L\gamma_\mu\nu_L),$$
$$\mathcal{O}_{S_1} = (\bar{c}_L b_R)(\bar{\tau}_R\nu_L),$$
$$\mathcal{O}_{S_2} = (\bar{c}_R b_L)(\bar{\tau}_R\nu_L),$$
$$\mathcal{O}_T = (\bar{c}_R\sigma^{\mu\nu} b_L)(\bar{\tau}_R\sigma_{\mu\nu}\nu_L),$$

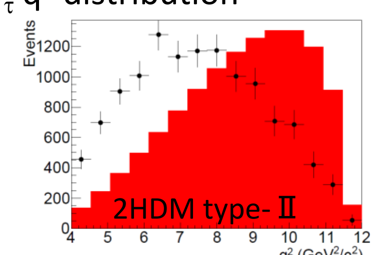


←With R(D(*)) and the q^2 dependence at Belle Ⅱ 5ab^{-1}(dotted) and 50ab^{-1}(solid). q^2 also has the sensitive to NP scenarios

B→Dτν, $\tau^- \to l\nu_l\nu_\tau$ q^2 distribution



Full Belle data



50ab^{-1} BelleII(SM toy)

DHMV

1407.8526 + 1503.03328

- Improved QCDF approach
- Ball-Zwicky Form Factor approach

ABSZ

1411.3161 + 1503.05534,

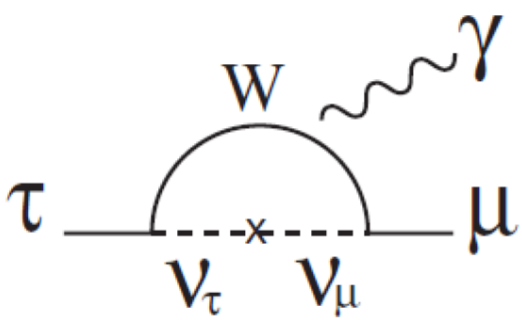
- Form factors from light cone sum rules

LFV enhancement in τ

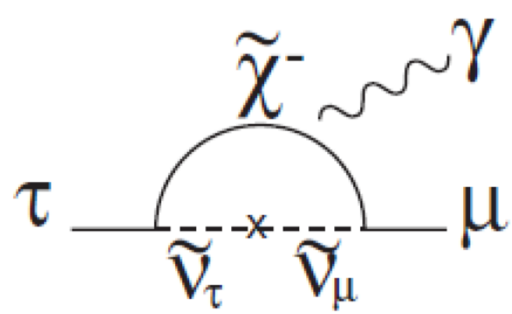
		$\tau \to \mu\gamma$	$\tau \to \ell\ell\ell$
SM + ν mixing	EPJ C8 (1999) 513	10^{-45}	--
SM + heavy Maj νR	PRD 66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z’	PLB 547 (2002) 252	10^{-9}	10^{-8}
SUSY SO(10)	PRD 68 (2003) 033012	10^{-8}	10^{-10}
mSUGRA+seesaw	PRD 66 (2002) 115013	10^{-7}	10^{-9}
SUSY Higgs	PLB 566 (2003) 217	10^{-10}	10^{-7}

Numbers corresponding to the most optimistic case

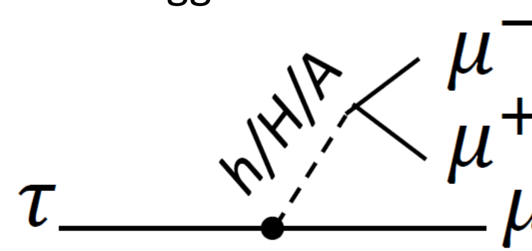
SM



SUSY



Higgs mediated



Slide from Tomoyuki Konno@NuFact2016

b→sγ

Dark photon

Systematics R(D*) and P_τ(D*)

PRD97.012004(2018)

Source	$R(D^*)$	$P_\tau(D^*)$
Hadronic B composition	$^{+7.7\%}_{-6.9\%}$	$^{+0.134}_{-0.103}$
MC statistics for PDF shape	$^{+4.0\%}_{-2.8\%}$	$^{+0.146}_{-0.108}$
Fake D^*	3.4%	0.018
$\bar{B} \to D^{**}\ell^-\bar{\nu}_\ell$	2.4%	0.048
$\bar{B} \to D^{**}\tau^-\bar{\nu}_\tau$	1.1%	0.001
$\bar{B} \to D^{*}\ell^-\bar{\nu}_\ell$	2.3%	0.007
τ daughter and ℓ^- efficiency	1.9%	0.019
MC statistics for efficiency estimation	1.0%	0.019
$\mathcal{B}(\tau^- \to \pi^-\nu_\tau, \rho^-\nu_\tau)$	0.3%	0.002
$P_\tau(D^*)$ correction function	0.0%	0.010
Common sources		
Tagging efficiency correction	1.6%	0.018
D^* reconstruction	1.4%	0.006
Branching fractions of the D meson	0.8%	0.007
Number of $B\bar{B}$ and $\mathcal{B}(\Upsilon(4S) \to B^+B^-$ or $B^0\bar{B}^0)$	0.5%	0.006
Total systematic uncertainty	$^{+10.4\%}_{-9.4\%}$	$^{+0.21}_{-0.16}$

K*(892) and K*(1430)

$K^*(892)$ WIDTH

CHARGED ONLY, HADROPRODUCED

VALUE (MeV)	*EVTS*	*DOCUMENT ID*	*TECN*	*CHG*	*COMMENT*
50.8±0.9 OUR FIT					
50.8±0.9 OUR AVERAGE					

$K_0^*(1430)$ WIDTH

VALUE (MeV)	*EVTS*	*DOCUMENT ID*	*TECN*	*CHG*	*COMMENT*
270 ±80 OUR ESTIMATE					