

Belle II Theory Interface Platform (B2TiP)

Satoshi Mishima (KEK)

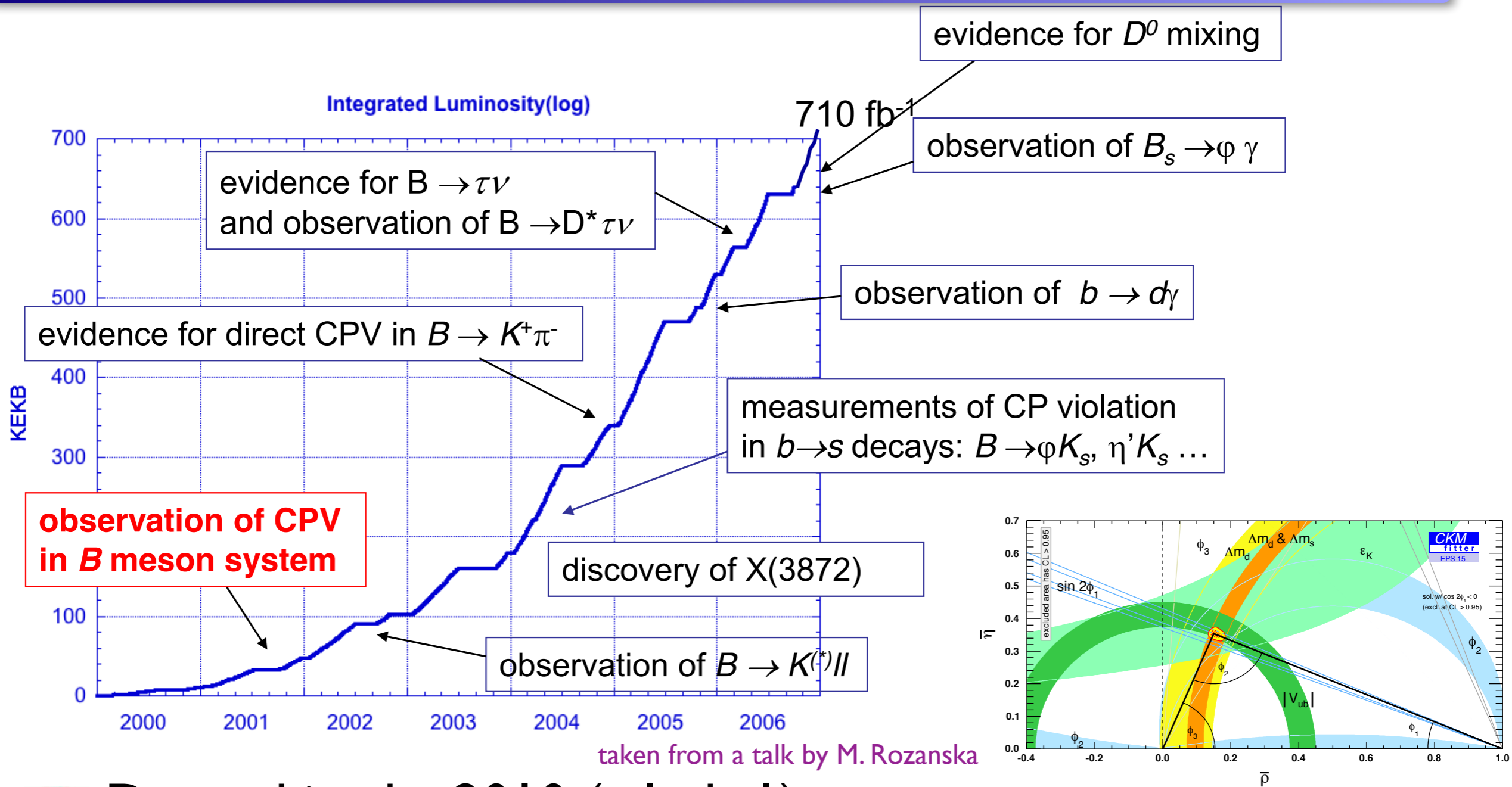


*World Research Unit for Heavy Flavor Particle Physics
Symposium 2016*

“Interplay between LHC and Flavor Physics”

Nagoya, Japan, 14-15 March, 2016

Major achievements at Belle



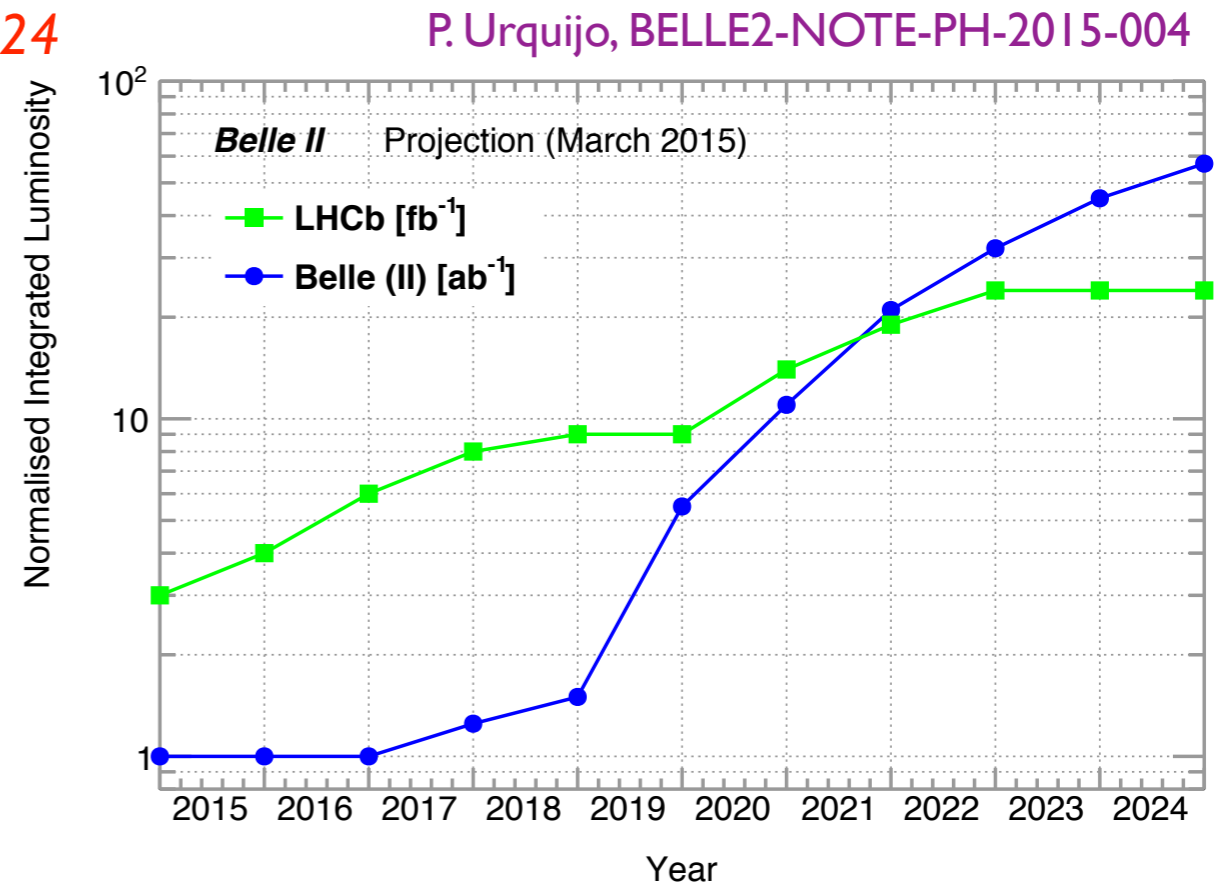
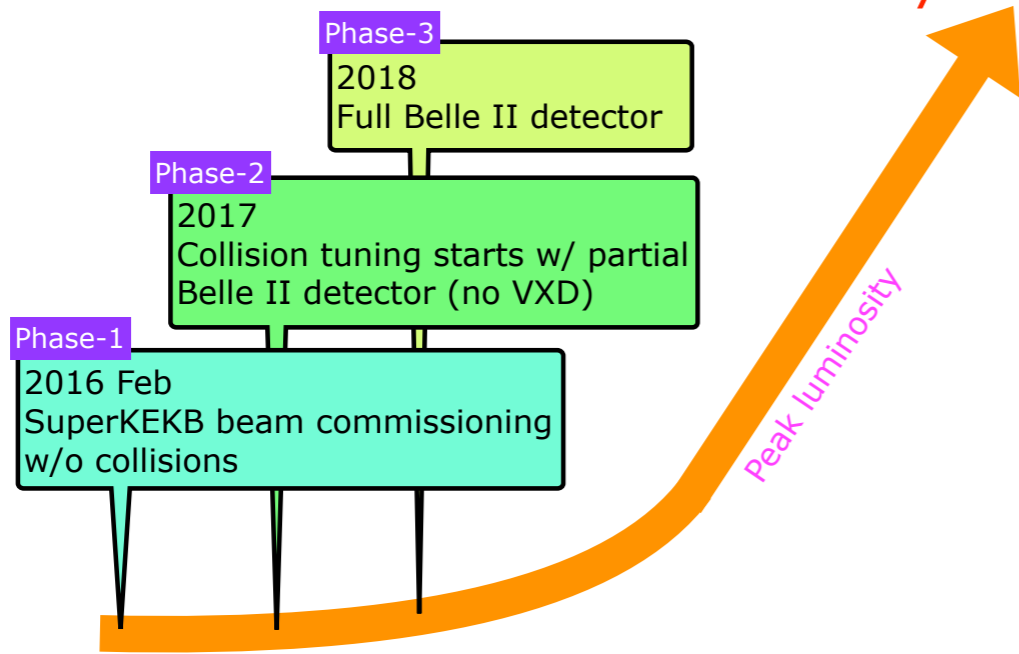
- Data taking by 2010 (>1 ab⁻¹).
- The data are basically consistent with the SM expectations, but a couple of 2-3 sigma tensions have been remaining!

SuperKEKB / Belle II

- SuperKEKB: $L = 8 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$ \Rightarrow *higher statistics!*
- Indirect searches for NP through quantum effects, which enable us to explore above TeV scale.
- Complementary to direct searches for NP at the LHC.

When does Belle II experiment start ?

50 ab^{-1} by 2023-2024



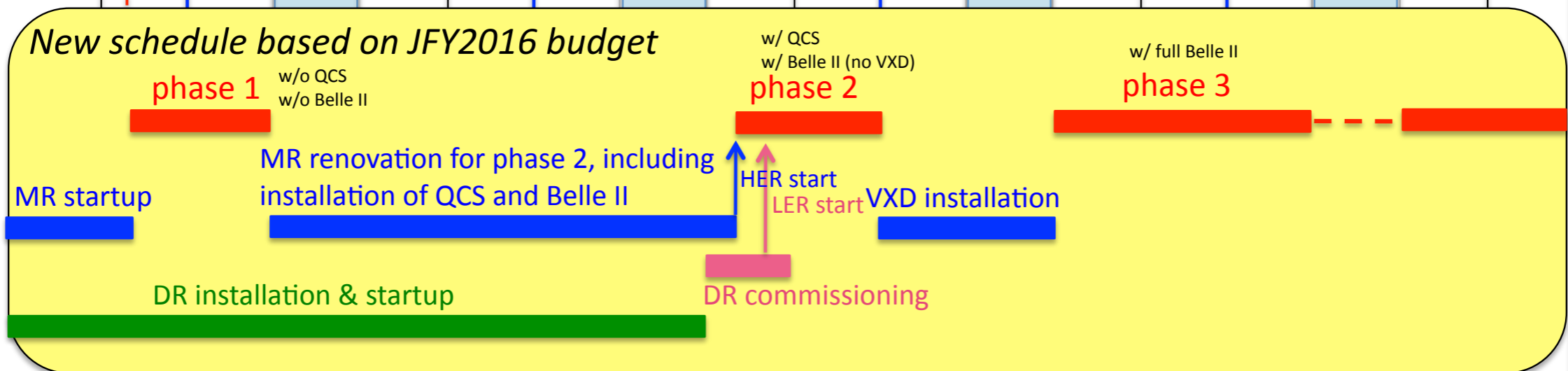
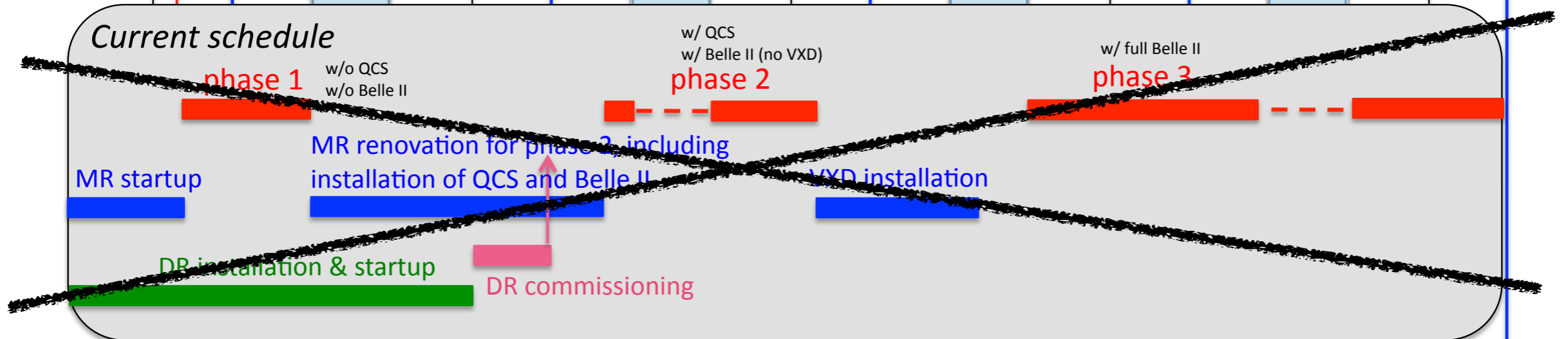
SuperKEKB / Belle II schedule



SuperKEKB operation schedule



Calendar year	2016	2017	2018	2019	...
Japan FY	JFY2016	JFY2017	JFY2018	JFY2019	
	Summer shutdown (power saving)	Summer shutdown (power saving)	Summer shutdown (power saving)	Summer shutdown (power saving)	



LHCb vs. Belle II

● LHCb:

- huge statistics
- (very) rare decays to clean final states

$$B_{d,s} \rightarrow \mu^+ \mu^-, B \rightarrow K^* \mu^+ \mu^-, \dots$$

● Belle II:

- well-defined initial state (full reconstruction of B)
- very clean environment
- final states with neutrals

$$B \rightarrow \pi^0 \pi^0, B \rightarrow K_S \pi^0, B \rightarrow K_S \pi^0 \gamma, \dots$$

- final states with missing particles

$$B \rightarrow \tau \nu, B \rightarrow D^{(*)} \tau \nu, B \rightarrow K^{(*)} \nu \nu, \dots$$

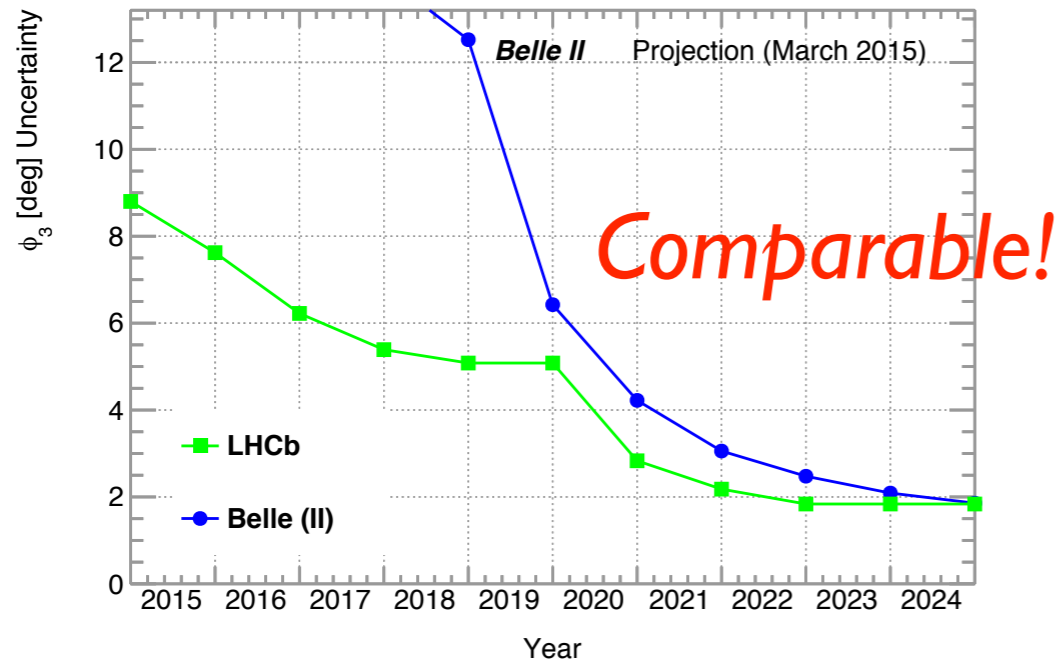
- inclusive modes

$$B \rightarrow X_s \gamma, B \rightarrow X_s \ell^+ \ell^-, \dots$$

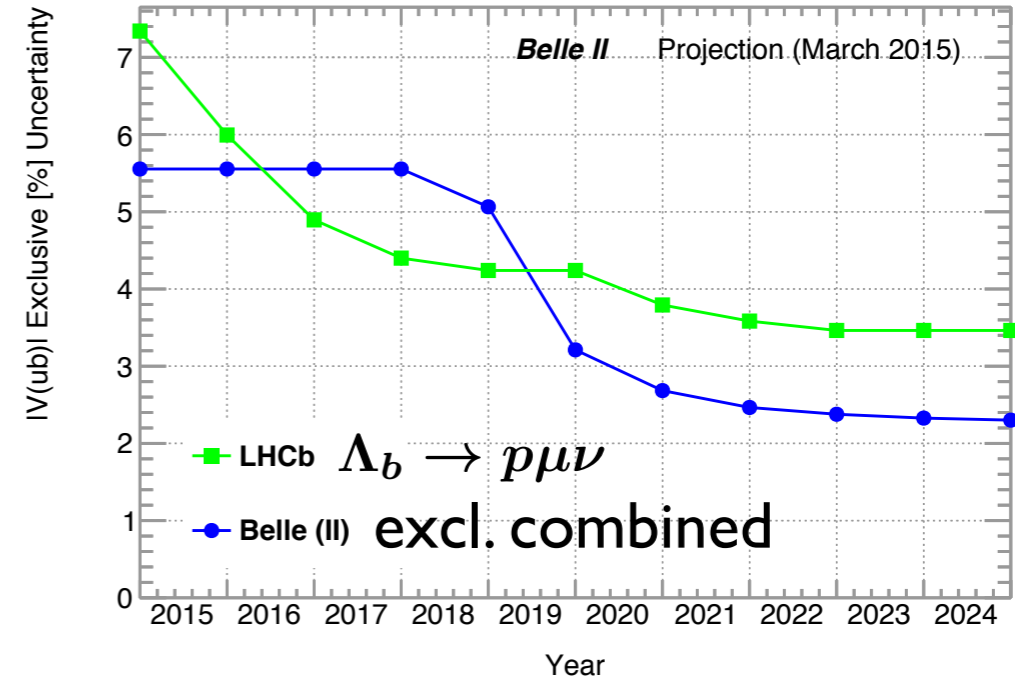
Competition and complementarity

P. Urquijo, BELLE2-NOTE-PH-2015-004

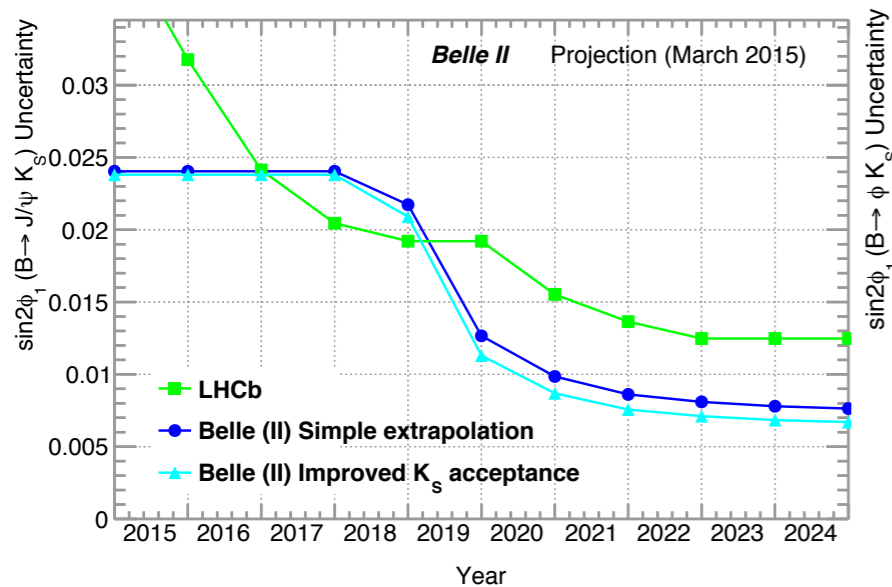
ϕ_3



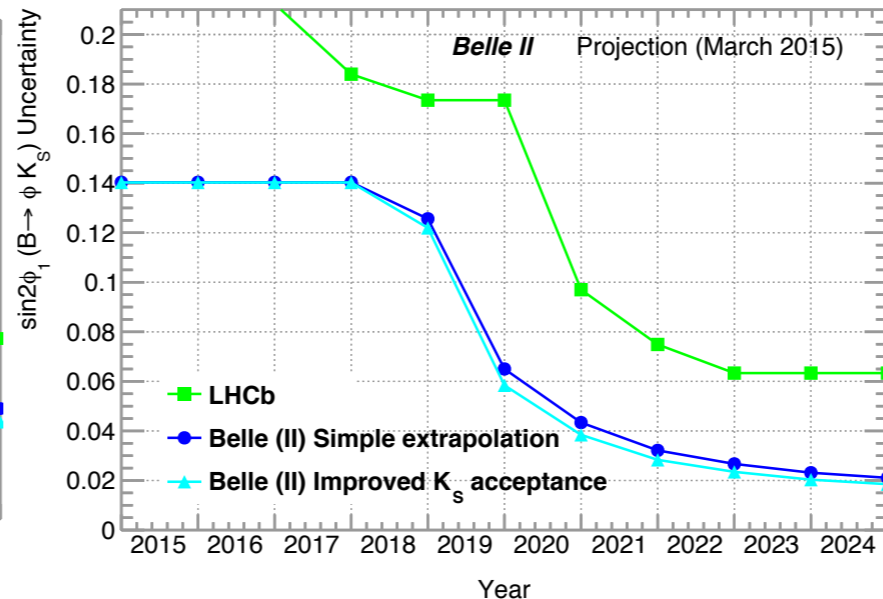
$|V_{ub}|$



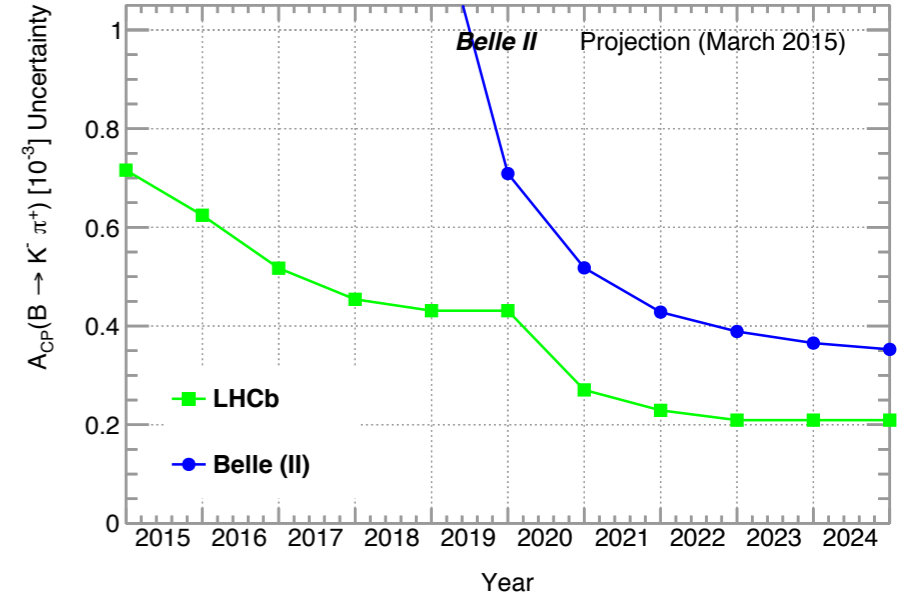
$\sin(2\phi_1)$



$S_{\phi K_S}$



$A_{CP}(B \rightarrow K^- \pi^+)$

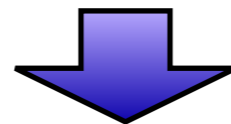


Belle II K_s eff. wins!

LHCb wins!

Strong physics cases?

- What's new after the *LOI* for SuperKEKB in 2004?
 - More results from Babar/Belle
 - High-energy data from ATLAS/CMS (and CDF/D0)
 - Flavor data from LHCb, ...
 - Theoretical progresses (QCD calculations, NP models and their constraints, etc.)
 - Detailed simulations based on Belle II Monte Carlo



What are strong physics cases at Belle II?

Belle II Theory Interface Platform (B2TiP)

- Initiative to coordinate **a joint theory-experimental effort** to study the potential impacts of the Belle II program.

Close cooperation between experiment and theory is essential for progress in this field.

- Detailed information on B2TiP is available at

<https://belle2.cc.kek.jp/~twiki/bin/view/B2TiP>

Committees

black = exp. blue = th.

● Organizing committee:

Toru Goto (KEK)

Emi Kou (LAL)

Phillip Urquijo (Melbourne)

Belle2 physics coordinator

● Report editors:

Satoshi Mishima (KEK)

Christoph Schwanda (HEPHY)

● Ex officio:

Hiroaki Aihara (Tokyo) *Belle2 EB chair*

Thomas Browder (Hawaii) *Belle2 spokesperson*

Marco Ciuchini (Rome3) *KEK-FF advisory*

Thomas Mannel (Siegen) *KEK-FF advisory*

● Advisory committee:

Tim Gershon (Warwick)

Bostjan Golob (IJS Ljubljana)

Shoji Hashimoto (KEK)

Francois Le Diberder (LAL)

Zoltan Ligeti (LBL)

Hitoshi Murayama (IPMU)

Matthias Neubert (Mainz)

Yoshihide Sakai (KEK)

Junko Shigemitsu (Ohio)

WGs and Coordinators

black = exp. blue = th.

43 coordinators!

- **WG1: Semileptonic & Leptonic B decays**
G. De Nardo (Naples), A. Zupanc (IJS Slovenia),
A. Kronfeld (Fermilab), F. Tackmann (DESY), M. Tanaka (Osaka), R. Watanabe (IBS)
- **WG2: Radiative & Electroweak Penguins**
A. Ishikawa (Tohoku), J. Yamaoka (PNNL), T. Feldman (Siegen), U. Haisch (Oxford)
- **WG3: $\alpha = \phi_2$ & $\beta = \phi_1$**
L. Li Gioi (MPI Munich), S. Mishima (KEK), J. Zupan (Cincinnati)
- **WG4: $\gamma = \phi_3$**
J. Libby (Madras), M. Blanke (KIT), Y. Grossman (Cornell)
- **WG5: Charmless Hadronic B Decay**
P. Goldenzweig (KIT), M. Beneke (TUM), C.-W. Chiang (NCU), S. Sharpe (Washington)
- **WG6: Charm**
G. Casarosa (Pisa), A. Schwartz (Cincinnati), A. Kagan (Cincinnati), A. Petrov (Wayne)
- **WG7: Quarkonium(like)**
B. Fulsom (PNNL), C. Hanhart (Juelich), R. Mizuk (ITEP), R. Mussa (Torino),
C. Shen (Beihang), Y. Kiyo (Juntendo), A. Polosa (Rome), S. Prelovsek (Ljubljana)
- **WG8: Tau, low multiplicity & EW**
K. Hayasaka (Niigata), T. Ferber (UBC), J. Hisano (Nagoya), E. Passemar (Indiana)
- **WG9: New Physics**
F. Bernlochner (Bonn), R. Itoh (KEK), Y. Sato (Nagoya),
J. Kamenik (IJS Ljubljana), U. Nierste (KIT), L. Silvestrini (Rome), S. Simula (Rome3)

B2TiP Report

- Outcome = **Summary Report**
 - **New developments** in detectors, simulations, softwares and theory.
 - Experimentally and theoretically **achievable precisions** of some important observables (“**golden modes**”) and their impacts on the understanding of the SM and beyond.
 - **Milestone table** to clarify the targets for the first 5 to 10 ab⁻¹ of data, as well as for the final goal at 50 ab⁻¹.
 - To be published as a **KEK Report** before the Belle II physics run (2017-).

Report planning

- **Phase 1: Planning and discussion** **2014-2015**
 - Identify “golden modes”
 - Propose and discuss the layout of the sections
 - Identify resources and share the work
- **Phase 2: Work on the physics analysis, write draft** **2015-2016**
 - Detailed studies of the golden modes
 - Studies based on Belle II simulation where possible
 - Draft theory and experimental sections

We are here!
- **Phase 3: Editing** **2016**
 - Finalize performance parameters from Belle II simulation
 - Final editing
 - Finalize physics analyses
- **Publish** ***by the end of 2016***

Workshop schedule



- Feb. 2014: Approval at the Belle II executive board.
- B2TIP workshops at KEK (2014), Krakow (2015) and KEK (2015), and mini-workshops, so far.
- In 2016, 4th workshop at Pittsburgh and Report Camp (editorial meeting) at Munich.

Krakow workshop (~100 participants)



Golden modes

- Each WGG has proposed top priority observables (*Belle II golden modes*), and has been scrutinizing them by estimating the theoretical uncertainties and the achievable precision at Belle II with 5, 10 and 50 ab⁻¹ of data.
- Selection criteria for golden modes:
 - e.g.,
 - Sensitivity to NP is much better than Belle
 - Sensitivity is much better than (or competitive to) LHCb
 - Significant impact on NP study

WGI: Semileptonic & Leptonic B decays

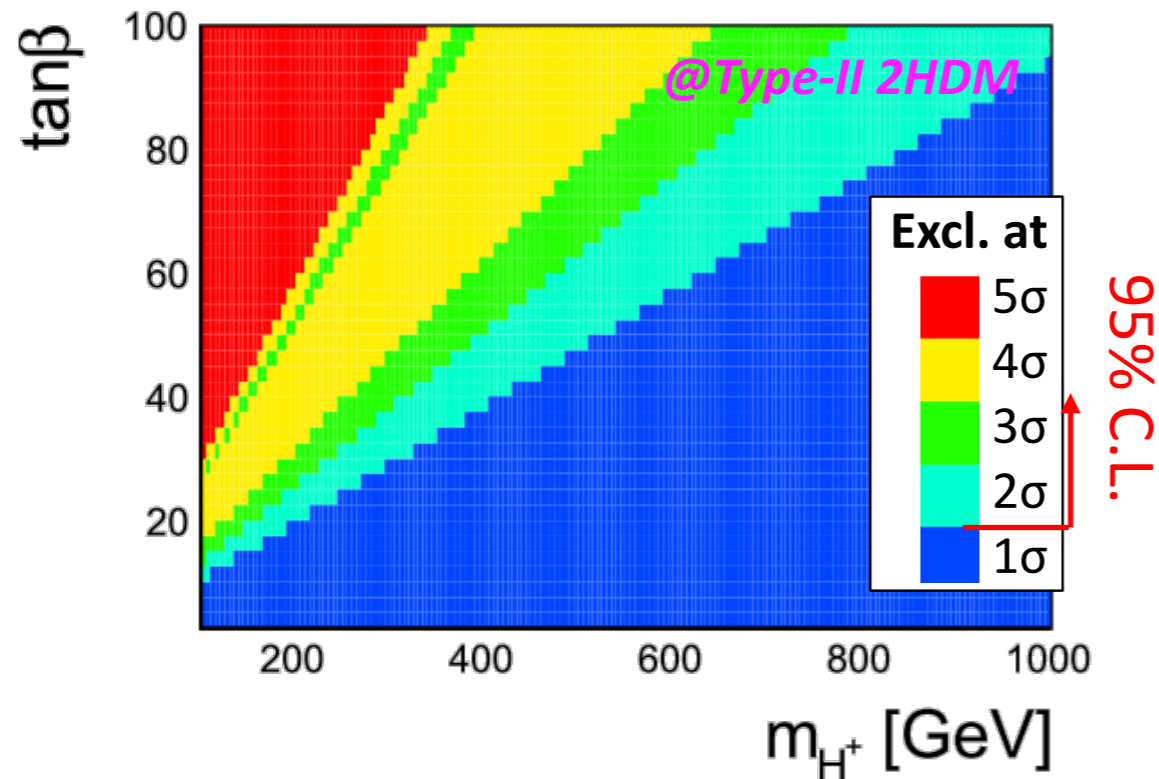
Missing energy = Belle II golden modes

- Purely leptonic B decays: $B \rightarrow \tau\nu, B \rightarrow \mu\nu$
- $B \rightarrow D^{(*)}\tau\nu$ \longrightarrow *Talk by M.Tanaka*
 - Measurements of R, q^2 distribution, and polarization/angular analysis
- Inclusive V_{cb} : $B \rightarrow X_c\ell\nu$
 - Spectra and moments of kinematical distributions
- Exclusive V_{ub} : $B \rightarrow \pi\ell\nu$
 - Rate and spectra of variables (q^2, E_l)
- Inclusive V_{ub} : $B \rightarrow X_u\ell\nu$
 - Precise measurement of differential distributions
- and (semi-)leptonic B_s decays at $\Upsilon(5S)$

Examples of sensitivity plots

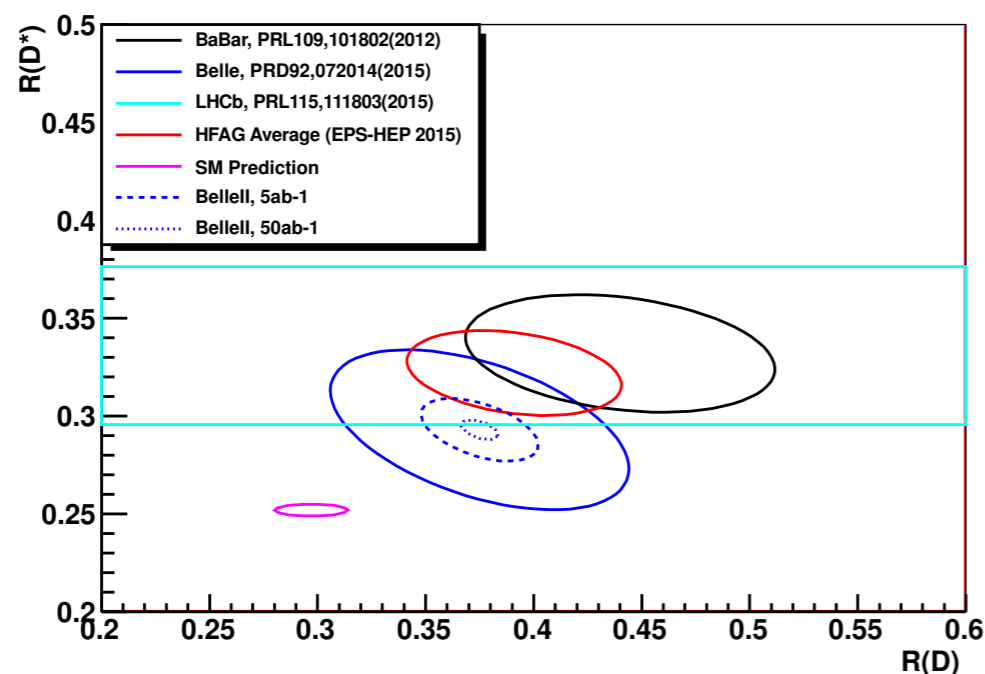
Combined analysis with *SuperIso*:

Y. Sato



1. $B \rightarrow D^* \tau \nu$: $0.293 \pm 0.038 \pm 0.015$
 - Belle, PRD 92, 072014 (2015)
2. $B \rightarrow D \tau \nu$: $0.375 \pm 0.064 \pm 0.026$
 - Belle, PRD 92, 072014 (2015)
3. $B \rightarrow \tau \nu$: $(0.91 \pm 0.23) \times 10^{-4}$
 - Belle average by semilept- & had-tag
PRD 92, 051102(R) (2015), PRL 110, 131801(2013)

Belle II sensitivity:



K. Hara at the LAL mini-workshop

WG2: Radiative & Electroweak Penguins

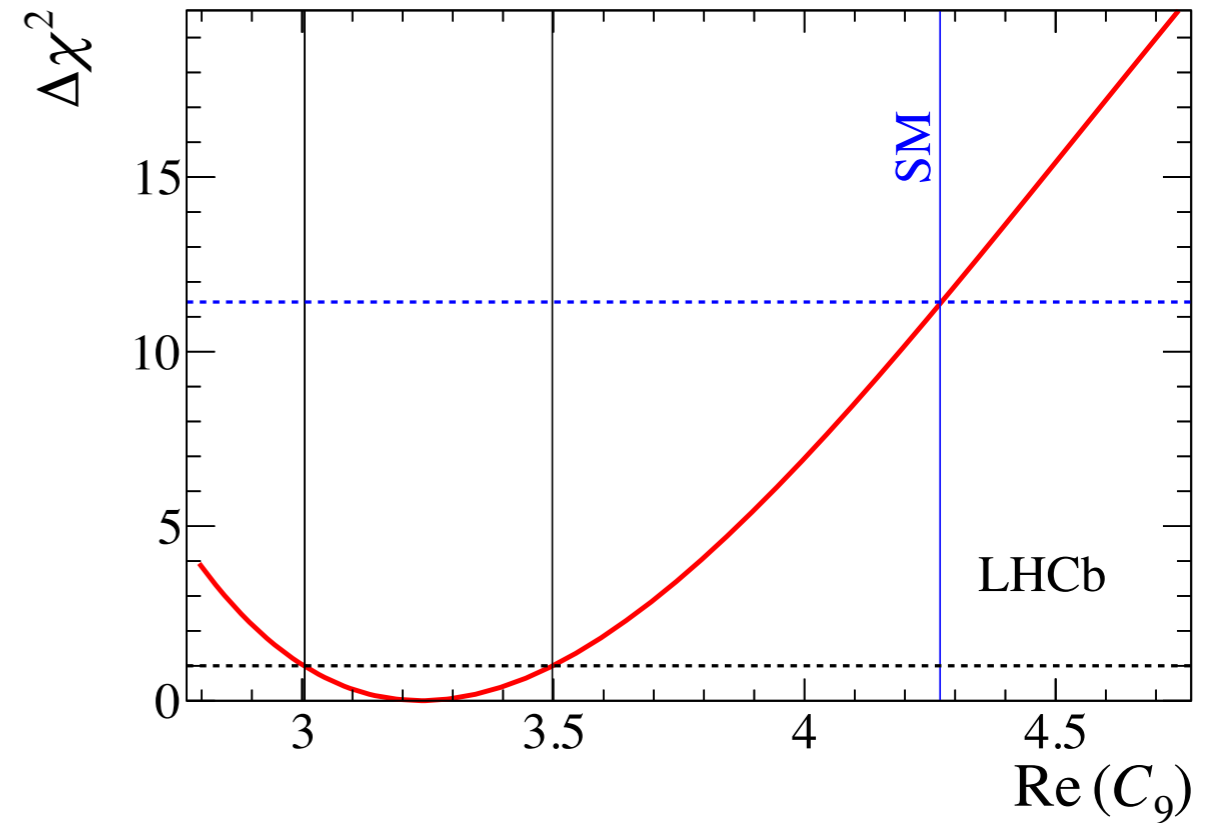
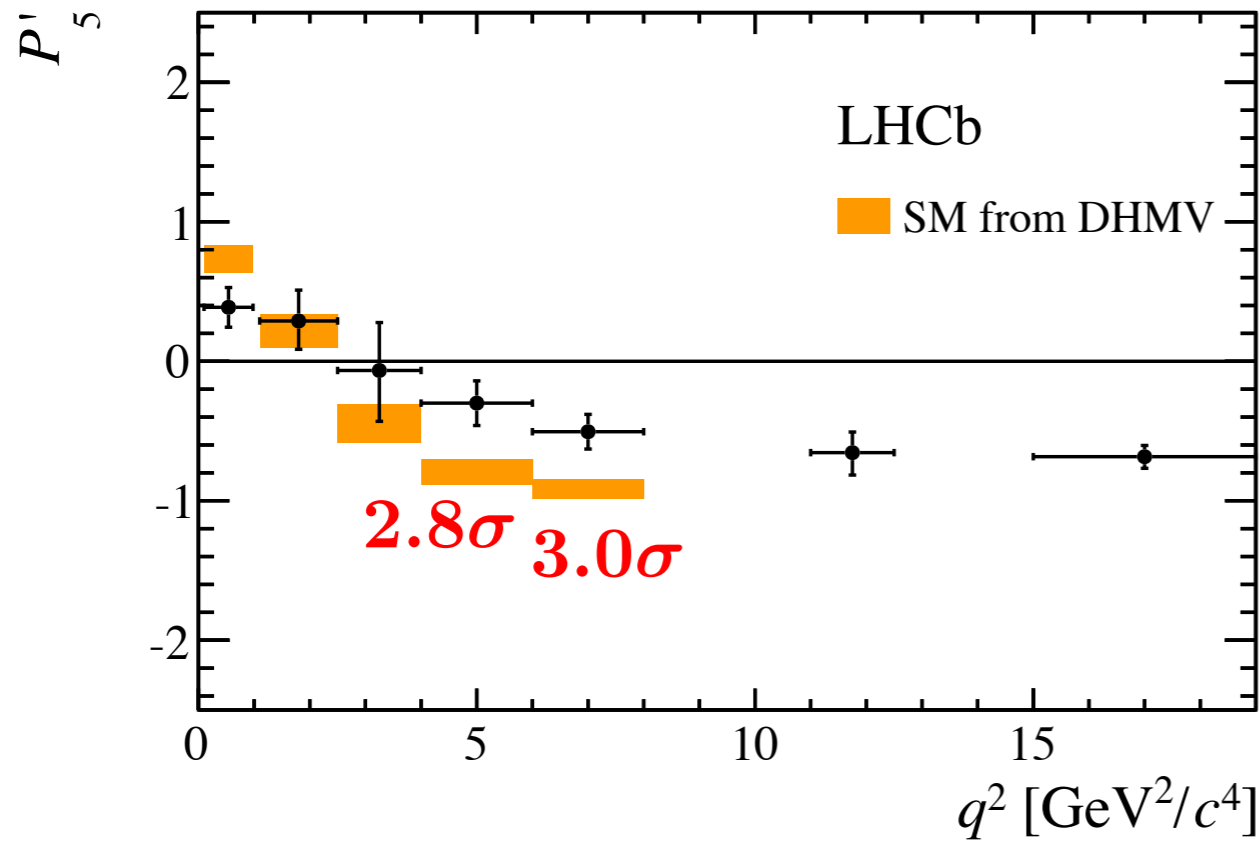
- A_{CP} in $B \rightarrow X_{s+d}\gamma$
- BF and A_{CP} in $B \rightarrow X_d\gamma$
- ΔA_{CP} in $B \rightarrow X_s\gamma$
- TCPV in $B \rightarrow K_S\pi^0\gamma$ and $B \rightarrow \rho\gamma$ (WG2&WG3)
- $B(B \rightarrow K^{(*)}\nu\bar{\nu})$
- R_{X_s} in $B \rightarrow X_s\ell^+\ell^-$

LHCb anomalies in $P5'$ and

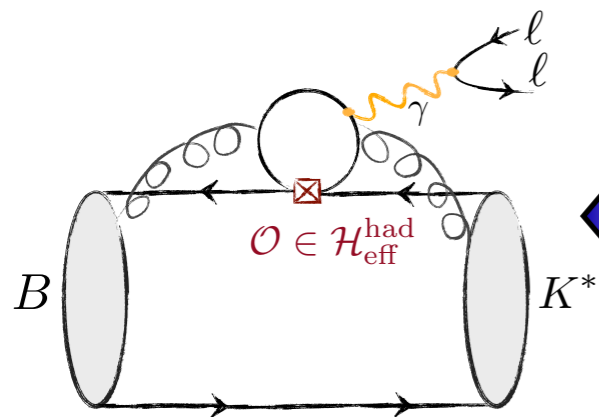
$$R_K = \frac{B(B \rightarrow K\mu\mu)}{B(B \rightarrow Kee)} = 0.745_{-0.074}^{+0.090} \pm 0.036$$

Anomaly?

LHCb, 1512.04442



DHMV = Descotes-Genon, Hofer, Matias & Virto (2014)



LCSR estimate

Khodjamirian et al. (2010)

$$C_9^{\text{NP}} < 0$$

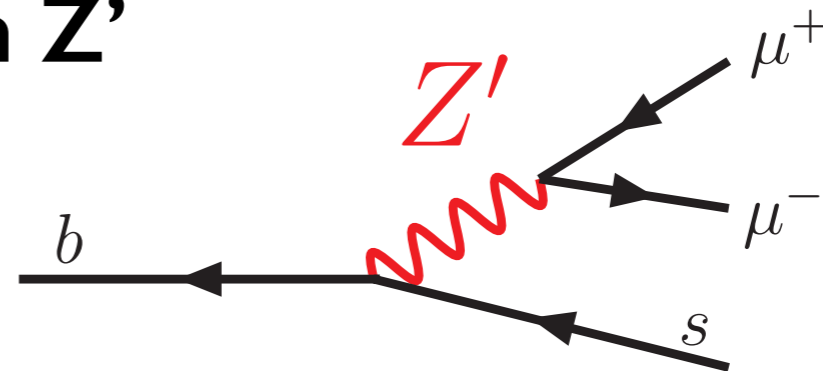
$$O_9 = (\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu l)$$

$$|C_9^{\text{NP}} / C_9^{\text{SM}}| \sim 25\%$$

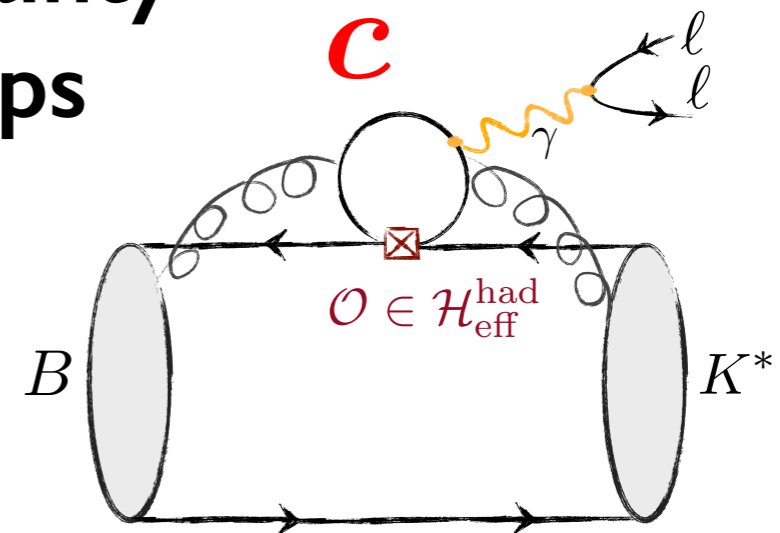
Possible interpretations

$$C_9^{\text{NP}} < 0 \quad O_9 = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)$$

- NP contribution, e.g., from Z'



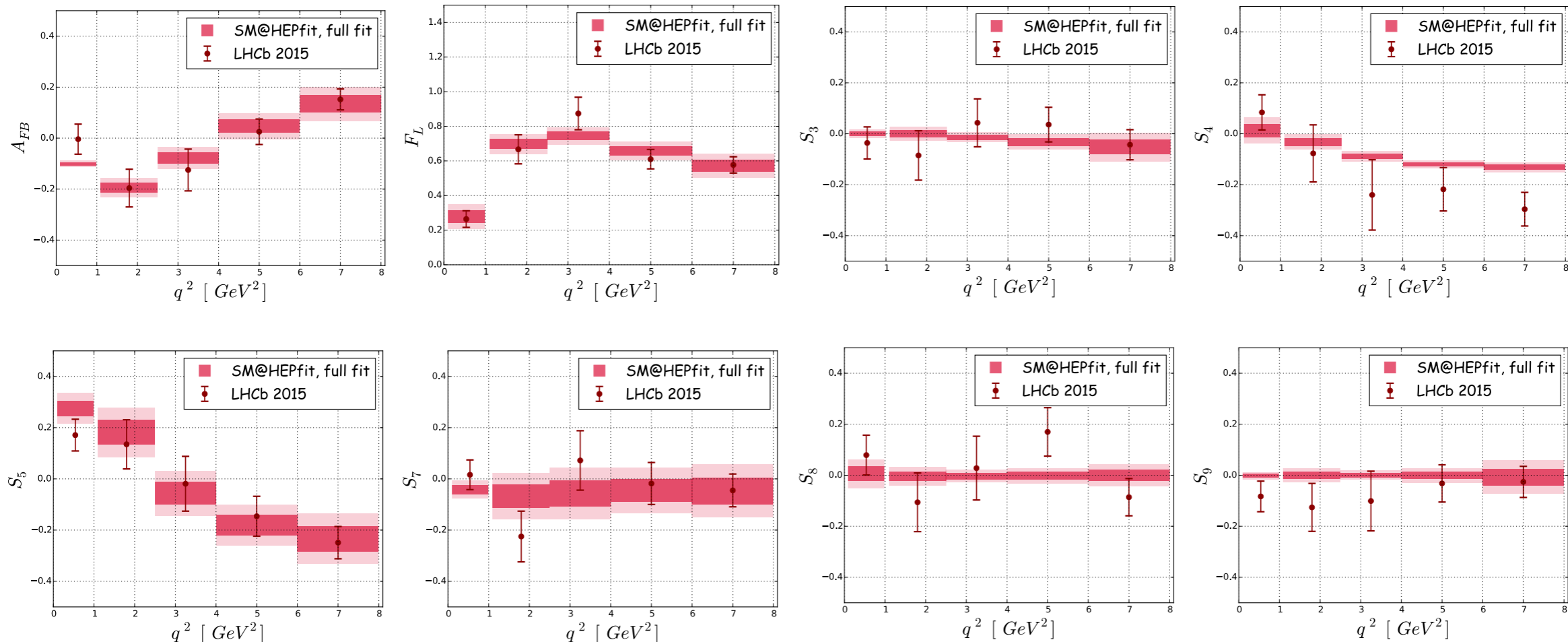
- Underestimate of SM uncertainty from long-distance charm loops



Results from *HEPfit*

M. Ciuchini, M. Fedele, E. Franco, **S.M.**, A. Paul,
L. Silvestrini & M. Valli, arXiv:1512.07157

Non-factorizable charm loop has been fitted from the data.



Observable	q^2 bin [GeV^2]	measurement	full fit	prediction
P'_5	[0.1, 0.98]	0.392 ± 0.146	0.781 ± 0.101	0.872 ± 0.087
	[1.1, 2.5]	0.297 ± 0.209	0.409 ± 0.104	0.485 ± 0.129
	[2.5, 4]	-0.076 ± 0.351	-0.133 ± 0.103	-0.153 ± 0.115
	[4, 6]	-0.301 ± 0.157	-0.383 ± 0.087	-0.430 ± 0.102
	[6, 8]	-0.505 ± 0.120	-0.477 ± 0.102	-0.314 ± 0.215

$$P'_5 = \frac{S_5}{\sqrt{F_L(1 - F_L)}}$$

No significant discrepancy!

$B \rightarrow X_s \ell^+ \ell^-$ at Belle II

- Inclusive $B \rightarrow X_s \ell^+ \ell^-$ has a complementary role in NP search to exclusive $B \rightarrow K^{(*)} \ell^+ \ell^-$.
- Theoretically cleaner
- 95% constraints on the high-scale WCs: $R_i = \frac{C_i(\mu_0)}{C_i^{\text{SM}}(\mu_0)}$

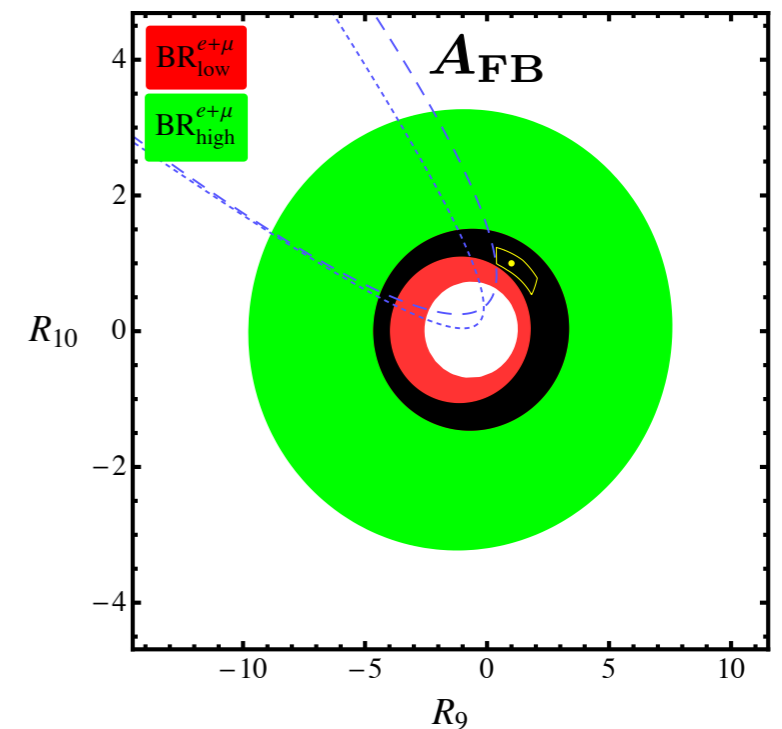
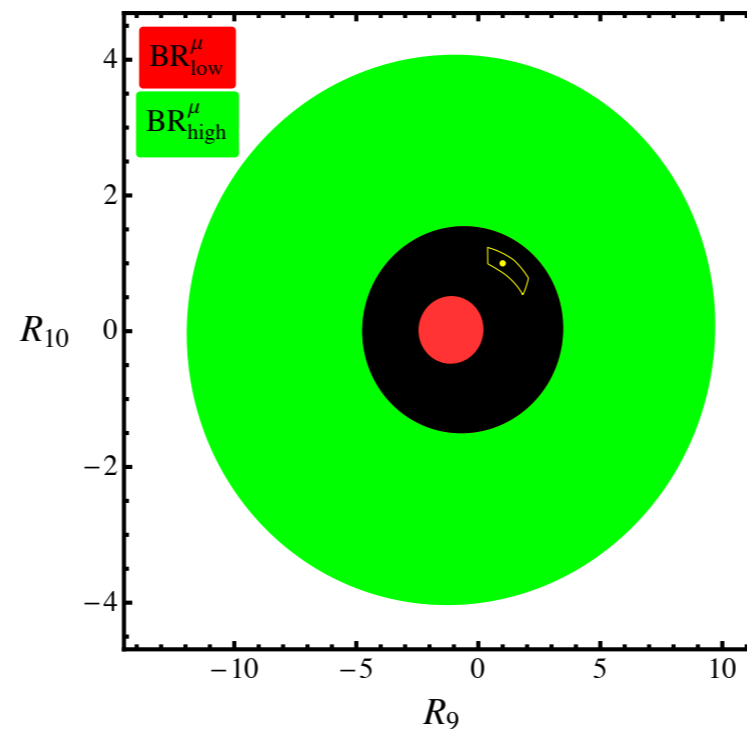
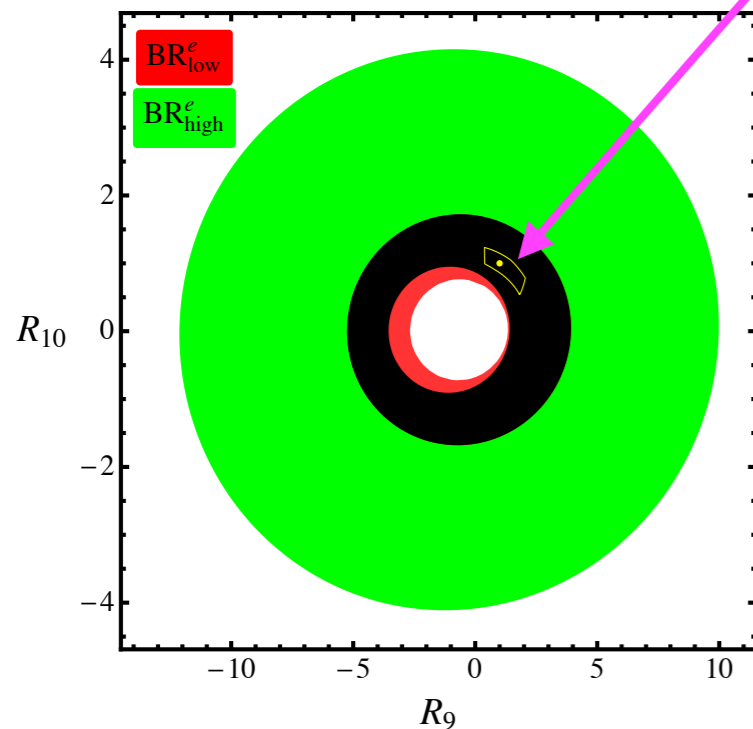
Belle II (50 ab⁻¹)

T. Huber, T. Hurth & E. Lunghi, arXiv:1503.04849

$B \rightarrow X_s e^+ e^-$

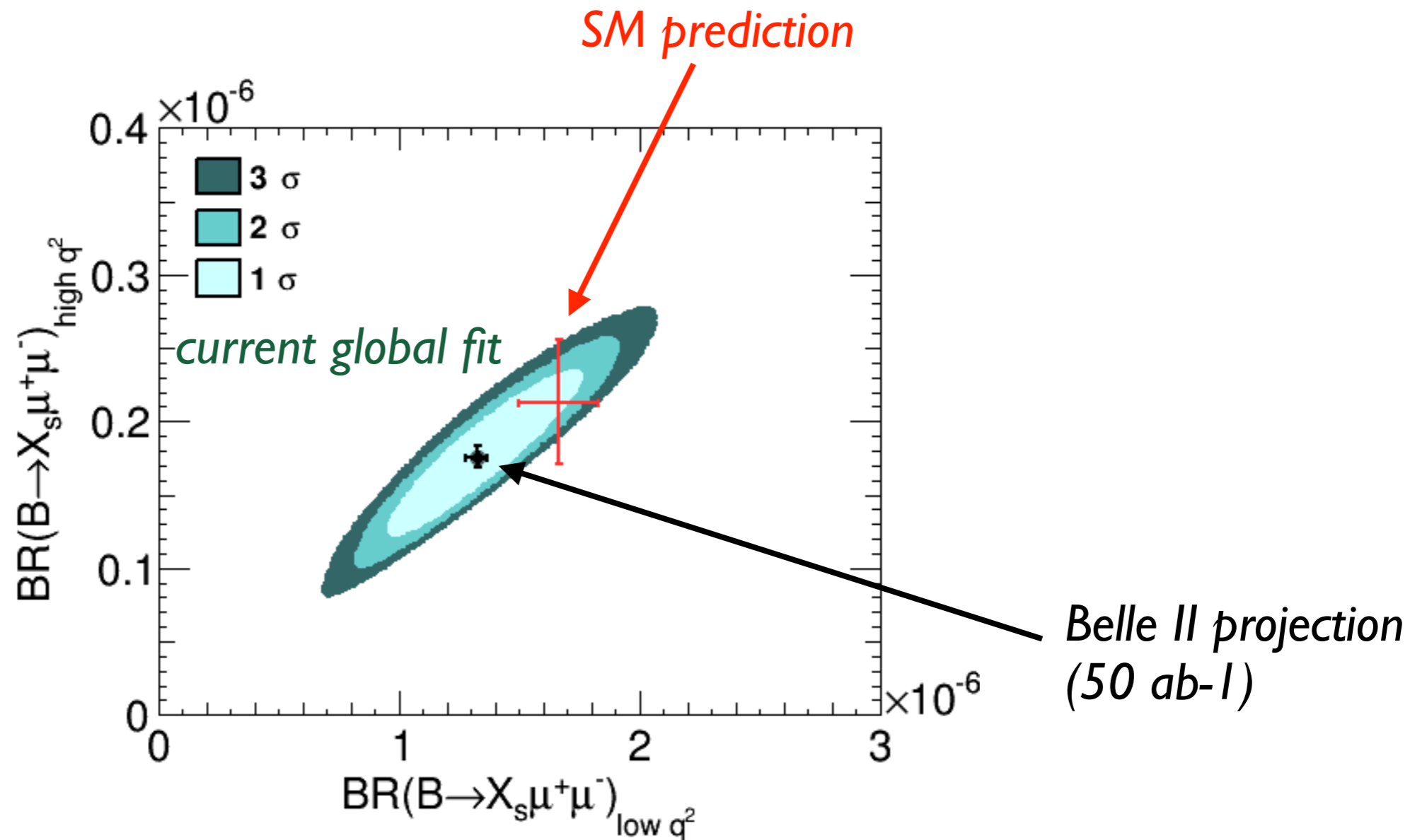
$B \rightarrow X_s \mu^+ \mu^-$

both



Belle II sensitivity

T. Hurth, F. Mahmoudi & S. Neshatpour, arXiv:1410.4545



Future measurements of the inclusive observables at Belle II will allow for a powerful crosscheck!

WVG3: $\alpha = \phi_2$ & $\beta = \phi_1$

Time-dependent analysis = Belle II golden modes

● ϕ_1 :

$$B_d \rightarrow J/\psi K_S$$

$$B_d \rightarrow \phi K_S \quad B_d \rightarrow \eta' K_S \quad B_d \rightarrow \pi^0 K_S$$

- sensitive to NP

● ϕ_2 :

$$B \rightarrow \pi\pi \quad B \rightarrow \pi\rho \quad B \rightarrow \rho\rho$$

- isospin analysis

● Radiative decay (WVG2&WVG3):

$$B_d \rightarrow K_S \pi^0 \gamma$$

- sensitive to the RH current

WG4: gamma = phi_3

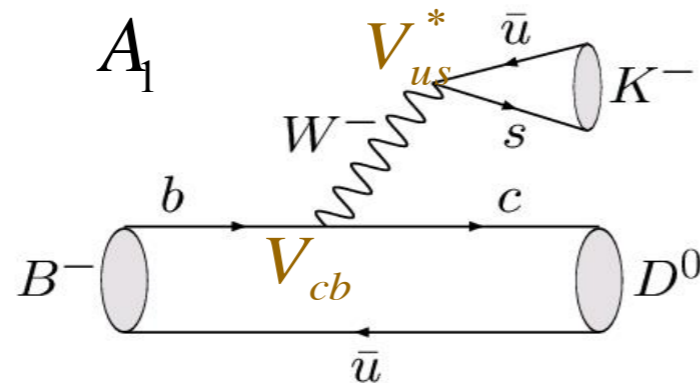
$B^- \rightarrow DK^-$: *free of theoretical uncertainties, since hadronic param's can be determined from data*

4/29/2015

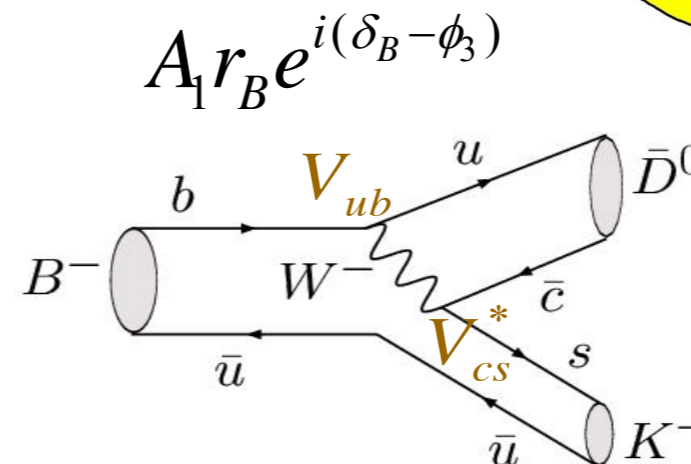
WG4 summary

3

Golden mode



Also, an annihilation process, but depends on same CKM elements



$$A_1 r_B e^{i(\delta_B - \phi_3)}$$

- Same final state for D and $\bar{D} \Rightarrow$ interference \Rightarrow **the possibility of DCPV**
- Three types of D final states generally used
 - **CP-eigenstates [GLW]**
 - Gronau & London, PLB **253**, 483 (1991), Gronau, & Wyler, PLB **265**, 172 (1991)
 - **K^+X^- ($X^-=\pi^-, \pi^0, \pi^-\pi^+\pi^0$) - CF and DCS [ADS]**
 - Atwood, Dunietz & Soni, PRD **63**, 036005 (2001)
 - **Self-conjugate multibody states: $K_S^0 h^+ h^-$ [Dalitz]**
 - Giri, Grossman, Soffer and Zupan, PRD **68**, 054018 (2003); Bondar (unpublished)
 - **None of the above (SCS): $K_S^0 K^+ \pi^-$ [GLS]**
 - Grossman, Ligeti and Soffer, Phys. Rev. D **67** 071301 (2003)



Toy impact plots for the CKM fit

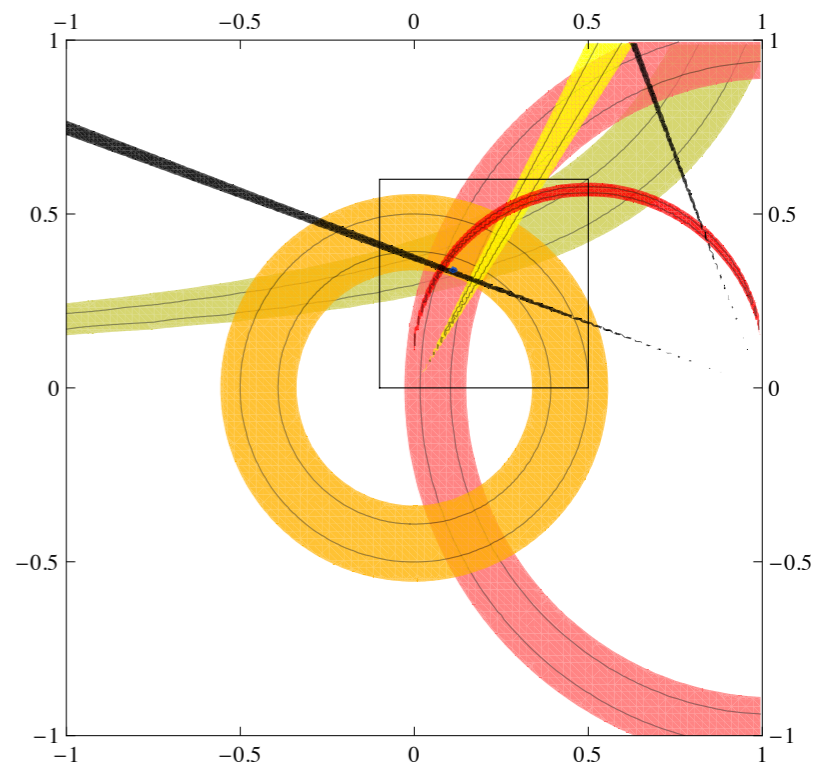
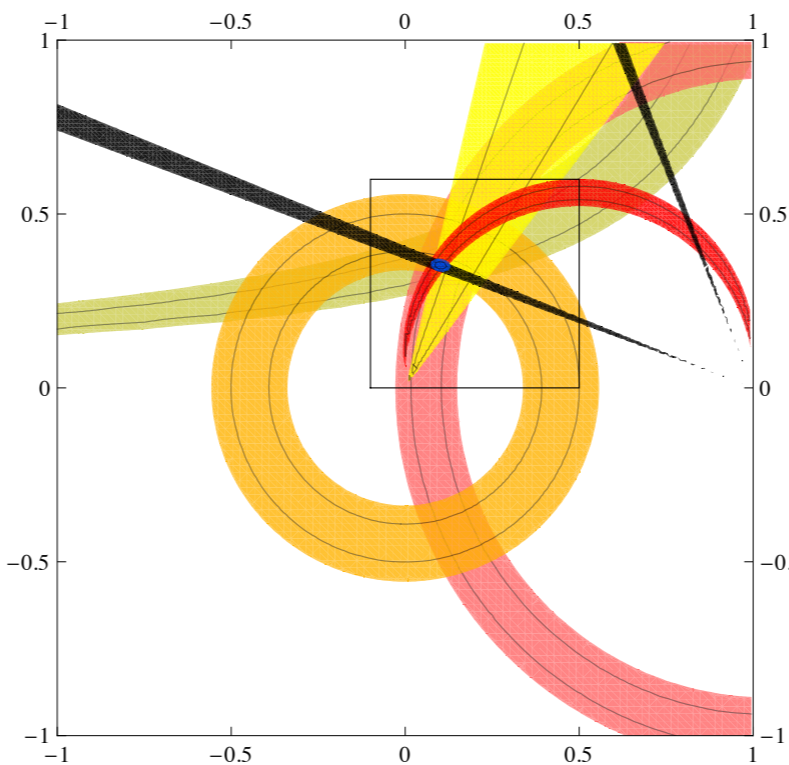
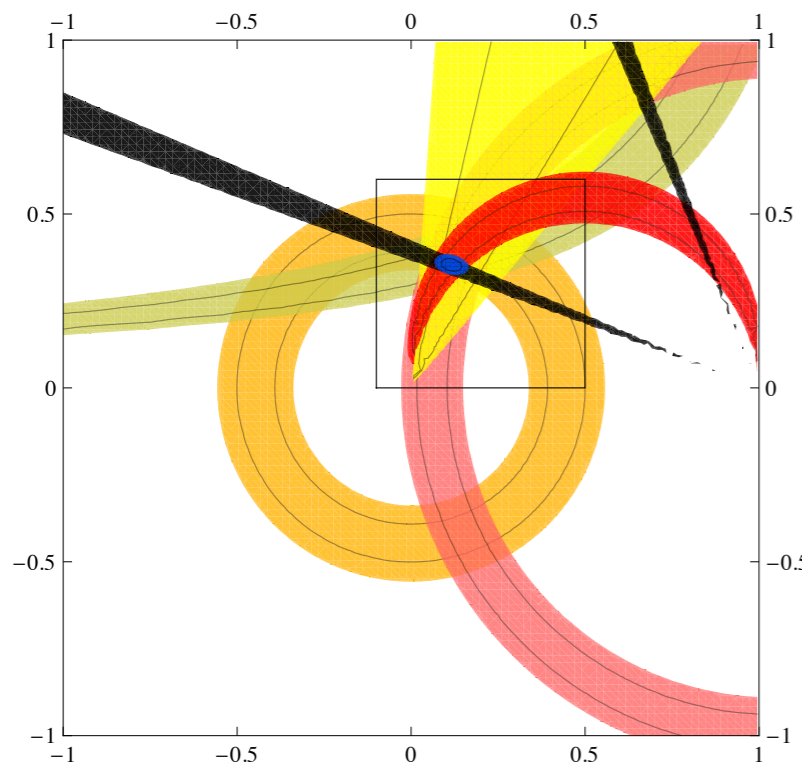
- Reducing only the errors of the angles at the current moment for an exercise.

Courtesy of E. Kou

Current

Future (5 ab⁻¹)

Future (50 ab⁻¹)



The angle measurements will be improved significantly!

WG5: Charmless Hadronic B Decay

Final states with neutral particles = Belle II golden modes

- $B \rightarrow K\pi$ system, with emphasis on $K_S\pi^0$ (WG3&WG5)
 - time-dependent CPV, isospin sum rule, $B \rightarrow K\pi$ puzzle
- $B \rightarrow K^*\pi, B \rightarrow K\rho$
 - isospin sum rule
- $B \rightarrow K^*\rho$
 - comparisons with the above channels
- $B_s \rightarrow K^0\bar{K}^0$
- $B_s \rightarrow \phi\pi^0$

“Golden mode” definition:

a mode in which Belle II will be competitive (with LHCb) and, if NP is present at a sufficiently large level, its signature will be measured/identified

Hadronic Modes

- (a) $D^0 \rightarrow K^+ \pi^-, K^+ K^-, \pi^+ \pi^-$ - TDCPV & mixing, time-integrated analyses, Acp
- (b) $D^0 \rightarrow K_S^0 K_S^0, \pi^0 \pi^0, D^+ \rightarrow \pi^+ \pi^0$ - time-integrated analyses, Acp
- (c) $D^0 \rightarrow K_S^0 K^+ K^-, K_S^0 K^+ \pi^-, K^+ \pi^- \pi^0, K_S^0 \pi^+ \pi^-, \pi^+ \pi^- \pi^0$
- TDCPV & mixing, Dalitz plot analyses

Semileptonic Modes

Leptonic and Radiative Decays

- (a) $D_{(s)}^+ \rightarrow e^+ \nu, \mu^+ \nu, \tau^+ \nu$ - important for lattice QCD
- (b) $D^0 \rightarrow \rho^0 \gamma, D^0 \rightarrow \gamma \gamma$ - NP searches

Other

- (a) missing energy modes - e.g., light dark matter searches
- (b) glueballs
- (c) $D_s^+ \rightarrow p \bar{n}$

WG7: Quarkonium(like)

WG7 summary at the 3rd B2TiP workshop

1. ISR $e^+e^- \rightarrow \pi^+\pi^-J/\psi(\psi')$, $K^+K^-J/\psi(\psi')$, $\pi^+\pi^-h_c(1P, 2P)$, $\omega/\phi \chi_{cJ}$, $\pi^+\pi^-X(3823)$, $\gamma X(3872)$, $DD^*\pi$, ... to search/study Z_c , Z_c' . Z_{cs} , ... all possible Y states, new resonances and understand the line shapes.
2. $Y(3S)$ decays including $Y(1D)$, $\eta_{cb}(1S,2S) \rightarrow \gamma \gamma$, $\chi_b(1P,2P)$, ...
3. Two-photon processes: $\gamma \gamma \rightarrow \phi J/\psi$ to confirm/deny $X(4350)$ and search for $Y(4140)$, study of $\eta_c(2S)$, $\gamma \gamma \rightarrow \omega J/\psi$, DD^* , $\eta_{c0} \pi^0$, ... to study $X(3915)$, search for $X(3872)$ -like states, ...
4. Data at the $Y(6S)$ peak:
 - study anomalous transitions from $Y(6S)$ to lower bottomonia (nature of $Y(6S)$);
 - search for missing bottomonia in $1D, 2D, 1F$ multiplets;
 - search for molecular states X_b , W_b via radiative and $\pi^+\pi^-$ transitions.High energy scan:
 - decomposition of R_b into $BB, BB^*, B^*B^*, BB^*\pi, \dots$ (nature of $Y(5S)$, $Y(6S)$);
 - scan of cross-sections $e^+e^- \rightarrow$ bottomonium + light hadrons (search for new vector states);
 - investigate Λ_b - Λ_b -bar threshold region.
5. B decays to:
 - charmonium (η_c , J/ψ , h_c , χ_{cJ} , $\eta_c(2S)$, $\psi(2S)$), light hadrons and kaon (search for the only missing narrow charmonium state $\eta_{c2}(1D)$, for new charmonium-like states and for new channels of known states);
 - open charm-anti-charm final states (DD , DD^* , $DD^*\pi$, $D_s D_s, \dots$) and kaon (search for elastic channels of known states, search for new charmonium(-like) states).

WG8: Tau, low multiplicity & EW

WG8 summary at the 3rd B2TiP workshop

5 Golden Modes of WG8, a proposal.



- > 1) Tau 1: LFV $\tau \rightarrow 3\mu$
- > 2) Tau 2: CPV $\tau \rightarrow K_S \pi\nu$ or $K\pi\pi\nu$
- > 3) Precision two track final states
 - “First Physics”: $\Upsilon(3S) \rightarrow \mu\mu$ to measure vacuum polarization (s-channel)
 - Dark Photon direct search into $\mu\mu$
 - ISR $ee \rightarrow \pi\pi(g)$ and $ee \rightarrow \mu\mu(g)$ @5ab⁻¹
 - AFB($\mu\mu$) @5ab⁻¹ (Contact Interactions) and @50ab⁻¹ (rho parameter)
- > 4) Dark: Dark Photon $A \rightarrow$ Invisible
- > 5) two photon: eta/pion transition form factor

→ *Talk by K. Hayasaka*

WG9: New physics

● NP WG tasks:

- **Benchmark models/points** for 5, 10, 50 ab⁻¹ of data with a milestone table for given NP models (providing theoretical predictions for various Belle II golden modes with those models).
- **Model-dependent and model-independent fits**, aiming at making **sensitivity (impact) plots** for model parameters with the inputs from WG1-8.
- Relation to measurements from other exp's (e.g., LHC, neutrino, dark matter, future exp's)
- Evaluation and developments of **theory codes** toward producing global fits.

● Those will be discussed intensively at the Pittsburgh workshop in May!

Report outline: common chapters

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To do

- Work on detailed simulations of the golden modes.
- Create Belle II impact (sensitivity) plots for NP searches.
- Complete the chapters, and review, edit and proofread them.

- 4th B2TIP workshop at Univ. of Pittsburgh (23-25 May)
- Report Camp (Editorial meeting) at MIAPP (Nov)
- and small editorial meetings

- Finalize the report by the end of 2016 **before phase 2 of the SuperKEKB operation starts.**

Summary

- **B2TiP** is a joint theory-experiment effort to study the potential impacts of the Belle II program, which are complementary/competitive to those of the LHC and of other experiments at intensity frontiers.
- The most important outcome will be **a KEK report**, which summarizes important observables (“*golden modes*”) at Belle II with their achievable precision and their impact on our understanding of the SM and/or NP.
~ by the end of 2016
- Please stay tuned and join the B2TiP activity!

4th B2TiP workshop, Pittsburgh, May 23-25

early registration by Apr. 15!

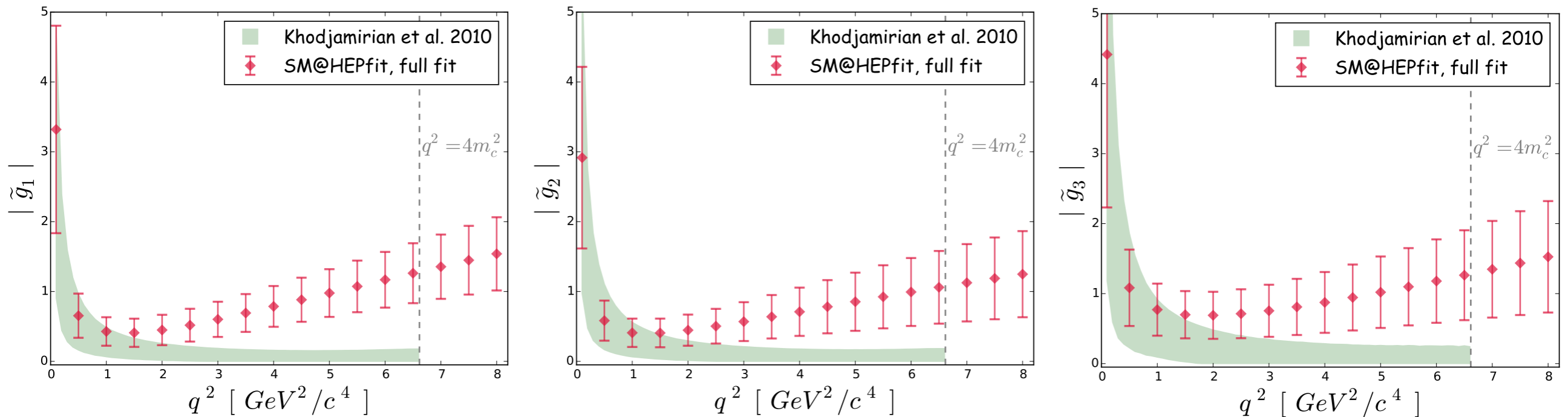
<https://kds.kek.jp/indico/event/19723/>



Backup

Fit result of the hadronic contributions

$$\tilde{g} \equiv \Delta C_9^{(\text{non pert.})} / (2C_1)$$



The hadronic cont's extracted from the data are compatible with the LCSR estimate for $q^2 \lesssim 1 \text{ GeV}^2$ and seem to grow towards charm resonances.

Fit result of the hadronic contributions

$$h_\lambda(q^2) = \frac{\epsilon_\mu^*(\lambda)}{m_B^2} \int d^4x e^{iqx} \langle \bar{K}^* | T \{ j_{\text{em}}^\mu(x) \mathcal{H}_{\text{eff}}^{\text{had}}(0) \} | \bar{B} \rangle$$

$$= h_\lambda^{(0)} + \frac{q^2}{1 \text{ GeV}^2} h_\lambda^{(1)} + \frac{q^4}{1 \text{ GeV}^4} h_\lambda^{(2)},$$

The first and second terms could be reinterpreted as a modification of C7 and C9, respectively.

Parameter	Absolute value	Phase (rad)
$h_0^{(0)}$	$(5.3 \pm 2.2) \cdot 10^{-4}$	3.41 ± 0.74
$h_0^{(1)}$	$(2.3 \pm 1.7) \cdot 10^{-4}$	-0.1 ± 1.2
$h_0^{(2)}$	$(2.7 \pm 2.1) \cdot 10^{-5}$	-0.1 ± 1.7
$h_+^{(0)}$	$(7.0 \pm 6.3) \cdot 10^{-6}$	0.0 ± 1.7
$h_+^{(1)}$	$(4.1 \pm 3.0) \cdot 10^{-5}$	-0.9 ± 1.6
$h_+^{(2)}$	$(1.6 \pm 1.1) \cdot 10^{-5}$	3.0 ± 1.6
$h_-^{(0)}$	$(4.7 \pm 2.0) \cdot 10^{-5}$	3.2 ± 1.5
$h_-^{(1)}$	$(4.9 \pm 3.6) \cdot 10^{-5}$	0.0 ± 1.8
$h_-^{(2)}$	$(2.7 \pm 1.1) \cdot 10^{-5}$	0.01 ± 0.76

