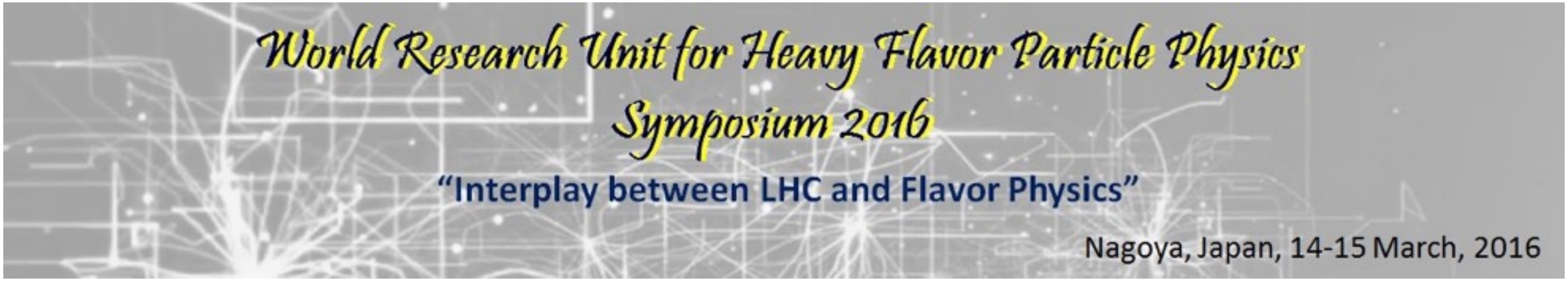
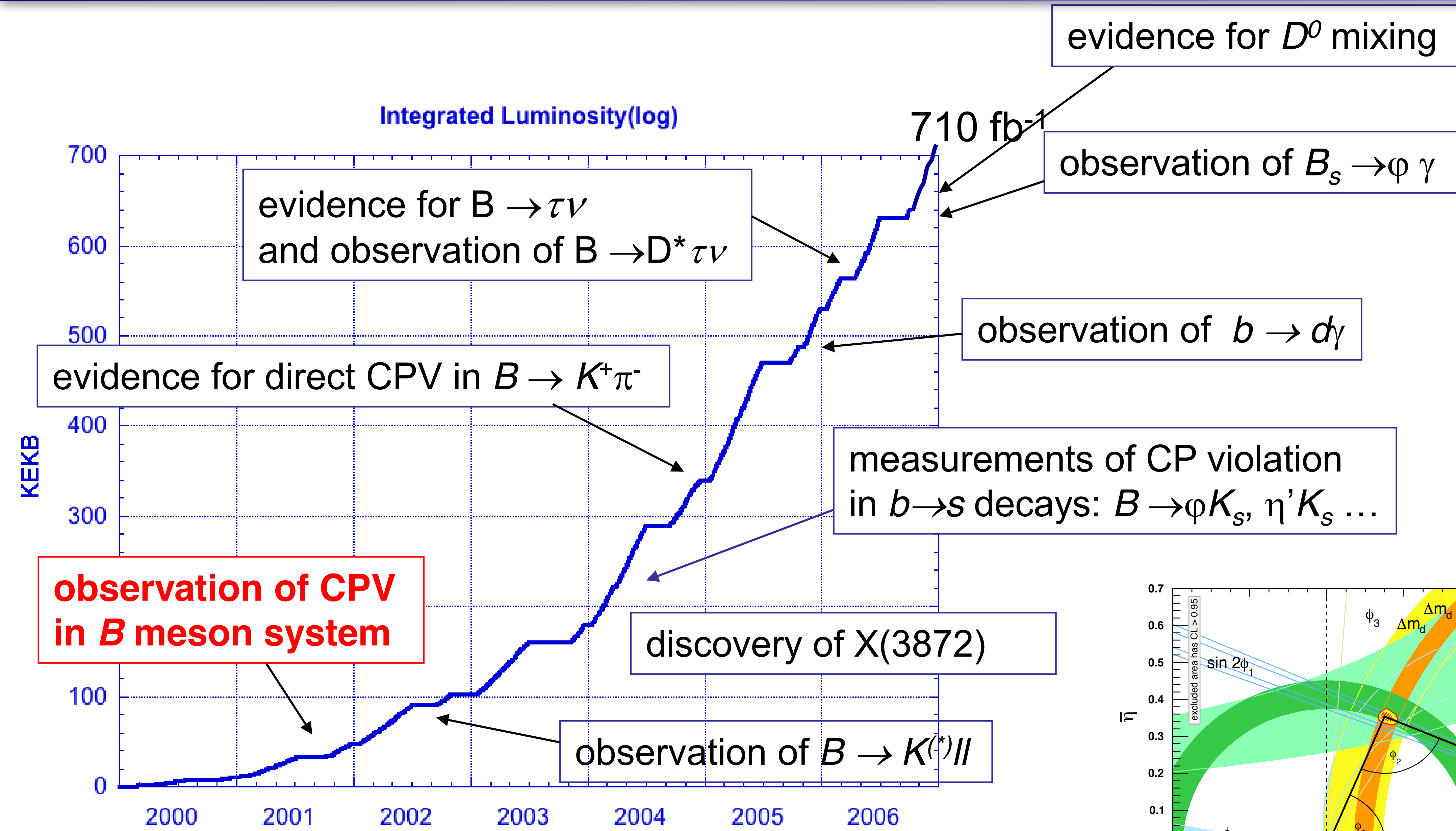
Belle II Theory Interface Platform (B2TiP)

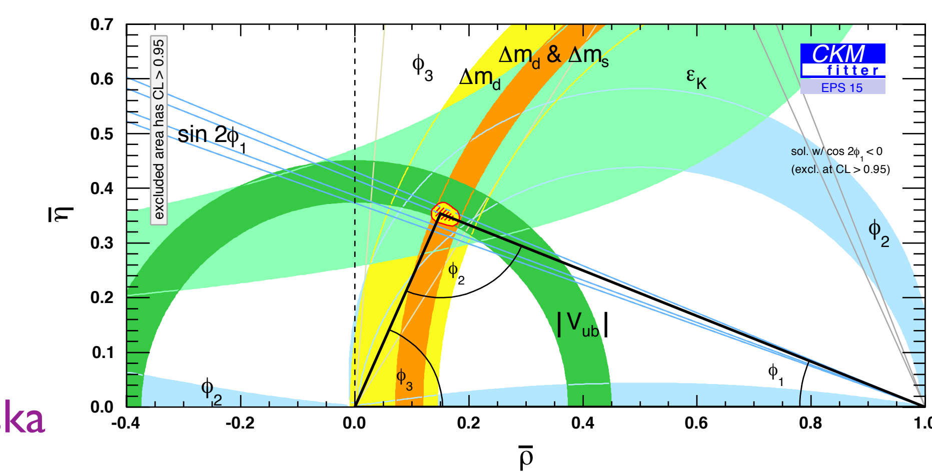
Satoshi Mishima (KEK)



Major achievements at Belle



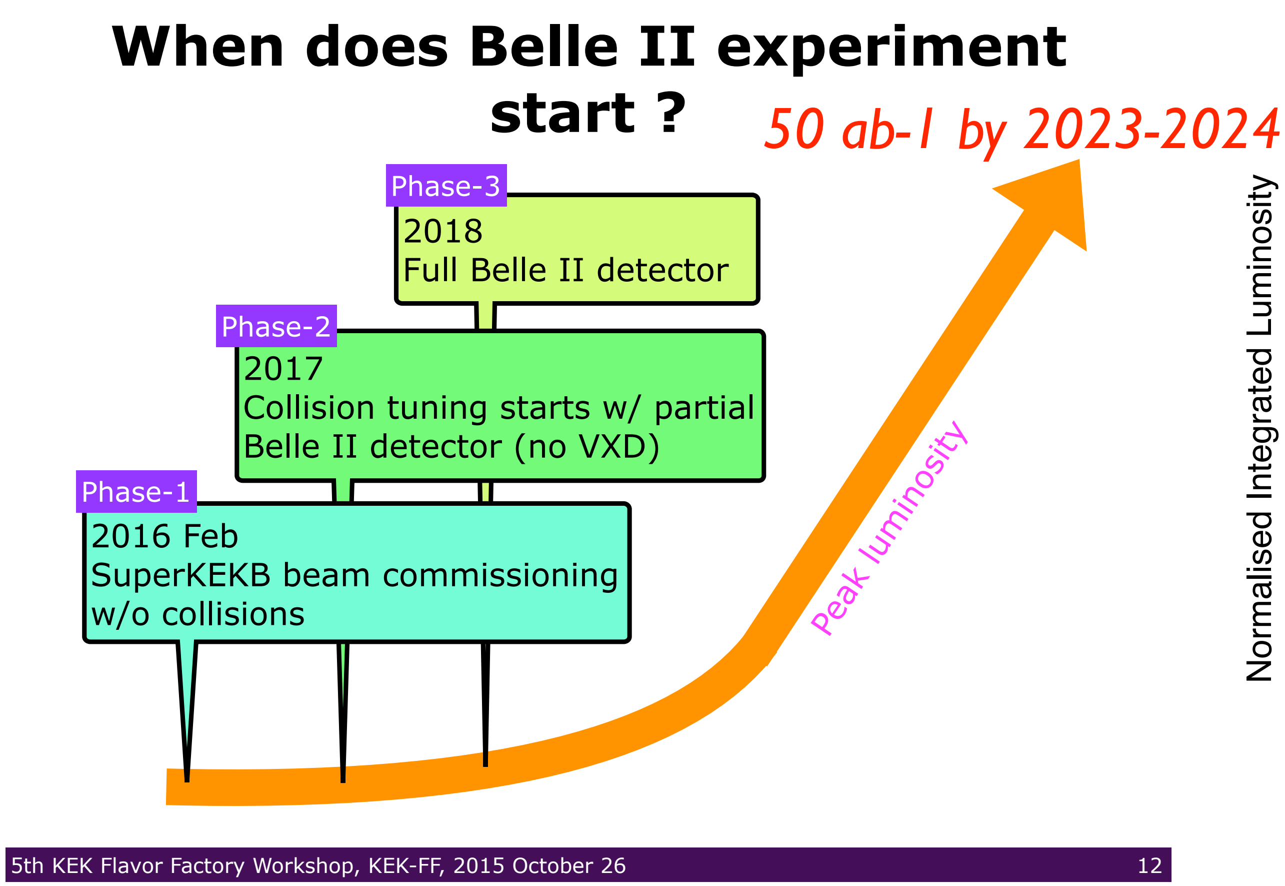
taken from a talk by M. Rozanska



- 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!

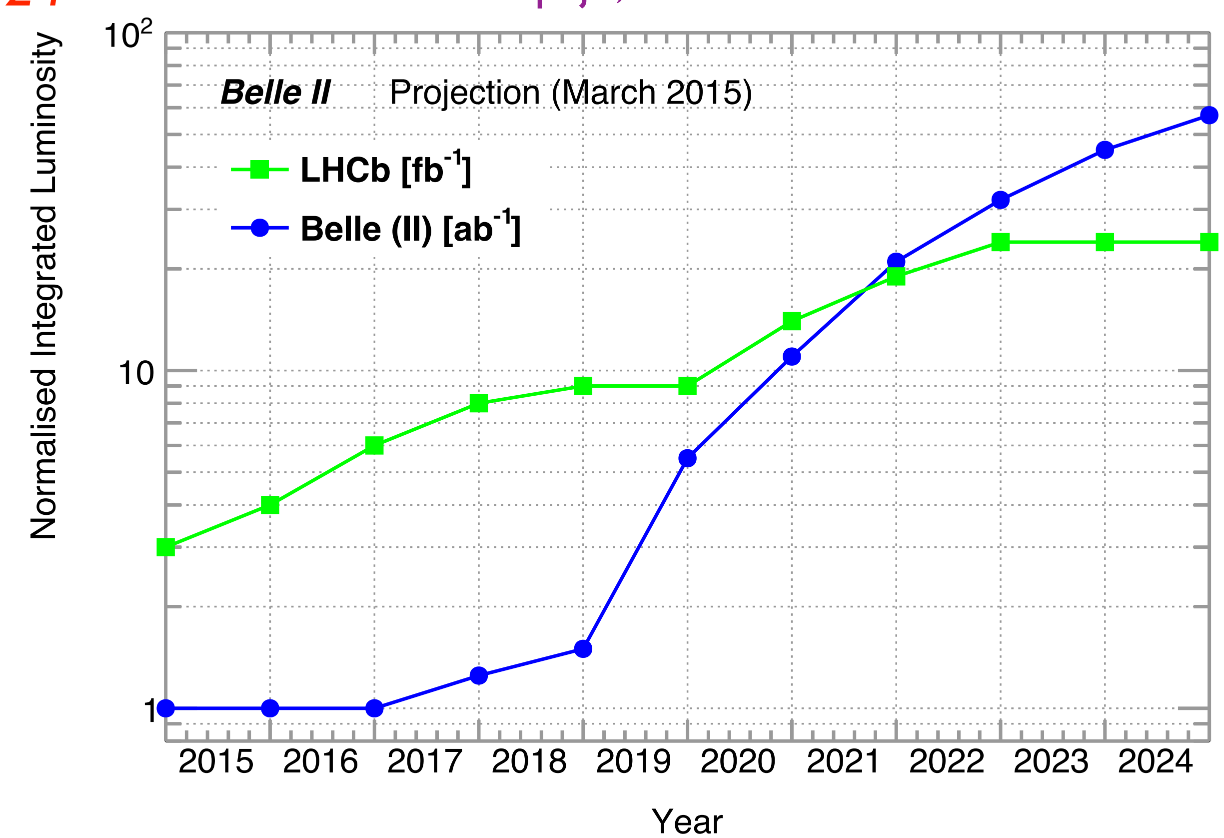
SuperKEKB / Belle II

- SuperKEKB: $L = 8 \times 10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ ⇨ *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.



I. Adachi, KEK-FF 2015

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



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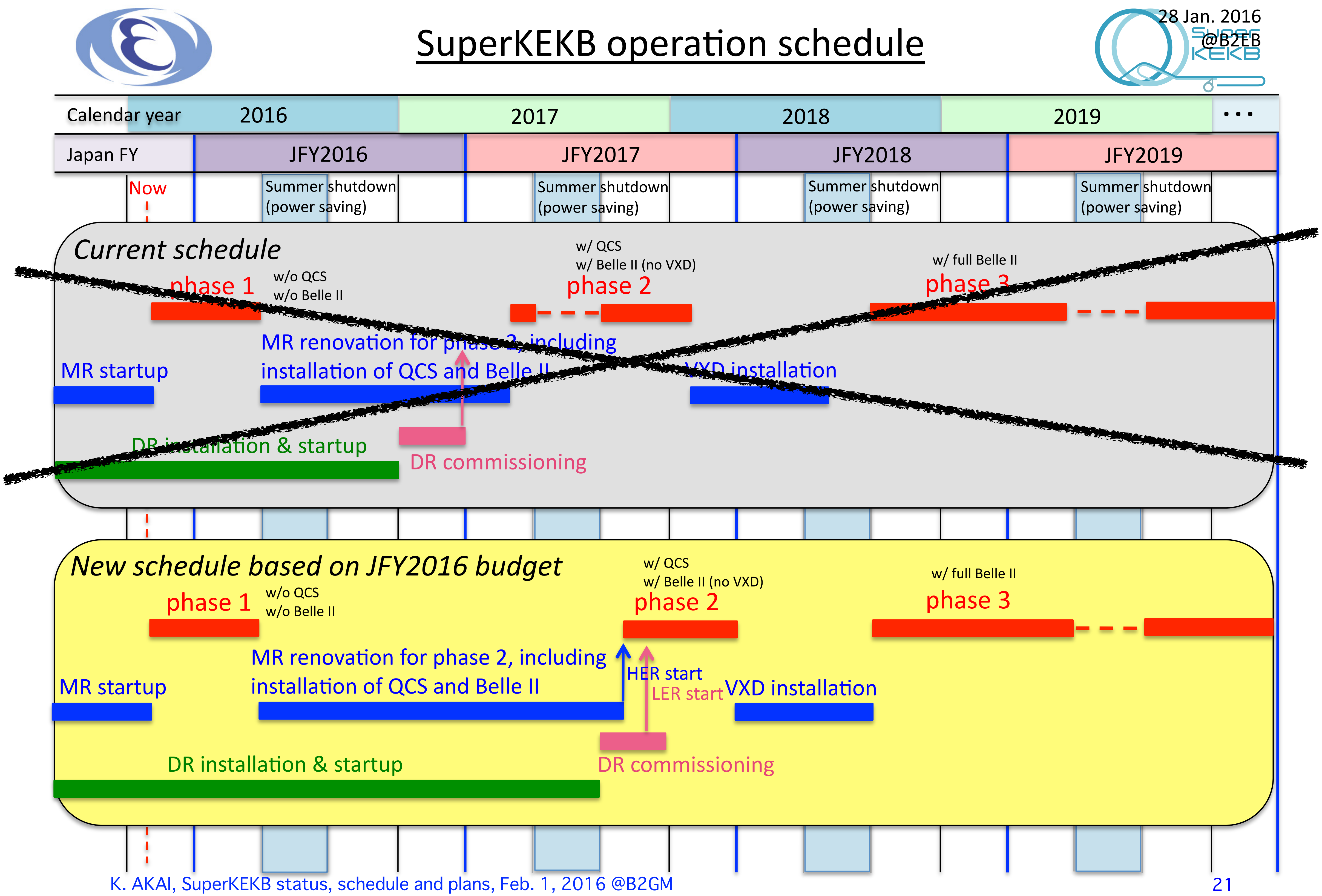
SuperKEKB / Belle II schedule



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LHCb vs. Belle II

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

    $$B_{d,s} \to \mu^+\mu^-,\ B \to K^*\mu^+\mu^-,\ \cdots$$

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

    $$B \to \pi^0\pi^0,\ B \to K_S\pi^0,\ B \to K_S\pi^0\gamma,\ \cdots$$

  - final states with missing particles

    $$B \to \tau\nu,\ B \to D^{(*)}\tau\nu,\ B \to K^{(*)}\nu\nu,\ \cdots$$

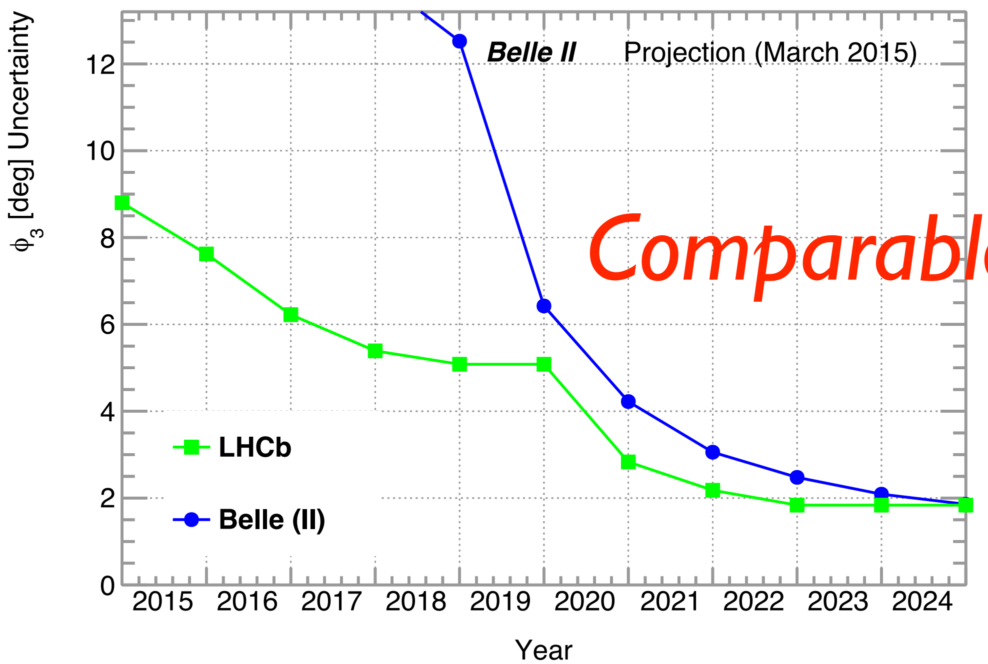
  - inclusive modes

    $$B \to X_s\gamma,\ B \to X_s\ell^+\ell^-,\ \cdots$$

Competition and complementarity

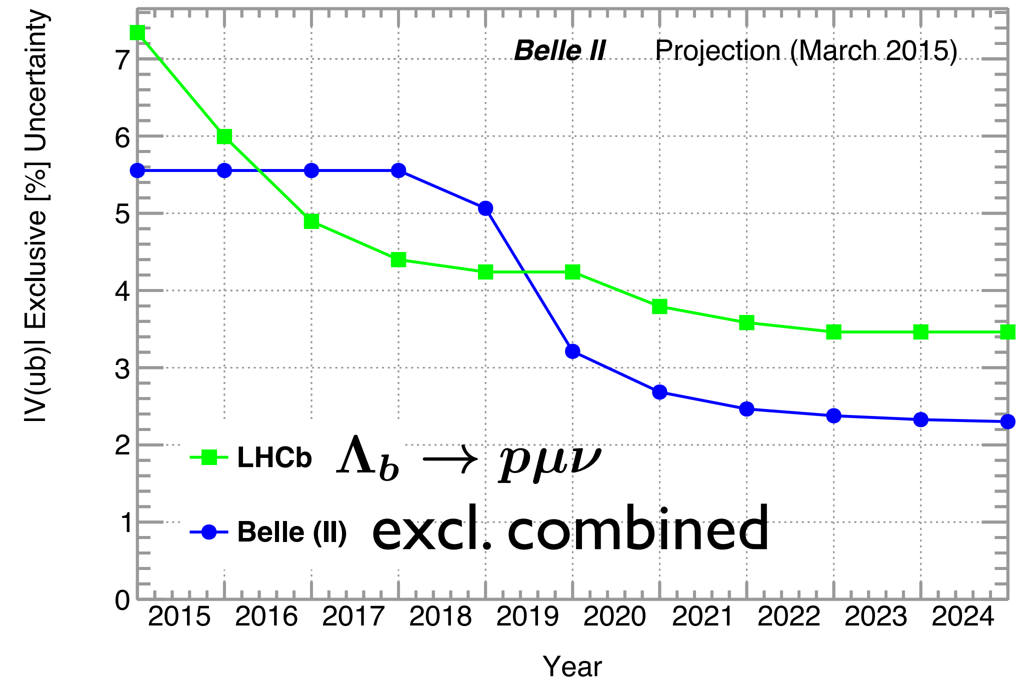
P. Urquijo, BELLE2-NOTE-PH-2015-004

ϕ_3

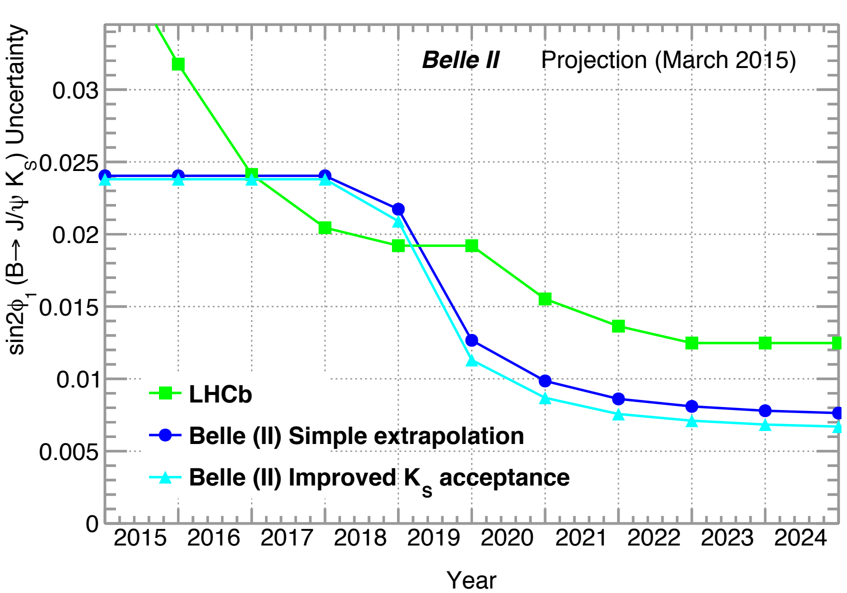


Comparable!

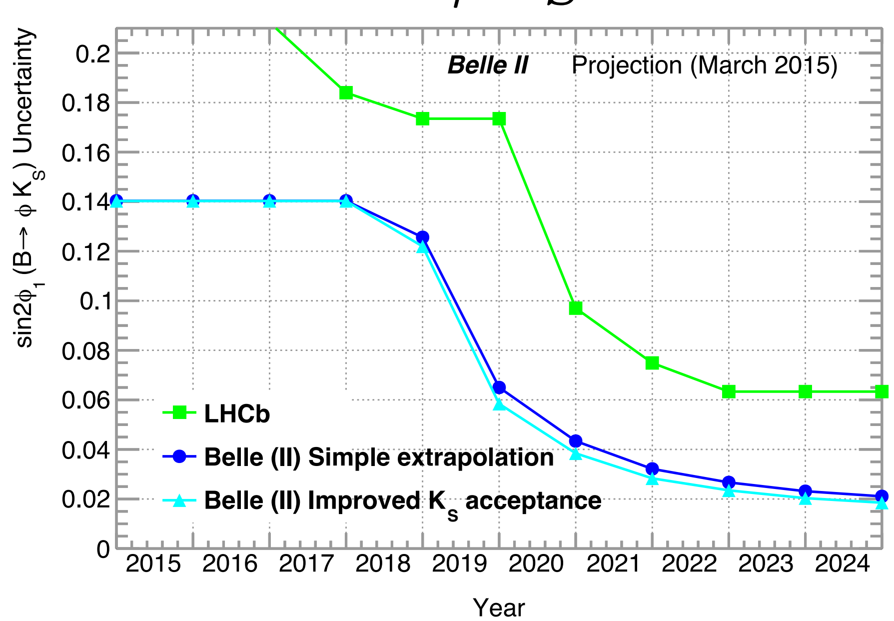
$|V_{ub}|$



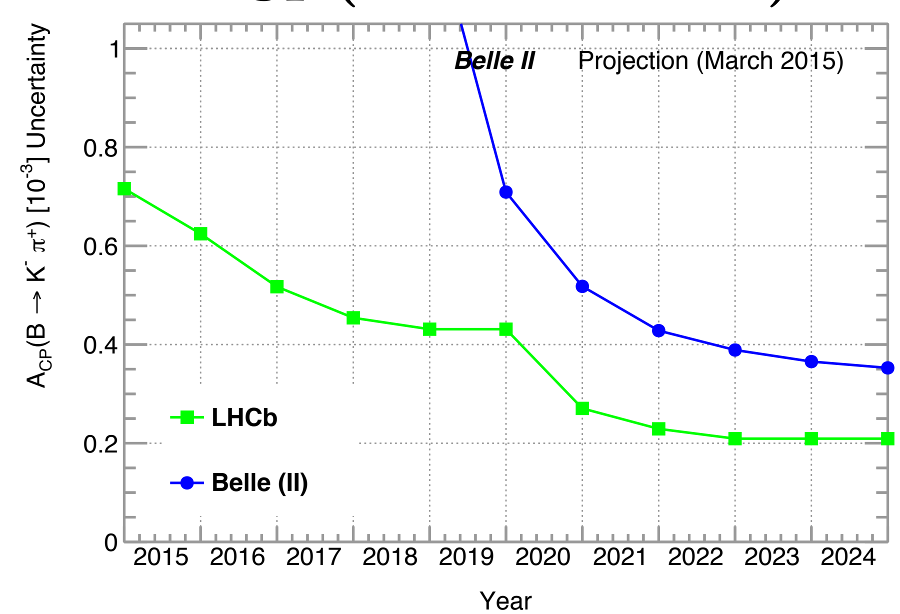
$\sin(2\phi_1)$



$S_{\phi K_S}$



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



Belle II Ks 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?

Satoshi Mishima (KEK)

B2TIP

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

Satoshi Mishima (KEK)

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)

- **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)

- **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*

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-).

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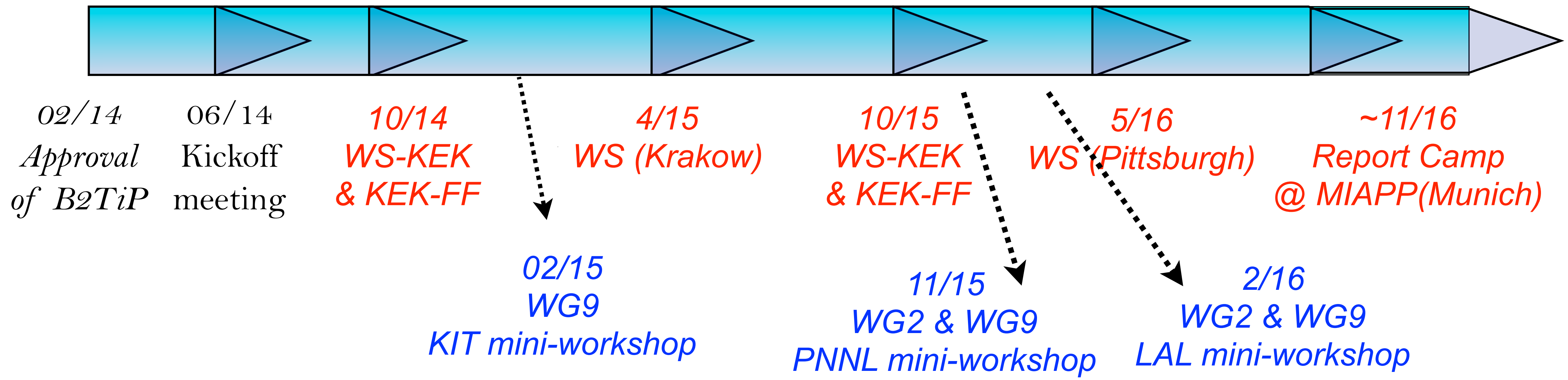
Report planning

- **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 WG 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

WG1: Semileptonic & Leptonic B decays

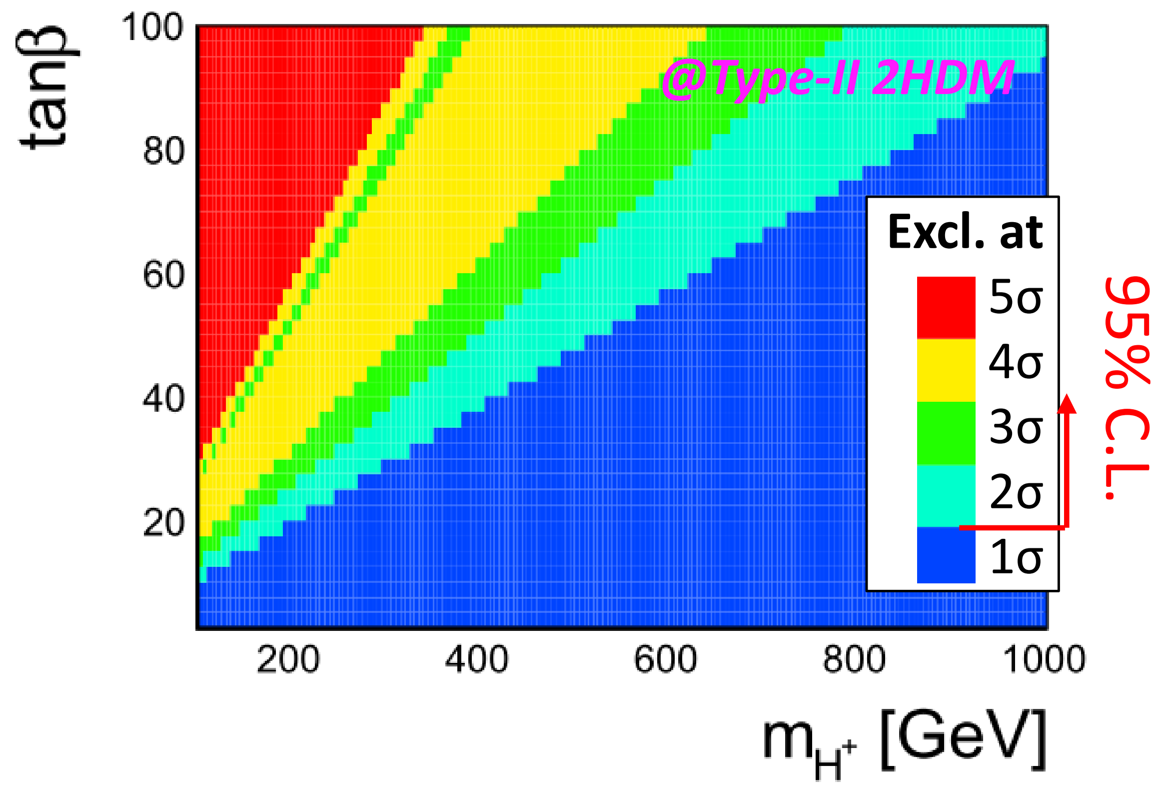
Missing energy = Belle II golden modes

- Purely leptonic B decays: $B \to \tau\nu,\ B \to \mu\nu$
- $B \to D^{(*)}\tau\nu$ → *Talk by M. Tanaka*
  - Measurements of R, q2 distribution, and polarization/angular analysis
- Inclusive Vcb: $B \to X_c \ell\nu$
  - Spectra and moments of kinematical distributions
- Exclusive Vub: $B \to \pi\ell\nu$
  - Rate and spectra of variables (q2, E_l)
- Inclusive Vub: $B \to X_u \ell\nu$
  - Precise measurement of differential distributions
- and (semi-)leptonic Bs decays at $\Upsilon(5S)$

Examples of sensitivity plots

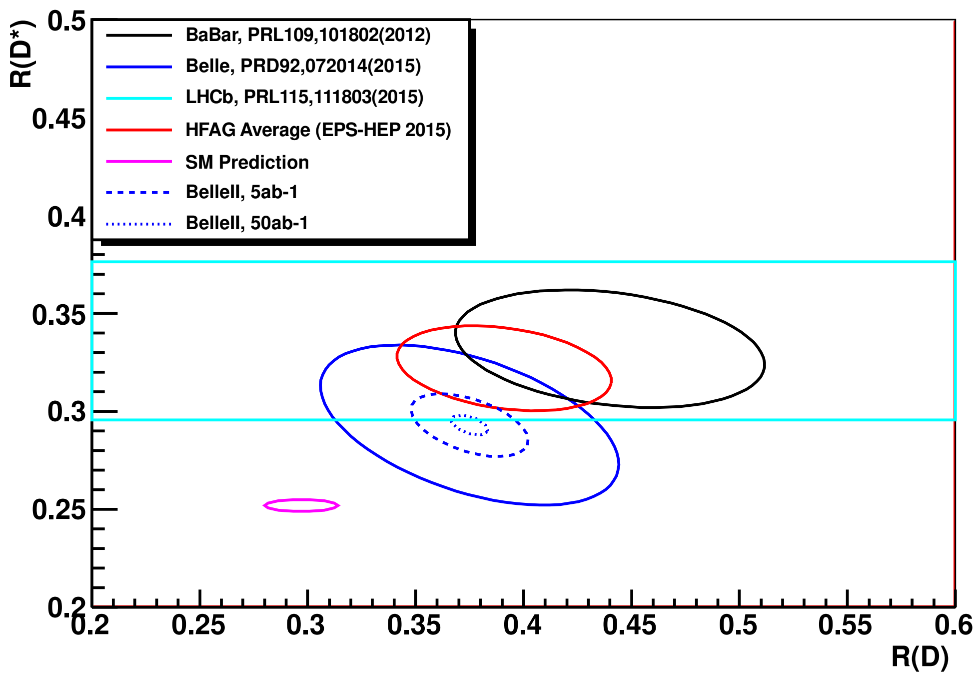
- Combined analysis with ***SuperIso***:

Y. Sato



1. **B → D*τν** : 0.293 ± 0.038 ± 0.015
   - Belle, PRD 92, 072014 (2015)
2. **B → D τν** : 0.375 ± 0.064 ± 0.026
   - Belle, PRD 92, 072014 (2015)
3. **B → τν** : $(0.91\pm0.23)\times10^{-4}$
   - 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

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

LHCb anomalies in P5' and

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

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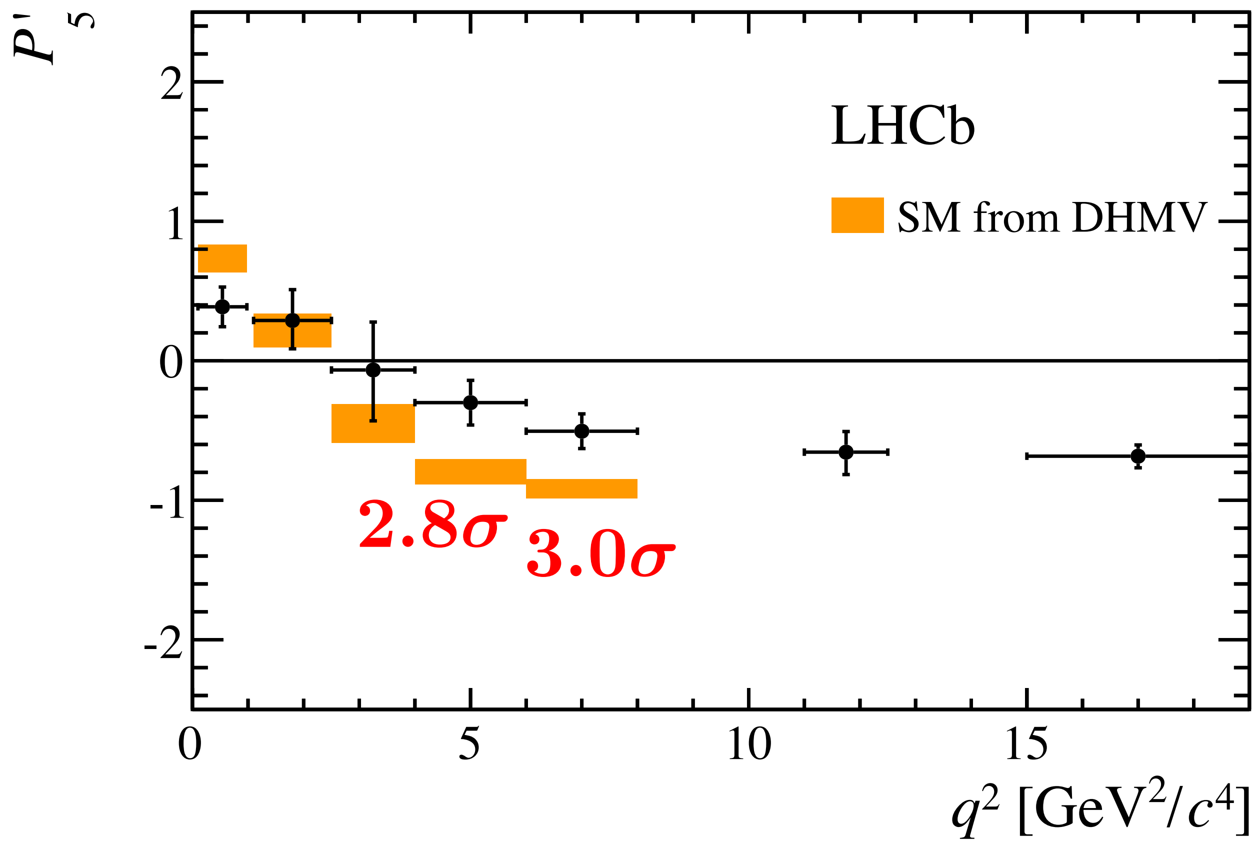
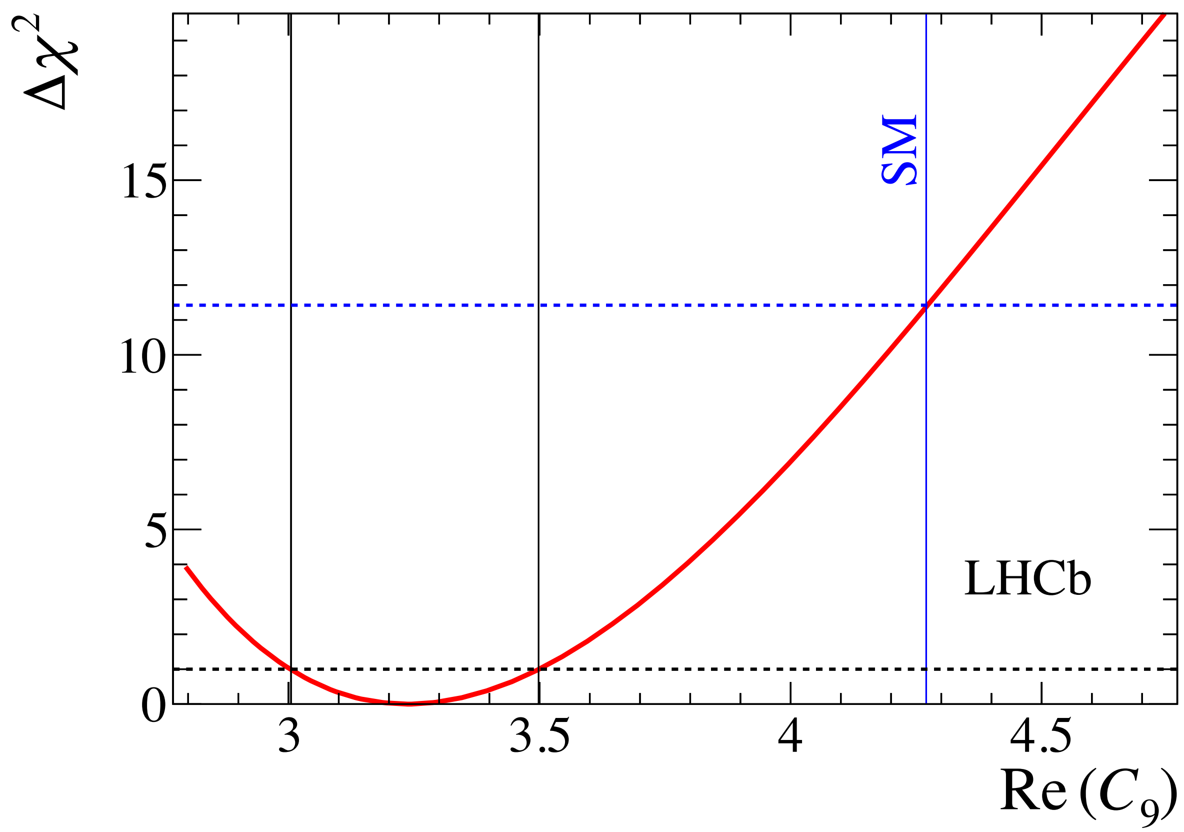
Anomaly?

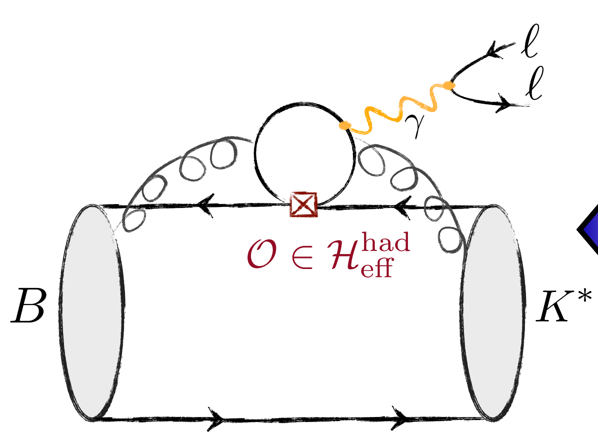
LHCb, 1512.04442





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

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



LCSR estimate

Khodjamirian et al. (2010)

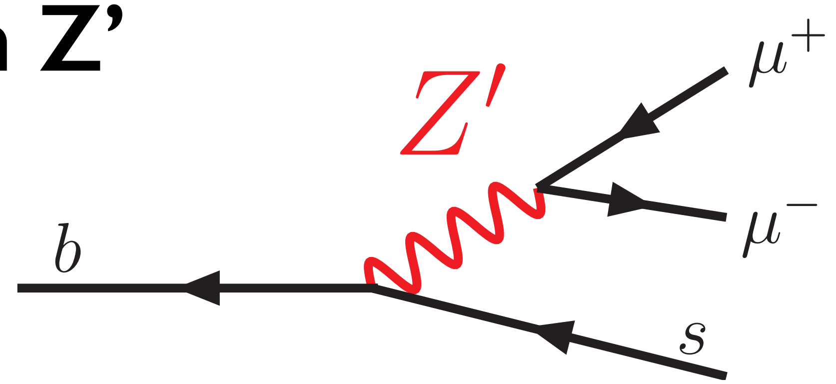
$$O_9 = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)$$

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

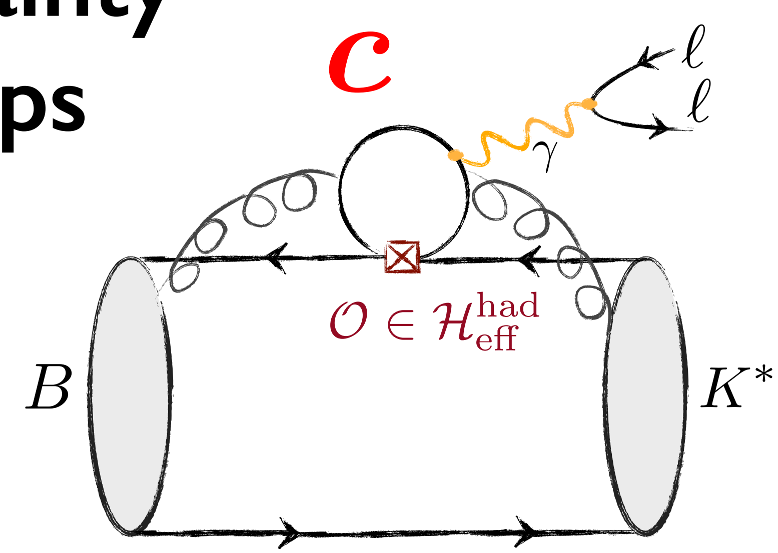
Possible interpretations

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

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



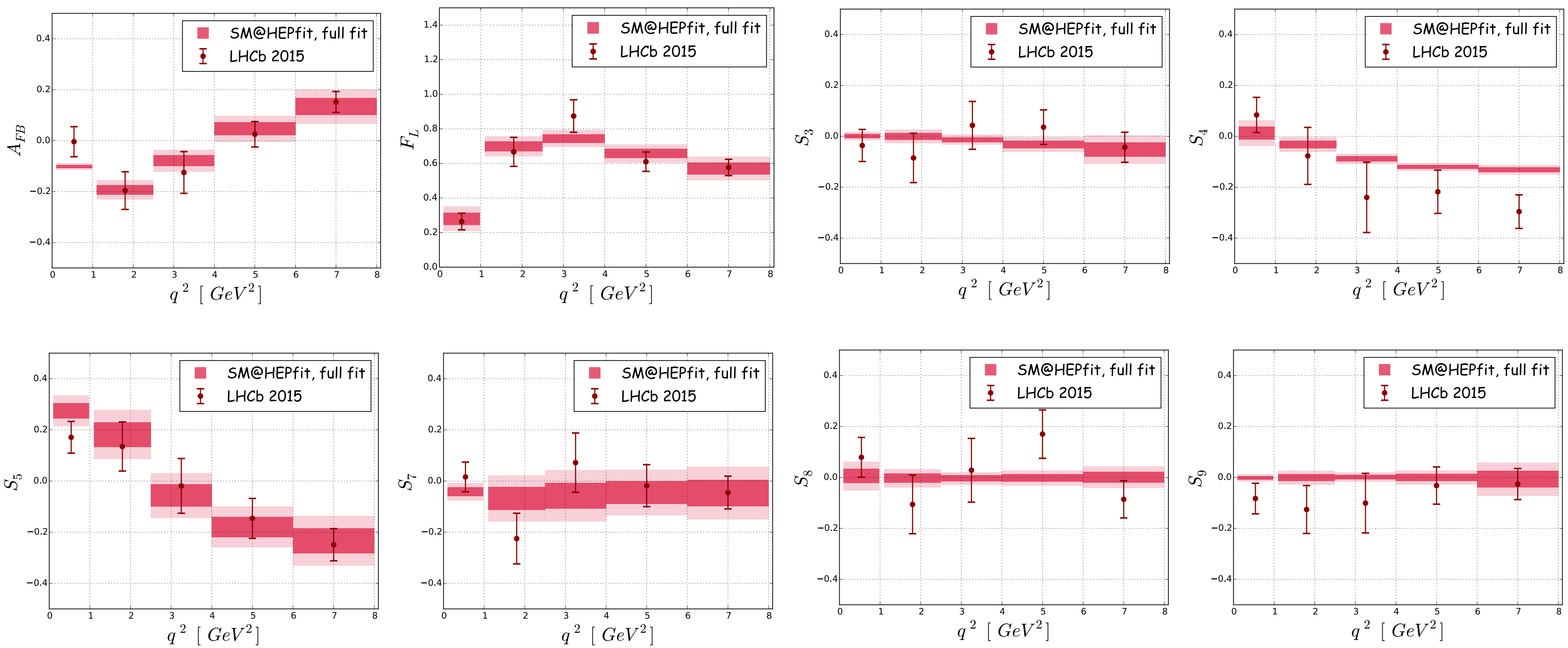
- **Underestimate of SM uncertainty from long-distance charm loops**



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

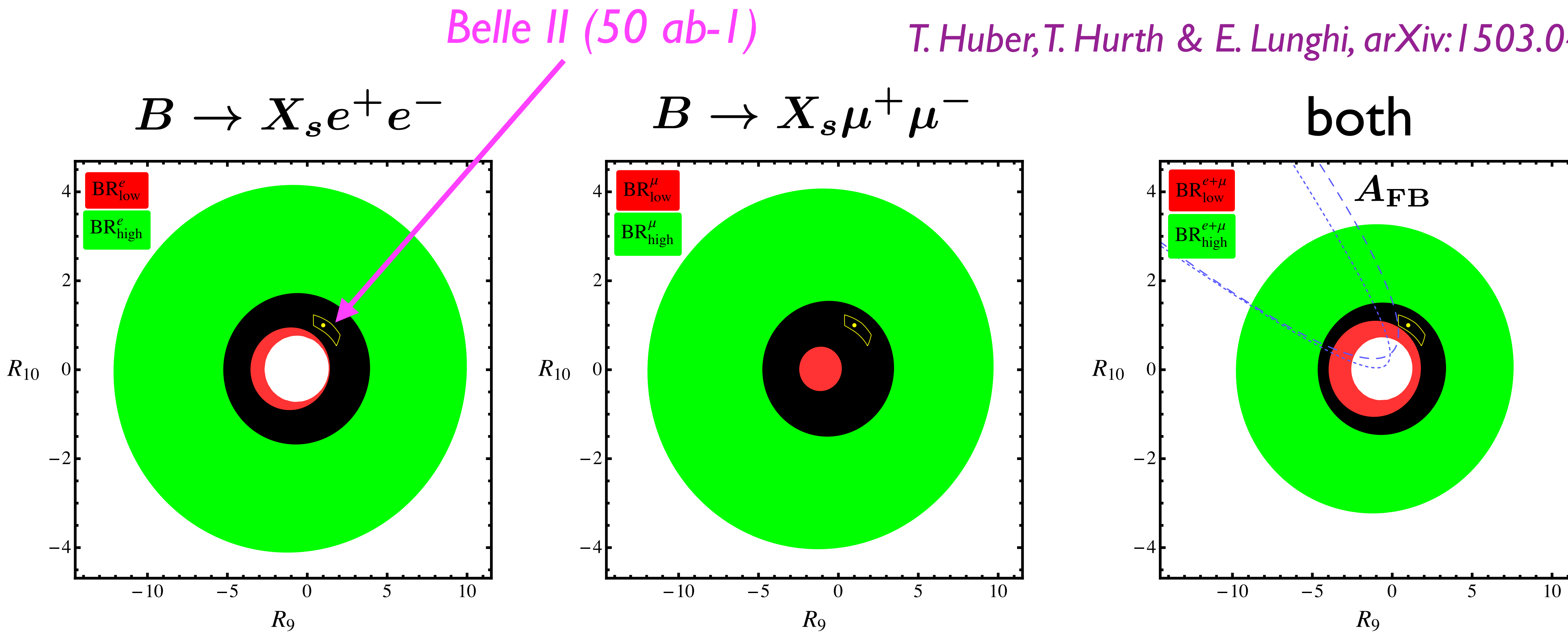
$$P_5' = \frac{S_5}{\sqrt{F_L(1 - F_L)}}$$

No significant discrepancy!

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

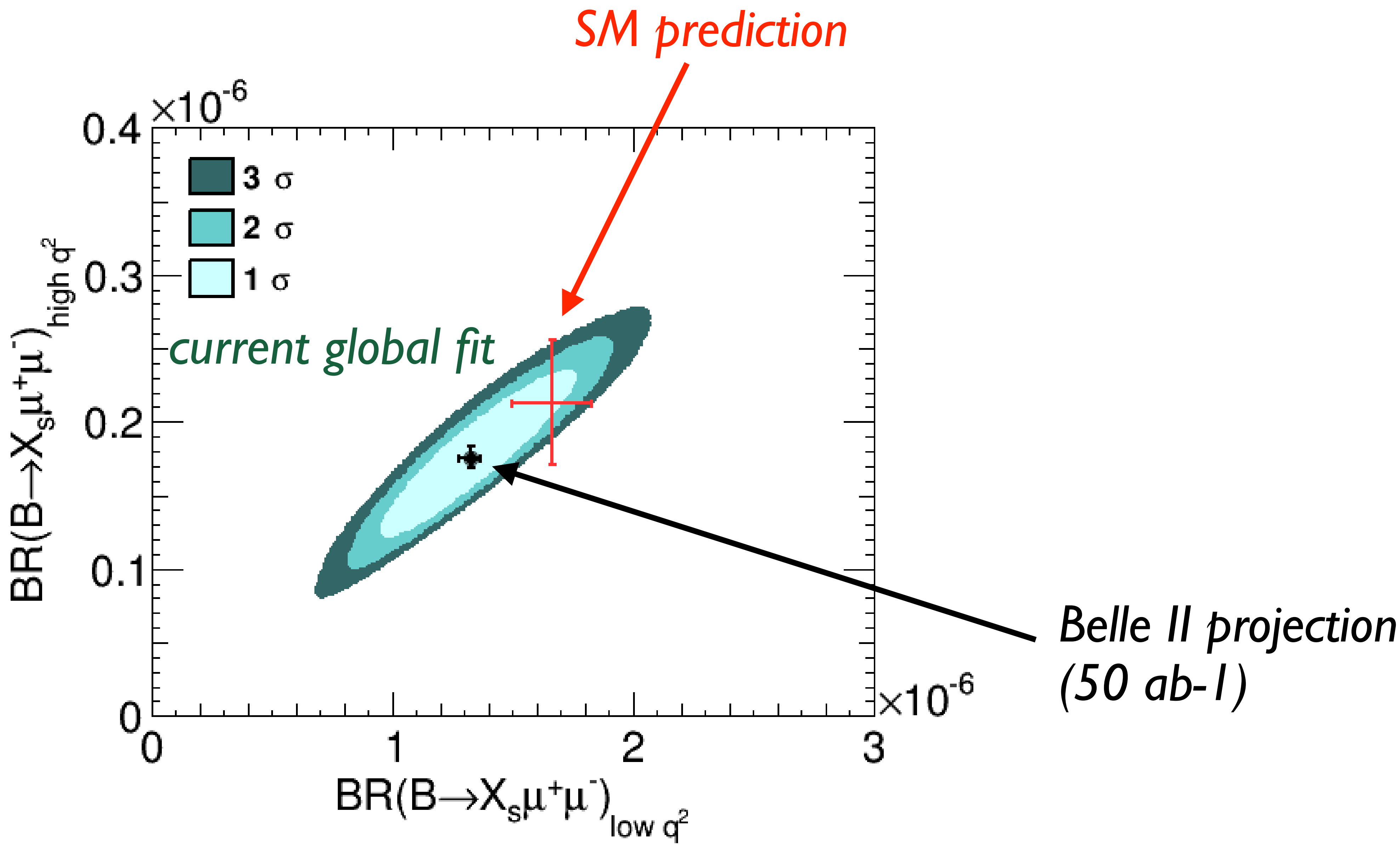
- Inclusive $B \to X_s \ell^+ \ell^-$ has a complementary role in NP search to exclusive $B \to K^{(*)} \ell^+ \ell^-$.
- Theoretically cleaner
- 95% constraints on the high-scale WCs: $R_i = \dfrac{C_i(\mu_0)}{C_i^{\mathrm{SM}}(\mu_0)}$

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



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!

WG3: alpha = phi_2 & beta = phi_1

Time-dependent analysis = Belle II golden modes

- ϕ_1 :

  $B_d \to J/\psi K_S$

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

  - sensitive to NP

- ϕ_2 :

  $B \to \pi\pi \quad B \to \pi\rho \quad B \to \rho\rho$

  - isospin analysis

- Radiative decay (WG2&WG3):

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

  - sensitive to the RH current

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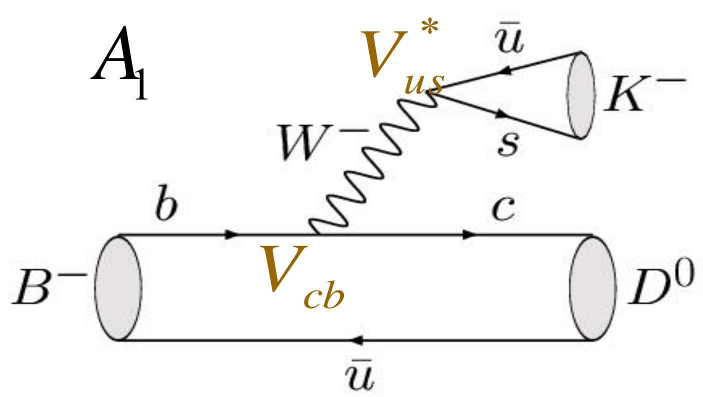
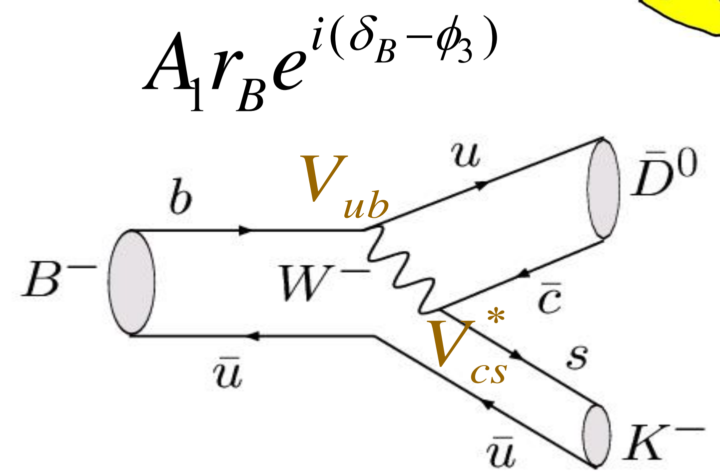
WG4: gamma = phi_3

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

Golden mode

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





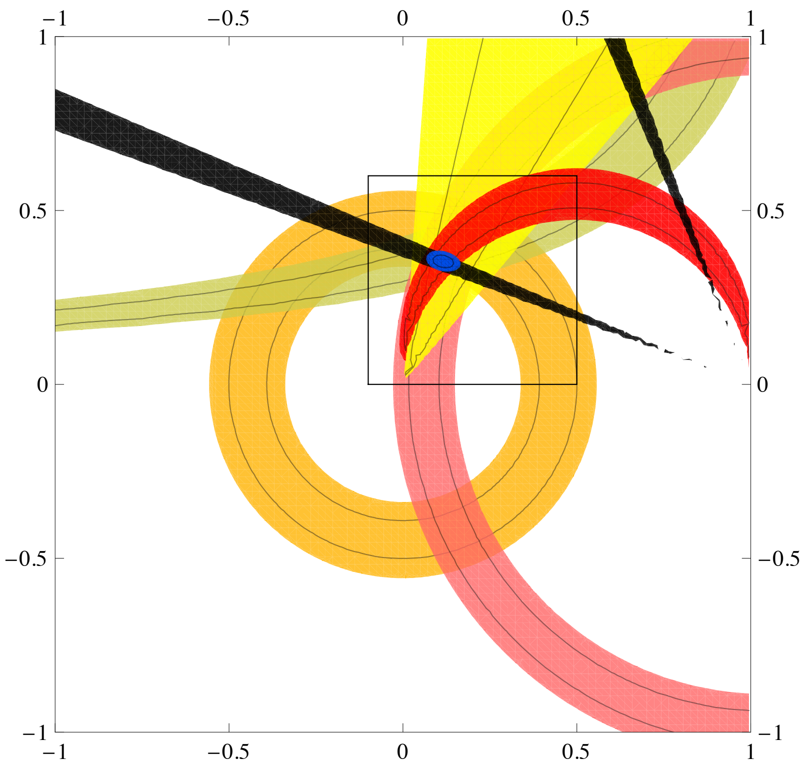
- Same final state for D and D $\Rightarrow$ interference $\Rightarrow$ **the possibility of DCPV**
- Three types of D final states generally used
  - **CP-eigenstates [GLW]**
    - Gronau & London, PLB **253**, 483 (1991), Gronau, & Wyler, PLB **265**, 172 (1991)
  - **K^+X^- ($X^-=\pi^-$, $\pi^-\pi^0$, $\pi^-\pi^-\pi^+$) - CF and DCS [ADS]**
    - Atwood, Dunietz & Soni, PRD **63**, 036005 (2001)
  - **Self-conjugate multibody states: $K_Sh^+h^-$ [Dalitz]**
    - Giri, Grossman, Soffer and Zupan, PRD **68**, 054018 (2003); Bondar (unpublished)
  - **None of the above (SCS): $K_SK^+\pi^-$ [GLS]**
    - Grossman, Ligeti and Soffer, Phys. Rev. D67 071301 (2003)

Toy impact plots for the CKM fit

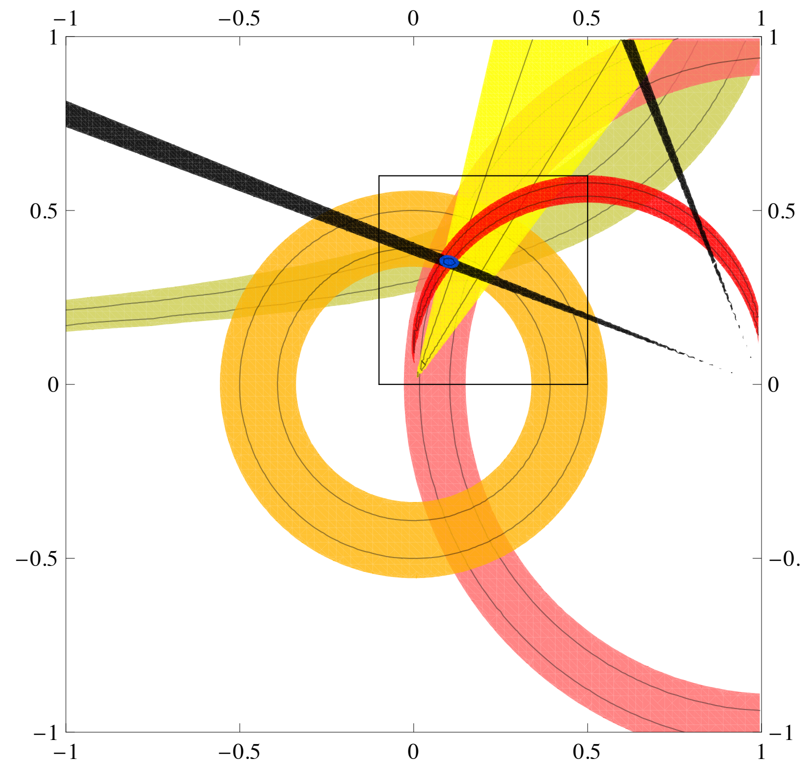
- Reducing only the errors of the angles at the current moment for an exercise.

Courtesy of E. Kou

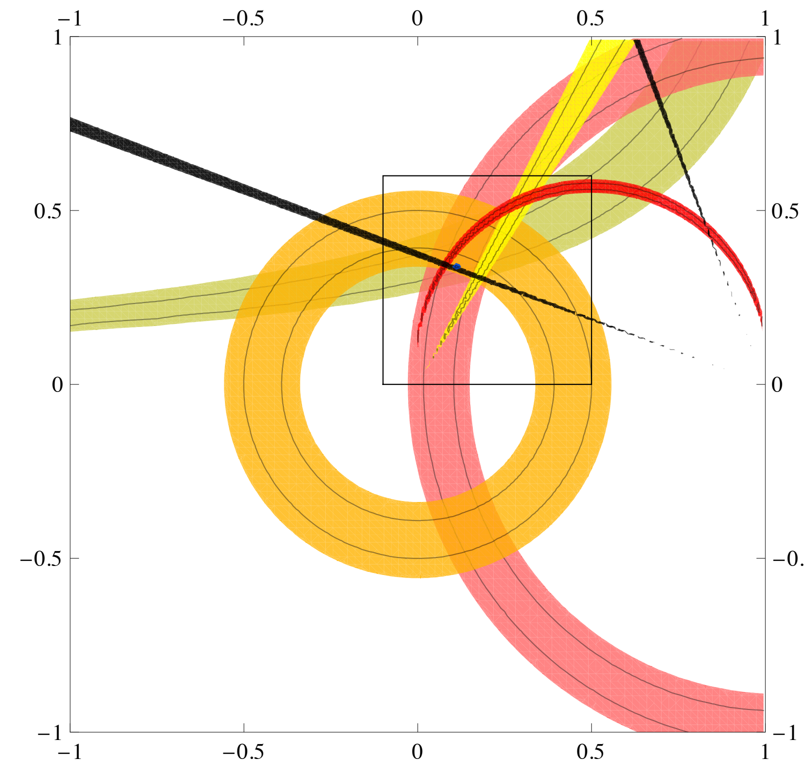
Current



Future (5 ab-1)



Future (50 ab-1)



The angle measurements will be improved significantly!

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WG5: Charmless Hadronic B Decay

Final states with neutral particles = Belle II golden modes

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

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WG6: Charm → *Talk by M. Staric*

"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) $D^0 \to K^+\pi^-,\ K^+K^-,\ \pi^+\pi^-$ - TDCPV & mixing, time-integrated analyses, Acp

(b) $D^0 \to K_S^0 K_S^0,\ \pi^0\pi^0,\ D^+ \to \pi^+\pi^0$ - time-integrated analyses, Acp

(c) $D^0 \to K_S^0 K^+K^-,\ K_S^0 K^+\pi^-,\ K^+\pi^-\pi^0,\ K_S^0 \pi^+\pi^-,\ \pi^+\pi^-\pi^0$ - TDCPV & mixing, Dalitz plot analyses

Semileptonic Modes

Leptonic and Radiative Decays

(a) $D_{(s)}^+ \to e^+\nu,\ \mu^+\nu,\ \tau^+\nu$ - important for lattice QCD

(b) $D^0 \to \rho^0\gamma,\ D^0 \to \gamma\gamma$ - NP searches

Other

(a) missing energy modes - e.g., light dark matter searches

(b) glueballs

(c) $D_s^+ \to p\bar{n}$

WG7: Quarkonium(like)

WG7 summary at the 3rd B2TiP workshop

1. ISR e+e- -> pi+pi-J/psi(psi'), K+K-J/psi(psi'), pi+pi-hc(1P, 2P), omega/phi chi_cJ, pi+pi-X(3823), gamma X(3872), DD(*)pi, ... to search/study Zc, Zc'. Zcs, ... all possible Y states, new resonances and understand the line shapes.

2. Y(3S) decays including Y(1D), etab(1S,2S)->gamma gamma, chi_b(1P,2P), ...

3. Tow-photon processes: gamma gamma -> phi J/psi to confirm/deny X(4350) and search for Y(4140), study of eta_c(2S), gamma gamma ->omega J/psi, DD*, etac pi0, ... 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 Xb, Wb via radiative and pi+pi- transitions.

   High energy scan:
   - decomposition of Rb into BB,BB*,B*B*,BB*pi,.. (nature of Y(5S), Y(6S));
   - scan of cross-sections e+e- -> bottomonium + light hadrons (search for new vector states);
   - investigate Lambda_b-Lambda_b-bar threshold region.

5. B decays to:
   - charmonium (eta_c, J/psi, h_c, chi_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, DsDs,..) and kaon (search for elastic channels of known states, search for new charmonium(-like) states).

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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

Satoshi Mishima (KEK)

Report outline: WG chapters

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Report outline: NP & Global fit chapter

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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

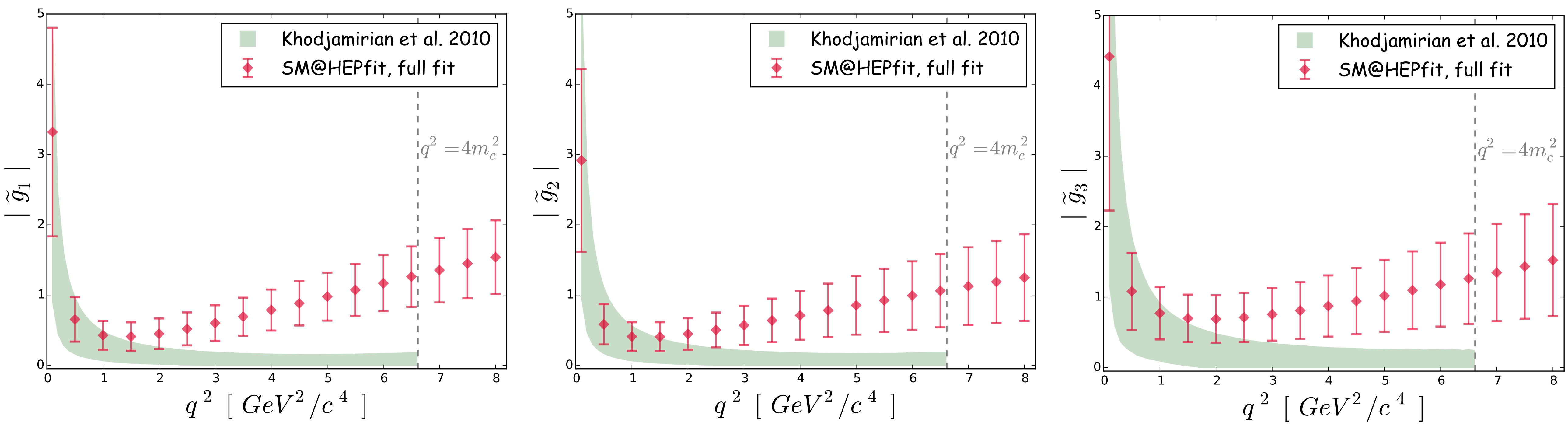
early registration by Apr. 15!

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 $q^2 \lesssim 1\ \mathrm{GeV}^2$ *and seem to grow towards charm resonances.*

Satoshi Mishima (KEK)

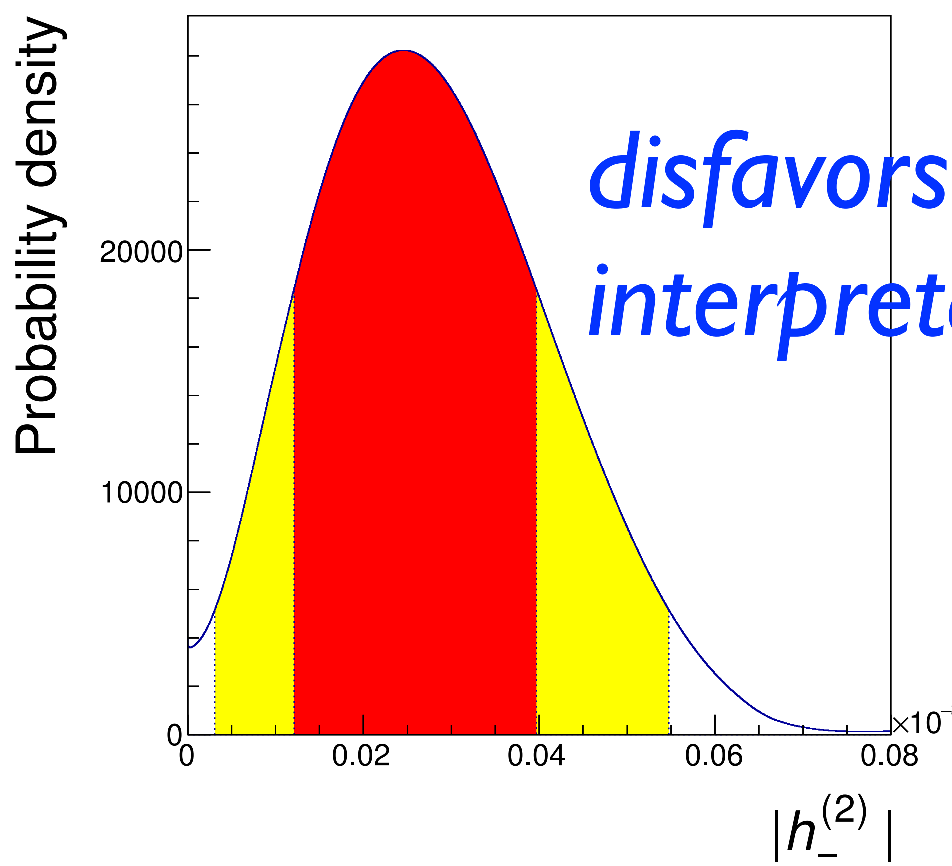
Fit result of the hadronic contributions

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

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

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



disfavors NP interpretation?

Satoshi Mishima (KEK)