Summary of the 2nd B2TiP workshop (Krakow)*

June 23, 2015

In this short note, we summarize the report from the working groups on the last day of the 2nd B2TiP Workshop at Krakow (26-29 April, 2015).

The working group conveners are asked to propose five top priority observables, i.e. *Belle II golden modes*, and scrutinize them within the B2TiP working groups, namely by estimating the precision of the theoretical uncertainties and the achievable precision at Belle II with 5, 10, and 50 ab^{-1} of data.

*Edited by the organizers, E. Kou (LAL-IN2P3) and P. Urquijo (Melbourne)

WG1: Semi-leptonic and Leptonic B Decays

Conveners: [Theory] A. Kronfeld (Fermilab), F. Tackmann (DESY), M. Tanaka (Osaka); [Experiment] G. De Nardo (Naples), A. Zupanc (IJS Slovenia)

At this workshop, the working group has focused on the $|V_{cb}|$ extraction (exclusive and inclusive) and new physics search at $B \to D^{(*)}\tau\nu_\tau$ while the $|V_{ub}|$ extraction (exclusive and inclusive semi-leptonic and pure-leptonic) were discussed at the 1st B2TiP workshop at KEK in 2014.

During the workshop, there was a detailed report from the Mainz $V_{ub} - V_{cb}$ workshop, which summarized very well the various issues in this subject [1]. Some interesting results by LHCb were presented during the workshop, namely on the $|V_{ub}|$ determination by using the $\Lambda_b^0 \to p\mu\nu$ channel (together with lattice QCD estimate of the form factors) [2] and the possible $B \to D^{(*)}\tau\nu_\tau$ measurement using three prong τ decays.

Golden modes proposal

- Purely leptonic modes ($B \to \tau\nu, B \to \mu\nu$)
  There are some studies to be done, such as the efficiency of the hadronic reconstruction (full simulation needed) and also the impact of the residual energy in the calorimeter.
- $B \to D^{(*)}\tau\nu_\tau$
  Full exploration of this channel including the R ratio, the q^2 distribution, polarization/angular analysis
- Inclusive $B \to X_c l\nu$
  Spectra and moments of kinematical distributions
- $|V_{ub}|$ determination with $B \to \pi l\nu$ mode
  Rate and spectra of variables
- Inclusive $|V_{ub}|$ determination with hadronic tags
  Precise measurement of the differential distributions

B_s physics with $\Upsilon(5S)$ data

There are variety of semi-leptonic B_s decays, such as:

$$B_s \to D_s l\nu, \quad X_c l\nu, \quad K^{(*)} l\nu, \quad , X - u l\nu, \quad \tau\tau$$

To investigate further, it is necessary to estimate the efficiency for B_s full reconstruction. The working group will clarify the most interesting measurements from theory point of view and complementarity with B_d physics.

WG2: Radiative and Electroweak Penguins

Conveners: [Theory] T. Feldmann (Siegen), U. Haisch (Oxford); [Experiment] A. Ishikawa (Tohoku), J. Yamaoka (PNNL)

Currently there are very intriguing LHCb anomalies observed in electroweak penguin processes, namely the angular distribution P_5' in $B \to K^* \mu^+ \mu^-$ channel (3.7σ) and the $Br(B \to K\mu^+\mu^-)/Br(B \to Ke^+e^-)$ ratio, R_K ratio (2.6σ). Although LHCb has advantages for these particular channels, with all the final state charged, due to its high statistics, there are many observables that only Belle II can do or Belle II can do better, namely, i) time dependent analysis (e.g. exclusive semi-leptonic $B \to V l^+ l^-$, radiative $b \to s\gamma, d\gamma$), ii) inclusive decays (e.g. angular analysis of inclusive $B \to X_s l^+ l^-$) and iii) missing energy channels (e.g. $B \to K^{(*)} \nu\bar{\nu}$). The presentations were focused in this direction. In particular, iii) is certainly the mode where a significant improvement is expected due to the much higher hadronic tagging efficiency with the Belle II 6-layer VTX. It should be also noted that recently the SM prediction became larger $(9.19 \pm 0.86 \pm 0.50) \times 10^{-6}$ [3] which makes this mode more accessible for Belle II. Concerning i) (see also WG3), the precision of the time dependent CP asymmetry of $b \to s\gamma, d\gamma$ will be significantly improved by Belle II with its high statistics. Further improvement is expected for $b \to d\gamma$ due to the reduction of the $B \to K^*\gamma$ background thanks to the improved Belle II particle identification. As the experimental precision will go down to a few percent level, the estimate of the SM theory uncertainty will become crucial for $b \to s\gamma$ modes. Detailed discussions have been made during the workshop and we hope that theorists will arrive to a consensus.

Golden modes proposal (To be finalized/reduced!)

The golden modes are chosen according to three criteria, i) sensitivity should be improved at least 5 times better than Belle, ii) sensitivity is much better than upgraded LHCb, iii) significant impact to new physics

- Direct CP asymmetry of $B \to X_s\gamma$, $\Delta A_{\rm CP}$
- Branching ratio and Direct CP asymmetry of $B \to X_d\gamma$
- Lepton Universality in $B \to X_s l^+ l^-$
- Time dependent CP asymmetry in $B \to K_S \pi^0 \gamma$
- Time dependent CP asymmetry in $B \to \rho\gamma$
- Branching ratio of $B \to K^* \nu\bar{\nu}$
- Branching ratio of $B_{d,s} \to \gamma\gamma$
- Lepton flavour/number violating B decays, $B \to K\tau\mu, K\tau e, \tau\mu, \tau e$
- Time dependent angular analysis of $B \to K_S \pi^0 l^+ l^-$

B_s physics with $\Upsilon(5S)$ data

$B_s \to \gamma\gamma$ is an interesting channel both for new physics and QCD. The SM prediction $Br(B_s \to \gamma\gamma) = (0.18 - 2.45) \times 10^{-6}$ is a factor of 10^{-3} smaller than the current experimental limit set with $120 fb^{-1}$ of data.

WG3: $\phi_2 = \alpha$ and $\phi_1 = \beta$

Conveners: [Theory] S. Mishima (KEK), J. Zupan (Cincinnati); [Experiment] L. Li Gioi (MPI Munich)

In this working group, many observables require time dependent analysis. With the upgraded SuperKEKB, the background will be increased and the boost will be reduced. Thus the challenges is to maintain the same vertex separation capability as Belle experiment. Continuing from the 1st B2TiP workshop, the status of the tag side vertex resolution and the time resolution was presented. The obtained result for now is Δt shift=-0.004 ps (0.20 ps at Belle), Δt resolution = 0.79 ps (0.92 ps at Belle), flavour tagging efficiency 34 % (29 % at Belle). Further improvement is expected.

Concerning $\phi_1(\beta)$ measurement, in most of the channels, including the $b \to s\bar{s}s$ modes, the systematic errors will dominate at Belle II. Thus, the detailed systematic error estimates (including theoretical ones) become very important. For $b \to c\bar{c}s$ channels , the penguin pollution, which have been neglected, may become important at the precision of Belle II and it was discussed extensively during this workshop.

Concerning $\phi_2(\alpha)$, isospin violating effect in $B \to \pi\pi, \pi\rho, \rho\rho$ channels were discussed. At the 1st B2TiP workshop, a possibility of time dependent analysis of $B \to \pi^0\pi^0$ with photon conversion was discussed. It required detailed sensitivity study of the photon conversion, which haven't been done so far. In relation to this, a new idea to measure the photon polarization of $b \to s\gamma$ with photon conversion of $B \to K^*\gamma$ was presented. The feasibility of this idea also should be evaluated. At the workshop, the LHCb new result on the $Br(B \to \rho^0\rho^0)$ was presented.

Golden modes proposal

- Time dependent CP asymmetry in $B_d \to J/\psi K_S$
- Time dependent CP asymmetry in $B_d \to \phi K_S$, $B_d \to \eta' K_S$, $B_d \to \pi^0 K_S$, $B_d \to K_S K_S K_S$
- Time dependent CP asymmetry in $B_d \to K_S \pi^0 \gamma$
- Time dependent CP asymmetry in $B_d \to \pi\pi$, $B_d \to \pi\rho$, $B_d \to \rho\rho$

WG4: $\phi_3 = \gamma$

Conveners: [Theory] M. Blanke (KIT), Y. Grossman (Cornell); [Experiment] J. Libby (Madras)

First of all, the working group has submitted the intermediate report after the 1st B2TiP workshop [4] and the scope is very well summarized there.

The naive luminosity scaling from Belle to Belle II leads to an achievable precision on ϕ_3 at 50 ab^{-1} of 1° to 2°. The latest theoretical error estimate shows that the irreducible theoretical error is $< 10^{-7}$ for $B \to DK$ channels [5] while it is enhanced for the $B \to K\pi$ channel up to $\sim 10^{-4}$ [6]. The averaged experimental error in ϕ_3 is currently dominated by LHCb and it will continue to be so for a while, the recent projection shows that once Belle II will reach its design luminosity, Belle II and LHCb will become competitive. Therefore, it is important to continue developing new ideas and new strategies.

It should be mentioned that the precise measurement of ϕ_3 relies on the external inputs from the charm sector. Both experiments use the information from the CLEO(-c) collaboration. For the future, it is expected to have further improvement in this direction once the BES-III results become available.

During this 2nd B2TiP workshop, discussions were held on the possible new physics contribution to ϕ_3. There are two types of new physics possible, i) tree level and ii) loop level. The limit on the tree level contribution was presented during the workshop. For ii), it boils down to measure the difference between ϕ_3 measurement in tree dominant decays (family of $B \to DK$, $B \to D\pi$ etc) and the loop dominant decays (such as $B \to K\pi$). The latter was discussed in the joint-session with the charmless working group.

Golden modes proposal
The golden channels are those which measure ϕ_3 from different types of D decays (those in parenthesis have not been studied by Belle):

- CP-eigenstate final state (GLW method)
  Example of finals states are: $K^+K^-, \pi^+\pi^-$ (CP-even) and $K_S\pi^0, K_S\eta$ (CP-odd) Time dependent CP asymmetry in $B_d \to J/\psi K_S$
- Cabibbo-Favoured and Double-Cabibbo-Suppressed (ADS method)
  Example of final states are: $K^\pm\pi^\mp, K^\pm\pi^\mp\pi^0, (K^\pm\pi^\mp\pi^+\pi^-)$
- Self-conjugate (GGSZ method)
  Example of final states are: $K_S\pi^+\pi^-, (K_SK^+K^-), (\pi^+\pi^-\pi^0)$
- Single-Cabibbo-Suppressed (GLS method)
  $(K_SK^\pm\pi^\mp)$

WG5: Charmless Hadronic B Decays

Conveners: [Theory] M. Beneke (TUM), C.-W. Chiang (NCU); [Experiment] P. Goldenzweig (KIT)

First of all, the working group has submitted the summary of the 1st B2TiP workshop [7].

The scope of the working group is very wide: a total of ~ 200 decay channels in charmless B decays and various observables, i.e. branching ratio, angular analysis, direct CP asymmetry. Moreover there are also many interesting channels in B_s decays. The charmless B decays are loop dominated so the branching ratios are relatively small and few modes are systematically limited for now. with Belle II, the statistical errors will be significantly reduced and also the improved K/π separation and π^0 reconstruction will help to further push down the current limit. The systematic experimental errors roughly scale with integrated luminosity:

$$\sigma_{\text{Belle II}} = \sqrt{(\sigma_{\text{stat}}^2 + \sigma_{\text{syst}}^2)\frac{\mathcal{L}_{\text{Belle}}}{50\text{ab}^{-1}} + \sigma_{\text{ired}}^2}$$

where σ_{syst} and σ_{ired} are, respectively, the so-called irreducible and irreducible systematic errors. The full projection of the HFAG 2012 table was shown at the 1st B2TiP workshop [8] and projection to HFAG 2014 is in progress. Concerning the irreducible error, it is known that the direct CP asymmetry with K_S receives significant uncertainties due to the asymmetry of $K^0/\overline{K}^0$ interactions in material, which is estimated to be $\sigma_{\text{ired}} \simeq 0.2$ %. It should be noted that the working group do not work on $\pi\pi, \rho\rho, \rho\pi, a_1\pi$ nor $\phi K_S, \eta' K_S, K_S K_S K_S$, which are of the mandates of WG3.

Golden modes proposal

In general Belle II has an advantage over LHCb for channels including neutral particles in the final state. The interests of the following channels are not only the branching ratio measurement but also direct CP and the angular analysis when it is available:

- 2-Body Final Sate:
  Long-lived final states such as $B \to K\pi, KK$, with special emphasis on the $B \to K^0\pi^0$.
- Quasi-2-Body Final State:
  Decays in which one or both of the decay products is a resonance (scalar, pseudoscalar, vector, axial-vector mesons), namely, $B \to K^*\pi, K\rho, B \to \phi K^*, B \to K^*\rho$. For the last two $B \to VV$ channels, the angular analysis is crucial.
- 3-Body Final State:
  Final states with π or K (or other resonances) e.g. $B \to K_S K^+ K^-, K^+ K^- \pi^0$, $B^+ \to K^+\pi^0\pi^0, K_S\pi^+\pi^0$.

B_s physics with $\Upsilon(5S)$ data

- 2-Body Final Sate:
  The $B_s \to hh(h = \pi, K)$ decays with an emphasis on $B_s \to K^0\overline{K}^0$.
- Quasi-2-Body Final Sate:
  $B_s \to \phi\pi^0$

WG6: Charm

Conveners: [Theory] A. Kagan (Cincinnati), A. Petrov (Wayne); [Experiment] G. Casarosa (Pisa), A. Schwartz (Cincinnati)

At this workshop, the status of the simulation study of the D^*-tagged D^0 production and decay vertex resolution was presented. It is found that the $D^{*+} \to D^0\pi^+$ beam-spot constrained fit yields an *unprecedented precision of the determination of the D^0 production vertex*, which may open a possible new measurement at Belle II. The D^0 proper time resolution was also presented: a factor 2 improvement on the proper time resolution, a factor 3.5 improvement on σ_t, and a factor 3 improvement in D^0 proper time significance were reported. Impacts of these new results on the mixing parameters were also presented. Comparing to the naive scaling (similar to the formulae used in WG5), which gives already a factor 6-10 improvements, the new simulation result shows a further 10-20% improvement on $x^{2\prime}$ and y'. It will be important to have projection of future LHCb and BESIII sensitivities.

The working group focuses on mainly three items i) New physic searches with leptonic, semi-leptonic, radiative channels, ii) Branching ratio and direct CP asymmetry of $D \to PP, PV, VV$ channels, iii) Charm time-dependent CP asymmetry. For the topics i), various new observables are proposed (branching ratios, angular distributions, extremely rare decays etc). For many of these channels, the lattice input is crucial. The progresses on the form factor computation as well as the decay constants ($f_{D_{d/s}}$) was presented in the 1st B2TiP workshop. These inputs are also important for determination of the CKM matrix element $V_{cd,cs}$. For the topics ii), a global fit of the branching ratios and direct CP asymmetry of the charm hadronic decays, namely $D \to PP, PV$, using the $SU(3)$ flavour symmetry have been discussed during the B2TiP workshops. Since these global fits require a complete set of final states, including the neutral particle final states, Belle II measurements are essential. The naive scaling using the same formula introduced in WG5 section is applied and Belle II projection was presented in the 1st B2TiP workshop [9]. These studies serve as an important input for the charm mixing parameter determination as mentioned below. For the topics iii), the new parameterization of the charm mixing parameters has been extensively discussed through the 1st and the 2nd B2TiP workshop. This new parameterization allows to relax the *real Γ_{12} assumption*, which is crucial at the era of Belle II when the sensitivity to the CP violation will considerably improves. The Belle II sensitivity is high enough to leave plenty of room for new physics. Moreover, the SM uncertainties can be further reduced by using the global fit result in subject ii).

Golden modes proposal (To be finalized !)
The golden modes are chosen according to three criteria, i) competitive with LHCb, ii) NP is large enough to be measured/identified

- Direct CP asymmetry of $D^0 \to K^+K^-, \pi^+\pi^-, \pi^0\pi^0$ and $D^+ \to \pi^+\pi^0$
- Time dependent CP asymmetry in the Dalitz plot of $D^0 \to K_S K^+K^-, K_S\pi^+\pi^-, \pi^0\pi^+\pi^-$
- Higher precision measurements of $D^+ \to l^+\nu, D_s^+ \to l^+\nu$
- New physics signatures in $D \to K^{(*)}l^+\nu$, $D \to \rho\gamma, \phi\gamma, \gamma\gamma$ and $D \to$ missing energy $+(n)\gamma, (n)\pi$

WG7: Quarkonium(like)

Conveners: [Theory] Ch. Hanhart (Julich), Y. Kiyo (Juntendo), A. Polosa (Rome), S. Prelovsek (Ljubljana); [Experiment] R. Mizuk (ITEP), R. Mussa (Torino), C. Shen (Beihang)

The scope of this working group is very large and it is difficult to converge on which decay modes are more important than others. Nevertheless, the working group has produced two documents, one summarizing the recent experimental results on the charmonium-like states by Belle and BESIII and its interpretation in lattice QCD [10] and one summarizing interesting measurements at Belle II to clarify the molecules/tetraquarks features of charmonium-like and bottomonium-like XYZ states [11]. During the workshop, there was extensive discussions on the radiative decays and also hadronic decays of conventional and non-conventional quarkonium states.

One of the most important mandate of this working group is to make the *first physics case* for the so-called BEAST-II phase. This is the period foreseen to test the SuperKEKB machine with only outer detectors installed. Two proposed plans are to run at the $\Upsilon(3S)$ and $\Upsilon(6S)$ peak energies. Startup request during BEAST-II is 150 fb^{-1} on the $\Upsilon(3S)$ peak which is about 5 times more than the data accumulated by the Babar collaboration. The $\Upsilon(6S)$ data has been even more limited (Belle accumulated only 5 fb^{-1}) and 100 fb^{-1} of data will allow us to clarify the structure of Υ states above $B\overline{B}$ threshold. During the workshop, the breakdown of the QCD multipole expansion above threshold was pointed out and new mechanism for hadronic transition was introduced. The test of this new model also motivates the run at the unexplored $\Upsilon(6S)$ (and above) regions.

Golden modes for First Physics at $\Upsilon(3S)$ run, and scanning above

- Search for $\Upsilon(3S) \to \eta\Upsilon(1S)$ (test of the hadron transition puzzle)
- First observation of $\Upsilon(3S) \to \pi^0 h_b$ and $\Upsilon(3S) \to \gamma\eta_b$
- High statistics study of $\Upsilon(3S) \to \pi\pi\Upsilon(1,2S)$ (charged/neutral)
- Systematic study of $E1-M1$ discrepancy in $\eta_b(1,2S)$ mass measurement via photon conversion and $\pi\pi\Upsilon(2S)$ tagging
- Dark matter, light-Higgs search
- Scan of $\Upsilon(1^3D_1)$ and $\Upsilon(2^3D_1)$

Golden modes for First Physics at $\Upsilon(6S)$ run and scanning above

- $\Upsilon(6S) \to \Upsilon(1S/2S/3S)\pi^+\pi^-$ to test the influence of the nearby threshold.
- Searching for missing bottomonium such as $h_b(1P,2P), \eta_b(2S)$ and the $2D-1F$ multiplet
- Searching for molecular states - partners of Z_b
- Scanning near and above $\Upsilon(6S)$, to clarify the structure of $\Upsilon(6S)$ state (R_b measurement), to search for vector bottomonium-like states and to study the $\Lambda_b\Lambda_b$ threshold region

WG8: τ, Low multiplicity & Electroweak precision measurement

Conveners: [Theory] E. Passemar (Indiana), J. Hisano (Nagoya); [Experiment] K. Hayasaka (Nagoya), T. Ferber (DESY)

In this workshop, the working group covered the following subjects. For non-τ topics: transition form factor and light-by-light scattering of muon $g-2$ and for τ topics: mainly the physics case using hadronic τ decays. Note the subjects covered in the 1st B2TiP workshop included Electroweak precision test with $e^+e^- \to \mu^+\mu^-$, muon $g-2$, and 2 photon physics for non-τ topics, and the leptonic τ decays (Michel parameters, etc.) and the inclusive τ decays (extraction of α_s, V_{us} etc) for τ topics. Analysis tools and systematics study are often different from those prepared for B physics. Dedicated sessions for the Monte Carlo simulation were included in the program of this 2nd workshop, namely PHOKHARA for ISR processes and TAUOLA for τ decays to discuss their status and how to develop them further for Belle II.

Golden modes proposal (incomplete)

The golden modes are not finalized yet since sensitivity study or naive scaling are missing in many channels (as mentioned above). The followings are the golden modes where some sensitivity study has been done. The list might extend as more simulation becomes available.

- Lepton Flavour Violating τ decays:
  $\tau \to \mu\mu\mu$
- CP violation in τ decay:
  $\tau \to K_S\pi\nu$, $\tau \to K\pi\pi\nu$
- Precision two track final states with ISR:
  ISR $e^+e^- \to \pi^+\pi^-(\gamma)$ and $e^+e^- \to \mu^+\mu^-(\gamma)$
- Precision two track final state with $e^+e^- \to \mu^+\mu^-$:
  Forward Backward Asymmetry of $e^+e^- \to \mu^+\mu^-$ to determine the contact interactions (5 ab^{-1}) and the rho parameter (at 50 ab^{-1})
- Two photon process: π/η transition form factors

Golden modes for First Physics at $\Upsilon(3S)$ run

- $\Upsilon(3S) \to \mu\mu$ to measure vacuum polarization (s-channel)
- $\Upsilon(3S) \to \mu\mu$ for direct search of Dark Photon

WG9: New Physics

Conveners: [Theory] U. Nierste (KIT), L. Silvestrini (Rome), J. Kamenik (IJS Ljubliana), V. Lubicz (Rome 3); [Experiment] R. Itoh (KEK), F. Bernlochner (Bonn), Y. Sato (Nagoya)

The working group has organized an intermediate workshop at KIT where many new physics models and the available new physics *public codes* were discussed [12].

The new physics models discussed include, Two Higgs doublet model, light weakly coupled particles (axion, etc.), Z' models, gauged flavour models, models with vector-like heavy quarks, supersymmetry, right-handed current models, new physics in $b \to u$ transitions, models including dark sector. In addition, model independent analysis on various channels was also discussed. Working group discussed which new physics model can exploit the strengths of Belle II, namely the modes with missing energy final state, tau leptons, (semi-)inclusive decays, etc.

One of the mandates of the working group is to discuss how to use the existing computing code to fit the data to new physics parameters and to specify which further codes need to be developed. As an example, projection of current Type-II 2HDM model parameters constraint to 5 ab^{-1}, 50 ab^{-1} have been performed by using SuperIso. The plan is to use various codes with different characteristics to extend this kind of work. At the KIT workshop, SuperIso, EOS, SUSY_FLAVOR, Susyfit, CKMfitter were presented. Also there are new statistical framework available such as GammaCombo, myFitter, and BAT. At the Krakow workshop, we had a brief tutorial of Susyfit.

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