Time-dependent CP violation measurements at Belle II

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on behalf of the Belle II Collaboration

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First Collisions at SuperKEKB

The SuperKEKB $e^+e^-$ collider operates at a CM energy corresponding (or close to) the mass of the Y(4S) resonance:

Thanks to nano-beam scheme:
- $\times 40$ instantaneous
- $\times 50$ integrated

design luminosity compared to KEKB

First collisions delivered on April 26th!

Current peak lumi record $\sim 5 \times 10^{33}$ cm$^{-2}$s$^{-1}$

Goals:
- $L = 8 \times 10^{35}$ cm$^{-2}$ s$^{-1}$
- $\int L = 50$ ab$^{-1}$

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The Belle II Detector

- Extensive upgrade of its predecessor (Belle) in all areas;
- Vast physics program: search for New Physics in B mesons, charm hadrons, \( \tau \) decays, exotic particles, dark sector, …;
- High luminosity does not come for free:
  - high event rate;
  - high machine backgrounds;
  - reduced energy asymmetry (\( \beta \gamma \) reduced from 0.45 to 0.28).

The Vertex Detector (VXD) has not been installed yet. In its place we have a suite of detectors dedicated to background studies (the BEAST 2 detector), which include a VXD “slice” that corresponds to \( \sim 10\% \) of the full system.
Detector highlights

Two areas are particularly important for TD CPV measurements:

**Vertex detectors:**
- spatial resolution of the new vertex detector a factor ~2 better than Belle;
- despite lower Lorentz boost, we expect O(30%) improvement in the separation of the B decay vertices!
- ~30% bigger acceptance for $K_S$ reconstruction;

**Particle Identification (PID):**
- $K-\pi$ separation is fundamental to distinguish among important final states and backgrounds;
- crucial ingredient for B flavor tagger;
- expected performance: $K$ ($\pi$) efficiency > 90%, with $\pi$ ($K$) fake rate < 10% for $p < 4$ GeV/c.
The CKM Unitarity Triangle

- The strength of the coupling of quarks via the charged weak current is described by the Cabibbo-Kobayashi-Maskawa (CKM) Matrix;
- The CKM Matrix is a 3x3 complex and unitary matrix;
- One of its unitarity conditions defines the CKM Unitarity Triangle;
- Time-dependent CP violation measurements in $B_d$ decays allow us to measure the angles $\phi_1$ and $\phi_2$.

$$V_{CKM} = \begin{pmatrix}
V_{ud} & V_{us} & V_{ub} \\
V_{cd} & V_{cs} & V_{cb} \\
V_{td} & V_{ts} & V_{tb}
\end{pmatrix}$$

\[ \phi_2 \equiv \arg \left[ -\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*} \right] \]

\[ \phi_1 \equiv \arg \left[ -\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*} \right] \]

Current precision: $\sim 5^\circ$

Current precision: $\sim 0.7^\circ$
Time Dependent CPV at Belle II

• Flagship analysis technique at the B factories, exploiting the coherent state of the neutral B pairs from the Y(4S) decay:

\[ \langle \Delta z \rangle \sim 130 \, \mu m \text{ at Belle II} \]

\[ \Delta z = \beta \gamma c \Delta t \]
\[ \Delta t = t_{CP} - t_{tag} \]

\[ A_f(\Delta t) = \frac{\Gamma(B^0(\Delta t) \rightarrow \eta' K_S^0) - \Gamma(B^0(\Delta t) \rightarrow \eta' K_S^0)}{\Gamma(B^0(\Delta t) \rightarrow \eta' K_S^0) + \Gamma(B^0(\Delta t) \rightarrow \eta' K_S^0)} \]
\[ = S_f \sin(\Delta m_B \Delta t) + A_f \cos(\Delta m_B \Delta t) \]
\[ S_f = -\eta_f \sin 2\phi_1 \]
Flavor Tagging

- Charged leptons, kaons, pions, Λ’s (and their correlations) from the unreconstructed B help determining whether it is a B⁰ or a B̄⁰;
- Brand new algorithm, exploiting more variables in two layers of MVA discriminators;
- Its performance has been tested already on Belle data:

\[ \varepsilon_{\text{eff}} = \sum_i \varepsilon_i (1 - 2w_i)^2 \]

- Old FT - Belle data: \( \varepsilon_{\text{eff}} = (30.1 \pm 0.4)\% \)
- New FT - Belle data: \( \varepsilon_{\text{eff}} = (33.6 \pm 0.5)\% \)
- New FT - Belle MC: \( \varepsilon_{\text{eff}} = (34.18 \pm 0.03)\% \)
- New FT - Belle II MC: \( \varepsilon_{\text{eff}} = (37.16 \pm 0.03)\% \)

Improvement w.r.t. Belle largely due to better PID

\[ \overline{B}^0 \rightarrow D^{*+} \nu_\ell \ell^- \]
\[ \quad \rightarrow D^0 \pi^+ \]
\[ \quad \rightarrow X K^- \]

\[ \overline{B}^0 \rightarrow D^+ \pi^- (K^-) \]
\[ \quad \rightarrow K^0 \nu_\ell \ell^+ \]

\[ \overline{B}^0 \rightarrow \Lambda_c^+ X^- \]
\[ \quad \rightarrow \Lambda \pi^+ \]
\[ \quad \rightarrow p \pi^- \]
**sin2ϕ_1 (sin2β) – golden modes**

- The best sensitivity comes from the B^0 → (c¯c) K^0 modes, which have a high branching ratio and are theoretically very clean:
  
  | Int. lumi: 426 fb^{-1} | BaBar: S = 0.687 ± 0.028 ± 0.012 |
  | Int. lumi: 711 fb^{-1} | Belle: S = 0.667 ± 0.023 ± 0.012 |
  | Int. lumi: 3.0 fb^{-1} | LHCb: S = 0.731 ± 0.035 ± 0.020 |

  HFLAV Average: S = 0.691 ± 0.017

- **Experimental challenge: reduce systematic uncertainties:**

<table>
<thead>
<tr>
<th>S_{c¯c} (50 ab^{-1})</th>
<th>No improvement</th>
<th>Vertex improvement</th>
<th>Leptonic categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>stat.</td>
<td>0.0027</td>
<td>0.0027</td>
<td>0.0048</td>
</tr>
<tr>
<td>syst. reducible</td>
<td>0.0026</td>
<td>0.0026</td>
<td>0.0026</td>
</tr>
<tr>
<td>syst. irreducible</td>
<td>0.0070</td>
<td>0.0036</td>
<td>0.0035</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A_{c¯c} (50 ab^{-1})</th>
<th>No improvement</th>
<th>Vertex improvement</th>
<th>Leptonic categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>stat.</td>
<td>0.0019</td>
<td>0.0019</td>
<td>0.0033</td>
</tr>
<tr>
<td>syst. reducible</td>
<td>0.0014</td>
<td>0.0014</td>
<td>0.0014</td>
</tr>
<tr>
<td>syst. irreducible</td>
<td>0.0106</td>
<td>0.0087</td>
<td>0.0035</td>
</tr>
</tbody>
</table>

- Two major sources of systematics do not scale with luminosity:
  1) vertex detector alignment;
  2) DCS decays on tag-side (does not affect leptonic categories)

- Measure B^0 → J/ψ π^0 (+ others) to constrain penguin pollution effects.
**sin2φ₁ (sin2β) – penguin-dominated modes**

- TD CP-violation measurements of $b \rightarrow q\bar{q}s$ transitions ($q = u, d, s$) are also sensitive to $\sin2φ₁$, but:
  - being mostly penguin-dominated, they are potentially very sensitive to competing New Physics amplitudes (and phases);
  - there are many different modes: it will be possible to disentangle long/short distance effects;
- Theory can make quite precise predictions on the difference $ΔS_f$ of the TD CPV parameter $S$ w.r.t. the golden modes:

<table>
<thead>
<tr>
<th>Mode</th>
<th>QCDF [32]</th>
<th>QCDF (scan) [32]</th>
<th>$SU(3)$</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^0K^0_s$</td>
<td>$0.07^{+0.05}_{-0.04}$</td>
<td>$[0.02, 0.15]$</td>
<td>$[-0.11, 0.12]$ [36]</td>
<td>$-0.11^{+0.17}_{-0.17}$</td>
</tr>
<tr>
<td>$\rho^0K^0_s$</td>
<td>$-0.08^{+0.08}_{-0.12}$</td>
<td>$[-0.29, 0.02]$</td>
<td></td>
<td>$-0.14^{+0.18}_{-0.21}$</td>
</tr>
<tr>
<td>$\eta'K^0_s$</td>
<td>$0.01^{+0.01}_{-0.01}$</td>
<td>$[0.00, 0.03]$</td>
<td>$(0 \pm 0.36) \times 2 \cos(φ₁) \sin γ$ [37]</td>
<td>$-0.05 \pm 0.06$</td>
</tr>
<tr>
<td>$ηK^0_s$</td>
<td>$0.10^{+0.11}_{-0.07}$</td>
<td>$[-1.67, 0.27]$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\phi K^0_s$</td>
<td>$0.02^{+0.01}_{-0.01}$</td>
<td>$[0.01, 0.05]$</td>
<td>$(0 \pm 0.25) \times 2 \cos(φ₁) \sin γ$ [37]</td>
<td>$0.06^{+0.11}_{-0.13}$</td>
</tr>
<tr>
<td>$ωK^0_s$</td>
<td>$0.13^{+0.08}_{-0.08}$</td>
<td>$[0.01, 0.21]$</td>
<td></td>
<td>$0.03^{+0.21}_{-0.21}$</td>
</tr>
</tbody>
</table>
\[ \sin 2\phi_1 (\sin 2\beta) \text{ – projections} \]

- ★ Full study based on Belle II simulation
- ♦ Extrapolation of Belle/BaBar results

<table>
<thead>
<tr>
<th>Channel</th>
<th>WA (2017)</th>
<th>5 ab(^{-1})</th>
<th>50 ab(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\sigma(S))</td>
<td>(\sigma(A))</td>
<td>(\sigma(S))</td>
</tr>
<tr>
<td>(J/\psi K^0)</td>
<td>0.022</td>
<td>0.021</td>
<td>0.012</td>
</tr>
<tr>
<td>(\phi K^0)</td>
<td>0.12</td>
<td>0.14</td>
<td>0.048</td>
</tr>
<tr>
<td>(\eta' K^0)</td>
<td>0.06</td>
<td>0.04</td>
<td>0.032</td>
</tr>
<tr>
<td>(\omega K_S^0)</td>
<td>0.21</td>
<td>0.14</td>
<td>0.08</td>
</tr>
<tr>
<td>(K_{S}^0 \pi^0\gamma)</td>
<td>0.20</td>
<td>0.12</td>
<td>0.10</td>
</tr>
<tr>
<td>(K_{S}^0 \pi^0)</td>
<td>0.17</td>
<td>0.10</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Note: extrapolations of the LHCb sensitivity are based on publicly available LHCb information
Determination of $\phi_2 (\alpha)$: isospin analysis

- The measurement of $\phi_2$ from $B \to \pi\pi$ (or $B \to \rho\rho$) final states comes from an isospin analysis:

  The following equalities hold:

  \[
  \frac{1}{\sqrt{2}} A^{+-} + A^{00} = A^{+0}, \\
  \frac{1}{\sqrt{2}} \tilde{A}^{+-} + \tilde{A}^{00} = \tilde{A}^{+0}, \\
  A^{+0} = \tilde{A}^{+0}
  \]

  Observables (for e.g. $B \to \pi\pi$):

  - branching fractions of: $B^0 \to \pi^+\pi^0$, $\pi^+\pi^-$, $\pi^0\pi^0$;
  - direct (time-independent) CP asymmetries: $C^{+-}$, $C^{00}$;
  - time-dependent CP asymmetries: $S^{+-}$, $S^{00}$.

- Belle II will be able to measure all these observables (modes with $\pi^0$'s in the final states are difficult at LHCb).

Gronau and London, PRL 65 (1990), 3381
Determination of $\phi_2 (\alpha)$: TD $B^0 \rightarrow \pi^0 \pi^0$

- Only at Belle II: TD CPV of $B^0 \rightarrow \pi^0 \pi^0$, exploiting $\pi^0 \rightarrow e^+ e^- \gamma$ Dalitz decays and $\gamma$ conversions;
- Expect $\sim 270$ signal events with full dataset;
- Predicted error on $S^{00} \sim 0.28$;
- This would reduce the ambiguity on $\phi_2$ by a factor 2 or 4 (depending on central value).

Filled area: extrapolation of Belle results to Belle II sensitivity.

Dashed line: same as above, but adding $S^{00}$.

$\Delta t_{res} \sim 1.13$ ps

$\Delta t_{res} \sim 1.41$ ps

Belle II simulation $\gamma$ conversion points

$(r, \phi)$ view
Determination of $\phi_2(\alpha)$: projections

- Also on $B^0 \to \pi^+\pi^-$ Belle II will be very competitive with LHCb;
- Unique sensitivity on $B^0 \to \rho^+\rho^-$ and $B^+ \to \rho^+\rho^0$;
- Combining all the analyses will bring the uncertainty well below $1^\circ$.

<table>
<thead>
<tr>
<th>Channel</th>
<th>$\Delta \phi_2 [^\circ]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current world average</td>
<td>$+4.4$ $-4.0$</td>
</tr>
<tr>
<td>$B \to \pi\pi$</td>
<td>4.0</td>
</tr>
<tr>
<td>$B \to \rho\rho$</td>
<td>0.7</td>
</tr>
<tr>
<td>$B \to \pi\pi$ and $B \to \rho\rho$ Combined</td>
<td>0.6</td>
</tr>
</tbody>
</table>
TD $b \rightarrow s \gamma$ transitions

- Even where TD CPV is not expected, we have high sensitivity to NP;
- In the SM, the photon in the $b \rightarrow s \gamma$ process is almost 100% polarized;
- In these kind of processes, interference between mixing and decay does not occur, so any large CP asymmetry would be an indication of New Physics (Right-handed currents, ...);
- Current WA limit on TD CPV $\sim 0.20$: plenty of space for New Physics;
- Most promising channels:
  - $B^0 \rightarrow K_S \pi^0 \gamma$: B decay vertex relies on extrapolation of $K_S$ momentum
  - $B^0 \rightarrow K_S \pi^+ \pi^- \gamma$: Rich resonance structure, Dalitz Plot analysis
    
  $K_1(1270) \rightarrow K_S \rho^0 / K^{*+} \pi^-$

<table>
<thead>
<tr>
<th>$\sigma(S)$</th>
<th>5 ab$^{-1}$</th>
<th>50 ab$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_S^0 \pi^0 \gamma$</td>
<td>0.10</td>
<td>0.031</td>
</tr>
<tr>
<td>$K_S^0 \pi^+ \pi^- \gamma$</td>
<td>0.12</td>
<td>0.037</td>
</tr>
</tbody>
</table>
Belle II Status

- Rediscovery of particle physics is underway!

- Mass resolutions within a few % of what expected by the simulation.
Belle II Status

D mesons have been observed in several channels:

For more channels, please see H. Atmacan’s talk later this afternoon

Impact of K PID on $\phi \rightarrow K^+ K^-$. 
Belle II Status

O(100) fully reconstructed B decays have been observed already.

The VXD slice is already well aligned $z_0$ for tracks coming from IP consistent with nano beam and 41 mrad crossing angle.
Outlook

- Belle II has collected \(\sim 400 \text{ pb}^{-1}\) (today showing results on up to \(\sim 250 \text{ pb}^{-1}\));
- Phase 2 of commissioning ends July 17\(^{th}\), green light to proceed to Phase 3!
- In the Fall we will install Layer 1 (pixels) and Layers 3-6 (strips) of the vertex detector: due to technical difficulties in the construction, Layer 2 of the pixel detector will not be installed until 2020;
- Physics run with increasing luminosity will start in February 2019.
Conclusions

- SuperKEKB and Belle II smoothly started operations, rediscovery of B (and D, τ, …) physics is underway;
- Time-dependent CP violation is an important part of the physics program of Belle II;
- Compared to its predecessor, the Belle II Detector has enhanced vertexing, PID, and flavor tagging capabilities;
- We expect to have the best precision or be competitive with LHCb on most channels sensitive to the CKM angles $\phi_1$ and $\phi_2$, in particular on the penguin dominated modes;
- Channels with $\pi^0$’s, $\eta^{(')}$’s, $K^0_L$’s, … in the final state will be much better determined at Belle II than LHCb;
- The physics run will start in February 2019.
Data taking scenarios

Goal of Belle II/SuperKEKB

Integrated Luminosity [ab^{-1}]

Belle II  Projection (Nov 2017)
- Belle II
- Belle II 6 of 9 months
- Belle (II) 6 of 9 months, slow ramp-up [ab^{-1}]

Peak luminosity (cm^{-2} s^{-1})

Calendar Year

Year

**Vertexing**

Tag side vertex fit: Using RAVE
Adaptive Vertex Fit (AVF) algorithm:

Kinematic fit: $J/\psi \rightarrow \mu^+ \mu^-$

- Belle II
  - Res. = 26 $\mu$m
- Belle converted MC
  - Res. = 43 $\mu$m

$\Delta t$ resolution

- Belle II
  - Bias = -0.03 ps
  - Res. = 0.77 ps
- Belle
  - Bias = 0.20 ps
  - Res. = 0.92 ps

All tracks apart from the ones from Ks

Bias = 6 $\mu$m
Res. = 53 $\mu$m

Bias = 29 $\mu$m
Res. = 89 $\mu$m
RAVE Adaptive Vertex Fitter

Down-weights outliers dynamically, instead of using hard cutoffs (important for 3+ track vertices).

Minimization of the weighted least sum of squares

\[
    w_i \left( \chi_i^2 \right) = \frac{\exp\left(-\chi_i^2/2T\right)}{\exp\left(-\chi_i^2/2T\right) + \exp\left(-\sigma_{\text{cut}}^2/2T\right)}
\]

Weight

“temperature” parameter

“softness” of the weight function

in each iteration step

the temperature parameter is lowered

\[
    T_i = 1 + r \cdot (T_{i-1} - 1)
\]

0<r<1

Flavor Tagger

Two steps process to determine the flavor of the $B_{\text{tag}}$:

1) Build 13 multivariate discriminators to look for the following topologies, which are (more or less) strongly correlated with the $B_{\text{tag}}$ flavor:

<table>
<thead>
<tr>
<th>Categories</th>
<th>Targets for $B^0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>$e^-$</td>
</tr>
<tr>
<td>Intermediate Electron</td>
<td>$e^+$</td>
</tr>
<tr>
<td>Muon</td>
<td>$\mu^-$</td>
</tr>
<tr>
<td>Intermediate Muon</td>
<td>$\mu^+$</td>
</tr>
<tr>
<td>Kinetic Lepton</td>
<td>$l^-$</td>
</tr>
<tr>
<td>Intermediate Kinetic Lepton</td>
<td>$l^+$</td>
</tr>
<tr>
<td>Kaon</td>
<td>$K^-$</td>
</tr>
<tr>
<td>Kaon-Pion</td>
<td>$K^-, \pi^+$</td>
</tr>
<tr>
<td>Slow Pion</td>
<td>$\pi^+$</td>
</tr>
<tr>
<td>Maximum P*</td>
<td>$l^-, \pi^-$</td>
</tr>
<tr>
<td>Fast-Slow-Correlated (FSC)</td>
<td>$l^-, \pi^+$</td>
</tr>
<tr>
<td>Fast Hadron</td>
<td>$\pi^-, K^-$</td>
</tr>
<tr>
<td>Lambda</td>
<td>$\Lambda$</td>
</tr>
</tbody>
</table>

Underlying decay modes:

- $B^0 \rightarrow D^{*+} \bar{\nu}_\ell \ell^-$
- $D^0 \rightarrow \pi^+$
- $X K^-$
- $B^0 \rightarrow D^+ \pi^- (K^-)$
- $K^0 \nu_\ell \ell^+$
- $B^0 \rightarrow A_\ell^+ X^-$
- $A \pi^+$
- $p \pi^-$

2) Use the output of the 13 discriminators above as input for another multivariate algorithm, whose output $y = q \cdot r$ is used in physics analyses.
## Flavor Tagger

Variables entering the multivariate discriminant for each category:

<table>
<thead>
<tr>
<th>Categories</th>
<th>Discriminating input variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>$\mathcal{L}_e, \ p^<em>, \ p_t^</em>, \ p, \ p_t, \ \cos \theta, \ d_0, \</td>
</tr>
<tr>
<td>Int. Electron</td>
<td></td>
</tr>
<tr>
<td>Muon</td>
<td>$\mathcal{L}_\mu, \ p^<em>, \ p_t^</em>, \ p, \ p_t, \ \cos \theta, \ d_0, \</td>
</tr>
<tr>
<td>Int. Muon</td>
<td></td>
</tr>
<tr>
<td>Kin. Lepton</td>
<td>$\mathcal{L}<em>e, \mathcal{L}</em>\mu, \ p^<em>, \ p_t^</em>, \ p, \ p_t, \ \cos \theta, \ d_0, \</td>
</tr>
<tr>
<td>Int. Kin. Lep.</td>
<td></td>
</tr>
<tr>
<td>Kaon</td>
<td>$\mathcal{L}_K, \ p^<em>, \ p_t^</em>, \ p, \ p_t, \ \cos \theta, \ d_0, \</td>
</tr>
<tr>
<td>Slow Pion</td>
<td>$\mathcal{L}_\pi, \mathcal{L}_e, \mathcal{L}_K, \ p^<em>, \ p_t^</em>, \ p, \ p_t, \ \cos \theta, \ d_0, \</td>
</tr>
<tr>
<td>Fast Hadron</td>
<td></td>
</tr>
<tr>
<td>Kaon-Pion</td>
<td>$\mathcal{L}<em>K, \ y</em>{Kaon}, \ y_{SlowPion}, \ \cos \theta_{K\pi}^*, \ q_K \cdot q_\pi$</td>
</tr>
<tr>
<td>Maximum P*</td>
<td>$p^<em>, \ p_t^</em>, \ p, \ p_t, \ d_0, \</td>
</tr>
<tr>
<td>FSC</td>
<td>$\mathcal{L}<em>{K</em>{Slow}}, \ p_{Slow}^<em>, \ p_{Fast}^</em>, \ \cos \theta_T^{<em>}_{Slow}, \ \cos \theta_T^{</em>}<em>{Fast}, \ \cos \theta</em>{SlowFast}^*, \ q_{Slow} \cdot q_{Fast}$</td>
</tr>
<tr>
<td>Lambda</td>
<td>$\mathcal{L}<em>p, \mathcal{L}</em>\pi, \ p_A^<em>, \ p_A, \ p_p^</em>, \ p_p, \ p_{\pi}^*, \ p_{\pi}, \ q_A, \ M_A, \ n_{K_S^0}, \ \cos \theta_{A,p_{A}}, \</td>
</tr>
</tbody>
</table>
Flavor Tagger

Belle II MC: Eff = 37%

Belle MC: Eff = 34% (Belle 30%)

July 6th 2018
A. Gaz
\[ \sin 2\phi_1 : B^0 \rightarrow \eta' K^0 \]

- This is the most sensitive penguin dominated mode, one of the theoretically cleanest, and a difficult one at LHCb;
- Several different combinations of 
  \( \eta' \rightarrow \eta(\gamma\gamma) \pi^+\pi^-, \eta(\pi^+\pi^-\pi^0) \pi^+\pi^-, \rho^0\gamma; \) 
  \( K_S \rightarrow \pi^+\pi^-, \pi^0\pi^0; K_L; \)
- One of the main challenges of this analysis is the correct choice of the signal candidate (versus the Self Cross-Feed – SXF);
- Optimal choice of the signal candidate currently under discussion;
- Impact of beam background on \( \Delta t \) resolution is also a concern;
- This (different to most others) mode will be dominated by systematics at the end of data taking.
\[ \sin 2\phi_1 : B^0 \rightarrow \eta' K^0 \]

- Crucial aspect of (every TD) analysis: \( \Delta t \) resolution function;
- Starting on the simulation with an approach “a la BaBar”: we fit the \( \Delta t \) resolution with the sum of three Gaussians;
- Fundamental to model many small effects (e.g. charm content in the ROE);
- This will be our highest priority once we get the first Phase3 data.
\[ \sin 2\phi_1 : B^0 \rightarrow \phi K^0 \]

- Another theoretically clean mode, there will be competition with LHCb;
- BaBar and Belle reached the ultimate sensitivity with a Dalitz Plot analysis of \[ B^0 \rightarrow K^+KK^0 \];
- In order to publish a result with the first 1-2 ab\(^{-1}\), we propose a simpler quasi-two body approach;
- We have to separate the \( \phi \) resonance from the non-negligible \( K^+K^- \) component, which carries a different weak phase;
- We plan to separate these two components using the pair of variables \( (m_{KK'}, \cos \theta_{hel}) \);
- No bias seen from the simulation.
$$\sin(2\beta) = \sin(2\phi_1)$$

Golden modes

- $B\rightarrow c\bar{c}s$ World Average
- $\psi K^0$ Average
- $\eta' K^0$ Average
- $K_S K_S K_S$ Average
- $\rho^0 K_S$ Average
- $\omega K_S$ Average
- $f_0 K_S$ Average
- $f_+ K_S$ Average
- $f_- K_S$ Average
- $f_0 K^0$ Average
- $\rho^0 K^0$ Average
- $K^- K^+ K^0$ Average

Penguin dominated modes

$$\sin(2\beta^{\text{eff}}) = \sin(2\phi_1^{\text{eff}})$$