Measurements of Hadronic D and B decays at Belle and Belle II

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Current Status of Hadronic D and B decays at **Belle** and **Belle II**

### Hadronic D decays
- **BFs and $A_{CP}$ in $D^0 \rightarrow \pi^+\pi^-\eta$, $K^+K^-\eta$ and $\eta\phi$** [Belle]
- **BFs and $A_{CP}$ in $D_S^\pm \rightarrow K^+(\pi^0,\eta)$ and $\pi^+(\pi^0,\eta)$** [Belle]
- **Mixing parameter $y_{CP}$ in $D^0 \rightarrow K_S^0\omega$** [Belle]
- **Dalitz-plot analysis of $D^0 \rightarrow K^-\pi^+\eta$** [Belle]
- **CP violation in $D^0 \rightarrow K^-K^+\pi^-\pi^+$** [Belle]
- **Measurement of $D^0$ and $D^+$ lifetimes** [Belle II]

### Hadronic B decays
- **$b \rightarrow c$ transition**
  - **Study of $B \rightarrow D^\ast h$ at Belle II** [Belle II]
  - **Measurement of Ratio and BFs in $B^0 \rightarrow D^-h^+$ decay** [Belle]
- **$b \rightarrow s,u$ transitions**
  - **Measurement of time-dependent CP violation parameters in $B^0 \rightarrow K_S^0K_S^0K_S^0$** [Belle]
  - **Measurement of branching fraction and Search for CP Violation in $B \rightarrow \phi\phi K$** [Belle]
  - **Measurement of the BFs of $B \rightarrow \eta'K$ decay** [Belle II]
  - **Search for direct CP-violating asymmetry in $B^0 \rightarrow K^0\pi^0$ decays at Belle II** [Belle II]
  - **Measurement of the BFs of $B^0 \rightarrow \pi^0\pi^0$ decay** [Belle II]
  - **Study of the $B^+ \rightarrow \rho^+\rho^0$ decays** [Belle II]  

**Topics in red are covered in this talk**
BFs and $A_{CP}$ in $D^0 \rightarrow \pi^+\pi^-\eta$, $K^+K^-\eta$ and $\phi\eta$ at Belle

- CP violation in charm physics is observed at LHCb in $D^0 \rightarrow \pi^+\pi^-, K^+K^-$
- Measure CP asymmetries and BFs with an additional $\eta$ meson

- Fitting the $Q$-values distributions $Q = M(K^+K^-\eta\pi^+_S) - M(K^+K^-\eta) - m_{\pi^+}$
- The reference mode $B(D^0 \rightarrow K^-\pi^+\eta) = (1.88 \pm 0.05)$%
- 2D fit of $M_{KK}$ -Q for $D^0 \rightarrow \phi\eta$

Branching Fractions results:

$B(D^0 \rightarrow \pi^+\pi^-\eta) = [1.22 \pm 0.02 \text{ (stat.)} \pm 0.02 \text{(syst.)} \pm 0.03(B_{\text{ref}})] \times 10^{-3}$

$B(D^0 \rightarrow K^+K^-\eta) = [1.80^{+0.07}_{-0.06} \text{ (stat.)} \pm 0.04 \text{(syst.)} \pm 0.05(B_{\text{ref}})] \times 10^{-4}$

$B(D^0 \rightarrow \phi\eta) = [1.84 \pm 0.09 \text{(stat.)} \pm 0.06 \text{(syst.)} \pm 0.05(B_{\text{ref}})] \times 10^{-4}$

First observation of color-suppressed decay $D^0 \rightarrow \phi\eta$

- Asymmetries results:

$A_{CP}(D^0 \rightarrow \pi^+\pi^-\eta) = [0.9 \pm 1.2 \text{ (stat.)} \pm 0.4 \text{(syst.)} ]\%$

$A_{CP}(D^0 \rightarrow K^+K^-\eta) = [-1.4 \pm 3.3 \text{ (stat.)} \pm 1.0 \text{(syst.)} ]\%$

$A_{CP}(D^0 \rightarrow \phi\eta) = [-1.9 \pm 4.4 \text{ (stat.)} \pm 0.6 \text{(syst.)} ]\%$

No evidence of CPV found in these decays
BFs and $A_{CP}$ in $D_s^+ \to K^+(\pi^0, \eta)$ and $\pi^+(\pi^0, \eta)$ at Belle

- Measure CP asymmetries in charm physics with higher precision to help improve the theoretical predictions
- Neural network (NN) based on input variables $p(D_s^+)$, $|d_{xy}|$ or $dr$, $\theta_{heli}(h^+)$, $N(K)$, $\theta^{thrust}$ and $\theta(p(D_s^+), \vec{r}_{vtx})$.
- Simultaneously fit for $M_{D_s^+}$ with $D_s^{*-}$-tagged and untagged $D_s^+$ samples from 921 fb$^{-1}$ Belle data
- BF of reference mode $B(D_s^+ \to \phi[\to K^+K^-]\pi^+)= (2.24 \pm 0.08)\%$

Asymmetries results:

<table>
<thead>
<tr>
<th>Decay mode</th>
<th>$A_{CP}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_s^+ \to K^+\pi^0$</td>
<td>$0.064 \pm 0.044 \pm 0.011$</td>
</tr>
<tr>
<td>$D_s^+ \to K^+\eta\gamma$</td>
<td>$0.040 \pm 0.027 \pm 0.005$</td>
</tr>
<tr>
<td>$D_s^+ \to K^+\eta\gamma_1$</td>
<td>$-0.008 \pm 0.034 \pm 0.008$</td>
</tr>
<tr>
<td>$D_s^+ \to K^+\eta\gamma_2$</td>
<td>$0.021 \pm 0.021 \pm 0.004$</td>
</tr>
<tr>
<td>$D_s^+ \to \pi^+\eta\gamma$</td>
<td>$0.002 \pm 0.004 \pm 0.003$</td>
</tr>
<tr>
<td>$D_s^+ \to \pi^+\eta\gamma_1$</td>
<td>$0.002 \pm 0.006 \pm 0.003$</td>
</tr>
<tr>
<td>$D_s^+ \to \pi^+\eta\gamma_2$</td>
<td>$0.002 \pm 0.003 \pm 0.003$</td>
</tr>
<tr>
<td>$D_s^+ \to \phi\pi^+$</td>
<td>$-$</td>
</tr>
</tbody>
</table>

These results show no evidence of CP violation.

Branching Fractions

<table>
<thead>
<tr>
<th>Decay mode</th>
<th>$B/B_{\pi^+}$ (%)</th>
<th>$B$ (10$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_s^+ \to K^+\pi^0$</td>
<td>$3.28 \pm 0.23 \pm 0.13$</td>
<td>$0.735 \pm 0.052 \pm 0.030 \pm 0.026$</td>
</tr>
<tr>
<td>$D_s^+ \to K^+\eta\gamma$</td>
<td>$8.04 \pm 0.32 \pm 0.35$</td>
<td>$1.80 \pm 0.07 \pm 0.08 \pm 0.06$</td>
</tr>
<tr>
<td>$D_s^+ \to K^+\eta\gamma_1$</td>
<td>$7.62 \pm 0.29 \pm 0.33$</td>
<td>$1.71 \pm 0.07 \pm 0.08 \pm 0.06$</td>
</tr>
<tr>
<td>$D_s^+ \to K^+\eta\gamma_2$</td>
<td>$7.81 \pm 0.22 \pm 0.24$</td>
<td>$1.75 \pm 0.05 \pm 0.05 \pm 0.06$</td>
</tr>
<tr>
<td>$D_s^+ \to \pi^+\pi^0$</td>
<td>$0.16 \pm 0.26 \pm 0.09$</td>
<td>$0.037 \pm 0.055 \pm 0.021 \pm 0.001$</td>
</tr>
<tr>
<td>$D_s^+ \to \pi^+\eta\gamma$</td>
<td>$85.54 \pm 0.64 \pm 3.32$</td>
<td>$19.16 \pm 0.14 \pm 0.74 \pm 0.68$</td>
</tr>
<tr>
<td>$D_s^+ \to \pi^+\eta\gamma_1$</td>
<td>$83.55 \pm 0.64 \pm 4.37$</td>
<td>$18.72 \pm 0.14 \pm 0.98 \pm 0.67$</td>
</tr>
<tr>
<td>$D_s^+ \to \pi^+\eta\gamma_2$</td>
<td>$84.80 \pm 0.47 \pm 2.64$</td>
<td>$19.00 \pm 0.10 \pm 0.59 \pm 0.68$</td>
</tr>
</tbody>
</table>

No significant signal of $D_s^+ \to \pi^+\pi^0$ is observed and an upper limit is set to be $B(D_s^+ \to \pi^+\pi^0) < 1.2 \times 10^{-4}$.
The CKM angle $\phi_3$

- Very precise theoretical prediction $\frac{\delta \phi_3}{\phi_3} \sim 10^{-7}$ \[\text{arxiv:1308.5663}\]
- Test physics beyond SM
- The interference between color-favored and color-suppressed processes can be related:
  \[
  A^{\text{suppr.}}_{B^- \rightarrow D^0 K^-} \frac{A^{\text{favor.}}_{B^- \rightarrow D^0 K^-}}{A^{\text{favor.}}_{B^- \rightarrow D^0 K^-}} = r_B e^{i(\delta_B - \phi_3)}
  \]
  $r_B$ - the magnitude of the ratio of amplitudes; $\delta_B$ - strong-phase difference

- 3 main methods to extract $\phi_3$:
  - GLW method: CP eigenstates: $K^- K^+, \pi^- \pi^+, K_S^0 \pi^0$
  - ADS method: DCS modes: $K^+ \pi^-, K^+ \pi^- \pi^0$
  - BPGGSZ method: self-conjugate multibody final states: $K_S^0 \pi^+ \pi^-, K_S^0 K^+ K^-, K_S^0 \pi^+ \pi^- \pi^0$

- Foreseen precision of $\phi_3$ is expected to be $O(1^\circ)$ (current world-average $\delta \phi \sim 4^\circ$) with the full Belle II dataset of 50 $ab^{-1}$ \[\text{Belle II Physics book: arXiv:1808.10567}\]

First Belle+Belle II combined results for the $\phi_3$ in $B^- \rightarrow D^0 (K_S^0 \pi^+ \pi^-) K^-$ will come soon!!!
Study of $B \to D^{(*)} h$ at Belle II

$h = \pi, K$

- The improved measurement of the color-favored hadronic two body decay of B meson helps to a better understanding of QCD effects

- Decay ratio to be extracted:
  \[
  R^{D(*)} = \frac{\Gamma[B\to D^{(*)}K]}{\Gamma[B\to D^{(*)}\pi]} \simeq \tan^2 \theta_C \left( \frac{f_K}{f_\pi} \right)^2
  \]
  which will eliminate some systematic uncertainties

- Unbinned 2D simultaneous fit of $\Delta E$ versus $C'$ (right plot) for $B^- \to D^0(K_S^0\pi^+\pi^-)K^-$

  \[
  N_{kaonID<0.6}^{D^{(*)}\pi} = (1 - \kappa_{kaonID>0.6}) N_{Total}^{D^{(*)}\pi}
  \]
  \[
  N_{kaonID>0.6}^{D^{(*)}\pi} = \kappa_{kaonID<0.6} N_{Total}^{D^{(*)}\pi}
  \]
  \[
  N_{kaonID<0.6}^{D^{(*)}K} = (1 - \epsilon_{kaonID>0.6}) R^{D(*)} N_{Total}^{D^{(*)}\pi}
  \]
  \[
  N_{kaonID>0.6}^{D^{(*)}K} = \epsilon_{kaonID>0.6} R^{D(*)} N_{Total}^{D^{(*)}\pi}
  \]

  \(\kappa\)- pion fake rate ; \(\epsilon\)-kaon efficiency

- Results of 62.8 fb$^{-1}$:

  \[
  R^D(B^- \to D^0(K^-\pi^+)h^-) = [7.66 \pm 0.55 \text{(stat.)} + 0.11^{+0.08}_{-0.08} \text{(syst.)}] \times 10^{-2}
  \]
  \[
  R^D(B^- \to D^0(K_S^0\pi^+\pi^-)h^-) = [6.32 \pm 0.81 \text{(stat.)} + 0.09^{+0.11}_{-0.11} \text{(syst.)}] \times 10^{-2}
  \]
  \[
  R^{D*}(B^- \to D^{*0}h^-) = [6.80 \pm 1.01 \text{(stat.)} \pm 0.07 \text{(syst.)}] \times 10^{-2}
  \]
  \[
  R^D(B^0 \to D^- h^+) = [9.22 \pm 0.58 \text{(stat.)} \pm 0.09 \text{(syst.)}] \times 10^{-2}
  \]
  \[
  R^{D*}(B^0 \to D^{*-}K^+) = [5.99 \pm 0.82 \text{(stat.)} + 0.17^{+0.08}_{-0.08} \text{(syst.)}] \times 10^{-2}
  \]
Measurement of Ratio and BFs in $B^0 \to D^- h^+$ decay at Belle $h = \pi, K$

- Similar method refers to Belle II for extracting the signal

- Preliminary Results:
  
  \[
  R^D = \frac{\Gamma[B^0 \to D^- K^+]}{\Gamma[B^0 \to D^- \pi^+]} = [8.20 \pm 0.20\text{(stat.)} \pm 0.20\text{(syst.)}] \times 10^{-2}
  \]
  
  \[
  \mathcal{B}(B^0 \to D^- (\to K^+ \pi^- \pi^-) \pi^+) = [2.50 \pm 0.01\text{(stat.)} \pm 0.10\text{(syst.)} \pm 0.04(\mathcal{B}(D \to K^+ \pi^- \pi^-))] \times 10^{-3}
  \]
  
  \[
  \mathcal{B}(B^0 \to D^- (\to K^+ \pi^- \pi^-) K^+) = [2.05 \pm 0.05\text{(stat.)} \pm 0.08\text{(syst.)} \pm 0.04(\mathcal{B}(D \to K^+ \pi^- \pi^-))] \times 10^{-4}
  \]

  These results are consistent with the previous measurement results.

  **Full Belle dataset result (711 fb$^{-1}$)!!**

- Previous Results:
  
  \[
  R^D = \frac{\Gamma[B^0 \to D^- K^+]}{\Gamma[B^0 \to D^- \pi^+]} = [8.22 \pm 0.11\text{(stat.)} \pm 0.25\text{(syst.)}] \times 10^{-2}
  \]
  
  \[
  \mathcal{B}(B^0 \to D^- \pi^+) = [2.55 \pm 0.05\text{(stat.)} \pm 0.16\text{(syst.)}] \times 10^{-3}
  \]
  
  \[
  \mathcal{B}(B^0 \to D^- K^+) = [1.89 \pm 0.19\text{(stat.)} \pm 0.10\text{(syst.)}] \times 10^{-4}
  \]

  - LHCb result in JHEP 2013.1(2013)
  - BaBar result in PRD 75(2007) 031101
  - LHCb result in PRL 107(2011) 211801
Measurement of TDCP violation parameters in $B^0 \rightarrow K_S^0 K_S^0 K_S^0$ at Belle

- Pure $b \rightarrow sq\bar{q}$ penguin transition is sensitive to new physics and provide an opportunity of measurement of $\sin 2\phi_1$
- In the previous measurement of $\sin 2\phi_1$, there is 1.6 $\sigma$ difference between Belle and BaBar result
- Unbinned 3D fit of $\Delta E - M_{bc} - T$(Transformed NN) to extract signal with full Belle dataset($711 \text{ fb}^{-1}$)  
  \[ M_{bc} = \sqrt{E_{beam}^2 - (\Sigma p_i)^2} \quad T = \log\left(\frac{NN - NN_{low}}{NN_{high} - NN}\right) \]
- Time-dependent CP(TDCP) Violation:  
  \[ \mathcal{A}_{CP} = \frac{P(B^0(\Delta t) \rightarrow f_{CP}) - P(B^0(\Delta t) \rightarrow f_{CP})}{P(B^0(\Delta t) \rightarrow f_{CP}) + P(B^0(\Delta t) \rightarrow f_{CP})} = S\sin(\Delta m\Delta t) + A\cos(\Delta m\Delta t) \]
- Results:
  \[ S = -0.71 \pm 0.23 \text{ (stat.)} \pm 0.05 \text{ (syst.)} \]
  \[ A = 0.12 \pm 0.16 \text{ (stat.)} \pm 0.05 \text{ (syst.)} \]
  Result improved and 2.5 $\sigma$ significance of CP violation away from (0,0)
Measurement of the BFs of $B \to \eta'K$ decays at Belle II

- $B \to \eta'K$ decays is dominated by penguin transition, measurement of CP violation is sensitive to new physics in the penguin loop
- Belle II detector well suited for neutral final states
- Aimed for early reconstruction and branching fraction measurement
  1. $B^\pm \to \eta'K^\pm$, with $\eta' \to \eta \pi^+\pi^-$ or $\eta' \to \rho\gamma$
  2. $B^0 \to \eta'K^0$, with $\eta' \to \eta \pi^+\pi^-$ or $\eta' \to \rho\gamma$
- 3D fit of $\Delta E - M_{bc} - C_{S_{\text{var}}}$ (continuum suppression discriminator)
  \[ C_{S_{\text{var}}} = \log\left(\frac{FBDT - FBDT_{\text{low}}}{FBDT_{\text{high}} - FBDT}\right) \]
- Results with 62.8 fb$^{-1}$
  \[ B(B^\pm \to \eta'K^\pm) = [63.4^{+3.4}_{-3.3} \text{(stat.)} \pm 3.2 \text{(syst.)}] \times 10^{-6} \]
  \[ B(B^0 \to \eta'K^0) = [59.9^{+5.8}_{-5.5} \text{(stat.)} \pm 2.9 \text{(syst.)}] \times 10^{-6} \]

The first measurement of branching fractions at Belle II
First search for direct CP-violating asymmetry in $B^0 \rightarrow K^0 \pi^0$ decays at Belle II

- Isospin sum rule

$$I_{K\pi} = A_{K^+\pi^-} + A_{K^0\pi^0} \frac{B(K^0\pi^0)}{B(K^+\pi^-)} \frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{K^+\pi^-} \frac{B(K^+\pi^0)}{B(K^+\pi^-)} \frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{K^0\pi^0} \frac{B(K^0\pi^0)}{B(K^+\pi^-)} \frac{\tau_{B^0}}{\tau_{B^+}}$$

  - Stringent null test of standard model (SM)
  - Sensitive to the presence of non-SM physics

- The reconstruction of $K_S^0$ and $\pi^0$ is challenging in this analysis

- Belle II unique access, major limitation in $I_{K\pi}$ determination

- Flavor tagging is required, fit of $\Delta E - M_{bc}$


- Results with 62.8 fb$^{-1}$:

  $${\cal B}(B^0 \rightarrow K^0\pi^0) = [8.5^{+1.7}_{-1.6} \text{(stat.)} \pm 1.2 \text{(syst.)}] \times 10^{-6}$$

  $${\cal A}(B^0 \rightarrow K^0\pi^0) = -0.40^{+0.46}_{-0.44} \text{(stat.)} \pm 0.04 \text{(syst.)}$$

  First Belle II measurement of the $B^0 \rightarrow K^0\pi^0$ decay
Isospin sum rule Uncertainty projection

- Extrapolate the uncertainty on $I_{K\pi}$ in the next decade
- Future projections with Belle II and LHCb expected luminosities
- Dominant uncertainty coming from $A_{K^0\pi^0}$
- Belle II will play a crucial role in pinning down the $I_{K\pi}$

Grey dashed curve is the case if only $A_{K^+\pi^-}$, $A_{K^+\pi^0}$ and $A_{K^0\pi^+}$ are updated

Red curve is the projection when updates on $I_{K\pi}$ measurements including $A_{K^0\pi^0}$
Measurement of the BFs of $B^0 \rightarrow \pi^0\pi^0$ decay at Belle II

- Unique Belle II capability to this kind of final states to extract CKM angle $\phi_2$
- Very challenging:
  - Only neutral final states of two $\pi^0$s (only photons to reconstruct)
  - Branching fraction is of $\mathcal{O}(10^{-6})$
- A fast boosted decision-tree (FBDT) training of 20 combined ECL variables is performed to suppress the background photons
- 3D fit of $(\Delta E, M_{bc}, T_c)$ to extract signal
  
  $T_c$ with 28 input training variables associated with event topology
- Right plots are the signal enhanced projections

Results with 62.8 fb$^{-1}$:

\[ N(B^0 \rightarrow \pi^0\pi^0) = (14^{+6.8}_{-5.6}) \]  

Signal significance of 3.4 $\sigma$

\[ B(B^0 \rightarrow \pi^0\pi^0) = (0.98^{+0.48}_{-0.39}(\text{stat.}) \pm 0.27(\text{syst.})) \times 10^{-6} \]

First measurement in Belle II data.

Much improved than Belle report of evidence of 3.4 $\sigma$ using 140 fb$^{-1}$
Study of the $B^+ \rightarrow \rho^+ \rho^0$ decay at Belle II

- $B \rightarrow \rho\rho$ decays to determine the $\phi_2$

- Pion-only final state and broad $\rho$ peak leads to large background

- Spin-0 decays to spin +1 and spin -1, requires angular analysis

- 6D fit including $\Delta E$, $T_c$ and $\rho$ mass to extract the signal; helicity angles to measure fraction $f_L$ of decays with longitudinal polarization

- Results with 62.8 fb$^{-1}$:
  \[
  N(B^+ \rightarrow \rho^+ \rho^0) = 104 \pm 16 \\
  \mathcal{B}(B^+ \rightarrow \rho^+ \rho^0) = (20.6 \pm 3.2 \text{ (stat.)} \pm 4.0 \text{ (syst.)}) \times 10^{-6} \\
  f_L = 0.936^{+0.049}_{-0.041} \text{ (stat.)} \pm 0.021 \text{ (syst.)}
  \]

  First measurement in Belle II data. 
  20% better precision than Belle on 78 fb$^{-1}$  
  PRL 91, 221801 (2003)
Summary

- First observation of color suppressed $D^0 \rightarrow \eta \phi$ with high statistical significance with Belle data is reported.

- Studies of precise determination of $\phi_3$ are ongoing with the brand new Belle II data. Especially the combined result of Belle + Belle II of $B^- \rightarrow D^0(K_S^0\pi^+\pi^-)K^-$ will come soon.

- Belle updated the measurement result of the CPV parameters in $B^0 \rightarrow K_S^0K_S^0K_S^0$ analysis.

- We measure the decay of $B \rightarrow \eta'K$ at Belle II.

- The measurements of isospin sum rule related ingredients are measured with Belle II data.

- Belle II is preparing for a leading role in $\phi_2$ measurement.

All the measurements done with Belle II data agree with the known results within uncertainties. With the data-taking carried on, Belle II will lead to more interesting results.

Meanwhile, Belle is still providing fruitful studies and result as well.
Thank you for listening！
感谢聆听！
More info. of $D^0 \to \pi^+ \pi^- \eta, K^+ K^- \eta$ and $\eta \phi$

- **Detail of $A_{raw}$**
  \[
  A_{raw} = A_{CP}^{D^0 \to f} + A_{FB}^{D^+} + A_{\pi^+}^{\pi^-} 
  \]
  The first term is what we want; the second term is the forward-backward asymmetry due to $\gamma - Z^0$ interference and higher-order QED effects in $e^+ e^- \to c\bar{c}$ collision; the third term is asymmetry resulting from a difference in reconstruction efficiencies between $\pi^-_S$ and $\pi^+_S$.

- **The corrected asymmetry is**:
  \[
  A_{corr}(\cos \theta) = A_{CP}^{D^0 \to f} + A_{FB}^{D^+}(\cos \theta) 
  \]
  The third term cancel with the weights for $\pi_{soft}(p_T, \cos \theta)$

- **The observable to extract**:
  \[
  A_{CP}(\cos \theta) = \frac{A_{corr}(\cos \theta) + A_{corr}(-\cos \theta)}{2} 
  \]
  \[
  A_{FB}(\cos \theta) = \frac{A_{corr}(\cos \theta) - A_{corr}(-\cos \theta)}{2} 
  \]

- **Systematic uncertainties**

<table>
<thead>
<tr>
<th>Systematic sources</th>
<th>$B(D^0 \to \pi^+ \pi^- \eta)$</th>
<th>$B(D^0 \to K^+ \pi^- \eta)$</th>
<th>$B(D^0 \to K^+ K^- \eta)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>PID efficiency correction</td>
<td>1.8%</td>
<td>1.9%</td>
<td>1.9%</td>
</tr>
<tr>
<td>Signal PDF</td>
<td>0.3%</td>
<td>0.5%</td>
<td>0.9%</td>
</tr>
<tr>
<td>Background PDF</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Mass resolution calibration</td>
<td>0.1%</td>
<td>0.3%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Yield correction with efficiency map</td>
<td>0.3%</td>
<td>0.7%</td>
<td>–</td>
</tr>
<tr>
<td>MC statistics</td>
<td>0.3%</td>
<td>0.4%</td>
<td>0.4%</td>
</tr>
<tr>
<td>$K_S^0$ veto</td>
<td>0.1%</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Interference in $M_{KK}$</td>
<td>–</td>
<td>–</td>
<td>2.5%</td>
</tr>
<tr>
<td>Total syst. error</td>
<td>1.9%</td>
<td>2.1%</td>
<td>3.3%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sources</th>
<th>$\sigma_{ACP}(D^0 \to \pi^+ \pi^- \eta)$</th>
<th>$\sigma_{ACP}(D^0 \to K^+ \pi^- \eta)$</th>
<th>$\sigma_{ACP}(D^0 \to \phi \eta)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal and bkg</td>
<td>0.004</td>
<td>0.010</td>
<td>0.006</td>
</tr>
<tr>
<td>cos $\theta^*$ binning</td>
<td>0.002</td>
<td>0.004</td>
<td>0.002</td>
</tr>
<tr>
<td>$A_{CP}(\pi_S)$ map</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Total syst. error</td>
<td>0.005</td>
<td>0.011</td>
<td>0.006</td>
</tr>
</tbody>
</table>
More info. Of Ratio and branching fraction in \( B^0 \rightarrow D^- h^+ \) decay

- Most of the systematic effects cancel in the ratio of the BF due to the kinematical similarity of the two decay modes \( B^0 \rightarrow D^- K^+ \) and \( B^0 \rightarrow D^- \pi^+ \)

- The main source of systematic uncertainty is from the \( K/\pi \) identification.

- We assumed all the systematic uncertainties to be independent.

- Total uncertainty is the sum in quadrature of the contribution from individual sources.

<table>
<thead>
<tr>
<th>Source</th>
<th>( R^D )</th>
<th>( B(B^0 \rightarrow D^+ \pi^-) )</th>
<th>( B(\bar{B}^0 \rightarrow D^+ K^-) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B(D^+ \rightarrow K^- \pi^+ \pi^+) )</td>
<td>-</td>
<td>1.71%</td>
<td>1.71%</td>
</tr>
<tr>
<td>Multiplicative uncertainties</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tracking</td>
<td>-</td>
<td>1.40%</td>
<td>1.40%</td>
</tr>
<tr>
<td>MC statistics</td>
<td>-</td>
<td>0.04%</td>
<td>0.04%</td>
</tr>
<tr>
<td>( \Delta N_{BB} )</td>
<td>-</td>
<td>1.37%</td>
<td>1.37%</td>
</tr>
<tr>
<td>( f_{00} )</td>
<td>-</td>
<td>1.23%</td>
<td>1.23%</td>
</tr>
<tr>
<td>PID efficiency of ( K/\pi ) (stat.)</td>
<td>0.01%</td>
<td>0.00%</td>
<td>0.31%</td>
</tr>
<tr>
<td>PID efficiency of ( K/\pi ) (syst.)</td>
<td>0.01%</td>
<td>0.04%</td>
<td>0.64%</td>
</tr>
<tr>
<td>Total multiplicative</td>
<td>0.01%</td>
<td>2.31%</td>
<td>2.42%</td>
</tr>
<tr>
<td>Additive uncertainties</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PDF parameterisation</td>
<td>( 0.199 \times 10^{-2} )</td>
<td>( 0.040 \times 10^{-3} )</td>
<td>( 0.028 \times 10^{-4} )</td>
</tr>
<tr>
<td>( D^+ ) mass selection window</td>
<td>( 0.002 \times 10^{-2} )</td>
<td>( 0.058 \times 10^{-3} )</td>
<td>( 0.047 \times 10^{-4} )</td>
</tr>
<tr>
<td>( J/\psi ) veto selection</td>
<td>( 0.003 \times 10^{-2} )</td>
<td>( 0.001 \times 10^{-3} )</td>
<td>( 0.000 \times 10^{-4} )</td>
</tr>
<tr>
<td>Fit bias</td>
<td>-</td>
<td>( 0.030 \times 10^{-3} )</td>
<td>( 0.020 \times 10^{-4} )</td>
</tr>
<tr>
<td>Total additive</td>
<td>( 0.199 \times 10^{-2} )</td>
<td>( 0.077 \times 10^{-3} )</td>
<td>( 0.058 \times 10^{-4} )</td>
</tr>
</tbody>
</table>
More info. of isospin sum rule

- **Uncertainty projection**

  ![Graph](image)

  \[ I_{K\pi} = -0.11 \pm 0.13 \text{ Belle+BaBar+LHCb+Belle II Winter 2021} \]

  - Red curve is the projection when updates on the complete set of \( K\pi \) measurements
  - Grey dashed curve is the case if only \( A_{K^+\pi^-} \), \( A_{K^+\pi^0} \), and \( A_{K^0\pi^+} \) are updated
  - Belle II will play a crucial role in pinning down the \( I_{K\pi} \)

- **Systematic uncertainties of \( B^0 \to K^0\pi^0 \) measurement**

<table>
<thead>
<tr>
<th>Source</th>
<th>( \delta B(%) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking efficiency</td>
<td>1.8</td>
</tr>
<tr>
<td>( K_S^0 ) reconstruction efficiency</td>
<td>3.8</td>
</tr>
<tr>
<td>( \pi^0 ) reconstruction efficiency</td>
<td>13.0</td>
</tr>
<tr>
<td>Continuum-suppression efficiency</td>
<td>2.4</td>
</tr>
<tr>
<td>( N(B\bar{B}) ) (as written in Eq. 3)</td>
<td>1.4</td>
</tr>
<tr>
<td>Signal model</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Continuum background model</td>
<td>1.4</td>
</tr>
<tr>
<td>Total</td>
<td>14.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>( \delta A_{K^0\pi^0} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flavor tagging modelling</td>
<td>0.03</td>
</tr>
<tr>
<td>( B^0 ) mixing parameter ( \chi_d )</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>( B )-decay background asymmetry</td>
<td>0.03</td>
</tr>
<tr>
<td>Continuum background asymmetry</td>
<td>0.01</td>
</tr>
<tr>
<td>Total</td>
<td>0.04</td>
</tr>
</tbody>
</table>
BF and direct CP-violation in $B^+ \to K^+\pi^0$ and $\pi^+\pi^0$ decays @Belle II

- Isospin sum rule

$$I_{K\pi} = A_{K^+\pi^-} + A_{K^0\pi^+} \frac{B(K^0\pi^+)}{B(K^0\pi^-)} \tau_{B^+}^T - 2A_{K^+\pi^0} \frac{B(K^0\pi^0)}{B(K^0\pi^-)} \tau_{B^+}^T - 2A_{K^0\pi^0} \frac{B(K^0\pi^0)}{B(K^0\pi^-)} \tau_{B^+}^T$$

I. Stringent null test of standard model (SM)
II. Sensitive to the presence of non-SM physics

- $B(B^+ \to \pi^+\pi^0)$ is an ingredient for an isospin-based determination of $\phi_2$ based on $B \to \pi\pi$
- One track + one $\pi^0$ can probe $\pi^0$ reconstruction and PID separation
- 2D fit of $(\Delta E, M_{bc})$
- Results:

$$B(B^+ \to K^+\pi^0) = [11.9^{+1.1}_{-1.0}(\text{stat.}) \pm 1.6(\text{syst.})] \times 10^{-6}$$
$$B(B^+ \to \pi^+\pi^0) = [5.5^{+1.0}_{-0.9}(\text{stat.}) \pm 0.7(\text{syst.})] \times 10^{-6}$$

$$A(B^0 \to K^+\pi^0) = -0.09 \pm 0.09 \text{ (stat.)} \pm 0.03(\text{syst.})$$
$$A(B^0 \to \pi^+\pi^0) = -0.04 \pm 0.17 \text{ (stat.)} \pm 0.06(\text{syst.})$$
BF and direct CP-violation in $B^0 \rightarrow K^+ \pi^-$, $B^+ \rightarrow K_S^0 \pi^+, \pi^+\pi^-$ decays @Belle II

- Isospin sum rule

$$I_{K\pi} = \left[ A_{K^+\pi^-} + A_{K^0\pi^0} \right]/\left[ B(K^0\pi^0) \right] = -2A_{K^+\pi^0} B(K^0\pi^0) \tau_B^0 - 2A_{K^0\pi^+} B(K^0\pi^0) \tau_B^+$$

I. Stringent null test of standard model (SM)
II. Sensitive to the presence of non-SM physics

- Two tracks final states can probe PID separation
- One $K_S^0$ and one track final state can validate the reconstruction of $K_S^0$
- 2D fit of ($\Delta E, M_{bc}$)

- Results:

$$B(B^0 \rightarrow K^+\pi^-) = [18.0 \pm 0.9 \ (stat.) \pm 0.9 \ (syst.)] \times 10^{-6}$$
$$B(B^+ \rightarrow K^0\pi^+) = [21.4^{+2.3}_{-2.2} \ (stat.) \pm 1.6 \ (syst.)] \times 10^{-6}$$
$$B(B^0 \rightarrow \pi^+\pi^-) = [5.8 \pm 0.7 \ (stat.) \pm 0.3 \ (syst.)] \times 10^{-6}$$

$$A(B^0 \rightarrow K^+\pi^-) = -0.16 \pm 0.05 \ (stat.) \pm 0.01 \ (syst.)$$
$$A(B^0 \rightarrow K^0\pi^+) = -0.01 \pm 0.08 \ (stat.) \pm 0.05 \ (syst.)$$

First Belle II measurement of the $B^- \rightarrow K^0\pi^0$