PROSPECTS OF CHARM PHYSICS WITH Belle II

Giulia Casarosa on behalf of the Belle II Collaboration
Outline

- SuperKEKB and Belle II
- Today: Status of the Detector and the Accelerator
- Selection of Belle II Prospects on Charm
Belle and BABAR have produced a large number of important results, since the beginning of their data taking. Competition between the two experiments has helped in pulling out the best from the two datasets. First Results of combined analysis are coming out.

Belle II will provide a significantly larger data sample (x50 Belle) that will allow to continue the investigation with a much more powerful instrument.
Road to 50 ab\(^{-1}\)…

- **Goal of Belle II / SuperKEKB**
- **Today**
- **Start of physics run**
- **5 ab\(^{-1}\)**

![Graph showing the integrated luminosity and peak luminosity over time with key milestones indicated.](image)
...on the leading edge of Luminosity

Peak luminosity trends for $e^+e^-$ collider

+2 orders of magnitude!
High-Luminosity Asymmetric B Factory

- Target luminosity is $\mathcal{L} = 8 \times 10^{35}$ cm$^{-2}$s$^{-1}$ (x40 w.r.t. KEKB)
- Achievable in the *nano-beam scheme* (P. Raimondi for SuperB)
  - double beam currents
  - squeeze beams @ IP by 1/20

$$L = \frac{\gamma \pm (1 + \frac{\sigma^*_y}{\sigma^*_x}) I_\pm \xi \xi}{2e_r (1 + \frac{\sigma^*_y}{\sigma^*_x})} \frac{R_L}{R_x} \frac{R_L}{R_y}$$

<table>
<thead>
<tr>
<th>parameters</th>
<th>KEKB</th>
<th></th>
<th>SuperKEKB</th>
<th></th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LER</td>
<td>HER</td>
<td>LER</td>
<td>HER</td>
<td></td>
</tr>
<tr>
<td>beam energy</td>
<td>$E_b$</td>
<td></td>
<td></td>
<td></td>
<td>GeV</td>
</tr>
<tr>
<td>CM boost</td>
<td>$\beta \gamma$</td>
<td>0.425</td>
<td></td>
<td>0.28</td>
<td>mrad</td>
</tr>
<tr>
<td>half crossing angle</td>
<td>$\varphi$</td>
<td>11</td>
<td></td>
<td>41.5</td>
<td>mrad</td>
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<tr>
<td>horizontal emittance</td>
<td>$\varepsilon_x$</td>
<td>18</td>
<td>24</td>
<td>3.2</td>
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<td>emittance ratio</td>
<td>$\kappa$</td>
<td>0.88</td>
<td>0.66</td>
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<td>0.40</td>
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<tr>
<td>beta-function at IP</td>
<td>$\beta_x^<em>/\beta_y^</em>$</td>
<td>1200/5.9</td>
<td>32/0.27</td>
<td>25/0.30</td>
<td>mm</td>
</tr>
<tr>
<td>beam currents</td>
<td>$I_b$</td>
<td>1.64</td>
<td>1.19</td>
<td>3.6</td>
<td>2.6</td>
</tr>
<tr>
<td>beam-beam parameter</td>
<td>$\xi_y$</td>
<td>129</td>
<td>90</td>
<td>0.0881</td>
<td>0.0807</td>
</tr>
<tr>
<td>beam size at IP</td>
<td>$\sigma_x^<em>/\sigma_y^</em>$</td>
<td>100/2</td>
<td></td>
<td>10/0.059</td>
<td>μm</td>
</tr>
<tr>
<td>Luminosity</td>
<td>$\mathcal{L}$</td>
<td>2.1$ \times 10^{34}$</td>
<td></td>
<td>8$ \times 10^{35}$</td>
<td>cm$^{-2}$s$^{-1}$</td>
</tr>
</tbody>
</table>
High-Luminosity Asymmetric B Factory

- Target luminosity is $\mathcal{L} = 8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$ (x40 w.r.t. KEKB)
- Achievable in the *nano-beam scheme* (P. Raimondi for SuperB)
  - double beam currents
  - squeeze beams @IP

<table>
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<tr>
<th>parameters</th>
<th>LER</th>
<th>HER</th>
</tr>
</thead>
<tbody>
<tr>
<td>beam energy</td>
<td>3.5</td>
<td>8</td>
</tr>
<tr>
<td>CM boost</td>
<td>0.425</td>
<td>0.28</td>
</tr>
<tr>
<td>horizontal emittance</td>
<td>24</td>
<td>3.2</td>
</tr>
<tr>
<td>vertical emittance</td>
<td>0.66</td>
<td>0.37</td>
</tr>
<tr>
<td>beam aspect ratio at the IP</td>
<td>5.9</td>
<td>32/0.07</td>
</tr>
<tr>
<td>beam size at IP</td>
<td>1.19</td>
<td>3.6</td>
</tr>
<tr>
<td>beam-beam parameter</td>
<td>290</td>
<td>0.0881</td>
</tr>
<tr>
<td>Lorentz factor</td>
<td>8x10^{34}</td>
<td>10/0.059</td>
</tr>
</tbody>
</table>

- $x40$ luminosity
  - higher background rates (~10-20x)
    - detector occupancy, radiation damage, fake hits, pile-up noise in the calorimeter
  - higher event rate
    - higher trigger rate, DAQ, computing
  - $x40$ produced signal events

- Achievable in the *nano-beam scheme* (P. Raimondi for SuperB)
  - double beam currents
  - squeeze beams @IP

- $x40$ luminosity
  - reduced vertex separation, $\Delta t$ resolution
  - increased detector hermeticity

- $x40$ luminosity
  - $8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$

- $8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$
The Belle II Detector

- **EM calorimeter**
  - CsI(Tl), waveform sampling electronics (barrel)
  - Pure CsI + waveform sampling (end-caps) later

- **Vertex Detector**
  - PXD: 2 layers Si pixels (DEPFET)
  - SVD: 4 layers double sided Si strips (DSSD)

- **Central Drift Chamber**
  - He(50%):C₂H₆(50%)
  - smaller cell size, longer lever arm, fast electronics

- **K_L & μ Detector**
  - Resistive Plate Counter (barrel outer layers)
  - Scintillator + WLSF + MPPC (end-caps, inner 2 barrel layers)

- **Particle Identification**
  - Time-of-Propagation counter (barrel)
  - Proximity focusing Aerogel Cherenkov Ring Imaging detector (forward)

- **Electrons (7 GeV)**
- **Positrons (4 GeV)**

- **Dimensions**
  - 7.4 m
  - 5.0 m

- **Trigger Rates**
  - L1 trigger rate = 30kHz
  - HLT trigger rate = 10kHz
**Belle II Performance Improvements**

- **B-Factory advantages over hadron collider detectors:**
  - clean event environment
  - high trigger efficiency
  - high-efficiency detection of neutrals ($\gamma$, $\pi^0$, $\eta$, $\eta'$, …)
  - many control samples to study systematics
  - good kinematic resolution (Dalitz plots analysis)
  - missing energy and missing mass analysis are straightforward (for B physics)

**IMPROVEMENTS wrt Belle**

- primary and secondary vertex resolution
- $K_S$ and $\pi^0$ reconstruction
- $K/\pi$ separation
- PID and $\mu$ ID in the end caps
Today: Current Status of Detector and Accelerator
# SuperKEKB and **Belle II** Schedule

<table>
<thead>
<tr>
<th>Calendar year</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan FY</td>
<td>JFY2016</td>
<td>JFY2017</td>
<td>JFY2018</td>
<td>JFY2019</td>
<td>JFY2019</td>
</tr>
<tr>
<td></td>
<td>Summer shutdown (power saving)</td>
<td>Summer shutdown (power saving)</td>
<td>Power saving after mid July 2018</td>
<td>Summer shutdown (power saving)</td>
<td></td>
</tr>
</tbody>
</table>

**Phase2 Goals:**
- ✓ understand machine background and detector performances
- ✓ global cosmic ray runs
- ✓ peak luminosity of $2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

> **Phase2 detector:** *Belle II* with no VXD but the Beast2 detector = one VXD ladder per layer installed on the horizontal plane + dedicated beam-background detectors

> **First collisions recorded on April 25th 2018!!**
SuperKEKB Final Focus

Superconducting final focus QCSL being prepared for final integration, January 2018

Final Focus installation, February 2017
The –almost– BelleII Detector

- **Belle II** without the vertex detector: CDC, TOP, ARICH, ECL, KLM, plus
- Beast2: one VXD ladder per layer, plus beam-background dedicated detectors

QCSR & backward side of Belle II, Feb 9, 2018

*Belle II* rolled-in on beam line on Apr 11, 2017
...and the missing part, the VXD!
Bhabha candidate event
exp3 run126 ev73
Apr. 26, 2018

Phase 2 Vertex Detector

TOP bar

CDC hits

ECL hit

Belle II

Super KEKB
Luminosity Run, 26th April 2018  First Hadronic Event

Experiment 3  Run 125  Event 223

note: vertex detector not shown
...first bumps observed!

- Evidence of $K_s$ and $\pi^0$ in the collected data sample of 5/pb
- First preliminary plots, calibrations at a very early stage, no PID cuts applied
We got Charm :) 

- Evidence of $D^*$ and $D^0$ in the collected data sample of 5/pb 
- First preliminary plots, calibrations at a very early stage, no PID cuts applied 

$1.845 < M(K\pi) < 1.885$ (GeV/c$^2$)  

$0.144 < \Delta M < 0.146$ (GeV/c$^2$)
The following projections are extrapolated from Belle measurements

$$\sigma_{Belle II} = \sqrt{(\sigma_{stat}^2 + \sigma_{sys}^2) \cdot \frac{L_{Belle}}{50 \text{ ab}^{-1}}} + \sigma_{ired}^2$$

- we assumed that most of the systematics scale with statistics
- There maybe (other) sources of systematic errors that do not scale with statistics, that show up only in very high statistics samples
  - Belle II will have high statistics control samples to keep them under control
- The detector improvements w.r.t. Belle will be helpful, but their effect is not included in these extrapolations unless otherwise stated
Prospects for CP Asymmetries

\[ \sigma_{\text{Belle II}} = \sqrt{\left(\sigma_{\text{stat}}^2 + \sigma_{\text{sys}}^2\right) \frac{L_{\text{Belle}}}{50 \text{ ab}^{-1}}} + \sigma_{\text{ired}}^2 \]

<table>
<thead>
<tr>
<th>mode</th>
<th>( \mathcal{L} ) (fb(^{-1}))</th>
<th>( A_{CP} ) (%)</th>
<th>Belle II at 50 ab(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D^0 \to K^+K^- )</td>
<td>976</td>
<td>(-0.32 \pm 0.21 \pm 0.09)</td>
<td>( \pm 0.03)</td>
</tr>
<tr>
<td>( D^0 \to \pi^+\pi^- )</td>
<td>976</td>
<td>(+0.55 \pm 0.36 \pm 0.09)</td>
<td>( \pm 0.05)</td>
</tr>
<tr>
<td>( D^0 \to \pi^0\pi^0 )</td>
<td>966</td>
<td>(-0.03 \pm 0.64 \pm 0.10)</td>
<td>( \pm 0.09)</td>
</tr>
<tr>
<td>( D^0 \to K_S^0\pi^0 )</td>
<td>966</td>
<td>(-0.21 \pm 0.16 \pm 0.07)</td>
<td>( \pm 0.03)</td>
</tr>
<tr>
<td>( D^0 \to K_S^0\eta )</td>
<td>791</td>
<td>(+0.54 \pm 0.51 \pm 0.16)</td>
<td>( \pm 0.07)</td>
</tr>
<tr>
<td>( D^0 \to K_S^0\eta' )</td>
<td>791</td>
<td>(+0.98 \pm 0.67 \pm 0.14)</td>
<td>( \pm 0.09)</td>
</tr>
<tr>
<td>( D^+ \to \phi\pi^+ )</td>
<td>955</td>
<td>(+0.51 \pm 0.28 \pm 0.05)</td>
<td>( \pm 0.04)</td>
</tr>
<tr>
<td>( D^+ \to \eta\pi^+ )</td>
<td>791</td>
<td>(+1.74 \pm 1.13 \pm 0.19)</td>
<td>( \pm 0.14)</td>
</tr>
<tr>
<td>( D^+ \to \eta'\pi^+ )</td>
<td>791</td>
<td>(-0.12 \pm 1.12 \pm 0.17)</td>
<td>( \pm 0.14)</td>
</tr>
<tr>
<td>( D^+ \to K_S^0\pi^+ )</td>
<td>977</td>
<td>(-0.36 \pm 0.09 \pm 0.07)</td>
<td>( \pm 0.03)</td>
</tr>
<tr>
<td>( D^+ \to K_S^0K^+ )</td>
<td>977</td>
<td>(-0.25 \pm 0.28 \pm 0.14)</td>
<td>( \pm 0.05)</td>
</tr>
<tr>
<td>( D_s^+ \to K_S^0\pi^+ )</td>
<td>673</td>
<td>(+5.45 \pm 2.50 \pm 0.33)</td>
<td>( \pm 0.29)</td>
</tr>
<tr>
<td>( D_s^+ \to K_S^0K^+ )</td>
<td>673</td>
<td>(+0.12 \pm 0.36 \pm 0.22)</td>
<td>( \pm 0.05)</td>
</tr>
</tbody>
</table>

- \( A_{CP} \) precision will reach \( o(10^{-4}) \), also in channels with neutrals in the final state
- \textit{Belle II} is favoured on measurements with neutrals in the final state
- Other interesting channels not included in this table: \( D^+ \to \pi^+\pi^0 \), \( D^0 \to K_SK_S \), 3-body final states (DP analysis), radiative decays (in the next slide)
Radiative Decays $D^0 \rightarrow V \gamma$

1. **CP Violation**: SM expectations on the order of $10^{-3}$, NP contributions can enhance it up to an order of magnitude

2. **Tests of QCD**: transitions dominated by long-range diagrams

   - $A_{CP}$ and BR measurements of decays $D^0 \rightarrow V \gamma$ completed at Belle
   - Dominant error for $A_{CP}$ is statistical, Belle II can significantly improve the precision

   - Studies on Belle II official MC have shown that $m(D^0)$ and $\cos(\theta_{hel})$ distributions have resolutions similar to Belle, allowing an extrapolation based on luminosity

<table>
<thead>
<tr>
<th>$A_{CP}$ estimated error on</th>
<th>$Belle$</th>
<th>$Belle II$ statistical error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0 \rightarrow \rho^0 \gamma$</td>
<td>± 0.152 ± 0.006</td>
<td>± 0.07 ± 0.04 ± 0.02</td>
</tr>
<tr>
<td>$D^0 \rightarrow \Phi \gamma$</td>
<td>± 0.066 ± 0.001</td>
<td>± 0.03 ± 0.02 ± 0.01</td>
</tr>
<tr>
<td>$D^0 \rightarrow \bar{K}^0 \gamma$</td>
<td>± 0.020 ± 0.000</td>
<td>± 0.01 ± 0.005 ± 0.003</td>
</tr>
</tbody>
</table>
## Mixing & Indirect CPV Prospects

### Belle II Measurements Extrapolated to 50 ab\(^{-1}\)

<table>
<thead>
<tr>
<th>Channel</th>
<th>Observable</th>
<th>Belle (~1\text{ ab(^{-1})})</th>
<th>Belle II (~50\text{ ab(^{-1})})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(D^0 \to K^+\pi^-)</td>
<td>(x'^2) (%)</td>
<td>± 0.022</td>
<td>± 0.003</td>
</tr>
<tr>
<td></td>
<td>(y') (%)</td>
<td>± 0.34</td>
<td>± 0.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>± 0.6</td>
<td>± 0.06</td>
</tr>
<tr>
<td></td>
<td>(\phi)</td>
<td>± 25°</td>
<td>± 2.3°</td>
</tr>
<tr>
<td>(D^0 \to \pi^+\pi^-)</td>
<td>(\gamma_{\text{CP}}) (%)</td>
<td>± 0.22</td>
<td>± 0.04</td>
</tr>
<tr>
<td>(D^0 \to K^+K^-)</td>
<td>(A_{\Gamma}) (%)</td>
<td>± 0.20</td>
<td>± 0.03</td>
</tr>
<tr>
<td>(D^0 \to K_S\pi^+\pi^-)</td>
<td>(x) (%)</td>
<td>± 0.19</td>
<td>± 0.08</td>
</tr>
<tr>
<td></td>
<td>(x) (%)</td>
<td>± 0.15</td>
<td>± 0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>± 0.16</td>
<td>± 0.06</td>
</tr>
<tr>
<td></td>
<td>(\phi)</td>
<td>± 11°</td>
<td>± 4°</td>
</tr>
</tbody>
</table>

### Systematics

- **t-dependent Dalitz**: model related systematics (resonance parameters - masses, widths, form factors, angular dependence etc.)
- **CP asymmetry of modes with \(K_0^0\)**: asymmetry of \(K_0^0/\bar{K}_0^0\) interactions in material (PRD 84, 111501 (2011)), irreducible 

\[ \sigma_{\text{Belle II}} = \sqrt{\left(\sigma_{\text{stat}}^2 + \sigma_{\text{sys}}^2\right) \frac{L_{\text{Belle}}}{50 \text{ ab}^{-1}} + \sigma_{\text{ired}}^2} \]

### Prospects

- **Model-independent approach** to reduce the systematics can be improved using a model-independent approach to reduce the systematics!
- Systematics primarily scales with integrated luminosity, with two exceptions: 
  - t-dependent Dalitz: model related systematics (resonance parameters - masses, widths, form factors, angular dependence etc.)
  - \(A_{\Gamma}\) of modes with \(K_0^0\): asymmetry of \(K_0^0/\bar{K}_0^0\) interactions in material (PRD 84, 111501 (2011)), irreducible

- Extrapolation:
  \[ \frac{\sigma_{\text{Belle II}}}{\text{Belle}} = \left(\frac{L_{\text{Belle II}}}{50 \text{ ab}^{-1}}\right) \left(\frac{\sigma_{\text{stat}}^2 + \sigma_{\text{sys}}^2}{\sigma_{\text{ired}}^2}\right) \]

- **Belle II perspectives on charm measurements at KEK FF 2014**

- **Belle measurements extrapolated to 50 ab\(^{-1}\)**

- **Systematics** limited by systematics related to DP Model

- **Belle II measurements extrapolated to 50 ab\(^{-1}\)**

- **Model-independent approach** to reduce the systematics can be improved using a model-independent approach to reduce the systematics!
- $D^0$ mass-constrained vertex fit yields a resolution of the vertex position of $\sim 40 \mu m$ in transverse plane and also in the longitudinal direction.

- $D^{*+} \to D^0 \pi^+$ beam-spot constrained fit yields an unprecedented precision of the determination of the $D^0$ decay vertex.
The factor 2 improvement on the track impact parameters directly reflects on charm reconstruction.

Is there a way to determine the flavour of the prompt $D^0$, i.e. not coming from a charged $D^*$ decay?

… work in progress …
Impact on WS $D^0 \rightarrow K^+\pi^-$

The WS $D^0 \rightarrow K^+\pi^-$ mixing and CPV analysis is almost systematic-free, perfect candidate to evaluate the impact of an improved resolution of the proper time.

- **ToyMC studies: w/o CPV allowed**
  - fit decay time distribution for mixing and CPV parameters $R_D$, $x'$, $y'$, $|q/p|$, $\phi$ (sensitive to the sign of $x'$!)
  - use different PDFs for $D^0$ and $\bar{D}^0$ (both convolved with a Gaussian resolution function)

\[
D^0(t) = e^{-\frac{t}{\tau}} \left\{ R_D + \frac{q}{p} \sqrt{R_D(y' \cos \phi - x' \sin \phi)}(\tau t) + \frac{q^2}{p^2} \frac{2(x'^2 + y'^2)}{4}(\tau t)^2 \right\}
\]

\[
\bar{D}^0(t) = e^{-\frac{t}{\tau}} \left\{ R_D + \frac{p}{q} \sqrt{R_D(y' \cos \phi + x' \sin \phi)}(\tau t) + \frac{p^2}{q^2} \frac{2(x'^2 + y'^2)}{4}(\tau t)^2 \right\}
\]

<table>
<thead>
<tr>
<th>estimated error on</th>
<th>current</th>
<th>Belle + BABAR scaled</th>
<th>Toy MC with improved $\sigma_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HFAG</td>
<td>1.5/ab</td>
<td>50/ab, no CPV</td>
</tr>
<tr>
<td>$x'$ (%)</td>
<td>–</td>
<td>(*) 0.98</td>
<td>(*) 0.45</td>
</tr>
<tr>
<td>$x'^2$ (%)</td>
<td>–</td>
<td>0.0195</td>
<td>0.009</td>
</tr>
<tr>
<td>$y'$ (%)</td>
<td>–</td>
<td>0.321</td>
<td>0.16</td>
</tr>
<tr>
<td>$</td>
<td>q/p</td>
<td>$</td>
<td>0.1</td>
</tr>
<tr>
<td>$\Phi$ (deg)</td>
<td>10</td>
<td>–</td>
<td>5.7</td>
</tr>
</tbody>
</table>

**Improved sensitivity, beyond increase of luminosity!**
Full Charm Event Reconstruction

- use the **recoil method** successfully exploited for $D_s$ decays:

\[ e^+ e^- \rightarrow c\bar{c} \rightarrow D_{tag} X_{frag} D_{sig} \]

light mesons ($K, \pi, \ldots$)

reconstructed in several channels
($D^0, D^*, D_s, \ldots$)

- use energy and momentum conservation to search for the desired final state:

  - **example**:

    \[ D_{sig} = D^{*+} \rightarrow D^+ \pi_{slow}; \quad D^+ \rightarrow \mu^+ \nu \]

  - “miss” quantities computed for the system:

    \[ D_{tag} + X_{frag} + \pi_{slow} + \mu^+ \]

\[ M_{miss}^2(\nu) = (E_{miss} - |\mathbf{p}|_{miss})(E_{miss} + |\mathbf{p}|_{miss}) \]
Leptonic Decays: $D_{(s)}^- \rightarrow \mu^- \nu$

- $D_s^+ \rightarrow \mu^+ \nu$ Belle Analysis:
  
  \[
e^+e^- \rightarrow D_{\text{tag}}X_{\text{frag}}^{}K\bar{D}_s^{*+}
  \\
  D_s^{*+} \rightarrow D_s^+ \gamma
  \]

  - require one charged track passing muon-ID pointing the IP
  - fit the missing mass distribution.

- Same analysis method for the $D^+$ channel
  - Belle simulation with 5.5 ab$^{-1}$, scaled to 50 ab$^{-1}$, yields:

<table>
<thead>
<tr>
<th>yields</th>
<th>$D_s^+ \rightarrow \mu^+ \nu$</th>
<th>$D^+ \rightarrow \mu^+ \nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>inclusive</td>
<td>exclusive</td>
</tr>
<tr>
<td>Belle, 913 fb$^{-1}$</td>
<td>94400</td>
<td>490</td>
</tr>
<tr>
<td>BelleII, 50 ab$^{-1}$</td>
<td>5.2 x 10$^6$</td>
<td>27 x 10$^3$</td>
</tr>
</tbody>
</table>

$\delta(|V_{cs}|) = 0.004$, $\delta(|f_{Ds}|) = 0.9$

statistical error \~1/3 of the theory error

$\delta(\bar{f}_d|V_{cd}|) = 1.3$

competitive with CLEOc and BESIII
D^0 Decays to Invisible: D^0 \rightarrow \nu \nu

→ D^0 \rightarrow \nu \nu Belle Analysis:

\[ e^+ e^- \rightarrow D_{\text{tag}} X_{\text{frag}} D^{*+} \]
\[ D^{*+} \rightarrow D^0 \pi^+_s \]

• require no extra-charged tracks of photons, \pi^0, …
• fit the missing mass and ECL energy distributions.

<table>
<thead>
<tr>
<th>yields</th>
<th>inclusive D^0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belle, 924 fb(^{-1})</td>
<td>695000</td>
</tr>
<tr>
<td>Bellell, 50 ab(^{-1})</td>
<td>38 \times 10^6</td>
</tr>
</tbody>
</table>

nearly 40M inclusive D^0 decays to search for forbidden/rare decays
Inclusive $\Lambda_c^+$ Sample

Extension of the Full Charm Event Reconstruction with:

\[ e^+e^- \rightarrow D_{\text{tag}} X_{\text{frag}} p (\Lambda_c^+) \]

- in this case $M_{\text{miss}} = \Lambda_c^+$ mass

$\Rightarrow$ Belle II simulation scaled to 50 ab$^{-1}$ yields $2.8 \times 10^6$ inclusive $\Lambda_c^+$

$\Rightarrow$ Unique sample that allows to:
  - measure absolute branching fractions
  - measure semileptonic decays
  - search for rare decays with missing energy
**Rare/Forbidden D^0 Decays**

- **Belle II** can improve on many of these channels up to one order of magnitude at 50 ab^{-1}, having largest impact on the modes with \( \pi^0 \)s (and electrons) in the final state.
Rare/Forbidden $D_{(s)}^+$ Decays

$\Rightarrow$ Belle II can improve on many of these channels up to one order of magnitude at 50 $\text{ab}^{-1}$
Conclusions

☑️ SuperKEKB is completing commissioning phase, first collisions achieved one month ago!

☑️ Phase2 data taking started:
  - understand the machine and the backgrounds, detector and software checkout, possible initial physics studies
  - all efforts to ensure rapid luminosity ramp up and a 9 months per year running period

☑️ Physics Run will start in less than a year, at the beginning of 2019

☑️ A rich charm physics program ahead, ready to improve precision on:
  - direct CP asymmetries, mixing and CPV parameters
  - $V_{cd}$ and $V_{cs}$ from semileptonic decays, decay constants $f_D$, $f_{Ds}$
  - measurements of charm baryons
  - limits on rare and forbidden decays
Belle II VS Belle

in colours the new components

SVD: 4 DSSD lyr → 2 DEPFET lyr + 4 DSSD lyr
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling (+pure CsI for endcaps)
KLM: RPC → Scintillator +MPPC (endcaps, barrel inner 2 lyr)
No coherent production of the $D^0 - \bar{D}^0$ state:
- no access to strong phases
- $D^0$ flavour tagging with $D^{*+}$ decays (lower efficiency, higher purity w.r.t. untagged $D^0$)
  + tagged prompt $D^0 + \bar{D}^0$ from $B$ decays
- Time-dependent analysis are possible assuming that $D$ are produced at the interaction point
  \[ t = \ell / (\beta \gamma c) \]
  + benefits from the improved tracking
- $D$ full reconstruction for neutrinos and inclusive analyses (precise test of LQCD and NP searches in (semi)leptonic decays)

Belle II expected performance
- The Belle II expected performances allow to develop reconstruction algorithms and experimental techniques that were not feasible at the B-Factories

D full reconstruction for neutrinos and inclusive analyses (precise test of LQCD and NP searches in (semi)leptonic decays)

```
e^+ e^- \rightarrow c\bar{c} \rightarrow \bar{D}_{tag} X_{frag} D^{(*)}_{recoil}
```

BELLE
Prompt $D^0$ Flavour Tagging

- Only 1/4 of the $D^0$ produced in the $e^+e^- \rightarrow c\bar{c}$ events are flavour tagged with $D^{*+}\rightarrow D^0\pi^+$ and used for CP violation measurements.

- Implement a reconstruction technique that allows to tag the flavour the rest 75% of produced $D^0$ looking at the rest of the event.
  - select events with one single $D^0$ and one single charged K in the rest of the event.
  - flavour mis-tagging due to $c\bar{c}ss$ events that introduce un-correlated charged kaons into the rest of the event.
  - irreducible bkg due to DCS decays.
  - First studies on generated events (no reconstruction) are encouraging: 20% reconstruction efficiency.
### Heavy Flavour Averaging Group Summary Tables

<table>
<thead>
<tr>
<th>Parameter</th>
<th>No CPV</th>
<th>No direct CPV in DCS decays</th>
<th>CPV-allowed</th>
<th>CPV-allowed 95% CL Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x$ (%)</td>
<td>0.46 $^{+0.14}_{-0.15}$</td>
<td>0.41 $^{+0.14}_{-0.15}$</td>
<td>0.32 ± 0.14</td>
<td>[0.04, 0.62]</td>
</tr>
<tr>
<td>$y$ (%)</td>
<td>0.62 ± 0.08</td>
<td>0.61 ± 0.07</td>
<td>0.69 $^{+0.06}_{-0.07}$</td>
<td>[0.50, 0.80]</td>
</tr>
<tr>
<td>$\delta_{K\pi}$ (°)</td>
<td>8.0 $^{+9.7}_{-11.2}$</td>
<td>4.8 $^{+10.4}_{-12.3}$</td>
<td>15.2 $^{+7.6}_{-10.0}$</td>
<td>[−16.8, 30.1]</td>
</tr>
<tr>
<td>$R_D$ (%)</td>
<td>0.348 $^{+0.004}_{-0.003}$</td>
<td>0.347 $^{+0.004}_{-0.003}$</td>
<td>0.349 $^{+0.004}_{-0.003}$</td>
<td>[0.342, 0.356]</td>
</tr>
<tr>
<td>$A_D$ (%)</td>
<td>−</td>
<td>−</td>
<td>−0.88 ± 0.99</td>
<td>[−2.8, 1.0]</td>
</tr>
<tr>
<td>$</td>
<td>q/p</td>
<td>$</td>
<td>−</td>
<td>0.999 ± 0.014</td>
</tr>
<tr>
<td>$\phi$ (°)</td>
<td>−</td>
<td>0.05 $^{+0.54}_{-0.53}$</td>
<td>−12.9 $^{+9.9}_{-8.7}$</td>
<td>[−30.2, 10.6]</td>
</tr>
<tr>
<td>$\delta_{K\pi\pi}$ (°)</td>
<td>20.4 $^{+23.3}_{-23.8}$</td>
<td>22.6 $^{+24.1}_{-24.4}$</td>
<td>31.7 $^{+23.5}_{-24.2}$</td>
<td>[−16.4, 77.7]</td>
</tr>
<tr>
<td>$A_{\pi}$ (%)</td>
<td>−</td>
<td>0.02 ± 0.13</td>
<td>0.01 ± 0.14</td>
<td>[−0.25, 0.28]</td>
</tr>
<tr>
<td>$A_K$ (%)</td>
<td>−</td>
<td>−0.11 ± 0.13</td>
<td>−0.11 ± 0.13</td>
<td>[−0.37, 0.14]</td>
</tr>
<tr>
<td>$x_{12}$ (%)</td>
<td>−</td>
<td>0.41 $^{+0.14}_{-0.15}$</td>
<td>[0.10, 0.67]</td>
<td></td>
</tr>
<tr>
<td>$y_{12}$ (%)</td>
<td>−</td>
<td>0.61 ± 0.07</td>
<td>[0.47, 0.75]</td>
<td></td>
</tr>
<tr>
<td>$\phi_{12}$ (°)</td>
<td>−</td>
<td>−0.17 ± 1.8</td>
<td>[−5.3, 4.4]</td>
<td></td>
</tr>
</tbody>
</table>