Semi-tauonic B-meson decays at Belle and Belle II
\[ R = \frac{b \rightarrow q \tau \bar{\nu}_\tau}{b \rightarrow q \ell \bar{\nu}_\ell} \]

\[ R(D^{(*)}, \pi, J/\psi) \]

1. How do we measure these ratios at Belle?

2. Potential at Belle II
Overview

\[ R = \frac{b \rightarrow q \tau \bar{\nu}_\tau}{b \rightarrow q \ell \bar{\nu}_\ell} \]

\( \ell = e, \mu \)

1. Leptonic or Hadronic \( \tau \) decays?

Some properties (e.g. \( \tau \) polarisation) only accessible in hadronic decays.

2. Albeit not necessarily a rare decay of \( \mathcal{O}(\%) \) in BF, TRICKY to separate from normalisation and backgrounds

LHCb: Isolation criteria, displacement of \( \tau \), kinematics

B-Factories: Full reconstruction of event (Tagging), matching topology, kinematics
Semileptonic decays at B Factories

- $e^+/e^-$ collision produces $Y(4S) \rightarrow B\bar{B}$

- Fully reconstruct one of the two $B$-mesons (‘tag’) → possible to measure momentum of signal $B$

- Missing four-momentum (neutrinos) can be reconstructed with high precision

$$p_{\text{miss}} = (p_{\text{beam}} - p_{B\text{tag}} - p_{D(*)} - p_{\ell})$$

✓ Small efficiency (~0.2-0.4%) compensated by large integrated luminosity
Hadronic Tagging

Tagging approach in a nut-shell:

- $e^+ / e^-$ collision produces $Y(4S) \rightarrow B\bar{B}$
- Fully reconstruct one of the two $B$-mesons ('tag') $\rightarrow$ possible to measure momentum of signal $B$
- **Missing four-momentum (neutrinos)** can be reconstructed with high precision

$$p_{\text{miss}} = (p_{\text{beam}} - p_{B\text{tag}} - p_{D^*(\nu)} - p_{\ell})$$

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- Missing four-momentum (neutrinos) can be reconstructed with high precision

$\vec{p}_{\text{miss}} = (\vec{p}_{\text{beam}} - \vec{p}_{\text{B tag}} - \vec{p}_{D^*} - \vec{p}_\ell)$

✓ Small efficiency (~0.2-0.4%) compensated by large integrated luminosity

✓ Demand matching topology

Nice Illustration from C. Bozzi
Semi-leptonic Tagging

Tagging approach in a nut-shell:

- $e^+/e^-$ collision produces $Y(4S) \rightarrow BB$
- Fully reconstruct one of the two $B$-mesons (‘tag’) → **possible to assign all particles** to either signal or tagging $B$
- Matching topology & Extra-energy from unassigned neutrals powerful discriminator: $E_{\text{extra}}$ or $E_{\text{ECL}}$

$$E_{\text{extra}} = E_{\text{ECL}} = \sum_i E_i^\gamma$$

✓ Higher efficiency (~0.5-2%) but additional impurities and challenges
Semi-leptonic Tagging

Tagging approach in a nut-shell:

- $e^+/e^-$ collision produces $Y(4S) \rightarrow BB$

- Fully reconstruct one of the two $B$-mesons (‘tag’) \rightarrow possible to assign all particles to either signal or tagging $B$

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Inclusive Tagging

Tagging approach in a nut-shell:

- e^+/e^- collision produces $Y(4S) \rightarrow BB$
- Fully reconstruct one of the two B-mesons (‘tag’)
  - First reconstruct signal side; then construct tag from all remaining charged particles and calorimeter depositions
- Veto events with leptons on tag side to maximize hadronic modes

✓ Highest efficiency but also lowest purity
Meet the “Measurement Matrix”

<table>
<thead>
<tr>
<th>Hadronic or inclusive tagging</th>
<th>SL tagging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leptonic (\tau)</td>
<td>✓</td>
</tr>
<tr>
<td>Hadronic (\tau)</td>
<td>✓</td>
</tr>
</tbody>
</table>

\[ q^2 = (p_B - p_{D^*})^2 \]

\[ P_{D^*}, P_{\ell} \]

Belle:
- Phys. Rev. D 97, 012004 (2018) (\(D^*\) had tag)

Belle:

LHCb:
- Phys. Rev. Lett. 120, 171802 (2018) (\(D^*,\) Hadronic \(\tau\))

BaBar:
- Phys. Rev. D 88, 072012 (2013) (\(D/D^*\) had tag, \(q^2\))

New!
- & older work, e.g.
$R(D^*)$ vs $R(D)$

Contours hold 68% CL

- **LHCb**
- **BaBar**
- **Belle**
- **World Average**
- **SM (BLPR)**

- 4 B-Factory measurements
- 2 LHCb measurements

+ 1 B-Factory measurement of $R(\pi)$

1 LHCb measurement of $R(J/\psi)$
Use of $\tau \rightarrow e\nu\nu$ and $\tau \rightarrow \mu\nu\nu$ to reconstruct $\tau$-lepton

Simultaneous analysis of $R(D)$ vs. $R(D^*)$ using $B^0 \rightarrow D^*\tau\nu$, $B^- \rightarrow D^{*0}\tau\nu$, $B^0 \rightarrow D^-\tau\nu$, $B^- \rightarrow D^0\tau\nu$
$R(D)$ and $R(D^*)$ with had. tagging

- Next step after tag & signal reconstruction: **suppress backgrounds**
- Very powerful variables: $|p_l^*|$, $m_{\text{miss}}^2$

$$ (p_{\text{beam}} - p_{B \text{tag}} - p_{D(*)} - p_\ell)^2 = m_{\text{miss}}^2 $$
$R(D)$ and $R(D^*)$ with had. tagging

- Next step after tag & signal reconstruction: suppress backgrounds
- Very powerful variables: $|p_l^*|$, $m_{\text{miss}}^2$

(D/D* had tag, $q^2$)
$R(D)$ and $R(D^*)$ with had. tagging

- Next step after tag & signal reconstruction: suppress backgrounds
- Very powerful variables: $|p_l^*|$, $m_{\text{miss}}^2$

\[\text{Normalisation} \quad \text{Signal} \quad \text{Other Background} \quad m_{\text{miss}}^2 \quad |p_l^*| \quad m_{\nu^2}^2 \quad m_{\text{miss}}^2 \quad m_{\nu^2}^2\]
**R(D) and R(D*) with had. tagging**

- Next step after tag & signal reconstruction: **suppress backgrounds**

- Very powerful variables: \(|p_{l^*}|, m_{\text{miss}}^2, E_{\text{ECL}}\)

\[ E_{\text{ECL}} = \text{unassigned neutral energy in the calorimeter} \]

---

**Signal / Normalisation**

**Backgrounds**

![Graph](image.png)

**Figure 4.** Projections of the fit results and data points with statistical uncertainties in a signal-enhanced region of \(M_{2\text{miss}}^2 > 2\) GeV in the \(E_{\text{ECL}}\) dimension. Top left: \(D^+\ell\); top right: \(D^*\ell\); bottom left: \(D^0\ell\); bottom right: \(D^{\ast 0}\ell\).

Values in this alternate model are

\[ R(D) = 0.329 \pm 0.060(\text{stat}) \pm 0.022(\text{syst}) \]

\[ R(D^*) = 0.301 \pm 0.039(\text{stat}) \pm 0.015(\text{syst}) \]

The effect on the measured \(R(D^*)\) value is very small but the measured value for \(R(D)\) is significantly lower.

For the prediction in the 2HDM of type II, we use formula (20) in Ref. [11]; the expected values are

\[ R(D)_{\text{2HDM}} = 0.590 \pm 0.125 \]

\[ R(D^*)_{\text{2HDM}} = 0.241 \pm 0.007 \]

Figure 7 shows the predictions of \(R(D)\) and \(R(D^*)\) as a function of \(\tan\beta/m_H^+\) for the type II 2HDM, together with our results for the two studied values of 0 (SM) and 0.5 GeV. In contrast to BaBar's measurements, our results are compatible with the type II 2HDM in the \(\tan\beta/m_H^+\) regions around 0.45 GeV and zero.

The observable most sensitive to NP extensions of the SM with a scalar charged Higgs is \(q^2\). We estimate the signal \(q^2\) distributions by subtracting the background, using the distributions from simulated data and the yields from the fit procedure, and correcting the distributions using efficiency estimations from simulated data. The \(D^+\ell\) and \(D^{0}\ell\) samples and the \(D^{\ast +}\ell\) and \(D^{\ast 0}\ell\) samples...
\( R(D) \) and \( R(D^*) \) with had. tagging

- Next step after tag & signal reconstruction: suppress backgrounds

- Very powerful variables: \( |p_t^*|, m_{\text{miss}}^2, + q^2 \) + 3 other variables

\( E_{\text{ECL}} = \) unassigned neutral energy in the calorimeter

Multivariate Classifier

Normalisation

\( D^* + \ell \)

Events with \( m_{\text{miss}}^2 < 0.85 \text{ GeV} \)

Events with \( m_{\text{miss}}^2 > 0.85 \text{ GeV} \)

simultaneous unbinned ML fit of all Channels

\( D^+ \ell \)
\( D^0 \ell \)
\( D^* + \ell \)
\( D^*0 \ell \)

(D/D* had tag, \( q^2 \))
$R(D)$ and $R(D^*)$ with had. tagging

\[ R(D) = 0.375 \pm 0.064 \text{ (stat) } \pm 0.026 \text{ (syst)} \]
\[ R(D^*) = 0.293 \pm 0.038 \text{ (stat) } \pm 0.015 \text{ (syst)} \]

✓ Combination is 1.8σ from SM
$R(D^*)$ with SL tagging

- Use of $\tau \rightarrow e\nu\nu$ and $\tau \rightarrow \mu\nu\nu$ to reconstruct $\tau$-lepton and set of $D^*$ modes

![Diagram of $R(D^*)$ with SL tagging](image)
Another powerful variables: \( \cos \theta_{B-D^*} \)

\[
\cos \theta_{B-D^*\ell} \equiv \frac{2 E_{\text{beam}} E_{D^*\ell} - m_B^2 c^4 - M_{D^*\ell}^2 c^4}{2 |\vec{p}_B| \cdot |\vec{p}_{D^*\ell}| c^2}.
\]

visible particles  
beam or Y(4S) properties

\( B \to D(\ast)\ell\nu \)

\( \cos \theta_{B-D^*} \)

\begin{align*}
\cos \theta_{B-D^*\ell} & \equiv \frac{2 E_{\text{beam}} E_{D^*\ell} - m_B^2 c^4 - M_{D^*\ell}^2 c^4}{2 |\vec{p}_B| \cdot |\vec{p}_{D^*\ell}| c^2}.
\end{align*}
Another powerful variables: \( \cos \theta_{B-D^*} \)

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\]

visible particles
beam or Y(4S) properties

\( B \rightarrow D^{(*)}\ell \nu \)

**Signal**

\( \cos \theta_{B-D^*} \)

\[-1 \rightarrow 1\]
Another powerful variables:

\[ \cos \theta_{B-D^*l}, m_{\text{miss}}^2 + \text{total visible Energy} \]

\[ \cos \theta_{B-D^*l} \equiv \frac{2E_{\text{beam}}E_{D^*l} - m_B^2c^4 - M_{D^*l}^2c^4}{2|\vec{p}_B| \cdot |\vec{p}_{D^*l}|c^2} \]

Visible particles: beam or Y(4S) properties

2D ML fit

\[ \mathcal{O}_{NB} \oplus E_{\text{ECL}} \]

Signal


(D*, SL tag, p_{D*}, p_l)
**$R(D^*)$ with SL tagging**

- **Another powerful variables:** \( \cos \theta_{B-D^*}, m_{\text{miss}}^2 \) + total visible Energy

\[
R(D^*) = \frac{1}{2B(\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau)} \cdot \frac{\varepsilon_{\text{norm}}}{\varepsilon_{\text{sig}}} \cdot \frac{N_{\text{sig}}}{N_{\text{norm}}},
\]

\[R(D^*) = 0.302 \pm 0.030 \text{ (stat) } \pm 0.011 \text{ (syst)}\]

\( \checkmark \) 1.6\( \sigma \) above SM


(D*, SL tag, pD*, p)

**2D ML fit**

\( \mathcal{O}_{NB} \oplus E_{\text{ECL}} \)
R(D*) and τ Polarisation

- Decay angles of $\tau \rightarrow \pi\nu$ and $\tau \rightarrow \rho\nu$ encode τ-polarisation, sensitive to NP!

✓ Need to reconstruct helicity angle, but a-priorio τ-restframe not accessible

✓ Luckily there is a relation between $(\vartheta h)$ in τν-frame and this angle

\[\begin{align*}
\nu_2 & \quad \tau [W] & \quad \rho [W] & \quad \rho [\tau] \\
\downarrow & \quad \downarrow & \quad \downarrow & \quad / \\
\downarrow & \quad \downarrow & \quad \downarrow & \quad / \\
\downarrow & \quad \downarrow & \quad \downarrow & \quad / \\
\nu_1 & \quad / & \quad v_2 \\
\hline
W \text{ rest frame} & \quad \tau \text{ rest frame} \\
\end{align*}\]
\( R(D^*) \) and \( \tau \) Polarisation

- Decay angles of \( \tau \to \pi \nu \) and \( \tau \to \rho \nu \) encode \( \tau \)-polarisation, sensitive to NP!

  ✓ Need to reconstruct helicity angle, but a-priorio \( \tau \)-restframe not accessible

  ✓ Luckily there is a relation between \( \langle \tau h \rangle \) in \( \tau \nu \)-frame and this angle

- Signal extraction via \( E_{ECL} \) (unassigned energy in the calorimeter) and in two bins of helicity angle \( \cos \theta_{hel} \) with binned likelihood fit

\[
R(D^*) = \frac{\epsilon_{\text{norm}} N_{\text{sig}}^{ij}}{B_{ij}} = \frac{1}{N_{\text{norm}}} \frac{N_{\text{sig}}^{ij}}{N_{\text{norm}}},
\]

\[
P_{\tau}(D^*) = \frac{2}{\alpha_i} \frac{N_{\text{sig}}^{F_{ij}} - N_{\text{sig}}^{B_{ij}}}{N_{\text{sig}}^{F_{ij}} + N_{\text{sig}}^{B_{ij}}},
\]

Normalisation: \( B \to D^* \ell \nu \)

\( E_{ECL} = E_{\text{Extra}} \)
**$R(D^*)$ and $\tau$ Polarisation**

- Decay angles of $\tau \rightarrow \pi \nu$ and $\tau \rightarrow \rho \nu$ encode **$\tau$-polarisation**, sensitive to NP!

  ✓ Need to reconstruct helicity angle, but a-priorio $\tau$-restframe not accessible

  ✓ Luckily there is a relation between $\theta(\tau h)$ in $\tau\nu$-frame and this angle

---

**Nice Illustration**
$R(\pi)$ with hadronic tagging

- Reconstruct $\tau \rightarrow \ell \nu \nu$, $\tau \rightarrow \pi \nu \nu$, $\tau \rightarrow \rho \nu \nu$, $\tau \rightarrow a_1 \nu \nu$ and charged pion

\[
R(\pi) = \frac{B(B \rightarrow \pi \tau \bar{\nu}_\tau)}{B(B \rightarrow \pi \ell \bar{\nu}_\ell)}
\]

1D fit in $E_{\text{ECL}}$ determines

$R(\pi) = 1.05 \pm 0.51$

$R(\pi)_{\text{SM}} = 0.641 \pm 0.016$


2.4 \sigma significance over background-only hypothesis

![Graph](image)
**$F_L^{D^*}$ with inclusive tagging**

- **First:** reconstruct signal side: $\tau \rightarrow \ell \nu \nu$ and $\tau \rightarrow \pi \nu$ plus $D^{*-} \rightarrow D^0 \pi^-$ with pure $D^0$ modes

- **Inclusive Tag:**
  \[ E_{\text{tag}} = \sum_i E_i \quad p_{\text{tag}} = \sum_i p_i \]
  
  sum over all remaining particles

---

Diagram showing the decay processes and tagging variables.
**$F_L^{D*}$ with inclusive tagging**

- **First**: reconstruct signal side: $\tau \rightarrow \ell \nu \nu$ and $\tau \rightarrow \pi \nu$ plus $D^* \rightarrow D^0 \pi^-$ with pure $D^0$ modes

- **Inclusive Tag**:
  
  Check validity of tag:
  
  $\Delta E_{tag} \in [-0.3, 0.05] \text{ GeV}$

  ![Diagram](PRL 99, 191807)

  **Inclusive Tag**:
  
  $E_{tag} = \sum_i E_i \quad p_{tag} = \sum_i p_i$

  $\Delta E_{tag} = E_{beam} - E_{tag}$

  $M_{tag} = \sqrt{E_{beam}^2 - p_{tag}^2}$

  Check validity of tag:

  ![Graph](PRL 99, 191807)
**$F_L^{D^*}$ with inclusive tagging**

- **First:** reconstruct signal side: $\tau \rightarrow \ell \nu \nu$ and $\tau \rightarrow \pi \nu$ plus $D^* \rightarrow D^0 \pi^-$ with pure $D^0$ modes

- **Inclusive Tag:**

  \[
  E_{tag} = \sum_i E_i \quad p_{tag} = \sum_i p_i
  \]

  Check validity of tag:

  \[
  \Delta E_{tag} \in [-0.3, 0.05] \text{ GeV}
  \]


  \[
  \Delta E_{tag} = E_{beam} - E_{tag}
  \]

  \[
  M_{tag} = \sqrt{E_{beam}^2 - p_{tag}^2}
  \]

  sum over all remaining particles

  \[
  E_{tag} = E_{beam} - E_{tag}
  \]
**$F_L^{D*}$ with inclusive tagging**

- **First:** reconstruct signal side: $\tau \rightarrow \ell \nu \nu$ and $\tau \rightarrow \pi \nu$ plus $D^* \rightarrow D^0 \pi^-$ with pure $D^0$ modes

- **Inclusive Tag:**
  
  $E_{\text{tag}} = \sum_i E_i$ \hspace{1cm} $p_{\text{tag}} = \sum_i p_i$

  Check validity of tag:
  
  $\Delta E_{\text{tag}} \in [-0.3, 0.05] \text{ GeV}$

Further clean-up:

- Zero event charge
- No leptons in $B_{\text{tag}}$
- $E_{\text{extra}} < 0.8 \text{ GeV}$
- $q^2 > 4 \text{ GeV}$

\[ \Delta E_{\text{tag}} = E_{\text{beam}} - E_{\text{tag}} \]
\[ M_{\text{tag}} = \sqrt{E_{\text{beam}}^2 - p_{\text{tag}}^2} \]
$F_{L}^{D*}$ with inclusive tagging

- **Unbinned ML** fit in **categories of**
  - $\tau$ & D-Decay mode and **bins** of $\cos \theta_{\text{hel}} (D^*)$

\[ W^{*+} \rightarrow B^{0} \rightarrow D^{*-} \theta_{\text{hel}} \rightarrow \pi^{-} D^0 \]

---

$F_L^{D*}$ with inclusive tagging

- **Unbinned ML fit in categories of**
  - $\tau$ & D-Decay mode and **bins of** $\cos \theta_{hel}(D^*)$

  - $D \rightarrow K\pi$
  - $D \rightarrow K2\pi$
  - $D \rightarrow K3\pi$

  $\tau \rightarrow \pi \nu_{\tau}$

  $\tau \rightarrow e\bar{\nu}_{e} \nu_{\tau}$

  $\tau \rightarrow \mu \bar{\nu}_{\mu} \nu_{\tau}$

  $M_{tag} = \sqrt{E_{beam}^2 - p_{tag}^2}$

  - **Restrict measurement to [-1,0] due to low efficiency for slow pions in [0,1]**

  - Slow pions in [-1,0]

$F_L^{D*}$ with inclusive tagging

- Fit longitudinal polarisation fraction: $F_L^{D*}$

\[
\frac{1}{\Gamma} \frac{d\Gamma}{d\cos \theta_{\text{hel}}(D^*)} = \frac{3}{4} [2F_L^{D*} \cos^2(\theta_{\text{hel}}(D^*)) + (1 - F_L^{D*}) \sin^2(\theta_{\text{hel}}(D^*))]
\]

\[
F_L^{D*} = 0.60 \pm 0.08(\text{stat.}) \pm 0.035(\text{syst.})
\]

- SM Expectation

SM: $F_L^{D*} = 0.46 \pm 0.03$ (Phys. Rev. D 95, 115038 (2017), A.K. Alok, et al) (1.5 $\sigma$)

SM: $F_L^{D*} = 0.441 \pm 0.006$ (arXiv:1808.03565, Z-R. Huang, et al) (1.8 $\sigma$)
Summary of Belle R(D/D*) measurements

Several results using different techniques:

- $\tau \rightarrow e\nu\nu$ and $\tau \rightarrow \mu\nu\nu$, hadronic tag
  
  $R(D) = 0.375 \pm 0.064$ (stat) $\pm 0.026$ (syst)
  $R(D^*) = 0.293 \pm 0.038$ (stat) $\pm 0.015$ (syst)

- $\tau \rightarrow e\nu\nu$ and $\tau \rightarrow \mu\nu\nu$, semi-leptonic tag
  
  $R(D^*) = 0.302 \pm 0.030$ (stat) $\pm 0.011$ (syst)

- $\tau \rightarrow \pi\nu$ and $\tau \rightarrow \rho\nu$, hadronic tag
  
  $R(D^*) = 0.270 \pm 0.035$ (stat) $\pm 0.027$ (syst)
  $P_{\tau(D^*)} = -0.38 \pm 0.51$ (stat) $\pm 0.18$ (syst)

- $\tau \rightarrow e\nu\nu$, $\tau \rightarrow \mu\nu\nu$ and $\tau \rightarrow \pi\nu$, inclusive tag
  
  $F_L(D^*) = 0.60 \pm 0.08$ (stat) $\pm 0.04$ (syst) First measurement of $D^*$ polarisation

Analysis very similar to BaBar

First measurement of $\tau$ polarisation

First measurement of $D^*$ polarisation


$R(D)_{SM} = 0.299 \pm 0.003$

$R(D^*)_{SM} = 0.257 \pm 0.003$
Summary of Belle measurements

Several results using different techniques:

- $\tau \to e\nu\nu$ and $\tau \to \mu\nu\nu$, hadronic tag
  
  $R(D) = 0.375 \pm 0.064$ (stat) $\pm 0.026$ (syst)
  
  $R(D^*) = 0.293 \pm 0.038$ (stat) $\pm 0.015$ (syst)

Analysis very similar to BaBar

- $\tau \to e\nu\nu$ and $\tau \to \mu\nu\nu$, semi-leptonic tag

  $R(D^*) = 0.302 \pm 0.030$ (stat) $\pm 0.011$ (syst)

First measurement of $D^*$ polarisation

- $\tau \to \pi\nu$ and $\tau \to \rho\nu$, hadronic tag

  $R(D^*) = 0.270 \pm 0.035$ (stat) $\pm 0.027$ (syst)
  
  $P\tau(D^*) = -0.38 \pm 0.51$ (stat) $\pm 0.18$ (syst)

First measurement of $\tau$ polarisation

- $\tau \to e\nu\nu$, $\tau \to \mu\nu\nu$ and $\tau \to \pi\nu$, inclusive tag

  $F_L(D^*) = 0.60 \pm 0.08$ (stat) $\pm 0.04$ (syst)  
  First measurement of $D^*$ polarisation

✓ All $R(D^{(*)})$ measurements consistent but above SM
Belle II

“I am here to help”
Tagging in Belle II: Meet the FEI

The algorithm relies machine learning to automatically identify plausible candidates. For instance, a multivariate classifier can be used to discriminate correctly identified candidates. The procedure is summarised in Figure 2.

FIG. 2: Schematic overview of the FEI algorithm.

1. Introduction

2. Selection

2.1. Overview

2.2. Information Flow

2.3. Improvement

2.4. Selection

3. Implementation

3.1. Software

3.2. Hardware

3.3. Combinatorics

4. Performance

5. Conclusion

References

Appendix
Full Event Interpretation (FEI) Performance:

<table>
<thead>
<tr>
<th></th>
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<th>other algorithms</th>
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<tr>
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<td>$B^\pm$</td>
<td>$B^0$</td>
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<tr>
<td></td>
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<td>$B^0$</td>
</tr>
<tr>
<td>Hadronic</td>
<td></td>
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<tr>
<td>FEI with FR channels</td>
<td>0.53 % 0.33 %</td>
<td>FR 0.28 % 0.18 %</td>
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<tr>
<td>FEI</td>
<td>0.76 % 0.46 %</td>
<td>SER 0.4 % 0.2 %</td>
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<td>Semileptonic</td>
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<tr>
<td>FEI</td>
<td>1.80 % 2.04 %</td>
<td>FR 0.31 % 0.34 %</td>
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<tr>
<td></td>
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<td>SER 0.3 % 0.6 %</td>
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▶ Significant improvement of performance
Tagging in Belle II: Meet the FEI

Full Event Interpretation (FEI) Performance:

<table>
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Significant improvement of performance

Felix Metzner's talk will show details of the first FEI analysis using Belle data!
FEI validation with first Belle II data

- Validated FEI functionality in first Belle II data
- **Classifier output** of 0.5/fb Phase II data
  - After applying a shape fit to normalise B-Meson and continuum contributions properly

![Signal Probability vs Number of Events](image)

- Blue line: $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$
- Orange area: Continuum
- Data points marked with symbols
FEI validation with first Belle II data

- Validated FEI functionality in first Belle II data
- **Classifier output** of 0.5/fb Phase II data
  - After applying a shape fit to normalise B-Meson and continuum contributions properly

- Found **374 ± 40** charged and **176 ± 23** neutral B meson candidates from fitting
  
  \[ M_{bc} = \sqrt{s/4 - |\vec{p}_B|^2} \]
R(D) and R(D*) in the Belle II era

<table>
<thead>
<tr>
<th></th>
<th>5 ab⁻¹</th>
<th>50 ab⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>(R_D)</td>
<td>((\pm 6.0 \pm 3.9)%)</td>
<td>((\pm 2.0 \pm 2.5)%)</td>
</tr>
<tr>
<td>(R_{D^*})</td>
<td>((\pm 3.0 \pm 2.5)%)</td>
<td>((\pm 1.0 \pm 2.0)%)</td>
</tr>
<tr>
<td>(P_T(D^*))</td>
<td>(\pm 0.18 \pm 0.08)</td>
<td>(\pm 0.06 \pm 0.04)</td>
</tr>
</tbody>
</table>

2HDM of type II at \(\tan \beta/m_{H^\pm} = 0.5\) \((\text{GeV}/c^2)^{-1}\).
Summary:

Belle II will be highly competitive measuring semi-tauonic decays

Belle data still very useful to prototype or develop new analysis strategies

The years to come will be exciting!
Backup
And including the competition (older numbers for Belle II)

![Graph showing R(D) and R(D*) values with data points for LHCb and Belle II, along with confidence intervals.](image)
Impact of $\tau$-polarisation in $\tau^- \rightarrow \ell^- \bar{\nu}_\ell \nu_\tau$ decays:

- secondary lepton emitted preferentially in the direction of the $\tau$
  - Carries more momentum of the $\tau$-lepton

+ secondary lepton emitted preferentially against the direction of the $\tau$
  - Carries less momentum of the $\tau$-lepton

![Benchmark point](image1.png)

<table>
<thead>
<tr>
<th>Probability/GeV²</th>
<th>$m^2_{\text{miss}}$ (GeV²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.20</td>
<td>0.15</td>
</tr>
<tr>
<td>0.10</td>
<td>0.05</td>
</tr>
<tr>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

| Probability/GeV | $|p_\ell^*|$ (GeV) |
|-----------------|-----------------|
| 1.50            | 1.00            |
| 0.50            | 0.00            |

2HDM Type II
pol. frac.

Benchmark point

- Benchmark point

SM

- Benchmark point

- $\tan \beta / m_{H^+} = 0.3 \text{ GeV}^{-1}$
- $\tan \beta / m_{H^+} = 0.5 \text{ GeV}^{-1}$
- $\tan \beta / m_{H^+} = 1 \text{ GeV}^{-1}$