Flavour Tagging Calibration
for $B_s^0 \rightarrow D_s^{\pm} K^{\pm}$
Analysis

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1 LHCb experiment

2 $B_{s}^{0} \rightarrow D_{s}^{\pm} K^{\pm}$ analysis

3 Flavour Tagging
   - What is Flavour Tagging? (tagging calibration?!)
   - Why in $B_{s}^{0} \rightarrow D_{s}^{-} \pi^{+}$ channel?
   - What am I doing on tagging calibration?

4 Summary
The LHCb experiment

LHCb aims

- precise test of the Standard Model predictions (CP violation)
- indirect search for new physics beyond the Standard Model

Measurements

- CKM mixing matrix parameters in $B$ meson decays $\rightarrow$ via the angle of the Unitarity Triangles
- rare decays of $B$ and $D$ mesons

- Single-arm forward spectrometer at LHC
- High-precision Vertex detector and Tracker system
- Particle ID: Ring-imaging Cherenkov detectors, calorimeters and muon detector
- Efficient Trigger system
$B_s^0 \rightarrow D_s^{\pm} K^\pm$ Decay analysis

- Tree-level decays $\rightarrow$ more clean measurements
- both $B_s^0$ and $\bar{B}_s^0$ can decay in the same final state
- Measurement of $\gamma$ from time-dependent CP asymmetries
- Challenging measurements:
  - Small Branching ratio: $10^{-5}$
  - Fast oscillation $\rightarrow \Delta m_s = 17.768 \, \text{ps}^{-1}$ $\rightarrow$ time resolution plays an important role
  - Flavour Tagging is needed $\rightarrow$ we need to distinguish between $B_s^0$ and $\bar{B}_s^0$
  - Many background sources
- Four decay rates: $B \rightarrow f$, $\bar{B} \rightarrow f$, $B \rightarrow \bar{f}$ and $\bar{B} \rightarrow \bar{f}$

$$\Gamma_{B \rightarrow f}(t) = |A_f|^2 (1 + |\lambda_f|^2) \frac{e^{-\Gamma_s t}}{2} (\cosh(\frac{\Delta \Gamma_s}{2} t) + D_f \sinh(\frac{\Delta \Gamma_s}{2} t) + C_f \cos(\Delta m_s t) - S_f \sin(\Delta m_s t))$$

$$A_{CP}(t) = \frac{\Gamma_{B \rightarrow f}(t) - \Gamma_{\bar{B} \rightarrow f}(t)}{\Gamma_{B \rightarrow f}(t) + \Gamma_{\bar{B} \rightarrow f}(t)} = \frac{C_f \cos(\Delta m_s t) - S_f \sin(\Delta m_s t)}{\cosh(\frac{\Delta \Gamma_s}{2} t) - D_f \sinh(\frac{\Delta \Gamma_s}{2} t)}$$ (1)
What is Flavour tagging? [1]

- Tagging a neutral particle $\rightarrow$ it is $B$ or $\bar{B}$ at production time

How can we tag the $B$ mesons? $\rightarrow$ need some hints: $(b-\bar{b})$ pair produced together

- $\rightarrow$ in the Opposite Side of my $B$ signal there is an opposite flavor $b$-hadron that I can identify through different decay process (semi-leptonic decay, $b\rightarrow c\rightarrow s$, Vertex Charge)

- $\rightarrow$ in the fragmentation for my $B$ signal (Same Side) the pair of light quarks $(s\bar{s}, d\bar{d}, u\bar{u})$ that is involved can produce a charge particle that is correlated with the flavor of the $B$ signal

$\Rightarrow$ several Tagging algorithms

- Opposite Side taggers: OS$_e$, OS$_\mu$, OS$_K$, OS Vertex Charge $\rightarrow$ OS combined

- Same Side taggers: SS$_\pi$, SS$_p \rightarrow B_d$, SS$_K \rightarrow B_s$
What is Flavour Tagging? [2]

**Tagging Algorithms**

- The Flavour is determined by the charge of the particle used to tag \((K,e,\mu,\pi)\)
- but there is a non-zero probability that the tagging decision is wrong (mixing opposite \(B\), Mis-ID of the tagging particle, contamination from other processes)
- Each Tagging algorithm depending on the charge of the selected tagging particle provides:
  1. a **tagging decision** (with a given tagging efficiency)
  2. depending on the kinematical characteristics of the tagging particle a Neural Network is trained to give the **mistag probability** \((\eta_{\text{pred}})\) for each \(B\) meson candidates

\[
\text{Mistag} = \frac{\text{Wrong}}{\text{Tagged}} \quad \text{Tagging Efficiency} \quad \epsilon_{\text{tag}} = \frac{\text{Tagged}}{\text{Untagged} + \text{Tagged}}
\]

**How can we measure the tagging performance and calibrate the mistag probability?**

- Tagging Performances \(\epsilon_{\text{tag}} D^2 = \epsilon_{\text{tag}} \sum \frac{(1 - 2\omega)^2}{N_{\text{tag}}}
- \(\omega = p_0 + p_1 (\eta_{\text{pred}} - <\eta>)\)
- we use control channels for the tagging calibration
- Once it’s calibrated, \(\omega\) becomes an ingredient in the analysis of CP channels
What is Flavour tagging? [3]

Control channels $\rightarrow$ Flavour Specific Decays
\[ B_s^0 \rightarrow D_s^- \pi^+ \rightarrow \text{forbidden for } \bar{B}_s^0 \]
\[ \bar{B}_s^0 \rightarrow D_s^+ \pi^- \rightarrow \text{forbidden for } B_s^0 \]

- **Charged Flavour Specific Channels:** \[ B^+ \rightarrow J/\psi K^+ , B^+ \rightarrow \bar{D}^0 \pi^+ \]
  - OK only for OS taggers

- **Neutral Flavor Specific Channels:** \[ B^0 \rightarrow D^- \pi^+ \rightarrow SS\pi , SS\bar{p} , \]
  \[ B_s^0 \rightarrow D_s^- \pi^+ \rightarrow SSK \]
  - OK for OS and SS taggers
  - no contamination of other particles in the fragmentation

**Drawbacks** \[ B^0 \text{ mesons can oscillate: the only way to extract the information is doing a full fit to the mixing asymmetry} \]
If the channel on which we perform the calibration is neutral, like $B^0_s \rightarrow D_s^- \pi^+$:

- **Fit to the time distribution** $A_{\text{meas}}(t) \approx (1 - 2\omega)e^{-\frac{(\Delta m_s \sigma_t)^2}{2}}A_{\text{th}}(t; \Delta m_s)$
- $\omega = p_0 + p_1*(\eta_{\text{pred}} - \langle \eta \rangle)$ that calibrates the particular tagging algorithms
- $p_0$ and $p_1$ are used in Physics analyses in which the calibration process is not possible (es: $B^0_s \rightarrow D^\pm_s K^\pm$) 
- calibrated tagger: $p_0 = \langle \eta \rangle$, $p_1 = 1$

For the tagging calibration we can use two approaches:

- **Fit of $\eta_{\text{pred}}$ (unbinned)** $\rightarrow p_0$ and $p_1$
- **Fit in Category of $\eta_{\text{pred}}$** $\rightarrow \omega_{\text{cat}} \rightarrow p_0$ and $p_1$

**NB:** Time Resolution should be well known

*In the Time PDF the tagging dilution $1 - 2\omega$ is multiplied by the time dilution $D_t$ (important in $B^0_s \rightarrow D_s^- \pi^+$ since $\Delta m_s \ast \sigma_t[50fs] \rightarrow D_t = 0.7$) due to the uncertainties on the time measurements.*
Why $B_s^0 \to D_s^- \pi^+$?

**$B_s^0 \to D_s^\pm K^\pm$ Analysis**

- a first analysis has been already done (*LHCb-CONF-2012-029, October 2012*)
- at that time only **OS tagger** was used
- an updated of the previous analysis is ongoing using **SSK tagger**
- the **SSK** can be calibrated only in $B_s^0 \to D_s^- \pi^+$: my contribution

- $B_s^0 \to D_s^- \pi^+$ is used as control channel for the $B_s^0 \to D_s^\pm K^\pm$ analysis (time resolution model, fit model ecc) since it has a larger statistics and it is topologically and physically similar to the $B_s^0 \to D_s K$ which can help in the measurement of $\gamma$
- We can apply the tagging calibration of $B_s^0 \to D_s^- \pi^+$ to $B_s^0 \to D_s^\pm K^\pm$

**$B_s^0 \to D_s^- \pi^+$ Analysis**

- 2011 data ($\approx 26k$ evts)
- for the update of the analysis
- Tagging Calibration of: **OS, SSK cutbased, SSK nnet taggers**
**$B_s^0 \rightarrow D_s^- \pi^+$ analysis strategy**

**sFit approach**

- new simpler Fit approach, widely used in LHCb analysis [arXiv:0905.0724v1]
- it's possible to fit separately the observables if they are not correlated
- from mass distribution fit with backgrounds components $\rightarrow$ Signal Weights
- in the time distribution fit applying Signal Weights ev. by ev. only Signal events are fitted

**Graphs**

- **$B_s \rightarrow D_s \pi$ Mass PDF**
  - Parameters:
    - $\alpha = -0.005063 \pm 0.00034$
    - $f_{cb1} = 0.468 \pm 0.014$
    - $m_{Bs} = 5370.11 \pm 0.13$
    - $n_{BdDsPl_m} = 16.0 \pm 2.1$
    - $n_{Bd_m} = 0 \pm 14$
    - $n_{DsK_m} = 134 \pm 86$
    - $n_{DsRho_m} = 5.07 \pm 0.65$
    - $n_{DsPiPl_m} = 262.7 \pm 3.2$
    - $n_{Lb_m} = 64 \pm 95$
    - $n_{comb_m} = 2540 \pm 138$
    - $n_{sig_m} = 26842 \pm 195$

- **Signal**
  - Events / (0.074 ps)
Predicted mistag $[\eta_{\text{pred}}]$ distribution and Tagging Efficiency

**Additional informations**

- **Tagging Decision:** $+1$ ($B_s$) -1 (anti-$B_s$) or 0 (the tagger isn't able to take a decision on the flavour of that $B_s$)

**OS** $\rightarrow$ combination of all the OS taggers ($e, \mu, K$ and VtxCharge)

**SSK cutbased** $\rightarrow$ tagging particle ($K^\pm$) selection based on Kinematical cuts

**SSKnnnet** $\rightarrow$ tagging particle ($K^\pm$) selection based on Neural Network outputs

**Eta distribution**

- h3: Entries 14419, Mean 0.4092, RMS 0.06029
- h2: Entries 4574, Mean 0.3501, RMS 0.04845
- h: Entries 11706, Mean 0.382, RMS 0.08342

**Tag decision**

- h6: Entries 29854, Mean 0.008612, RMS 0.6936
- h5: Entries 29854, Mean 0.003555, RMS 0.3897
- h4: Entries 29854, Mean -0.006939, RMS 0.6208

**SSKnnnet** has the larger $\varepsilon_{\text{tag}}$
Confirmation of the results obtained in the higher statistics channel $B^+ \rightarrow J/\psi K^+$

**Systematic uncertainties**

- Initial Flavour Asymmetry
- Magnet Polarization
- $B_s$ Transverse Momentum
- Number of tracks
- Other channels: $B^+ \rightarrow \bar{D}^0 \pi^+$, $B^+ \rightarrow J/\psi K^+$, $B^0 \rightarrow J/\psi K^{*0}$

syst. evaluation: $\Delta p_0 = \pm 0.0044$, $\Delta p_1 = \pm 0.027$
SSK taggers

\[ B_s^0 \rightarrow D_s^- \pi^+ \] Reco12, 2011, data

<table>
<thead>
<tr>
<th>tagger</th>
<th>unbinned fit</th>
<th>Fit in Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSK (cut-based)</td>
<td>( p_0 = 0.371 \pm 0.015 )</td>
<td>( 0.3713 \pm 0.015 )</td>
</tr>
<tr>
<td>SSK (cut-based)</td>
<td>( p_1 = 1.633 \pm 0.298 )</td>
<td>( 1.613 \pm 0.313 )</td>
</tr>
<tr>
<td>SSK nnet</td>
<td>( \Delta p_0 = 0.021 \pm 0.015 )</td>
<td>( 0.020 \pm 0.0152 )</td>
</tr>
<tr>
<td>SSK nnet</td>
<td>( \langle \eta \rangle = 0.351 )</td>
<td>( 0.3512 )</td>
</tr>
<tr>
<td></td>
<td>( \varepsilon_{\text{tag}} = 15.15 )</td>
<td>( 0.3719 \pm 0.0151 )</td>
</tr>
<tr>
<td></td>
<td>( \varepsilon_{\text{tag}} = 1.37 )</td>
<td>( 1.633 \pm 0.298 )</td>
</tr>
</tbody>
</table>

- SSK cutbased and SSK nnet syst. uncertainties has been studied
- SSK nnet is better calibrated than SSK cutbased
SSK nnet has been chosen instead of SSK cutbased since:

1. $\varepsilon_{tag} D^2 = 2.18\%$ is higher
2. $\varepsilon_{tag} = 47.72\%$ is 3 time larger than the SSK cutbased $\varepsilon_{tag}$

**Systematic uncertainties**

- Initial Flavour Asymmetry: $K^+$ and $K^-$ interact differently with matter
- Fit Method
- $B_s$ Tranverse Momentum
- Number of tracks
- Time Resolution Model

syst. evaluation: $\Delta p_0 = \pm 0.007$, $\Delta p_1 = \pm 0.10$
$B_s^0 \rightarrow D_s^{\pm} K^{\pm}$ analysis strategy [2]

- OS cutbased and SSK nnet are independent taggers $\rightarrow$ no correlation

$$C(OS;SSK\text{nnet}) = 0.00066$$

For taking advantage of the smaller stat. errors of $p_0$ and $p_1$ in $B^+ \rightarrow J/\psi K^+$

<table>
<thead>
<tr>
<th>Samples</th>
<th>$\varepsilon_{\text{tag}}$ [%]</th>
<th>$\varepsilon_{\text{tag}} D^2$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>OScutbased &amp; SSKnnet</td>
<td>18.88 ± 0.23</td>
<td>2.20 ± 0.05 ± 0.21</td>
</tr>
<tr>
<td>OScutbased only</td>
<td>19.80 ± 0.23</td>
<td>1.65 ± 0.035 ± 0.23</td>
</tr>
<tr>
<td>SSKnnet only</td>
<td>28.85 ± 0.27</td>
<td>1.35 ± 0.21 ± 0.17</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>67.53</strong></td>
<td><strong>5.20</strong></td>
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</tbody>
</table>
In this 1\textsuperscript{st} year of my PhD I’m joined to the LHCb collaboration, in particular I’m mostly involved in the data analysis.

The purpose of my research activity was to provide the Tagging Calibration for the $B_s^0 \to D_s^{\pm} K^{\pm}$ analysis.

I built the mass fitter and the time sFit fitter for $B_s^0 \to D_s^{-} \pi^{+}$ Tagging Calibration, which was also validated by the fitters used by the $B_s^0 \to D_s^{\pm} K^{\pm}$ group.

The Tagging Calibration has been done for: OScutbased, SSKcutbased and SSK nnet on Reco12 2011 and Reco14 2011+2012 data.

I also investigated the systematic effects connected to the tagging calibration parameters p0 and p1.
I participated to Flavour Tagging and $B_s^0 \rightarrow D_s^{\pm} K^{\pm}$ analysis working groups with presentations about my work and results.

I spent some time to test the Front-End Boards for the Muon detector of LHCb.

I participated to the XCIX Congresso Nazionale della Societa’ Italiana di Fisica with a presentation on my master thesis.

I have been in Legnaro for a detector School and in Sass-Fee (Switzerland) for a ROOT Workshop.

I followed classes on Quantum Field theory, Simulation and seminars on B Physics.

I participated to three of the LHCb collaboration meeting held at CERN.