B-hadrons: CPV and semileptonic decays

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Tu Dortmund University

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Outline

• Introduction

• CPV in B decays @ LHC
  • $\phi_s$
  • $\gamma$
  • $\alpha$
  • $+ \Delta m_s$

• Semileptonic Beauty decays @ LHC
  • $|V_{ub}|/|V_{cb}|$
What & Why

- CKM matrix: connects the "weak" and the "mass" states of the quarks
  - Complex and unitary $\rightarrow$ 6 Unitary triangles
  - $V_{ud} V_{ub}^* + V_{td} V_{tb}^* + V_{cd} V_{cb}^* + 1 = 0$

$$V_{CKM} \sim \begin{pmatrix}
V_{ud} & V_{us} & |V_{ub}|, \gamma \\
V_{cd} & V_{cs} & |V_{cb}|
\end{pmatrix}
$$

- Beauty decays: excellent terrain to test CKM picture
  - CP violation: CKM complex phase
  - Mixing and Semileptonic rates $\rightarrow$ CKM’s amplitudes
    - Laboratory to study LFU anomalies (Alessandra’s Talk on Tuesday)

- Tensions are a clear sign for New Physics
CPV in B decays
\( \phi_s \) with \( B_s^0 \rightarrow J/\psi \phi \) decays: theory

- CP-violating phase \( \phi_s \): interference between decay and the mixing of \( B_s^0 \) mesons
  - Well-known within SM:
    \[ \phi_{s}^{SM} \simeq -2\beta_{s} = -36.89^{+0.70}_{-0.81} \text{ rad} \] [CKMfitter]
  - New Physics contributes to \( B_s^0 \) mixing loop
- Golden mode \( B_s^0 \rightarrow J/\psi \phi \):
  - Large statistics \( \checkmark \), dominated by trees \( \checkmark \), access to a wealth of information (\( \Delta \Gamma_s, \Gamma_s, \lambda, \Delta m_s, \ldots \)) \( \checkmark \)
  - Have to control penguin diagrams \( \times \)
  - \( P \rightarrow VV \) decay: admixture of CP odd/even states → angular analysis is needed \( \times \)
  - \( + \) S-wave \( \times \)

\[ \frac{d\Gamma}{dt \ d\Omega} = \sum_{k=1}^{10} f^k(t, \phi_s, \Delta \Gamma_s, \ldots) g^k(\theta, \psi, \phi) \]
$\phi_s$ with $B^0_s \rightarrow J/\psi \phi$ decays: experiment

- Statistical sensitivity to $\phi_s$:
  \[ \propto \sqrt{\frac{S}{S+B}} \sqrt{\epsilon_{\text{tag}}(1-2\omega)^2} e^{-\sigma_t^2 \Delta m_s^2} \]

- Signal purity (trigger constrains versus offline selection)

- Flavour-tagging to infer the flavour at production (smart algorithms versus challenging LHC environment)

- Excellent decay time resolution to solve fast $B^0_s$ oscillation (vertexing/tracking systems)
  - More details in Vitalii’s talk today

- Systematics: control decay-time and angular efficiencies (detector geometry and analysis cuts)
$\phi_s$ with $B^0_s \rightarrow J/\psi \phi$ decays @ CMS [Phys. Lett. B 816(2021)136188]

- 2017 + 2018 CMS data = 96.4 fb$^{-1}$
- Unique trigger: $J/\psi(\mu\mu)$ for the signal + additional tagging muon from $b \rightarrow \mu X$
  - Low signal yield($\sim 50k$) but high tagging power
- Flavour tagging using only Opposite-side $\mu$: use novel Deep NN to discriminate against hadronic fakes
  - Another DNN to estimate mistag probability per event, calibrated on data using $B^+ \rightarrow J/\psi K^+$ decays
  - Calibrated Tagging power: $(10.5 \pm 0.1)\%$
- Silicon tracking system: $\sigma_t \sim 50 - 70$ fs
$\phi_s$ with $B_s^0 \rightarrow J/\psi \phi$ decays @ CMS [Phys. Lett. B 816(2021)136188]

- 6-D (3 angles, decay time, mass, mistag probability and decay time error) likelihood fit
- Decay time and angular observables efficiencies: detector geometry and selection
- $\phi_s = -0.011 \pm 0.050\text{(stat.)} \pm 0.010\text{(sys.)}$
- Systematic dominated by angular efficiency and model bias
$\phi_s$ with $B_s^0 \to J/\psi \phi$ decays @ CMS [Phys. Lett. B 816(2021)136188]

- Combine results from current and Run 1 ($\sqrt{s} = 8$ TeV) analyses
- Systematic sources assumed uncorrelated
- Results are in agreement with each other and agree with SM predictions

\[ \phi_s = -0.021 \pm 0.045 \text{ rad} , \quad \Delta \Gamma_s = 0.1032 \pm 0.0106 \text{ ps}^{-1} \]

- Full Run 2 analysis is ongoing, possibility to add additional triggers/taggers

More in Adam’s talk yesterday
2015 – 2017 ATLAS data: 
$80.5 \, fb^{-1} \at \sqrt{13} \, TeV$

Trigger: two $\mu$ candidates making $J/\psi(\mu\mu)$ mass ($\Delta m \sim 50 \, MeV$)

- "Low" $p_T$ cut, no decay time/impact parameter cuts
- High signal yield ($\sim 45k$)

Flavour tagging using Opposite-side leptons ($\mu, e$) or b-jet-charge tagging

- Calibrated Tagging power: $(1.75 \pm 0.01)\%$

Silicon pixels and strips tracker: $\sigma_t \sim 65 \, fs$

Decay time and angular observables efficiencies: detector geometry and selection
\( \phi_s \) with \( B_s^0 \rightarrow J/\psi \phi \) decays @ ATLAS

- 6-D (3 angles, decay time, mass, mistag probability and decay time error) likelihood fit to extract \( \phi_s \)
- \( \phi_s = -0.081 \pm 0.041 \text{(stat.)} \pm 0.022 \text{(sys.)} \)
- Systematic dominated by calibration of Flavour tagging (\( B^+ \) versus \( B_s^0 \) MC size, pile-up dependence)
Combine results from current and previous Run 1 analyses @ $\sqrt{s} = 8, 7$ TeV

Correlation matrix and correlation of systematic sources are included in the combination

Results are in agreement with each other and agree with SM predictions

$$\phi_s = -0.087 \pm 0.042 \, \text{rad}, \quad \Delta \Gamma_s = 0.0641 \pm 0.0049 \, \text{ps}^{-1}$$

Full Run 2 analysis is ongoing: additional $60 \, \text{fb}^{-1}$

More in Adam’s talk yesterday
$\phi_s$ with $B_{s}^{0} \to J/\psi \phi$ decays @ LHCb [Eur. Phys. J. C79 (2019) 706]

- Most recent analysis in $B_{s}^{0} \to J/\psi \phi$ using 2015-2016 data: $4.9 \text{ fb}^{-1}$
  - $\sigma_t \sim 45.5 \text{ fs}$, Tagging power: $(4.73 \pm 0.34)\%$
  - $\phi_s = -0.083 \pm 0.041(\text{stat.}) \pm 0.006(\text{sys.})$
- Combined with Run 1: $\phi_s = -0.080 \pm 0.032$
Measurements done at LHCb with many different channels:

- $B_s^0 \rightarrow D_s^- D_s^+$ (Run 1), $B_s^0 \rightarrow \psi(2S) \phi$ (Run 1), $B_s^0 \rightarrow J/\psi KK$ (high mass, Run 1), $B_s^0 \rightarrow J/\psi \pi^+ \pi^-$ (Run 1+2)

Combination of all measurements from LHCb:

$$\phi_s = -0.041 \pm 0.025 \text{ rad } , \Delta \Gamma_s = 0.0813 \pm 0.0048 \text{ ps}^{-1}$$

Full Run 2 analysis is ongoing: additional $\sim 4 \text{ fb}^{-1}$
$\phi_s$ @ world average from [HFLAV]

- HFLAV performs world average of all available measurements to date

$$\phi_s = -0.041 \pm 0.025 \text{ rad} \ , \ \Delta \Gamma_s = 0.082 \pm 0.005 \text{ ps}^{-1}$$

- Combination is statistically dominated
- Consistent with SM and consistent with no CP violation in the interference
- Different "full Run 2" analyses are ongoing $\rightarrow$ expect to improve $\phi_s$ soon
Bonus: $\phi_s$ @ LHCb with $B_s^0 \rightarrow J/\psi(\text{ee})\phi$ [arXiv:2105.14738, submitted to EPJC]

- Use full Run 1 data at LHCb $\sim 13k$ signal events
- Bremsstrahlung:
  - Degrades $J/\psi(\text{ee}), B_s^0$ mass resolution and trigger efficiency
  - Corrections to $e^+e^-$ pair → complicate analysis (systematics)
- First time dependent angular analysis with an electron final state:
  $\phi_s = 0.00 \pm 0.28 \pm 0.05 \text{ rad}, \Delta \Gamma_s = 0.115 \pm 0.045 \pm 0.011 \text{ ps}^{-1}$
- Result not yet included in HFLAV world average

![Graphs showing candidates distributions](image-url)
• $\gamma \propto \arg(V_{ub})$, least known among CKM angles
• Measured via interference $b \rightarrow u$ and $b \rightarrow c$ transitions
• $\gamma$-tree = $(72.1 \pm 5.4)\degree$ theoretically clean, indirect $\gamma = (65.7^{+1.0}_{-2.5})\degree$
  • Discrepancy would indicate New Physics
• Can be accessed through neutral B mesons but golden modes are $B^+$ decays
\( \gamma \) with \( B^+ \rightarrow D(\ast)h^+ \) decays [JHEP 04 (2021) 081]

- \( \gamma \) through Tree-level decays \( B^+ \rightarrow D(\ast)h^+ \)
- Use \( D^0 \rightarrow K^+K^-\,\pi^+\pi^-\,K^\pm\pi^\mp + \pi^0 \)
- Accessed through time-integrated asymmetries between \( B^+, B^- \) yields
- Simultaneous fit to 16 different decays using Full Run 2 data set
\( \gamma \) with \( B^+ \rightarrow D^{(*)+} h^+ \) decays [JHEP 04 (2021) 081]

- Full LHCb combination with previous measurements \( \rightarrow \gamma = (67 \pm 4)^\circ \)
  - Most precise determination to date
  - Compatible with indirect determination of \( \gamma (= 65.7^{+1.0}_{-2.5})^\circ \)

- More details in Alessandro’s Talk yesterday
Decay of neutral B to charmless final states, CP violation in both decay and the interference

Time dependent CP asymmetries in $B_s^0 \rightarrow K^+K^-$ and $B^0 \rightarrow \pi^+\pi^-

- Constrained to $\alpha, \gamma, \beta_s$ and direct CP violation
- Requires: Flavour tagging(4.5% – 5.1%) and decay time resolution($\sim 44$ fs)

Time-integrated CP in $B^0 \rightarrow K^+\pi^-$, $B_s^0 \rightarrow K^-\pi^+$

- Access decay-specific CP asymmetry
- Requires excellent understanding of fine experimental/physics asymmetries(production, detection, PID, etc ...)

$\alpha$ with $B_{(s)}^0 \rightarrow h^+h^-$ [JHEP 03(2021)075]
First observation of time-dependent CP violation in $B^0_s$ decays using 1.9 fb$^{-1}$ of Run 2 data

$S_{\pi\pi} = -0.706 \pm 0.042 \pm 0.013$, $S_{KK} = +0.123 \pm 0.034 \pm 0.015$

$A_{CP}^{B^0 \rightarrow K^+\pi^-} = -0.082 \pm 0.003 \pm 0.003$, $A_{CP}^{B^0_s \rightarrow K^-\pi^+} = +0.236 \pm 0.013 \pm 0.011$
$\Delta m_s$ with $B_s^0 \to D_s^- \pi^+$ Full Run 2 [arXiv:2104.04421, submitted to Nature Physics]

- $\Delta m_s$ oscillation frequency for $B_s^0$: constrain $V_{ts}$, input for $B_s^0$ CPV measurements
- Time-dependent analysis in $B_s^0 \to D_s^- \pi^+$
  - Requires Flavour tagging ($\sim 6\%$) and excellent decay time resolution
  - Full Run 2 data 6 fb$^{-1}$: $\sim 400k$ events $\to$ need to control systematics
- Combination of all LHCb measurements: $\Delta m_s = 17.7656 \pm 0.0057$ ps$^{-1}$
- Most precise measurement to date
Semileptonic Beauty decays
$|V_{ub}|/|V_{cb}|$: introduction

- $|V_{ub}|, |V_{cb}|$: coupling strength between $b$ and $u (c)$ quarks
- Complementary experimental approaches: inclusive versus exclusive
- **CKMfitter**: uses exclusive + inclusive averages of $|V_{ub}|$ & $|V_{cb}|$ and adds $|V_{ub}|/|V_{cb}|$ from LHCb separately
- **HFLAV**: Combine all exclusive measurements from LHCb, BaBar and Belle:
  
  \[
  |V_{ub}| = (3.49 \pm 0.13) \times 10^{-3}
  \]
  
  \[
  |V_{cb}| = (39.25 \pm 0.56) \times 10^{-3}
  \]
- Inclusive & exclusive measurements are in disagreement ($\sim 3\sigma$)
\[ |V_{ub}|/|V_{cb}| \text{ in } B^0_s \rightarrow K^- \mu^+ \nu_\mu \text{ [Phys. Rev. Lett. 126 (2021) 081804]} \]

- Measure of BRs ratio of \( B^0_s \rightarrow K^- \mu^+ \nu_\mu \) & \( B^0_s \rightarrow D^- \mu^+ \nu_\mu \)

\[
\frac{\mathcal{B}(B^0_s \rightarrow K^- \mu^+ \nu_\mu)}{\mathcal{B}(B^0_s \rightarrow D^- \mu^+ \nu_\mu)} = \frac{|V_{ub}|^2}{|V_{cb}|^2} \times \frac{d\Gamma(B^0_s \rightarrow K^- \mu^+ \nu_\mu)/dq^2}{d\Gamma(B^0_s \rightarrow D^- \mu^+ \nu_\mu)/dq^2}
\]

- Theory input is sensitive to \( q^2 \): Complementary predictions from LQCD and LCSR

- Using 2 fb\(^{-1}\) of LHCb data: \( N_{B^0_s \rightarrow D^- \mu^+ \nu_\mu} \sim 200k \), \( N_{B^0_s \rightarrow K^- \mu^+ \nu_\mu}\text{(low)} \sim 13k \)

**Low \( q^2 \)**

**High \( q^2 \)**
Results: $\mathcal{B}(B^0_s \rightarrow K^- \mu^+ \nu_\mu)$ [Phys. Rev. Lett. 126 (2021) 081804]

$$
\mathcal{B}(B^0_s \rightarrow K^- \mu^+ \nu_\mu) = (1.06 \pm 0.05(\text{stat}) \pm 0.04(\text{syst}) \pm 0.06(\text{ext}) \pm 0.04(\text{FF})) \times 10^{-4}
$$

$$
|V_{ub}|/|V_{cb}|(\text{low}) = 0.0607 \pm 0.0015(\text{stat}) \pm 0.0013(\text{syst}) \pm 0.0008(D_s) \pm 0.0030(\text{FF})
$$

$$
|V_{ub}|/|V_{cb}|(\text{high}) = 0.0946 \pm 0.0030(\text{stat})^{+0.0024}_{-0.0025}(\text{syst}) \pm 0.0013(D_s) \pm 0.0068(\text{FF})
$$

- First observation of the golden channel: $B^0_s \rightarrow K^- \mu^+ \nu_\mu$
- Discrepancy $|V_{ub}|/|V_{cb}|(\text{low})$: clash in theory predictions $\rightarrow$ solved when measuring full $q^2$ shape of $B^0_s \rightarrow K^- \mu^+ \nu_\mu$
Conclusion

• Most precise measurements of $\phi_s$ using data from LHC experiments
  • Work ongoing from LHCb, ATLAS & CMS to update with the rest of Run 2 data
• Most precise determination of $\gamma$ angle using a combination of LHCb measurements with charged $B^+$ decays
  • $\gamma$ from direct versus indirect measurements are compatible
• First observation of CP violation in $B^0_s \rightarrow K^+K^-$ decays from LHCb
• Most precise measurement of $\Delta m_s$ in $B^0_s \rightarrow D^-\pi^+$ using LHCb’s full Run 2 data
• First measurement of $|V_{ub}|/|V_{cb}|$ in $B^0_s \rightarrow K^-\mu^+\nu_\mu$ decays
  • Great potential to reduce theory uncertainties but first solve theory disagreement using LHCb data
• Run 3 & beyond: constrain CKM picture to unprecedented level with CPV & semileptonic observables Francesca’ talk on Monday
Backups
### $\phi_s$ with $B_s^0 \to J/\psi\phi$ decays @ ATLAS: Run 2 results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Statistical uncertainty</th>
<th>Systematic uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi_s \text{ [rad]}$</td>
<td>$-0.081$</td>
<td>$0.041$</td>
<td>$0.022$</td>
</tr>
<tr>
<td>$\Delta\Gamma_s \text{ [ps}^{-1}]$</td>
<td>$0.0607$</td>
<td>$0.0047$</td>
<td>$0.0043$</td>
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<tr>
<td>$\Gamma_s \text{ [ps}^{-1}]$</td>
<td>$0.6687$</td>
<td>$0.0015$</td>
<td>$0.0022$</td>
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<tr>
<td>$</td>
<td>A_\parallel(0)</td>
<td>^2$</td>
<td>$0.2213$</td>
</tr>
<tr>
<td>$</td>
<td>A_0(0)</td>
<td>^2$</td>
<td>$0.5131$</td>
</tr>
<tr>
<td>$</td>
<td>A_S(0)</td>
<td>^2$</td>
<td>$0.0321$</td>
</tr>
<tr>
<td>$\delta_\perp - \delta_S \text{ [rad]}$</td>
<td>$-0.25$</td>
<td>$0.05$</td>
<td>$0.04$</td>
</tr>
</tbody>
</table>

**Solution (a)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Statistical uncertainty</th>
<th>Systematic uncertainty</th>
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</thead>
<tbody>
<tr>
<td>$\delta_\perp \text{ [rad]}$</td>
<td>$3.12$</td>
<td>$0.11$</td>
<td>$0.06$</td>
</tr>
<tr>
<td>$\delta_\parallel \text{ [rad]}$</td>
<td>$3.35$</td>
<td>$0.05$</td>
<td>$0.09$</td>
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</table>

**Solution (b)**

<table>
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<td>$\delta_\parallel \text{ [rad]}$</td>
<td>$2.94$</td>
<td>$0.05$</td>
<td>$0.09$</td>
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</table>
### φs with $B^0_s \to J/\psi \phi$ decays @ CMS: Run 2 results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fit value</th>
<th>Stat. uncer.</th>
<th>Syst. uncer.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi_s$ [mrad]</td>
<td>$-11$</td>
<td>$\pm 50$</td>
<td>$\pm 10$</td>
</tr>
<tr>
<td>$\Delta \Gamma_s$ [ps$^{-1}$]</td>
<td>0.114</td>
<td>$\pm 0.014$</td>
<td>$\pm 0.007$</td>
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<tr>
<td>$\Delta m_s$ [h ps$^{-1}$]</td>
<td>17.51</td>
<td>$\pm 0.10$</td>
<td>$\pm 0.03$</td>
</tr>
<tr>
<td>$</td>
<td>\lambda</td>
<td>$</td>
<td>0.972</td>
</tr>
<tr>
<td>$\Gamma_s$ [ps$^{-1}$]</td>
<td>0.6531</td>
<td>$\pm 0.0042$</td>
<td>$\pm 0.0024$</td>
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<tr>
<td>$</td>
<td>A_0</td>
<td>^2$</td>
<td>0.5350</td>
</tr>
<tr>
<td>$</td>
<td>A_\perp</td>
<td>^2$</td>
<td>0.2337</td>
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<tr>
<td>$</td>
<td>A_s</td>
<td>^2$</td>
<td>0.022</td>
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<tr>
<td>$\delta_\parallel$ [rad]</td>
<td>3.18</td>
<td>$\pm 0.12$</td>
<td>$\pm 0.03$</td>
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<tr>
<td>$\delta_\perp$ [rad]</td>
<td>2.77</td>
<td>$\pm 0.16$</td>
<td>$\pm 0.04$</td>
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<tr>
<td>$\delta_{s\perp}$ [rad]</td>
<td>0.221</td>
<td>$+0.083$</td>
<td>$\pm 0.048$</td>
</tr>
</tbody>
</table>
\( \phi_s \) with \( B_s^0 \rightarrow J/\psi \phi \) decays @ LHCb: Run 2 results

\[
\begin{align*}
\phi_s &= -0.083 \pm 0.041 \pm 0.006 \text{ rad} \\
|\lambda| &= 1.012 \pm 0.016 \pm 0.006 \\
\Gamma_s - \Gamma_d &= -0.0041 \pm 0.0024 \pm 0.0015 \text{ ps}^{-1} \\
\Delta\Gamma_s &= 0.077 \pm 0.008 \pm 0.003 \text{ ps}^{-1} \\
\Delta m_s &= 17.703 \pm 0.059 \pm 0.018 \text{ ps}^{-1} \\
|A_\perp|^2 &= 0.2456 \pm 0.0040 \pm 0.0019 \\
|A_0|^2 &= 0.5186 \pm 0.0029 \pm 0.0023 \\
\delta_\perp - \delta_0 &= 2.64 \pm 0.13 \pm 0.10 \text{ rad} \\
\delta_\parallel - \delta_0 &= 3.06^{+0.08}_{-0.07} \pm 0.04 \text{ rad}.
\end{align*}
\]
Results: $|V_{ub}|/|V_{cb}|$ ingredients

$$\frac{\mathcal{B}(B^0_s \to K^- \mu^+ \nu_\mu)_{q^2 < 7}}{\mathcal{B}(B^0_s \to D^- \mu^+ \nu_\mu)_{\text{Full} \ q^2}} = (1.66 \pm 0.08\text{(stat)} \pm 0.07\text{(syst)} \pm 0.05(D_s)) \times 10^{-3}$$

$$\frac{\mathcal{B}(B^0_s \to K^- \mu^+ \nu_\mu)_{q^2 > 7}}{\mathcal{B}(B^0_s \to D^- \mu^+ \nu_\mu)_{\text{Full} \ q^2}} = (3.25 \pm 0.21\text{(stat)} + 0.16\text{(syst)} \pm 0.09(D_s)) \times 10^{-3}$$

\[ K & R \]

JHEP08(2017)112


$\text{FF}_K = 4.14 \pm 0.38 \text{ps}^{-1}$, $\text{FF}_K = 3.23 \pm 0.46 \text{ps}^{-1}$, $\text{FF}_{D_s} = 9.15 \pm 0.37 \text{ps}^{-1}$
Neutrino reconstruction

- Transverse component of the neutrino momentum $p_\perp$ is trivial to calculate
- Longitudinal component $p_\parallel$ is determined up to a two-fold ambiguity with the quadratic equation

$$p_\parallel = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a},$$

$$a = |2p_\parallel, x_\mu m_{X_\mu}|^2,$$

$$b = 4p_\parallel, x_\mu (2p_\perp p_\parallel, x_\mu - m_{miss}^2),$$

$$c = 4p_\perp^2 (p_\parallel, x_\mu + m_{B_0}^2) - |m_{miss}^2|^2,$$

$$m_{miss}^2 = m_{B_0}^2 - m_{X_\mu}^2.$$
• Analysis requires $q^2$ reconstruction:
  1. Infer $P_\nu$ from $B_s^0$ topology $\rightarrow$ two-fold ambiguity
  2. Use linear regression (JHEP 02 (2017) 021) to choose correct $P_\nu$ solution

• $B_s^0 \rightarrow K^- \mu^+ \nu_\mu$ & $B_s^0 \rightarrow D_s^- \mu^+ \nu_\mu$
  • Fit data using "corrected mass"
  • $M_{\text{corr}} = \sqrt{M_{X\mu}^2 + p_{\perp}^2 + p_{\perp}}$

• Similar vetoes to select/reconstruct $B_s^0 \rightarrow K^- \mu^+ \nu_\mu$ & $B_s^0 \rightarrow D_s^- \mu^+ \nu_\mu$
  • Use inclusive $D_s^- \rightarrow K^+ K^- \pi^-$ decays
Systematics breakdown

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>$\frac{\mathcal{B}(B_s \rightarrow K_{\mu\nu})}{\mathcal{B}(B_s \rightarrow D_{s\mu\nu})}$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No $q^2$ sel.</td>
</tr>
<tr>
<td>Tracking</td>
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<tr>
<td>Trigger</td>
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<tr>
<td>Particle ID</td>
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<tr>
<td>$m_{\text{corr}}$ error</td>
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<tr>
<td>Isolation</td>
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<tr>
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<tr>
<td>$q^2$ migration</td>
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<tr>
<td>$\varepsilon$ gen&amp; reco</td>
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<tr>
<td>Fit template</td>
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<td></td>
<td>-2.9</td>
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<tr>
<td>Total</td>
<td>+4.0</td>
</tr>
<tr>
<td></td>
<td>-4.3</td>
</tr>
</tbody>
</table>

$\mathcal{B}(D_s^{-} \rightarrow K^{-}K^{+}\pi^{-})$  

- Similar contribution to systematic budget from fit and $\varepsilon$
- Multiple Systematic sources for fit and $\varepsilon$ are reducible with larger data sets and simulation samples