# Optimising the search for *CP* violation in $D_S^+ \to K^+ \pi^+ \pi^-$ decays at LHCb

Using forward-backward asymmetry as a probe for CPV

### Summer Project 2021 Olaf Massen

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### Removing background: BDTG

- $D_{\rm S}^+$  Impact parameter of primary vertex
- Secondary vertex  $\chi^2$
- $D_{\rm S}^+$  Pseudorapidity
- $D_{\rm S}^+$  transverse and total momentum
- $D_{\rm S}^+$  decay length and lifetime
- $D_{\rm S}^+$  flight distance to primary vertex
- Daughter track isolation variables





Cut a signal efficiency of 75%  $\rightarrow$  Background rejection 82%





### **FOCUS** collaboration

Resonances: *K*\*(892)  $\rho(770)$ NR *K*\*(1410)  $K_0^*(1430)$  $\rho(1450)$ 



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### Improved Model

### **Resonances:**

*K*\*(892)  $\rho(770)$ NR *K*\*(1410)  $K_0^*(1430)$  $\rho(1450)$  $f_0(980)$  $f_0(1370)$  $K_{2}^{*}(1430)$  $\omega(782)$  $f_2(1270)$ 



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### Based on $3.5 \cdot 10^6$ events

Improvement, yet still incomplete. Still useful for sensitivity study!

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### **Regional charge asymmetry**

$$A_{CP} = \frac{\#D_s^+ - \#D_s^-}{\#D_s^+ + \#D_s^-}$$



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### Forward-Backward charge asymmetry in helicity angle



Z.-H. Zhang, Phys.Lett.B 820 (2021)  $\rightarrow$  Twice as much statistics

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### Simulating CP violation



# $\begin{aligned} A_{\rho} &= |A| e^{i\phi} \\ \rightarrow \Delta |A| \in \{-0.2\%, -0.1\%, 0\%, 0.1\%, 0.2\%\} \\ \rightarrow \Delta \phi \in \{-0.2^{\circ}, -0.1^{\circ}, 0^{\circ}, 0.1^{\circ}, 0.2^{\circ}\} \end{aligned}$

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# Sensitivity results (1 toy example)

### Significance of ACP



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### $1.5 \cdot 10^7 D_S^+ \& 1.5 \cdot 10^7 D_S^-$

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# Sensitivity results (1 toy example)

| $\Delta A$ | $\Delta \phi$  | Global A <sub>CP-FB</sub>   | σ   | Angle  | Best Bin       | $A_{CP}$   | σ   | Best Bin       | $A_{CP-FB}$   | $\sigma$   | Ang   |
|------------|--|---|---|--|----------------|--|---|----------------|---|--|---|
| 0.0 %      | $  -0.1^{\circ} +0.1^{\circ}$  | $ \begin{vmatrix} (-0.013 \pm 0.018)\% \\ (-0.018 \pm 0.018)\% \end{vmatrix} $                        | $\left \begin{array}{c} 0.7\\ 1.0\end{array}\right $        | $egin{array}{c} 	heta_{13} \ 	heta_{12} \end{array}$                     | 11<br>12       | $(0.158 \pm 0.074)\%$<br>$(0.614 \pm 0.268)\%$   | $\begin{vmatrix} 2.1 \\ 2.3 \end{vmatrix}$                  | 10<br>12       | $ \begin{array}{l} (-0.388 \pm 0.136)\% \\ (0.630 \pm 0.268)\% \end{array} $                          | $\begin{array}{c c} 2.9\\ 2.4 \end{array}$           | $egin{array}{c} 	heta_1 \ 	heta_1 \ 	heta_1 \ 	heta_1 \end{array}$  |
| -0.1%      | $  \begin{array}{c} -0.1^{\circ} \\ 0.0 \\ +0.1^{\circ} \end{array}  $ | $ \begin{vmatrix} (0.030 \pm 0.018)\% \\ (-0.038 \pm 0.018)\% \\ (-0.043 \pm 0.018)\% \end{vmatrix} $ | $ \begin{array}{ c c c } 1.7 \\ 2.1 \\ 2.4 \\ \end{array} $ | $\begin{array}{c} \theta_{13} \\ \theta_{12} \\ \theta_{23} \end{array}$ | 21<br>26<br>11 | $\begin{array}{l}(0.242\pm0.109)\%\\(-0.353\pm0.119)\%\\(-0.152\pm0.074)\%\end{array}$ | $ \begin{array}{c c} 2.2 \\ 3.0 \\ 2.0 \end{array} $        | 21<br>26<br>11 | $ \begin{array}{ } (-0.253 \pm 0.109)\% \\ (-0.353 \pm 0.119)\% \\ (-0.152 \pm 0.074)\% \end{array} $ | $ \begin{array}{c c} 2.3 \\ 3.0 \\ 2.0 \end{array} $ | $\begin{array}{c c} \theta_1 \\ \theta_1 \\ \text{All t} \\ \theta_{12} \text{ an} \end{array}$   |
| +0.1%      | $  \begin{array}{c} -0.1^{\circ} \\ 0.0 \\ +0.1^{\circ} \end{array}  $ | $ \begin{vmatrix} (0.028 \pm 0.018)\% \\ (-0.026 \pm 0.018)\% \\ (-0.045 \pm 0.018)\% \end{vmatrix} $ | $ \begin{array}{ c c c } 1.6 \\ 1.4 \\ 2.5 \\ \end{array} $ | $\begin{array}{c} \theta_{23} \\ \theta_{13} \\ \theta_{12} \end{array}$ | 9<br>9<br>13   | $(-0.288 \pm 0.103)\%$<br>$(-0.215 \pm 0.103)\%$<br>$(-0.190 \pm 0.068)\%$             | $ \begin{array}{ c c c } 2.8 \\ 2.1 \\ 2.8 \\ \end{array} $ | 21<br>21<br>13 | $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$   | $ \begin{array}{c c} 2.8 \\ 2.2 \\ 2.8 \end{array} $ | $egin{array}{c} 	heta_1 \ 	heta_1 $ |

Forward-backward charge asymmetry not twice as sensitive, but in some regions more sensitive than "regular" charge asymmetry

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### Outlook

With an increased number of MC events  $\rightarrow$ Improve BDTG

 $\rightarrow$ Improve detector efficiency map

### In general

 $\rightarrow$ Introduce CPV in multiple resonances

 $\rightarrow$ Use K-matrix formalism

 $\rightarrow$  Performing the CPV analysis on data





# Back Up

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## MC Efficiency for BDTG cut at 0.4



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### Detector efficiency estimation



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### Example of residual background subtraction



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## Dalitz plot of Improved model



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# Uniform binning of DP



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# Phase over DP: Physical Binning



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### Phase over DP: Uniform binning



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## **Uniform Binning results**

| $\Delta A$ | $\Delta \phi$ Global $A_{CP-FB}$                       | σ  | Angle  | Best Bin       | $A_{CP}$   | σ  | Best Bin       | $A_{CP-FB}$   | σ  | Ang   |
|------------|--|--|--|----------------|--|--|----------------|---|--|---|
| 0.0 %      |  | 0.7<br>1.0   | $	heta_{13} \\ 	heta_{12}$   | 11<br>12       | $\begin{array}{l} (0.158 \pm 0.074)\% \\ (0.614 \pm 0.268)\% \end{array}$  | $\begin{vmatrix} 2.1 \\ 2.3 \end{vmatrix}$           | 10<br>12       | $\begin{array}{l}(-0.388\pm 0.136)\%\\(0.630\pm 0.268)\%\end{array}$                                | $2.9 \\ 2.4$                                       | $\left  \begin{array}{c} 	heta_{12} \\ 	heta_{13} \end{array} \right $                                |
| -0.1%      | $\begin{array}{ c c c c c c c c c c c c c c c c c c c$ | $     \begin{array}{c c}       1.7 \\       2.1 \\       2.4     \end{array} $ | $\begin{array}{c} \theta_{13} \\ \theta_{12} \\ \theta_{23} \end{array}$ | 21<br>26<br>11 | $(0.242 \pm 0.109)\%$<br>$(-0.353 \pm 0.119)\%$<br>$(-0.152 \pm 0.074)\%$  | $ \begin{array}{c c} 2.2 \\ 3.0 \\ 2.0 \end{array} $ | 21<br>26<br>11 | $\begin{array}{l}(-0.253 \pm 0.109)\% \\(-0.353 \pm 0.119)\% \\(-0.152 \pm 0.074)\%\end{array}$     | $\begin{array}{c c} 2.3 \\ 3.0 \\ 2.0 \end{array}$ | $\begin{array}{c c} \theta_{13} \\ \text{All th} \\ \theta_{12} \text{ and} \end{array}$              |
| +0.1%      | $\begin{array}{ c c c c c c c c c c c c c c c c c c c$ | $1.6 \\ 1.4 \\ 2.5$  | $\theta_{23}\\\theta_{13}\\\theta_{12}$                                  | 9<br>9<br>13   | $(-0.288 \pm 0.103)\%$<br>$(-0.215 \pm 0.103)\%$<br>$(-0.190 \pm 0.068)\%$ | 2.8<br>2.1<br>2.8                                    | 21<br>21<br>13 | $\begin{array}{c} (-0.308 \pm 0.109)\% \\ (-0.237 \pm 0.109)\% \\ (-0.190 \pm 0.068)\% \end{array}$ | 2.8<br>2.2<br>2.8                                  | $\left  \begin{array}{c} \theta_{13} \\ \theta_{13} \\ \theta_{12} \end{array} \right _{\theta_{12}}$ |

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