UNIVERSITY OF CAMBRIDGE

LHCb

CP violation

No matter how charming

HEP Extravaganza 2023

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Overview of activities

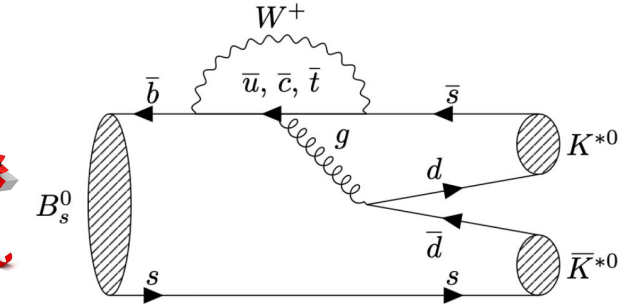
- Charmless B→VV analyses:
  - $B^0_{(s)} \to K^{*0}\overline{K}^{*0}$
  - $B^0 \to \rho^0 K^{*0}$
  - $B^0_{(s)} \to \phi K^{*0}$
  - $B^+ \to \rho^0 K^{*+}$
- Measuring CKM-angle γ :
  - $B^0_s \to D^{\mp}_s K^{\pm}$
  - Gammacombo

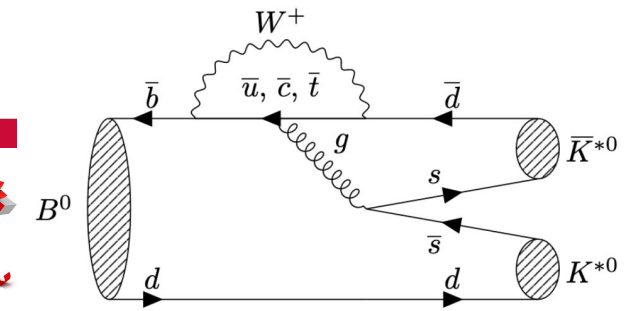
Decay topologies of non-leptonic beauty decays

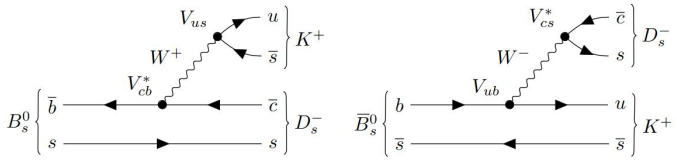
CP violation

$$V_{CKM,\text{Wolfenstein}} = \begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & -|V_{ts}|e^{i\beta_s} & |V_{tb}| \end{pmatrix} + \mathcal{O}(\lambda^5)$$

- *CP* violation reveals itself in the interference of two decay amplitudes
  - Must be a weak and strong phase difference
- Sometimes, neutral meson mixing necessary: **interference in mixing and decay**
  - Decay-time dependent analysis required
  - Situation for $B^0_{(s)} \to K^{*0}\overline{K^{*0}}$ decays actually a bit more complex due to loop







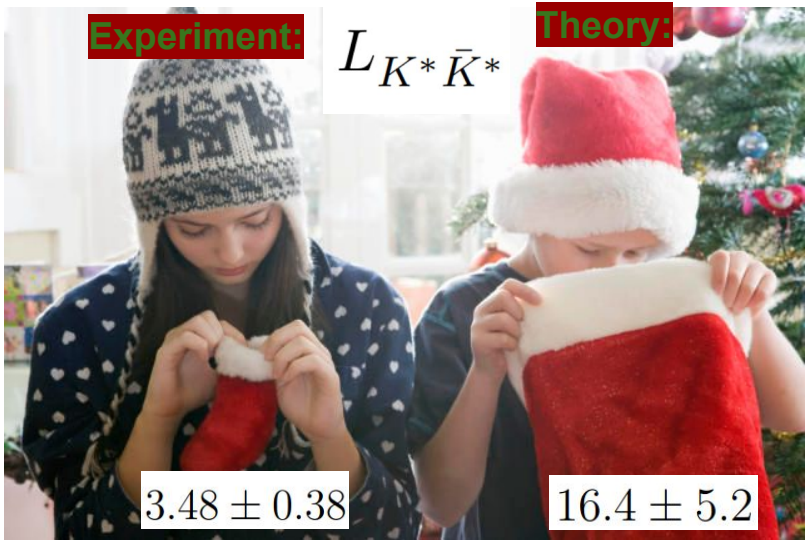
Other parameters of interest

- Time-integrated *CP* violation in $B^0 \to \rho^0 K^{*0}$
- Branching fractions
- Fractions of angular contributions

$$f_{L,\|,\perp} = \frac{|A_{0,\|,\perp}|^2}{|A_0|^2 + |A_\||^2 + |A_\perp|^2}$$

  - Tensions between theory and experiment
- Easier to compare the ratio:

$$L_{K^*\bar{K}^*} = G\frac{\mathcal{B}(B_s^0 \to K^{*0}\overline{K}^{*0})}{\mathcal{B}(B^0 \to K^{*0}\overline{K}^{*0})}\frac{f_L^{B_s^0 \to K^{*0}\bar{K}^{*0}}}{f_L^{B^0 \to K^{*0}\bar{K}^{*0}}}$$

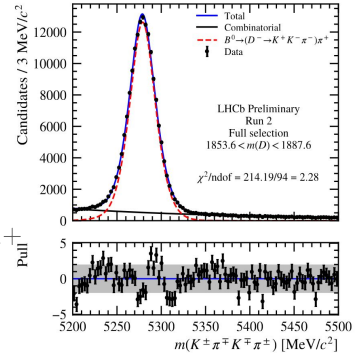


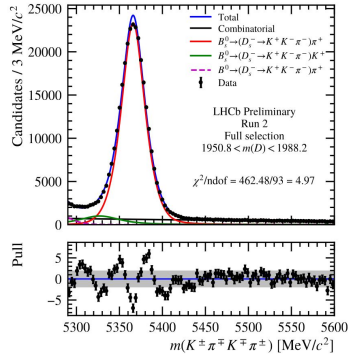
Run 1 and Run 2 data

Branching fraction of $B^0_{(s)} \to K^{*0}\overline{K^{*0}}$ decays

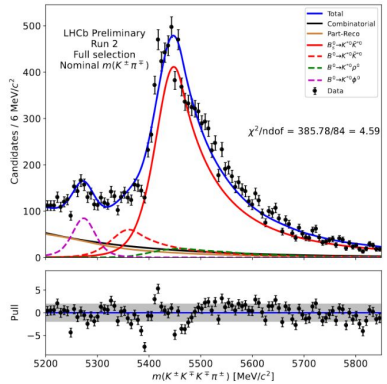
- Almost there for branching fraction measurement
- Simultaneous fit to signal and misID backgrounds
  - *e.g.* m(KPiPi), m(KKKPi), m(KPiPiPi)
- Normalisation channels: $B^0 \to D^-\pi^+$ and $B^0_s \to D^-_s\pi^+$
- Train Combinatorial and PID BDTs
- Amplitude analysis and time-dependent measurement will follow

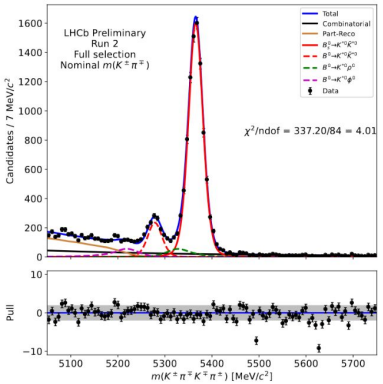
Normalisation channels

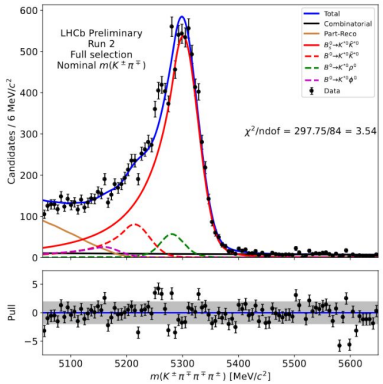




Signal

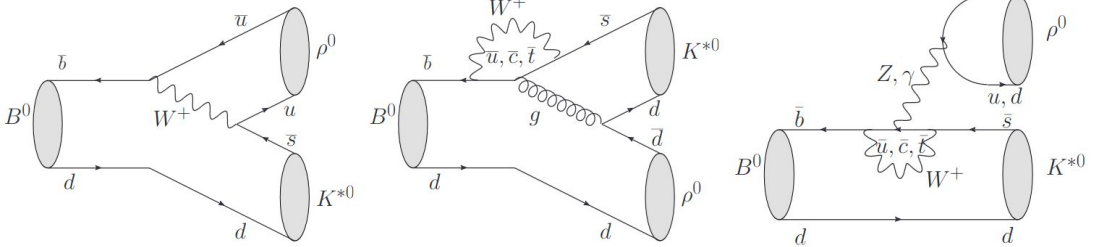




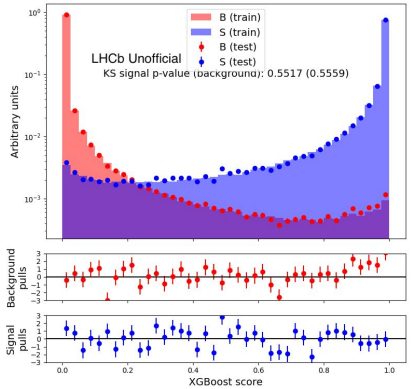


Study of $B^0 \to \rho^0 K^{*0}$ decays

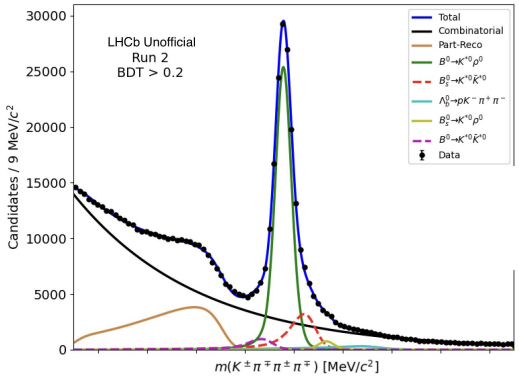
- Also involves amplitude analysis of $B^0 \to (\pi^+\pi^-)(K^+\pi^-)$
  - Including various resonances
- *CP* violation due to penguin-tree interference
  - Similar decay signature as
  - Combinatorial BDT in place
  - Observe $B_s^0 \to \rho^0 K^{*0}$?



Leading Feynman diagrams

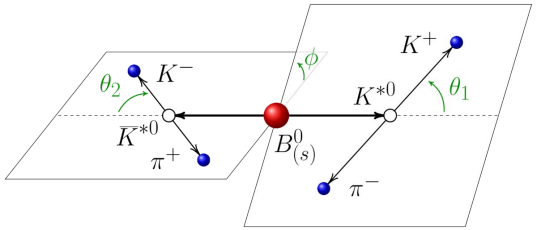


Combinatorial BDT performance



Preliminary mass fit with loose BDT cut

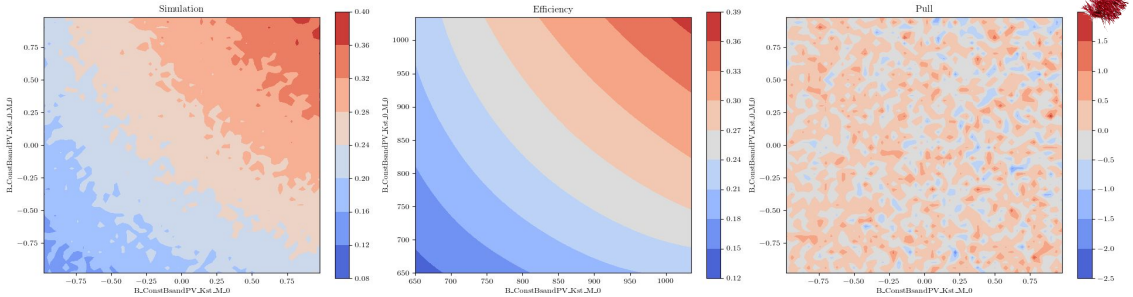
B2VV acceptance studies



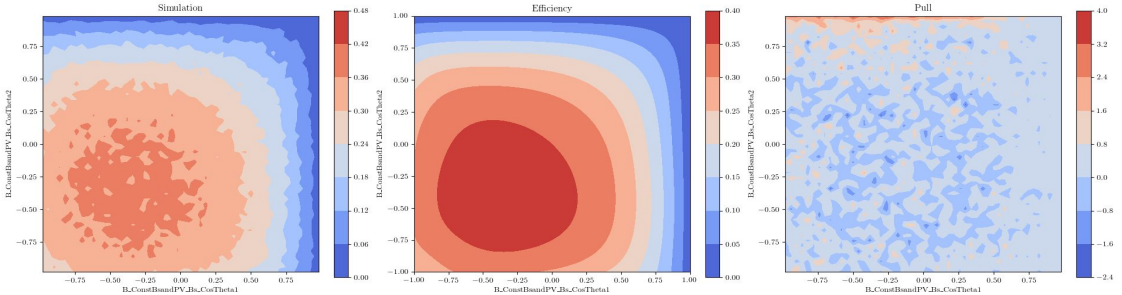
- Model the 5D acceptance of $m(K^{*0})$, $m(\overline{K^{*0}})$, $\cos(\theta_1)$, $\cos(\theta_2)$, ϕ
- Model using Legendre Polynomials
- Verified using a BDT method
- Method can be used across B2VV analyses

First Few Legendre Polynomials:

$P(x,0)$	1
$P(x,1)$	x
$P(x,2)$	$\frac{1}{2}(3x^2-1)$
$P(x,3)$	$\frac{1}{2}(5x^3-3x)$
$P(x,4)$	$\frac{1}{8}(35x^4-30x^2+3)$



Results for $m(K^{*0})$ vs $m(\overline{K^{*0}})$



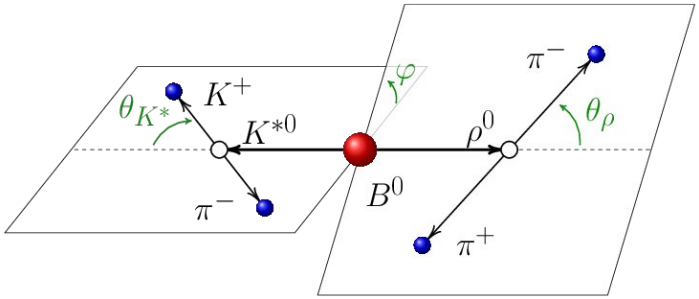
Results for $\cos(\theta_1)$ vs $\cos(\theta_2)$

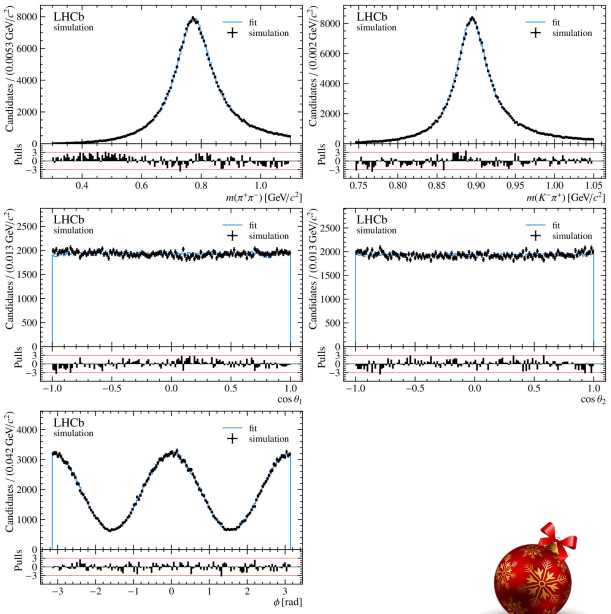
B2VV angular fitter

- Work in progress
- Angular fit to the vars: $m(V_1), m(V_2), \cos(\theta_1), \cos(\theta_2), \phi$
- Depending on the decay, many amplitudes and interferences can contribute

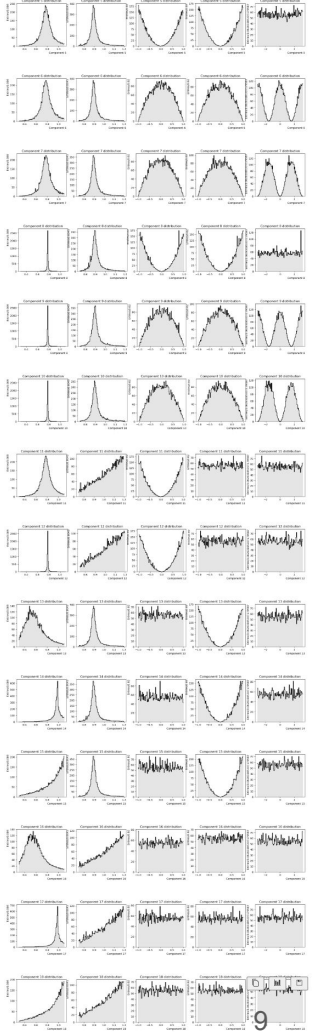
$$\begin{aligned}
&\mathcal{A}_{VV} + \mathcal{A}_{VS} + \mathcal{A}_{SV} + \mathcal{A}_{SS} \\
&= -\frac{3N}{4\pi}\Big[\big(A_0 \cos\theta_1 \cos\theta_2 + \frac{A_\parallel}{\sqrt{2}} \sin\theta_1 \sin\theta_2 \cos\phi \\
&\quad + i\frac{A_\perp}{\sqrt{2}} \sin\theta_1 \sin\theta_2 \sin\phi\big)\ \mathcal{M}_1(m_1)\mathcal{M}_1(m_2) \\
&\quad - \frac{A_{VS}}{\sqrt{3}} \cos\theta_1 \mathcal{M}_1(m_1)\mathcal{M}_0(m_2) + \frac{A_{SV}}{\sqrt{3}} \cos\theta_2 \mathcal{M}_0(m_1)\mathcal{M}_1(m_2) \\
&\quad - \frac{A_{SS}}{3} \mathcal{M}_0(m_1)\mathcal{M}_0(m_2)\Big],
\end{aligned}$$

6 amplitudes in $B_s^0 \to K^{*0}\overline{K}^{*0}$





Fit to generator level MC

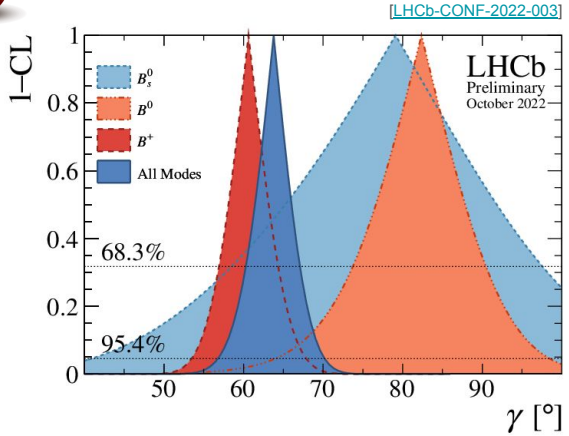


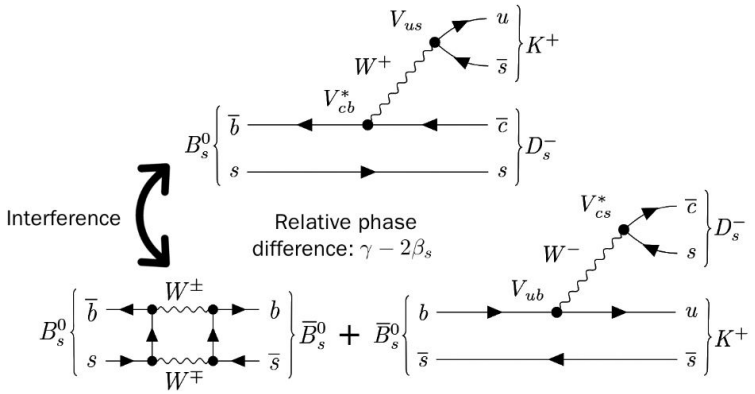
14 amplitudes in $B^0 \to \rho^0 K^{*0}$

Determination of γ

- CKM Fitter:
  $\gamma = (65.5^{+1.1}_{-2.7})^\circ$
- LHCb Combination:
  $\gamma = (63.8^{+3.5}_{-3.7})^\circ$
- **New:** Run 2 measurement $B_s^0 \to D_s^\mp K^\pm$
  $\gamma = (74 \pm 11)^\circ$

[LHCb-CONF-2022-003]





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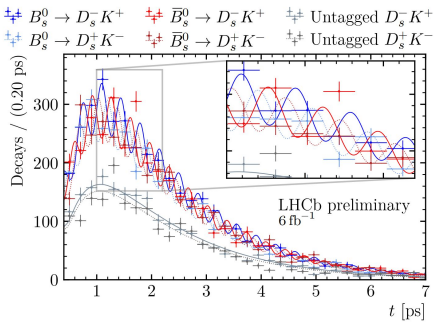

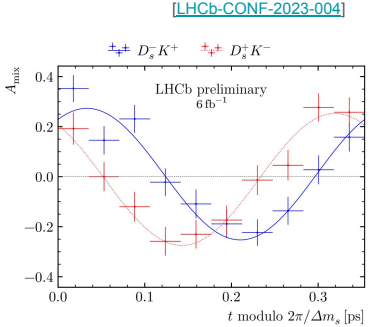


Thanks for your attention!
Matthew
Francesca
Callum
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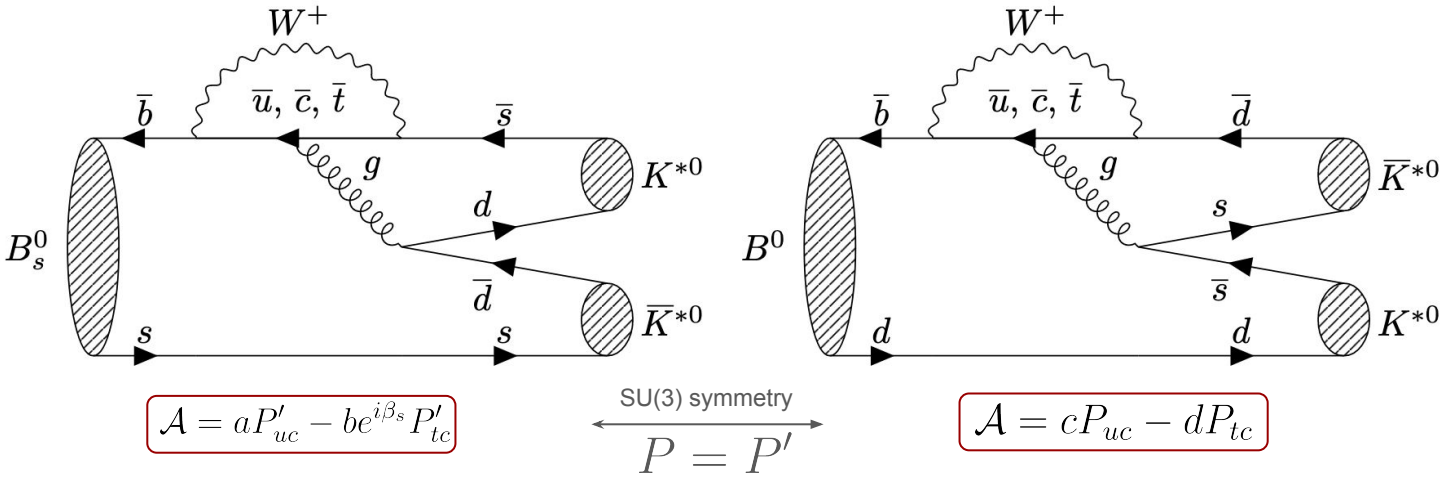
Davide
Jordy
Tianqi

Backup

CP violation, less simplified



a, *b*, *c* and *d* well known