Measurement of $B^+ \to J/\psi\, \rho^+$ at LHCb

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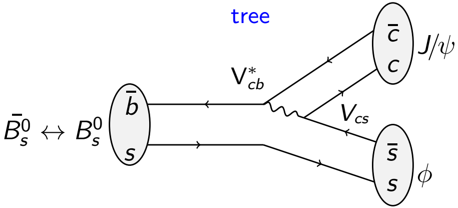
Terascale Workshop 2018
DESY Hamburg
18-11-27

Penguin Pollution in $B_s^0 \to J/\psi\,\phi$



- New physics could enlarge angle ϕ_s from *CPV* between mixing and decay, see S. Stemmle's talk
- ϕ_s^{tree} predicted precisely for "Golden mode" $B_s^0 \to J/\psi\,\phi$

$$\phi_s^{\text{obs}} = \phi_s^{\text{tree}} + \Delta\phi_s^{\text{NP}}$$

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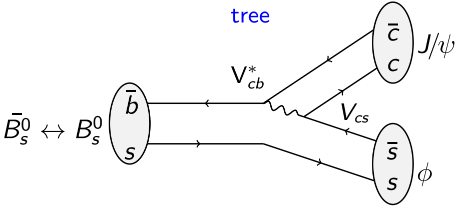

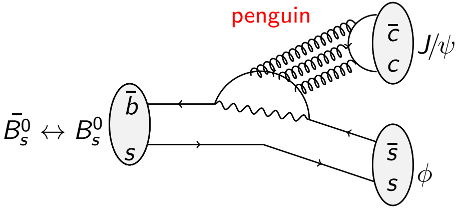

- New physics could enlarge angle ϕ_s from *CPV* between mixing and decay, see S. Stemmle's talk
- ϕ_s^{tree} predicted precisely for "Golden mode" $B_s^0 \to J/\psi\,\phi$,but additional shift from penguin decay:

$$\phi_s^{\text{obs}} = \phi_s^{\text{tree}} + \Delta\phi_s^{\text{NP}} + \Delta\phi_s^{\text{peng}}$$

$\Rightarrow$ Need to measure $\Delta\phi_s^{\text{peng}}$ to probe for $\Delta\phi_s^{\text{NP}}$
$\Rightarrow$ Measure CPV in decays with similar topology, but CKM suppressed tree amplitude $\Rightarrow$ Use SU(3)$_f$ to infer $\Delta\phi_s^{\text{peng}}$

current exp. precision

$\sigma(\phi_s^{\text{obs}}) \approx 31$ mrad
$\Delta\phi_s^{\text{peng}} = 3 \pm 14$ mrad

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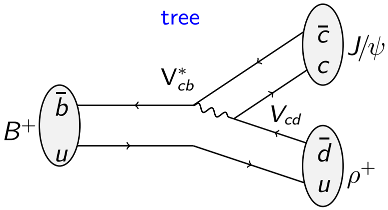
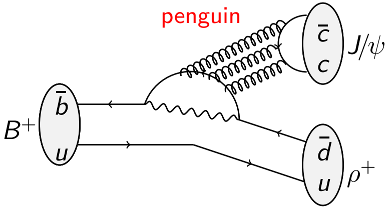




- New physics could enlarge angle ϕ_s from *CPV* between mixing and decay, see S. Stemmle's talk
- ϕ_s^{tree} predicted precisely for "Golden mode" $B_s^0 \to J/\psi\,\phi$, but additional shift from penguin decay:

$$\phi_s^{\text{obs}} = \phi_s^{\text{tree}} + \Delta\phi_s^{\text{NP}} + \Delta\phi_s^{\text{peng}}$$

$\Rightarrow$ Need to measure $\Delta\phi_s^{\text{peng}}$ to probe for $\Delta\phi_s^{\text{NP}}$
$\Rightarrow$ Measure CPV in decays with similar topology, but CKM suppressed tree amplitude $\Rightarrow$ Use $SU(3)_f$ to infer $\Delta\phi_s^{\text{peng}}$

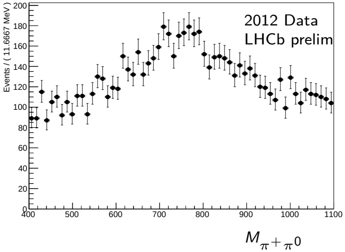
current exp. precision

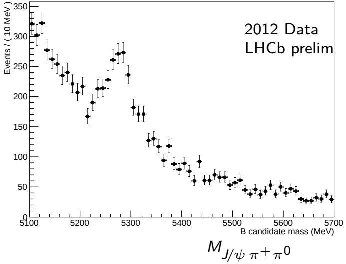
$\sigma(\phi_s^{\text{obs}}) \approx 31$ mrad
$\Delta\phi_s^{\text{peng}} = 3 \pm 14$ mrad

Can use $\mathcal{A}^{CP}$ of $SU(3)_f$ related decays like $B^+ \to J/\psi\,\rho^+$ to constrain $\Delta\phi_s^{\text{peng}}$

Strategy $B^+ \to J/\psi\,\rho^+$

- Use data corresponding to $3\,\text{fb}^{-1}$ taken in RunI
- Reconstruct $J/\psi \to \mu^+\mu^-$ and $\rho^+ \to \pi^+(\pi^0 \to \gamma\gamma)$
- hadronic environment $\Rightarrow$ large background due to γ and of π^0 from pp collision
- Neural net to reduce both combinatoric background from random γ and π^0 and partially reconstructed background from e.g. $B^+ \to J/\psi\,K^{*+}$, where $K^{*+} \to \pi^+(K^0 \to \pi^0\not\pi^0)$
- 2D fit in $M_{\pi^+\pi^0}$ and $M_{J/\psi\,\pi^+\pi^0}$ to distinguish $B^+ \to J/\psi\,\rho^+$ from swave $B^+ \to J/\psi\,\pi^+\pi^0$
- use $B^+ \to J/\psi\,K^+$ as normalisation channel to measure $\mathcal{B}(B^+ \to J/\psi\,\rho^+) = \frac{\mathcal{B}(B^+\to J/\psi\,K^+)}{\mathcal{B}(\pi^0\to\gamma\gamma)} \times \frac{\varepsilon_{B^+\to J/\psi\,K^+}}{\varepsilon_{B^+\to J/\psi\,\rho^+}} \times \frac{N_{fit,B^+\to J/\psi\,\rho^+}}{N_{fit,B^+\to J/\psi\,K^+}}$
- for charged B^+ no flavour-tagging needed to measure asymmetry: $\mathcal{A}^{CP}(B^+ \to J/\psi\,\rho^+) \approx \frac{N^{B^-}-N^{B^+}}{N^{B^-}+N^{B^+}}$





$B^+ \to J/\psi\,\rho^+$ and $B^+ \to J/\psi\,\pi^+\pi^0$ PDFs

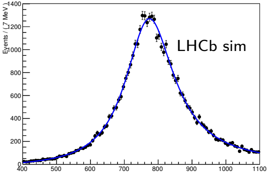
Need 2D fit to distinguish non-resonant $B^+ \to J/\psi\,\pi^+\pi^0$ from $B^+ \to J/\psi\,\rho^+$

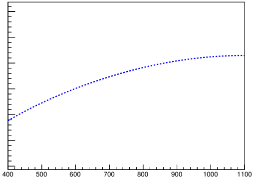
$B^+ \to J/\psi\,\rho^+$

M_{ρ^+}: rel Breit Wigner
$M_{J/\psi\,\rho^+}$: double crystal ball with floating mean and widths

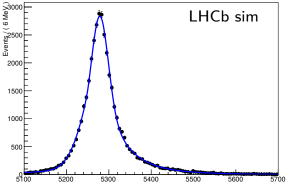
$B^+ \to J/\psi\,\pi^+\pi^0$

$M_{\pi^+\pi^0}$: phase space
$M_{J/\psi\,\pi^+\pi^0}$: **same shape as** $B^+ \to J/\psi\,\rho^+$





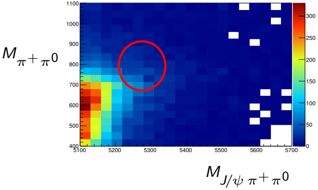
$M_{\pi^+\pi^0}$

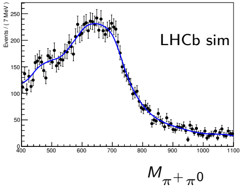


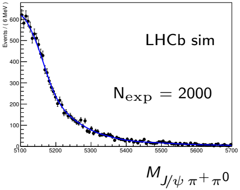
$M_{J/\psi\,\pi^+\pi^0}$

correlations between $M_{\pi^+\pi^0}$ and $M_{J/\psi\,\pi^+\pi^0}$ $\Rightarrow$ include in pdf

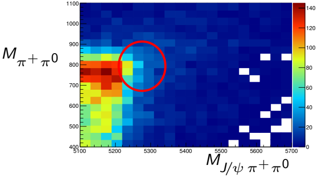
$B^+ \to J/\psi\, K^{*+}$ with $K^{*+} \to \pi^+ K^0$ and $K^0 \to \pi^0 \not{\pi}^0$

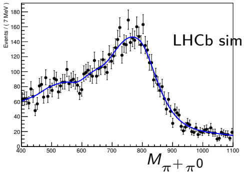


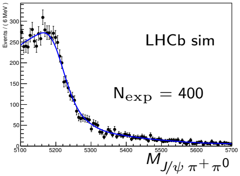




$B_s^0 \to J/\psi\, \phi$ with $\phi \to \pi^+ \pi^0 \not{\pi}^-$



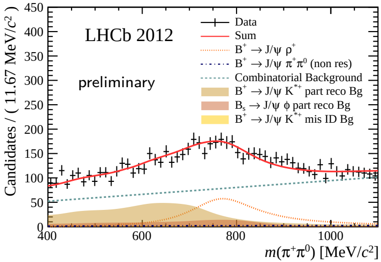


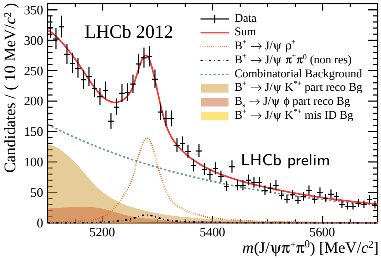


Branching Ratio

- simultaneous for 2011 and 2012 with independent yields, shared pdf shapes and $B^+ \to J/\psi\,\pi^+\pi^0$ fraction
- large combinatoric background component from random π^0 from PV described with polynomial in $M_{\pi^+\pi^0}$ and exponential in $M_{J/\psi\,\pi^+\pi^0}$
- fit simultaneously for $\mathcal{B}(B^+ \to J/\psi\,\rho^+) = \frac{\mathcal{B}(B^+\to J/\psi\,K^+)}{\mathcal{B}(\pi^0\to\gamma\gamma)} \times \frac{\varepsilon_{B^+\to J/\psi\,K^+}}{\varepsilon_{B^+\to J/\psi\,\rho^+}} \times \frac{N_{fit,B^+\to J/\psi\,\rho^+}}{N_{fit,B^+\to J/\psi\,K^+}}$
- leading systematic uncertainties:
  - π^0 reconstruction efficiency: $\pm 0.24 \times 10^{-5}$
  - pdf shapes: $\pm 0.15 \times 10^{-5}$

$$\mathcal{B}(B^+ \to J/\psi\,\rho^+) = (3.81^{+0.25}_{-0.24}(\mathrm{stat}) \pm 0.35(\mathrm{syst})) \times 10^{-5}$$

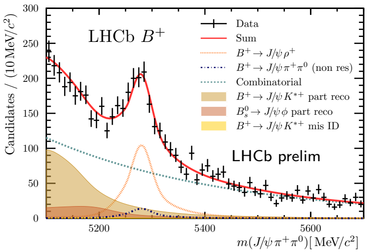


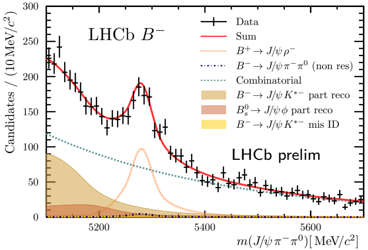


CP Asymmetry

- simultaneous for 2011 and 2012 with independent yields, shared pdf shapes and $B^+ \to J/\psi \pi^+ \pi^0$ fraction
- split samples by charge of $\pi^\pm$
- fix $\mathcal{A}^{\text{fit}}$ of $B_s^0 \to J/\psi \phi$ and $B^+ \to J/\psi K^{*+}$ to known values
- fit for $\mathcal{A}^{CP}(B^+ \to J/\psi \rho^+) = \frac{N_{\text{sig}}^- - N_{\text{sig}}^+}{N_{\text{sig}}^- + N_{\text{sig}}^+} - \mathcal{A}^{\text{prod}}(B^+)$
- many uncertainties cancel in ratio, largest remaining:
  - $\mathcal{A}^{\text{prod}}(B^+)$, $\mathcal{A}^{CP}$ $(B^+ \to J/\psi K^{*+})$: $\pm 0.6\%$
  - pdf shapes: $\pm 0.5\%$

$$\mathcal{A}^{CP}\ (B^+ \to J/\psi \rho^+) = (-4.5^{-5.6}_{+5.7}(\text{stat}) \pm 0.8(\text{syst}))\%$$

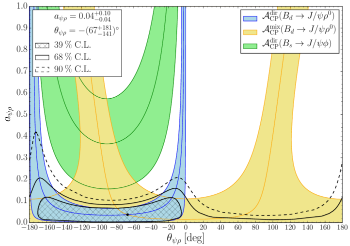




- Now one can use $\mathcal{A}^{dir}_{CP}(B^+ \to J/\psi\,\rho^+) = \frac{2a \sin\theta \sin\gamma}{1 - 2a\cos\theta\cos\gamma + a^2}$
- a, $\theta \approx$ relative strength and **strong** phase between penguin and tree
- constrain $\Delta\phi_s^{\mathrm{peng}}(a,\theta)$ with $\tan \Delta\phi_s^{\mathrm{peng}} = -\frac{2a\epsilon\cos\theta\sin\gamma - a^2\epsilon^2\sin 2\gamma}{1 - 2a\epsilon\cos\theta\cos\gamma + a^2\epsilon^2\cos 2\gamma}$
- $\epsilon = \frac{\lambda^2}{1-\lambda^2} \approx 0.05$ relative CKM suppression of penguin between $b \to ccs$ and $b \to ccd$

$$\mathcal{A}^{CP}\,(B^+ \to J/\psi\,\rho^+) = (-4.5^{-5.6}_{+5.7}(\mathrm{stat}) \pm 0.8(\mathrm{syst}))\%$$

K. De Bruyn, R. Fleischer [JHEP 03 (2015) 145]



blue area: constraint for
$$\mathcal{A}^{CP}_{\mathrm{dir}}(B^0 \to J/\psi\,\rho^0) = (-6.3 \pm 5.6_{\mathrm{stat}} \pm^{1.9}_{1.4\,\mathrm{syst}})\%$$
$\Rightarrow$ can expect similar/better constraint from $B^+ \to J/\psi\,\rho^+$

Conclusion

- ultimate precision on ϕ_s depends also on the exact determination of the penguin pollution $\Delta\phi_s^{\mathrm{peng}}$ $\Rightarrow$ determine it with CP observables from $\mathrm{SU}(3)_f$ related modes
- LHCb measured from ≈ 1600 $B^+ \to J/\psi\,\rho^+$ decays in Run I
  $\mathcal{B}(B^+ \to J/\psi\,\rho^+) = (3.81^{+0.25}_{-0.24}(\mathrm{stat}) \pm 0.35(\mathrm{syst})) \times 10^{-5}$
  - $\mathcal{B}(B^+ \to J/\psi\,\rho^+)_{\mathrm{BaBar}} = (5.0 \pm 0.7_{\mathrm{stat}} \pm 0.3_{\mathrm{syst}}) \times 10^{-5}$
- measured $\mathcal{A}^{CP}\,(B^+ \to J/\psi\,\rho^+) = (-4.5^{-5.6}_{+5.7}(\mathrm{stat}) \pm 0.8(\mathrm{syst}))\%$
  - $\mathcal{A}^{CP}(B^+ \to J/\psi\,\rho^+)_{\mathrm{BaBar}} = (-11 \pm 12_{\mathrm{stat}} \pm 8_{\mathrm{syst}})\%$

Thanks for your attention!

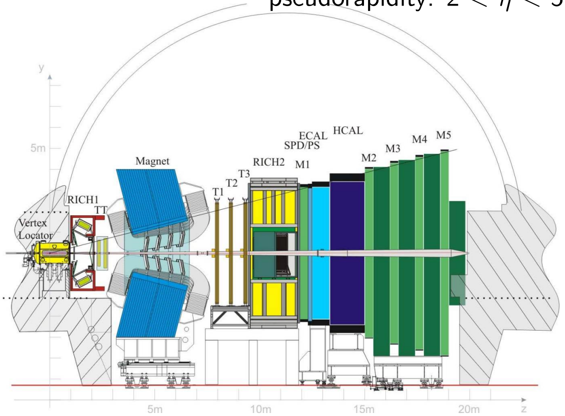
Backup

The LHCb detector

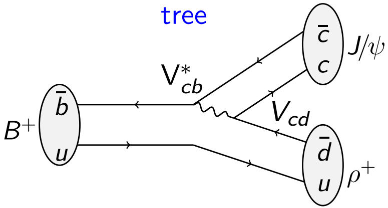
[JINST 3 (2008) S08005]

- Forward spectrometer designed for study of beauty and charm physics
- momentum resolution (0.5 - 1.0)% up to 200 GeV
- impact parameter resolution (15 $+29/p_{\mathrm{T}}$ [GeV]) $\mu\mathrm{m}$
- tracking and PID efficiency $>90\%$

pseudorapidity: $2 < \eta < 5$

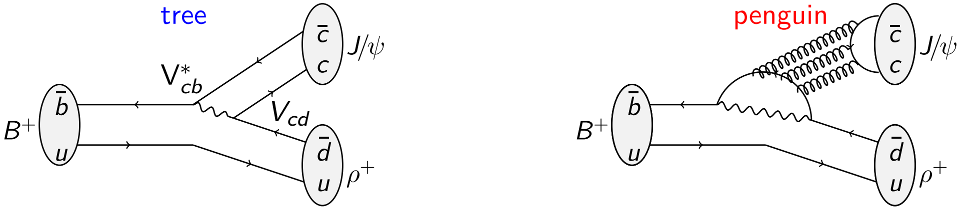


How can $\Delta\phi_s^{\text{peng}}$ be estimated?



- $A(B^+ \to J/\psi\,\rho^+) = V_{cd}\, a e^{i\theta} e^{i\gamma} \mathcal{A}$

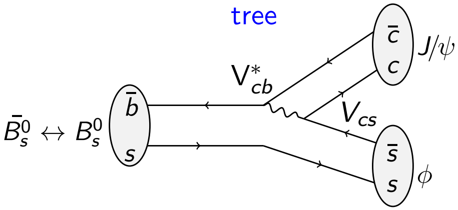
$a e^{i\theta} \approx$ **relative** strength of topology and strong phase difference of penguin wrt tree,
$\epsilon = \frac{\lambda^2}{1-\lambda^2} \approx 0.05$ relative CKM suppression of penguin between $b \to ccs$ and $b \to ccd$

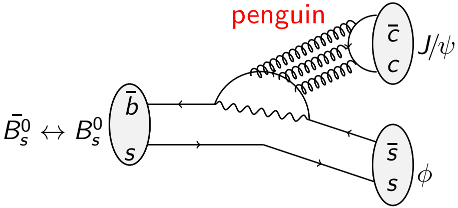


- $A(B^+ \to J/\psi\,\rho^+) = V_{cd}(1 - ae^{i\theta}e^{i\gamma})\mathcal{A} \Leftarrow$ penguin not suppressed

$ae^{i\theta} \approx$ **relative** strength of topology and strong phase difference of penguin wrt tree,
$\epsilon = \frac{\lambda^2}{1-\lambda^2} \approx 0.05$ relative CKM suppression of penguin between $b \to ccs$ and $b \to ccd$

How can $\Delta\phi_s^{\text{peng}}$ be estimated?





- $A(B^+ \to J/\psi\,\rho^+) = V_{cd}(1 - ae^{i\theta}e^{i\gamma})\mathcal{A}$ ⇐ penguin not suppressed
- $A'(B_s^0 \to J/\psi\,\phi) = V_{cs}(1 + \epsilon a' e^{i\theta'} e^{i\gamma})\mathcal{A}'$ ⇐ penguin suppressed

$ae^{i\theta} \approx$ **relative** strength of topology and strong phase difference of penguin wrt tree,
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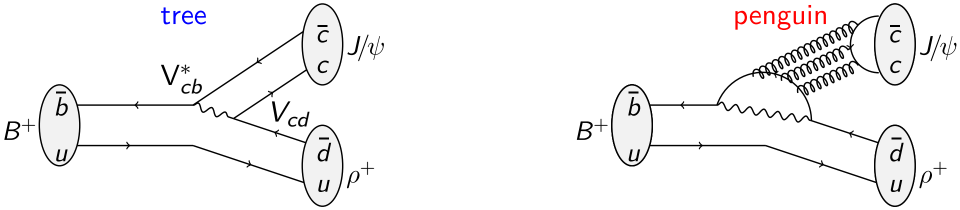

- $A(B^+ \to J/\psi\,\rho^+) = V_{cd}(1 - ae^{i\theta}e^{i\gamma})\mathcal{A} \Leftarrow$ penguin not suppressed
- $A'(B_s^0 \to J/\psi\,\phi) = V_{cs}(1 + \epsilon a' e^{i\theta'} e^{i\gamma})\mathcal{A}' \Leftarrow$ penguin suppressed
- $\mathrm{SU}(3)_f$: $a' e^{i\theta'} = ae^{i\theta}$

$ae^{i\theta} \approx$ **relative** strength of topology and strong phase difference of penguin wrt tree,
$\epsilon = \frac{\lambda^2}{1-\lambda^2} \approx 0.05$ relative CKM suppression of penguin between $b \to ccs$ and $b \to ccd$

Can use $\mathcal{A}^{CP}$ $(B^+ \to J/\psi\,\rho^+)$ to constrain $\Delta\phi_s^{\text{peng}}$

Systematic Uncertainties Branching Ratio

- reconstruction efficiency of π^0 determined from $B^+ \to J/\psi\, K^{*+}$ with $K^{*+} \to \pi^0 K^+$, dominant uncertainty: $\sigma(\mathcal{B}(B^+ \to J/\psi\, K^{*+})) = 5.6\%$
- Most fit shapes determined from simulated samples, models and parameters varied to assess uncertainty

Source of uncertainty	rel. uncertainty [%]
Trigger efficiency	1.4
track reconstruction efficiency	0.5
π^0 reconstruction efficiency	6.3
Hadron identification efficiency	2.1
Muon identification efficiency	0.4
Selection efficiency $B^+ \to J/\psi\, K^+$	0.1
Selection efficiency $B^+ \to J/\psi\, \rho^+$	1.8
Multiple candidates	1.2
Fit shapes	4.0
$B^+ \to J/\psi\, \rho^+$ polarization	2.2
Fit ranges	1.6
Nonresonant line shape	1.5
Neglecting interference	2.8
Quadratic sum	9.1