CP asymmetries in $B_s \rightarrow \phi\phi$

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Physik E5

LHCb

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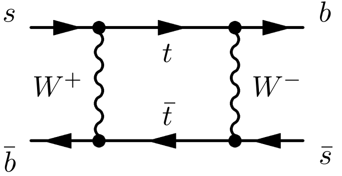
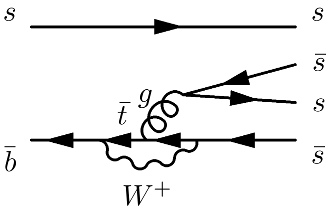
Why $B_s \to \phi\phi$?





Mixing parameter: $\frac{q}{p} = -e^{-i\Phi_M}$ with $\Phi_M \approx 2\,\mathrm{arg}(V_{tb}V_{ts}^*)$

Decay parameter: $\frac{\bar{A}_{\bar{f}}}{A_f} = e^{i\Phi_D}$ with $\Phi_D \approx \mathrm{arg}(\frac{V_{tb}V_{ts}^*}{V_{tb}^*V_{ts}})$

CP violation induced by interference $\propto \mathrm{Im}\lambda_f$

$$\lambda_f = \eta_{\mathrm{CP}} \frac{q}{p} \frac{\bar{A}_f}{A_f}$$

For $B_s \to \phi\phi$: $\mathrm{arg}(\lambda_f) := \Phi_s \approx 0$

Measurement of Φ_s in $B_s \to \phi\phi$

- sensitive to differences between penguin and box diagram contribution
- theoretically clean due to nil test
- $\Phi_s \neq 0 \quad \Rightarrow$ physics beyond the Standard Model
- natural complement to other channels measured by LHCb ($B_s \to J/\Psi\phi$, etc. . .)
- relatively low (visible) branching fraction – no “first physics“

Branching fraction measured by CDF

$[2.40 \pm 0.21(\text{stat}) \pm 0.27(\text{syst}) \pm 0.82(\text{BR})] \cdot 10^{-5}$ (presented at HEP EPS 09)

Amplitudes and angular distribution

$B_s \to \phi\phi$ is a P → V(PP) V(PP) decay

- three final states with angular momentum L=0,1,2
- CP-even and CP-odd final state differ by factor η_{CP} in λ_f
- disentangle by angular analysis.

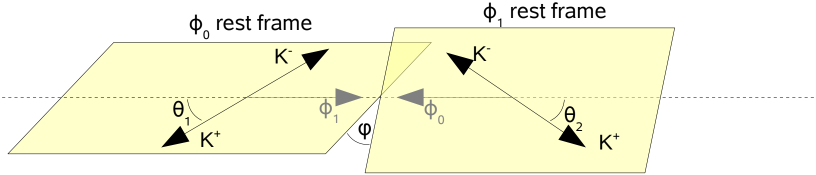
Angular distributions from helicity formalism:

$$\frac{d^3\Gamma}{d\cos\theta_1\ d\cos\theta_2\ d(\varphi_1+\varphi_2)} \propto \left| \sum_{h=-1}^{1} H_h(t) D^{1*}_{h,0}(\varphi_1,\theta_1,0) D^{1*}_{h,0}(\varphi_2,\theta_2,0) \right|^2$$

Transversity Base

L	CP	linear polarization amplitude
0/2	even	$A_0 = H_0$
0/2	even	$A_\parallel = \frac{1}{\sqrt{2}}(H_{+1} + H_{-1})$
1	odd	$A_\perp = \frac{1}{\sqrt{2}}(H_{+1} - H_{-1})$

Angular distributions



$$\frac{d^3\Gamma}{d\cos\theta_1\ d\cos\theta_2\ d\varphi} \propto$$

$$\begin{aligned}
|A_0(t)|^2 \quad &\cdot \quad 4\ \cos^2\theta_1\ \cos^2\theta_2 \\
+\left|A_{\|}(t)\right|^2 \quad &\cdot \quad \sin^2\theta_1\ \sin^2\theta_2\ (1+\cos 2\varphi) \\
+|A_{\perp}(t)|^2 \quad &\cdot \quad \sin^2\theta_1\ \sin^2\theta_2\ (1-\cos 2\varphi) \\
+\mathrm{Im}(A_{\|}^*(t)A_{\perp}(t)) \quad &\cdot \quad -2\sin^2\theta_1\ \sin^2\theta_2\ \sin 2\varphi \\
+\mathrm{Re}(A_0^*(t)A_{\|}(t)) \quad &\cdot \quad \sqrt{2}\ \sin 2\theta_1\ \sin 2\theta_2\ \cos\varphi \\
+\mathrm{Im}(A_0^*(t)A_{\perp}(t)) \quad &\cdot \quad -\sqrt{2}\ \sin 2\theta_1\ \sin 2\theta_2\ \sin\varphi
\end{aligned}$$

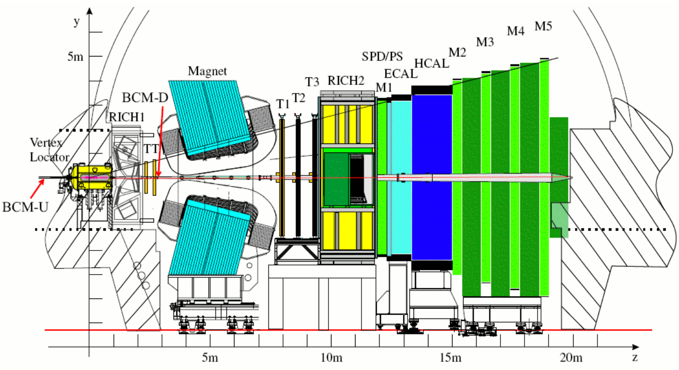
Time dependend amplitudes

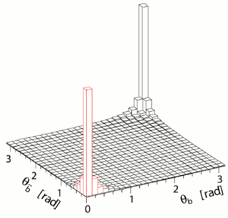
$$\begin{aligned}
|A_0(t)|^2 &= \frac{1}{2}|A_0(0)|^2 \left[(1+\cos\Phi_s)e^{-\Gamma_L t} + (1-\cos\Phi_s)e^{-\Gamma_H t} + 2e^{-\Gamma t}\sin(\Delta m t)\sin\Phi_s\right] \\
|A_\parallel(t)|^2 &= \frac{1}{2}|A_\parallel(0)|^2 \left[(1+\cos\Phi_s)e^{-\Gamma_L t} + (1-\cos\Phi_s)e^{-\Gamma_H t} + 2e^{-\Gamma t}\sin(\Delta m t)\sin\Phi_s\right] \\
|A_\perp(t)|^2 &= \frac{1}{2}|A_\perp(0)|^2 \left[(1-\cos\Phi_s)e^{-\Gamma_L t} + (1+\cos\Phi_s)e^{-\Gamma_H t} - 2e^{-\Gamma t}\sin(\Delta m t)\sin\Phi_s\right] \\
\mathrm{Im}(A_\parallel^*(t)A_\perp(t)) &= |A_\parallel(0)||A_\perp(0)| \\
&\quad \cdot \left[e^{-\Gamma t}(\sin\delta_1\cos(\Delta m t) - \cos\delta_1\sin(\Delta m t)\cos\Phi_s) - \frac{1}{2}(e^{-\Gamma_H t} - e^{-\Gamma_L t})\cos\delta_1\sin\Phi_s\right] \\
\mathrm{Re}(A_0^*(t)A_\parallel(t)) &= \frac{1}{2}|A_0(0)||A_\parallel(0)|\cos(\delta_2-\delta_1) \\
&\quad \cdot \left[(1+\cos\Phi_s)e^{-\Gamma_L t} + (1-\cos\Phi_s)e^{-\Gamma_H t} + 2e^{-\Gamma t}\sin(\Delta m t)\sin\Phi_s\right] \\
\mathrm{Im}(A_0^*(t)A_\perp(t)) &= |A_0(0)||A_\perp(0)| \\
&\quad \cdot \left[e^{-\Gamma t}(\sin\delta_2\cos(\Delta m t) - \cos\delta_2\sin(\Delta m t)\cos\Phi_s) - \frac{1}{2}(e^{-\Gamma_H t} - e^{-\Gamma_L t})\cos\delta_2\sin\Phi_s\right]
\end{aligned}$$

Determination of Φ_s

maximum likelihood fit

The LHCb experiment

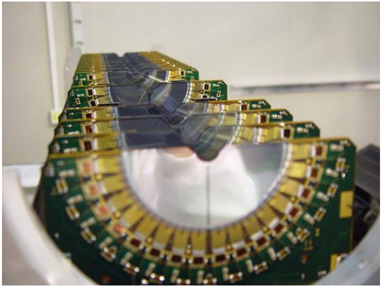




- Single arm forward spectrometer: $1.6 < \eta < 4.9$
- $2 \cdot 10^4$ b-quarks per seconds within detector acceptance

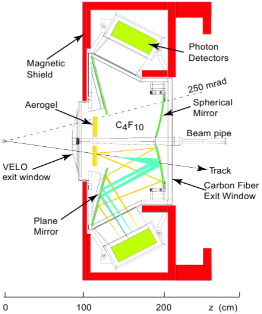
Decay length reconstruction and particle ID

Vertex Locator



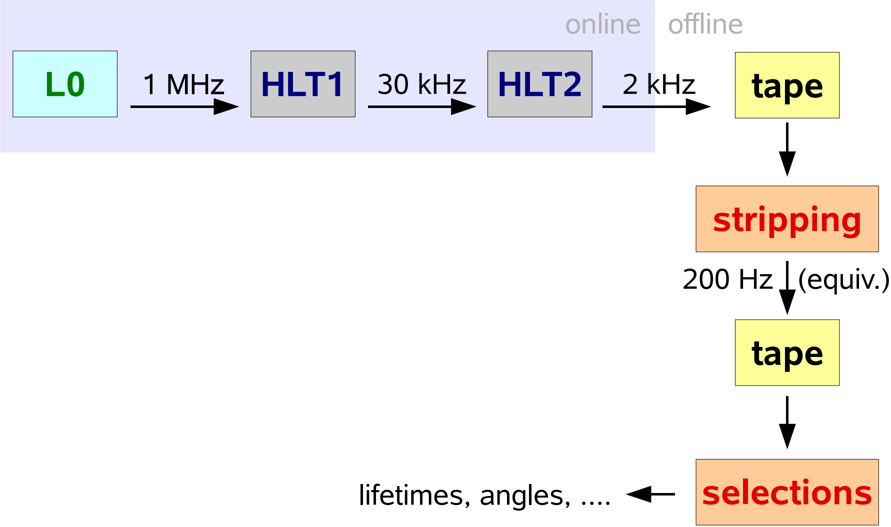
proper time resolution LHCb: 40 fs

Ring Imaging Cherenkov Detector



“$K \rightarrow K$” $\approx 97\%$, “$\pi \rightarrow K$” $\approx 4\%$

LHCb data flow



online

offline

L0

1 MHz

HLT1

30 kHz

HLT2

2 kHz

tape

stripping

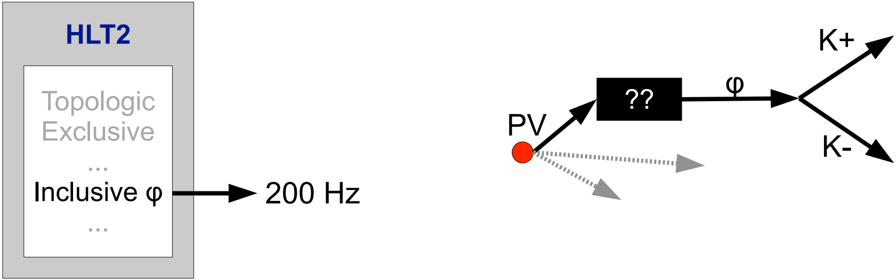
200 Hz (equiv.)

tape

selections

lifetimes, angles, ...

The HLT2 Inclusive ϕ Trigger



HLT2

Topologic
Exclusive
...
Inclusive φ
...

200 Hz

- Trigger designed to reconstruct and select non-prompt $\phi \to K^+K^-$
- Uses the RICH information to distinguish between kaons and pions
- Main trigger line for $B_s \to \phi\phi$

Stripping

Only global stripping runs over whole data set

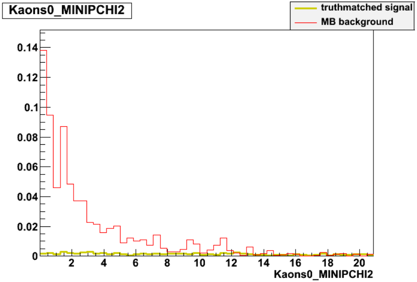
- Can be repeated, but not frequently
- First reduction by factor ≈10
- Presorting and categorization of data into different streams
- Keep all necessary info, but constrained by maximum rate per channel

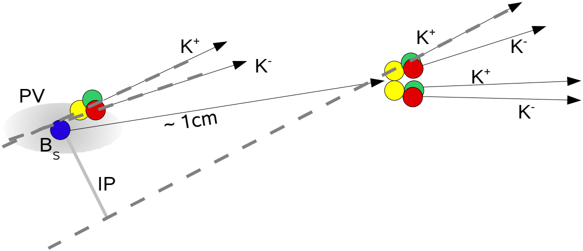
Final selection

- Run on stripped data set
- Apply final (harder) cuts
- Can be re-run more often, i.e. with newest software version

Background sources

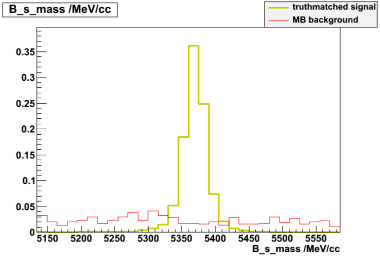
- large number of ϕ ($\geq$1 in 8% of all MB events)
- high combinatorics with K and misidentified π mesons
- effectively suppressed by Kaon IP-significance cut → lifetime bias!



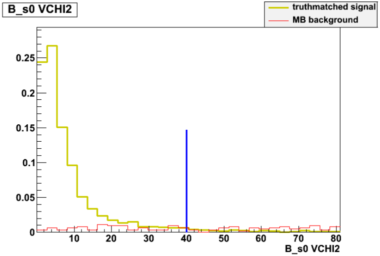


Further stripping cuts

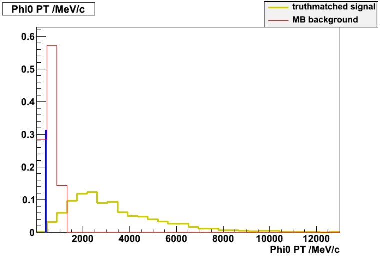
B_s mass



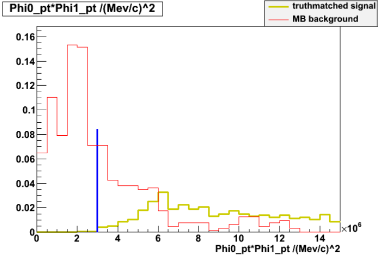
Vertex quality



Transverse momentum



$\mathrm{p_t}(\phi_0) \cdot \mathrm{p_t}(\phi_1)$



Futher: particle-ID and ϕ mass.

Efficiency including HLT2, stripping and final selection

signal	$\approx 2\%$	
$b\bar{b}$ background	$\approx 6 \cdot 10^{-8}$	(Poisson, 95% CL upper limit)

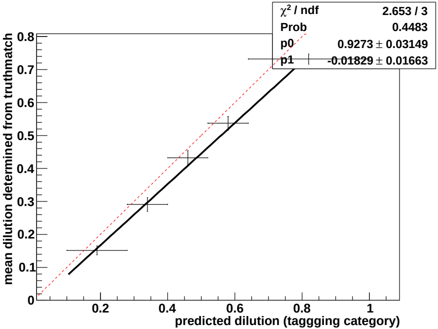
Event yield

in 2 fb^{-1}: 4800 (L0+Hlt1+Hlt2+selection)
$B_{b\bar{b}}/S < \mathcal{O}(10)$ (limited by background sample size!)

- low statistics
- neglects b purity of trigger ($\approx \frac{1}{3}$)

Tagging on MC09, Hlt2 true

tagging efficiency	0.650 ± 0.003
mean misstag	0.323 ± 0.004

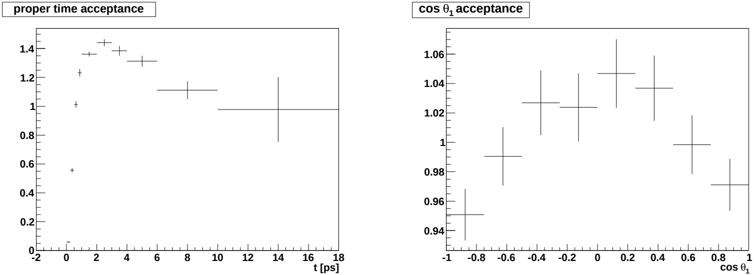


Tagging power

using mean misstag	0.08 ± 0.02	
using per event dilution	0.10	$(\int \epsilon(D)\ D^2\ dD)$

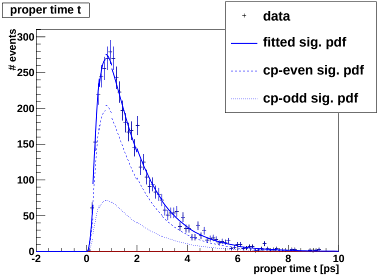
MC09 acceptance (projections)

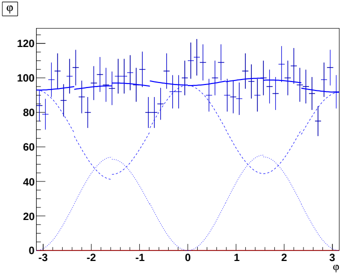
determined on 19k Hlt2 passed, selected signal monte carlo events

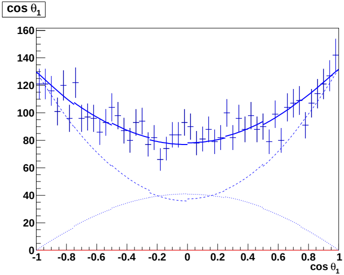


Fit to monte carlo

on 4800 Hlt2 passed, selected signal events







CP-even const $+ \cos^2 \varphi$
CP-odd $\sin^2 \varphi$

CP-even const $+ \cos^2 \theta$
CP-odd $(1 - \cos^2 \theta)$

Conclusions

- $B_s \rightarrow \phi\phi$ shows no CPV in the SM ($\Phi_S \approx 0$)
- Beyond standard model physics could introduce additional CP phase
- Measurement of CP phase possible at LHCb
- $\sigma(\Phi_S) \approx 0.1$ with one year of nominal LHCb data
  $\sigma(\Phi_S) \approx 0.05$ with five years (LHCb-2007-047)
- Discrimination between BSM models with respect to Φ_s