Flavour Tagging at LHCb

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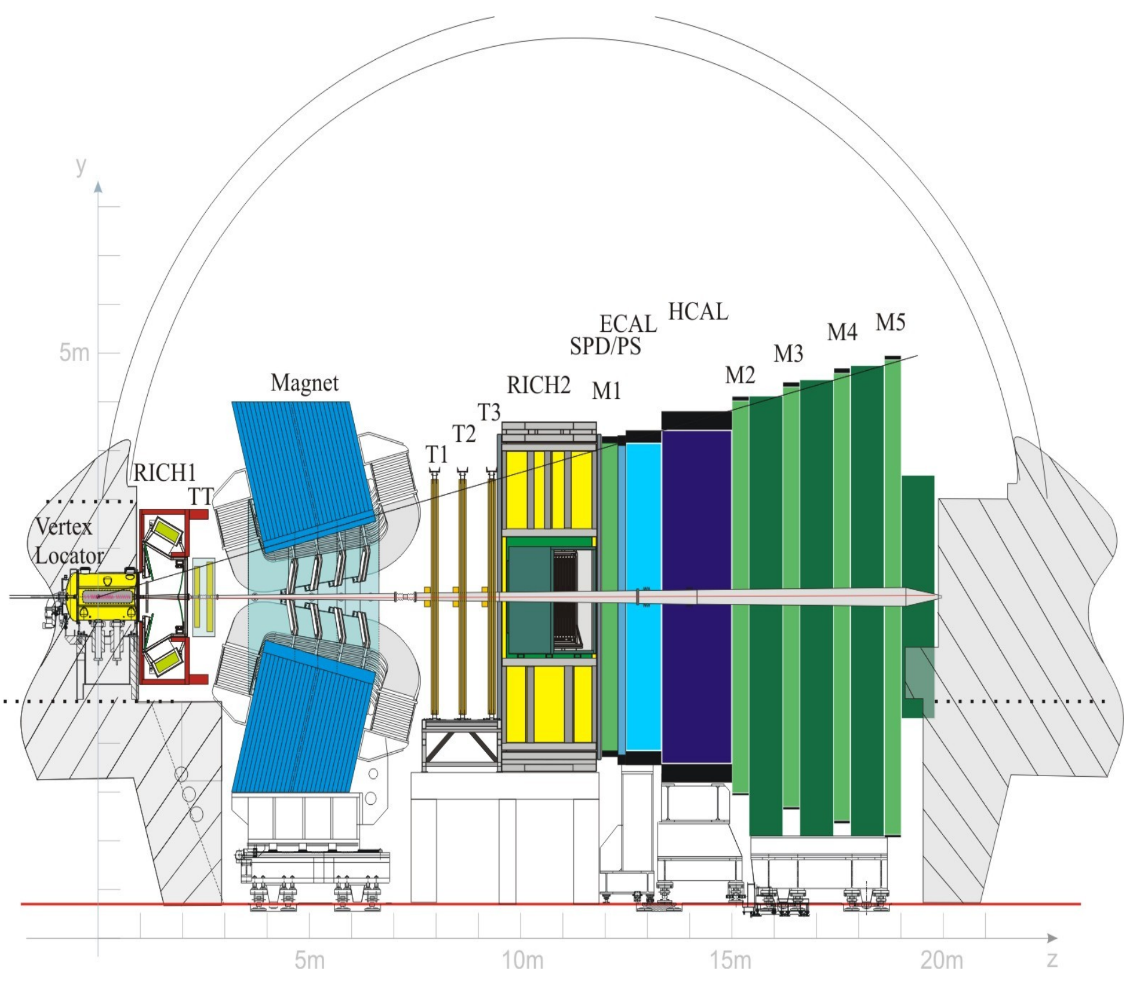
65th Scottish Universities Summer School in Physics: LHC Physics

The LHCb detector

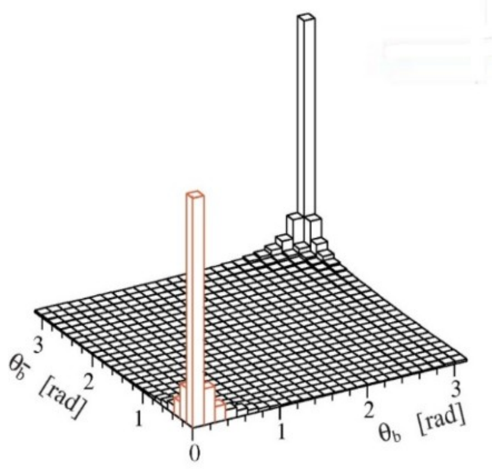


LHCb is characterized by excellent tracking and vertexing, particle identification system (good π – k separation capability), as well as a very good proper-time resolution and high trigger efficiencies, particular for muons.

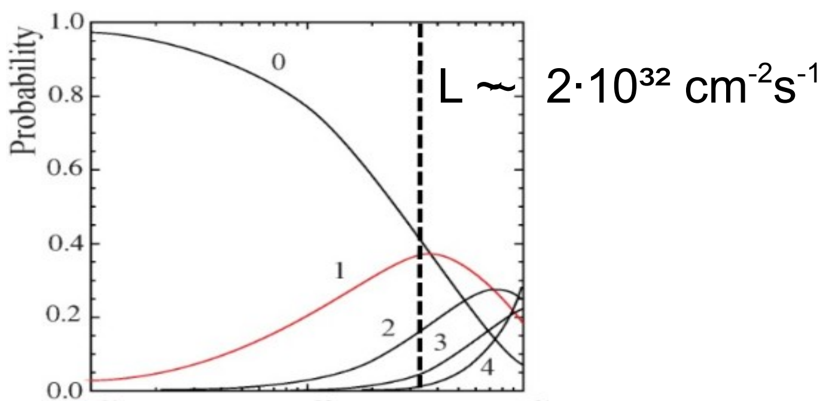
The experiment is commissioned and awaiting first collisions.

The LHCb detector is dedicated to the study of CP violation, flavour oscillation and rare decays in the B meson sector.

It is a forward spectrometer, with a 0.3 rad polar angle acceptance. This geometry is well suited to the forward correlated production of B mesons.



The nominal operating luminosity at LHCb will be tuned to optimise the number of single interaction events.

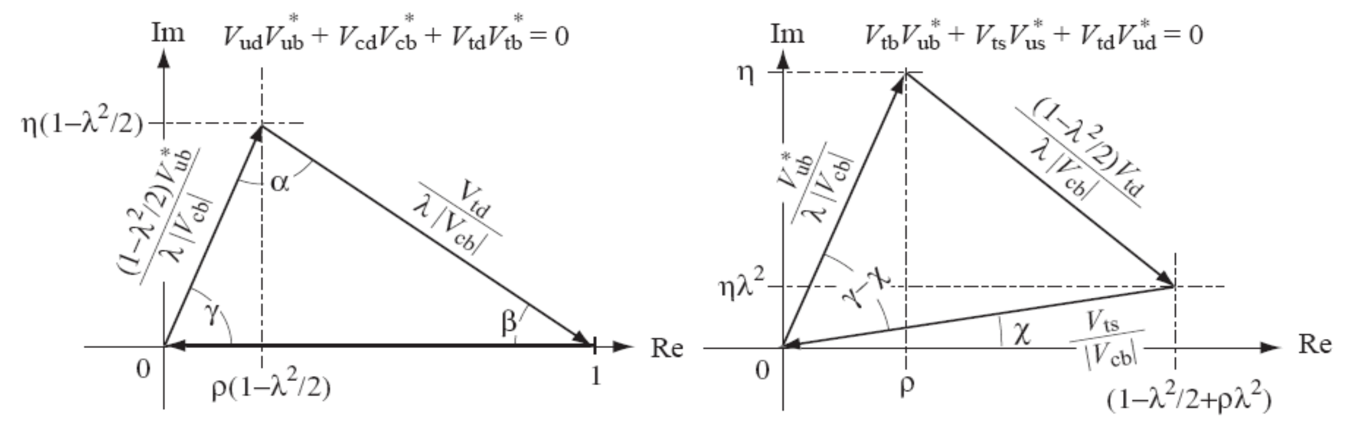


CP Violation in the B sector

In the SM CP violation is introduced through the CKM matrix, which describes the rotation between the weak eigenstates (d', s', b') and the mass eigenstates (d, s, b).

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

The unitarity of CKM matrix implies various relations among its elements, two of which are specially interesting for B physics. Each of these relations requires the sum of three complex quantities to vanish. Thus they can be geometrically represented in the complex plane as triangles.



$$\alpha = arg\left[-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right],$$

$$\beta = arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right],$$

$$\gamma = arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right],$$

$$\alpha + \beta + \gamma = \pi\ ,$$

$$\chi = arg\left[-\frac{V_{cb}V_{cs}^*}{V_{tb}V_{ts}^*}\right].$$

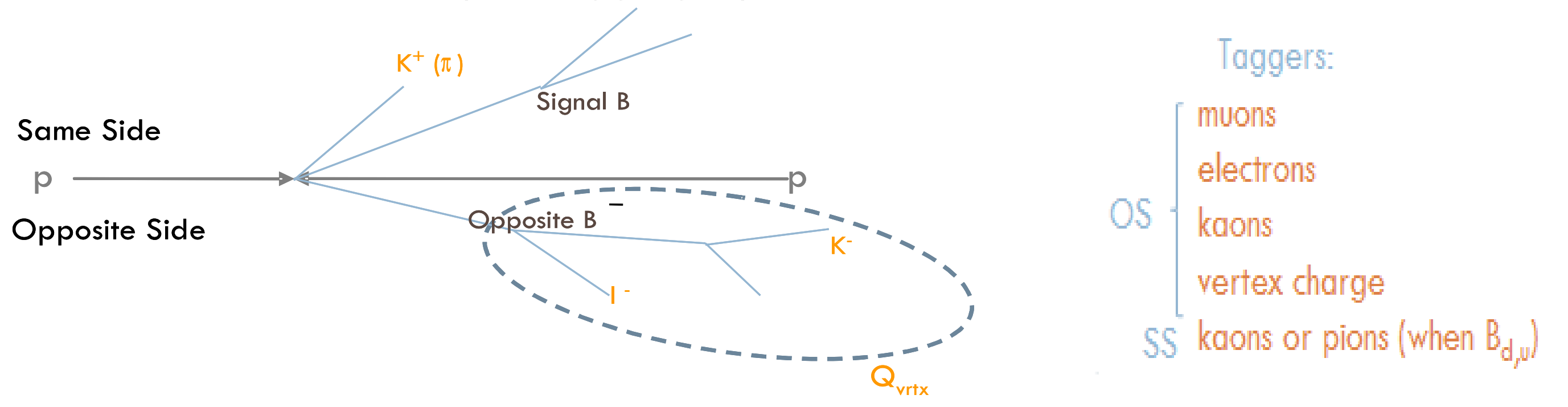
CP violation can manifest itself in the decay (interference among decay amplitudes), in the mixing (asymmetry in transitions $B^0 \rightarrow \overline{B}^0$ and $\overline{B}^0 \rightarrow B^0$) or in the interference of the two.

$$\mathcal{A}_{CP} = \frac{\Gamma(\overline{B}\to\overline{f}) - \Gamma(B\to f)}{\Gamma(\overline{B}\to\overline{f}) + \Gamma(B\to f)} = \frac{1-|\overline{A}_{\overline{f}}/A_f|^2}{1+|\overline{A}_{\overline{f}}/A_f|^2} \qquad \mathcal{A}_T = \frac{\Gamma(|\overline{B}^0_{phys}(t)\rangle \to l^+\nu X) - \Gamma(|B^0_{phys}(t)\rangle \to l^-\overline{\nu} X)}{\Gamma(|\overline{B}^0_{phys}(t)\rangle \to l^+\nu X) + \Gamma(|B^0_{phys}(t)\rangle \to l^-\overline{\nu} X)} \qquad \mathcal{A}_{fCP}(t) = \frac{\Gamma(|\overline{B}^0_{phys}(t)\rangle \to f_{CP}) - \Gamma(|B^0_{phys}(t)\rangle \to f_{CP})}{\Gamma(|\overline{B}^0_{phys}(t)\rangle \to f_{CP}) + \Gamma(|B^0_{phys}(t)\rangle \to f_{CP})}$$

The LHCb will make precise measurements of many CP violating asymmetries, as well as CP-conserving rate B-decays. All time dependent CP violating measurements require the knowledge of the initial flavour of the B-mesons – this is flavour tagging.

Tagging principles

The Flavour Tagging is the procedure which determines the flavour at the production of the reconstructed B meson, i.e. whether the meson contained a b or a b̄ quark. Tagging algorithms are usually classified into two groups: same side (SS) and opposite side (OS) algorithms. SS algorithms exploit the correlation of the charge of mesons produced in the fragmentation chain of the original flavour of the B signal. OS algorithms exploit the anti-correlation between the B hadrons produced in the same event, by looking at the decay products of the opposite B (the tagging B).



Tagging and dilution

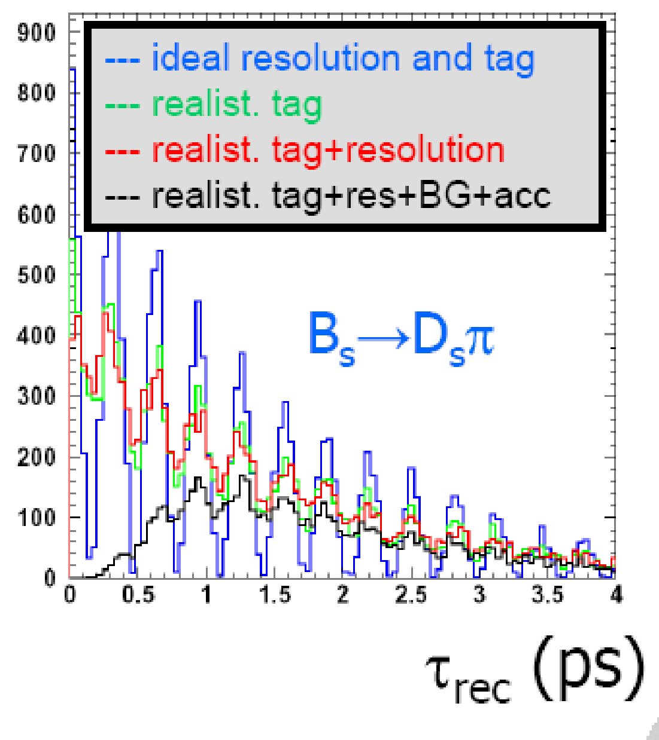
As the tagging decision is in general not perfect, the observed CP-asymmetry will be diluted with respect to the true asymmetry.

$$A_{measured} = \frac{\overline{N}(1-\omega) + N\omega - (\overline{N}\omega + N(1-\omega))}{\overline{N}+N} = (1-2\omega)\frac{\overline{N}-N}{\overline{N}+N} = DA_{true}$$

A perfect tagging would give D=1, while a totally random tagging (ω=50%), D=0. The statistical uncertanty on the measured CP asymmetries is directly related to the effective tagging efficiency, defined as

$$\varepsilon_{eff} = \varepsilon_{tag}D^2 = \varepsilon_{tag}(1-2\omega)^2$$

where ε_{tag} is the tagging efficiency (the probability that the tagging algorithm gives an answer), D the dilution term, and ω is the wrong tag fraction (the probability of the tagging assigment to be wrong)



Taggers

Opposite side taggers
The selection of tagging leptons and kaons is based on kinematical and topological cuts and particle identification, all tuned to maximize ε_{eff} (table below). If several candidates tracks exist of the same type, the one with highest p_t is selected.

	p_T (GeV/c)	p (GeV/c)	IP/σ
$\mu^\pm$	>1.1		
$e^\pm$	>1.1	>4	
$K^\pm$	>0.4	>4	>3.5

The opposite side B meson is also exploited by reconstructing an inclusive secondary vertex, weighting the charge of the tracks according to their p_t assuming that the vertex charge corresponds to that of the b quark.

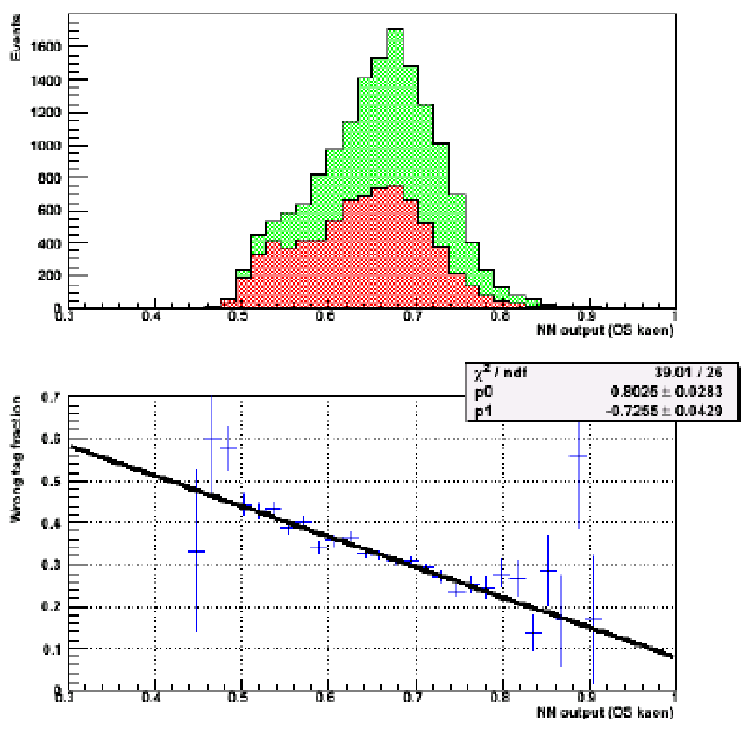
Same Side
In the fragmentation cascade, the accompanying quark in the B meson gives rise to a quark with opposite charge, which tends to form a pion (kaon) for B^0 (B^0_s)

The selection of pions and kaons requires cuts on p, p_t, Impact Parameter (IP), as well as rapidity and azimuthal angle cuts to select particles produced close in momentum space to the signal B hadron.

Tagger	B^0 ($B^0 \to \pi^+\pi^-$)			B_s ($B_s \to D_s K$)		
	ϵ_{tag} (%)	ω (%)	ϵ_{eff} (%)	ϵ_{tag} (%)	ω (%)	ϵ_{eff} (%)
OS $\mu^\pm$	8.7	32	1.14 ± 0.07	11.9	29.3	1.94 ± 0.09
OS $e^\pm$	3.6	33	0.39 ± 0.04	3.3	32.4	0.41 ± 0.04
OS $K^\pm$	28	36	2.09 ± 0.73	17.2	32.7	2.05 ± 0.10
OS vertex	22	39	1.01 ± 0.07	35.5	39.6	1.53 ± 0.09
SS $\pi^\pm/K^\pm$	15	39	0.73 ± 0.06	29.3	33.6	3.14 ± 0.12
Total	51	34	5.05 ± 0.22	62.6	31.2	8.83 ± 0.18

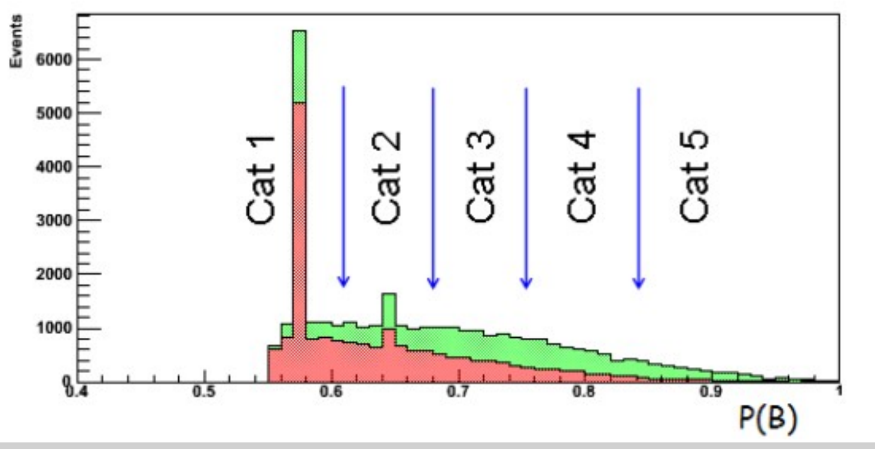
Combination

The final decision is taken combining all the individual tagger decisions. For each event, a wrong tag probability is computed for each of the tagger candidates using a Neural Net (NN). The NN takes as input several properties of the tagger and it is trained on independent MC samples. Each tagger gives an ω_i as a function of the NN output, comparing right and wrong tags (Figure: $B^+ \to J/\psi\ K^+$) .



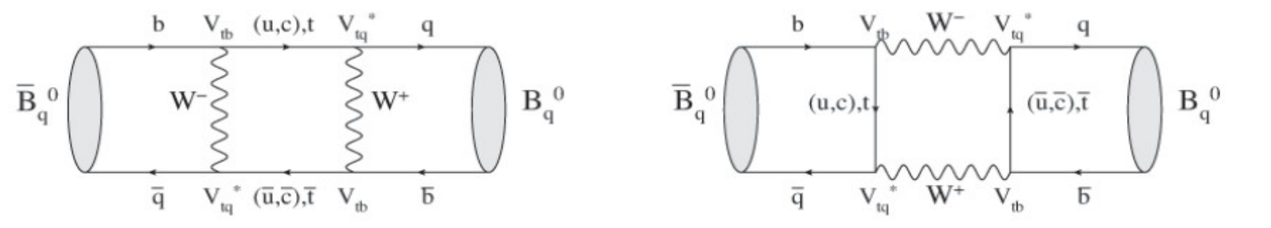
The calibration of ω_i needs to be performed with real data on control channels. It can be extracted from self-tagging control channels, where the flavour is determined by the charge of the decay products (i.e. $B^+ \to J/\psi\ K^+$), or by fitting the known oscillation pattern (i.e. $B^0 \to J/\psi\ K^{*0}$)

The global tag of the event is obtained by combaining the individual ω_i of the taggers in an overall ω. To calculate the final effective efficiency, events are grouped together in 5 categories of decreasing ω, to improve the global performance of the tagging.

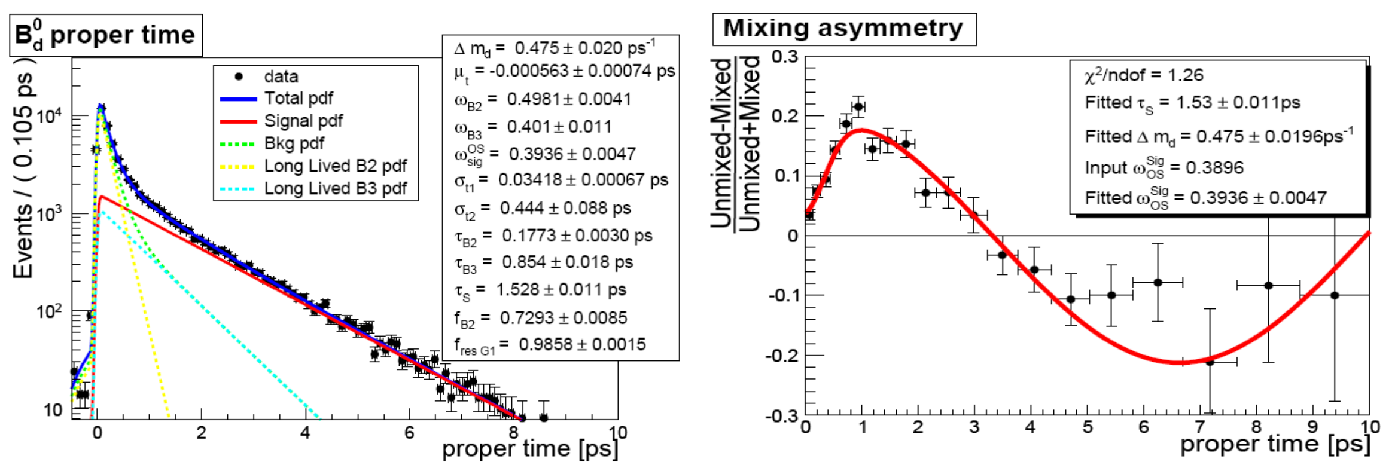


Example: measurement of β

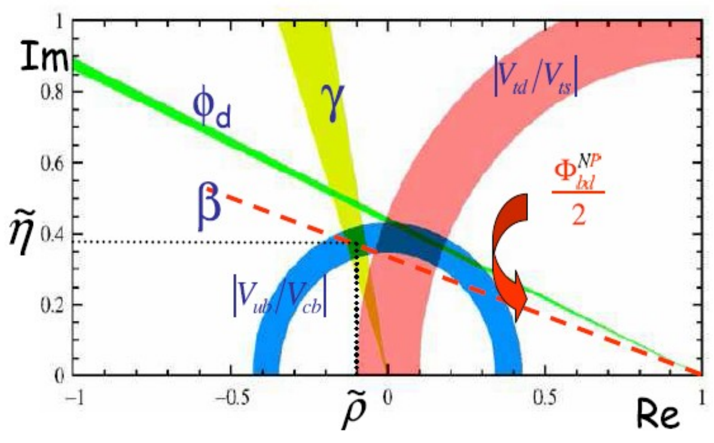
The interference between B^0 decays to $J/\psi\ K_S$ either directly or via oscillation, gives rise to a CP violating asymmetry which in the SM is sin(2β). The measurement of this phase will be a benchmark for LHCb.



For the evaluation of the mistag rate, we will use $B^+ \to J/\psi\ K^+$ to obtain the dependence of the mistag rate on the neural net output for each tagger, and obtain a combined probability per event used to subdivide $B^0 \to J/\psi\ K^{*0}$ and $B^0 \to J/\psi\ K_S$ events into 5 categories. The flavour oscillations in the $B^0 \to J/\psi\ K^{*0}$ channel will be fitted as a funtion of proper time, in each of the 5 categories, in order to measure the mistag rates which can then be used for the $B^0 \to J/\psi\ K_S$ CP channel.



The expected precision in the measurement of sin(2β) at LHCb will be σ(2β) ~ 0.03 for 2fb⁻¹ of data.



Possible scenario after one year of data taking at LHCb, with a contribution of new physics

References:
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J. Albrecht et al, LHCB-ROADMAP3-002

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