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Flavour Tagging performance in LHCb

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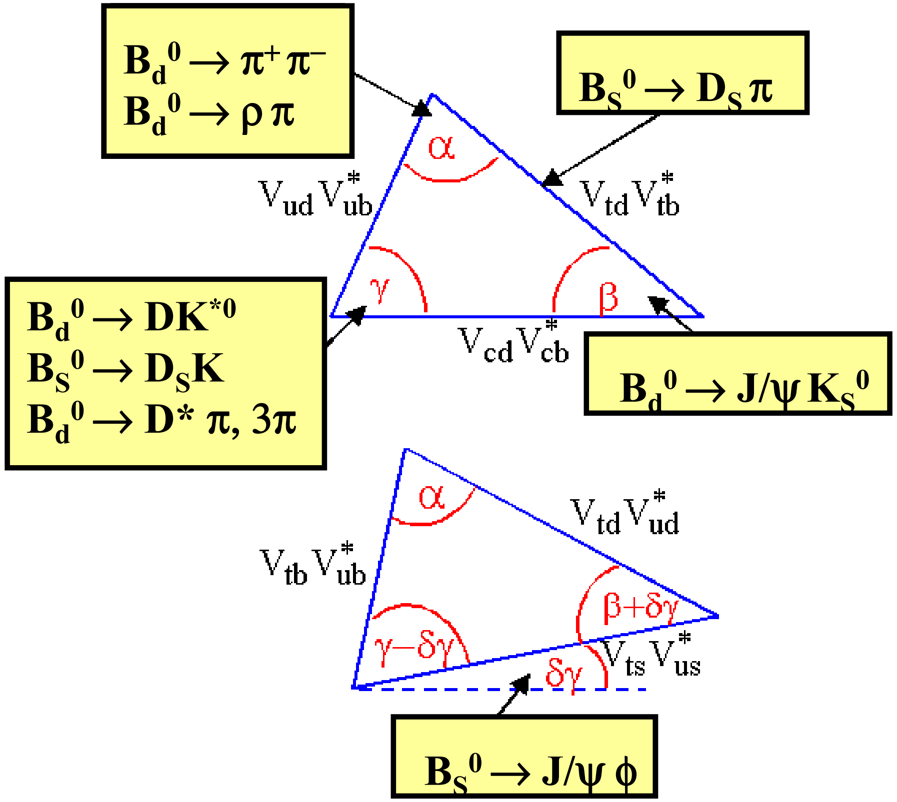
on behalf of the LHCb collaboration

Motivation

- LHCb is a 2nd generation precision experiment coming after B-Factories and Tevatron
- Improve precision on γ and other CKM parameters
- Many measurments require the knowledge of the initial flavour of the B meson

Unitarity Triangles



$B_d^0 \to \pi^+\pi^-$
$B_d^0 \to \rho\,\pi$

$B_S^0 \to D_S\,\pi$

$B_d^0 \to DK^{*0}$
$B_S^0 \to D_S K$
$B_d^0 \to D^*\,\pi,\ 3\pi$

$B_d^0 \to J/\psi\, K_S^0$

$B_S^0 \to J/\psi\,\phi$

Importance of tagging

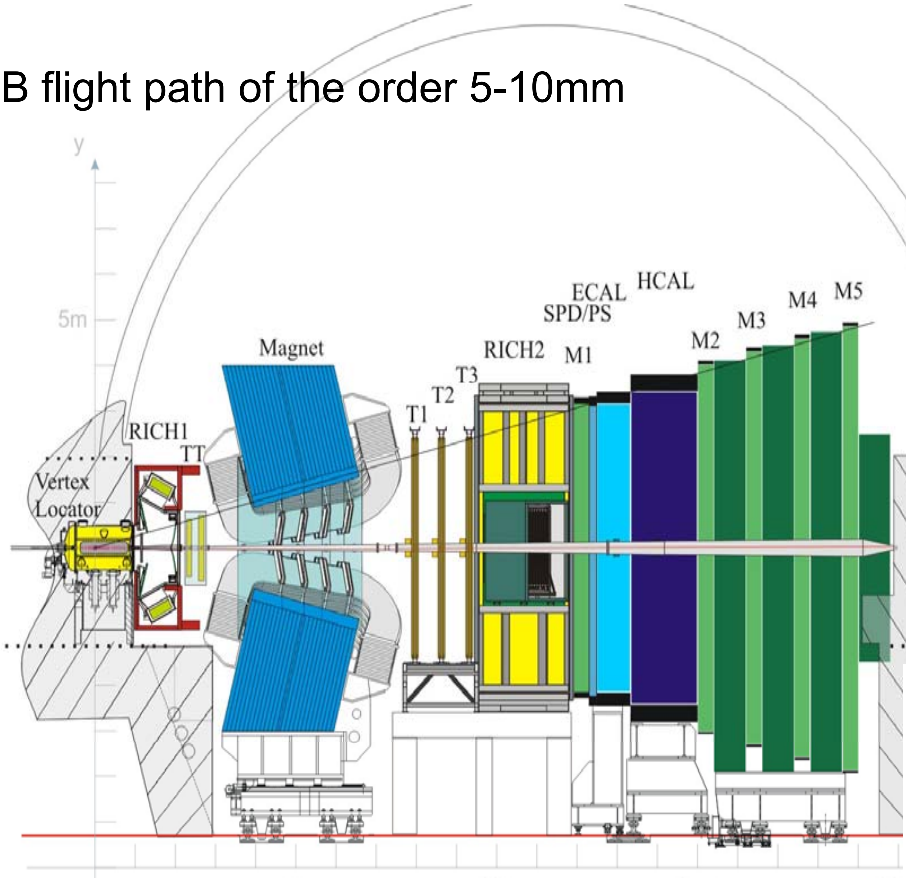
- B_s oscillation frequency, phase and $\Delta\Gamma_s$ ($B_s \to D_s\pi$, $J/\Psi\Phi$, $J/\Psi\eta$, $\eta_c\Phi$)
- Measure the CKM parameters
  - α from $B_d \to \pi^0\pi^-\pi^+$
  - β with $B_d \to J/\psi K_S$ as a proof of principle (β from $b \to s$ penguin)
  - γ in various channels, with different sensitivity to new physics:
    - Time-dependent CP asymmetry of $B_s \to D_s^- K^+$ and $D_s^+ K^-$
    - Time dependent CP asymmetries of $B_d \to \pi^+ \pi^-$ and $B_s \to K^+K^-$
    - Comparison of decay rates in the $B_d \to D^0(K^+\pi^-, K^-\pi^+, K^+K^-)K^{*0}$ system
    - Comparison of decay rates in the $B^- \to D^0(K^+\pi^-, K^+\pi^-\pi^+\pi^-)K^-$ system
    - Dalitz analysis of $B^- \to D^0(K_S\pi^-\pi^+)K^-$ and $B_d \to D^0(K_S\pi^-\pi^+)K^{*0}$
- Rare B decays
  - Radiative penguin $B_d \to K^* \gamma$, $B_s \to \Phi\gamma$, $B_d \to \omega\gamma$
  - Electroweak penguin $B_d \to K^{*0} \mu^+\mu^-$
  - Gluonic penguin $B_s \to \Phi\Phi$, $B_d \to \Phi K_s$
  - Rare box diagram $B_s \to \mu^+\mu^-$
- B_c , b-baryon physics + unexpected !

TAGGING REQUIRED

LHCb Overview

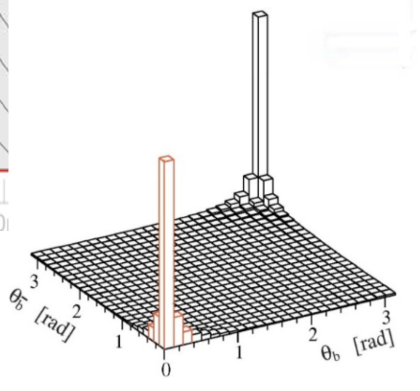
Requirements for CP measurements in B the sector are
Good particle Id,
excellent tracking and vertexing

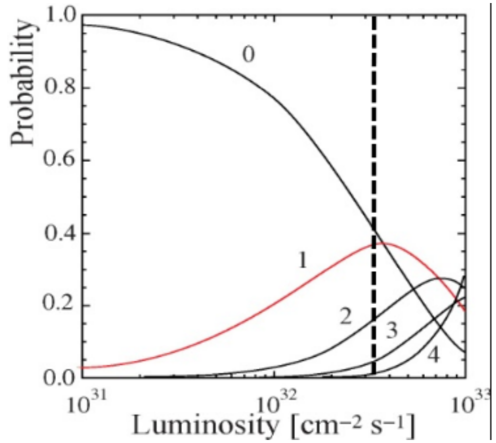
B flight path of the order 5-10mm



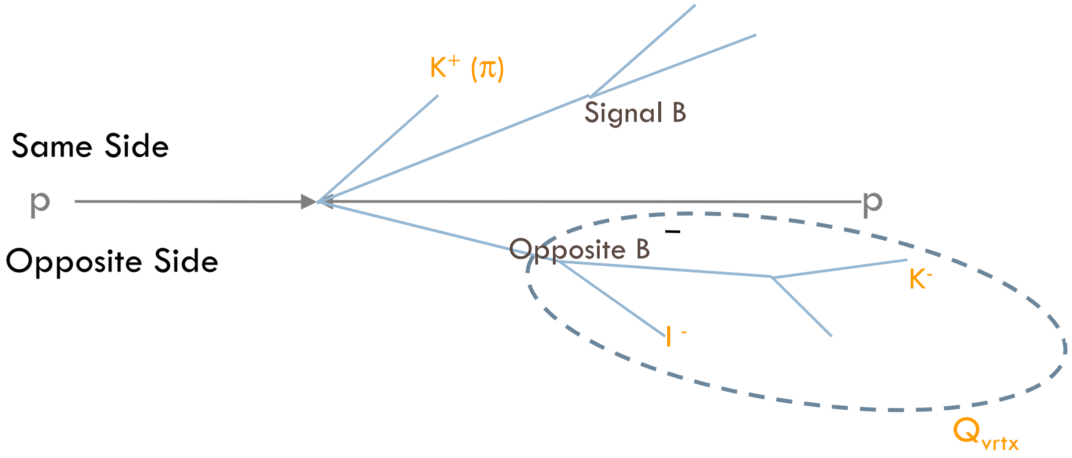
Tracking:
δp/p= 0.35% to 0.55%
Vertexing:
~10μm transverse plane and ~60μm in z
Expected Impact parameter resolution
σ_{IP} =14μm + 35μm/p_T
Calorimeter resolution:
σ_E/E = 1% + 10%√E (E in GeV)

RICH:
Particle identification, important to distinguish between Kaon and pions.





Flavour Tagging



Taggers:

- OS
  - muons
  - electrons
  - kaons
  - vertex charge
- SS kaons or pions (when $B_{d,u}$)

If several candidates for the same tagger exist → Select the one with highest Pt.

Tagging efficiency

$$\varepsilon_{tag} = \frac{N_R + N_W}{N_R + N_W + N_U}$$

Wrong tag fraction

$$\omega = \frac{N_W}{N_R + N_W}$$

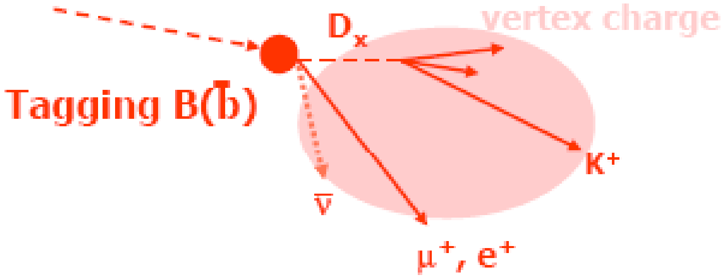
Effective efficiency

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

Taggers make individual decisions about the flavour with varying accuracy, which is evaluated by a NNet.

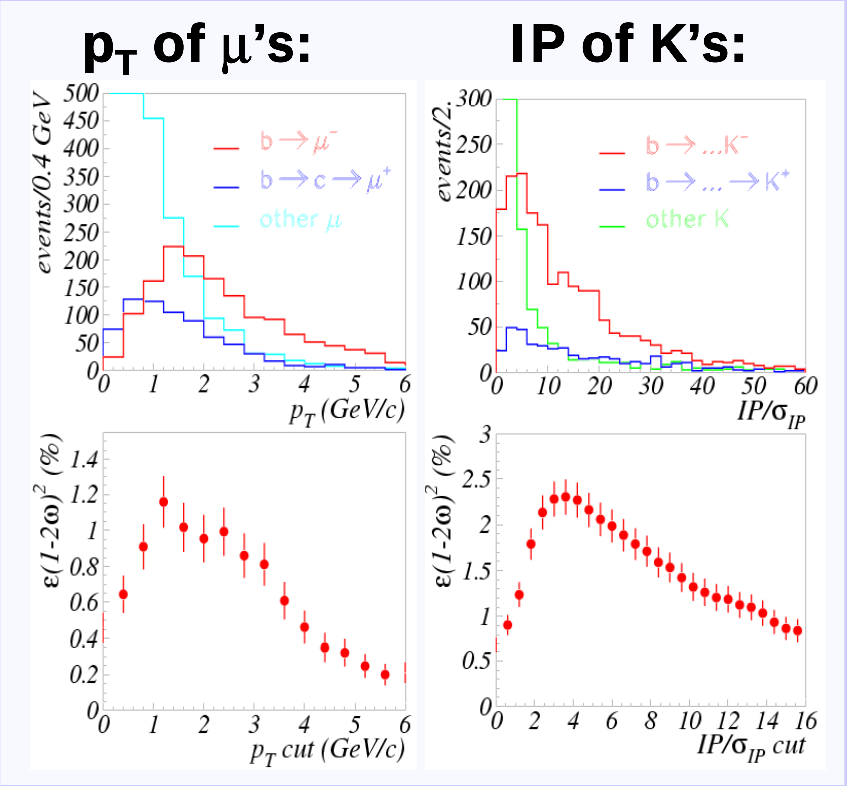
Opposite-side tagger (OS)

- ☐ Tagging *objects* from b → c → s chain.



- ☐ Kinematic and geometrical variables (IPS, P, Pt,...) show a dependence in purity of right vs wrong tags → CUTS

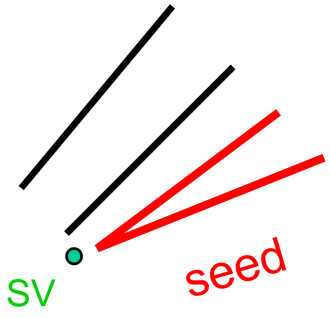
	p_T (GeV)	p (GeV)	IP/σ
$\mu^\pm$	> 1.1		
$e^\pm$	> 1.1	> 4	
$K^\pm$	> 0.4	> 4	> 3.5

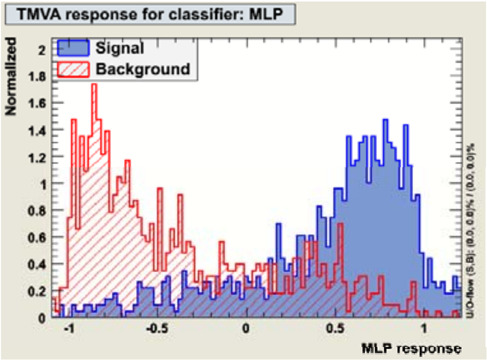

p_T of μ's:

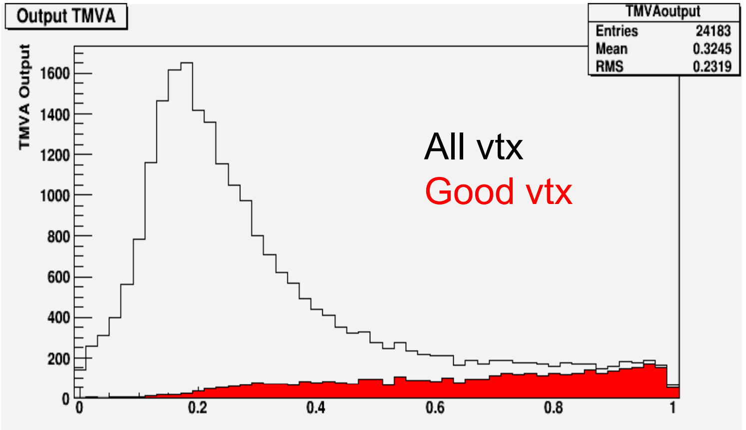
IP of K's:

OS Vertex Charge tagger

- ☐ Use long tracks to build a 2-seed vertex after some kinematic cuts
- ☐ Use a NN to select good candidate (2-seed) to SV



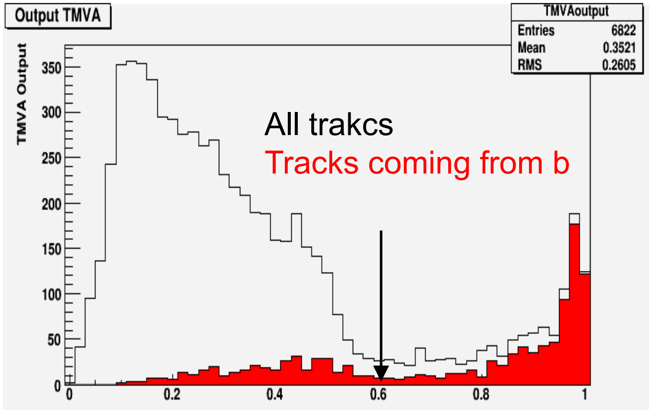




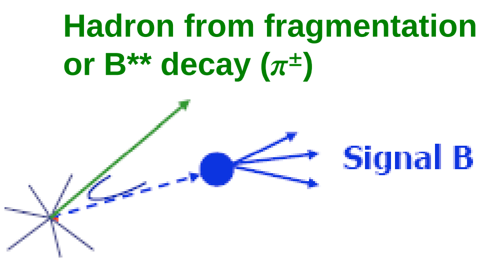
- ☐ Other tracks are added iteratively
- ☐ Weighted charge can be used as a tagger

$$Q_{\mathrm{vtx}} = \frac{\sum_i p_{\mathrm{T}}^{\kappa}(i) Q_i}{\sum_i p_{\mathrm{T}}^{\kappa}(i)}$$

Typical performance: ε = 43% ω = 42% $\varepsilon_{\mathrm{eff}}$ = 1.14%

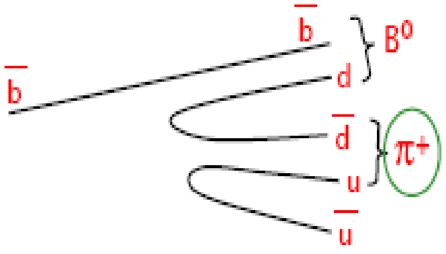


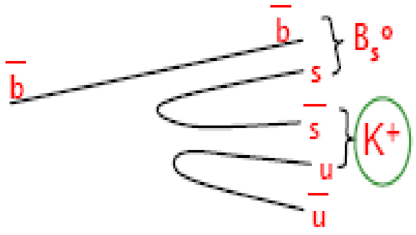
Same-side tagger (SS)



Hadron from fragmentation ($K^\pm \pi^\pm$) or B decay ($\pi^\pm$)**

Signal B





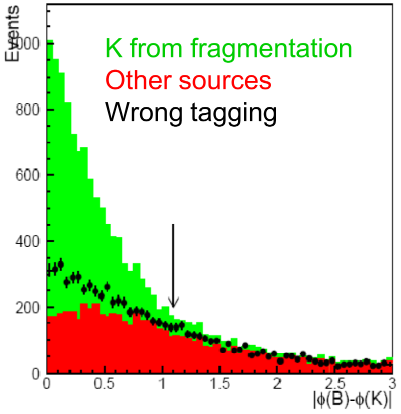
- Particle selection cuts

	p_T (GeV)	p (GeV)	IP/σ
$\pi^\pm$	> 0.2	> 2	< 3
$K^\pm$	> 0.6	> 4	< 3.5

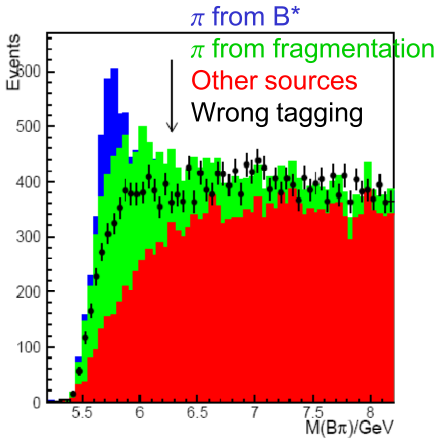
- Proximity to signal b

	Δη	Δφ	$M(B\pi^\pm(K^\pm))-M(B)$
$\pi^\pm$	ΔR < 1.2		< 1.5 GeV
$K^\pm$	< 1	< 1.1	< 2.5 GeV

Typical performance: $\varepsilon = 25.5\%$ $\omega = 35.6\%$
$\varepsilon_{eff} = 2.13\%$



$B_s \to D_s K$



$B^0 \to \pi^+ \pi^-$

Taggers

- ☐ The tag (b or bbar) is decided by the charge of the tagging object
- ☐ Combine the taggers to obtain a final decision of the tag
- ☐ Sort in 5 categories depending on the probability of the tag to be correct

Neural Net

- Obtain a wrong tag fraction (ω) for each event from the NN output
- Has a higher efficency

Combine Particle IDentification (PID)

- Sort events based on the PID of the track ordering them in ω
- NN independent. Simple method
- Has a lower efficency

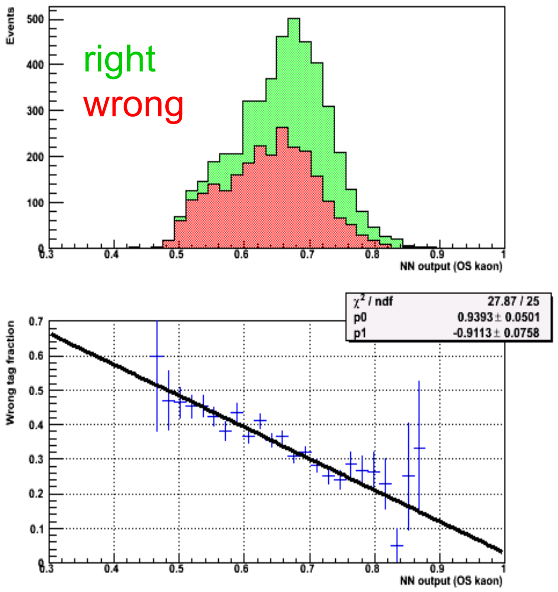
- ☐ Each method will give a tag and a category (related with the reliability)

Neural Net method

- ☐ For each event, each tagger will give an ω as a function of the NN output.
- ☐ The wrong tag fraction is fit linearly on the Neural Net output.

$B_s \rightarrow J/\psi\ \phi$

Opposite kaon



$\omega_{tagger(K)}$ (NNet) = $a_0 + a_1$ NNet

Combination of taggers

- ☐ Each tagger will have its own ω_{tagger} (NNet).
- ☐ The final probability for the event will be a combination of the tagger wrong tag fractions:

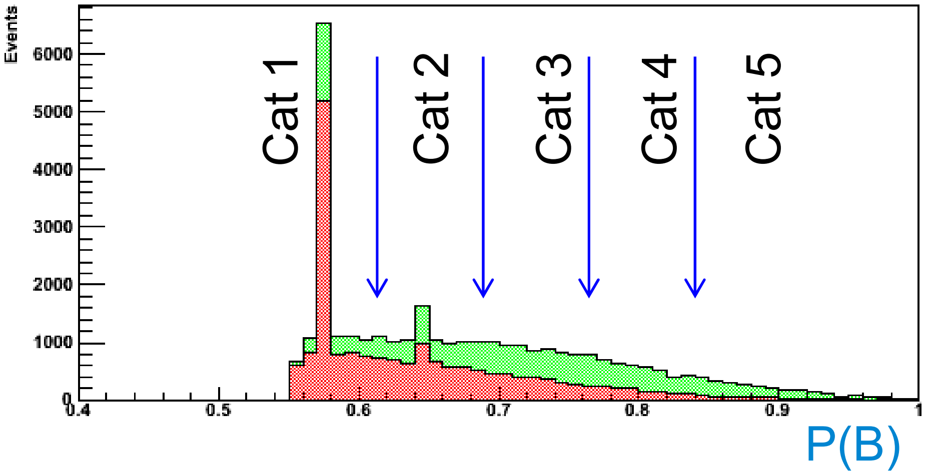
$$P^{+1} = (1-\omega_k)\,\omega_e \ldots$$

$$P^{-1} = \omega_k\,(1-\omega_e) \ldots$$

$$P(B) = P^{+1} \Big/ \left(P^{+1} + P^{-1}\right)$$

$$P(\bar{B}) = 1 - P(B)$$

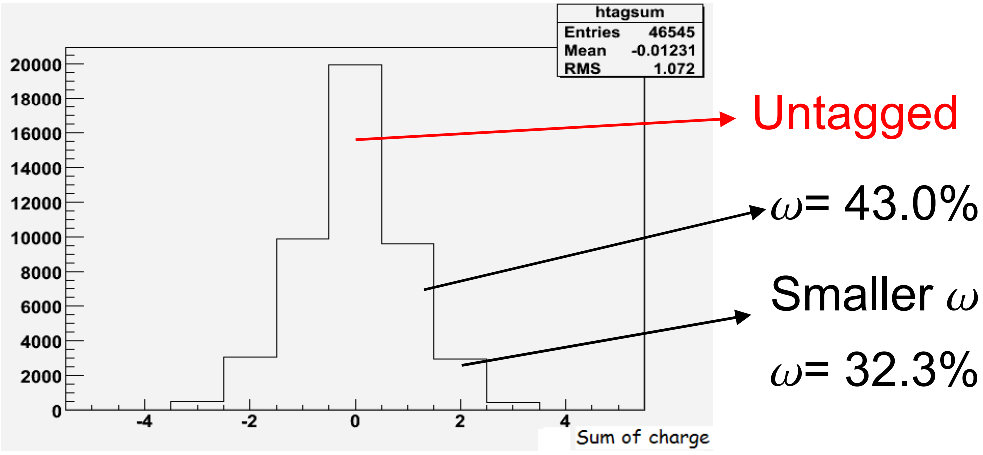
If P(B) < 0.55 events is left untagged



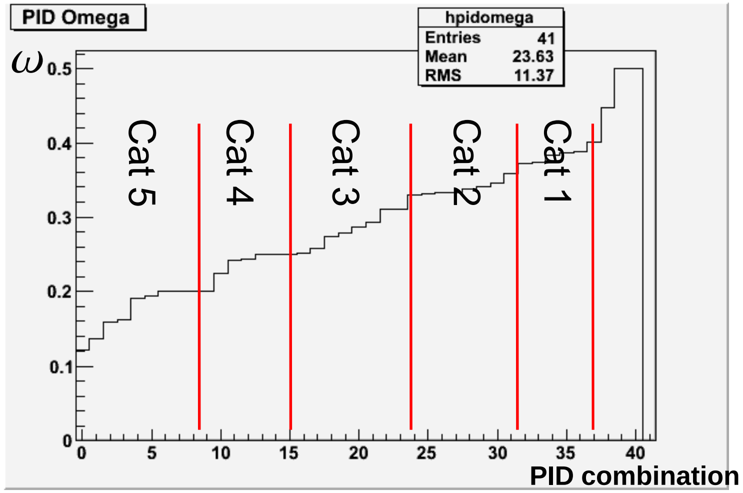
☐ To calculate the final combined effective efficiency, we bin the events in 5 categories (and treat them separately in the CP fits).

PID based combination of taggers

- Form possible combinations according:
  - Particle Identification (PID) Muons, electrons , kaons, kaons or pions SS , vertex charge
  - Sum of the individual tagger decisions (sum of charges) abs(sum) > 1



- Sort all possible combinations, including the case when abs(sum)>1, according to the ω estimated on a control channel (62 possible combinations, but only 41 non empty)



- Bin events in 5 categories

Results, ex. $B_s \rightarrow J/\psi\ \phi$

- Performance of taggers:

	ε_{tag}	ω	ε_{eff}
muons	6,15 ± 0,08	32,5 ± 0,6	0,76 ± 0,05
electrons	2,78 ± 0,05	29,9 ± 0,9	0,45 ± 0,04
kaons	15,33 ± 0,12	34,4 ± 0,4	1,49 ± 0,07
SS kaons	25,56 ± 0,14	35,6 ±0,3	2,13 ± 0,09
vtx charge	32,79 ± 015	40,8 ± 0,3	1,11 ± 0,07

- Combine all taggers to obtain the global effective efficency, which is the direct sum of ε_{eff} in the 5 tagging categories.

	ε_{tag}	ω	ε_{eff}
Using Nnet	53,96 ± 0,16	33,13 ± 0,21	6,14 ± 0,14
PID combination	56,65 ± 0,17	35,33 ± 0,22	4,89 ± 0,14

- NNet ε_{eff} increases by ~20%

Performances for a few channels

	ε_{eff} %	ε %	ω %
$B_s \rightarrow D_s\pi$	8.85 ± 0.18	60.7	30.9
$B_d \rightarrow J/\psi\ K^*$	4.29 ± 0.09	53.2	35.8
$B_d \rightarrow \pi\pi$	5.52 ± 0.16	56.8	34.4
$B_u \rightarrow J/\psi\ K^+$	4.11 ± 0.11	53.1	36.1

Differences can be due to different signal B spectra, trigger…

Control channels

- Accumulate high statistics in various flavour-specific modes
- ω can be extracted by:
  - $B^{\pm}$: just comparing tagging with observed flavour
  - B_d and B_s need fit of oscillation

Channel	Yield/2 fb^{-1}	B/S	$\delta\omega / \omega$ ($2fb^{-1}$) estimate
$B^+ \to J/\psi(\mu\mu)K^+$	1.7 M	0.4	0.15%
$B^+ \to D^0\pi^+$	0.7 M	0.8	0.25%
$B^0 \to J/\psi(\mu\mu)K^{*0}(K^+\pi^-)$	0.7 M	0.2	0.2%
$B_s \to D_s^+ \pi^-$	0.08 M	0.3	0.7%
$B_d^0 \to D^{*-} \mu^+ \nu$	9 M	0.4	0.05%
$B^+ \to D^{0(*)} \mu^+ \nu$	3.5 M	0.6	0.1%
$B_s \to D_s^{(*)} \mu^+ \nu$	2 M	0.1	0. 5%

Topology close to that of signal channels

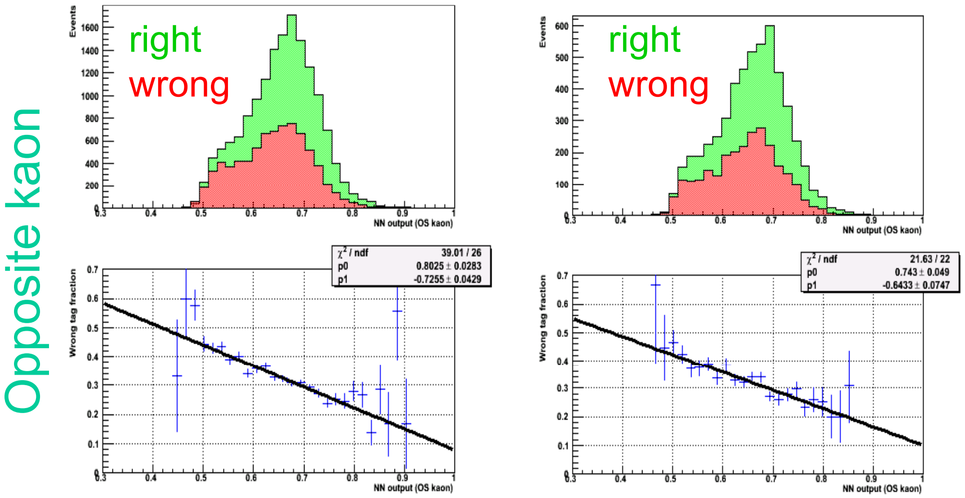
Semileptonics:
- High statistics
- More difficult topology

- Taggers can be calibrated using these control channels.

Use of control channels

- $B^+ \rightarrow J/\psi\ K^+$ is a flavour specific channel
- No true MC information needed
- The ω obtained in a given tagger for $B^+ \rightarrow J/\psi\ K^+$ can be used the same taggers in other channels

$B^+ \rightarrow J/\psi\ K^+$ $B_d \rightarrow J/\psi\ K_s$



$\omega_{tagger(K)}\ (NNet) = a_0 + a_1\ NNet$

- Control channels will allow to measure ω directly from data, with the statistical accuracy required for physics measurements

Mistag extraction for $B^0 \rightarrow J/\psi\ K_s$

One of the first measurements requiring flavour tagging of the B will be sin 2β from $B^0 \rightarrow J/\psi(\mu\mu)K_S$ as a benchmark to demonstrate LHCb capability in CP-asymmetry measurements

For the evaluation of the mistag rate, the following strategy, using $B^+ \rightarrow J/\psi(\mu\mu)K^+$ and $B^0 \rightarrow J/\psi(\mu\mu)K^{*0}$ as control channels, is foreseen:

- With $B^+ \rightarrow J/\psi(\mu\mu)K^+$ events determine for each tagger the dependence of the mistag rate on the kinematical properties of the tagger.

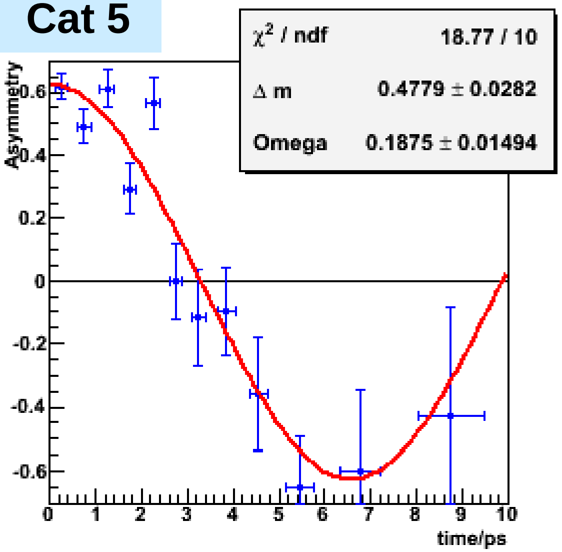
  Combine these probabilities into a single probability per event.

- Use this function to subdivide $B^0 \rightarrow J/\psi(\mu\mu)K^{*0}$ and $B^0 \rightarrow J/\psi(\mu\mu)K_S$ events into 5 samples of decreasing mistag-rate (tag categories).

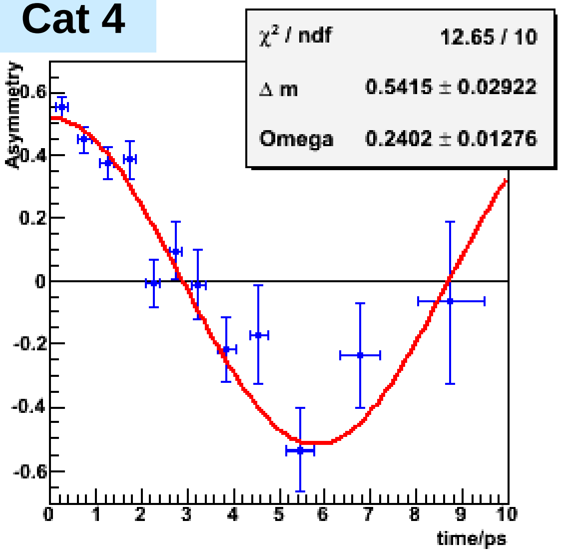
- Fit to flavour oscillations of $B^0 \rightarrow J/\psi(\mu\mu)K^{*0}$ events, as a function of propertime, in each of the 5 samples, to measure the mistag rate per category. Use these 5 mistag rates in the CP fit of $B^0 \rightarrow J/\psi(\mu\mu)K_S$ events, also subdivided into 5 categories.

Fit to flavour oscillations of $B_0 \rightarrow J/\psi\ K^*_0$ in 5 categories

Cat 5

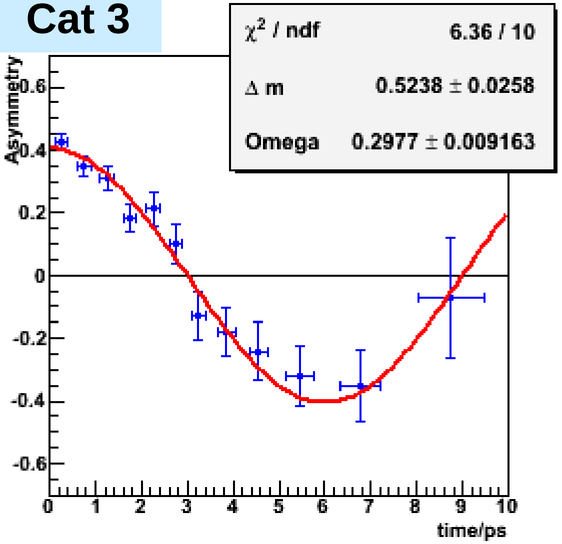


Cat 4



Only signal events considered here

Cat 3



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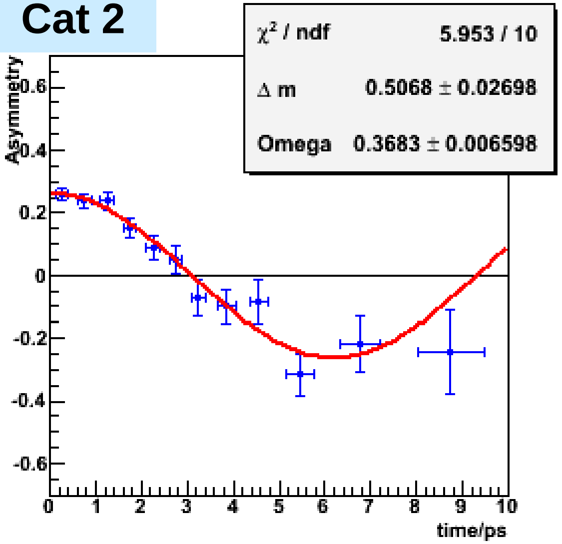
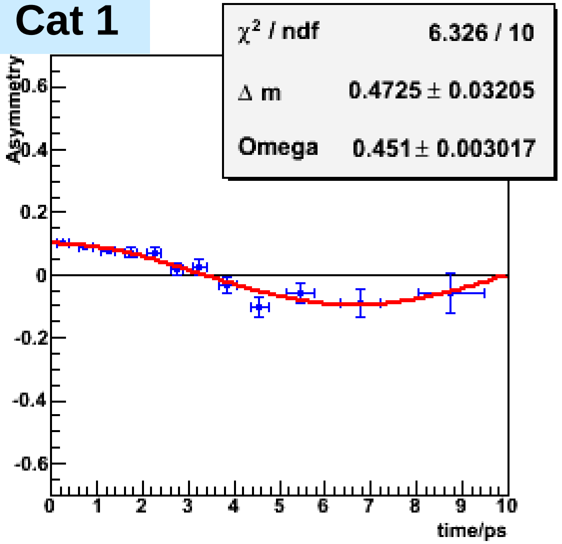


Cat 1



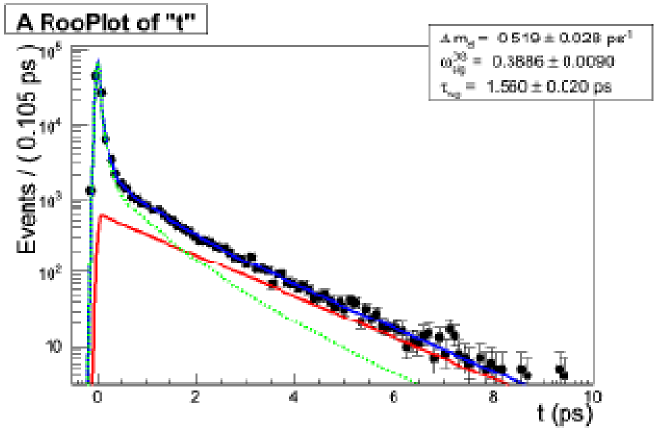
Control channel check

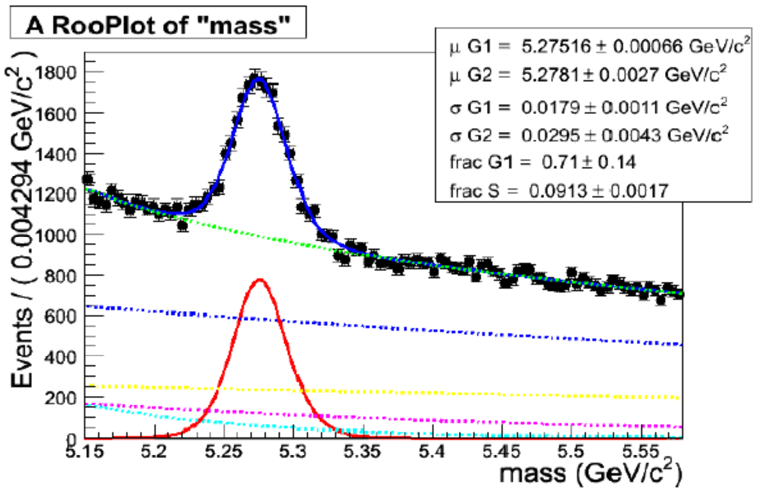
		from MC truth	from propertime fit
category	$B^0 \to J/\psi K_S$	$B^0 \to J/\psi K^{*0}$	$B^0 \to J/\psi K^{*0}$
ω_1 (%)	45.4 ± 0.3	44.8 ± 0.2	45.1 ± 0.3
ω_2 (%)	35.7 ± 0.7	36.8 ± 0.5	36.8 ± 0.7
ω_3 (%)	28.3 ± 0.9	29.7 ± 0.7	29.8 ± 0.9
ω_4 (%)	23.5 ± 1.3	23.7 ± 0.9	24.0 ± 1.3
ω_5 (%)	17.3 ± 1.5	18.8 ± 1.1	18.8 ± 1.5

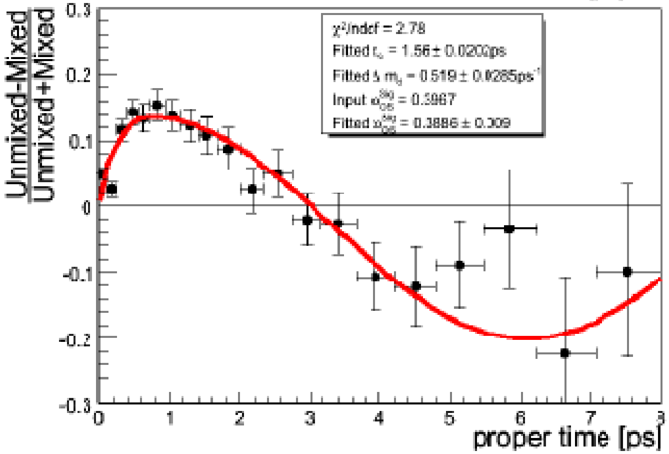
- Results from propertime fit are compatible to MC truth.
- In one year, 2/fb, with 215k events, $\sigma(\sin 2\beta) \sim 0.02$

Background on control channels

- ☐ Control channels will be used with data events, where full account of background has to be taken.
- ☐ We have devised the strategies to cope with it.
- ☐ For $B_d^+ \rightarrow J/\psi\ K^*$







Conclusions

- Flavour tagging is a fundamental ingredient for B physics measurements in LHCb.

- Control channels will allow to measure ω directly from data, with the required statistical accuracy, taking into account many possible effects (backgrounds, trigger, etc.)

- Expected effective tagging efficiency at LHCb is ~ 6 – 9 % for B_s and ~ 4 – 5 % for $B_{d,u}$ channels