Strategies for Combating Systematics at LHCb

- Reconstruction Distortions
- Systematic Issues in CP Asymmetry Measurements
- Extracting Unbiased Tagging Dilutions from Data
- Control Channels for Proper Time and PID Studies
- Summary and Outlook

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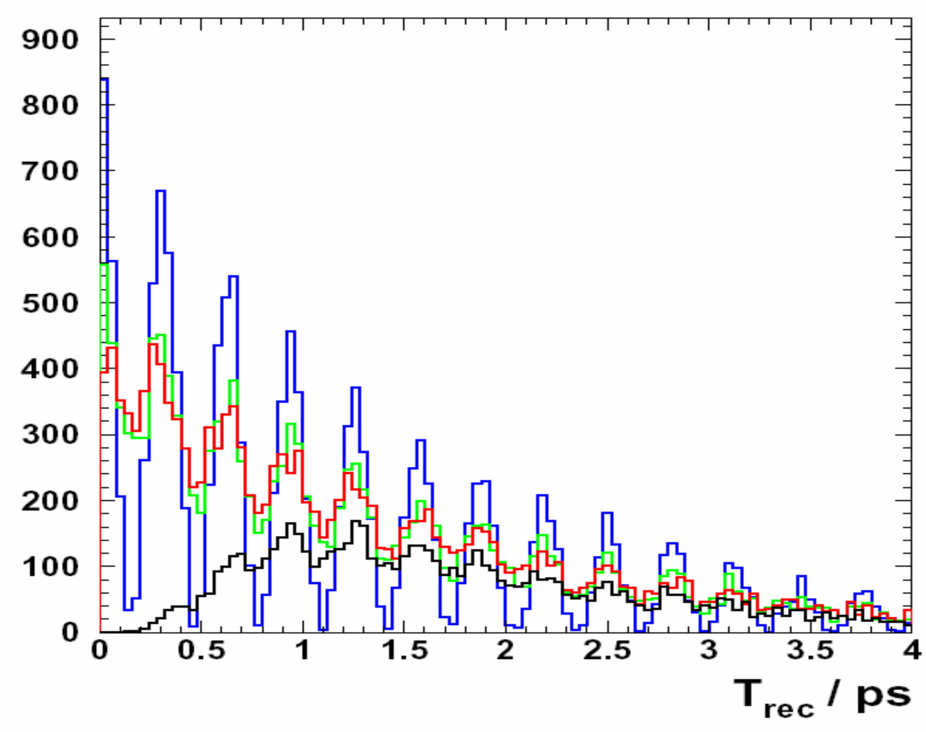
Physics Signals After Reconstruction Distortions

LHCb is an experiment committed to ***measurements***. Must understand how trigger & reconstruction effects distort underlying physics distributions.

A simple visual example – oscillations in $B_s \rightarrow D_s\pi$:



--- ideal resolution and tag
--- realistic tag
--- realistic tag+resolution
--- realistic tag+res+BG+acc

Even for an 'easy' measurement, the signal effect is not self-evident !

Now consider the more important case of a CP asymmetry analysis

CP Asymmetries and Dilutions

Both mistags (ω) & finite proper time resolution (σ_t) dilute CP asymmetries:

$$A^{meas}(t\ rec) \cong D_{tag}\, D_{res}\, A^{true}(t\ rec)$$

where

$$D_{tag} = (1 - 2\omega)$$

$$D_{res} = \exp\left[-(\Delta m\ \sigma_t)^2 / 2 \right]$$

- Gaussian approximation
- D_{res} only relevant for B_s

So both these factors need to be well known to get back A^{true} !

Consider for example $B_s \rightarrow D_s K$. One year statistical error on $A^{true} \sim 0.10$. Aim for systematic error contributions of < 0.05. For the case ω=0.35, σ_t = 40 fs & Δm_s = 25 ps^{-1} we require $\Delta\omega/\omega < 0.02$ and $\Delta\sigma_t/\sigma_t < 0.05$.

Very demanding ! This for a 'low yield' channel – $J/\Psi\phi$ has 20x more events!

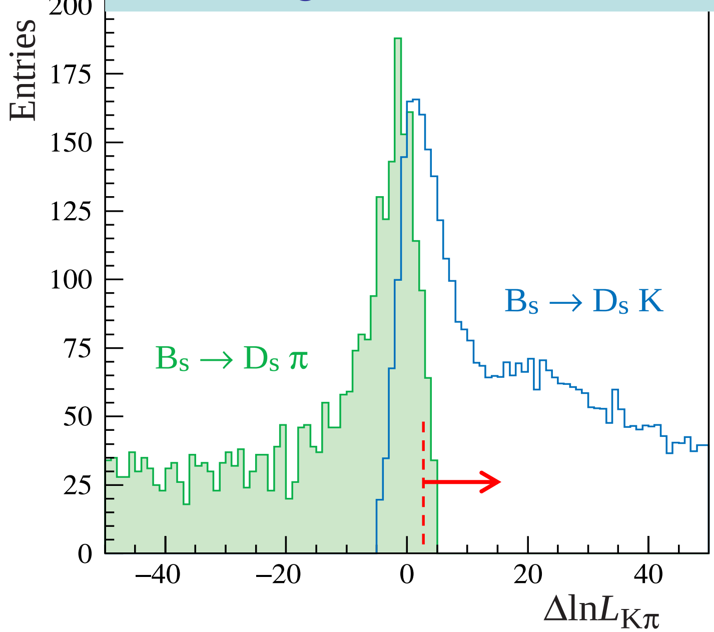
Good control of tagging & proper time resolution crucial in CP measurements.

CP Asymmetries and RICH PID

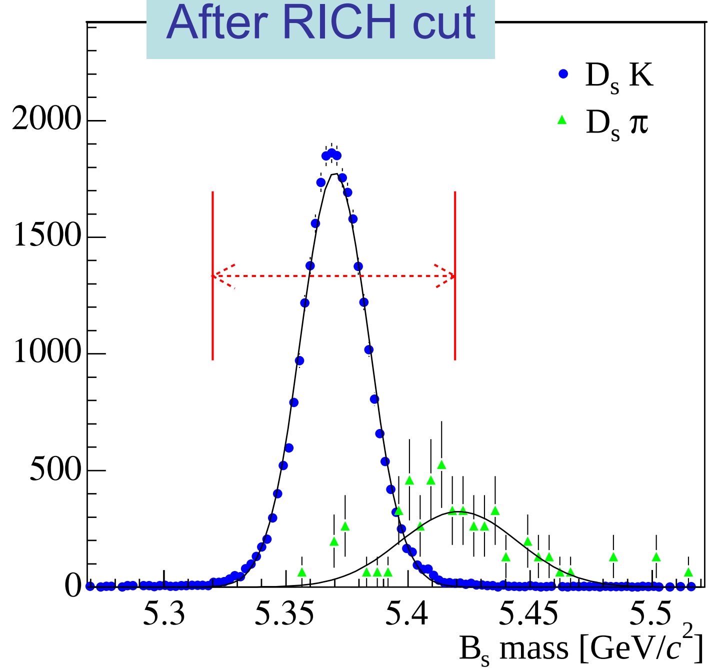
Many rare modes rely on RICH to kill same topology background with $\pi \leftrightarrow K$

Good example: separation of $B_s \to D_s K$ and 10x more abundant $B_s \to D_s \pi$

RICH log likelihood variable



After RICH cut



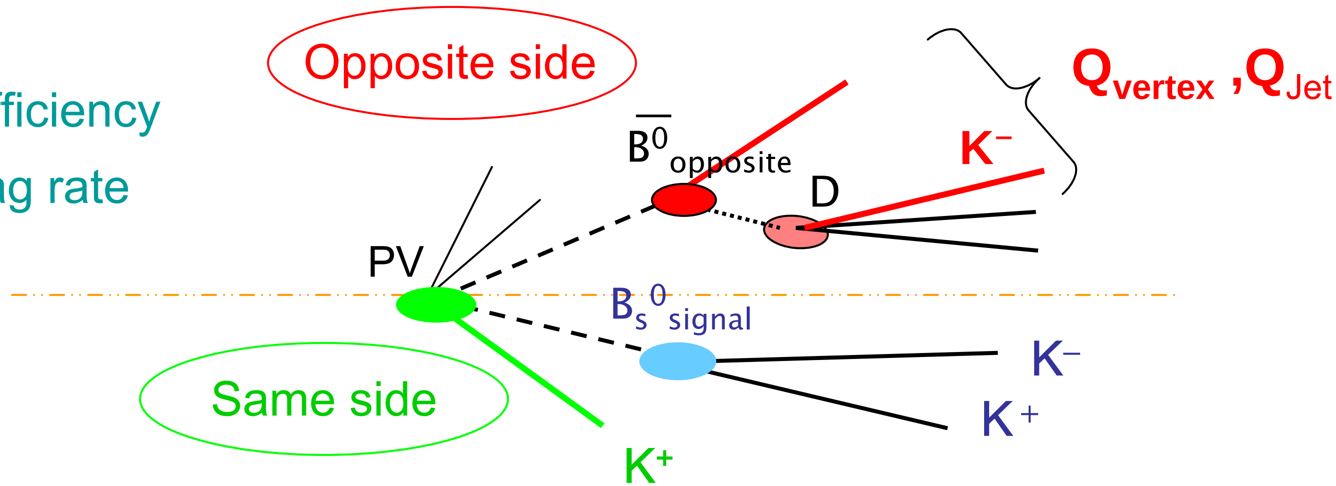
To control residual peaking background, must understand PID very well !

LHCb Flavour Tagging

Various signatures can be exploited to tag the signal B flavour at birth

ε tag efficiency

ω mistag rate



LHCb now uses:

- Opposite side e, μ, K
- Opposite side vertex charge
- Same side K (B_s) and π (B_d)

Expected performance, $\varepsilon_{eff} = \varepsilon\,(1\text{-}2\omega)^2$

4.3% for B_d , 7.5% for B_s

(this for a ‘simple’ combination –
more clever approaches can do better)

Knowledge of tagging performance

Knowledge of tagging performance essential ! Mistag rate, ω, enters as first order correction to CP asymmetries: A_{CP} meas = $(1-2\omega)$ A_{CP} true

Undesirable to use simulation to fix ω. Many things we don't properly know:

- Production mechanisms
  Kinematical correlation between signal and tagging B depends on how $b\bar{b}$ are produced – predictions of relative contribution of various mechanisms ($q\bar{q}$, gg, qg…) have significant uncertainties…
- Material effects
  K^+ and K^- interact differently with the material of the detector. This affects tag efficiency and mistag rates.
- Other
  B hadron composition, B decay modelling, PID performance etc etc

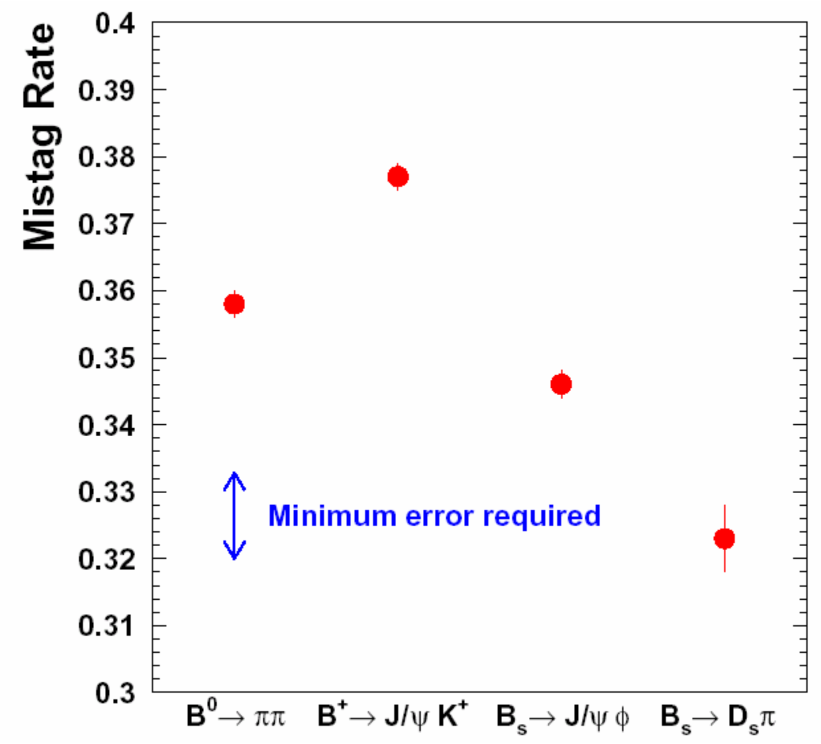
Therefore intend to measure performance from data using control channels

Control Channels for Flavour Tagging

LHCb will accumulate high statistics in many flavour specific decay modes

Control channel	Yield / 2 fb^{-1} (1 yr)
$B^+ \to J/\psi(\mu\mu)K^+$	1740 k
$B^0 \to J/\psi(\mu\mu)K^{*0}$	670 k
$B^0 \to K^+ \pi^-$	135 k
$B_s{}^0 \to D_s{}^+ \pi^-$	80 k

(Results from reoptimisation TDR)



ω (and ε) can be directly evaluated on these events. Problem solved?

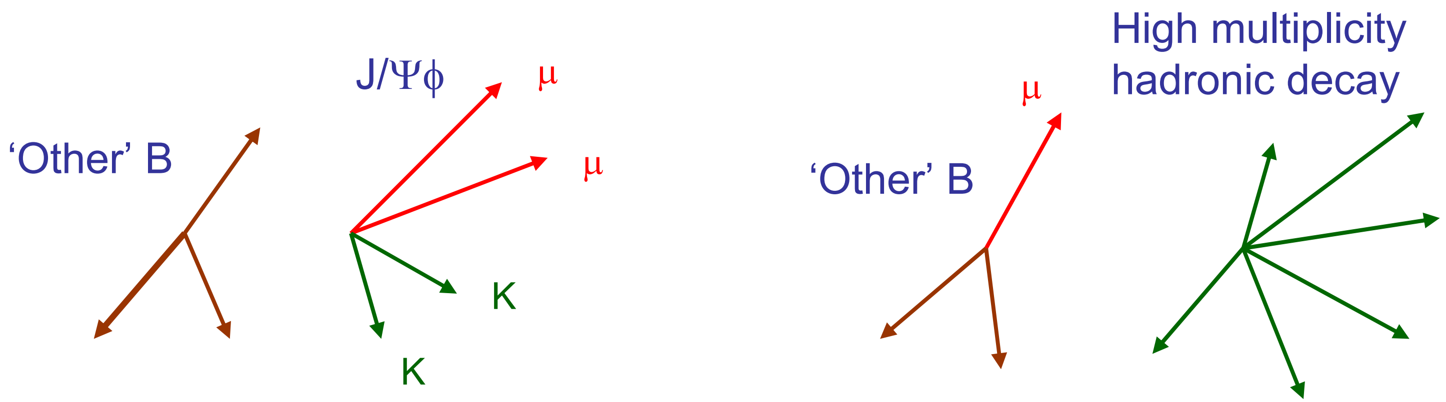
No, because there is a variation in ω from channel to channel !

Differences arise from biases introduced by trigger-tagging correlations

Correlations between trigger and tagging

Both L0 (high p_t μ , e or h) and L1 trigger (2 tracks with significant IP and some p_t , or 2 μ's, or…. [see Teubert talk]) can bias tagging performance.

Firstly, each mode will be fired by trigger components in different ratios.



Channels with clear signatures (eg. di-muons) will fire easily at L0 on the signal decay; harder channels will have greater proportion of triggers from 'other' B (ie. semi-leptonic decay), which will enhance tag performance.

On the other hand, an L1 trigger on 'other' B will bias its proper time and increase its probability of mixing, hence increasing mistag probability

The TIS/TOS Postulate

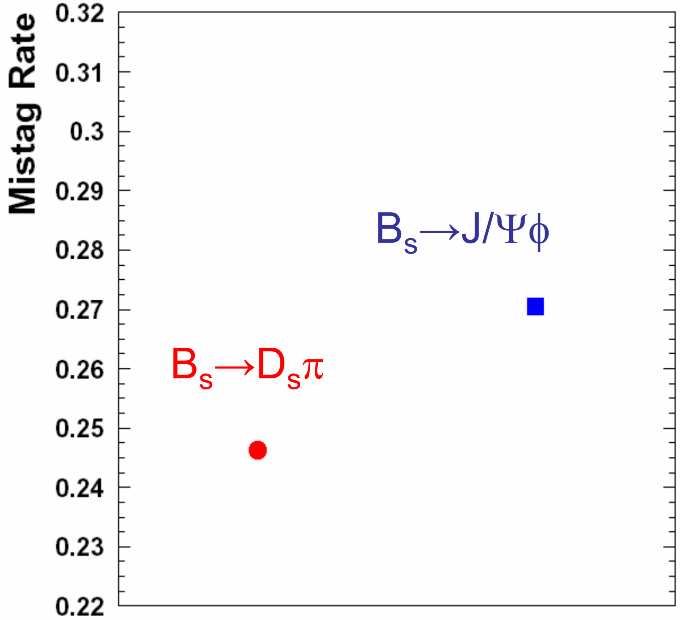
"These biases should disappear if we sort events into classes according to whether trigger was on the signal (TOS) or independent of signal (TIS)"

Test this assertion with high statistics fast simulation, including:
- full modelling of tracking acceptance and trigger
- simple tagging - muon, e, k (same & opposite side) – majority decision

Results on ***all*** triggered events →

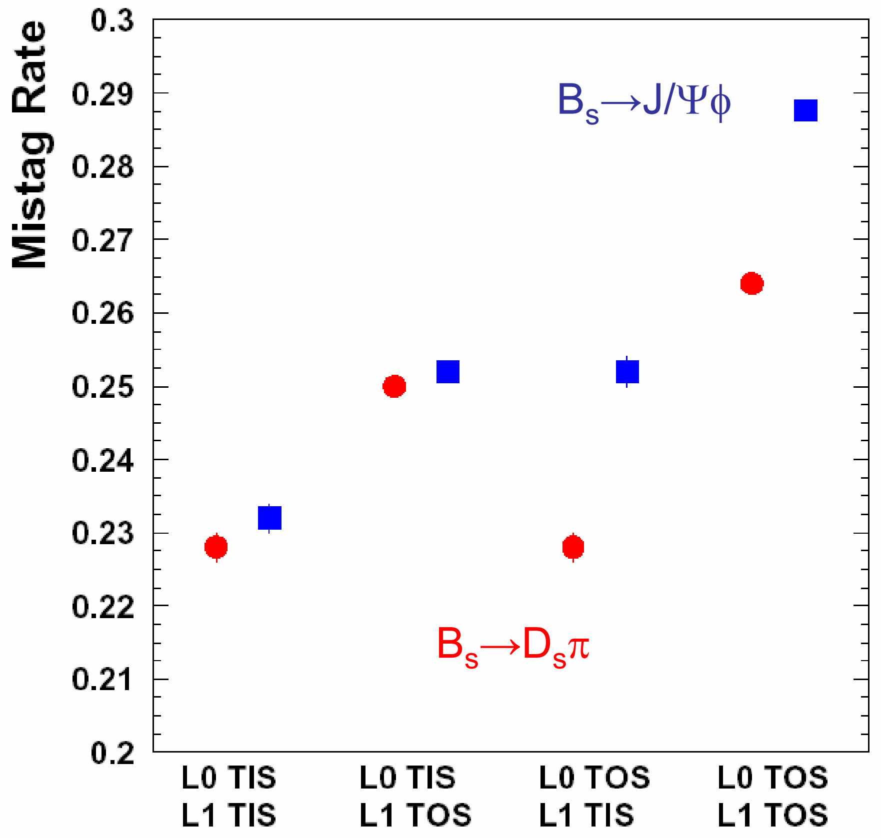
Same pattern as seen in full simulation (although as expected absolute numbers differ – simpler tag scheme and generator study).

Now subdivide into TIS/TOS…



Tagging performance against trigger class

Divide fast simulation events into 'trigger on signal' (TOS) and 'trigger independent of signal' (TIS), taking account of both L0 and L1 possibilities



Performance very similar for "L0 TIS, L1 TIS" (and for "L0 TIS, L1 TOS"),

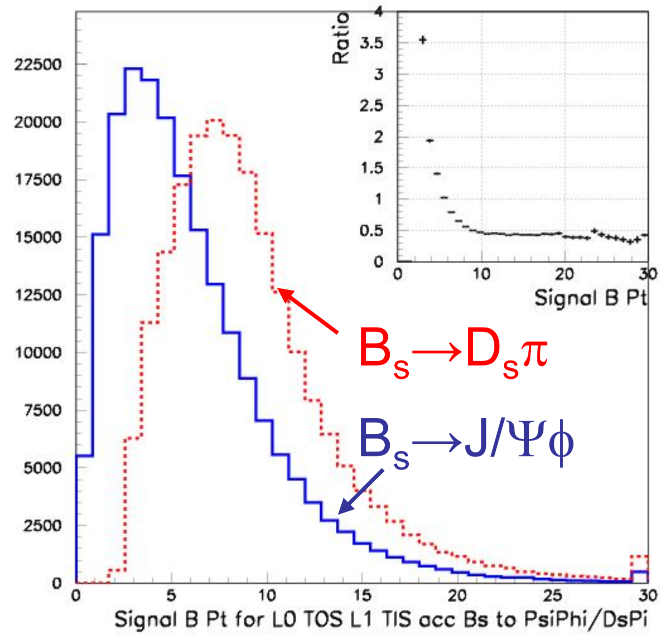
So tagging performance of events triggered on 'other' side is indeed invariant amongst modes!

But poor agreement in "TOS" classes (especially "L0 TOS")

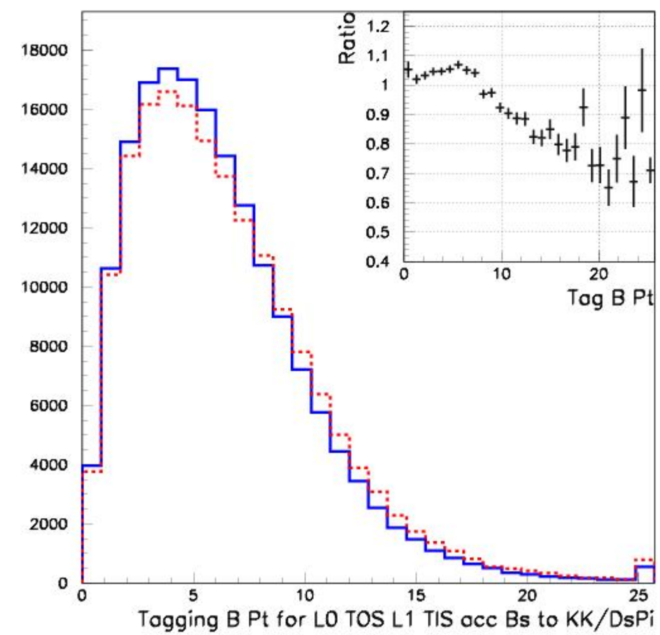
The TOS Problem and Kinematic Correlations

Signal and ‘other’ B are kinematically correlated. The acceptance and p_t cuts used to trigger on the signal biases the kinematics of the tagging B (and the underlying event). This biasing will differ between channels.

Signal B pt for L0 T0S L1 TIS



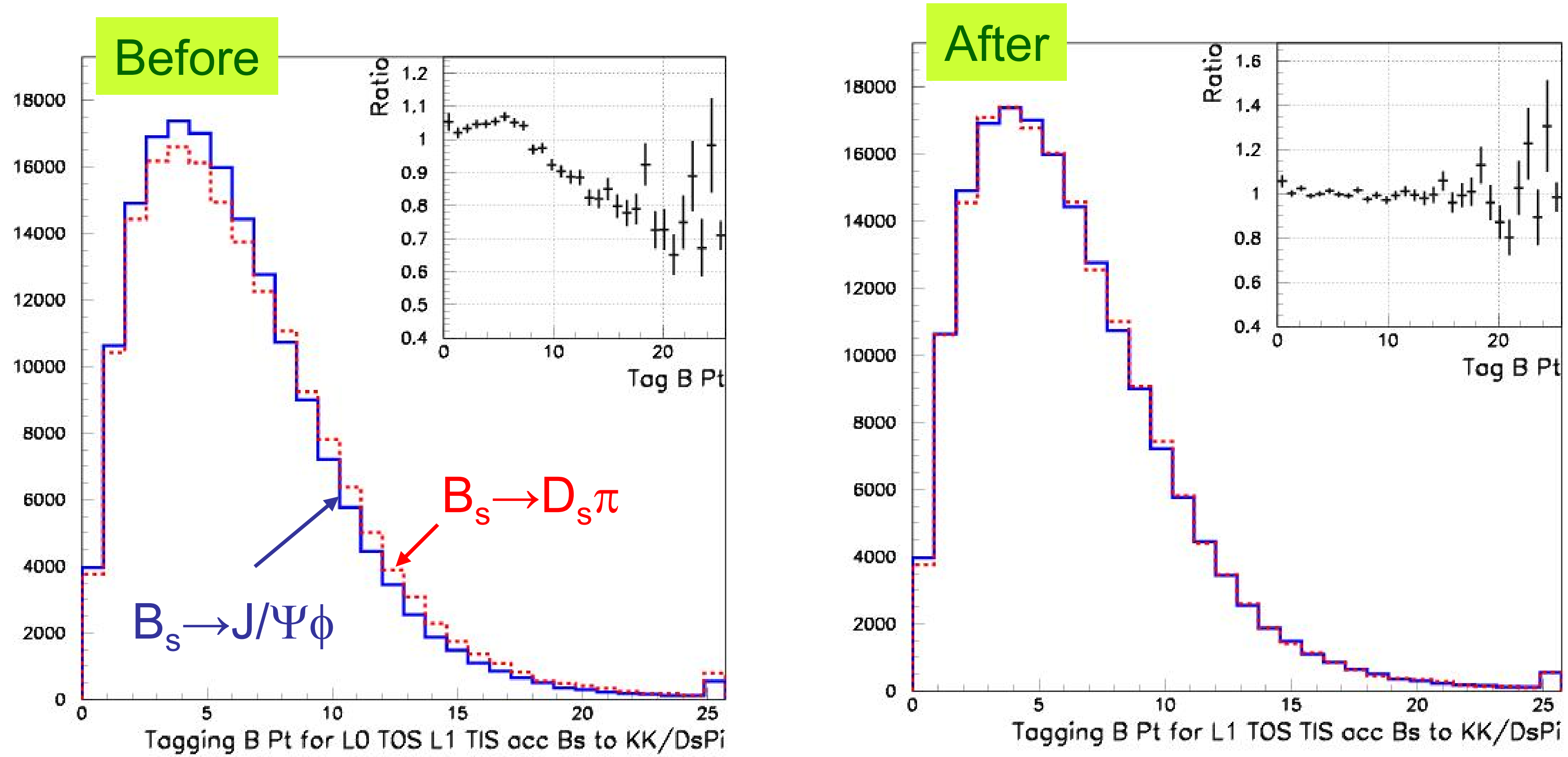
Tagging B pt for L0 TOS L1 TIS



Therefore in calculating tagging performance in TOS events we must re-weight control channel in bins of signal B p_t to match signal mode.

Tagging B p_t in TOS events after re-weighting

Re-weight ***signal*** p_t of control channel to match that of channel of interest



This procedure has effect of making ***tagging*** p_t distributions agree !

The TOS Problem and Kinematic Correlations

Modified TIS/TOS postulate:

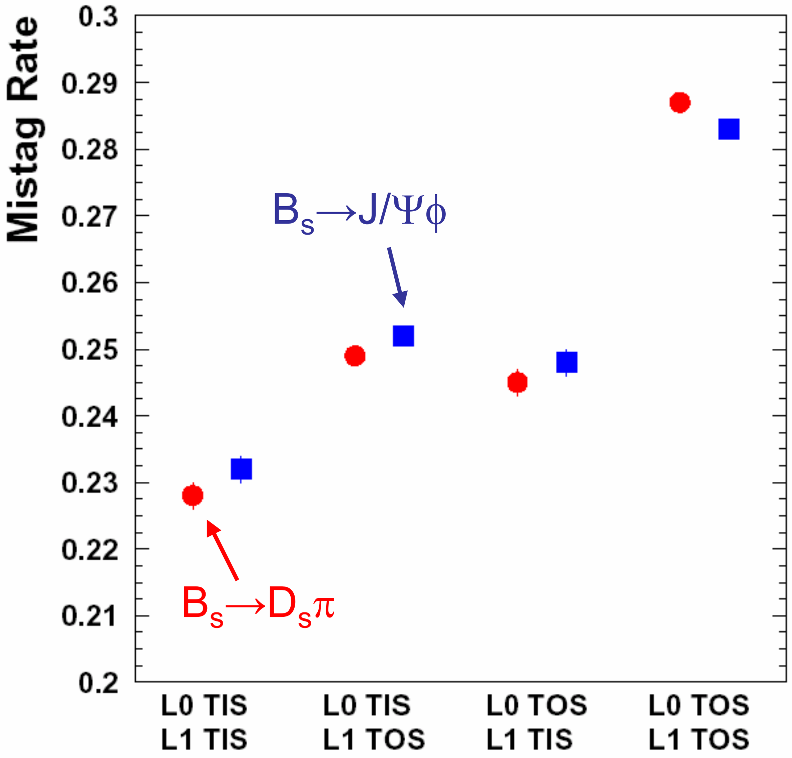
"Control and signal channels should have identical tagging performance if first sorted into TOS and TIS classes. Furthermore TOS performance must be evaluated in bins of appropriate kinematical variable (eg. signal p_t)."

Mistag rates divided into TIS/TOS categories…

… & after TOS re-weighting

Good agreement - this procedure seems to work!

But what about real data ?



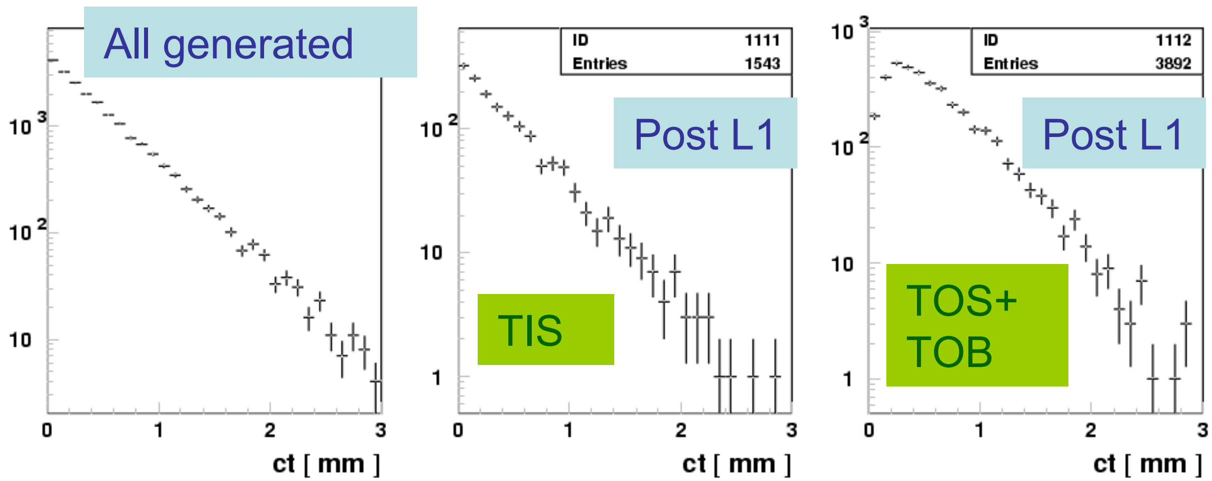
Buffer Tampering

To deploy procedure on data we need to know which tracks triggered event

"Buffer-tampering": offline, mask hits in raw buffer lying in a road around a track of interest, and then re-apply trigger algorithm. By masking signal associated hits, and then other hits, decide if event is TIS or TOS (or both)

Proper time of TIS & TOS events (according to buffer-tampering)

Looks sensible!

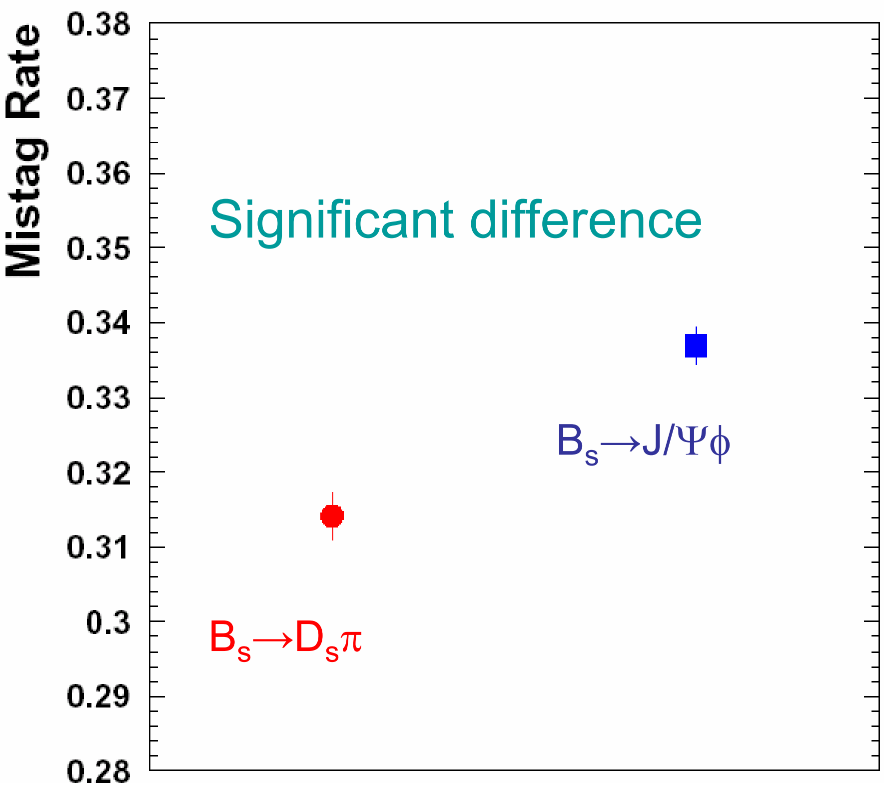


A third possibility: L1 is not single-track, and hence can Trigger On Both contributions from signal and non-signal ! We call such events "TOB".

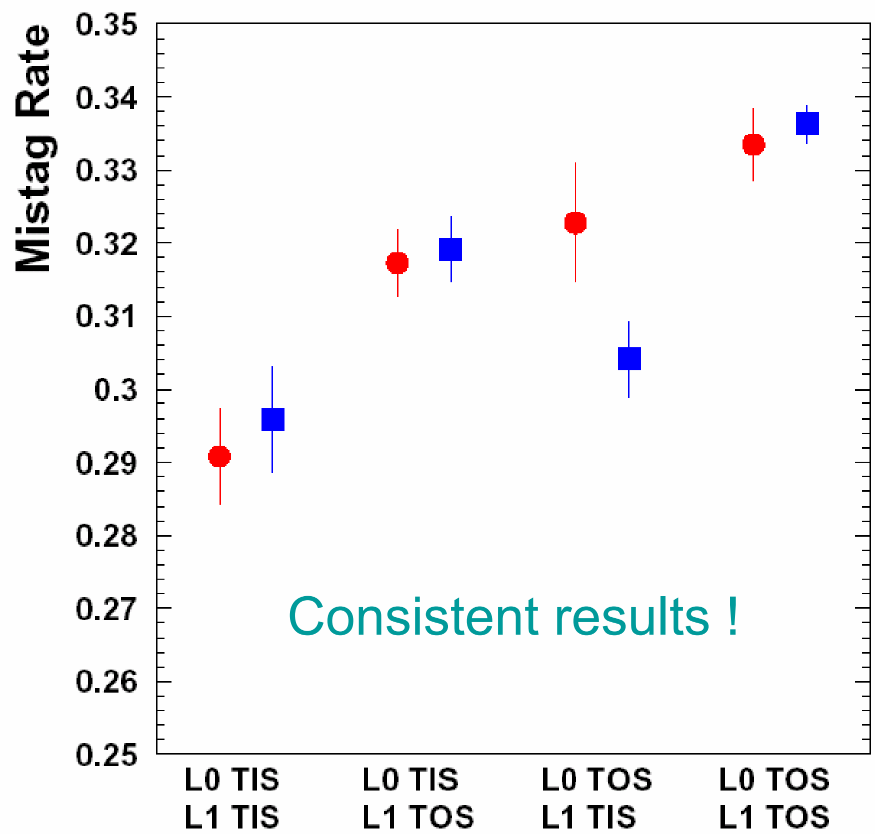
(TOB events are a non-dominant (eg. 20% in $D_s\pi$), but undesirable class, as their tagging performance cannot easily be calibrated from data alone.)

Preliminary Results with Buffer Tampering on Full Simulation

Raw results after trigger and reconstruction



After buffer tampering TIS/TOS separation and p_t re-weighting

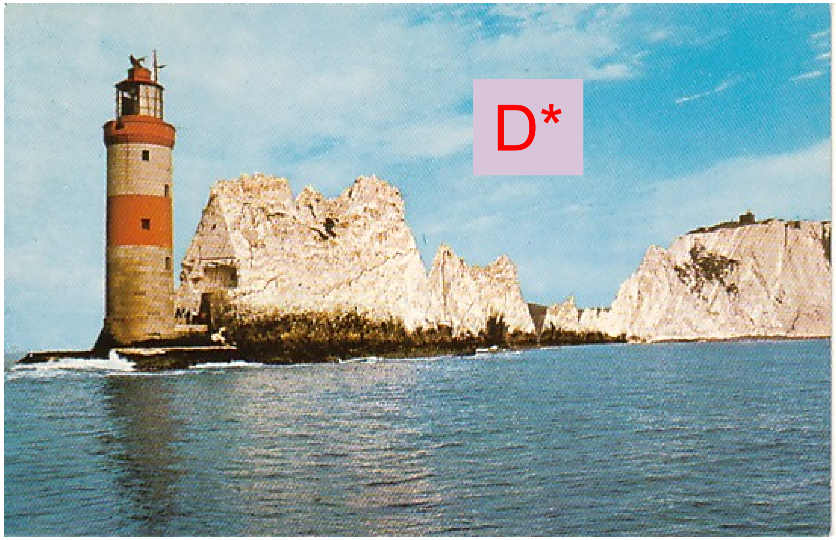


Procedure works well on full simulation, and so should work well with data

Lighthouse channels for LHCb

To protect LHCb from dangers of detector malfunction, mis-calibration, & systematics, augment core physics stream in high level trigger (200 Hz) with high rate 'lighthouse channels'…

Di-muons (600 Hz) selected without lifetime information



$D^* \rightarrow D^0(h^+h^-)\pi$ selected without PID information (300 Hz)

These will be of particular use in calibrating proper time resolution and PID

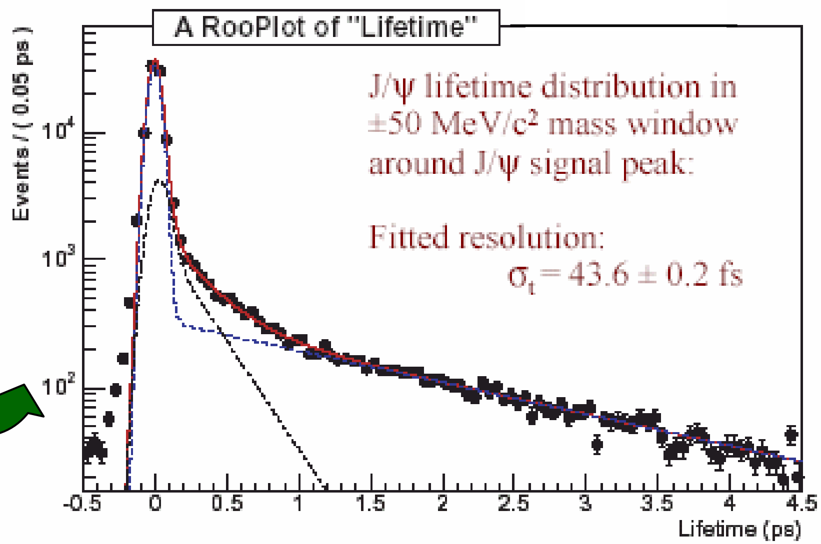
Lifetime unbiased dimuon trigger

High rate dimuon trigger will provide invaluable calibration tool.

- Distinctive mass peaks: J/Ψ…, ϒ…, Z…
  → can be used to fix mass scale (muon chambers cover almost full angular and momentum acceptance of LHCb)

- Sample selected ***independent of lifetime*** information will be dominated by prompt J/Ψ and will allow study of IP and proper time resolution in data.

  Preliminary study using fully simulated J/Ψ & 'toy MC' generated background (Signal fitted with single Gaussian)

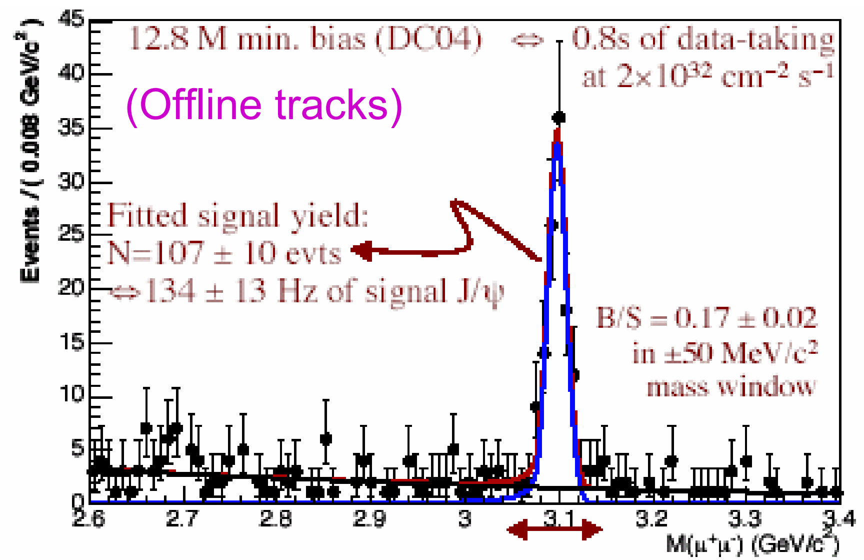


- Overlap with other triggers will allow proper time acceptance to be studied

Dimuon event yields

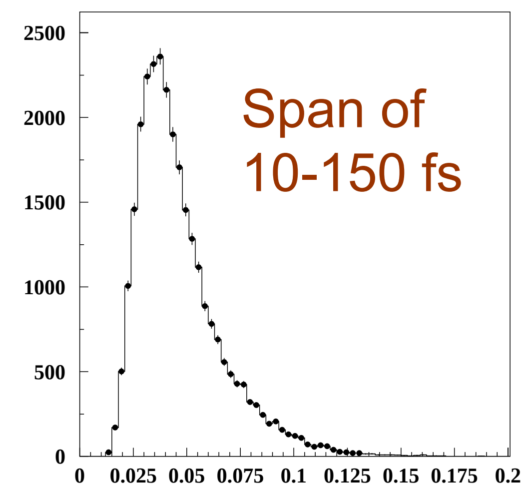
Preliminary HLT selection studies take L0*L1 output and use online tracks to look for dimuon combination with J/Ψ mass or above.

Running on < 1s of minimum bias



True J/Ψ rate ~ 130 Hz
→10^9 events / year !

Huge stats will allow ***full spectrum*** of proper resolution to be calibrated:

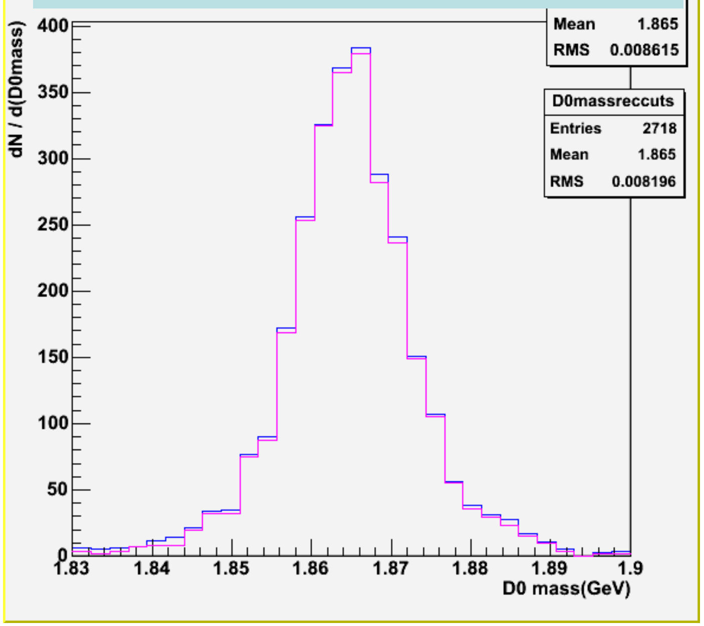


Knowing this will allow us to use event-by-event errors in CP fits

D* Selection without RICH

Dedicated D* selection in HLT will yield very large numbers of D^0 ($K\pi$) events. Possible to achieve very clean samples even without RICH.

D^0 peak in $B \to D^*\pi$ events



D^0 peak in 13M minimum bias

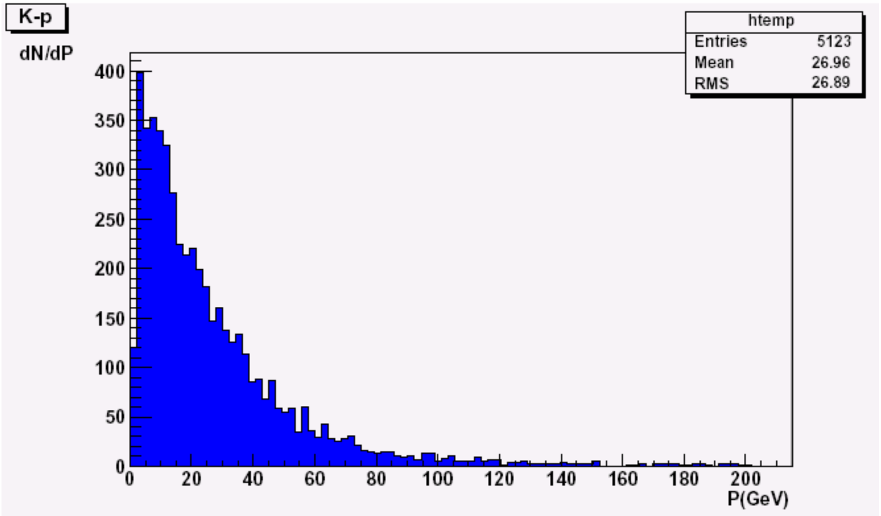
Ideal tool for unbiased PID calibration studies with K and π samples.
Clean signal peak will also allow for invaluable tracking & vertexing checks.

D* yields and PID studies

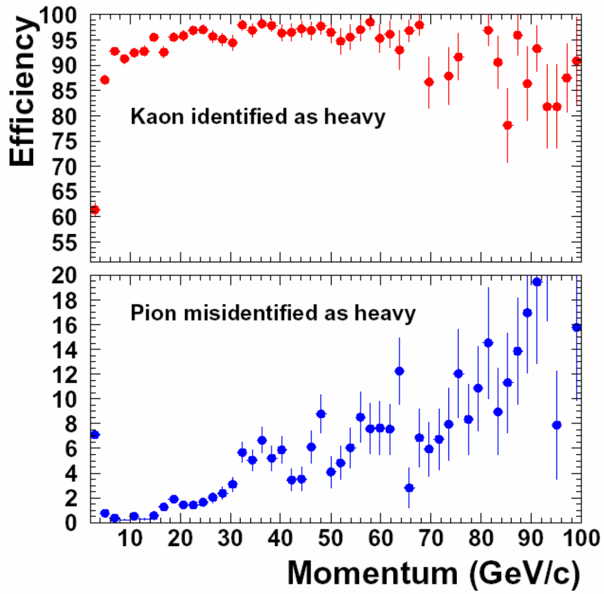
Preliminary studies give HLT trigger rate of ~300 Hz, and $D^*\to D^0(K\pi)\pi$ yield of ~30 Hz

→ 300 M events / year !

Momentum spectrum of kaons:



Use tracks to map out PID curves, as below, but with *real data*



Well matched to LHCb physics requirements!

1M events sufficient to control *global* id/misid scale to 0.1%. 300 M will allow for such understanding in bins of phase-space (& charm physics too!)

Summary and Outlook

Excellent statistical precision of LHCb demands excellent systematic control

We are preparing for this challenge – here we considered two examples:

- Interplay between trigger and flavour tagging
  Separation into trigger classes with buffer tampering tool, and use of kinematical re-weighting allows performance to be determined on data

- Determination of proper time resolution and PID
  Performance will be determined in bins of phase space from very high statistics (lifetime unbiased) dimuon and (RICH unbiased) D* events

Systematic robustness will also be a main consideration in planning the operation. For example, regular dipole polarity inversions are anticipated.

Believe we are well equipped to make high precision CP measurements !