Towards B mixing in semi-leptonic decays at LHCb

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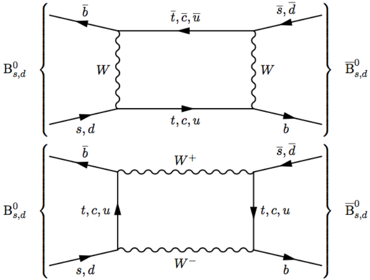
What is B mixing

- Neutral B mesons can oscillate to their anti-particles in SM via two box diagrams
- Mass difference of eigenstates is the frequency of oscillation
- Measuring the ratio, measures one side of a CKM triangle, many uncertainties also cancel in this

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s}}{m_{B_d}} \xi^2 \frac{|V_{ts}|^2}{|V_{td}|^2}$$



- New physics can influence oscillation, test of SM
- CDF: $\Delta m_s = 17.77 \pm 0.10 \pm 0.07$, PDG: $\Delta m_d = 0.505 \pm 0.004$
- LHCb needs Δm_s and Δm_d as an inputs for other measurements
  - A_{fs}, the asymmetry in the fraction of B^0_s created
  - β_s, the phase of the B^0_s oscillation

How can we measure Δm_d or Δm_s

- There are two main channels to measure Δm_d or Δm_s
- Hadronic channels $B^0 \to D\pi$ and $B_s^0 \to D_s\pi$
- Semileptonic channels $B^0 \to D\mu\nu$ and $B_s^0 \to D_s\mu\nu$
- However, both have different advantages ...

- LHCb has more semileptonic events after reconstruction and selection
  - $35\,pb^{-1}$ of data from 2010, which contains:
  - $\sim 1,000$ B_s^0 hadronic events compared to $\sim 25,000$ semileptonic
  - $\sim 6,000$ B^0 hadronic events compared to $\sim 14,000$ semileptonic
- Hadronic is fully reconstructed, semileptonic has missing momentum from ν
  - Very important since measured lifetime inversely proportional to momentum

$$\tau = \frac{m_B(\vec{F} \cdot \vec{P_B})}{cP_B^2}$$

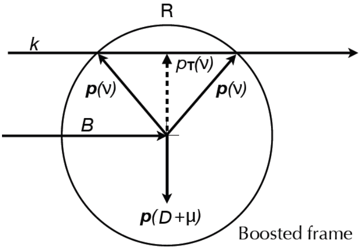
- Where τ is the lifetime, $\vec{F}$ is the flight distance vector, P_B is the B momentum, m_B is B mass and c is speed of light

Measurement Strategy

- Already measured hadronically in LHCb $\Delta m_s = 17.63 \pm 0.11 \pm 0.04$ps $\Delta m_d = 0.499 \pm 0.032 \pm 0.003$ps in LHCb-ANA-2011-005 and LHCb-ANA-2011-015
- However this talk will focus on the semi-leptonic channels

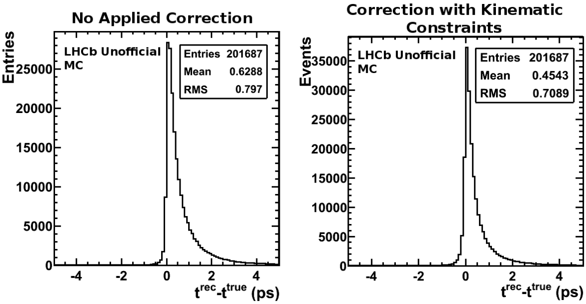
1. Momentum must be corrected to measure proper time correctly
   - Three different momentum correction methods were attempted
   - Kinematic Constraints
   - Neural Network
   - K-Factor
2. Proper time resolution of correction and the effect on the oscillations
3. Flavour tagging
4. Proper time backgrounds
5. Measure Δm_d and Δm_s

- Kinematic constraints on the decay were used for reconstruction
  - Could find the exact value of ν momentum,
  - Simply solve conservation of energy and momentum formulae



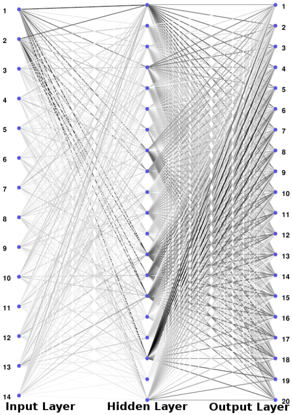
- Must make a few assumptions, only one missing massless neutrino
- The solution is a quadratic equation, impossible to tell which of the two solutions is correct
- Full derivation in backup slides

- Study effect of this correction method in Full LHCb Monte Carlo
- Reconstructed lifetime minus MC truth is plotted using $\tau = \frac{m_B(\vec{F}\cdot\vec{P_B})}{cP_B^2}$

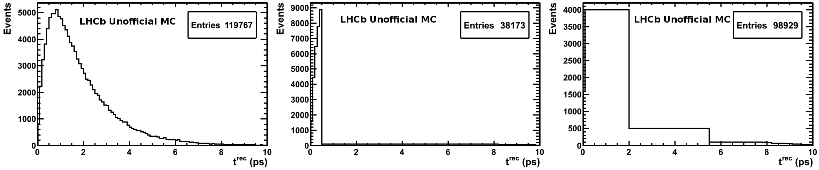


- Resolution is better, RMS down from 0.80 to 0.71
- Bias is reduced, mean moved from 0.63 to 0.45
- Still highly biased

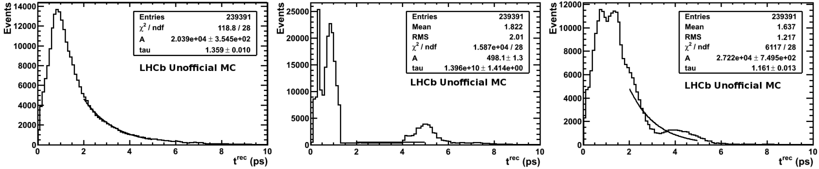
- Neural network using NeuroBayes, arXiv:physics/0402093
- Network is trained with target of the MC true lifetime using Full LHCb MC
- Inputs were kinematic variables and variables which indicate event quality
- The input proper time distribution was changed to make sure that output was calculated on a candidate-by-candidate basis
- Many different trainings were performed and output of each was studied



- Example of three different trainings, input true lifetime distribution

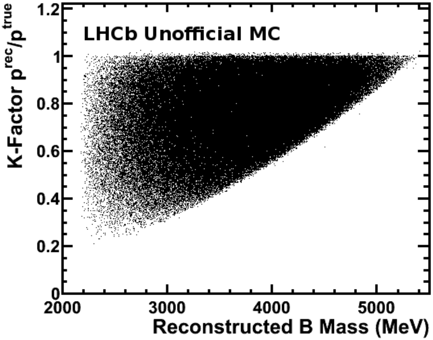


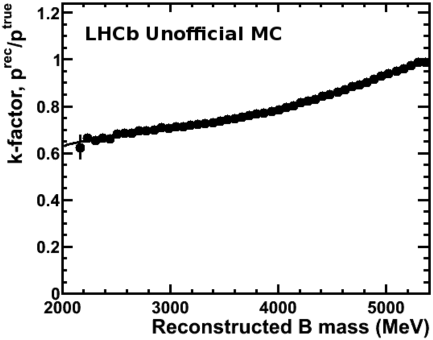
- Neural network output for each training, should be identical



- Heavily biased by the input used for training, unsuitable
- NeuroBayes shaped the output distribution to look like the input

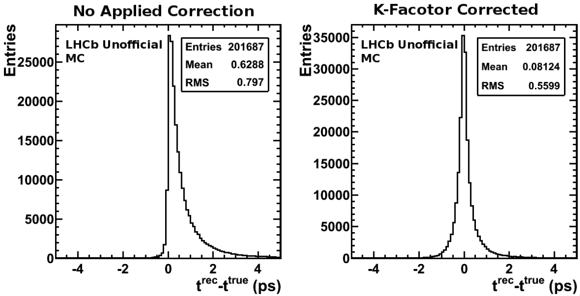
- MC based correction: K-Factor
- Proper time multiplied by correction factor, k
- k is calculated by fitting $p_B^{reconstructed} / p_B^{MCtrue}$ as a function of B mass
- Wide spread in k at low B mass, better at higher B mass
  - Since at higher mass there is less missing energy





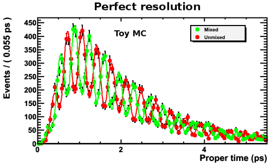
K-Factor Resolution

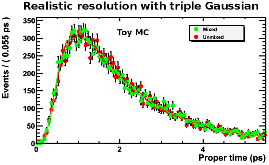
- Reconstructed minus true proper time is plotted from Full MC

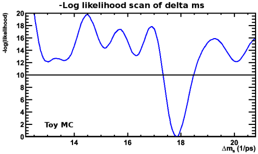


- Best reconstruction method so far
  - Less biased than the kinematic method means are 0.08 and 0.45
  - K-Factor has smaller spread RMS is 0.56 compared to 0.71
- Fitted with triple Gaussian, dominated by Gaussian with $\sigma = 400$fs
- But, wide resolution function, can we still measure Δm_s?

- A RooFit Toy MC used to simulate effect of the resolution
- The amplitude of oscillation is already reduced by mistag on the LHS
- B lifetime plots with acceptance function caused by different factors like the trigger and detector geometry



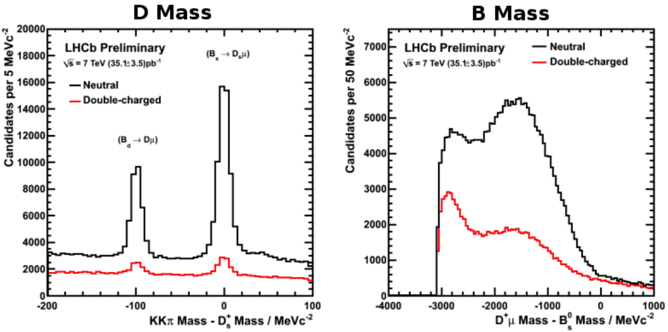




- The resolution blurs the oscillations, hard to see high frequency oscillations by eye
- Despite this the fit is able to converge and correctly determine Δm_s
- Plot on RHS shows its able to determine Δm_s to 5σ

Data Selection and Flavour Tagging

- Use cut based selection on Real Data, with $S/B \sim 1$
- B mass plot not Gaussian due to missing Neutrino momentum



- In order to decide if a B has oscillated, need to know its initial flavour
- For this analysis will use the standard LHCb flavour tagging
- Effective tagging power, $\varepsilon D^2 = 1.97 \pm 0.31\%$
- See LHCb note: LHCb-CONF-2011-003

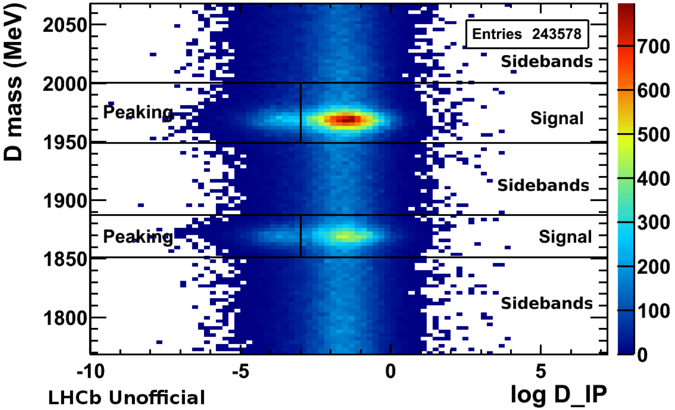
Proper Time Backgrounds

- Using an inclusive approach to background fitting
- Fit in D mass sideband regions (outside of D mass signal peaks)
- This alone does not allow separation of prompt D backgrounds
- Using a 2d fit of D mass and log(D impact parameter with PV) to separate into two backgrounds

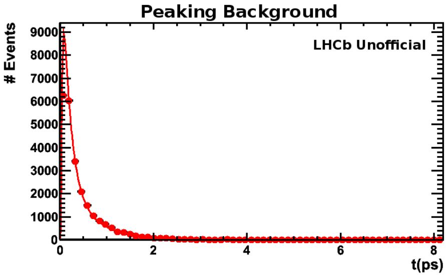
- Peaking background
  - Caused by prompt D
  - In the D mass signal region, but low in log of D impact parameter
  - Seen Full MC, but distribution unknown
- Sideband background
  - Other B mesons, combinatoric background
  - In high, middle and low sidebands

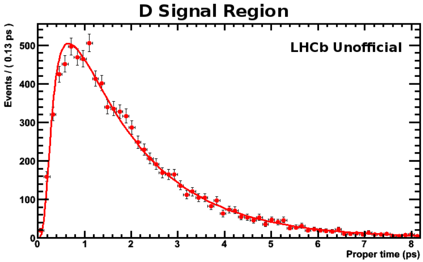
Proper Time Backgrounds

- Peaking background: In the D mass signal region, but low in log of D impact parameter
- Sideband background: In high, middle and low sidebands



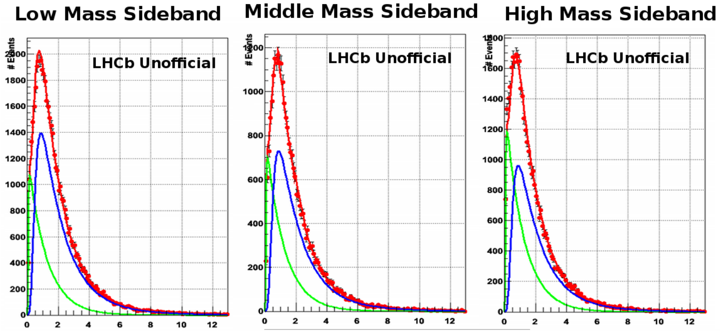
- A background caused by D mesons coming directly from the PV
- Distribution previously not known
- Acceptance function different to signal and other backgrounds
- Very short lifetime ($\sim$ 0.1ps) compared to the signal (1.5ps)





Sideband Background

- Proper time fitted in the sideband regions



- Two distributions ratio of which is dependant on D mass
- Both have very different acceptance functions
- Background shapes now well understood

- Next step, include backgrounds into fitter, determine Δm_d and Δm_s

Summary

- Determined that K-Factor was best momentum correction method for measurement of Δm_s and Δm_d
- Determined the proper time resolution associated with K-Factor correction
- Understood the shape of the backgrounds

- Now working towards Δm_s and Δm_d in the very near future

Neutrino Momentum from Kinematic Constraints

$P^{\parallel}_{D_s\mu}$, $P^{\perp}_{D_s\mu}$ are components of the $D_s\mu$ momentum parallel and perpendicular to the flight direction $\hat{F}$.
$\vec{F} = \vec{E} - \vec{S}$, $\hat{F} = \vec{F}/|\vec{F}|$ where $\vec{E}$ is the B end vertex position, and $\vec{S}$ is the position of the primary vertex.

$$P^{\parallel}_{D_s\mu} = \hat{F} \cdot \vec{P_{D_s\mu}} \quad (1)$$

$$P^{\perp}_{D_s\mu} = \vec{P_{D_s\mu}} - \left(\hat{F} \cdot \vec{P_{D_s\mu}}\right)\hat{F} \quad (2)$$

Using conservation of momentum and energy,

$$P^{\perp}_{D_s\mu} = -P^{\perp}_{\nu} \quad (3)$$

$$P_B = P^{\parallel}_{D_s\mu} + P^{\parallel}_{\nu} \quad (4)$$

$$E_B = E_{D_s\mu} + E_{\nu} \quad (5)$$

Then using $E^2 = m^2 + P^2$ Equation 5 can be re-written in terms of Equations 3 and 4 to make a quadratic equation in the form of

$$0 = aP^{\parallel 2}_{\nu} + bP^{\parallel}_{\nu} + c \quad (6)$$

where a, b and c are defined as the following

$$a = 4\left(P^{\perp 2}_{D_s\mu} + m^2_{D_s\mu}\right) \quad (7)$$

$$b = 4P^{\parallel}_{D_s\mu}\left(2P^{\perp 2}_{D_s\mu} - \left(m^2_B - m^2_{D_s\mu}\right)\right) \quad (8)$$

$$c = 4P^{\perp 2}_{D_s\mu}\left(P^{\parallel 2}_{D_s\mu} + m^2_B\right) - \left(m^2_B - m^2_{D_s\mu}\right)^2 \quad (9)$$

where m_B is the Particle Data Group mass of the B and $m_{D_s\mu}$ is the reconstructed mass of the $D_s\mu$ combination. This can then be solved using

$$P^{\parallel}_{\nu} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad (10)$$

NeuroBayes Inputs

Input	Input name	Relevance[1] in Sigma	Description
0	B0_V_FD_OWNPV	284.2	separation distance between the B decay vertex and its associated best PV
1	B0_BPVDIRA	30.8	cosine of the angle between the B-momentum and the B-flight direction
2	B0_BPVVDCHI2	294.8	separation distance between the B decay vertex and its associated best PV in units of χ^2
3	B0_DeltaZ	51.9	separation distance between the B decay vertex and the D decay vertex in the beam direction
4	B0_VFASPF_VCHI2_VDOF	3.78	a measure of the vertex quality of the B decay, the $\chi^2/n.d.f.$
5	B0_MMERR	4.5	measurement uncertainty on the B-mass
6	B0_DOCA	8.1	distance of closest approach between the D and μ daughters
7	Mu_MIPCHI2DV_PRIMARY	256.0	minimum impact parameter between the μ and any primary, in units of χ^2
8	Mu_PT/1000	13.7	transverse momentum of the μ
9	D_MIPCHI2DV_PRIMARY	265.3	minimum impact parameter between the D and any primary, in units of χ^2
10	D_PT/1000	30.4	transverse momentum of the D
11	D_BPVDIRA	125.1	cosine of the angle between the D-momentum and the D-flight direction
12	D_BPVVDCHI2	243.3	separation distance between the D decay vertex and its associated best PV in units of χ^2
13	D_BPVVDZ	205.1	separation distance between the B decay vertex and its associated best PV in the beam direction
14	D_VFASPF_VCHI2_VDOF	3.5	a measure of the vertex quality of the D decay, the $\chi^2/n.d.f.$
15	D_MMERR	14.7	measurement uncertainty on the D-mass
16	k	5.8	k-factor
17	tauRec	328.5	proper time estimate with no correction
18	tauCorrHigh	327.2	proper time estimate with the high solution of the neutrino reconstruction method
19	tauCorrLow	319.3	proper time estimate with the low solution of the neutrino reconstruction method

[1]The relevance is the significance of the correlation between the input variable and the target variable after input regularization.

Data Selection Cuts

Variable	Cut	MC09 Presel	Old Tuned	New Tuned
BPVDIRA (B,D)	>	(0.997,0.99)	(0.998,0.99)	**(0.998,0.99)**
BPVVDCHI2 (B,D)	>	(1,49)	(1,144)	**(1,144)**
Vtx χ^2 prob (B,D)	>	0.00025	0.015	**0.015**
BPVVDZ (D)	>	1 mm	1 mm	**1 mm**
ΔZ (D-B)	>	0 mm	0 mm	**0 mm**
B Mass	>	2.2 GeV	2.2 GeV	**2.2 GeV**
	<	6.3 GeV	6.3 GeV	**6.3 GeV**
D Mass	>	-200 MeV	-200 MeV	**-200 MeV**
	<	+100 MeV	+100 MeV	**+100 MeV**
PT (D,μ,K,π)	>	(1.0, 0.5, 0.3, 0.3)	(1.5, 0.6, 0.4, 0.3)	**(1.5, 0.7, 0.4, 0.3)**
IP χ^2 (D,μ,K,π)	>	(--,2,4,4)	(--,2,4,7)	**(--,2,4,16)**
IP (μ,K,π)	>	(0.01, 0.03, 0.01)	(0.01, 0.03, 0.01)	**(0.01, 0.04, 0.04)**
Tr χ^2 (μ,K,π)	<	(9,9,16)	(5,10,10)	**(5,5,9)**
μ PID (π,K,p)	>	(-5,-10,--)	(-3,-10,--)	**(-1,0,--)**
π PID (μ,K,p)	>	(-5,--,--)	(-5,-20,-40)	**(-5,-10,-40)**
K PID (μ,π,p)	>	(--,-5,--)	(-10,0,-10)	**(5,0,-10)**