$B \longrightarrow hh$ misalignment studies

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Outline

- Motivation and Overview
- VELO & IT/OT Misalignments
- VELO z-scale Misalignments
- Fast Geometry
- Misalignments and `B2hhFit`
- Plans and Conclusions

Introduction

VELO & IT/OT Misalignments

VELO z-scale Misalignments

Fast Geometry

Misalignments and `B2hhFit`

Plans and Conclusions

Motivation

- Study effects of a misaligned tracking system on measurements with $B \longrightarrow hh$.
- Chapter 1 (presented here)
  - Systematically study effect of misalignments purely based on their size.
  - Does not involve any assumptions on quality of metrology or alignment software.
  - Gives a good overview and shows critical alignment DOFs.
- Chapter 2 (future studies)
  - Study remaining misalignment effects after application of alignment algorithms.
  - Use alignment challenge data.
  - Detect potential bias coming from alignment software.

Chapter 1

- Create random misalignments for VELO sensors/modules and IT/OT layers.
- Choose scale (Gaussian sigma) to be $\approx$ 0.3 of the detector's single hit resolution. (called 1σ)
- Generate 10 sets of '1σ' misalignments and apply each to $2k$ $B_d \to \pi\pi$ events[1].
  $\Rightarrow$ This gives a $20k$ sample suppressing potentially 'friendly' or 'catastrophic' misalignment sets.
- Create other sets with misalignment scales increased by factors 3 (3σ) and 5 (5σ).

[1] Misalignment are applied at reconstruction level (Brunel v32r2) to events generated with perfect geometry.

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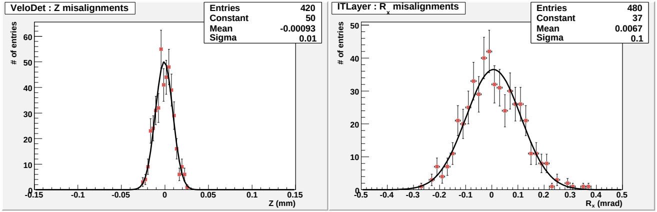
Misalignment scales

- Scales shown here are for the 1σ set (in $\mu\mathrm{m}$ and mrad).

	translations			rotations		
	Δ_x	Δ_y	Δ_z	Δ_α	Δ_β	Δ_γ
VELO sensor	3	3	10	1.00	1.00	0.20
VELO module	3	3	10	1.00	1.00	0.20
IT layer	15	15	50	0.10	0.10	0.10
OT layer	50	0	100	0.05	0.05	0.05



T station misalignment and pattern recognition

- Pattern recognition efficiencies with T station misalignments (IT/OT layers) only.

	$\epsilon_{forward}$		ϵ_{match}	
Brunel	v31r11	v32r2	v31r11	v32r2
0σ	0.86	0.86	0.81	0.81
1σ	0.15	0.86	0.81	0.81
3σ	0.15	0.86	0.80	0.80
5σ	0.15	0.85	0.77	0.77

- Problems in forward PR reported previously were genuine and due to '0 misalignment tolerance' of the PR.
- With new tracking framework (`Tf`, used in Brunel v32) numbers become much nicer!
- Thanks to Stephanie Hansmann-Menzemer for her support!

Overview of misalignment effects

- Effects on resolutions from both VELO & IT/OT misalignments.

Resolution	Affected by VELO misalignments	Affected by T misalignments
π momentum	NO	YES
B mass	NO	YES
B vertex	YES	NO
B IP	YES	NO
B $c\tau$	YES	NO

NO = very small/ negligible effects

YES = significant effects

Resolutions in numbers

- Resolutions as affected by VELO & IT/OT misalignments
- Resolutions are always measured as sigma of a single-Gaussian fit

	$\pi\ \sigma(p)/p$ (%)	B mass (MeV)	Primary z-vertex (μm)	B z-vertex (μm)	B $c\tau$ (fs)
0σ	0.495	22.5	41	147	37.7
1σ	0.504	22.3	48	159	40.9
3σ	0.560	25.1	84	214	58.0
5σ	0.630	25.5	153	260	78.6
	T dominated		VELO dominated		

On resolutions

- Misalignments can
  - deteriorate resolution
    $\Rightarrow$ sigma of $X_{rec} - X_{true}$ distribution
  - produce a bias
    $\Rightarrow$ mean of $X_{rec} - X_{true}$ distribution
- For 10 different misalignment configurations,
  we measure sigma of $X_{rec} - X_{true}$ distribution for all samples.
  $\Rightarrow$ combine effects of worsened resolution and bias
- Therefore look at
  - average sigma
  - RMS of mean
- ... and calculate $< sigma > /RMS(mean)$
  $\Rightarrow$ should be large for negligible bias

On resolutions - II

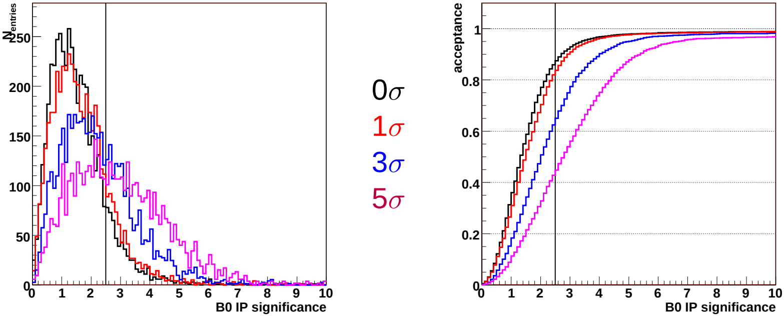
- ... and calculate $< sigma > /RMS(mean)$ for all measured resolutions

	min $< sigma > /RMS(mean)$	max $< sigma > /RMS(mean)$
0σ	14	36
1σ	6	19
3σ	5	18
5σ	3	15

- No large effect due to misalignment-induced bias.
- Also, $< sigma >$ not accurate due to low statistics.

$\Rightarrow$ take measured values as conservative estimate that may be at most 10% too high.

Effect on selection



- Biggest effect comes from tight upper cut on B impact parameter significance ($IPS(B_d) < 2.5$).
- Additional effect on lower IPS cut of daughters.

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Input misalignments

- Use 1σ misalignment scales from VELO & T.
- Create 10 sets with random misalignments
- In addition, introduce z-scaling:
  $z_{module} \rightarrow z_{module} \times (1 + scale)$
- Study different samples with
  $scale = \frac{1}{3} \times 10^{-4}, \quad 10^{-4}, \quad \frac{1}{3} \times 10^{-3}, \quad 10^{-3}$
- On the 1 m length of the VELO these scale mean additional
  $33\ \mu\text{m}$, $100\ \mu\text{m}$, $333\ \mu\text{m}$, $1000\ \mu\text{m}$

Resolutions in numbers

- Resolutions as affected by VELO z-scale misalignments

z-scale	π $\sigma(p)/p$ (%)	B mass (MeV)	Primary z-vertex (μm)	B z-vertex (μm)	B $c\tau$ (fs)
1.00000	0.495	22.5	41	147	37.7
1.00003	0.502	22.7	55	162	42.3
1.00010	0.495	22.7	57	158	42.1
1.00033	0.501	22.5	60	163	42.8
1.00100	0.511	23.2	83	199	49.7

Effect on vertices

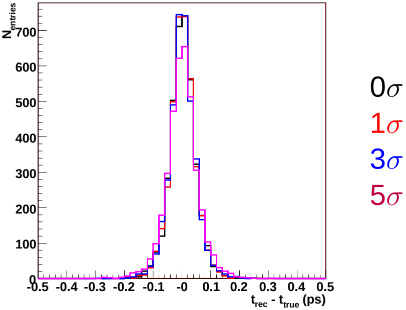
- Vertex resolution after standard $B \to hh$ selection.

z-scale	Primary vertex resolution (in μm)	Primary vertex bias (in μm)	B vertex resolution (in μm)	B vertex bias (in μm)
1.00000	41	2	147	13
1.00003	55	-2	162	16
1.00010	57	2	158	18
1.00033	60	3	163	17
1.00100	83	16	199	22

Effect on proper time

- Proper time resolution after standard $B \to hh$ selection.

z-scale	proper time resolution (in fs)	proper time bias (in fs)
1.00000	37.7	1.8
1.00003	42.3	3.1
1.00010	42.1	2.7
1.00033	42.8	1.6
1.00100	49.7	1.4



A fast test

- Fast geometry uses greatly simplified description of material in LHCb
- Test performance (without misalignments) compared to detailed geometry
- $\Rightarrow$ No obvious difference in pattern recognition observed
- $\Rightarrow$ Physics parameters follow...

Resolutions in numbers

- Resolutions of standard reconstruction and 'fast geometry'

geometry	π $\sigma(p)/p$ (%)	B mass (MeV)	Primary z-vertex (μm)	B z-vertex (μm)	B $c\tau$ (fs)
standard	0.495	22.5	41	147	37.7
fast	0.502	22.9	41	145	37.7

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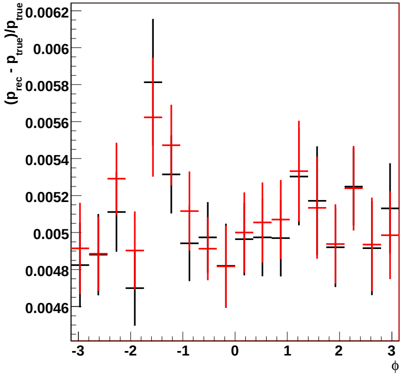
A closer look



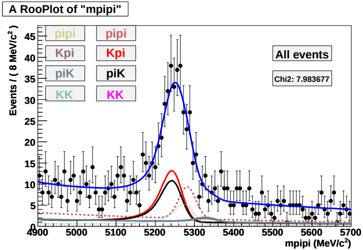
- Due to simplifications, effects are expected as function of ϕ
- Check momentum resolution vs ϕ
- No significant deviation from standard geometry observed

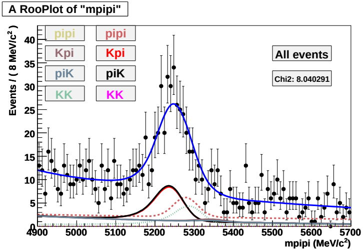
B2hhFit

- Use `B2hhFit` v5r6
- Run 200 toys with reduced statistics ($\approx 0.2\ \mathrm{fb}^{-1}$)
- As full fit didn't work yet:
  - Run mass fit for B_d and B_s combined
  - Run simultaneous mass & time fit separately for B_d and B_s
- Vary input values for mass resolution and proper time resolution according to output of misalignment studies with VELO & T misaligned.

Mass fit only

- Mass resolution:
  - 22.5 MeV (ideal, left)
  - 25.5 MeV (VELO & T '5σ' case)
  - 30.0 MeV (extreme, right)





- Slight deterioration on fit parameter precision and bias
  $\Rightarrow$ overall stable fit

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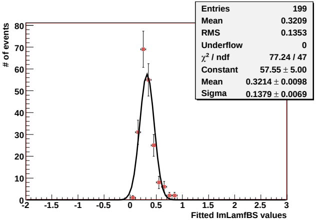
Combined mass & time fit

- Use VELO & T misalignment results for 0σ, 3σ, 5σ
- Do separate fits for B_d and B_s
- B_s seems to be more sensitive to misalignments
- affected variables are:
  - $\Delta\Gamma(B_s)$
  - $\Im(\lambda_f(B_s))$
  - $\Re(\lambda_f(B_s))$
  - $\omega(B_s)$
- First misalignment studies with a lifetime fit!

Combined mass & time fit - II

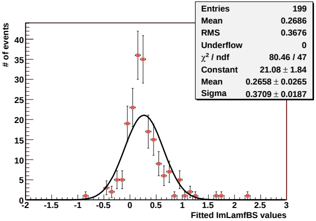
- Towards a *CP* sensitivity

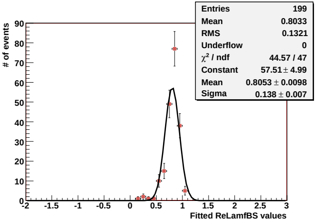


$\longleftarrow 0\sigma$

$\Im(\lambda_f(B_s))$

$5\sigma \longrightarrow$

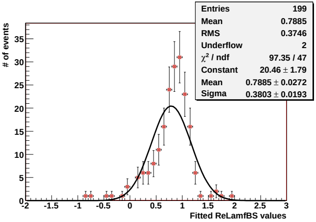




$\longleftarrow 0\sigma$

$\Re(\lambda_f(B_s))$

$5\sigma \longrightarrow$



Combined mass & time fit - III

- No significant impact of misalignments on *CP* asymmetries observed
- Impact of misalignments on *CP* asymmetry sensitivities (uncertainties):

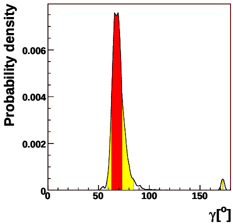
	B_d		B_s	
	A_{mix}	A_{dir}	A_{mix}	A_{dir}
0σ	0.12	0.14	0.13	0.14
3σ	0.18	0.20	0.26	0.18
5σ	0.15	0.15	0.52	0.56

- Effect on B_d hardly significant
- Large effects on B_s, particularly at 5σ

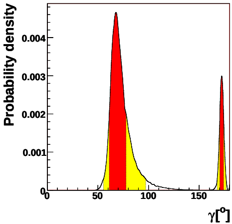
$\Rightarrow$ take these sensitivities and extract sensitivity on γ!

Combined mass & time fit - IV

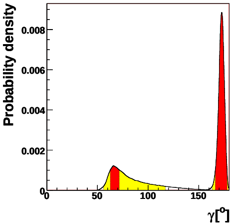
- Measuring γ
- Sensitivities scaled by $1/\sqrt{10}$ as 0.2 fb^{-1} numbers were too large
- Input: θ, θ' free; $d/d' = [0.8, 1.2]$; $\gamma = 65^\circ$
- Output: values quoted for 68% probability interval



0σ: $(68.0 \pm 5.2)^\circ$



3σ: $(69.5 \pm 8.3)^\circ$
$(172.2 \pm 1.9)^\circ$



5σ: $(67.1 \pm 4.4)^\circ$
$(172.1 \pm 5.8)^\circ$

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Plans

- Write a detailed note
  $\Rightarrow$ first draft already in internal circulation
- Use misaligned events as direct input for `B2hhFit`
  $\Rightarrow$ enables also the use of z-scaling events directly
- *Chapter 2*:
  Study the 're-aligned' case in the alignment challenge
  $\Rightarrow$ getting closer...

Conclusions

- VELO misalignments strongly affect $B \longrightarrow hh$ selection and proper time resolution
- VELO z-scaling should not be a problem
- T misalignments have moderate effect on momentum and mass resolution
- Fast geometry looks fine so far
- `B2hhFit` sensitive to large misalignments and small statistics
- If software alignment is of the order of our '1σ' case things look fine
- Looking forward to chapter 2!

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