Impact of misalignments on B → h h

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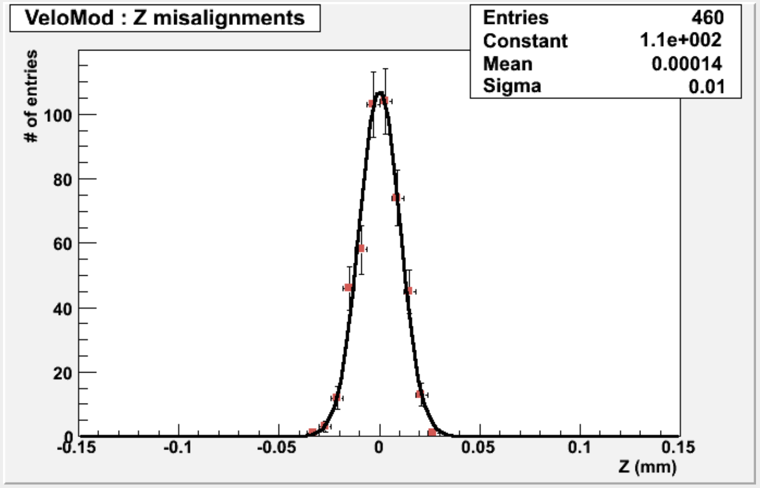
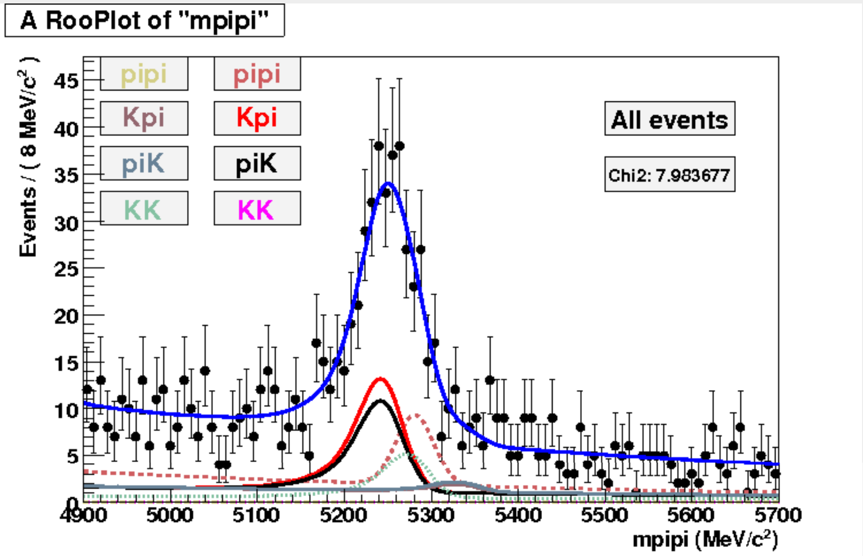




Motivation and overview

Mission statement

Study effects of misaligned tracking system on measurements of B $\rightarrow$ hh decays

✓ **“Chapter I”:**

- Systematic study of 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 degrees-of-freedom
- Effects on selection and subsequent CP-sensitivity analysis

✘ **“Chapter II” – connection to alignment challenge:**

- Study remaining misalignment effects after application of alignment algorithms
- Exploit the data samples of the alignment challenge
- Identify potential problems/biases of alignment procedure

Outline

Motivation and overview

- connection to alignment challenge

Implementation of misalignments

- misalignment scales and conditions databases
- data samples

Impact of misalignments on selection of $B \to hh$ decays

- VELO misalignments
- IT and OT misalignments

Impact of misalignments on combined $B \to hh$ fit

- RooFit analysis of combined $B \to hh$ decays

Outlook and future

Implementation of misalignments

Procedure (1/2)

Misaligned databases:

- ❑ Create random misalignments for VELO sensors/modules and IT and OT layers
- ❑ Choose scale (Gaussian sigma) to be ~1/3 of the detector single hit resolution (called “1σ”)
- ❑ Generate 10 sets of “1σ” misalignments for each sub-detector
- ❑ Likewise, create similar sets with misalignment scales increased by factors of 3 (3σ) and 5 (5σ)
- ❑ Every 10 sets of VELO / IT / OT 1σ / 3σ / 5σ misalignments stored in a conditions database

$\Rightarrow$ 9 (small) slice databases in total:

- VELO 1σ / 3σ / 5σ misalignments
- IT and OT 1σ / 3σ / 5σ misalignments
- VELO, IT and OT 1σ / 3σ / 5σ misalignments

Procedure (2/2)

Data samples:

- Generate 10 x 2K events each of which with a different set of the 10 sets of "1σ" misalignments for each sub-detector

  $\Rightarrow$ 20K $B \to \pi\pi$ events for each of the misalignment scenarios:

  - no misalignment (0σ)
  - 1σ / 3σ / 5σ misalignments for VELO, IT/OT, VELO and IT/OT

  suppressing potentially "friendly" or "catastrophic" misalignment sets

- In total, 200K $B \to \pi\pi$ events generated

Event processing:

- Events generated with perfect geometry (up to DIGI level)
- DSTs produced with Brunel version v32r2,

  misalignments applied solely at reconstruction level

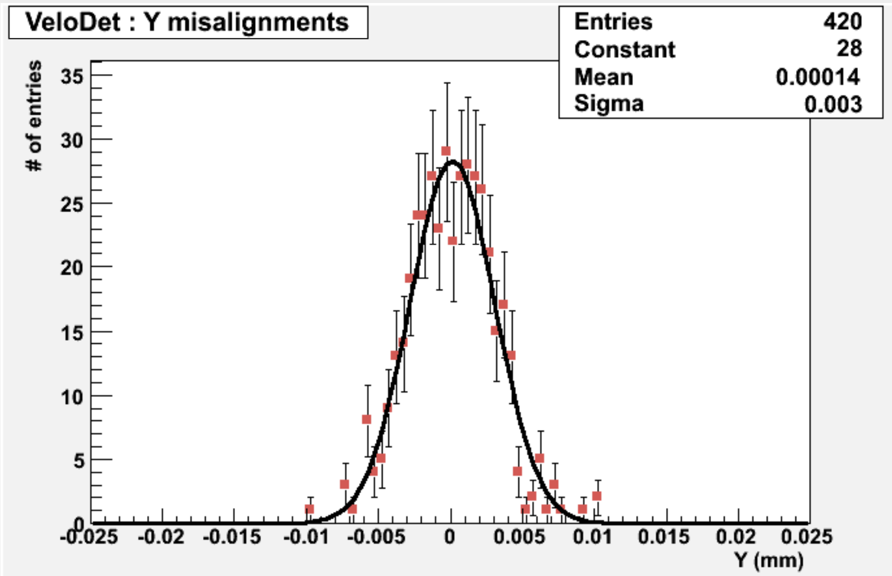
- Physics analysis later performed with DaVinci v19r9

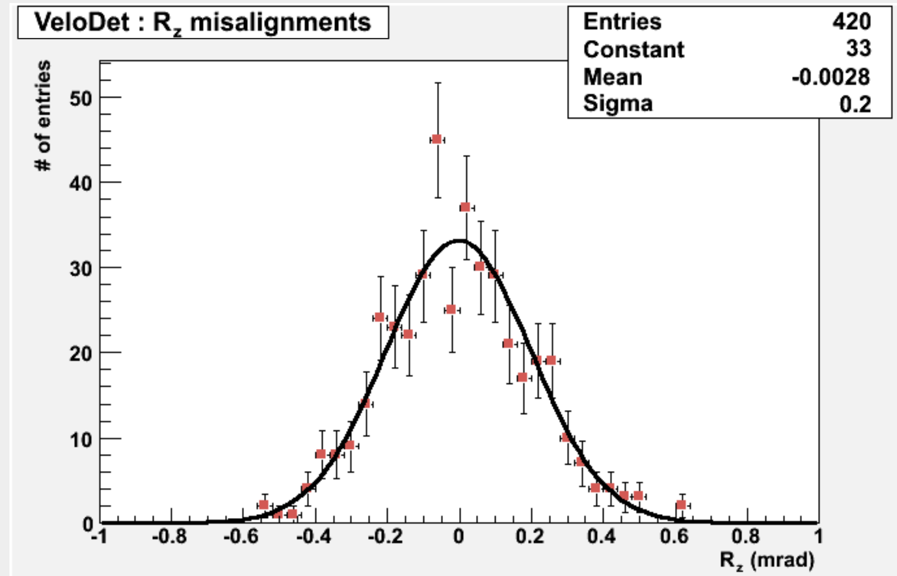
Misalignment scales and conditions databases (1/2)

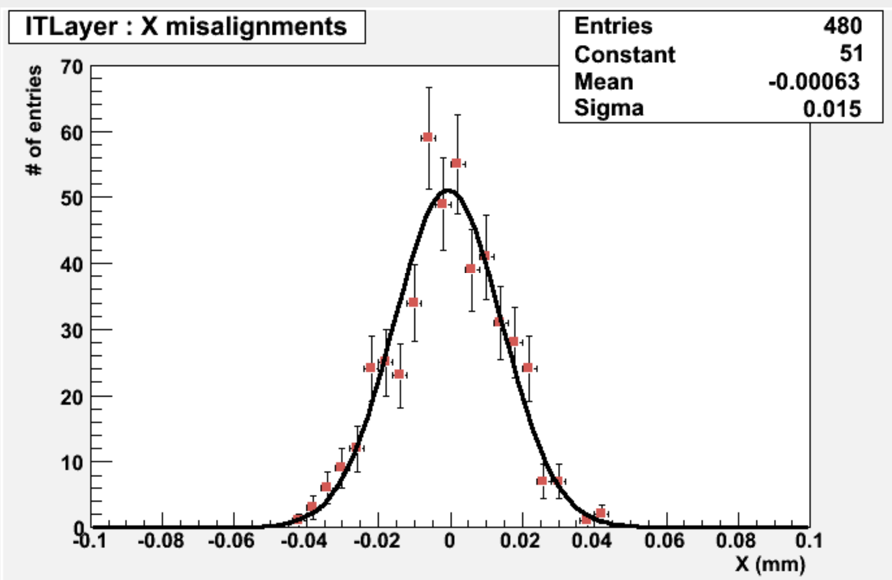
- **Scales for the "1σ" misalignment set:**

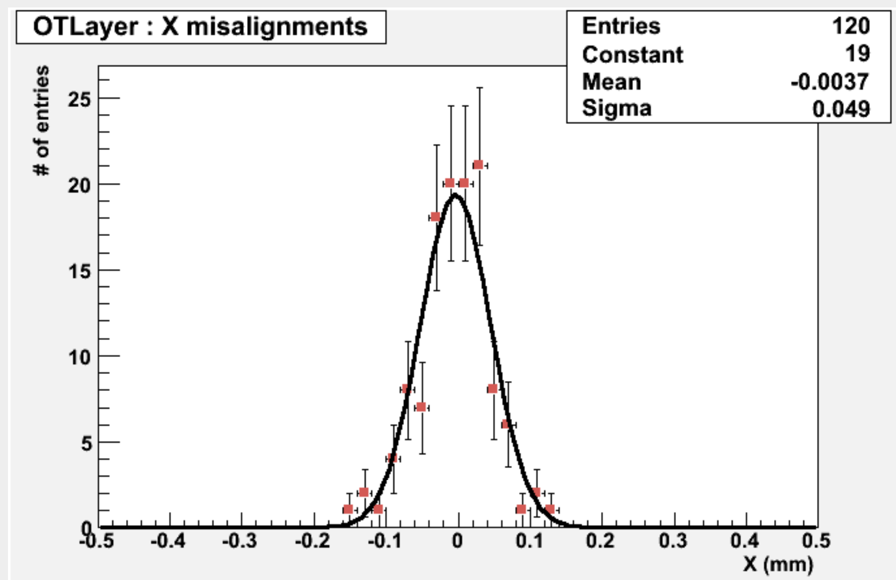
SUB-DETECTOR	Translations (μm)			Rotations (mrad)		
	Δ_x	Δ_y	Δ_z	R_x	R_y	R_z
VELO sensor VELO module	3	3	10	1.00	1.00	0.20
IT layer	15	15	50	0.10	0.10	0.10
OT layer	50	0	100	0.05	0.05	0.05

Misalignment scales and conditions databases (2/2)









Impact of misalignments on selection of $B \to hh$ decays

The B → hh analysis, in short (1/2)

Goal:

- Extraction of γ angle from $B \to \pi\pi$ and $B_s \to KK$ events
- From measurement of CP asymmetries assuming U-spin symmetry

$$A_{CP}(t) = \frac{\Gamma(\overline{B}^0_{d,s} \to f) - \Gamma(B^0_{d,s} \to f)}{\Gamma(\overline{B}^0_{d,s} \to f) + \Gamma(B^0_{d,s} \to f)} = \frac{A^{dir}_{CP}\cos(\Delta m\, t) + A^{mix}_{CP}\sin(\Delta m\, t)}{\cosh(\frac{\Delta\Gamma}{2}t) - A^{\Delta\Gamma}_{CP}\sinh(\frac{\Delta\Gamma}{2}t)}$$

- This asymmetry is a function of γ and a series of hadronic parameters
  (parameterizing magnitude and phase of penguin-to-tree amplitude ratio)

- Analysis involves several $B \to hh'$ decays, where $h = \pi$, K

The B $\rightarrow$ hh analysis, in short (2/2)

Selection cuts consist of various requirements:

- **Particle identification:**
  - K-π separation based on PID likelihood difference ($\Delta \ln \mathcal{L}_{K\pi}$)
- **Topological:**
  - clear separation of primary vertex and B-decay vertex
  - B-daughters impact parameter (IP) and B-decay length significance
- **Kinematic:**
  - minimal B-candidate and B-daughters transverse momentum
- **Vertexing:**
  - χ^2 of vertex fit to B-daughters
- **Mass:**
  - mass window cut on invariant mass of B-daughters

Impact of VELO misalignments (1/5)

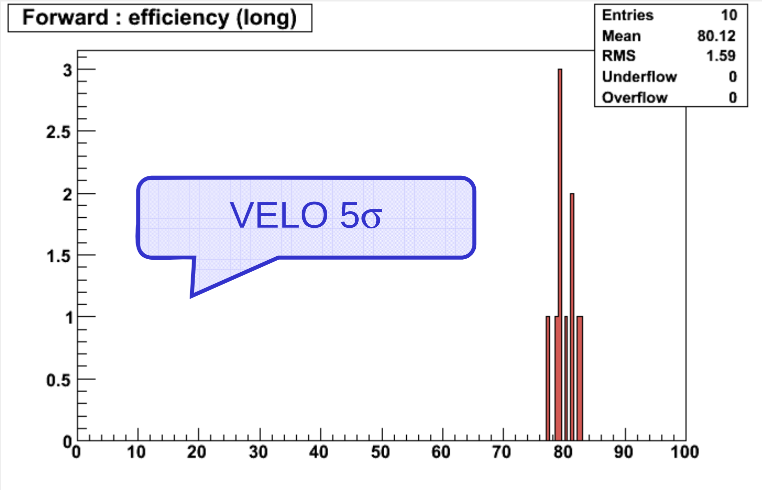
- **Selected event numbers and pattern recognition efficiencies *after* standard $B \rightarrow hh$ selection**

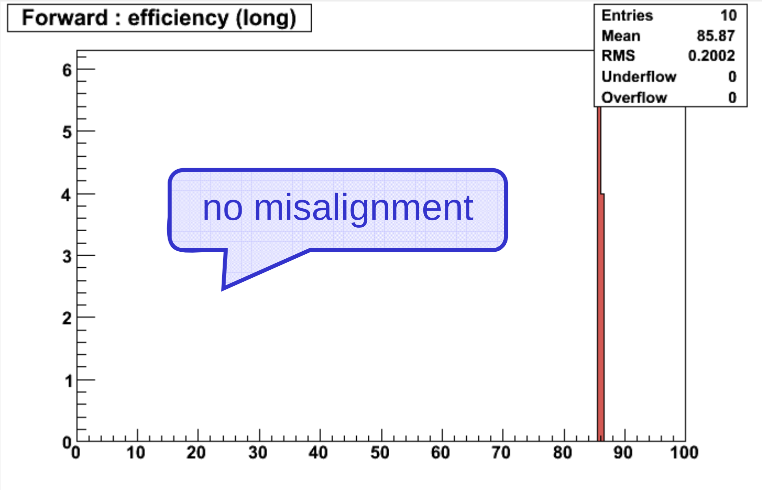
	$N_{selected\ B}$	$\varepsilon_{PatForward}$ (%)	$\varepsilon_{Matching}$ (%)
0σ	4229	85.9	81.1
1σ	3904	85.6	80.9
3σ	2241	83.1	78.3
5σ	1106	80.1	75.5

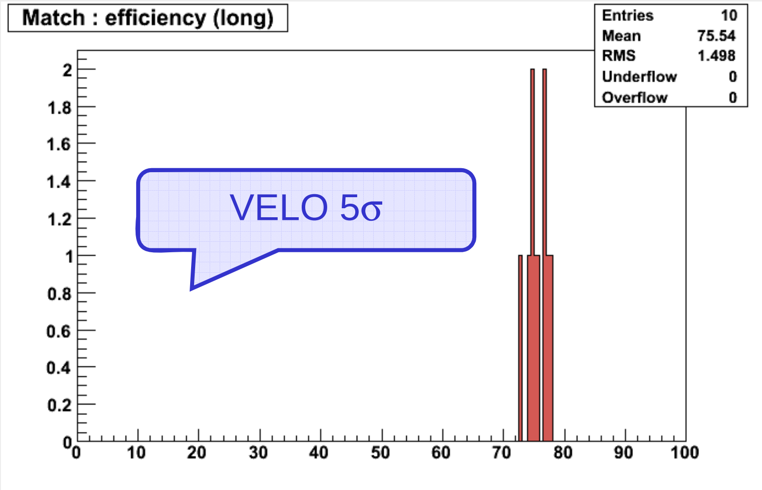
- Effect on pattern recognition is small-ish
- Very significant loss of events, has to come from the selection itself …
  - ⇒ misalignments have serious impact on some selection variables
  - ⇒ systematic check of all of them …

Impact of VELO misalignments (2/5)

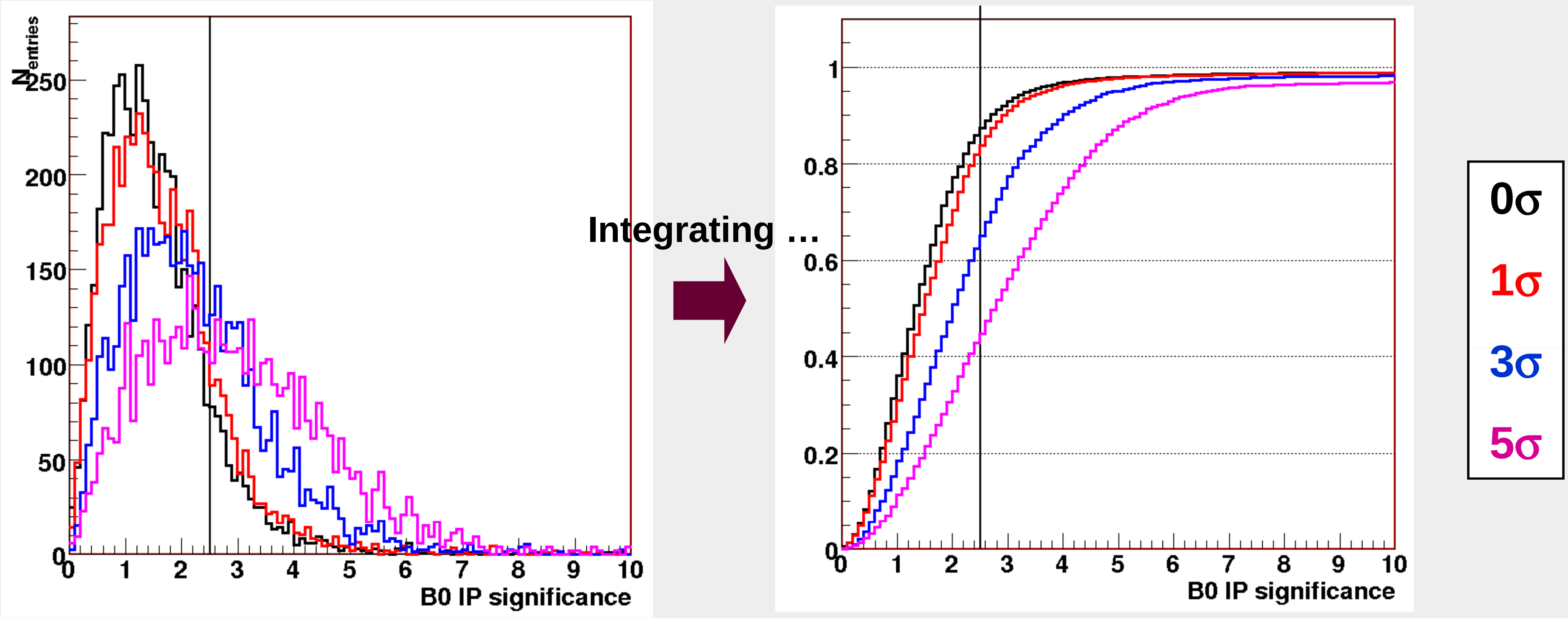
❖ **Example of PR efficiency distributions obtained with the 10 sets of 2K events produced with Brunel**







Impact of VELO misalignments (3/5)



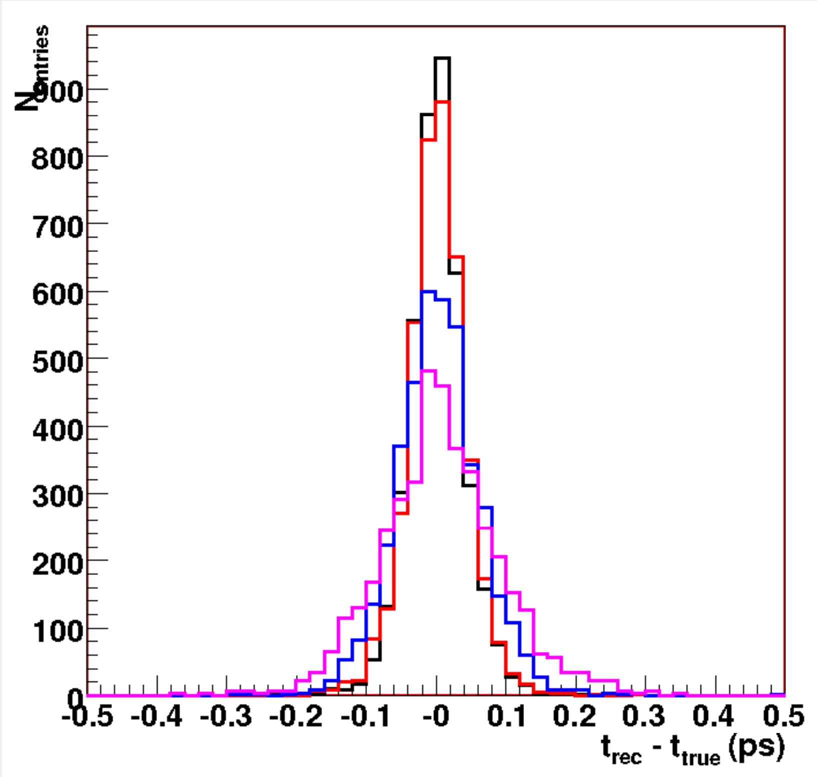
- ❑ **Biggest effect comes from tight upper cut on the B-candidate IP significance, IPS < 2.5**
- ❑ **Additional effect on lower IPS cut of B-daughters**
- ❑ **Also χ^2 of B-vertex fit is rather affected**

Impact of VELO misalignments (4/5)

❖ **Propertime resolution *after* standard B → hh selection**

	τ resolution (fs)
0σ	37.7
1σ	39.4
3σ	58.1
5σ	82.0

(sigma of Gaussian fit)



2^{nd} order effects:

- ❑ **B-daughters momentum resolution: 0.50 → 0.52 %**
- ❑ **B mass resolution: 22.5 → 23.5 MeV**

Impact of VELO misalignments (5/5)

- Primary vertex and B-decay vertex resolutions in selected B $\rightarrow$ hh events

Resolution	Primary vertex (μm)		B-decay vertex (μm)	
	x/y	z	x/y	z
0σ	9	41	14	147
1σ	10	48	15	155
3σ	16	81	21	226
5σ	25	147	29	262

First ever check of impact of misalignments on vertex resolutions

Impact of IT and OT misalignments (1/3)

➢ **Selected event numbers and pattern recognition efficiencies *after* standard B $\rightarrow$ hh selection**

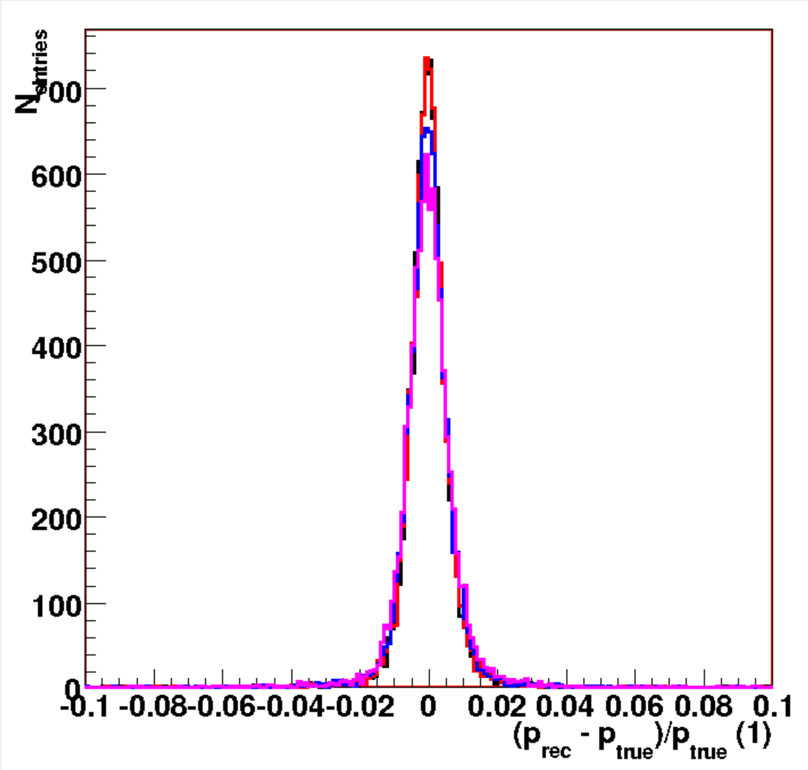
	$N_{selected\ B}$	$\varepsilon_{PatForward}$ (%)	$\varepsilon_{Matching}$ (%)
0σ	4229	85.9	81.1
1σ	4226	85.8	81.0
3σ	4187	85.6	79.9
5σ	4073	85.4	77.2

- **Effect on pattern recognition is small**
- **Loss of events much smaller compared to the VELO case**

Impact of IT and OT misalignments (2/3)

❖ Momentum resolution *after* standard B → hh selection

	p resolution (%)
0σ	0.50
1σ	0.50
3σ	0.54
5σ	0.59



0σ
1σ
3σ
5σ

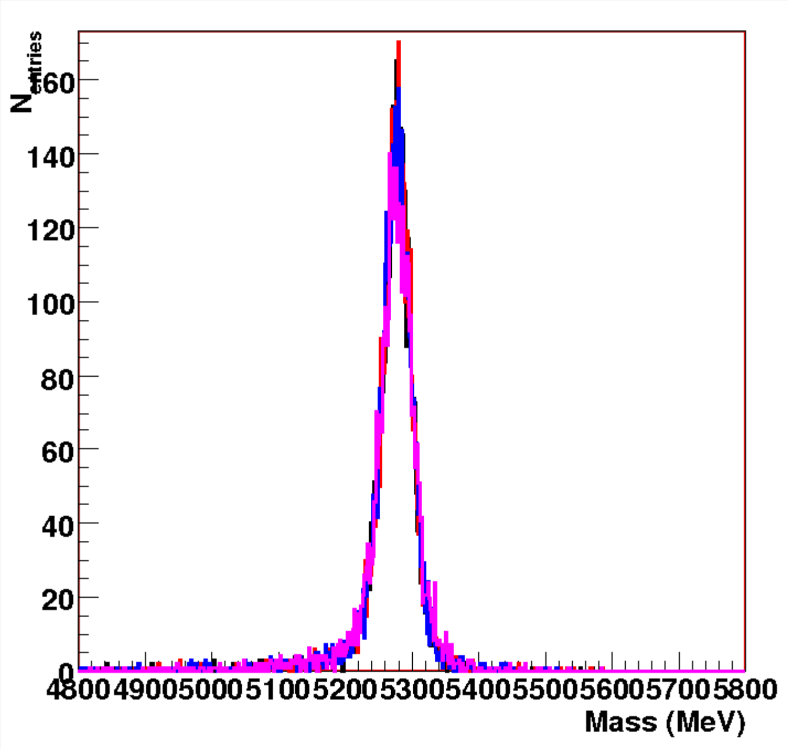
2nd order effects:

- E.g. B propertime resolution: 37.7 → 38.8 fs

Impact of IT and OT misalignments (3/3)

❖ Mass resolution *after* standard B $\rightarrow$ hh selection

	Mass resolution (MeV)
0σ	22.5
1σ	22.6
3σ	23.4
5σ	25.8



0σ

1σ

3σ

5σ

➢ at most of order 10% effect

Impact of combined VELO, IT and OT misalignments (1/2)

➢ **Selected event numbers, PR efficiencies and resolutions *after* standard $B \rightarrow hh$ selection**

	$N_{selected\ B}$	$\varepsilon_{PatForward}$ (%)	$\varepsilon_{Matching}$ (%)	τ res. (fs)	*p* res. (%)	Mass res. (MeV)
0σ	4229	85.9	81.1	37.7	0.50	22.5
1σ	3892	85.6	80.8	40.9	0.50	22.3
3σ	2086	83.3	77.3	58.0	0.56	25.1
5σ	1040	78.5	70.6	78.6	0.63	25.5

- ❑ **Effects are roughly the combined effects of VELO and IT+OT misalignments**
- ❑ **The selection efficiency is *not* ∝ PR efficiencies and resolutions :**

  pattern recognition efficiencies and resolutions have worse than linear effect on statistical power of analysis!

Impact of combined VELO, IT and OT misalignments (2/2)

RESOLUTION	Affected by VELO misalignments	Affected by T misalignments
B-daughters momentum	no	yes
B mass	no	yes
B vertex	yes	no
B Impact Parameter	yes	no
B propertime	yes	no

("no" taken here as "small effect")

Impact of misalignments on combined $B \to hh$ fit

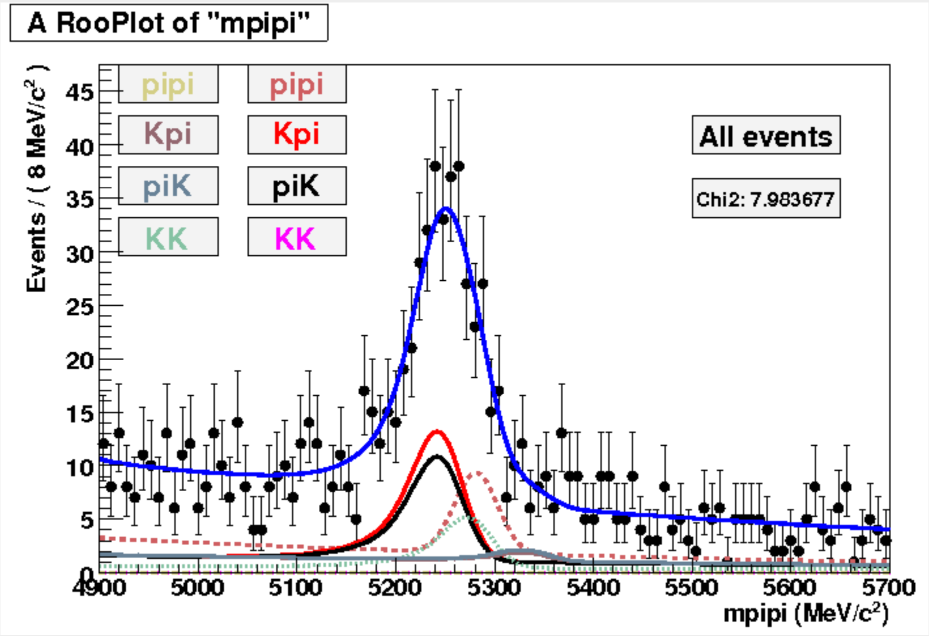
The B2hhFit toy MC fitter, in short

- Allows for CP-sensitivity studies with B $\rightarrow$ hh decays
- Fast toy Monte Carlo fitter based on RooFit to study effect of misalignments purely based on their size
- Combined fit of 8 B/$\bar{B}$ $\rightarrow$ hh' decays
- An unbinned extended maximum likelihood fit is performed on the combined conditional PDF of the mass and time signal and background events (with >17 free parameters)
- Uses as input outcome of B $\rightarrow$ hh selection studies such as propertime and mass resolutions

- Using latest version in CVS
- Simultaneous mass and lifetime fit not yet available

  $\Rightarrow$ study of mass fit with B^0 /B_s together

  $\Rightarrow$ study of mass and lifetime fit separately for B^0 and B_s channels



(Typical output: invariant mass distribution)

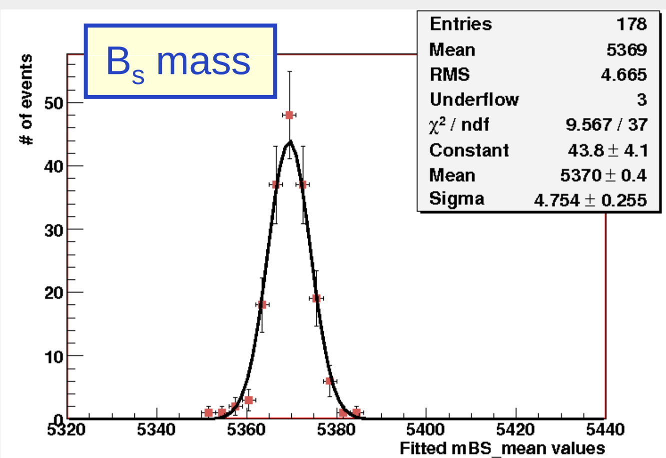
B2hhFit toy - mass fit (1/2)

Variable	Input value	Fit value +/- error
B02Kpi_A	-0.123	-0.124 +/- 0.096
N_B02KpiSig	8822.000	8726.893 +/- 836.927
N_B02pipiSig	2289.000	2267.514 +/- 449.456
N_BS2KKSig	2158.400	2116.102 +/- 328.123
N_BS2piKSig	589.000	550.018 +/- 343.148
mB0_mean	5279.000	5279.127 +/- 2.173
mBS_mean	5369.000	5369.517 +/- 4.754
smB1	22.500	22.419 +/- 2.032

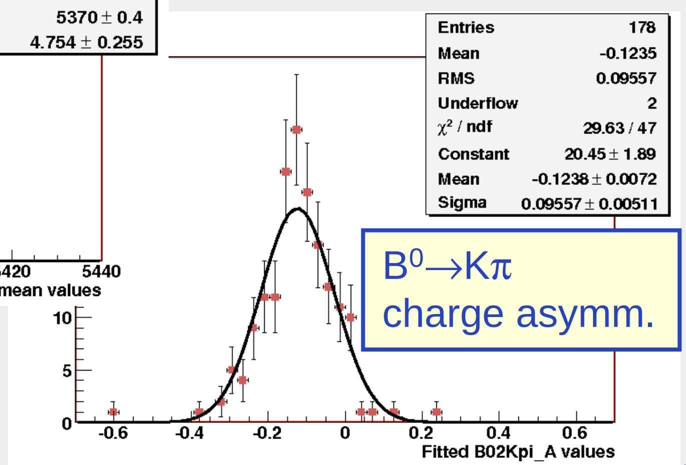
Stats = 0.2 fb^{-1}, 200 toys!

B2hhFit result

Mass resolution of 22.5 MeV



(Fit value and error refer to mean and sigma of Gaussian fit to dist. of 200 experiments)

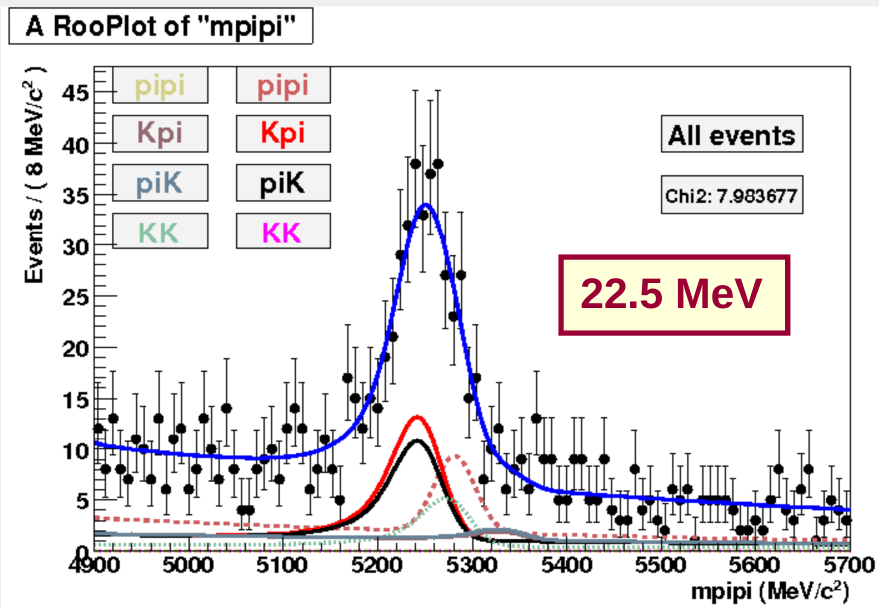


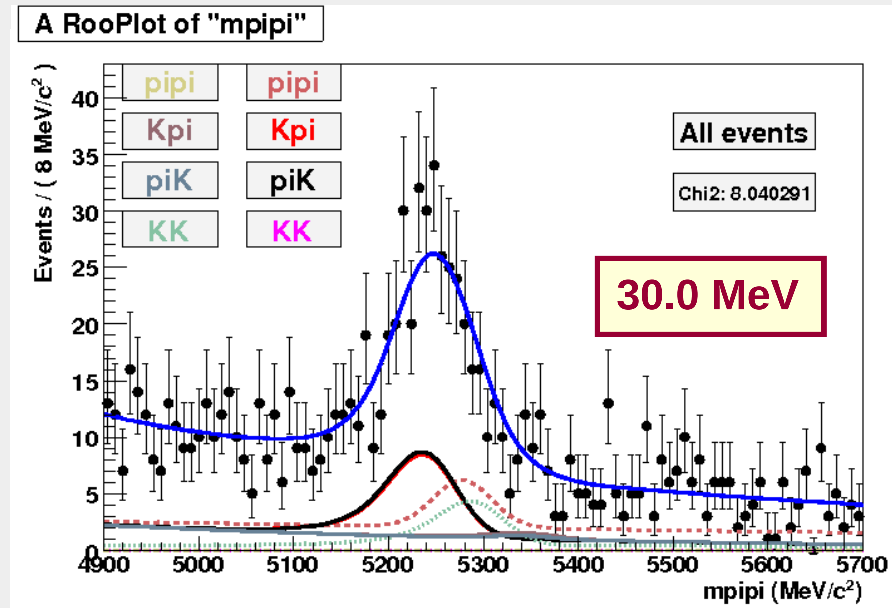
Variable	Pull mean	Pull sigma
B02Kpi_A	-0.01	1.05
N_B02KpiSig	-0.10	1.00
N_B02pipiSig	-0.02	1.05
N_BS2KKSig	-0.03	0.89
N_BS2piKSig	-0.06	0.89
mB0_mean	0.04	1.06
mBS_mean	0.09	1.14
smB1	-0.05	1.06

B2hhFit toy - mass fit (2/2)

➢ **Checked effect of mass resolution:**

22.5 → 25.5 (VELO & IT/OT 5σ misalignments) → 30.0 MeV (“extreme case”)





- **Errors on fitted parameters tend to increase, but only marginally**
- **Pull distributions do not deteriorate, i.e. fit quality does not “collapse”**
- **Though biases in pulls increase slightly**

B2hhFit toy - lifetime fit (1/3)

- **Lifetime fitter run separately for B^0 and B_s decays**

Stats = 0.2 fb^{-1}, 200 toys!

- **Sensitivity to CP parameters such as $Im(\lambda_f)$ and $Re(\lambda_f)$ and Δm_s, $\Delta\Gamma_s$, ω_{tag}**

$$C_f \equiv A_{CP}^{dir} = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2} \quad , \quad S_f \equiv A_{CP}^{mix} = \frac{2\,\mathrm{Im}(\lambda_f)}{1+|\lambda_f|^2}$$

$$\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f}$$

$\Rightarrow$ **γ, d and θ can be determined once C and S are known (U-spin symmetry at 20% level)**

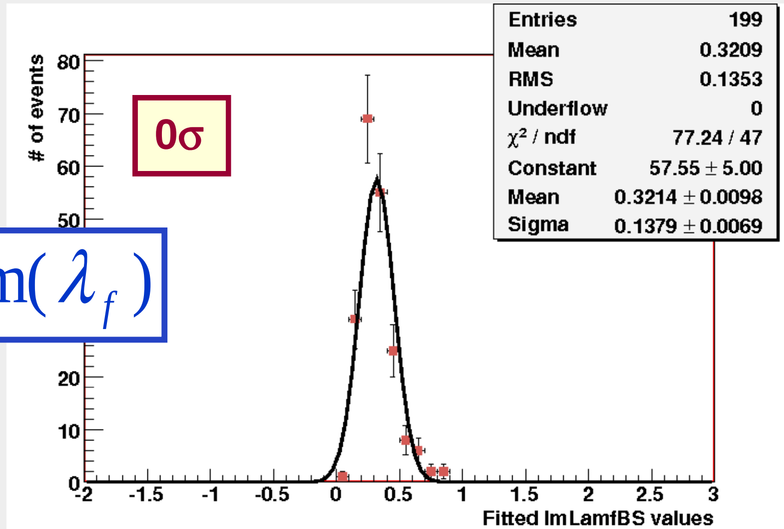
❖ **First misalignment study with a lifetime fitter!**

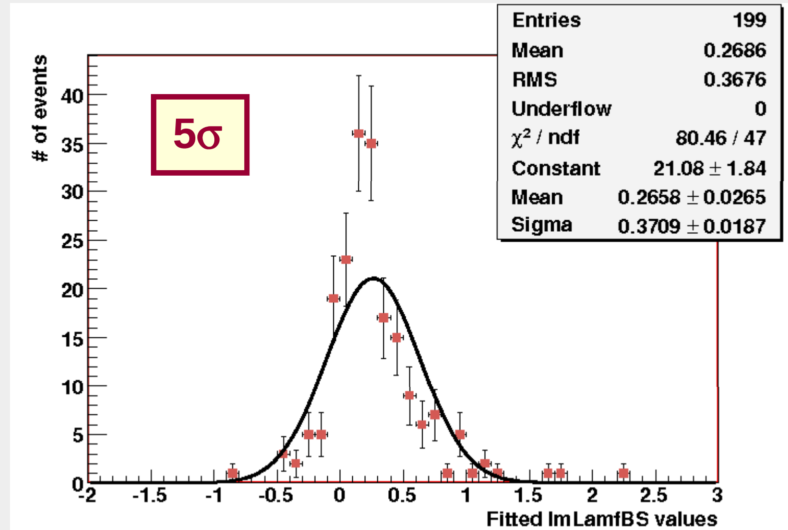
B2hhFit toy - lifetime fit (2/3)

Example of B_s fit

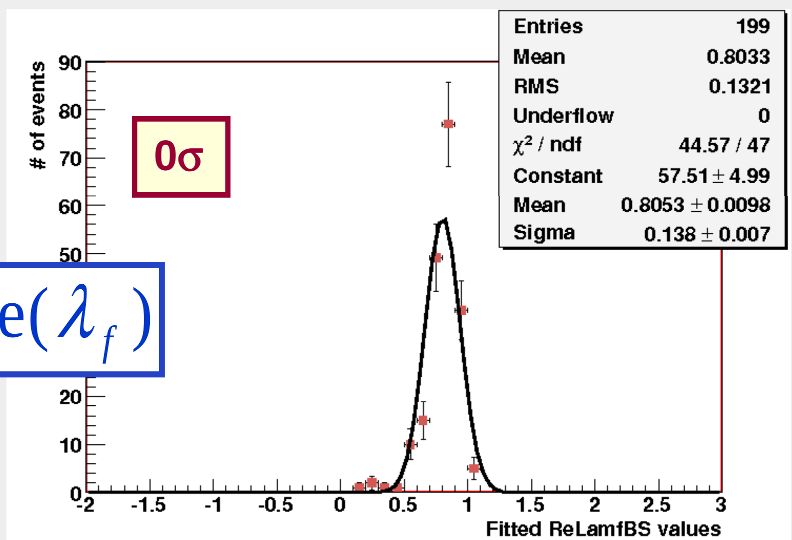
- **Checked effect of propertime resolution:**

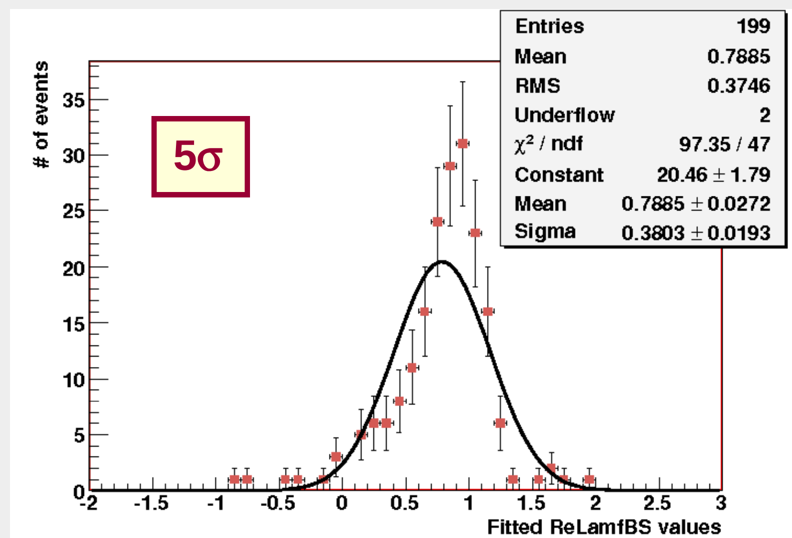
$\mathrm{Im}(\lambda_f)$





$\mathrm{Re}(\lambda_f)$





B2hhFit toy - lifetime fit (3/3)

- Good quality fits; pull distributions are rather good
- The B_s fit is more sensitive to misalignments than the B^0 fit (under investigation)
- Misalignments clearly deteriorate the intrinsic quality of the determination of the interesting physics parameters!

0σ

Variable	Input value	Fit value	+/-	error
BS2Kpi_A	0.140	0.140	+/-	0.057
DeltaGammaBS	0.368	0.391	+/-	0.392
DeltaMassBS	107.380	107.721	+/-	0.725
ImLamfBS	0.309	0.321	+/-	0.138
N_BS2KKSig	2158.400	2155.777	+/-	46.856
N_BS2piKSig	589.000	589.947	+/-	39.868
ReLamfBS	0.828	0.805	+/-	0.138
deltaBS2KK	1.310	1.303	+/-	0.043
deltaBS2piK	1.310	1.306	+/-	0.022
etaBS2KK	0.990	0.989	+/-	0.042
etaBS2piK	0.990	0.994	+/-	0.022
mBS_mean	5369.000	5369.369	+/-	0.385
mBS_width	16.000	15.994	+/-	0.422
muBS2KK	0.001	0.001	+/-	0.000
muBS2piK	0.001	0.001	+/-	0.000
tauBS	0.272	0.271	+/-	0.011
wBS	0.290	0.278	+/-	0.055

5σ

Variable	Input value	Fit value	+/-	error
BS2Kpi_A	0.140	0.140	+/-	0.061
DeltaGammaBS	0.368	0.404	+/-	0.518
DeltaMassBS	107.380	107.311	+/-	2.371
ImLamfBS	0.309	0.266	+/-	0.371
N_BS2KKSig	2158.400	2157.446	+/-	47.705
N_BS2piKSig	589.000	594.140	+/-	41.144
ReLamfBS	0.828	0.788	+/-	0.380
deltaBS2KK	1.310	1.309	+/-	0.046
deltaBS2piK	1.310	1.305	+/-	0.023
etaBS2KK	0.990	0.997	+/-	0.024
etaBS2piK	0.990	0.994	+/-	0.022
mBS_mean	5369.000	5369.097	+/-	0.298
mBS_width	16.000	15.986	+/-	0.420
muBS2KK	0.001	0.001	+/-	0.000
muBS2piK	0.001	0.001	+/-	0.000
tauBS	0.272	0.269	+/-	0.012
wBS	0.290	0.218	+/-	0.138

Outlook and future

- **A lot of work done recently !**
  - redid everything presented in December with latest Brunel and DaVinci
  - looked also at combined effect of VELO, IT and OT misalignments
  - checked effects on all cut variables used in the B $\rightarrow$ hh selection
  - detailed check of impact of misalignments on physics with toy fitter: combined (RooFit) fit, with the B2hhFit toy

- **VELO misalignments strongly affect selection and propertime and IP resolutions**
- **T-stations misalignments affect mainly momentum and mass resolutions**

- **If software alignment is of order or better than "1sigma" we are in business!**
- **Looking forward to our "chapter II"**

  $\Rightarrow$ **needs standard alignment procedure, outcome of the alignment challenge**

Acknowledgments

Many thanks to the organisers for very pleasant workshop!

Great food, also!!! … quoting e.g. Jan ;-)