VELO systematics and physics

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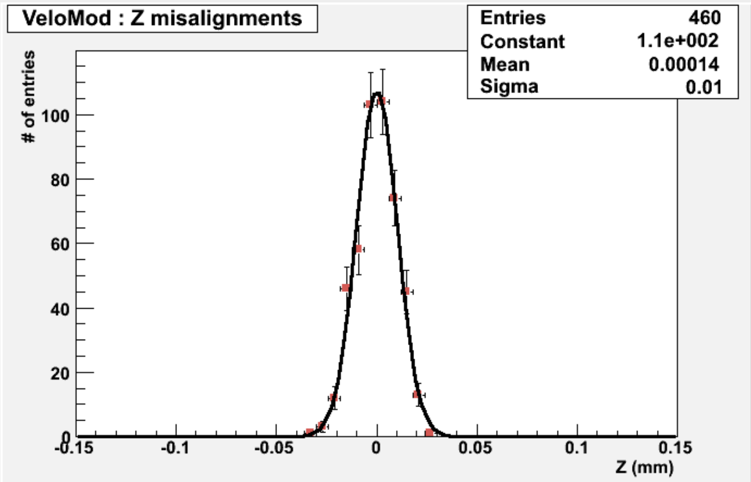
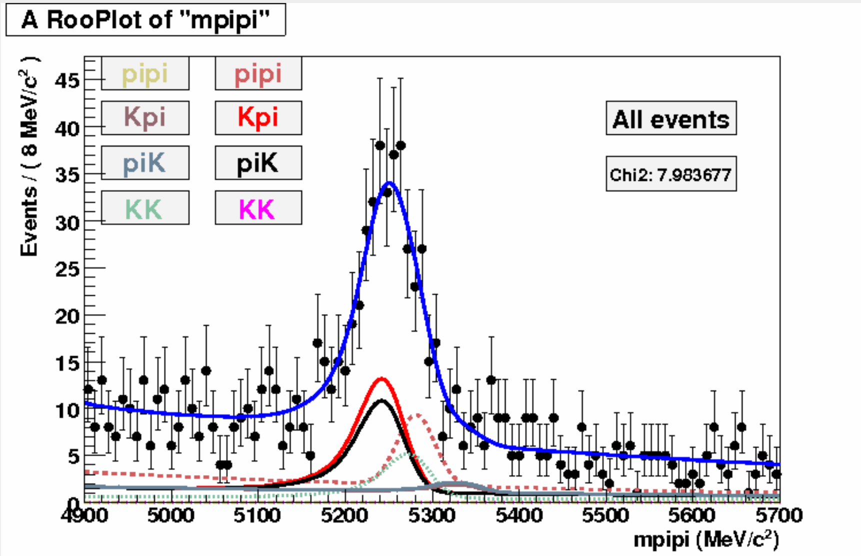
LHCb VELO meeting, CERN, 28 March 2008





VELO systematics and physics

What are VELO systematics?

- **Any systematic effects / biases introduced by mis-understanding / simplifications of VELO calibration / response / data reconstruction / …**

General thoughts

- **VELO group has so far focused on detector design, construction, installation and commissioning**
- **Time to use all the expertise to bridge with studies of relevance to physics analysis**
- **Group needs to tackle assessment/impact of VELO performance on the quality of the physics output**
- **We are in an ideal situation to do so … ;-)**

A non-exhaustive shopping list

Main idea:

Brainstorming with VELO experts on areas of reconstruction that can be improved among those that have most impact on physics performance

- **Improvements in clustering algorithms**
- **Eta correction to cluster position → impact on tracking?**
- **Tuning of resolutions with data: so far simulation has tuning from test-beam data, but better estimate resolutions directly from data**
- **Cross-talk corrections from data: is this issue fully solved? Do we have the machinery in place and implemented?**
- **Study of calibration strategies from (real) data**
- **VELO data quality and vertexing (measurements errors)**
- **B-field in VELO: really negligible / irrelevant for e.g. K_s analyses?**
- **Propertime resolution models studies:**
  c.f. studies from Laurence Carson, see next page
- **Some of these issues are also relevant for the trigger**
- **Effects of VELO misalignments on quality of physics analyses**
  → discussed here, today …

Propertime resolution model for B→hh

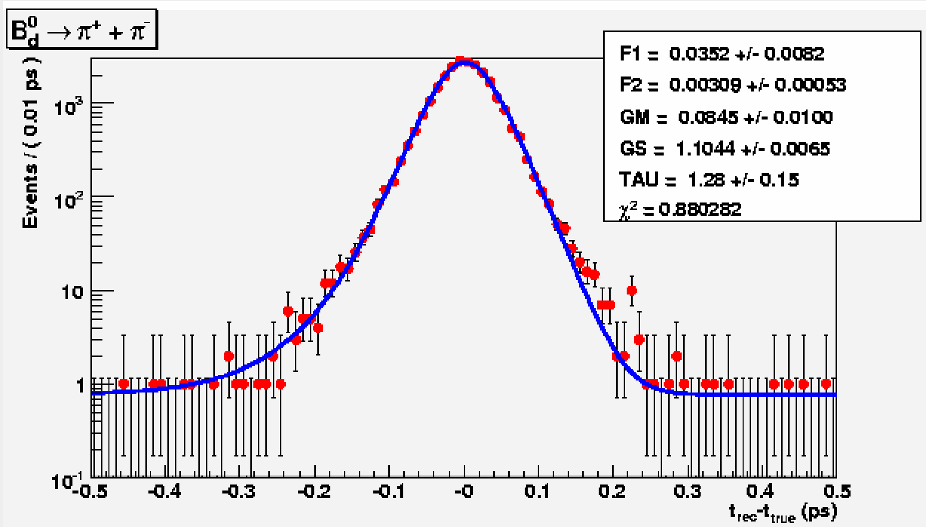
Laurence Carson, Glasgow

- **The proper time is defined as**

$$\tau = \frac{m}{|p|^2}\vec{p} \bullet \vec{L}$$

- **The proper time resolution, σ_τ, of the detector needs to be known because it dilutes A_{CP}:**

$$\frac{A_{CP\,(meas)}}{A_{CP\,(true)}} \propto \exp(-\frac{(\Delta m_q \sigma_\tau)^2}{2})$$



Goal:

- **Determine resolution model directly from data**
- **Using propertime value and error on an event-by-event basis**

- **Studies near completion**
- **Laurence will present full details soon at propertime WG … stay tuned!**

Impact of VELO misalignments on physics

Work done with Marco Gersabeck and Jacopo Nardulli

(Full account given at the Tracking and Alignment Workshop in Ferrara, 28 Feb. 2008)

Outline

Specific case studied

Analysis of the B $\rightarrow$ hh decay channel

Motivation and overview

Implementation of misalignments

- misalignment scales and conditions databases
- data samples

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

- pattern recognition and reconstruction performance
- selection variables

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

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

Motivation and overview

- 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

- We also plan to study remaining misalignment effects after application of alignment algorithms
- Identify potential problems/biases of alignment procedure

Implementation of misalignments

Procedure (1/2)

Misaligned databases:

- Create random misalignments for VELO sensors/modules
- Choose scale (Gaussian sigma) to be ~1/3 of the detector single hit resolution (called "1σ")
- Generate 10 sets of "1σ" misalignments

- Likewise, create similar sets with misalignment scales increased by factors of 3 (3σ) and 5 (5σ)

- Every 10 sets of VELO 1σ / 3σ / 5σ misalignments stored in a conditions database

  $\Rightarrow$ 3 (small) slice databases in total:

  - VELO 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

  $\Rightarrow$ 20k B $\rightarrow$ $\pi\pi$ events for each of the misalignment scenarios:

  - no misalignment (0σ)
  - 1σ / 3σ / 5σ misalignments for VELO

  suppressing potentially “friendly” or “catastrophic” misalignment sets
- In total, 80k B $\rightarrow$ $\pi\pi$ events generated

Event processing:

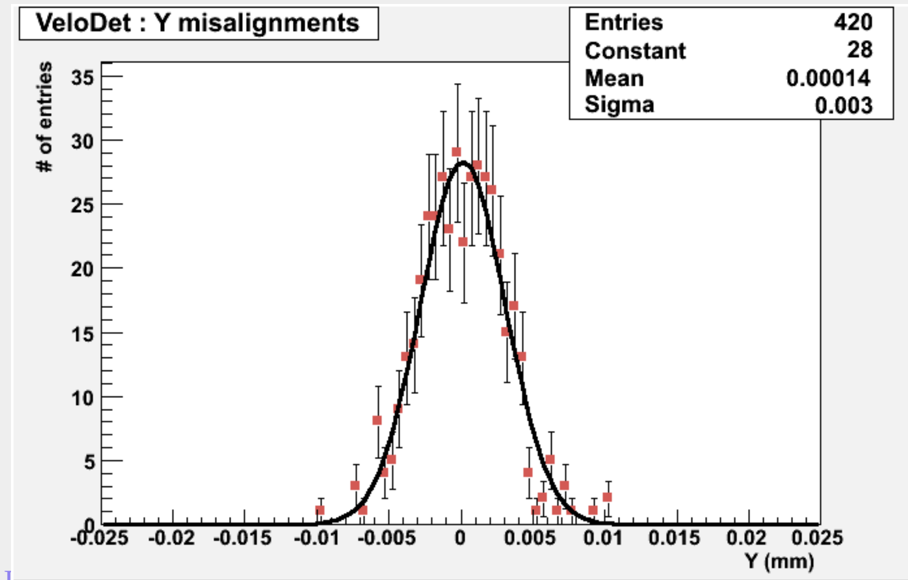
- Events generated with perfect geometry (up to DIGI level)
- DSTs produced with Brunel version v32r2,

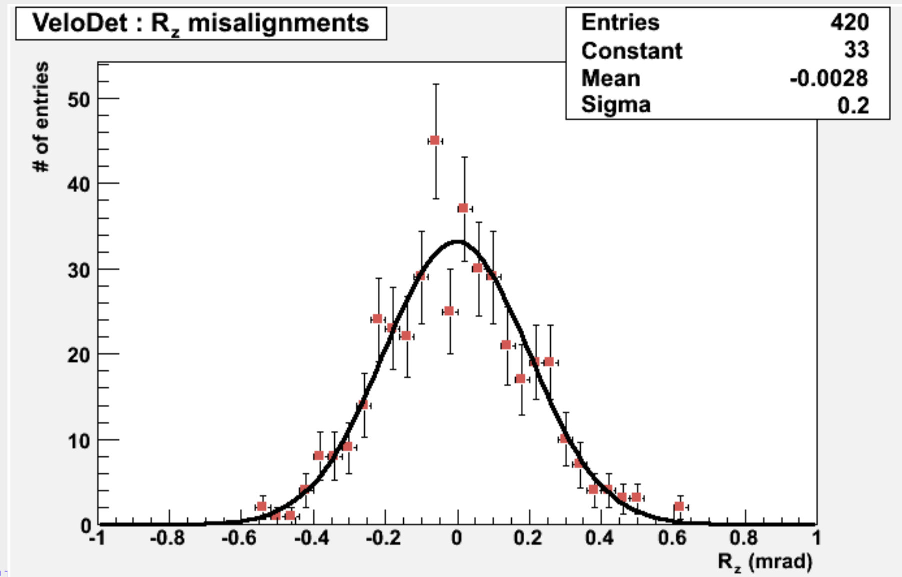
  misalignments applied solely at reconstruction level
- Physics analysis later performed with DaVinci v19r9

Misalignment scales and conditions databases

- **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	3	3	10	1.00	1.00	0.20
VELO module	3	3	10	1.00	1.00	0.20





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

The B $\rightarrow$ hh analysis, in short (1/2)

Goal:

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

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

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

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

- Sensitivity to CP parameters such as Im(λ_f) and Re(λ_f) and Δm_s, $\Delta\Gamma_s$, ω_{tag}
  $\Rightarrow$ γ, d and θ can be determined once C and S are known
  (U-spin symmetry at 20% level)
- Hadronic parameters d and θ parameterize magnitude and phase of penguin-to-tree amplitude ratio
- Analysis involves several B $\rightarrow$ hh' decays, where h = π, K

The B $\to$ 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 (1/10)

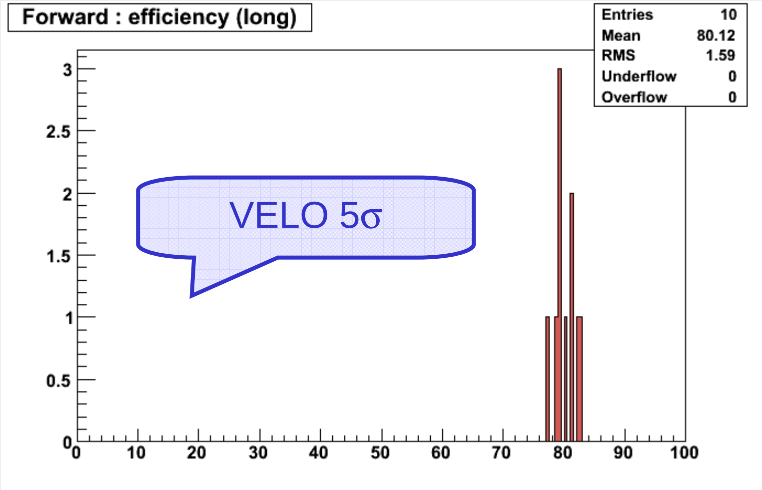
- **Selected event numbers and pattern recognition efficiencies *after* standard B $\rightarrow$ hh selection**

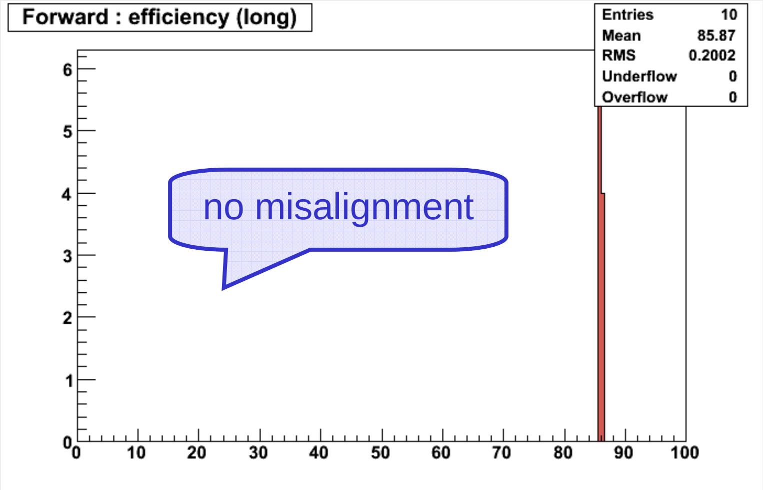
	$N_{\text{selected B}}$	$\varepsilon_{\text{PatForward}}$ (%)	$\varepsilon_{\text{Matching}}$ (%)
0σ	4229	85.9	81.1
1σ	3904	85.6	80.9
3σ	2241	83.1	78.3
5σ	1106	80.1	75.5

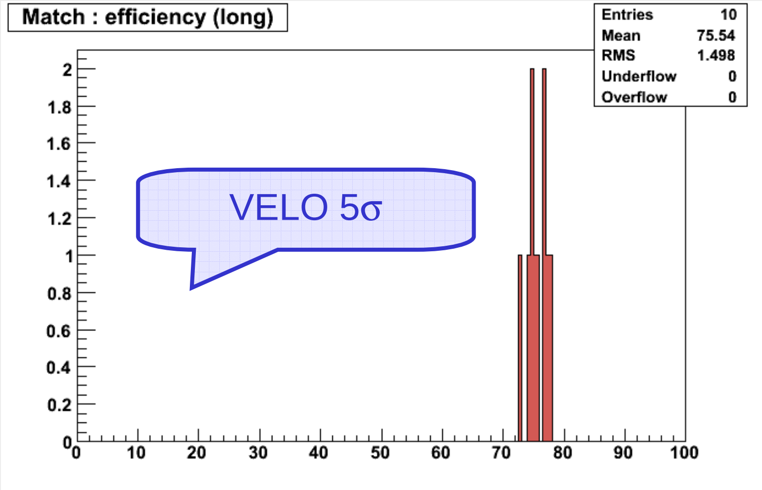
- **Effect on pattern recognition is small-ish**
- **Very significant loss of events, has to come from the selection itself …**
  - $\Rightarrow$ **misalignments have serious impact on some selection variables**
  - $\Rightarrow$ **systematic check of all of them …**

Impact of VELO misalignments (2/10)

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







Impact of VELO misalignments (3/10)

0σ

Pat. Rec.	# tracks	Ghost rate
VeloRZ	87	10.41 %
Velo3D	79	7.02 %
VeloTT	10	25.44 %
Forward	30	15.36 %
Match	27	11.28 %
TSA	56	9.68 %
Downstream	35	36.66 %
Best	109	21.06 %

1σ

Pat. Rec.	# tracks	Ghost rate
VeloRZ	88	10.44 %
Velo3D	79	7.32 %
VeloTT	10	25.61 %
Forward	30	15.47 %
Match	27	11.35 %
TSA	56	9.68 %
Downstream	35	36.66 %
Best	109	21.28 %

3σ

Pat. Rec.	# tracks	Ghost rate
VeloRZ	88	10.56 %
Velo3D	76	9.81 %
VeloTT	10	28.13 %
Forward	30	16.67 %
Match	26	12.46 %
TSA	56	9.68 %
Downstream	35	36.66 %
Best	107	23.13 %

5σ

Pat. Rec.	# tracks	Ghost rate
VeloRZ	88	10.96 %
Velo3D	73	12.54 %
VeloTT	9	30.63 %
Forward	29	18.03 %
Match	26	13.82 %
TSA	56	9.68 %
Downstream	35	36.66 %
Best	104	25.13 %

Impact of VELO misalignments (4/10)

0σ

Pat. Rec. :	Efficiency		Clones	
	long	long > 5 GeV	long	long > 5 GeV
VeloRZ :	98.0 %	98.9 %	2.4 %	1.8 %
Velo3D :	97.0 %	98.2 %	2.4 %	1.9 %
VeloTT :	2.4 %	1.0 %	1.1 %	0.8 %
Forward :	85.9 %	93.1 %	1.8 %	1.4 %
Match :	81.1 %	88.2 %	0.0 %	0.0 %
TSA :	91.8 %	95.9 %	0.7 %	1.0 %
Best :	97.4 %	98.6 %	5.2 %	3.3 %

1σ

Pat. Rec. :	Efficiency		Clones	
	long	long > 5 GeV	long	long > 5 GeV
VeloRZ :	98.0 %	98.9 %	2.4 %	1.8 %
Velo3D :	96.7 %	98.0 %	2.5 %	1.9 %
VeloTT :	2.4 %	0.9 %	1.1 %	1.0 %
Forward :	85.6 %	92.9 %	1.8 %	1.4 %
Match :	80.9 %	88.0 %	0.0 %	0.0 %
TSA :	91.8 %	95.9 %	0.7 %	1.0 %
Best :	97.3 %	98.5 %	5.2 %	3.4 %

Impact of VELO misalignments (5/10)

3σ

Pat. Rec. :	Efficiency		Clones	
	long	long > 5 GeV	long	long > 5 GeV
VeloRZ :	98.0 %	98.8 %	2.8 %	2.2 %
Velo3D :	93.9 %	96.2 %	2.9 %	2.3 %
VeloTT :	2.2 %	0.9 %	1.5 %	1.1 %
Forward :	83.1 %	90.8 %	2.1 %	1.7 %
Match :	78.3 %	85.9 %	0.0 %	0.0 %
TSA :	91.8 %	95.9 %	0.7 %	1.0 %
Best :	96.2 %	98.0 %	5.7 %	3.9 %

5σ

Pat. Rec. :	Efficiency		Clones	
	long	long > 5 GeV	long	long > 5 GeV
VeloRZ :	97.7 %	98.4 %	3.8 %	3.5 %
Velo3D :	91.1 %	94.1 %	3.4 %	2.8 %
VeloTT :	2.1 %	0.9 %	1.9 %	1.1 %
Forward :	80.1 %	88.2 %	2.4 %	1.9 %
Match :	75.5 %	83.4 %	0.0 %	0.0 %
TSA :	91.8 %	95.9 %	0.7 %	1.0 %
Best :	95.1 %	97.2 %	6.2 %	4.5 %

Impact of VELO misalignments (6/10)

0σ

Pat. Rec. :	Purity		Hit efficiency	
	long	long > 5 GeV	long	long > 5 GeV
VeloRZ :	99.5 %	99.6 %	96.5 %	97.4 %
Velo3D :	99.3 %	99.4 %	95.7 %	97.1 %
VeloTT :	98.4 %	98.0 %	93.2 %	93.8 %
Forward :	98.8 %	99.0 %	94.8 %	96.9 %
Match :	99.2 %	99.3 %	87.3 %	87.8 %
TSA :	98.3 %	98.3 %	87.9 %	88.4 %
Best :	98.7 %	98.9 %	89.6 %	94.1 %

1σ

Pat. Rec. :	Purity		Hit efficiency	
	long	long > 5 GeV	long	long > 5 GeV
VeloRZ :	99.5 %	99.6 %	96.5 %	97.4 %
Velo3D :	99.3 %	99.4 %	95.4 %	96.9 %
VeloTT :	98.4 %	98.0 %	92.8 %	93.4 %
Forward :	98.8 %	98.9 %	94.8 %	96.9 %
Match :	99.2 %	99.3 %	87.3 %	87.8 %
TSA :	98.3 %	98.3 %	87.9 %	88.4 %
Best :	98.7 %	98.8 %	89.5 %	93.9 %

Impact of VELO misalignments (7/10)

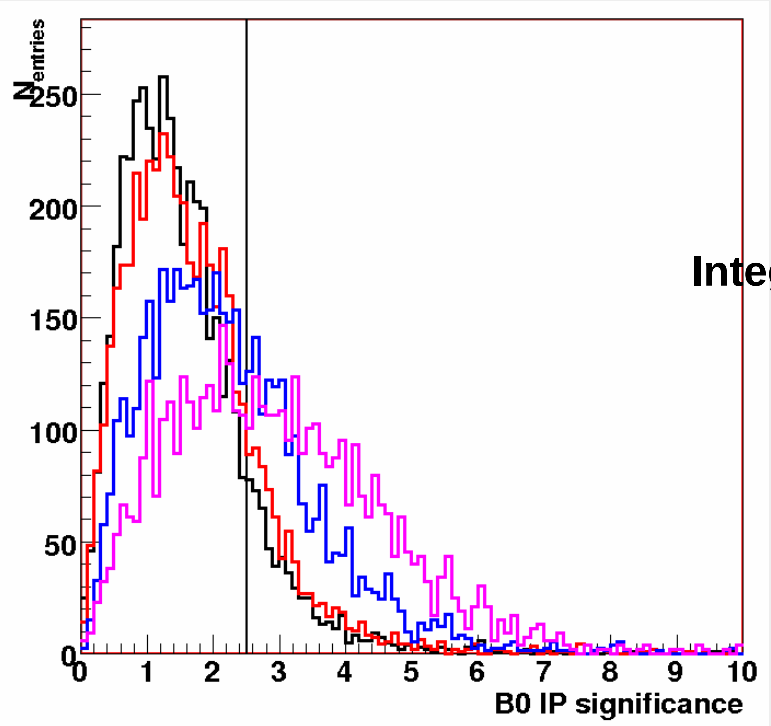
3σ

Pat. Rec. :	Purity		Hit efficiency	
	long	long > 5 GeV	long	long > 5 GeV
VeloRZ :	99.5 %	99.6 %	96.2 %	97.0 %
Velo3D :	98.9 %	99.0 %	93.0 %	95.0 %
VeloTT :	97.9 %	97.3 %	90.0 %	90.8 %
Forward :	98.7 %	98.9 %	94.8 %	96.9 %
Match :	99.1 %	99.2 %	87.4 %	87.8 %
TSA :	98.3 %	98.3 %	87.9 %	88.4 %
Best :	98.5 %	98.7 %	88.0 %	92.5 %

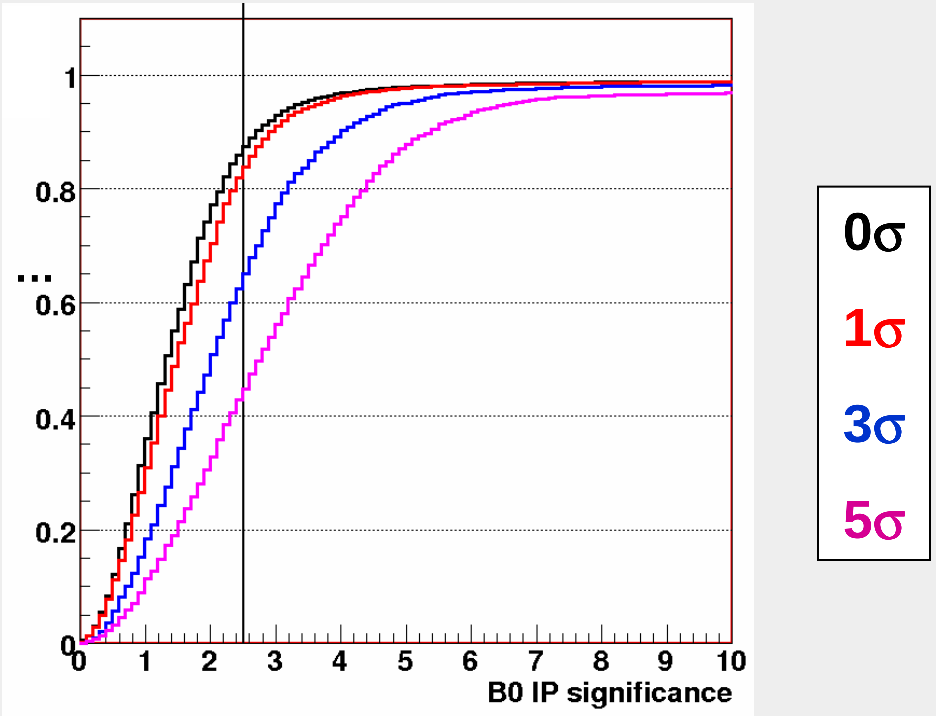
5σ

Pat. Rec. :	Purity		Hit efficiency	
	long	long > 5 GeV	long	long > 5 GeV
VeloRZ :	99.5 %	99.5 %	95.0 %	95.7 %
Velo3D :	98.4 %	98.6 %	90.0 %	92.2 %
VeloTT :	97.3 %	96.3 %	86.8 %	86.5 %
Forward :	98.6 %	98.8 %	94.8 %	96.8 %
Match :	99.0 %	99.1 %	87.4 %	87.8 %
TSA :	98.3 %	98.3 %	87.9 %	88.4 %
Best :	98.2 %	98.4 %	86.1 %	90.5 %

Impact of VELO misalignments (8/10)



Integrating …



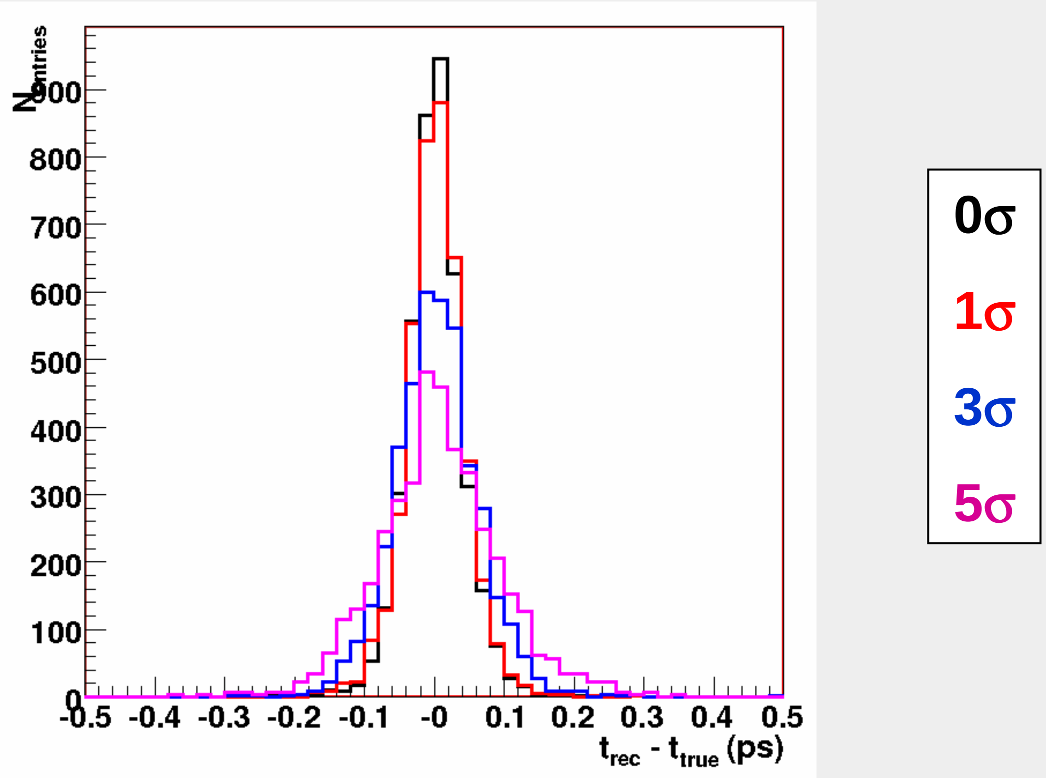
- Biggest effect comes from tight upper cut on the B-candidate IP significance, IPS < 2.5
- Additional effect on lower IPS cut of B-daughters
- Also χ^2 of B-vertex fit is rather affected

Impact of VELO misalignments (9/10)

❖ **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 (10/10)

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

Resolution	Primary vertex (μm) x/y	Primary vertex (μm) z	B-decay vertex (μm) x/y	B-decay vertex (μm) 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 combined VELO, IT and OT misalignments

- One can do the same kind of analysis for misalignments of the other tracking stations
- Full account given at the Tracking and Alignment Workshop in Ferrara, 28 Feb. 2008

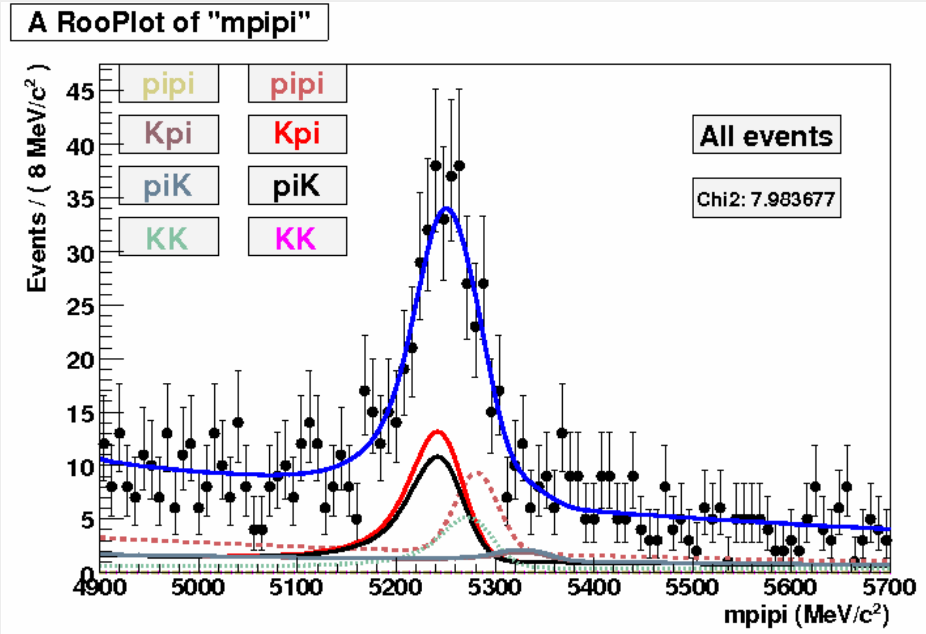
RESOLUTION	Affected by VELO misalignments	Affected by T misalignments
B-daughters momentum	no	yes
B mass	no	yes
B vertex	yes	no
B Impact Parameter	yes	no
B propertime	yes	no

("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 → 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/B̄ → 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 → hh selection studies such as propertime and mass resolutions**



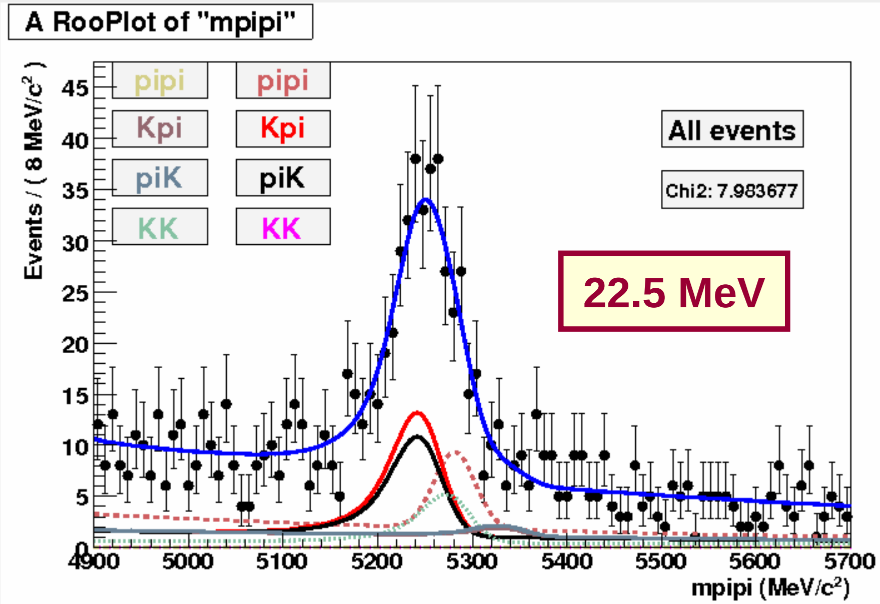
(Typical output: invariant mass distribution)

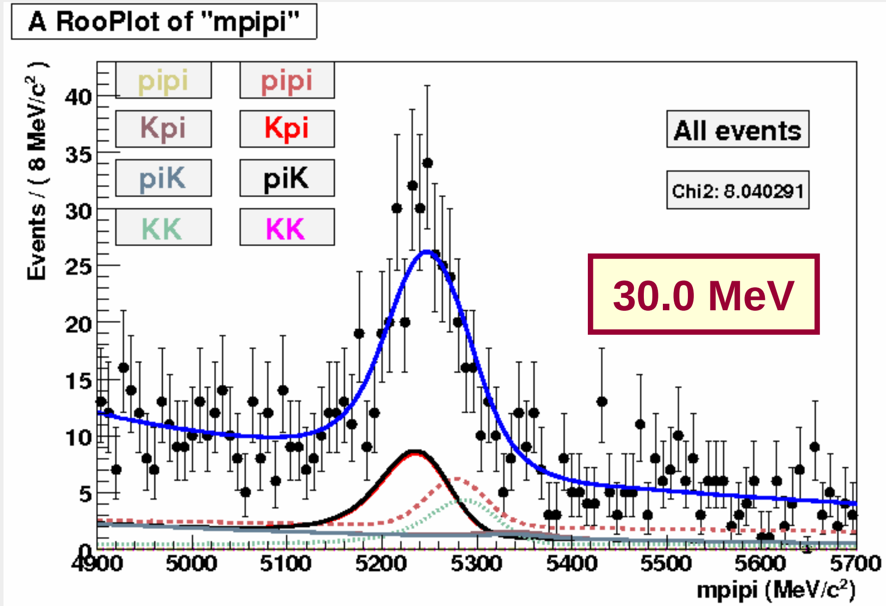
- **I will not present many details here (see Ferrara presentation)**
- **Just examples to get a feeling …**
- **Work ongoing …**

Typical B2hhFit toy results (1/2)

➢ **Checked effect of mass resolution:**

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



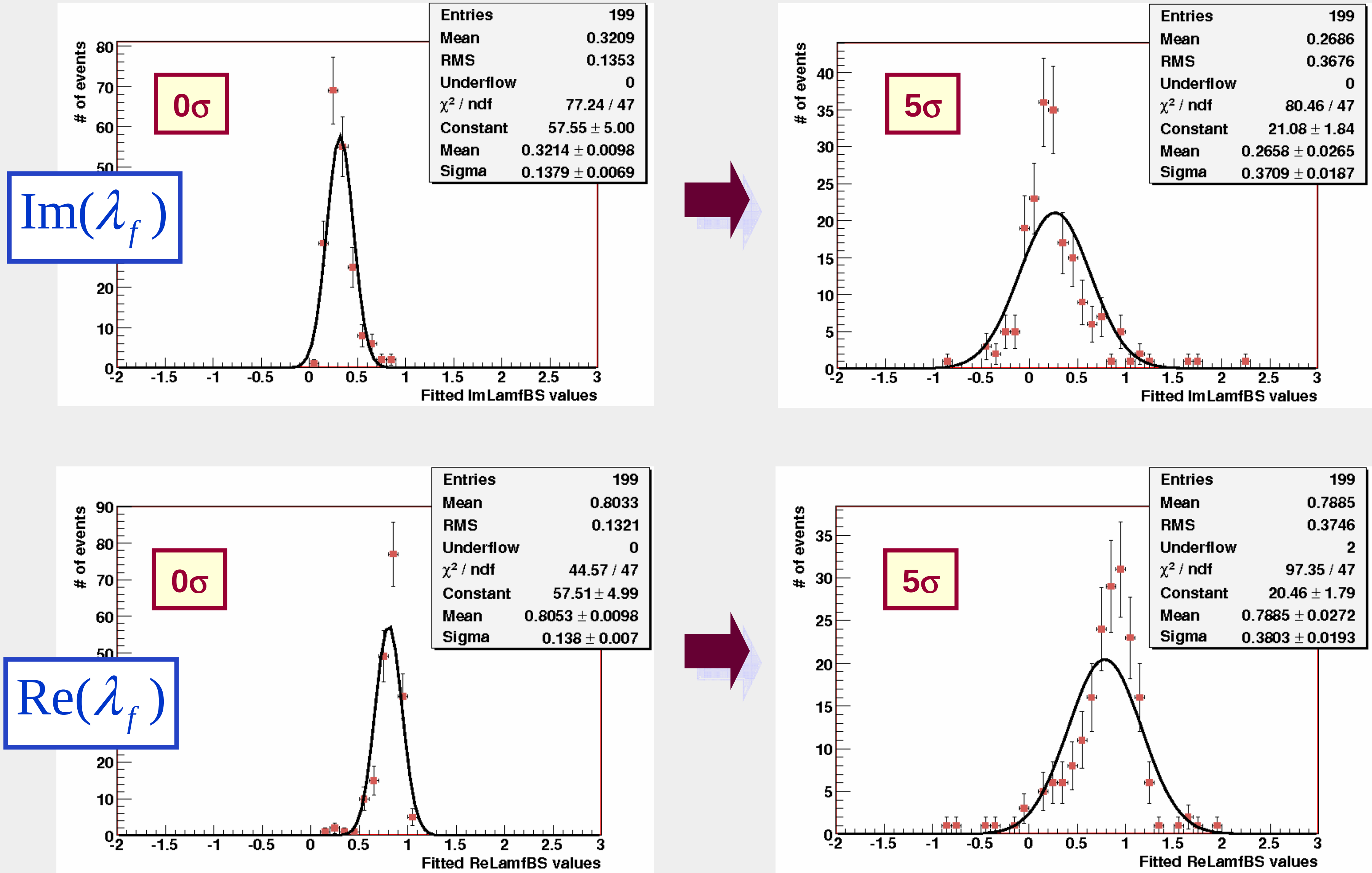


- ❑ **Errors on fitted parameters tend to increase, but only marginally**
- ❑ **Pull distributions do not deteriorate, i.e. fit quality does not "collapse"**
- ❑ **Though biases in pulls increase slightly**

Typical B2hhFit toy results (2/2)

Example of B_s fit

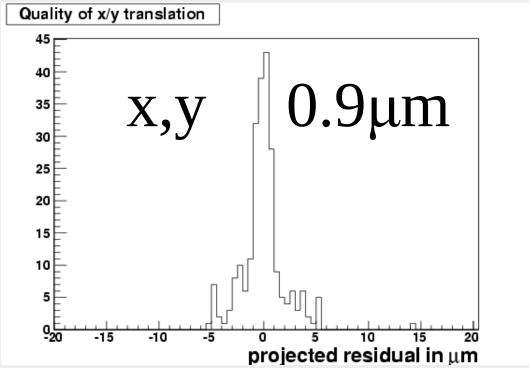
- **Checked effect of propertime resolution:**



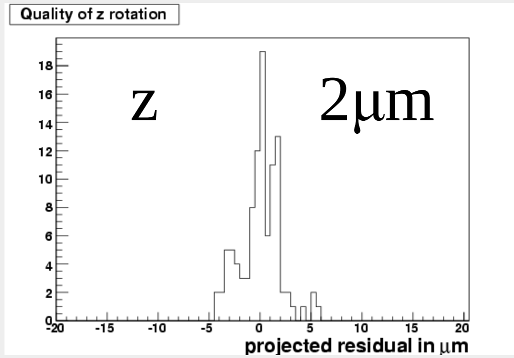
Outlook and future

- ❑ **Impact of VELO misalignments has been assessed in detail "throughout the analysis chain"**

  - VELO misalignments strongly affect selection and propertime and IP resolutions



VELO alignment results on testbeam data



- ❑ **If software alignment is of order or better than "1sigma" we are in business!**
- ❑ **(effect of z-scaling presently being investigated …)**

❖ **We should encourage further work on impact of "VELO systematics" on physics!**