THE ALIGNMENT OF THE LHCb VERTEX DETECTOR: PERFORMANCE IN RUN 2 AND STUDIES FOR THE UPGRADE

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- 1 The LHCb experiment
 - The LHCb Vertex Locator (VELO)

- 2 The alignment
 - Real time alignment

- 3 Performance during Run 2

- 4 Getting ready for Run 3
 - Run 3 alignment

THE LHCb EXPERIMENT

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- **Forward arm spectrometer**
- **Measuring decay properties of beauty and charm hadrons**
- **Tracking system (VELO, TT, IT, OT)**
- **Calorimeter (ECAL, HCAL)**
- **Particle identification (RICH, Muon system)**
- **Operated until the end of Run 2 (2015-2018)**

THE LHCb VERTEX LOCATOR (VELO)

- Silicon strip detector around the LHCb luminous region
- Provides primary and secondary vertex reconstruction
- Precise lifetime measurements
- 42 modules arranged perpendicularly to the beam.
- The sensors have radial geometry

- Two movable halves
- Operating in a secondary vacuum with bi-phase CO_2 cooling at temperature -30°
- This detector operated by the end of 2018
- Now → Upgrade I (2019-2021)
- Completely new detector!

► CERN-LHCC-2001-01

► LHCb-TDR-13

► JINST 9(2014)P09007

THE ALIGNMENT

THE ALIGNMENT

- Correctly distinguishing primary and secondary vertices
- Improves the quality of the impact parameter

► Int. J. Mod. Phys. A 30, 1530022 (2015)

► LHCb-TDR-13

THE ALIGNMENT PROCEDURE

- **Method based on Kalman filter track fit**
- **Takes a sample of reconstructed tracks**
- **Minimum χ^2 algorithm** → **determine the position of the detector elements**

Iterate until the χ^2 -difference is below a threshold

r : tracks residuals, V : covariance matrix, R : residuals' covariance matrix

- **Alignment for 6 degrees of freedom : translations (T_x, T_y, T_z) and rotations (R_x, R_y, R_z)**
- **Vertex and mass constraints can be used**
- **VELO halves and modules can be aligned**

DATA TAKING STRATEGY

- Run 2 real time analysis model developed by LHCb → new trigger model
- Events buffered on disk while performing real-time alignment and calibration
- Physics analysis performed directly from the trigger output (Turbo)

► INST 14 (2019) P04006

► INST 14 (2019) P04013

- no offline processing in Run 2

REAL TIME ALIGNMENT

► S. Borghi ► JINST 14 (2019) P04013

- Run automatically at the start of each fill
- Selecting a dedicated data sample
- Compute the new alignment constants in few minutes
- Automatic update if the variations are significant
- The new constants are used in full reconstruction

VELO alignment thresholds

dof	Threshold
$T_x, T_y (\mu\text{m})$	1.5
$T_z (\mu\text{m})$	5
$R_x, R_y (\mu\text{rad})$	4
$R_z (\mu\text{rad})$	30

PERFORMANCE DURING RUN 2

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Alignment Stability

- Each point shows the difference between the initial alignment constants and the new ones
- Stable VELO alignment with update of constants every few fills

► LHCb-FIGURE-2019-015

PERFORMANCE DURING RUN 2

Track reconstruction efficiency

Decay time resolution

Impact Parameter resolution

PV z resolution vs number of tracks

PERFORMANCE DURING RUN 2

Temperature dependency

- The VELO operates at -30°
- The modules' shrinkage at different temperatures that has been measured in lab conditions
- At the end of Run 2 a test with a temperature scan from -30° to -20° with 4 stages (-30° , -26° , -24° , -20°) was made
- Data samples, taken at each temperature of the VELO, are used to study the detector movements as function of the temperature
- Alignment was evaluated using data at the 4 heating stages
- Different alignment scenarios are used

PERFORMANCE DURING RUN 2

Temperature dependency

Halves alignment

► LHCb-FIGURE-2019-001

Linear fit result T_x vs temp:

$$y = p_1 x + p_0$$

$$p_1 = -0.942 \pm 0.003 \text{ } \mu\text{m}/^\circ$$

$$p_0 = -28.24 \pm 0.06 \text{ } \mu\text{m}$$

Shrinkage study in
lab conditions

Variations of translation d.o.f [μm]

PERFORMANCE DURING RUN 2

Temperature dependency

- Variations of the alignment constants wrt -30° are calculated
- Linear dependence in temperature (T_x)
- Variations for T_x are largest with $1\text{ }\mu\text{m}$ per degree
- Comparison with measurements on a single module
- **Studies consistent!**

Modules alignment

- Variations vs z position of modules are analyzed
- Largest variation temperature -20°

GETTING READY FOR RUN 3

GETTING READY FOR RUN 3 (2021-2023)

The Run 3 VELO

- VELO pixel detector
- $55 \times 55 \mu\text{m}^2$ pixels
- 52 modules
- 4 sensors at each module
- 3 Velopix ASICs for each sensor
- 40 MHz readout

► LHCb-TDR-13

► more details P.Svihra poster at IEEE

Improved efficiencies and IP resolution

RUN 3 ALIGNMENT PROCEDURE

- Real time procedure
- Kalman filter
- Using the VeloPix geometry
- Alignment for halves, modules and sensors

RUN 3 ALIGNMENT STUDIES

- Starting from misaligned detector (applying large misalignment!)

First look at the alignment for the VeloPix

- Distance between x/y/z positions of the reconstructed primary vertices reconstructed with the tracks in each VELO half
- The procedure finds correction of the misalignment applied

► LHCb-FIGURE-2019-003

SUMMARY

- **New strategy for the software trigger has been developed that allowed the alignment and calibration to be performed in real-time**
- **Alignment of the detector in few minutes**
- **Same online-offline reconstruction and performance**
- **Physics analysis possible from the trigger output**
- **Within Run 2 the alignment of the LHCb VELO proved to be stable**
- **The variation of alignment constants at different temperatures has been studied**
- **A first look in the Run 3 alignment procedure is made**

Thank you!

BACKUP

RECONSTRUCTION AND PARTICLE TYPES

TRIGGER STRATEGY IN RUN 1 (2009-2013)

LHCb Run I trigger diagram

ALIGNMENT STABILITY

► LHCb-FIGURE-2019-015

LHCb UPGRADED DETECTOR

VELOPIX DETECTOR

Module layout

Comparison of VELO z-layouts

— Current
— Upgrade

Module at testbeam at CERN