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Alignment studies for the LHCb SciFi Detector

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Abstract

Kurzfassung

Hier steht das selbe wie im Abstract nur auf deutsch.

Inhaltsverzeichnis

1 Introduction

2 Particles and The Large Hadron Collider

Spin-$\frac{1}{2}$-fermions are called leptons, if they do not interact via the strong interaction. The three generations e, and are also called flavors. In each of these families there is a charged lepton, which is present in both (händigkeiten) and a corresponding left-handed neutrino. A particle is called left-handed if its spin direction is opposite to the direction of flight. Right-handed particles have a spin direction pointing with the direction of flight. Per family, a left-handed isospin doublet and a right-handed singlet are formed. Neutrinos interact, unlike the charged leptons, only via the weak interaction. The quarks are spin-$\frac{1}{2}$-particles and carry an electric charge. In each of the three generations there is one isospin doublet. The quarks are ordered by ascending mass. In the first generation are the two lightest quarks, up and down quark in the second generation the charm- and strange quark and in the third generation the top- and bottom quark doublet. Quarks carry a color charge, red, green or blue, which is an artificially introduced degree of freedom to guarantee the distinguishability. There are eight quark color states. The octet forms the generators of the SU(3) (special unitary group of dimension 3) which is generated from the eight quark color states. Since there are no free quarks, they come together to form bonding states, the so called hadrons. On the one hand there are the mesons, which consist of a quark and an antiquark.

$$|\mathrm{M}\!>=|q\,\bar{q}'> \tag{2.1}$$

These may be from the same family (i.e. [u,d], [c,s], [t,b]), or from different families. Mesons have a baryon number of 0. Accordingly, quarks carry the baryon number $\frac{1}{3}$. The quarks constructing a meson therefore carry color and the corresponding anticolor. The second type are baryons. The content consists of either three quarks or three antiquarks. However, it cannot be that one quark and two antiquarks and vice versa occur, because baryons must have the baryon number B = 1. Because baryons are stable final states as well as the mesons, the sum of their quark colors must be white. Therfore, every (anti)color must occur once in a baryon.

$$|\mathrm{B}\!> = |qq'q''> \tag{2.2}$$
$$|\mathrm{B}\!> = |\bar{q}\bar{q}'\bar{q}''> \tag{2.3}$$

2.1 The Standard Modell

The standard model of particle physics describes the known elementary particles and their interactions. It consists of 12 matter particles, the fermions and five interaction particles, which are called vector bosons. The fermions can be grouped in two categories, to six quarks and six leptons. The quarks as well as the leptons are divided into three generations. Each matter particle also has an antiparticle, with an opposite charge. The interactions are obtained from the vector bosons mentioned above. There exist three relevant interactions. The electromagnetic interaction, the weak interaction and the strong interaction. Gravitation is is not considered here, because it does not make a significant contribution. By the em(electromagnetic) interaction one understands the exchange of a photon between the particles. The strength of one of those interactions is described by a coupling constant. In the em interaction this is the fine structure constant[4]. The range of the em-interaction is in principle infinite, but decreases with increasing distance between the interacting particles. The em interaction is described by quantum electrodynamics. The potentials are described by operators, which create and annihilate the photons.

The exchange particles of the weak interaction are on the one hand the $W^{\pm}$-bosons and on the other hand the Z-boson. The weak interaction processes are called currents. Changing the charge during the interaction by a W-boson is called charged current. The exchange reaction of a Z boson in, for example, processes such as $e_\nu \mu \rightarrow e_\nu \mu$ is called neutral current. Analogous to the electromagnetic interaction, the potentials are again understood as operators, but here there are no propagators. Propagators are used in *FEYNMAN*-diagrams of QED to represent the interaction particles. A so-called V-A structure is used here instead. Here, V stands for vectorboson and A is the axialvector. This structure is needed to disregard the right-handed particles and left-handed antiparticles, since these lead to the charge-parity violation. Thus one adjusts the Lorentz factors in the following way

$$\gamma_\mu \rightarrow \gamma_\mu(1-\gamma_5)$$

In the strong interaction, the exchange particles are the eight different gluons. The strong interaction is described by quantum chromodynamics (QCD). According to this, color is transfered during the interaction. Gluons have no mass and are spin-1 particles. Gluons carry a color and a different anti-color. Gluons can also couple to themselves. Moreover, the coupling constant $\alpha_s \approx 0.1$. The interaction with quarks is described with a potential.

$$\mathrm{V}_{q\bar{q}} = -\frac{4\alpha_s}{3r} + \sigma \cdot r \tag{2.4}$$

mit

$$\sigma = 1\,\frac{\mathrm{GeV}}{\mathrm{fm}} \tag{2.5}$$

Quarks thus tend to attract each other very strongly. If now quark and antiquark are moved away from each other, a lot of energy has to be expended. This energy can become so large that new particles can be created.

2.2 particle decays and hadrons

For you, this is because the bending and momentum of particles (and the location where they decay) is important to the way we can align things. Which sorts of particles can produce long tracks? etc.

2.3 The LHC and LHCb

2.3.1 The LHC

The Large Hadron Collider (LHC)[2] is the most powerfull particle-accelerator on planet earth. With a circumference of $26,7$km it is also the longest ring accelerator and it lies between 45m and 170m below the surface near Geneva in Swizerland. The tunnel was constructed for the LEP experiment between 1984 and 1989 and is operated by the European Organization for Nuclear Research (CERN). The LHC can produce centre of mass energies of $\sqrt{s} = 13\,\mathrm{TeV}$ in proton-proton collisions during Run 2. After the upgrade the LHC will collide particles with the centre of mass energy $\sqrt{s} = 13\,\mathrm{TeV}$. An image of the accelerators and the experiments is shown in fig. 2.1[1].

By ionizing hydrogen gas, protonsare created and accelerated to 50 MeV by the linear accelerator (LINAC 2). Afterwards the beam is injected into the Proton Syncrotron and the Super Proton Synchrotron to a maximum of 450 GeV before the beam is brought into the LHC. The beam containts several bunches with around $1{,}15 \cdot 10^{11}$ and a bunch spacing of 25 ns, which is a collision rate of 40 MHz. The LHC houses four major experiments. ATLAS and CMS are classified as general purpose detectors with a detection range of close to 4π. The interaction in these detectors is located in the very center so that tracks going in every direction can possibly be found. Searches for the Higgs Boson is just one of many physics aspects these detectors are build for. The other two Experiments located at the LHC are ALICE and LHCb. The ALICE experiment main studies the quark gluon plasma during

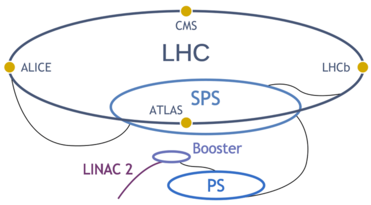


Abbildung 2.1: an overview of the LHC facilities.

the runs with lead ion collisions instead of protons. In this thesis the Scintillating Fibre Tracker (SciFi Tracker) located at the LHCb will be focused at and discussed on the following chapters.

2.3.2 The LHCb

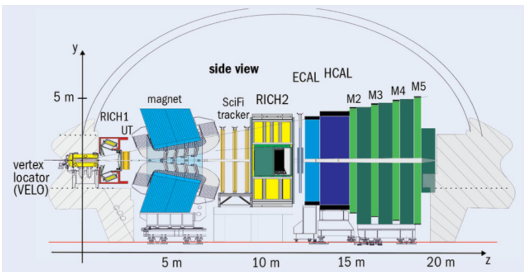


Abbildung 2.2: a sideview of the LHCb experiment.

The LHCb experiment[5] is a forward spectrometer covering $2 < \eta < 5$ in the pseudorapidity range. This experiments main physics goal is beauty quark physics and for high energies, b- and $\bar{b}$-hadrons are heavily produced in a tight forward direction[1]. A sideview of the LHCb is shown in figure 2.2. The LHCb consists of several smaller detector components namely the Vertex Locator (VELO) right on the intercation point, two Ring Imaging Cherenkov counter (RICH 1 and RICH 2),

[1] They are also produced in a tight backward direction but the experiment is only build for the forward cone.

in front of the spectrometers lies the Trigger Tracker and behind them the SciFi Tracker which is the important part of this thesis. Further back a Scinitllator Pad Detector (SPD) and a Preshower (PS) are mounted followed by the electromagnetic calorimeter (ECAL) and the hadronic calorimeter (HCAL). In the very back, several muon chambers are mounted for every track that is yet to be determined.

In this section, a general overview about the requirements for the SciFi Tracker as well as the layout will be discribed based on the presentation in the *technical design report*[3] of the upgrade.

The upstream and downstream trackers provide a good precision estimate of the momentum of charged particles so that mass resolution of decayed particles can be precisely measured. For particle identification the reconstructed trajectories of charegd particles are used as input for the RICH detectors. The limiting factor for the momentum resolution is multiple scattering for tracks with a momentum lower than 80 GeV/. For tracks with a higher momentum the detector resolution is the limiting factor.

The SciFi Tracker replaced the inner Tracker (IT) and the outer Tracker (OT) and is located in the same place as the downstream trackers that were previously installed.

The instantaneous luminosity after the upgrade is expected to be $1\,1/(\mathrm{cm}^2\,\mathrm{s})$ bis $2 \cdot 10^{33}\,1/(\mathrm{cm}^2\,\mathrm{s})$. The bunch spacing will be 25 ns and the number of proton-proton interactions per bunch crossing will be $\nu = 3.8$ during the ramp-up phase of the LHC and $\nu = 7.6$ "during the active phase." (how can i write this differently?)

2.3.3 Layout of the Detector

The SciFi Tracker consists of three (T-)stations T1, T2 and T3 with each having four Layers $(X1, U, V, X2)$. The orientation of these planes with respect to the vertical axis are $(0°, 5°, -5°, 0°)$. The tilted layers are called stereo layers and serve the purpose of 3D hit localization. Each layer consists of 8 fibremats A right-handed coordinate system is used with positive z pointing away from the interaction point following the beam direction. positive y points upwards, towards the surface and positive x and negative x are defined as A-Side and C-Side[3].

2.4 The LHC data cycle

(not sure if that's a good name, but like, an explanation of how electrical information is turned into hits and then tracks, and also when alignment runs in the system of data taking)

3 The Theory of Alignment

3.1 kalman filters and track reconstruction

talk pdf. quelle herausfinden!

3.2 alignment using derivatives

wouter pdf. quelle herausfinden!

martinelli pdf! use some of that information -> alignment is a minimizing problem (chi2) thats why i looked at chi2 plots

-> global translation and sheering motion don't change chi2 values because residuals are unchanged.

-> weak modes: presence of weak modes affect the convergence (poor, takes many iterations), bias in track parameters.

-> most visible weak modes is the "curvature bias" (sophie has mentioned it sometime. must be on one of my sheets) also look at twiki!

goals: source for now: DPG2021 pdf exact source will be included!

4 Main part

taking notes for now so i know what plots to use

1. started with null tests.
2. which constraint does what?
3. which degree of freedom moves what part of the scifi?
4.

need to be sorted to according part of the story.

compare 1000 to 7000 events for Tx flo versus my constraints. what exactly were flo's changes?

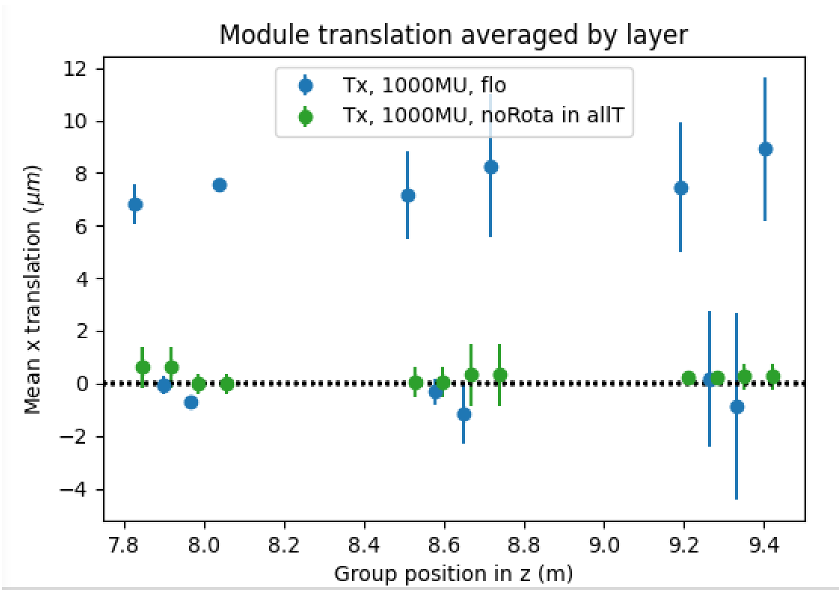


Abbildung 4.1: comparison of different configurations without rotational constraints in every station, magnet up and 1000 events. plotted is translation in x versus global z.

maybe show this plot 4.3

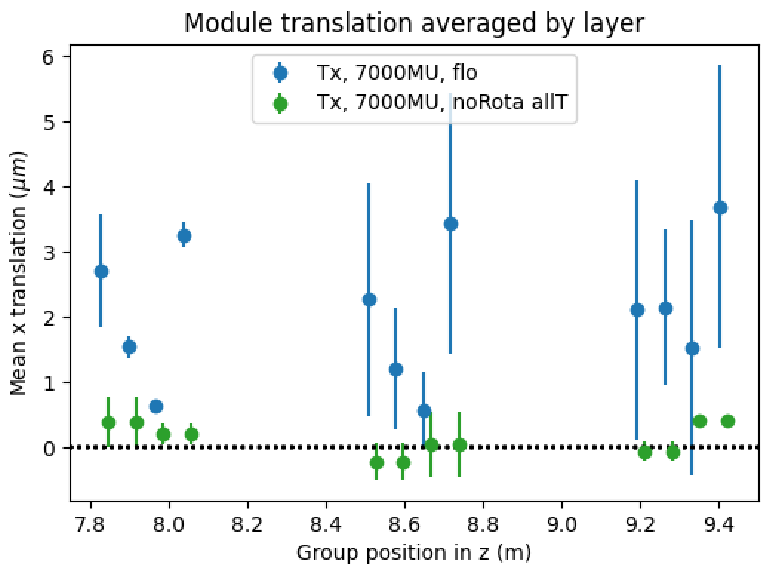


Abbildung 4.2: comparison of different configurations without rotational constraints in all stations, magnet up and 7000 events. plotted is x translation versus global z.

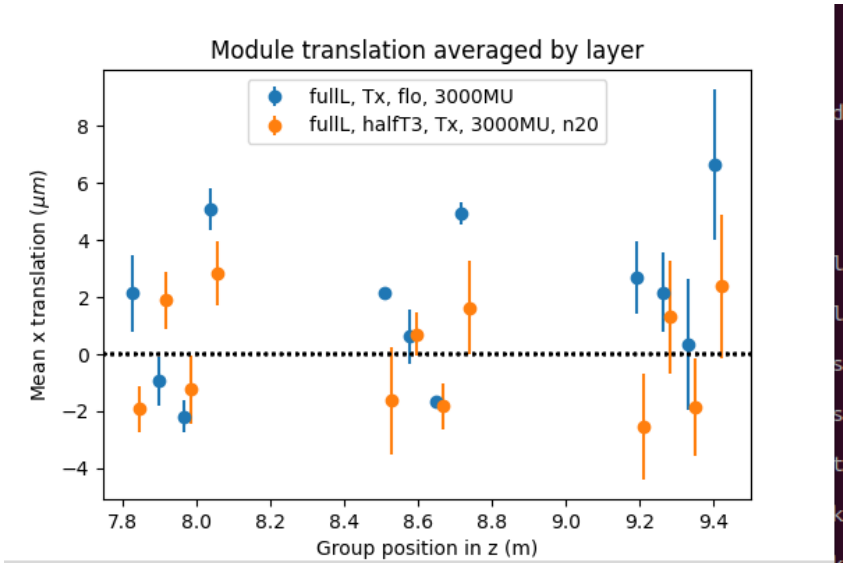


Abbildung 4.3: analysed 20 iterations for x translation behavior (look up exact constraints and dofs)

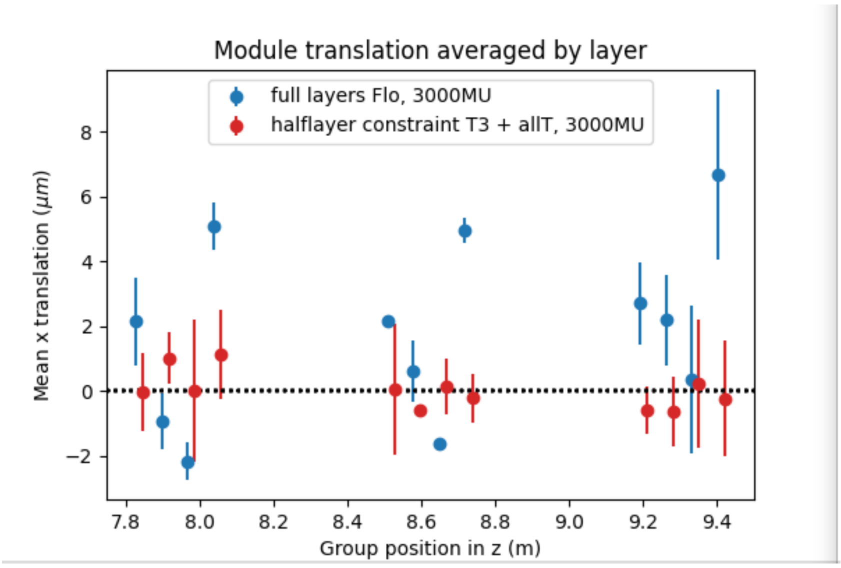


Abbildung 4.4: halflayer constraints and full layer constraint, very strict (look up exact constraints and dofs)

the figure in 4.4 shows that very strict Tx constraints make Tx look better but when comparing to Tz as we can see in figure 4.5 a clear layer separation is visible. because of the many constraints that are applied to T3, a compensation is happening in the other two stations.

Looking at figure 4.6, the last two layers in station 3 are seperation from the first two. Especially the last station should be fixed around zero with the constraints added. The sum of all translations should be zero with each individual layer movement being small.

test 3:

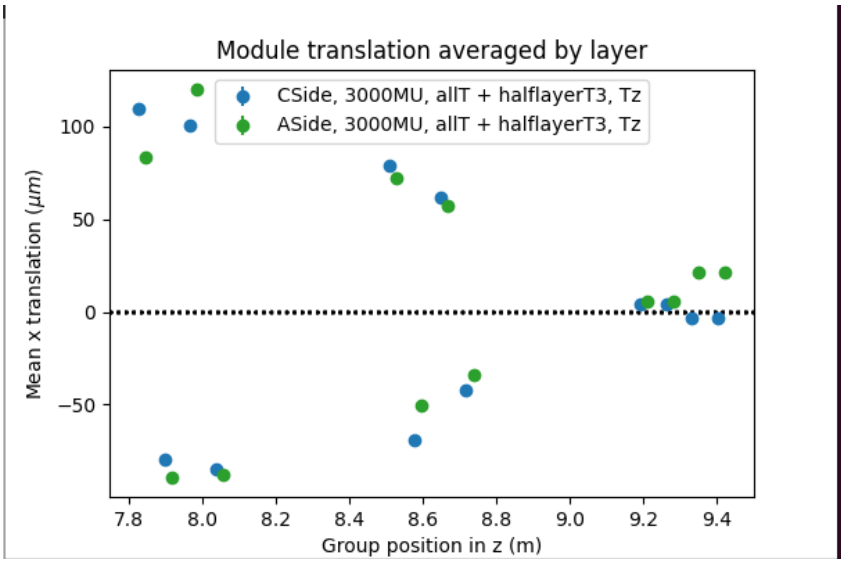


Abbildung 4.5: compare C-Side to A-Side for Translation in z direction. (look up exact constraints and dofs)

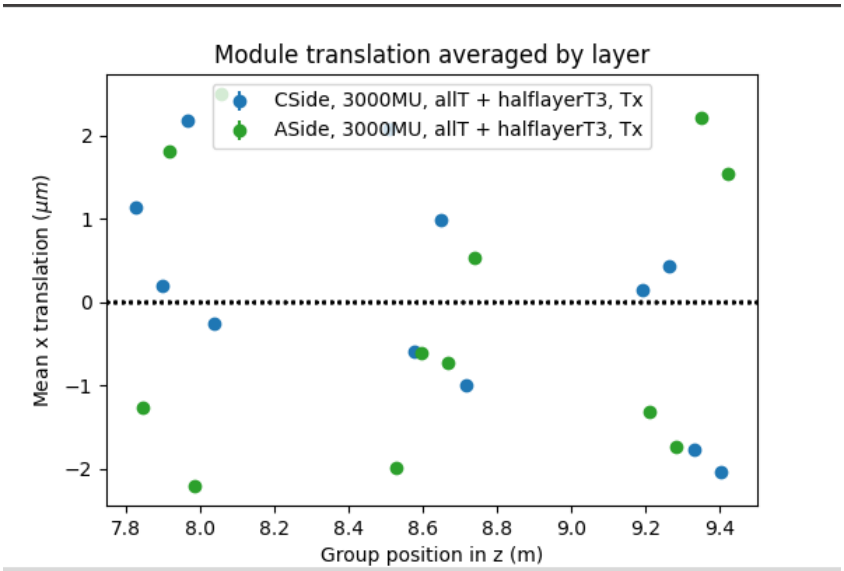
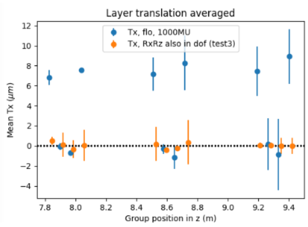
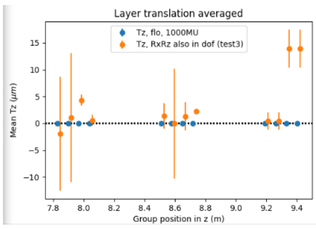


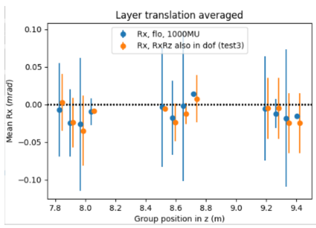
Abbildung 4.6: compare C-Side to A-Side for Translation in x direction. (look up exact constraints and dofs)



(a) Tx versus global z.



(b) Tz versus global z.



(c) Rx versus global z.

Abbildung 4.7: Testing a configuration versus florians changes.

5 Continuing Work

6 Future Work

7 Conclusion and Outlook

Literatur

[1] *A diagram showing the complete structure of the LHC facility at CERN.* URL: https://www.researchgate.net/figure/A-diagram-showing-the-complete-structure-of-the-LHC-facility-at-CERN-There-are-the-4_fig8_348806406 (besucht am 09. 03. 2022).

[2] *LHC Machine.* URL: https://cds.cern.ch/record/1129806/files/jinst8_08_s08001.pdf (besucht am 09. 03. 2022).

[3] *LHCb Tracker Upgrade Technical Design Report.* URL: https://cds.cern.ch/record/1647400/files/LHCB-TDR-015.pdf (besucht am 09. 03. 2022).

[4] *Physical Constants.* URL: http://pdg.lbl.gov/2019/mobile/reviews/pdf/rpp2018-rev-phys-constants-m.pdf (besucht am 11. 08. 2019).

[5] *The LHCb Detector at the LHC.* URL: https://cds.cern.ch/record/1129809/files/jinst8_08_s08005.pdf (besucht am 09. 03. 2022).

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Eidesstattliche Versicherung

Ich versichere hiermit an Eides statt, dass ich die vorliegende Abschlussarbeit mit dem Titel „Alignment studies for the LHCb SciFi Detector“ selbstständig und ohne unzulässige fremde Hilfe erbracht habe. Ich habe keine anderen als die angegebenen Quellen und Hilfsmittel benutzt, sowie wörtliche und sinngemäße Zitate kenntlich gemacht. Die Arbeit hat in gleicher oder ähnlicher Form noch keiner Prüfungsbehörde vorgelegen.

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