

LHCb TT Module Properties

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Abstract

The LHCb Trigger Tracker Station is a silicon micro strip detector. It consists of 896 silicon micro strip sensors in 4 detection layers. Sensors are organised in 128 modules each containing seven sensors grouped in two or three readout sections. The production of modules and the test programme to assure the quality of the modules have recently been completed. Around two terabyte of data was collected while testing and is stored in the production data base. Data mining tools for module quality grading and an analysis of module properties will be described.

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1 Introduction

The Large Hadron Collider Beauty (LHCb) experiment [1] is embedded in the LHC Project at CERN. LHCb is designed to do precision measurements of CP-violating and rare decay modes of B-mesons. The research group of Prof. U. Straumann at University of Zurich is responsible for the design and construction of the LHCb Silicon Trigger Tracker Station (TT Station, [2]). Key part of the TT Station are about 900 silicon micro strip sensors¹ organised in 128 modules each containing seven sensors grouped in two or three readout sections. The production of modules and the Burnin test programme to assure the quality of the modules have recently been completed. Around two terabyte of data was collected while testing and is stored in the production data base. Data mining tools to allow module quality grading and an analysis of module properties will be described after giving a short overview about the TT Station detector modules.

1.1 LHCb TT Station

The LHCb experiment consists of several sub-detectors. One of them is the TT Station. The TT station will act both as a triggering device to select interesting events and as a tracking station to determine the trajectories of charged particles. The TT Station has 4 detection layers, with an approximate size of 1.8 m² each. All sensors inside the TT station have to be precisely placed to allow track reconstruction within $\pm 50\mu\text{m}$. In addition they all must be connected to readout electronics, high and low voltage. Sensors are grouped into modules containing 7 silicon sensors in a row (Figure 1). A total of 30 modules per layer cover the acceptance of the experiment as indicated in Figure 2.

On a module, sensors are grouped in two or three readout sections. Within a readout section, sensors are connected strip by strip through wire bonds. As particle flux increases close to the beampipe, small readout sections, i.e. short readout strips, are required at the centre part of the detector to achieve appropriate hit occupancies. Therefore the six sensors around the beam pipe are read out separately (yellow marked sensors in Figure 2) and two different types of modules are produced:

- On 4-3 type modules sensors are split into two readout sections. A long one called L containing four sensors and a shorter one called M1 containing 3 sensors.
- On 4-2-1 modules sensors are split into three readout sections. The L section (4 sensors), M2 section (2 sensors) and the short K section containing the single sensor near the beam pipe.

¹TT sensors are produced by HPK Hamamatsu, Japan. Properties: 500 μm thick, 9.64 cm wide, 9.44 cm long, 512 readout strips, strip pitch 183 μm .

At one end of the modules, front-end readout hybrids carrying each four Beetles and providing connection to backend readout electronics and mechanical connection to the support frames are located. A Beetle can read out 128 channels and is connected with the same number of readout strips via a short pitch adapter for the L section and via Kapton cables in case of M and K sections. As upside and downside mechanical connections to the support frame are different, two types of L hybrids exist as indicated in Figure 3. After construction and extensive testing two modules are glued together end to end and become a supermodule having an L1 hybrid at the upper and an L2 hybrid at the lower end. The numbers of modules and sensors are listed in Table 1.

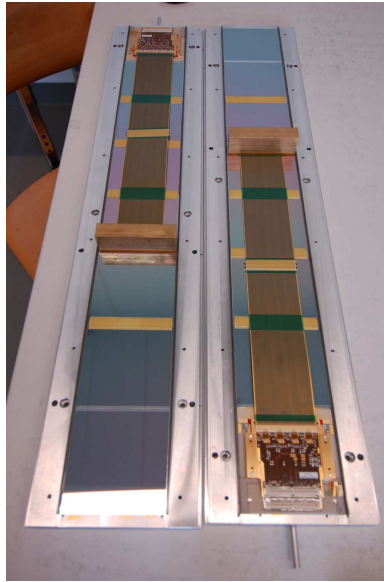


Figure 1: Photograph of the frontside of two modules in their production templates. Readout Hybrids are located at one end of each module. The M section is connected through a Kapton cable to its frontend readout hybrid carrying 4 Beetles.

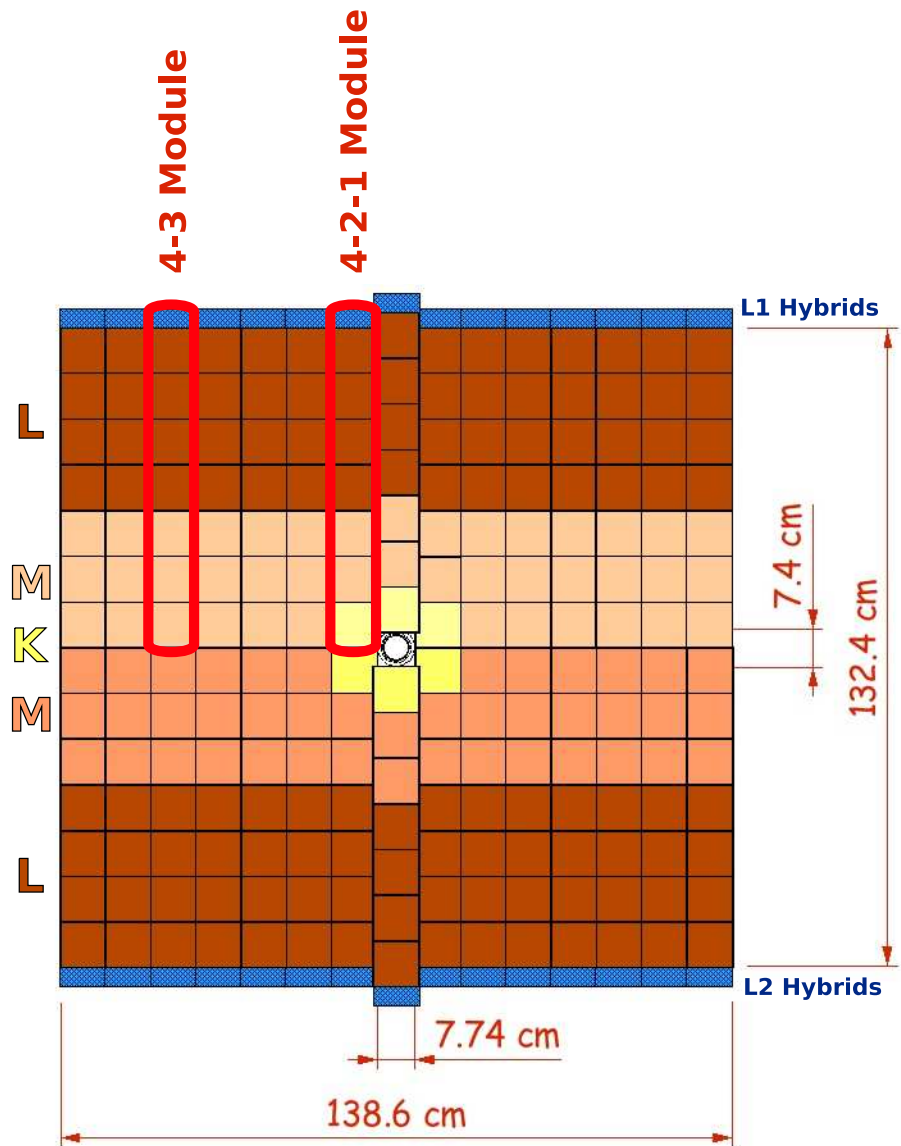


Figure 2: Sketch of one of the four silicon planes of the TT Station (TTa x-layer) consisting of 14 supermodules and two "4-2-1 type" modules covering the middle part. Each rectangle symbolises a sensor. Readout sections are in different colours: brown: "L-section", 4 sensors; light-brown and orange: "M-section", 3 respectively. 2 sensors; yellow: "K-section", single sensors around the beampipe.

Modules	
4-3 type:	104
4-2-1 type:	24
total:	128
Readout sections	
L:	128
M 4-3 type:	104
M 4-2-1 type:	24
K:	24
total:	280
Number of sensors:	896
Number of readout strips on sensor:	512
Number of Beetles:	1120
Number of readout strips (channels):	143120

Table 1: Numbers of components for the TT Station.

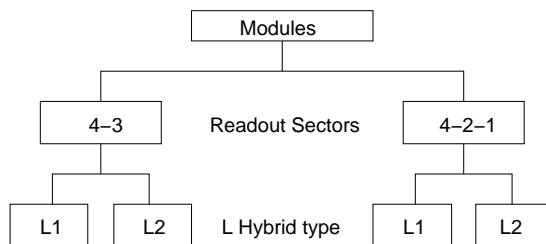


Figure 3: The four different types of modules: L1 4-3, L2 4-3, L1 4-2-1 and L2 4-2-1. As mechanical connections for modules at the upper and lower side of the TT Station are different, an L1-type and an L2-type module have to be glued together end to end. To adjust readout sections according to the expected particle density in the detector, sensors are grouped into readout sections of various strip lengths. Within a section, sensors are connected strip by strip through wire bonds. Therefore, strip length $s_n = n \cdot l$ where the sensor length $l = 9.44$ cm and the number of sensors in a readout section is n .

1.2 Module Quality Assurance

During production, the modules have been subject to extensive tests in the *Burnin* teststand [3]. All data acquired is stored in the TT Production Database². As the TT station will be operated at a temperature of +5°C to minimize the effect of radiation damage on the sensors, all tests have been performed both at room temperature, referred to as warm, and at around

²The database is implemented in PostgreSQL and located at http://lhcb/admin/phppgadmin/lhcb_tt. An online documentation providing detailed information is at <http://www.postgresql.org/docs/>.

+5°C, referred to as cold within this text. Tests of the following module properties were performed:

- **Full depletion voltage:** The full depletion voltage is the reverse bias voltage that has to be applied to the sensor in order to completely deplete the silicon bulk. This test is performed on the bare sensors before they are assembled into modules.
- **Sensor alignment:** At the end of the module assembling the position of the sensors is measured with a coordinate measurement machine. Details are given in Section 3.6.

The following tests are performed in the *Burnin* test stand where modules are subject to exhaustive tests and the operating environment of modules can be simulated.

- **Leakage current:** Measurement of the sensor leakage current as a function of the applied bias voltage and the temperature.
- **Noise:** Noise measurements are performed to identify bad Beetle chips and bad readout strips.
- **Pulse-shape scans / Remainder:** The amplitude of the Beetle output signal is measured as a function of time. An empirical function is fitted to the resulting pulse-shape and the remainder of the output signal 25 ns after the maximum is calculated. Details are given in Section 3.2.
- **Charge collection:** To estimate the operation voltage of the detector, the output signal amplitude was measured as a function of applied bias voltage.

It was found that the analysis and interpretation of the charge collection data was less straightforward than we had assumed. Since there was no time for more detailed studies, it was decided not to use these data in the module grading.

1.3 Grading, Mating and Mapping

A module quality grading has been determined by evaluating the data from the different test results. Some module properties determining the module quality will be discussed in Chapter 3. The goal was to grade each module as A: very good, B: good or C: acceptable, and to match pairs of modules in order to create the best supermodules possible. The mapping will be the process of evaluating the position of the supermodules in the four detection layers. The best supermodules will be placed near the beam pipe where particle densities are highest. About 15% more modules than required have been produced. Some of the grade C modules will not be built in and remain as spares.

2 Data Mining

Creating the necessary data input for the module grading was achieved in two steps. First, the data relations customised to the needs of module grading had to be created on the database. This was done by creating *views* to the tables of the database that contain the test results. A list of the created views is given in Appendix B. In addition, a commented view definition is given in Appendix B.2 to illustrate PostgreSQL syntax. The creation of data relations, sorting and grouping of data and computations on data groups have been done whenever possible within the database to provide easy data access.

The second step was to create web interfaces to the database. The following interfaces displaying the data customised for module grading are integrated in the TT Construction Web³ :

- *Matching Spreadsheet*⁴
- *Remainder Spreadsheet (incl. median)*⁵

These interfaces were programmed in PHP⁶. PHP was used for server side scripting, i.e. to query the database, and to display the answers in an appropriate way. Both interfaces have the same structure:

1. The query is defined according to the PostgreSQL syntax.

```
SELECT columnname: Choose column of the table to be read out.  
FROM tablename: Indicate the table the column is from.  
(optional WHERE condition: Define a condition to restrict the  
selection.)  
(optional ORDER BY columnname: Define a sort mode.)
```

Example⁷:

```
$query_matching_bad_channels = //  
"SELECT module_serial, hyb_type, num_bad_channels "  
  
$query_matching_bad_channels .= //  
"FROM matching_bad_channels ";
```

³<http://lhcb.physik.uzh.ch/tt/database>

⁴http://lhcb.physik.uzh.ch/tt/database/grading/matching_spreadsheet.php

⁵http://lhcb.physik.uzh.ch/tt/database/grading/remainder_median.php

⁶The online documentation on PHP is located at <http://www.php.net>

⁷Examples of the code are in verbatim and are given for the program of *Matching Spreadsheet*. Two slashes at the end of a line indicate additional linebreaks included for layout reasons. They do not belong to the code.


```
$query_matching_bad_channels .= //
"ORDER BY module_serial";
```

2. The result of the query is stored in a multidimensional array.

Example:

```
$ans_query_matching_bad_channels = //
$db->select($query_matching_bad_channels);
```

3. If necessary, further calculations are made and the data is prepared for output.
4. A table is generated and filled with the resulting values selected from the database.
5. Data output is written into a comma separated values text file allowing easy download of the data.

Example:

```
fwrite($fhandler, "{$bad_channels_new[$fulldepvolt_shift
//
['module_serial']] ['L']}, ");
```

2.1 Matching Spreadsheet

This interface generates a list of the most important module properties, except for the remainder. On remainder data, a detailed analysis turned out to be necessary and therefore a separate spreadsheet was developed. A screenshot of the web interface is displayed in Figure 4. Information on the following module properties is given:

- **Serial number** is the label of the module.
- **mt (module type)** is 4-3 or 4-2-1 and indicates whether the module contains two or three readout sections.
- **ht (hybrid type)** is L1 for upside or L2 for downside modules.
- **Full depletion voltage:** For sections L and M, the minimal and maximal full depletion voltages of the sensors in the section are determined and displayed in the spreadsheet. As K sections consist of only a single sensor, this sensor's full depletion voltage is displayed. Full depletion voltages are given in Volt.
- **Leakage Current @ 500 V:** Leakage currents for each readout section are given for the maximal possible operation voltage of 500 Volts. Leakage currents are given in μA .

- **Bad channels:** For each readout section the number of bad readout strips (bad channels) is given. The sum for each section is calculated based on the table of the database containing an entry for each bad channel.
- **Sensor shift:** Alignment test results stored in the database are the offset `$shift_1` of one corner of the sensor and the angle `$tilt_value` describing the tilt of the sensor as described in Section 3.6. First, the offset of the second corner `$shift_2` is calculated as follows:

```
$shift_2[$module_serial][$sensorpos]= //
round($tilt_value*$sensor_length+$shift_1 //
[$module_serial][$sensorpos],0);
```

Then the maximal and minimal offsets are determined for each readout section and the difference $\Delta s = max_{\text{offset}} - min_{\text{offset}}$ is calculated. The unit of the displayed data is μm .

2.2 Remainder Spreadsheet

The remainder of the detector output signal describes the height of the amplitude 25 ns after its maximum. Details on the remainder analysis and its results will be described in Section 3.2. In each pulseshape scan, remainders are measured for several readout channels of each Beetle. In addition, each Beetle undergoes several pulse-shape scans. All remainders ever measured on a Beetle are banded together to calculate appropriate results for the matching of modules, i.e. the order of the criteria the data is sorted into small groups⁸ is:

1. Temperature
2. Beetle

Additional hardware information provided on the interface is relevant to summarise the remainder data on level module, but not for data sorting. The interface provides detailed information on remainder data as shown in Figure 5.

Hardware information:

- **m**: Serial number of the module.
- **ht**: Hybrid type the Beetle is on. The hybrid type is identical with the readout section type.
- **b_id**: Beetles are labelled uniquely by the number `beetle_id`.

Test information:

- **p**: The position on the hybrid of the Beetle is indicated by the value of `p`. There are four Beetles on each hybrid labeled by $p = 1, 2, 3, 4$. Remainder data on Beetles $p = 1, 2, 3$ has been measured using internal testpulses. Remainder data on Beetles in position four has been measured using laser testpulses.
- **T**: The environment temperature at which the remainder values were measured is indicated as cold (c) or warm (w).
- **# s**: The number N_j of remainder values measured on channels of Beetle chip `j` is displayed.

Values calculated on the remainder data:

In the following definitions, the number `beetle_id` is referred to as `j`. The remainder of measurement `i`, $i=1,2,\dots,N_j$ on Beetle chip `j` is r_{ji} .

⁸In average twelve remainder values have been measured per Beetle.

- **avg:** The average of the remainders measured on the Beetle chip j

$$a_j = \frac{1}{N_j} \left(\sum_i r_{ji} \right).$$

- **median:** The median m_j of the remainders measured on Beetle chip j.
- **stddev:** The standard deviation⁹. of the remainders measured on Beetle chip j

$$\sigma_j = \sqrt{\frac{1}{N_j - 1} \sum_i (r_{ji} - a_j)^2}.$$

- **min:** The minimum $\min_{i=1,2,\dots,N_j} (r_{ji})$
- **max:** The maximum $\max_{i=1,2,\dots,N_j} (r_{ji})$

The average values are displayed as button labels. Clicking the button will pop up a new window (Figure 6) that shows all remainders of the Beetle measured at the selected temperature. In the new window, hyperlinks on the fill number guide to the module overview from where the complete set of informations about the module tests can be accessed, e.g the graph of a pulse-shape scan.

Two similar interfaces are defined for displaying remainder data. *Remainder Spreadsheet (incl. Median)* as shown in Figure 5 provides the column “median”, but is quite slow due to the algorithm used to determine median values. Therefore a second interface *Remainder Spreadsheet* was defined that generates the same output without the column “median”. Each reload of either spreadsheet generates a csv file¹⁰ for instant data access and further use. As the interface *Remainder Spreadsheet (incl. Median)* is not expected to be used frequently, no effort has been made yet to improve its speed performance. The poor speed performance is due to the user defined SQL functions that are used to determine the median of the data sets and could probably be improved by replacing the SQL functions by a C function fulfilling the same task¹¹. The functions are defined following the definition given in [5] as:

```
SELECT round(x.remainder,2) AS median
FROM remainder_cold AS x, remainder_cold AS y
WHERE x.beetle_id=$1 AND y.beetle_id=$1
```

⁹This definition was used due to implementation of aggregate function std() in PostgreSQL.

¹⁰The files remainder_median.csv and remainder.csv are located in the directory <http://lhcb.physik.uzh.ch/tt/database/files/test>.

¹¹The functions are remainder_median_cold() and remainder_median_warm(). Location: <http://lhcb/admin/phppgadmin/>, database: lhcb_tt, schema: public, folder: functions.

```
GROUP BY x.reminder
HAVING (SUM(CASE WHEN y.reminder <= //
x.reminder THEN 1 ELSE 0 END)>=(COUNT(*)+1)/2) //
AND SUM(CASE WHEN y.reminder >= x.reminder //
THEN 1 ELSE 0 END)>=(COUNT(*)/2)+1
```

ST Construction Web

[HOME](#) | [Interface Root](#) | [Reload Matching Spreadsheet](#) |

[download data file](#)

serial number	type		full depletion voltage min max			leakage current @ 500 V cold warm			bad channels			sensor shift max-min							
	mt	ht	L	M	K	L	M	K	L	M	K	L	M	K					
8	421	L1	175	200	180	180	185	0.58	2.11	0.12	0.65	0.12	0.61	2	1	2	36	8	3
9	43	L1	190	190	180	185	-	1.01	3.35	0.22	1.34	-	-	1	0	0	96	19	-
10	43	L1	195	195	195	200	-	0.27	1.9	0.68	1.99	-	-	1	2	0	15	28	-
11	43	L2	230	230	240	240	-	1.27	8.23	23.1	56.4	-	-	3	0	0	19	39	-
12	43	L2	230	230	235	235	-	0.89	2.52	26.5	85.5	-	-	0	0	0	20	12	-
13	43	L1	200	200	200	200	-	0.23	2.31	0.18	1.05	-	-	0	0	0	86	63	-

Figure 4: Screenshot of http://lhcb.physik.uzh.ch/tt/database/grading/matching_spreadsheet.php.

The units are: full depletion voltage: V, leakage currents: μA , sensor shifts: μm .

ST Construction Web

[HOME](#) | [Interface Root](#) | [Reload Remainder Spreadsheet \(incl. median\)](#) |

Remainder

m=module_serial, ht=hybrid_type, b_id=beetle_id, p=beetle position on hybrid, #s= number of scans.
 colors: blue=cold, red=warm.

Laser-testpulses on beetles in position 4. Intern testpulses on beetles in position 1-3.
 Standard deviation (stddev) is calculated as $\sqrt{1/(N-1) \sum (x_i - \text{mean})^2}$.

[download data file](#)

m	ht	p	b_id	#s	avg	median	stddev	min	max	T
8	K	1	1441	8	18.89	19.82	4.39	8.19	21.73	c
8	K	1	1441	8	29.87	31.42	4.08	20.00	32.51	w
8	K	2	1442	8	21.93	21.96	0.66	20.50	22.63	c

Figure 5: Screenshot of [remainder_median.php](http://lhcb.physik.uzh.ch/tt/database/grading/remainder_median.php). Clicking on buttons in column "avg" will pop up a new window shown in Figure 6 displaying the values the average is calculated of. The unit of the remainder is %.

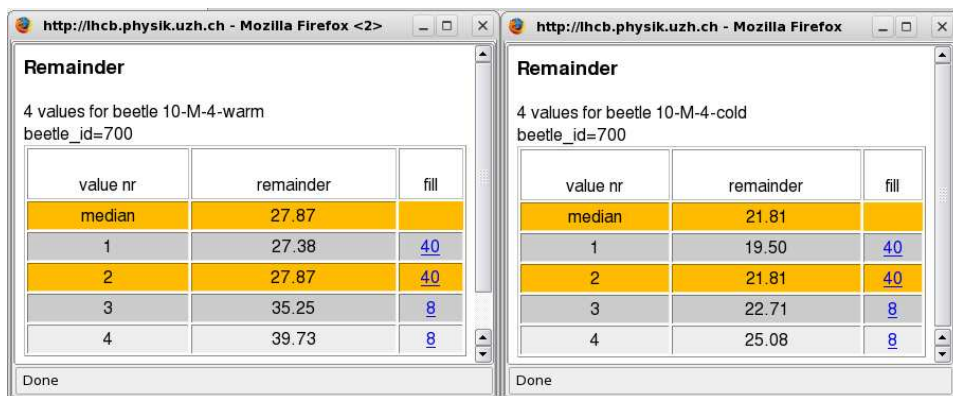


Figure 6: Screenshot of [remainder_value_group_warm.php](http://lhcb.physik.uzh.ch/tt/database/grading/remainder_value_group_warm.php) and [remainder_value_group_cold.php](http://lhcb.physik.uzh.ch/tt/database/grading/remainder_value_group_cold.php). All remainder values determined on the Beetle are displayed. Median is marked in orange. The hyperlink reference on the fill number will guide the user to the site *Burn in Summary* on the TT Construction Web containing information about the module the Beetle is on. 10-M-4-warm indicates module number - section - position of Beetle on hybrid - temperature.

3 Module Properties

3.1 Delay scans

To test the Beetle chips and readout hybrids and to determine the remainder of the output signal 25 ns after the maximum of the signal¹², delay scans are performed. Detector signals were simulated by two different methods:

- **Laser testpulses:** A pulsed infrared laser beam is sent to the sensor to create electron hole pairs in the silicon bulk. The holes drift due to the electric field in the sensor to the readout strip and create an electric signal. The Beetle amplifies and shapes the detector signal and samples the signal amplitude at a given time. Normally this time will be chosen at the maximum of the pulse, but the pulse shape can be measured by varying this sampling time. In our case the signal amplitudes were measured in 4 ns intervals around the maximum. Plotting $A(t_n)$ results in a signal shape as shown in Figure 7.
- **Internal testpulses:** Internal testpulses are created by charge injection directly into the input stage of the Beetle. They are the amplified, shaped and sampled in the same way as detector signals.

To the data points, the function

$$f(t) = A_0 \cdot \left(\frac{(t - t_0)^2}{2 \cdot \tau^2} - \frac{(t - t_0)^3}{6 \cdot \tau^3} \right) \cdot e^{-\frac{t-t_0}{\tau}}$$

is fitted. The fitparameter t_0 describes the time-offset of the test pulse with respect to the readout time. It is not relevant for the pulse-shape and will therefore not be discussed in the following. A_0 is the amplitude of the signal and the time constant τ describes the width of the signal.

Table 2 shows the averages and errors on the average of all τ values, sorted by readout section, temperature and the type of the test pulse. The distributions of τ for each category are shown in Appendix A.5. The following trends can be observed:

- The number of entries for internal testpulse scans is much higher than that for laser testpulse scans, since for a given readout section 16 channels on three Beetle chips each were supplied with an internal testpulse whereas only two channels on one Beetle chip recieved a laser testpulse.

¹²This is the bench-crossing rate at which colliding protons will cause events in the experiment later on.

- At low operation temperature signal shapes are narrower than at room temperature. This was expected and is due to the behaviour of Beetle chips which are "faster" at low temperature.
- The largest values of τ of each data set are in section M1. This was also expected since these readout sectors have the largest strip capacitance and Beetle chips get "slower" as the load capacitance increases.
- Internal testpulses create broader pulse-shapes than laser pulses. This effect is not understood.
- The standard deviations of the distributions of τ for laser testpulses is larger than for internal testpulses (Figures 34 to 37). This effect could be related to the larger spread in test pulse amplitudes (as shown on section L data of the amplitude A_0 in Figures 8 and 9 at cold temperature).

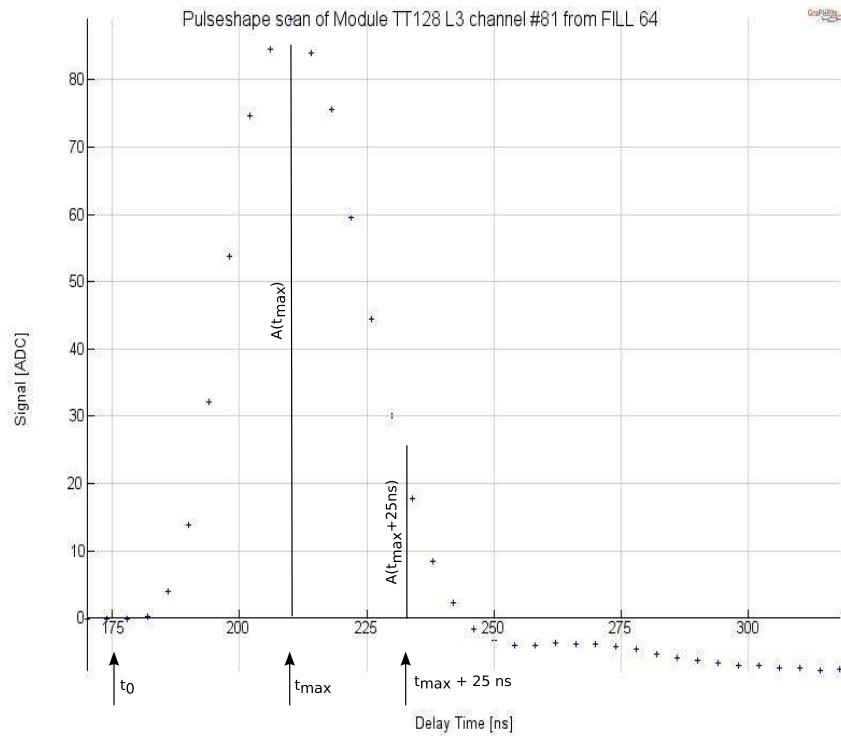


Figure 7: Pulse-shape of module tt 128, section L, Beetle 3, channel 81 measured in fill 64.

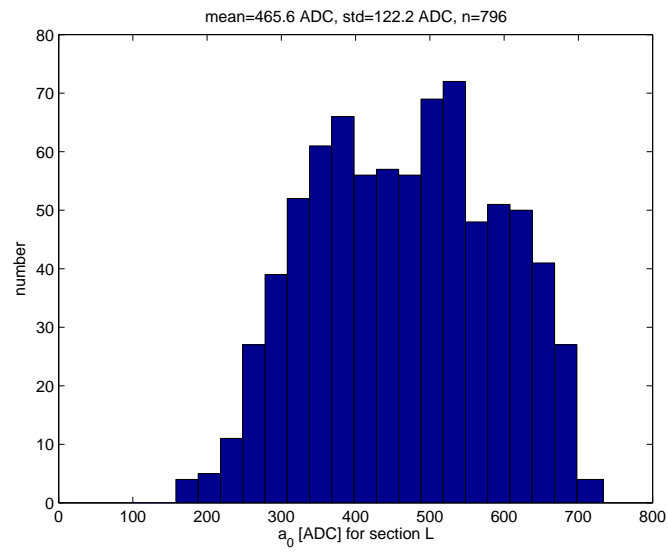


Figure 8: Histogram of fitparameter A_0 : cold, laser testpulses, section L.

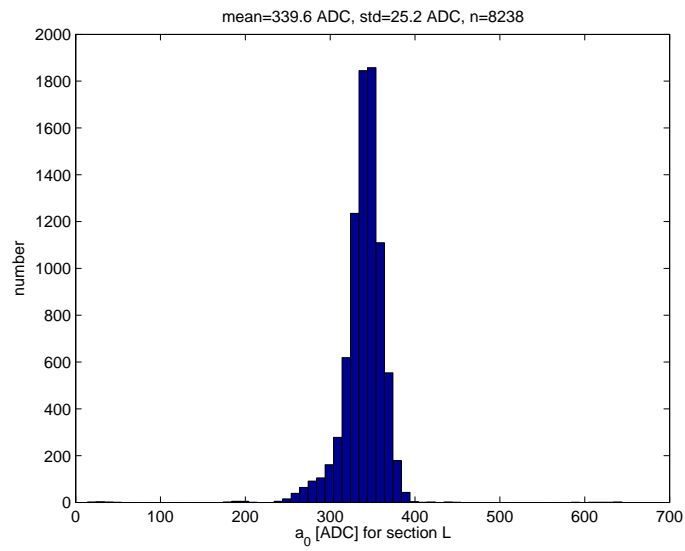


Figure 9: Histogram of fitparameter A_0 : cold, internal testpulses, section L .

3.2 Remainder

The relevant quantity for operation in LHCb is $A(t_0 + 25\text{ns})$, the remaining ADC value of a signal pulse at the time at which a next event would occur at the LHC. As ADC values are arbitrarily defined, we define the remainder r as the ratio of the remaining amplitude after 25 ns to the signal amplitude in the maximum:

$$r = \frac{A(t_{max} + 25\text{ns})}{A(t_{max})} \cdot 100$$

Remainders are given in units of $[r] = \%$. Clearly, the remainder is strongly correlated with the time constant τ , large values of τ imply large remainders. The function $f(t)$ introduced above is used to calculate the amplitudes $A(t) = f(t)$. The remainder should not exceed a value of 50%. Modules having large remainders are not welcome at the centre part of the detector where the particle density is high. Therefore modules containing sections with high remainder values have to be identified and given a lower grading.

As a lot¹³ of pulse-shape scans were performed, the process of identifying these modules had to be automated. The first idea was to use the existing web interface *Burnin Histograms*¹⁴ providing a function to create histograms of the remainder values r and mark all modules having a remainder $r \notin [r - 2 \cdot \sigma, r + 2 \cdot \sigma]$ as outliers. As the pulse-shape of the Beetle chip depends on temperature and on the capacitance C_{strip} (Table 7) of the readout strip, the data had to be selected separately for each readout section and temperature, which is also provided by the interface. The result was that more than 20% of the modules should have been marked as outliers. This number was too large to be useful and in addition this analysis made not much sense because of several lacks in the sort mode used to create the data groups.

- The first problem was that the existing interface did not allow to select only remainders measured with either laser test pulses or internal testpulses. As shown above, these lead to different pulse-shapes and therefore have to be separated within the analysis.
- The second problem was that the values for M sections could not be separated by the given interface according to M1 (M section of 4-3 type module) and M2 (M section of 4-3 type module), which is necessary due to different strip capacitances C_{strip} .
- Thirdly, on average 210 remainder values were determined per module, each of which created an entry in the histogram. The interface did not provide an easy way to count the numbers of outliers for a given module

¹³The number of remainder values stored in the database is: 31514.

¹⁴http://lhcb.physik.uzh.ch/tt/database/grading/burnin_disp_histogram_select.php

and to decide if an single outlier is due to a single "bad" measurement or due to a "slow" Beetle chip.

Due to these reasons, a more detailed analysis of the remainder data was necessary and the *Remainder Spreadsheet* (Figure 5) was created.

The same grouping as for the τ data was performed on the remainder data. For each readout section the minimum, maximum, average, median and standard deviation of all remainder measurements was determined. The distributions of the quantities remainder r_{ji} , average a_j , standard deviation σ_j , median m_j for the different categories are shown in Appendix A. In Figure 10 the difference $\Delta r_j := a_j - m_j$ indicates that there is a tendance to high outliers within the remainder data group of a Beetle because the average is more sensitive on outliers than the median is. Module grading is based on the outliers in the distribution of averages.

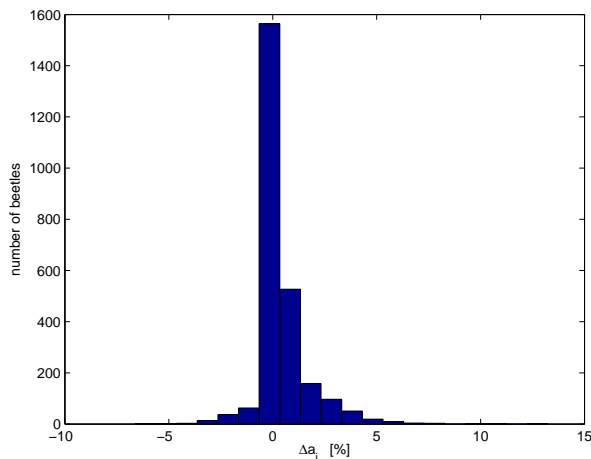


Figure 10: Difference $\Delta r_j := a_j - m_j$

3.3 Bad Channels

Bad channels were identified by an analysis of noise measurements. A list of bad channels for each readout section, together with the type of failure (open, short, pinhole, other) is stored in the database. As bad channels will not help us detecting particles, modules containing bad readout strips will be placed as far from the beampipe away as possible. Figure 11 shows the distribution of the number of bad channels per module. Only a few modules have more than five bad channels. Five bad channels are equivalent to one percent of the channels in a readout section. Figures 12 and 13 show distributions of numbers of bad channels per readout section and per Beetle, respectively. Detected defect types and their occurrence is shown in Figure

		L		M1		M2		K	
T	pulse	$\bar{\tau}$	σ	$\bar{\tau}$	σ	$\bar{\tau}$	σ	$\bar{\tau}$	σ
cold	lp	17.0	0.04	17.2	0.06	16.8	0.09	16.9	0.09
warm	lp	19.2	0.05	19.4	0.06	19.1	0.14	19.5	0.10
cold	itp	18.9	0.01	19.5	0.01	18.7	0.02	18.7	0.02
warm	itp	20.7	0.01	21.2	0.01	20.7	0.02	20.8	0.01

Table 2: Mean and its error $\sigma = \frac{\text{std}}{\sqrt{n}}$ of τ values sorted by temperature, testpulse and readout section where standard deviation std and total number of entries n is from the data sample used to create the according histograms in Figures 34, 36, 35 and 37. $[\bar{\tau}] = \text{ns}$, $[\sigma] = \text{ns}$.

		L		M1		M2		K	
T	pulse	\bar{r}_{ji}	σ	\bar{r}_{ji}	σ	\bar{r}_{ji}	σ	\bar{r}_{ji}	σ
cold	lp	18.9	0.21	19.5	0.32	17.3	0.46	17.0	0.58
warm	lp	31.1	0.23	31.1	0.29	30.8	0.55	30.9	0.53
cold	itp	26.2	0.03	29.1	0.04	25.1	0.08	25.3	0.09
warm	itp	34.4	0.03	36.4	0.04	34.5	0.06	34.8	0.07

Table 3: Mean \bar{r}_{ji} and its error $\sigma = \frac{\text{std}}{\sqrt{n}}$ of remainder values r_{ji} sorted by temperature, testpulse and readout section where std is the standard deviation and n is the total number of entries of the data used to create the histograms in Figures 24, 25, 26, 27. All remainder values ever calculated are histogrammed except of a few outliers where the fit went completely wrong and data is not useful. $[\bar{r}_{ji}] = \%$, $[\sigma] = \%$.

		L		M1		M2		K	
T	pulse	\bar{a}_j	σ	\bar{a}_j	σ	\bar{a}_j	σ	\bar{a}_j	σ
cold	lp	18.8	0.30	19.8	0.48	17.2	0.52	17.2	0.74
warm	lp	30.8	0.37	31.3	0.40	30.9	0.72	30.9	0.71
cold	itp	26.1	0.10	29.1	0.10	25.0	0.24	25.2	0.21
warm	itp	34.4	0.10	39.4	0.09	34.5	0.16	34.8	0.17

Table 4: Mean \bar{a}_j and its error $\sigma = \frac{\text{std}}{\sqrt{n}}$ of average remainder values a_j sorted by temperature, testpulse and readout section where std is the standard deviation and the total number of entries n of the data used to create the histograms in Figures 28, 29. $[\bar{a}_j] = \%$, $[\sigma] = \%$.

		L		M1		M2		K	
T	pulse	\overline{m}_j	σ	\overline{m}_j	σ	\overline{m}_j	σ	\overline{m}_j	σ
cold	lp	17.7	0.34	18.4	0.54	15.4	0.59	16.1	0.71
warm	lp	29.2	0.39	30.0	0.36	29.0	0.75	30.0	0.65
cold	itp	25.9	0.11	28.8	0.10	24.7	0.26	25.0	0.20
warm	itp	34.3	0.10	36.3	0.09	34.2	0.20	34.8	0.16

Table 5: Mean \overline{m}_j and its error $\sigma = \frac{\text{std}}{\sqrt{n}}$ of standard deviation m_j sorted by temperature, testpulse and readout section where standard deviation std and total number of entries n is from the data sample used to create the according histograms in Figures 32 and 33. $[\overline{m}_j] = \%$, $[\sigma] = \%$.

		L		M1		M2		K	
T	pulse	$\overline{\sigma}_j$	σ	$\overline{\sigma}_j$	σ	$\overline{\sigma}_j$	σ	$\overline{\sigma}_j$	σ
cold	lp	4.2	0.22	2.5	0.22	3.7	0.43	1.5	0.33
warm	lp	4.8	0.25	2.6	0.22	4.6	0.45	1.5	0.22
cold	itp	1.7	0.06	1.1	0.05	1.6	0.09	1.1	0.06
warm	itp	1.6	0.06	1.1	0.04	1.4	0.06	1.0	0.05

Table 6: Mean $\overline{\sigma}_j$ and its error $\sigma = \frac{\text{std}}{\sqrt{n}}$ of standard deviation σ_j sorted by temperature, testpulse and readout section where standard deviation std and total number of entries n is from the data sample used to create the according histograms in Figures 30 and 31. $[\overline{\sigma}_j] = \%$, $[\sigma] = \%$.

readout sector	sensor length [cm]	cable length [cm]	C_{strip} [pF]
L	37.76	-	54.9
M1	28.32	39.1	57.3
M2	18.88	39.1	44.1
K	9.44	58.0	38.4

Table 7: Total strip capacitances. M1: M section of 4-3 type module, 3 sensors. M2: M section of 4-2-1 type module, 2 sensors. Data from [4], p.7.

14. Figure 15 shows that the defects are distributed uniformly on all Beetles. An interesting result is that the first readout channel (channel zero) on a Beetle has a defect significantly more often than other readout channels. Maybe uncareful handling of sensors caused this cumulation of defects.

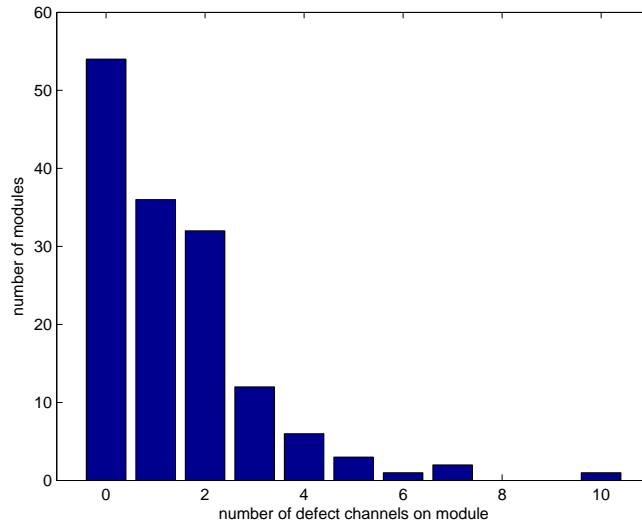


Figure 11: Occurrence of bad channels on modules.

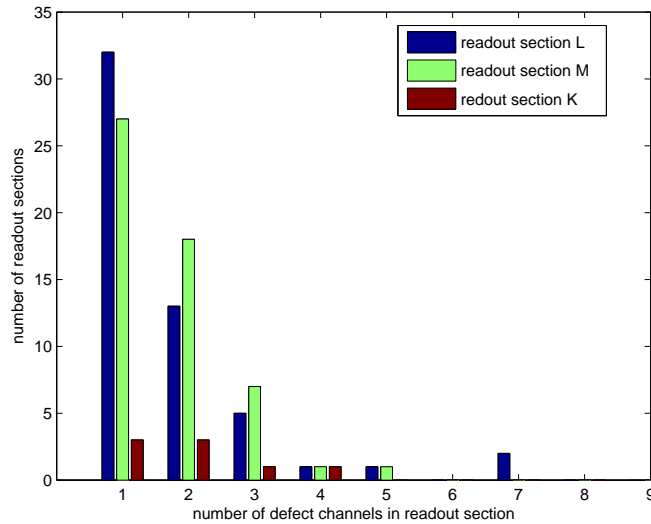


Figure 12: Occurrence of bad channels in readout sections.

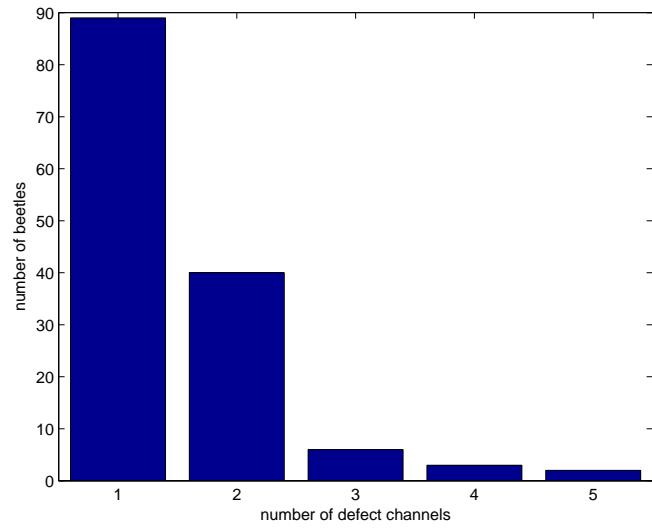


Figure 13: Distribution of Beetles on number of bad channels on Beetle.

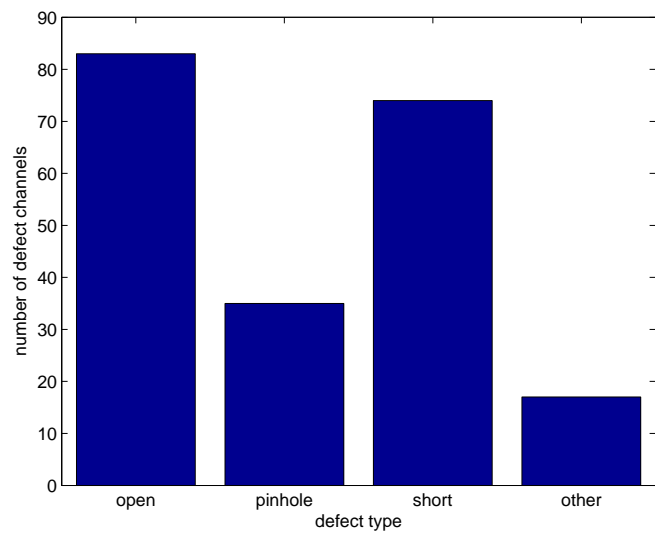


Figure 14: Defect types and their occurrence.

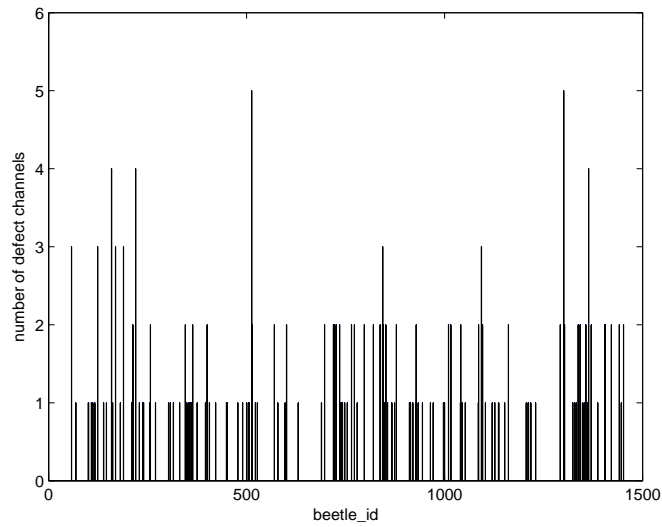


Figure 15: Number of bad channels on each Beetle. Beetles are labelled with a number called *beetle_id* $\in [0, 1500]$. In average each channel has 1.6 defects.

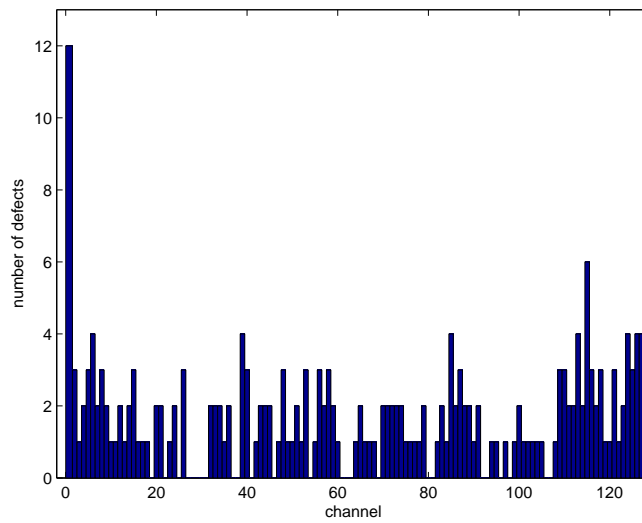


Figure 16: Occurrence of defects on channel. Note the high number of 12 defects on channel zero.

3.4 Full Depletion Voltage

The full depletion voltage gives a measure for the minimal operation voltage of the detector. In fact the detector will be operated at a higher voltage to optimise charge collection by speeding up the drift velocity of electrons and electron holes in the silicon bulk. Figure 17 shows the distribution of full depletion voltages for all sensors. As all sensors on a given readout section will be operated at the same voltage, sensors having more or less the same full depletion voltage have been selected to build a module. Figure 18, where the distribution of the difference of maximal and minimal full depletion voltage in each readout section is shown, demonstrates that the selection of similar sensors was done successfully. The full depletion voltage is not used in module grading but will be used in the mapping of modules since several readout sections will be connected to a common high voltage power supply and will therefore have to be operated at the same bias voltage.

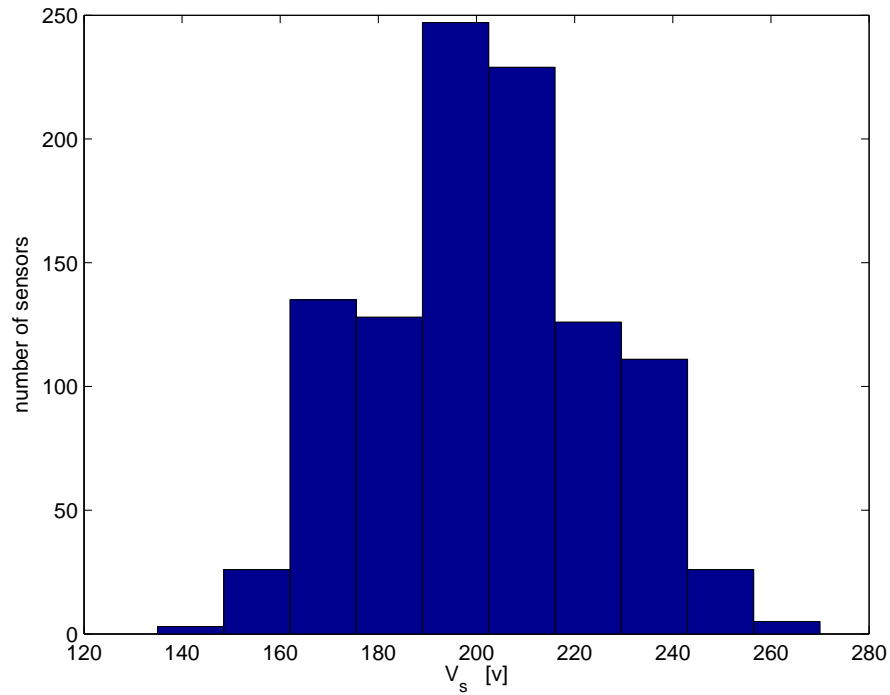


Figure 17: Full depletion voltage values V_s of of each sensor. $s = \text{sensor_id}$.

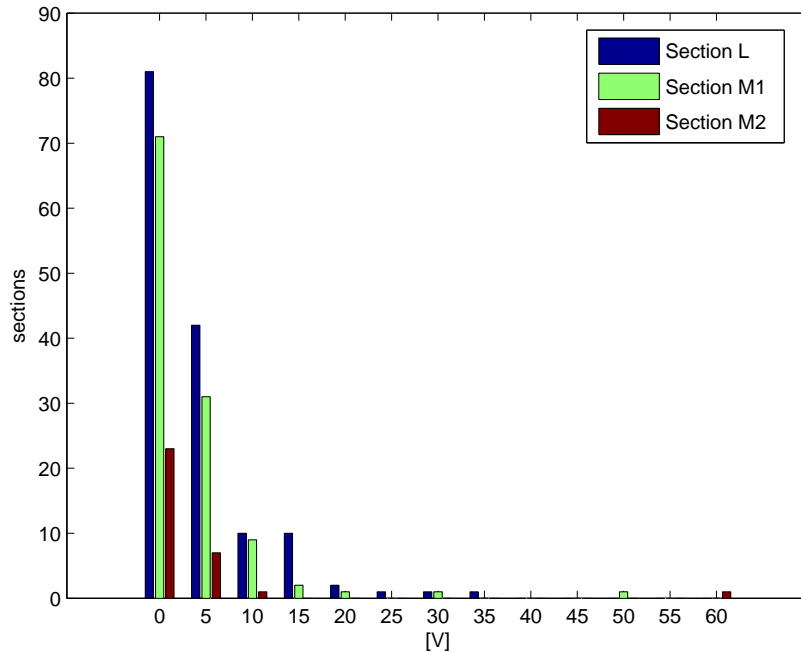


Figure 18: Difference of maximal and minimal full depletion voltage $\Delta V = V_{max} - V_{min}$ in section.

3.5 Leakage Currents

As Figure 19 indicates, sensors leakage currents depend on temperature. In the teststand modules have been subject to temperature cycles in a range of 5 to 28°C. During these cycles, modules were biased at 500 V and leakage currents were measured continuously. Figure 19 shows one example of such a temperature cycling. The operation temperature and the leakage currents for one readout sector are shown as a function of time. Complete correlation is observed. Figures 20 and 21 show the distribution of leakage currents at 500 V separately for the different types of readout sections and at warm respectively cold temperatures. The measured leakage currents are very low. Modules with heigher than normal leakage currents will get a lower grading.

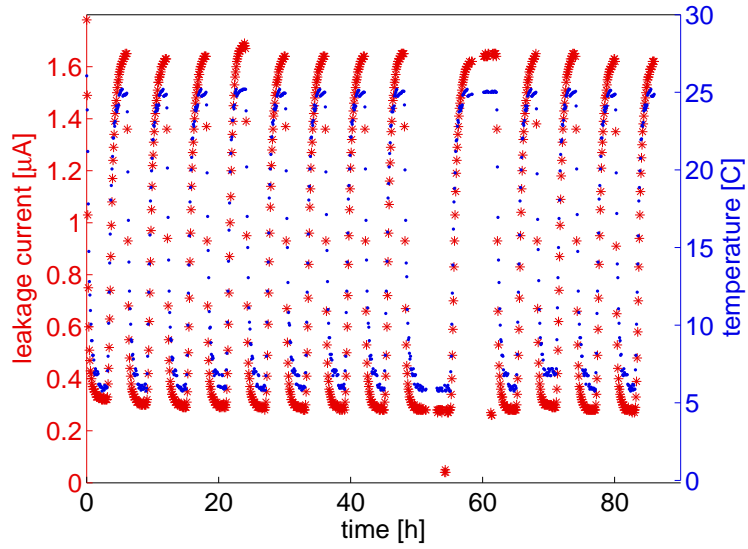


Figure 19: Leakage current and temperature as a function of time.

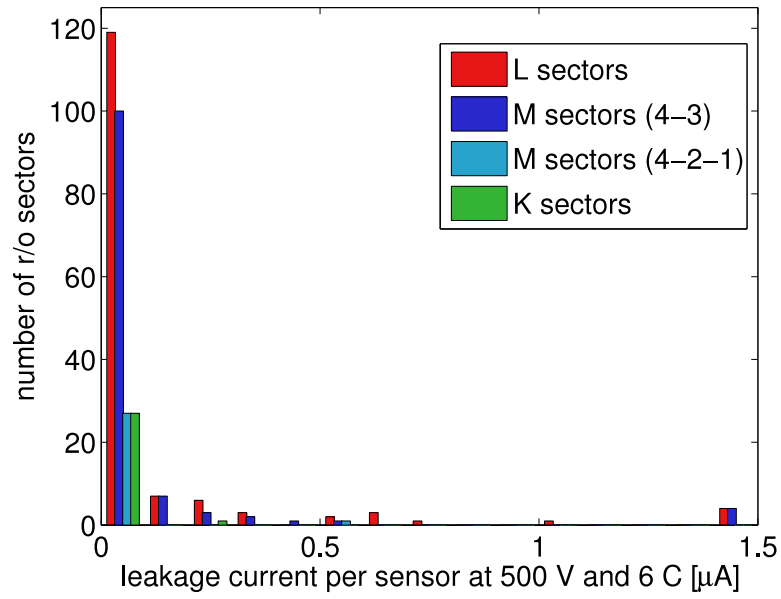


Figure 20: Leakage currents determined at cold temperature

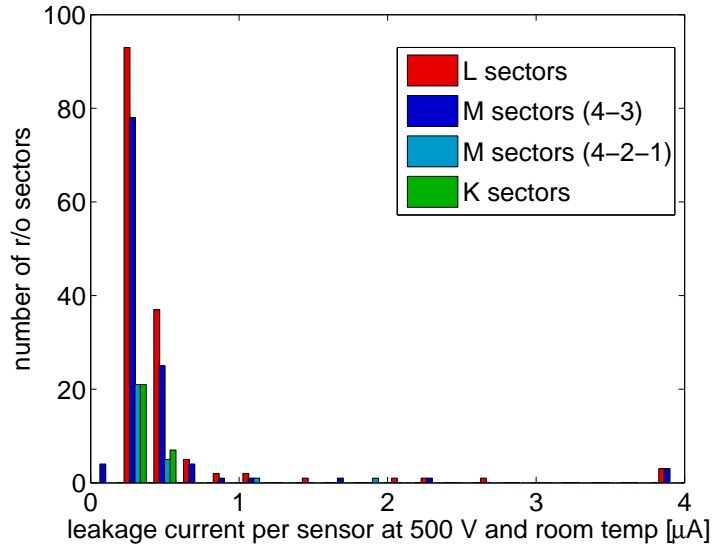


Figure 21: Leakage currents determined at room temperature.

3.6 Sensor Alignment

Sensors carry alignment marks in each corner. The marks on one side of each of the seven sensors on a module are measured under a coordinate measurement machine and a line is fitted to these measurements. The relative position of the sensor is determined measuring the offset of one corner to the line and the angle between the line and the sensors side.

Good sensor alignment on modules is important because it will permit to treat the complete module as a unit in software alignment. Doing software alignment corrections on the level of sensors would give seven times more alignment parameters and result in a much more complicated alignment task. Figure 22 shows the distribution of relative offsets and tilts of the sensors on a module. The rms of these distributions is much smaller than the expected spatial resolution of $50\mu\text{m}$. The distribution of "maximal offsets" per readout sector, as defined in Section 2.1 is shown in Figure 23. It is this quantity that will be used in module grading: modules with a large maximal offset will receive a lower grading.

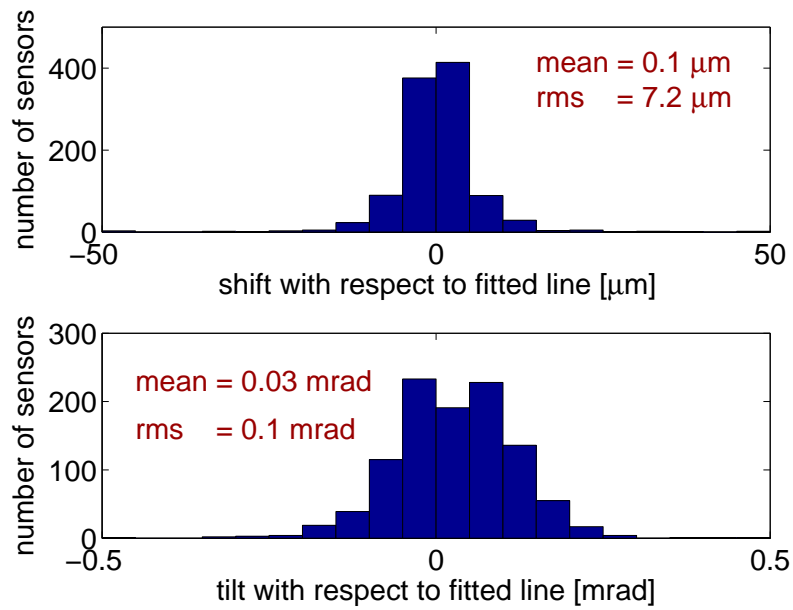


Figure 22: Sensor alignment in terms of offset and angle with respect to fitted line.

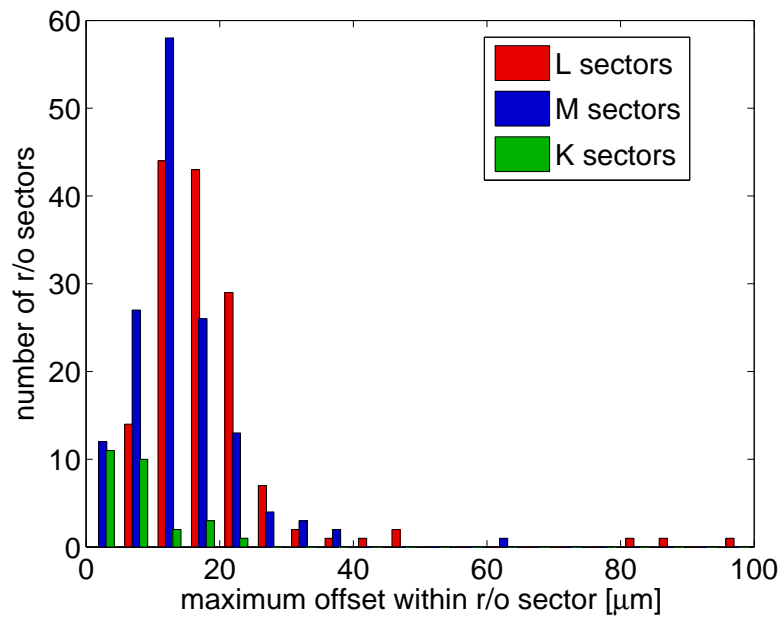


Figure 23: Maximal deviation on section.

4 Summary

The module production for the LHCb Trigger Tracker Station has recently been completed. A total of 128 modules, each consisting of seven silicon micro strip sensors organised in two or three readout sections have been constructed. Extensive tests have been performed on the modules for the quality assurance. Around two terabytes of data collected within the tests has been stored in the LHCb TT Production Database.

The subject of this thesis was to extract relevant data from the database (data mining) and to process it to provide information on module properties for the module quality analysis and the module grading. The generated information is displayed on two web interfaces of the TT Construction Web. Distributions of the relevant data have been checked and it was found that the overall module quality was very good. The results of this work have been used for the module grading, which was not a topic of this thesis.

References

- [1] LHCb Reoptimized Detector Design and Performance Technical Design Report, CERN-LHCC-2003-030 (2003).
- [2] J.Gassner et al., The mechanical Design of the LHCb Silicon Trigger Tracker, LHCb-2004-110 (2004).
- [3] O.Steinkamp et al., Design and Production of Detector Modules for the LHCb Silicon Tracker, LHCb-2006-063 (2006).
- [4] M. Siegler, F. Lehner, M. Needham, O. Steinkamp, Expected Particle Fluences and Performance of the LHCb Trigger Tracker, LHCb-2004-070 (2004).
- [5] Ales Spetic, Jonathan Gennick, Transact-SQL Cookbook, O'Reilly (2002).

A Delay Scan and Remainder Histograms

A.1 Remainder r_{ji}

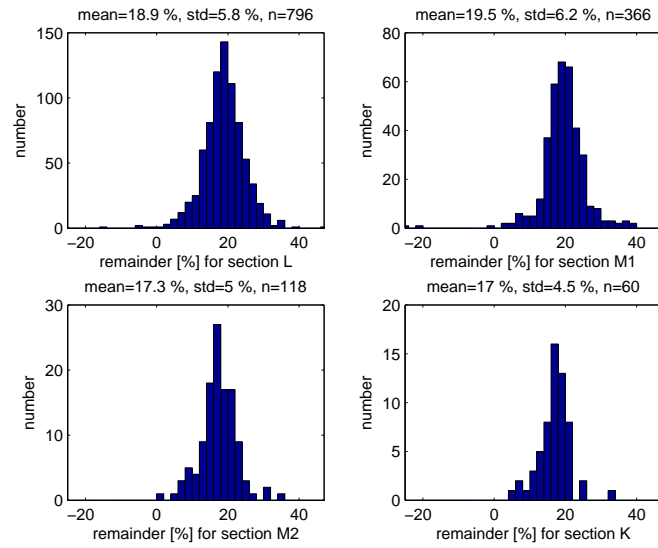


Figure 24: Remainder values for cold, laser testpulses.

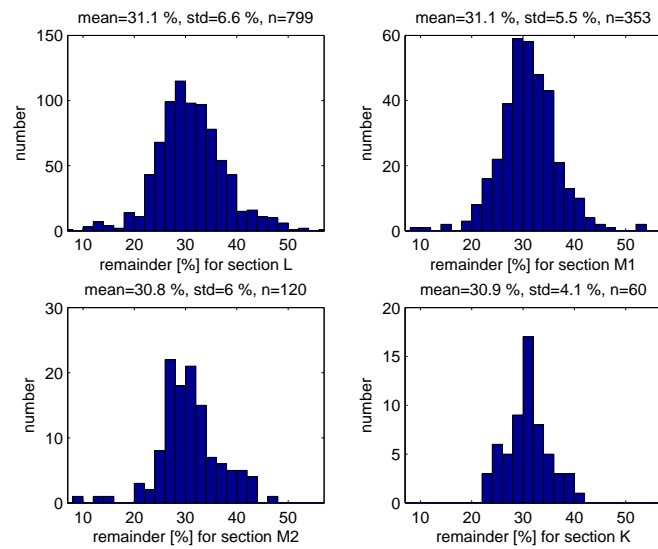


Figure 25: Remainder values for warm, laser testpulses.

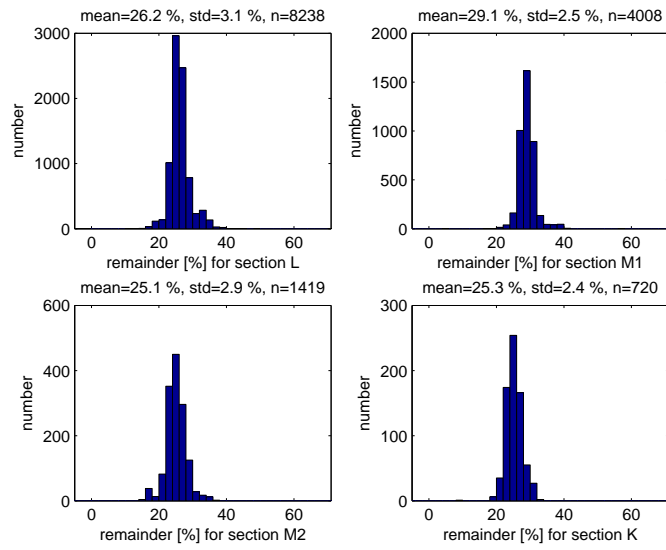


Figure 26: Remainder values for cold, internal testpulses.

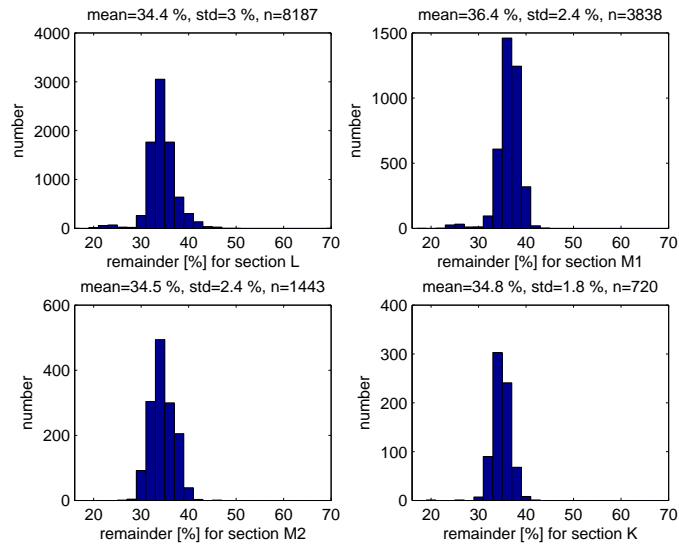


Figure 27: Remainder values for warm, internal testpulses.

A.2 Average a_j of Remainder

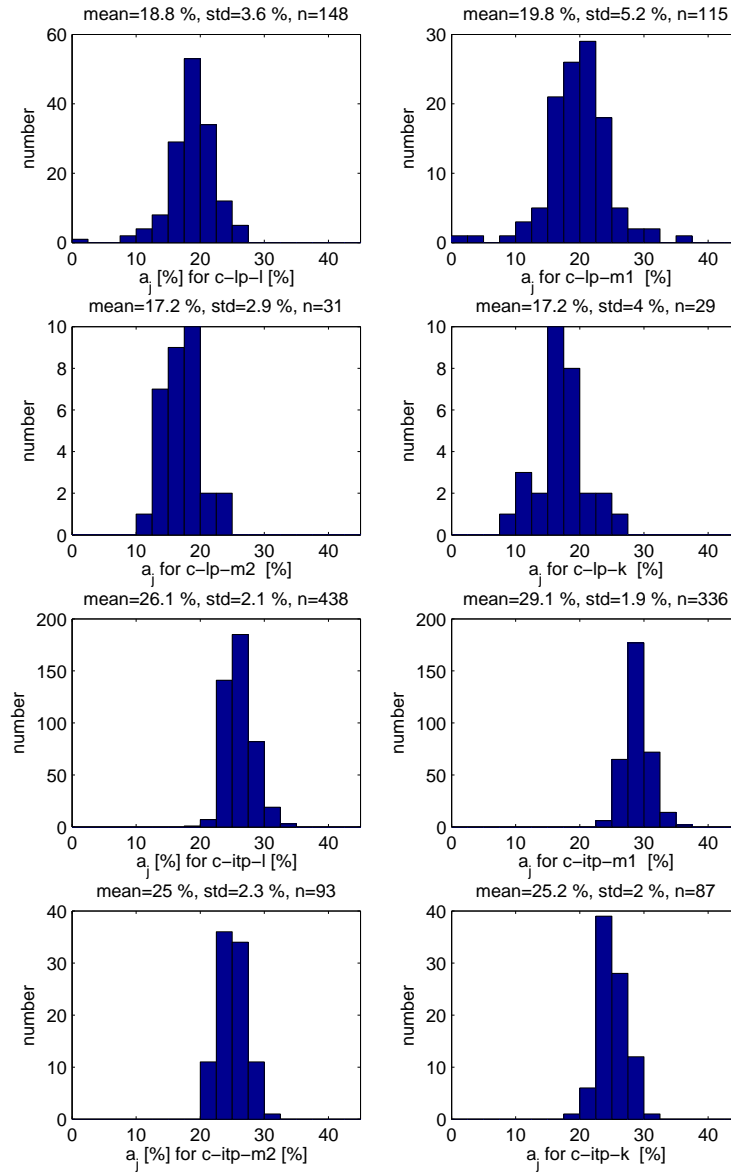


Figure 28: Average remainder values a_j : cold.

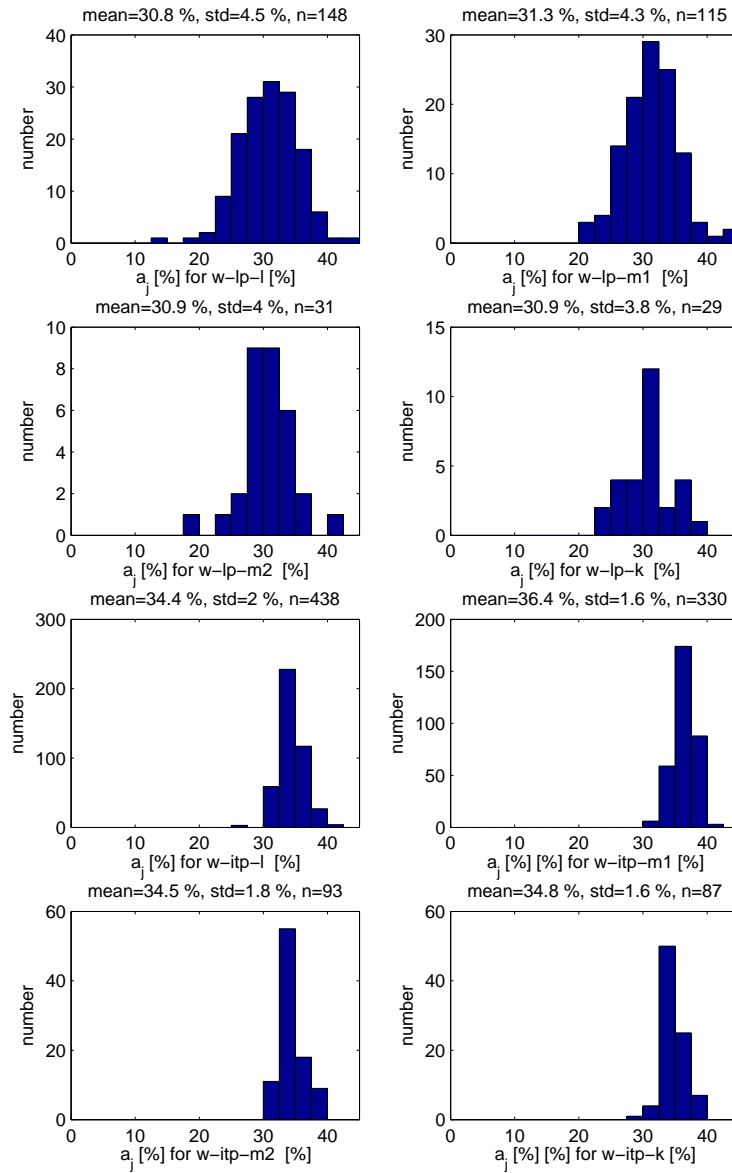


Figure 29: Average remainder values a_j : warm.

A.3 Standarddeviation σ_j of Remainder

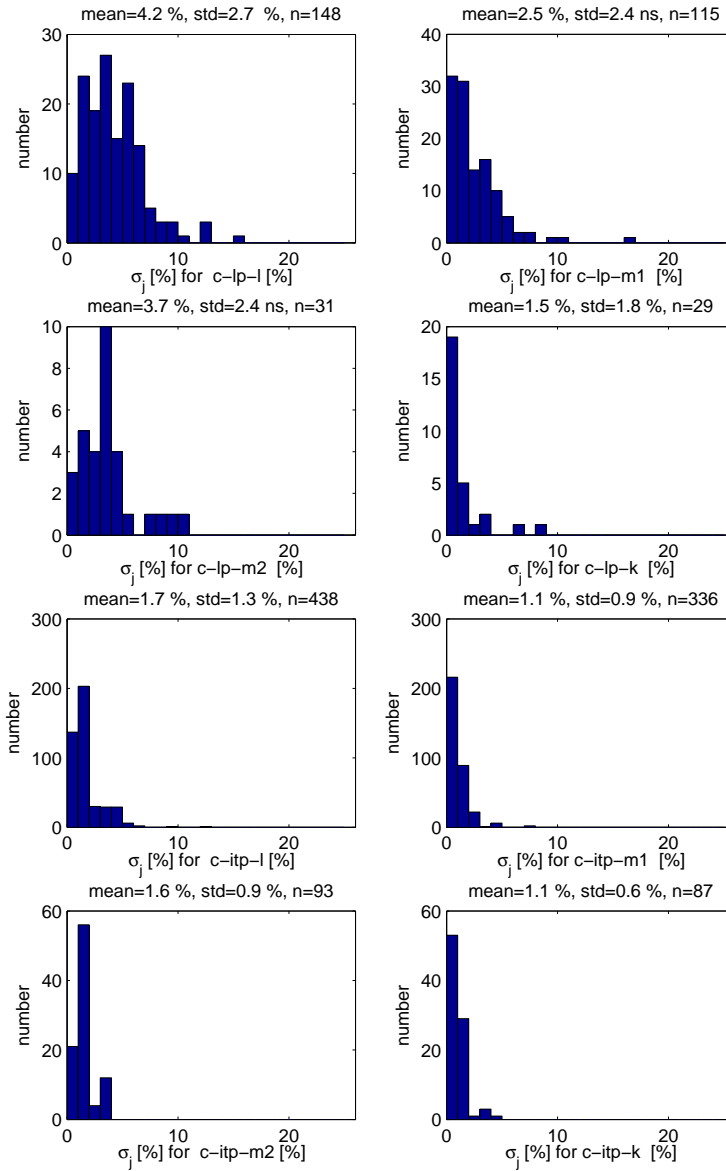


Figure 30: Standard deviations σ_j : cold.

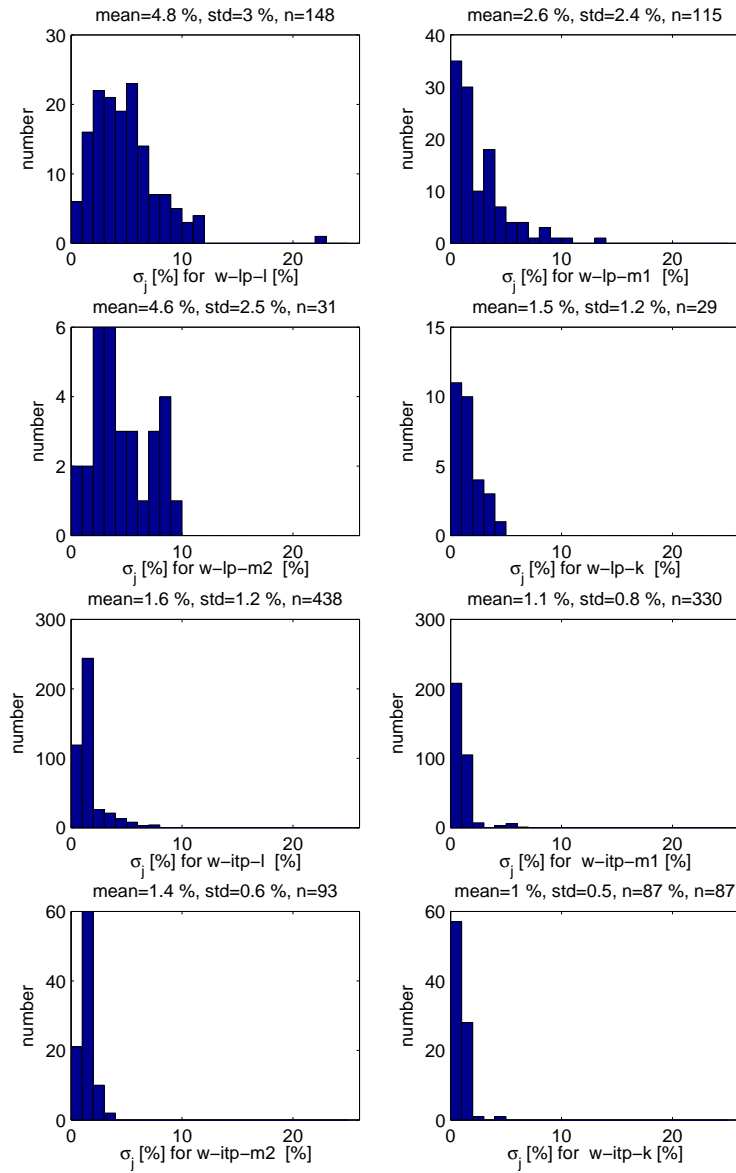


Figure 31: Standard deviations σ_j : warm.

A.4 Median m_j of Remainder

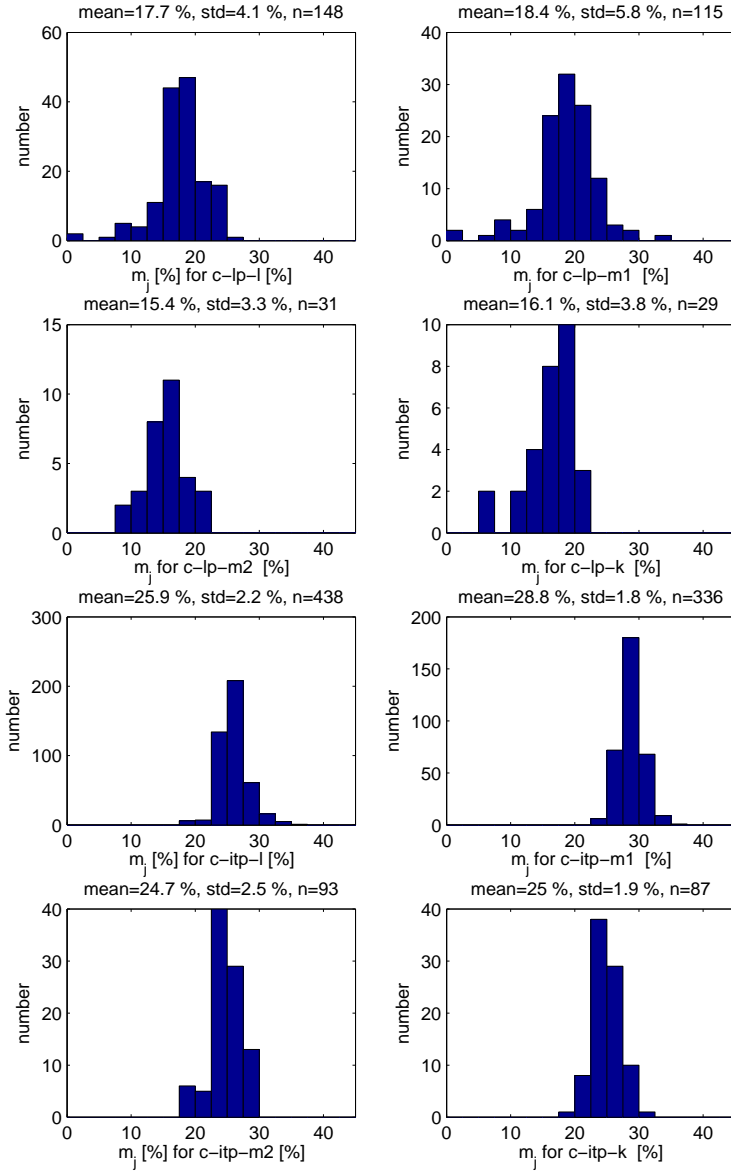


Figure 32: Median values m_j of remainder, cold.

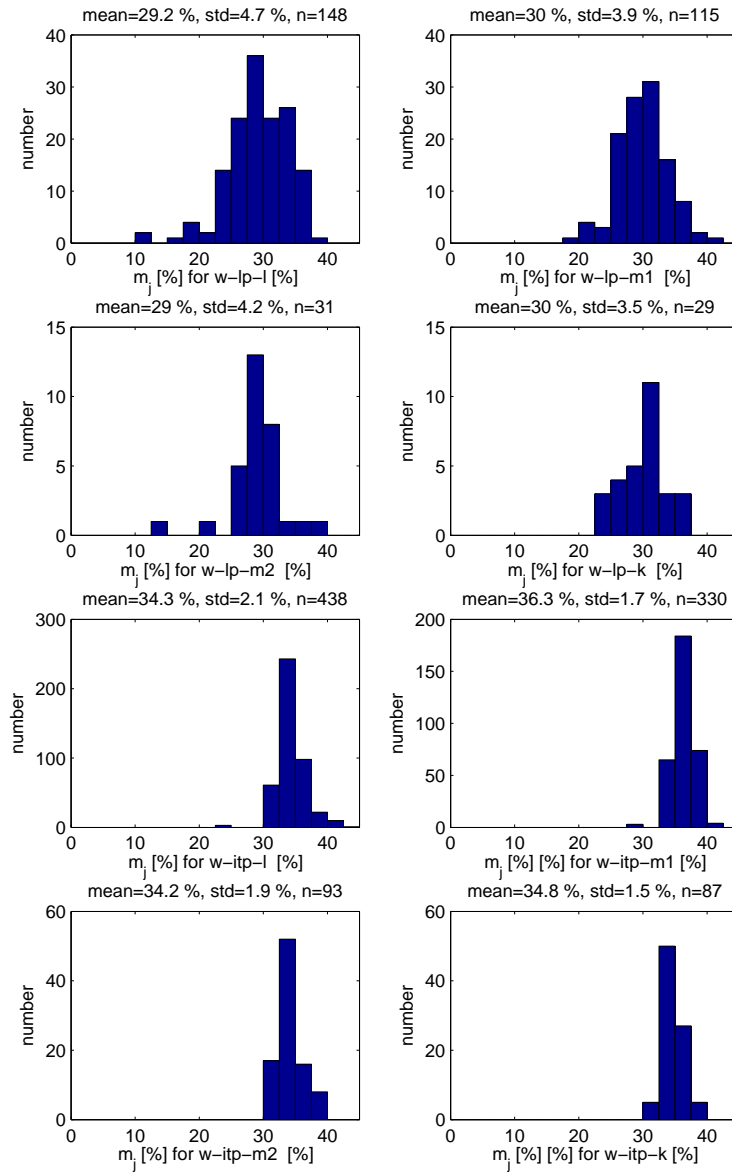


Figure 33: Median values m_j of remainder, warm.

A.5 Pulse Width τ

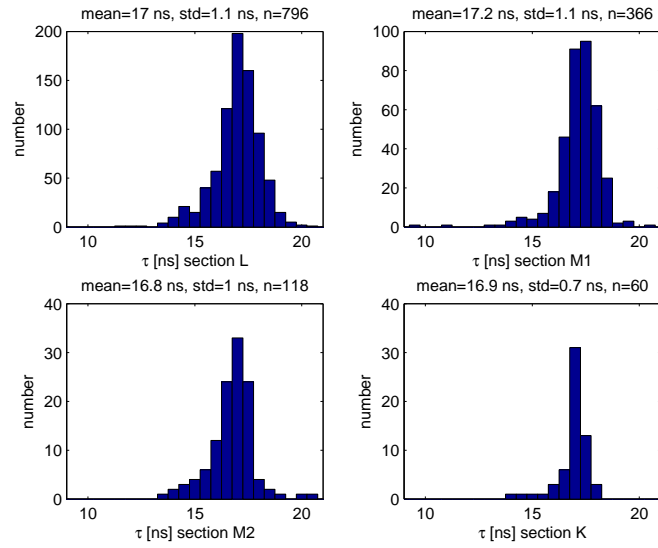


Figure 34: Histogram of fitparameter τ : cold, laserpulses.

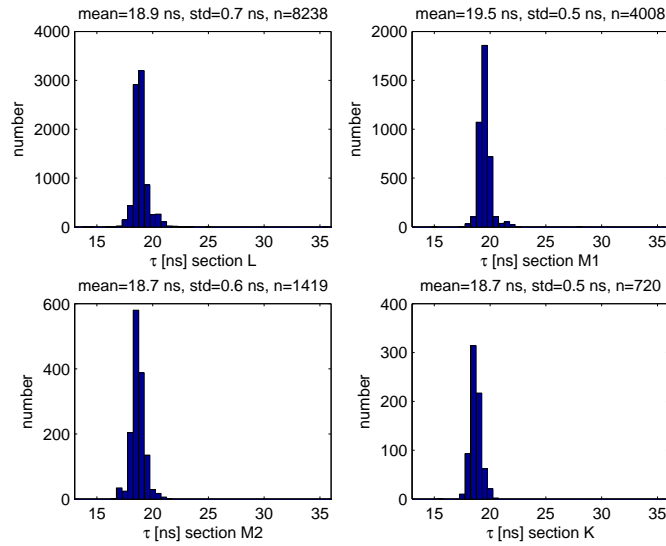


Figure 35: Histogram of fitparameter τ : cold, internal testpulses .

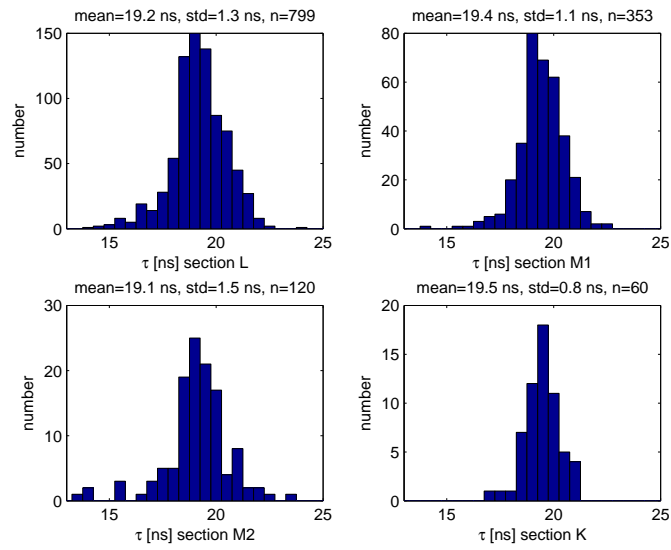


Figure 36: Histogram of fitparameter τ : warm, laserpulses .

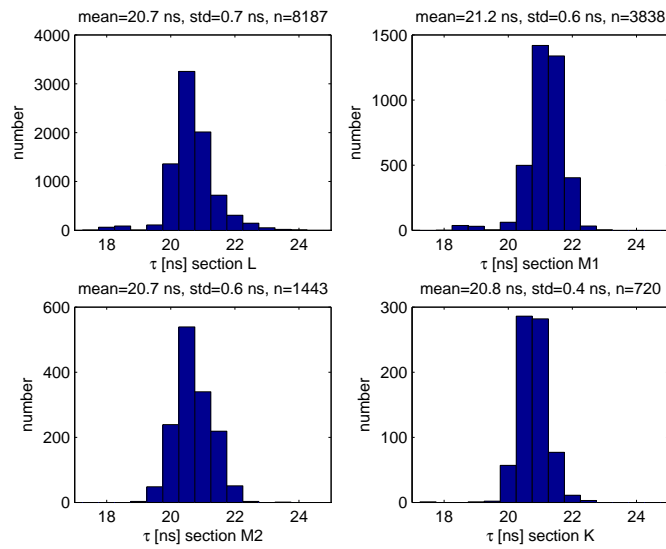


Figure 37: Histogram of fitparameter τ : warm, internal testpulses .

A.6 ADC Amplitude A_0

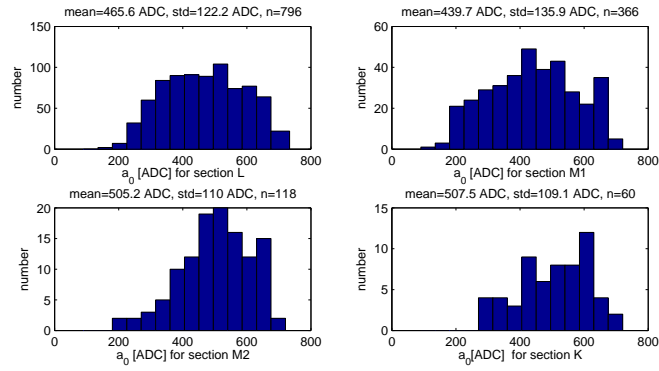


Figure 38: Histogram of fitparameter A_0 : cold, laserpulses.

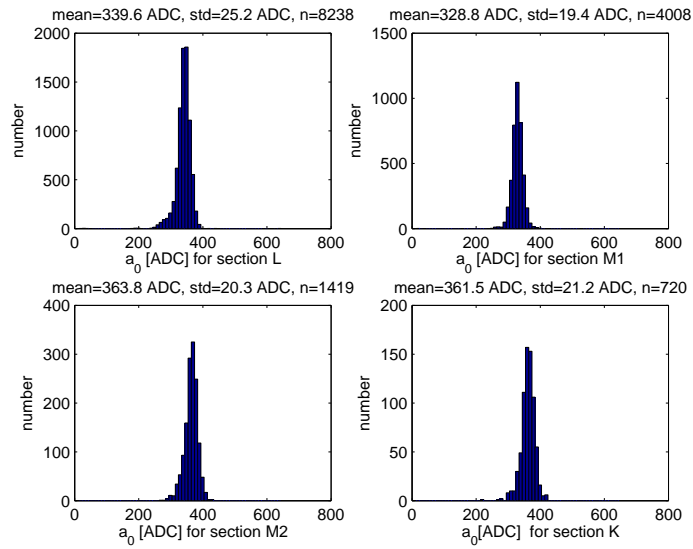


Figure 39: Histogram of fitparameter A_0 : cold, internal testpulses .

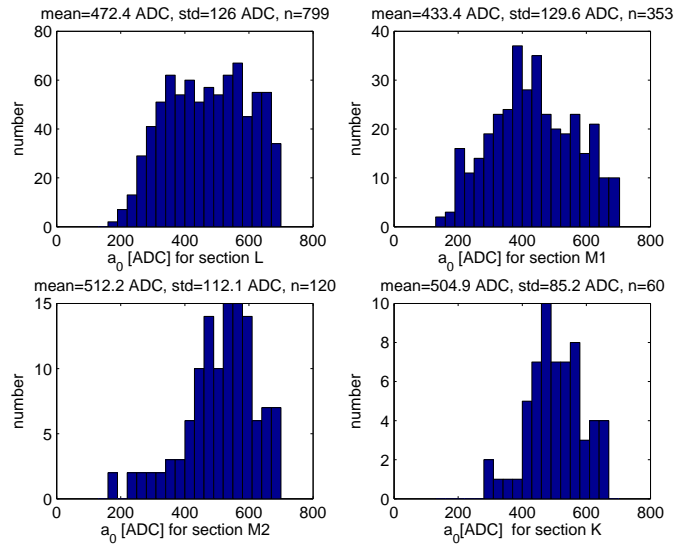


Figure 40: Histogram of fitparameter A_0 : warm, laserpulses .

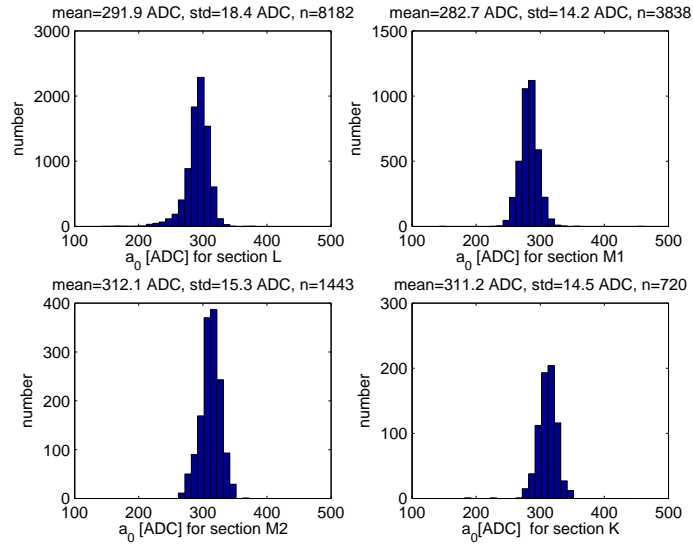


Figure 41: Histogram of fitparameter A_0 : warm, internal testpulses .

B Views of Data Tables

B.1 List of Views

match_leakage_cold	matching_mfulldepvolt_sensorpos_4_5
match_leakage_k_cold	matching_mfulldepvolt_sensorpos_4_5_6
match_leakage_k_warm	remainder_warm_median
match_leakage_l_cold	remainder_warm_values
match_leakage_l_warm	pulseshape_v
match_leakage_m_cold	real_hybrids
match_leakage_m_warm	real_beetles
match_leakage_warm	real_modules
match_leakage_warm	real_sensors
matching_L_M3_M2_K_fulldepvolt_mt	remainder_cold
matching_bad_channels	remainder_cold_median
matching_fulldepvolt_shift	remainder_cold_values
matching_mfulldepvolt_sensorpos_0_1_2_3	remainder_warm

Table 8: List of views created. View definitions are located in <http://lhcb/admin/phpgadmin/>, database: lhcb_tt, schema: public, folder: views

B.2 Definition of the View pulseshape_v

```
CREATE VIEW pulseshape_v AS SELECT
remainder_cold.module_serial, remainder_cold.module_id,
remainder_cold.module_type, remainder_cold.hybrid_id,
remainder_cold.hyb_type, remainder_cold.beetle_id,
beetles.position_on_hybrid,
count(remainder_cold.remainder) AS scans,
round(avg(remainder_cold.remainder::numeric), 2) AS average,
round(min(remainder_cold.remainder::numeric), 2) AS min,
round(max(remainder_cold.remainder::numeric), 2) AS max,
round(stddev(remainder_cold.remainder::numeric), 2) AS stddev

FROM remainder_cold

LEFT JOIN beetles ON beetles."beetleID" = remainder_cold.beetle_id

GROUP BY remainder_cold.beetle_id,
beetles.position_on_hybrid, remainder_cold.hybrid_id,
remainder_cold.hyb_type, remainder_cold.module_id,
remainder_cold.module_serial, remainder_cold.module_type

ORDER BY remainder_cold.module_serial, remainder_cold.hyb_type,
```

```
beetles.position_on_hybrid;
```

The command `CREATE VIEW viewname AS SELECT table.columnname` creates a new view "viewname" of existing tables. After the select statement follow all columns selected to appear in the new view. It has to be specified which table the columns are from. Therefore always `tablename.columnname AS newcolumnname` and the new columnname in the view is indicated. Aggregate Functions as calculating an average `avg(columnname)` can be applied to the data to generate new information about the existing data set. Creating a new relation in between of data from different tables `remainder_cold` and `beetles`, is done by linking the tables with a join condition:

```
table1 LEFT JOIN table2 ON table1.columnname=table2.columnname
```

The `GROUP BY` clause defines how the data gets grouped in the new view, i.e if there are ten remainder values measured on a Beetle there will be one line displayed in the new view containing the average, minimum, etc of these ten values. In above example, data gets grouped first by `beetle_id`, then by `hyb_type`,.... As grouping by `beetle_id` is the most strict way to group selected data by, the following group conditions like `hyb_type` do not have any effect on the data groups anymore, but must be named to satisfy PostgreSQL syntax. In general, aggregate functions are evaluated on data groups defined by the `GROUP` clause. With `ORDER BY` the sort mode of the table is defined. For further Information about PostgreSQL syntax visit <http://www.postgresql.org/docs/8.0/interactive/index.html>.