# A New Beam Monitor for the DESY Test Beam

## DESY Summer Students 2012 Project Report

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September 5, 2012

**Abstract**

A new setup for the measurement of the particle flux in the DESY Test Beam lines has been prepared for installation. A Linux-based application with a graphical user interface has been developed to control this measurement and to present its results in real time. This report describes motivations and framework of the development, application features and several tests of the program, as well as some guidelines for future improvements. It has been validated in various tests, that the application is well suited on-line beam monitor and also a tool for collecting long-time measurements.

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# Contents

# 1 Introduction

The DESY Test Beam is a facility for testing particle detectors prototypes. It provides 3 beam lines of electrons or positrons with energies from 1 to 6 GeV and with typical flux values around 1000 particles/cm$^2$/second [1]. To create the beams, a carbon fibre target is placed in DESY II accelerator beam pipe, producing bremsstrahlung photons. Those photons are then converted in copper or aluminium targets into electron-positron pairs, which are bent with a magnet, to select the desired particle type and energy. The beam is collimated using a set of collimators and enters the Test Beam area after passing the final lead collimator, where users can install their devices. Up to now, problems establishing the presence of the beam in the Test Beam area have been reported frequently by users. Due to lack of any measurement instrumentation between the final collimator and the user devices, it has not been possible to check the beam presence. As a solution to these problems, it has been decided to install a simple and reliable device, able to measure the particle flux right after the final collimator and to present it to users in the Test Beam control hut.

Purpose of this project was to develop an application providing a graphical user interface for this measurement.

# 2 Environment

## 2.1 Hardware

It has been decided to install particle detectors, namely scintillators with photomultiplier tubes (PMT), in the Test Beam area, which are going to be powered by TTi CPX400DP [2] or similar power supply and connected to the EUDET JRA1 Trigger Logic Unit (TLU) [3]. Both, the TTi and the TLU, were connected to a PC running the application remotely from the Test Beam control hut. The TLU was connected with the PC via USB port, while the TTi via serial (RS232) port.

## 2.2 Software

The application was dedicated to run on Linux-based systems. It was tested on Scientific Linux 5.5 and Ubuntu 11.10. It depends on the EUDAQ (`http://eudaq.hepforge.org/`) and ROOT (`http://root.cern.ch`) libraries. The EUDAQ libraries are used for communication with the TLU, while the ROOT libraries are base for GUI and timing structure.

# 3 Functionalities

The main feature of the application is showing on-line plots of particle flux in real time, as seen on Figure 1. Voltage and current on each channel of TTi power supply are

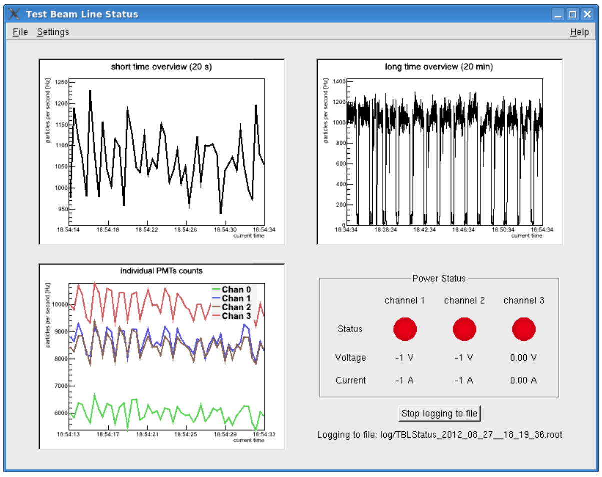


Figure 1: Screenshot of the main window, while running in the Test Beam.

also displayed in the main window. Additional features are: logging data to .root file, saving current plots to .pdf file, TLU settings, TTi settings, and advanced settings of application timing. All features has been described in details in the user manual [4].

# 4 Timing

The application is multi-threaded and based on asynchronous timers, implemented using the ROOT TTimer class. There are three independend timers, which are responsible for TLU readout, TTi readout and logging data to file. The graphical user interface (GUI) is updated and redrawn in the main loop, which is not based on timer. The main loop has a hard-coded sleep time of 40ms to prevent from too frequent refreshing on fast machines. This has been left to change in future (see section 6). On every readout of TLU and TTi data, the read values are stored in memory as TLU and TTi objects' attributes. These values can be accessed by GUI or logger objects whenever it is needed. On each TLU and TTi readout, their attributes are overwritten, which means that GUI and logger can always access only last read values.

# 5 Tests

The application has been tested in numerous ways and has proved being a good on-line monitor, as well as a tool for collecting long-time measurements data.

## 5.1 ELAB - background measurements

### 5.1.1 Experiment Setup

First tests were performed in the electronics laboratory - ELAB - using two and three scintillators. Scintillators were placed one on top of another and connected to the TLU channels 1, 2, and 3 in order from top to bottom. First short time tests were performed with a mask set to each channel separately. Afterwards long time tests were performed with an 1 AND 2 mask as well as with 1 AND 2 AND 3 mask.

### 5.1.2 Results

Outcome of testing each channel's coincidences with itself (e.g. counting channel 2 hits and coincidences with an AND mask set to channel 2 only) was far from expected. It turned out, that with these settings, the TLU generates random coincidences, while not always counting real hits. This can be seen on Figure 2 below. One would expect to see hits and triggers exactly in the same time, which means that on each green dot there should be a red dot and behind each red dot there should be a green dot. This is not the case, which can be a reason to question performance of the TLU. Nevertheless further tests have shown, that for multiple channel coincidences, the TLU does not show this behaviour.

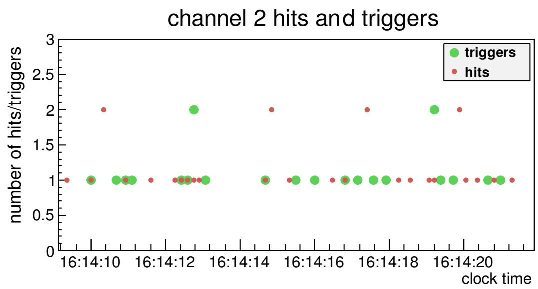


Figure 2: Hits and triggers in channel 2 only

A 51-minutes test using an 1 AND 2 coincidence mask has shown that the background caused by PMTs noise, TLU random triggers and cosmic rays is negligible. During the test only 57 particles were counted as coincidence, even though hit rates in each individual channel were much higher. Testing with an 1 AND 2 AND 3 mask gave even better results. In 97-minutes test only 13 particles were counted as coincidence.

The Table 1 below presents mean hit rates in each channel in Hz, calculated from the collected data, as well as the coincidence rate and the total number of counted particles. With these statistics, one can say, that all hit rates are statistically equal to zero. In the worst case, which is channel 2 in first test, it can be calculated, that with 95% confidence level, hit rate is lower than 5.5 Hz. This would mean a fake hit each 18 ms, which compared to 450 ns pulse-width of output signal in discriminator board of TLU, is more than sufficient. With this comparison, it is clear, that probability of fake coincidences between two channels is very low.

| channels | time [s] | chan 1 [Hz] | chan 2 [Hz] | chan 3 [Hz] | coinc. [Hz] | total |
|---|---|---|---|---|---|---|
| 1&2 | 3087 | 0.3±1.1 | 1.7±2.3 | - | 0.02±0.25 | 57 |
| 1&2&3 | 5851 | 1.2±2.1 | 0.9±1.8 | 0.4±1.2 | 0.002±0.090 | 13 |

Table 1: Results of tests without radiation source

## 5.2 ELAB - radiation source measurement

### 5.2.1 Experiment Setup

Further tests have been performed using a Ruthenium-106 radiation source. The experimental setup was the same as before, placing only the source above the scintillators.

### 5.2.2 Results

The results in Table 2 below show that indeed the background level is negligible in comparison to real particle flow. The hit rates in channel 1, closest to the source are 3-4 orders of magnitude higher than background level, while in channel 2 difference is 2-3 orders of magnitude. Similar factor applies to coincidence rate in two-channels test. The low hit rate in channel 3 and the coincidence rate in second test is due to the thickness of scintillators and low energy of particles. A large fraction of emmited electrons was not able to reach the third scintillator. Nevetheless it is clear, that with this experiment setup, one can reliably measure the number of particles in a beam.

| channels | time [s] | chan 1 [Hz] | chan 2 [Hz] | chan 3 [Hz] | coinc. [Hz] | total |
|---|---|---|---|---|---|---|
| 1&2 | 51.57 | 2466±97 | 795±54 | - | 82±18 | 4180 |
| 1&2&3 | 87.49 | 1568±81 | 1195±65 | 100±19 | 1.8±2.7 | 163 |

Table 2: Results of tests with Ruthenium-106 radiation source

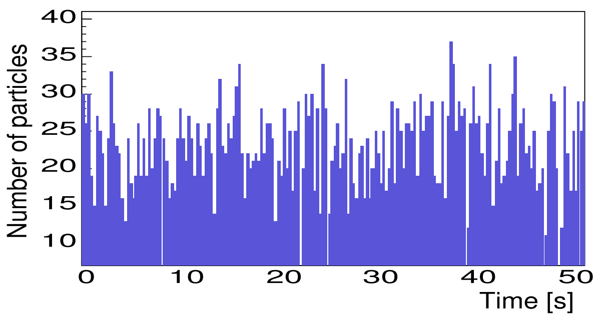


Figure 3: Particles counted in a test using the 1 AND 2 mask

## 5.3 Test Beam measurements

### 5.3.1 Experiment Setup

The test has been performed in the DESY Test Beam 21 area, using four scintillators already installed there. Due to lack of a TTi Power Supply in the area, the PMTs voltage was not monitored. A beam of 2 GeV positrons has been monitored for over 19 hours.

### 5.3.2 Results

The good long time performance of the application has been demonstrated in this test. With the collected data, the basic structure of the beam has been plotted (Figure on the right). Furthermore, a periodic structure on the minute scale has been shown. On Figure 5 it can be seen that each 80[a] seconds there is a drop in particle flux, which is caused by injection to PETRA III storage ring. Before each injection, the beam intensity is lowered to 115 Hz, then after 5 s the beam is totally extracted from DESY II to PETRA III for 7 s and finally after the next 3 s, the intensity is increased again. This can be also clearly seen on flux value distribution, Figure 6. When the period during the injections was cut out, it was calculated, that mean flux in Test Beam 21 in running mode during the test was equal to 1113 ± 97 Hz. Moreover, the background in this setup was checked, resulting in only 3 particles in 22-hours test. This gives signal to noise ratio at a remarkable level $3 \cdot 10^7$.

[a] All time values in this section are estimated from plots and were not calculated.

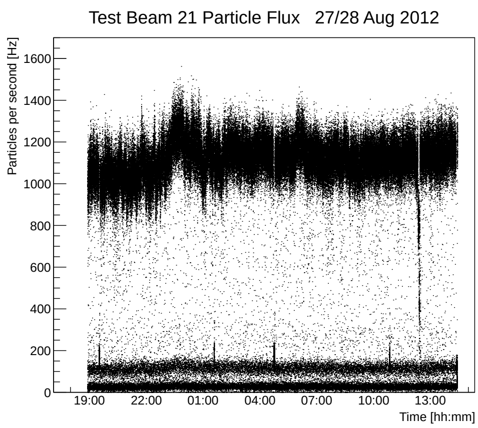


Figure 4: Overall structure of the particle flux in the Test Beam 21 area

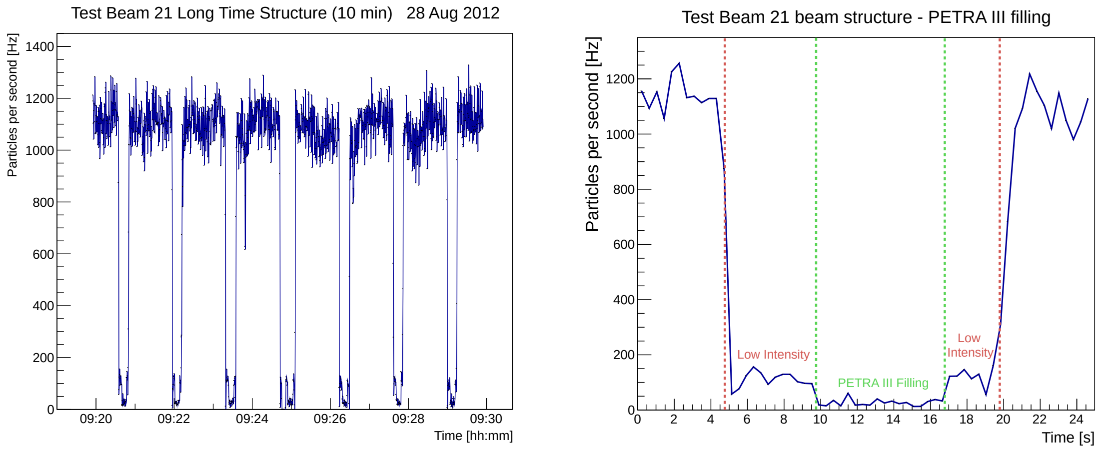


Figure 5: a) The beam structure in 10 minutes range with extraction to the PETRA III storage ring every 80 seconds. b) The structure of a flux drop in 25 seconds range. Three phases of the beam extraction has been marked.

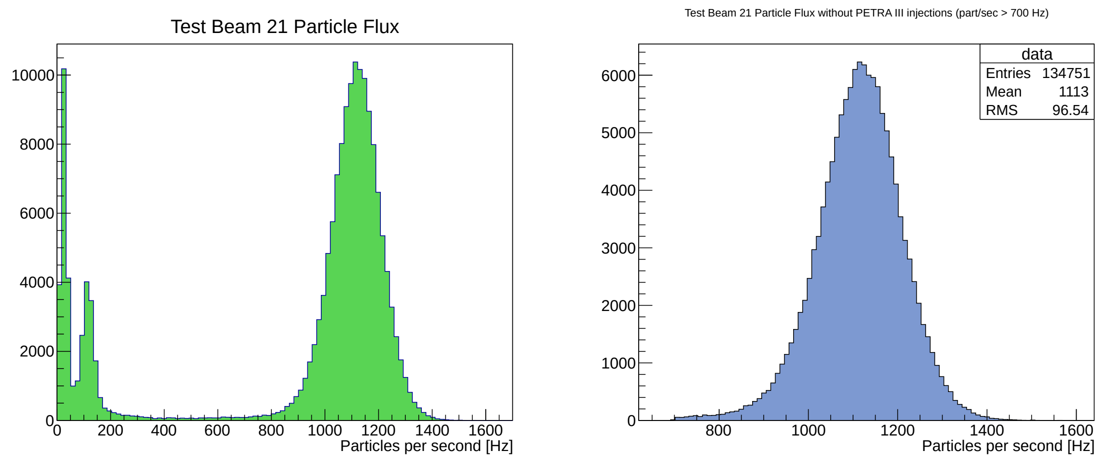


Figure 6: a) The Test Beam 21 particle flux distribution. The beam extraction phases and normal running mode can be distinguished. b) The same distribution with the beam extraction cut out.

## 5.4 Changing the position of the primary target

### 5.4.1 Experiment setup

Another test has been performed in Test Beam 21 area, using the same setup as before. The monitor program was run remotely from the DESY accelerators control room, where the position of the primary target (the carbon fibre in DESY II beam pipe) can be controlled. A series of measurements for a 12 mm range of target positions with 1 mm step has been taken in order to find the best position (resulting in the highest particle flux) and to identify the beam profile.

### 5.4.2 Results

In this test, the application has proven to be a very good on-line monitor. While changing the target position, changes of the particle flux in Test Beam 21 area were seen in real-time. Without any off-line data analysis, the best target position was easily found to be around -58mm (the step motor position controlled from the control room).

Off-line analysis of collected data has shown, how the particle flux had been changing in time, while moving the target (Figure 7). Also the mean flux value for different positions has been calculated from distributions shown on Figure 8a. Due to only a few-seconds samples, statistics are very low and uncertainties very high. Regardless of that fact, the mean values were used to plot the beam profile (Figure 8b), which turned out to fit very well a gaussian distribution. However, seven data points are not enough for a precise measurement of the beam profile.

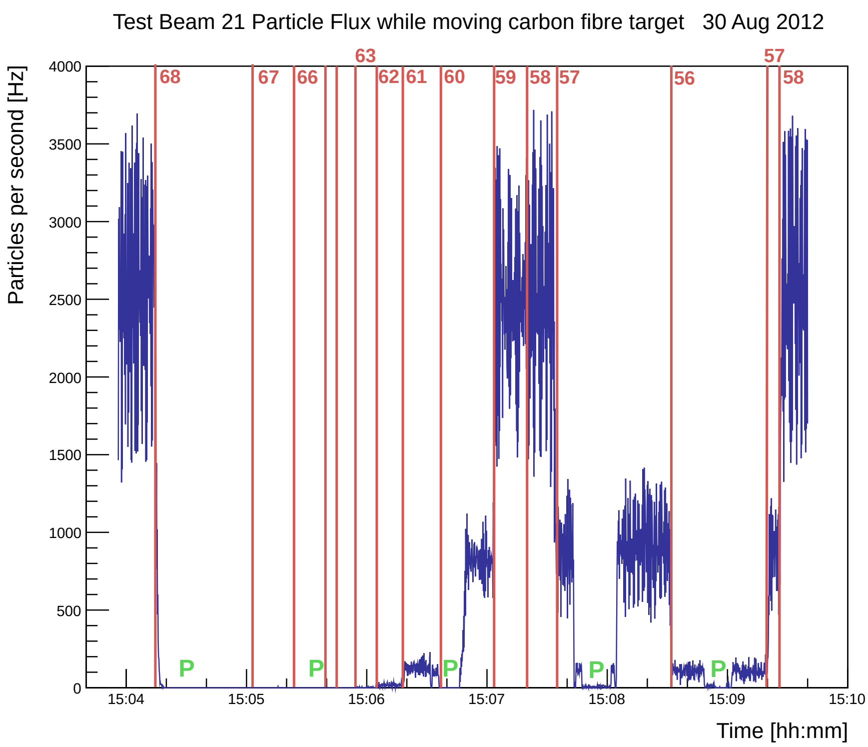


Figure 7: Test Beam 21 particle flux while changing primary target position. Different positions are marked with red lines and values in mm. PETRA III injections are also marked with green P (first two are estimated from last three).

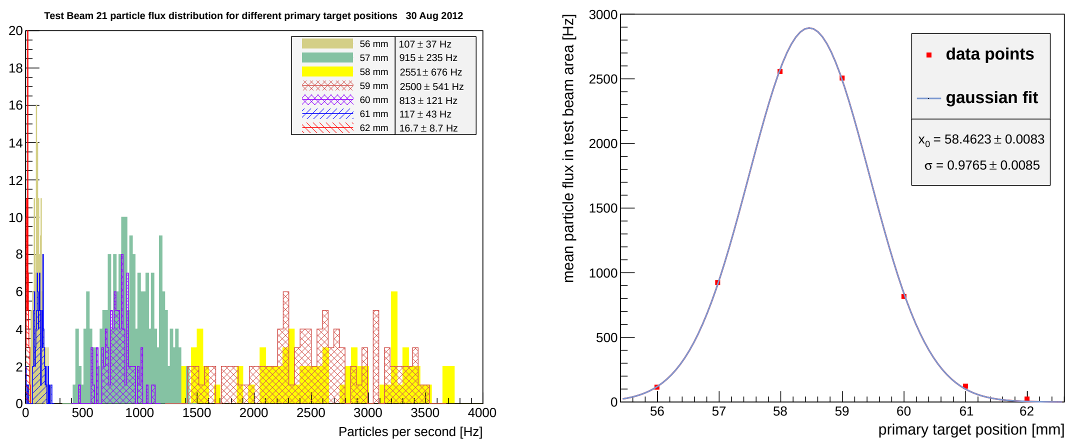


Figure 8: a) Test Beam 21 particle flux distribution for different primary target positions. b) Beam profile with fitted gaussian curve.

# 6 Guidelines for future changes

Due to finite time for this project, some minor changes and improvements could not have been made. Those are listed below.

- Enabling change of the main loop sleep time in advanced settings and/or defining this time dependently on CPU.
- Considering rewriting the GUI refreshing code from main loop to TTimer, leaving the main loop empty. The main loop would then only listen to Ctrl+C (interrupt) event, e.g. with 100 ms interval.
- Changing the simple autoscaling of short-time overview plot to a 'smart' autoscaling. This would have on purpose to prevent rapid changes of the Y axis range.
- Adding third channel in TTi settings, as well as implementing its display in power status box. Also optimal voltage and current values have to be defined and LED-like indicators changing needs to be implemented.
- Providing the planned hardware setup, including a 3-channel TTi power supply, to take full advantage of the application's features.

# 7 Conclusion

The primary purpose of this project was to make an application, which would be used as on-line beam monitor in the DESY Test Beam. The program written during this project has been tested in various setups and conditions, proving to fulfil this requirements very well. Moreover, it has been shown, that the application is also a valuable tool for collecting long-time data for further analysis. When all devices for planned measurement setup will be available, the application can be widely used by the Test Beam coordinators and can also be introduced to the Test Beam users. As the application has demonstrated to be a good on-line monitor while changing the primary target position, the access to the application from the DESY accelerators control room is planned.

# 8 Acknowledgement

I would like to express here my gratitude to my supervisor, Marcel Stanitzki, for being always helpful and remarkably patient in answering my numerous questions. I am also grateful to others, who helped me with this project, especially Igor Rubinskiy, Ulrich Koetz, Richard Peschke and Ingrid-Maria Gregor. I would also like to thank the organizers of the DESY Summer Student Programme in Hamburg, Olaf Behnke, Andrea Schrader and Doris Eckstein for creating perfect conditions for learning, working and enjoying the time spent in Hamburg. Next, I would like to thank people from DESY/Hamburg International Office for solving all the administration mysteries for me.

In addition, I want to thank all the people from DESY ATLAS Group for creating a nice and friendly working atmosphere. It was a great pleasure and a great life- and scientific experience to participate in this programme!

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