Energy measurement and calibration of the DESY test beam in beam line 21 using the DATURA telescope

Torben Lange, University of Hamburg, Germany

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Abstract

The test beam areas at the DESY site in Hamburg are providing electron and positron beams with up to 6 GeV energy. They are used for testing and calibrating new detector components from future particle experiments around the world. My task as a summer student was to performe an energy calibration and energy-resolution study for the beam of test beam area 21 with the DATURA telescope. Therefore the leptons were deflected in a dipole field. The energy was determined from the deflection angle measured by DATURA using EUDAQ and EUTelescope. In difference to previous measurements, this study provides also a single particle energy determination. This report gives an overview of the used setup and hardware, the necessary software and the different steps of my analysis. As well as an comparison between this study and a previous study from Paul Schütze.

Contents

1 Introduction

The test beam areas at DESY provide important tools for the detector development of groups around the world, including groups for recent particle experiments such as ATLAS or CMS.
The idea behind the test beam areas is to deliver a particle beam with well known properties, that can be used for testing and calibrating of new hardware components. One of this properties is the beam energy. Since a precise knowledge of the energy is crucial for some of the experiments, that for example are used to test and calibrate calorimetric devices, a good calibration of the DESY test beam is necessary. A measurement in 2013 of the former summer student Paul Schütze has shown a deviation between the expected and measured energy of the beam. My task as a DESY summer student was to repeat the energy measurement with a different setup that shall increase the energy resolution and check if the problems of 2013 were fixed. In the following chapters the setup of the DESY test beam facility is described as well as the hardware and software components used in this analysis.

1.1 Desy II

DESY II is a particle accelerator for electrons up to 6 GeV. It is used as pre accelerator for PETRA III and the oldest of the running accelerators at DESY. Beside that DESY II is also used for the creation of the of the test beams.

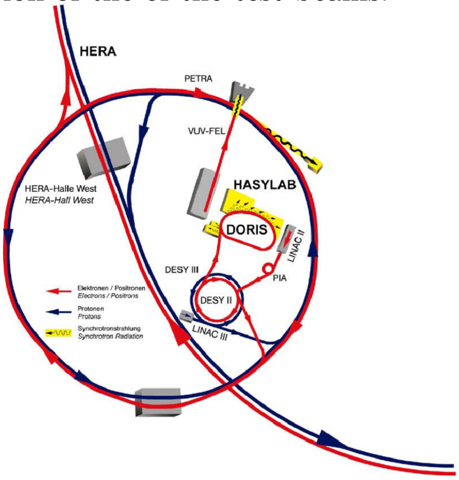


Figure 1: The different accelerators at the DESY site in Hamburg including DESY II.

1.2 DESY test beam

The setup for the production of the test beam can be seen in figure (3) and (4).
To produce a electron or positron beam for the three test beam areas at DESY, a carbon fiber target is moved into the electron beam of DESY II. Scattering of the electrons on this target create bremsstrahlung. Since photons are neutral the created photon beam is not bend by the magnets in DESY II and leaves the circular accelerator.

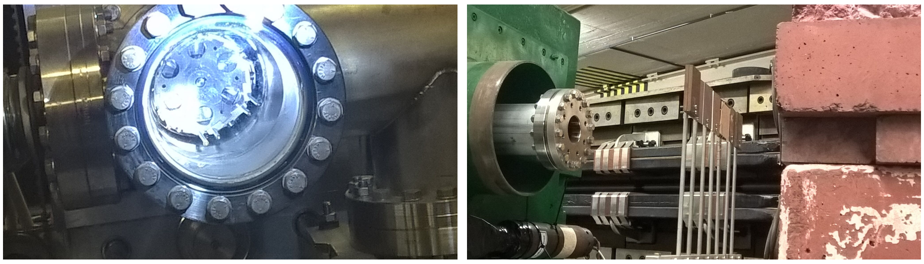


Figure 2: The carbon-fiber target in the DESY II beam pipe (left) and the converter targets (right)

A metal plate is then used to convert the beam of bremsstrahlung's photons into electron and positron pairs. After leaving the converter target the charged particles are deflected in a magnet to separate them by their charge and their energy. Behind the magnet a collimator with a sizable opening is placed, so that only particles within a certain energy window and the correct charge can pass. Since the position of the collimator is fixed, the charge and energy of the test beam particles depend on the current in the collimator magnet. Before the beam enters the test beam area where the experimental setups are placed it has to pass a shutter that is closed when the beam is not used. In the area itself a second exchangeable collimator shrinks the beam on the required beam size.

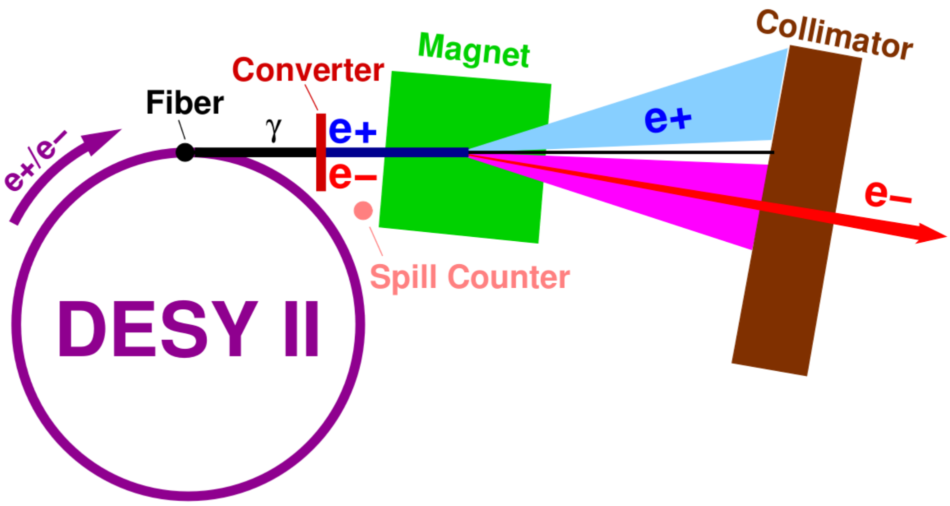


Figure 3: The setup for test beam production (scheme)

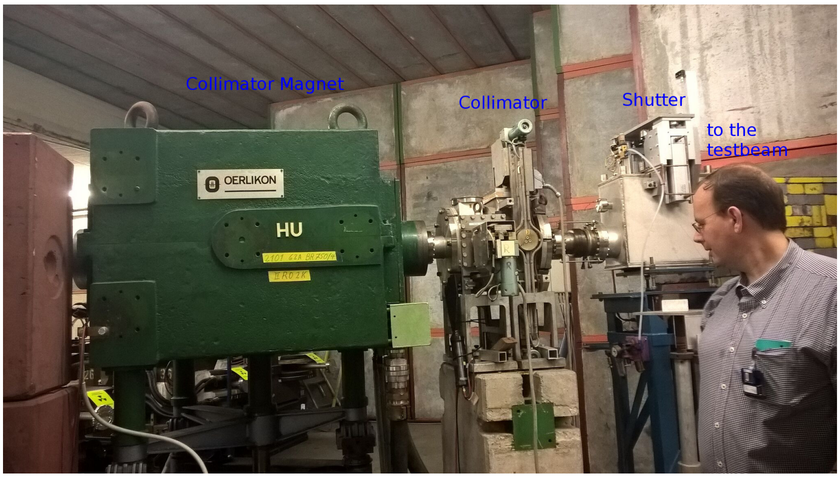


Figure 4: A foto of the setup for test beam production with the DESY test beam coordinator Marcel Stanitzki on the right side

1.3 DATURA telescope

Additionally to the test beam itself, two of the test beam areas also provide MIMOSA 26 pixel telescopes like the DATURA telescope used in test beam area 21. They consist of 6 Planes with MIMOSA 26 sensors. The sensors have a thickness of 50 μm and consist of 1152x576 pixels with 18.4 μm x 18.4 μm size. Four scintillator tubes (two on each side of the array) are used for the event triggering. The telescope can be used to determine the track of the charged leptons up to a resolution of $(3.2 \pm 0.09)\mu m$ (average) and $(1.83 \pm 0.03)\mu m$ (center) [1]. The telescope is normally used to test and calibrate other tracking devices. Therefore the device under test (DUT) is placed in the middle of the telescope (three planes before and three planes after the DUT).

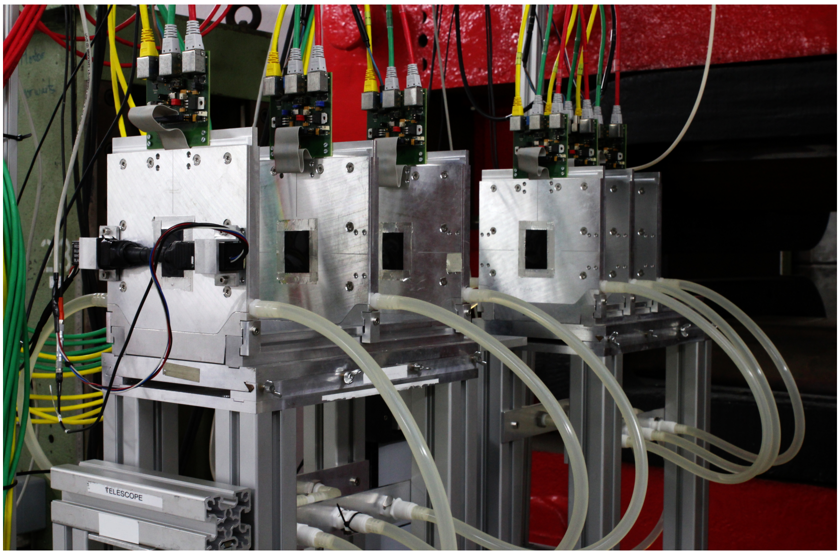


Figure 5: The DATURA telescope

1.4 EUDAQ and EUTelescope

The data acquisition for the six pixel sensors and the DUT is done by using the EUDAQ framework. It configurates the hardware and allows the user to access the data from several different producers, for example the different pixel sensors, the Trigger Logic Unit (TLU) or the DUT. The framework combines the single data streams and writes them together in one file that can be accessed for example by EUTelescope for the data analysis.[2]

The analysis presented in this report is done with the help of the EUTelescope framework. EUTelescope analyses the RAW data of the pixel sensors and translates it into higher level objects like particle tracks going through the telescope. This process is modular and consists of several different steps. The basic steps for this analysis are described in the following.

First the binary RAW data is converted into another file format, the so called LCIO data format. After that EUTelescope can search for clusters of pixels that fired at the same time. Some pixels fire nearly every time even without signal. EUTelescope marks those "noisy" or "hot" pixels. In the next step all clusters that do not contain hot pixels are translated into hits. That means that EUTelescope calculates the center of the cluster on the MIMOSA sensor and then translates this position into a position in the lab frame. For that EUTelescope uses a gear file that contains the positions of the different pixel planes relative to each other. Since the positions in the gear file are typically measured by hand, they are not precise enough to receive the μm resolution mentioned above. To improve this EUTelescope does several alignment steps to correct the position information of the gear file. For the alignment EUTelescope tries to combine the hits in the different planes into tracks and minimize the overall differences between the tracks and the hits by correcting the positions of the planes. This alignment is done in an iterative way since EUTelescope should find more tracks when the alignment gets better. For this analysis a pre-alignment and two additional alignment steps were used.

1.5 Setup

A sketch of the used setup can be seen in figure (6). Test beam area 21 contains a dipole magnet ("big red magnet") with a field strength with up to 1.4 T. The basic idea was to deflect the beam entering the area through the second collimator and then measure the deflection angle with the help of the DATURA telescope to determine the energy. This was already done before in 2013 by Paul Schütze. [3] The telescope was placed behind the big red magnet to measure the outgoing angle of the deflected lepton relative to the original beam axis. The problem with this setup is that only the angle between the beam axis and the particle direction after the magnet can be maesured. Since the incoming particles have a certain spread in their direction, this angle may differ from the deflection angle. Without knowing the incoming angle of the particle before entering the magnet, only the average deflection angle is measured correctly. Therefore the telescope was splittetd in two triplets of three planes each, to get a setup that allows an energy measurement for every single particle by measuring the particle direction before and after the magnet. The single particle energy measurement is needed to get a better energy resolution and also makes it possible to study beam properties like the energy spread of the beam.

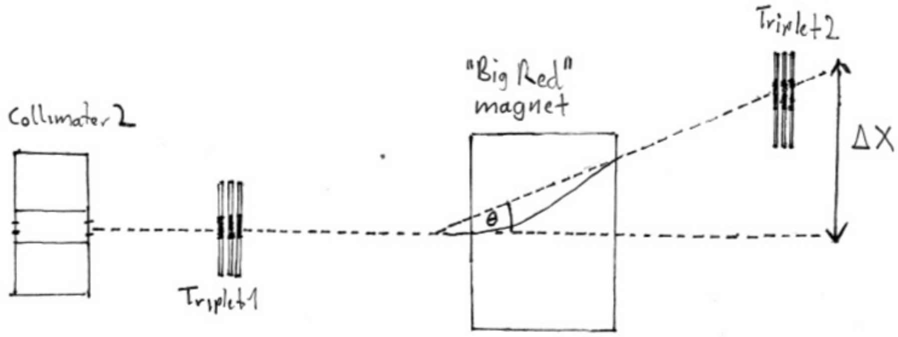


Figure 6: The setup for the energy measurement

The energy resolution of this kind of setup is mainly limited by the resolution of the angular measurement. Between the first triplet and the second triplet the particles have to cross ~ 3 m of air. The multiple scattering in this air is the main contribution to the angular resolution. One possibility to reduce this effect is to use a large magnetic field to have a huge deflection angle even for GeV particles. Using the maximum available field of about 1.4 T the deflection angle goes up to 0.45 rad. This leads to a deviation of the beam Δx from the original axis of 60-80 cm. Therefore the second triplet has to be movable so that the beam still hits the sensor even for large deflection angles, since the pixel sensors are only 2 cm wide. To make this possible the second telescope triplet was placed on a PI-Stage that allows a maximum Δx of 20 cm and the PI stage was placed on another less precise stage that can be moved in ranges of up to ~ 1 m.

As mentioned in chapter 1.4 EUTelescope has to align the different planes to interpretate the pixel hits in the lab frame correctly. Since the alignment procedure is only possible for straight tracks, the alignment information of additional alignment runs without a field of the big red magnet were used. But the alignment of those zero measurements is only valid for the runs with magnetic field if the planes are not moved relative to the position in the zero measurement. To solve this problem there are two possibilities: either correct the alignment information for the runs with the magnetic field for the movement of the stages and than make a track fit for determining the two angles what requires a high precision in the steering of the stages, or just determine the angles using the respective triplet, without making a track fit through all six planes. The second option is possible if the relative positions of the planes to the other planes in the triplet and the angle between the triplet and the original beam axis doesn't change while moving the stage. To have the possibility of trying both in the analysis, three different setups were done:

1. A setup with low magnetic fields ($\frac{I_B}{E} < 30\frac{\text{A}}{\text{GeV}}$), in wich the beam stays inside the sensors for all energies even without moving the second triplet.
2. A second setup with medium magnetic fields ($\frac{I_B}{E} < 350\frac{\text{A}}{\text{GeV}}$), in wich only the precise PI stage was used for moving the second triplet.
3. A third setup with the large magnetic fields ($I_B = 1400\ A$ $(2 - 6$ GeV); $I_B =$ 700 A (1 GeV)), in wich both stages were used to move the second triplet.

A logbook with all the taken measurements can be found in the appendix (chapter 5). In the end the second option was used for the analysis, since a complete track fit including the position correction would be much more difficult.

2 Analysis

2.1 Angle determination

The goal of this analysis is to determine the beam energy for several current settings of the collimator magnet to check if the energy calibration is correct. For that the deflection angle of the particles crossing the setup described in chapter (1.5) has to be determined. If the z axis is pointing in the direction of the original beam axis without magnetic field and the leptons are deflected in x direction, the ingoing and outgoing angle are simply given by: $\theta_{In/Out} = \arctan \frac{\Delta x}{\Delta z}$ with Δz the length of the 1st/2nd triplet and Δx the difference in the x coordinate between the first and the third plane of the 1st/2nd triplet. The deflection angle is then given by the difference of ingoing and outgoing angle. The alignment of the planes is never perfect, so that the mean θ_{in} and θ_{out} is not exactly zero, therefore the angles are also measured in the runs with magnetic field are corrected by the mean θ_{in} and θ_{out} of the zero measurements.

2.2 Energy determination with Boris method

Now the deflection angle has to be translated to a particle energy. Therefore the deflection angle of the particles in the magnetic field is simulated for different particle energies using a numerical simulation. The used tool is based on the work in [3]. It uses the so called boris method. This is an algorithm invented in 1970 to describe the passage of charged particles through a magnetic field in a proper way, using a numerical simulation. It is needed since a simple discretization of the lorentz force $\frac{\Delta \vec{p}}{\Delta t} = m \cdot \frac{\Delta \vec{v}}{\Delta t} = q \cdot \vec{v} \times \vec{B}(\vec{x})$ leads to an energy gain of the simulated particle by numerical imprecision[5]. The algorithm used here is given by:

$$\vec{x}^{n+1} = \vec{x}^{n} + \vec{v}^{n+1}\Delta t$$

$$\vec{v}^{n+1} = \vec{v}^{n} + \left(\vec{v}^{n} + \vec{v}^{n} \times \vec{t}\right) \times \vec{s}$$

$$\vec{t} = \frac{q\Delta t}{2\gamma m}\vec{B}(\vec{x}) \qquad \vec{s} = \frac{2\vec{t}}{1+|\vec{t}|^2}$$

The tool uses the energy, incoming angle and the magnetic field inside the big red magnet given by a interpolation of an field map for the used current I_B to simulate the outgoing angle. To determine the particle energies the simulation tool determines the outgoing angle for several different energies until the simulated and measured angle differ less than 0.00001 rad.

3 Results

3.1 Results of the energy measurement

The energy was measured for different settings of the current in the collimator magnet corresponding to expected energies of $1, 2, 3, 4, 5$ *and* 5.6 GeV in setup 1 and 2 and $1, 2, 3, 4, 5$ GeV in Setup 3. The resulting energy distributions for setup 1 can be seen in figure(7). To better compare them to each other the histograms are normalized to theire number of entries.

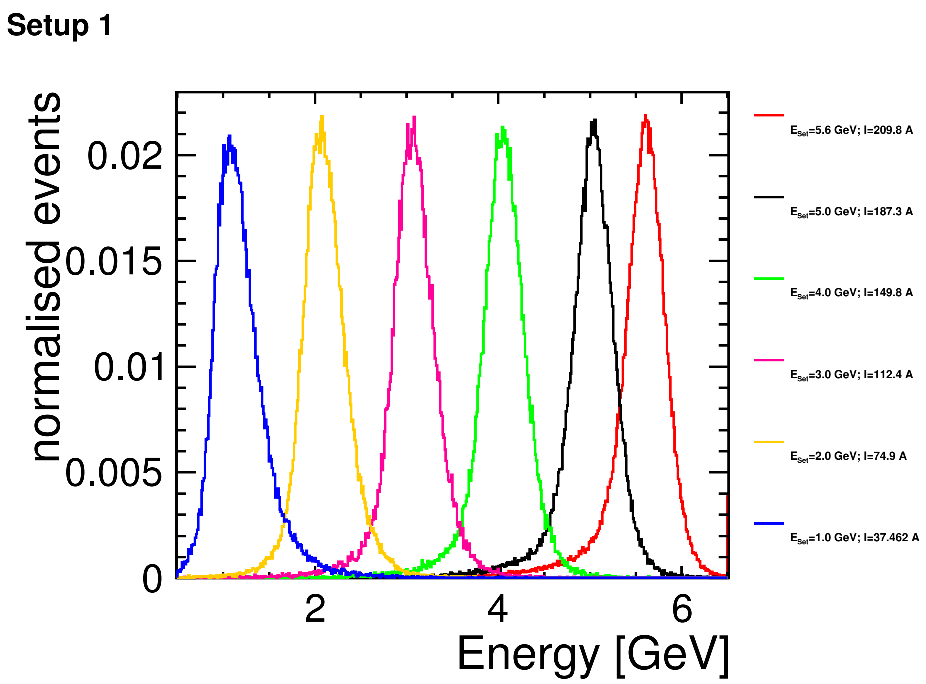


Figure 7: The energy distributes for the different energies set for setup 1

As can be seen, the measured energies are distributed in a gaussian like distribution arround the expected mean values. In addition, the distributions corresponding to $1, 5$ and 5.6 GeV show a tale to high/low energies. The beam does not have one single energy but consists out of particles within a certain energy range. This energy spread rises two effects that could explain this asymmetry: Since the particles are deflected in the field of the big red magnet, they are sorted due to their energy on the x axis, so that the lateral distribution directly corresponds to the energy distribution inside the beam. In setup 1 the particles are deflected within the width of the sensor in x direction without moving the second triplet. Therefore the beam moves from one side of the sensor to the other while increasing the energy, cutting some part of the beam on the edges for the highest and the lowest energy and therefore cutting away some part of the energy distribution witch leads to an asymmetry in the energy distribution.

Another effect is the energy dependence of the particle rate. The rate of particles created at the converter target varies with the energy of the particle, as can be seen in figure (8).

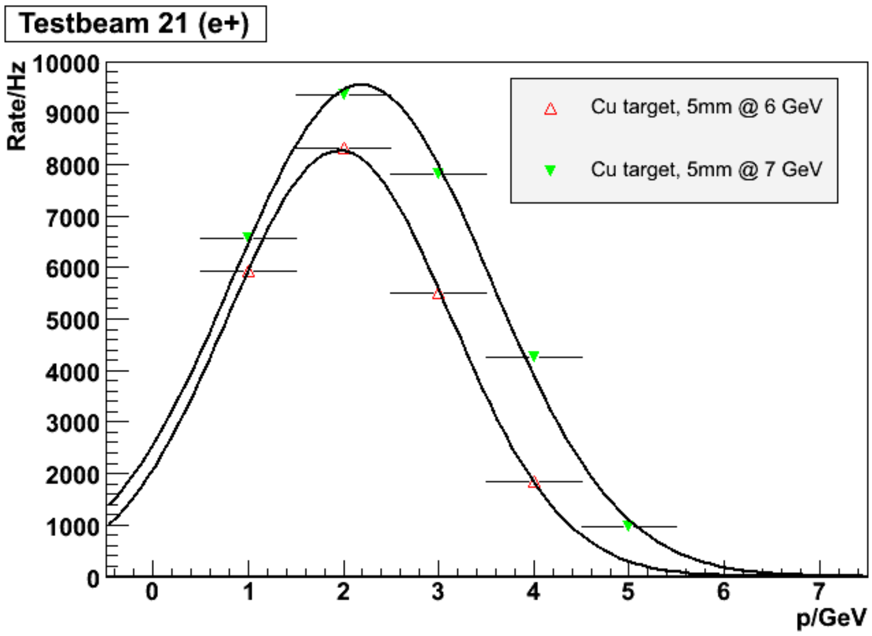


Figure 8: The particle rate for different converter targets at the test beam as function of the particle energy.

It can be seen that for energy windows at lower energies particles with a higher energy are more probable and for high energies vice versa, what would also contribute to a tail to high/low energies. Plots for the distributions of the other two setups can be found in the appendix (see chapter 5).

3.2 Comparison to previous results and energy calibration

For the energy calibration it is sufficient to concentrate on the gaussian parts of the energy distribution. To compare the measured energies with the expected values, the central part of the different energy distributions where fitted with a gaussian to determine the mean energy. The result for setup 2 can be seen in figure (9).

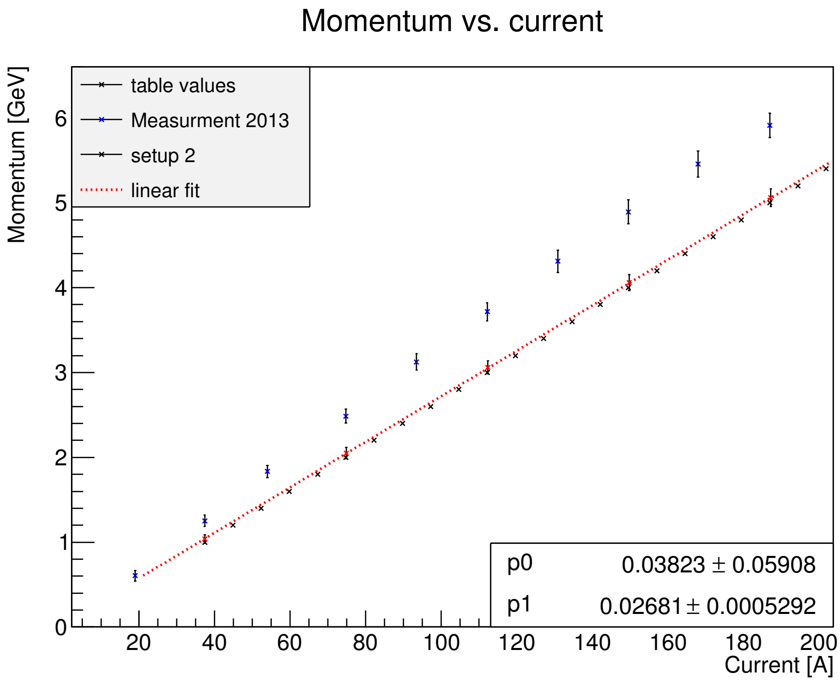


Figure 9: The mean measured energies for setup 2 compared with the expected values and the measurement of 2013 by Paul Schütze

The current calibration is given by an lookup table that corresponds different magnet settings for the collimator magnet to beam energies. As can be seen by looking at the linear fit the measured energies grow linear with the current at the collimator magnet and fit with the expected values of the calibration table within 1 σ. The displayed error is given by quadratical sum of the width of the energy distribution and an systematical error respecting an uncertainty on the used field maps.

3.3 Determination of the energy spread

Beside the energy itself another interesting beam property for potential users is the energy spread mentioned in chapter (3.1). The total width of the measured energy distributions consists of this energy spread and the experimental energy resolution of our energy measurement. Therefore the energy resolution needs to be known to determine the energy spread. The energy depends on the measured angles and the B field of the big red magnet. Since fluctuations in the magnet current are negligible, the main distribution to the experimental resolution is given by the angular resolution. To get these resolution distributions of the difference angle $\Delta\theta = \theta_{out} - \theta_{in}$ from the zero measurements where fitted with a gaussian. The angular resolution is then approximately given by its width.

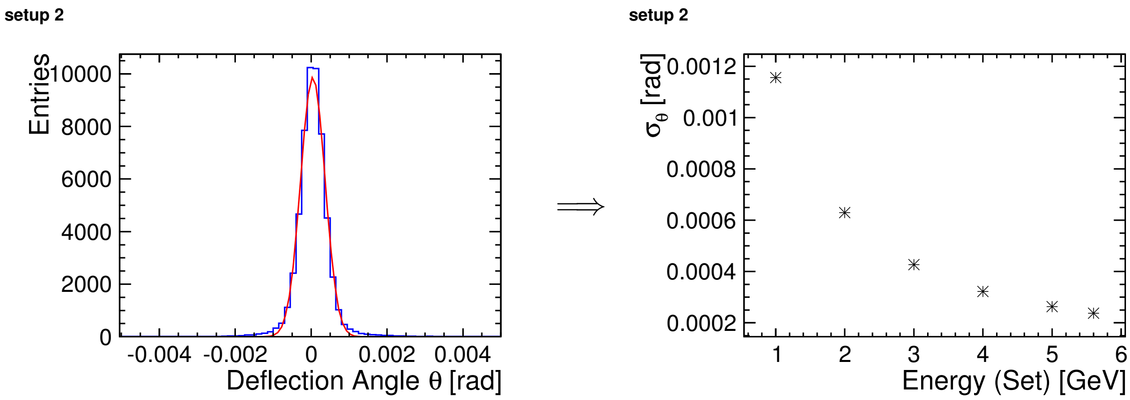


Figure 10: The difference angle in the zero measurements are fitted e.g for 3 GeV (left) to determine the angular resolution (right) for all used energies.

Assuming that the angular resolution is approximately constant over the width of the measured energy distributions, the angular resolution can be translated in an energy resolution by determining by wich value the mean of the energy distributions is shifted when θ_{out} is variated by 1σ using the tool mentioned in chapter 2.2. This assumption is not completely valid since the angular resolution is energy dependent as can be seen in figure (10), but it is good enought for a first approximation to the energy spread. The resulting relative uncertainty on the energy can be seen in figure (11).

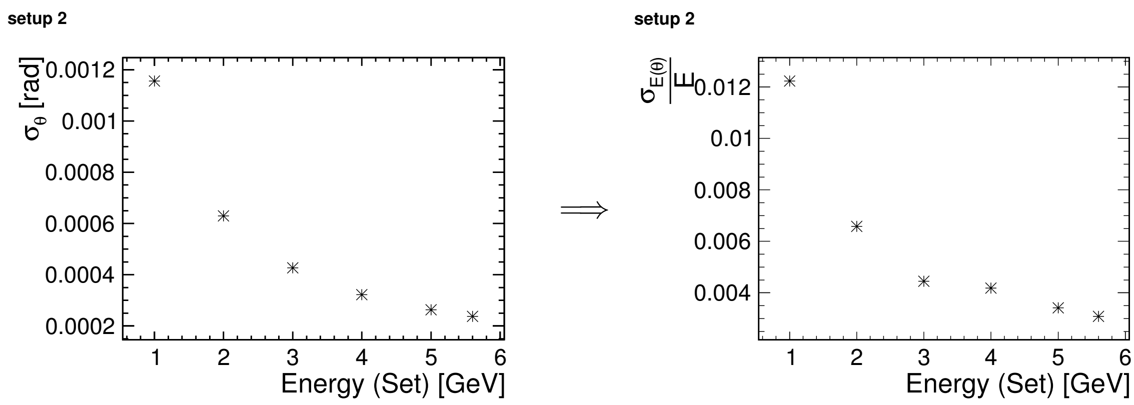


Figure 11: The angular resolution (left) was translated into an energy resolution (right).

If the true energy distribution of the beam without experimental errors is assumed to have nearly gaussian shape, the width of the measured energy distribution can be approximated by: $\sigma = \sqrt{\sigma_{E(\theta)}^2 + (\Delta E)^2}$ with ΔE the width of the true energy distribution (the energy spread) and $\sigma_{E(\theta)}$ the experimental energy resolution. Resolving this equation for σ, ΔE is given by: $\Delta E = \sqrt{\sigma^2 - \sigma_{E(\theta)}^2}$. The result for setup 2 can be seen in figure (12).

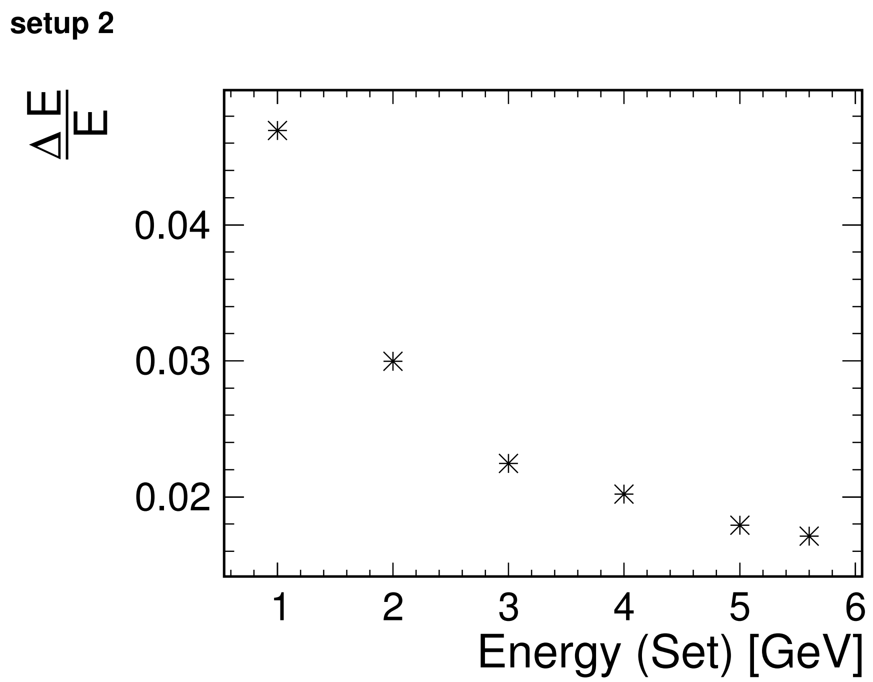


Figure 12: Relative energy spread for different energies in setup 2.

The energy spread is energy dependent and approximately between 2 and 5% (setup 2). This value should be understood only as an approximation to the true energy spread.

For a full analysis the shape of the energy distribution should be simulated. It should also be mentioned that the determined energy spread is different for the three setups. The values coincide for high energies but differ for low energies. This is a result of the beam spread that gets bigger for large magnetic fields. For 1 and 2 GeV the beam spread is bigger than the sensor so that parts of the beam get cutted away at the edge of the sensor. This leads to a smaller energy spread. Since this effect depends on the magnetic field, the measured spread is smaller at low energies for the setups with higher magnetic field.

4 Conclusion and further tasks

In this project the current energy calibration of test beam area 21 at DESY was verified. The measured energies coincide well in an 1 σ band arround the expected values. Further the energy spread was determined to be approximately between $2 - 5\%$.

A further task would be to determine shape and width of the beam energy distribution using a monte carlo simulation. This could also show if the tales in the measured energy distribution are interpreted correctly. Besides that this analysis only peaked into the measured data. With the remaining data the dependence of the energy spread on the used collimator width could be studied as well as the dependence of the experimental resolution on the used magnetic field of the big red magnet.

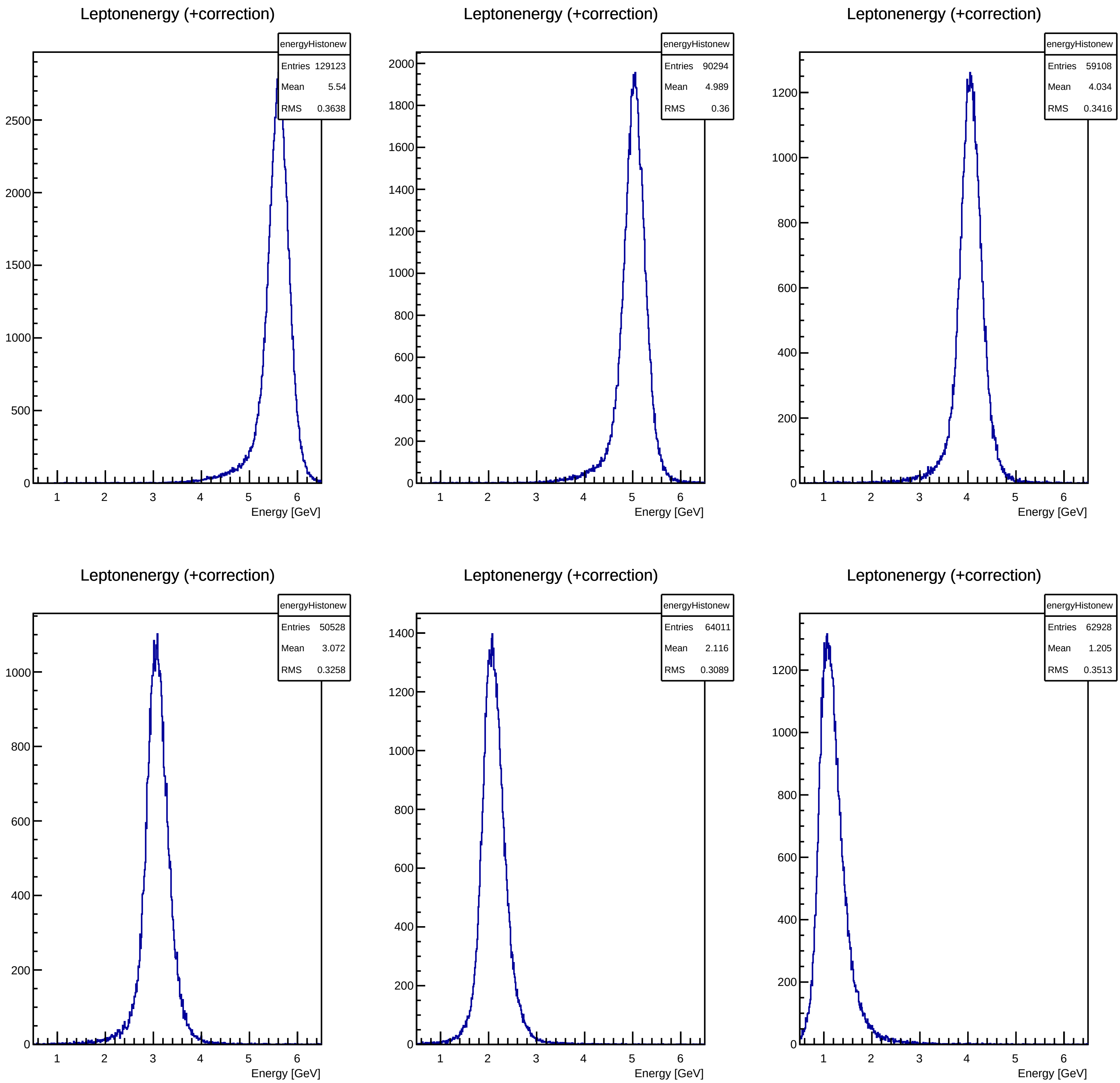
5 Appendix

5.1 Logbook

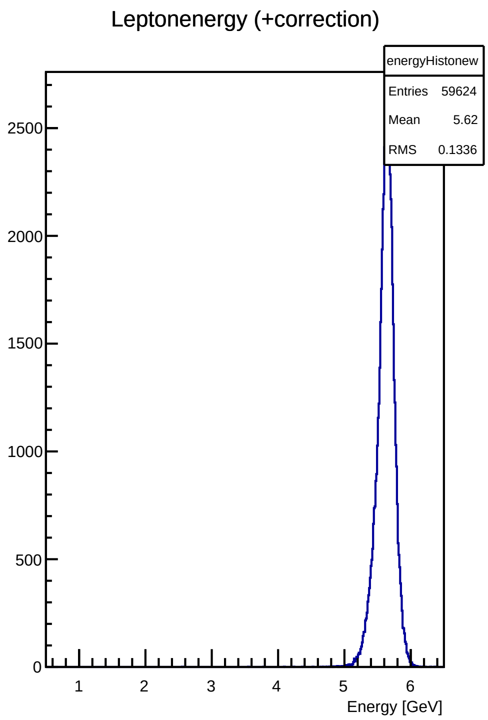
				General Log book																			
			Threshold	Collimator		zplane					PI Stage	Green Stage		Comments	Setup								
Run Number	Trigger (kHz)	Events	Telescope	No. 3 (up, east, down, west)	Lead Block	zp1 [cm]	zp2 [cm]	Energy (GeV)	Magnetic Amps (A)	zp1-zp4 [m]	mum-stage pos	x-pos	y-pos			Date	time start	time end	delta t		comments		
522	0,660999	202161	5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	1	0	2,98	0	559,5	50,2			3. August 2016	15:50:17	15:55:30	00:05:13		Converter Target: Cu 5 mm		1
521	1,01718	203153	5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	2	0	2,98	0	559,5	50,2			3. August 2016	15:45:19	15:48:45	00:03:26		Mimosa Temperature: 18 Celsius		1
520	0,967473	200742	5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	3	0	2,98	0	559,5	50,2	zero measurmen/allignmen		3. August 2016	15:40:39	15:44:14	00:03:35				1
519	0,7087	205008	5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	4	0	2,98	0	559,5	50,2			3. August 2016	15:34:50	15:39:46	00:04:56				1
518	0,382	201567	5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	5	0	2,98	0	559,5	50,2			3. August 2016	15:25:01	15:33:51	00:08:50	00:26:00			1
517	0,125	210418	5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	5,6	0	2,98	0	559,5	50,2			3. August 2016	14:48:41	15:21:53	00:33:12				1
530	0,582	202351	5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	1	25	2,98	0	559,5	50,2			3. August 2016	17:24:26	17:30:20	00:05:54				1
529	0,79124	254558	5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	2	50	2,98	0	559,5	50,2			3. August 2016	17:16:49	17:22:17	00:05:28				1
527	0,719021	202053	5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	3	75	2,98	0	559,5	50,2			3. August 2016	17:04:32	17:09:20	00:04:48				1
526	0,532324	200948	5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	4	100	2,98	0	559,5	50,2	Energy ramp		3. August 2016	16:55:29	17:01:53	00:06:24				1
525	0,269533	201816	5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	5	125	2,98	0	559,5	50,2			3. August 2016	16:37:45	16:50:20	00:12:35				1
524	0,103246	200283	5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	5,6	140	2,98	0	559,5	50,2			3. August 2016	16:04:10	16:36:36	00:32:26				1
531	1,07425	209105	5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	2	10	2,98	0	559,5	50,2			3. August 2016	17:35:45	17:39:06	00:03:21				1
532	1,0876	202798	5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	2	20	2,98	0	559,5	50,2			3. August 2016	17:41:14	17:44:22	00:03:08				1
533	1,04139	204572	5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	2	30	2,98	0	559,5	50,2			3. August 2016	17:47:03	17:50:33	00:03:30				1
534	0,936364	202190	5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	2	40	2,98	0	559,5	50,2	ramp magnet		3. August 2016	17:51:25	17:55:07	00:03:42				1
535	0,636338	206938	5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	2	50	2,98	0	559,5	50,2			3. August 2016	17:56:41	18:02:13	00:05:32				1
536	0,576936	201196	5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	2	60	2,98	0	559,5	50,2			3. August 2016	18:03:21	18:09:21	00:06:00	02:32:00	end day 1		1
@ run 519			5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	4	0	2,98	0	559,5	50,2						0				0
@ run 526			5	+3.2; +3.3; -3.2; -3.0	8x8	15,2	12,7	4	100	2,98	0	559,5	50,2		Setup 1: Mimosa				0				0
538	0,267254	200391	5	+3.2; +1,4; -3.2; -1,5	8x8	15,2	12,7	4	0	2,98	0	559,5	50,2			4. August 2016	09:44:17	09:57:01	00:12:44		comparing run 537 and 538: noticed a significant smaller rate for B field on-> low energy halo? or injecktion?		1
537	0,16954	200289	5	+3.2; +1,4; -3.2; -1,5	8x8	15,2	12,7	4	100	2,98	0	559,5	50,2			4. August 2016	09:23:14	09:43:03	00:19:49				1
539	0,840543	207716	5	+3.2; +5; -3.2; -5.1	8x8	15,2	12,7	4	0	2,98	0	559,5	50,2			4. August 2016	10:02:12	10:06:26	00:04:14				1
540	0,715483	203234	5	+3.2; +5; -3.2; -5.1	8x8	15,2	12,7	4	100	2,98	0	559,5	50,2			4. August 2016	10:08:16	10:13:14	00:04:58				1
542	1,44778	201199	5	+3.2; +9.8; -3.2; -10.2	8x8	15,2	12,7	4	0	2,98	0	559,5	50,2			4. August 2016	10:18:59	10:21:32	00:02:33				1
541	1,43375	208096	5	+3.2; +9.8; -3.2; -10.2	8x8	15,2	12,7	4	100	2,98	0	559,5	50,2			4. August 2016	10:15:23	10:18:02	00:02:39				1
543	1,59678	212596	5	+3.2; +18,4; -3.2; -17.7	8x8	15,2	12,7	4	0	2,98	0	559,5	50,2			4. August 2016	10:24:42	10:27:08	00:02:26				1
544	1,67021	219784	5	+3.2; +18,4; -3.2; -17.7	8x8	15,2	12,7	4	100	2,98	0	559,5	50,2	Collimator run		4. August 2016	10:28:10	10:30:29	00:02:19				1
549	0,733097	200613	5	+3.2; +3.1; -3.2; -3.1	20x20	15,2	12,7	4	0	2,98	0	559,5	50,2			4. August 2016	11:01:19	11:06:07	00:04:48				1
550	0,281864	201672	5	+3.2; +3.1; -3.2; -3.1	20x20	15,2	12,7	4	100	2,98	0	559,5	50,2			4. August 2016	11:07:12	11:19:14	00:12:02				1
548	1,62609	201653	5	+3.2; +9,6; -3.2; -10.3	20x20	15,2	12,7	4	0	2,98	0	559,5	50,2			4. August 2016	10:55:57	10:58:15	00:02:18				1
547	1,68427	228455	5	+3.2; +9,6; -3.2; -10.3	20x20	15,2	12,7	4	100	2,98	0	559,5	50,2			4. August 2016	10:51:26	10:53:56	00:02:30				1
545	1,77384	226911	5	+3.2; +18,4; -3.2; -17.7	20x20	15,2	12,7	4	0	2,98	0	559,5	50,2			4. August 2016	10:42:13	10:44:28	00:02:15				1
546	1,83006	202460	5	+3.2; +18,4; -3.2; -17.7	20x20	15,2	12,7	4	100	2,98	0	559,5	50,2			4. August 2016	10:48:11	10:50:16	00:02:05				1
551	0,939756	201184	5	+3.2; +3.1; -3.2; -3.1	-	15,2	12,7	4	0	2,98	0	559,5	50,2			4. August 2016	11:25:05	11:28:53	00:03:48				1
552	0,932048	204840	5	+3.2; +3.1; -3.2; -3.1	-	15,2	12,7	4	100	2,98	0	559,5	50,2			4. August 2016	11:30:32	11:34:25	00:03:53				1
554	1,65756	209931	5	+3.2; +9.8; -3.2; -10.0	-	15,2	12,7	4	0	2,98	0	559,5	50,2			4. August 2016	11:40:43	11:43:04	00:02:21				1
553	1,73868	200665	5	+3.2; +9.8; -3.2; -10.0	-	15,2	12,7	4	100	2,98	0	559,5	50,2			4. August 2016	11:36:49	11:38:59	00:02:10		Upstream tower was touched when inserting the lead collimator. Doing new alignment run now anyway...		1
557	0,128394	512149	5	+3.2; +3.0; -3.2; -3.1	8x8	15,2	12,7	5,6	0	2,98	0,7225	559,5	50,2	allignment 2.0 for setup 1		4. August 2016	11:56:48	13:03:29	01:06:41				1
647	0,594628	200569	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	1	0	2,98	0,7225	565,7	51,8			5. August 2016	18:17:31	18:23:16	00:05:45				1
646	0,833665	201105	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	2	0	2,98	0,7225	565,7	51,8			5. August 2016	18:12:24	18:16:31	00:04:07				1
645	0,765028	203575	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	3	0	2,98	0,7225	565,7	51,8	Zero measurement		5. August 2016	18:06:30	18:11:03	00:04:33		these zero B field measurments we did after switching back from setup 3 to setup 2 (still with only three szintilators)		1
644	0,595326	201519	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	4	0	2,98	0,7225	565,7	51,8			5. August 2016	17:59:41	18:05:26	00:05:45				1
643	0,314561	200449	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	5	0	2,98	0,7225	565,7	51,8			5. August 2016	17:47:43	17:58:26	00:10:43				1
642	0,129237	200109	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	5,6	0	2,98	0,7225	565,7	51,8			5. August 2016	17:20:38	17:46:34	00:25:56				
589	0,340741	201037	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	1	312,5	2,98	-132,0000	559,5	53			4. August 2016	17:49:14	17:59:04	00:09:50			rate is possibly wrong	1
588	0,713344	199994	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	2	625	2,98	-132,0000	559,5	53			4. August 2016	17:42:20	17:47:07	00:04:47			From here on 3 scintillators (AND 7), adjusted 3th scinti	1
587	0,661438	212042	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	3	937,5	2,98	-132,0000	559,5	53	Energy ramp		4. August 2016	17:33:49	17:39:22	00:05:33		go @ the end of the PI stage and variate the magnetic current until the beam is on the senso		1
590	0,46354	203611	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	4	1000	2,98	-105,2775	559,5	53			4. August 2016	18:03:59	18:11:26	00:07:27				1
591	0,245891	201609	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	5	1250	2,98	-105,2775	559,5	53			4. August 2016	18:13:15	18:27:01	00:13:46				1
593	0,0915332	203991	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	5,6	1400	2,98	-105,2775	559,5	53			4. August 2016	18:44:18	19:21:34	00:37:16	04:52:01			1
601	0,6110000	203000	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	4	200	2,98	-20	559,5	53		Setup 2: PI Stage	5. August 2016	09:52:52	09:58:41	00:07:14				1
600	0,5660000	222000	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	4	400	2,98	-40,5	559,5	53			5. August 2016	09:44:34	09:51:18	00:06:44				1
599	0,5570000	227700	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	4	600	2,98	-63,1665	559,5	53	ramp magnet		5. August 2016	09:35:18	09:42:12	00:06:54		scan the magnetic field in the possible range for 2 GeV and find a position on the PI stage where the beam is hitting the sensors		1
598	0,5290000	200000	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	4	800	2,98	-84,222	559,5	53			5. August 2016	09:27:13	09:33:43	00:06:30				1
597	0,5050000	201000	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	4	1000	2,98	-105,2775	559,5	53			5. August 2016	09:18:47	09:25:31	00:06:44				1
596	0,4830000	205000	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	4	1400	2,98	-147,3885	559,5	53			5. August 2016	09:08:01	09:15:15	00:07:14				1
594	0,549553	305045	5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	5,05	4	0	2,98	0,7225	559,5	53	alignment setup 2		4. August 2016	19:28:48	19:38:10	00:09:22				1
606	0,078	195000	5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2,0	5.6	0	2,98	0,7225	565,7	51,8	alignment setup 3		5. August 2016	10:31:45	11:14:07	00:42:22	Downstream planes have now 2.0mm distance	We have noticed scintilator 2 and 3 are switched. Thus, for all runs, 3rd scinti goes into ch. 3 and 4th scinti goes into ch. 2. Last scinti aligned.	4 scintillators (AND 15), adjusted 4th scinti	1
607	0,227	220000	5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2	5	0	2,98	0,7225	565,7	51,8			5. August 2016	11:18:14	11:30:37	00:12:23				1
608	0,485	202000	5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2	4	0	2,98	0,7225	565,7	51,8			5. August 2016	11:31:34	11:38:56	00:07:22				1
609	0,65	213000	5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2	3	0	2,98	0,7225	565,7	51,8	Zero measurement		5. August 2016	11:39:36	11:45:38	00:06:02		go @ the end of the green stage and variate the magnetic current until the beam is hittig the sensors (if B field is not to big for the minimum distance between two sensors)		1
610	0,61	212000	5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2	2	0	2,98	0,7225	565,7	51,8			5. August 2016	11:45:59	11:51:51	00:05:52				1
611	0,367	207000	5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2	1	0	2,98	0,7225	565,7	51,8			5. August 2016	11:52:50	12:03:30	00:10:40				1
614	0,272	206000	5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2	5	1400	2,98	-122	565,7	51,8			5. August 2016	12:22:55	12:35:41	00:12:46		Again, AND mask 7 due to massive rate loss at 15 5.6 Gev sample seen 593		1
615	0,511	203000	5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2	4	1400	2,98	-153	565,7	51,8			5. August 2016	12:39:15	12:46:02	00:06:47				1
616	0,609	212000	5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2	3	1400	2,98	-202	565,7	51,8	Energy ramp		5. August 2016	12:48:14	12:54:09	00:05:55				1
618	0,426237	252913	5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2	2	1400	2,98	-95	359,7	51,8			5. August 2016	13:18:48	13:28:55	00:10:07				1
622	0,234508	204956	5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2	1	700	2,98	-95	359,7	51,8			5. August 2016	13:38:39	13:53:20	00:14:41				1
																			0				1
@618	0,426237	252913	5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2	2	1400	2,98	-95	359,7	51,8		Setup 3: plus Green				0				0
624	0,492491	201429	5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2	2	1200	2,98	-51,8968	359,7	51,8			5. August 2016	14:12:09	14:18:58	00:06:49				1
625	0,57781	223160	5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2	2	1000	2,98	-8,7936	359,7	51,8	ramp magnet		5. August 2016	14:21:16	14:27:53	00:06:37		scan the magnetic field in the possible range for 2 GeV and find a position on the green stage where the beam is hitting the sensors		1
627	0,601696	210336	5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2	2	800	2,98	-171,6904	565,7	51,8			5. August 2016	14:41:15	14:47:17	00:06:02				1
629	0,713652	210610	5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2	2	600	2,98	-128,5872	565,7	51,8			5. August 2016	15:12:39	15:17:41	00:05:02				1
630	0,752901	216031	5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2	2	400	2,98	-85,4840	565,7	51,8			5. August 2016	15:19:45	15:24:38	00:04:53				1
@608			5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2	4	0	2,98	0,7225	565,7	51,8						0				0
@615			5	+3.2; +3.3; -3.2; -3.0	5x5	15,2	2	4	1400	2,98	-153	565,7	51,8						0				0
635	0,247277	200590	5	+3.2; +1,4; -3.2; -1,5	5x5	15,2	2	4	0	2,98	0,7225	565,7	51,8			5. August 2016	16:12:43	16:26:20	00:13:37				1
634	0,183098	200228	5	+3.2; +1,4; -3.2; -1,5	5x5	15,2	2,00	4	1400	2,98	-153	565,7	51,8			5. August 2016	15:46:32	16:04:51	00:18:19				1
636	0,954249	203046	5	+3.2; +5; -3.2; -5.1	5x5	15,2	2	4	0	2,98	0,7225	565,7	51,8	Collimator run		5. August 2016	16:28:38	16:32:18	00:03:40				1
637	0,870861	215957	5	+3.2; +5; -3.2; -5.1	5x5	15,2	2	4	1400	2,98	-153	565,7	51,8			5. August 2016	16:35:32	16:39:47	00:04:15				1
639	1,53535	217268	5	+3.2; +10.1; -3.2; -9.8	5x5	15,2	2	4	0	2,98	0,7225	565,7	51,8			5. August 2016	16:49:38	16:52:07	00:02:29				1
638	1,39316	224509	5	+3.2; +10.1; -3.2; -9.8	5x5	15,2	2	4	1400	2,98	-153	565,7	51,8			5. August 2016	16:44:49	16:47:37	00:02:48				1
640	1,50612	203056	5	+3.2; +18,4; -3.2; -17.7	5x5	15,2	2	4	0	2,98	0,7225	565,7	51,8			5. August 2016	16:53:37	16:55:59	00:02:22				1
641	1,61375	201038	5	+3.2; +18,4; -3.2; -17.7	5x5	15,2	2	4	1400	2,98	-153	565,7	51,8			5. August 2016	16:58:18	17:00:30	00:02:12				1
																			11:48:45		switched back again to setup 2 for zero measurments		0

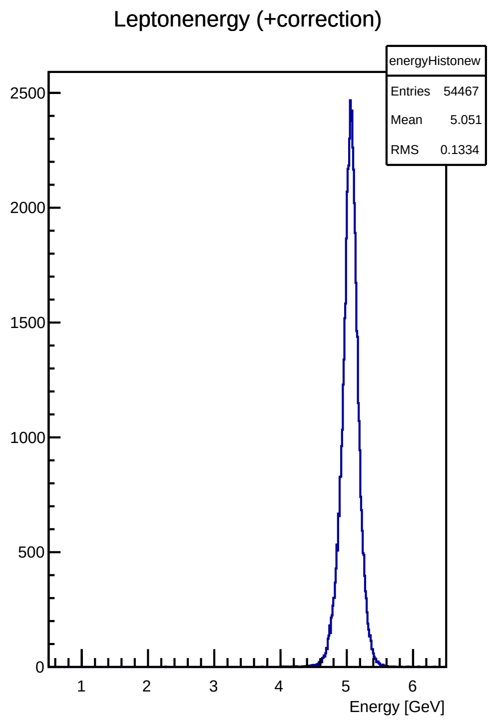
	General Log book																						
			Threshold	Collimator		zplane					PI Stage	Green Stage		Comments	Setup								
Run Number	Trigger (kHz)	Events	Telescope	No. 3 (up, east, down, west)	Lead Block	zp1 [cm]	zp2 [cm]	Energy (GeV)	Magnetic Amps (A)	zp1-zp4 [m]	mum-stage pos	x-pos	y-pos			Date	time start	time end	delta t		comments		
																							80
652	693.499	276891	5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	4	0	2,98	0,7225	565,7	51,8	Magnet Controll measurments		15. August 201	16:06:00	16:12:52					
			5	+3.2; +3.0; -3.2; -3.1	5x5	15,2	5,05	4	1400	2,98	-135	565,7	51,8										

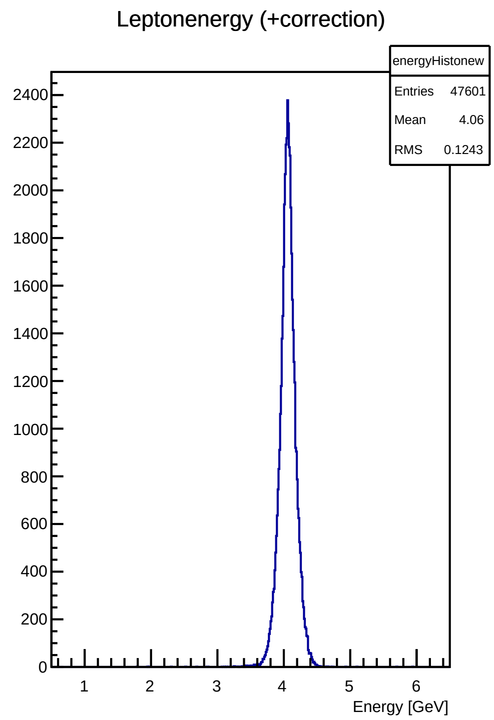
5.2 Energy Distributions of Setup 1

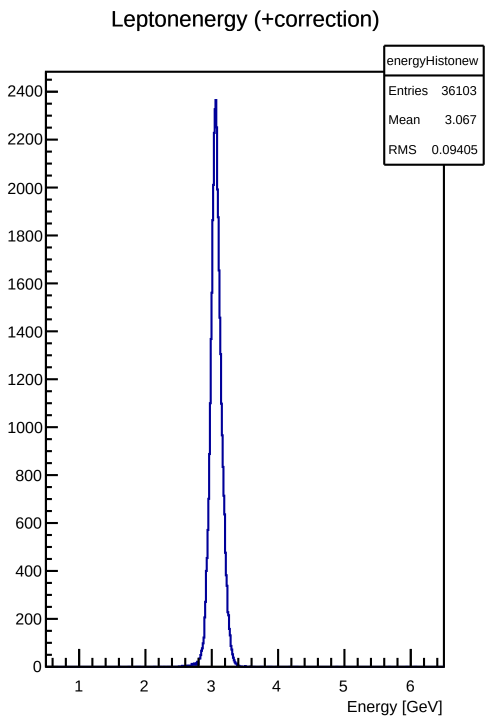

Leptonenergy (+correction)
energyHistonew
Entries 129123
Mean 5.54
RMS 0.3638
Energy [GeV]
Leptonenergy (+correction)
energyHistonew
Entries 90294
Mean 4.989
RMS 0.36
Energy [GeV]
Leptonenergy (+correction)
energyHistonew
Entries 59108
Mean 4.034
RMS 0.3416
Energy [GeV]
Leptonenergy (+correction)
energyHistonew
Entries 50528
Mean 3.072
RMS 0.3258
Energy [GeV]
Leptonenergy (+correction)
energyHistonew
Entries 64011
Mean 2.116
RMS 0.3089
Energy [GeV]
Leptonenergy (+correction)
energyHistonew
Entries 62928
Mean 1.205
RMS 0.3513
Energy [GeV]

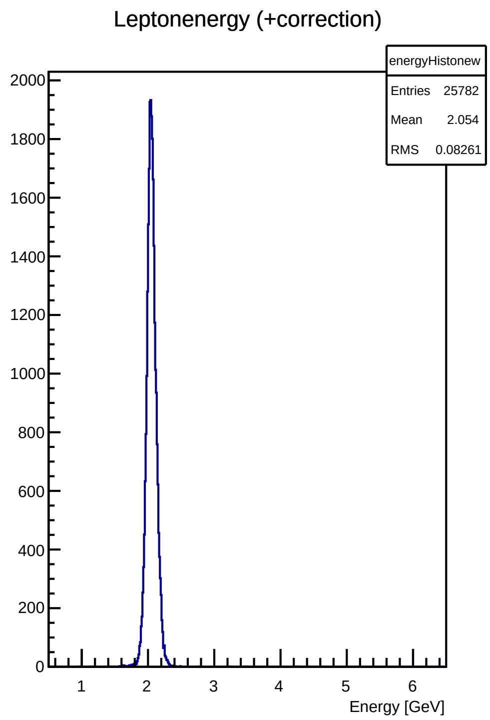
5.3 Energy Distributions of Setup 2

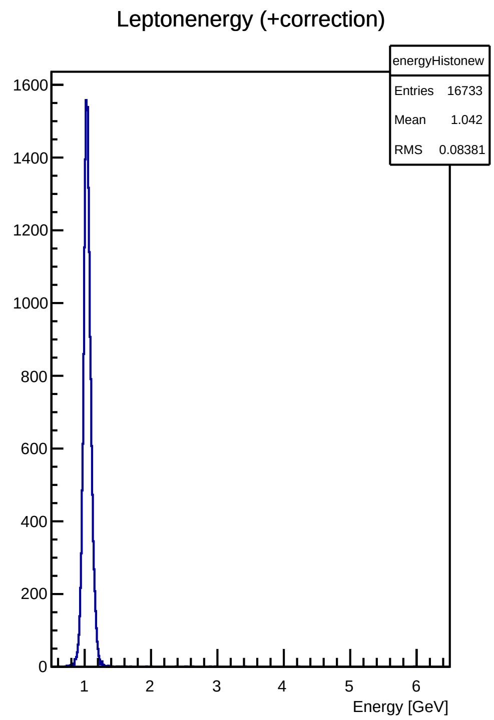

Leptonenergy (+correction)
energyHistonew
Entries 59624
Mean 5.62
RMS 0.1336
Energy [GeV]


Leptonenergy (+correction)
energyHistonew
Entries 54467
Mean 5.051
RMS 0.1334
Energy [GeV]

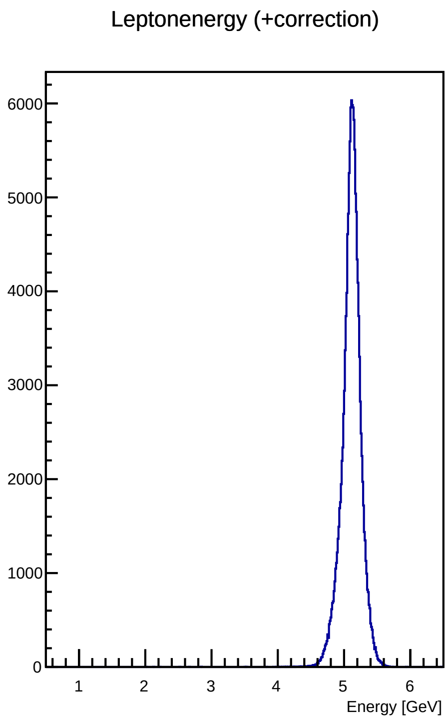

Leptonenergy (+correction)
energyHistonew
Entries 47601
Mean 4.06
RMS 0.1243
Energy [GeV]

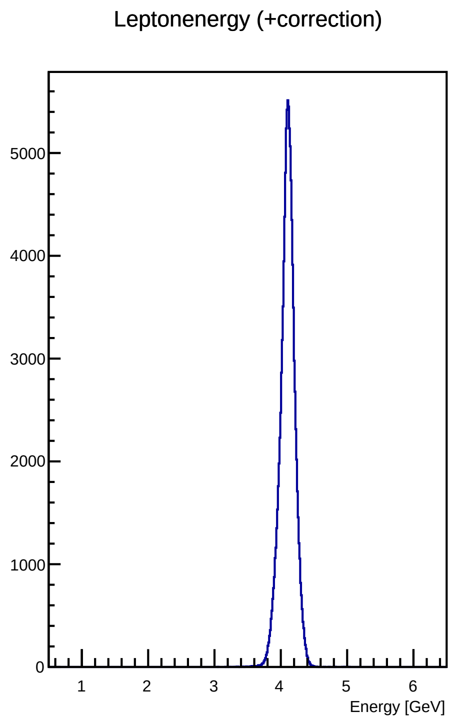

Leptonenergy (+correction)
energyHistonew
Entries 36103
Mean 3.067
RMS 0.09405
Energy [GeV]

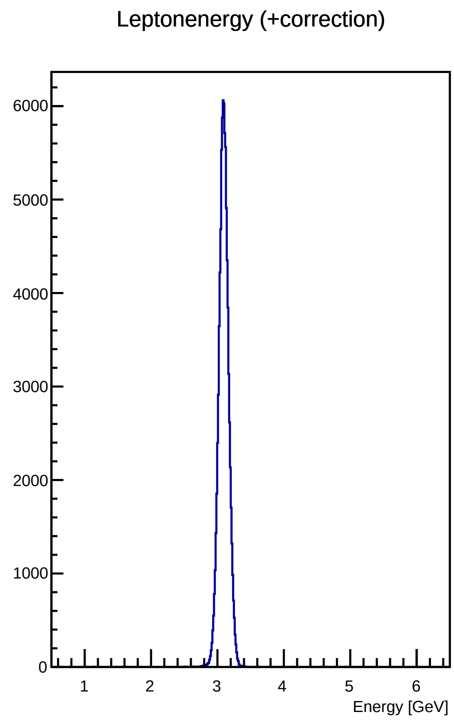

Leptonenergy (+correction)
energyHistonew
Entries 25782
Mean 2.054
RMS 0.08261
Energy [GeV]

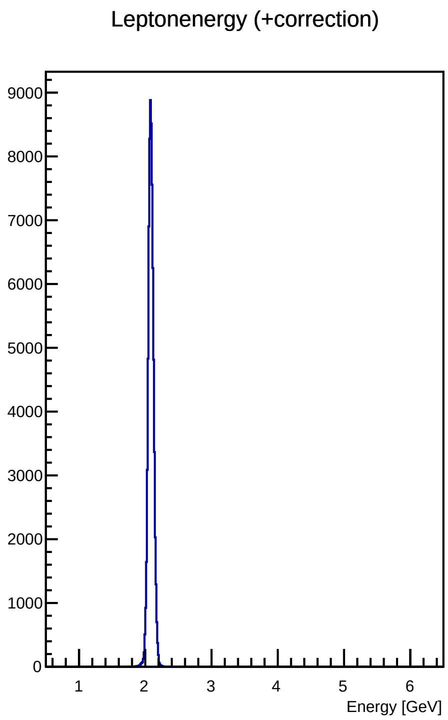

Leptonenergy (+correction)
energyHistonew
Entries 16733
Mean 1.042
RMS 0.08381
Energy [GeV]

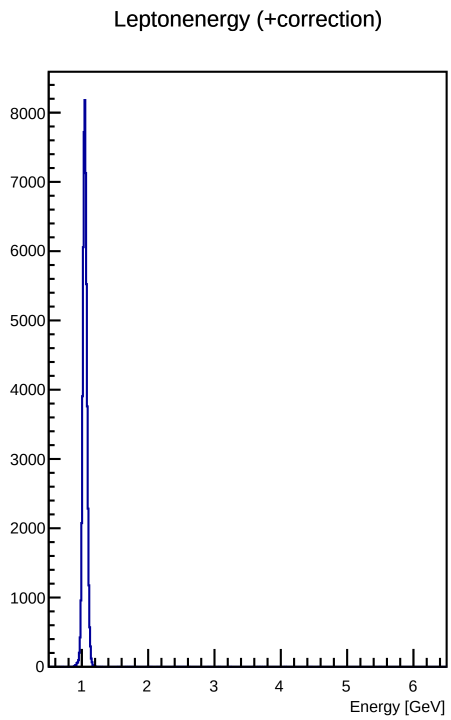
5.4 Energy Distributions of Setup 3


Leptonenergy (+correction)
0
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
Energy [GeV]


Leptonenergy (+correction)
0
1000
2000
3000
4000
5000
1
2
3
4
5
6
Energy [GeV]


Leptonenergy (+correction)
0
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
Energy [GeV]


Leptonenergy (+correction)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
1
2
3
4
5
6
Energy [GeV]


Leptonenergy (+correction)
0
1000
2000
3000
4000
5000
6000
7000
8000
1
2
3
4
5
6
Energy [GeV]

References

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[2] EUDAQ Software User Manual, *EUDAQ Development Team*, eudaq.github.io/manual/EUDAQUserManual.pdf

[3] Energy calibration of the DESY test beam in beamline 21, *Paul Schütze*

[4] The DESY telescope website, https://telescopes.desy.de/

[5] Particle Push in Magnetic Field (Boris Method), https://www.particleincell.com/2011/vxb-rotation/

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