



Kísérleti eszközök fejlesztése a nagyenergiájú fizika számára

Töltött Higgs-bozon keresése a CERN-i L3 detektornál és precíziós
helyzetmeghatározó-rendszer építése a
CERN-i CMS detektor Müion rendszeréhez

doktori (PhD) értekezés tézisei

Development of experimental methods for the high-energy physics

Search for charged Higgs-bosons at the L3 experiment and
development of a precision alignment system for the CMS
detector at CERN

abstract of PhD dissertation

Szillási Zoltán

Debreceni Egyetem
Fizikai Tudományok Doktori Iskola
Debrecen, 2007.

1. INTRODUCTION

Where did we come from? What we are made up of? These questions inspired both the ancient philosophers and the modern physicists thinking about the structure of matter. Physicists create more and more complex theories to explain the properties of particles, the basic constituents of the nature and the forces among them. Theories must contain forecasts that can be verified by experiments. Therefore the model itself undergoes a verification, too: if its forecasts can be verified the model describes successfully the behavior of nature. In case of failure, however, a new, better model needs to be built. Currently the most successful model of particles is the Standard Model. But it leaves some important questions open, for example why the particles have mass. In order to explain the mass question in accordance with the facts the existence of a new particle is required. This is the so called Higgs-particle. Since the Higgs-particle has never been seen so far many ways of the Higgs-mechanism can be imagined. The simplest one contains only one Higgs particle, but as the model gets to be more and more complex the number of arising Higgs-bosons increases. Some of these Higgses are neutral, but there are charged ones, too. Simultaneously many models must be investigated at a time since only the experiment can judge which one describes better the properties of the nature. The first part of my thesis is devoted to my work on the search of the charged Higgs-boson among data collected By the LEP collider's L3 experiment at CERN, Geneva.

Currently a new collider is under construction at CERN, the Large Hadron Collider (LHC). It will accelerate particles to an unprecedented energy. Its main goal is to hunt for the so far hidden Higgs-boson or the members of its family and to check the validity of theories beyond the Standard Model. One of the big detectors situated on the LHC is the Compact Muon Solenoid (CMS). The muon detectors play fundamental role in the operation of the trigger system of CMS. This is because of the large amount of data created by the particles emerging from the proton-proton collisions in the inner detectors. It is impossible to read out this amount of data in real time if the collision rate is at the designed 40 MHz. On the other hand, only few particles reach the muon system. They create data that can be handled much easier. In order to provide reliable data both to the analysis and the trigger system and to be able to measure the momenta of muons with the required precision it is inevitable the precise knowledge of certain detector parts.

The task of our groups at the University of Debrecen and in the Nuclear Research Institute of the Hungarian Academy of Sciences (ATOMKI) is to design, develop and calibrate such an alignment system which is able to provide precision data on the position of each of the 250 barrel muon chambers of CMS. This system must be operable during the full lifetime of the experiment and withstand the 4 T magnetic field produced by the solenoid of the CMS. In addition such a system must be able cope with the radiation background created by particle collisions and the activated detector parts. Second part of my thesis contains my research and development works on the alignment system.

2. GOALS

Between 1997 and 2000 I participated in the work of the Higgs workgroup of the L3 experiment. My task was to build up an analysis method on data collected at center of mass energies between 130 and 189 GeV. It was also my duty to search for evidence of a charged Higgs-boson in its hadronic decay channel.

Unfortunately, Higgs-models do not make predictions on the mass of the Higgs-particle. Therefore the only possible procedure is to look for evidence for the Higgs-particle at all the reachable beam energies.

The simplest Higgs-model contains only one Higgs-boson. It can not be excluded, however, that the behavior of nature cannot be explained so easily. It is necessary therefore to test more complex models, too. The second simplest model is the so called Two-Higgs-Doublet Model which contains five Higgs-bosons. Three of them are neutral while the rest are charged. Due to their properties predicted by the model charged Higgs-bosons are created in pairs in the electron-positron colliders. Then they decay dominantly into $H^\pm \rightarrow cs$ or $H^\pm \rightarrow \tau \nu_\tau$ at LEP energies. The decay branching ratio depends on the details of the applied model. I have developed –together with my colleagues– an analysis method where the result is independent of the branching ratio. In order to fulfill this requirement, we created the following three independent analyses:

- $H^+H^- \rightarrow c\bar{c}s\bar{s}$
- $H^+H^- \rightarrow cs\bar{\tau}^-\bar{\nu}_\tau, cs\tau^+\nu_\tau$
- $H^+H^- \rightarrow \tau^+\nu_\tau\tau^-\bar{\nu}_\tau$

In my thesis, I describe mainly the purely hadronic decay channel. These processes are characterized by four quark jets, therefore they have large particle multiplicity, and relatively large number of calorimetric clusters. In addition, almost full energy of such an event can be recorded by the detector and both the longitudinal and transverse momenta are balanced. Unfortunately, however, not only Higgs-events have the above mentioned signature, but the W- and Z-pair events have it as well. In addition, there are

$e^+e^- \rightarrow q\bar{q}(\gamma)$ events where one (or both) of the jets emit a gluon at the final stage. Due to this fact it may happen that jet-finder algorithms identify these events as four-jet events. During the development of the analysis it was my goal to construct a selection where all these background events are suppressed, while at the same time the Higgs-signal efficiency is kept as high as possible.

The alignment system of the CMS Muon Barrel System is a complex system realizing a concept based on an optogeometrical network having optomechanical, optoelectrical, electronic, informatical and data handling aspects. All these details require solutions for numerous questions based on research and development. In my thesis I describe those parts of this extensive and long running research and development work, where I contributed dominantly with my work.

Since the alignment system contains several thousands of elements for which the necessary precision cannot be provided by manufacturing the key issue for the net precision of the system and therefore its usability is the high precision calibration of the elements. During one of these calibration procedures the positions of LED sources mounted on the LED-holders have to be measured with respect to references on a mechanical stand. My task was to develop the method, utilities and devices of the LED holder calibration process. I had to study and eliminate factors having negative effect on the precision. I had to solve issues concerning the data taking, data handling, analysis and the effective reporting/monitoring. In addition, I had to apply the developed concepts and methods to the calibration of the optomechanical reference objects (LED-holders) and the muon chambers. I also had to perform the statistical analysis of the results obtained during the calibration.

3. RESULTS

1. I have developed a method in order to search for the charged Higgs-boson in its hadronic decay channel on measurement data taken by the L3 experiment.

The method is a classical cut-based analysis that does not depend on the mass of the charged Higgs. The applied cuts only slightly depend on the center of mass energy. In the table below the selection efficiencies of different simulated Higgs-signals can be seen for all the reachable center of mass energies. The last column of the table shows the expected number of background events normalized to the amount of data taken.

E_{CM} (GeV)	Selection efficiency (%) $m_H^{\pm} =$								Number of expected background events
	45	50	55	60	65	70	75	80	
130-136	36	41	44	46	—	—	—	—	19,0
161	37	45	51	44	45	46	—	—	15,2
172	35	45	45	43	41	39	—	—	25,9
183	29	36	39	40	38	34	—	—	99,4
189	—	—	—	39	38	38	34	30	359,4

Table 1 Selection efficiencies achieved by the analysis of the hadronic decay channel of charged Higgs-bosons and the number of expected background events at different center of mass energies.

2.a Applying the method described in point 1 to the analysis of measurement data the existence of the charged Higgs-bosons could be excluded below the mass limit 57.5 GeV/c².

These measurements were carried out on data collected by the L3 experiment at four points of the center of mass energy range $\sqrt{s} = 130 - 183$ GeV (130, 161, 172, 181 GeV).

In Figure 1 the invariant mass distribution of the expected integrated background and the collected data can be seen. I have also depicted a simulated charged Higgs signal with 60 GeV rest mass. This figure suggests that the collected data is compatible rather with the background than the background + Higgs-signal. It can also be seen that at some invariant mass values the data and the background estimation are different. Due to this fact the branching ratio-independent exclusion is limited to 57.5 GeV when the results of the three decay channels are combined.

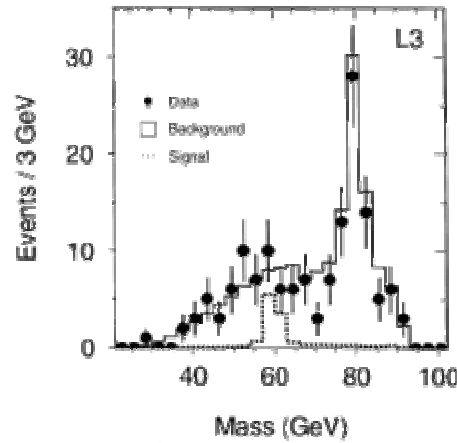


Figure 1 Distribution of data and the expected background events with respect to the invariant mass on the center of mass energy range between 130 and 183 GeV. A Higgs-signal with 60 GeV mass is also shown.

2.b Applying the method described in point 1 on data taken after the improvement of the experimental conditions I provided a result on the hadronic decay channel which allowed to modify the exclusion limit up to 65.5 GeV

This result was based on data collected by the L3 detector at center of mass energy $\sqrt{s} = 189$ GeV.

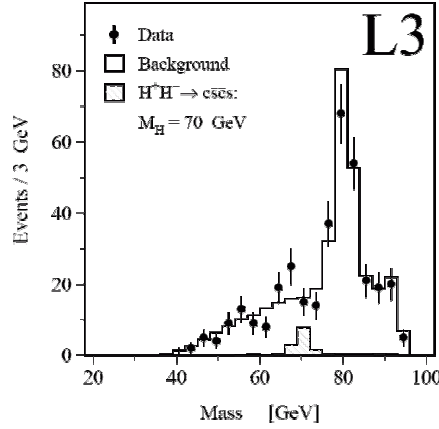


Figure 2 Distribution of data and the expected background events with respect to the invariant mass at 189 GeV center of mass energy. A Higgs-signal with 60 GeV mass is also shown.

In Figure 2 the invariant mass distribution of the expected integrated background and the collected data can be seen. A simulated charged Higgs signal with 70 GeV rest mass is also indicated. Similarly to point 2a, this figure also suggests that the collected data is compatible rather with the background than the background + Higgs-signal. It can also be seen that at some invariant mass values the data and the background estimation are different. Due to this fact the branching ratio-independent exclusion is limited to 65.5 GeV when the results of the three decay channels are combined.

3. I have developed a method for the calibration of the elements of the CMS muon position monitor in which the positions of the light sources of the LED-holders are determined with respect to etalon light sources in an environment close to that in which the given element will be used.

To achieve that first I found a proper etalon light source using fiber optics with incoherent illumination. Applying the calibration method to a test-element with known light (preliminary measured in metrology lab) source positions I managed to reconstruct the relative positions of these light sources below 10 microns. With this test I have successfully proved that my method is able to perform the calibration task with the required precision. The applied method does not require any previous calibration of the device and does not make great demands on the stability of the device itself since all the optical sources are measured in the same geometry by the same camera. In our application, however, the LEDs are installed on both the faces of the LED-holder. Therefore one camera cannot measure all the LEDs. Using a well designed calibration device and properly positioned etalon light sources the systematic error arising from the presence of two observer cameras could be excluded.

4. Using experimental and simulation methods I have developed the optimal algorithm for the evaluation of the images created by optical sources (aka. centroid calculation). This algorithm is very insensitive for the background noises and intensity fluctuations and the result of centroid calculation does not depend on the spot position on the sensor surface.

During development it had a key importance to work out a good method for spot definition. According to the proposed algorithm on the image the first pixel with maximum intensity is determined and then a decision on each neighbouring pixel is made whether it is part of the spot or not. By finding all the pixels of the spot, this spot can be cut off from the image and the procedure can be restarted for the remaining part of the image. At the end of this iterative process all the spots can be found on the image. The algorithm is also able to disentangle direct spots from their reflected images. This feature is very important for the chamber calibration process since the optical sources are installed inside a reflective aluminium profile. I have developed a general method for disentangling the direct spot from its reflections. Besides, another approach can also be used where the reflections can be estimated based on the relative geometry of the aluminium profile and the LED holder installed into it. Together with one of my students I have developed a method where a spot formation can be simulated while the gains of the individual pixels can be set.

5. Using experimental methods I have studied the magnitude of the measurement error arising from the statistical fluctuation of video sensor sensitivity. I have developed a statistical method to decrease this error.

I have shown that if the centroid calculation method described at point 4 is used and the average of 20 images is calculated the resolution of a video-sensor having 12x12 micron sensitive cells is 2% of the cell size.

6. I have studied the effect of the intensity of the optical source on the measurement precision during the calibration process. I have also determined the optimal parameters.

I have shown that if the centroid calculation is used as is described in point 4 the result of the calculation is independent of the intensity in wide range of intensities therefore this method can be used safely for the measurements. The practical reason of this study is that the LEDs are located at various distances from the cameras in the full alignment system. With this study I have shown that the centroid determination precision goes wrong only at extremely high intensities. In addition, as a by-product of this study, ideal LED currents have been determined for all the distance values used in the final system.

7. Applying results described in points 4-6 I have designed and built a calibration device which was capable to measure 1200 LED-holders.

Calibration method of the LED holders is based on the so called seeking where the LED holder is put into the calibration device which is installed on a two-dimensional precision moving table with reproduction precision of 1 micron. Then one light source on either the LED holder or the calibration device is illuminated and the moving table climbs until the observed centroid of the light source reaches a predetermined position on the corresponding observer camera. This iterative process can be performed on all light sources of the LED holder and of the calibration device. In order to collect data sample that can be handled statistically the full measurement is needed to be reproduced several times. The advantage of this measurement concept is that it does not require a previous calibration of the observer cameras because the light spot is created in the same region of the sensor. This eliminates the effect of geometrical errors of the lens and uneven gain distribution of the video sensor pixels.

This calibration device was built at the Institute of Experimental Physics of the University of Debrecen. In addition to the device itself I created a data taking system and solved the data storage and handling issues as well including the remote access to the results by other CMS groups. Due to the large number of LED-holders, I designed an almost fully automatic measurement process (except the LED-holder installation into the calibration device which required human intervention). Due to this automatic nature, it was a key issue to ensure the data quality, so I developed an automatic method to select bad measurements. By the statistical analysis of the data of the full LED-holder set. I have proved the usability of the calibration device and the reliability of the measurements.

8. Applying results described in points 4-6 I have developed a calibration device to measure all the 250 barrel muon chambers of the CMS experiment at CERN.

The operational concept of this calibration differs from that of the LED holders described in point 7 since here due to the size of the muon chamber the seeking method can not be used. Therefore the cameras looking down into the alignment passages of the muon chambers and observing the LED holders were fixed to the calibration bench. Here observer cameras had to be calibrated before the chamber calibration. It was done together with the geometrical survey of the full bench. Oddity of this system is that positions of LED holders must be described in the frame of reference created by the corner blocks of the muon chambers while these corner blocks remain unobservable by our cameras. Therefore, during the measurement our group worked together with the CERN TS-SU group and the two measurements were combined.

In addition to the device itself –similarly to the LED-holder calibration device– it was also a key issue to create a data taking system, the safe data handling and the presentation of the results to the CMS collaboration. This device was successfully used during the calibration of the full chamber set.

4. APPLICATION OF RESULTS

My charged Higgs-analysis applied to data of the L3 experiment sets the limit on the minimum mass of the charged Higgs-boson due to the data-background incompatibility in some of the bins. It was obvious therefore, that after my departure the L3 Higgs group checked my results with a revised analysis. This analysis was completed with data collected between 192 – 202 GeV center of mass energies and gave the lower limit of 67.4 GeV on charged Higgs mass. Later the Higgs group revised again the analysis and rerun it on the center of mass energy range 189 – 209 GeV. The result of this analysis raised the lower limit to 76.5 GeV.

Developing a method for precise calibration of LED holders of the Barrel Muon Alignment System, I have created a device that is capable to measure optical sources of any small objects. Therefore its industrial application is also conceivable. The same statement is valid for the muon chamber calibration system, but the difference is of the size of the object to be calibrated: this device is able to accept much bigger objects.

5. PUBLICATIONS

5a. Articles concerned to the thesis

1. Acciarri M., Baksay G., Raics P., **Szillási Z.**, Sztaricskai T., Zilizi Gy., + 411 coauthors (L3 Collaboration) ³ : *Search for charged Higgs boson in $e+e-$ collisions at $\sqrt{s} = 189$ GeV.*
^{SCI} Physics Letters B **466** (1999)71-78.
2. Acciarri M., Baksay G., **Szillási Z.**, Zilizi Gy., + 422 coauthors (L3 Collaboration) ³ : *Search for charged Higgs bosons in $e+e-$ collisions at centre-of-mass energies between 130 and 183 GeV.*
^{SCI} Physics Letters B **446** (1999)368-377.

5b. Articles not detailed in the thesis

1. Simon A., Pintye Z., **Szillási Z.**, Raics P., Béni N., Molnár J.: *A new method for alpha-particle detection in a classroom experiment.*
Atomki Annual Report 2005
2. **Szillasi Z.** Higgs bozonok keresese, Természet Világa 2000. III. Különszám

+ 350pcs other articles

5c. Lectures and posters concerned to the thesis

1. **Szillasi Z.** *Higgs Search at L3*
European Committee for Future Accelerators, Budapest 1999 szeptember 3.
2. **Szillási Z.**, Bencze Gy. L., Béni N., Imrek J., Molnár J., Novák D., Raics P., Szabó Zs., Székely G.: *Data acquisition and management in the calibration processes of the CMS barrel muon alignment system.*
12th Workshop on Electronics for LHC and Future Experiments. Valencia, Spain, 25-29 Sept., 2006
3. Novák D., Fenyvesi A., Molnár J., Székely G., Végh J., Béni N., Kapusi A., Raics P., Szabó Zs., **Szillási Z.**, Bencze Gy. L.: *Integration study and first test results of the CMS Muon Barrel Alignment system.*
10th Workshop on Electronics for LHC and Future Experiments. Boston, USA, 13-17 Sept., 2004

5d. Lectures and posters not detailed in the thesis

1. **Szillasi Z.** *Direct and indirect Standard Model Higgs search at LEP*
International Europhysics Conference on High Energy Physics, Tampere 1999
2. Bencze Gy. L., Imrek J., Molnár J., Novák D., Raics P., Szabó Zs., Székely G., **Szillási Z.:** *PIConNET based distributed system dedicated to magnet test of the CMS muon barrel alignment.*
11th Workshop on Electronics for LHC and Future Experiments. Heidelberg, Germany, 12-16 Sept., 2005
3. Székely G., Bencze Gy., Courtens K., Molnár J., Novák D., Raics P., Szabó Zs., **Szillási Z.**, Végh J.: *Muon Barrel Alignment system based on a net of PC/104 board computers.*
9th Workshop on Electronics for LHC Experiments. CERN - NIKHEF, Amsterdam, The Netherlands, 29 Sept. - 3 Oct., 2003
4. Bencze Gy. L., Fenyvesi A., Kerek A., Norlin L. -O., Molnár J., Novák D., Raics P., Szabó Zs., **Szillási Z.:** *Radiation tolerance tests of CMOS active pixel sensors used for the CMS muon barrel alignment.*
8th Workshop on Electronics for LHC Experiments. Colmar, France, 9-13 Sept., 2002
5. Baksay G., Baksay L., Behrens M., Nagy S., Raics P., **Szillási Z.**, Szabó József., Sztaricskai T., Zilizi Gy.: *Az SMD lézerrendszer adatainak kiértékelése a CERN-i L3 kísérletben. (in Hung.)*
MicroCAD'98. Biofizika és számítógépes fizika. Miskolc, 1998. febr. 24-26.
6. **Szillási Z.:** *New laser displacement monitoring system for the L3 experimental at CERN.*
International Conference of Physics Students. Szeged, Hungary, 18-24 Aug., 1996

+ 187pcs other conference talks

