CZECH TECHNICAL UNIVERSITY IN PRAGUE
FACULTY OF NUCLEAR SCIENCE AND PHYSICAL ENGINEERING

BACHELOR THESIS

Calorimetry for Future Particle Physics Experiments

Praha, 2008 **Autor: Petr Gallus**

Prohlášení

Prohlašuji, že jsem svou diplomovou (bakalářskou) práci vypracoval samostatně a použil jsem pouze podklady (literaturu, projekty, SW atd.) uvedené v přiloženém seznamu.

V Praze dne ______________ ____________________

podpis

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Abstrakt

Tato práce se zabývá kalolimetrii pro budoucí projekt ILC- International Linear Collider. V této práci jsou popsány stávající i uvažované koncepty detektorů s důrazem na projekt ILC, obzvláště na kalorimetry určené pro tento pokus. Pro testování vlastností těchto detektorů byl postaven prototyp a tato práce se zabývá zpracováním dat z jeho části elektromagnetického kalorimetru.

Klíčová slova: ILC, Kalorimetrie, CALICE, ECAL.

Abstract

This work is about calorimetry for future project ILC- International Linear Collider. One part of this work is about today's and future concepts of particle detector and accelerators. It is focused on ILC and his calorimeters, moustly on the prototype of them CALICE ECAL and to work with his data.

Key words:ILC, Calorimetry, CALICE, ECAL.

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Contents

Chapter 1

Actual problems in high energy physic

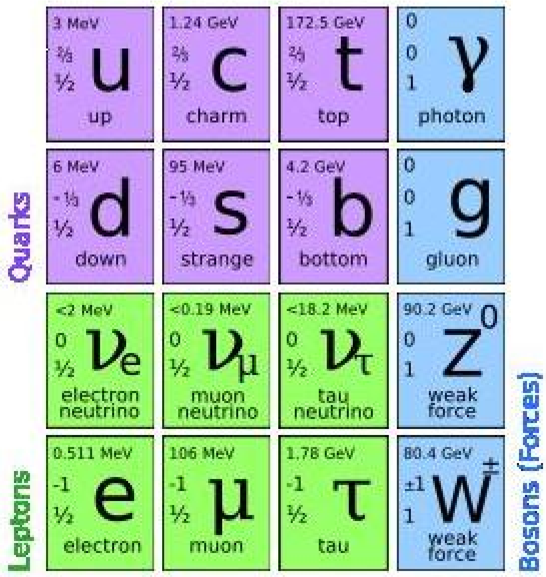
1.1 Introduction

In this part of work I will describe today's situation in high energy physic. But at first I must show the basics of this part of physic. The history of high energy physics was born in 1897, with J.J. Thomson's discovery of the electron. After that we found proton, photon but for my work is the most important discovery of the positron In 1928 Dirac predicted from quantum mechanic that there must be particle same as electron, but with opposite charge. And in 1932 Carl D. Anderson discovered this particle in cloud chamber and gave it her name, positron. Next mile point came in 1947, before this date every ones thing that everything in particle physics is done. But in December of that year Rochester and Butler published the cloud chamber photograph of cosmic rays.

There is something strange in this picture, some negative charge particle decay into two charged secondarily π^+ and π^-, forming the upside-down V. That particle was new and it has more mass than two pions, now we call it the kaon K^0 . Later was found K^+, Δ, Ξ^0, Ξ^-,Σ^+,Σ^- and this was impulse for formulation of conservation laws. The conservation of baryon number (A) and strangeness (S). Now the physics saw that there is much more ways how to make particles. So they looked for way how to show this possibilities. After some inter grades and founding some new particles they came with standard model. [5]

1.2 The Standard model

The Standard model of particle physic is a theory, which describes how the particles respond to three of four known fundamental interaction between the elementary particles. It describes that we have two families of fundamental spin 1 particles (fermions), six quarks and six leptons. Basic description is in the table tab.1.1. But this table show us more than only fermions, there are bosons in this table. Bosons are particles of forces.



3 MeV ⅔ ½ u up	1.24 GeV ⅔ ½ c charm	172.5 GeV ⅔ ½ t top	0 0 1 γ photon
6 MeV -⅓ ½ d down	95 MeV -⅓ ½ s strange	4.2 GeV -⅓ ½ b bottom	0 0 1 g gluon
<2 MeV 0 ½ ν_e electron neutrino	<0.19 MeV 0 ½ ν_μ muon neutrino	<18.2 MeV 0 ½ ν_τ tau neutrino	90.2 GeV 0 1 Z^0 weak force
0.511 MeV -1 ½ e electron	106 MeV -1 ½ μ muon	1.78 GeV -1 ½ τ tau	80.4 GeV ±1 1 $W^\pm$ weak force

Figure 1.1: The Standard Model [1]

Electromagnetic interactions are responsible for virtually all phenomena in extra-nuclear physics, in particular for the bound states of electron with nuclei, i.e. atoms and molecules, and the intermolecular forces in liquids and solids. This interaction are mediated by photon (γ) exchange.

Strong interaction are responsible for binding the quarks in the neutron and proton and the neutrons and proton within nuclei. The inter quark force is mediated by massless particle, the gluon (g).

Weak interaction are typified by the slow process ß-decay, involving the emission by a radioactive nucleus of an electron and neutrino. The mediators of the weak interactions are $W^\pm$ and Z^0 bosons. With masses of order 100 times the proton mass.

Last force, which is not described by Standard model is gravitational interaction. It act between all types of particle. On the scale of experiments in particle physics, gravity is by far the weakest of all fundamental interactions It is supposedly mediated by exchange of a spin 2 boson, the graviton. [7] For better orientation in interactions look to the picture fig. 1.2. In this diagram we see that leptons can interact only by weak and electromagnetic interaction but quarks interact by all types of interaction. Small part of diagram is Higgs Boson, that predicted particle is not found in this moment but it is part of standard model how we define it and it give us the most probable way how to solve some problems in Standard Model. This year will start LHC and we hope that we will found it.

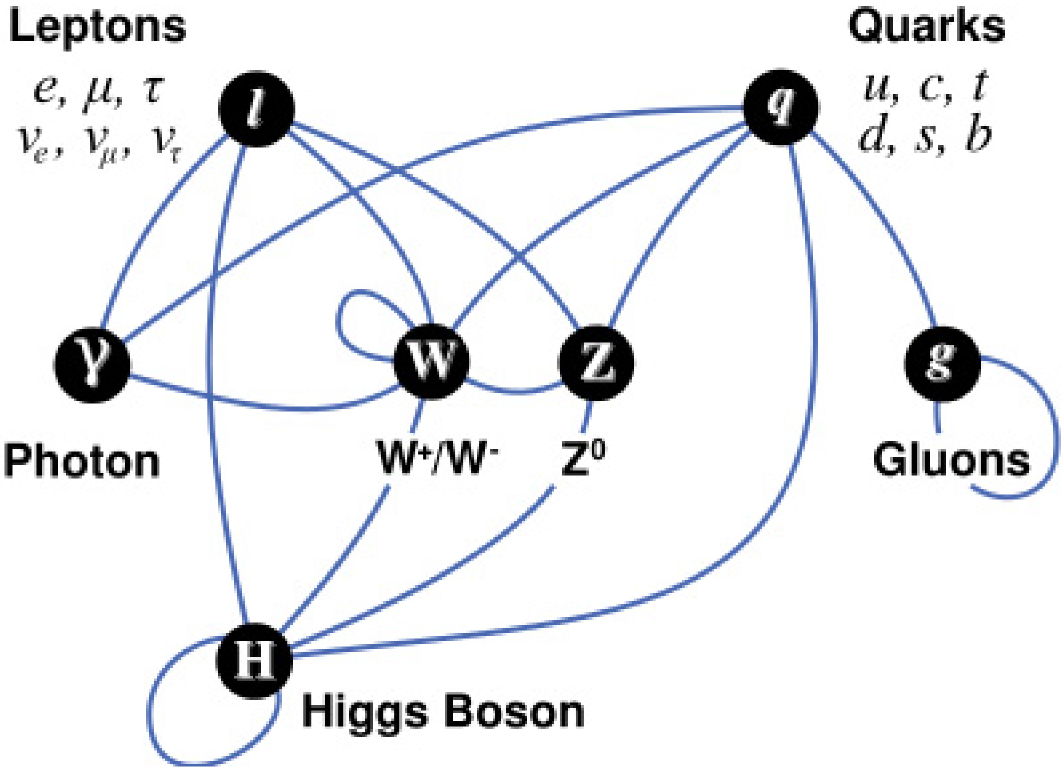


Figure 1.2: Summary of interactions between particles described by the Standard model[1]

The strong interaction causes that quarks don't exist alone in normal conditions. So quarks make pairs or groups of three. And because the color charge must be white, its makes pair of quark and antiquark, that we call mesons or groups of three quarks or antiquarks with same law, its calls baryons. The particles made from quarks we call hadrons.

1.3 Physics beyond the Standard Model

The standard model is very good for answering lot of question about matter, but it don't give us so much prediction what will happen if particles has higher energy. Or it can't explain why we observe 4 forces, what is dark matter and more. For this we think up some theories and I will describe basics of them. LHC and ILC will be first machines, which can observe most of manifestations of physics beyond the Standard Model.

1.3.1 Higgs physics

It is still part of the Standard Model, but because it can have mass M_H 115 GeV or more, we can not measure it before Tevatron (Tevatron cms energy is 1.96 TeV) was build. But on the Tevatron it wasn't find until now. We hope that we will find him on LHC, because when it is not exist we must change SM.

1.3.2 SUSY- Supersymmetry

Supersymmetry (SUSY), which predicts the existence of a partner to every known particle that differs in spin by $\frac{1}{2}$, is widely considered as the most attractive extension of the SM. At first, SUSY has many theoretical virtues, as including Einsteins's theory of gravity when it is make local, and it appears naturally in superstring theories. For this it is posible to make the unification of all forces including gravity. However, the most compelling arguments for SUSY are phenomenological ones: when it is realized at low energies, it can solve three problems of the SM. Indeed, the main reason for introducing low energy supersymmetric theories in particle physics is their ability to solve the fine–tuning problem: SUSY prevents M_H from acquiring very large radiative corrections as the quadratic divergent loop contributions of the SM particles are exactly canceled by the corresponding loop contributions of their supersymmetric partners. In fact, SUSY allows one to understand the origin of the electroweak symmetry breaking itself in terms of radiative corrections triggered by SUSY breaking, which must occur as the newly predicted superparticles have not been observed until now and so it must be heavy. In addition, the new SUSY particle spectrum contributes to the evolution of the three gauge couplings and allows their unification at a scale $M_{GUT} \approx 2{\cdot}10^{16}$ GeV. Finally, a discrete symmetry called R–parity can be naturally present with the major consequence that the lightest supersymmetric particle is absolutely stable; in many cases. [4,7]

Chapter 2

Present and future particle physics experiments

This part will be about experiments in particle physic. There are two basic types of the experiment, first experiments with cosmic rays and second with beams made by us.

2.1 Cosmic rays

First experiments in particle physics used particles which came from cosmos, this particles can have very high energy, much higher then we can make. There is many particles which was found in cosmic rays, for example positron, strange particles K^0 and more. Short history of high-energy cosmic rays is in this time line.

1912 — Hess discovered cosmic rays

1927 — Cosmic rays seen in cloud chamber

1932 — Anderson discovered antimatter. Debate over cosmic rays

1937 — Discovery of muon.

1938 — Auger discovered extensive air showers

1946 — First air shower experiments

1949 — Fermi's theory of cosmic rays

1962 — First 10^{20} eV (100 EeV or 10^8 TeV) cosmic ray detected

1966 — Proposal of GZK cut-off energy for cosmic rays

1991 — Fly's Eye detected highest-energy cosmic ray (Oh-my-God particle with energy approximately 3.2 x 10^{20} eV)

1994 — AGASA high-energy event

1995 — Pierre Auger Project begun

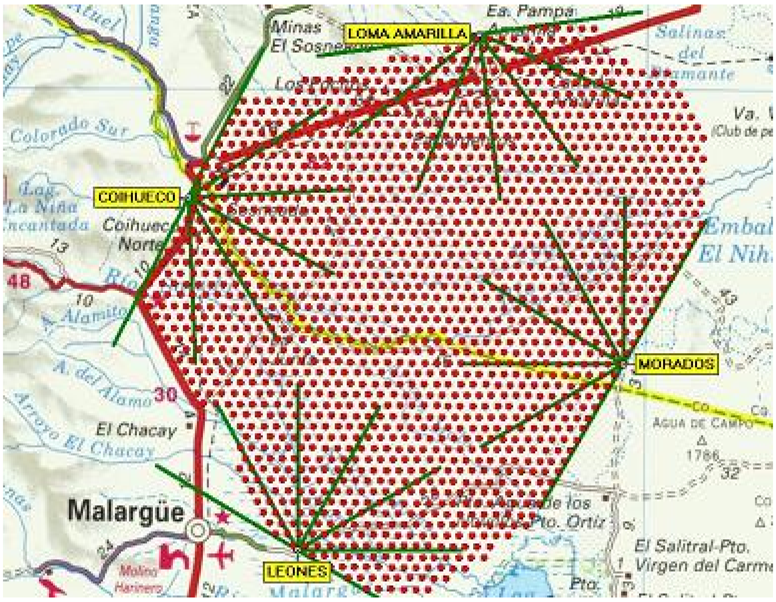


Figure 2.1: The Pierre Auger Observatory in South America [1]

Today we have lot of experiments which used cosmic rays, but the biggest one is experiment in South America, the Pierre Auger Observatory. This experiment is orientated to air showers of particles with very-high energy. Because this particles are very rare, this experiment is very large more than Rhode Island. In picture figure 2.1 is map of this experiment. The red points are water Cerenkov particle detectors and in centre of green lines are atmospheric fluorescence detectors.

2.2 Particle accelerators

The accelerators used electric field to accelerate charged particles to higher energies. One of the simplest machine is high-voltage source (known as Van de Graff accelerator), this machine can make beam with energies about 20 MeV. When we need higher energies, we must make more cycles of accelerating kicks. One possible way is have a accelerating elements in line or second in cycle.

2.2.1 Linear accelerators

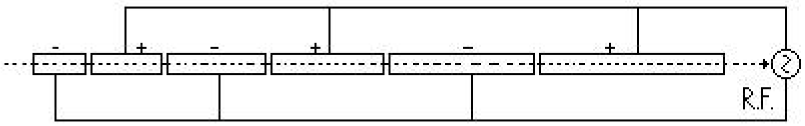


Figure 2.2: Scheme of a proton linear accelerator

In picture figure 2.2 is a scheme of linear accelerator. There are metal drift tubes, with alternate tubes attached to either side of a radio-frequency voltage. This type is useful for smaller energies or for higher energies but with injector and it is very long. But there are linacs which has a cms (centre of mass) energy over 1 GeV, the biggest one is SLAC linac with maximum of cms energy 90 GeV and because of the velocity, it has 240 same drift tubes. The velocity is near the light velocity, so particle go same way independently of the energy.

2.2.2 Cyclic accelerators

The most of the modern accelerators are circular, or nearly so. Scheme of synchrotron is in picture figure 2.3. There are many types of cyclic accelerators but for us is the most important synchrotron In synchrotron we use electric field for accelerating and magnetic field for curving of the charged particles. But this scheme has some limits. One is magnetic field, if we have synchrotron the maximum of momentum dependant to radius of ring and maximum of magnetic field. But this limit is not to important because we stile can make this maximum bigger. But second limit is the synchrotron radiation, when charged particle accelerate it produce the synchrotron rays. For heavier particles is that limit very high, but for electron is very near. For electron is non-economic use synchrotron for energies higher than 0.2 TeV.

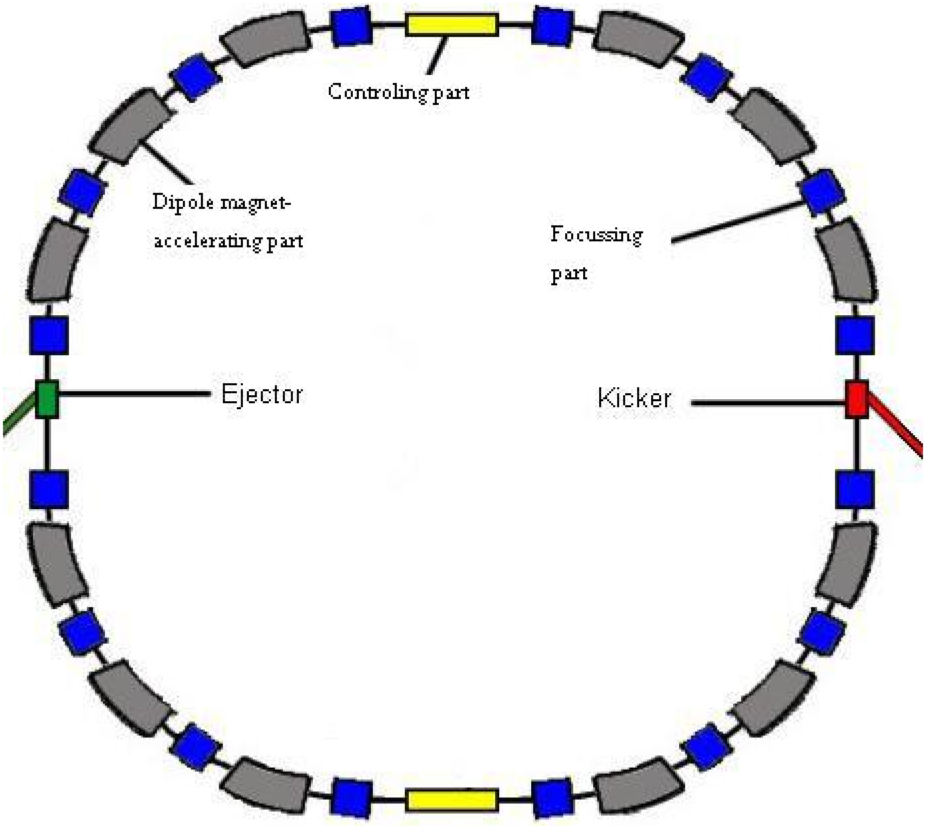


Figure 2.3: Schema of the synchrotron

2.3 Today's experiments

We have two basic types of experiments, collider and with fixed target. Now we prefer colliders, because cms energy, in collider we can easily have higher energy in centre of mass. In collider, both of particles have velocity so momentum of system is much smaller than in system with fixed target, where only one of particles have velocity. Second reason for this choice is spatial distribution of ending particles. In fixed target the most of the particles are in small angle around line of beam. This is not true for colliding system, mostly for colliding particles with same mass, in this example cms energy is sum of energies. Today's the fixed target is mostly used for testing and producing some types of particles- antiprotons, positrons, neutrinos etc.

2.3.1 Experiments centres

2.3.1.1 SLAC

Today's the biggest linear collider SLC, but it will in 2009 become the injector for the Linacs Coherent Light Source, the world's first hard X-ray free electron laser.

2.3.1.2 RHIC

This collider is source for four experiments with ions collisions The most of experiments use Au-Au collisions The experiments are PHENIX, STAR, PHOBOS, BRAHMS.

2.3.1.3 Fermilab

The biggest collider is Tevatron with experiments D0 and CDF. In this experiments was discovered top quark. This collider has 1.96 TeV cms energy for proton antiproton collision

2.3.1.4 CERN

This centre of high-energy physics is one of the leaders in research in Europe, there was many important synchrotrons as SPS, LEP and this year will start LHC- Large Hadron Collider. There are four bigger experiments on LHC ATLAS, ALICE, LHCb, CMS and three smaller LHCf, TOTEM and FP420. FP420 and LHCf are for forward physics. TOTEM is in the same cavern as CMS and it may measure total cross section, elastic scattering and diffractive processes. And now bigger experiments.

ATLAS- In scheme pic.2.4. we can see from which parts is detector made. On the example of ATLAS detector we can see the most popular construction of the detector on the colliding beams. Inner detector (the tracker) in the centre is important for good particle tracking. They only read tracks, after inner detector there are electromagnetic calorimeter, this part of the detector measure the momentum of the light charged particles as electron and photons and filtered them, mostly by electromagnetic cascades. Next is hadronic calorimeters, they measure the momentum of hadrons and slow them. The muon detector can be after that two calorimeters, because muons has much longer decay length and they stocks only small part of they energy. On the sides are forward calorimeters and muons detectors. One of the most important part of detectors are magnets, ATLAS has two systems of magnets, End Cap Toroids with field 4.7 Tesla and central solenoid with field 2 Tesla. The ATLAS is made for p-p collisions and it's collaboration has many

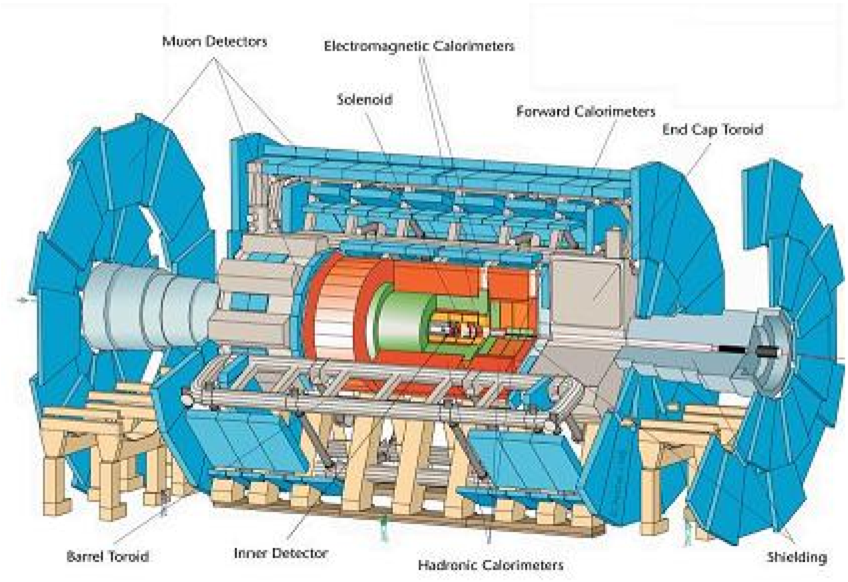


Figure 2.4: Schema of ATLAS detector [2]

research groups, the biggest one is Higgs group, which finding higgs boson, next one is top quark, they goal is measure its mass and qualities more precisely, the exotic group do research in physics out of Standard model or SUSY, for example the micro black holes or magnetic monopoles, SUSY has also working group and Standard model also and that is not all of them.

ALICE is only one detector on LHC which is primary orientated to the ion-ion collisions. So its main object of research is quark-gluon plasma and it is optimised for it.

LHCb is made for b-physic, particularly it will measure the parameters of CP violation in interaction of b-hadrons.

CMS has same goals as another detectors, to explore physics at the TeV scale, to discover the Higgs boson, to look for some evidence of physics beyond standard model (SUSY or extra dimensions). It's main power is in tracking muons and in his magnetic field, it has 4 Tesla. In picture pic. 2.5. we can see how the parts of detectors works with different particles.

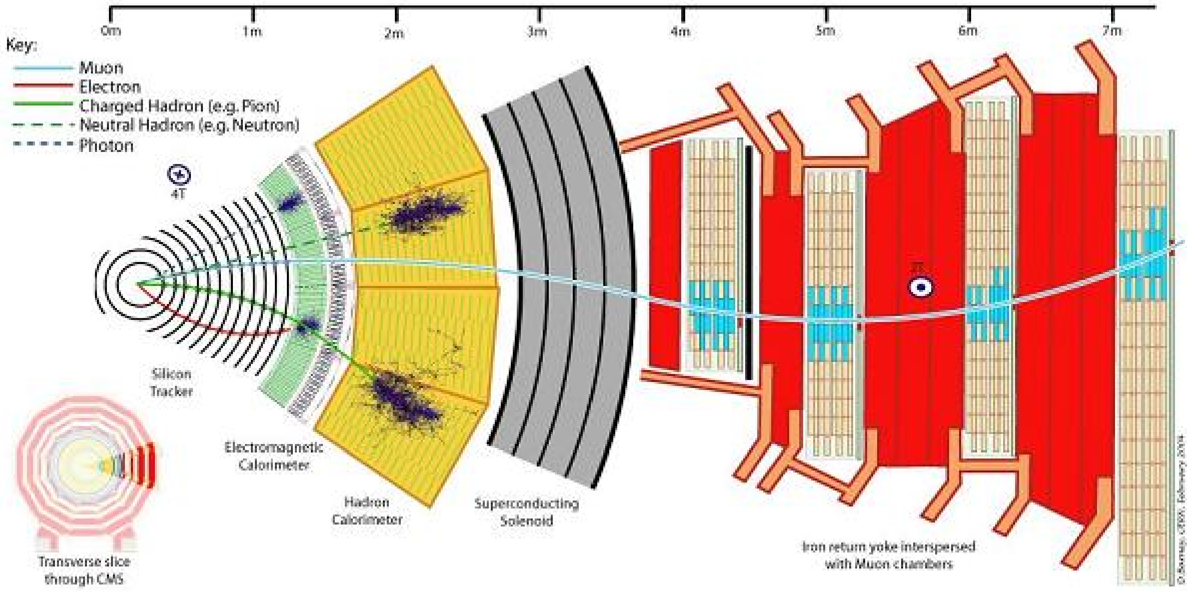


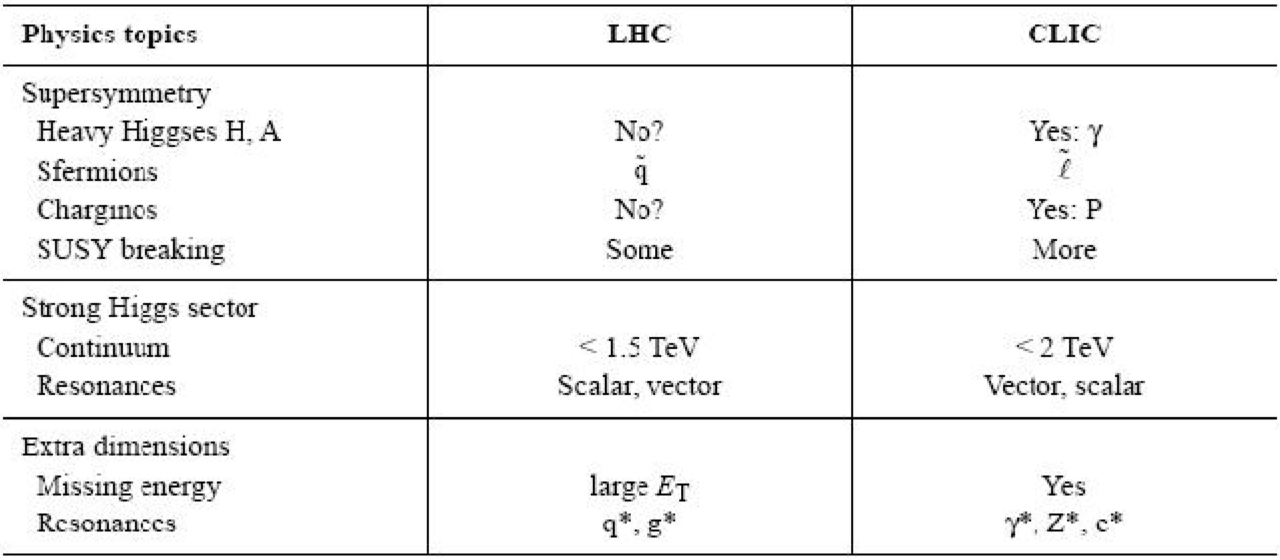
Figure 2.5: model of particle interaction in CMS detector [1]

2.4 Future experiment

That was today's detectors and LHC which will start in early 2009. But in this time we thing about what will came after LHC. For this we primary need to know which physics will be done in LHC, so in table 2.1 we can see that we can measure lot of physics but not all and not precisely, so we will need experiment with smaller background (for example CLIC). And the best way to this is using positron- electron collider, but there is problem with synchrotron radiation, so it must have linear accelerator as last part. There are two projects how to do it, one on which worked in CERN is CLIC (Compact Linear Collider), second is ILC(International Linear Collider).

2.4.1 CLIC

CLIC may have 1-5 TeV cms energy, now physicist are focused on 3 TeV version. This collaboration came with some new ideas. At first, they used second electron beam for accelerating positron and electron beams, as second they plans make collider for photons to and used high energy electron and positron for making it. All we can see in picture figure 2.6. [3]



Physics topics	LHC	CLIC
Supersymmetry		
Heavy Higgses H, A	No?	Yes: γ
Sfermions	$\tilde{q}$	$\tilde{\ell}$
Charginos	No?	Yes: P
SUSY breaking	Some	More
Strong Higgs sector		
Continuum	< 1.5 TeV	< 2 TeV
Resonances	Scalar, vector	Vector, scalar
Extra dimensions		
Missing energy	large E_T	Yes
Resonances	q*, g*	γ*, Z*, c*

Table 2.1: Table of physics which would be on LHC and CLIC [3]

2.4.2 ILC

But for us is more important project ILC, at first this project have bigger collaboration and mostly because they have more made, there done more works on detectors. But at first let's talk about accelerator, they to used preaccelerators for giving starting energy to particles and after that they have main linac. The main linac is made from superconducting cavities made from niob. The first test of this cavities will be XFEL laser, this X-ray source will use linear accelerator as source of electrons with high energy. It will be 3.2 km long and it will be in DESY. Start of building this project will be in 2008 and it will be make in 2013. The ILC will use experience from this experiment. All scheme of the ILC is very similar as CLIC. But for ILC we have some concepts of detectors. There was 4 concepts. They are GLD,LDC, SiD and 4th.

The physics to be studied at the International Linear Collider (ILC) encompasses a wide variety of processes over the energy region mass of Z^0 to 1 TeV. Key ILC physics processes include production of gauge bosons (W or Z), heavy flavour quarks (b and c), and/or leptons (e, μ,τ), either as direct products of e^+ e^- collisions or as decay daughters of heavy particles (SUSY particles, Higgs boson, top quark, etc.). For these studies, it is essential to reconstruct events at the level of the fundamental quanta, the quarks, leptons, and gauge bosons. The detectors at the ILC must identify them efficiently, and measure their fourmomenta precisely. [4]

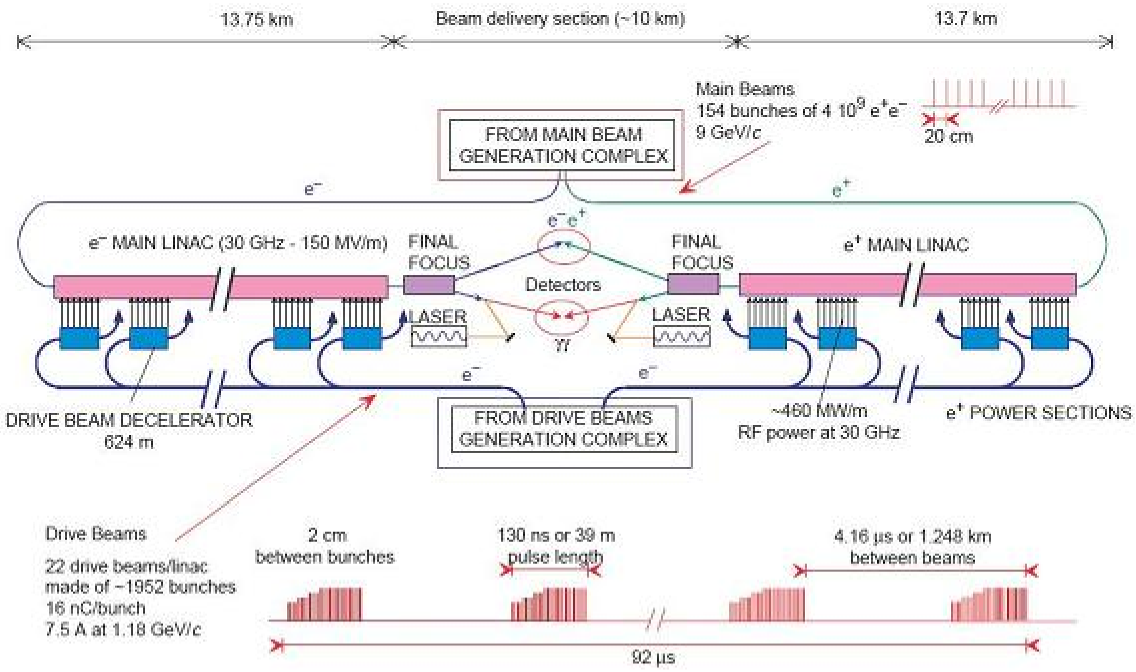


Figure 2.6: Scheme of CLIC main accelerator [3]

An in next sections we will describe, what is different in each detector concept and why.

2.4.2.1 GLD

In figure 2.7 we can see how is GLD concept.

When we go from centre to out, as first we meet vertex detector(VTX . The inner radius of the VTX is 20 mm and outer 50. It consists of three doublet layers. All of the concepts has pixel VTX, GLD VTX is based on fine pixel CCD, with pixel size 5 x 5 μm^2.

A TPC (Time Projection Chamber is used as main tracker of GLD. For better resolution we use inner silicon tracker between VTX and TPC.

The electromagnetic calorimeter calorimeter (ECAL consist of 30 layers of tungsten and scintillator sandwich. The light emitted in the scintilators will be detected by now developed multi pixel photon counter.

The hadron calorimeter consists from 46 layers of iron and scintilators.

There are also calorimeters for forward calorimetry, FCAL and BCAL. FCAL will consist of 55 layers of tungsten and Si sandwich. BCAl is not in this moment made.

Detector magnet is superconducting solenoid with field 3 Tesla.

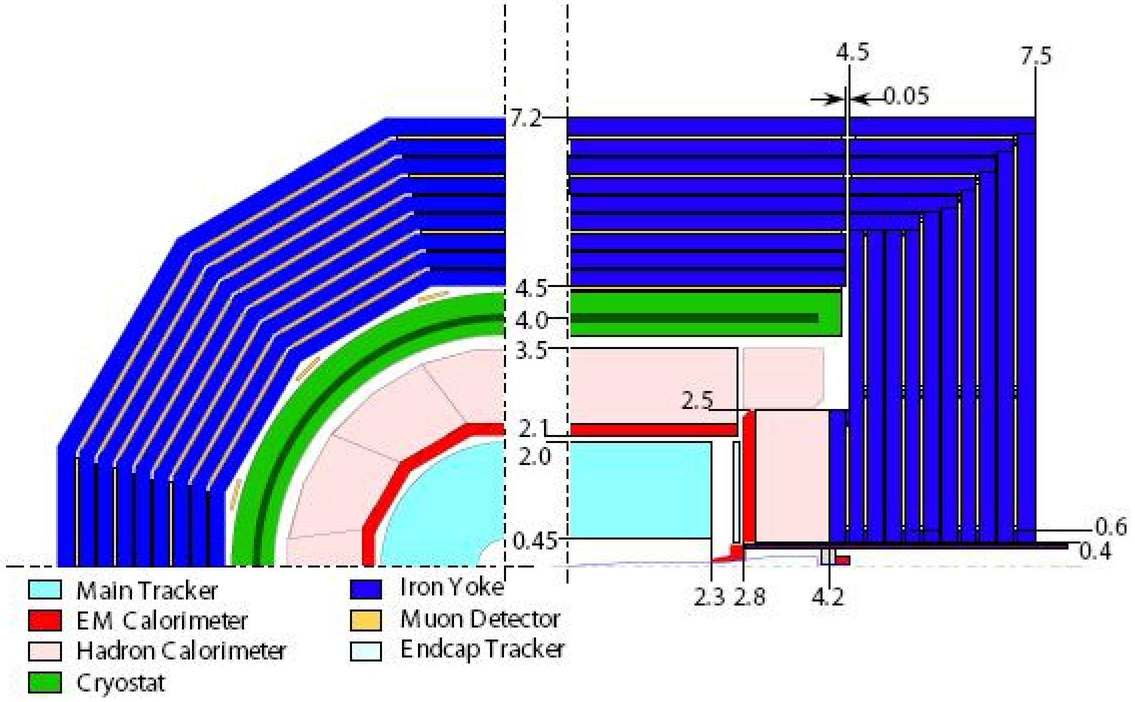


Figure 2.7: GLD concept [4]

After magnet is muon detector. It is inside of magnet flux return yoke. 9 layers of muon detector are placed between iron return yoke blocks.

2.4.2.2 LDC - The Large Detector Concept

Also in figure 2.8 is scheme of the one quadrant of the detector. We see that it looks same as GLD but it used some different choices. First big and the most important difference is that it use silicon tungsten sandwich for ECAL. We will talk more about this type of calorimeter in section 3. Now the GLD group and LDC group make new concept ILD-International Large Detector, but it is in progress so there are not much information about it.

2.4.2.3 SiD - Silicon Detector design study

In figure 2.9 is scheme of the one quadrant of the detector. It use same system of detector as GLD but it used some different choices. One of them is that it use silicon tungsten sandwich for ECAL. About this type of calorimeter, we will talk later in section 3. As next, this concept don't use TPC as a tracker, in this detector we choise Si Tracker, this type of tracker was used in CMS.

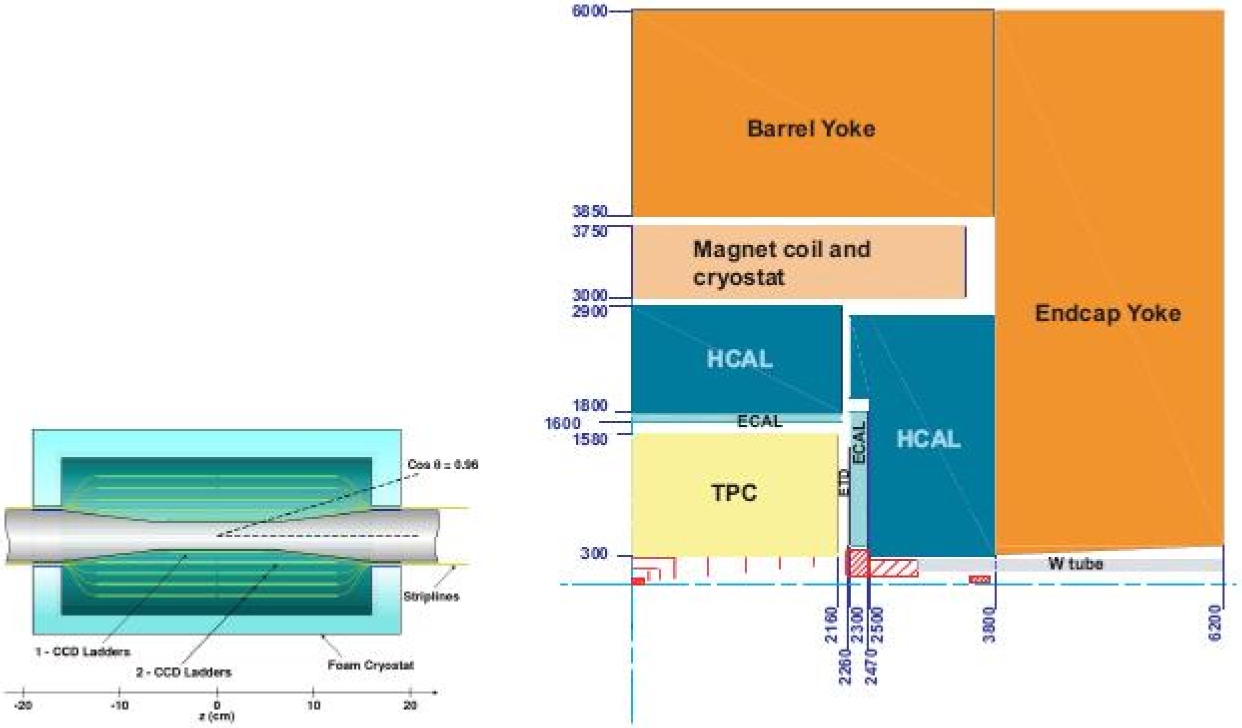


Figure 2.8: LDC concept [4]

2.4.2.4 4th - Fourth concept detector

The Fourth Concept detector differs from the other three concepts in several respects. It has three pillars an ultra-low mass tracking drift chamber, a dual readout calorimeter and a unique magnetic field configuration. But still it use canonic configuration of a detector. That are parts of a detector.

The VTX use same design as the SiD concepts.

The TPC include the He-based gas. The gaseous central tracker is a cluster-counting drift chamber modelled on the successful KLOE main tracking chamber.

The calorimetry use projective towers of dual-readout fibre sampling calorimeters, for measuring hadrons and leptons in shower separately. For leptons they use crystals and ECAL read both of Cerenkov and scintillation light. And HCAL use dual fibres, this type of calorimeter was used in DREAM calorimeter.

The magnetic field is make by two different solenoids with field 3.5 and -1.5 Tesla. It can measure muon momenta to high precision.

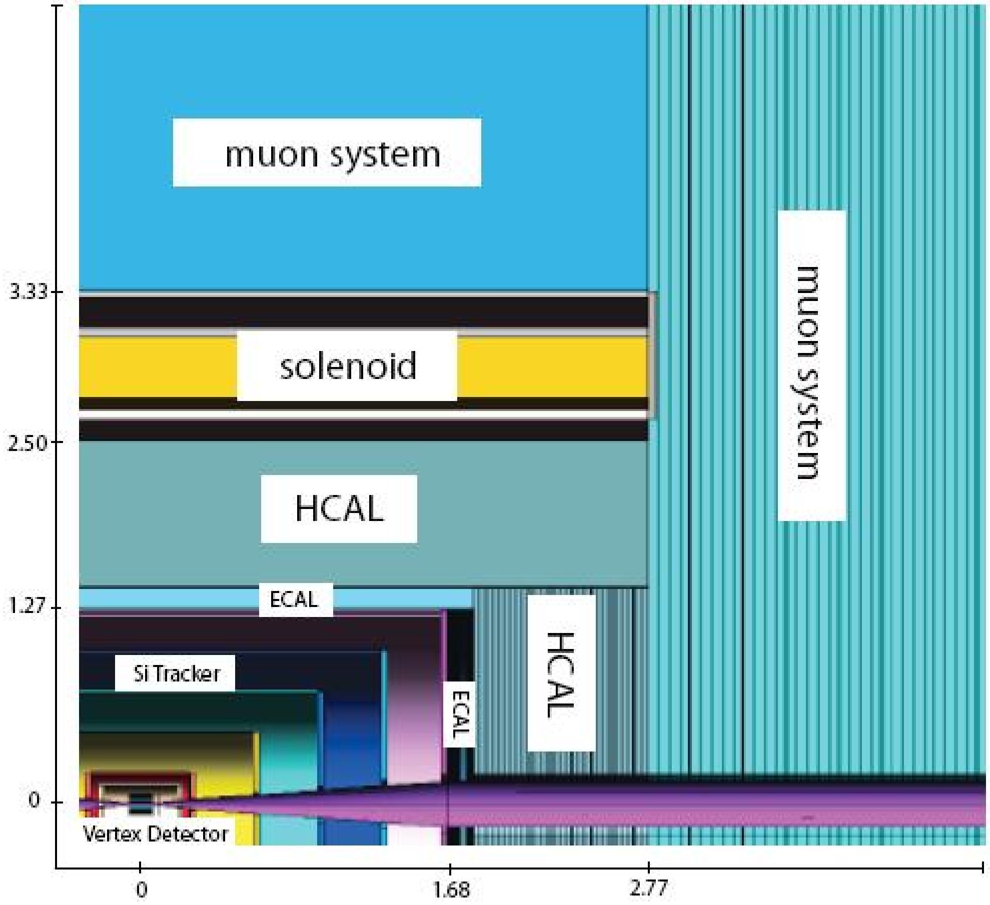


Figure 2.9: SiD concept [4]

2.4.2.5 Concepts summary

In the table 2.2 we can see table of detector concepts.

	GLD	LDC	SiD	4th
VTX	pixel	pixel	pixel	pixel
# of layers	6	5	5	5
# of disks	2	0	4	4
inner radius (cm)	2.0	1.6	1.4	1.5
outer radius (cm)	5.0	6.0	6.1	6.1
Main tracker	TPC/ Si	TPC/ Si	Si	TPC/ drift
inner radius (TPC/ Si)(cm)	45	30 (16)	20	20
outer radius (TPC/Si)(cm)	200	158 (27)	127	140
half length (TPC/Si)(cm)	230	208 (140)	168	150
# of TPC points	200	200	-	200/ 120
# of Si points (barrel)	4	2	5	
# of Si points (endcap)	7	7	4	
ECAL	Scint.-W	Si-W	Si-W	Cystal
inner radius (cm)	210	160	127	150
outer radius (cm)	229.8	177	140	180
half length (barrel,cm)	280	230	180	240
# X_0	27	23	29	27
HCAL	Scint-Fe	Scint - Fe	RPC/ GEM - W	fiber Dream
inner radius (cm)	229.8	180	141	180
outer radius (cm)	349.4	280	250	2.80
half length (barrel, cm)	280	230	277.2	2.8
# of λ	5.8	4.6	4.0	9
Magnet				
type	main	main	main	inner/ outer
field strength (T)	3	4	5	3.5 / -1.5
radius (cm)	400	300	250	300 / 550
half length (cm)	475	330	275	400/ 600
Overall Detector				
radius (cm)	720	600	645	550
half-length (cm)	750	620	589	650

Table 2.2: ILC concepts [4]

Chapter 3

Calorimetric systems

We use calorimeters for two main uses. One is to measure how much of energy they left in detector and second is their position. Because there are some difference how hadrons and leptons are deaccelerating, we have two types of calorimeters, electromagnetic for light particles, like electron or photon and hadron for hadrons. At first we have electromagnetic calorimeters, they can be smaller, because light particles has 1000 times bigger loses than particles with bigger mass, as hadrons in non-relativistic energies. Electrons has the biggest loses by radiation, which is dependent on square of the nucleus number of the material.

3.1 Electromagnetic calorimeters (ECAL)

There is many types of ECALs. That we can see in example of detector for ILC. It use two different ways, first use some material with small Moliere radius and after that some counter, like silicon pixel or scintillator, and second is all make from crystals and it detect light from deaccelerating the particles. The range of energies of electrons and photons suggests a thickness of about 24 radiation length for the ECAL.

3.1.1 Silicon Absorber Sandwich Calorimeter

This type of calorimeter use tungsten or lead like a absorber, because it has small Moliere radius, and that minimalize the transversal shower spread. Good example of this type of ECAL is made by CALICE collaboration. They used silicon tungsten sandwich. In figure 3.1 we can see how it is made. It has layers of tungsten and silicon sensor, with quadratic pads of 5x5 mm^2 size. The pads detector is not only one which we can use, we can use monolithic active pixel sensors, which is make by CMOS technology. They are cheaper then pads and in this moment CMOS is widely used in semiconductor industry.

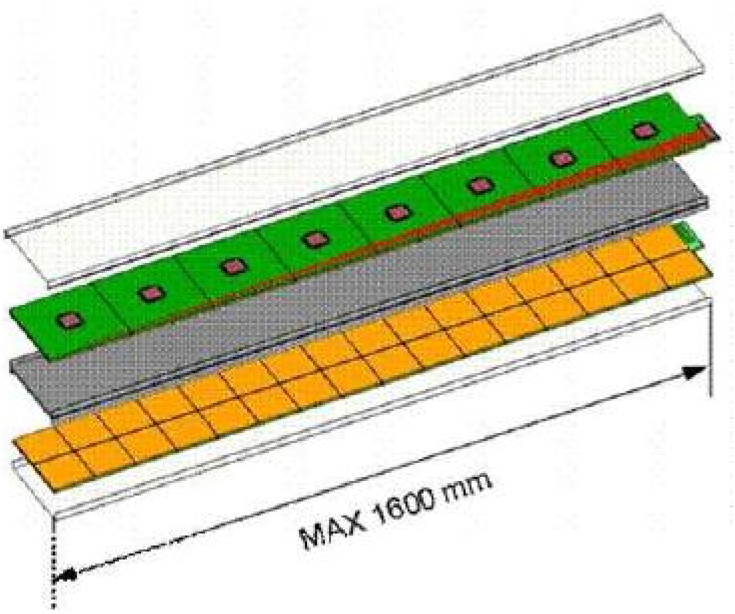


Figure 3.1: A single detector slab which will inserted into the ECAL support structure. The tungsten absorber plate (grey) is attached at both sides by silicon pad sensors with FE chips on top [4]

3.1.2 Scintillator Absorber Sandwich Calorimeter

For a calorimeter with a large radius, a finely segmented scintillator-based sandwich calorimeter may have a particle flow performance similar to a compact silicon-tungsten calorimeter,but might have lower cost. A group of Asian Labs within CALICE plans a sandwich calorimeter using plastic scintillator as sensor. Layers of scintillator strips, oriented perpendicular to each other as shown in Figure 3.2, are placed in between tungsten absorber plates. The effective segmentation given by the strip width is 1x1 cm^2. Each strip or tile is equipped with a wavelength-shifting fibre readout by novel Geiger mode photo-diodes, called here multi-pixel photon counter, MPPC.

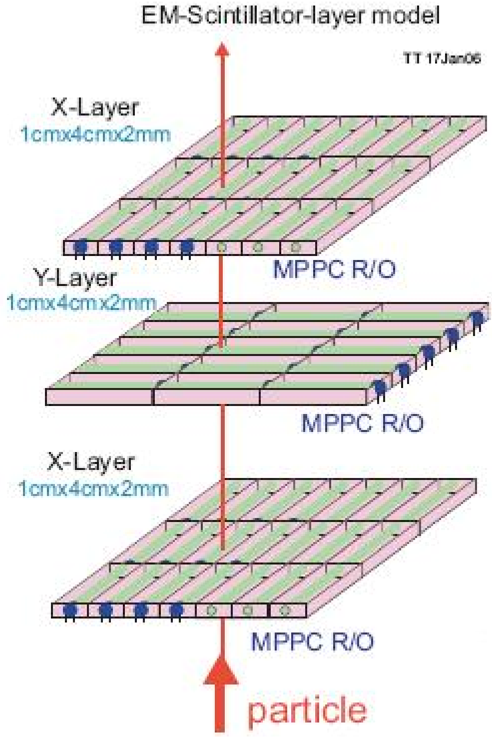


Figure 3.2: A possible strip sequence of the ECAL for GLD. Layers of scintillator strips are oriented perpendicular to each other. Each strip is equipped with a wavelength-shifting fibre(green) and readout by a MPPC(blue dots) [4]

3.2 Hadron calorimeters

Several technologies of fine-segmented sampling calorimeters are under investigation with either analog or digital readout. The analog read out calorimeters use scintillator tiles or scintillator strips as active part. Digital calorimeters use GEMs (Gaseous Electron Multipliers), Micromegas (Micro mesh gaseous structures) or RPCs (Resistive Plate Chambers) as sensors.

3.2.1 Analog HCAL

Analog HCAL use as active part the scintilators, and steel or lead as absorber. For readout is make by photo-sensors, in example of CALICE, they used Silicon Photo-multipliers, or they could used MPPC or else photon counter. The photons goes from scintillators to sensors by wavelength shifting fibres. In figure 3.3 we can see one way how can be layers of scintillators make.

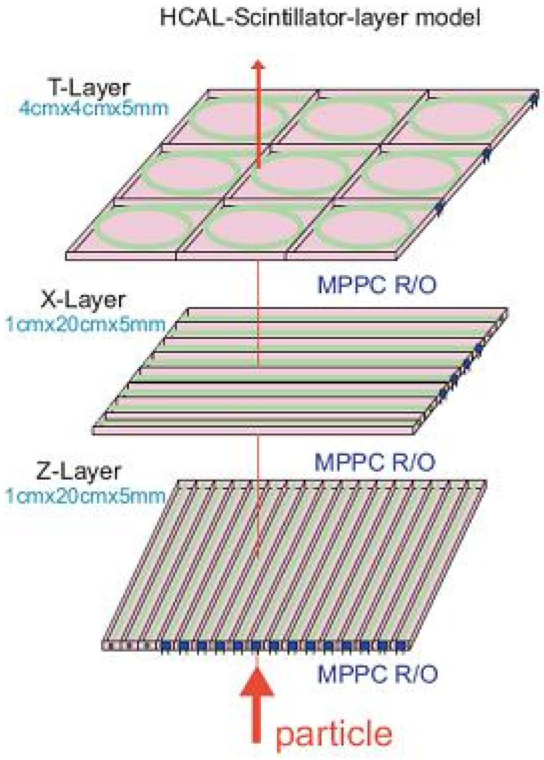


Figure 3.3: A possible tile sequence for the analog HCAL. The first two layers consist of scintillator strips which are in right-angle with neighbours layers, the third layer is made of quadratic tiles. Each strip and tile is equipped with a wavelength-shifting fibre and readout by a MPPC. [4]

3.2.2 Digital HCAL

Digital HCAL designs use gas chambers, they are thin and large. There are some basics designs of them, they are GEMs, Micromegas, RPCs and more. The chamber anode has small pads of about 1 cm^2 size.

In figure 3.4 is a structure of GEMs sensors. It created electric field between the cathode and the first kapton foil, so when particles ionized the electrons, they are forced to drift to the kapton foil. The kapton foil is metallized on both sides and perforated with holes of about 70μm diameter.

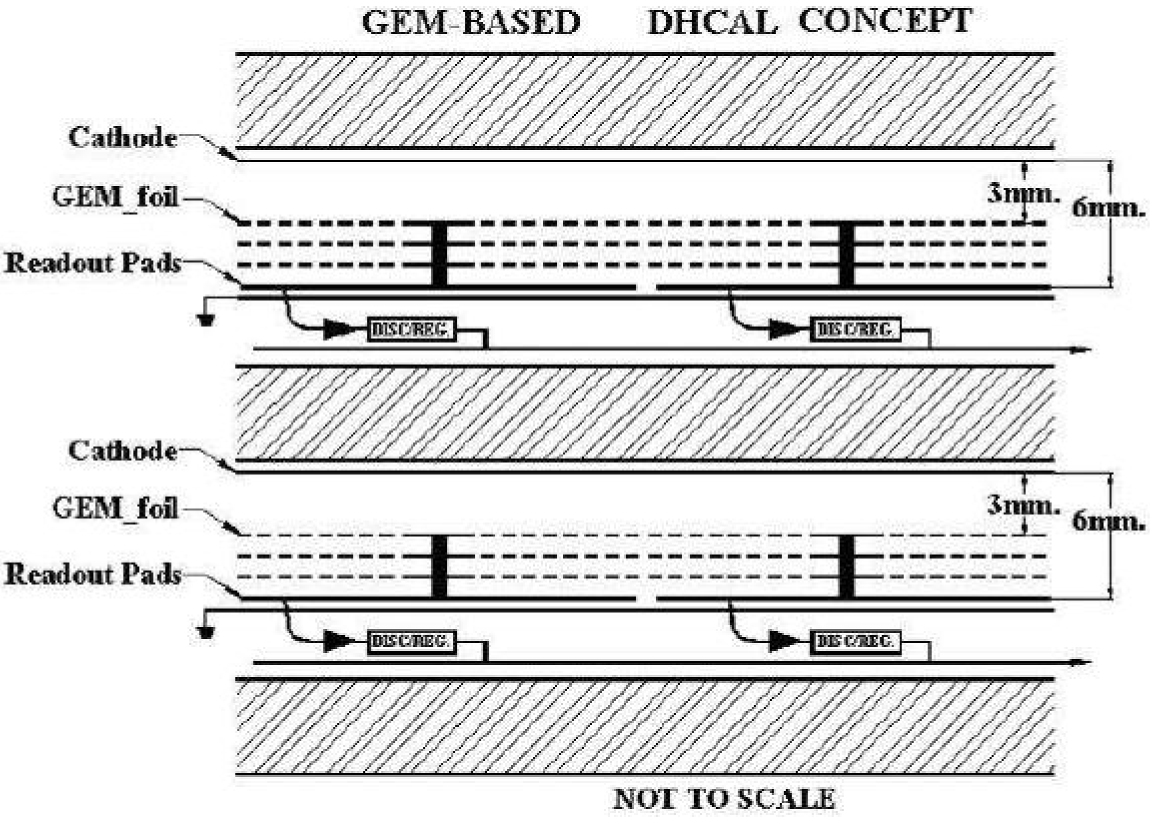


Figure 3.4: The structure of the digital HCAL equipped with GEMs. Gas amplification occurs in several layers of GEM foils. The signal is picked up from anode pads. The reading electronics unit is on the pad. [4]

Micromegas function is show in figure 3.5, it use drift of ionized particles in electric field. It can be very thin, about 4 mm.

3.3 Particle Flow Algorithm- PFA

Basic of PFA is the reconstruction of the four-vectors of all visible particles in an event. Present particle flow algorithms are best for energies of the individual particles in a jet are below about 100 GeV. The momentum of the charged particles is reconstructed in the tracking system with an accuracy which exceeds the energy and angle measurements

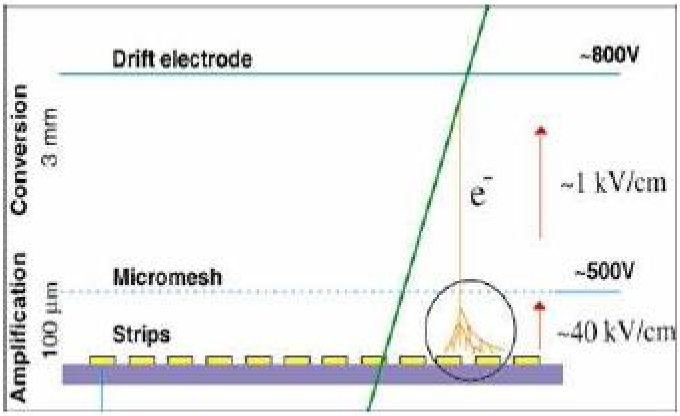


Figure 3.5: The working principle of Micromegas. Electrons from ionization drift in an electrical field to the mesh and induce an avalanche when crossing it. Signals can be picked up from anode strips or pads.[4]

in the calorimeters. Hence, in order to attain the best reconstruction of events, the charged particle measurement must be solely based on the tracking information, while the reconstruction of photons and neutral hadrons is performed with calorimeter system. The crucial step of the particle flow algorithm is the correct assignment of calorimeter hits to the charged particles and the efficient discrimination of close-by showers produced by charged and neutral particles. [4]

Chapter 4

Silicon pad sensors for detection of particles showers

This chapter is about test's of the detector concepts. I focused on Si-W ECAL for which I made analysis of one run.

4.1 Test beam in CERN 2006

The CALICE Collaboration has built prototypes of such calorimeters and operated some of them in test beams in 2006 with the aim to establish the technology which allows these high granularities and to study the one structures of particle showers to benchmark and improve existing shower models and reconstruction algorithms.

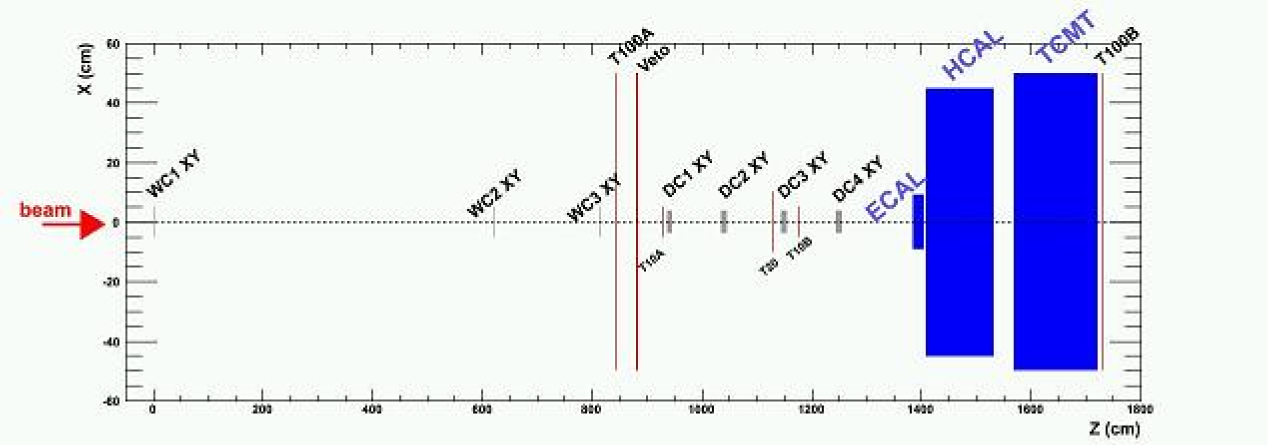


Figure 4.1: Scheme of test beam in CERN 2006 [4]

In figure 4.1. is scheme of the test beam. It has few parts, ECAL with 30 layers of tungsten and 30 layers of silicon detectors, first 12 layers don't have one third of them(figure 4.3), HCAL with 29 layers of absorber and with 15(23) active modules. After that there was tail-catcher and muon-tracker (TCMT). This apparatus was installed in CERN SPS Test Area and took took data from electron, muon, and pion beams during two periods in summer 2006.

4.2 Test beam data analysis

4.2.1 Data structure

Test beam data are available in three variants. First of them is binary, also called native format. It is lowest level data available, basically it is direct binary output from the data acquisition system. Next are raw LCIO files, which are native data converted to the LCIO format. They contain for example ADC values and trigger FIFO. The third and most processed are reconstructed files which contain nothing less than collection of hits and their corresponding positions and the deposited members. [6]

4.2.2 Data analysis

The ing. Michal Marčišovský wrote a program which covert data from LCIO to root files, based on Marlin processing framework, end from this root file I made analysis in which I used histograms. I used data from ECAL runs with muons. They are this runs: 330523 and 330613. Both was muon runs with energy 80 GeV and they has 250 000 events.

4.2.2.1 Deponeted energy

In figure 4.2 is a histogram which show distribution of energy in this runs. Muons are important, they represent so called Minimum Ionizing Particles (MIPs) and they do not usually create electromagnetic showers and they deposit only a nicely defined spectrum of energies, which is described by Landau distribution. The peak on the left side of the plot represent noise of electronics.

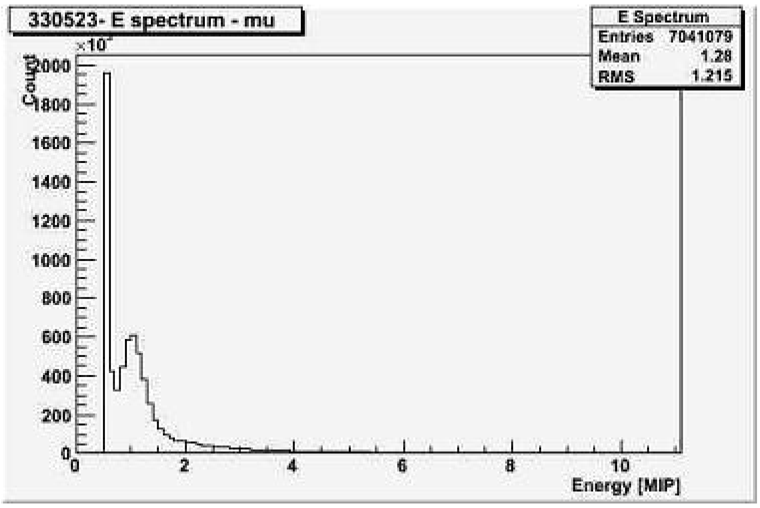


Figure 4.2: Spectrum of measured energies in run 330523

Next figure 4.3 is a map of hits to the detector. We can see lost labels.

4.2.2.2 Hits to the layers

In figure 4.4 are maps of deponeted energy. In the layer 0 we see missing part of the detector but other parts work very good. In layer 5, we see that this layer has small responds to the beam, it could be because of high level of noise or it is in bad contacts. When we look to other runs we see that this is systematic, it is same as two areas with the hier level of responds. Next is layer 17, this is almost good layer, just first part of them has a smaller respond, so we measured lower energies. At last layer 29, this layer has dead pixels on the top, also it has problem with reading of energies in border areas.

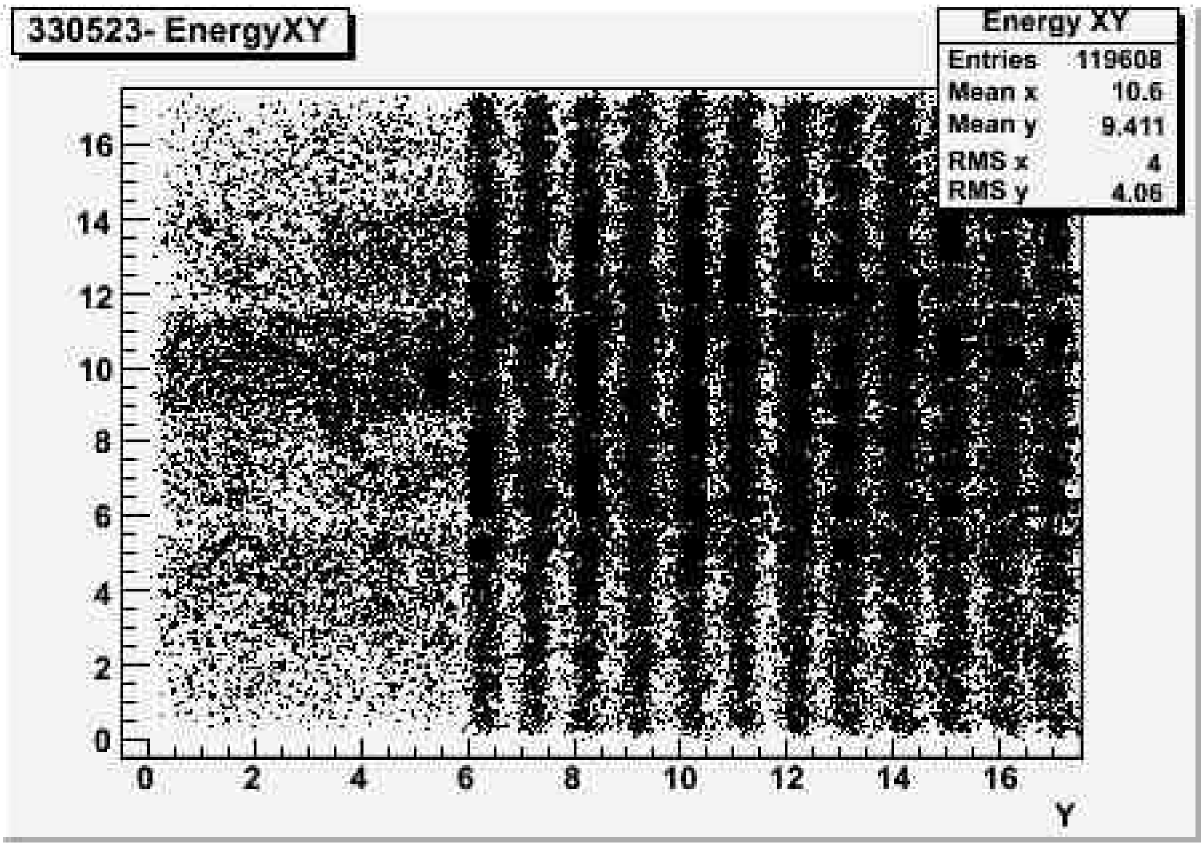


Figure 4.3: Map of the hits of the detector

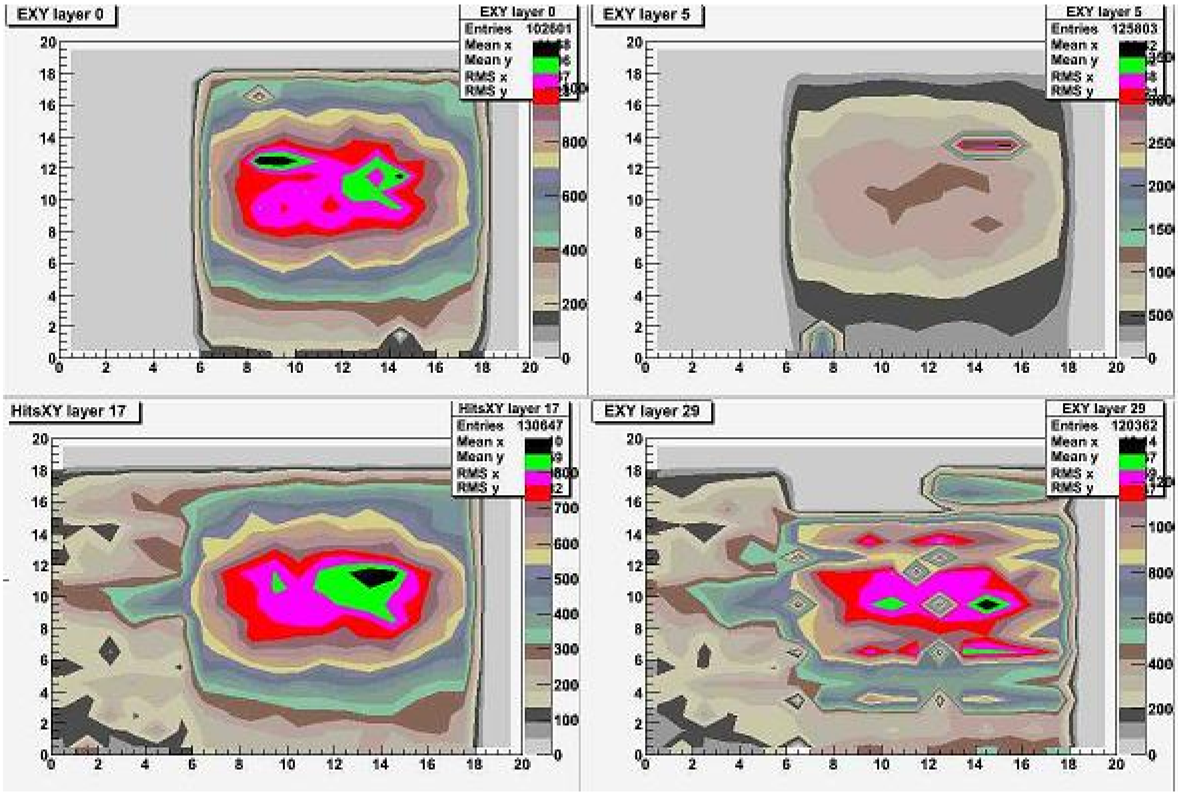


Figure 4.4: Map of the hits in label 0,5,17 and 29

Chapter 5

Conclusion

In this thesis are presented following results and conclusion:

- We expect discovery of new physics on LHC and for more precise measurement of them, we will need new collider, the best one is electron positron collider as CLIC or ILC.
  - The physics in ILC or CLIC give us some reqirements for the detector. In this work I descibed parts of the detector and show some of today's and future detectors. The focus was on detectors for ILC.
  - The one of important part of detector is calorimeter and I described his function and main difference between ECAL and HCAL.
  - The SiW ECAL is one of possible candidate for part of ILC detector. This work show how it is working and how it was testing. From this test beams I made some basic analysis and confront them with other conclusion in the CALICE colaboration.

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