Simulation Study of GEM Gating at ILC-TPC

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The feasibility of GEM gating under LC-TPC condition such as high magnetic field and high $\omega\tau$ gas has been studied by simulation. We found the best electron transmission is 70% at a current condition due to the high magnetic field.

1 Introduction

Future ILC experiment is a dedicated experiment for precise measurement of nature of Higgs particle and beyond the standard model with its clear experimental condition comparing to Hadron experiments. However beam bunch trains squeezed to the order of nano meter at the interaction point introduce various beam background as well as physics background such as two photon processes. Time Projection Chamber(TPC) is one of candidates for tracking system in ILC detector concepts.

TPC suffers huge background activities such as photon and neutron as well as charged particles during bunch train crossing at IP (1msec) every 200msec. It takes 50μsec for electrons to drift a full length of drift distance(2m), while ions take 10^4 longer time than electron. As ions cannot be swept away from TPC drift region before the next beam train, they will be piled up by following bunch trains. But the most of ions are produced at gas multiplications and these ions must be blocked at the gate device near the sensor which has to transmit electrons from drift region to the sensor when gate is open. Gate system must be about 1cm above a gas amplification device in order to hold all ions produced at gas multiplications during 1msec beam collision.

F.Sauli had applied Gas Electron Multiplier(GEM) [2] as a gating device by just reversing the electric field in GEM hole when Gate is closed. The electron transmission is the key issue for this and has been measured for several gas mixtures and two different GEM [3]. He shows the clear improvement in the electron transmission at a low voltage operation by changing a hole radius larger(Figure 1-a). The best transmission is 70% at 10 volts for 50μm thick GEM with 100 μm diameter hole and 150 V/cm, 300 V/cm for a drift and transfer field in Argon CO_2 gas mixture(70:30).

2 Method to understand electron transmission

We have tried to understand a mechanism of this improved electron transmission at low V_{GEM} operation and hope to find a reliable gate condition for LC-TPC. In order to understand behavior of a electron transmission, it is divided into two factors, a collections efficiency and extraction efficiency. Each efficiency is evaluated by GARFIELD [4] simulation based on 3 dimensional electric field map calculated by Maxwell3D [5].

The collection efficiency is defined as the number of electron reach to a entrance of GEM hole divided by the number of generated electrons uniformly over a cell unit at $500\mu m$ above GEM surface, while the extraction efficiency is defined as the number of electrons which could come out from holes divided by the number of electrons reach to hole entrance. Electric field is calculated 500 μm above and below GEM as well as its inside.

When we use Garfield, STEP size is always defined by a length, where STEP size is an interval to update electron position in Garfield. In Monte Carlo simulation, results of calculation sometime depend on a choice of STEP size especially under rapidly changing field. After studies of efficiency dependence on a step size, we compromised to choose 2μm because it seems to provide a result close enough to one with a finer step size, and we could not choose finer step size due to the limited maximum number of steps.

Though we try to use a precise field map with fine elements, GARFIELD could only accept $\mathcal{O}(10^5)$ elements. A systematic difference in the extraction efficiency at higher field is still observed when we change a size of elements by twice larger under the same geometry. While the collection efficiency is not sensitive to the element size as electric field associated to this effect is lower. As the gating GEM is used at low voltage, the limited number of elements seems not to be a big problem here. But we have to notice these calculations always include an ambiguity, but it must not exceed 5%.

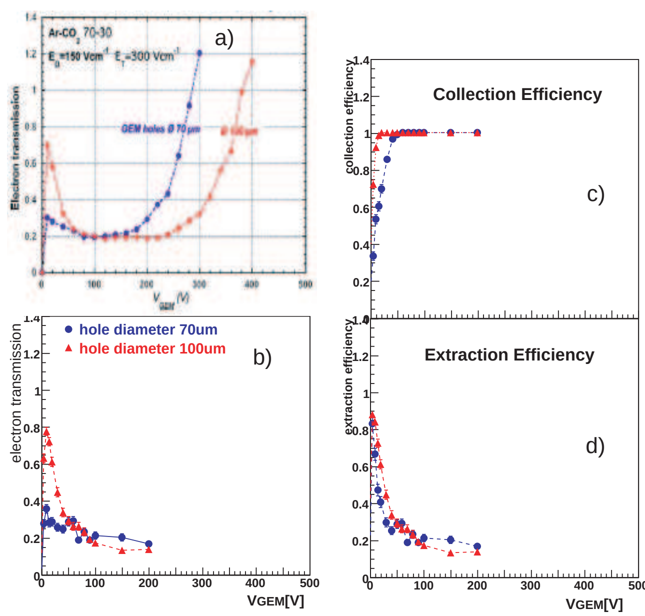

Figure 1: Comparison of electron transmission between Sauli's data (a) and simulation(b). (c) and (d) show collection and extraction.

3 Comparison to experimental results

Comparing to the Sauli's data of $Ar : CO_2 = 70 : 30$ with 2 different hole sizes, the electron transmissions are well reproduced by the simulation quantitatively below 150 volts in

V_{GEM} though above 150 volts results of simulation are different (shown in Figure 1) as they don't include gas amplification effect, where 150 V/cm and 300 V/cm is applied for drift and transfer regions respectively. GEM with 100 μm diameter hole provides 70∼80 % efficiency in the electron transmission at 10 volts in V_{GEM} though the standard GEM provides less than 40% transmission at the best. This difference can be attributed to the different behavior of the collection efficiency largely depend on a hole aperture. A behaviour of the collection efficiency has been studied by Aachen group based on a ratio of hole filed(E_h) to outer field(E_d) [6] and our result is also well explained by this.

The extraction efficiency is rather complicated. The area of field lines passing through GEM hole is shrunk as E_h and the effect of transverse diffusion become important. Electrons are easily get out from the area of passing-through field lines due to the diffusion and move along returning field line to the bottom electrode of GEM. It explains why extraction efficiency decrease as E_h. On the other hand very low E field ($E_h \sim 0$), the diffusion is very large where electrons can reach to wall of the hole and decrease the extraction efficiency.

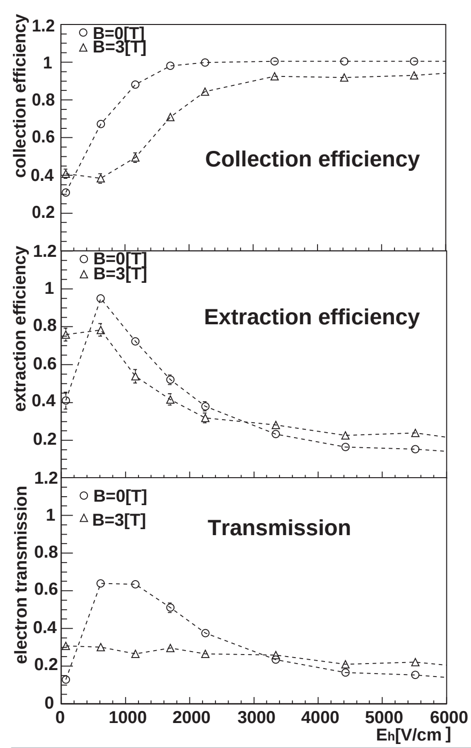

Figure 2: Collection and extraction efficiency and electron transmission under magnetic and non-magnet field for $ArCF_4$ with $100\mu m$ diameter hole, $E_d = 150V/cm$ and $E_t = 300V/cm$.

4 Effect of magnetic field

When we use TPC at Linear Collider experiment, the strong magnetic field is necessary for a good jet energy resolution ensured by neutral-charged particle separation for Particle Flow Algorithm as well as for a good local position resolution due to low transverse diffusion. In order to achieve $100\mu m$ accuracy for 2 m long drift, $ArCF_4$ gas mixture is a promising candidate for LC-TPC.

$ArCF_4$ provides a good transmission under 0 magnetic field as shown in Figure 2. However, once 3 Tesla field is applied, transmission becomes below 40% because the collection efficiency become very worse at low E_h (distribution seems to be shift to higher E_h).

The degradation of the collection efficiency seems to be coming from $E \times B$ effect when electron move towards holes near the GEM surface. $ArCF_4$ gas provides large Lorentz angle to electron drifting under non parallel electric and magnetic field which disturb electron motion toward hole center and increase a chance to be absorbed at the upper electrode of GEM. Increasing of E_h field initiate this electron motion high above the GEM surface and increase a probability of electron going into a hole.

Comparing to the case witout magnetic field, the extraction efficiency is increased at low $E_h \sim 0$ due to the low transverse diffusion under magnetic field. It is less at $E_h < 2000\,V/cm$ as a electron does not follow electric field line and may move into hole at a distant place from the center due to $\mathrm{E} \times \mathrm{B}$ effect. But it is increased again at high E_h due to the same effect happened at the collection efficiency.

Under 3 Tesla magnetic field, we can obtain 60% electron transmission with E_d=50 V/cm which results in a unacceptable low drift velocity for LC-TPC. However these results are based on a standard GEM which is developed as gas multiplication device and there must be a room to optimize GEM itself and a operation condition as a gate specific device.

5 Optimization of GEM

Parameters we can change in GEM itself are 1) hole size/pitch, 2) hole shape and 3) GEM thickness(insulator thickness and metal thickness). However there are limitation of parameter space in each items mainly due to production techniques.

5.1 Hole size/pitch

Making hole size larger in the same pitch seems to improve the collection efficiency at low E_h region due to a geometrically lager hole aperture. However hole size in the same pitch limited by technical reason when GEM is produced in any kind of etching. While hole pitch is related to local resolution as local position information of each electron will disappear through hole due to diffusion and ExB effects. We cannot enlarge pitch size unlimited. The best local resolution achieved in the similar condition is about 50μm at zero drift distance and pitch/$\sqrt{12}$ should not beyond this number.

5.2 Hole shape

Shape of hole is largely depend on processing method when holes are drilled. Chemical etching used to produce bi-conical shape hole, while dry etching provide more straight cylinder like hole. When magnetic field is not applied to the detector, hole shape would not affect to the extraction efficiency as almost electron pass though near central region of hole. But electrons can pass through near a hole wall under magnetic field and straight hole provide slightly better extraction efficiency.

5.3 GEM thickness

Thickness of insulator is related to a chance of electron absorption at a wall of hole because a transverse diffusion of electron increase as traveling distance. 25μm-thick insulator improves transmission by 10% and 12.5μm does another 10%. Electrode thickness also contribute to a total length of hole and improves transmission by 10% reducing thickness to 1μm from 5μm. A production of very thin GEM would not be easy, but it is worth trying if obtained result is good enough.

5.4 Operation condition

GEM operation is determined by the field at drift and transfer region and V_{GEM}. E_d is determined by the drift velocity and diffusion of electron in order to obtain the best performance of TPC. The transmission is largely depend on a gas property(transverse diffusion as a function of electric and magnetic field) as well as the field ratio. E_d has the largest contribution to the transmission. When E_d is reduced to $100V/cm$, you will get another 10% increase.

In any case, back-drifting ions are blocked more than 99.9% when a reversed V_{GEM} is applied to the gating GEM by 10 volts.

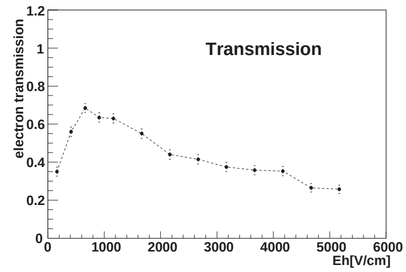

Figure 3: The best electron transmission with a special GEM having $12.5\mu m$ thick insulator and $1\mu m$ thick electrodes.

6 Summary

We may achieve 70% electron transmission with very thin GEM gate under LC-TPC operation condition. We are not sure this number is acceptable or not but we need some more improvements as well as experimental understanding of GEM gating scheme rather than just a simulation.

7 Acknowledgments

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