SIMULATION OF THE FINE MESH PHOTOMULTIPLERS IN THE TOF OF AMS-02

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The photomultiplers Hamamatsu R5946 "fine mesh" have been simulated in order to understand their behavior in magnetic field, in view of their use in the TOF system of AMS-02 experiment, a cosmic ray spectrometer to be operated in space after 2005. The simulation, compared with the data taken, has been a usefull tool in finding a proper calibration procedure in the laboratory, calibration whose results are crucial for the final phototubes displacement on the whole TOF structure.

1. Introduction

The *Alpha Magnetic Spectrometer* (AMS) is the first large particle detector that will be installed on the International Space Station and will measure cosmic ray fluxes for at least three years in a low orbit (about 400 km) around the earth[1]. It will detect rigidities up to 2.5 TV, by using a superconducting magnet which will provide a maximum field of 0.87 T[a]. The photomultiplier tubes of the plastic scintillator Time Of Flight System of AMS-02 will operate in the strong (2-3 kG) and badly shaped fringing field of the dipole magnet[2]. That led to the choice of the R5946 Hamamatsu "fine mesh" tubes, for their intrinsic capability of tolerating the magnetic field[3]. Since the year 2000, a simple model of the fine mesh photomultipliers was used to understand their time behavior in magnetic field. Later the model has been refined to reproduce the gain characteristics. Finally, the model–data permitted to identify the main parameters to look for during calibration.

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[a] The detector is nicknamed AMS-02 (TOF-02) in the following.

2. Fine mesh simulation

Since the year 2000 a proper simulation of the Hamamatsu fine mesh has been developed with the aim of understanding the time response of the PMs just tested in magnetic field. The data taken and the result of this first simulation (properly tuned for the purpose) have been shown at the ICRC 2001[4]. Later a complete simulation, of both the single photoelectron response and the gain in magnetic field, has been implemented[10].

In the following the model on which is based the complete simulation of fine mesh PM is given and some features of it are described.

2.1. *The model*

The basic model of the fine mesh simulation starts with a single photoelectron (phe) extracted from a random point at the surface of the photocathode. Then, the phe is followed, solving the equations of motion with electric[b] and magnetic field, up to the first dynode: during its way, it can miss the first dynode surface and is lost. The cathod–first dynode distance is 3.4 mm and the voltage drop twice that for the following 16 dynodes whose spacing is 0.9 mm[c]. The electron impinging the first dynode surface extracts secondaries, up to a maximum number, when all the avaiable energy is over. Therefore the simulation implements multiplication on an energy basis[d]: in the energy computing, it's followed the phenomenological distribution of the secondary electrons shown in Fig.1, taking into account the energy given to the whole lattice and the minimun energy threshold for extraction. This threshold energy depends on the angle of incidence of electron on dynode surface[e] and consequentely is related to the angle θ between $\vec{B}$ and the PM axis, because at high θ there are more inclined electrons that seem to extract more easily (see Ref.[8]).

The dynodes are a planar mesh of orthogonal wires (Fig.2 shows a mesh). The photoelectron can thus pass through a hole of the first dynode, without extracting secondaries[12], and go to the following stage[f]. It has been implemented this possibility as an overall probability (namely the

[b]Assumed uniform to semplify the model.
[c]The partition ratios beeing 2:1:1:1:1:1:1:1:1:1:1:1:1:1:1:1:1:1
[d]Not using a poissonian distribution of secondaries as in other models simulated previously (see the one described in Ref.[7]).
[e]Being θ_{inc} the electron angle of incidence on mesh surface, the energy threshold is written as a function of θ_{inc}, around the work function of the mesh material.
[f]And this is valid for each stage, even if is more critical for the cathod–first dynode stage[10].

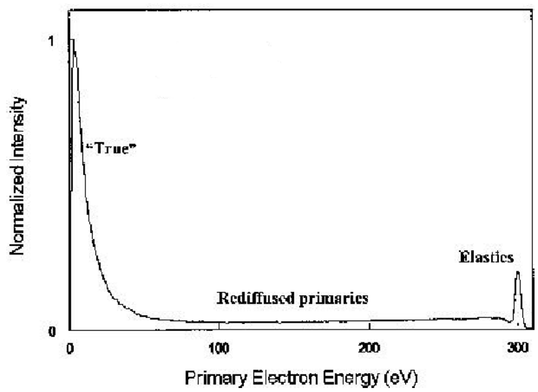

Figure 1. Phenomenological distribution of Secondary Electrons Emitted (SEE) energy at the dynodes for an electron of 300 V (see Ref.7)

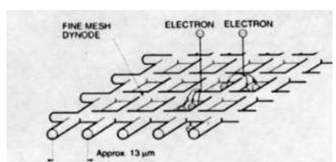

Figure 2. Structure of a fine mesh dynode (see Ref.3)

"transparency" T) whose value has been tuned on real data and which is described in the next paragraph. After the first dynode, each extracted electron is followed up to the second dynode, and so on, solving equation of motion for each electron (getting lost those outside the dynode boundaries and considering the effect of the transparency) and following the multiplication avalanche[g] up to the anode.

2.2. *The "transparency" and the single photoelectron response*

The transparency parameter T has been found very efficient to tune our model on the experimental data. The experimental gain as function of the High Voltage is fitted assuming a linear dependence of T on the voltage drop

[g]A proper indexing algorithm is used in order to minimize the program vectors dimensions.

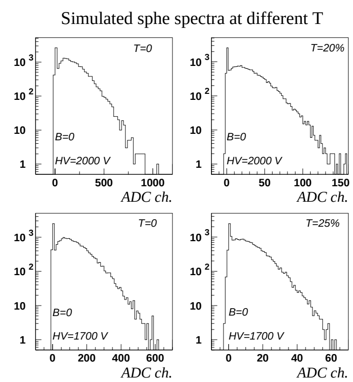

Figure 3. Simulated sphe response at different T and B=0. The peak of the single phe signal is well separated at zero transparency, but not at T$\sim$ 20%: the electrons who skipped the dynode do not multiplicate, resulting in a lower gain.

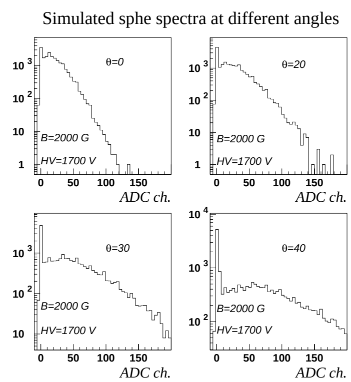

Figure 4. Simulated sphe response at different angles θ, HV=1700 V and B=2000 G. As you can see, the sphe resolution degrades notably as the angle increases (and this almost independently on the B-field magnitude).

between dynodes: at higher voltage electrons are directed more efficiently on the electrode wires and the transparency decreases. The overall mean value of T is tuned to reproduce the single photoelectron response. In fact, the model at $T = 0$ gives the typical "dimple" observed in non fine mesh photomultiplierss, whereas for $T \sim 20\%$ our model can reproduce reasonably well the shape for R5946 tubes (see Fig.3).

Finally the T parameter can be tuned to reproduce the behaviour of the "fine mesh" in magnetic field. This is shown in Fig.4 for the single photoelectron (sphe) spectrum. The effect of the magnetic field is double: on one side as θ increases more and more electrons are deflected outside the dynodes area and are lost, degrading the sphe resolution[h]; on the other side the transparency T depends geometrically on the electron angle of incidence (θ_{inc}) on the planar mesh[i] decreasing for high inclined electrons.

[h]Defined as the $\frac{\sigma_{peak}}{peak}$ of the 1-started phe final gaussian distribution.

[i]$T \propto cos\theta_{inc}$

2.3. *The PM time response in magnetic field*

The time of each electron in the simulated avalanche can be recorded. The anode distribution of the the transit time[j] simulated are compared with the data taken of two PMs (low gain and high gain) in Fig.5, for a magnetic field of 3000 Gauss and at different θ angles. From these plots, the conclusion is that the transit time worsens with the angle, critically for PMs working at higher voltage. Moreover, the transit time itself, at $B = 0$, is higher for the high gain phototubes[k].

2.4. *The PM Gain in magnetic field*

From the simulated single photoelectron distribution, in the case that just 1 phe has been extracted from the cathode, it is possible to calculate the gain, which is by definition the number of final electrons at the anode. In absence of a correct function which can describe the fine mesh single photoelectron spectra, it can be assigned their mean value to the gain. In this way, various gains have been simulated at various B-fields and at various θ. The results of the simulation compared to the data taken are shown in Fig.6: the phototubes show a higher gain with the angle, up to a limit (almost 40 degrees) over which the gain has an abrupt fall; this almost independently on the intensity of the B field, as both data than simulation results show.

3. Conclusions

A complete fine mesh simulation has been shown, of both timing than gain characteristics, in magnetic field and at various inclination θ of the PM axis in the field. From the simulation results, together with the data taken, it is clear that a calibration procedure based on the usual fit of single photoelectron spectra, is no more applicable, due to the influence of the “Transparency” on the whole distribution. Those difficulties widen with increasing B-field and angle θ, and they are particularly critical for PMs working at higher HV, because one cannot increase freely their tension, which has shown to be the best treatment. The politics chosen by the TOF of AMS-02 is that of putting high gain PMs at the critical positions, after a calibration properly tuned for the fine mesh (not based on single

[j] Transit time is defined as arrival time at $B \neq 0$ minus the arrival time at $B = 0$
[k] Of a factor of about 2 ps/Volt (from both data[4] than simulation[10])

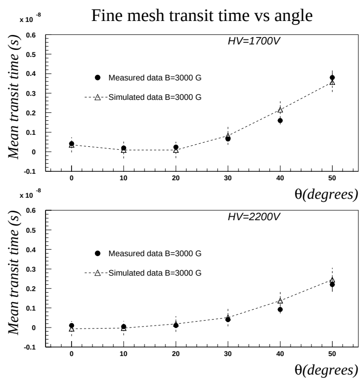

Figure 5. Measured and simulated transit time of two different PMs in a magnetic field of 3000 G as a function of the angle θ. High gain PM on top picture, low gain PM on bottom.

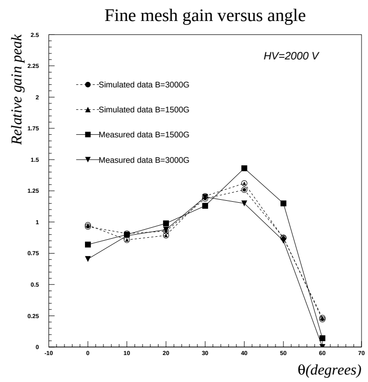

Figure 6. Measured and simulated relative gain of fine mesh response at various angles θ and B-fields. The data and the simulation show an increasing gain with the angle up to almost 40 degrees.

photoelectron fitting functions at all), whose tension can be, during the three years on ISS, increased as necessary to contrast the worsening of their time characteristics.

References

1. The AMS collaboration, Physics Reports, vol. 366/6 (Aug.2002), pp.331- 404.
2. C.Sbarra *et Al.*, "The Time of Flight System of the AMS-02 Space Experiment", Proc. of the 7th ICATPP (2001). Printed by World Scientific.
3. Hamamatsu Photonics: "Photomultipler tube R5946", 1994.
4. L.Brocco *et Al.*.,"Behavior in strong magnetic field of the photomultipliers for the TOF system of the AMS-02 space experiment", Proc. 27th ICRC (2001).
5. B. Bencheick *et Al.*., **NIM A 315** (1992) 349.
6. C.Sbarra, AMS-BO Int. Note (2002)
7. G.Barbiellini *et Al.*, "A simulation study of the behaviour of fine mesh photomultipliers in magnetic field", **NIM A 362** (1995) 245-252.
8. R. Chechik *et Al.*.,**WIS-93**/63/Jul-PH (1993).
9. C.Sbarra, "Comparison between fit functions of simulated Single Phe spectra", AMS-BO Int. Note (2003).
10. Amati L. *et Al.*, "Simulazione dei fotomoltiplicatori "fine mesh" per il TOF di AMS-02", presented at the LXXXIX SIF (2003).
11. Amati L. *et Al.*, "Algoritmo genetico per l'ottimizzazione dei fotomoltiplicatori del TOF di AMS-02", presented at the LXXXIX SIF (2003).
12. I Chirikov-Zorin *et Al.*, **NIM A 456** (2000) 310-324.