News from HELLAZ
(dedicated to Tom Ypsilantis)

P. GORODETZKY
PCC - Collège de France, IN2P3 / CNRS, 11 place Marcelin Berthelot
75005 Paris, France
E-mail: philippe.gorodetzky@cern.ch

on behalf of the HELLAZ collaboration
(J. DOLBEAU, T. PATZAK, P. SALIN, A. SARRAT and J.C. VANEL)

ABSTRACT

Tom Ypsilantis invented the HELLAZ concept some 10 years ago. He died last August and it is a terrible loss for all of us. I'll try to honor his memory by showing how HELLAZ was born and what is its present status.

1. Tom and HELLAZ

I have known Tom for the last ten years, mainly in building 29 (LAA) at CERN. He died last August, at the age of 72 of a heart attack, without visible pain. He had heart surgery twice and was fighting a cancer.

Even if he was well known as a technical physicist who invented new detectors, he always did so because he wanted to solve a physics problem in need of an unexisting detector. He was very «pure», extremely honest and made no compromissions. I will limit myself to one of his best ideas: a solar neutrino spectrometer he called HELLAZ (HELium At Liquid Azote). The goal was to achieve a high resolution (better than 10%) neutrino energy for low energies through a precisely known cross section so that an accurate comparison between pp and ^{7}Be yields, the crucial neutrino graal, can be seen, just at the glance of an eye.

Fig. 1. Tom's notebook (listing of reactions leading to background).

He started in 1983 on this idea by making calculations about cross sections, backgrounds and different possible solutions. Fig. 1. illustrates how he went to the ultimate point of a problem. Not only was he a very intelligent man, very charming and open to new ideas, he was also a hard worker. For years, I was his neighbour in building 29 (LAA) at CERN and I have always, I mean always, seen him there saturdays and sundays on top of the week. He had also a strong sense of humor (the name HELLAZ is by itself an example) and he used it when he had an idea which, he knew, would be immediately adopted. Fig. 2. shows how he was thinking to merge HELLAZ and NESTOR with the help of his great friend Leo Resvanis . He finally proposed in 1992, right here at «Neutrino Telescopes» in Venice[1], the idea of HELLAZ. The co-authors are J. Seguinot and A. Zichichi. Nino is still present here today, and I must make a parenthesis about a special aspect of Tom's life: the people who helped him. Socially, Tom was extremely modest. He never asked for personnal financial help and found himself, at times, in difficult situations. And a few people admired him, trusted him and helped him.

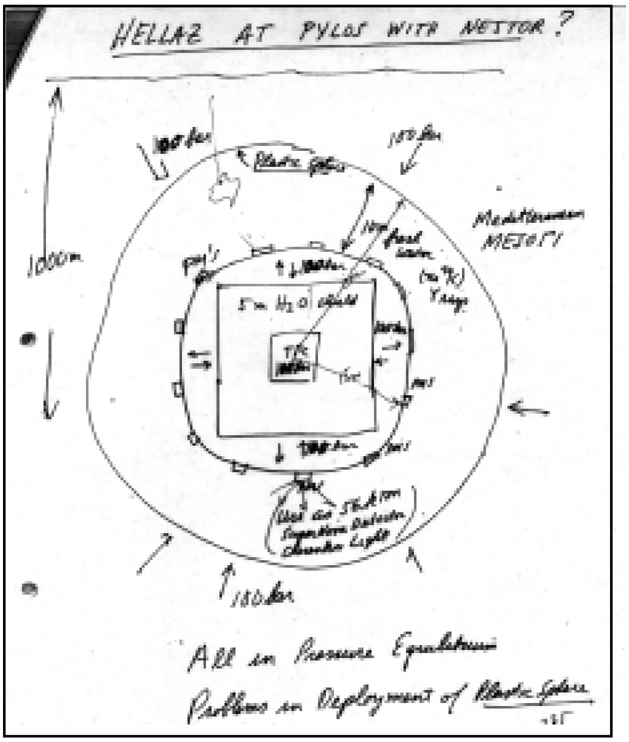

Fig. 2. Tom's notebook.

—When Tom came to France, Patrick Fleury, from the Ecole Polytechnique, helped him (including writing his «notice de travaux») so that he became Director of Research at CNRS and this is how he was linked with my lab at the College de France in Paris.

—Marcel Froissart, then head of the lab at College, who supported him without failure on all his projects (and that's why HELLAZ is mainly developed at the College de France) and allowed him to stay at CERN.

—Nino Zichichi who helped him strongly at CERN so that he could built his prototypes (and everything else). When Tom retired from CNRS at the legal french barrier of 65, Nino helped him get a position as professor at Bologna where he spent 3 days / week working on his AQUARICH project which he called, with a smile «hyperK, or SuperK with glasses» because of the mirrors focussing the Cerenkov rings. Nino Zichichi and Tom Ypsilantis mutual respect and friendliness can be expressed in this third degree joke, for which I assume total personal responsability: Saturday noon, Tom and Nino have a drink at the COOP. The CERN saturday visitors pass by in their bus. One of them looks out by the window, sees Nino and Tom and says: «Who is the guy next to Tom?»

—Jacques Seguinot was Tom alter ego and Tom would have never realized all he did without him.

—And then there are Tom's friends, for anybody in contact with Tom invariably became his friend. And this is a long story...

2. What is HELLAZ?

HELLAZ[2)] is a «digital Time Projection Chamber» where the neutrino scatters elastically with the electrons of the gas. The struck electron (same kinematics than the Compton scattering) recoils and makes a track of ionisation electrons. The cross section is extremely well known, and its differences between ν_e and ν_μ make possible to distinguish these two species for energies lower than 500 keV (pp spectrum).

Under an electrical field, the ionisation electrons drift until they hit a 2D gas detector. To reconstruct the neutrino energy, one needs the angle θ of the track with the sun direction and the electron energy. This last quantity is not too difficult to get (developed lenght of the track, charge integration of the electrons along a time long enough, counting of all the track electrons...). However, θ is more difficult because the electron energy being low (down to 100 keV), the track shows a lot of multiple scattering. To get a good resolution on θ, one needs a maximum number of information. This is the critical part of HELLAZ: to measure individually each ionisation electron of the track. Hence the name «digital TPC».

—Helium as the filling gas has been chosen for:

a) It can be made without any impurity leading to radioactive background through boil-off.

b) It is a slow (about 1 mm/µs @100 V/cm) gas for drifting electrons so it is easier to separate each incoming ionisation electron.

c) Its coefficient of diffusion is very low {140 µm / sqrt(drift distance in cm)}: a track keeps its shape for long drifts.

—The pressure is such that a track has the correct lenght: we have chosen 5 cm for 100 keV leading to 20 bar at room temperature. (Tom's original design had the same density with 5 bar and liquid nitrogen temperature. Tom agreed the disadvantages of having to deal with a huge dewar could be alleviated by going to room temperature and purifying the gas at low temperature in the recirculation system. We kept the name HELLAZ!)

—The volume of HELLAZ is such that one measures about 15 neutrinos per day (pp + ^{7}Be): hence 2000 m^3.

—The endcap gas detector should be fast (<10 ns duration pulses) to minimize pile-up and have a high gain (>10^6) to see single electrons. We have chosen the Charpak-Giomataris MICROMEGAS[3)].

3. Status of HELLAZ on simulations.

The very first problem to solve in order to assess the validity of the HELLAZ concept is: is it possible to reconstruct θ with a good enough accuracy despite the fact we deal with electron tracks as low as 100 keV in He at 20 bar?

Jean Dolbeau and Antony Sarrat tackled that problem for more than two years and the result is a success.

—Tracks were made with the GEANT Monte-Carlo program.

—Efficiencies were calculated, taking into account the characteristics of the MICROMEGAS pulses and the Time To Digital unit (CAEN # 673A) in charge of measuring the times in the TPC. They are around 85%.

—Electron energy resolution was simulated by different methods. It appears it is always very compatible with a 1/√N, where N is the number of ionisation electrons (about 5000 for a 100 keV track).

—The beginning of the track was fitted as a straight line (giving better reults, for the time being, than the $z^{3/2}$ diffusion law[4]) in which, by the way, Tom Ypsilantis believed very strongly).

—The angular resolution is shown Fig. 3. for 3 drifts lenghts and 4 electron energies. The results were fitted by an analytical formula.

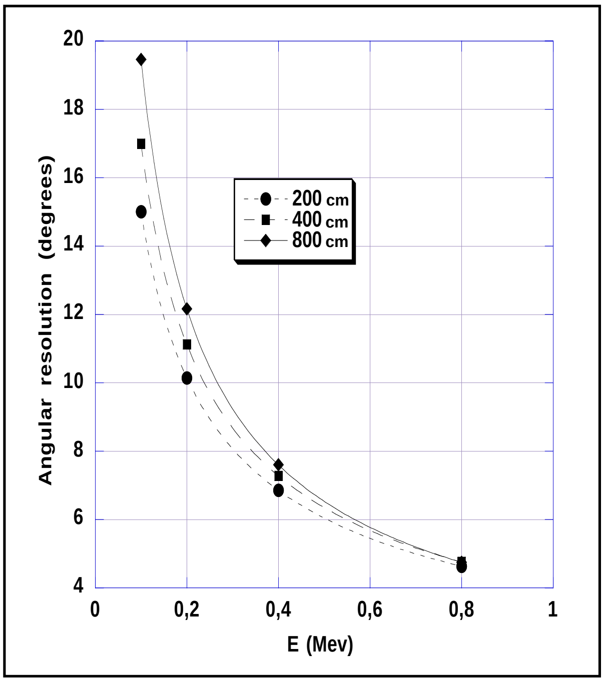

Fig. 3. Angular resolution obtained in a simulation if one can detect the individual ionisation electrons of the tracks.

—This angular resolution and energy resolution were fed in a program[6]) reconstructing the neutrino energy. Fig. 4. shows the reconstructed 5 years spectrum as predicted by J. Bahcall or S. Turck-Chieze[5]). The neutrino energy resolution is 6%. In this program, one can introduce sources of radioactive background (γ-ray emitting U-Th part of the materials containing the gas). First, one removes double Comptons. Then taking into account the directionality of the recoil electron with respect to the sun, and the fact that the sun «rotates» around HELLAZ, while the radioactive sources do not, one can subtract the data taken 12 hours earlier. Fig. 5. shows the results for 10000 backgrounds per day, corresponding to a radio-purity of the order of 10^{-13}g/g, assuming that radioactive materials are in the

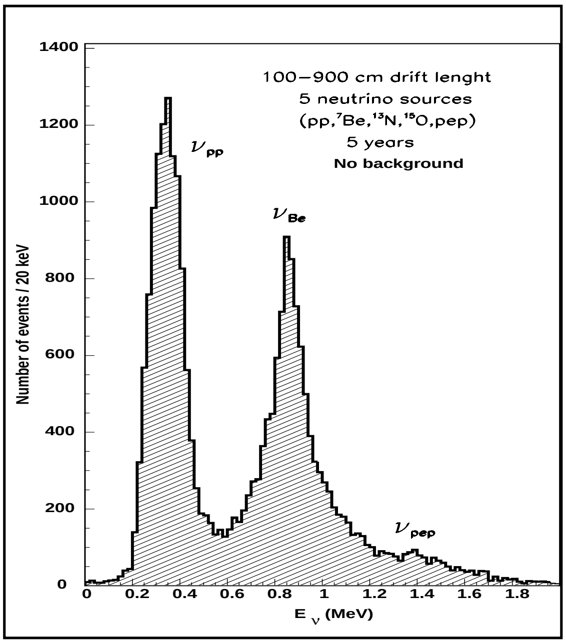

Fig. 4. Reconstructed solar neutrino spectrum. The energy resolution is 6%.

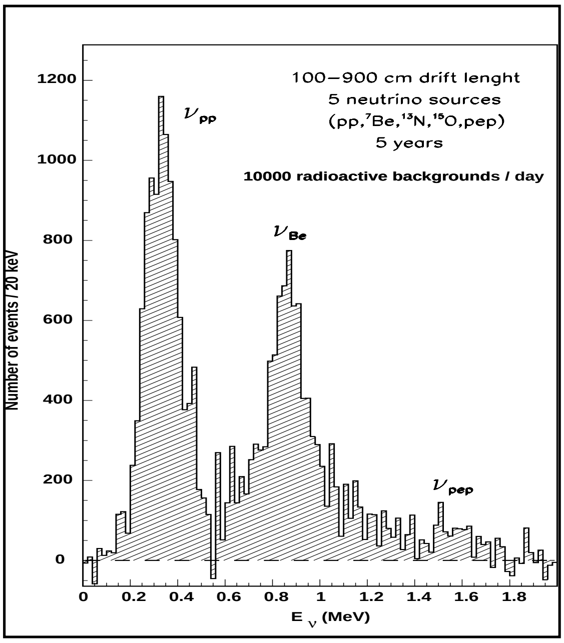

Fig. 5. Same, with 10^4 Comptons background events per day added to the 15 due to solar neutrinos.

vessel, the field cage and the MICROMEGAS detectors, easily reached by the BOREXINO collaboration[7)]. The resolution in neutrino energy is still better than 10%, a very good result.

Yes, it is possible to reconstruct θ with a good enough accuracy despite the fact we deal with electron tracks as low as 100 keV in He at 20 bar!

3. Status of HELLAZ on hardware.

The second problem to solve in order to assess the validity of the HELLAZ concept is: is it possible to get a gain high enough (>10^6) with a MICROMEGAS detector in helium at 20 bar? At one bar, with 10% isobutane as quencher, we got immediately a gain of a few 10^6.

But, as soon as we increased the pressure, if the pulse shape remained quite the same (Fig. 6.), the gain deteriorated, for the density itself acts like a quencher.10^4 was obtained with 0.5% isobutane (same partial pressure than 10% at 1 bar), a percentage low enough so that isobutane is still gaseous (and we have to mix our cylinders ourselves).We found out that at such a pressure, gas purity (in terms of O_2 and H_2O) is critical and we were lucky to be able to use a gas analyser sensitive to 10^{-8}. Even if Steve Biagi's simulations[9)] show that we can reach very high gains, sparking occured at a gain of about 10^4. In order to get a more «insulating» gas, we introduced 2% CH_4 on top of the 0.5% isobutane. The gain could be raised to 10^5, still too low, still limited by sparking.

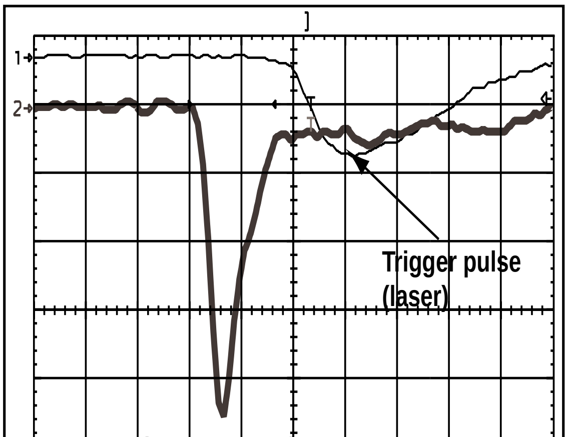

Fig. 6. Pulse shape for a single electron from a MICROMEGAS in He at 20 bar. One horizontal division is 5 ns.

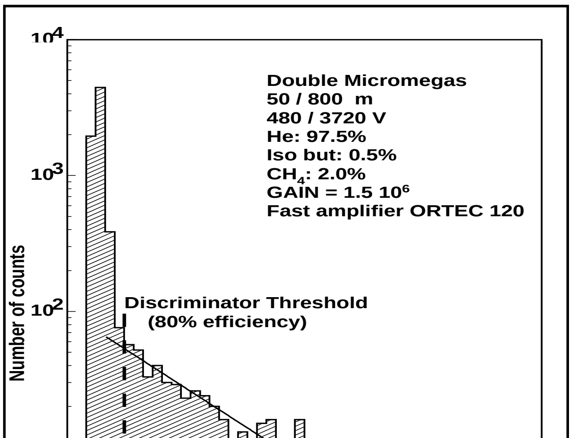

Fig. 7. Single electron spectrum with an exponential shape.

Then, we had the idea to test a 2-stage MICROMEGAS with the central electrode common to both stages. This ensures that the drift is instantaneous between the 2 stages and the obtained pulses are still shorter than 10 ns.

The gain (calibrated in an absolute way by shining the photocathode with a strong pulsed

UV lamp while increasing slowly the electrostatic field until a plateau is reached[8]) obtained is a few 10^6 good enough for a single electron efficiency of about 80%, as one can see in Fig. 7. The spectrum was obtained by a 300 ps pulsed 250 nm collimated laser, extracting photo-electrons from the top Ni mesh. The spectrum is exponential, as should be when the gain is uniform along the gaps.

Another advantage of the double gap design is the easiness to make a 2-D detector: the bottom electrode can be made of strips in one direction and the intermediate of strips in the perpendicular direction.

4. Conclusions

a) If it is possible to detect one electron in a time shorter than 10 ns, the neutrino energy can be reconstructed from the angle and energy of the scattered electron with a high resolution. Furthermore, radioactive background can be easily tolerated up to 10000 Comptons per day corresponding to 10^{-13} $g/g_{U\text{-}Th}$ assuming that radioactive materials are in the vessel, the field cage and the MICROMEGAS detectors.

b) We have realized a 2-D gas detector with a gain > 10^6 such that single electron efficiency is about 80%. Operation is extremely stable. Pulses are shorter than 10 ns. Hence, conditions in a) are fulfilled. HELLAZ is a valid concept. Tom, you were right again!

Now, we are setting up to measure real low energy electron tracks.

5. References

1) J. Séguinot, T. Ypsilantis and A. Zichichi, Neutrino Telescopes Conference, Venice, Italy, 10-13/3/1992
2) A. de Bellefon, Nucl. Phys. B (Proc. Suppl.) 70 (1999) 386
P. Gorodetzky et al. “Identification of solar neutrinos by individual electron counting in HELLAZ”, Nucl. Instr. and Meth. A 443 (1999) 554.
J. Seguinot, T. Ypsilantis, G. Bonvincini, P. Giusti, G. Laurenti and A. Zichichi, CERN-LAA/95-11
3) Y. Giomataris et al., Nucl. Instr. and Meth. A 376 (1996) 29.
4) See for instance the Booklet, Particle Data Group, AIP, LBL, Berkeley, USA.
5) J. Bahcall, S. Basu and M. Pinsonneault, Phys. Lett. B, 433, 1, 1998.
A.S. Brun, S. Turck-Chieze and P. Morel, Astro. Journal, 506, 913, 1998.
6) G. Laurenti, S. Tzamarias, G. Bonvicini, A. Zichichi, J. Seguinot and T. Ypsilantis, CERN/LAA/PC/93-10
7) Borexino Coll. submitted to Astro. Particle Phys. (Nov 2000)
8) J. Derre, Y. Giomataris, P. Rebourgeard, H. Zacconne, J.P. Perroud and G. Charpak, Nucl. Instr. and Meth. A 449, 314, 2000
9) S. Biagi Monte-Carlo programs: NMONTE and IMONTE44, Nucl. Instr. and Meth. A 421 (1999) 234.