CONCLUDING REMARKS

(E.W. Otten)

At some conferences it is a custom to give an award to the best poster presented. If there would be an award for the best transparency I would vote for the conclusion shown by Ottokar Dragoun (T1). Because it reads in the first line: "We would like to participate in the sub-eV m_υ-project and offer.........".

This is really what is needed for the project to become as successful as this workshop. But not only from the side of the experimentalists also from the many participating theoreticians we received a lot of positive input and support. They have taken the task quite seriously and have analyzed explicitly the limits and chances, such a project would have in the general frame of neutrino physics. We experimentalists are grateful for having got the message. Still, if I should tell you the theory which I immediately and most easily understood, I would choose Boris Kayser`s conclusion (T2), the last sentence of which reads:

" Tritium decay could play a starring role".

Coming to the subject, I would like to show you once more the development of m_υ^2 in tritium decay experiments in the last ten years running down to the limits of a few eV^2, presently achieved in Mainz and Troitsk (T3). You may imagine that in the "wild years", when all of us were fighting with largely unphysical negative m^2 values, our funding situation was quite difficult; in fact, it has since never recovered really beyond a miserable survival rate. In this sense, things can only change to the better. But also the scientific reputation was going to be shattered somehow, at least in the view of the particle data group which placed in these years the limit high up in the "milky way" at 225 eV^2, taken from the supernova 1987 A event. However, this has been revised in the latest edition from last year and the astrophysicists already took notice of this change: Georg Raffelt remarked in his talk that vice versa the present absolute mass limit should serve as input parameter in analyzing neutrino emission from supernovas.

Setting an absolute scale for neutrino masses is the primary motivation to continue this research for the sake of particle and astrophysics. Manfred Lindner summarized this in a quite instructive transparency in which he added a freely floating base line to the experimental indications of possible splittings of the three mass eigen values (T4). As a trained atomic spectroscopist, I would call them a fine and a hyperfine structure. But where is the gross structure? Does it exist at all? Or does the base line coincide more or less with the lowest of these eigen states? That is the question! In this respect, Andrew Hamilton tried to strengthen our hopes by telling us that the power spectrum of the Lyman alpha forest might be fitted well with a 2 eV neutrino mass (T5). I promise, as soon as we have confirmed this value, I will sit down and learn all about the Lyman alpha forest!

We all know that single beta decay is not the only access to the absolute neutrino mass. Neutrinoless double beta decay is another one and even can achieve lower limits as seen from the mere experimental standpoint of view. Alexis Smirnoff and other theoreticians at this workshop tought us, however, that one should regard these two measurements rather as complimentary than competitive ones. Because they yield primarily different observables a weighted mass $\overline{m}$ from single and an effective mass m_{ee} from double beta decay. The two are connected via a very important and largely unknown factor containing mixing angles ϑ between neutrino flavours and phases φ defining the state of majorana neutrinos (T6).

Let us turn to the proposed experiment. Guido Drexlin showed the layout with the three main sections: The gaseous and the frozen tritium source with an overall length of about 40 m, the large spectrometer tank which has to achieve a resolution of about 1 eV at high yield, and finally, the detector. All three of them are highly demanding tasks (T7)! By force of the already existing experimental hall at Karlsruhe - not by our fetischistic minds - they are bent to the nice ν-shape which you discover on the view graph. The present yet preliminary status of our plannings for these three items have been presented by Oleg Kazachenko, Jochen Bonn and Klaus Eitel. I will try to confine myself here only to the estimated sensitivity for m_ν which Christian Weinheimer calculated on the basis of the planned design parameters (T8). After three years` time of measurement one will have reached a sensitivity of slightly better than .1 eV^2 for m_ν^2. It is composed of a rather flat statistical error as a function of the lower boundary of the fit interval and of a systematic error which essentially vanishes for fit intervals shorter than 20 eV below the endpoint E_0. How can this be explained? Discussing the signature of m_ν versus background in an actual measurement, Jochen Bonn pointed out that for the planned spectrometer the ratio of these two decisive paramters peak very close to the endpoint, actually at a distance of less than 10 eV (T9). This explains the stability of the statistical error as long as one does not cut into this region of high sensitivity. As for the systematic error, I remind you of a transparency shown by Vladimir Lobashev which shows the energy loss function of monochromatic electrons passing the gaseous source of the Troitsk experiment. Lowering the MAC-E-filter potential from right to left one notices that the transmission first reaches a plateau more than 10 eV wide before it rises further to full value (T10). This plateau marks the elastic fraction which passes the source with no energy loss, whatsoever. Only thereafter excitation of electronic states can start. At the very end of the beta spectrum one therefore deals essentially with beta particles which do not have lost any energy in the source.

The sudden increase of the nuclear charge in beta decay leads in almost 50 % of the cases to an electronic excitation of the daughter molecule $(T^3He)^+$. Again, the first excited level of this molecule lies more than 20 eV above its electronic ground state. Alejandro Saenz has shown us the onset of this internal excitation as a slight upkink in the Currie-plot of the T_2 beta spectrum (T11). The precision of these calculations which have been performed consistently by several groups has also been corroborated finally by the experiments in Mainz and Troitsk which fit the theoretical beta spectrum over intervals larger than the range of the molecular excitation spectrum which extends to about 100 eV. Anyway, in the planned experiment, this part of the spectrum will hardly be needed anymore for the analysis. What will be left over, however, is the excitation of rotations and vibrations of the daughter molecule by the recoil to the ^3He nucleus. This appears as a tiny slope with a width of about .4 e V at the very end of the Currie-plot. Although, this residual excitation spectrum seems to be under good theoretical control, the experimentalists may still dream of an atomic tritium source as the ultimate solution.

Wolfgang Quint has introduced us to another modern field of brilliant precision experiments, namely, rf-spectroscopy in ion traps. He has shown us the example of measuring the cyclotron frequency of anti-protons with a resolution of 10^{-10} (T 12). It proves, that there is a realistic chance to measure by such means the T-^3He mass difference to a precision of .1 eV. Can we really dare to accept such a precious gift in the analysis of T_2 decay by fixing $E_{0,}$ rather than fitting it from the measured spectrum? Let us assume that we can the fix the voltage of our electrostatic filter with the same precision (a difficult task indeed!) then we still have the problem that the residual error δE_0 correlates strongly to that of the mass by the relation:

$$\delta m^2 \approx (E_0-E)\, \delta E_0.$$

Here, the correlation factor (E_0-E) is just the interval over which we analyze the beta spectrum. If we like the resulting δm^2 not to exceed .1 eV^2, we have to live only on the last electron volt of the spectrum with a given δE_0 of .1 eV, hence! This would be very tough, indeed, but not quite impossible.

Andreas Piepke showed us the perspectives of the various proposals for improving the mass limit in neutrinoless double beta decay experiments (T13). They are a factor of 10 typically below the limit, a T_2 decay experiment can hope for. As an outsider to this particular field, I cannot give preference to any of these proposals. Instead, I may dare the slightly unphysical suggestion to multiply these limits with the price of the experiment. How would these "hybrid limits" look like?

Anyway, how can a single beta decay experiment hold the stage against this Armada of double beta decay experiments? Apart from the theoretical support mentioned above, one might look for allies! Indeed, there is one at the horizon. Ettore Fiorini has shown us in his talk the great resolution and fascinating universality of cryogenic detectors for any kind of low level counting, including double and single beta decay. Their noise is only limited by phonon statistics. It is decreasing rapidly at low temperature as shown on a transparency by Klaus Eitel who considers such a detector array also for the planned T_2 decay experiment at Karlsruhe (T14). At a resolution on the level of eV they may become competitive even with the present electrostatic filters, provided the pile-up problem can be solved. The groups in Milano and Genova have both started cryogenic experiments on ^{187}Re decay with an endpoint energy of only 2.5 keV in search of the neutrino mass. Flavio Gatti has shown us very surprising modulations on the low energy side of the beta spectrum (T14) which stem from interference effects in the regular Re-lattice, known otherwise as Xefas-effect in photo electron spectroscopy. Nobody has seen this before in a beta spectrum, except for Simson in fact, who noticed a slight indication of that sort at the lower end of the tritium-beta decay spectrum in a silicon detector and, unfortunately misinterpreted it as the well known 17 keV neutrino! Stimulated by their success, the Genova-group has started a new effort in order to push their neutrino mass limit from the present value of 26 eV down into the eV and sub-eV range (T15). In view of the difficulty and importance of neutrino mass research, an alternative experiment to the electrostatic filters would be highly welcome.

The last transparency which I pick up again is from Guido Drexlin`s introduction to the new project. There, he has shown us that only the future Zeppelin, the cargo lifter, will be able to transport the huge spectrometer from the factory to Karlsruhe (T 16). Stimulated by this drawing and by Alexander Ossipowicz`s dream of a hugh spectrometer in space in the far future, I am tempted to the following proposal: We should enlarge the size of the spectrometer to that of the Zeppelin. Being evacuated, such a superb instrument would even fly by itself from the factory to the site of the experiment and solve the transport problem in a simple manner! To the right of the tank, you may recognize the name "KATRIN" [1] which the present collaboration likes to give to the planned experiment; it stands for **KA**rlsruhe **TRI**tium **N**eutrino Experiment. So, let me toast to

KATRIN - take-off!

Coming to the end, let me also point out how fascinated I was by the enormous breadth of this small workshop whose subject has bridged John Ng`s super

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[1] German version of the christian name "Catherine"

symmetry with the quantum chemistry of Alejandro Saenz and the astrophysics of Andrew Hamilton and Georg Raffelt to the surface physics of Paul Leiderer.

My thanks to the organizers and participants, who made this workshop so pleasant and fruitful.