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PROPOSAL
ON
ELECTRON ANTI-NEUTRINO MASS MEASUREMENT AT INS

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I would like to comment on a proposed experiment, a measurement of electron anti-neutrino mass at Institute for Nuclear Study, University of Tokyo, Japan. Hereafter, I'll call various types of neutrinos simply by neutrino without any notice.

Neutrino, almost massless neutral fermi particle, was introduced by Pauli as early as 1930 from the study of energy-momentum conservation in the β-decay of nucleus, and in 1934 the famous Fermi theory was published. Since their historical works on the weak interaction theory, 50 years have passed and many experimental efforts have been concentrated to determine the mass of neutrinos. As a finite mass of neutrino plays an important role in basic theory of elementary particle physics, experimental determination of neutrino mass is very important and one of dreams of high energy experimentalists.

Table 1 shows all of the experimental results[1-11] of electron anti-neutrino mass measurements, so far. As you can see, recently Russian group[11] reported for the first time that the neutrino mass is between 14 and 46 eV with 99% confidence level. All measurements, except Beck, used tritium as a β-decay source, becouse β-rays from tritium has the suitable lowest end point energy of 18.6 KeV and a proper life time of 12.3 years for experimental purposes.

Fig.1 shows the Kurie plot for β-decay of tritium. The effect of the phase-space modification due to the non-zero mass of neutrino is essentially confined to the very uppermost part of the spectrum. To identify this small deviation from the zero mass case, high resolution and high statistics measurements of the β-ray energy are required.

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* talk presented at Japan-Italy Symposium on Fundamental Physics, Tokyo, January 27-30, 1981.

Fig.2 are the observed β-spectrums by some previous experiments. An upper limit of neutrino mass had been decreased by improving the spectrometer resolution and statistical errors. The area which is sensitive for the determination of neutrino mass are indicated in the figure, and you can see where these improvement are important on the spectrum.

Our experimental goal is to determine neutrino mass more accurately and reliably than any other previous measurements and to comfirm or check the most recent Russian data. If we get the same result with them, it must be a great impact to the present theory of elementary particle interactions.

Althought high statistics and high resolution are the essential factors to get accurate data, they impose contradictory requirements on spectrometer and tritium source, as seen in Fig.3. Other important factor is the rate of background. Main background will come from the β-decay of tritium that evaporated from the surface of the source. Getting good source, having low evaporation rate and high activity of ^3H, is essential to succeed in the experiment by suppressing relatively large background contribution against true β-decay rate at the end point energy region. Our source candidates are listed in Table 2, and those might have lower evapolation rate in the vaccum than valine. Tritiated Titanium target, which is commonly used in the field of atomic physics as a neutron source bombarded by deuteron, is also one of good candidates for our sources.

Fig.4 is a schema of our spectrometer, double focus $\sqrt{2}\pi$air core spectrometer [12], at Institute for Nuclear Study,University of Tokyo. This spectrometer was built in 1967 as a device for accurate spectroscopic study of nuclei and atoms. Radius of central orbit is 75 cm which is the 2nd largest in the world.

Table 3 compares the characteristics of our and Russian spectrometers. Our spectrometer has a better momentum resolution and a smaller absolute energy uncertainty. However, our solid angle and source area are extremely small compared with Russian's and our counting rate is expected to be very low. So, we are planning to enlarge these by modifing the spectrometer with a little sacrifices of good momentum resolution and energy uncertainty, as shown in Table 3. Other large difference, that can not be seen on Table 3, is the momentum acceptance. Russian group obtained one (or a few) data point at one measurement and scanned in a certain energy range. While our spectrometer has a momentum acceptance of 4% that covers, for instance, the energy range between 17.85 and 19.30 KeV. When we divide this range by 10eV energy bin, we can gain statistical improvement of factor 145 (48) against Russian's. This wide momentum acceptance might reduce systematic uncertainty of the measurement comparing with Russian's scan method, and might improve the reliability of the measurement.

Expected event rate at 10 eV bin-size and 30 days data taking is plotted on Fig.5. This accumulated event rate is about 10 times higher than Russian's. We estimate the total energy resolution to be about 30 eV from both the spectrometer resolution and the energy spread of β-rays due to energy loss in the source. Expected β-ray spectrums smeared with 30 eV resolution are shown in Fig.6 with 0, 20 and 40 eV neutrino mass. Expected statistical accuracy of our measurement is listed in Table 4 with 30 days data taking. We will get neutrino mass with less than 10 eV accuracy.

While, other large uncertainty for deduction proceedure of neutrino mass from the measured spectrum comes from the ambiguity of β-decay transition probability to excited final atomic states of ^{3}He. Contamination of these excited final states modify the Kurie plot for the case of pure ground state of ^{3}He. Moreover, labelled compound, like valine ($C_5H_{11}NO_2$) which Russian used, might make situation more complex. We are collaborating with theorists to calculate above effects on the β-spectrum.

Our present status are the followings ;

(1) Detailed calculation of the particle trajectory in the INS spectrometer for modification noticed above is in progress.

(2) Production and test of tritium sources are planned in this spring.

(3) β-ray detector, avalanche chamber, is under construction.

(4) Funds for experiment is not yet approved !

Table captions

Table 1 : List of results of $\bar{\nu}_e$ mass measurements.

Table 2 : Comparison of spectrometer characteristics between ours and Russian's.

Table 3 : List of our source candidates.

Table 4 : Expected accuracy of $\bar{\nu}_e$ mass.

Figure captions

Fig.1 : Kurie plot of β-decay of tritium.
Only ground level of the final atomic state of ^{3}He is considered.

Fig.2 : Three previous measurements of β-spectrum.
Sensitive area for determination of neutrino mass at a few tens eV level is indicated by arrows in the figure.

Fig.3 : Schema of relation among essential factors of experiment.

Fig.4 : Schema of INS double focus $\sqrt{2}\pi$ air core spectrometer.

Fig.5 : Expected event rate at 10 eV bin-size and 30 days data taking with our proposing spectrometer.
Fig.5 and 6 do not include the contribution of excited levels of ^{3}He.

Fig.6 : Expected observed spectrums smeared with $\Delta E_{total} = 30$ eV.

TABLE 1
MEASUREMENTS OF $\bar{\nu}_e$ MASS

UPPER LIMIT ON MASS (eV/c^2)	CONFIDENCE (%)	REFERENCE	
< 250		LANGER	1952 (1)
< 500		HAMILTON	1953 (2)
< 550		FRIEDMAN	1958 (3)
<4100	67	BECK	1968* (4)
< 200	90	SALGO	1969 (5)
< 75	90	DARIS	1969 (6)
< 60	90	BERGKVIST	1972 (7)
< 86	90	RŌDE	1972 (8)
< 35	90	TRETYAKOV	1976 (9)
< 70	95	SIMPSON	1979 (10)
$14 \leq m_\nu \leq 46$	99	LYUBIMOV	1980 (11)

* ν_e MASS MEASUREMENT USING ^{22}NA

TABLE 2
SOURCES

MATERIAL	ACTIVITY (mC/2μg)
SODIUM BOROHYDRIDE $\mathrm{NaB\underline{H_4}}$	3.1
ALAINE L[3-^{3}H] $\mathrm{C\underline{H_3}CH(N\underline{H_2})COOH}$	1.9
LEUCINE L[3,4,5-^{3}H] $\mathrm{(C\underline{H_3})_2C\underline{H}C\underline{H_2}CH(NH_2)COOH}$	1.6
LEUCINE L[4,5^{3}H]	2.2
ISOLEUCINE L[4,5^{3}H] $\mathrm{C\underline{H}_3C\underline{H}_2CH(CH_3)CH(NH_2)COOH}$	1.8
PROLINE L[2,3,4,5-^{3}H] $\mathrm{HNC\underline{H}_2C\underline{H}_2C\underline{H}_2C\underline{H}COOH}$	1.9

TABLE 3
CHARACTERISTICS OF SPECTROMETERS

EXPERIMENT	TRETYAKOV (1976) LYUBIMOV (1980)	INS (AIR CORE) ORIGINAL →	IMPROVED
MOMENTUM RESOLUTION ($\Delta p/p$)	1.2×10^{-3}	10^{-4}	3×10^{-4}
ABSOLUTE ENERGY UNCERTAINTY	~5 eV	~0.4 eV	~1.1 eV
SOLID ANGLE (4π)	8.7×10^{-2}	8.9×10^{-4}	10^{-3}
SOURCE AREA (cm^2)	(~22 ?)	0.05	2
SOURCE ACTIVITY (mC/cm^2)	~1	~3	~3
SOURCE THICKNESS ($\mu g/cm^2$)	~2	~2	~2
SOURCE MATERIAL	^3H TAGGED VALINE COMPOUND	SODIUM BOROHYDRIDE	OR TRITIUM TARGET
BACKGROUND RATE (COUNT/MIN)	2 - 6		

TABLE 4

EXPECTED ACCURACY OF M_ν MEASUREMENT

ERROR DUE TO STATISTICS (30 DAYS RUNNING)

IF M = 0 eV ΔM = 5 - 10 eV

M = 10 eV ΔM = 2 eV

M = 20 eV ΔM = 1 eV

M = 30 eV ΔM = 1 eV

M = 40 eV ΔM = 0.5 eV

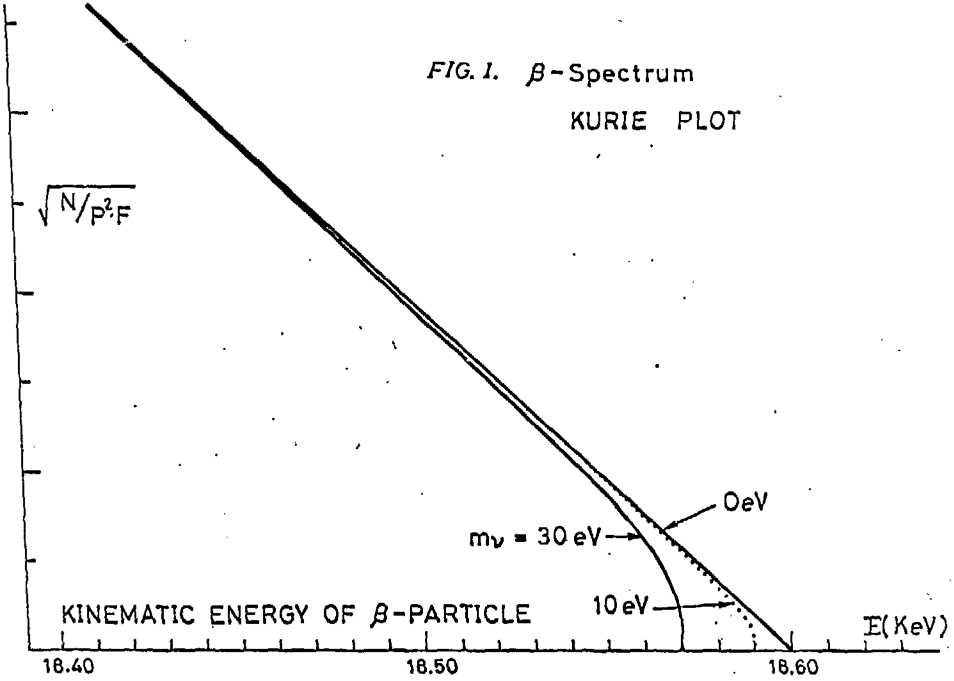
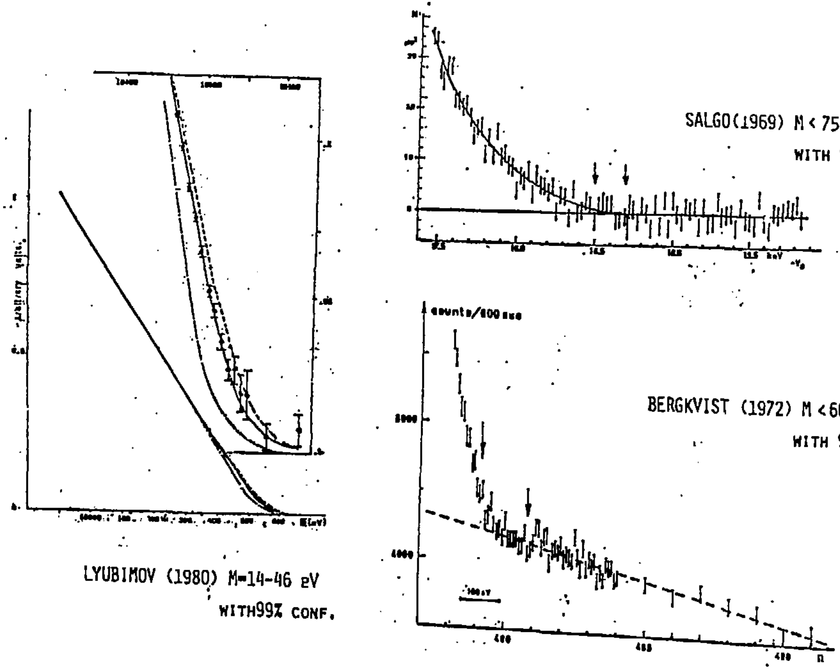


FIG. 1. β-Spectrum

KURIE PLOT



LYUBIMOV (1980) M=14-46 eV

WITH 99% CONF.

SALGO (1969) M < 75 eV

WITH 90% CONF.

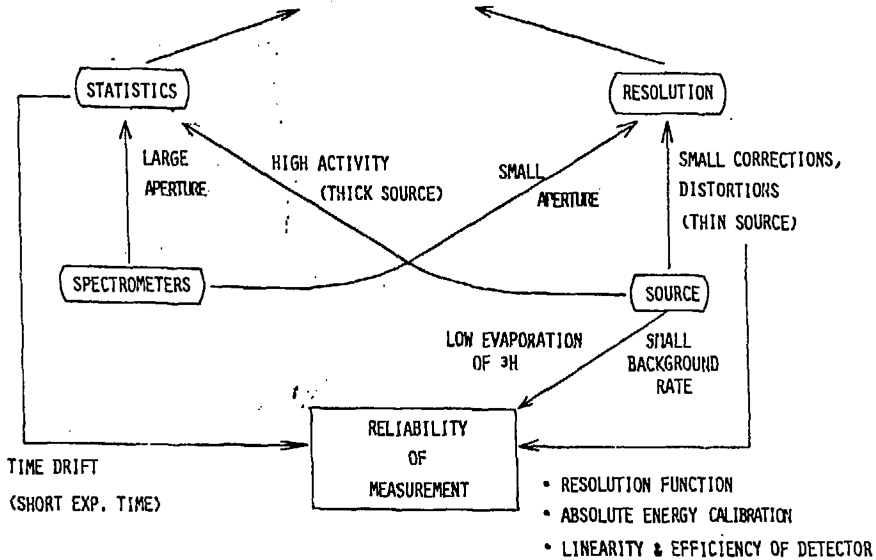
BERGKVIST (1972) M < 60 eV

WITH 90% CONF.

FIG. 2

FIG. 3

$\bar{\nu}_e$ - MASS MEASUREMENT



INS Double Focus $\pi\sqrt{2}$ AIR CORE SPECTROMETER

$B_z\,(r.o) \propto 1/\sqrt{r}$ $(r_0 = 75\,\mathrm{cm})$

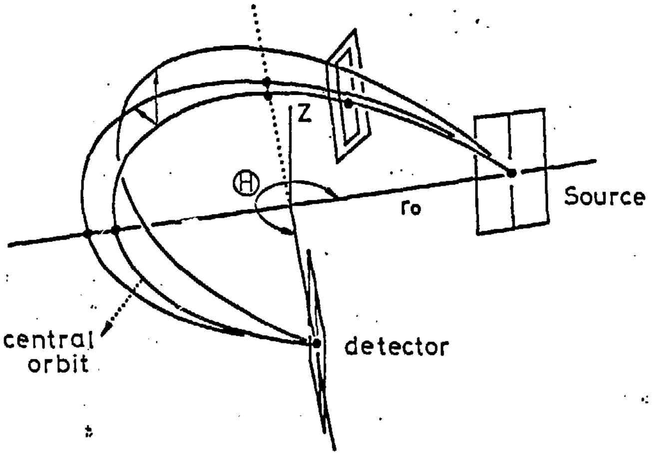
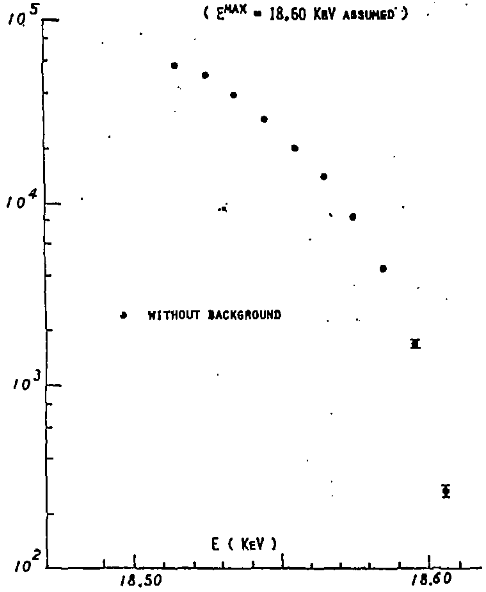


FIG. 4

FIG.5. EXPECTED EVENT RATE
AT 10 eV BIN-SIZE AND 30 DAYS DATA TAKING
(E^{MAX} = 18.60 KeV ASSUMED)



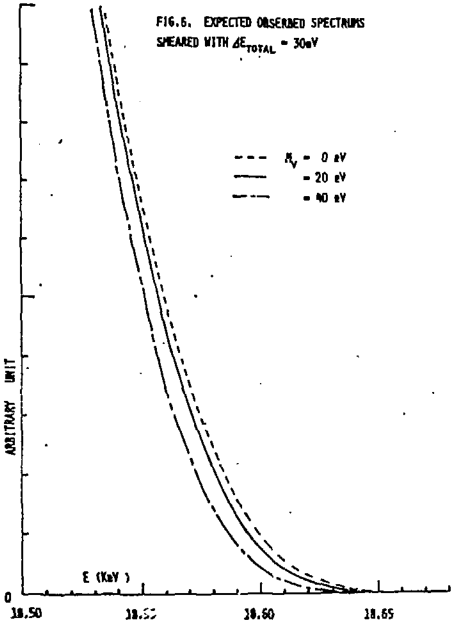


FIG.6. EXPECTED OBSERVED SPECTRUMS
SMEARED WITH ΔE_{TOTAL} = 30eV