JAPANESE FUTURE E^+E^- COLLIDER PROGRAM "TRISTAN"

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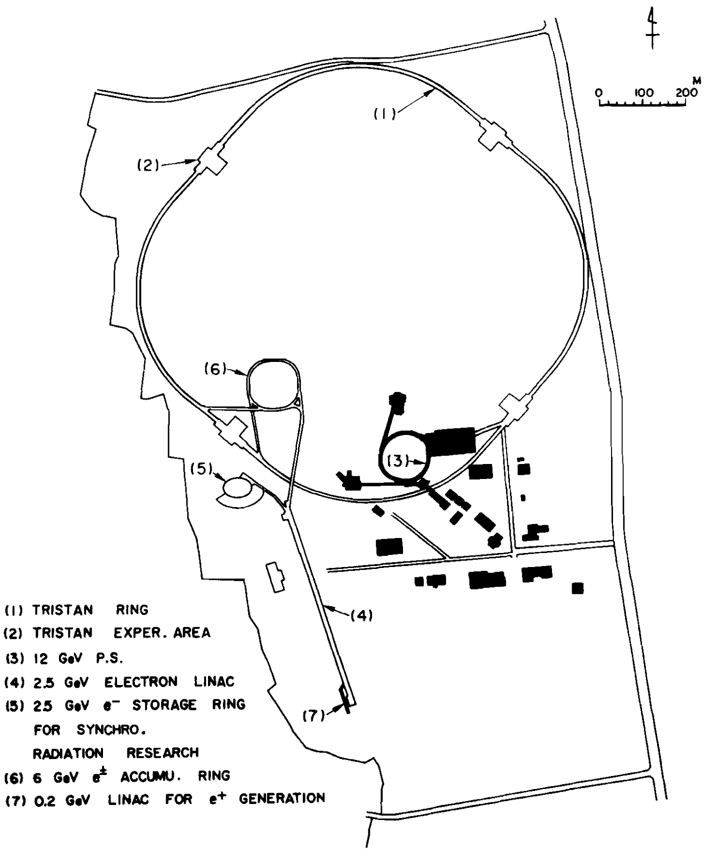
There has been a long standing desire in Japan to build a high energy accelerator so that Japan can join a fore front physics program at home. The first stage in realization of this desire was a construction of a 12 GeV proton synchrotron. Although the energy available from this accelerator was too low for the frontier physics of today the experiences gained from this accelerator as well as those from earlier construction and operation of a 1.5 GeV electron synchrotron at INS gave us a firm self confidence for the next large scale project "TRISTAN"$^{1)}$.

In this paper, I will present the TRISTAN phase I program (e^+e^- collider in the energy range of $\sqrt{s} \sim 60$ GeV) and will express our invitation for you to join us in a collaborative research using this new facility. TRISTAN phase II (currently thought to be a $e^\pm$-p collider in the energy range of 25 GeV electron on 400 ∿ 600 GeV proton) will be left as a future program for the time being.

TRISTAN, which stands for Transposable Ring Intersecting STorage Accelerator in Nippon will be built on the KEK site, Tsukuba, Scientific New Town. It is located about 70 km north of Tokyo and ∿50 km northwest of New Tokyo International Airport. The site has an area of ∿1 km × 2 km; the main electron ring tunnel will just about fill the site. Conversely the size of the laboratory site limits the maximum total energy available in this collider to ∿60 GeV. As shown in Fig. 1, the TRISTAN e^+e^- complex consists of three accelerator units. First, electrons are accelerated to 2.5 GeV using the electron linear accelerator; a part of KEK Photon Factory (synchrotron radiation facility) which is being built on the site with the target date of early 1982. Positrons will be produced with a separate 200 MeV electron LINAC and fed to the 2.5 GeV LINAC at the source end. Electrons (positrons) are injected into the Accumulating Ring (AR) the parameters for which are shown in Table 1a and b. The purpose of the intermediate ring is to obtain a short damping time at the time of injection so as to gain high current density.



General Parameters of the TRISTAN Accumulation Ring

Circumference	C	= 377 m
Average machine radius	R	= 60.0 m
Average radius of curved section	R'	= 47.6 m
Bending radius	ρ	= 23.3 m
Length of long straight sections	L_s	= 2 × 19.45 m
Length of RF sections	L_{RF}	= 2 × 19.45 m
Length of dispersion suppressing straights	L_{ds}	= 8 × 5.5 m
Number of cells in arc	N_c	= 32
Length of a normal cell	L_c	= 8.8 m
Number of bending magnet	n_B	= 56
Number of quadrupoles	n_Q	= 86
Betatron oscillation tune in	ν'_x	= 7
curved section	ν'_y	= 7
Momentum compaction factor	α	= 0.013
Revolution frequency	f_{rev}	= 0.795 MHz
RF frequency	f_{RF}	= 508.58 MHz
Harmonic number	h	= 640
Whole length of RF cavities	L_{cav}	= 29.6 m
Injection energy	E_{inj}	= 2.5 ∿ 3 GeV
Extraction energy	E_{ext}	= 6 ∿ 8 GeV

Beam Parameters of the TRISTAN Accumulation Ring
(Electron-Positron Colliding Mode Operation)

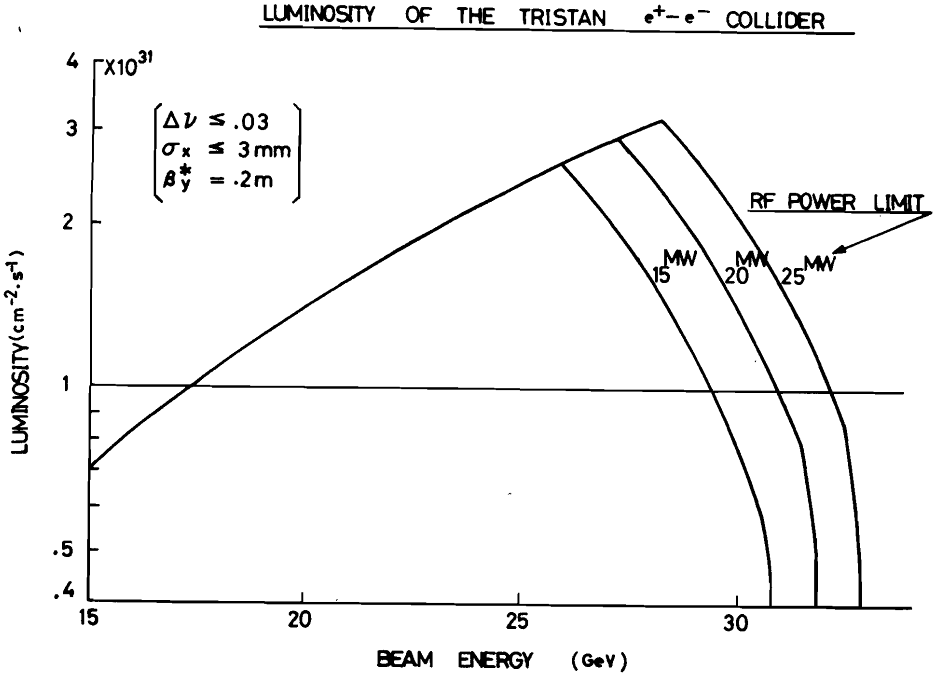
Beam energy	E_0	= 6 GeV
Bending field	B	= 0.86 T
Energy loss per turn	U_0	= 4.8 MeV
Damping time	τ_x	= 3.3 ms
	τ_y	= 3.2 ms
	τ_E	= 1.6 ms
Natural energy spread	σ_E/E_0	= 1.1×10^{-3}
Natural horizontal emittance	ϵ_{x0}	= 2.5×10^{-7} m·r
Over voltage ratio (τ_q = 24 hr)	q	= 2.06
RF peak voltage	V_{RF}	= 9.9 MV
RF bucket height	$\Delta E/E$	= 6.7×10^{-3}
Synchrotron oscillation frequency	f_s	= 35 kHz
Natural bunch length	σ_z	= 1.9 cm
R.M.S. beam size in normal cell		
	$\sigma_{x,\ max}$ (zero coupling)	= 2.4 mm
	$\sigma_{y,\ max}$ (full coupling)	= 1.4 mm
Length of experimental insertion	L_{exp}	= ± 2.5 m
Amplitude functions at colliding point	β^*_x	= 2.0 m
	β^*_y	= 0.1 m
R.M.S. beam size at colliding point (optimum coupling)		
	σ^*_x	= 0.69 mm
	σ^*_y	= 0.034 mm
Number of bunches per beam	N_B	= 1, 2
Luminosity (beam-beam tune shift $\Delta\nu_{bb} \leqq 0.03$)		= $1 \sim 2 \times 10^{31}$ $cm^{-2} \cdot s^{-1}$

Electrons (positrons) are accelerated to $\sim$8 GeV prior to injection into the main ring. Incidentally, the Accumulating ring can also run in the storage collider mode with the maximum total energy of $\sqrt{s}$ = 13 GeV with the optimum luminosity of 1 $\sim$ 2 × 10^{31} $cm^{-2}sec^{-1}$ at $\sqrt{s}$ = 12 GeV.

The parameters of the main ring which is $\sim$3 km in circumference are as shown in Table 2a, b and c. It should be noted that the length of the straight section is quite long in comparison to the overall accelerator circumference. This is due mainly to the need of employing a long RF section (377 m) in order to overcome a high rate of synchrotron radiation loss at high energy. There are four experimental insertions, each with 20 meters in length for standard configuration. Each insertion can be shortened down to 6 meters for mini β operation. The luminosity calculated for the standard insertion is shown in Fig. 2 as a function of energy and as a parameter of RF power. It gives a luminosity L = 1.5 × 10^{31} $cm^{-2}sec^{-1}$ at $\sqrt{s}$ = 60 GeV for 20 MW RF. The gain in the luminosity with mini β (6 m insertion) is estimated to be a factor of 3.

Considering the underground soil composition structure which was studied using boring data, the floor of the main ring will be set at 11 meters below ground level. Each of four insertions will have an underground experimental hall. Two of the four halls, i.e. Northeast and Southwest halls, will have an extra length in the beam direction so as to accomodate ep colliding beams, a possibility in the future program.

With the maximum total energy of $\sim$60 GeV, TRISTAN obviously cannot produce Z° the mass of which is predicted to be $\sim$93 GeV2) according to the current theory. The research activity at TRISTAN, therefore, will be directed toward the exciting physics below Z° production, such as a search for top quark states, Higgs bosons and heavy sequential leptons. Further study of jets at higher energy, leading to the study of QCD will also be of interest. In the TRISTAN energy range the foward-backward asymmetry of leptons due to the electro-magnetic and weak interference will become as large as 40%, giving the chance to see the effect of Z°. A search for new phenomena in e^+e^- interaction in the new energy domain, certainly, is also one of our research goals.



General Parameters of the TRISTAN Electron-Positron Collider

Circumference	C	=	3018.08 m
Average machine radius	R	=	480.34 m
Length of straight sections	L_s	=	4 × 193.35 m
Average radius of curved section	R'	=	357.25 m
Bending radius	ρ	=	249.93 m
Number of normal cells in arc	N_c	=	120
Cell length	L_c	=	16.12 m
Number of dispersion suppressing cells	N_{ds}	=	20
Cell length	L_{ds}	=	15.52 m
Number of cells in RF section	N_{RF}	=	28
Cell length	L_{RF}	=	18.86 m
Revolution frequency	f_{rev}	=	99.33 kHz
RF frequency	f_{RF}	=	508.58 MHz
Harmonic number	h	=	5120
Whole length of RF cavities	L_{cav}	=	377 m
Number of interaction regions	N_{int}	=	4
Number of bunches per beam	N_B	=	1, 2, 4
Length of experimental insertion	L_{exp}	=	± 10 (3.0) m
Amplitude functions at	β_x^*	=	3.2 (1.1) m
colliding point	β_y^*	=	0.2 (0.07) m

Optics Parameters of the TRISTAN Electron-Positron Collider

Number of bending magnets	n_B	=	280
Number of cell quadrupoles	n_{CQ}	=	320
Number of insertion quadrupoles	n_{IQ}	=	48
Beam energy	E_0	=	30 GeV
Length of experimental insertion	L_{exp}	=	± 10 (3.0) m
Betatron oscillation tune	ν_x	=	34.25 (31.25)
	ν_y	=	37.13 (35.13)
Tune in arc	ν_x'	=	24.07
	ν_y'	=	24.13
Phase advance per normal cell	$\mu_x = \mu_y$	=	60°
Momentum compaction factor	α	=	1.471×10^{-3}
Natural chromaticity	$\xi_x = \Delta\nu_x/(\frac{\Delta p}{p})$	=	- 72.38 (- 60.78)
	$\xi_y = \Delta\nu_y/(\frac{\Delta p}{p})$	=	- 122.7 (- 79.54)
Amplitude functions in normal cell	β_{max}	=	27.0 m
	β_{min}	=	9.65 m
Dispersion functions in normal cell	η_{max}	=	0.937 m
	η_{min}	=	0.585 m
Bending field	B	=	0.40 T
Strength of cell quadrupoles	B'	=	16.06 T/m

Beam Parameters of the TRISTAN Electron-Positron Collider

Beam energy	E_0	= 30 GeV
Energy loss per turn	U_0	= 286 MeV
Damping time	τ_x	= 2.12 ms
	τ_y	= 2.11 ms
	τ_E	= 1.05 ms
Partition number	J_x	= 0.997
	J_E	= 2.003
Natural energy spread	σ_E/E_0	= 1.627×10^{-3}
Natural horizontal emittance	ε_{x0}	= 1.727×10^{-7} m·r
Overvoltage ratio (τ_q = 24 hr)	q	= 1.311
RF peak voltage	V_{RF}	= 375 MV
Bucket height	$\Delta E/E$	= 1.08×10^{-2}
Synchronous phase angle	ψ_s	= 130.3°
Synchrotron oscillation frequency	f_s	= 9.78 kHz
Natural bunch length	σ_z	= 1.16 cm

R.M.S. beam size in normal cell

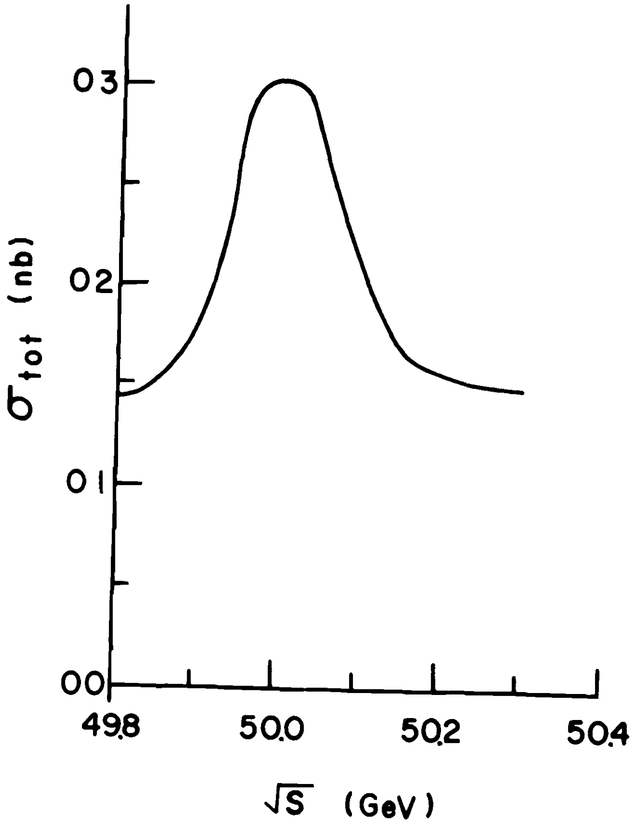
$\sigma_{x,\,max}$ (zero-coupling) = 2.64 mm

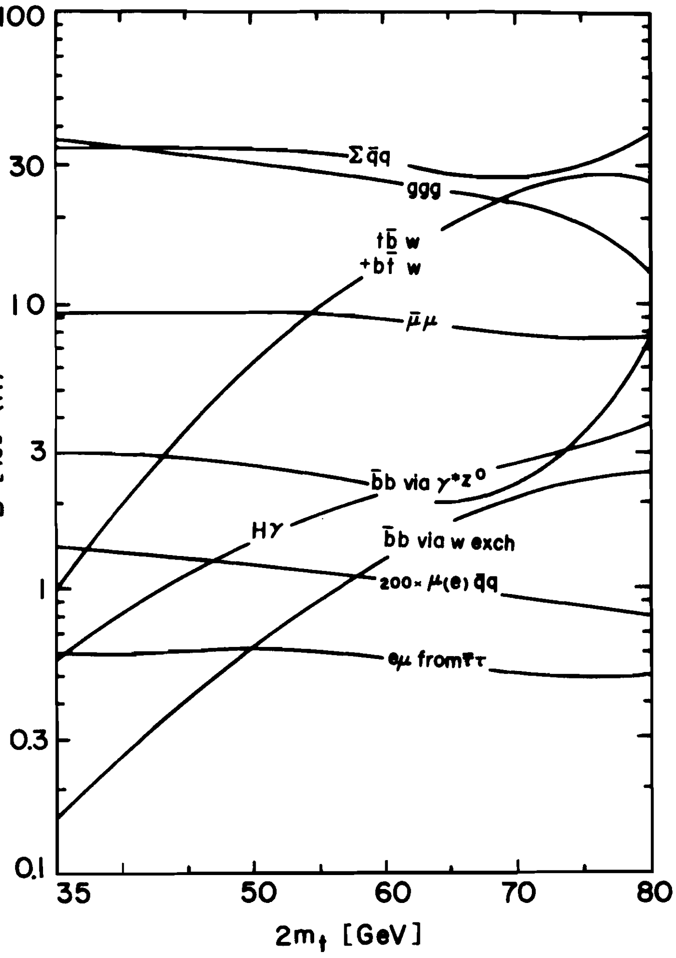
$\sigma_{y,\,max}$ (full coupling) = 1.53 mm

R.M.S. beam size at collidng point (optimum coupling)

$\sigma_x^* = 0.72 / 0.43$ mm for $\beta_x^* = 3.2 / 1.1$ m

$\sigma_y^* = 0.045 / 0.027$ mm for $\beta_y^* = 0.2 / 0.07$ m





We, most certainly, expect that the sixth quark, "top quark", exists. Unfortunately, however, we have no reliable theory to calculate the mass of the quark. Experimentally, we know that the mass of the lowest bound state of (t$\bar{t}$) is not less than 36.7 GeV[3], the maximum energy at which the search was made at PETRA. There are a few predictions[4] which place the mass in the range of 40 ∼ 50 GeV. Figure 3 shows the total hadronic cross sections, corrected for the beam energy spread and radiative correction, vs total beam energy[5]. Here an assumption was made that M(t$\bar{t}$) = 50 GeV;Γ_e = 4.8 keV, Γ_t ∼ 45 keV and the beam energy spread σ_W = 60 MeV. Taking 0.15 nb to be the net total hadronic cross section and 2 × 10^{31} cm^{-2}sec^{-1} to be the luminosity at 50 GeV, one expects ∼10 such events per hour or ∼1000 events per week; the cross section is small since it decreases with 1/s dependence but the number of events is sufficient to carry out meaningful research.

The study of R ratio, spherisity, etc. should give us the clear information needed to observe the opening of new regime with 6th quark. If the quark is indeed that with the flavor of "top" with charge 2/3, the effect on the value of R-ratio should be reasonably large. After finding the first vector (t$\bar{t}$) bound state, (t$\bar{t}$) spectroscopy should give us the t-quark potential and t-quark mass.

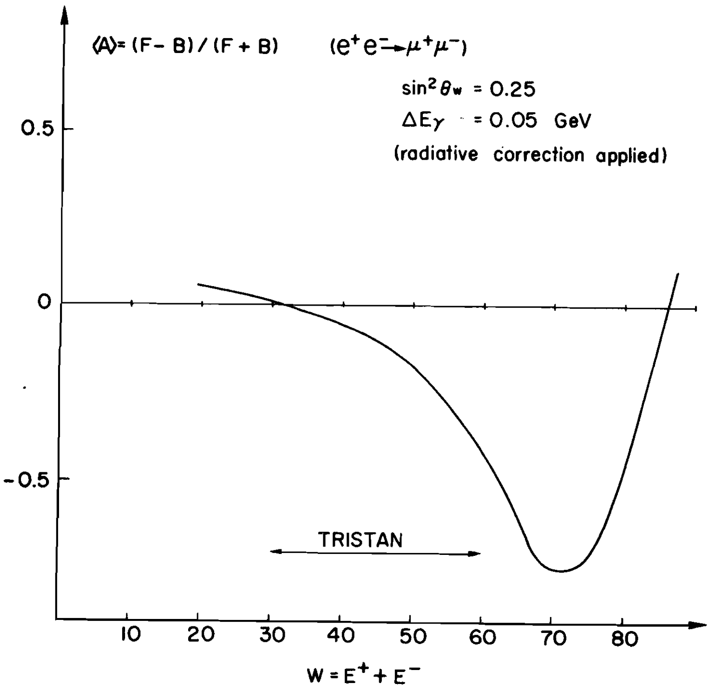
If the Higgs boson exists with a reasonable mass[6], (t$\bar{t}$) state can decay to Higgs via an emission of a hard mono-chromatic γ ray as in the reaction (t$\bar{t}$) → γ + H°. In this energy domain, a large number of soft γ rays are expected. However hard and isolated γ rays such as those from the decay to Higgs should give us a clear signature. If one takes the branching ratio of 1% for this decay, one expects ∼10 events/week. Figure 4 shows prediction of various decay branching ratio[7] of topponium.

The number of weak decay events of topponium, with mass as high as 50 GeV is predicted to be ∼70 per week. This process itself is very interesting physics, especially to determine the Kobayashi-Masukawa angles[8]. However, the lack of clear signature for detection in this energy region presents an experimental difficulty. This problem is now being studied.

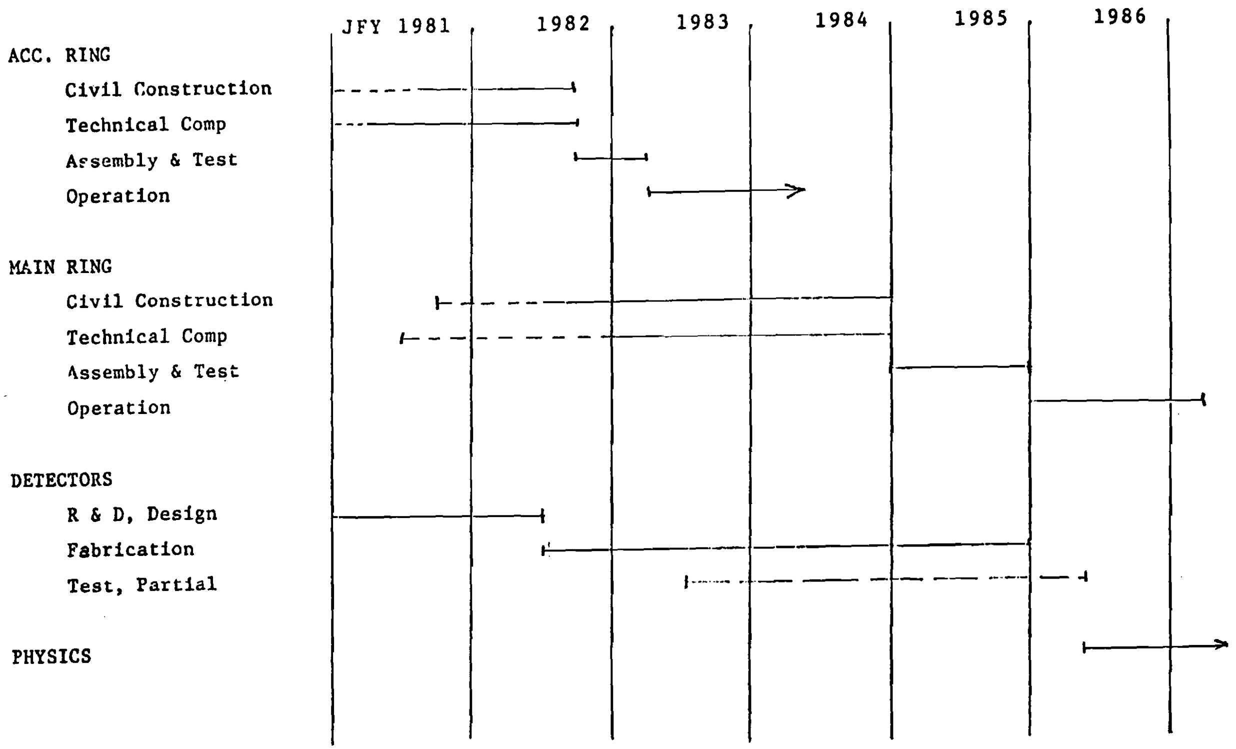
Although one of its members, "t", is still to be found, three generation of lepton doublets and quark doublets are in good shape according to the popular theory. A discovery of another heavy lepton[9] will suggest the existence of the forth generation of lepton doublet and infer the forth generation of quark doublet. Charged and neutral heavy leptons other than sequential ones have also been suggested. Although we have no knowledge of mass and cross-section of such leptons at present, hunting for such particle is of importance and excitement.

Turning to a less dramatic but important subject, at TRISTAN we will have a chance to see the weak electro-magnetic interference which is mediated by Z^0. Figure 5, which shows the forward-backward asymmetry10) as a function of energy, gives the asymmetry at 50 GeV to be ∿40%; large enough for it to be observed at TRISTAN. An extension to higher energy of QCD checks which is now in progress at PETRA and PEP will also be a natural research subject to be carried out at TRISTAN.

Before the discussion of the construction schedule, I wish to take this opportunity to state that we, in the spirit of ICFA, would welcome the international participation in the TRISTAN program. The participation can be either in a form of an individual collaboration in the on going research program or construction project, or an institutional or group participation with a substantial contribution in the form of manpower, equipment and/or research fund. In the former case, the collaboration, in most cases can be handled within the existing framework of the scientific collaboration. In the latter case, a separate bilateral arrangement may have to be established.



The construction of the accelerator complex began last April, 1981 and is scheduled to complete in five years, i.e. in mid 1986. The rough construction schedule is as shown in the bar-chart shown in Figure 6. With this schedule in mind, physicists in Japan are now actively engaged in the detector development and design. A construction of major detector system at two insertion area has been budgeted for in the initial planning. The detectors for other two insertions will have to be planned later depending on the development of the situation, including that of an international collaboration in the construction of such detectors. In order to discuss the research plan the type of detector devices to be built, we will have a TRISTAN physics workshop on November 6 ∿ 11th, 1981 at KEK. We would be very happy if we could see many oversea's participations in this workshop. A call for the proposals for the first two detectors will be made at that time, with initial evaluation some time in March of 1982.


JFY 1981
1982
1983
1984
1985
1986
ACC. RING
Civil Construction
Technical Comp
Assembly & Test
Operation
MAIN RING
Civil Construction
Technical Comp
Assembly & Test
Operation
DETECTORS
R & D, Design
Fabrication
Test, Partial
PHYSICS

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Discussion

J. Adams, CERN: The aims of Tristan Phase I seem to be very similar to those of the extended Petra machine, namely a top energy of 2×30 GeV. Is this correct? They are even planned to come into operation at about the same time.

S. Ozaki: Yes, apparently. By the way, the energy quoted is with room temperature RF. With superconducting RF, we can increase the energy. We are currently involved in R+D work for superconducting RF cavities and magnets with good progress.