“Perspective for μ^+/μ^- and e^+/e^- circular colliders in particle physics”

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Contents

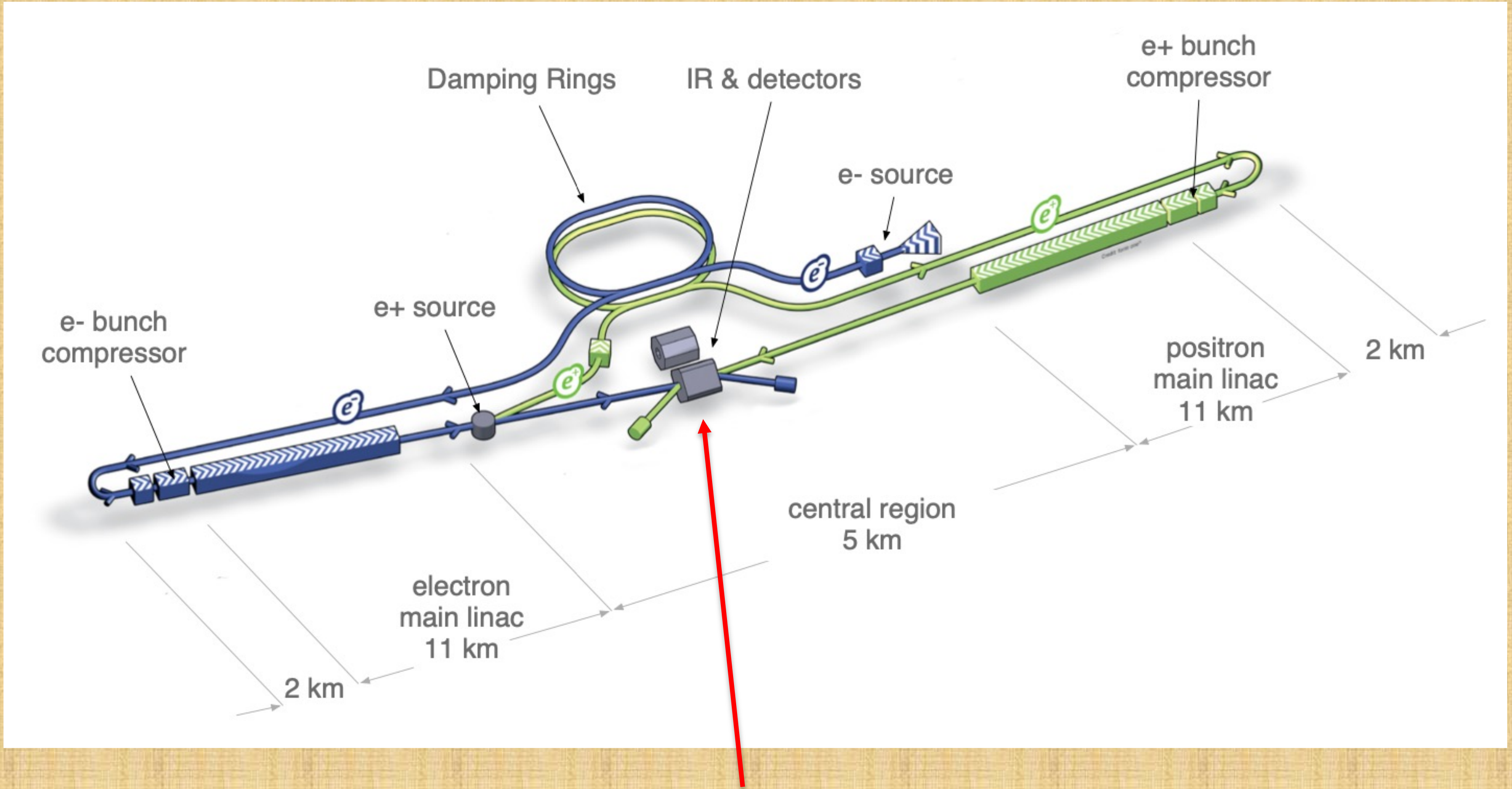
I. Why did I begin to make a plan circular colliders ?

(1) I have been considering Japan's future project.
As an example, we have proposed Φ-factory at KEK
in around the end of 1980s.
(*Progress of Theoretical Physics Supplement, 119 (1995)*)

(2) Ten years later, the super B-factory would be closed at KEK.
How about future project after the super B-factory
in Japan ?

(3) One example: ILC (International Linear Collider)
I am wondering the feasibility of the ILC project,
because Japan Islands are always moving due to
tidal force and seasonable change (below evidence)

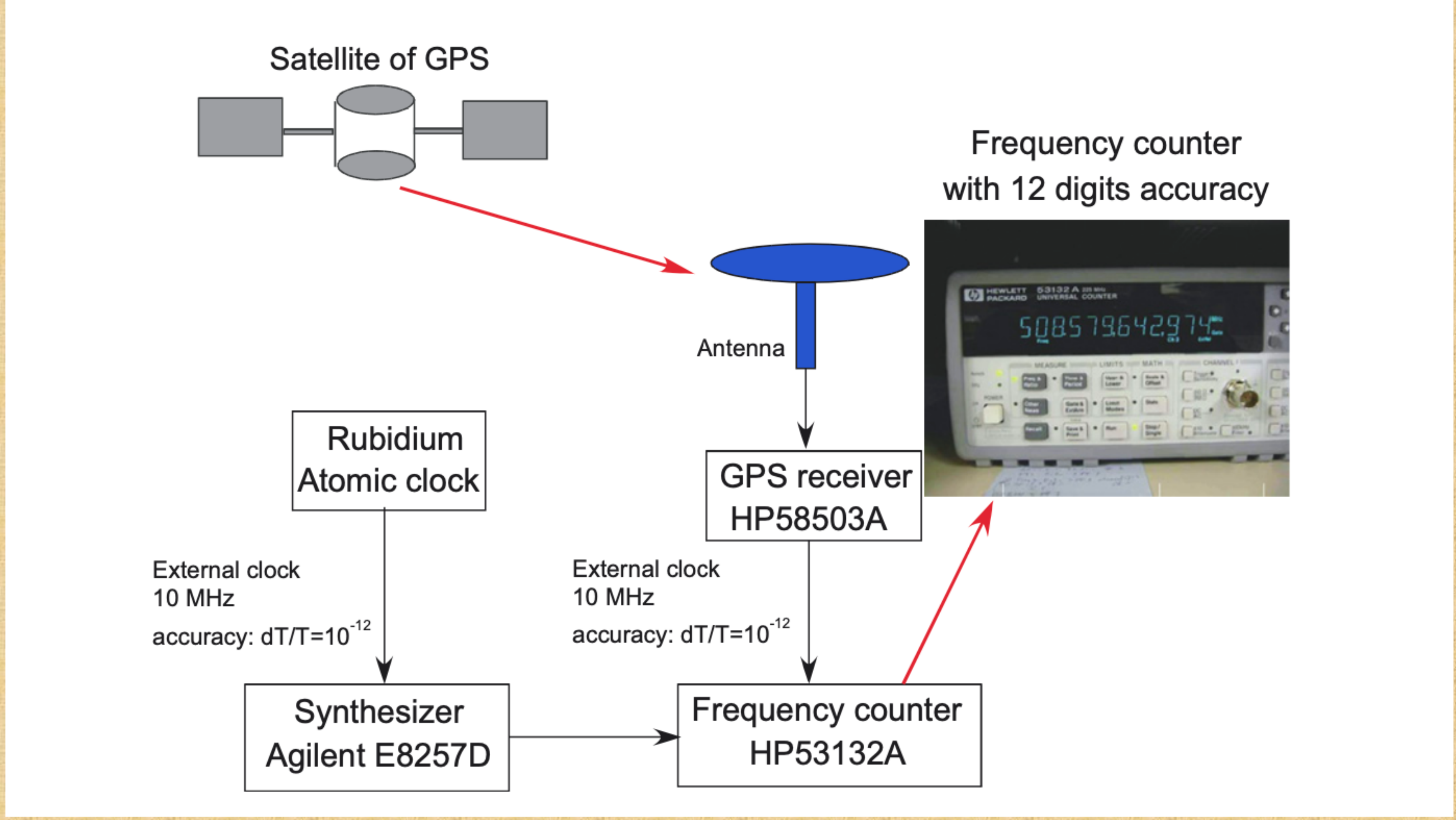
ILC collision area



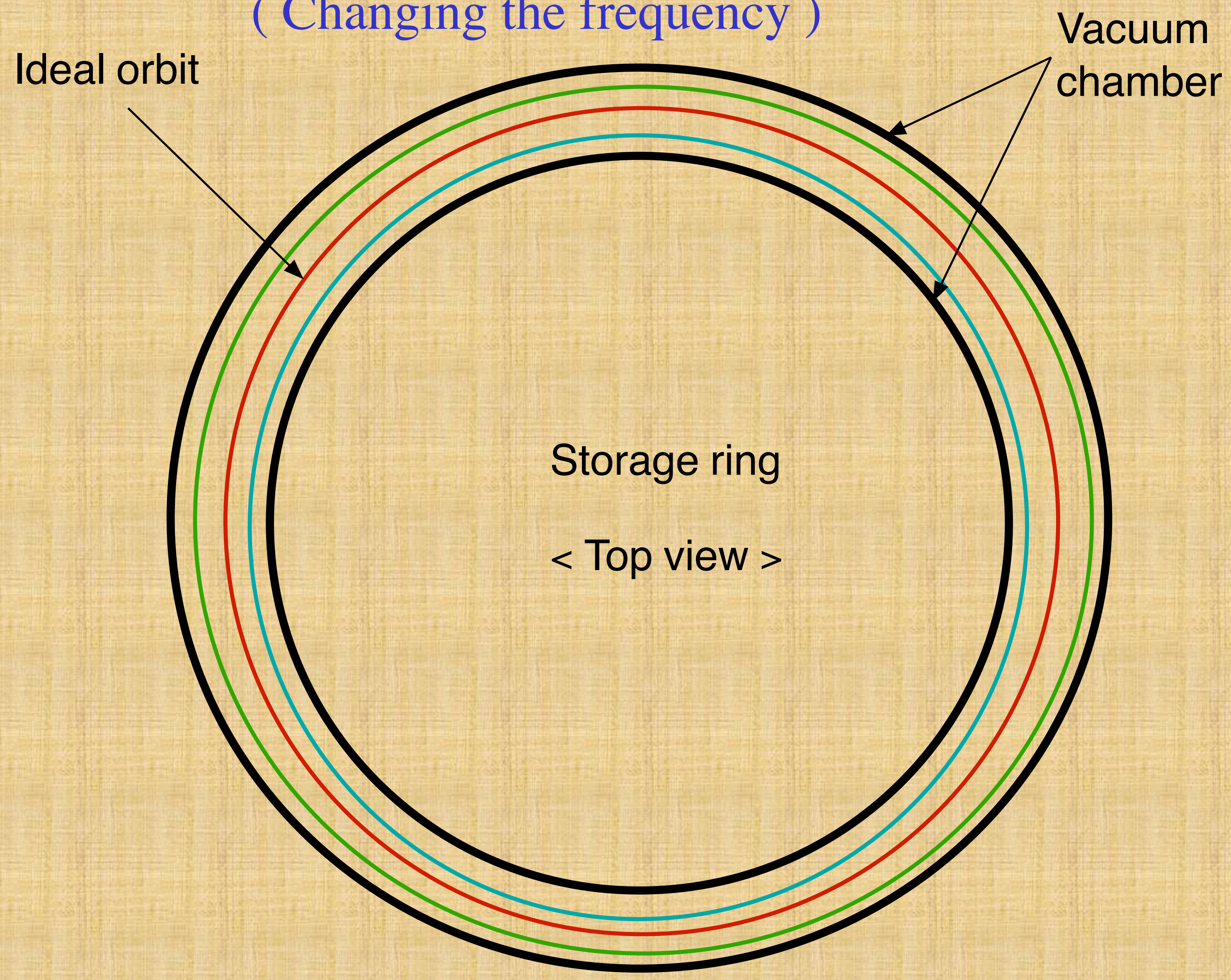
ILC project requires ~nm accuracy at the area of collision point

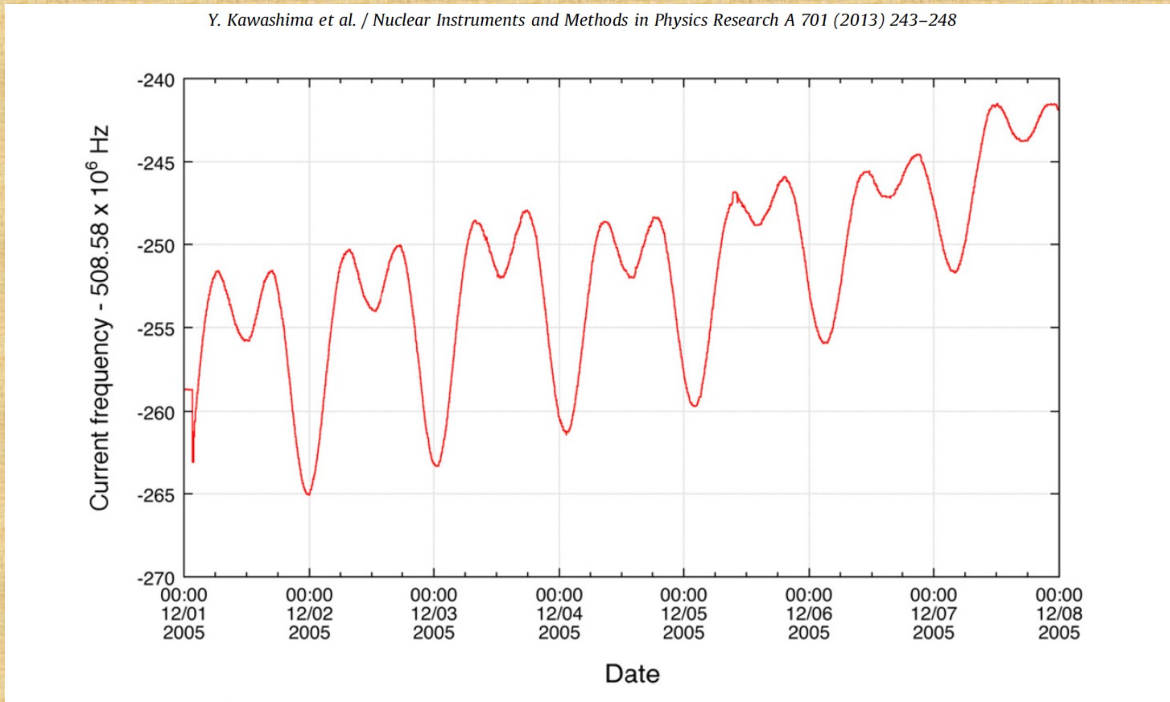
* I joined a big project in Japan in 1990.
* I was in charge of RF system for the SPring-8
(*Super Photon Ring 8 GeV*).

The fundamental frequency (508.58 MHz) at SPring-8



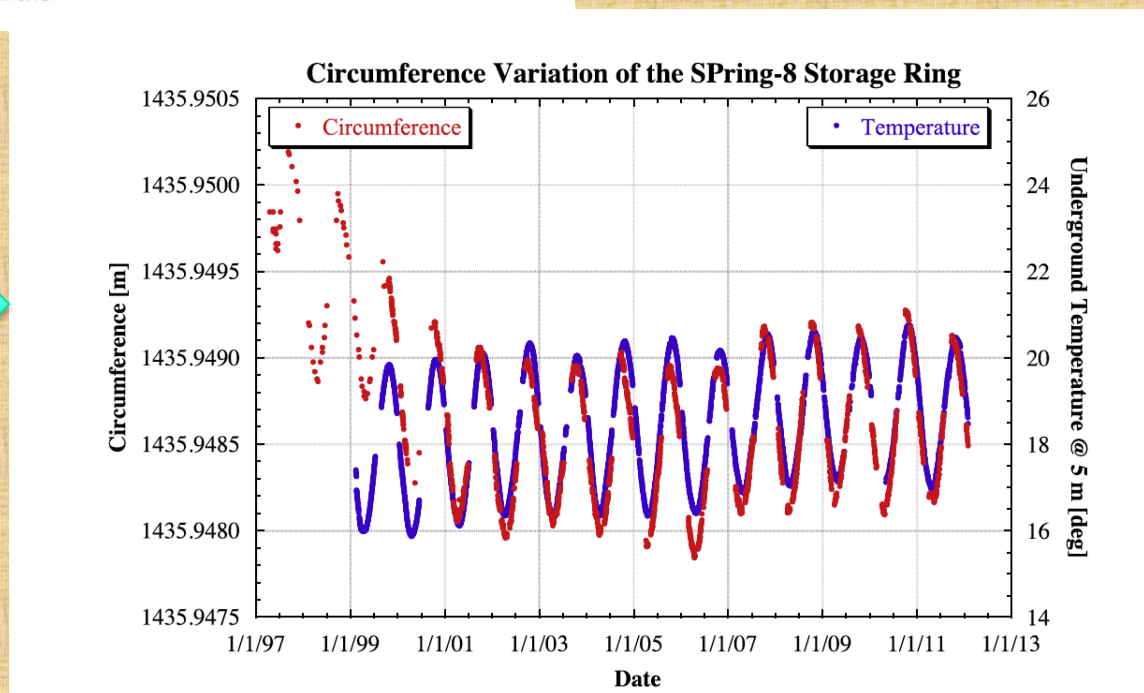
Beam orbit correction method
(Changing the frequency)





Tidal force
Movement rate :
~0.1nm/(5min.58cm)

Seasonable
change



The paper is available :

Nuclear Instruments and Methods in Physics Research
A 701 (2013) 243-248

Our data is negative against the ILC project.

(4) I have been considering a new project instead of ILC in Japan.
It is a muon collider.
In the muon collider, synchrotron radiation loss is very small.
The ring of B-factory is available for future project.

Synchroton radiation loss for heavier particles than an electron

$$\frac{dP}{dt} = (2.8779 \times 10^{-1})(\frac{1}{mc^2})^4(\frac{E^4}{\rho^2})[eV/s].$$

Synchrotron radiation loss for an electron

$$\frac{dP}{dt} = (\frac{2}{3})r_0(\frac{m_e c^2}{c^3})(\frac{B_T}{3.336 \times E})^2 c^4 (\frac{E}{mc^2})^4 = 3.793 \times 10^{11} \cdot B_T^2 \cdot E^2 [GeV/s] = 4.22 \times 10^{12} \cdot \frac{E^4}{\rho^2}[eV/s].$$

For example: Let's consider B-factory ring, ~ 3km

Energy loss due to synchrotron radiation

<u>Beam energy : 100 GeV</u>

(i) for a muon : 10.13 eV/turn

(ii) for an electron : 18.5 GeV/turn

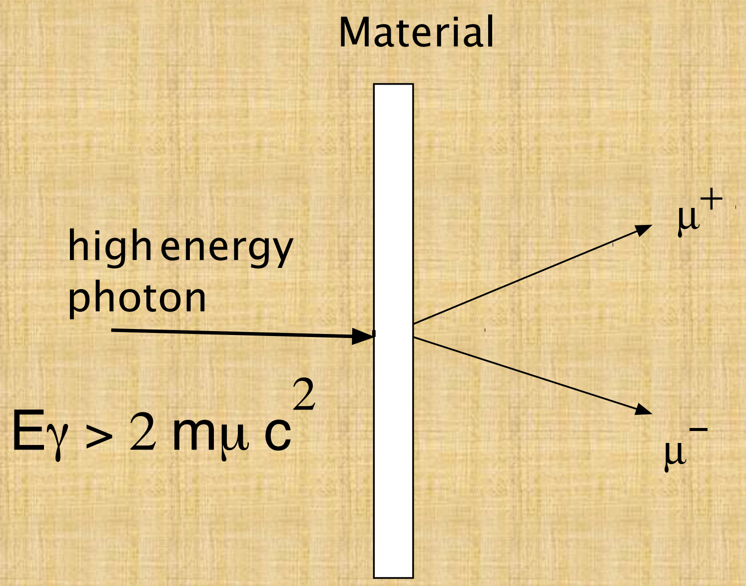
II. On muon circular colliders

How to produce so many muon pairs ?

Common method: weak decay processes through pions and kaons decays.

* I have calculated the number of muon pair production with high energy photons.

* My idea is to make use of photons to produce muon pairs.



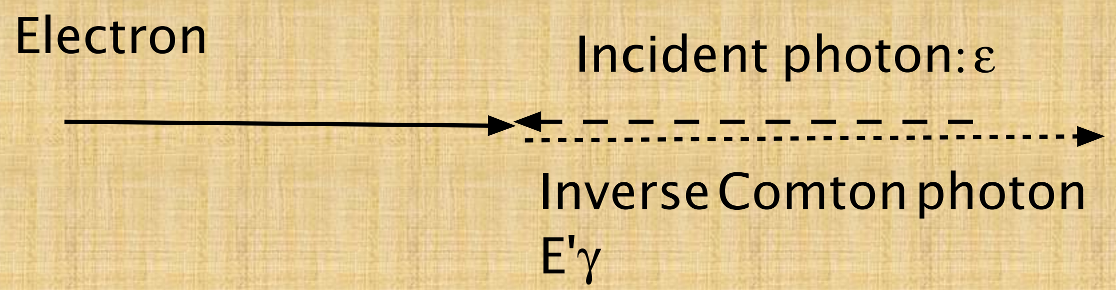
In order to produce high energy photons, I make use of inverse Compton process. After long calculation time, I obtained a simple formula.

(*Reference : Proceedings of FLS2006, Hamburg, Germany*)

$$E'_{\gamma} = 4\gamma^{2} \cdot \varepsilon$$

γ :Lorents factor for electron (2 GeV)

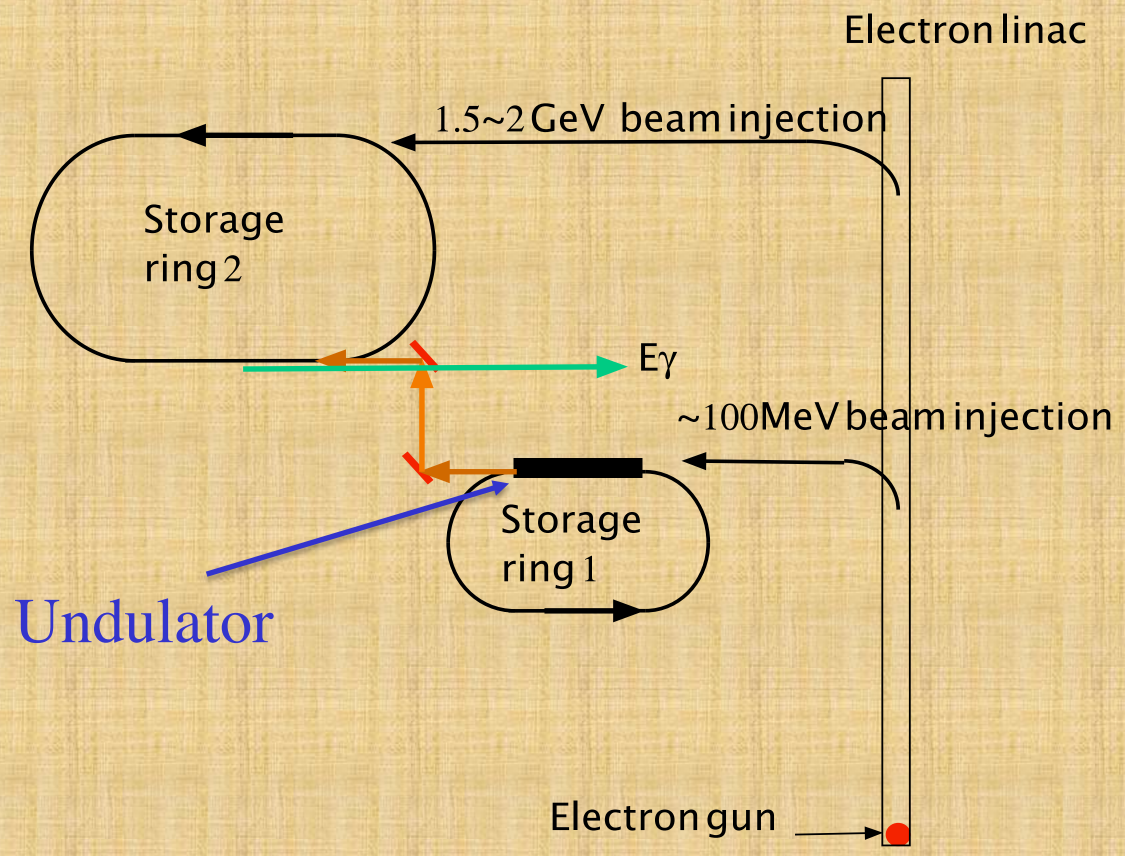
ε : Photon energy before collision



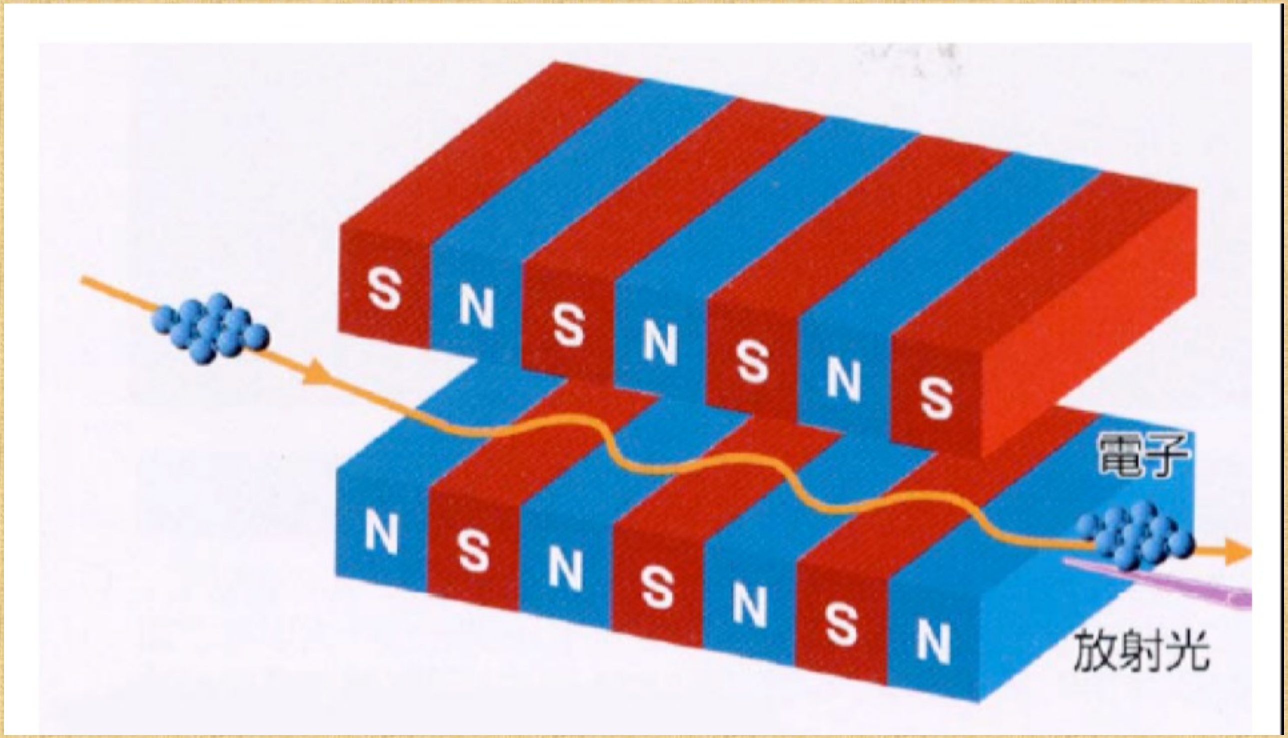
Incident photon angle : 0 degree

Inverse Compton photon angle : -180 degrees

Accelerators complex to obtain high energy photons
(The director of RCNP, Nakano-san, gave me the idea.)



* An undulator



Reference:
David Attwood, "Undulator equation and radiated power", University of California, Berkeley, http://www.coe.berkeley.edu/AST/srms

Step1: Production of photons with arbitrary energy by an undulator

B[T]	λu [cm]	K-value	N	I [A]	Stored beam energy Ee [GeV]	Obtained photon energy [eV]	Power [W]
0.04	12	0.448176	35	1	0.24	4.33	0.0173
0.04	12	0.448176	35	1	0.26	5.09	0.0204
0.04	12	0.448176	35	1	0.3	6.77	0.0271
0.04	12	0.448176	35	1	0.34	8.70	0.0348
0.04	12	0.448176	35	1	0.37	10.3	0.0412
0.04	12	0.448176	35	1	0.39	11.4	0.0458
0.04	12	0.448176	35	1	0.43	13.9	0.0557
0.04	12	0.448176	35	1	0.45	15.2	0.0610
0.04	12	0.448176	35	1	0.47	16.6	0.0665

Step2: Calculation for the number of inverse Compton photons

$$N_\gamma = L_0 \cdot \sigma_{th}$$

L_0 : Luminosity: $$L_0 = \frac{N_e \cdot N_L \cdot f_c}{4 \cdot \pi \cdot \sigma^2}$$

N_e : the number of electrons,

N_L : the number of photons,

f_c : revolution frequency,

σ^2 : transverse spot size.

σ_{th}: Thomson cross section

$$\sigma_{th} = \frac{8\pi}{3}\gamma_e^2 = 0.665 barn = 6.65\times10^{-25} cm^2 = 6.65\times10^{-29} m^2$$

classical electron radius

$$r_e = \frac{e^2}{4\pi\varepsilon_0 m_e c^2} = 2.817\times10^{-15} m$$

Finally, we need to multiply N_γ and cross section for muon pair production, we obtain total number of muon pair.

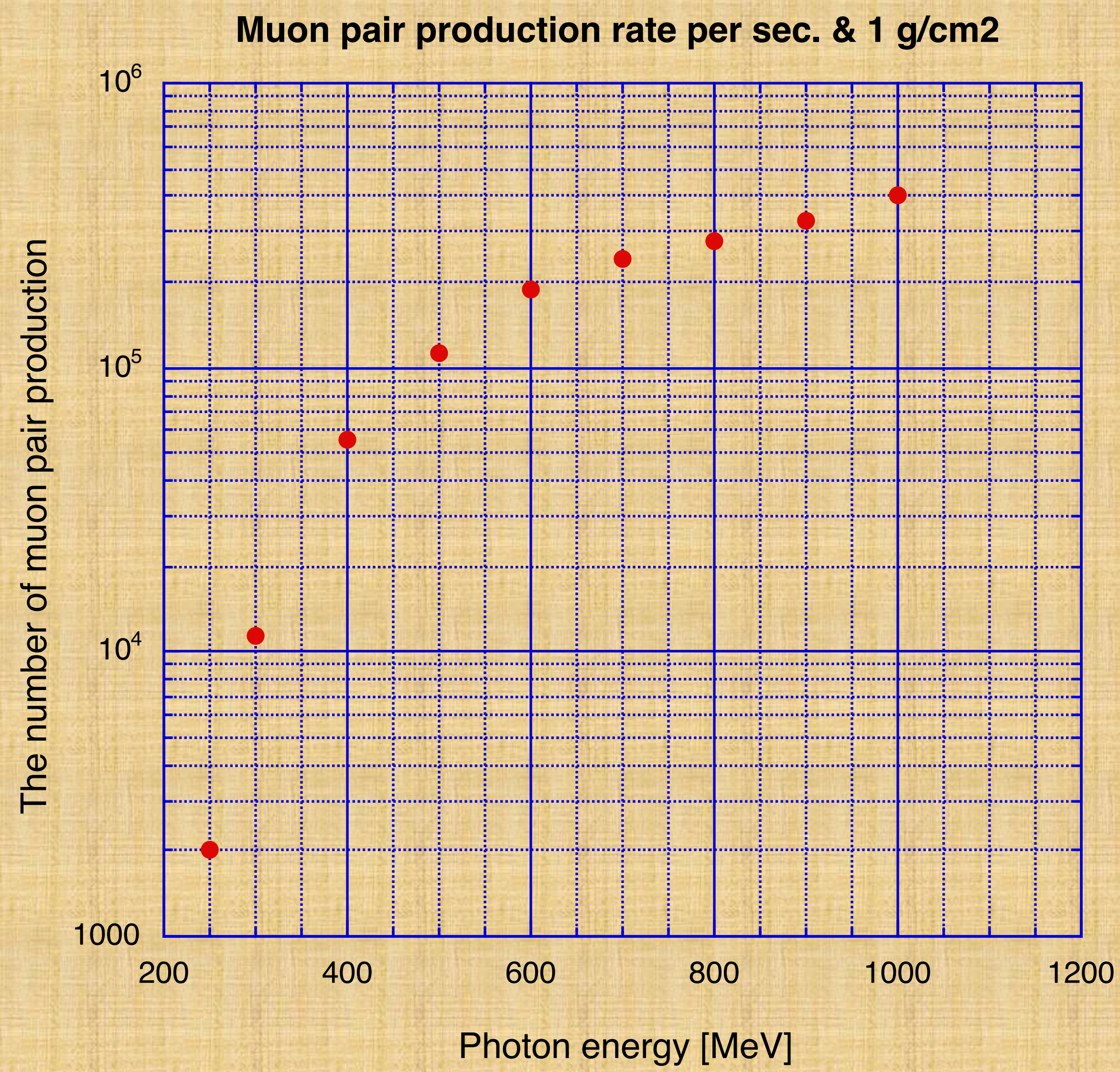
Step3: Muon pair production rate per 1 sec. & 1 g/cm^2

γ-ray energy [MeV]	Cross section [μb] (Reference: A.I. Titov et al.)	Na(Av)/A (per 1g/cm^2)	Muon pair production
250	0.8	2.445E-9	2.02E3/sec
300	4.5	1.376E-8	1.13E4
400	22	6.725E-8	5.55E4
500	45	1.376E-7	1.13E5
600	75	2.293E-7	1.89E5
700	95	2.904E-7	2.39E5
800	110	3.363E-7	2.77E5
900	130	3.974E-7	3.28E5
1000	160	4.891E-7	4.03E5

Target material : Gold

Reference: A.I.Titov et al.,

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 12, 111301 (2009)



Muon pair production rate per sec. & 1 g/cm2
The number of muon pair production
Photon energy [MeV]
10^6
10^5
10^4
1000
200
400
600
800
1000
1200

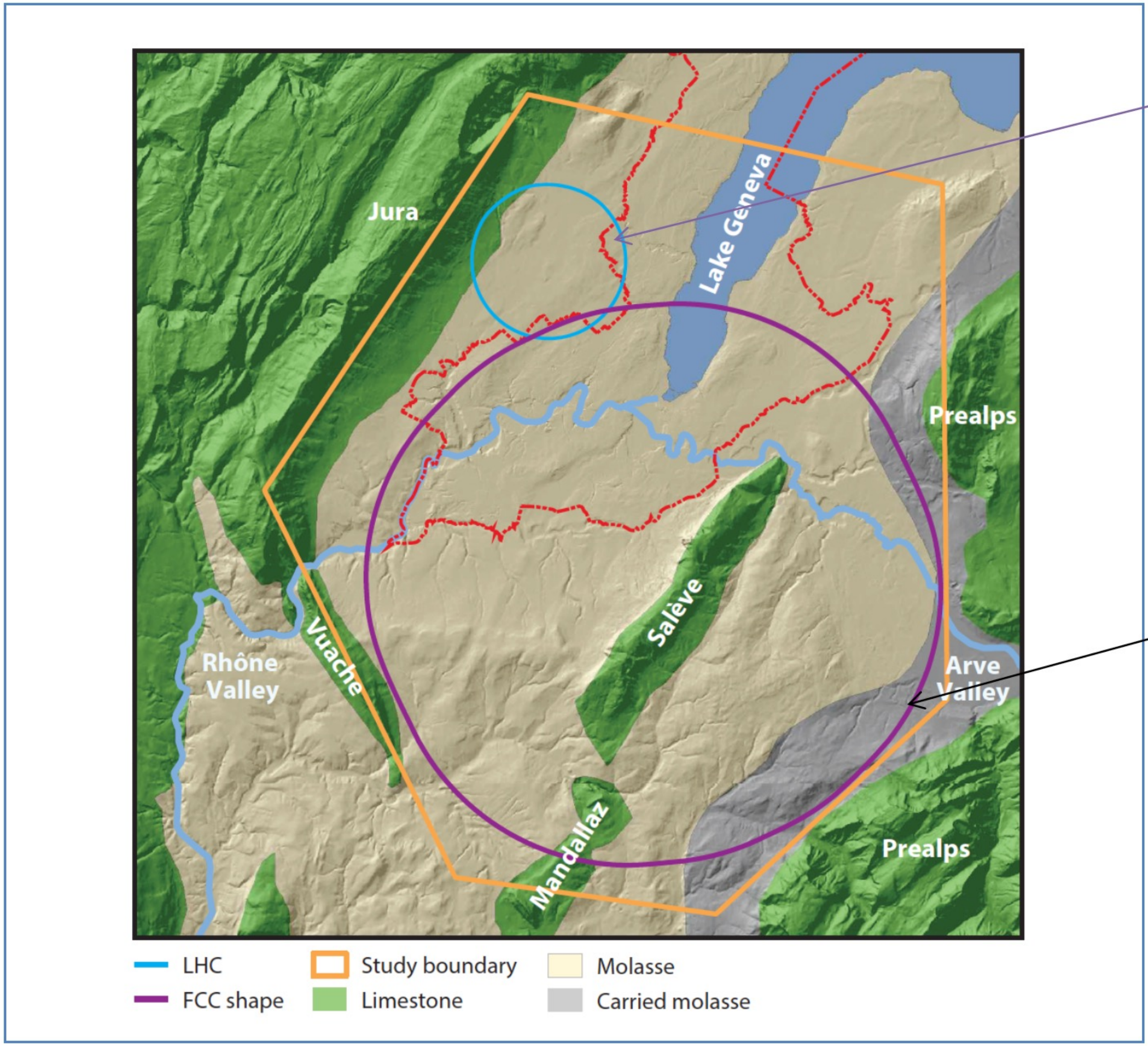
Obtained results:

The number of muon pair is roughly $\sim 10^5/(\sec . 1g/cm^2)$

This number is not good enough for muon collider.

* Two years ago, I found an interesting article published at CERN
* CERN’s future project is electron and positron collider.
* Circumference is around 100 km.
* It is named Futue Cicular Colliders (FCC).
  (e^+/e^- collider, furthermore pp collider)

Proposal location of the FCC at CERN



Large Hadron Collider

FCC Circumference: ~100 km

Table 5 Machine parameters of the FCC-ee for different beam energies (2)

	Z	WW	ZH	$t\bar{t}$[a]	
Circumference (km)	97.756				
Bending radius (km)	10.76				
Free length to IP l^* (m)	2.2				
Solenoid field at IP (T)	2				
Full crossing angle at IP, θ (mrad)	30				
SR power per beam (MW)	50				
Beam energy (GeV)	45.6	80	120	175	182.5
Beam current (mA)	1,390	147	29	6.4	5.4
Bunches per beam	16,640	2,000	328	59	48
Average bunch spacing (ns)	19.6	163	994	2,763	3,396
Bunch population (10^{11})	1.7	1.5	1.8	2.2	2.3
Horizontal emittance, ε_x (nm)	0.27	0.84	0.63	1.34	1.46
Vertical emittance, ε_y (pm)	1.0	1.7	1.3	2.7	2.9
Horizontal β_x^* (m)	0.15	0.2	0.3	1.0	
Vertical β_y^* (mm)	0.8	1.0	1.0	1.6	
Energy spread in collision, σ_δ (%)	0.132	0.131	0.165	0.186	0.192
Bunch length in collision, σ_z (mm)	12.1	6.0	5.3	2.62	2.54
Piwinski angle (SR/BS), ϕ	8.2/28.5	3.5/7.0	3.4/5.8	0.8/1.1	0.8/1.0
Energy loss per turn (GeV)	0.036	0.34	1.72	7.8	9.2
RF frequency (MHz)	400			400/800	
RF voltage (GV)	0.1	0.75	2.0	4.0/5.4	4.0/6.9
Longitudinal damping time (turns)	1,273	236	70.3	23.1	20.4
Energy acceptance (DA) (%)	±1.3	±1.3	±1.7	−2.8, +2.4	
Polarization time t_p (min)	15,000	900	120	18.0	14.6
Luminosity per IP (10^{34} cm^{-2} s^{-1})	230	28	8.5	1.8	1.55
Vertical beam–beam parameter, ξ_y	0.133	0.113	0.118	0.128	0.126
Beam lifetime (min)	>200	>200	18	24	18

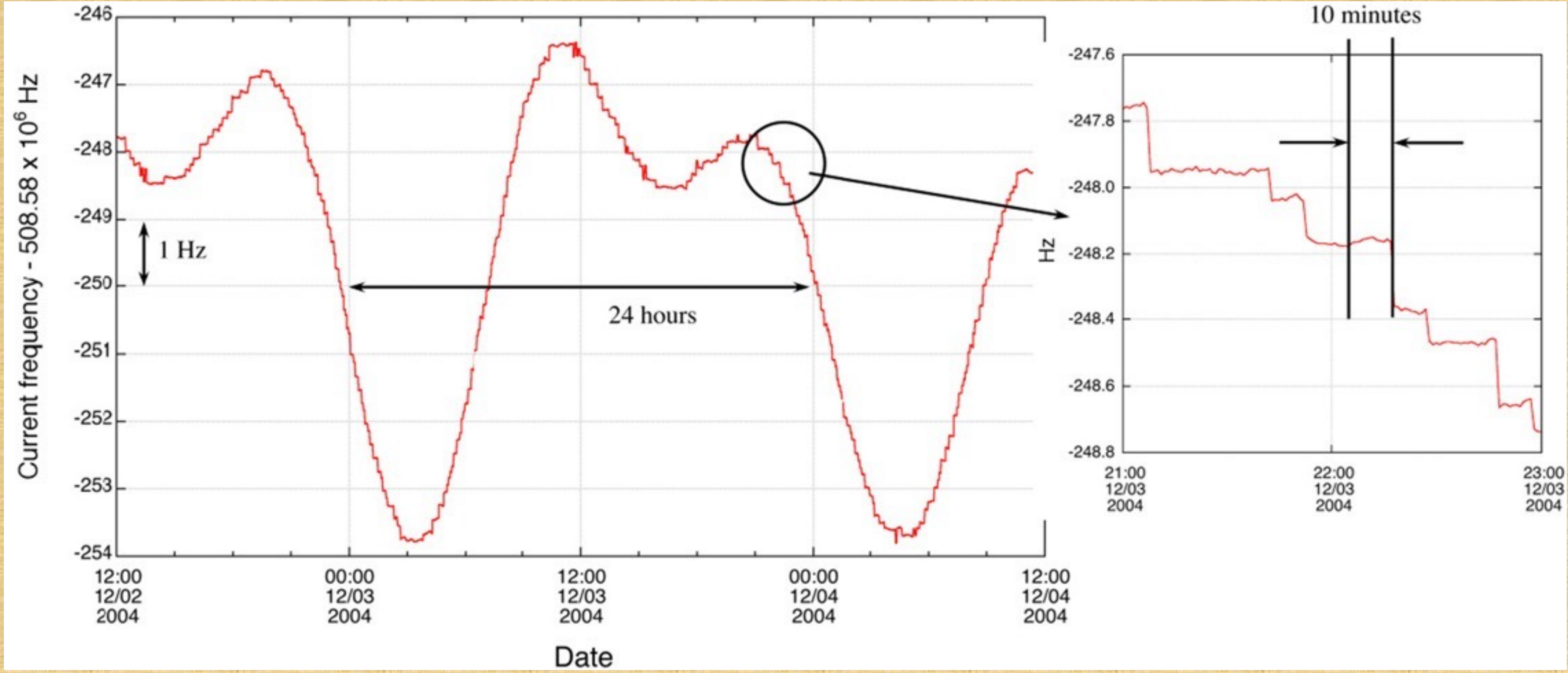
[a]A common RF system is used for $t\bar{t}$ operation. Abbreviations: BS, beamstrahlung; DA, dynamic aperture; FCC-ee, Future Circular Collider electron–positron collider; IP, interaction point; RF, radio-frequency; SR, synchrotron radiation.

III. Summary

(1) There is no future project for paticle physicists except ILC in Japan. I do not think that ILC is a feasible project.

(2) Therefore, I have considered a new muon collider, however, obtained result was negative.

(3) I think FCC (Future Circular Colliders) at CERN is very attractive project. Physicists in Japan should join it.



-246
-247
-248
-249
-250
-251
-252
-253
-254
Current frequency - 508.58 x 10^6 Hz
1 Hz
24 hours
12:00 12/02 2004
00:00 12/03 2004
12:00 12/03 2004
00:00 12/04 2004
12:00 12/04 2004
Date
10 minutes
-247.6
-247.8
-248.0
-248.2
-248.4
-248.6
-248.8
Hz
21:00 12/03 2004
22:00 12/03 2004
23:00 12/03 2004