ILC

Accelerator Overview

ILC Summer Camp 2020 (Online)

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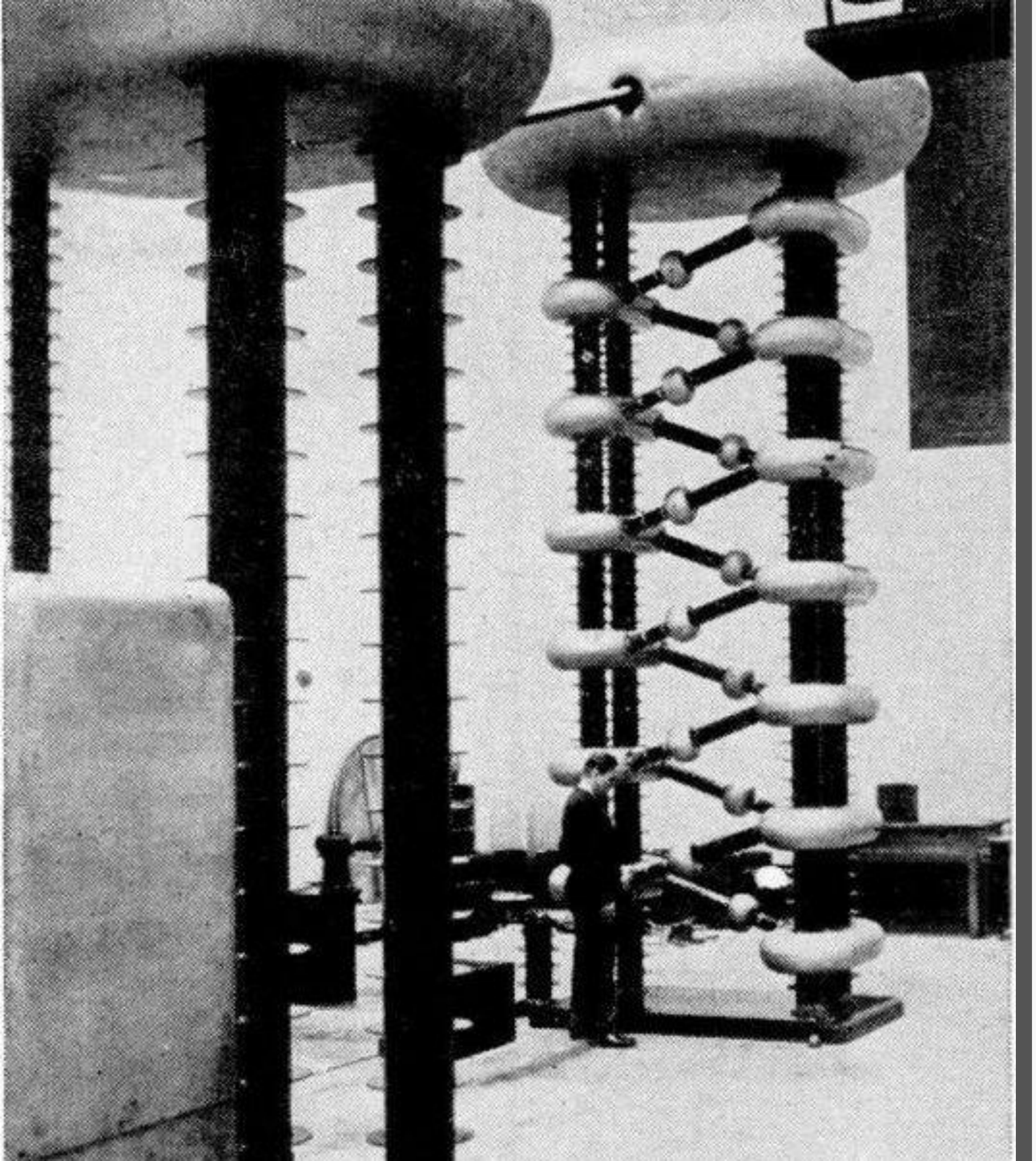
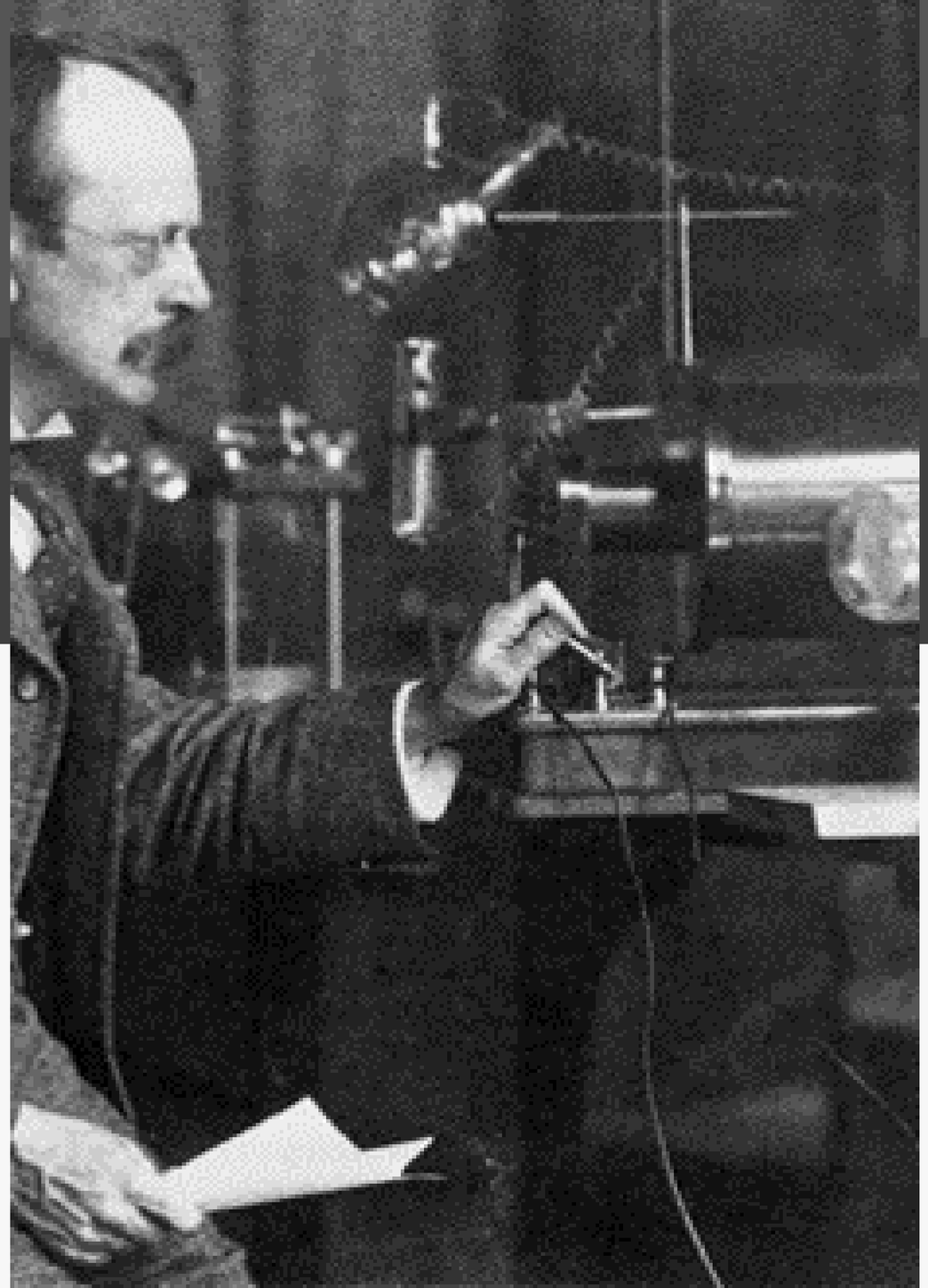
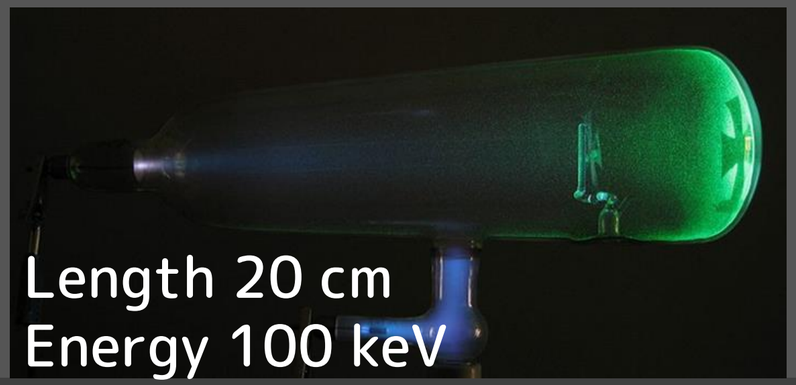


Accelerator History



1897 Discovery of electron by crookes tube.



Length 20 cm
Energy 100 keV

J. J. Thomson

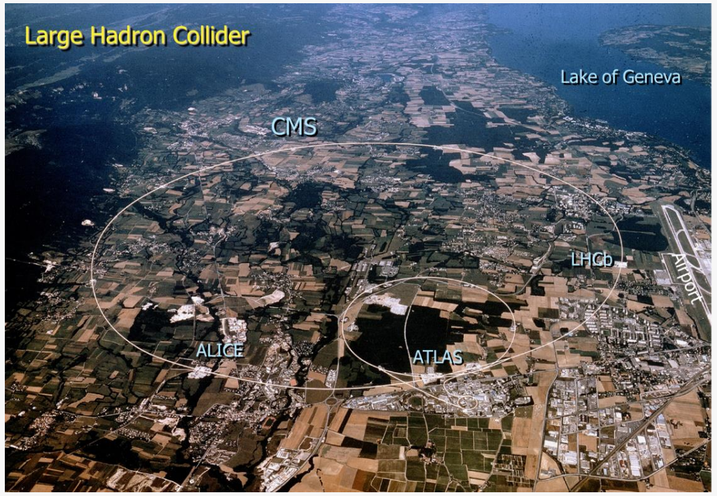
The first contact to elementary particles

2008 LHC starts at CERN

110 years

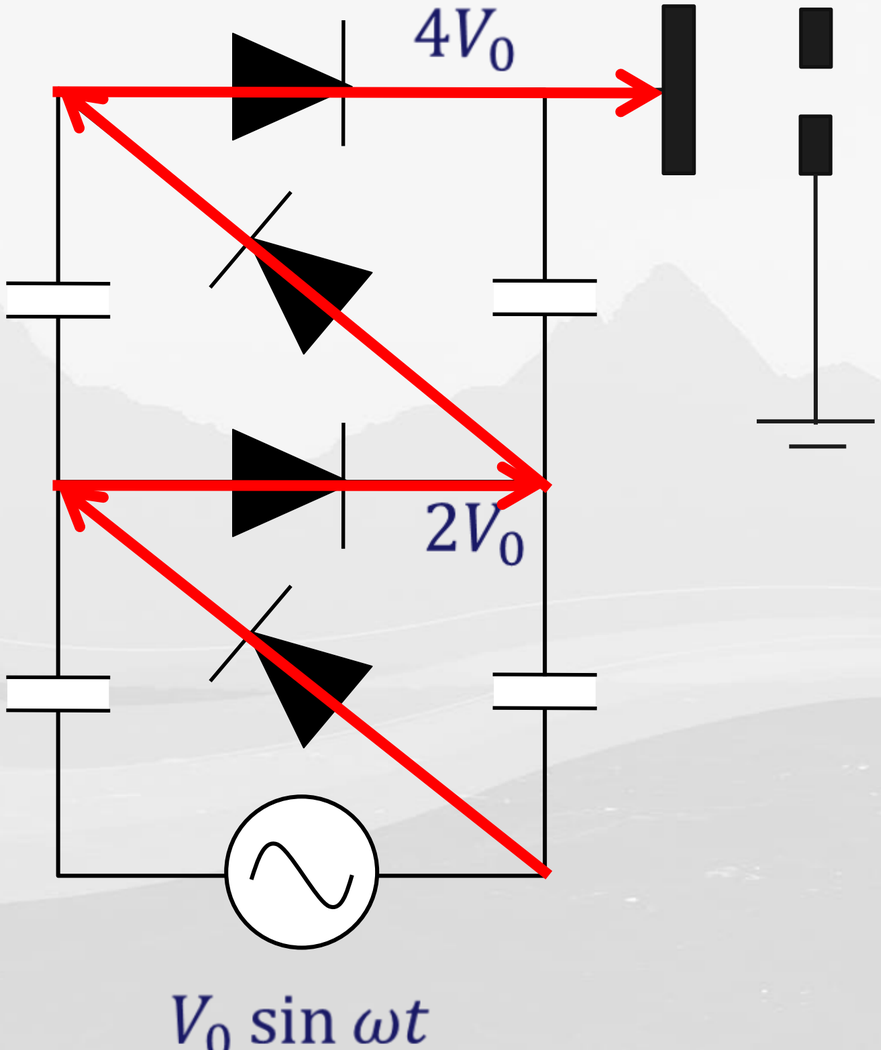
Length x 140000

Energy x 70,000,000



Circ. 27 km
Energy 7 TeV

DC Accelerator : Cockcroft-Walton



- Acceleration by static field.
- Acceleration voltage is limited by discharge.
- Acceleration is only once.
- The highest energy is limited by vacuum discharge.

DC Accelerator : Cockcroft-Walton

Question : The initial acceleration of KEK-PS (1977-2005) was done by a Cockcroft-Walton accelerator. The geometry is ~10 m x 10 m x 10m, whose volume is 1000 times of ILC cavity (31.5MV).

How much was the acceleration voltage of the Cockcroft Walton?

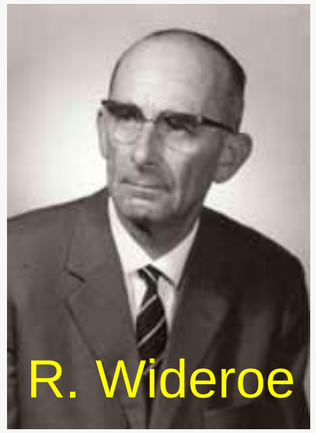
A. 700 kV

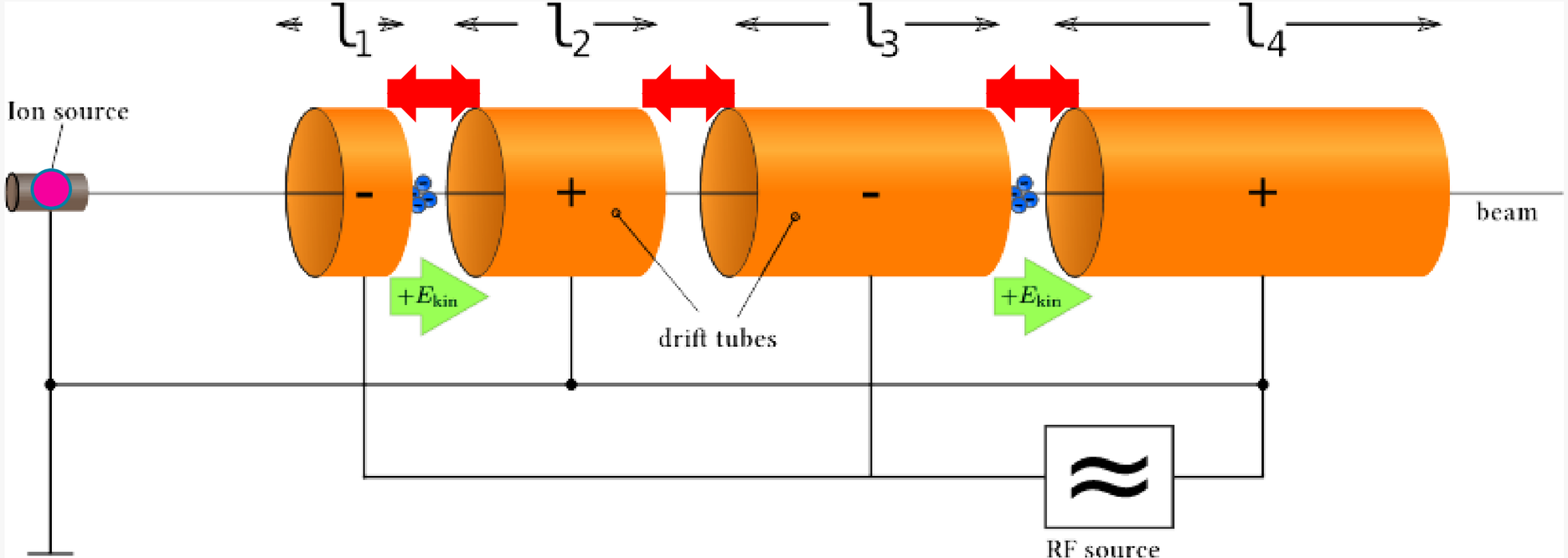
B. 70 MV

C. 315 MV

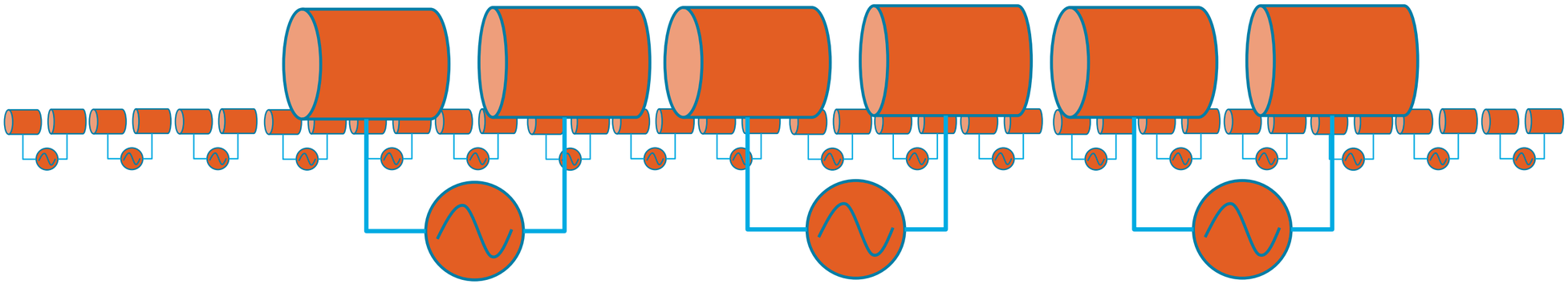
AC（RF） Accelerator

- Acceleration by temporary varying field.
- **Acceleration can be repeatable.**
- The energy is unlimited principally.
- All high energy accelerators is variations of Wideroe accelerator.





Linac (Linear Accelerator)



- Linac (Linear Accelerator) is composed from many cavities.
- The acceleration energy is unlimited in principle.
- Acceleration energy E

$$E = eVL$$

V: accelerator gradient (V/m)

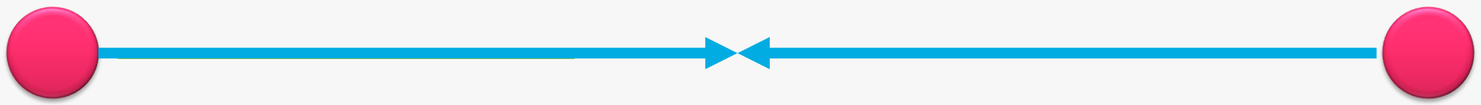
L: accelerator length (m)

Power of Collider

Don't move !

Beam energy for Higgs

Collider



125GeV + 125 GeV
(1 ILC)

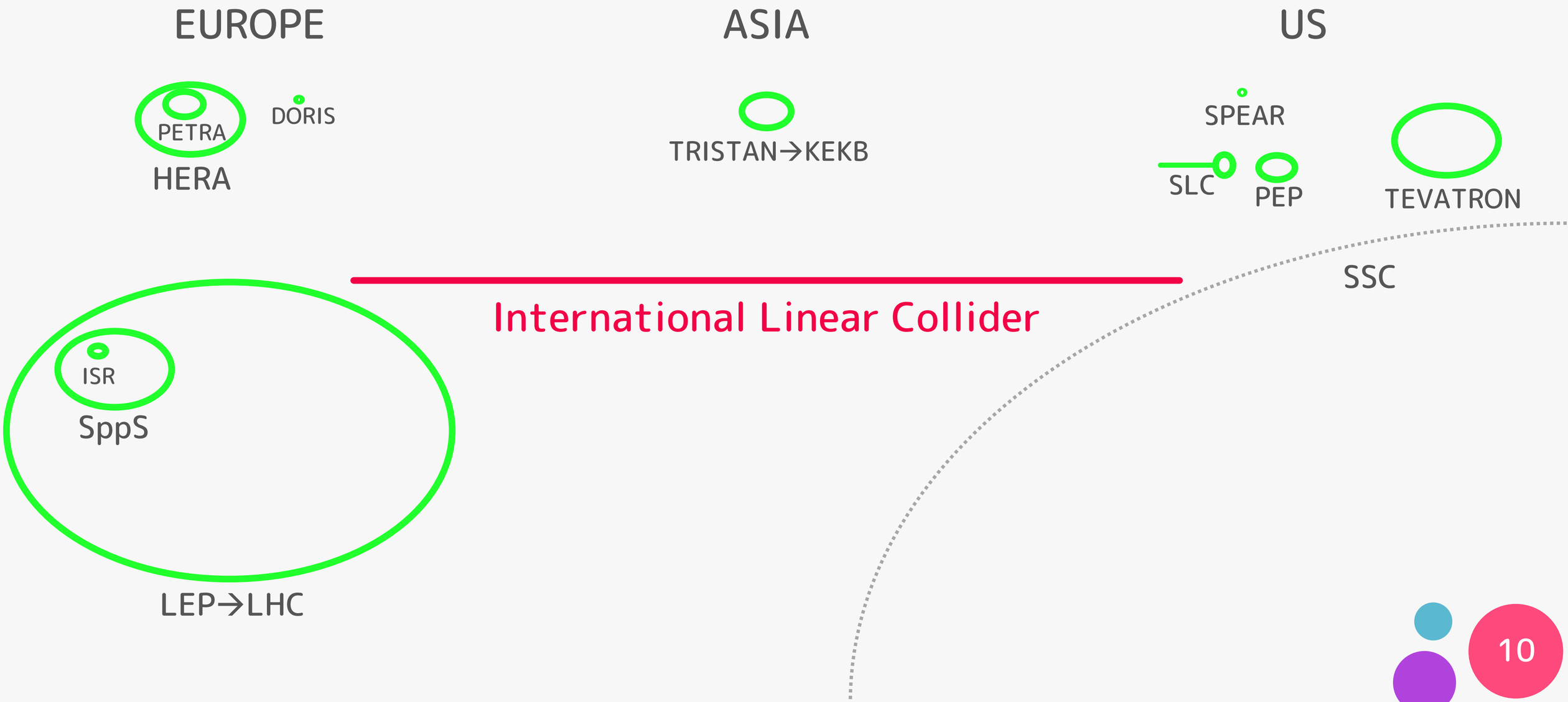
Fixed target

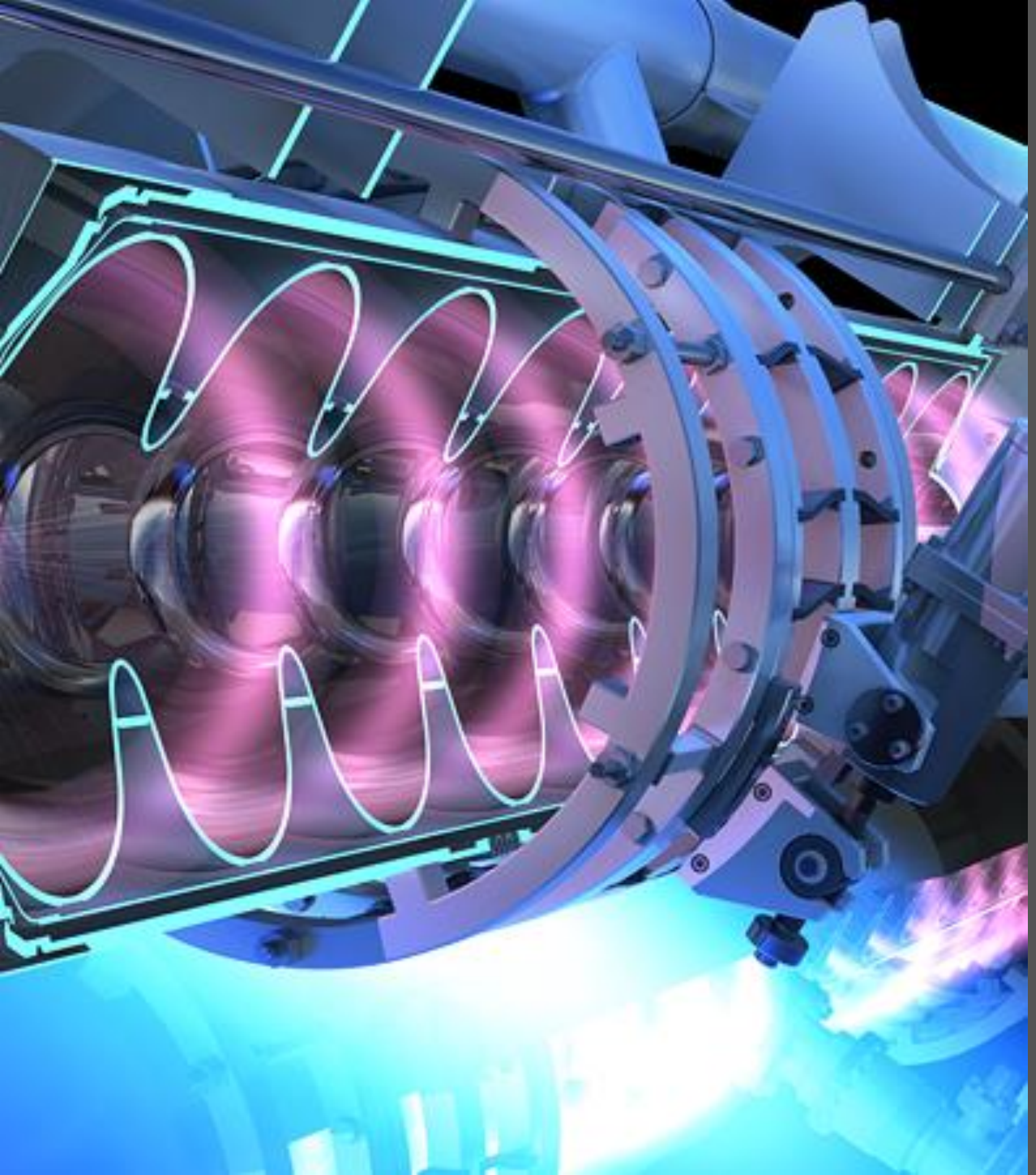
62,500,000 GeV
(250,000 ILC)

If the particles move after collision, less effective.

Energy Frontier

Many colliders have been built.

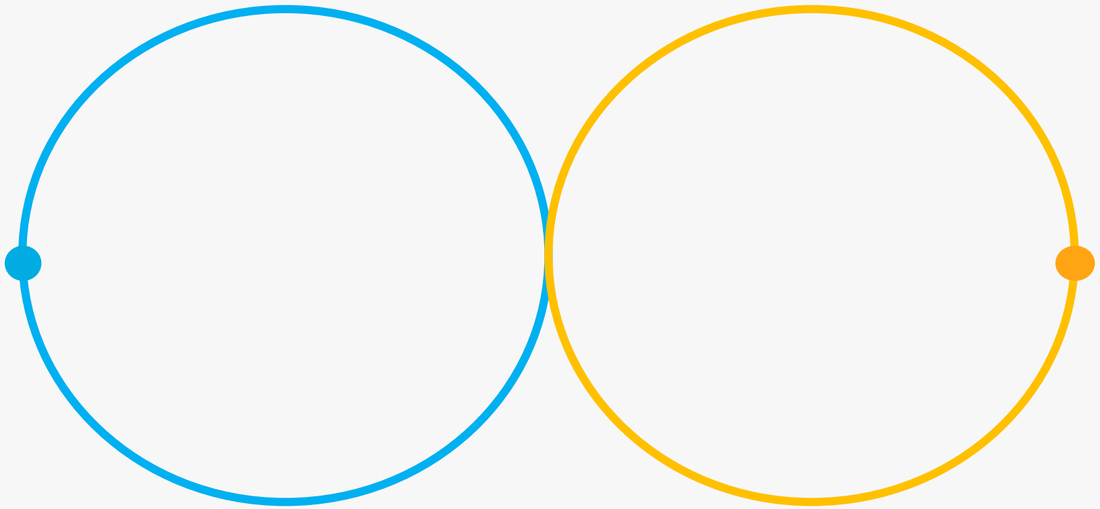




Why Linear Collider

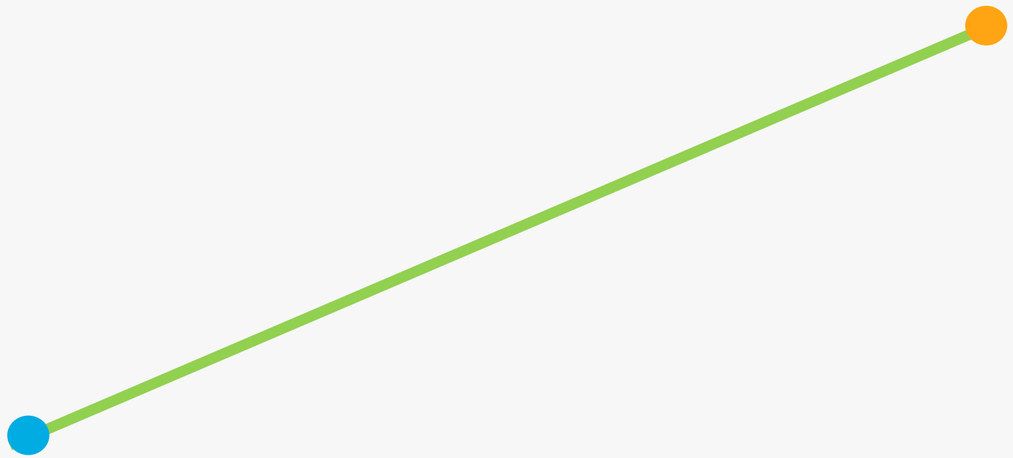
Two topologies

Ring or Linear



1. Beam is circulating.
2. High frequency collision.
3. Accelerating power is very few.

Because the injector beam current is 10^{-5} smaller than the stored current.



1. Beam is dumped after collision.
2. Low frequency collision.
3. The beam current can't e high, because beam power = Accelerator power.

Beam life in a Ring Collider

Birth

Electron and positron are generated by the sources.

t =0 sec.

Growing

The beam is accelerated up to the stored energy .

$t=10^{-6}$ sec.

Working

The collision is repeated.

~2 hours.

End of life

The beam is lost statistically by scattering , etc.

t=2 hours.

Beam life in a Linear Collider

Birth

Electron and positron are generated by the sources.

t =0 sec.

Growing

The beam is accelerated up to the collision energy .

$t=10^{-6}$ sec.

Working

The beam passes IP only once.

$\sim 10^{-11}$ sec.

End of life

The beam is dumped after the collision.

t=0.2 sec.

Paradigm change

Synhrotron radiation exceeds the limit!

According to local information, a revolution broke out in the capital of the RING empire. Huge waste of resources by synchrotron radiation got angry with the public. A caretaker government was established and measures such as freezing royal property were announced.

Beam life in a Ring Collider

If the beam energy is higher than "Threshold",

Birth

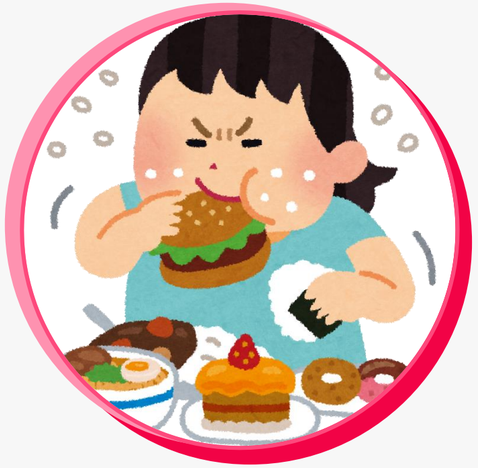
Electron and positron are generated by the sources.

t =0 sec.

Growing

The beam is accelerated up to the stored energy .

$t=10^{-6}$ sec.



Working

The collision is repeated, but the power to keep the beam energy is huge.

~2 hours.

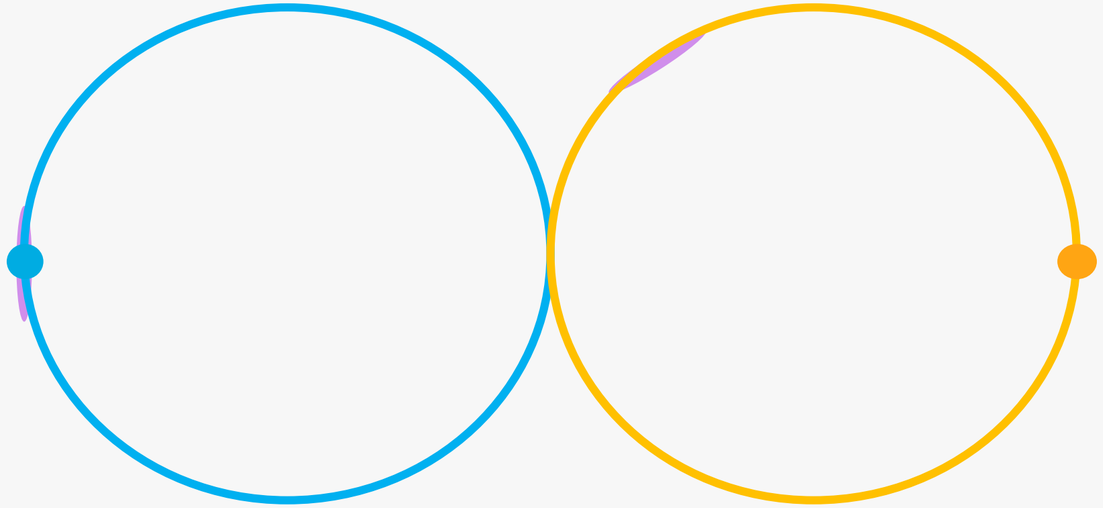
End of life

The beam is lost statistically by scattering , etc.

t=2 hours.

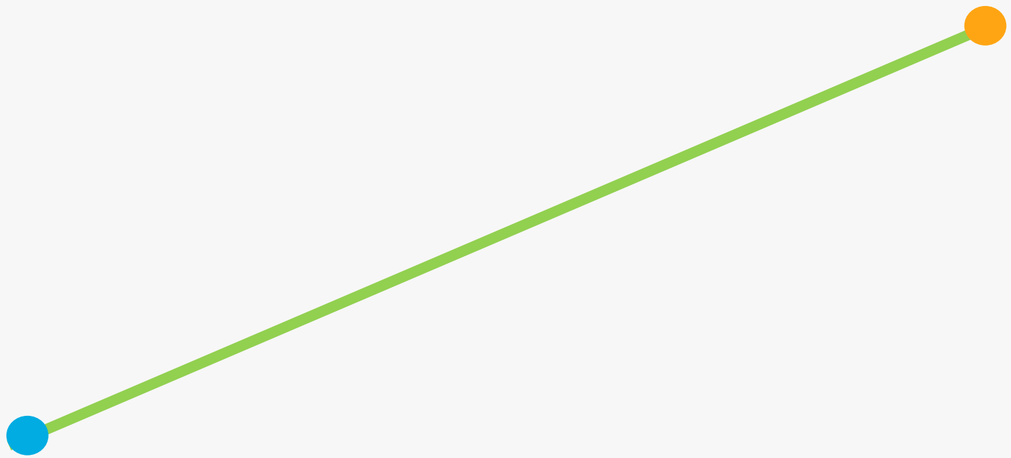
Two topologies (Above the threshold)

Ring or Linear



1. Beam is circulating.
2. High frequency collision.
3. Accelerating power is very few, but the power to keep the beam energy is huge.

$$P_{wall} = \eta\left(\frac{2IE}{\tau} + 2\frac{4\pi e^2}{3}\frac{\beta^4\gamma^4}{\rho}\right)$$



1. Beam is dumped after collision.
2. Low frequency collision.
3. Beam power = Accelerator power.

$$P_{wall} = \eta 2IE$$

Design Concept of Linear Collider

Pros and Cons of linear collider

Pros

- No energy loss by synchrotron radiation.
- The beam can be polarized.
- Strong against the beam-beam effect, because we don't care about the beam after collision.

Cons

- The beam power can't be high, otherwise the electricity could be huge.
- Need a high gradient, otherwise the length could be humongous.

Luminosity Gain for LC

A high luminosity with a limited beam power is a key of LC.

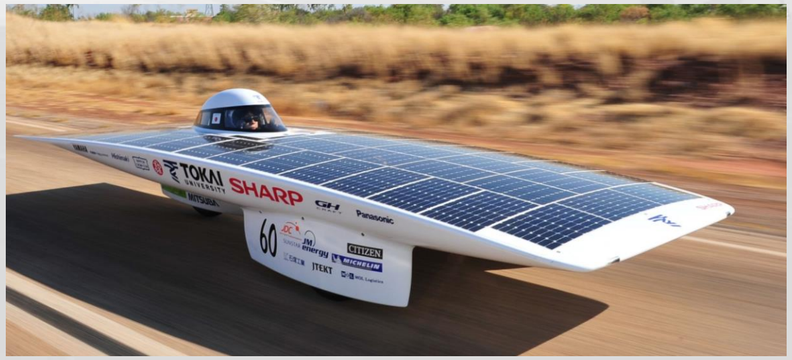
Suppress for saving electricity

Minimize for larger luminosity.

$$\mathcal{L} = \frac{f n_b N^2}{4\pi\sigma_x\sigma_y}$$

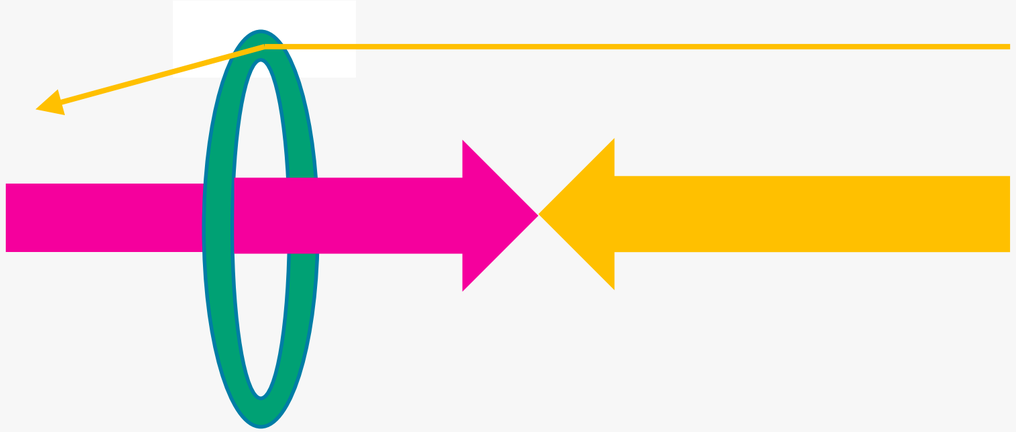
Ring Collider

Linear Collider



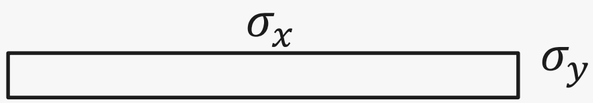
Beamstrahlung

- Synchrotron radiation with magnetic field generated by the collision partner.
- It causes the energy tail of the beam resulting a worse energy resolution.



Ampere's law

$\sigma_x \gg \sigma_x$



$$B = \frac{\mu_0 I}{2\pi r} \sim \frac{\mu_0 ceN}{2\sigma_x \sigma_z}$$

$$\delta_E = \left\langle -\frac{\Delta E}{E} \right\rangle \sim 0.209 \frac{N^2 {r_e}^3 \gamma}{\sigma_z} \left(\frac{2}{\sigma_x + \sigma_y} \right)^2 U_1(\Upsilon)$$

Luminosity Gain for LC

- A high luminosity with a limited beam power is a key of LC.
- To keep BS, only σ_y is minimized.

Suppress for saving electricity

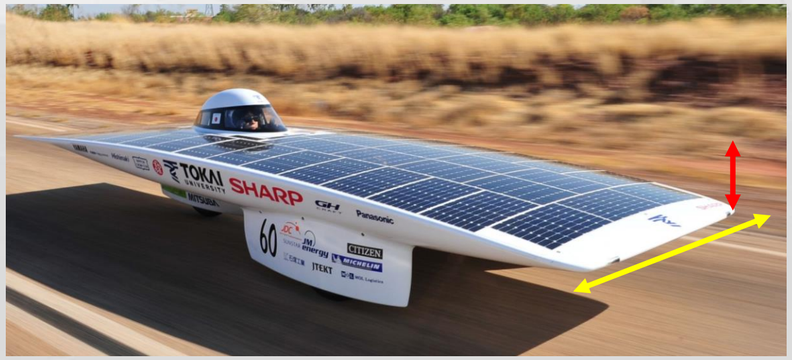
$$\mathcal{L} = \frac{f n_b N^2}{4\pi \sigma_x \sigma_y}$$

Minimize for large luminosity

To keep BS, it should not be too small.

Ring Collider

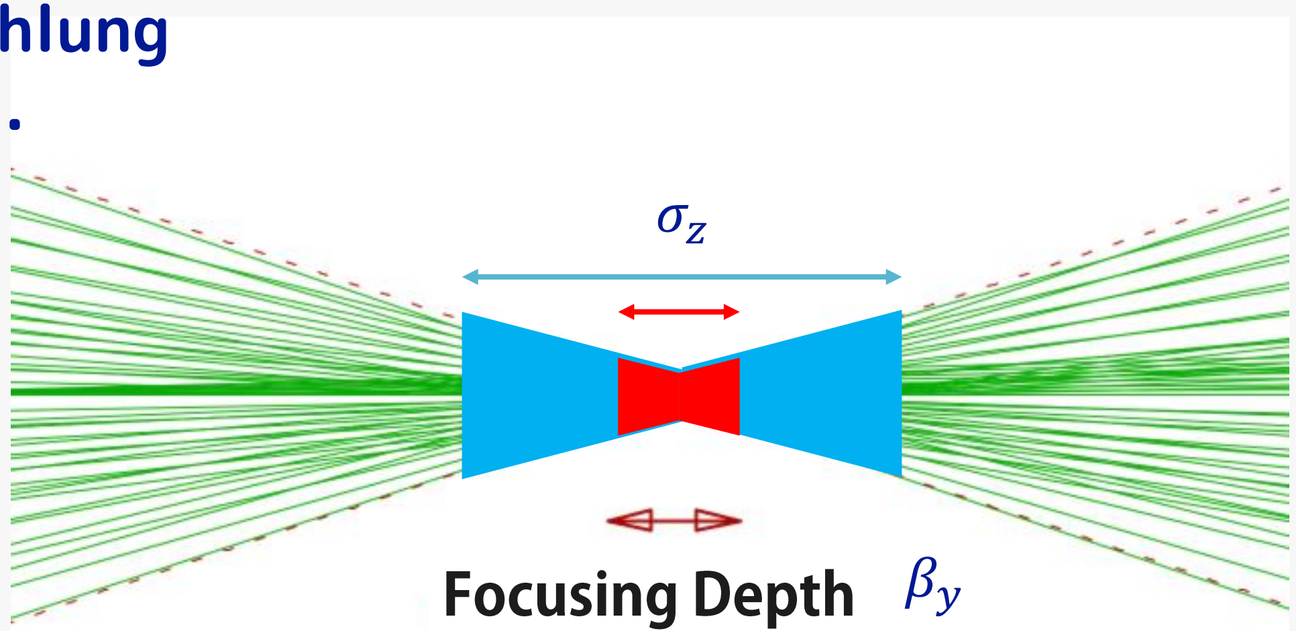
Linear Collider



Beam Focusing

- If $\sigma_z > \beta_y$, the luminosity is small, because only a fraction of beam is focused.
- If $\sigma_z = \beta_y$, the luminosity is large.
- $\sigma_z < \beta_y$,
  - No large enhancement for luminosity
  - Enhance Beamstrahlung
- $\sigma_z = \beta_y$ is the optimum.

β_y : Beam focusing depth at IP.
σ_z: Bunch length.



Luminosity Scaling

- Beam power and electricity $$P_{beam} = eEfn_bN = \eta P_{wall}$$
- Beam size at IP $$\sigma_{x,y} = \sqrt{\frac{\varepsilon_{x,y}\beta_{x,y}}{\gamma}}$$
- Energy spread by BS $$\delta_{BS} = \frac{N^2E}{{\sigma_x}^2\sigma_z}$$

Luminosity

$$\mathcal{L} = \frac{\eta P_{wall}}{E}\sqrt{\frac{\delta_{BS}}{\varepsilon_y}}\sqrt{\frac{\sigma_z}{\beta_y}} \sim \frac{\eta P_{wall}}{E}\sqrt{\frac{\delta_{BS}}{\varepsilon_y}}$$

Normalized Luminosity

$$\frac{\mathcal{L}}{P_{wall}} \sim \frac{\eta}{E}\sqrt{\frac{\delta_{BS}}{\varepsilon_y}}$$

Luminosity Scaling

Experimental
Design
Physics

Normalized Luminosity

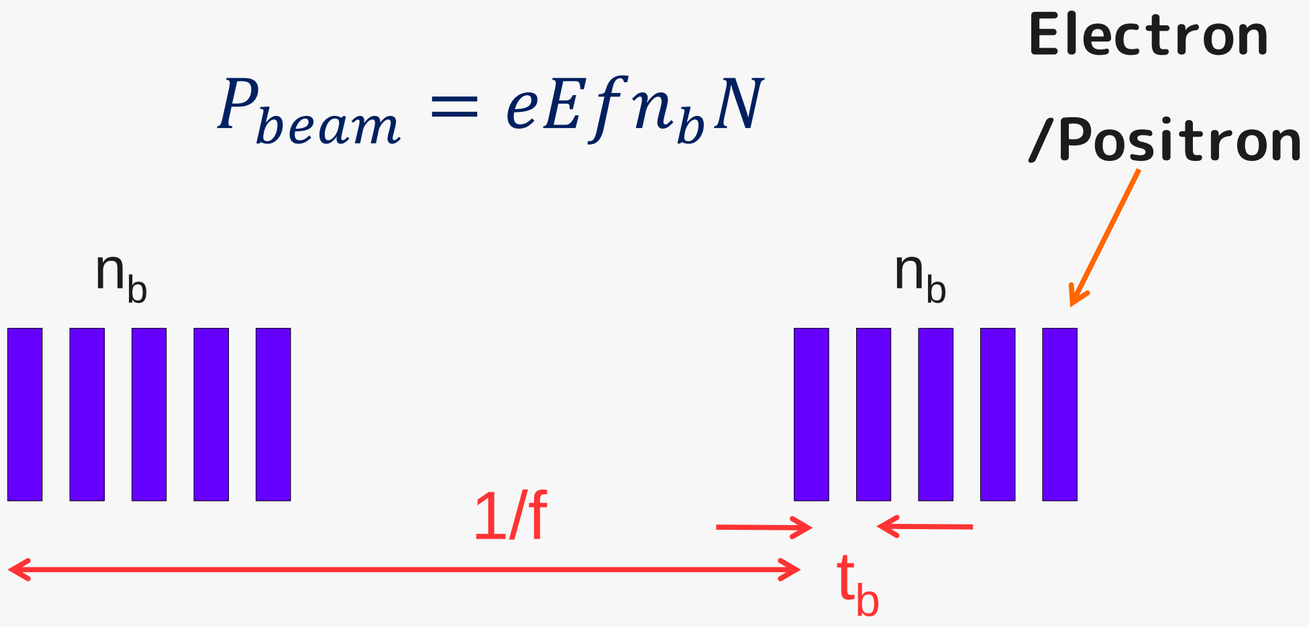
$$\frac{\mathcal{L}}{P_{wall}} \sim \frac{\eta}{E}\sqrt{\frac{\delta_{BS}}{\varepsilon_y}}$$

System
Optimization
Accelerator

Beam Format

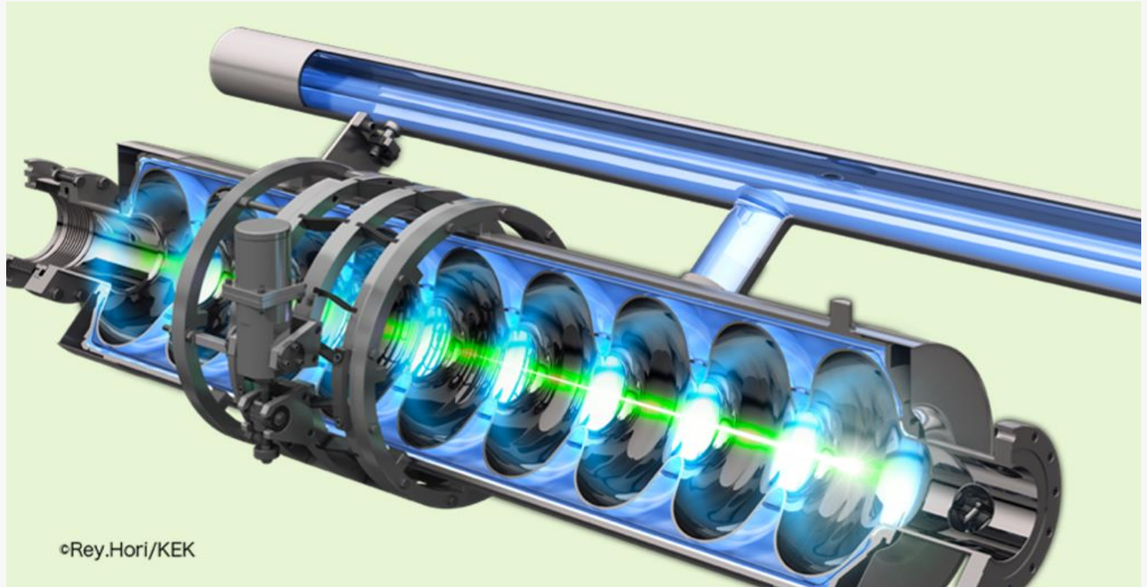
- Luminosity optimization decides the bunch geometry and average beam current, i.e. product of f and n_b.
- Pulse structure is decided by accelerator technology .

$$P_{beam} = eEfn_bN$$

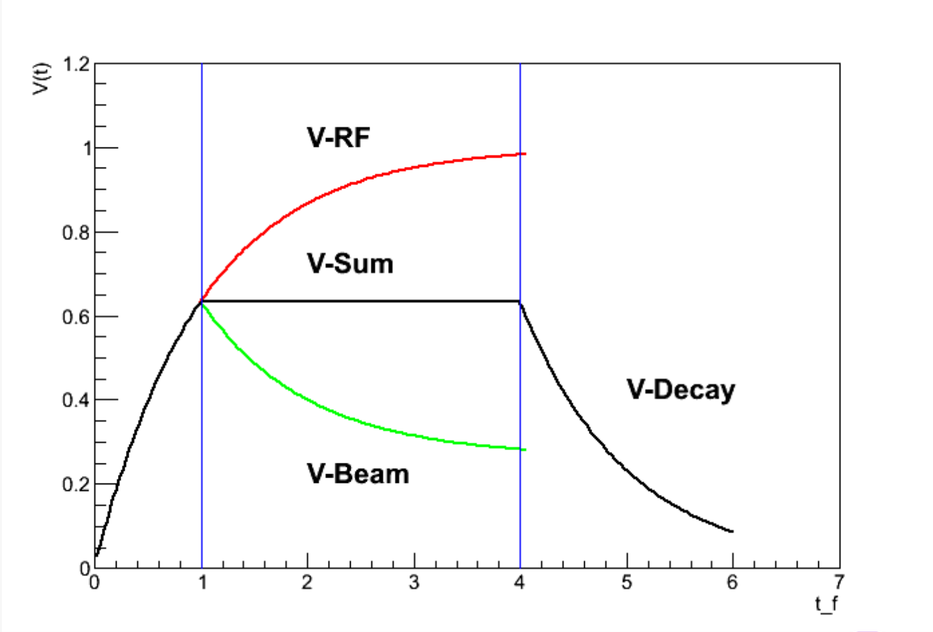


Superconducting Accelerator

- Tiny resistivity (not zero).
- Operation at extremely low temperature, 2.0K.
- SC cavity = Standing Wave cavity with zero group velocity, a long filling time.



- Cooling power : $P_{rise} + P_{beam} + P_{decay}$.
- Because of the small Carnot efficiency (0.6%, 2K-> 300K), cooling power is dominant.
- Longer t_{beam} gives better efficiency.

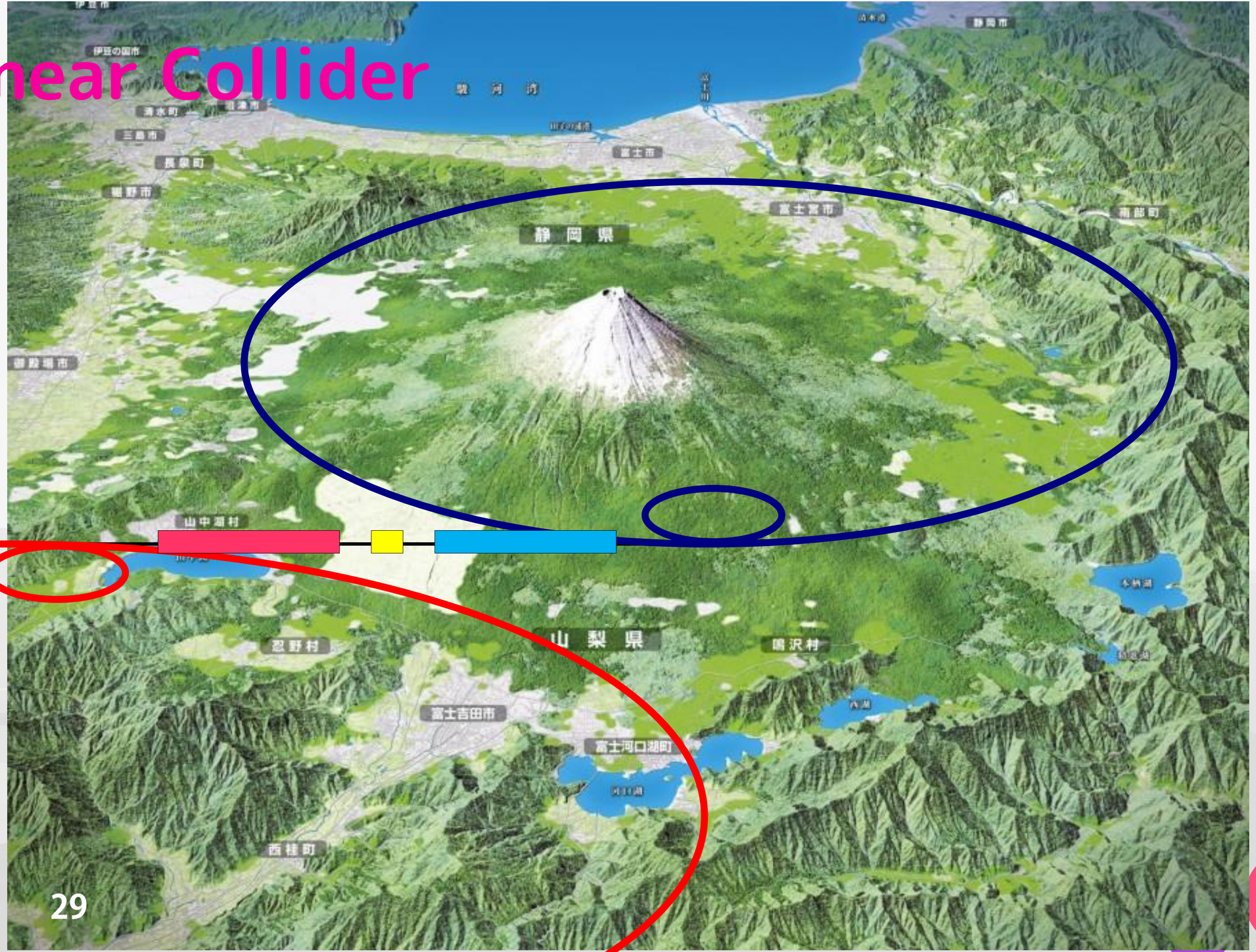


How To Fix t_B?

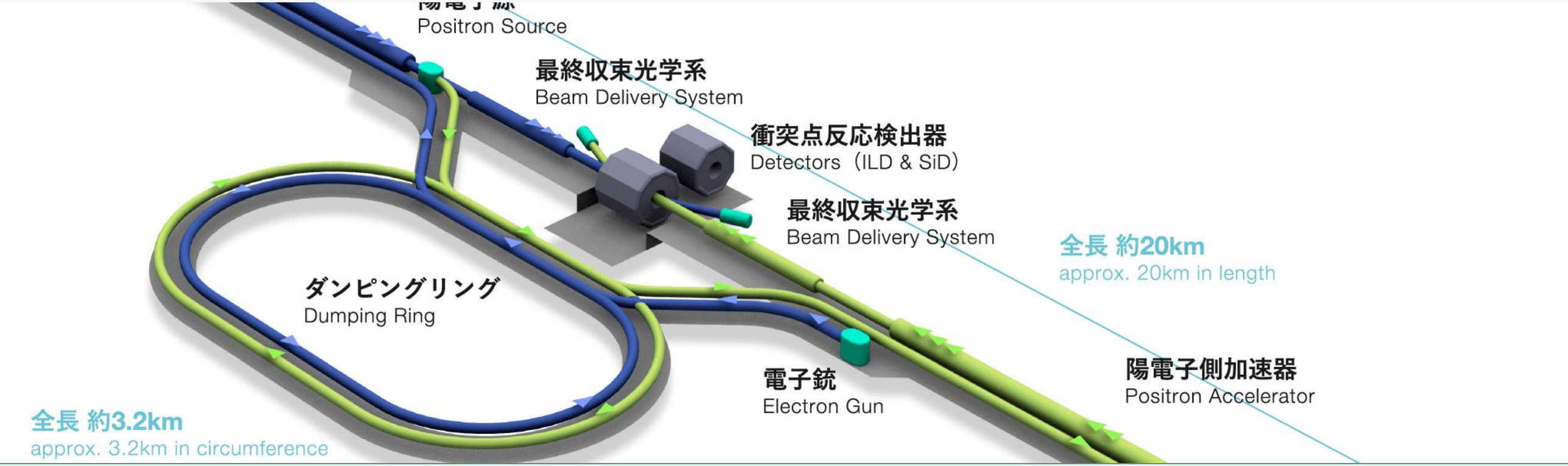
- By considering the efficiency of SC accelerator, t_B should be as long as possible.
- The beam for collision is made up by DR(Damping Ring). The whole pulse is stored in DR for 200 ms.
- DR circumference = t_B (0.5ms)x c(speed of light) ~150km.

Stupid Linear Collider

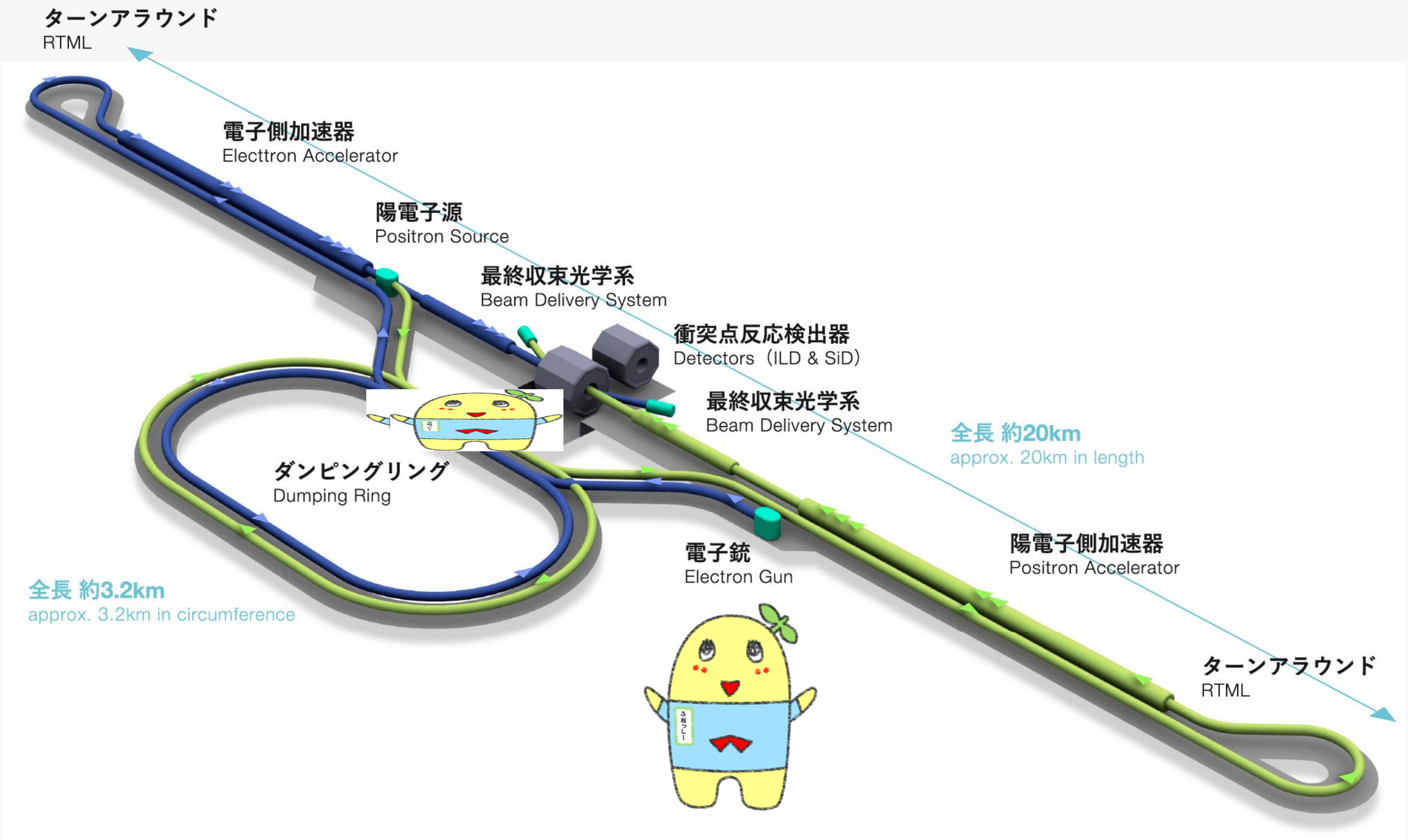
By a compressed storage, DR is now 3km.



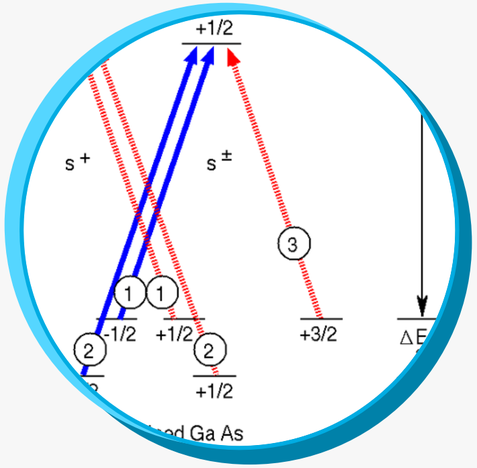
ILC Accelerator Overview



Functions


ターンアラウンド
RTML
電子側加速器
Electtron Accelerator
陽電子源
Positron Source
最終収束光学系
Beam Delivery System
衝突点反応検出器
Detectors（ILD & SiD）
最終収束光学系
Beam Delivery System
全長 約20km
approx. 20km in length
ダンピングリング
Dumping Ring
電子銃
Electron Gun
陽電子側加速器
Positron Accelerator
全長 約3.2km
approx. 3.2km in circumference
ターンアラウンド
RTML

Components

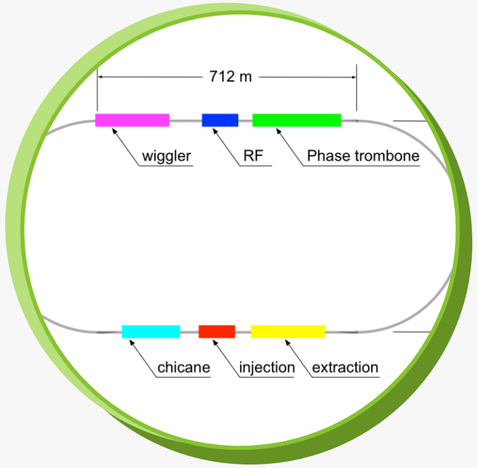


Particle Sources

Electron and Positon

Generate (polarized) electron and positron.

Wait for Masa's Lecture

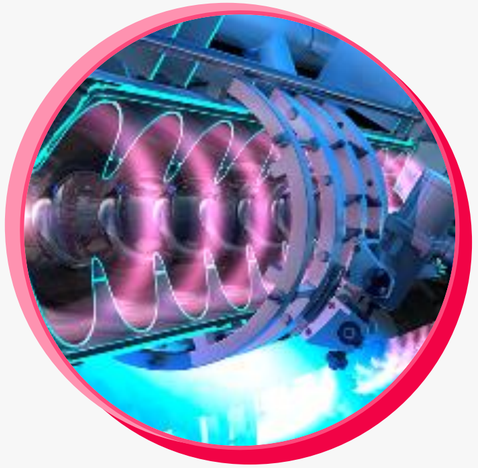


Damping Ring

Flat beam

Where the beam is prepared for collision

$\varepsilon_x \gg \varepsilon_y$.



Main Linac

Super conducting Cavity

Boost up the beam to 125 GeV.

Wait for Kirk's Lecture.

Final Focus and Dump

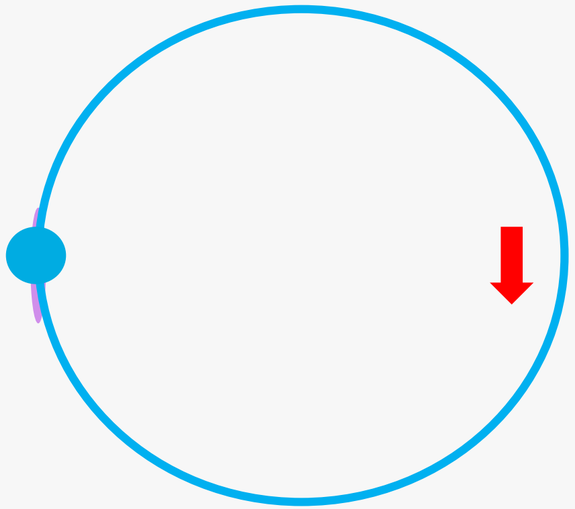
Before and after collision

Focus the beam down to nm at IP.

Wait for Kiyoshi's and Yu's lectures.

Damping Ring

Cool down the beam



Radiation Damping

Quantum Excitation

1. Beam loose their energy by SR.

2. The energy is recovered by re-acceleration .

3. SR decreases the momentum in x, y, and z, but cavity provide only p_z. The beam is aligned and cooled.

4 . Photon emission by SR is a quantum phenomenon which increases the momentum spread like a random walk.

5. The effect occurs only in horizontal direction. The horizontal emittance is equilibrium state of radiation damping and quantum excitation.

6. The vertical emittance becomes smaller and smaller (limited by misalignment).

Summary

1. Journey to higher energy

Accelerator has increased their energy by innovations.

2. Collider is a powerful tool

Collider is an ideal tool to obtain a highest CME state with the given beam energy.

3. New epoch

Due to the huge energy loss by SR, the linear collider is the only solution to realize e+e- collision above the threshold.

4. Eco and powerful machine

To obtain an enough luminosity with a limited beam power, the beam collides in a flat shape.