2nd Workshop
Energy for Sustainable Science at Research Infrastructures

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Energy Management at KEK, Strategy on Energy Management, Efficiency, Sustainability

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HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION

Outline

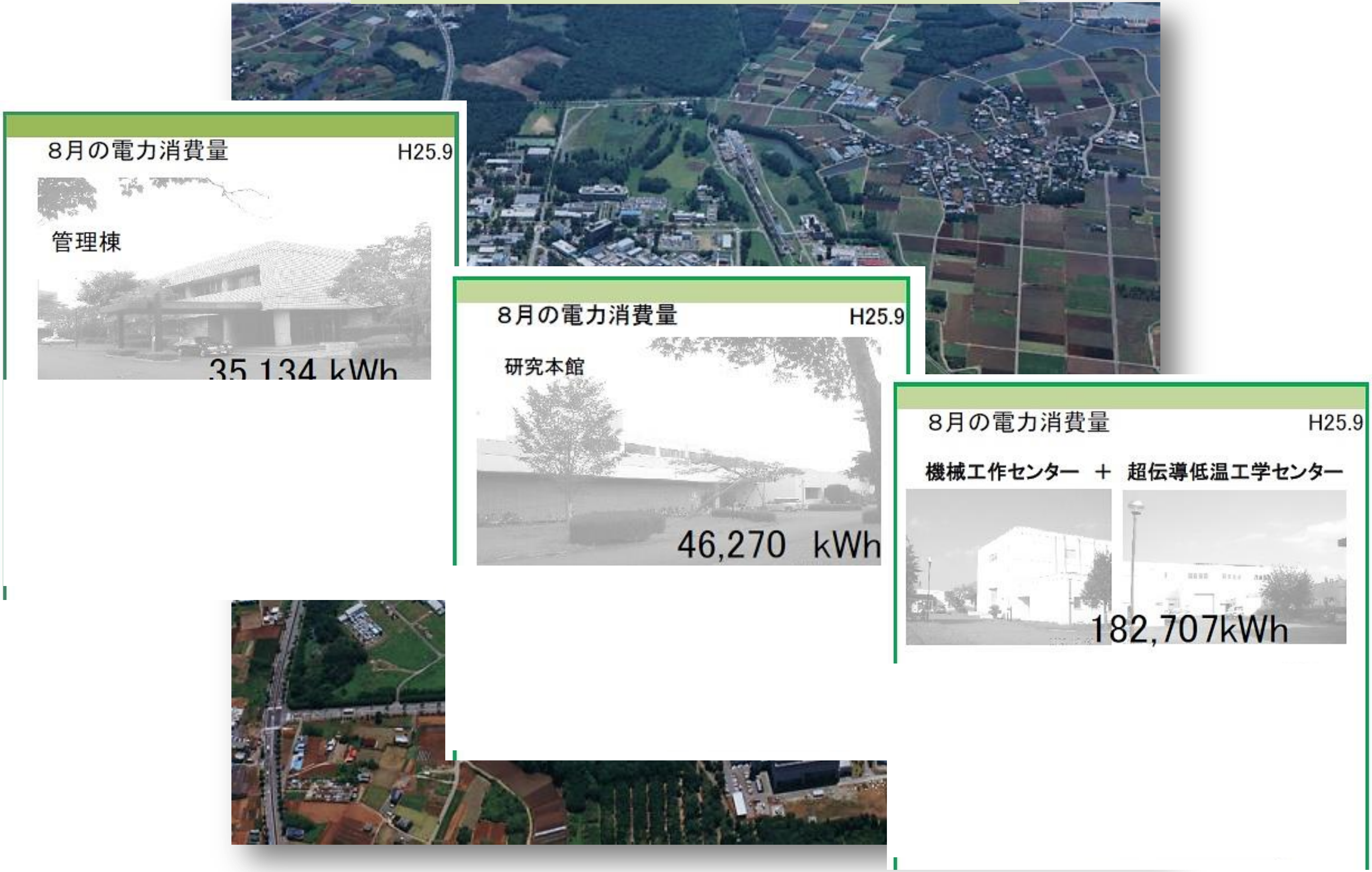
1. Energy Management at KEK
2. Improve Efficiency of Power Consumption in Accelerator Operation

    2.1 How to Improve RF Efficiency
    2.2 How to Save Power in Cryogenics
    2.3 How to Recover Beam Dump Energy

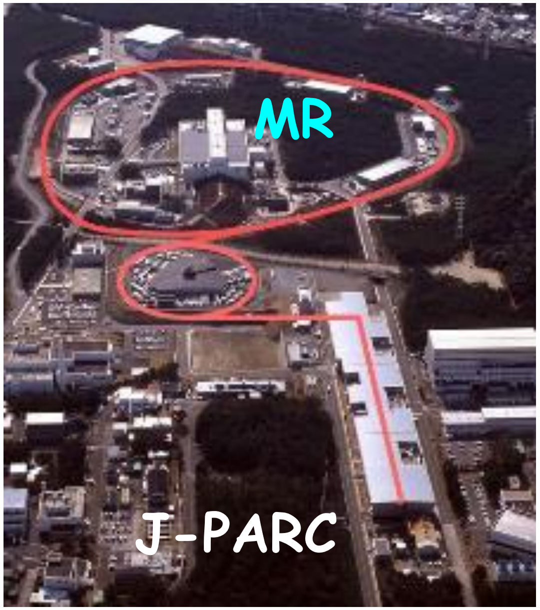
3. Improve Power Storage to Reuse
4. Summary

1. Energy Management at KEK

Daily Management at KEK
: Saving Power Consumption

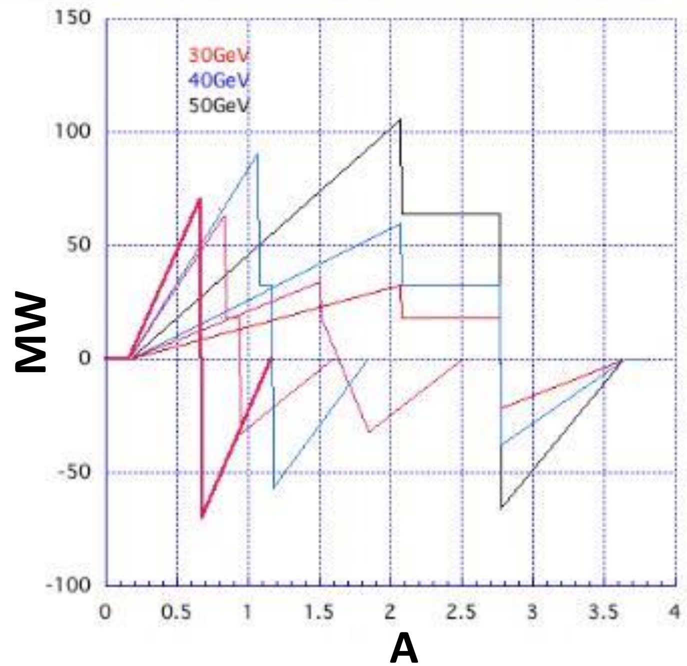


Energy Storage for Power Fluctuation Compensation at J-PARC MR



Power Amplitude of J-PARC-MR Operation Cycle

(1 – 4 sec. cycle)

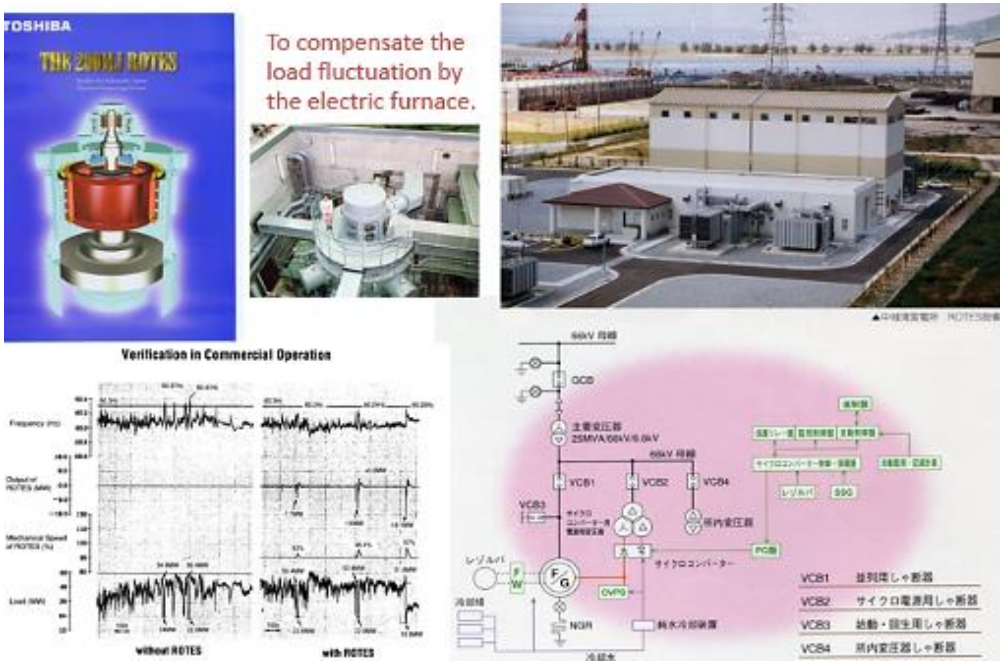


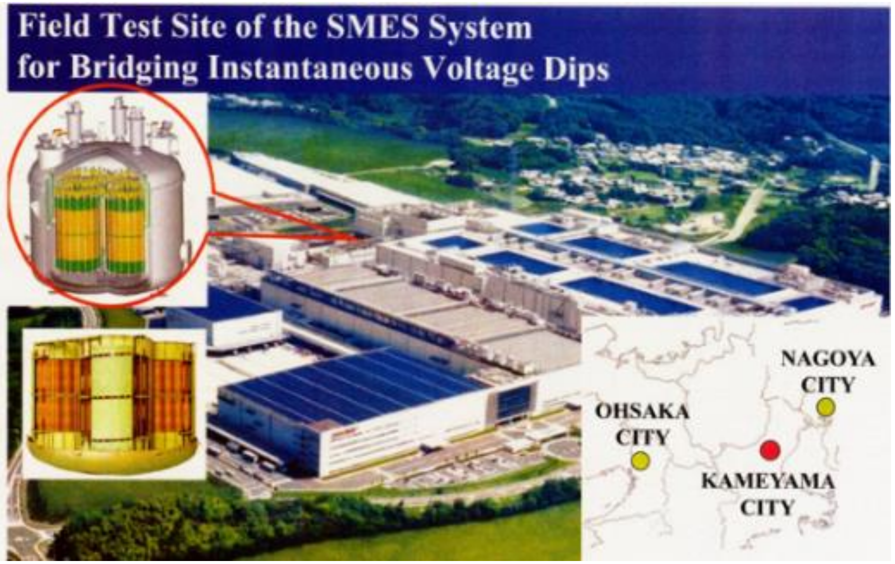
	J-PARC MR
Reputation (sec.)	3.64
Power (MW)	105
Line Voltage (kV)	66/22/6.6
Compensation Type	Fly Wheel : 51 MVA
	SMES : 90 MVA

Developing new MGs with large capacitor energy storage: F. Kurimoto's talk

Fly -Wheel and SMES Status in Japan

200 MJ Kinetic Energy Storage (Fly Wheel) in Okinawa

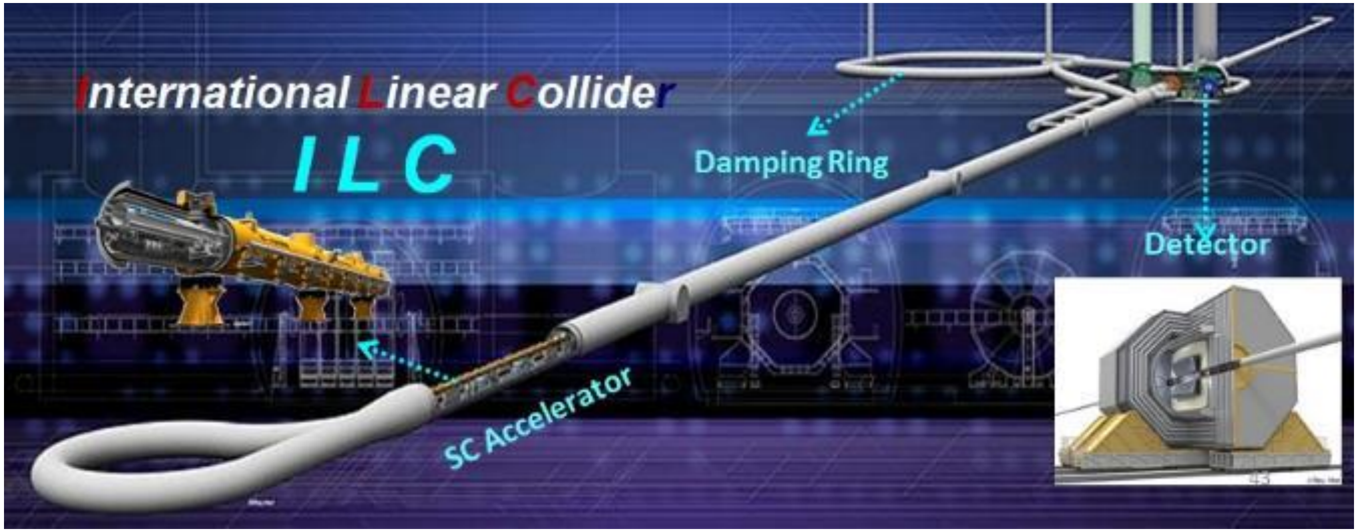




20 MJ Advanced Large Liquid Crystal plant in Kameyama since 2003

2. Improve Efficiency of Power Consumption in Accelerator Operation

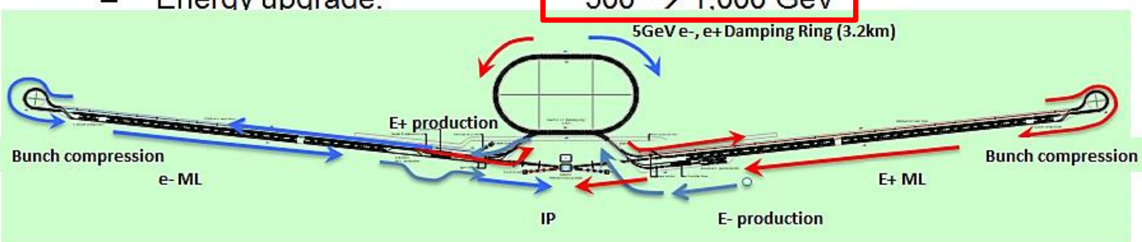
serious issue for ILC



Power Balance of Consumption and Loss in ILC

Requirements from Physics Exp.

- Basic requirements :
  - Luminosity : $\int Ldt$ = 500 fb^{-1} in 4 years
  - E_{cm} : 200 – 500 GeV and the ability to scan
  - E stability and precision: < 0.1%
  - Electron polarization: > 80%
- Extension capability :
  - Energy upgrade: 500 → 1,000 GeV



ILC 500 GeV Total Power : ～200 MW

Improve efficiency

	loss rate
Infrastructure : 50 MW	50 % : 25 MW
RF System : 70 MW	50 % : 35 MW
Cryogenics : 70 MW	90 % : 60 MW
Beam Dump : 10 MW	100 % : 10 MW
200 MW	～ 130 MW

Increase recovery

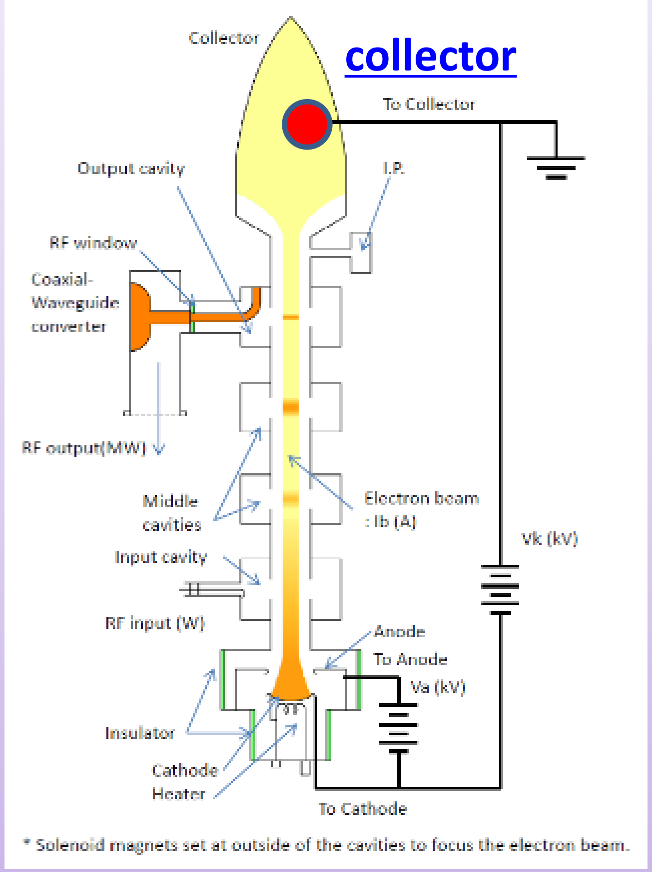
Obligation to Us

2.1 How to Improve RF Efficiency

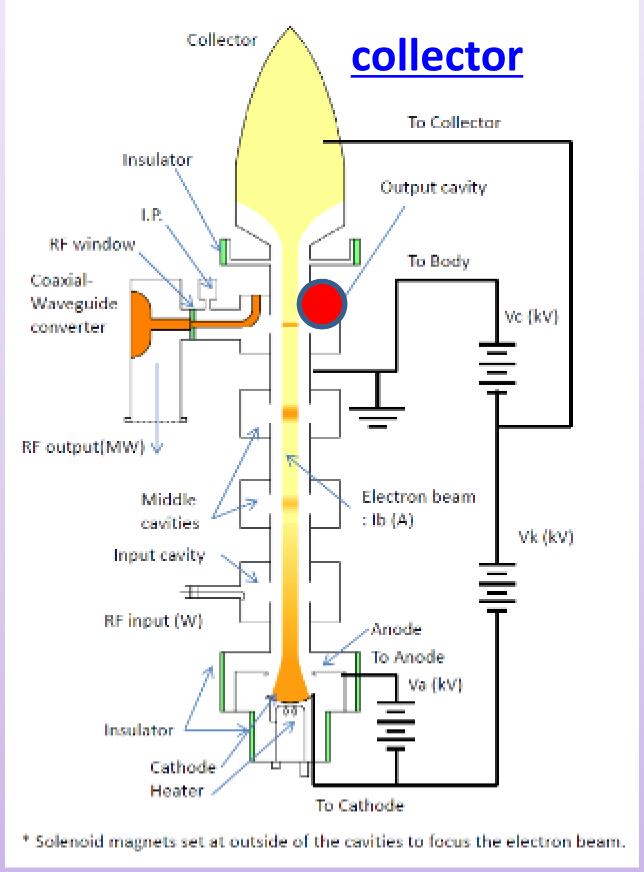
R&D of CPD (Collector Potential Depression) Klystron

CPD is an energy-saving scheme that recovers the kinetic energy of the spent electrons after generating rf power.

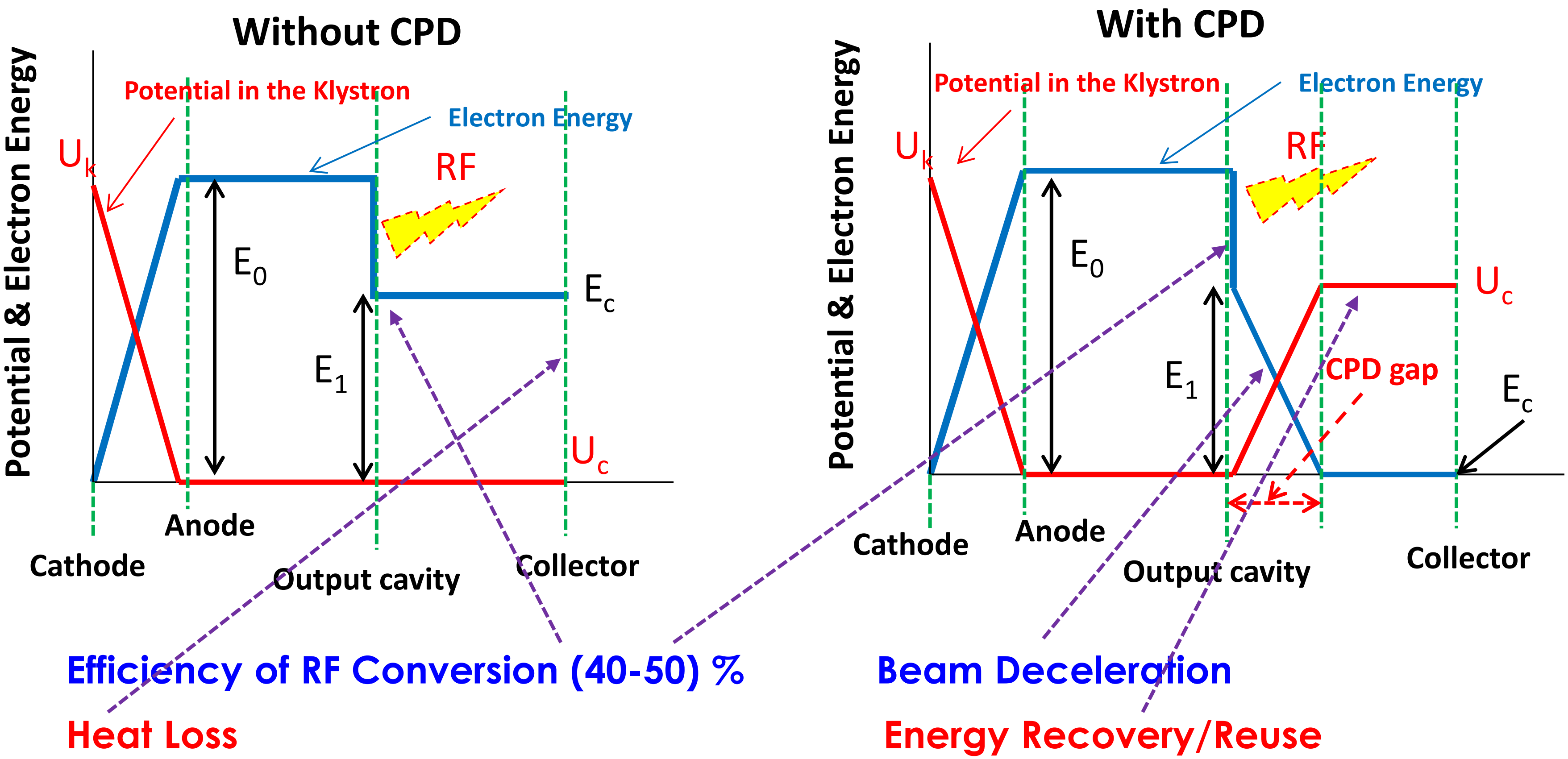
Conventional



Schematic diagram of CPD



Simplified Schematic Concept

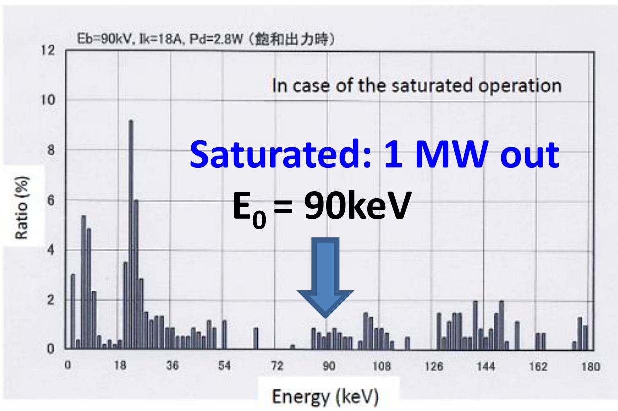


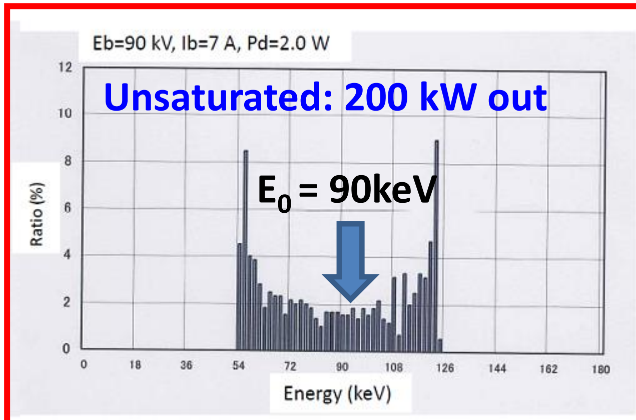
Potential denotes the electron potential energy, eV. For simplicity, input and intermediate cavities are omitted here and the anode potential is set to zero.

Issues must be addressed for CPD Klystron

(I) Energy spread

The spent electron beam has large energy spread through electromagnetic interaction in the cavities. Therefore, the collector potential cannot be increased beyond the lower limit of energy distribution of the spent electron beam, otherwise backward electrons hit the cavities or the gun, and then deteriorate the klystron performance.





(II) Pulse-to-DC conversion

The spent electron beam is longitudinally bunched, so that pulsed voltage is induced on the collector. An adequate pulse-to-DC converter has to be implemented.

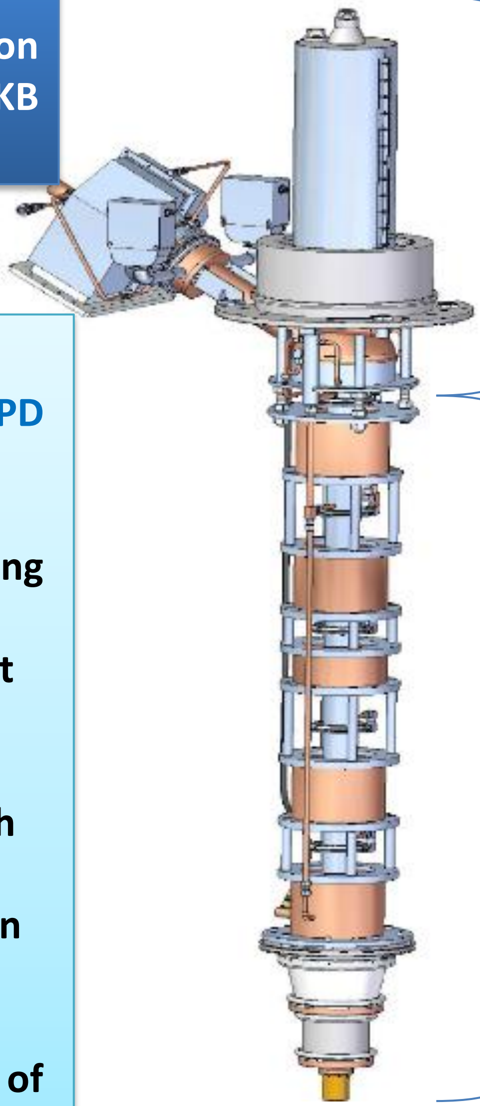
(III) RF Leakage

CPD klystron has to be equipped with an insulator between the collector and the body column in order to apply CPD voltage to the collector. Thus, it would be possible for the CPD klystron to leak rf power out more or less from the insulator.

Present Status of R&D

Target

proof-of-principle of CPD in the unsaturated region (a maximum rf power of 500 kW) using a KEKB 1.2MW-klystron



Newly fabricated components

- collector
- ceramic insulator
- output cavity
- output coupler

Recycled components

- electron gun
- input cavity
- intemediate cavities

R&D Schedule

2013.3: Modification of an existing klystron to CPD klystron (already done)

2014.3: until then, preparation and commissioning of the test station

~2014: Verification of klystron operation without CPD

~2015: Measurement of rf leakage from the gap between the body column and the collector (with no CPD voltage applied)

Measurement of induced pulse voltage on the collector with CPD

~2017: Test of rectification by Marx circuit

Integration test of the proof-of-principle of CPD operation

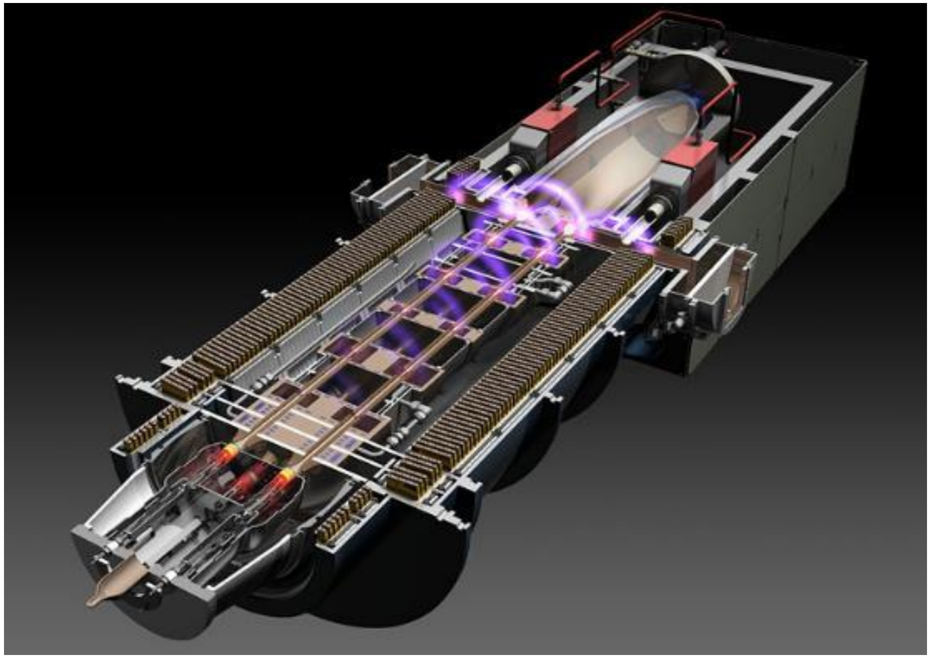
80 % efficiency

Multi(6) – Beam Klystron (MBK) for 26 Cavities for ILC

DEVELOPMENT OF TOSHIBA L-BAND MULTI-BEAM KLYSTRON FOR EUROPEAN XFEL PROJECT

Y. H. Chin, KEK, Tsukuba, Japan,
A.Yano, S. Miyake, TOSHIBA ELCTRON TUBES & DEVICES Co., Ltd., Ohtawa-shi, Japan,
S. Choroba, DESY, Hamburg, Germany

- The design goal is to achieve 10 MW peak power with 65 % efficiency at 1.5 ms pulse length at 10 Hz repetition rates.
- MBK has 6 low-perveance beams operated at low voltage of 115 kV for 10 MW to enable a higher efficiency than a single-beam klystron.

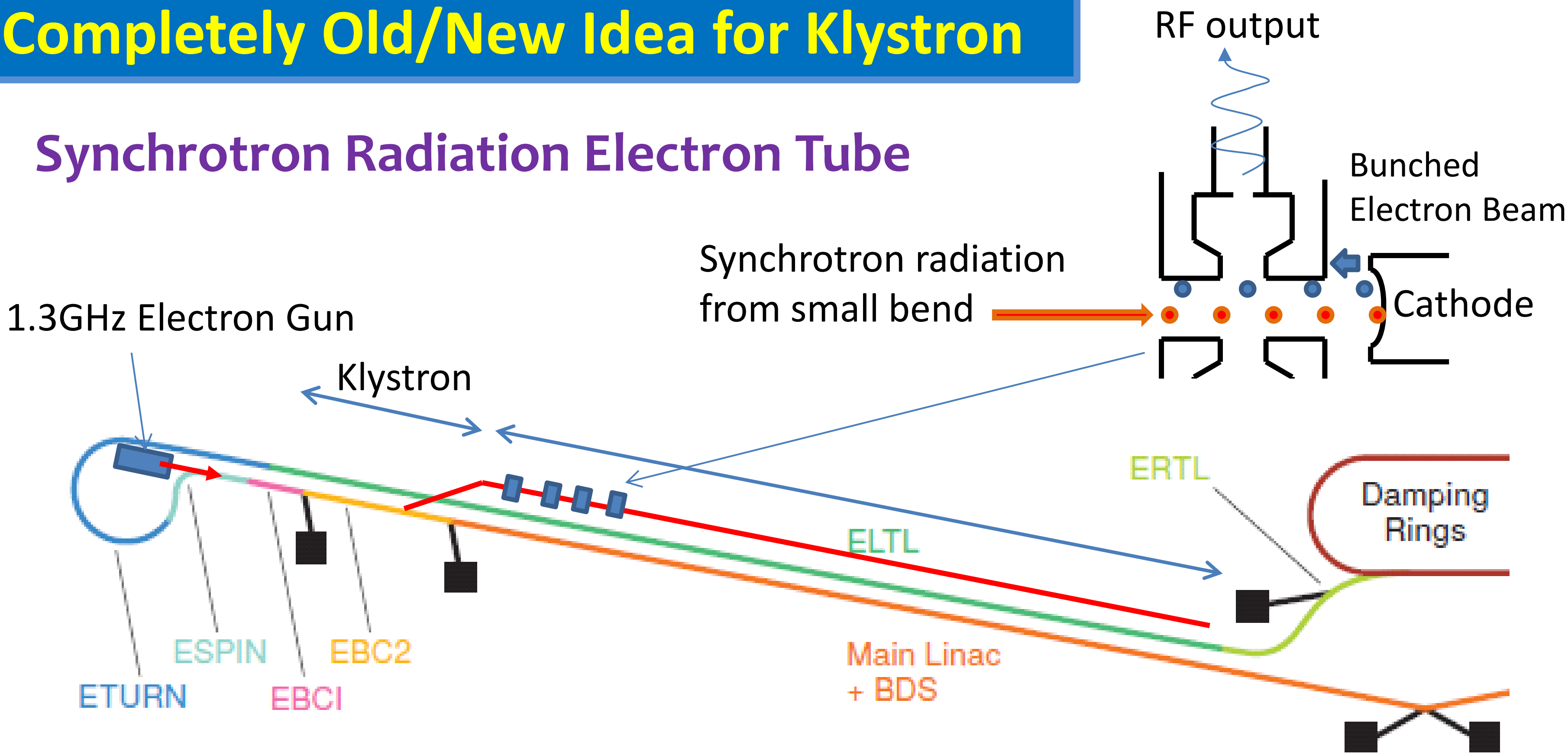


re 2: Electron Gun of the E3736.

Frequency	1.3 GHz
Peak power	10 MW
Pulse width	1.6 ms
Rep. rate	5 Hz
Average power	78 kW
Efficiency	65 %
Gain	47dB
BW (- 1dB)	3 MHz
Voltage	120 kV
Current	140 A
Lifetime	40,000 h

Completely Old/New Idea for Klystron

- **Synchrotron Radiation Electron Tube**



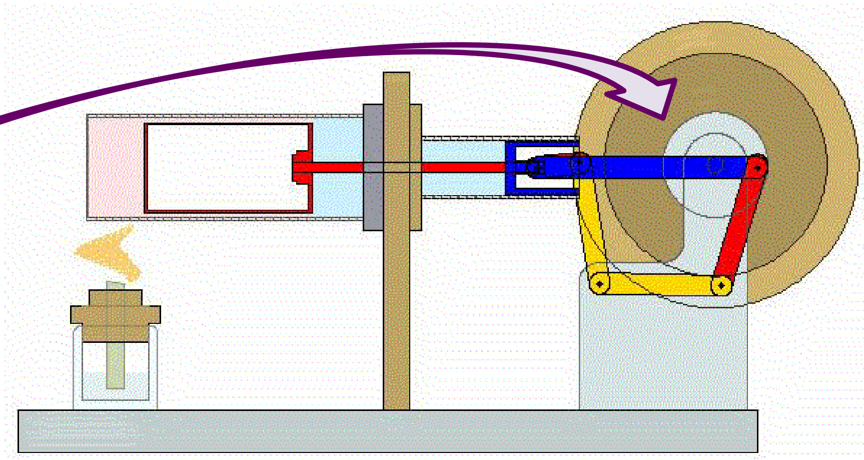
Advantages

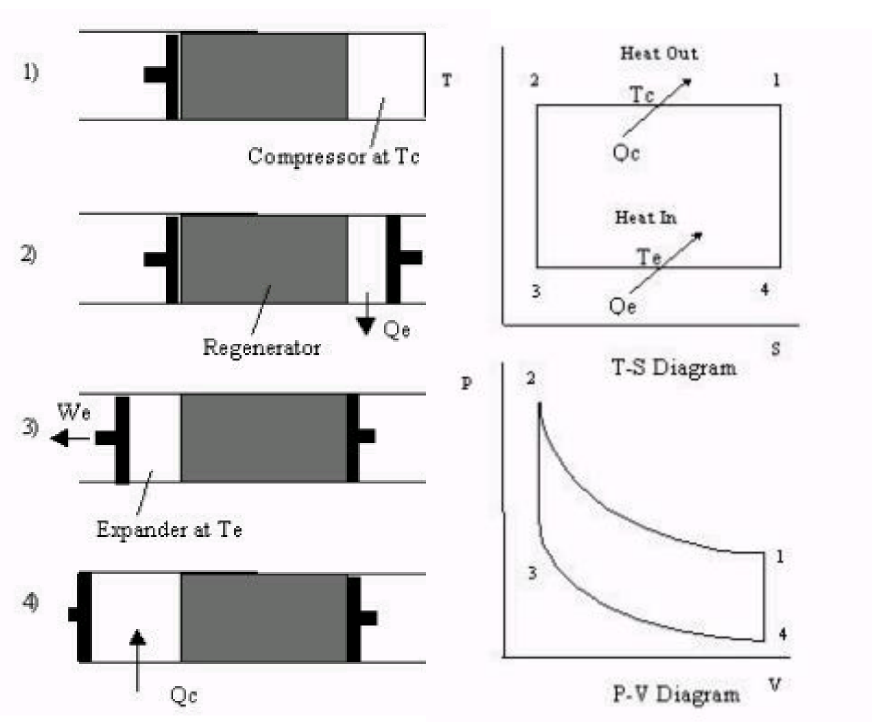
- > 90% efficiency (small transient time factor by short bunch)
- Stabled by space charge limit operation
- Drivn from low charge low energy 1.3GHz electron beam (1/10 klystron ?)
- Very low cost and long lifetime
- Low cost beam line
- No switch, only HV & capacitor

2.2 How to Save Power in Cryogenics

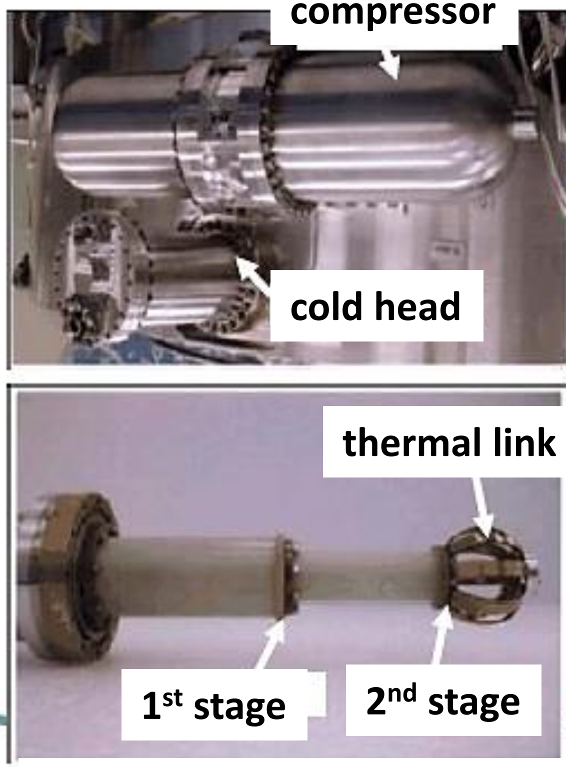
Cryogenics/Stirling Cryocooler

- High temperature operation
  - Klystron collector
  - RF Dummy load

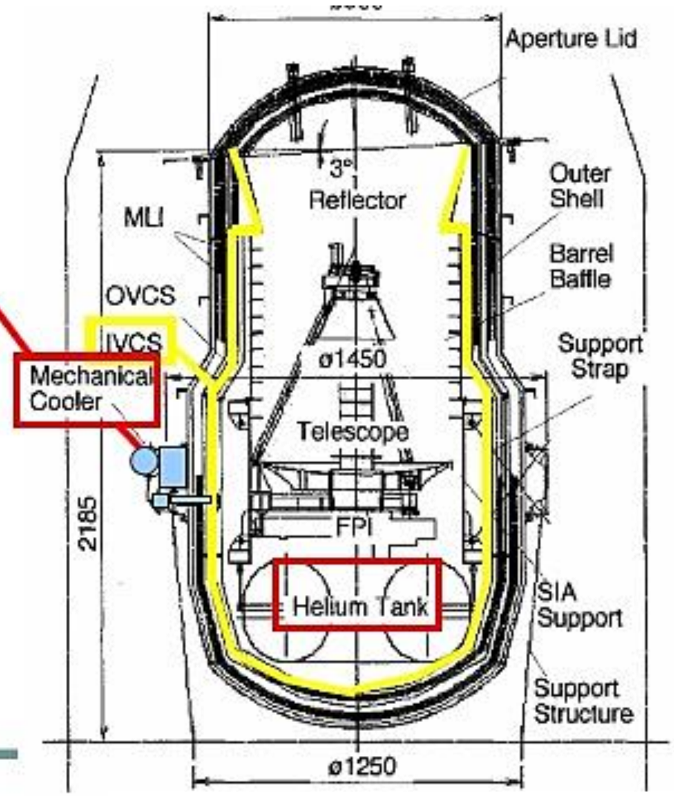




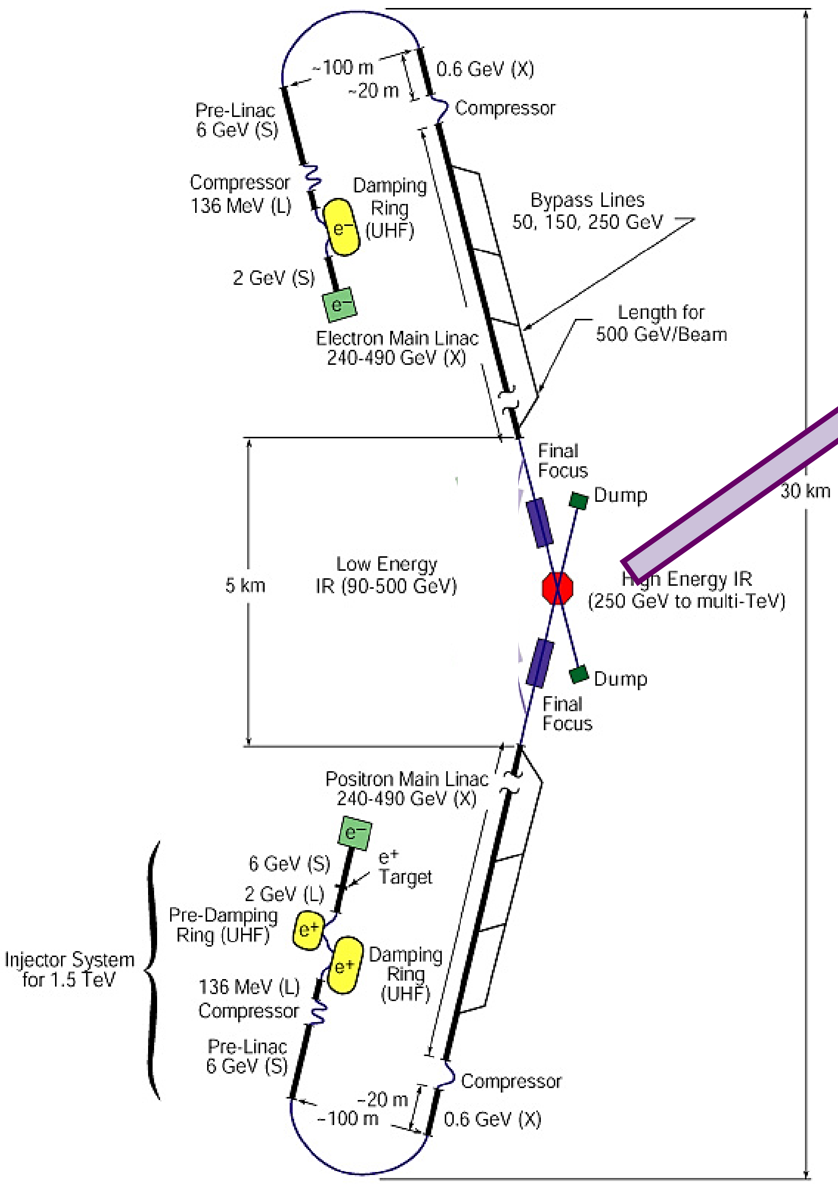
Multiple Stirling Cooling System

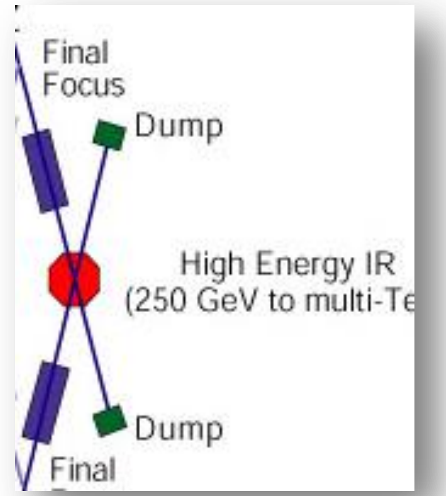


2 Stage-Stiling Cryocooler



2.3 How to Recover Beam Dump Energy (～10 MW)





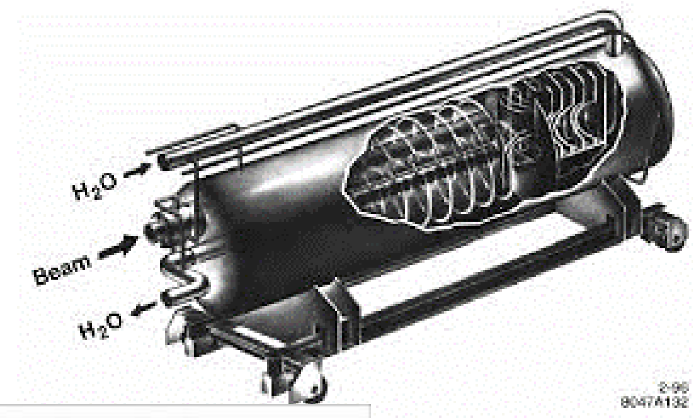
- **Recover Beam Energy**
- **Reduce Radio-Activation**

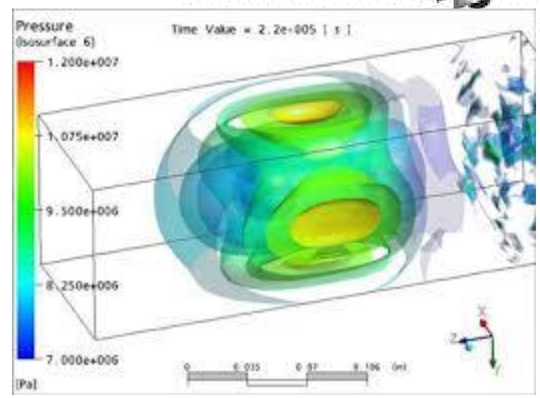
Water Dump

Water Vortex Dump
(25 m long x 15 m height for 1 TeV)

- Issue : shock wave management
- Issue : management of tritium gas and tritiated water in vapor form

SLAC Dump for 800 kW





Noble Gas Dump

- About 1km of a noble gas (Ar looks the most promising) enclosed in a water cooled iron jacket (transport the heat).
- This gas dump design may ease some issues such as radiolysis and tritium production.
- Issue : particle beam heating of the gas and ionization effects.

Plasma Deceleration Dumping

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 13, 101303 (2010)

Collective deceleration: Toward a compact beam dump

H.-C. Wu,[1] T. Tajima,[1,2] D. Habs,[1,2] A. W. Chao,[3] and J. Meyer-ter-Vehn[1]
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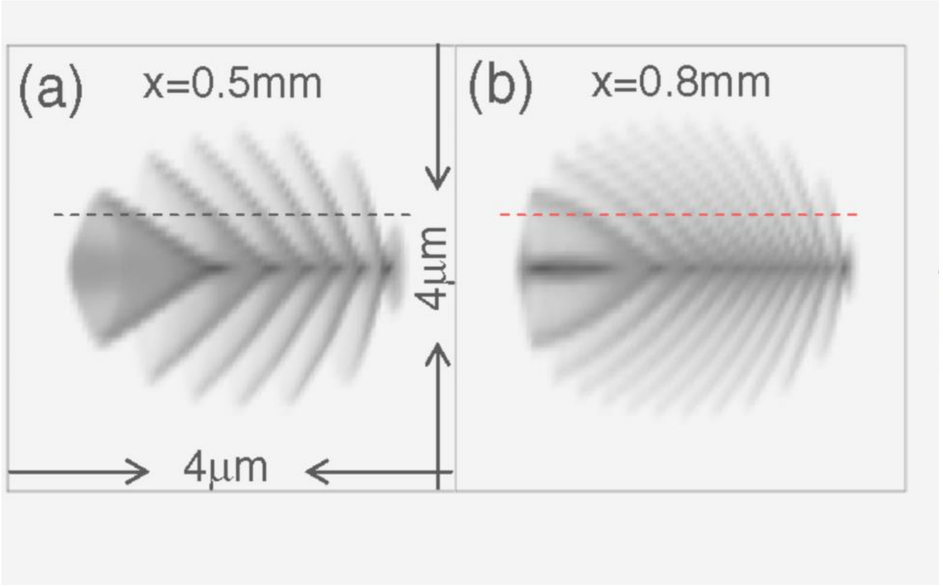
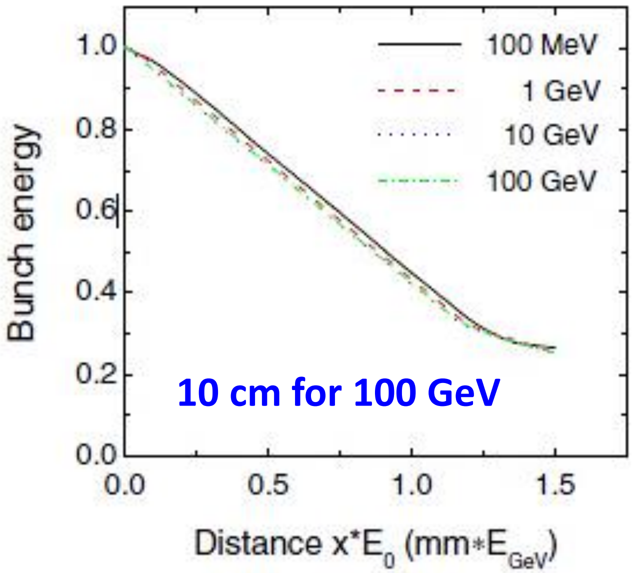
[3]*SLAC National Accelerator Center, Stanford University, Stanford, California 94309, USA*
(Received 10 December 2009; published 5 October 2010)

Use Collective Fields of Plasmas for Deceleration





- The deceleration distance in the underdense plasma is 3 orders of magnitude smaller than the stopping in condensed matter.
- The muon fluence is highly peaked in the forward direction.

Collective Stopping Power for ILC

$$L_{dump}\,[\mathrm{m}] \approx 1.7 \times 10^{13} \frac{\sigma_T^2\,[\mathrm{cm}]}{N_b} E_0\,[\mathrm{GeV}]$$

$$here \quad \sigma_T \geq 0.6\sigma_L \;\&\; \quad \sigma_T \geq 1.9 \times 10^{-6}\sqrt{N_b \sigma_L}$$

(electron bunch)

ILC $\quad N_b = 2 \times 10^{10} \quad E_0 = 500\mathrm{GeV}$

$$L_{dump}\,[\mathrm{m}] \approx 4.3 \times 10^{5} \sigma_T^2\,[\mathrm{cm}]$$

$\sigma_T \approx 50\ \mu m$, $\sigma_L \approx 3\ \sigma_T \approx 150\ \mu m$

→ L = 10 m for Li gas

Next Trials

- Experiment of Proof-of-Principle
- Deposit mechanism of Wake-Field energy

3. Improve
:
Power Storage to Reuse

	Ross Rate
Infrastructure : 50 MW	50 % : 25 MW
RF System : 70 MW	40 % : 28 MW
Cryogenics : 70 MW	100 % : 70 MW
Beam Dump : 10 MW	100 % : 10 MW
	~ 130 MW

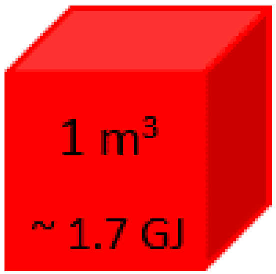
Improve efficiency (→ Ross Rate)

Increase recovery (→ ~ 130 MW)

Storage of Thermal Energy

Heat Capacity Iron vs. Water

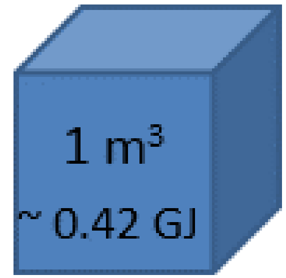
Heat Capacity of Iron



$\Delta T = 500$ ºC

$\Delta E = m \times Cp \times \Delta T$
= 8000 kg
x 0.1 kcal/kg/ºC
x 500 ºC
x 4.2k J/ kcal
= 1680000 k J
= 1.68GJ

Heat Capacity of Water

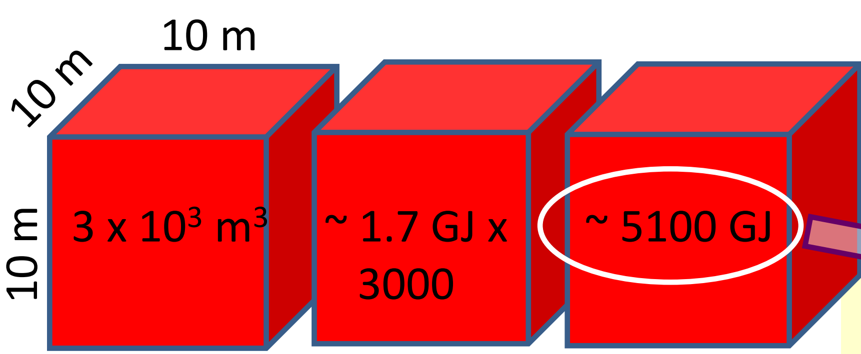


$\Delta T = 100$ ºC

Heat Capacity of Water

Cc.c.	=	4.2	J/c.c./ºC
C_L	=	4.2	kJ/ L / ºC
C_{m3}	=	4.2	MJ/m³/ ºC

Storage of Electric Energy as Heat in Iron



Store the surplus electric energy as thermal energy

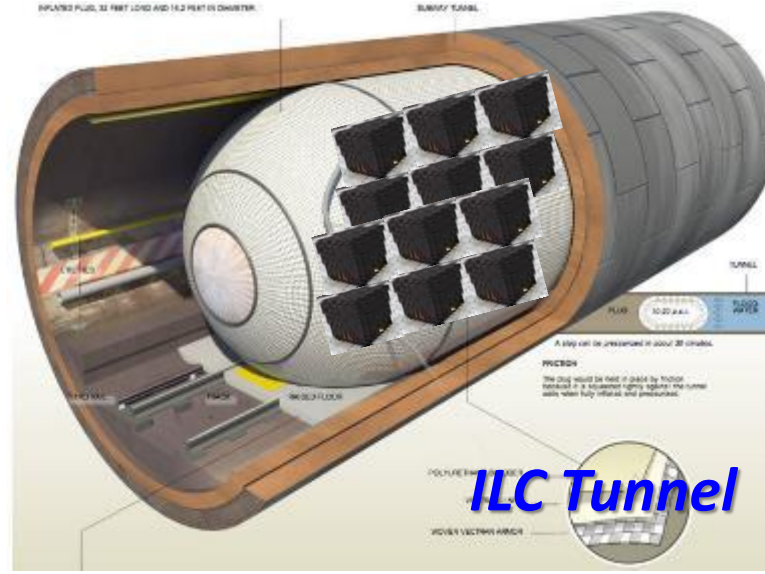
Electric Energy
100 MW x 1 0 hours

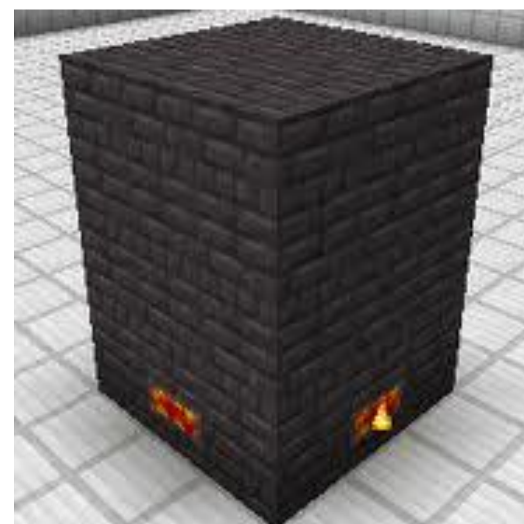
E = 100 M J / sec
x 3600 sec / hr x 10 hr
= 3600 GJ

how to keep iron heat

Blast Furnace

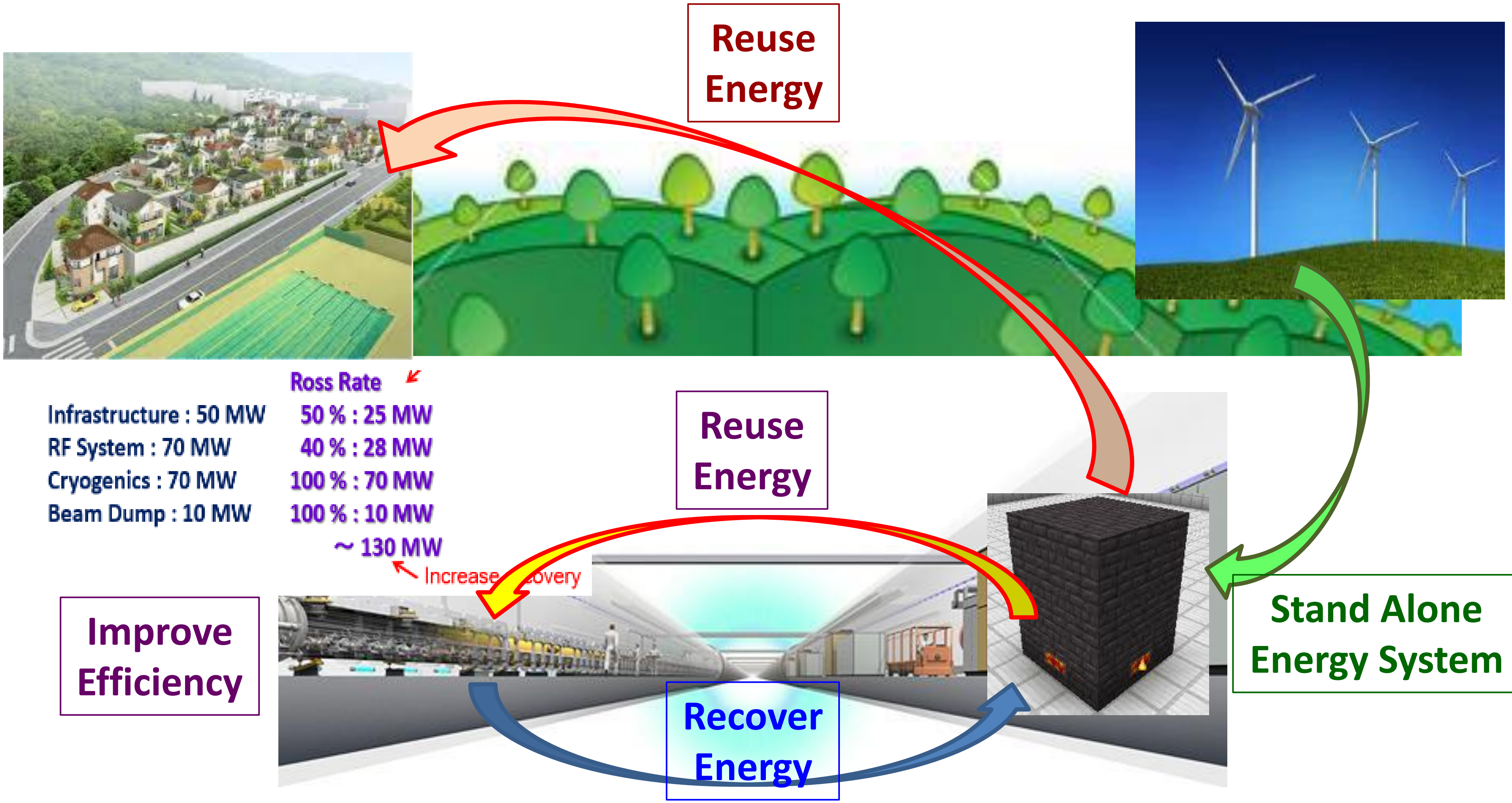
Fire Brick





4. Summary


ILC


Reuse Energy
Ross Rate
Infrastructure : 50 MW
RF System : 70 MW
Cryogenics : 70 MW
Beam Dump : 10 MW
50 % : 25 MW
40 % : 28 MW
100 % : 70 MW
100 % : 10 MW
~ 130 MW
Increase
Reuse Energy
Improve Efficiency
Recover Energy
Stand Alone Energy System

➢ The muon fluence is highly peaked in the forward direction.

Extraction → Usage
No Extraction → Decay

Fixed Field Alternating Gradient Accelerator