Technical Suggestions on Linear Accelerator Design for SASE-FEL

Tsumoru Shintake

RIKEN SPring-8
Harima Japan

R&D Issues for X-ray SASE-FEL

- Low Emittance Beam Generation and Acceleration
- Bunch Compressor
- Undulator Technology
- X-ray Beam Handling
- Seeding, Spectral Control
- Machine Stability

Big Funding and Big Challenge

- The first difficulty in XFEL is
  how to get funding.

  Even if you have (€ , $, ¥) …!(^-^)/

- The next difficulty is
  how to pass the electron beam in such a
  long-long undulator, safely, and very straight.

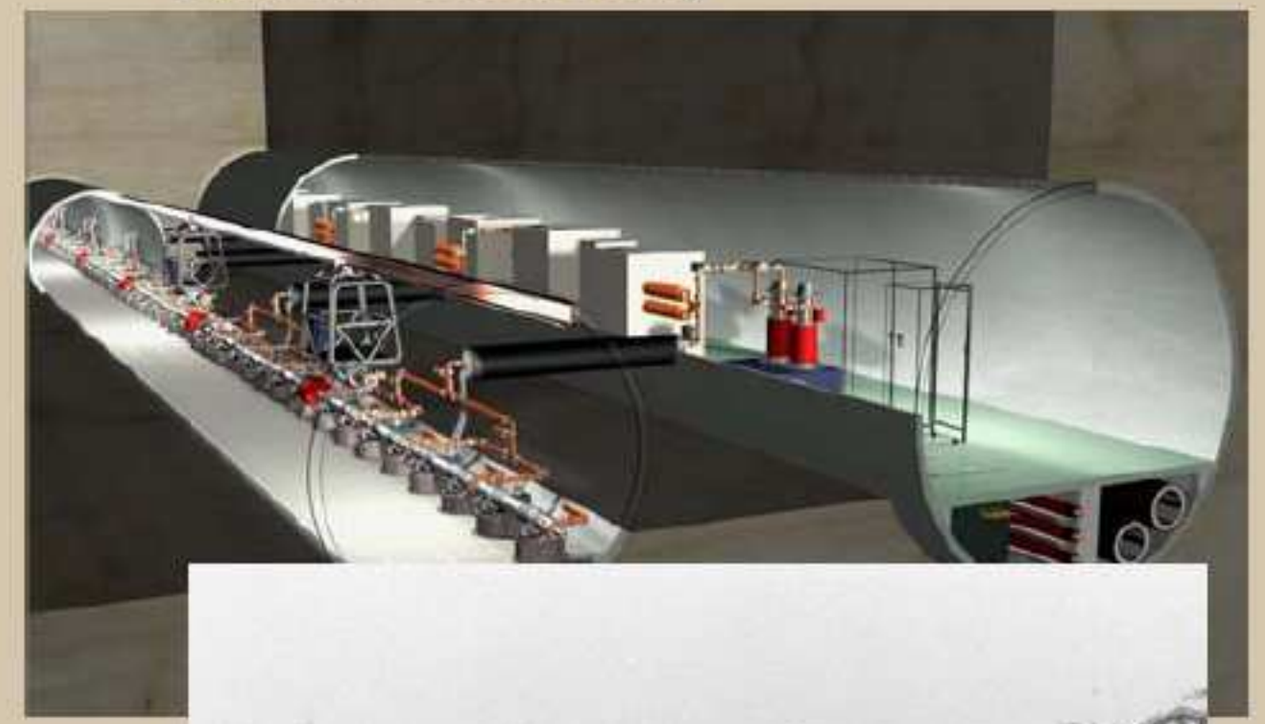
- To do this, we need a very stable and reliable machine, and stable clean electron beam.

Linac Base Machine is not Stable

Storage-Ring is A Spinning-Top

Very Stable and Quiet

Linac is “A Archery”



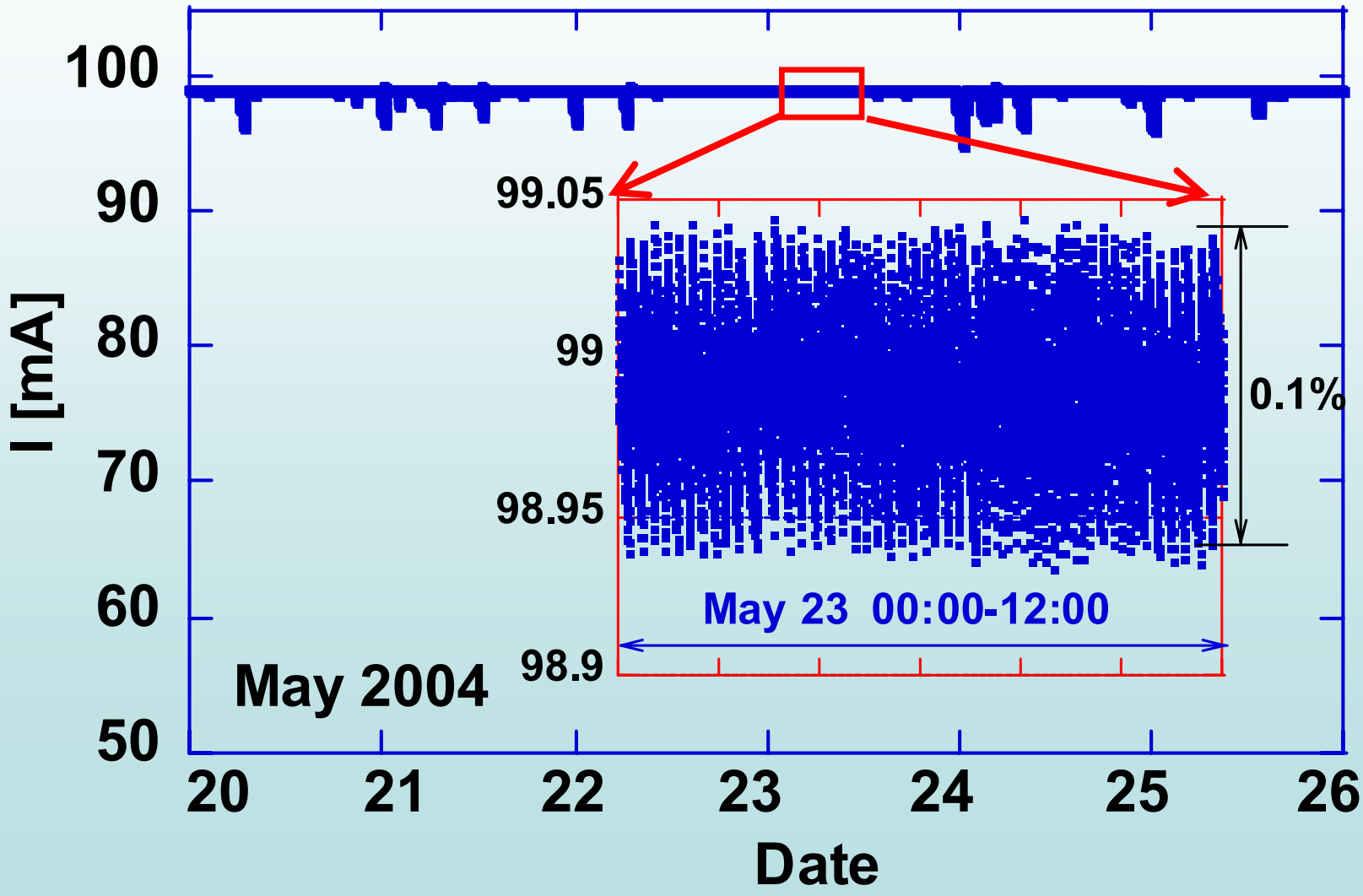
Shooting is not stable, it is a game, sometimes noisy.

Storage Ring v.s. Linear Accelerator

	Storage Ring Machine	Linear Accelerator (Pulse Mode Machine)
Machine Condition	All the hardware are in steady state condition.	Transient condition. (less reliable)
Trajectory	Closed-Trajectory (Eigen-vector)	Open-Trajectory (No eigen vector)
Damping	Synchrotron damping	No Damping Effect
Beam Cleaning	Many turns: Synchrotron excitation and beam life-time makes Gaussian beam.	Single Pass: No natural beam cleaning. Dark-current contamination is a big problem. Need mask and collimator.
Noise bandwidth	~ 1 kHz Narrow tune resonance.	~ GHz, Bunched electron samples all the noise in wide frequency band.
Energy and Intensity Stability	$10^{-5} \sim 10^{-6}$	$10^{-2} \sim 10^{-3}$

Hitoshi Tanaka

Stored Current Variation in Top-up Operation



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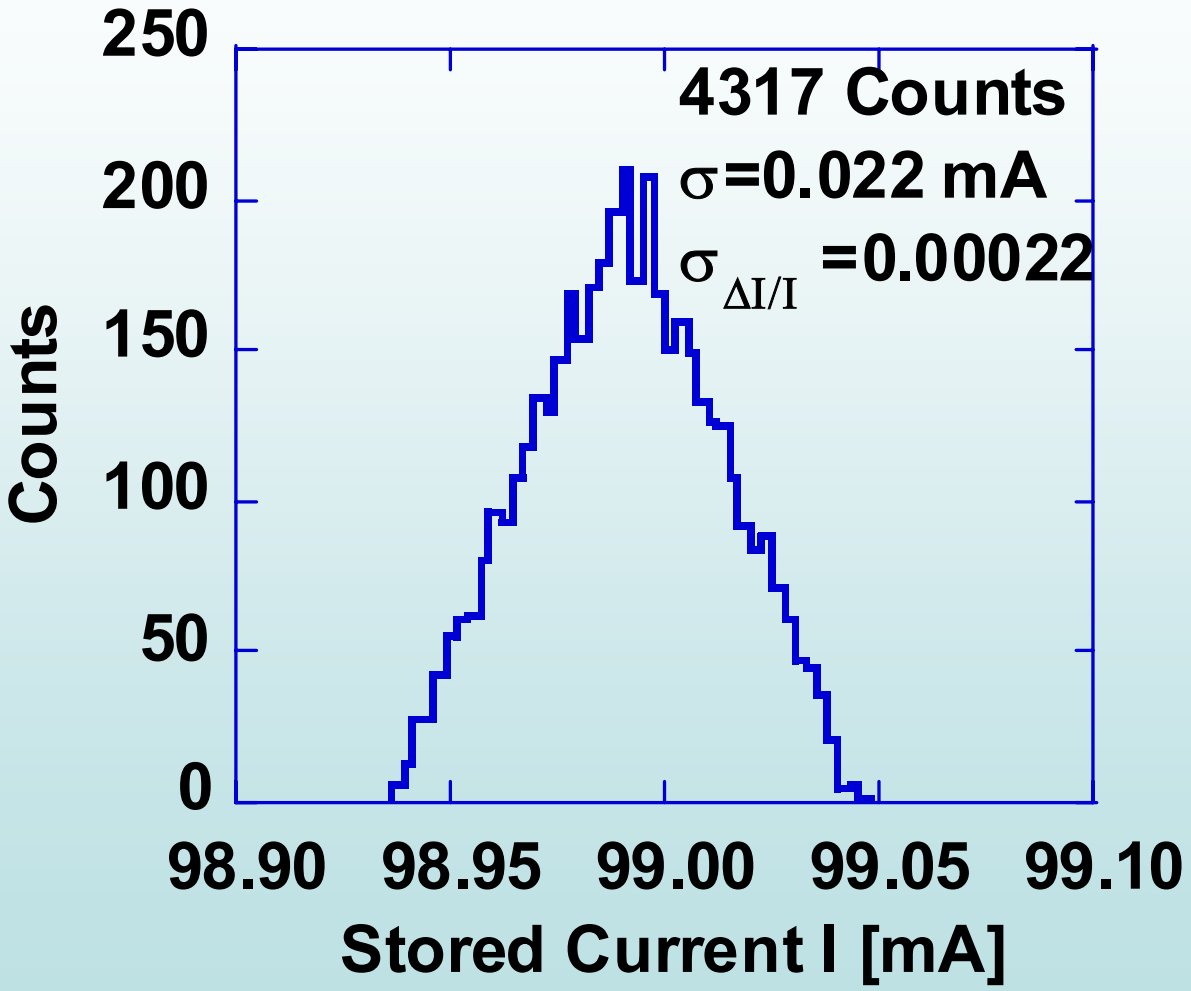
Statistics for 12 hrs in May 23



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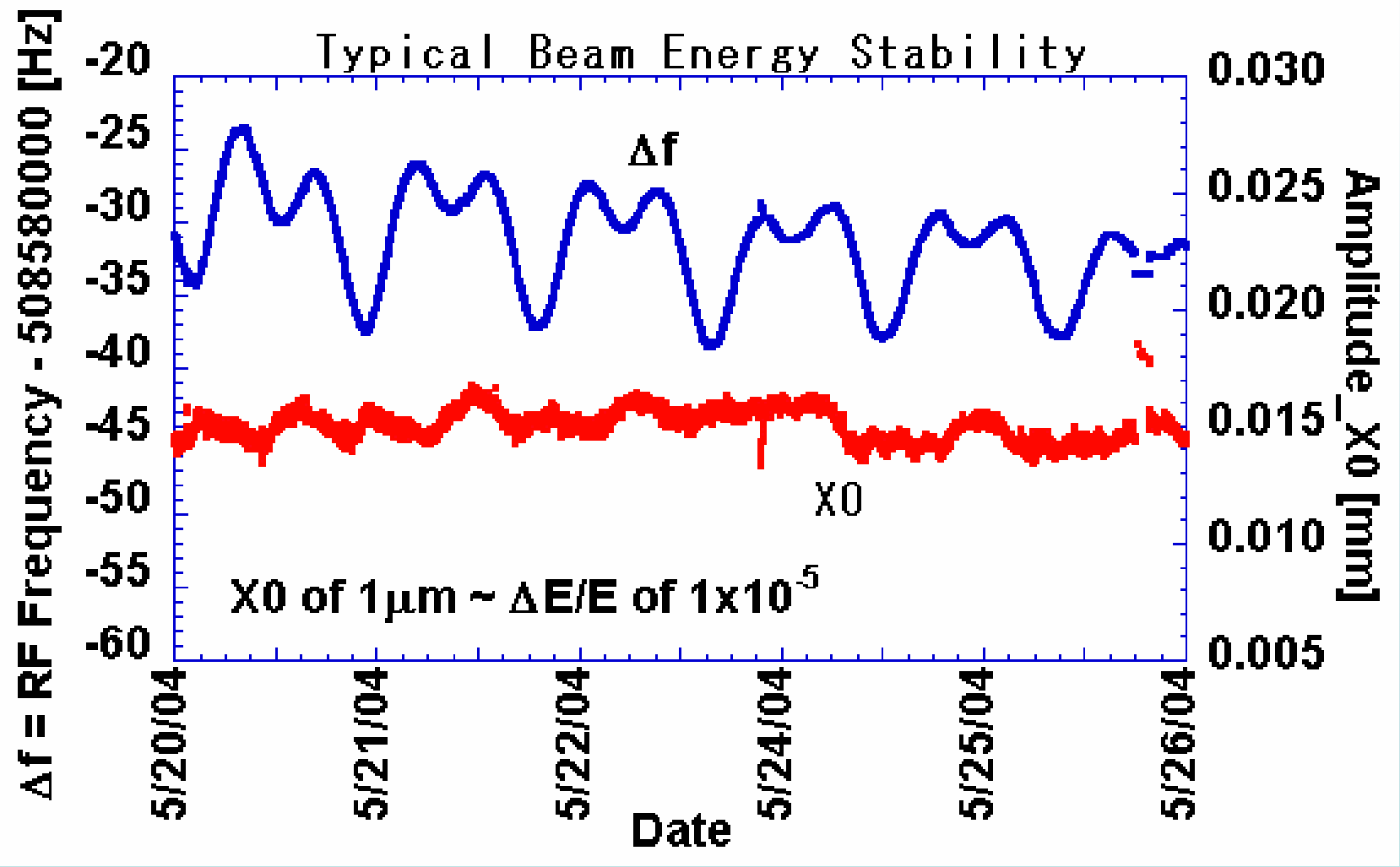
Energy Stability in Top-up Operation



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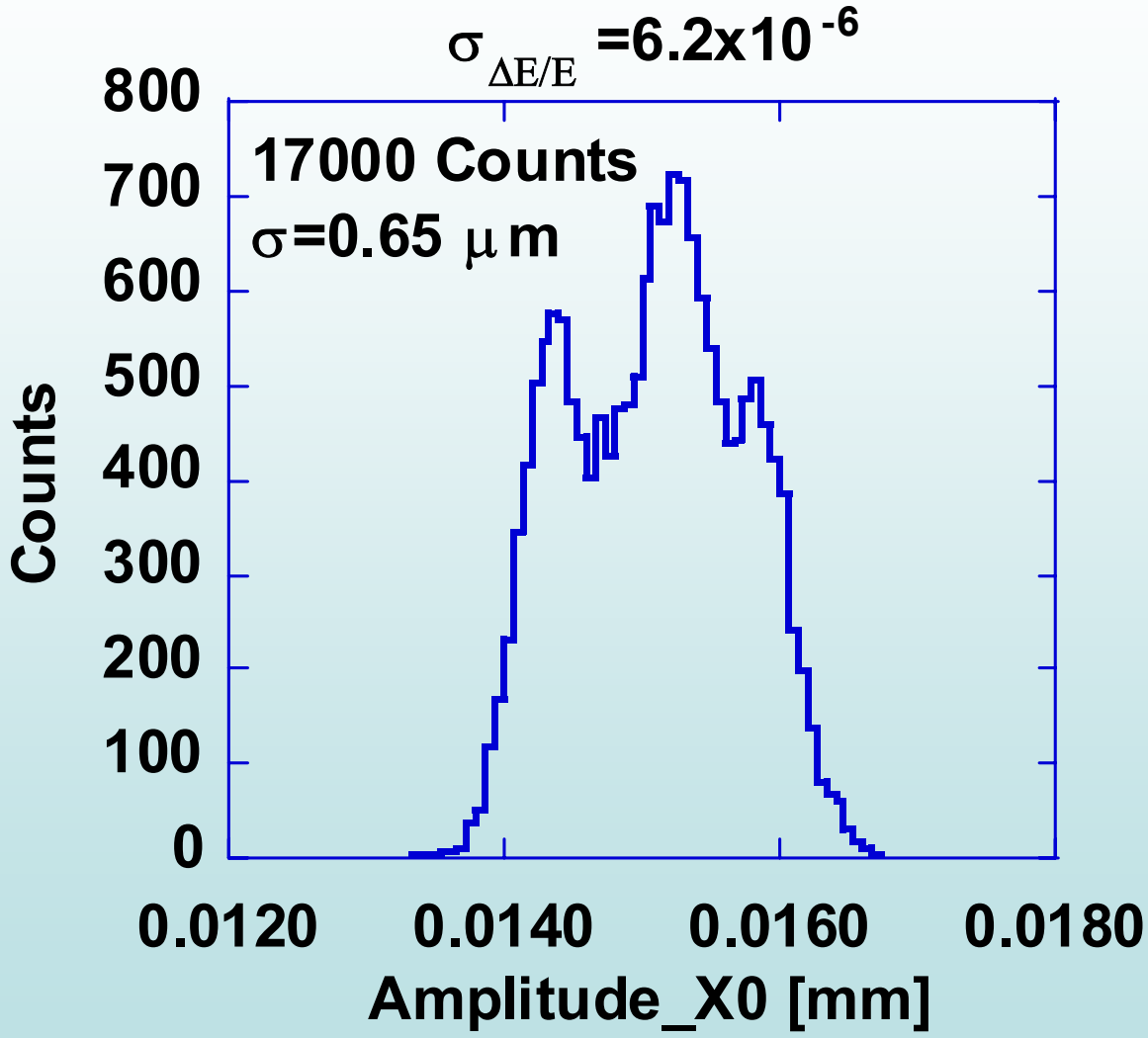
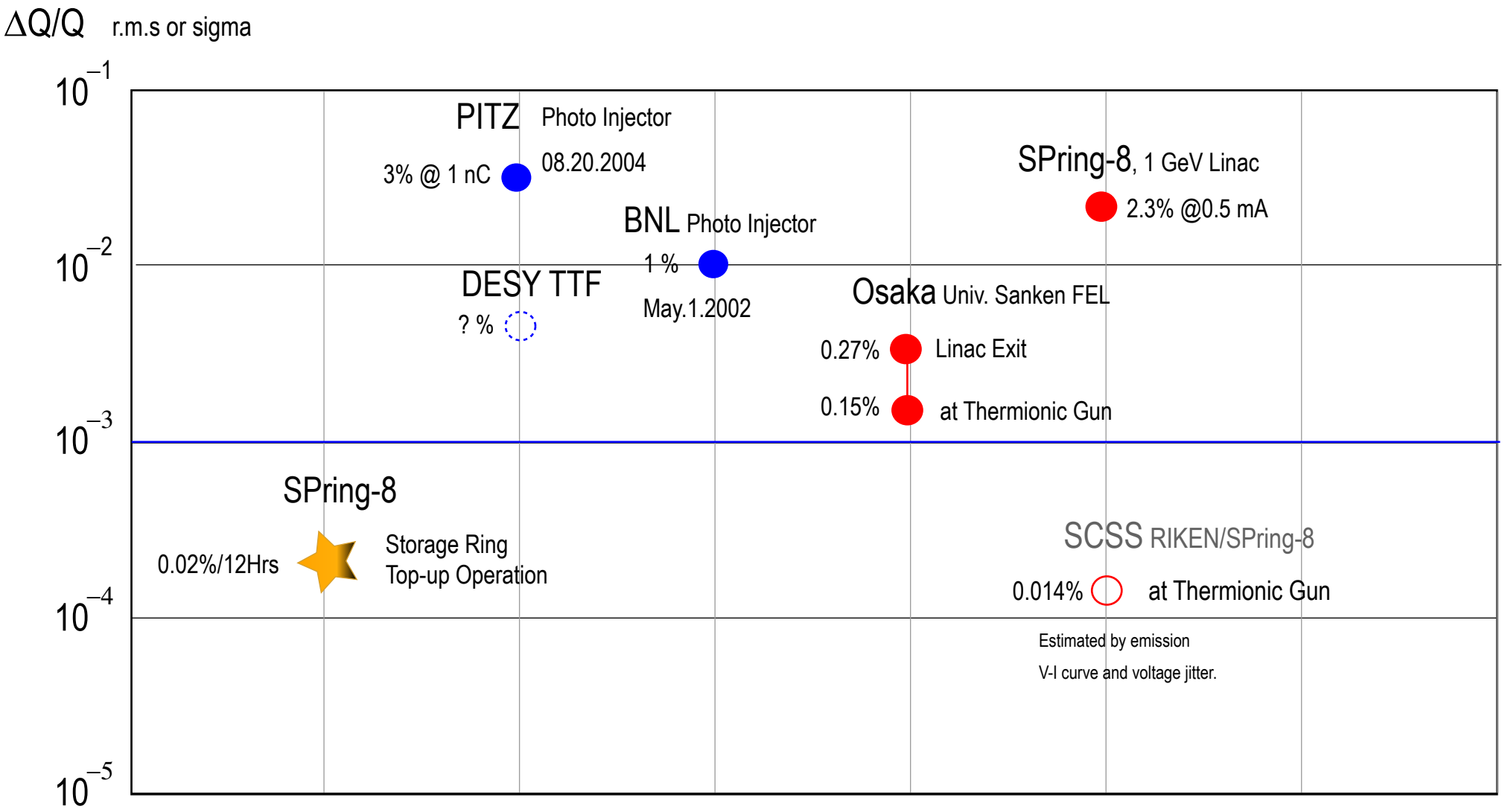
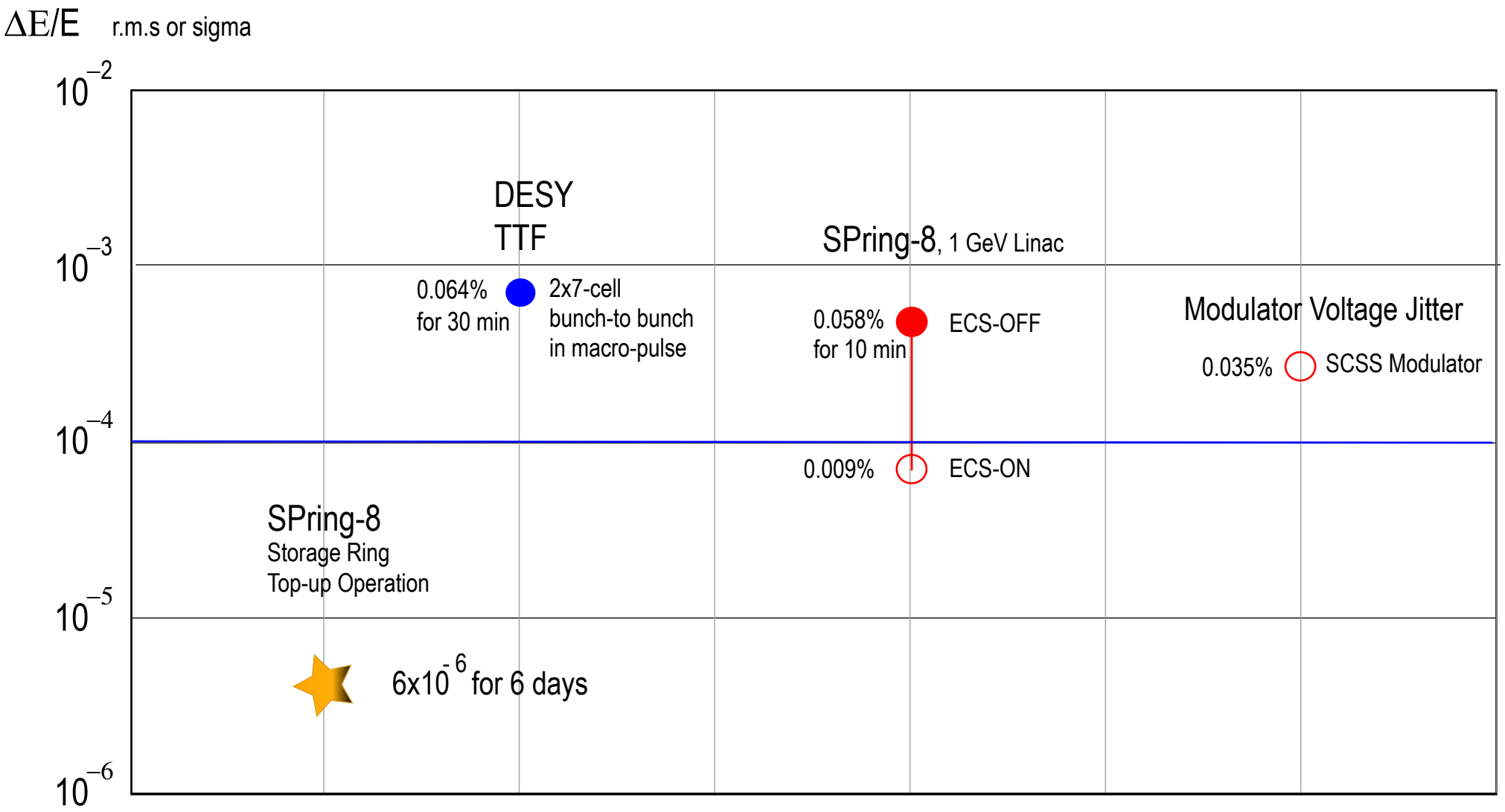
Statistics for 6 Days



Charge, Beam Current Stability



Beam Energy Stability



Need to Cure All the Sources of Jitter

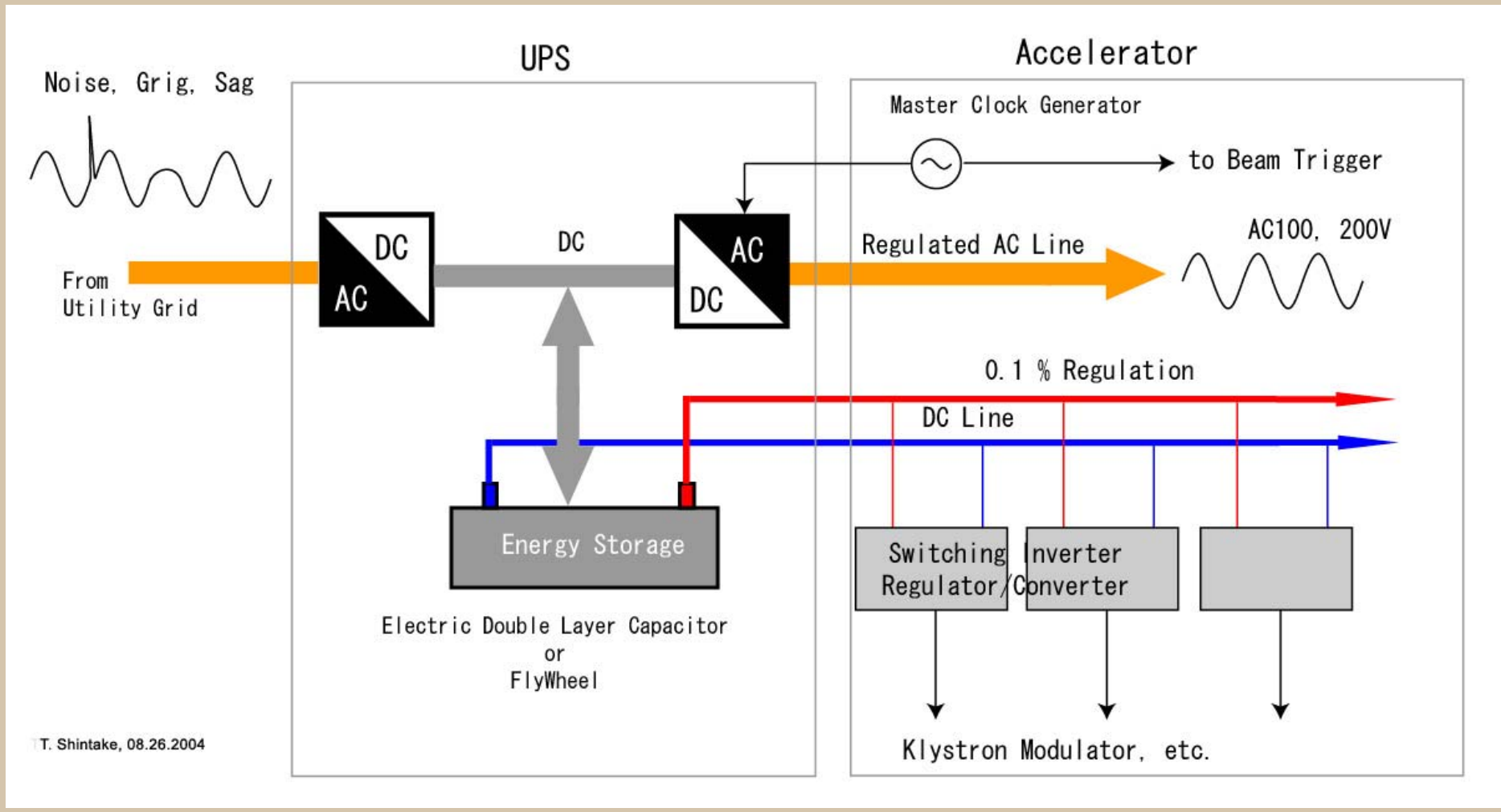
- AC line fluctuation.
- Power Supply Fluctuation
- Switch-tube pulse-to-pulse jitter.
- Switching Noise Fluctuation.
- AD, DA digitizing noise.
- Temperature fluctuation in electrical circuit.
- Ground Motion. Natural and human activity.

AC Line Stabilization

- AC Line is the source of energy to your accelerator.
  - Short-term power glitches or sags cause out-of-control the beam, and strikes the undulator magnet, resulting in damage.
  - AC line voltage fluctuation generates various kind of parameter change, such as, klystron and thyratron heater power variation cause amplitude and timing jitter. Charging voltage variation on flash-lamp capacitor cause laser power and timing jitter.

⇒ UPS System improves quality of AC power, and reliability.
  - Fly-Wheel
  - Electric Double Layer Capacitor

UPS as Regulator/Converter



(By: Michio Okamura)

What is an Electric Double Layer Capacitor?

http://www.okamura-lab.com/ultracapacitor/edlc/edlc1Eng.htm (1/8) [2004/08/26 11:14:23]

molecules and second layer of diffusion were detected and named electric double layer by Helmhortz in 1879.

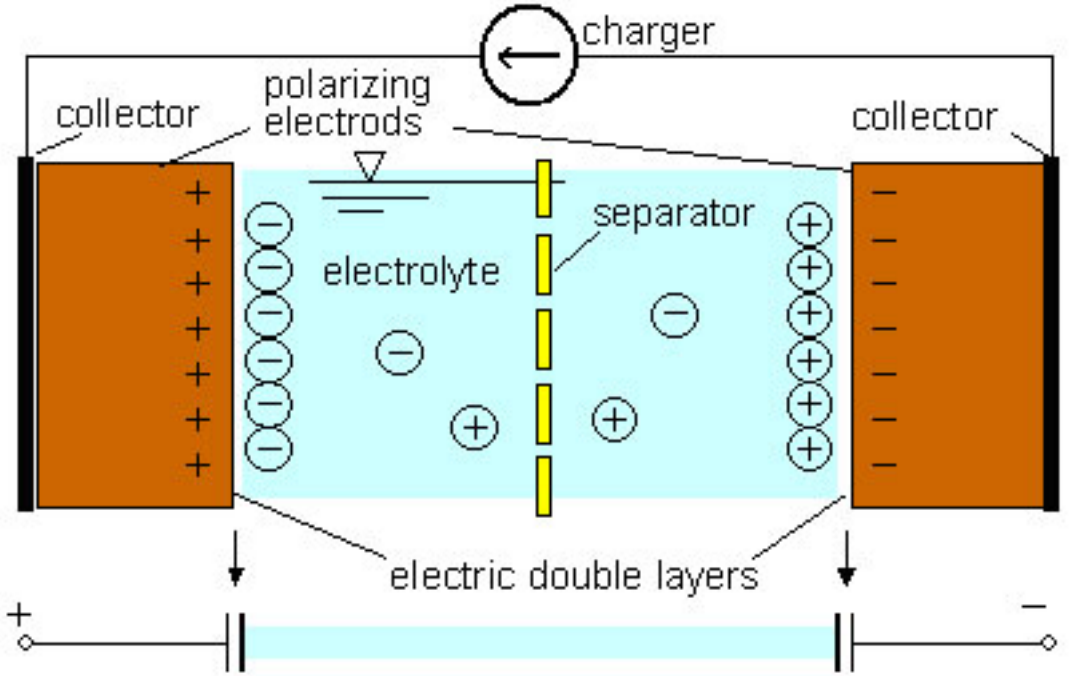


Figure 1: Principle of electric double layer capacitor

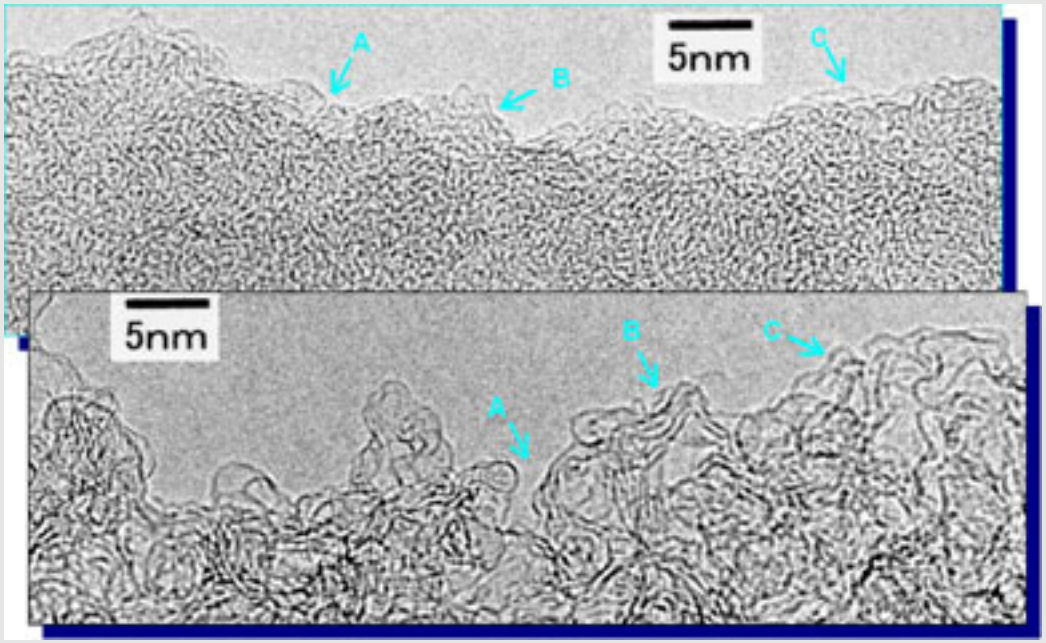


Figure 3: Pores before and after activation of carbon as observed by TEM

There was strong belief that capacitors were good at large pulse power but not at high energy density, and to show this feature, capacitor should have very low resistance. In the US, the Department of Energy promoted a project including four national laboratories and 13 industries from 1992. Unfortunately, the project was terminated in 1998 with a conclusion of little prospects. This greatly discouraged the industries of this field not only in US but also in Japan. Promising customers such as car manufacturers and electric power companies accordingly lost their belief in the potential of capacitor storage.

What is Energy Capacitor Systems *ECaSS*®?

++ *ECaSS*® was born ++

On the first day of 1992, by hitting on an idea, I started to move toward one direction. Since all the leading

(By: Michio Okamura)

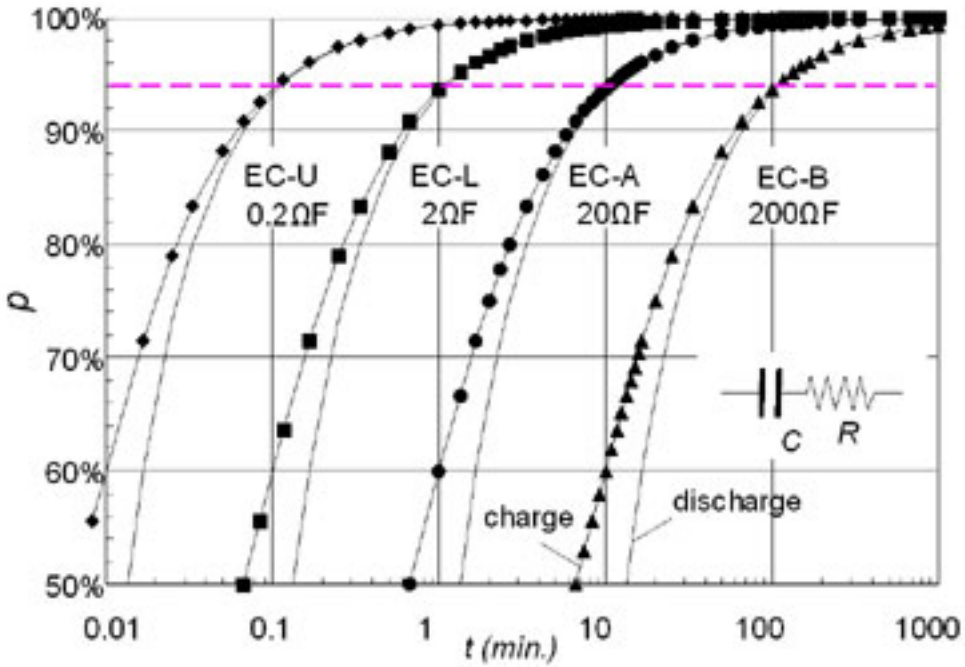


Figure 2: Charging/discharging efficiency versus internal resistance.

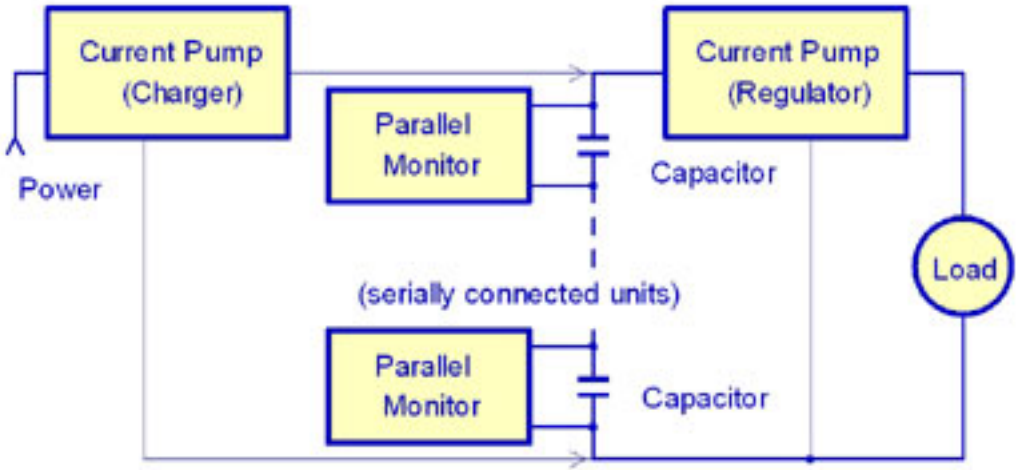


Figure 3: Basic configuration of ECaSS

== Reference ==

[1] M. Okamura and H. Nakamura: "Energy Capacitor System - Part 1 and 2: Capacitors and their Control" The 11th international seminar on double layer capacitors and similar energy storage devices. Dec.3-5, 2001

++ How Safe are Capacitors and Batteries? ++

(By Michio Okamura)

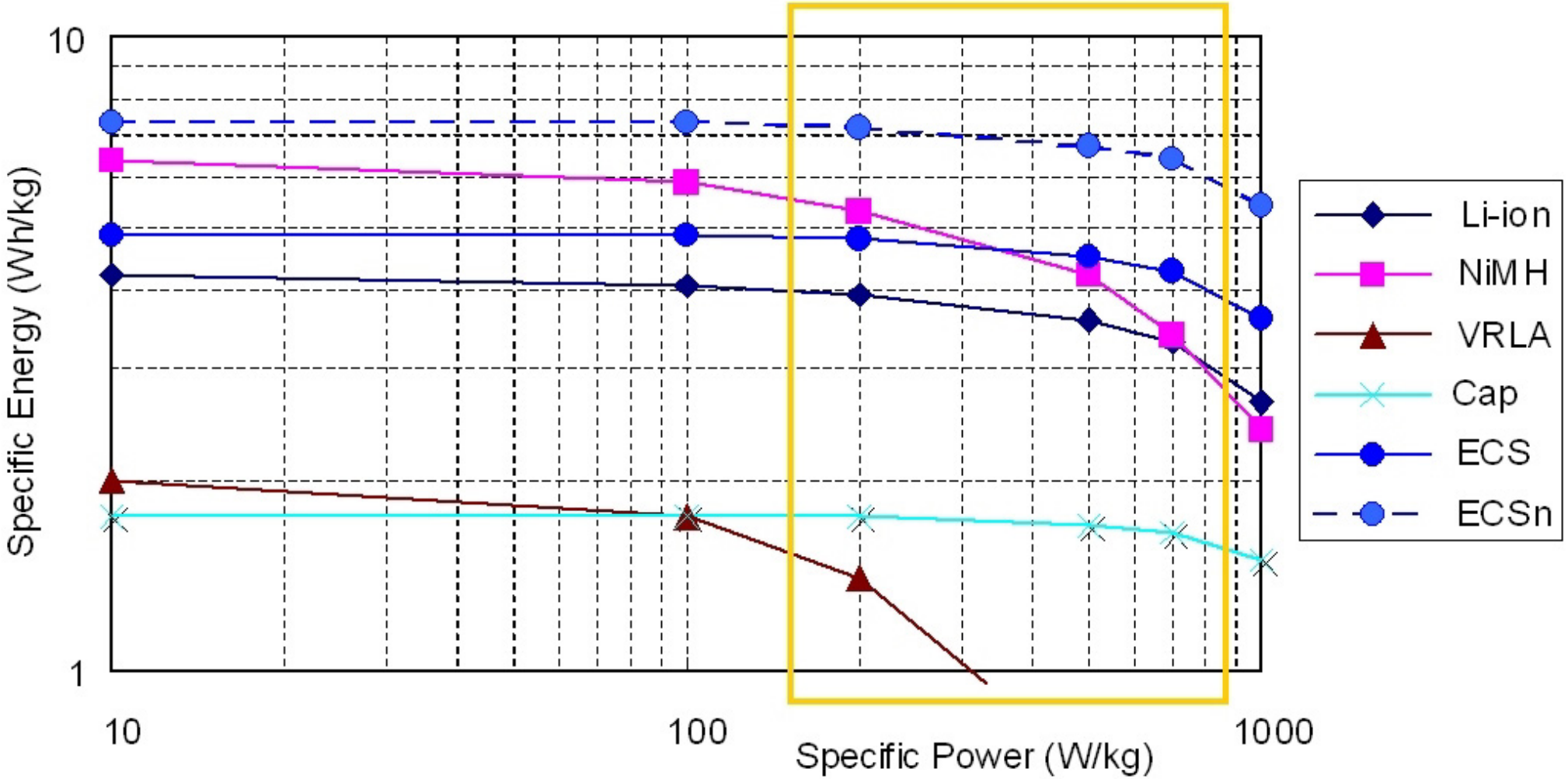
(a)Danger caused by stored electricity
(b)Danger of abnormal chemical reaction due to failure or accident
(c)Danger with generated material caused by leaking or burning

In case of capacitors, (b) is safe enough and depends upon (c). Excluding ECaSS and other Japanese capacitors, the major capacitor manufactures use acetonitrile (AN). This is a good solvent for capacitors. By using this, twice the specific energy is obtainable at the same internal resistance compared to propylene carbonate (PC). Unfortunately, AN is flammable with a 5•‹C flash point, and generates cyanide gas on burning.

Figure 3: ECaSS commercially produced capacitors L type modules
(From left, Nissan Diesel, Sizuki Electric, PowerSystems shown by permission of them)

++ Is Capacitor Energy Density Smaller? ++

Everybody understands that capacitors have longer lives than batteries, but smaller capacity, or more precisely, energy density (energy per volume) or specific energy (energy per weight). However, this is not correct. The official capacity of a battery is defined at the full discharge value without considering its life. For applications such as a hybrid vehicle, several million large current charge/discharge cycles are required, so a shallow setting of depth of discharge is mandatory to maintain battery life.



(By Michio Okamura)

Figure 4: Capacitor 100 kVA UPS by Sizuki Electric. (Permission obtained)

Figure 4 is a photo of a 100 kVA uninterruptible power supply backed up by EDLC, which is manufactured by Sizuki Electric Co. in Nishinomiya, Japan and started being sold on the market. Three models of 200, 100 and 50 kVA are available.

For commercial vehicles, Nissan Diesel Motor Co. improved their capacitor hybrid bus developed under contract as a NEDO project. Figure 5 is taken a picture taken in 2001, but better mileage rating has been obtained in 2002. In the back of the picture, a capacitor hybrid truck is barely visible.

Figure 5: Capacitor series hybrid bus at 2000 Tokyo Motor Show

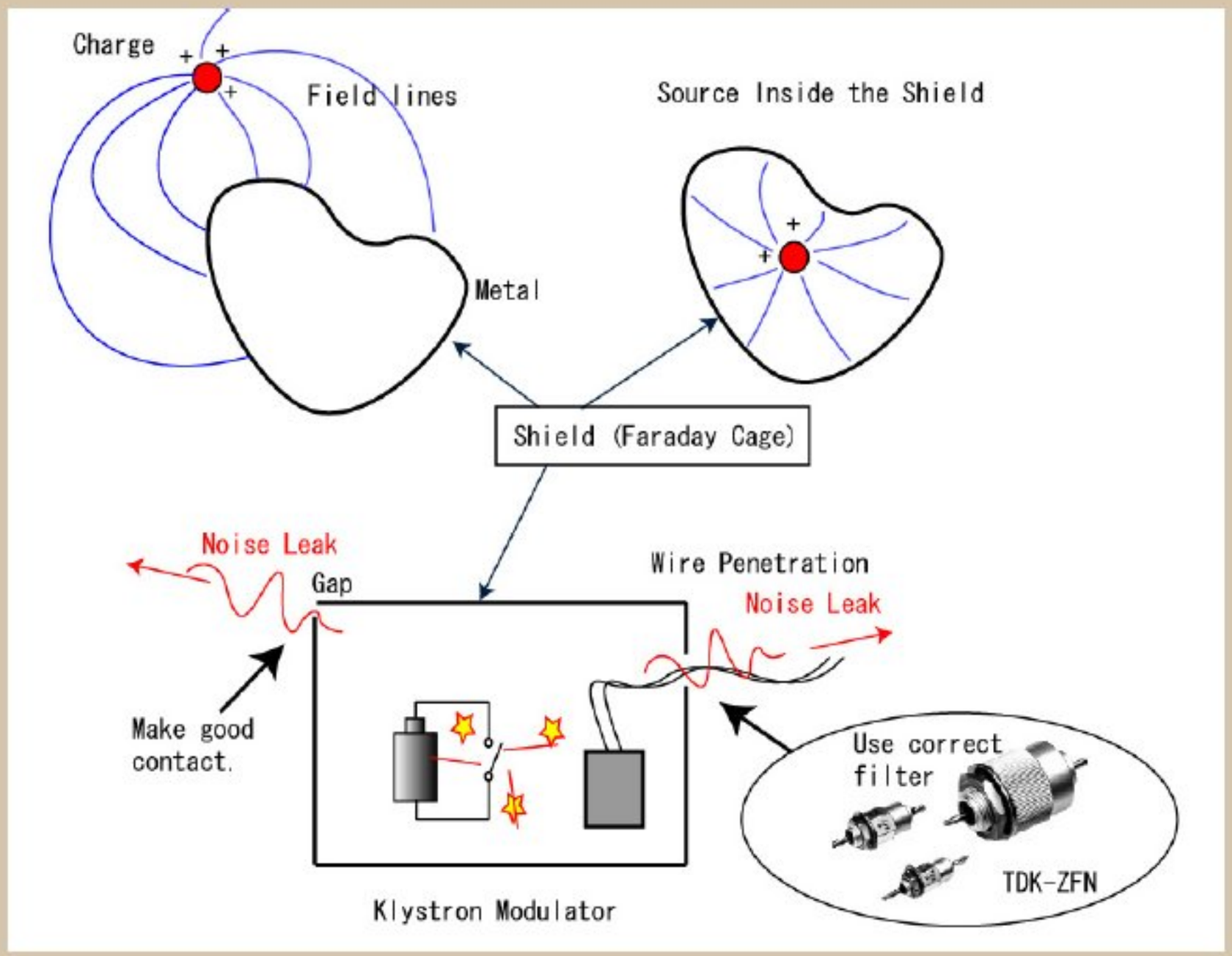
== Reference ==

[1] M. Okamura and H. Nakamura: "Energy Capacitor System - Part 1 and 2: Capacitors and their Control" The 11th international seminar on double layer capacitors and similar energy storage devices. Dec.3-5, 2001

EM Noise Inside Accelerator

- Pulse electron accelerator uses pulse power supply, which is the largest noise source.
- Inverter switching noise, at various frequency, and random phase.
- Switch noise leakage cause various effects in accelerator.
  - BPM readout error
  - Feedback loop error (RF, orbit, temperature, etc.)
  - If noise is large enough, it causes a Bit error in control system

⇒ Cure for EM Noise



Use Faraday Cage Concept for EM shielding.

If there is gap, or wire penetration, EM noise leaks.

Make good Faraday cage, and use correct filters

Use Optical Link

Example: SCSS Klystron Modulator

- Compact.
  W 1.7 m x D 1.2 m x H 1m.
- Good EMI shield.
- Better cooling for
  HV component.
- Eliminating cooling air fan.
- No dust accumulation
  due to high voltage in air.
- No environmental effects:
  moisture and temperature variation.

Si Technology will make Further Advanced Accelerator System

- ASIC custom RF detector/modulator will replace old fashion RF circuit.
  - Compact, accurate (laser trim), low cost.
  - Temperature regulation becomes easier.
  - Smaller size makes lower EM noise interference.
- Standardization becomes easier.
  - We can easily share our custom designs between accelerator laboratories.
- Hardware in fiber optics communication systems will match soon to distribute very accurate RF signal (sub-pico-second)
- High power solid-state switch will be mature soon.

SiGe Mixed Signal and RF ASIC Technology

RF and Wireless ASICs

Fiber ASICs

Test and Measurement ASICs

SiGe Mixed Signal and RF ASIC Technology

Featuring Our SiGe (Silicon Germanium) Processes

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Maxim is uniquely qualified to solve your high-frequency ASIC needs with our Complementary Bipolar, Bipolar, BiCMOS, SiGe (Silicon Germanium), or SiGe BiCMOS process technologies. Our RF ASIC offering includes Customer Owned Tooling (COT) and Foundry Services. Maxim offers:

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- Simulation Models
- Packaging
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Fiber ASICs

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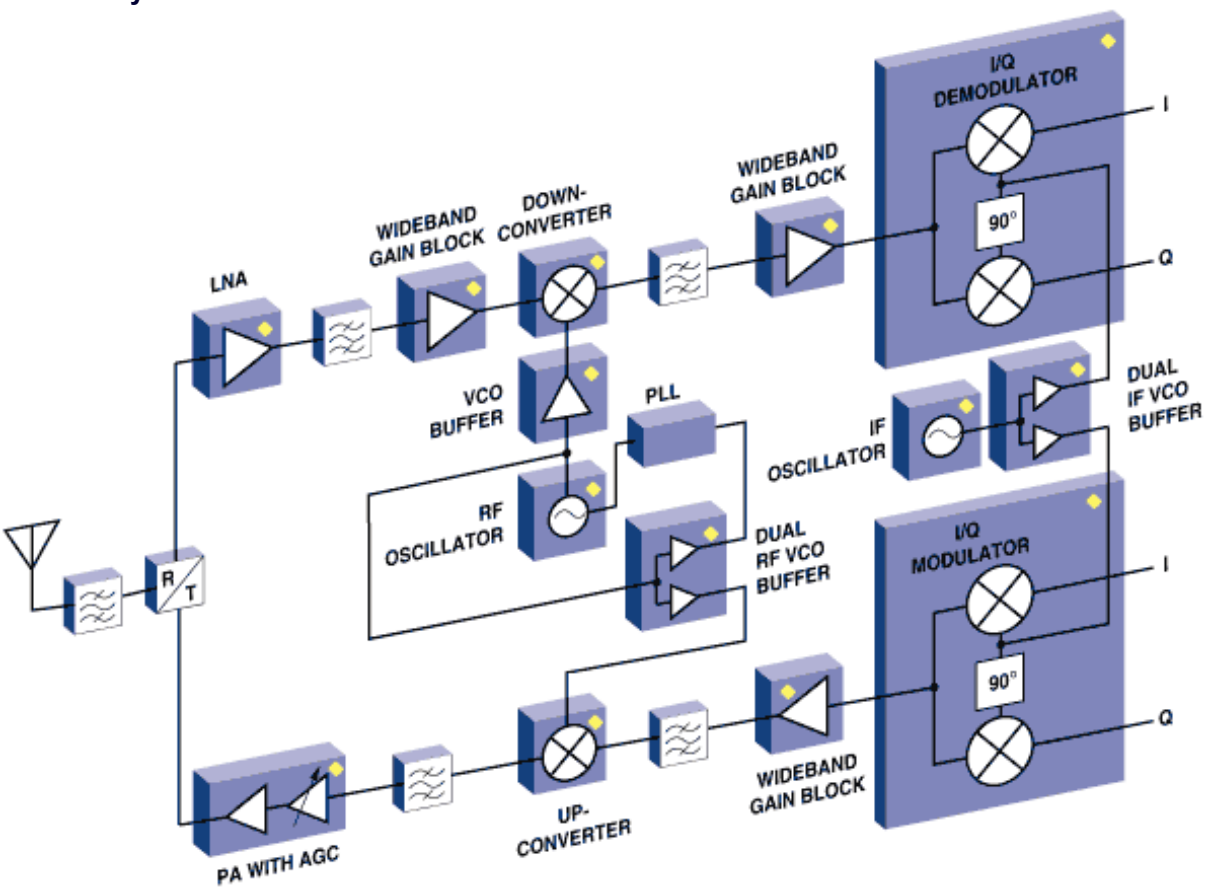
Applications

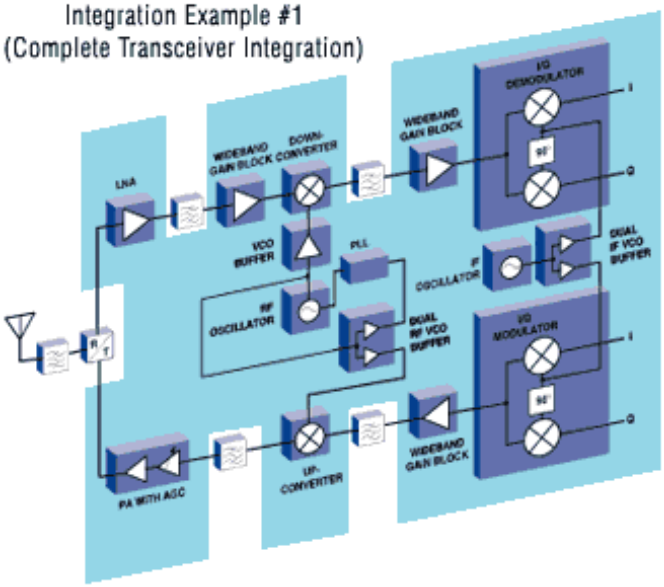
- Cellular/PCS, including both hand-held terminals and infrastructure
- Direct Broadcast Services via Satellite
- Global Position System Receivers
- Wireless/Broadband Radios
- Cable TV

Typical blocks suitable for integration:

Click any block for more information

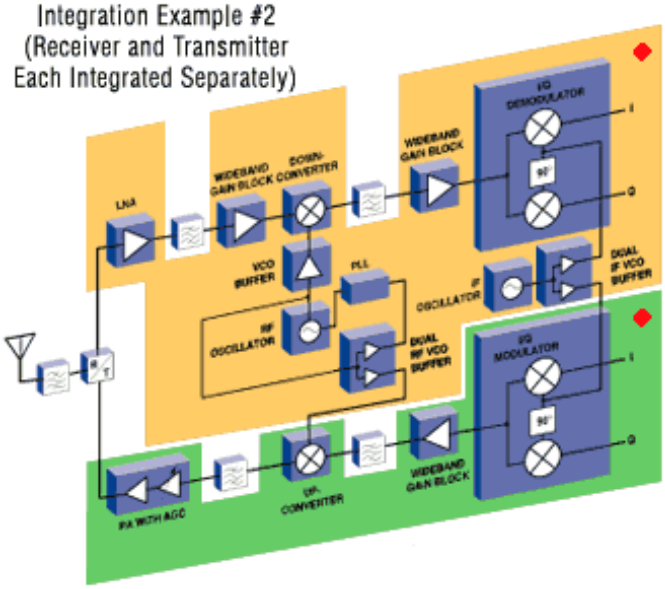


Integration Example #1
(Complete Transceiver Integration)

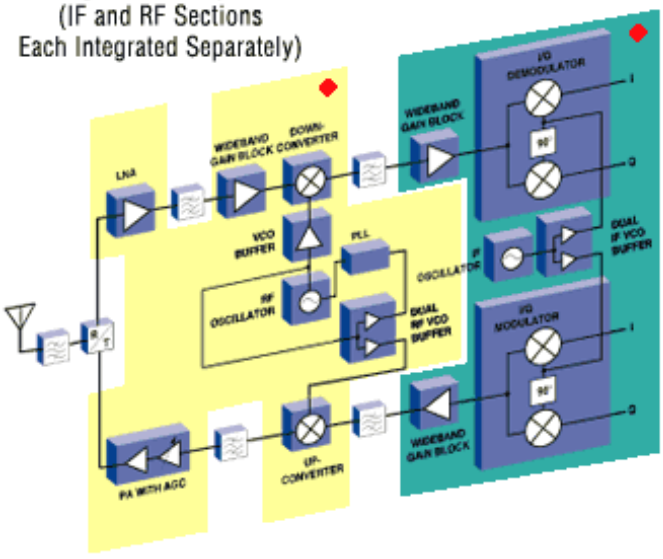


Click any block for more information

Integration Example #2
(Receiver and Transmitter
Each Integrated Separately)



Integration Example #3
(IF and RF Sections
Each Integrated Separately)



Undulator for XFEL

Stable Beam Control in Very Long Undulator

Even if you do beam-based-alignment..

- Position of focusing Q-magnet, BPM need to be very stable.

  ⇒ Design lower beam line level from the concrete floor

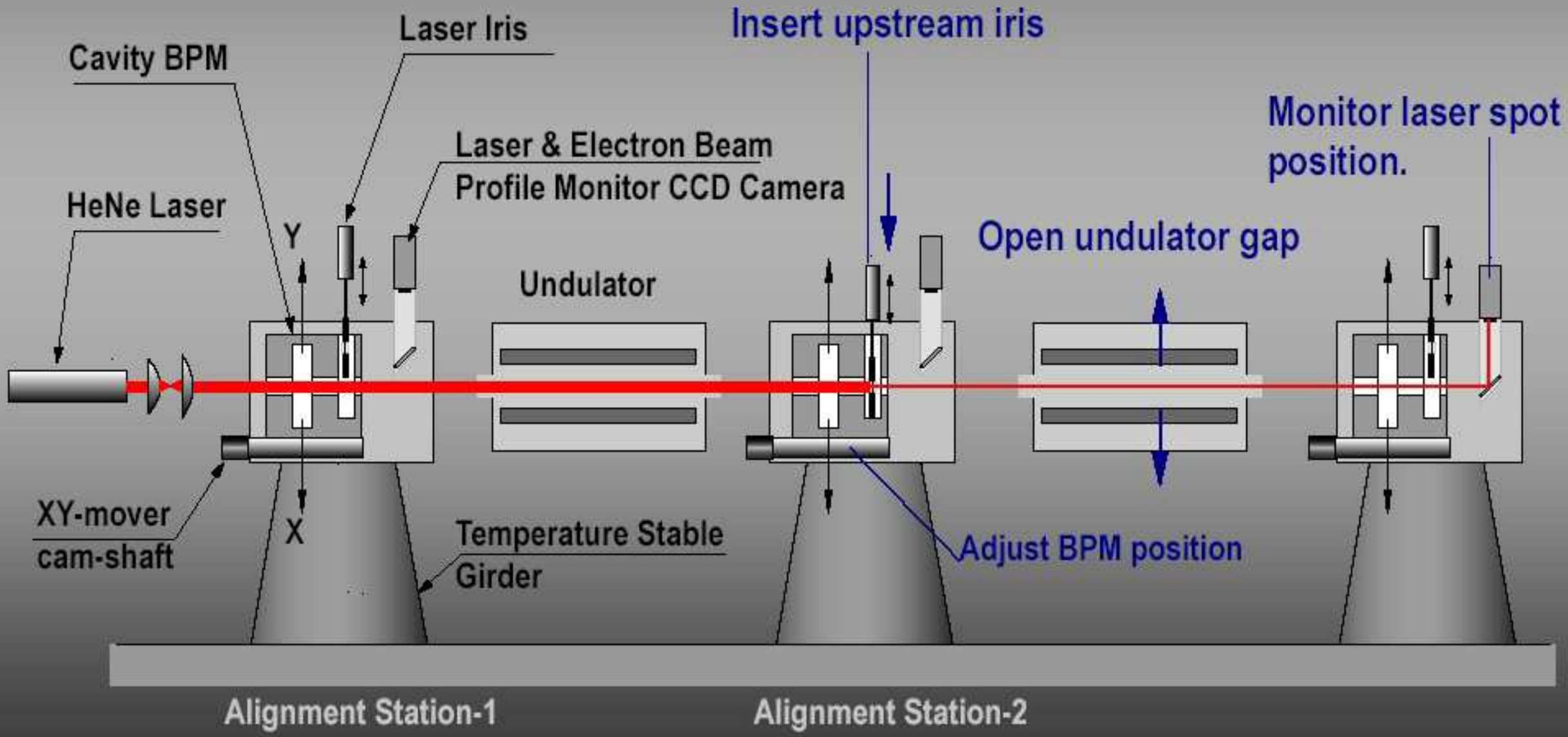
  ⇒ Use stable support stand (not traditional steel design)

- Clean beam is required, since beam halo-component cause BPM readout error.

  ⇒ Design optimum beam collimators to cut dark-current emission from the electron gun and followed accelerating cavities.

⇒ Alignment using HeNe laser beam runs inside the same beam pipe can help beam tuning.

BPM Alignment System for SASE FEL



Cavity BPM Design

- Absolute Position Accuracy
  < 10 micron meter
- Resolution ~30 nm for 1nC.
- x, y read out in one cavity.
- COM Free slot design.
- Laser-slit will be integrated for alignment.

Stability and Reliability Aspect on Undulator

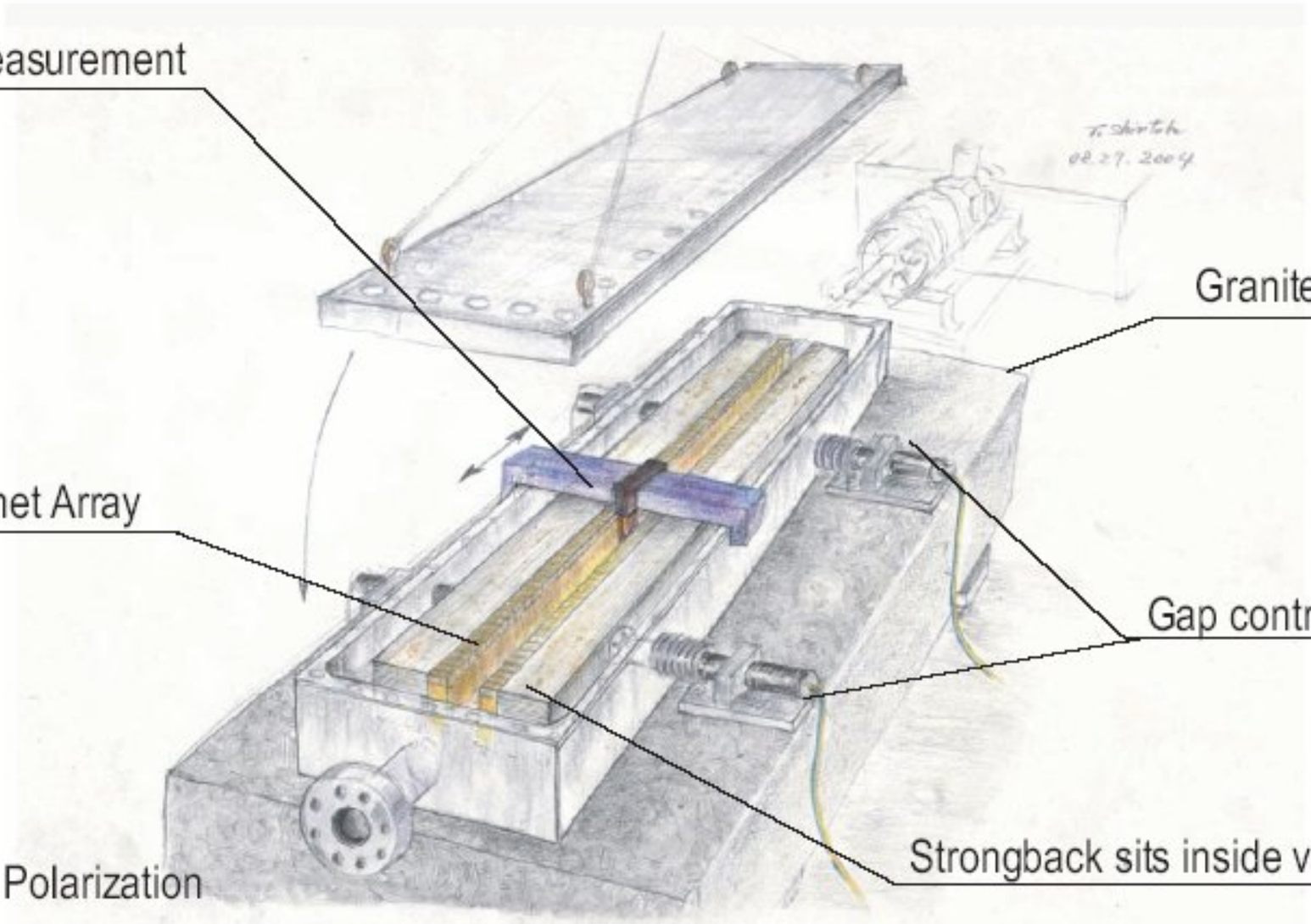
- Gap size is the most sensitive parameter.
- Gap position is in-sensitive.

⇒ Use high-rigidity design to support magnet gap.
  - Bring a big strong back inside vacuum.
  - Fix on a massive, high-rigidity structure . ⇒ Stone Table
  - Steel support is not suitable (higher thermal expansion, less rigid, not massive, remnant field)

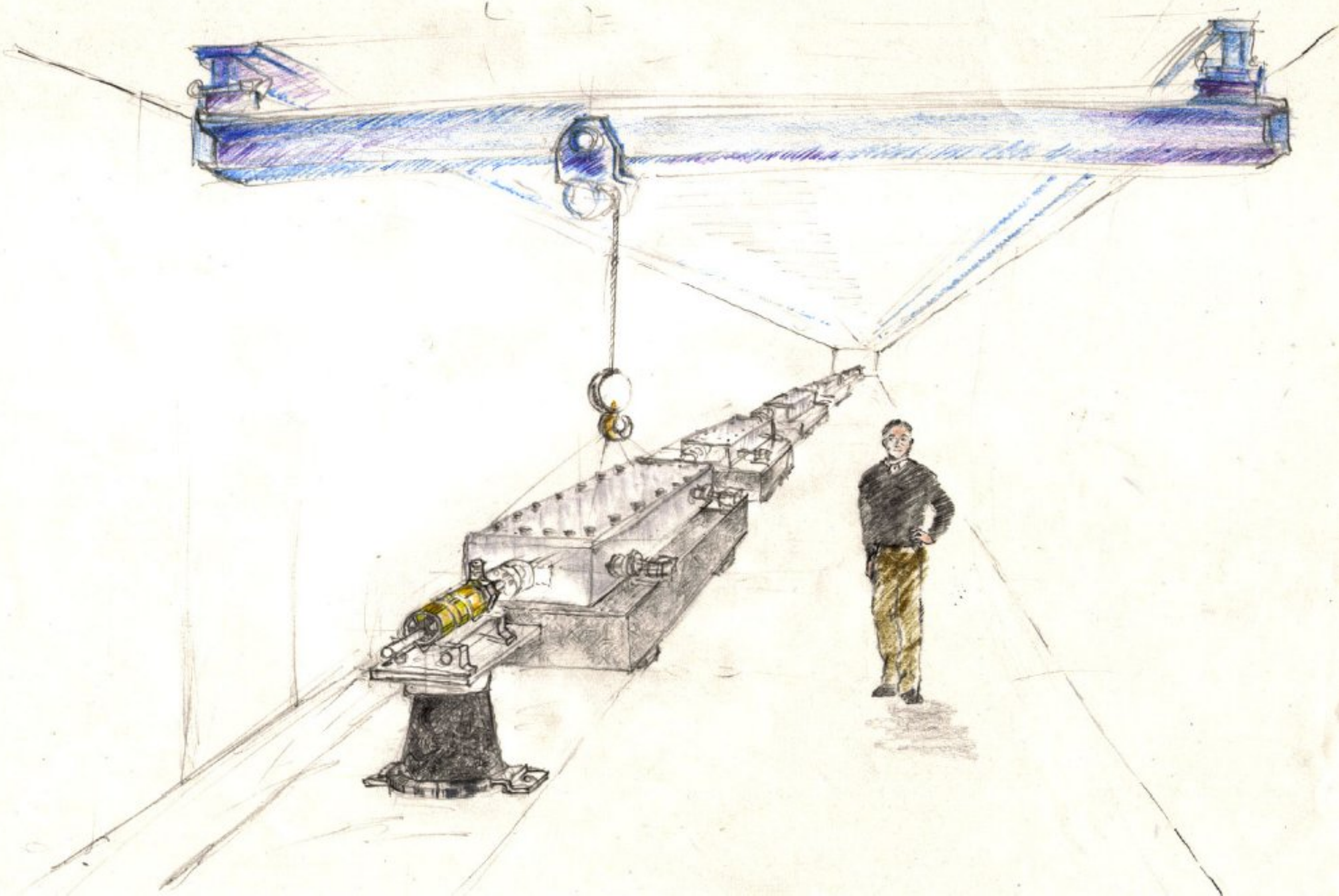
⇒ In situ field measurement and tuning is indispensable.
  - Final check, scheduled maintenance, look for radiation damage.

High-rigidity Stone Table supports Undulator Gap Precicely

Undulator, on Stone Table, Insitu Field Measure, Full-Open Chamber



T. Y. Shintake, 27.Aug. 2004



Water Cooling System for Better Quality of Your Life

- It's a Noise Source. ⇒ Lower the water pressure and flow speed.
- Need optimum design on flow rate.
  - ⇒ Carefully specify the requirements.
  - ⇒ Prepare testing device (flow resistance measurement on coil, power supply, etc.)
- Large cooling system needs longer stat-up time, and cause temperature fluctuation.
  - ⇒ Use local feedback.
  - ⇒ Fast start up time of whole system.

Beam Time: From 9 to 5 O'clock,

No Night Shift !!!

Conclusions

X-FEL is a big technical challenge.

Make your hardware 100% sure,
Which will make
quality of your life better

Good Luck!