# X-ray FEL Project at SPring-8 Japan (SCSS)

T. Shintake, H. Kitamura and T. Ishikawa

***presented by T. Shintake***

- **Project Overview**
- **Milestone**
- **Key Technology**
  - **Electron Gun**
  - **High-gradient C-band Accelerator**
  - **In-vacuum Undulator**
  - **Alignment Tool**

# SCSS Group

**RIKEN/SPring-8**

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Z. Chao
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S. Takahasi
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**KEK/Tsukuba**

H. Matsumoto
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# Existing 1 km Beam Line Space

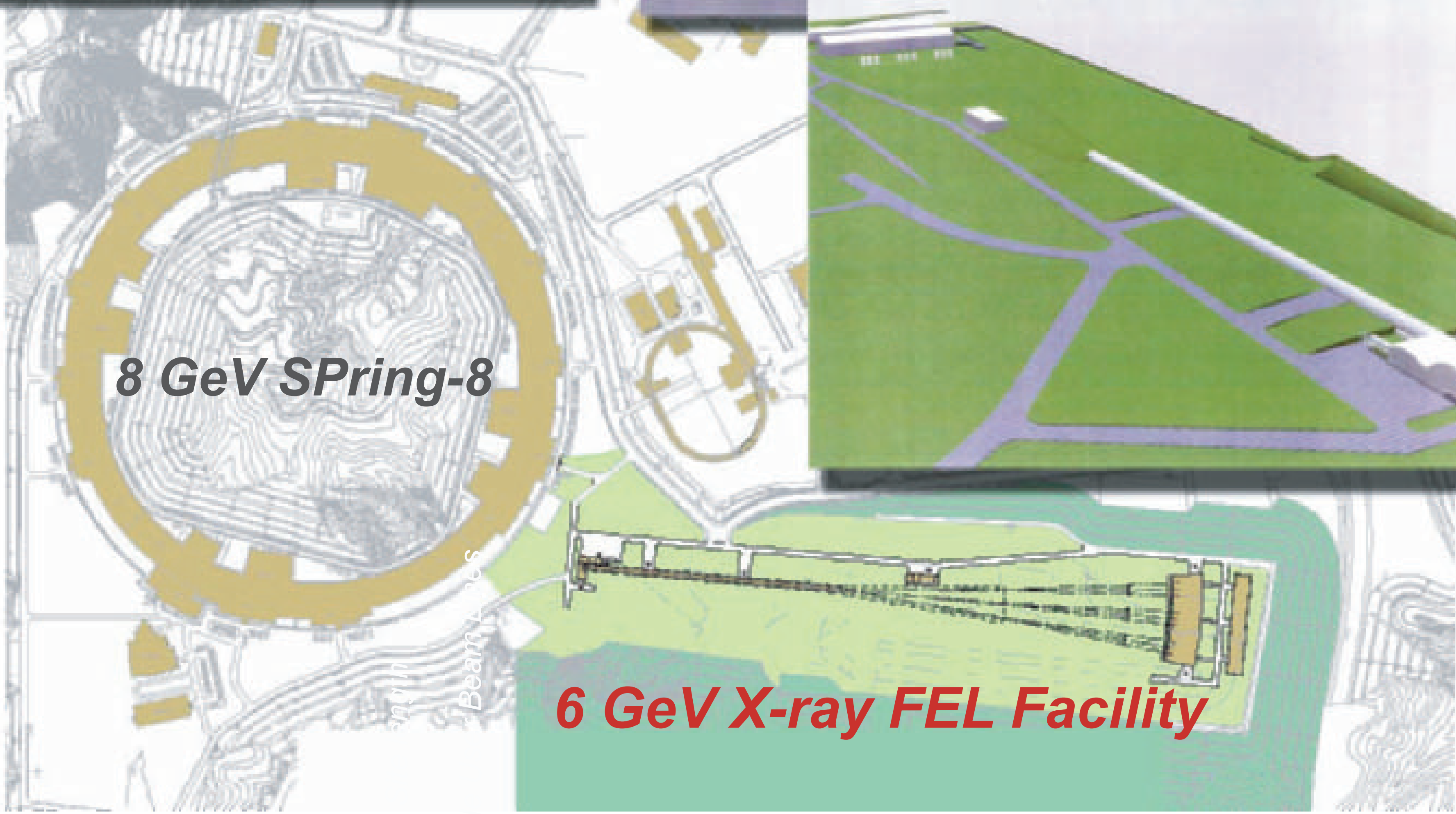
## *Future X-ray FEL at SPring-8*

*Target Wavelength 1 A*

*6 GeV C-band Accelerator*

*1 km Site Length*

*Multiple User Beam Lines*

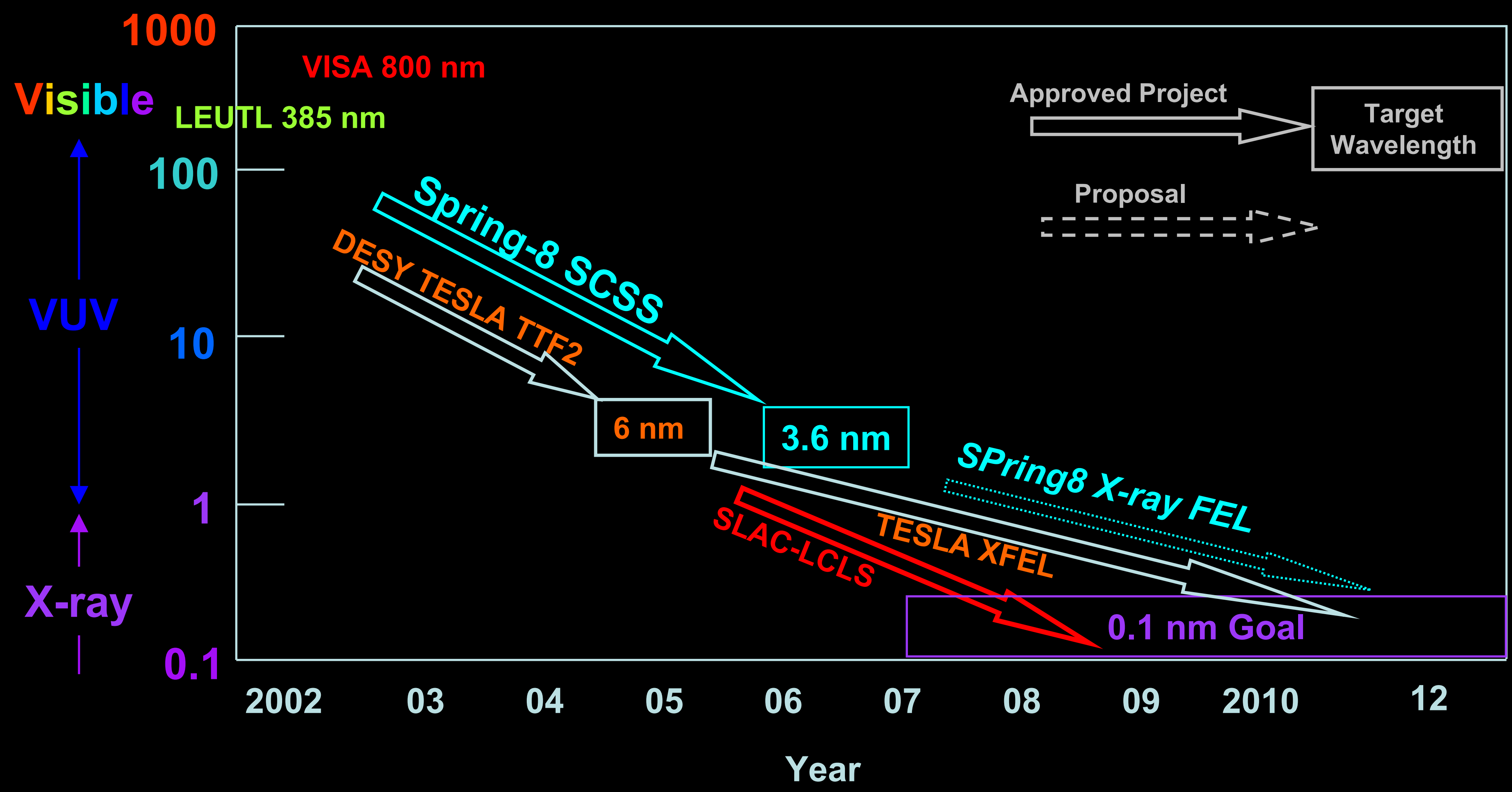


# Organization

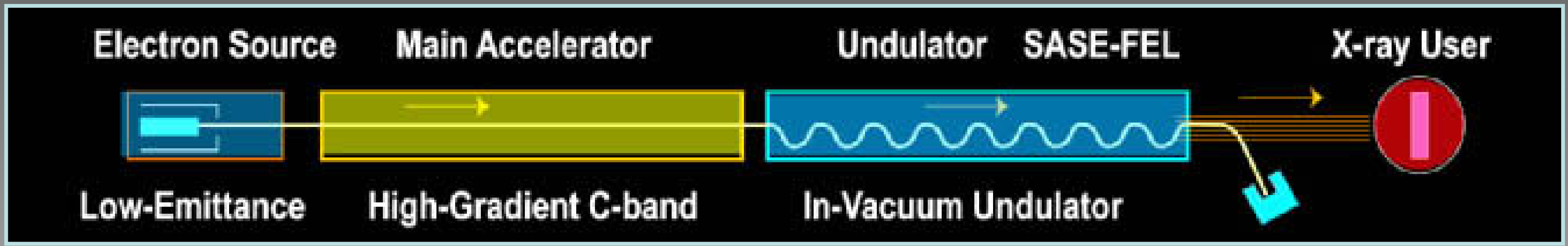
- Injector
  - T.Shintake: RIKEN
- Main Accelerator
  - H. Matsumoto: KEK
- Undulator
  - H. Kitamura: RIKEN SPring-8
- FEL Beam Line
  - T. Ishikawa: RIKEN SPring-8


KEK: High Energy Accelerator Research Organization (Tsukuba, Japan)
RIKEN SPring-8: The Institute of Physical and Chemical Research, Harima Institute / SPring-8 (Sayo, Hyogo, Japan)

# Milestone of Spring-8 X-FEL



# SCSS : SPring-8 Compact SASE Source



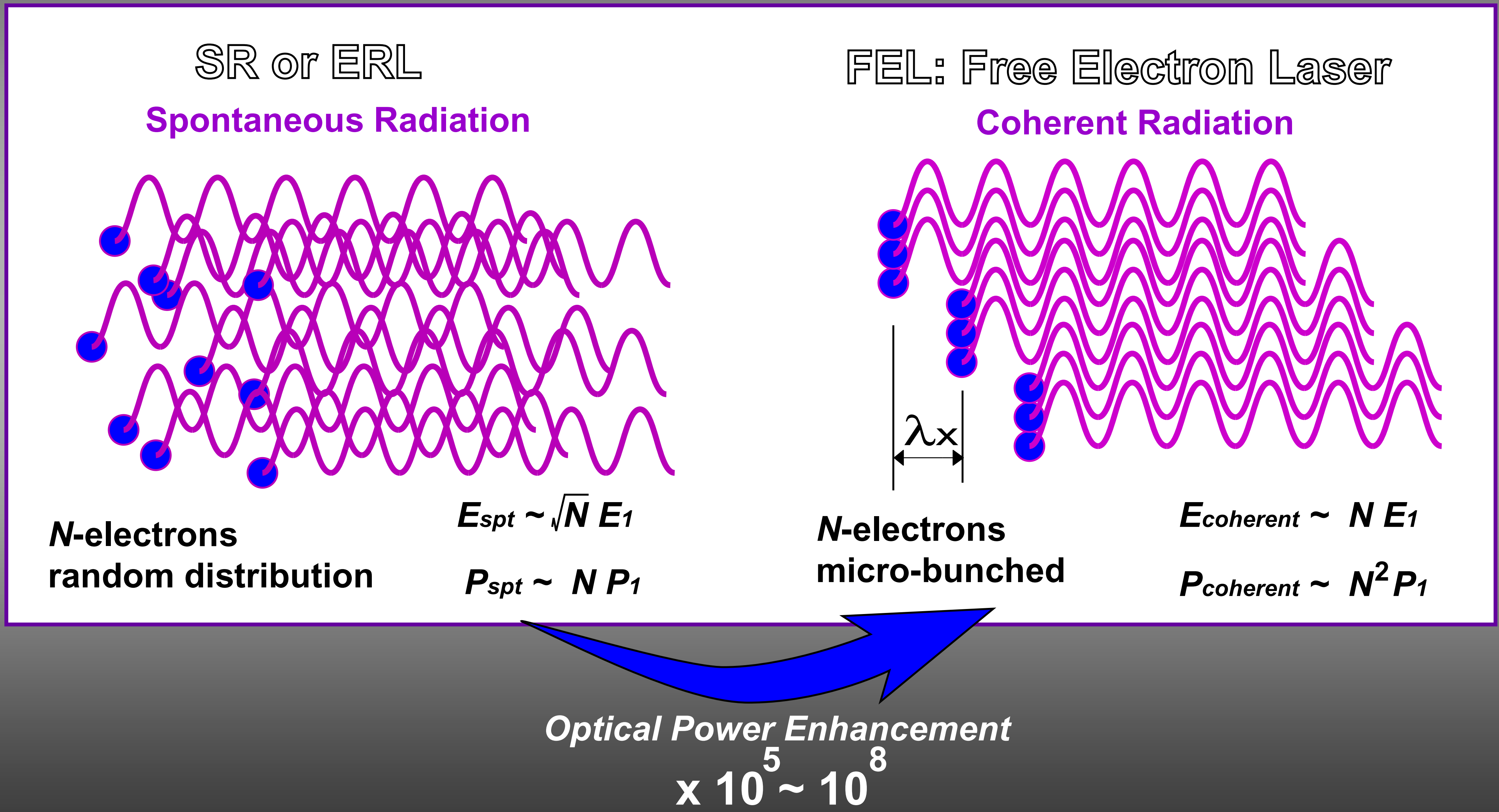

- **Low Emittance Injector** → **Short Saturation Length**
- **High Gradient Accelerator** → **Short Accelerator Length**

  **KEK C-band 35 MV/m x 30 m = 1 GeV**

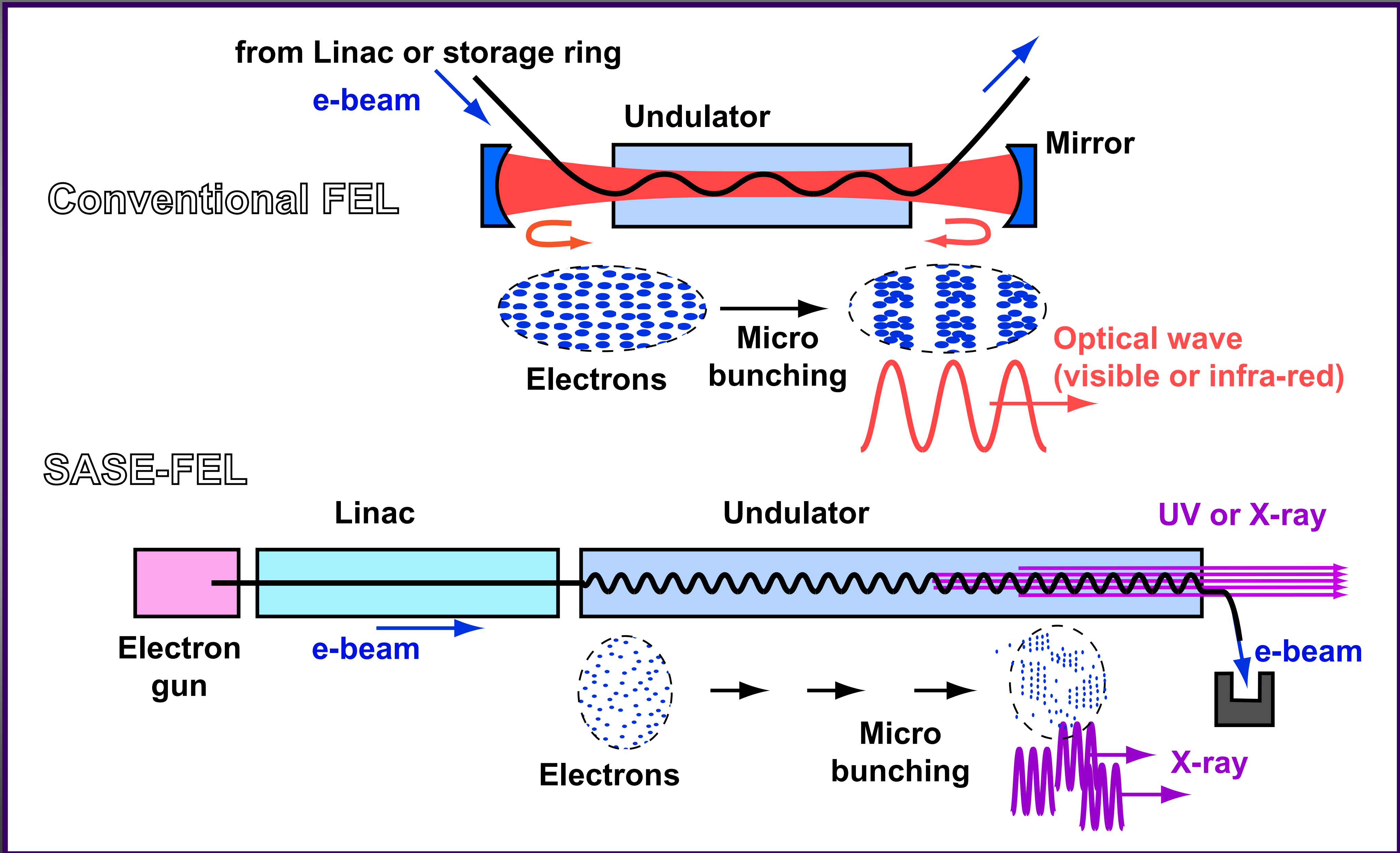
  **35 MV/m x 180 m = 6 GeV**
- **Short Period Undulator** → **Lower Beam Energy and Short Saturation Length**

**with Kitamura's In-Vacuum Undulator : E = 6GeV, $\lambda u$ = 15 mm, $\lambda x$ = 0.1 nm**

# From SR to FEL



# From Cavity Type FEL to SASE-FEL



# SCSS & X-ray FEL Beam Parameter

at undulator section

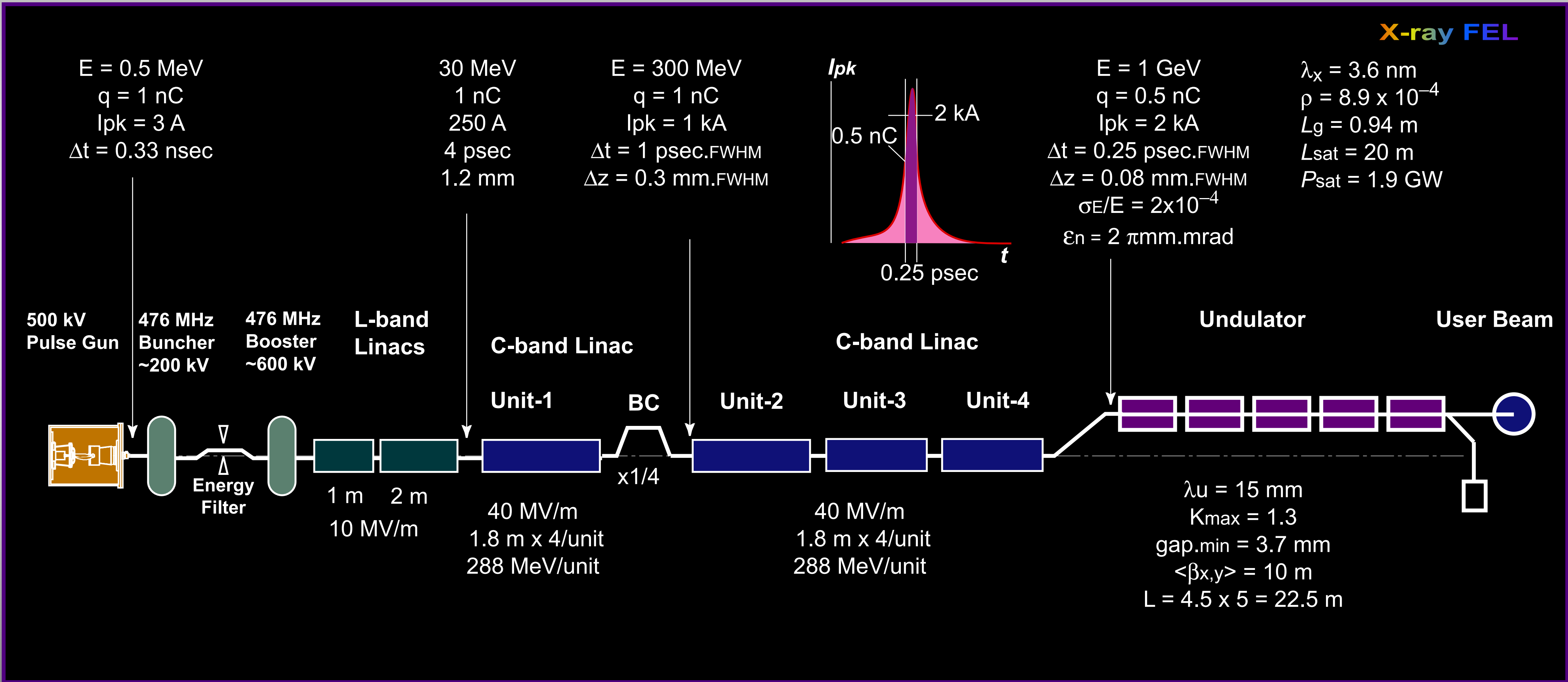
| | | SCSS | X-ray FEL | |
|---|---|---|---|---|
| Beam Energy | $E$ | 1.0 | 6.0 | GeV |
| X-ray Wavelength | $\lambda$ | 3.6 | 0.1 | nm |
| Beam Emittance | $\varepsilon_n$ | 2 | 0.5 | πmm.mrad |
| Bunch Length | $\Delta z$ FWMH | 150<br>0.5 | 75<br>0.25 | μm<br>psec |
| Transverse Beam Size | $\sigma_{x,y}$ | 100 | 25 | μm |
| Peak Current | $I_p$ | 2 | 4 | kA |
| Charge per bunch | $q$ | 1 | 1 | nC |
| Undulator Parameter | $\lambda_u$ | 15 | 15 | mm |
| | $K$ | 1.3 | 1.3 | |
| Length | $L$ | 22.5 | 50 | m |
| FEL Saturation Length | $L_{sat}$ | 20 | 40 | m |

# X-FEL (SASE) vs Normal Undulator Light

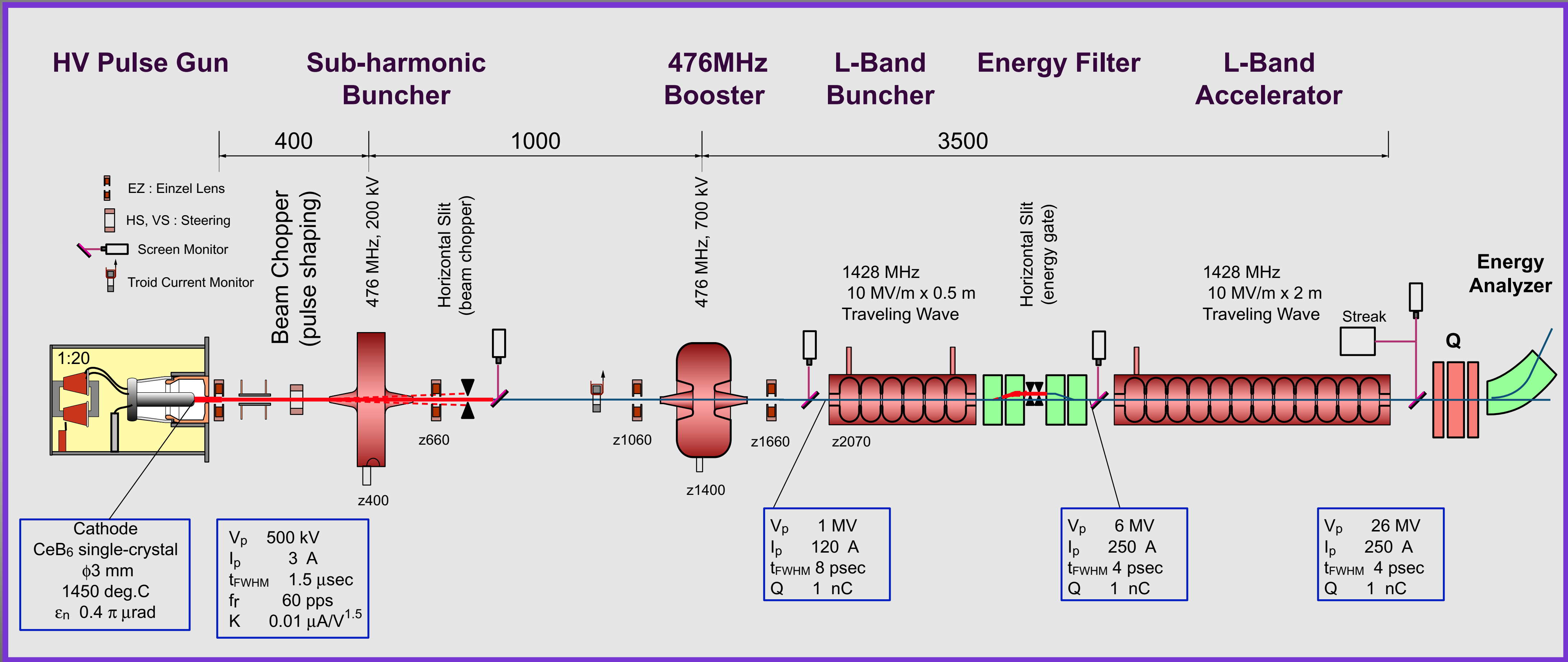
- Peak Brilliance
  $10^{30}$~$10^{33}$ [Photons/sec/mm2/mrad2/0.1%bandw]
  undulator ~$10^{24}$
- Pulse Length
  100~10 fsec — undulator ~1 psec
- Coherent Length
  a few micron-meter (shorter than light pulse) — undulator Non
- Pulse Repetition Rate
  10 Hz ~ 10 kHz — undulator 100 kHz
  pulse machine — cw machine
- Spectral Stability < $10^{-3}$ — undulator <$10^{-6}$
- Power Stability < 30% — undulator <$10^{-6}$

# SPring-8 Compact SASE Source (SCSS)

***Beam line layout at 1 GeV, 3.6 nm***



# Low Emittance Injector for SCSS



# Why don't we use RF-Gun

- Charge of 0.2 ~ 1 nC/bunch is enough.
- RF-Kick in RF-Gun deteriorate Emittance
- Laser is not quite stable.
  - Fluctuation of transverse mode pattern.
- Photo-cathode & Laser system need manpower

**Scalar potential acceleration is ideal**

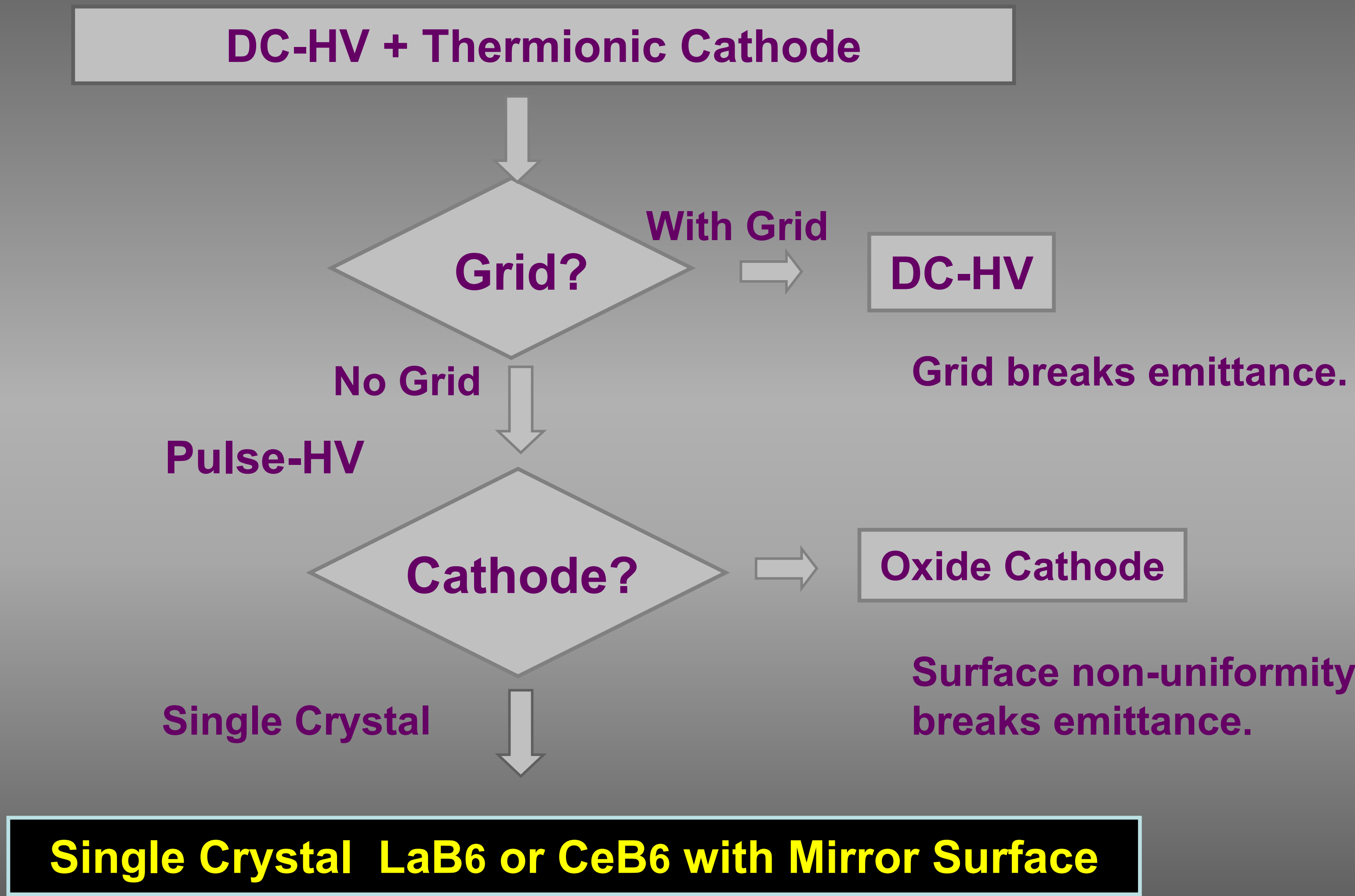
⬇

**Pulse High-Voltage Gun**

# Merits of Thermionic HV-gun.

- **Thermionic gun is stable and long life.**
  - **High temperature single-crystal cathode operates quite stably and long life ( > 10,000 hours)**
- **Uniform Electron Density.**
  - **Single crystal $CeB_6$ cathode provide uniform emission density ( very low slice emittance)**
  - **No hallo beam**
- **Wide Range of Tuneability.**
  - **Sub-harmonic buncher + buncher configuration enable one-by-one tuning of beam parameter.**

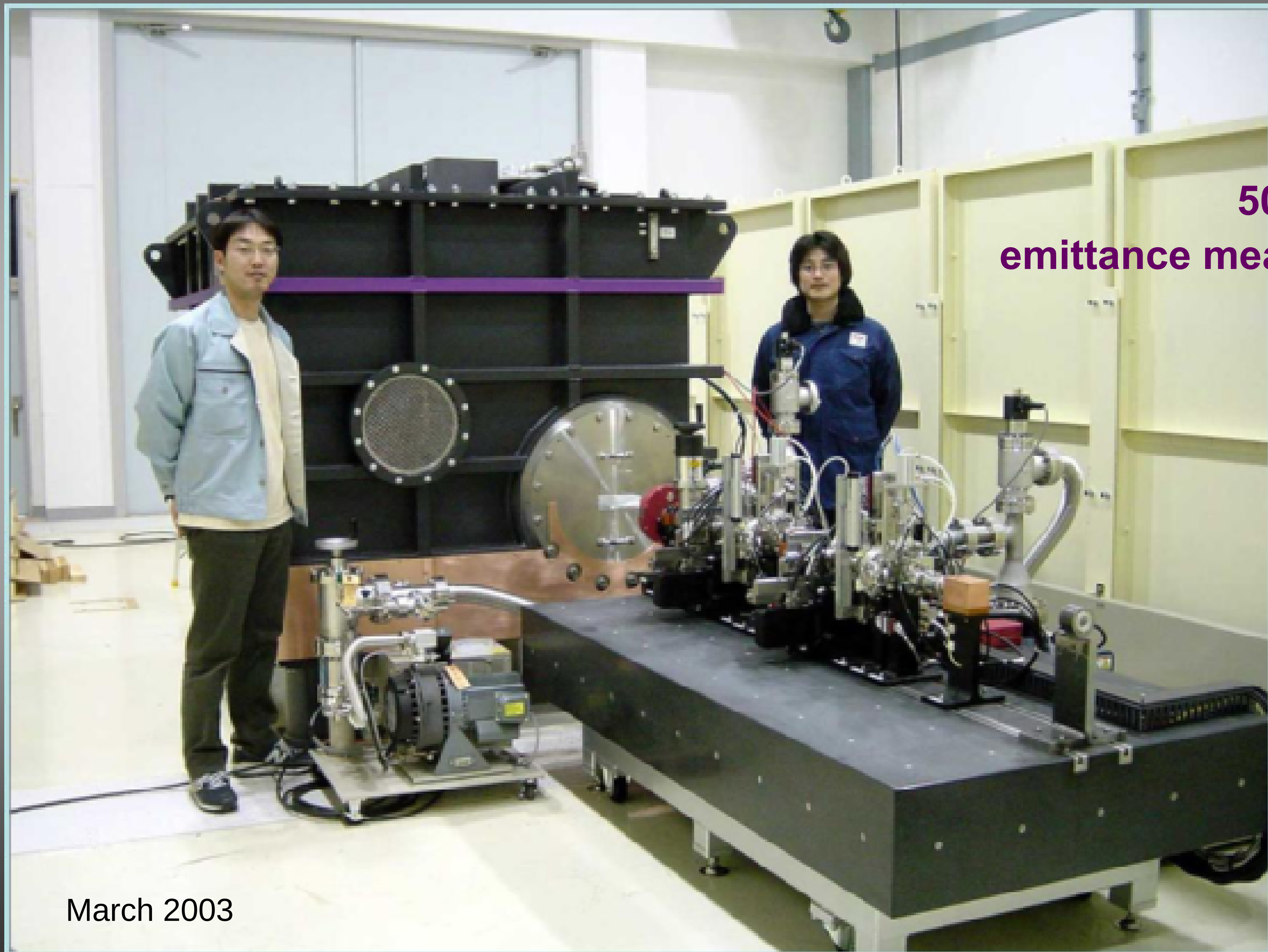
# How to Realize Pulse HV Gun?



# $CeB_6$ Cathode & Heater Assembly

- $CeB_6$ Cathode 3 mm Diameter
- Emittance 0.4 $\pi$.mm.mrad
  (thermal emittance, theoretical )
- Beam Current 3 Amp. at 1450 deg.C
  (using graphite heater)
- Current Density > 40 $A/cm^2$

# Low-Emittance 500kV Electron Gun R&D

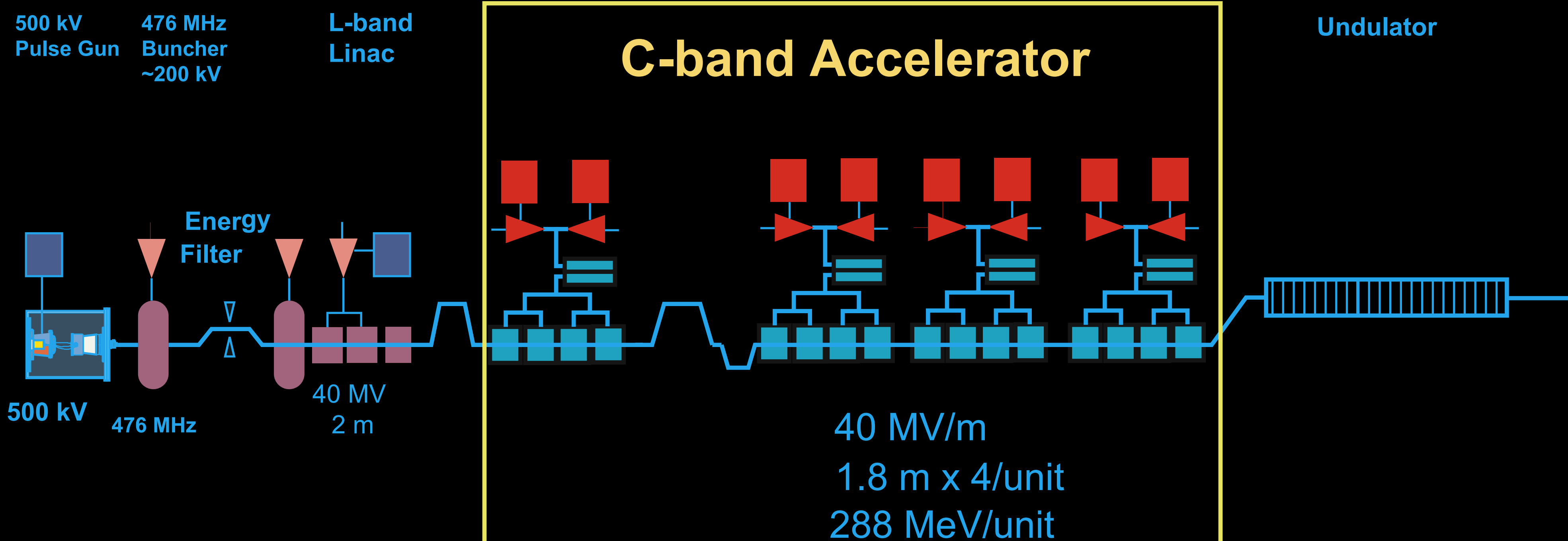



**500 kV gun tank and emittance measurement system.**

# Compact HV Pulse Modulator Supply


- **Driving 50 MW klystron,**
  **and 500 kV electron gun.**
- **Compact, Oil Filled Design**
  **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.**

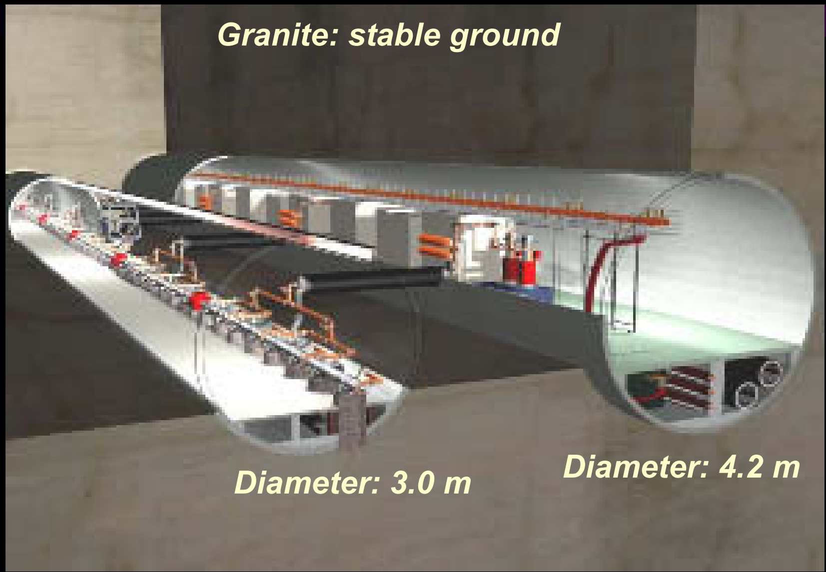
# C-band String Test at SPring-8 X-Ray FEL Project (SCSS)

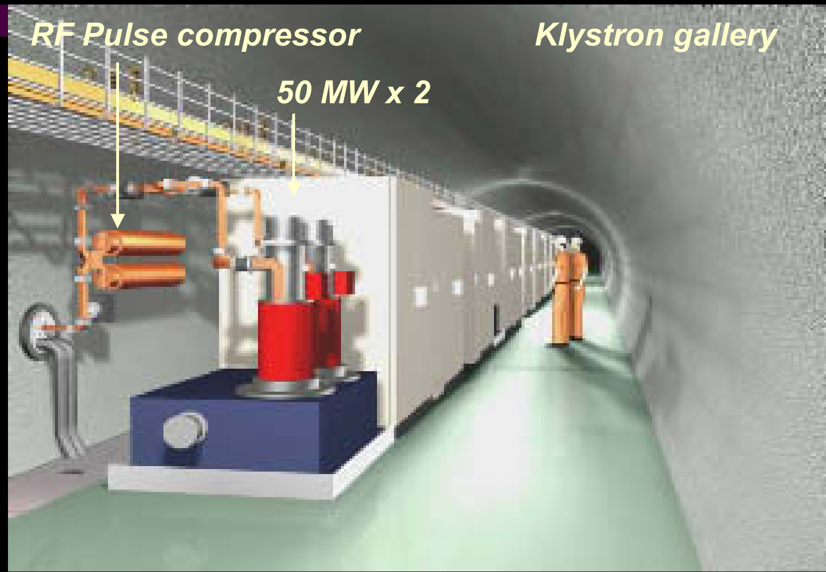



**C-band Unit x 4**
**50 MW Klystron x 8**
**Modulator x 8**
**Acc Structure x16**

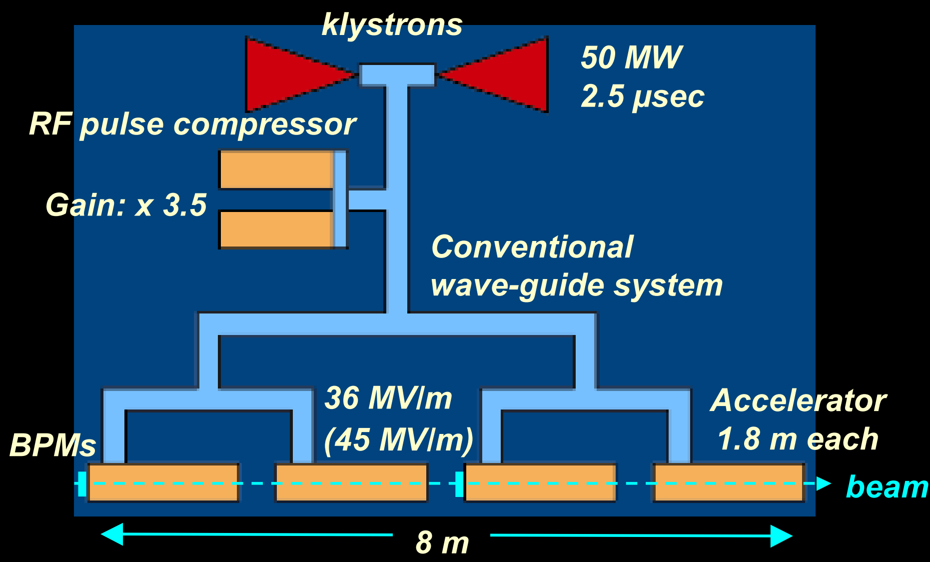
PPM type
Closed type
Choke-Mode type

# JLC C-band (5712 MHz) Main Linac Tunnel

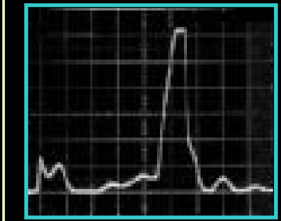
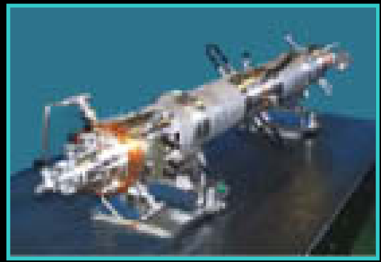






# Phase-I R&D Summary

| C-band Klystron | Klystron Modulator | RF Pulse Compressor | Accelerating Structure |
|---|---|---|---|
| 50 MW, OK<br>2.5 sec, 47 % | 110 MW OK<br>100 pps | Flat Pulse<br>Gain 3.3 | 1.8 m OK<br>Choke-Mode |
| Life test >5000 hour, OK.<br> | Smart modulator using inverter HV charger.<br>Running for klystron life test.<br> | Three-cell cavity.<br><br>1 m long cold model.<br><br>Need High Power Test | Beam acceleration at 50 MV/m was done at ATF-KEK, with S-band model.<br>HOM damping performance was proved by ASSET-SLAC test, 1998.<br> |

# C-band Main Linac R&D: Summary 2002~2003

T. Shintake and H. Matsumoto

- **Collaboration**

  KEK and RIKEN/SPring8 Collaborating on C-band main linac in SCSS X-FEL project.

- **Klystron Modulator**

  Newly developed for 50 MW klystron, closed type insulating oil filled.
  Currently running to drive 50 MW klystron and 500 kV electron gun.

- **Inverter HV power supply (50 kV, 35 kW)**

  Newly developed to drive 50 MW klystron modulator.
  Currently running for high power testing at SPring8.

- **RF Pulse Compressor ( 3-cell SLED-III )**

  Temperature stabilized cavity using invar metal.
  High Power Testing at KEK. Processed up to 105 MW output (target 160 MW)

- **Accelerating Structure (Choke Mode Cavity)**

  Structure Ver 2.0 has been fabricated.
  Trapped mode (found in ASSET test 1998) as solved by tuning the cavity dimensions (disk thickness 3 --> 4 mm).
  High power test is scheduled in Autumn 2003.

# New HV Inverter Power Supply

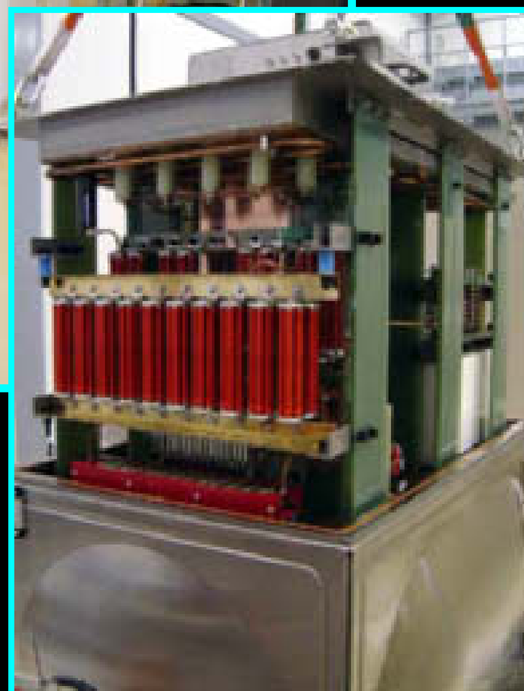
for C-band 50 MW klystron modulator.

- Maximum Output Voltage: 50 kV
- Average Output Current: 1.5 A
- Average Charge Rate: 30 kJ/sec
- Regulation (stability) ~ 0.12%
- Power Factor > 85 %
- Efficiency > 85%

By TOSHIBA Logistic Support Co.

2002 Feb.

# *Closed Compact Modulator*



- Compact.
  W 1.7 m x D 1.2 m x H 1m.
- Good EMI shield.

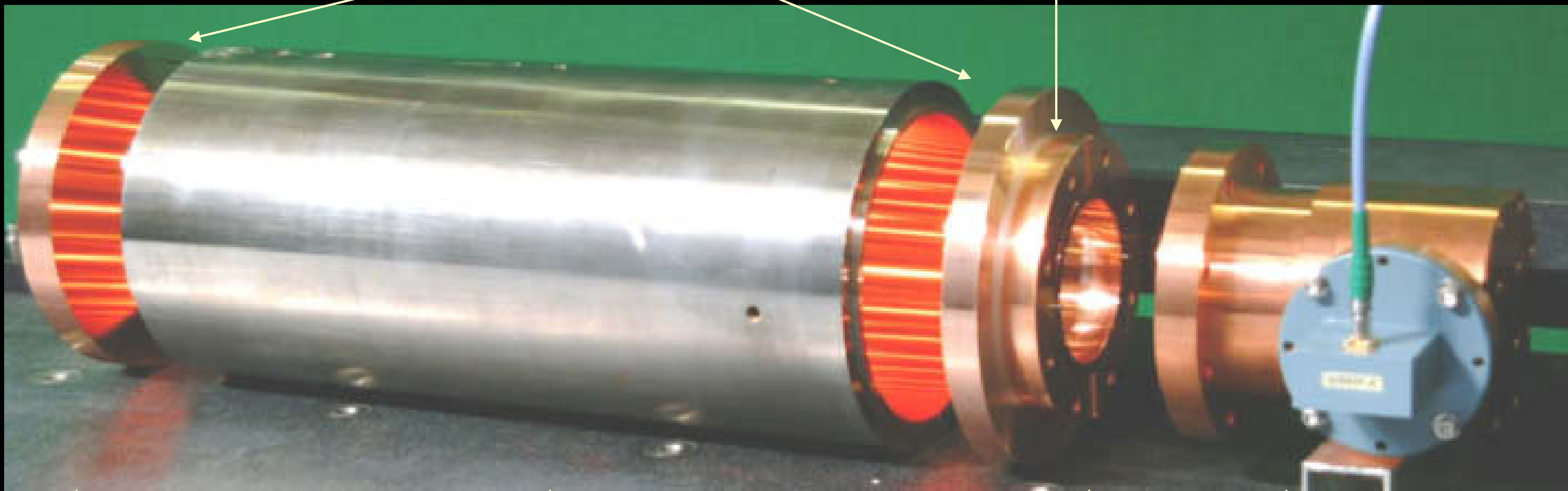
- Better cooling for
  HV component.

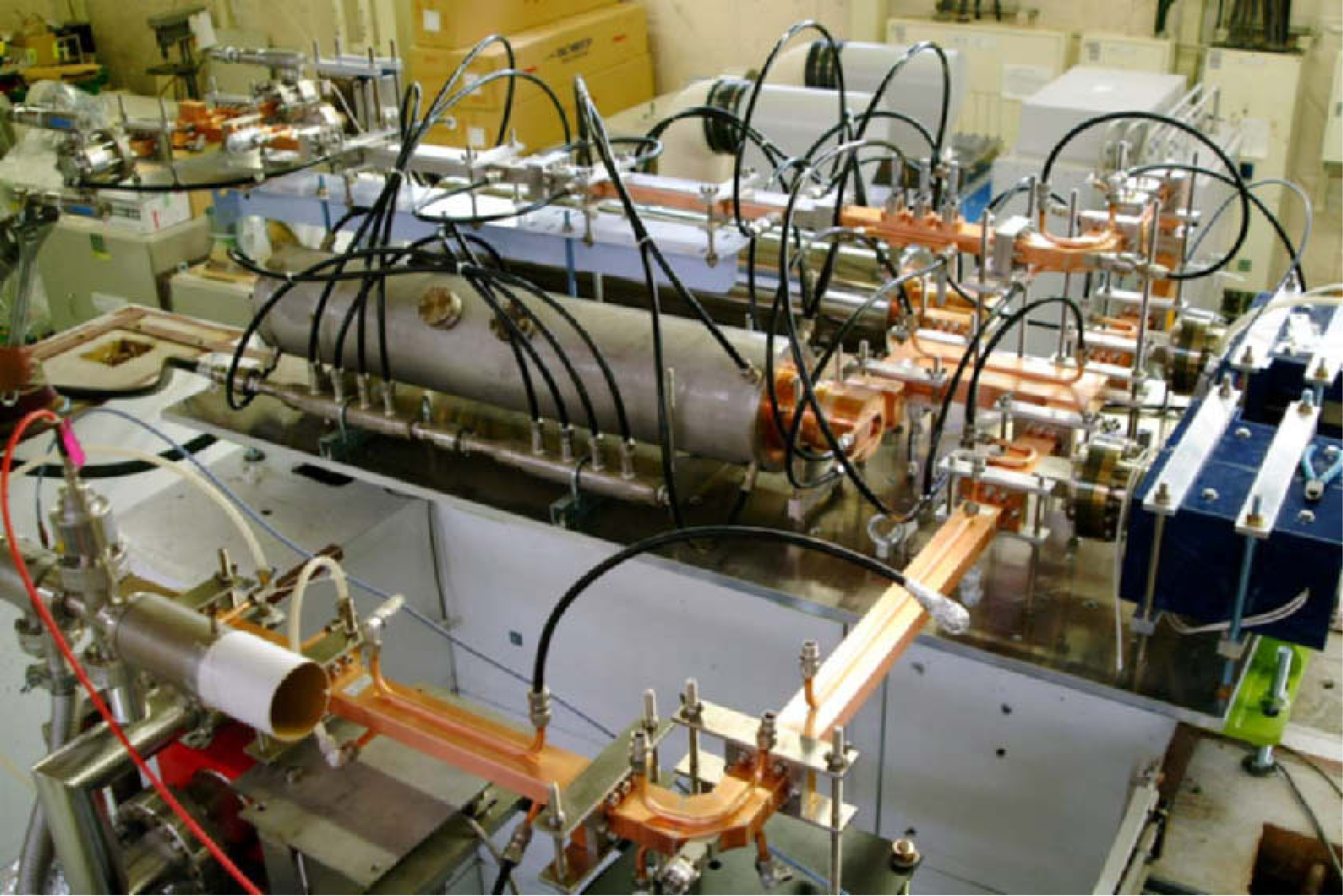
- Eliminating cooling air fan.
- No dust accumulation
  due to high voltage in air.

- No environmental effects:
  moisture and temperature
  variation.

# $TE_{01,15}$ test cavity

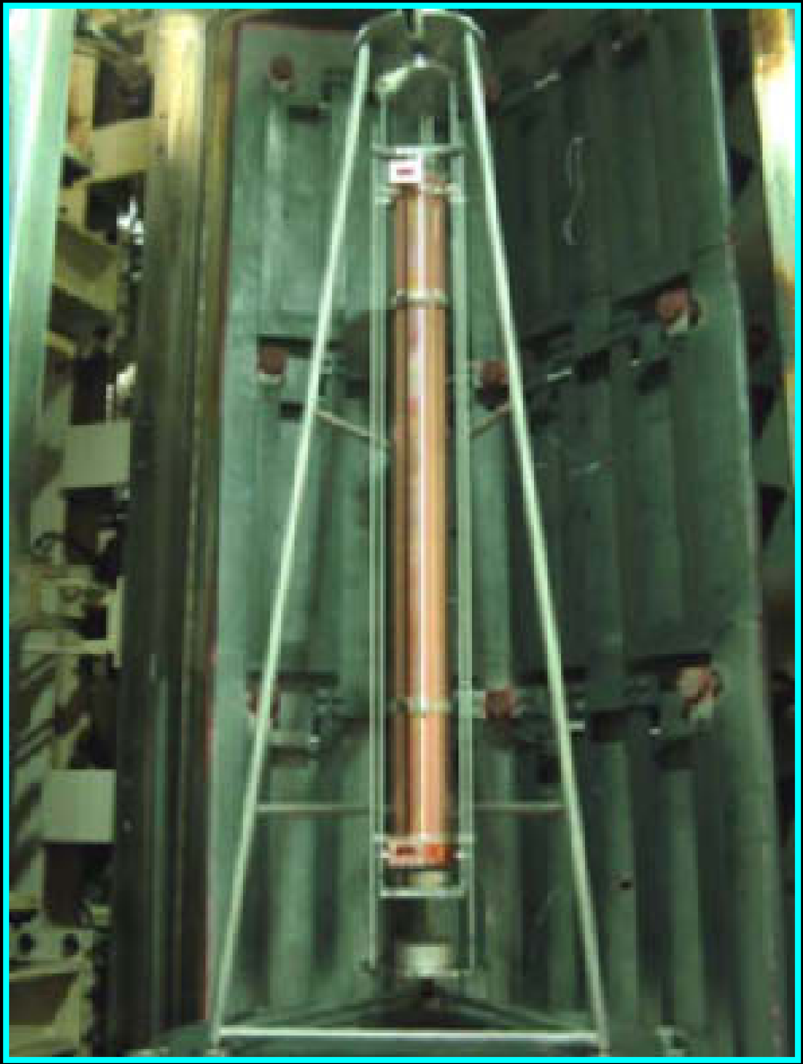
$Q_0$ = 185000(97%) , $Q_{ext}$ = 18400, 13 kHz/degC





# C-band Accelerating Structure for SCSS

Ver. 2002

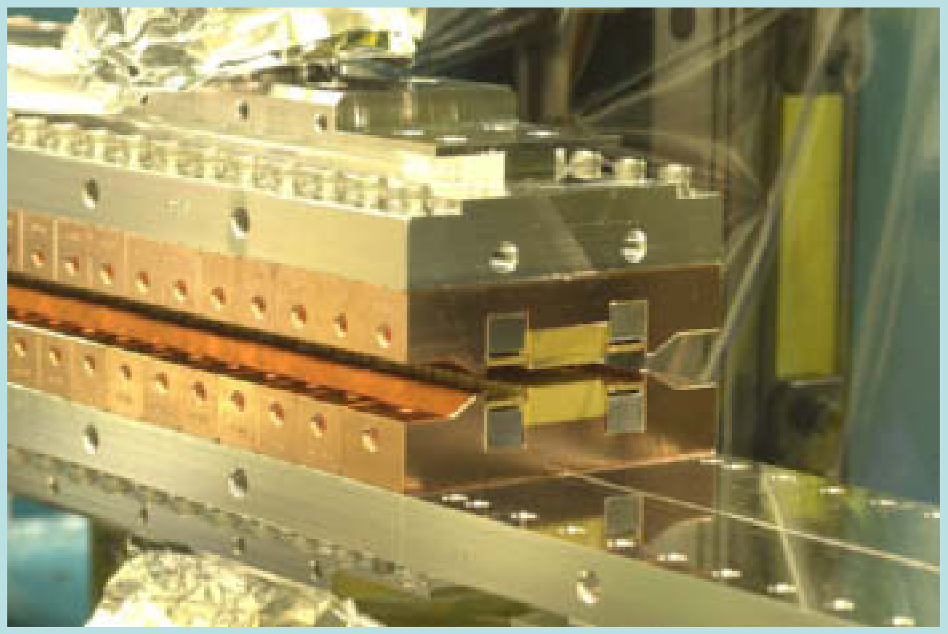


- HOM Damping by Choke-Mode Cavity
- 1.8 m long, 91 Cells, CG-structure
- $3\pi/4$-mode
- Brazing Bonding
- SiC by Tungsten wire-spring.
- Double-feed Coupler
- High-power test will be Summer 2003

# *In-Vacuum Undulator for SCSS X-FEL*

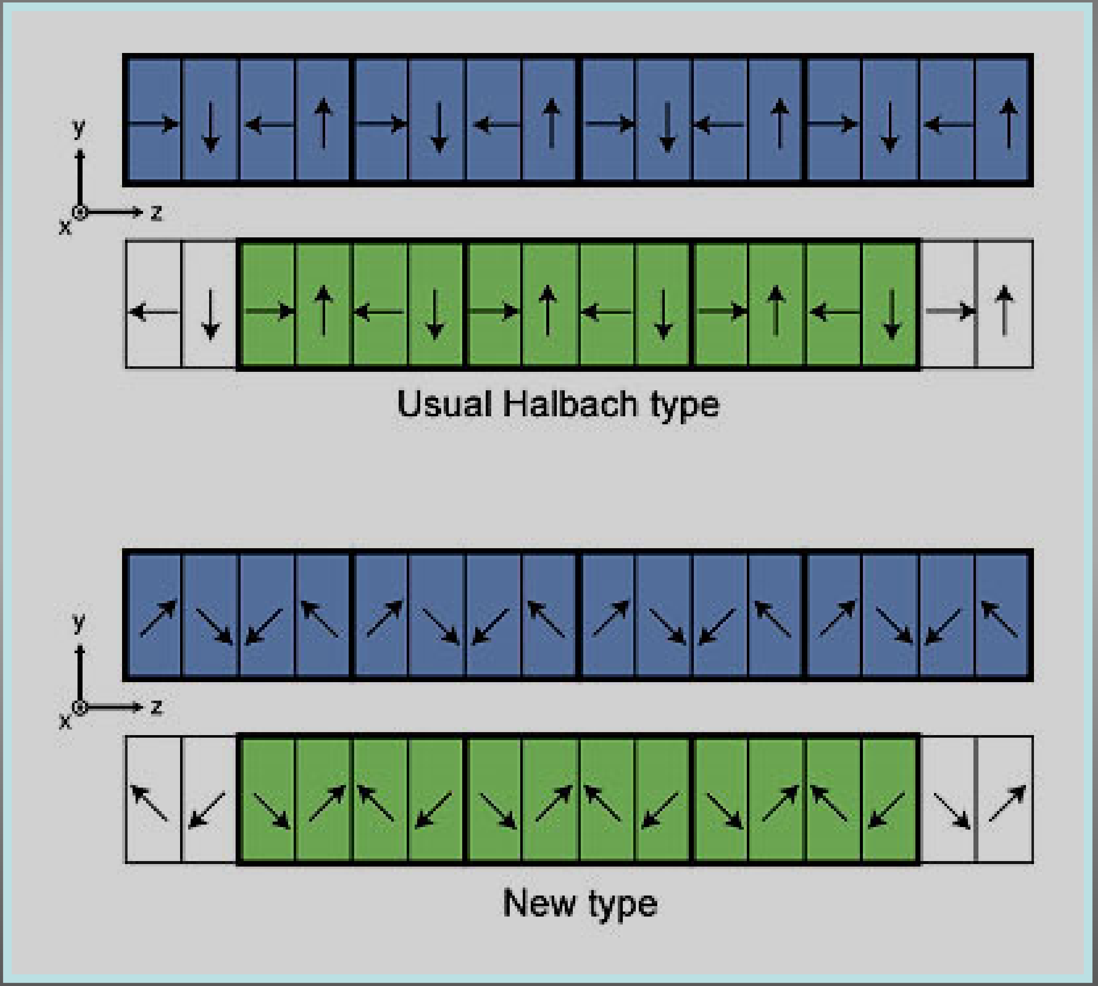
- Segment length   4.5 m
- N = 300/segment, $\lambda_u$=15mm
- K~1.3, at Nominal gap 3.5 mm
- Mechanical minimum gap = 2mm
- 45-deg. tilted Halbach type
- More compact than ordinary ones

First prototype model

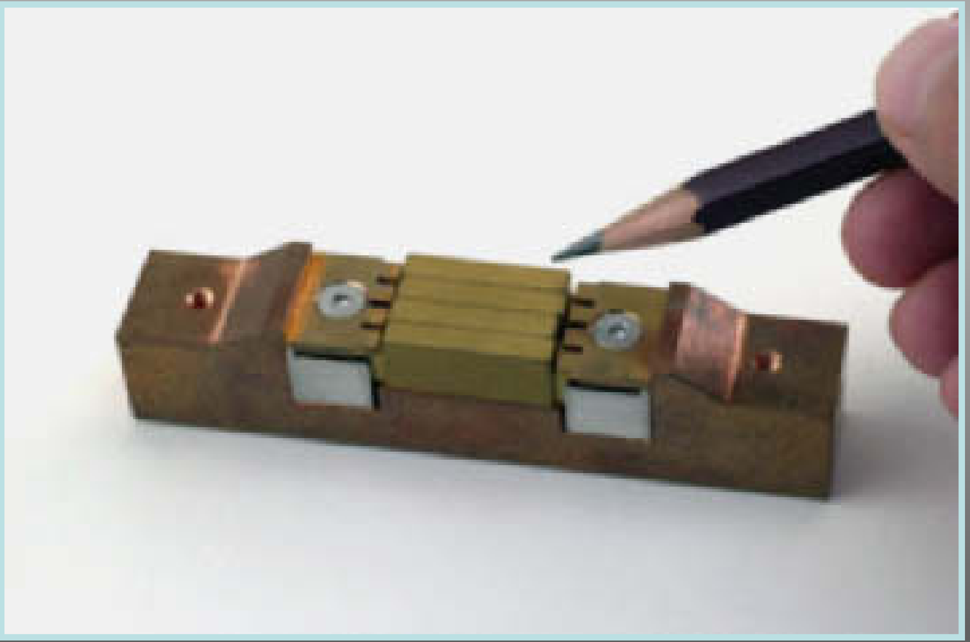


Gap can full-open 25 mm, which provides optical alignment laser pass, and enough beam acceptance at the beam commissioning time.

# New Magnet Array



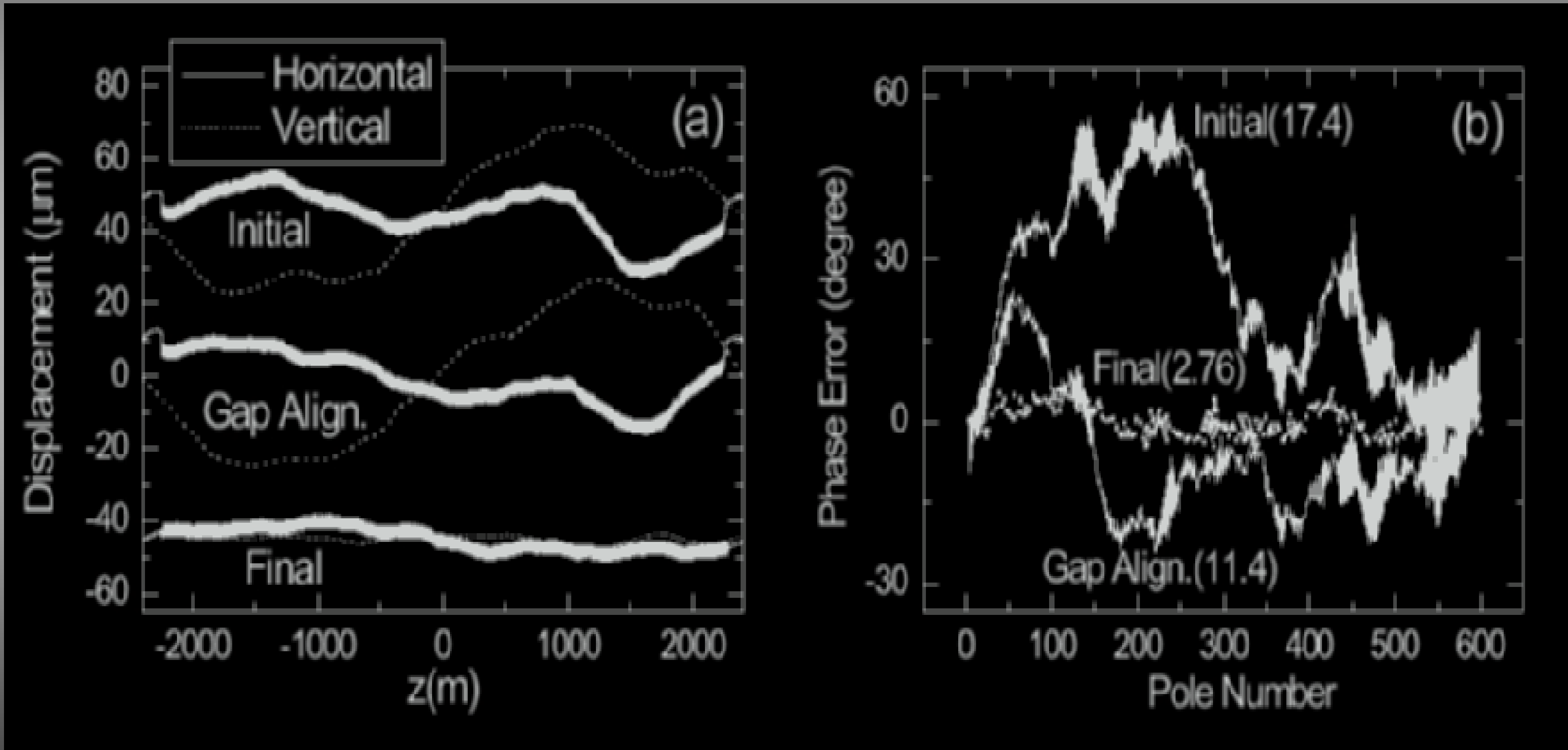

- Four magnets in one block
- 45-deg. tilted array
  - More freedom for in-situ sorting (field correction)



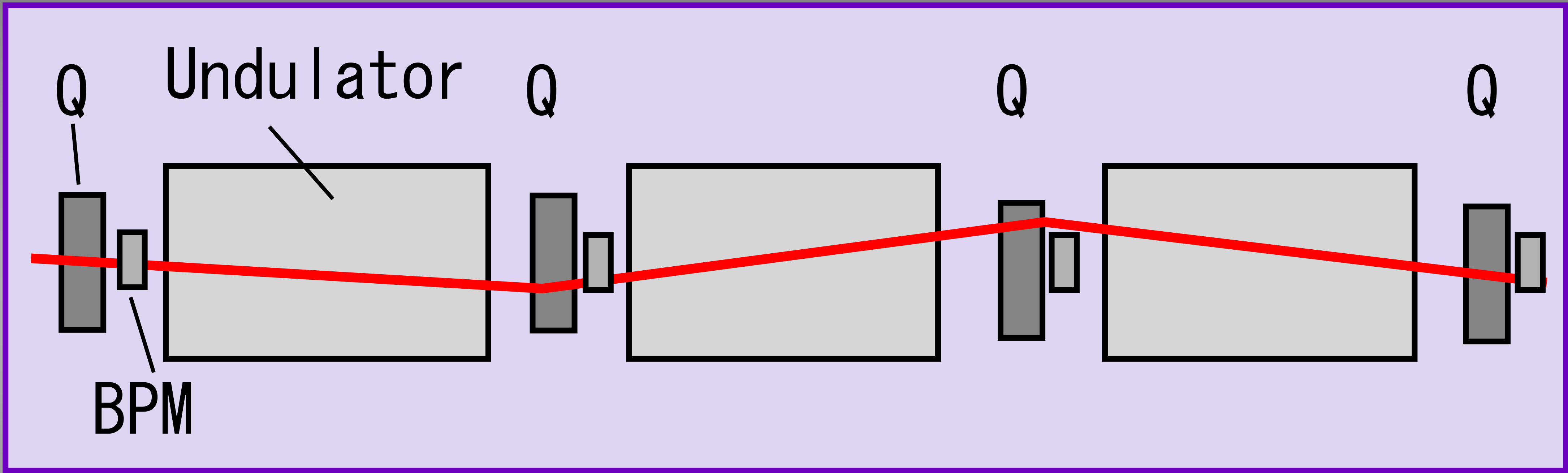
Magnet piece: thickness 3.75, pole face width 20, h 8 mm
NdFeB with TiN coating

# Field Performance of SCSS Undulator

by T. Tanaka and T. Seike



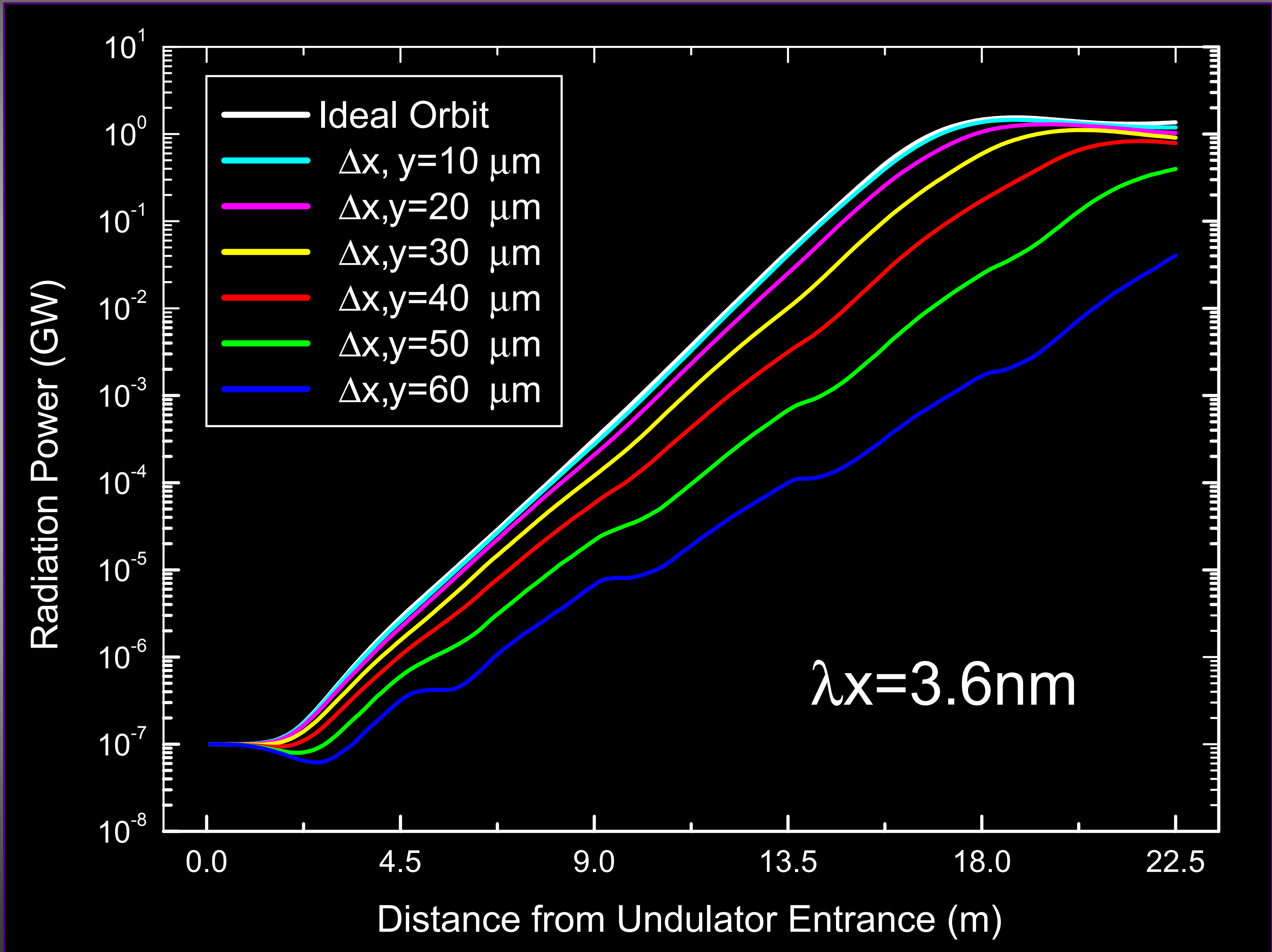
# *Electron Beam Trajectory Error Model*



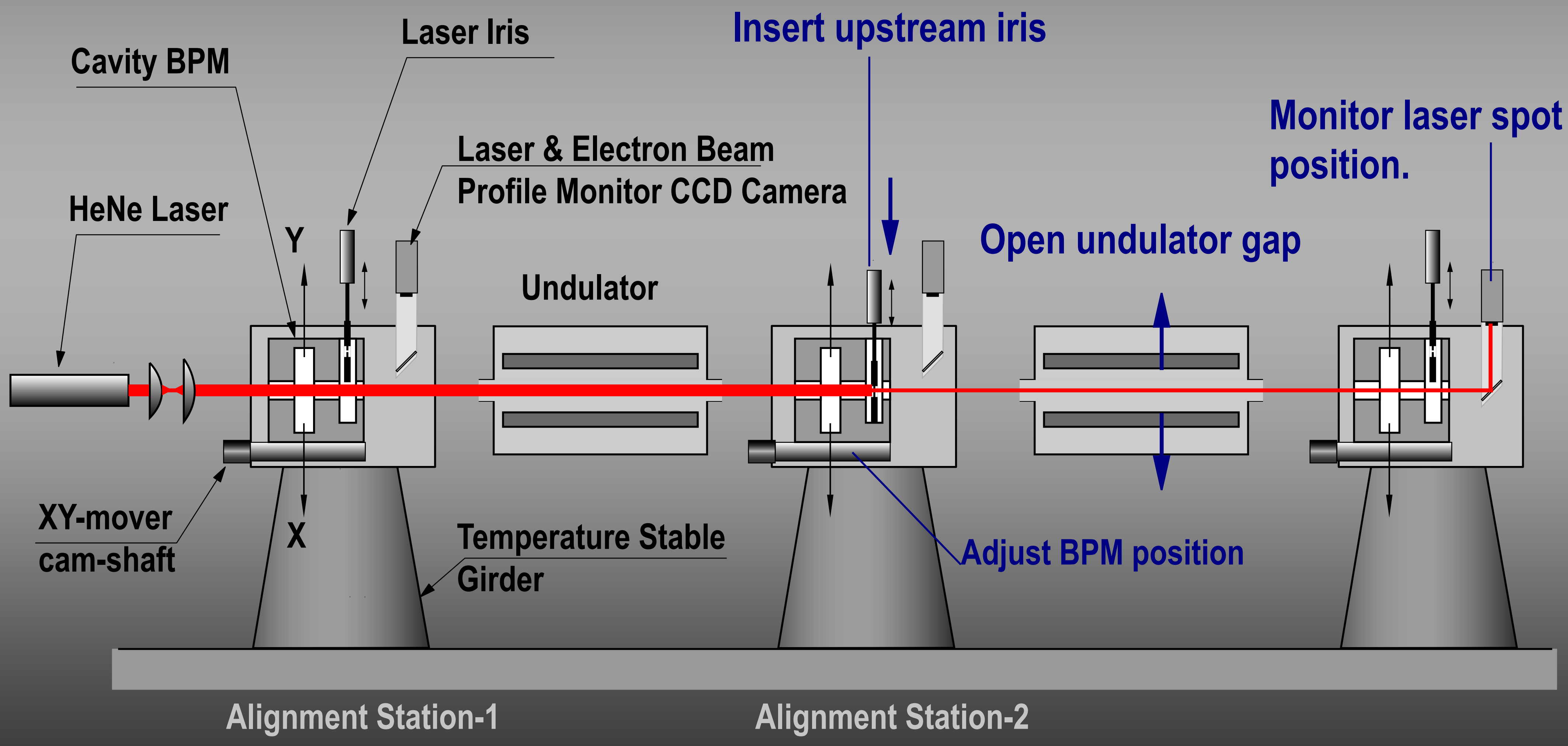

Q-magnet position error and field error at undulator matching section create beam trajectory error: zig-zag shape. Beam runs fairly straight line in each undulator.

# FEL Gain Loss due to Alignment Error

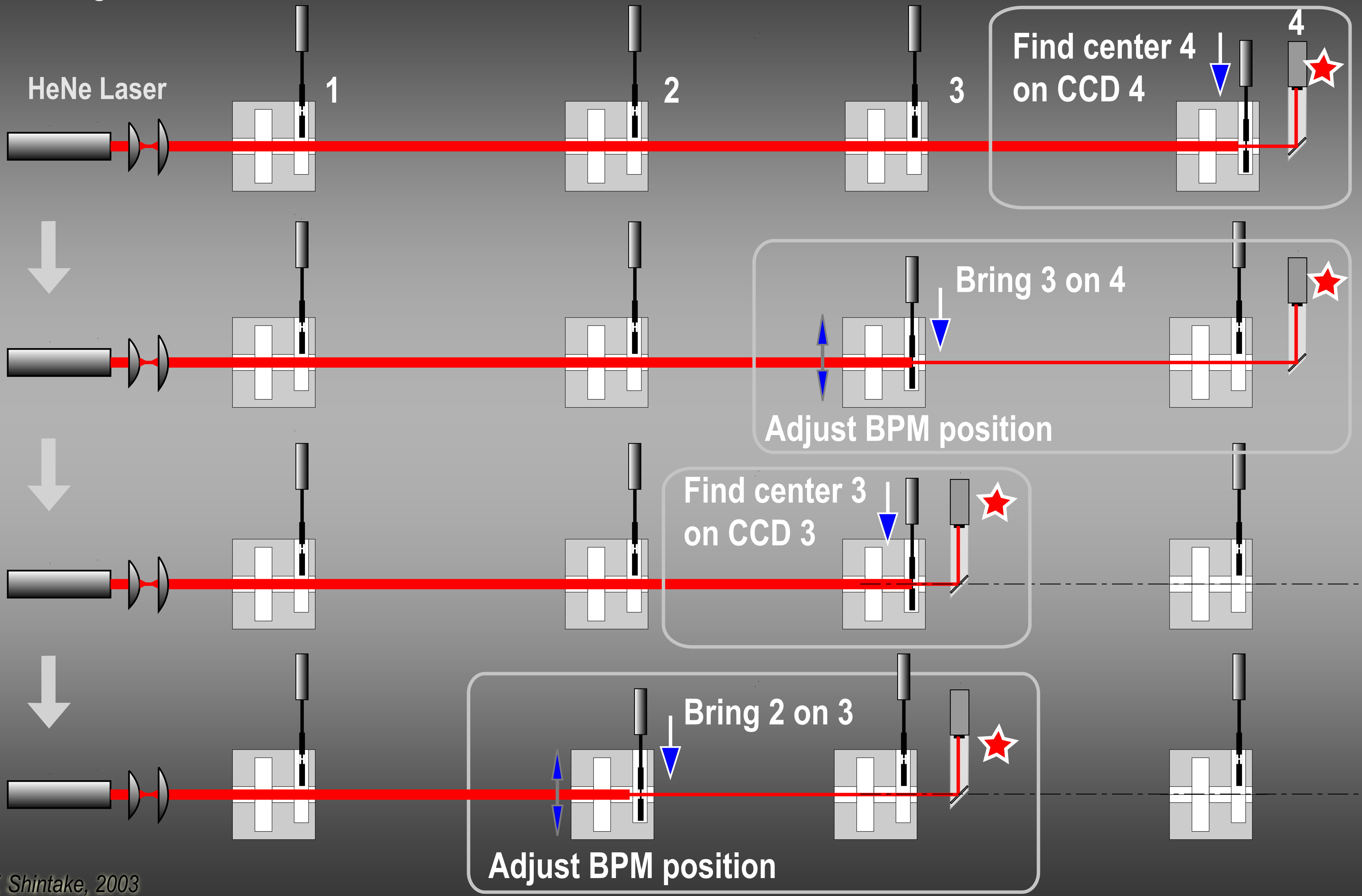
*by Takashi Tanaka*



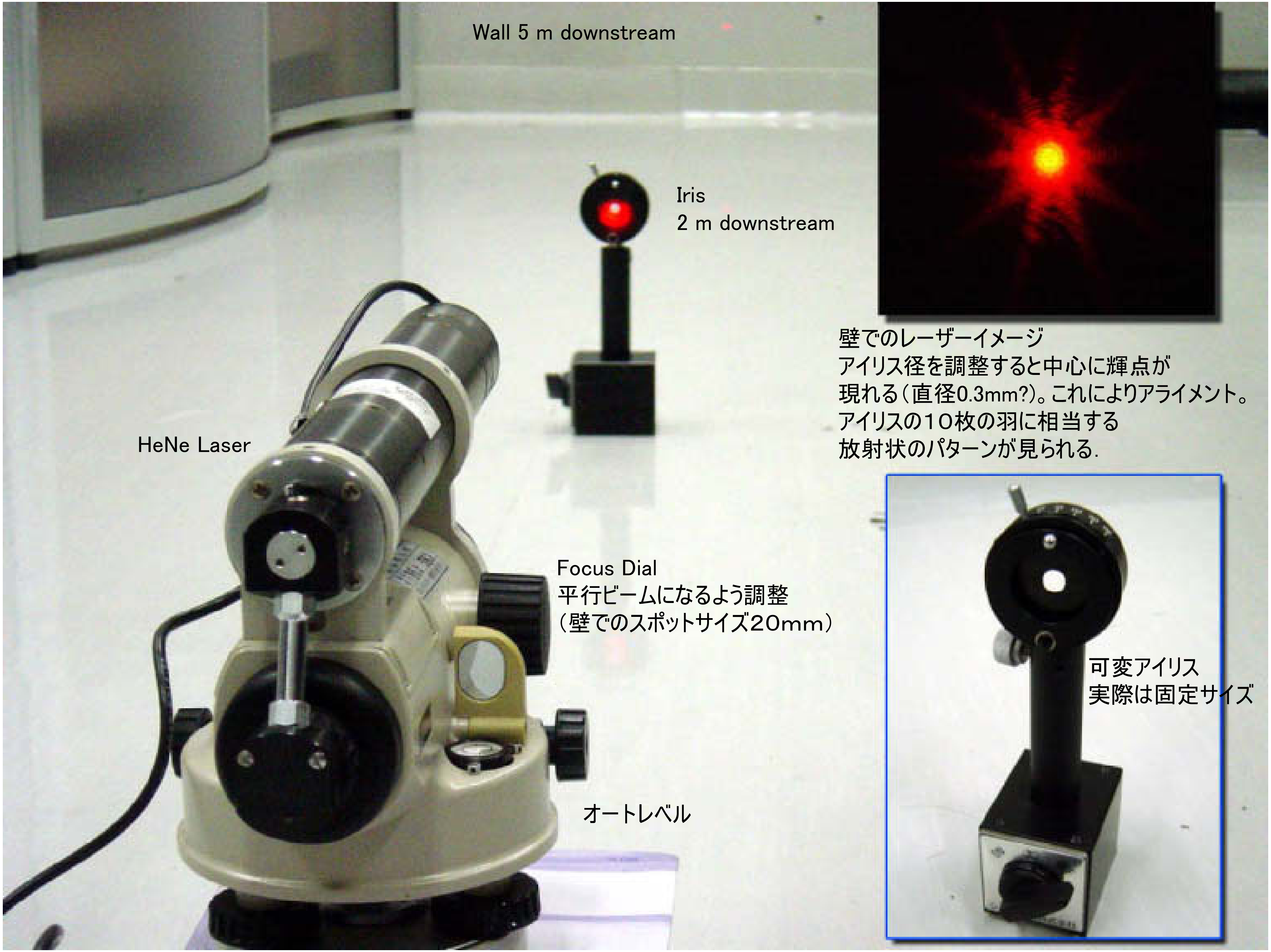
# BPM Alignment System for SASE FEL

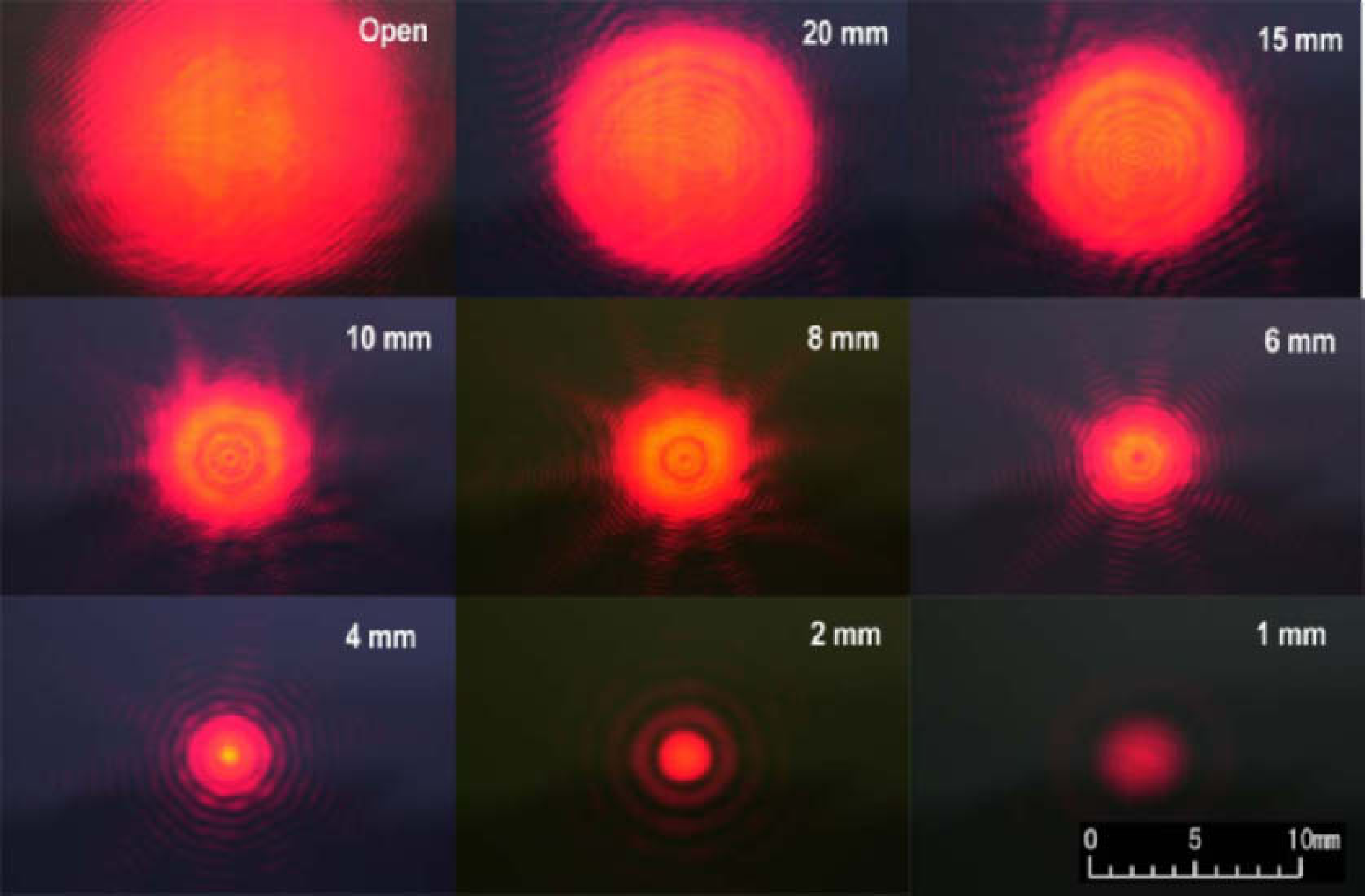


# BPM Alignment Procedure



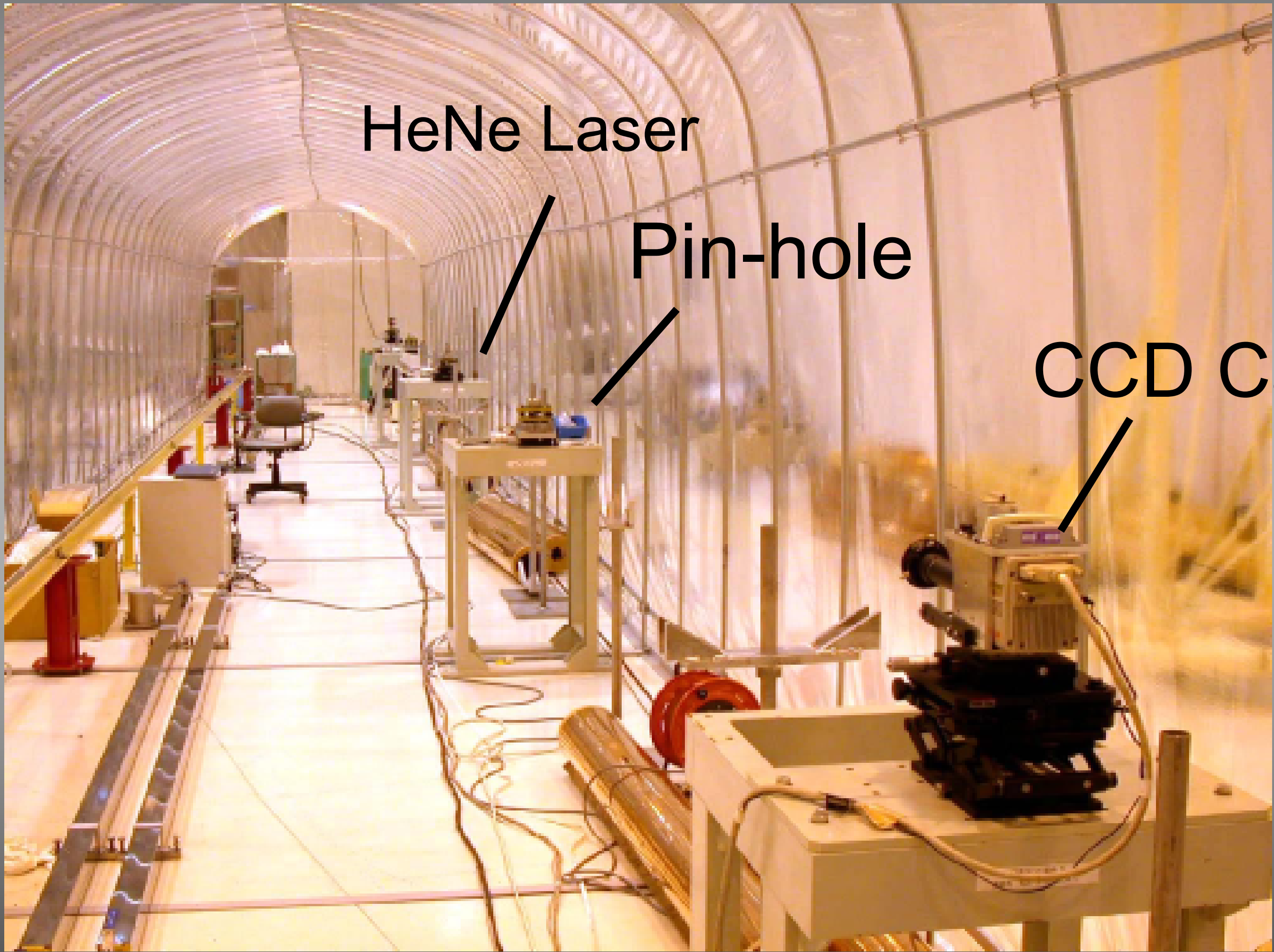

T. Shintake, 2003


Wall 5 m downstream
Iris
2 m downstream
壁でのレーザーイメージ
アイリス径を調整すると中心に輝点が
現れる（直径0.3mm?）。これによりアライメント。
アイリスの10枚の羽に相当する
放射状のパターンが見られる.
HeNe Laser
Focus Dial
平行ビームになるよう調整
（壁でのスポットサイズ20mm）
オートレベル
可変アイリス
実際は固定サイズ


Open
20 mm
15 mm
10 mm
8 mm
6 mm
4 mm
2 mm
1 mm
0
5
10mm

# Laser Alignment Test in Air

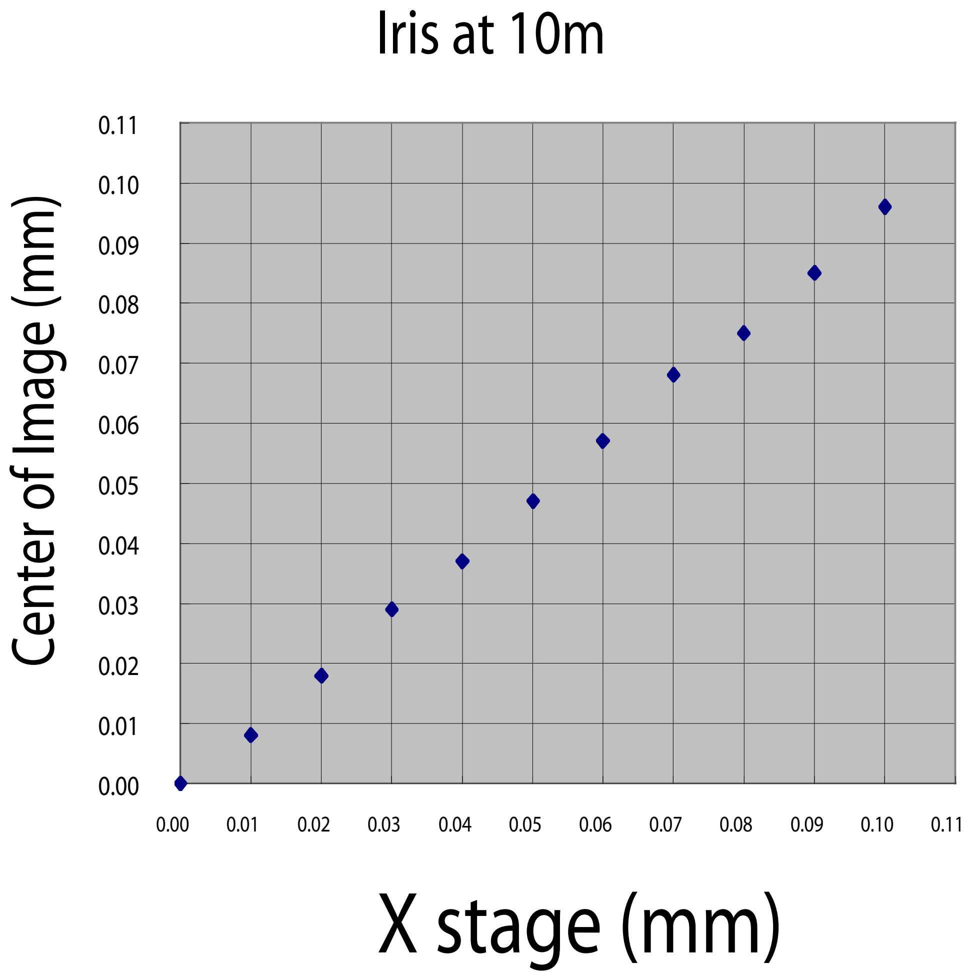
*by S. Matsui,*
*and Zhang Chao*

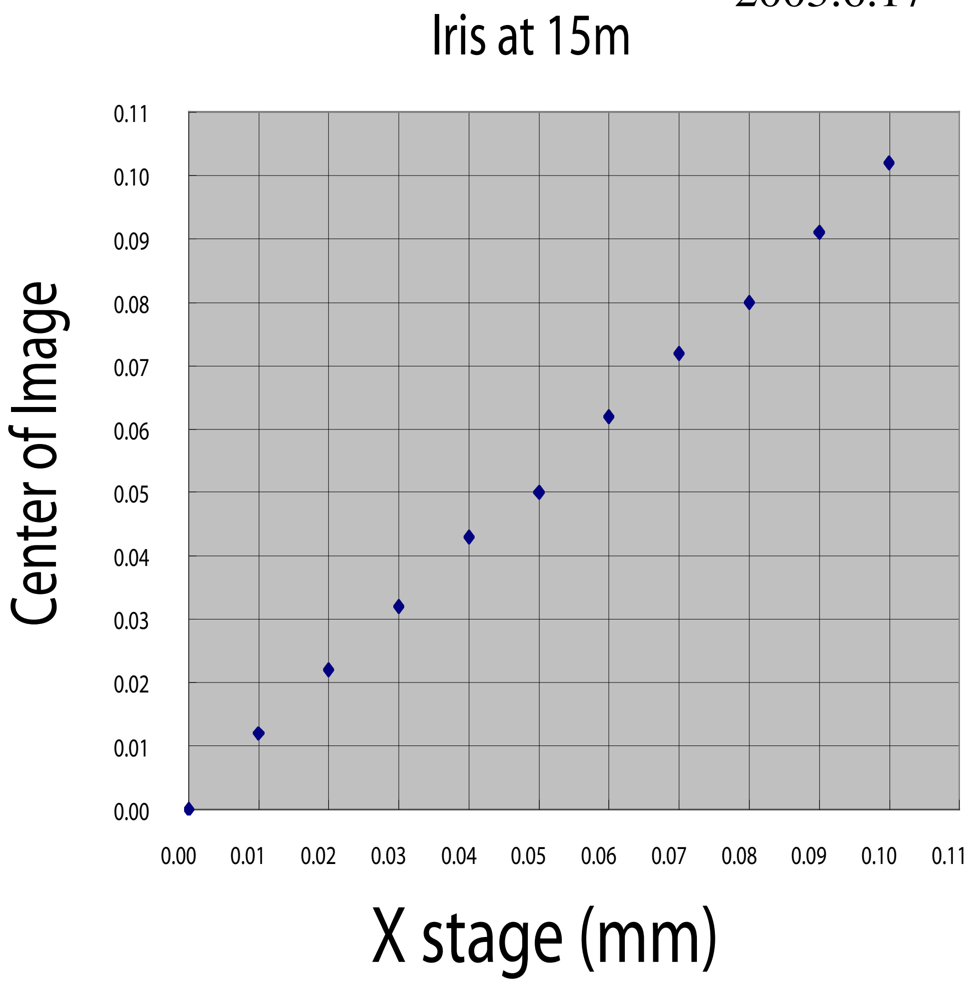



Distance from HeNe-laser to CCD : 20 m
Move pin-hople position
Readout laser-spot position on CCD.

# Alignment Test Result

2003.6.17



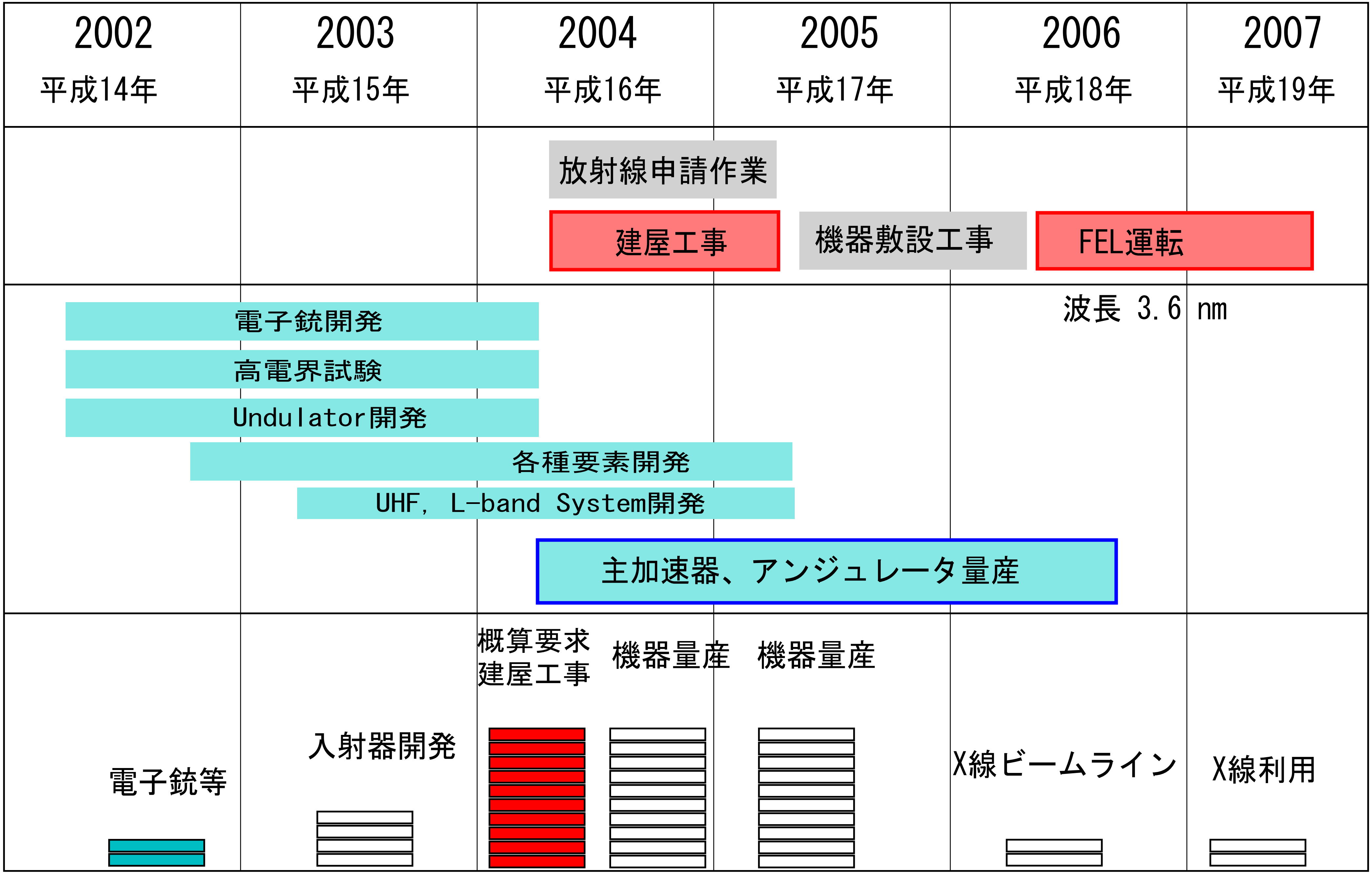




**Averaging 10 frames on CCD,pixel mean center was determined.**

# Cavity BPM Design

Absolute Position Accuracy
< 10 micron meter

# SCSS　X線FEL　年次計画



*Visit us* **http://www-xfel.spring8.or.jp**

## Information on C-band RF & X-ray FEL

- Free Software Download
  - 3D FEL Simulator SIMPLEX
  - 2D Radiation Simulator
- Publications and Presentations
  - C-band klystron
  - Klystron Modulator
  - Accelerating Structure
  - RF-BPM
  - 500 kV Gun
  - others