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LINAC 2008

8 GeV C-band Accelerator Construction for XFEL / SPring-8

Takahiro Inagaki

for XFEL project in SPring-8, RIKEN & JASRI

Members

RIKEN & JASRI Joint Project for XFEL : Takao Asaka, Yoshihiro Asano, Hitoshi Baba, Teruhiko Bizen, Hiroyasu Ego, Toru Fukui, Shunji Goto, Hirohumi Hanaki, Toru Hara, Atsushi Higashiya, Toko Hirono, Naoyasu Hosoda, Takahiro Inagaki Shinobu Inoue, Miho Ishii, Toshiro Itoga, Yoshitaka Kawashima, Hiroaki Kimura, Masanobu Kitamura ,Toshiaki Kobayashi, Satoru Kojima , Chikara Kondo, Togo Kudo, Hirokazu Maesaka , Xavier Marechal, Sakuo Matsui,

Hiroshi Matsumoto (KEK), Tomohiro Matsushita, MItsuru Nagasono, Noriaki Nariyama, Yoshinori Nishino, Haruhiko Ohashi, Toru Ohata, Takashi Ohshima, Kazuyuki Onoe(Ulvac), Yuji Otake, Tatsuyuki Sakurai, Mutsumi Sano, Takamitsu Seike, Katsutoshi Shirasawa, Shinsuke Suzuki, Kazuhiko Tahara, Tetsuya Takagi, Sunao Takahashi, Takeo Takashima, Hideki Takebe, Masao Takeuchi, Kenji Tamasaku, Hitoshi Tanaka, Ryotaro Tanaka, Takashi Tanaka, Yoshihito Tanaka, Shingo Taniguchi, Takanori Tanikawa, Tadashi Togashi, Kazuaki Togawa, Hiro Tomizawa, Shukui Wu, Makina Yabashi, Akihiro Yamashita, Kenichi Yanagida, Chao Zhang , Tsumoru Shintake, Noritaka Kumagai, Tetsuya Ishikawa, Hideo Kitamura, ･･･

Total: 117 members

Outline

X-ray FEL

1) Introduction

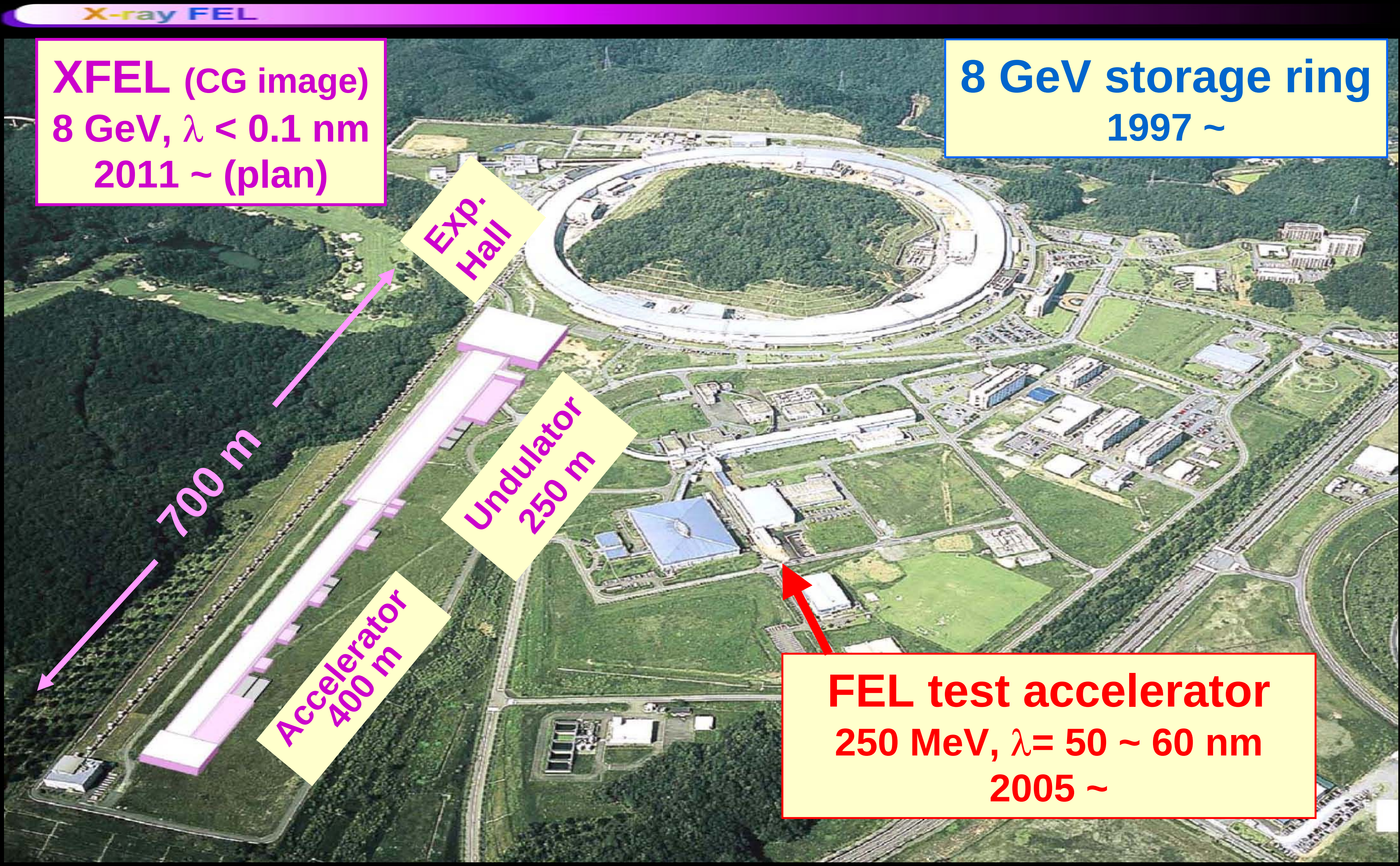
2) Overview of the C-band accelerator

3) Performance of the high gradient acceleration at the test accelerator

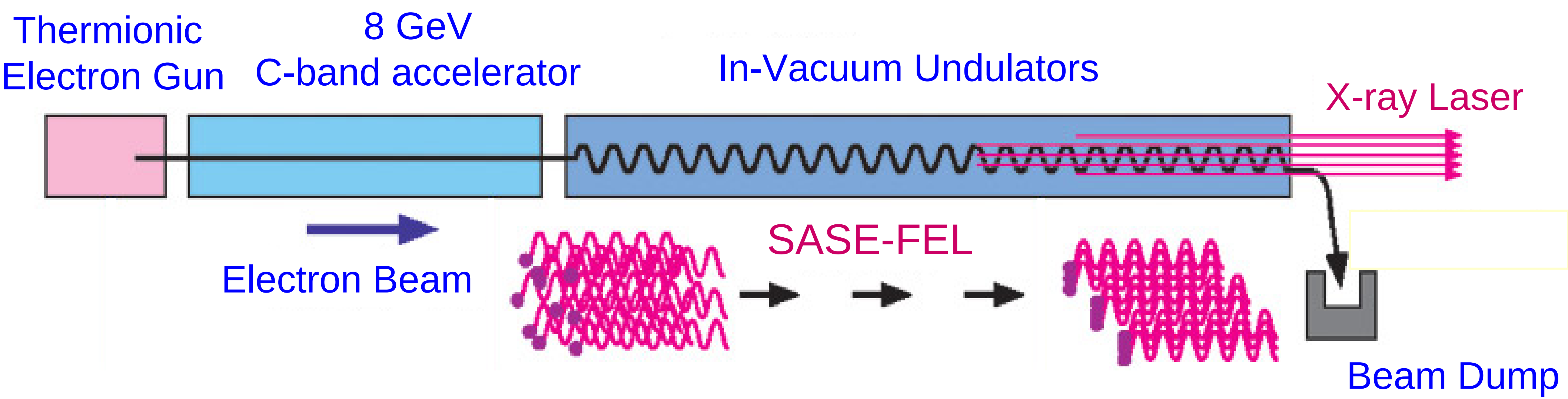
4) Improvement of the pulse-to-pulse stability

5) Schedule & Summary

XFEL in SPring-8, Japan



Concept of XFEL/SPring-8



1) Electron gun **<u>Low emittance</u> (ε_N ~ 0.7π mm*mrad)**

Higher electron density at the undulator.

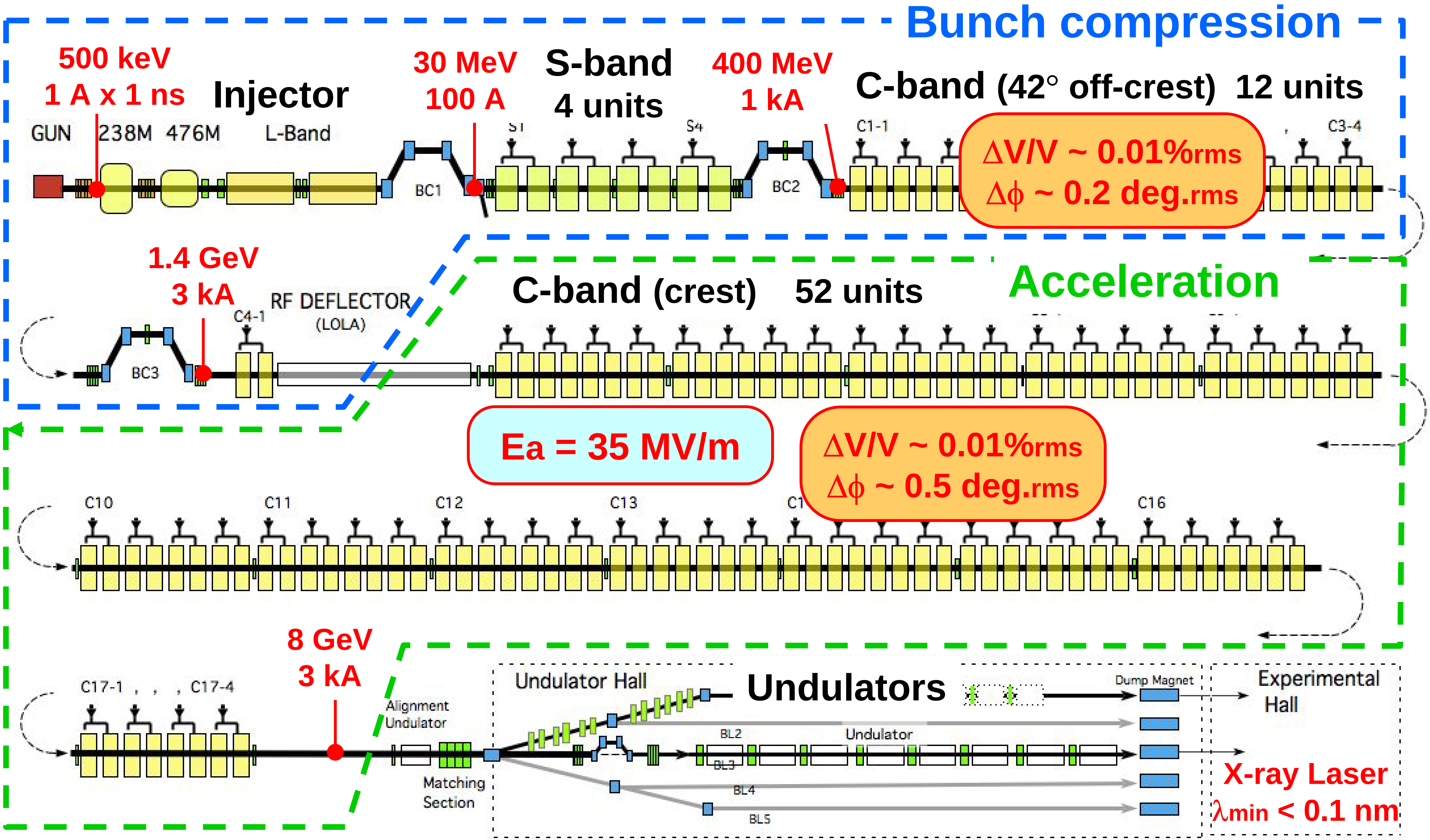
2) C-band accelerator **<u>High gradient</u> (E_a ~ 35 MV/m)**

Compact accelerator.

3) In-vacuum undulator **<u>Short period</u> (λ_u ~ 18 mm)**

Shorter wavelength
with lower electron energy.

8 GeV XFEL Machine Layout



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X-ray FEL

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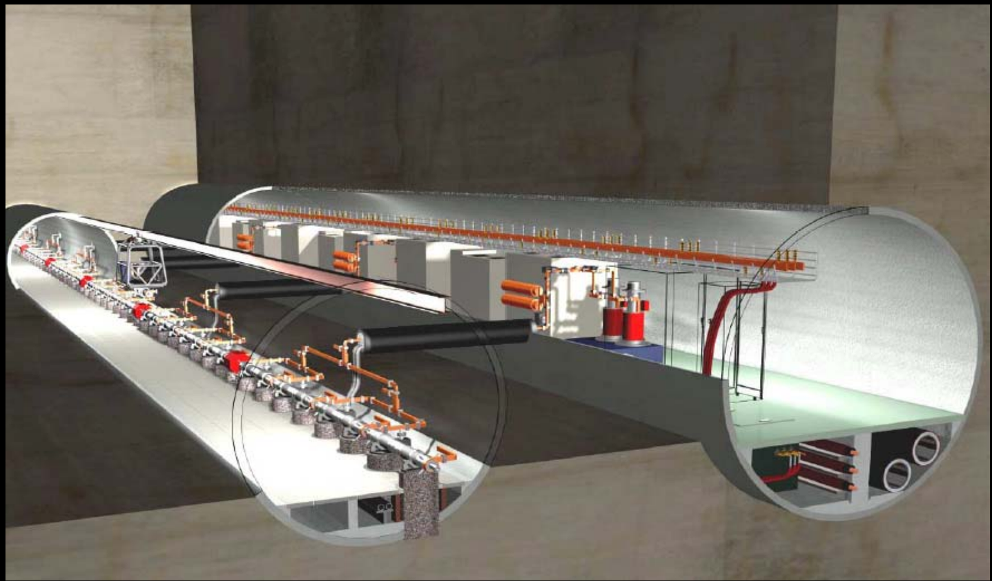
Why we use C-band ?

X-ray FEL

- High acceleration gradient (Ea = 35 MV/m)
  - From 1.4 GeV to 8 GeV,   length = 210 m.
    including the beam duct, magnets, beam monitors.
  - "Effective" acceleration gradient = 31 MV/m,
  - Compact machine with low cost.
- Normal conducting rf
  - Low construction cost.
- Potential of the multi-bunch operation
  - Maximum 50 bunches x 60 pps.
- Components are available
  - Initially developed at KEK for the linear collider project

500 GeV Linear Collider, C-band design

X-ray FEL



4000 C-band units in 14 km

Developed at KEK (1996~2000)

- Klystron
- Waveguide
- RF pulse compressor
- Accelerating structure

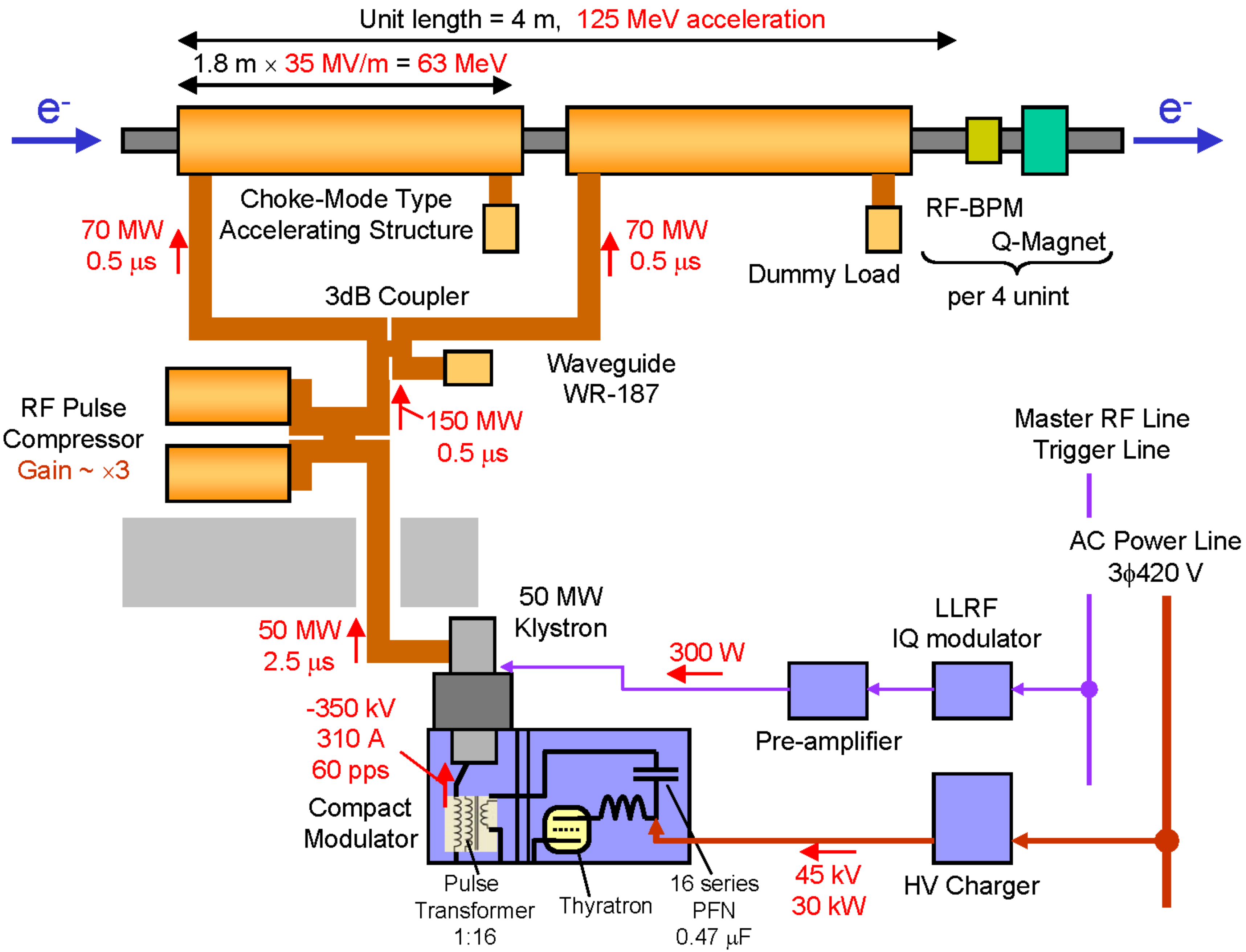
Original members at KEK

Prof. Shintake,

Prof. Matsumoto,

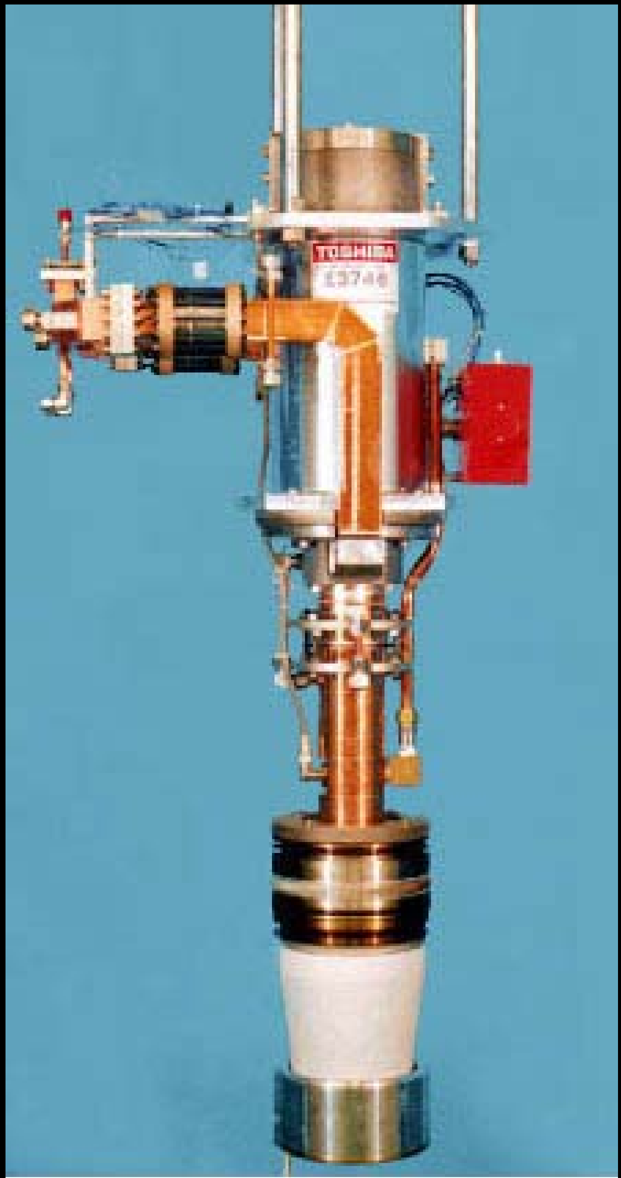
Prof. Baba, ….

C-band (5712 MHz) RF system



50MW pulse klystron

TOSHIBA ELECTRON TUBES & DEVICES CO.LTD.



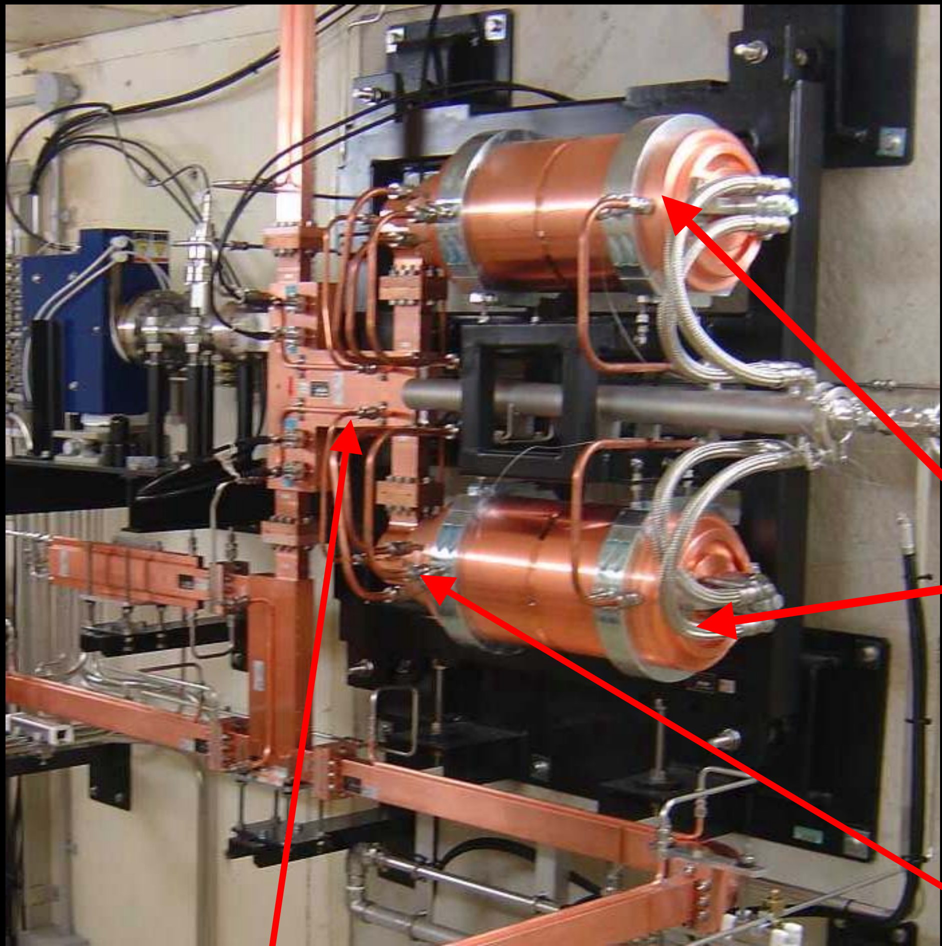
Model No. E37202

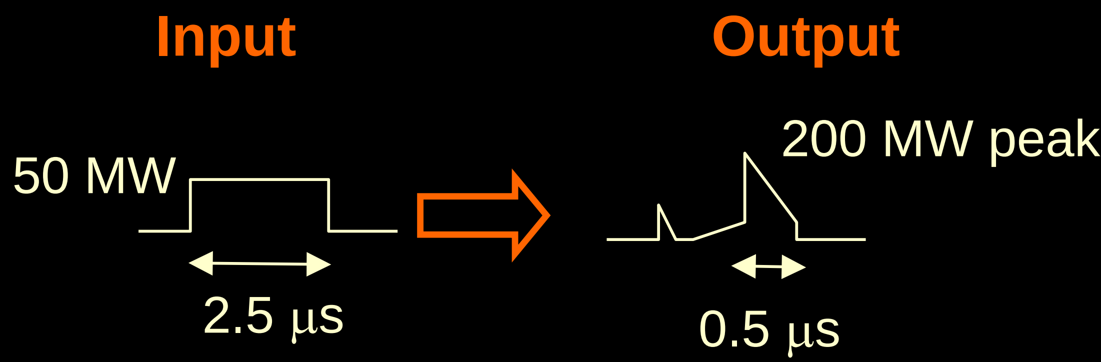
Output power :	50 MW
RF pulse width:	2.5 μsec
Beam Voltage:	-350 kV
Beam Current:	310 A
Repetition:	60 pps

In the test accelerator,
no trouble for 3,000 hours

RF pulse compressor

Fabricated by Mitsubishi Heavy Industries Ltd.





Directional coupler

High-Q cavities

mode: $TE_{0,1,15}$

Q0 : 190,000

β : 9.5

Mode converters (Shintake 1996)

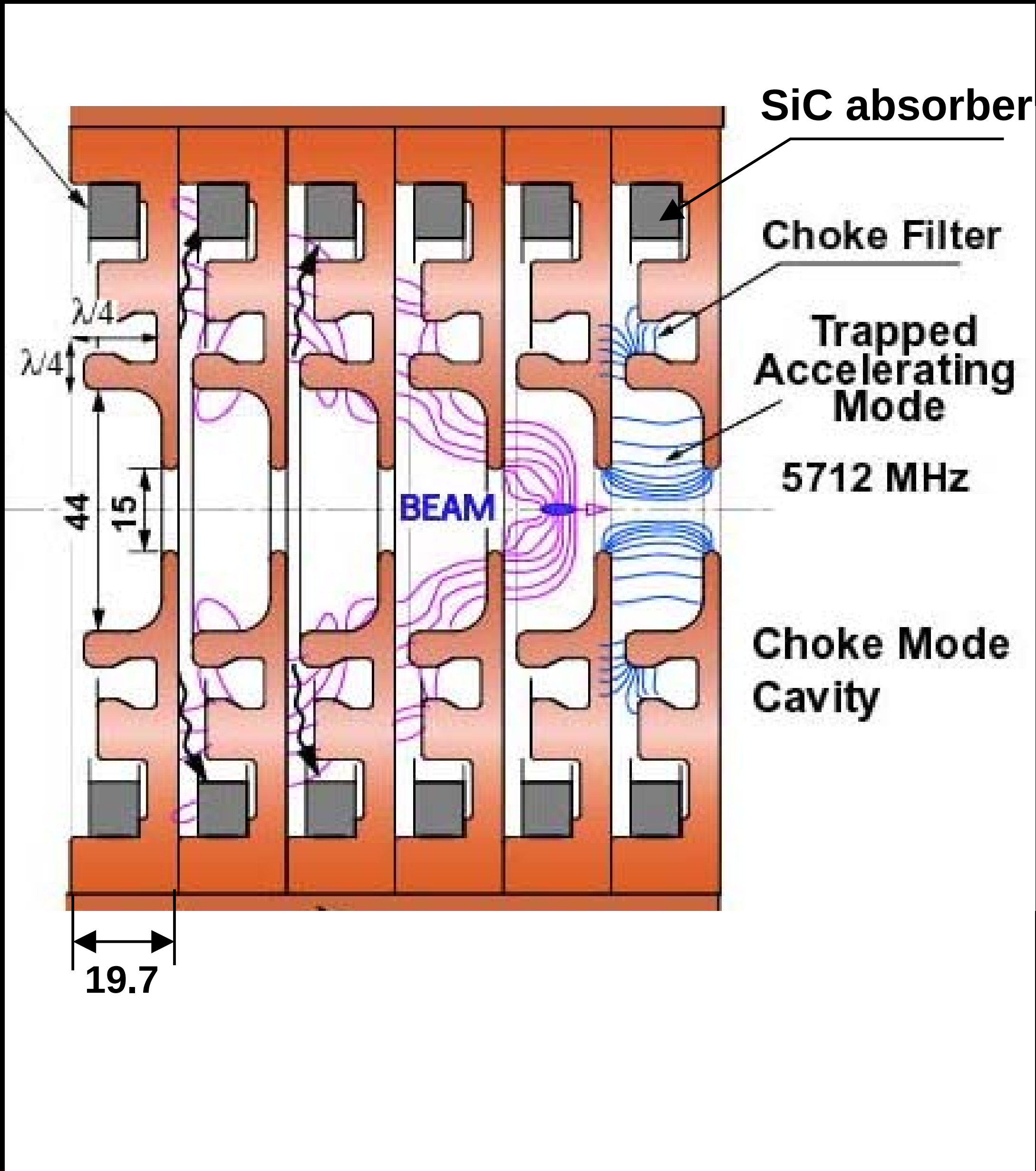
- Waveguide(TE_{10}) ⇔ Circular($TE_{0,1,x}$)
- 4 coupling holes

⇒ Lower rf field at the coupling hole

Accelerating structure (Shintake structure)

Fabricated by Mitsubishi Heavy Industries Ltd.

X-ray FEL



Choke mode cavity (Shintake 1992)

- traps the accel. mode (5712 MHz)
- eliminate HOM (not 5712 MHz)

⇒ multi-bunch operation

High acceleration gradient

R~ 54 MΩ/m, τ ~ 0.53, L=1.8 m

Ea = 35 MV/m

with 63 MW x 300 nsec rf power

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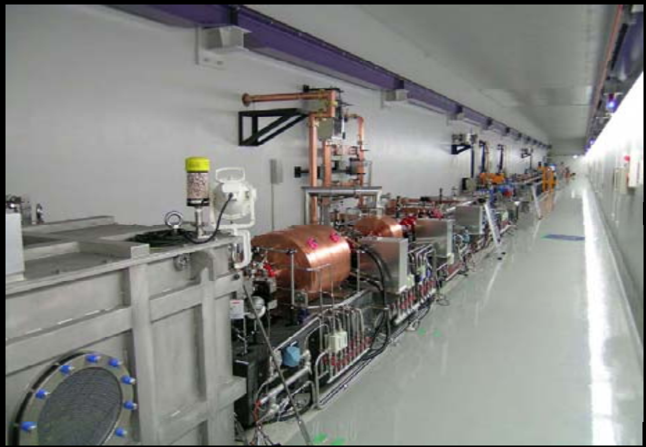
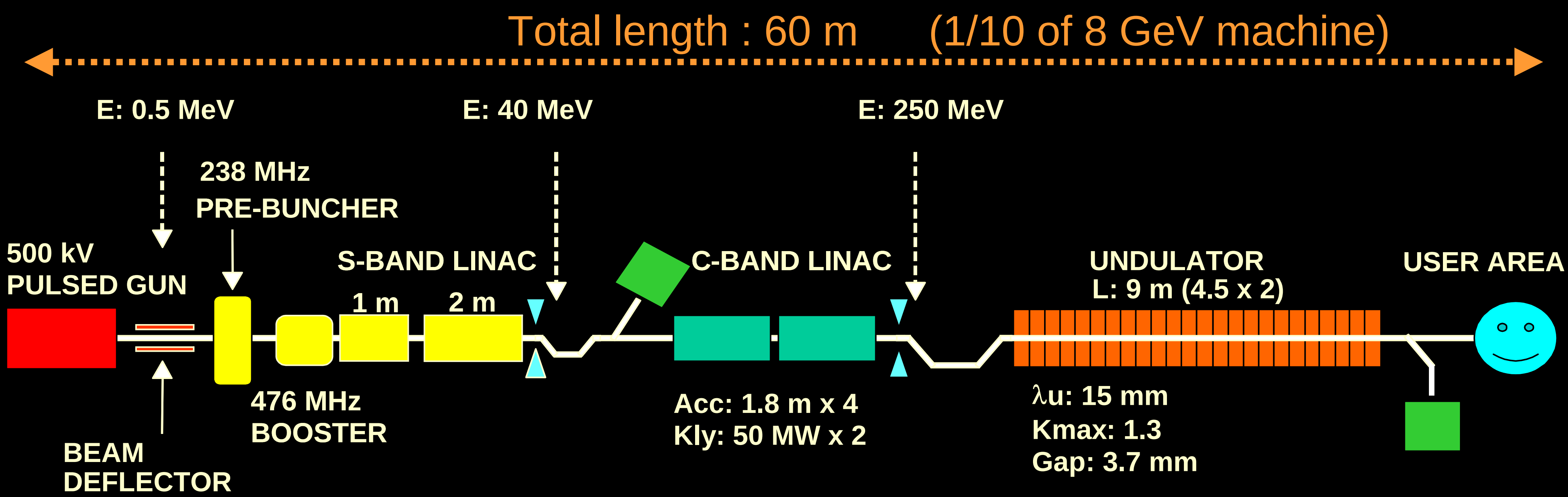
FEL test accelerator (2005~)

X-ray FEL

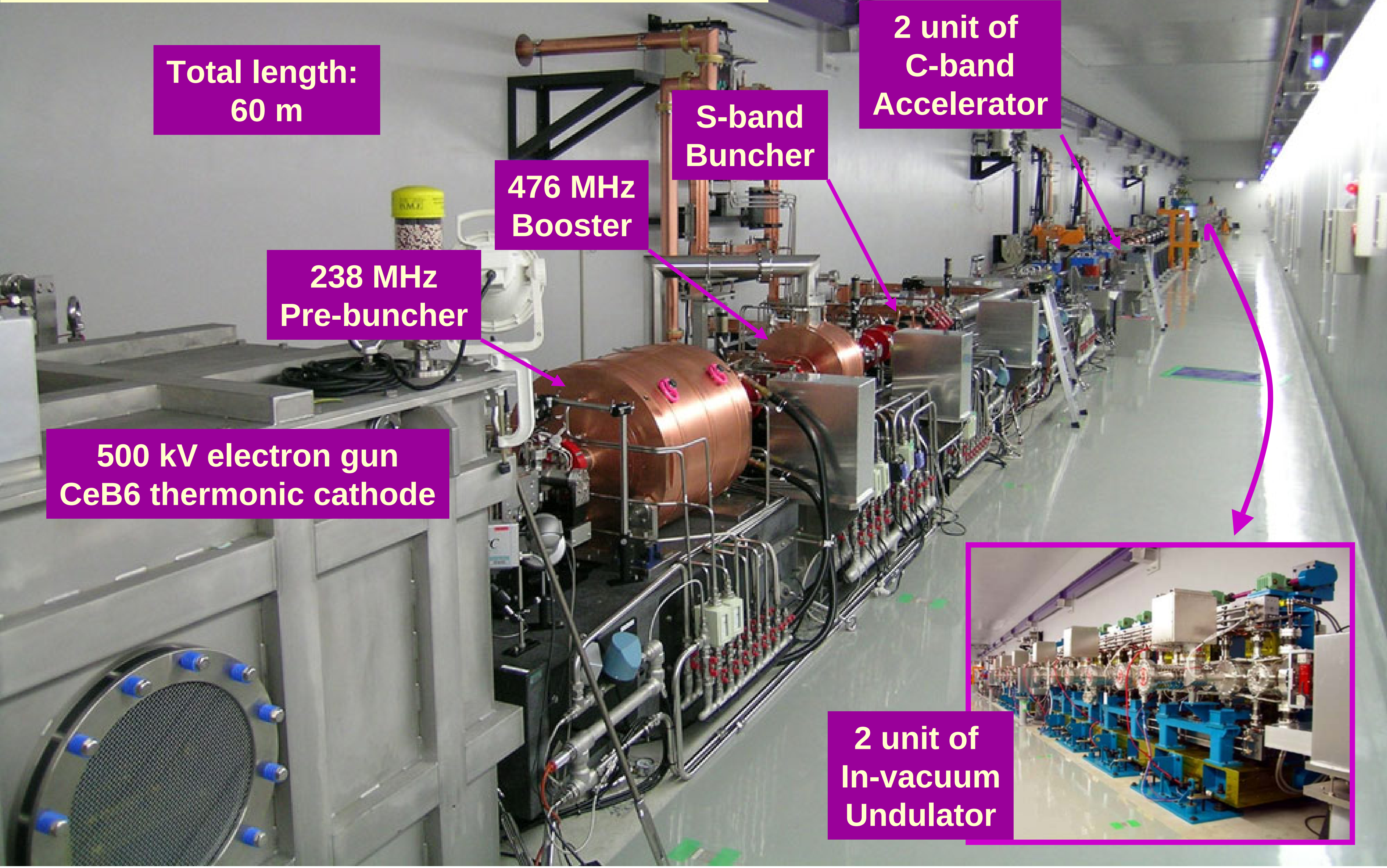


To confirm feasibility of

1. Bunch compression for SASE lasing
2. Accelerator components
3. Experiment with FEL light.



250 MeV test accelerator



Status of the FEL test accelerator

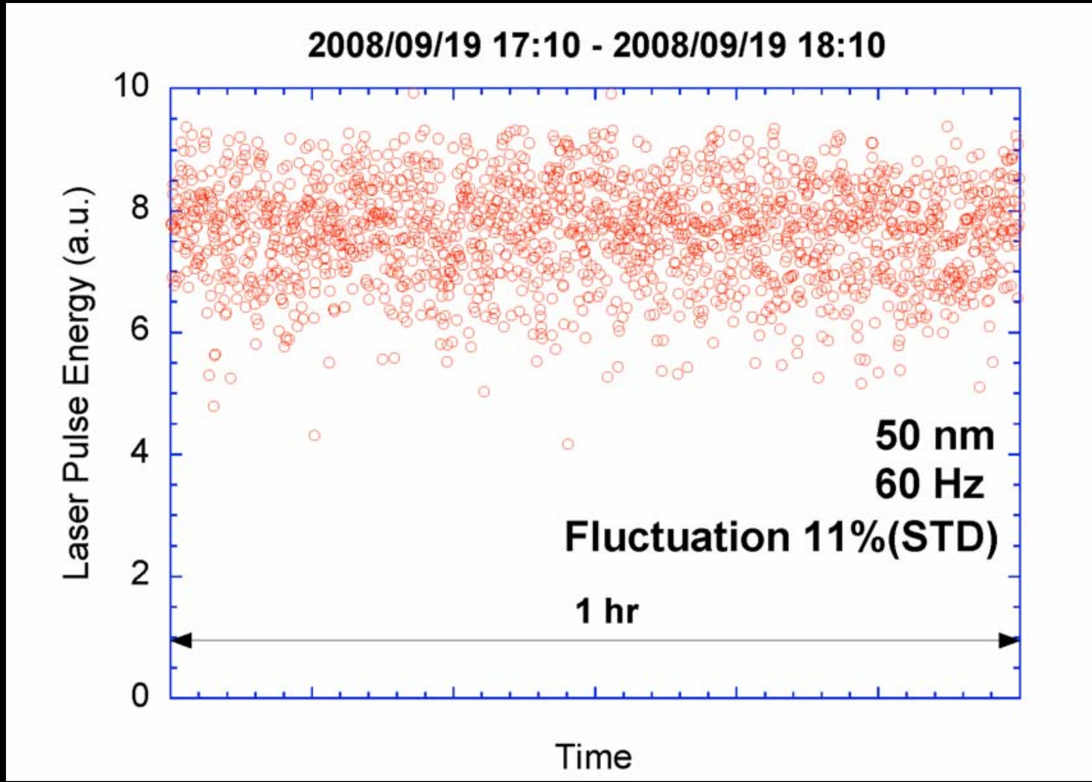
X-ray FEL

- 2005 Commissioning start
- 2006 First lasing at 49 nm
- 2007 Full saturation at 50 ~ 60 nm
- User run stated
- 2008 C-band 37 MV/m acceleration

Total operation time ~ 3,000 hours

Running always in saturation mode
- 50~60 nm
- 30 μJ/pulse energy

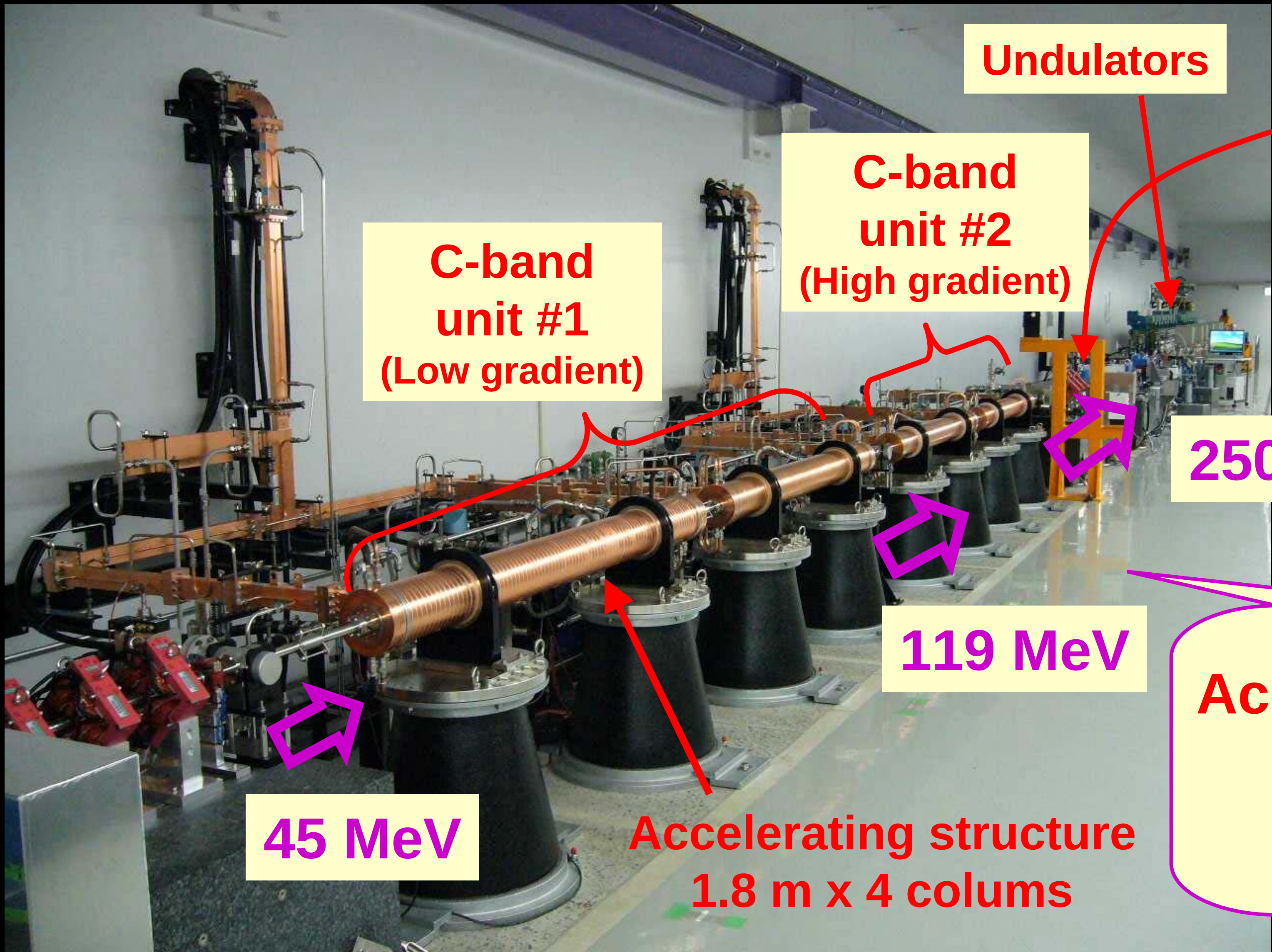
User experimental area



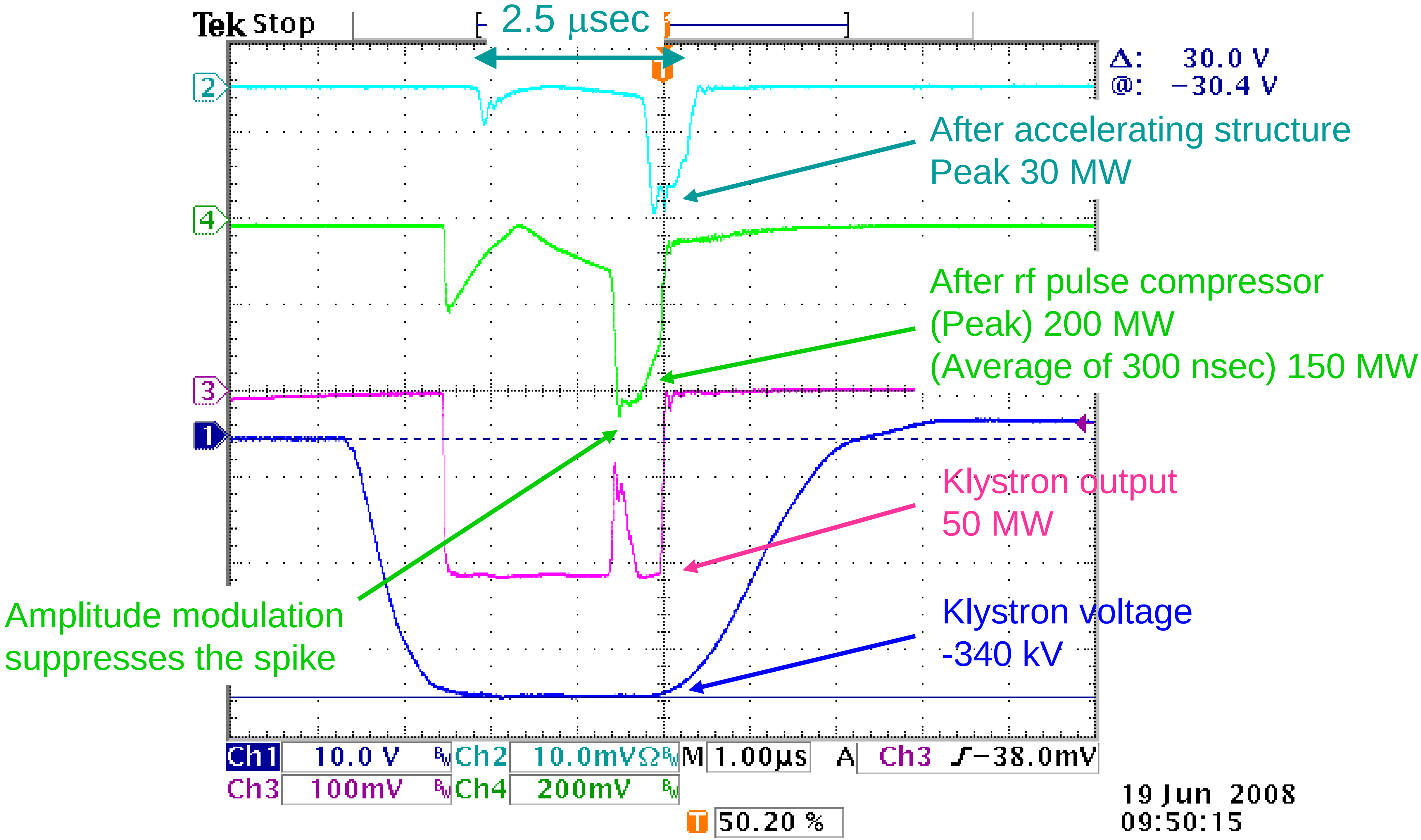
Trend graph of the laser intensity.
Fluctuation comes from SASE itself.
Stably running in saturation mode,
even in C-band 37 MV/m acceleration.

High gradient acceleration (May 2008~)

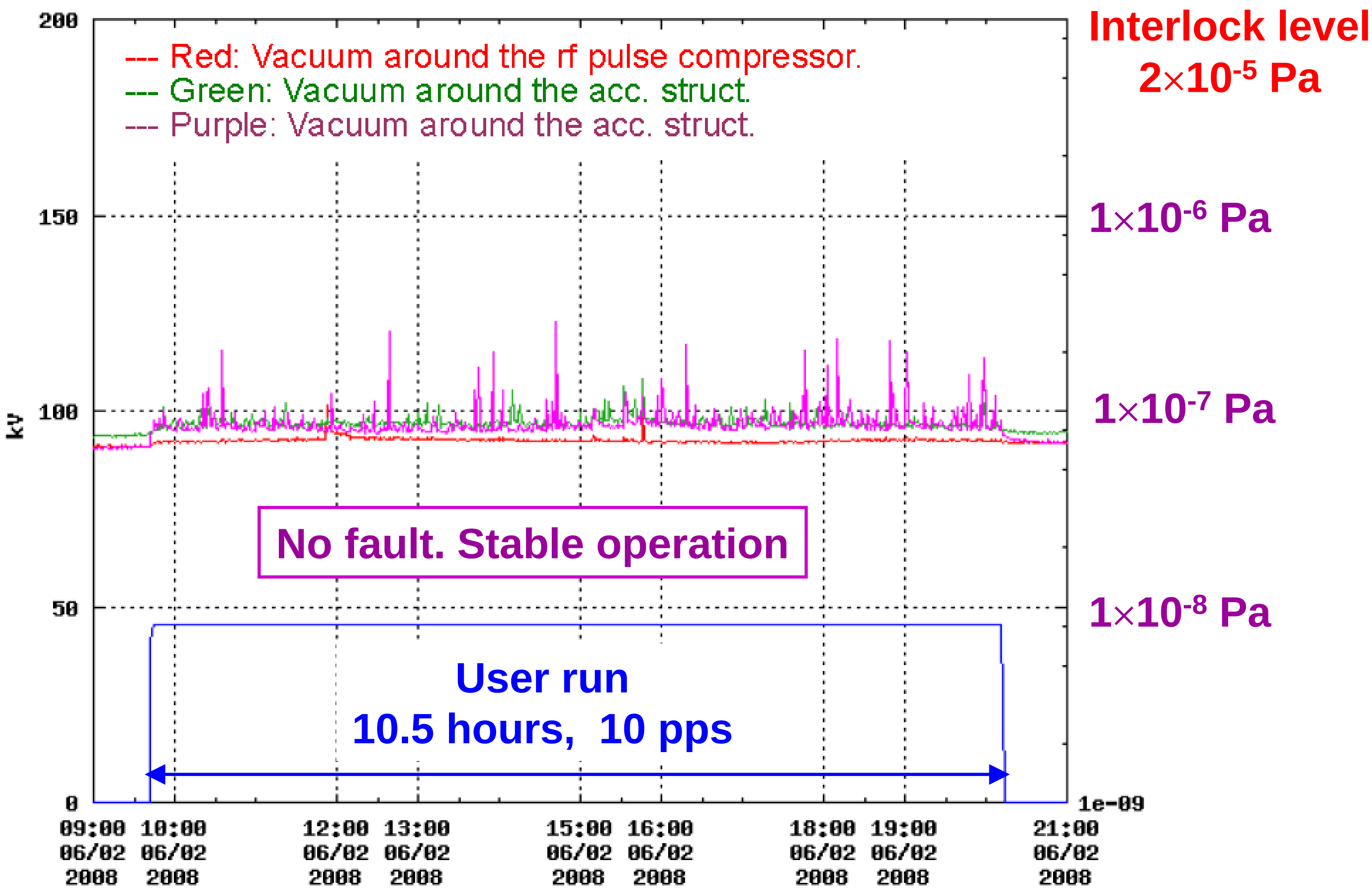
X-ray FEL



RF waveform at 37 MV/m



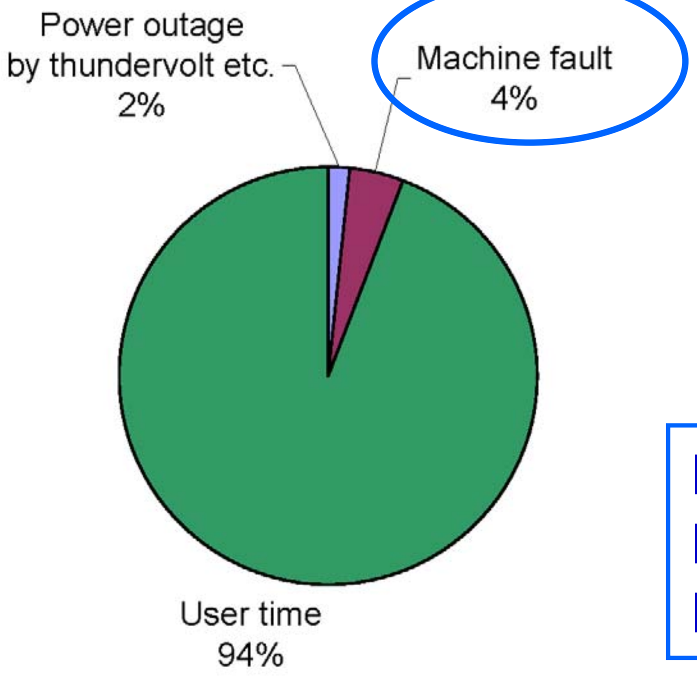
Vacuum pressure at 37 MV/m

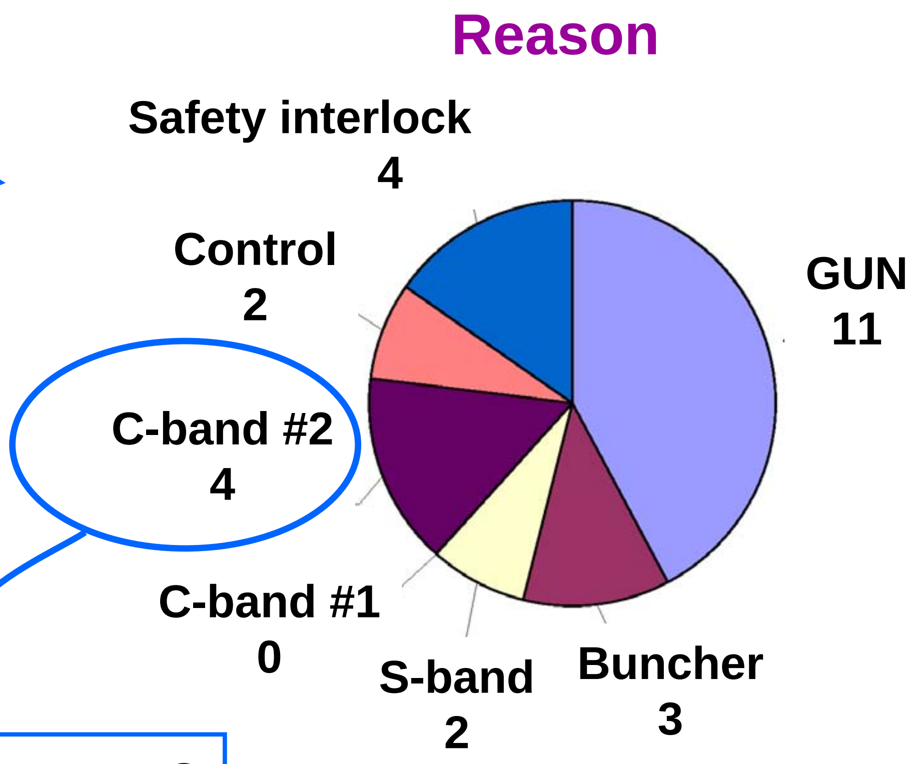


RF trip rate in 37 MV/m operation

X-ray FEL

User run (May 2008 ~ July 2008)
Total: 299 hours, 10 pps
Fault: 26 times





RF trip	2
High voltage	1
Fake interlocked	1

This is acceptable rate for XFEL
C-band is stably operated.

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Stabilities of rf amplitude and phase

X-ray FEL

XFEL requires ultra-high stability to accelerators.

Required stability of C-band rf amplitude ~ ±0.01 % (100 ppm) (rms)

C-band rf ohase ~ ±0.2 ° (rms)

But… at the test accelerator,

Beam energy stability ~ 0.06 % (600 ppm) (rms)

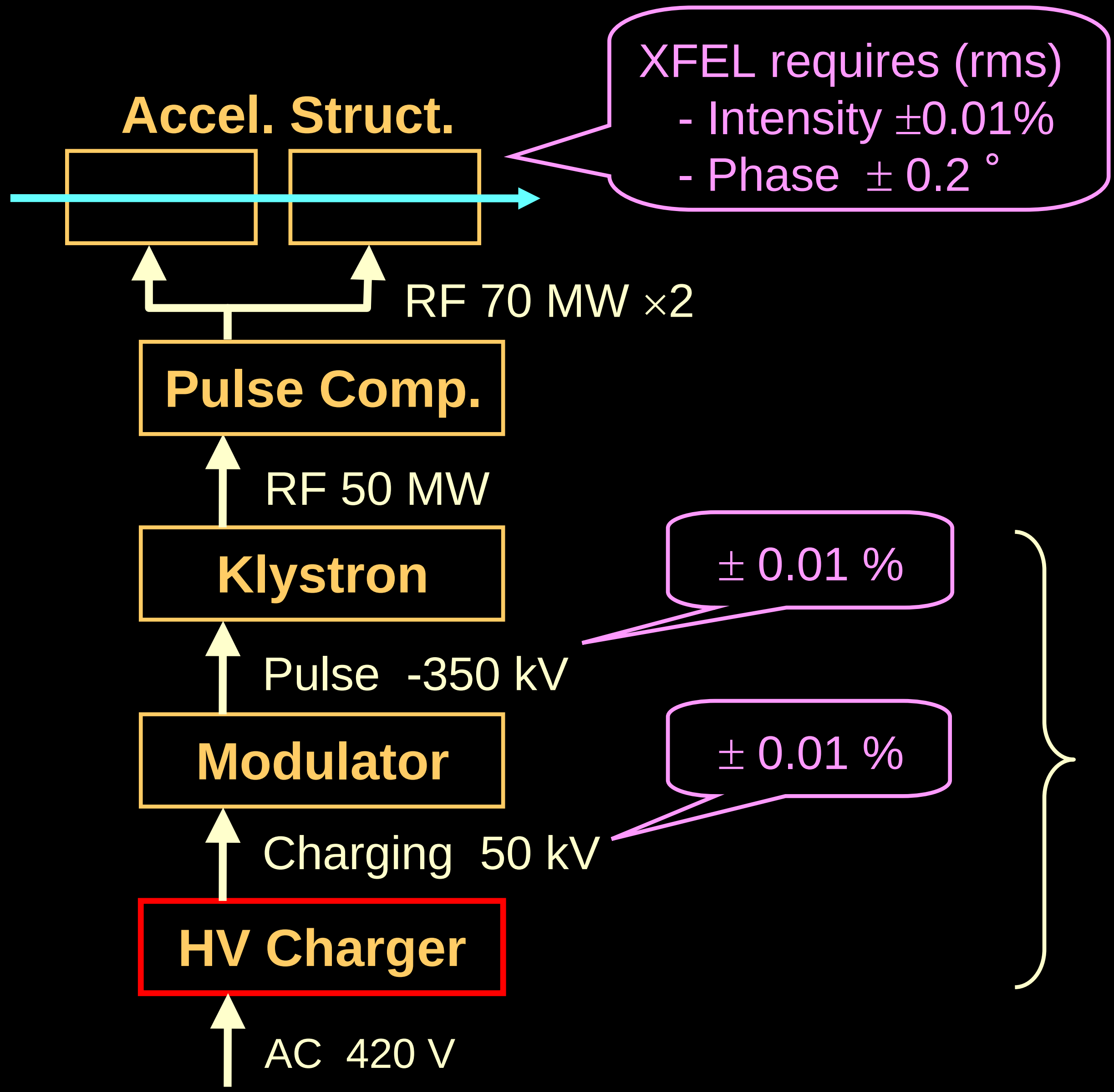
Mainly comes from the stability of the C-band (~0.1 %).

Source of the instability

- Drift (long term) ⇒ Feedback control can compensate.
- Jitter (pulse-to-pulse) ⇒ Un-controllable!

Pulse-to-pulse jitter from the klystron voltage

X-ray FEL

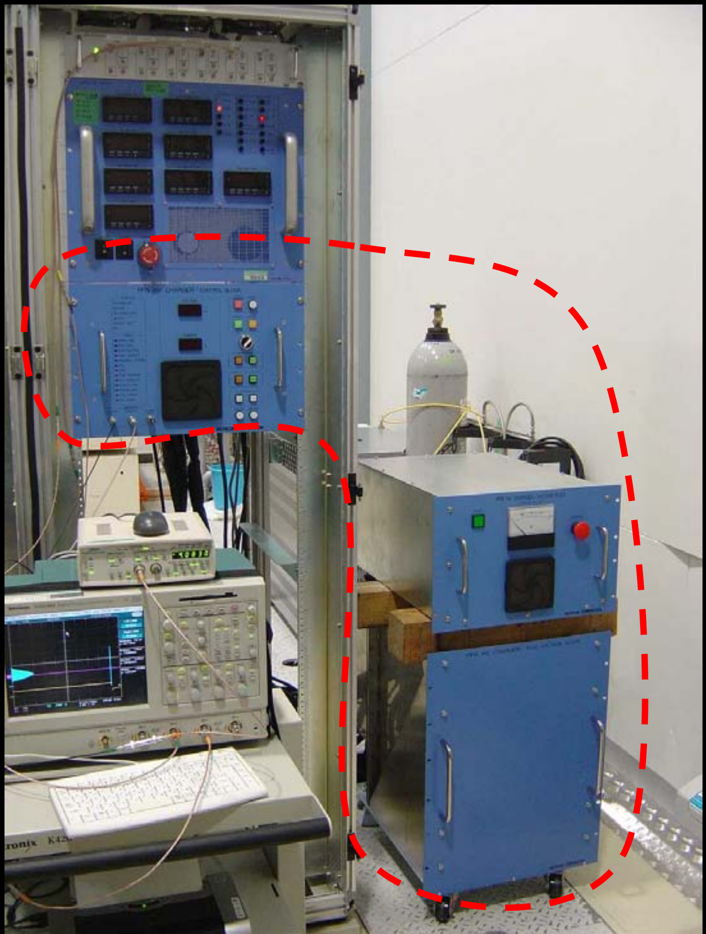


We developed
the new modulator and
the new HV charger
with <0.01% (100 ppm) stability

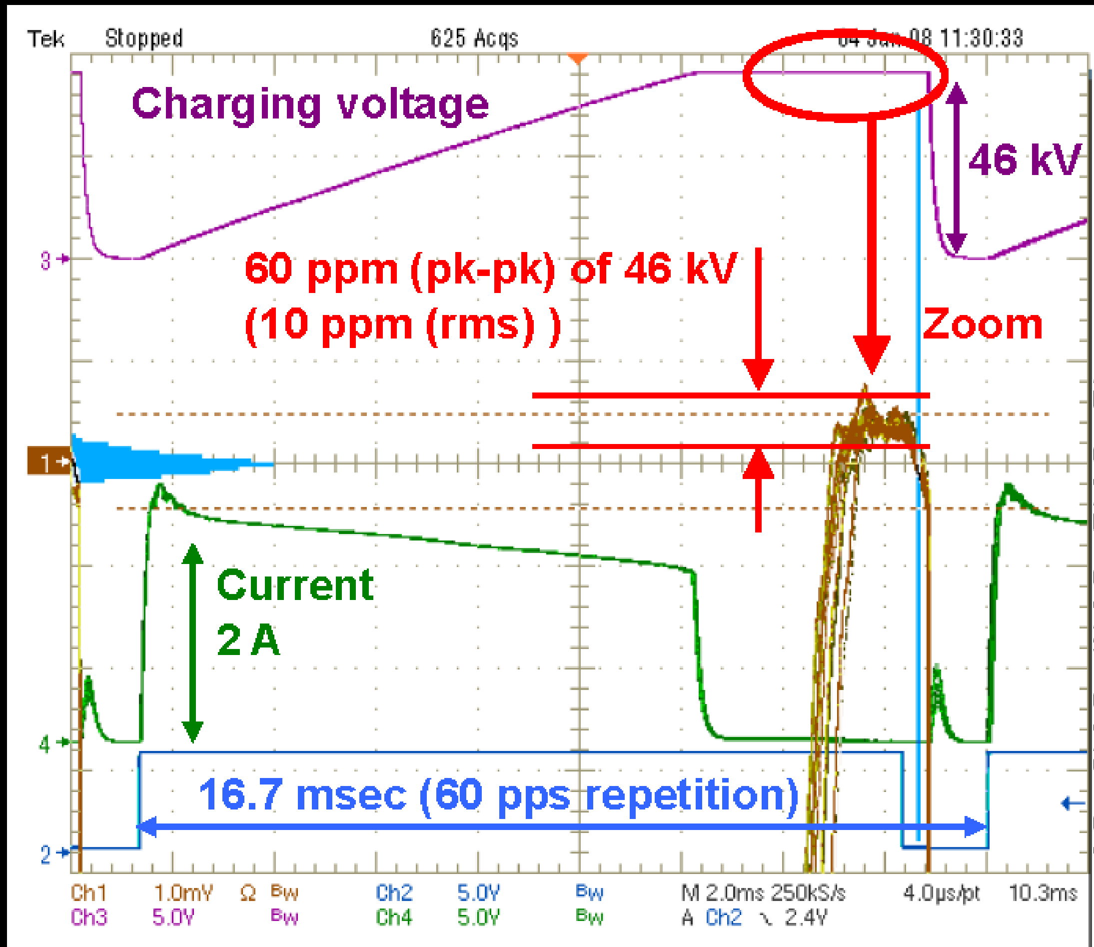
New HV charger with 10 ppm $_{(rms)}$ stability

X-ray FEL

Prototype model
Feb. 2008, Nichicon Corp.



Typical HV charging cycle
(Tens of waveforms are overlaid)



This satisfies the requirement of <100 ppm stability.

New modulator with EM noise shielding

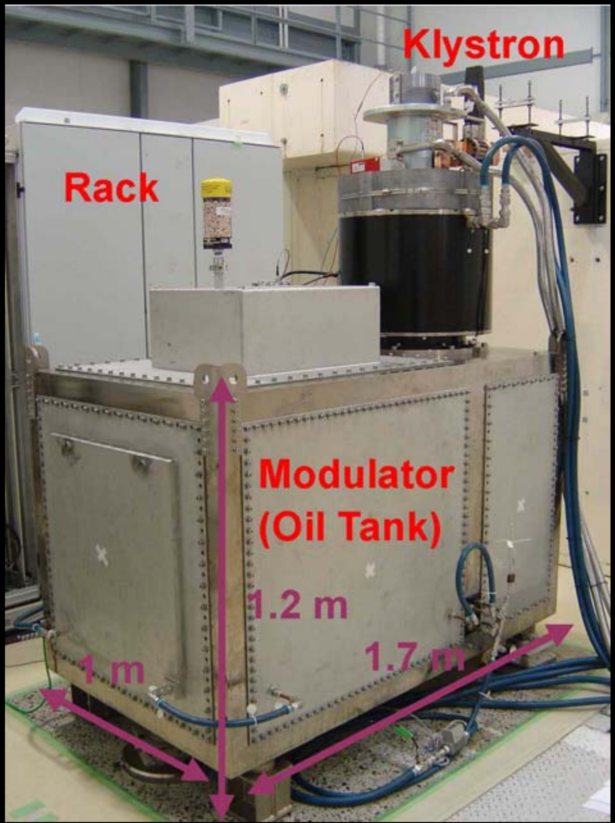
X-ray FEL

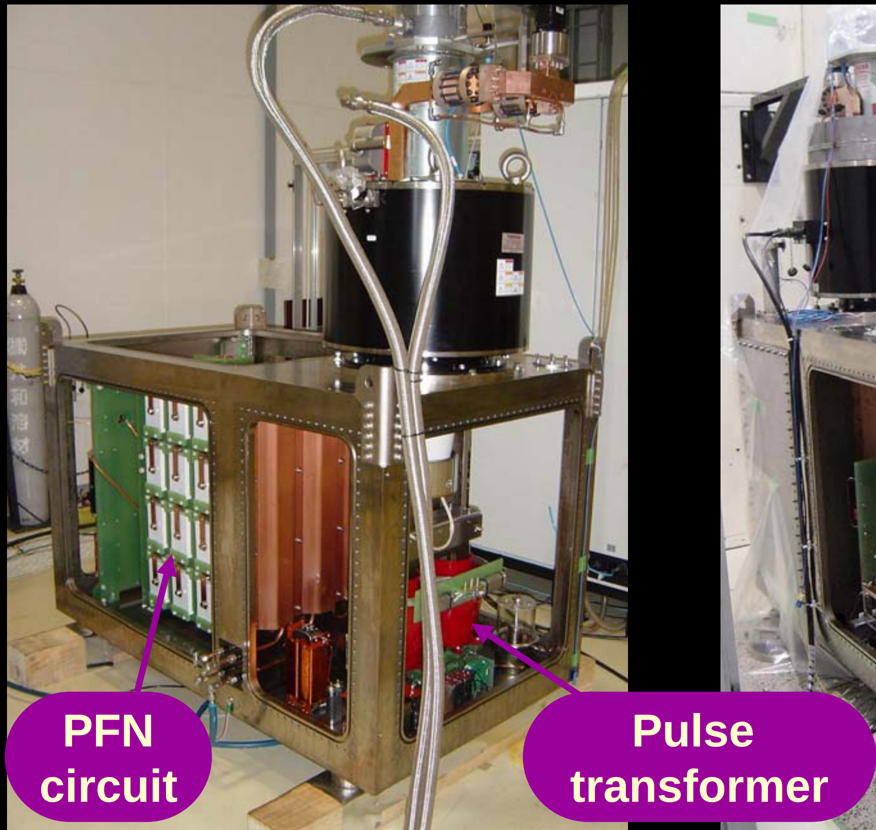
Electrical noise causes
- deterioration of monitor resolution
- fake interlocked

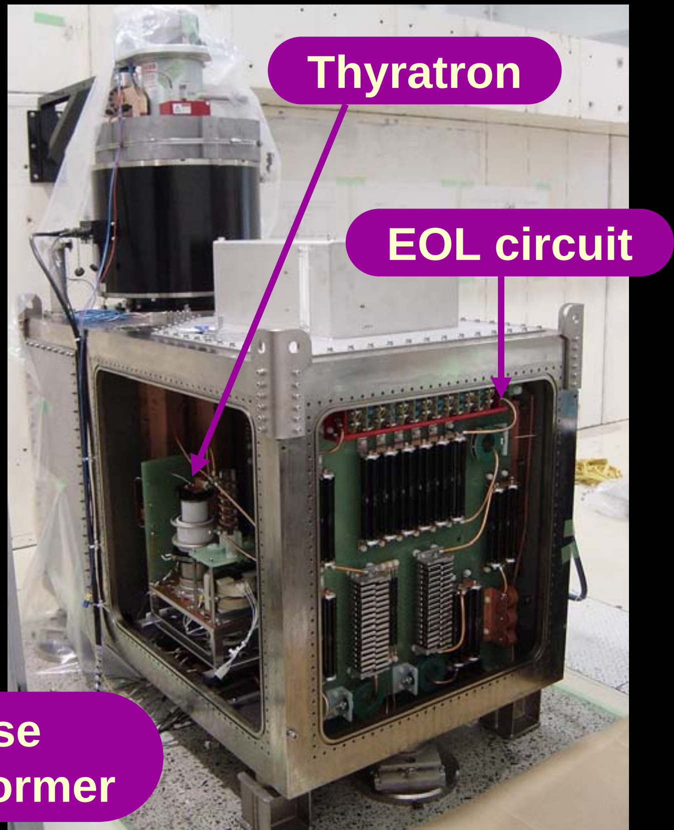
Prototype model Oct. 2007, Nihon-Koshuha CoLtd.

HV components in one steel tank
- EM noise shielding

HV components in the insulation oil
- Compact
- Free from humidity or dust







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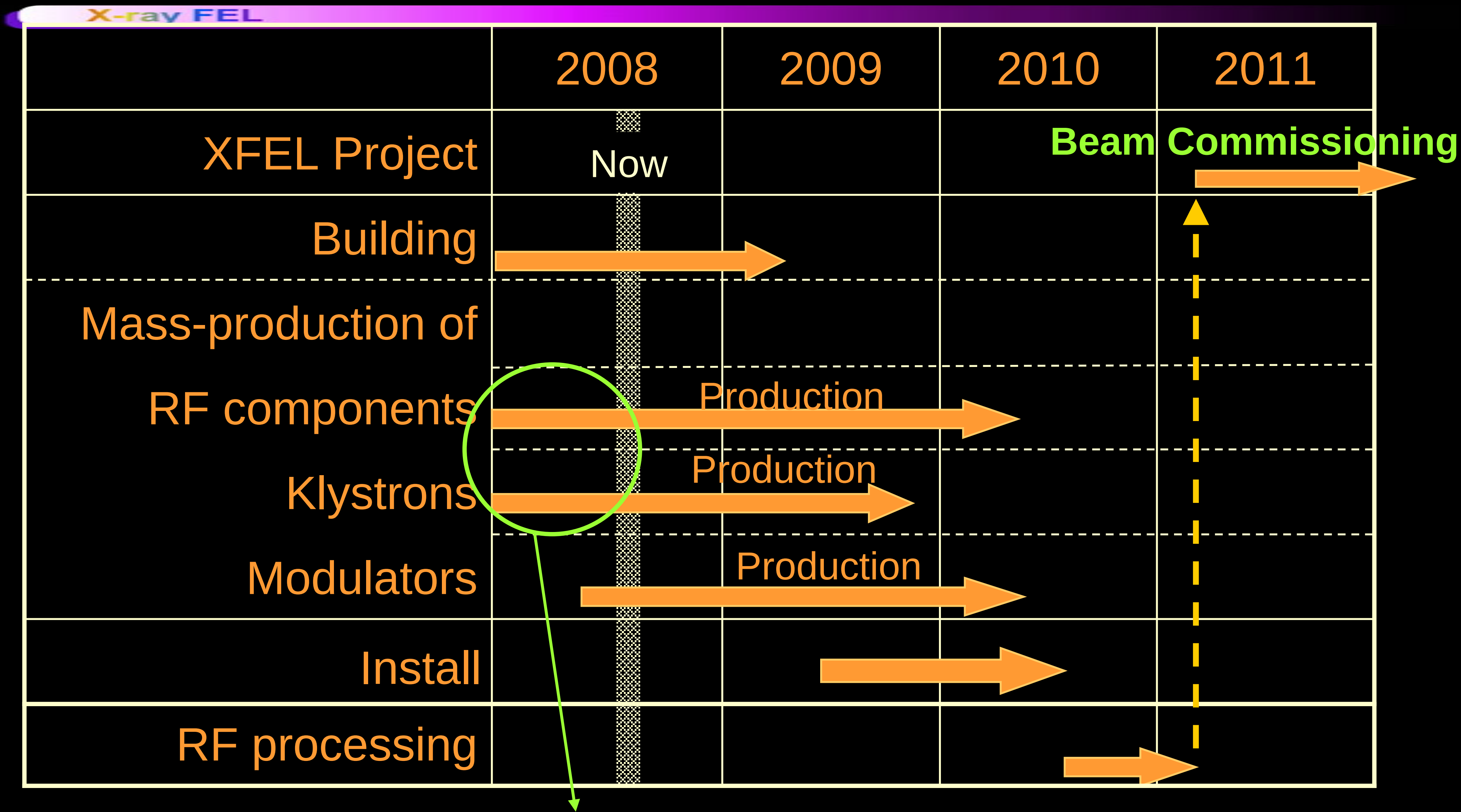
Construction schedule of XFEL



On-schedule,   roughly 30% were delivered.

Building construction (2007~2009)

X-ray FEL

Mass production of the accelerating structure
@ Mitsubishi Heavy Industries Ltd.

X-ray FEL

Precise lathe

Dr. Miura
(Mitsubishi)

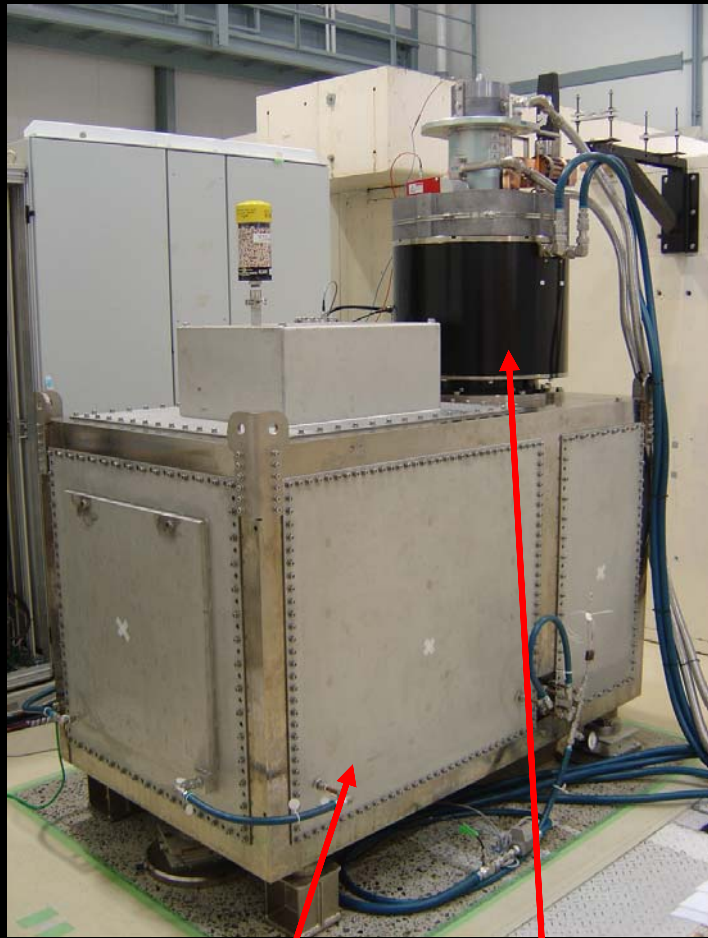
Cells

Shipping

High power rf test bunker (July 2008 ~)

X-ray FEL

In order to check quality of the delivered components,
we constructed the test bunker. Now, rf processing is in progress.



Summary

X-ray FEL

High gradient operation

- In the test accelerator, C-band is operated under 37 MV/m.
- No trouble, acceptable fault rate, quite stable operation.
- Nominal gradient (35 MV/m) for XFEL is confirmed.

Pulse-to-pulse stability

- Our prototype modulator and the HV charger have extremely high stability (10 ppm rms), which satisfies the requirement of XFEL.

Schedule

- High power rf components were delivered on schedule.
- Quality will be checked at the rf test bunker.
- 2009~2010 installation
- 2011~ Beam commissioning

Posters of XFEL

X-ray FEL

Tuesday

- TUP077 K. Yanagida

  "Development of Screen Monitor with a Spatial Resolution of Ten Micro-meters for XFEL/SPring-8"

Thursday

- THP104 T. Ohshima

  "Low Level RF and Timing System for XFEL/SPring-8"

- THP085 C. Kondo

  "Cooling System of Klystron Modulator Power Supply for XFEL Project at SPring-8"