Review of Activities in Japan

JAERI/TIT

Makoto Shiho

Japan Atomic Energy Research Institute/
Tokyo Institute of Technology

1. Introduction
2. Engineering R&D
3. Topics in Physical Research
4. Summary

Summary

- Engineering R&D
  - Large Size Finemet/ Ferrite Core
  - High rep. Rate By Solid State Devices(GTO, SIT)
  - Active Wave Form Control
- Physics
  - Beam Transport
  - High Efficiency Millimeter & Microwave FEL
  - Active Beam Bunch Generation
  - Laser Drive Ion Source
- New Concept
  - Induction Synchrotron (Super Bunch)

Induction Accelerator Related Activities

JAERI/TIT

•Kanazawa Univ./Saitama Univ. Prof. S.Kawasaki

–1975~1985; First R&D Machine ; 100keV, 10A, 1 μ s, FEL and H+ beam transport

•KEK Prof.K.Takayama, J.Kishiro

–1984~1997 800keV, 1.6MeV electron linac ; Xband FEL for L.C.

–1995~2002 Colab. with JAERI and TIT Induction Synchrotron

–1997~ Induction Synchrotron Research ; neutrino phys.

•TIT Prof.M.Ogawa, K.Horioka, E.Hotta

–1997~2002 160keV, 400 ns ion accelerator ; Fusion Driver

–1998~2002 Induction Synchrotron Module/Concept study ; neutrino phys.

Material Research, Solid State

•JAERI M.Shiho, S.Maebara, K.Sakamoto

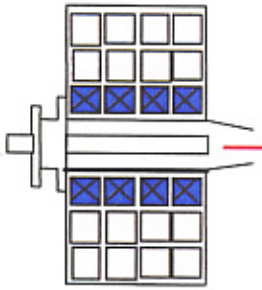
–1986~1990 MTX Project at LNNL : Plasma Heating

–1984~2002 1MeV, 2.5MeV electron linac ; High Power Microwaves

Large System Dev.

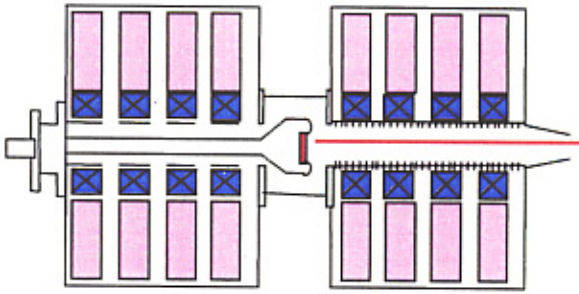
Induction Linacs in Japan

JAERI/TIT



LAX-1: 1MeV,~3kA,100ns

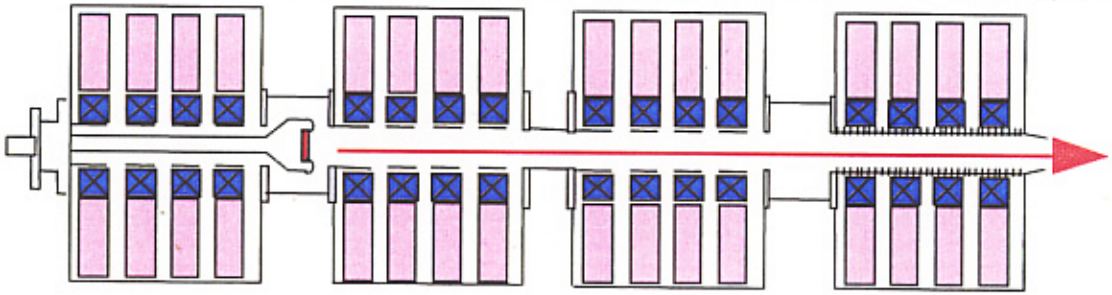
KEK: 0.8MeV, ~2KA, 80nS → TIT: 160KeV, 400nS



JLA : 2.5 MeV,~3kA,160ns

KEK: 1.6MeV.2KA. 80 nS

KEK:1.6MeV,~3kA,80ns JLA: 2.5 MeV,~3kA,160ns



: 4.1 MeV,~3kA,80ns

Engineering R&D

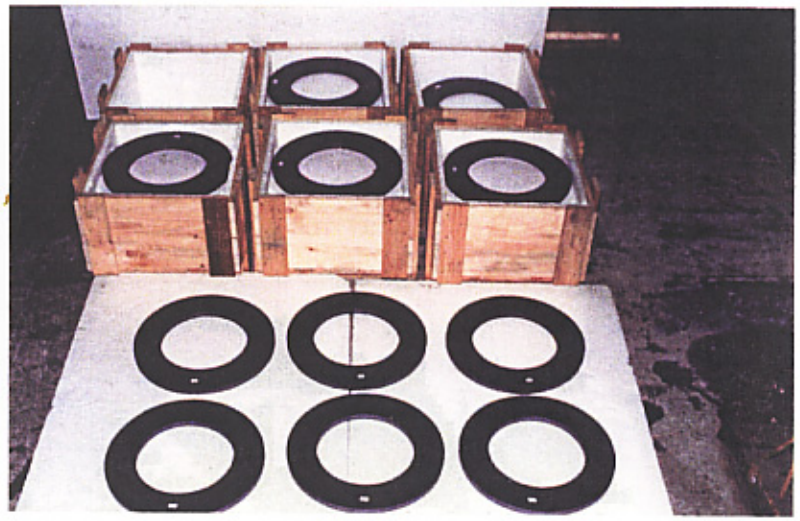
JAERI/TIT

- KEK Ferrite Core, Metglass Core -65cm dia.
  Solid State Driver-SIT proposed by
  Prof.J.Nishizawa
- TIT Core Characteristic Study
  Solid State Driver
  Waveform Contraol By Solid State Device
  Ion Injecter -Laser Drive
- JAERI Large Finemet Core -90cm dia.
  Large Ferrite Core
  Tunable PFL

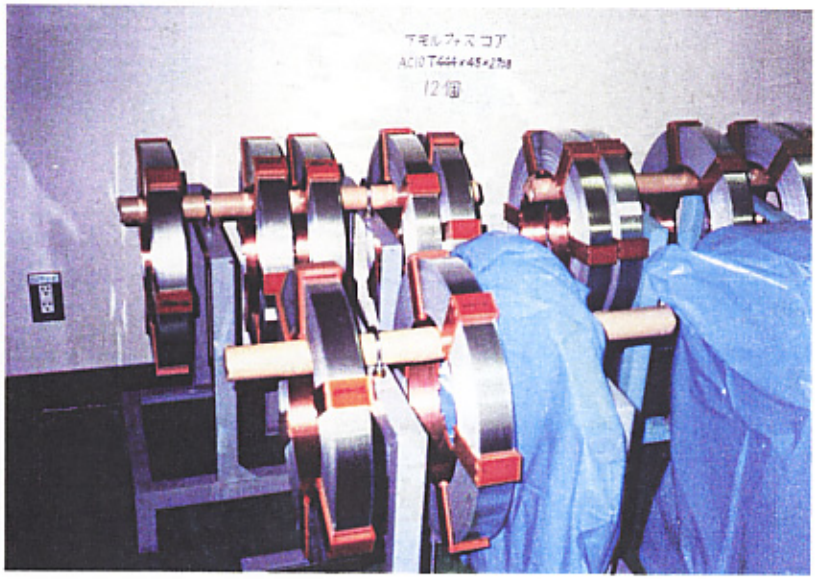
Hitachi Metal
TDK.
Hitachi. Toshiba
Nichikon. Nisshin.

Engineering R&D Core

JAERI/TIT



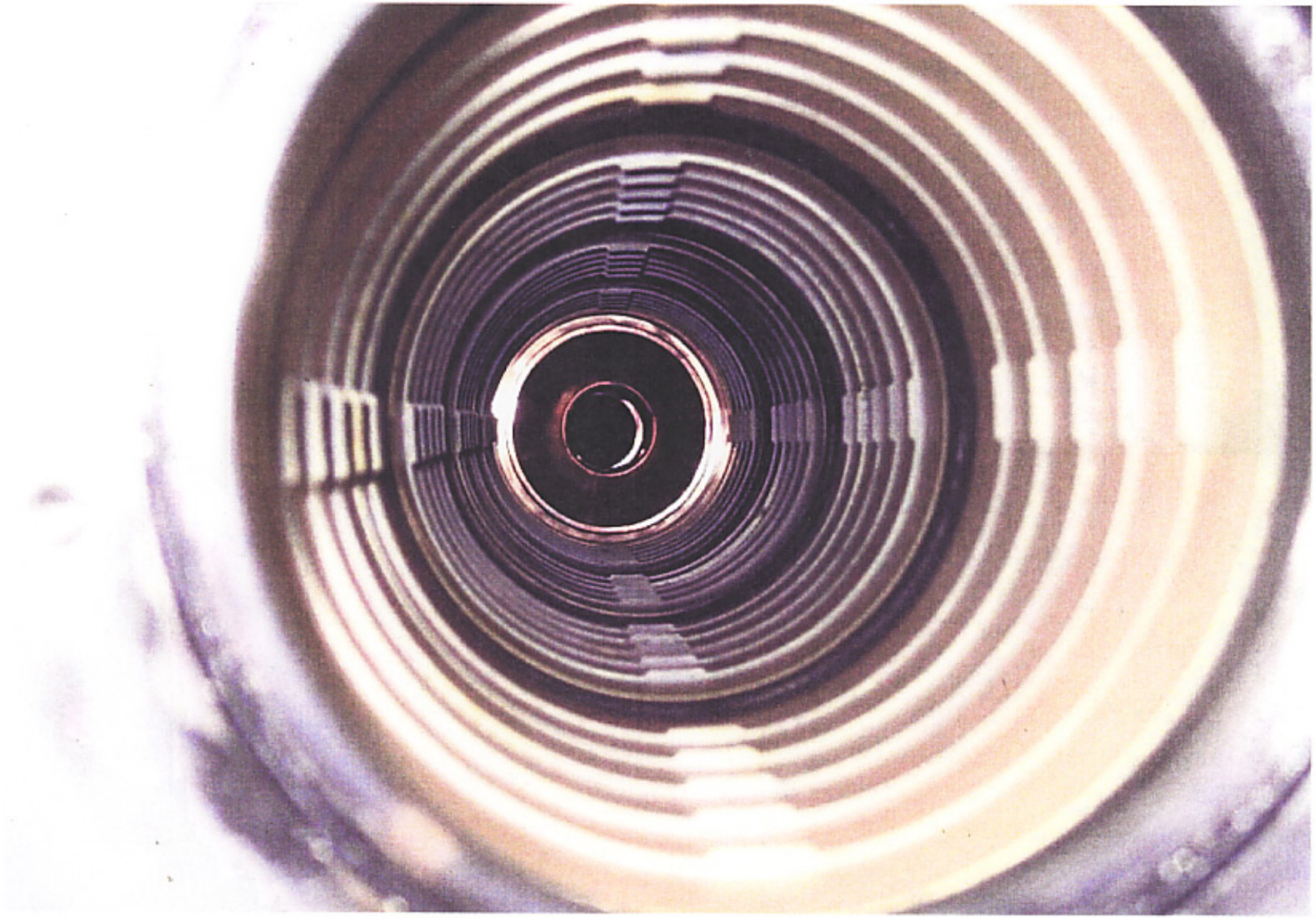
Ferrite



Finemet

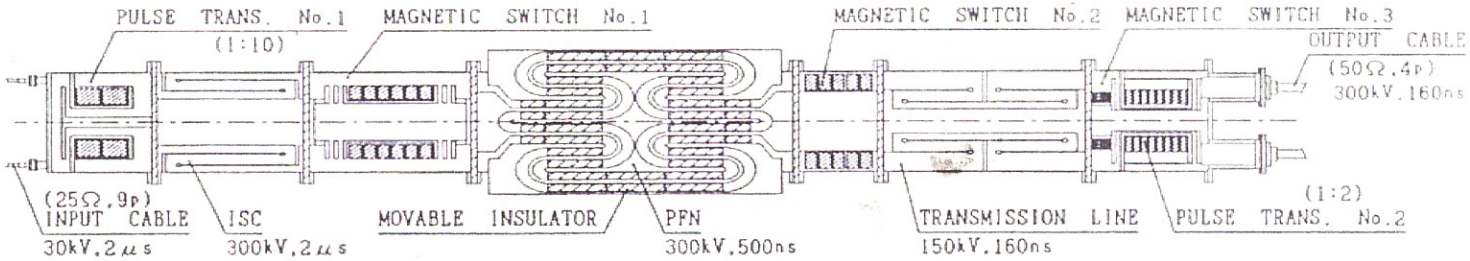
Accelerating Structure

JAERI/TIT

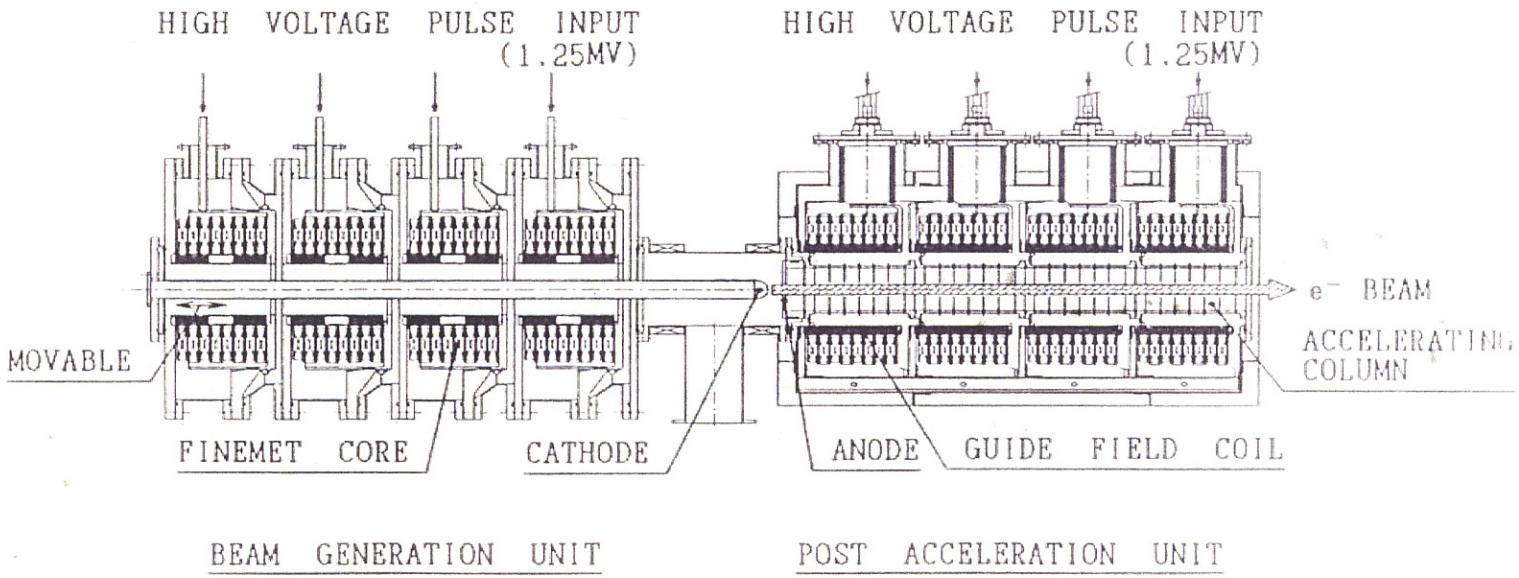


JLA Cross Section

(A) Tunable Pulse Forming Network

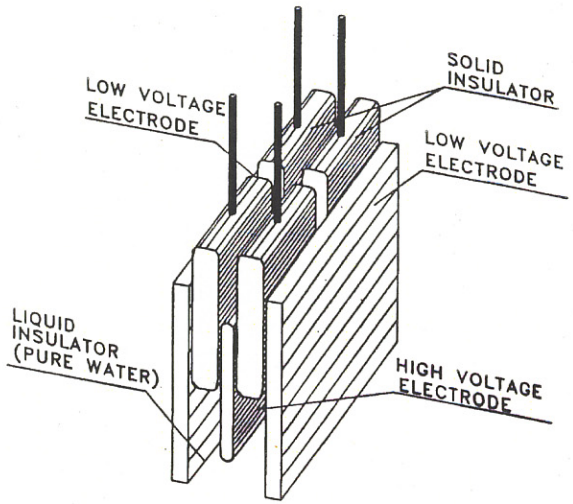


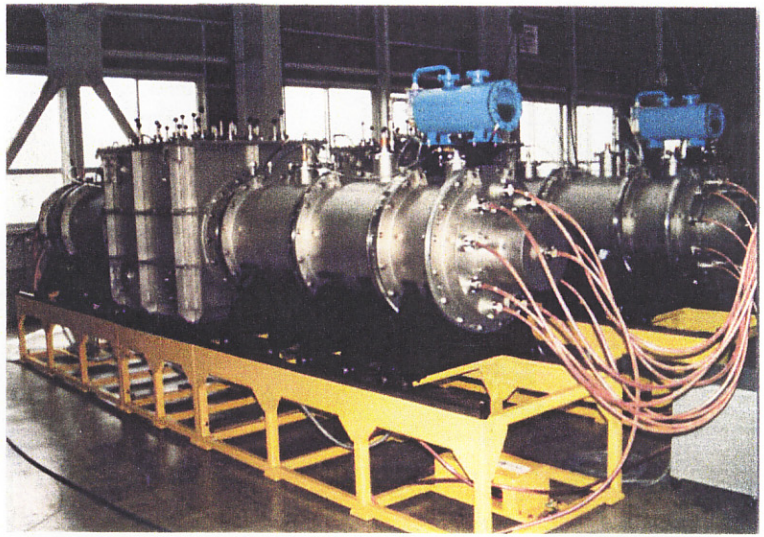
(B) Accelerator

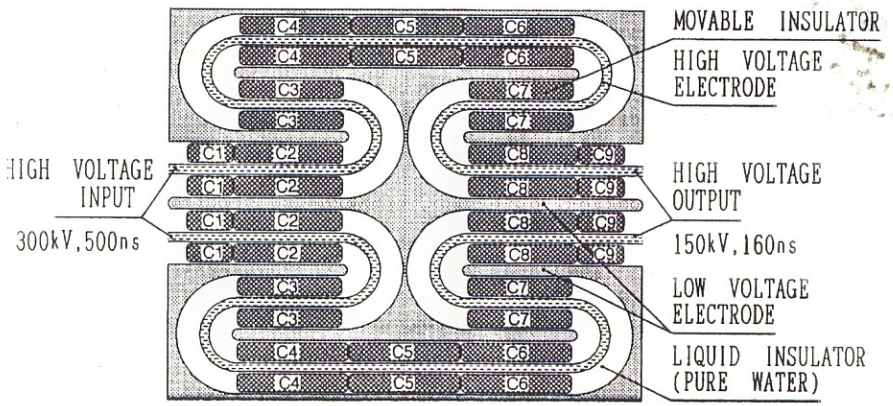


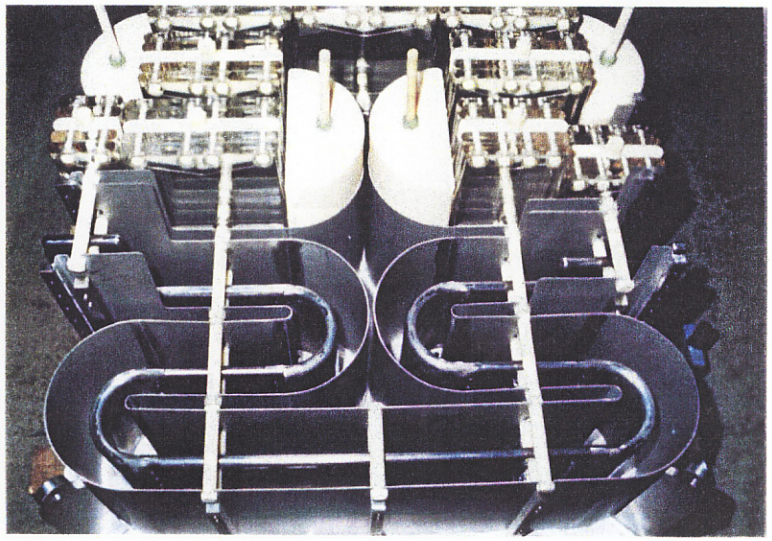
Tunable Pulse Forming Line

JAERI/TIT





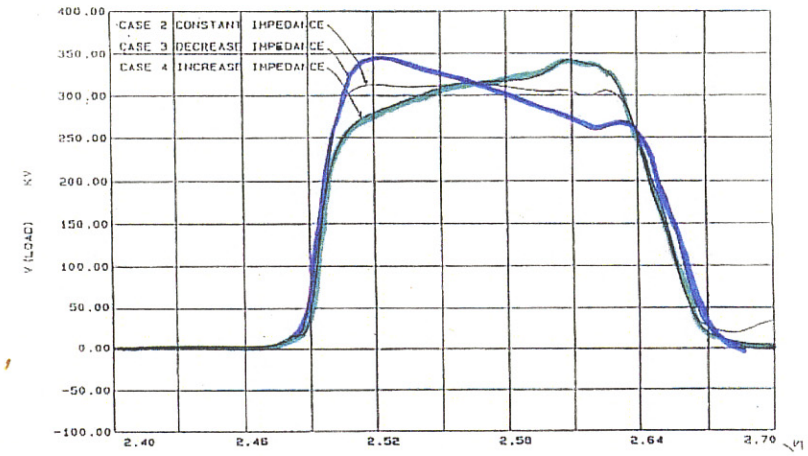




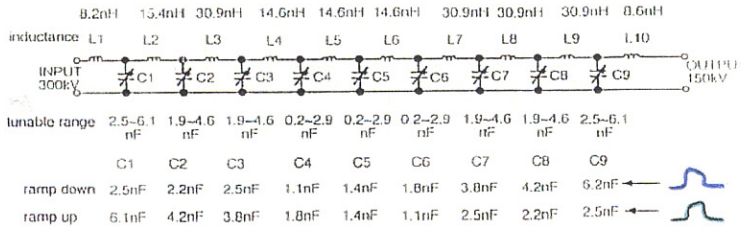
Tunable Pulse Forming Line

JAERI/TIT

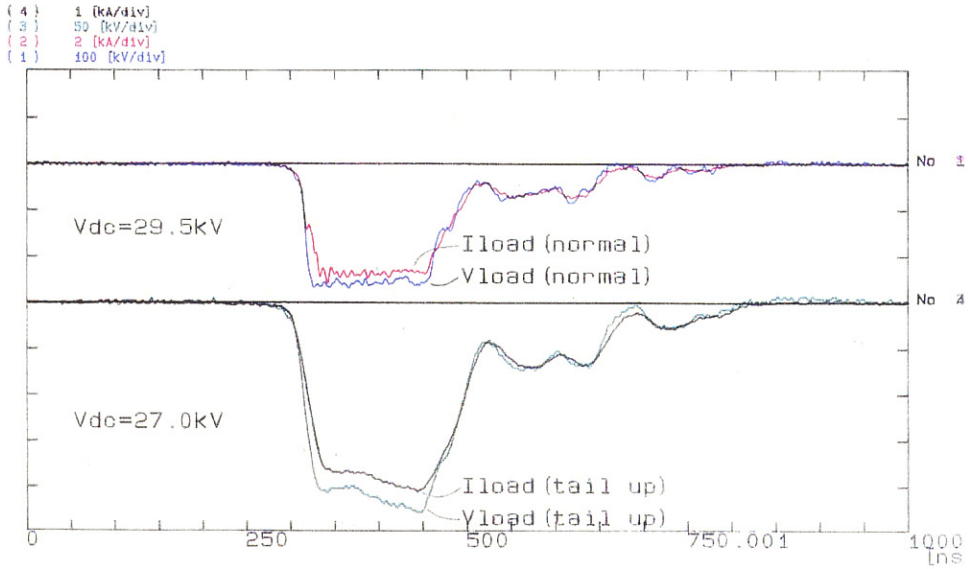
Simulated Wave Form



EQUIVALENT CIRCUIT OF TUNABLE PFN



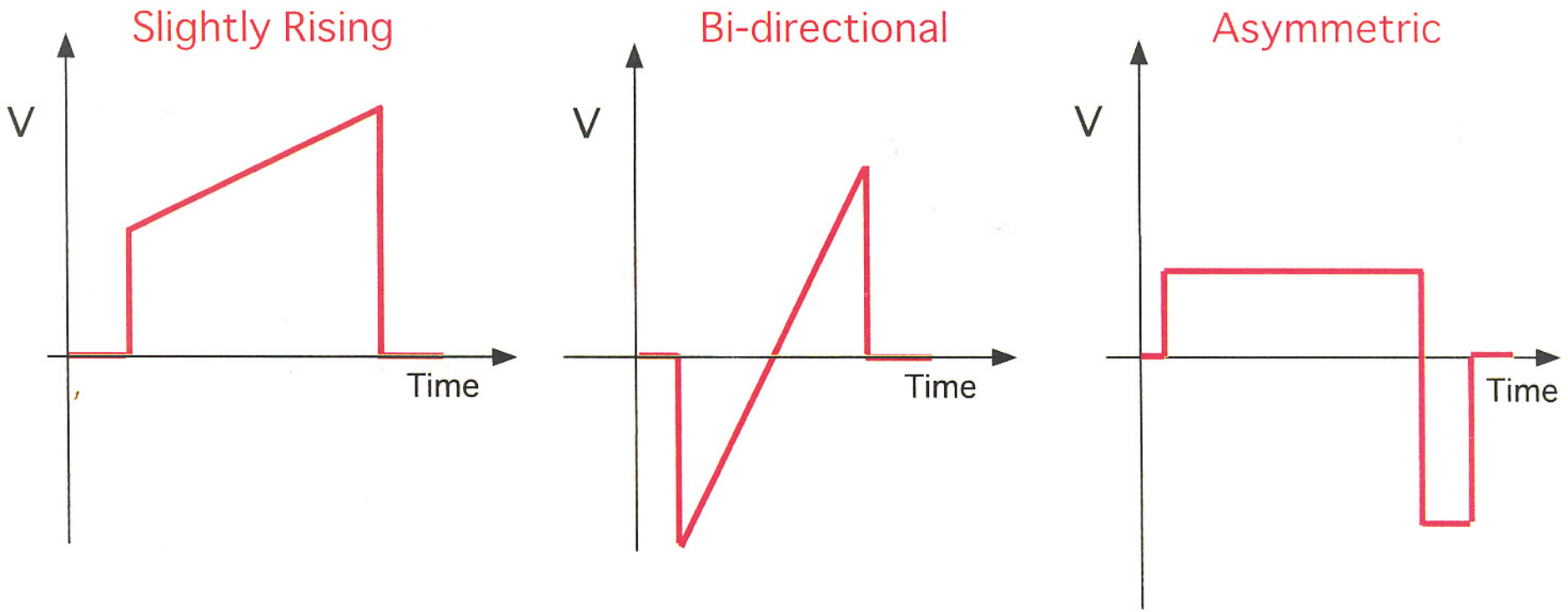
- 17% ramp up and ramp down by changing C along PFL



File name: 4061101A+77D

Tokyo Institute of Technology

Waveform Requirements for Induction Modulator



Induction Linac

Buncher

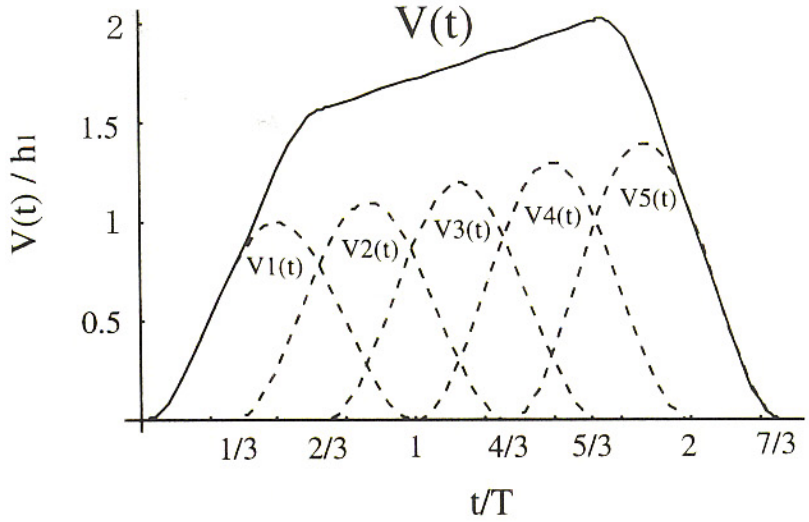
Recirculator

Carefully programmed waveforms are required ⟶ Stacked modules

Waveform Synthesis by one-cycle Sinusoidal Modules

Advantages

- Modules with sinusoidal waveforms
- Formed by simple L-C based circuit
- Robust against switching jitter
- Low core loss



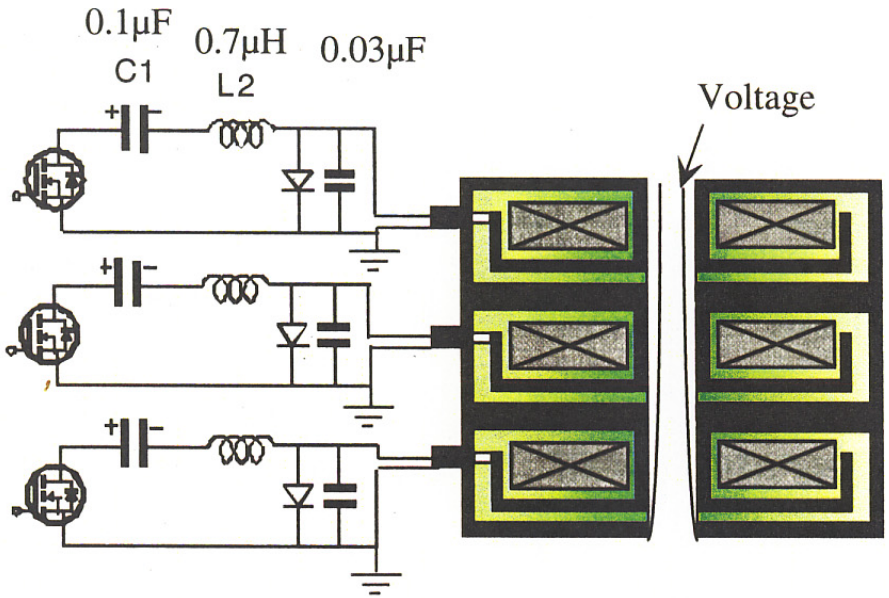
$$V(t)=\sum V_N(t)$$

$$V_N(t)=\{1-\cos(\omega t-\delta_N)\}h_N/2$$

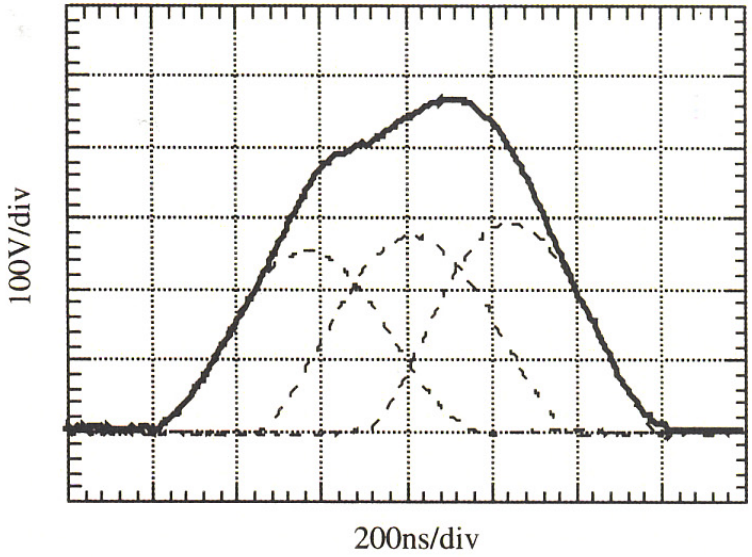
$$\delta_N/\omega \leqq t \leqq (\delta_N+2\pi)/\omega$$

Tokyo Institute of Technology

Rising Waveform Synthesized by 3-modules

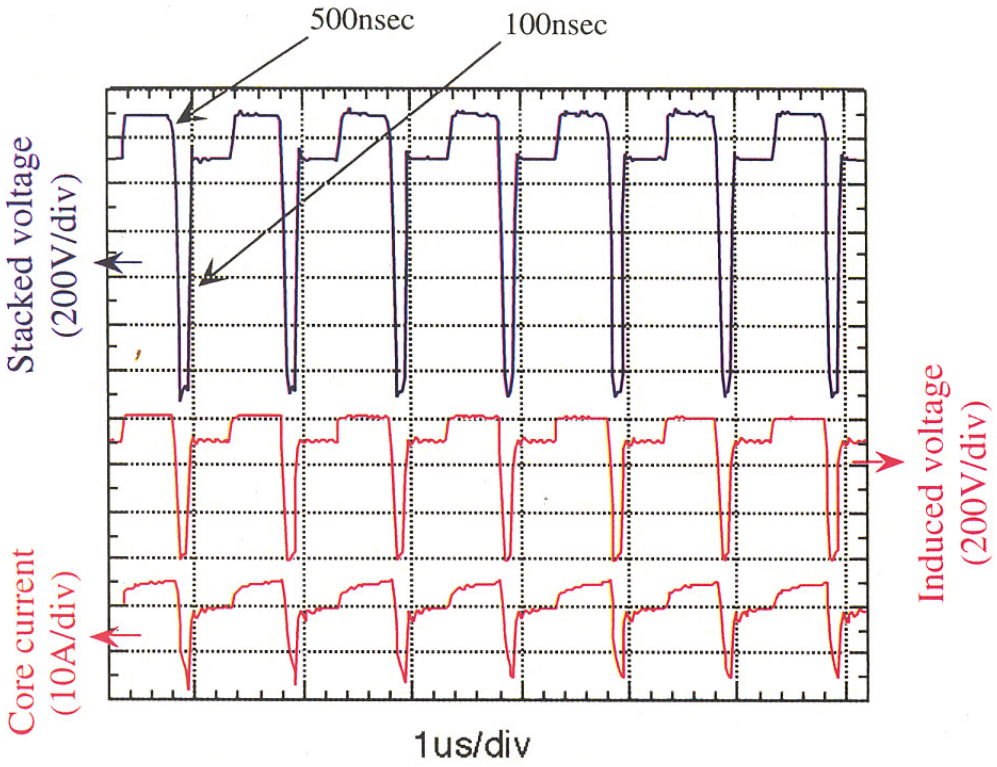


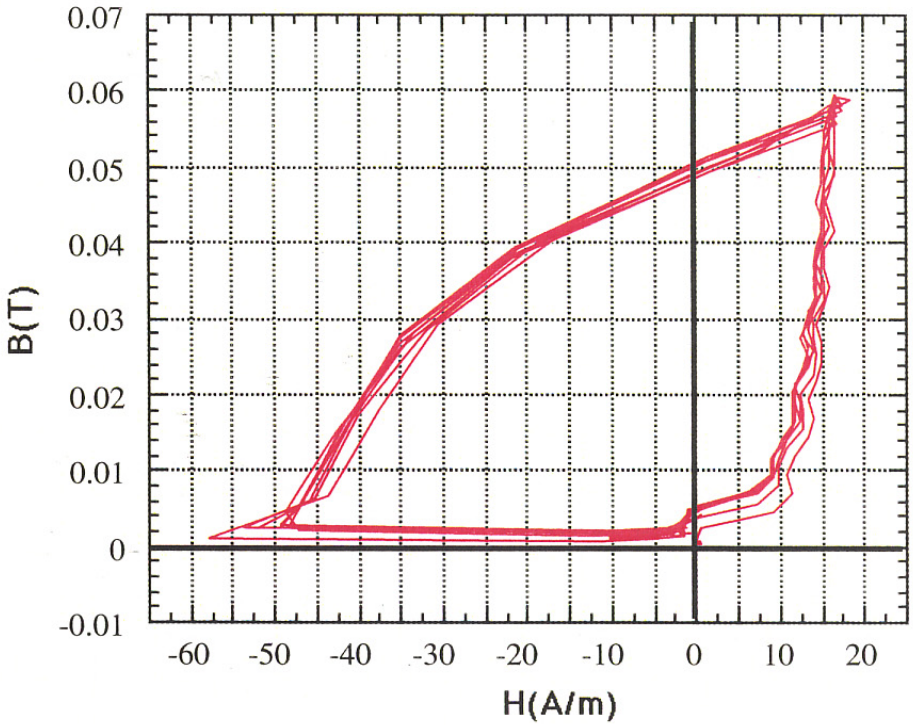
Schematic diagram of 3 module circuits



Example of synthesized waveform

Waveforms and hysteresis loops of stacked module for non-symmetric magnetization mode at 1MHz





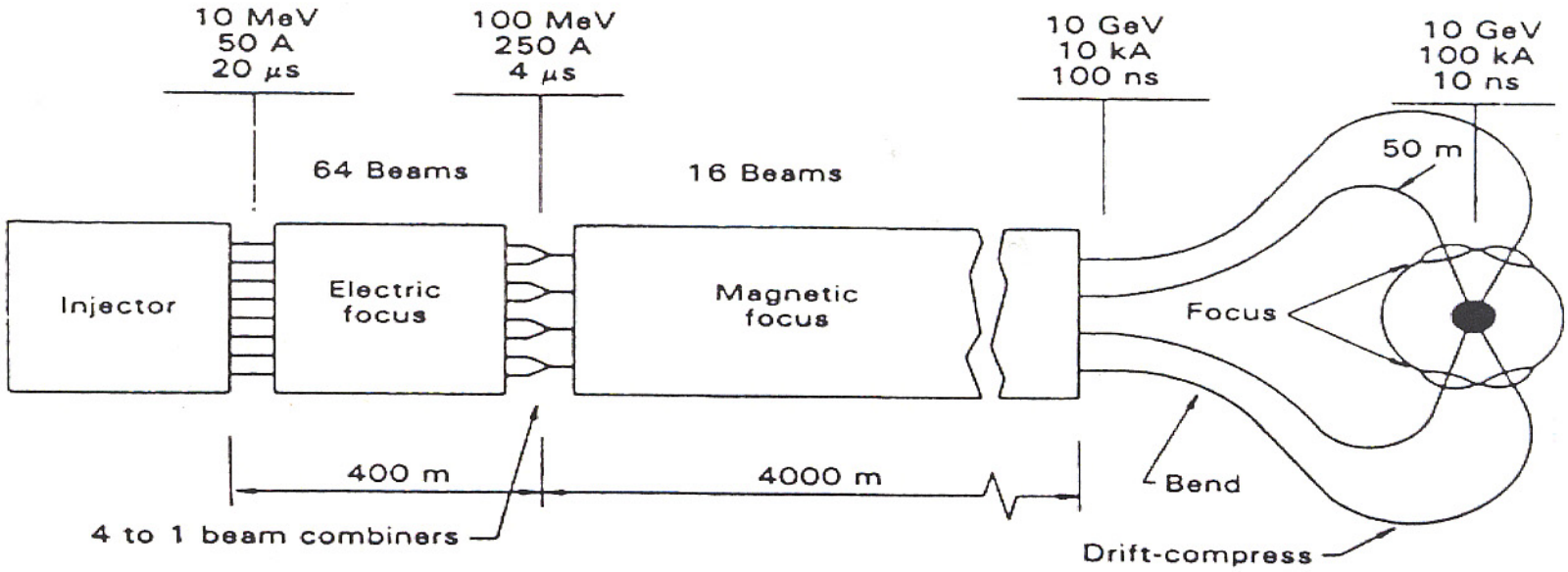
Physics Research

JAERI/TIT

- **KEK** Linear Collider
  - Ion Channel Beam Gude
  - X-band FEL
  - Pre-bunched FEL
  - Induction Synchrotron Proposal and R&D
- **TIT** Inertia Fusion
  - Core Material Study- data base up to 10T/μs
  - Wave Form Control by Solid State Device
  - Ion Injecter Study - Cu^{+} ion
  - System Design for Heavy Ion Fusion Driver
- **JAERI** Magnetic Fusion
  - Large Size Ferrite and Finemet Core
  - Tunable PFL
  - Focusing Wiggler FEL
  - BWO as a Pre-buncher

Beam Driver for Inertial Fusion

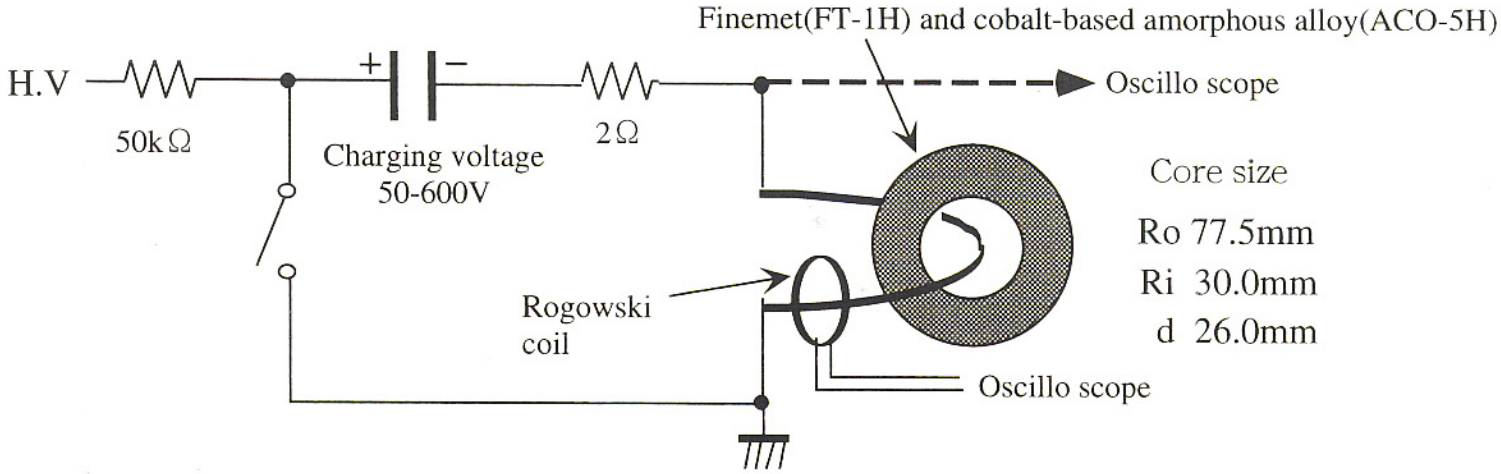
JAERI/TIT



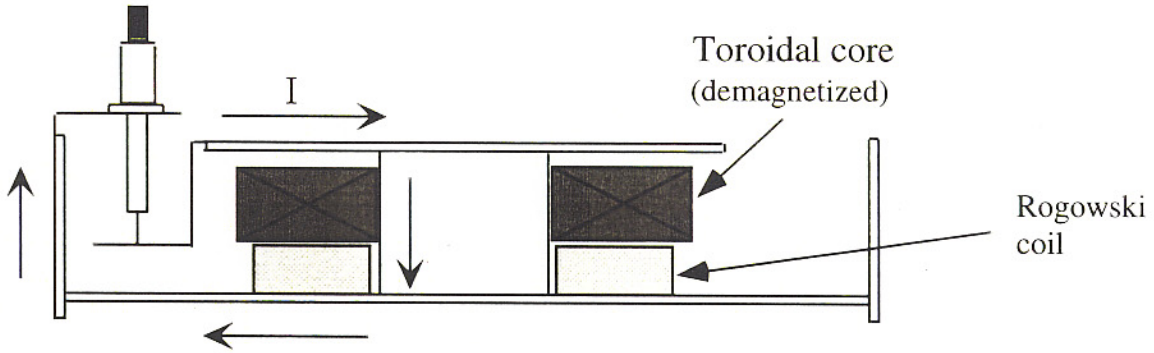
Pulse energy	4.0 MJ	Relativistic factor (βγ)	.332
Particle energy	10.0 GeV	Emittance (unnormalized)	3×10^{-5} m-r
Particle type	Hg^{+++} (A=200)	Momentum spread	±0.3
Peak power	400 TW	Spot radius	4 mm
Pulse length	10 ns	Convergence half angle	15 mr
Rep. rate	10 Hz	Standoff to final magnet	8 m
Number of beams	16	Target gain	80
Net pulse charge	1200 μC	Net electric power	1000 MWe

Fig. 6 Schematics of heavy ion induction linac system for inertia confinerment fusion reactor.

B-H curves are measured as functions of magnetization rate*(dB/dt)*.



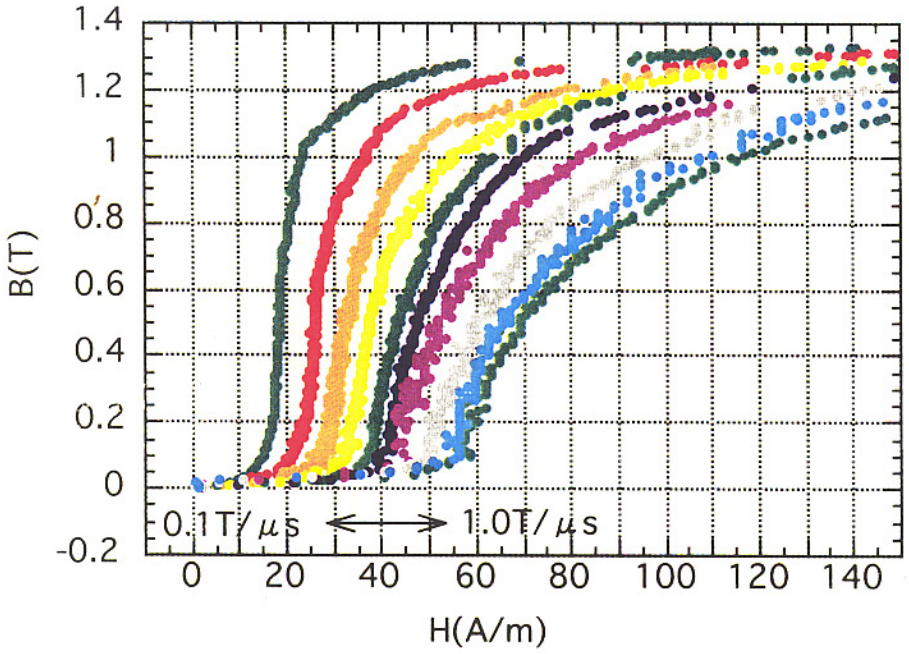
Schematic diagram of capacitor discharge circuit.



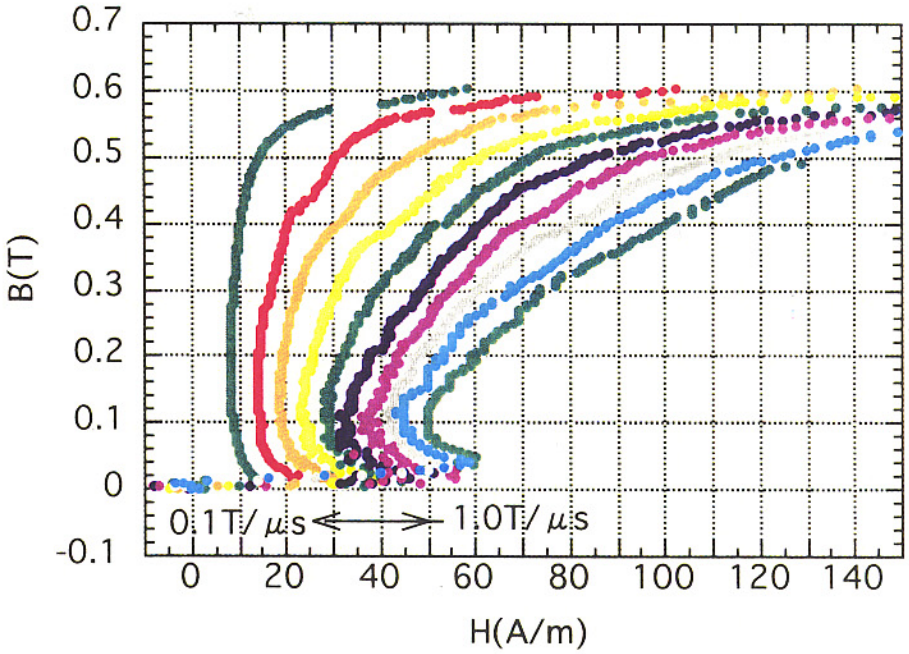
Experimental arrangement
for characterization of magnetic materials

B-H curves for Finemet(FT-1H) and Cobalt-based Amorphous(ACO-5H) with magnetization rate as a parameter

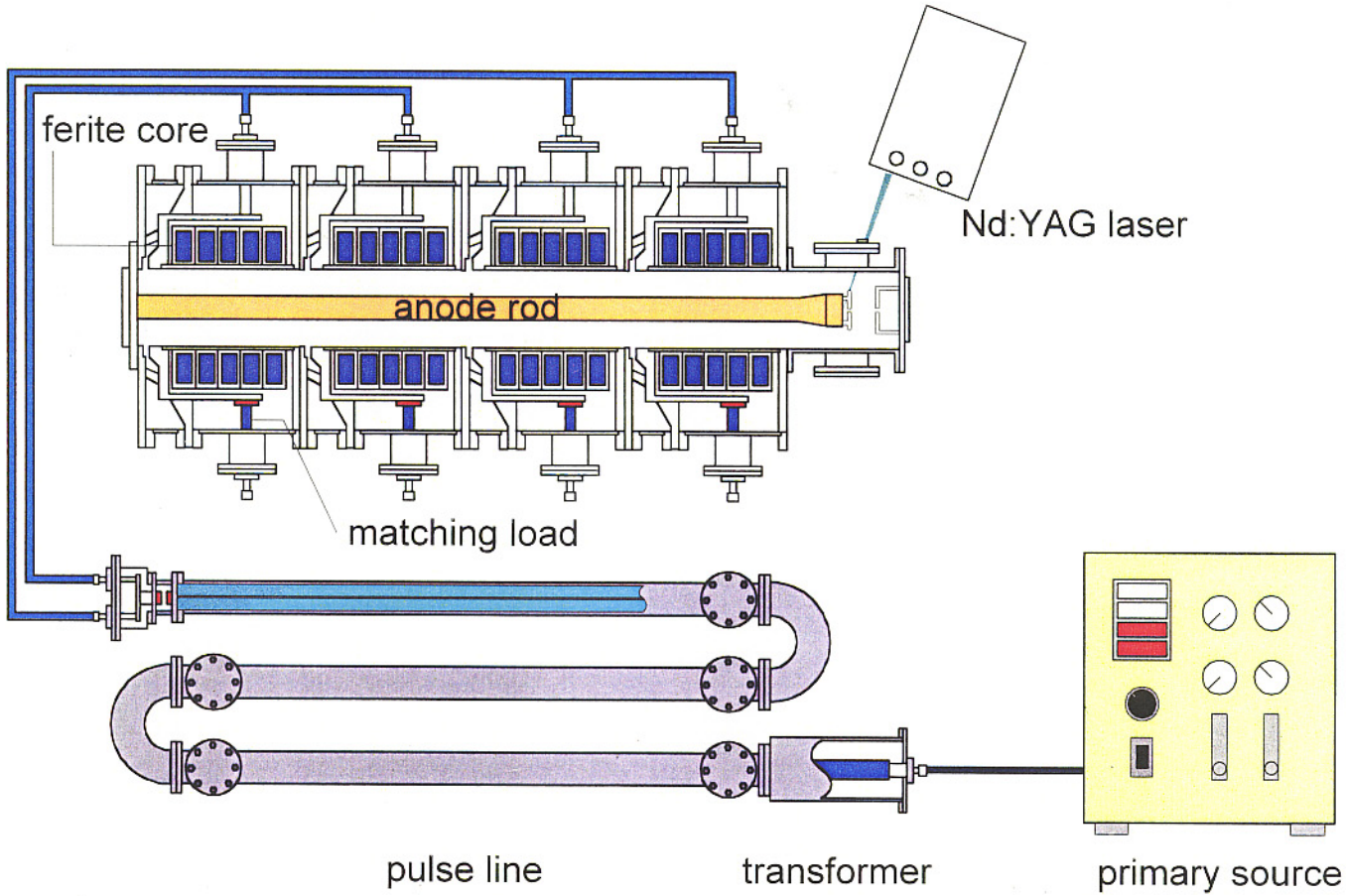
Finemet(FT-1H)



Co-based amorphous (ACO-5H)

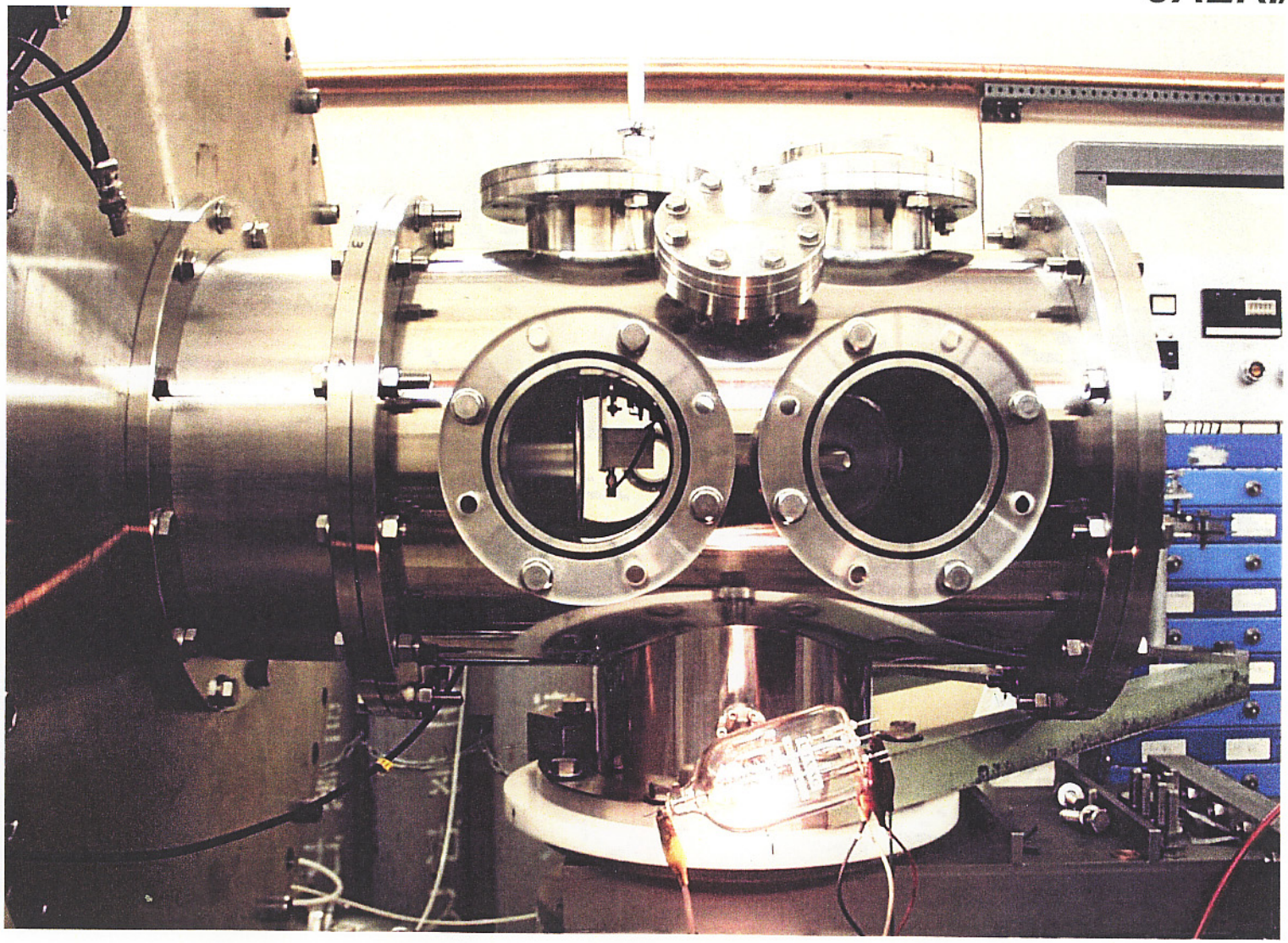


TIT Laser Drive Ion Injection -1



TIT Laser Drive Ion Injection -2

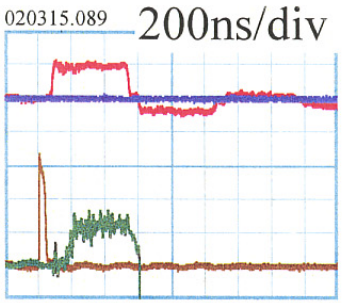
JAERI/TIT

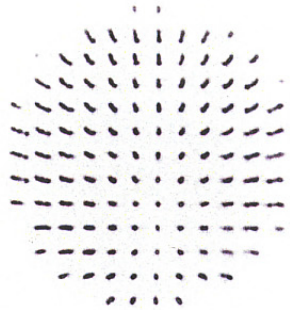


TIT Laser Ion Injection -3

JAERI/TIT

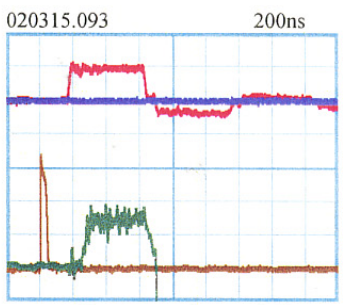
100nsec

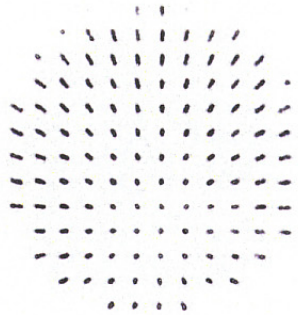




accel. 120kV/div
current 40mA/div

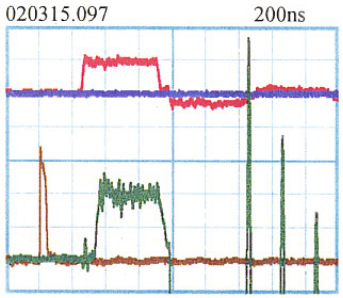
200nsec

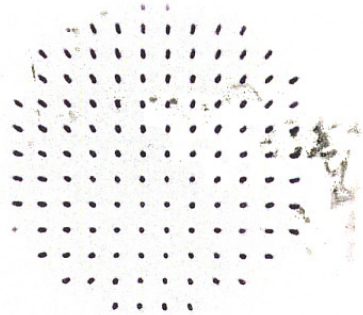




accel. 120kV/div
current 40mA/div

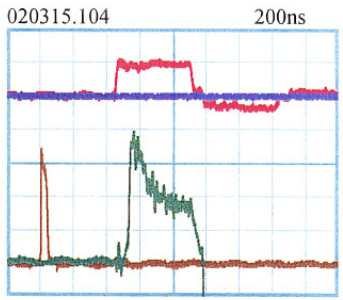
300nsec

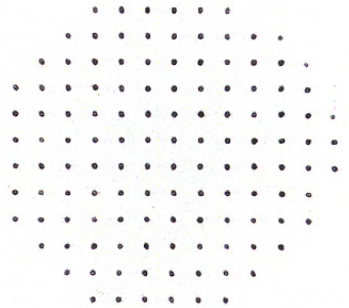




accel. 120kV/div
current 40mA/div

500nsec

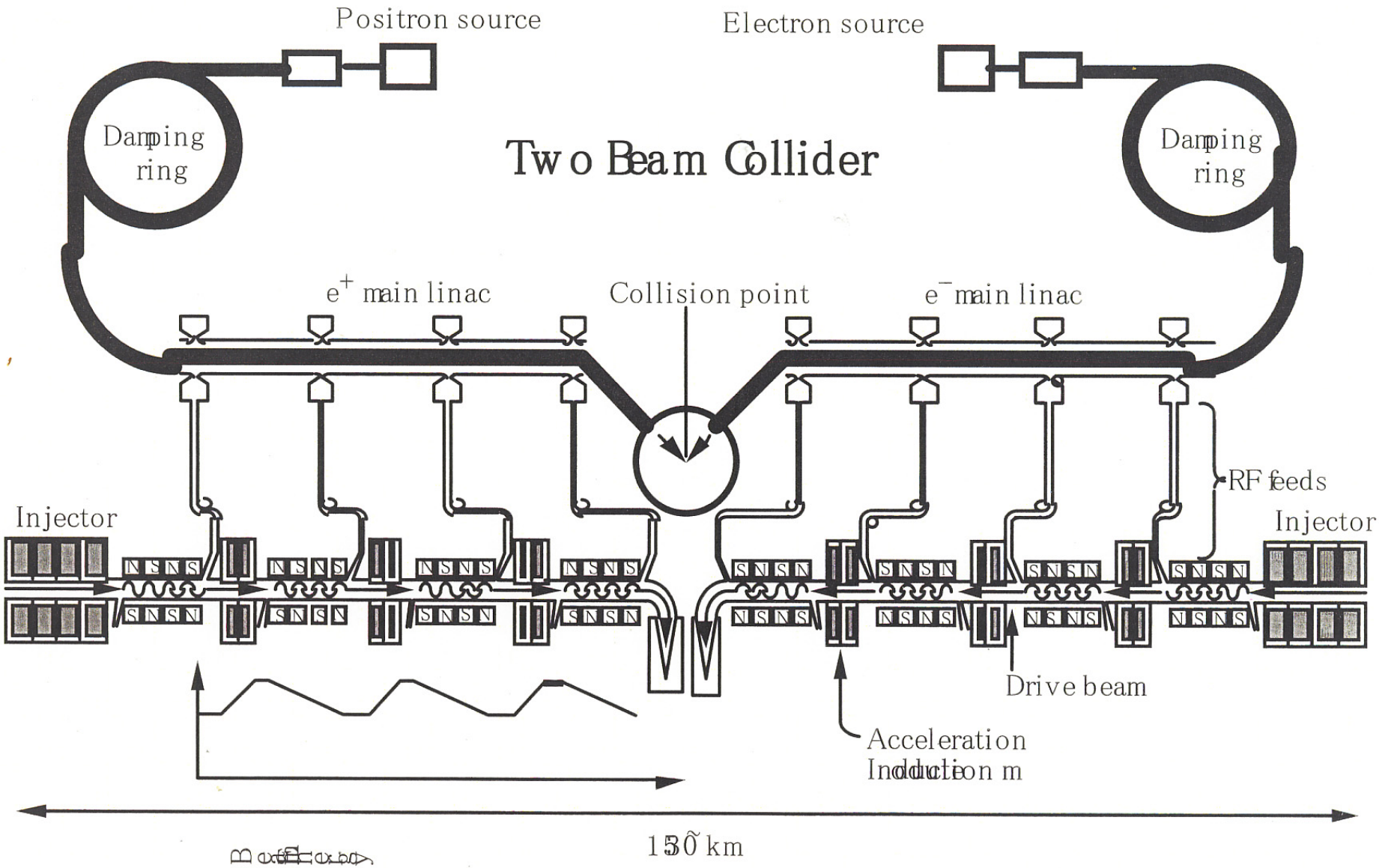




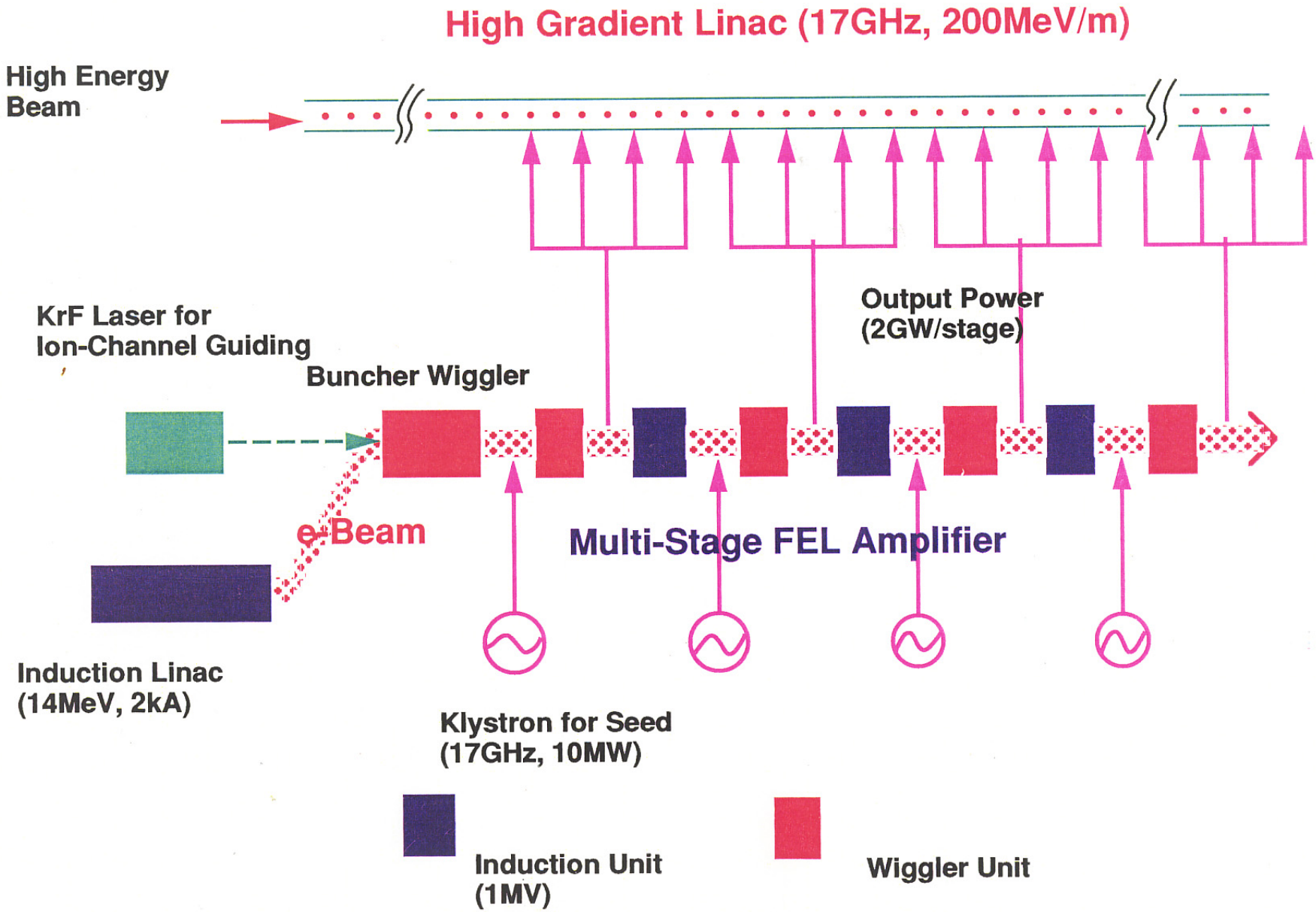
accel. 120kV/div
current 40mA/div

Two Beam Collider

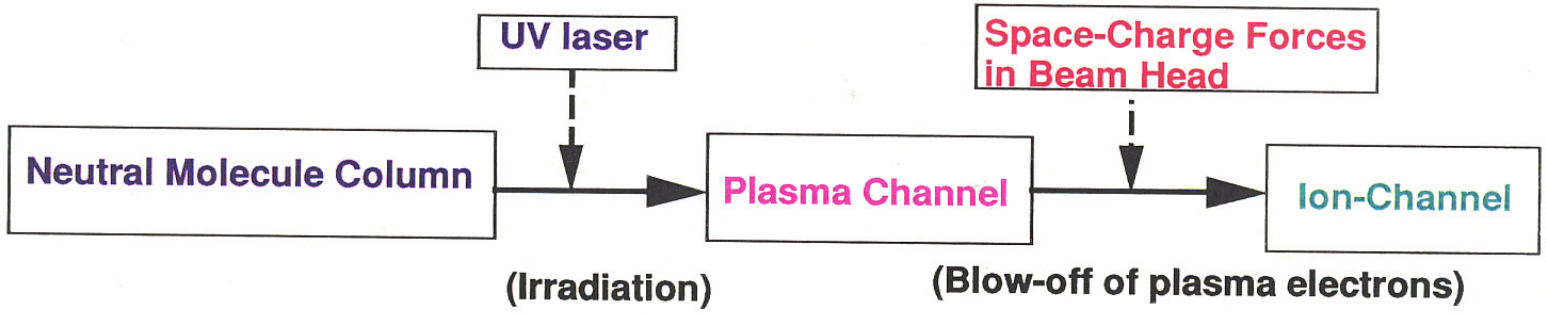
JAERI/TIT

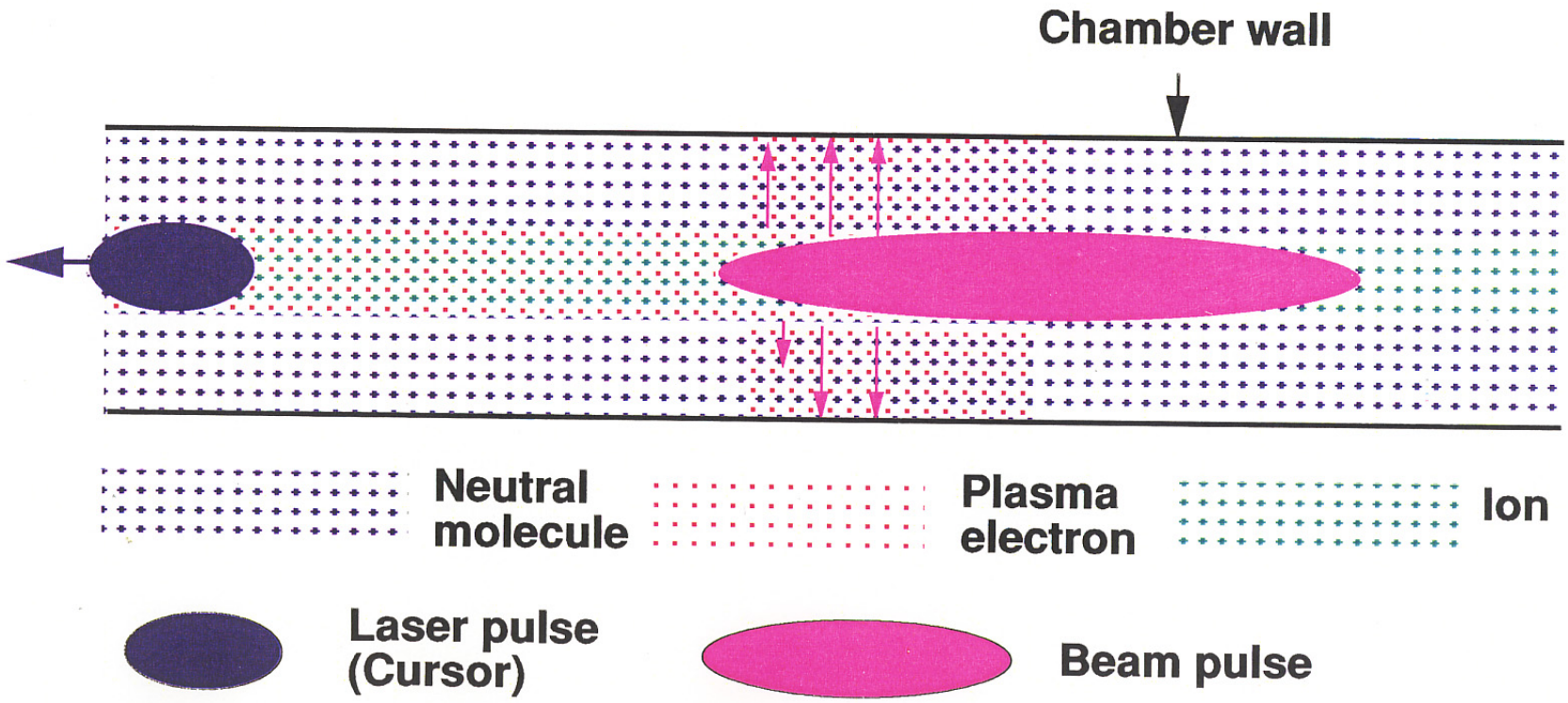


The Two-Beam Accelerator(TBA) consists of a Multi-Stage FEL Amplifier & a High Gradient LINAC



Principle of Ion-Channel Guiding





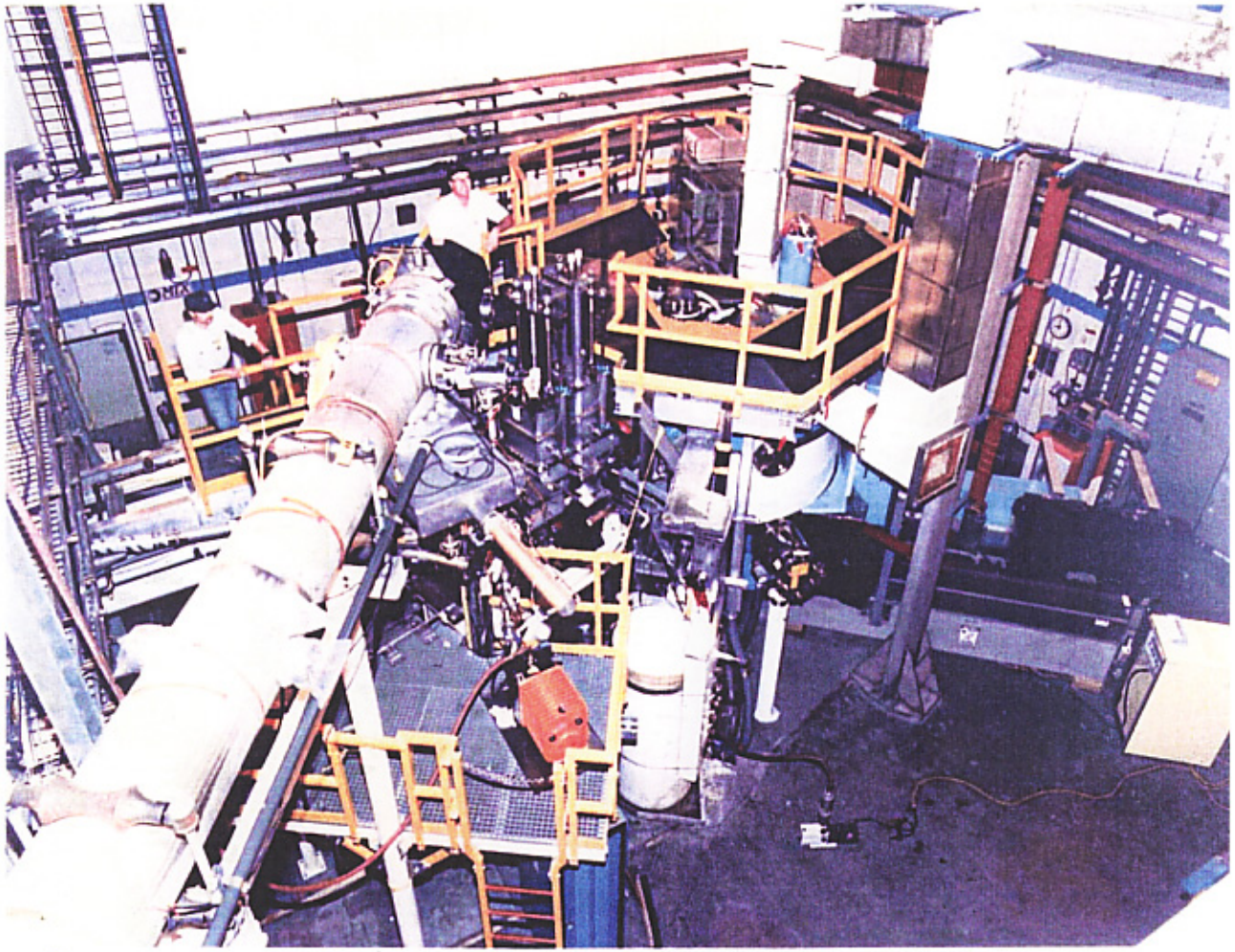
Characteristics & Parameters

- **Distingushed from other 1MeV-class μ-FELs:**
  - Ion channel guiding(ICG) from e-Gun through wiggler.
  - Eddy-current assisted planar wiggler.
  - Efficient *Over-sized* input and output couplers.

Wiggler	Period[cm]	16
	Length[m]	2.4
E-Beam	Energy[MeV]	1.5
	Current(In/Out)[A]	650/450
	Acceptance[cm rad]	0.06-0.04
Microwave	Frequency[GHz]	9.4
	Waveguide(axb)[cm]	11x5.5
	Seed power[kW]	77
	Mode	TE01
Ion-Channel	Ion density[$10^{10}cm^{-3}$]	2.0

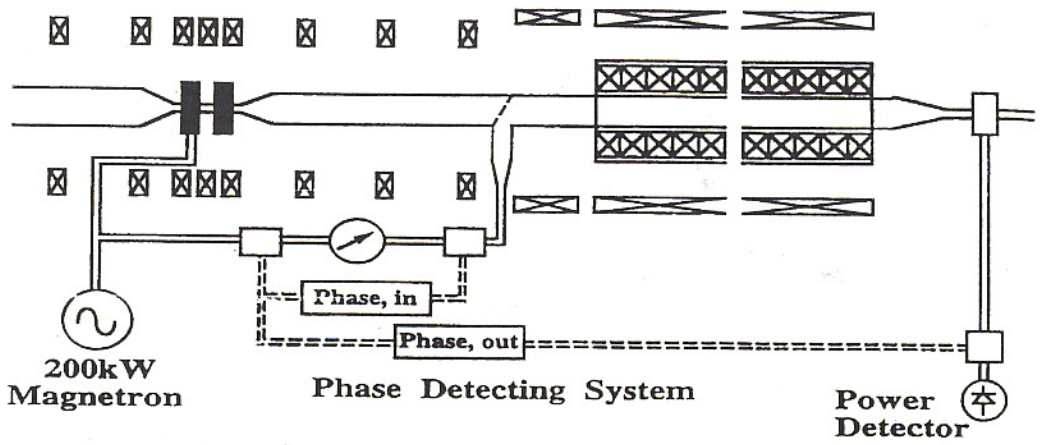
MTX Experiments

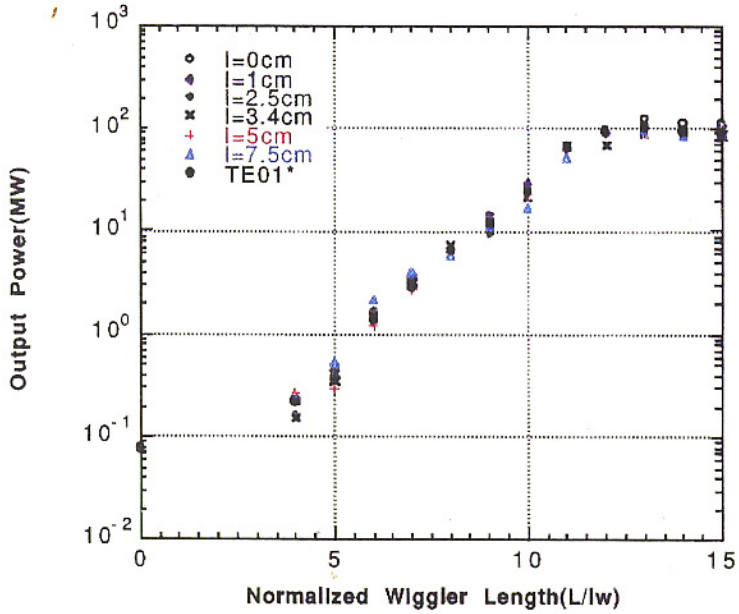
JAERI/TIT



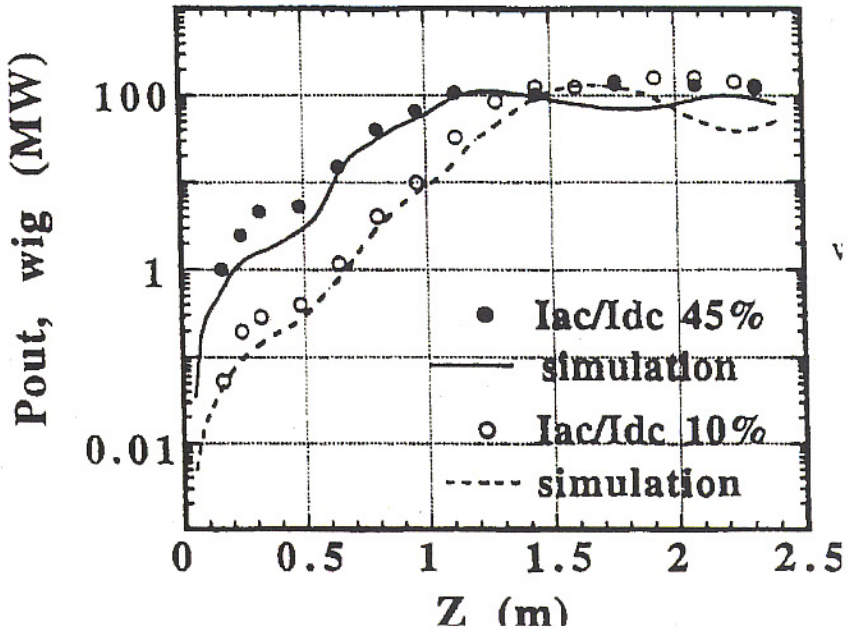
KEK Prebunched Xband FEL

JAERI/TIT





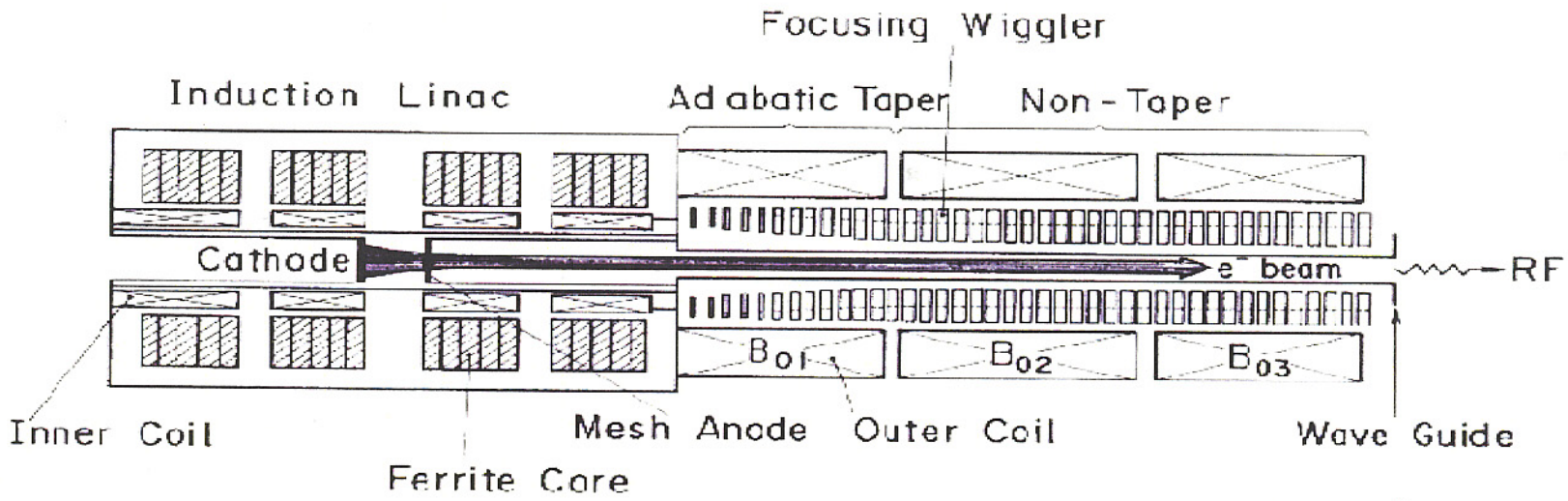
21dB/m



76dB/m

FEL System

JAERI/TIT



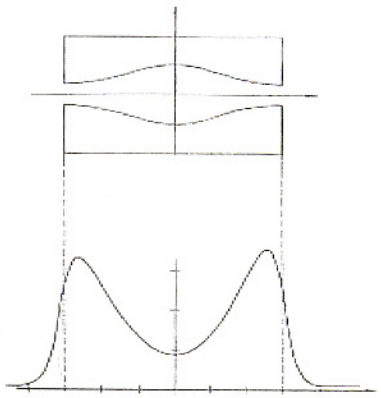
Focusing Wiggler

$B_x=(k_x/k_y)\, B_\omega \sinh(k_x x)\sinh(k_y y)\cos(k_\omega z)$

$B_y=B_\omega \cos k_\omega z \cosh(k_x x) \cosh(k_y y)$

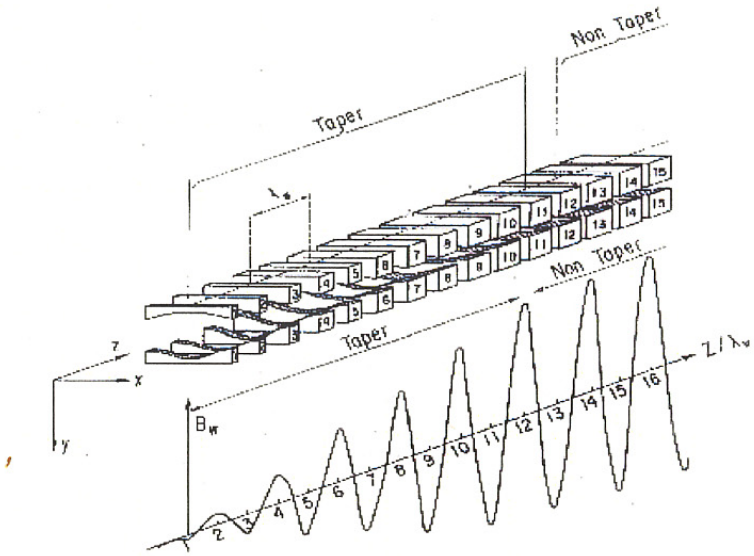
$B_z=-(k_\omega/k_y) B_\omega \cosh(k_x x) \sinh(k_y y) \sin(k_\omega z)$

$k_x^2 + k_y^2 = k_\omega^2$, k: wave number

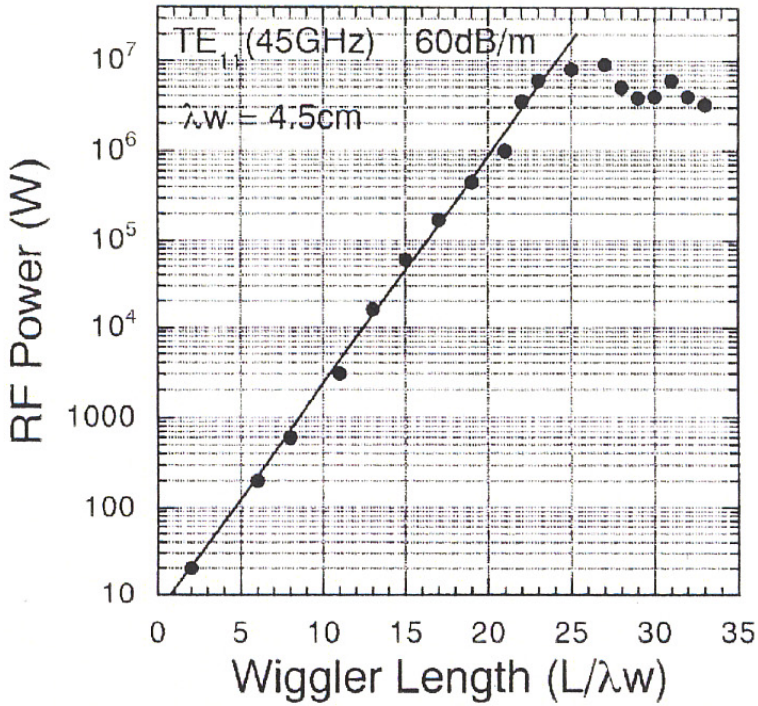


Millimeter FEL

JAERI/TIT

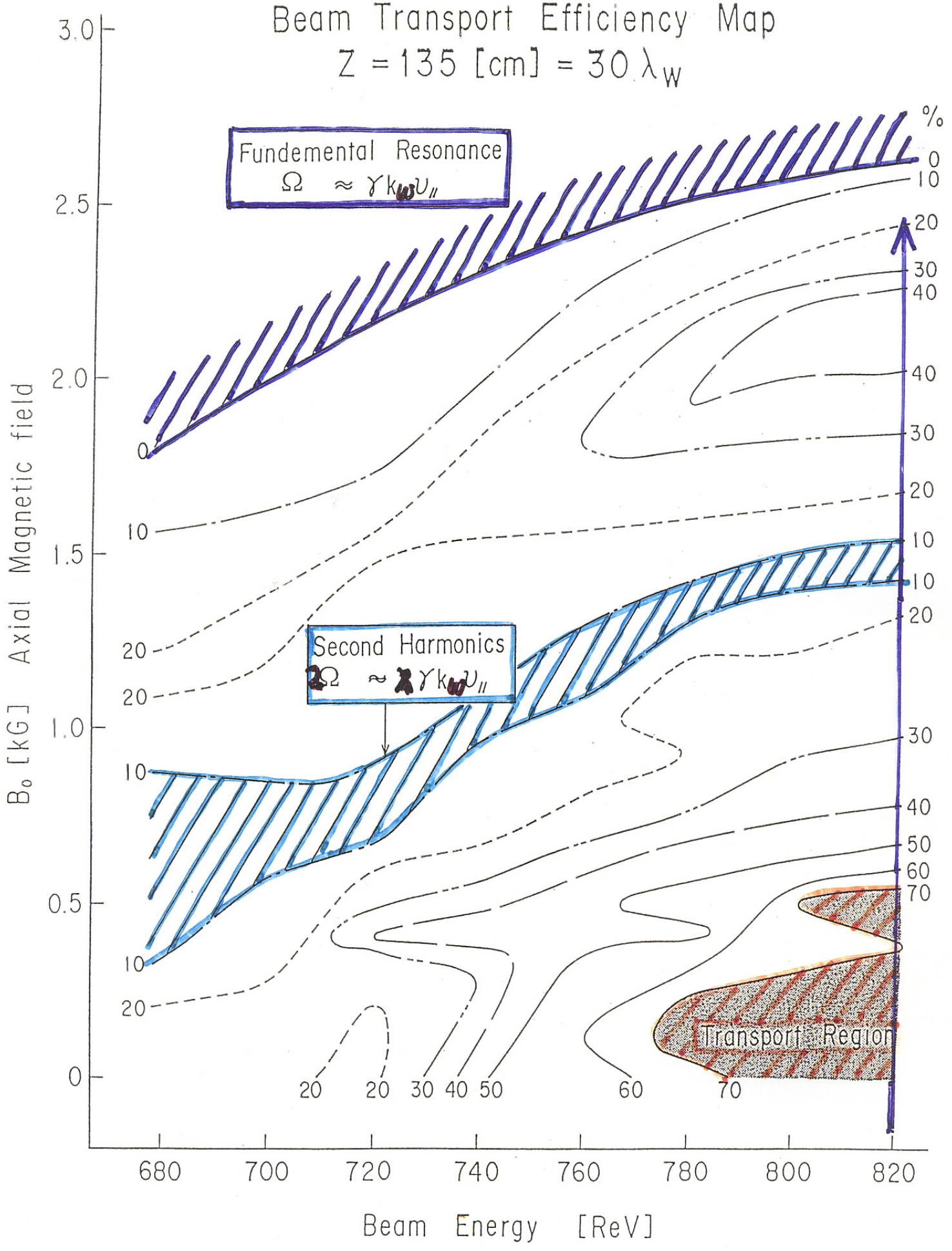


B_0=0.7 kG
$B_{\omega 0}$=1.8kG
λ_ω=4.5cm
$k_x=k_y=k_\omega$
Input Power:200W



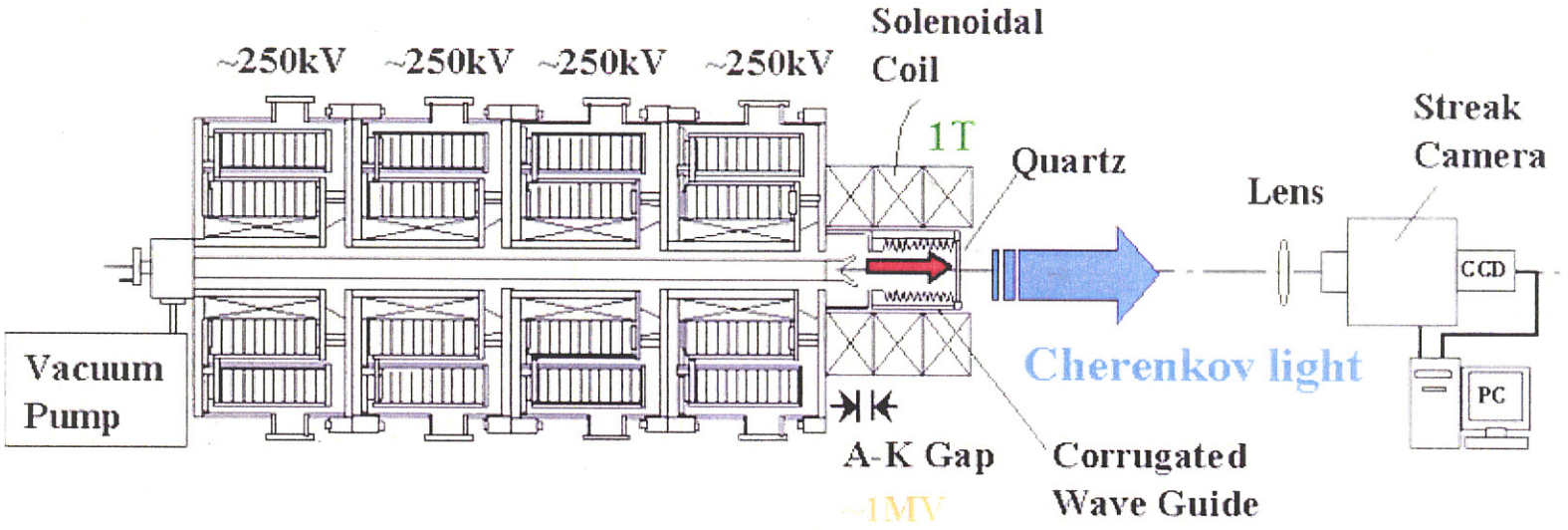
Spatial growth rate : 45dB/m
Total gain : 52 dB

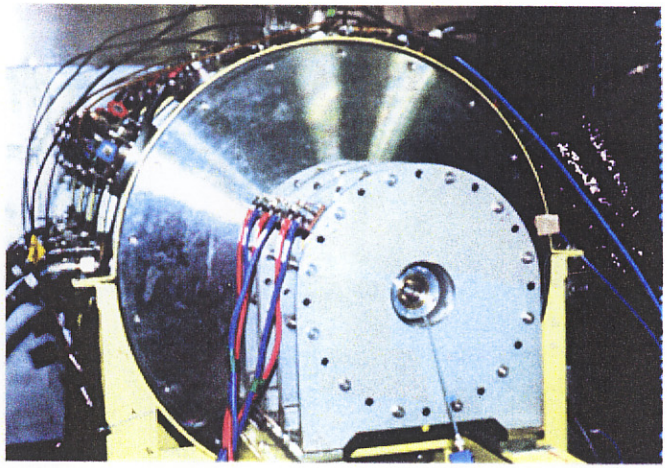
Fig.4

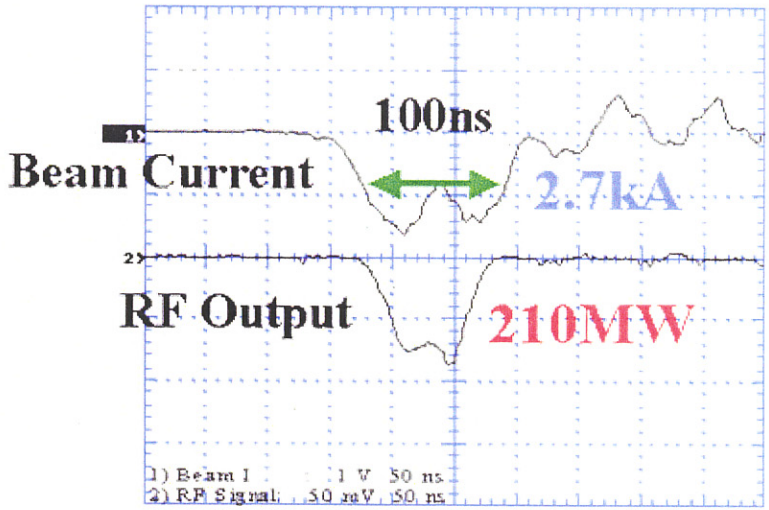

Beam Transport Efficiency Map
Z = 135 [cm] = 30 λw
Fundemental Resonance
Ω ≈ γ kw v//
Second Harmonics
2Ω ≈ γ kw v//
Transport Region
%
0
10
20
30
40
50
60
70
B0 [kG] Axial Magnetic field
3.0
2.5
2.0
1.5
1.0
0.5
0
680
700
720
740
760
780
800
820
Beam Energy [ReV]

BWO-Experiments

JAERI/TIT







BWO Experimental Results

JAERI/TIT

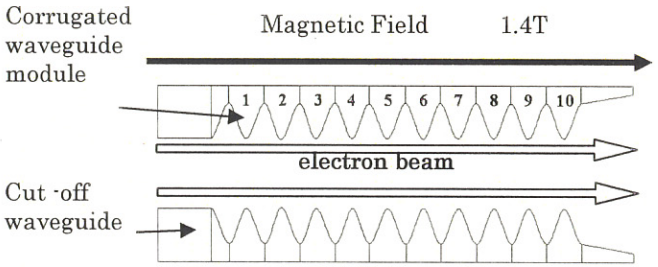


Fig.1

Fig.1 Schmatic of SWS structure. The corrugation number is changeable from1 to 10.

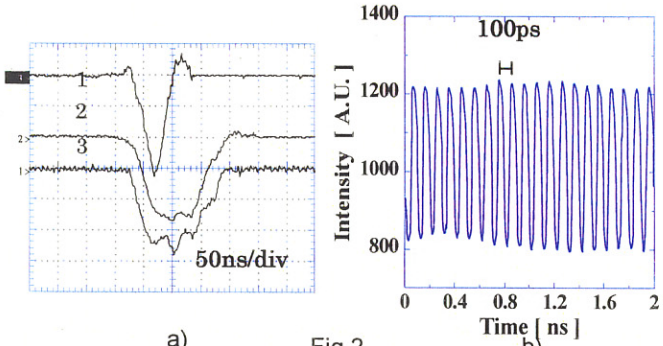
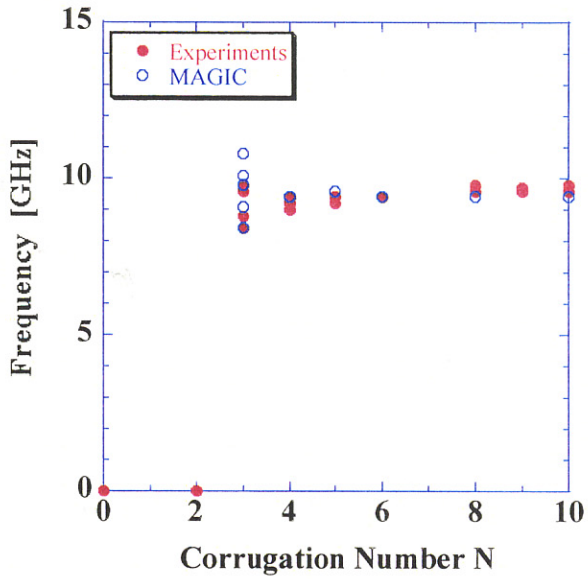
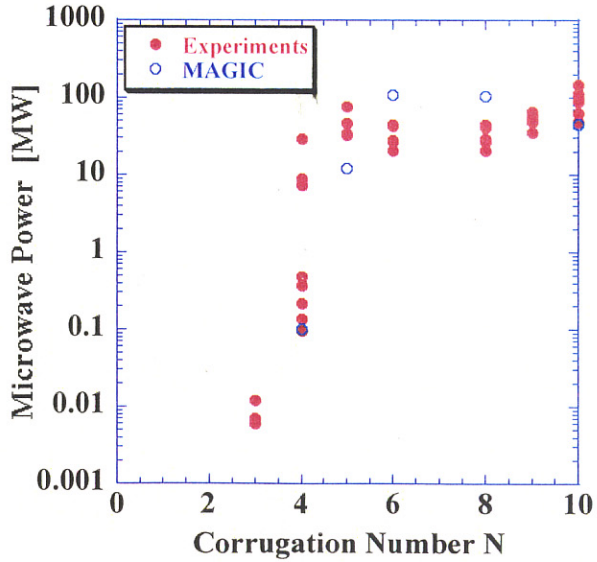


Fig.2

a) 1: Microwave power 2: Beam voltage
3: Beam current

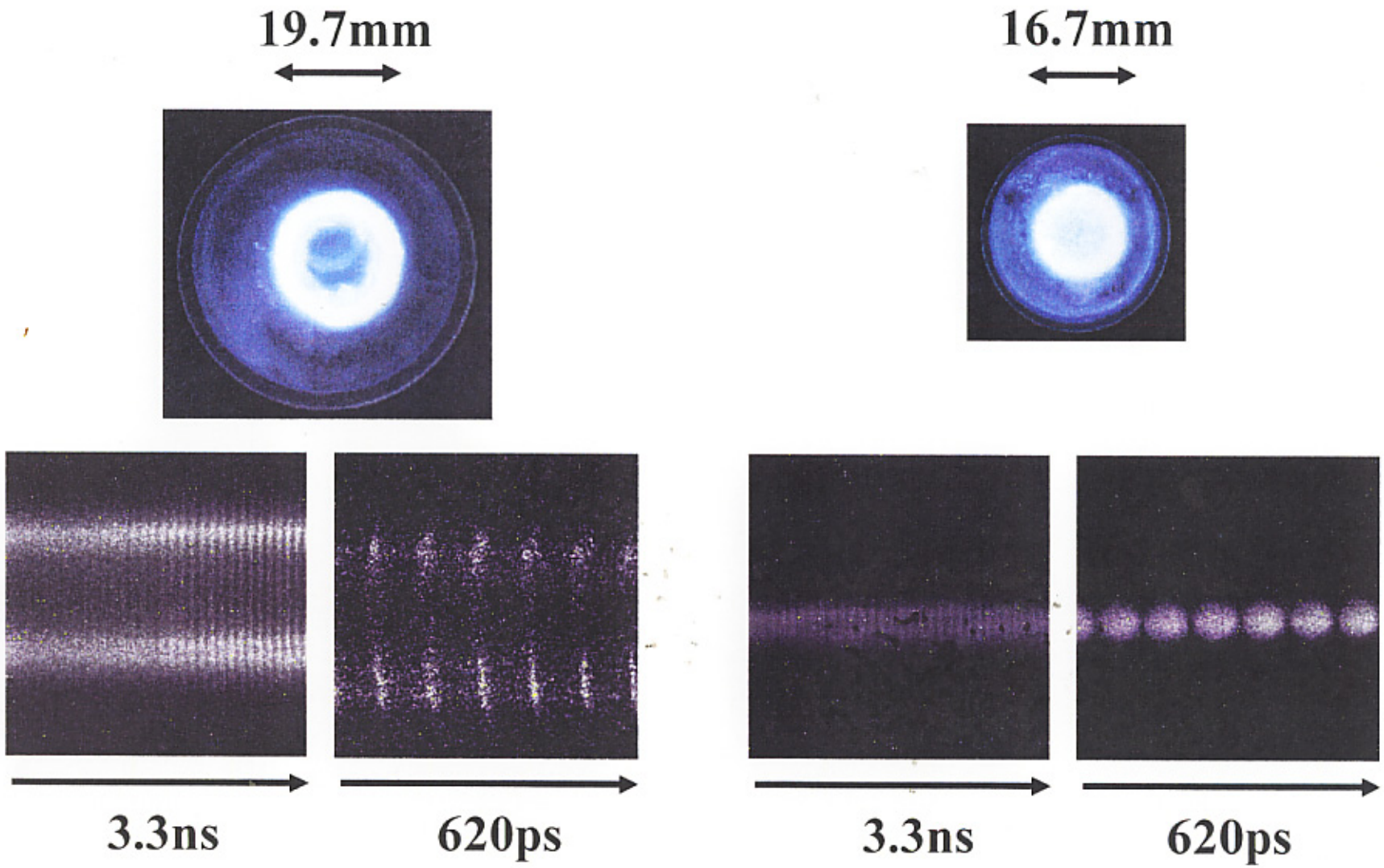
b) Microwave waveform measured by high speed oscilloscope.





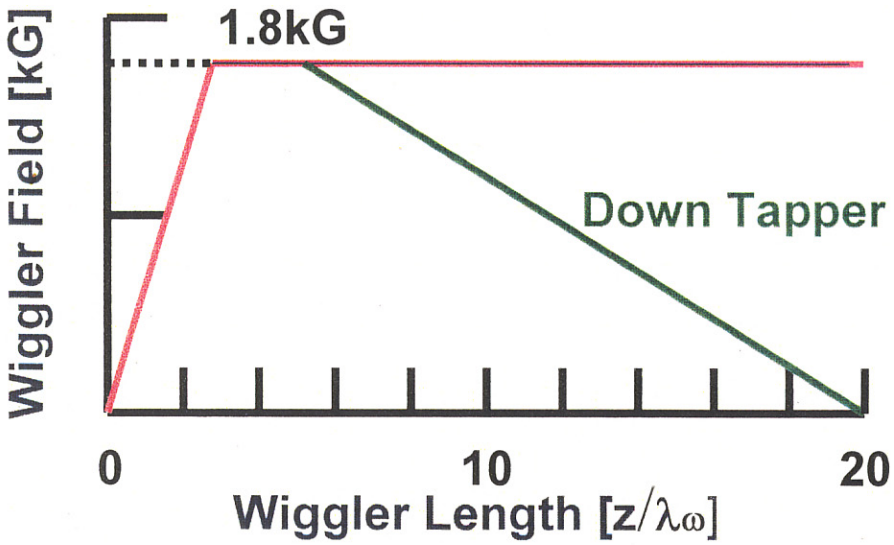
Beam Bunching by BWO

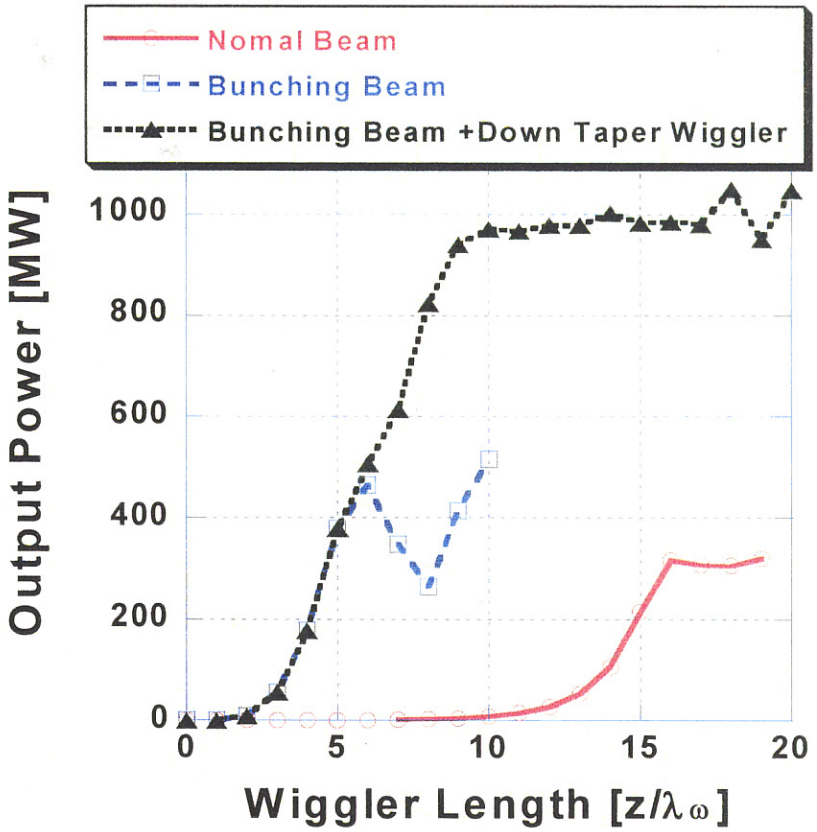
JAERI/TIT



X-band FEL Growth Simulation

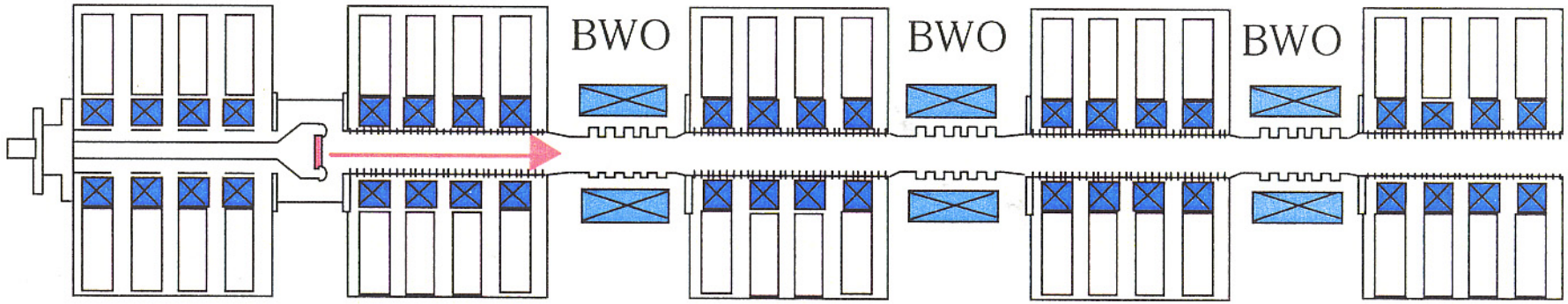
JAERI/TIT

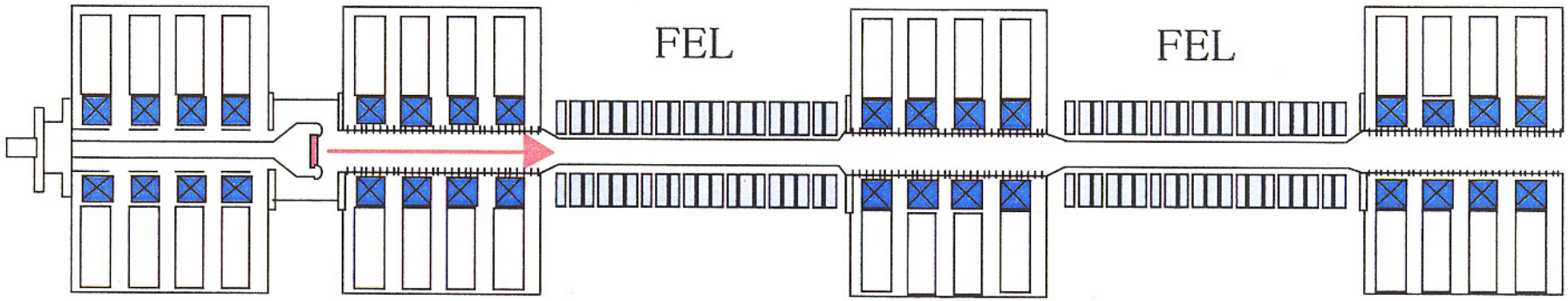




Combined Experiment

JAERI/TIT





JLA Experimental Setting JAER-KEK

JAERI/TIT