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Electron Accelerator Complex at Tohoku University, 42-Year-Operation and Future

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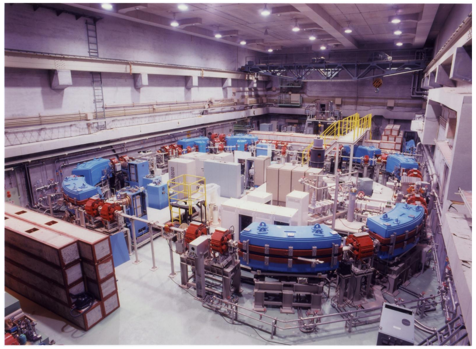
outline

- introduction about the facility
  History (How We Did Business)
- present status
  - operation status
  - machine status (feature and difficulties)
- machine improvements
- future prospects
- summary

facility introduction (since 1966)

Laboratory of Nuclear Science (LNS),
Faculty of Science
established in 1966



first pulse-neutron generation
pulsed neutron source (1971 ~ 1994)
M. Kimura , NIM 71, 102 (1969)

1.2 GeV Booster Synchrotron
STB ring (since 1997)
hadron phys. by GeV - γ

present

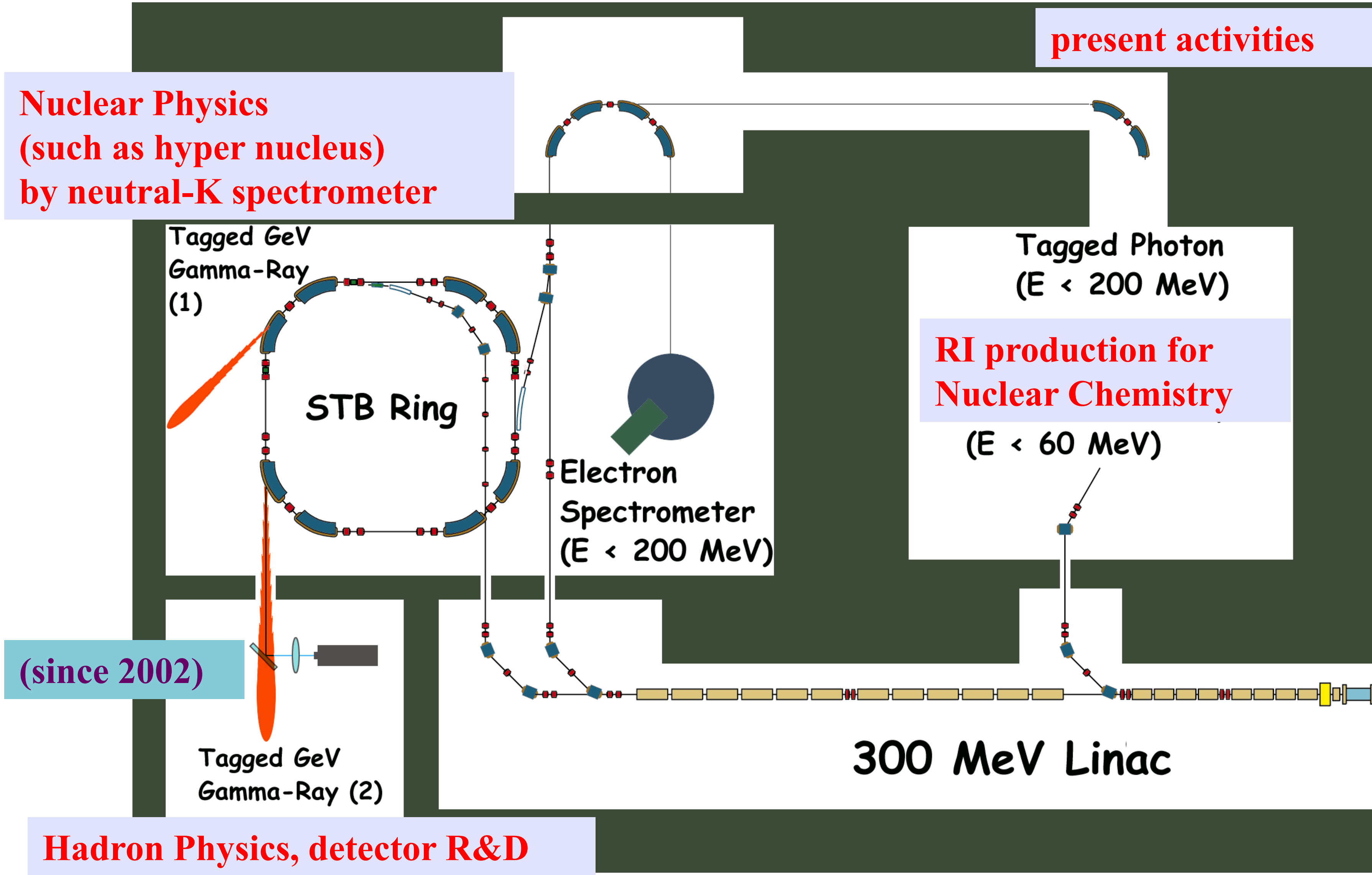
300 MeV Electron Linac
(since 1967)
42-year-old

nuclear phys. by c.w. e-beam
150 MeV pulse stretcher (1981 ~ 1994)
T. Tamae , NIM-A 264, 173 (1988)

first observation of coherent SR
T. Nakazato *Phys. Rev. Lett.* 63 1245, (1989)

Research Center of
Electron Photon Science
target : user facility opened
for worldwide
reorganized in 2009

Experimental Halls and Accelerators



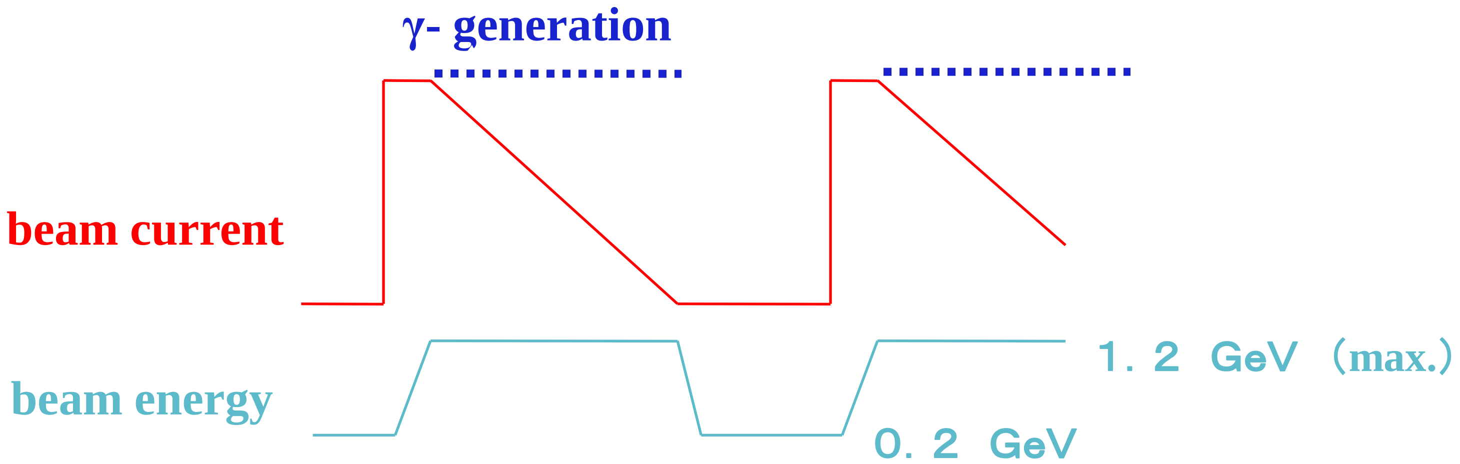
1.2 GeV Booster Synchrotron (STB ring)

Stretcher mode (slow extraction with 3rd-resonance)

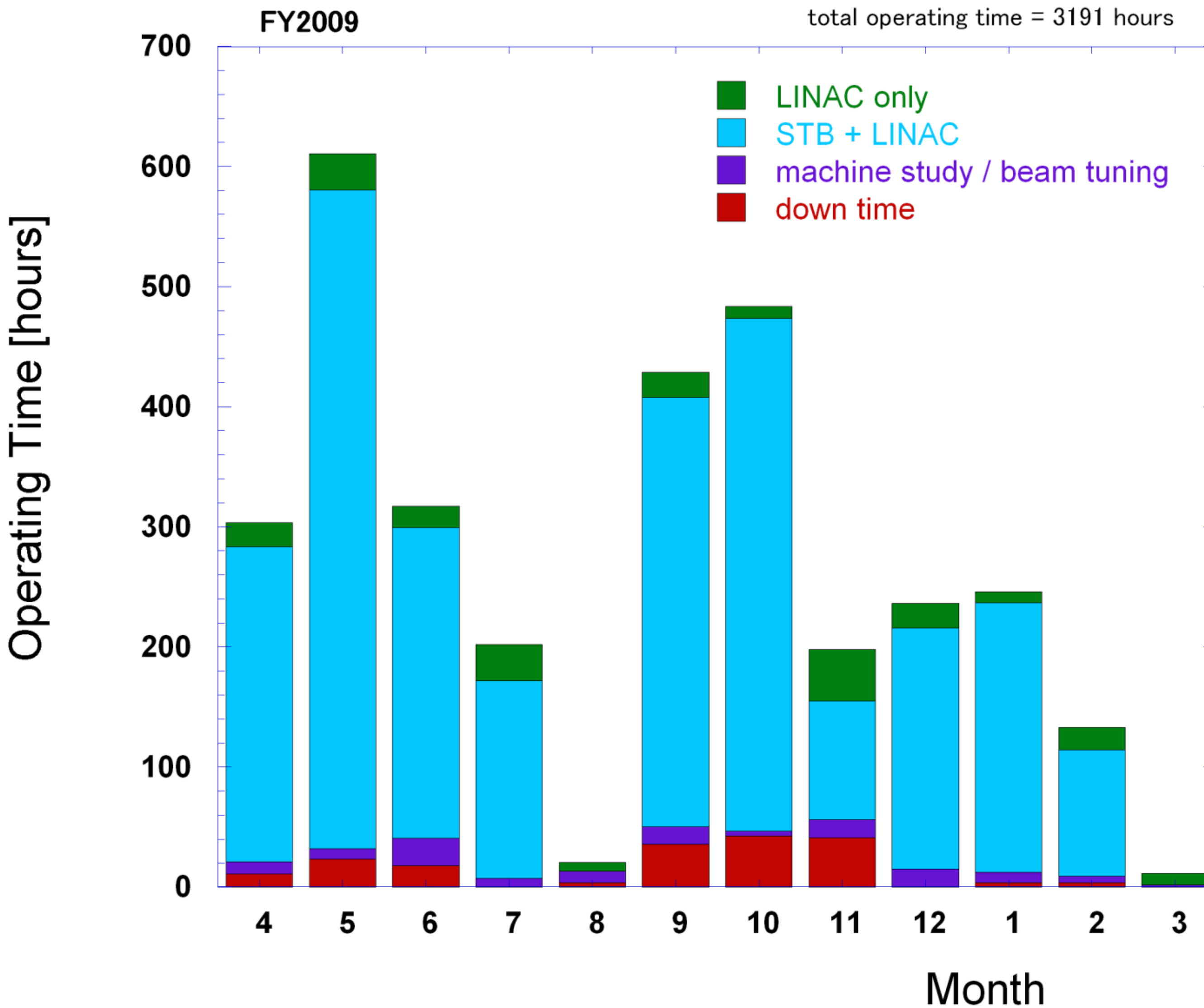
Convert pulsed beam to c.w.-beam (Eb = 140 ~ 200 MeV)

Booster (storage) mode

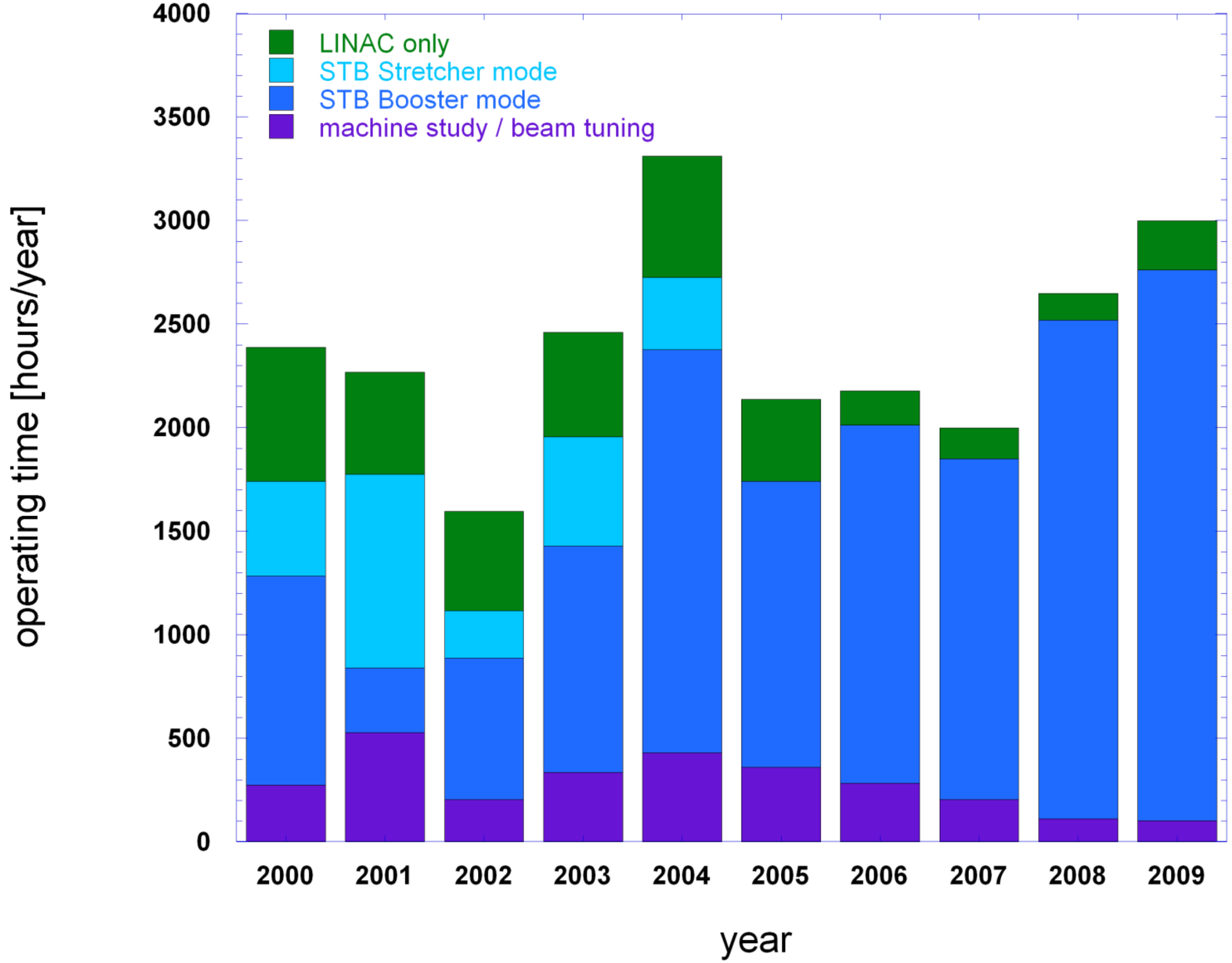
- Injected beam with the E_b = 150 or 200 MeV is ramped up to 1.2 GeV (max.) in about 1 second.
- After the consumption of circulating beam due to high energy gamma-ray generation via bremsstrahlung, beam injection is repeated.
  (radiator : 10 μm carbon fiber)



operation status in FY2009



record of beam operating times



machine status (features & difficulties)

300 MeV Linac

20 acc. structures driven by 5 klystrons.
typical energy = < 50 MeV (for low-energy mode)
150 ~ 200 MeV (for high-energy mode)
300 Hz repetition (max) → High average current (~150 μA)

1. Very very old (since 1967) with essentially no-update
   → vacuum leak, much trip rates in modulators,
   old modulators make a wide energy spread
2. Poor design of the injector part and no well-considered beam optics
   → give a lot of beam loss, large beam emittance (200 mmmrad)
   low BBU threshold (<100 mA), poor beam monitors

1.2 GeV Synchrotron

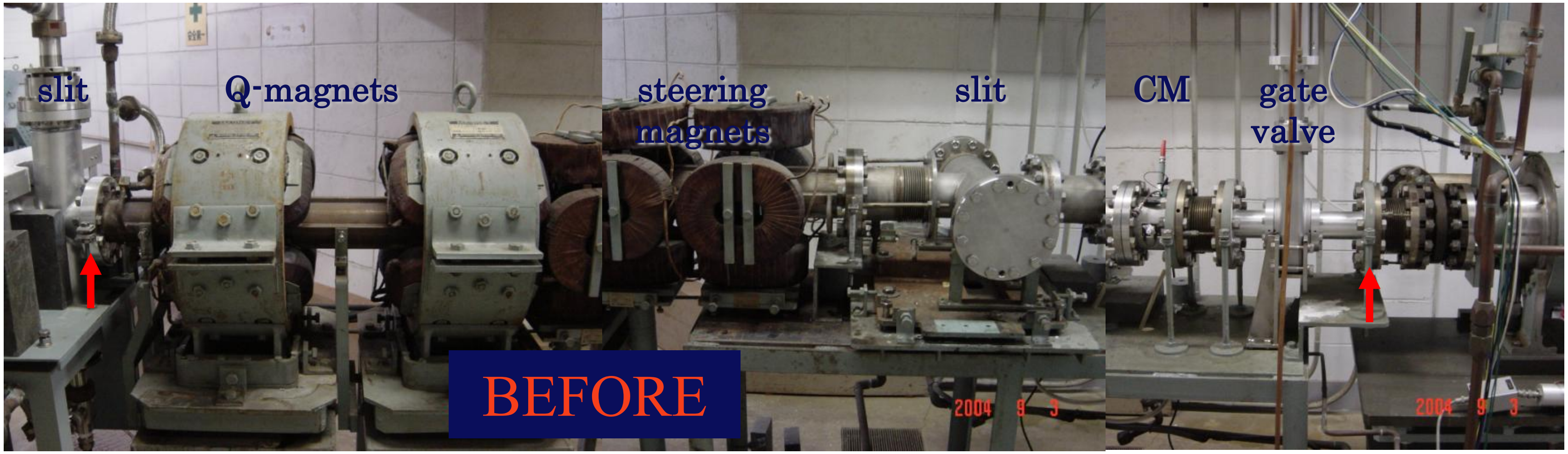
One linac burst gives 20~30 mA.
Ramp-up time ~ 1 sec. @1.2 GeV

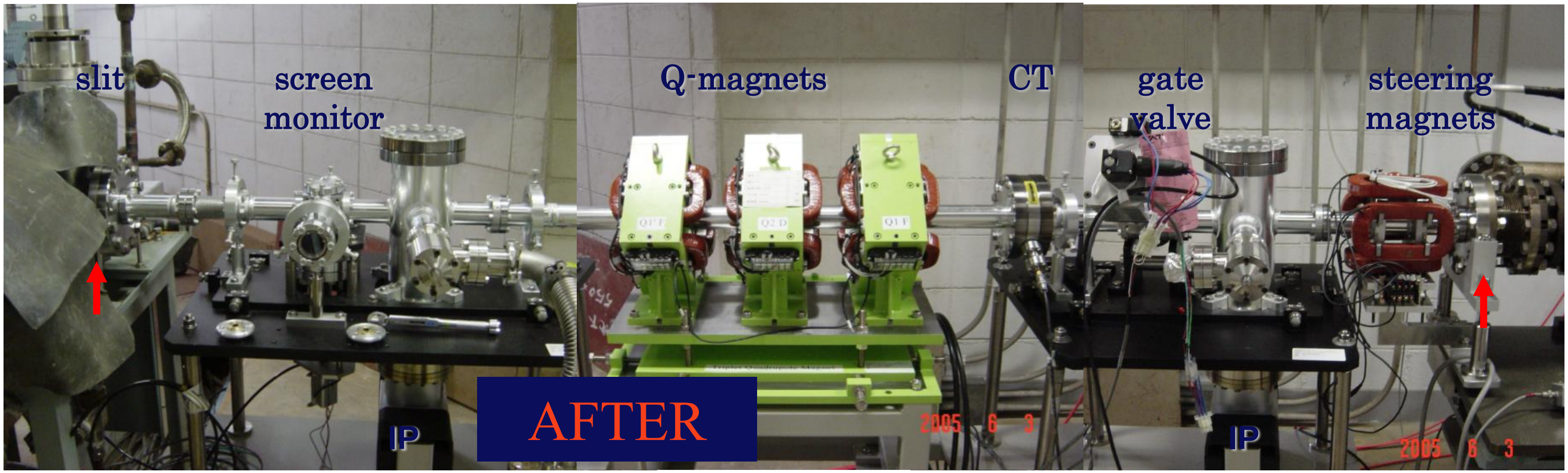
1. Poor vacuum → lifetime ~10 min.@1.2GeV
2. High ring impedance (may be |z/n|=100 Ω) → microwave instability
3. Many HOMs in a used cavity → Serious coupled-bunch inst.
4. No chromatic sextupole !! → a lot of problems

machine improvements

- replacement of LINAC beam line (still under progress)
  installed more IPs and beam monitors
  → improved vac. performance, beam tuning work
- replacement of a component in DC-gun power supply
  IVR → inverter power supply
- replacement of some components in a LINAC modulator (still under progress)
  IVR → inverter power supply
  old thylatron (F-175) and driver → CX2411
- replacement of controller for synchrotron magnet power supplies

replacement of linac beam-line





machine improvements

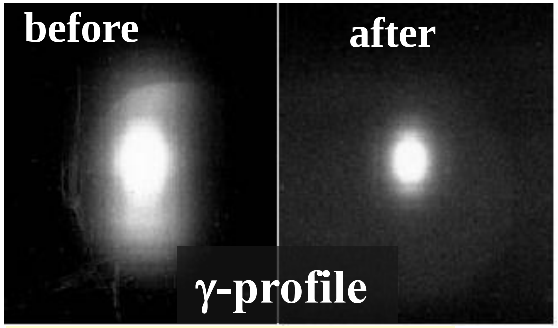
- replacement of LINAC beam line (still under progress)
  installed more IPs and beam monitors
  → improved vac. performance, beam tuning work
- replacement of a component in DC-gun power supply
  IVR → inverter power supply (improved reliability)
- replacement of some components in a LINAC modulator (still under progress)
  IVR → inverter power supply
  old thylatron (F-175) and driver → CX2411
  suppressed the down time
- replacement of controller for synchrotron magnet power supplies (almost completed)

progress in machine operation

- **establishment of operation parameters**
  There are many operation modes depending on user.
  shorten the beam tuning time

- **introducing lattice modification for the 2nd GeV-γ beam line**
  huge spread of γ-profile and poor tagging efficiency

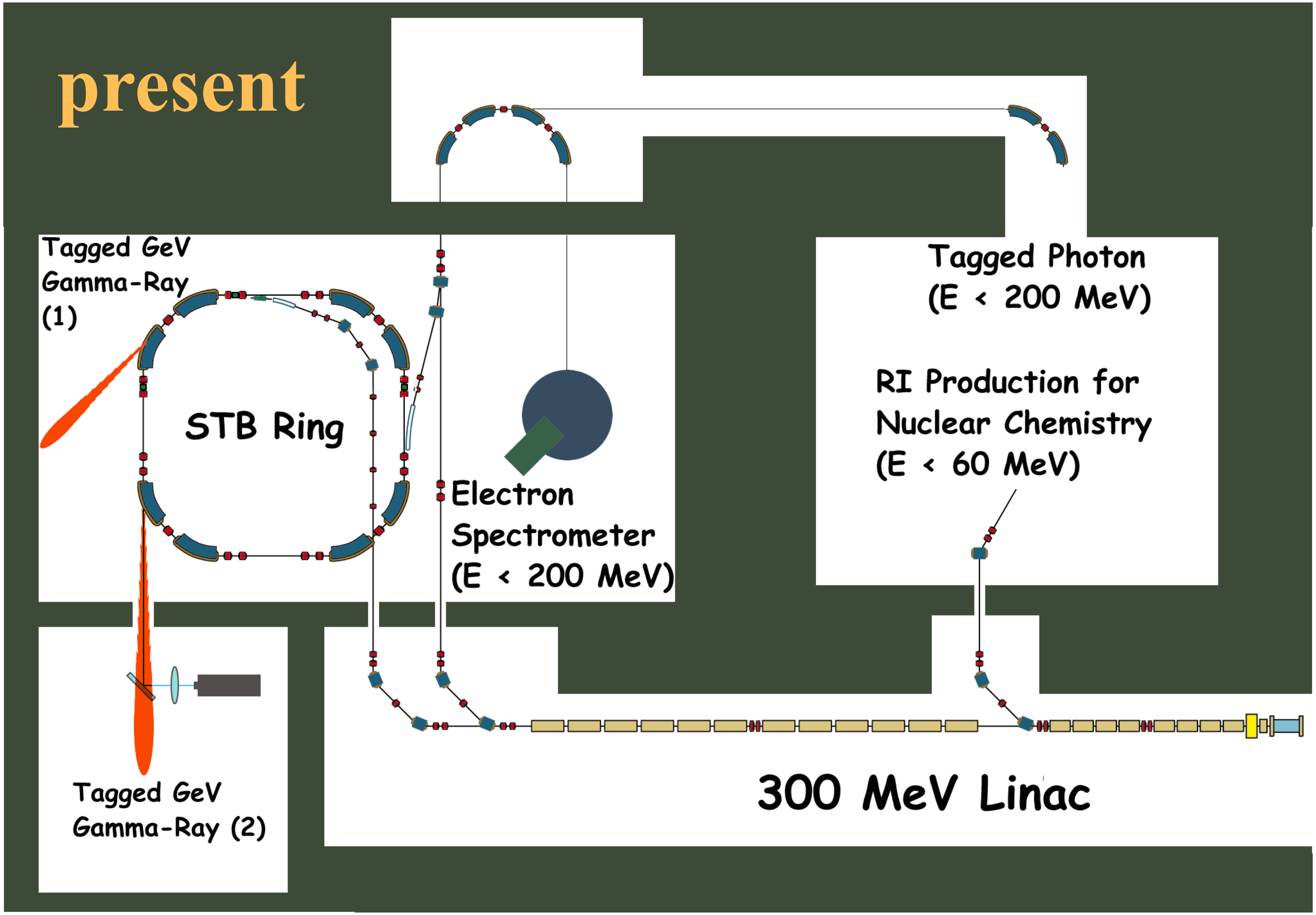
  improvement of γ-ray beam quality and tagging efficiency (ε = 20 → 80 %)
  (PAC'05 by F. Hinode et.al.)



- **transverse phase space manipulation by a mono-frequency RFKO in stretcher-mode operation**
  quasi-CW beam for nuclear physics (e^- scattering exp.)

  emittance reduction for extracted beam (PAC'05 by A. Miyamoto et.al.)

upgrade plan of injector



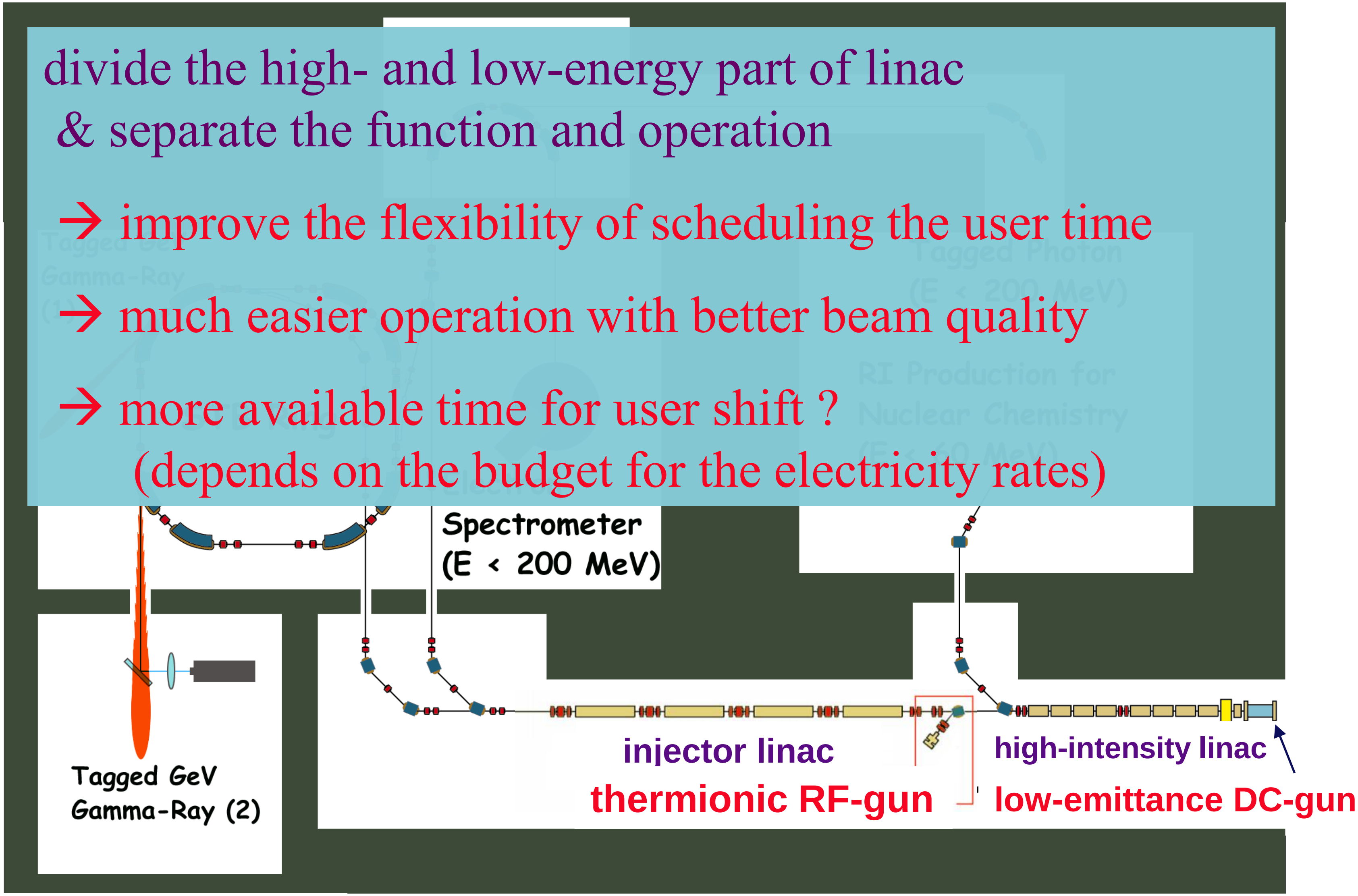
upgrade plan of injector

divide the high- and low-energy part of linac
& separate the function and operation

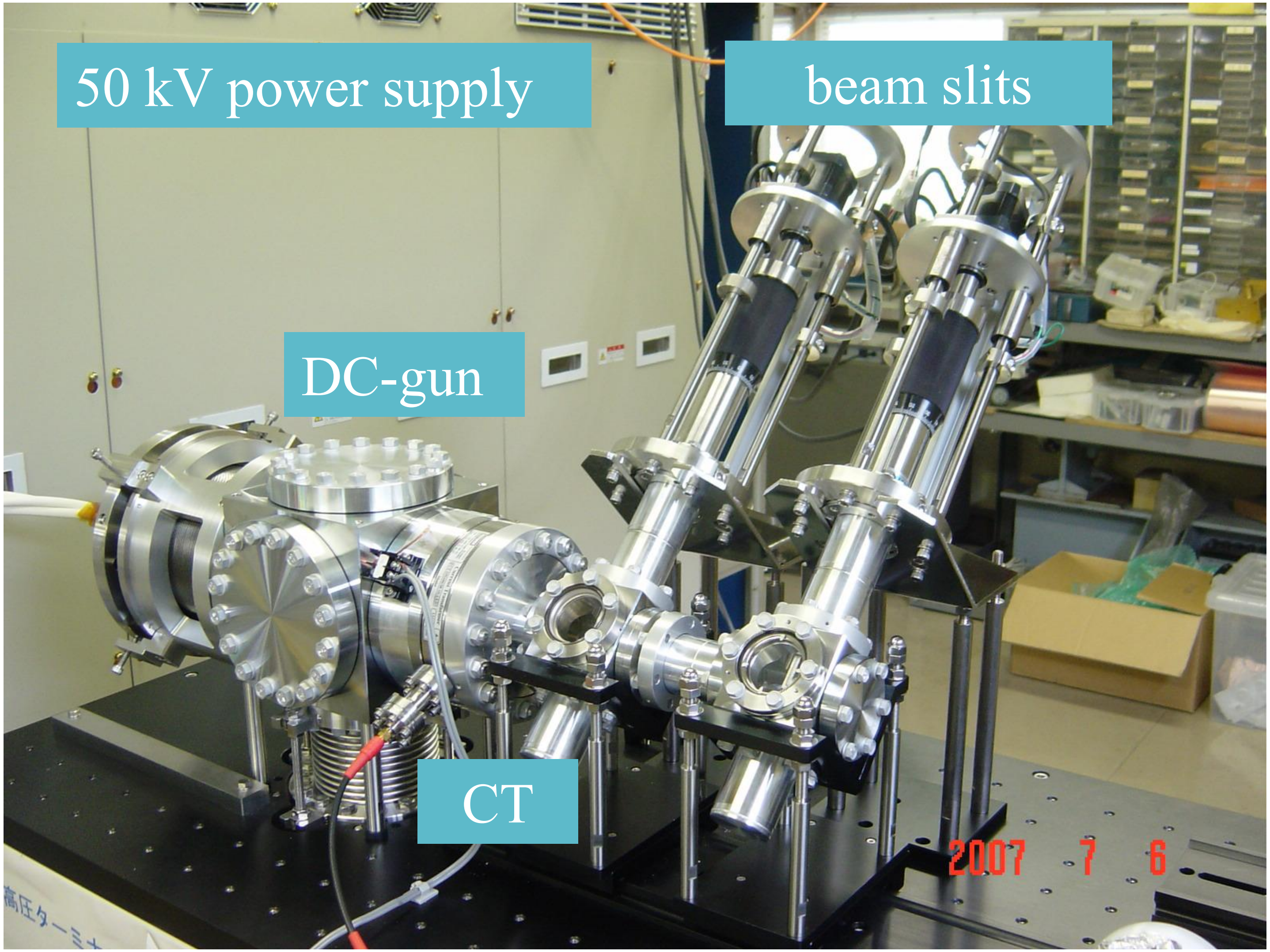
→ improve the flexibility of scheduling the user time

→ much easier operation with better beam quality

→ more available time for user shift ?
(depends on the budget for the electricity rates)



Low Emittance DC-gun



Design parameters of DC-gun

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	Design	Measured
Beam energy (acceleration voltage)	**50 keV (Max.)**	**← OK**
Electron beam current	**> 300 mA**	**← OK**
Pulse width (FWHM)	**1-5 μsec**	**← OK**
Repetition rate	**300 pps (Max.)**	**← OK**
Normalized emittance	**<5π mm mrad.**	**<2π mm mrad**
Normalized thermal emittance	**0.25 π mm mrad.** (*theoretical)	—
LaB_6 Cathode diameter	**1.75 mmφ**	**←**

Low Emittance DC-gun

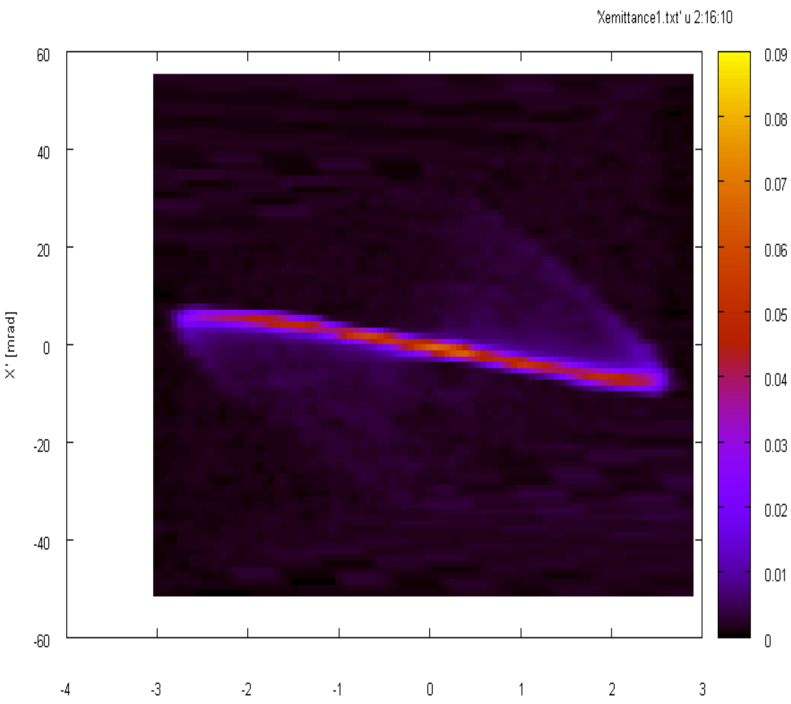
Phase space from double slit measurement

HV : 50 kV

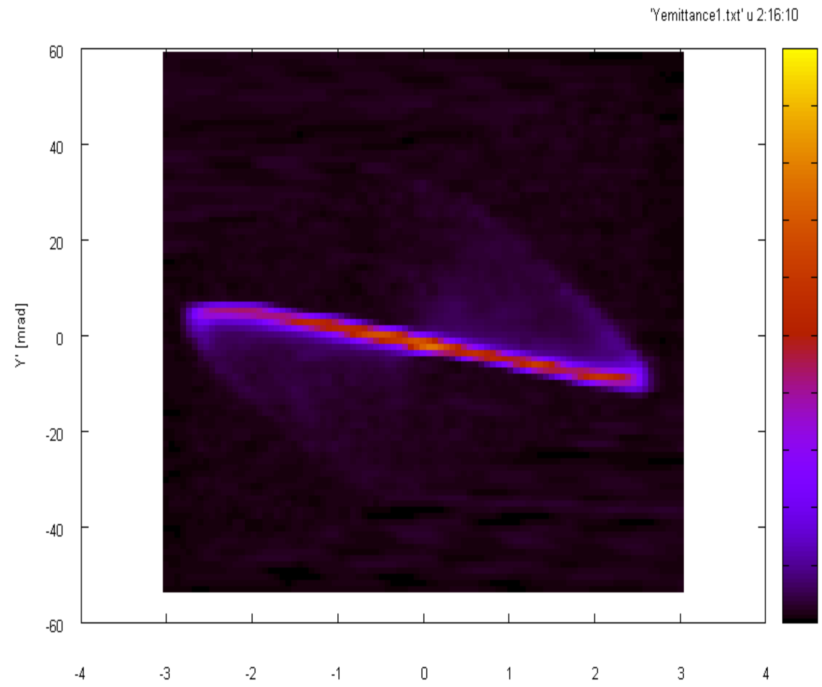
Beam current : 492 mA

Heater current : 8 A

Solenoid current : 3.2 A



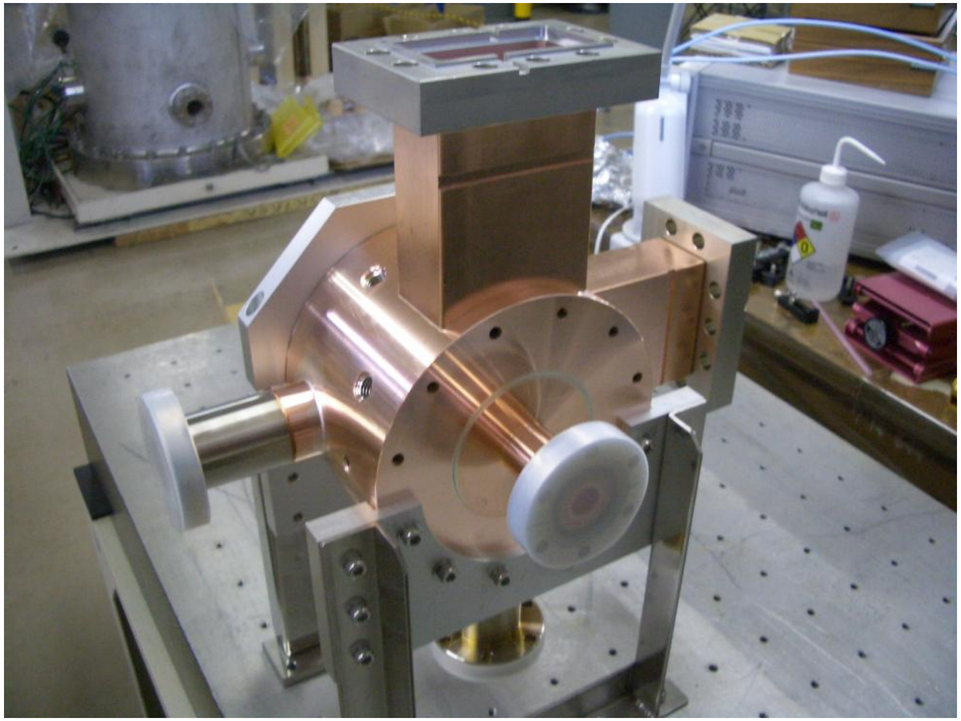
Horizontal X(mm)



Vertical Y(mm)

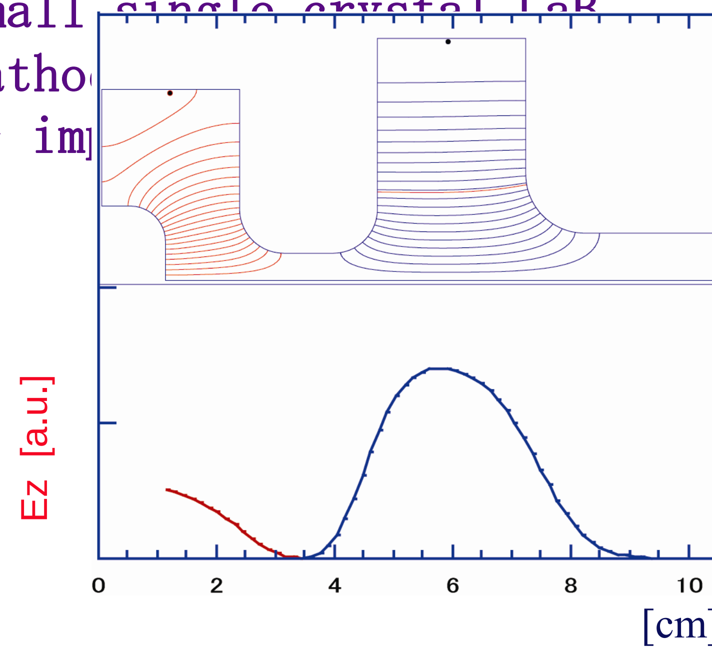
Norm. emittance ＜ 2πmm mrad

Independently Tunable Cells RF-Gun



ITC RF-Gun

- uncoupled two cells with each other
  → manipulation of phase space dist.
- small single crystal LaB catho
  → im



Why thermionic RF Gun ?

Simple ! No buncher. No high-voltage stage

Back-bombardment effect can be acceptable by introducing small size cathode and short macropulse operation.

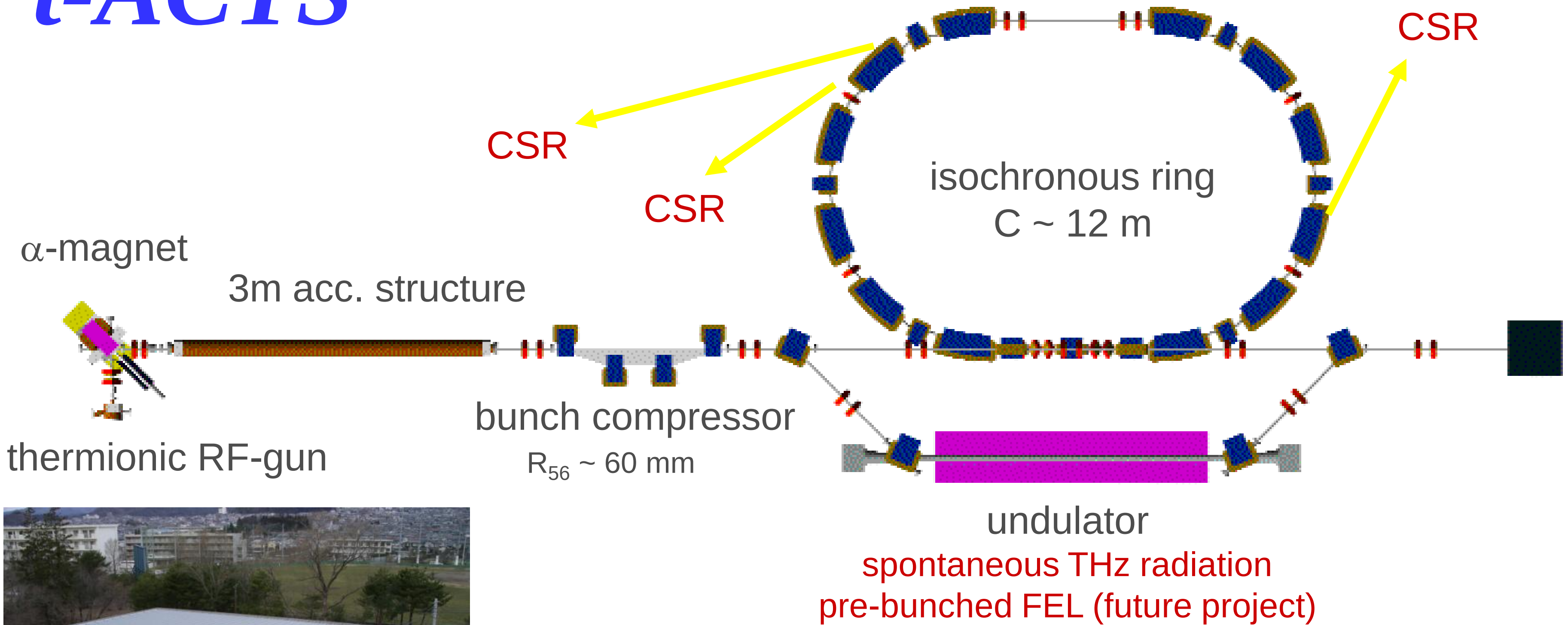
summary

- User group takes over the beam operation from the accelerator staff after the beam tuning.
  → to be reliable and stable,
  preparation of manuscripts of the trouble-shooting for user,
  otherwise down-time ...
- continuing the machine maintenance
  progressing in R&D work for upgrade and new fields
- towards the further prosperity, aiming at the user facility authorized by the government

Both efforts would be important
to keep and/or develop the machine performance as high as possible,
and the same time to get the more budget.
(Presently, the machine time has been mainly limited by budget for the electricity rates.)

test Accelerator as Coherent THz Source

t-ACTS



end

Present performance of the STB ring

Stretcher Mode

Energy region	140 – 200 MeV
Beam current at injection	~100 mA @0.2 GeV
Repetition rate	300 pps (max.)
Extracted beam current	＞ 1 μA
Duty factor	＞ 90 %
Extraction efficiency	＞ 50 %

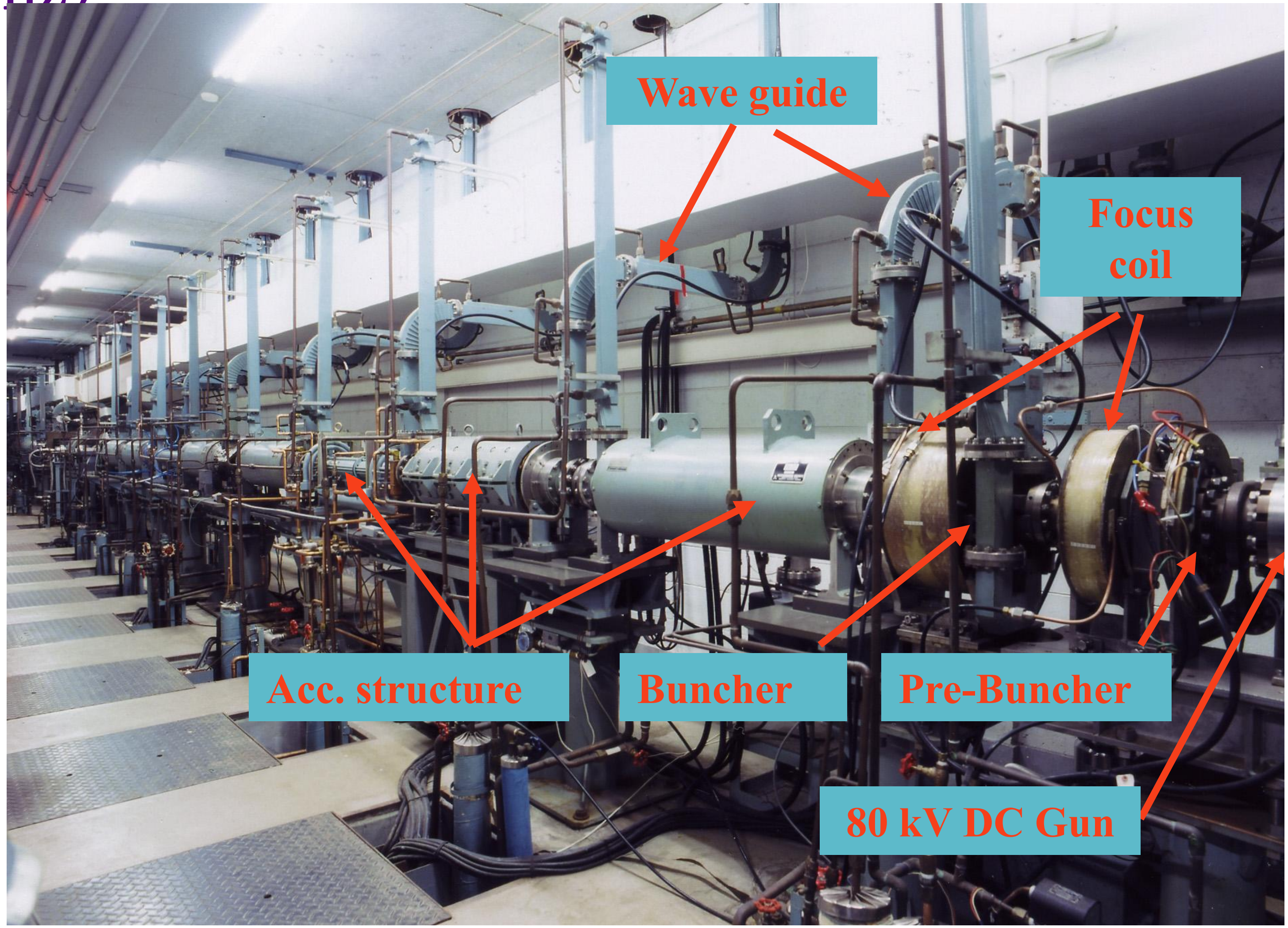
Booster Mode

Beam current @1.2GeV	~40 mA
Ramp-up time @1.2GeV	1.1 sec (min.)

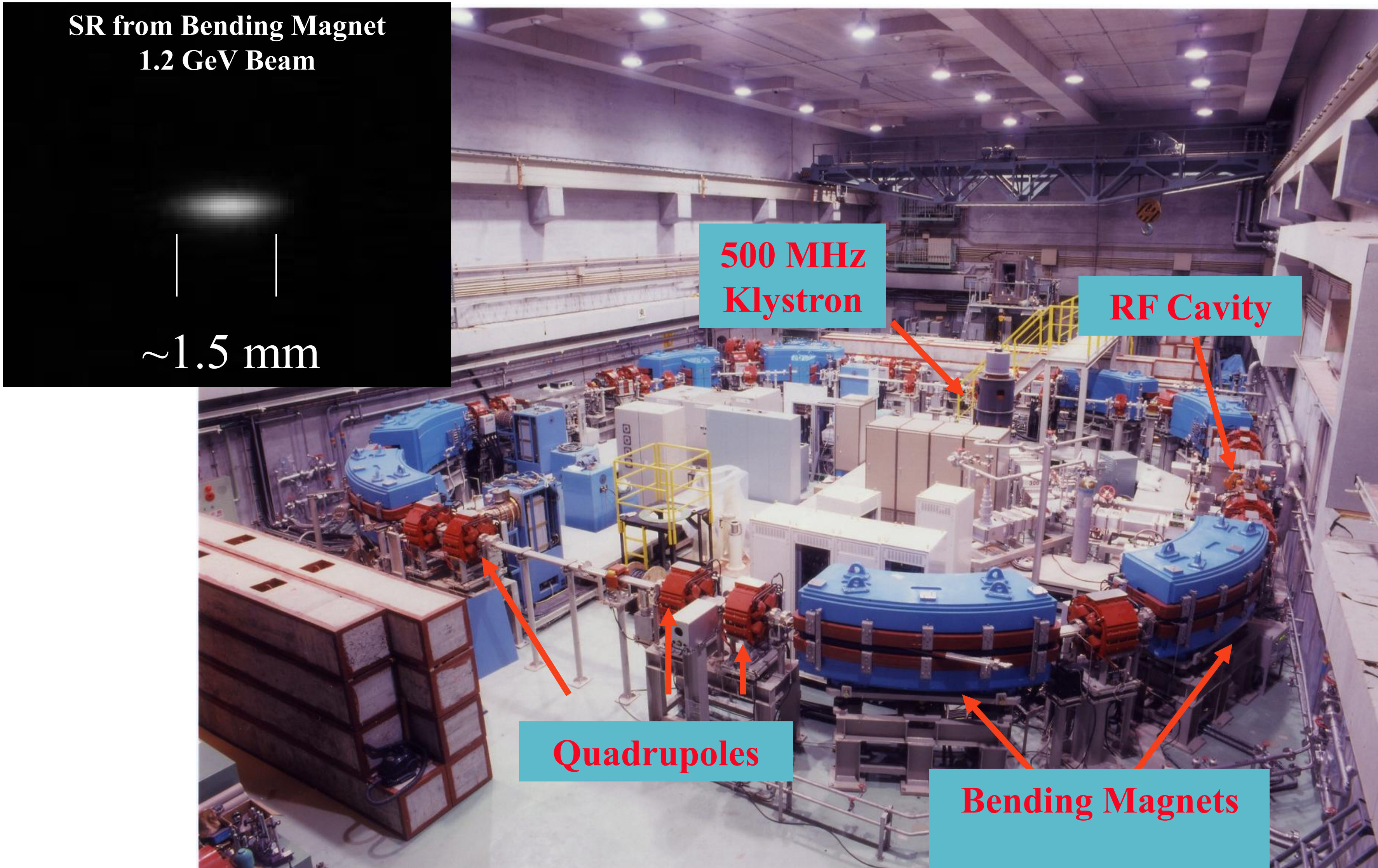
Specification 1.2 GeV Synchrotron (since 1997)

1. Nominal injection 150 MeV
2. One linac burst gives 20~30 mA
3. Ramping time from 0.2 to 1.2 GeV is 1sec
4. Poor vacuum
   > lifetime ~10 min.@1.2GeV
5. High ring impedance (may be |z/n|=100 Ω)
   > microwave instability
6. Many HOMs in a used cavity
   > Serious coupled-bunch inst.
7. <u>No chromatic sextupole</u> !!
   > a lot of problems

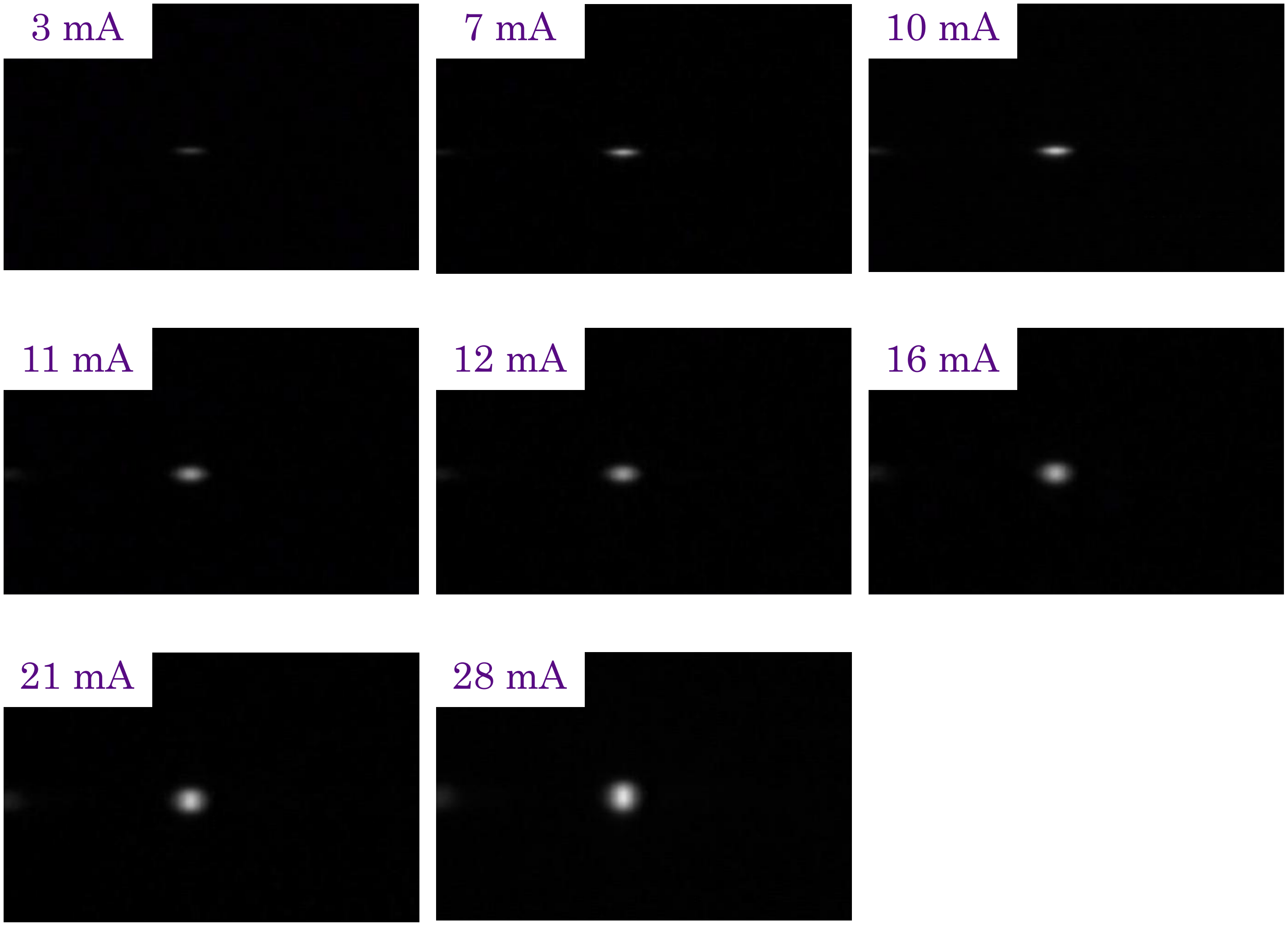
300 MeV Linac (42-year-old)
(20 Acc. Structures, 5 Klystrons, 300 Hz)



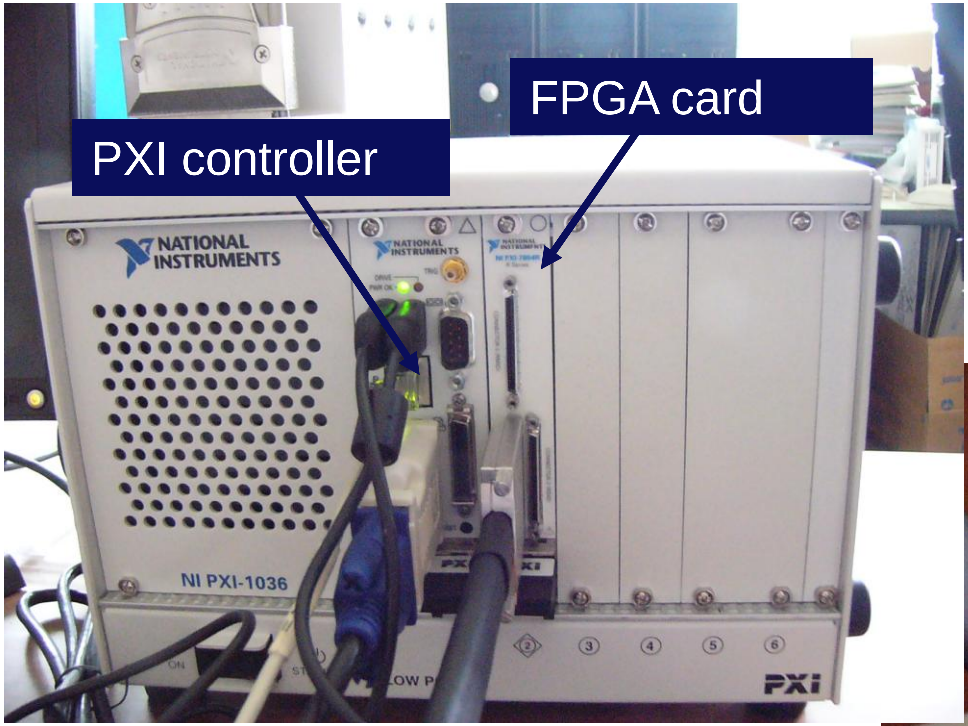
1.2 GeV Booster and Storage Ring (200 MeV Pulse-Stretcher)



Ion trapping

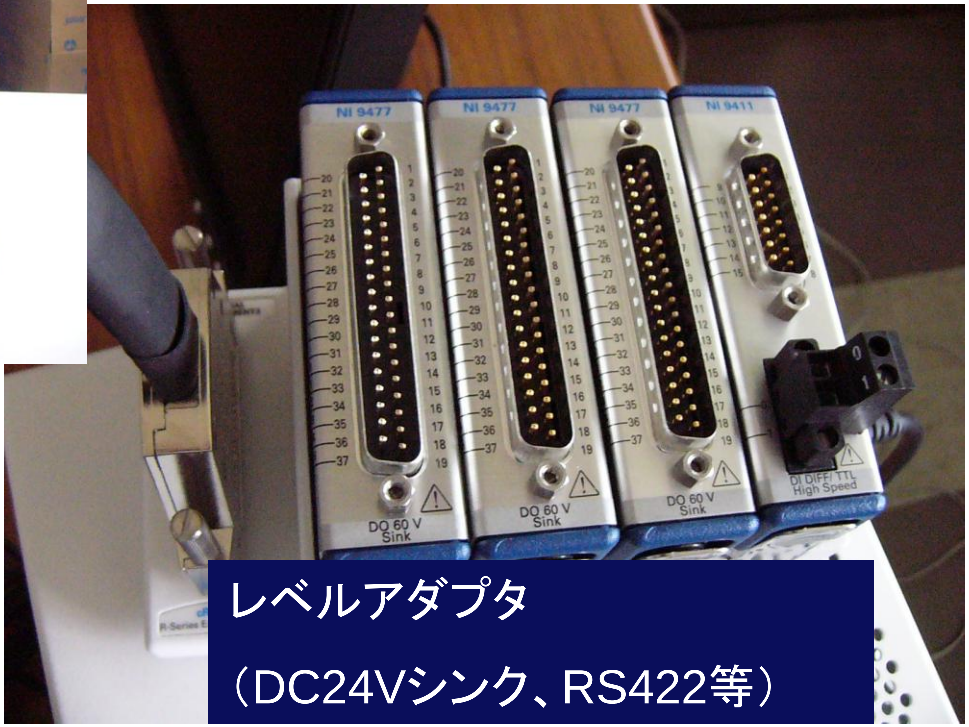


PXI controller for synchrotron magnet power supplies



PCI eXtensions for Instrumentation（PXI）

FPGA (Field Programmable Gate Array)

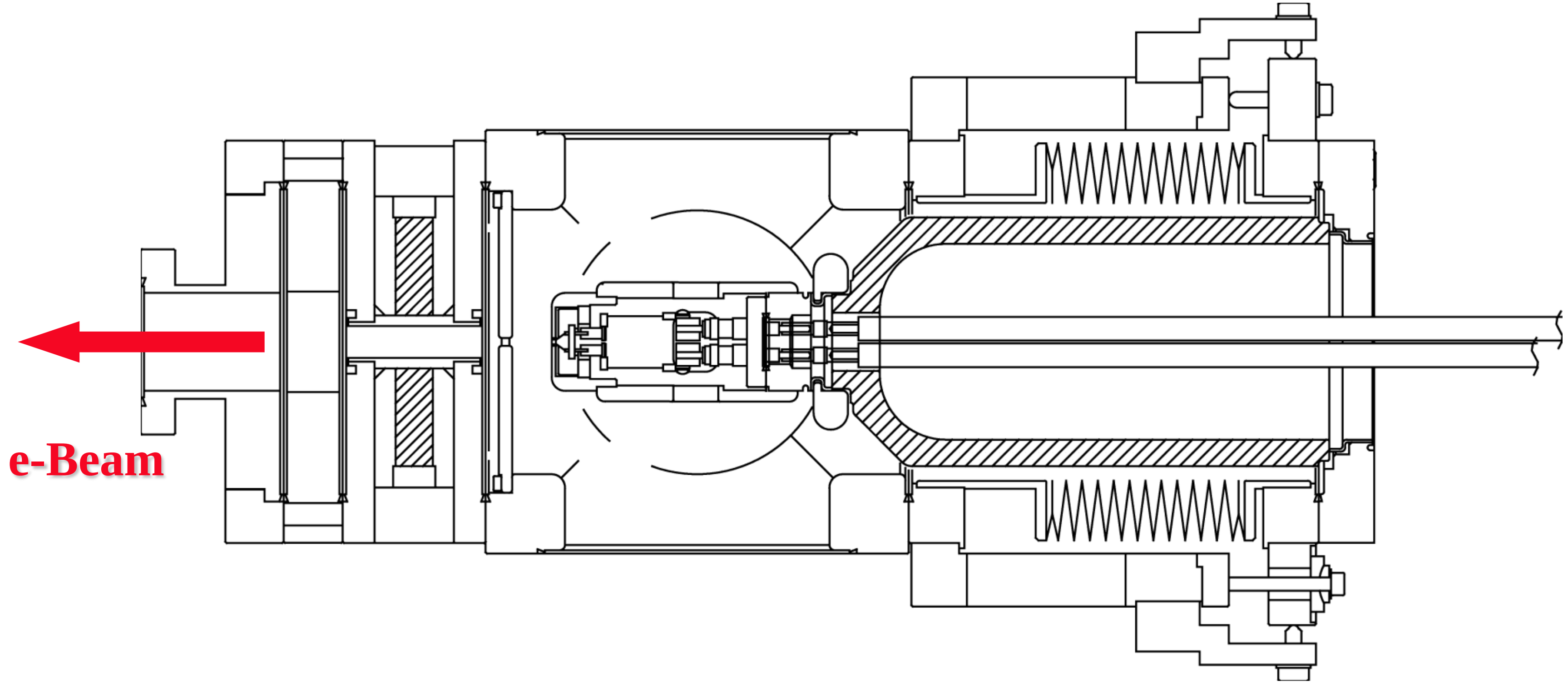


PCI eXtensions for Instrumentation（PXI）

- PCベースのオープンプラットフォーム
- コンパクトPCIがベース
  (バースト転送時の帯域幅は132MB/sec)
- 1200種を超えるモジュール
- 比較的安価
- 同期バス信号

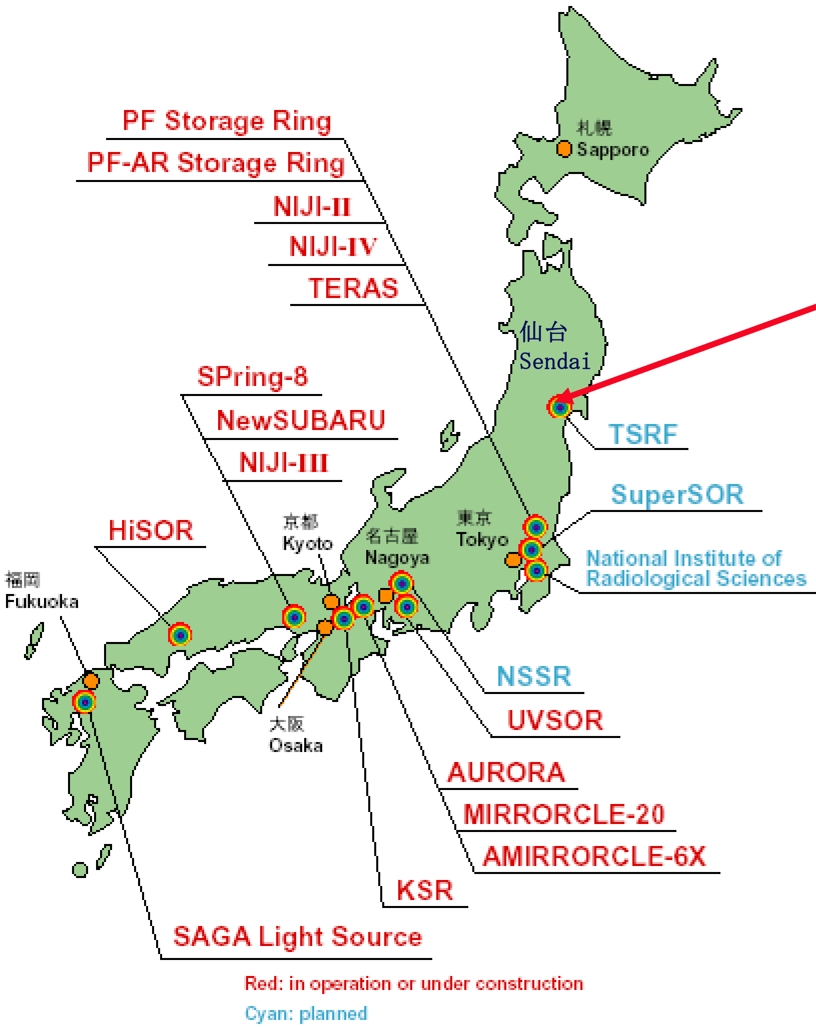
- LHCのコリメータコントローラなど
  (VMEの代替として)

Low Emittance DC-gun



日本の放射光施設

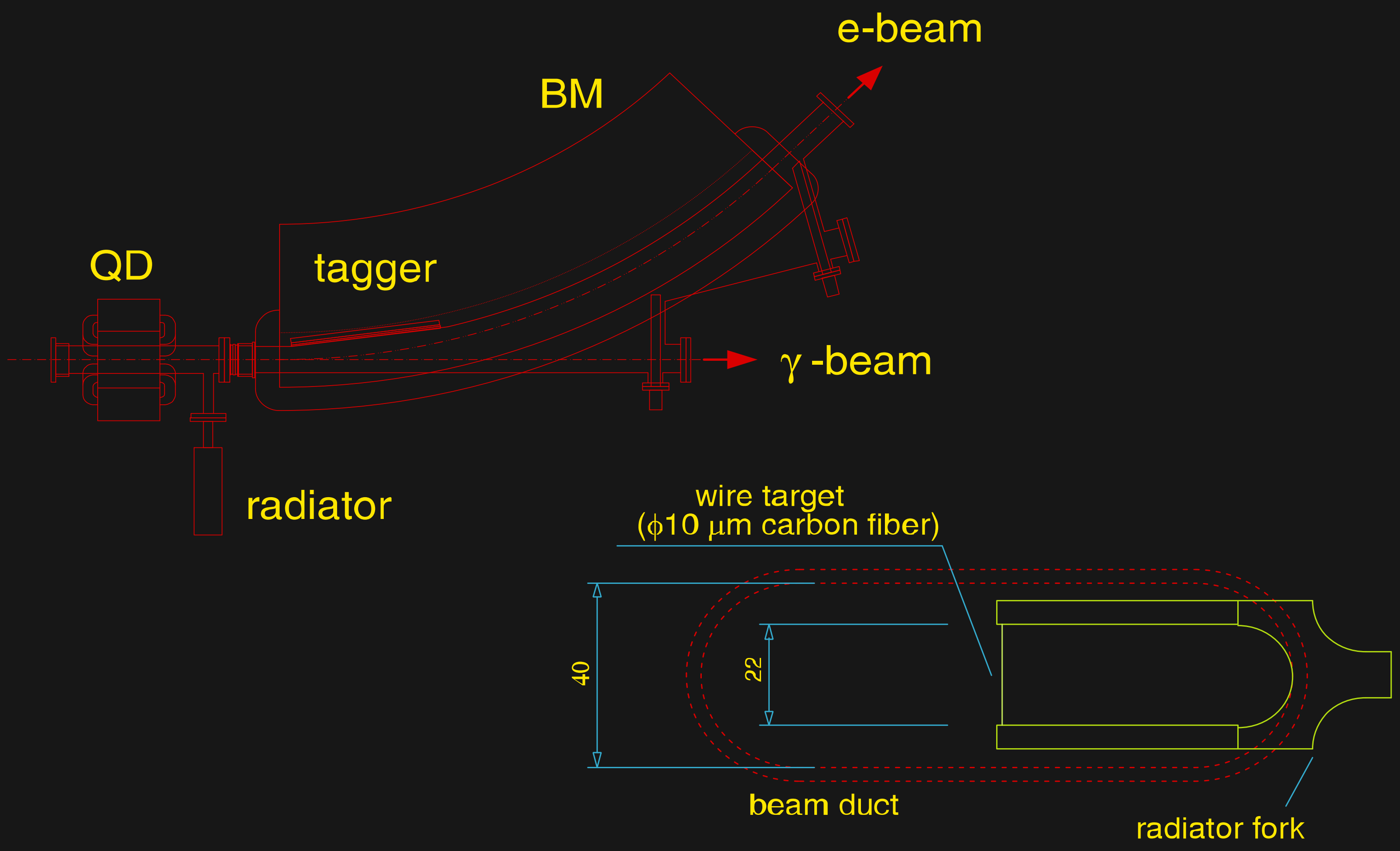
SR Facilities in Japan



Laboratory of Nuclear Science (LNS)
Faculty of Science
Tohoku University

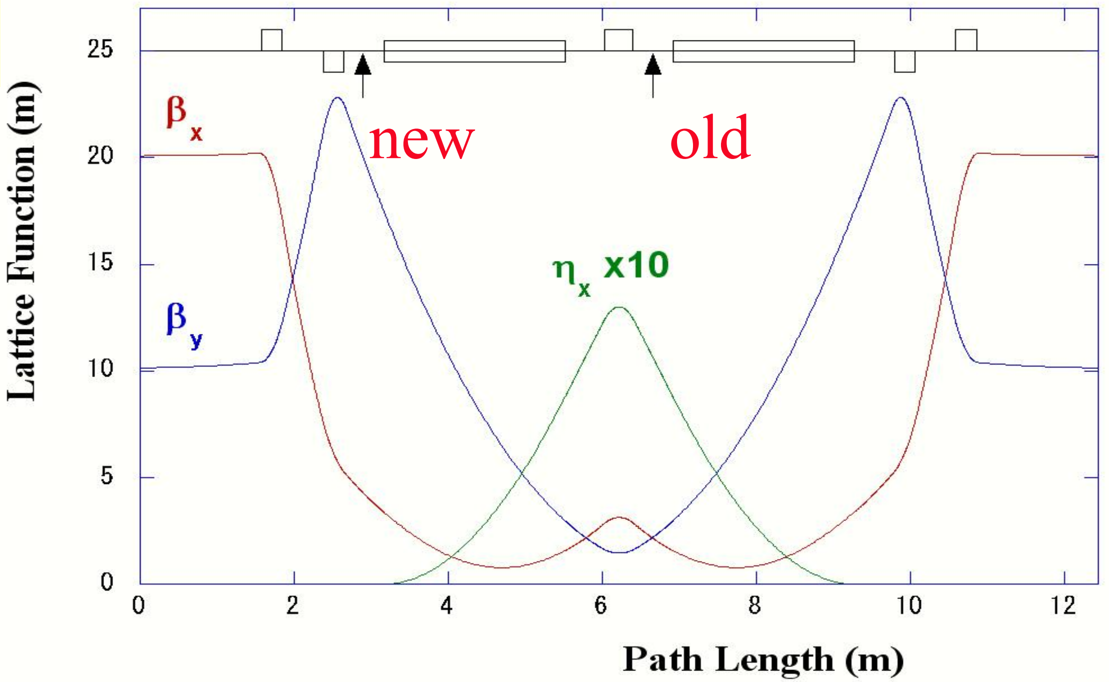
GeV-energy gamma-ray generation

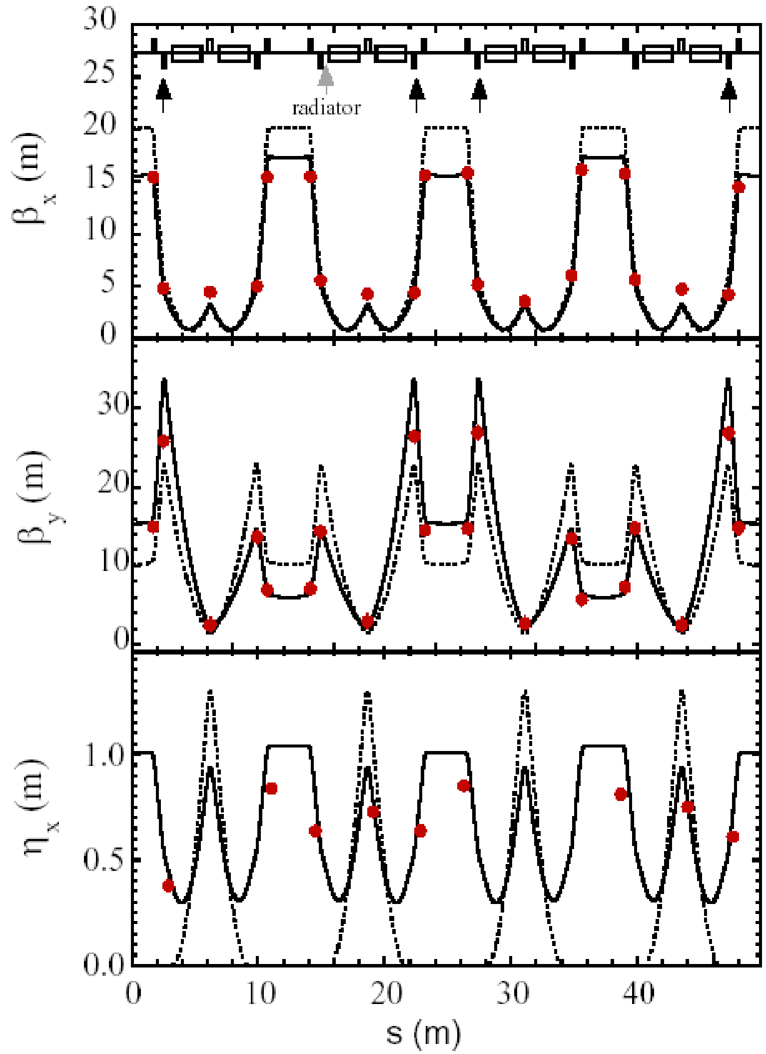
via Bremsstrahlung from internal target wire



STB main parameters

Lattice type	Chasman-Green
Superperiodicity	4
Circumference	49.7 m
Maximum energy	1.2 GeV
Injection energy	0.2 GeV (nominal)
Betatron tune	(3.22, 1.15) *
Chromaticity	(~-5.5, ~-4.7)*
RF frequency	500.14 MHz
RF voltage	140 kV
Harmonics	83
Natural emittance	170 nmrad (@ 1.2 GeV)
Momentum compaction	0.0378
Dispersion	< 10 cm*
x-y coupling coefficient	0.005*
Beam current	< 20 mA* (@ 1.2 GeV)
Lifetime	~ 10 min* (@ 1.2 GeV)





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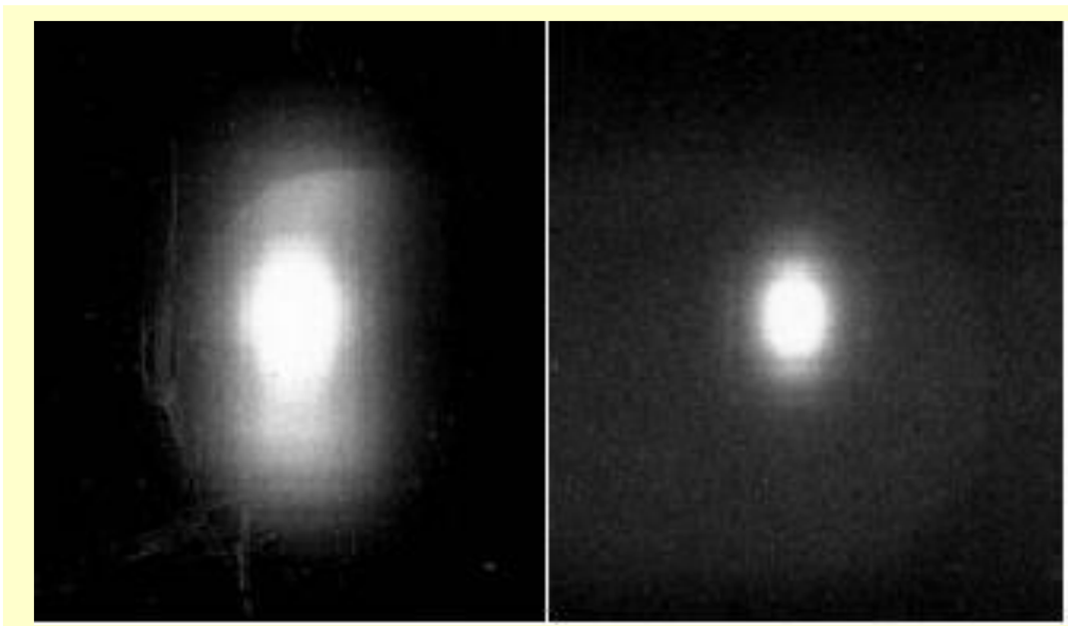
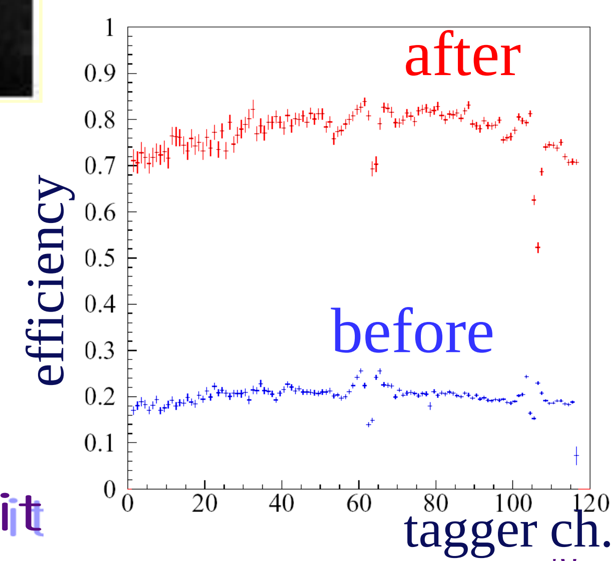
Improvement in gamma profile



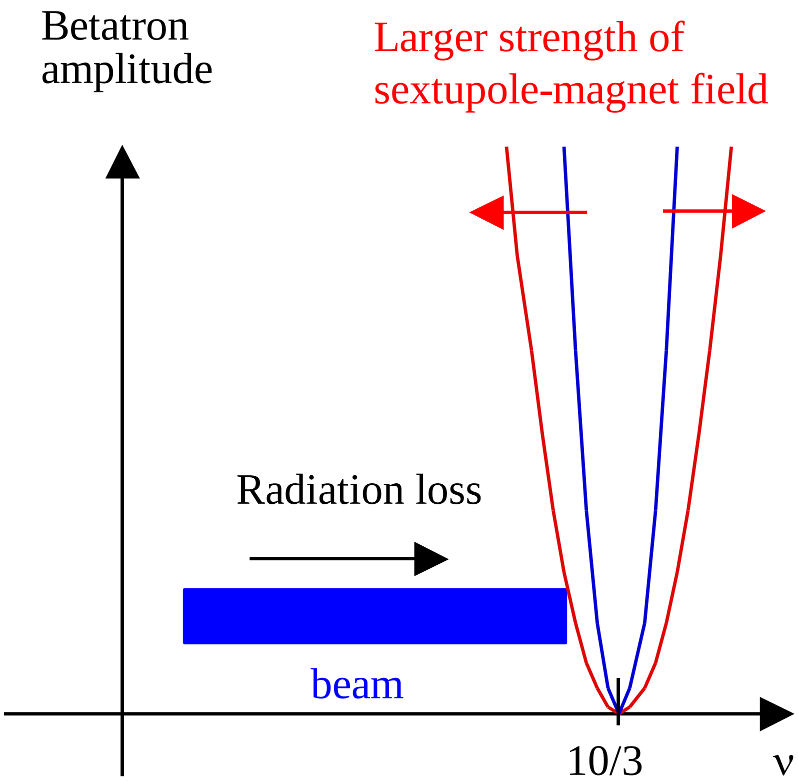
before after



Pulse stretcher

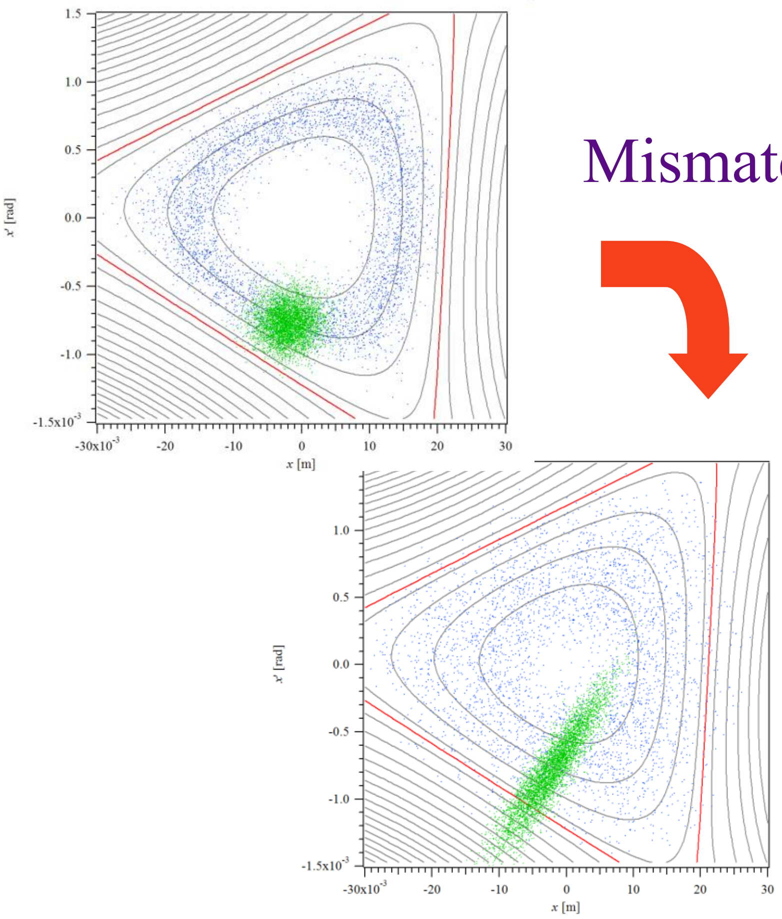
converts pulse beam generated by RF linac into quasi-continuous beam.

Schematic Diagram of Beam Extraction

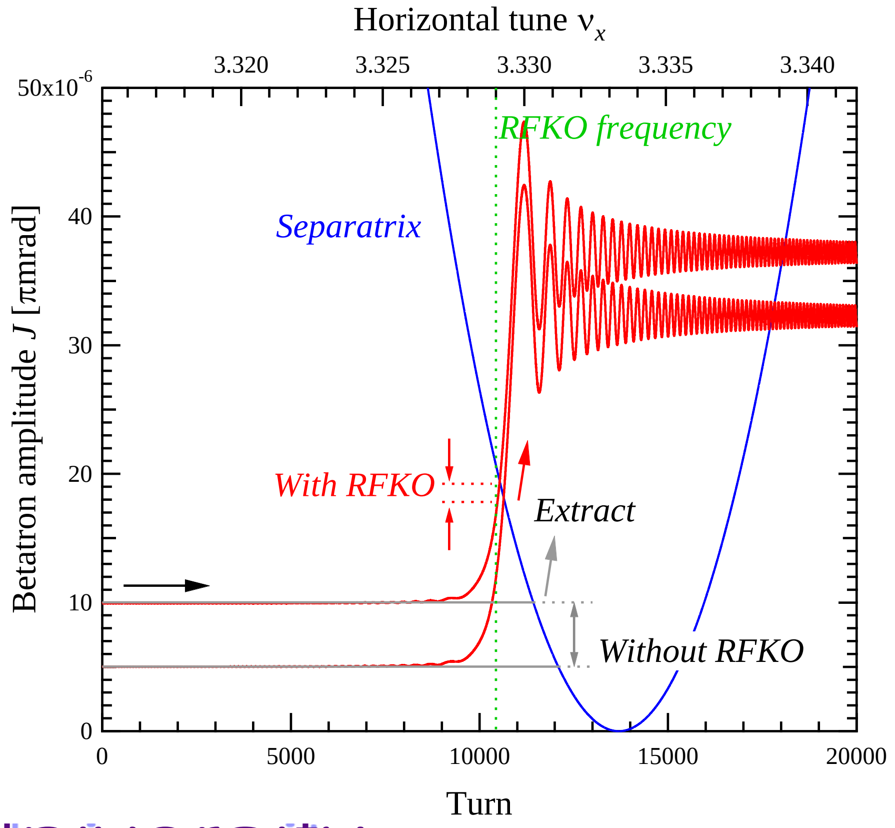


Emittance reduction for extracted beam by using an RF shaker driven by a mono-frequency.

(by A. Miyamoto)



Mismatched optics



東北大学原子核理学研究施設

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STBリング

Lattice　Chasman-Green
Superperiodicity　4
Circumference　49.751 m
Beam energy　200 MeV (nominal)
Betatron tune　(3.31, ~1.20)
Natural Chromaticity
(−5.79, −4.98)
Energy loss / turn　46 eV @ 2
MeV
Repetition period　3.33 ms @ 200 MeV
Relative energy loss / period
0.46 % @ 200 MeV
Horizontal tune shift / period
0.0267 @ 200 MeV
Twiss at injection point
β_x=20.2, α_x=−0.06
Number of harmonic sextupole