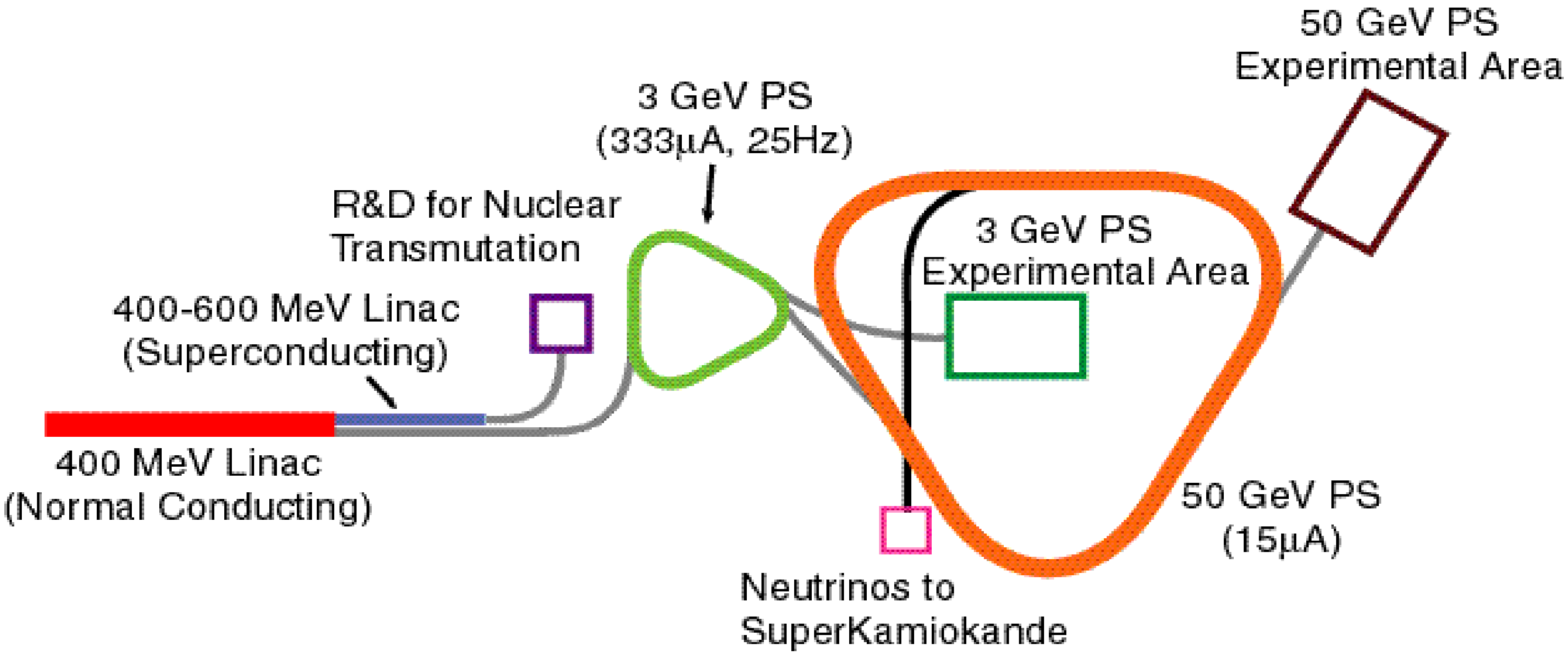
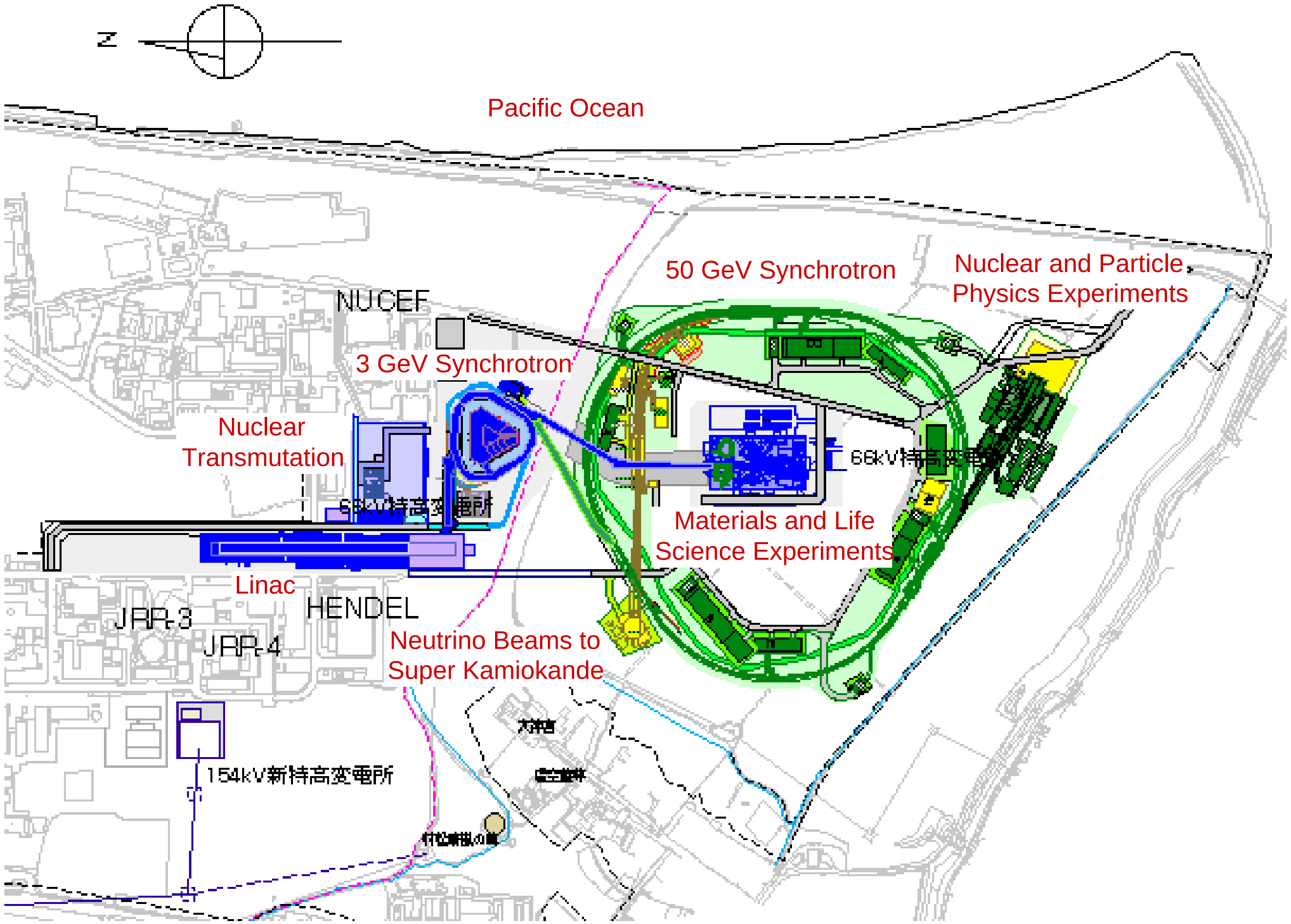
Accelerator Complex of Joint Project in Japan

Yoshiharu Mori (KEK)

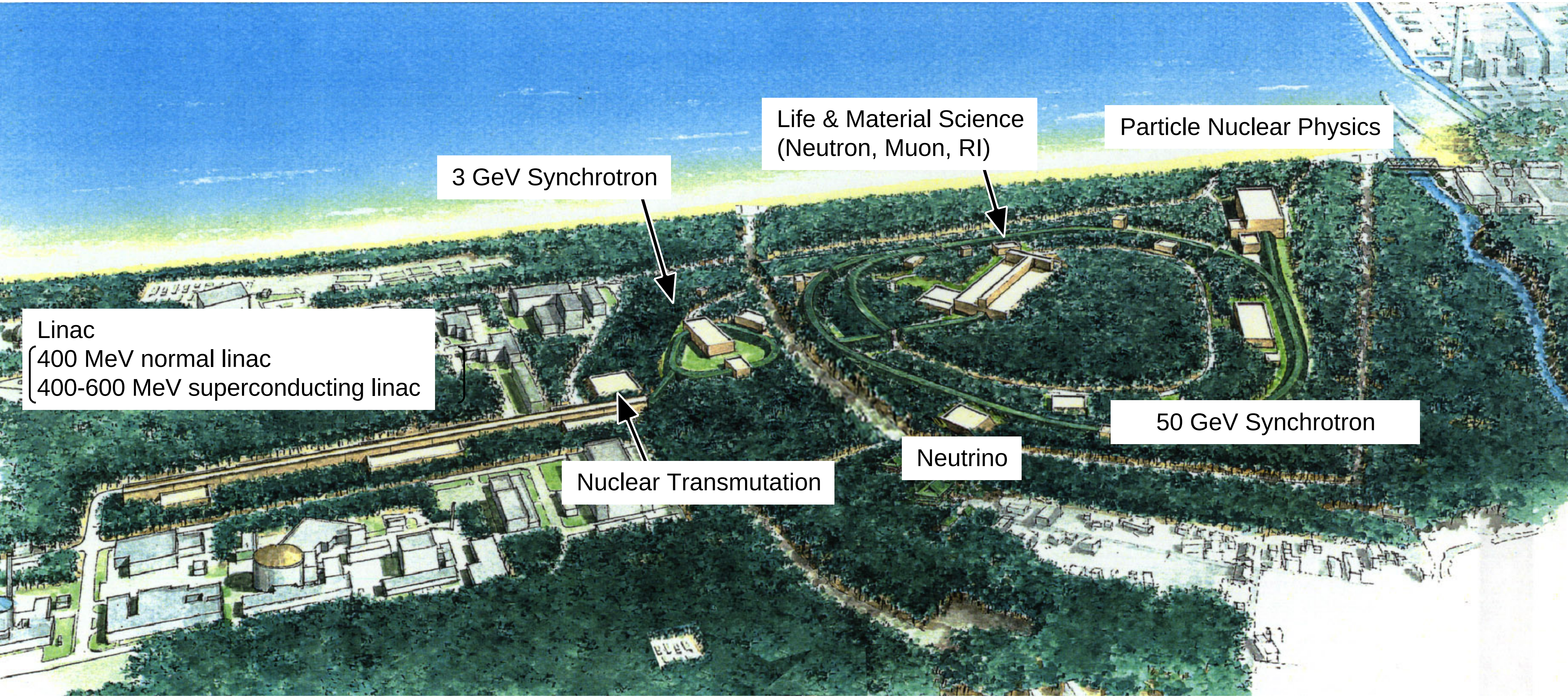
Configuration of the Accelerator Complex



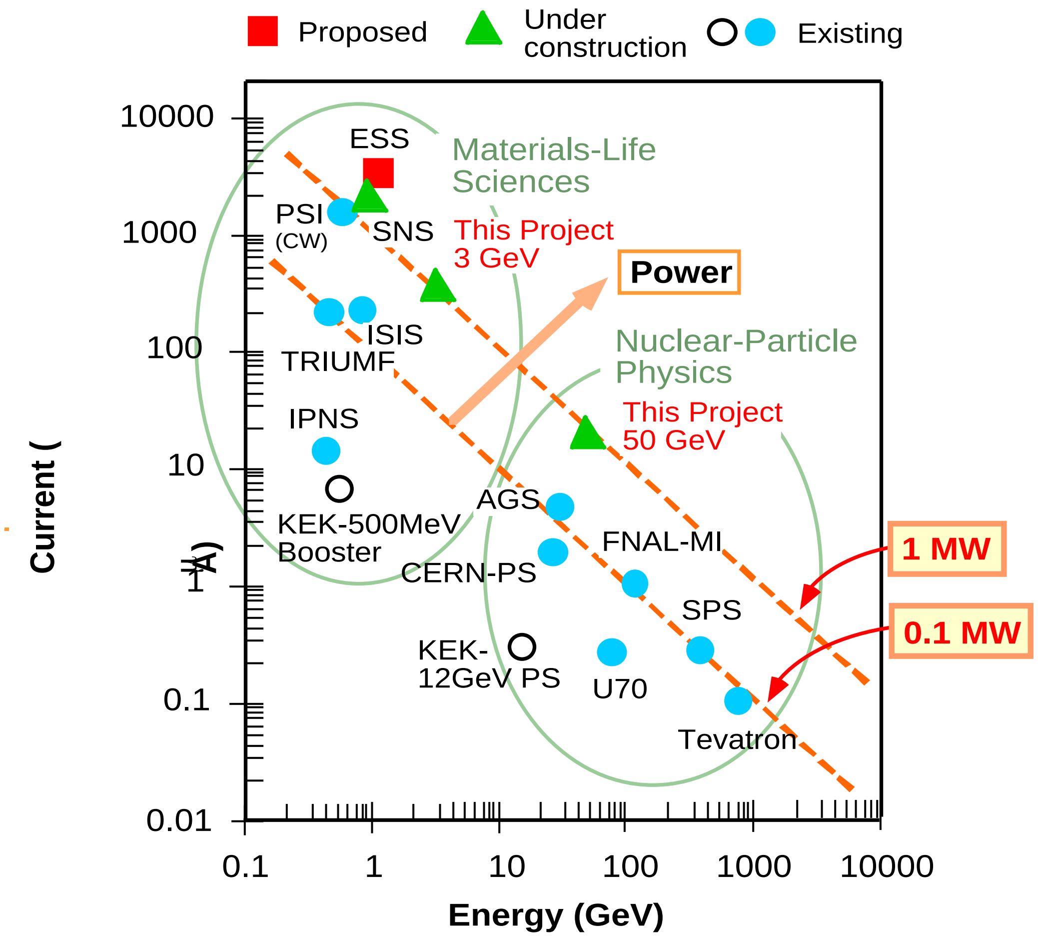
Plan View of the Facility



Site View of the Project



World's Proton Accelerator



Requirement

- **~ 50-GeV, 15 μA, slow and fast extraction for nuclear and particle physics experiments**
- **~ 1 MW(~ GeV), <1μs, ~ 25 Hz for spallation neutron source**

Features of the Accelerator Complex

- *Synchrotron based cascade system*
  --> suitable for the several-ten GeV machine

LINAC + RCS(Rapid Cycling Synchrotron) + MR (Main Ring)

400(600)MeV 3GeV 50GeV

RCS vs AR advantages

- **Lower Beam Current (Higher Beam Energy)**
- **Lower Injection Energy**
- **Higher Injection Beam Loss is allowed.**

  (If one increases the beam energy by a factor of 7.5 times, the allowed beam loss during the injection is 7.5 times as high as that for AR with the same beam power.)
- **Perhaps immune against the e-p instability**

RCS vs AR disadvantages

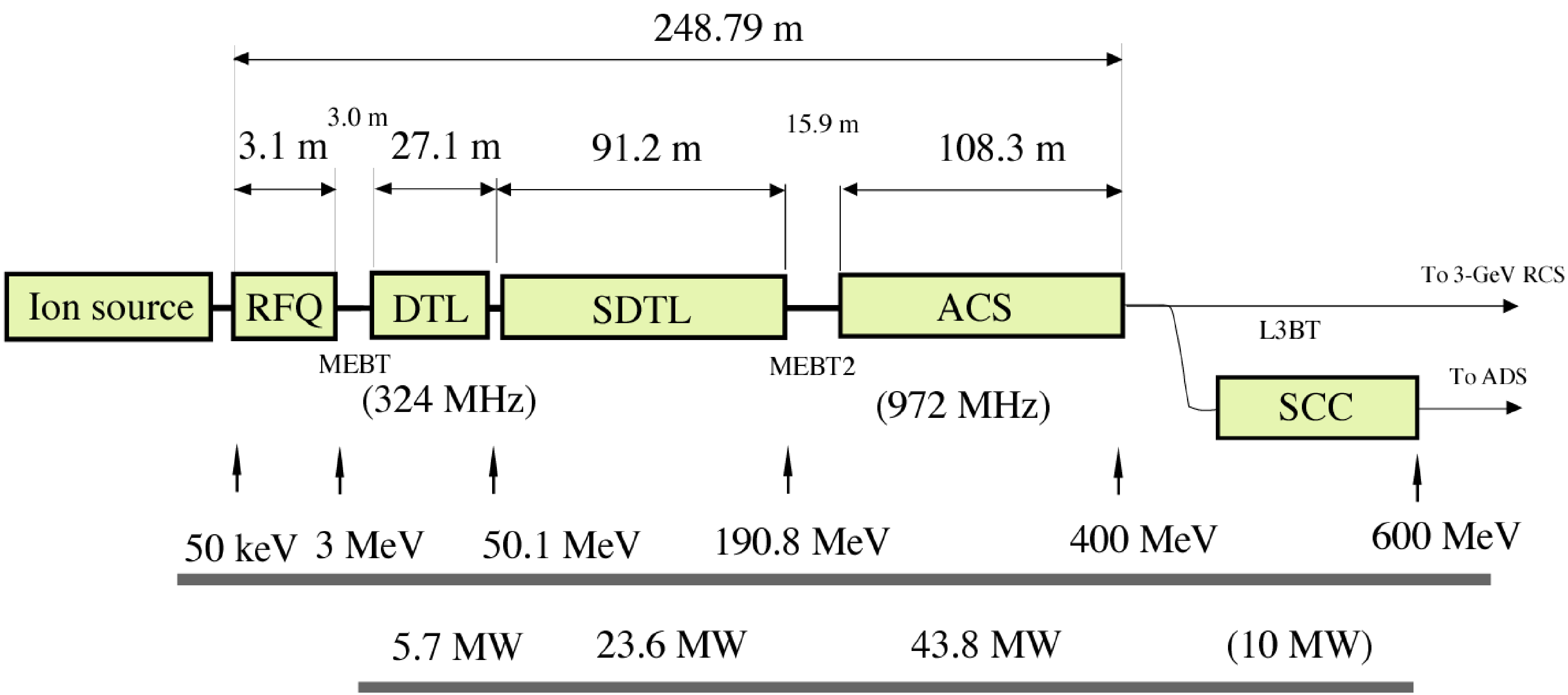
RCS Challenges

- **Lower injection energy in turn implies higher space charge effect. Large aperture magnets are required, giving rise to large fringing fields.**
- **Powerful RF accelerating system**
- **Ceramics vacuum chamber with RF shield to avoid the eddy current effect**
- **Stranded coil to overcome the eddy current effect on the magnet coils.**
- **Precise magnet field tacking is necessary for each family of magnets**

Proton Linac Requirements

- Current
  - Average 675 μA
  - Peak 50 mA
- Pulse
  - Pulse width 500 μsec
  - Repetition 50 Hz
  - Chopping ratio 54 %
  - RF duty (600 μsec) ~ 3%
- Beam
  - Energy 400 MeV
  - Momentum width $\Delta p/p = \pm 0.1\%$ (100%)
  - Emittance 3 ~ 5 π mm-mrad (99%)

Proton linac



Features of the Linac Design

Conflicting Requirements

- **Higher accelerating frequency is preferable**
  - **lower bunch current**
  - **short focusing period**
- **Electromagnet is preferable in order to keep the flexible knob (Large Drift Tubes, Lower frequency)**
  - **Both the equipartitioning and constant phase advance are realized**
  - **The parametric resonance can be avoided**

Coil of Electromagnet in Drift Tube

The coil is electroformed and Wire-cutted.

Issues of the Linac Design

- Beam loss, and beam quality degradeation arise at the transitions
- Beam halos arise from the mismatching

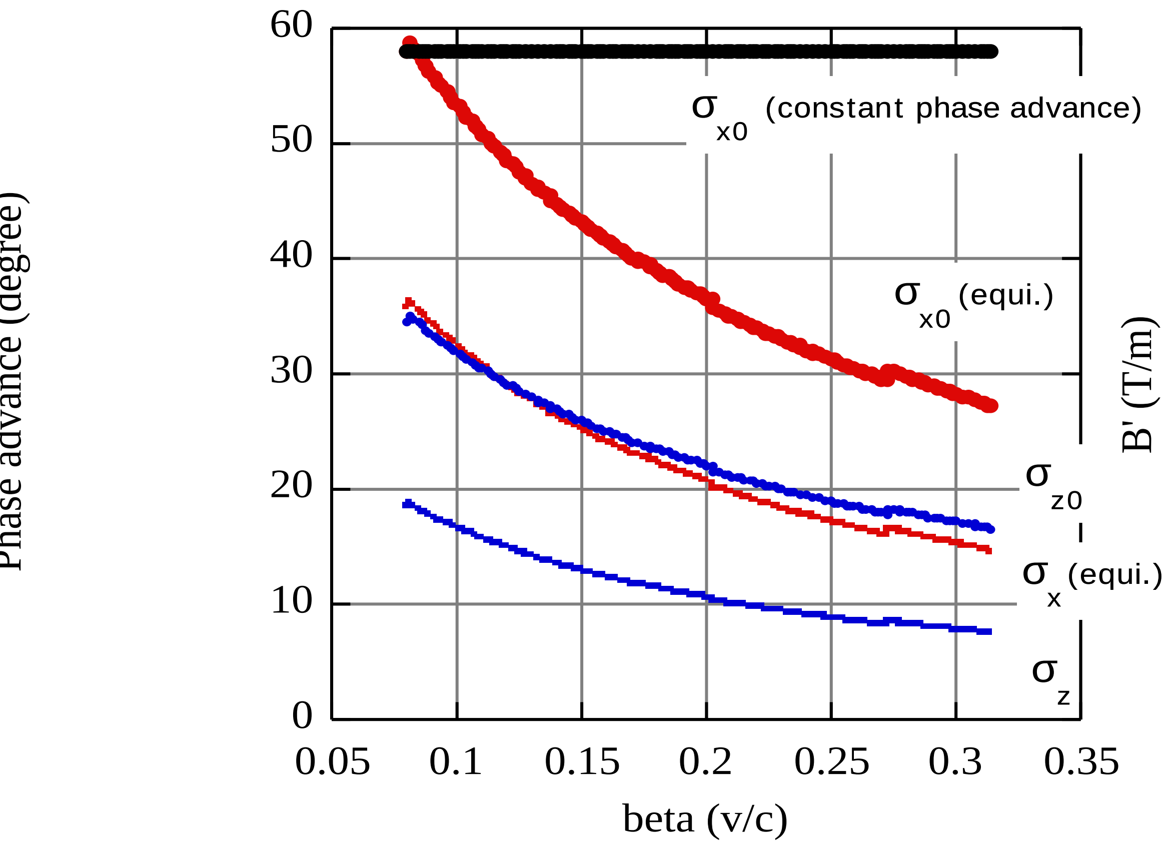
  ->Longitudinal transition (200 MeV from SDTL to ACS) is separated from the transverse transition (50 MeV from DTL to SDTL)

  ->1% amplitude control, 1-degree phase control, ~ 50 μm alignment (perhaps actually ~ 0.1 mm at best), axial symmetry

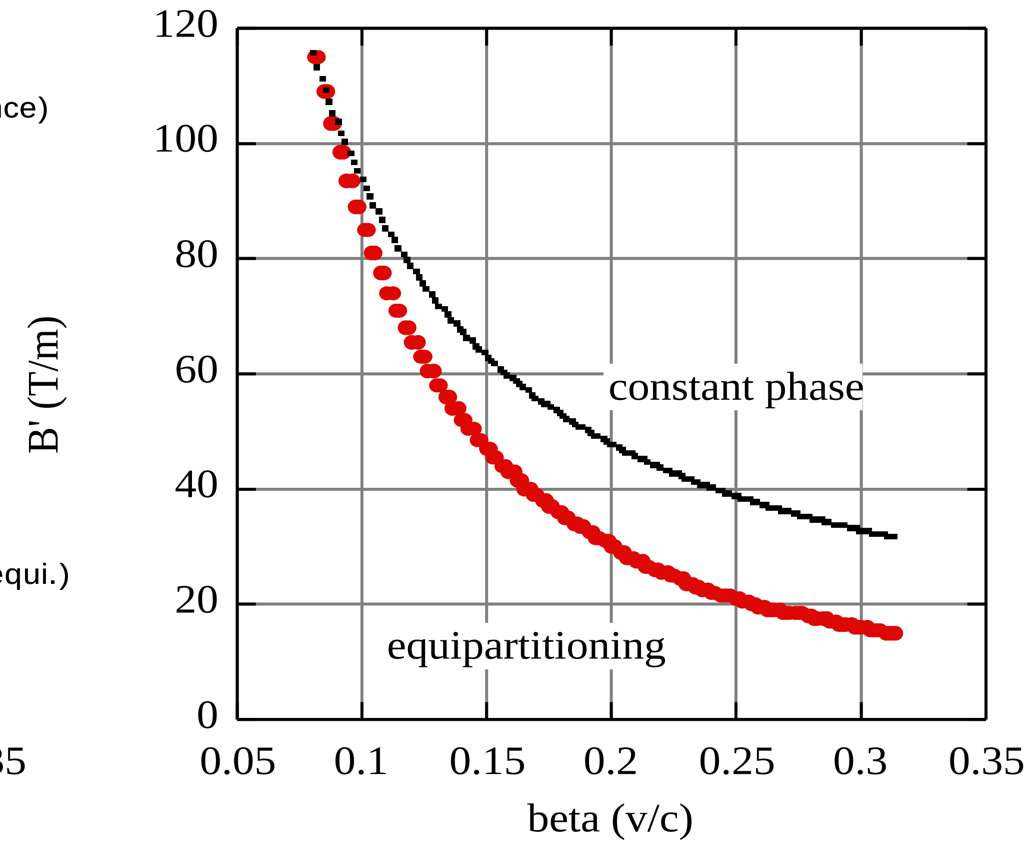
Technics Supporting Design Features

- π-mode stabilizing loop (PISL)
- High-quality electroplating technique (PR-method)
- Electroformed coil
- Axially symmetric high-energy accelerating structure: Annular-Ring Coupled Structure (ACS)
- Chopping system

Focusing scheme in the DTL



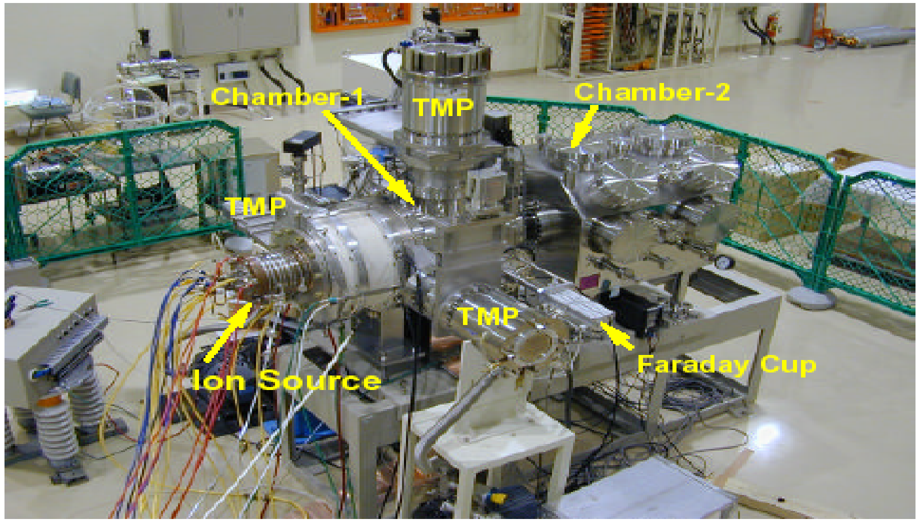
Phase advances in the DTL for equipartitioning and constant phase-advance focusing schemes.

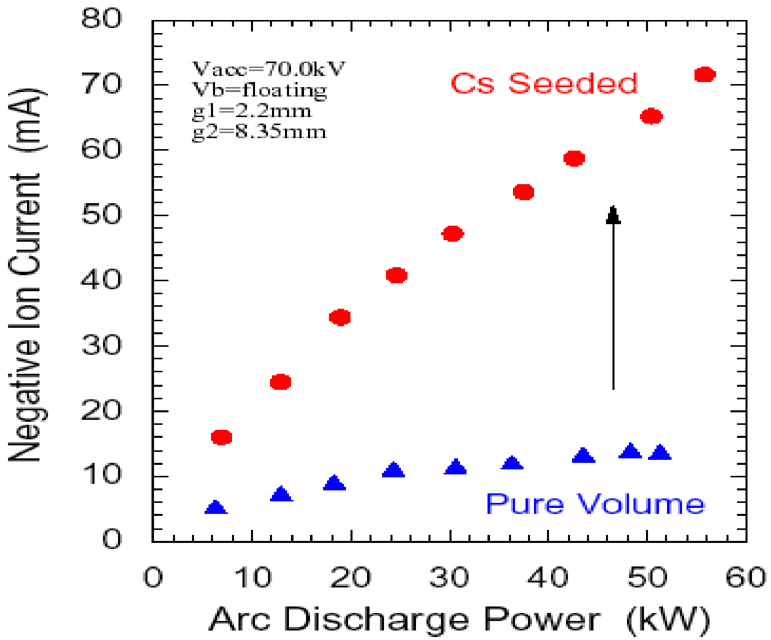


Required magnetic field gradient for equipartitioning and constant phase-advance focusing schemes.

Cs-seeded Ion Source

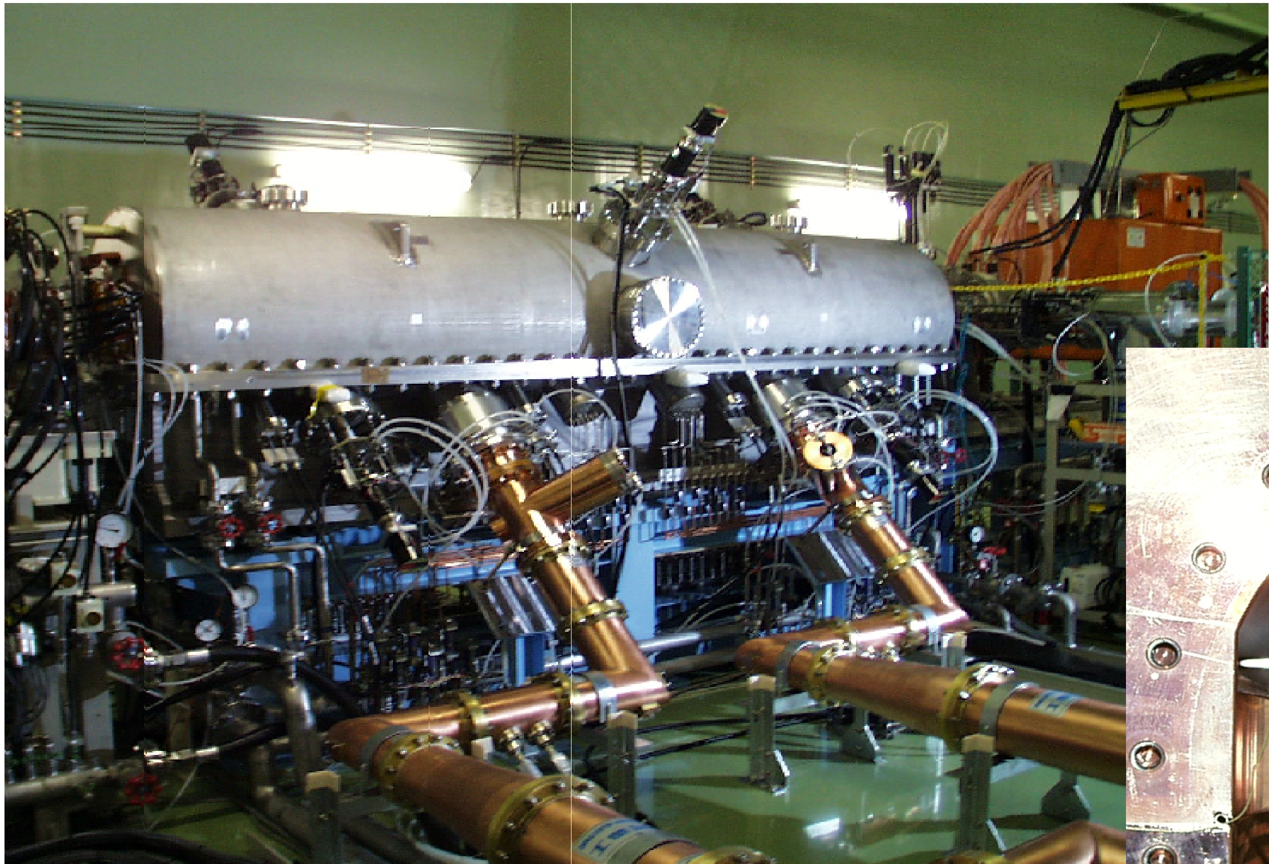
KEK/JAERI
The Joint Project Team



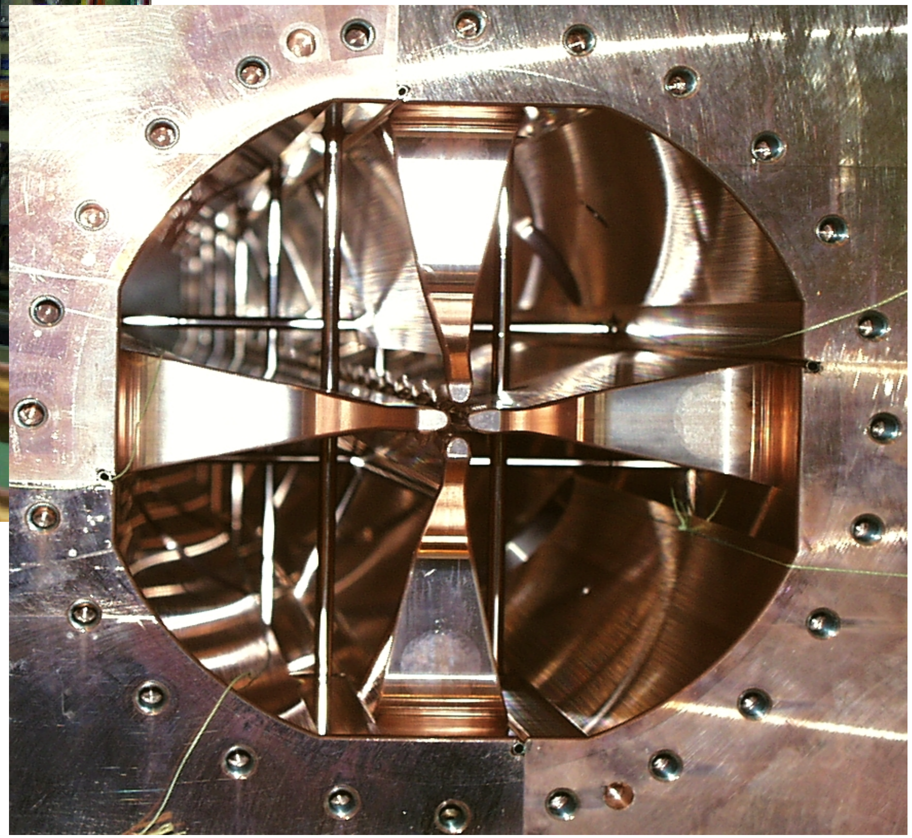


Volume Production Type Negative Ion Source

30mA RFQ



Inside view of the RFQ stabilized with PISLs

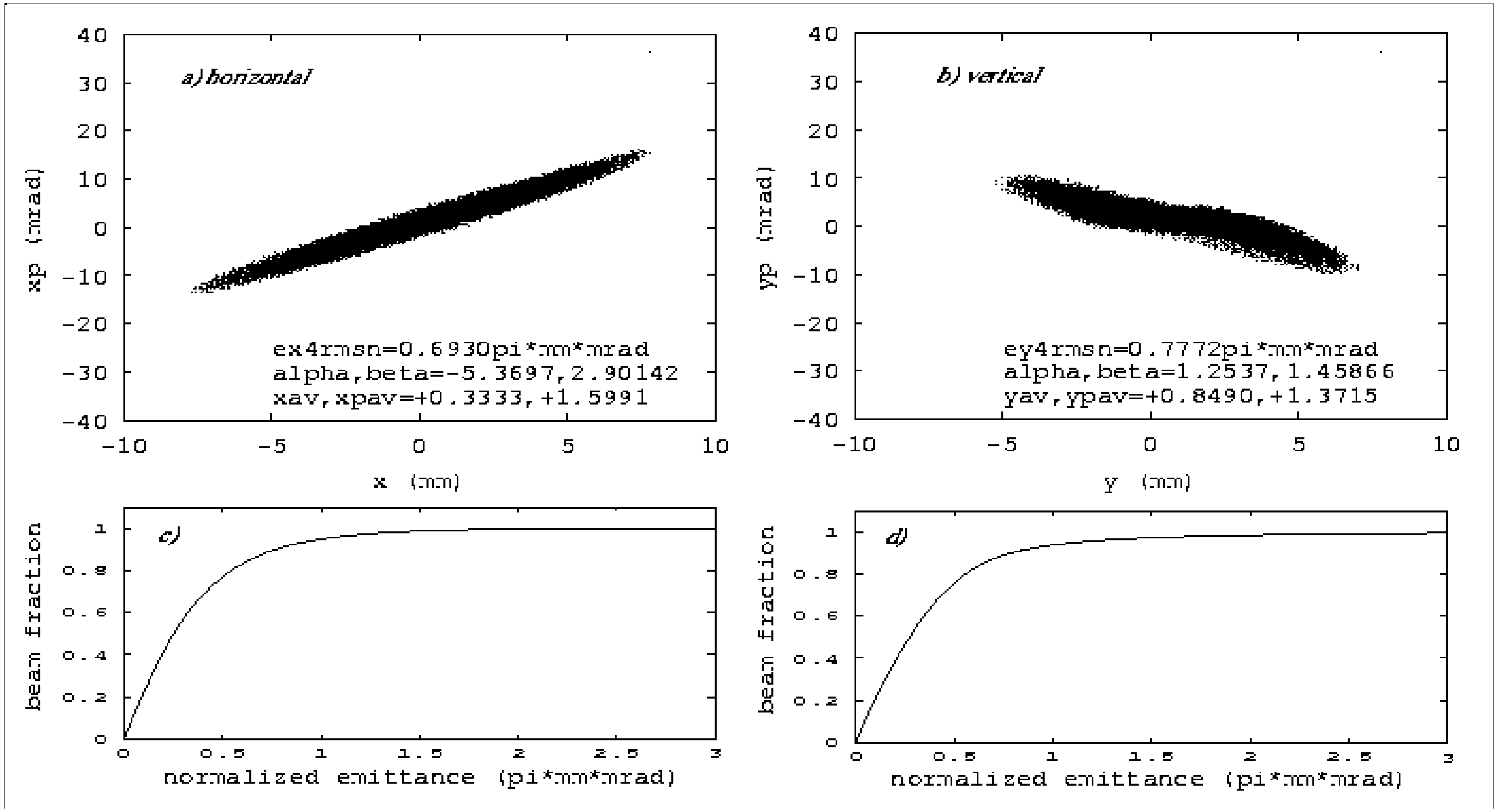


The 30mA RFQ installed in the test area

Emittances at the RFQ exit

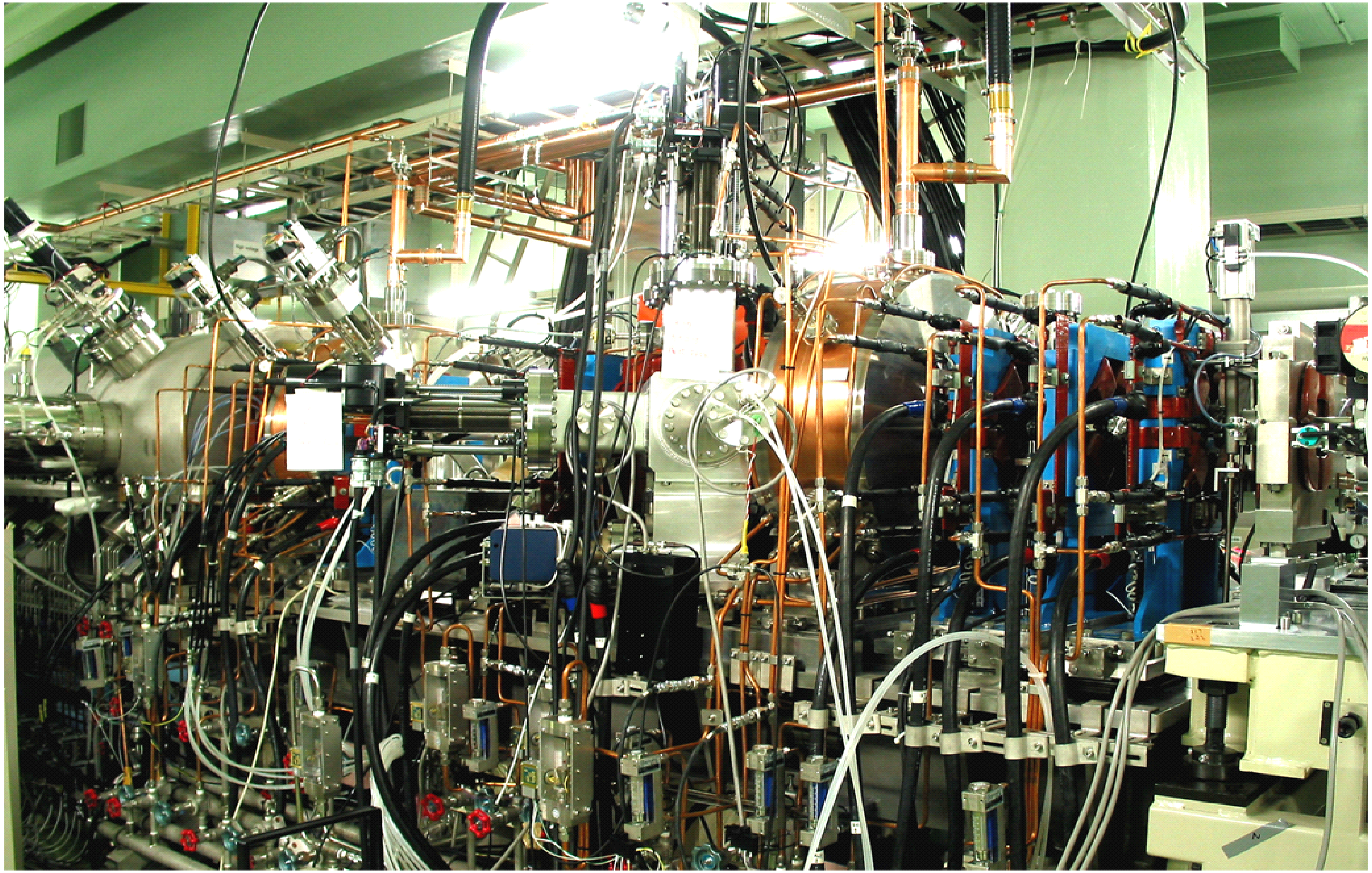
At I = 11 mA

horizontal vertical

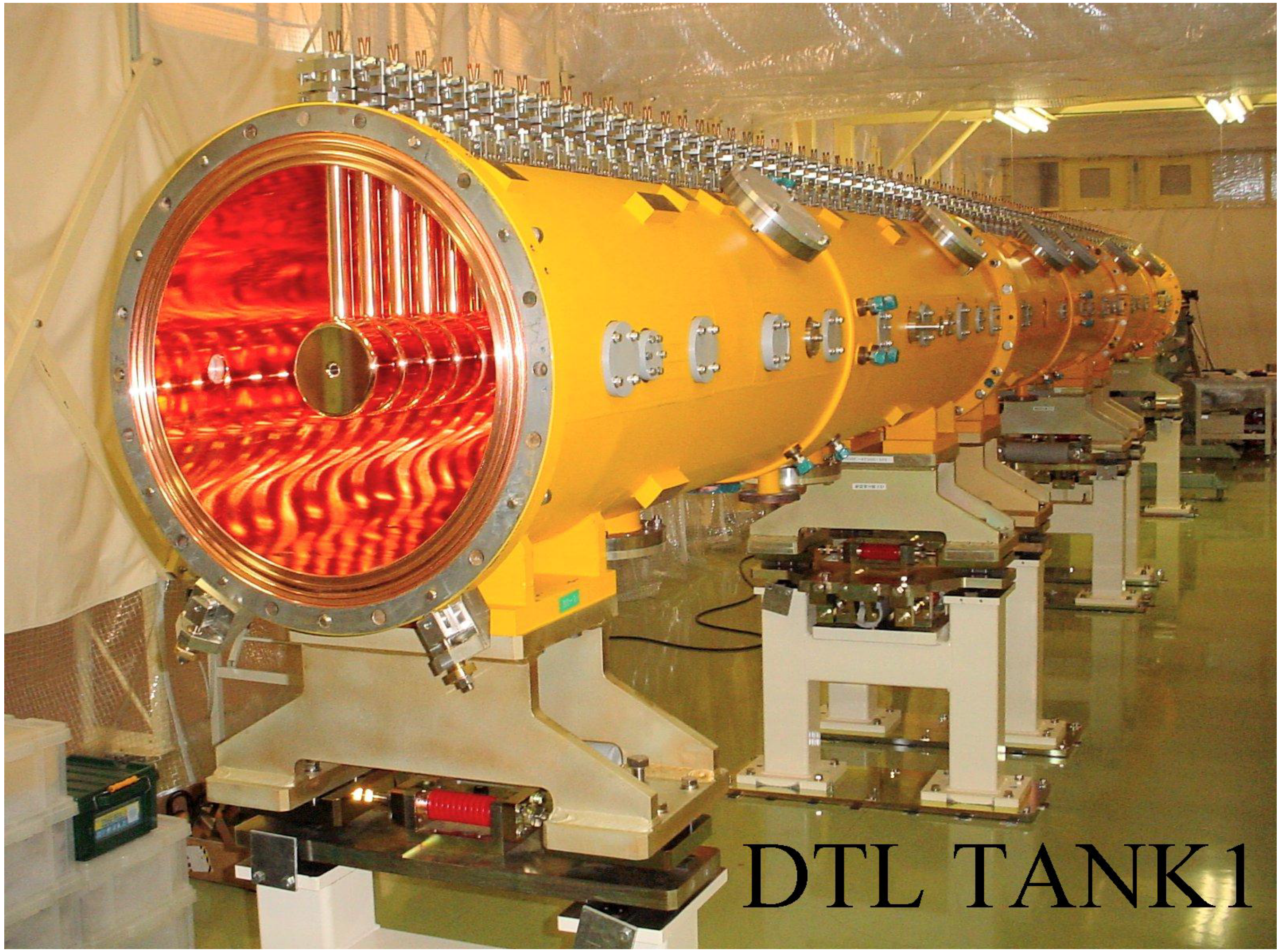


normalized ε_{4rms}=0.69π-mm-mrad ε_{4rms}=0.78π-mm-mrad

MEBT Photograph



DTL Tank 1 with DT's Installed



Comparison of the Lattice Parameters of the 3-GeV Synchrotron (1)

----- The Circumference is increased by a factor of 10/9 ---

	New Lattice	Previous
Circumference	348.3 m	313.5 m
Typical Tune	(6.72, 6.35)	(7.35, 5.8)
Transition Gamma	9.17	9.05
Maximum RF Voltage	450 kV	420 kV
Maximum RF Voltage per Cavity	42 kV	42 kV
The Number of RF Cavities	11 (+1)	10 (+1)

Comparison of the Lattice Parameters of the 3-GeV Synchrotron (2)

----- The Emittance is increased by a factor of 3/2 ---

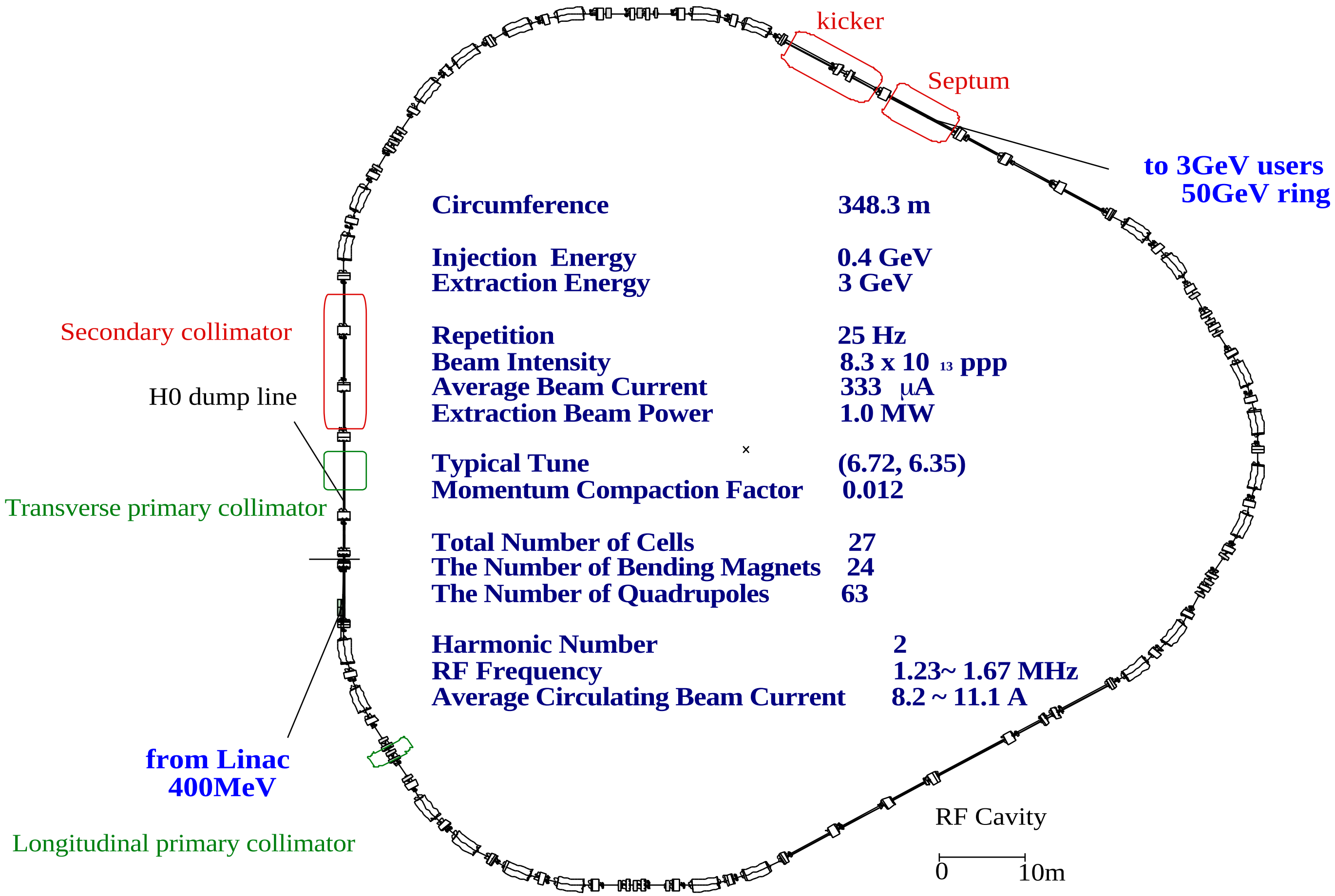
	New Lattice	Previous
Painting Emittance at Injection(π mm.mrad)		
	216	144
Collimator Acceptance	324	216
Physical Aperture	486	324
Bunching Factor with 2nd harmonic		
	0.41	0.41
Incoherent Tune Shift with	0.16	0.23
Bunching Factor without	0.27	0.27
Incoherent Tune Shift	0.24	0.35

Comparison of the Lattice Parameters of the 3-GeV Synchrotron (3)

The Emittance is increased by a factor of 3/2,while the gap of the BM is as it is.
The number of families is increased.

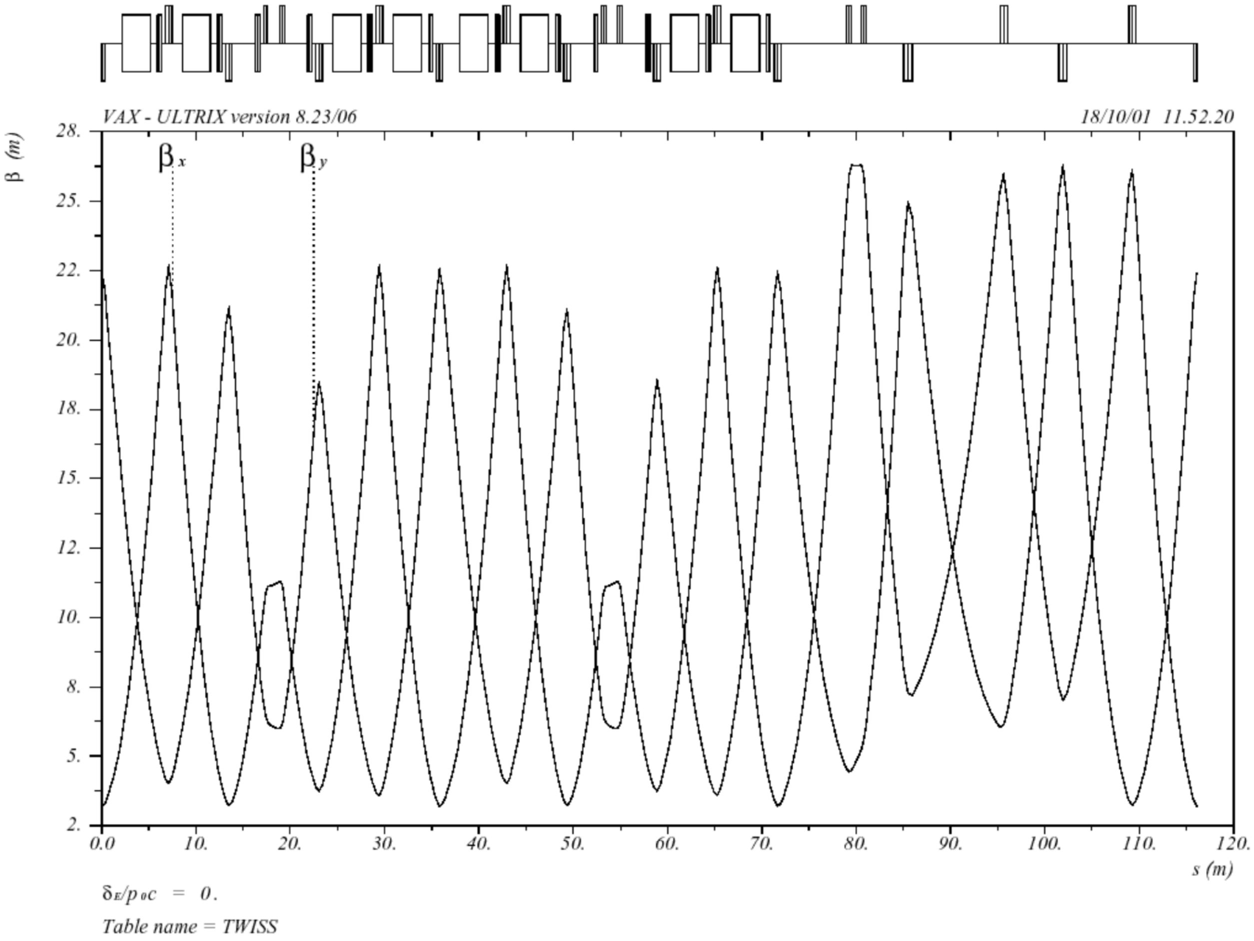
	New Lattice	Previous
Bending		
The Number of Magnets	24	24
Gap Height	210 mm	210 mm
Good Field Region	200 mm	190 mm
Quadrupole		
The Number of Magnets	63	66
The Number of Families	11	7

RCS Configuratiion

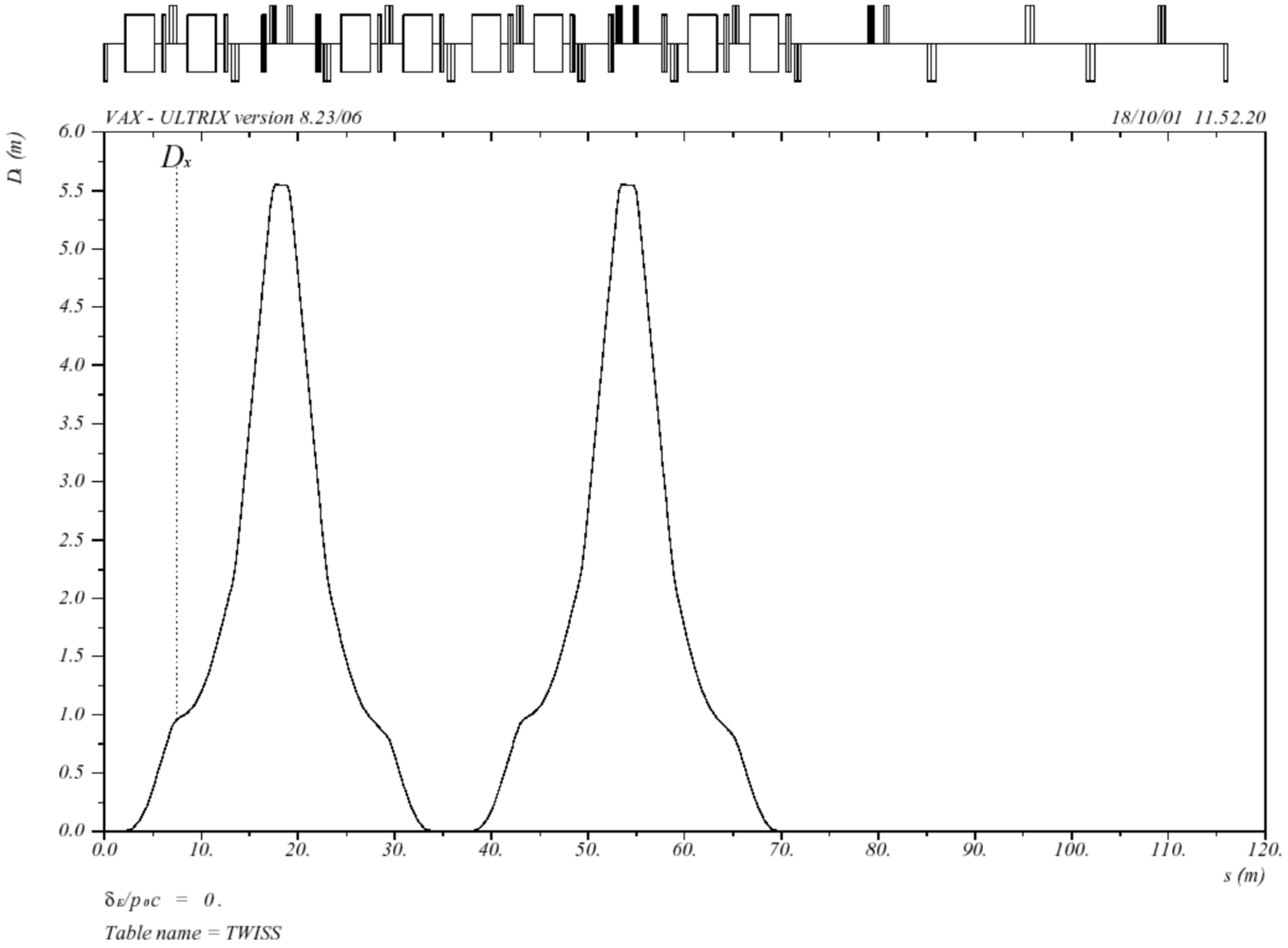


Circumference	**348.3 m**
Injection Energy	**0.4 GeV**
Extraction Energy	**3 GeV**
Repetition	**25 Hz**
Beam Intensity	**8.3 x 10^{13} ppp**
Average Beam Current	**333 μA**
Extraction Beam Power	**1.0 MW**
Typical Tune	**(6.72, 6.35)**
Momentum Compaction Factor	**0.012**
Total Number of Cells	**27**
The Number of Bending Magnets	**24**
The Number of Quadrupoles	**63**
Harmonic Number	**2**
RF Frequency	**1.23~ 1.67 MHz**
Average Circulating Beam Current	**8.2 ~ 11.1 A**

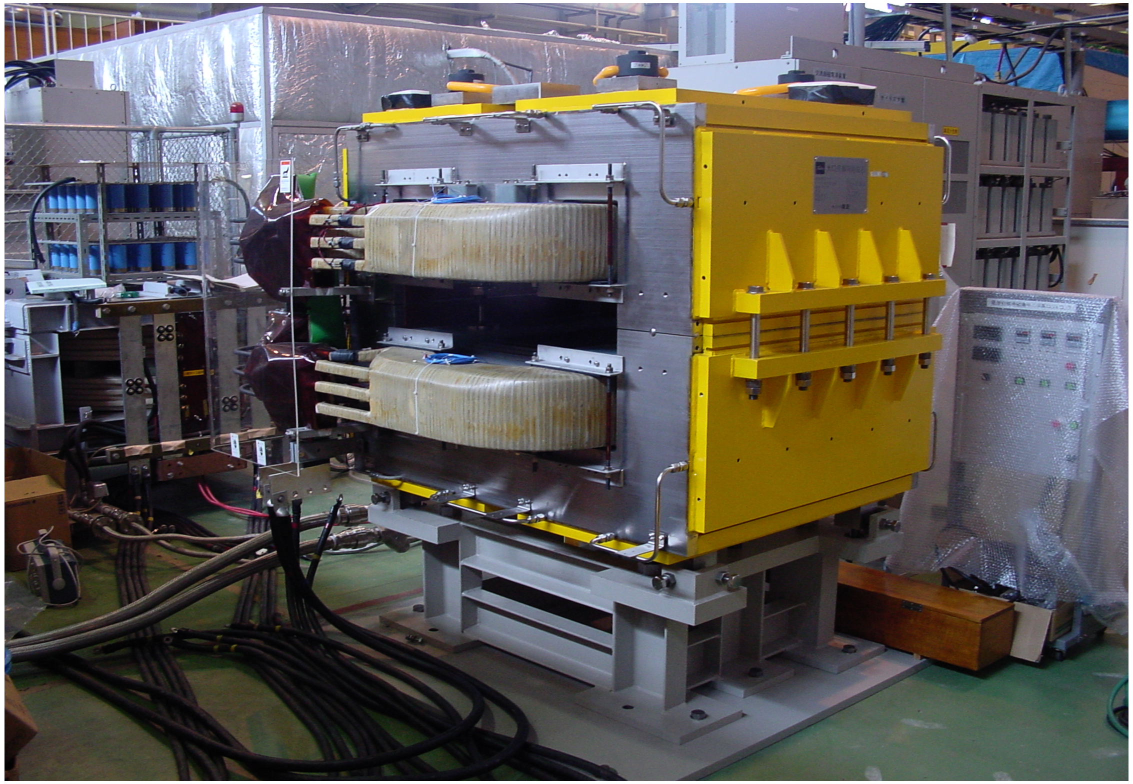
Beta Function of RCS



Dispersion Function of RCS



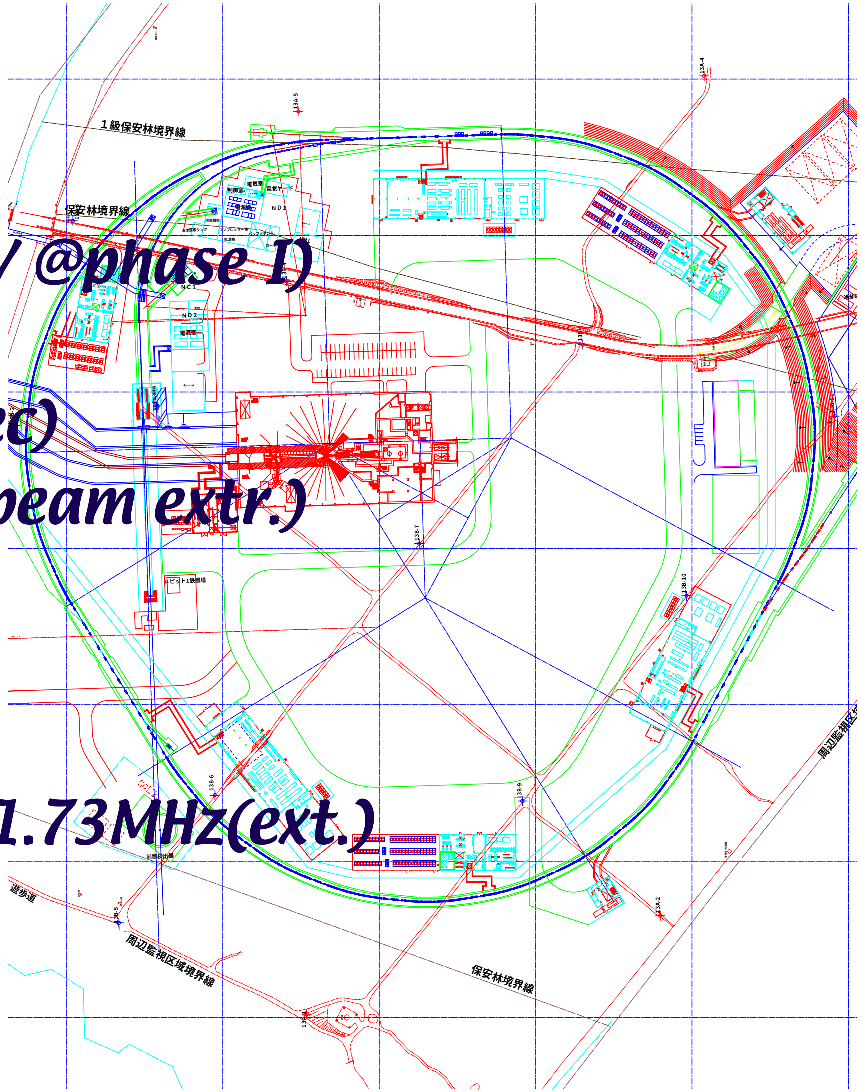
R&D Dipole Magnet for 3-GeV Synchrotron



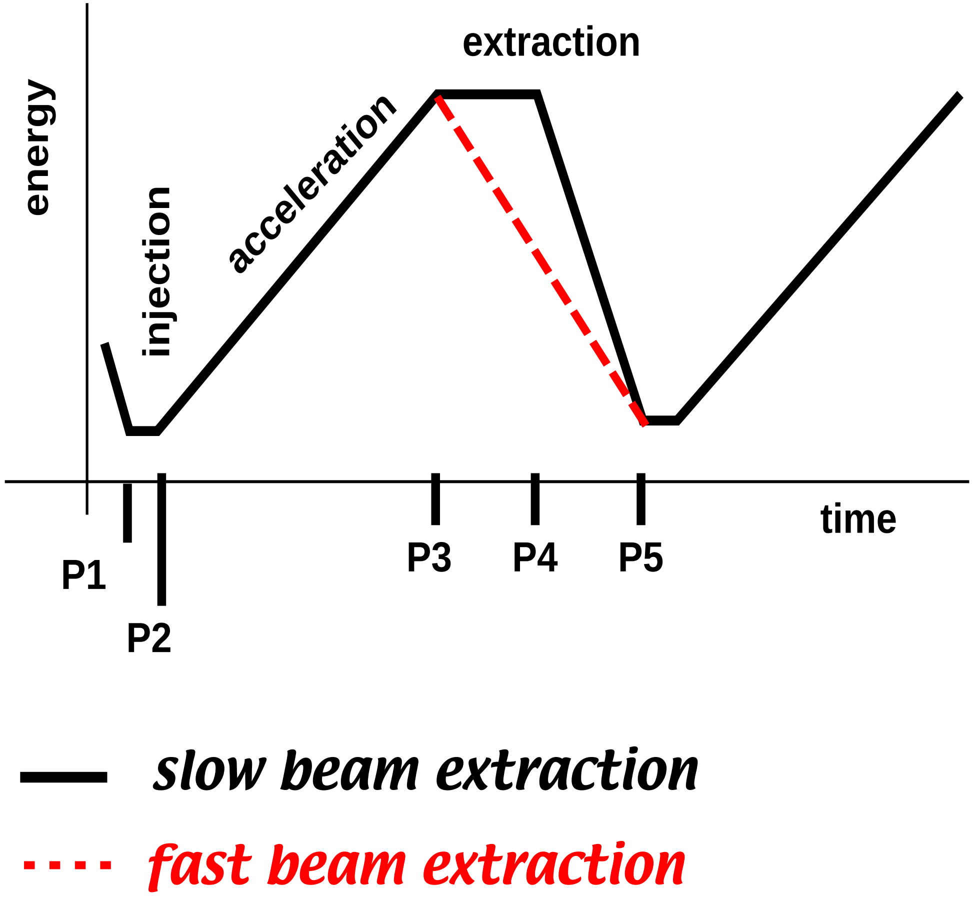
Repetition rate : 25[Hz],
Core length : 1.0[m], Gap height : 210[mm]
Max. field : 1.1[T]（at 3GeV）, Min. field : 0.27[T]（at 400MeV）

Specifications of 50 GeV Main Ring

injection energy	3 GeV
extraction energy	50 GeV (40 GeV @phase I)
# of protons	3.3 x10^{14} ppp
repetition rate	0.3 Hz (~3.6 sec)
ave. beam current	15 ∝A (@slow beam extr.)
beam power @50GeV	0.75 MW
superperiod	3
harmonic number	9
rf frequency	1.68MHz(inj.)-1.73MHz(ext.)

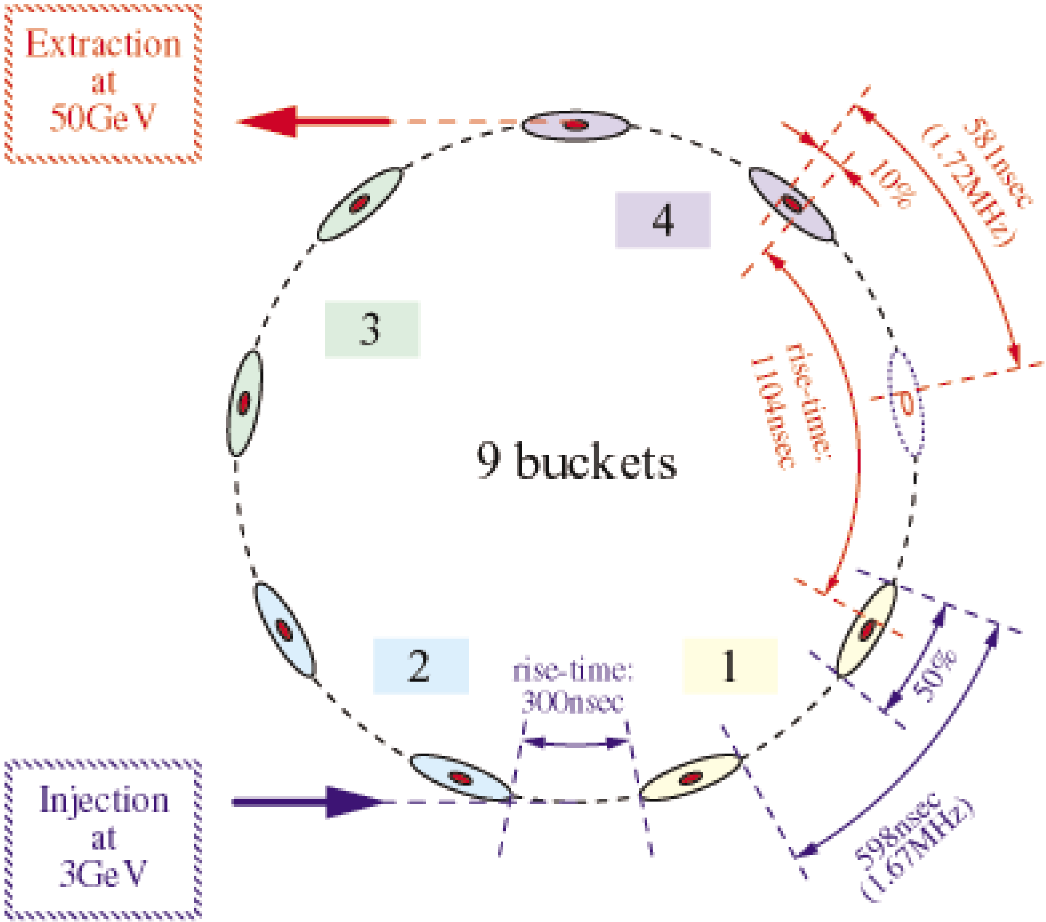


Acceleration Cycle



P1 - P2(injection)	0.14 s
P2 - P3(acceleration)	1.9 s
P3 - P4(extraction)	0.7 s
P4 - P5	0.9 s
total	3.64 s
slow beam extraction	
duty factor	0.20
average current	15∝A

Injection/Extraction Scheme for 50 GeV Ring



Minimization of Beam Loss : key issue for reality

"radiation safety" & "maintenance"

beam loss-> * controlled : localized and shielded (cf. ESS at extraction)

* uncontrolled : whole ring ~1W/m

allowed beam losses :

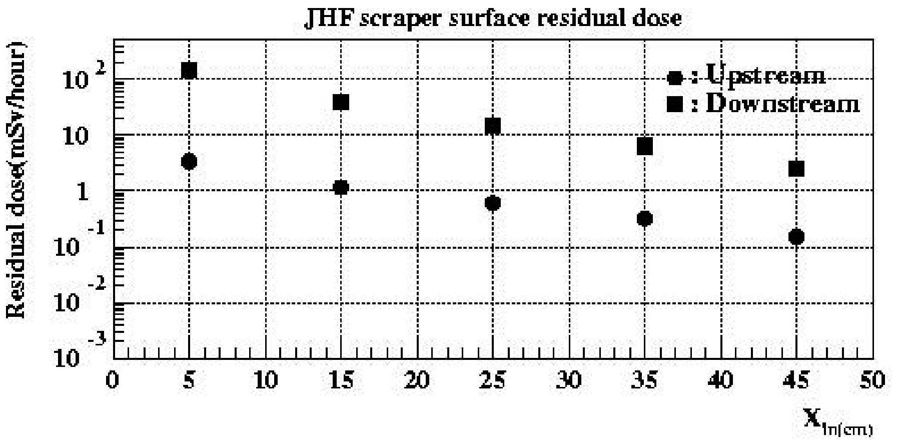
-Injection	135W	0.3%	cont.
-collimator	450W	1%	cont.
-ring	0.5W/m	0.36%	uncont.
-slow beam ext.	7.5kW	1%	cont.
-fast beam ext.	1.125kW	0.15%	cont.
total	8.9kW	2.7%	@slow beam ext.
	2.5kW	1.8%	@fast beam ext.

Residual Radiation Activity

example -> 3-50GeV BT collimator

. Inner side @ Jaw

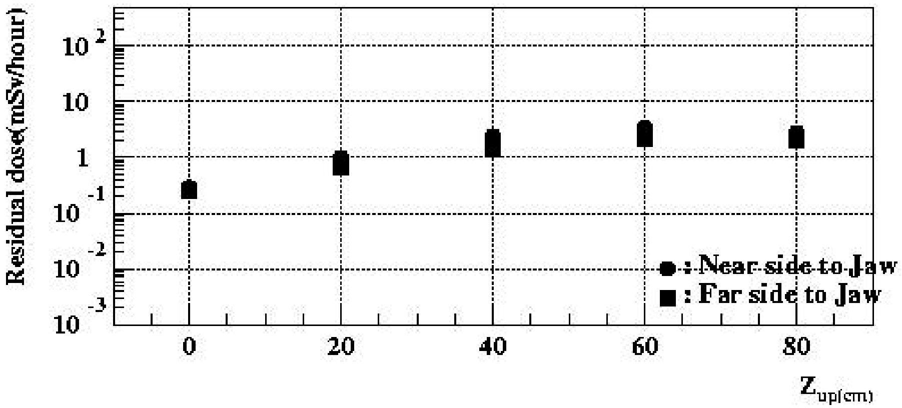
> 0.1Sv/h (beam loss 0.45kW)



. Outer shield surface

shield : 45cm iron

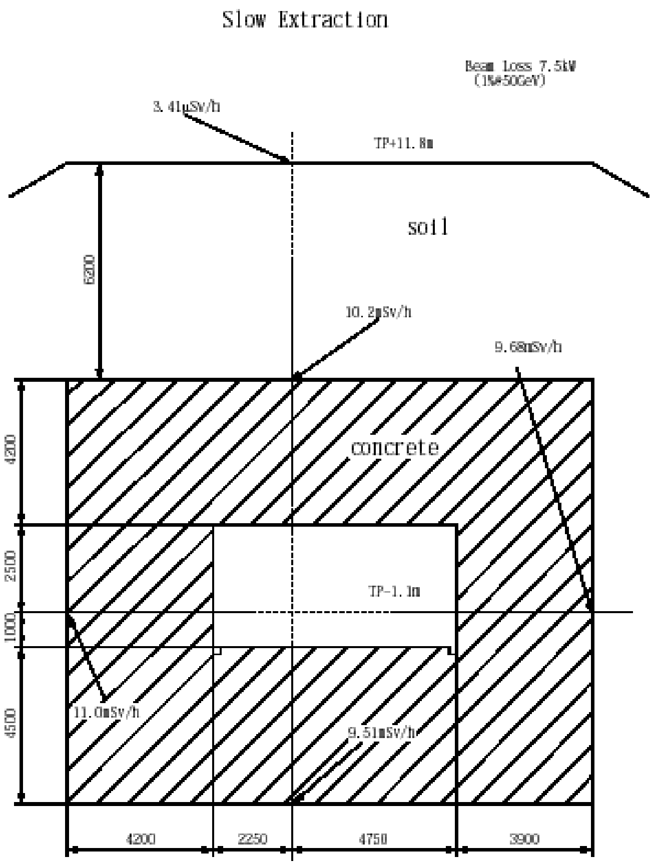
~3mSv/h



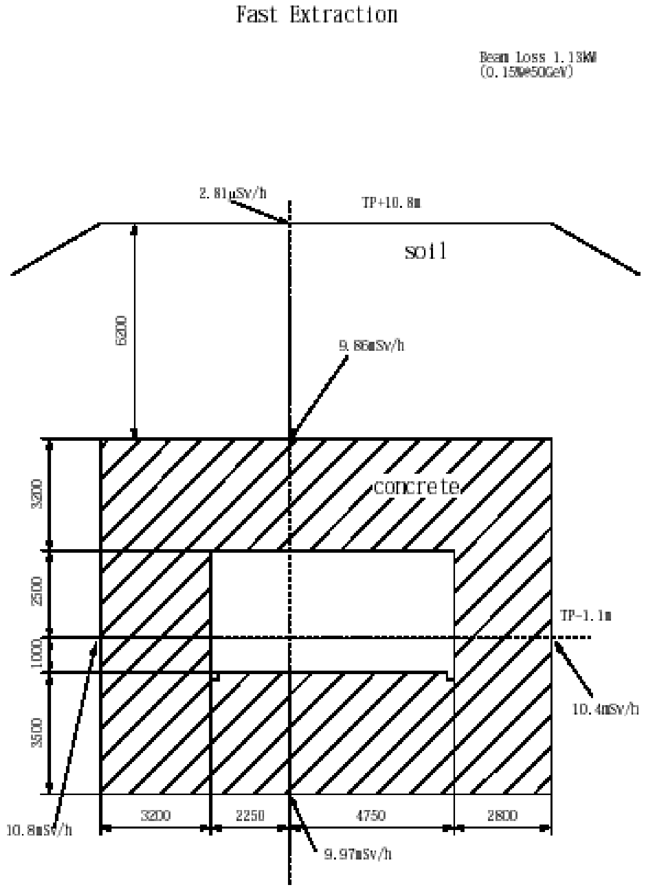
* after 1day cooling off following 30days operation

Radiation Shield at Beam Extraction Area

slow extraction



fast extraction



What causes beam loss?

Beam Dynamics:

high intensity beam behaviors

- Space Charge Effect

  coherent, incoherent, non-linearity, halo formation

- Instabilities

  microwave, e-p, coupled bunch, etc.

- others?

large acceptance

- fringe-field effect

Space Charge Effect -Laslett tune shift(spread): ΔQ-

. 50GeV MR

ΔQ=- 0.14

*emittance	54 πmm.mrad
*beam intensity	3.3×10^{14} ppp
*bunching factor	0.27
*form factor	1.7

$$\Delta Q = -\frac{rFN_p}{\pi\varepsilon\beta^2\gamma^3 B_f}$$

. 3GeV RCS (for 50GeV MR)

ΔQ=-0.22

*emittance	144 πmm.mrad
*beam intensity	8.3×10^{13}ppp
*bunching factor	0.42

Emittance & Acceptance for 50GeV PS

	emit. (πmm.mrad)	nor. emit. (πmm.mrad)	collimator accep.	physical accep.
3GeV PS				
injection	144	146	324	486
extraction	54(core)	220	-	486
3GeV BT				
collimator	54	220	54	120
50GeV PS				
injection	54	220	54-81	81
extraction (30GeV)	10	330	-	81
extraction (50GeV)	6.1	330	-	81

3GeV PS, injection → extraction (nor. emit.): 1.5times

50GeV PS, injection → extraction (nor. emit.): 1.5times

Lattice of 50GeV PS

*Imaginary transition gamma :

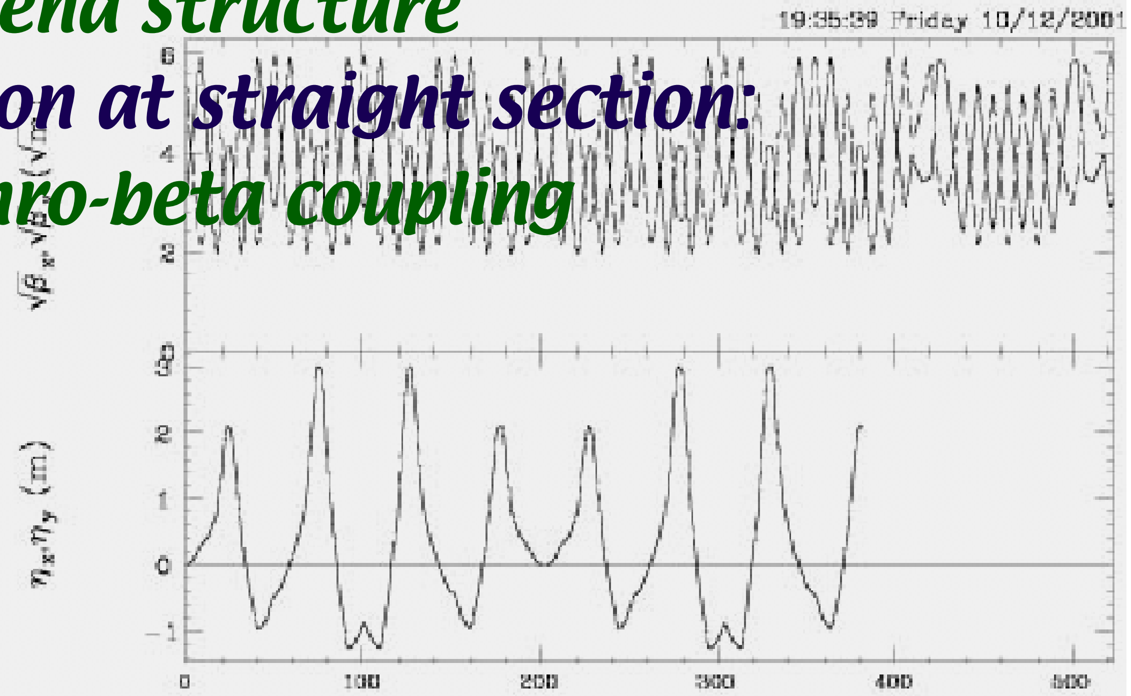
γ -> 32i (no transition energy)

* Negative dipspersion at bending magnets :

missing-bend structure

*Zero dispersion at straight section:

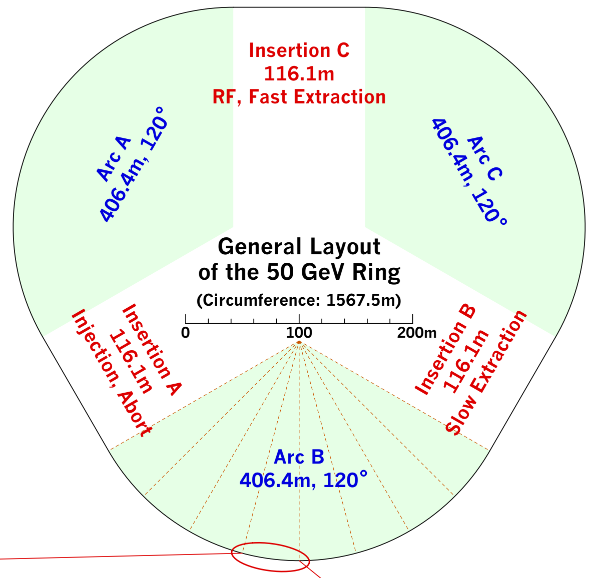
non synchro-beta coupling

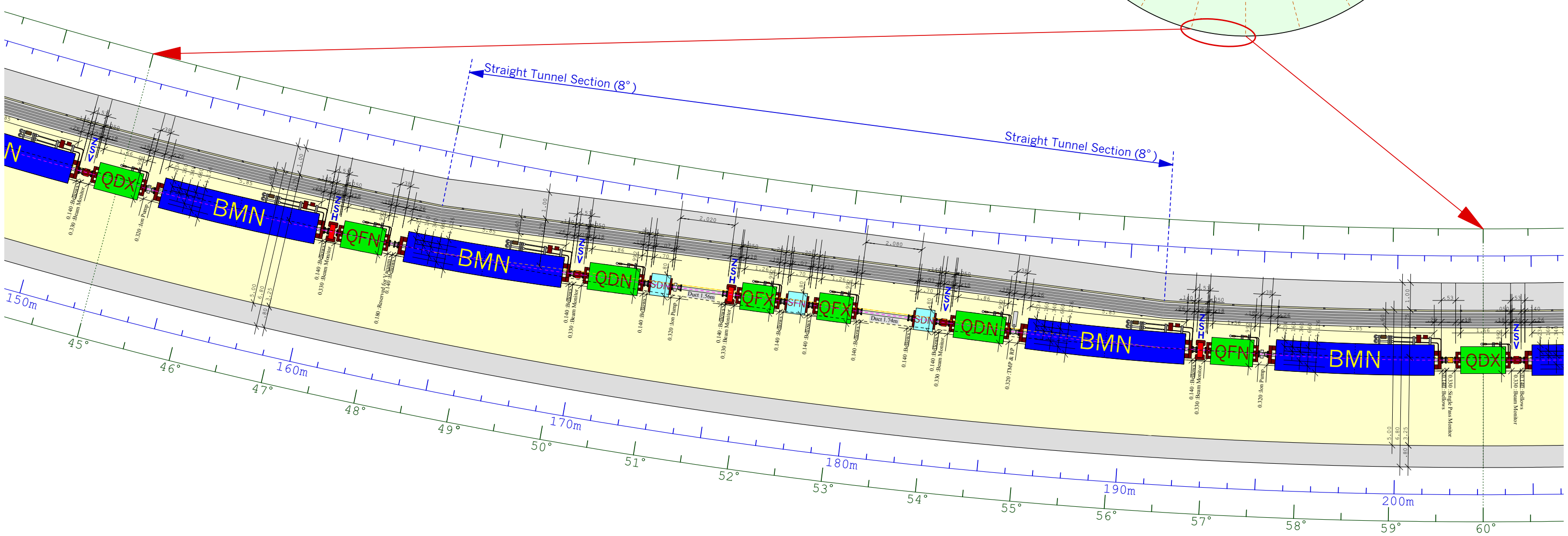


Layout of Magnets -Missing Bend. Mag. Section-

50 GeV Ring

--- 1 Module (15°) of the Arc ---

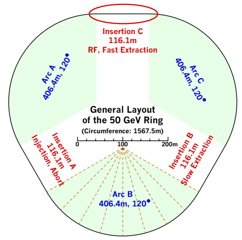


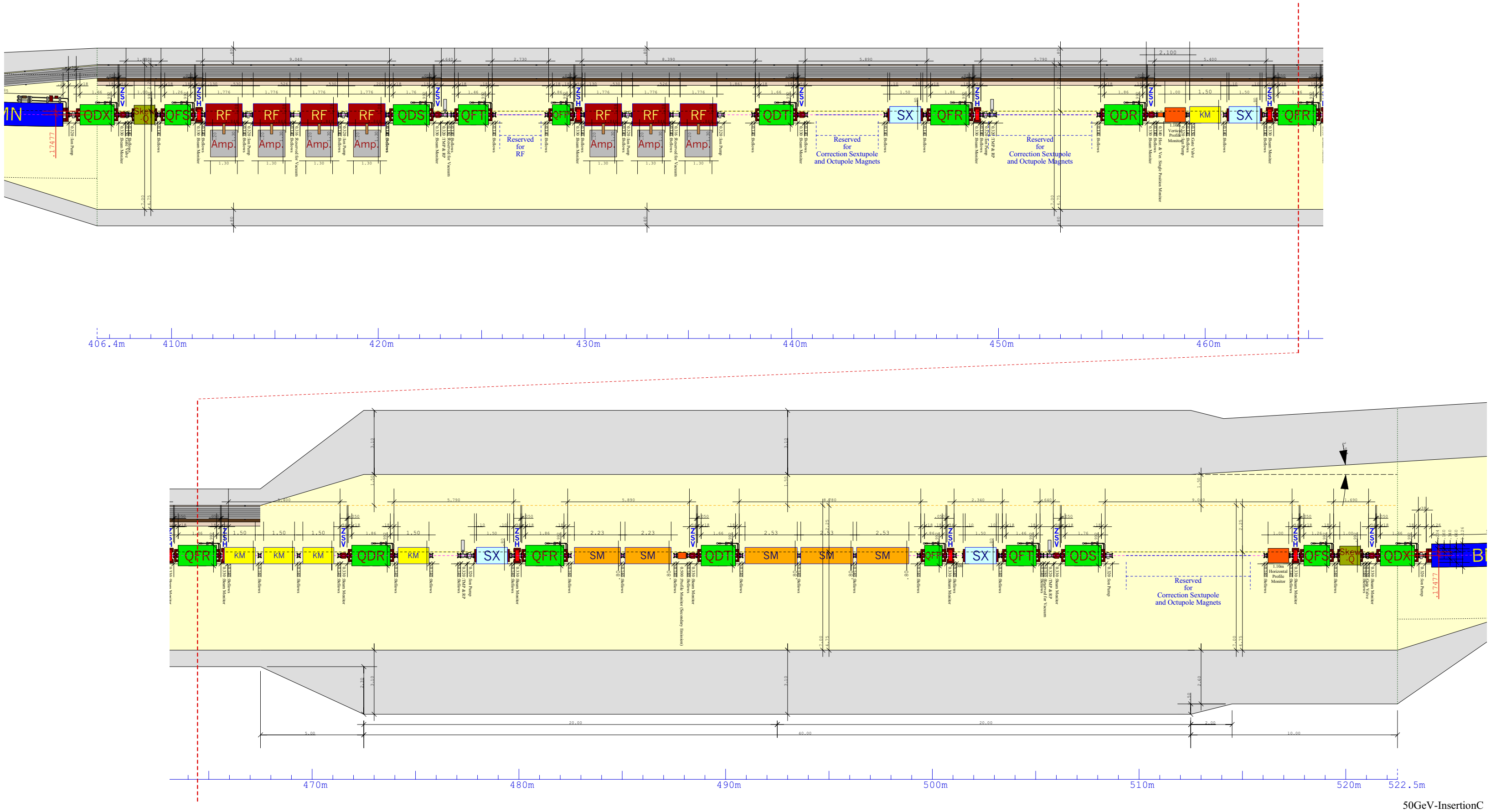


Layout of Magnets -straight section (RF & fast. ext.)-

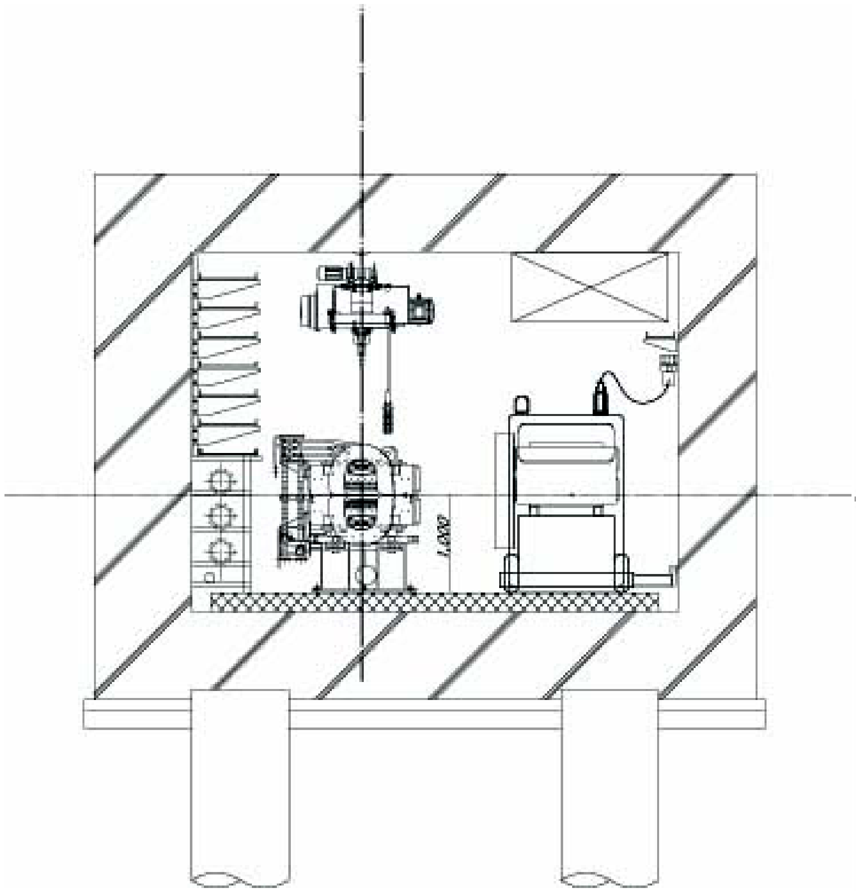
50 GeV Ring

--- Insertion C / RF & Fast Extraction ---

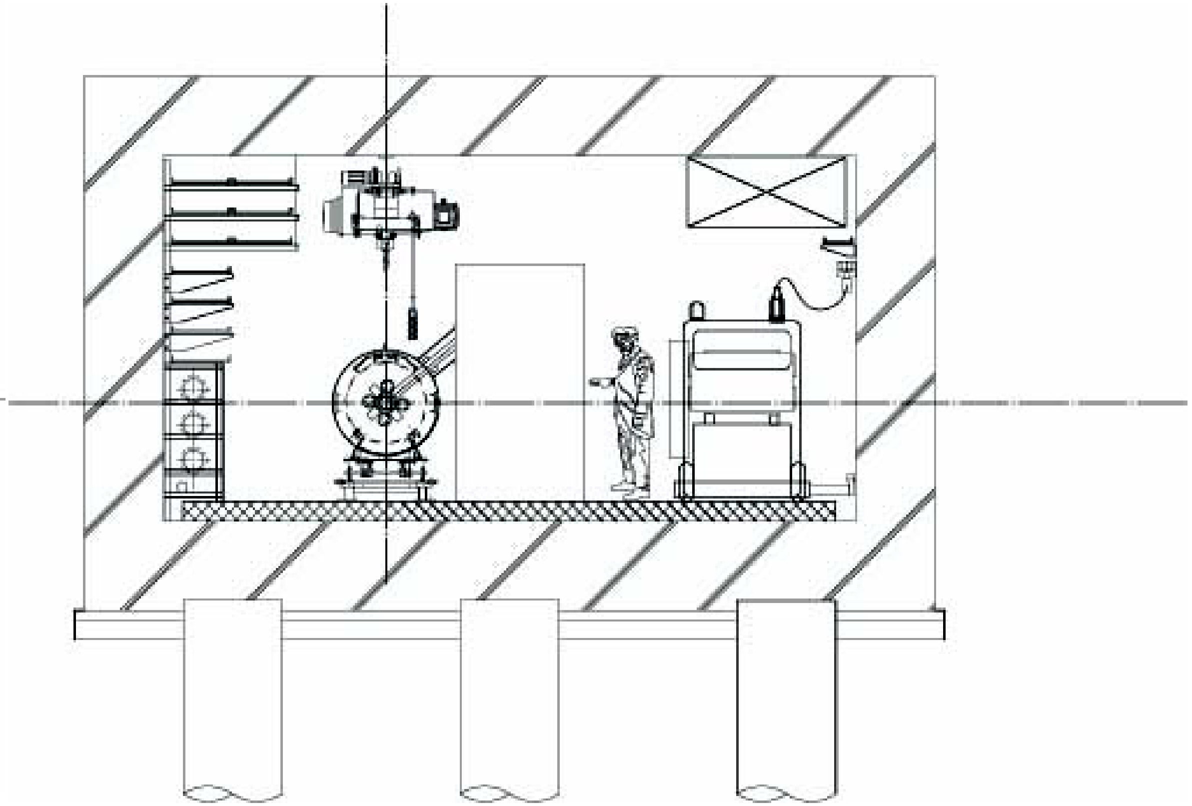




Tunnel -cross section-



arc section



staright section

Hardwares

1) Magnets

   1.9 T - D magnet, large bore Q magnet

2) Magnet Power Supply

   low ripple & 100% power factor with IGBT

3) RF System

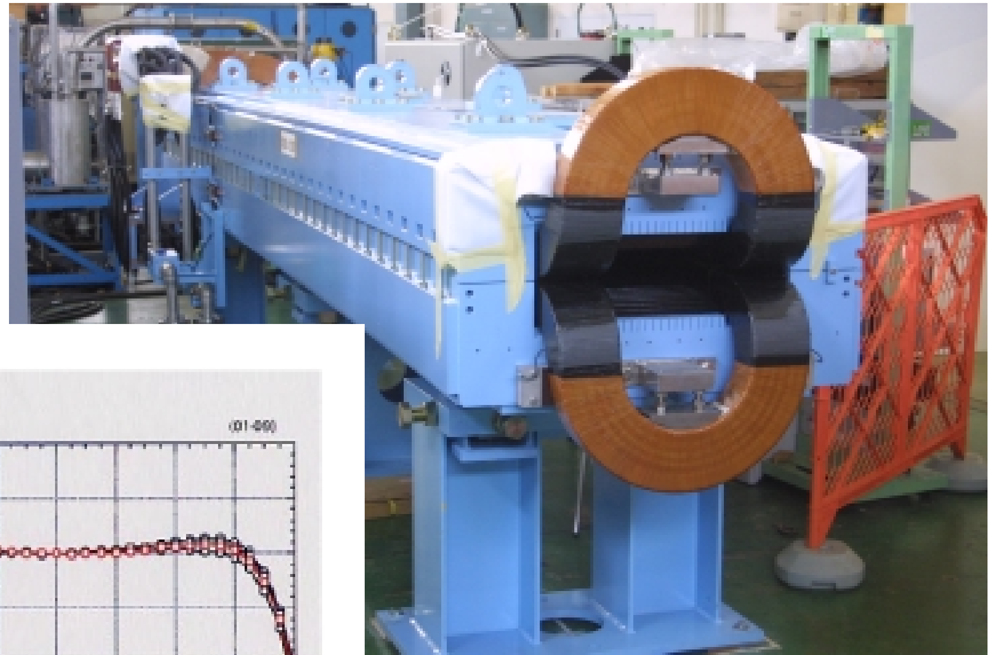
   High gradient RF cavity with Magnetic Alloy

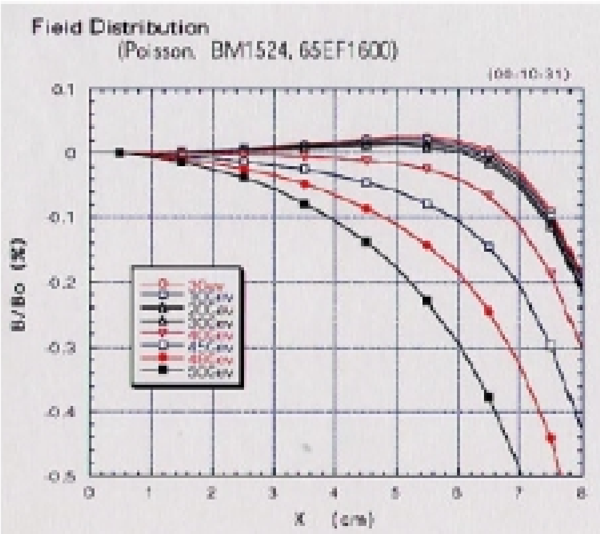
4) Electro-static Septum

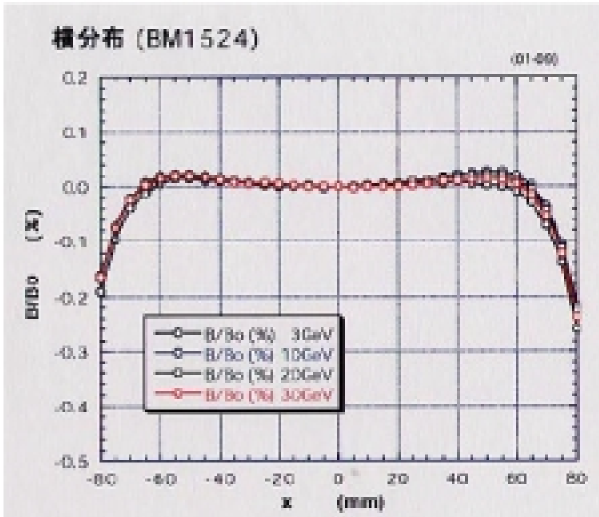
   Small beam loss at slow beam extraction

Dipole Magnet for 50GeV MR (R&D)

gap Height	106mm
useful Aperture	120mm
field	0.143-1.9T
length	5.85m
weight	34 ton



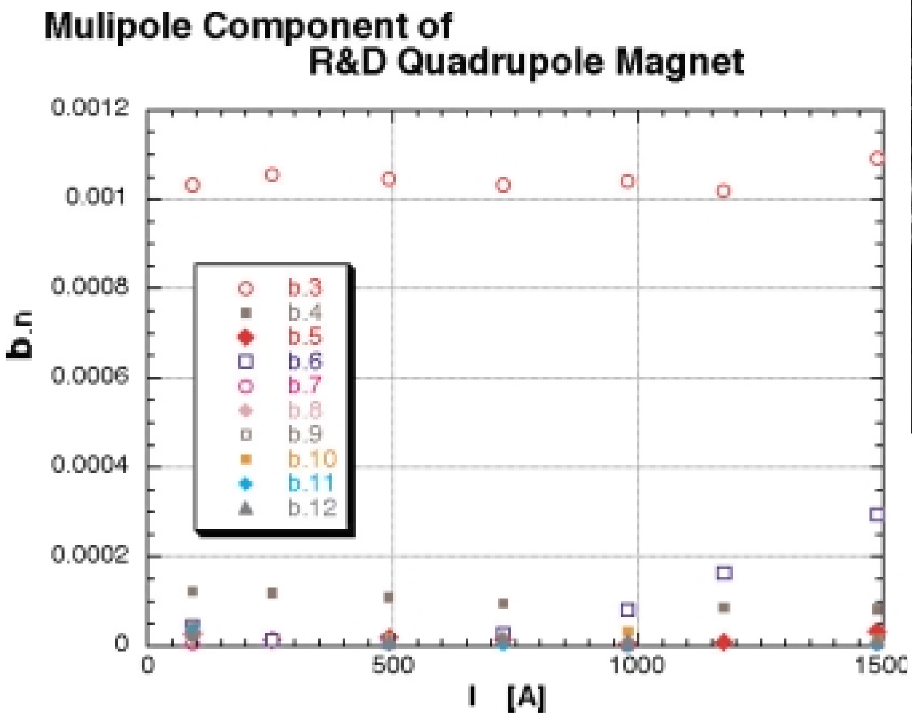


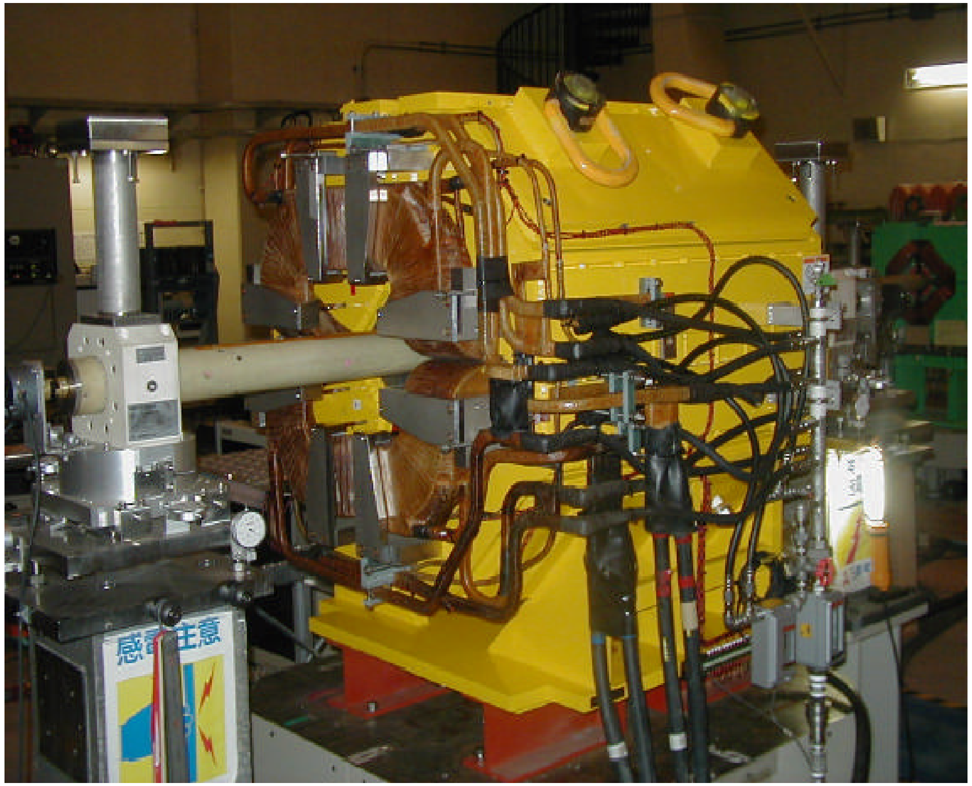


good agreement with calculations!

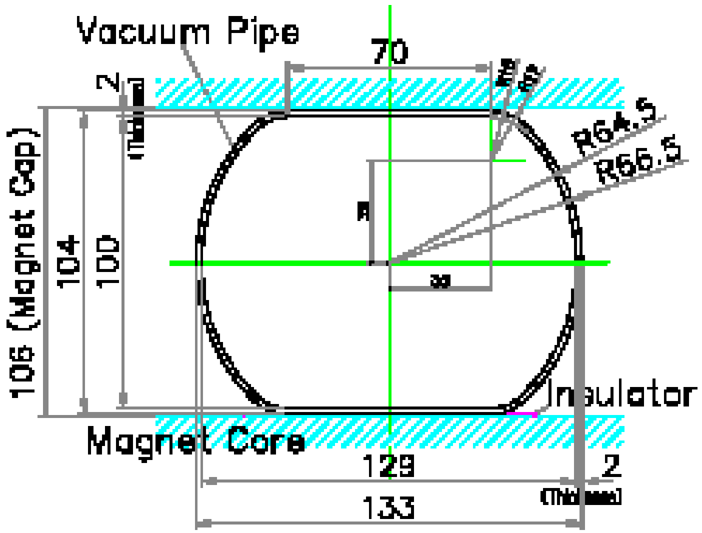
Quadrupole Magnet of 50GeV PS (R&D)

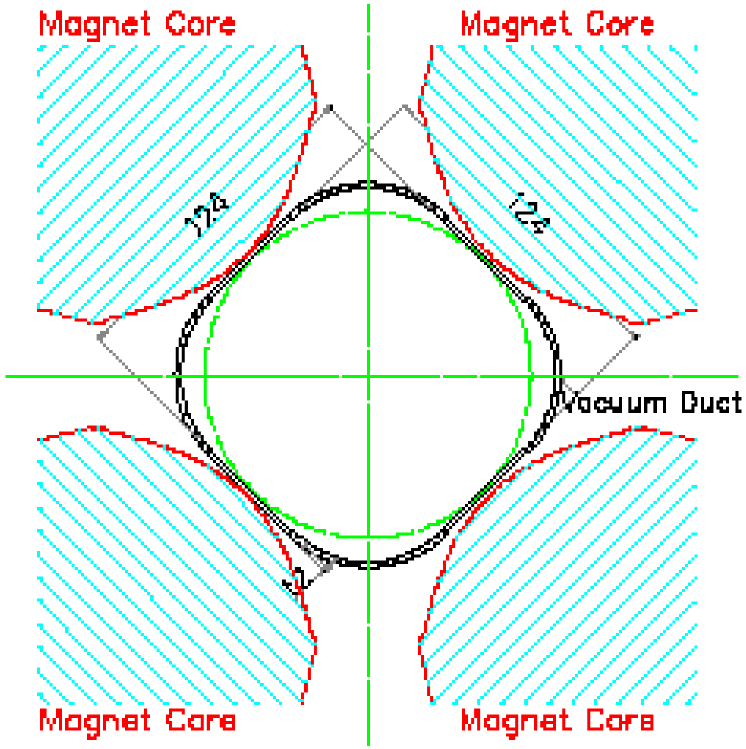
Bore Radius	63mm
Useful Ap.	132mm
Max. Field	18T/m
Length(max.)	1.86m





Vacuum Chamber





bending magnet

quadrupole magnet

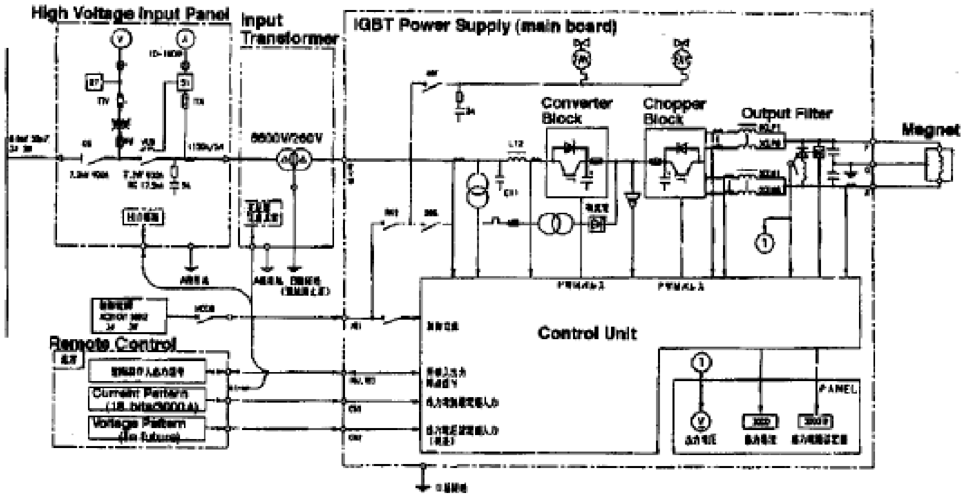
Magnet Power Supply

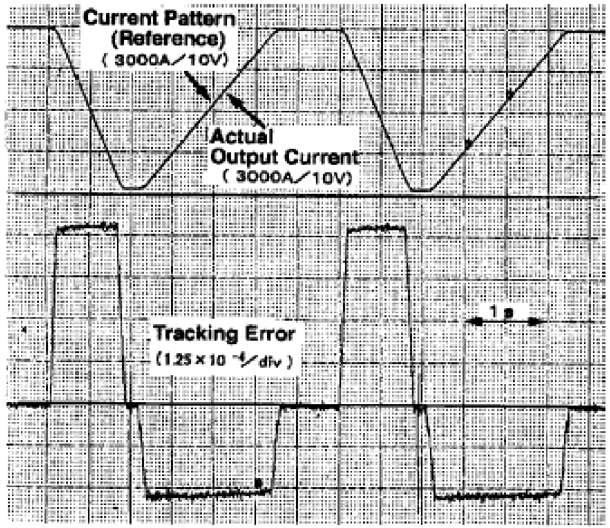
* development of new type high power switching devices (IGBT, IEGT)

accelerator	year	spec.	w.f.	conv.
INS-ES	1962	21.5Hz	sin.	MG
KEK-booster	1974	20Hz	sin.	SCR
KEK PS	1976	0.5Hz	trape.	SCR
SPring-8 syn.	1996	1Hz	trape.	SCR
JHF R&D	1999	0.3Hz	trape.	IGBT
Tsukuba U.	2000	0.4Hz	trape.	IGBT
50GeV MR	2007	0.3Hz	trape.	IGBT/IEGT(120MVA)

Magnet Power Supply (R&D)

* self-converter(PWM) type (high freq. switch. ~20kHz)
* no reactive power 100 % power factor
* ripple ~ 10^{-6}
* tracking error ~10^{-4}



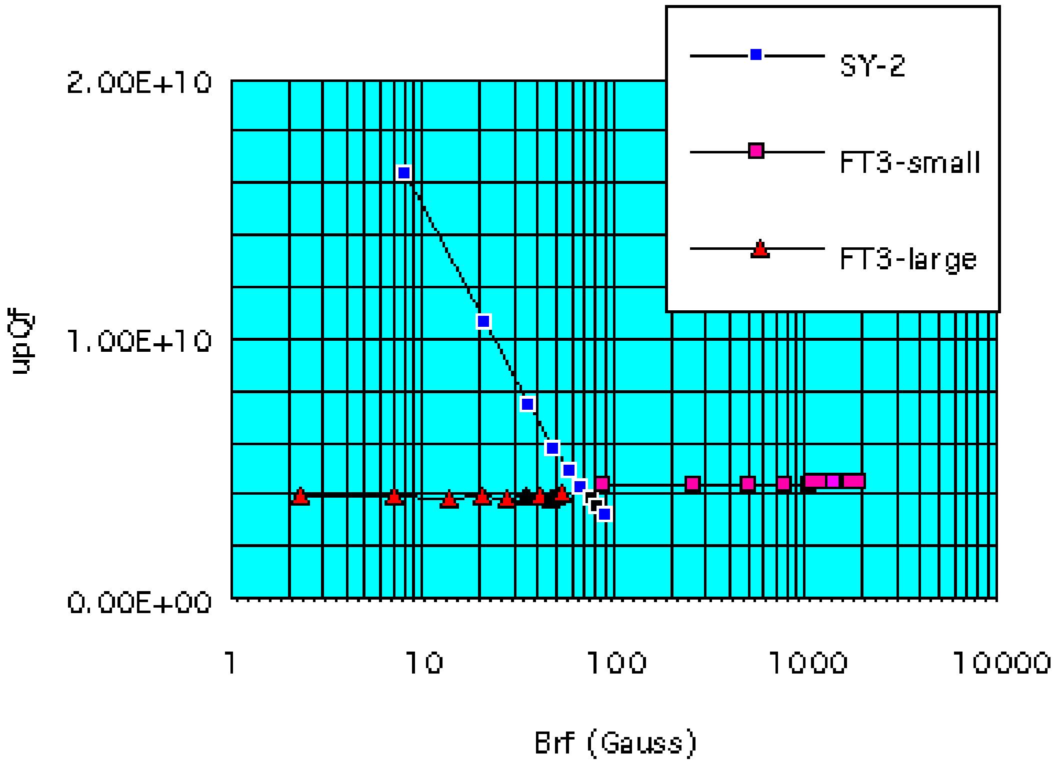


RF Cavity with Magnetic Alloy

* RF behaviour at high field E>40kV/m

$\propto$Qf (shunt.imp.) vs. B_{rf}

$\propto$Qf

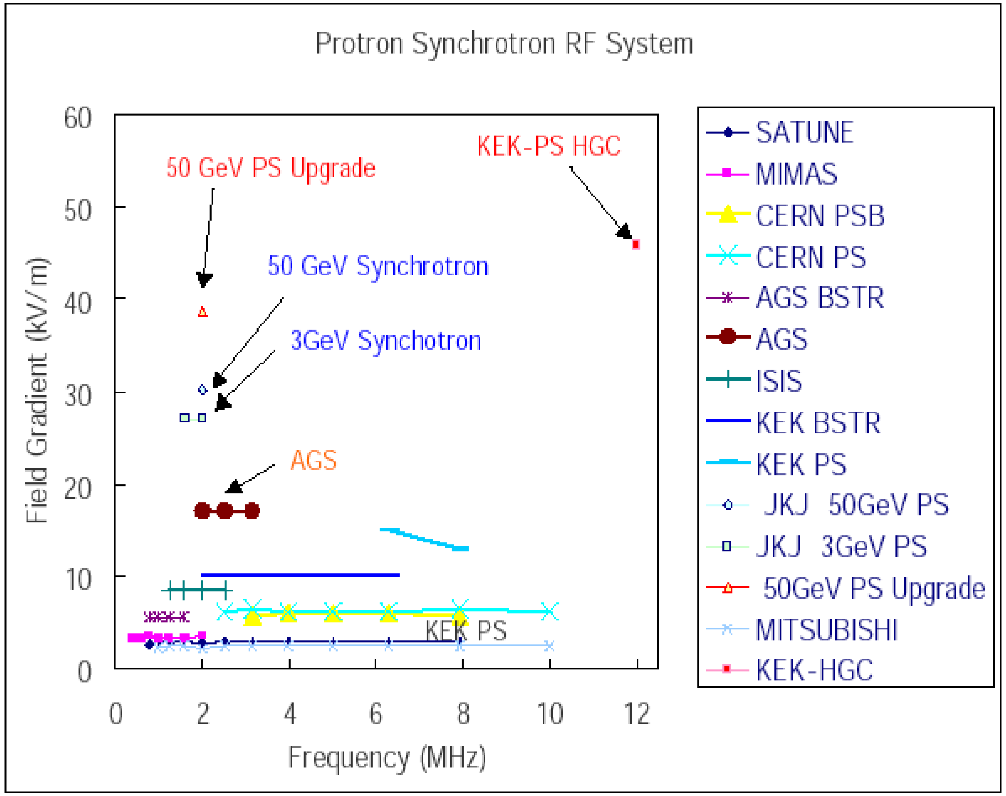


B_{rf}

High Field Gradient RF Cavity with Magnetic Alloy

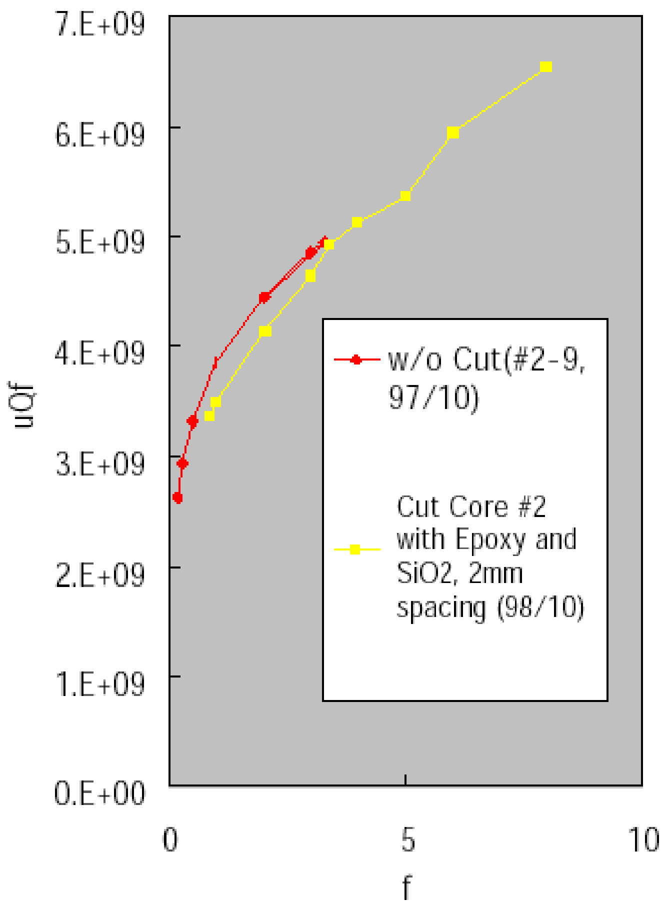
-MA Cavity-

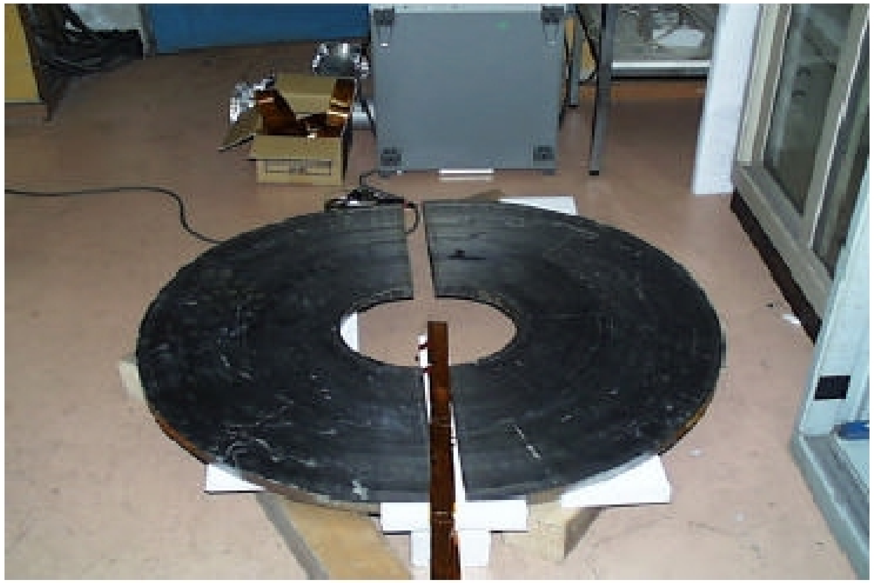
Field Gradient of RF Cavity



MA Cavity - Cut Core

* Increase of Q-value with cut core -> curing beam loading



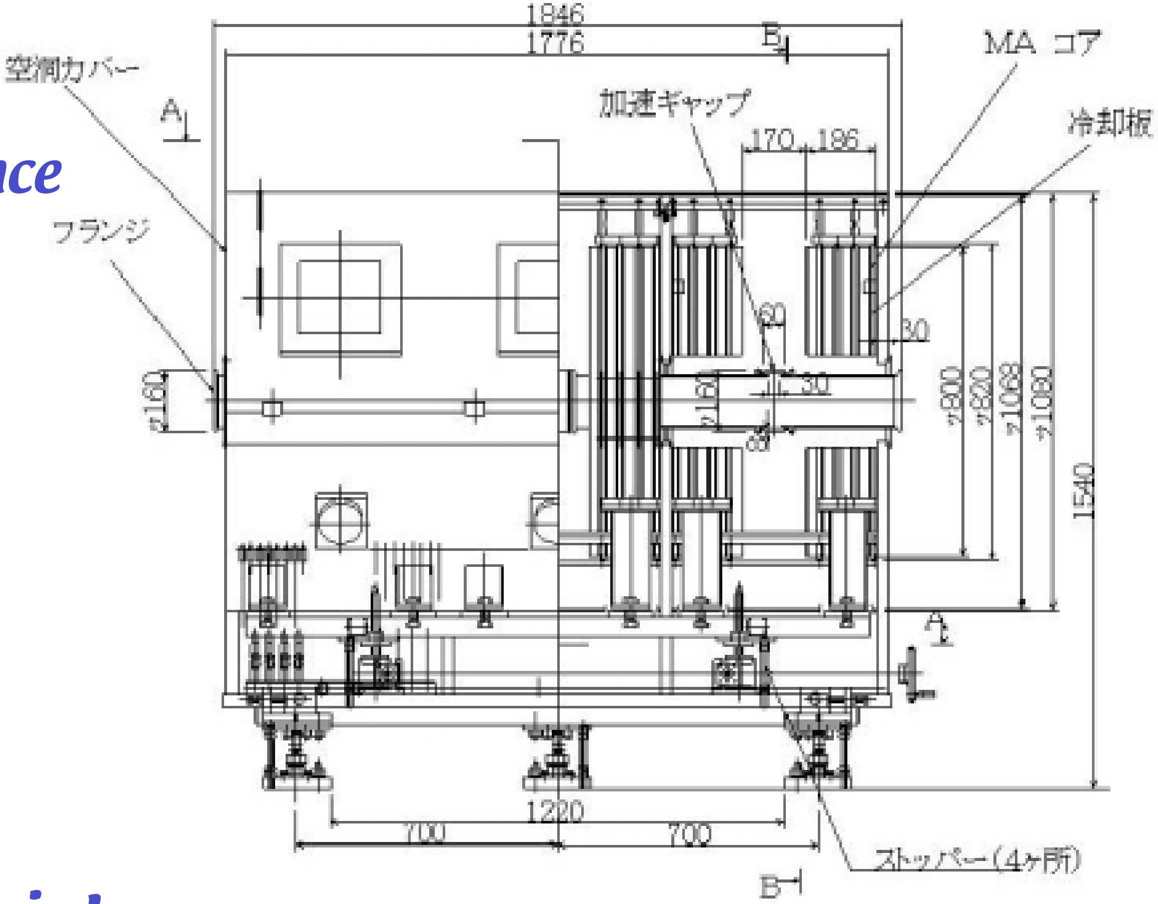


High Gradient MA Cavity (R&D)

* Cooling (indirect)

- -copper cooling plate
- -keeping high shunt impedance

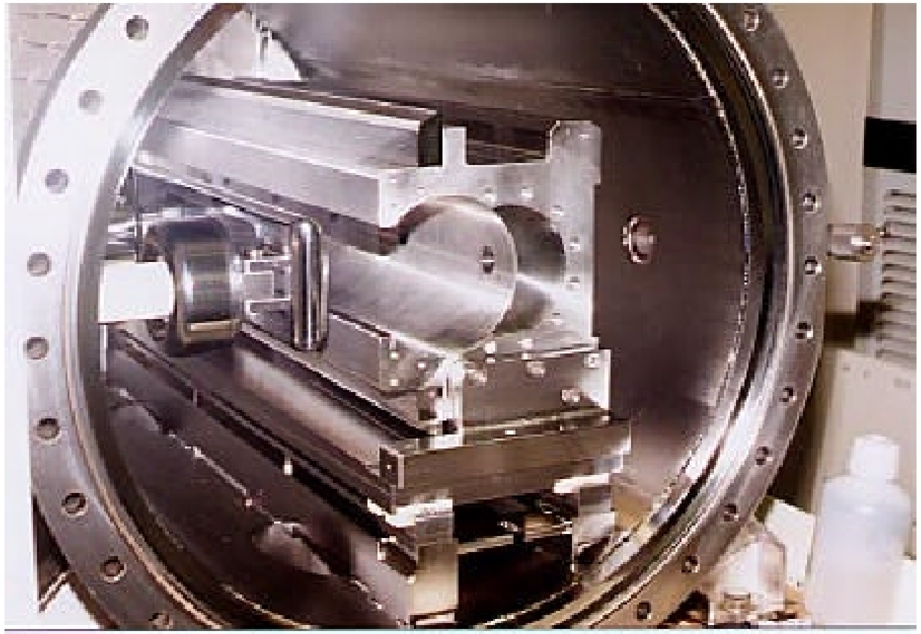
core cutting with water-jet



MA Caivty

Electro-static Septum (R&D)

* High Field -> 237kV :achieved(1.4 x design voltage)
* Need high quality ceramic feedthrough



ESS(R&D) assembly

Summary Linac Schedule Milestones

- **JFY01: Most components for 200-MeV Linac and Bldg. to be ordered**
- **Mid JFY02: Most components for 400-MeV Linac to be ordered**
- **Summer JFY04 : Bldg. Completed, Installation to be started**
- **March JFY05: Commissioning to be started**
- **Mid JFY 06: Beam injection to RCS to be started**

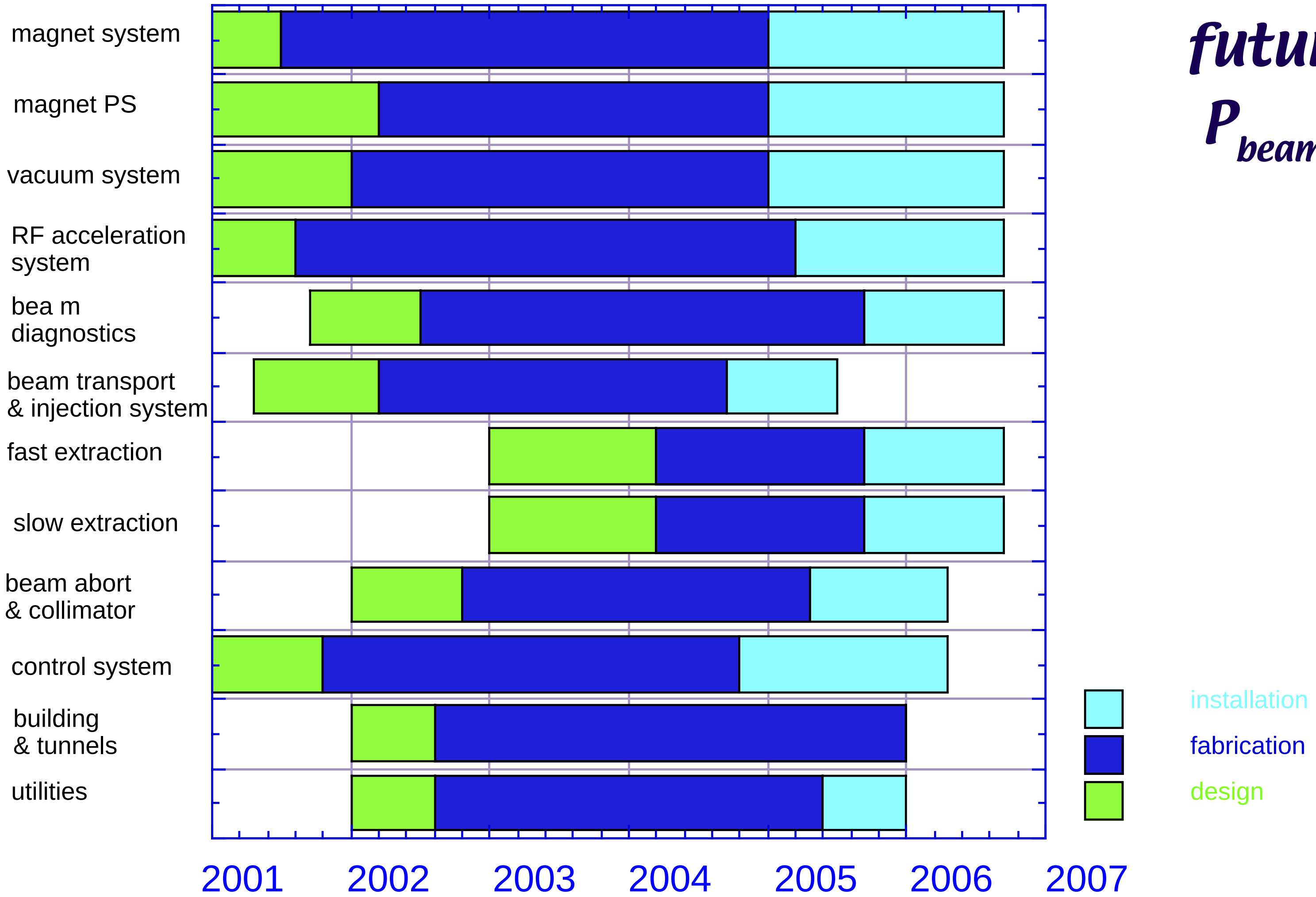
Summary RCS Schedule Milestones

- **JFY02: Half of components for and Bldg. to be ordered**
- **JFY03: Remaining half of components to be ordered**
- **March JFY04 : Bldg. Completed, Installation to be started**
- **Mid JFY06: Beam injection to RCS, that is, RCS commissionng to be started**
- **March JFY06: Beam extraction to the Neutron Source and to the 50-GeV Ring**

Summary 50-GeV Ring Schedule Milestones

- **JFY01: Most of magnets and power supplies have been ordered.**
- **JFY02: Remaining components to be ordered**
- **Mid JFY05 : Bldg. Completed, Installation to be started**
- **March JFY06: Beam injection to the 50-GeV Ring and its commissioning to be started**
- **Mid JFY07: Beam extraction to the Nuclear and Particle Experimental area**

Summary schedule



future upgrade

P_{beam} ~4MW