Proton driver in Japan: JHF status

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July 4, 2002

contents

- Introduction
- Design philosophy
  - Minimizing beam loss
- Hardware R&D

Physics motivation

- 1E14 ppp source of secondary particle (K, pi, mu, nu, etc.)
  - 50 GeV MR
- 1 MW spallation neutron source
  - 3 GeV RCS
- Transmutation, both for physics and enginearing.
  - 600 MeV Linac

3GeV RCS: LAR(linac and acumulator) vs. RCS(rapid cycling synchrotron)

- 3GeV RCS is an injector of 50GeV MR.
  - Higher injection energy of 50 GeV MR is preferable.
- The higher the extraction energy is, the lower the current.
  - Beam power = energy x current
- More beam loss is tolerable at injection.
  - The same reason above.

- Beam stays longer in the machine.
  - 20ms(RCS) vs. 1ms(LAR)
- Hihger RF total voltage is necessary.
- All the magnet should be synchronized, especially the tracking of quads.
- Need some cure against eddy current.

Layout

大強度陽子加速器施設配置案
太平洋
3GeVシンクロトロン
核変換実験施設
600MeVリニアック
物質・生命科学
実験施設
原子核・素粒子
実験施設
ニュートリノ
実験施設
50GeVシンクロトロン
154kV特高変電所

Specifications

- 50 GeV MR
  - Protons per pulse 3.3E14 ppp
  - Repetitions 0.3 Hz (3.64s)
  - Average current 15 microA
  - Beam power 0.75 MW

- 3GeV RCS
  - Injection 400 MeV
  - Protons per pulse 0.83 E14 ppp
  - Repetition 25 Hz (40ms)
  - Average current 333 mircoA
  - Beam power 1 MW

Design philosophy

Minimizing beam loss

Definition of beam loss and its limit

- Controlled loss
  - Localized and shielding takes care
  - 4kW @ 3GeV RCS collimator
  - 7.5kW @ 50GeV MR ESS septum

- Uncontrolled loss
  - Not localized and no special shielding. If this happens to be large, total beam intensity is decreased.
  - About 1W/m

Expected at each area (or element)

3GeVRCS			
– Injection and collimator	4kW	2%	controlled
– Around the ring	1W/m	0.1%	uncontrolled
– extraction	1kW	0.1%	uncontrolled
total	5.33kW	2.2%	
3-50GeVBT			
– collimator	450W	1%	controlled
– Other area except collimator	1W/m	0.44%	uncontrolled
50GeVMR			
– injection	135W	0.3%	uncontrolled
– collimator	450W	1%	controlled
– Around the ring	0.5W/m	0.36%	uncontrolled
– Slow extraction	7.5kW	1%	controlled
– Fast extraction	1.125kW	0.15%	uncontrolled
total	8.9kW	2.7%	(slow extraction)
	2.5kW	1.8%	(fast extraction)

Example of radiation calculation (3GeV RCS collimator region)

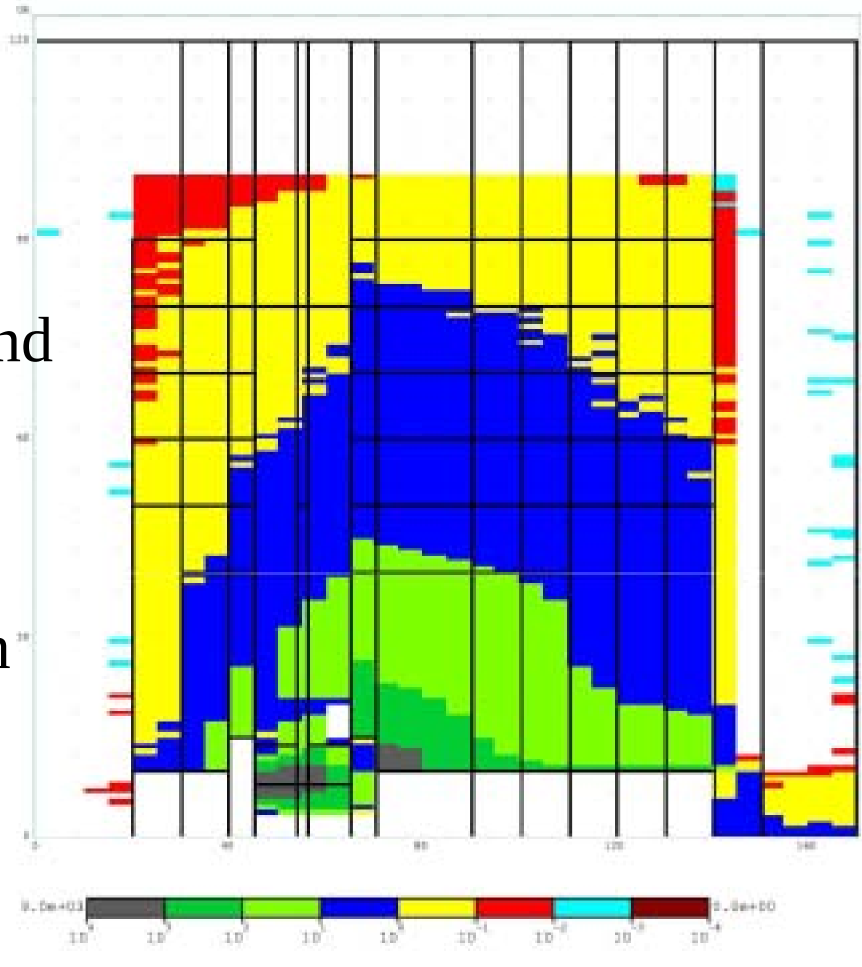
•Inside collimator (near JAW)

> 1Sv/h (1.2kW/piece)

•Outside the shield (300mmFe and 400 mm concrete)

7mSv/h

*radiation after 30days operation and 1day cooling



What makes beam loss?

- We do not know the behavior of a high intensity beam
  - Space charge effects
  - E-p instability
  - Some other reasons?

- Intensity independent effects
  - Fringe fields due to large core magnets

Space charge tune spread

- 3GeVRCS
  - 0.15 assuming the following value
    - emittance 216 pi mm-mrad
    - intensity 0.833 E14 ppp
    - Bunching factor 0.42
- 50GeV MR
  - 0.14 assuming the following values
    - emittance 54 pi mm-mrad
    - intensity 3.33 E14 ppp
    - Bunching factor 0.27
    - Form factor 1.7

Some efforts to minimize space charge effects

- Enlarge physical aperture to minimize vertical beta function at the bending magnets.
- Enlarge transverse emittance and control it with injection painting @ 3GeV RCS
- Control longitudinal emittance with RF manipulation.
  - Shaking of rf phase or voltage in 3 GeV RCS.
- Search best bare tune points away from any resonances.

Emittance and acceptance (Transverse-1)

	emittance (pi mm-mrad)	Collimator acceptance	Physical acceptance
L3BT			
Exit of linac	10		
Right after L3BT collimator	4		
3GeVRCS			
After painting	216	324	486
extraction	81 (core)		
	324 (tail)		

- core means the number simply determined by adiabatic damping of 1.5 times the painted beam.
- tail means the maximum possible amplitude within collimator.

Emittance and acceptance (Transverse-2)

	emittance (pi mm-mrad)	Collimator acceptance	Physical acceptance
3GeVRCS			
Paining injection	144	324	486
extraction	54 (core)	324	486
	324 (tail)	324	486
3GeVBT			
Right after 3-50 GeVBT collimator	54	54	120
50GeVMR			
injection	54	54-81	81
Extraction (30GeV)	10		
Extraction (50GeV)	6.1		

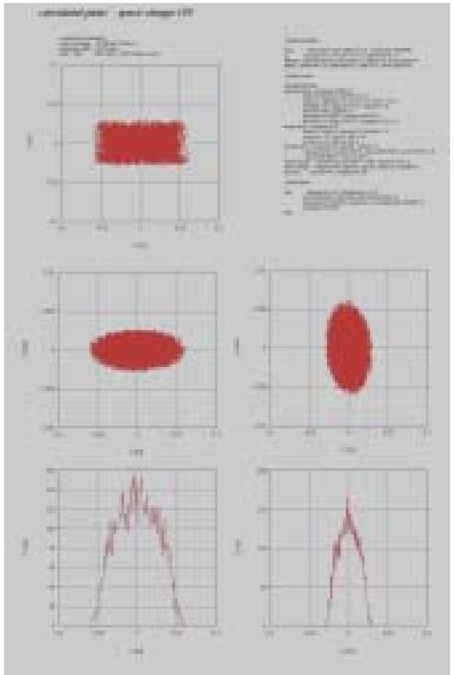
Longitudinal emittance and dp/p

	emittance (eV seconds)	dp/p(%)
L3BT		
Right after L3BT collimator		+/-0.1
3GeVRCS		
injection	5	+/-0.75
Extraction (for 3GeV users)	5	+/-0.42
Extraction (for 50GeVMR)	5	+/-0.24

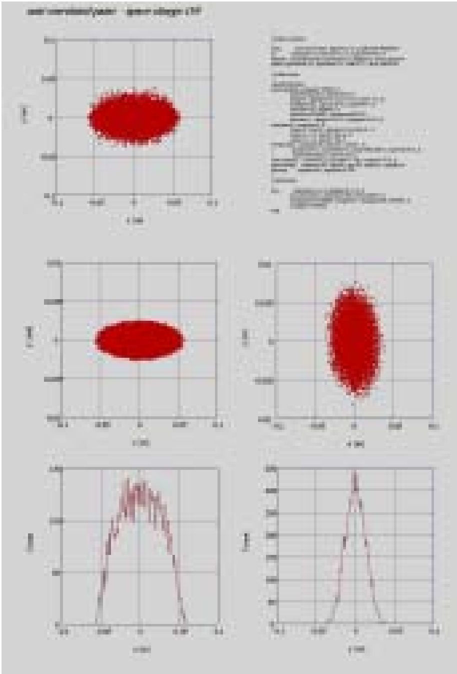
Injection painting

- Anti-correlated painting
  - Start from small emittance in horizontal and large emittance in vertical.
- Correlated painting
  - Start from small emittance in both horizontal and vertical.

- Which is a better way?
- How we match the linac beam to the acceptance
  - What is the optimized twiss parameters of linac beams.



Correlated

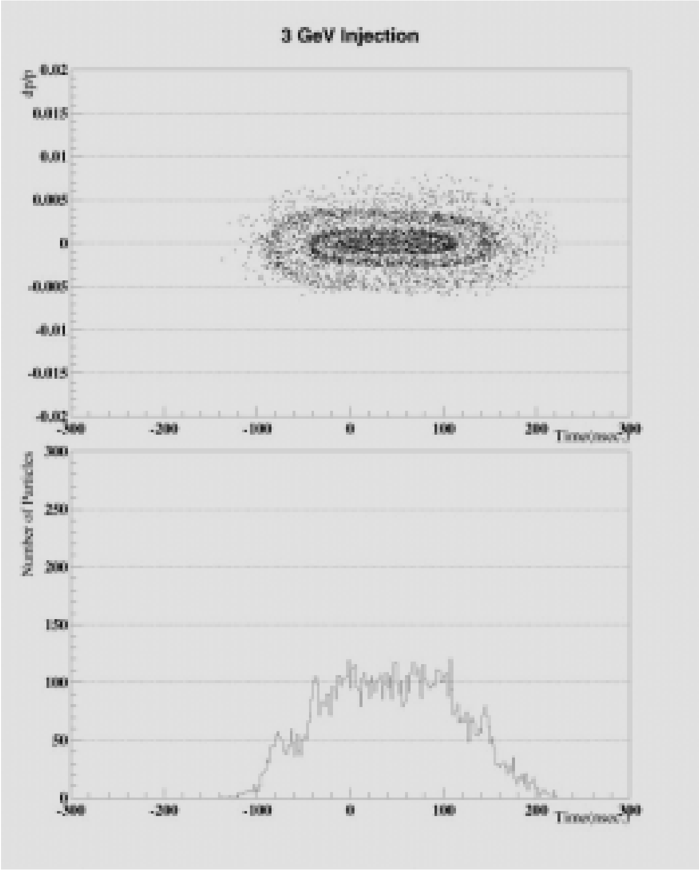


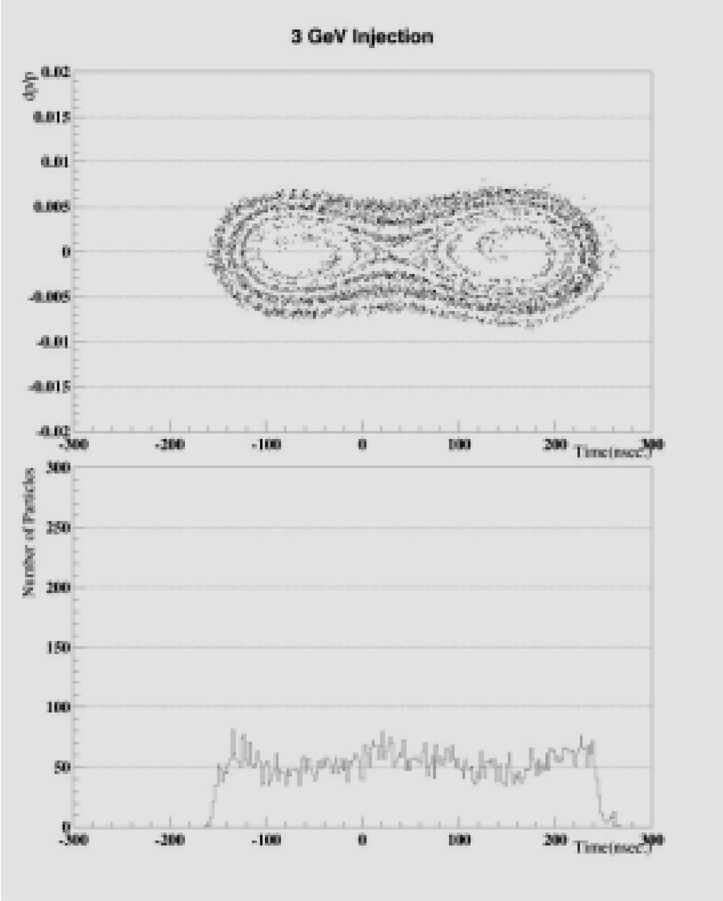
Abti-correlated

Maximize bunching factor

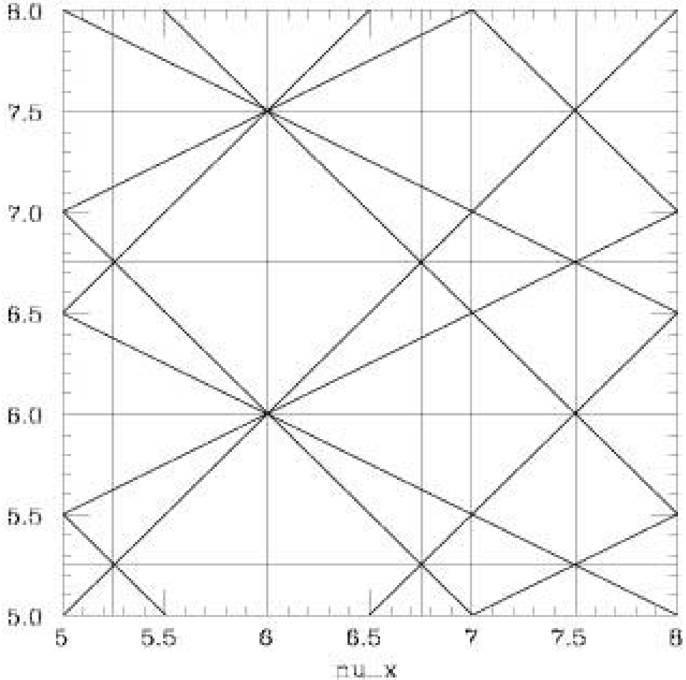
- Off-Momentum (+0.3%) injection

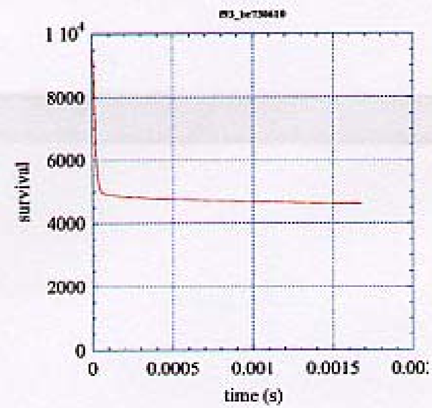
0.25 0.40



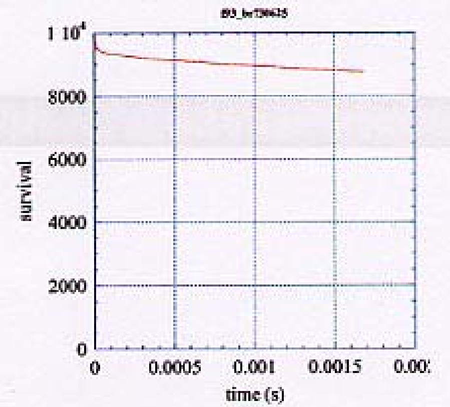


Beam loss at different bare tune

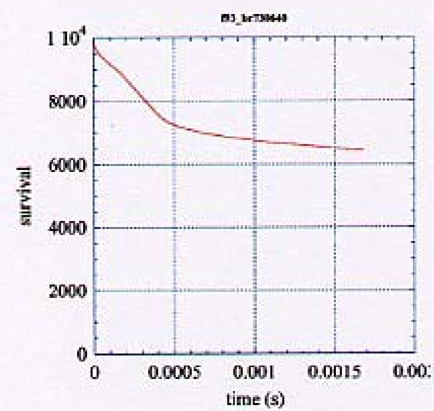




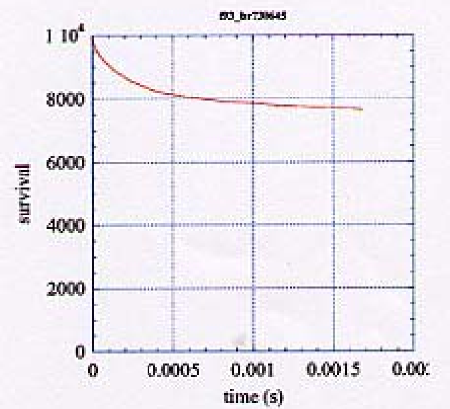
(7.30, 6.10)



(7.30, 6.25)



(7.30, 6.40)

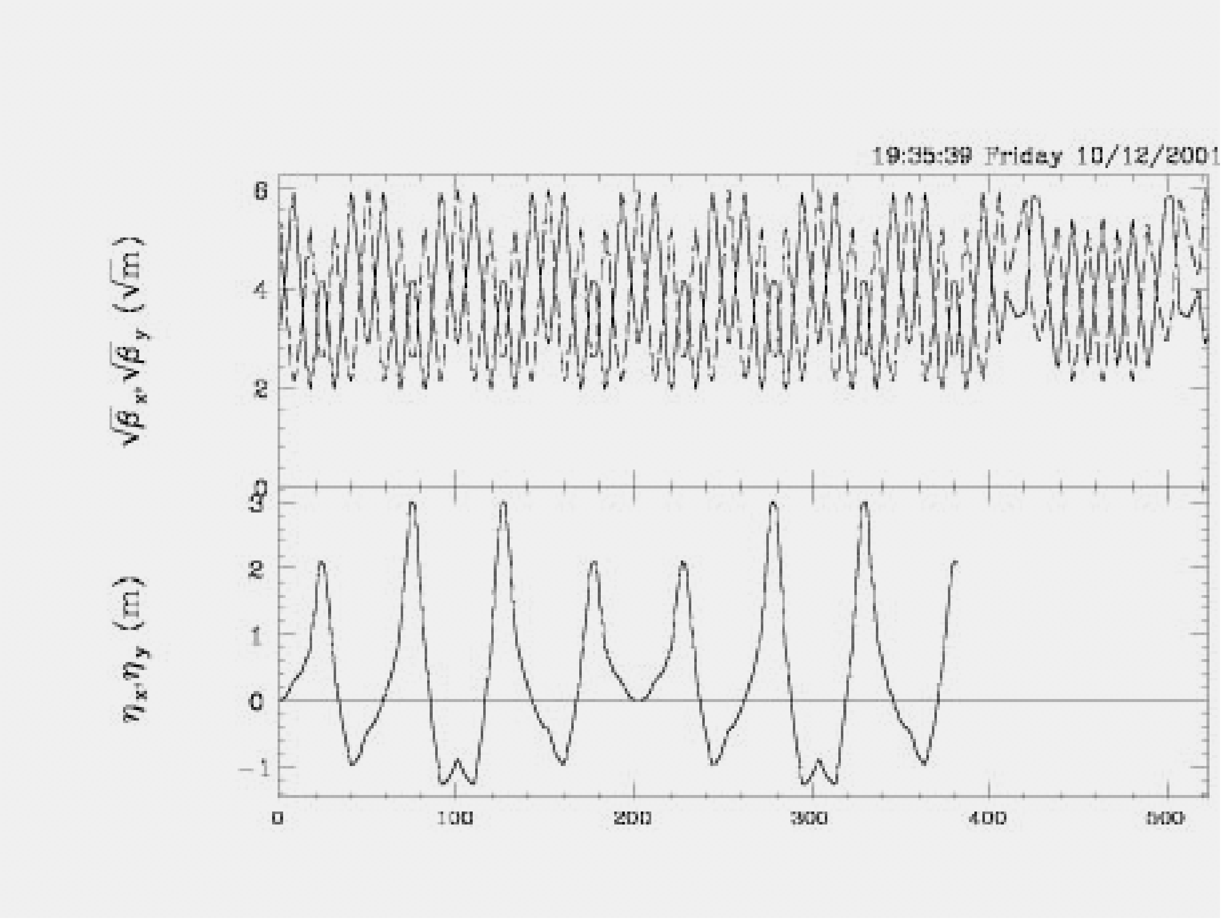


(7.30, 6.45)

Ny=6.10: near integer
Ny=6.40: near sum resonance

50GeVMR lattice

- Negative dispersion at bend magnets with missing magnets.
- Transition gamma is 32i
- 3DOFO module with total 11 quad families.



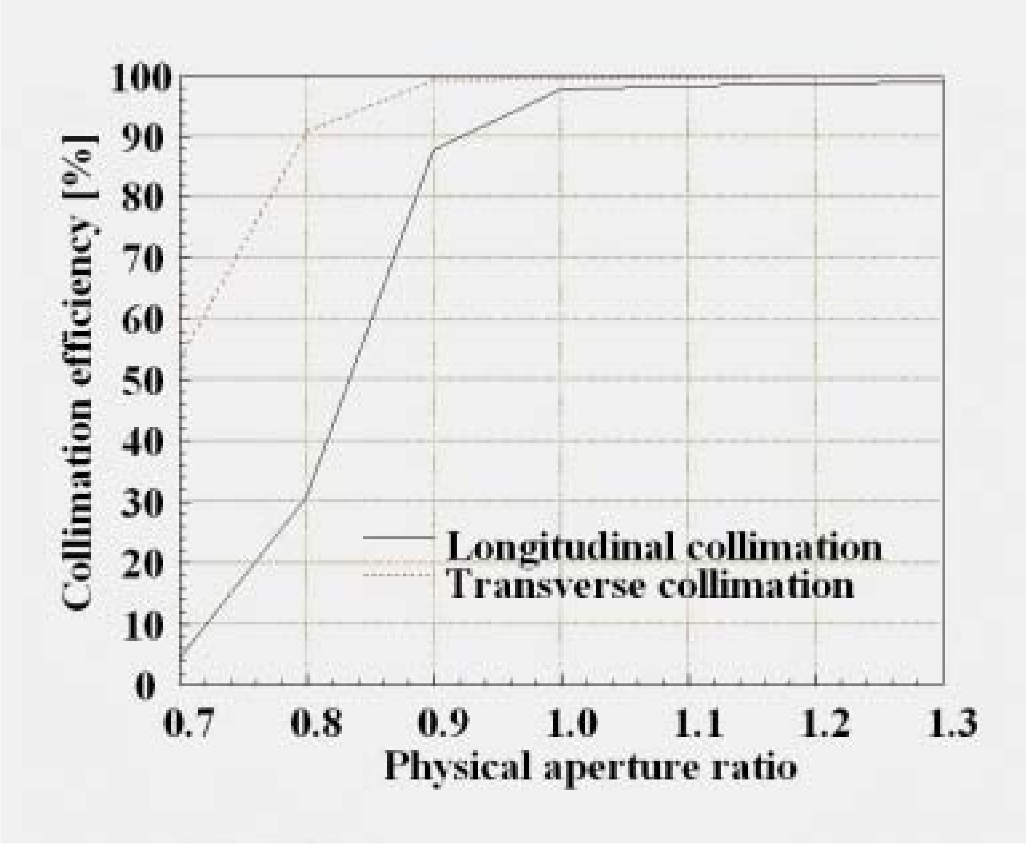
E-p instability

- Serious problem at PSR @ LANL and e+-e- colliders
- We just start looking at the effects based on the JHF parameters.

Localized beam loss

- Makes beam loss controlled.
- Collimator at
  - L3BT
  - 3GeVRCS
  - 3GeVBT
  - 50GeVMR
    (only transverse)
- What is the necessary

Physical aperture when the Collimator aperture is fixed.?

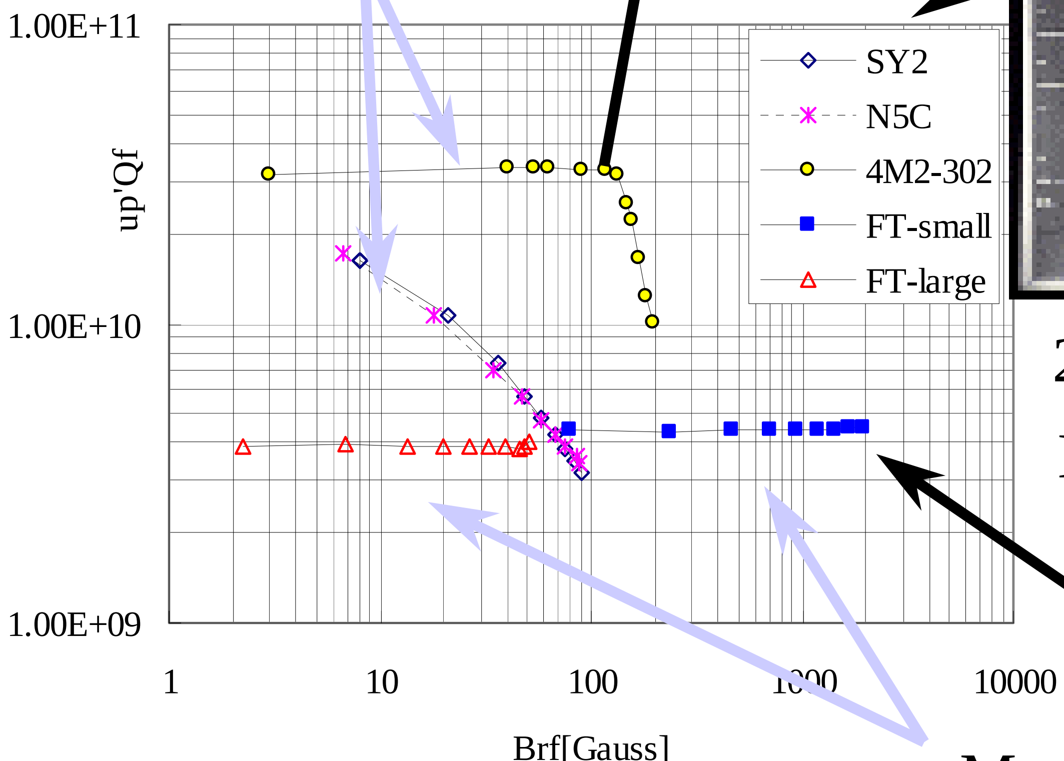


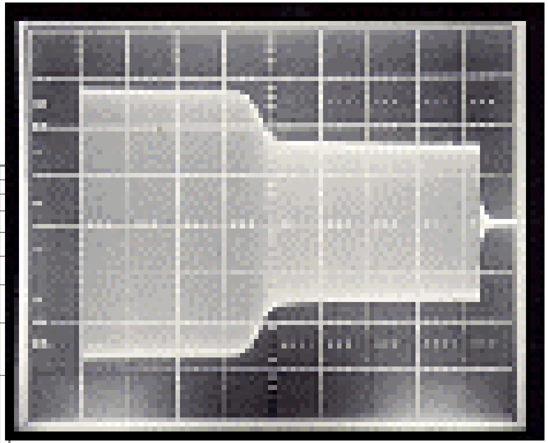
R&D of hardware

- 3 GeV RCS
  - Injection and extraction elements
  - Tracking 11 families of quadrupoles
  - Ceramic chamber and RF shielding
  - RF acceleration cavity with 450kV total voltage
  - Charge exchange foil
- 50 GeV MR
  - Bending magnet with 1.9 T
  - Patterned power supply with IGBT.
  - RF acceleration cavity with 280 kV total voltage
  - Slow extraction with 1% beam loss.

Characteristics of materials (Ferrite vs. FINEMET)

Ferrites



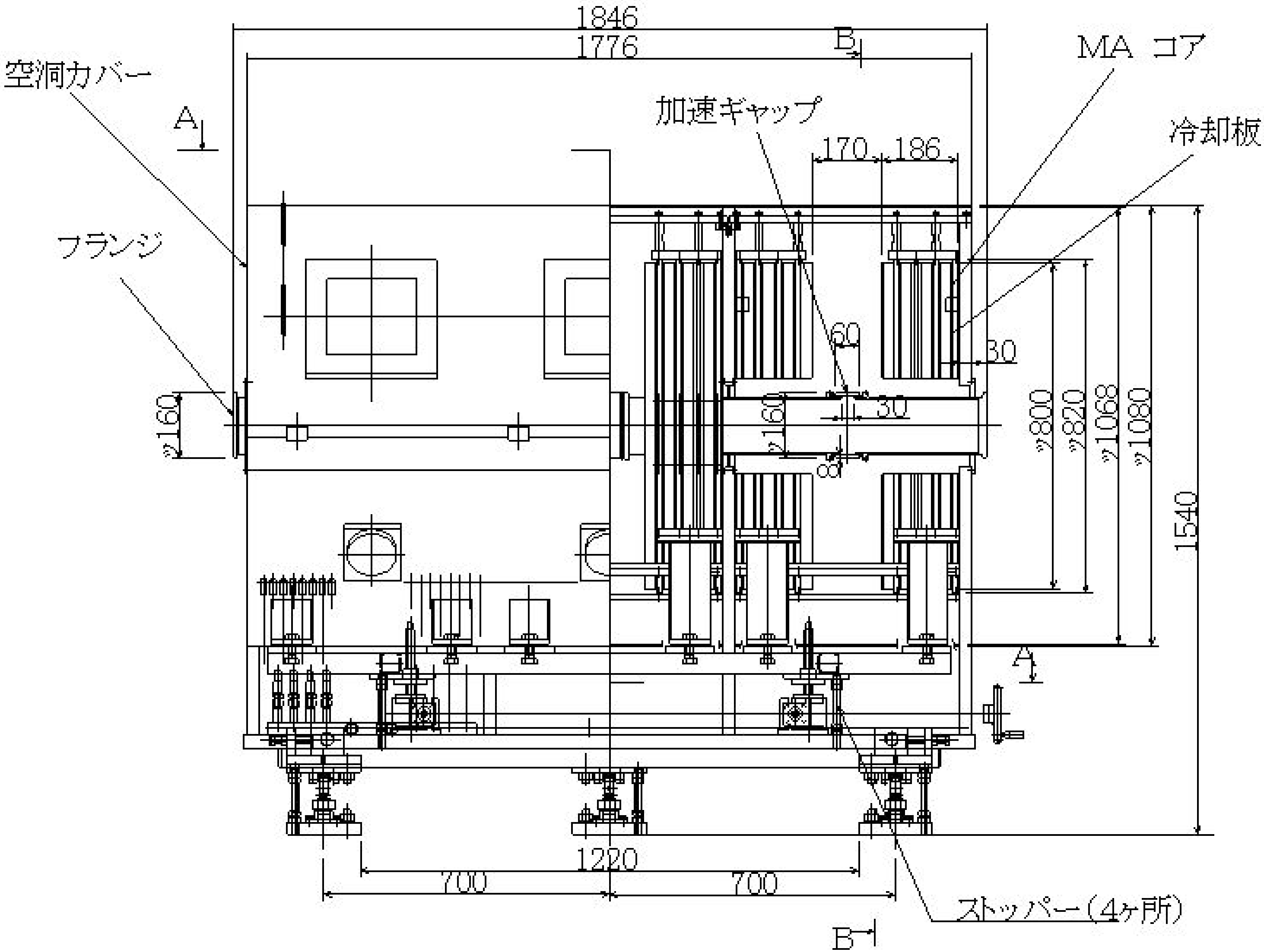


200V/div, 5ms/div

High Loss Effect

2000 Gauss

Magnetic Alloys



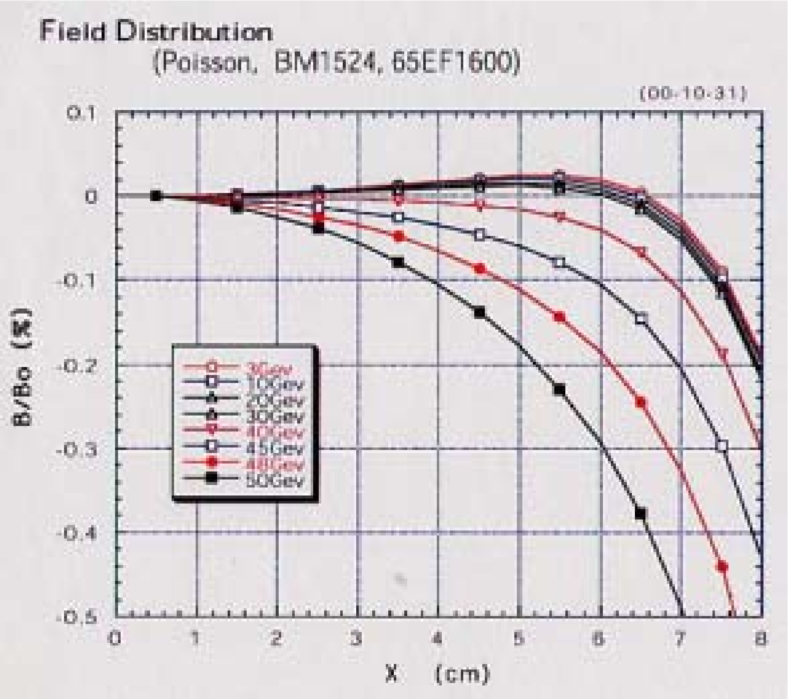
Cavity with indirect cooling

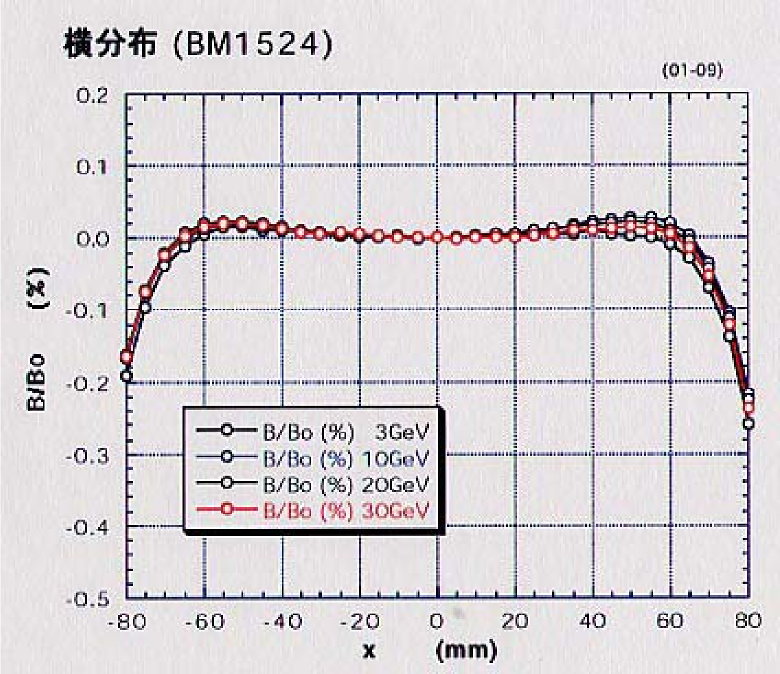
50 GeV MR bending magnet(R&D model)

Gap height	106 mm
Useful aperture	120 mm
Field	0.143-1.9T
Length	5.85 m

Field measurement of R&D model

Good agreement with calculation so far.



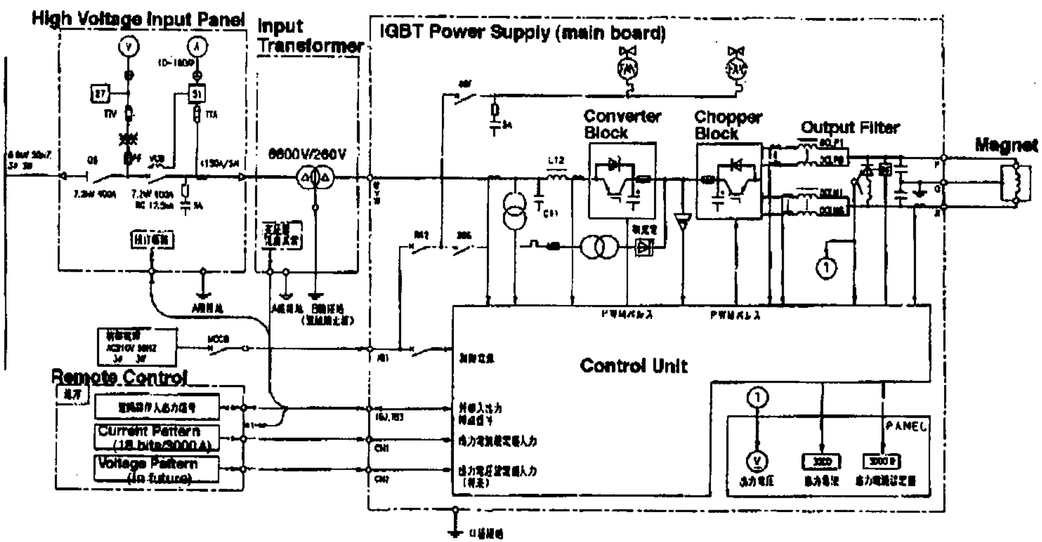


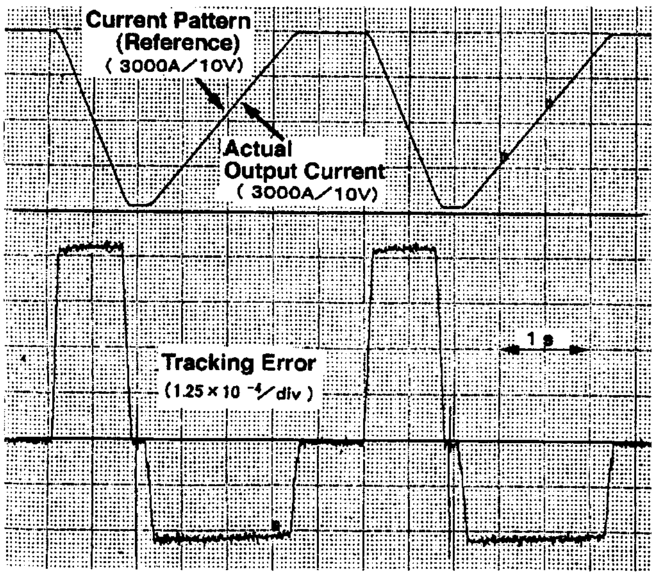
50GeV MR R&D quadrupole

Bore radius	63 mm
Useful aperture	132 mm
Maximum gradient	18 T/m
Maximum length	1.86 m

Magnet power supply

- Current pattern is controlled by the chopper downstream of capacitance after the converter.
- No reactive power.
- 100 kHz switching
- Ripple 10E-5
- Tracking error 10e-4

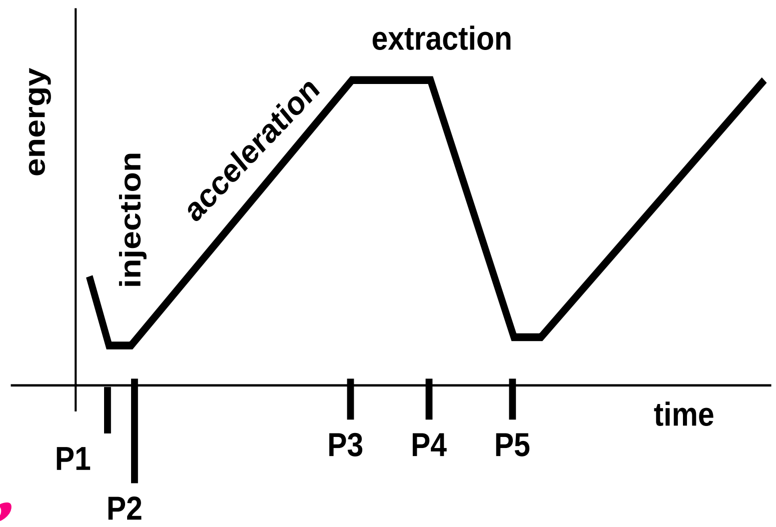




MR hardware status

- All main magnets are ordered.
- All main magnet power supply are ordered.
- Vacuum chamber is ordered.
- Part of RF cavities are ordered.
- Monitor will be ordered soon.

Possible Upgrading Path in Future



1) Increase main ring cycle

MR cycle 3.64 sec. --> 1.5 sec.

Beam Power ~ 2 MW

* rf voltage : x2

* maget power supply : FWG

" no needs to change main parts"

— slow beam extraction

2) Increase beam intensity

Beam stacking 4 batches ---> 8 batches @ injection

Beam Power ~ 4MW

* barrier bucket beam stacking : modest space charge

" Beam losses have to be reduced"