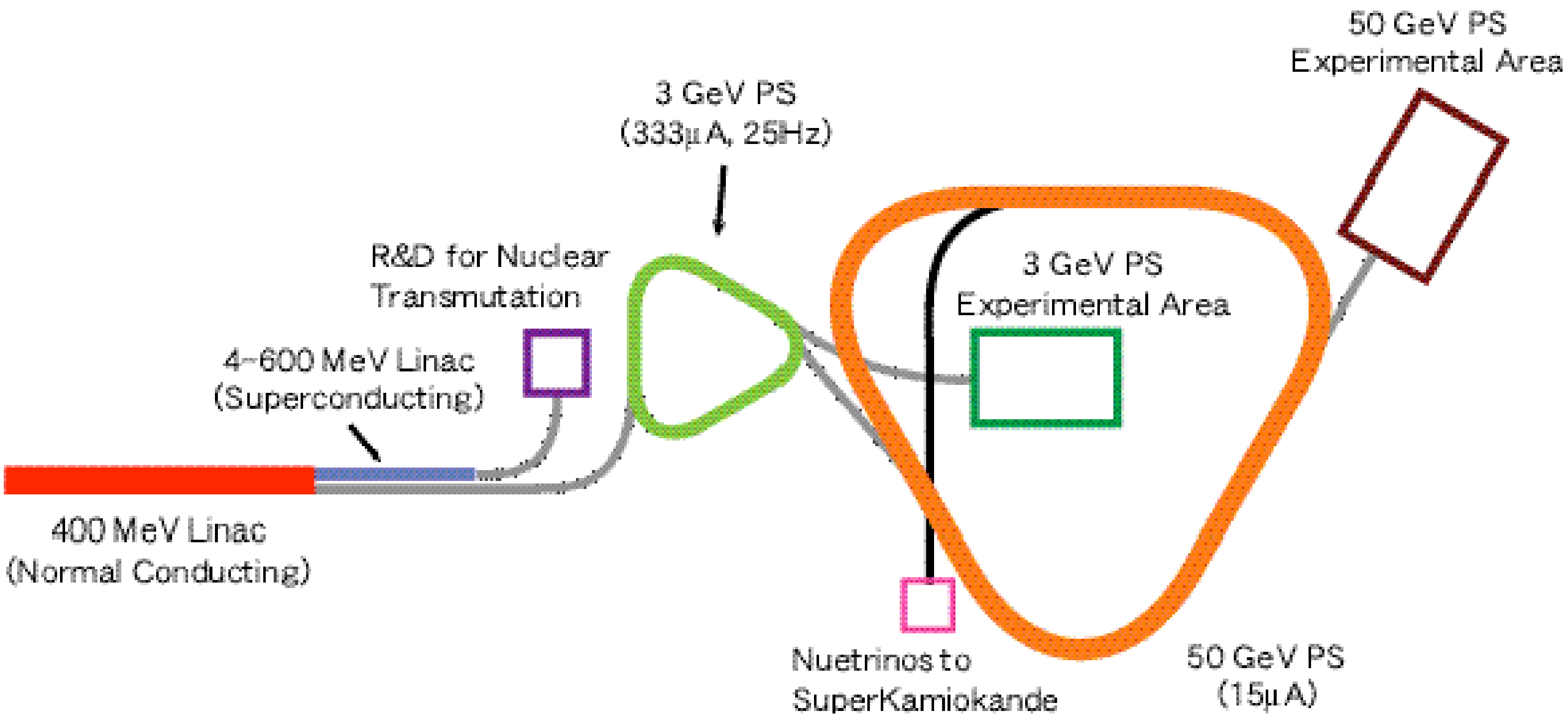
J-PARC 50GeV Proton Synchrotron

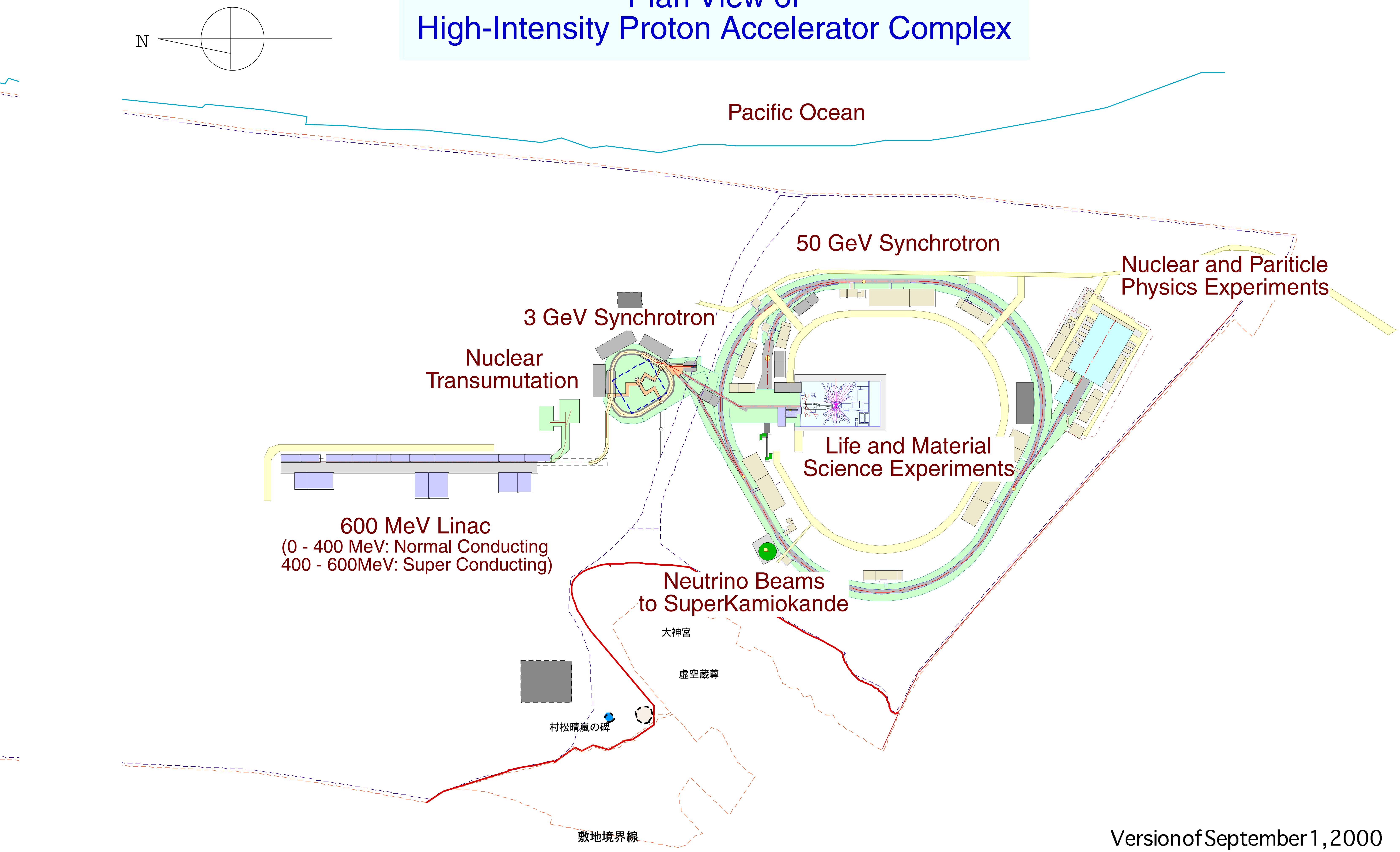
Y. Mori (KEK)

1. Introduction
2. Design parameter
3. Specification
4. Hardwares
5. Summary

Configuration of the Accelerator Complex

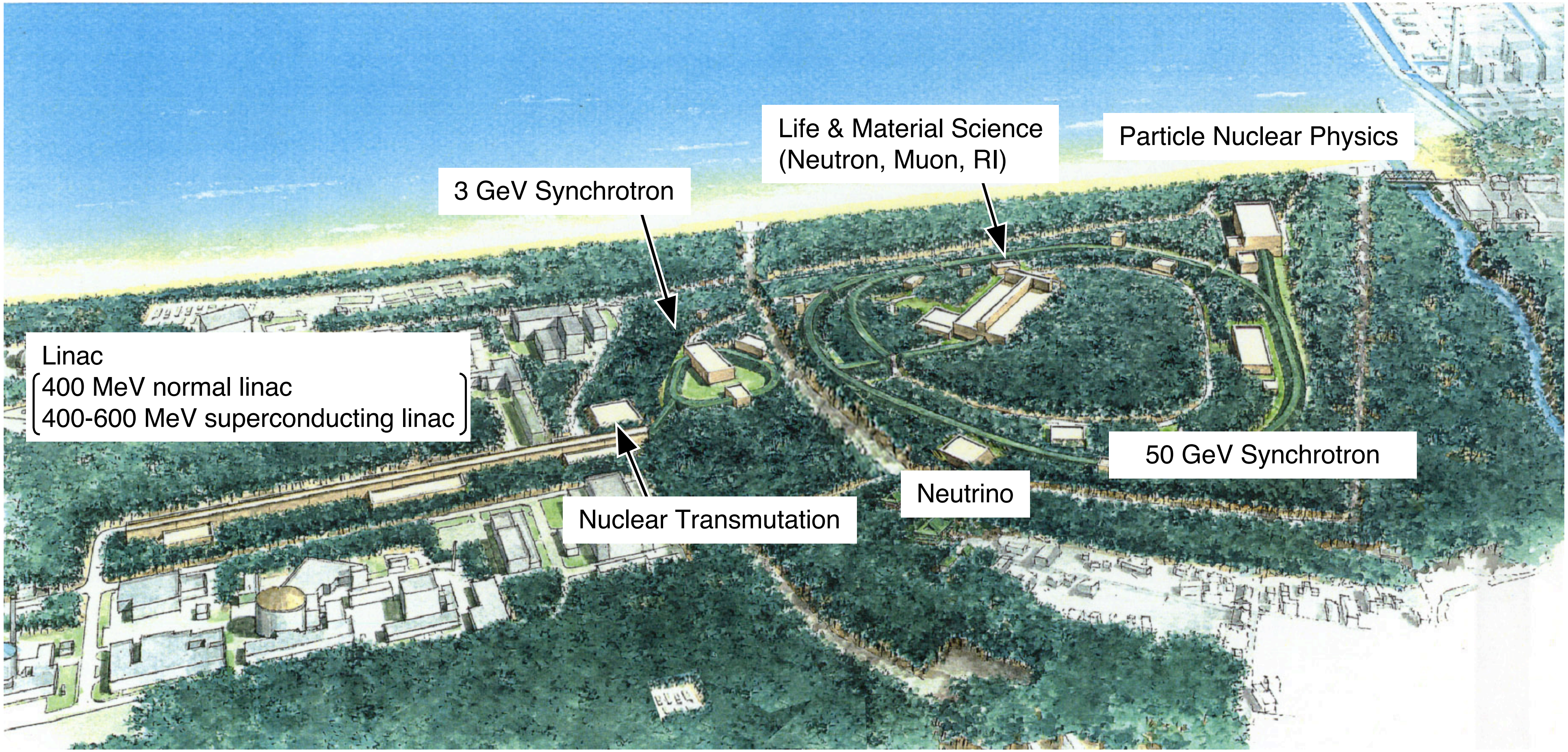


Plan View of
High-Intensity Proton Accelerator Complex

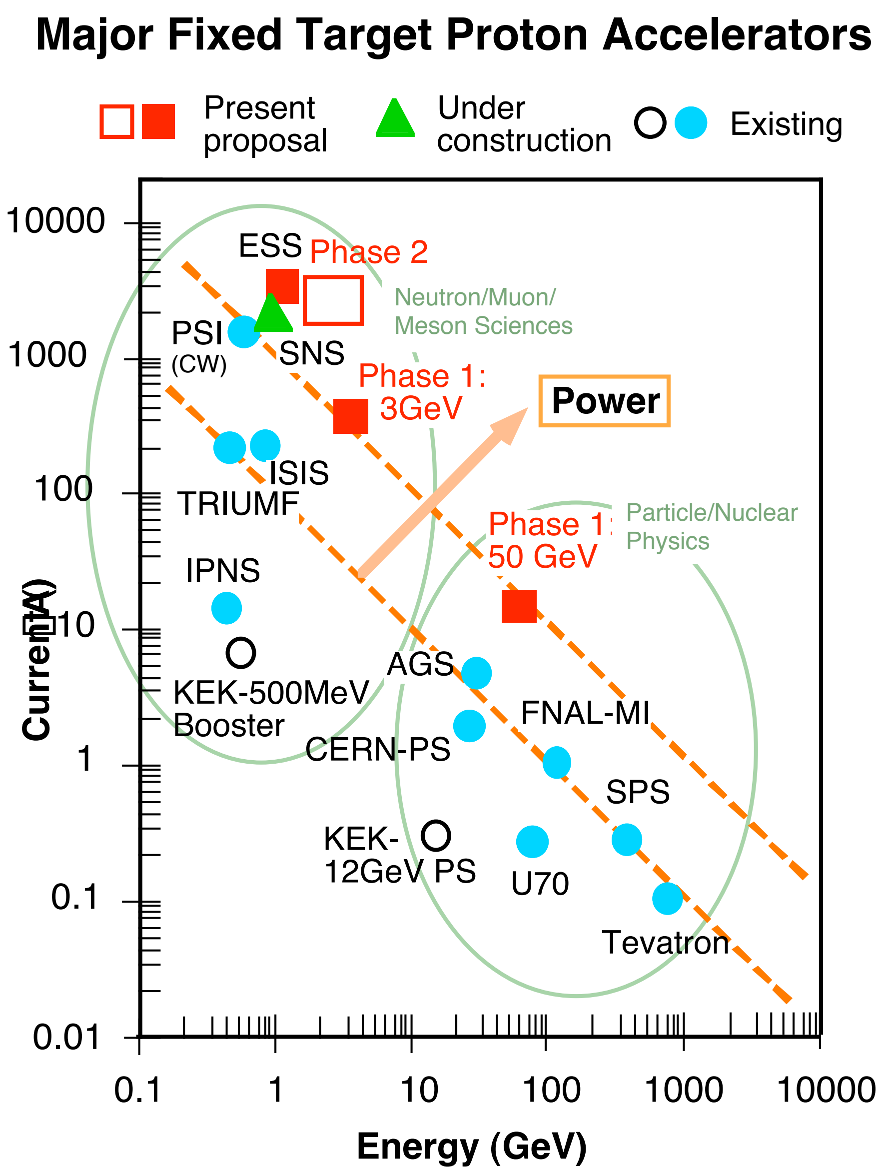


Version of September 1, 2000

Overview of the High Intensity Proton Accelerators

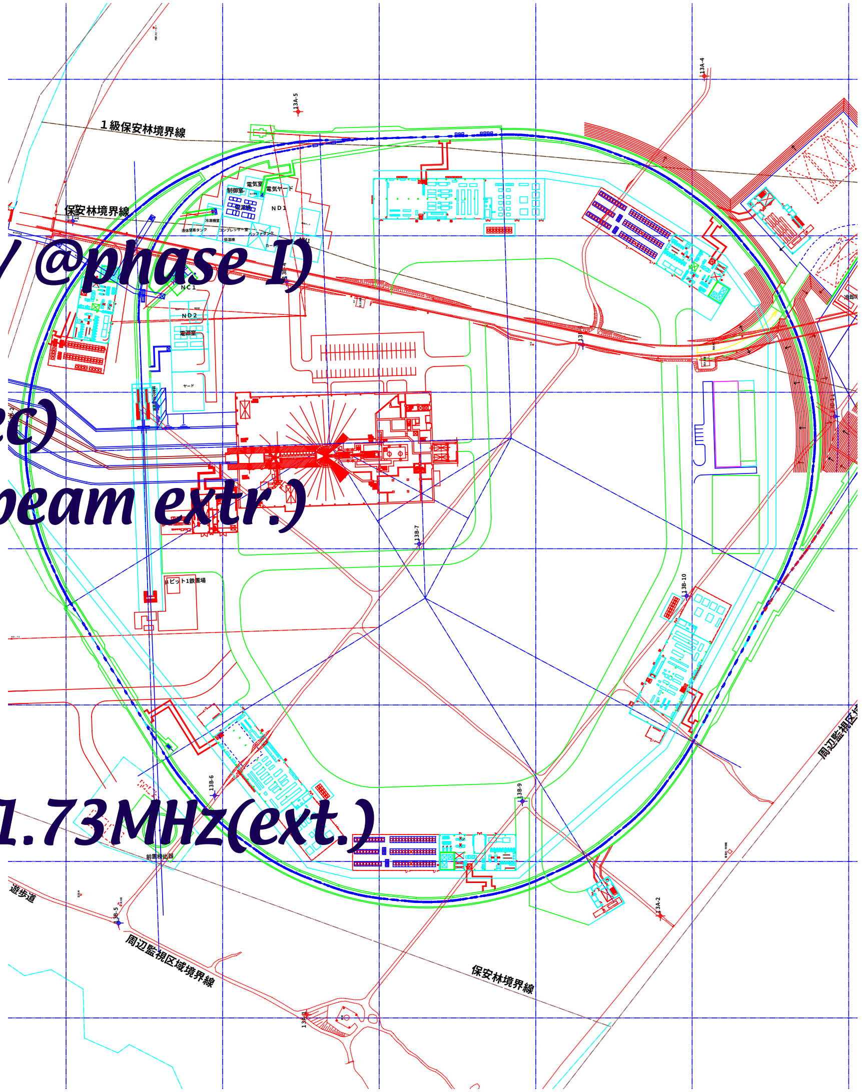


World's Proton Accelerators

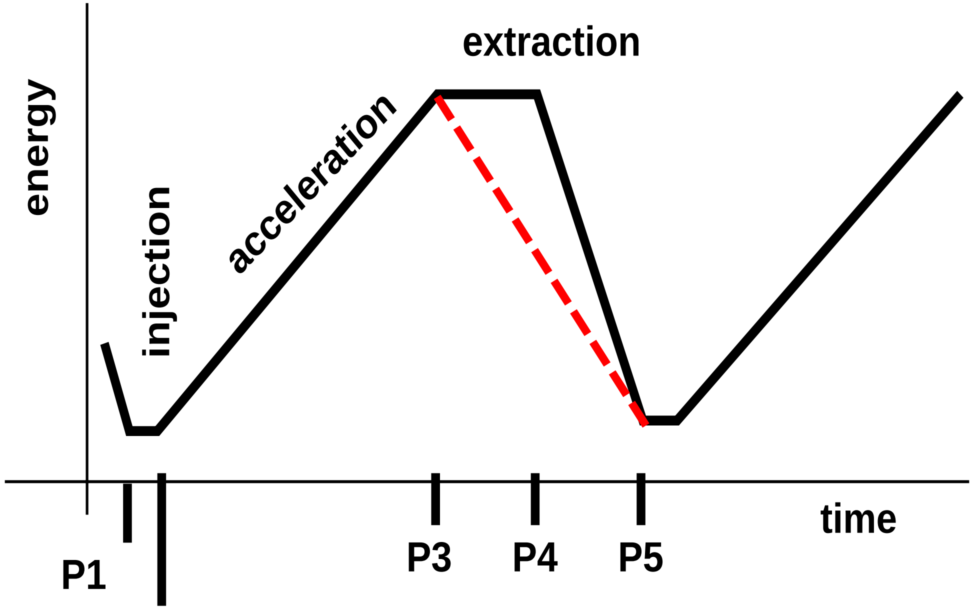


Parameters: 50 GeV Main Ring

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 μA (@slow beam extr.)*
beam power @50GeV	*0.75 MW*
superperiod	*3*
harmonic number	*9*
rf frequency	*1.68MHz(inj.)-1.73MHz(ext.)*



Acceleration Cycle

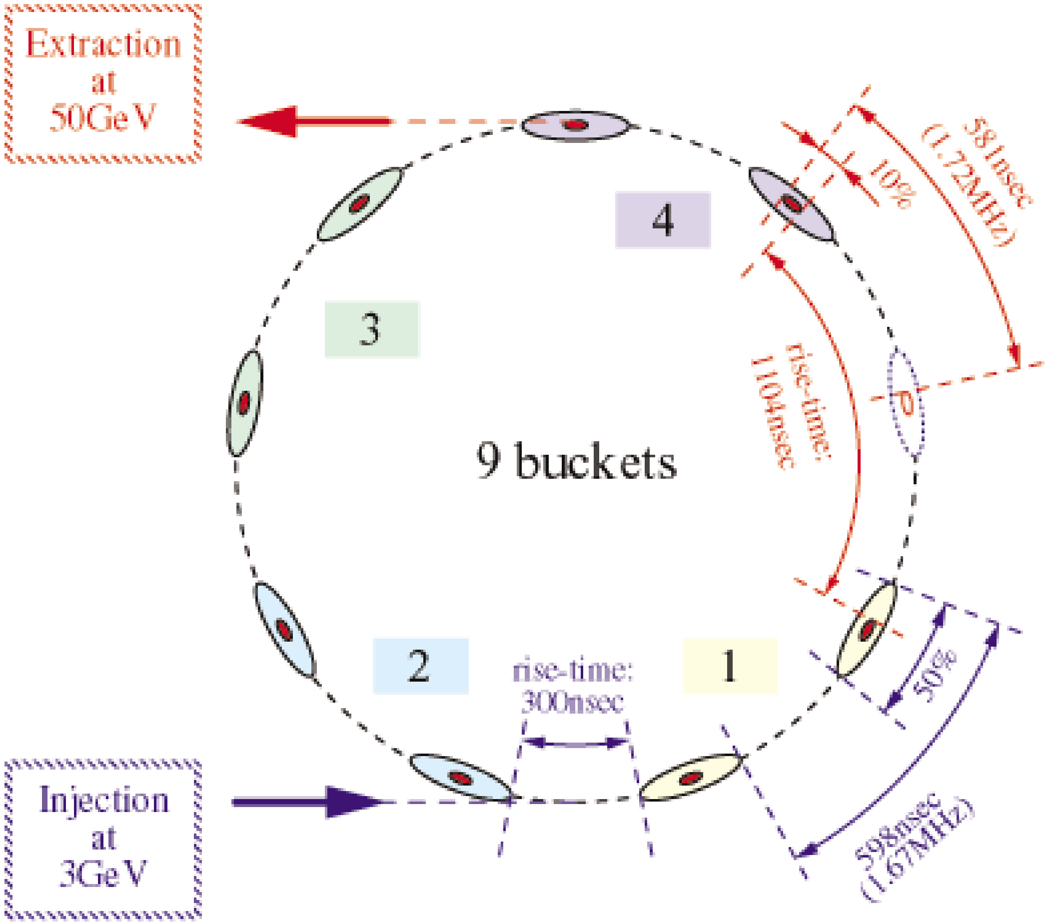


▬ *slow beam extraction*

- - - - *fast beam extraction*

P1 - P2(injection)	0.17 s
P2 - P3(acceleration)	1.96 s
P3 - P4(extraction)	0.7 s
P4 - P5	0.7 s
total	3.53 s
slow beam extraction	
duty factor	0.20
average current	15μA

Injection/Extraction Scheme for 50 GeV Ring



Lattice of 50GeV PS

***Imaginary transition gamma :**

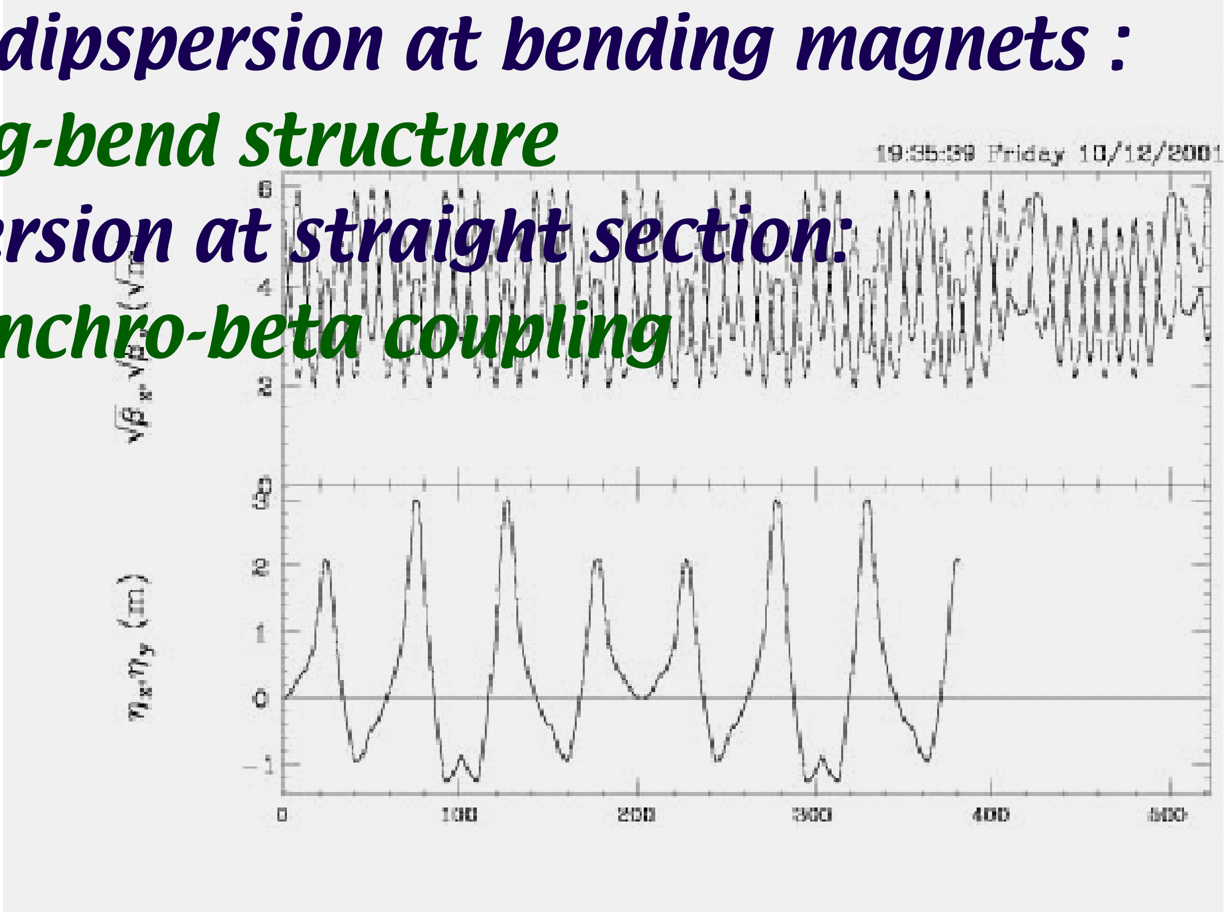
γ *-> 32i (no transition energy)*

*** Negative dipspersion at bending magnets :**

missing-bend structure

***Zero dispersion at straight section:**

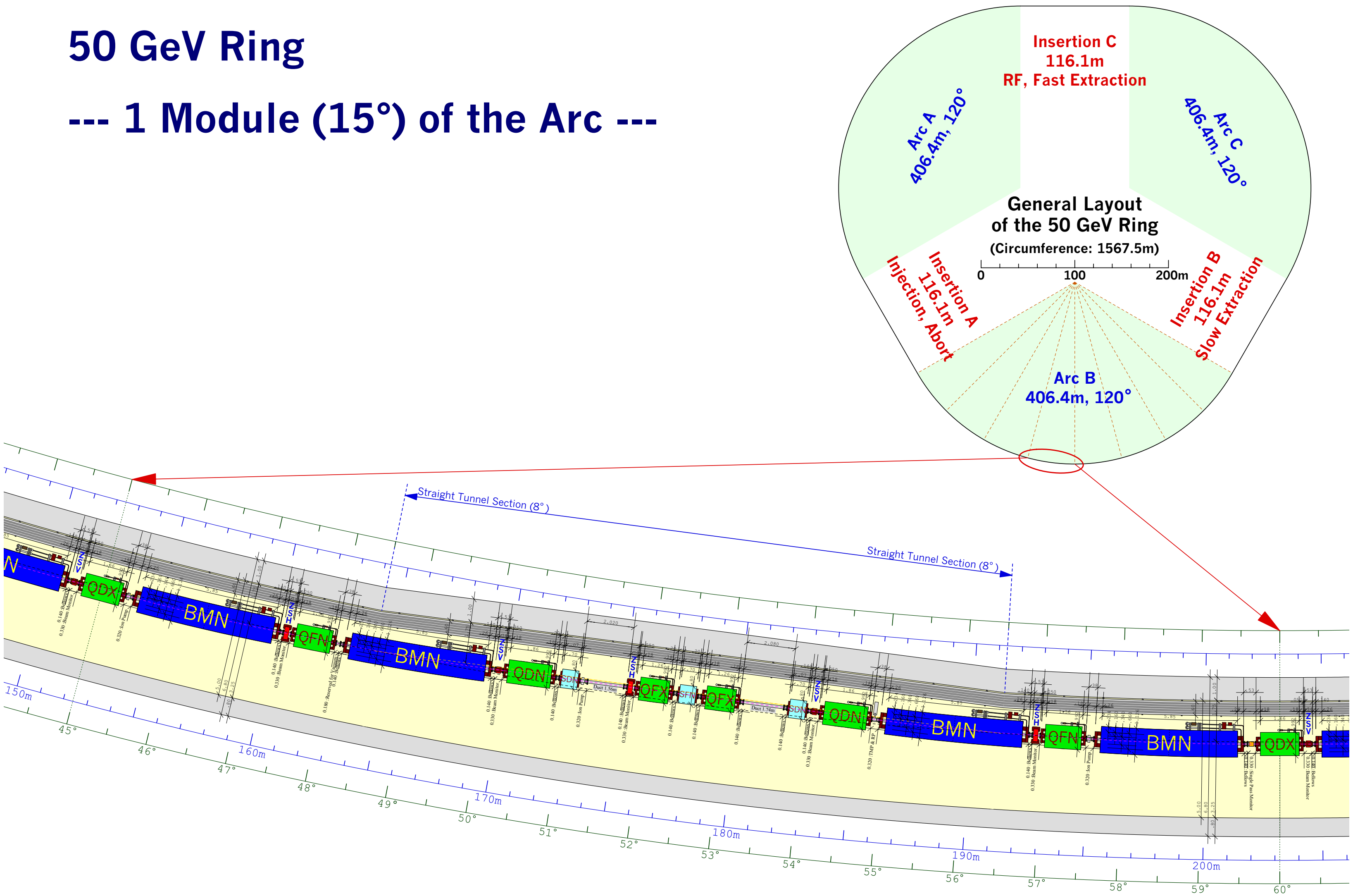
non synchro-beta coupling



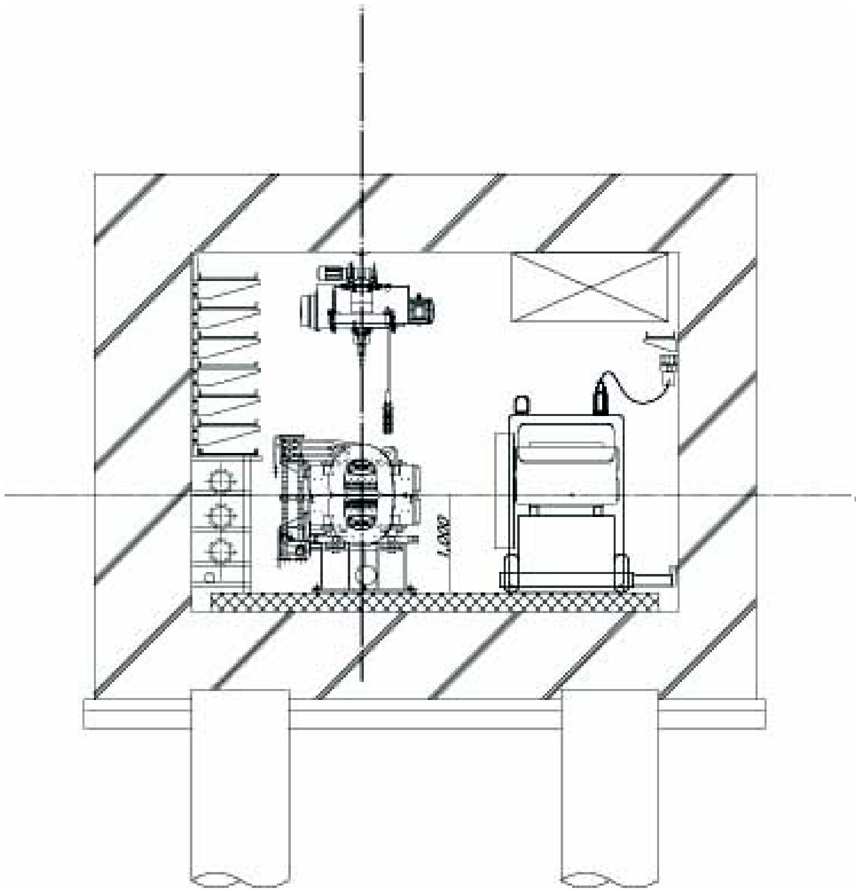
Layout of Magnets *-Missing Bend. Mag. Section-*

50 GeV Ring

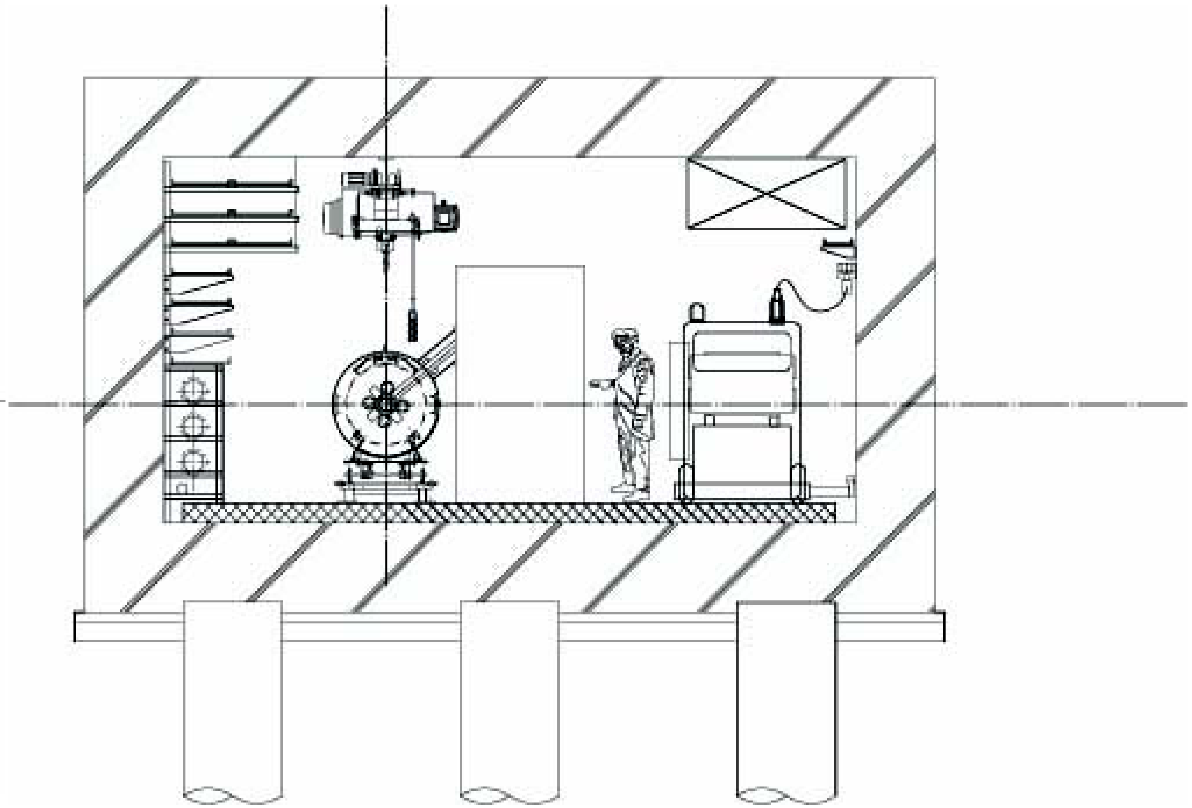
--- 1 Module (15°) of the Arc ---



Tunnel *-cross section-*



arc section



staright section

Minimization of Beam Loss : key issue for reality

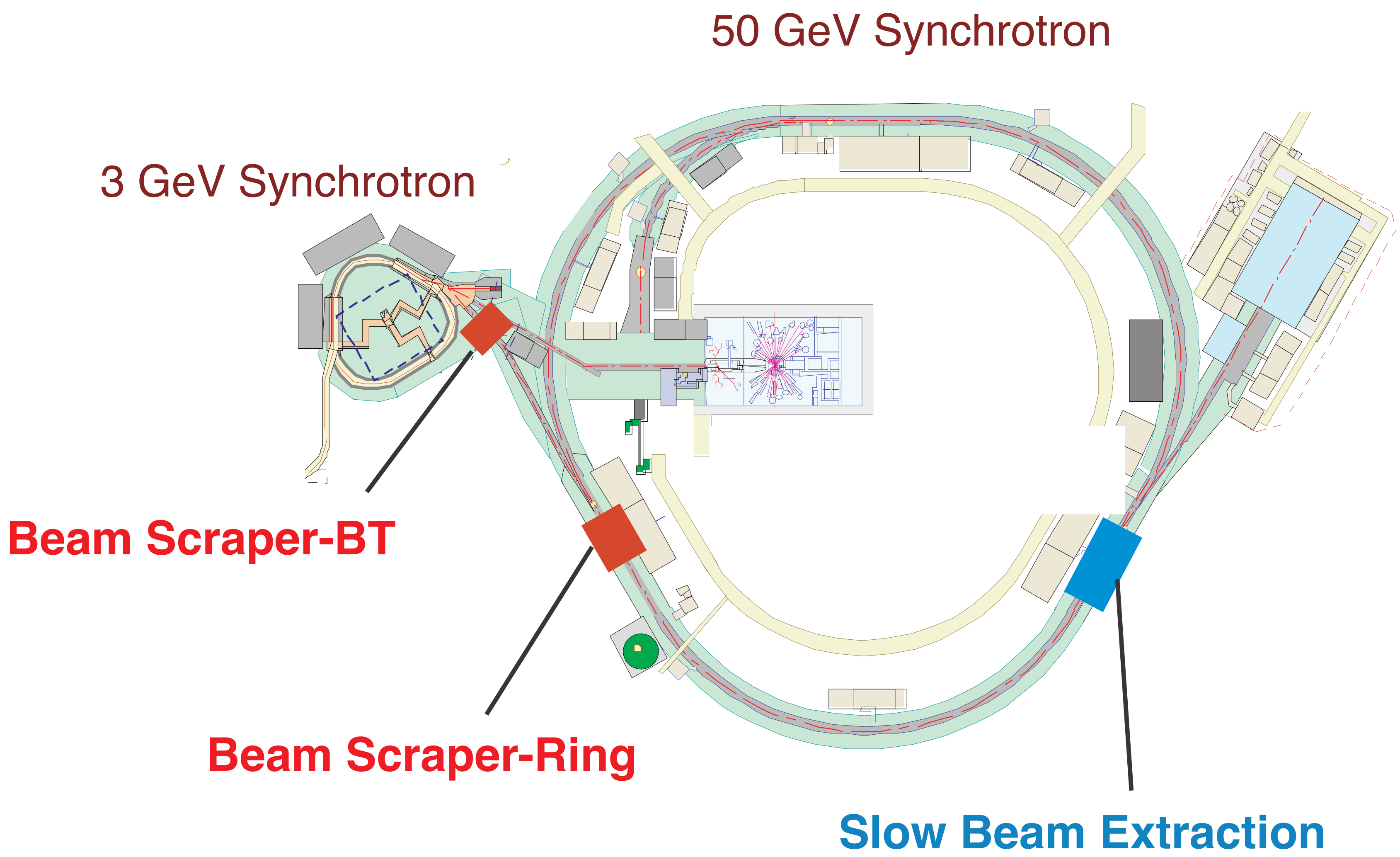
"radiation safety" & "maintenance"

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.

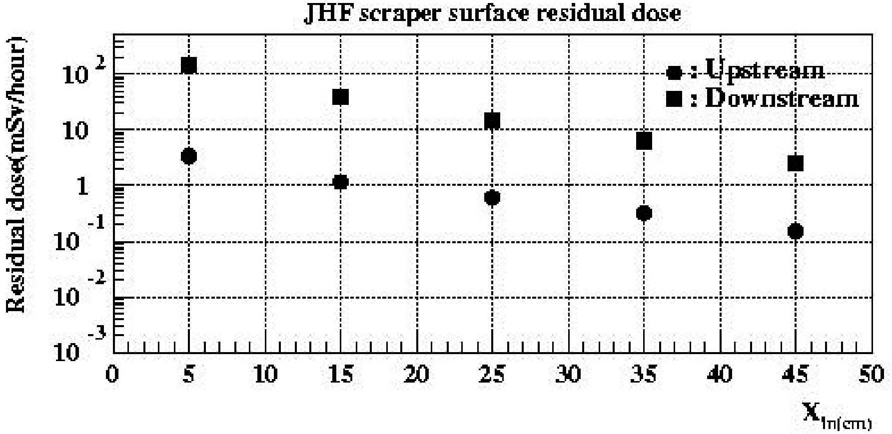

50 GeV Synchrotron
3 GeV Synchrotron
Beam Scraper-BT
Beam Scraper-Ring
Slow Beam Extraction

Estimation of Residual Radiation Activity : MARS

example -> 3-50GeV BT collimator

. Inner side @ Jaw

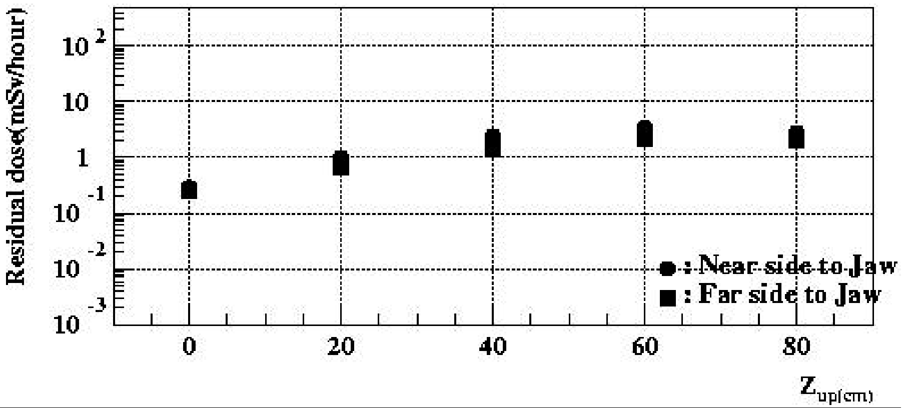
> 0.1Sv/h (beam loss 0.45kW)



. Outer shield surface

shield : 45cm iron

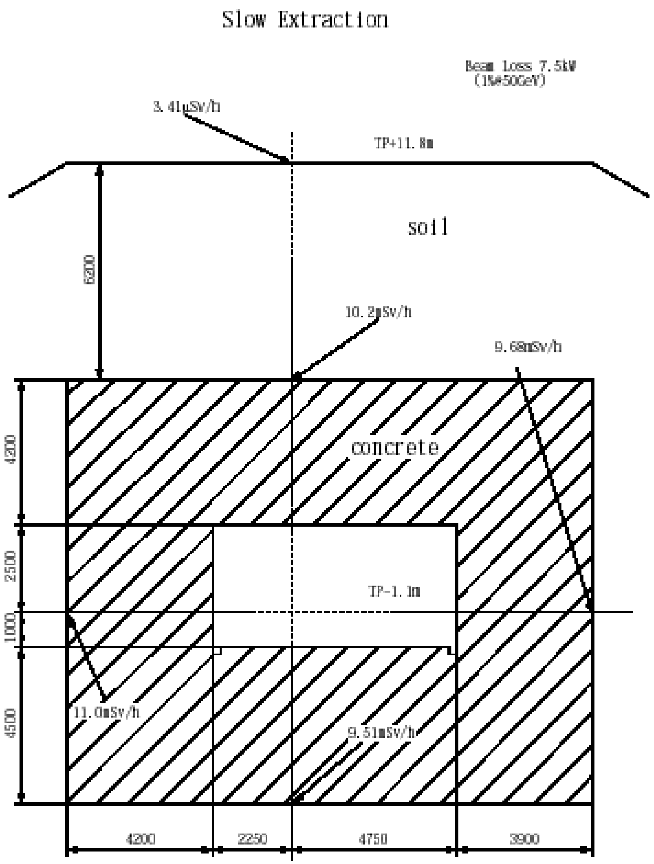
~3mSv/h



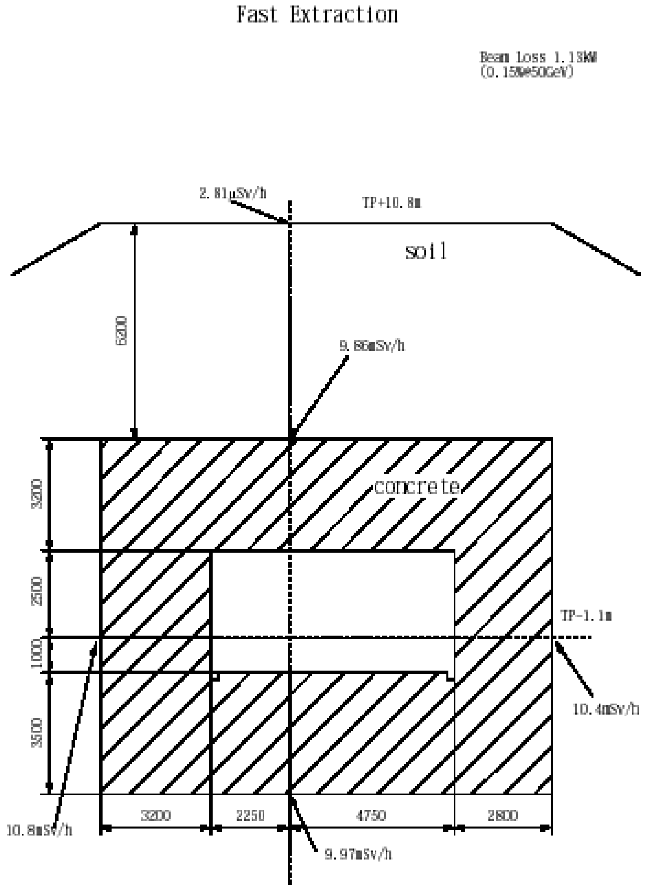
* after 1day cooling off following 30days operation

Radiation Shield at Beam Extraction Area

slow extraction



fast extraction



What causes beam losses?

Beam Dynamics: Growth of beam size

High intensity beam behaviors

- Space Charge Effect

  coherent, incoherent, non-linearity, halo formation

- Instabilities

  microwave, e-p, coupled bunch, etc.

Resonance beam extraction

- Non-linear resonance/Step size(turn separation)

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	1.5times	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	1.5times	-	81
extraction (50GeV)	6.1	330		-	81

50GeV MR Slow Extraction

- ***full beam power : 750kW @50GeV***

  -------> beam loss: 1% (7.5kW) level

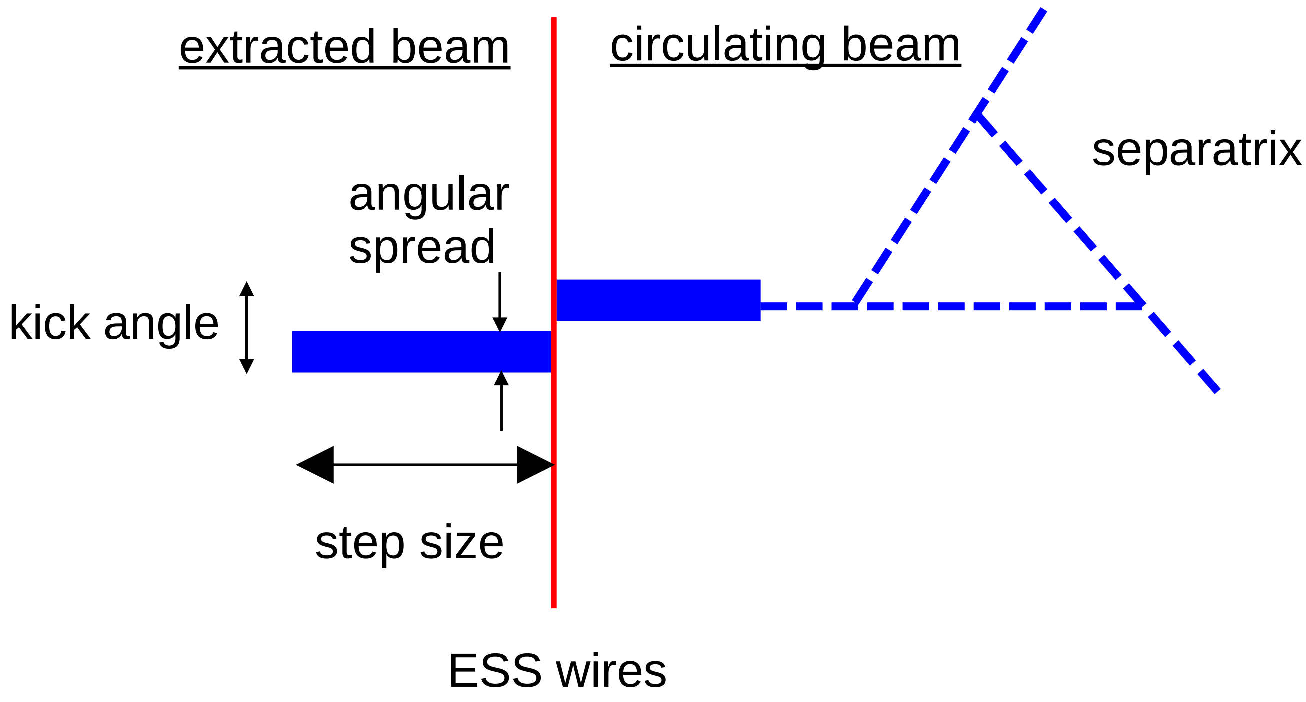
- ***extraction time/acceleration cycle*** 0.7s/3.64s

- ***coasting beam extraction***

- ***third integer resonance***

  mechanism is simple

  easy to change separatrix angle and step size



- ***large step size***
- ***small angular spread***

reduce beam loss at ESS or 1st SM

Chracteristics of 50GeV MR slow extraction

- ***All of ESS, SMs, bump magnets are placed in 116m long SS***

  localize hot region caused by beam loss at ESS wires

  no sextupole magnets in bump orbit

- $\Delta\Phi_x$ ***between ESS and 1st SM is near 90x3deg***

  make enough space for beam collimation and shielding if needed

- ***ESS is placed between two focusing quadrupole magnets***

  large β_x, small α_x

  -----> large step size at ESS

  eam it : feasi e

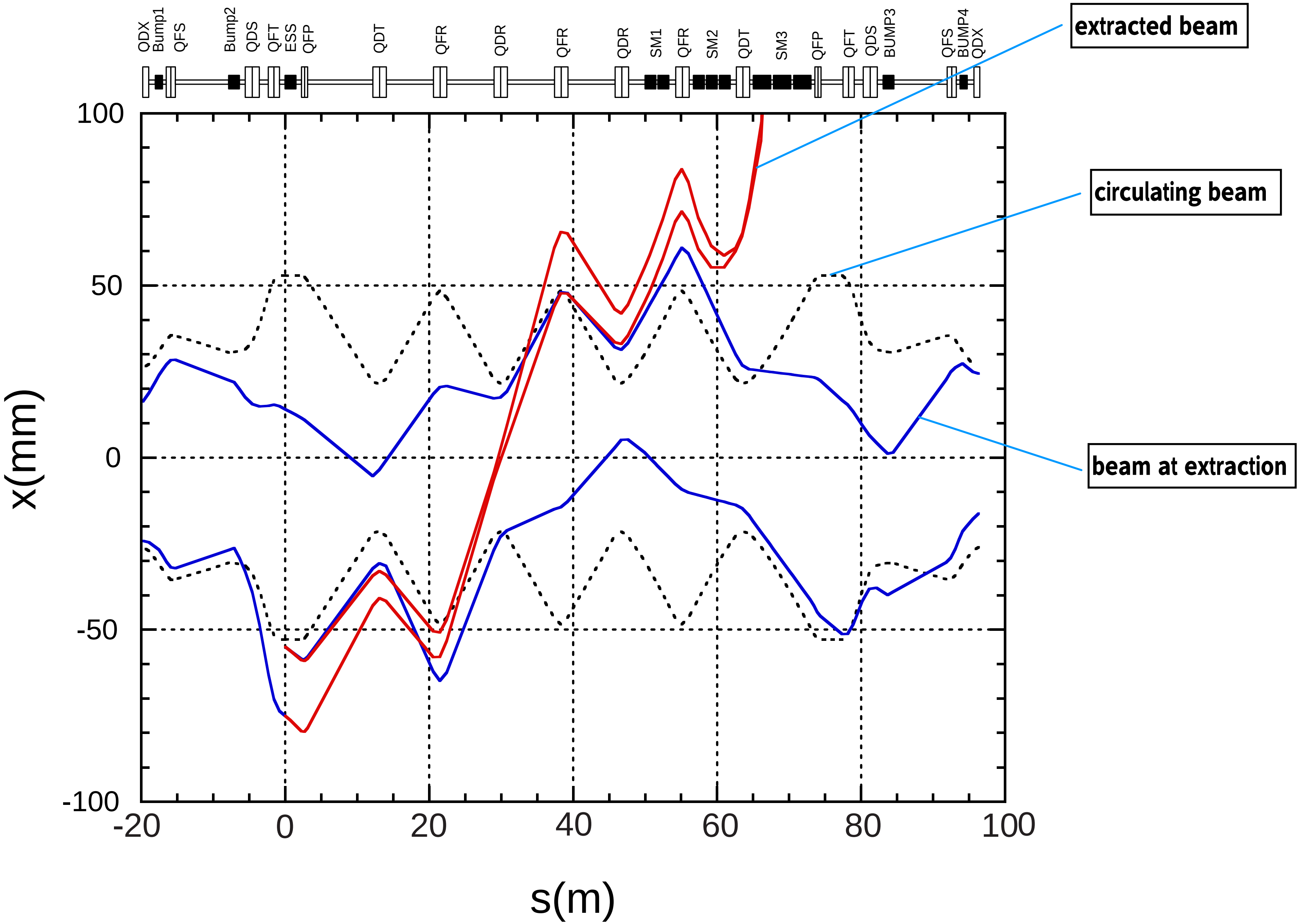
- ***zero dispersion in the long SS***

  zero Qxí (choromatic) operation

  -----> separatrix and extraction orbit does not depend on $\Delta p/p$

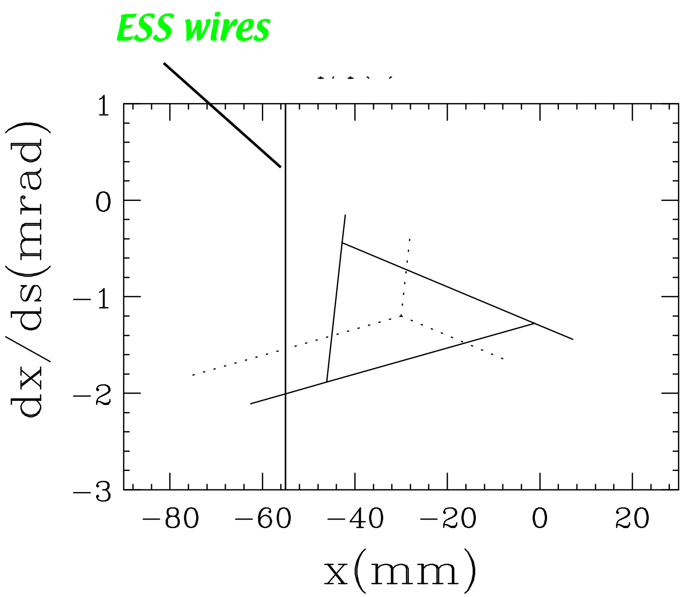
- ***moving bump-orbit during extraction (dynamic bump)***

  -----> drastically reduce angular spread of extraction beam at ESS

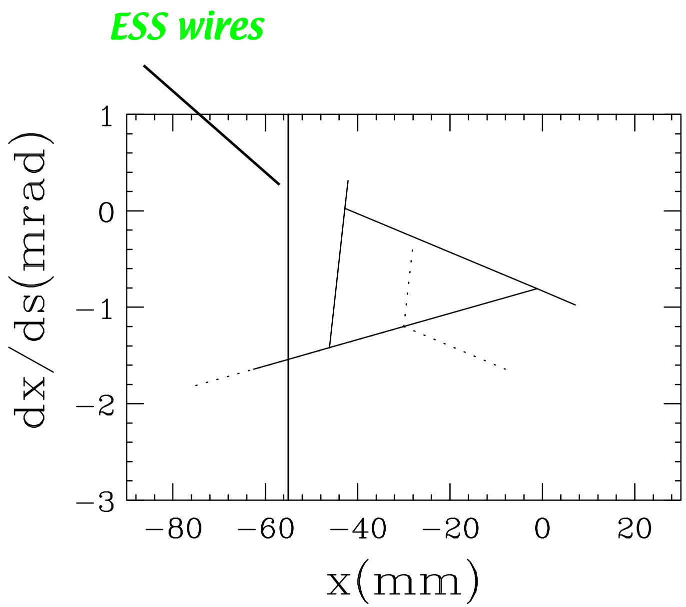


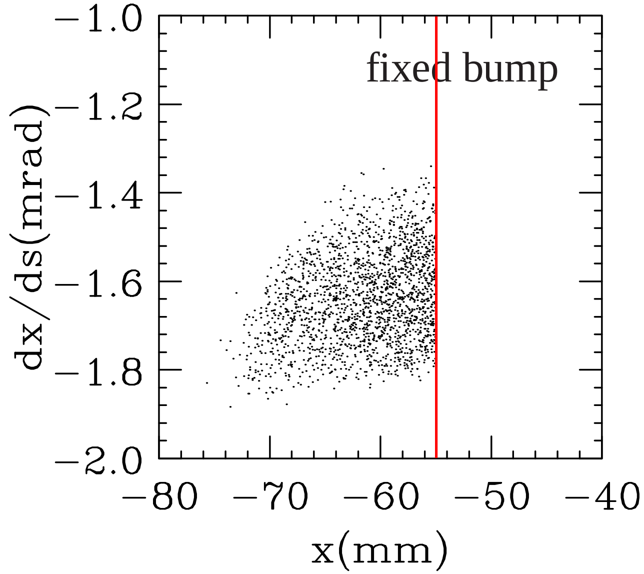
QDX
Bump1
QFS
Bump2
QDS
QFT
ESS
QFP
QDT
QFR
QDR
QFR
QDR
SM1
QFR
SM2
QDT
SM3
QFP
QFT
QDS
BUMP3
QFS
BUMP4
QDX
extracted beam
circulating beam
beam at extraction
x(mm)
s(m)
100
50
0
-50
-100
-20
0
20
40
60
80
100

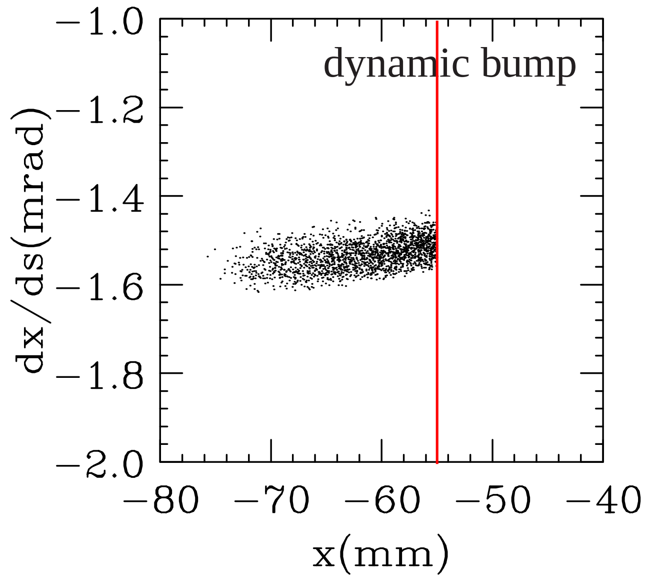
fixed bump



dynamic bump




fixed bump
dx/ds(mrad)
x(mm)


dynamic bump
dx/ds(mrad)
x(mm)

Beam hit on the ESS wires

- Generate secondary particles ---- neutrons, protons, pions

  residual dose around the ESS?

  life time of magnet just after the ESS?

- Scatter incident protons

  transported in the LSS and circulated in the ring

  loss map of scattered protons in the ring?

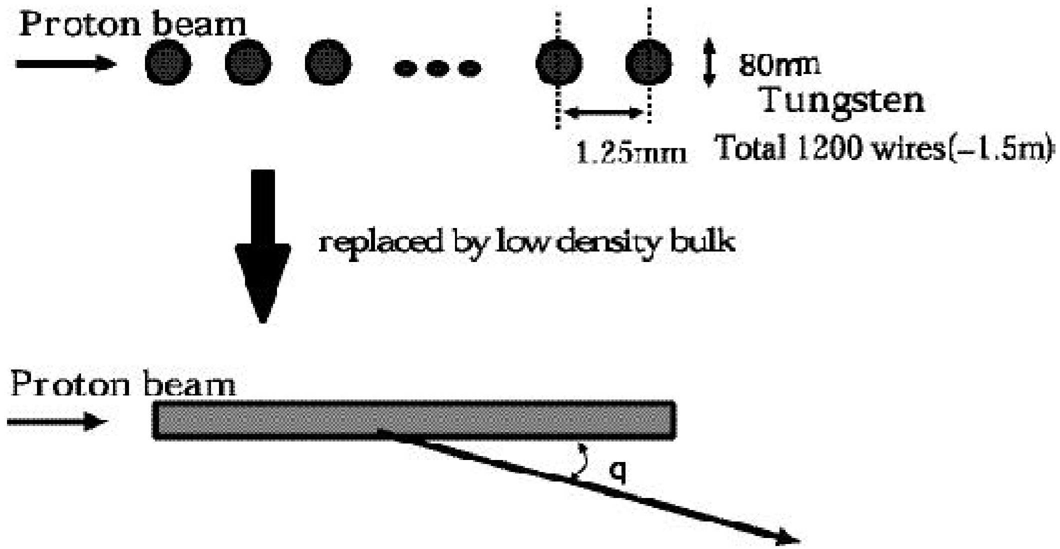
  scattered protons extracted from the ring?

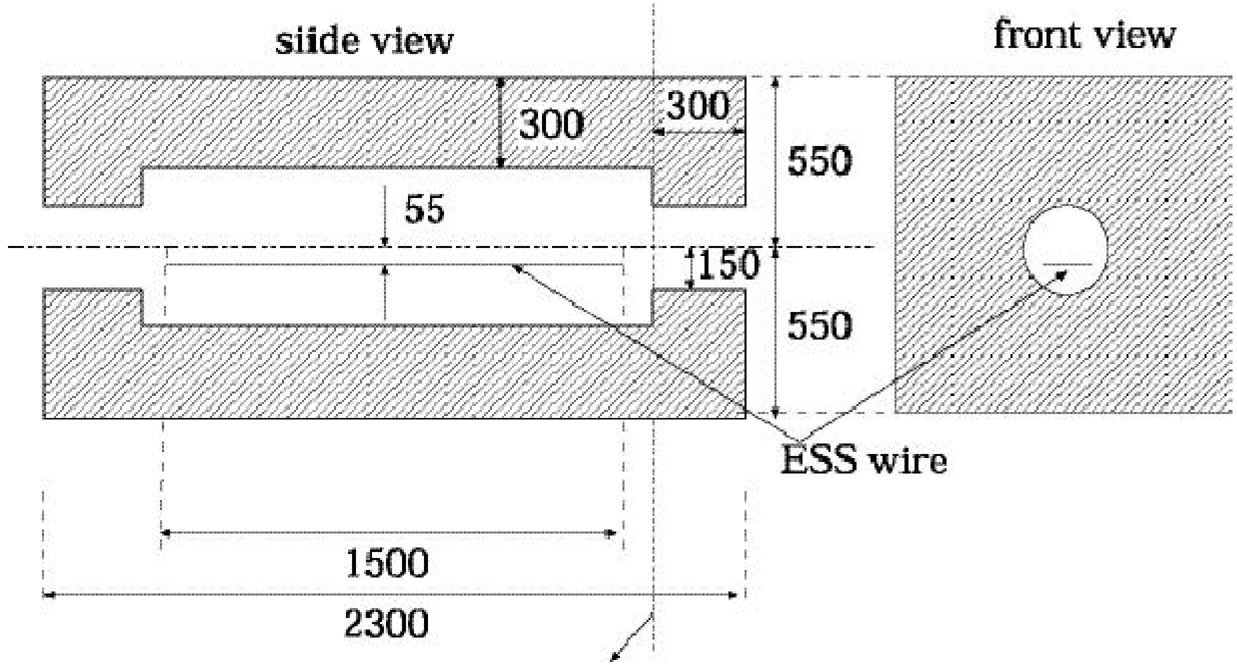
These effects are estimated with

residual dose simulation	MARS
scattered particle tracking	SAD

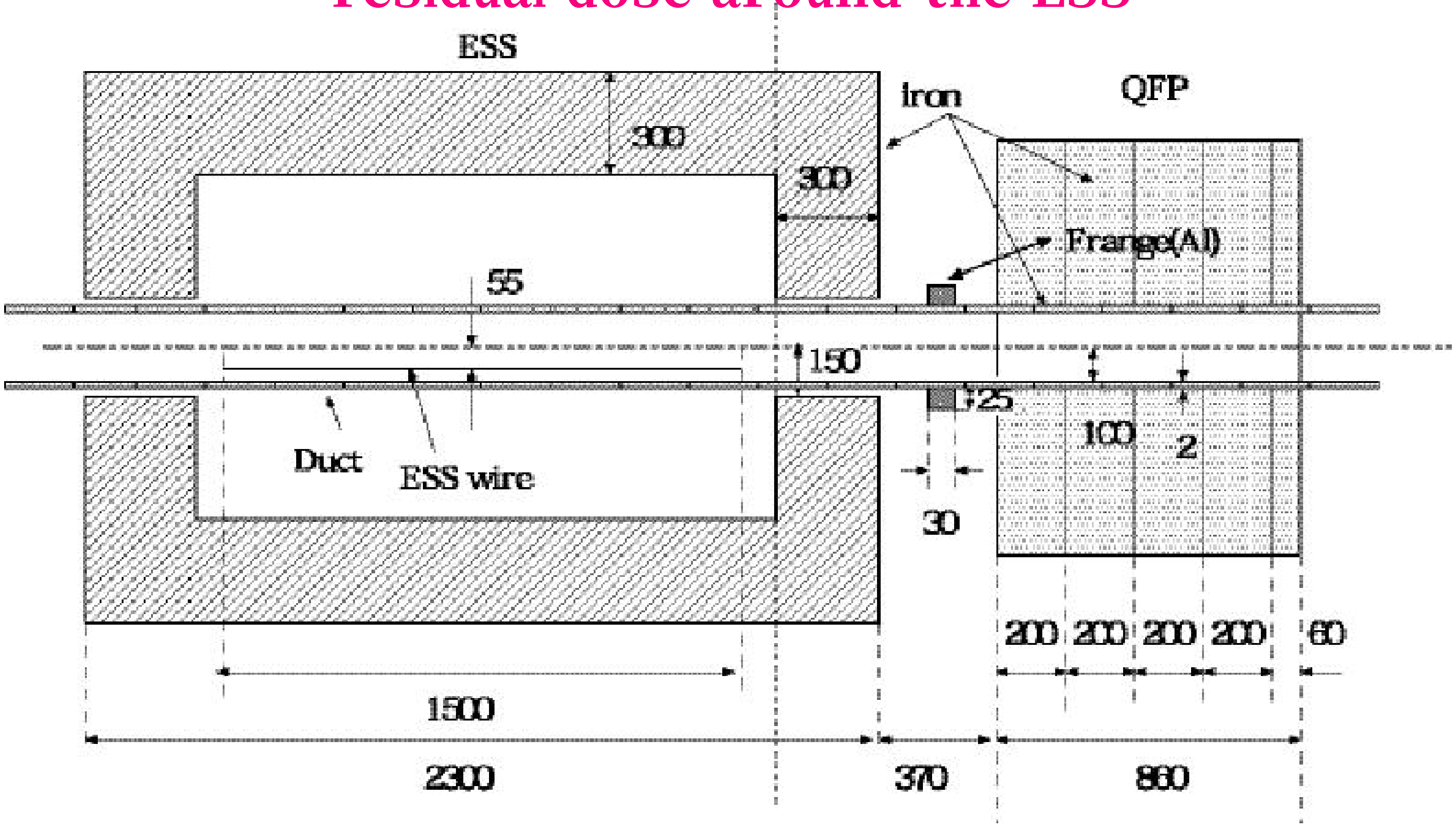
Model for simulation with MARS

Uniformly distrubuted beam(H:80mm, v:2cm) hits the ESS wires normally





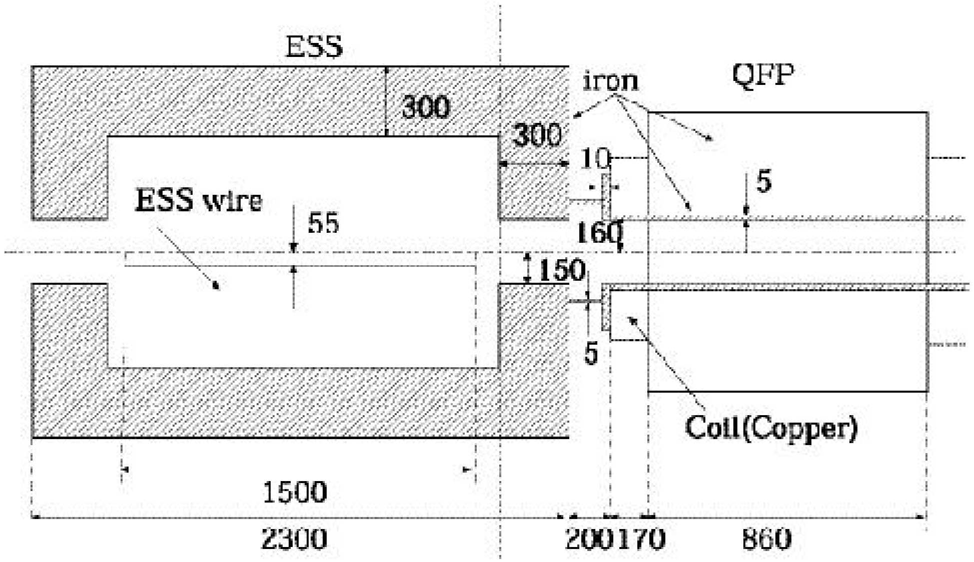
residual dose around the ESS

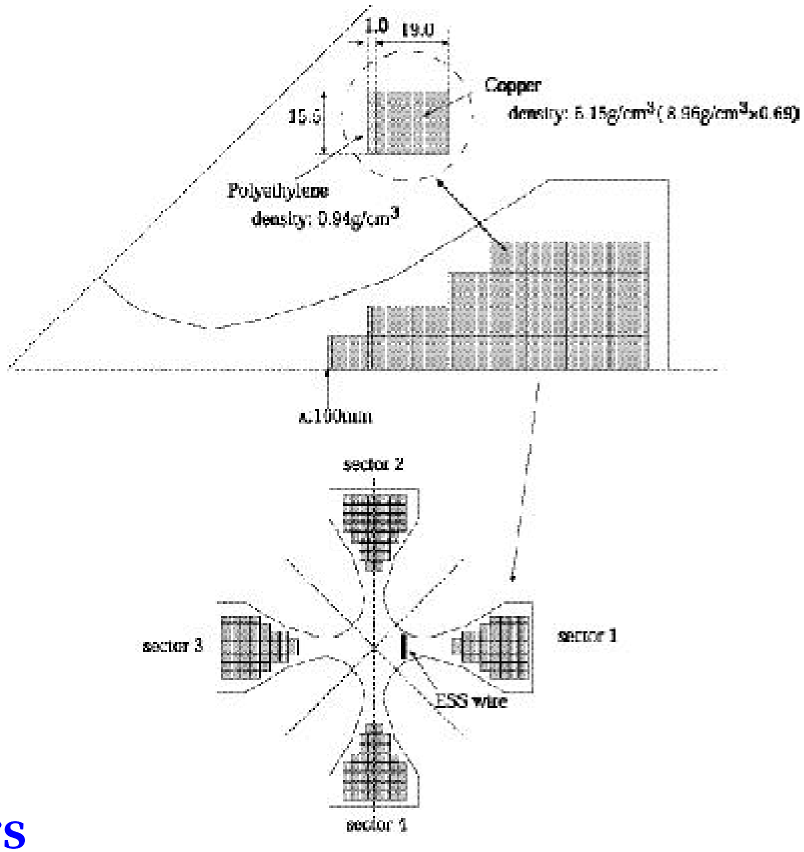


30day operation
+1day cooling

side of ESS: max 6mSv/h
SUS-duct: max 150mSv/h (Ti duct :1/3 of SUS)
side of QFP: max 15mSv/h
inside of QFP: max 250mSv/h

Absorption dose in the Q-magnet (QFP) just after the ESS





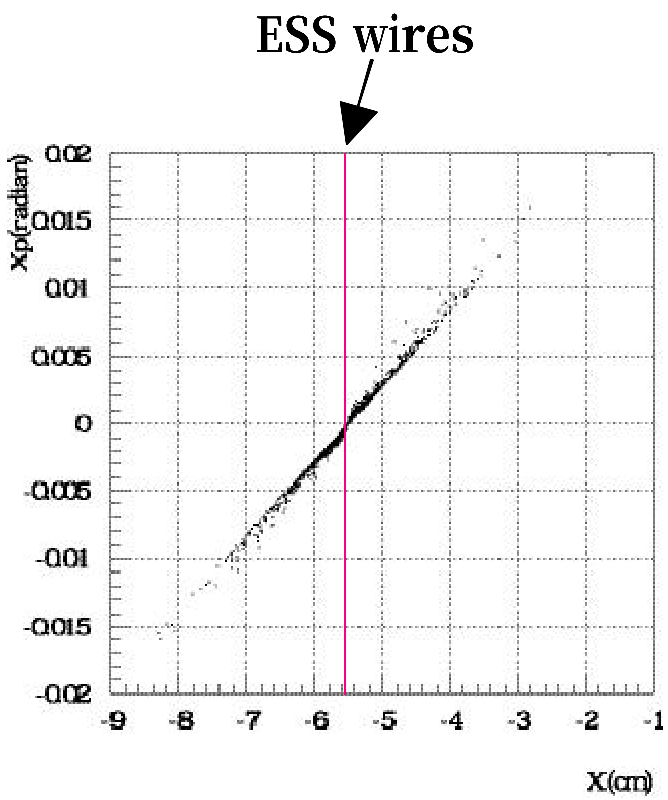
1% hit on the wires
5000h/y operation

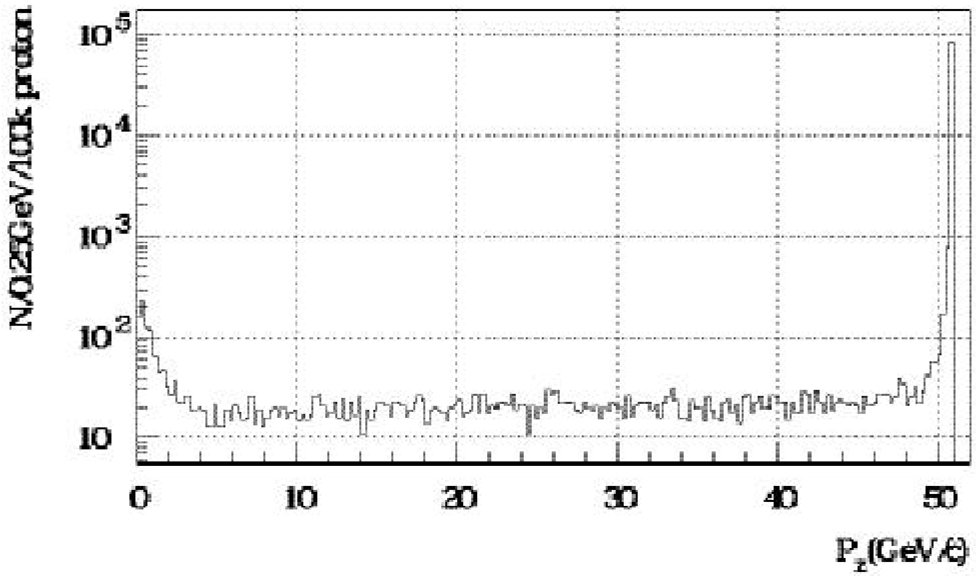
→

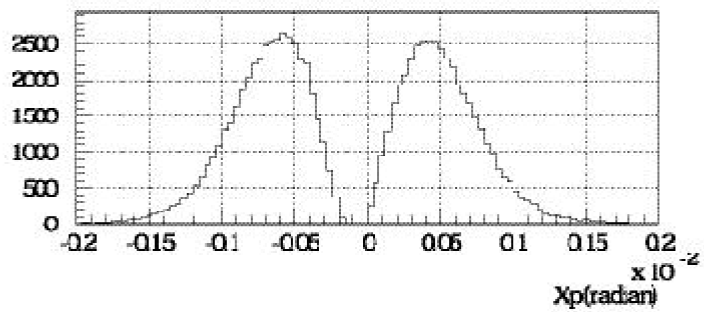
~16MGy/y
life time ~25years

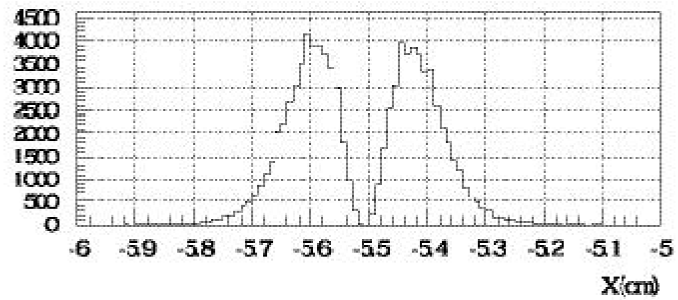
Protons scattered
by the ESS wires

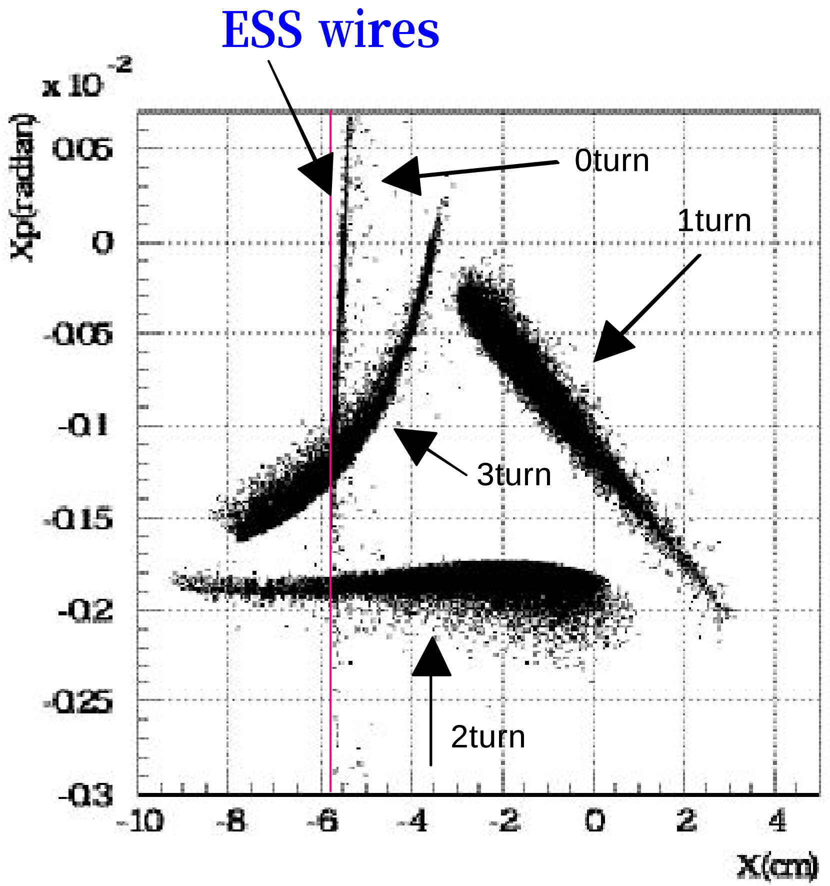
MARS output at the ESS exit
SAD input







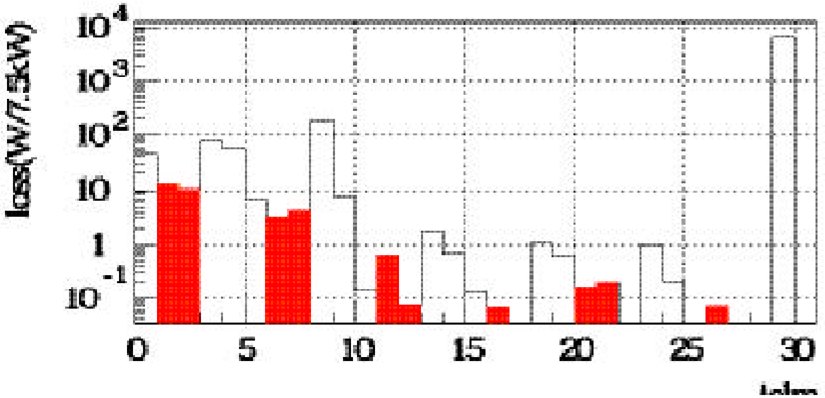




extracted rate
of scattered protons

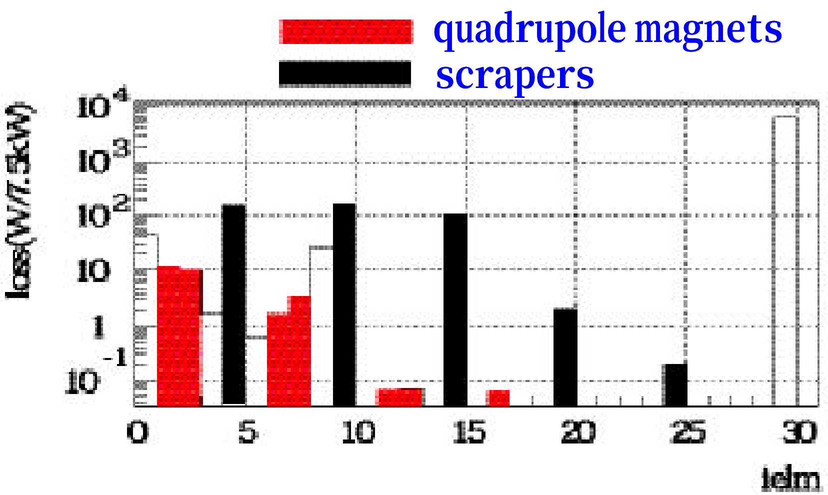
0 turn: ~50%
2 turn: ~1%
3 turn: ~25%
sum. 76%

loss map of particles scattered by the wires
(the ESS exit to the 1st Septum magnet)



without scrapers

duct loss	max. 200W
Q-mag. loss	max. 10W



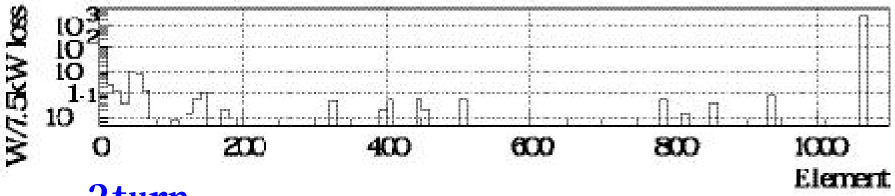
with scrapers

duct loss	max. 30W
Q-mag. loss	max. 10W

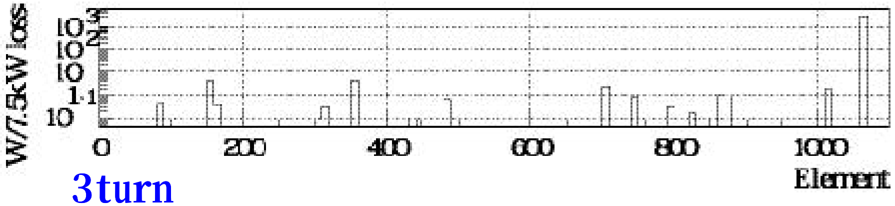
Loss map of particles scattered by the wires
(up to three turns)

without scrapers

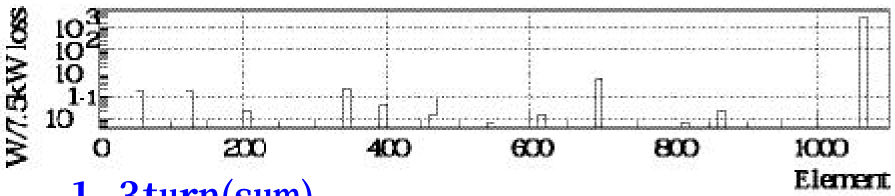
1turn



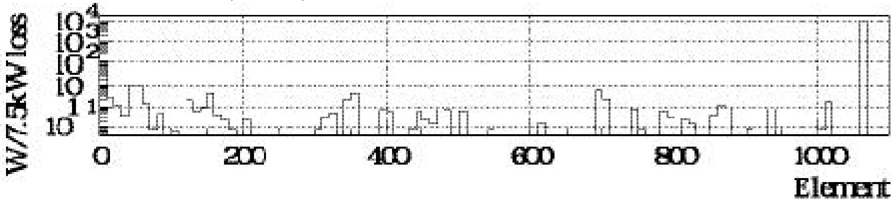
2turn



3turn



1 - 3turn(sum)

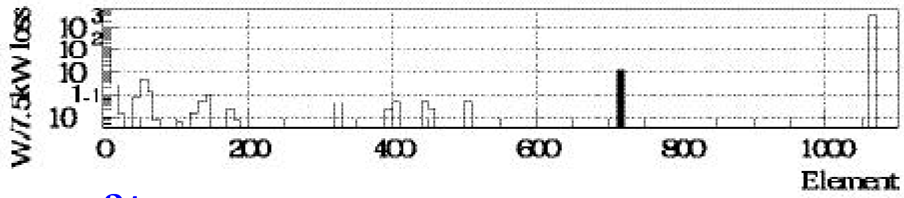


survived 3110 W

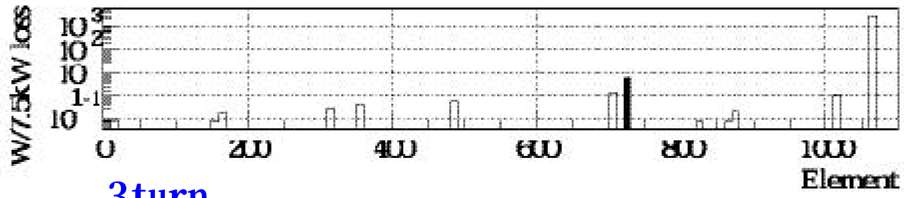
ring loss 172 W

with scrapers

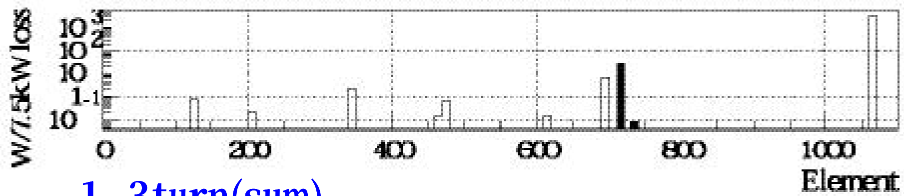
1turn



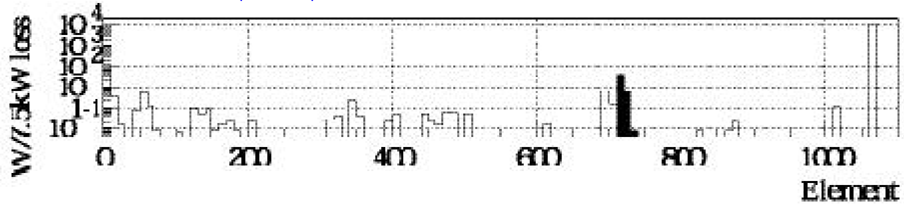
2turn



3turn



1 - 3turn(sum)



survived 3085 W

ring loss 50 W

scrapers 151 W

Summary of beam loss at slow extraction

1% of 750kW beam hits the ESS wires

- Quadrupole magnet (QFP) just downstream of the ESS

  life time 25 years

- residual dose around the ESS (30day operation, 1day cooling)

  side of the ESS :6mSv/h, side of the QFP :10mSv/h, SUS duct :150mSv/h

  (Ti duct, remote flange handling system)

- Loss map of scattered protons over three turns shows

  main beam loss occurs at a short section

  between the ESS and the 1st SM

  loss at other sections seems to be not serious

  scrapers downstream of the ESS are very

  effective to localize beam loss.

- How does remained 24% of scattered protons behave?
- What is the beam emittance and dp/p of extracted-scattered protons?

It determines specification of scrapers placed at high energy BT.

Beam Abort:
due to RF/Magnets break down

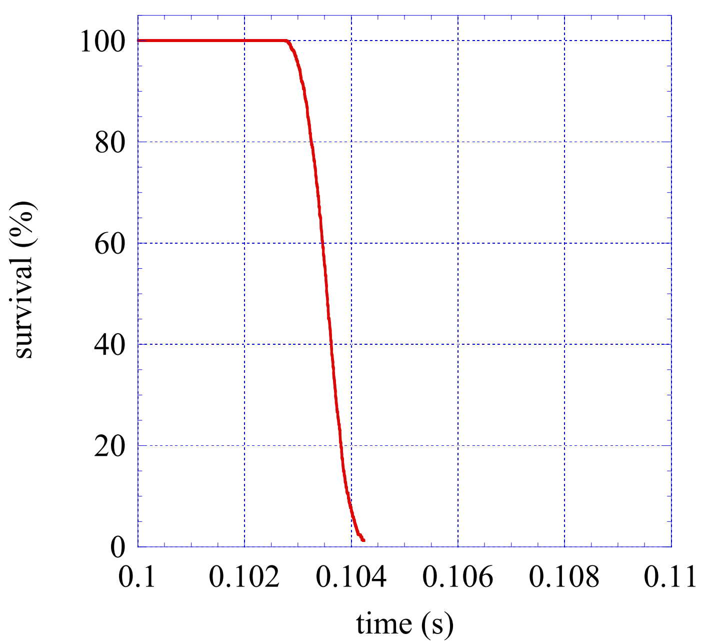
Momentum change :largest@0.1sec aft acc. starts-->~ 6.1GeV/c/sec

1) RF : all voltage down ---> < 10 micro-sec, Q<10

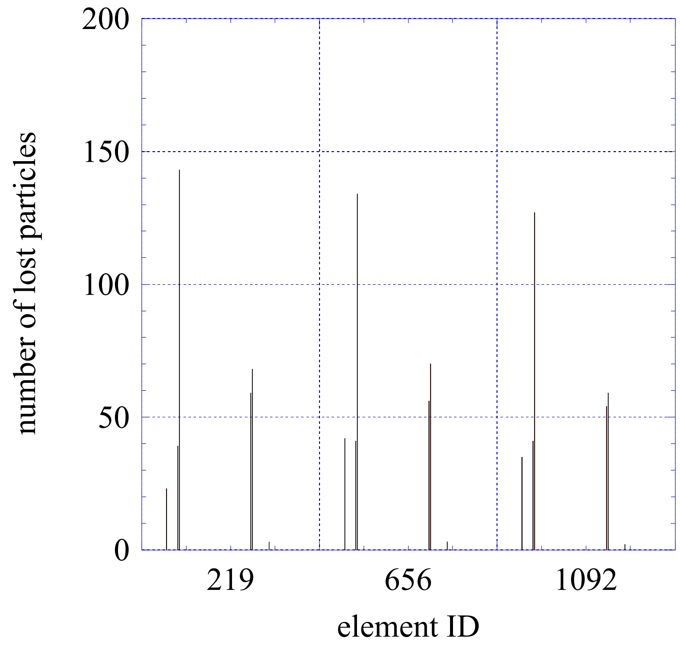
2) Magnet : field break down
time const. ---> ~ 0.1s

How fast trigger for beam abort system should be? -->loss process

RF break down



t<3ms

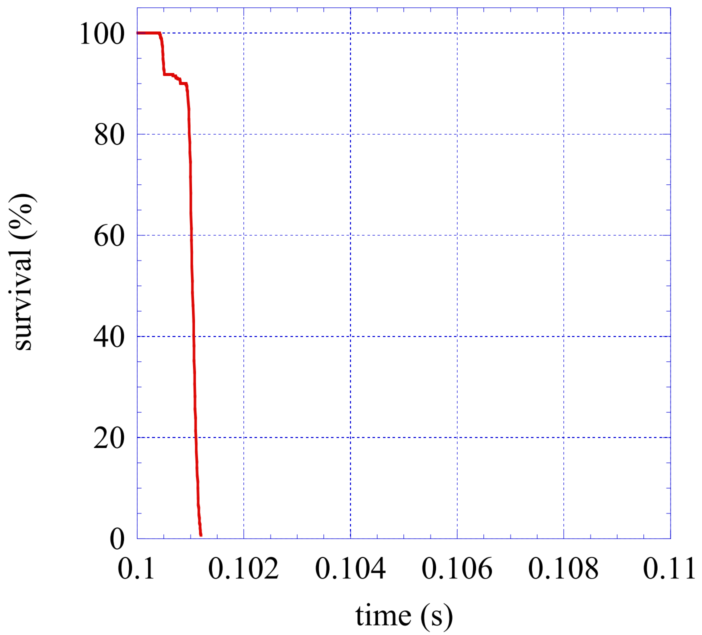


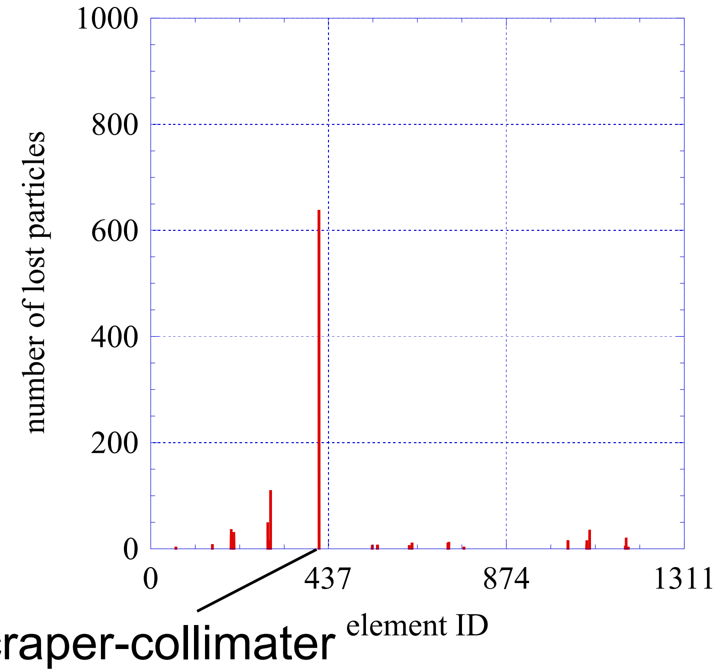
RF down at 0.1sec after acceleration start

Beam loss points

B-magnet break down

COD : corrected





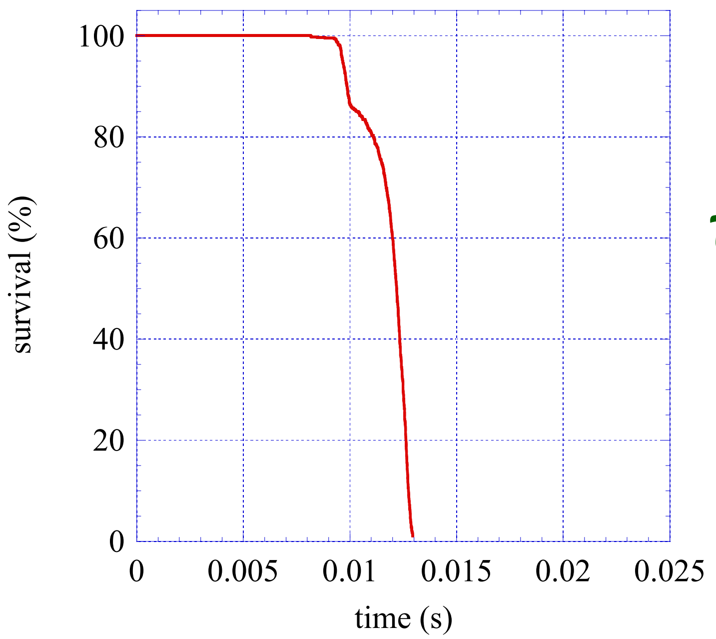
break down at 0.1sec

after acceleration starts

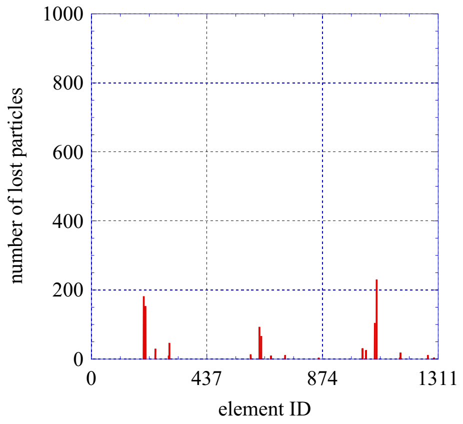
beam loss points

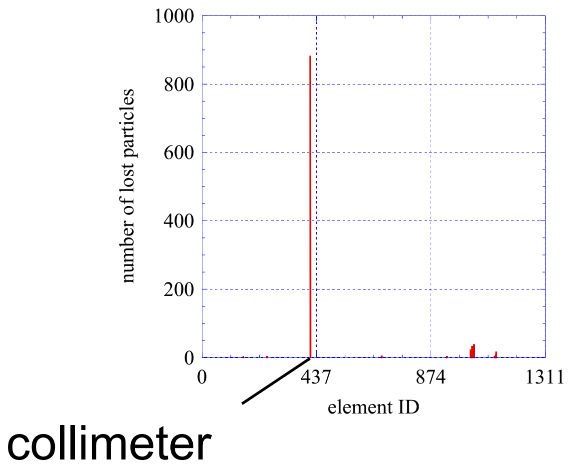
Q-magnet break down

COD : corrected



t<10ms





QFN down at 0sec

Summary : beam loss due to break down

1) RF break down

t<3ms

t: duration before starting the losses

beam loss -> at large dispersive points (COD=0)

2) B magnets break down

t<1ms without RF feedback

t<10ms with RF feedback

beam loss -> mostly at collimater (COD=0)

3) Q magnets(one of 13 families) break down

t<10ms

beam loss -> depend on Q-family

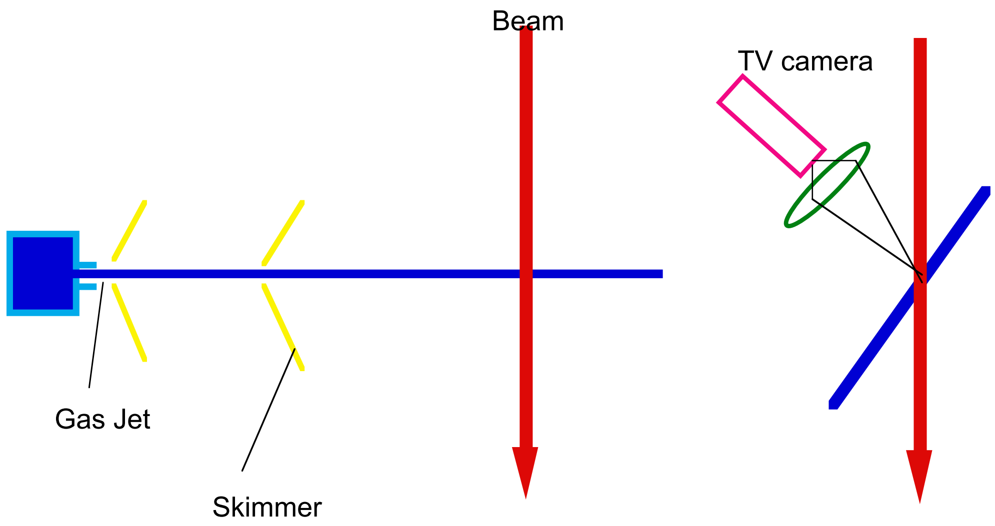
Beam Monitor

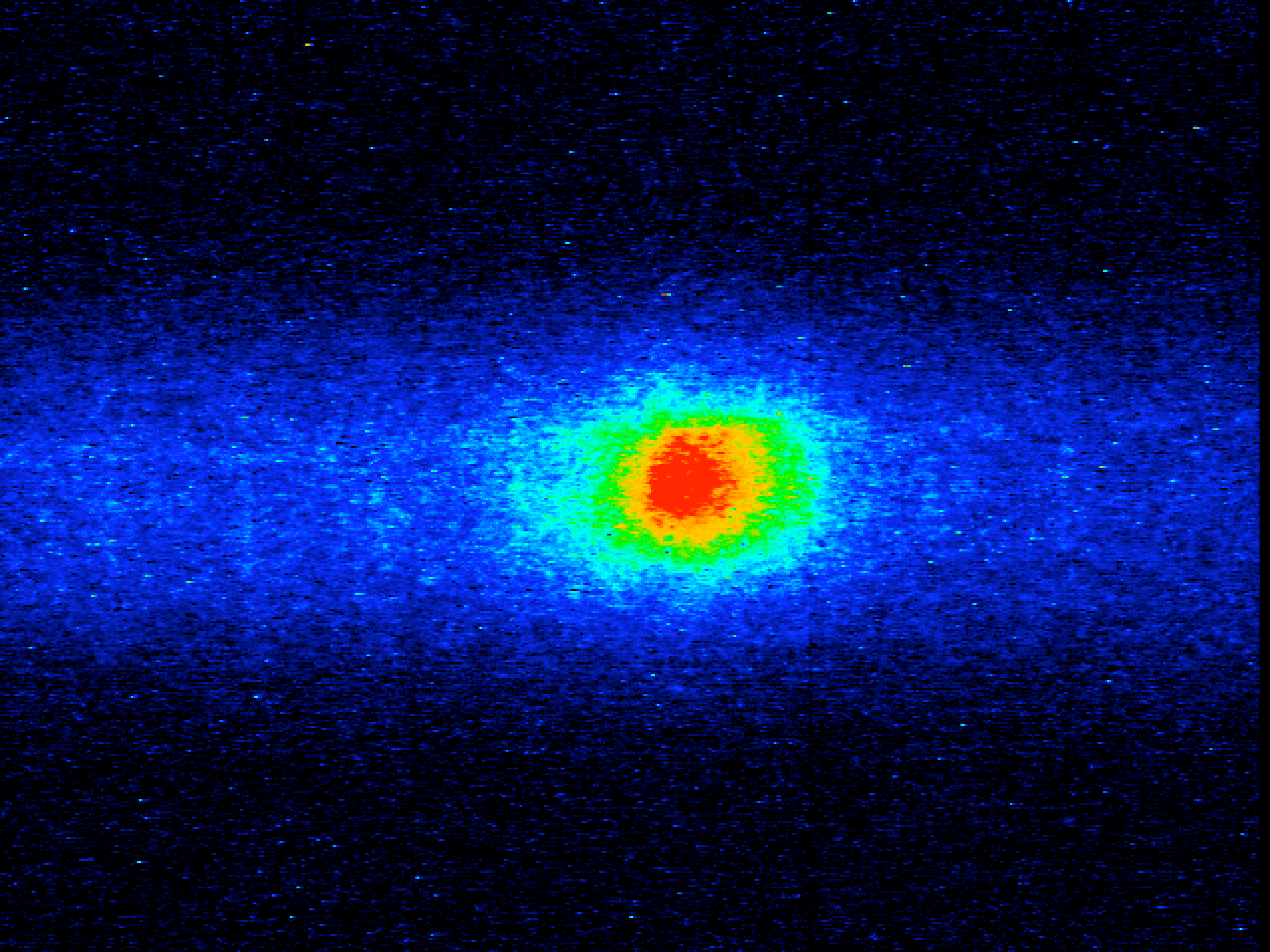
Beam Loss ~ 1% : still very big beam power
Beam loss of < 1% is difficult to measure!

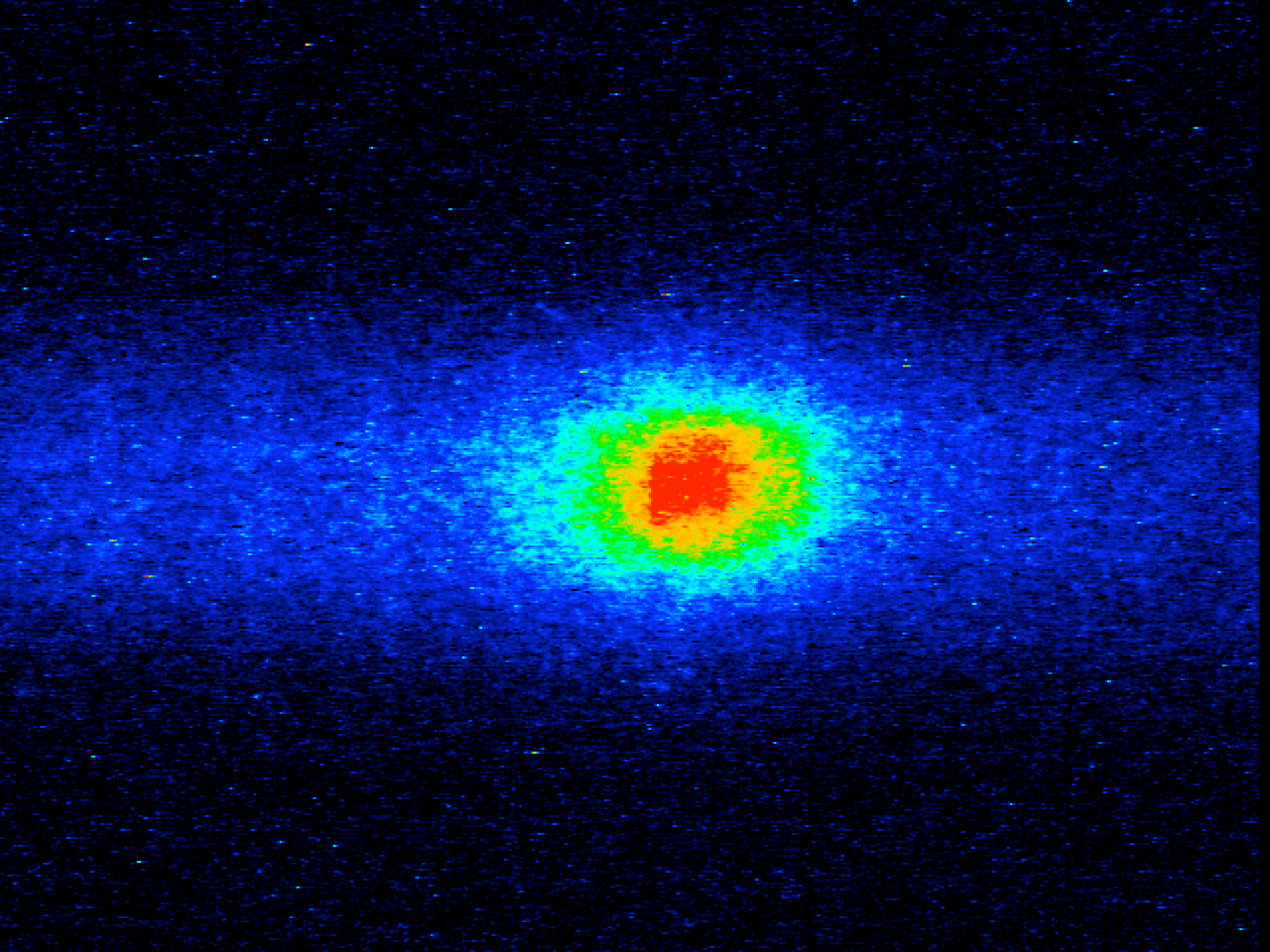
One possibility : very fast beam profile monitor
----> "Sheet beam gas profile monitor"

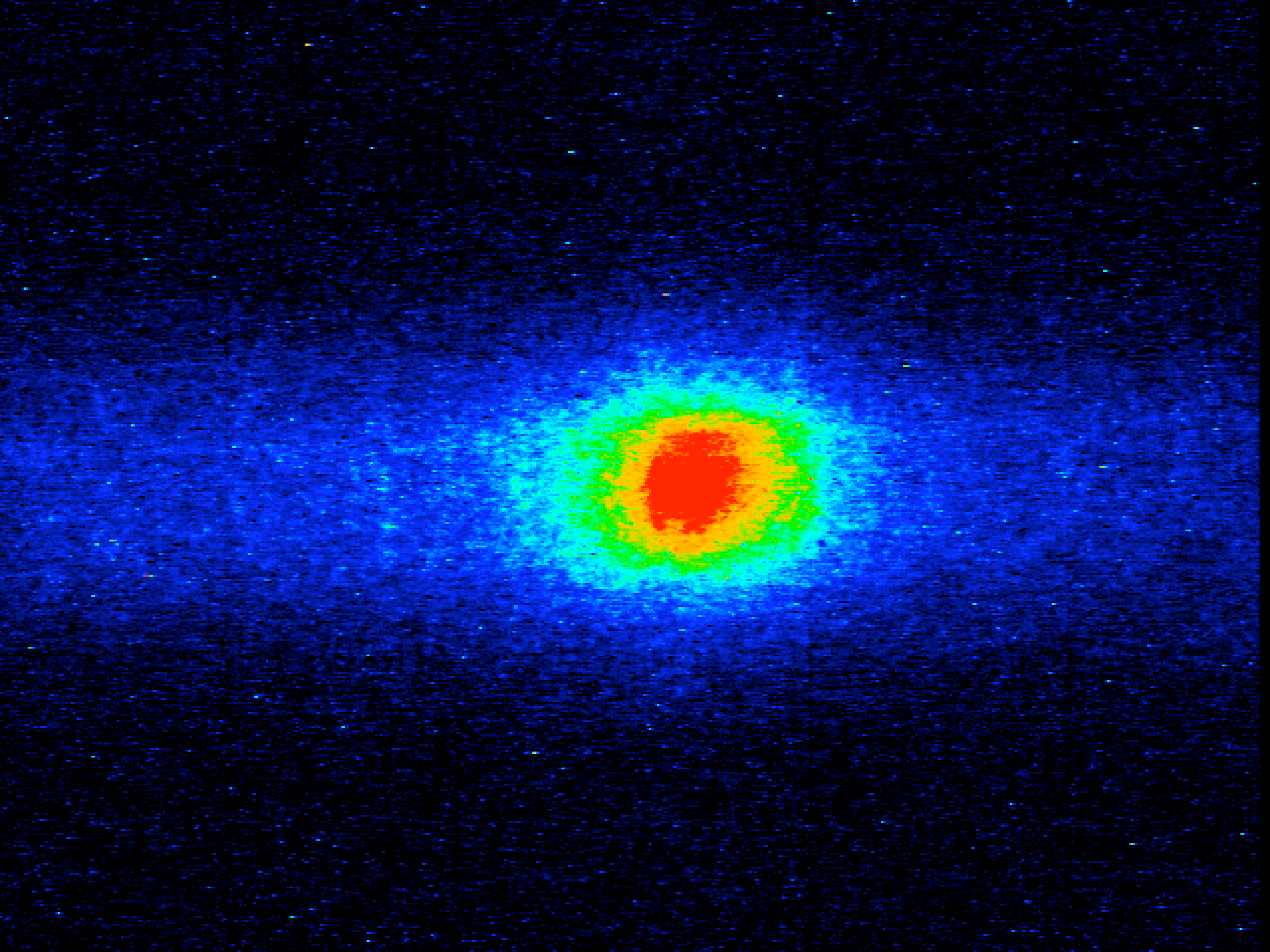
Preliminary Exp. @HIMAC

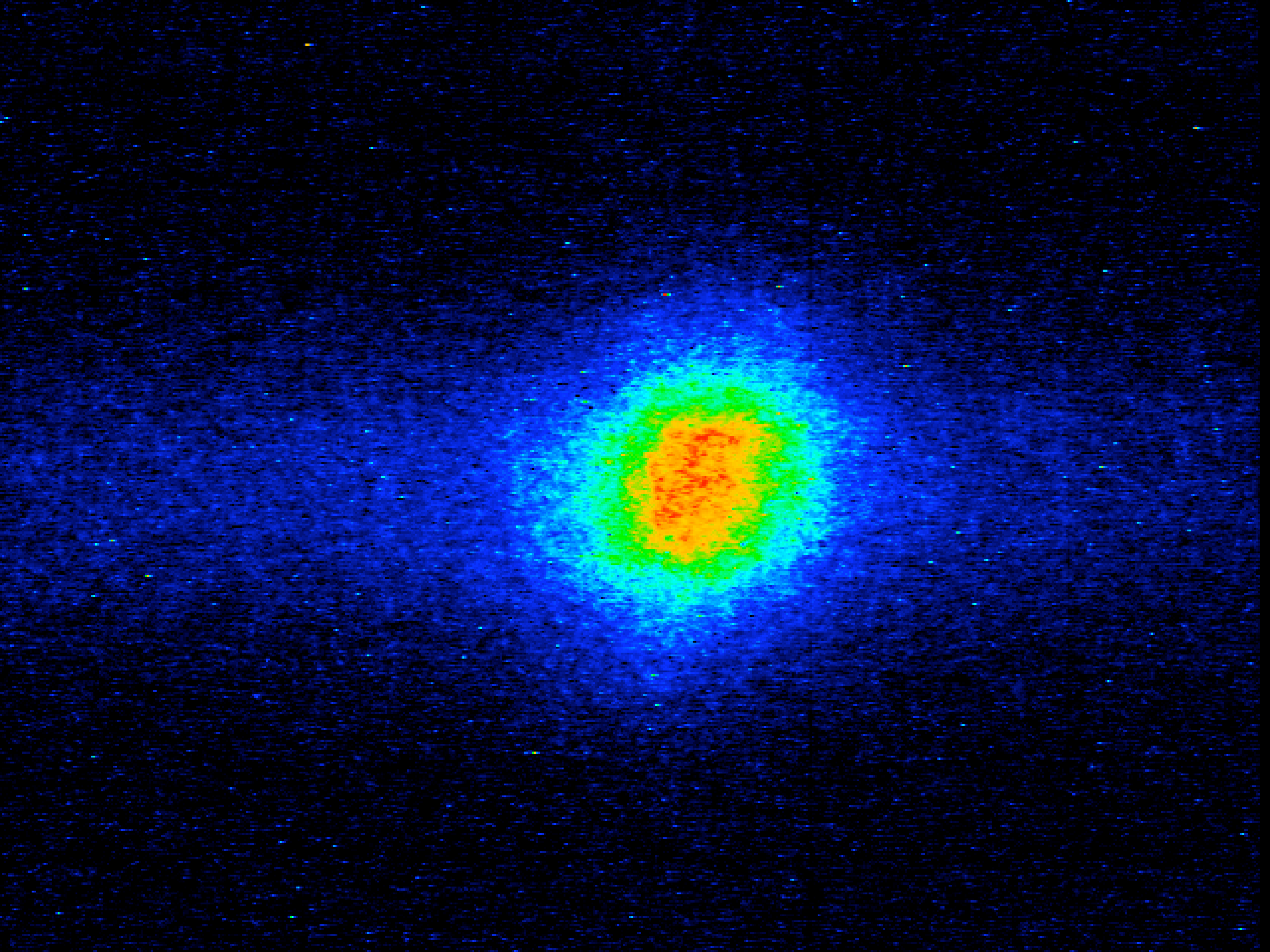
electron-cooled Ne ion beam

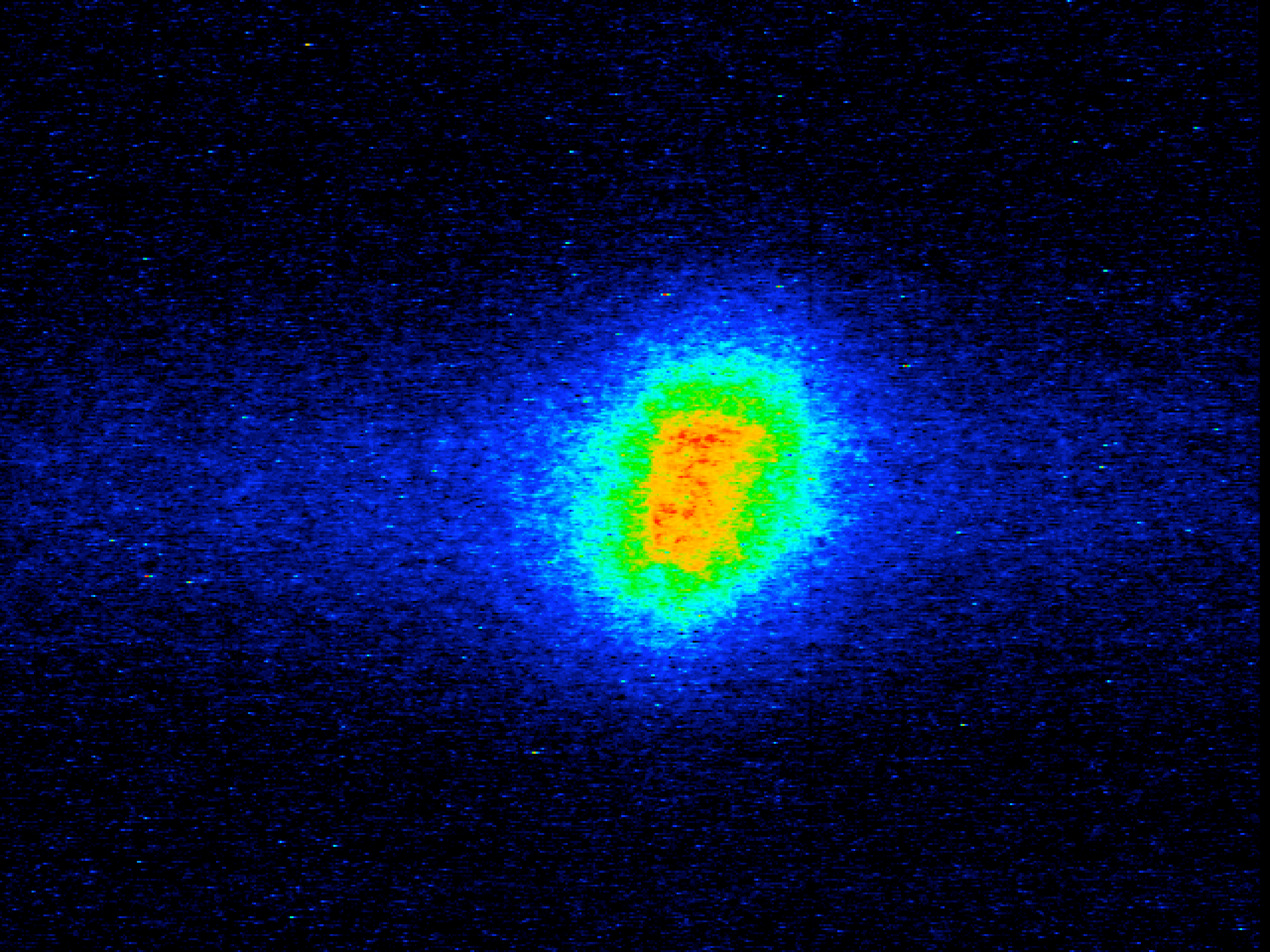


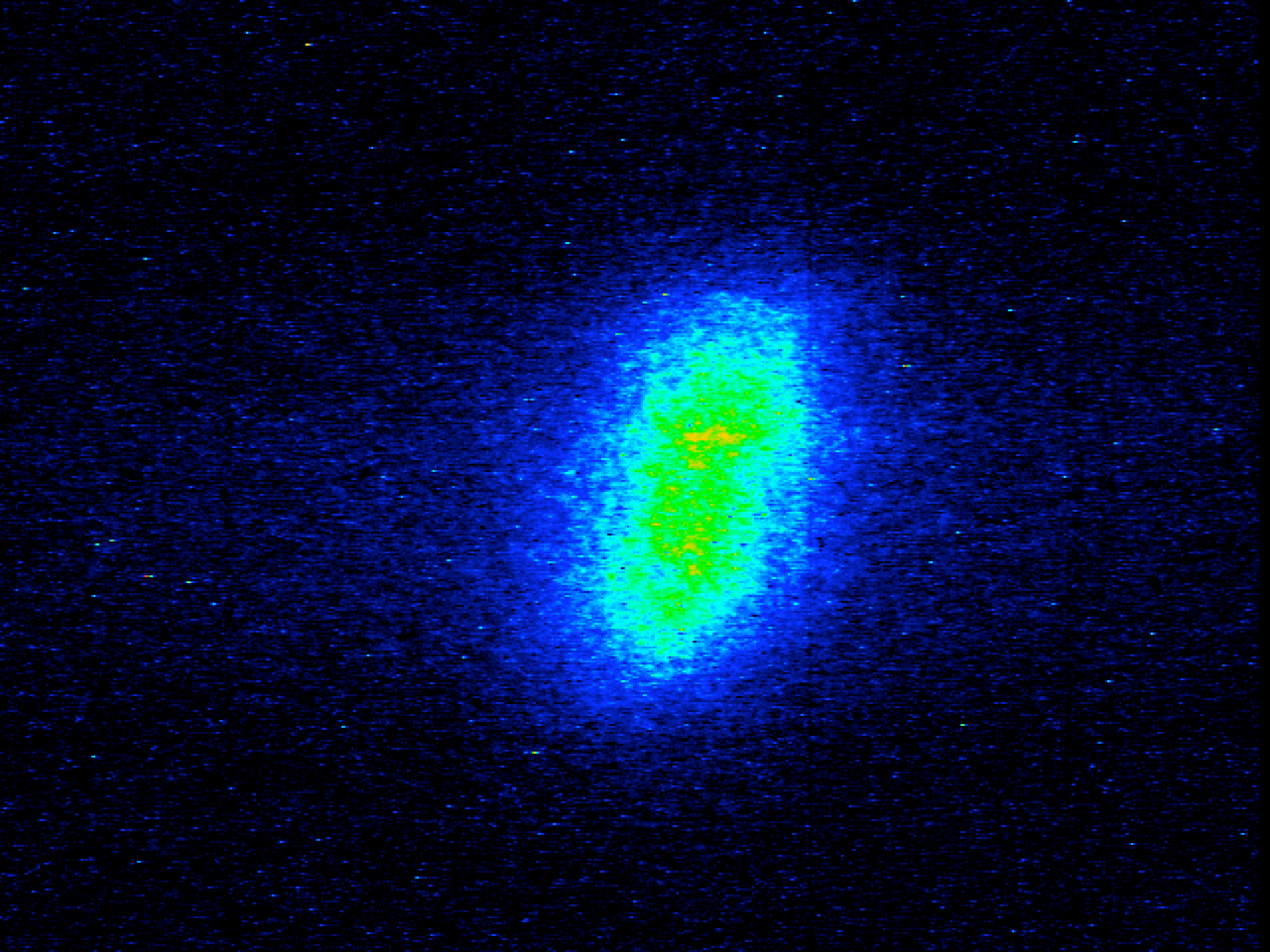


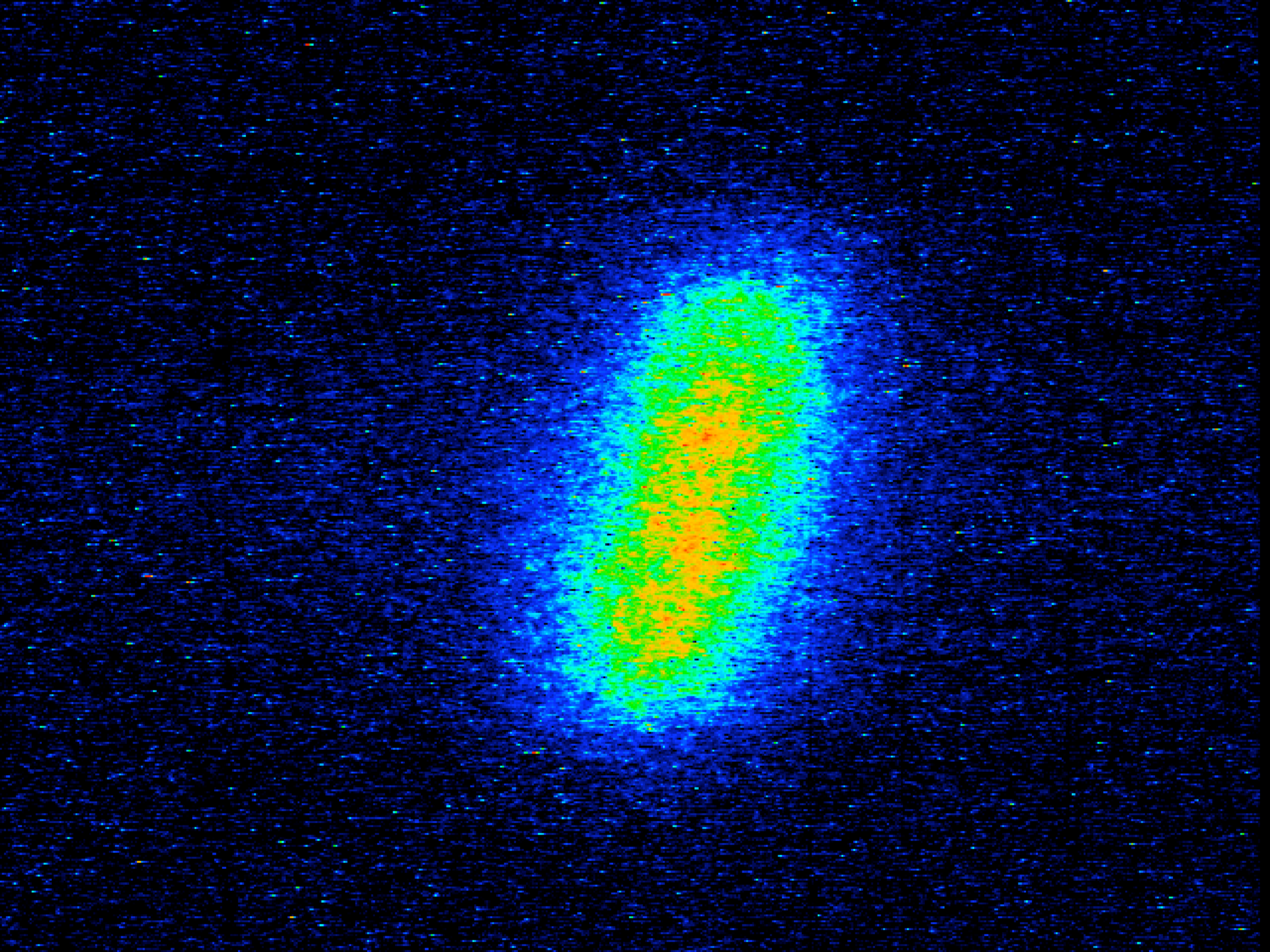


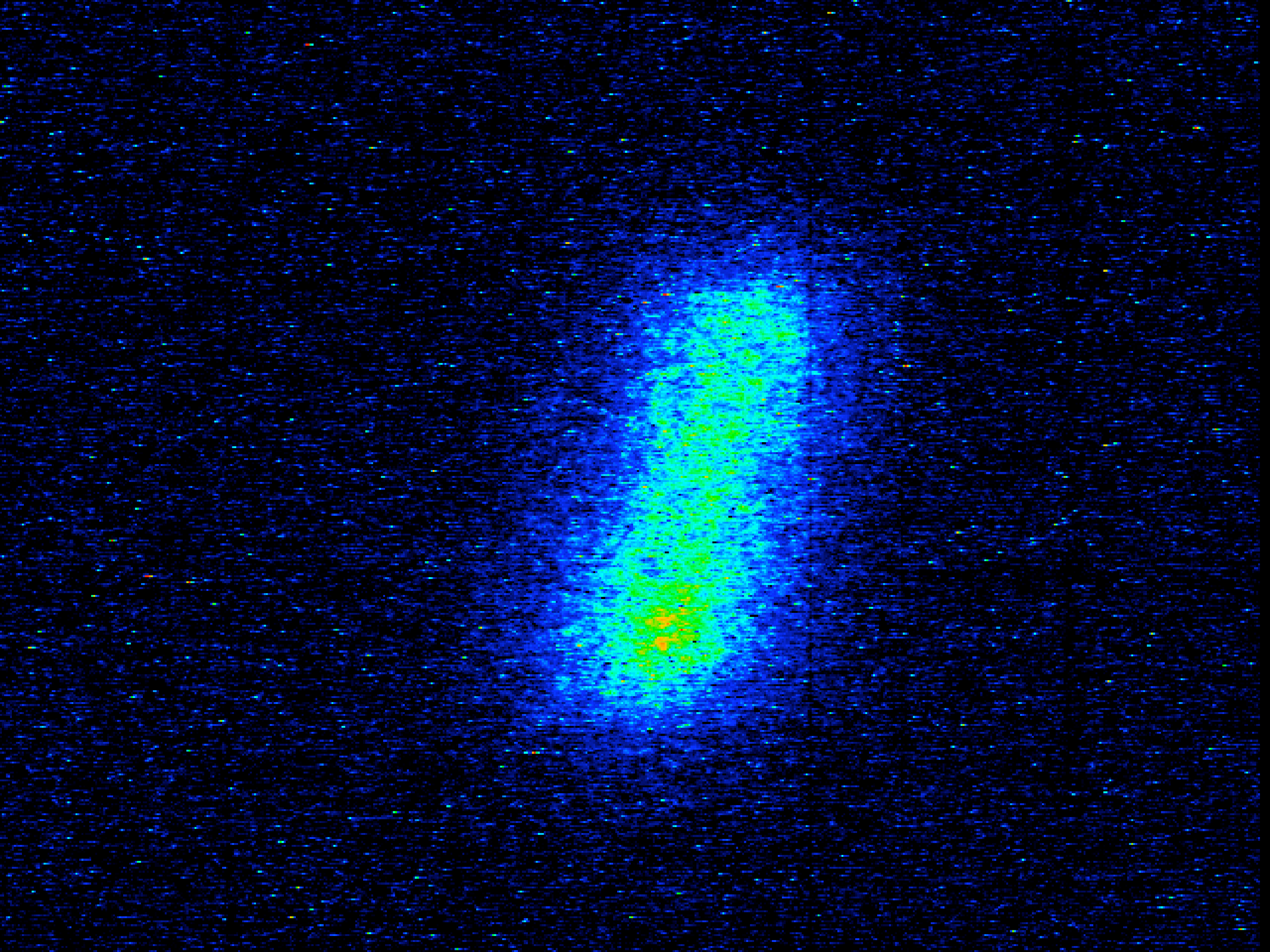


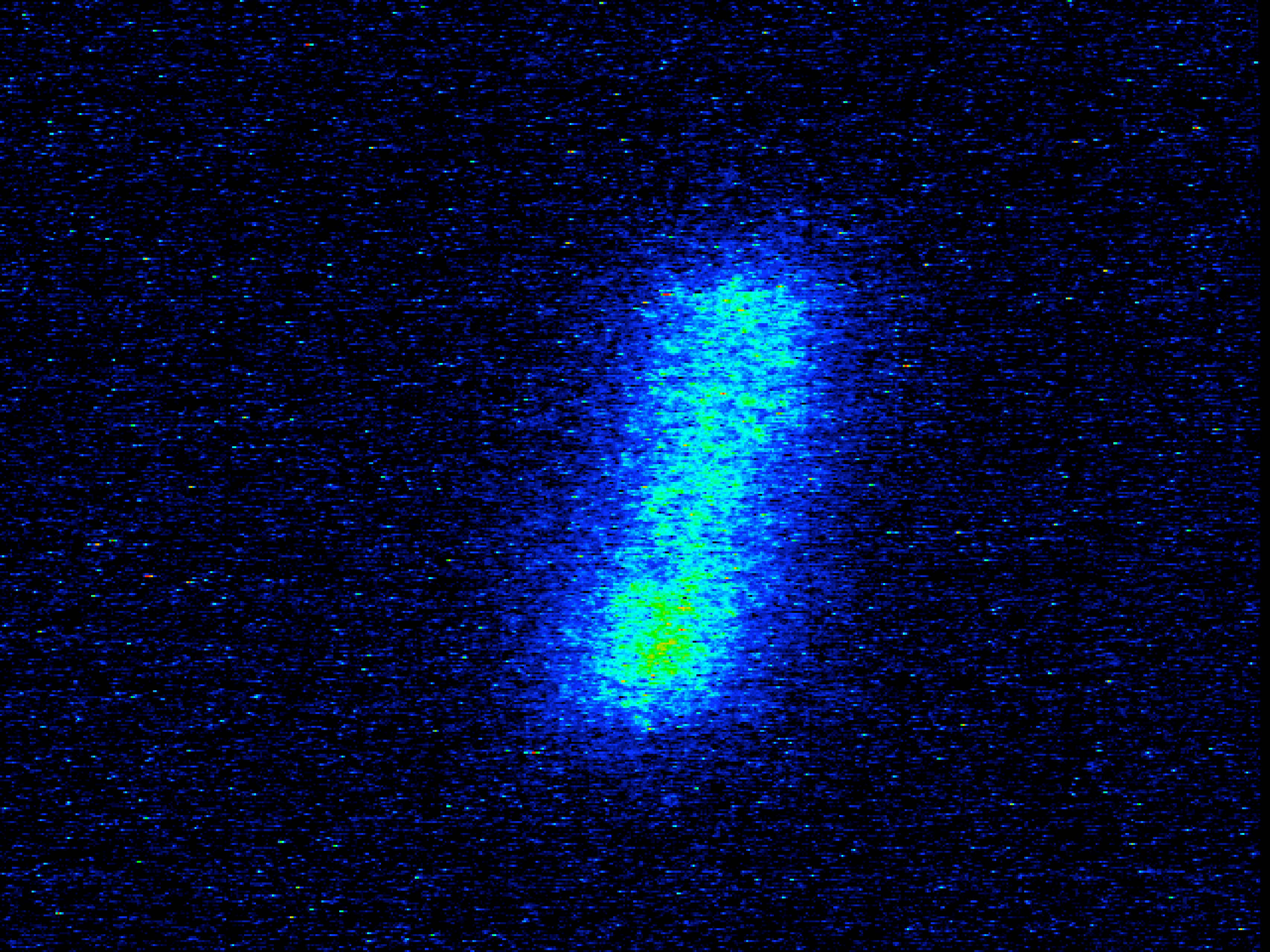


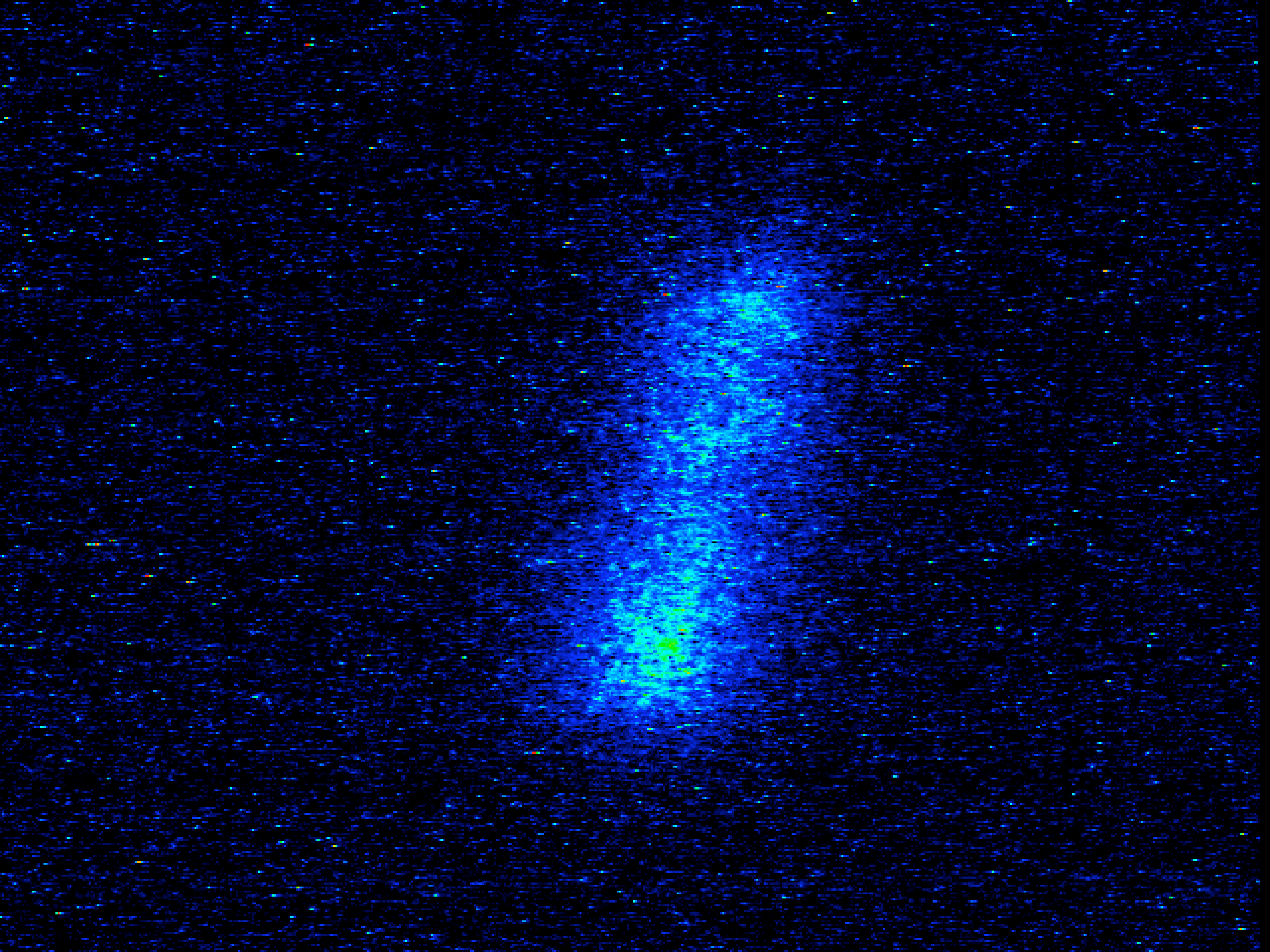












Hardwares

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

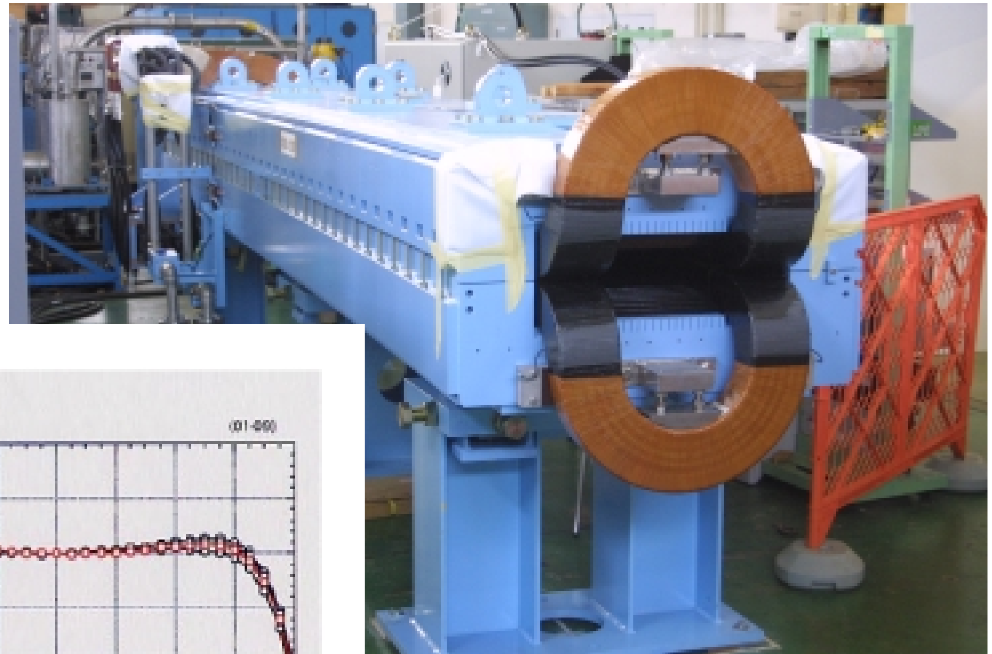
   High gradient RF cavity with Magnetic Alloy

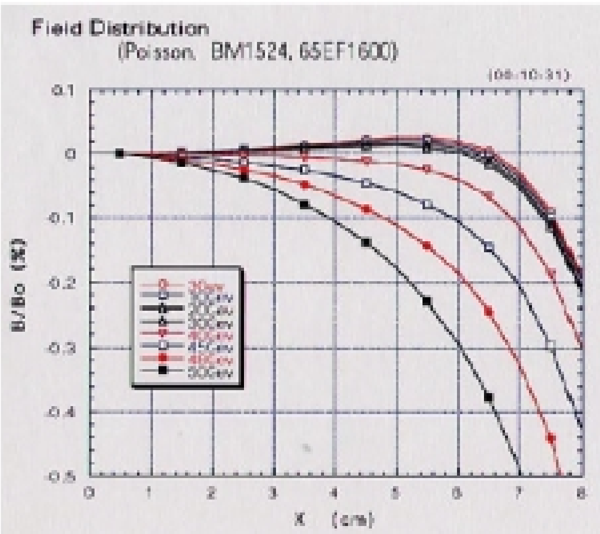
4) Electro-static Septum

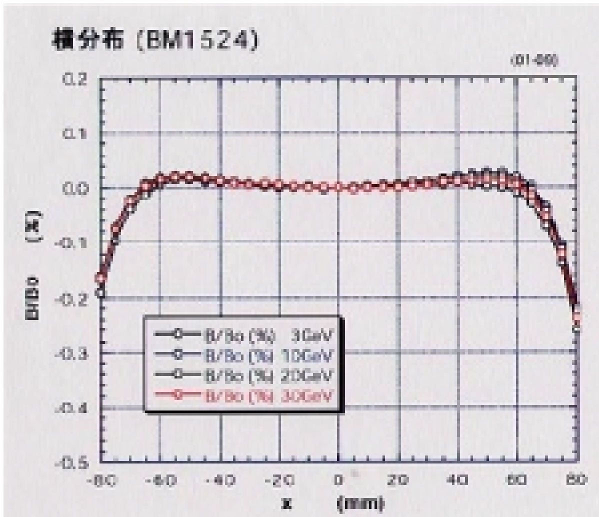
   Small beam loss at slow beam extraction

Dipole Magnet for 50GeV MR (R&D)

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



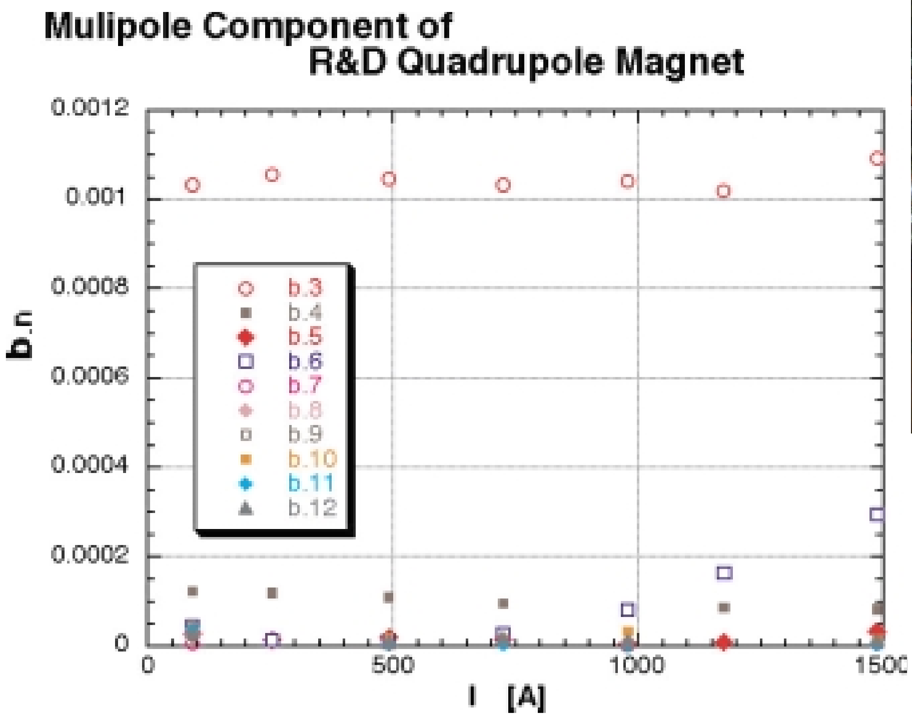


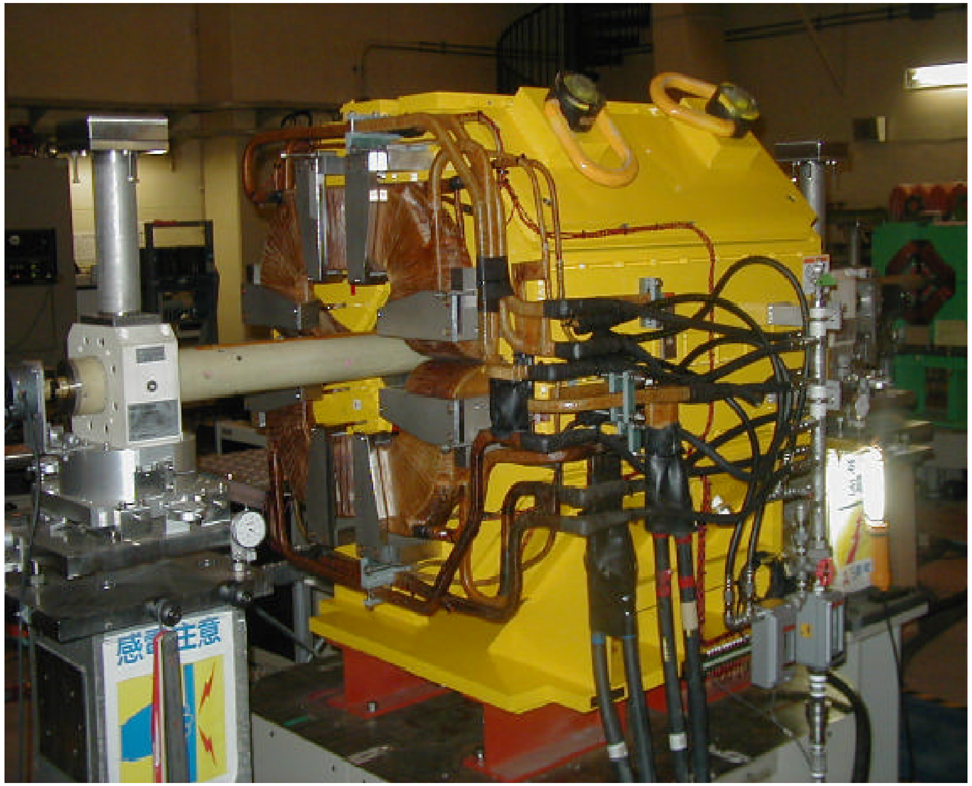


good agreement with calculations!

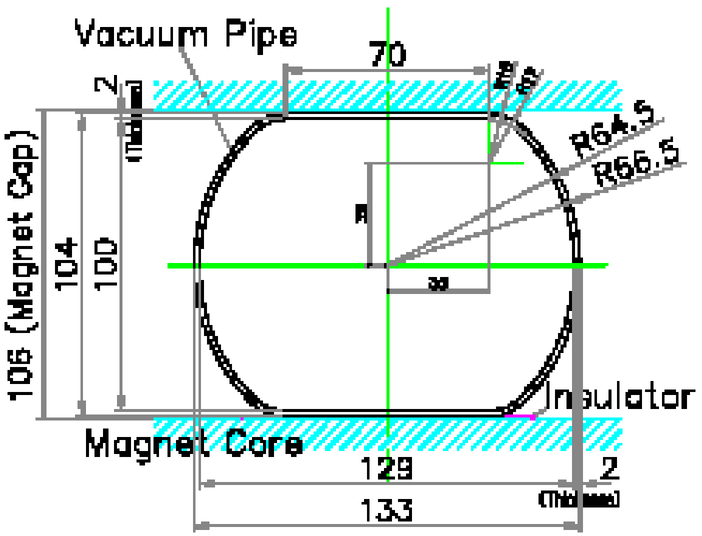
Quadrupole Magnet of 50GeV PS (R&D)

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

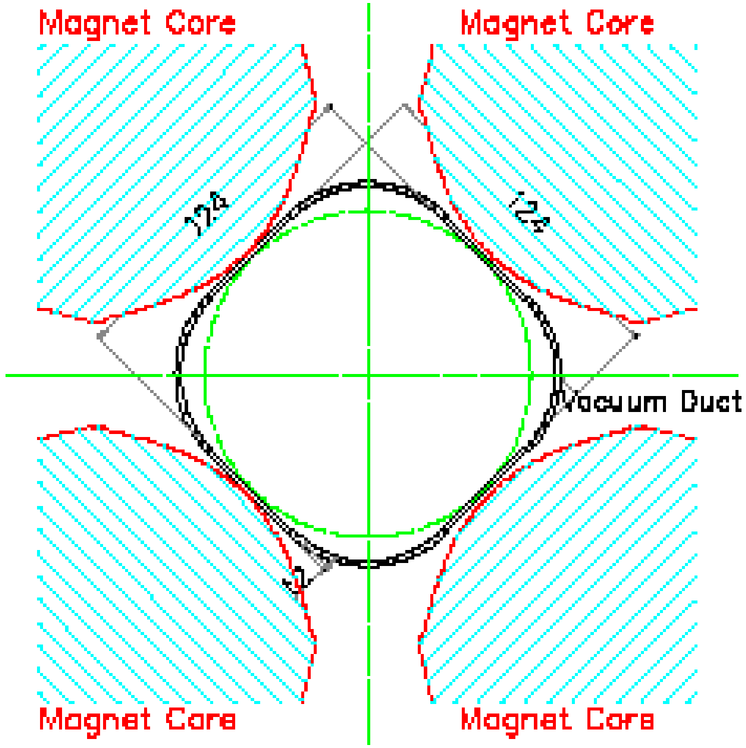




Vacuum Chamber



bending magnet



quadrupole magnet

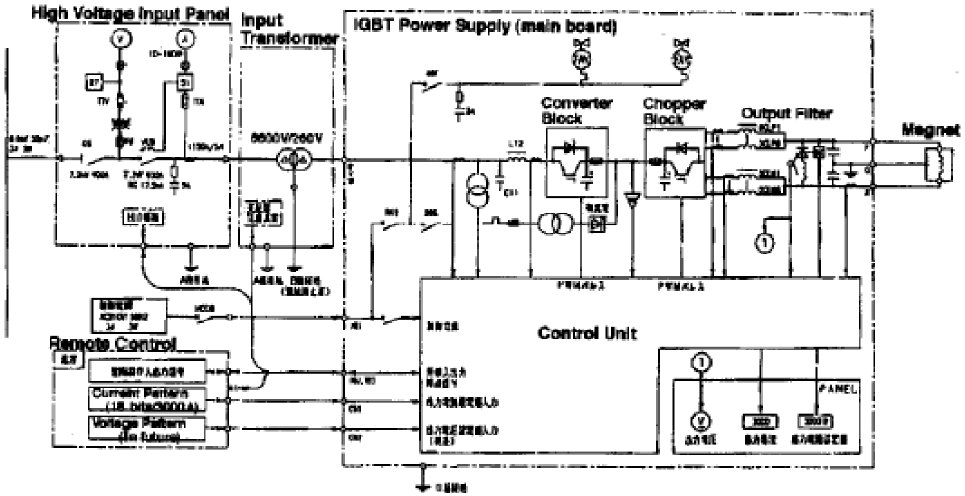
Magnet Power Supply

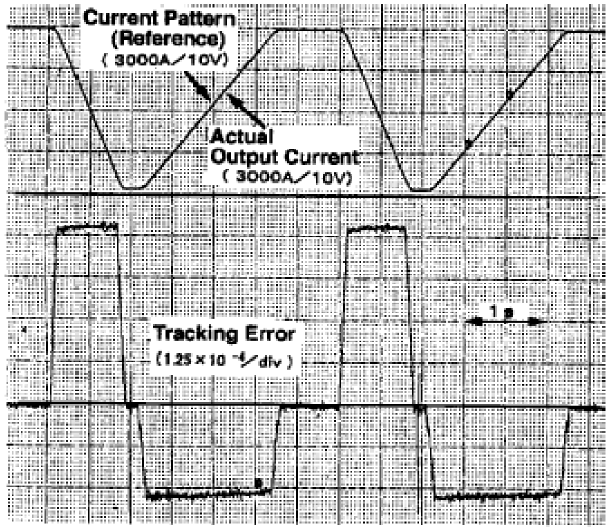
* self-converter(PWM) type (high freq. IGBT ~2kHz)

* no reactive power 100 % power factor

* ripple ~ 10^{-6}

* tracking error ~10^{-4}



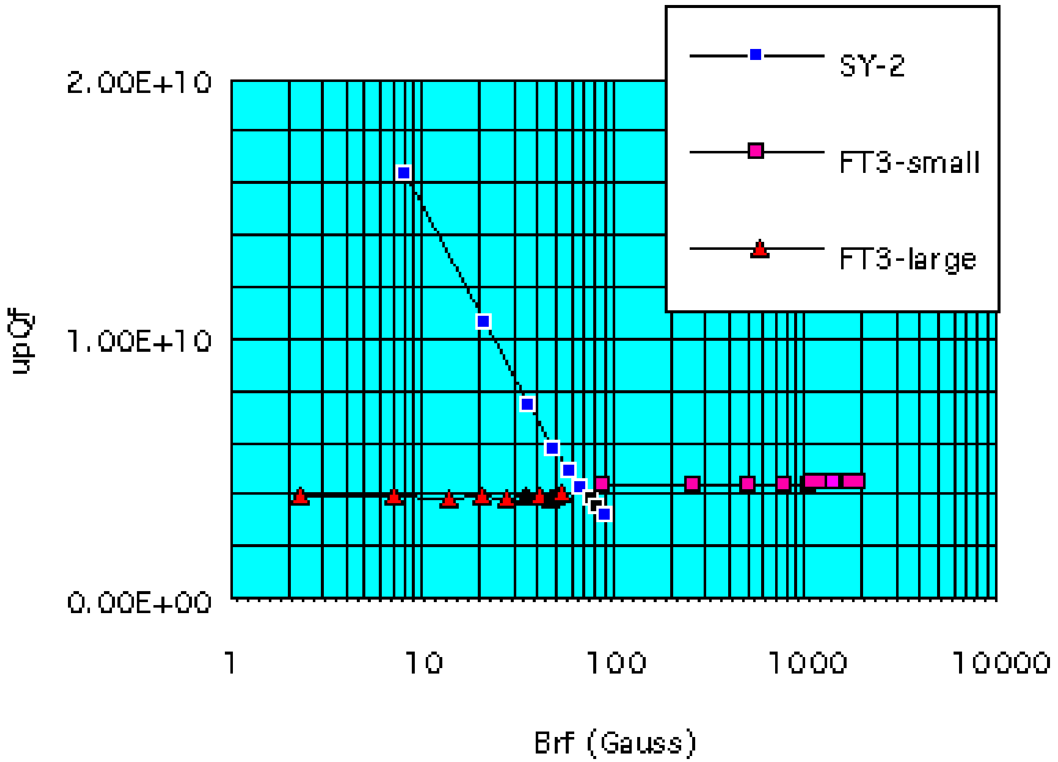


RF Cavity with Magnetic Alloy

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

  μQf (shunt.imp.) vs. B_{rf}

μQf

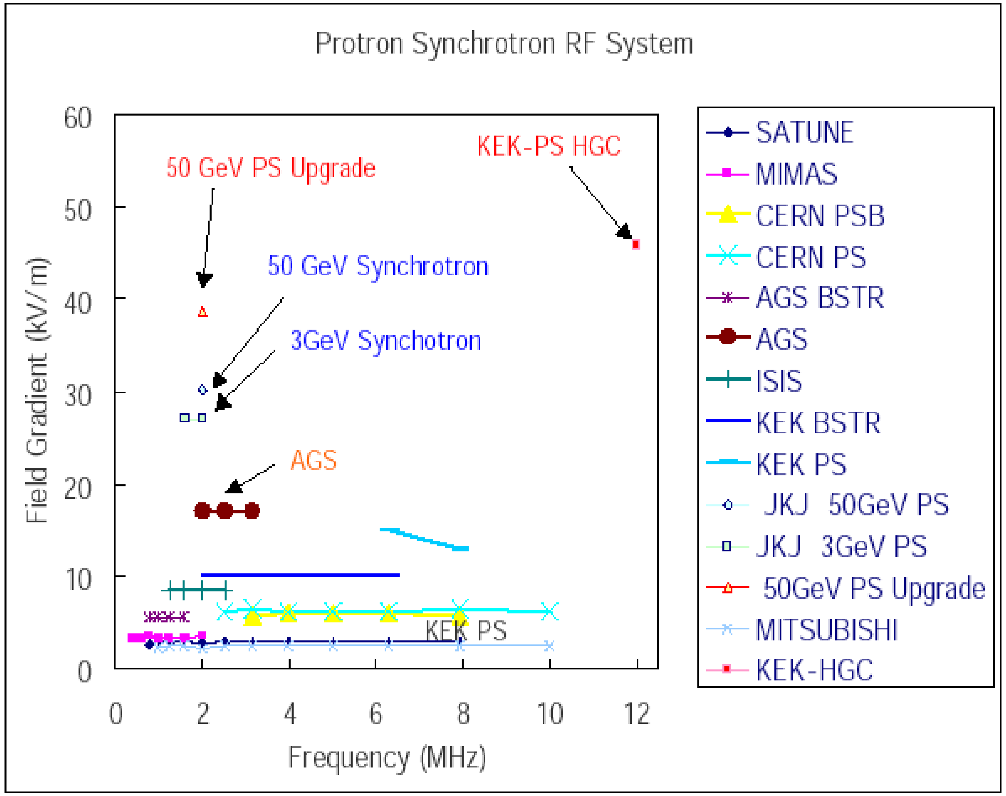


B_{rf}

High Field Gradient RF Cavity with Magnetic Alloy

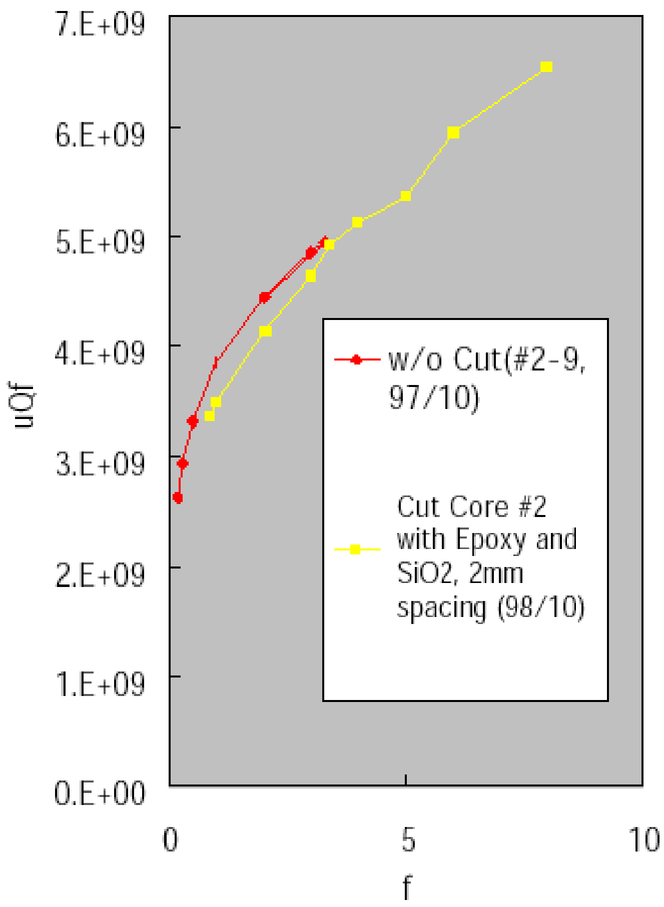
-MA Cavity-

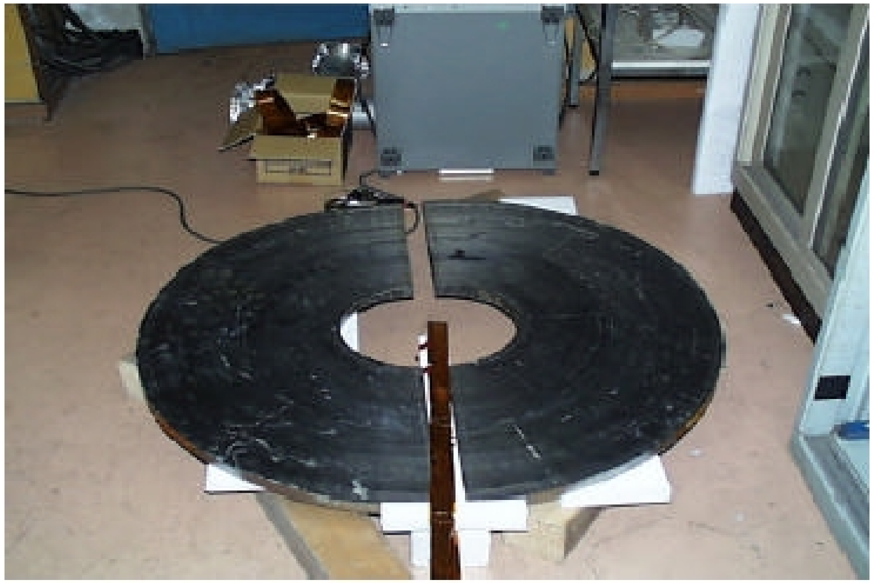
Field Gradient of RF Cavity

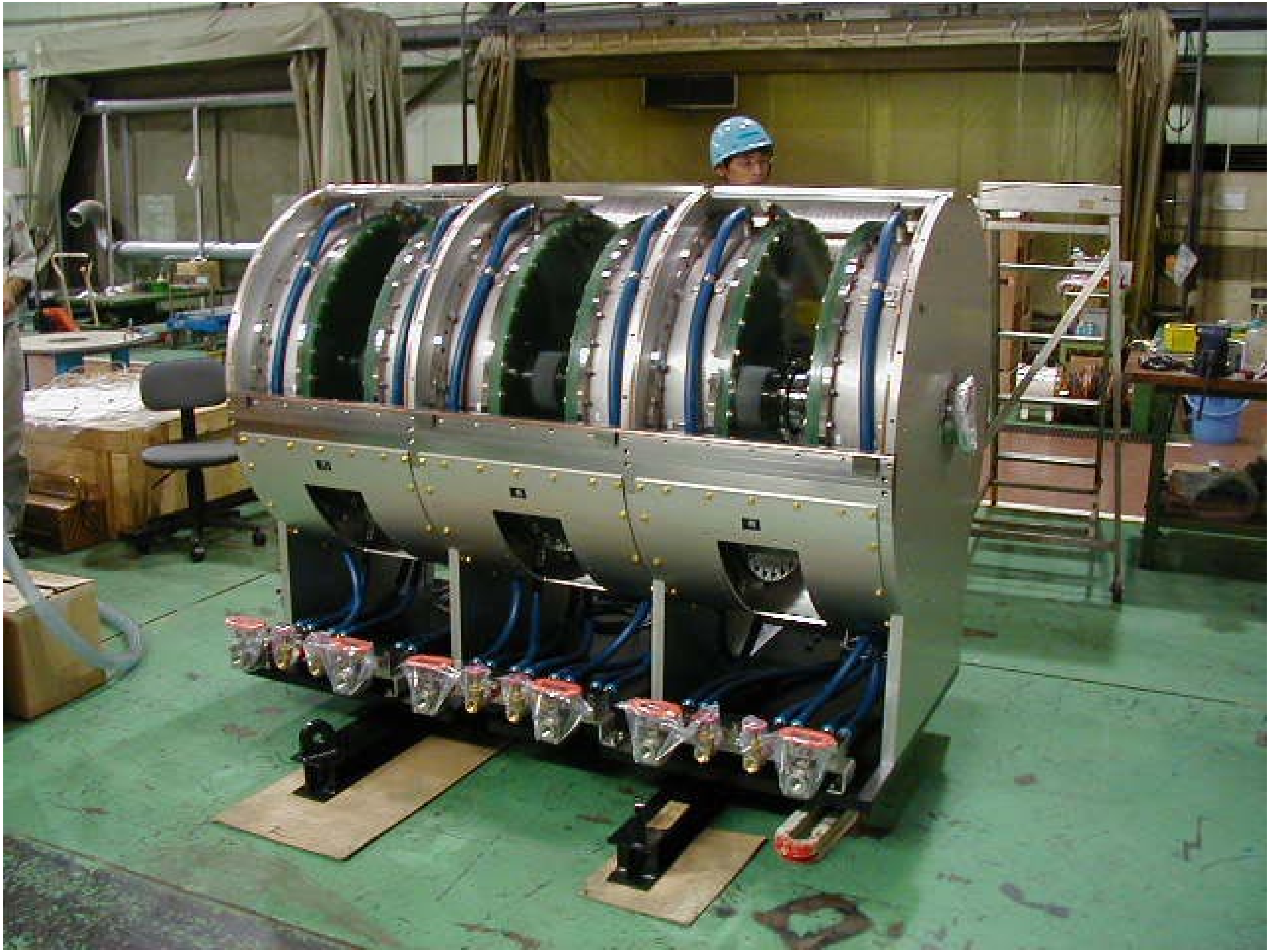


MA Cavity - Cut Core

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

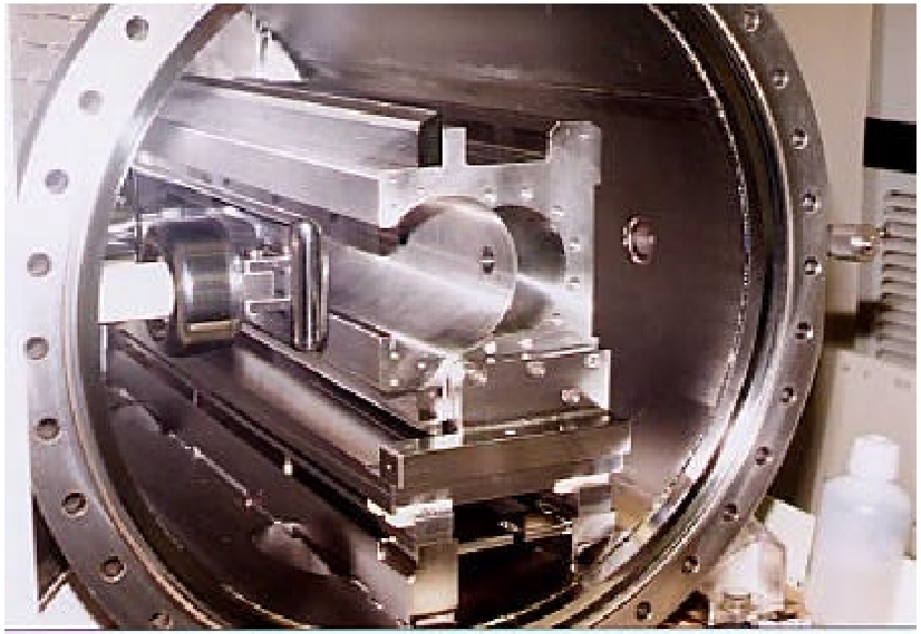






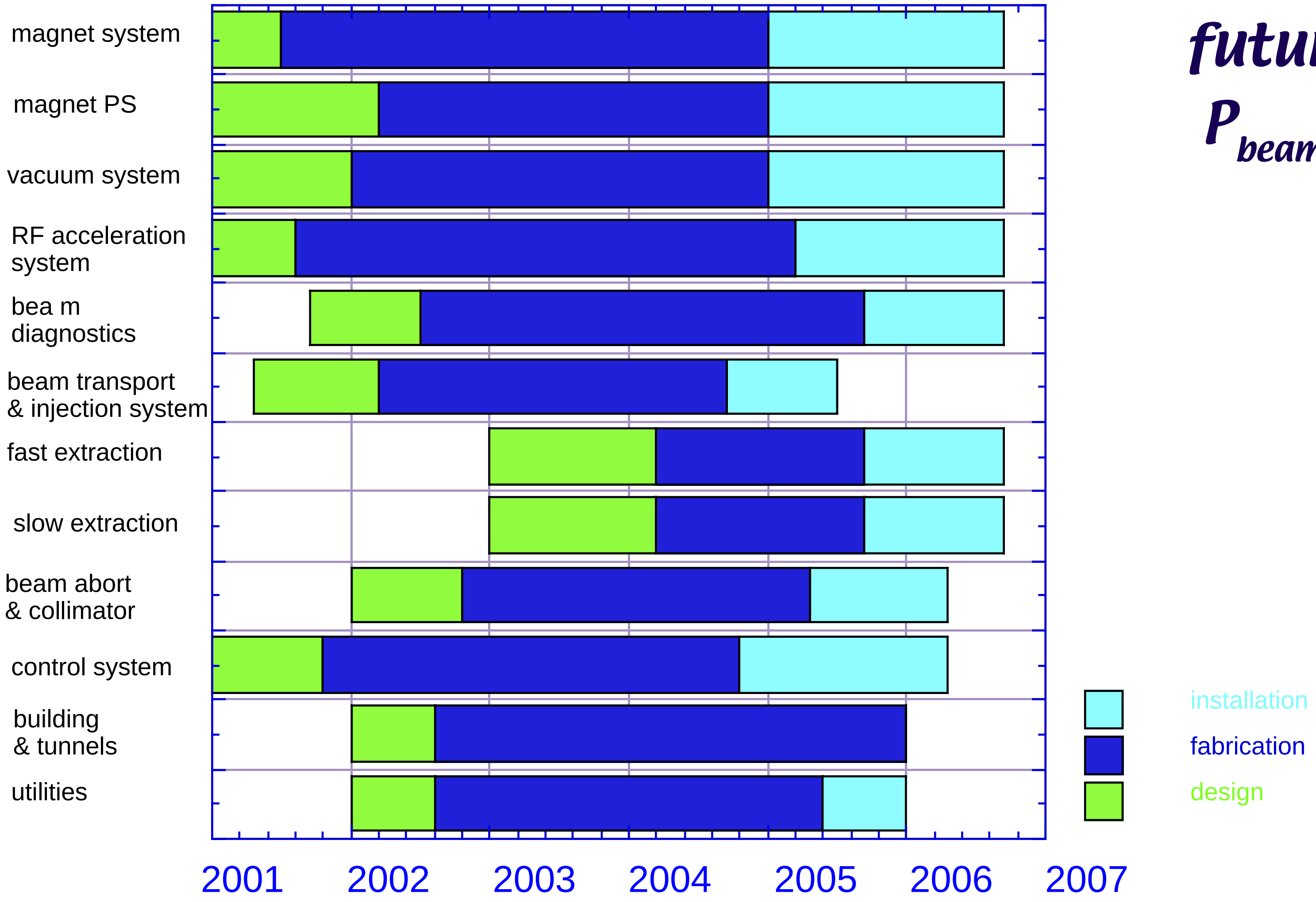
Electro-static Septum (R&D)

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



ESS(R&D) assembly

Summary schedule



future upgrade

P_{beam} ~4MW

Linac energy reduction

Linac energy : 400 MeV ---> 181MeV

Beam Intensity of 3-GeV RCS

---> 0.4-0.6 times of nominal value

Beam power

Beam Power = Energy x Current (ave.)

Constraints:

Max. Energy?

Max. Current?

Max. beam energy

Peak electric power: >100MW@50GeV

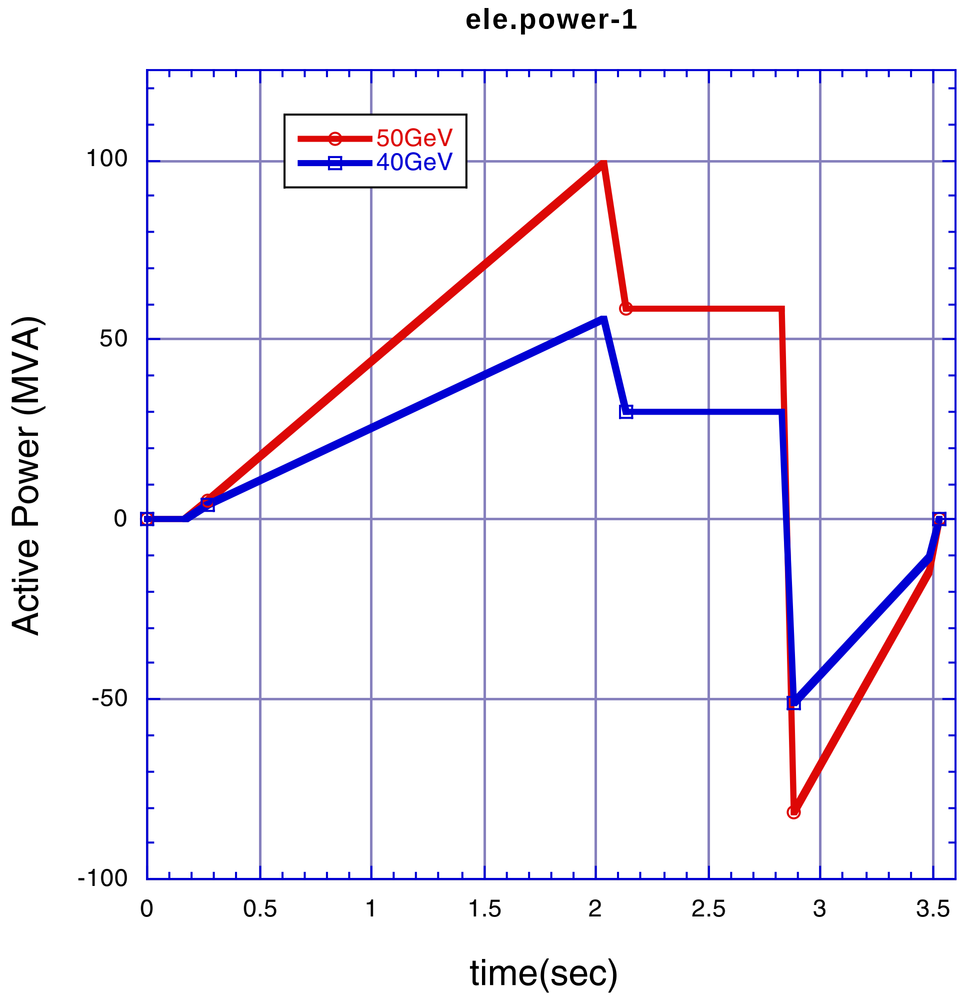
*Electric power line stability

*Flicker

---> Need “Power Storage”

[Fly Wheel Generator]

phase 1 ----> E=40GeV



beam current constraints

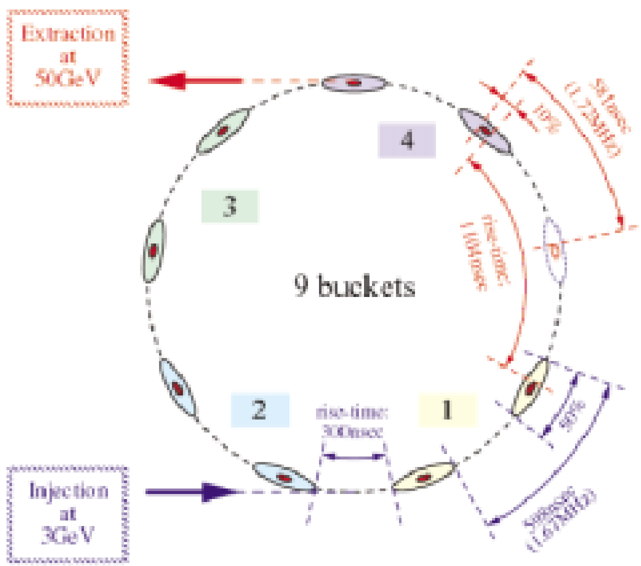
beam current = # of particles x repetition rate

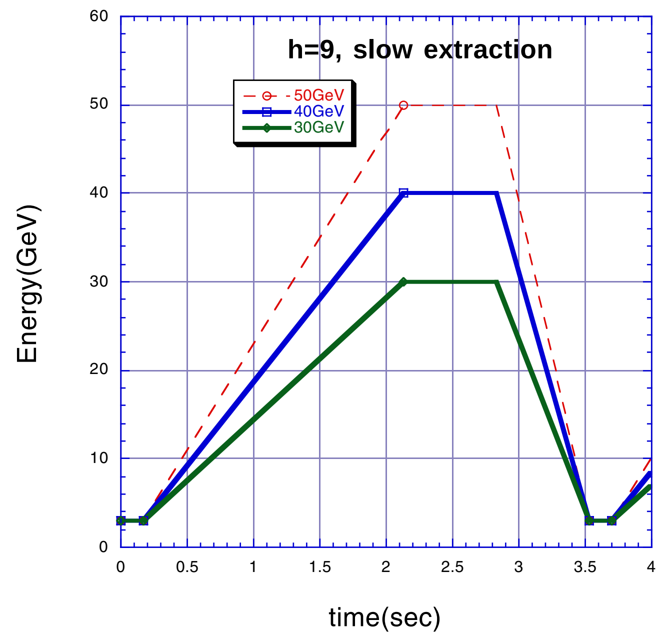
Design values

# of particles:3.33×10^{14}

rep. rate :1/3.

current : 15μ





Repition rate

Fast extraction: no flat-top

----> 1.2 times fast rep. rate

Number of particles in Main Ring

Limit : Space charge

tune shift = -0.14 @ 3.33×10^{14} ppp

relatively modest!

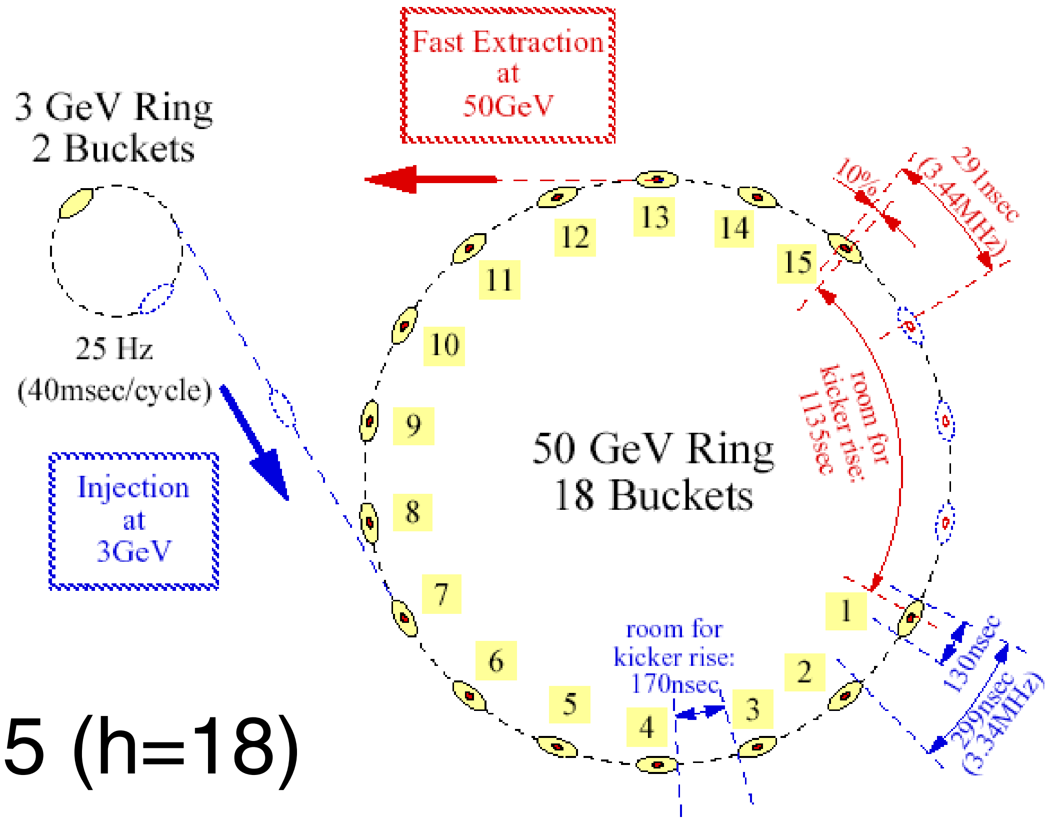
If injected beam intensity is small, various RF gymnastics for beam stacking are available.

cf. increase harmonics

barrier bucket, etc.

Harmonic number : h=9 ---> h=18

Injection/Fast Extraction Scheme for the 50 GeV Ring



# of bunches : 15 (h=18)

----> ~1.9 times more beams can be injected.

Beam Power

fast ext. α: rel. beam power of RCS (a=1 for design value)

energy	harm.	bunch	T	current	power
40GeV	9	8	3.53s	15mA	0.6MW
40	9	8	2.83	18.8xαa	0.75xα
40	18	15	3.26	30.6xαa	1.22xαa
slow ext.					
30GeV	9	8	3.53s	15mA	0.45MW
40	9	8	3.53	15xα	0.6xα
30	18	15	3.96	25.2xαa	0.75xαa
40	18	15	3.96	25.2xαa	1.0xαa

Technical issues for h=18 operation

1. RF cavity : f=3.4MHz

   <--- feasible with MA cavity

2. Injection kicker : rise-time <170 ns

   <--- feasible with line-type kicker

3. Thermal stress of neutron target

   <--- need to be checked