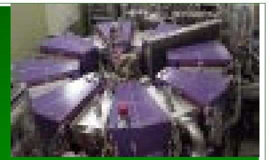


Neutrino Factory in Japan

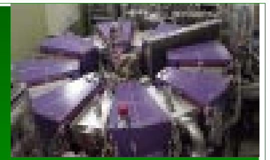
Yoshiharu Mori

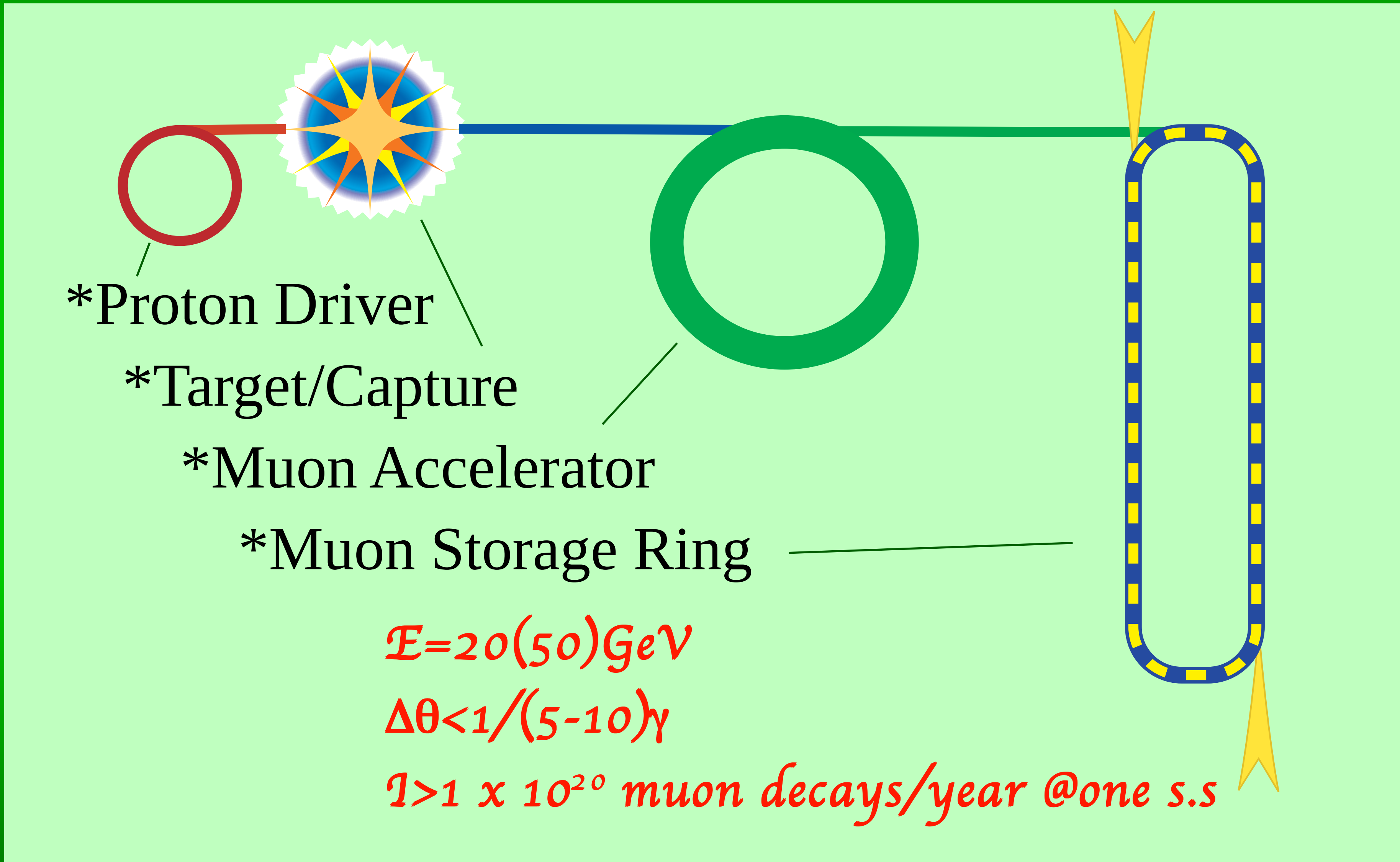
KEK

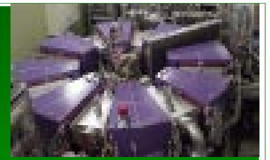
Outline

- Basic paremeters
- Proton driver
- Muon prodction/capture
- Muon acceleration
- FFAG chain
- Hardeware R&D

Neutrino Factory



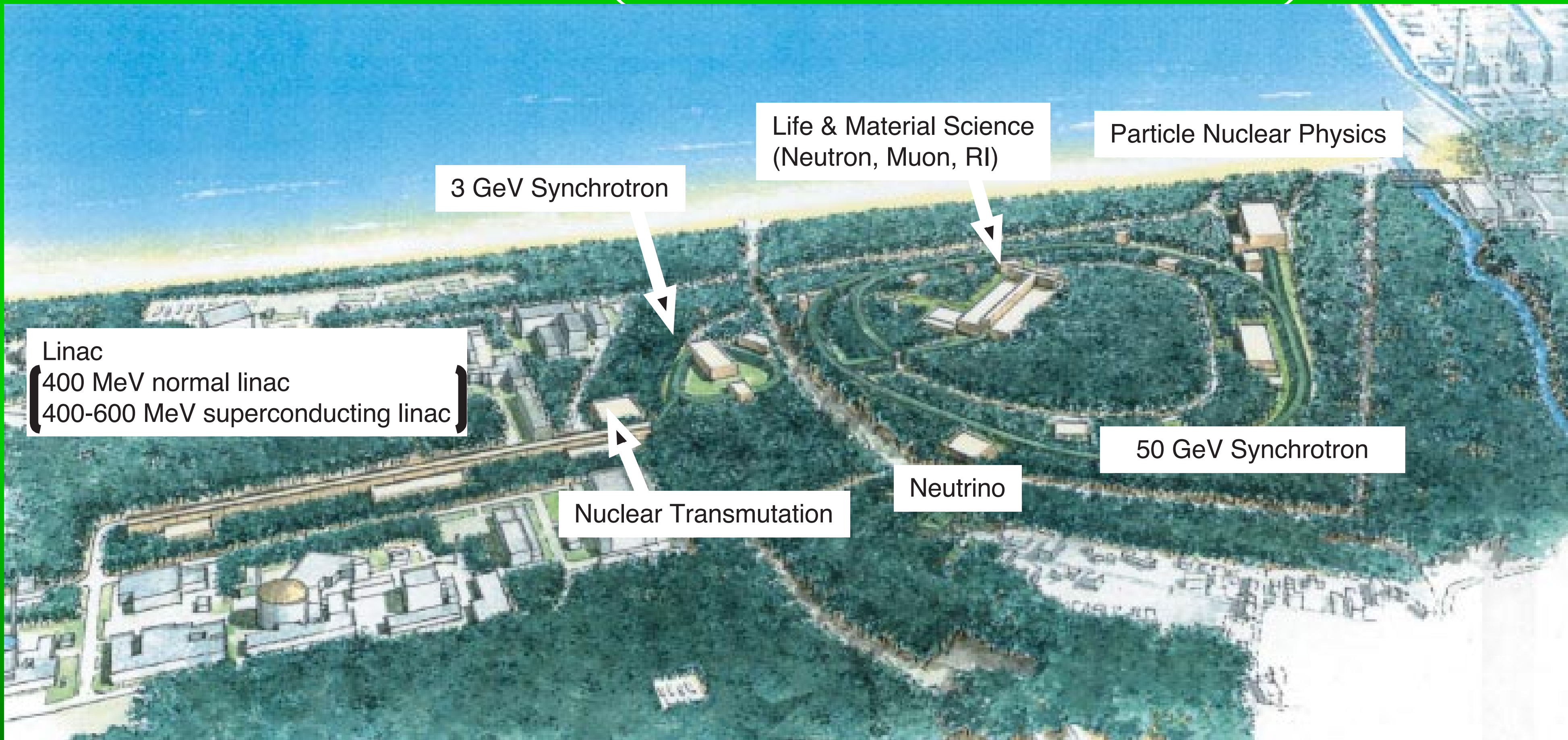


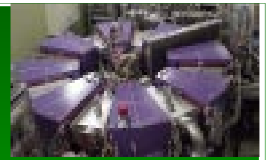


Proton Driver

High Intensity Proton Accelerator Facility : J-PARC

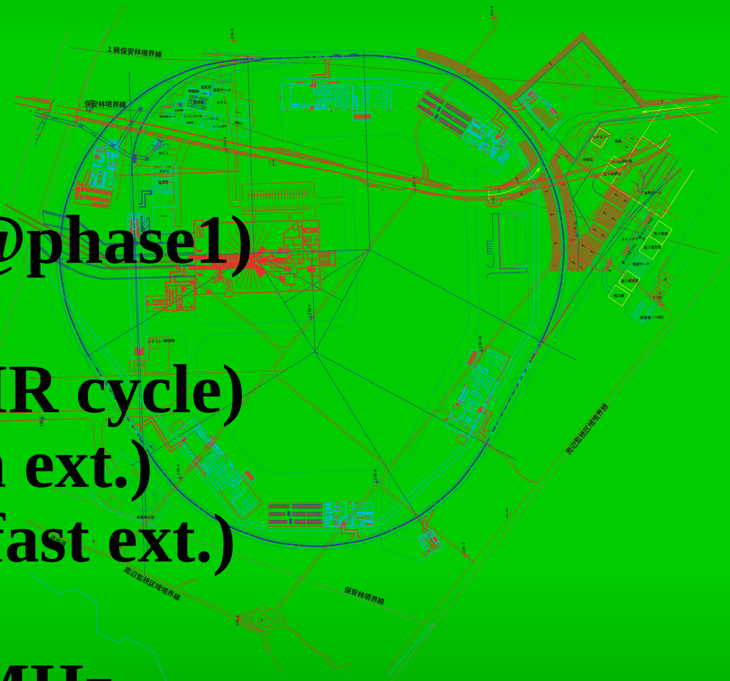
under construction (Tokai Lab. : KEK/JAERI)



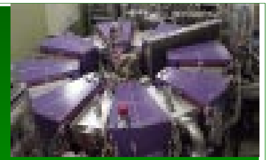


Proton Driver : 50GeV PS

main parameters



inj. energy	**3GeV**
max. ext. energy	**50GeV(40GeV @phase1)**
num. of protons/pulse	**3.3×10^{14}ppp**
rep. rate	**0.3Hz(~3.6sec-MR cycle)**
beam current (ave.)	**15μA(slow beam ext.)**
beam power (50GeV)	**0.75MW(1MW:fast ext.)**
harmonic num.	**9**
rf frequency	**1.68MHz - 1.73MHz**

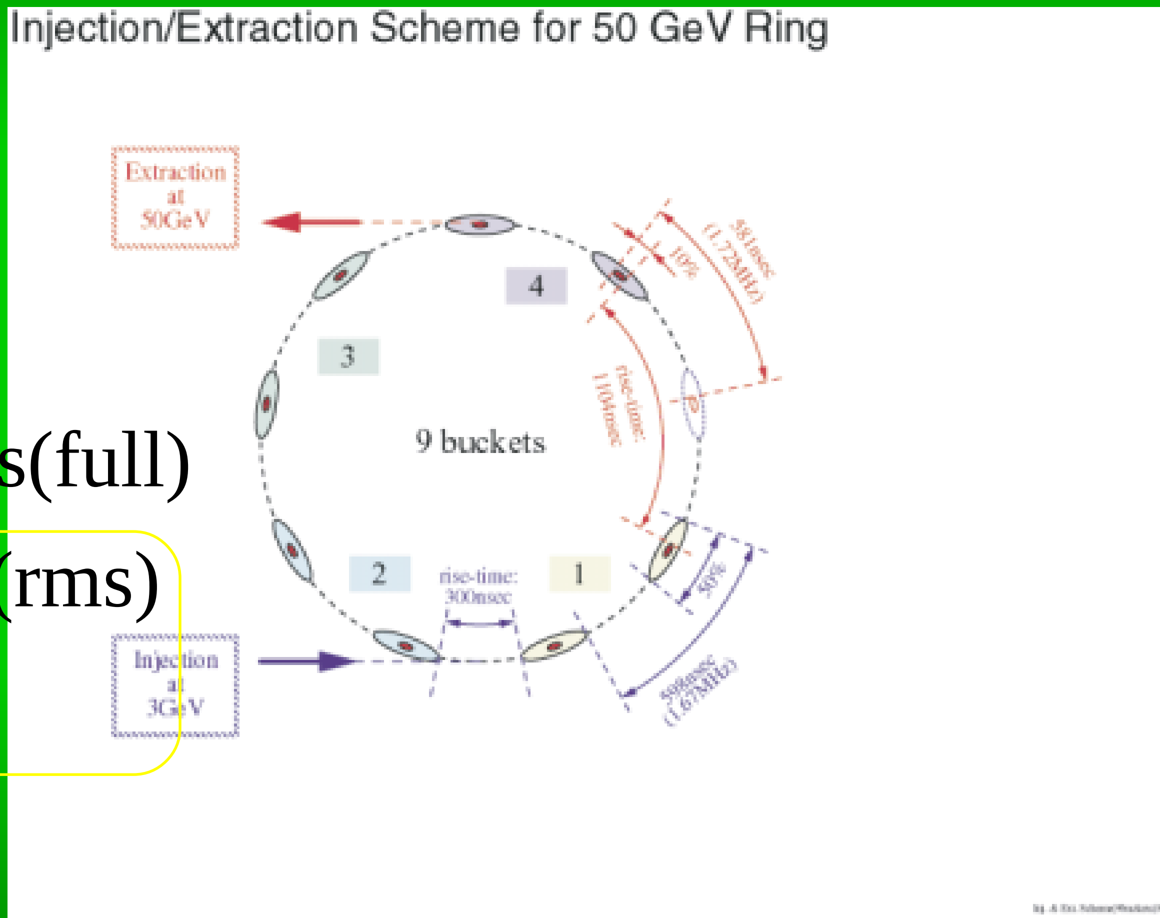


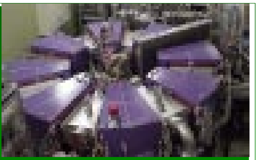
Proton Driver : bunch configuration

50-GeV PS

num. of rf buckets	9
num. of bunches	8
inj. bunch width	300ns(full)
ext. bunch width	12ns(rms)

---> ~6ns(rms) : possible





Muon Production Rate : required

How many muons per single proton must be captured by muon accelerator?

Assumptions:

1) proton flux	$1.9x10^{14}$ protons/sec
2) beam loss through accelerator	50% (incl. decay loss)
3) portion of single s.s in MSR	30%
4) operating hours	4,000 hours/year

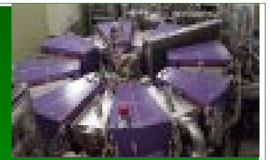
To achieve $I=1x10^{20}$ *muon decays/year@one-s.s.*

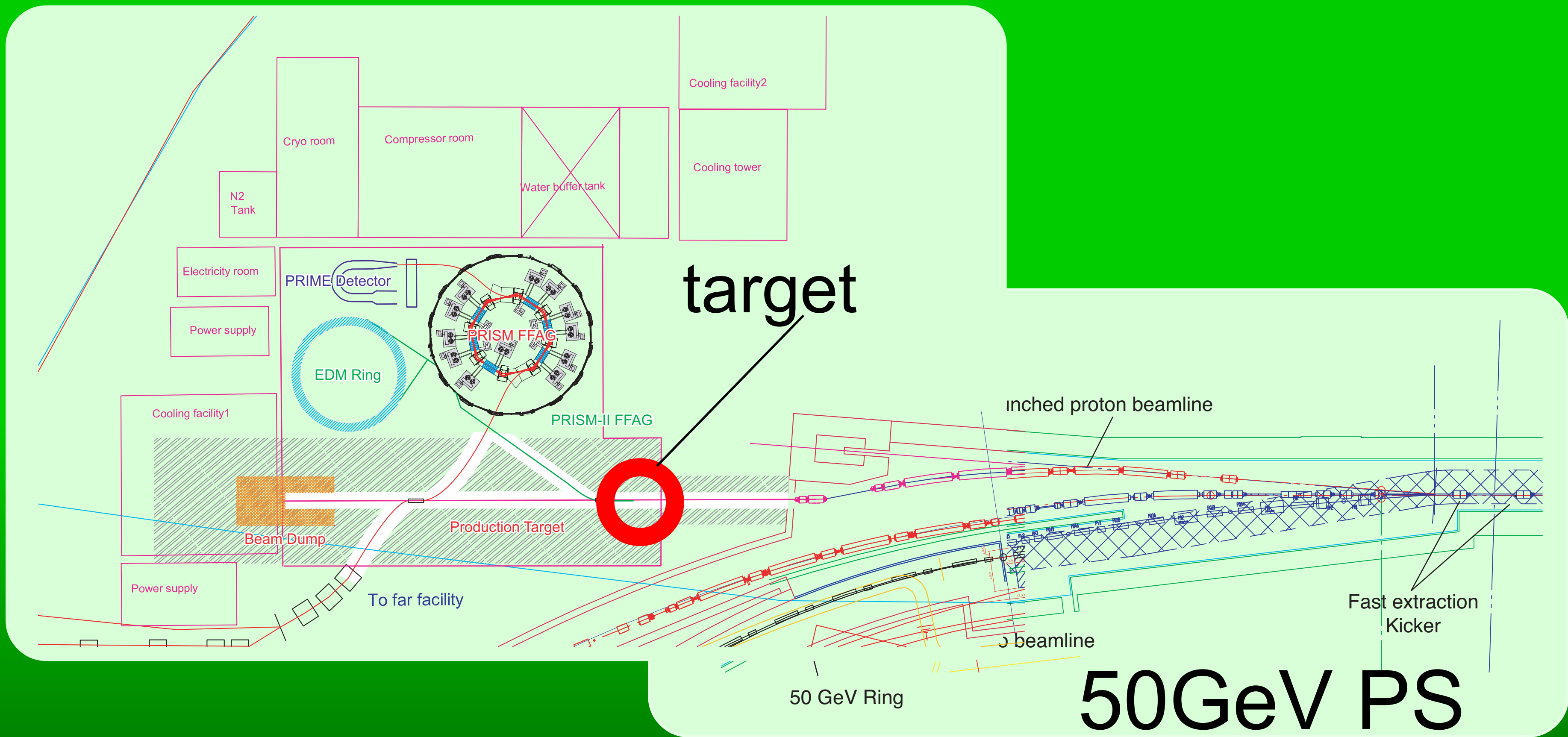
> 0.24 muons/proton

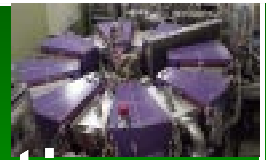
Production Target

New Beam Line and Facility : proposal

(Fast Proton Facility: PRISM,EDM, muon(g-2),pbar)







Production Target / Pion Capture ;schematic

*target W/graphite

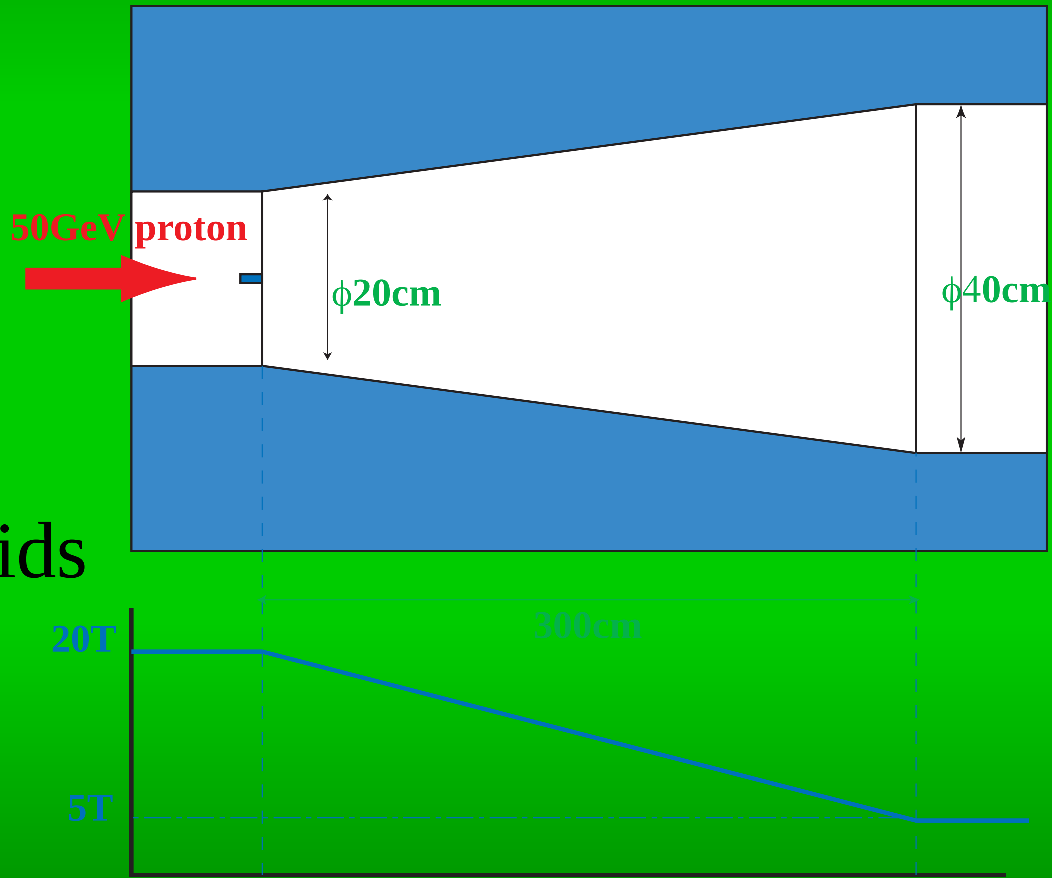
*Solenoid

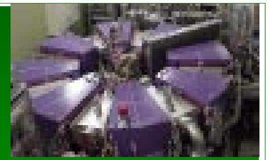
1st 20T(bore 20cmϕ)

2nd 5T(bore 40cmϕ)

*Distance btw. two Solenoids

300cm

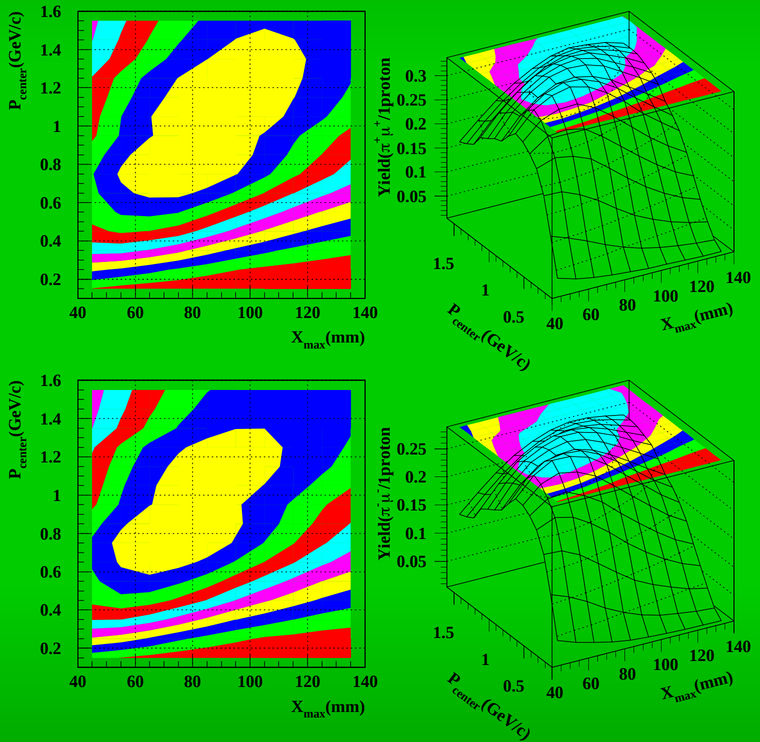




Muon Beam Brightness: after cap. solenoid

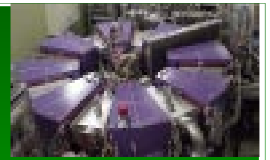
transverse

longitudinal



muon yield(muon/proton)=0.3 for $\varepsilon_{h,v}^{n}$=0.03m.rad & ε_{L}^{n}=4.6eV.sec

Brightness → Q=72.5 muons/proton/(m.rad)^2(eV.s)



Muon acceleration : decay

Muon decay in accelerating system

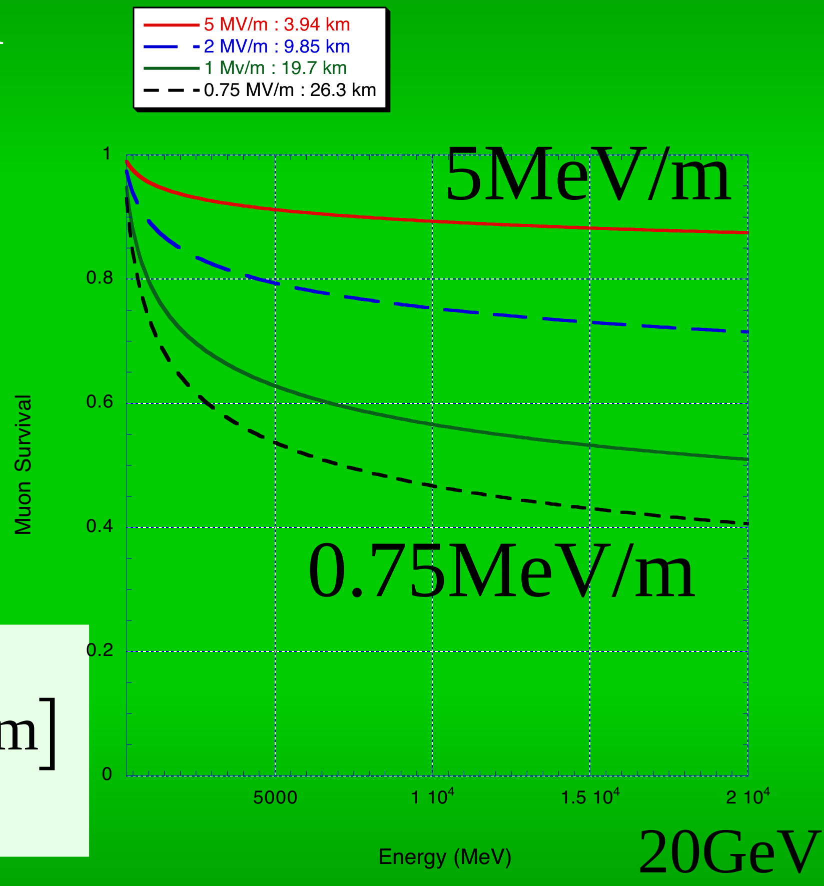
$$\frac{dN}{N} = -\frac{m_\mu c^2}{\tau_\mu c[eV']}\frac{d\gamma}{\gamma} \qquad (\gamma >> 1)$$

eV': accelerating rate (eV/m)

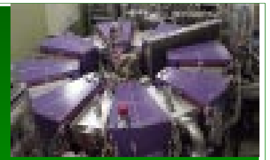
Decay loss must be small

during acceleration.

$$\frac{m_\mu c^2}{\tau_\mu c[eV']} << 1 \quad \Rightarrow eV' >> \frac{m_\mu c^2}{\tau_\mu c} = 0.016[\mathrm{MeV/m}]$$



Ave. Acc. Rate :1MeV/m --> 50% survival



Muon Intensity

$$I = \phi \cdot Q \cdot A_h \cdot A_v \cdot A_L \cdot \eta \cdot f \cdot T$$

ϕ : proton flux $= 1.9 \times 10^{14}\ p/\mathrm{sec}$

Q : brightness $= 72.5\left(\mu / p / (m.rad)^2 / (eV.\mathrm{sec})\right)$

$A_{h,v,L}$: normalized value of accelerator acceptance

η : muon survival rate after acceleration = 0.5@1MeV / m

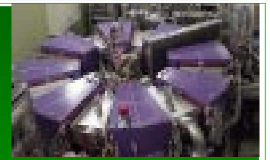
f : fraction of one - straight section per ring = 1 / 3

T : total period of experiment / year = 4000hours

If Accelerator has $A_{h,v}$ =0.03m.rad, A_L=4.6eV.sec, then

$I = 1.2\ \mathrm{x}10^{20}$ muon decays/year @one-s.s

No need - Muon Cooling !



Muon Acceleration : FFAG

FFAG (Fixed-Field Alternating Gradient)

* Large Acceptance (trans. & long.)
* Quick Acceleration

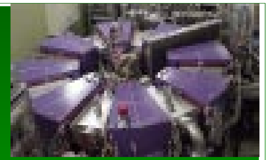
Two types of FFAG

1) Scaling type

betatron tune =const. : “Zero chromaticity”

2) Non-scaling type

betatron tune =not const. : “Linear field”



Scaling type of FFAG

Original idea ---> Ohkawa (1953)

“Zero chromaticity”

betatron eq.

$$x'' + g_x x = 0\ ;\quad g_x = \frac{K^2}{K_0^2}(1-n)$$

$$z'' + g_z z = 0\ ;\quad g_z = \frac{K^2}{K_0^2}\, n$$

geometrical

$$\frac{\partial}{\partial p}\left(\frac{K}{K_0}\right)\bigg|_{\theta=const.} = 0$$

field index

$$\frac{\partial n}{\partial p}\bigg|_{\theta=const.} = 0$$

$$B(r,\theta) = B_i\left(\frac{r_i}{r}\right)^{n_0} F\left(\theta - \varsigma \ln\frac{r}{r_i}\right)$$

radial sector

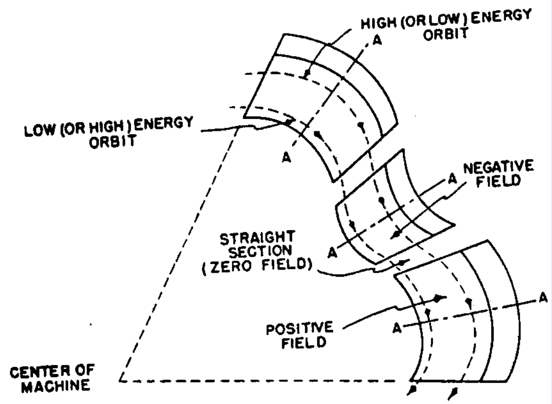


FIG. 2. Plan view of radial-sector magnets.

spiral sector

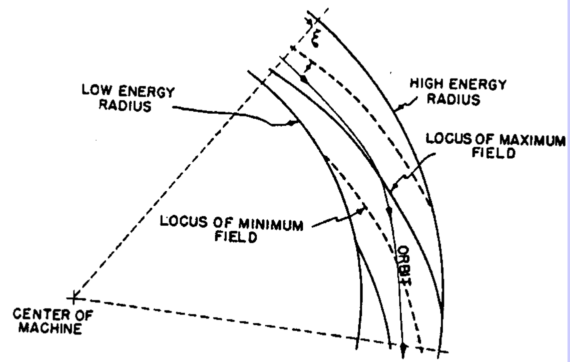
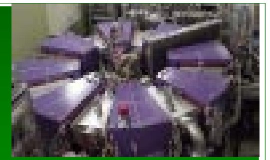
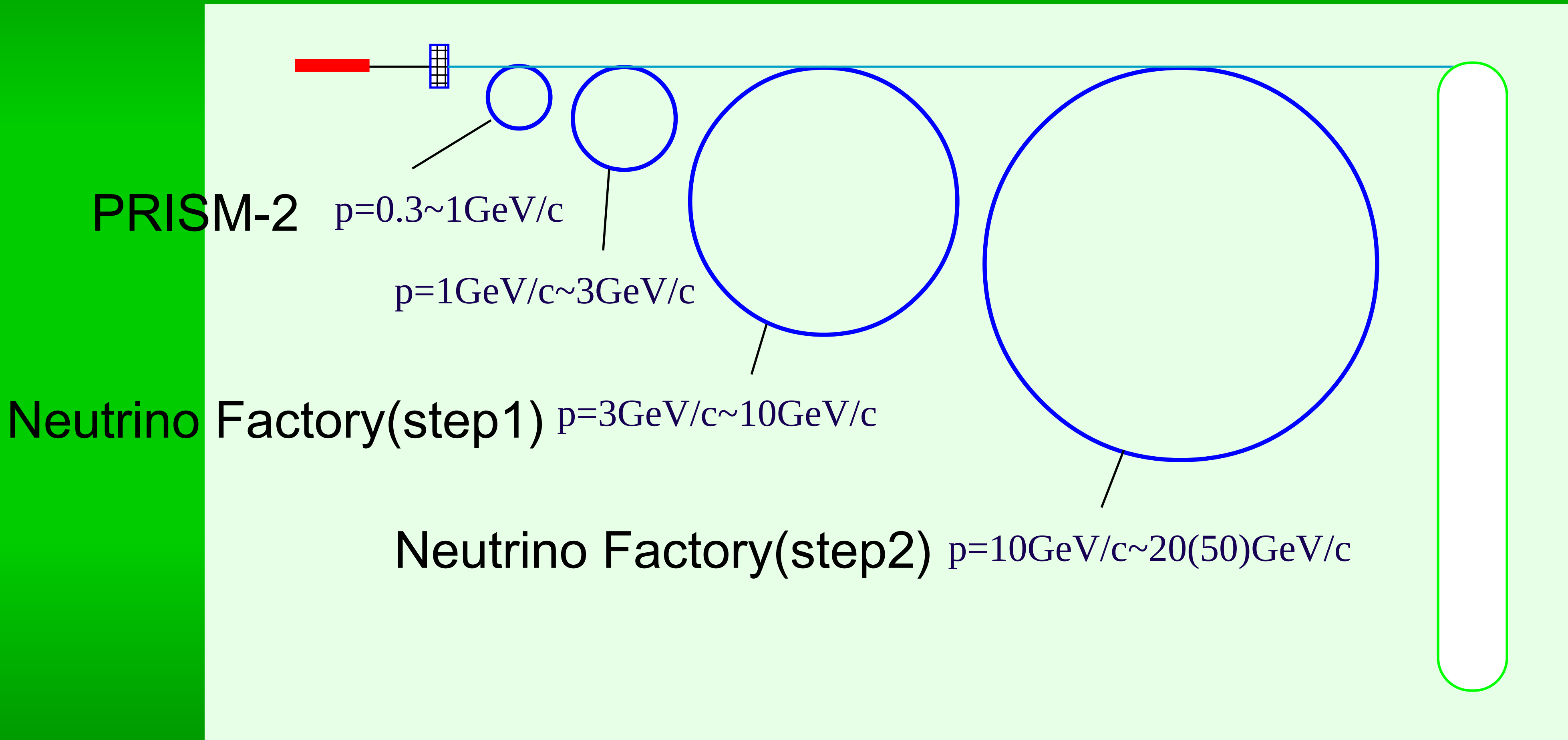


FIG. 3. Spiral-sector configuration.



FFAG Chain



PRISM-2
p=0.3~1GeV/c
p=1GeV/c~3GeV/c
Neutrino Factory(step1)
p=3GeV/c~10GeV/c
Neutrino Factory(step2)
p=10GeV/c~20(50)GeV/c

Change from the previous design :FFAG

Major Change ----> 3rd and 4th rings

	old	new
1)Lattice	triplet	singlet

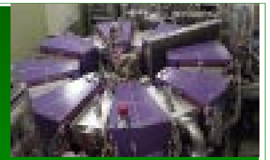
*allowed large k-value to achieve
small excursion & small aperture

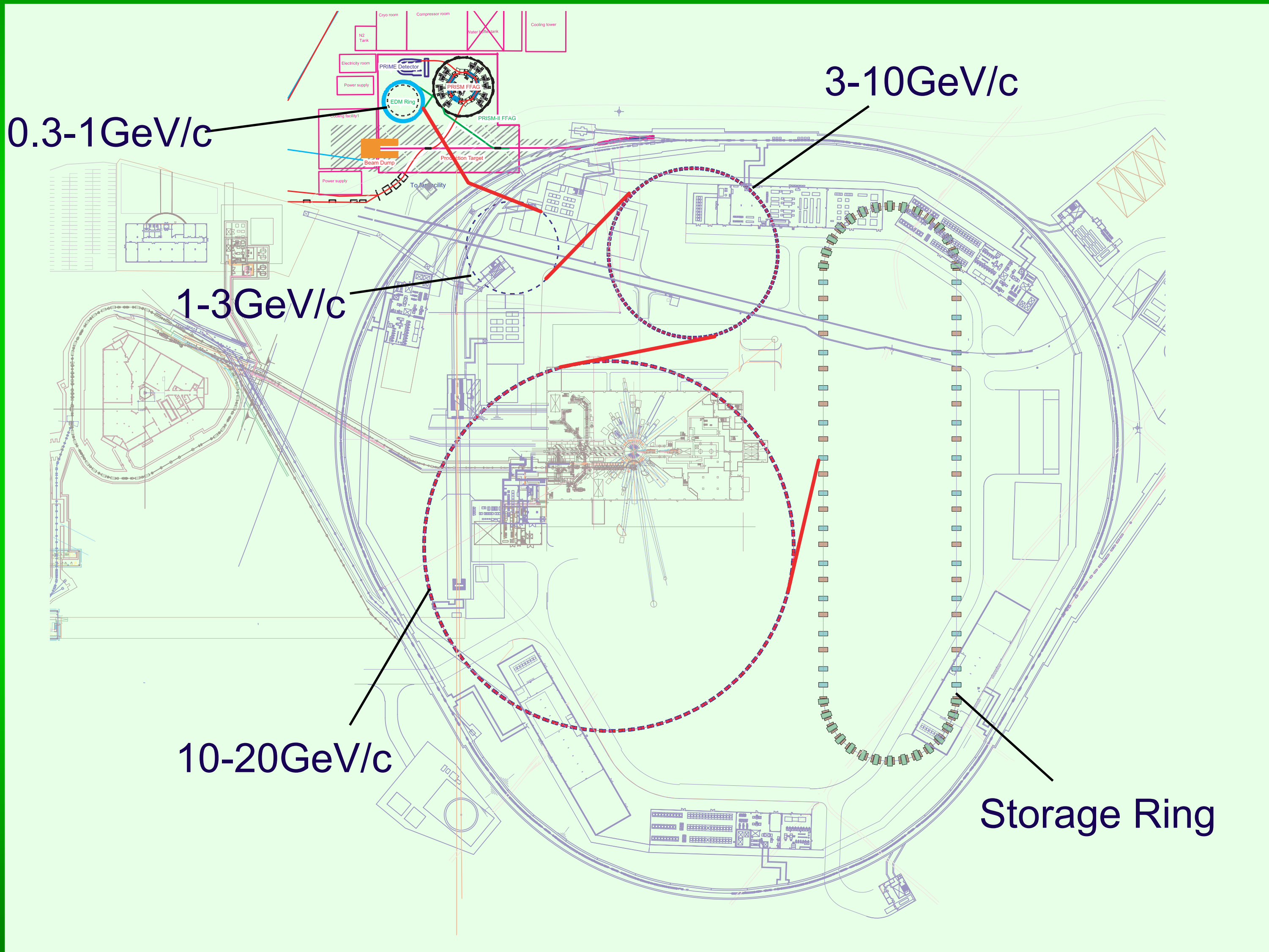
2)Size	200m	120m :radius

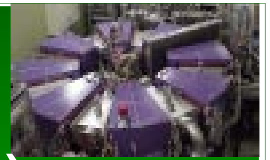
*reduced numbers of magnets

*reduced total rf voltage

Neutrino Factory : FFAG based





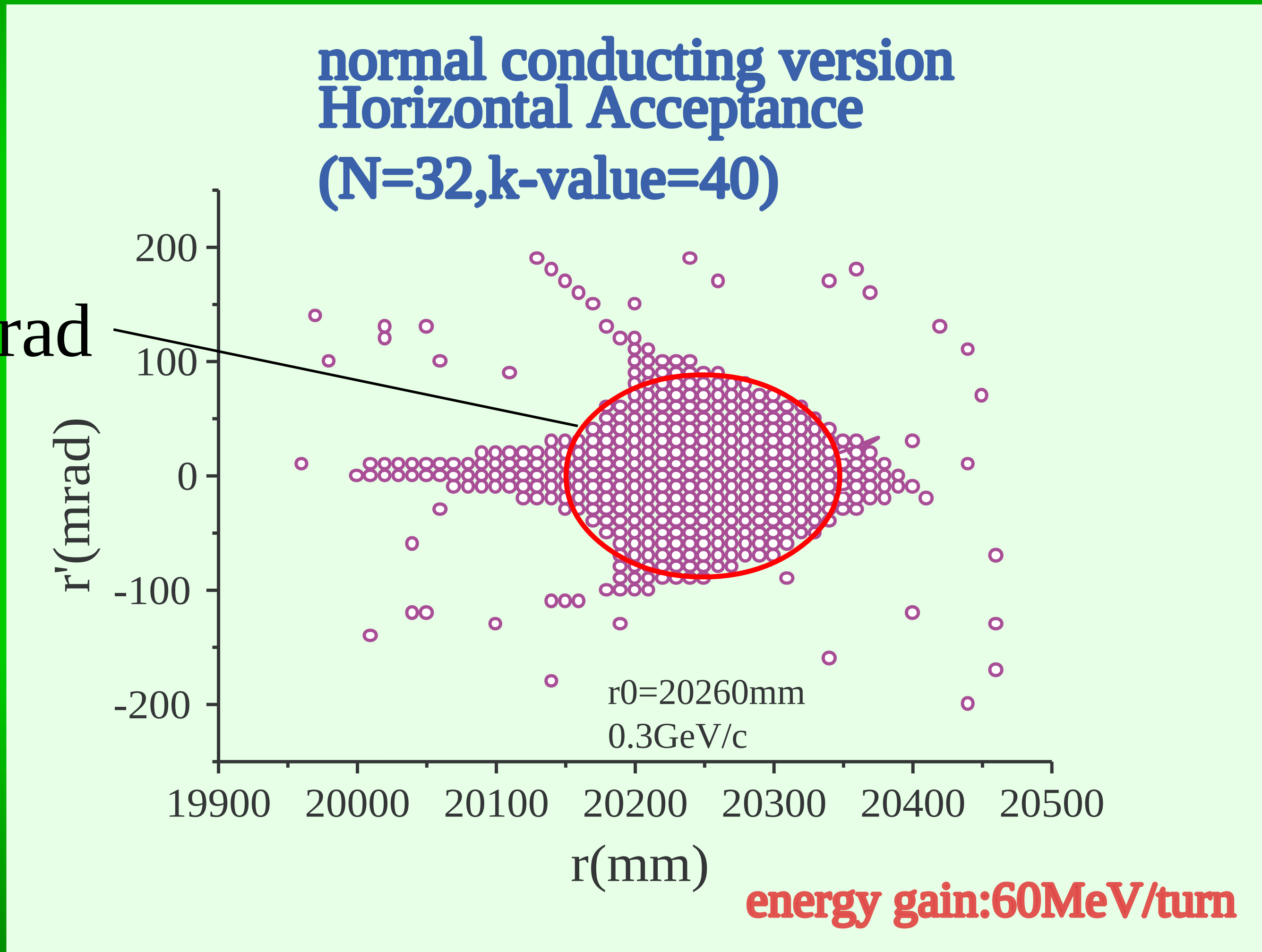


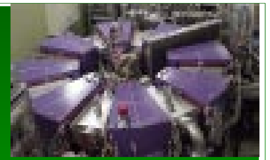
Acceptance of FFAG (1st ring:0.3-1GeV/c)

Simulation

transverse acceptance

A_h^N=0.03m.rad



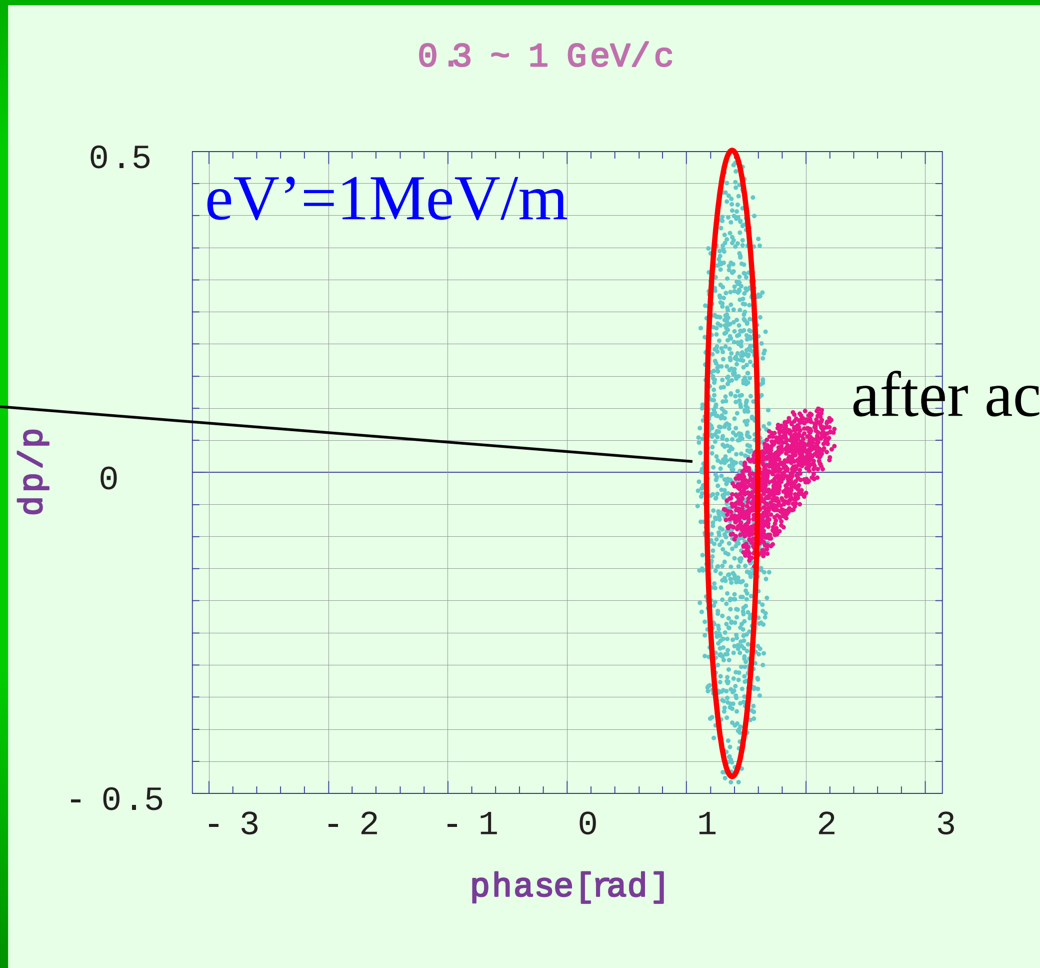


Acceptance of FFAG (1st ring:0.3-1GeV/c)

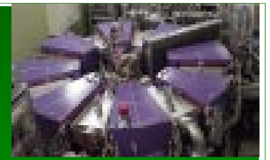
Simulation

longitudinal acceptance

A_L^N=4.6eV.sec



after acceleration



Muon acceleration in scaling FFAG

Momentum compaction :const. $\alpha = \frac{1}{1+k}$

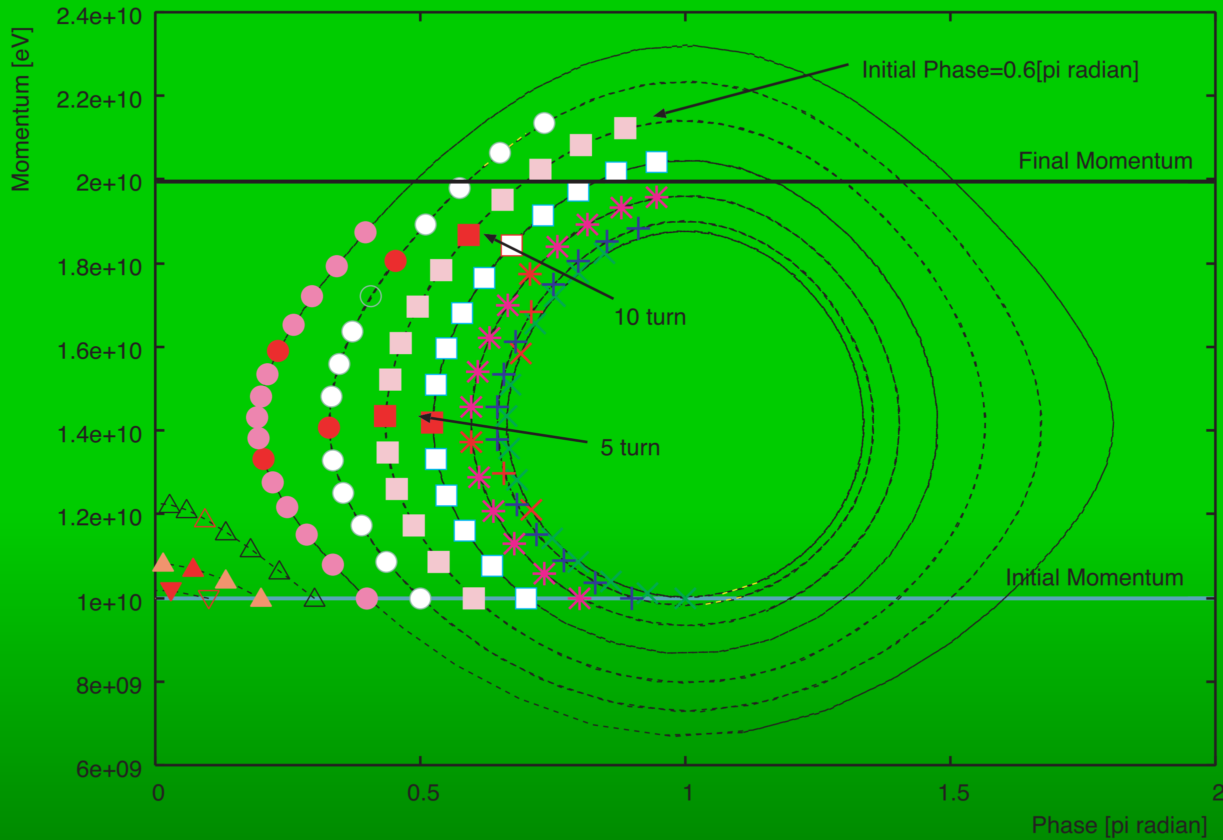
stationary rf bucket

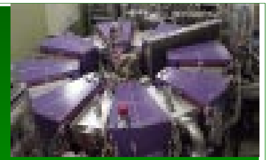
(rf frequency=const.)

cf. FFAG last ring

E=10-20GeV

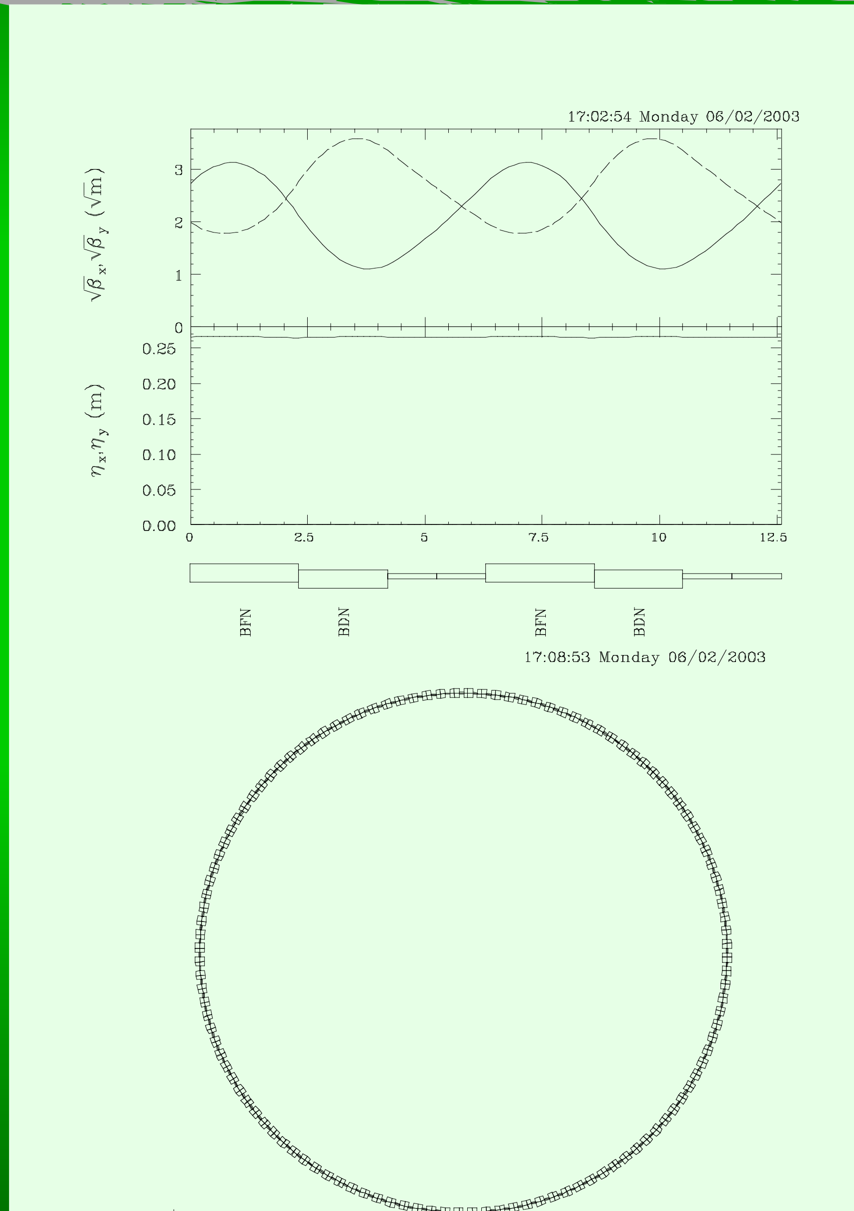
eV'=0.7MeV/m

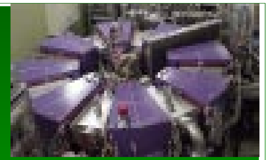




FFAG 10-20GeV ring

type	singlet(FD)
# of cells	100
field index(k)	350
max. field(F)	6.04T
max. field(D)	5.69T
phase advance(h)	123.1
phase advance(v)	57.2
ring radius	55m
orbit excursion	0.18m
drift	0.125m





FFAG 10-20GeV ring

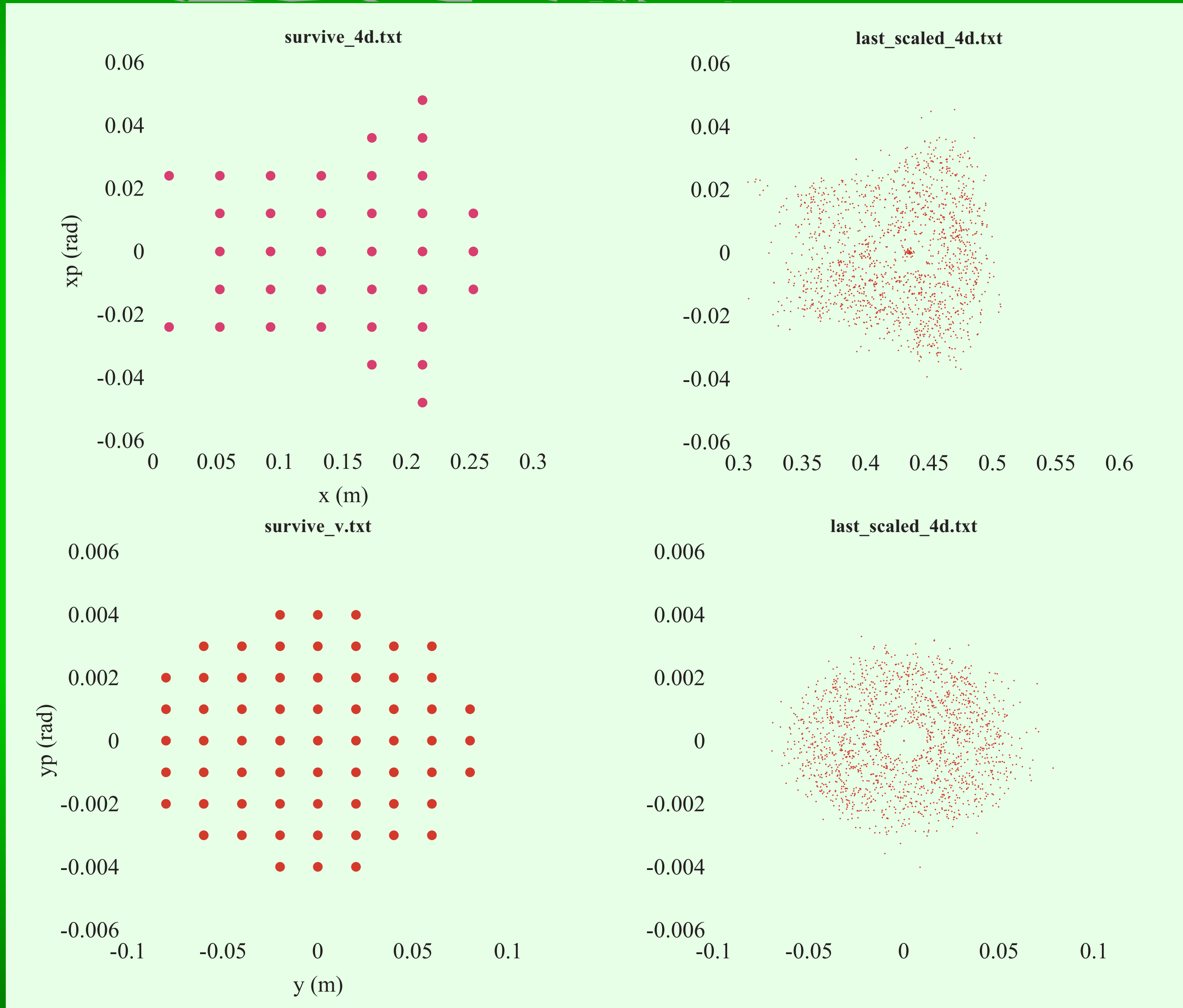
Transverse 4D acceptance
with acceleration

Acceptance

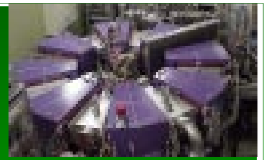
A_h^n =0.15m.rad

A_v^n=0.032m.rad

Both >0.03m.rad



injcection extraction



RF system for 10-20GeV ring

Low Frequency or High Frequency?

High Frequency (~200MHz)

(pro) high field (5MV/m)

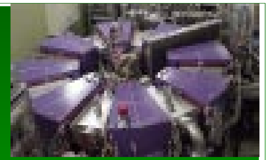
(con) need phase rotation/buncher

Low Frequency(~25MHz)

(pro) no need phase rotation/buncher

(con) low field (1MV/m)

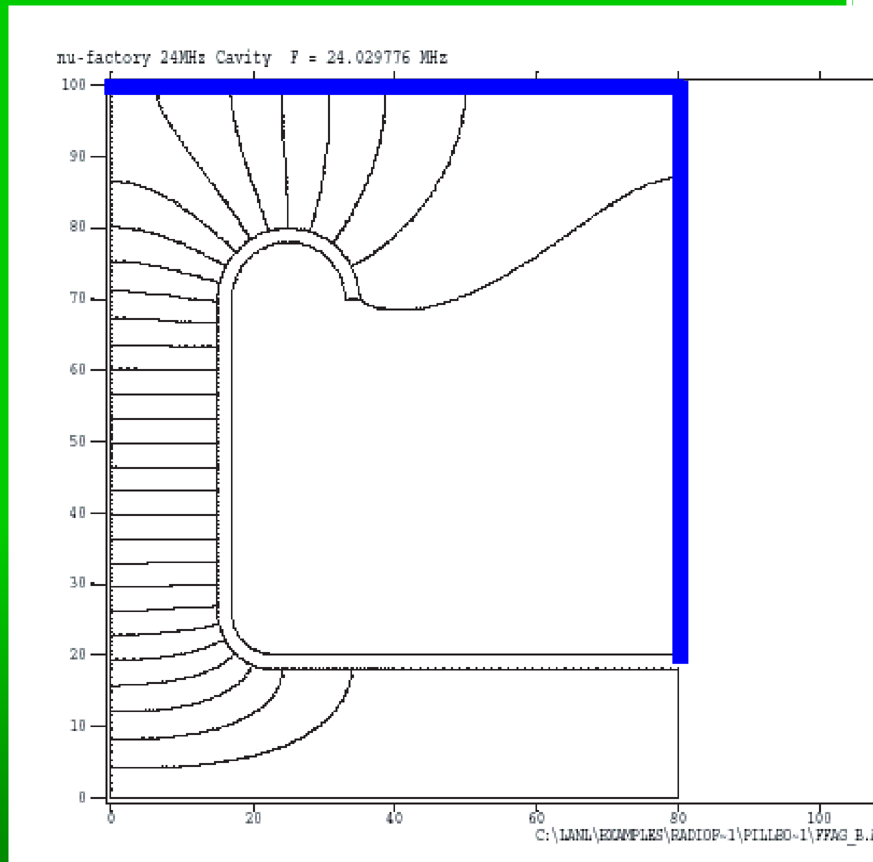
We choose “Low Frequency”.

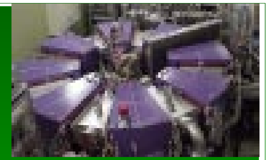


RF System

RF parameters by Ohmori

- Kinetic Energy : 10 => 20 GeV
- Radius : 120 m (Circumference 754 m)
- Longitudinal Emittance : 4.6 eVs
- RF freqeucney : 18 or 24 MHz (Fixed Frequency)
- Bucket Height : 10 GeV
- η : 0.002
- Field Gradient 0.55-0.75 MV/m(average) γ~large
- Cavity Length 1.6 m
- Cavity Radius 1 m
- Number of Cavity 120 (1 cavity/cell)
- Gap Voltage : 1.8-2.43 MV
- Beam Pipe : 360 φ

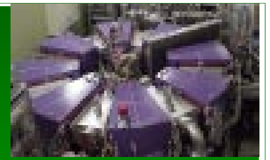




RF power source :10-20GeV ring

RF Amplifier (150kW tetrode) 120 sets

- Load : 3.53 MΩ
- Vgap: 2.43 MV
- 1 AMP per Cavity
- Driven by 150 kW tube
- Anode Voltage : 30kV
- Peak Cathode Current: 120A (Max. 140 A)
- RF Output Power: 0.84MW (duty < 0.16%)
- Operation : Class B
- Cathode DC Current: 38 A (peak)



FFAG R&D in Japan

1) pop FFAG (INS/KEK) "world first proton FFAG"

beam comissioning 2000, June

2) 150-MeV FFAG(KEK) under development:2001~

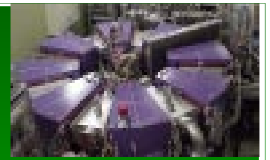
first circulating beam 2003, April

3) 150(200)-MeV FFAG(Kyoto U.) constraction starts: 2003~

neutron source for ADS of nuclear power

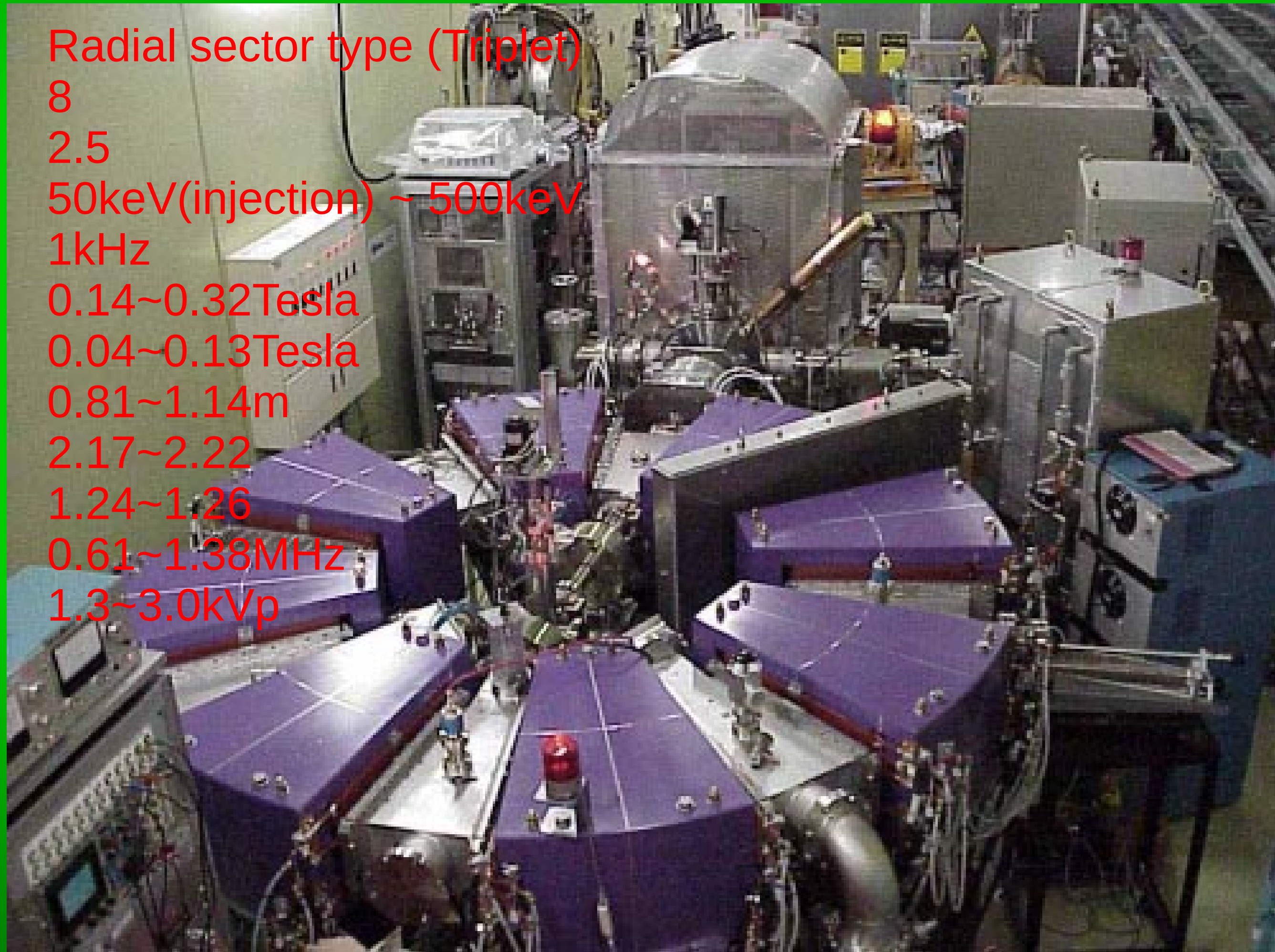
4) PRISM(Osaka U.) construction starts: 2003~

muon phase rotation/cooling

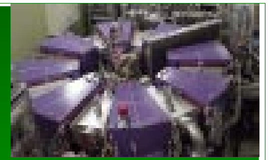


PoP FFAG

World first proton FFAG



Type of magnet		Radial sector type (Triplet)
No. of sectors		8
Field index(k-value)		2.5
Energy		50keV(injection) ~ 500keV
Reptition rate		1kHz
Magnetic field	Focus:	0.14~0.32Tesla
	Defocus:	0.04~0.13Tesla
Radial of closed orbit		0.81~1.14m
Betatron tune	Horizontal :	2.17~2.22
	Vertical :	1.24~1.26
rf frequency		0.61~1.38MHz
rf voltage		1.3~3.0kVp



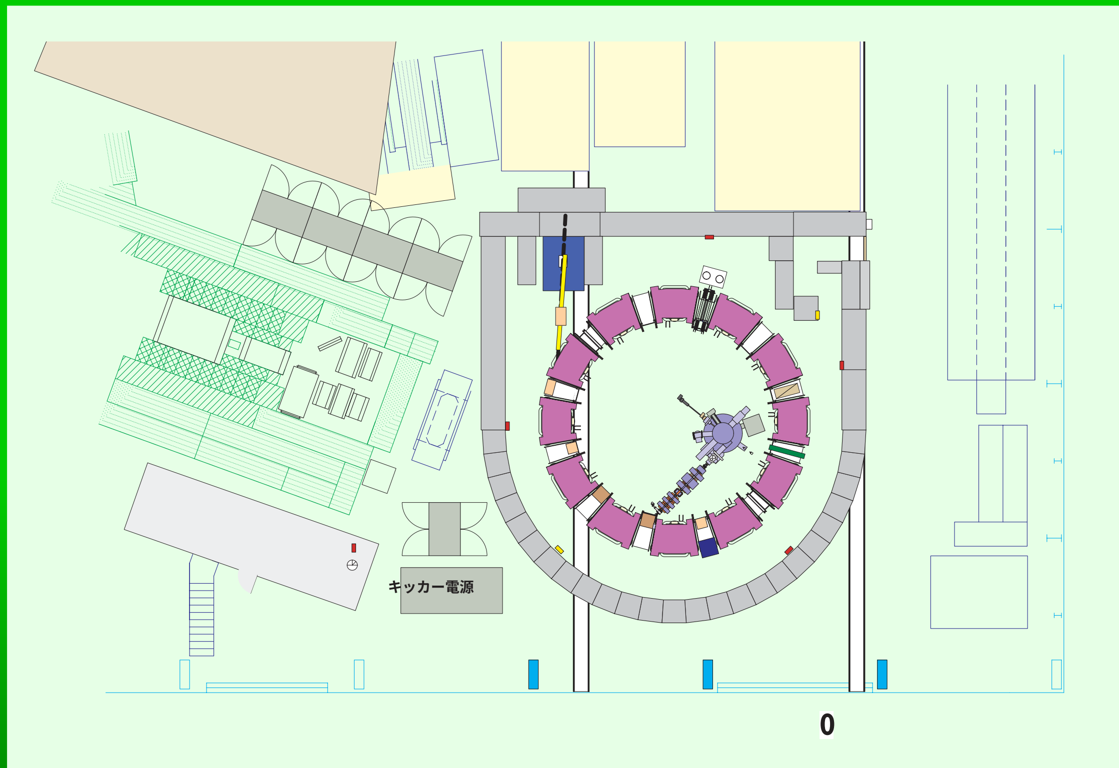
150-MeV FFAG in KEK

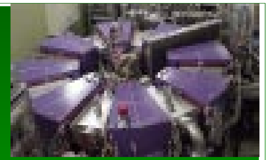
parameters

particle	proton
No. of sectors	12
Field index	7.5
Energy	150MeV
Repetition rate	250Hz
Mac. field(F)	1.63T
Max. field(D)	0.13T
Radius(max.)	5.3m
Tunes	
hor.	3.8
ver.	2.2
rf frequency	1.5-4.6MHz

prototype for various applications

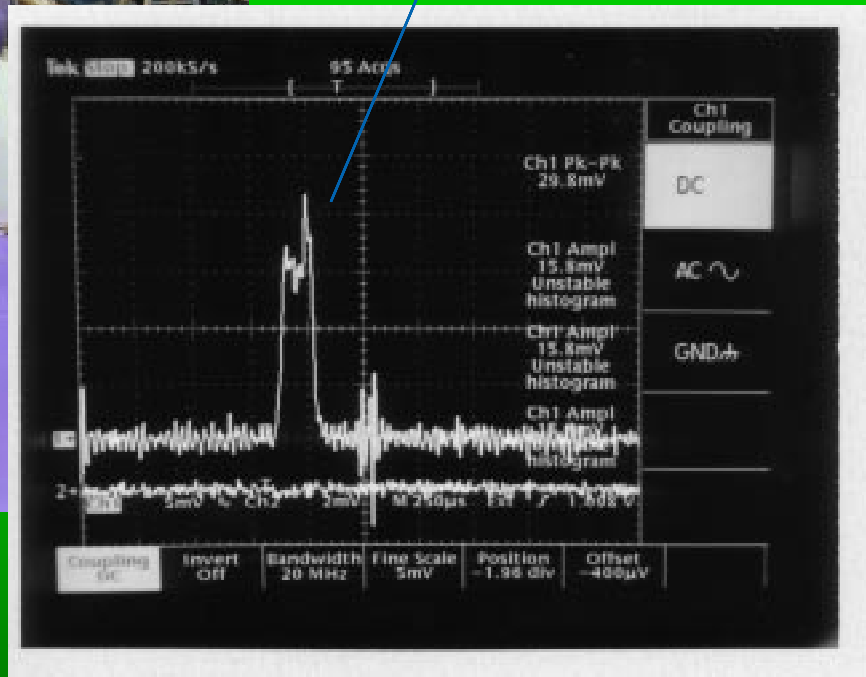
medical, neutron, muon etc.

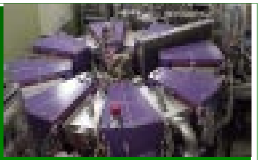




150-MeV FFAG

150MeV FFAG 1st turn April 24th, 2003





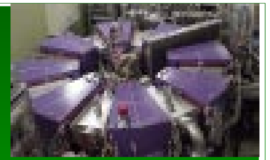
Hardware Components R&D

1) Target & Capture SC Solenoid — WG2&3

Yoshimura, Ohnishi

2) SC magnet of FFAG — WG3

Yoshimoto



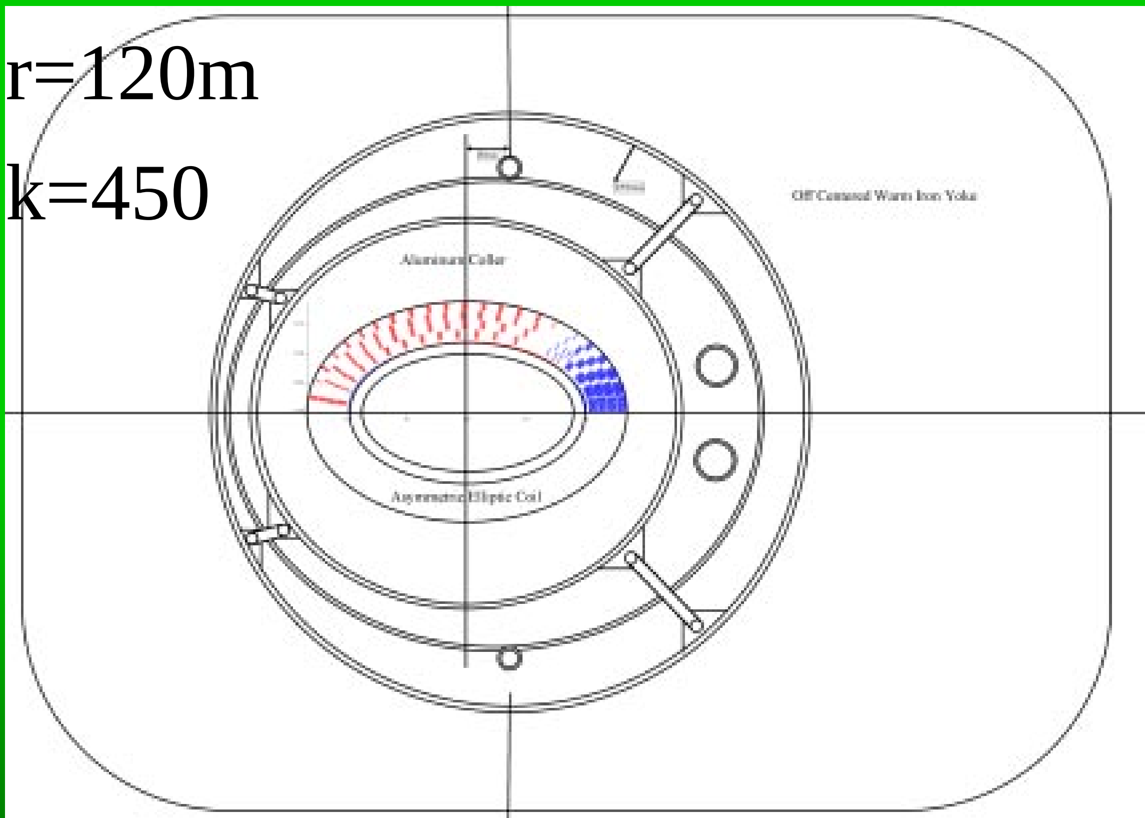
Superconducting magnet

Reference Design (10-20 GeV FFAG) by Ogitsu

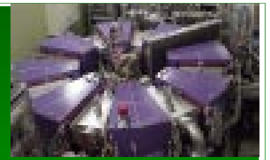
B=6.0T

r=120m

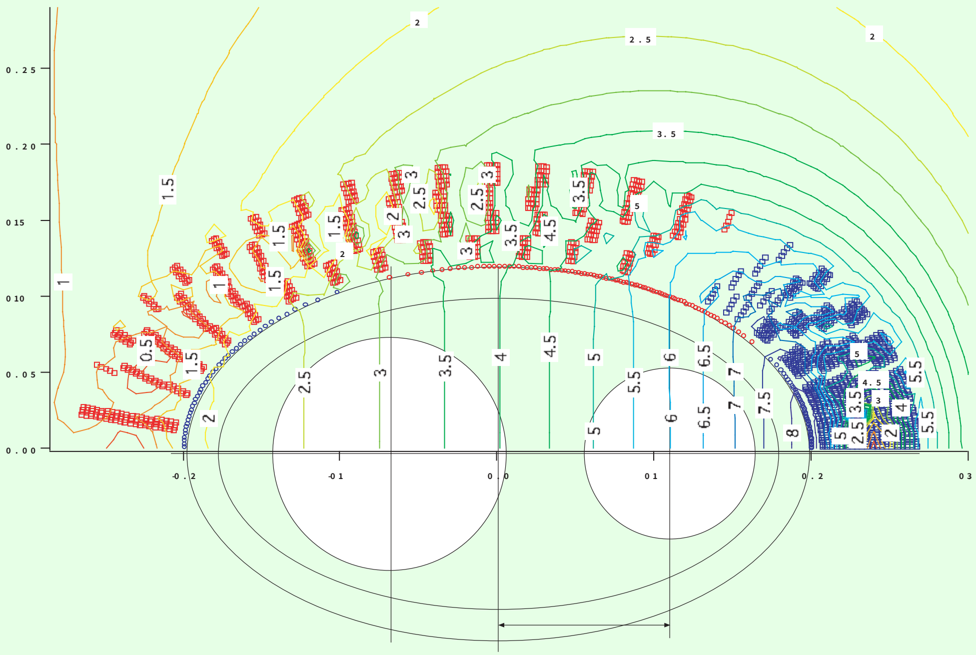
k=450



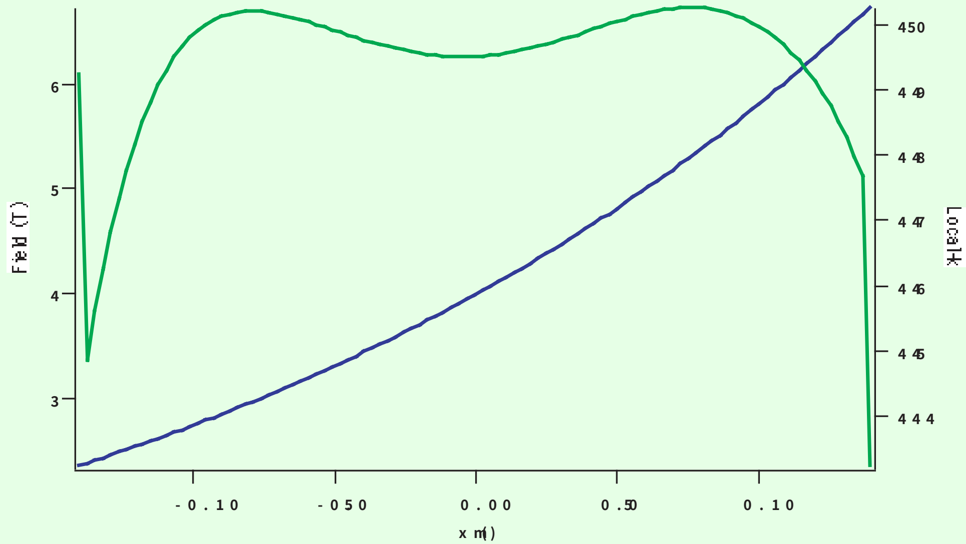
1. Main Coil
   - Asymmetric & Elliptic
   - Rutherford Cable~ 2X15mm
   - Operation Current ~6.8kA
   - Stored Energy: ~1MJ/m
2. Corrector Coil
   - Wind & glue (BNL)
   - ~10A/delta-K
3. Collar
   - Pre-stress ~90MPa
   - Horizontal EMF ~ 3.9 MN
   - Aluminum collar to gain



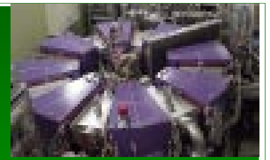
Superconducting magnet



Field Map & BeamAerture



Field quality



Summary

Neutrino Factory (Phase I) in Japan

*Proton Driver J-PARC(50GeV PS) 1MW beam

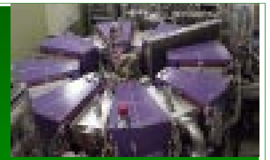
*FFAG Accelerator 4 rings(may be 3 rings)

Large Acceptance No need Muon Cooling!

trans. ~0.03m.rad
long. ~4.6eV.sec

*Muon Energy 20GeV(to be determined by physics and cost)

*Muon Intensity *I=1x10*^{20} *muon decays/year/one s.s*



Muon Factory:Before Neutrino Factory-I

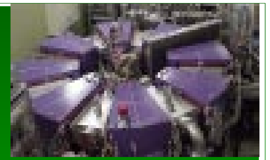
PRISM-I

- High-intensity low-energy muon source (for rare muon decays)
  - 10T pion capture & Phase rotation at PRISM-FFAG
- Pμ=68 MeV/c (KE=20 MeV)
- Injection momentum:$\Delta p/p = 50\%$
- 10^{19} muons/(107sec) in the ring
- Based on 1-MW 50-GeV PS

PRISM-II

- Acceleration with an additional accelerator (FFAG)
- 10^{20} muons/(10^{7}sec) in the ring
- Give a modest neutrino source

Summary



Neutrino Factory (Phase II) in Japan

*Proton Driver J-PARC(50GeV PS) 4MW beam

*FFAG Accelerator

*Muon Energy 20-50GeV

*Muon Intensity *I=4x10^{20} muon decays/year/one s.s*

Need Hardware R&D : FFAG, Target/Capture,

SC magnet, RF system, etc.

International collaboration is very important.

"International Workshop on FFAG Accelerators, July 7-12,2003,KEK"

http://hadron.kek.jp/FFAG/FFAG03/