PRISM status report

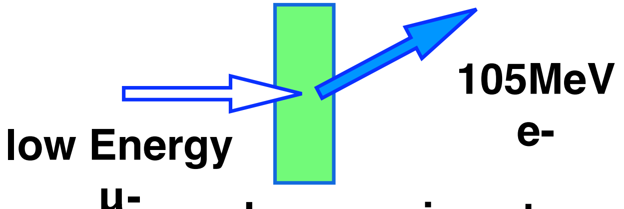
Osaka University
Akira SATO

5th Dec. 2005 / FFAG-Workshop `05 @ KURRI

PRISM

Phase Rotated Intense Slow Muon source

Search for Lepton Flavor violation
$B(\mu\text{-}N \rightarrow e\text{-}N) < 10^{-18}$



stopped μ experiment

High Intensity

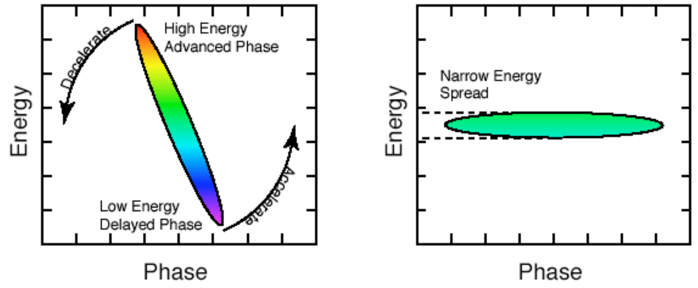
intensity : 10^{11}-10^{12} $\mu^{\pm}$/sec
beam repetition : 100-1000Hz
muon kinetic energy : 20 MeV (=68 MeV/c)

high power p beam,
super cond. solenoid pi capture
large acceptance FFAG

Narrow energy spread

kinetic energy spread : ±0.5-1.0 MeV

phase rotation

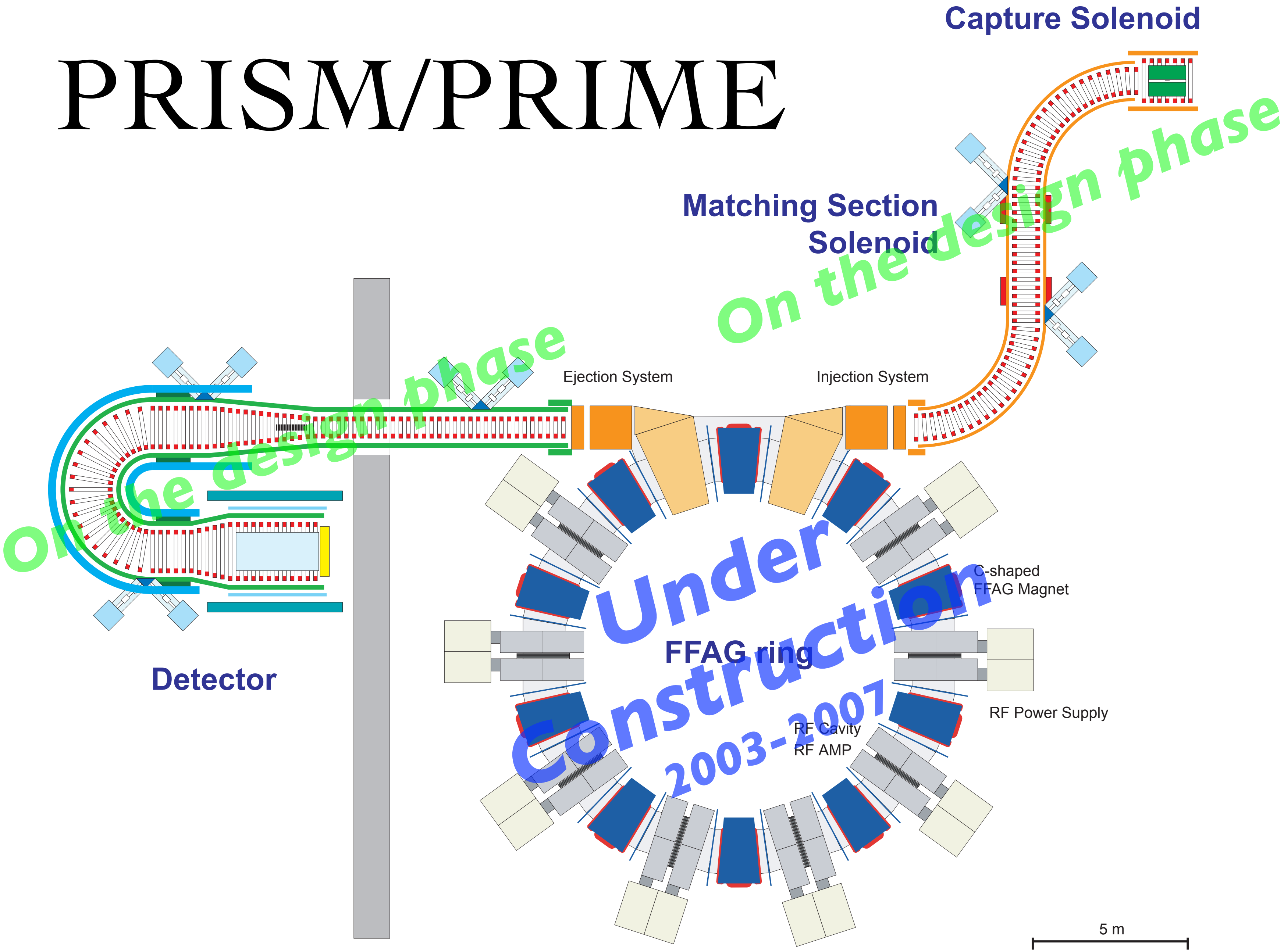


long flight length in the FFAG

Less beam contamination

π contamination < 10^{-18}

PRISM/PRIME

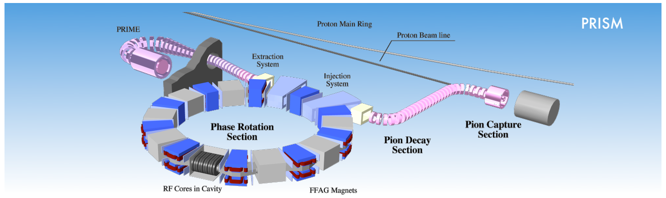


Capture Solenoid
Matching Section
Solenoid
On the design phase
Ejection System
Injection System
On the design phase
C-shaped
FFAG Magnet
Under
Construction
2003-2007
FFAG ring
Detector
RF Power Supply
RF Cavity
RF AMP
5 m

PRISM workshop

- **1st International PRISM Workshop**
  - 30th Nov. - 2nd Dec. 2005 @ Osaka-Univ.
- **Topics**
  - **Status of PRISM**
    - Beam optics and tracking
    - FFAG magnet
    - Kicker system for Inj./Ext.
    - Pion capture
    - PRIME detector
    - Pulsed proton beam
  - **Discussed issues**
    - FFAG tracking
    - FFAG performance test
    - Kicker system
    - Solenoid Channels
    - Detector of mu-e conv. exp.

International PRISM Workshop 2005



Programme

Wednesday 30th November

9:00-9:15 : **Introduction**, Y. Kuno
9:15-9:45 : **Overview of PRISM-FFAG**, M. Aoki
9:45-10:15 : **Beam Optics of PRISM-FFAG**, A. Sato
10:15-10:45 : **Development of PRISM-FFAG Magnet**, Y. Arimoto
10:45-11:00 : **Coffee Break**

11:00-12:00 : **Lecture on Solenoid Beam Optics I**, R.B. Palmer
15:00- : **Discussion: Solenoid optics**

Thursdaty 1st December

9:00-9:30 : **Simulation of Pion Production by GEANT4**, M. Takayanagi
9:30-10:00 : **Injection and Extraction**, A. Sato
10:00-10:30 : **Kicker System**, R.B. Palmer
10:30-10:45 : **Coffee Break**

10:45-11:15 : **Kicker Magnet and Power Supply**, T. Oki
11:15-12:15 : **Lecture on Solenoid Beam Optics II**, R.B. Palmer
13:30- : **Discussion: FFAG Kicker System**

19:30- : **Workshop Dinner**

Friday 2nd December

9:00-9:30 : **Diagnostics for PRISM-FFAG**, T. Itahashi
9:30-10:00 : **Tracking Simulations in Scaling FFAGs using the Ray-Tracing Code Zgoubi**, F. Meot
10:00-10:30 : **Particle Tracking Simulation by Zgoubi**, Y. Kuriyama
10:30-10:45: **Coffee Break**

10:45-11:15 : **PRIME Detector**, A. Sato
11:15-11:45 : **Fermilab Proton Driver and PRISM/PRIME**, D. Neuffer
11:45-12:00 : Prospect, Y. Kuno
13:30- : **Discussion: FFAG Test**

Towards a New Basic Science; Depth and Synthesis The 21 st century COE Program

Date : Nov.30~Dec.2

Meeting Room : H701, H-Main Building, Graduate School of Science (South Block),Toyonaka Campus, Osaka University

Chair : Yoshitaka Kuno (Osaka U.)

Contact person : Yasushi Arimoto (Osaka U.)

http://www-kuno.phys.sci.osaka-u.ac.jp/~prism/ws0512/

Contents

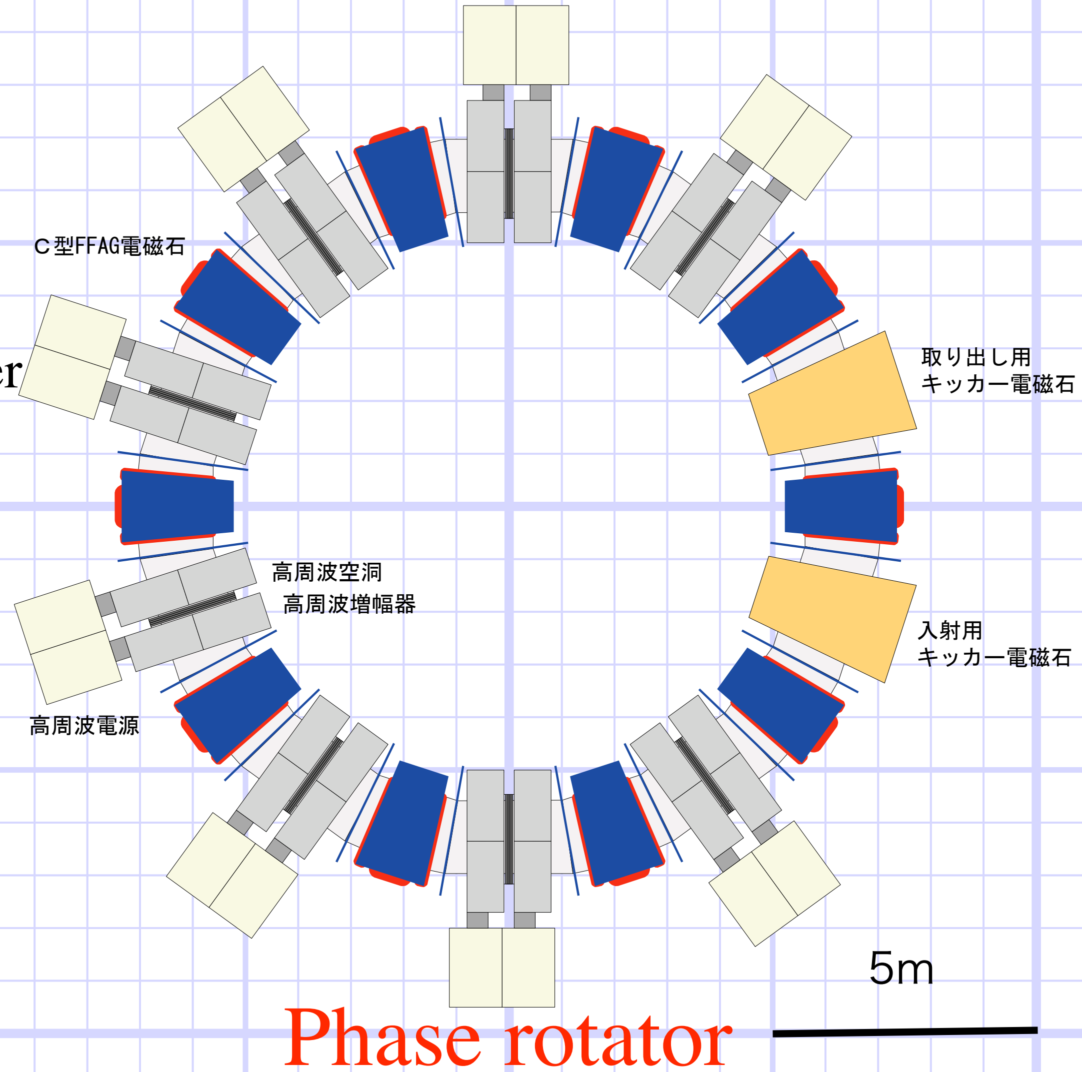
Summary talk on the PRISM Workshop
PRISM-FFAG related topics

- PRISM-FFAG
  - Lattice
  - Magnets
  - RF system
- Injection/Extraction
  - Vertical scheme
  - Kicker design
- Tracking issue
- Diagnostics

PRISM-FFAG

PRISM-FFAG

- N=10
- k=4.6
- F/D(BL)=6.2
- r0=6.5m for 68MeV/c
- half gap = 17cm
- mag. size 110cm @ F center
- Radial sector DFD Triplet
  - $\theta_F/2$=2.2deg
  - θ_D=1.1deg
- Max. field
  - F : 0.4T
  - D : 0.065T
- tune
  - h : 2.73
  - v : 1.58



PRISM-FFAG Features

- Large transverse acceptance
  - Horizontal : 38,000 π mm mrad
  - Vertical : 5,700 π mm mrad
- High field gradient RF system
  - field gradient ~200kV/m (~2MV/turn)
    - quick phase rotation (~1.5μs)
    - large mom. acceptance (68MeV/c +- 20%)
- Radial sector type, Scaling FFAG
- F/D and k value : variable

Construction Schedule

- Beam optics design
- Magnet design
- 2005/12 - 2006/03 : Construction of 3 magnets
  - 2006/03 - 2006/05 : Field measurement
- 2006/04 - 2006/11 : Construction of 7 magnets
- 2006/12 - : Construction of FFAG-ring
- 2007 : Commissioning and performance test

Feature of PRISM-FFAG Magnet

scaling radial sector

Conventional type. Have larger circumference ratio.

triplet (DFD)

F/D ratio is variable. Ds have field crump effects to realize the large packing factor. the lattice functions has mirror symmetry at the center of a straight section.

large aperture

important for achieve a high intensity muon beam.

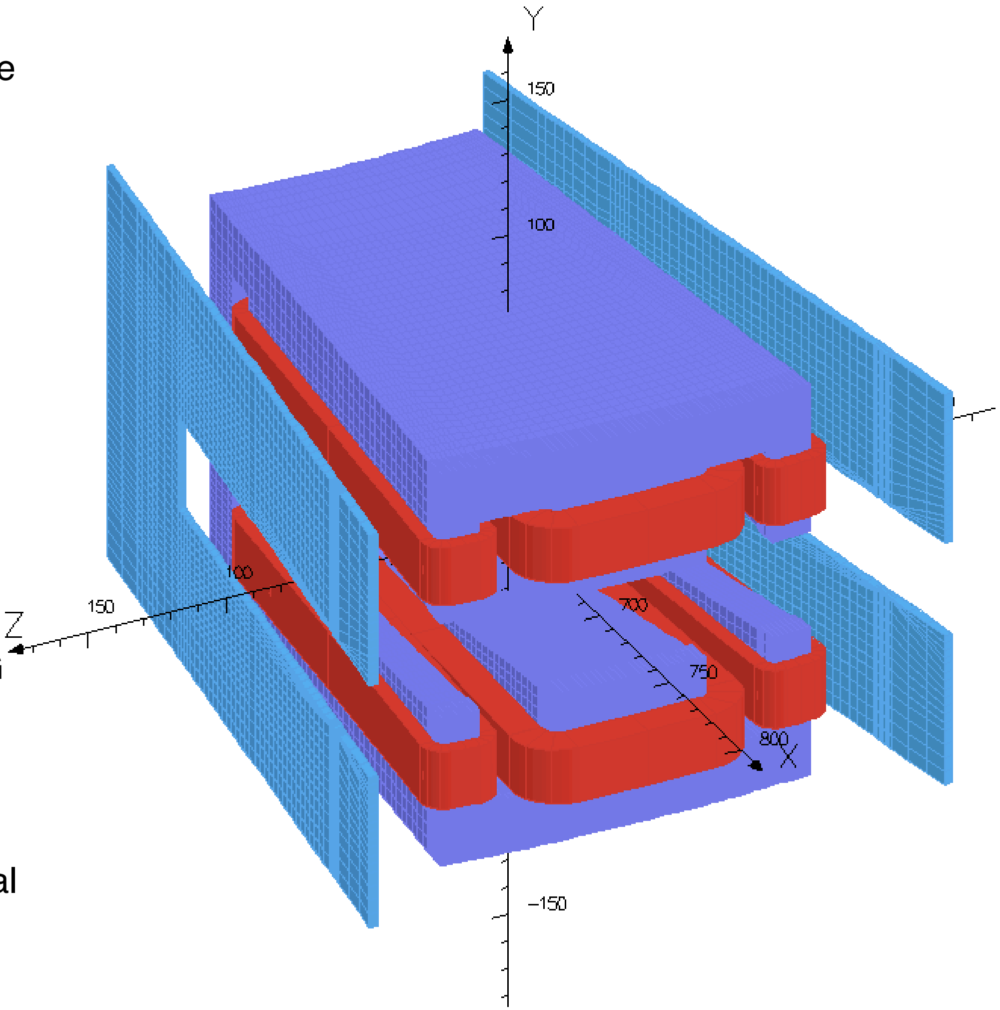
thin

Magnets have small opening angle. so FFAG has long straight sections to install RF cavities as mach as possible

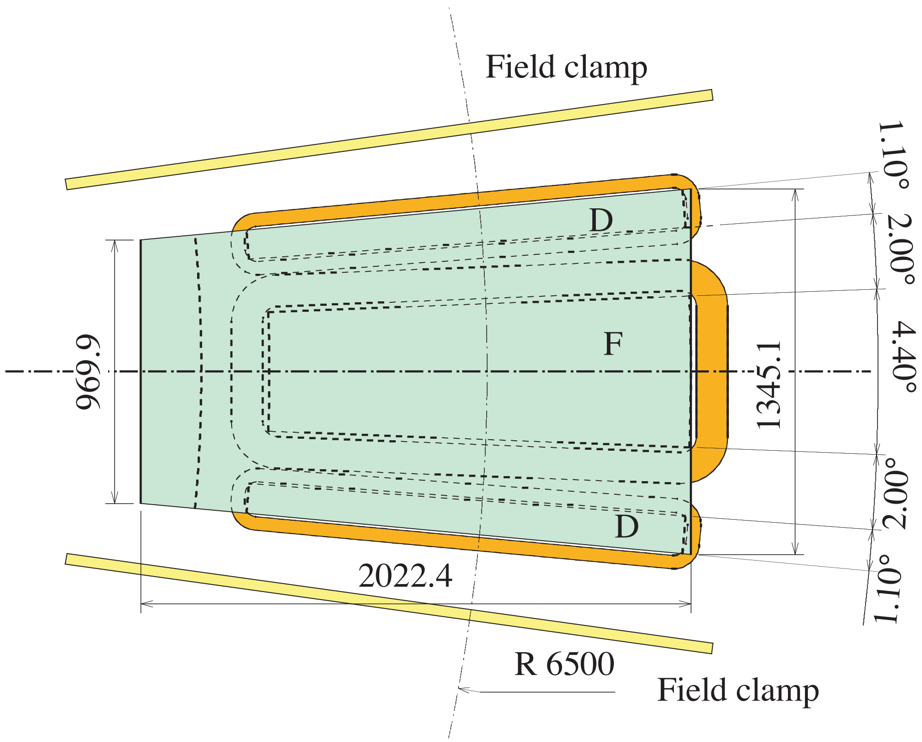
trim coils

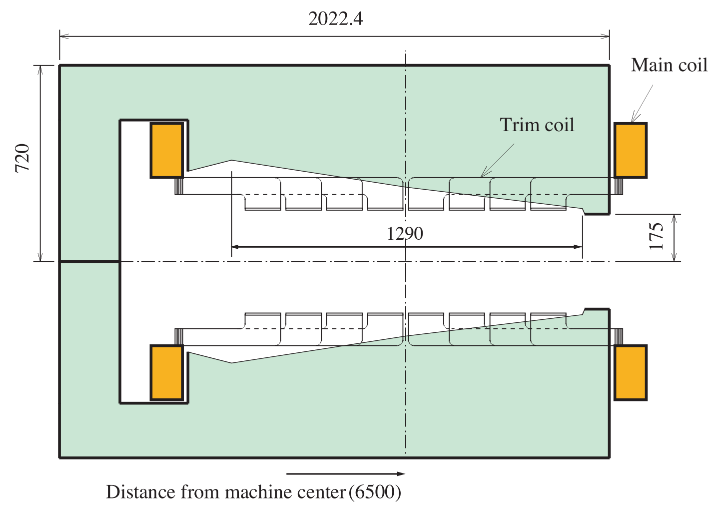
k value is variable. Therefore, not only vertical tune and also horizontal tune are tuneable.

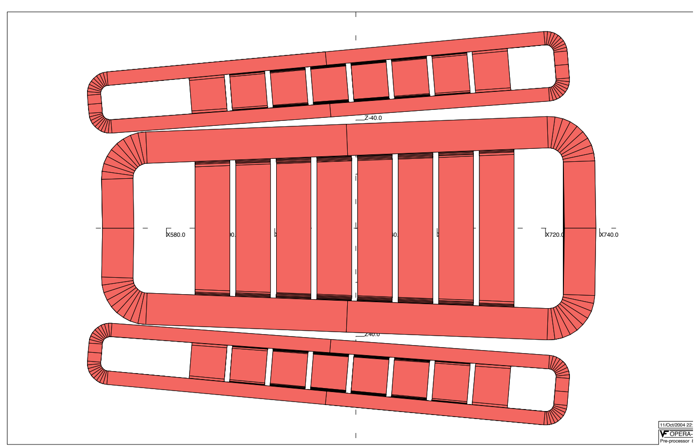
C-shaped



VECTO

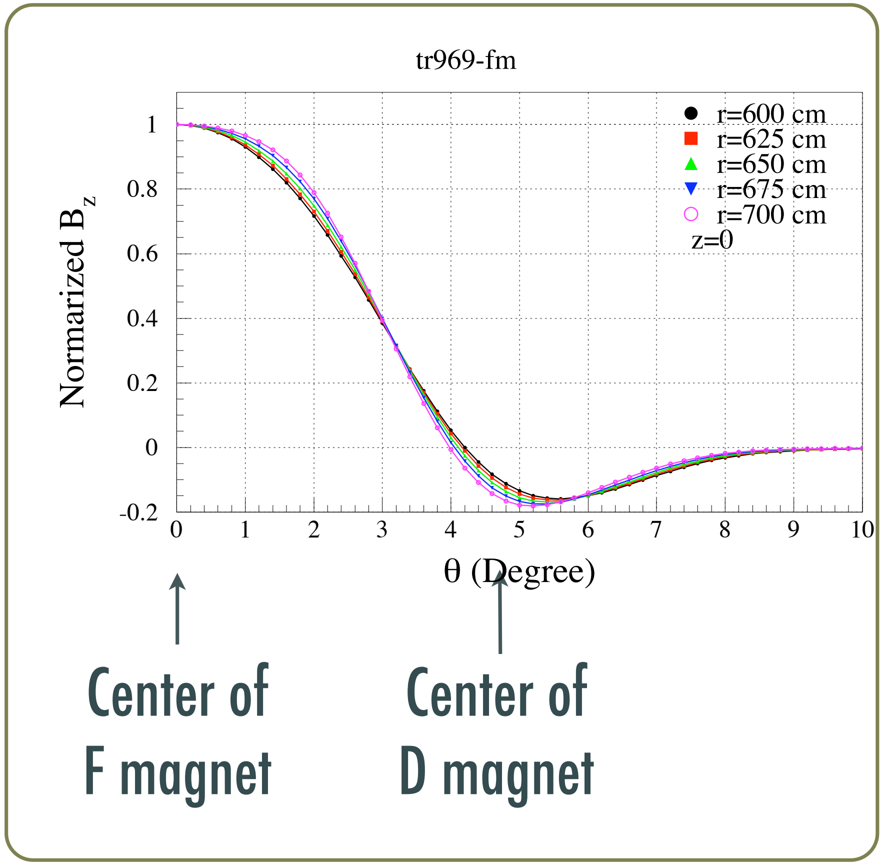


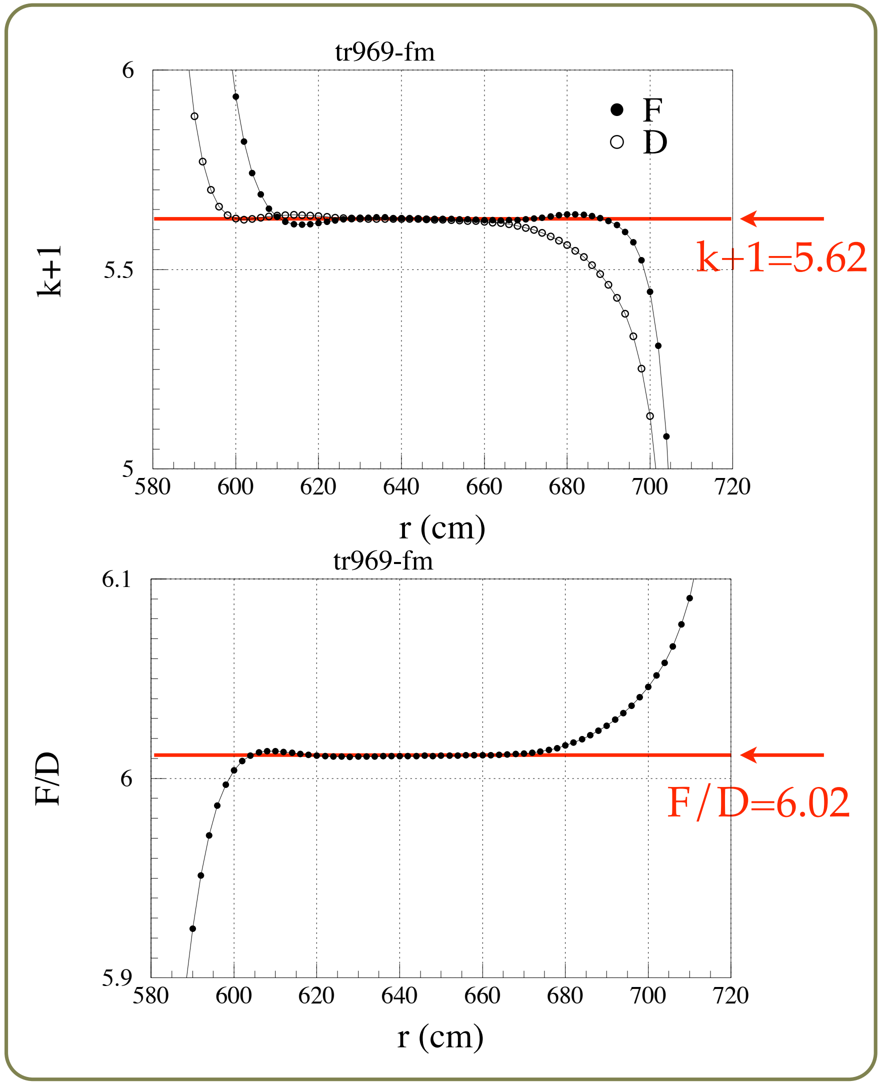




- Total Mass of yoke: 14 t / cell
- F Main coil : 78000 A*T / coil (F/D=4)
- D Main coil : 26000 A*T / coil (F/D=4)
- F trim coil : 1200 A/coil
- D trim coil : 500 A/coil
- Electric Power for F Main coil : 740 kW/Ring
- Electric Power for D Main coil : 441 kW/Ring

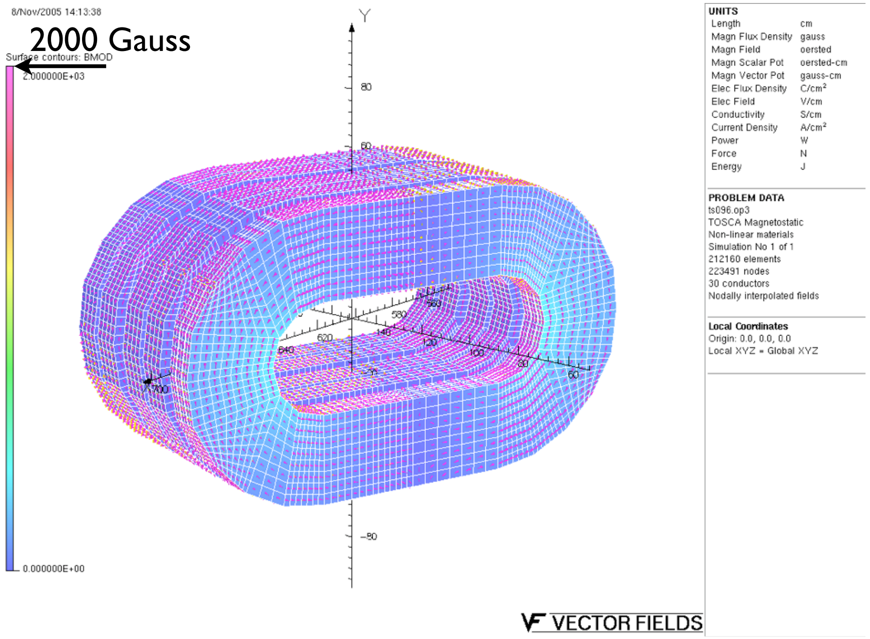
Field Calculation

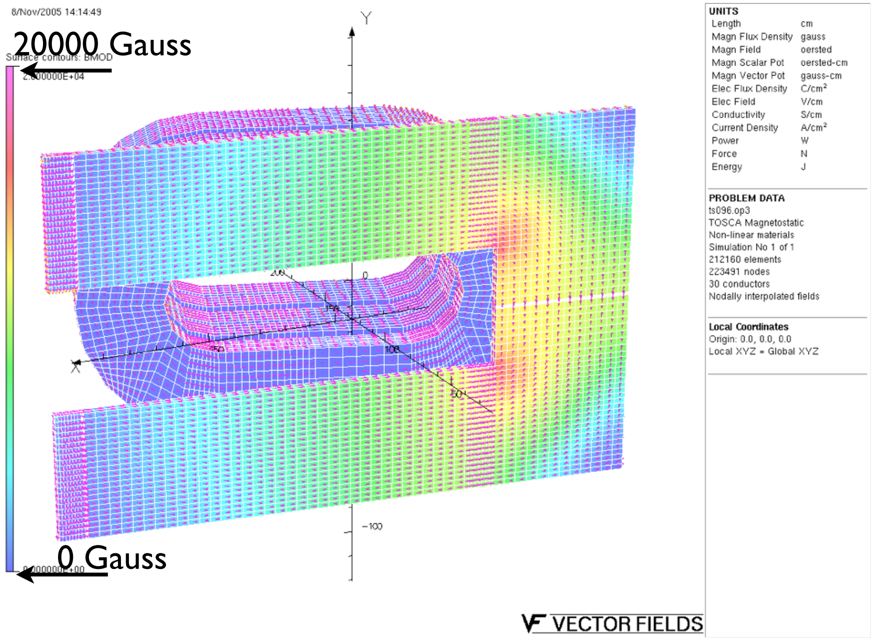




Y.Arimoto

Stray Field to RF cores





Averaged flux in the 1st core ~ 150 gauss

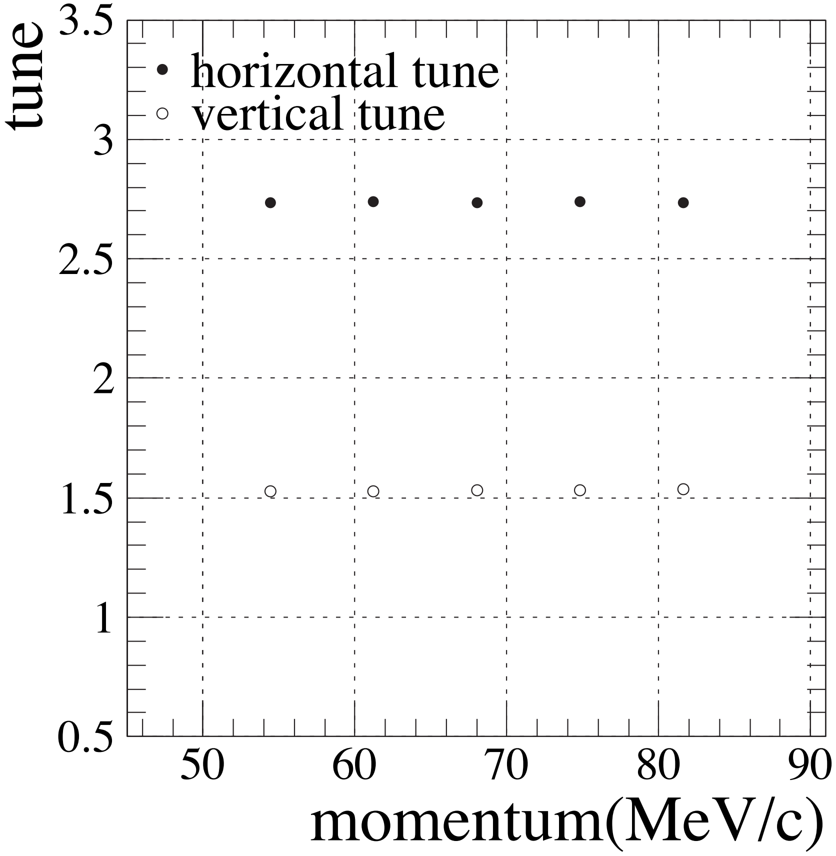
Y.Arimoto

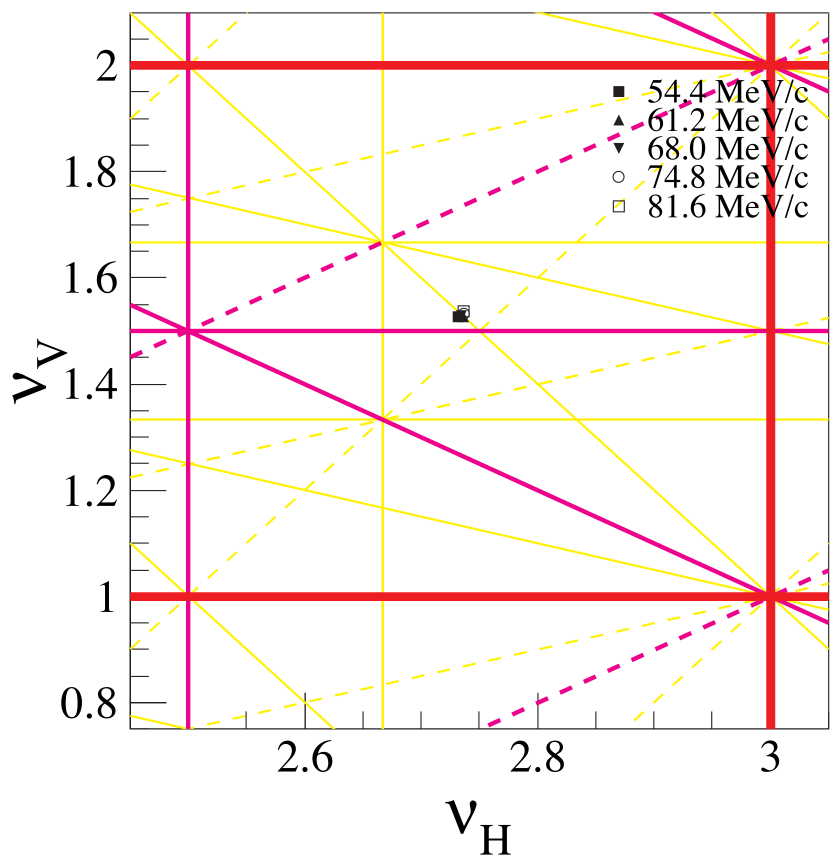
Magnets Params.

Weight of magnet		17 t / 1 cell
Current (per 1 coil)	F magnet	1750 A / 84000 A*T
	D magnet	1034 A / 30000 A*T
Power		100 kW / 1 cell
Flow rate of cooling water	F magnet	61.7 ℓ / min
	D magnet	38.3 ℓ / min
Pressure drop (per 1path)	F magnet	4.8 kg / cm^2
	D magnet	1.9 kg / cm^2

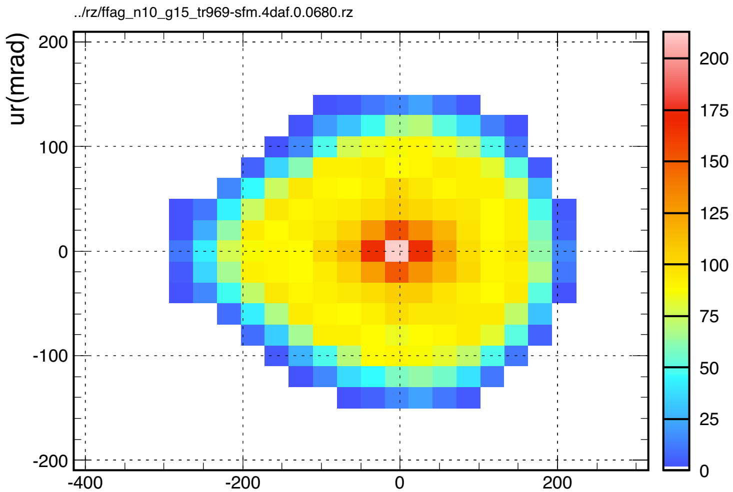
Zero Chromaticity

../rz/ffag_n10_g15_tr969-sfm.base.rz

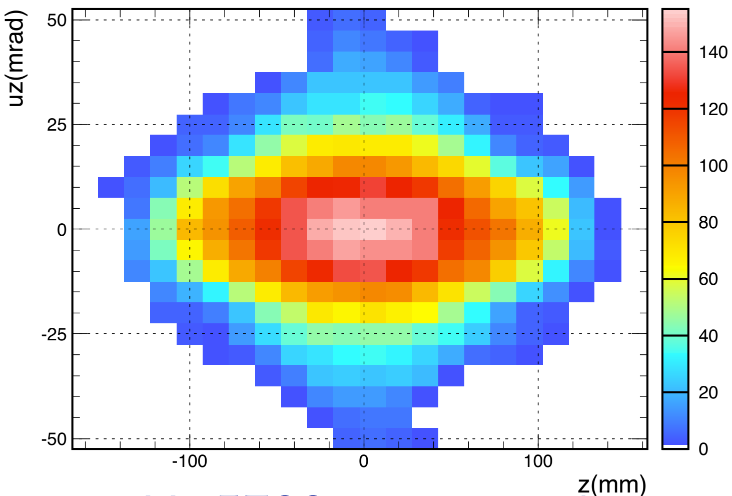




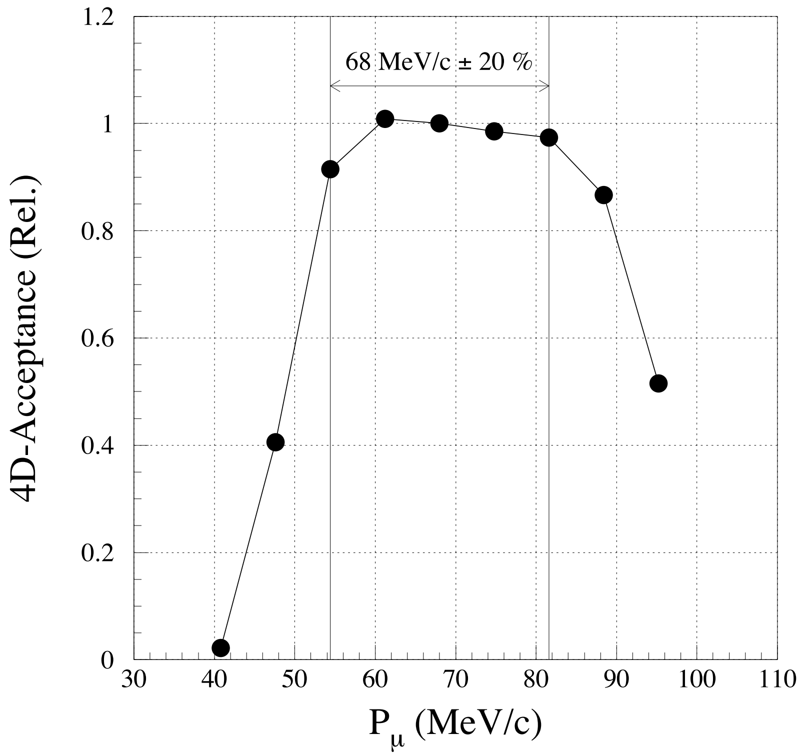
4D Acceptance



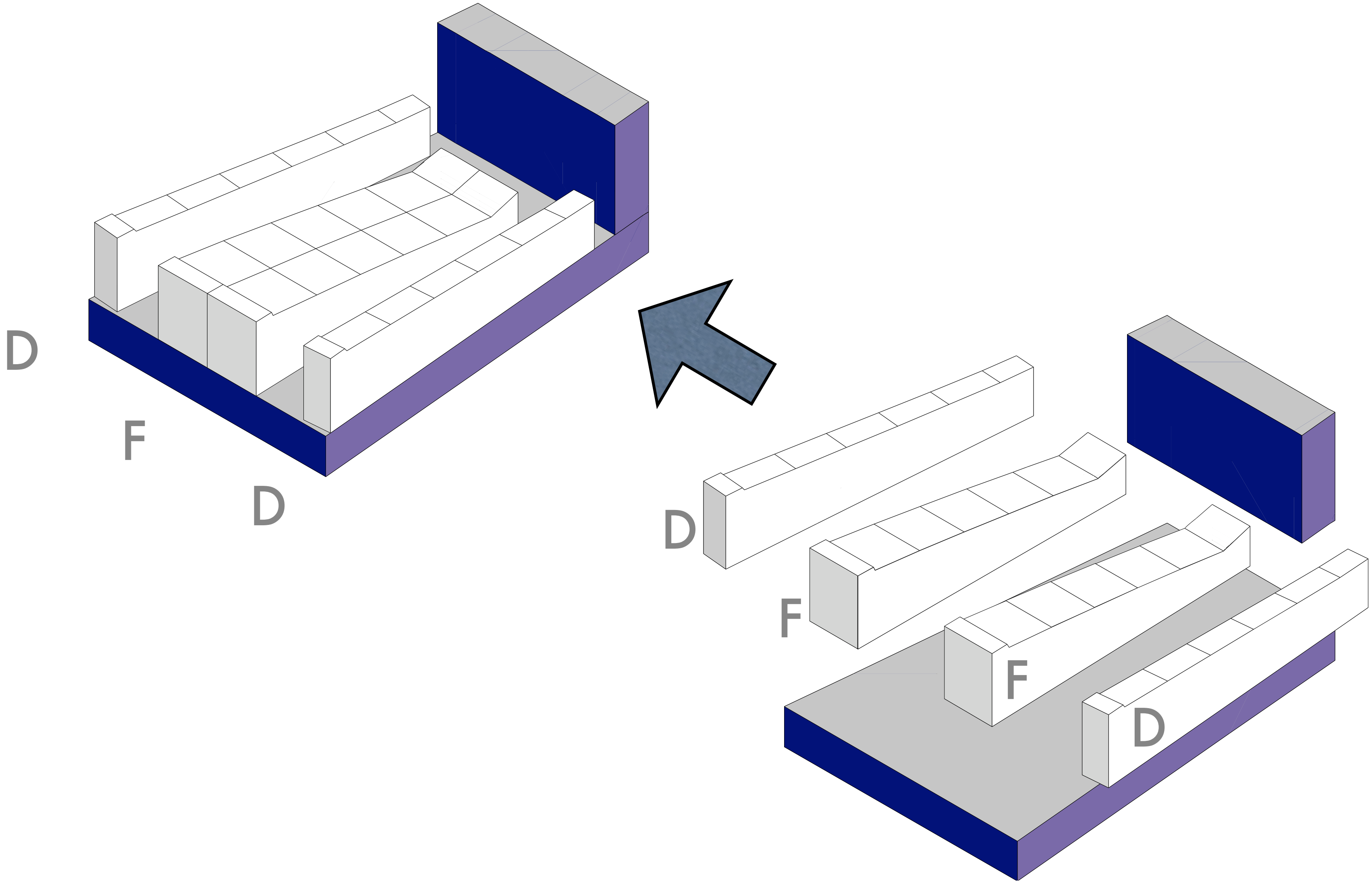
H : 38000π mm mrad

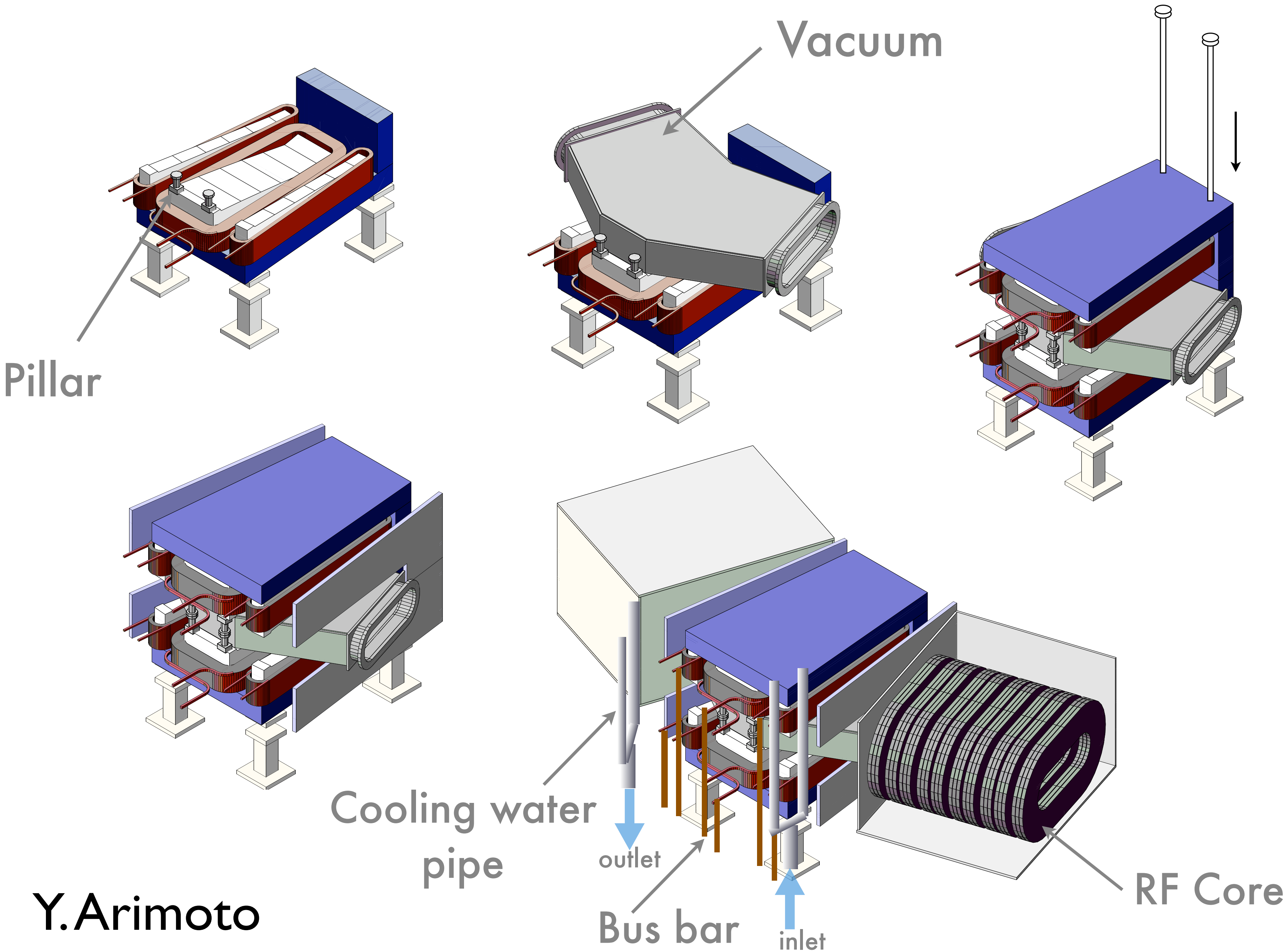


V : 5700π mm mrad



Assembly of Magnet





Vacuum
Pillar
Cooling water pipe
outlet
Bus bar
inlet
RF Core

Y.Arimoto

Status of Construction

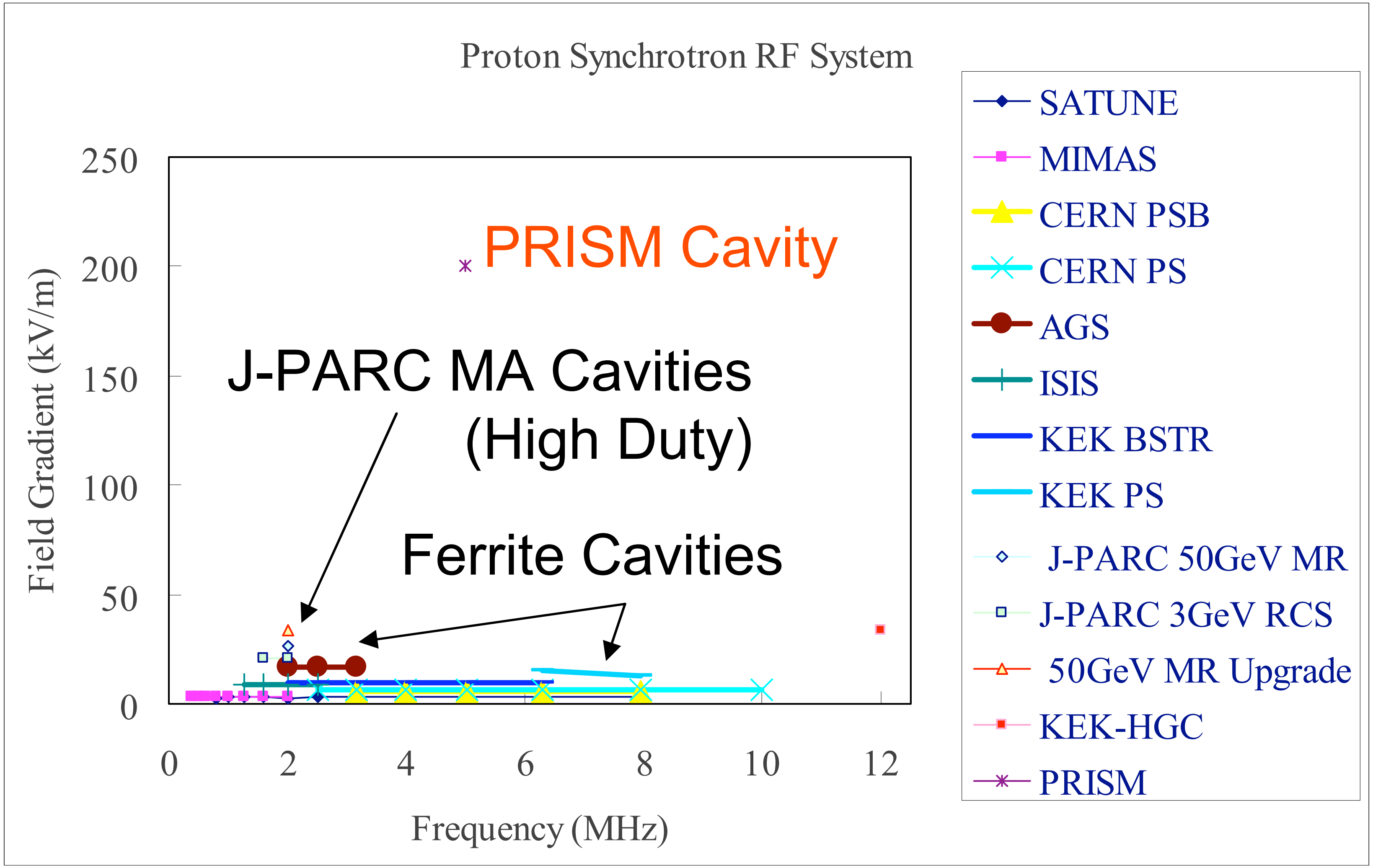
- Main coils have been produced.
- 3 FFAG magnets will be build by Mar. 2006.
- Field measurement in Mar.-Apr.

D coils

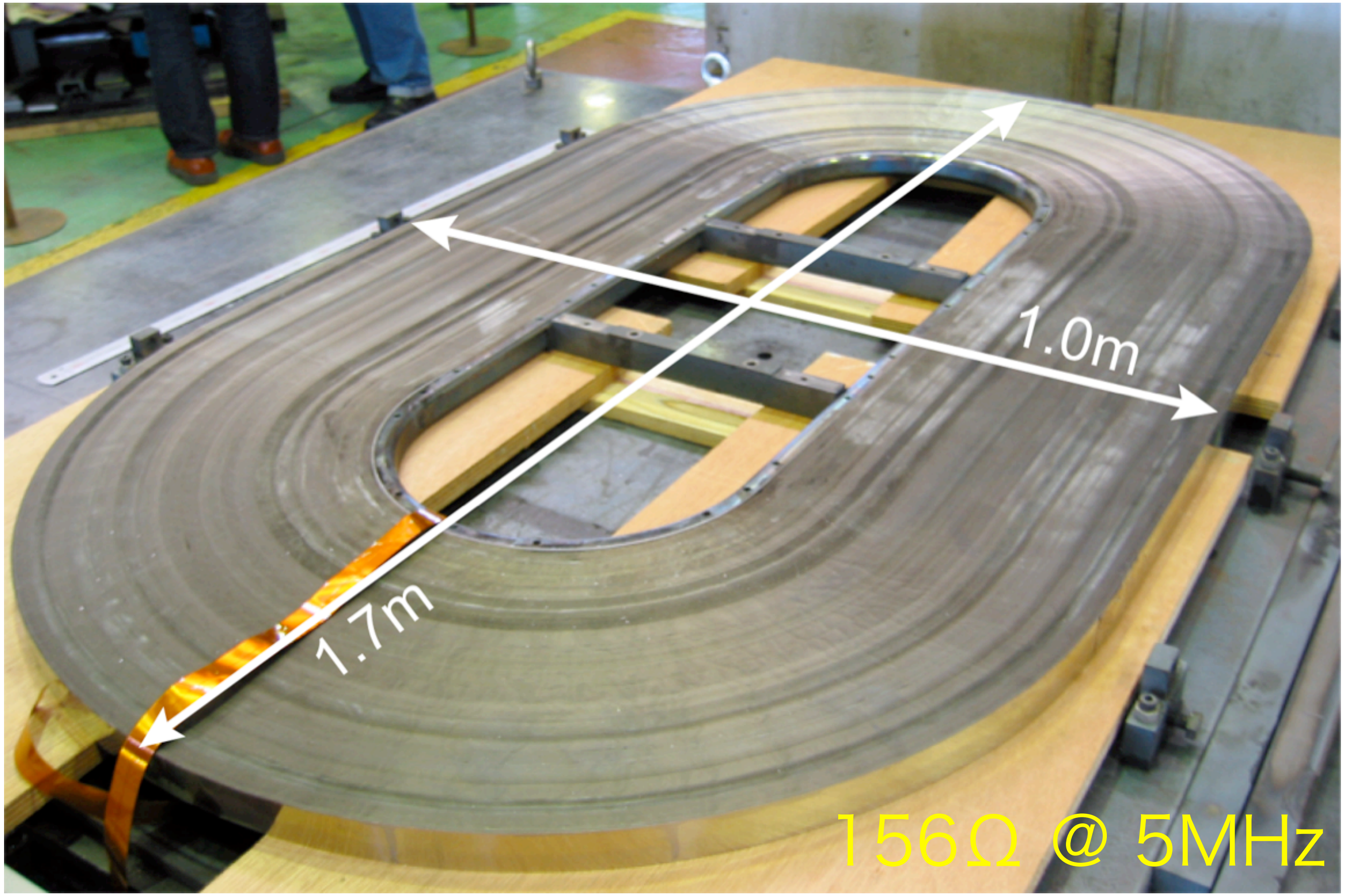
F coils

RF System

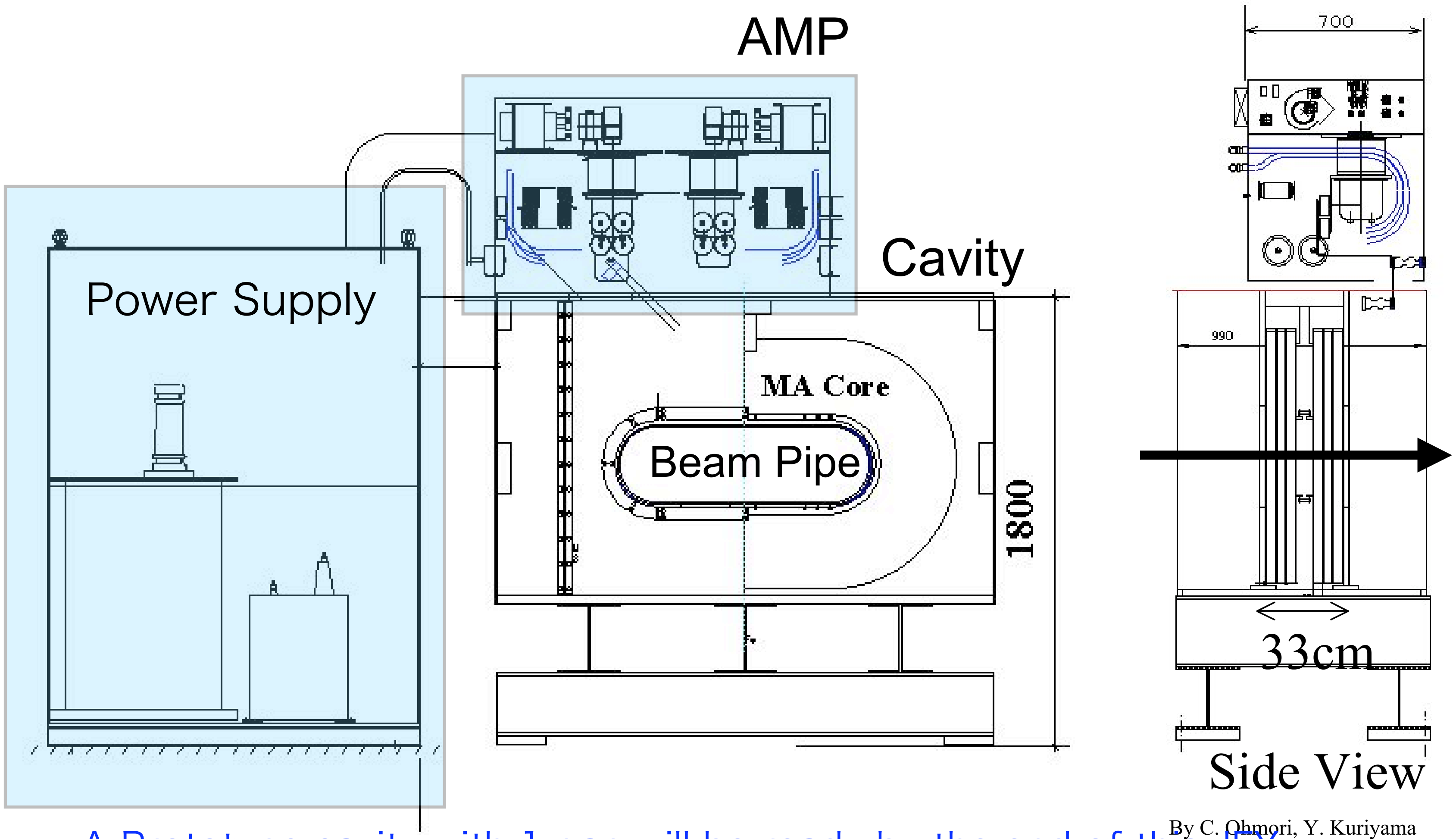
High field gradient RF



RF core (Magnetic Alloy)



PRISM-RF System

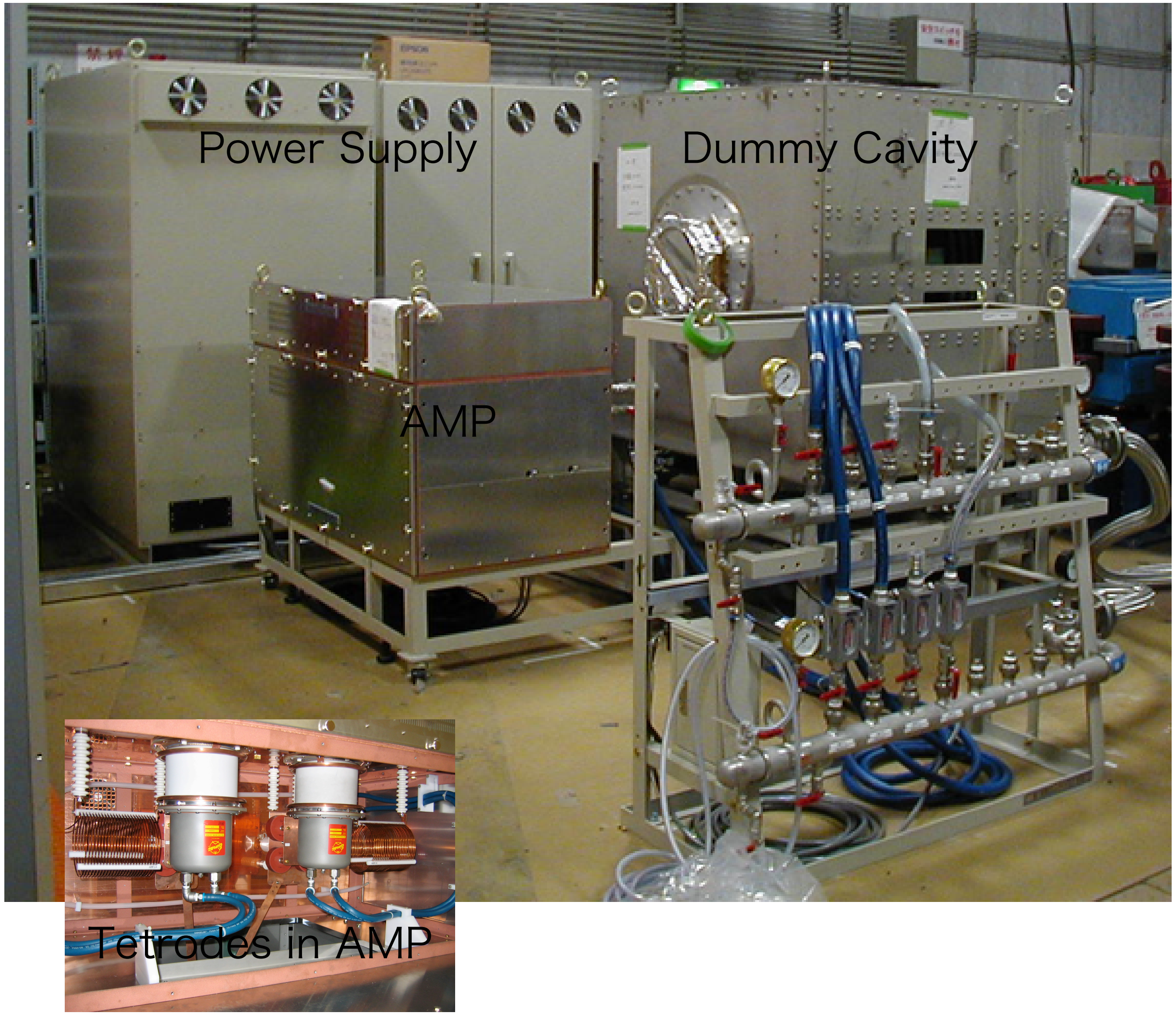


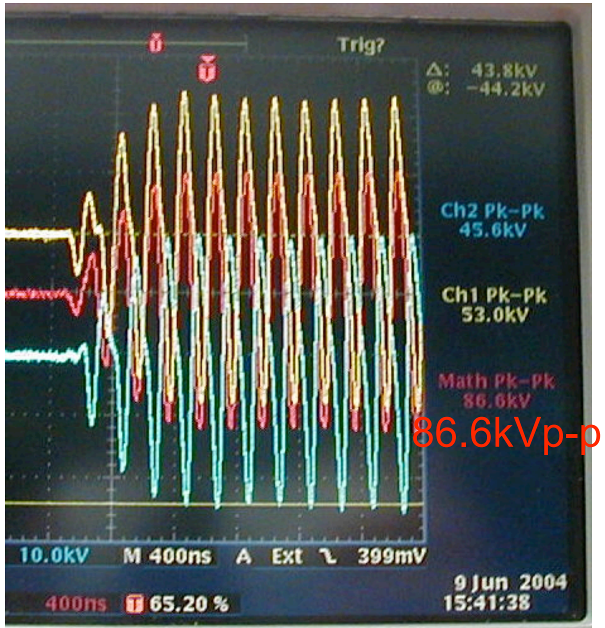
A Prototype cavity with 1 gap will be ready by the end of this JFY.

Parameters of RF system

Number of gap per cavity	5
	33cm/gap
Number of core per gap	6
core material	Magnetic Alloy
core shape	race track
core size	1.7m x 1.0m (inner 1.0m x 0.3m)
Shunt impedance	0.9kohm/gap
Field gradient	150~200kV/m
Flux density in core	~320 Gauss
Power tube	4CW100kE, DC33-37kV, 1.5MW(peak for 10us), Max current 60A
	Air cooling (duty 0.1%)

RF AMP R&D

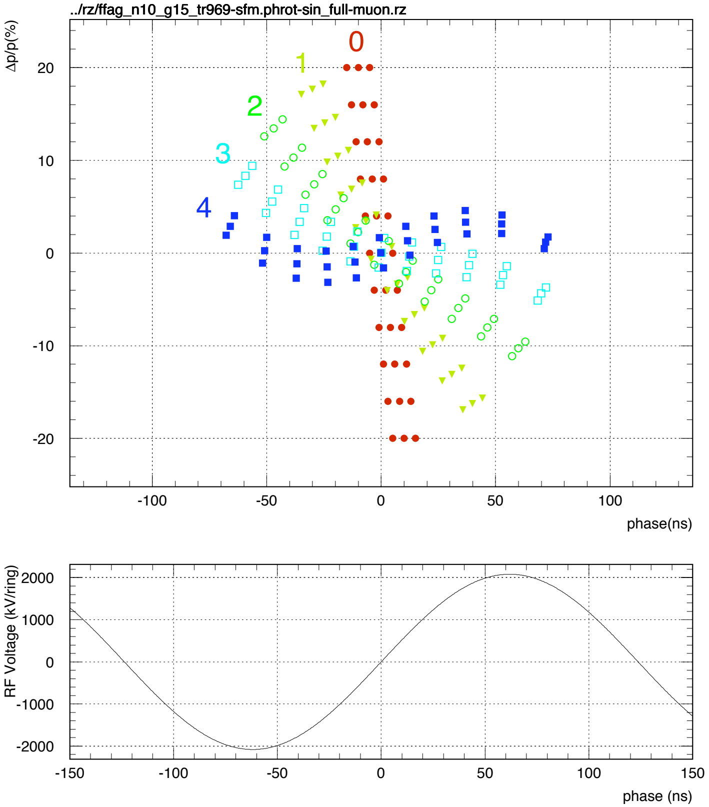




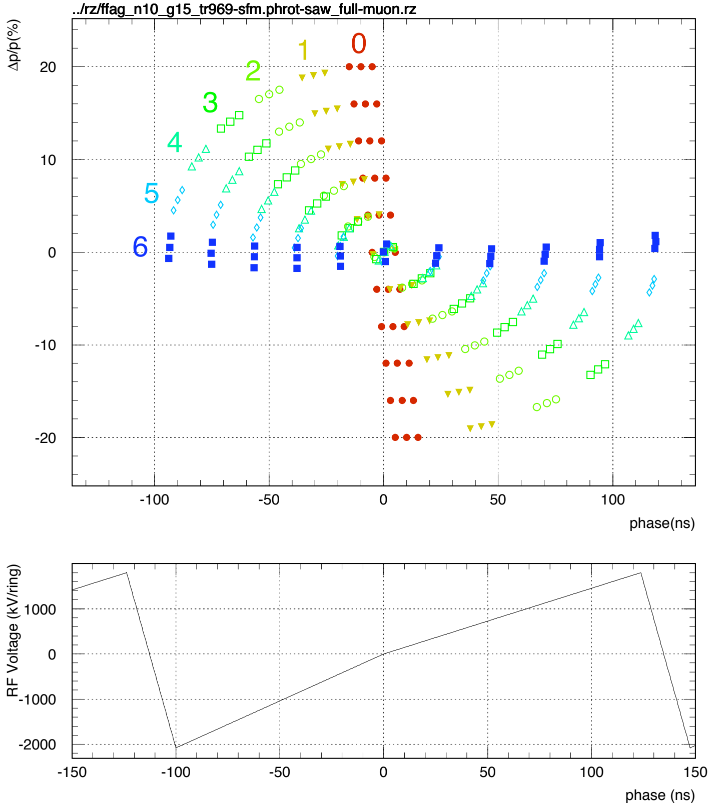
43kV/gap
w/ 734Ω dummy cavity
@5MHz

expected gradient
w/ PRISM-cavity (954Ω)
56kV_gap = 170kV/m

RF Wave Shape



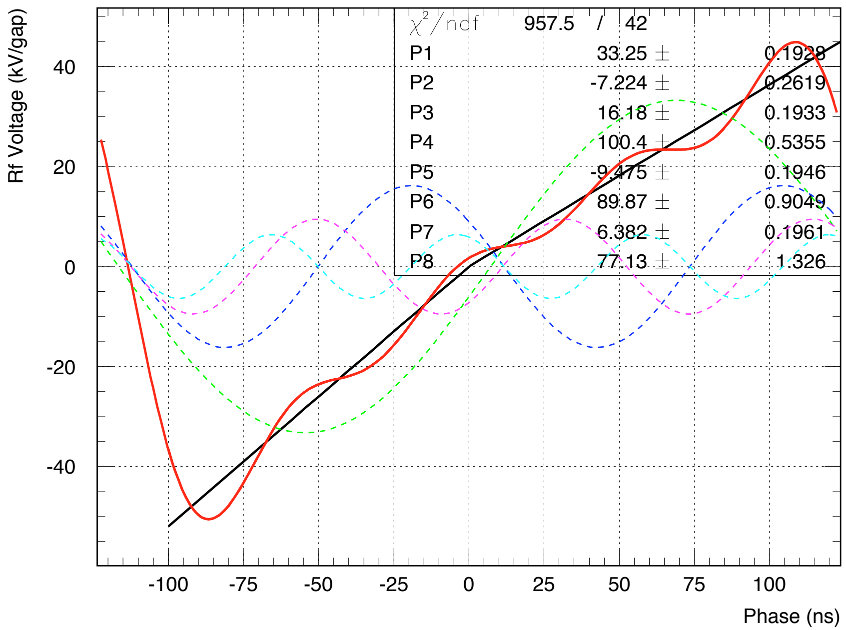
$\Delta p/p$: 4%
num. of turn : 4
time : 1.0μs
μ survival rate : 68%

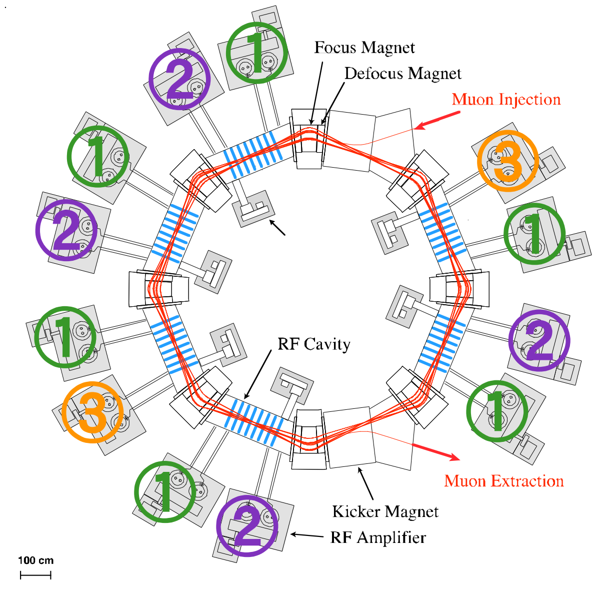


$\Delta p/p$: 2%
num. of turn : 6
time : 1.5μs
μ survival rate : 56%

Saw-tooth is better

- How to realize saw-tooth
  - 1) each gap has not only h=1 but also higher order (h=2,3) harmonics.
  - 2) one gap has just sinusoidal

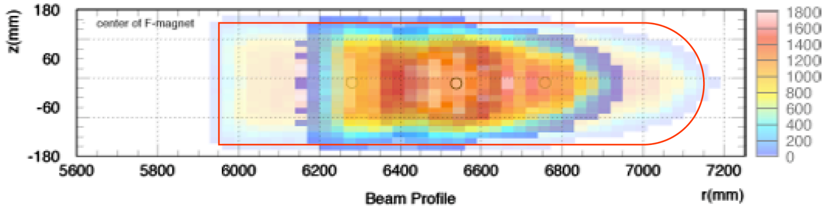


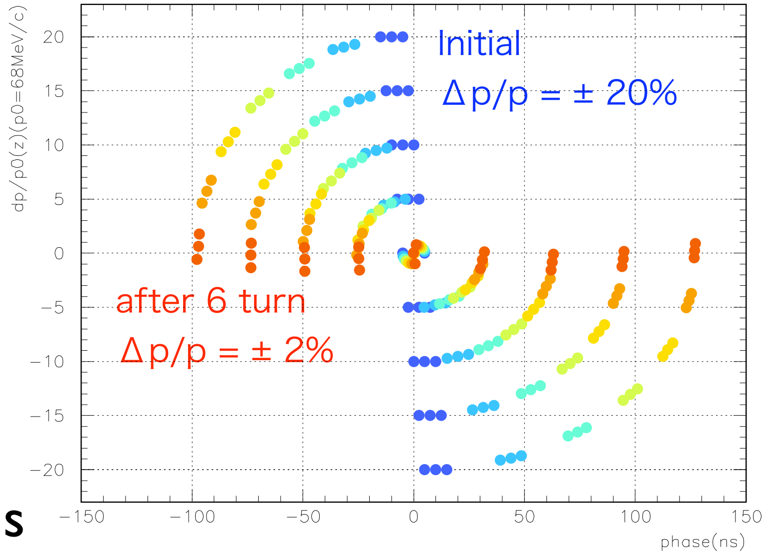


Injection / Extruction

Muon Beam

- at Injection
  - momentum : 68MeV/c+-20%
    - beam size
      - 100cmx30cm
  - time dist.: 40ns(/270ns)
    - kicker fall time < 230ns
- at Extraction
  - momentum : 68MeV/c+-2%
    - beam size
      - 70cmx30cm
  - time dist. : 200ns(/270ns)
    - kicker rise time < 70ns-100ns



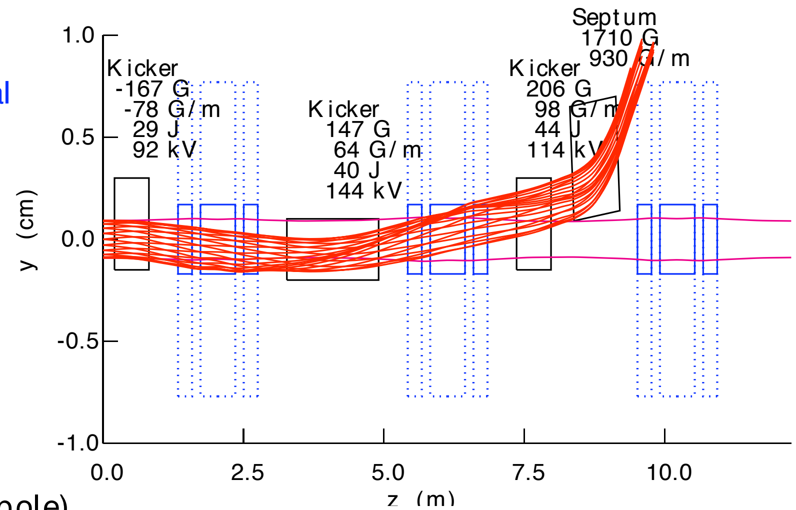


Injection/Extraction Issue

- B.Palmer proposed vertical injection/extraction

Conclusions on Injection/Extraction

- Vertical injection/extraction much easier than horizontal
  - Needs Much less Magnetic energy
  - Needs much lower Voltage
  - Chromatic correction easy
- But Remaining Design Questions
  - Needs larger vertical apertures in special magnets
  - Kicker Energy still much greater than normal kickers
  - Need two pulses in each kicker
  - Kicker aspect ratio unnatural
  - Needs gradient in kicker field (dipole + skew quadrupole)
- Study needs repeating with real fields and beam
- But this looks plausible

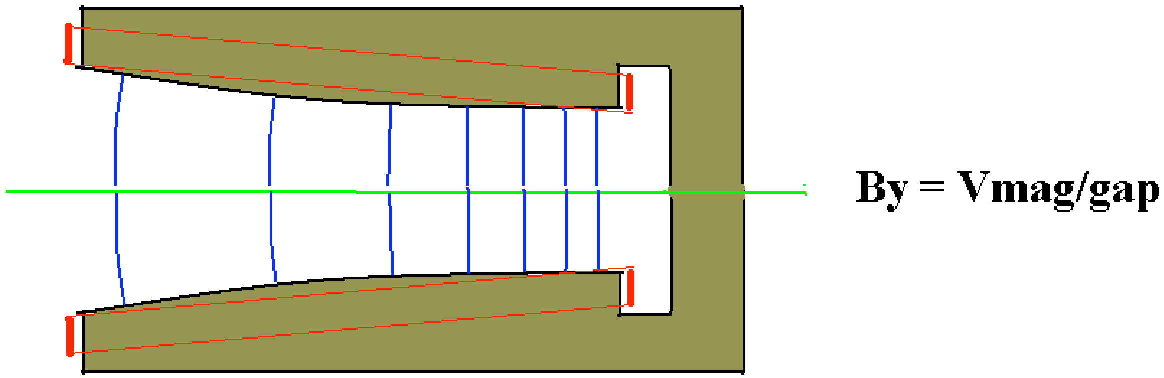


R.B.Palmer @ FFAG04 KEK

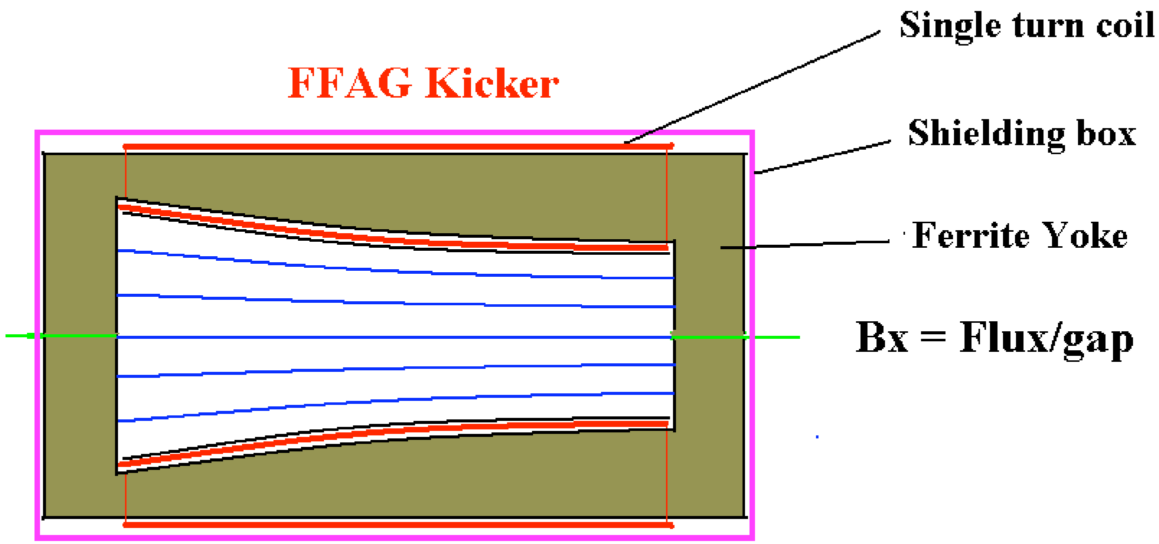
* I studied that scheme with the present PRISM design.

field clumps, real gap size,
TOSCA field for FFAG magnets,
hard edge field for kickers and septums, geant3 tracking code

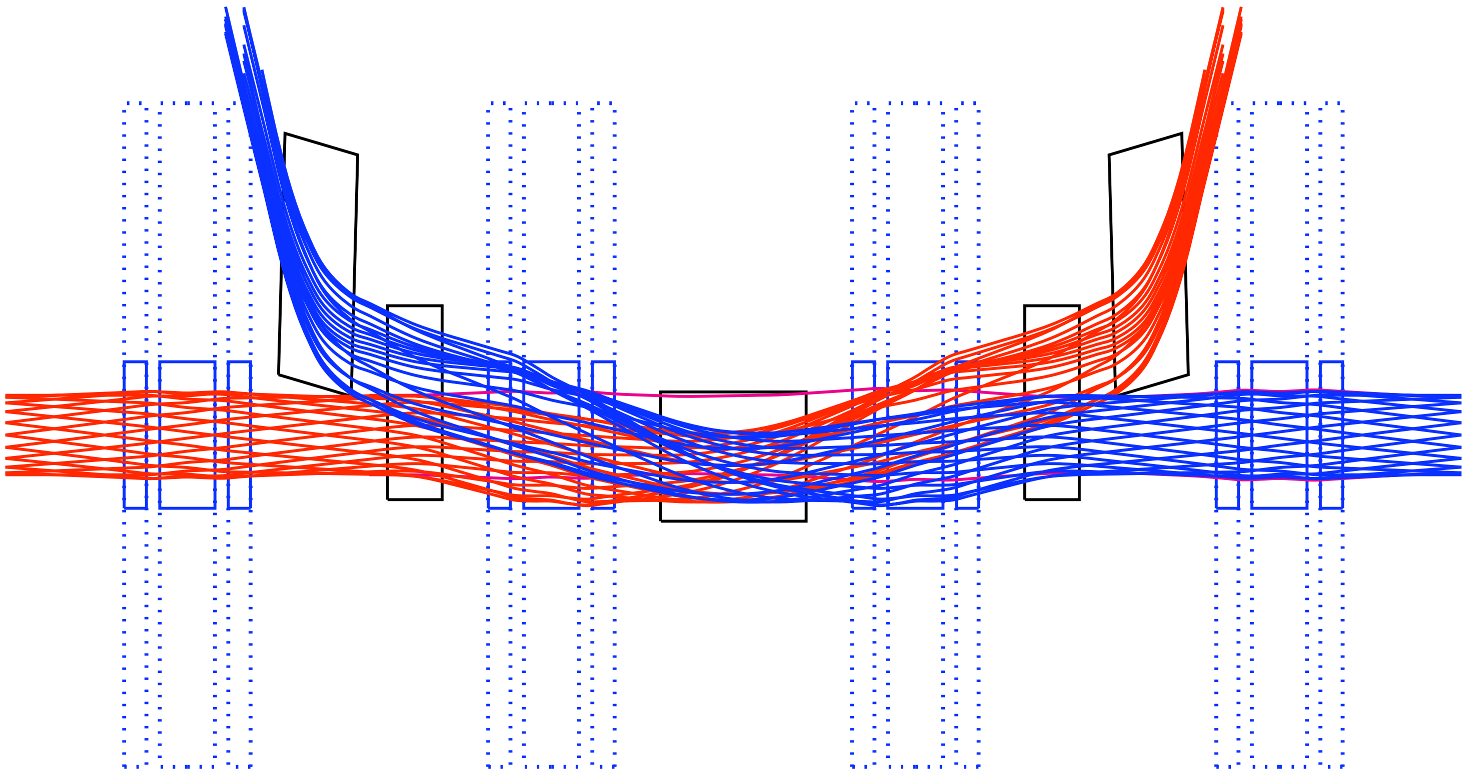
FFAG Magnet



FFAG Kicker



R.B.Palmer @ FFAG04



R.B.Palmer @ FFAG04

Vertical Injection/Extraction

	B (T)	Gradient (T/m)	rise time (ns)	fall time (ns)	Length (cm)	Height (cm)	Width (cm)	Single Turn Voltage (kV)	Stored Energy (J)
Kicker1	-0.0167	-0.0078	50	200	56	30	95	-56	16
Kicker2	0.0147	0.0064	50	200	140	30	95	123	30
Kicker3	0.0600	0.0500	50	200	56	50	95	336	335
Septum	0.2500	0.1500	50	200	56	80	95		

Optimizing now

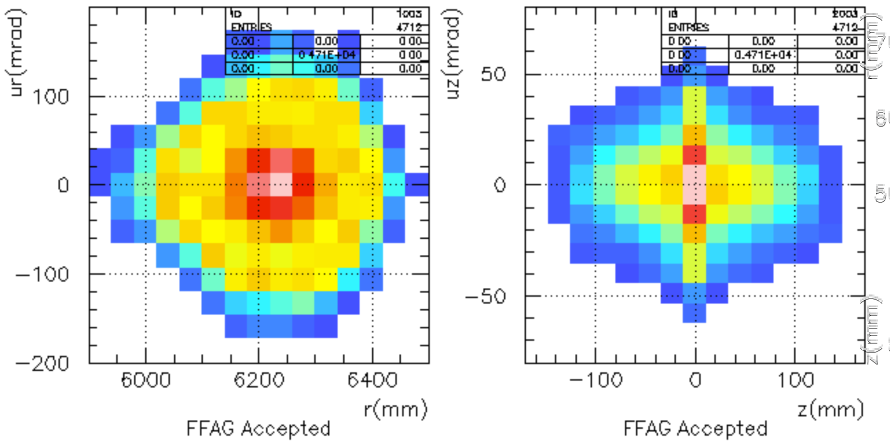
B.Palmer's results

		dz m	len m	ht m	wid m	tilt deg	B G	Grad G/m	V_0 kV	U J
1	Kicker	0.51	0.61	0.45	0.95	0	-167	-78	92	29
2	Kicker	0.00	1.63	0.30	0.95	0	147	64	144	40
3	Kicker	-.51	0.61	0.45	0.95	0	206	98	114	44
4	Septum	0.61	0.82	0.56	0.95	4	1710	930		
Max	(Total)								144	(113)
Horiz		0	1.22	.34	1.2		1080		3160	2038

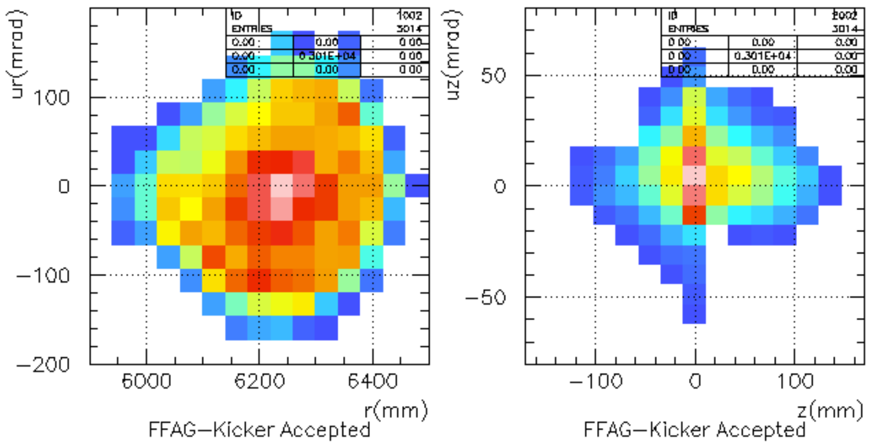
- It would work with the present PRISM design.

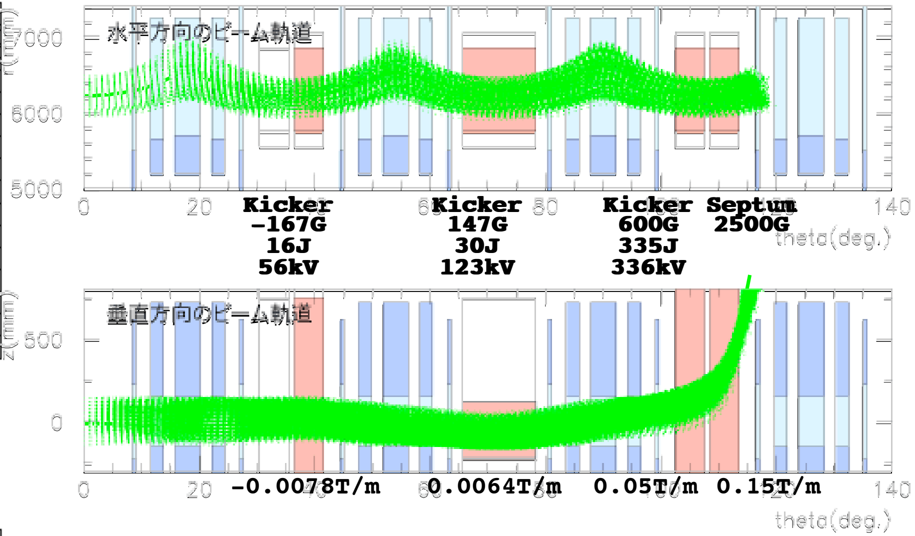
Vertical Injection/Extraction

FFAG's 4D Acc. : 1.0G(mm mrad)^2



FFAG-Kicker's 4D Acc. : 0.64G(mm mrad)^2



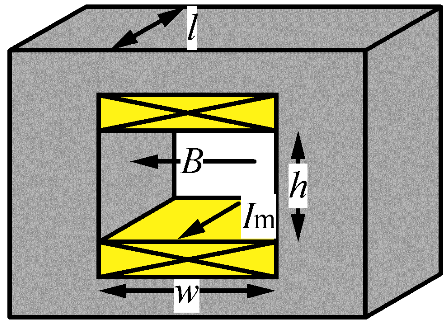


- (FFAG)/(FFAG-Kicker) = 64%

preliminary

PRISM-FFAG Kicker System

- $V_0 < 40$kV, Im ~ 6kA
- $\tau < 50$nsec, $\tau s \sim 25$nsec
- L ~ 0.5μH



To reduce the voltage swing: R < V_0 / Im ~ 5Ω

To realize fast rise time: L < R ($\tau - \tau s$) ~ 0.125μH

$$I_m = \frac{w\,B}{\mu_0},\; L = \mu_0 \frac{h\,l}{w}$$

The kicker Magnet should be divided (3 ~ 5units), and each unit should be driven separately.

Power = Im^2 R × unit number × duty (R = 5Ω, duty 0.02%)

#1 kicker (0.363 μH , 3units):108kW (6kA)

#2 kicker (0.647 μH , 5units): 61kW (3.5kA)

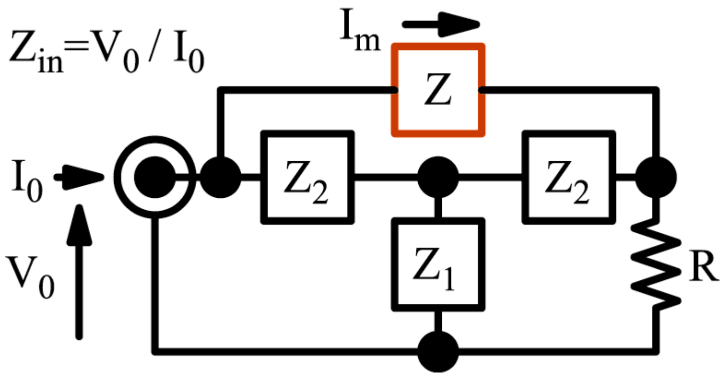
#3 kicker (0.363 μH , 3units):164kW (7.4kA)

Total 334kW for Extraction

T. Oki

Matching Scheme (2)

All Pass Network (APN)

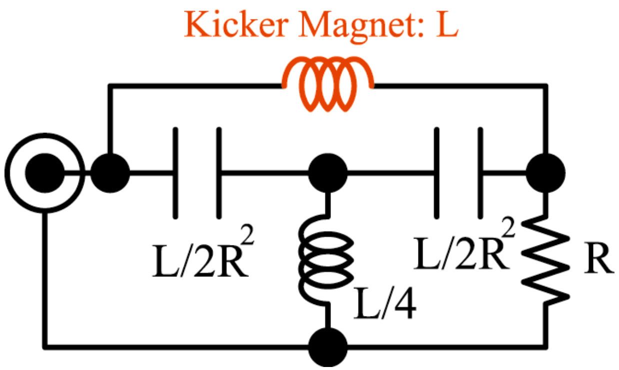


$$z_{in} = \frac{z\,z_2(2z_1+z_2)+R\left(z_2(z+z_2)+z_1(z+2z_2)\right)}{z_2(z+z_2)+R(z+2z_2)+z_1(z+2z_2)}$$

Matching Condition for $z_{in} = R$:

$$\left(z_1 = 4z,\ z_2 = \frac{R^2}{2z}\right)$$

Lumped type Magnet (Z) with APN



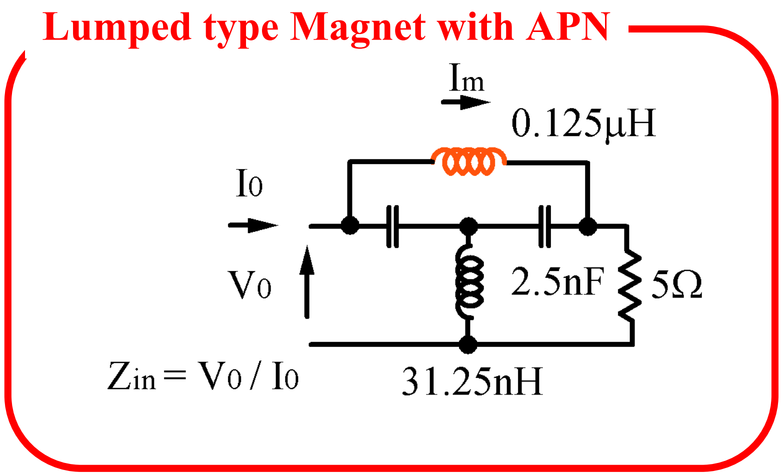
- There is no great difference in rise time characteristic.

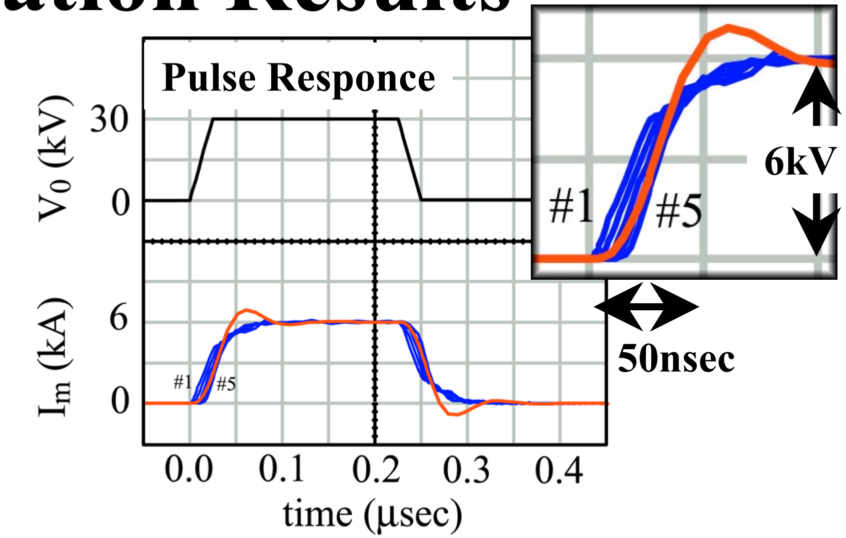
But…,

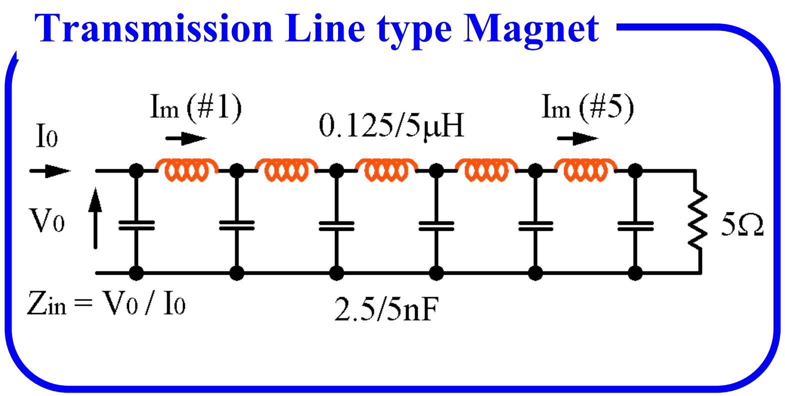
- Constant Input impedance across any frequency range.
  - > No damage due to reflection !
- Any component can be treated as lumped circuit.
  - > No vacuum enclosure required !
  - > The compact magnet will be helpful for the installation into the limited straight section.

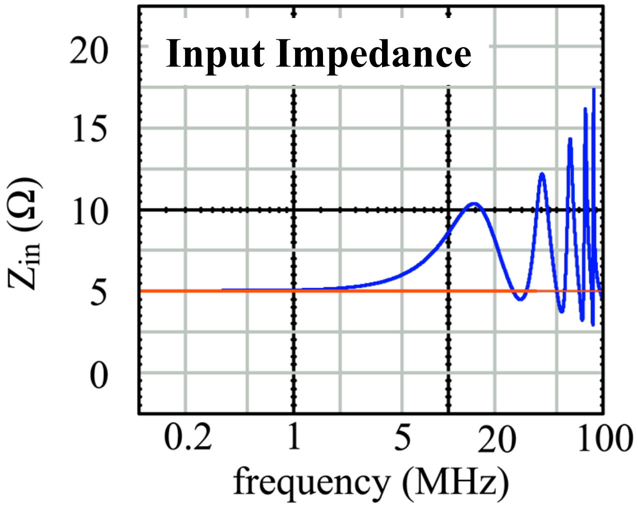
T. Oki

Spice Simulation Results



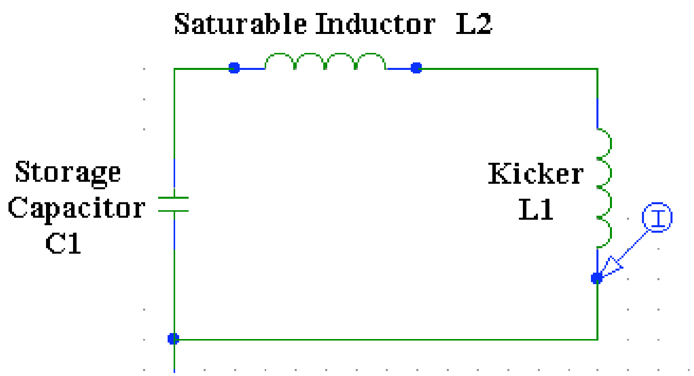






T. Oki

1 Resonant Magnetic-Amplifi



- A single compression stage;
- Negligible cable distance from driver to kicker;
- A sudden saturation at I_s from an initial large inductance L_1 to a small inductance L_2;
- A purely inductive kicker magnet with inductance L;
- I start the clock at t=0 with the drive capacitor C charged to V_o and no current flowing.

Initially, we have a simple resonant ciruit with a long time constant τ_L

$$\tau_L = \sqrt{(L + L_1)C}$$

Bob Palmer

Tracking Issue

Particle Tracking Codes

Purpose of Tracking for PRISM

Study beam optics

Estimate background

- Geant3.21
  - Runge-Kutta
  - single precision → *double precision*
  - physics process

It worked well at the design stage of PRISM-FFAG

Commissioning requires more precision

Next Tracking codes

- Geant4
  - Runge-Kutta
  - double precision
  - not-symplectic
  - physics process

for full simulation

- iCOOL
  - Runge-Kutta
  - double precision
  - not-symplectic
- Zgoubi
  - double precision
  - symplectic

for dynamics study

PRISM-FFAG study

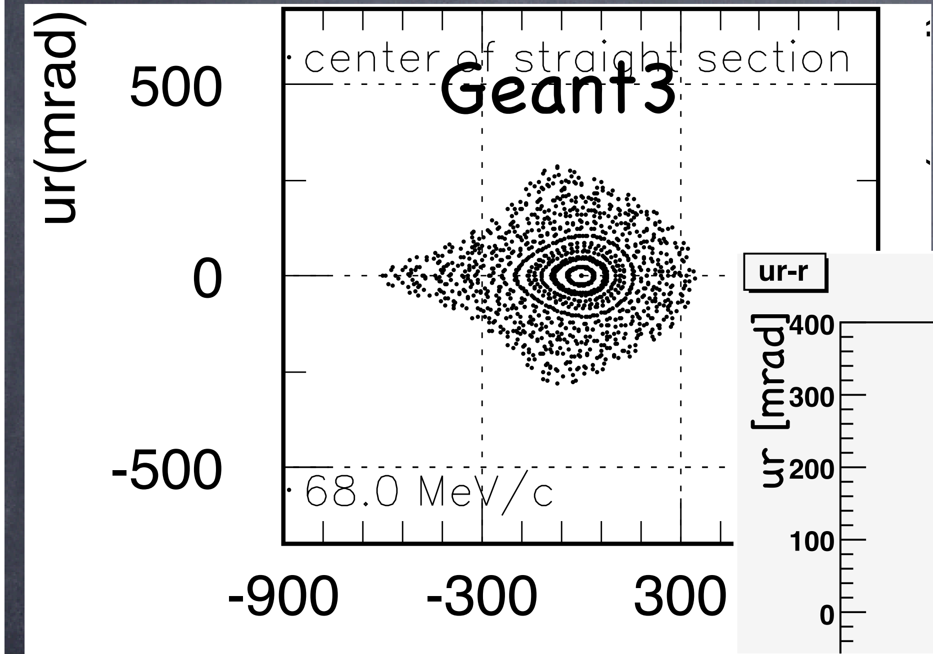
Bob

Meot , Kuriyama

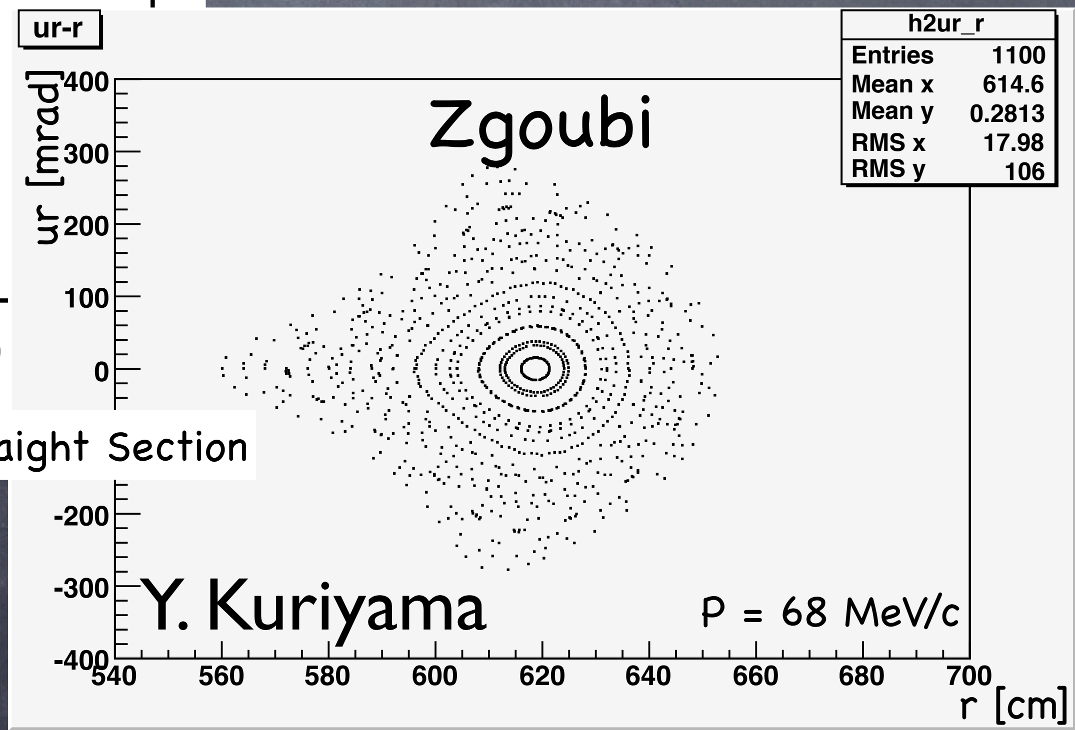
phase space plot 1 (Horizontal)

Input Particles :
$|dr| \equiv | r - r_0 | >= 4$ cm,

$r' = z = z' = 0$

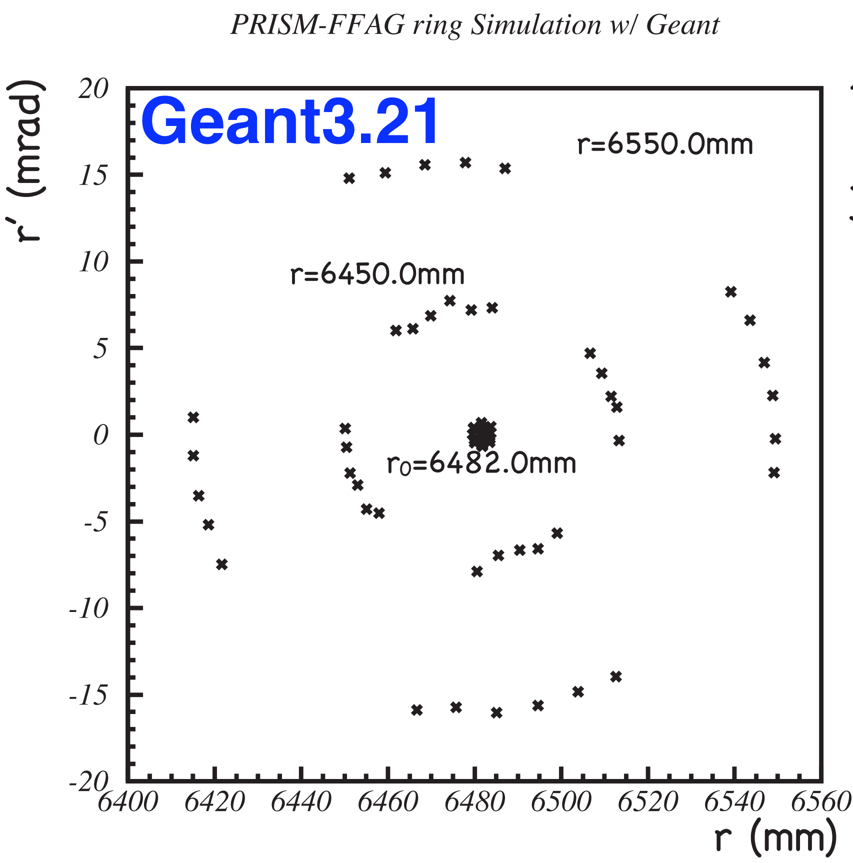


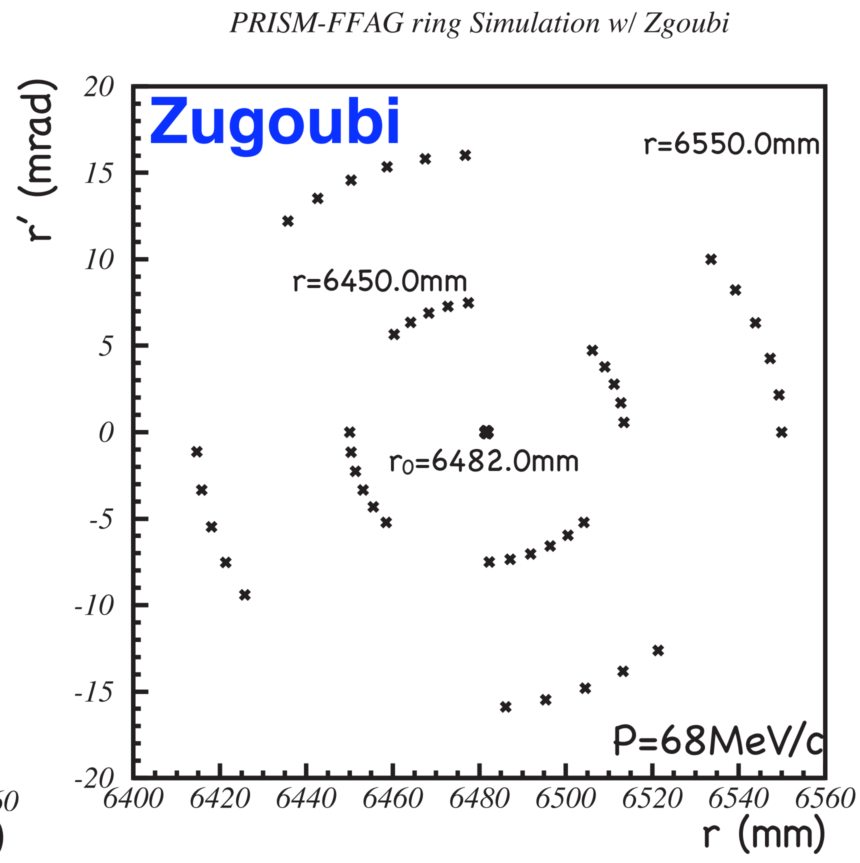
@ Center of Straight Section



acceptance
with 5 turns

Symplectic or not





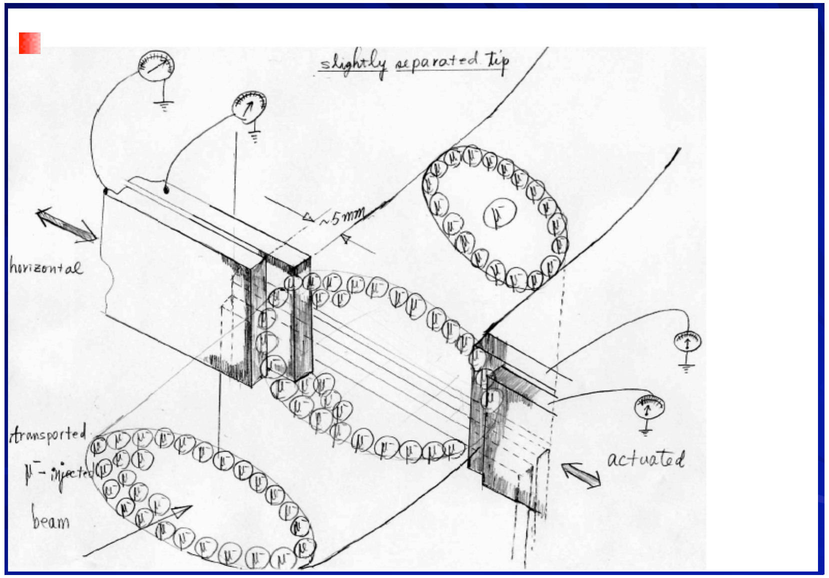
Y. Kuriyama

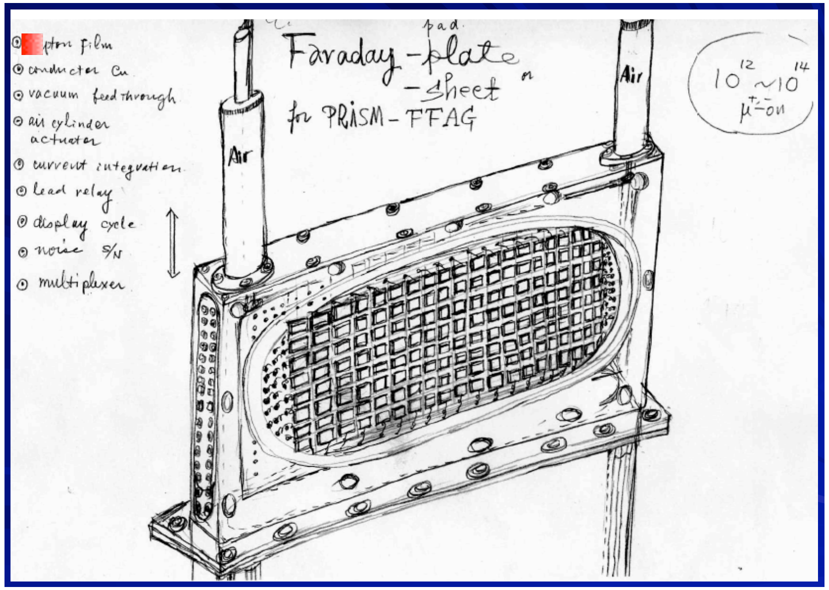
Diagnostics

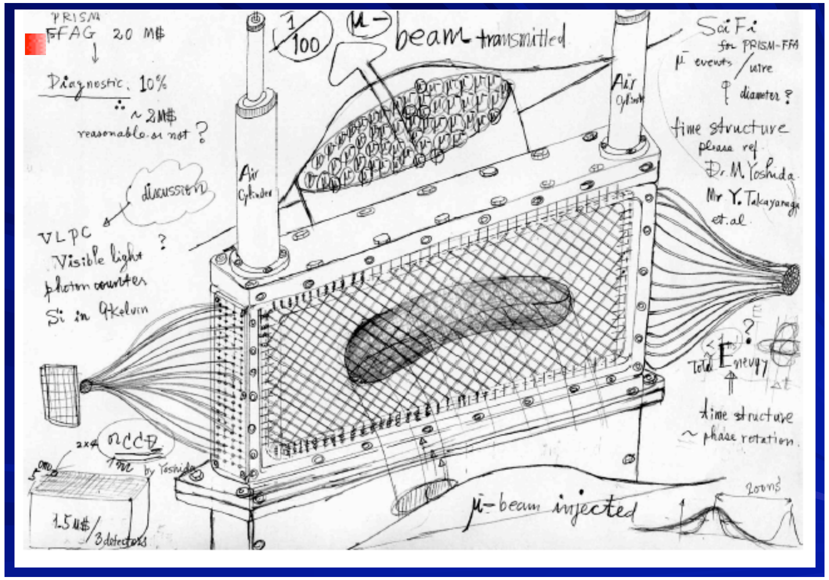
Beam Monitor for Muon Beam

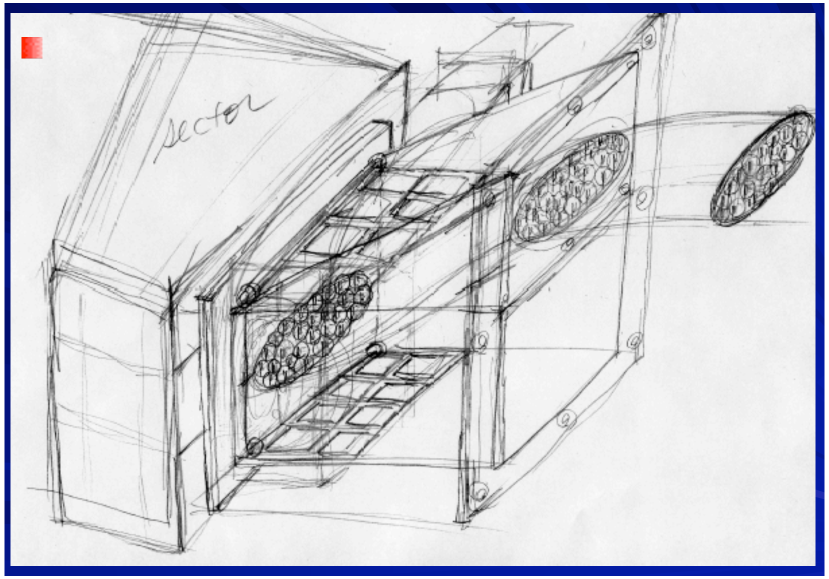
- Beam profile
- Beam oscillation
- Synchrotron freq.
- Betatron tune
- ...

Gallery of Itahashi's drawings









Summary

- PRISM-FFAG is under construction at Osaka-Univ.. Commissioning will be started in 2007.
- High field gradient RF system has been successfully developed. ~170kV/m
- Developing the vertical injection/extraction system.
- Study of commissioning scheme is underway.
- There are a lot of things to be studied for PRISM-FFAG. Please join us to discuss them.