PRISM

Yoshitaka KUNO
Osaka University

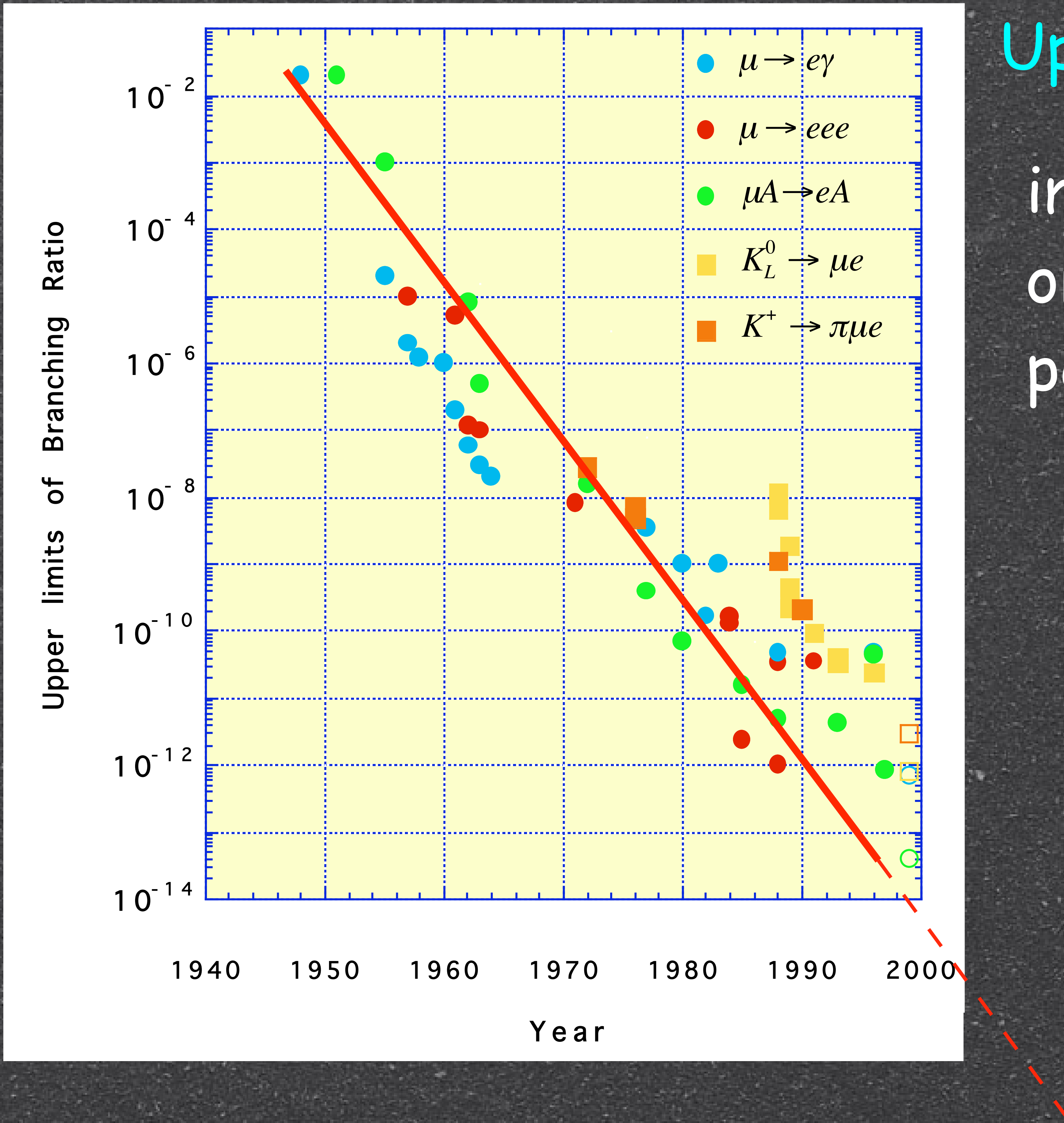
The RHIC/AGS Users Workshop
May 14th, 2004

Outline

- Muon Lepton Flavor Violation
- Experimental
- What is PRISM ?
- PRIME
- PRISM R&D
  - PRISM FFAG Construction
- J-PARC Case (Muon Factory)
- J-PARC Case (Neutrino Factory)
- Conclusion

Lepton Flavor Violation

History of LFV Searches



Upper limits of Searches

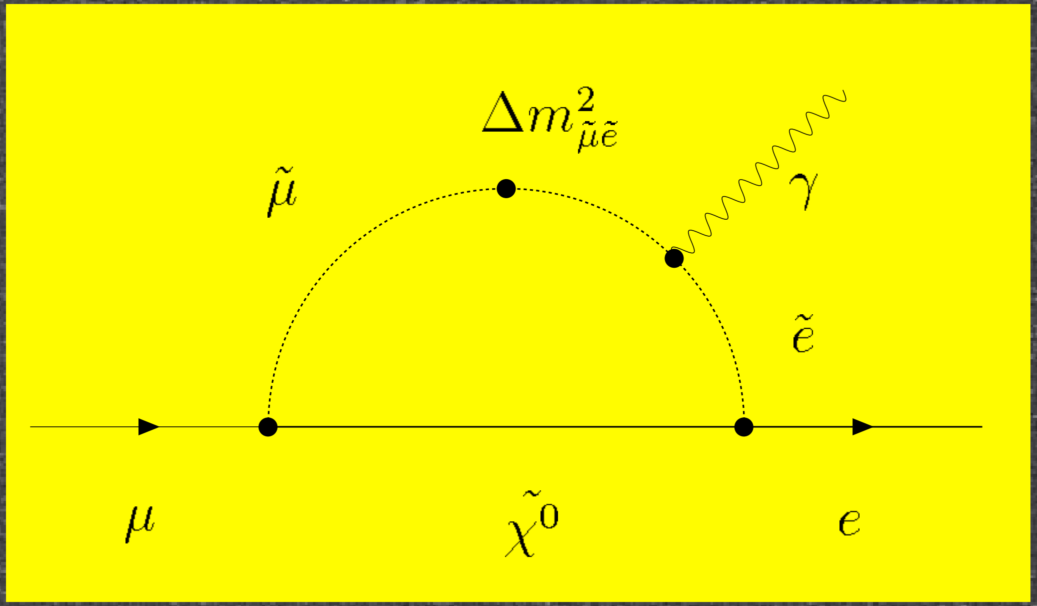
improved by two orders of magnitude per decade.

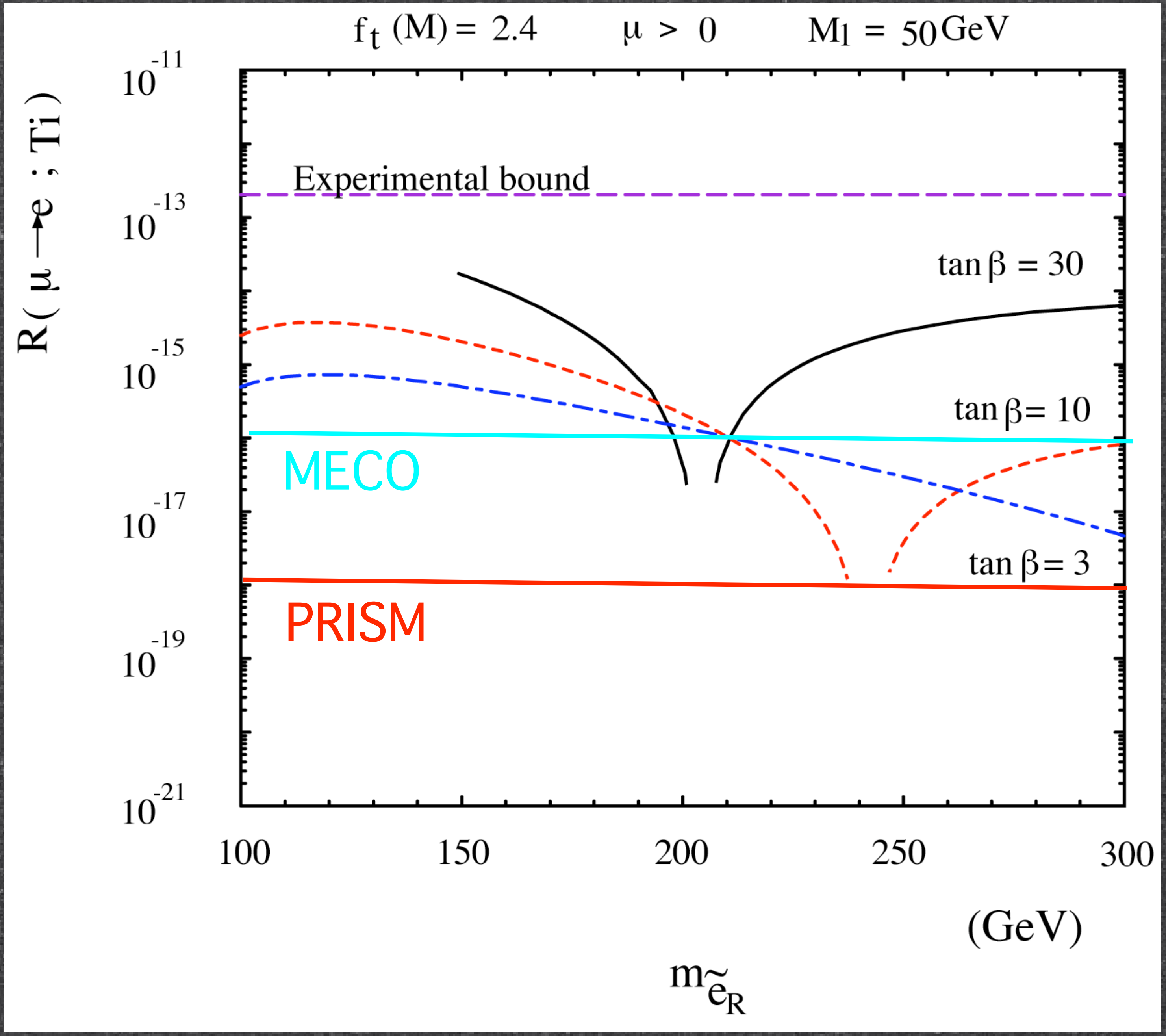
coming to

10^{-16} to 10^{-18}

SUSY-GUT

LFV induced from finite slepton mixing through radiative correction





- SUSY SU(5) predictions

  BR (μ→eγ) ≈ $10^{-14} \div 10^{-13}$

- SUSY SO(10) predictions

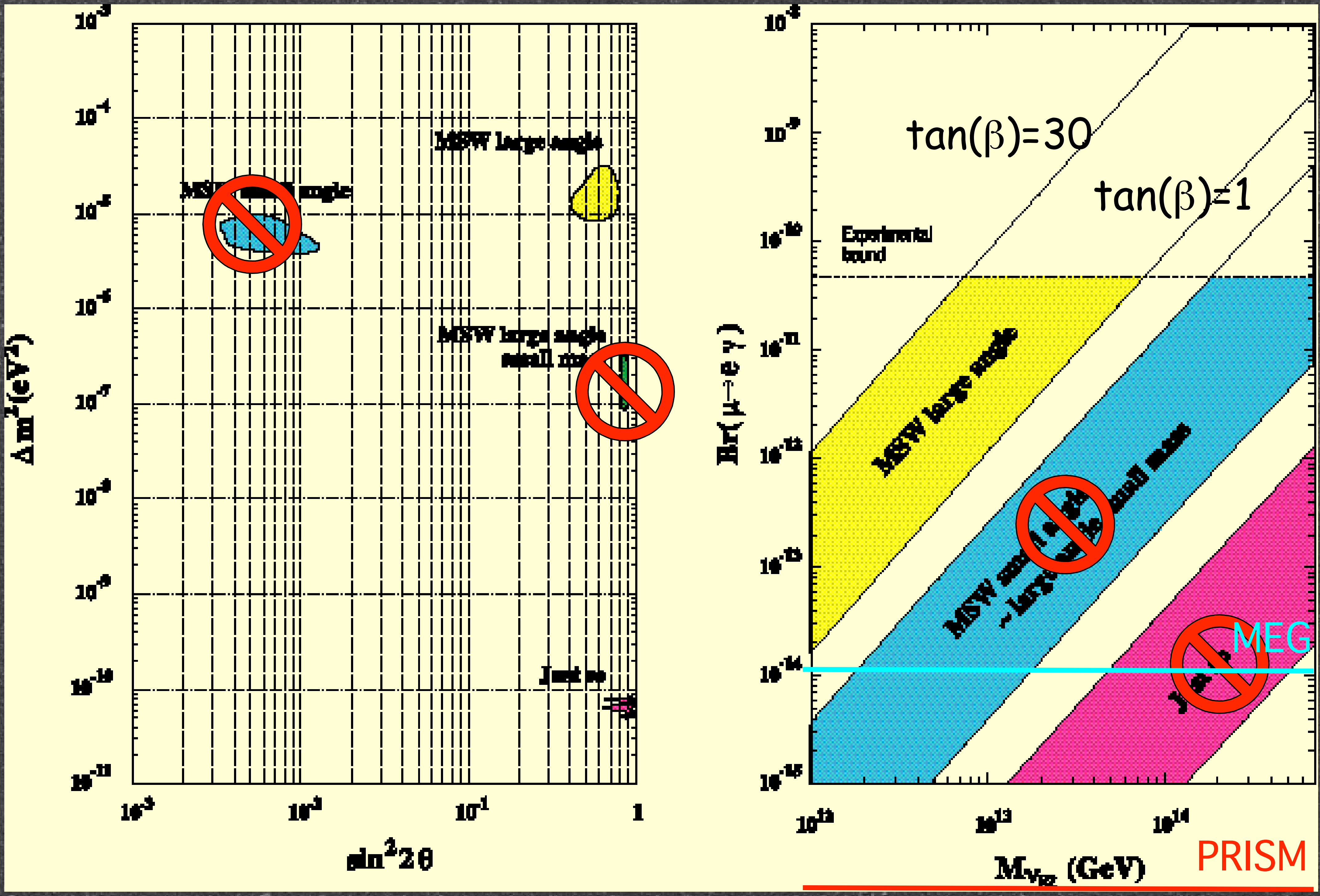
  $BR_{SO(10)} \approx 100\ BR_{SU(5)}$

R. Barbieri *et al.*, Phys. Lett. B338(1994) 212

R. Barbieri *et al.*, Nucl. Phys. B445(1995) 215

MSSM with RH Neutrino

Neutrino Mixing→Slepton Mixing→Charged Lepton Mixing



Why Muon LFVs ?

Reaction	90 % CL upper limit
$B(\mu^+ \to e\gamma)$	4.2×10^{-11}
$B(\mu^+ \to e^+e^-e^+)$	1.0×10^{-12}
$B(\mu^- Ti \to e^- Ti)$	6.1×10^{-13}
$B(\mu^- Pb \to e^- Pb)$	4.6×10^{-11}
$B(\mu^- Ti \to e^+ Ca)$	1.7×10^{-12}
$B(\mu^+e^- \to \mu^-e^+)$	$G_{MM} < 3 \times 10^{-3} G_F$
$B(\tau \to e\gamma)$	2.7×10^{-6}
$B(\tau \to \mu\gamma)$	3.0×10^{-6}
$B(\tau \to \mu\mu\mu)$	1.9×10^{-6}
$B(\tau \to eee)$	3.3×10^{-6}
$B(K_L \to \mu e)$	5.0×10^{-11}
$B(K^+ \to \pi^+\mu^+e^-)$	4.0×10^{-11}
$B(K_L \to \pi^+\mu^+e^-)$	3.2×10^{-9}
$B(D^0 \to \mu e)$	1.9×10^{-5}
$B(D^0 \to \tau e)$	5.3×10^{-4}
$B(D^0 \to \Phi\mu e)$	3.4×10^{-5}
$B(B \to \mu e)$	5.9×10^{-6}
$B(B \to K\mu e)$	1.8×10^{-5}
$B(Z^0 \to \mu e)$	2.3×10^{-6}
$B(Z^0 \to \tau e)$	7.3×10^{-6}
$B(Z^0 \to \tau\mu)$	1.0×10^{-5}

beam will increase by 10^4 (10^6) at MF(NF)

beam will increase by 10^2 at Super-B

The muon might be the best !

LFV Catalog

For the muons,

ΔL=1

- $\mu^+ \to e^+ \gamma$
- $\mu^+ \to e^+ e^+ e^-$
- $\mu^- + N(A,Z) \to e^- + N(A,Z)$

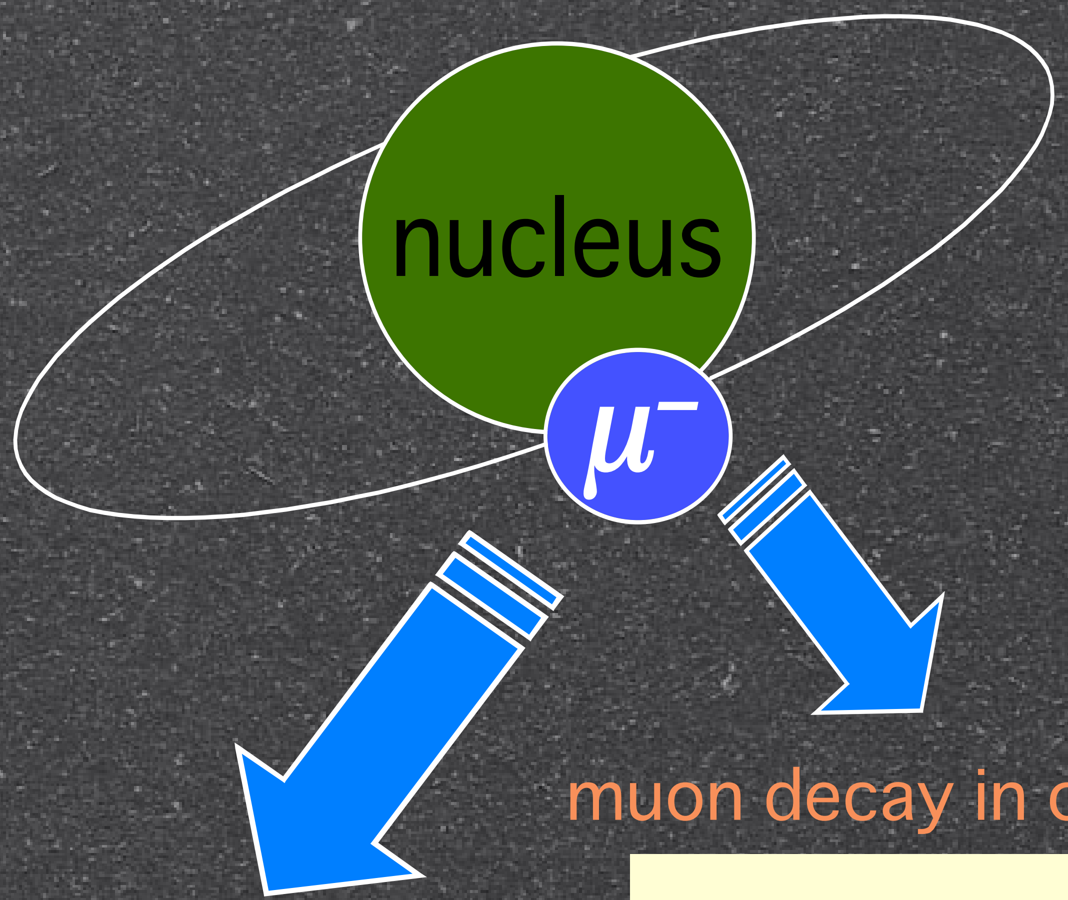
- $\mu^- + N(A,Z) \to e^+ + N(A,Z-2)$

ΔL=2

- $\mu^+ e^- \to \mu^- e^+$
- $\mu^- + N(A,Z) \to \mu^+ + N(A,Z-2)$
- $\nu_\mu + N(A,Z) \to \mu^+ + N(A,Z-1)$
- $\nu_\mu + N(A,Z) \to \mu^+ \mu^+ \mu^- + N(A,Z-1)$

What is μ-e conversion?

1s state in a muonic atom



muon decay in orbit

$$\mu^- \rightarrow e^- \nu \bar{\nu}$$

nuclear muon capture

$$\mu^- + (A, Z) \rightarrow \nu_\mu + (A, Z-1)$$

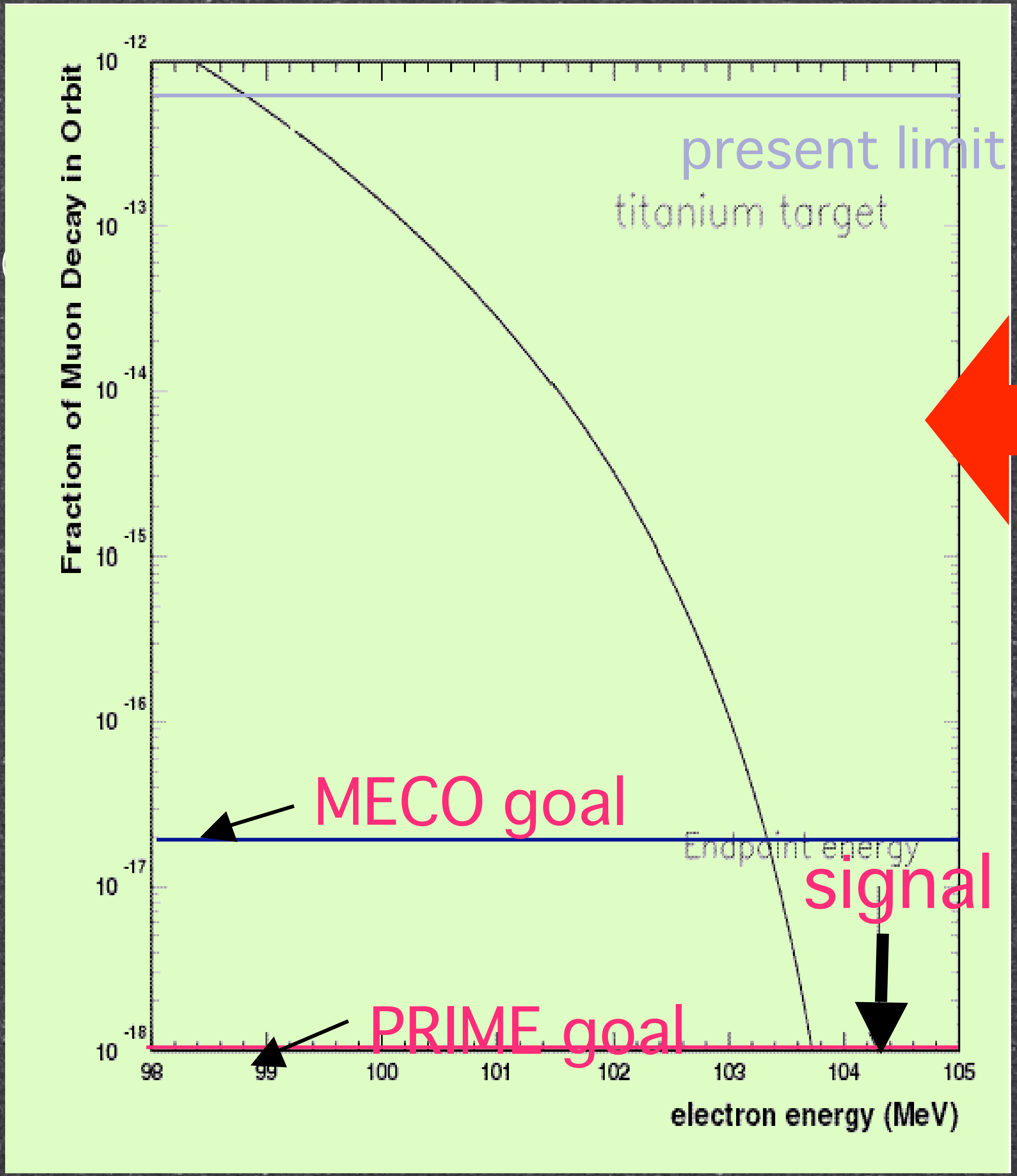
Neutrino-less muon nuclear capture (=μ-e conversion)

$$\mu^- + (A, Z) \rightarrow e^- + (A, Z)$$

lepton flavors changes by one unit.

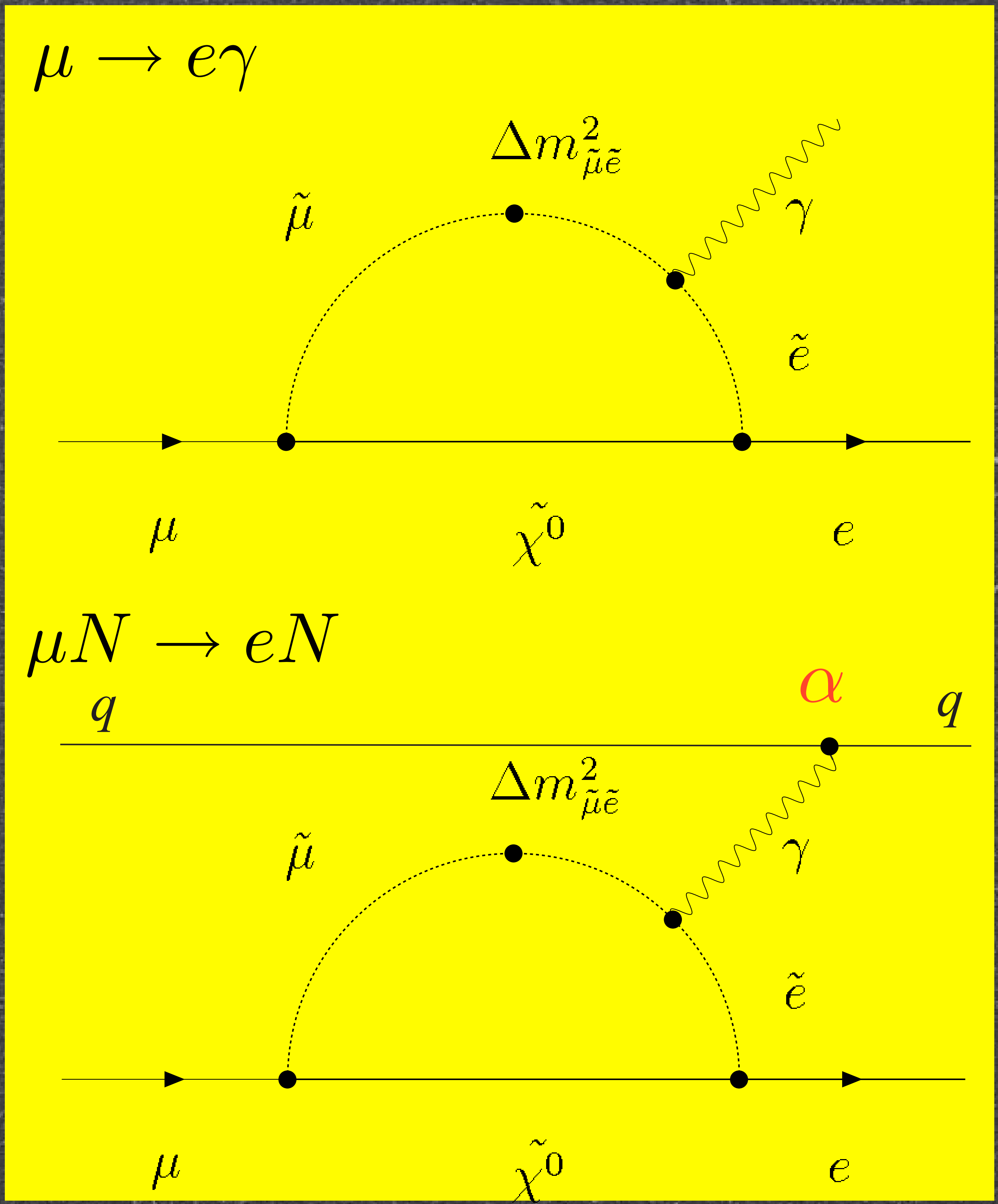
$$B(\mu^- N \rightarrow e^- N) = \frac{\Gamma(\mu^- N \rightarrow e^- N)}{\Gamma(\mu^- N \rightarrow \nu N')}$$

μ-e conversion Signal & Backgrounds



- Backgrounds
  - muon decay in orbit
    - endpoint comes to the signal
    - $\propto (\Delta E)^5$
  - radiative muon capture
  - radiative pion capture
    - pulsed beam required
    - wait until pions decay.
  - cosmic rays
  - and many others.

Photon-mediated LFV



$\mu - e$ conversion vs. $\mu \to e\gamma$

If photon-mediated,

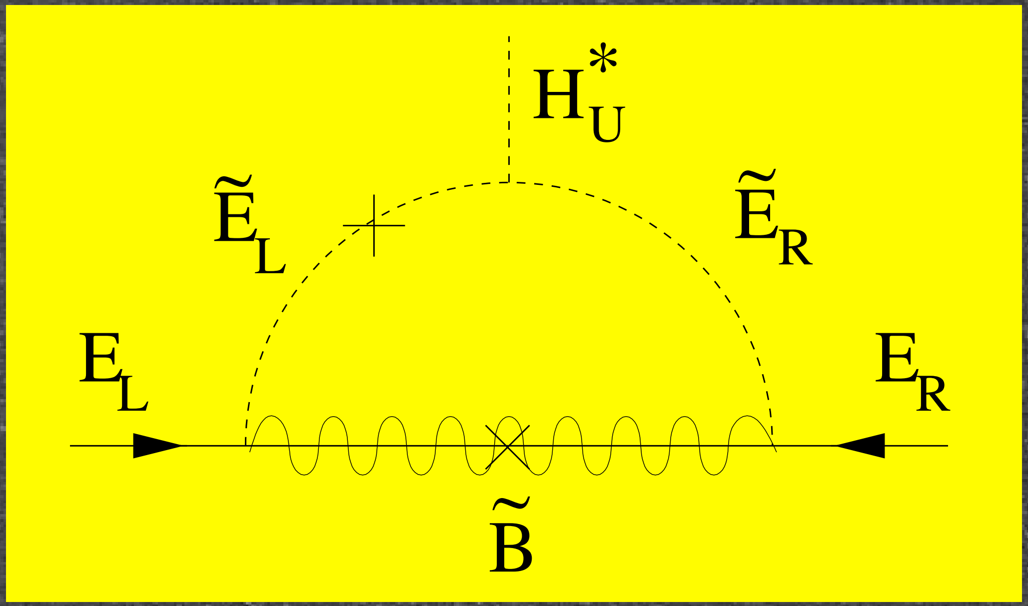
$$\frac{B(\mu N \to eN)}{B(\mu \to e\gamma)} \sim \frac{1}{100}$$

But, experimentally,

$\mu \to e\gamma$	$< 1.2 \times 10^{-11}$
$\mu N \to eN$	$< 6 \times 10^{-13}$

Higgs-mediated SUSY LFV

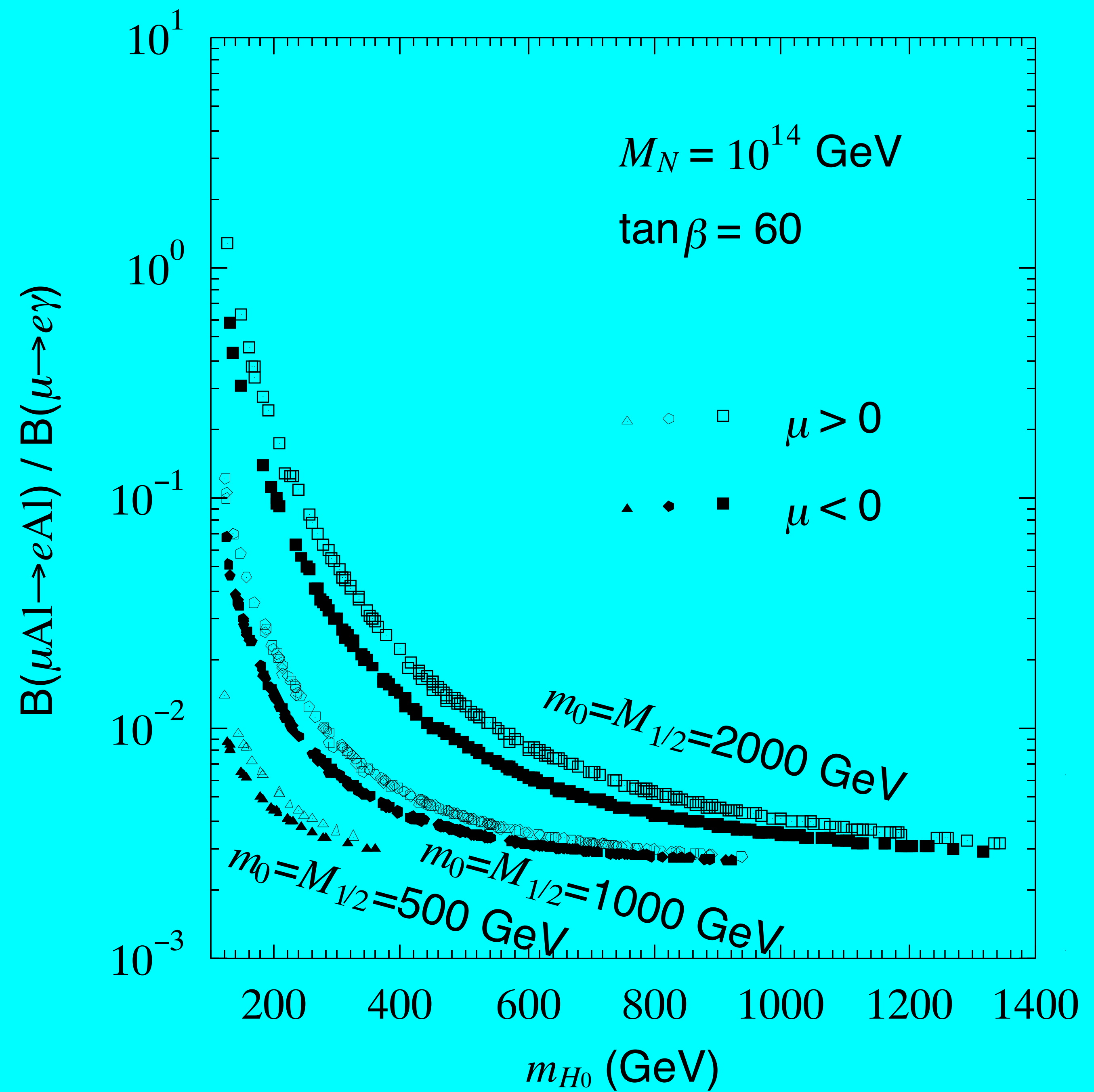
Higgs-exchange for LFV in SUSY Seesaw model



When H_0 mass is small, Higgs-mediated diagram contributes more.

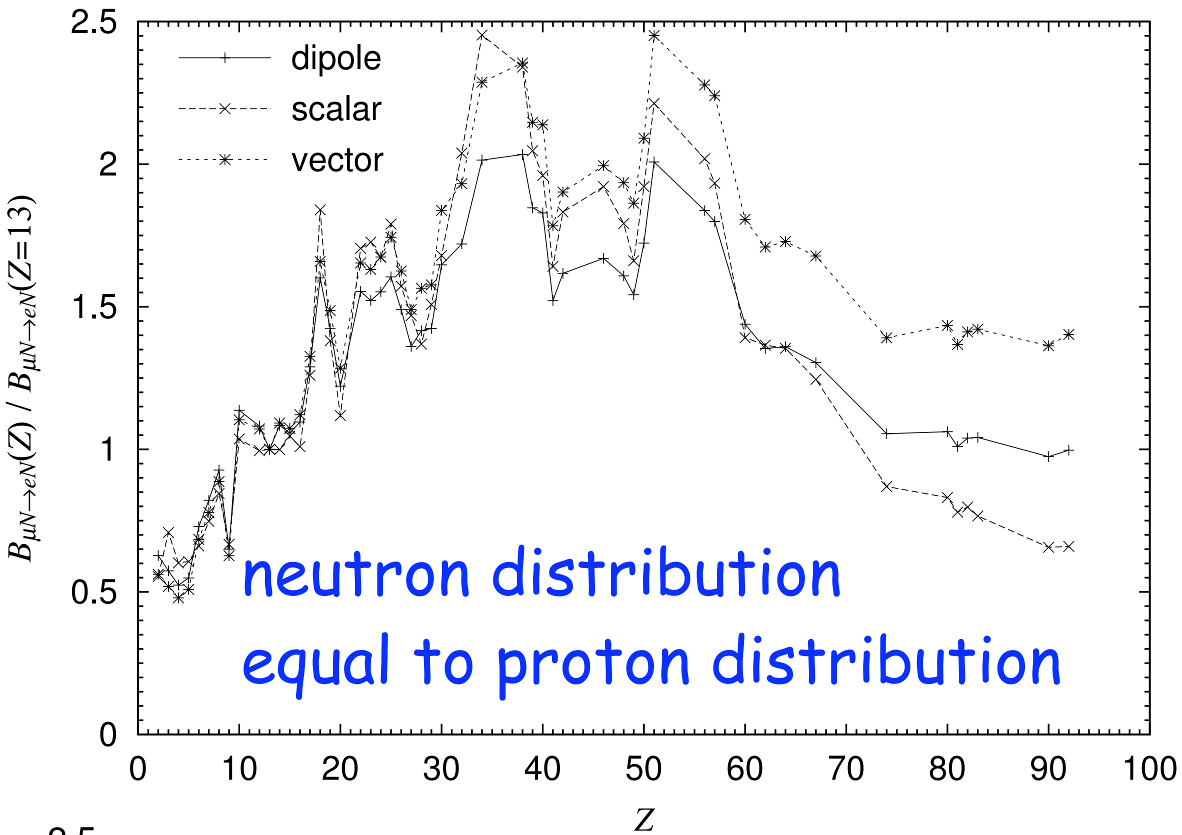
$$\frac{B(\mu N \to eN)}{B(\mu \to e\gamma)} \sim O(1)$$

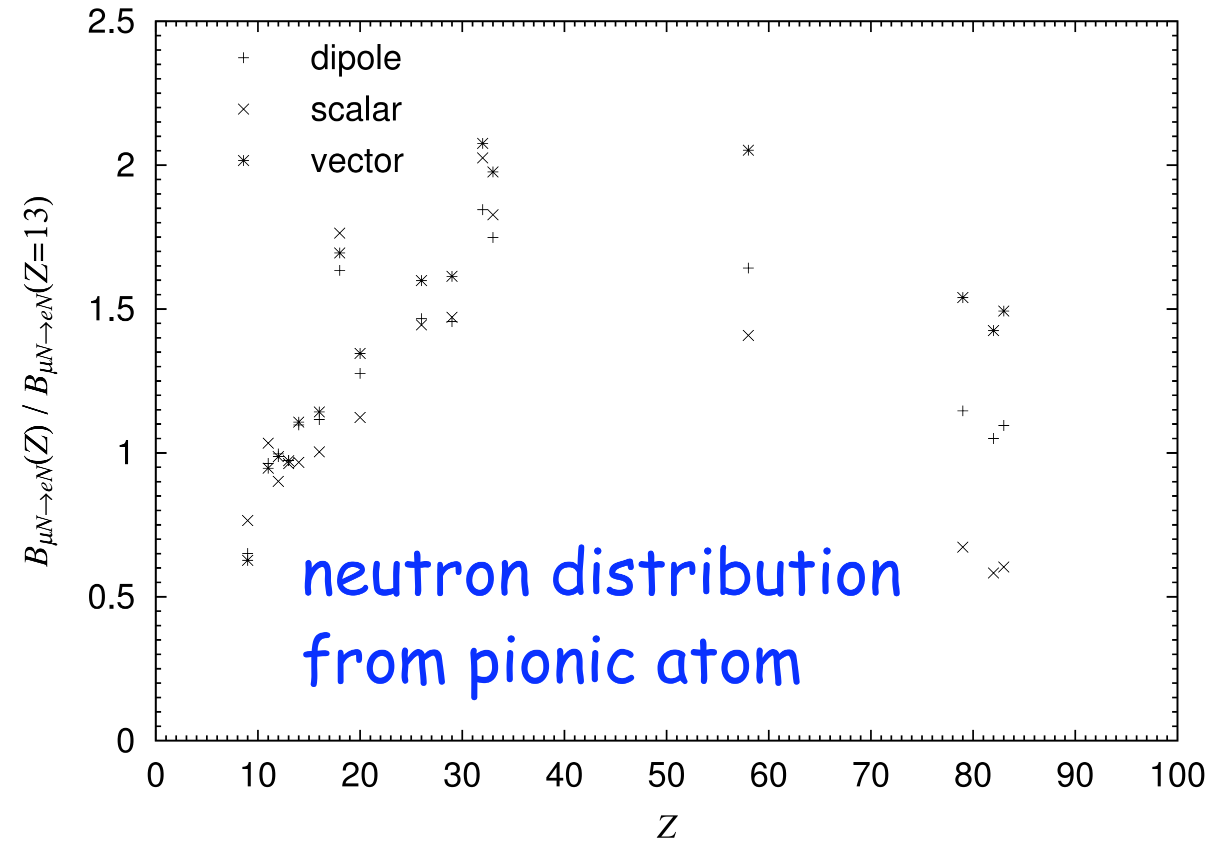
at $H_0 \sim 200$ GeV

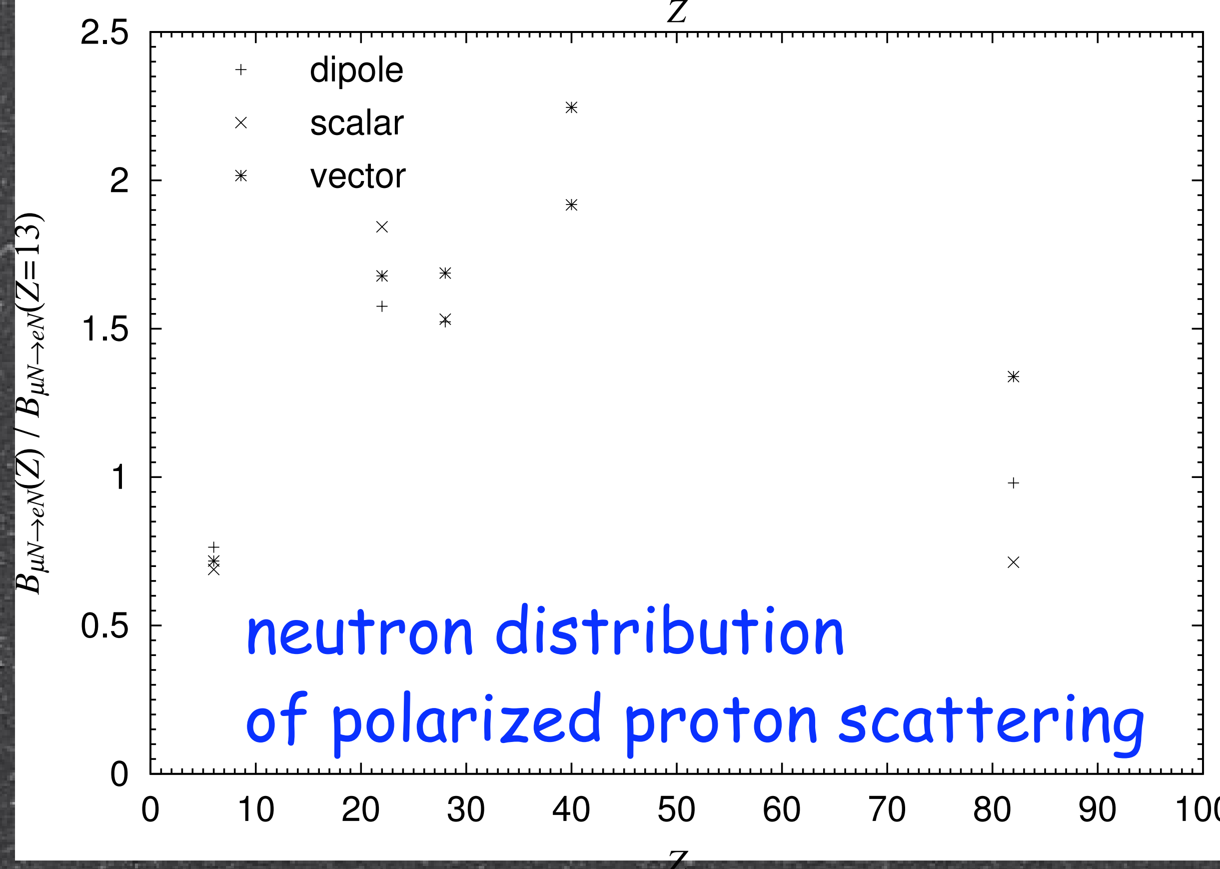


Kitano, Koike, Komine, Okada

Z dependence



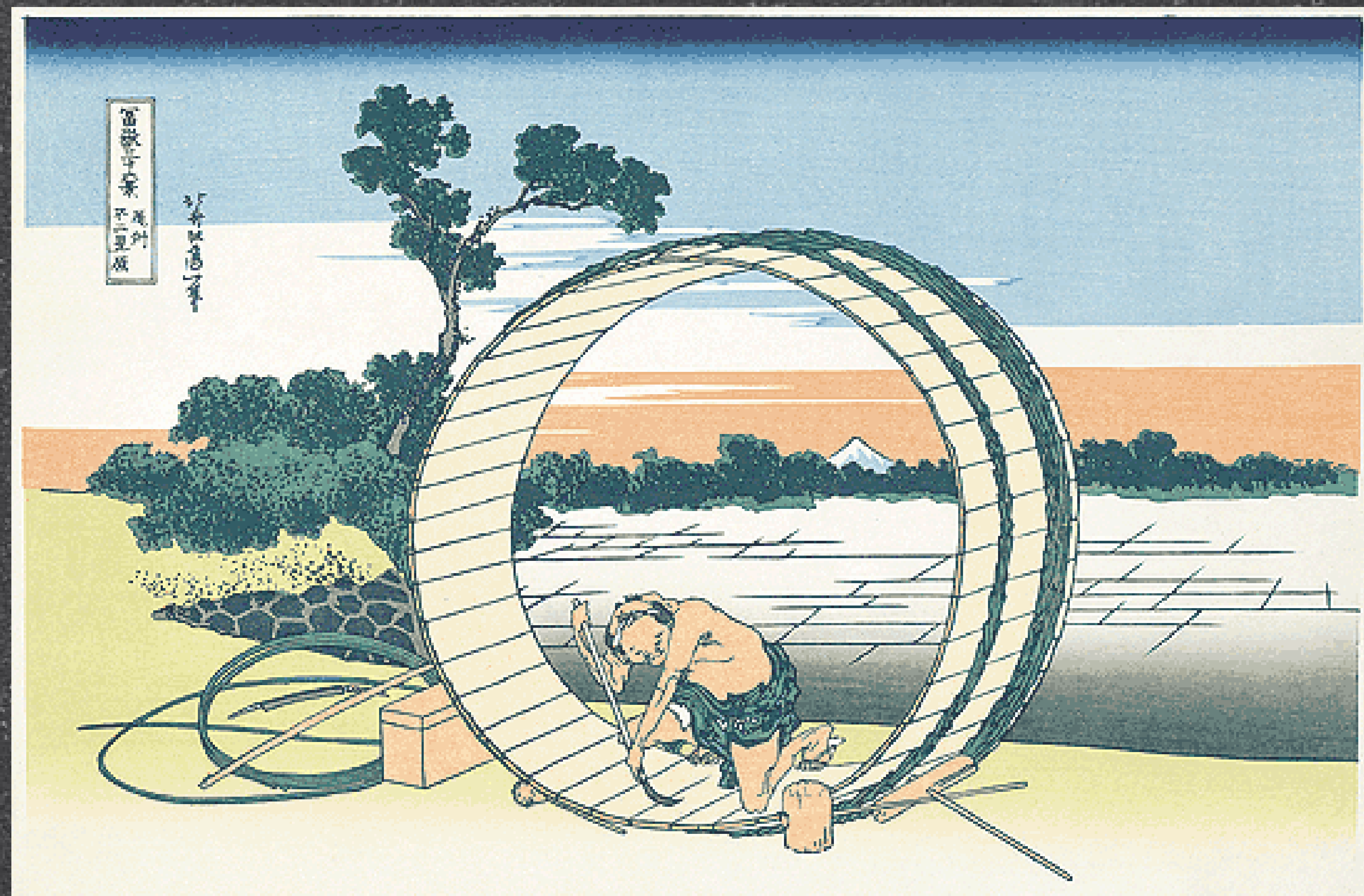




normalized at Al target.

For heavy target, difference of the interactions might be seen ?

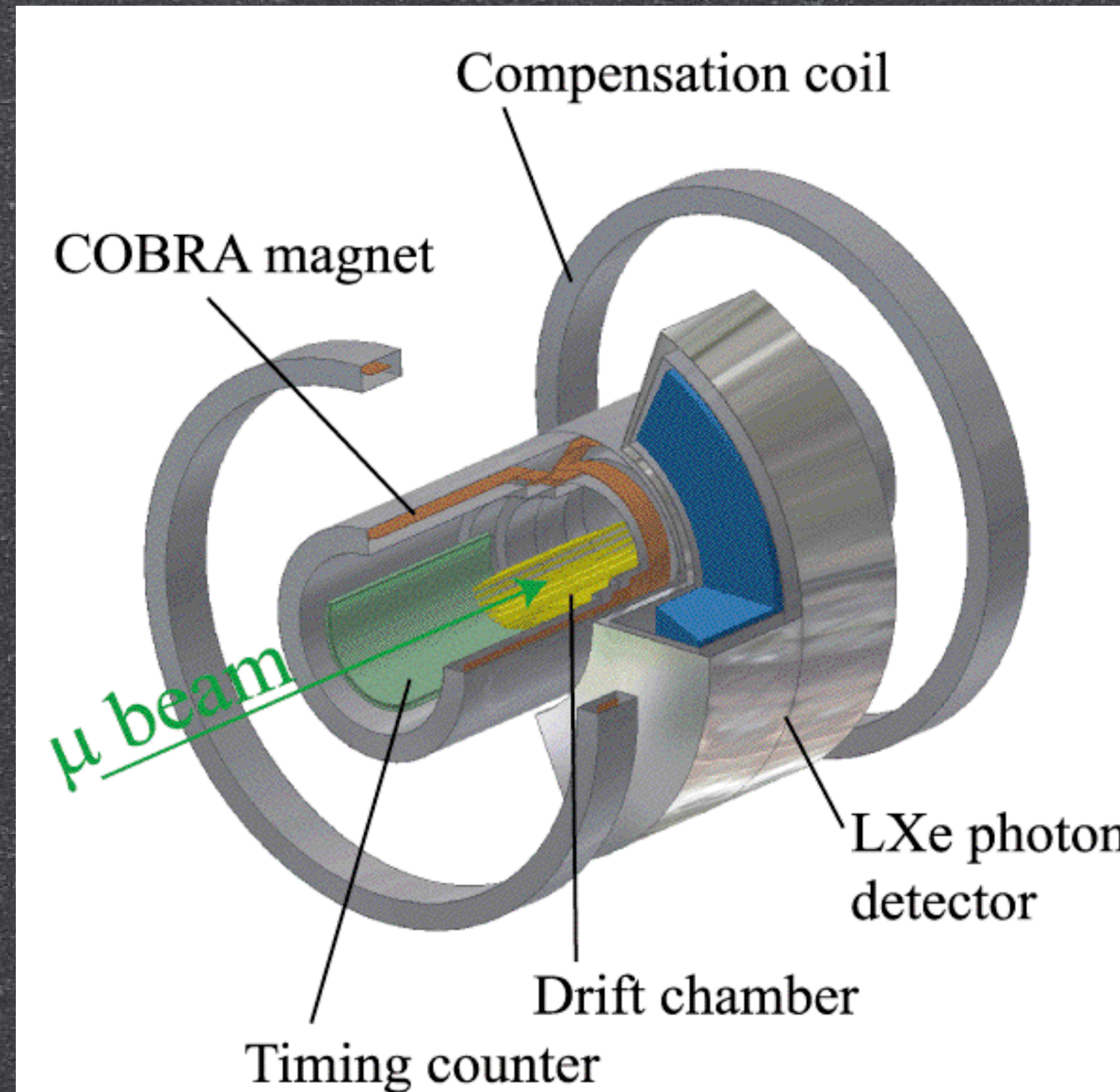
R. Kitano, M. Koike, and Y. Okada, 2002

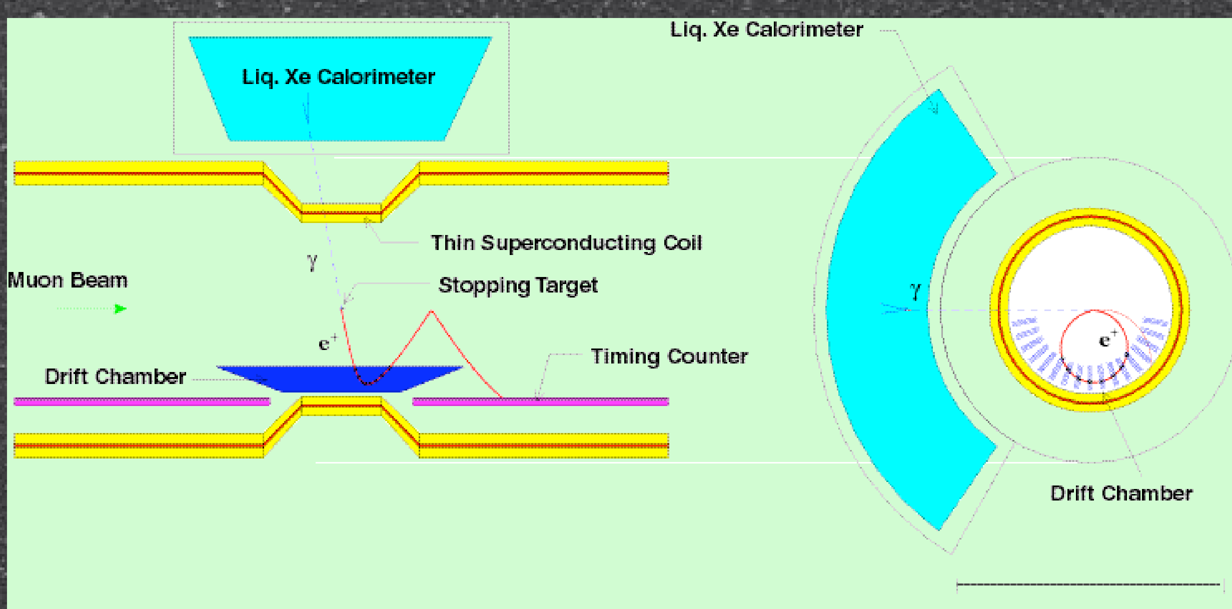


Experimetal

MEG at PSI

- $\mu \rightarrow e\ \gamma$
  - MEG at PSI, 2004~
    - DC beam 10^{8} μ/s
    - BR~10^{-13}
  - Accidental background
  - Detector Improvement
  - Polarization





Accidental Background

$$\text{Accidental Background} \propto \left(R_\mu\right)^2 \times \Delta E_e \times \left(\Delta E_\gamma\right)^2 \times \Delta t_{e\gamma} \times \left(\Delta\theta_{e\gamma}\right)^2$$

Place	Year	ΔE_e	ΔE_γ	$\Delta t_{e\gamma}$	$\Delta\theta_{e\gamma}$	R_μ	Upper Limit	References
SIN	1977	8.7%	9.3%	1.4 ns	-	5×10^5	$< 1.0 \times 10^{-9}$	A. Van der Schaaf, *et al.*, NP A340(1980)249
TRIUMF	1977	10%	8.7%	6.7 ns	-	2×10^5	$< 3.6 \times 10^{-9}$	P. Depommier *et al.*, PRL 39(1977)1113
LANL	1979	8.8%	8%	1.9 ns	37 mrad	2.4×10^6	$< 1.7 \times 10^{-10}$	W.W. Kinnison *et al.*, PR D25(1982)2846
Crystal Box	1986	8%	8%	1.8 ns	87 mrad	4×10^5	$< 4.9 \times 10^{-11}$	R.D. Bolton, *et al.*, PR D38(1988)2077
MEGA	1999	1.2%	4.5%	1.6 ns	17 mrad	2.5×10^8	$< 1.2 \times 10^{-11}$	M.L. Brooks, *et al.*, PRL 83(1999)1521
PSI	2004?	0.7%	1.4%	0.15 ns	12 mrad	10^8	$< 10^{-14}$	T. Mori, *et al.*, Research Proposal to PSI (1999)

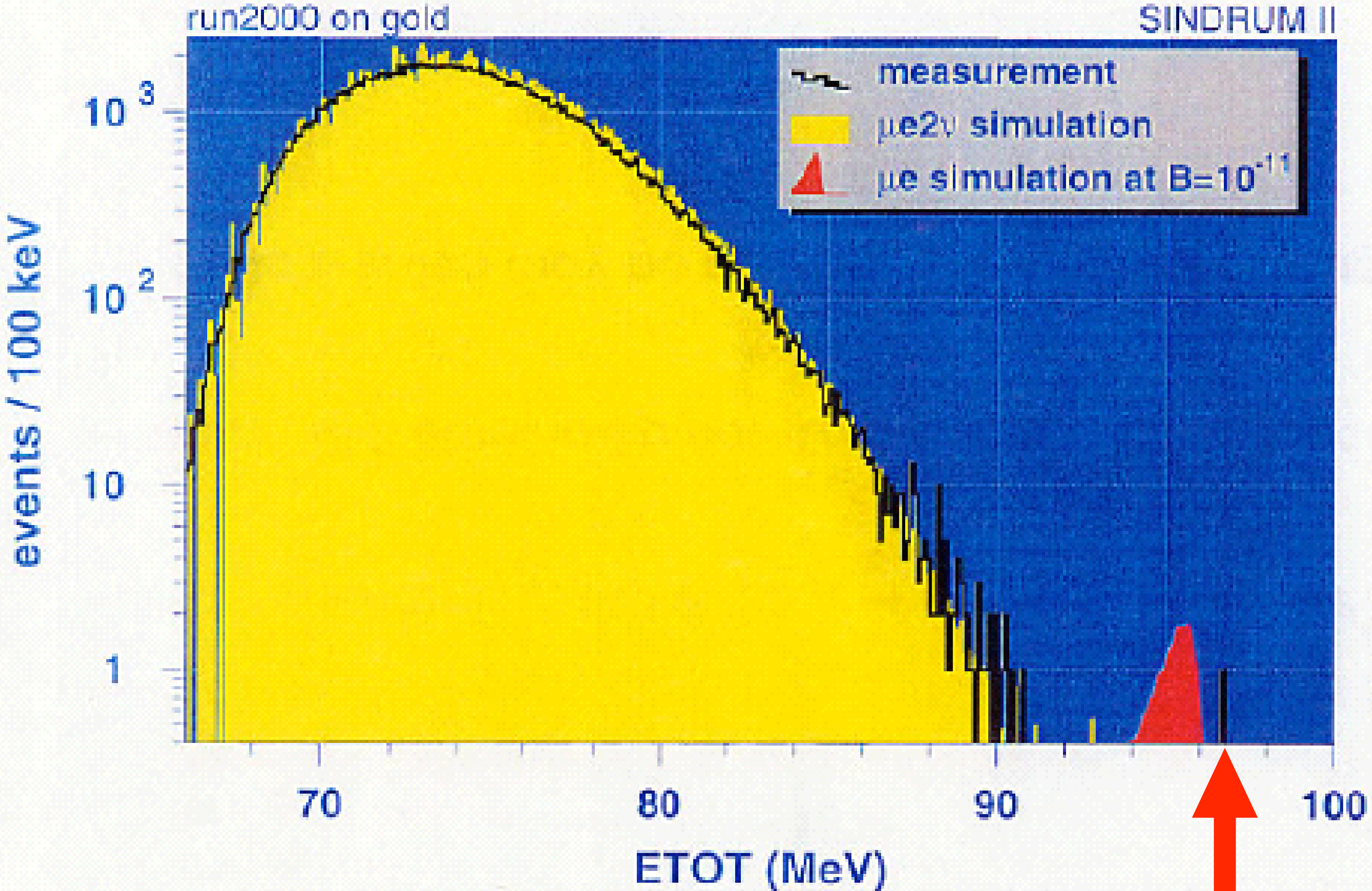
$B_{\mu\to e\gamma} = 10^{-14}$
$N_b = 0.5$ events

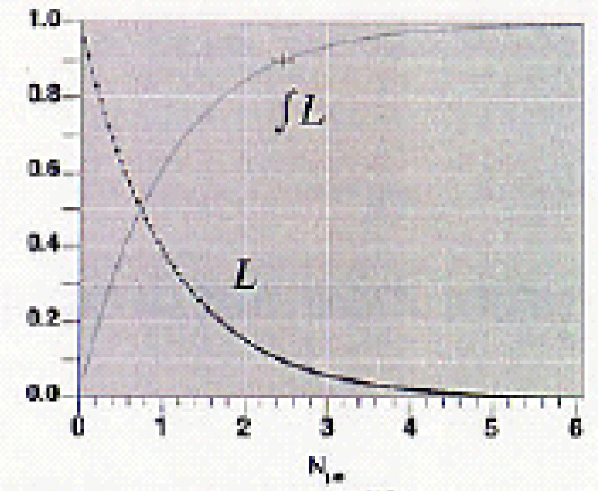
$B_{\mu\to e\gamma} = 10^{-16}$
- $R_\mu = 10^{10}$ μ/s
- $N_b \sim 10^4$ events?

SINDRUM-II Results

Final result

μe Conversion on Gold





$\mathcal{L}(N_{\mu e})$ and $\int_0^{N_{\mu e}^{max}} \mathcal{L}(n)dn.$

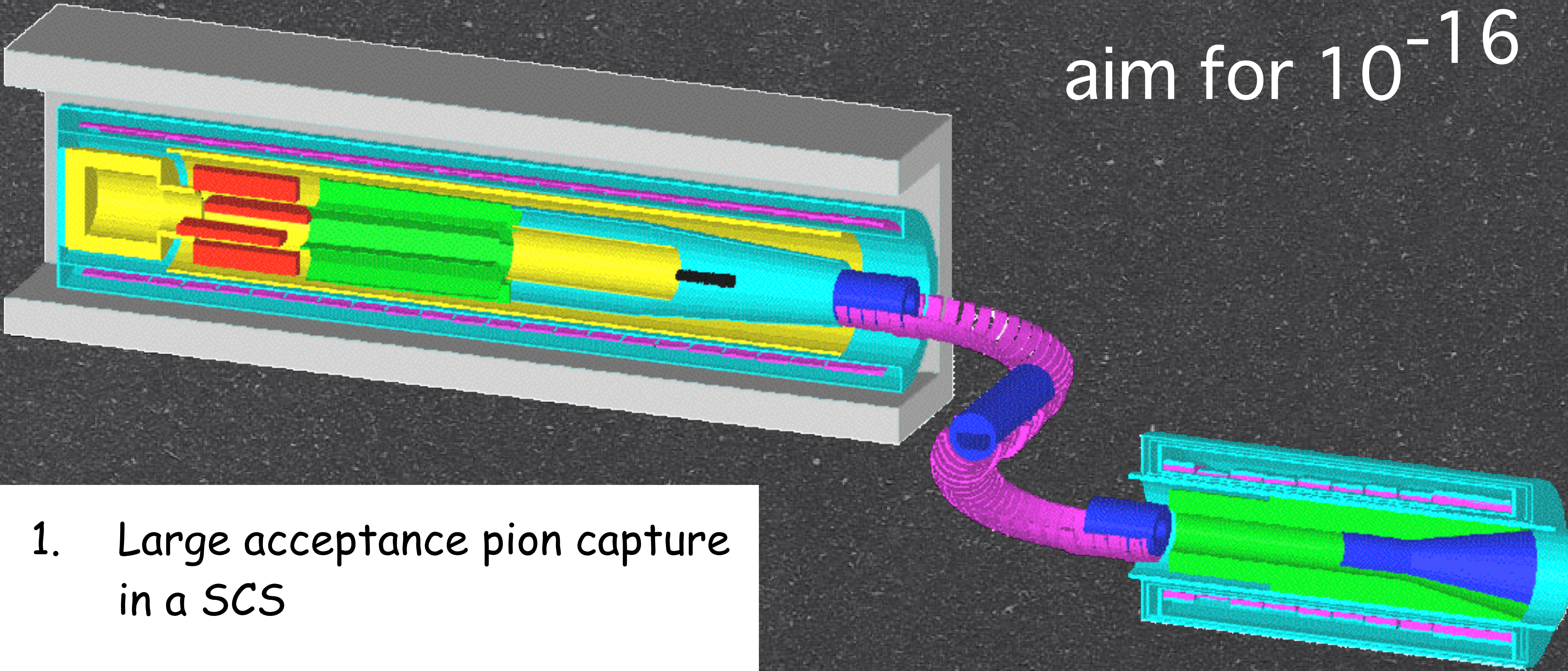
μ^- stops	$4.4 \pm 0.3 \times 10^{13}$
$f_{cap} \times \Omega \times \epsilon_{tot}$	7.0%
single event sensitivity	$3.3 \pm 0.2 \times 10^{-13}$
90% C.L. limit	2.45 events

In the likelihood analysis of the energy distribution a flat background from cosmic rays and radiative pion capture was allowed.

Result: $B_{\mu e}^{\text{gold}} < 8 \times 10^{-13}$ 90% C.L.

MECO at BNL

aim for 10^{-16}



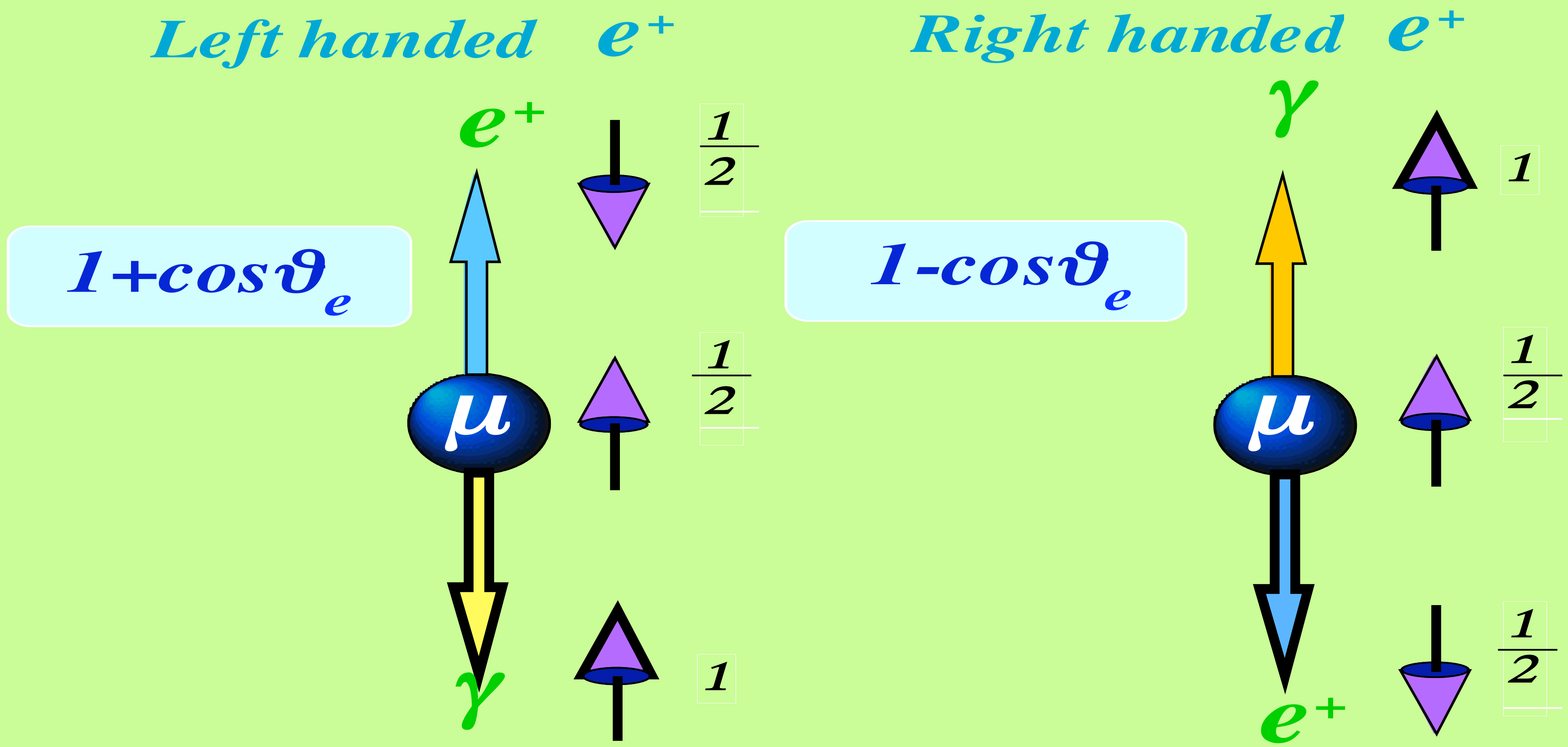
1. Large acceptance pion capture in a SCS
2. Muon transport (60 – 120 MsV/c) in a curved solenoid
3. Long detector solenoid with muon stpping target and tracking system

Bill's talk

Go Further...

- If MECO finds the signal, precision studies are needed with higher statistics.
- If MECO does not find the signal, further searches are highly desirable.
- In any case, a muon beam of high intensity and high quality is needed to go beyond.

Polarization in LFV



useful to distinguish different theoretical models

SU(5) SUSY-GUT	*non-unified SUSY with heavy neutrino* *Left-right symmetric model*

SO(10) SUSY-GUT

Y.Kuno and Y. Okada, Physical Review Letters 77 (1996) 434

Y.Kuno, A. Maki and Y. Okada, Physical Reviews D55 (1997) R2517-2520

applicable to mu-e conversion, although the muon polarization is smaller (1/6) in a muonic atom.

Which Muon LFV Process Next ?

	issue	beam requirement
$\mu \longrightarrow e\gamma$	detector-limited	a continuos beam
$\mu \longrightarrow eee$	detector-limited	a continuos beam
$\mu N \longrightarrow eN$	beam-limited	a pulsed beam

Beam Requirements for μ-e conversion

Beam is critical element for μ-e conversion

MECO

- Higher muon intensity
  - more than 10^{12} μ^-/sec
- pulsed beam
  - rejection of background from proton beam

- Less beam contamination
  - no pion contamination
    - ⇛ long flight path
  - beam extinction between pulses
    - ⇛ kicker magnet

- Narrow energy spread
  - allow a thinner muon-stopping target
    - ⇛ better e^- resolution and acceptance

- Point Source
  - allow a beam blocker behind the target
    - ⇛ isolate the target and detector
    - ⇛ tracking close to a beam axis

PRISM

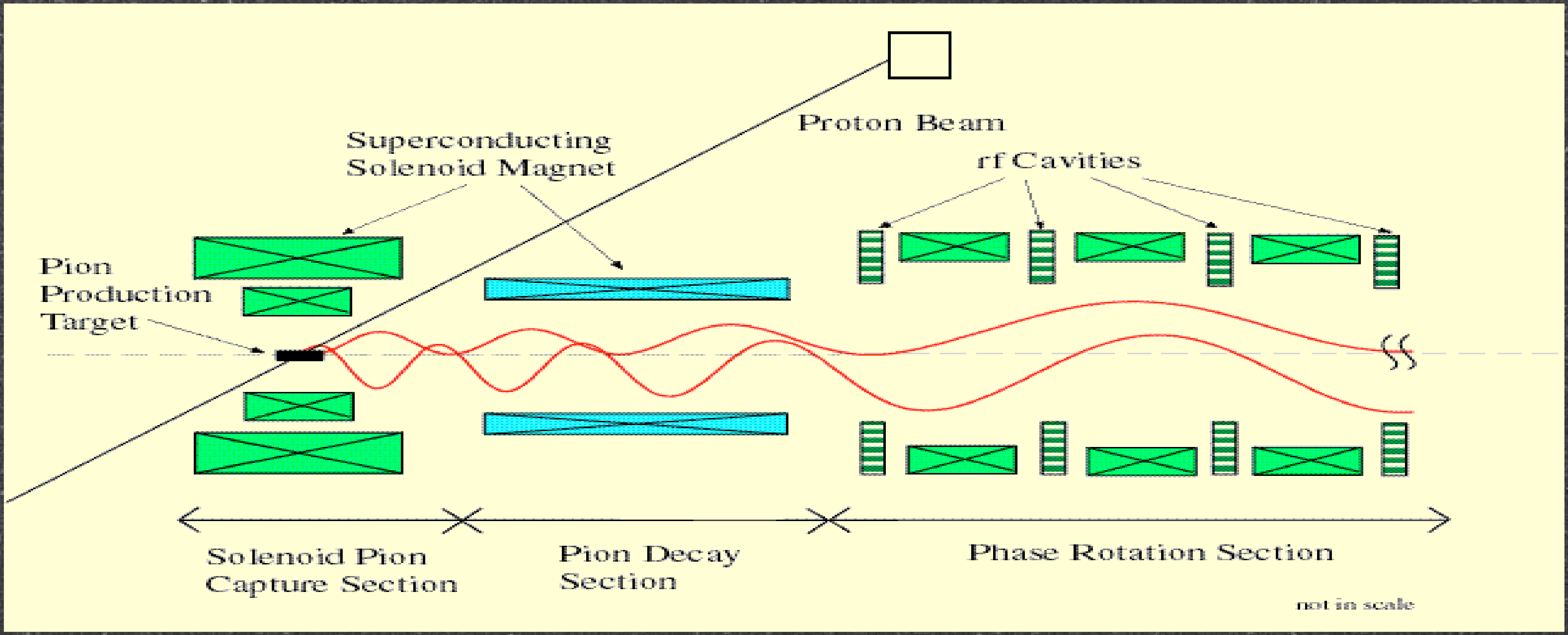
What is PRISM ?

PRISM

PRISM=Phase Rotated Intense Slow Muon source

PRISM is a high intensity muon source with narrow energy spread and high purity.

- high intensity: (Solenoid Pion Capture)
- narrow momentum width: (Phase rotation)
- small emittance (in future): (Cooling)

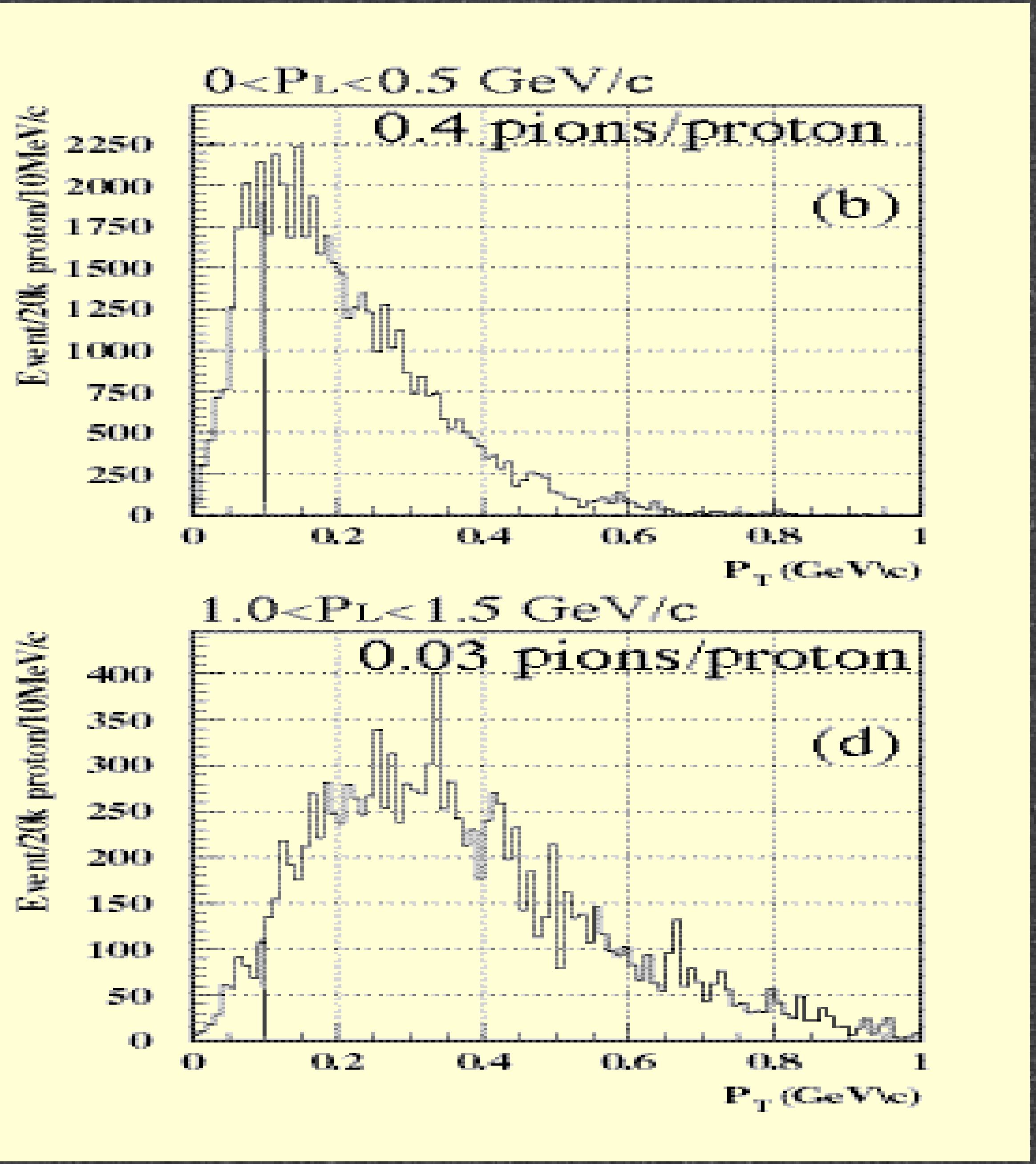


Solenoid Pion Capture

- maximum transverse momentum

$$P_T(MeV/c) = 0.3 \times H(kG) \times \left(\frac{R}{2}\right)(cm)$$

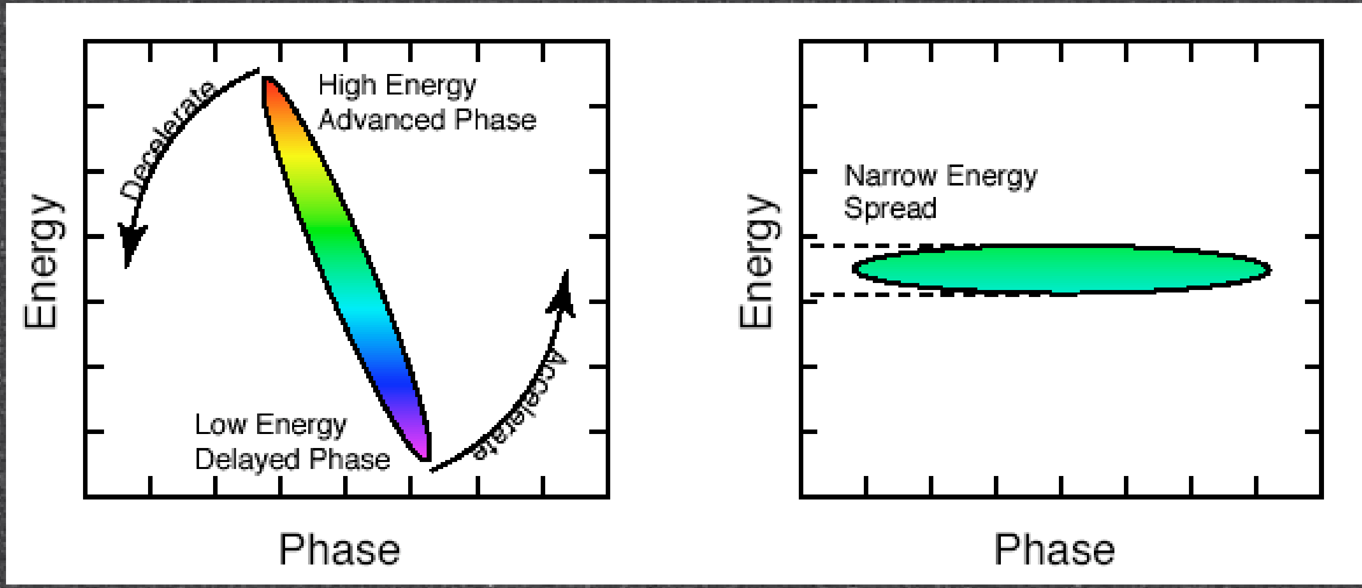
  - *R* : radius of magnet
  - *ex: H*=120kG(=12T), *R*=5cm
    - $P_T < 90$ *MeV/c*
- capture yields



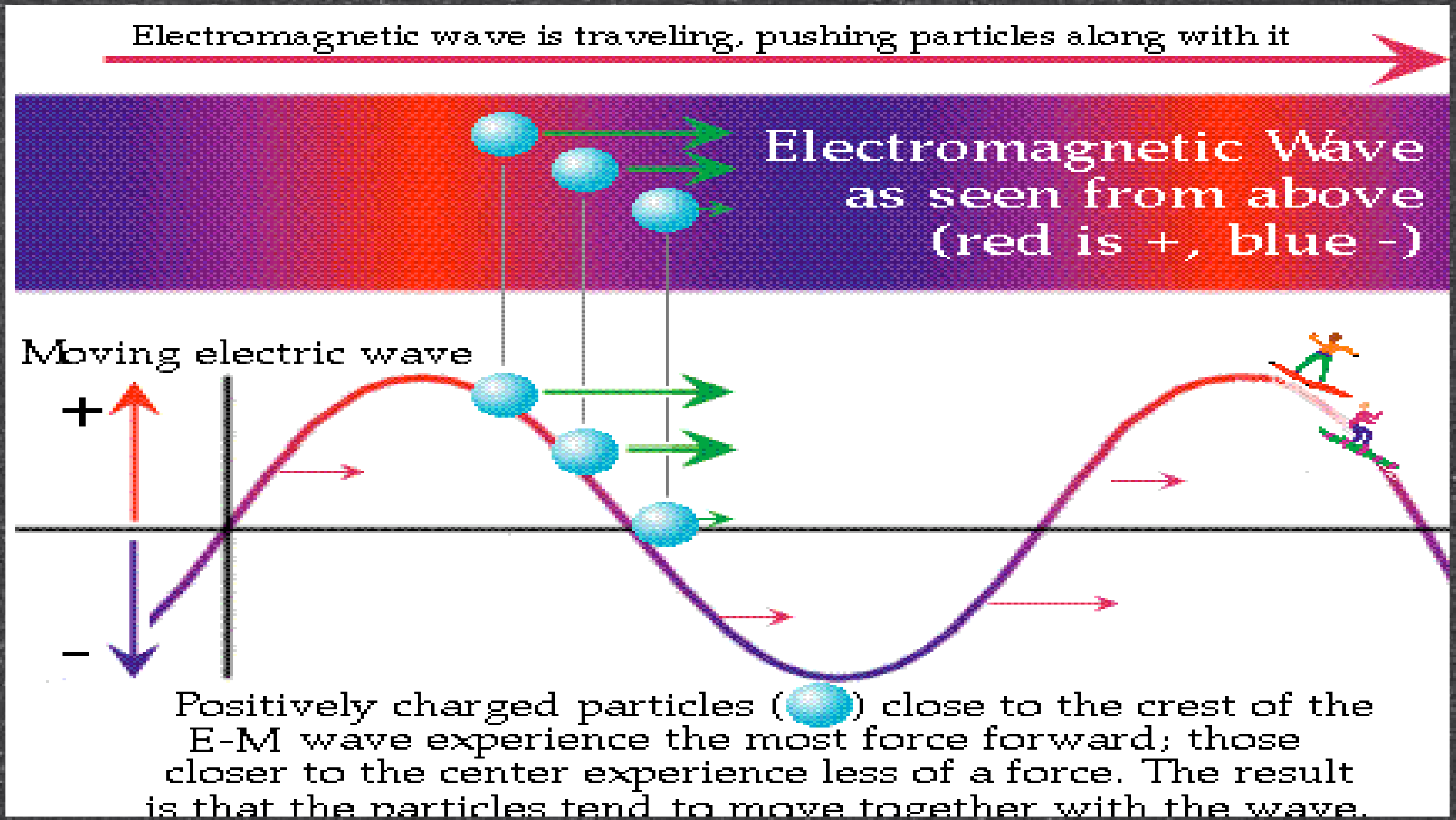
for 50GeV protons

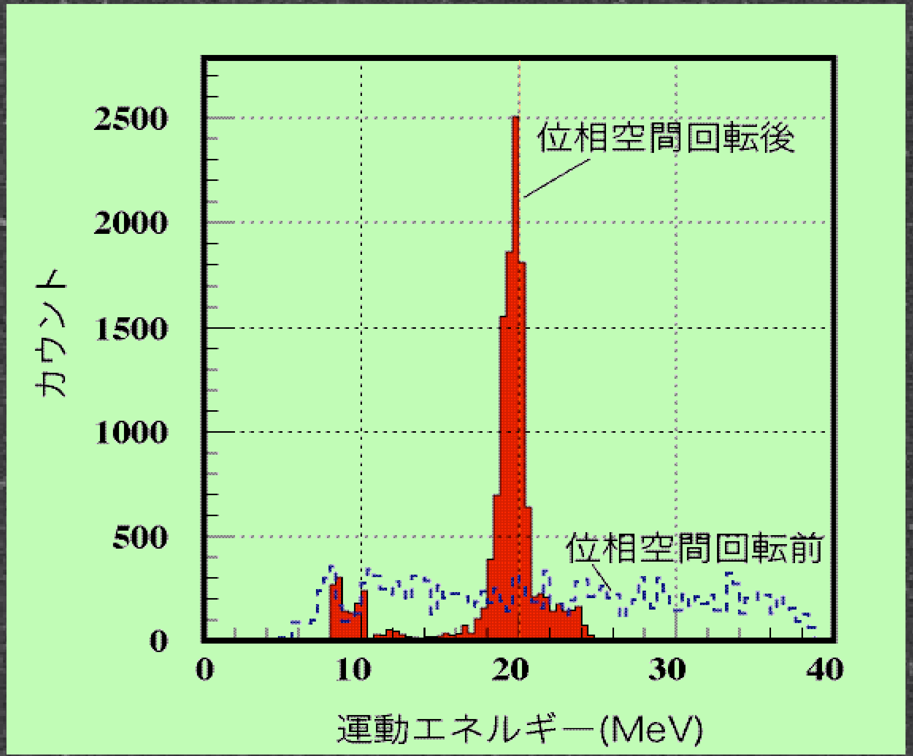
What is Phase Rotation ?

Phase rotation = decelerate particles with high energy and accelerate particle with low energy by high-field RF so as to make the energy spread narrower.



If proton bunch is narrow, high-energy particles come earlier and low-energy particles come late.





FFAG for Phase Rotation

- a ring instead of linear systems
  - reduction of # of rf cavities
  - reduction of rf power consumption
  - compact

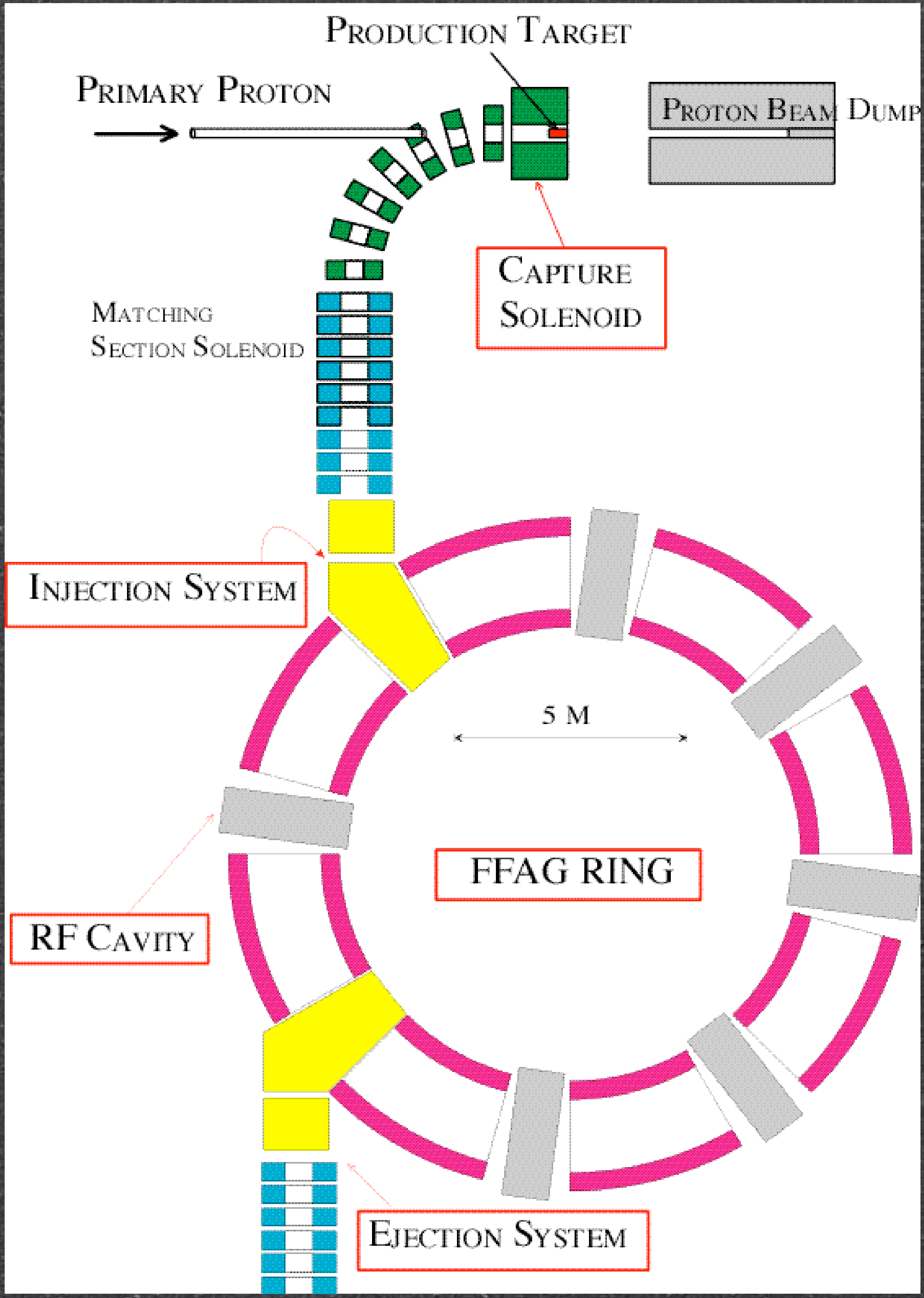
FFAG = Fixed Field Alternating Gradient Synchrotron

- synchrotron oscillation for phase rotation
  - not cyclotron (isochronous)
- large momentum acceptance
  - larger than synchrotron
  - ± several 10 % is aimed
- large transverse acceptance
  - strong focusing
  - large horizontal emittance
  - reasonable vertical emittance at low energy

PRISM

PRISM=Phase Rotated Intense Slow Muon source

- Specifications
  - muon intensity: 10^{11}~10^{12} /sec
  - central momentum: 68 MeV/c
  - momentum width: 3 % (<--- 30 %)
    - by phase rotation (5turns)
  - Repetition : 100 Hz
  - pion contamination : 10^{-18} for 150m



PRISM Yield Estimation

estimated by simulations.

depend on technology choice、and not fully optimized yet.

Target material	Capture field	Transport field	Muon yield per 10^{14} protons	Muon yield per 4×10^{14} protons
Graphite	16 T	4 T	4.8×10^{10}	19×10^{10}
	16 T	2 T	3.6×10^{10}	14×10^{10}
	12 T	4 T	3.6×10^{10}	14×10^{10}
	12 T	2 T	3.0×10^{10}	12×10^{10}
	8 T	4 T	3.0×10^{10}	12×10^{10}
	8 T	2 T	2.4×10^{10}	9.6×10^{10}
	6 T	4 T	1.8×10^{10}	7.2×10^{10}
	6 T	2 T	1.8×10^{10}	7.2×10^{10}
Tungsten	16 T	4 T	13×10^{10}	50×10^{10}
	16 T	2 T	11×10^{10}	46×10^{10}
	12 T	4 T	9.6×10^{10}	38×10^{10}
	12 T	2 T	9.0×10^{10}	36×10^{10}
	8 T	4 T	6.0×10^{10}	24×10^{10}
	8 T	2 T	7.2×10^{10}	29×10^{10}
	6 T	4 T	4.2×10^{10}	17×10^{10}
	6 T	2 T	4.8×10^{10}	19×10^{10}

Target length
  3 interaction length
FFAG acceptance
  H:20000πmm mrad
  V:3000π mm mrad
$\varepsilon_{dispersion} = 100\%$
$\varepsilon_{FFAG} = 100\%$

for 50 GeV protons of 10^{14}/sec (0.75 MW).

PRIME

PRIME

PRIME = PRIsm Mu E experiment

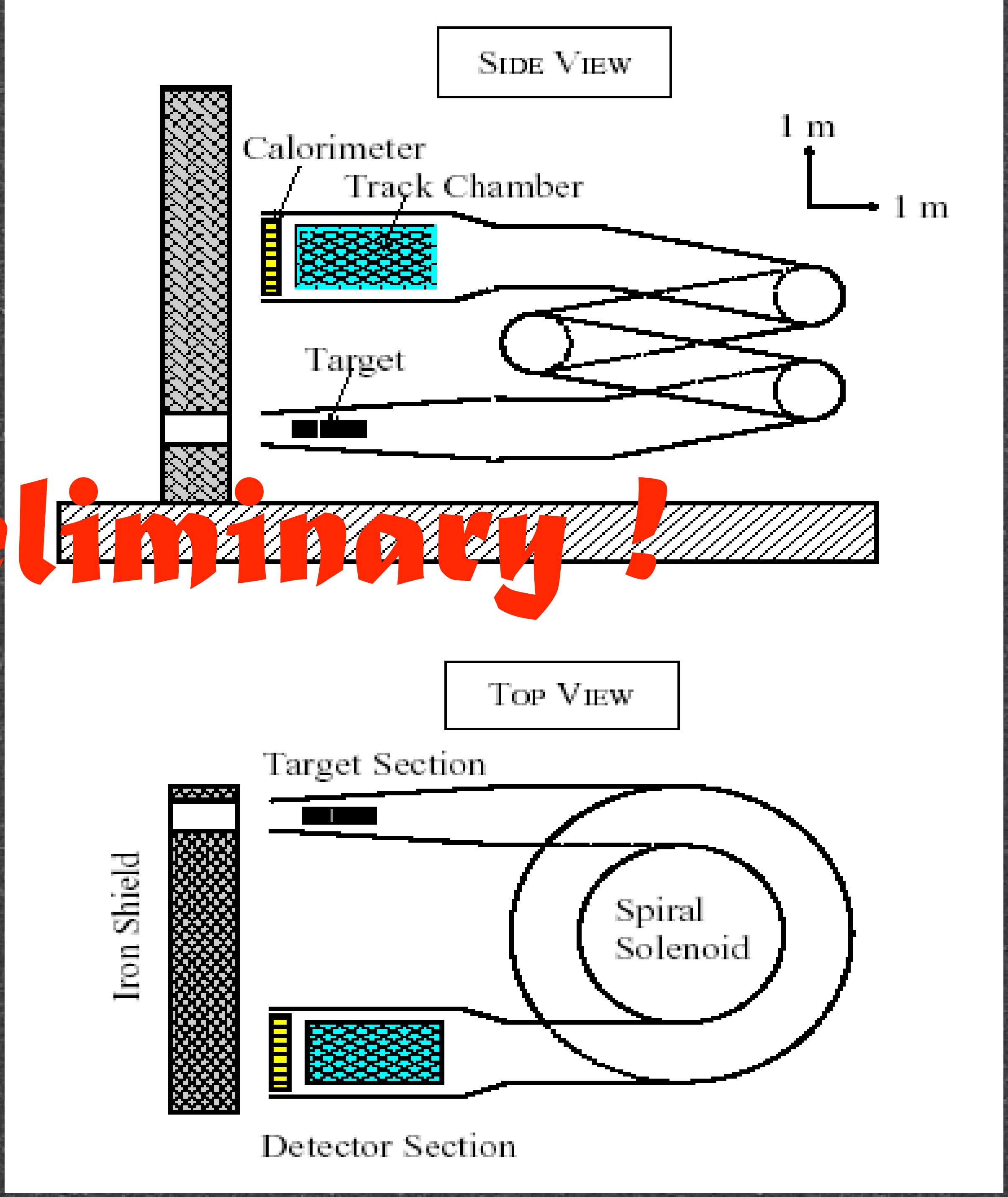
using PRISM **Aim at 10^{-18}**

Detector Option:
Spiral solenoid spectrometer

eliminate low
energy particles
by a toroidal
magnetic field

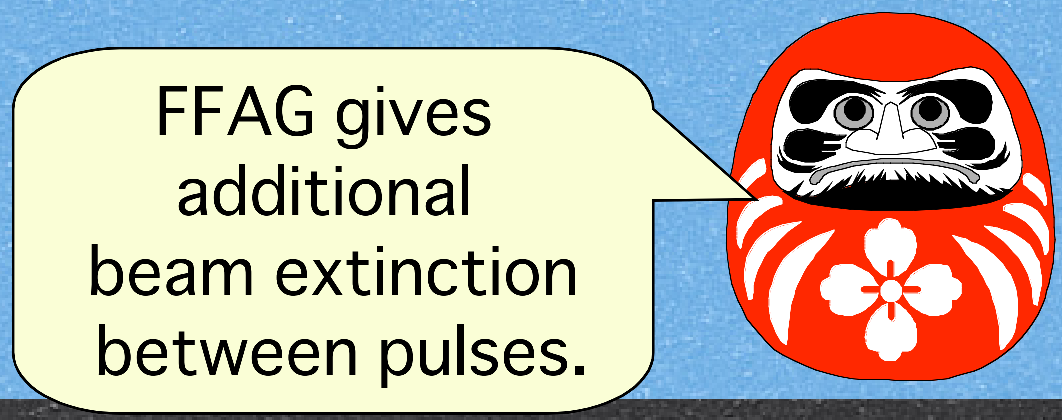
$$D = \frac{1}{0.3B}\frac{s}{R}\frac{(p_s^2 + \frac{1}{2}p_t^2)}{p_s}$$

Preliminary !

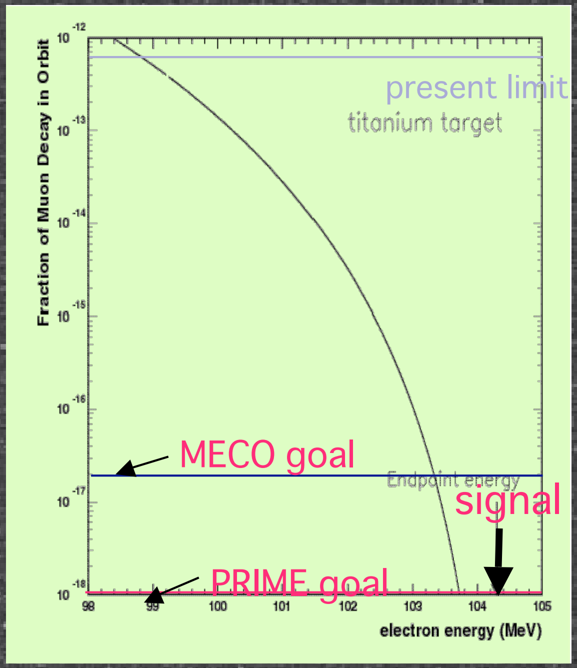


BG Rejection Summary

- ***muon decay in orbit***
  - $(E_0-E)^5$
  - better e^+ momentum resolution
    - a thin muon stopping target is helpful. (=several 100 g)
- ***radiative muon capture***
  - endpoint for Ti = 89.7MeV
    - signal = 104.3 MeV
  - better e^+ momentum resolution
    - a thin muon stopping target
- ***radiavtive π capture***
  - long flight length (150m)
    - 30 m FFAG circumference x 5 turns
  - π surviving rate:
    10^{-18} at 68 MeV/c
- ***cosmic ray backgrounds***
  - 1kHz (duty factor: 1/1000)
- ***long transit time backgrounds***
  - FFAG timing (kicker)
- ***anti-proton***
  - absorber before FFAG
- ***beam electrons, electrons from muon decay in flight***
  - FFAG's momentum accpetance:
  - different β (out of time)
  - not bunched at FFAG ?



PRIME Background Rates



Muon Decay in Orbit ($\propto (E_{\mu e} - E_e)^5$)

Detector Resolution $\Delta E_e = 235$ keV

Preliminary !

at the sensitivity of 10^{-18}

Background	Rate	comment
Muon decay in orbit	0.05	energy reso 350keV(FWHM)
Radiative muon capture	0.01	end point energy for Ti=89.7MeV
Radiative pion capture	0.03	long flight length in FFAG, 2 kicker
Pion decay in flight	0.008	long flight length in FFAG, 2 kicker
Beam electron	negligible	kinematically not allowed
Muon decay in flight	negligible	kinematically not allowed
Antiproton	negligible	absorber at FFAG entrance
Cosmic-ray	< 10^-7 events	low duty factor
Total	0.10	

Ideas Beyond PRIME

How to handle high instantaneous rate (from muon target and beam dump) if goes into higher muon beam intensity at Front-end of NF ?

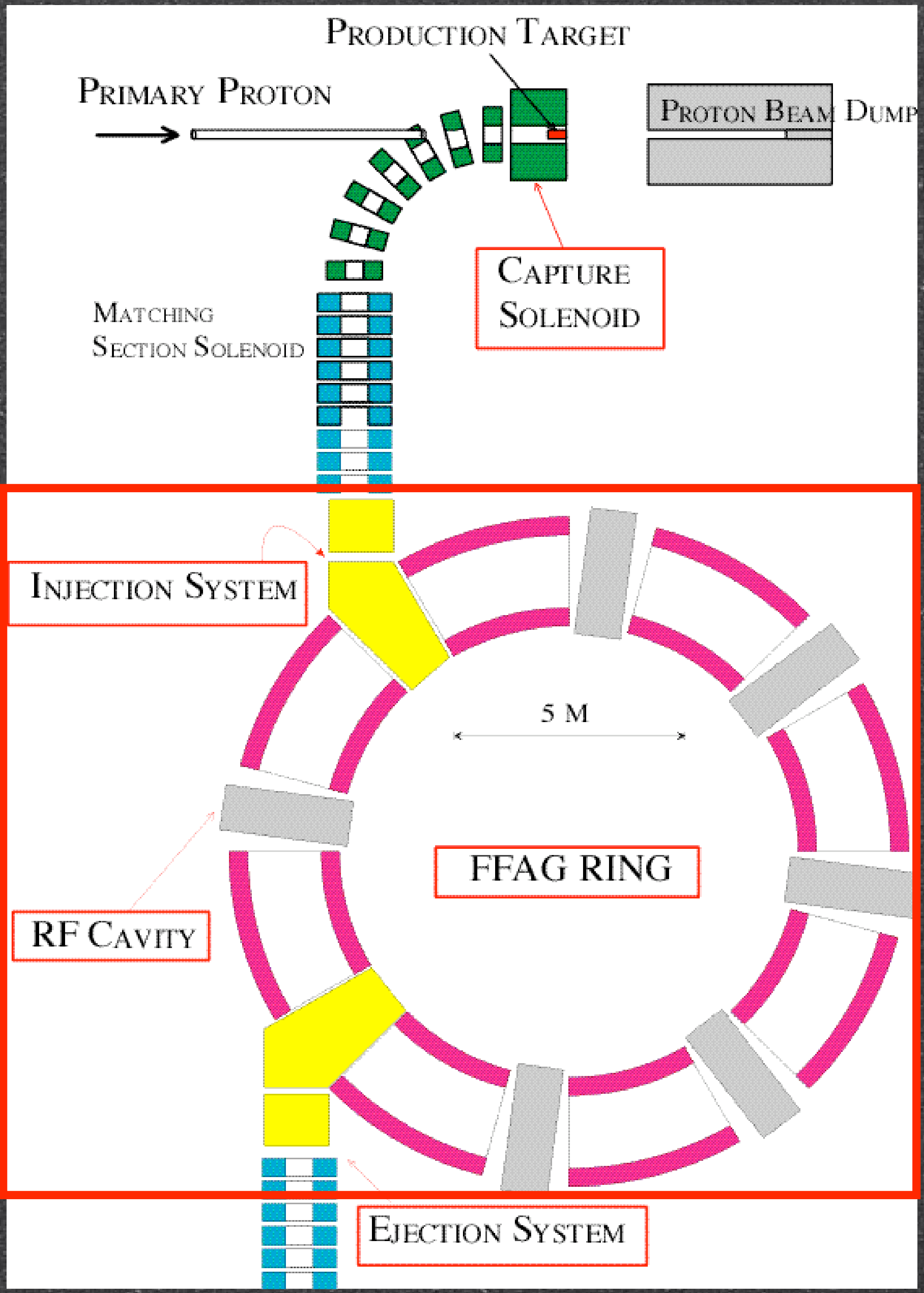
- At Snowmass 2001
  - trap the mu-e electron (electrically)
  - store the mu-e electron in a circular ring
- measurements can be done after prompt.
- Need more studies !

PRISM R&D

PRISM Ring Construction

PRISM ring construction has been approved in JFY2003.

- FFAG ring
- 5 year plan
  - construction at Osaka university
- Plan before J-PARC
  - proton/muon phase rotation
  - muon acceleration
  - muon beam cooling



What is FFAG ?

Scaling type of FFAG

a)Geometrical similarity   b)Constant n

$$(a)\ r\left(\frac{\partial\theta}{\partial r}\right)_{\vartheta} = \varsigma = const.\,, \qquad (\mathrm{b})\ \ n_{\Gamma} = -\frac{r}{B}\left(\frac{\partial B}{\partial r}\right)_{\theta}$$

FFAG magnetic field

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

Two types of magnet configurations

a) Radial Sector

/tunable

/short straight section

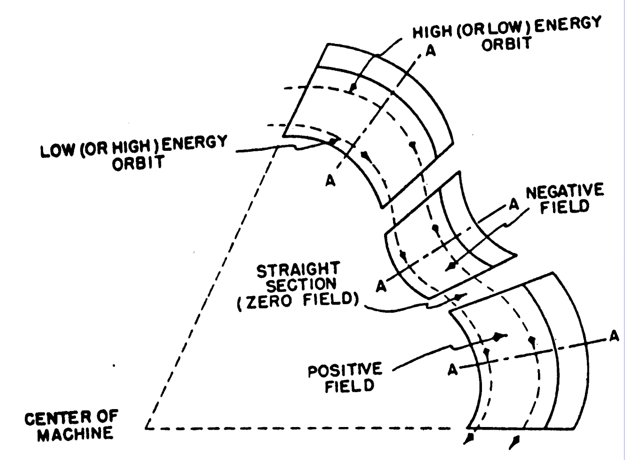


FIG. 2. Plan view of radial-sector magnets.

b) Spiral Sector

/small excursion

/less tunable

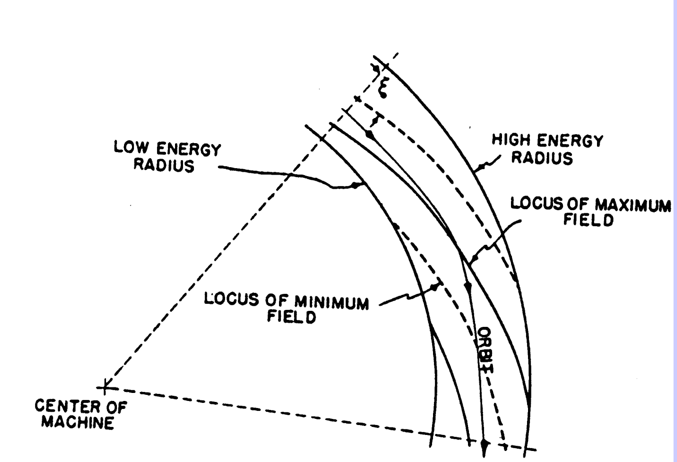
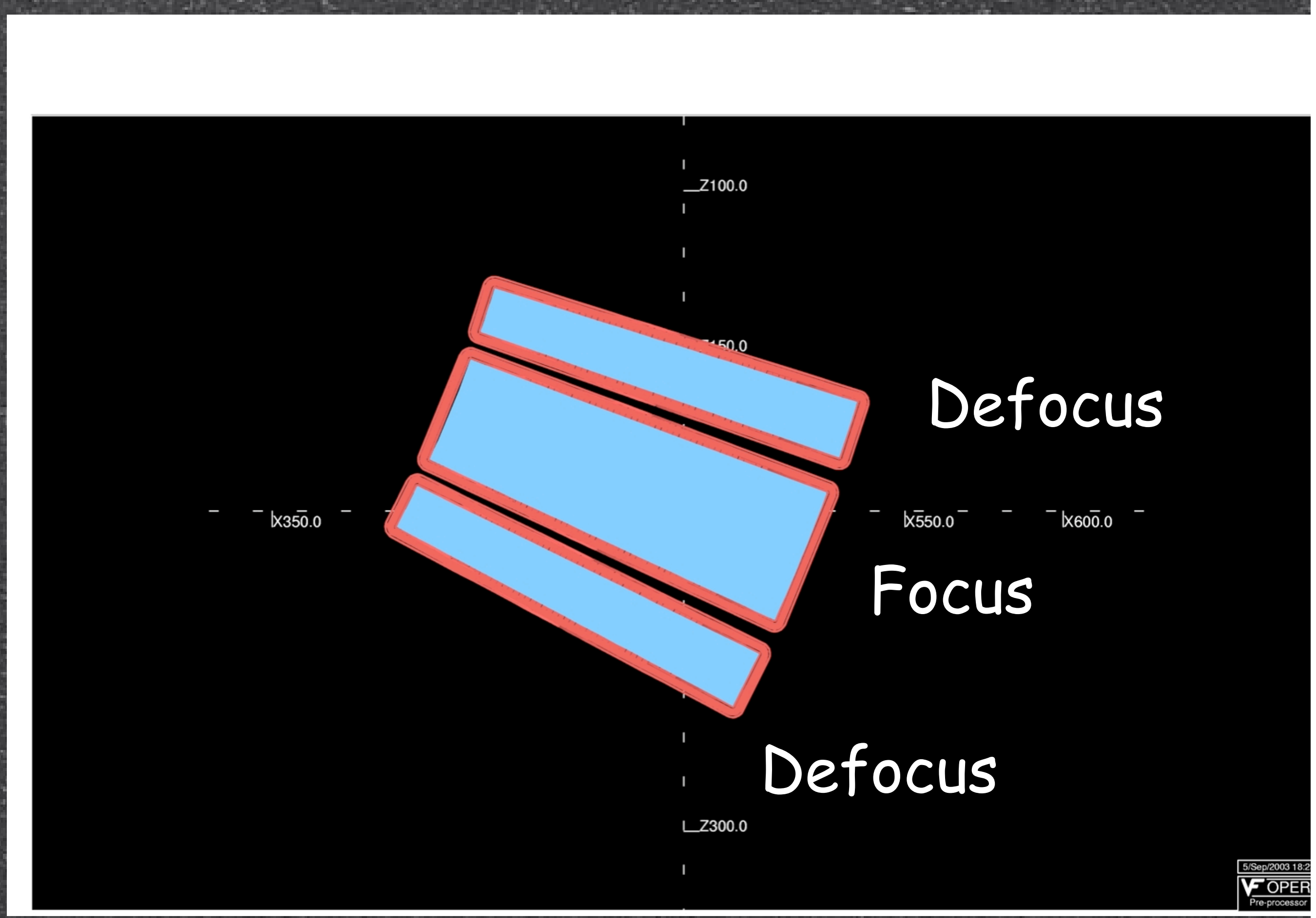


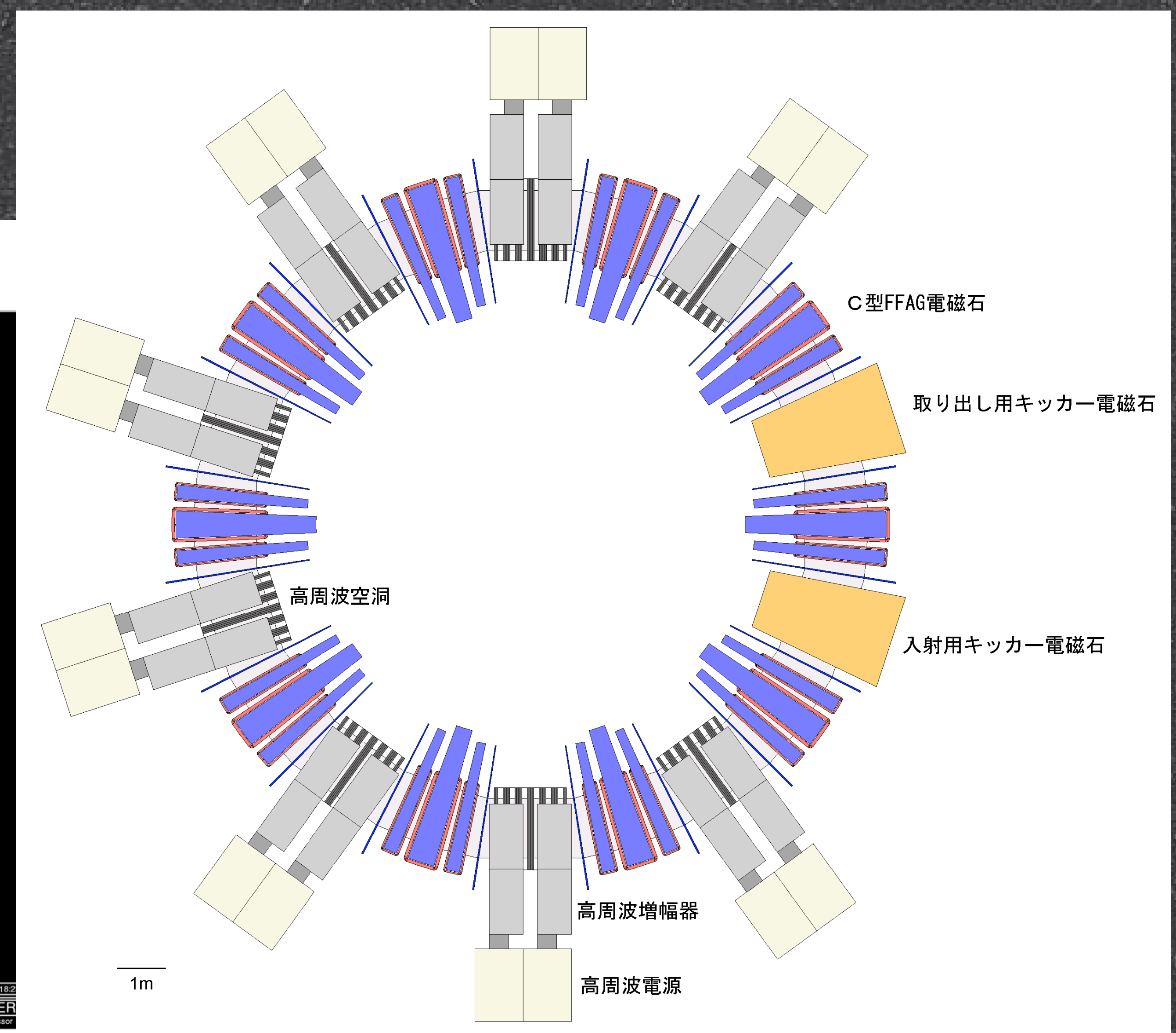
FIG. 3. Spiral-sector configuration.

FFAG Magnet Design

FFAG field $$B(r) = B_0 \left(\frac{r}{r_0}\right)^k$$

Radial Sector Type
DFD triplet





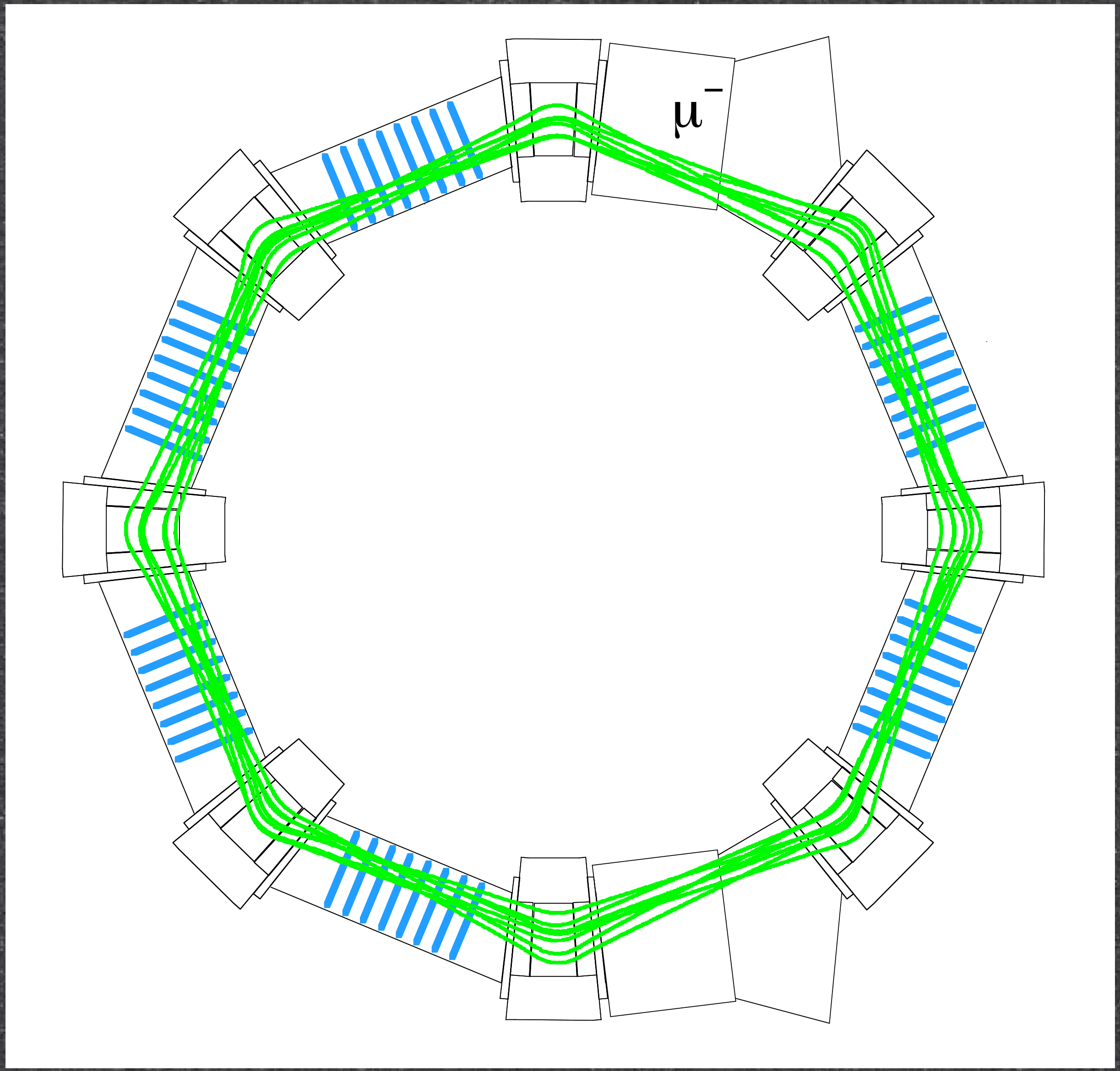
PRISM-FFAG Lattice

PRISM-FFAG Lattice

- Goal :
  - determine the FFAG lattice (optics) having large acceptance
- FFAG type selection
  - Scaling FFAG
  - Radial sector type
  - DFD triplet
- Issues
  - how many cells ?
  - what is horizontal tune chosen ? (k value)
  - what is vertical tune chosen ? (F/D ratio)

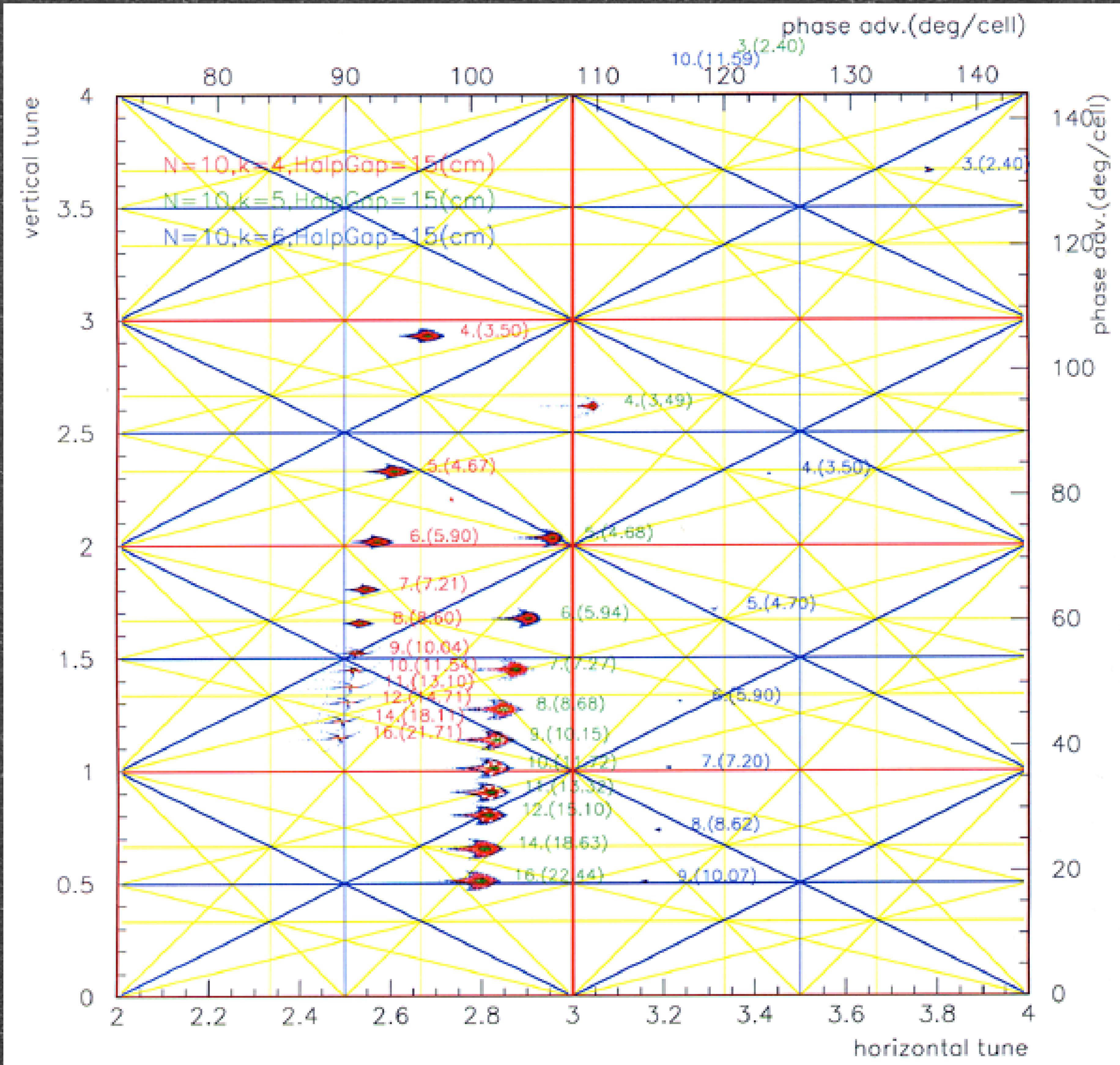
Tracking Simulation

- Scaling FFAG has to treat non-linear magnetic field.
- Standard linear approach of accelerator design does not work !
- Use GEANT simulation with 3-D magnetic field calculated by TOSCA (as we high energy physicits usually do.)



GEANT3 simulation with TOSCA 3-D magnetic field

Horizontal Tune Diagram



DFD Triplet

#sectors = 10

half gap = 15cm

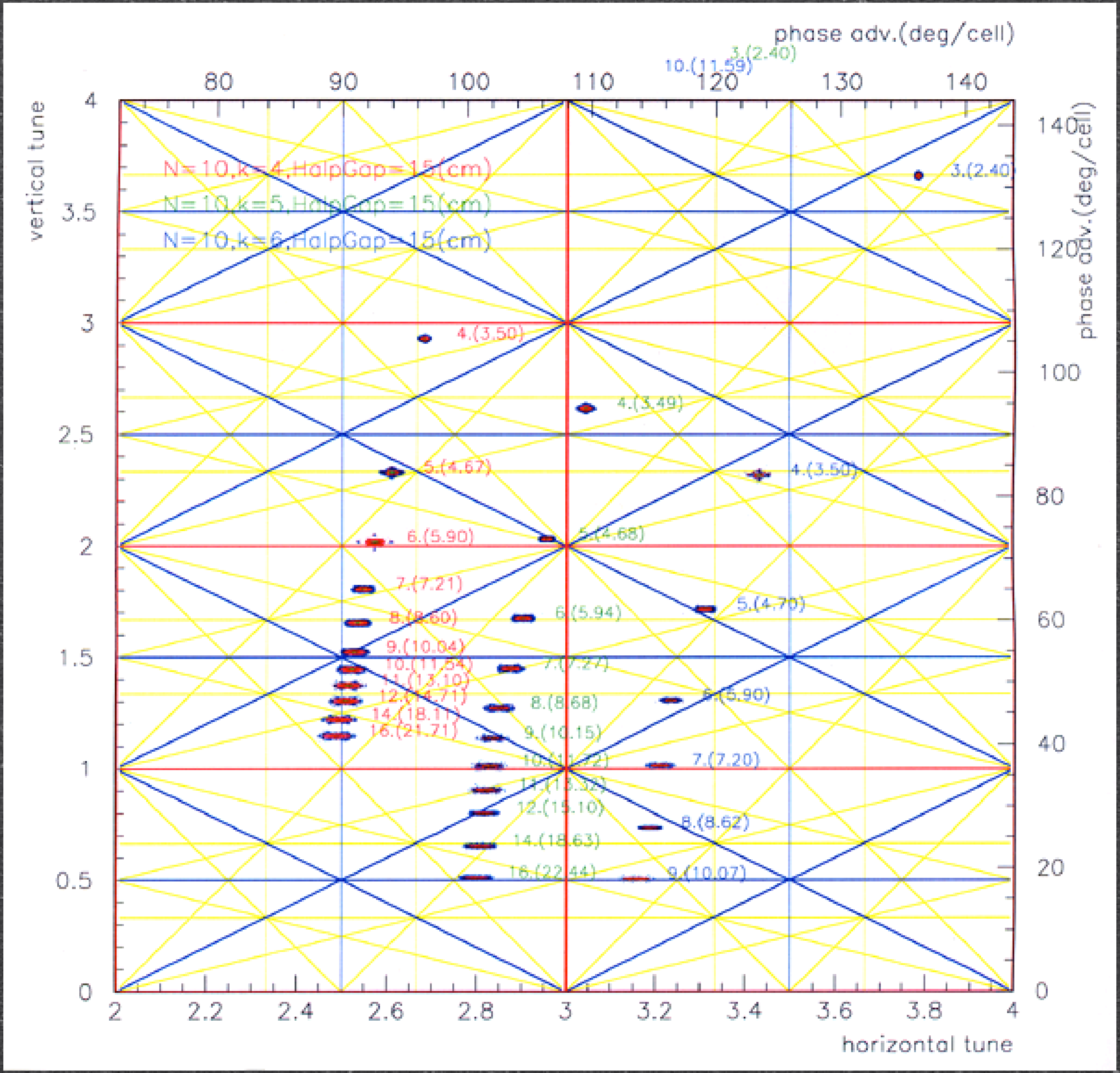
r0 = 6.5 m

68 MeV/c

without field clamp

by Akira Sato

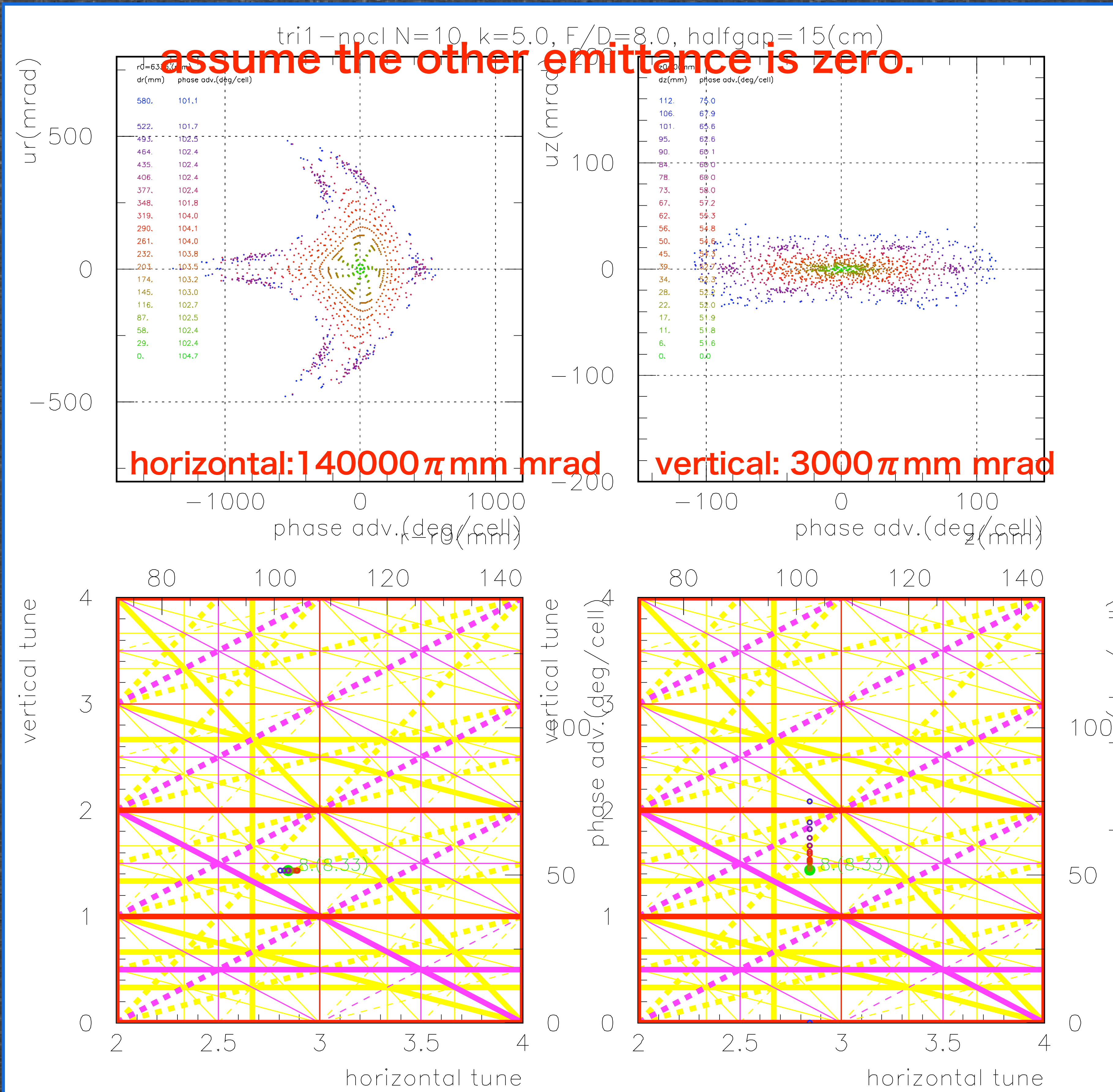
Vertical Tune Diagram



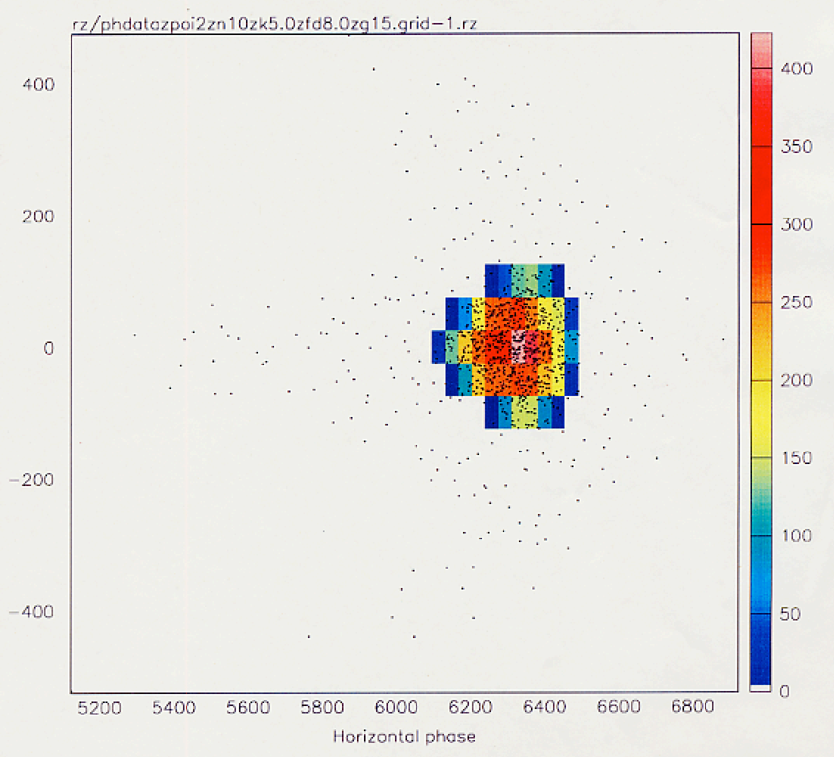
DFD Triplet
#sectors = 10
half gap = 15cm
r0 = 6.5 m
68 MeV/c
without field clamp

by Akira Sato

Acceptance



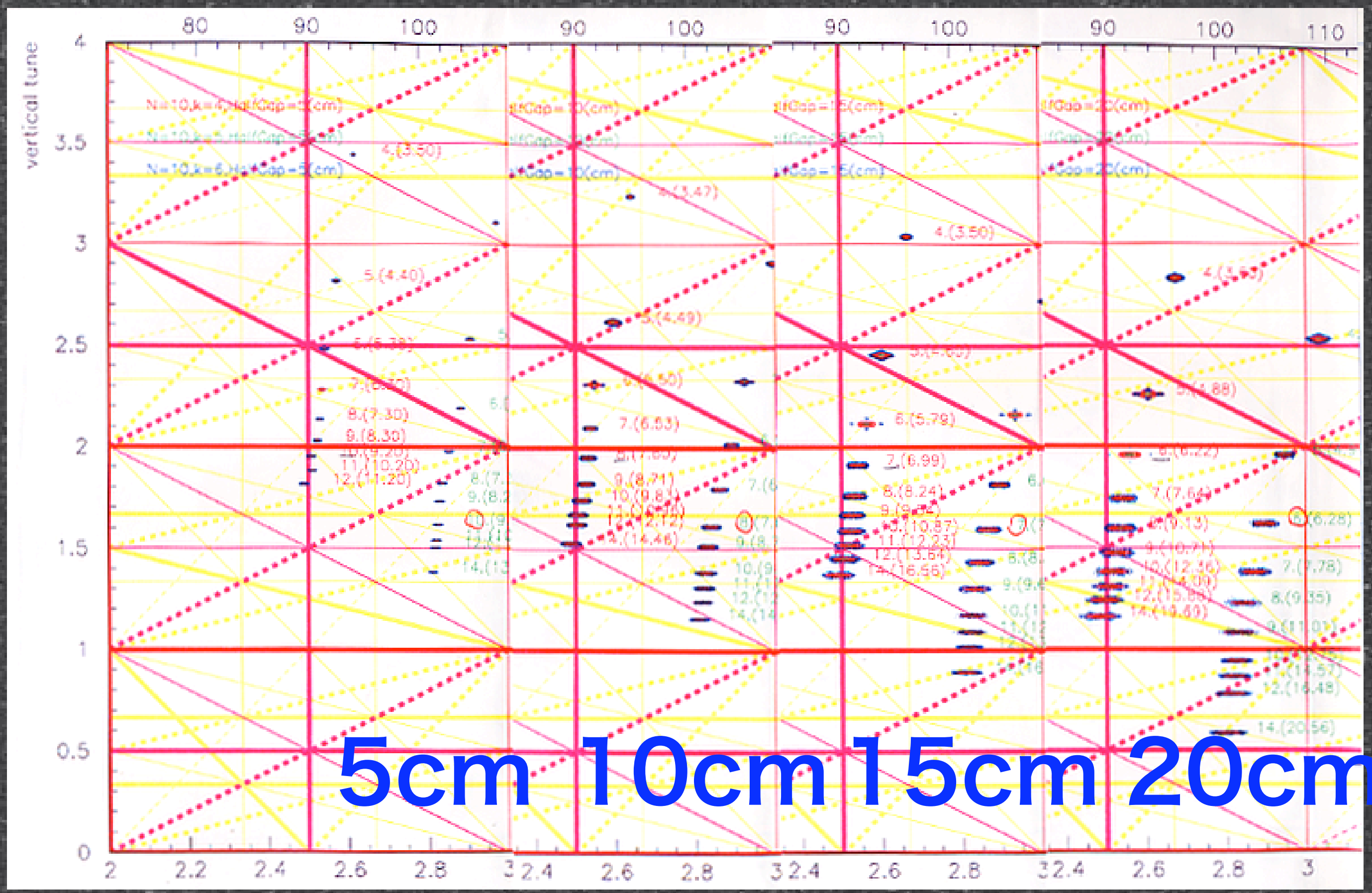
N=10
F/D=8
k=5
r0=6.5m
H:2.86
V:144



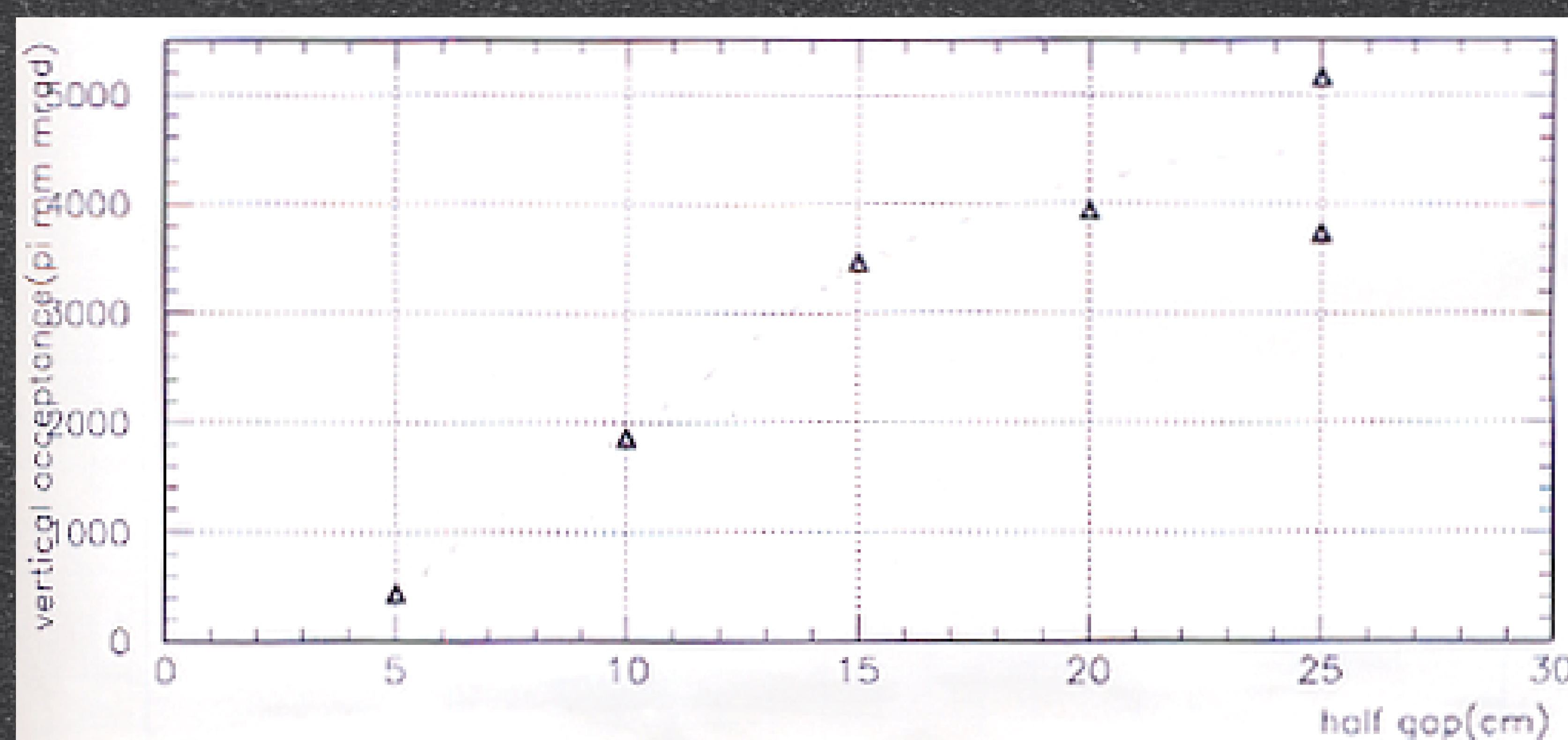
Horizontal: 35000πmm mrad

by Akira Sato

Gap Dependence

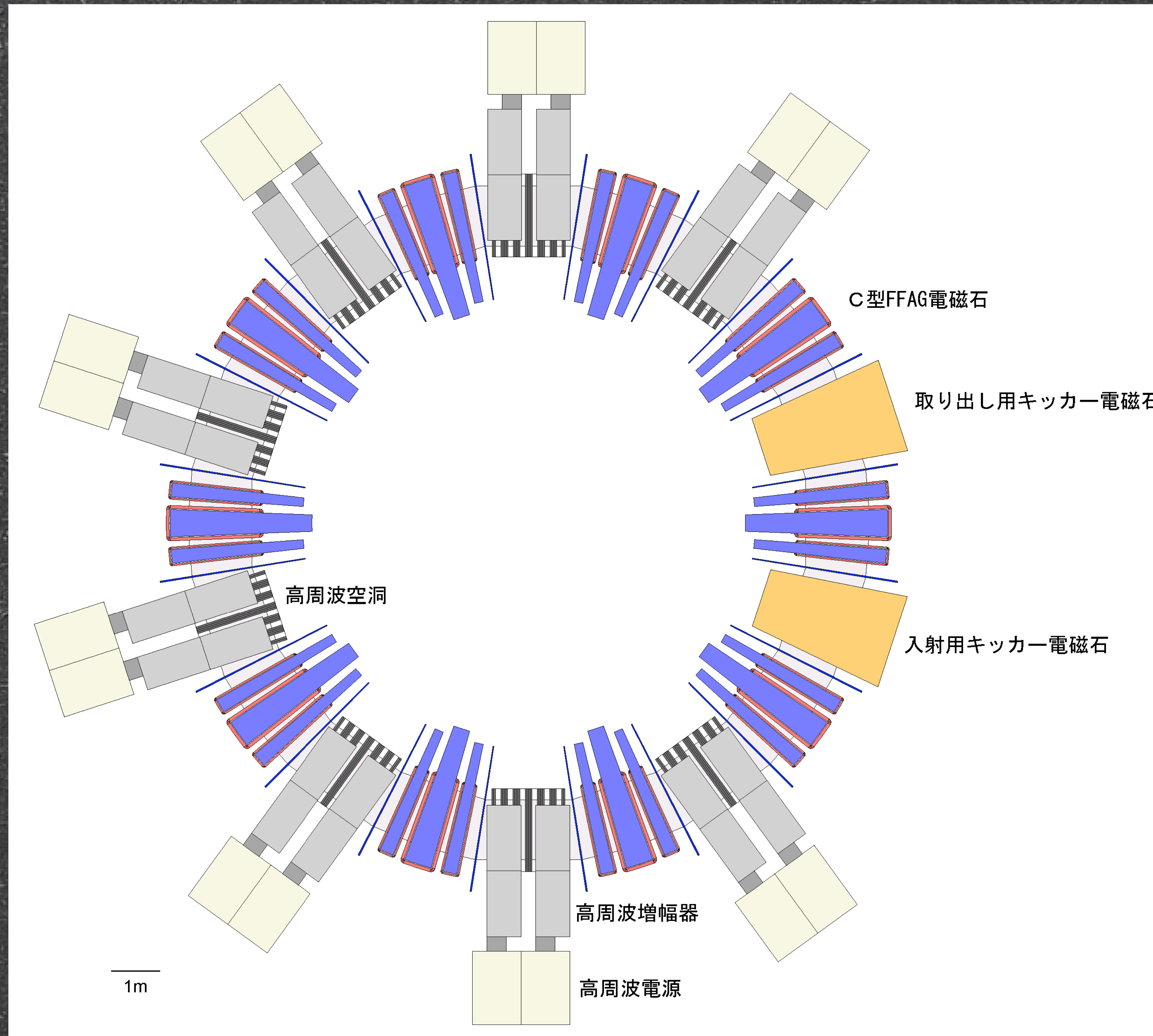


Half gap of the PRISM FFAG magnet of 15cm might be sufficient.



PRISM Lattice

- N=10
- k=5(4.6-5.2)
- F/D(BL)=8
- r0=6.5m for 68MeV/c
- half gap = 15cm
- mag. size 110cm @ F center
- Triplet
  - θ_F=4.40deg
  - θ_D=1.86deg
- tune
  - h : 2.86
  - v : 1.44
- acceptance
  - h : 140000 π mm mrad
    - --> **35000 π mm mrad**
  - v : 3000 π mm mrad



PRISM-FFAG Magnet

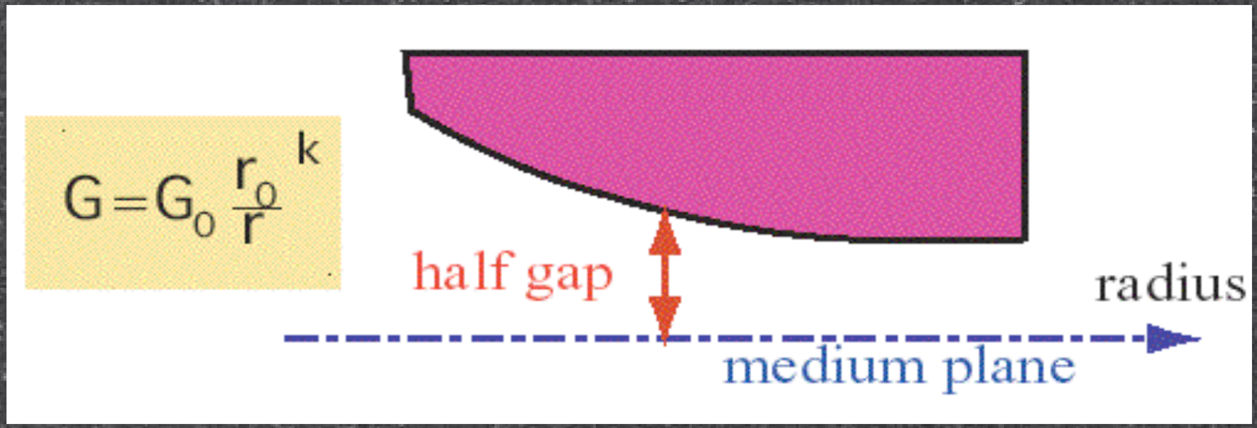
Spec. for PRISM Magnets

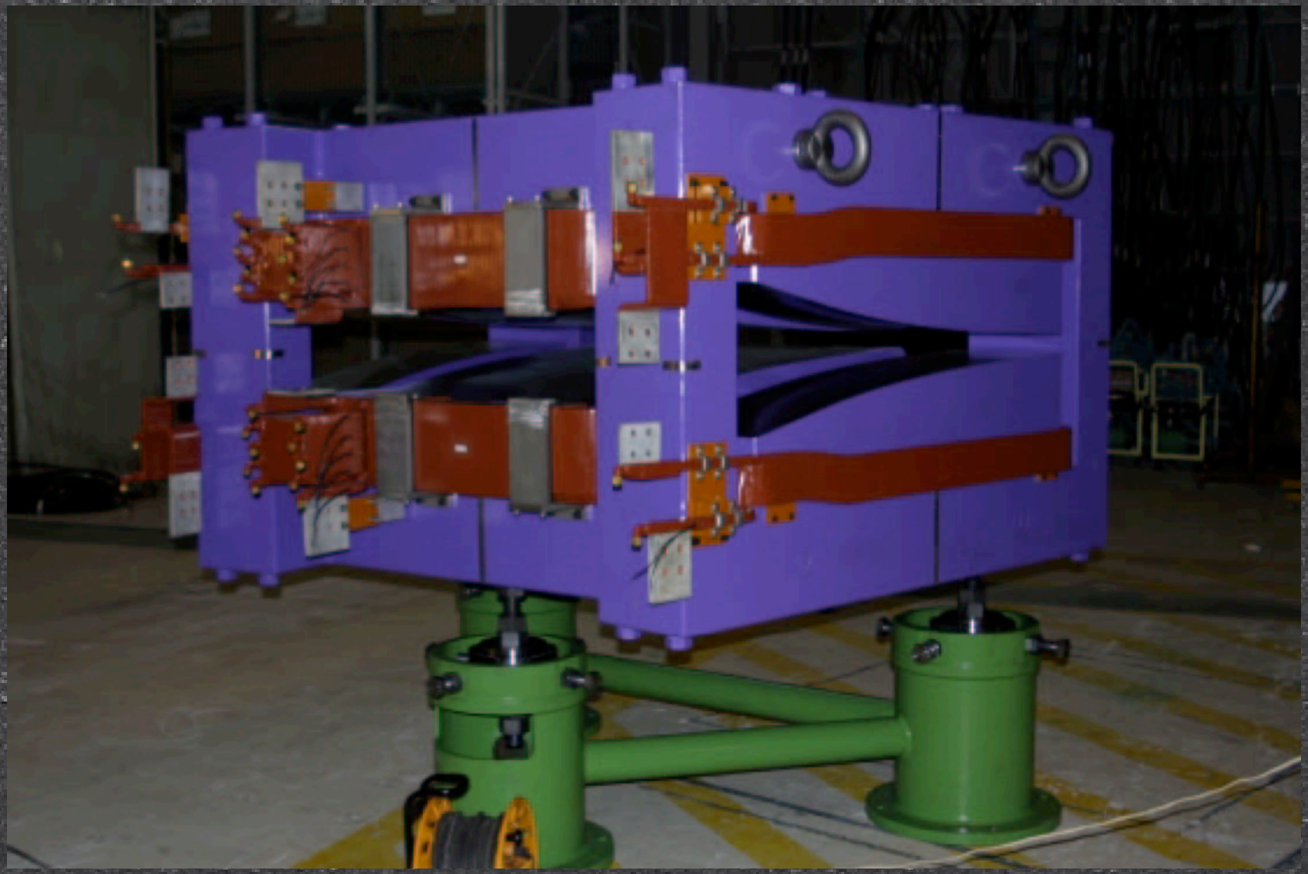
- Central Momentum : 68 MeV/c
- Central Orbit Radius : 6.5 m
- # of cells : 10
- F/D Ratio : 8 (variable)
- k value (field gradient) : 4.4 ~5.2 (variable)
  - trim coils
- BL(F) : 0.16 Tm
- Effective Field Region
  - R: 595-705cm
  - z: +-15cm
- C-type Magnets (injection/extraction)

FFAG Magnet Types

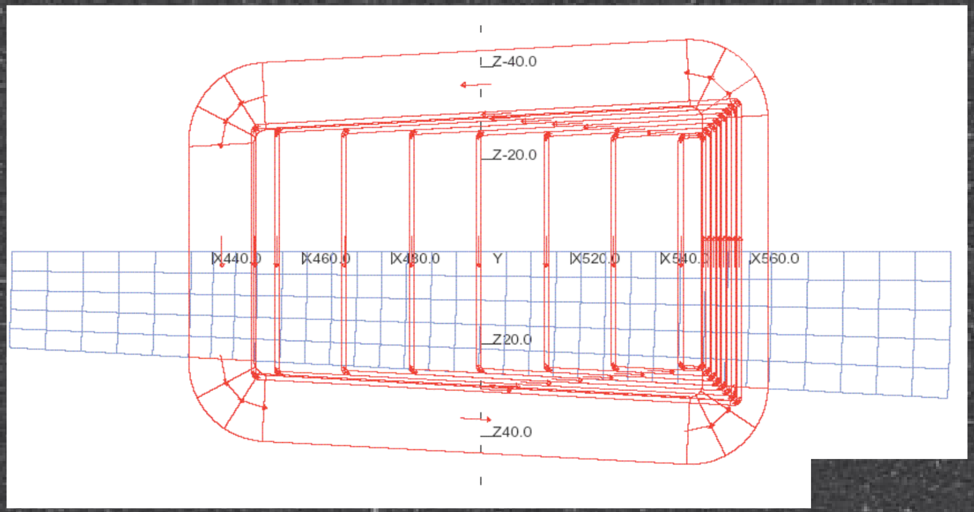
$$B(r) = B_0\left(\frac{r}{r_0}\right)^k$$

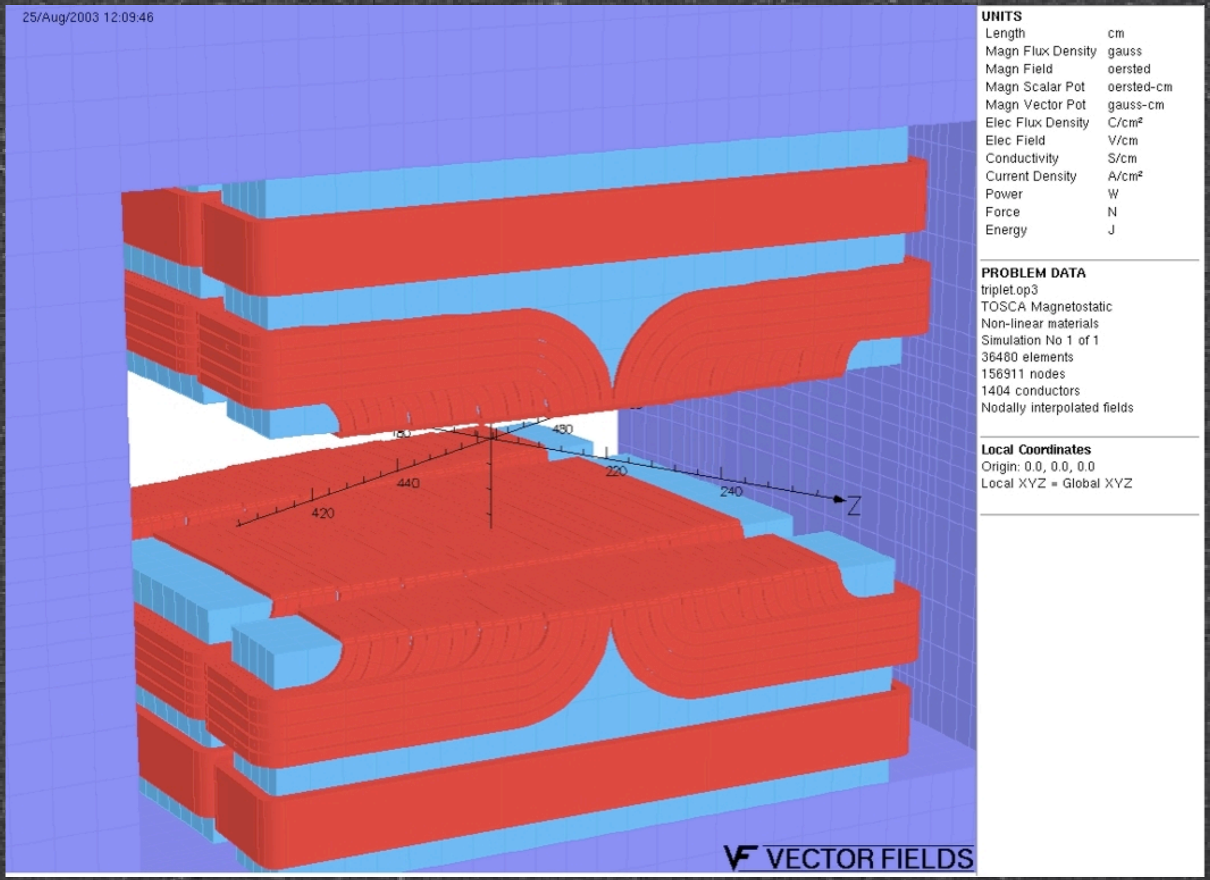
Variable Gap Type



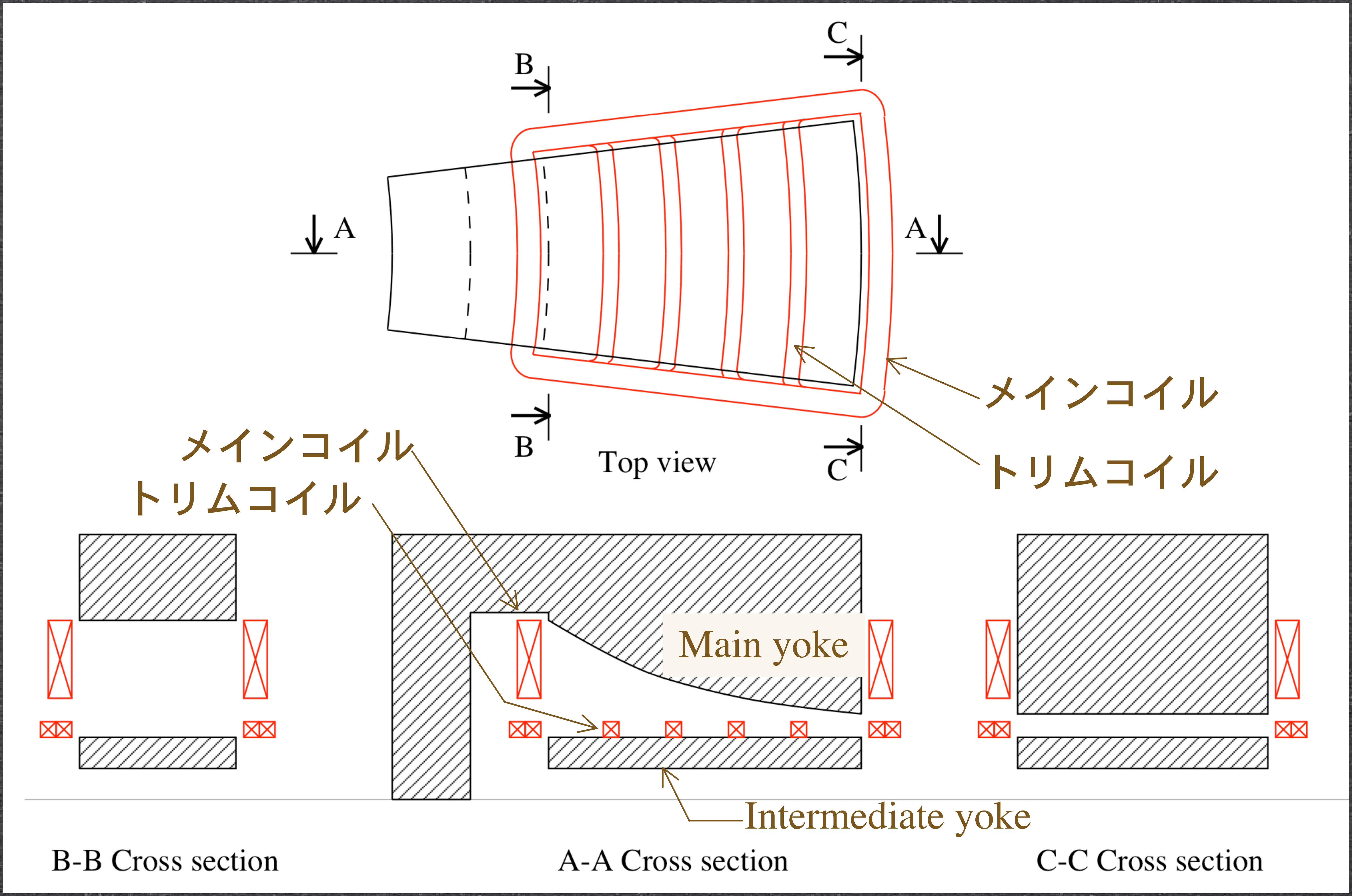


Multi Trim Coil Type

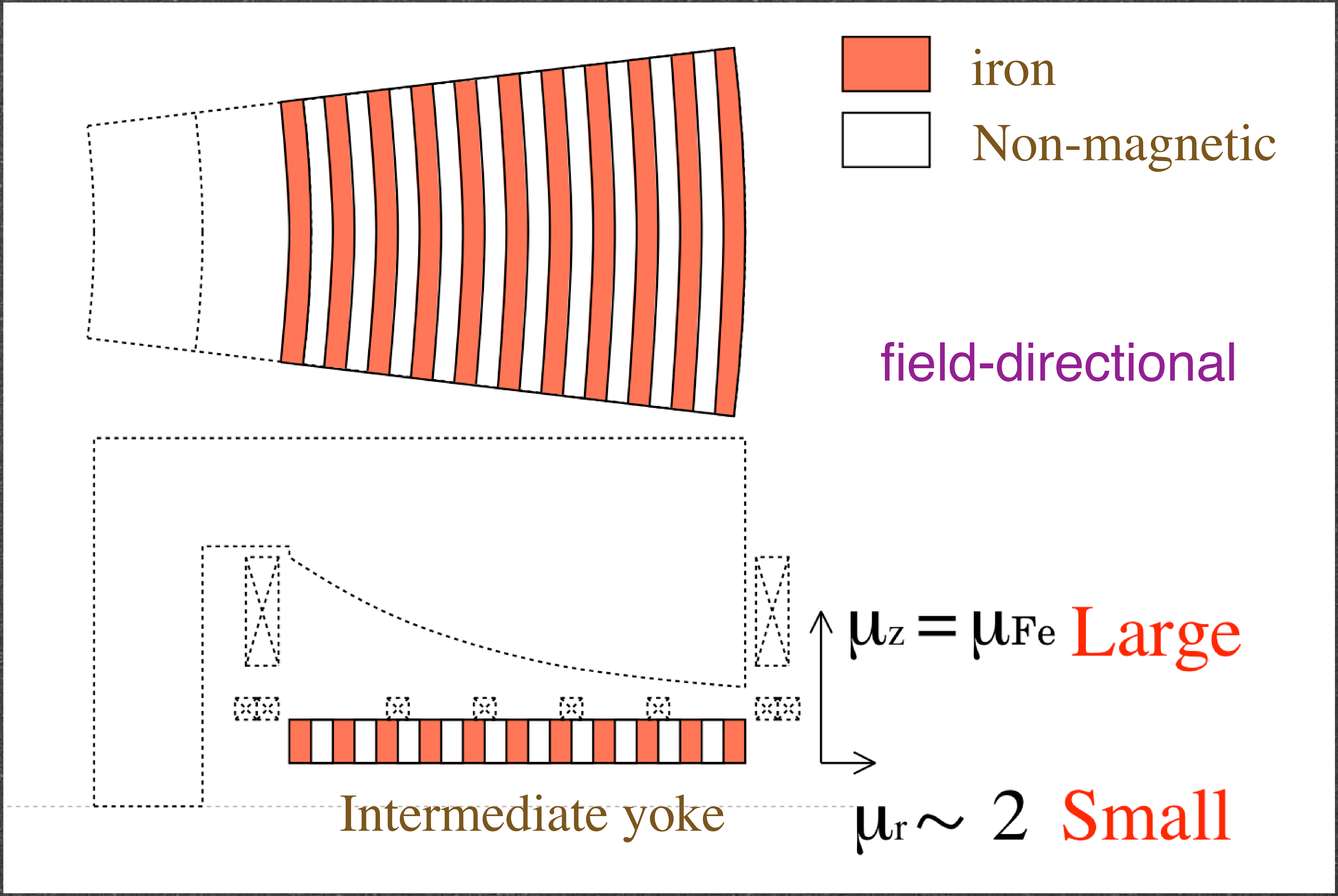




New Magnet Structure



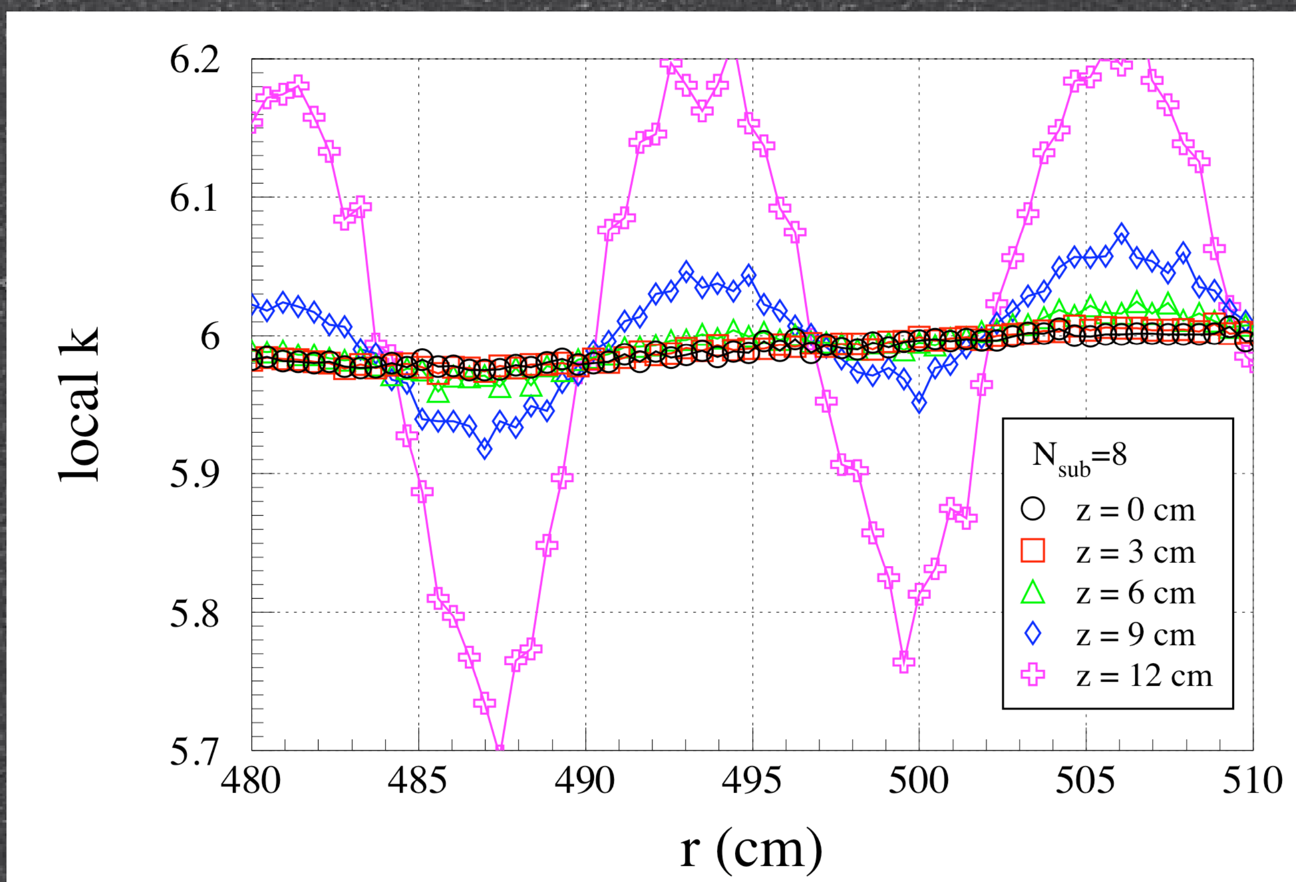
Intermediate Yoke (IY)



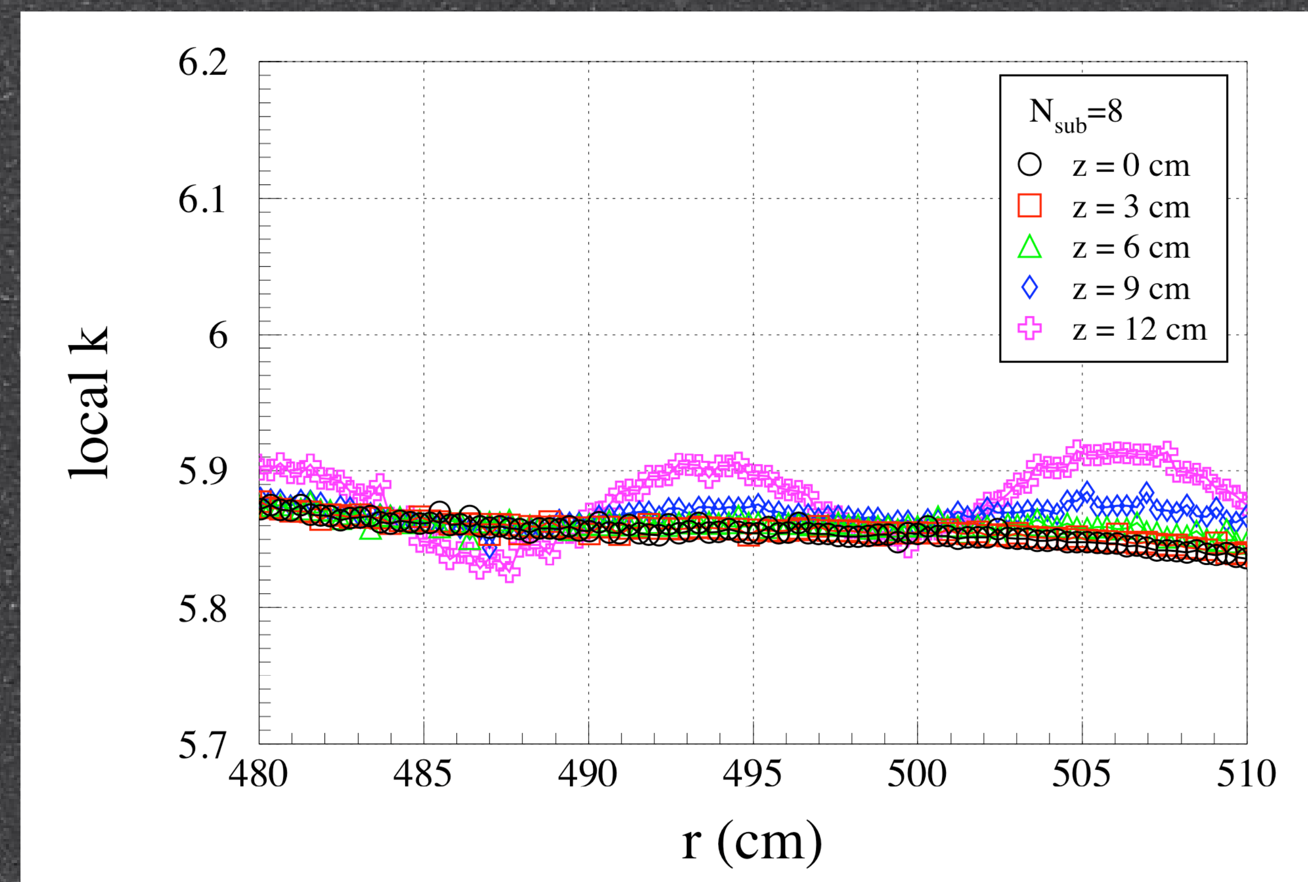
Advantage of IY

Intermediate yoke

$$local\_k = \left(\frac{\partial B_z}{\partial r}\right)\frac{r}{B_z}$$



without directional intermediate yoke



with directional intermediate yoke

Magnet Design

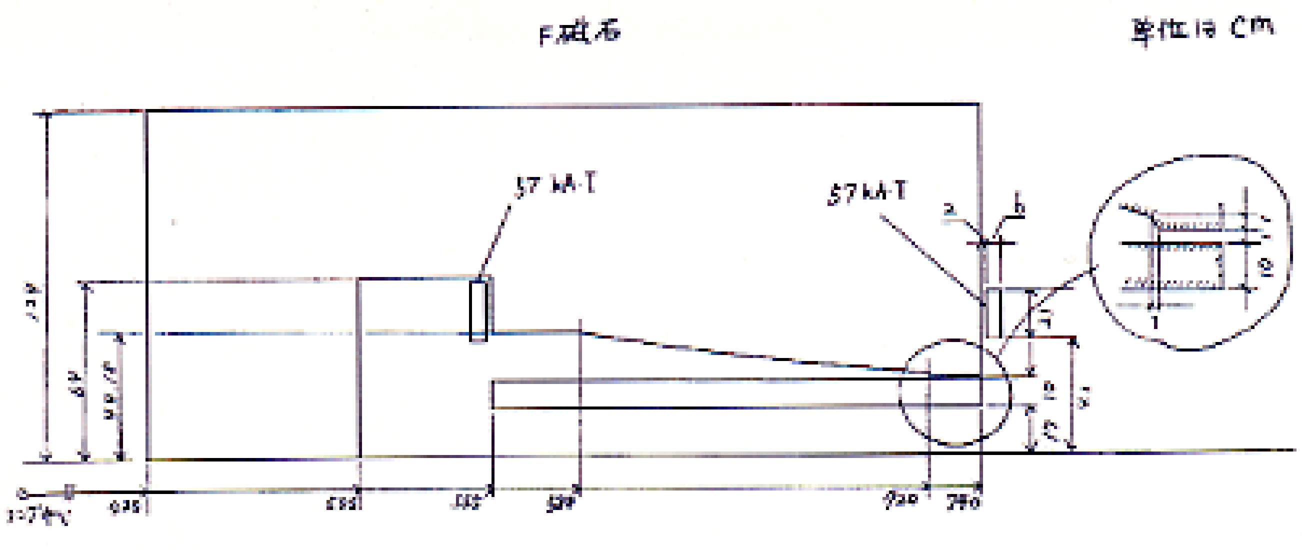


図 2: F磁石正面図

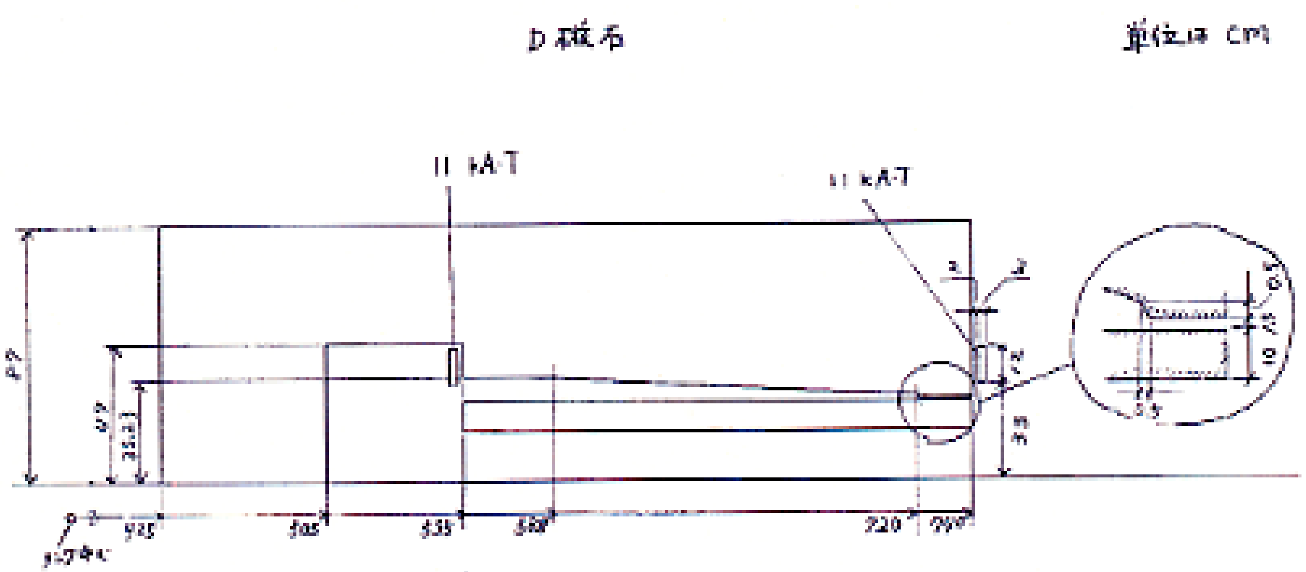


図 3: D磁石正面図

F磁石メインコイル電流	57 kA·T
D磁石メインコイル電流	11 kA·T
k 値 (目標値)	4.6
F/D 比 (目標値)	8
F磁石開口角	4.4
D磁石開口角	2.2
BL 積で見た時の積分磁場	6.4 T·cm
ギャップ幅	± 15 cm
中間磁極の厚み	10 cm

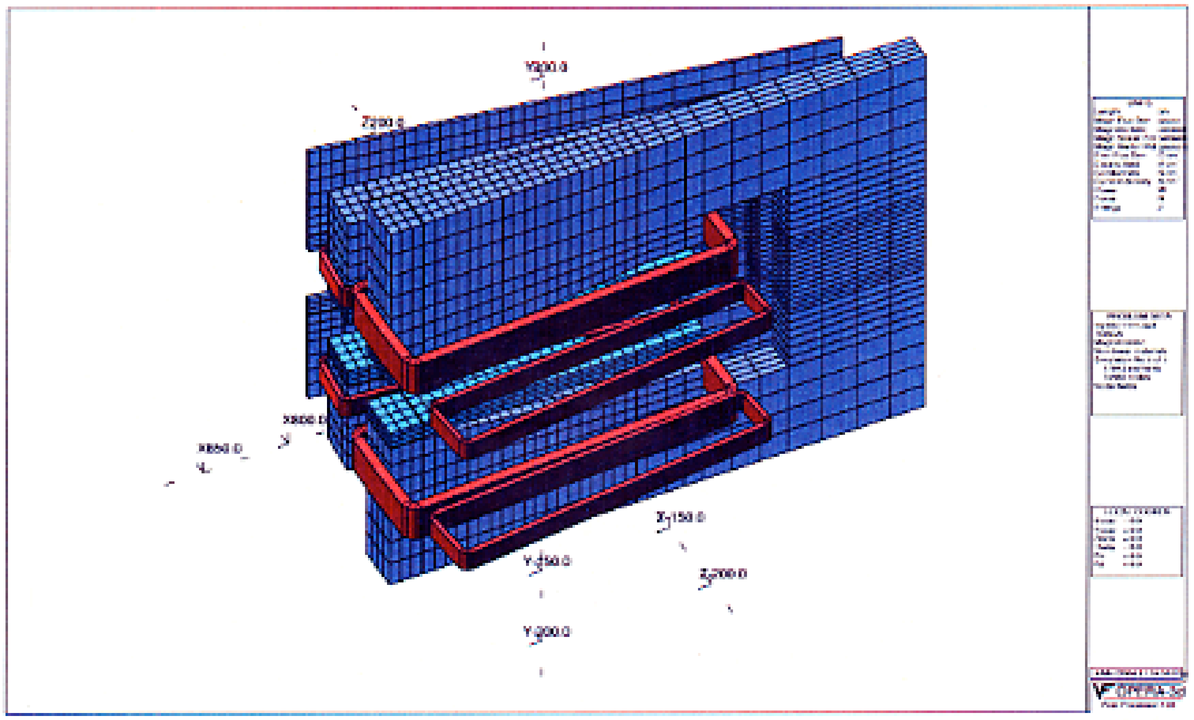
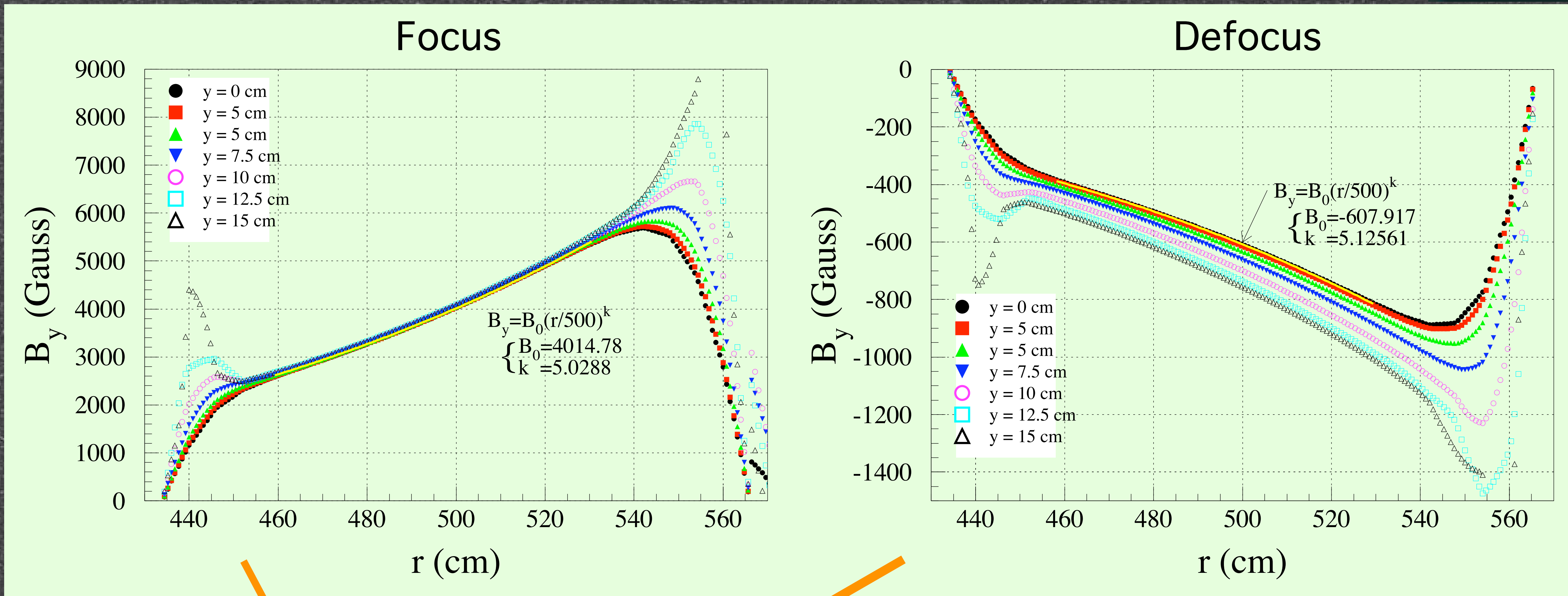
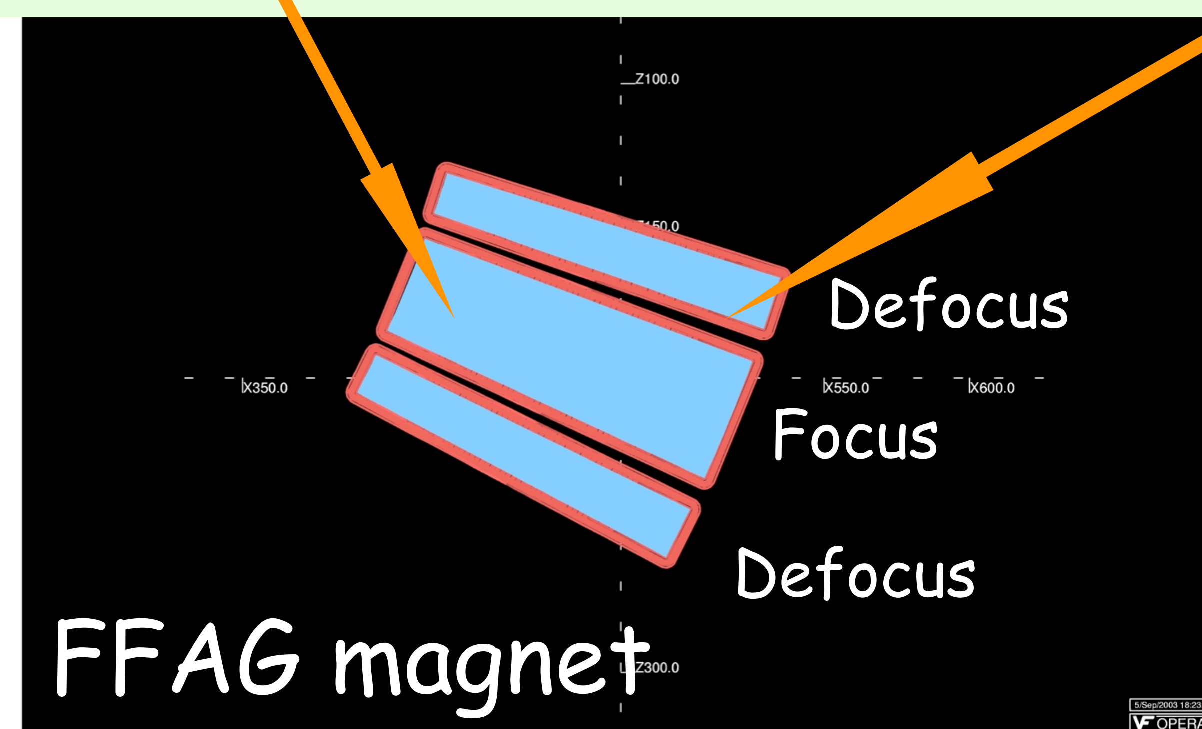


図 1: 外観図

The design has to been set soon.

TOSCA Field Calculation





3-dim. Field Calculation

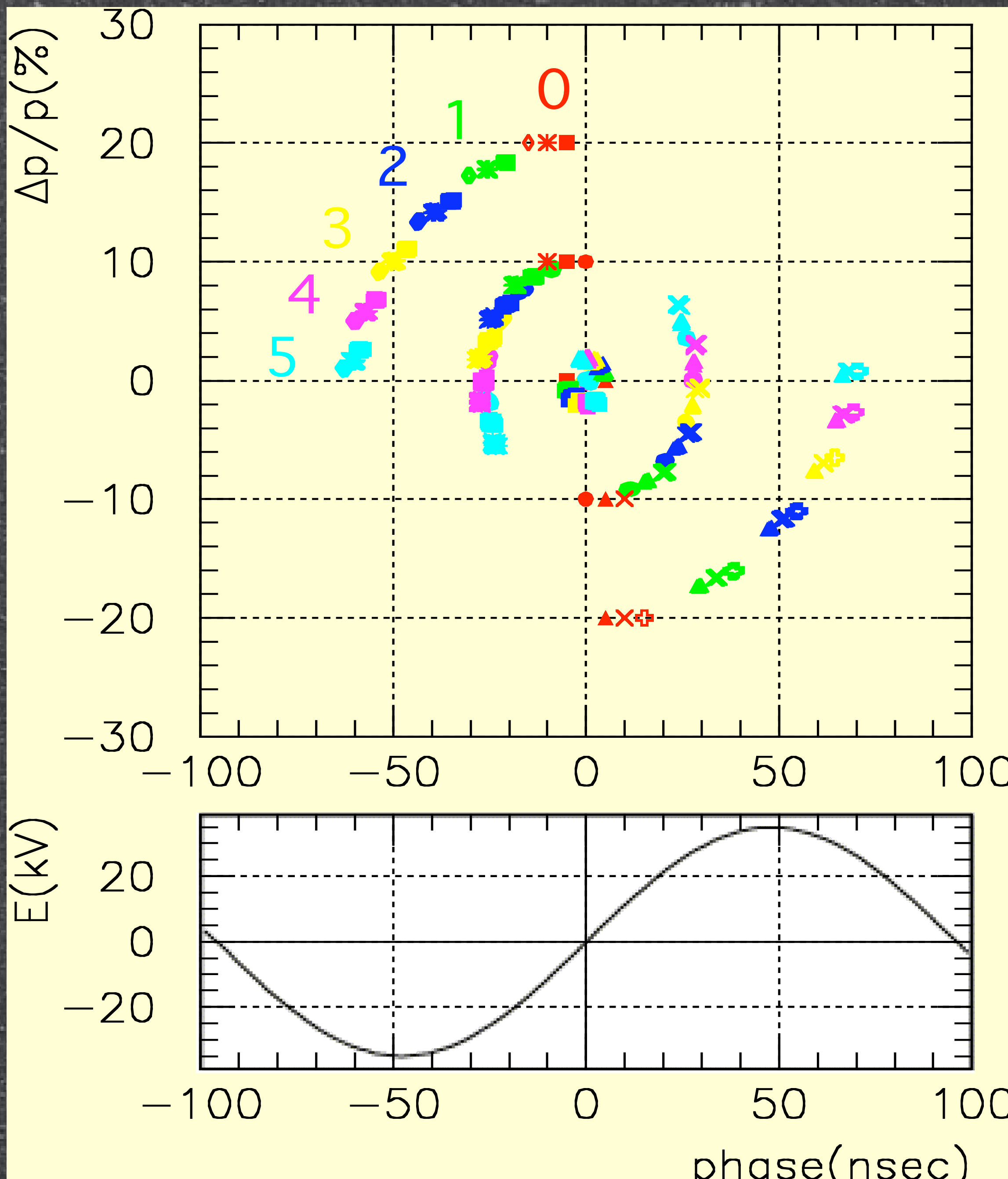
$$B(r) = B_0\left(\frac{r}{r_0}\right)^k$$

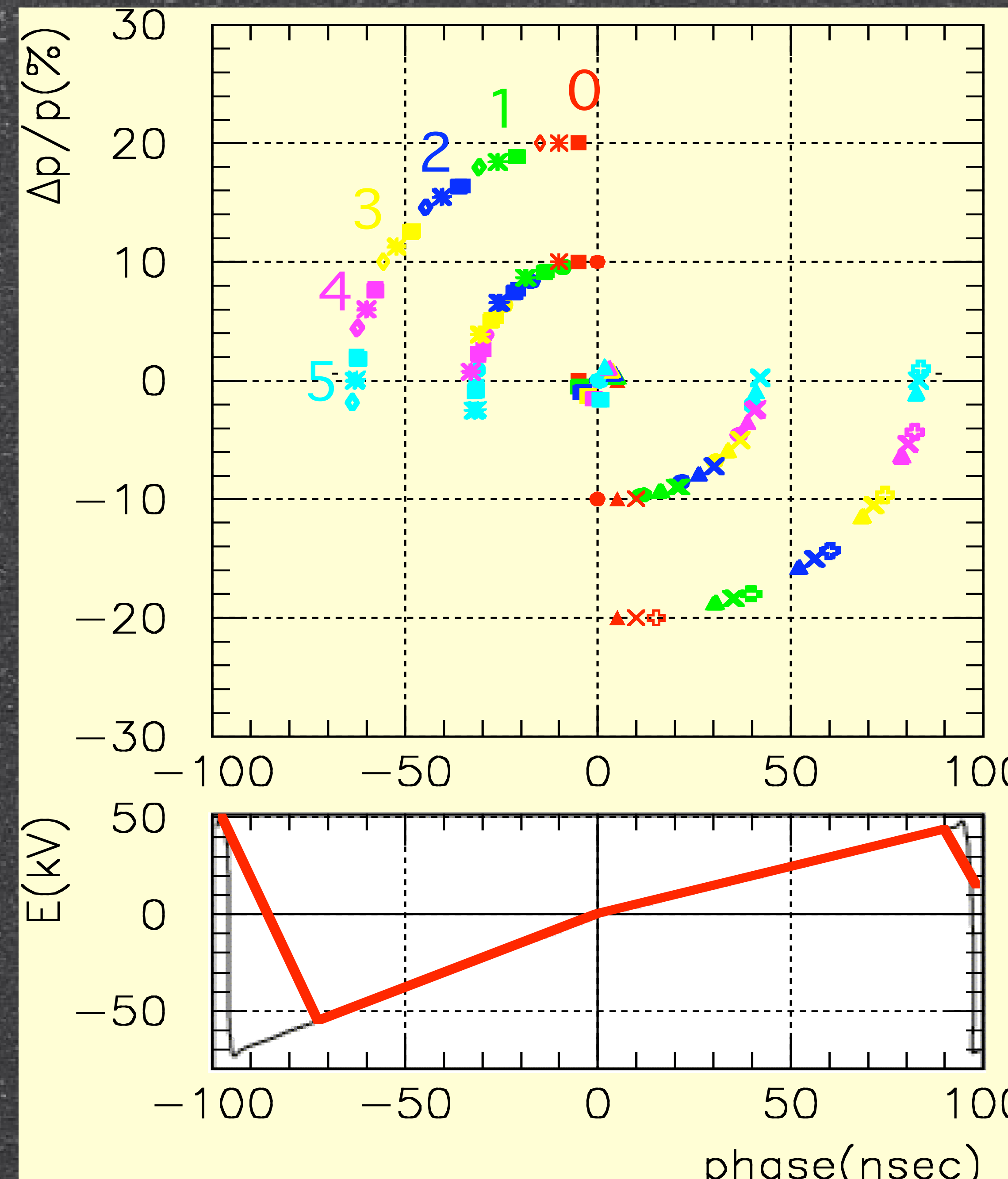
Y. Arimoto

PRISM-FFAG Phase Rotation Simulation

RF and Phase Rotation

$\pm 5nsec$ muon width at given momentum





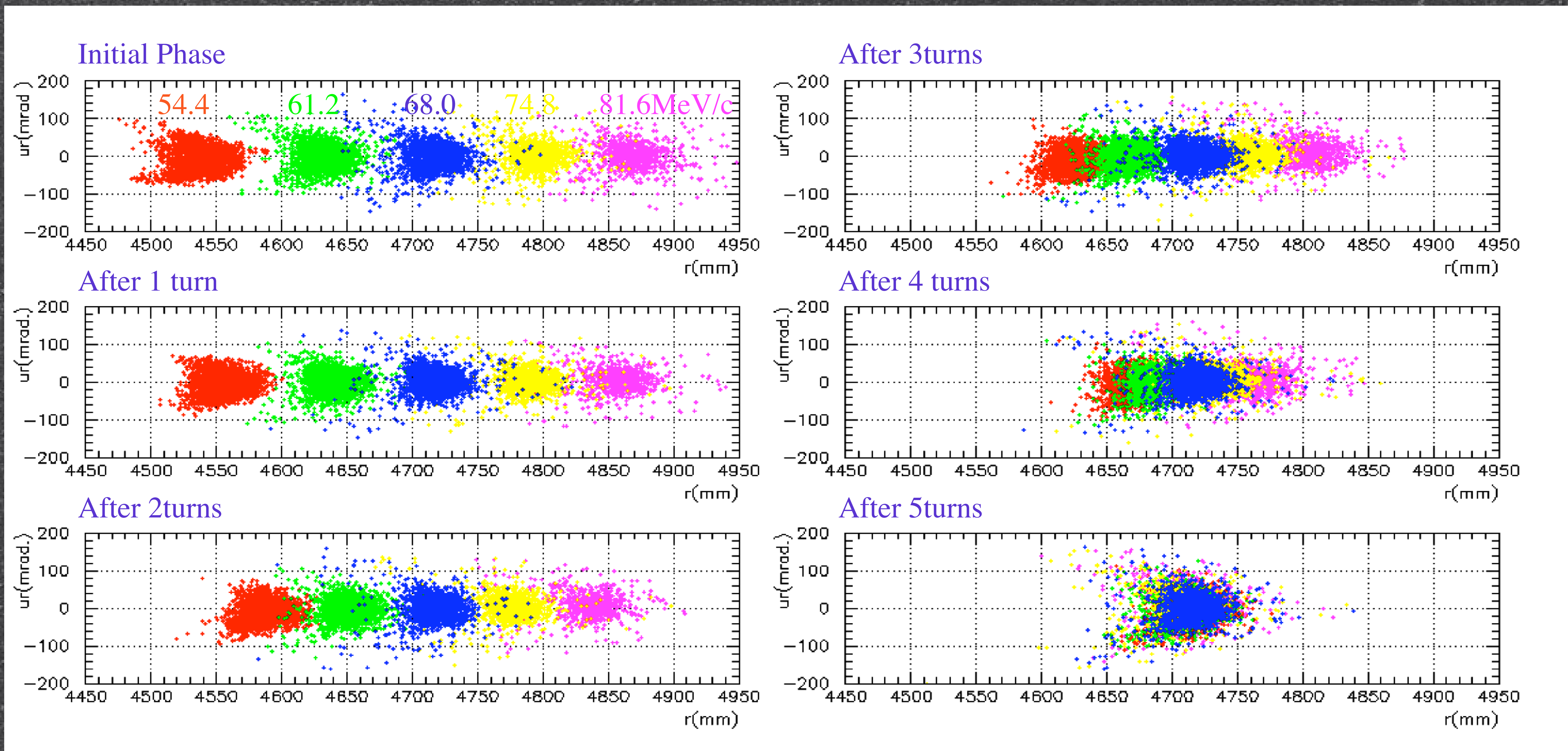
not a sinusoidal, but a saw-tooth shape is needed.

RF 5MHz, 250 kV/m

$\Delta p/p = \pm 3\ \%$

Phase Rotation Simulation

Horizontal

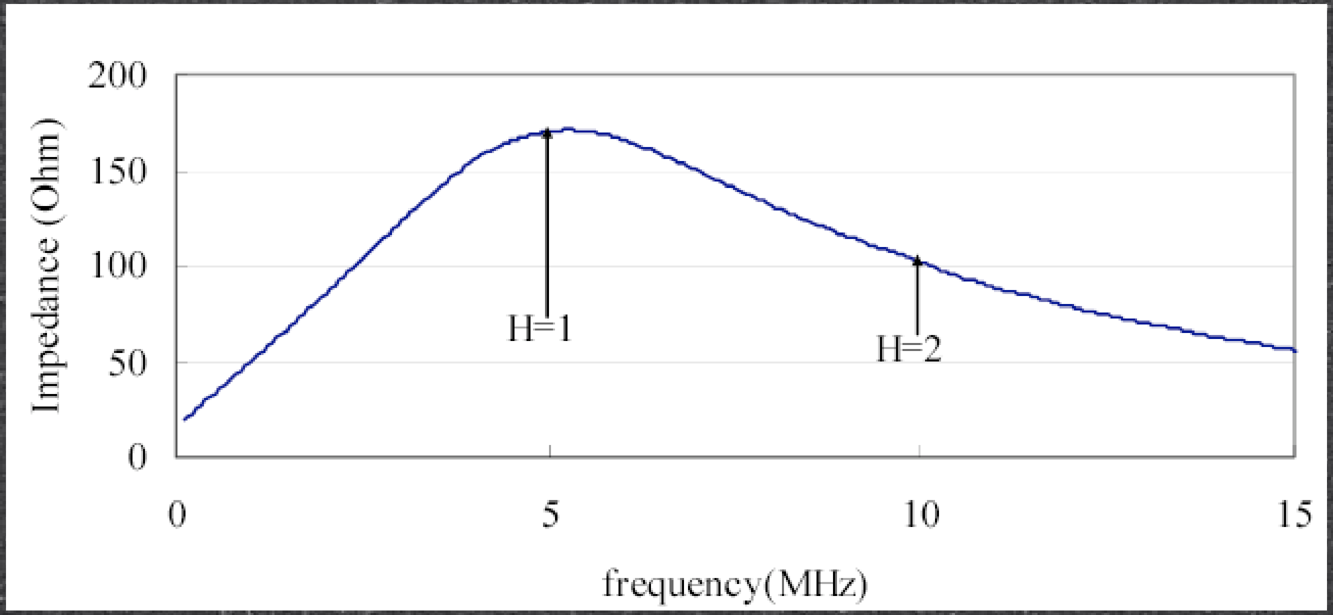


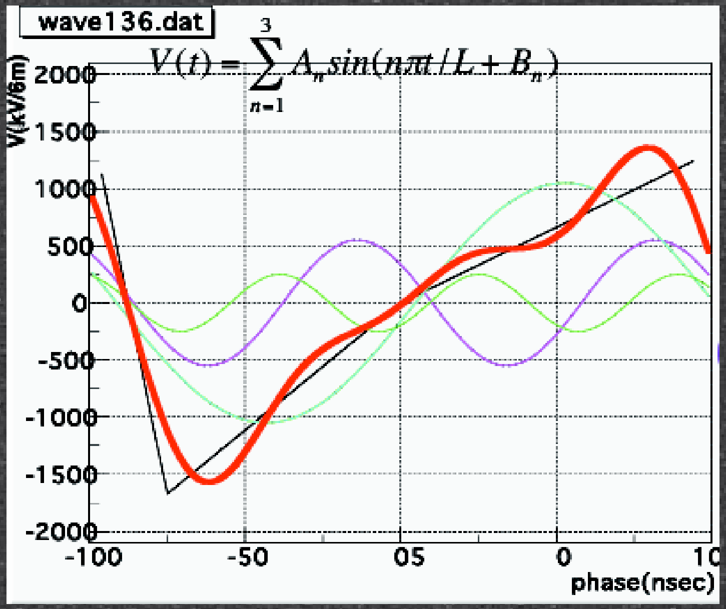
A. Sato

PRISM-FFAG
RF

Spec. for PRISM RF

- High accelerating field gradient (250 kV/m)
  - muon is unstable.
- Low Frequency RF (5 MHz)
  - muons of low energy spread longitudinally.
- Saw-tooth RF shape
  - low-Q cavity to allow higher harmonics
  - Magnetic Alloy (Finemet) core is employed.



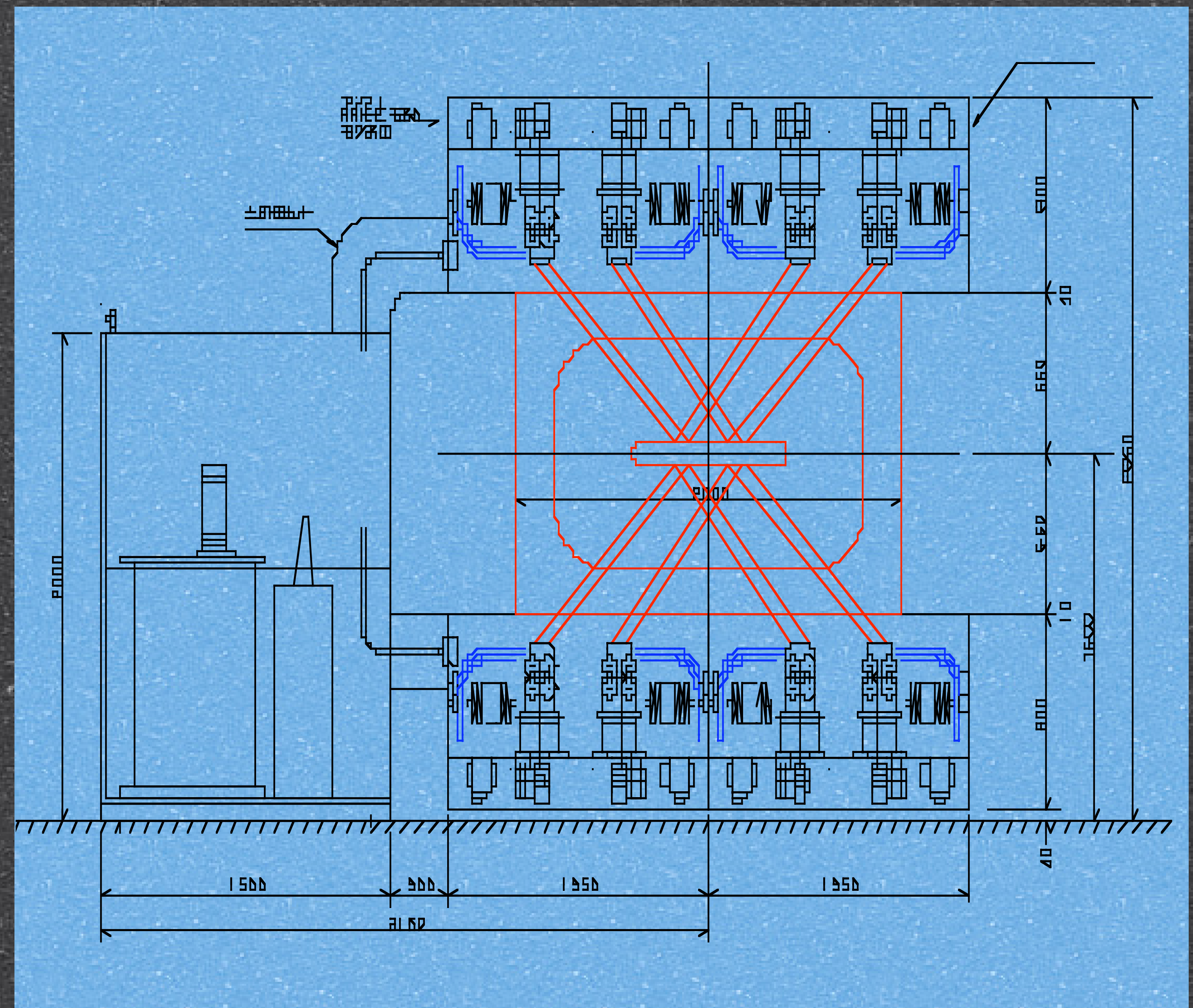


μ=2000
@5MHz
Q<1

PRISM RF System

C. Ohmori, M. Aoki

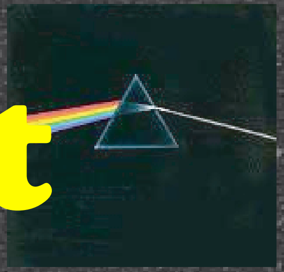
Field gradient	250kV/m
# of gaps	4
Impedance	1 kohm/gap
core	MA 4 cores/gap
Duty	0．1％ air cooling
Power Tube	EIMAC 4CW150K DC35-40kV 900 kW(peak)
Amplifier	AB-class, push-pull for each gap

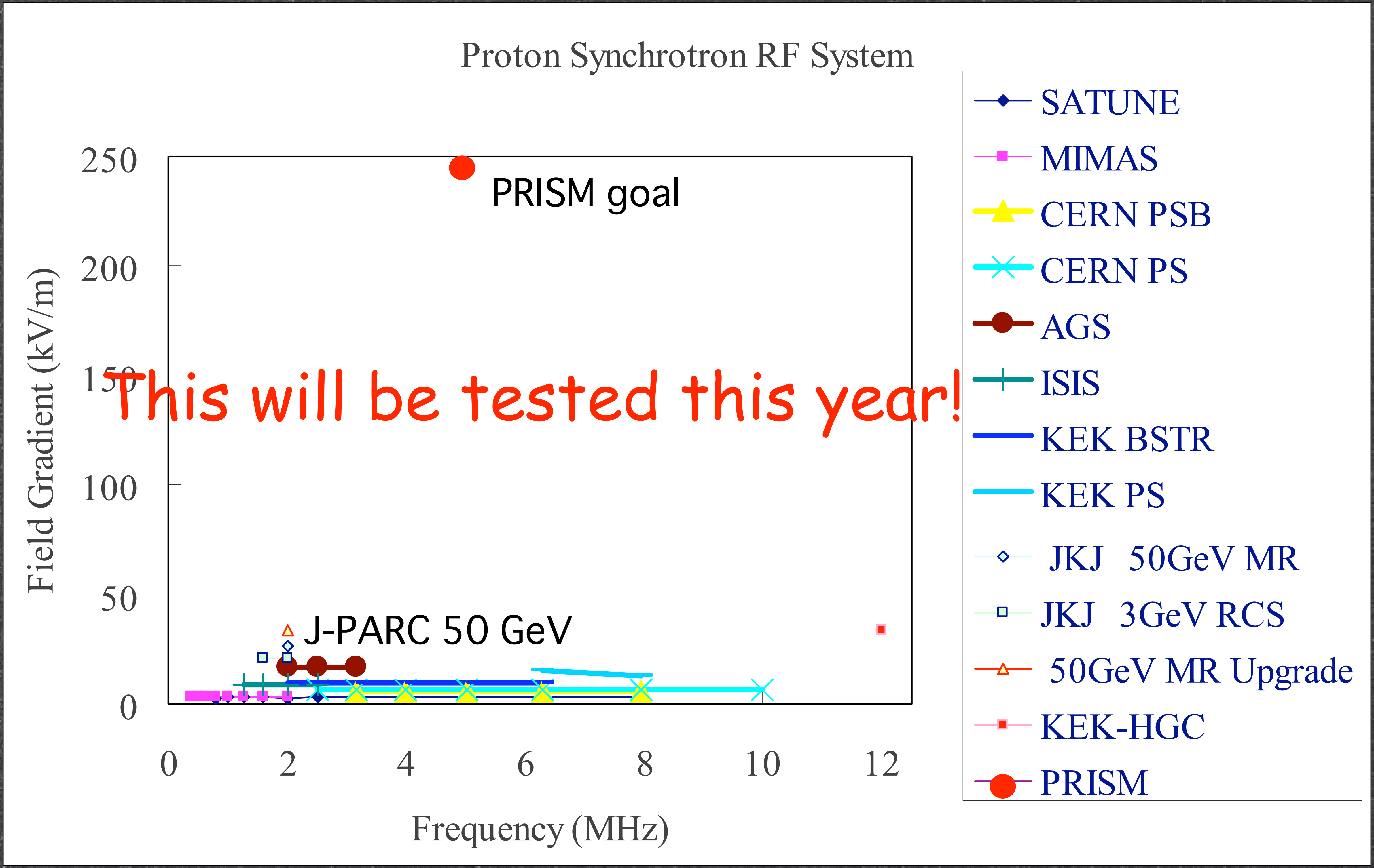


RF amplifier constructed (2003)

RF cavity constructed (2004)

PRISM RF Field Gradient





PRISM goal > 250 kV/m

Construction Schedule

- JFY2003: RF amp. production
- JFY2004: RF cavity construction, FFAG magnet construction
- JFY2005: FFAG magnet production (continue)
- JFY2006: FFAG magnet construction (completed)
- JFY2007: test muon acceleration and phase rotation, cooling?

A Phase-roted Beam for Muon EDM

Statistical Req. for EDM

@BNL/AGS

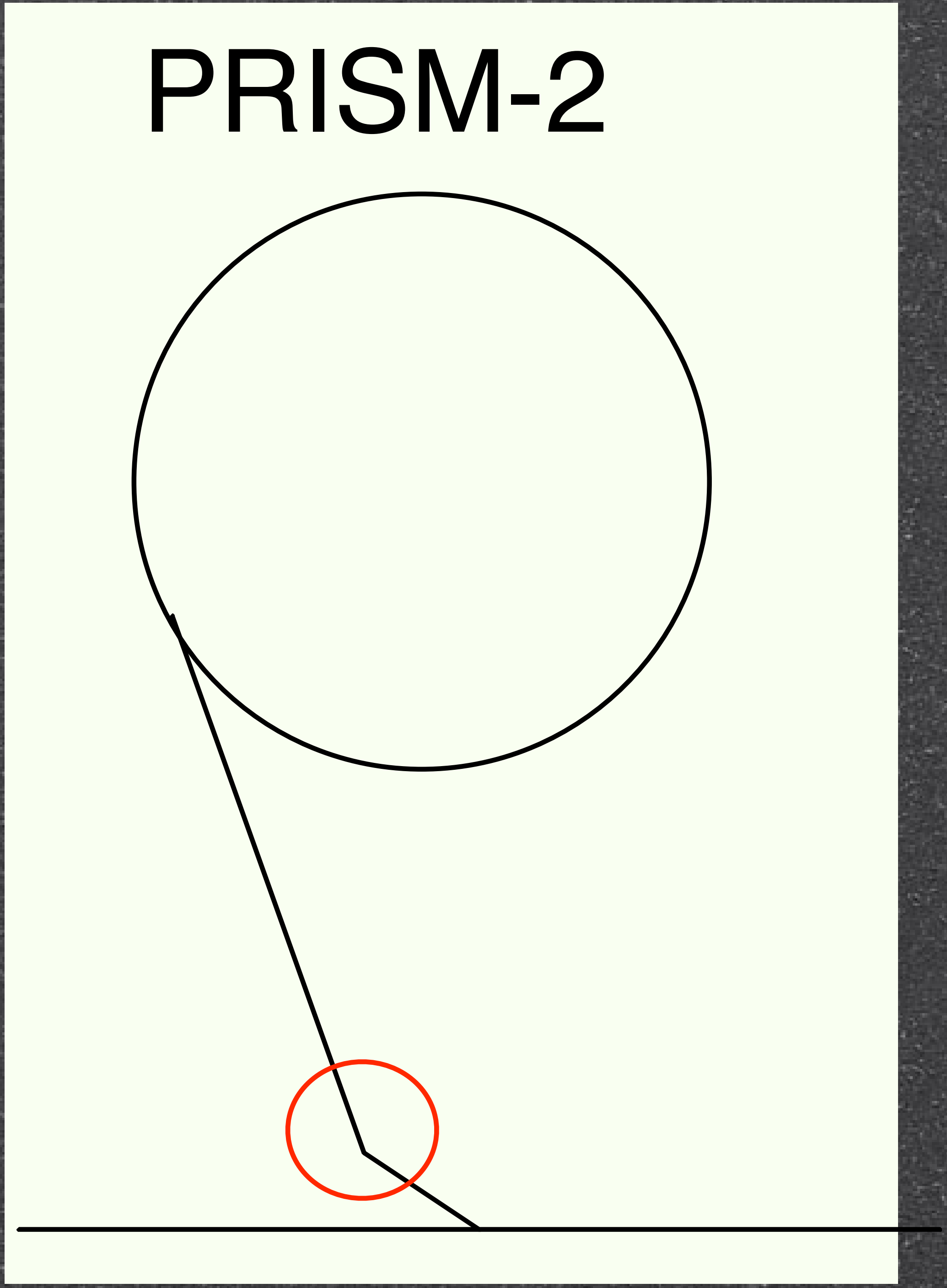
- **stage 1:** $N_\mu P_\mu^2 = 10^{12}$
  - use the existing g-2 ring but with weak magnetic focusing
  - aim at 10^{-22} e cm (400 hours)
- **stage 2:** $N_\mu P_\mu^2 = 10^{16}$
  - strong focusing
  - aim at 10^{-24} e cm (4000 hours)

@J-PARC

- **stage 3:** $N_\mu P_\mu^2 = 10^{20}$
  - use cooled muon beams from the stage II of the front end of NuFact.
    - ⇛ momentum : 0.2-0.5 GeV/c
    - ⇛ 10^{11} muons/sec
  - new storage ring
  - aim at 10^{-26} e cm (for a year)

PRISM-II

PRISM-II = FFAG-based phase rotator for the muon EDM measurement.



Increase N (intensity)

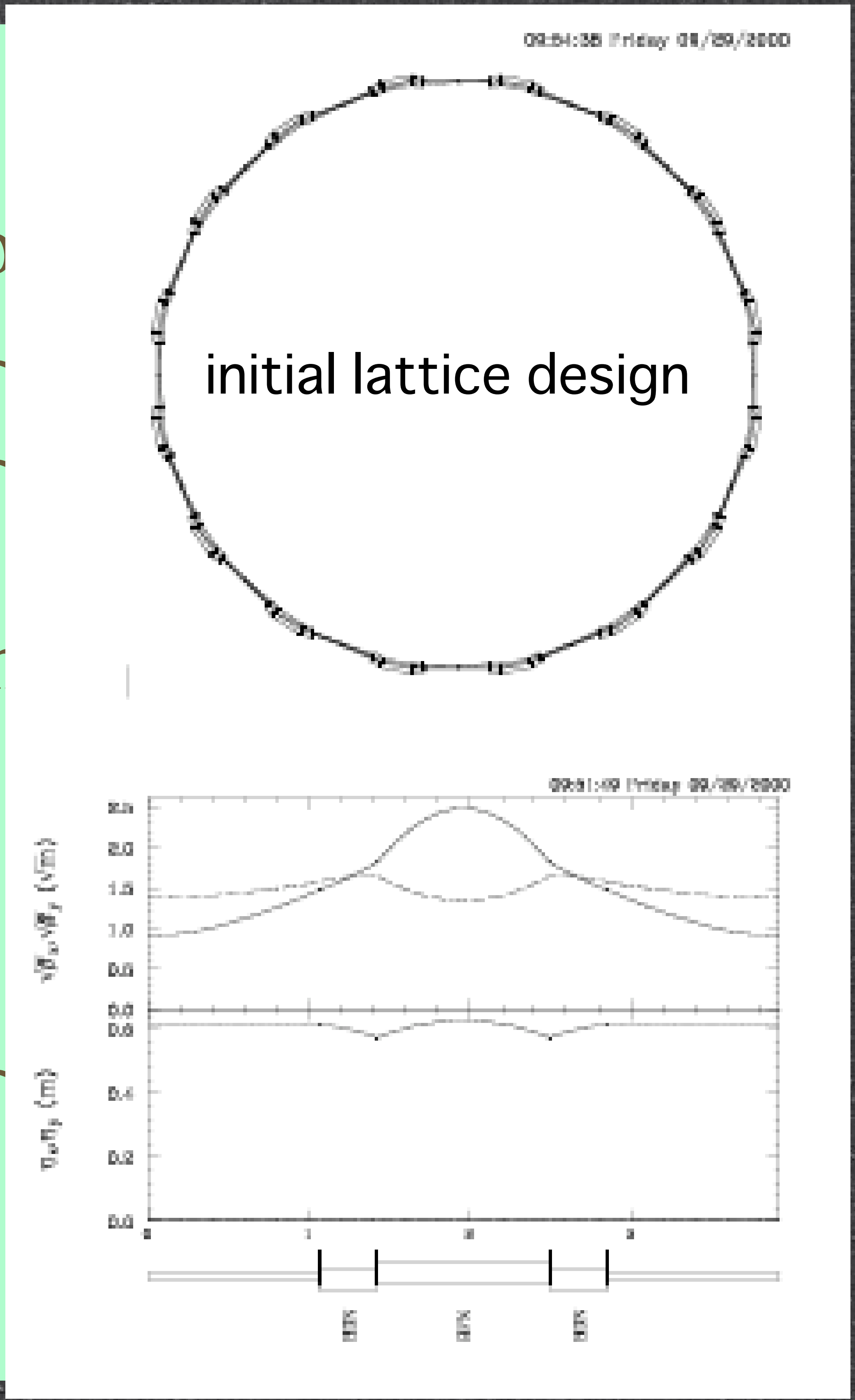
→ phase rotation to increase intensity within the given momentum band

Increase P (polarization)

→ curved solenoid to select (parent) pion momentum to keep reasonable muon polarization.

PRISM-II

- $d_\mu < 10^{-24}$ e.cm → $NP^2 > 10^{16}$ total
- Long decay section with pion mo
  - Initial muon ~
  - Polarization ~
    - Backward decay of pions
- Accept 500 MeV/c muons and ph
  - Transverse 800 π mm.mrad
  - Momentum acceptance ±30%
    - →±1~2% for muon strage ring
  - Decay survivability ~
  - $NP^2 = 10^9 \sim 10^{10}$

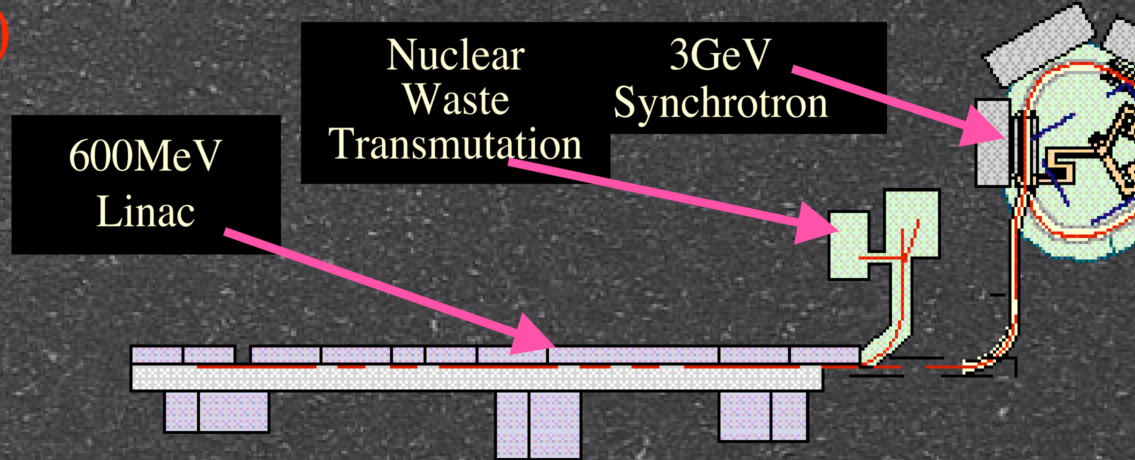


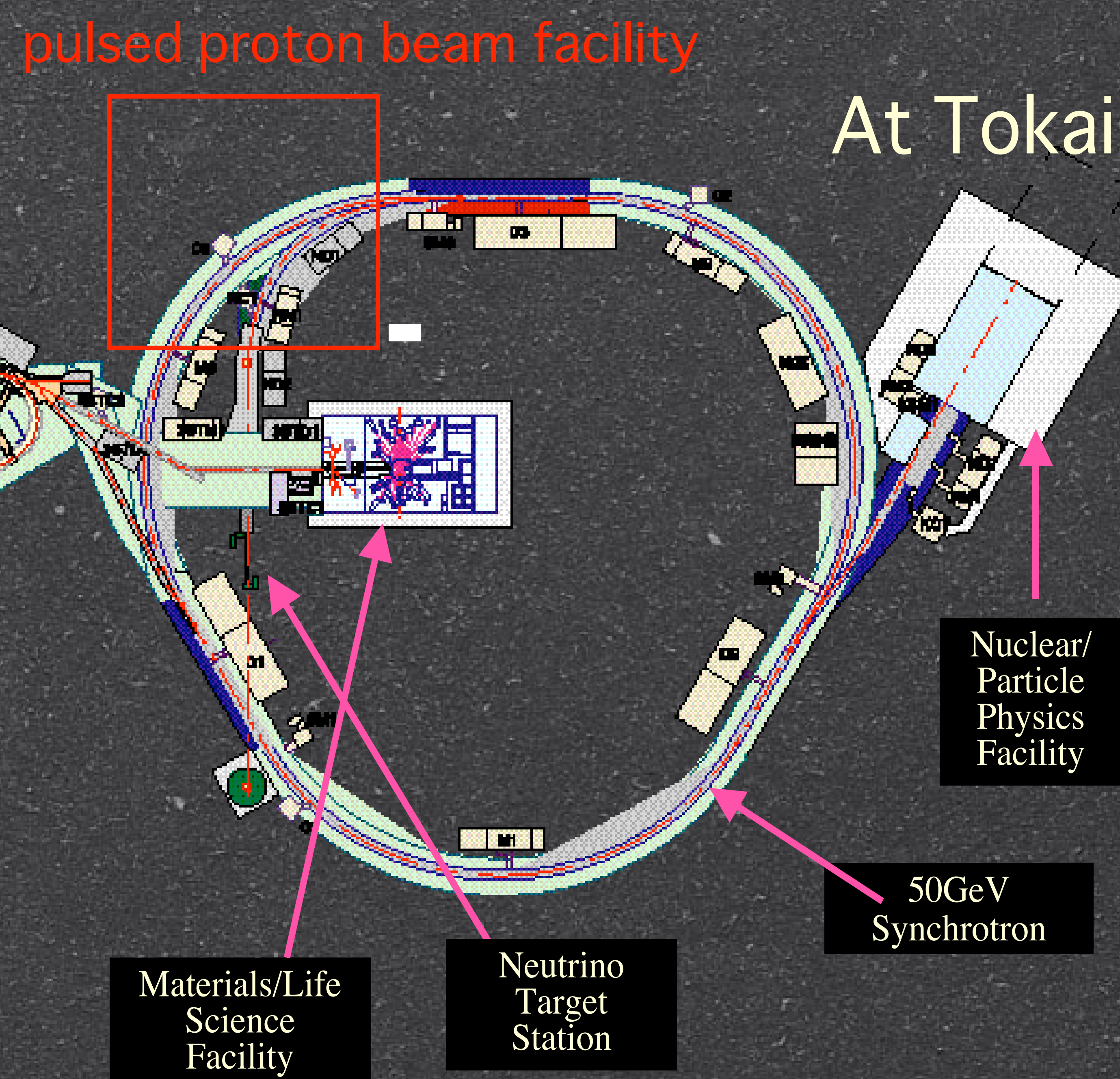
J-PARC Case
(Muon Factory)

J-PARC at Tokai

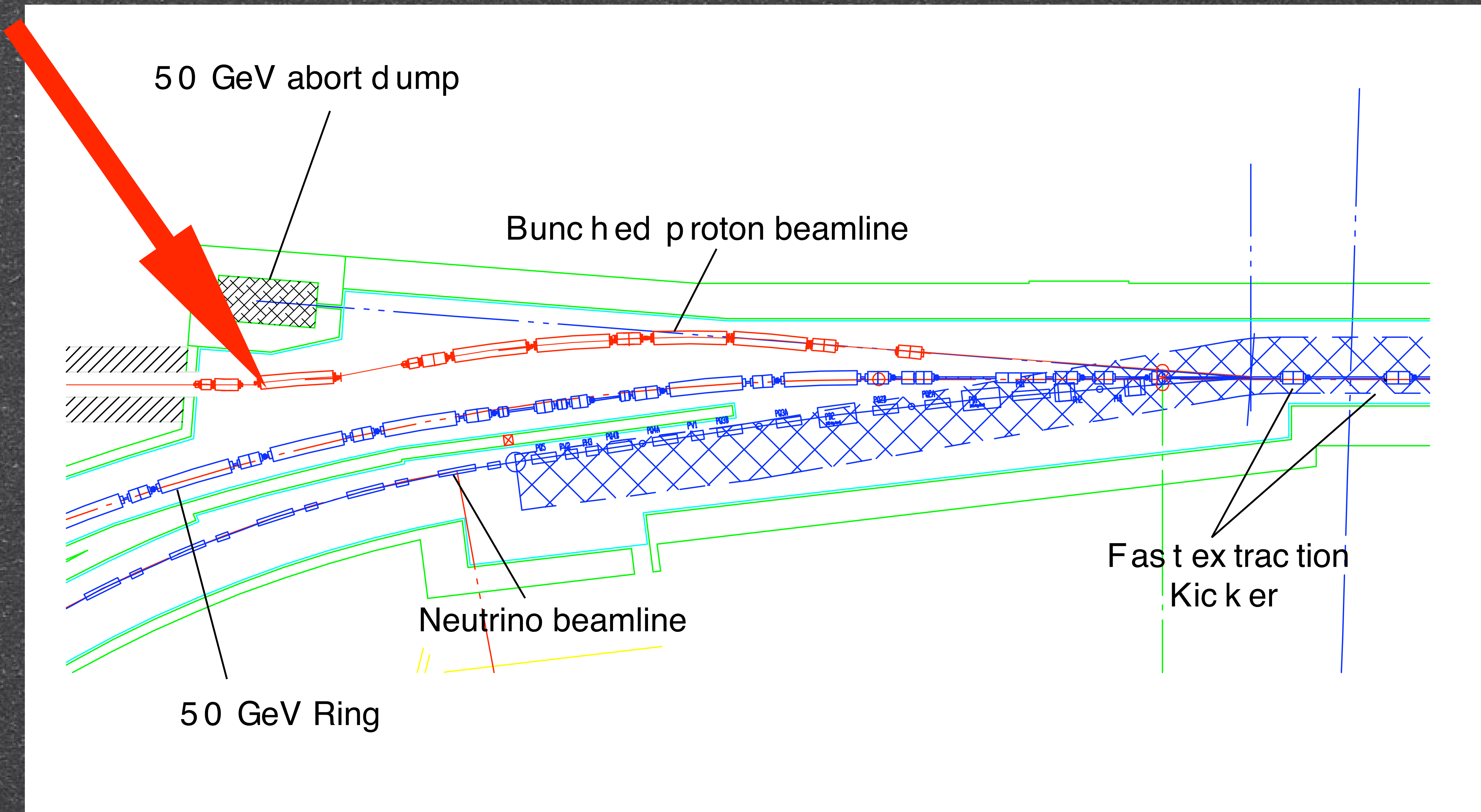
J-PARC = Japan Proton Accelerator Research Complex

400 (200) MeV proton linac
3 GeV proton synchrotron (330μA)
50 GeV proton synchrotron (15μA)
(40)





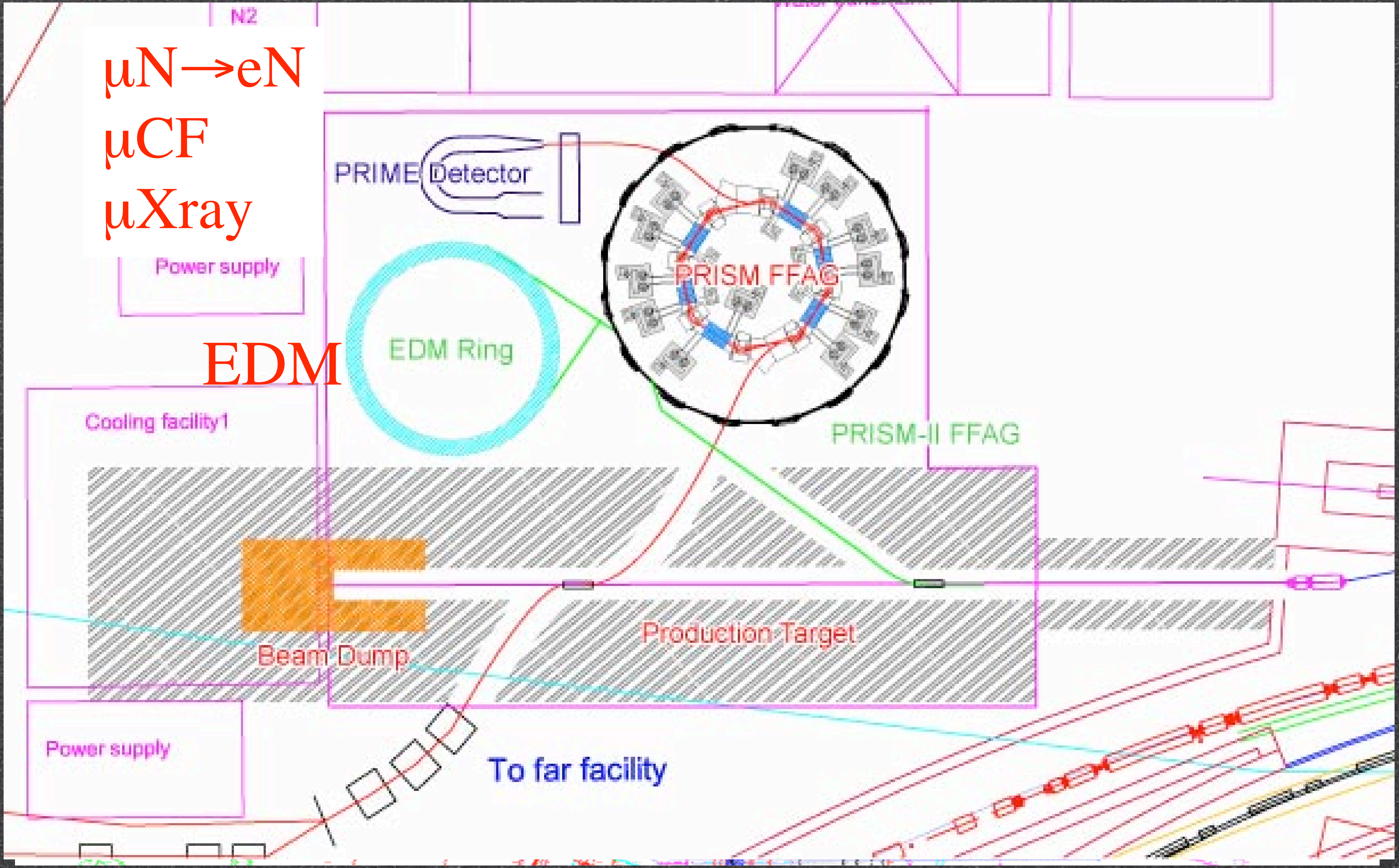
Proposed Fast Extraction



North-east side of the 50-GeV Ring

Muon Factory@J-PARC

Pulsed Proton Beam Facility is newly requested to J-PARC.



Multi Bunch Extraction

NP02, Sept.13, 20002

Many bunches for PRISM

PRISM project :

~100 bunches & bunch width ~10ns

After debunching, re-bunch in h=90 operation:

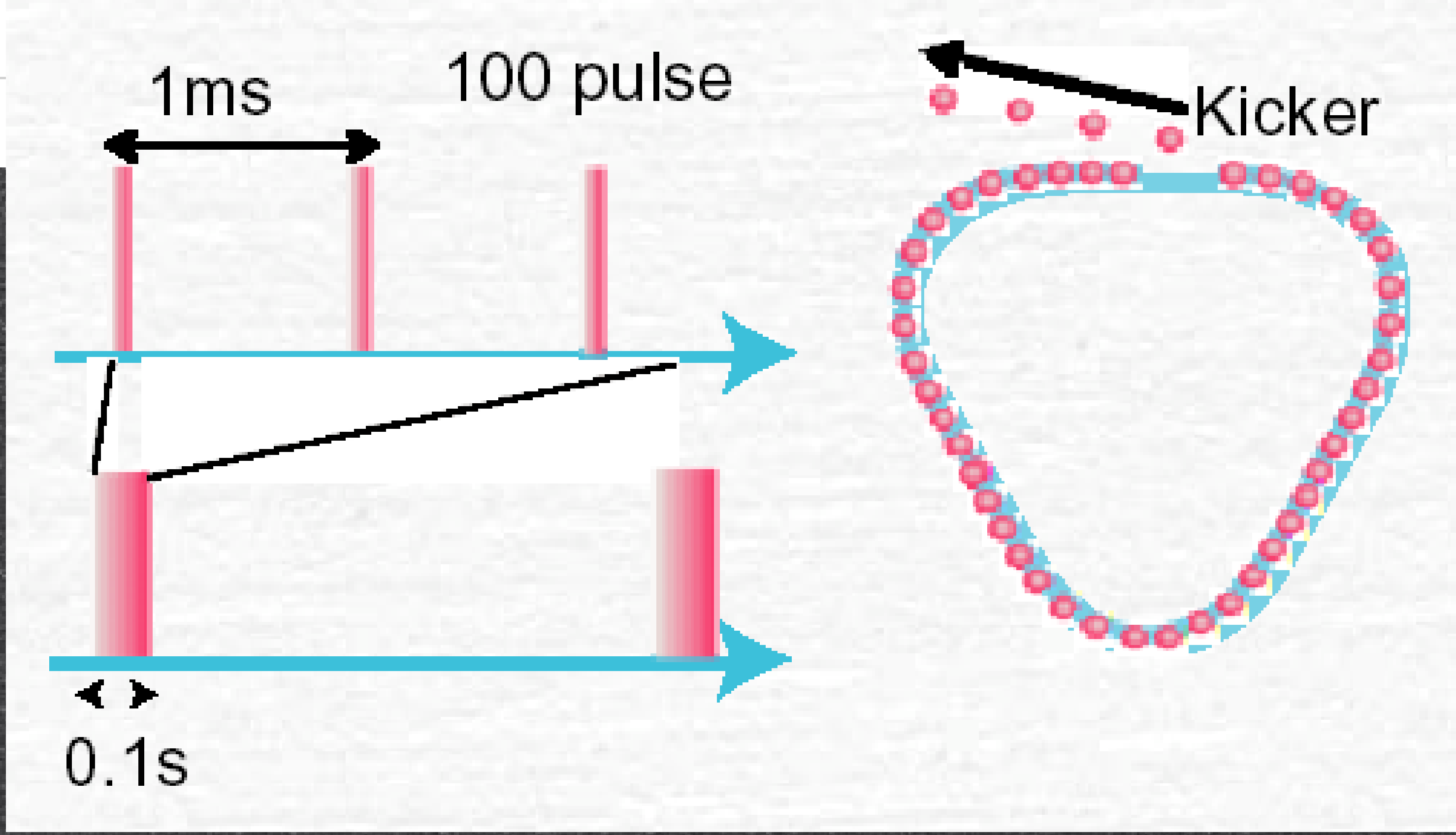
1) RF cavity (h=90) ---> f =17MHz

Large peak RF voltage : Vrf is propotional to h.

Vrf ~ 3 MV (10 times)

2) fast rise&fall-time kicker ---> dT ~50ns

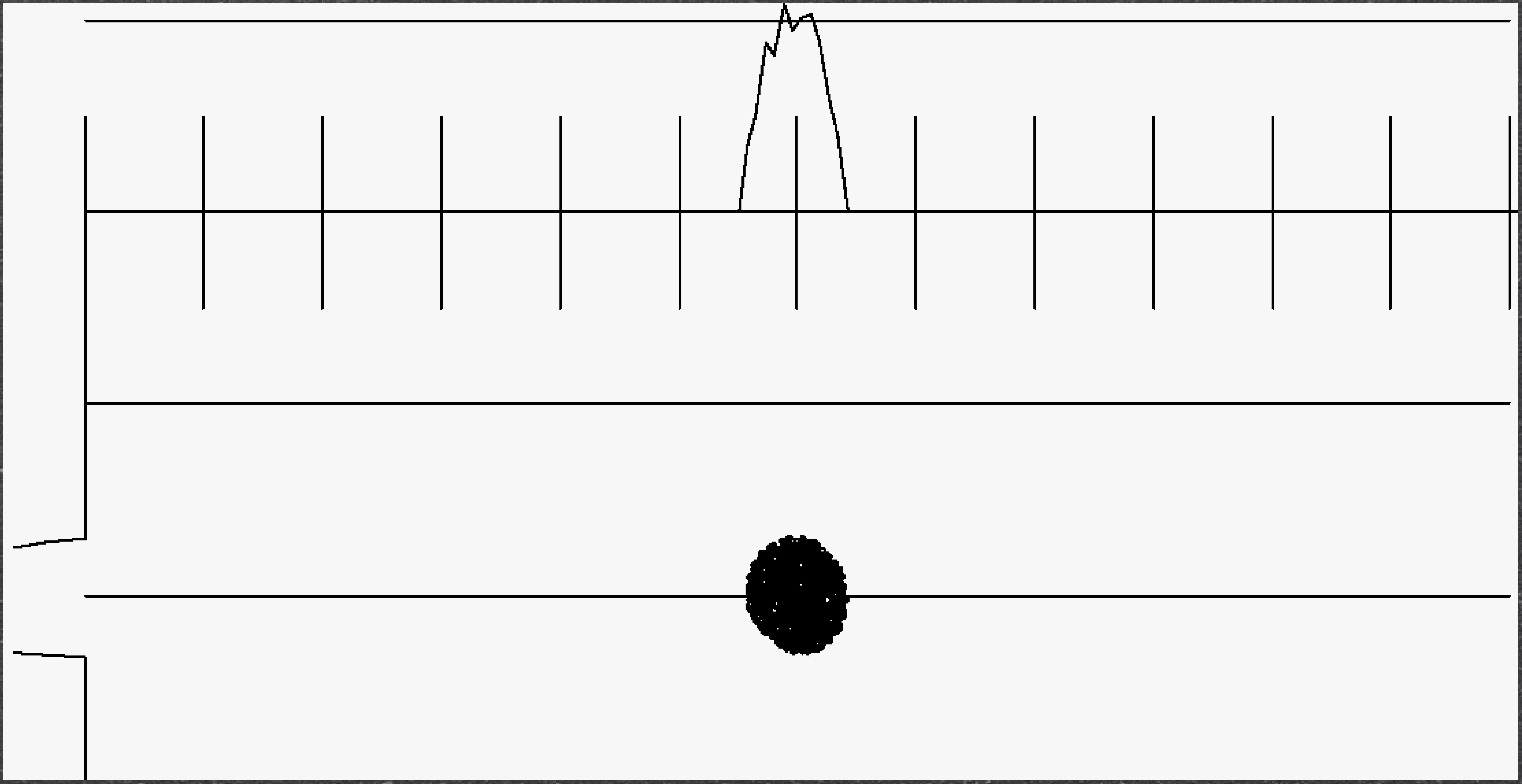
Proposed Multi-Bunch Fast Extraction Scheme



good for muon g-2 and PRISM, PRISM-II

Re-bunching Simulation (1)

Re-bunching RF = 1 MV



LOI to J-PARC

reviewed in June, 2003

	title	contact persons
1	The PRISM Project - A Muon Source of the World-Highest Brightness by Phase Rotation -	Y. Mori, K. Yoshimura, N. Sasao, Y. Kuno
2	An Experimental Search for the μ-e Conversion Process Towards an Ultimate Sensitivity of the Order of 10^{-18}	Y. Mori, K. Yoshimura, N. Sasao, Y. Kuno
3	Request for A Pulsed Proton Beam Facility at J-PARC	R.S. Hayano, Y. Kuno
4	A Study of Neutrino Factory in Japan	Y. Mori, Y. Kuno
5	Search for a Permanent Muon Electric Dipole Moment at 10^{-24} ecm Level	Y. Semertzidis, J. Miller, Y. Kuno
6	An Improved Muon (g-2) Experiment at J-PARC	L. Roberts
7	A Study of a Target System for a 4-MW, 50-GeV Proton Beam	K. McDonald, H. Kirk, Y. Kuno, Y. Yoshimura

A pulsed proton beam is required for all.

The Muon Trio

Muon g-2

$$0.7\text{ppm} \rightarrow 0.05 \text{ ppm}$$

Muon LFV

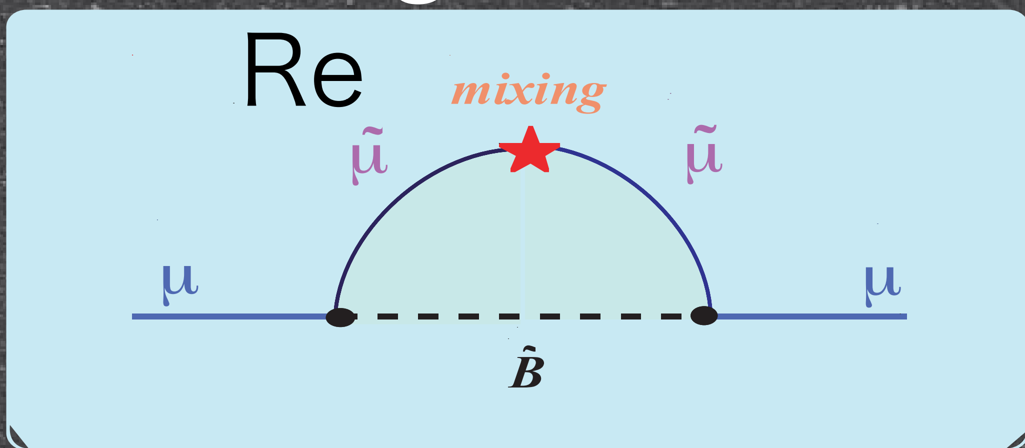
$$B(\mu^- N \rightarrow e^- N) < 10^{-18}$$

Muon EDM

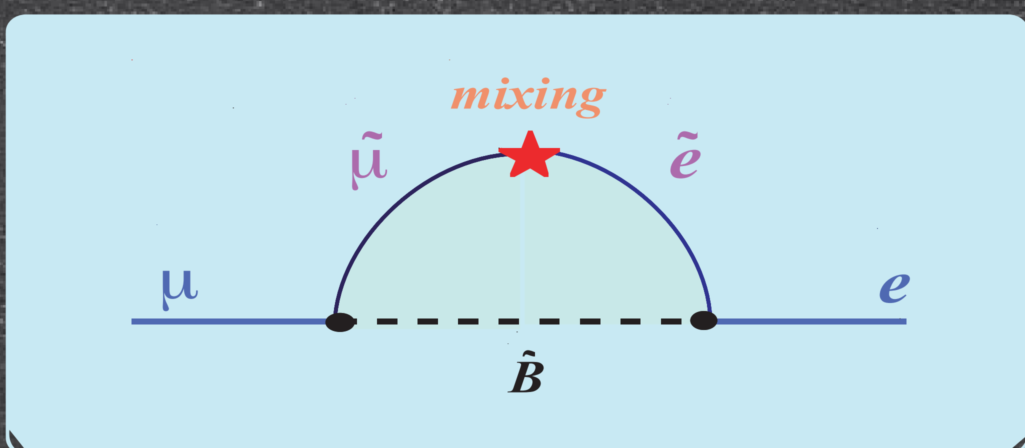
$$d_\mu < 10^{-19} e \cdot cm \rightarrow d_\mu < 10^{-24} e \cdot cm$$

The Muon Trio

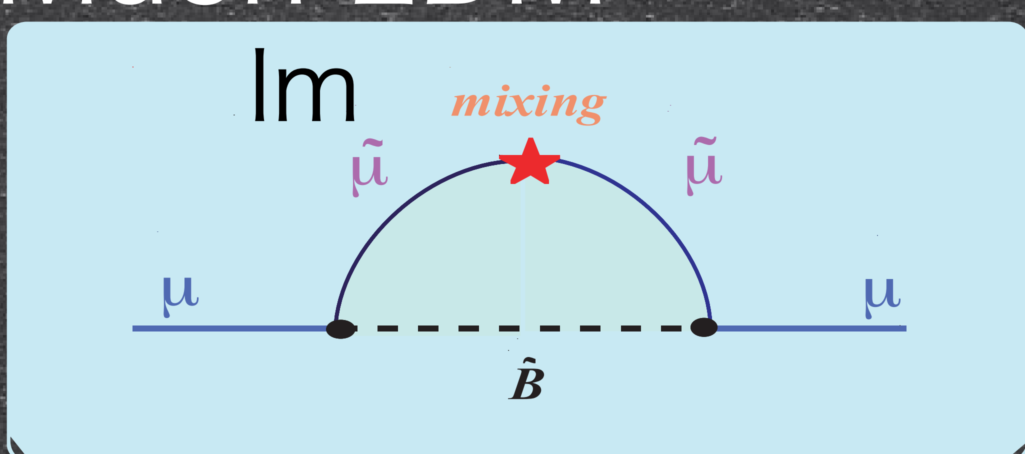
Muon g-2



Muon LFV



Muon EDM



in SUSY case

Slepton mixing matrix

$$\begin{pmatrix} m^2_{\tilde{e}\tilde{e}} & \Delta m^2_{\tilde{e}\tilde{\mu}} & \Delta m^2_{\tilde{e}\tilde{\tau}} \\ \Delta m^2_{\tilde{\mu}\tilde{e}} & m^2_{\tilde{\mu}\tilde{\mu}} & \Delta m^2_{\tilde{\mu}\tilde{\tau}} \\ \Delta m^2_{\tilde{\tau}\tilde{e}} & \Delta m^2_{\tilde{\tau}\tilde{\mu}} & m^2_{\tilde{\tau}\tilde{\tau}} \end{pmatrix}$$

Hints for SUSY breaking

J-PARC Phasing

- Phase-1 (2001-2008)
  - J-PARC original budget : about 190 B JYen
  - 135 B JYen approved in JFY2001 : Phase-1
  - will be completed by spring, 2008.
- Phase-1.5? (2004-2008)
  - Neutrino Program approved in JFY2004 (16 B JYen) for 5 years
- Phase-2
  - Rest in the original budget
- Phase-3
  - something new

Phase 2+

LOI Evaluations

Aug. 2003

L25

An Experimental Search for the $\mu \rightarrow e$ Conversion Process at an Ultimate Sensitivity of Order of 10^{-18} with PRISM

Contact Persons: Y. Mori, K. Yoshimura, N. Sasao, and Y. Kuno

Schedule: Phase 2+

Comments:

This LoI describes an experiment called PRIME, which is designed to search for the Lepton-Flavor-Violating (LFV) $\mu \rightarrow e$ conversion process. Discovery of a signal in this mode would have enormous impact and would constitute unambiguous evidence of physics beyond the standard model. PRIME's target sensitivity of 10^{-18} in branching ratio provides sensitivity to a large portion of the available parameter space of various supersymmetric extensions to the standard model.

The committee rates the physics goals of PRIME extremely high and recommends that it be considered as a Phase II proposal.

In J-PARC News Letter

=-

J-PARC Project Newsletter

_______ No. 14 November, 2003 _______

~~~~~~

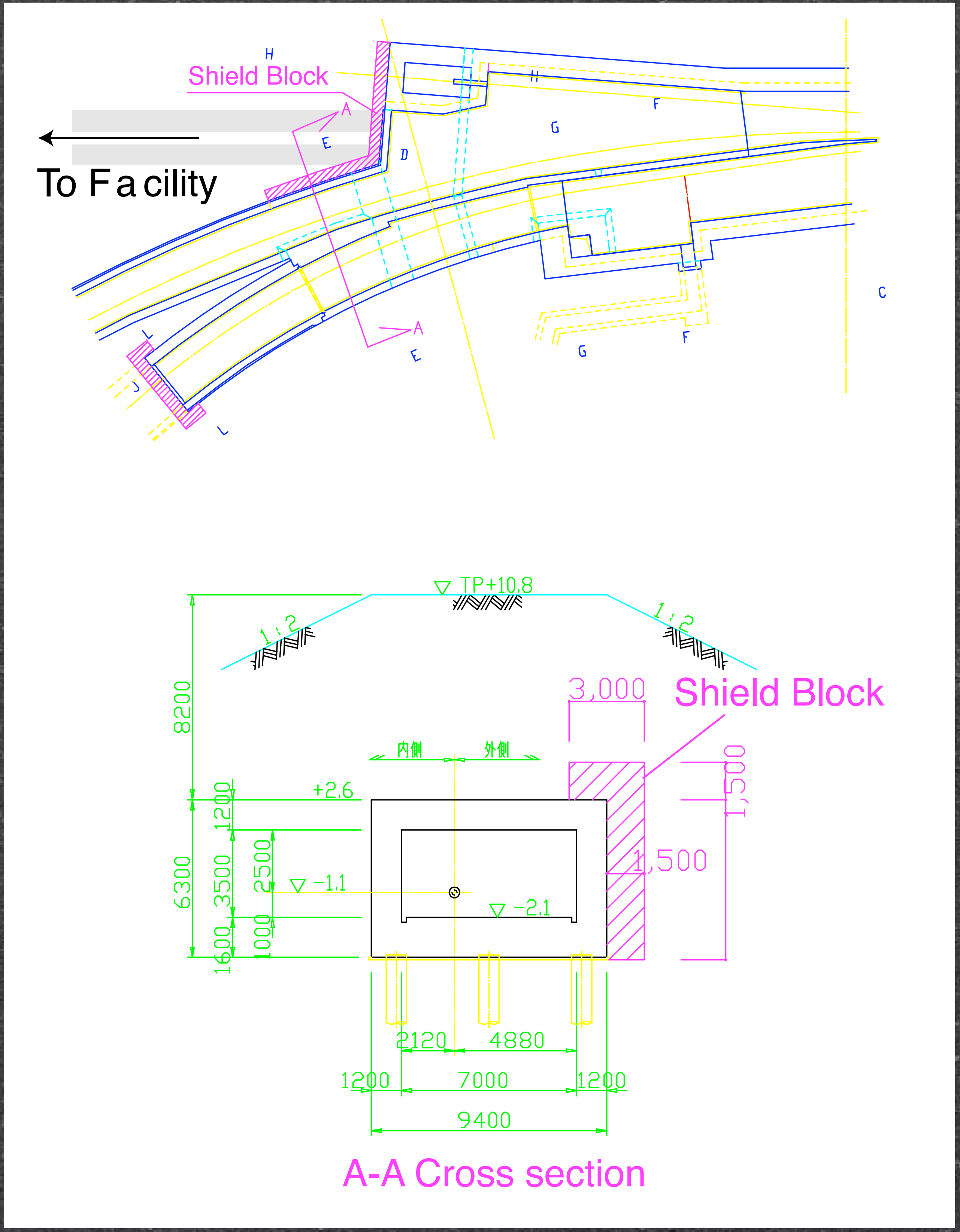
1. <<Overview>> By Shoji NAGAMIYA

~~~~~~

On the other hand, for nuclear and particle physics experiments, presentations of 30 LoI's were made at two meetings in March and June. The results were sent to the Project Director. The committee recommended two important experiments for Day-1 at 50 GeV.
Also, the committee recommended the importance of a test beam line. About 16 experimental proposals were submitted for Phase 1 (but not for Day-1). The committee examined all the proposals carefully and ranked them. The Project Office is currently modifying the design of the experimental hall to allow important experiments for Day-1 and also in Phase 1. In addition to these proposals, many new proposals that require new beam lines were also submitted. They are classified as Phase 2+ experiments. Several excellent proposals were submitted in this Phase 2+ category. The project team decided to prepare a new second fast-extraction beam line in addition to the first fast-extraction beam line for the neutrino project.

Status in JFY2004

- At J-PARC Phase-1, we have requested budget for shielding to prevent soil activation for the proposed pulsed-proton beam line (2003, LOI).
- In JFY2004, we receive from KEK about 25 M JYen. The shielding will be constructed and placed.



More Works to do...

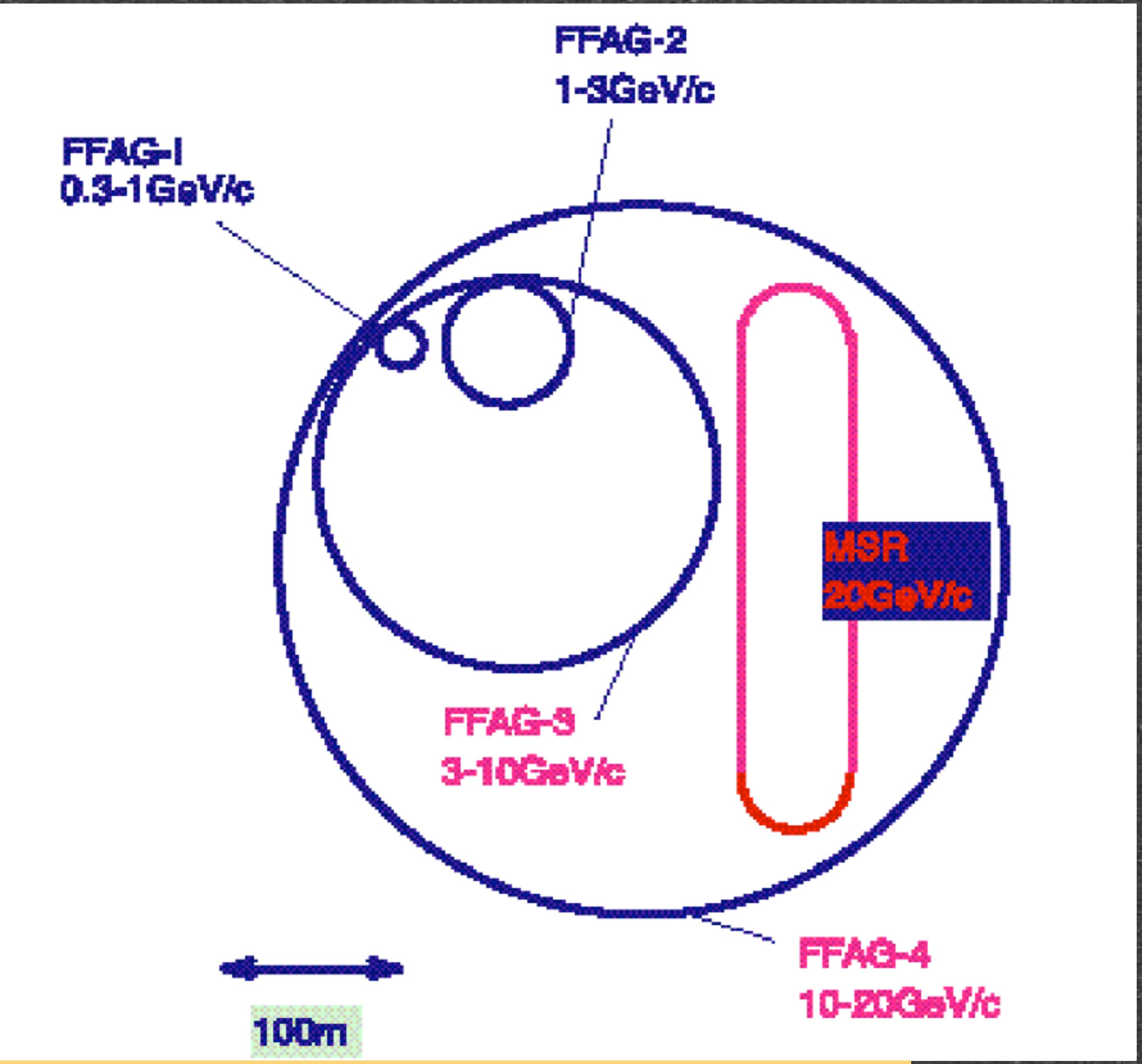
- Multi Proton Bunching scheme in the 50-GeV Ring
- Fast proton kicker magnet
- Design of the proton beam optics
- Targetry
- Cost Estimation of the Facility

J-PARC Case
(Neutrino Factory)

FFAG-based Acceleration

- FFAG
  - Large acceptance
  - Fast acceleration
  - Muon cooling is not mandatory (better if available).
- Advantages
  - less RF cavities and power.
  - simple and compact
- Either Scaling or Non-scaling !!!

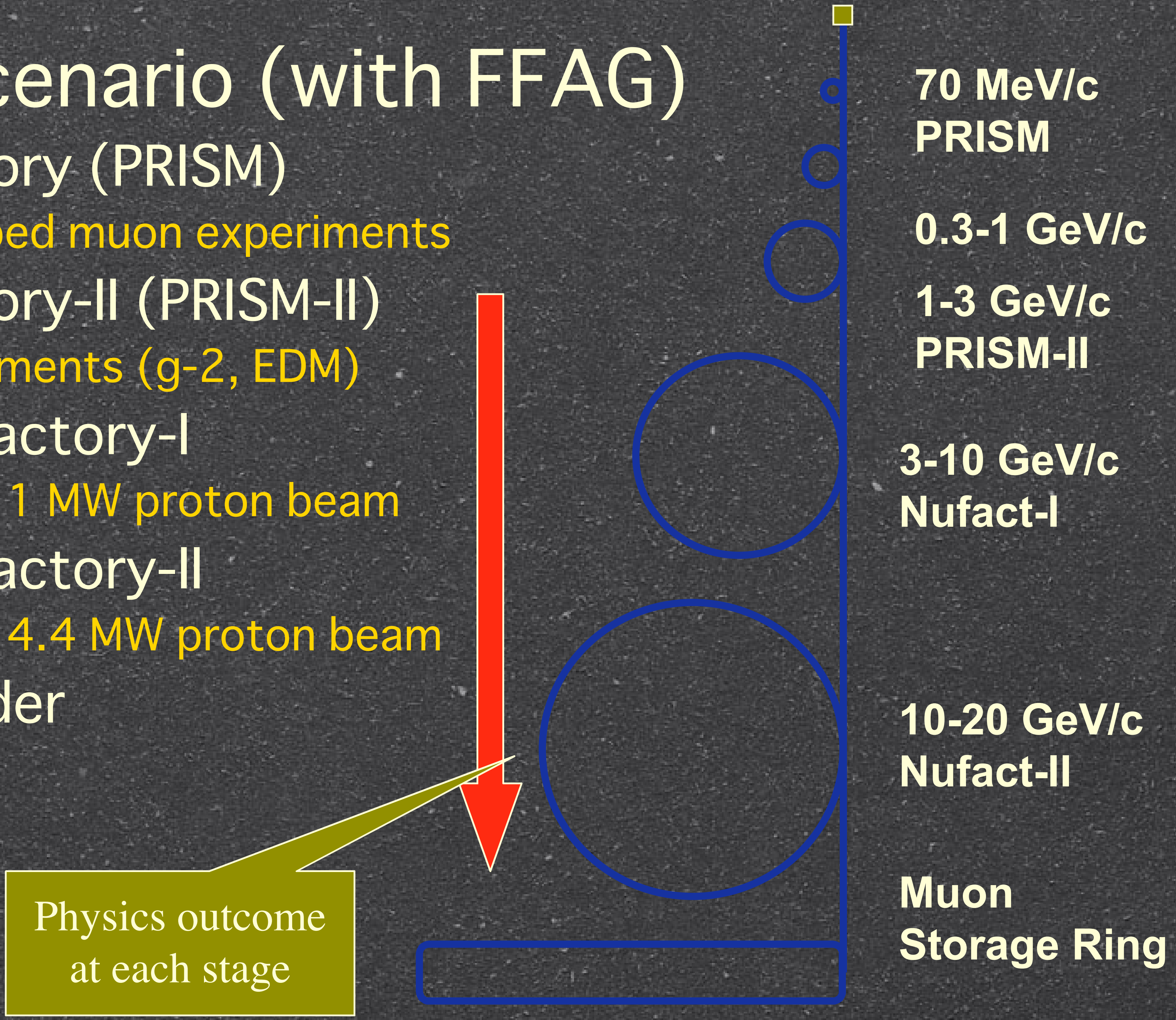
A series of 3-4 FFAG rings



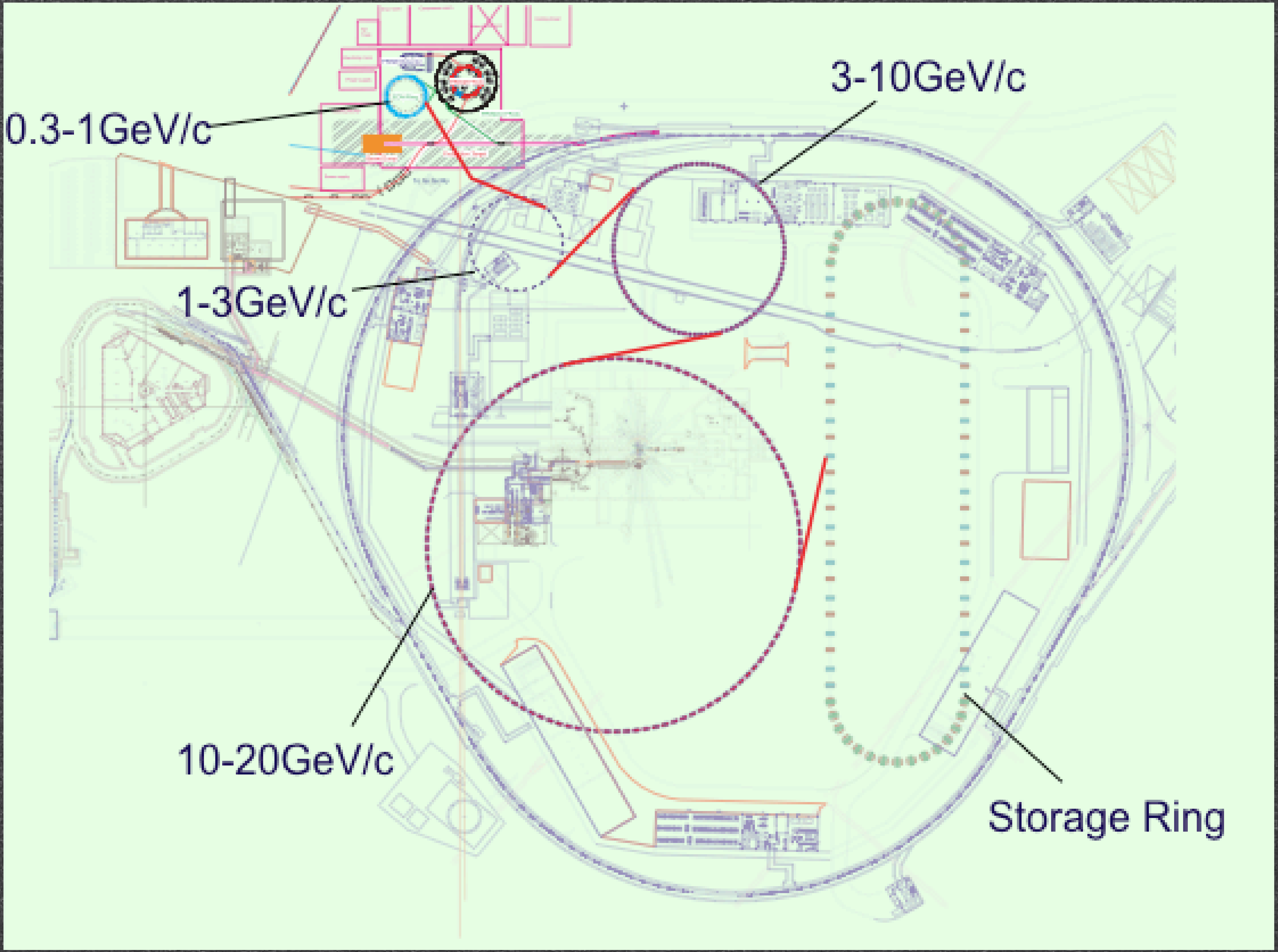
Muon Acceleration based on a series of FFAGs

From MF to NF

- Staging scenario (with FFAG)
  - Muon Factory (PRISM)
    - For stopped muon experiments
  - Muon Factory-II (PRISM-II)
    - Muon moments (g-2, EDM)
  - Neutrino Factory-I
    - Based on 1 MW proton beam
  - Neutrino Factory-II
    - Based on 4.4 MW proton beam
  - Muon Collider



NuFACT at J-PARC



Summary

- PRISM is a dedicated muon source of high intensity, narrow energy width, and high purity.
- PRIME is to search for mu-e conversion at a sensitivity of 10^{-18} with PRISM (PRISM-II is for muon EDM search.)
- The PRISM-FFAG ring construction has started at Osaka University (5 years).
- A plan of muon factory (with PRISM) is shown as well as scenario towards a neutrino factory.
- Would provide opportunity of great discovery.

Welcome to join us !

NuFact04

July 26-August 1, 2004
Osaka University, Japan

WG4:High Intense
Muon Physics
Yannis Semertzidis (BNL)
Marco Grassi (Pisa)
Katsu Ishida (Riken)