Neutrino Factory (based on Muon Storage Ring) in Japan

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JHF-NP01 Workshop, KEK

December 11th, 2001

Advantages of Neutrinos from Muon Decays

- High neutrino intensity at high energy
  - 2×10^{20} neutrinos/year (10^{20}-10^{22})
  - about 100 times intensity at a few 10 GeV energy range
- Both muon and electron neutrinos available
  - Energetic electron neutrino
- Extremely low beam backgrounds
  - Less than 10^{-4} level
    - a few % level at the conventional sources.
- Precise knowledge on neutrino intensity and emittance

Oscillation Physics Programs

- Observation of $\nu_e \rightarrow \nu_\mu$ oscillation
  - Sign of δm^2 (pattern of neutrino masses)
  - Matter effect
- First observation of $\nu_e \rightarrow \nu_\tau$ oscillation
- Unitarity of MNS matrix
- Measurement of oscillation $\nu_\mu \rightarrow \nu_\tau$ $\nu_\mu \rightarrow \nu_e$
- Search for CP violation
  $P(\nu_e \rightarrow \nu_\mu) - P(\bar{\nu}_e \rightarrow \bar{\nu}_\mu)$
  - Matter effect
- Search for T violation
  $P(\nu_e \rightarrow \nu_\mu) - P(\nu_\mu \rightarrow \nu_e)$
  - No matter effect
  - Detection harder
- Search for CPT violation
  $P(\nu_e \rightarrow \nu_\mu) - P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$

Direct and Indirect Search

- Indirect CP search

$$\kappa^2 \approx \sum_j \frac{[N_j(\delta) - N_j(\delta = 0)]^2}{\sigma_j^2}$$

  - Sensitive to cos(δ)
  - Higher sensitivity, but indirect measurement.
  - Higher neutrino energy is preferred.

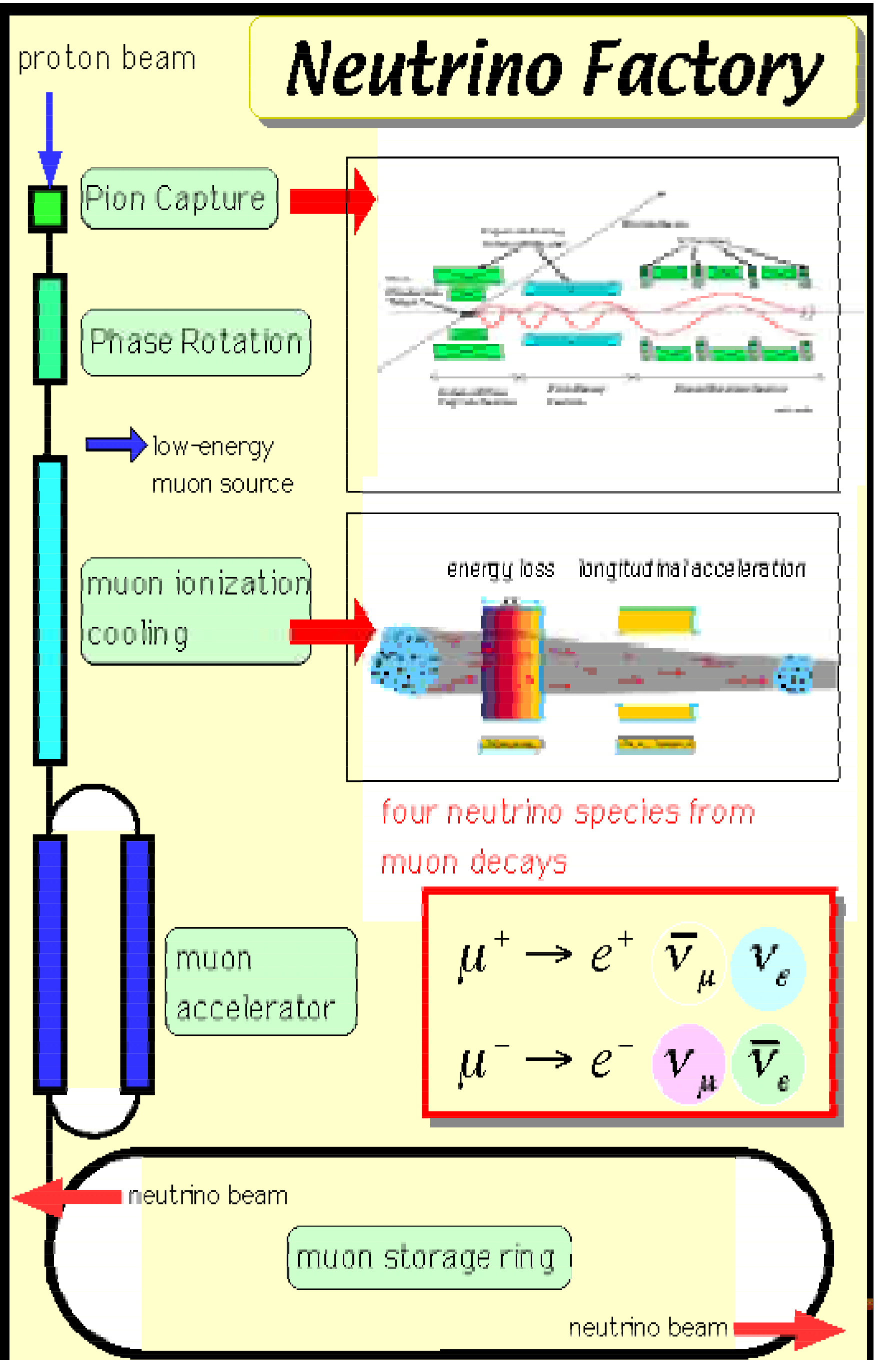
- Direct CP search

$$\kappa^2 \approx \sum_j \frac{[N_j(\delta) - 2\overline{N}_j(\delta)]^2}{\sigma_j^2}$$

  - Sensitive to sin(δ)
  - Lower sensitivity, but direct measurement
  - Lower neutrino energy is preferred.

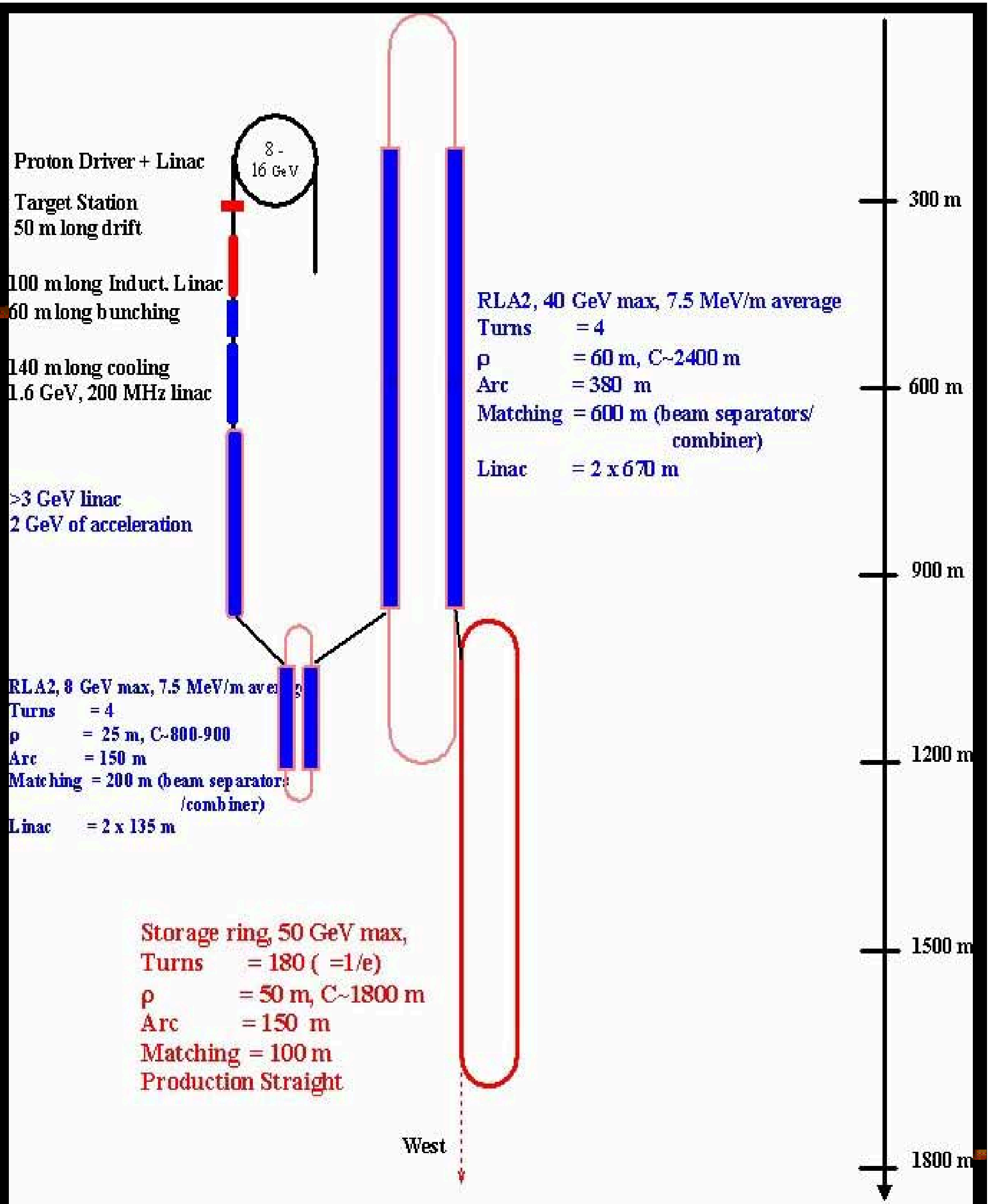
Neutrino Factory Scheme

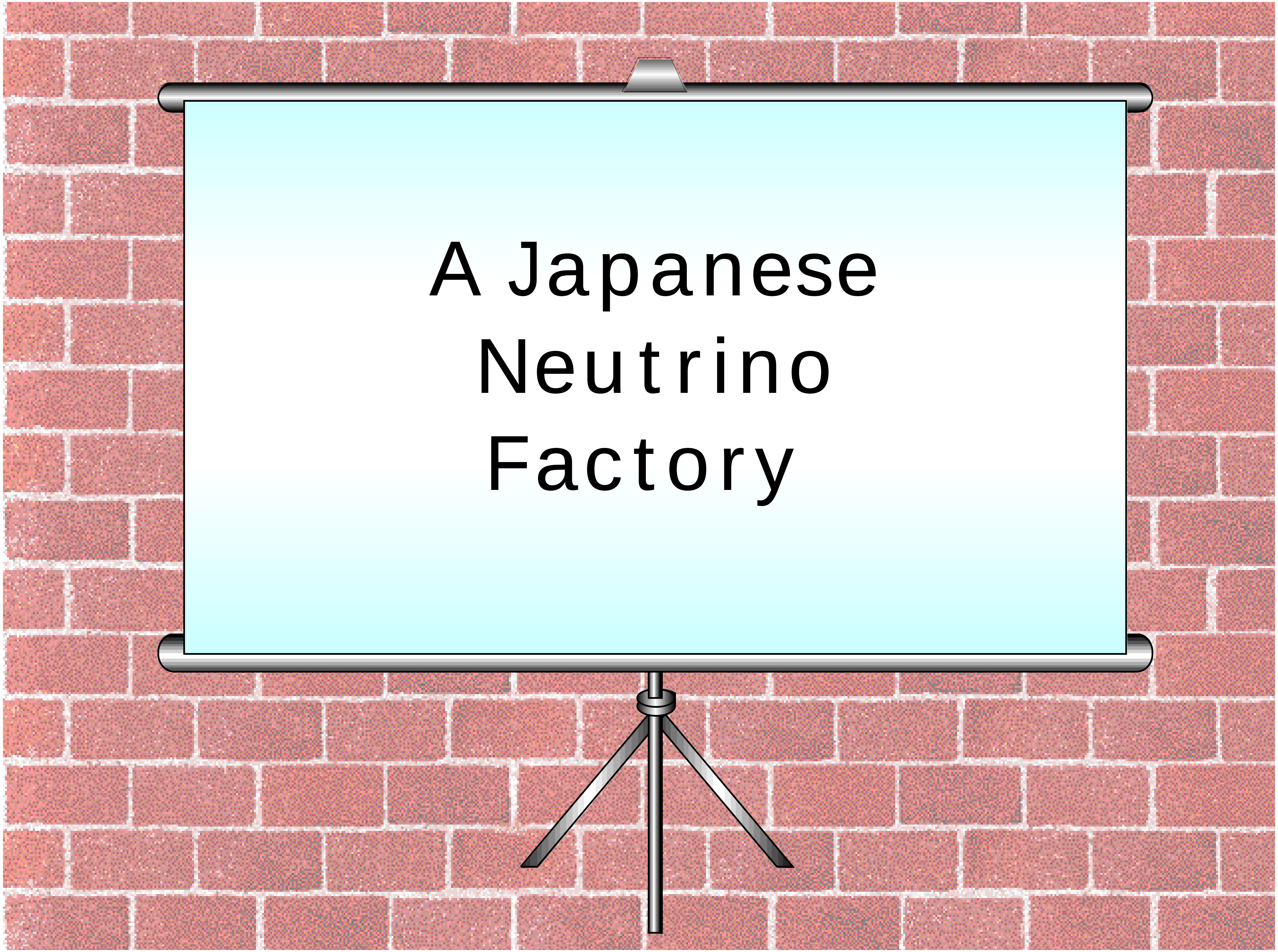
- Proton on target
- Pion capture
- Phase rotation
- Ionization cooling
- Acceleration
- Muon storage ring



Neutrino Factory

- FNAL




A Japanese
Neutrino
Factory

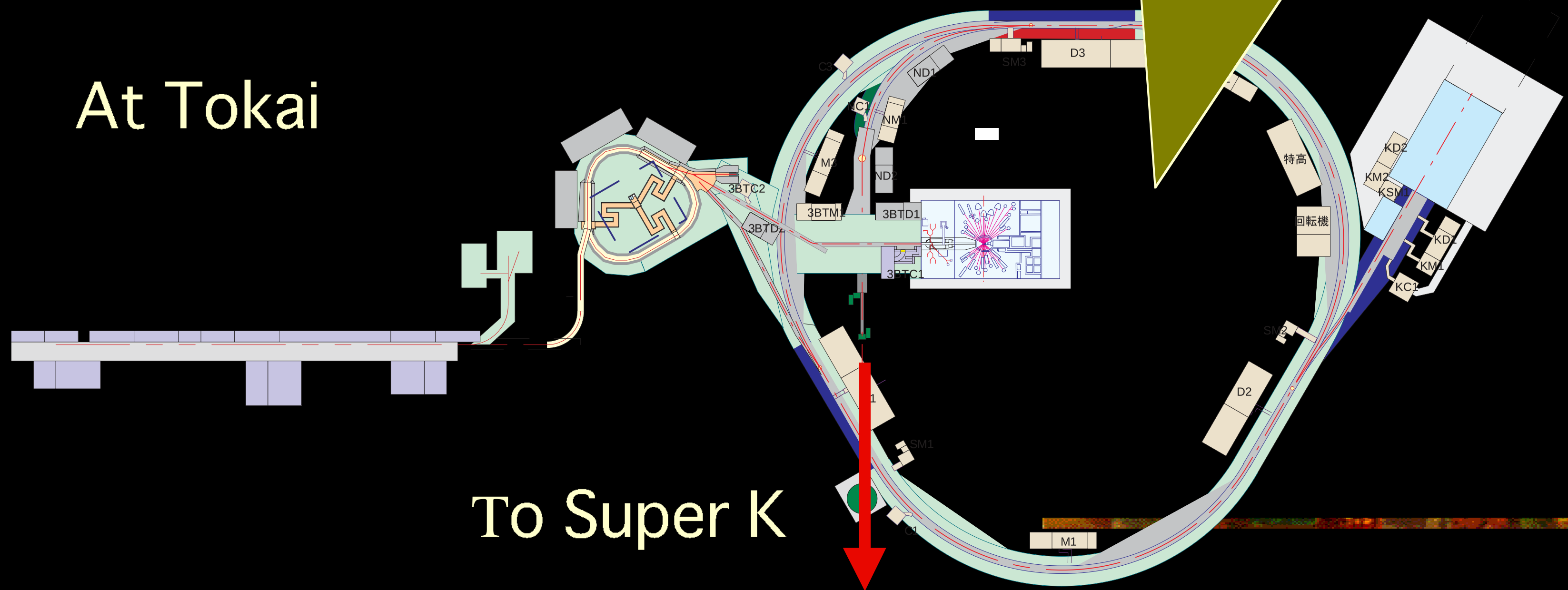
Proton Driver in Japan

KEK/JAERI JOINT PROJECT (JHF)

600 (400) MeV proton linac
3 GeV Proton synchrotron (330μA)
50 GeV Proton synchrotron (15μA, 20μA)

Construction has started in FY2001. The first beam will be In FY2007.

At Tokai



To Super K

Neutrino Factories

Neutrino Factory-I

- 1 x 10^{20} muon decays/year at one straight section
- Based on 1-MW 50-GeV PS
- Muon energy: 20 GeV
  - Energy is determined by cost and physics topics.
- Location: JAERI Tokai campus

Neutrino Factory-II

- 4.4x10^{20} muon decays/year at one straight section
- Based on upgraded 4.4-MW 50-GeV PS
- Muon energy: 20 - 50 GeV

Unique Japanese Approach

US/Europe NuFact Approach

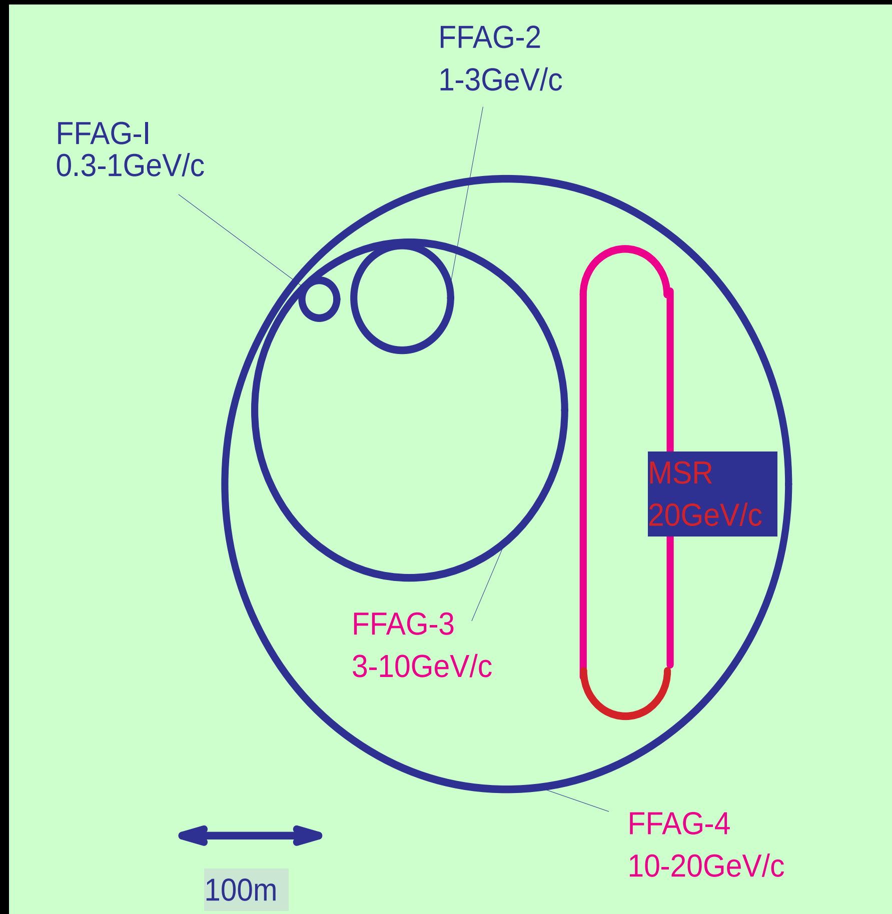
- Linear-acceleration based
  - Need high frequency rf
  - Aperture becomes small
  - Cooling is mandatory
  - Low energy muons are collected

Japanese NuFact Approach

- Circular machine-acceleration based
- FFAG
  - Large transverse and longitudinal acceptance
  - A fixed field allows quick acceleration
- No phase rotation / cooling !!!!!!

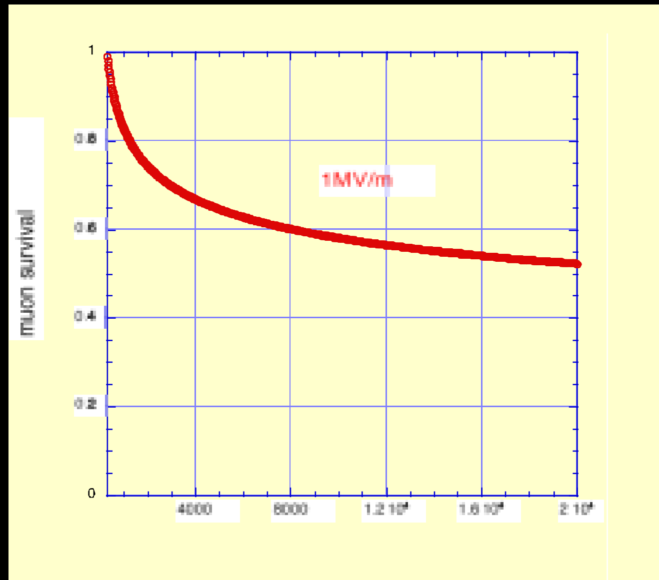
Configuration

- Scheme with FFAG acceleration
  - No muon cooling at the initial stage
- Advantages
  - Costs saving
  - Simple, compact
  - Earlier readiness



Neutrino Yield Estimation

- Inputs
  - 0.3 muons/proton
    - Acceptance : 20,000 π mm•mrad
  - Proton intensity : 2 x 10^{21} /year
  - Muon survival rate : 0.52 (E=1MV/m to 20 GeV)
  - Fraction of one straight section : 0.3

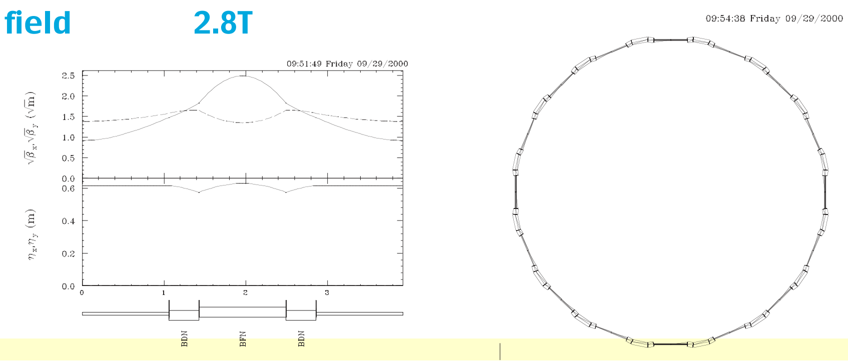


Yield = 2 x 10^{21} x 0.3 x 0.52 x 0.3
= 1 x 10^{20} muons/decay/year

NuFactJ FFAG Lattice Design

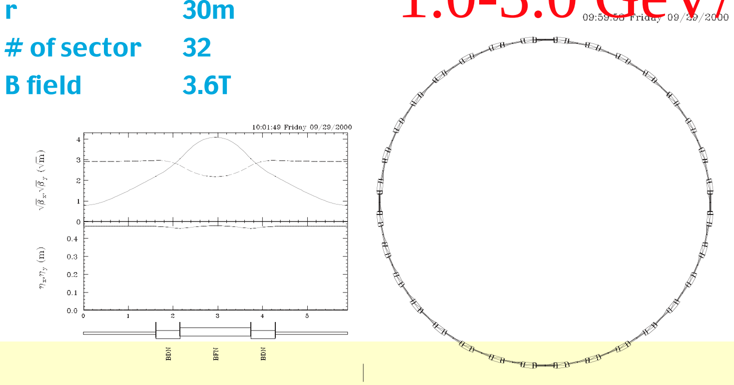
r	10m
# of sector	16
B field	2.8T

0.3-1.0 GeV/c



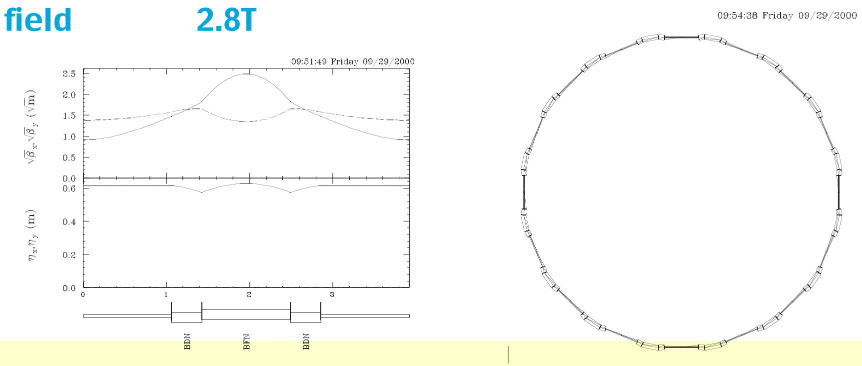
r	30m
# of sector	32
B field	3.6T

1.0-3.0 GeV/c



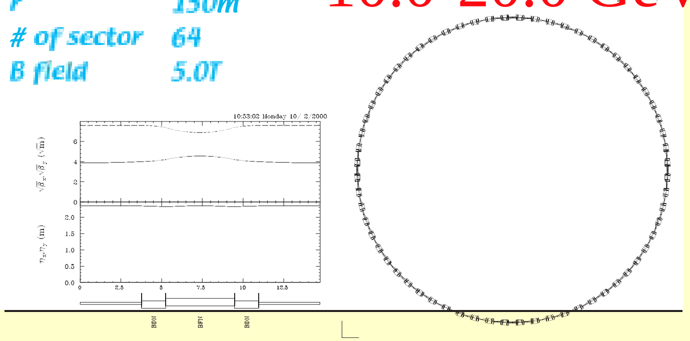
r	10m
# of sector	16
B field	2.8T

3.0-10.0 GeV/c

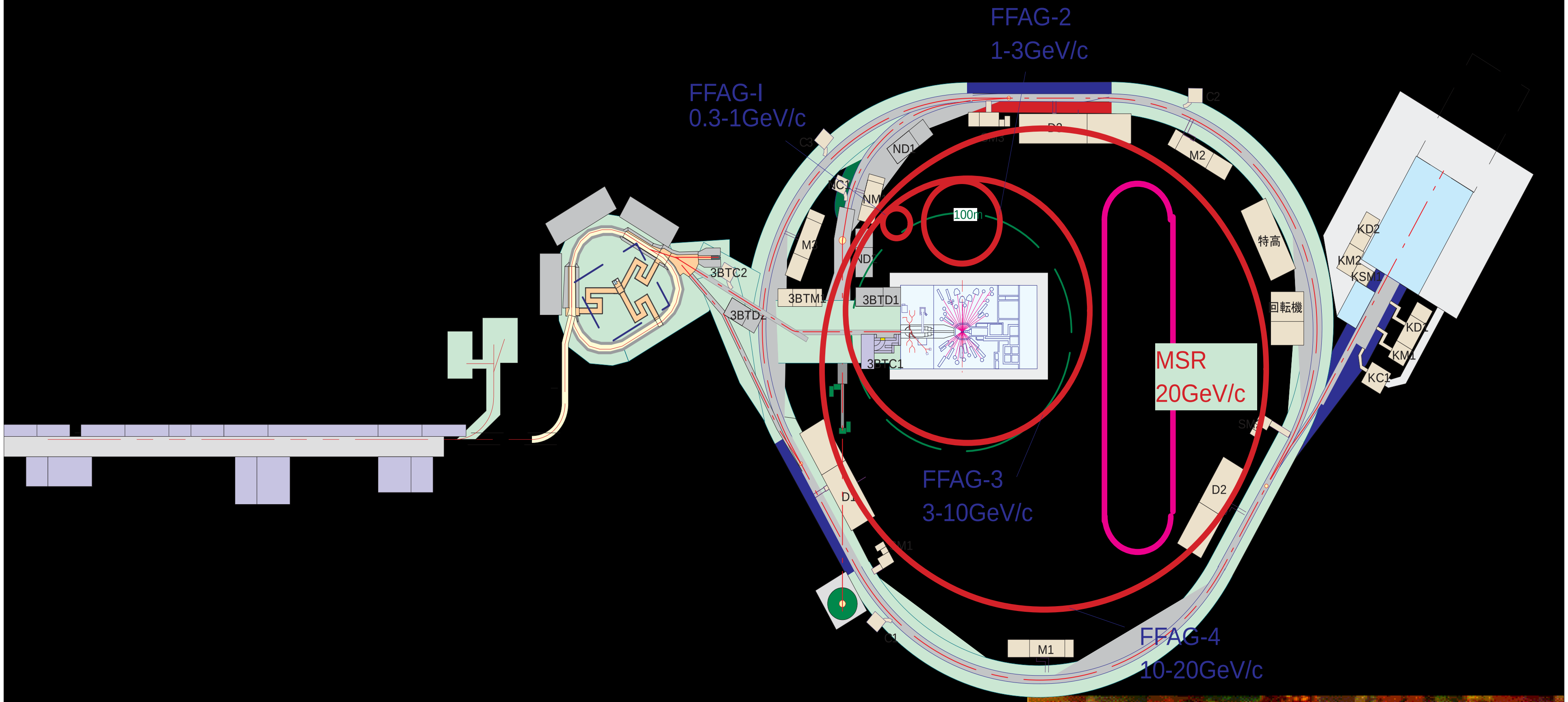


r	150m
# of sector	64
B field	5.0T

10.0-20.0 GeV/c



FFAG based Neutrino Factory



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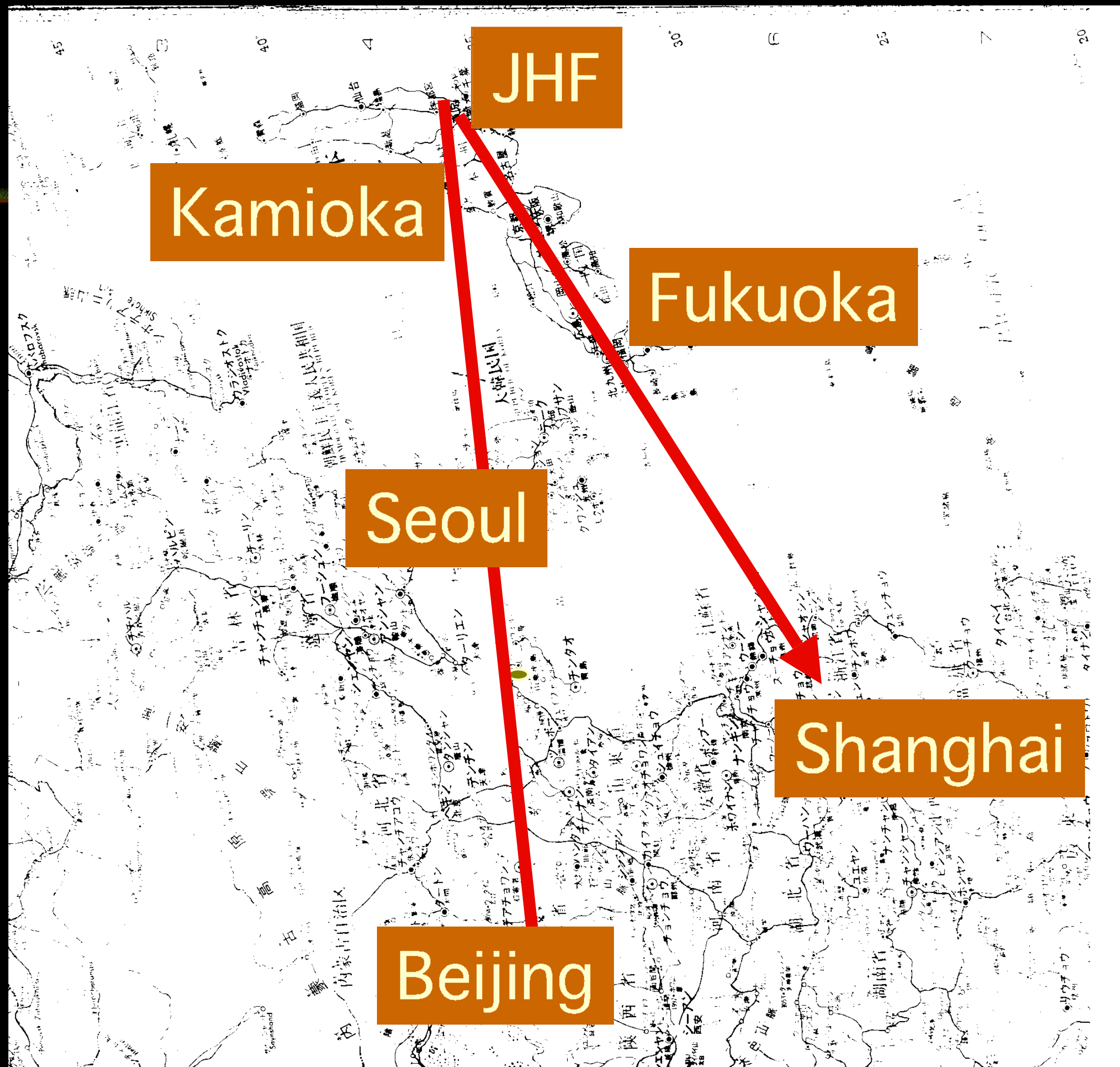
Baseline



NuFact Staging

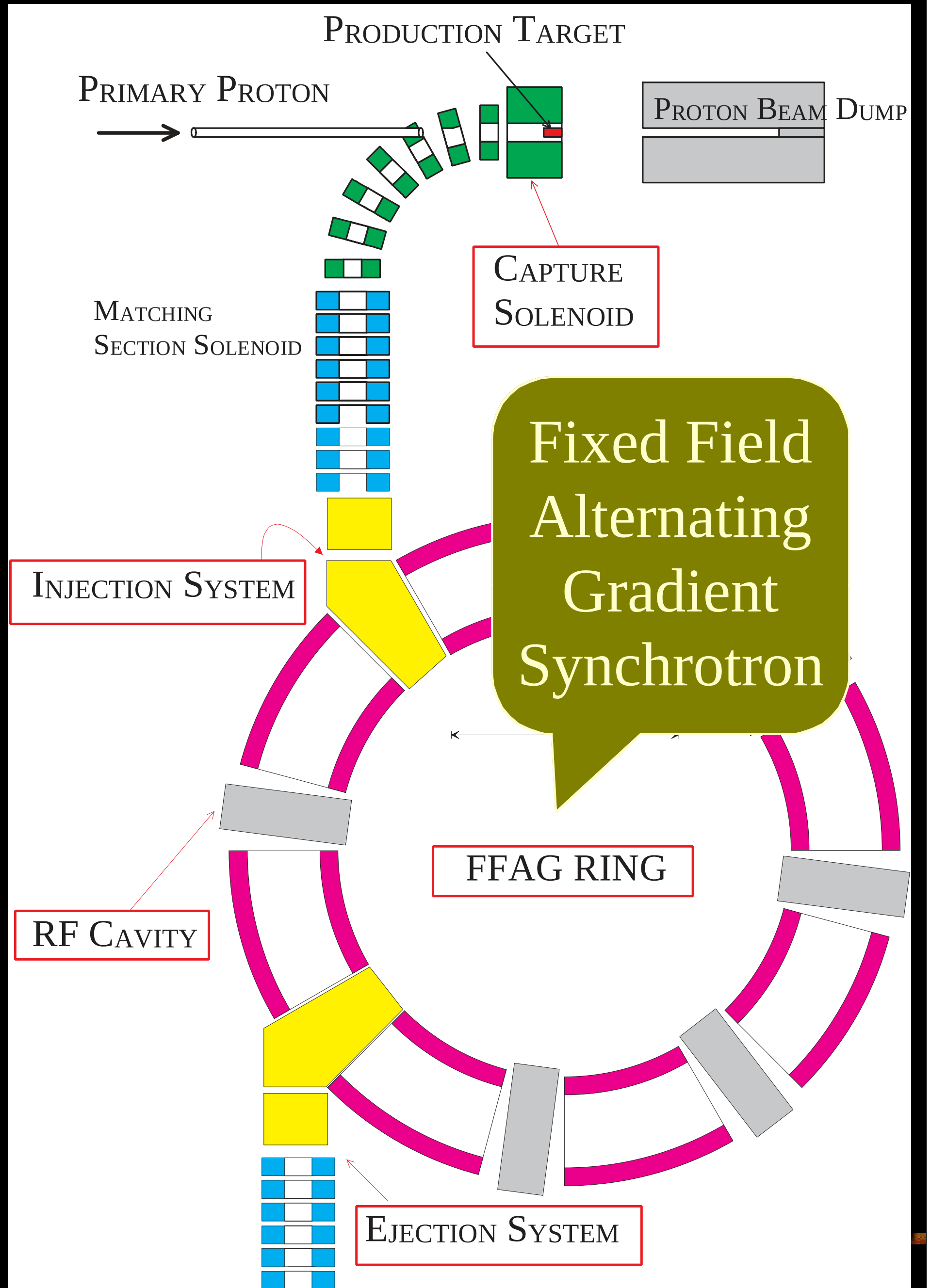
- Muon Factory (PRISM)
  - For stopped muon experiments
- Muon Factory-II (PRISM-II)
  - Muon moments
- Neutrino Factory
  - Based on 1 MW proton beam
- Neutrino Factory-II
  - Based on 4.4 MW proton beam
- Muon Collider

Physics outcome at each stage

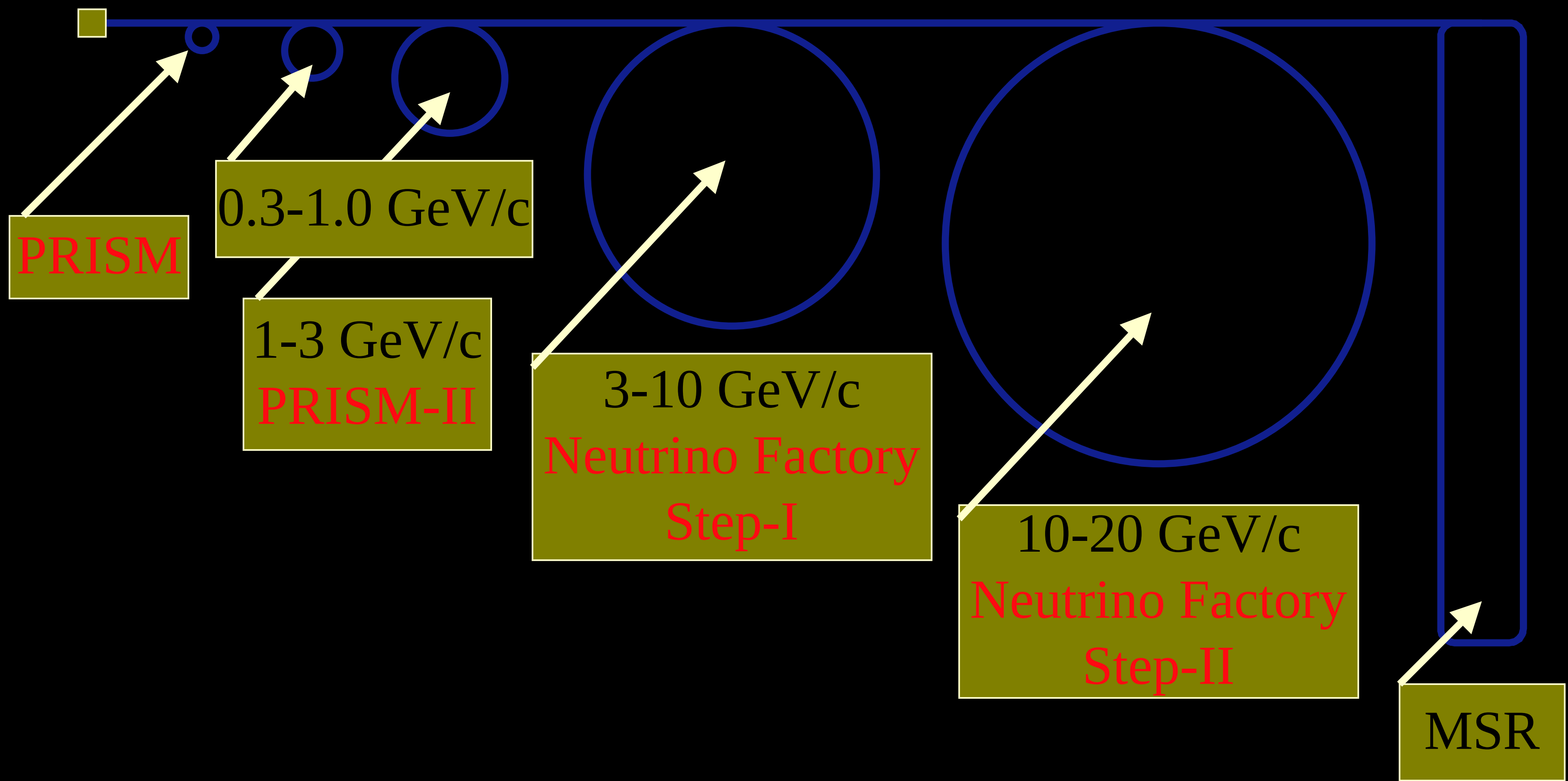
PRISM

- PRISM = Phase-Rotated Intense Slow Muon source
  - Phase rotation at PRISM-FFAG
  - P_μ=68 MeV/c (KE=20 MeV)
  - 10^{19} muons/(10^7sec) in the ring
  - Based on 0.8-MW 50-GeV PS

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



FFAG-based Staging Scenario

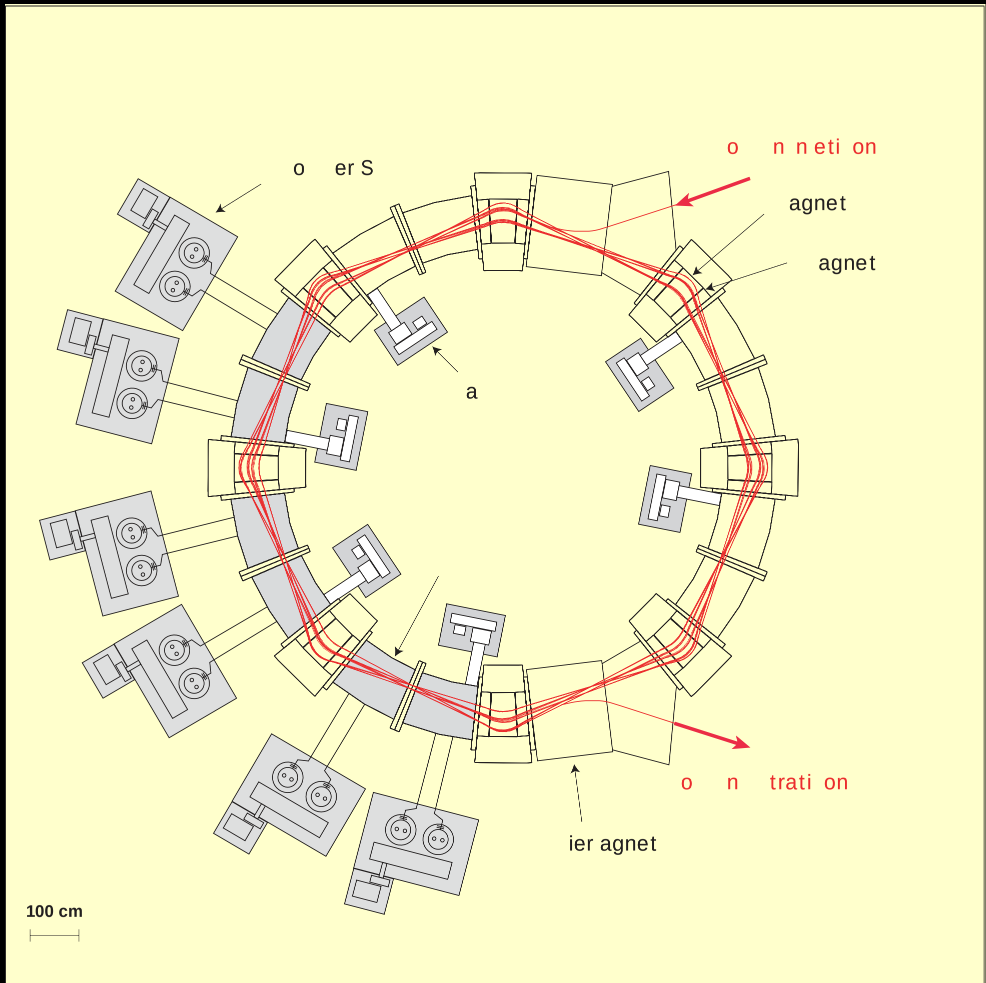


FFAG R&D

- 0.5-MeV Proton FFAG at KEK

- 150 MeV Proton FFAG at KEK
  - Under construction

PRISM FFAG Ring



Acceptance of FFAG should be Examined.

3-dimensional beam Simulation is studied.

Realistic layout is studied.

Budget request has been made with 6 RFs.

MICE

- MICE = Muon International Cooling Experiment
  - Demonstrate muon ionizatition cooling
  - Either at PSI or at RAL
  - Europe, US and Japan
  - Start in 2004, 2005
  - CERN budget problem = 0.3MSFR

Flavor Physics Summary

	quarks	squarks
	$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$	$\begin{pmatrix} \Delta\tilde{m}_e^2 & \Delta\tilde{m}_{12}^2 & \Delta\tilde{m}_{13}^2 \\ \Delta\tilde{m}_{21}^2 & \Delta\tilde{m}_\mu^2 & \Delta\tilde{m}_{23}^2 \\ \Delta\tilde{m}_{31}^2 & \Delta\tilde{m}_{32}^2 & \Delta\tilde{m}_\tau^2 \end{pmatrix}$
neutrinos (RH)	neutrinos (LH)	sleptons
$\begin{pmatrix} Y_{11}e^{i\Phi_1} & & \\ & Y_{22}e^{i\Phi_2} & \\ & & Y_{33}e^{i\Phi_3} \end{pmatrix}$	$\begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} \end{pmatrix} \begin{pmatrix} 1 \\ e^{i\phi_1} \\ e^{i\phi_2} \end{pmatrix}$	$\begin{pmatrix} \Delta\tilde{m}_e^2 & \Delta\tilde{m}_{12}^2 & \Delta\tilde{m}_{13}^2 \\ \Delta\tilde{m}_{21}^2 & \Delta\tilde{m}_\mu^2 & \Delta\tilde{m}_{23}^2 \\ \Delta\tilde{m}_{31}^2 & \Delta\tilde{m}_{32}^2 & \Delta\tilde{m}_\tau^2 \end{pmatrix}$

Leptogensis

Neutrino oscillation

? CPV in LFV /EDM?

Muon Lepton Flavor violation

Double beta decays