J-PARC Accelerator and Beam Simulations

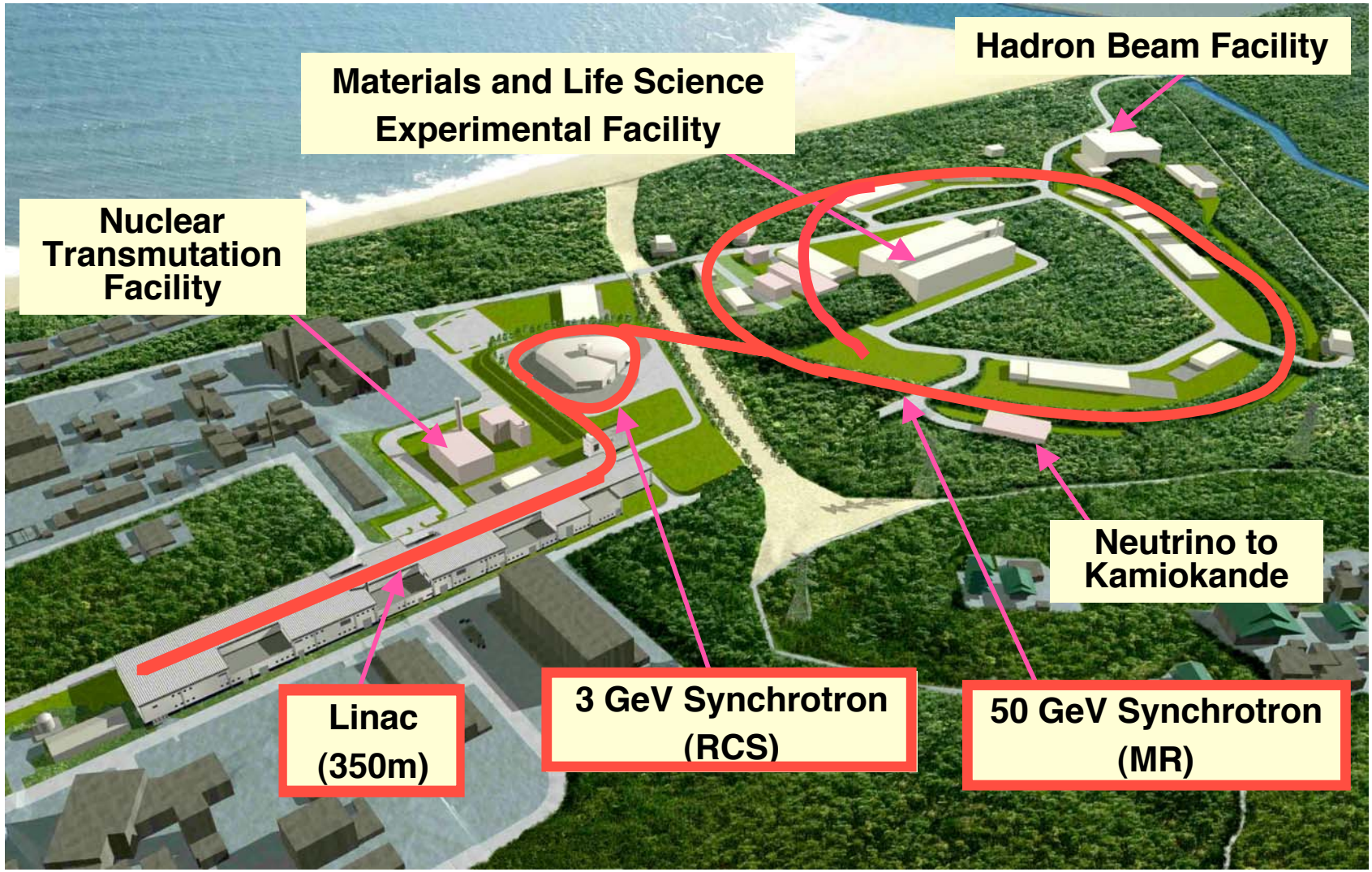
Sep. 7th, SAD2006

Masahito Tomizawa

J-PARC Main Ring G., KEK

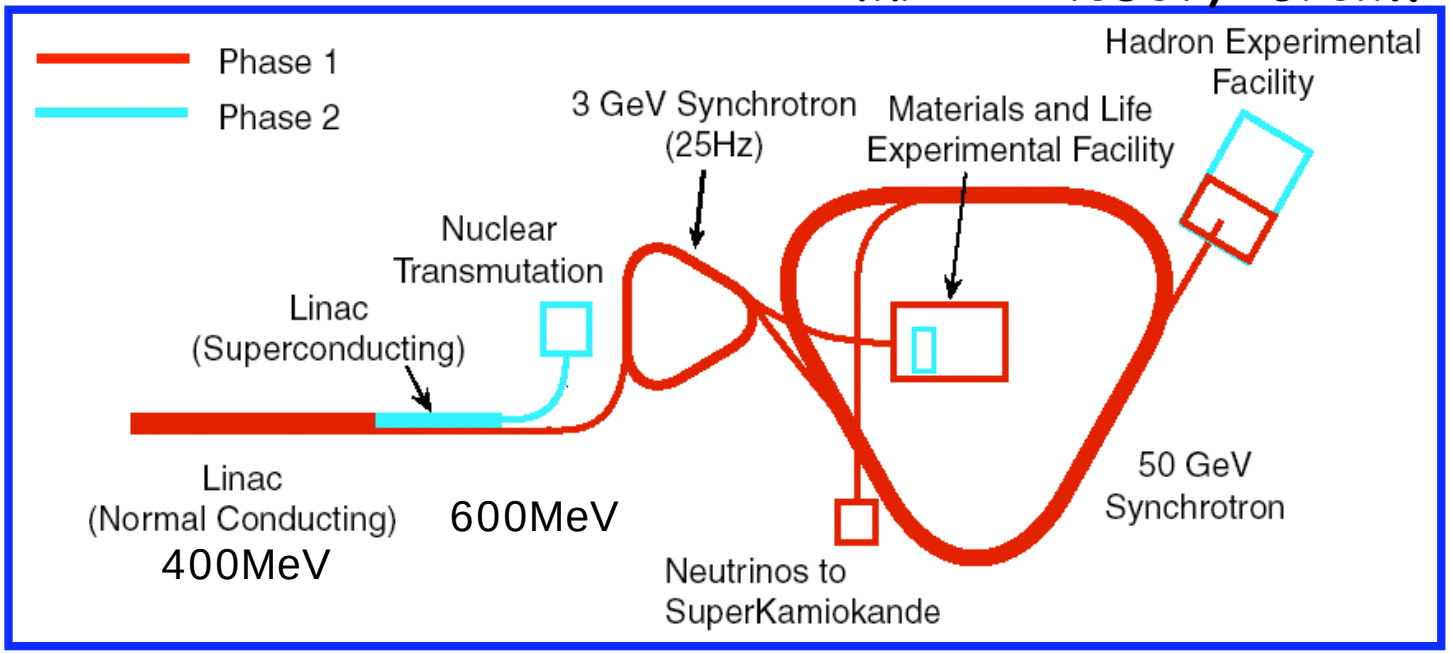
- Outline of J-PARC Accelerator
- Characteristics of High Intensity Proton Machines
- Beam Codes and Examples
- Summary

J-PARC Facility



Phase I

- day-1
  - Linac 180MeV, 30mA, 25Hz
  - RCS 3GeV, 0.6MW
  - MR 40GeV, 400kW
- Next Stage
  - Linac 400MeV, 50mA, 25Hz
  - RCS 3GeV, 1.0MW
  - MR 40GeV, 670kW



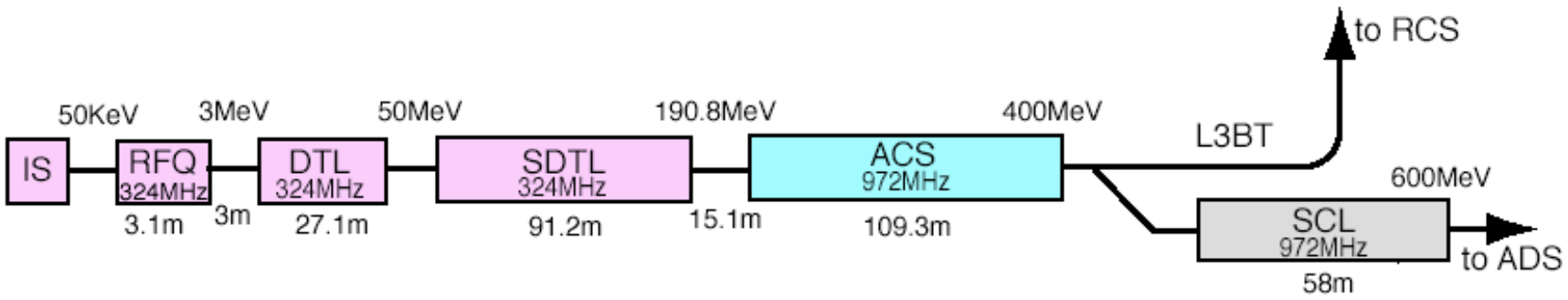
Phase II

- Nuclear Transmutation Facility(ADS)
  - →Linac 600MeV,50Hz
- Extension of Hadron and Neutron Facility
- MR 50GeV, 750kW

Linac structures and parameters

- Ion Source: Volume Production Type
- RFQ: Stabilized Loop
- DTL: Electro-Quad in DT, 3 tanks
- Separated DTL(SDTL): no quad in DT, short tank(5cells), 32tanks
- Annular Coupled Structure (ACS): axial symmetric
- Super Conducting Linac (SCL): wide aperture, high acceleration gradient

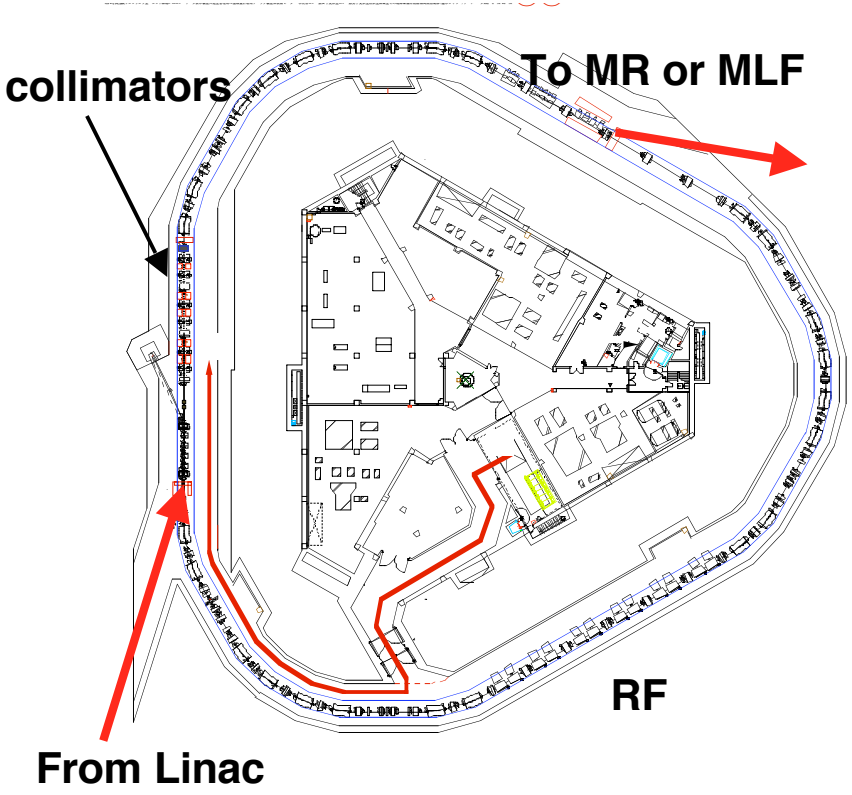
- particles: H^-
- Energy: 181 MeV (RCS injection)
  400 MeV (RCS injection)
  600 MeV (to ADS)
- Peak current: 30 mA @181MeV
  50 mA @400 MeV
- Repetition: 25 Hz (RCS Injection)
  50 Hz(RCS Injection + ADS application)
- Pulse width: 0.5 msec



3GeV Synchrotron (RCS)

- Rapid Cycle (25Hz)
- High Output Beam Power 1MW
- H^- Injection by long lived carbon foil
- Horizontal/Vertical and Longitudinal Painting Injection
- High Efficiency Transverse and Longitudinal Collimation

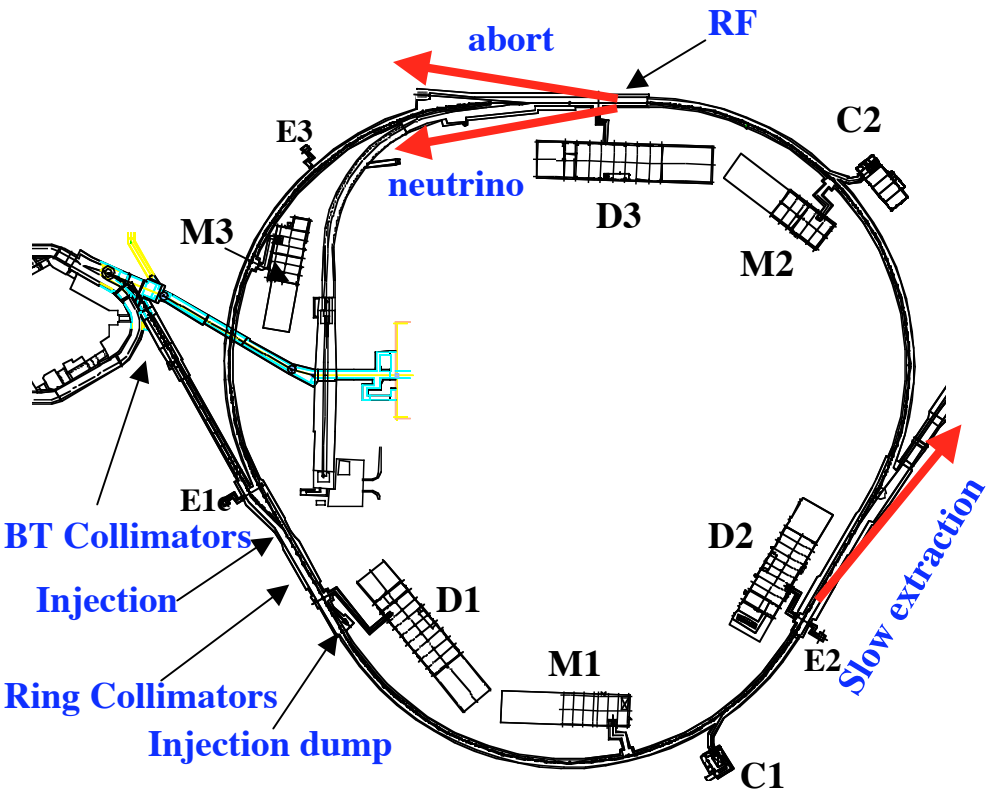
•Circumference	348.3m
•Repetition	25Hz(40ms)
•Injection Energy	180/400 MeV
•Output Energy	3GeV
•Beam Power	0.6/1MW
•Harmonic	2
•Bunch Number	2
•Nominal Tune	(6.72, 6.35)
•Transition γ_t	9.14
•S.C. Tune Shift	-0.2



50GeV Synchrotron (Main Ring)

- Imaginary Transition γ lattice
- High Efficiency Slow Extraction
- Both Sides Fast Extraction for Neutrino and Abort line
- High Efficiency Transverse Collimation in Transfer Line and Ring

•Injection Energy	3GeV
•Output Energy	30GeV (slow)
	40GeV (fast)
	50GeV (Phase II)
•Circumference	1567.5m
•Beam Power	0.75MW
•Repetition	0.3Hz
•Harmonic	9
•Bunch Number	8
•Nominal Tune	(22.4, 20.8)



Beam Commissioning Schedule

- Linac 2006 Dec.~
- RCS 2007 Sep.~
- MR 2008 May~

  slow extraction 2008 Dec.~

  fast extraction 2009 May~

Linac

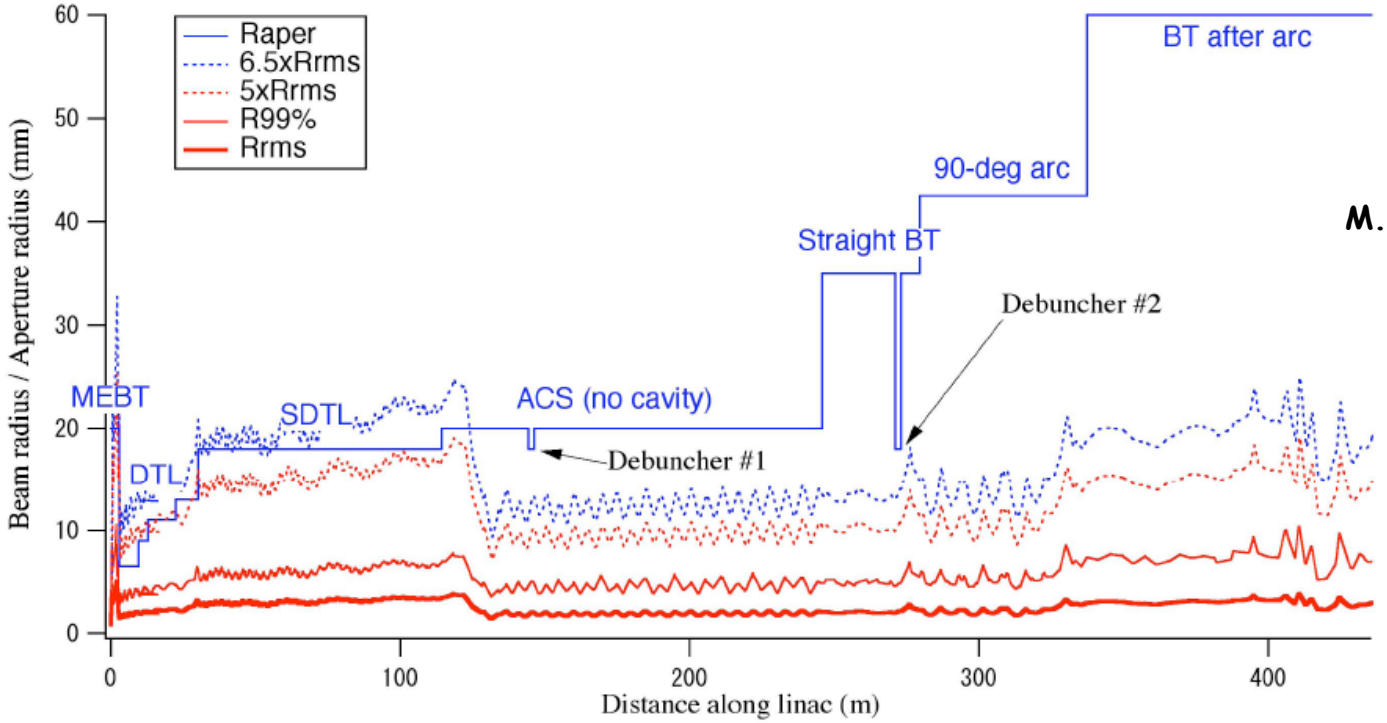
- RFQ PARMTEQ-M: PIC, electrode image effect is included
- DTL,SDTL,ACS, matching sections,L3BT

  Trace-3D: linear optics with space charge force

  PARMILA: PIC, 2D,3D

  IMPACT: PIC, 3D, foil scattering

  (LINSAC: particle-particle code by T. Kato)



M. Ikegami

Characteristics of High Intensity Proton Ring

- High Energy Proton Beam loss

  radiation

  soil activation --> ground water

  sky-shine

  cooling water activation

  air in the tunnel activation

  instruments activation -- serious maintenance

  ∝beam intensity x energy (W)

Loss Minimization

Loss Localization (local shielding and special maintenance)

Hallo Collimators (finite loss limit)

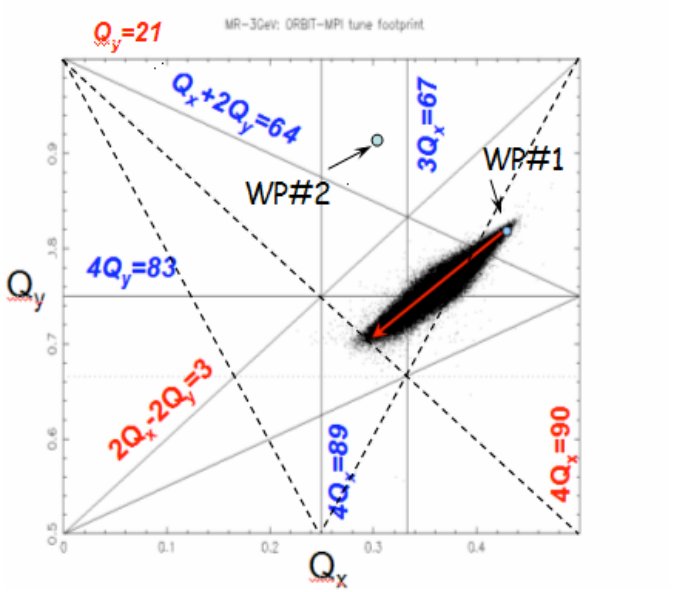
Permitted Beam Loss of J-PARC Rings

- RCS (400MeV injection,1MW output)
  - injection area 1kW (0.75%)
  - extraction area 1kW (0.1%)
  - collimator 4kW (3%)
  - other area 1W/m (0.3%)
  - --> total 4%
- RCS to MR transfer line (3GeV,45kW)
  - collimator 0.45kW (1%) [1.3kW is possible from shielding]
  - other area 1W/m (0.5%)
  - --> total 1.5%
- MR (0.75MW output, fast extraction operation)
  - injection area 0.135kW (0.3%)
  - fast extraction area 1.1kW (0.15%)
  - collimator 0.45kW (1%)

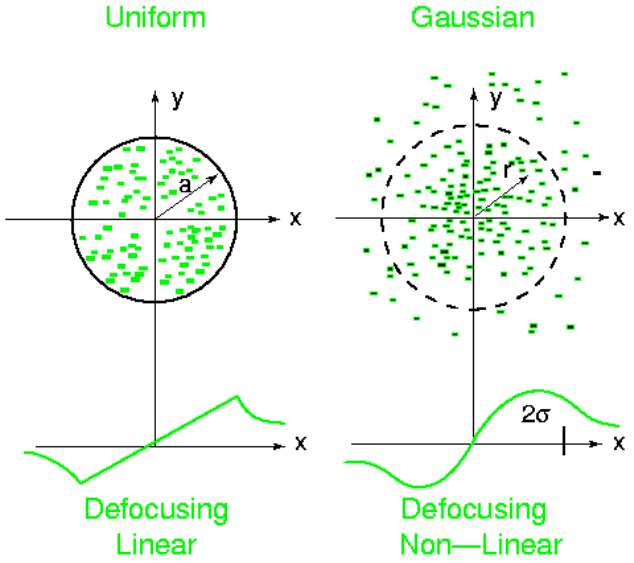
Space Charge and Halo

- nonlinear space charge force
- tune spread->ring/space charge resonance
- environment dependence: mirror charge/current

$$\Delta\nu = -\frac{r_p n_t}{2\pi\beta^2\gamma^3\varepsilon B_f}$$



by A. Molodozhentsev



by E. Wilson

Aperture

RCS

- physical 486 π mm·mrad + COD3mm + Δp/p 1%

  painting 216 π mm·mrad@0.18GeV --> 34 π mm·mrad @3GeV
  (linac 6 π mm·mrad)

  collimator 324 π mm·mrad@0.18GeV --> 54 π mm·mrad @3GeV

  extraction 324 π mm·mrad

RCS-MR transfer line

collimator 54 π mm·mrad

MR

- physical 81 π mm·mrad + COD1mm + Δp/p 0.63%

collimator 54-81 π mm·mrad

extraction 20-40 π mm·mrad

Ring Lattice Design

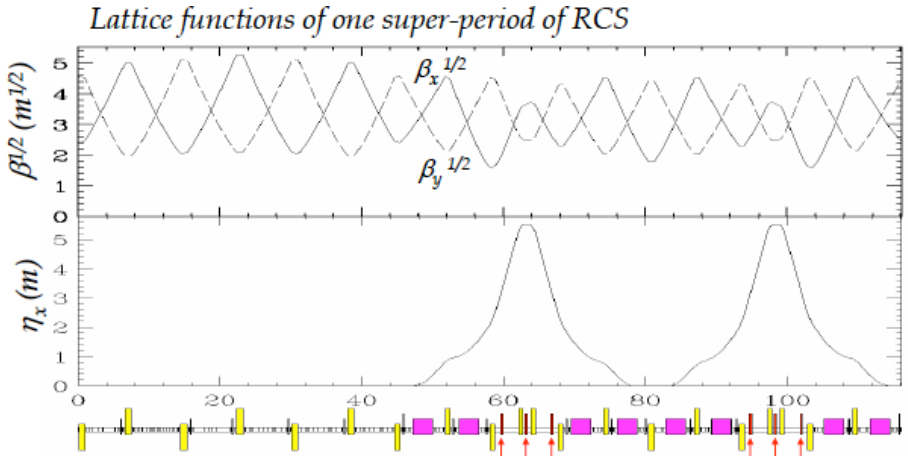
$$\alpha = \frac{1}{\gamma_t^2} = \frac{1}{C}\oint_C \frac{\eta(s)}{\rho(s)} ds$$

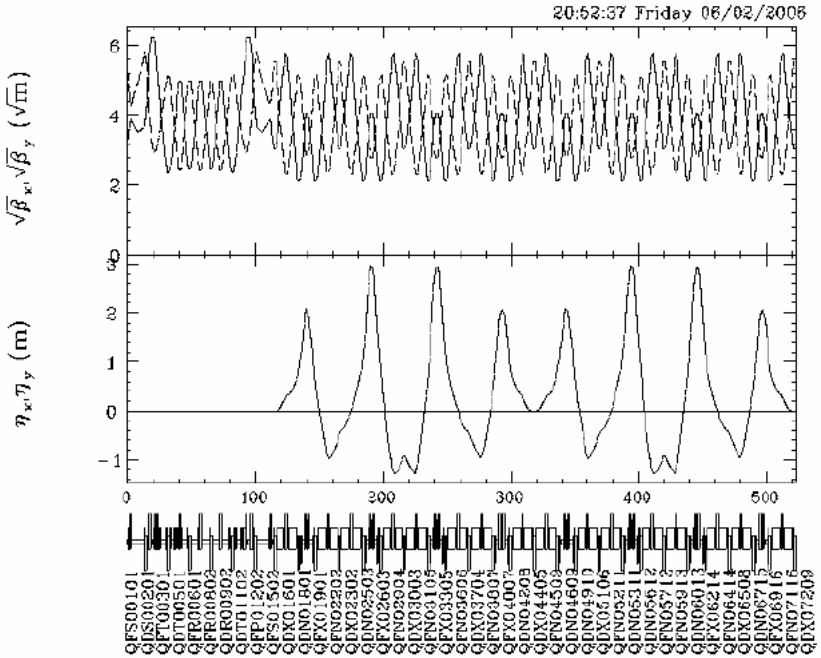
- SAD

RCS: high γ_t lattice, dispersion free LSS

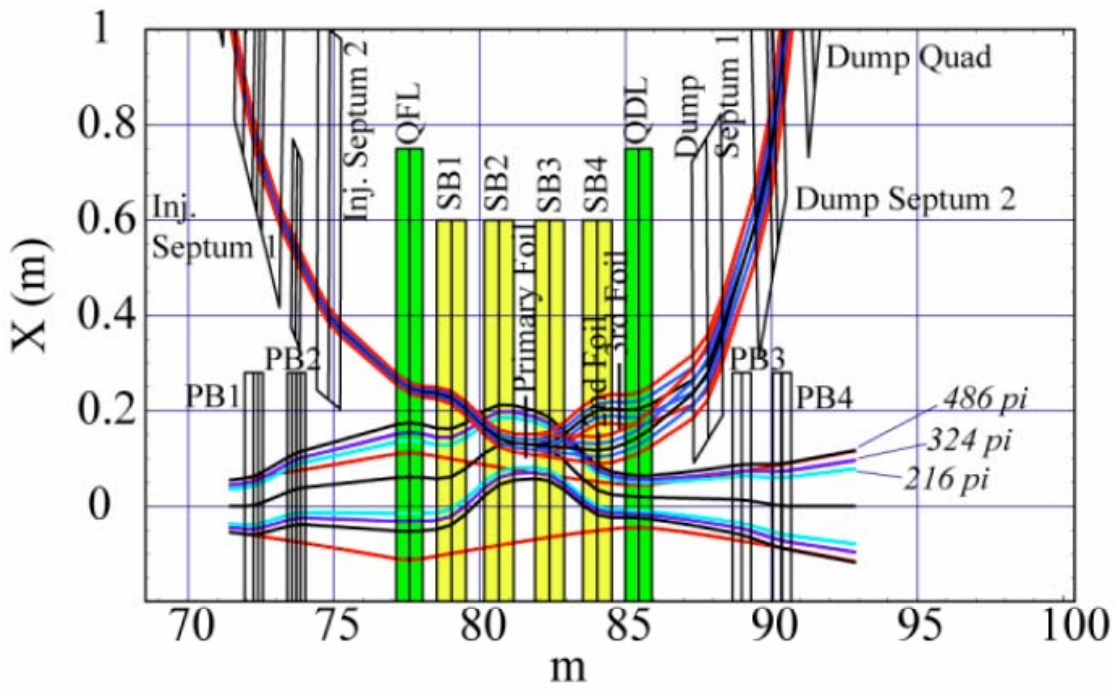
MR: imaginary γ_t lattice, dispersion free LSS

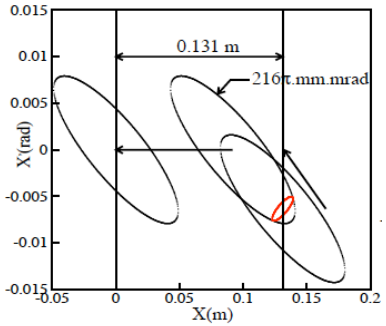
MR optics

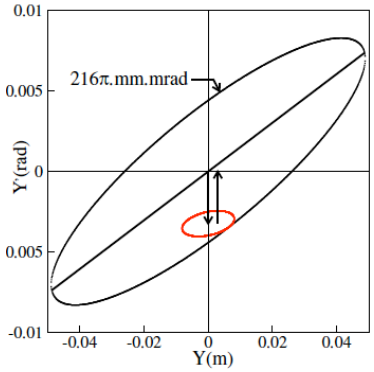




RCS Injection







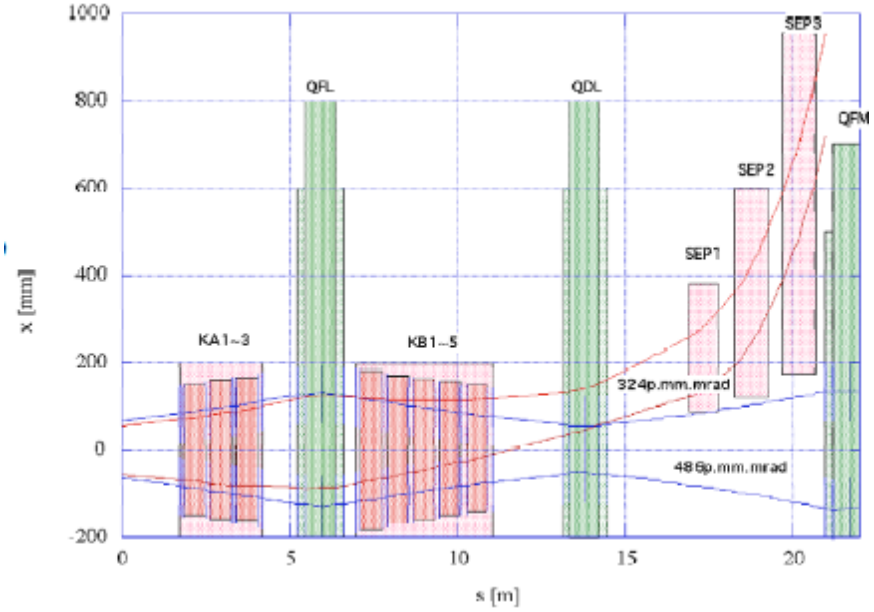
- orbit design: SAD
- foil scattering: GEANT+SAD
- coupling between shift bumps quad:
  3D OPERA data+tracking code (M. Shirakata) ,SAD
- painting process: Simpsons, ORBIT

RCS, MR Fast Extraction and MR Injection (one turn)

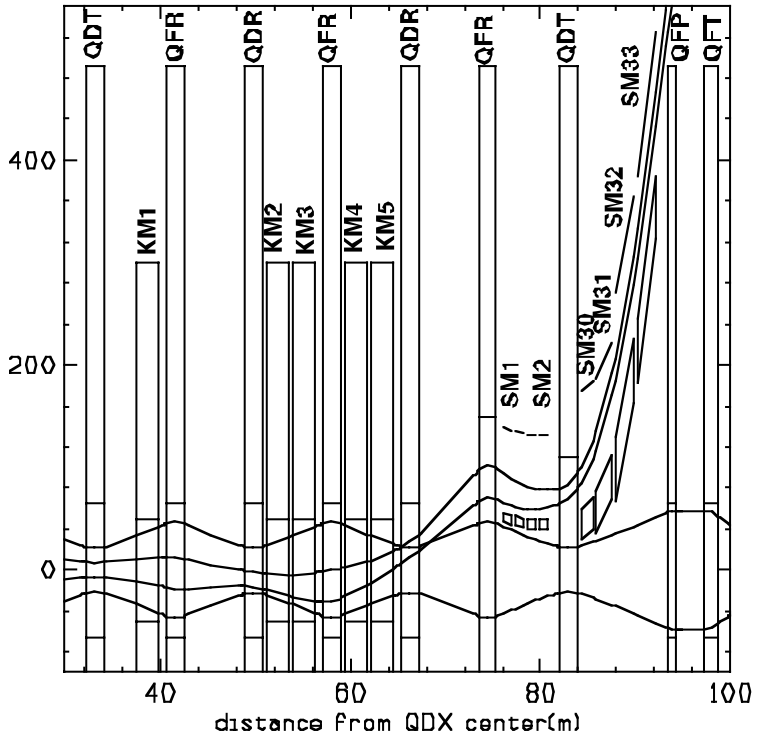
- SAD

  orbit -> envelope

RCS extraction



MR fast extraction



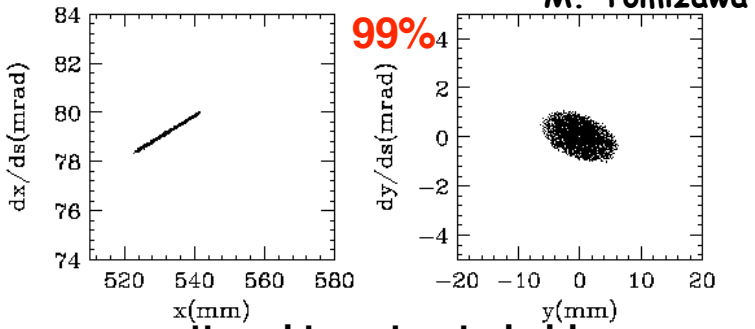
Slow Extraction

Extraction efficiency 99.75%

Primary extracted beam

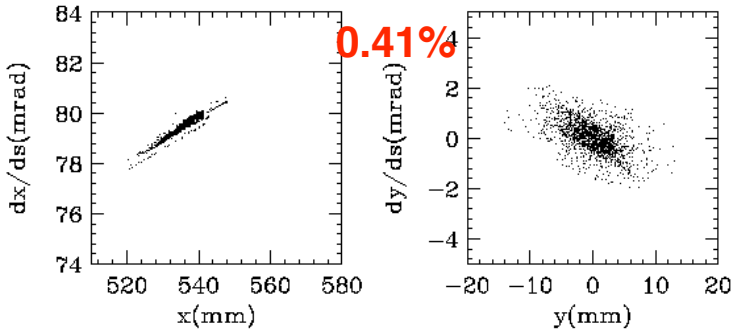
Sca0122 3 044

M. Tomizawa



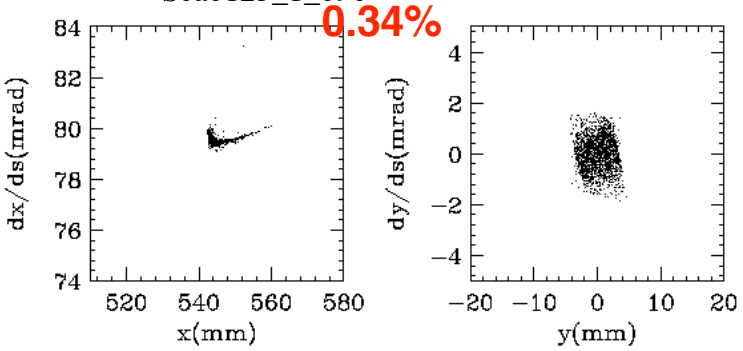
scattered to extracted side

sca0122_2_044



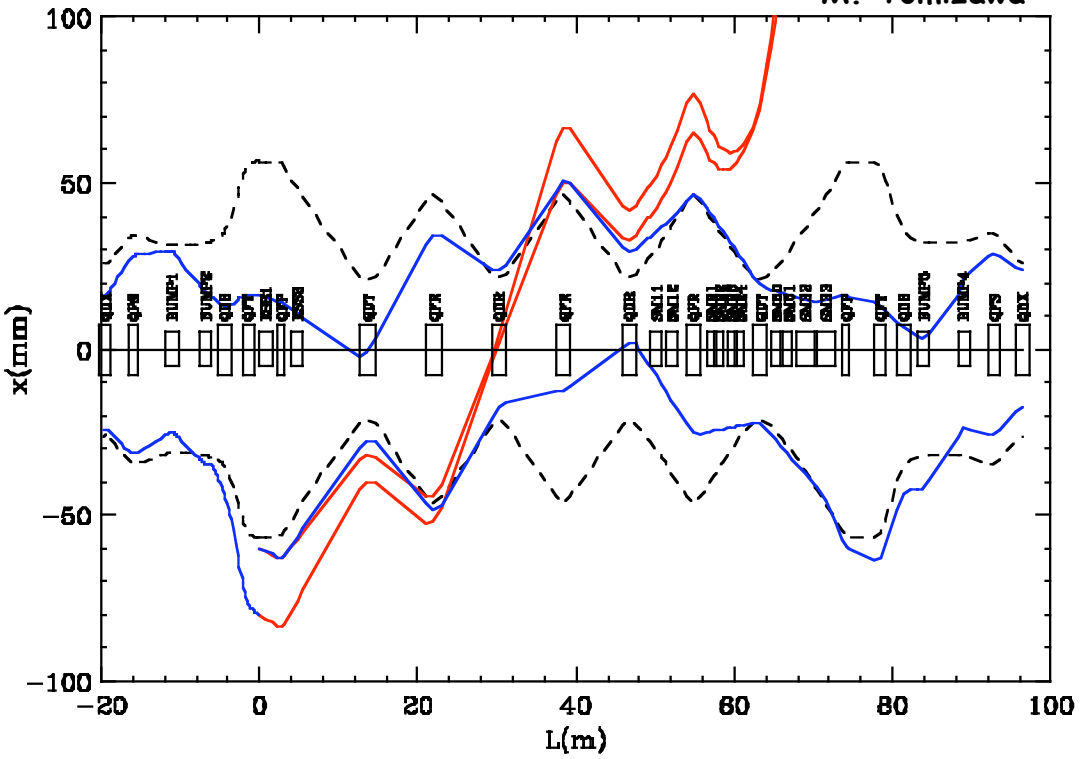
scattered to circulated side

Sca0123_1_090



- Analytical approach
- tracking
  - My code
  - MAD
  - MARS, GEANT (ESS wires scattering)

M. Tomizawa



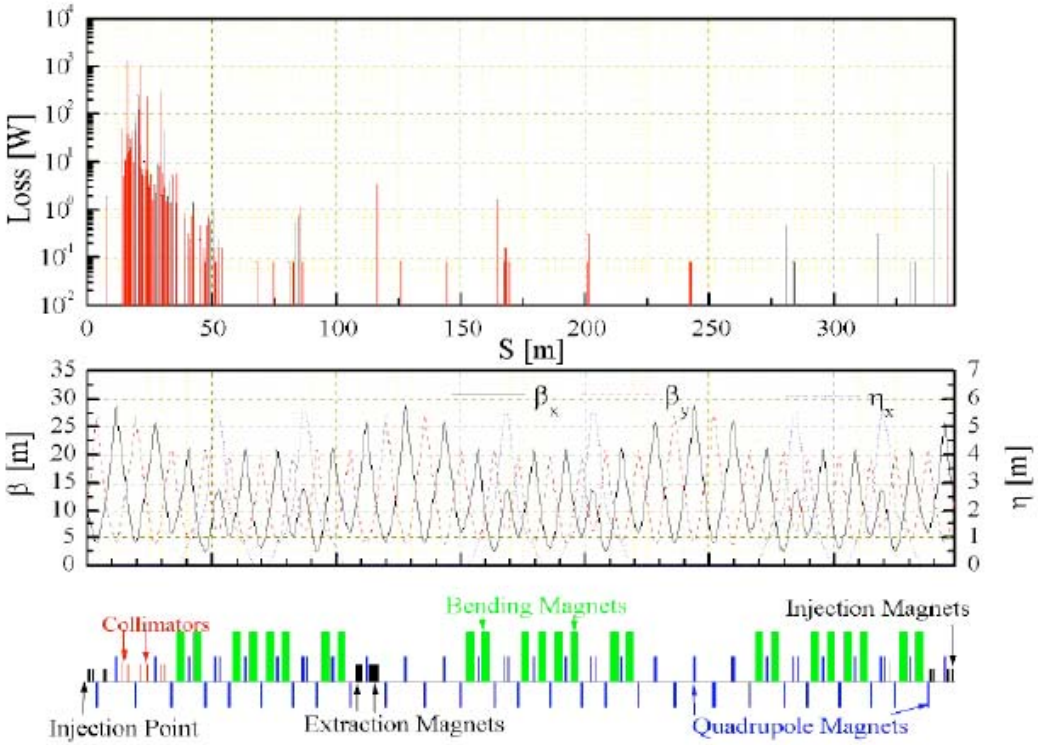
Beam Collimations

- STRUCT

  interaction/scattering with material and tracking

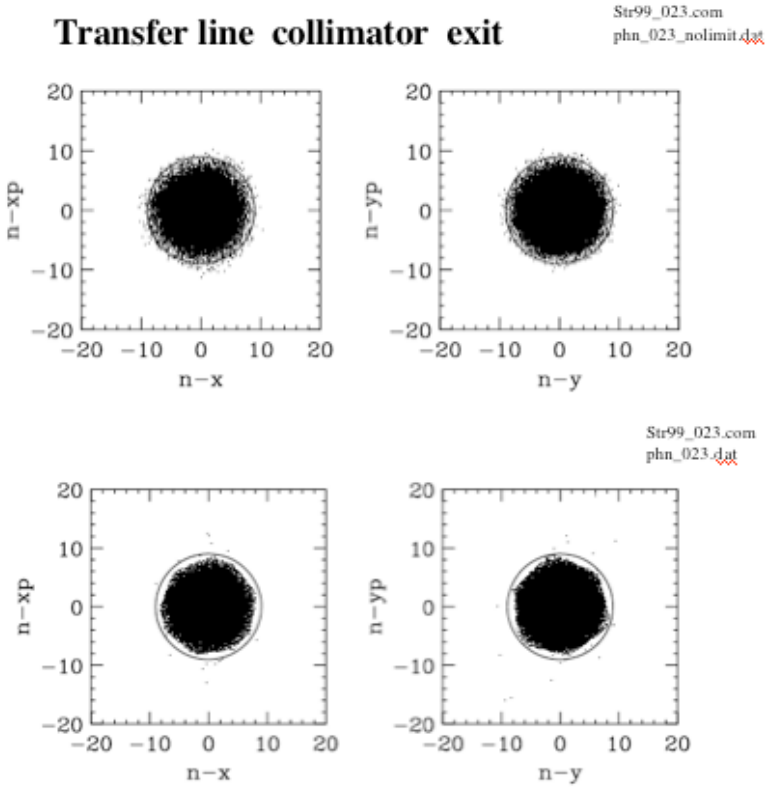
4kW RCS collimators

K. Yamamoto



450W 3-50BT collimators

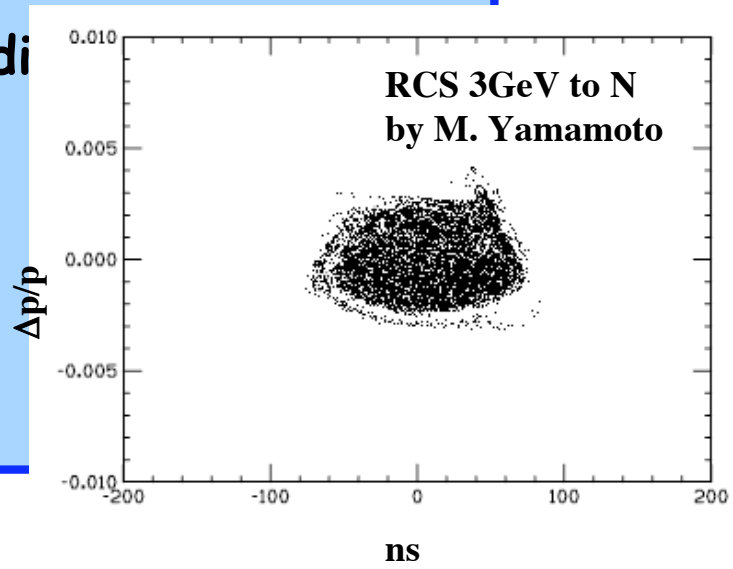
M. Tomizawa



Longitudinal Motion

- LAMA
  - gives rf voltage and phase patterns
  - includes longitudinal space charge effect
  - by analytical approach
  - Hofmann-Pedersen distribution assumed

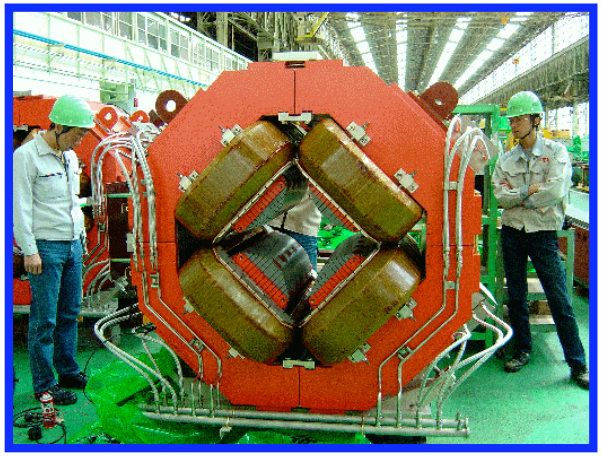
- tracking simulations code
  - by M. Yamamoto(JAEA), K.Hara (KEK)
  - space charge force in arbitrary di
  - longitudinal painting
  - higher bunching factor
    (higher harmonics)
  - RCS/MR matching
  - emittance brow up



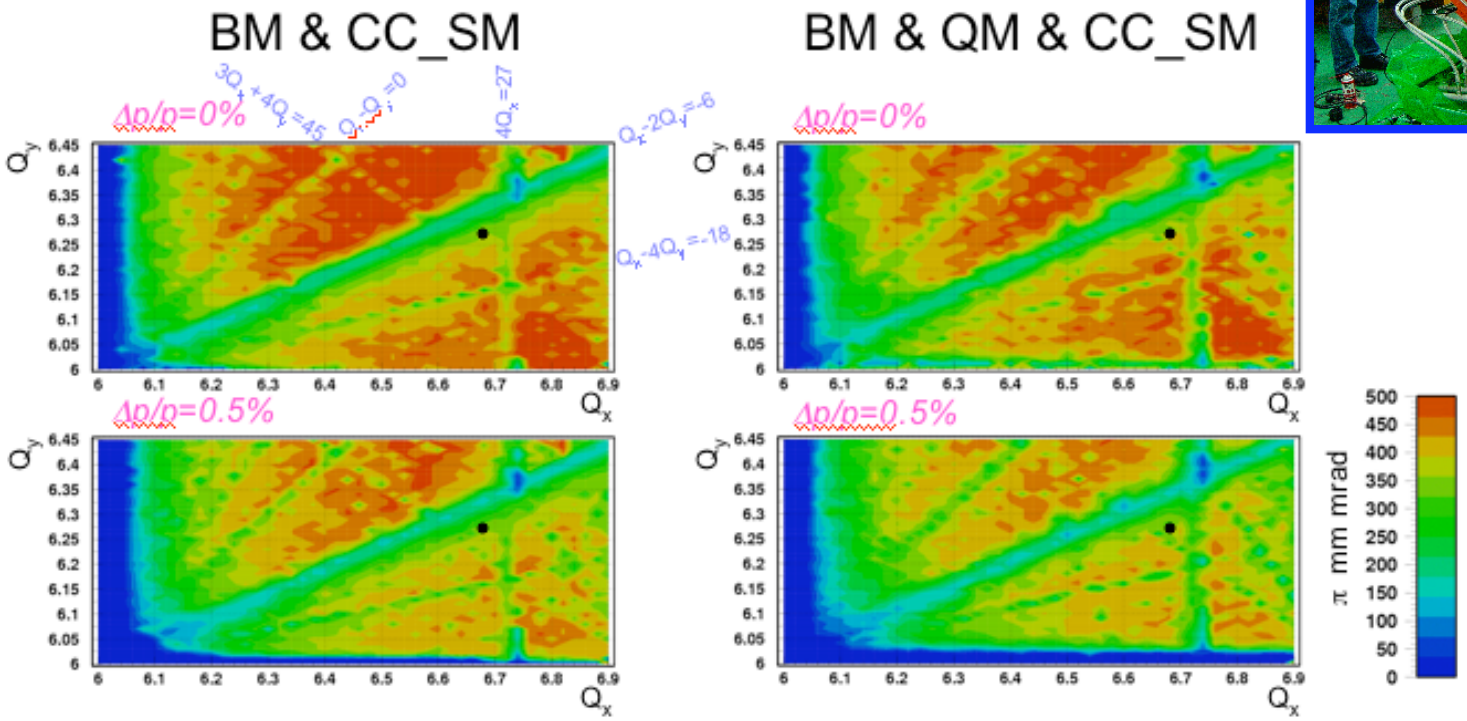
Tracking Simulation

multipole,fringe field, (deviations, interference, alignment error)

- SAD
- MADX-PTC (3D field map), COSY



RCS dynamic aperture by SAD (H. Hochi)



Space Charge Tracking Simulations

*PIC codes

space charge, self-consistent

- (ACCIM, PATRASH)
- Simpsons
- ORBIT/MPI

parallel

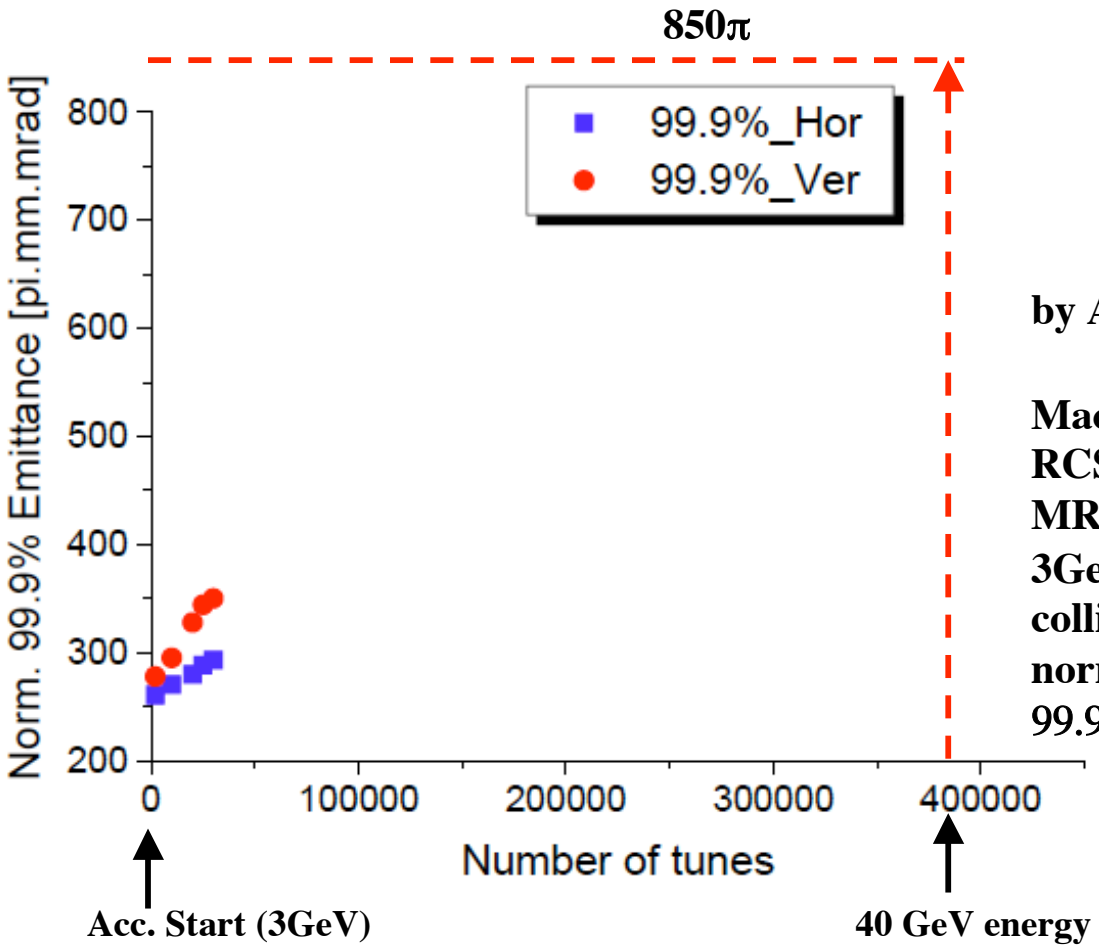
foil scattering, painting, time varying field, impedance

--> Installation in KEK and JAEA

super computer has been completed

Space Charge Tracking Simulations (cont.)

Long Term Space Charge Simulation (MR)



by A.Molodojentsev

Macro particle number 91000
RCS: 2.5×10^{13} ppp (300kW)
MR: (h=9,V=210kV), 1×10^{14} ppp
3GeV--> acceleration
collimator 70π
normalized acceptance(40GeV) 850π
99.9% beam emittance

Present machine
> 100 days
Super Computer
< 1 week

Impedance and Instability

Longitudinal and Transverse Impedance

- Analytical approach
- Wake implementation in Simpsons (Y.Shobuda)
- ORBIT

E-P instability

Simulation code by K. Ohmi

Radiation

- **MARS**

  Interaction with material

  beam tracking in the given field

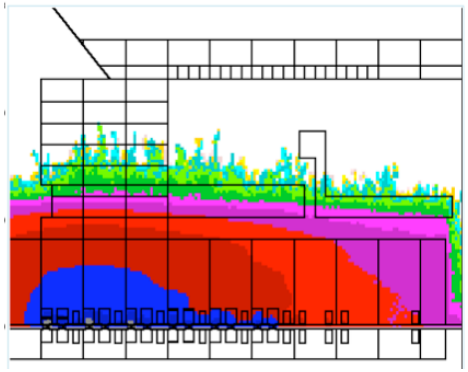
  Radiation Dose

  Activation

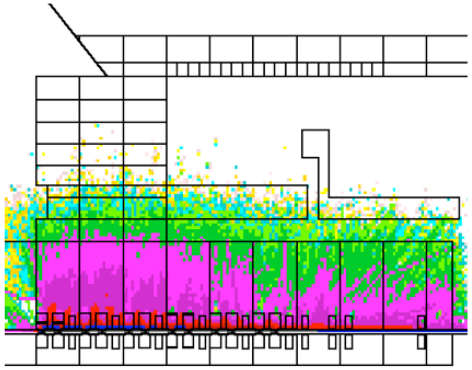
3-50BT collimator (by T. Suzuki)

Radiation Distribution:
3GeV P hits No 1 Ta Scraper

Neutral Fluence Distribution



Charged Fluence Distribution



Summary

- Various beam simulation codes are utilized for intensive studies of J-PARC accelerators

- Goal of ring beam simulation (my personal view)

  present space charge PIC codes (realistic, reliable)

  *fringe,multipole,interference, deviations, alignment error, scattering, collimators, environments (mirror,impedance,,,)

  *full acceleration process

  *through RCS to MR

  --> Optimizations to minimize beam loss of both RCS/MR

  operating tunes, painting, longitudinal

  not impossible!!

Thanks for their cooperation

F. Noda, H. Hochi, A. Molodozhentsev, M. Ikegami, A. Ueno