Overview of Neutrino Factory Simulations

R.C. Fernow

BNL

NuFact03 Workshop

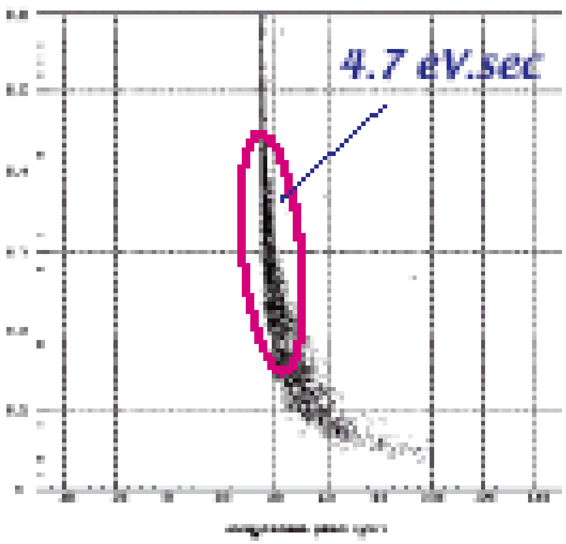
7 June 2003

What will be covered?

- neutrino factories (not superbeams or muon colliders)
- accelerator physics (not particle physics)
- "simulations"
  go beyond Monte Carlo tracking → computer system-designs
- but not hardware device designs
  e.g. magnets, cavities, kickers, horns, …
- not demo experiments, e.g. MICE, targetry, …
- not theory

NuFact02 – Proton driver simulations

- AGS 1 MW upgrade study (Weng[39*])
- transitionless lattice (Johnstone[41])
- JHF (J-PARC) status (Machida[40])
- 8 and 30 GeV lattices (Rees[38])
- Japanese NF R&D (Mori[44])

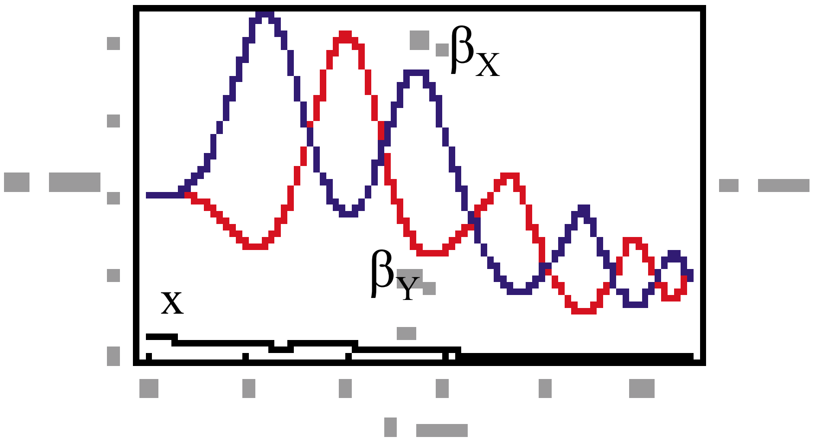


π distribution from 50 GeV J-PARC beam, 6 ns proton bunch, 6 m from target (Mori)

* superscripts give reference numbers in NuFact02 Machine WG summary

NuFact02 – Front end simulations

- μ collection in AG channel (Meot[7])
- 200-300 MHz phase rotation (Neuffer[19])
- CERN 88 MHz system (Hanke[20])
- magnetic chicane lattice (Pasternak[21])
- magnetic chicane lattice (Rees[22])
- dE/dx in hydrogen (Allison[24])
- quad linear precooler (Johnstone[25])
- ring coolers, RFOFO (Palmer [26,28])
- Balbekov tetra-ring (Kahn[27])
- pole face focused rings (Cline[29])



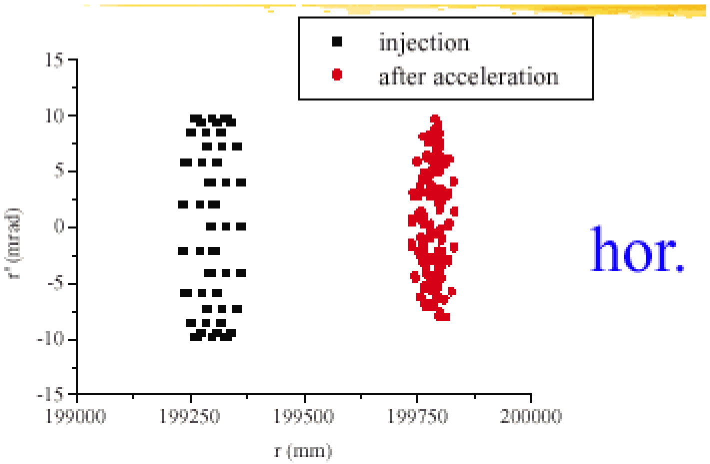
CERN funnel optics (doublet + ¼ wave transformer -> FODO)
Merges π beams from several targets to common decay channel (Meot)

tools: Geant, ICOOL, Path, SYNCH, MAD, ZGOUBI, BeamOptics, Simucool, COSY

NuFact02 – μ accelerator simulations

- recirculating linear accelerator (Bogacz[42])
- FFAG acceleration (Machida[45])
- phase rotation in PRISM FFAG (Sato[46])
- FFAG concepts & studies (Neuffer[47])
- FFAG with high frequency RF (Johnstone[48])
- ionization cooling with FFAG (Schonauer[49])
- fast ramping synchrotron (Summers[50])

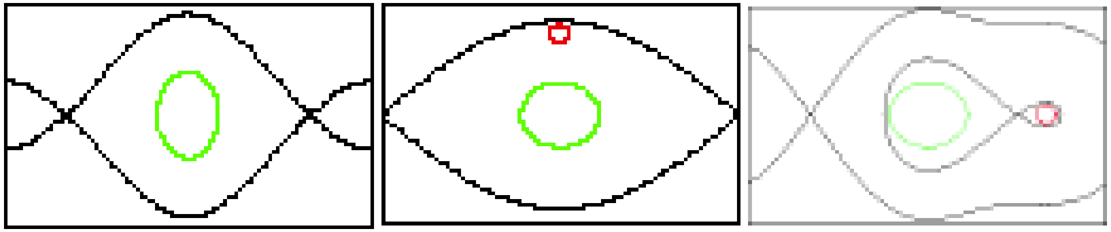
tools: ACCSIM, SAD, DIMAD,Geant



Horizontal phase space,
10-20 GeV FFAG ring, 7 MHz RF,
multipole magnet model (Machida)

NuFact02 – New concepts

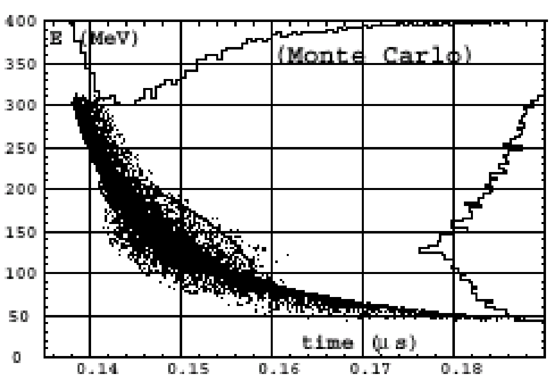
- frictional cooling channel (Galea[30])
- beta-beam facility (Lindroos[17])



Energy vs. time in bunch rotation stacking,
decay ring is also accumulator, uses asymmetric bunch pair merging, small bunch embedded in dense region of larger one, new bunch off-momentum in high dispersion region, rotates quarter turn in phase space, use dual-harmonic RF, Steady state (left), injected and stacked bunches (middle), start of merging (right). (Lindroos)

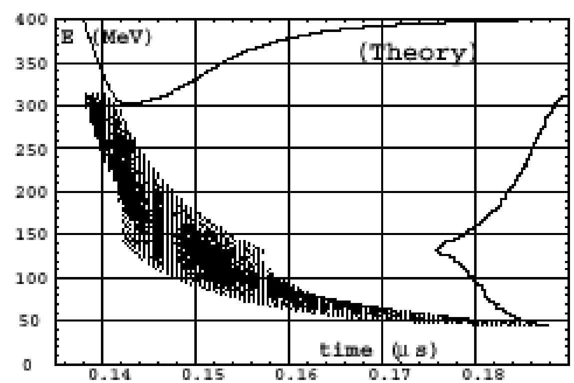
π collection and decay channel for CERN NF

- 6D Monte Carlo simulations with ZGOUBI
  - realistic quads, dipoles and solenoids
  - tracking using symplectic Taylor series maps
  - includes π decay
- developed theory of π / μ beam transport for checking
- work in progress
  - analytic model of transverse phase space
  - finite size of parent bunch



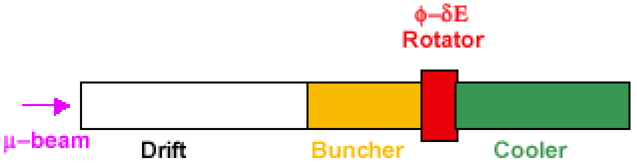
ZGOUBI longitudinal phase space of μ bunch 40 m from target (Meot) *

* blue names denote WG3 talks



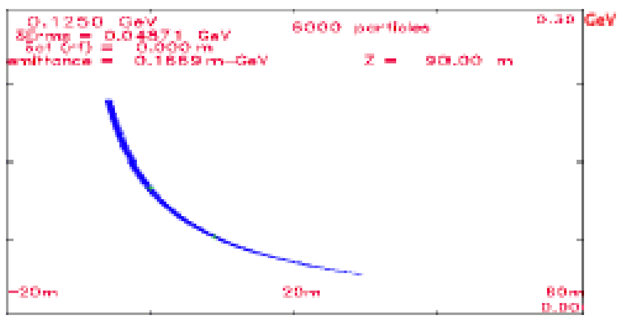
MATHMATICA implementation of theory (Autin)

Adiabatic buncher and phase rotation

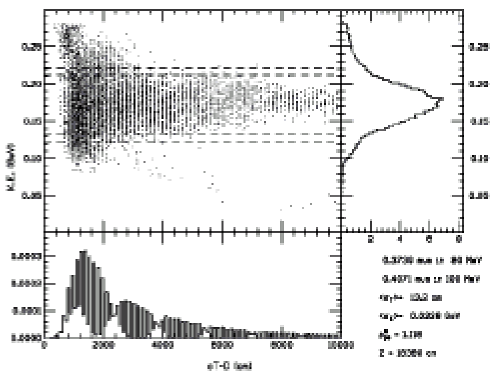


- idea (D. Neuffer et al)
    1. get E-t correlation from the drift
    2. adiabatically bunch with varying frequency RF
    3. 90^o phase rotation
       vernier – slight variation in frequency
    4. match to cooling channel
- advantages over FS2 induction linac approach
    simpler and cheaper
    collects both μ charges
- present simulations give 0.22 μ/p ~ FS2

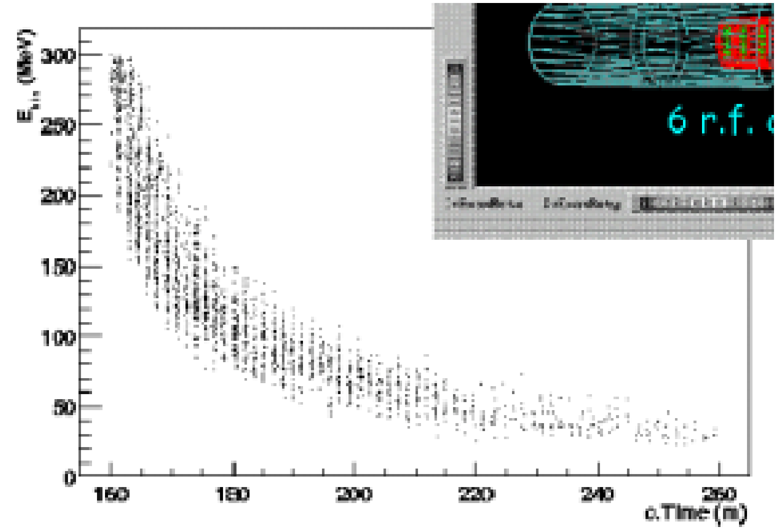
Adiabatic buncher simulations



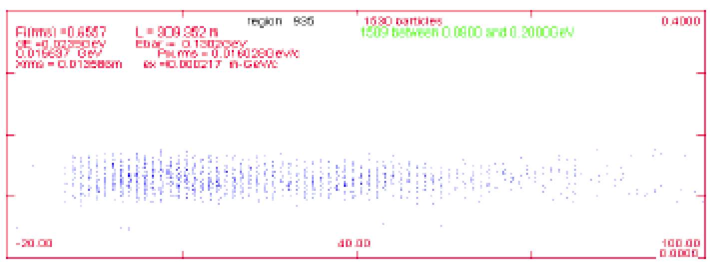
Neuffer-2D after drift



SIMUCOOL after phase rotation



GEANT4 after bunching



ICOOL after mismatched cooling

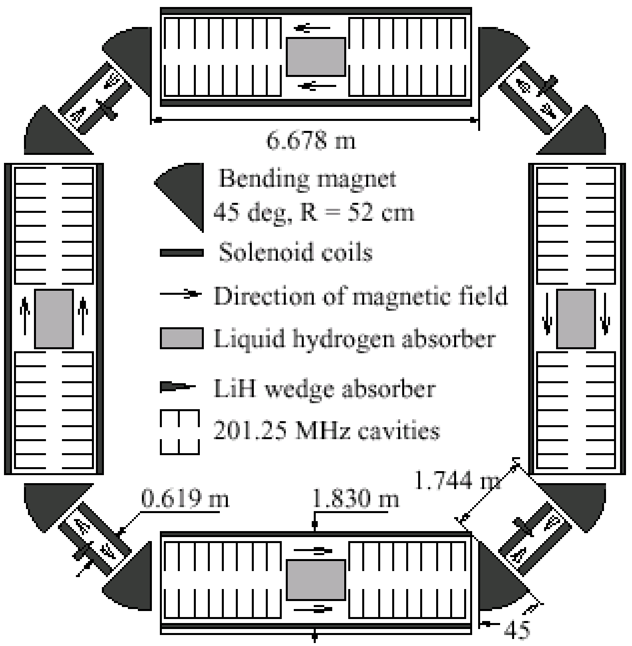
Adiabatic buncher plans

- look at variations
  e.g. shorter bunch trains
- continue optimizing parameters
- design new matched cooling channel
  buncher emittance ~20 mm
  FS2 channel acceptance ~12 mm

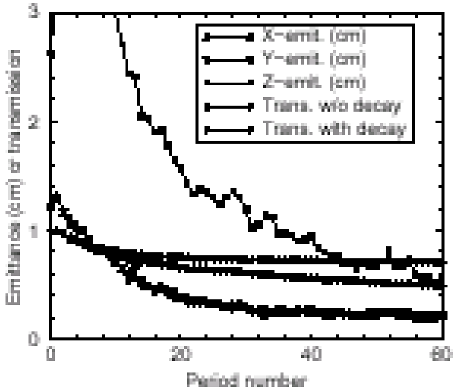
Balbekov tetra cooling ring

- first successful 6D cooling ring
- hard edge field model
  - "Balbecode"
  - ICOOL
  - Geant
- typical M ~ 40 – 90

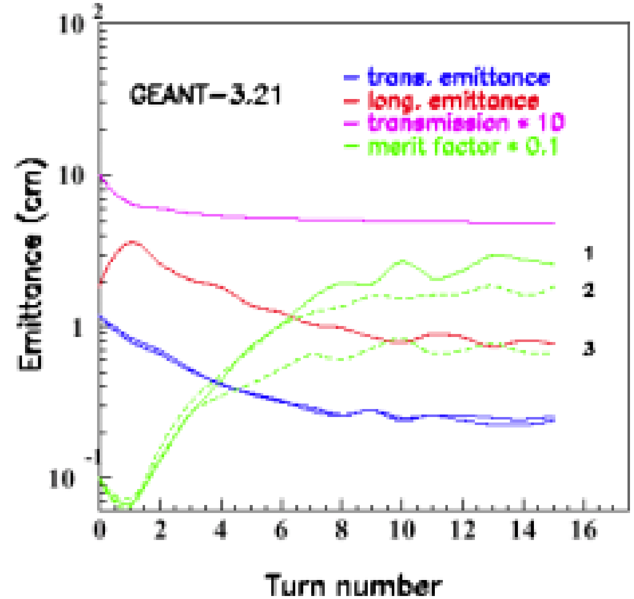
  $M = (\varepsilon_6^{initial} / \varepsilon_6^{final}) * Tr$

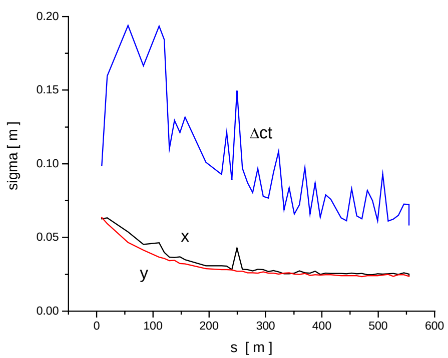


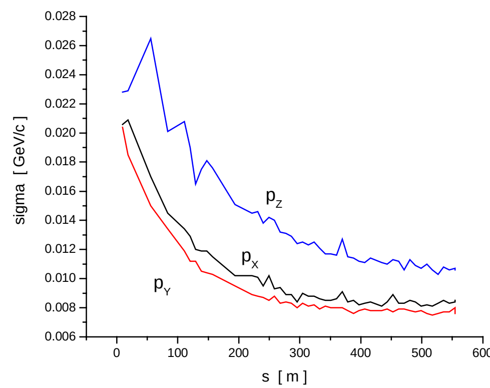
Balbekov ring results



Balbecode 6D cooling





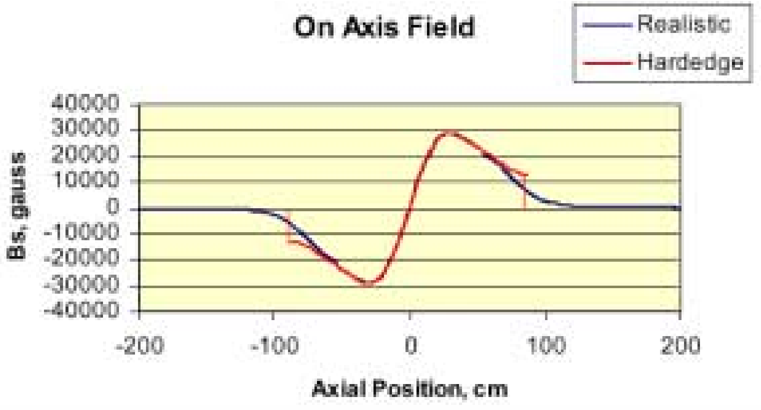


ICOOL bunch sigmas

GEANT 1: no decay,
2: decay,
3: decay + 360 μm Al absorber window

Balbekov ring problems and plans

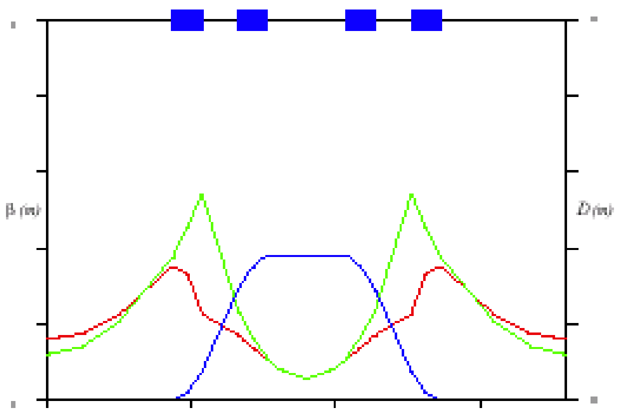
- need realistic model of the fields
  - study hard-edge lattice with gaps (Kahn)
  - iteration from TOSCA fields
  - COSY non-linear maps (Makino)
- how to inject/extract with long cells
- MITER – automate GEANT RF tuning (Raja)



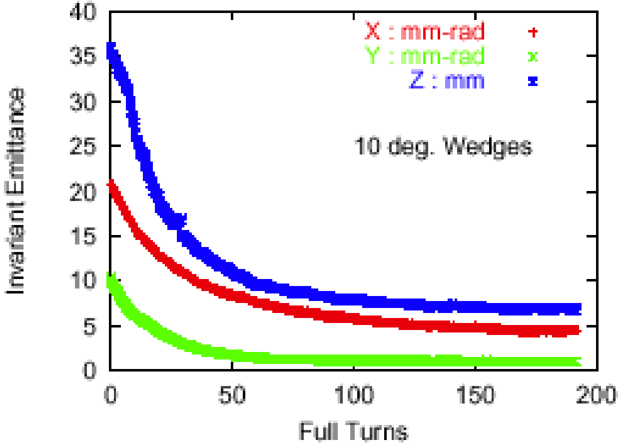
TOSCA field from short solenoid (Kahn)

"Quad" cooling rings

- conventional rings with quads or edge-focus dipoles (Kirk)
- approach so far
  - SYNCH - basic lattice design
  - ICOOL – tracking with hard-edge fields gives cooling performance
  - COSY – explore effects of fringe fields



SYNCH dipole-only ring (Garren)



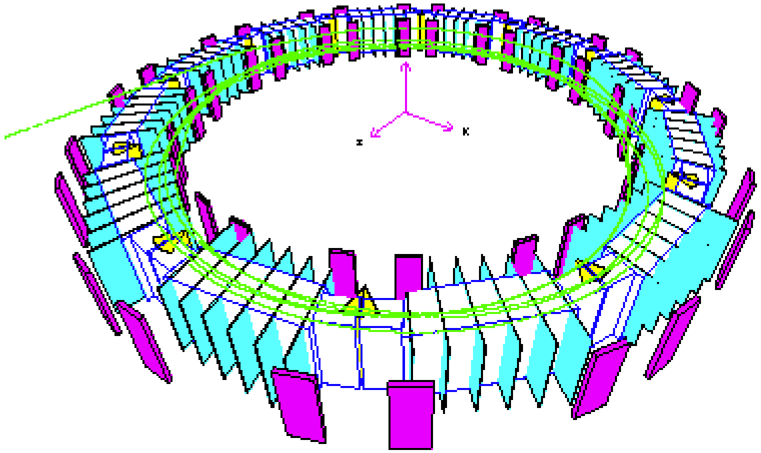
ICOOL cooling simulation (Kirk)

“Quad” hard-edge ring summary

- hard-edge models give good M for variety of lattices
- compact 3.5 m circumference lattice for cooling demo?
- very low emittance using Li lens absorbers? (Fukui)
- needs windows & realistic field modeling
- limited acceptance with realistic apertures (ICOOL)
- limited acceptance with fringe fields (COSY)

Alternating solenoid focus rings

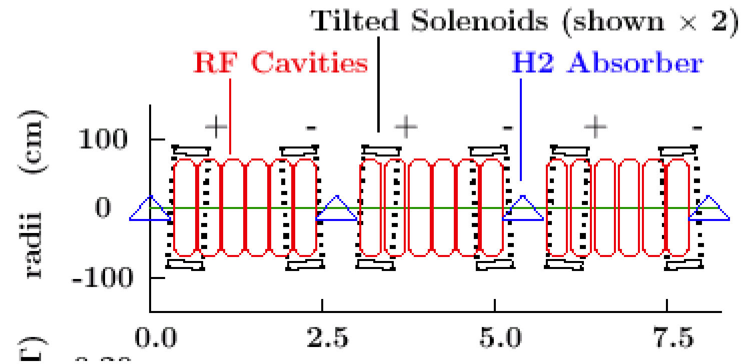
- pure solenoidal focussing
- bending from external dipole or tipped solenoids
- currently most realistic ring design
- simulated with ICOOL, Balbecode, GEANT



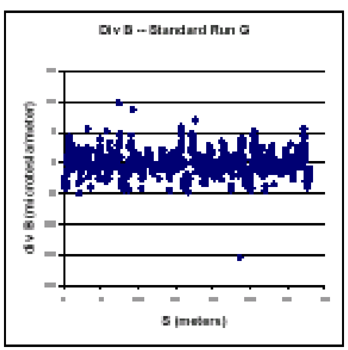
GEANT model of RFOFO ring (Mississippi)

RFOFO ring

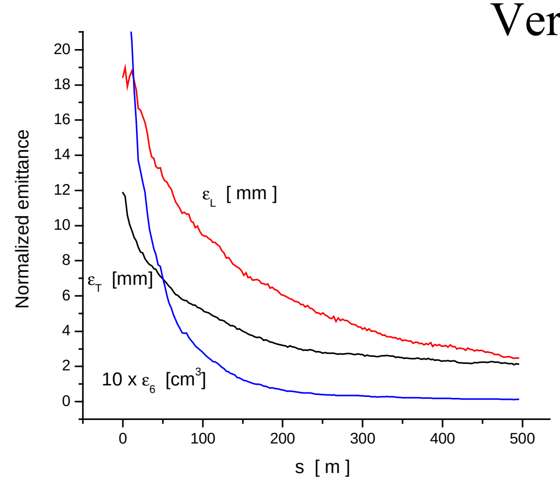
- realistic fields from tipped solenoids
- $C = 33$ m, $L_{cell} = 2.75$ m
- 201 MHz, 12 MV/m, wedge = 100° LH_2
- $\beta_T = 38$ cm, D = 8 cm
- M ~ 125 (no windows, injection)



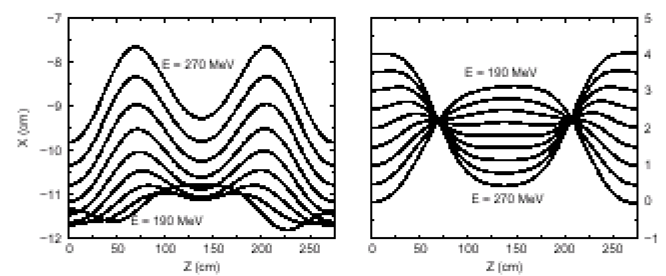
Vertical section through 3 cells (Palmer)



div B for tipped solenoid field, horz. scale s [m], vert. scale [μT/m] (Mississippi)



ICOOL emittances vs. length



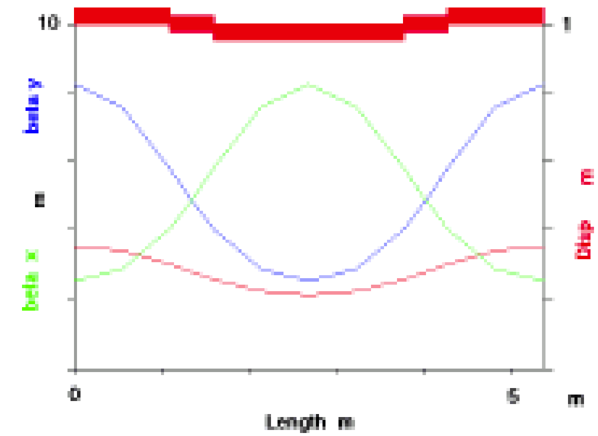
Balbecode RFOFO closed orbits, radial (left), vertical (right), 10 MeV steps

Future ring cooler studies

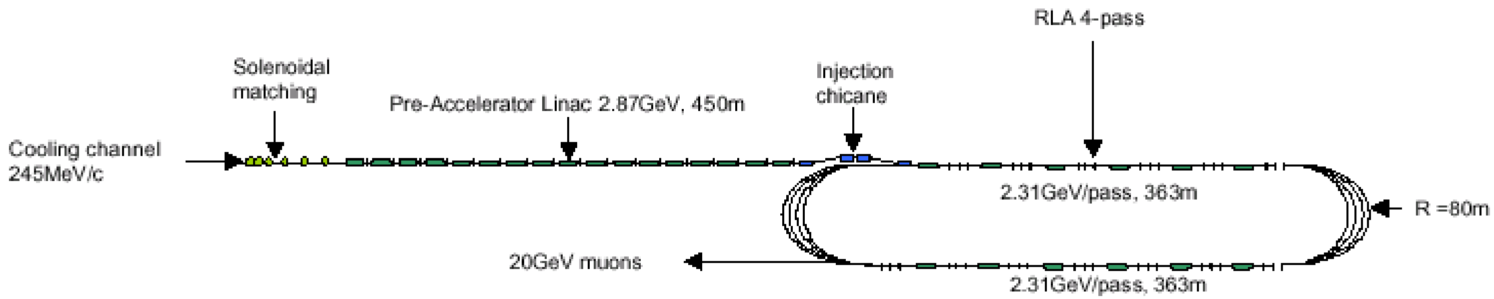
- iterate with engineers
  - practical window thickness (Cummings)
  - practical absorber material and shape
  - practical kicker design
- model injection/extraction (Palmer)
  - field model
  - modify lattice
- match with rest of system (Balbekov)
  - bunch compression rings
- special applications
  - early cooling
  - low emittance cooling
  - cooling demonstration

μ acceleration studies

- Recirculating Linear Accelerators (Bogacz)
  - complete linear lattice design
  - preaccelerator, linacs, 7 arcs
  - $\Delta\varepsilon_T$ growth in linac arcs is now small
- Very Rapid Cycling Synchrotron (VRCS)
  - 4-16 GeV preliminary design (Summers)
- Fixed Field Alternating Gradient (FFAG)



SYNCH design of VRCS lattice cell (Garren)

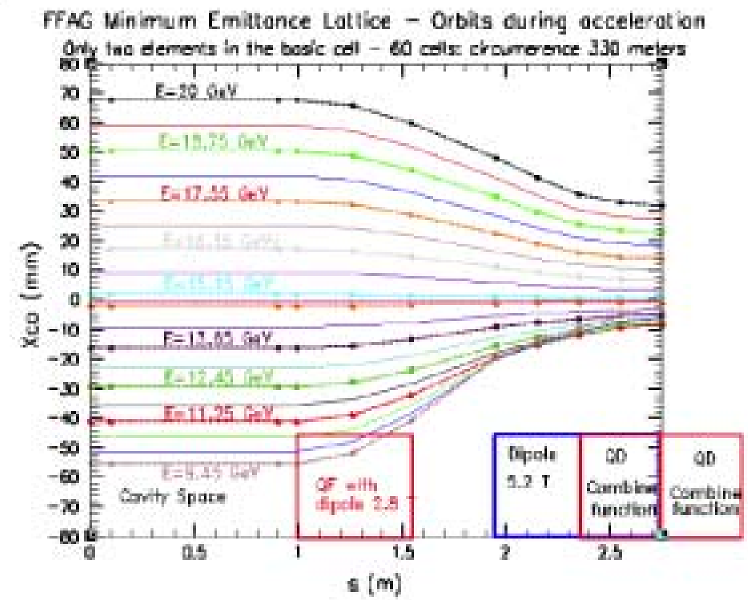


Improved FS2 RLA design (Bogacz)

FFAG designs

- lots of activity
- two main classes

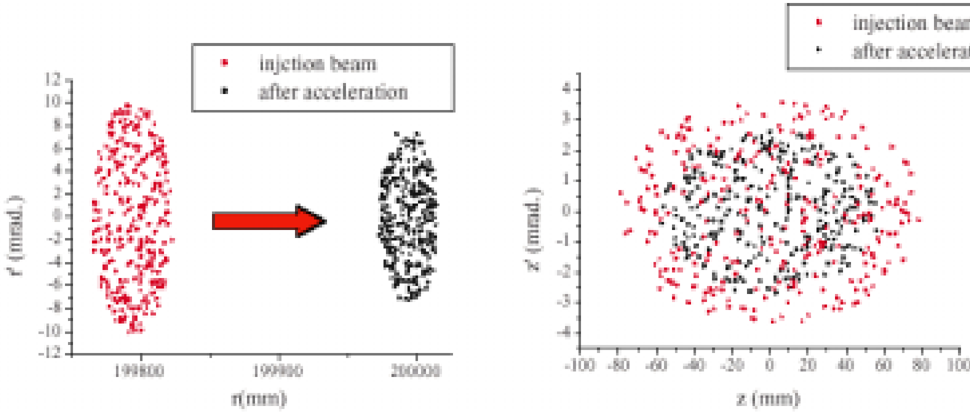
  1. scaling (Machida)
     - Japanese NF design
     - complicated nonlinear magnet
     - constant tune, closed orbit scales with E
  2. non-scaling
     - more linear, large DA
     - lower RF requirements
     - examples (Palmer)
       - FODO lattice (Johnstone)
       - minimum emittance lattice



Closed orbit excursion during acceleration (Trbojevic)

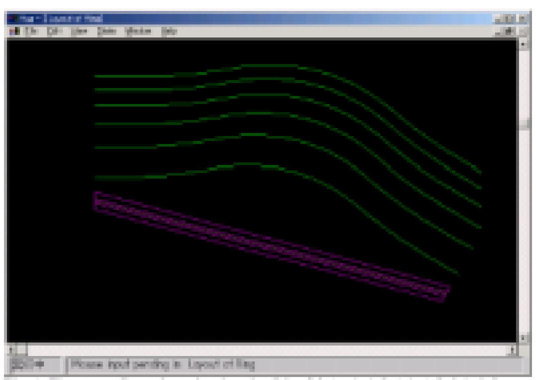
tools: SYNCH, MAD, COSY, TEAPOT, PTC

FFAG simulations



Scaling FFAG, acceleration 10-20 GeV,

24 MHz, 0.75 MV/m average, 13 turns (Aiba)



PTC 150 MeV scaling FFAG, closed orbits vs. δ (Machida)

- PTC tracking studies are ongoing (Machida)
- PTC = polymorphic tracking code
- checked with Runge-Kutta tracking
- soft-edge model (Enge function ends)
- studying focusing configurations & acceptances

Other simulation work

- improvements in Monte Carlo techniques (van Ginneken)
    - pathlength fluctuations in thick targets
    - selection of ΔE & θ_{MS} via Edgeworth series
- MARS study of solenoid taper and π decay channel (Paul)
- linear quadrupole cooling channel (Berz)
    - fully simulated with fringe fields in COSY
    - matched to adiabatic buncher
- cooling ring at RAL (Rees)
- bunch compression rings (Balbekov)
- frictional cooling (Galea)
- cooling using gas absorber (Johnson)
- velocity-compliant bunching scheme (Iwashita)
- probably more, sorry

Neutrino factory simulation plans

- continue studying lower cost schemes
- continue topical workshops
  - FFAGs (Oct. 2002, July 2003)
  - ring coolers (Nov. 2002, Aug. 2003)
  - collection and phase rotation (later this year?)
- monthly FFAG video conferences
- aim for new NF Study 3 in ~2 years