Theory and Simulations: Introduction and Plans

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BNL

Mutac Review
BNL

29 April 2004

Outline of MC simulation activities

- design simulations for future muon-based facilities
  - major focus is on beam dynamics
    - 1) front end
      - neutrino factory
      - muon collider
    - 2) accelerators (S. Berg)

- related simulation efforts in support of the experimental program
  - targetry (R. Samulyak)
  - MICE (K. Long)
  - Muons Inc. (R. Johnson)

- theory

Theory and simulation committee

R. Fernow (BNL)	Chair
H. Kirk (BNL)	Targetry coordinator
D. Neuffer (FNAL)	Front end systems coordinator
S. Berg (BNL) / C. Johnstone (FNAL)	Acceleration coordinators
A. Sessler (LBNL)	Theory coordinator
M. Berz (MSU)	
E. Keil (CERN)	
R. Palmer (BNL)	
S. Koscielniak (TRIUMF)	

Major responsibilities

- planning to foster this work
- hold workshops
- advertise, interview, select postdocs for new positions

Recent simulation workshops

Ring coolers	UCLA	March 2003
FFAG	KEK	July 2003
Emittance exchange	FNAL	August 2003
Targetry	BNL	September 2003
FFAG	BNL	October 2003
Ring coolers	Tucson	December 2003
Emittance exchange	Riverside	January 2004
Ring coolers	Mississippi	March 2004
FFAG	TRIUMF	April 2004

Code development

- ongoing effort on simulation code development
- front end

  ICOOL

  Geant (several varieties)

  COSY

  MARS
- acceleration

  COSY

  private codes – optimization, cost estimates
- targetry

  FronTier

Ionization cooling rings

- three families of ring coolers have been successfully simulated
- all show significant 6D cooling
  - tetra ring
  - RFOFO ring
  - dipole ring
- ring with Li lens elements are under study
- recent highlights
  - RFOFO ring simulated with Geant
  - dipole ring modeled with realistic fields
  - dipole ring may be suitable for “table top” demonstration

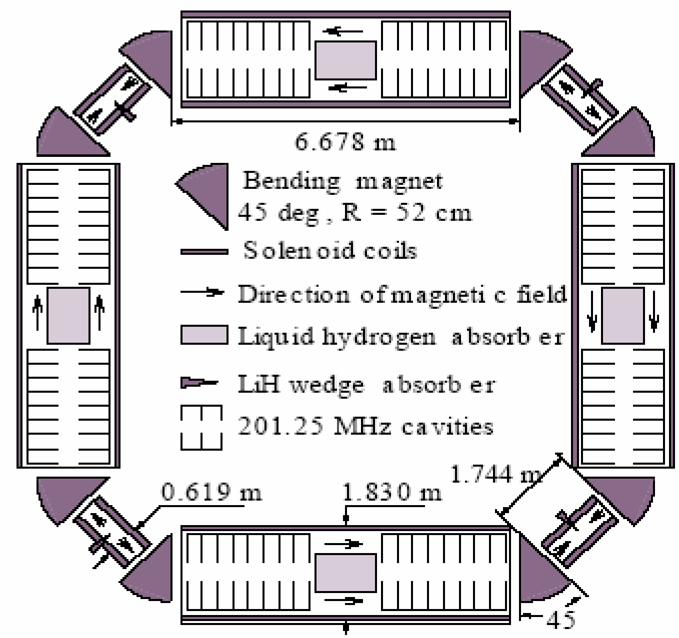
Tetra ring cooler

- first cooling ring design by V. Balbekov, FNAL
- only fully simulated with hard edge fields
- drawbacks

  large diameter, high B solenoids

  field overlap at corners

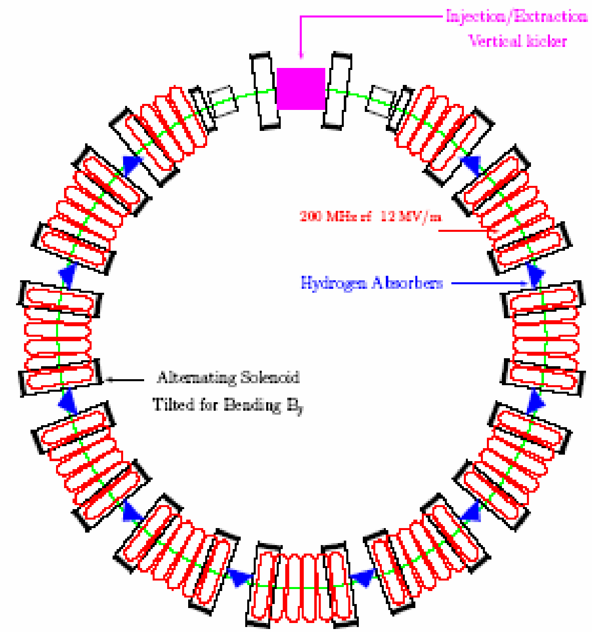
  injection space hurts performance



(V. Balbekov, FNAL)

RFOFO ring cooler (1)

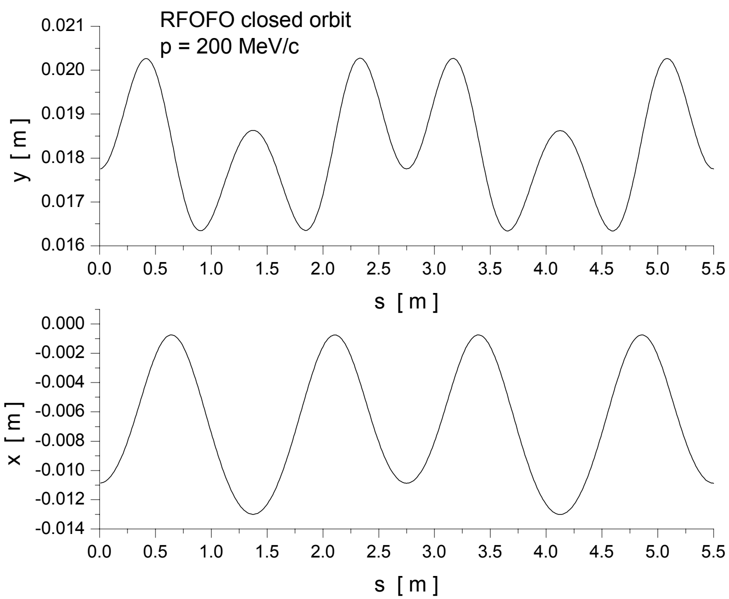
- designed by R. Palmer, BNL
- first ring simulated with realistic fields
- lattice has 12 identical cells, C = 33 m
- focusing from 2. 8 T solenoids
- bending from tipping the solenoids
- wedge shaped LH_2 absorbers
- 201 MHz RF, 12 MV/m
- effects of windows, empty cells studied

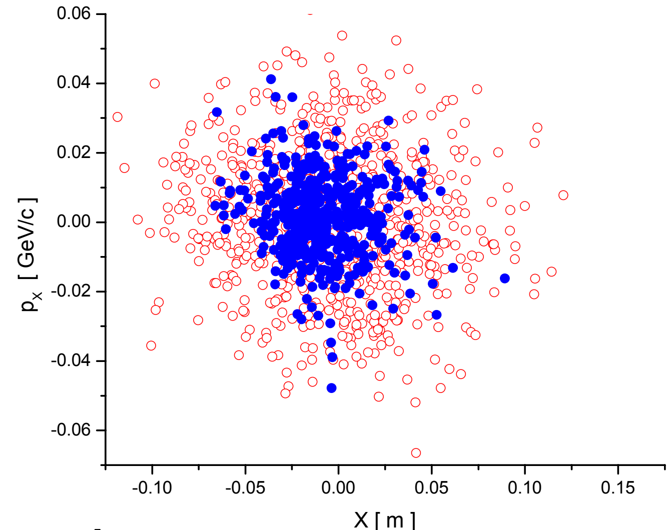


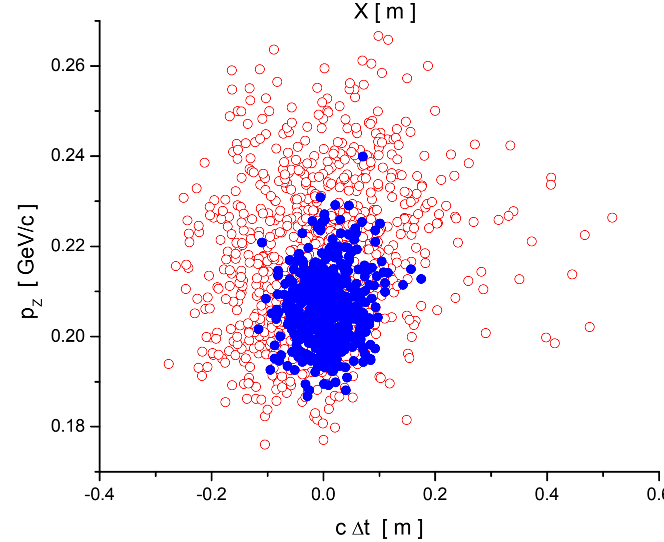
(R. Palmer, BNL)

RFOFO ring cooler (2)

- reference momentum is 203 MeV/c
- minimum $\beta_\perp$ = 40 cm at wedge absorber
- dispersion is 8 cm at wedge
- closed orbit leaves the midplane
- gives significant increase in muon density

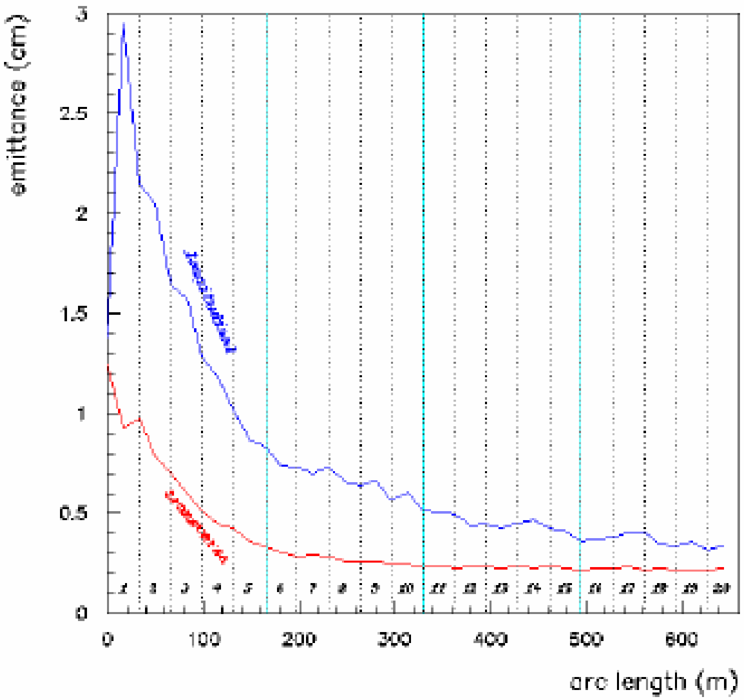


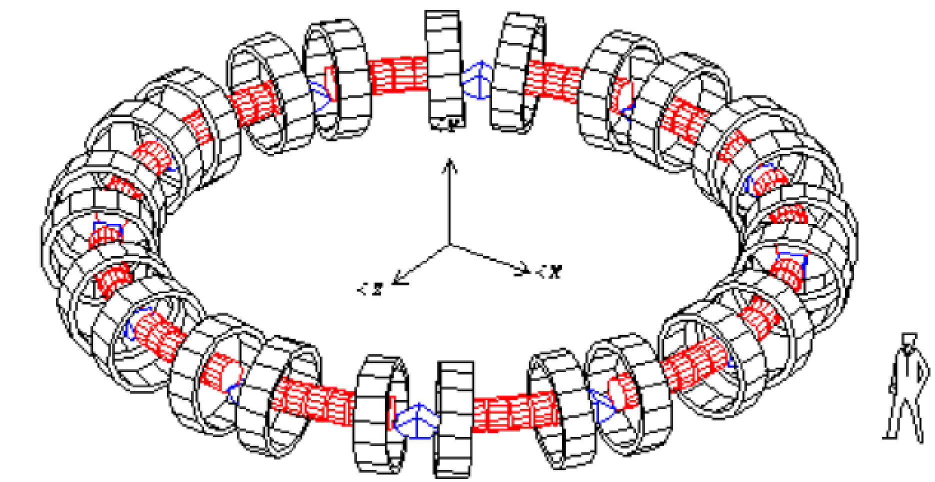




RFOFO ring cooler (3)

- recently simulated with Geant
- parameter tuning underway
- needs better initial matching
- current results ≈ ICOOL





(Amit Klier, UC Riverside)

Dipole ring cooler (1)

- focusing from dipole body and edge angle, no solenoids
- examined many designs

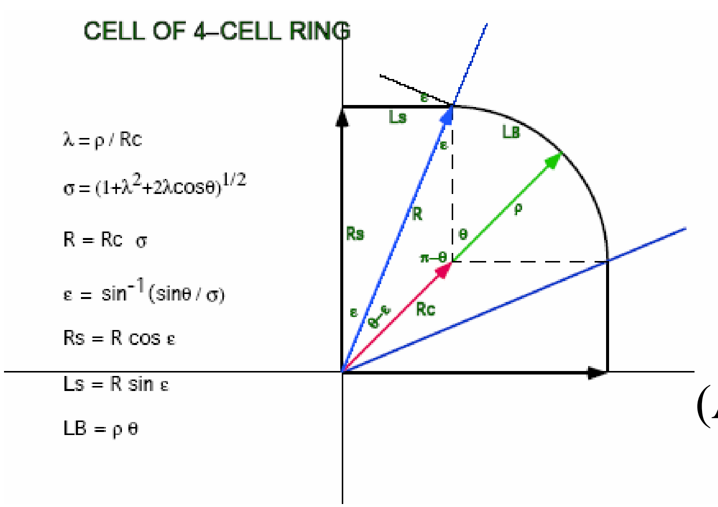
  weak focus

  strong focus (FFAG-like)
- developed successful design algorithm

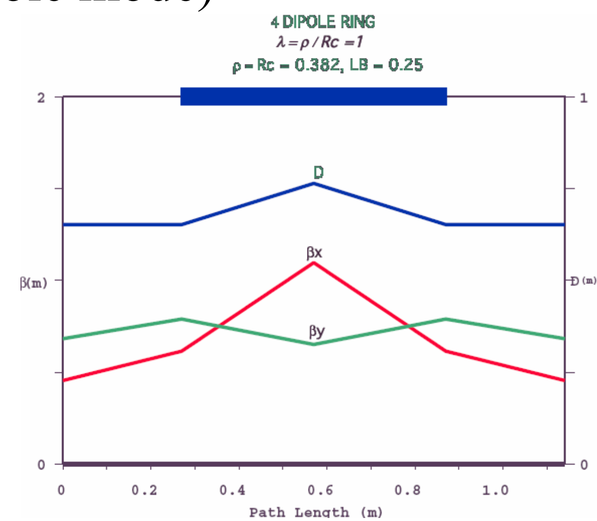
  design initial lattice using SYNCH

  parameter optimization with ICOOL (hard edge mode)

  realistic fields with TOSCA, ICOOL (multipole mode)

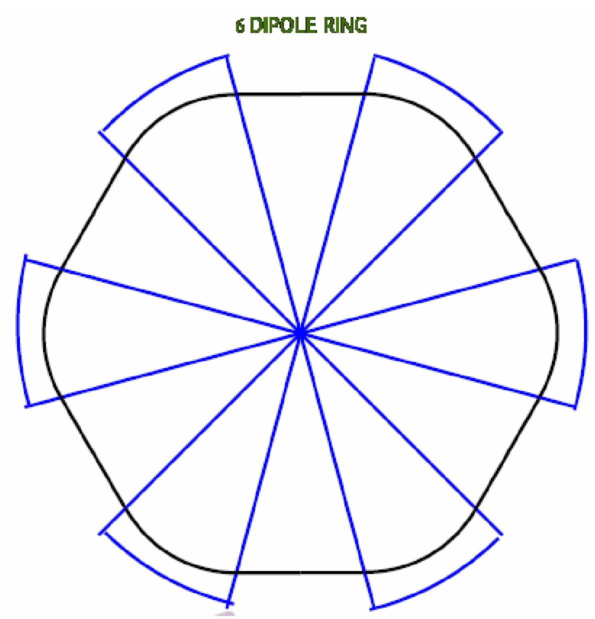


(A. Garren, UCLA)

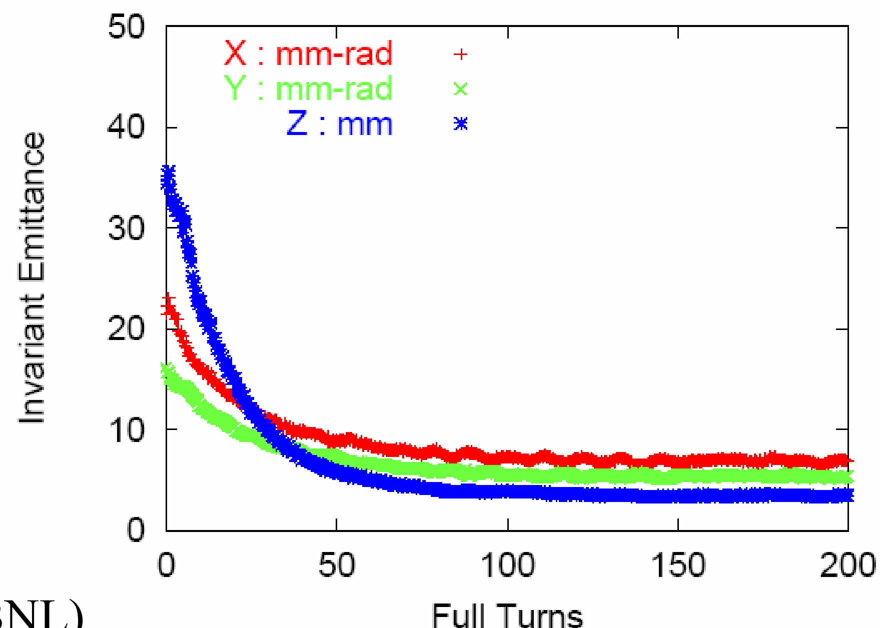


Dipole ring cooler (2)

- weak focusing ring
- H_2 gas filled, want β_T small and constant
- 201 MHz
- skew quads give transverse mixing



(H. Kirk, BNL)

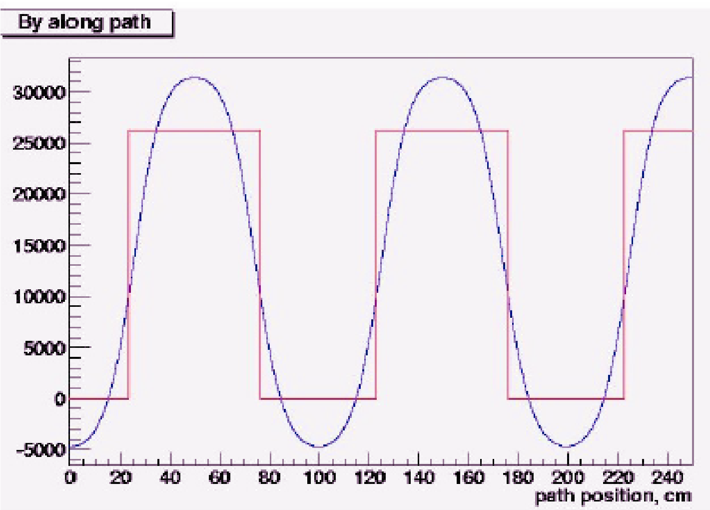


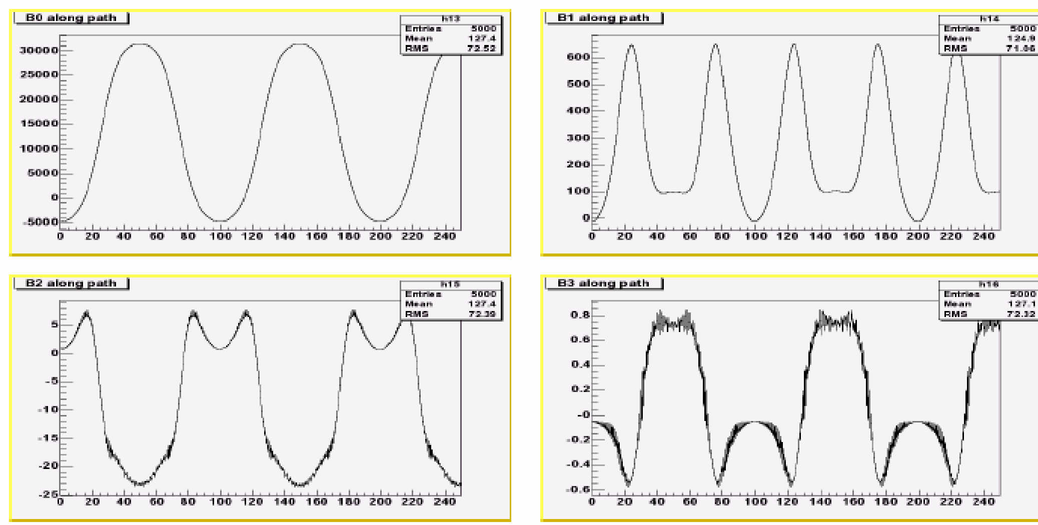
Dipole ring cooler (3)

- 4 cell weak focus ring was simulated with realistic fields
- B reverses sign between cells
- realistic field gives similar lattice parameters ≈ SYNCH
- dynamic aperture studies show

  realistic ≈ hard edge (in horizontal plane)

  realistic ≈ ½ hard edge (in vertical plane)



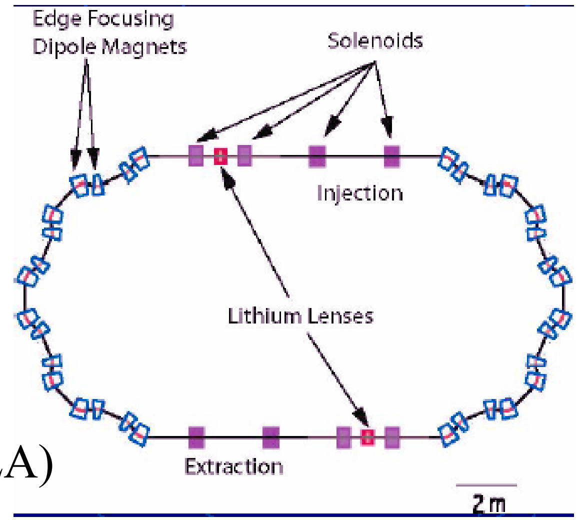


(S. Kahn, BNL)

Li lens cooling

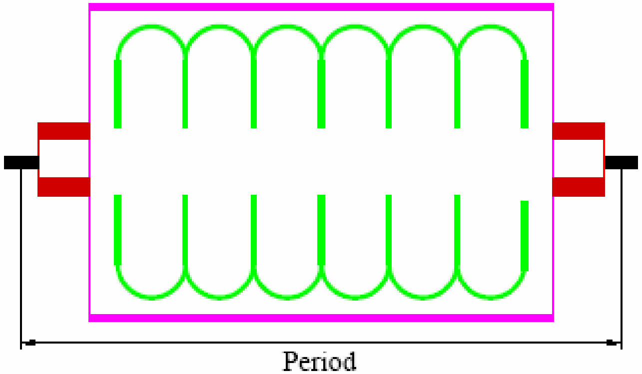
- present ring designs get ε_{TN} ~ 2 mm (β_T=40 cm, B=3 T)
- we need ε_{TN} ~ 0.2 mm for a muon collider

  - preliminary ring modeling gets ε_{TN} ~0.3 mm (β_T ~1 cm)
  - studying field overlap between solenoids and Li lens



(Y. Fukui, UCLA)

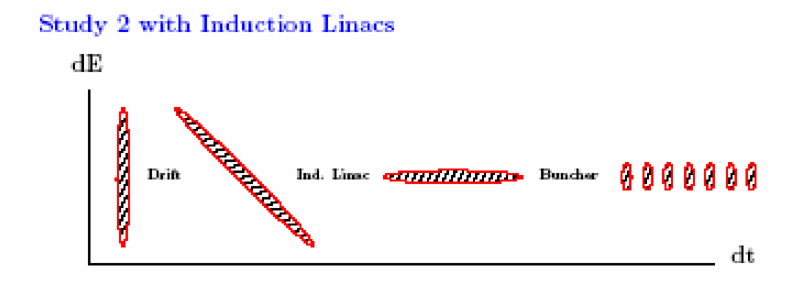
  - linear channel had 35 x 2.6 m cells
  - Li lens: 13.5 cm long, 3 cm radius, 355 A/mm², β_T ~4 cm
  - matching between lenses is difficult
  - preliminary ε_{TN} ~ 0.5 mm

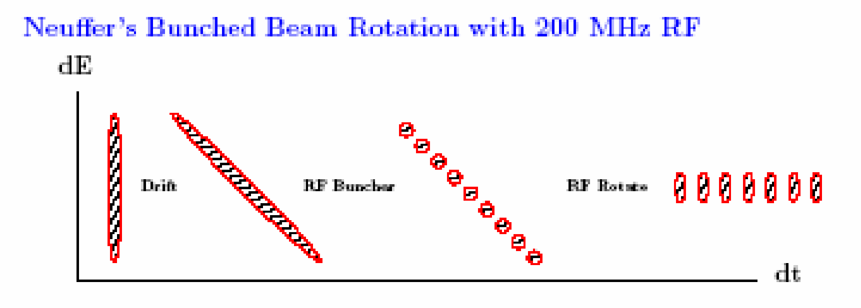


(V. Balbekov, FNAL)

Study 2a Front End

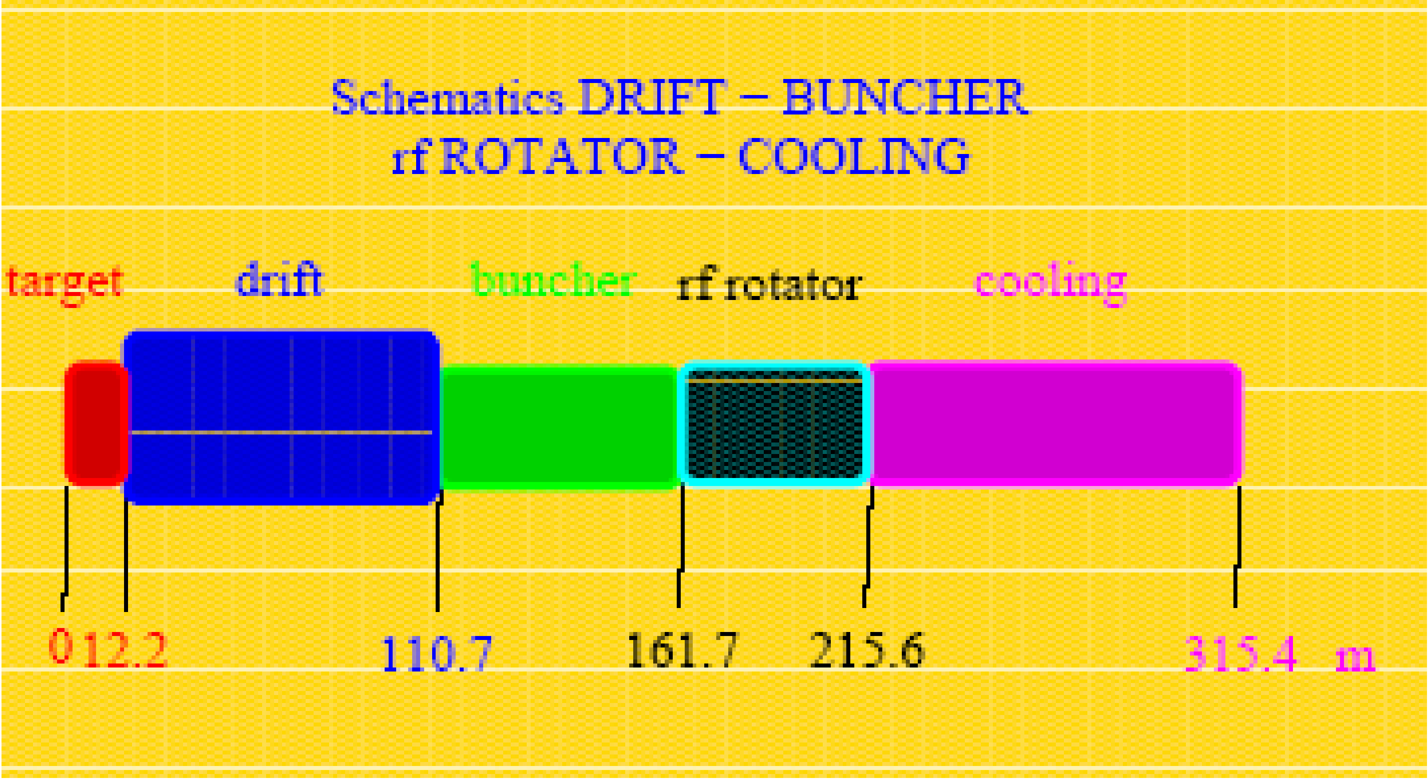
- objective: significant neutrino factory cost reduction from FS2
- major new elements
  (1) adiabatic RF bunching and phase rotation (D. Neuffer, FNAL)
    - eliminate induction linacs
  (2) new linac front end with A_{TN} = 30 mm acceptance (R. Palmer et al)
  (3) new simplified cooler design (R. Palmer)
    - fewer components
    - lower magnetic field





New front end design

- overall configuration by R. Palmer



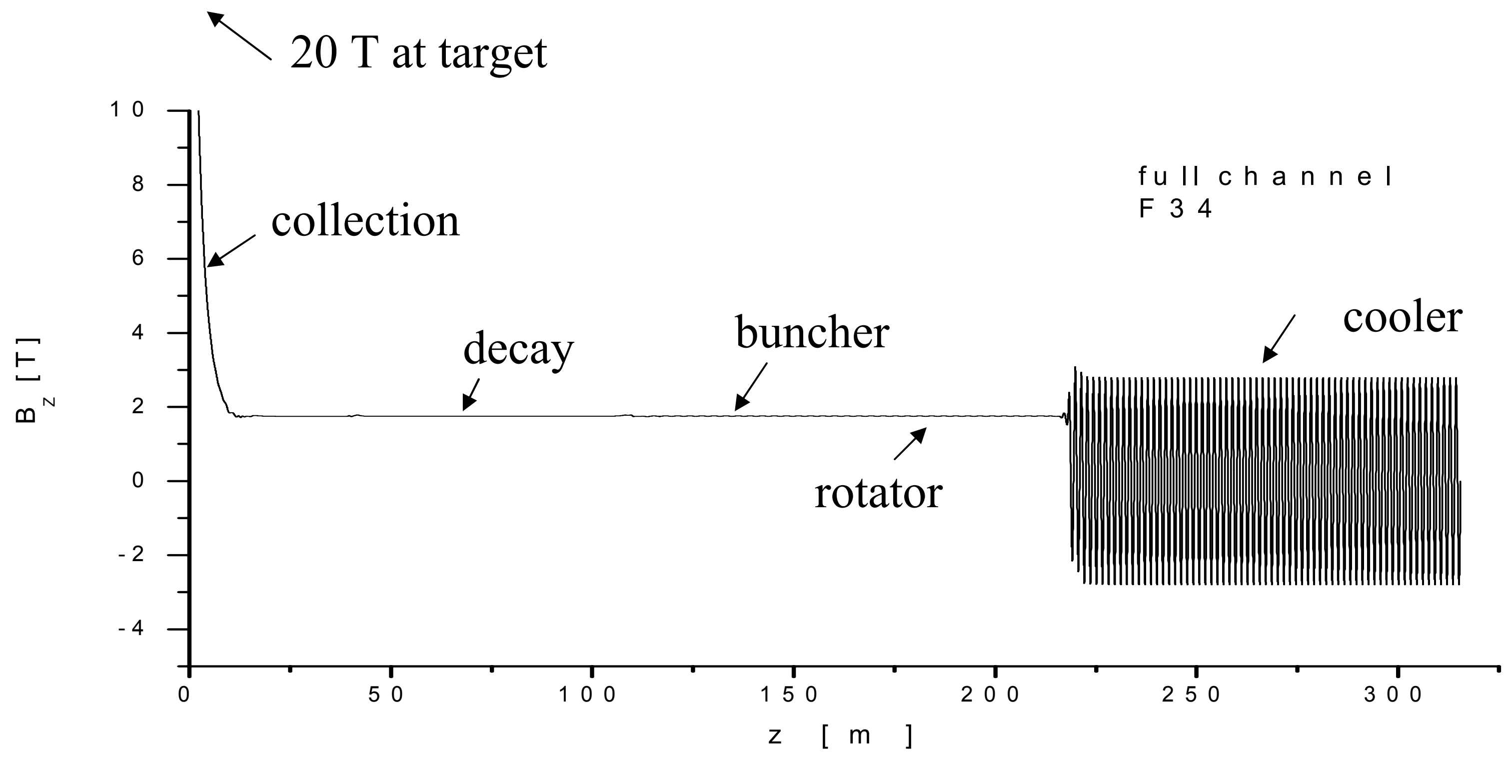
(J. Gallardo, BNL)

Realistic design

- Mawellian field from table of coils
  - constant fields → periodic solenoids
  - careful matching at transitions
  - coils near the target moved radially for extra lifetime
  - optimized collection profile
- radial constraint from tapered beam pipe
- RF windows in buncher
- discrete frequency buncher and rotator cavities
- cooler frequency exactly at 201.25 MHz
- Be coating over LiH absorbers
- new beam distribution using new B over target

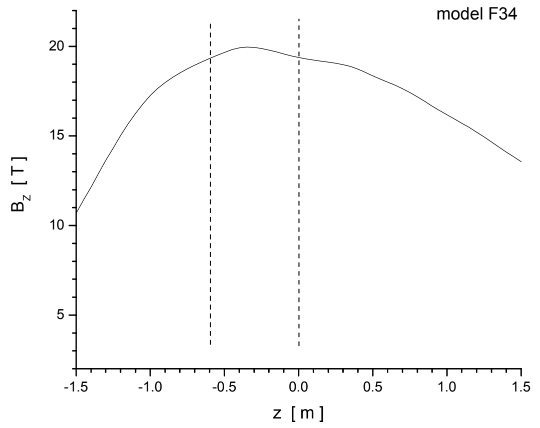
Field configuration

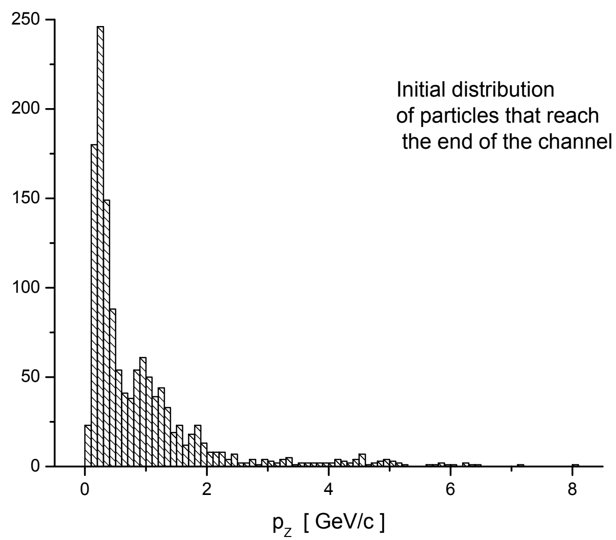
- front end uses 490 solenoids

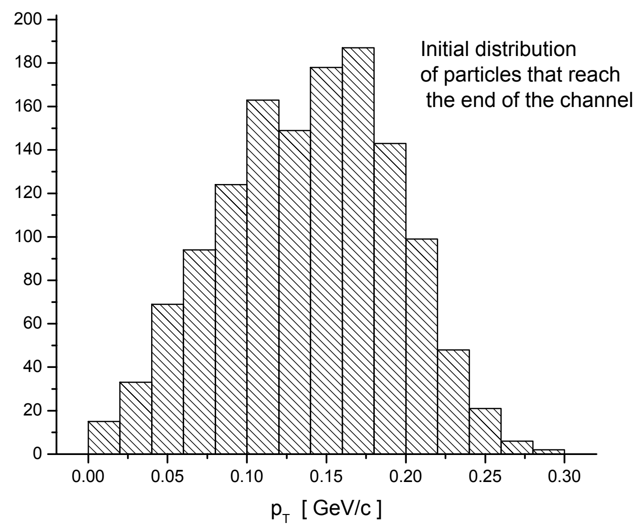


Target

- 24 GeV protons on Hg jet
- jet at 100 mr from B axis, beam 67 mr from B axis
- particle creation using MARS (H. Kirk)

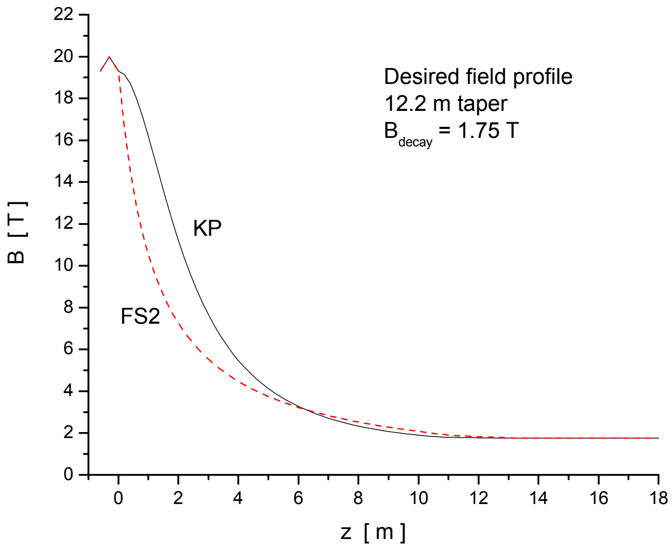


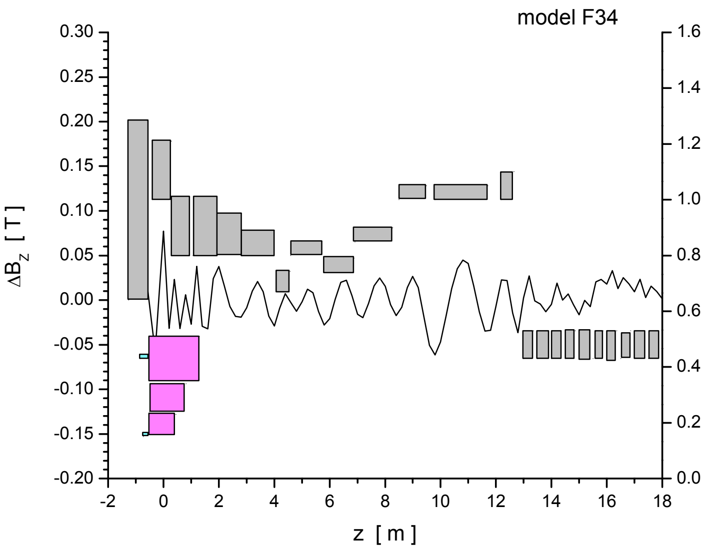




Pion/muon collection

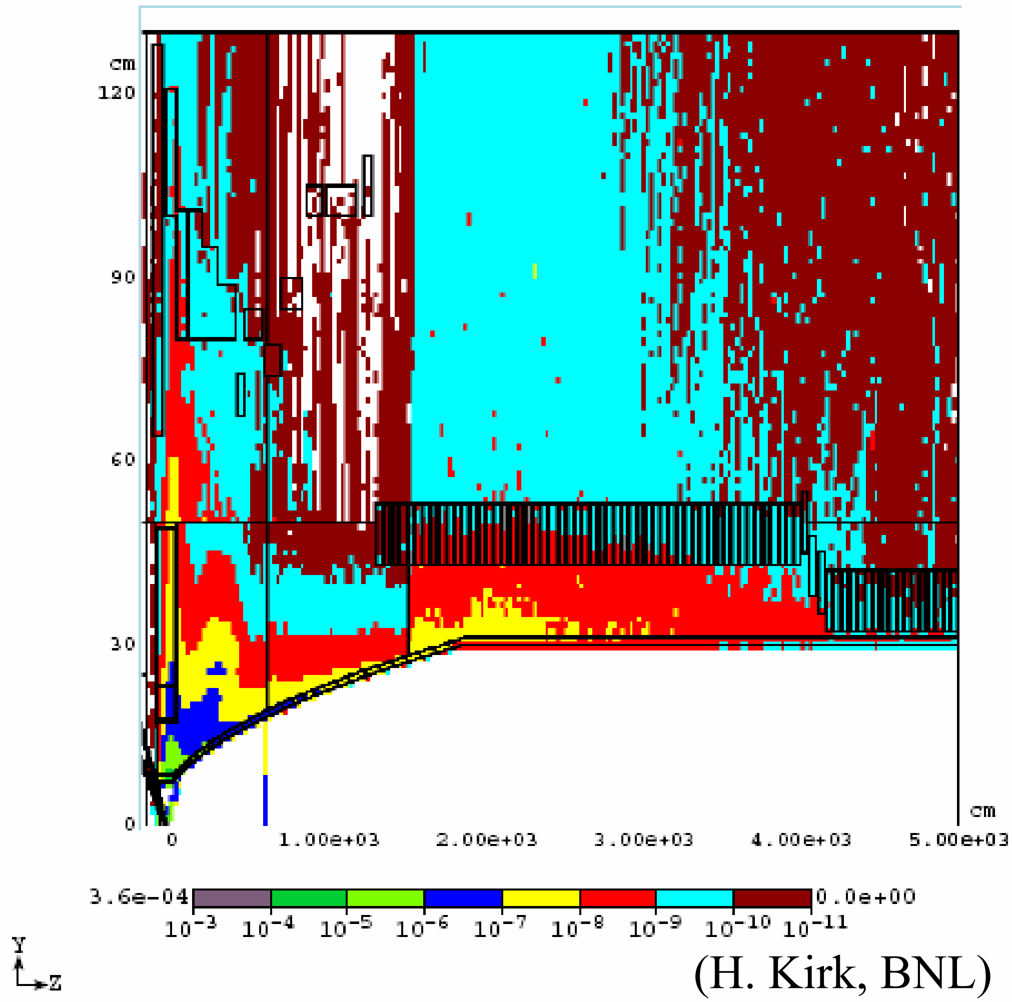
- 12.2 m taper from 20 T to 1.75 T
- improved collection design (K. Paul, U. Illinois)
- increased accepted μ / p by 13%





Radiation

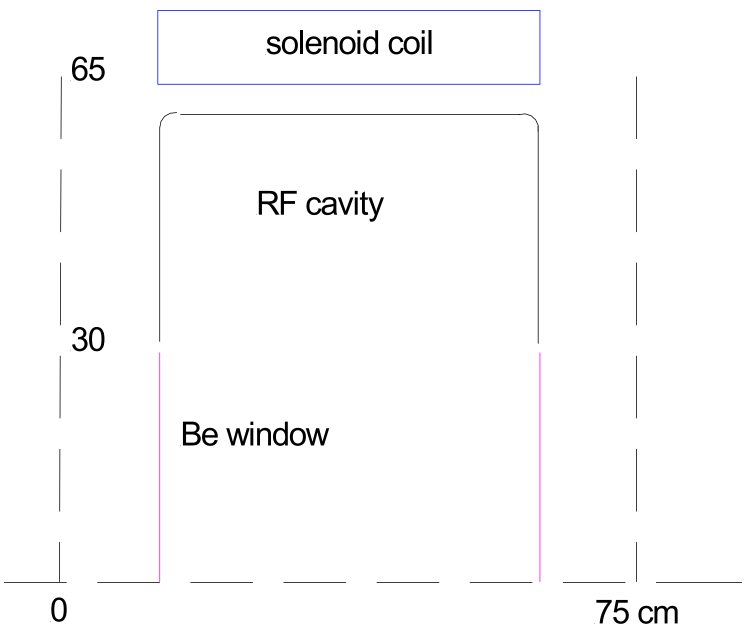
- MARS calculations
  of absorbed dose (H. Kirk)
- peak deposition in SC coils
  is ~ 1MGy/yr
- no problem with SC lifetime

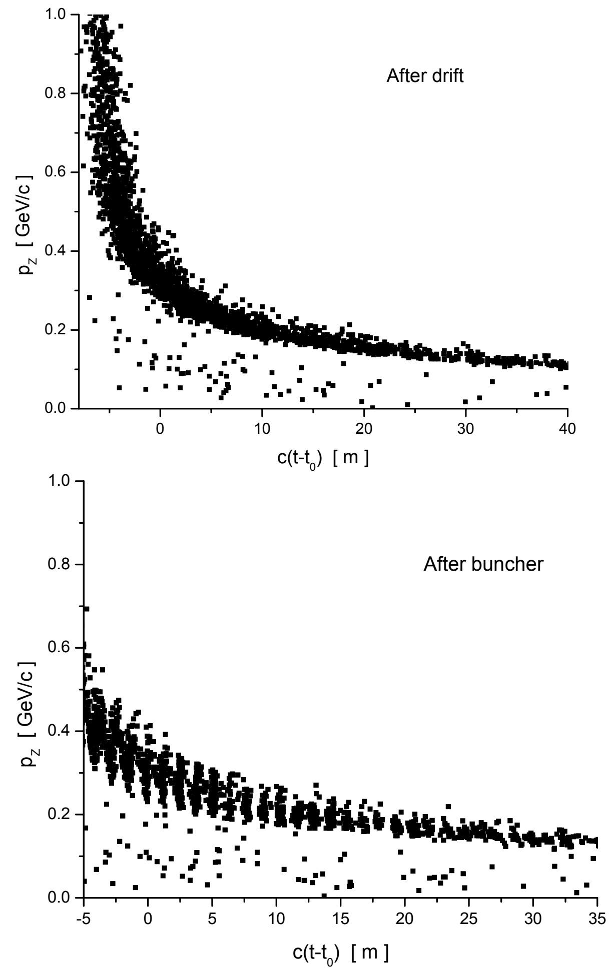


(H. Kirk, BNL)

Buncher

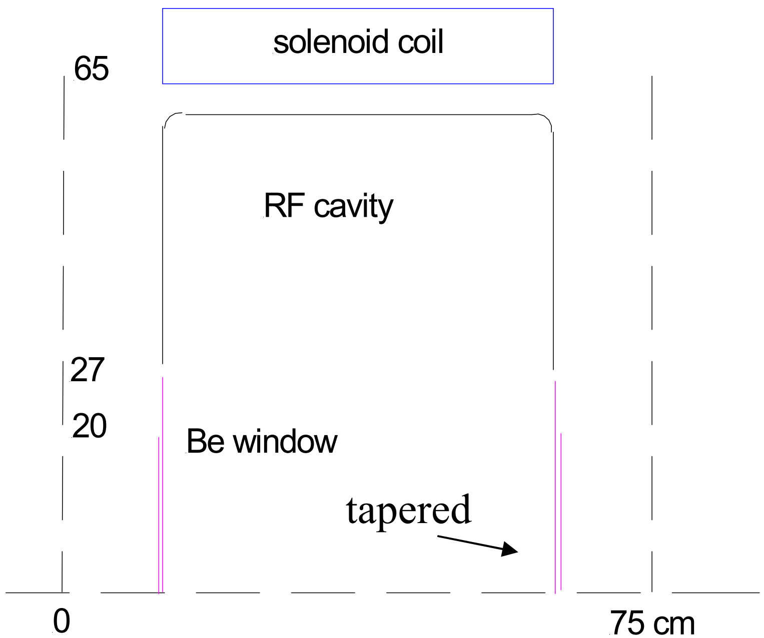
- 51 m long
- 31 cavities with 19 different frequencies (332→232 MHz)
- gradients (0.9 → 9 MV/m)
- 51 bunches in train

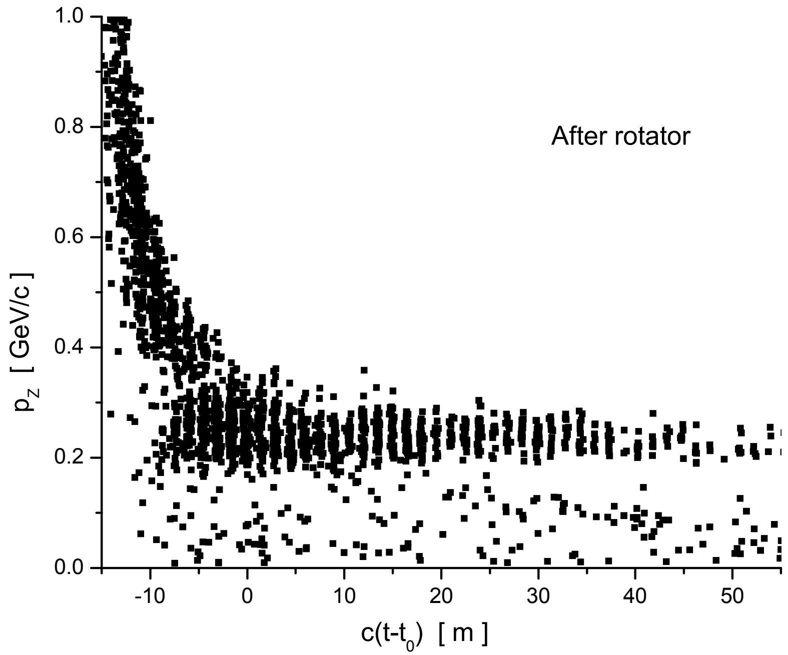




Rotator

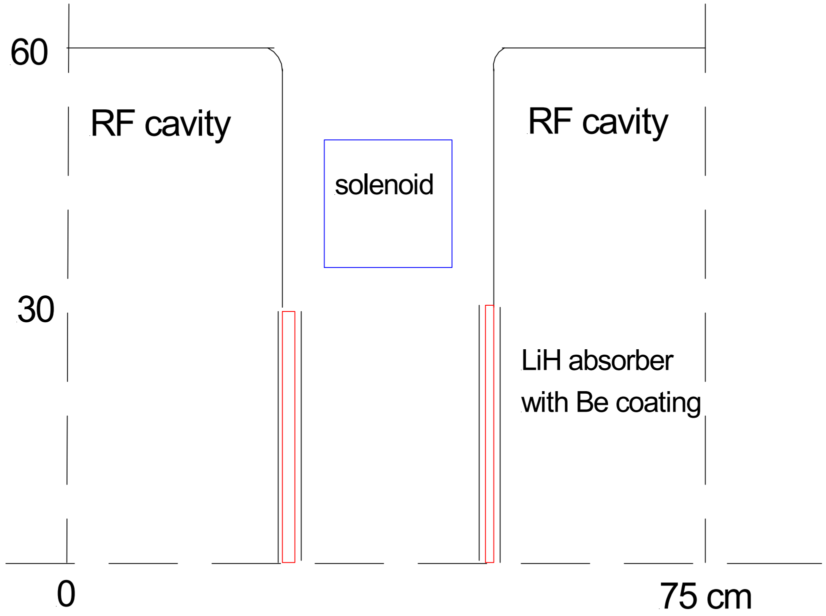
- 54 m long
- 72 cavities with 18 different frequencies (232→201 MHz)
- gradient 12.5 MV/m

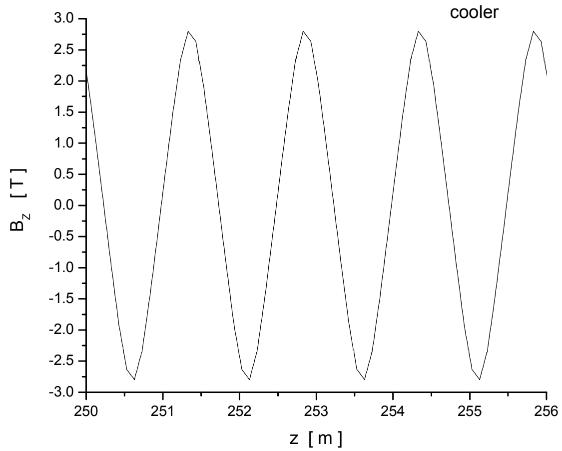


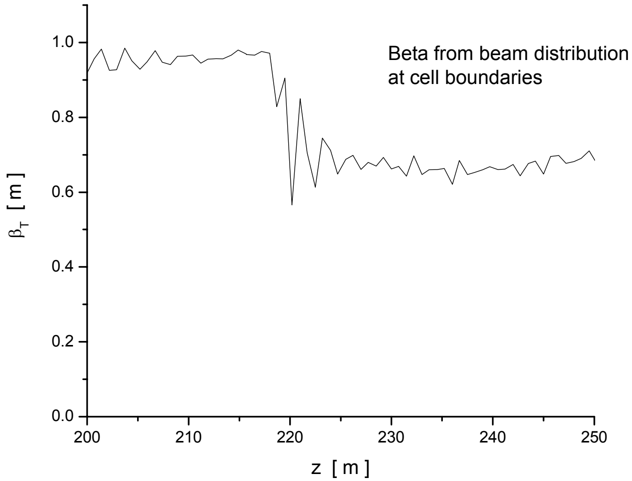


Cooler design

- 100 m long alternating solenoid channel, $B_S = 2.8$ T
- large, relatively flat $\beta_\perp \sim 70$ cm
- use LiH absorbers as RF windows

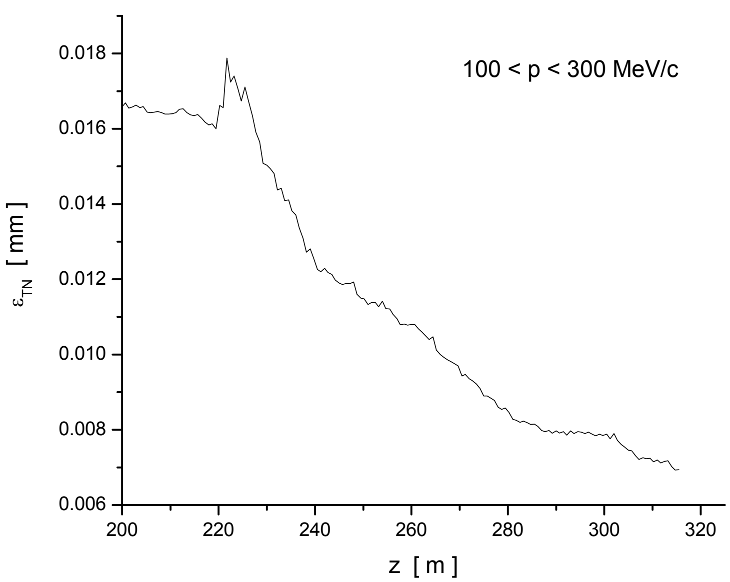


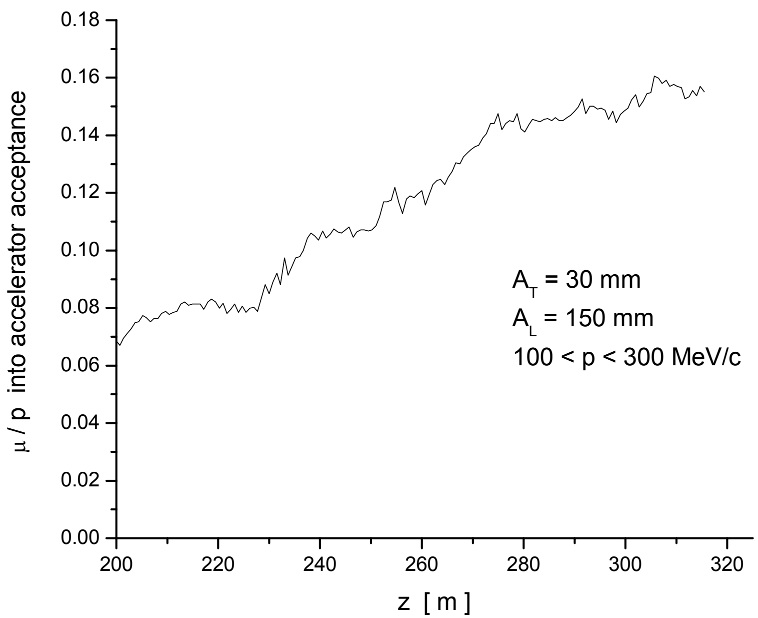




Cooler performance

- cooling increase μ density into accelerator acceptance by factor of ~2
- cools normalized transverse emittance by factor of ~2.4
- final ε_{TN} = 7 mm (equilibrium value for LiH is ~5 mm)





Status of Study 2a

- current best result is $\mu / p = 0.144 \pm 0.007$ into accelerator acceptance
- achieved approximately same performance as Study 2
- but this design gives muons of both signs
  - potential gain of a factor of 2 in neutrino flux
- there is still hope for further progress
  - observed transverse cooling from the windows in the phase rotator
  - can try different absorbers

Future simulation plans

neutrino factory

- complete Study 2a
- continue work on FFAG acceleration scenario
  - design for electron demonstration model
- do preparation work for Study 3

muon collider

- work on injection/extraction for ring coolers
- produce design for "table top" ring cooler
- use ring coolers in self-consistent front-end design