Neutrino Factory Front End With Cooling Ring

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Introduction

- can we substantially decrease acceleration costs by including a ring cooler in the front end of the neutrino factory?
- are the acceleration cost savings > cost of ring and other additional systems?

The RFOFO ring can achieve

$\varepsilon_{TN} = 2.1$ mm

$\varepsilon_{LN} = 2.5$ mm

Present accelerator acceptance with 200 MHz

$a_{TN} = 30$ mm $\rightarrow$ $\varepsilon_{TN} \approx 7$ mm

$a_{LN} = 150$ mm $\rightarrow$ $\varepsilon_{LN} \approx 35$ mm

- so with ring we could start accelerating at 400 MHz

Front end system considered here

FS2 target
FS2 tapered collection solenoid (truncated)
adiabatic buncher
phase rotation
precooler

Constraints from ring cooler

(1) kicker

preliminary design (the MOAK)

Palmer, Reginato & Summers (MC256)

constraints on front end design

50 ns risetime

maximum injected bunch train

$= 33 - 2x2.75 - (0.9 \times 3\ 10^{8} \times 50\ 10^{-9})$

$= 33 - 19 = 14$ m

9 bunches at 201 MHz

(2) ring acceptance

standard RFOFO design by Palmer et al (MC273)

$\varepsilon_{TN} \approx 12$ mm

$\varepsilon_{LN} \approx 18$ mm

$160 < p < 260$ MeV/c

Problem of the bunch train length

- baseline adiabatic buncher (ADIB) designs produce a long bunch train
  e.g. D. Neuffer (MC269) gives a ~100 m bunch train

- given the ring cooler constraints you can
  (1) redesign the ADIB to give shorter bunch train
  (2) use intermediate bunch compression stage
  (3) use multiturn injection & stacking in the ring
  (4) redesign ring cooler with larger circumference
  (5) ???

Problem of the bunch train length (continued)

(1) Short bunch length ADIB

- cf. my talk at FNAL meeting, August 2003
- must drastically shorten decay region
- time-energy correlation cannot develop properly
- beam bunches, but has large emittance
- best example [C15]

$\varepsilon_{TN} \approx 20$ mm

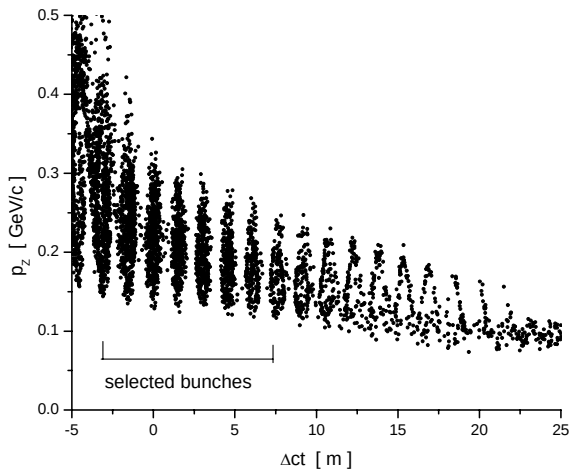
$\varepsilon_{LN} \approx 120$ mm

=> need 6D linear precooler before the ring

x2 transverse

x6 longitudinal

=> extra costs, not useful



Problem of the bunch train length (continued)

(2) Bunch compression

- has to come after the ADIB because you need
  stretched, correlated beam for ADIB to work
- bunch compression ring for muon collider (V. Balbekov MC272)
  - we have 100 m long input beam vs 15 m for collider
  - this ring is more expensive than the cooling ring
    C = 73 m, 36 MHz RF
  - kicker problem just gets moved to this ring
    => not useful
- solenoidal delay line & stacking scheme (Y. Fukui MC209; C. Kim MC070)
  - use time dependent kicker to inject earlier bunches with larger angles
  - particles drift in constant field solenoid
  - compression efficiency is very small
  - long drift without RF destroys bunching
    => not useful

Problem of the bunch train length (continued)

(3) Multiturn injection & stacking

- can conceive schemes to allow stacking
  kickers, septums, modified lattice cells
- only works if 1-turn cooling is significant
- problems
  how to extract cooled beam without destroying small emittance
  empty bunches or need kicker worse than the MOAK

=> not useful

Problem of the bunch train length (continued)

(4) Large circumference RFOFO ring

- redesigned ring with 66 m circumference
- new Maxwellian map from tipped solenoids
- dip angle = 30 mr
- results

  $\varepsilon_{TN} = 2.0$ mm

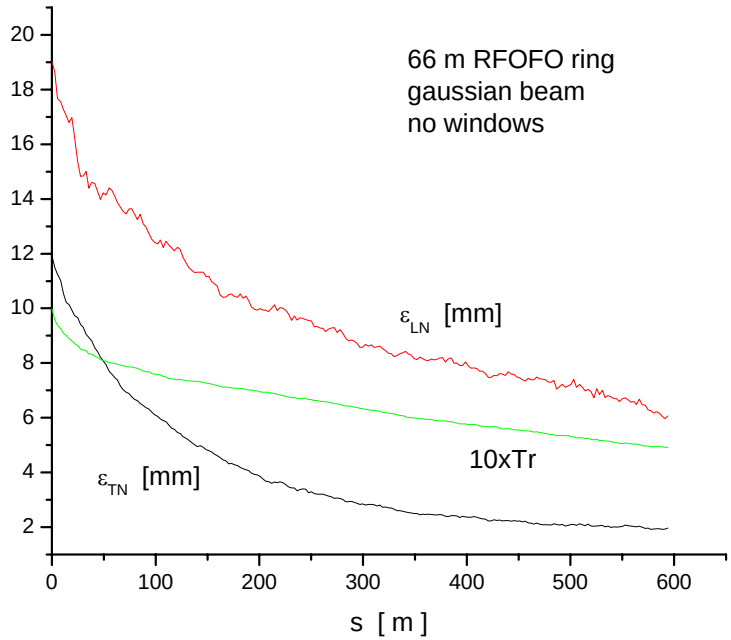
  $\varepsilon_{LN} = 6.1$ mm

  Tr = 0.49

  M = 61
- with the MOAK the ring can accept

  66 – 19 = 47 m long bunch train

  31 bunches at 201 MHz



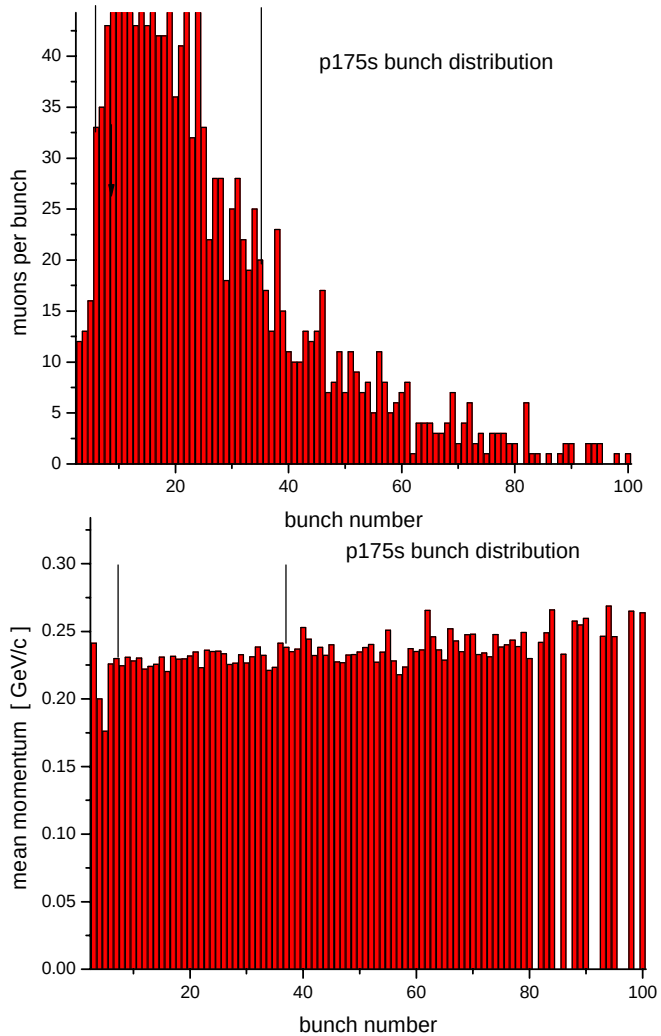
Long bunch train front end scenario

- use version of RBP new baseline NF design
  - 12 m π collection to 1.75 T
  - 99 m decay region
  - 51 m ADIB
  - 54 m phase rotation
  - 3 m match
  - 50 m transverse precooler

- add
  - select best 31 contiguous bunches
  - 5 m match from 0.75 to 2.75 m lattice
  - 66 m RFOFO ring

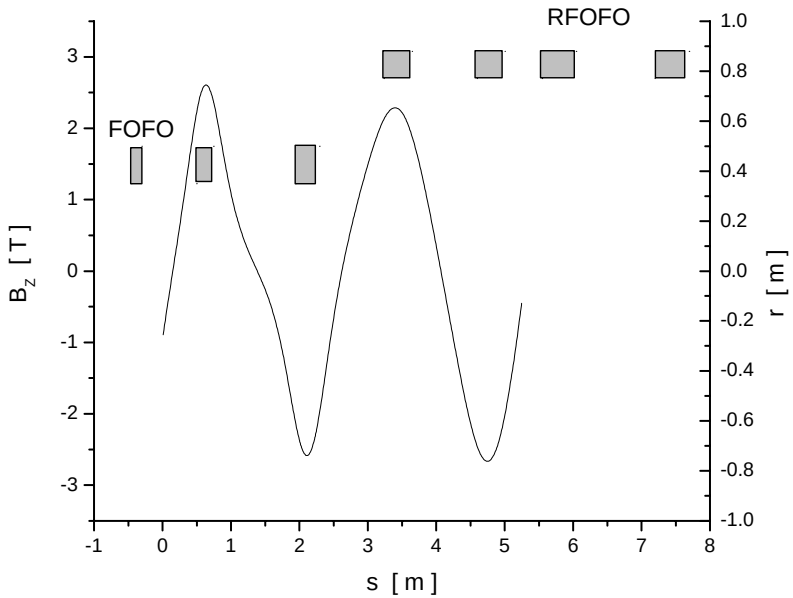
Beam out of precooler

- ~150 m total bunch train length
  $\varepsilon_{TN} = 9.4$ mm
  $\varepsilon_{LN} = 70$ mm
- still have problems !
  ε_{LN} still too large
  lost μs in tails



Matching section

5.25 m long
201 MHz RF, G: 14 → 12 MV/m
2-4 cm thick LiH absorbers
95% transmission



Simulation results

	ε_{TN} [mm]	ε_{LN} [mm]	μ/p	μ/p (200)	μ/p (400)
precool	9.3	74	0.534	0.209	0.069
precool + ring	2.1	7.2	0.135	0.133	0.116
precool + match + ring	2.1	7.4	0.137	0.135	0.120

200 MHz: a_{TN}=30 mm, a_{LN}=150 mm
400 MHz: a_{TN}=15 mm, a_{LN}=75 mm (assume reoptimized)

Conclusions

- all schemes to include cooling ring require additional hardware ($$$)
- best current result is ~0.12 μ/p into optimized 400 MHz acceptance
- but this does not include
  - discretized buncher and rotator frequencies
  - RF windows in the buncher
  - tracking thru injection/extraction lines
  - windows or empty lattice cells in ring
- appears impractical to use a cooling ring for neutrino factory
- this could change if efficient linear 6D precooler is developed