A 3 Pass, Dog-bone Cooling Channel

G H Rees, ASTeC, RAL

Introduction

Studies for the ISS:

1. Proton booster and driver rings for 50 Hz, 4 MW and 10 GeV.

2. Pairs of triangle and bow-tie, 20 (50 GeV) $\mu^{\pm}$ decay rings.

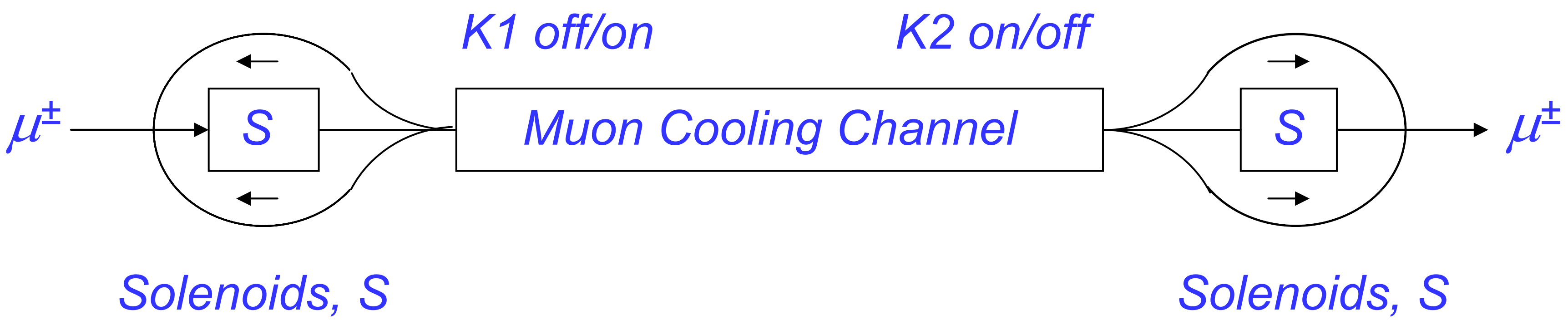
Studies after the ISS:

1. A 3 - 5.45 MeV electron model for the 10 GeV, proton NFFAG.

2. An alternative proton driver using a 50 Hz, 10 GeV, RCS ring.

3. A three pass, $\mu^{\pm}$ cooling, dog-bone re-circulator.

Schematic of Dog-bone Re-circulator



Mode Of Operation

- *Solenoids match the $\mu^{\pm}$ beams between the input and output transport lines and the cooling channel*
- *Additional solenoid matching is needed between the cooling channel and the re-circulator end loops*
- *The kickers contribute to the beam matching and are integral parts of the first (last) lattice cell of the rings*
- *Initially, kicker K1 is off, and it is switched on after a bunch train is in the cooling channel, but before it returns to K1*
- *Kicker K2 is kept on until it is turned off for beam extraction Ring operation is close to but below its transition energy*

Potential Advantages

- *Compatibility with the trains of 80 μ^+ and 80 μ^- bunches*
- *Common, dispersion free, input and output $\mu^\pm$ beam lines*
- *Lower power kickers for field rise and fall times > 300 ns*
- *Single transits of the end loops for three channel passes*
- *Enhanced cooling due to the three (or 5) channel transits*
- *Cooling ahead of entry into the down and upstream loops*
- *Improved μ to ν divergence angle ratio in the decay rings*

End Loop Lattice Requirements

- *Entry and exit ring closure after completion of a 180° bend*
- *Mirror symmetry about the input or the output $\mu^{\pm}$ beam lines*
- *Zero dispersion at entry must transform to zero (D,D') at exit*
- *Equal β_h, β_v values at entry must match to same β at exit*
- *Equal α_h, α_v at entry must change sign, but not value, at exit*
- *Lattice functions must not vary too much around the rings*
- *Optimisation for the design of the K1 and K2 kickers*

Re-circulator End Loop

Bend sequence:

Kicker – 9°

BN – 42°

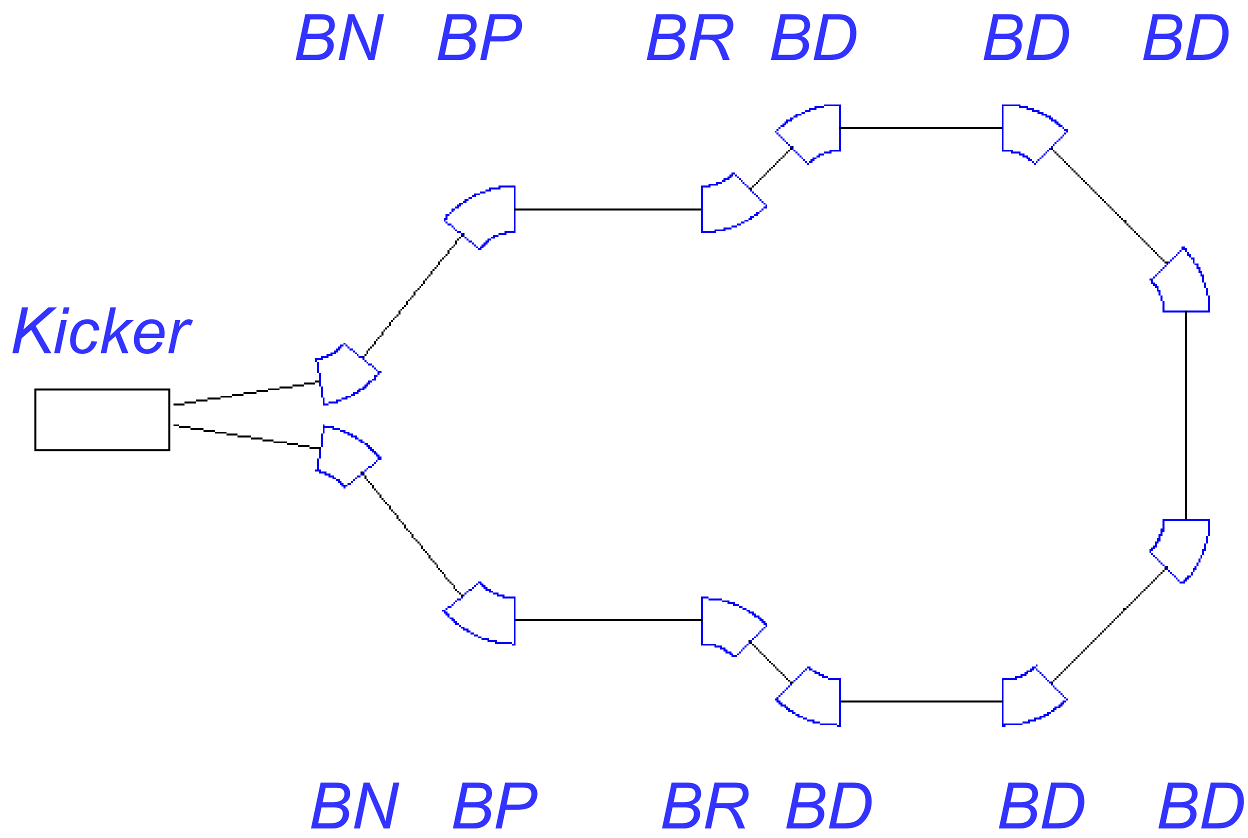
BP + 51°

BR – 45°

BD + 45°

BD + 45°

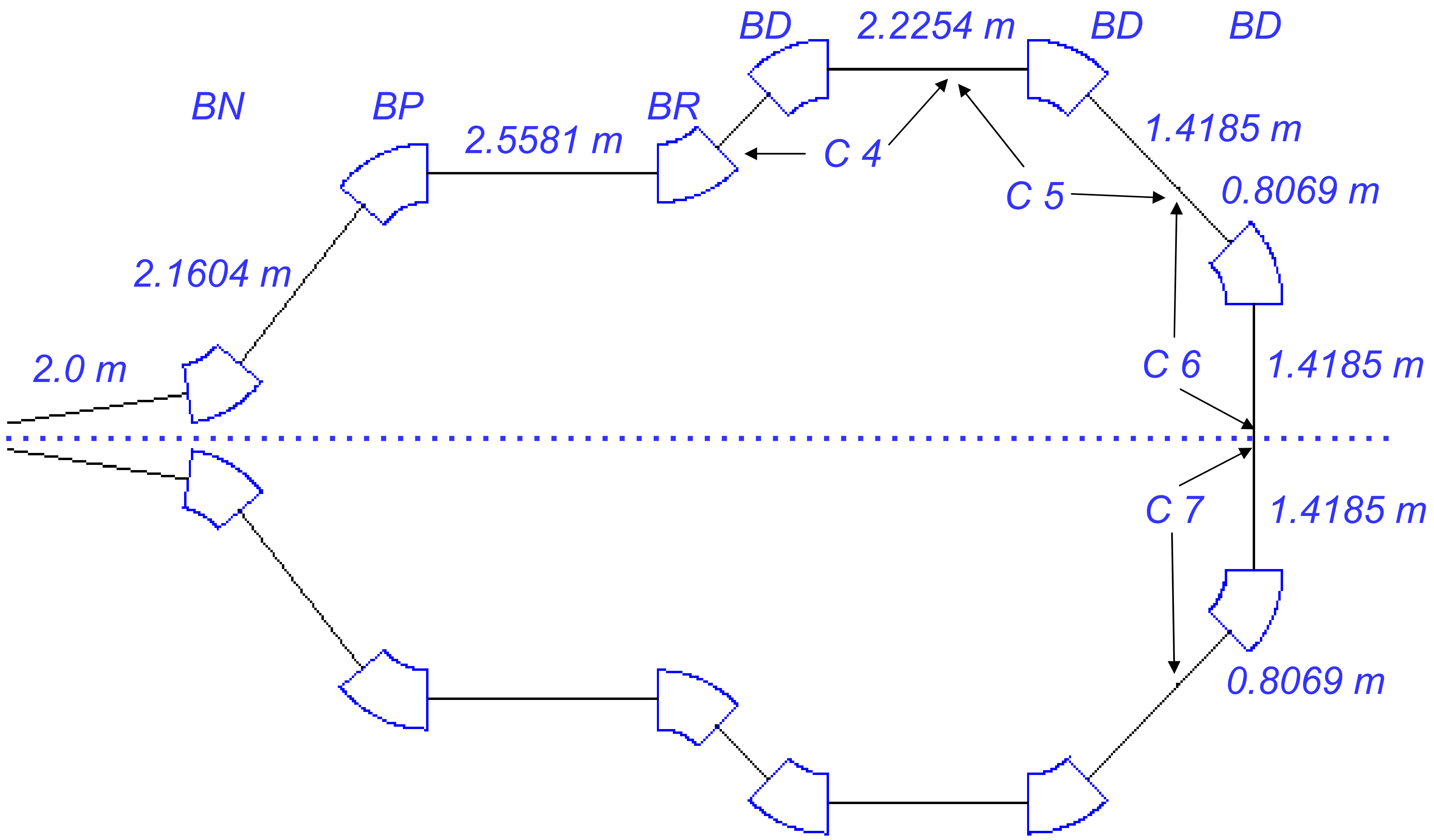
BD + 45°



Mirror symmetry

for return bends

End Loop Geometry



BD (45°, n<1) are asymmetric in the μ = 60°, cells C4, C5, C6.

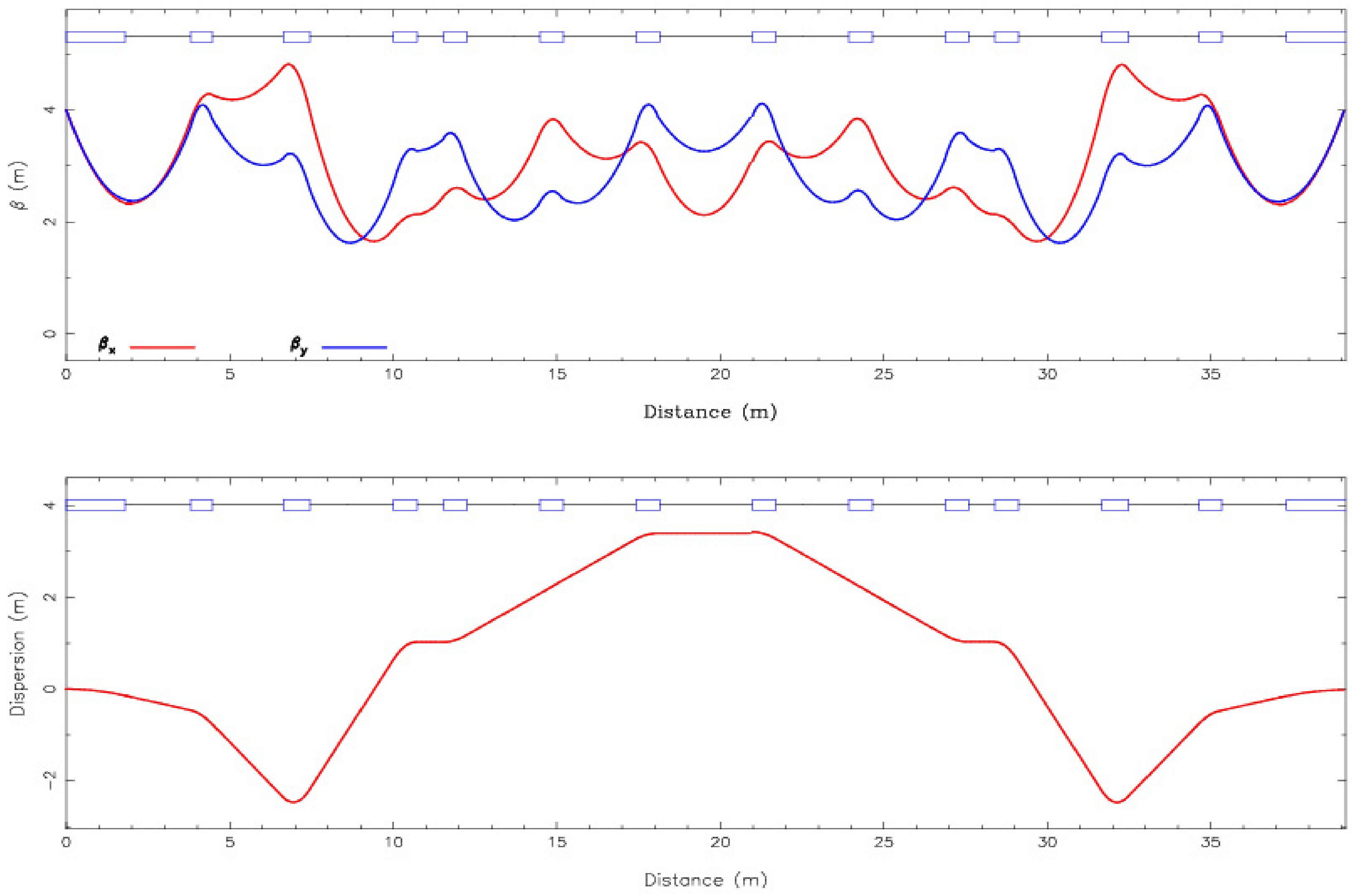
End Loop Matching

- Kicker requirements set inputs at $\beta = 4.0$ m and $\alpha = 0.82$
- BD (and BR) require an $n = 0.5886$ to obtain $\mu = 60°$ cells
- Need $\alpha_v = \alpha_h = D'_h = 0$ at 3-BD π section and half way point
- Variables are n and θ_{bend} of BN, BP, and straights next to BP
- Ring closure and approximate matching sets the θ_{bend} values
- This leaves four parameters to find a three parameter match
- Ring closure is restored via asymmetry of BD cell positions
- Input-output matching obtained but not cell to cell matching

Lattice Parameters

- *Zero dispersion on entry becomes negative after kicker but positive after BR magnet & then continues to increase until half way around the ring, where D = 3.4216 m and D' = 0.*
- *Functions change in a mirror symmetric way on return to the kicker. Due to π phase shift for 3 adjacent BD cells, the point between (– + –) and (+ + +) sections also has D' (and α) zero*
- *Beta functions are matched from input to output but not from cell to cell, due to asymmetric BD cells and other effects. The kicker deflection is over a region of reducing β_h (4.0 to 2.3 m)*
- *The β_v variation over the kicker is similar (4.0 to 2.4 m), and the maximum value of β_v around the ring reaches 4.102 m, while the maximum value for β_h in the ring is 4.757 m.*

Loop Betatron and Dispersion Functions



Magnet Parameters

Magnet	Length (m)	Angle	B_o (T)	n
K1,2	1.800	– 9°	0.07947	0.00000
BN	0.672	+ 42°	0.99334	0.65624
BP	0.816	– 51°	0.99334	0.59333
BR	0.720	– 45°	0.99334	0.58863
BD	0.720	+ 45°	0.99334	0.58863

Isochronous Position

- *For an isochronous point ahead of the end loop, its gamma-t must be < the muon gamma of 2.7705462 (at 273 MeV/c)*
- *The isochronous path length for the gamma-t of 2.621948 is $(2.7705462 / 2.621948)^2$ x 39.125404 m (ring path length)*
- *Thus, the isochronous position ahead of the end loop is at a distance of 2.321435 m from the input end of the kicker*
- *The path length from and back to the point is 43.68592 m while 63 ($\beta\lambda/2$) for the 201.25 MHz cavities is 43.76085 m*

Kicker Magnets

- *Max. normalised input emittances at K1: 45,000 (π) mm mr*
  Max. normalised input emittances at K2: 30,000 (π) mm mr
- *The beam size is reduced for the first K1 pass (when it is off) and this requires an extra pulsing system for the focusing*
- *K1,2 have 9° kick, 435 mm gap, 794.7 G field, 300 ns fall time and 51.9 kV /section for push-pull drives & subdivision in two*
- *Each of eight pulse systems need 428.3 J of energy per pulse, while earlier coolers needed 10,000 J, and typical kickers. 20J*
- *Kicker R and D remains an important issue, because of the required high level of the pulse currents at 27.509 kA*

Future Work

- Chromatic correction for the end loops ($B = B_o\,(r/r_o)^{-n}$?)
- Inclusion of cooling channel in re-circulator (C Rogers)
- Input and output matching for re-circulator (C Rogers)
- Muon tracking studies for the three channel transits
- Determine losses, emittance and momentum acceptance
- Study the possibility of adding an end loop to MICE