Rapid Cycling Acceleration

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Accelerate muons to 750 GeV with one 8 GV Linac

- **Components:**
  Low energy cool muon source.
  One 8 GV Linac.
  One Dogbone.
  One 1000 m radius ring with rapid cycling magnets.
  One 1000 m radius ring with interleaved dipoles
  (Fixed superconducting dipoles and rapid cycling dipoles).
  One collider ring for μ^+ storage, while waiting for μ^- cycle.

RF Frequency Choice: 805 MHz or 1300 MHz

- **Red Flag:** $2\,\mathrm{x}\,10^{12}\,\mu$ extract 8% energy w/1300 MHz cavity.
  Estimate longitudinal wakefields. Ref: V. Yakolev et al.
  $k(||) = [N(\Gamma(1/4)Z_0 c)/(\pi^{5/2}a)]\sqrt{g/\sigma}$ = loss factor
  N = 9 cells/cavity, a = 35 mm, g = 115 mm
  $\Gamma(1/4) = 3.63$, $Z_0 = 377\Omega$, σ = bunch length = 10 mm
  $k(||)$ = 5.1 V/pC/cavity, 2 x $10^{12}\mu$ = 320 nC
  $k(||)$ = 1.6 MV/cavity and a cavity is a meter long...
  This can make the bunch length increase.
- What klystrons are available at 805 MHz? Ask S. Henderson.
  SNS uses 750 kW, 8% duty cycle costing $170k each
  13% more per MW than 10 MW, 1300 MHz ILC klystrons.
  But SNS allows 8% duty factor and ILC only has 2%!
- Work out power needed to run an 8 GV Linac.
  Consider $2\,\mathrm{x}\,10^{12}\mu$ in a 1000 m radius ring.
  160 750 kW klystrons will keep up. Cost: $27M for klystrons.
- Do 8 dogbone passes in the 805 MHz, 8GV Linac.
  Get up to 60 GeV with very high muon survival.
  Count on stored cavity energy for these 8 passes.

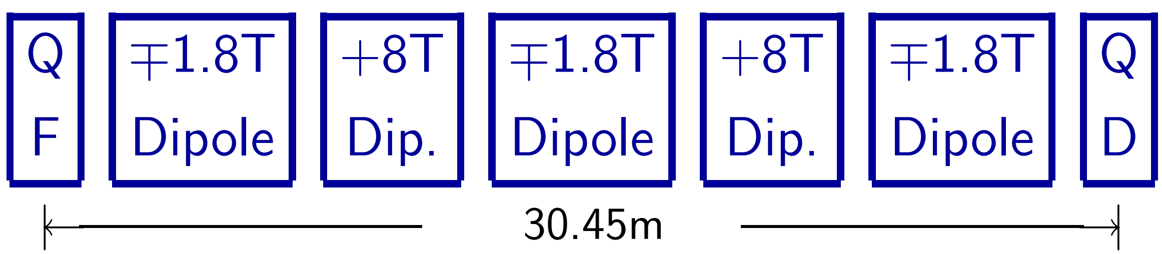
60 to 400 GeV, 260 Hz Synchrotron

- 60 $\rightarrow$ 400 GeV in 43 orbits (0.9 ms)
  8 GV Superconducting RF (805 MHz)
  Muon Survival = 79%   Radius = 1000m

- Duplicate the Fermilab Main Ring FODO Lattice
- 1.7m, 30T/m Quadrupoles, f = 260Hz
- 6.3m, 1.8T Dipoles (8/60.9m cell), f = 260Hz
  Muon transverse emittance = 25 μm, γ(60 GeV) = 570
  h = 6σ = 6 $\sqrt{25\mu\text{m}\ 99\text{m}/(6\pi\beta\gamma)}$ = 4mm
  Beam is small, but need OPTIM to get real magnet gaps.

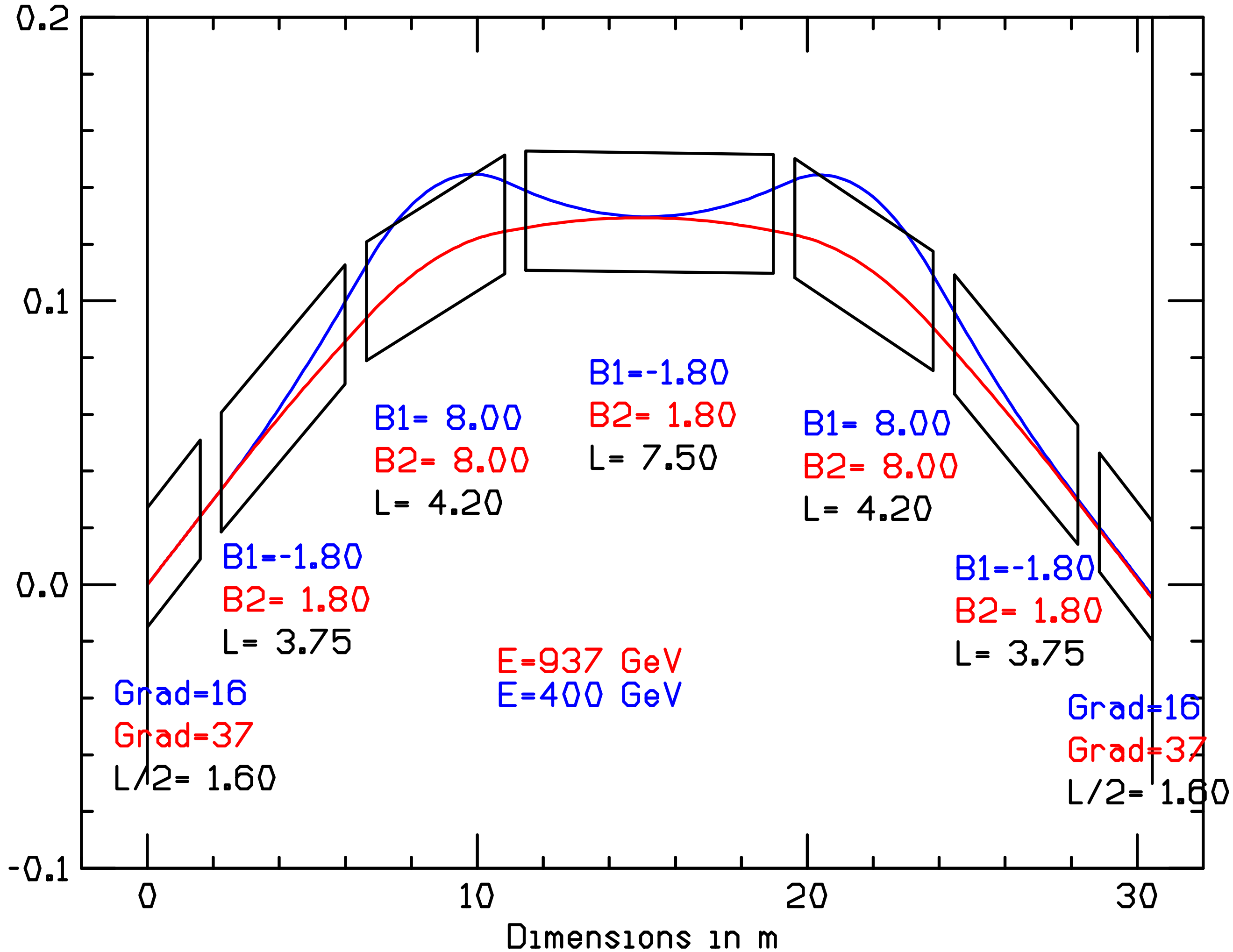
400 to 750 GeV, 550 Hz Hybrid Synchrotron

- 400 $\longrightarrow$ 750 GeV in 44 orbits (0.92 ms) Radius = 1000m
  8 GV, 805 MHz Superconducting RF; Muon Survival = 92%
- Approximate the Fermilab Main Ring FODO Lattice
- 3.2m, 30T/m Quadrupoles, f = 150Hz
- 4.2m, 8T Fixed Superconducting Dipoles
- 3.75/7.5/3.75m, -1.8 $\longrightarrow$ +1.8T Dipoles, f = 550Hz
  5mm$\times$50mm$\times$8.2m bore, N=2; $I = B\,h/\mu_0 N$ = 3600A
  W = $\int \frac{B^2}{2\mu_0} d\tau = .5\,LI^2 = .5\,CV^2$, $f = 1/2\pi\sqrt{LC}$; V = 4700V
  Core Loss (B@1.6T) = $4.38 \times 10^{-4} f^{1.67} B^{1.87}$ = 40 W/kg
  780 Tons @ 13Hz Duty Cycle $\longrightarrow$ 1200kW/ring



- Dipoles oppose, then act in unison
- 1/40000 Path Length Difference during an acceleration cycle
  Adjust radius; 1000 $\longrightarrow$ 1000.025 m

Particle Paths in a 400 to 750 GeV Hybrid Half Cell



- **Dipoles oppose at injection, then act in unison at extraction. Edge focusing changes during the cycle. Can quads correct? Try to simulate focusing with OPTIM.**

Grain Oriented 3% Silicon Steel EI Transformer Laminations

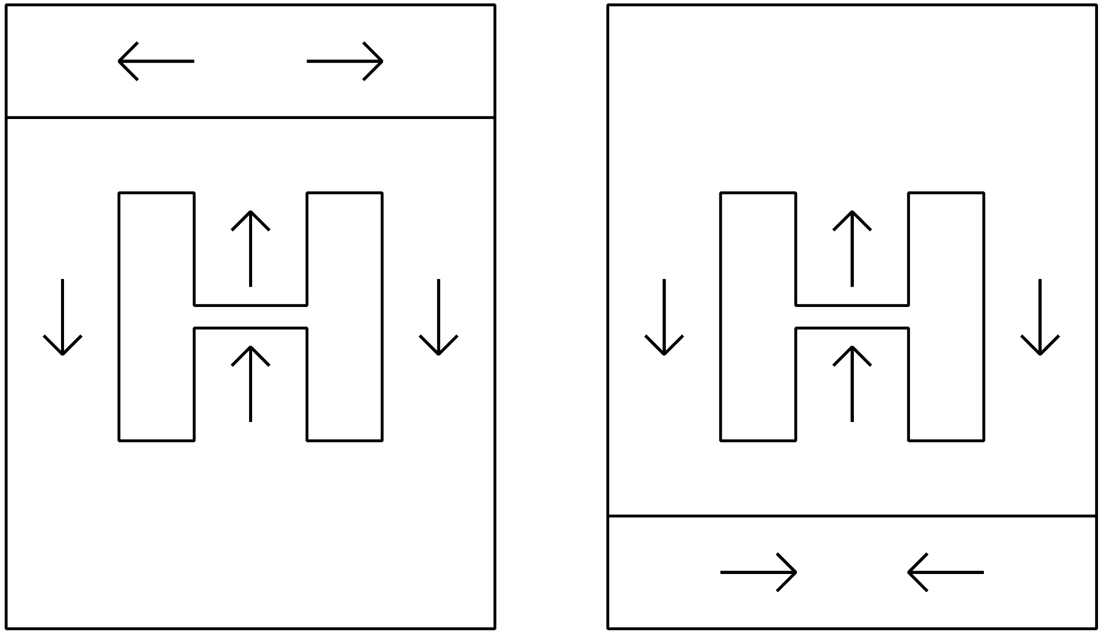


Table 1: Resistivity (ρ), coercivity (H_c), and permeability (μ) of steels. Higher resistivity lowers eddy current losses. Low coercivity minimizes hysteresis losses. Grain oriented 3% silicon steel has a far higher permeability parallel ($\|$) to than perpendicular ($\perp$) to its rolling direction and permits minimal energy ($B^2/2\mu$) storage, as compared to low carbon steel at 1.8 T.

Steel	ρ(nΩ-m)	H_c(A/m)	μ(1.0 T)	μ(1.5 T)	μ(1.8 T)
.0025% Carbon	100	80	$4400\mu_0$	$1700\mu_0$	$240\mu_0$
Oriented ($\|$) Si	470	8	$40000\mu_0$	$30000\mu_0$	$3000\mu_0$
Oriented ($\perp$) Si	470		$4000\mu_0$	$1000\mu_0$	

RF is not Dispersed! Requires separate μ^+ and μ^- cycles.

- Store μ^+ in collider for 2 ms. Magnets reset. μ^- accelerate.
  At 750 GeV, one gets 88% μ^+ survival in 2 ms.
  Thanks to Dan Kaplan for this suggestion.

- At 13 Hz, the RF duty cycle is 5%
  750 kW, 805 MHz klystrons at SNS allow 8% duty factor.

- Acceleration with one 8GV, 805 MHz Linac looks interesting.

- Feature of separate μ^+ and μ^- acceleration cycles.
  50% muons $\longrightarrow$ muon collider.
  50% muons $\longrightarrow$ neutrino beams, rare decay experiments...