Thoughts on Acceleration for a Muon Collider

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Muon Collider vs. Neutrino Factory

- Muon collider has only a single bunch
- Transverse acceptance
  - Neutrino factory: 30000 μm
  - Muon collider: 50 μm
- Longitudinal
  - Neutrino factory: 150 mm *acceptance*
  - Muon collider: 68 mm *emittance*
    - For comparison: 150 mm acceptance would be 1.5σ with this emittance
- The difficulty is clearly going to be the longitudinal emittance

Emittance vs. Acceptance

- What matters to first order for neutrino factories is acceptance
  - The size (in phase space) of the hole that the beam needs to fit into
  - Any distortion to the ellipse gets clipped (square peg/round hole)
  - Square of radius in phase space gets third-order correction from nonlinearities
- What matters for muon colliders is emittance
  - Computed from second order moments
  - Third order moments don't affect emittance
  - Fourth order moments give lowest order correction from nonlinearities
  - If get too close to dynamic aperture (bucket edge): blow up emittance significantly
- Small emittance growth easier than small acceptance growth, but for given emittance, muon colliders require larger acceptance

Types of Acceleration

- Recirculating Linear Accelerators (RLAs)
- Fixed Field Alternating Gradient (FFAG) Accelerators
- Fast Ramping Synchrotrons

Recirculating Linear Accelerators (RLAs)

- Essentially arbitrarily large longitudinal acceptance
  - Lots of RF available
  - Going off-crest increases bucket height significantly while affecting acceleration little
- Each arc designed separately: get cavity phases right
- Switchyard is the problem
  - Lots of beamlines, but small aperture
  - Small energy spreads and beams may make easier

Fixed Field Alternating Gradient (FFAG) Accelerators

- Get less expensive per unit acceleration at higher energy
- At higher energy, can shift cavity frequency (piezo,. . .)
  - Instead of fancy "gutter acceleration," have something more like standard synchrotron oscillation
  - Longitudinal acceptance ceases to be a problem
- At lower energies, worry about acceptance
  - May be forced to lower frequencies than other designs
- Large aperture beamlines
- Limited energy range: many stages
- Small emittance: nonlinear magnets?

Fast Ramping Synchrotrons

- Stored energy, length L of magnets with field B and aperture a: $\dfrac{B^2 L\pi a^2}{2\mu_0}$
- Revolution time, average gradient G: $\dfrac{\Delta E}{qGc}$
- Relate dipole length L to field: $L = \dfrac{2\pi(pc/q)}{Bc}$
- Peak power ($\Delta E \sim pc$): $\dfrac{\pi^2 B a^2 G}{\mu_0}$
  - Should add factor of 2 for other magnets
  - Independent of energy!
  - Magnet aperture is critical
  - 1 cm aperture, 1 T field, 6 MV/m gradient, result is 4.7 GW

Fast Ramping Synchrotrons (cont.)

- Aperture increases at lower energy, power requirement increases
- Acceleration time
  - For 1 TeV, about 0.5 ms total cycle time
    - Long time to hold the peak power
  - Note at 1 T, just the bends give a period of 0.07 ms.
    - Multiply by 4 at least: only a couple turns!
    - Can go to higher fields, but more peak power, still few turns
- With all this RF, can make bucket arbitrarily large
- RF phasing a non-issue at high energy

Low Energy

- Longitudinal acceptance is a significant issue at low energy
- Linac acceptance: 150 mm is already pushing it at 200 MHz
  - Need closer to 1 m for collider
  - Probably can't even accelerate required acceptance in cooling lattice at 200 MHz
  - Lower frequencies required
- FFAGs also have acceptance problem
  - Probably can't start FFAGs until higher energy (10 GeV?)
- Working on computing the correct relationship between FFAG parameters and emittance transmitted