Status of Muon Acceleration

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18 October 2001
Outline

- Study II acceleration studies
- Future R&D
  - Dynamics studies of conventional scheme
  - Hardware issues
  - Dogbone geometry
  - FFAG Schemes
Study II Acceleration Studies

- Work primarily performed by V. Lebedev and A. Bogacz at Jefferson Lab (and Fermilab)
- Described scheme to accelerate from 129 MeV (KE) to 20 GeV.
  - Linac to 2.48 GeV
  - Single 4-pass recirculating accelerator to 20 GeV
- Compared to Study I
  - Less energy gain in linac
  - Lower final energy (20 vs. 50 GeV), one RLA
  - Cost reduction
E = 129 MeV

Preaccelerator
linac

2.87 GeV

2.48 GeV

4 pass recirculator

2.31 GeV

2.31 GeV

20 GeV
Study II: Linac

- Matching section from cooling to accelerating linac
  - Adiabatically converts beta functions from cooling values to acceleration values
  - Partially accelerates
- Linac cryostats: three types
  - Initially large beam size: need short focal length
  - Gain real-estate gradient by having fewer solenoids later
    - Additional space also needed for shielding
    - Long gap between cavities to decouple
  - Reduce aperture later on
    - Higher gradient
    - Shorter distance to decouple
  - Real-estate gradients: 4.47, 5.59, 7.79 MV/m
- Limited to two-cell cavities: power into coupler, mechanical
Study II: Recirculating Accelerator

- Four passes
  - Switchyard limits
- Triplet focusing: reduces envelope (beta function) chromaticity
- Linac cryomodules like long cryomodules from initial linac
- Input full energy width $\pm 7.5\%$, output $\pm 1.6\%$
- Preliminary arc design
  - Factor of 2 transverse emittance blowup
  - Output acceptance is $30\pi \text{ mm}$
- Beam loading has only minor effect
R&D: Dynamics Studies

- Full nonlinear study
  - Magnets are relatively short, large aperture: substantial end effects
  - Study with full nonlinearities
    - Fringe fields
    - Sextupoles
  - Substantial emittance growth
    - Understand
    - Cure
- More detailed studies of bunches with beam loading
- Improving longitudinal dynamics: further reduction in output energy spread?
R&D: Hardware

- Magnets: short, large aperture
  - Fringe fields
    - Determine for given design
    - Correct with pole tip, etc.
  - Need to keep cost down: many arcs

- Switchyard
  - Ensure that optics and floor layout are consistent for large momentum spread beam
R&D: Dogbone Geometry

- Geometry allows tradeoff between arc and linac costs
  - Same number of linac passes, half as much linac
  - Same amount of linac, about half as much arc
  - In reality, something in-between
- Switchyard easier
- Fewer decays
- Cost optimization/comparison graph
- Increased costs
  - Tunneling
  - Beamline crossings
Costs for Different Geometries

- **Dogbone Total**
- **Racetrack Total**

Costs as a function of Linac Passes.
R&D: FFAG Recirculating Accelerators

- Replace multiple arcs with single arc having large energy acceptance
- Hope for cost reduction
  - More turns, less linac required
  - Single arc less costly than multiple arcs
  - Some aspects more costly
    - Wide energy acceptance arc more expensive than small acceptance
    - Multiple arc accelerator can cover larger energy range than single arc
- Switchyard eliminated
- Dynamic aperture
  - Recent progress encouraging (C. Johnstone)
FFAG Recirculating Accelerators (cont.)

- Path length variation with energy
  - FFAG arc has significant variation in path length with energy
  - Unable to make bunch return to same RF phase at all energies
  - Cannot shift phase of RF quickly enough at low energies
    ★ To push power in requires $Q$ too low: high power requirements
    ★ Ferrite shifters most likely reduce $Q$ too much also
  - Requires isochronous-type operation
  - Quadratic variation of path length with energy
    ★ May be more complicated when nonlinearity considered
Path length problem not as bad as expected
  • For a given range of path length, expect maximum number of turns before phase slips too far
  • If choose parameters correctly, arbitrary number of turns
    ★ Crosses crest three times
    ★ Must choose initial phase and reference path length correctly
    ★ More turns, initial phase further off-crest
    ★ Linac length limits to nonzero value for large number of turns
    ★ Acceptance not addressed

Alternate method: phase each cavity separately (Koscielniak)
  ★ Energy gain on each pass same
  ★ Approx 30% excess voltage required
  ★ 5 turns at 200 MHz gives very large acceptance (1 eV-s)
  ★ Adding harmonics improves more
RF Phase Evolution
3.1-7.9 GeV, 15 Half-turns, 30 cm Path Error
Optimized FFAG Isochronous Acceleration
3.1-7.9 GeV, 30 cm Path Error
Input Bunch Distribution
Koscielniak FFAG Phase Scheme

![Graph showing the Input Bunch Distribution for Koscielniak FFAG Phase Scheme](image-url)
RF phasing methods

- Can allow non-isochronous operation
  - Better for beam loading
  - Smaller energy spread
  - Requires relative frequency shift of $10^{-3}$ to $10^{-2}$

Storage cavity methods

- Store energy in high-$Q$ cavity: low peak power
- Rapidly transfer to low-$Q$ cavity, only there when beam present
- Shift frequency in low-$Q$ cavity

Ferrite/PIN diode methods

- Tend to lower $Q$ significantly
- Placement and material choice may improve