# Overview of Muon Collider Acceleration Scenarios

J. Scott Berg
Brookhaven National Laboratory
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# Acceleration Design Issues

- Efficiency = cost
  - Hardware efficiency
  - Power efficiency
- Collective effects
  - Large bunch charge
  - Beam loading of fundamental mode
  - Beam stability

# Hardware Efficiency

- Don't want to pay for 750 GeV of linac to accelerate to 750 GeV
- Maximize passes through RF systems
  - Cost inversely proportional to turns?
- Without paying too much for the bendy bits. . .
  - Could be proportional to turns (RLA)
  - Could be flat cost (synchrotron)

# Power Efficiency

- Between 7 (high current) and 16 MW (low current) of muon beam power
- 50% plug to microwave, 50% fill loss: 28–64 MW
- Efficiency:

$$\frac{\text{Energy Delivered to Beam}}{\text{RF Energy Delivered to Cavity}}$$

- If efficiency low, power requirements could be really high. . .

# Power Efficiency

- Efficiency depends on product of
  - Fractional energy extraction per bunch (train)
  - Number of turns
- Fractional energy extraction
  - Larger at higher frequency
  - Larger with higher bunch (train) charge
  - Beam loading is *good*
- Product ideally about 4 (≈24 turns for high charge, 1.3 GHz)

# Collective Effects

- Beam loading, high charge case: about 8.3% energy extraction per bunch passage for 1.3 GHz
- Additional wake effects (HOMs and propagating modes) give significant additional contribution
- To mitigate effect
  - Lower frequency RF (power efficiency loss!)
  - Strong synchrotron oscillations
  - Few turns

# Collective Effects
# Strong Synchrotron Oscillations

- Few ways of viewing the problem
- Linac and arc act like a ring (short range wake)
  - Linac impedance not bad for one turn?
  - Requires RF be distributed around ring
- Mode coupling viewpoint: higher synchrotron tune separates modes more

# RF Input Couplers

- Must replace extracted energy from cavities
- High train charge: significant extracted energy
- Minimize decays: short circumference
- Power through input coupler limited (500–1000 kW?)
- Push toward fewer RF cells per cavity

# Proposed Solutions: High Energy

- RLA based solution
- Fast ramping synchrotron
- More detailed talks to follow
- Brief, probably biased, outline here
- Other possibilities, but even less studied. . .

# RLA Solution

- RLA most straightforward
  - Re-use linac
    - But only small number of passes: switchyard
  - Arcs return beam to linac for each individual energy
- Some ideas to get more passes

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# RLA Solution
# More Passes

- Ramp magnets in linac
  - Ramping rate is large, but
  - Beam centered in magnets: small aperture
- Use FFAG-like arcs
  - Two passes per arc
  - Arcs now have larger aperture, more cost
  - Matching into linac
- Still small number of passes, but improved

# Fast Ramping Synchrotron

- Allows arbitrary number of passes
- Magnets ramped extremely rapidly
  - Power supplies become costly
  - Also in RLA solution, but not nearly as much
- Keep power down: small apertures
- Keep average bend field high (efficiency)
  - Ramping magnets have low field limit
  - Hybrid lattice with SC magnets

# Fast Ramping Hybrid Synchrotron

- SC magnets fixed, others ramped
- Beam not centered in magnet
- Ensure beam remains synchronized to RF
- Optimization problem
  - Vary quad and ramped dipole fields
    - Potentially different patterns
  - Keep time of flight and tunes fixed
  - Minimize horizontal position variation

# Fast Ramping Hybrid Synchrotron

- Consider design choices for lattice
- Optimal way to arrange lattice cell
  - E.g., where to place fixed and ramping magnets
- How to include RF
  - Space in every cell
  - Separate RF straights

# Fast Ramping Synchrotron Impedances

- Iron magnets behind ceramic vacuum chambers
- Similar to a kicker
- Kickers have *large* highly resistive low-frequency impedance
  - Normally a significant contribution to impedance
- We're proposing to make an entire ring out of them. . .

# Lower Energy Acceleration

- RLAs are the no-brainer
  - But have the aforementioned efficiency concerns
- Non-scaling FFAGs will get many turns
  - Small transverse emittance eliminates main challenge
  - Lack synchrotron oscillations

# My Opinions
# Overall Plan and Preferences

- Synchrotrons from lowest workable energy
  - Good hardware and power efficiency
  - Strong synchrotron oscillations
- Challenges to face
  - Do the fast ramped magnets work?
  - Does ramped magnet system cost outweigh the benefit?
  - Is the magnet impedance unmanageably large?

# My Opinions
# Overall Plan and Preferences

- Non-scaling FFAGs at lower energy
  - Will get many turns
  - More efficient as energy rises
  - Smaller transverse beam size: more efficient
- Challenges to face
  - Injection and extraction are difficult
  - Easier than neutrino factory: smaller beam
  - No synchrotron oscillations

# My Opinions
# Overall Plan and Preferences

- RLAs can be anywhere in system
- Generally less efficient than above options
- Fewer technological questions
  - But tricks to gain more efficiency introduce these challenges

# R&D Priorities
# RLA

- Put together complete system (ramped magnets, FFAG arcs, etc.)
- Convince ourselves that this works

# R&D Priorities
# Ramping Synchrotron

- Do system tests on magnets
  - Can we program magnet field as desired?
- Understand magnet costs
  - Including power supply costs!
- Compute impedance for magnet/chamber system
- Do detailed lattice design studies
- Injection and extraction

# R&D Priorities
# Collective Effects

- Study collective dynamics with high impedance and rapid acceleration
- Assess importance/benefit of synchrotron oscillations
- Evaluation of impedance sources
  - Cavities
  - Ramping magnets
  - Other important sources?