# Acceleration Concept Specifications

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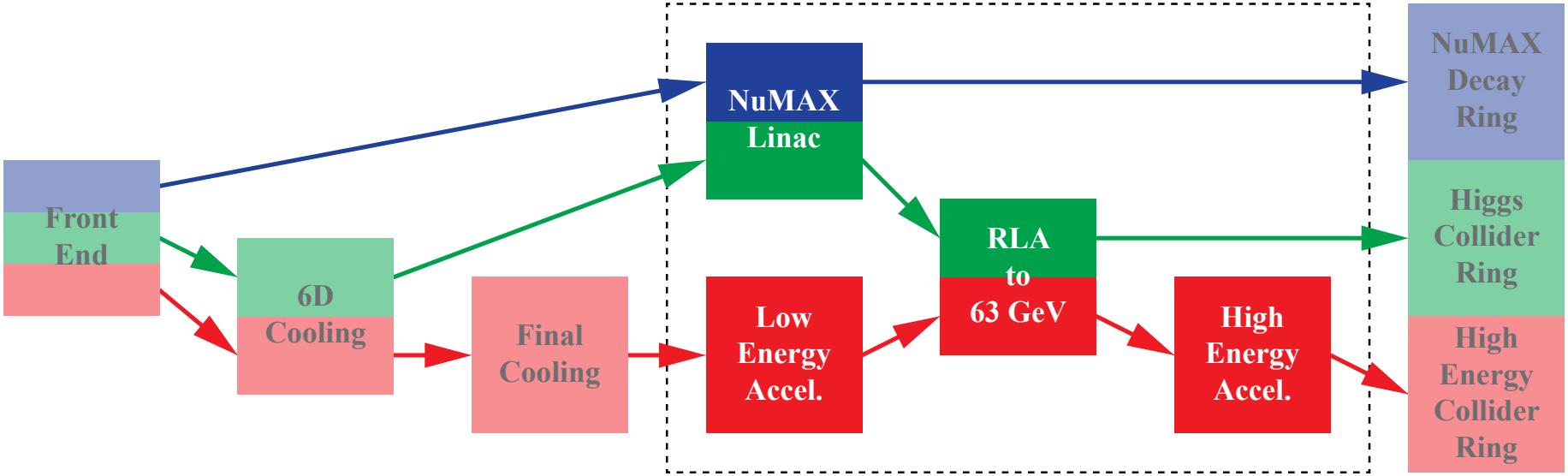
# Muon Accelerators



# Muon Acceleration

- Three classes of machines
  - NuMAX: neutrino factory to 5 GeV
  - Higgs factory: 63 GeV collider
  - High energy colliders: 1.5, 3, ≈6 TeV, and higher CoM
- Four acceleration subsystems
  - Linacs for NuMAX
  - RLA to reach 63 GeV
  - Low energy acceleration for colliders
  - High energy acceleration beyond 63 GeV: pulsed synchrotrons
- Some acceleration subsystems can be reused for different machines

# Factors Governing Design Choices



- Sufficient longitudinal (and sometimes transverse) acceptance
- High average gradient to limit decays
- Limiting emittance growth
- Reducing impact of collective effects
- Cost control

| | NuMAX | Higgs | 1.5 TeV | 3 TeV | ≈6 TeV |
|---|---|---|---|---|---|
| $E_{\text{max}}$ (GeV) | 5 | 63 | 750 | 1500 | ≈3000 |
| $\epsilon_{\perp}$ ($\mu$m) | 2600 | 200–400 | 25 | 25 | 25 |
| $\epsilon_{\parallel}$ (mm) | 24 | 1.0–1.5 | 70 | 70 | 70 |

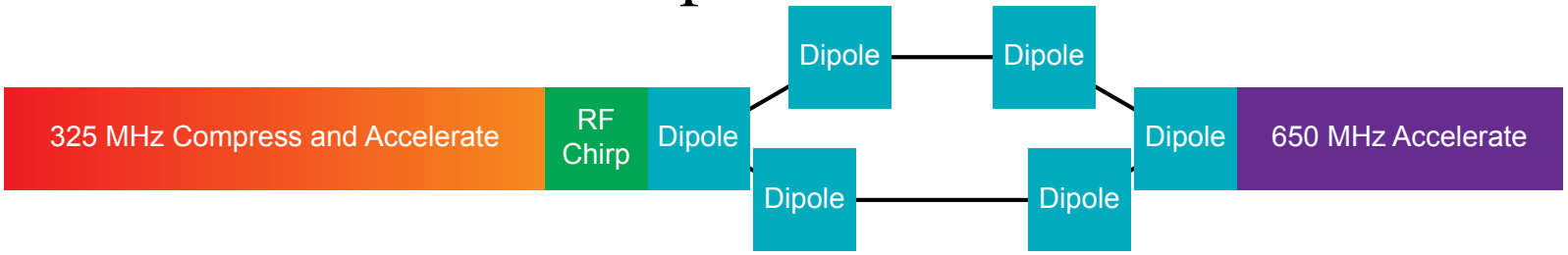
# SRF Parameters



| Frequency (MHz) | 325 | 650 | 975 | 1300 |
|---|---|---|---|---|
| Gradient (MV/m) | 20 | 25 | 30 | 35 |
| Cells per cavity | 4 | 5 | 7 | 9 |
| Input power per cavity | | 1.2 | | |

# NuMAX Linac

- Accelerates muons from front end to 5 GeV
  - Assumes some 6-D cooling of both signs
- 325 MHz SRF linac for initial muon acceleration
  - Large longitudinal and transverse acceptance
- 650 MHz SRF linac to final energy (5 GeV)
  - Shared with $H^-$ beam
- Double chicane between these linacs
  - One charge delayed going from 325 to 650 MHz (bunch train)
  - Additional bunch compression



# NuMAX Linac: Issues

- Linac designed based solely on muons
- Compatibility with $H^-$
  - $H^-$ stripping (unusually strong focusing)
    - Intrabeam scattering
    - Lorentz stripping: magnets and RF
  - Power requirements due to differing pulse/current structures (RF session later today)
  - Other $H^-$ compatibility issues (later this session)
- Energy deposition—discussed in review
  - Magnitude and localization
  - Cavities (SC!) can't be shielded!
  - Problem everywhere, not just NuMAX linac
  - Plan to address in 325 MHz initial linac

# NuMAX Linac: Issues

- Replace initial cooling with warm acceleration???

# RLA to 63 GeV

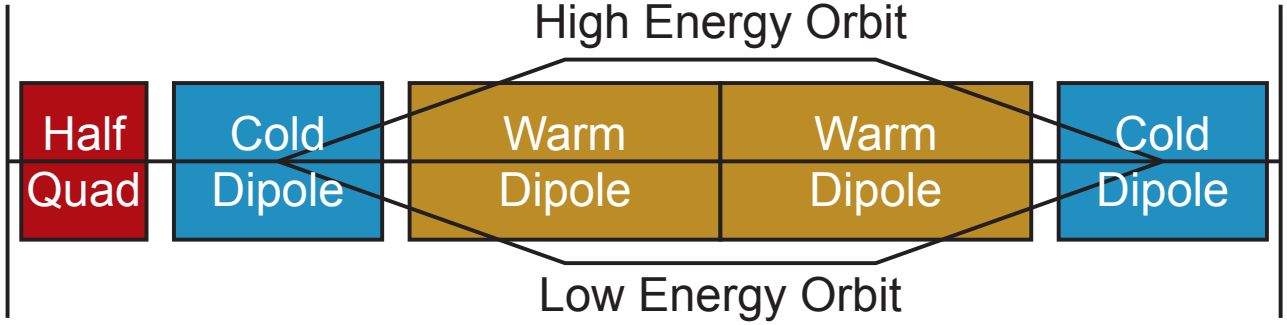
- Dogbone RLA accelerating to 63 GeV
- Compatible with both Higgs factory and high energy collider beams
  - Must accept 70 mm longitudinal emittance of high energy colliders
  - 5 GeV injection for Higgs beam (from NuMAX), may be higher for high energy collider beam
- Beam loading limits passes
  - $2 \times 10^{12}$ muons per sign
  - No time to top off RF
  - 9 linac passes for 325 MHz
  - 3 linac passes for 650 MHz

# RLA to 63 GeV

- Next step is to choose frequency
  - Look approximately cost-neutral
  - Much easier switchyard for 650 MHz
  - Concern with longitudinal acceptance for 650 MHz solution, checking

# Pulsed Synchrotrons

- Acceleration to 750 GeV, 1.5 TeV, ≈3 TeV
  - Highest energy chosen to fit on Fermilab site
- Average acceleration rate at least 3.5 MeV/m
  - Keep decays to required level
- Pulsed dipole field limited to 1.5 T
- Two types: ordinary and hybrid
  - Ordinary: fields (almost) proportional to momentum
  - Hybrid: interleave 10 T fixed dipoles with bipolar pulsed dipoles



# Pulsed Synchrotrons: Configuration

- Accepts beam from 63 GeV RLA
- Two stages to get to 750 GeV
  - One ordinary, one hybrid
  - Share tunnel
- Hybrid ring reaching 1.5 TeV
- Hybrid ring reaching maximum energy fitting on Fermilab site
  - Some sacrifice on decays to get to highest energy

| Output energy (GeV) | ≈375 | 750 | 1500 | ≈3000 |
|---|---|---|---|---|
| Type | Ordinary | Hybrid | Hybrid | Hybrid |

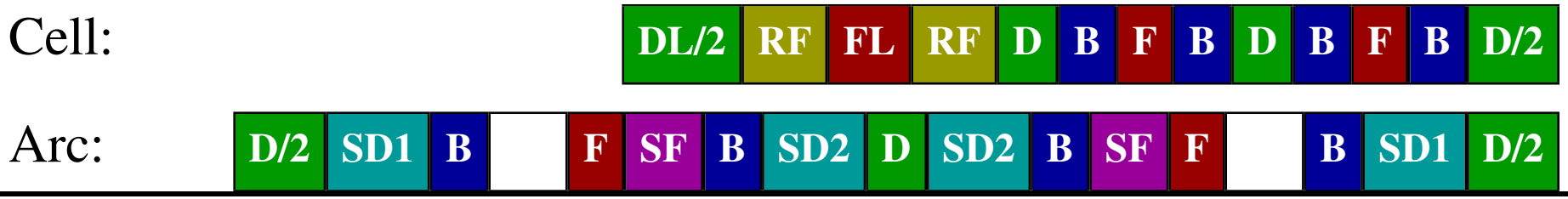
# Pulsed Synchroton: Lattice Design



- Interleaved arc cells and linacs
- Maintain constant tune through acceleration
- Zero dispersion in linacs
- Correct global chromaticity (collective effects)
- Maintain high synchrotron tune (collective effects)
- Reduce beam excursion
- Have sufficient longitudinal acceptance
- Have sufficient accelerating gradient
  - Energy is discrete, magnet fields are continuous
  - Matches, tunes, etc. will not be exact
  - Want as many acceleration steps as is reasonable
  - Compact arc cells

# Pulsed Synchrotron: Arc Cell

- Unit cell with arc and linac
- Minimum amount of bend per cell to create
  - First-order achromat
  - Cancellation of sextupole geometric nonlinearities
- Arc is $2\pi$ achromat with four $\pi/2$ FODO cells
  - D quads on ends to minimize horizontal orbit excursion
  - 3 sextuple families to correct
    - Chromaticity for full cell
    - Second-order dispersion
- Linac has 3 internal quads, different from arc quads
  - Permits variation of cell tune



# Low Energy Acceleration

- Accelerate from final cooling (very low energy) to ≈ GeV
- Initially use RF systems and lattices that are similar to those in final cooling, but in reverse
  - Large longitudinal emittances
- Switch to superconducting RF at higher energy
  - May go straight into an RLA for larger longitudinal acceptance
- Inject into RLA from Higgs factory
- Probably can't use NuMAX linac (longitudinal acceptance)
- Won't start designs until final cooling defined

# Status Summary

| | |
|---|---|
| NuMAX linac | 325 MHz done. 650 MHz needs matches and phasing. Chicane parameters to be finalized. |
| RLA to 63 GeV | Next: choose 325 or 650 MHz based on longitudinal dynamics |
| Pulsed synchrotron | Next: choosing lattice parameters |
| Low energy | Awaiting final cooling |

# Remainder of Meeting

- Details of NuMAX design
- Discussion: compatibility of muon design of NuMAX linac with $H^-$ beam
- Discussion: plan to look at energy deposition
- Joint RF session
  - Superconducting RF status
  - Discussion: RF power for both muon beam and $H^-$ beam
- Joint magnet session: pulsed dipoles