An FFAG as a Final Acceleration Stage for a 10 GeV Neutrino Factory

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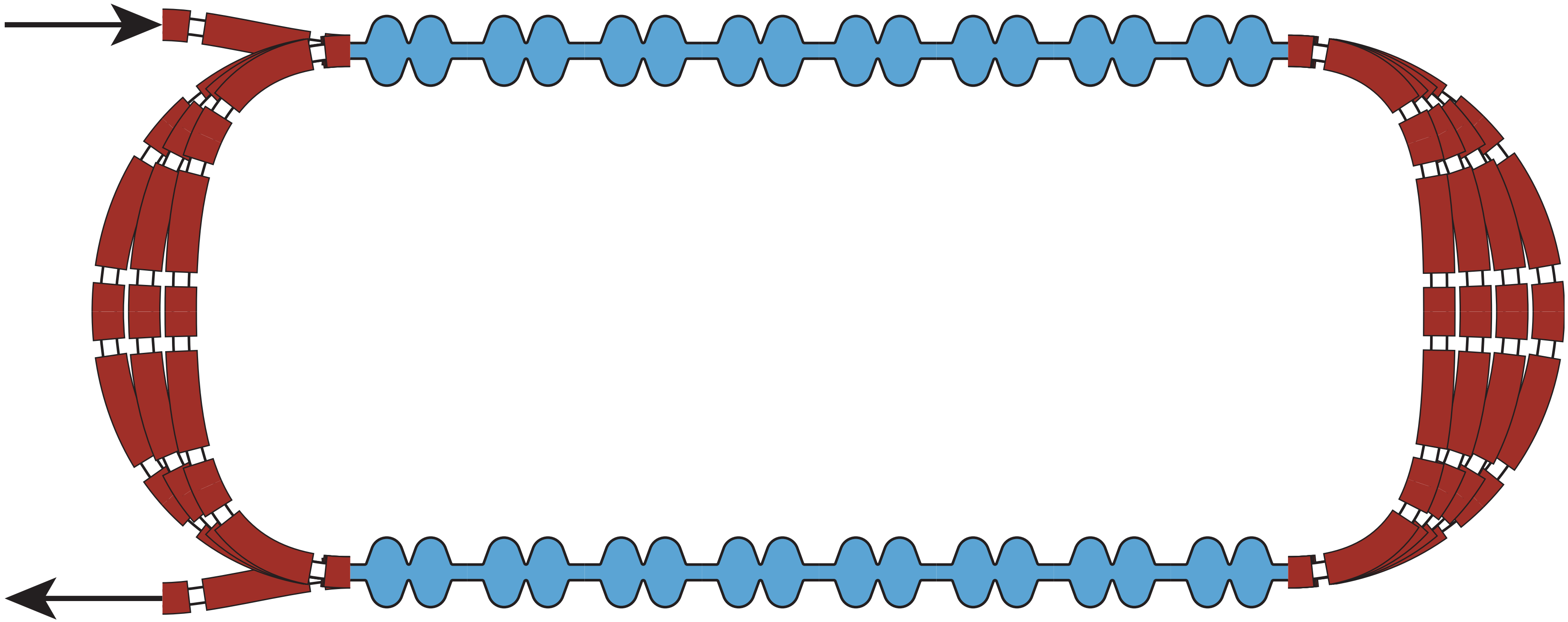
Outline

- FFAG motivation
- 10 GeV FFAG design
- Cost comparison of scenarios

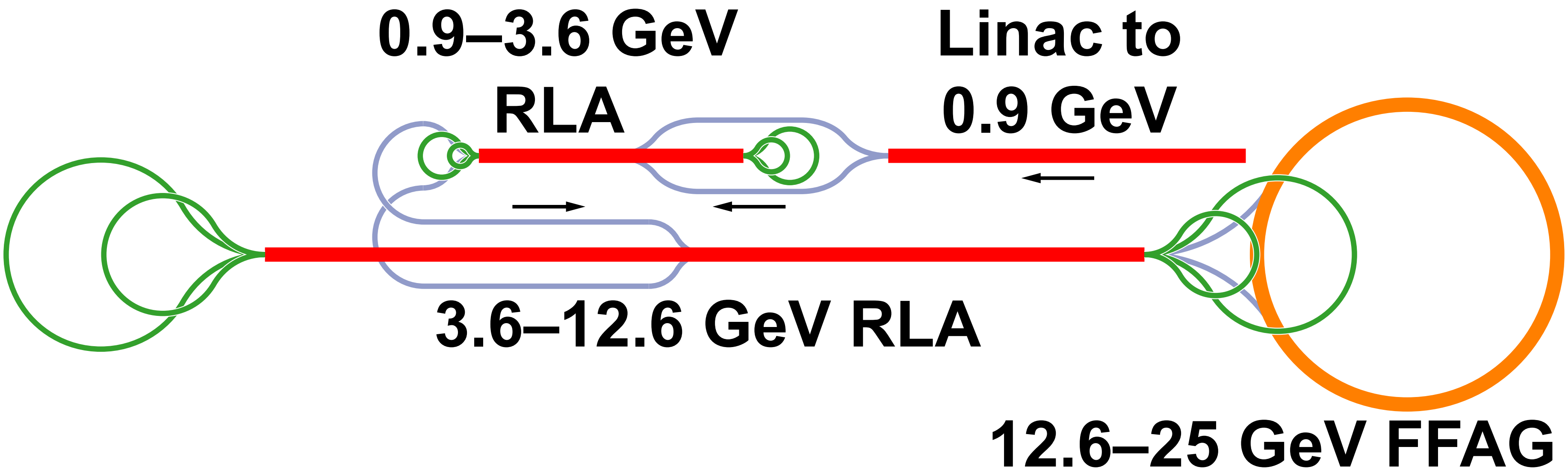
FFAG motivation

- Acceleration of muons for a neutrino factory
- Many passes through RF to reduce cost
- Muons decay, need rapid acceleration
  - No time to ramp magnets
  - Need high average RF gradient
- Recirculating linear accelerator (RLA)
  - Multiple passes through linac
  - Separate arc for each energy
  - Density at arc switchyard limits passes
- Fixed field alternating gradient accelerator
  - Arc with wide energy acceptance
    - No switchyard, many more turns
  - Alternating gradient focusing to keep apertures down

FFAG motivation



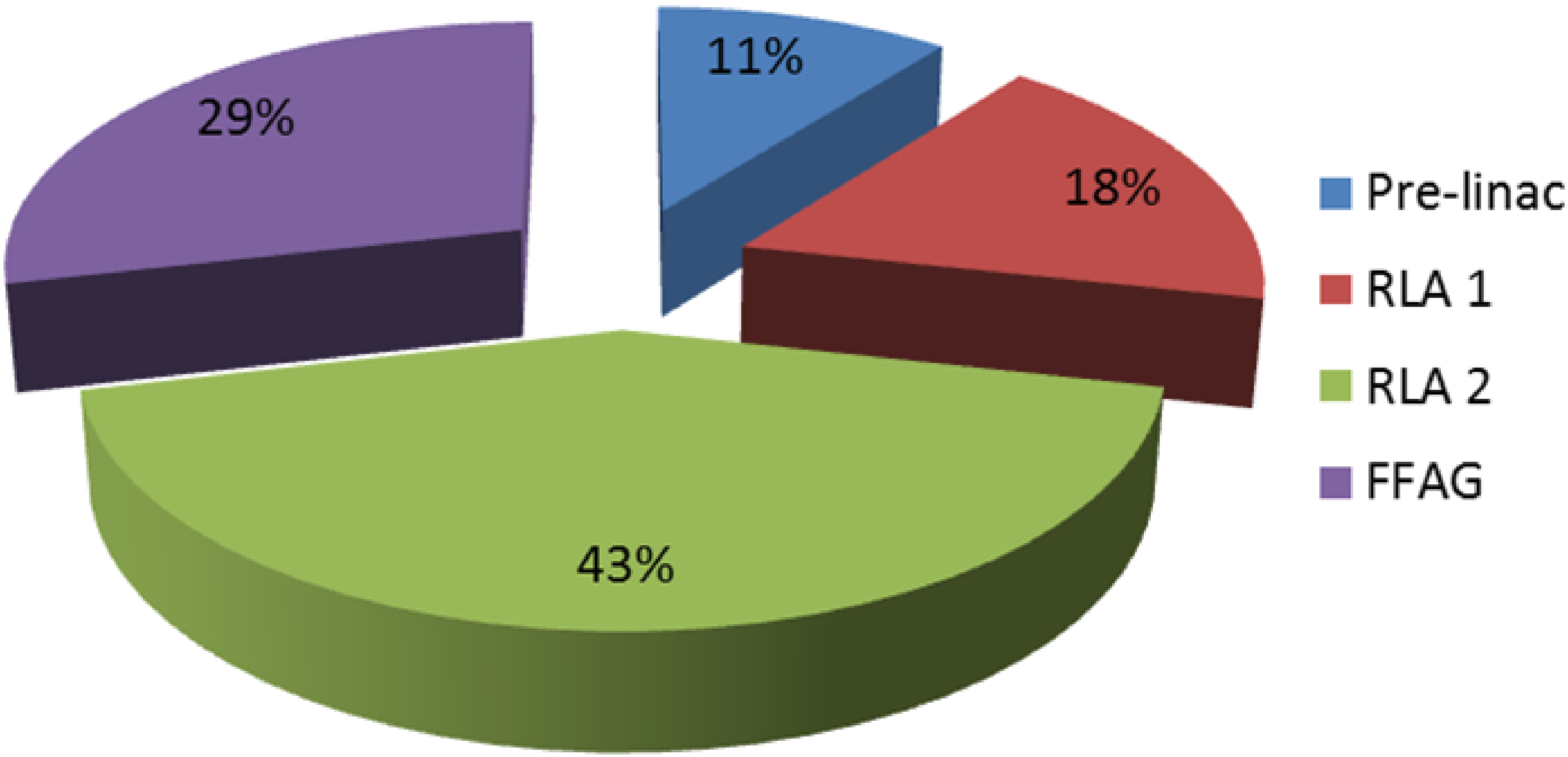
25 GeV ν Factory Acceleration



Neutrino Factory 25 to 10 GeV

- Original design for 25 GeV
- Accelerate with linac, two RLAs, and an FFAG
  - FFAG has clear cost benefit over using RLA
- Large value of θ_{13}: 10 GeV optimal energy
- Does FFAG provide cost benefit for acceleration to lower energy?
  - FFAGs become less efficient at lower energy

Neutrino Factory 25 to 10 GeV

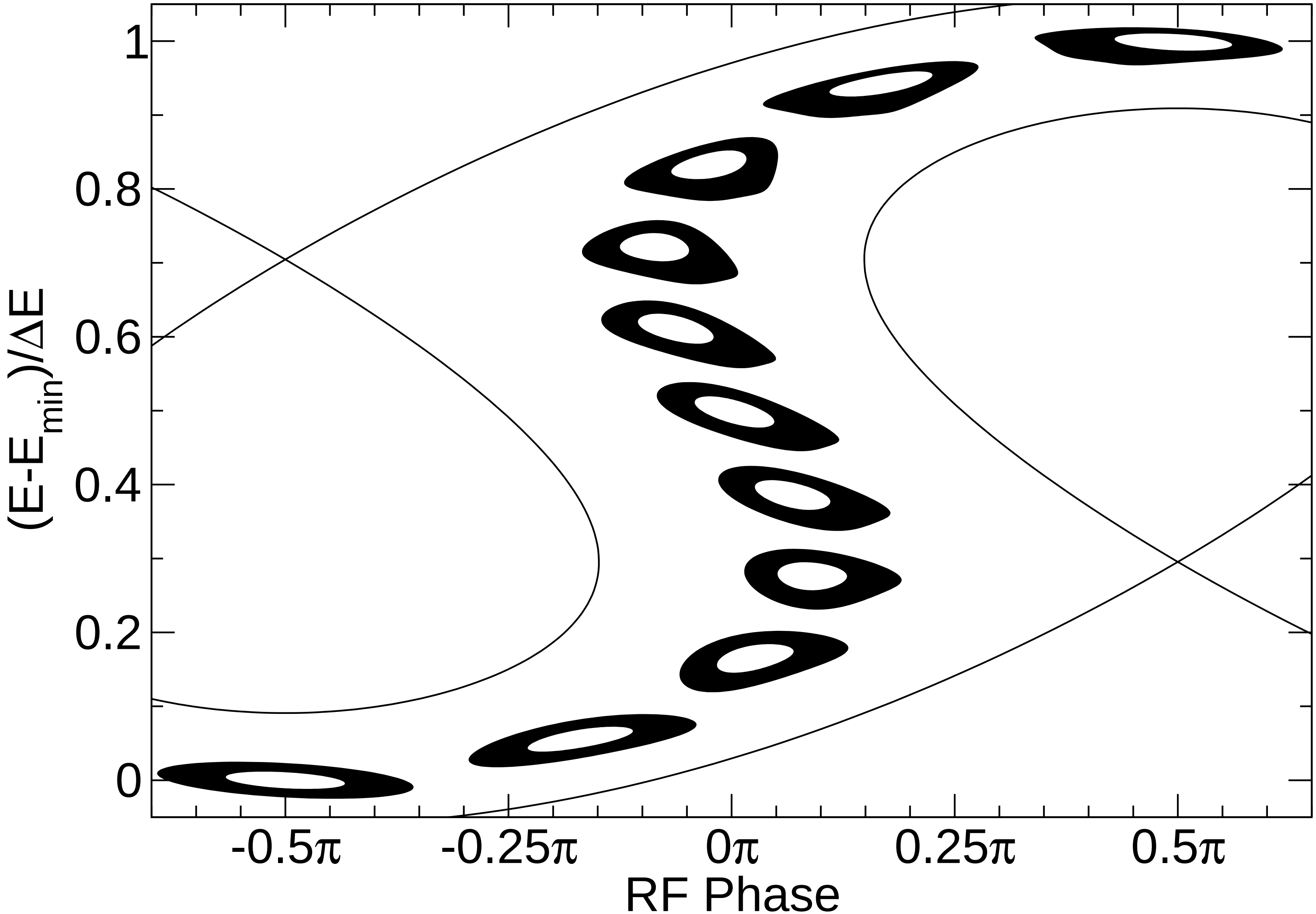


A. Kurup, 18 April 2012

FFAG Design

- Design consists entirely of identical FDF triplets
- Cavities in most long drifts
  - 17 free drifts for injection/extraction, diagnostics
- Sufficient voltage to
  - Accelerate from minimum to maximum energy
  - Make serpentine channel wide enought for acceptable longitudinal ellipse distortion
- Long drift sufficient for two-cell cavity
  - Includes space for cryostats, etc: 4.3 m total
  - 3.0 m drift shown: understand benefit of reduced space
- Minimize cost function within these constraints

Serpentine Acceleration



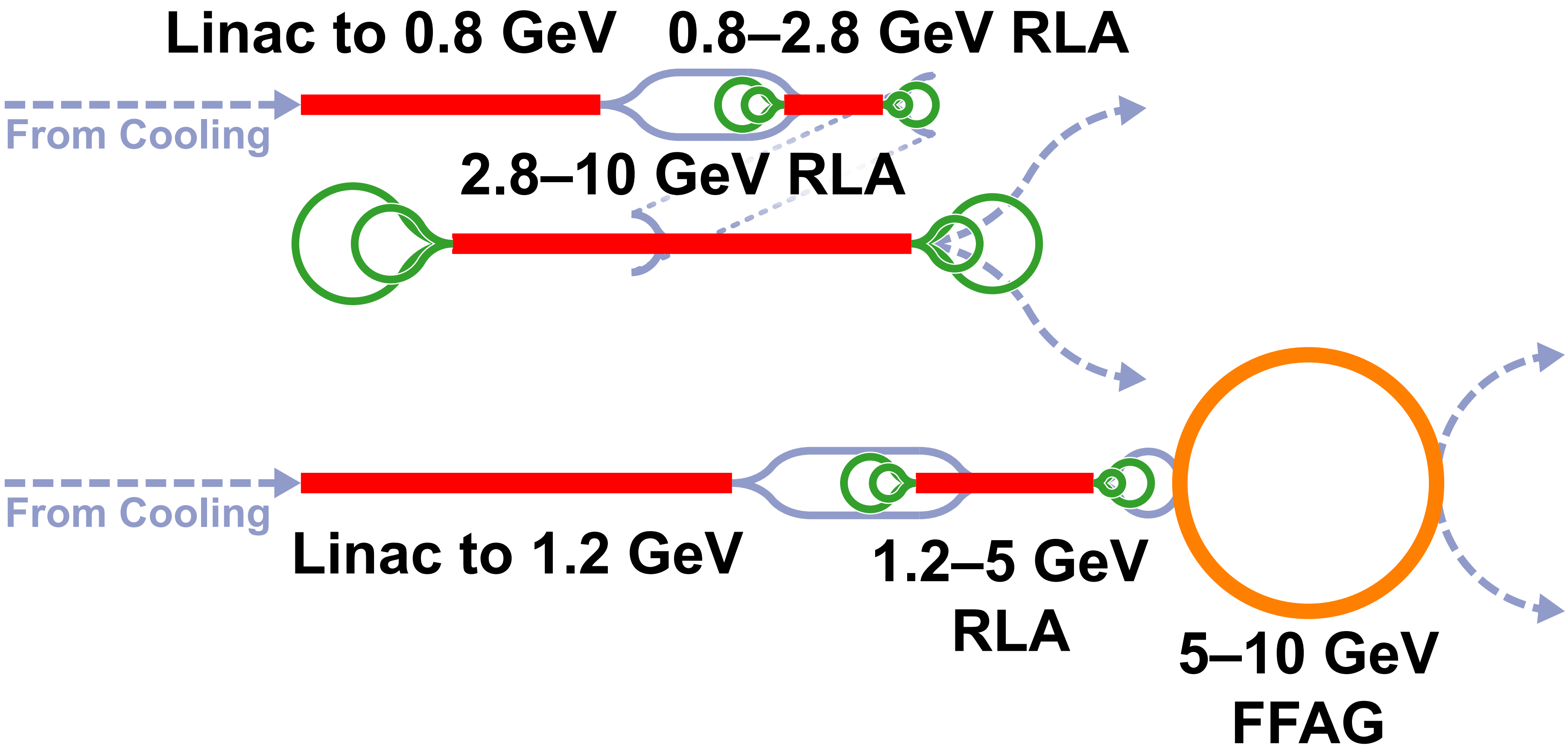
FFAG Design Parameters

Min Energy (GeV)	12.6	5	5
Max Energy (GeV)	25	10	10
Long drift (m)	5.0	4.3	3.0
Cells	67	55	51
Cavities	50	38	34
Turns	11.6	6.4	6.9
Circumference	699	492	380
Max D field (T)	6.3	3.9	4.5
D radius (mm)	130	175	156
Max F field (T)	4.5	3.0	3.1
F radius (mm)	160	205	195
Energy gain/cell (MV)	15.9	14.2	14.1
Cost (A.U.)	162	130	115

FFAG Design Parameters

- Only 20% cost reduction from 25 to 10 GeV
  - Fewer turns: high voltage needed for longitudinal acceptance
  - Less field but higher magnet apertures
- Making ring longer and reducing voltage would reduce cost
  - Energy gain per cell would drop rapidly
    - Time of flight variation with transverse amplitude proportional to this
    - Tracking losses would increase significantly
  - Modest increase in decay losses
- Similar argument against 1 RF cell per cavity

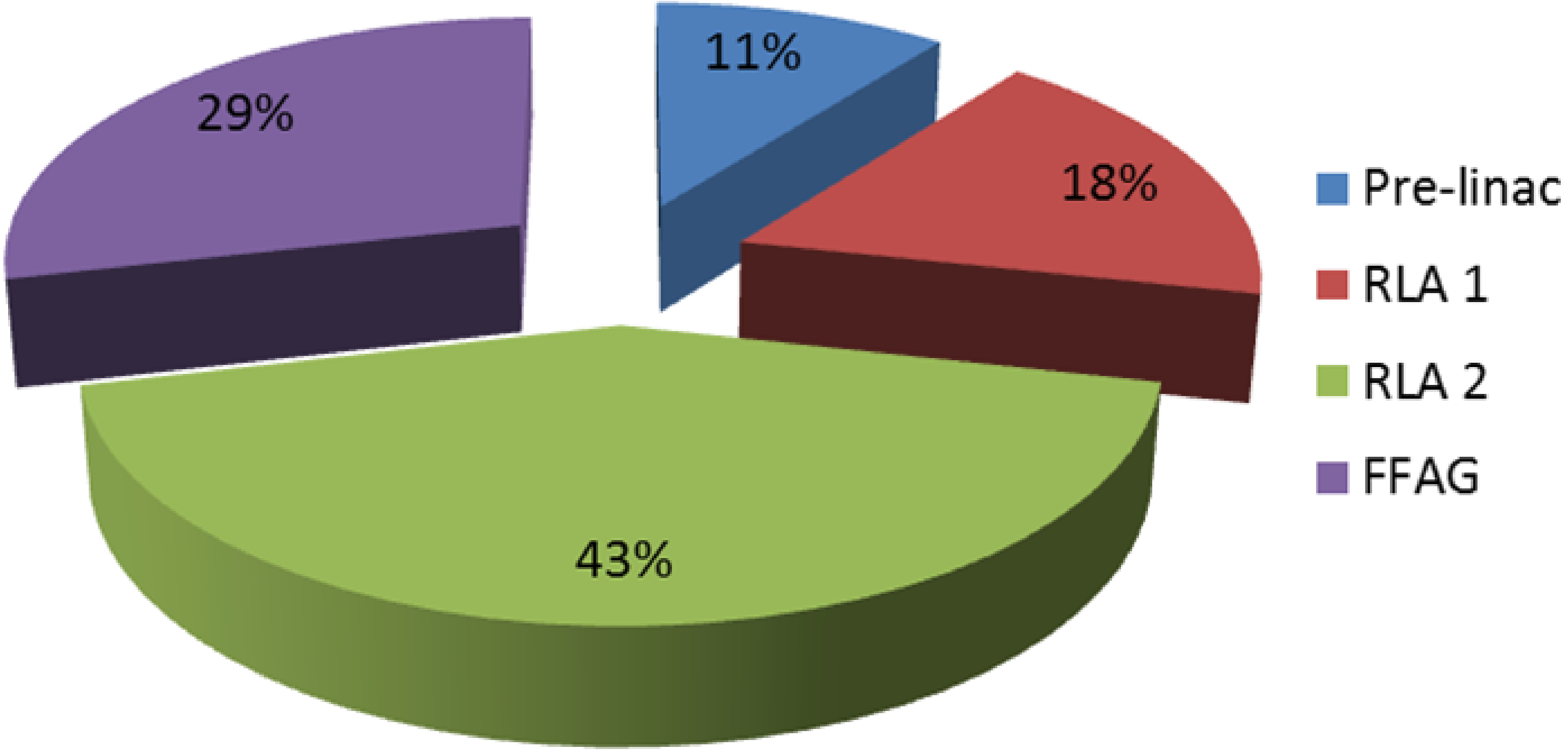
Acceleration Scenarios



Acceleration Scenarios

- Compare acceleration scenarios for 10 GeV neutrino factory
  - Linac → RLA → RLA
    - Linac to 0.8 GeV
    - RLA to 2.8 GeV
    - RLA to 10 GeV
  - Linac → RLA → FFAG
    - Linac to 1.2 GeV
    - RLA to 5 GeV
    - FFAG to 10 GeV

Cost Comparison



Cost Comparison

- Use percentages from IDS-NF preliminary cost
  - Scale linac by cell count
  - Scale RLA by cost/GeV linearized in inverse final energy
  - Scale FFAG by costing from optimization
- Include comparison for 25 GeV acceleration without FFAG
  - Linac to 1.5 GeV
  - RLA to 6 GeV
  - RLA to 25 GeV

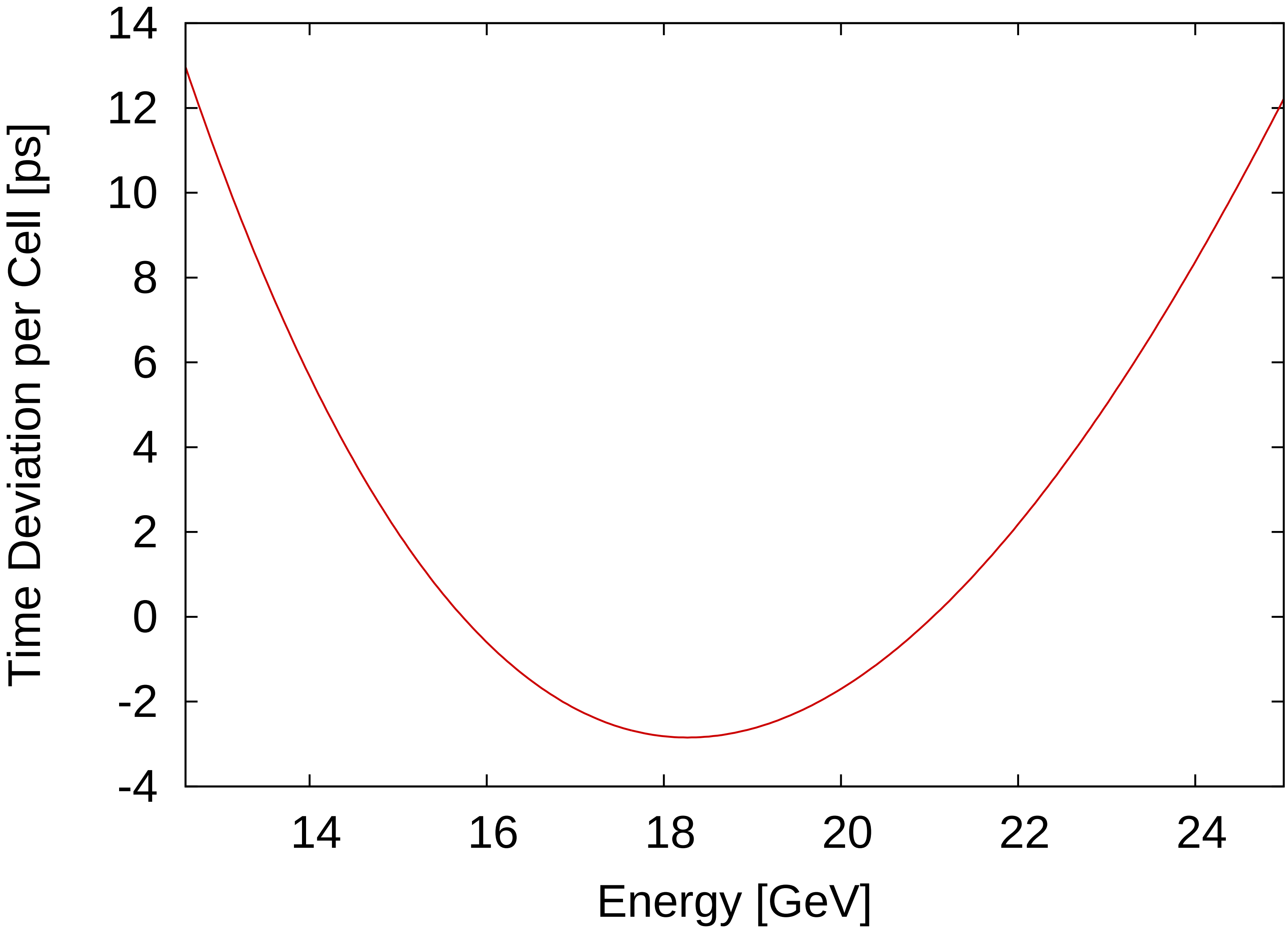
Cost Comparison

	FFAG 25 GeV	RLA 25 GeV	RLA 10 GeV	FFAG 10 GeV
Linac	11	16.9	10.0	14.0
RLA 1	18	25.2	14.8	22.5
RLA 2	43	83.7	35.8	
FFAG	29			23.3
	101	125.8	60.7	59.8

Increase Energy Range

- Earlier study: FFAGs with max to min energy ratios of 1.7, 2, and 2.8
  - 2, 3, or 4 stages to cover a factor of 8
  - Factor of 2 is optimal
  - Small penalty for 1.7, large penalty for 2.8
  - Implies that 2 is near optimal
- Longitudinal acceptance criterion: $a = V/(\omega\Delta T\Delta E)$
- Time of flight parabolic function of energy
  - Time of flight range (ΔT) goes as square of ΔE
  - a increases slowly with ΔE
  - Thus fewer turns ($\Delta E/V$) with increased energy range

Increase Energy Range



Criteria for Decision

- Two criteria: cost, performance, ease of implementation
- Cost criterion: equal
- Performance: tracking is a concern in FFAG
  - Significant longitudinal distortion
  - Time of flight depends on transverse amplitude
  - Have made progress in improving
    - Computed optimal injection distribution
    - Know how to optimally “center” time of flight curve
  - Still exepct more longitudinal distortion than RLAs
    - No comparable tracking RLAs
- Implementation: FFAG is additional type of system
  - Injection/extraction challenging

Discussion

- It is time to decide on an acceleration scenario for the IDS-NF RDR
  - RLA designers need to know what to work on
  - We need to do engineering and costing
  - RDR coming up really soon!
- Even if FFAG not used for IDS-NF RDR, still important for muon acceleration
  - Clear benefit for an energy upgrade (non-standard physics, etc.)
  - Acceleration for a muon collider
- Let's make a decision
  - The right bodies are here
  - Will not get more information in enough time