Status of Muon Acceleration

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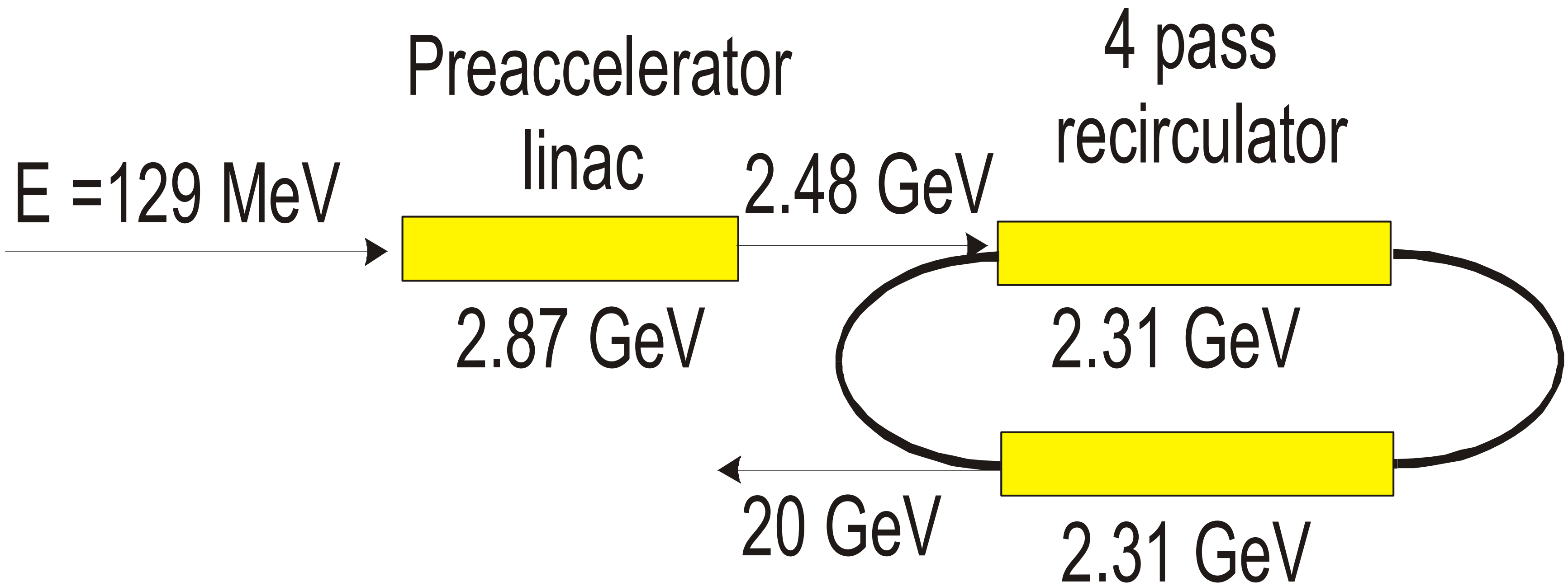
Outline

Muon Collaboration

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

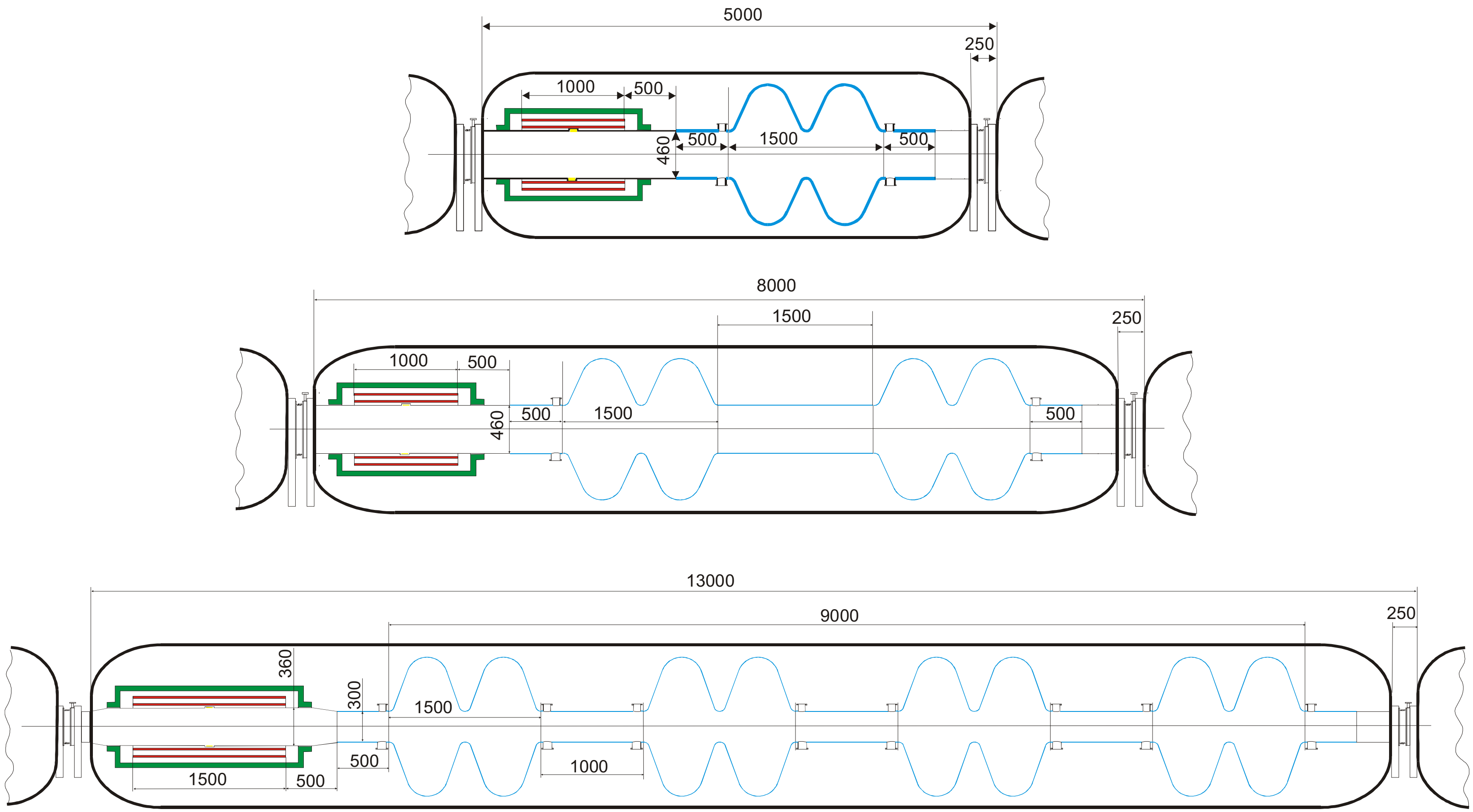
Study II Acceleration Studies

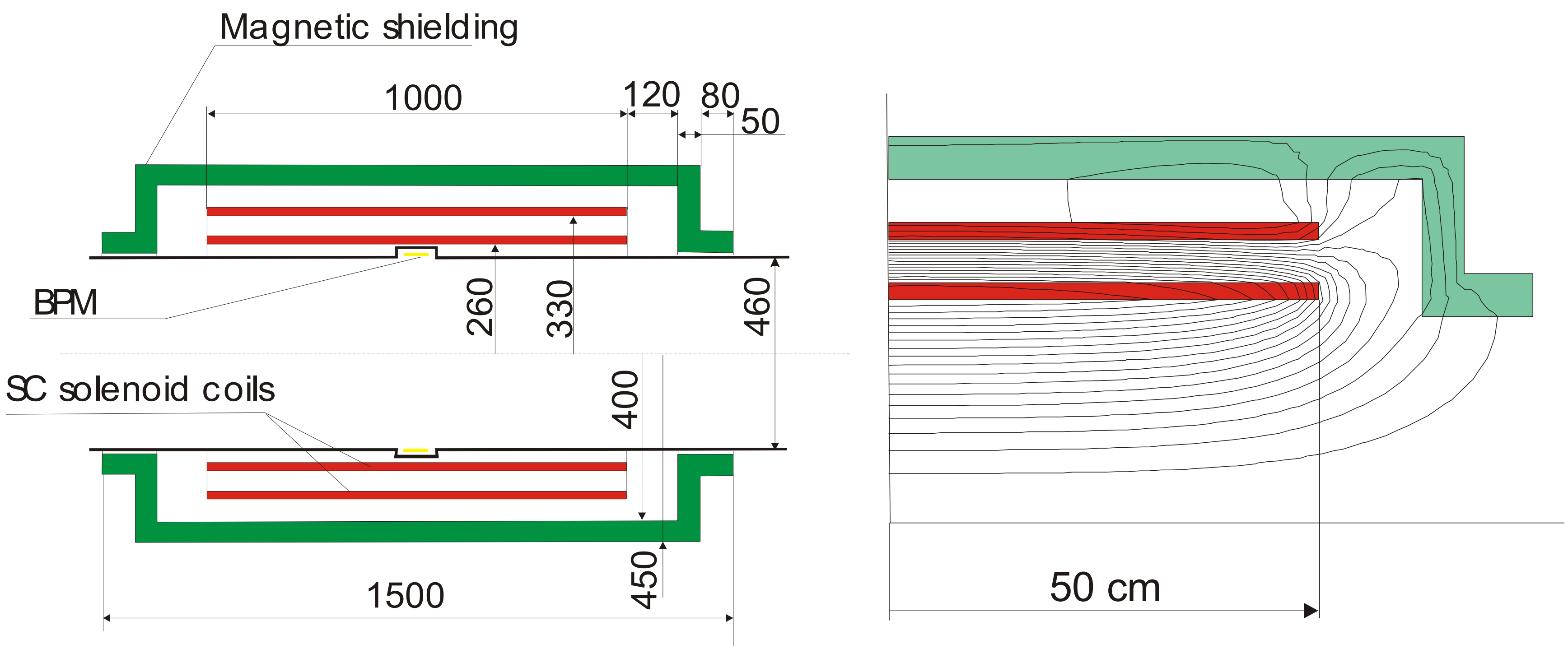
- Work primarily performed by V. Lebedev and A. Bogacz at Jefferson Lab (and Fermilab)
- Described scheme to accelerate from 129 MeV (KE) to 20 GeV.
  - Linac to 2.48 GeV
  - Single 4-pass recirculating accelerator to 20 GeV
- Compared to Study I
  - Less energy gain in linac
  - Lower final energy (20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


Preaccelerator
linac
4 pass
recirculator
E =129 MeV
2.48 GeV
2.87 GeV
2.31 GeV
20 GeV
2.31 GeV

Study II: Linac

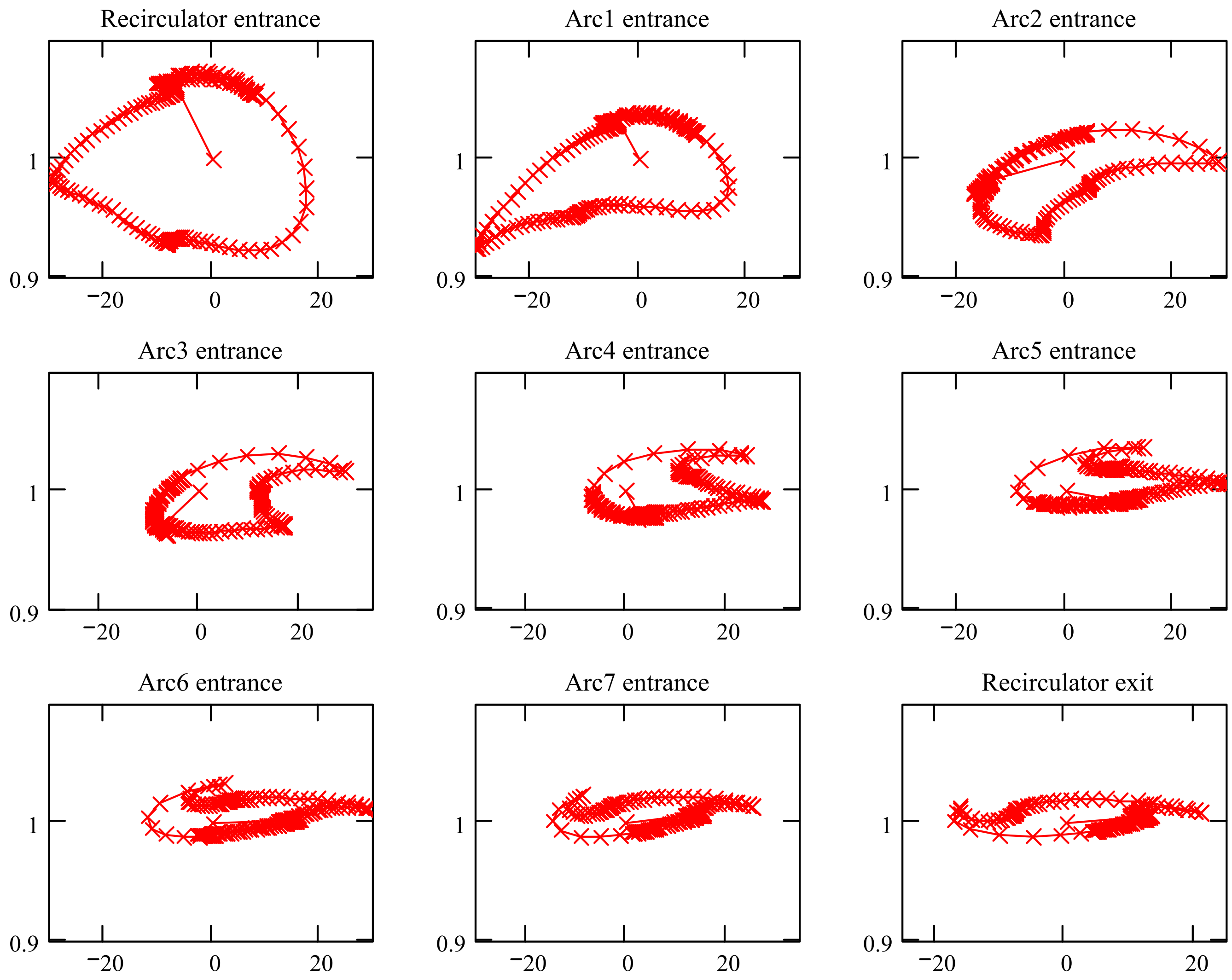
- Matching section from cooling to accelerating linac
  - Adiabatically converts beta functions from cooling values to acceleration values
  - Partially accelerates
- Linac cryostats: three types
  - Initally large beam size: need short focal length
  - Gain real-estate gradient by having fewer solenoids 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


5000
250
1000
500
460
500
1500
500
8000
1500
250
1000
500
460
500
1500
500
13000
9000
250
360
300
1500
500
1000
1500
500


Magnetic shielding
1000
120
80
50
BPM
260
330
460
SC solenoid coils
400
450
1500
50 cm

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 30π mm
- Beam loading has only minor effect


Recirculator entrance
Arc1 entrance
Arc2 entrance
Arc3 entrance
Arc4 entrance
Arc5 entrance
Arc6 entrance
Arc7 entrance
Recirculator exit
1
0.9
−20
0
20

R&D: Dynamics Studies

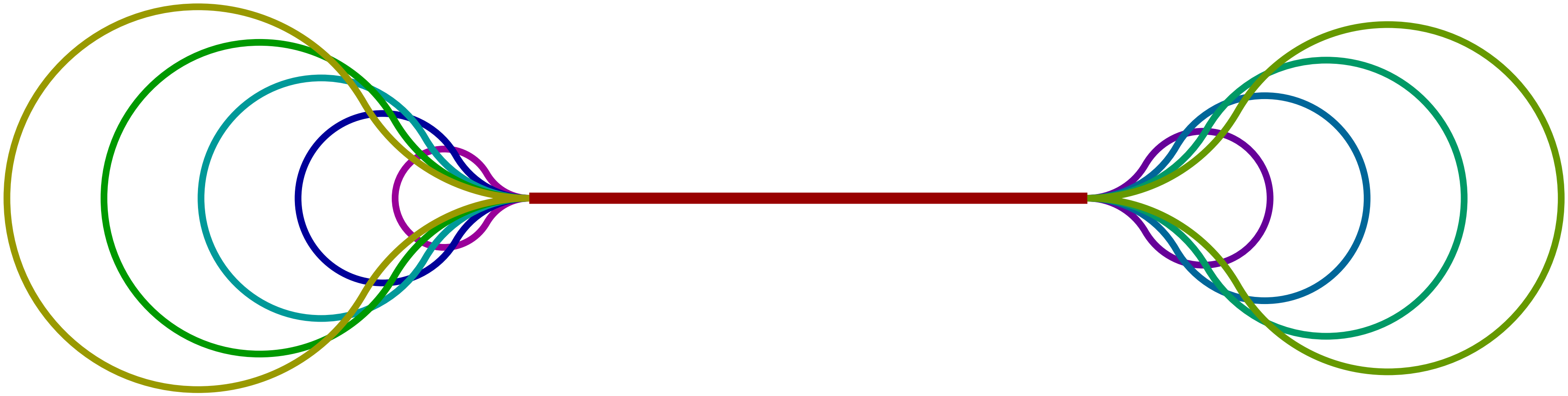
- Full nonlinear study
  - Magnets are relatively short, large aperture: substantial end effects
  - Study with full nonlinearities
    - Fringe fields
    - Sextupoles
  - Substantial emittance growth
    - Understand
    - Cure
- More detailed studies of bunches with beam loading
- Improving longitudinal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

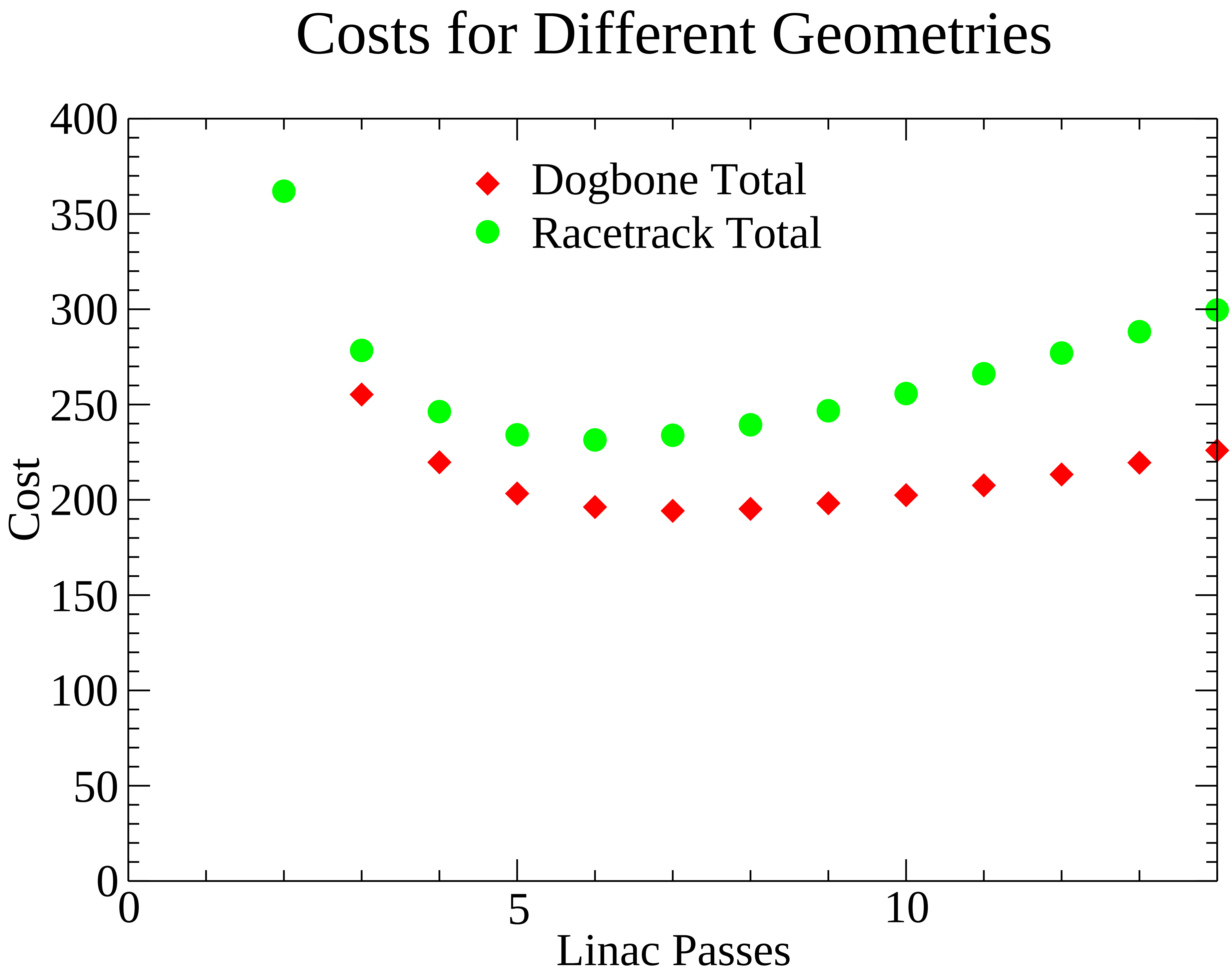
R&D: Hardware

- 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
Cost
Linac Passes
0
50
100
150
200
250
300
350
400
0
5
10

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.)

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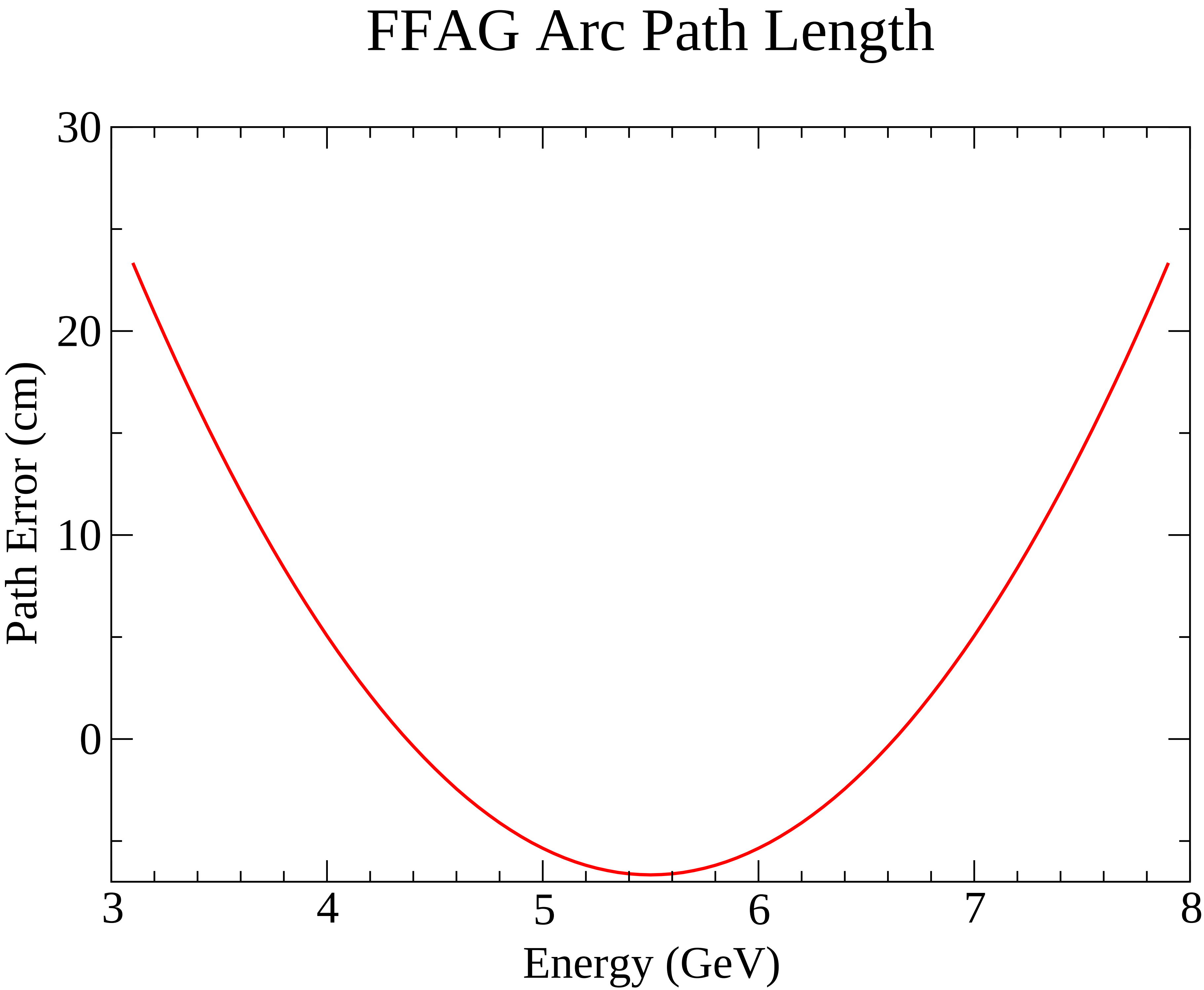
- Path length variation with energy
  - FFAG arc has significant variation in path length with energy
  - Unable to make bunch return to same RF phase at all energies
  - Cannot shift phase of RF quickly enough at low energies
    - To push power in requires Q too low: high power requirements
    - Ferrite 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


FFAG Arc Path Length
Path Error (cm)
30
20
10
0
3
4
5
6
7
8
Energy (GeV)

FFAG Recirculating Accelerators (cont.)

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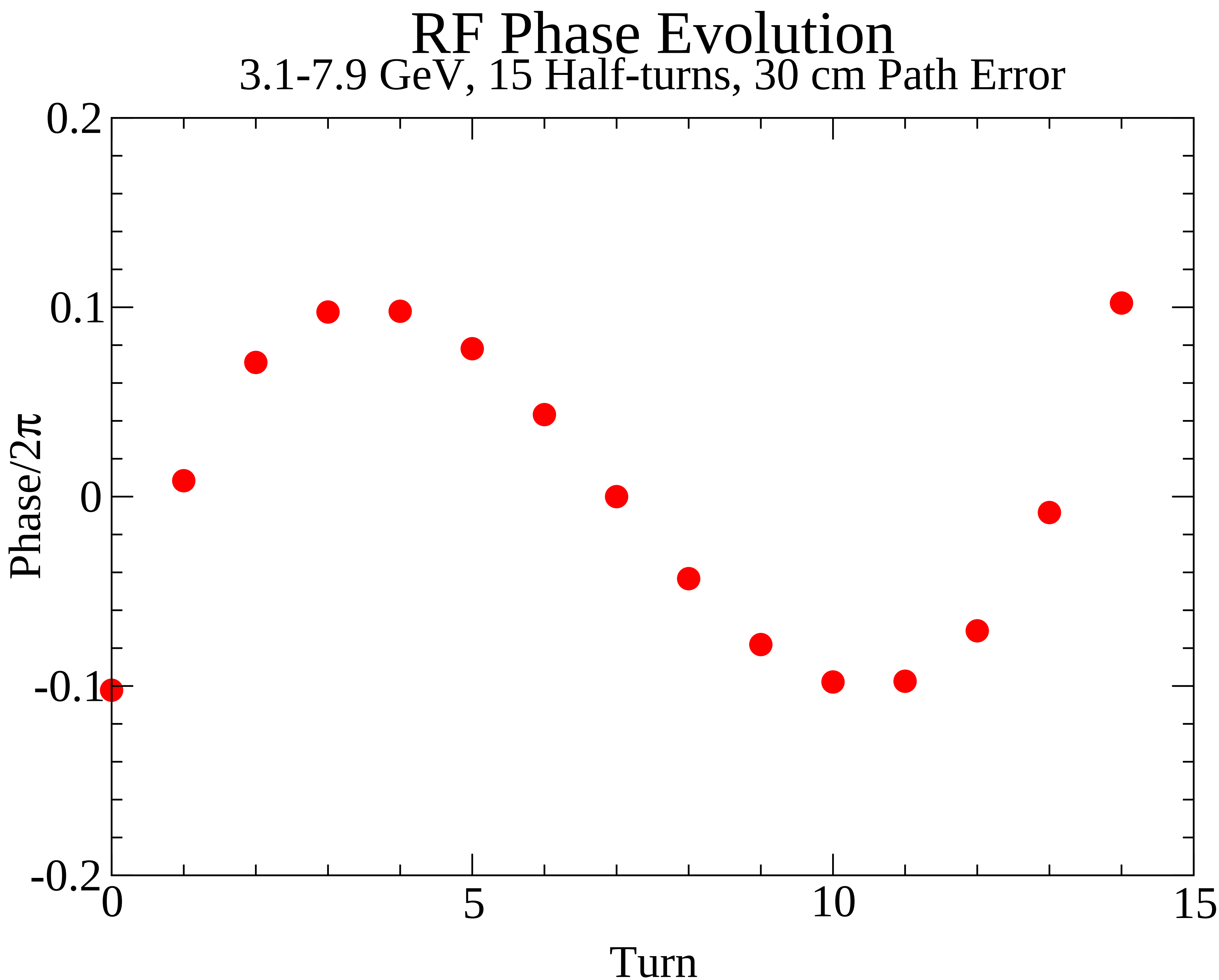
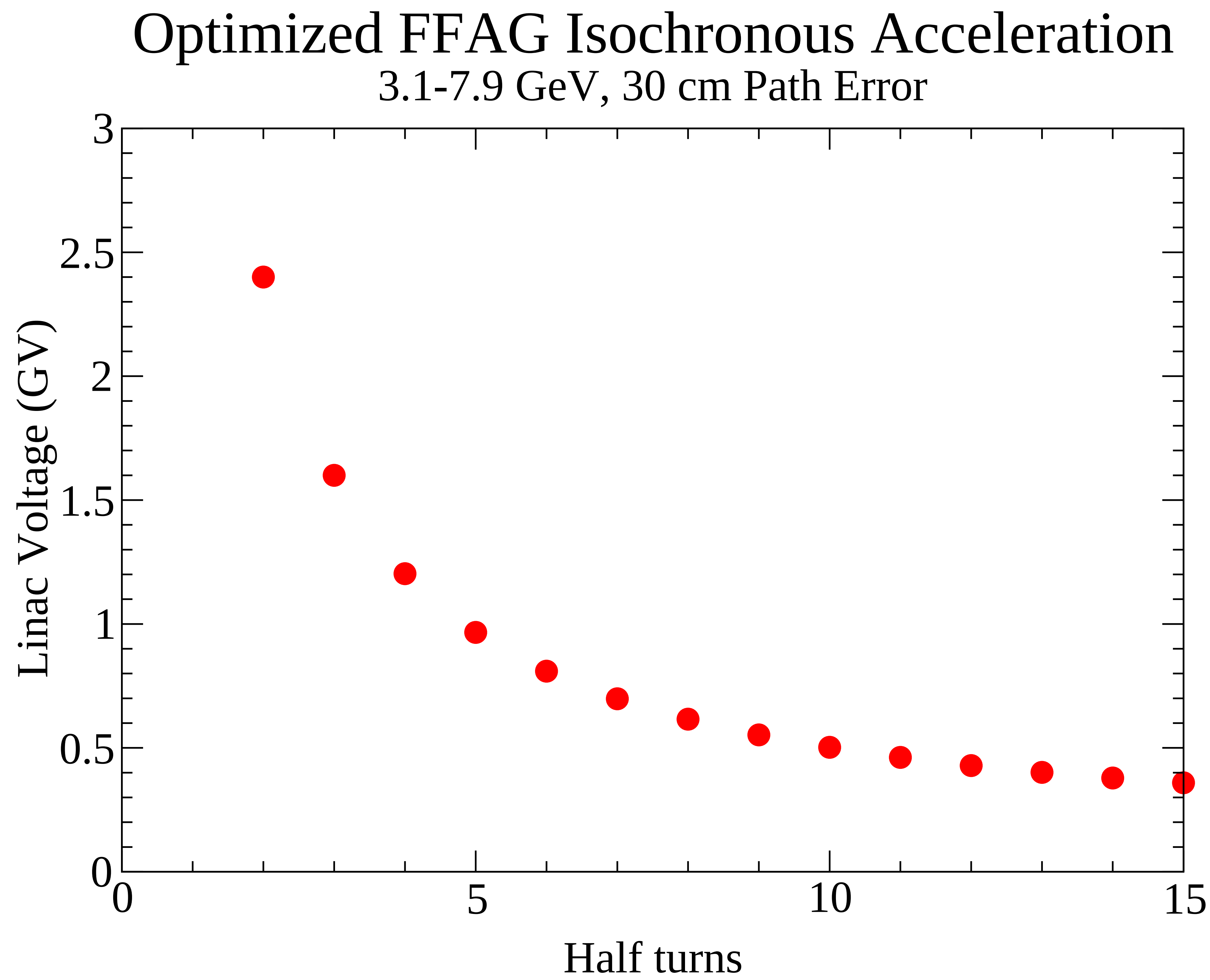
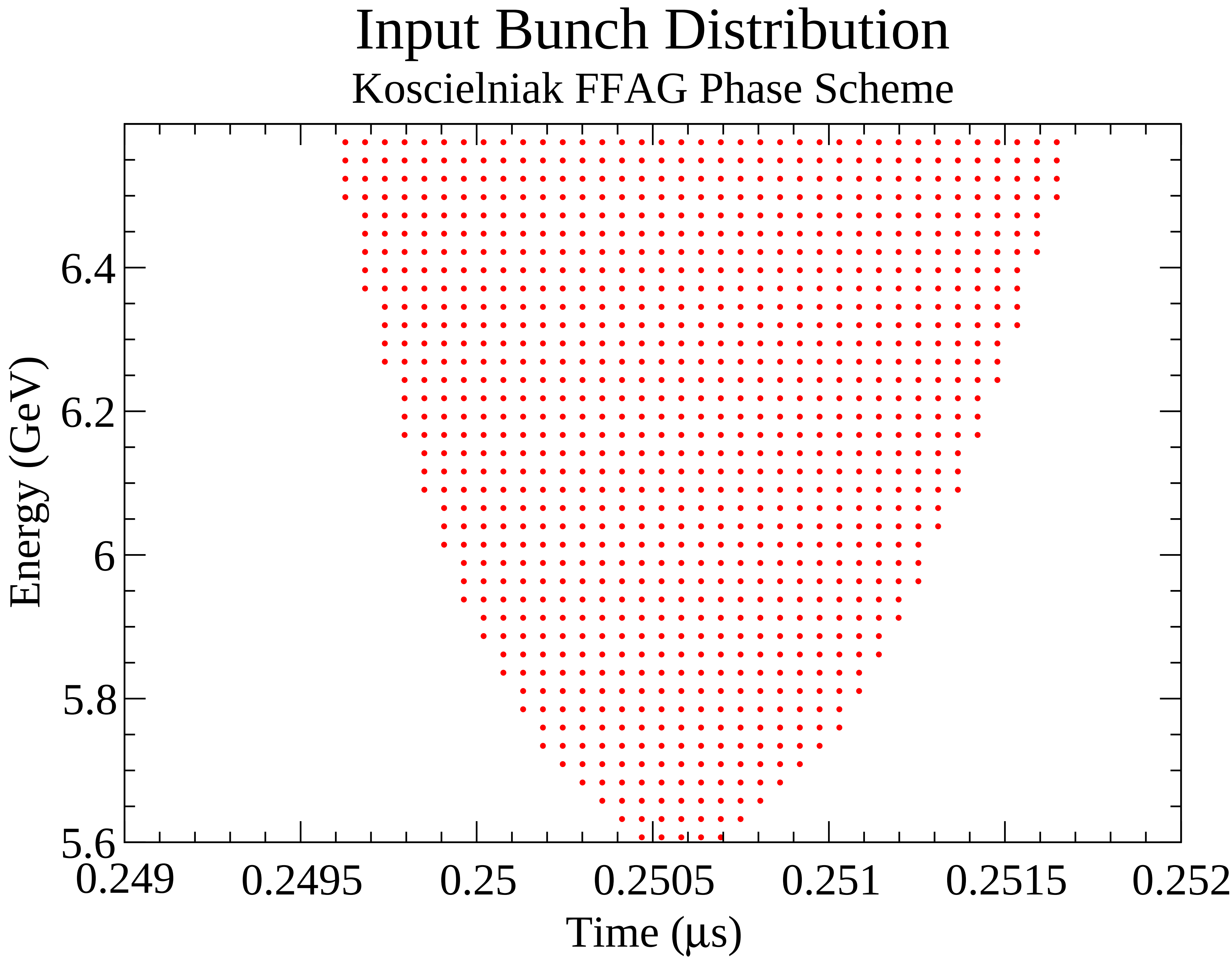
- Path length problem not as bad as expected
  - For a given range of path length, expect maximum number of turns before phase slips too far
  - If choose parameters correctly, arbitrary number of turns
    - ⋆ Crosses crest three times
    - ⋆ Must choose initial phase and reference path length correctly
    - ⋆ 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

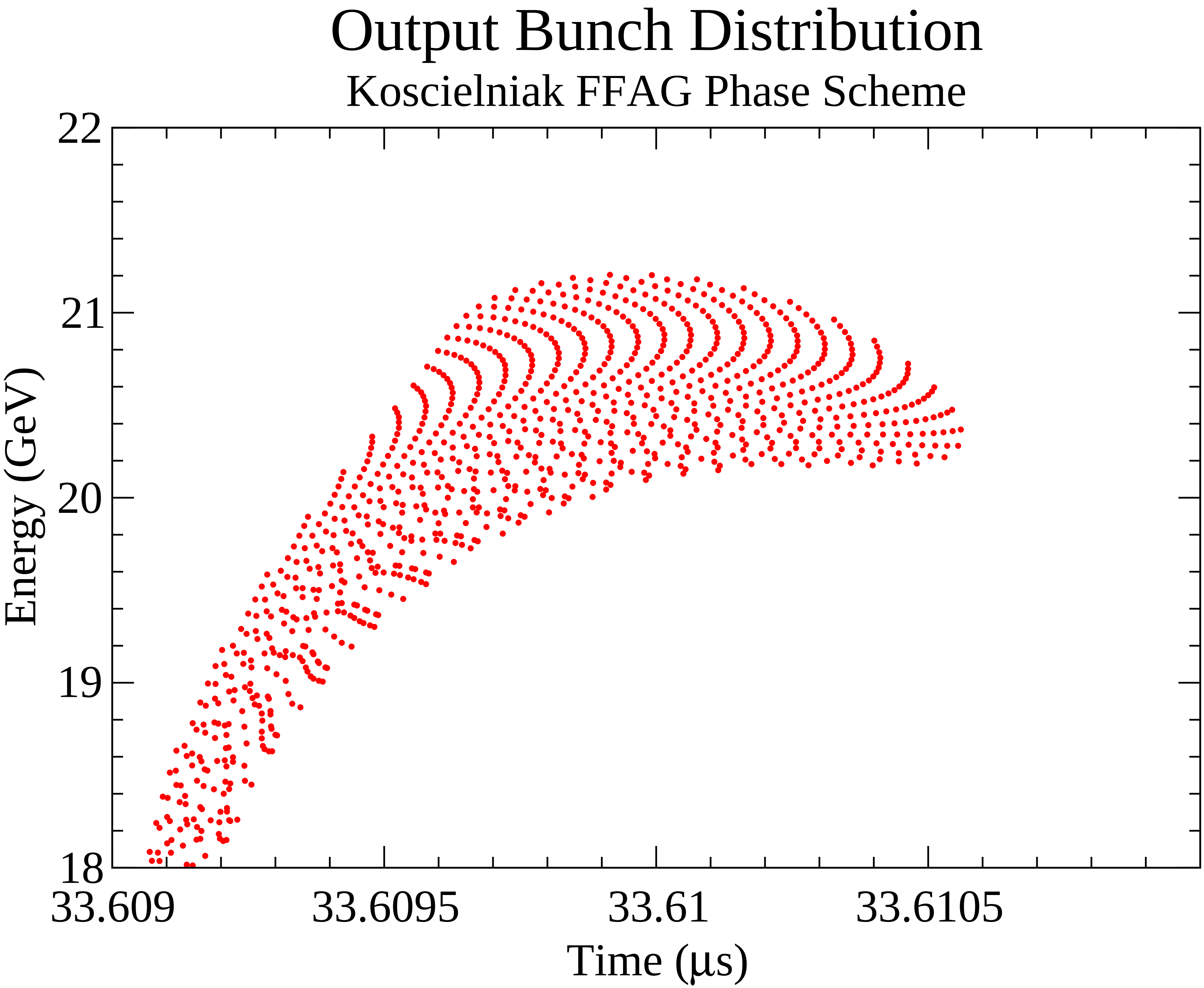


RF Phase Evolution
3.1-7.9 GeV, 15 Half-turns, 30 cm Path Error
Phase/2π
Turn
0.2
0.1
0
-0.1
-0.2
0
5
10
15


Optimized FFAG Isochronous Acceleration
3.1-7.9 GeV, 30 cm Path Error
Linac Voltage (GV)
Half turns
0
0.5
1
1.5
2
2.5
3
0
5
10
15



Input Bunch Distribution
Koscielniak FFAG Phase Scheme
Energy (GeV)
6.4
6.2
6
5.8
5.6
0.249
0.2495
0.25
0.2505
0.251
0.2515
0.252
Time (μs)


Output Bunch Distribution
Koscielniak FFAG Phase Scheme
Energy (GeV)
22
21
20
19
18
33.609
33.6095
33.61
33.6105
Time (μs)

FFAG Recirculating Accelerators (cont.)

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- 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