Lattices Optimized with Empty Cells “Pre-Accelerator” Linac Design

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Muon Collaboration Friday Meeting

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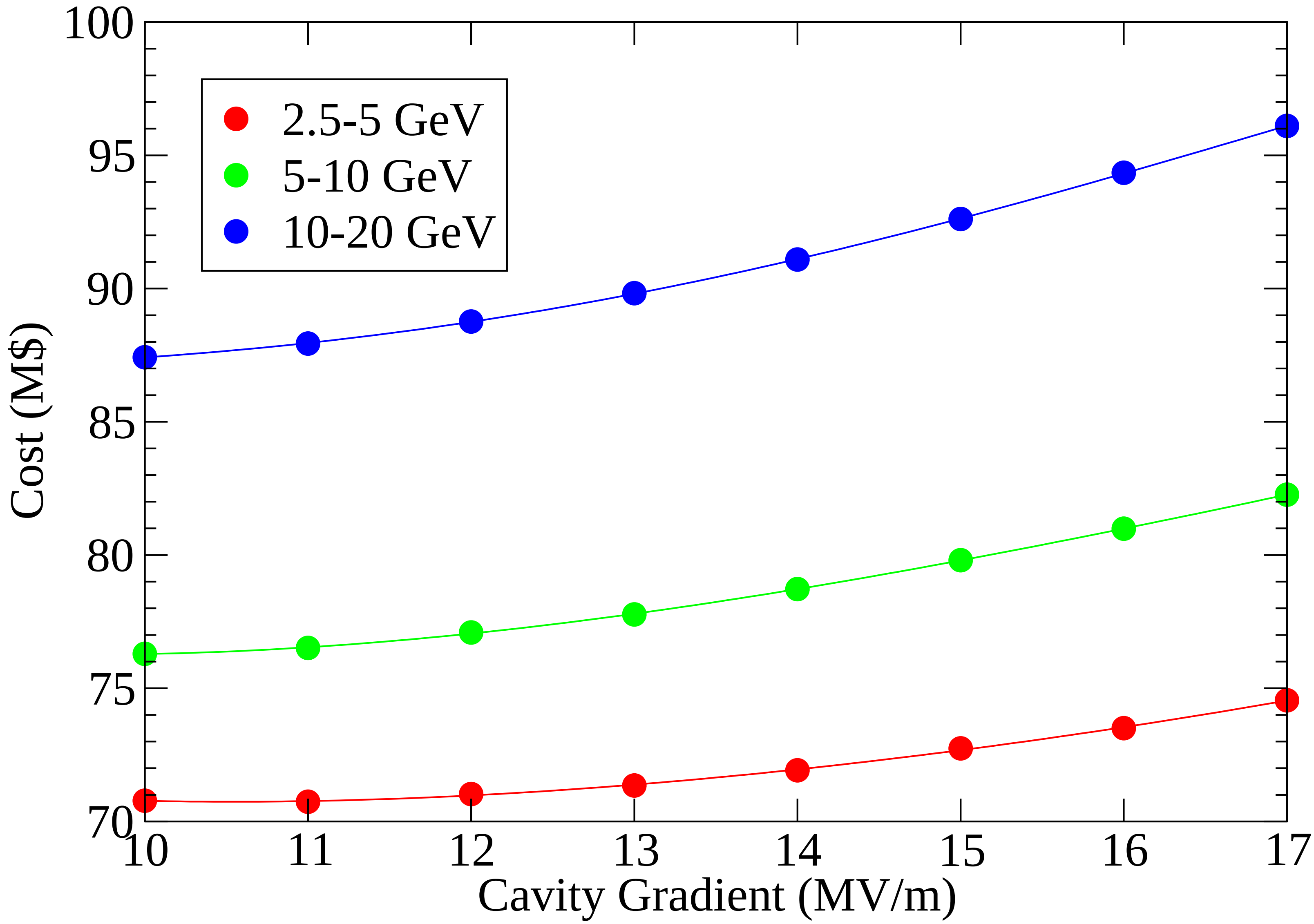
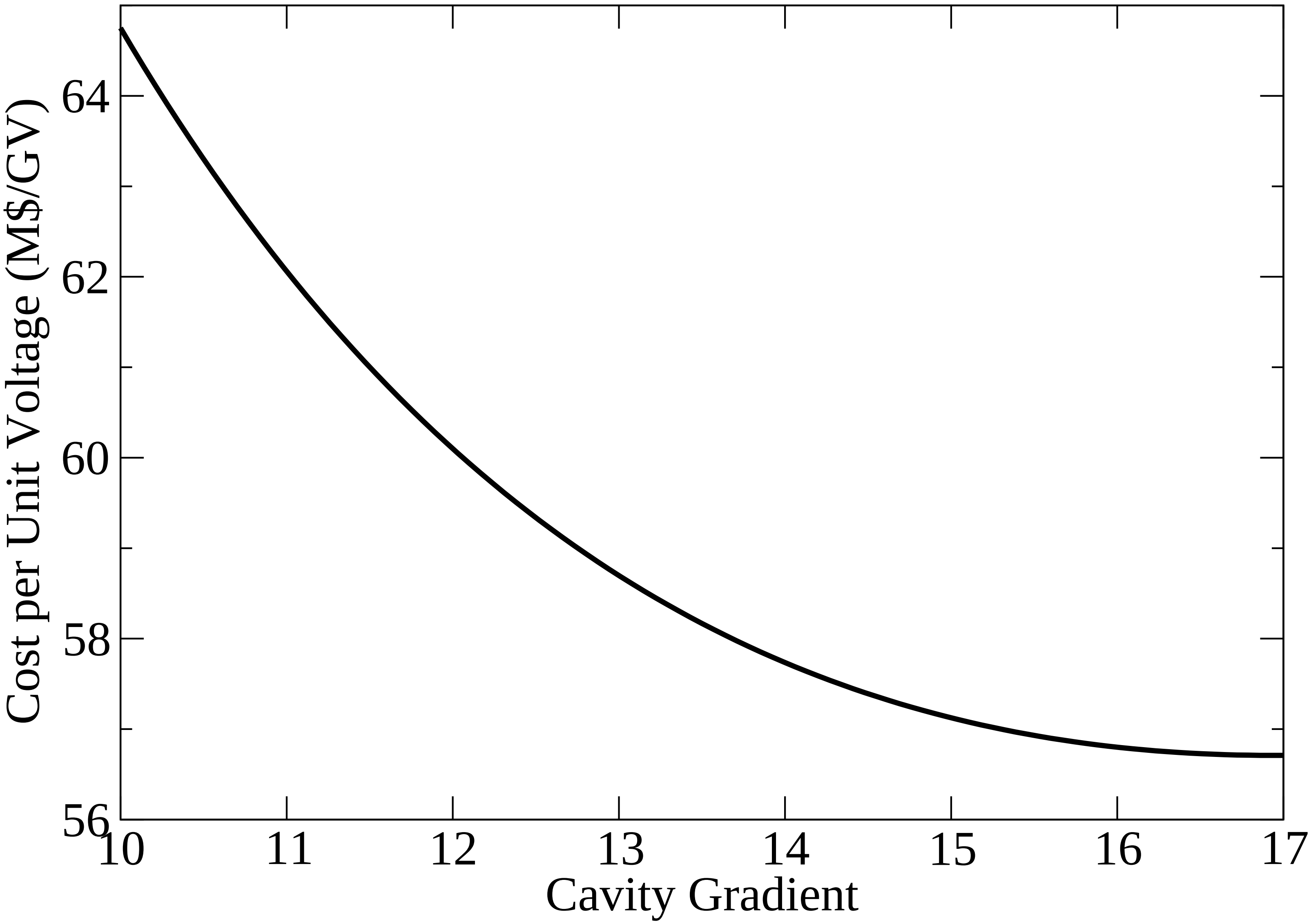
The Old Optimization

- Assumed that every cell (except for 8) was filled with an RF cavity
- Bizarre result: cost increased with increasing RF gradient
  - Not correct: RF cost per GeV is cheaper at 10 MV/m than at 15 MV/m
  - Take design at 10 MV/m, put in fewer RF cavities with higher gradient
- The problem: as gradient increases:
  - Amount of RF increases
  - Ring size reduces
  - Reducing ring size does not reduce lattice cost as fast as RF cost increases
    - ⋆ In fact, lattice cost is increased when ring size decreases
- Allow optimization to fill as many cells with cavities as it wants to

Plot: Cost vs. Voltage



Plot: Cavity Cost vs. Gradient



The Big Table o' Cost Optimum Lattices

Minimum total energy (GeV)	2.5			5			10		
Maximum total energy (GeV)	5			10			20		
$V/(\omega \Delta T \Delta E)$	1/6			1/8			1/12		
Type	FD	FDF	FODO	FD	FDF	FODO	FD	FDF	FODO
No. of cells	89	70	91	140	111	145	191	153	197
D length (cm)	58	93	55	71	109	67	87	128	81
D radius (cm)	13.0	16.0	15.8	9.5	11.5	11.3	7.1	8.6	8.3
D pole tip field (T)	3.2	3.1	2.7	3.6	3.6	3.1	4.4	4.4	3.8
F length (cm)	86	46	87	98	55	96	115	67	110
F radius (cm)	16.8	15.1	21.3	11.7	10.6	14.4	8.6	8.09	10.5
F pole tip field (T)	2.1	2.3	1.6	2.6	2.7	2.1	3.2	3.3	2.7
No. of cavities	47	49	63	45	47	57	43	46	55
RF voltage (MV)	350	363	465	332	350	426	321	343	405
$\Delta E/V$	7.1	6.9	5.4	15.1	14.3	11.7	31.1	29.2	24.7
Circumference (m)	351	340	493	587	575	855	863	859	1164
Decay (%)	10.7	10.0	11.3	18.2	17.0	19.6	27.0	25.5	28.6
Magnet cost (PB)	35.7	41.5	49.2	29.6	34.7	37.5	27.7	32.4	32.6
RF cost (PB)	22.7	23.6	30.3	21.7	22.7	27.6	20.8	22.2	26.4
Linear cost (PB)	8.8	8.5	12.3	14.7	14.4	20.4	21.6	21.5	29.1
Total cost (PB)	67.2	73.6	91.8	65.9	71.8	85.5	70.1	76.1	88.1
Cost per GeV (PB/GeV)	26.9	29.4	36.7	13.2	14.4	17.1	7.0	7.6	8.8

Analysis of Cost Optimum Lattices

- Very little voltage required
  - Very low RF cost
- High energy lattices: magnet cost is decreasing with increasing circumference
  - Longer lattice, reduced dispersion, reduced aperture
  - Linear cost is only thing increasing
- Way too many decays
  - Need to assign a cost per muon to get the optimum
- Beam loading impractically high also
  - Should be considered in optimization
- Compare old method of filling (almost) all cells
  - Higher cost, fewer decays
  - Hopefully upper bound on cost, but depends on cost per muon

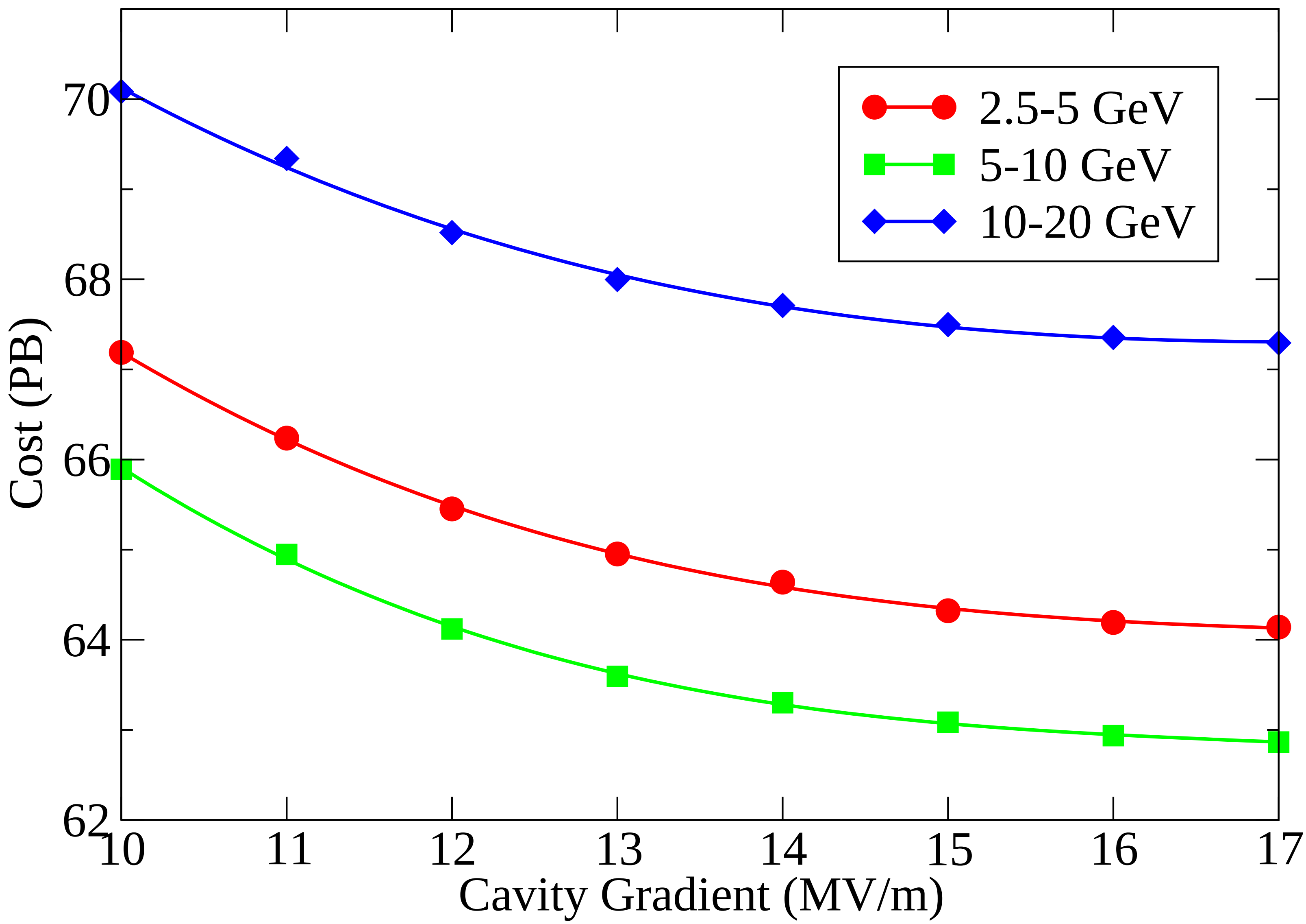
The Big Table o' Short Lattices

Minimum total energy (GeV)	2.5			5			10		
Maximum total energy (GeV)	5			10			20		
$V/(\omega \Delta T \Delta E)$	1/6			1/8			1/12		
Type	FD	FDF	FODO	FD	FDF	FODO	FD	FDF	FODO
No. of cells	65	60	76	79	72	91	93	85	105
D length (cm)	62	96	56	82	119	77	105	143	98
D radius (cm)	13.6	16.5	16.0	10.2	12.7	11.7	7.8	9.7	8.7
D pole tip field (T)	3.7	3.3	1.9	4.6	4.2	3.8	5.8	5.5	5.0
F length (cm)	99	48	93	126	64	119	162	85	151
F radius (cm)	19.1	15.8	22.8	15.3	12.8	17.8	12.7	10.9	14.6
F pole tip field (T)	2.2	2.4	1.7	2.8	3.1	2.2	3.5	3.7	2.8
No. of cavities	57	52	68	71	64	83	85	77	97
RF voltage (MV)	428	390	510	533	480	623	638	578	728
$\Delta E/V$	5.8	6.4	4.9	9.4	10.4	8.0	15.7	17.3	13.7
Circumference (m)	268	295	418	362	393	543	481	521	681
Decay (%)	6.8	8.2	8.8	7.4	8.9	9.4	8.5	10.1	10.4
Magnet cost (PB)	36.4	41.6	49.6	32.8	37.4	40.0	34.1	39.2	38.4
RF cost (PB)	27.7	25.3	33.0	34.5	31.1	40.3	41.3	37.4	47.1
Linear cost (PB)	6.7	7.4	10.4	9.1	9.8	13.6	12.0	13.0	17.0
Total cost (PB)	70.8	74.3	93.1	76.3	78.3	93.8	87.4	89.6	102.5
Cost per GeV (PB/GeV)	28.3	29.7	37.2	15.3	15.7	18.8	8.7	9.0	10.2

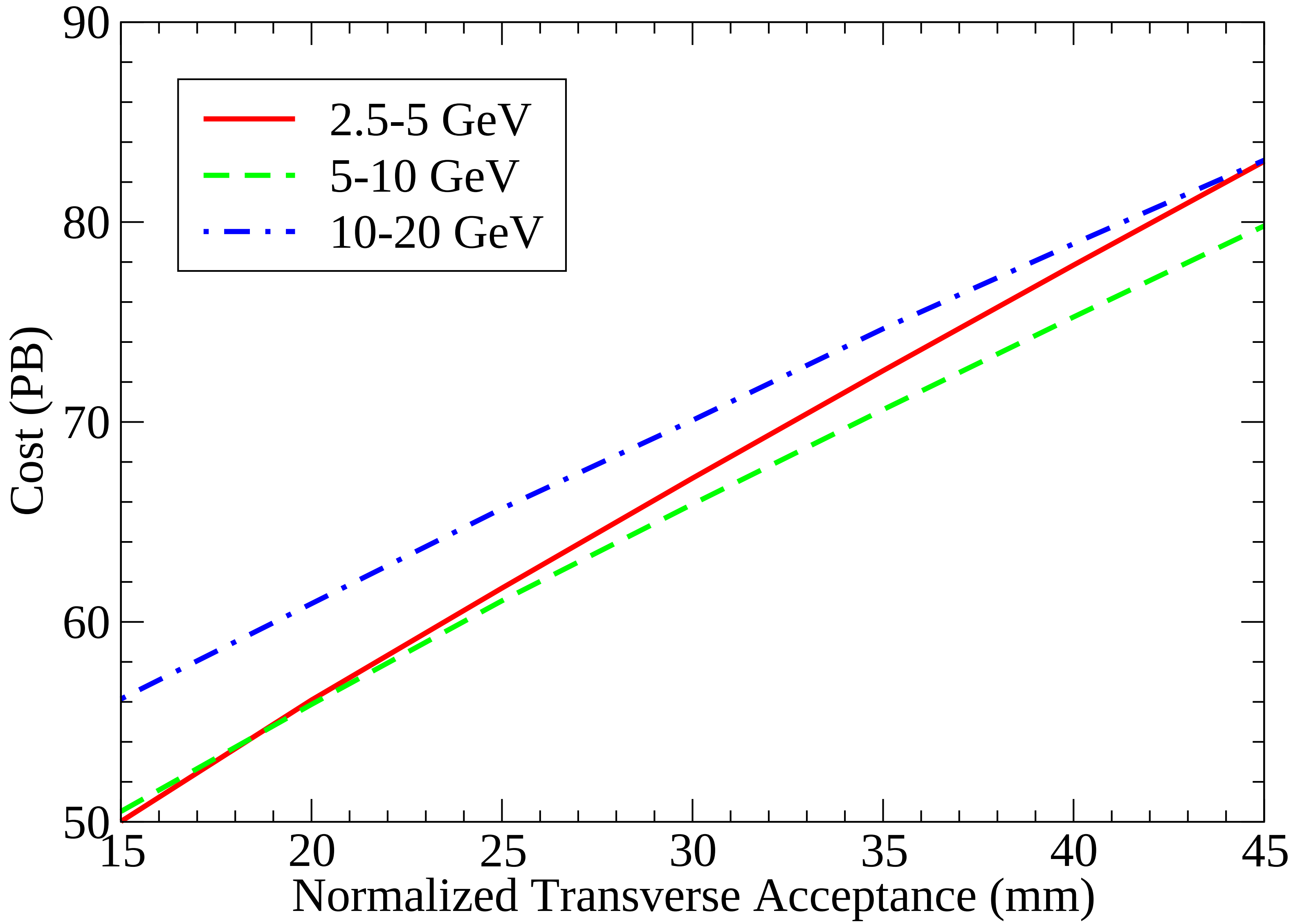
Parametric Dependence of Optimized Cost

- Increasing cavity gradient
  - Slight decrease in cost
  - RF cost was a relatively small fraction of cost
  - Cost per GeV of RF is fairly flat
- Changing acceptance
  - Very strong dependence on acceptance
  - Large fraction of cost in magnets
  - Need cost per muon vs. acceptance cut
- In case of solution with more RF
  - There will be more RF cost AND more magnet cost
  - RF dependence will be somewhat stronger
  - Acceptance dependence should be similarly strong
    - ⋆ More dispersion, so less dependence on acceptance
    - ⋆ But greater total magnet cost also

Plot: Optimial Cost vs. Voltage



Plot: Optimial Cost vs. Acceptance



Pre-Acceleration Linac Design

- Solenoid focused
- Length of cryostat increases as you accelerate
  - Acceptance changes with momentum, length, aperture

$$A = \frac{pca^2}{\beta mc^2}$$

    A is acceptance, p is momentum, a is half-aperture, β is beta function, m is particle mass
  - β is proportional to L for a given tune: compute from Study II
  - Thus, as p gets larger, you can use longer (and more efficient) cryostats
- If we use the old Study II cryostats:
  - Problem: acceptance has doubled
  - Must start acceleration at momentum of 420 MeV/c!

Study II Cryostats

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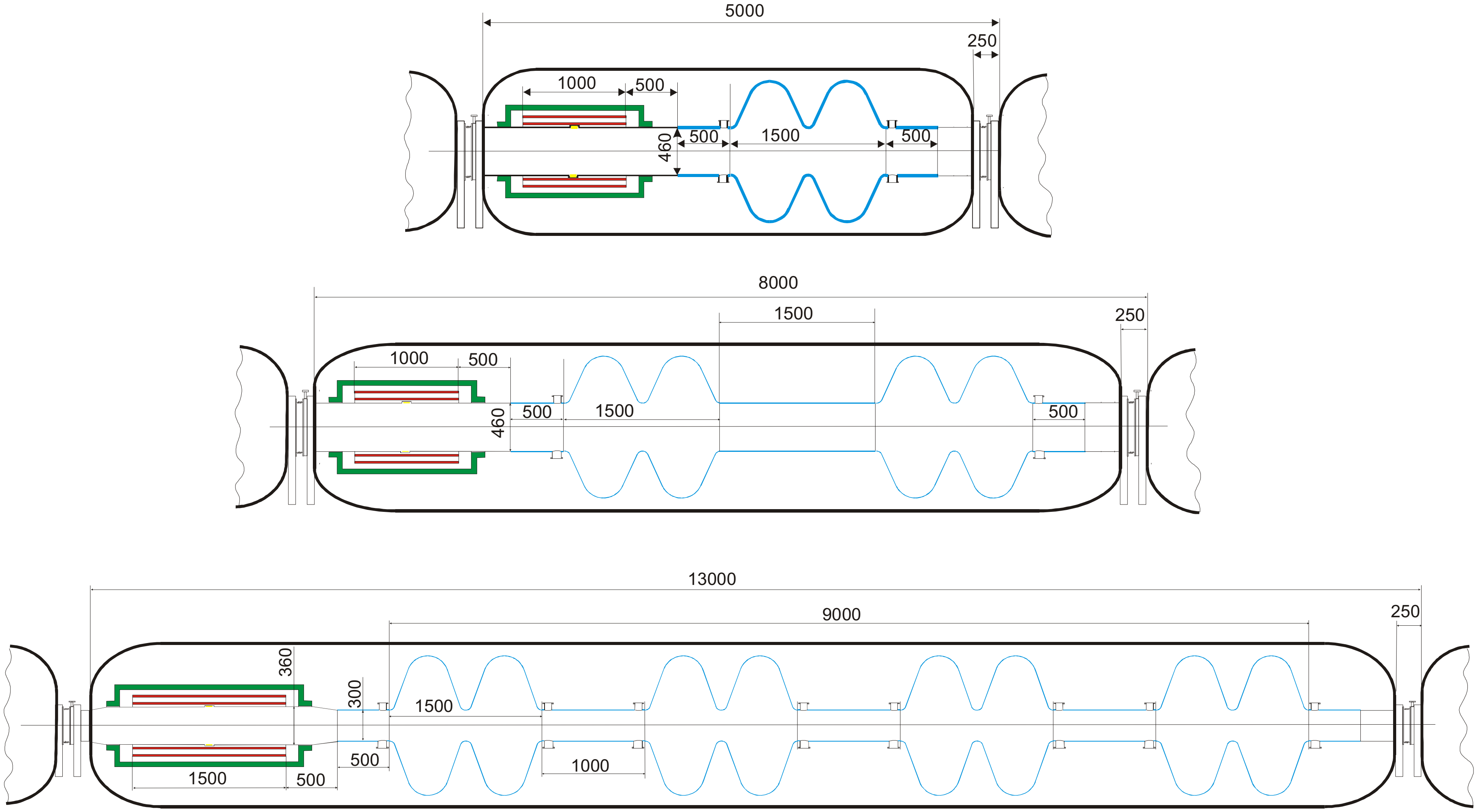

Linac Design (cont.)

- Try to shorten cryostats
  - Study II has 75 cm for cryostat at end; make 50 cm
  - Drop 25 cm between solenoid and cavity input coupler
    - ⋆ Solenoid field with shield below 0.1 T just outside shield
  - 75 cm betwen cavities
  - Make very short cell with only one cell in cavity
- No long cryostats: minimum momentum is 1612 MeV/c, only accelerate to 1496 MeV/c
- RF phase variation
  - Phase varies approximately linearly from a nonzero value at the beginning to zero at the end
  - Value at the beginning based on stationary bucket area
    - ⋆ Adjust by computing Study II area, and making area the same here

Linac Parameters

Length (m)	3.25	4.50	6.75
Minimum allowed momentum (MeV/c)	273	378	567
Number of modules	18	12	23
Cells per cavity	1	2	2
Cavities per cell	1	1	2
Maximum energy gain per cavity (MeV)	11.25	22.5	22.5
RF Frequency (MHz)	201.25	201.25	201.25
Solenoid length (m)	1	1	1
Solenoid field (T)	2.1	2.1	2.1