Lattices Optimized with New Cost Formula
Effect of RF Gradient

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Palmer's New Cost Formula: Magnets

$$\text{Cost} = (C_0 + C_1 \hat{B}^{k_B}) \hat{R} (L + k_G \hat{R}) f_S(B_+, B_-)(n_0/n)^{k_N}$$

$$f_S(B_+, B_-) = \frac{1}{4\sqrt{2}} \left[\frac{(X+3D)^{3/2}}{(X+D)^{1/2}} + \begin{cases} 0 & Q \leqslant D \\ \dfrac{(X-3D)^{3/2}}{(X-D)^{1/2}} & Q > D \end{cases} \right]$$

$$\hat{B} = B_+ + |B_1|\, k_C B_+ \quad \hat{R} = k_R R + k_M \hat{B} \quad B_\pm = |B_0| \pm |B_1|\, k_R R$$

$$D = \frac{B_+ + B_-}{2B_+} \quad Q = \frac{B_+ - B_-}{2B_+} = 1 - D \quad X = \sqrt{D^2 + 8Q^2}$$

$k_B = 1.5$	$k_C = 2.47$ mm/T	$k_G = 36$
$k_M = 2$ mm/T	$k_N = 1/3$	$k_R = 1.3$
$n_0 = 300$	$C_0 = 101$ k\$/m^2	$C_1 = 16.78$ k\$/m^2/T$^{1.5}$

Cost Model

- Magnet costs: comparison to before
  - Zero-radius magnet has cost proportional to field
  - Zero-field magnet has finite cost
  - Coefficient k_G has increased: magnets tend to be longer
  - Symmetry factor makes combined-function less expensive
- RF costs

$$\frac{C_C V G_0}{G} + \frac{C_P V G}{G_0},$$

  - $C_C = 30$ M\$/GV, $C_P = 26.8$ M\$/GV, $G_0 = 16$ MV/m
- Linear costs: length times 25 k\$/m

The Big Table o' Lattices

E_{min} (GeV)	2.5			5			10		
E_{max} (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
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
Magnet cost (PB)	36	42	50	33	37	40	34	39	38
RF cost (PB)	28	25	33	34	31	40	41	37	47
Linear cost (PB)	7	7	10	9	10	14	12	13	17
Total cost (PB)	71	74	93	76	78	94	87	90	102
Cost per GeV (PB/GeV)	28.3	29.7	37.2	15.3	15.7	18.8	8.7	9.0	10.2

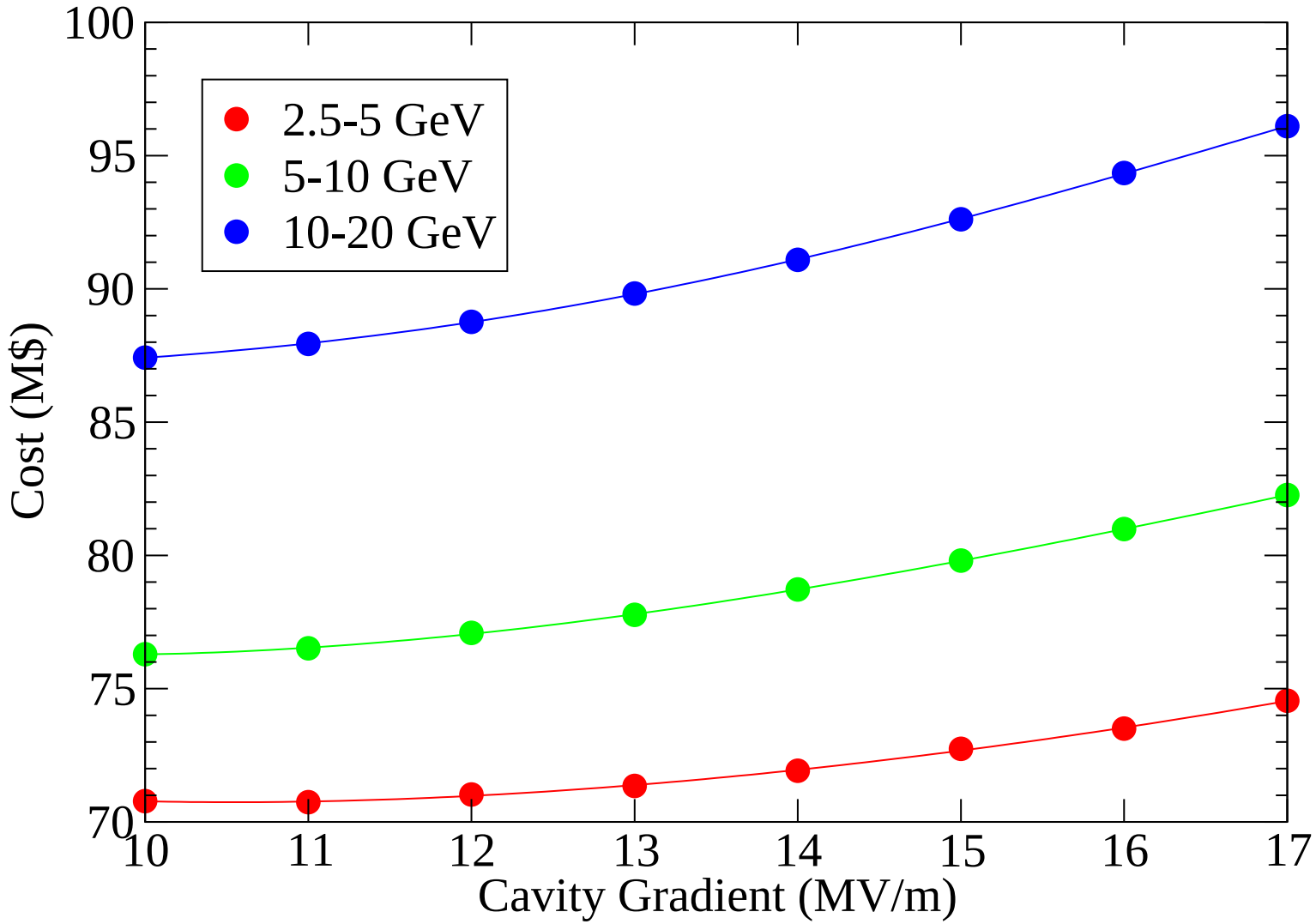
Comparison to Old Model

- Pole tip fields are up
  - Cost flattens out at low field
  - Fields still reasonable, but not the small values from before
- Circumferences are down
- Voltages are down
- Qualitatively, these seem more in accord with experience
  - Fields high but not too high
  - Circumference lower

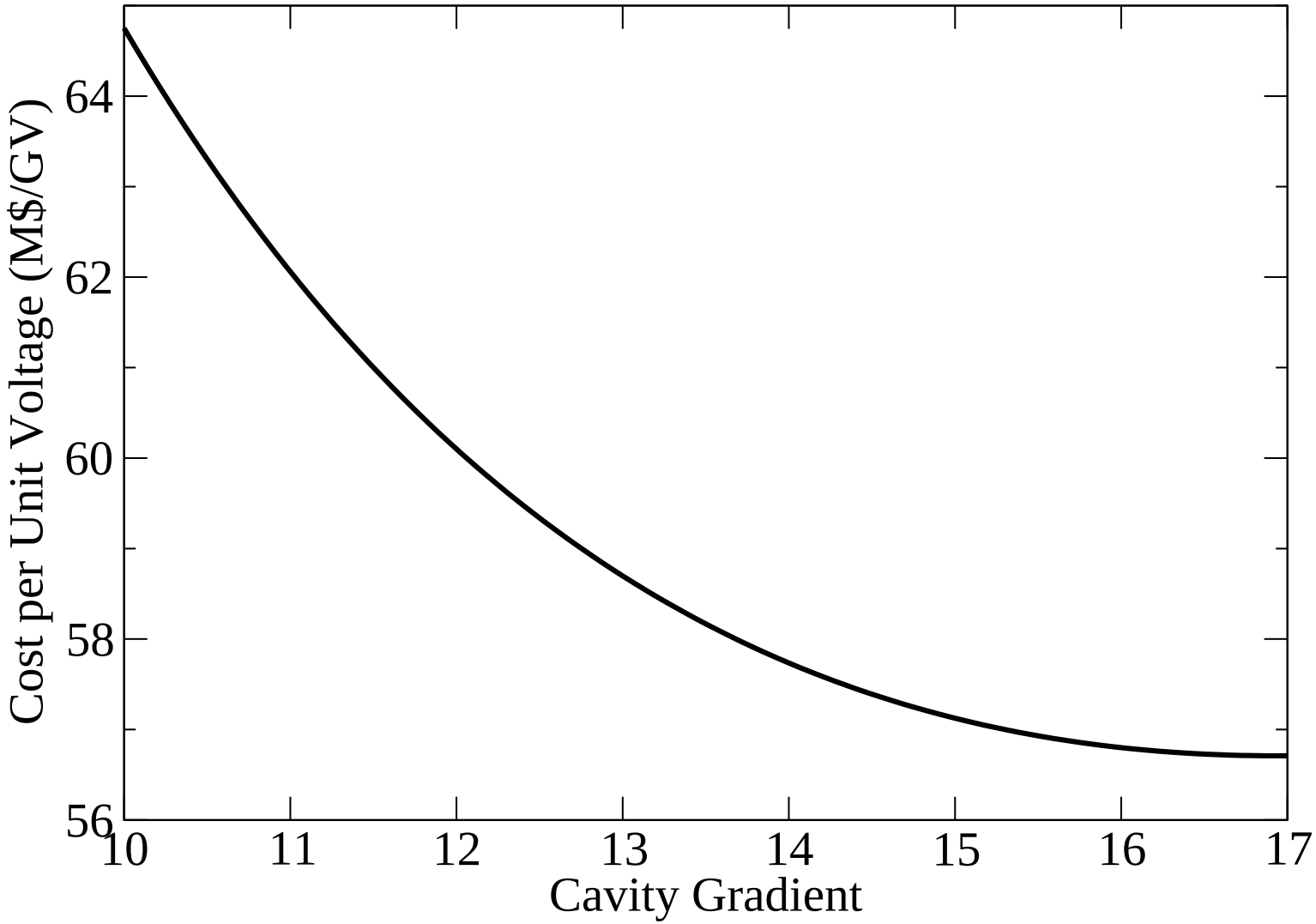
Cost Versus Voltage

- Up to now, assumed a modest 10 MV/m
- How much do we save by going to higher gradient?
- Plot cost vs. gradient
  - Increases with increasing gradient!
  - This can't be right
    - For a given voltage, optimum gradient is near 17 MV/m!
    - Get lower cost using same voltage and not filling all cells with RF
- Problem is with optimization
  - Assumed maximum number of cells filled with cavities
    - This is sometimes the right thing to do (if optimum requires too much cavity gradient)
  - Allow optimizer to determine the number of cells filled with RF at a given gradient
    - If too many cells filled, optimize as before

Plot: Cost vs. Voltage



Plot: Cavity Cost vs. Gradient



Conclusions

- With Palmer's updated cost formula:
  - Fields are higher than before
  - Lattices are shorter than before, and use less voltage
- The optimization technique I used is flawed
  - Need to allow for the possibility of many empty cells
  - General trends given above are likely to hold