Structure Proposal for Recirculating Race-Track Design of the LHeC e^- Linac

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My Problem: Conceptually

- LHeC: electron-proton collider (site of new highest-energy e-p physics)
- I have looked specifically at the e^- linac design.
- Basic design: linac will be connected to a recirculation track (why?)
- Goal: to determine a design for the linac + recirculation structure that will…

  --Optimize $$$

  --Minimize radiative energy loss

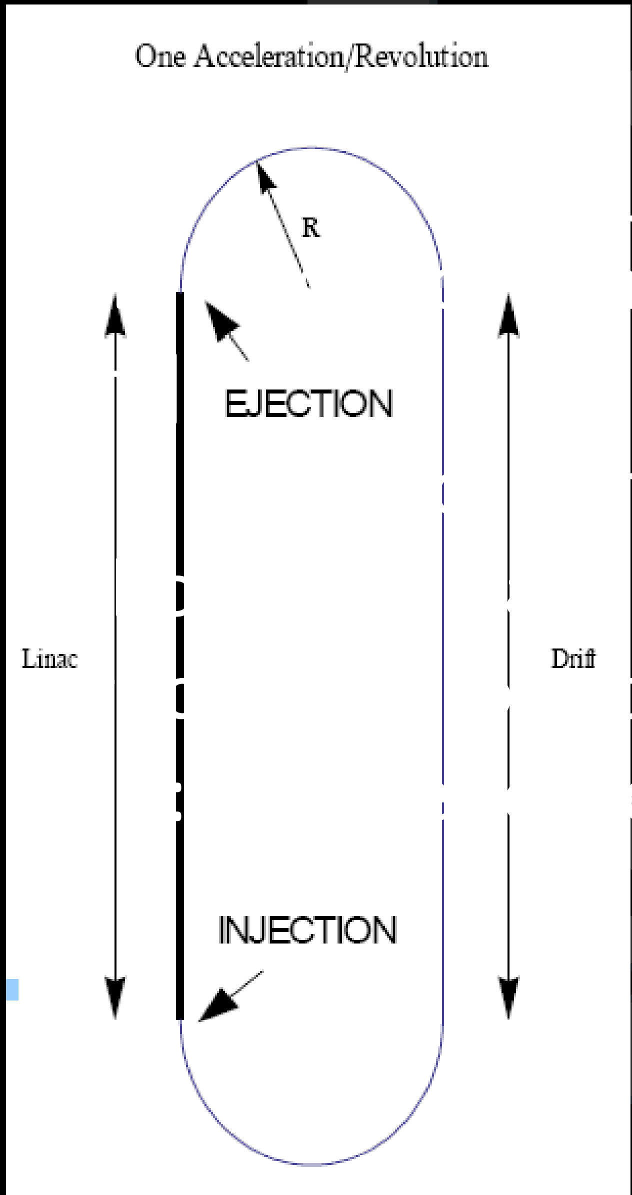
Primary Considerations in Finding Optimal Design

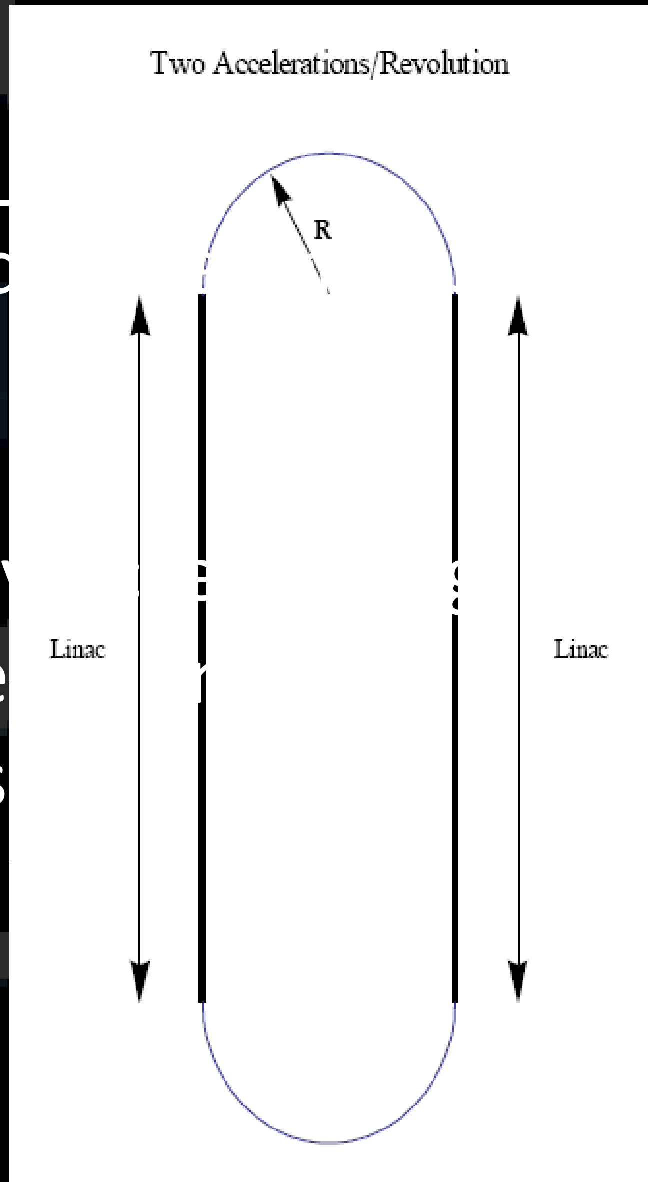
- Cost
- Structure (number of accelerations per revolution)
- Shape
- Size
- Number of revolutions
- Radiative energy loss

Secondary Considerations

- Transverse emittance growth from radiation (every effective machine must constrain this)
- Number of dipoles needed to keep upper bound on emittance growth
- Average length of dipoles
- Maximum bending dipole field needed to recirculate beam

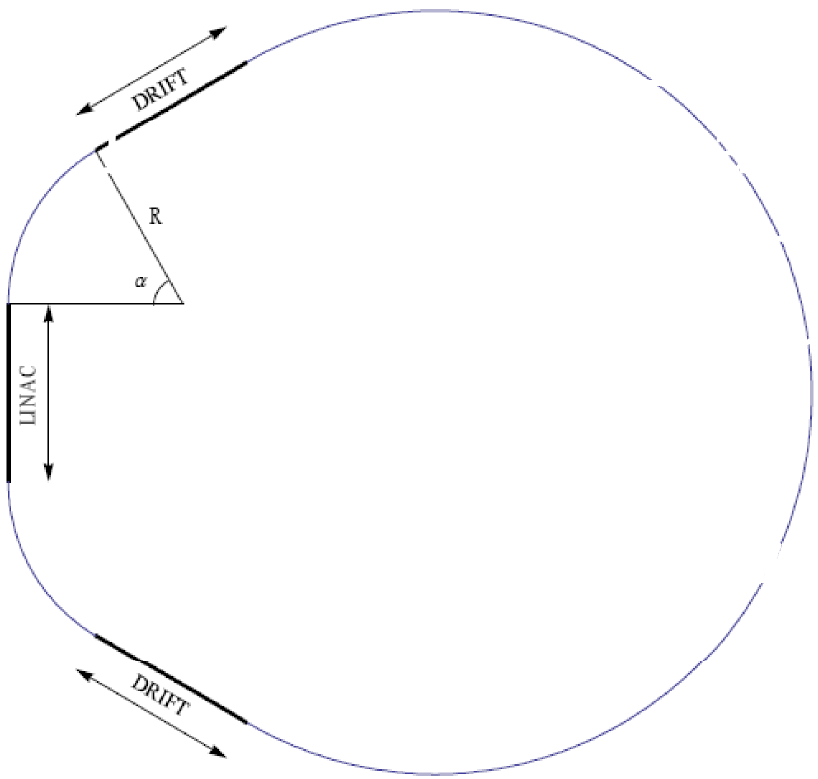
Primary Shape Studied:
The "Race Track" Design

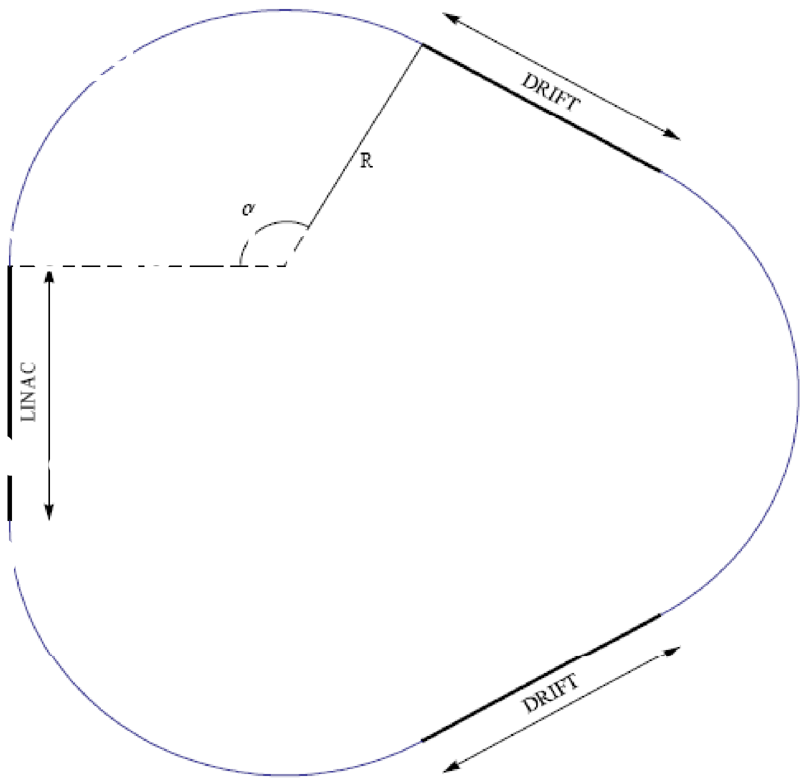




My Shape Proposal (Secondary Consideration this Summer):

The “Ball Field” Design





My Problem: Analytically

Energy Loss to Radiation:

Energy Gain in Linac:

So an e^- that passes angle θ in circular track of radius R, will experience radiation energy loss:

$$P_{syn} = \frac{e^2 c}{6 \pi \epsilon_0} \frac{1}{(m_0 c^2)^4} \frac{E^4}{R^2}$$

$$\Delta E(L) = \frac{dE}{dx} L$$

E^4 ... Where I = ... θ ... 2π R

$$\text{Where } a = \frac{e^2}{3 \epsilon_0} \frac{1}{(m_0 c^2)^4} \text{ and } dt = \frac{R d\phi}{c}$$

My Problem: Computationally (my algorithm)

- This optimization problem calls for 8 variables:
- 1. Injection energy
- 2. Target energy
- 3. Energy gradient (energy gain per meter in Linac)
- 4. No. of revolutions
- 5. bool: singly acc. structure corresponds to 0, while doubly acc. corresponds to 1
- 6. Cost of linac per meter
- 7. Cost of drift section per meter
- 8. Cost of bending track per meter

Algorithm (cont.)

- The whole goal is to reduce the cost function to 2 variables—radius and length—then minimize it
- Total Cost (R,L) =

  2π R N \$bend + (1+$\delta_{1,\ bool}$) L \$linac + $\delta_{0,\ bool}$L \$drift
- Looking at our structure, and using the energy formulas from the previous slides, you can construct a function that gives the final energy value of the e-beam, E = E (Ei, R, L, dE/dx, revs, bool)
- We now have the necessary restriction to our optimization problem: the final energy for the dimensions (R and L) must equal the target energy.

The Parameters Used

- 1. Injection energy = 500MeV
- 2. Target energy = {20, 40, 60, 80, 100, 120} GeV
- 3. Energy gradient = 15 MeV/m
- 4. No. of revolutions: trials from 1 to 8
- 5. bool: trials with both 0, 1
- 6. Cost of linac per meter = $160k/m
- 7. Cost of drift section per meter = $15k/m
- 8. Cost of bending track per meter = $50k/m

But how do we minimize energy loss?

- Create “effective cost,” which incorporates a weight parameter that gives a cost per unit energy loss
- Effective Cost = Total Cost + $\lambda \times |\Delta E_{rad}|$
- Minimize this!!
- Now you have the dual effect: optimize cost and, to the variable extent of the weight parameter, minimize energy loss

Key Results

- Across range of target energies and λ values studied, found singly-accelerating structure to be optimal for both total cost and total effective cost
- Other optimal parameters (radius, length, number of revolution) depend on target energy and λ value chosen

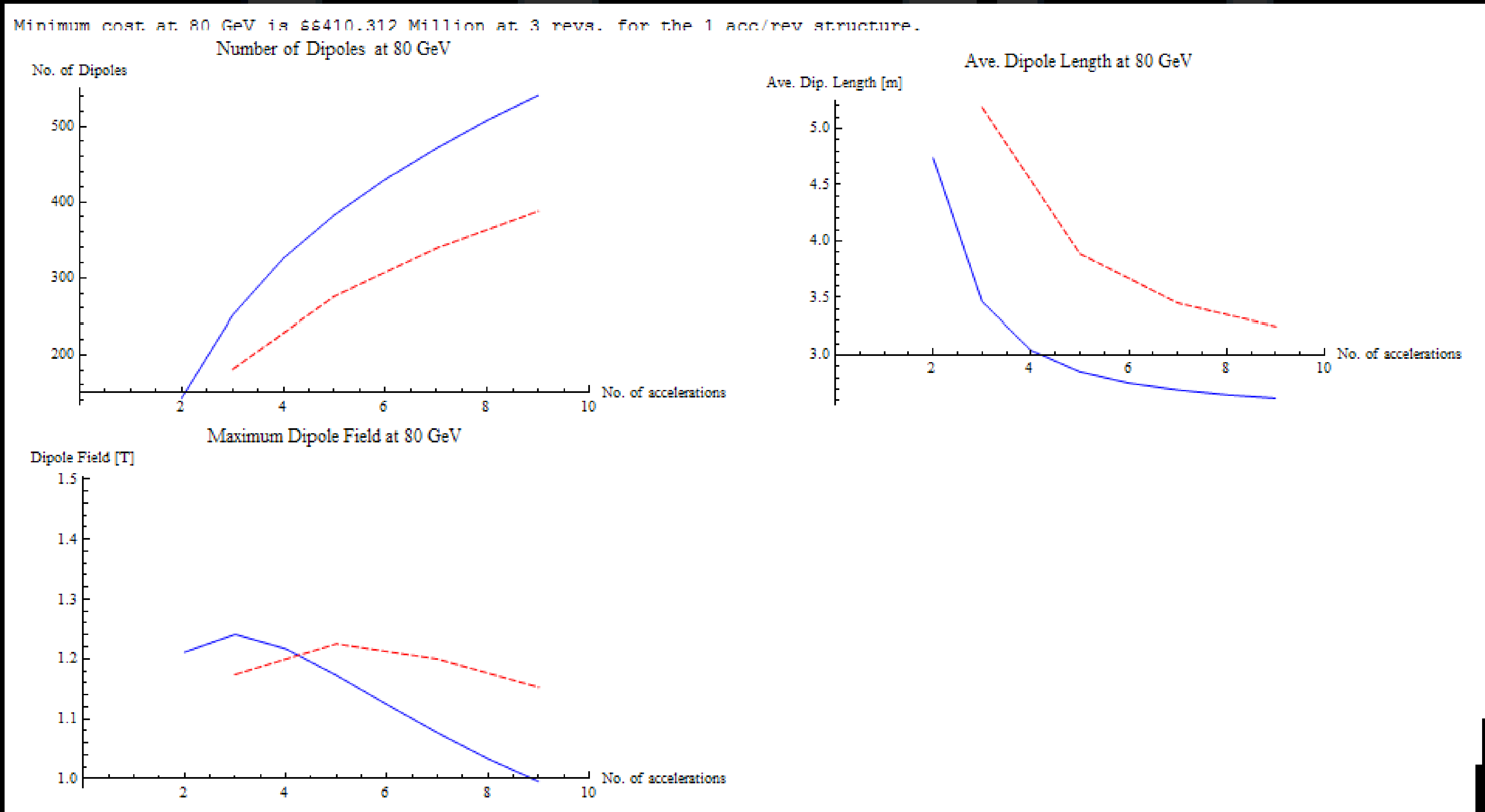
Optimal Cost Results
(optimal number of revolutions)

λ / E_t	20	40	60	80	100	120
0	8	6	4	3	3	3
1	8	5	4	3	3	2
10	7	4	3	3	2	2
100	4	2	2	2	1	1
1000	2	1	1	1	1	1
10000	1	1	1	1	1	1

Optimal Effective Cost Results

λ / E_t	20	40	60	80	100	120
0	8	6	4	3	3	3
1	7	5	4	3	3	2
10	5	3	2	2	2	1
100	3	2	1	1	1	1
1000	1	1	1	1	1	1
10000	1	1	1	1	1	1

Sample Result
E = 80 GeV, λ = $10 million/GeV



Limitations

- Assumes cost of bending track independent of size of bend. In reality, the cost of a bending magnet increases with the dipole strength, k $\propto 1/R$.
- Model does not yet consider a detailed lattice structure or any aspects of beam dynamics. It gives a "first look" at optimal structure by analyzing macroscopic effects (cost, energy loss, etc).
- Model does not yet consider operating cost.

Questions?


Genève, je te manquerai!!!

Acknowledgements

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