Dogbone RLA Design

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Outline

- Quick introduction
- Beam loading
- Droplet arc design
- Longitudinal emittance growth
- Machine designs
- Conclusions

RLA to 63 GeV

- Accelerate from 5 to 63 GeV
- Use dogbone RLA
- Tolerate 10% emittance growth (original spec: 6%)

N	2×10^{12}	4×10^{12}	2×10^{12}
$\epsilon_{\parallel}$ (mm)	1.5	1.5	70

Beam Loading

- No time to top of RF: run on stored energy
- Can tolerate ≈ 30% voltage reduction

Passes	$\Delta V/V$ (%)	
	325 MHz	650 MHz
3	5	16
5	8	26
7	11	36
9	15	47

- 9 passes fine at 325 MHz (switchyard limited)
- 3 passes fine at 650 MHz, 5 passes marginal

Droplet Arc Design

- Sequence: match, bend out, dispersion flip, bend in

Cells	2	n_o	2	n_i	2	n_o	2
Angle	$-\theta_m/2$	$-\theta$	0	θ	0	$-\theta$	$-\theta_m/2$
Length	L_m	L	L	L	L	L	L_m

- All cells $\pi/2$ phase advance
- $n_i = 5n_o + 8$, $L_m \approx L$, and $\theta_m \approx \theta \approx \pi/(3n_o + 6)$
- Longitudinal behavior determined by n_o and average bend field

$$T_1 \equiv \frac{dT}{dE} \approx \frac{7L\theta^2(7n_o+9)}{16pc^2} \approx \frac{7\pi^3(7n_o+9)}{432(n_o+2)^3qBc^2}$$

Longitudinal Emittance Growth

- Based on nonlinear ellipse distortion
  - Assumes full filamentation, less for partial filamentation
  - Lowest order, possibly worse with higher order

$$\frac{\Delta\epsilon}{\epsilon} = \frac{5}{48}\frac{U^2\omega^4T_1^3\epsilon}{\mu^2\sin^3\mu}\frac{\langle J^2\rangle}{\epsilon^2} \qquad 2\sin\frac{\mu}{2} = \sqrt{T_1 U\omega\tan\phi}$$

- Design energy gain U per pass, RF phase ϕ
- Worse at higher RF frequencies, larger T_1
- Prefer larger values of $\mu^2\sin^3\mu$
  - $\sin\mu$ and $\sin(\mu/2)$ arise from lumped RF
  - $\mu^2\sin^3\mu < 3.06$, reached when $\mu \approx 1.91$
    - RF bucket edges break up when $\mu > 1$

Machine Design

- Choose $\mu \approx 1.91$
- Make arc cell lengths in first pass similar to minimum linac cell length
  - Keep linac-to-arc match smooth
  - Arc cells will need to be longer in reality
    - Large initial energy gain: can't have $\pi/2$ phase advance at end of first linac pass
    - Quad lengths not counted in linac cell lengths

f_{RF} (MHz)	ϕ (deg.)	n_o	B (T)	L_{arc} (km)	L_{lin} (km)	G (MV/m)
325	25	12	0.44	16.6	0.9	2.5
650	22	24	0.68	2.5	1.6	8.4

Conclusions

- Longitudinal dynamics: 325 MHz worse than 650 MHz
- 650 MHz looks acceptable, but:
  - Requires long arcs, with lots of cells (184!)
  - Large energy gain in first linac pass will require longer arc cells
    - Betatron phase advance less than $\pi/2$ at end first pass
    - Longer $\pi/2$ arc cells to match beta functions
- Racetrack geometry is likely better
  - Limited by longitudinal phase advance per pass
  - Downside is more complex switchyard
- Check if emittance growth calculations are pessimistic for small number of passes