Driver distribution in a multistage plasma-based accelerator facility

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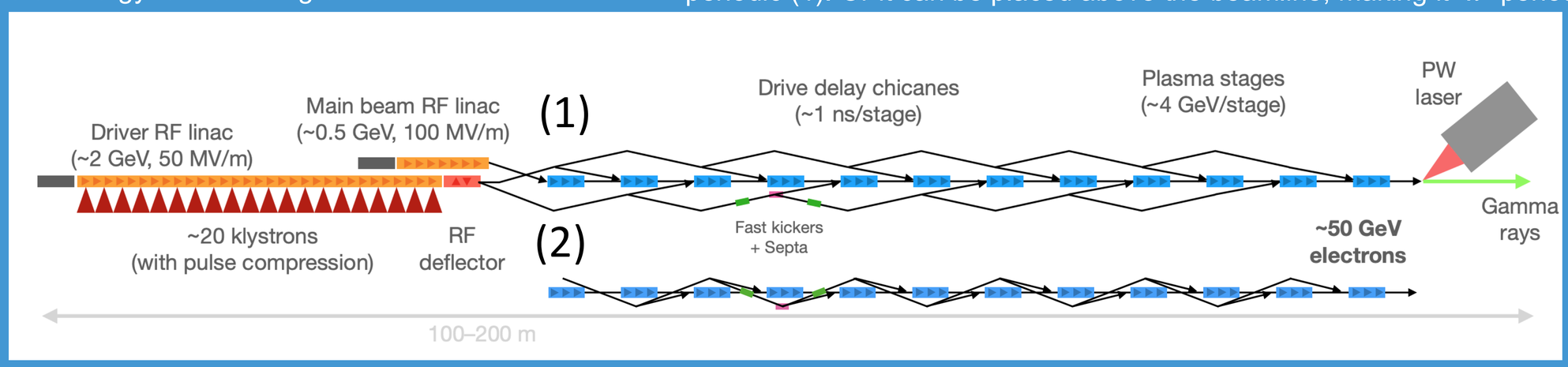
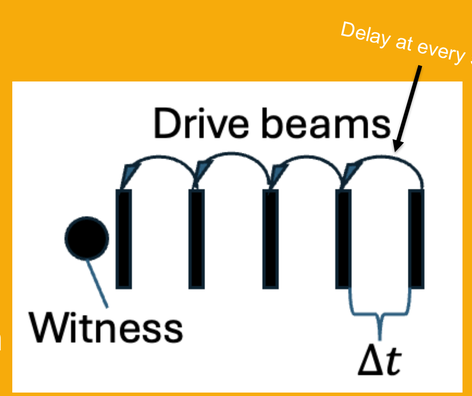
1. Introduction — the SPARTA project

- The SPARTA project [1,2] plans to design a plasma-based accelerator facility to do SFQED experiments.
- We consider using electrons to drive strong wakes in the plasma, allowing for high accelerating gradients (~1 GV/m).
- Our current conceptual design uses 8–16 plasma stages to transfer energy to the trailing bunch.
- Staging requires us to introduce a delay for all electron drivers but one (the first).
- There are several ways of designing a delay chicane, here we present one possible solution, an oscillating chicane [3].
- The longer delay, the lower the peak power in the RF accelerator, resulting in fewer klystrons and lower cost.
- Two chicanes can be placed on each side of the main beamline, making it "2π" periodic (1). Or it can be placed above the beamline, making it "π" periodic (2).



2. Why do we need delay?

- It is Important to keep same phase between driver and trailing bunch.
- All drivers must be delayed by the same amount for every stage.
- By the n^{th} stage, the n^{th} driver will have been delayed n-1 times, adding up to total delay of $\Delta t(n-1)$

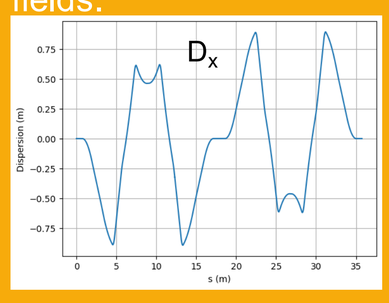


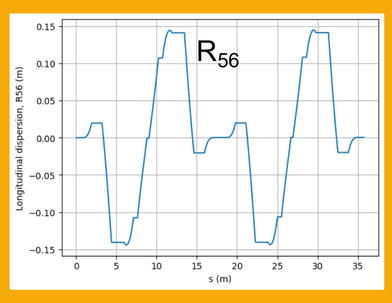
3. Matching and optics requirements

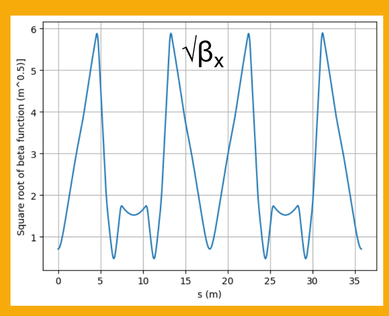
- To make the beam suitable for kickers, we want dispersion to be zero:

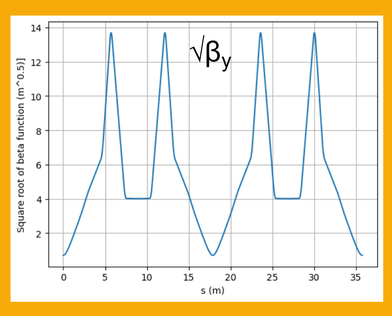
  $D_x = 0$
- To make the beam consistent throughout the beamline, we need periodic beam parameters and a constant bunch length:

  $\beta_x = \beta_{x,0} \qquad \beta_y = \beta_{y,0} \qquad R_{56} = 0$
- Below is the result of matching 5 quadrupoles and a dipole. A mirror symmetric lattice is added, and this total lattice is repeated once with dipoles of opposite magnetic fields.



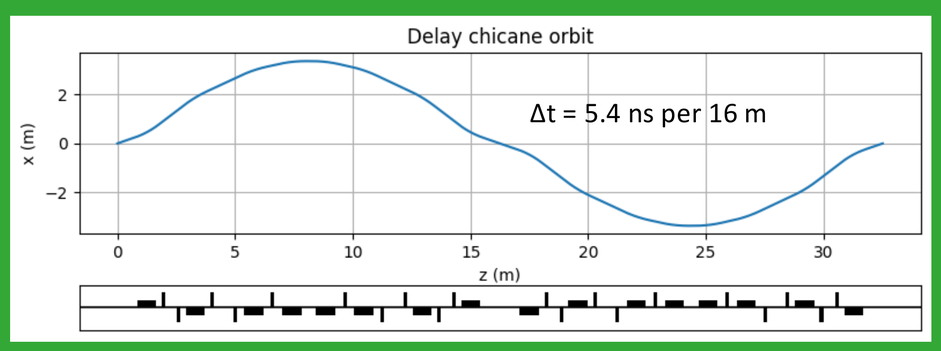






4. The oscillating chicane beamline

- This solution fulfills our requirements from section 3 and has a delay of 5.4 ns per stage.
- The current solution (work in progress) is ~16 m per stage, projected longitudinally, but should be made shorter.
- Dipole number 1, 8, 9 and 16 are 1.8 T, with the rest being 1.2 T.



5. Challenges

- The required number of quadrupoles, and the required space between them, means we get a long chicane with small β-functions. Ideally, it would be shorter.
- We have not accounted for chromatic effects so far; we may need to include sextupoles to cancel chromaticity.
- The chicane is very wide (~6m) and will contribute to cost when building tunnels, especially in option (1) (see top figure).

6. Conclusion and Outlook

- We have shown a delay chicane that achieves 5.4 ns delay in ~16 m.
- Although a long delay is good, a shorter chicane would be even better. This is hard to achieve due to the number of quadrupoles required.
- Next steps are to include the effects of second order dispersion, chromaticity, ISR and CSR.
- This solution is only one way of delaying drive beams, but more will be investigated in the future.

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Contribution ID: 470

7th European Advanced Accelerator Conference

References:

[1] European Commission, "Staging of plasma accelerators for realizing timely applications" (2023).

[2] C.A. Lindstrøm et al., "The SPARTA project: toward a demonstrator facility for multistage plasma acceleration", Proc. 16th Int. Particle Accelerator Conf. (IPAC'25), Taipei, Taiwan, June 2025, p. 1586.

[3] Adli et al. "A Beam Driven Plasma-Wakefield Linear Collider: From Higgs Factory to Multi-TeV" (2013), arxiv:1308:1145.

European Research Council
Established by the European Commission

The project is funded by the European Research Council (project SPARTA, ERC Grant Agreement No. 101116161).