

MOO1T02

The Ghost Collider: An innovative Higgs Factory

R. Apsimon

on behalf of the Ghost Collider consortium:

A. Hutton¹, P. Williams^{2,4}, R. Apsimon^{3,4}, B. R. Gamage¹, M. Joshi^{3,4}, K. Yokoya⁵

¹Jefferson Lab, 12000 Jefferson Ave., Newport News, 23693, USA

²STFC, Accelerator Science and Technology Centre (ASTeC), Daresbury, UK

³Lancaster University, Lancaster, LA1 4YW, UK

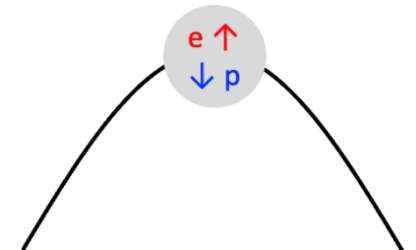
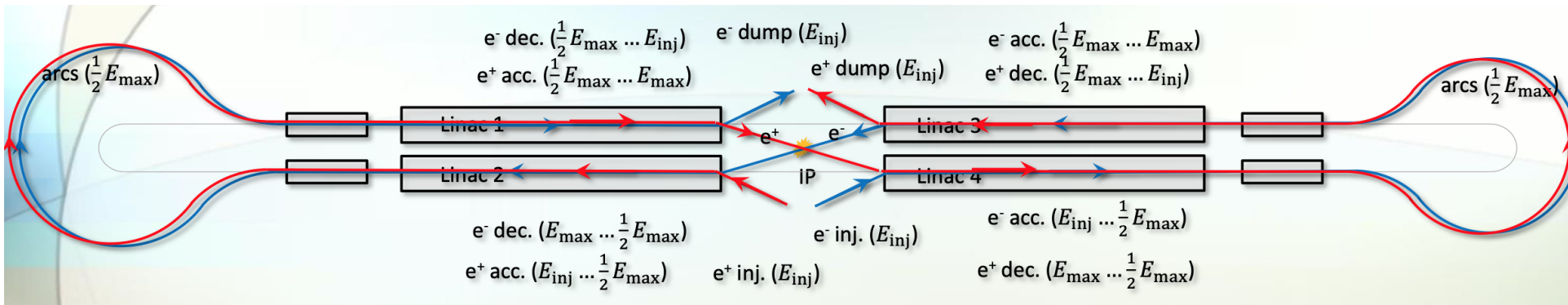
⁴Cockcroft Institute, Daresbury Laboratory, Daresbury, UK

⁵KEK, Tsukuba, Japan



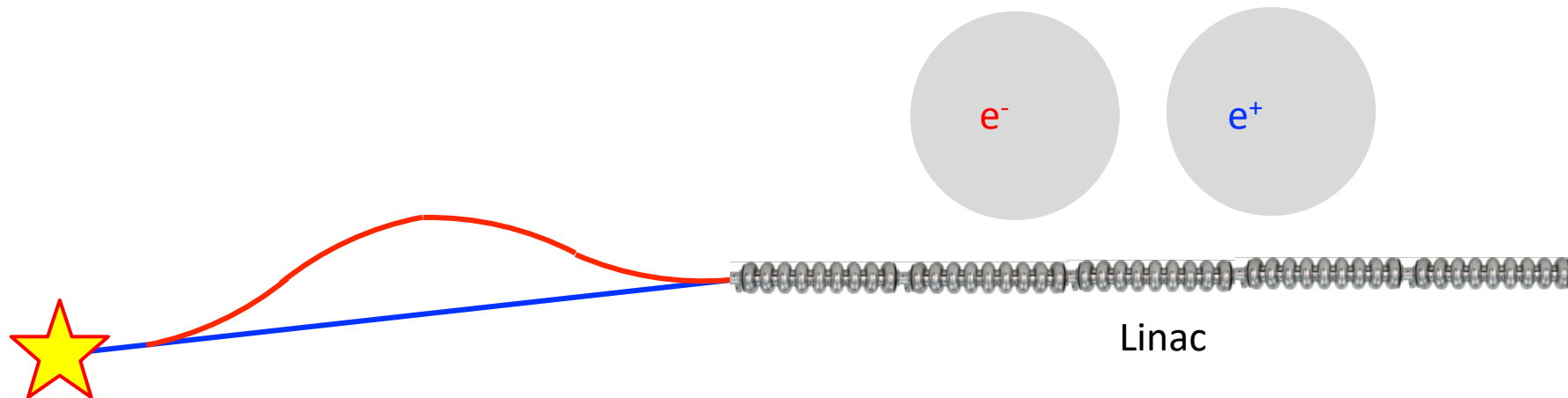
What is the Ghost Collider?

- An energy recovery linac where energy exchanged between e^- and e^+ at the same phase
 - Energy recovery in conventional ERLs require electron bunches which are 180° out of phase with each other
 - The Ghost Collider (GC) is an entirely new class of ERL technology, where energy recover occurs intra-bunch
 - All particles recycled, thus e^+ source requirements similar to storage rings
- Bunches in the GC comprised of equal numbers of e^- and e^+ , creating electrically neutral bunches
 - We refer to these as “ghost bunches”
 - No beam loading of the accelerating mode in the linacs
 - Conventional ERLs rely on beam loading
- Design concept inspired by previous work by Valeri Telnov and Erk Jensen



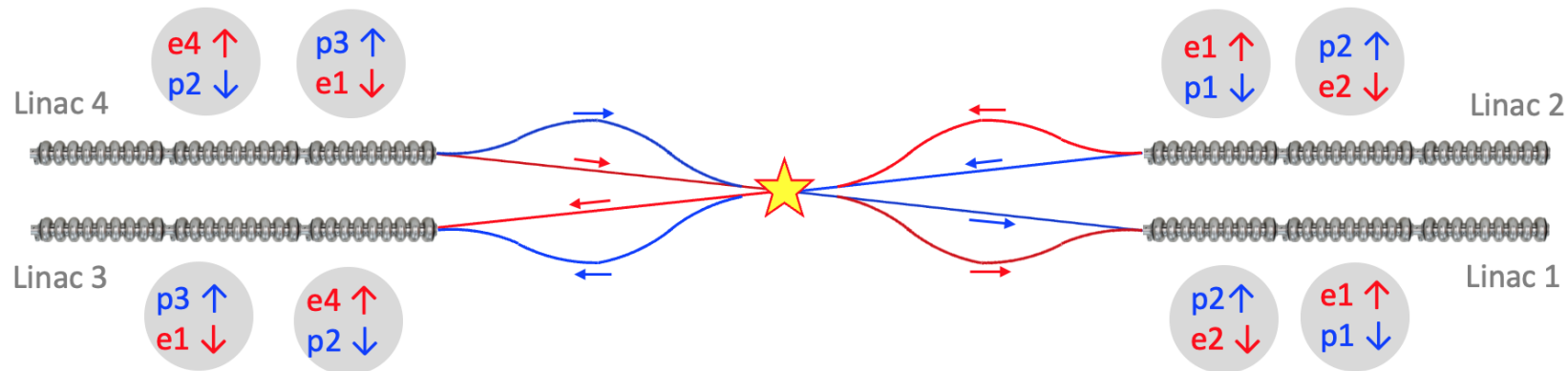
Interaction region delay concept

- Bunches in the linacs have alternating accelerating electrons and positrons
 - At the end of the linac, the low energy bunches are extracted and the high energy ones are collided
 - We want to create ghost bunches of high energy positrons and electrons
 - Need to delay one to overlap with the other before IP, then separate them before passing into the decelerating linac
- Let's say high energy electrons are in one bucket and positrons in the next bucket, separated by $\lambda_{linac}/2$
 - Need to introduce a chicane to delay the electrons by $\lambda_{linac}/2$



Interaction region delay concept

- After the IP, we need another chicane to delay the positrons by $\lambda_{linac}/2$ to allow for deceleration
 - In total, we need four chicanes
 - This layout means each electron and positron bunch passes through one chicane
 - Restores symmetry to the bunches, balancing chromatic effects

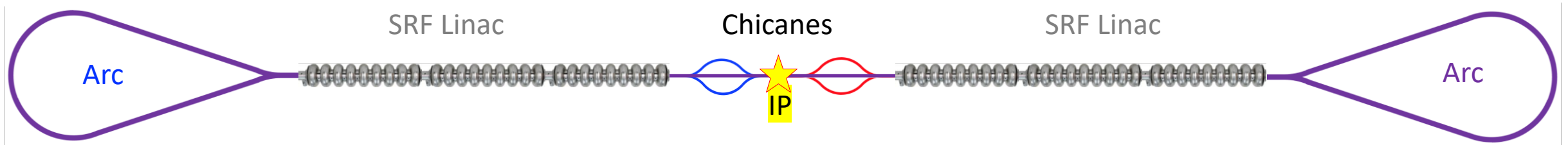


Ghost collisions

- A ghost bunch (e^- and e^+ in a single bunch) are brought into collision with another ghost bunch
- First tried (unsuccessfully) at Orsay by the DCI Storage Ring Group
 - Further theoretical studies concluded that the neutral bunch plasmas were in an unstable equilibrium
- All considered moderately high disruption parameters (between 5 and 10)
 - Incompatible with storage ring equilibrium
 - For GC, bunches are recycled as positron production rates are too low
 - High disruption parameters would make it impossible to damp the beam again quickly enough
- Theoretical studies indicate that GC would operate in a stable regime
- Choose to go for round beams to minimise disruption parameter for a given luminosity
 - Neutral bunch collisions eliminate disruption parameter to first order

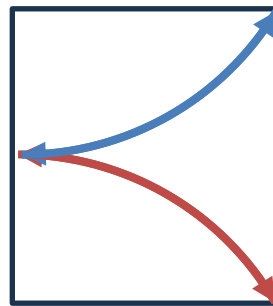
Single linac

- Ghost bunches have much reduced electromagnetic interaction with counter-propagating ghost bunches
 - This allows for a major simplification: a single, bi-directional linac on each side of the IP
 - There will be head-on collisions in the linac, but the luminosity will be low, as will the disruption parameter
 - Electrons and positrons accelerated in both directions in one linac and decelerated in the other linac
- Based on ILC technology, each linac would only need to be half the length due to the dual pass scheme.
- Counterpropagating ghost bunches have, to first order, no quadrupolar beam-beam focusing
 - A second order dipolar charge separation instability exists, which is currently under study



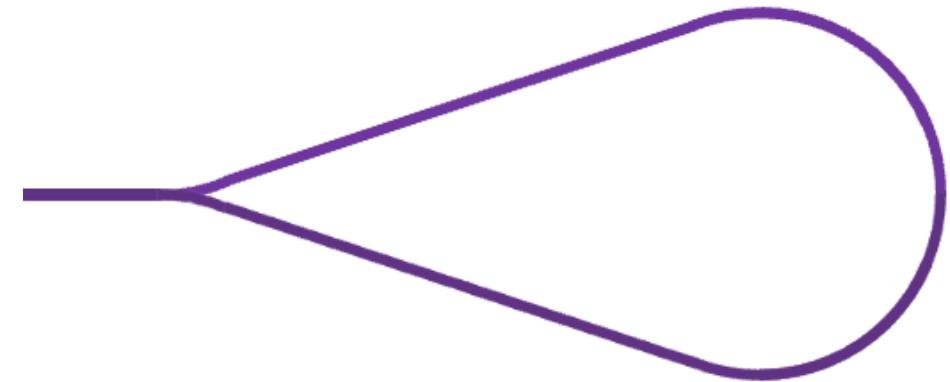
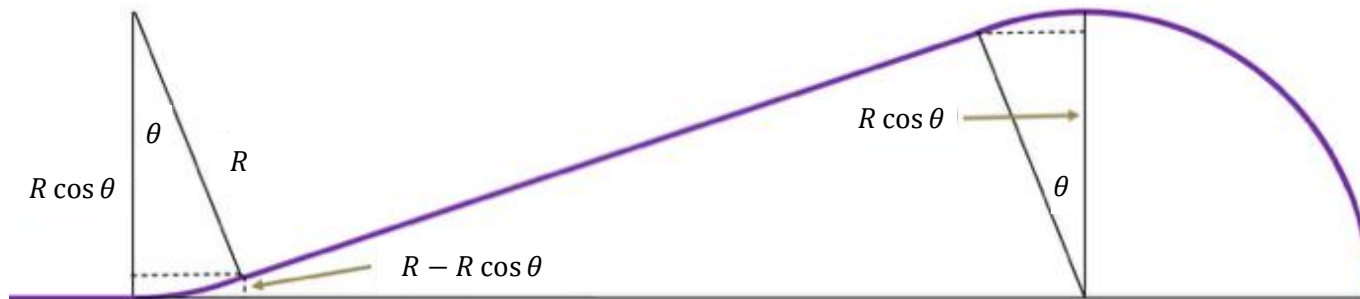
Turnaround arcs

- One technical challenge faced with the Ghost Collider are how to turn around both e^- and e^+
 - Both deflected in the opposite direction by any electromagnetic elements
 - However, if electrons and positrons pass through a dipole in opposite directions they will follow the same trajectory.
 - Now if we join everything together, we have a turnaround arc to accommodate both charge species



Turnaround arcs

- The arcs are a tear-drop shape
 - The straight sections avoid the need for additional bending at the expense of additional length
 - The total bending angle is $\theta_{tot} = 180^\circ + 4\theta$
- The current design opts for $\theta = 22.5^\circ$ and a bending radius of 3,096 m
 - With a filling factor of 88%, this gives an arc radius of 3,500 m, which is the same as LEP
- Reduces synchrotron radiation loss by 38% compared to traditional arc shape

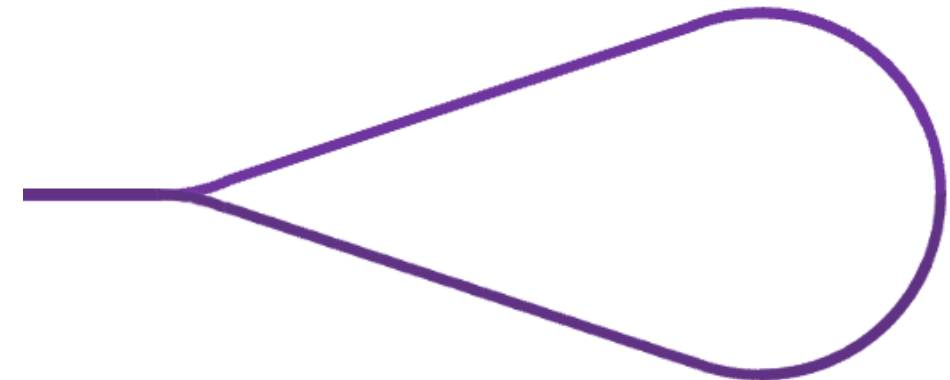
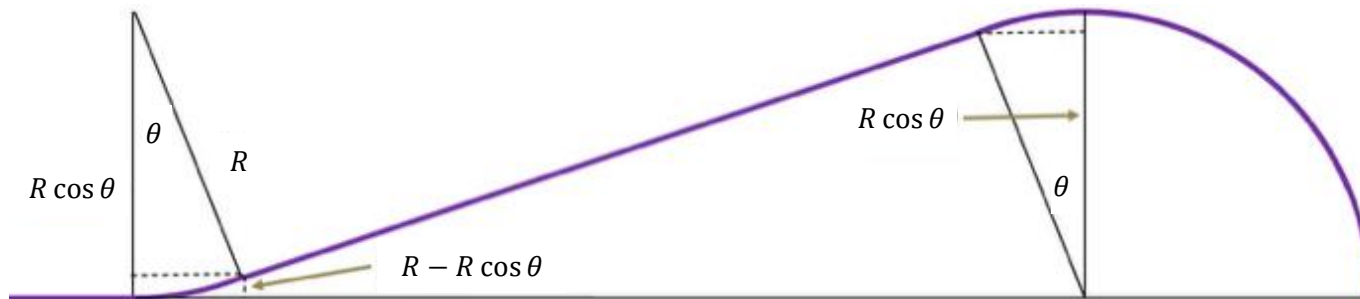


Turnaround arcs

- The electrons have 5 GeV at injection and a peak energy of 275 GeV
 - In the arcs they are at 140 GeV
- For a full 360° arc, the synchrotron radiation loss is:

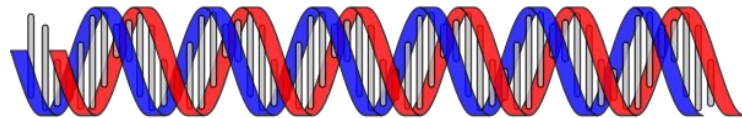
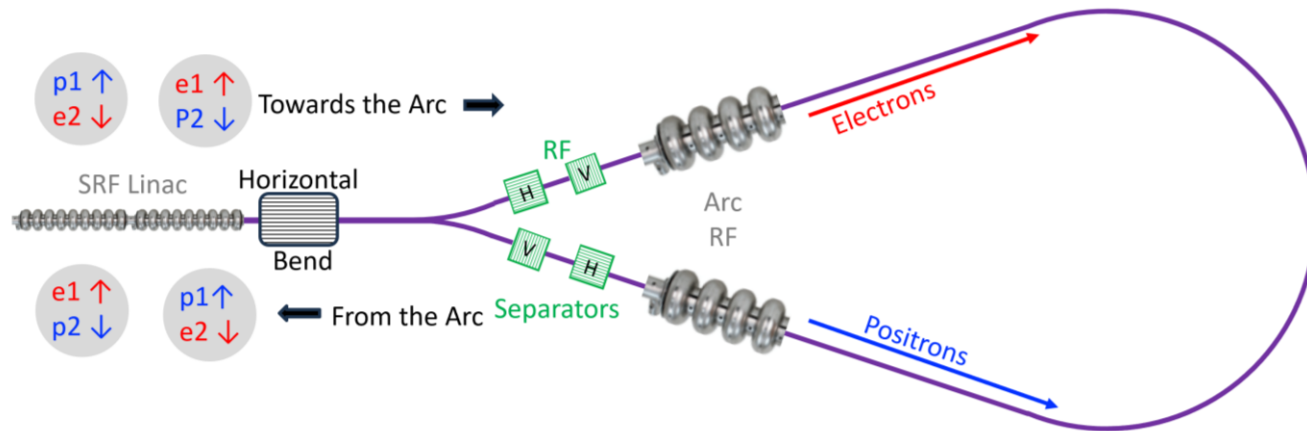
$$U = 8.85 \times 10^{-5} \frac{E^4}{\rho} = 11 \text{ GeV}$$

- The tear-drop design only complete 270° of an arc, so the synchrotron radiation loss per arc is 8.24 GeV
 - This loss needs to be compensated by placing low frequency RF cavities in the straight sections of the arcs



Arc-Linac interface

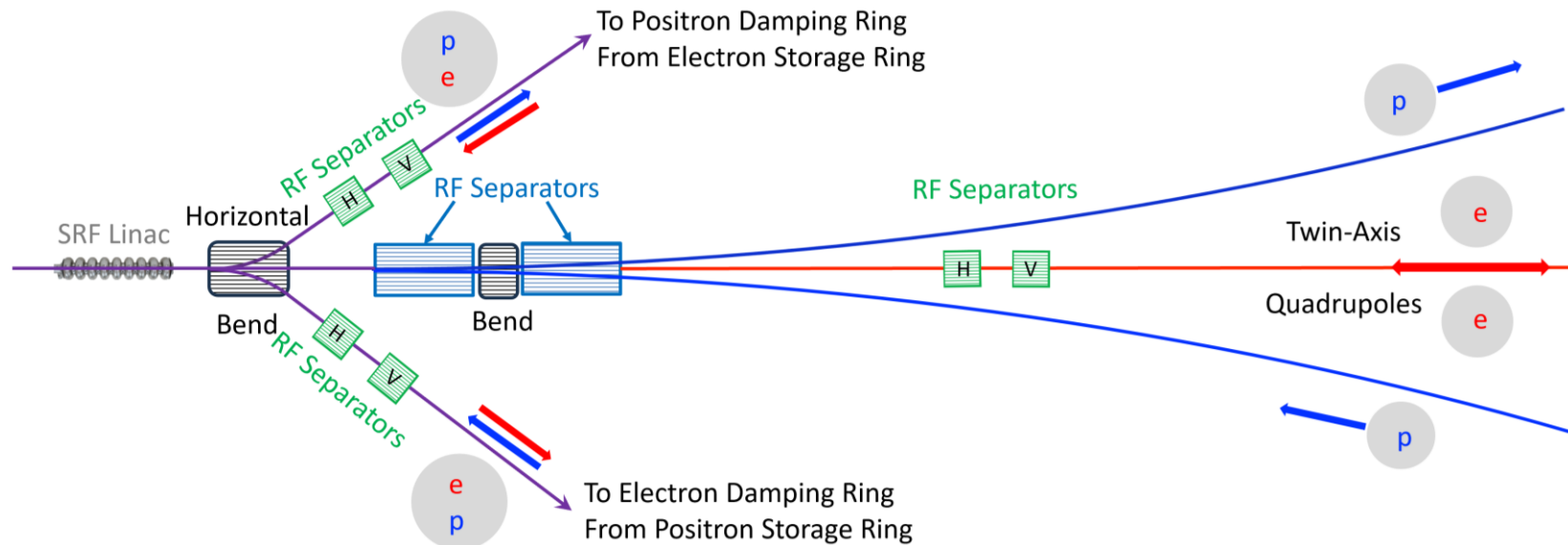
- Electrons and positrons counter-propagating around the arc
 - Electromagnetic forces during collisions would severely degrade the beam quality
- RF separators used to establish helical paths through the arcs, allowing counter-propagating bunches to avoid each other
 - This configuration has been used to great effect at Tevatron



The electron and positron trajectories are like the strands of DNA or the famous double staircase at the Chateau de Chambord in France, designed by Leonardo da Vinci

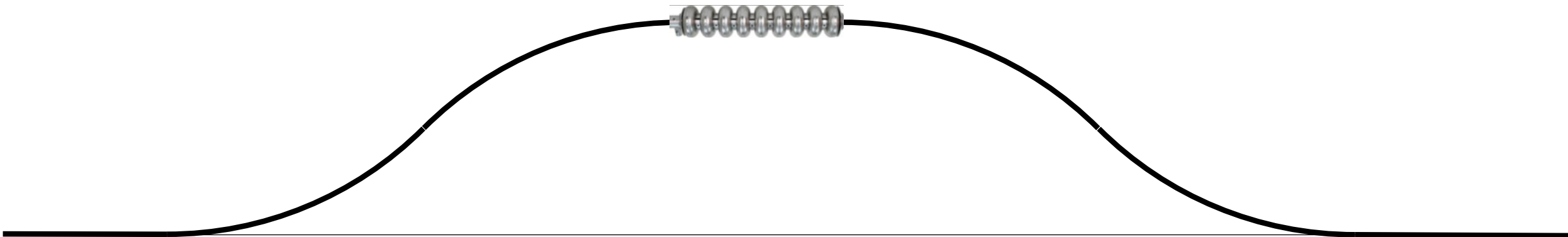
The Linac-Chicane Interface

- Bending magnet deflects allows for injection/extraction of low energy electrons and positrons
 - Negligible kick to high-energy bunches
- RF separators to start or complete the positron chicanes while leaving electrons undeflected
 - RF separators for electrons to avoid charged beam collisions
 - The other interface deflects electrons in the chicanes rather than positrons



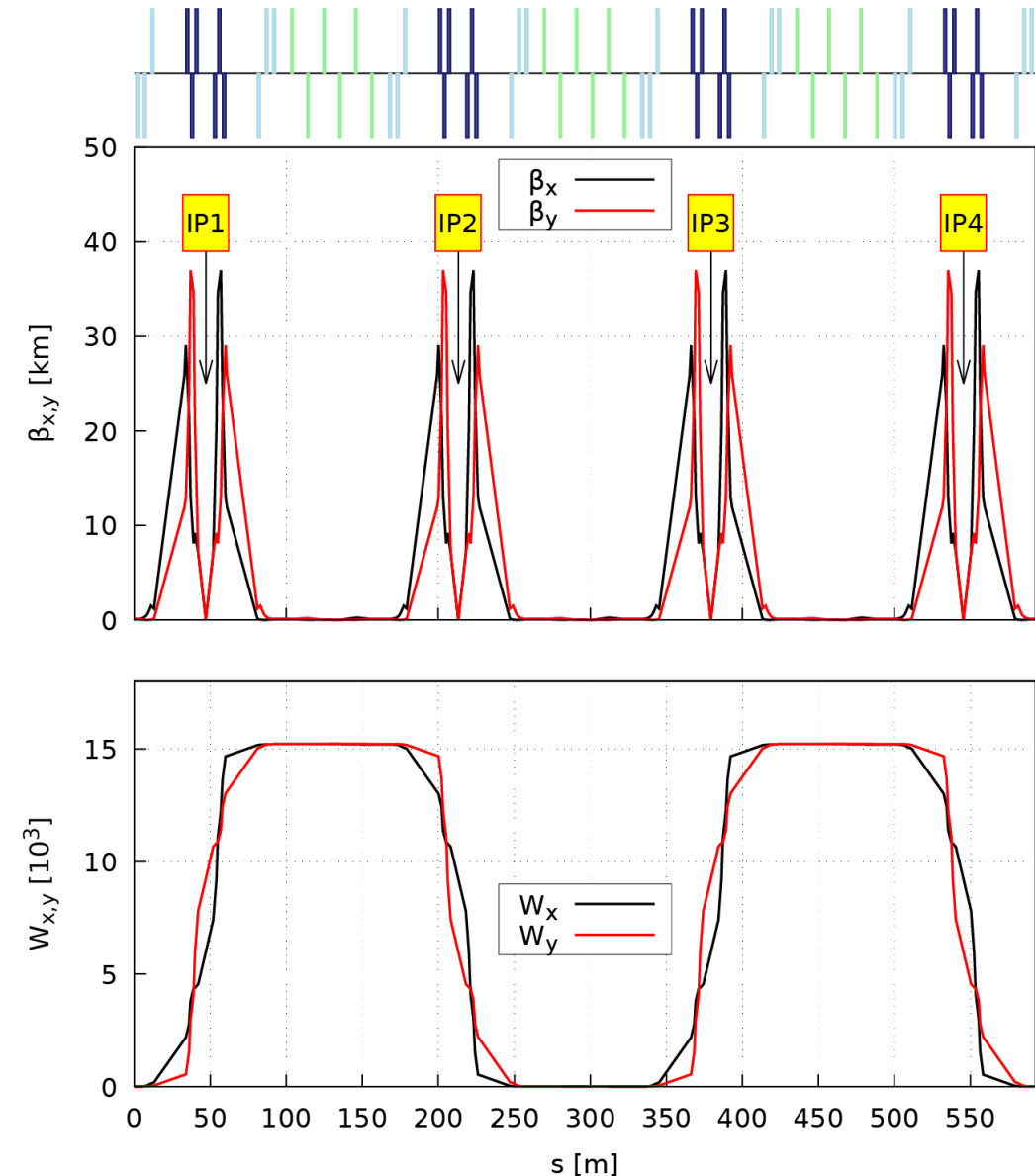
Chicane design

- The electrons and positrons need the same energy at the IP, regardless of whether they passed through a chicane or not.
 - Need another RF system to replace the energy loss from synchrotron radiation
 - Option to partially compensate the energy loss to allow us to distinguish between e^+e^- and e^+e^+/e^-e^- collisions
- For a bending radius of 12 km, the chicane length is 1.4 km
- Synchrotron radiation loss is 1 GeV



The Interaction Region

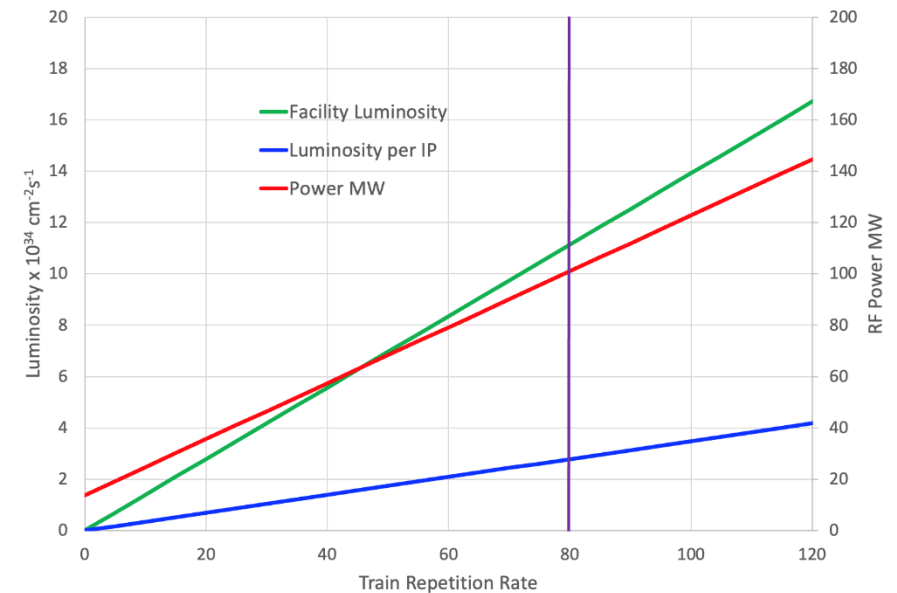
- Ghost bunches arrive from both directions at the IR, focused by the same IP quadrupoles
- Equal horizontal and vertical beta functions and emittances
 - More details in WEP1313
- Round beams give highest luminosity for a given disruption parameter
 - Reduced disruption from beam-beam collisions at IP due to neutral bunch collisions
 - Allows us to operate with four IPs in series, which allows us to quadruple the total luminosity
- No crossing angle at IPs and relatively large ($100 \mu\text{m}$) round beams to relax alignment tolerances



RF power and luminosity

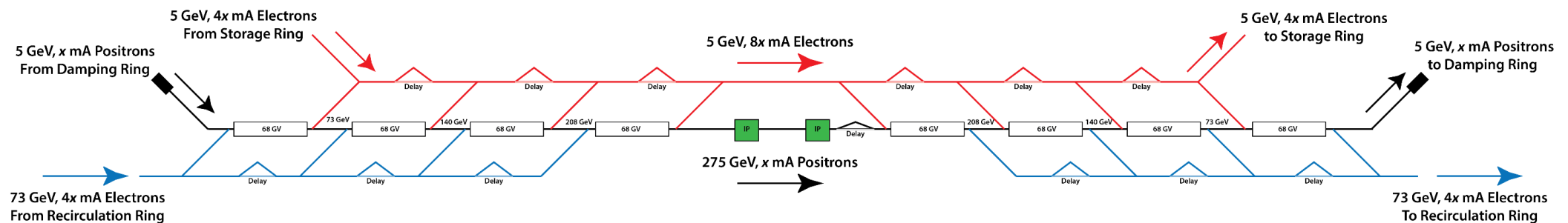
- The power required is related to the repetition rate, R
 - Train consists of 656 ghost bunches from an ILC-size damping ring
 - The RF is pulsed at the same rate with a gradient of 32 MV/m, assuming the use of an FE-FRT to reduce reflected power.
- Choose to set luminosity per IP to $1.6 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ to limit facility power consumption to 100 MW
 - Total facility luminosity is $6.3 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

Arcs & chicanes	$0.39R \text{ MW}$
Linac RF	$0.042R \text{ MW}$
Damping rings	13.8 MW
Cryogenics	$0.66R \text{ MW}$
Total	$13.8 + 1.09R \text{ MW}$



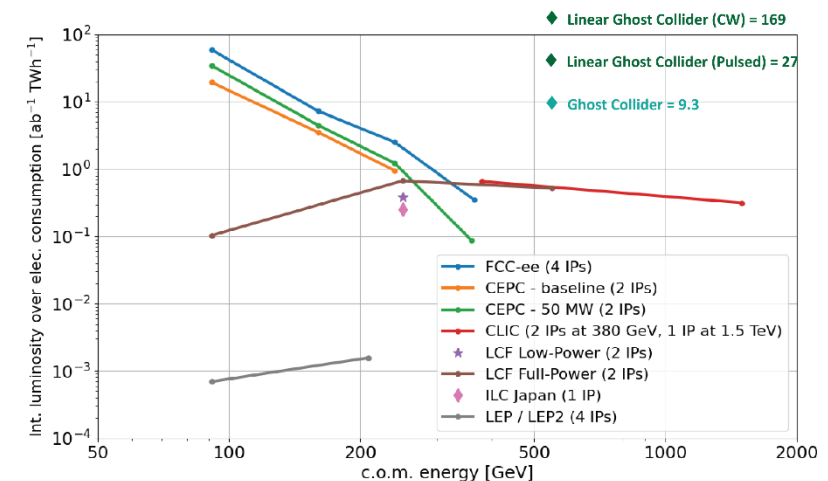
The linear Ghost Collider

- Concept developed by P. Williams (presenting a poster today – MOP1022)
- Remove the arcs by treating ghost partners as drive bunches which don't collide
 - Large reduction in SR power loss and therefore lower electrical power consumption
 - Effectively doubles the linac length
- Ghost partners need only have matching velocities, not energy
 - Allows linac to be split into n stages, with drive bunches only accelerated and recirculated at $\sim \frac{550}{n}$ GeV
 - Choose n such that recirculation and damping rings occupy same tunnel
- Large reduction in emittance and energy spread degradation
 - Reducing need for damping rings and providing higher luminosity



Conclusions

- Neutral bunches of electrons and positrons co-propagate in the same RF bucket
 - No beam loading and potentially reduced excitation of higher order modes
- Single, bidirectional linacs to accelerate/decelerate either side of IR
 - Linacs half the length of an equivalent ILC machine
- New arc shapes, reducing synchrotron radiation by 38%
- Facility luminosity of $6.3 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ to limit total power consumption to 100 MW
- Please come and visit the poster presentations on Ghost Collider work at IPAC!
 - MOP1022 – The Linear Ghost Collider: An Efficient Higgs Factory
 - WEP1313 – Chromaticity compensation of a Ghost Collider





Thank you for listening!
Questions?