

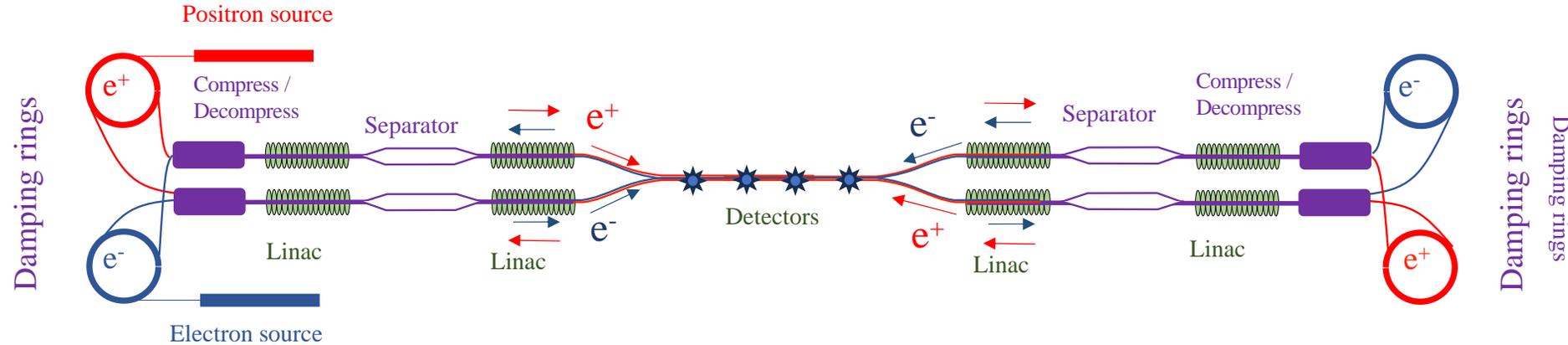
Energy and Particle Recovery Upgrades: Part 2

RLC – Recycling Linear Collider

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RLC – Polarized* Recycling Linear Collider



- RLC is two-linac version of single-linac ReLiC using space-charge compensated collision
- Collided beams are decelerated in the opposite linacs, cooled (for a portion of damping time) in damping rings and send again for next collision. This process recycles both the beam energy as well as all particles*
- Merging electron and positron beams from two parallel linacs allows to eliminate beam-beam effect
 - **Most importantly – no beamstrahlung** (*affect req energy acceptance of the rings and reduces energy resolution for collisions*)
 - No emittance growth in collisions: eases cooling requirement and focuses on polarization
- Compensated collision allow to collide beams multiple time – hence, there can be multiple detectors without reduction in luminosity
- RLC luminosity scales linearly with its c.m. energy
- RLC can operate either in CW mode or in pulsed mode, which allows to increase accelerating gradient and reaching higher energy
- RLC also delivers “free of charge” e⁺e⁺ and e⁻e⁻ collisions at ½ of e⁻e⁺ luminosity – may be of interest for BSM studies?

* RLC recycles polarized electrons and positrons via Sokolov-Ternov polarization in the damping rings.

* With lifetime aimed at ~ 10 hours, necessary replacement of electrons and positrons is at 1 nA level

CW RCL parameters

	ILC	RLC ¹	RLC ²	RLC ³	RLC ³
Center-of-mass energy, GeV	250	250	250	250	500
Accelerating gradient, MV/m	31.5	18	18	18	27
SRF cavity Q, $\times 10^{10}$	1	4	4	3	3
LiHe temperature, K	2	2	2	4.5	4.5
Particles per bunch, $\times 10^{10}$	2	4	4	4	4
Collision frequency, MHz	2.71	0.025	0.025	0.025	0.025
Duty factor	0.0012	CW	CW	CW	CW
Bunch length, mm	0.3	0.3	0.3	0.3	0.3
Beam current, all beams, mA	0.04 (34)	0.64	0.64	0.64	0.64
Normalized emittance, (h μ m)/(v,nm)	5/25	5/2.5	5/2.5	5/2.5	5/2.5
β_h / β_v , mm	13/0.41	0.41	0.41	0.41	0.41
Beam size at IP(x/y), nm	520/7.7	93/2.1	93/2.1	93/2.1	65/1.5
Disruption parameter (x/y)	0.5/34.5	0/0	0/0	0/0	0/0
Y max	0.068	0	0	0	0
e^+e^- luminosity/detector, $10^{34} \text{ cm}^{-2}\text{sec}^{-1}$	1.35	284	284	284	568
e^+e^+, e^-e^- luminosity/detector, $10^{34} \text{ cm}^{-2}\text{sec}^{-1}$	N/A	142	142	142	284
Site power, MW	111	~220	~110	~110	~290

¹ RLC based on current “conventional” Nb SW SRF technology [5], Cryo system – 200 MW, DRs - 4 MW

² ReLiC based on Nb SW SRF technology, **but COP of 2K LiHe refrigerators improved 2-fold**
Cryogenics system – 100 MW, damping rings - 4 MW + others

³ ReLiC based on futuristic **SRF technology for Nb₃Sn SW cavity with Q=3e10**

250 GeV: Cryogenics system – 100 MW, damping rings - 4 MW

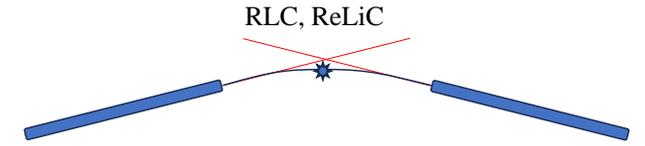
500 GeV: Cryogenics system – 225 MW, damping rings - 4 MW, need linac tunnel ~ 25 km

Pulsed RCL parameters

	RLC ¹	RLC ²	RLC ³	RLC ³	RLC ³
Center-of-mass energy, GeV	250	500	250	500	700
Accelerating gradient, MV/m	18	27	18	27	40
SRF cavity Q, $\times 10^{10}$	4	4	3	3	3
LiHe temperature, K	2	2	4.5	4.5	4.5
Particles per bunch, $\times 10^{10}$	4	4	4	4	4
Collision frequency, MHz	0.025	0.025	0.025	0.025	0.025
Duty factor	0.5	0.5	0.5	0.5	0.25
Bunch length, mm	0.3	0.3	0.3	0.3	0.3
Beam current, all beams, mA	0.64	0.64	0.64	0.64	0.64
Normalized emittance, (h μ m)/(v,nm)	5/2.5	5/2.5	5/2.5	5/2.5	5/2.5
β_h / β_v , mm	0.41	0.41	0.41	0.41	0.41
Beam size at IP(x/y), nm	93/2.1	65/1.5	93/2.1	65/1.5	55/1.3
Disruption parameter (x/y)	0/0	0/0	0/0	0/0	0/0
Y max	0	0	0	0	0
e^+e^- luminosity/detector, $10^{34} \text{ cm}^{-2}\text{sec}^{-1}$	140	140	140	280	200
e^+e^+, e^-e^- luminosity/detector, $10^{34} \text{ cm}^{-2}\text{sec}^{-1}$	70	70	70	140	100
Site power, MW	~125	~125	~65	~125	~130

Could allow to reach 700 GeV c.m.

Possible issues for RLC upgrade



- Current ILC design needs 14 mrad crossing angle to avoid multiple collisions in the detector. Energy recovery requires returning beams into the opposite linac for deceleration, i.e. bending beams by 14 mrad at full energy of the collider
- RLC will need ~ 1 km between two linacs to bend trajectory by 14 milliradians with radius ~ 50 km. At the 500 GeV collider energy, this will result in 15.4 MeV loss of energy with critical photon energy of 0.7 MeV growth of the RMS energy spread per pass. SR power ~ 10 kW. Question can be the rest of 4.5 km between ILC linac used for SRF cavities?
- Self-consistent simulations are required to determine what level of damping is required to establish required steady-state beam parameters, including beam polarization. Similarly, a self-consistent simulations are required to establish loss level caused by Touschek scattering, scattering on residual gas and particle burn-off in collisions
- RLC relies on compensation of space charge forces and related beam-beam effects. It is well-known that such compensation may result in collective beam instability*: detailed studies are needed to define requirements the feedback system to suppress such instability
- Space charge compensation can be infringed by differences in bunch intensity and/or spatial beam parameters (beam sizes, optics functions..), and transverse and longitudinal misalignments of merged electron and positron bunches. Detailed studies are required to define required tolerances.

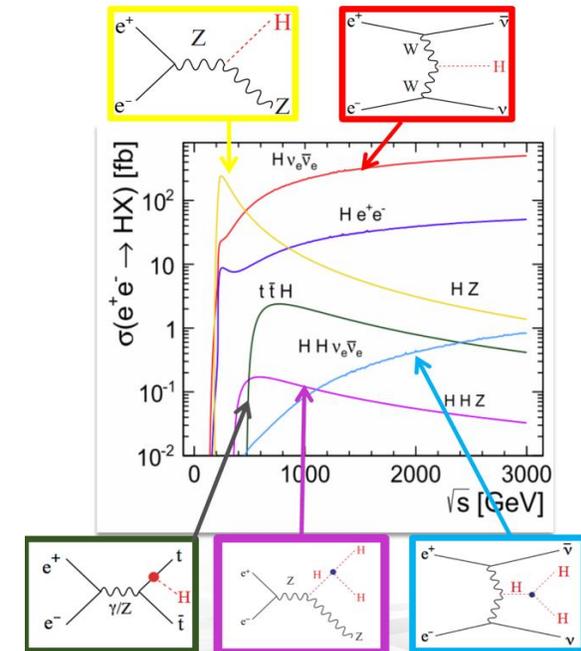
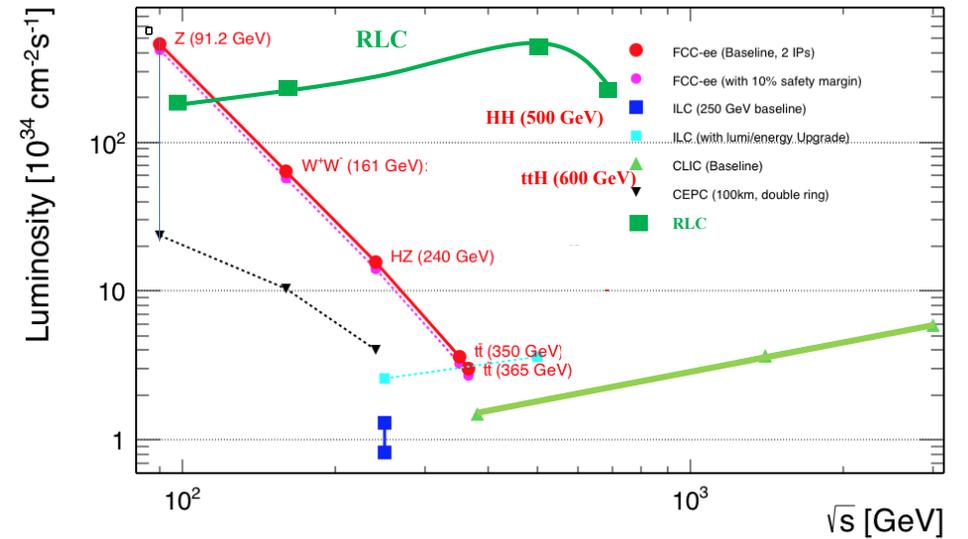
* Ya. S. Derbenev, "Collective instability of compensated colliding beams", Proc. of the 3rg All-union Conf. on Charge Particle Accel., Moscow, 1972, pp. 382-385. SLAC TRANS-151, 1973.

R&D required

1. Development of efficient SRF and cryogenic technology are critically important for reduction of the energy consumption:
 - ❑ Efficient LiHe refrigerators
 - ❑ High Q SRF cavities, including but not limited to Nb₃Sn
2. Demonstration of flat beams with 2,000 H/V emittance ratio.
3. High rep-rate and accurate kickers
4. Start-to-end simulations of the beam and the spin dynamics.

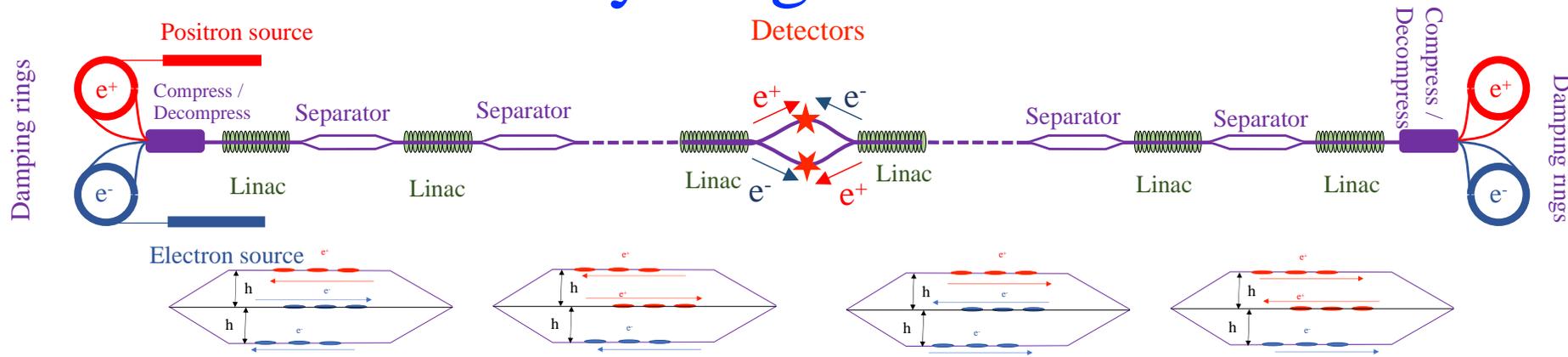
Instead of conclusion

- Recycling linear collider (RLC) offers interesting option of ILC upgrade which could provide high luminosity in polarized e^+e^- (as well as e^+e^+ and e^-e^-) collisions while eliminating beamstrahlung effects
 - *Important note: 10^{36} level of luminosity could be provided for Z and WW energies, not only for HIGS energies*
- RLC can operate in pulsed mode, which could allow to increase beam energy above 500 GeV
- It will greatly benefit from advances in SRF and cryogenic technologies
- Start-to-end simulation are important to validate this concept
- Optimization of collider parameters is possible if higher luminosities are required?



Back up slide

ReLiC – Recycling Linear Collider



- Flat beams cooled in damping rings with “top off” to replace burned-off particles
- Bunches are ejected with collision frequency, determined by the distance between beam separators
- Beams are accelerated **on-axis** in SRF linacs collide in one of detectors
- After collision at the top energy, they are decelerated in the opposite linacs
- Bunch trains are periodically separated from opposite beam, with accelerating beam propagating **on-axis**
- Decelerated beams are injected into cooling rings
- After few damping times the trip repeats in the opposite direction and beams collide in a detector located in the opposite branch of the final separator

$$F_x = \pm e \left(E_x + \frac{v_z}{c} B_y \right) = \begin{cases} 0, \text{accelerating} \\ 2eE_x, \text{decelerating positrons} \\ -2eE_x, \text{decelerating electrons} \end{cases}$$

ReLiC collider recycles **polarized** electrons and positrons

- Reusing electron and positron beams cooled in damping rings provides for natural polarization of both beam via Sokolov-Ternov process. Depolarization in the trip between damping ring is minuscule, which would provide for high degree of polarization. With lifetime ~ 10 hours, necessary replacement of electrons and positrons is at 1 nA level – **this is major advantage of ReLiC**