High Energy High Luminosity e^+e^- Colliders using Energy-Recovery Linacs

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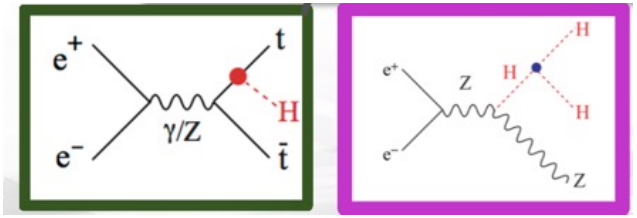
Key development: two concepts including

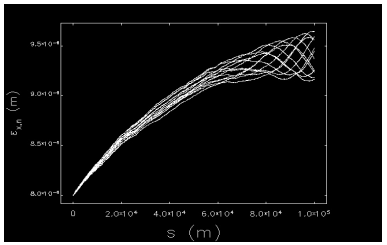
CERC (**C**ircular **E**nergy-**R**ecovery **C**ollider) and

ReLiC (**R**ecycling **Li**near **C**ollider)

Physics: Investigating details of:



Accelerator: Developing detailed start-to-end simulations



Checked possibility of colliding polarized electron and position beams

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Key for both concepts

- Using linear collider approach for IRs: flat low emittance beams with large vertical disruption parameters
- Recycling as much as possible of the beam energy
- Recycle and re-use collided electrons and positrons
- Use damping rings to prepare recycled beams for next collisions
- Resulting in
  - Increased luminosity and energy reach when compared with competing approaches
  - Possibility of colliding highly polarized electron and position beams

Motivation 1 – energy reach

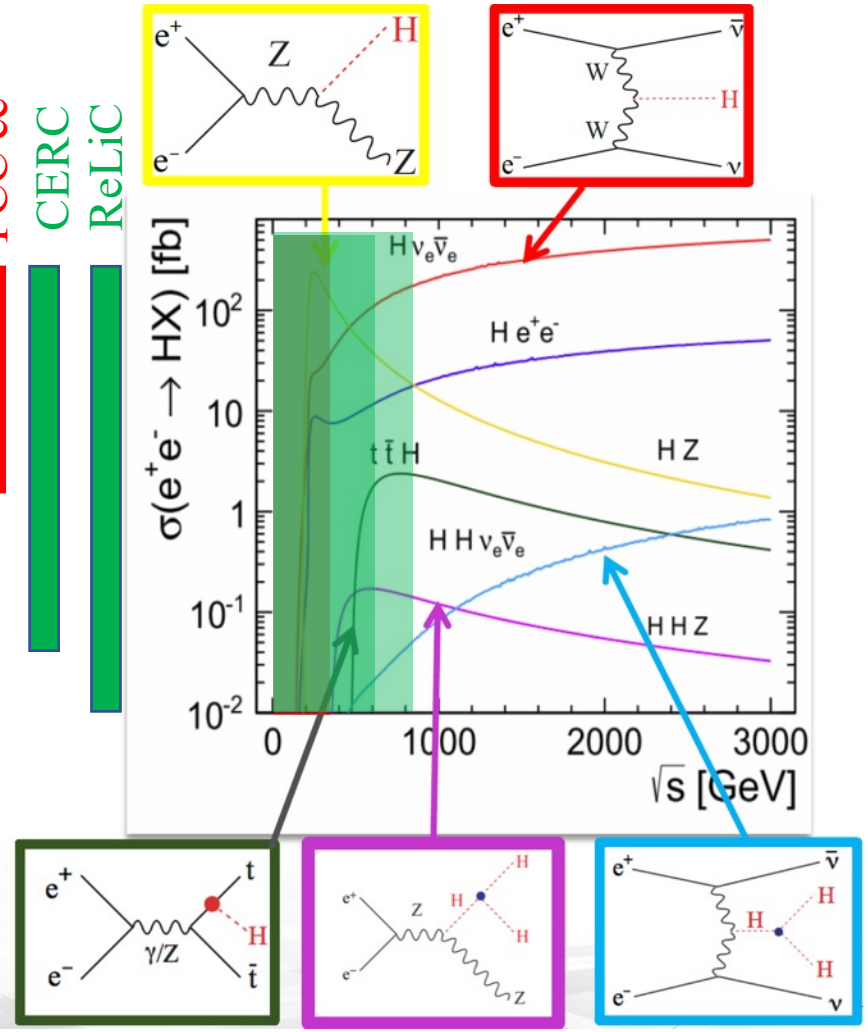
e+e- colliders

√s [GeV]	Science Drivers
90-200	EW precision physics, Z, WW
250	Single Higgs physics (HZ), Hvv
365	tt
500-600	HHZ, ttH direct access to Higgs self-couplings, top Yukawa couplings
1000-3000	HH$\nu\nu$ Higgs self-couplings in VBF

FCC ee

CERC

ReLiC



Precision measurement and search for new physics studying deviations from the SM

→ Need high luminosity (and energy)

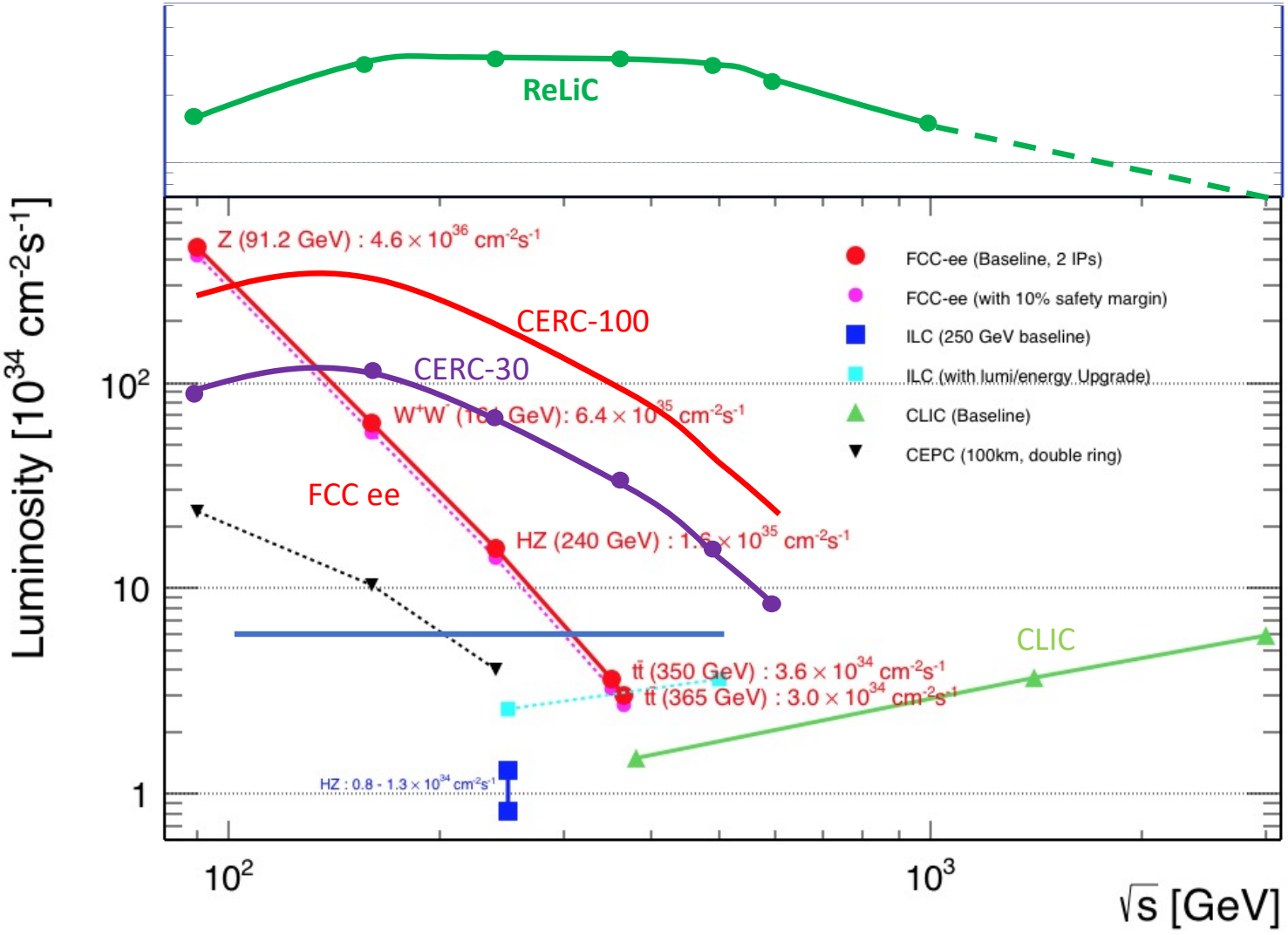
An ERL e^+e^- collider would provide higher luminosity and high-energy up to c.m. energy of 600 GeV to enable double-Higgs and ttbarH production

Motivation 2: Luminosity

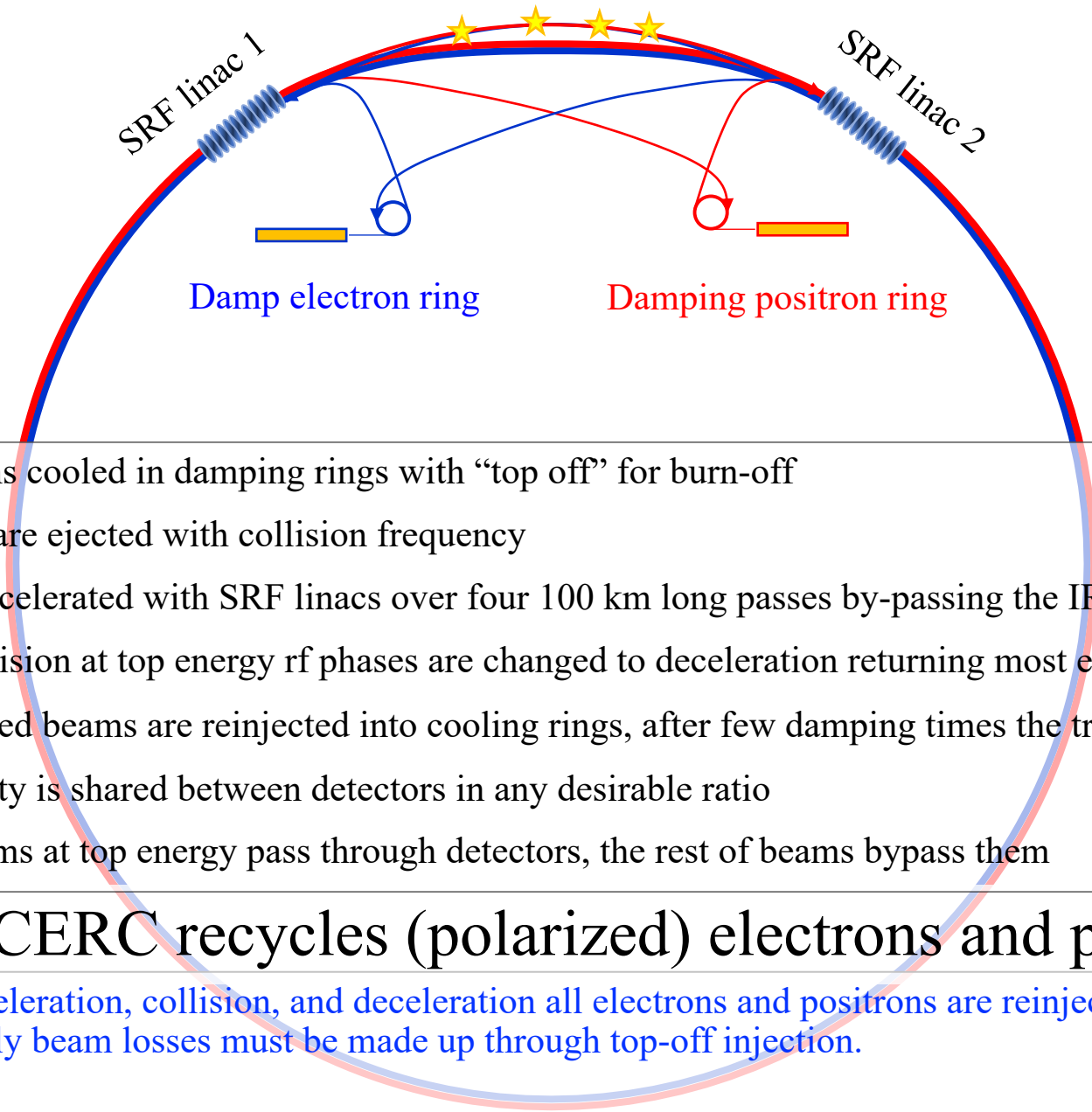
Green curve – ReLiC, Recycling Linear Collider

Violet curve : CERC, Circular ERL collider, with 30 MW of synchrotron radiation

Red curve – for CIRC with 100 MW of synchrotron radiation (as in FCC ee)



CERC - Circular ERL Collider

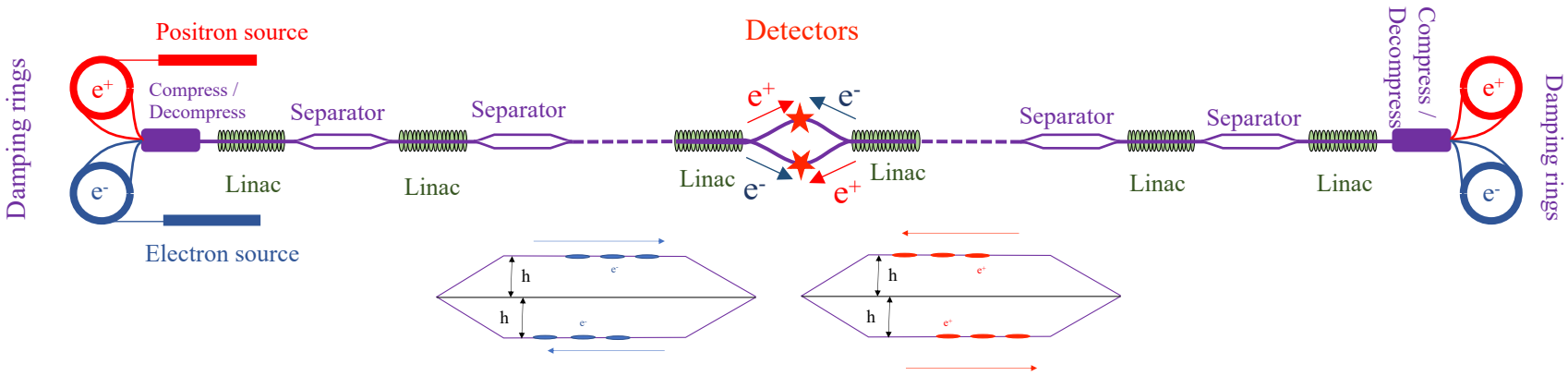


- Flat beams cooled in damping rings with “top off” for burn-off
- Bunches are ejected with collision frequency
- Beams accelerated with SRF linacs over four 100 km long passes by-passing the IR
- After collision at top energy rf phases are changed to deceleration returning most energy to SRF linac
- Decelerated beams are reinjected into cooling rings, after few damping times the trip repeats
- Luminosity is shared between detectors in any desirable ratio
- Only beams at top energy pass through detectors, the rest of beams bypass them

CERC recycles (polarized) electrons and positrons

- After acceleration, collision, and deceleration all electrons and positrons are reinjected into the cooling rings. Only beam losses must be made up through top-off injection.

ReLiC – Recycling Linear Collider



- Flat beams cooled in damping rings with “top off” for burn-off
- 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
- 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 …..

ReLiC collider recycles (polarized) electrons and positrons

- After acceleration, collision, and deceleration all electrons and positrons are reinjected into the cooling rings. Only beam losses must be made up through top-off injection.

Impact of polarization

Polarization		Scaling factor		
e^-	e^+	ZH(240GeV)	ZHH(500GeV)	ttH(600GeV)
Unpolarized		1.	1.	1.
-70	0	1.15	1.15	1.23
-70	+50	1.61	1.61	1.87
-70	-50	0.69	0.69	0.73
-70	+70	1.78	1.79	2.07
-70	-70	0.51	0.51	0.51
-50	+50	1.47	1.47	1.69
+50	-50	1.03	1.03	0.82
+70	0	0.85	0.85	0.69
+70	+50	0.60	0.60	0.56
+70	-50	1.09	1.09	0.83
+70	+70	0.51	0.51	0.51

The proper combination of polarization for electrons and positrons will significantly enhance the production cross section or will suppress it.

Conclusions

- CERC: energy reach 500-to-600 GeV
  - Originally published in Phys. Lett. B Volume 804, 135394, (2020)
  - We updated beam parameters, specifically bunch lengths of colliding beams and energies of damping ring, to address weak low energy tail associated with beamstrahlung. Energy acceptance of the system is increased to keep particle loss bellow 1 p.p.m.
  - Preliminary simulations confirmed our expectation that system will be capable of sustaining high degree of polarization in both electron and position beams
  - We developed a straw-man lattice and performed initial tracking simulation
  - *Main challenges – maintaining flatness of beams in transport and high rep-rate kickers*
- ReLiC: energy reach tested to 1 TeV, further increase is possible
  - The concept also can be used for pulsed SRF linac, with the average luminosity reduced proportionally to the duty factors
  - While this approach was rather obvious when we publish our CERC paper, we had not time to explore it till this November, Hence, while it is much simpler, it is also less explored
  - In contrast with circular ERL, synchrotron radiation losses and emittance growth can be kept ay negligible level in separators. This is indication that c.m. energy can be extended well above 1 TeV.
  - Main energy losses will occur in damping rings, with operating energies from 2 GeV to 8 GeV
  - *Main challenges – MHz rep-rate of kickers, high SR power in damping ring*
- Detailed studies are needed to fully validate both of concepts. Many opportunities for interested partners to collaborate