ILC Upgrade with Energy Recovery (ERLC)

LC Vision Community Event 2025

2025.1.9

Two Concepts

- Linear colliders with energy recovery potentially reach luminosities 2 orders of magnitude higher than ILC
- 2 different concepts of linear collider with energy recovery

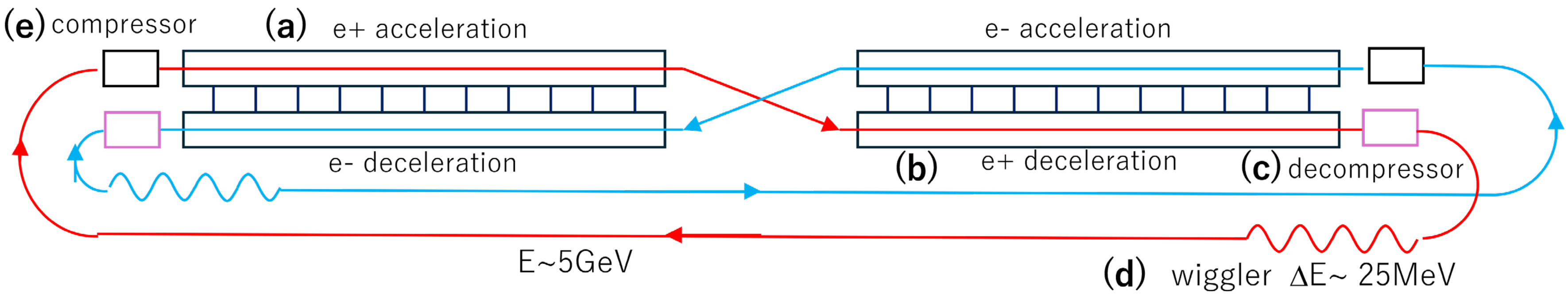
A) After IP, the beams are decelerated and stored in damping rings until the beam properties (emittance, energy spread, etc) are restored. Then, accelerated again.
→ examples: ReLiC, CLERC
→ Vladimir

B) After IP, the beams are decelerated and weakly damped by wigglers (single pass). Then, accelerated again.
→ examples: ERLC, Ghost Collider

- Each of these has pros and cons
- The question which is better is too early to ask

ERLC

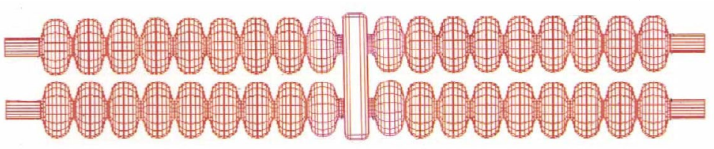
- Proposed by V. Telnov. JINST 16(2021)P12025.
- Latest version : arXiv2302.09758v3 (Dec.2024)



- Constraints
  - ✓Energy loss by beamstrahlung. Low energy tail of electrons must be captured in the return beamline
  - ✓Energy spread due to multiple beamstrahlung
  - ✓Beam-beam tune-shift limit $\xi_{x,y} < \sim 0.1$

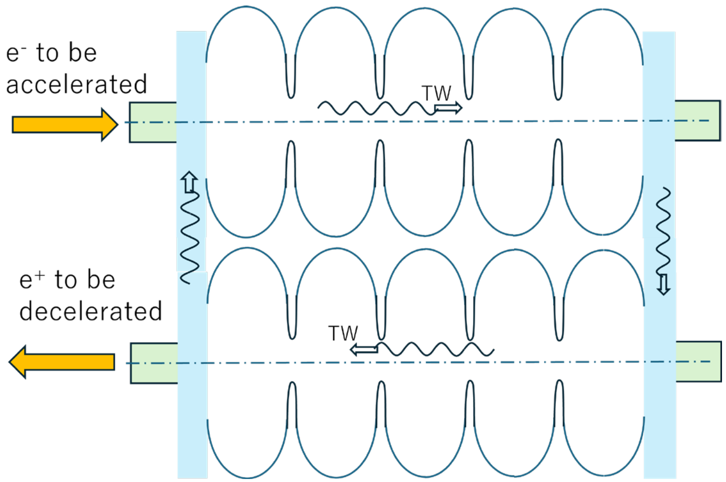
Twin-Axis Cavity

- Accelerating beam and decelerating beam travel along opposite direction
- Twin-axis cavity is needed for energy recovery (avoid beam encounter in the cavities)
  For example →



- Disadvantage (compared with a single-cavity case): RF loss is doubled
- Application of HELEN idea (TW:traveling wave) may be a cure
  - ✓ Can potentially give a higher accelerating gradient

TW Twin-Axis Cavity →



Luminosity Upgrade of ILC

- ERLC was originally proposed as an independent project
- If adopted as an upgrade of ILC, there are several additional constraints
  - ✓Tunnel cross-section to accommodate twin-axis cavity
  - ✓Crossing angle, layout
    - Small crossing angle (~2mrad) is better
    - If 14 mrad, must construct a return line after IP (issue is the emittance increase and energy loss by synchrotron radiation)
    - **LCF@CERN can be different in this respect**
  - ✓Tunnel length
    - Ideally, XX GeV ILC tunnel can accommodate XX GeV ERLC

Parameter Optimization

- Condition on the beamstrahlung and beam-beam tune shift
  - ✓Small bunch charge
  - ✓High beam current
- Major sources of power consumption
  a. Cooling of the RF heat
  b. Cooling of the HOM power
- Accelerating gradient
  - ✓(a) prop. G, (b) propt. 1/G
  - ✓There is a power optimum
  - ✓but we choose a higher G for shorter tunnel
- Table in the next page assumes most optimistic case
  - ✓TW type twin-axis cavity
  - ✓4.5K operation with Nb3Tn

preliminary parameters

	ILC	ERLC	ERLC	
Center-of-mass energy	250	250	500	GeV
Accelerating gradient	31.5	40	40	MV/m
Cavity Q_0	1	3	3	$\times 10^{10}$
Aperture radius	35	35	35	mm
Shunt impedance per unit length	996	1690	1690	Ohm/m
Operating temperature	2	4.5	4.5	K
Bunch population	2	0.075	0.081	$\times 10^{10}$
Bunch distance	166	0.23	0.23	m
Average beam current	0.021	157	169	mA
Beam energy in the return line		5	5	GeV
Total HOM power	0.014	2.9	5.85	MW
Energy acceptance of the return line		3	3	%
Radiation loss in the wiggler		25	25	MeV
Bunch length in main linac and IP	0.3	0.31	0.89	mm
Normalized emittance at IP (x/y)	5/35	10/35	10/35	μm / nm
Beta function at IP(x/y)	13/0.41	12/0.31	40/0.89	mm
Beam size at IP(x/y)	515/7.66	700/6.2	900/7.4	nm
Disruption parameter (x/y)	0.5/34.5	0.011/1.14	0.010/1.14	
Beam-beam tune shift (x/y)		0.033/0.097	0.036/0.098	
Upsilon (max)	0.068	0.00182	0.00106	
Luminosity	1.35	135	102	10^{34}/cm^2/s
AC power for RF heat cooling	5	91	181	MW
AC power for HOM cooling	1	35	71	MW
Total site power	111	170	320	MW

Required R&D

- Cavity material
  - ✓ Nb3Tn desired. Operation at 4.5K.
- High efficiency cryogenics system
- Cavity type
  - ✓ Twin-axis cavity is mandatory
  - ✓ TW-type desired
    - HELEN cavity is the first step
  - ✓ Complex cavity design (trapped modes, transverse deflection modes, etc)
  - ✓ Surface polishing method, tuning of twin cavities
- HOM absorber
  - ✓ Common to ERL for light sources
- Beamline issues
  - ✓ BBU in the main linac
  - ✓ Emittance increase by synchrotron radiation in various places
  - ✓ Emittance increase in main linac (the design emittance is the same as ILC but multiple pass)
  - ✓ Background in BDS (average beam current is 4 orders higher than in ILC)
  - ✓ Design of IR region
- How many years?
  - ✓ Hard to answer. More than 20 years?