Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

CERC: Circular Energy Recovery Collider

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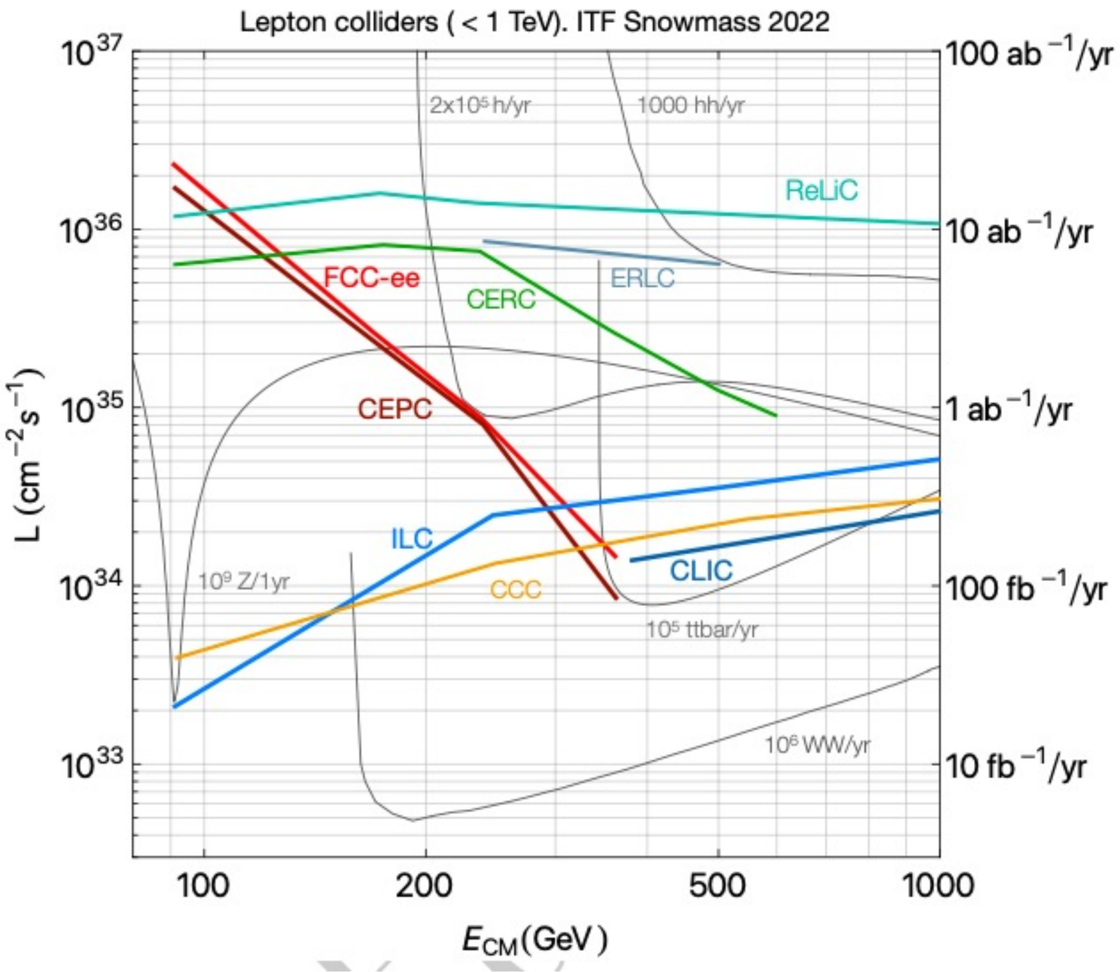
CERC physics potential

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

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

→ Need high luminosity (and energy)



Key for CERC (and ReLiC) concepts

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

Increased luminosity and energy reach when compared with other approaches
Possibility of colliding highly polarized electron and position beams

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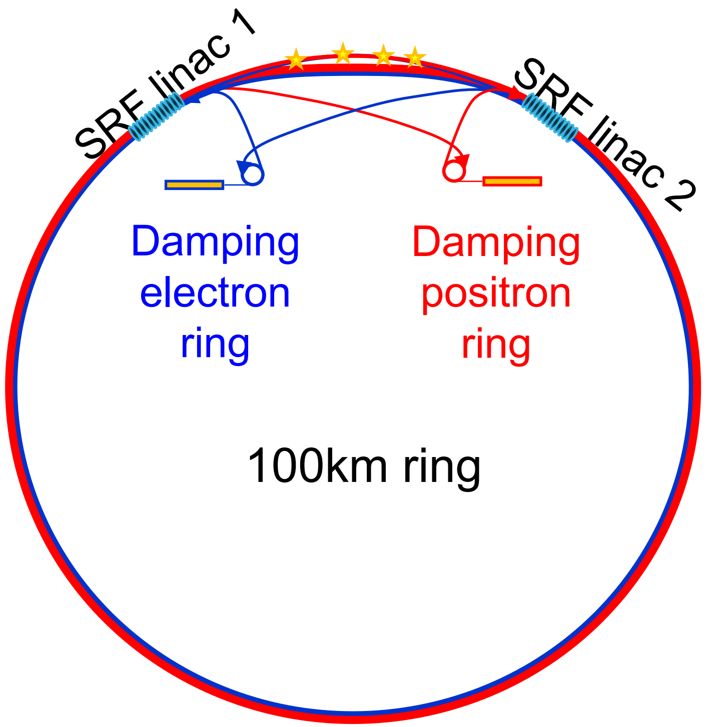
See presentation from V.Litvinenko for ReLiC

CERC Baseline design



- Flat beams cooled in damping rings with top off
- Bunches are ejected with collision frequency
- Beams accelerated with SRF linacs in two four-path ERLs
- 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

Combines advantages of existing colliders:

- Storage ring colliders: recycling beam energy and particles
- Linear colliders: efficient collisions using a large disruption parameter

CERC parameters

Table 1. Main parameters of ERL-based e^+e^- collider with synchrotron radiation power of 30 MW.

CERC	Z	W	H(HZ)	ttbar	HH	Httbar
Circumference, km	100	100	100	100	100	100
Beam energy, GeV	**45.6**	**80**	**120**	**182.5**	**250**	**300**
Hor. norm ε, μm rad	3.9	3.9	6.0	7.8	7.8	7.8
Vert. norm ε, nm rad	7.8	7.8	7.8	7.8	7.8	7.8
Bend magnet filling factor	0.9	0.9	0.9	0.9	0.9	0.9
βh, m	0.5	0.6	1.75	2	2.5	3
βv, mm (matched)	0.2	0.3	0.3	0.5	0.75	1
Bunch length, mm	2	3	3	5	7.5	10
Charge per bunch, nC	13	13	25	23	19	19
Ne per bunch, 10^{11}	0.78	0.78	1.6	1.4	1.2	1.2
Bunch frequency, kHz	297	270	99	40	16	9
Beam current, mA	3.71	3.37	2.47	0.90	0.31	0.16
Luminosity, 10^{35} $cm^{-2}sec^{-1}$	6.7	8.7	7.8	2.8	1.3	0.9
Energy loss, GeV	4.0	4.4	6	17	48	109
Rad. power, MW/beam	15.0	14.9	14.9	15.0	16.8	16.9
ERL linacs, GV	10.9	19.6	29.8	46.5	67.4	89
Disruption, D_h	2.2	1.9	0.8	0.5	0.3	0.3
Disruption, D_v	503	584	544	505	459	492
Damping ring energy [GeV]	2	2	2	3	4.5	8

Key technologies

- Two Superconducting RF Linacs with high Q_0 , 1.5K cryo-plant
- 703 MHz 5-cell cavity (so called BNL-3 5 cell design), ~20MV/m accelerating gradient with HOM couplers
- 16 m long cryostat housing 10 five-cell cavities
- Low emittance damping rings for electrons/positrons
- ~0.1MHz kickers to extract/inject bunches into the damping rings
- NC magnets with ~15 mm gap
- 16 transport lines: due to synchrotron radiation the recirculating beam lines for accelerated and decelerated beams have to be different

Accelerator design and challenges

Design: 6250 FODO cells with combined function (dipole, quadrupole and sextupole) magnets and zero chromaticity,

16m long and 90 degrees phase advance,

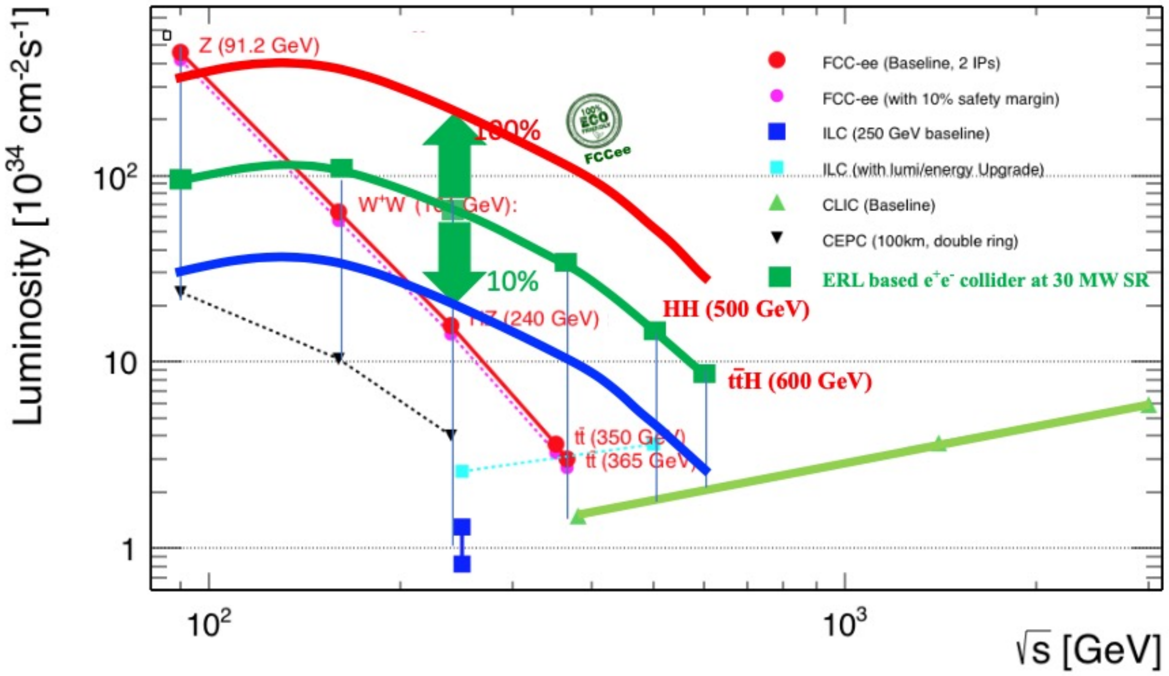
B=0.05T, GF/D = =±32.24 T/m, Sextupole moments SF=267 T/m2

Polarized beams, beam depolarization less 0.1%

- SRF cavities with Q_0~ $1x10^{11}$
- Transport beamline lattice preserving a small vertical emittance
- Damping rings with very flat beams $\varepsilon_h/\varepsilon_v$ =1,000 and large energy acceptance (~5%)
- (De-)compressing of electron/positron bunches to match energy acceptance of the damping rings
- Use of small gap magnets to reduce power consumption and cost of the multiple 100 km beamlines
- Absolute beam energy measuring systems with accuracy $\sim 10^{-5}$ at IRs as pioneered at CEBAF
- High repetition rate extraction and injection kickers for the damping rings

Upgrades/extensions/stageability

- CERC upgrades in luminosity possible by increasing the SR power
  - CERC luminosity for 30MW total SR power is shown in green
  - Luminosity scales linear with SR power
  - Luminosity increases by a factor 3 if the SR power is fixed to 100MW (solid red)
- CERC energy upgrade is included to cover the energy range √s ~500-600 GeV
- CERC can be used for hadron-electron and hadron-positron collider in conjunction with FCC hh



- CERC can be built in stages, increasing the energy by adding SRF cavities

Sustainability

Additional electric power reduction can be obtained with targeted R&D

30 MW of RF power will be need for CERC's second harmonic and damping ring RF systems to compensate for the energy lost to synchrotron radiation

Microphonics: CERN successfully tested ferro-electric tuners for SRF cavities and we assume they are available

Table 3. Estimation of the CERC AC power consumption

Mode	Beam Energy [GeV]	SR power [MW]	Microphonics [MW]	HOM [MW]	Total RF power [MW]	Magnet [MW]	1.8K Cryo load [kW]	Cryoplant AC power [MW]	Total AC power [MW]
Z	45.6	30.0	1.6	0.1	31.7	2.0	5	6.25	61
W	80	30.0	2.9	0.2	33.1	6.2	10	12.5	74
HZ	120	30.0	4.5	0.3	34.8	13.9	15	18.75	90
ttbar	182.5	30.0	7.0	0.2	37.2	32.0	23	28.75	123
HHZ	250	30.0	10.1	0.1	40.2	60.1	34	42.5	169
Httbar	300	30.0	13.4	0.0	43.4	86.6	45	56.25	215

HOM: estimated using the BNL-3 5 cell cavity and ferrite type HOM absorbers

Magnets: power consumption of the magnet is proportional to its gap and magnetic field squared, 16 beam-lines required for CERC electron and position beams will consume the same amount of power as a single storage ring with typical gap ~ 5 cm

Cryo plant: assumes 1.25 kW of cryo-plant power per 1 W loss at 1.8 K

State of proposal and R&D needs

- Preliminary simulations have been performed to study beam-beam effects, beam lattice, transport along beamline lattice, and optimization of accelerator parameters
- Full 3D simulations required to study collisions with flat beams, high disruption parameter, bunch de-compression schemes to match energy of damping rings
- R&D needs:
  - High Q_0 SRF cavities and SRF cryomodules
  - Multi-turn, high energy ERLs
  - High rep-rate kickers
  - Low-cost NC ring magnets, reduction of number of transport lines
  - High-efficient cryo plants

Maturity

- Design maturity: 3 - end to end preliminary design concept available
- R&D maturity: 1 - concept proposed, proof of principle R&D needed

Design Maturity	Maturity Criteria #1 (Design Maturity)	Maturity Criteria #2 (R&D Maturity)
0	No end-to-end design concept prepared	Concept proposed, but no systematic design requirements and/or parameters available.
1	No end-to-end design concept prepared	Concept proposed, proof-of-principle R&D underway
2	**End-to-end preliminary design concept** under development	Ongoing R&D to address **fundamental physics/technical issues.**
3	**End-to-end preliminary design concept** available	**Sub-system operating parameters established** based on **preliminary design concepts for novel/critical sub-systems**
4	**End-to-end integrated design concept** under development	**Preliminary design concepts with operating parameters established for all sub-systems.** Sub-system design R&D underway.
5	**End-to-end integrated design concept** available. **Enables end-to-end performance evaluation.**	**Sub-system preliminary designs** exist. **Sub-system design R&D** continues.
6	**End-to-end performance evaluation** complete. **Reference** (pre-CDR level) **Design Report** under development.	**Sub-system performance risk assessment** complete.
7	**Reference Design** available. **Sub-system parameters** and **high potential alternatives** documented.	**Sub-system detailed design** and **performance R&D** for **highest risk sub-systems** underway.
8	**Conceptupal Design Report** in preparation.	**Sub-system specifications with validated operating parameters** established. **High risk sub-system R&D** underway.
9	**Conceptual Design Report** and **detailed cost estimate** avaialable.	**High risk sub-system R&D** ongoing. **Risk mitigation strategy** for **sub-system performance** established.
10	Ready for **Construction Proposal.** Detailed Engineering Design being developed.	**Performance Optimization R&D** underway.

Summary

- The CERC collider promises significantly higher luminosities at CM energies above 160 GeV
- The CM energy can reach 600 GeV (enables ZHH and ttH production) with very high luminosities
- The CERC collider might be capable of colliding polarized electron and positron beams
- These features of the CERC collider are unique in this energy range. It outperforms the ring-ring design - by colliding beams only once - and linear colliders by using energy recovery and recycling of particles
- Extensive detailed studies are needed to fully validate this concept and
- R&D on key enabling technologies is needed: high-Q SRF, high-rep kickers, efficient cryo-plants