Linac-LHC ep Collider Options

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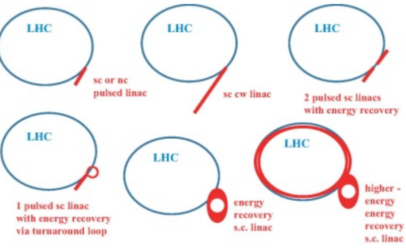
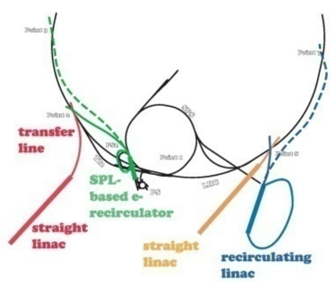
Abstract

We describe various parameter scenarios for a linac-ring ep collider based on LHC and an independent electron linac. Luminosities between 10^{31} and 10^{33} $cm^{-2}s^{-1}$ can be achieved with a s.c. linac, operated either pulsed or in cw mode with optional recirculation, at a total electric wall-plug power of order 20 MW. Higher luminosities of several 10^{33} $cm^{-2}s^{-1}$ can be reached by investing more electric power or by energy recovery. Finally, merits of a linac-ring ep collider are discussed

Scenarios



Example linac layouts

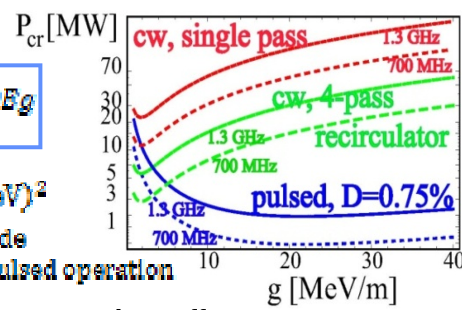


Cryogenics electric power vs. acc. gradient

$$P_{cr} = A\frac{E}{g} + BDEg$$

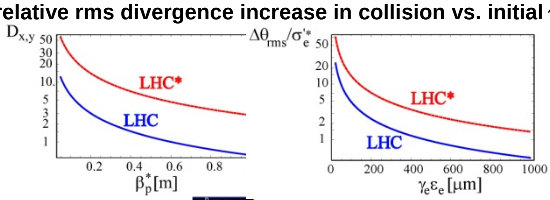
$A \approx 350$ W/m, $B \approx 10^{-10}$ Wm/(eV)^2

$$D \approx \begin{cases} 1 & \text{for cw mode} \\ 0.0075 & \text{for pulsed operation} \end{cases}$$



Collision effect on e-: e- disruption parameter vs. β^*_p (left)

relative rms divergence increase in collision vs. initial $\gamma_e\varepsilon_e$ (right)



$$P_{rf} = P_{beam}\frac{1-\eta_{ER}}{\eta_{rf\to beam}\eta_{wp\to rf}}$$

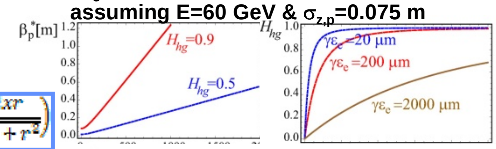
$$P_{total} \approx P_{cr} + P_{rf}$$

$$H_{hg}(x,r) = 2\sqrt{\pi}xre^{4x^2r^2/(1+r^2)}\,\mathrm{erfc}\left(\frac{2xr}{\sqrt{1+r^2}}\right)$$

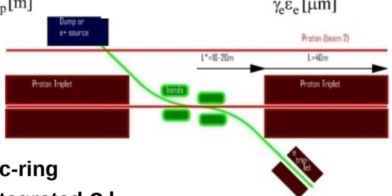
$$L = \frac{1}{4\pi e}\frac{N_{b,p}}{\varepsilon_p}\frac{1}{\beta^*_p}I_e H_{hg}\left(\frac{\beta^*_e}{\sigma_{z,p}}, \frac{\varepsilon_e}{\varepsilon_p}\right)$$

Hourglass effect:

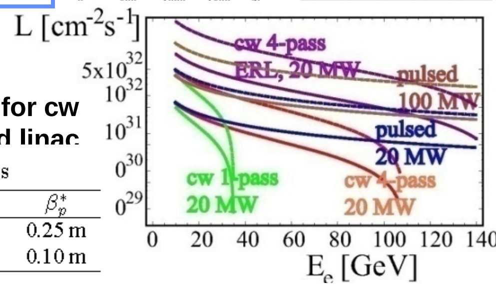
β^*_p vs. $\gamma_e\varepsilon_e$ for two values of H_{hg} (left), H_{hg} vs. $\gamma_e\varepsilon_e$ for three values of $\gamma_e\varepsilon_e$ (right), assuming E=60 GeV & $\sigma_{z,p}$=0.075 m



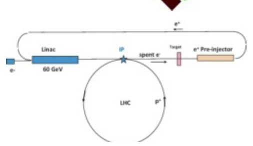
Schematic interaction region



Luminosity vs. e- energy for cw & pulsed linac



Schematic linac-ring collider with integrated e+ production (right) and simulated e+ yield for amorphous W target of varying thickness hit by a 60-GeV e- beam [$\gamma_e\varepsilon_e$ =20μm, $\sigma_{x,y,e}$=20 μm, β=10 m] (below).



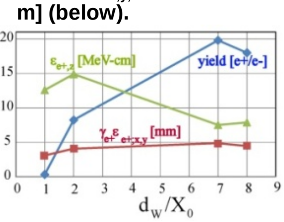


Table 1: Proton beam scenarios

	$N_{b,p}$	T_{sep}	$\varepsilon_p\gamma_p$	β^*_p
LHC	1.7×10^{11}	25 ns	3.75 μm	0.25 m
LHC*	5×10^{11}	50 ns	3.75 μm	0.10 m

Table 2: Electron-beam parameters for various (s.c.) linac-ring LHeC scenarios. The β^* values are calculated for a normalized e- emittance of 20 μm. Parameters marked by asterisks refer to 'LHC*' of Table 1.

energy [GeV]	20	20	60	60	60	120
option	cw 4-pass	cw 4-p. ERL	cw 4-pass	cw 4-p. ERL	pulsed	pulsed
bunch population $N_{b,e}$ [10^9]	0.06, 0.12*	1.3, 2.6*	0.1, 0.2*	0.3, 0.6*	17, 34*	7, 14*
average current [μA]	400	8650	74	2050	820	340
beam power at IP [MW]	8.0	172	4.5	120	49	48
IP beta function [m]	0.25, 0.098*	0.25, 0.098*	0.74, 0.30*	0.74, 0.30*	0.74, 0.30*	1.72, 0.69*
luminosity [10^{31} cm^{-2}s^{-1}]	2.7, 20*	58, 430*	0.5, 3.7*	14, 100*	5.5, 41*	2.3, 17*
total electrical power [MW]	20	20	20	20	100	100

Merits of linac-ring ep collider:

1) **Small e- emittance** means **luminosity can be increased for reduced β^*_p** & final e- **quadrupoles** far **from the collision point**. First elements: warm separation dipoles of 0.5-2 T
2)e&p beams can be **collided head-on**. **No crab cavities**, since e- are dumped &, with assumed IR layout, residual parasitic collisions uncritical.
3) **Staged construction** is possible. A first stage could use the **SPL as recirculator** for alternating e- & p operation, bringing the electrons to some 20 GeV, which would probe physics beyond HERA. Such SPL-based recirculator could later serve as injector for e- ring or extended linac. Beam energy could be raised in steps by adding further linac segments.
4)As linac not affected by synchrotron radiation, **no fundamental limit on electron beam energy**.
5) **Energy recovery** could ultimately gain another order of magnitude in luminosity.
6)Except for collision point, **linac tunnel fully separate** from LHC, minimizing construction downtime
7)The linac-ring collider would benefit from planned proton infrastructure upgrades, i.e. linac4, SPL and PS2.
8)e- beam can be **80% polarized**.
9)Numerous **important synergies with CLIC and ILC** (beam dynamics, e+ production, tunnel, etc.) may prepare ground for future linear collider.
10) **Electron-ion collisions**, as well as, via laser Compton backscattering, **γ-proton and γ-nucleus** collisions would also be possible.

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