An lepton energy-recovery-linac scalable to TeV

Vladimir N. Litvinenko
Stony Brook University, Stony Brook, NY, USA
Brookhaven National Laboratory, Upton, NY, USA
Center for Accelerator Science and Education

I present a conceptual design of Linear Energy Recovery Linac operating electron or positrons beams with energies scalable to TeV. Normally energy recovery is associated with bending the lepton beam, which results in prohibitively large energy loss for synchrotron radiation.
In my scheme these losses are circumvented.

Content

- Energy limitations by recirculating ERLs
  - Power of SR
  - Standard "Head-on" linear energy recovery… HOMs, multiple beam-beam effects
- Two scalable schemes
  - Energy transfer by a single p-beam
  - Energy transfer by multiple e-beams is also possible but more cumbersome

Why CW linac?

- Synchrotron radiation limits top e+e- energies even in FCC: in relevant units it is

$$P_{SR}[GW] = 88.46 \cdot 10^3 \frac{E_e^4[TeV] \cdot I[A]}{R[km]}$$

- Using linac-ring collider removes one of beam-beam limits and can provide for much higher luminosity
- Preserves polarization during acceleration
- CW e-beam is needed
  - for colliding hadron beam stability
  - for for luminosity and avoiding pile-up in detectors

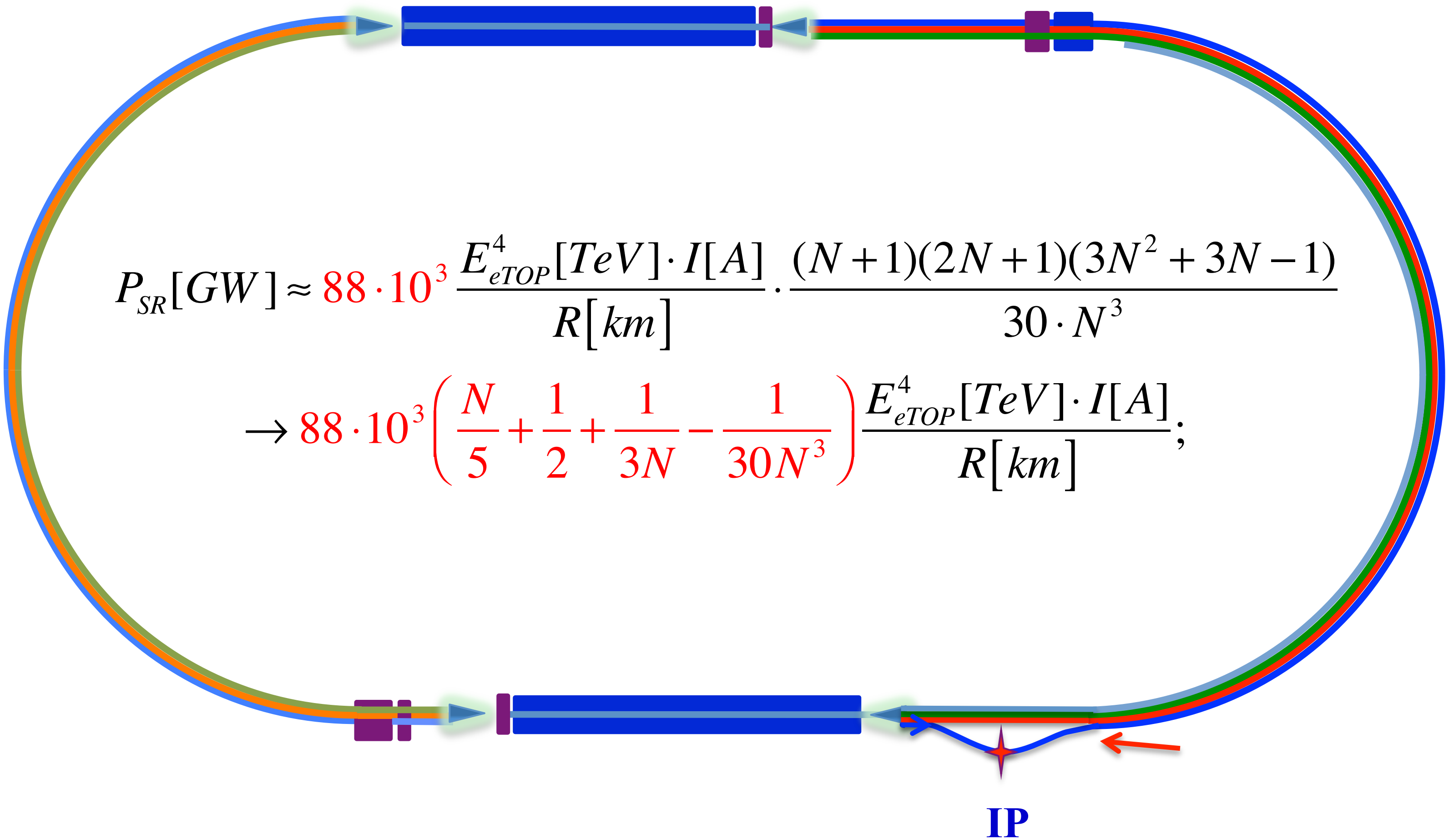
Why Linear ERL?

- It is simple – 100 GW level of SR power for 1 mA beam
- Or GW level of TeV ionizing radiation at the beam dump
- ERL with recirculating arcs has SR power even larger than storage ring of the same size – hence

$$P_{SR}[GW] = 88.46 \cdot 10^3 \frac{E_e^4[TeV] \cdot I[A]}{R[km]}$$

~ 10^{13} W/A for 1 TeV e-ebeam and R=8.85 km (C~80 km)

Recirculating ERL with N passes



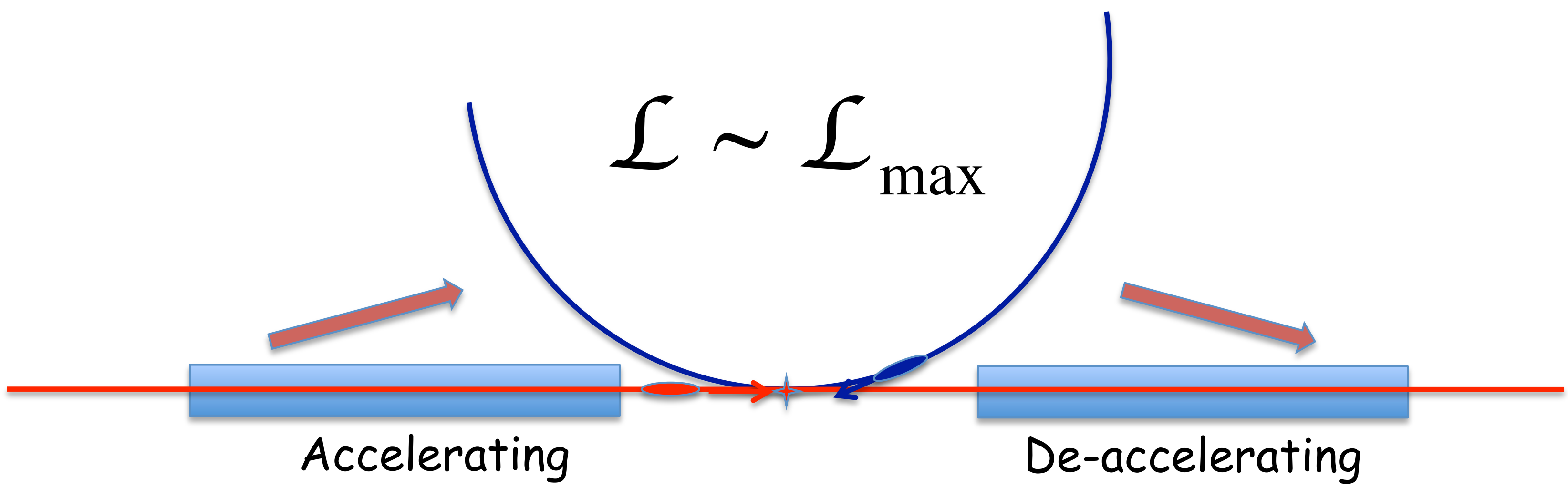
$$P_{SR}[GW] \approx 88 \cdot 10^3 \frac{E_{eTOP}^4[TeV] \cdot I[A]}{R[km]} \cdot \frac{(N+1)(2N+1)(3N^2+3N-1)}{30 \cdot N^3}$$

$$\rightarrow 88 \cdot 10^3 \left(\frac{N}{5} + \frac{1}{2} + \frac{1}{3N} - \frac{1}{30N^3} \right) \frac{E_{eTOP}^4[TeV] \cdot I[A]}{R[km]};$$

Linear ERL

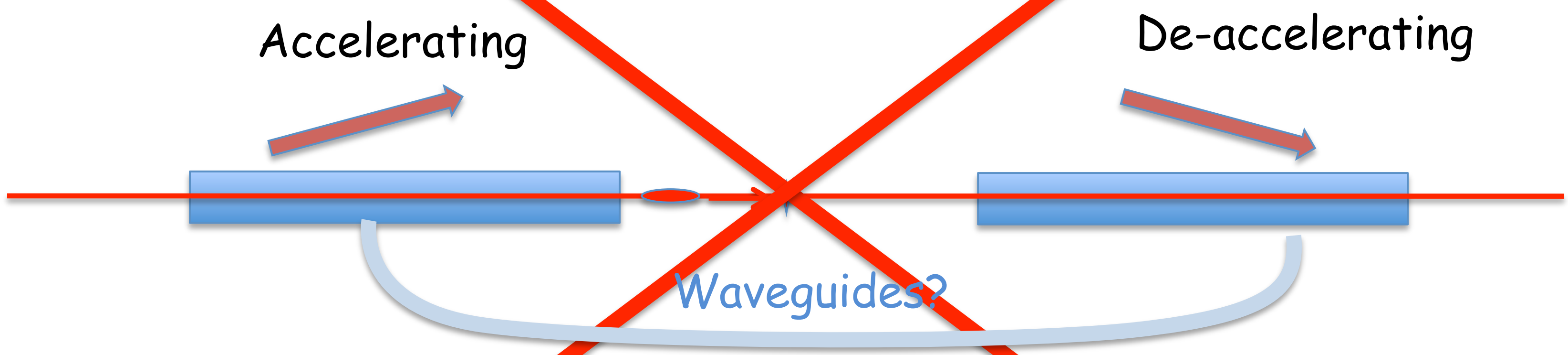
nearly 100% Energy recovery -> 2 linacs

What to do with the energy?



No power-imposed limitations either on the energy or beam current.

What to do with the energy? Feed it back?



e-beam current is ~ 1 A

Energy of e-beam is ~ 100 GeV

Power to transfer ~ 100 GW

Best RF coupler does 1 MW ->

2 x 100,000 couplers, 100,000 high precision waveguides…. – simply out of this world. Especially for SRF cavities with Q~10^{10} & micro-phonics!

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From CTF Landau & Lifshitz

$$\Delta E = \frac{2e^2}{3m^2c^3}\int \gamma^2 \left\{ \left(\vec{E} + \left[\vec{\beta} \times \vec{B} \right] \right)^2 - \left(\vec{\beta} \cdot \vec{E} \right)^2 \right\} dt$$

$$\gamma^{-2} = 1 - \vec{\beta}^2; \vec{\beta} = \vec{\mathrm{v}} / c.$$

On linac axis it is energy independent

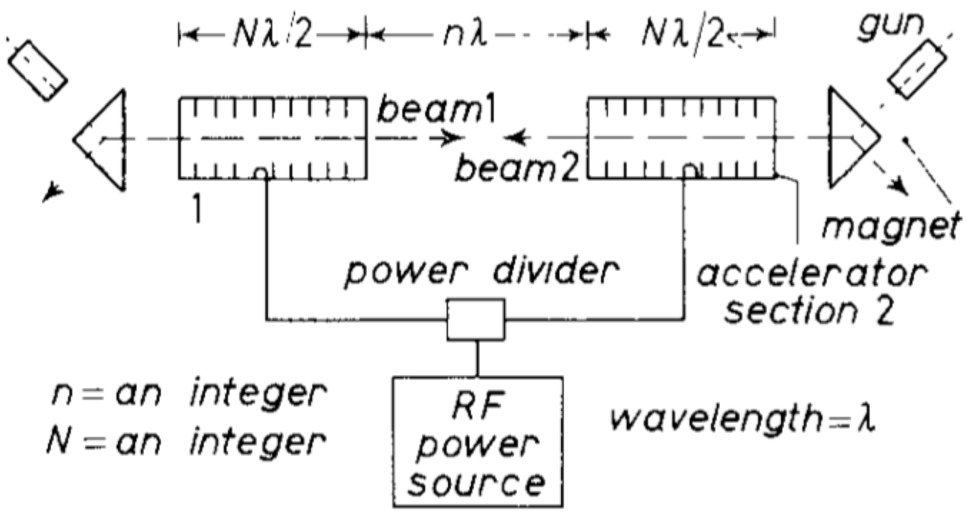
$$\vec{E} // \vec{\beta} \Rightarrow \Delta E = \frac{2e^2}{3m^2c^3}\int \vec{E}^2\, dt$$

"Off-axis" it is energy independent

$$\Delta E \propto \frac{2e^2}{3m^2c^3}\int \gamma^2 \left(\vec{E}_\perp + \left[\vec{\beta} \times \vec{B}_\perp \right] \right)^2 dt$$

Why not an "Head-on" ERL?

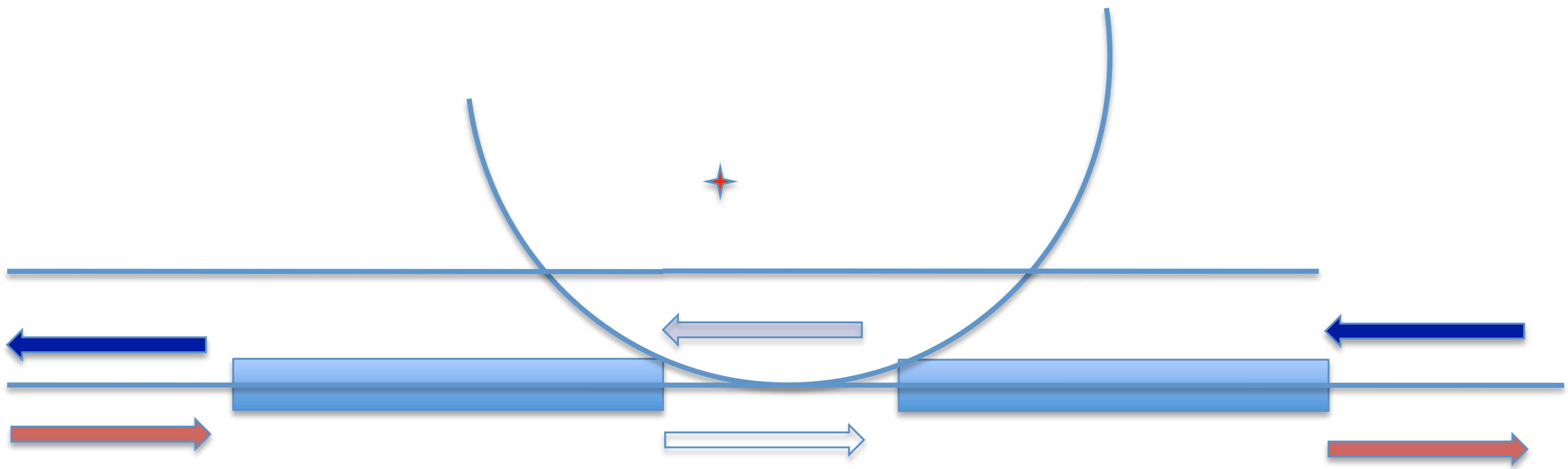
as originally proposed by M. Tigner



M. Tigner
Il Nuovo Cimento
Series 10
1 Giugno 1965,
Volume 37, Issue 3,
p. 1228

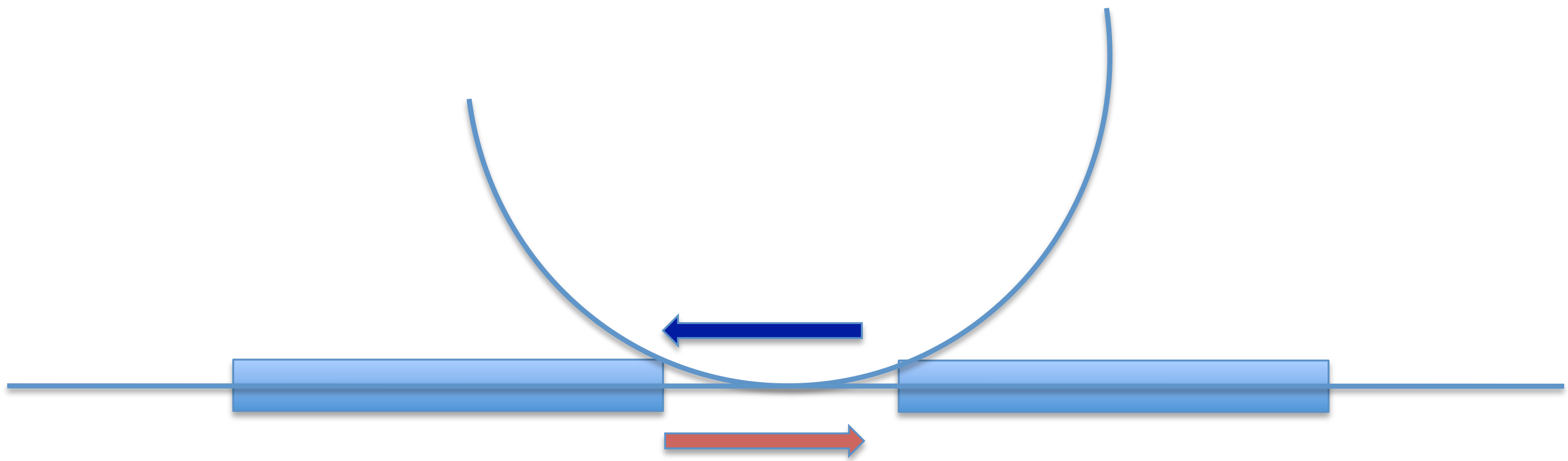
- "Head-on" works naturally for low rep-rate or pulsed schemes – otherwise beams collide head-on thousands of time through the entire length of the accelerator and are destroyed…
- Or requires transverse displacement, which excites transverse HOMs and generate time-dependent transverse fields -> SR+ emittnce degradation

100% Energy recovery
Period between = 2*(Linac+train)
Question – what is maximum transient loading?



$$\mathcal{L} \sim \frac{T}{L+T}$$

100% Energy recovery
Period between = 2*(Linac+train)



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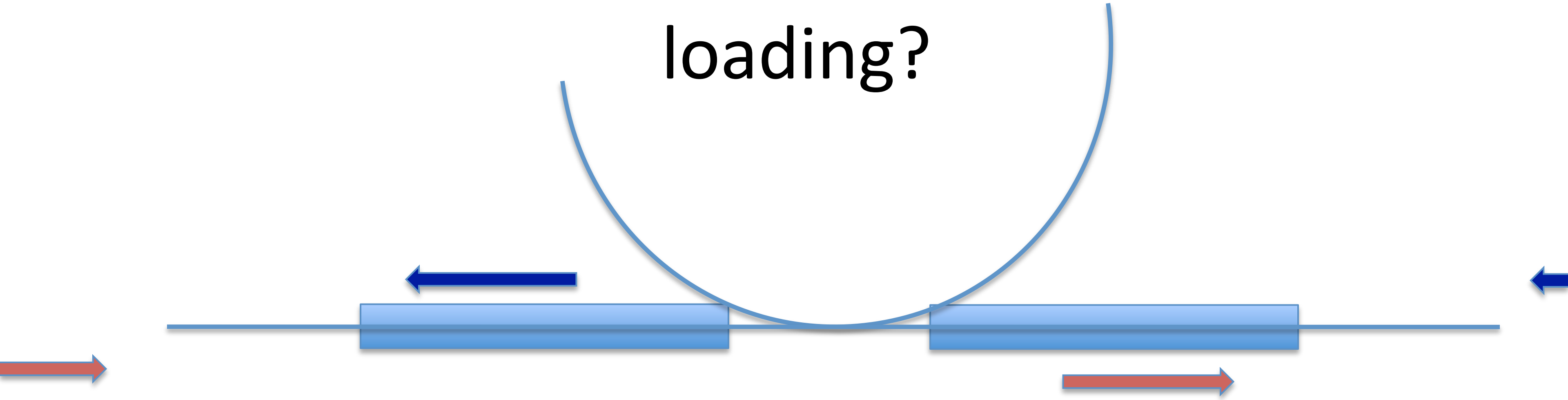

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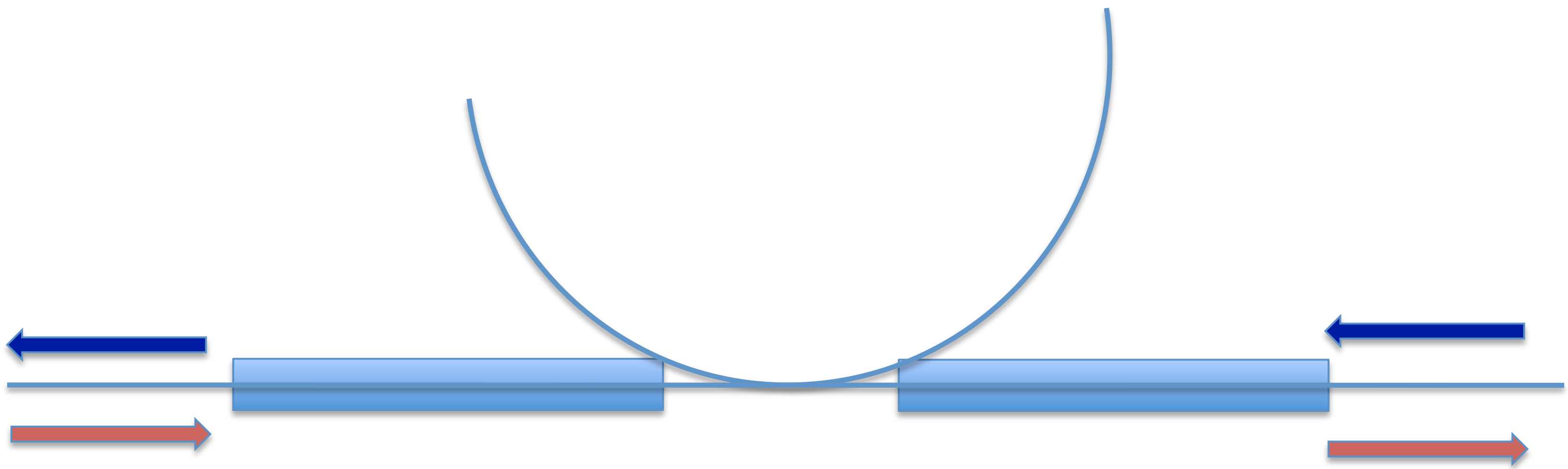

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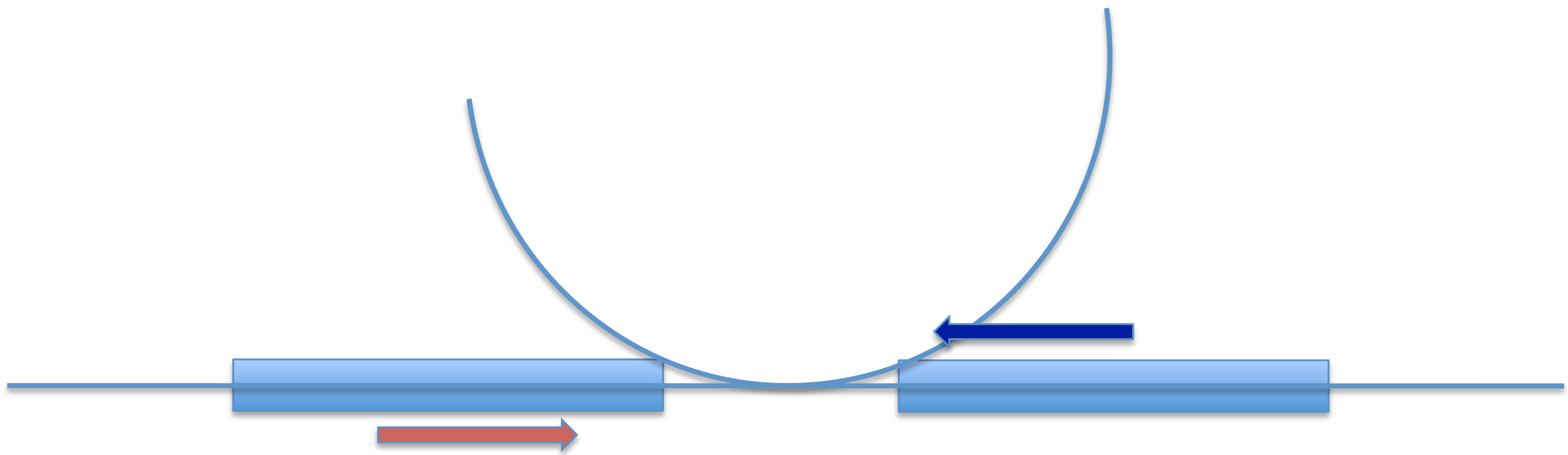
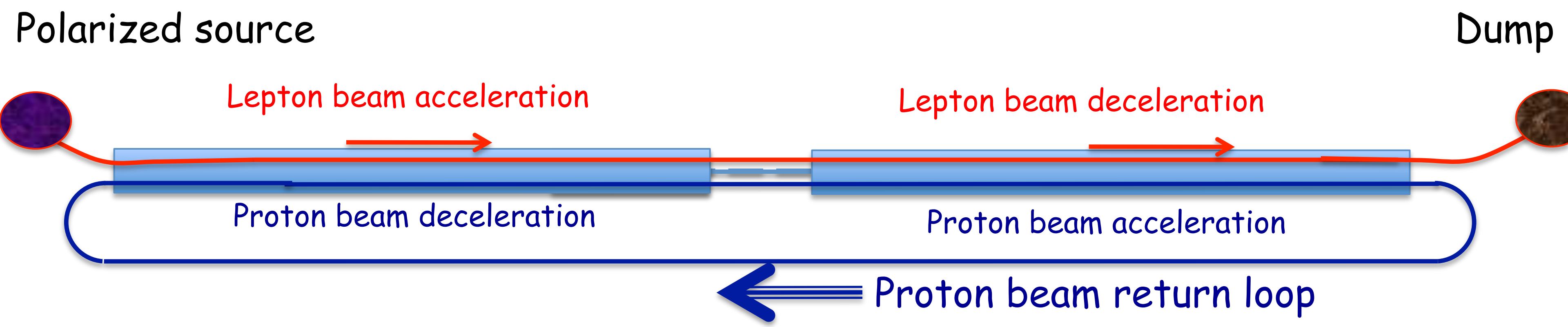


$$\mathcal{L} \sim \frac{T}{L+T}$$

Natural option of high energy high current ERL: proton beam is used to carry the energy

100% energy recovery



Energy flux is carried out by a proton beam

Synchrotron radiation is reduced ~10^{13} fold to watt level

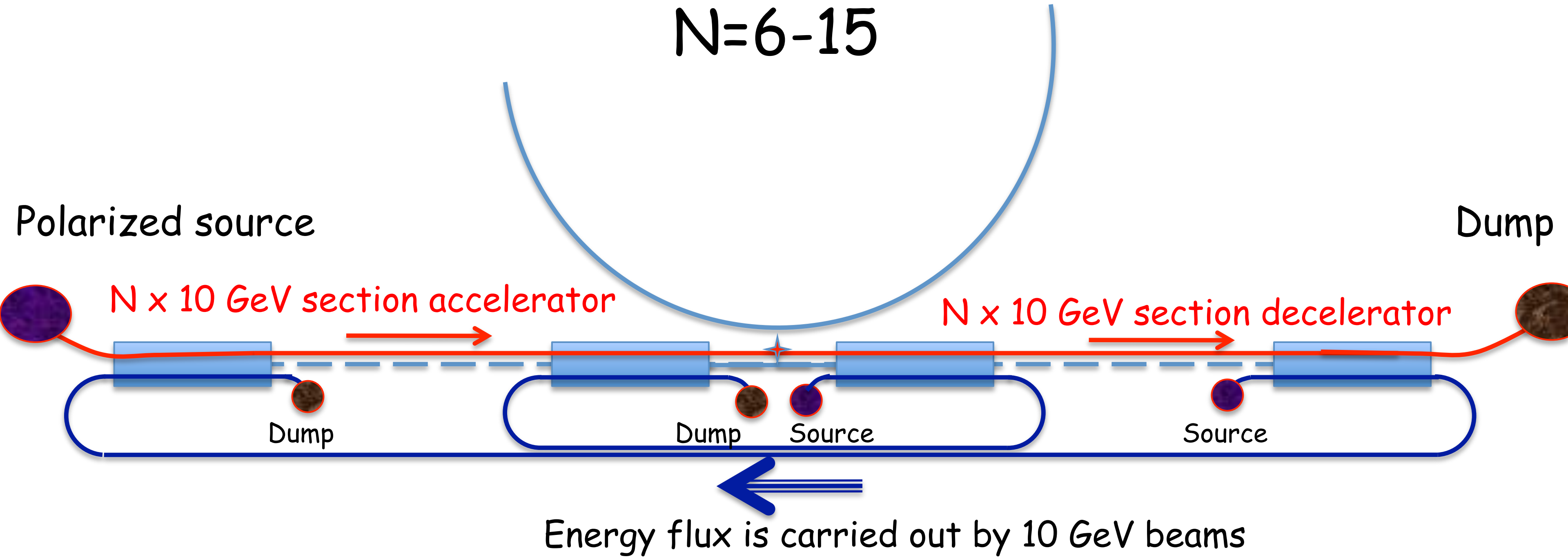
$$P_{SR}[W] = 7.79 \frac{E_p^4[TeV] \cdot I[A]}{R[km]}$$

Conclusions

- If TeV-range lepton beam is needed for ep collider – it can be build using linear energy recovery linac
- Energy recovery is accomplished by a proton beam
- Synchrotron radiation in reduced ~10^{13} fold
- Cost of the TeV-scale linac is a non-trivial consideration

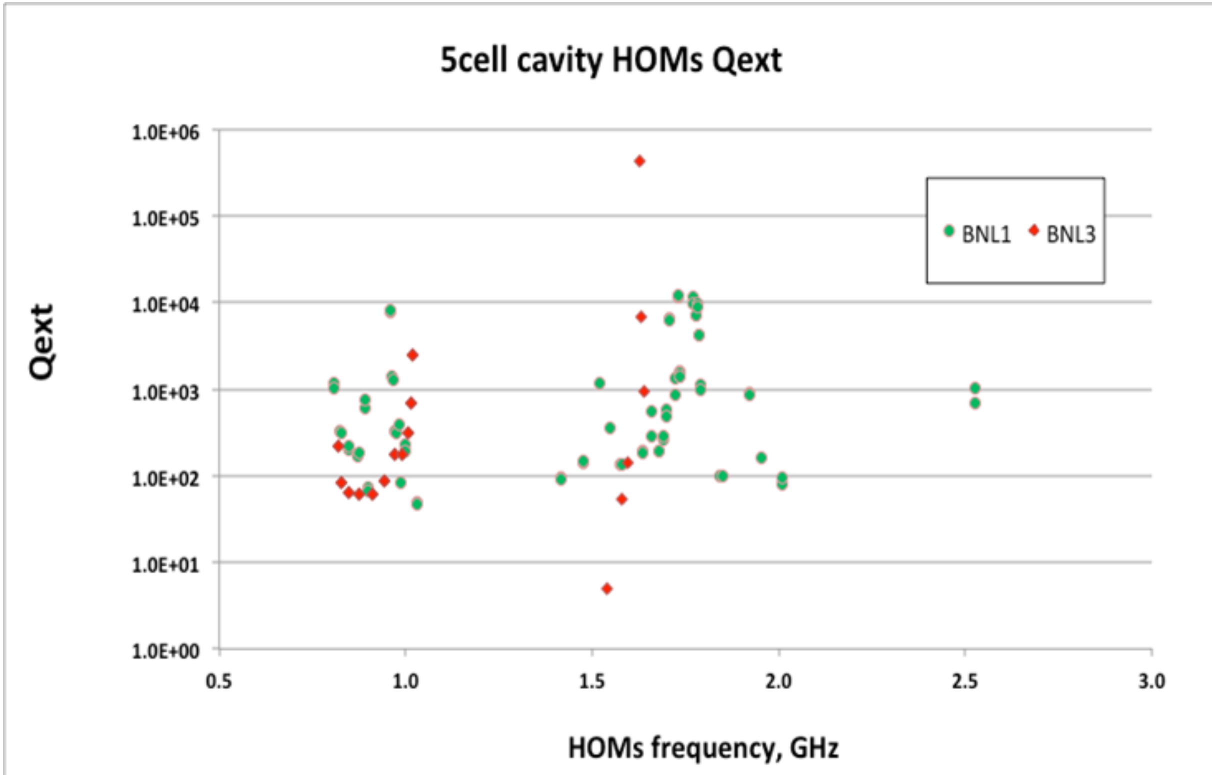
Back up

Nearly 100% energy recovery
LHeC II - E_e = 60-150... GeV
N=6-15



Synchrotron radiation a determined by energy of the returning beams. Losses grow linearly with the energy of the HE beam

HOMs used for BBU



Comparison of BNL1 and BNL3 dipole HOM's

BNL1

F (GHz)	R/Q (Ω)	Q	(R/Q)Q
0.8892	57.2	600	3.4e4
0.8916	57.2	750	4.3e4
1.7773	3.4	7084	2.4e4
1.7774	3.4	7167	2.4e4
1.7827	1.7	9899	1.7e4
1.7828	1.7	8967	1.5e4
1.7847	5.1	4200	2.1e4
1.7848	5.1	4200	2.1e4

BNL3

F (GHz)	R/Q (Ω)	Q	(R/Q)Q
1.01E+09	30.6	313.0	9562.7
1.01E+09	30.5	313.0	9551.2
1.63E+09	1.0	6730.0	7030.9
1.02E+09	7.7	693.0	5328.8
1.02E+09	7.6	693.0	5301.0
9.11E+08	67.2	61.1	4108.1
9.11E+08	67.1	61.1	4101.6
9.90E+08	22.7	176.0	3991.7