e-ERL as Injector for hh
(Barely good for a coffee discussion)

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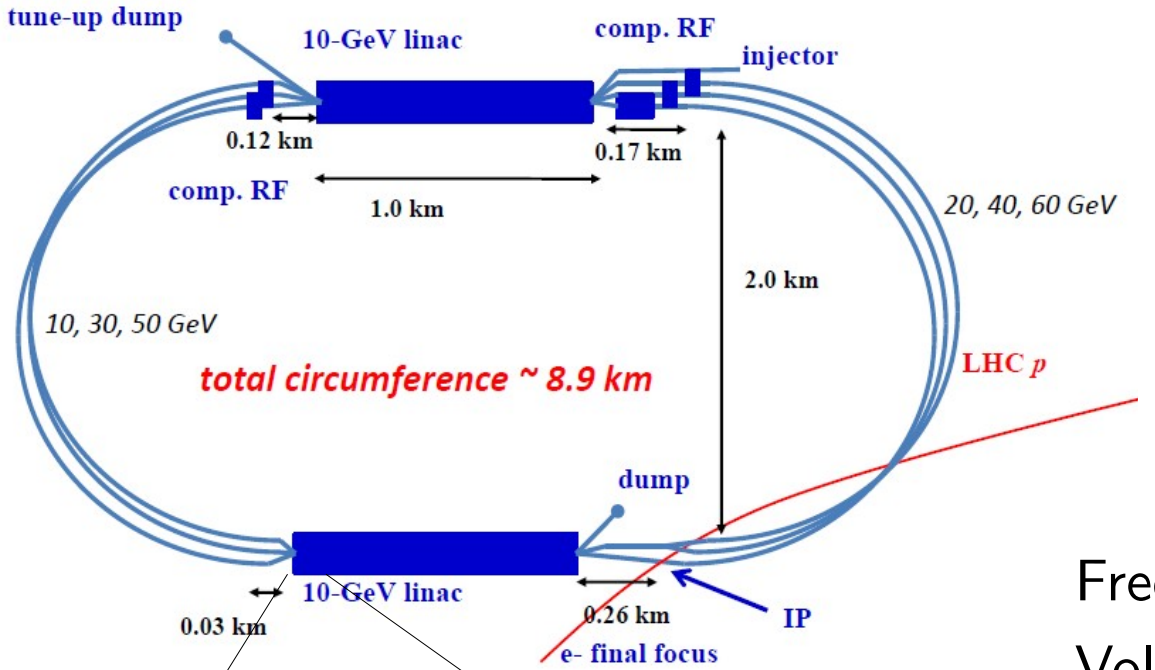
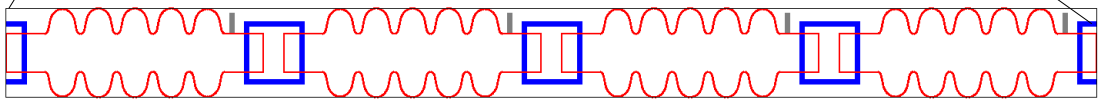
Ack: I. Ben-Zvi, O. Bruning, E. Jensen, E. Shaposhnikova for encouraging discussions

FCC -eh, ERL option





Basic unit: 5-cell cavity into 4-cavity module

Energy electrons: 60 GeV

Number of passes: 6

Beam current: 6.6-25.6 mA

Frequency: 801.58 MHz (h=20)

Voltage: 20 MV/cavity

R/Q: 393 Ω, Qe: 2×10^7

RF Power: 50 kW/cavity (25 MW)

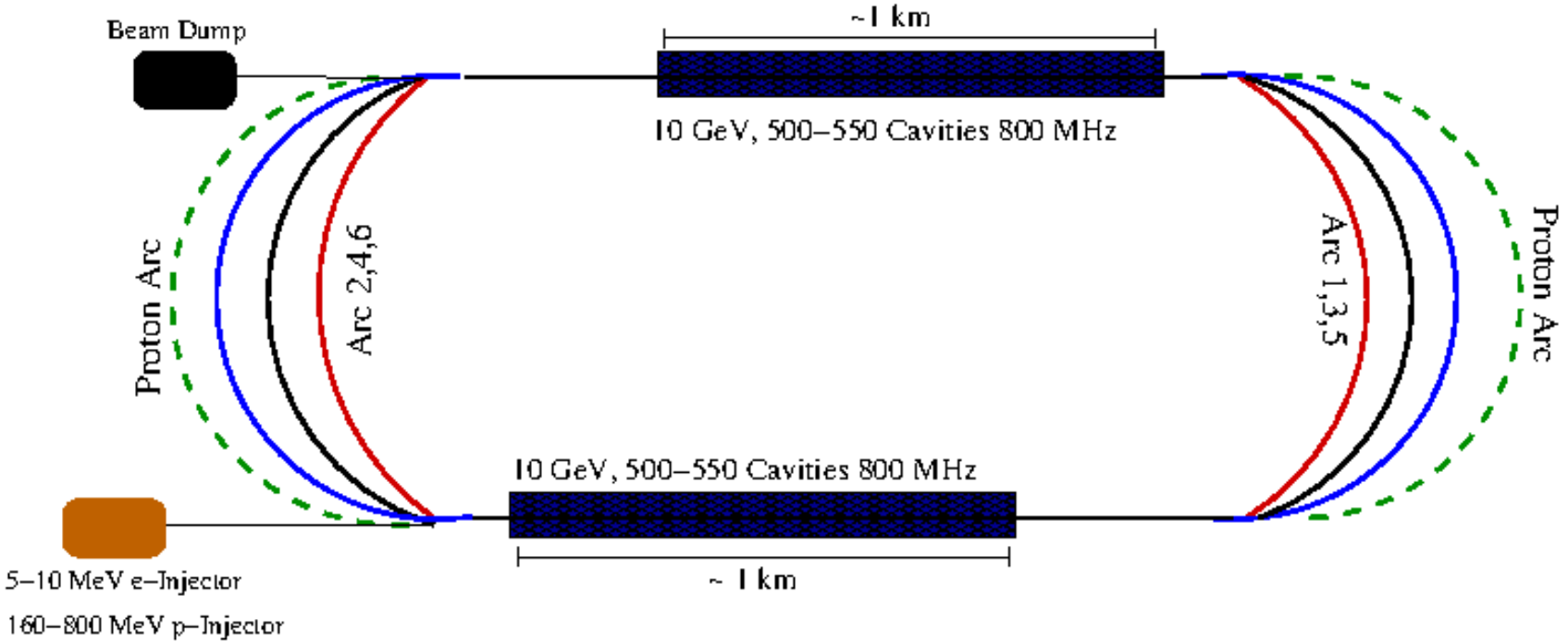
CW Cryo losses: (16 MW @5×10^{10})

Focus should be improve Q_0

e-ERL for Proton Injection

Recall: "SPL+PS2" as a new high brightness injector was already considered and abandoned for LHC

Proposal to use a single recirculating linac to directly inject to SPS (26 GeV) or SPS+ (~50 GeV), especially for 5ns bunch spacing.



** Production of the proton bunches (5-25 ns bunches) is ignored here

Why should we care

The 5ns bunch spacing as a means for reduced pile-up

FCC parameters for 5ns very difficult with present injectors (use linac)[1]

	LHC/HL	FCC-hh	FCC-hh	FCC-eh
Energy [TeV]	7	50	50	0.06
Bunch Spacing [ns]	25	**25**	**5**	5-25
Current, DC [A]	0.55-1.1	0.51	0.51	0.04
Bunch Intensity [10^{11}]	1.1-2.2	1.0	**0.2**	0.01
σ_z [cm]	7.55-9.0	8.0	8.0	7
ε_{xy} [μm]	2.5	2.2	**0.4**	50
Frequency [MHz]	400.79			801.58

[1]E. Shaposhnikova et al, FCC Berlin

eh-ERL for Proton Injection

Do we need really it, No

1. A "26 GeV" linac could provide a cleaner[1] way to make 5ns bunch spacing into SPS
2. A 2nd pass to recirculate the protons provides flexibility on the injection energy to the SPS(+), say up to 50 GeV

**** This contribution is only to motivate the idea w/o detailed studies that are required to validate the feasibility ****

If feasible, fill Protons in RL-mode + run Electrons for eh collisions in ERL-mode

Can It Work

At energy < 800 MeV, the rapid change in particle β implies a "pre-injector", for example Linac4+ for single shot injection into p-RL (intensity/bunch $\sim$ x10 more)

A pre-injector is useful for e-ERL for the reason of ER of spent beam below 1 GeV (?).

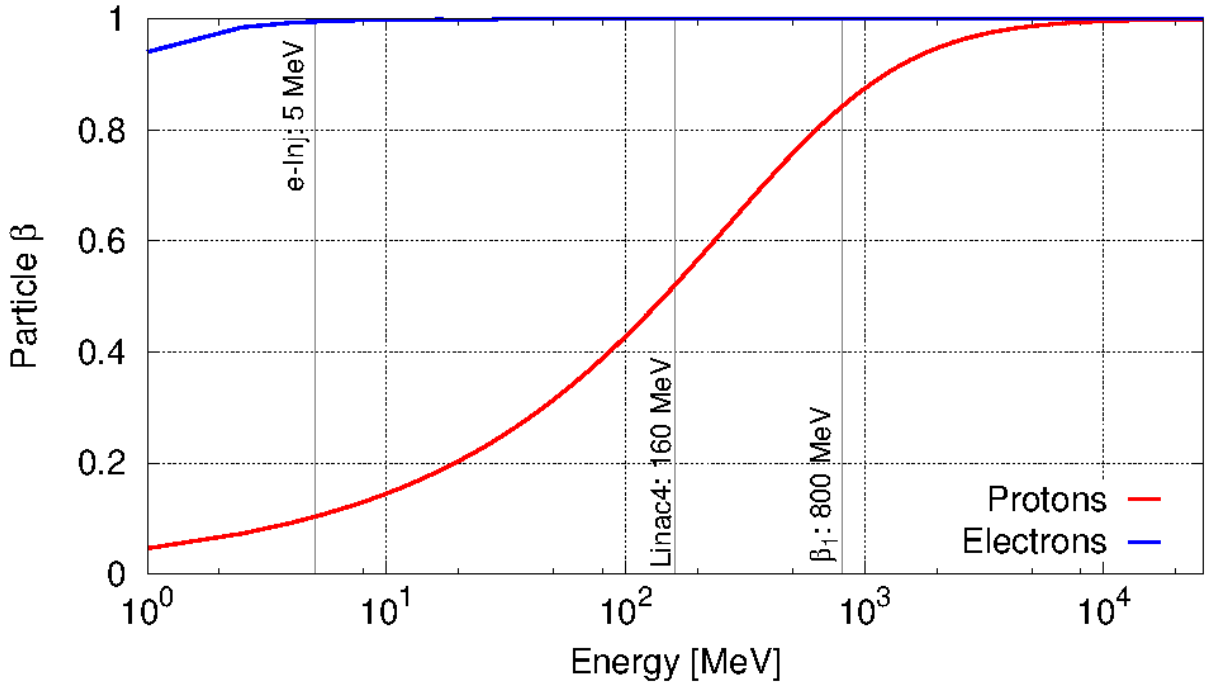
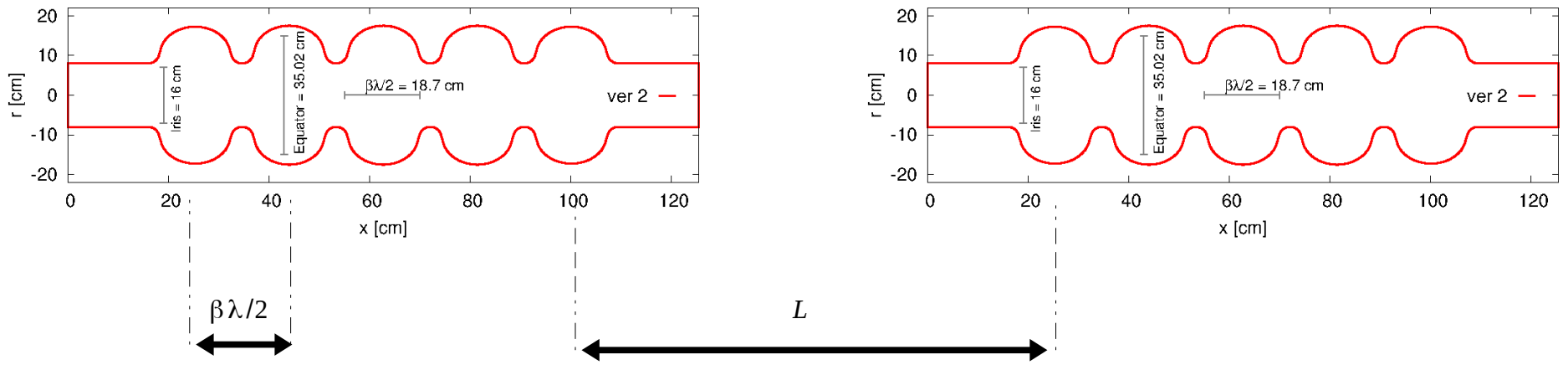


Table 1: main parameters of Linac4

		Linac4 phase I	SPL inject. phase II
length	[m]	80	88
beam energy	[MeV]	160	180
beam power	[kW]	5.1	205
bunch frequency	[MHz]	352.2	352.2
repetition rate	[Hz]	2	50
source current	[mA]	80	80
av. bunch current	[mA]	40	40
chopper beam on	[%]	62	62
beam pulse length	[ms]	0.4	0.57
particles per pulse	[10^{14}]	1.0	1.42
particles per bunch	[10^9]	1.14	1.14
tr. rms emittance	[mm mrad]	0.36	0.36
long. rms emittance	[deg MeV]	0.19	0.19

Garoby, EPAC06

802 MHz, 5-Cell Cavity As Example



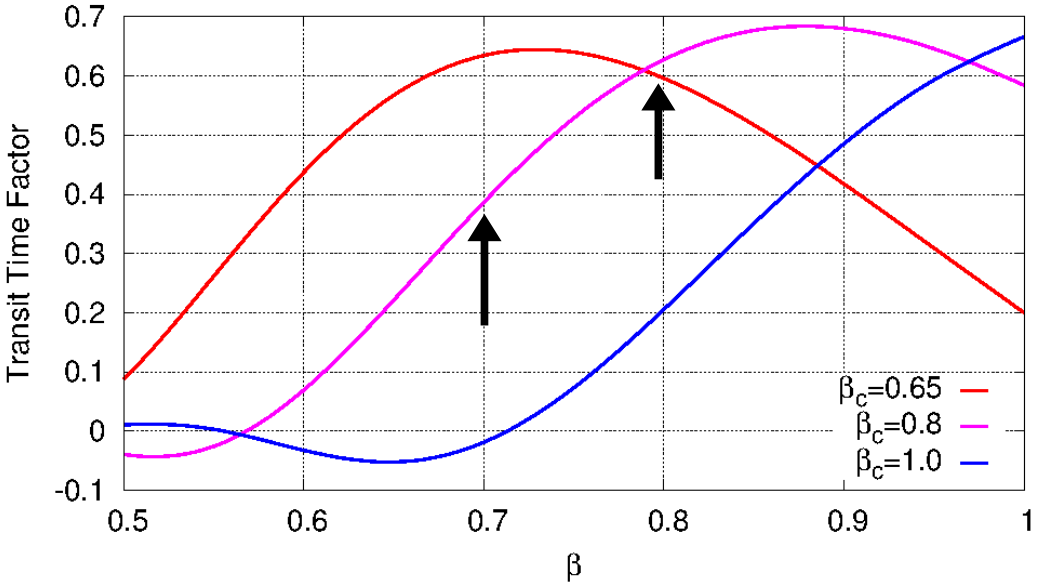
Energy Gain:

$$\Delta E = q \,.\, V_0 \,.\, T(\beta) \,.\, \cos\phi_s$$

Optimum transition energy and βc in the low energy part is essential

One possibility is to use 2-cell cavity or 0-mode in low energy part

For Protons $<$ 700 MeV, ERL (high β) not useful



802 MHz, 5-Cell Cavity As Example

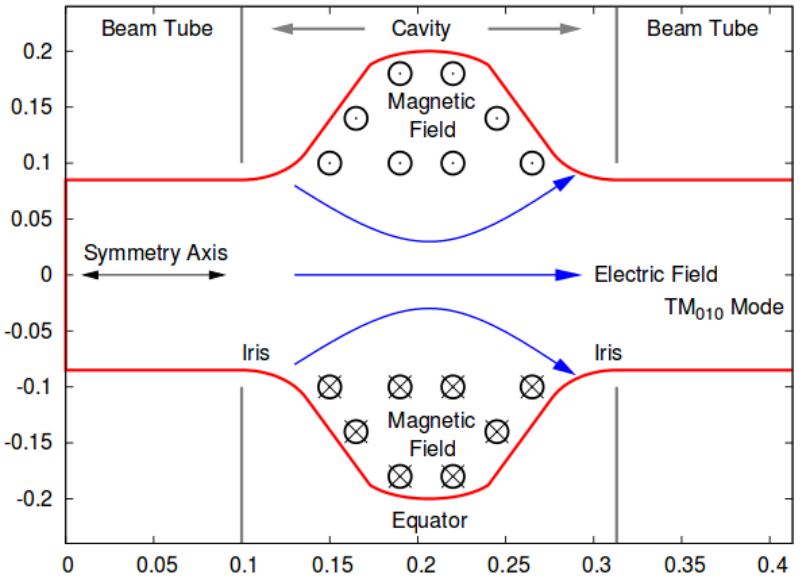
Longitudinal focusing (stable phase) & optimum ramping along the first section very important.

Transverse focusing especially at the low energy is critical to maintain the low emittance (0.4 μm) for protons through out the p-RL

RF transverse de-focusing:

$$\Delta p_r \propto \frac{1}{\lambda (\beta \gamma)^2}$$

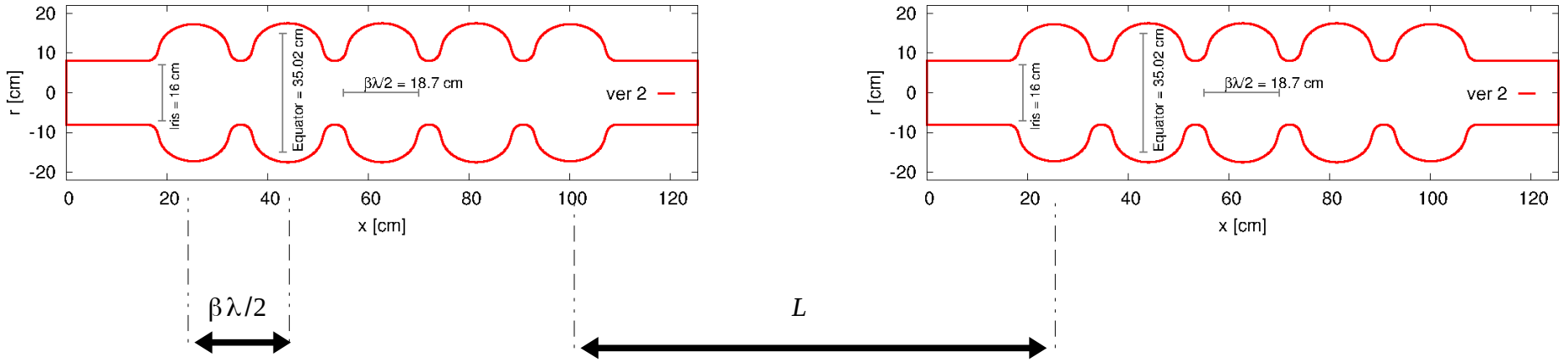
Space charge forces are also $1/\gamma^2$



Second Pass, Protons

Distance between cavities is fixed, optimized for e-ERL where the phase-slip in multiple passes is zero.

For protons, optimum length for the first 10 GeV linac is 10-20% shorter. So relative phase between cavities is adjusted.



However, round trip time is ~30 μs, so change in RF phase between passes is not feasible ($\tau_{cav} \sim 8$ms). Is it possible with return arc tuning + fast cavity tuning[1] using piezo's/ferro-electric materials

[1] also in discussions with I. Ben-Zvi, F. Gerigk

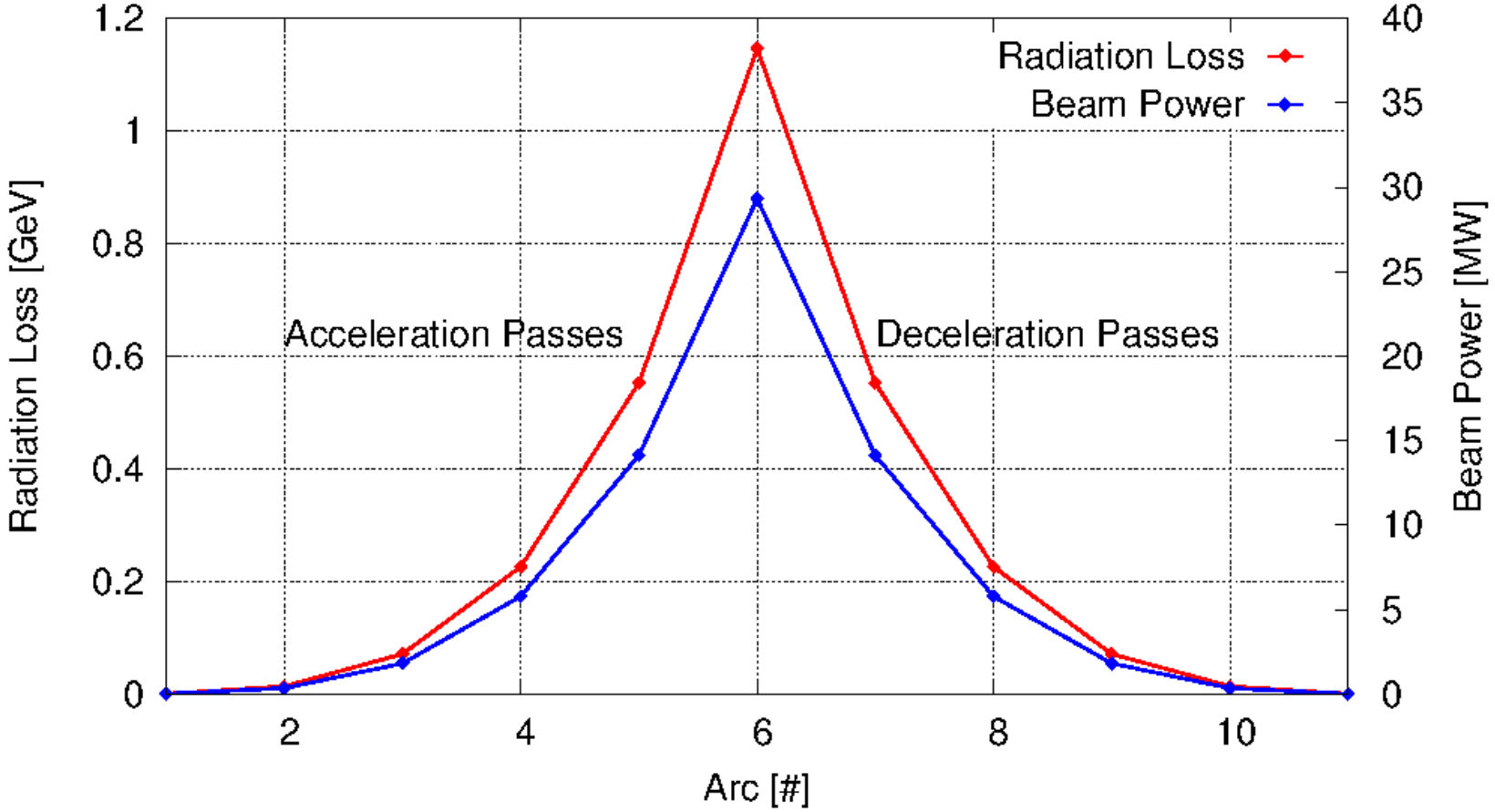
RF Power, e-ERL

Energy recovery after total 6 passes: 95.2 %

Sync radiation loss: 2.88 GeV (44-73.6 MW accumulated beam power†)

Assuming ~1000 cavities (20 MV/cavity) – 44-74 kW RF power/cavity

Some extra power for transient (Microphonics, LFD...)

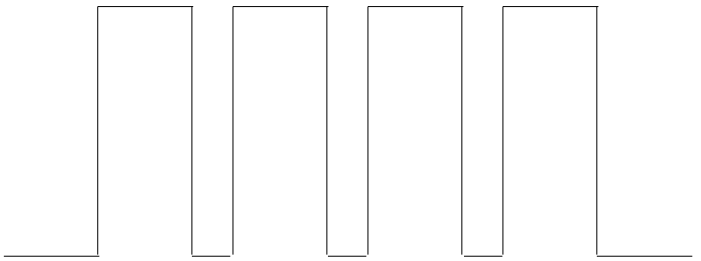


†30 MW can be saved if 60 GeV beam Is not bent

RF Power, p-RL

SPS macro-pulse example:

- 300 bunches x 10^{11} p/b = 0.3x10^{14} p/pulse
- Or the 5ns equivalent (0.2x10^{11} p/b)
- RF pulse flattop $\sim$ 20 μs ($\tau_{cav} \sim$ 8ms)



(25 ns x 72 + 8e) x 4 batches = 8 μs

Final Energy: 26 GeV (upto 50 GeV)

Total Beam Power: 5.8 MW using 10 Hz rep.rate

Consider 25% overhead: 7.3 MW (for transients)

Per Cavity: Assume 50 kW-CW maximum (maybe x2 more)

We can assume up to 200 kW/pulsed $<$ 1% duty cycle (MBT[1])

The RF power in pulsed mode maybe a limitation

[1]E. Montesinos

Some Remarks

RL as an injector to provide 5-25 ns spacing for protons

- A proton-RL seems feasible within the scope of e-ERL specs
- e-ERL at ~20 MV/cavity (RF loss limited), p-RL @25MV/cavity
- For energy $>$ 26 GeV, second pass required

Challenges

- Efficiency in the low energy part requires detailed look, a pre-injector ~700-800 MeV keeping big linac constant
- The choice of Q_L for electron & protons + RF power maybe an important limitation (has to be studied)

Second RL pass

- If a higher injection is desired for SPS+. Tuning of the return arc can + "cavity re-phasing"