Optics design studies for linac/ERL based LHeC

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<u>outline:</u>

introduction & 3 scenarios

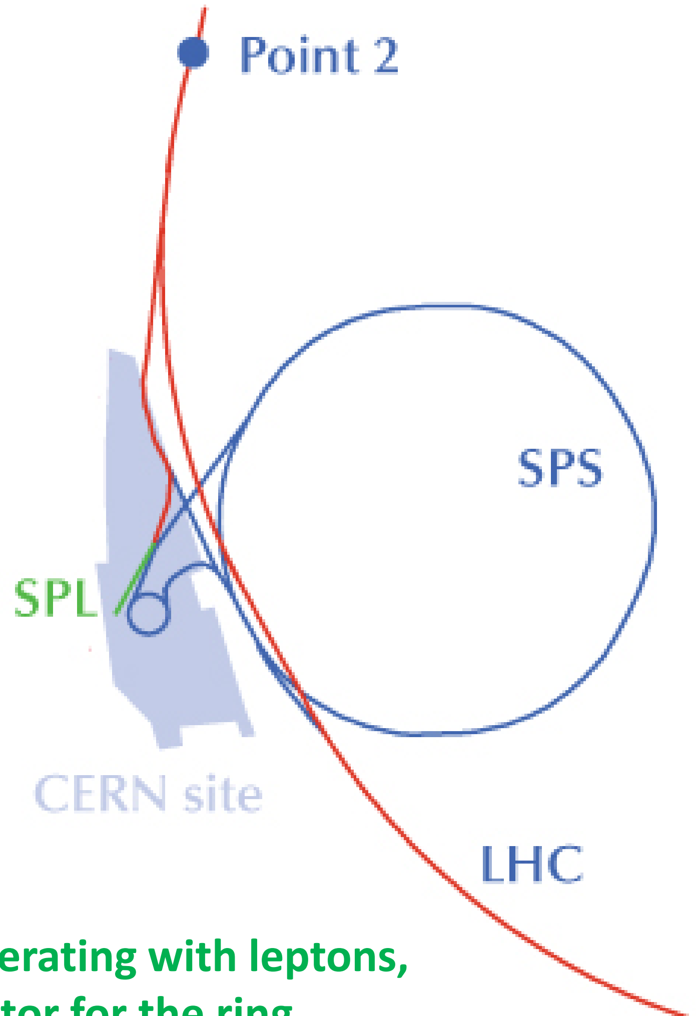
optics designs for 5 GeV injection

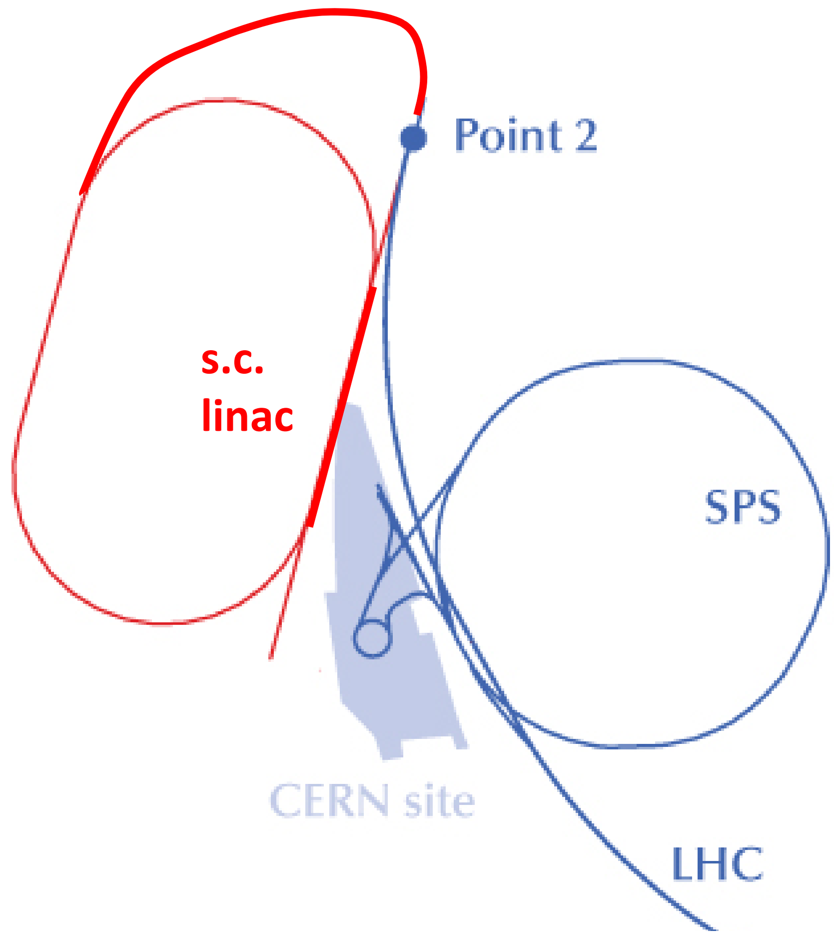
designs with lower injection energy

future work

option 1: “ring-ring” (RR)
e-/e+ ring in LHC tunnel

option 2: “ring-linac” (RL)

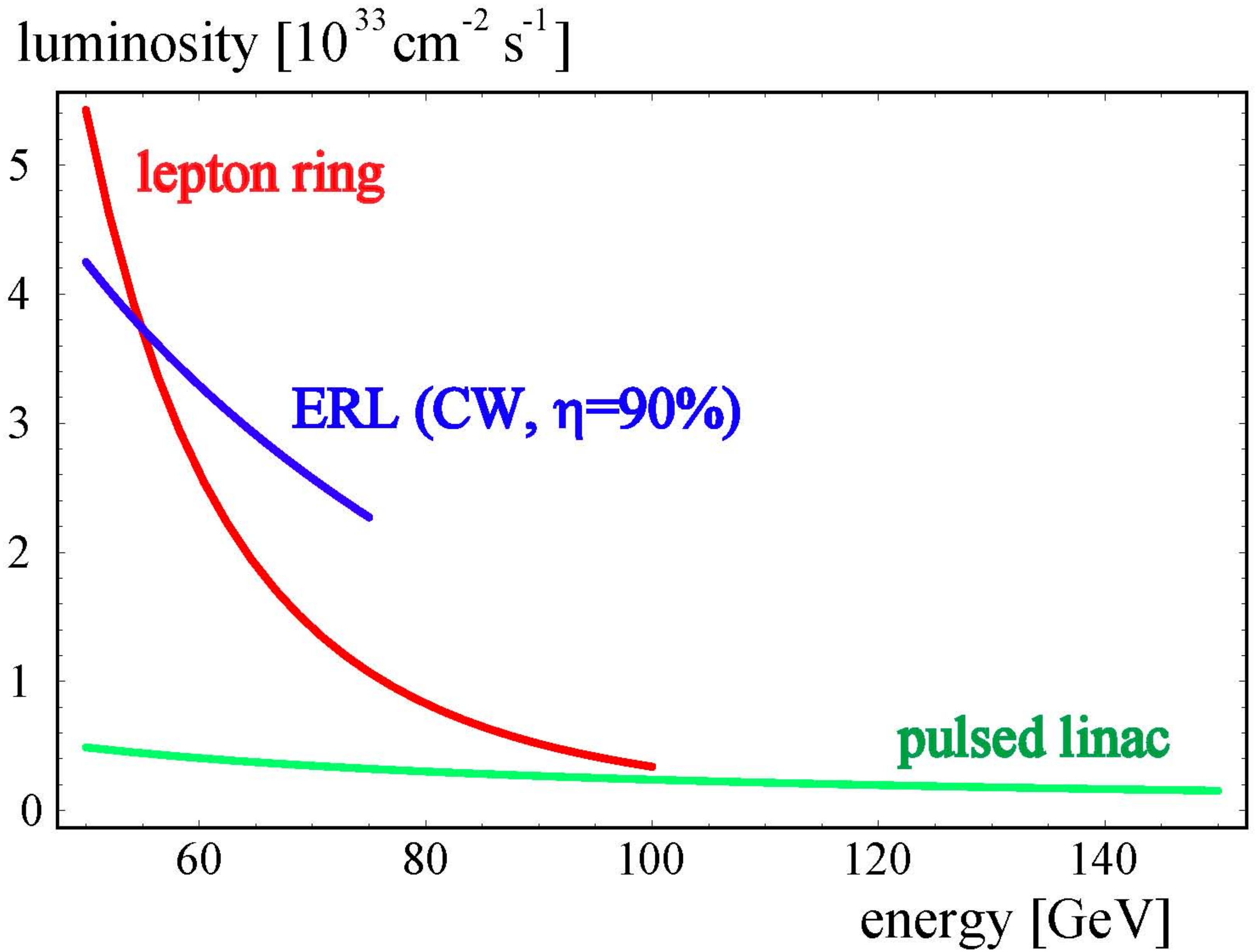




SPL, operating with leptons, as injector for the ring, possibly with recirculation;

up to 70 GeV: option for cw operation and recirculation with energy recovery;
> 70 GeV: pulsed operation at higher gradient ; γ-hadron option

luminosity vs energy



example parameters

	LHeC-RR	LHeC-RL high lumi	LHeC-RL 100 GeV	LHeC-RL high energy	ILC	XFEL
e^- energy at IP [GeV]	60	60	100	140	(2×)250	20
luminosity [10^{32} cm^{-2}s^{-1}]	29	$29^\dagger$ ($2.9^\ddagger$)	2.2	1.5	200	N/A
bunch population [10^{10}]	5.6	$0.19^\dagger$ ($0.02^\ddagger$)	0.3 (1.5)	0.2 (1.0)	2	0.6
e^- bunch length [μm]	~10,000	300	300	300	300	24
bunch interval [ns]	50	50	50 (250)	50 (250)	369	200
norm. hor.&vert. emittance [μm]	4000, 2500	50	50	50	10, 0.04	1.4
average current [mA]	135	$7^\dagger$ ($0.7^\ddagger$)	0.5	0.5	0.04	0.03
rms IP beam size [μm]	44, 27	7	7	7	0.64, 0.006	N/A
repetition rate [Hz]	CW	CW	10 [5% d.f.]	10 [5% d.f.]	5	10
bunches/pulse	N/A	N/A	71430	14286	2625	3250
pulse current [mA]	N/A	N/A	10	10	9	25
beam pulse length [ms]	N/A	N/A	5	5	1	0.65
cryo power [MW]	0.5	20	4	6	34	3.6
total wall plug power [MW]	100	100	100	100	230	19

Example LHeC-RR and RL parameters. Numbers for LHeC-RL high-luminosity option marked by `†' assume energy recovery with $\eta_{ER}$=90%; those with `‡' refer to η_{ER}=0%. ILC and XFEL numbers are included for comparison. Note that optimization of the RR luminosity for different LHC beam assumptions leads to similar luminosity values of about 10^{33}cm^{-2}s^{-1}

tentative SC linac parameters for RL

LHC 7-TeV *p* beam parameters

	$N_{b,p}$	T_{sep}	$\varepsilon_p \gamma_p$	$\beta^*_{p,min}$
LHC phase-I upgrade	**1.7x10^{11}**	**25 ns**	**3.75 μm**	**0.25 m**
LHC phase-II upgrade ("LPA")	**5x10^{11}**	**50 ns**	**3.75 μm**	**0.10 m**

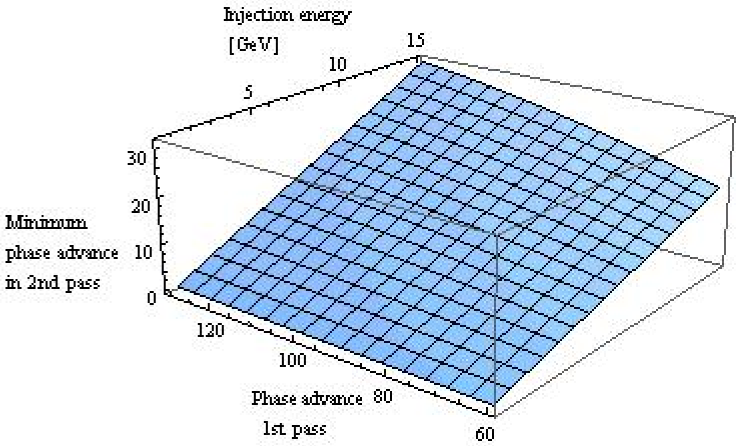
LHeC-RL scenario	lumi	baseline	energy
final energy [GeV]	60	100	140
cell length [m]	24	24	24
cavity fill factor	0.7	0.7	0.7
tot. linac length [m]	3000	2712	3024
cav. gradient [MV/m]	13	25	32
operation mode	CW (ERL)	pulsed	pulsed

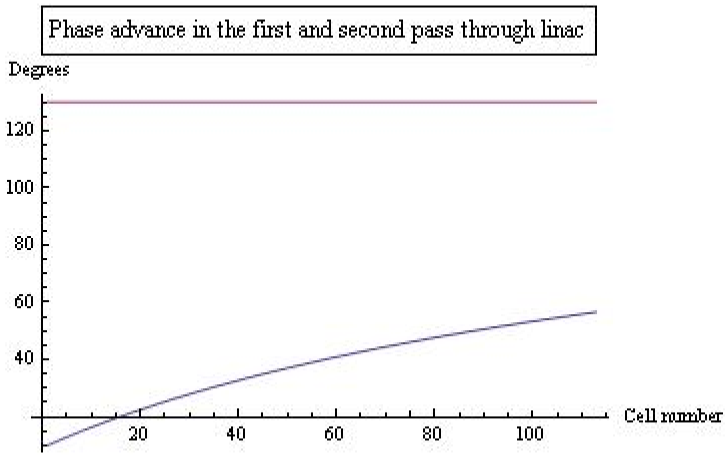
RF frequency: ~700 MHz

4 passes **2 passes**

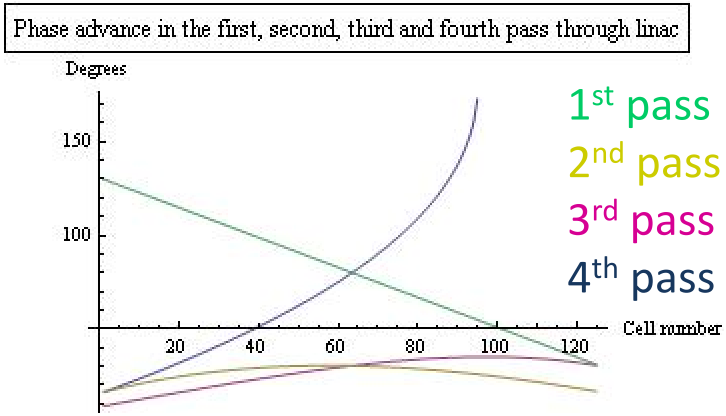
phase advance in linac

100 GeV





60 GeV ERL

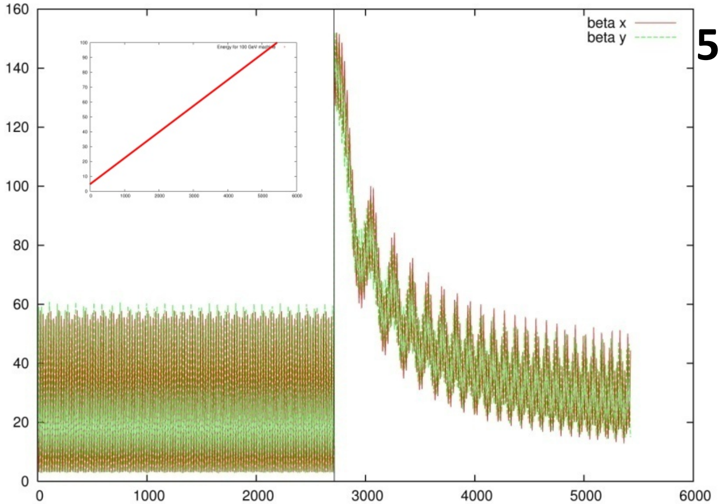


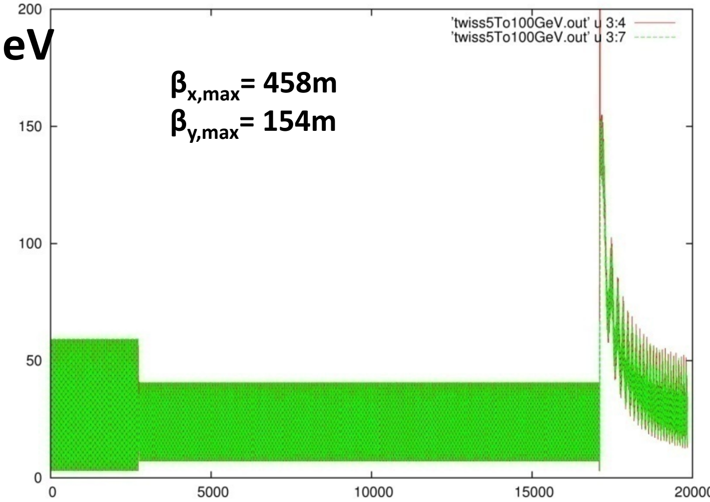
Using the same lattice for several passes through the linac at different energies requires a conscious choice of phase advance and injection energy

- in the 100GeV recirculating linac an injection energy of 5GeV and a constant phase advance of 130˚ is chosen for the first pass
- in the ERL the phase advance is set to decrease linearly from 130˚ to 30˚

Placet and MAD-X simulations

5 → 100 GeV

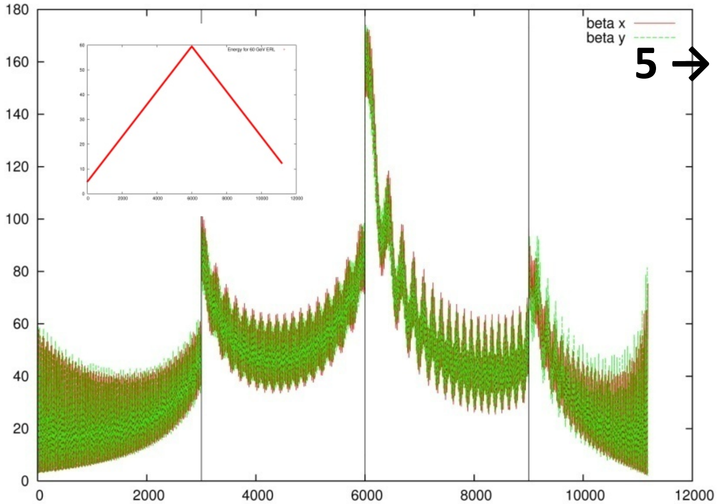


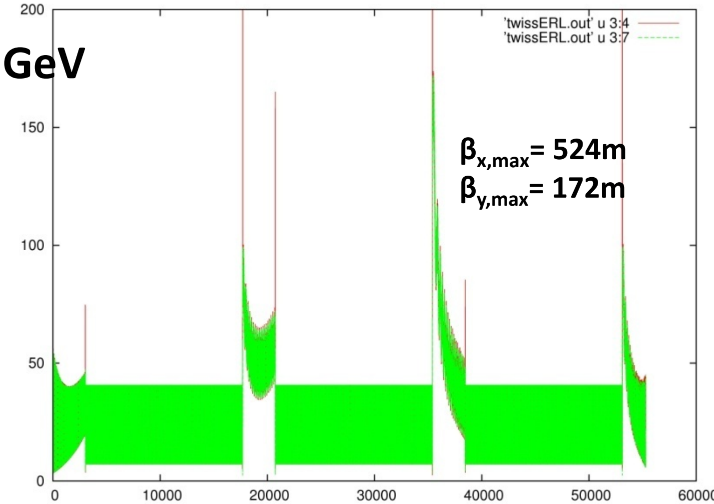


Placet (linac only)

MAD-X (with arcs)

5 → 60 → 13 GeV





lower injection energy

encouraged by Georg Hoffstaetter

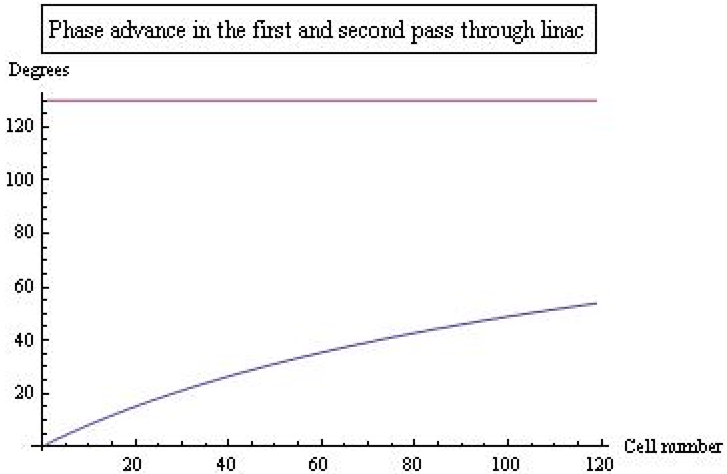
advantages:

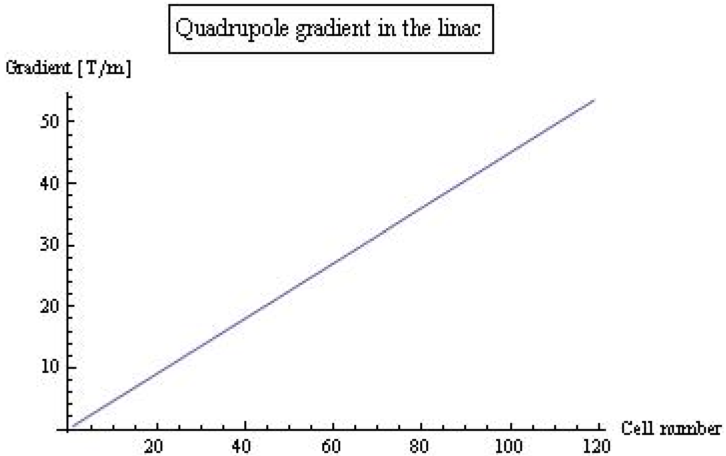
- for 2-pass recirculating linac (100 or 140 GeV)
  slightly reduced linac length ~2%
- strong impact on ERL efficiency
  $\eta_{max} \sim (E_{coll} - E_{inj} - \Delta E_{SR})/E_{coll}$, $L \sim 1/(1-\eta_{max})$

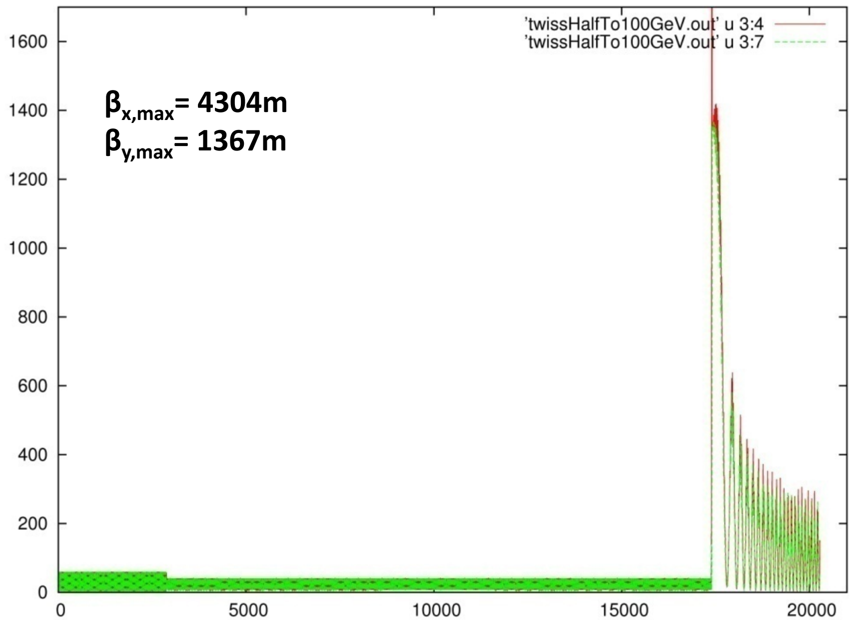
disadvantage:

- large beta functions at transitions & linac ends
- loss of adiabaticity and significant beating

from 0.5 to 100 GeV



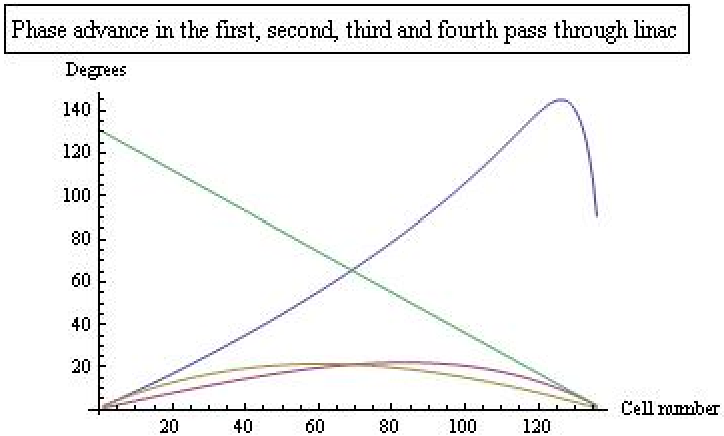


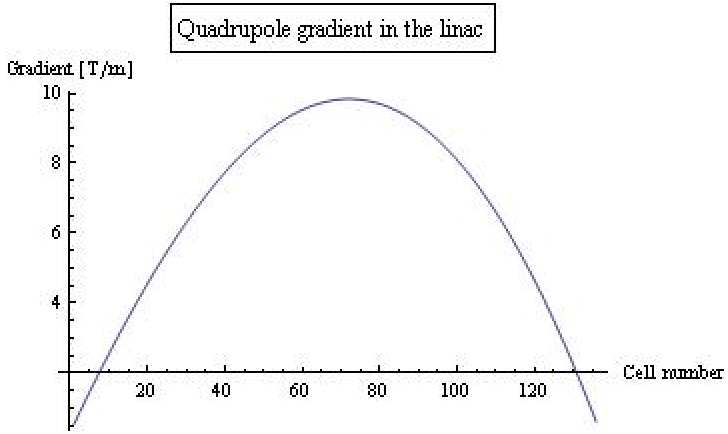


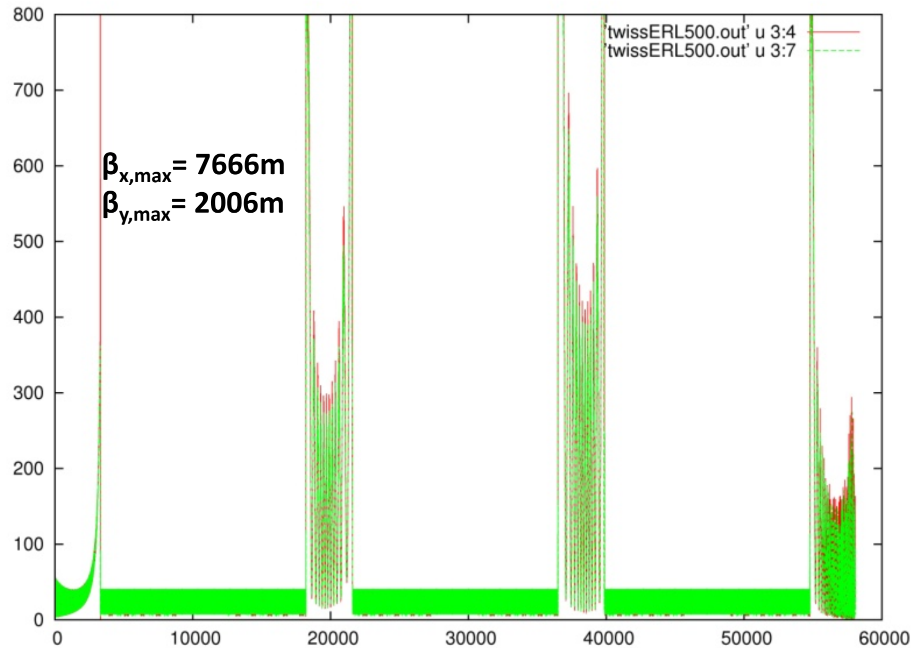
$\beta_{x,max}$= 4304m
$\beta_{y,max}$= 1367m

$E_{injection}$= 0.5 GeV
$E_{colision}$= 100 GeV
L_{linac}= 2856 m
$\beta_{max,linac}$= 1367 m

99% ERL scheme







$E_{injection/extraction}$= 0.5 GeV
$E_{colision}$= 60 GeV
L_{linac}= 3264 m
$\beta_{max,linac}$= 1865 m

next steps

- Tracking with MAD-X
  - Verify emittance growth from SR and compare with analytical estimate [10% growth for E_{final}=140 GeV]
  - Introduce cavities in MAD-X and observe effect on emittance
  - Observe chromatic effects, and, if needed and possible, implement chromatic correction with arc sextupoles and/or fine-tune the lattice [see next point]
- Improvement of lattice
  - Reduce β-peak in linac-to-arc transition regions
- Study wake-field effects in Placet
- Study Higher Order Mode heat loss
- Crosscheck power levels with Cornell & BNL