Velocity bunching in a main linac of ERL

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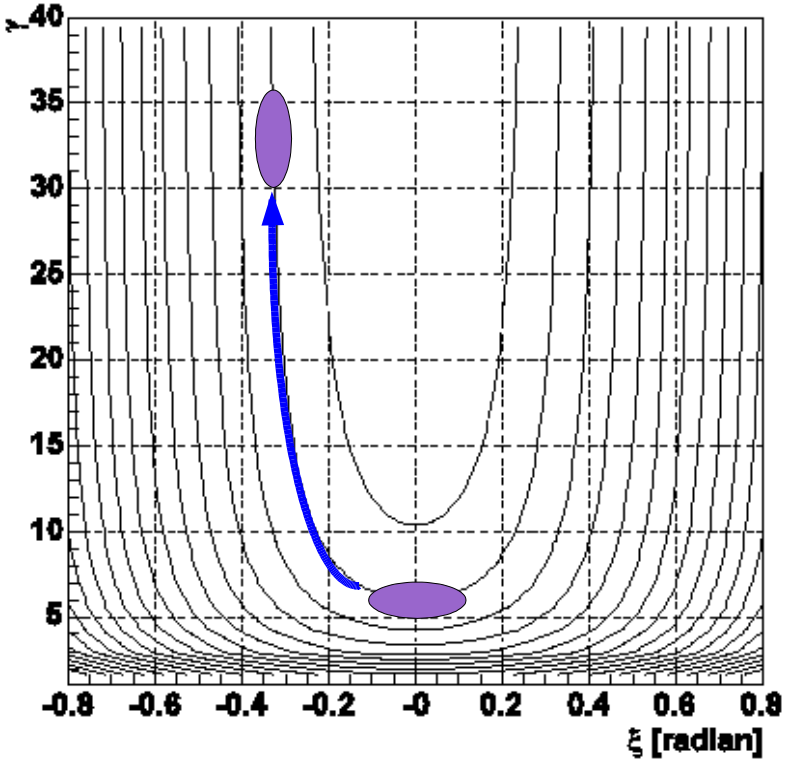
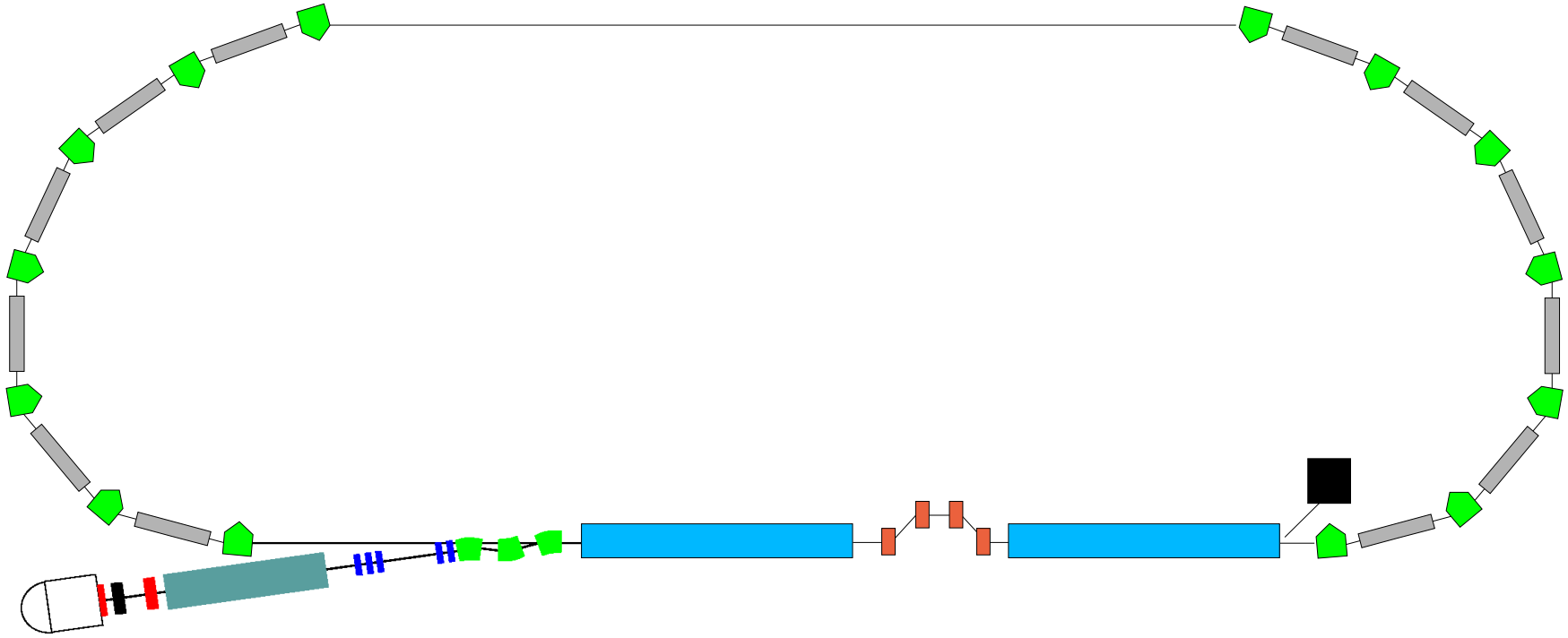


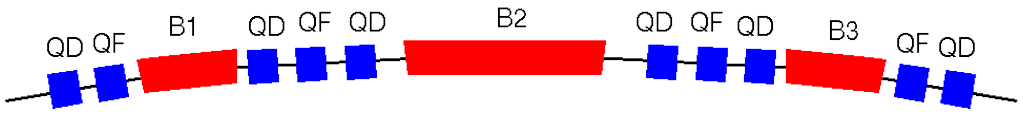
Bunch compression in an ERL light source



possible location for bunch compression

- magnetic bunching : merger, mid-energy, arc
- velocity bunching : injector, main linac

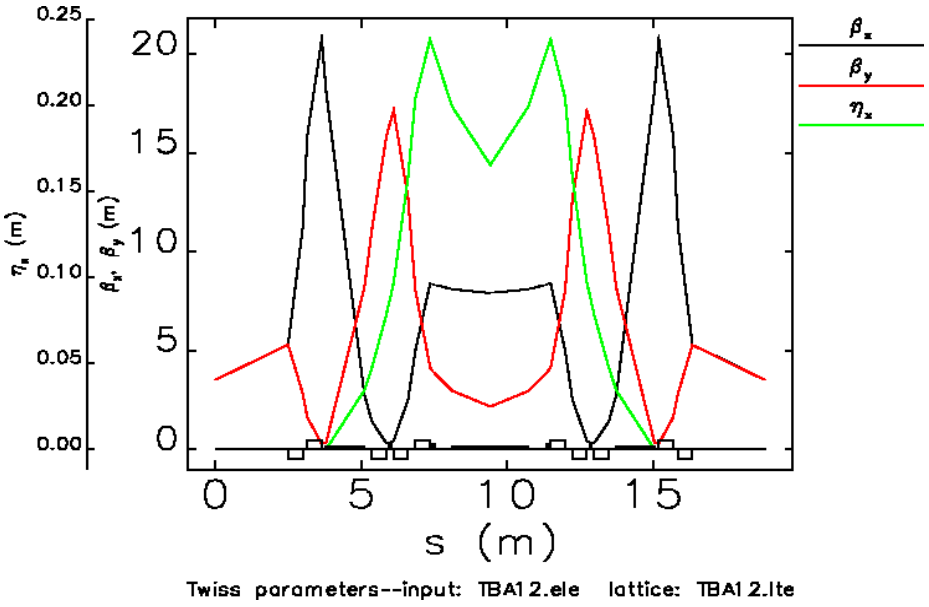
Bunch compression in a half-arc of 6-GeV ERL

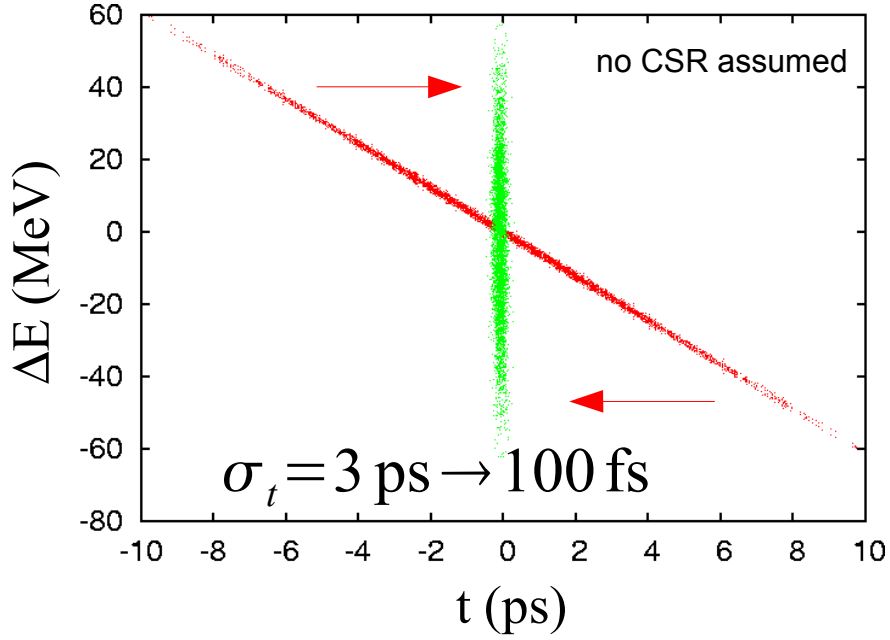


Triple Bend Achromat

$$\rho = 25\,m\,,\ \theta = 3+6+3 = 12\,\text{deg.}$$

$$R_{56} = 2\,\text{cm / cell}$$

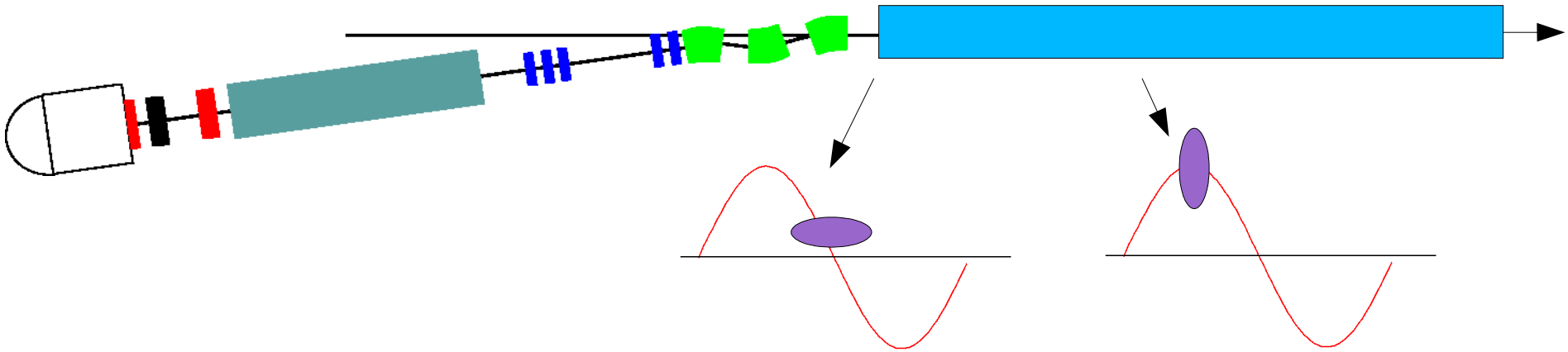




- a 3-ps bunch is compressed into 100 fs after 15-cell (half arc)
- fairly linear compression with sextupole correction
- relatively large energy spread remains $\sigma_E / E = 0.34\,\%$

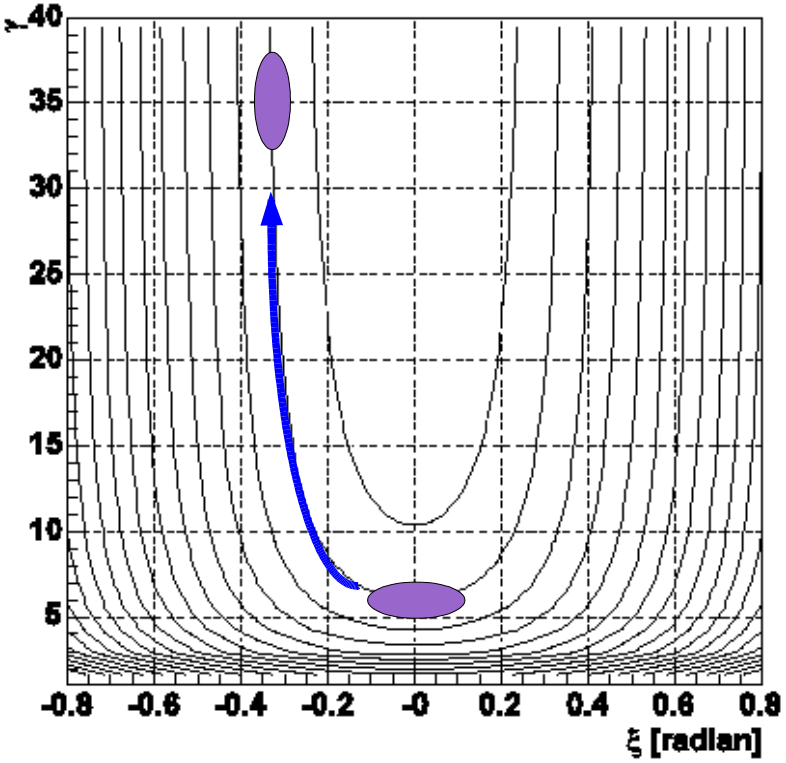
  -- may degrade brilliance of a long undulator

Velocity bunching in a main linac



Is it possible to make velocity bunching at the beginning of main linac ?

- how short bunch ?
- merging energy ?
- emittance growth ?
- energy-recovery OK ?
- HOM loading to the main linac ?
- residual energy spread ?



Compression factor

L. Serafini and M. Ferrario, AIP Conf. 581 (2001).

Hamiltonian is an invariant of motion.

$$\gamma - \beta_r \sqrt{\gamma^2 - 1} - \alpha \cos\xi = \gamma_0 - \beta_r \sqrt{\gamma_0^2 - 1} - \alpha \cos\psi_0$$

Final state — Initial state

$$C = \frac{\delta\psi_0}{\delta\xi_{ex}} = \frac{2\delta\psi_0 \left|\sin\overline{\xi_{ex}}\right|}{\sqrt{\delta\psi_0^4 + \left(\frac{1}{\alpha\overline{\gamma_0}}\frac{\delta\gamma_0}{\overline{\gamma_0}}\right)^2}}$$

$\delta\psi_0$: Injected bunch width

$\delta\xi_{ex}$: Extracted bunch width

ξ_{ex}: Extraction phase

γ_0 : Injected beam energy

$\delta\gamma_0/\gamma_0$: Energy spread

Dimensionless acc. gradient

Dimensionless Parameter
Representing the Strength of the Accelerating Field

$$\alpha = \frac{e E_0}{m c^2 k}$$

E_0 : Peak Accelerating Gradient [MV/m]

k : Wave Number, 27.2 [/m] for 1.3 [GHz]

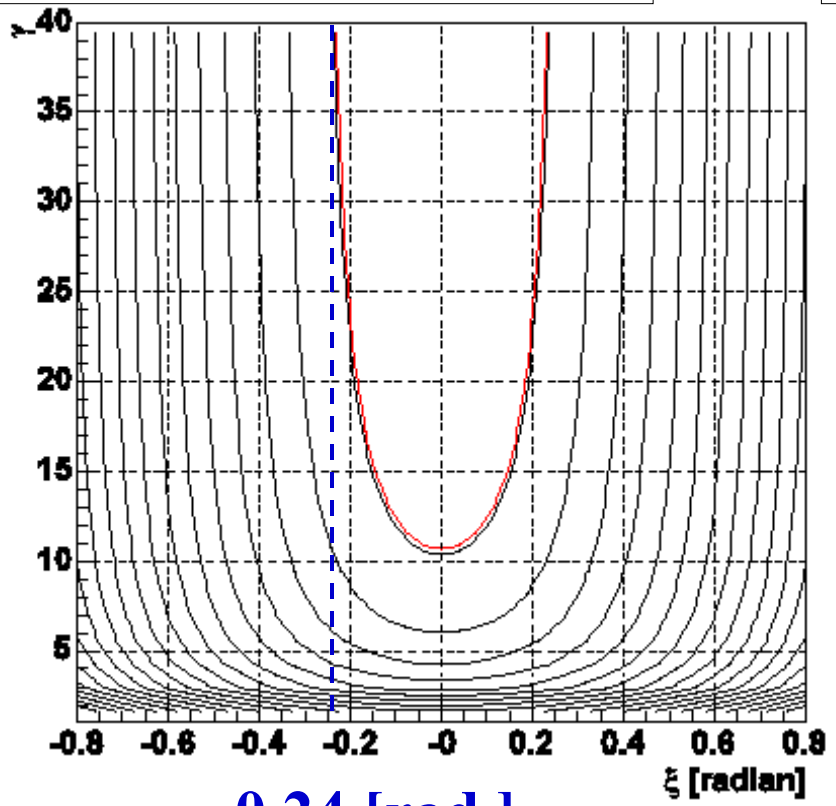
Ex. $\alpha = 1.29$ for $E_0 = 18$[MV/m]

Phase contour plot

We assume an initial bunch as 5MeV, 3.2ps (rms).

$\alpha = 1.29$

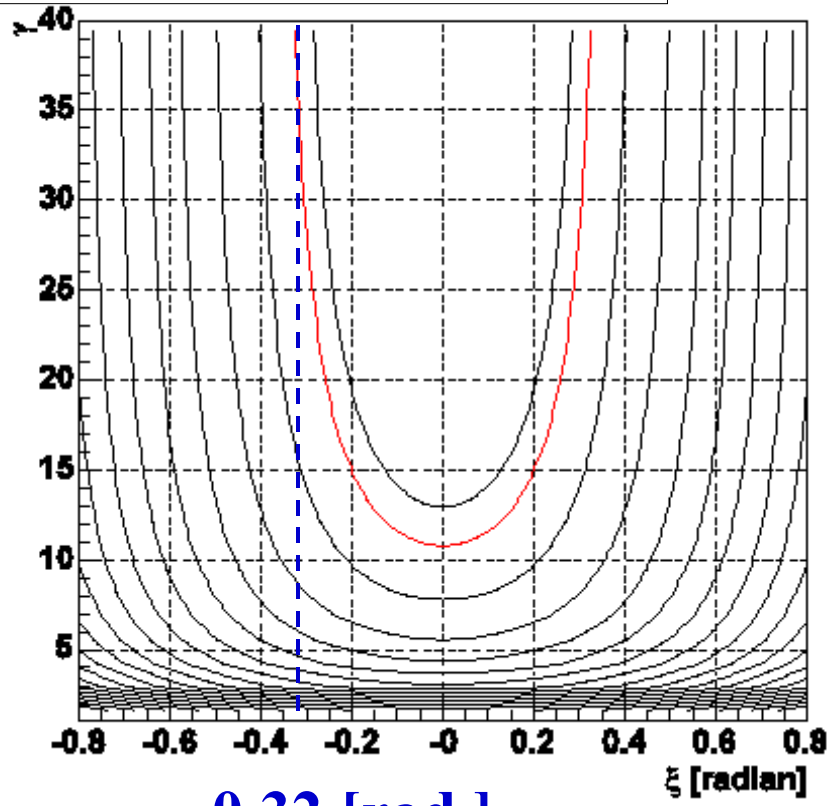
Phase contour for 18MV/m



-0.24 [rad.]
(-14 [deg.])

$\alpha = 0.64$

Phase contour for 9MV/m



-0.32 [rad.]
(-18 [deg.])

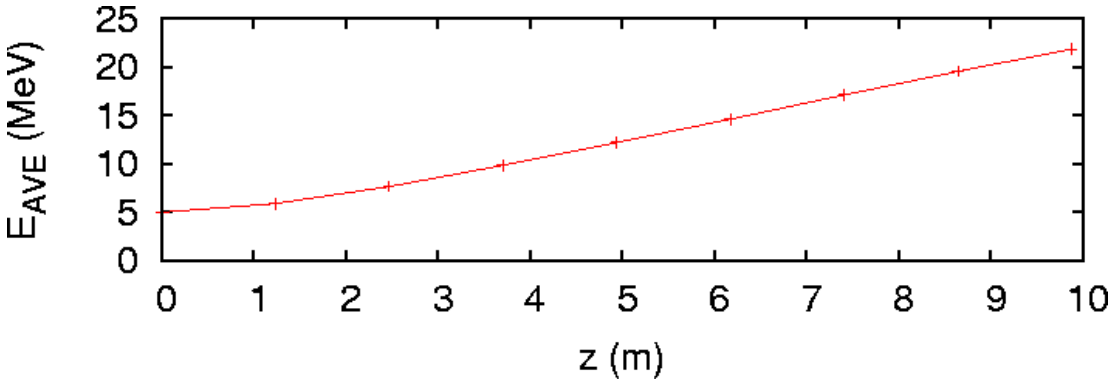
Expected bunch compression

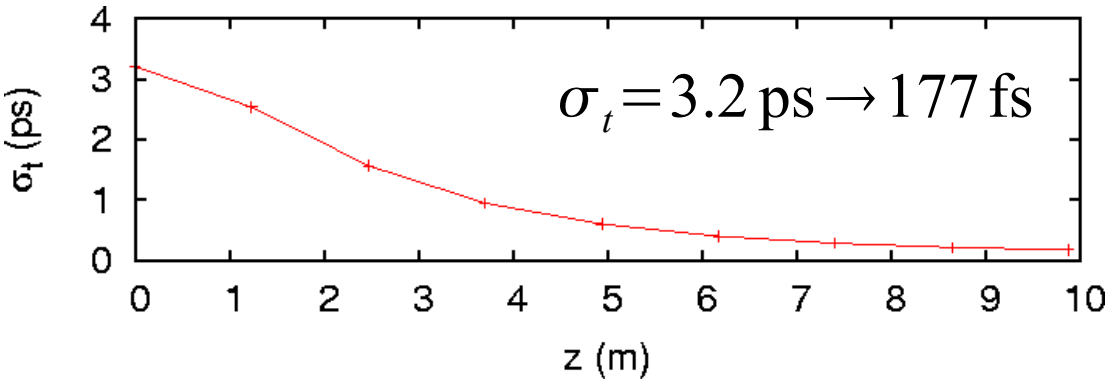
	case 1	case 2
Initial Width	3.2 [ps] (1.5 deg. for 1.3 GHz)	
Initial Energy	5.0 [MeV]	
Energy Spread	0.25 %	
Extraction Phase	-14 [deg.]	-18 [deg.]
Gradient	18 [MV/m]	9 [MV/m]
Normalized Amplitude α	1.29	0.64
Compression factor C	18	16
Bunch Width	180 [fsec]	200 [fsec]

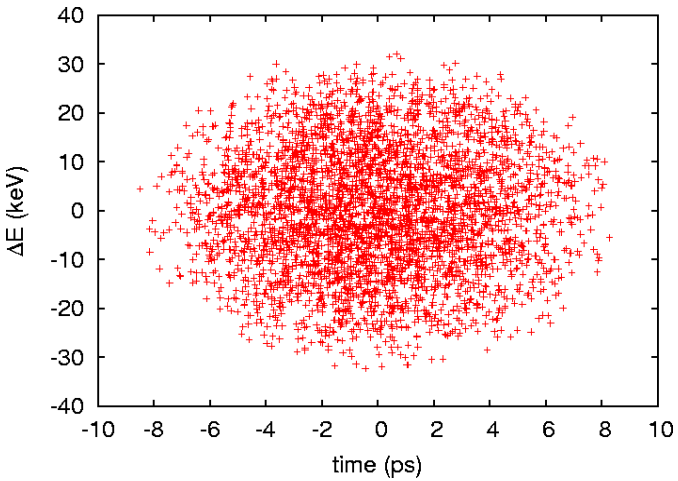
PARMELA simulation for velocity bunching

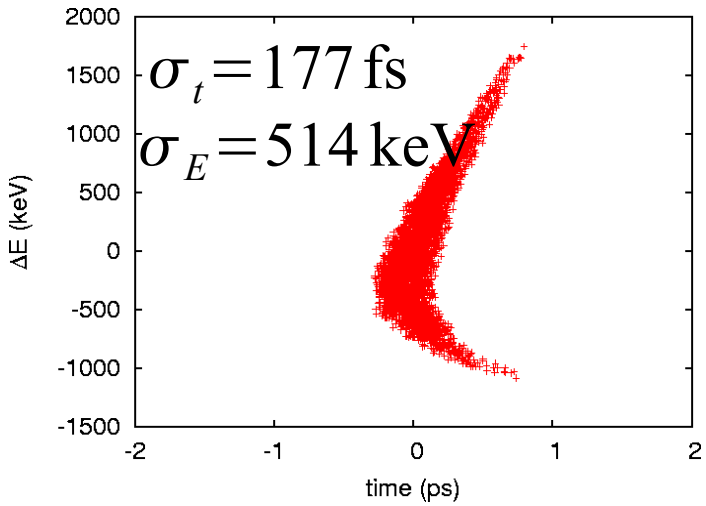
initial bunch parameters: 5 MeV, 3.2 ps, σ_E=12.5 keV, 77 pC, ε_n=1 mm-mrad

Eacc=8.2 MV/m (α=0.64), TESLA 9-cell x 8





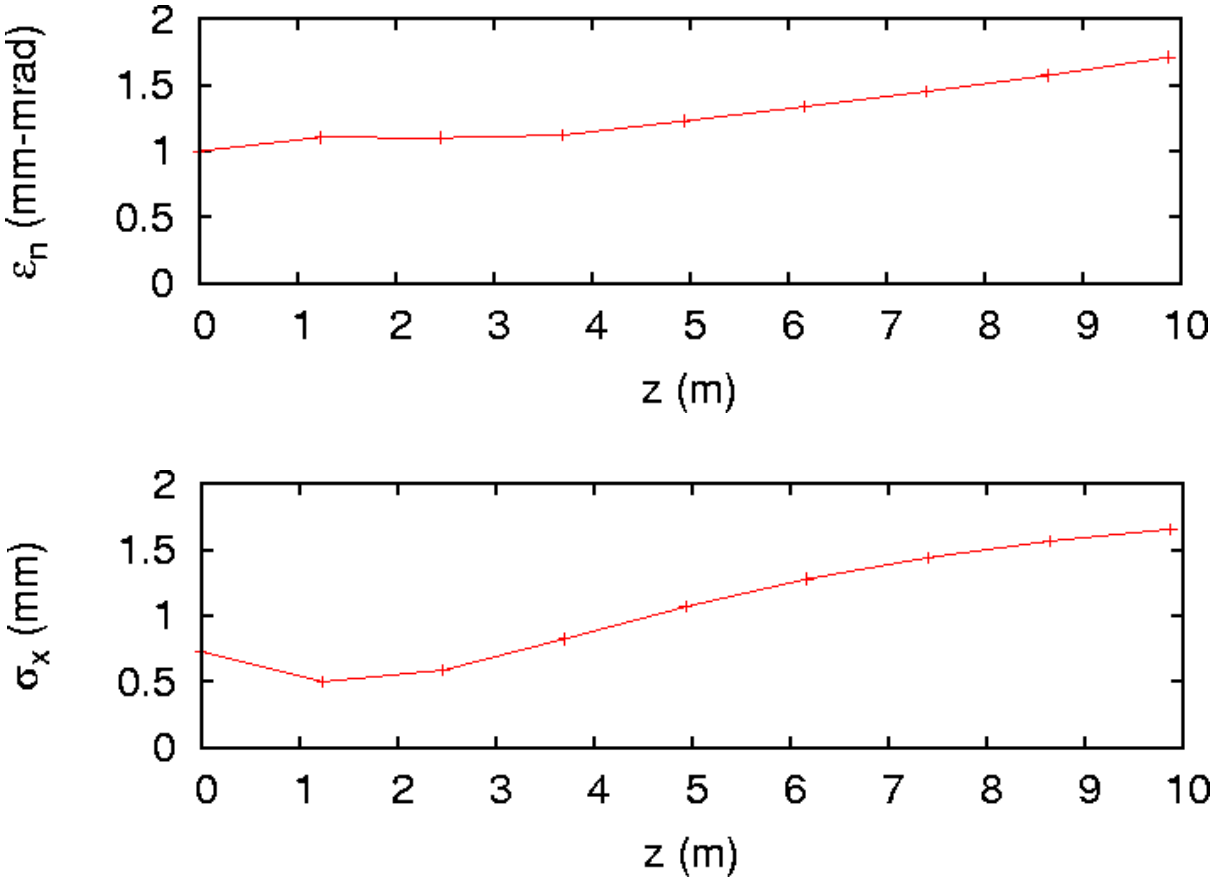




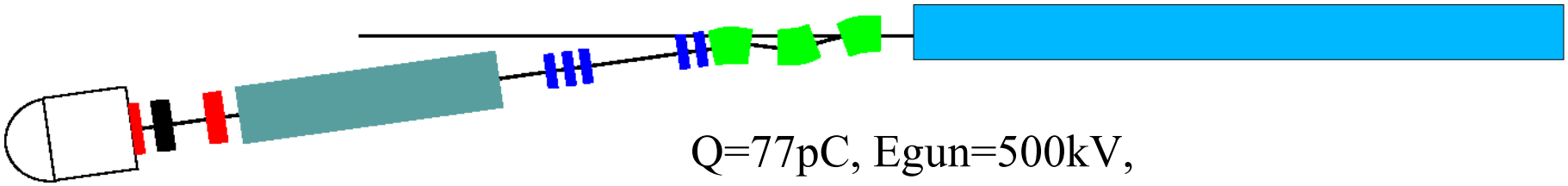
PARMELA simulation for velocity bunching

transverse emittance growth during velocity bunching

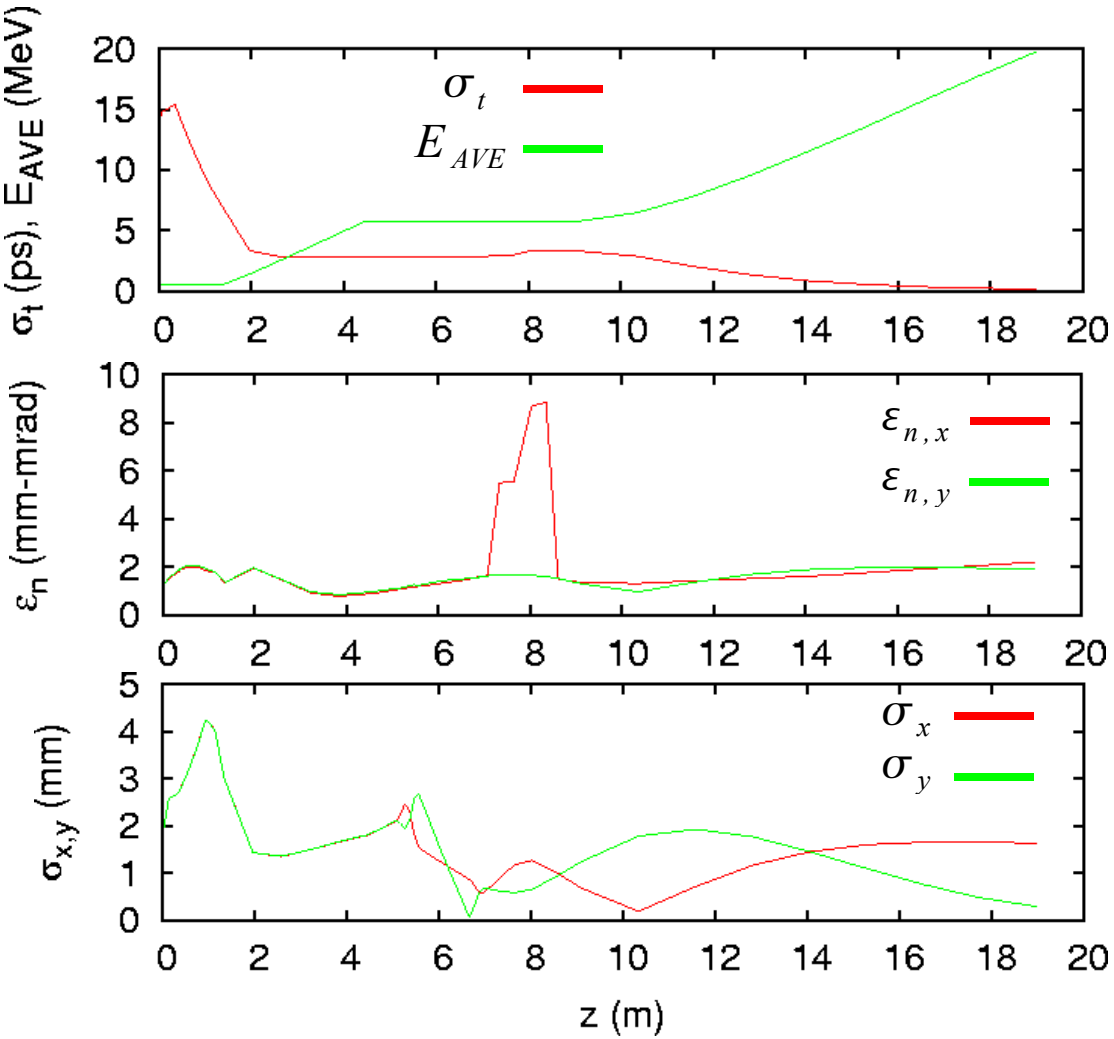
(no focusing solenoid nor quadrupole)



PARMELA simulation from a gun



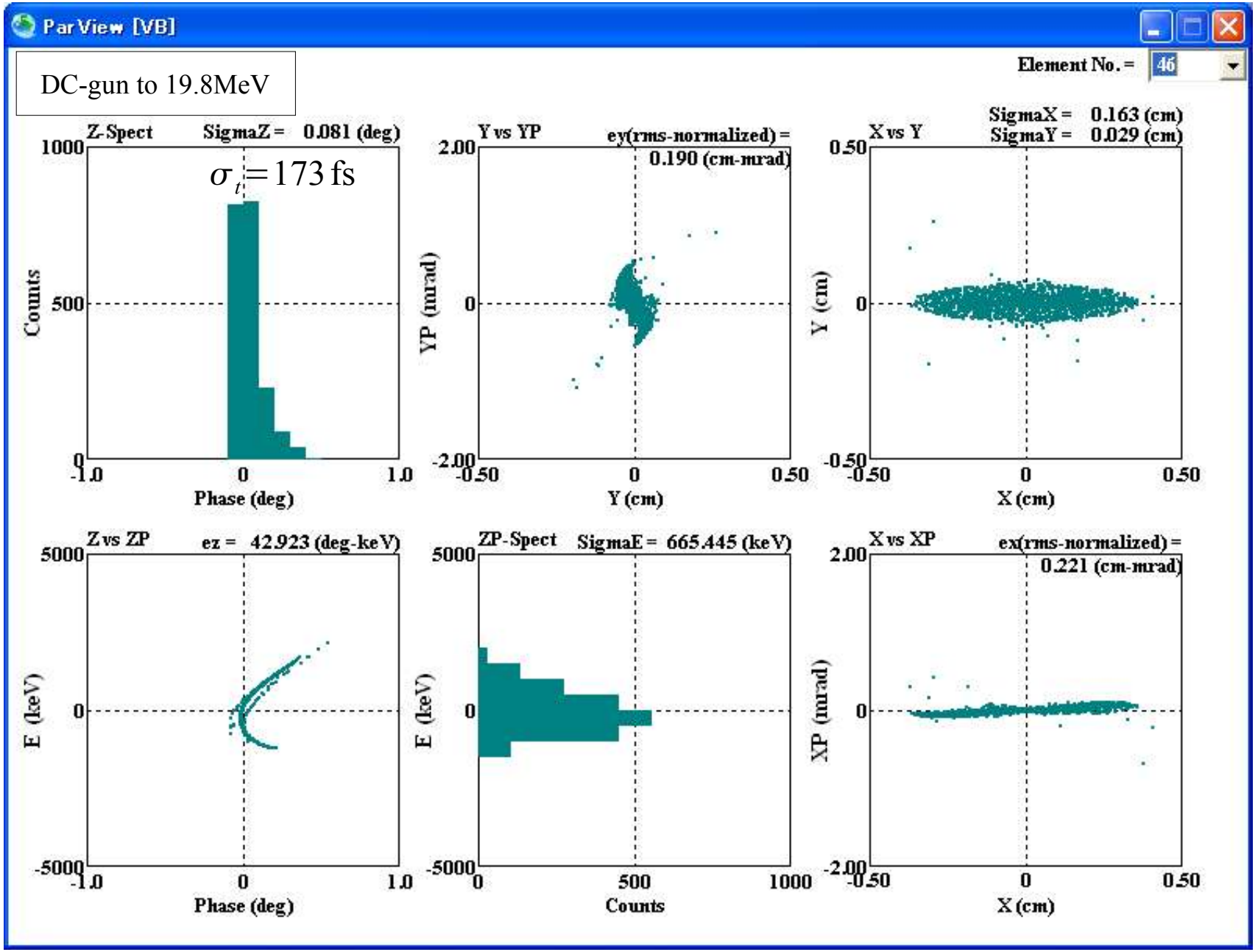
Q=77pC, Egun=500kV,
merging at 5.8MeV, Eacc=8.2MV/m for 9-cell



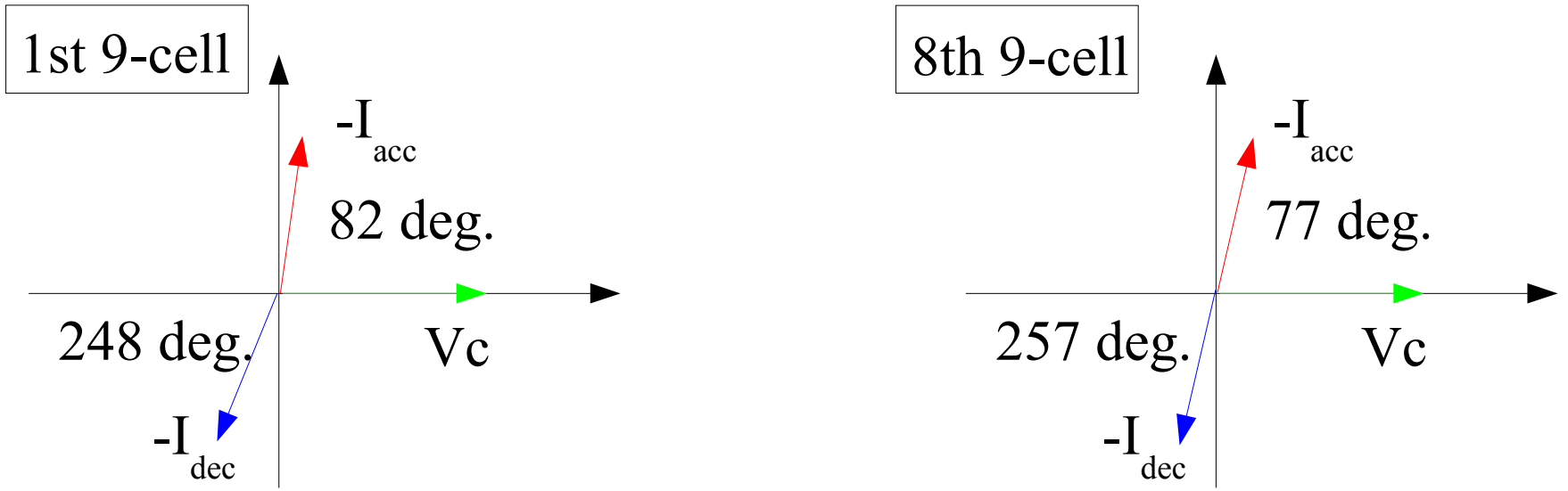
$\sigma_t = 15\,\text{ps (gun)} \rightarrow 3.2\,\text{ps (merger)}$
$\rightarrow 170\,\text{fs (after 9-cell x 8)}$

$\varepsilon_{n,x} = 2.2\,\text{mm-mrad}$
$\varepsilon_{n,y} = 1.9\,\text{mm-mrad}$

Phase space after the compression



RF power economics



RF generator power for the 1st 9-cell

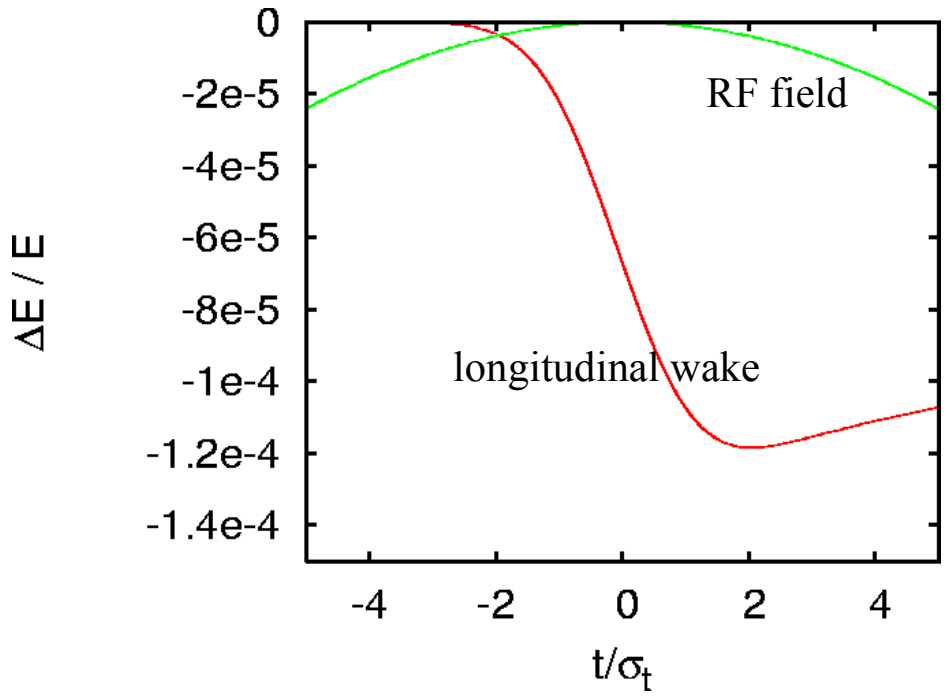
$Q_0 = 1\times10^{10}$, $Q_L = 1.7\times10^{7}$, $E_{acc} = 8.2\,\mathrm{MV/m}$ same Q_L as 3-ps acceleration.

P_g = 1.1 kW for zero-current (perfect ER)

P_g = 12.6 kW for 5 mA – acceptable for a 25 kW IOT.

The average current, 5mA, is reasonable, because the ultrashort-pulse mode for time-resolved pump-probe experiments will be operated at low repetition rate.

Energy Spread



correlated energy spread by longitudinal wake and RF curvature.

we assume a Gaussian bunch σ_t = 170 fs, Q=77 pC, TESLA cavity.

energy spread introduced by velocity bunching :

$\sigma_E/E = 1.1 \times 10^{-4}$ (final energy 6 GeV)

cf. $\sigma_E/E = 3.4 \times 10^{-3}$ for BC in a half-arc.

Summary

velocity bunching in a main linac of ERL is proposed.

- for 77 pC bunch and 5.8 MeV merging energy,
  170 fs bunch is obtained after 9-cell x 8-cavity acceleration.

- the operation is possible without any hardware modification,
  all we need is tuning the RF phase and amplitude.

- average current is limited by RF generator for the 1st cavity.
  HOM extraction in the main linac is not an issue.

  P_{RF} = 12.6 kW, P_{HOM} = 1.35 W /cavity
  for 77 pC x 65 MHz = 5 mA, 170 fs bunch.

- from the analytical formula, a bunch shorter than 170 fs will be obtained, if we have a shorter bunch from the injector, and / or longer linac for the bunching section.