Functions of the LC damping rings:

• Damp the emittance of the beam from the electron and positron sources prior to injection into the linac

• Damp the jitter (from the source) of the beam.

• (Delay bunches so that downstream feedback systems have time to compensate for bunch errors).

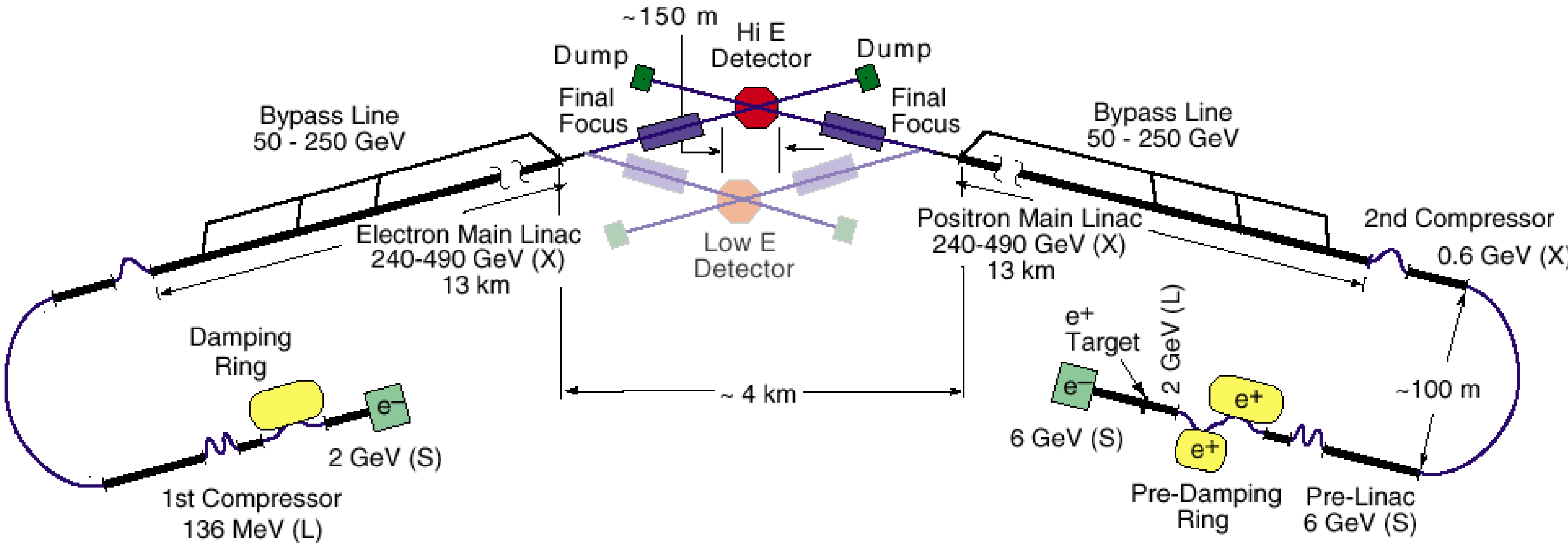
Design of the damping rings depends on the bunch pattern required by the linac:

Machine	TESLA	NLC	CLIC
number of bunches per pulse	2820	192	154
bunch spacing (ns)	337	1.4	0.67
bunch train length (μs)	950	0.267	0.102
pulse repetition rate (Hz)	5	120	200

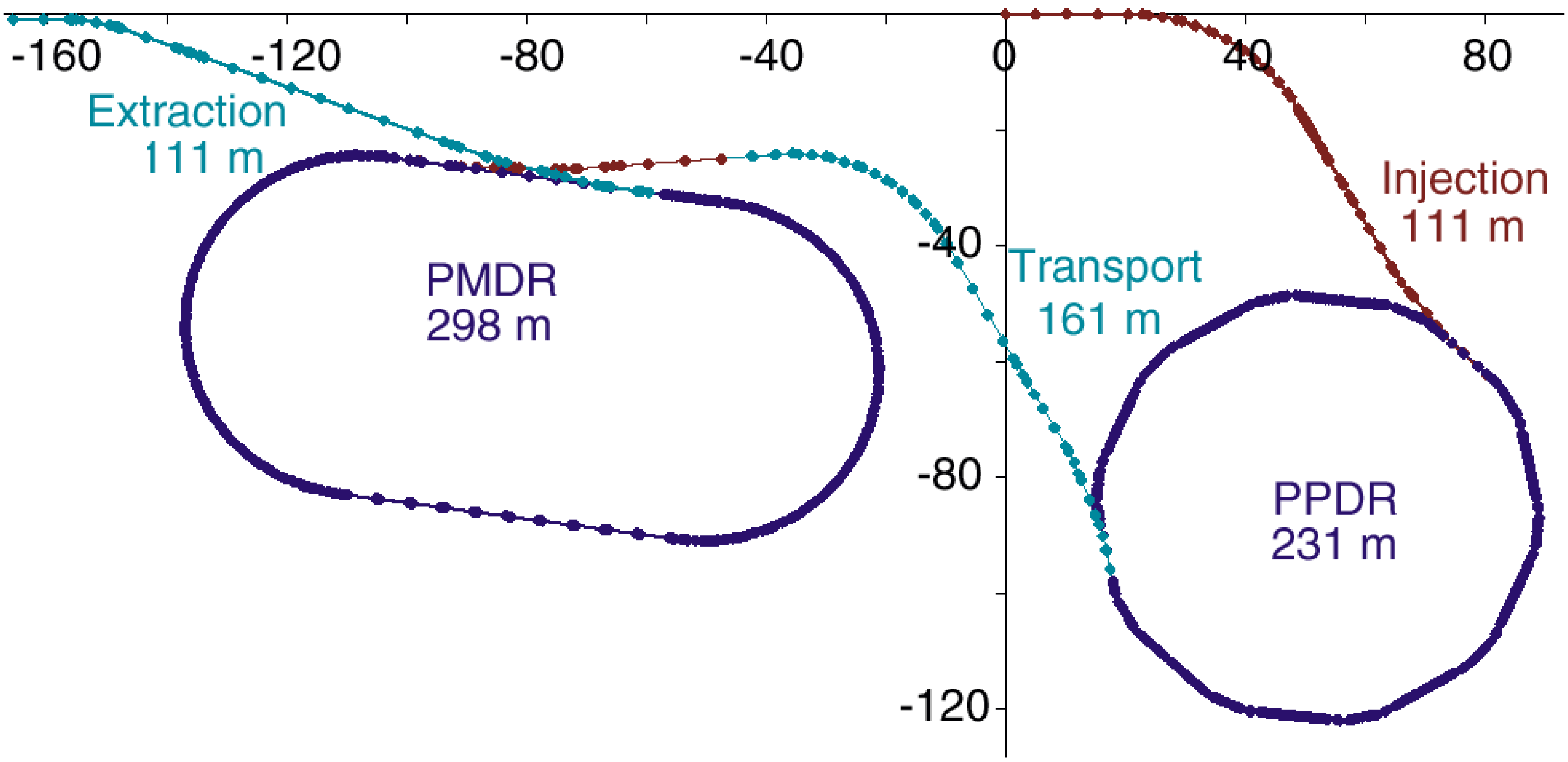
NLC: train length·*c* = 80 m. 3 trains fit into a small DR.

TESLA: train length·*c* = 280 km. Will *not* fit into a DR. Need to eject bunches individually. Bunch spacing in DR (determined by ejection kicker bandwidth) is 20 ns, so DR circumference is 17 km (beam folded on itself ×16).

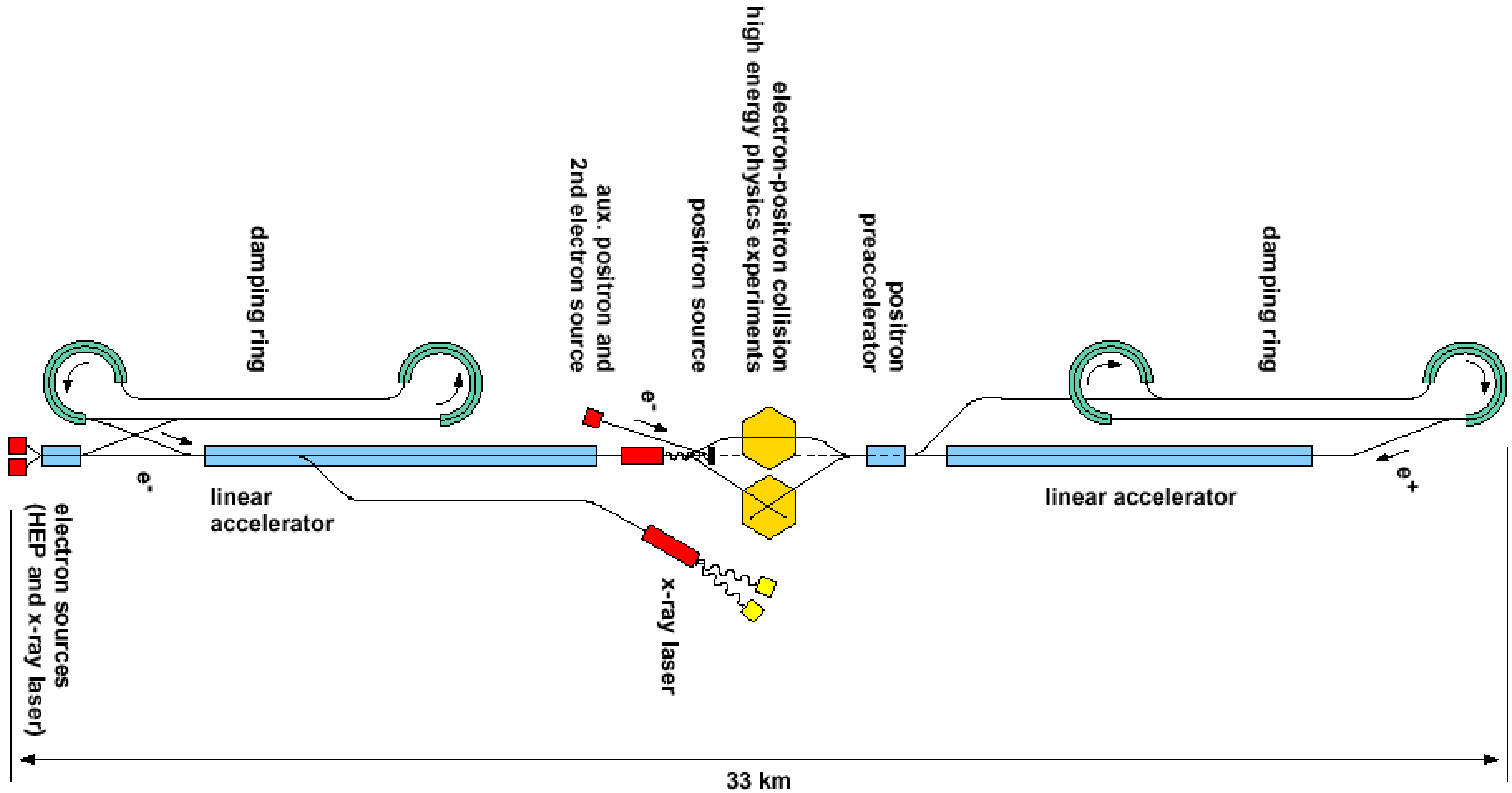
Layout of NLC (and JLC)



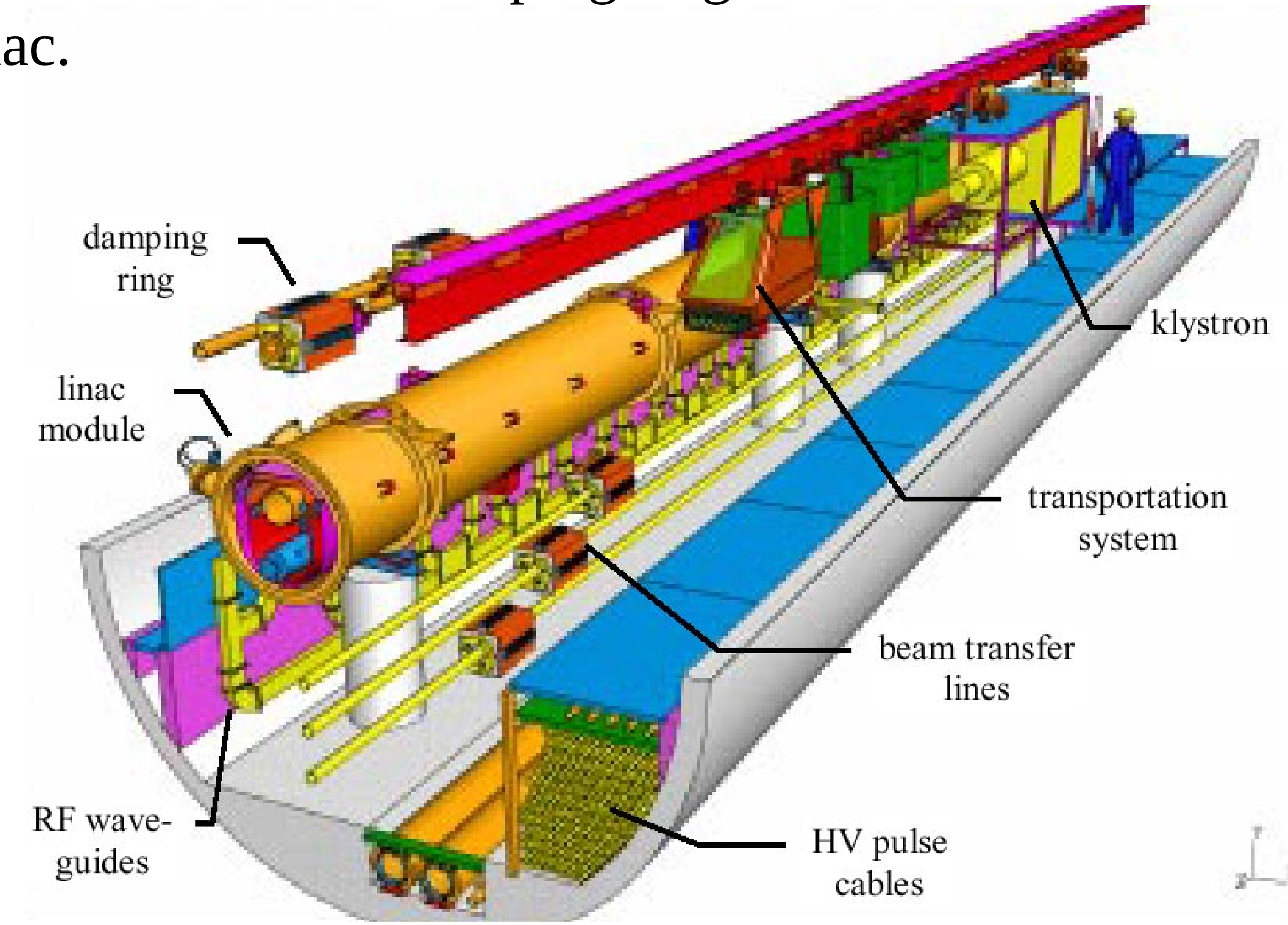
NLC positron pre-damping ring (PPDR) and main damping ring (PMDR).



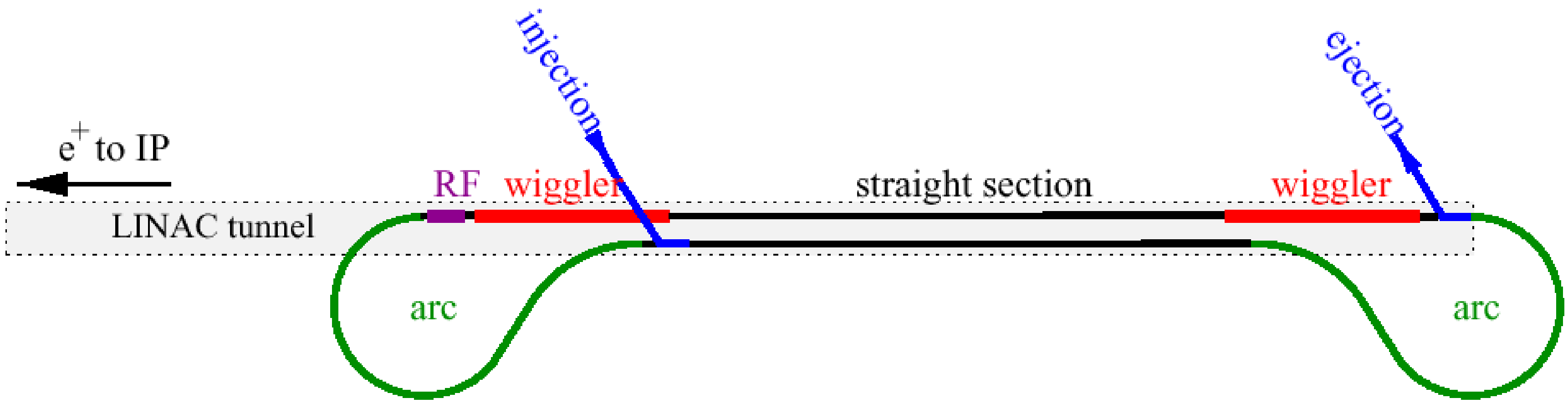
Layout of TESLA



TESLA tunnel: most of the damping ring shares the tunnel with the linac.



TESLA DR layout (the “dog-bone”)

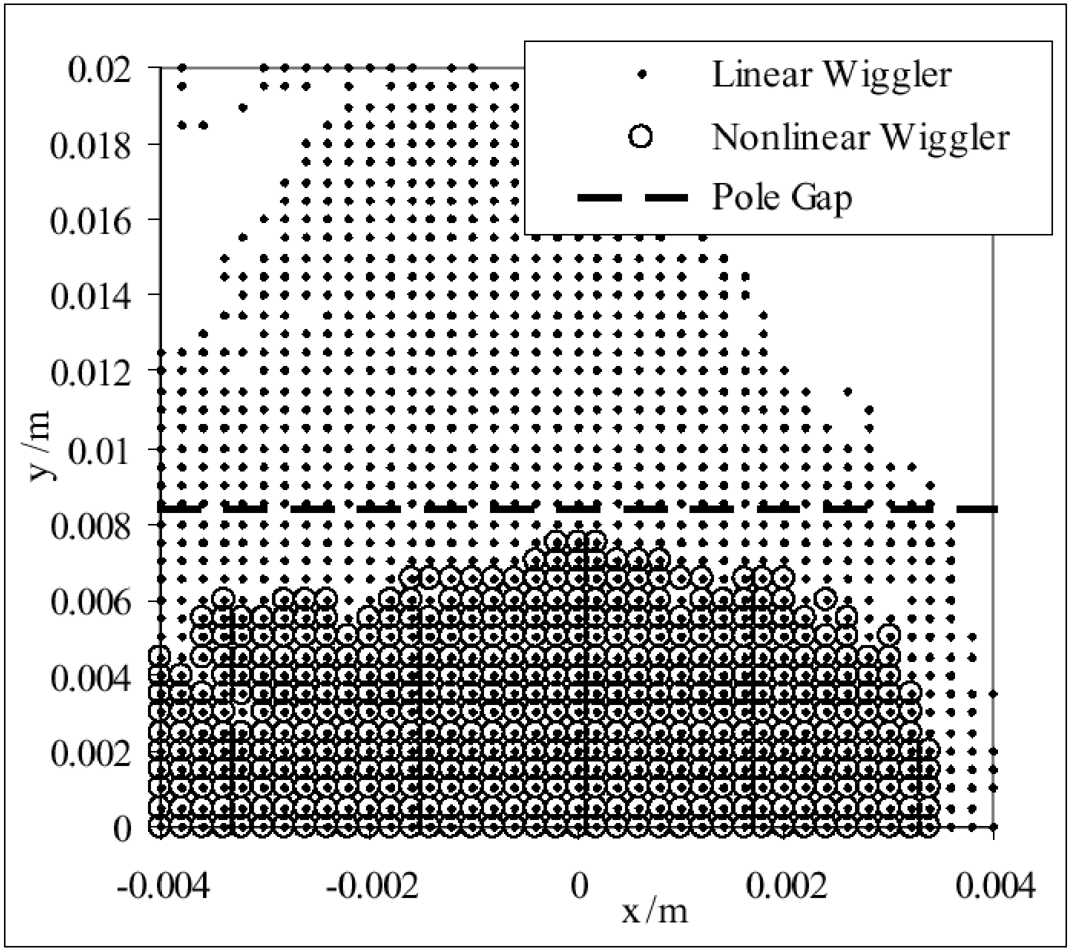


Lattices:
NLC/JLC: TME (theoretical minimum emittance cells) with 46 meters of 2.15 T permanent magnet hybrid wigglers in dispersion-free straight sections.

TESLA: TME (theoretical minimum emittance cells) with ≈400 meters of 1.67 T permanent magnet hybrid wigglers in dispersion-free straight sections.

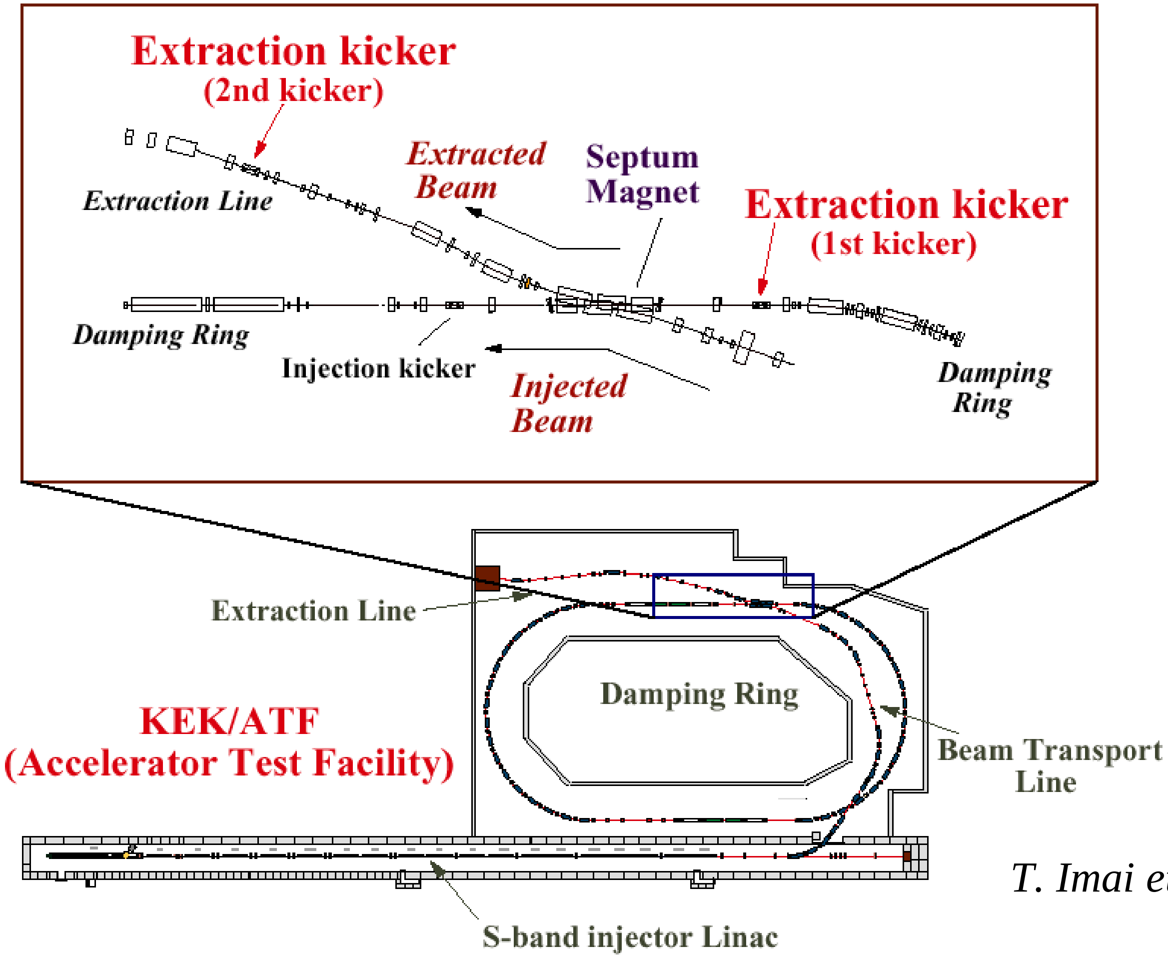
Most of the DR is a long straight section. Vertical space charge tune shift *would* be large ($\Delta Q_y \approx 0.23$), so the beam is intentionally *x*-*y* coupled at the beginning of the straight, and uncoupled again at the end, to make a large vertical beam size in the straight, producing $\Delta Q_y \approx 0.035$.

Dynamic aperture: effect of damping wigglers in NLC MDR



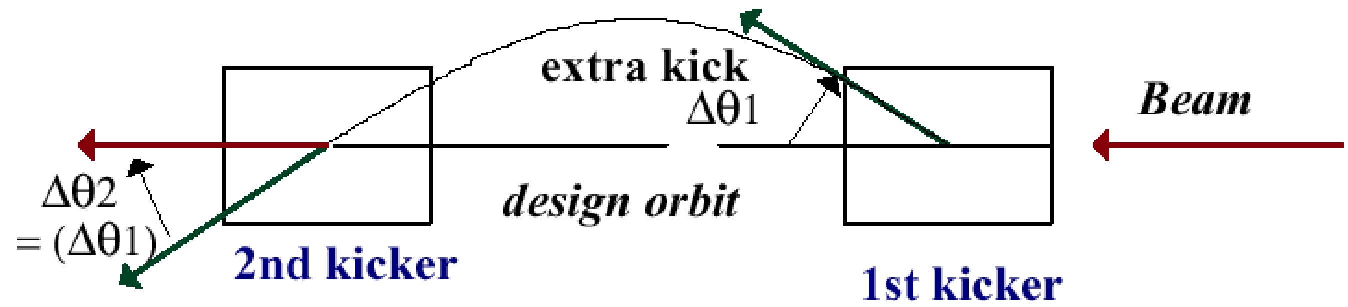
A.Wolski, J.N. Corlett, Y. Wu, PAC01

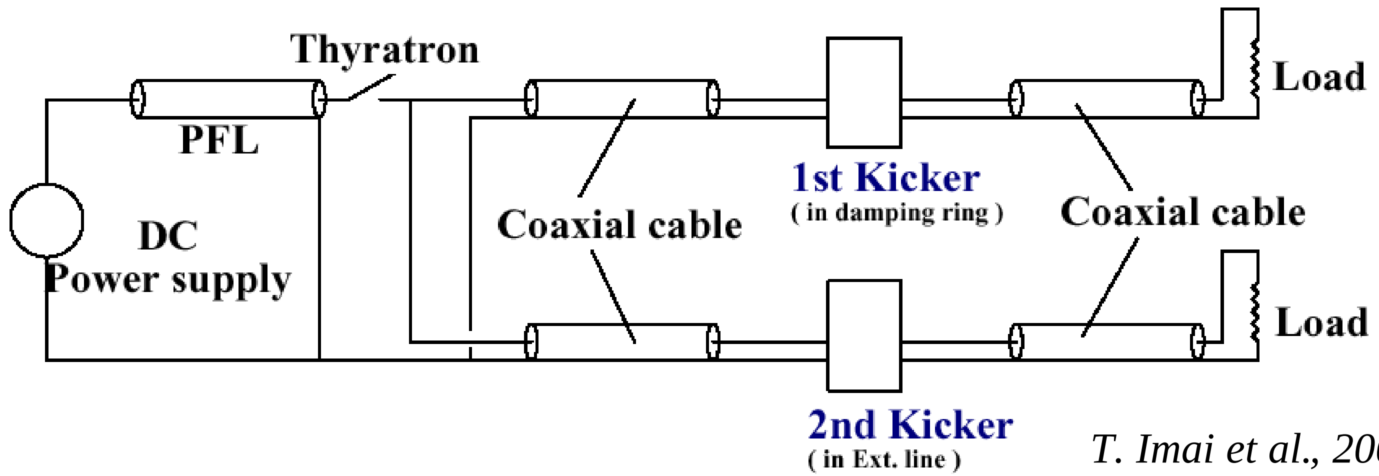
Extraction kickers: layout of KEK Accelerator Test Facility DR



T. Imai et al., 2000

Schematics of ATF DR double extraction kickers





T. Imai et al., 2000

Intrabeam scattering causes a growth of the emittance in all degrees of freedom:

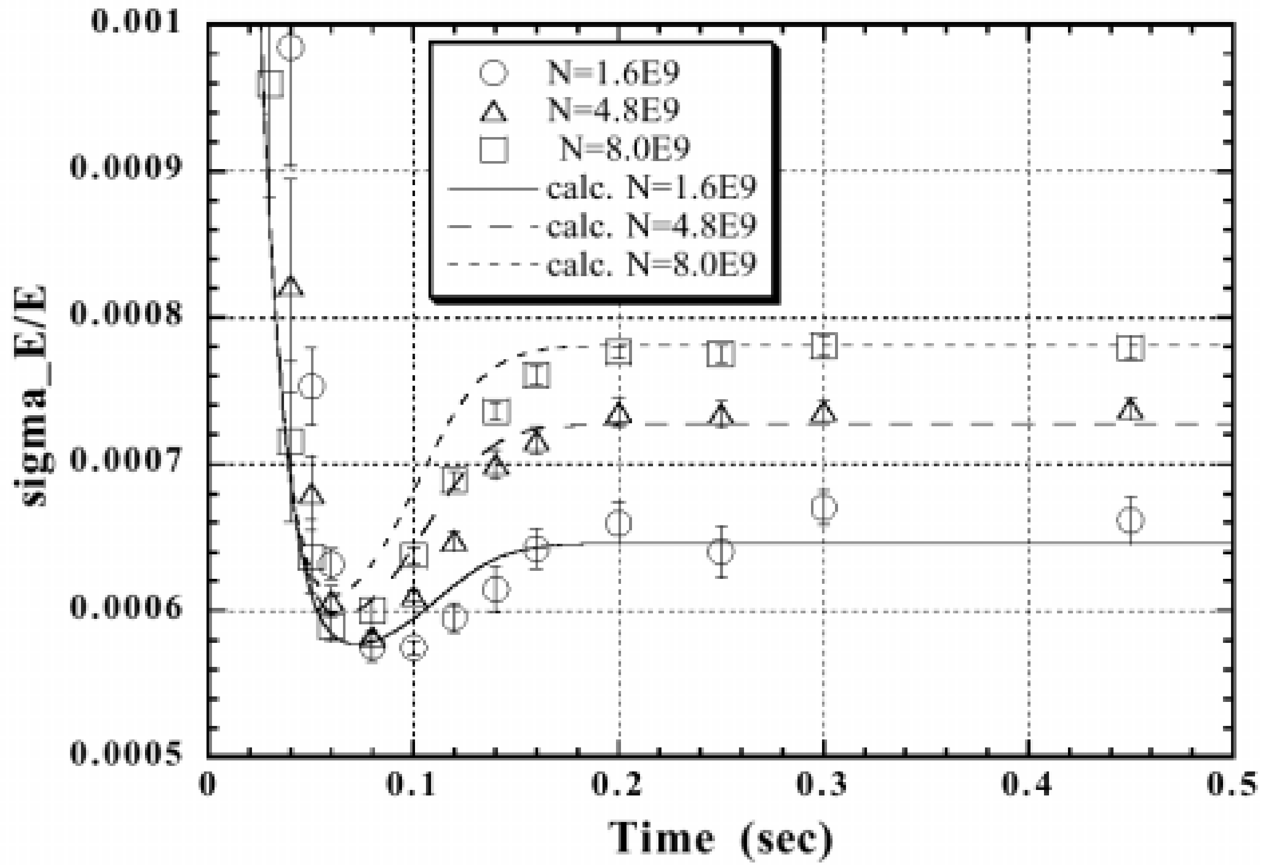
Piwinski-Raubenheimer-Bane approximation:

$$\frac{1}{T_p} \approx \frac{r_0^2 c N}{32\gamma^3 \varepsilon_x \varepsilon_y \sigma_s \left(\sigma_p / p\right)^2} \left(\frac{\varepsilon_x \varepsilon_y}{\langle \beta_x \rangle \langle \beta_y \rangle} \right)^{1/4} \ln\left(\frac{\langle \sigma_y \rangle \gamma^2 \varepsilon_x}{r_0 \langle \beta_x \rangle} \right)$$

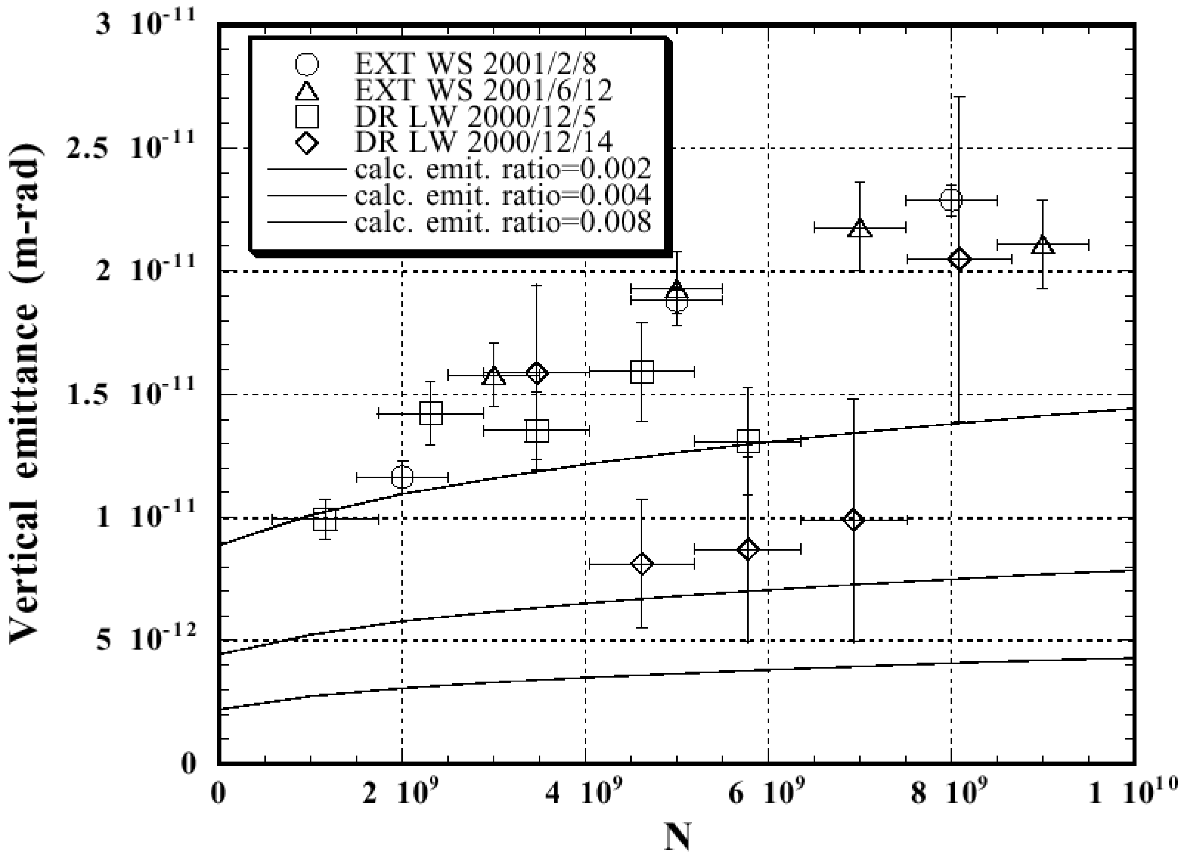
$$\frac{1}{T_{x,y}} \approx \frac{\sigma_p^2 \langle \mathcal{H}_{x,y} \rangle}{\varepsilon_{x,y}} \frac{1}{T_p}$$

Not a problem for TESLA (higher energy beam); critical for NLC/JLC; dominates DR design for CLIC.

Intrabeam scattering data from KEK ATF damping ring (energy spread):

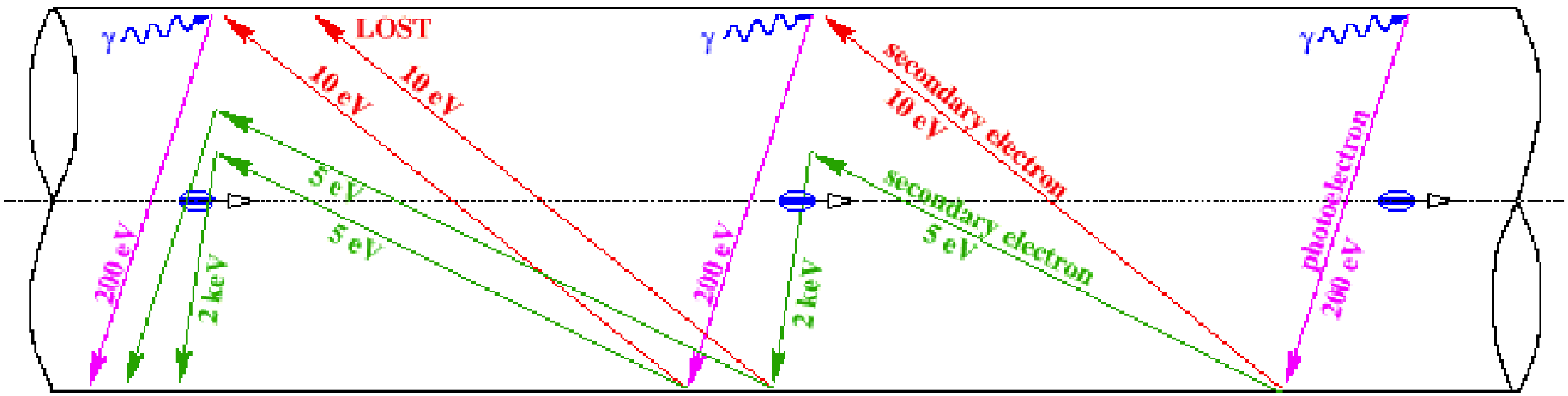


Intrabeam scattering data from KEK ATF damping ring (vertical emittance):



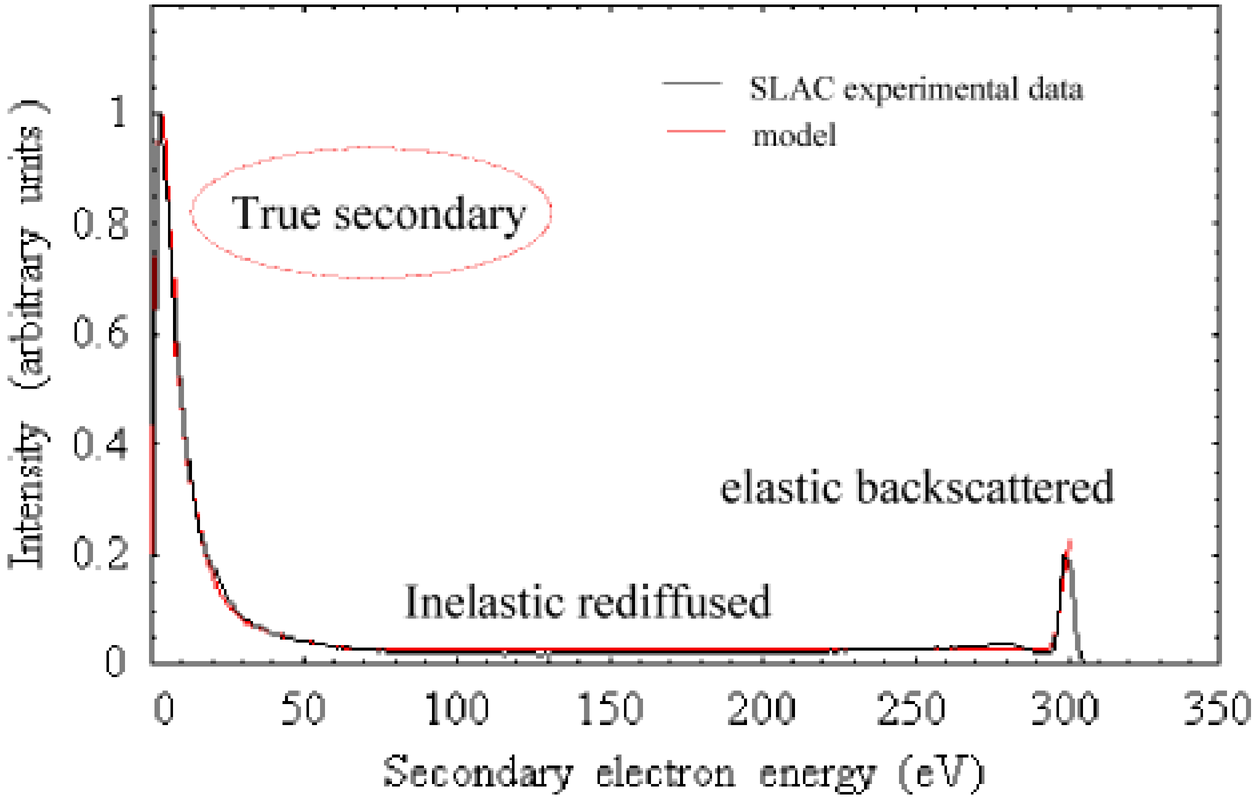
Electron cloud instability: electrons produced by photoemission or residual gas ionization are accelerated toward the chamber wall by the electric field of a positron bunch

- Secondary emission and multipacting
- Large background of electrons
- Head-tail and bunch-to-bunch coupling
- Instability

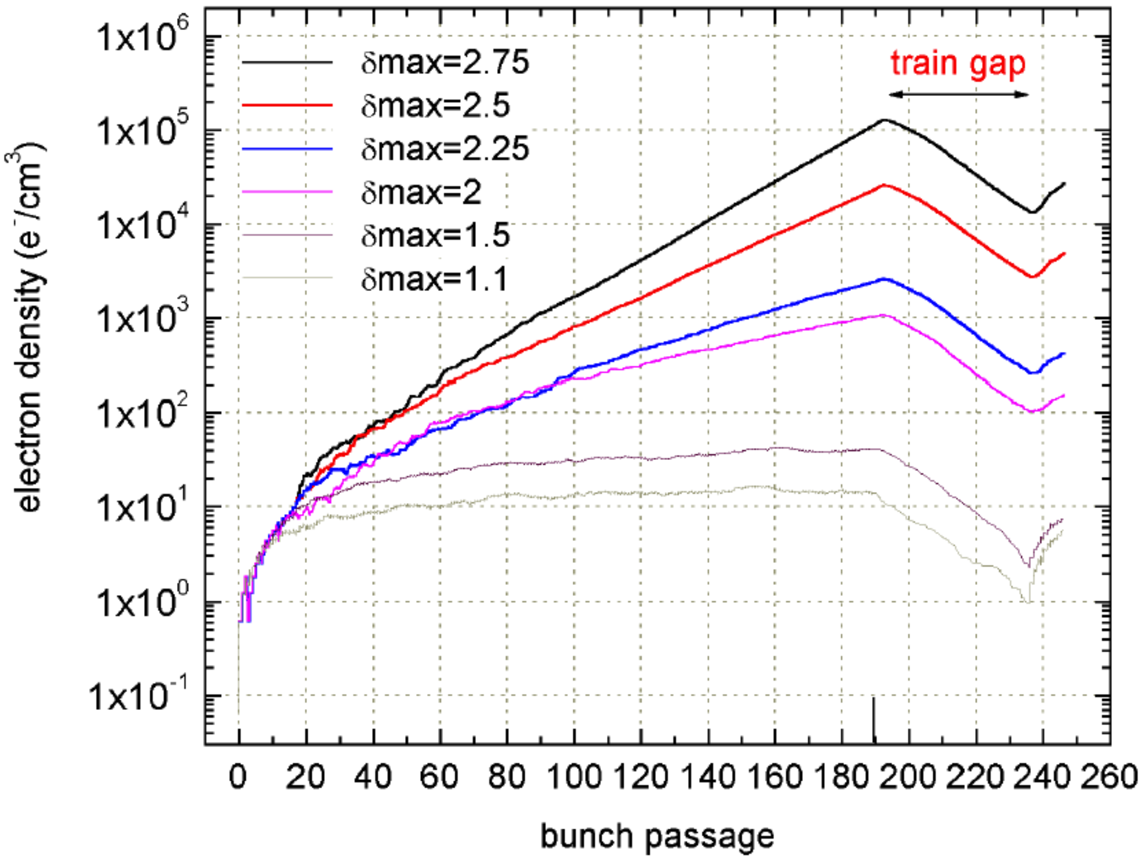


F. Ruggiero, CERN

Electron cloud instability: measured secondary emission yield of high-purity Al, degreased, NaOH etched and rinsed. (R. Kirby, SLAC).



Electron cloud instability: simulation of electron density (M. Pivi, M. Furman, LBNL, LC02 presentation).



Electron cloud instability: growth rates (A. Wolski, LBNL, LC02 presentation). State of art feedback can handle τ = few×0.1 μs.

Coupled Bunch Growth Rates

	NLC MDR	NLC PDR	TESLA
s_b /ns	1.4	1.4	20
n_0 /m^{-3}	2.2	0.56	0.22
R_s / MΩ m^{-1}	67	13	2,000
ω_c / 10^9 s^{-1}	1.92	3.84	0.0299
Q	5	5	5
τ / μs	14	72	27

Ion instabilities and tune shift

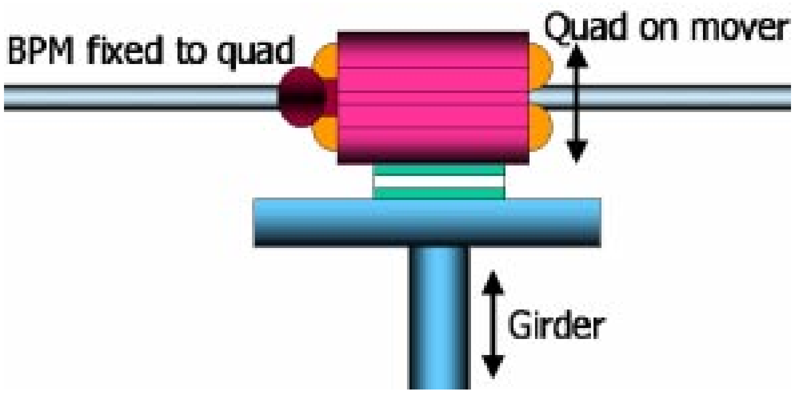
• Head-tail bunch coupling may cause instability

• Bunch-to-bunch coupling may cause instability (feedback systems can handle this if growth rate < few×0.1 μs).

• Nonlinear tune shift can cause resonance condition for transverse single-particle motion and loss of particles. Significant for (round) TESLA DR beams. T. Raubenheimer calculates $\Delta Q \approx 0.23$ for TESLA DR with $P = 10^{-9}$ Torr in straights. May require $P = 10^{-10}$ Torr.

Diagnostics and correction

- Emittances as small as those required by the LC damping rings have never been measured.
- Excellent monitors (laser wire,…) have been tested at the KEK ATF, but need refinement for utility in an LC DR.
- Ground motion and vibration are serious issues for the damping rings and require frequent automated correction. NLC plans to put quads on movers:



NLC/JLC and TESLA have well developed designs including lattices, wiggler designs, RF design, some mechanical design.

Extraction kicker prototypes have been tested at SLAC and KEK.

Prototype wigglers have not been built.

There are number of unsolved problems (electron cloud, ion effects, space-charge tune shift is large, dynamic aperture is marginal due to wigglers and strong sextupoles).