03/23/2004

The Cornell ERL Project

Georg Hoffstaetter (LEPP)

for the ERL endeavor

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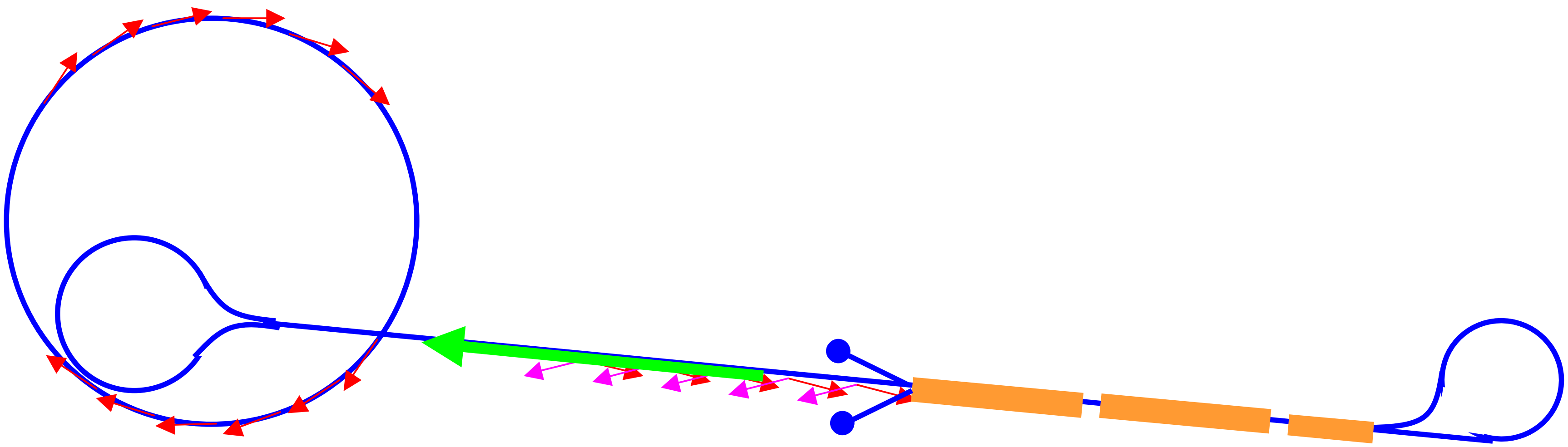

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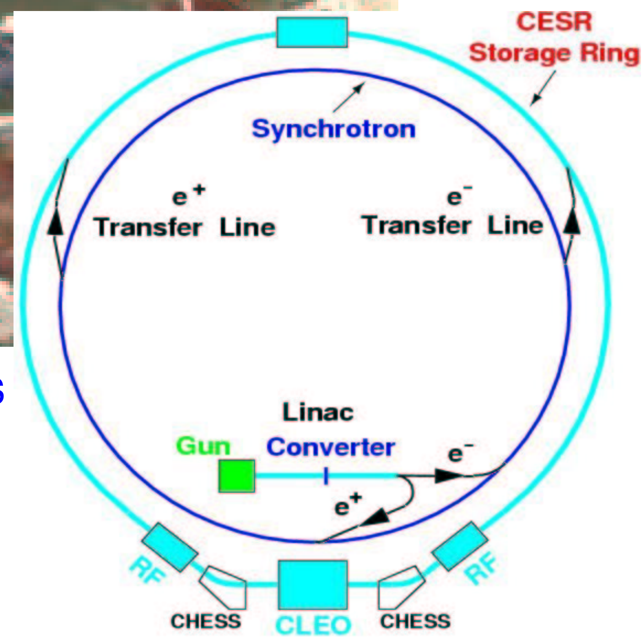
Could an ERL use the CESR tunnel



- An extension of the tunnel could easily conflict with buildings
- But the tunnel sealing is at about 836 ft ASL whereas
- The base of the deepest relevant building's foundation is at 862ft ASL, yielding about 10m of space.

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Synchrotron Radiation @ Cornell

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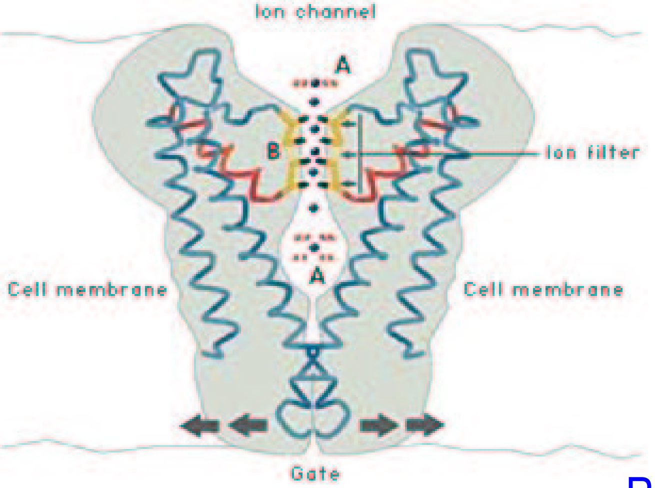
- 1947: 1st detection of synchrotron light at General Electrics. Soon advised by D.H.Tomboulian (Cornell University)
- 1952: 1st accurate measurement of synchrotron radiation power by Dale Corson with the Cornell 300MeV synchrotron.
- 1953: 1st measurement of the synchrotron radiation spectrum by Paul Hartman with the Cornell 300MeV synchrotron.
- Worlds 1st synchrotron radiation beam line (Cornell 230MeV synch.)
- 1961: 1st measurement of radiation polarization by Peter Joos with the Cornell 1.1GeV synchrotron.
- 1978: X-Ray facility CHESS is being build at CESR
- 2003: 1st Nobel prize with CESR data goes to R.MacKinnon

Dale Corson

Cornell's 8th president

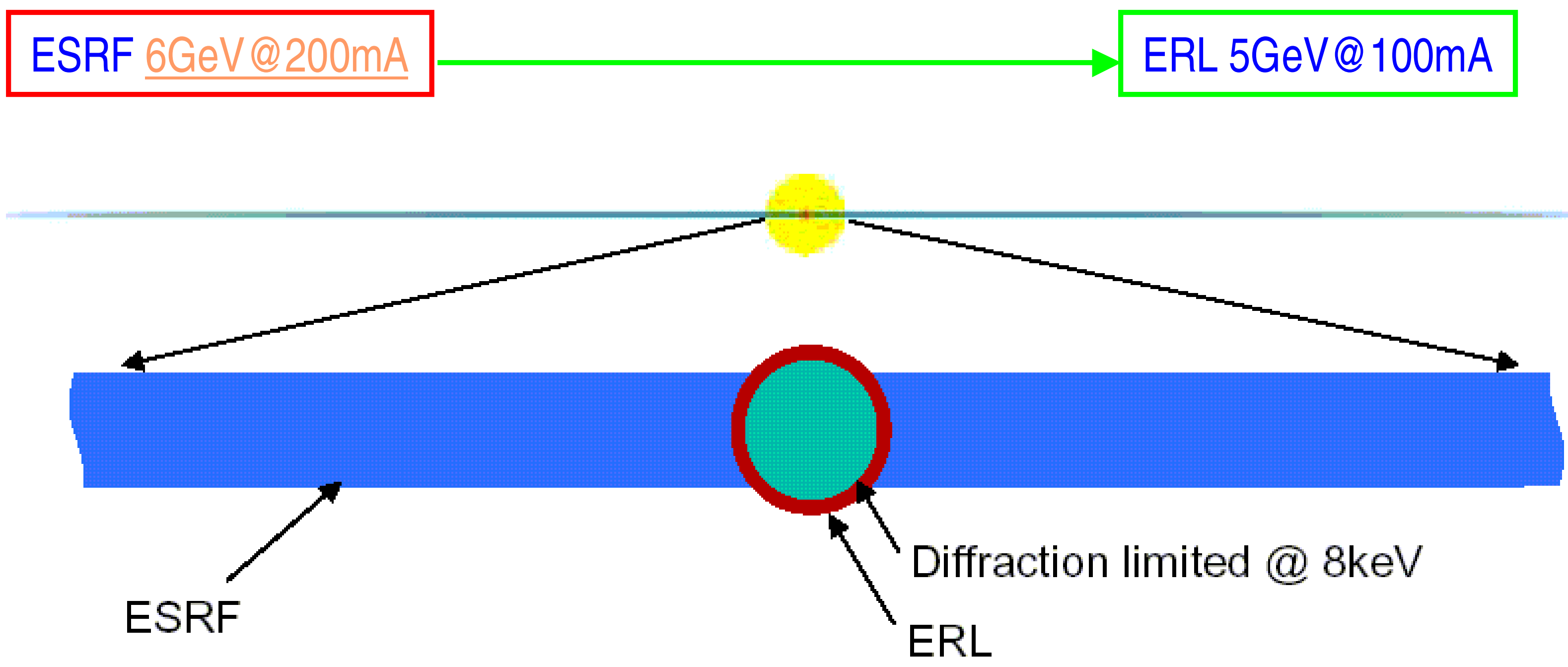


Roderick MacKinnon

Beam size in a linear accelerator

The beam properties are to a very large extend determined by the injector system:

- **The horizontal beam size can be made much smaller than in a ring**
- **While the smallest beams that are possible in rings have almost been reached, a linear accelerator can take advantage of any future improvement in the electron source or injector system.**



courtesy Ivan Bazarov

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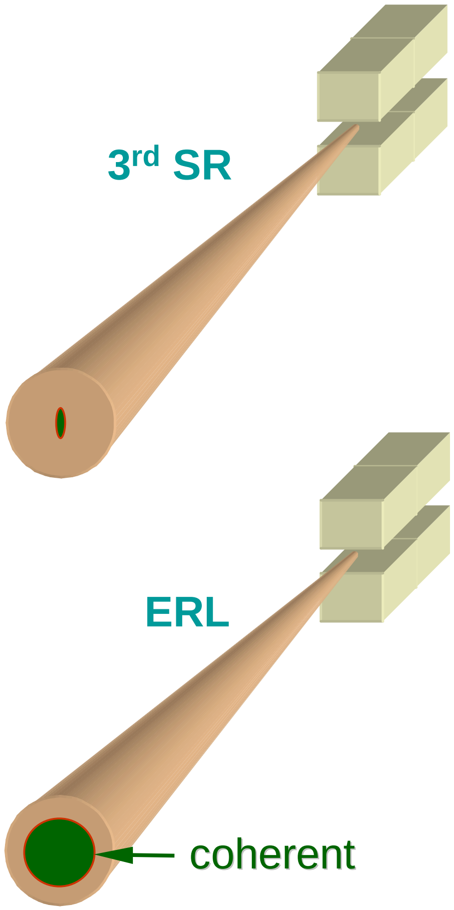
Smaller Beam → more Coherence

- Coherent x-ray diffraction imaging
- It would, in principle, allow atomic resolution imaging on non-crystalline materials.
- This type of experiments is completely limited by coherent flux.



Factor 100 more coherent flux for ERL
for same x-rays, or provide coherence for harder x-rays

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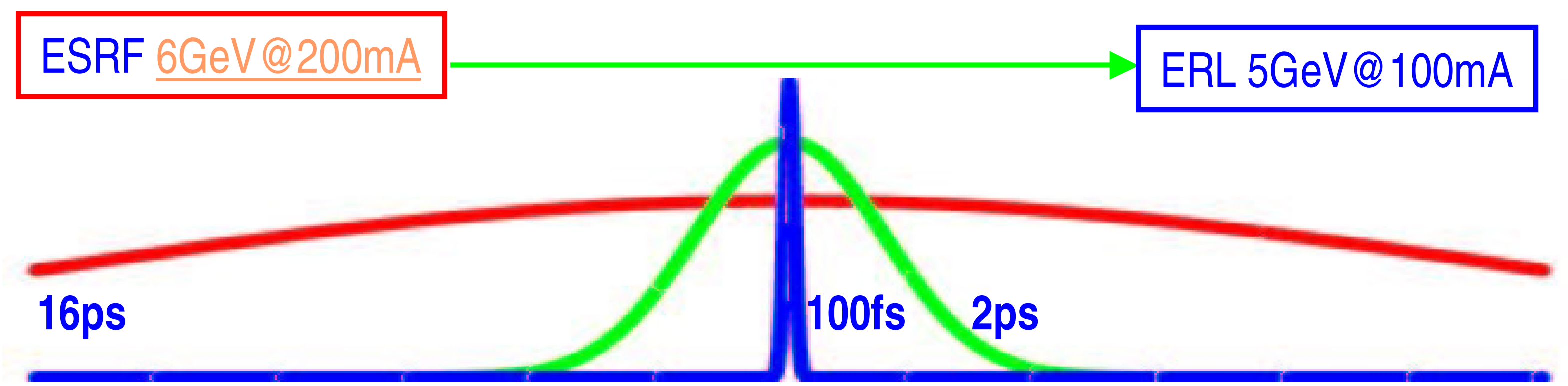
Bunch length in a linac

- The bunch length can be made much smaller than in a ring
- While the shortest bunches possible in rings have almost bean reached, a linear accelerator can take advantage of any future improvement in the source source or injector system.



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Flux and Brilliance

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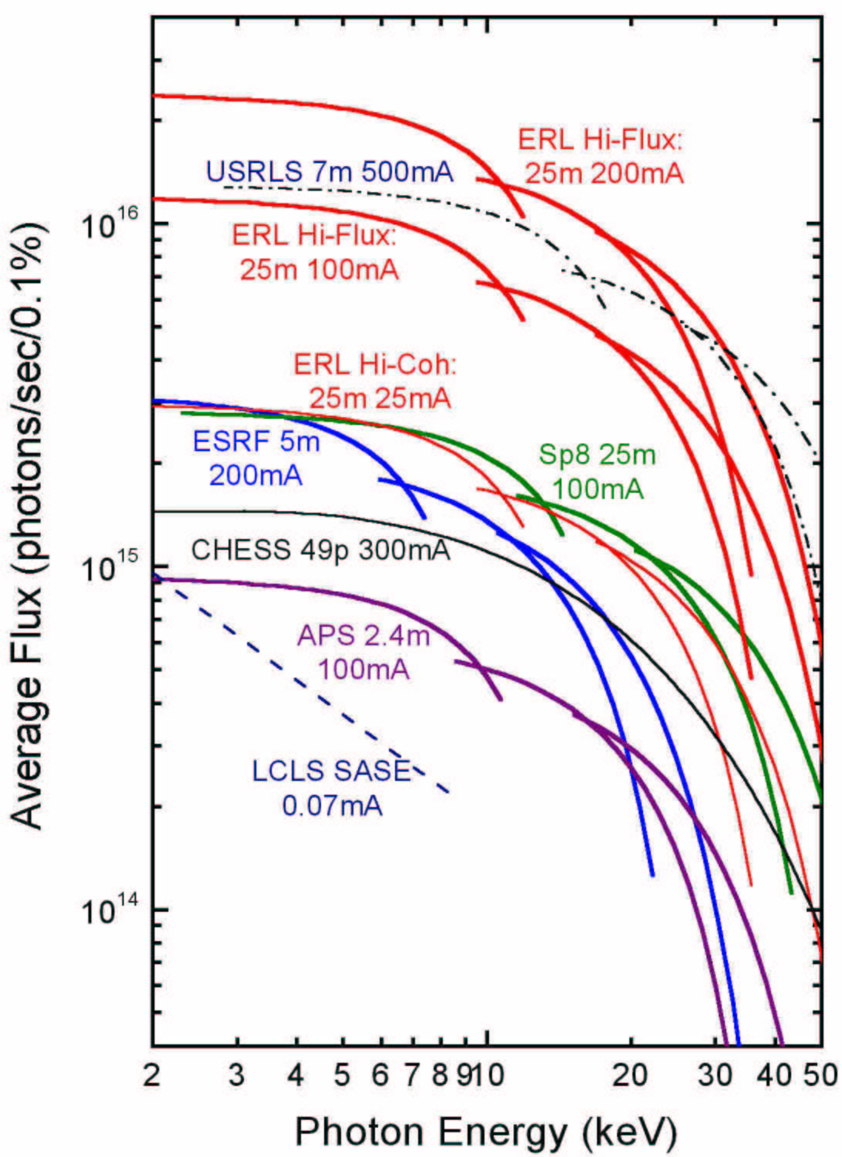

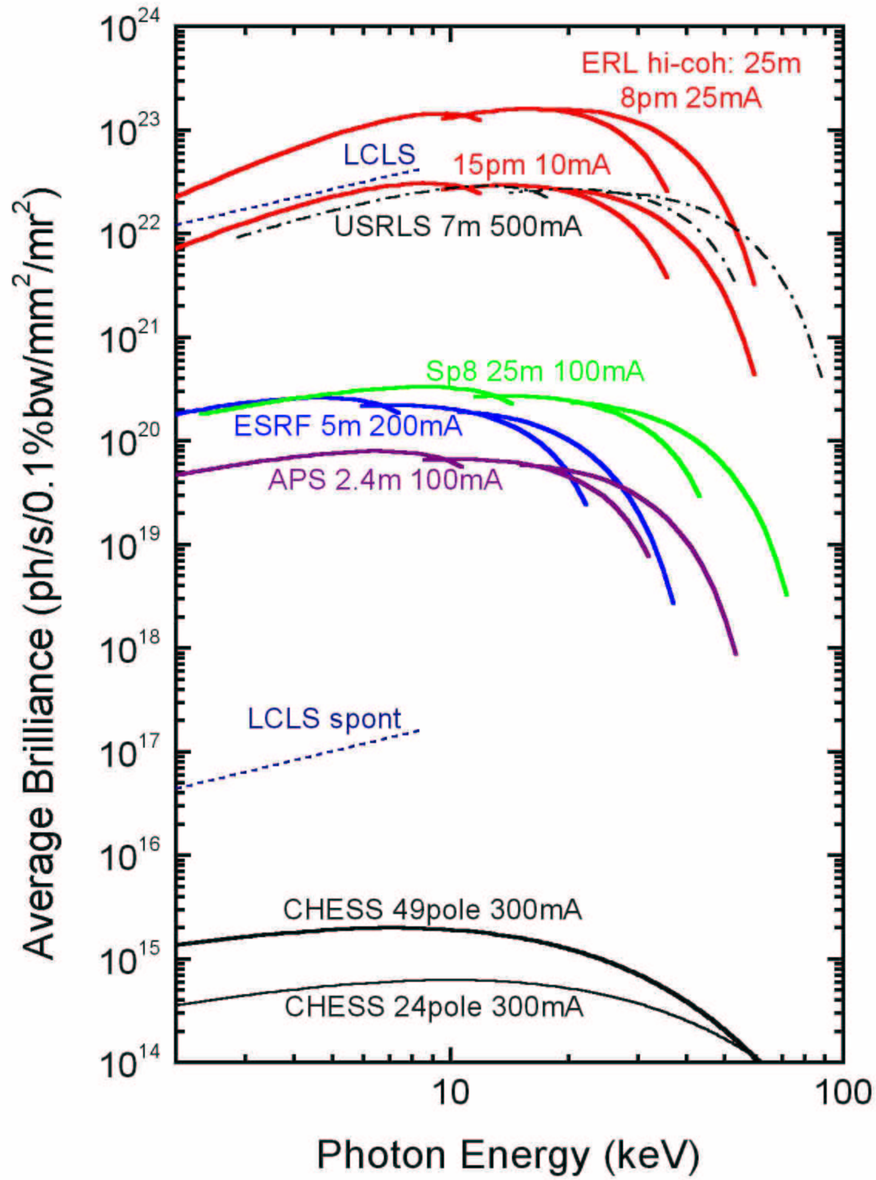

Time resolution and coherence

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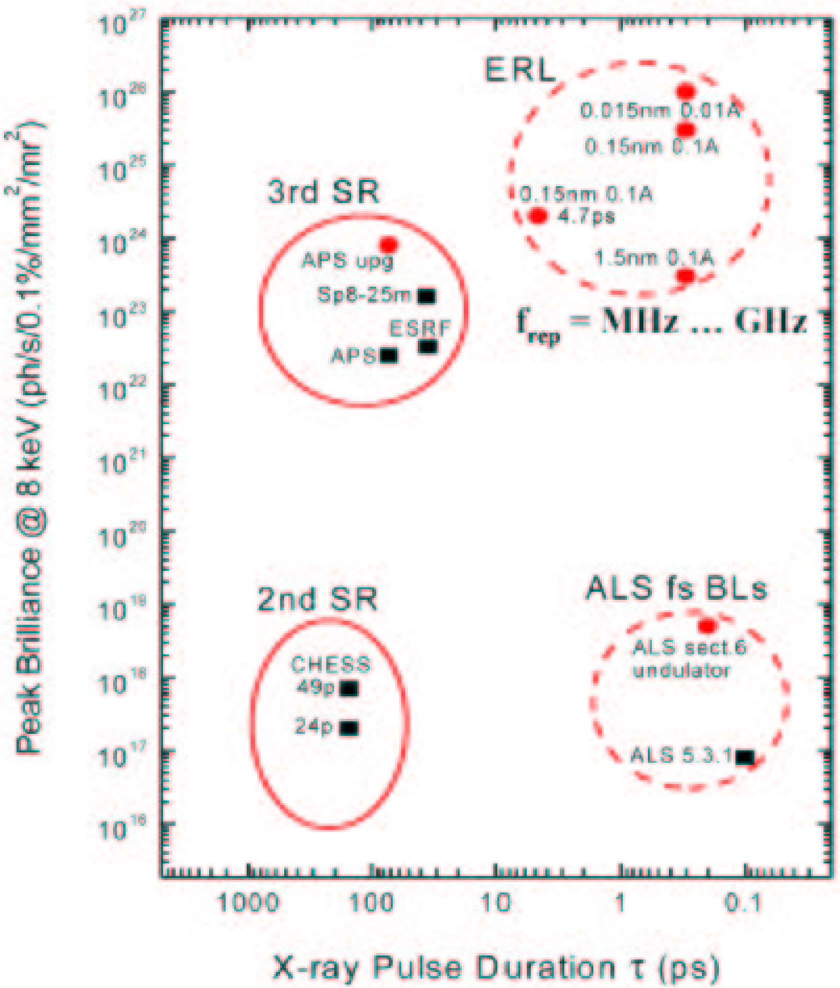
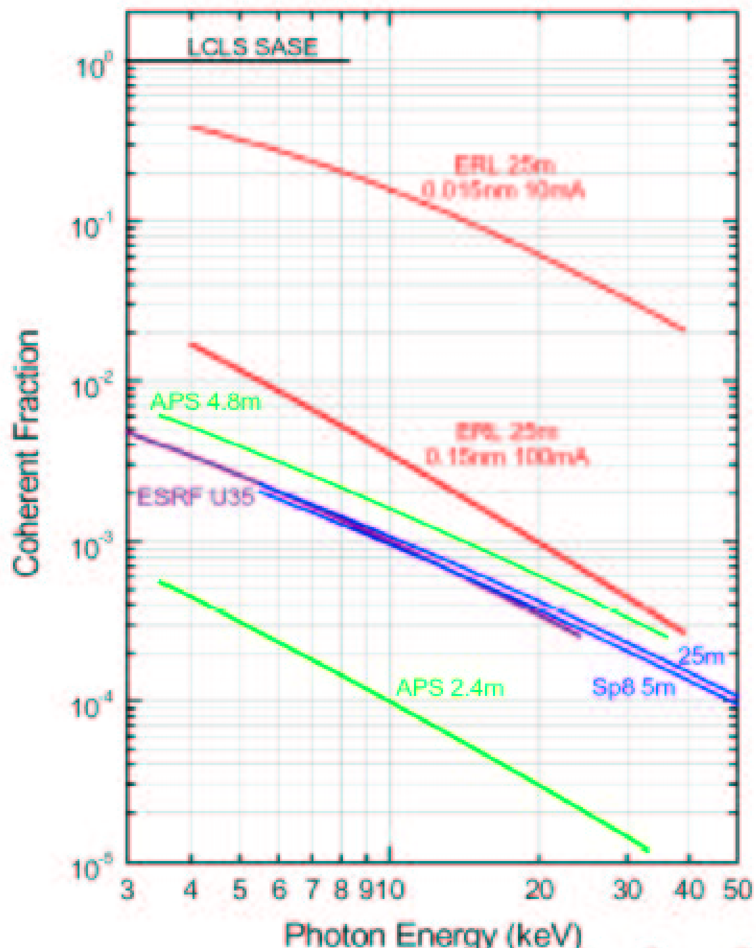
Short pulses, high brilliance:



High coherent fraction:



plots from Q. Shen

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Energy Recovery & Linear Coll.

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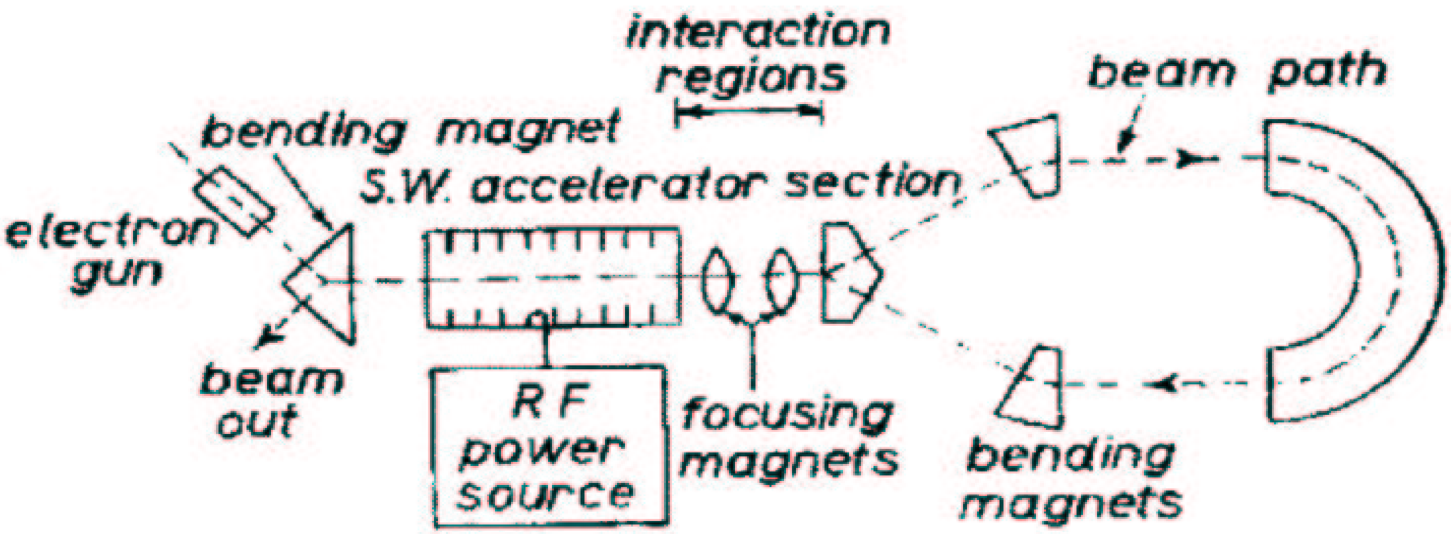
A Possible Apparatus for Electron Clashing-Beam Experiments (*).

M. TIGNER

Laboratory of Nuclear Studies, Cornell University - Ithaca, N. Y.

(ricevuto il 2 Febbraio 1965)



Energy recovery needs continuously fields in the RF structure

- Normal conducting high field cavities get too hot.
- Superconducting cavities used to have too low fields.

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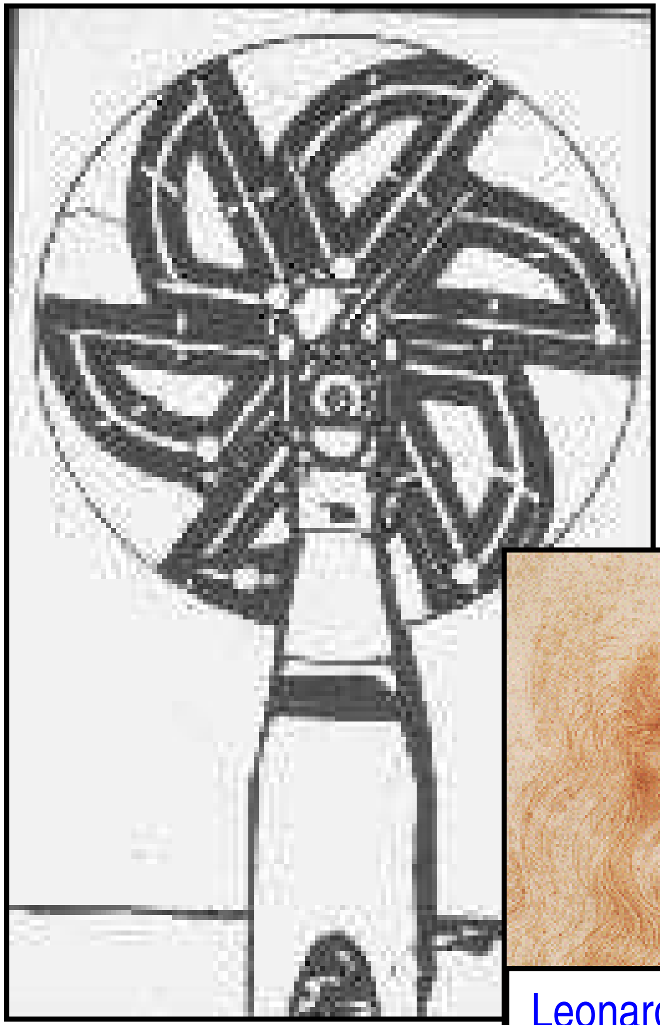
Previous Energy Recovery Linacs



Leonardo da Vinci
(1452-1519)

“Now, why should that not work?”

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ERLs in the World

After the success of high gradient super-conducting RF, several laboratories have worked on ERLs:

Upgrades of: TJNAF, JAERI

Light production: Brookhaven, Cornell, Daresbury, KEK, Novosibirsk

Electron Ion colliders: TJNAF

High energy electron cooling for RHIC: Brookhaven

Neither an electron source, nor an injector system, nor an ERL has ever been built for the required large beam powers and small transverse and longitudinal emittances.

- **A prototype at Cornell should verify the functionality**

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Limits to ERLs

Limits to Energy :

- Length of Linac and power for its cooling to 2K

Limits to Current :

- Beam Break Up (BBU) instability

For narrow beams :

- Coulomb expulsion of bunched particles (Space Charge)
- Radiation back reaction on a bunch (CSR)

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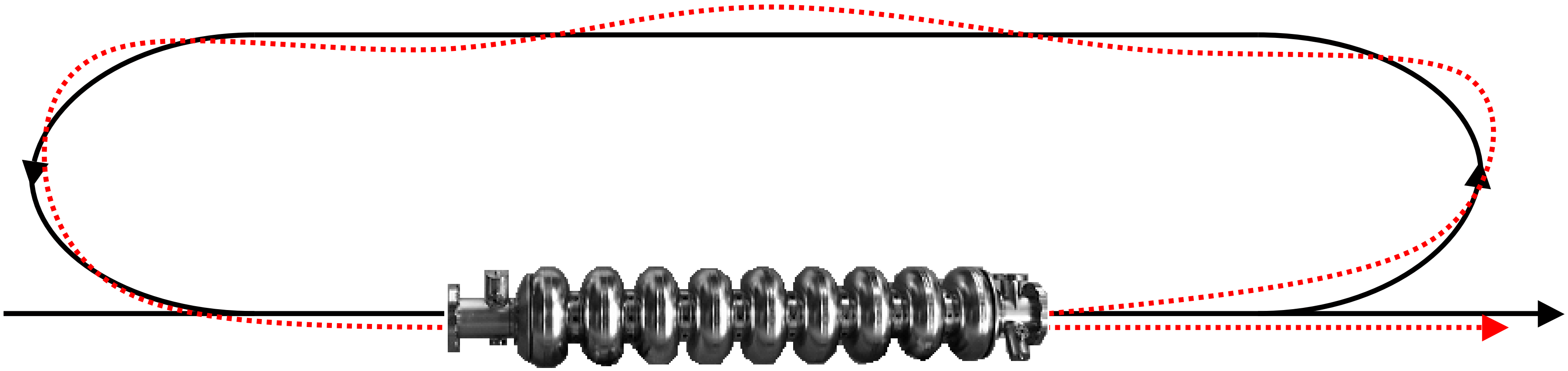
Instability with a single cavity and single Higher order mode



$$V_x(t) = \int_{-\infty}^{t} W_x(t-t')d(t')I(t')dt', \quad d_x(t) = T_{12}\tfrac{e}{c}V(t-t_r)$$

$$V_x(t) = T_{12}\tfrac{e}{c}\int_{-\infty}^{t} W_x(t-t')V(t'-t_r)I(t')dt'$$

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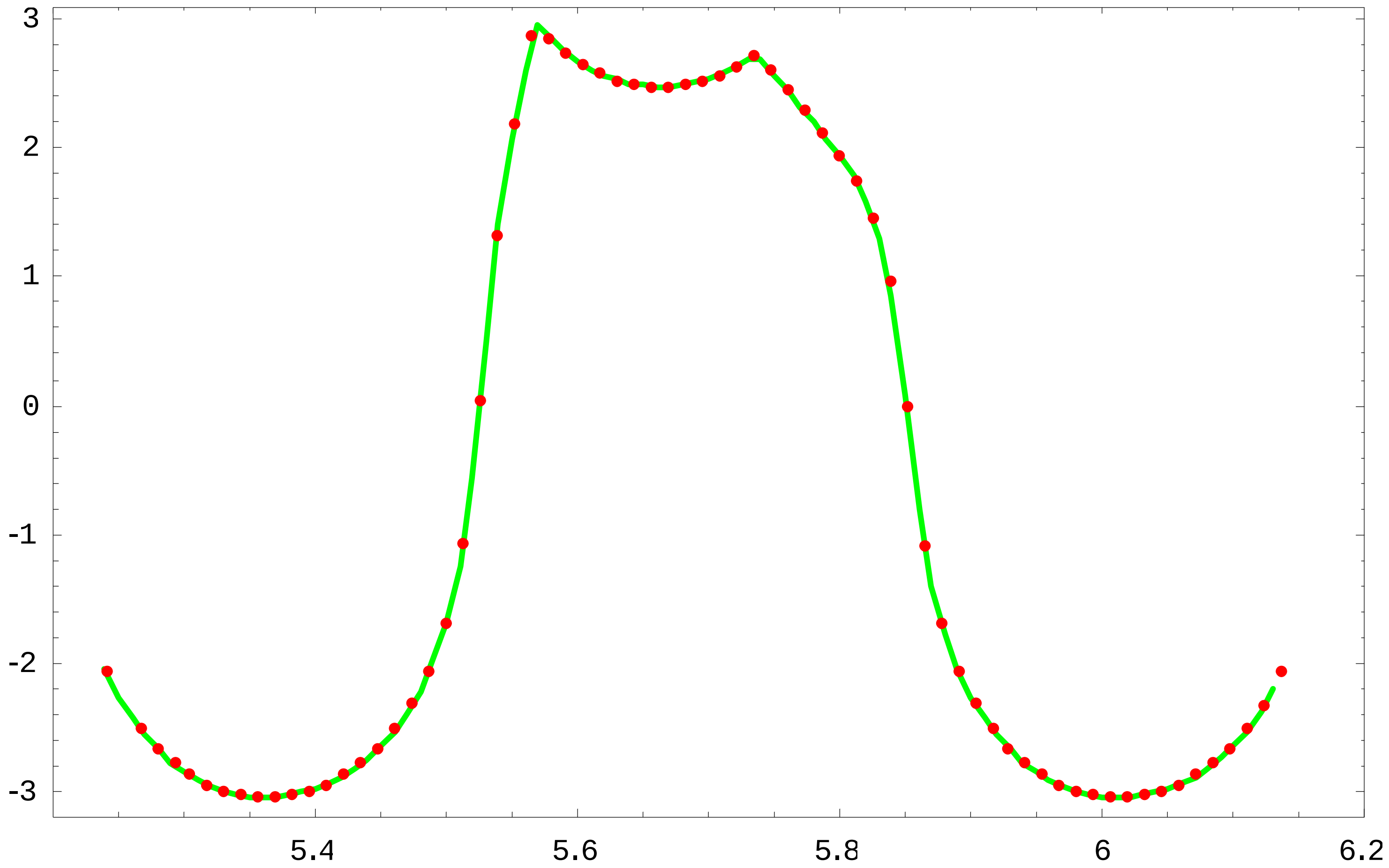
Comparison with Tracking



This agreement shows both, the quality of tracking and that of the theory.

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Results on BBU

Many HOMs in one cavity :

- only the most dangerous HOM contributes to the threshold.

HOMs in different cavities :

- HOMs in different cavities cannot cancel, but they can be decoupled by optical choices.

Multi turn recirculation :

- The threshold decreases approximately quadratically with the number of turns.

Closed orbit drift instability :

- Allways has a threshold that is larger than the coherent oscillation BBU

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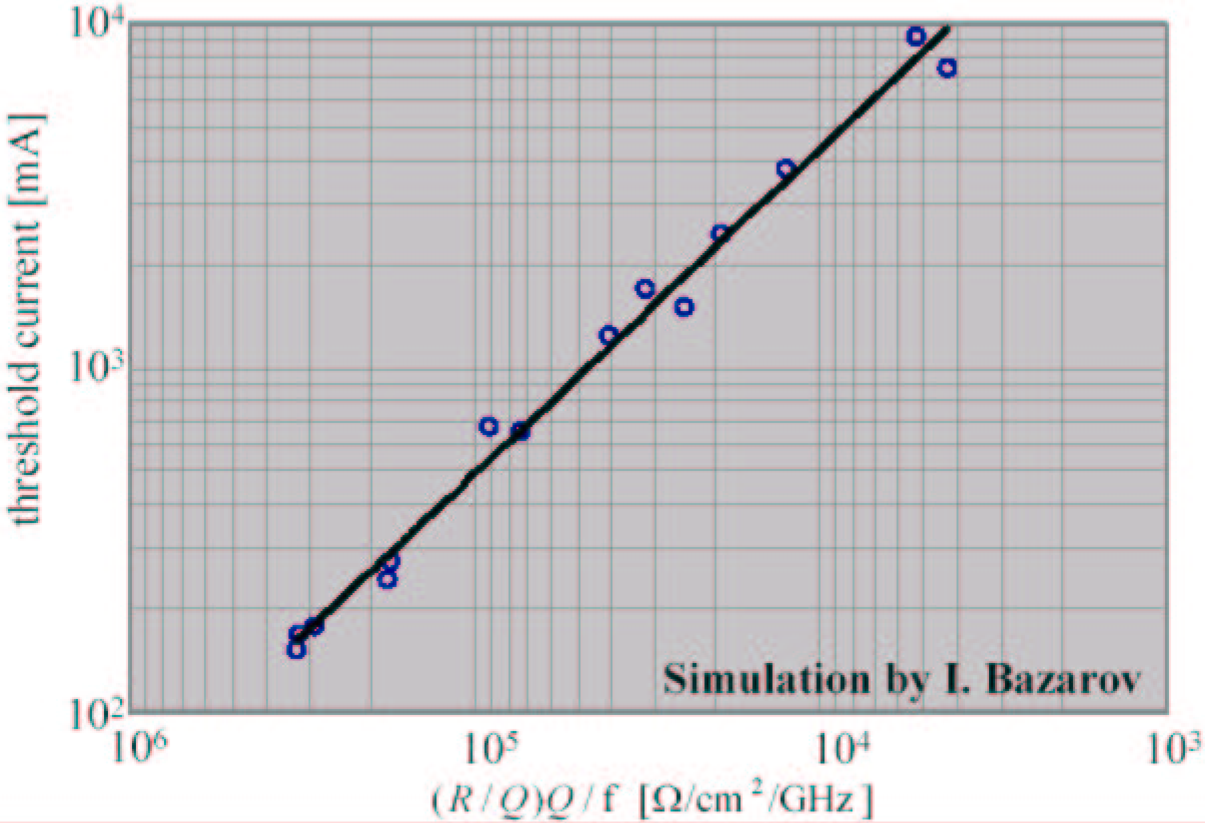
BBU limit for the 5GeV ERL



⇒ **$(R/Q)Q/f < 2\cdot 10^5\ \Omega/cm^2/GHz$ required for BBU instability current > 100 mA (with safety-factor).**

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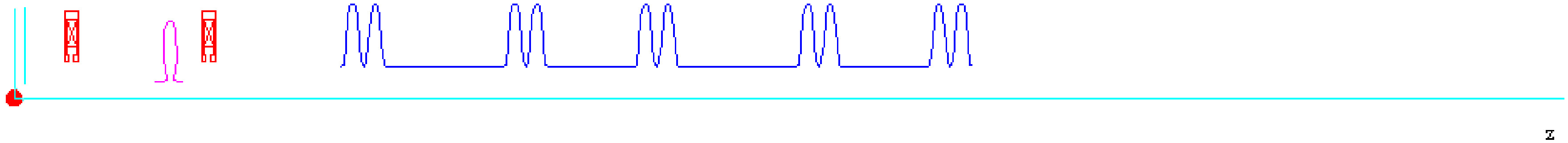
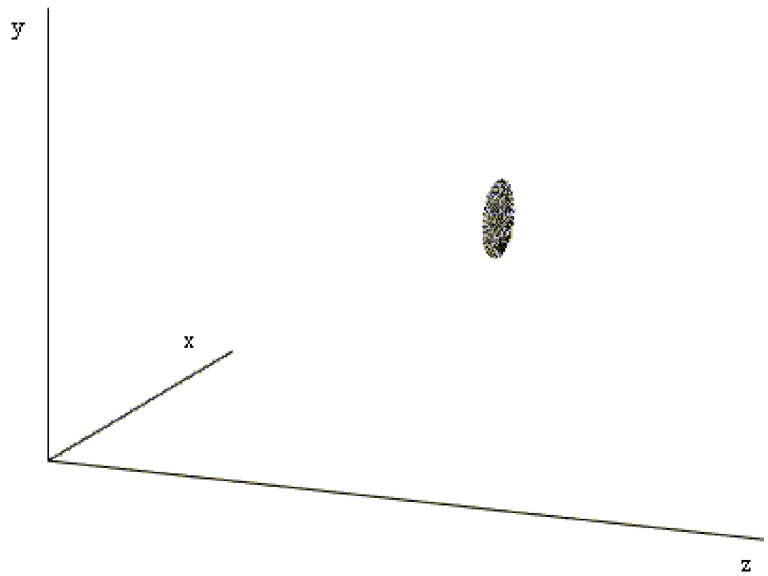
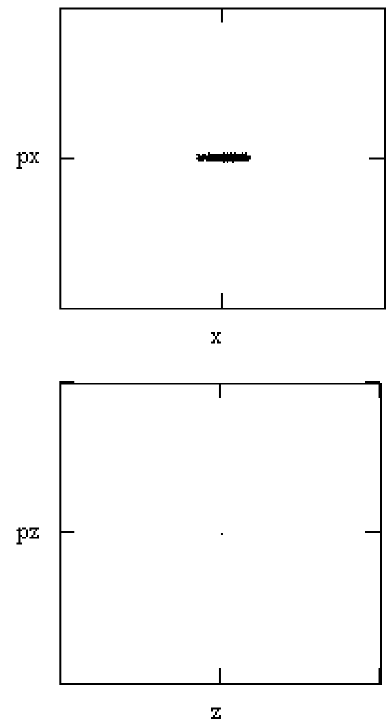
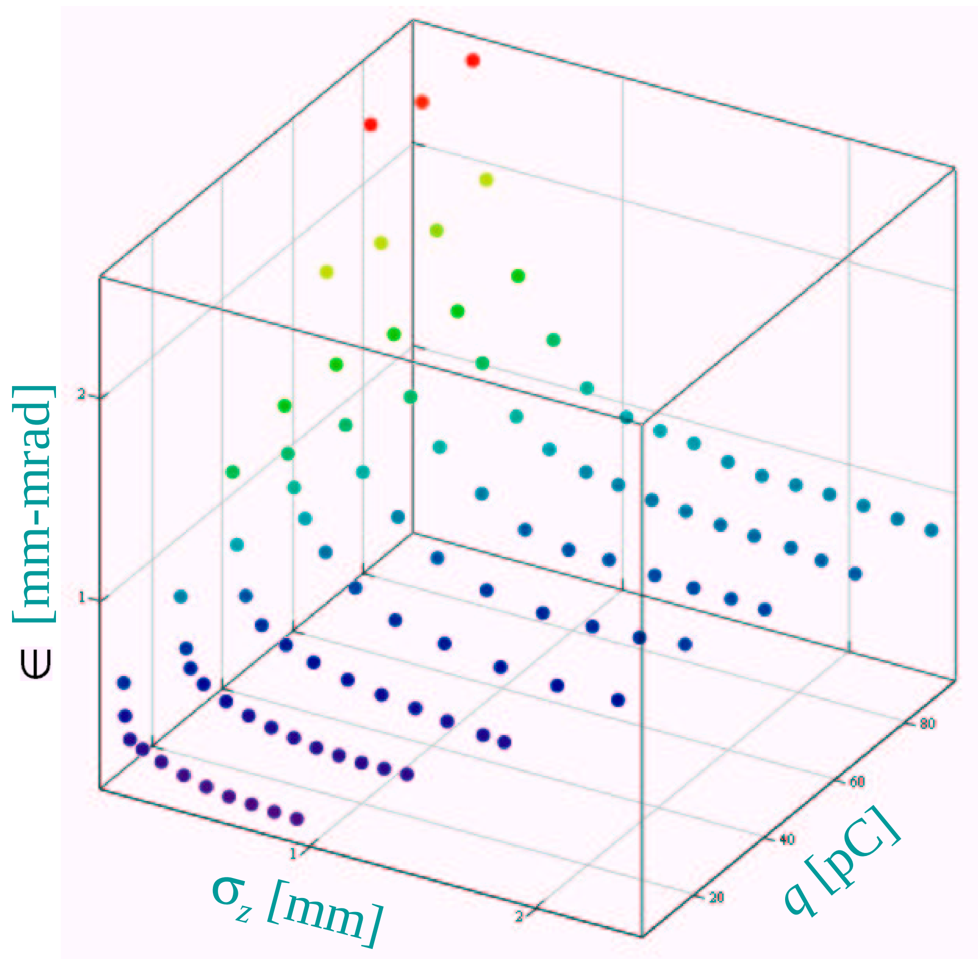
Gun simulations

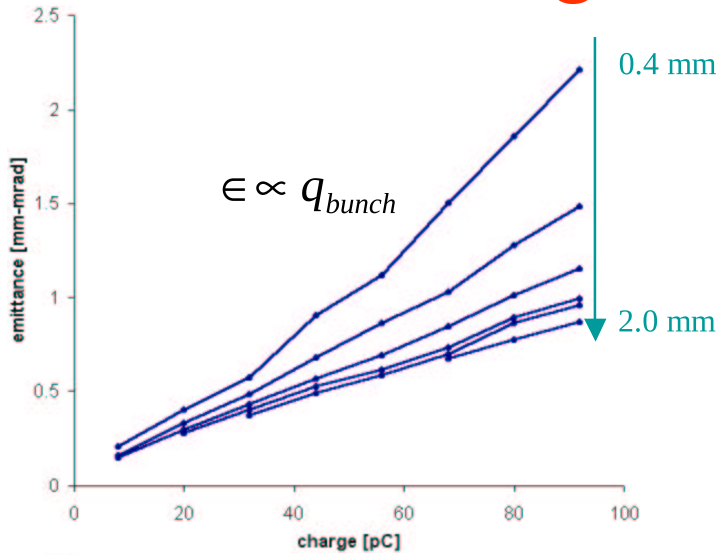


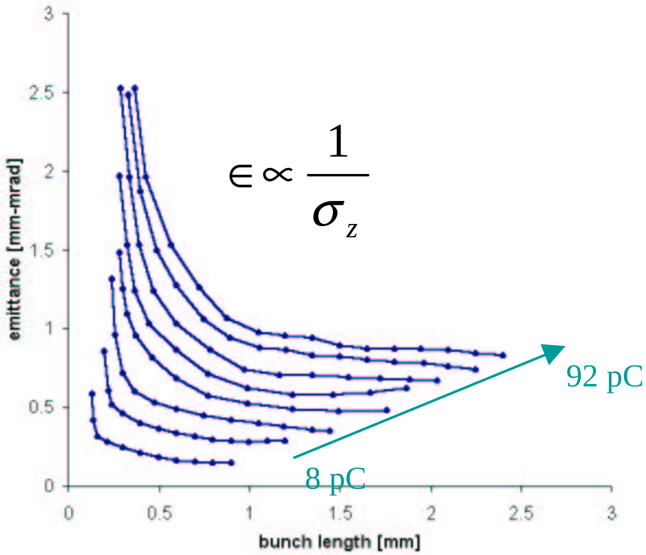




Emit. scaling vs. charge, vs. bunch length







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Optimization results

- Optimization for emittances in case of transverse uniform, longitudinal gaussian 'laser' profile:
  - 0.086 mm-mrad for 8 pC/bunch
  - 0.58 mm-mrad for 80 pC/bunch final bunch length < 0.9 mm
  - Ongoing simulations for an ideal gun lead to even much smaller emittances
  - 5.3 mm-mrad for 0.8 nC/bunch
- Simulations suggest that thermal emittance is not important for high charge / bunch (~ nC), but is important for low charge bunch (~ pC)
- Better results if longitudinal laser profile shaping can be employed
- Note: results are similar to those of RF guns

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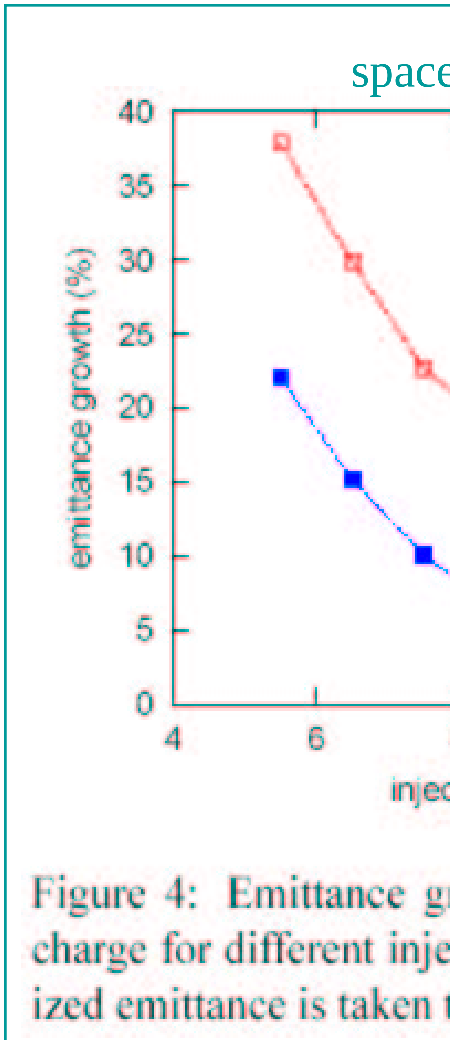
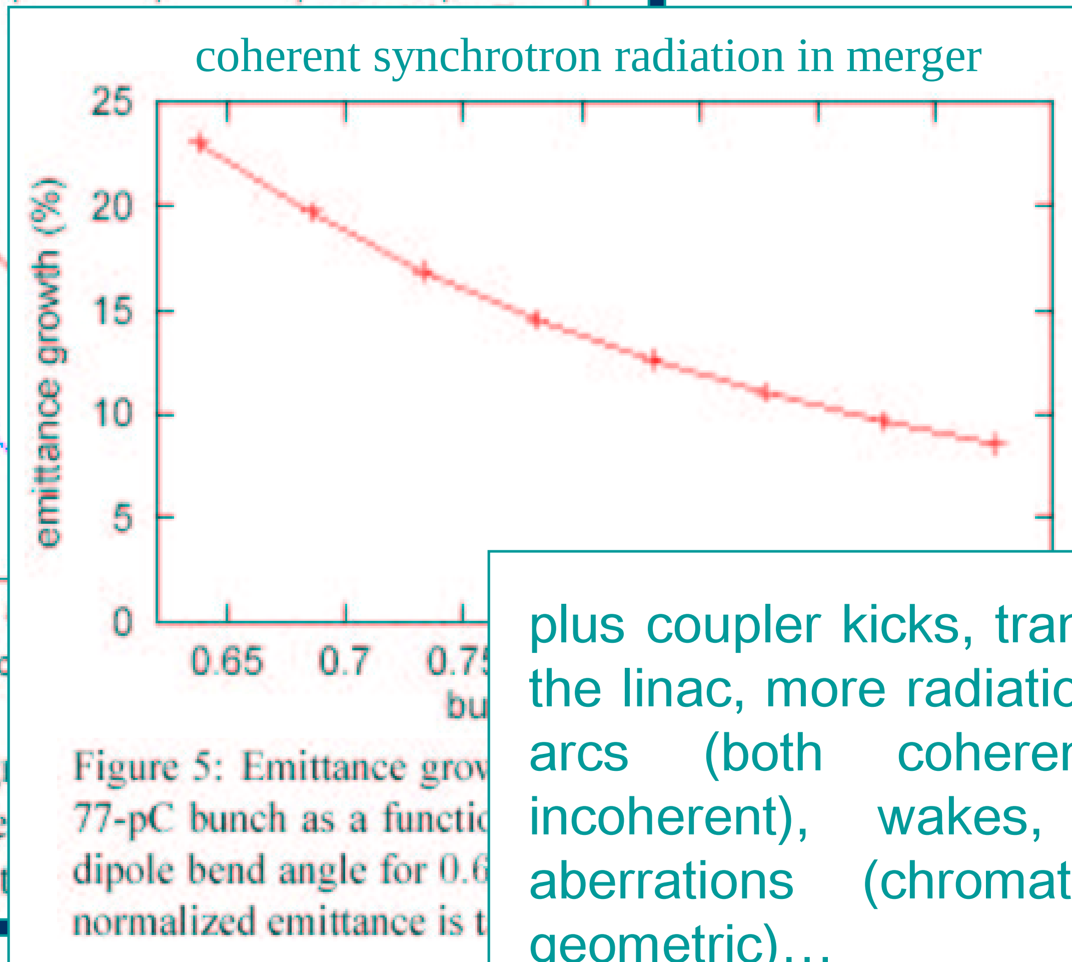
Emittance Growth in the Merger





plus coupler kicks, transport in the linac, more radiation in the arcs (both coherent and incoherent), wakes, optical aberrations (chromatic and geometric)…

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ERL Prototype Ia+Ib

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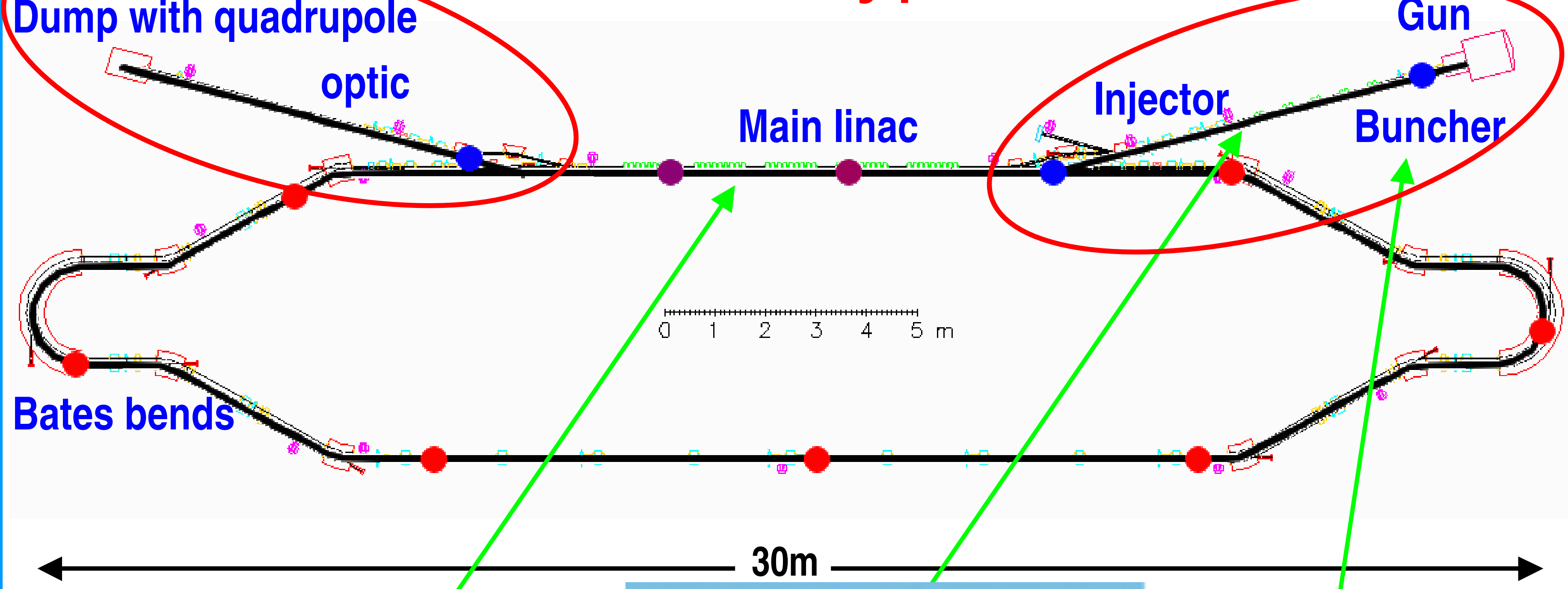

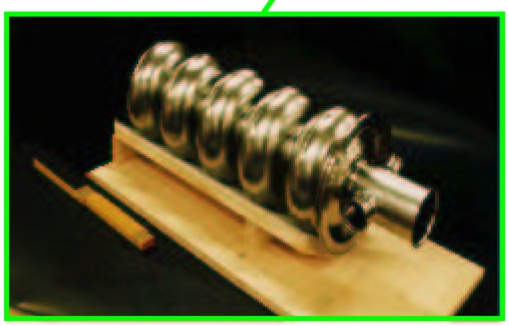

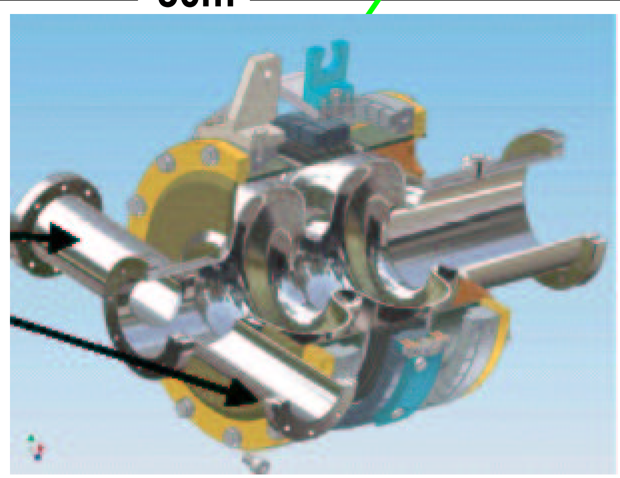

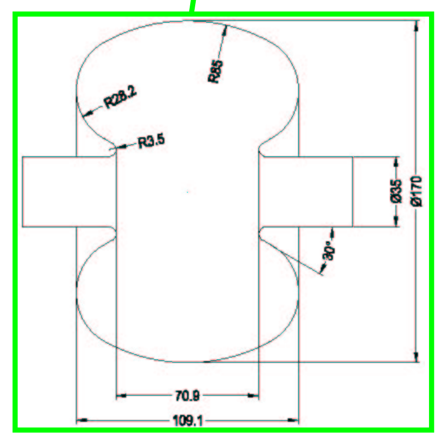

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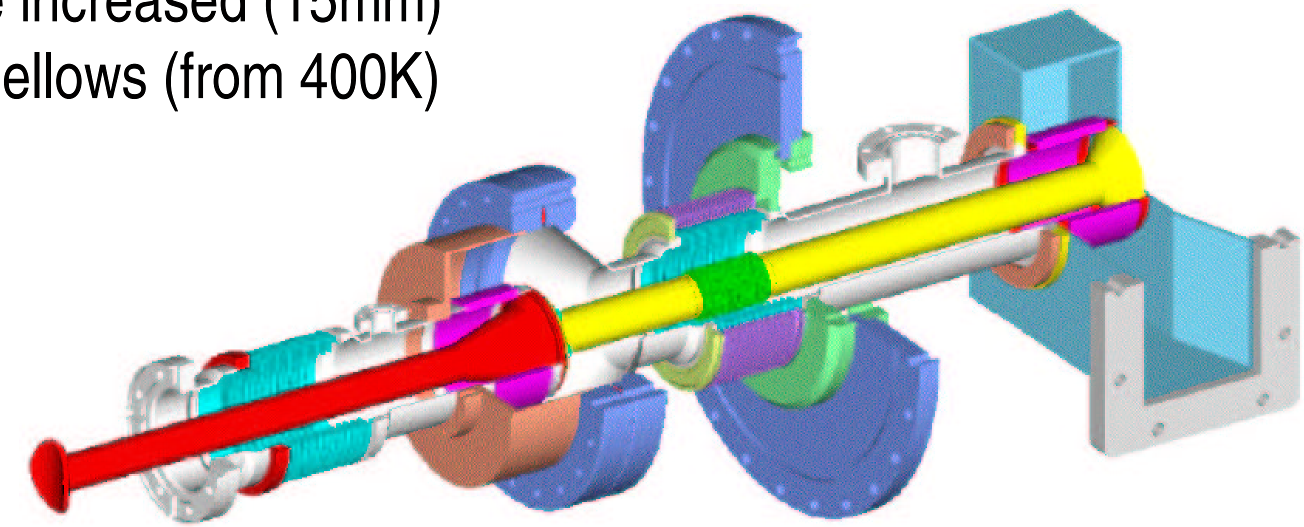
Injector coupler

- Coupling: 50 kW, but only 4% emittance growth due to coupler-focusing
- Flexibility: Energy gain = 1 to 3 MV, $Q_{ext} = 4.6 \cdot 10^4$ to $4.1 \cdot 10^5$
- Close to the TTF III coupler but:

62mm (from 40) coax line
multicasting free
larger antenna
travel range increased (15mm)
air-cooled bellows (from 400K)



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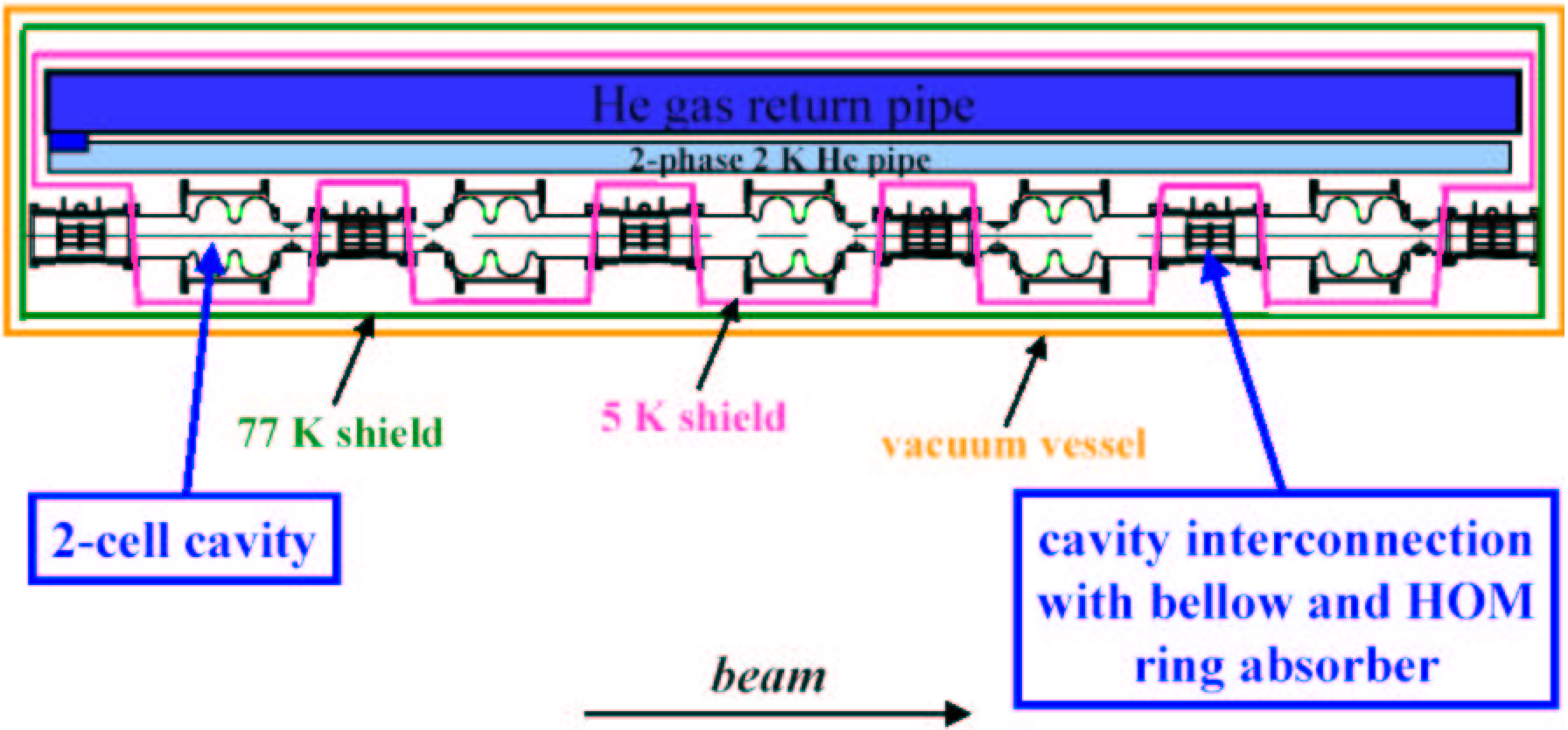
Injector cryomodule concept



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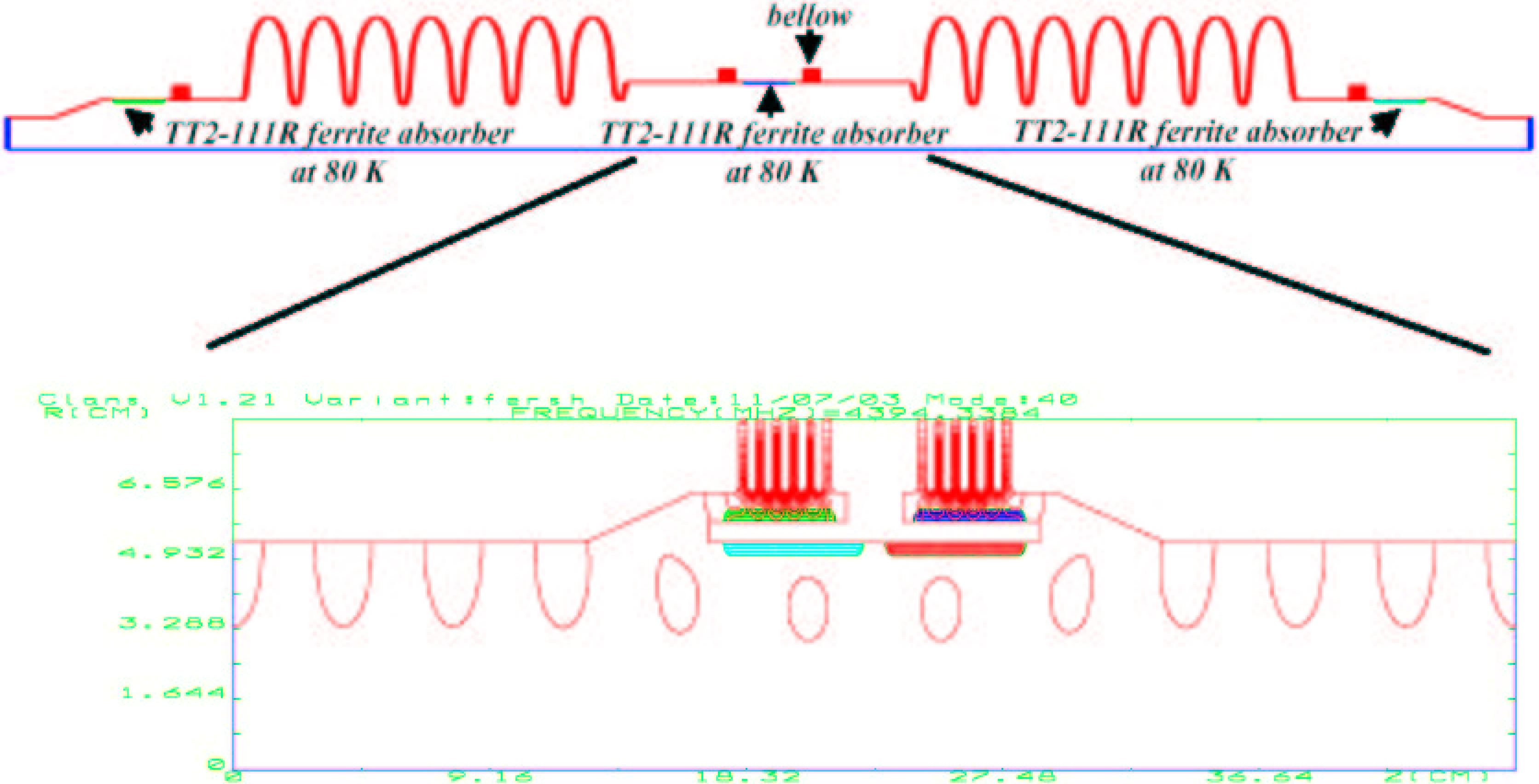
Ferrite shielded bellows



The bare bellows would lead to a loss factor of 1.2V/pC into the bellows.

The ferrite shielded bellows absorb the HOM power in the cooled ferrite.

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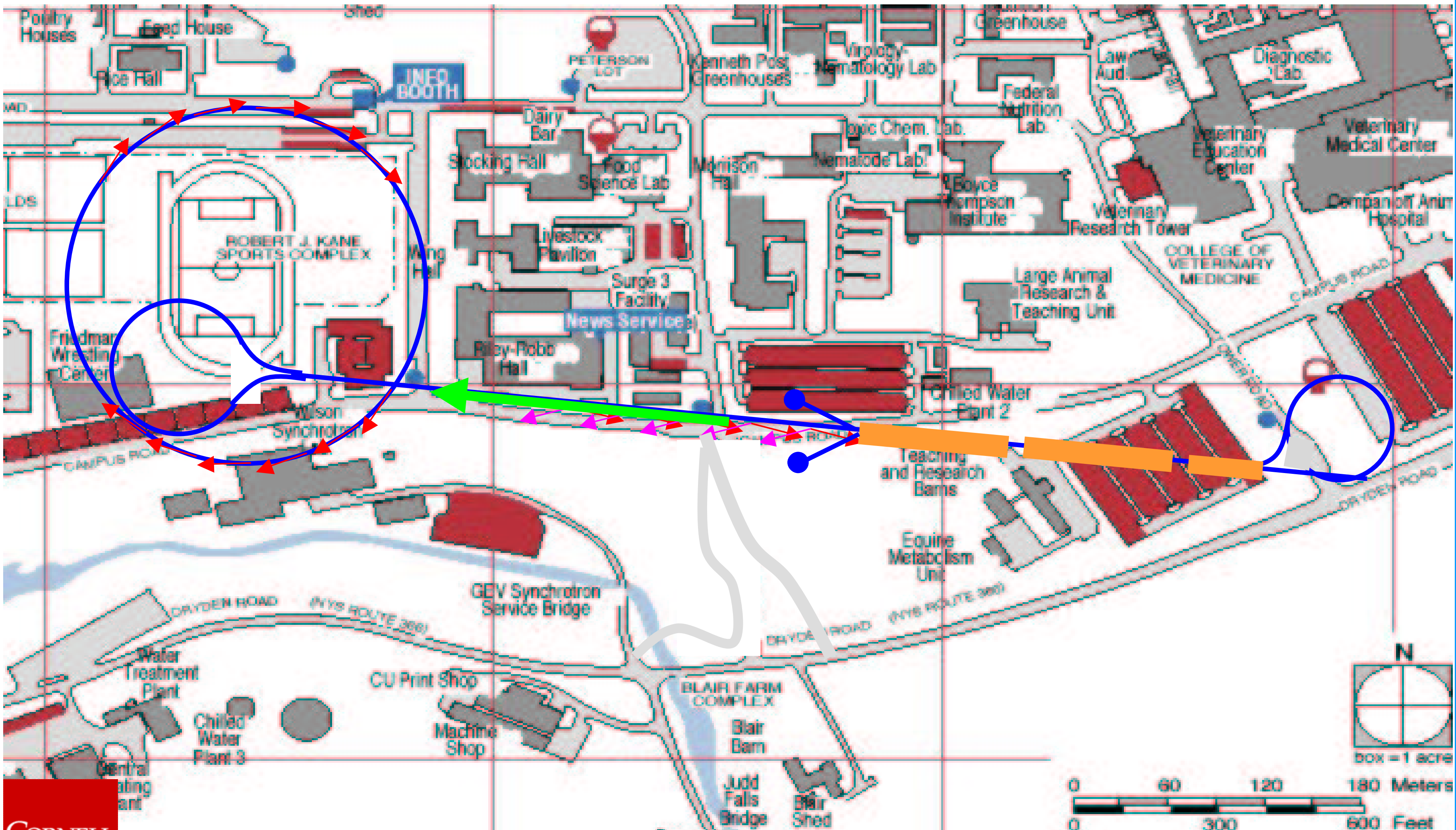
	ERL buncher cavity	ERL s.c. injector cavities	ERL s..c. main linac cavities
frequency [MHz]	1300	1300	1300
number of cavities	1	5	7
cells per cavity	1	2	7
R/Q [Ω] (circuit def.)	105	109	392
Q_0	20,000	$> 5 \cdot 10^9$	$> 10^{10}$
Q_{ext}	9,900	$4.6 \cdot 10^4$ ($4.1 \cdot 10^5$)	$2.6 \cdot 10^7$ for 25 Hz peak detuning
acc. voltage per cavity [MV]	0.12	1 (3)	≈ 16 (20 MV/m)
required klystron power per cavity [kW]	7	130	11
required relative amplitude stability (rms)	$8 \cdot 10^{-3}$	$1 \cdot 10^{-3}$	$3 \cdot 10^{-4}$
required phase stability (rms)	0.1°	0.1°	0.06°

ERL@CESR being analyzed



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Advantages of ERL@CESR

- Use the tunnel for ERL-Phase-Ib.
- Operation of CESR and ERL test simultaneously.
- Use all of the CESR tunnel, which would be more of an upgrade.
- Much more space for undulators.
- Space for future upgrades, like an FEL.
- Future extensions are possible.
- No basements of existing buildings to worry about.
- Only one tunnel for two linacs.
- Less cryo lines needed since there is only one linac tunnel.

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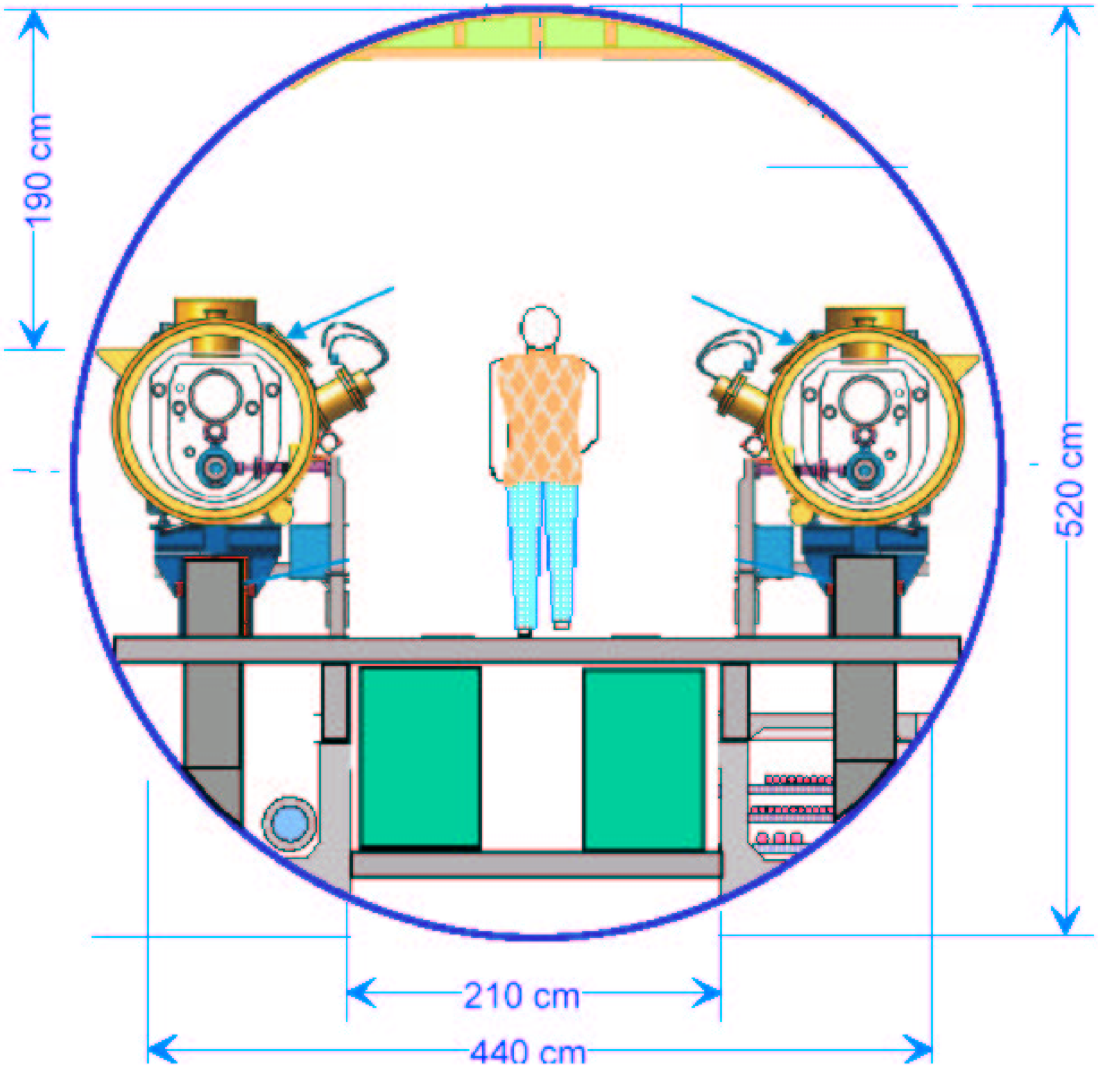
Double linac tunnel



Two modified TESLA type cryomodules, two times the 17kW IOTs, etc. in one tunnel.

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Parameters

Parameter		Prototype	Light source
Energy	(GeV)	0.1	5
Current	(mA)	100	100
Inj. energy	(MeV)	5–15	5–15
Rep. Rate	(GHz)	1.3	1.3
Acc. gradient	(MV/m)	20	20
Q of cavities	(10^{10})	1	1
external Q	(10^{7})	2.6	2.6
Charge/Bunch	(pC)	77	77
nominal σ_E	(10^{-3})	0.2	0.2
nominal σ_τ	(ps)	2	2
nominal ϵ_N	(μm)	2	2
short pulse σ_τ	(ps)	< 0.1	< 0.1
microbeam ϵ_N	(μm)	0.2	0.2
Main Linac Cavities		5	≈ 250
Cooling@2K	(kW)	0.2	≈ 17

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HOM Damping in the ERL Main Linac

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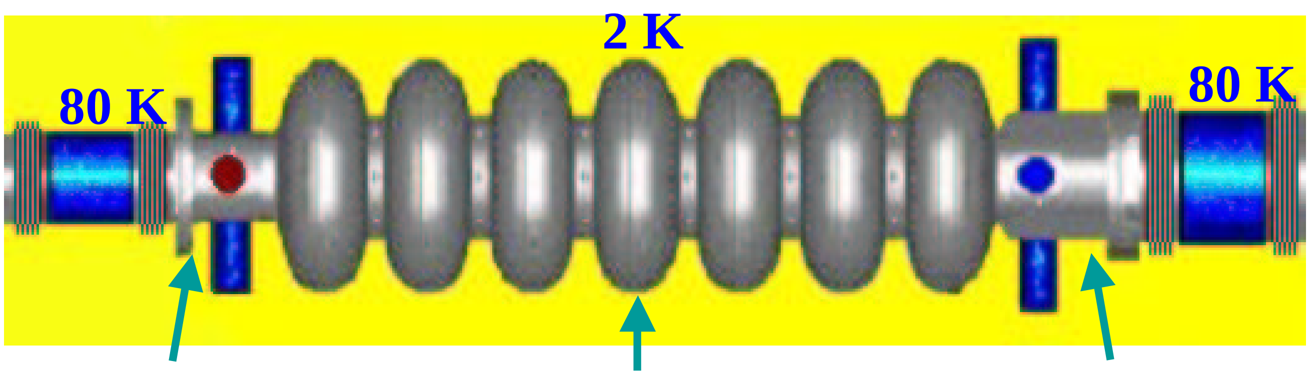

- In average 140 W losses per cavity from beam-excited monopole modes.
- Opposite HOM couplers to reduce transverse kicks.
- Enlarged beam tube on one side to propagate all TM monopole modes and most dipole modes.
- 6 HOM loop coupler per cavity to reduce power per coupler and to damp quadrupole modes reliable.
- Ferrite broadband absorbers at 80 K between cavities to damp propagating modes.

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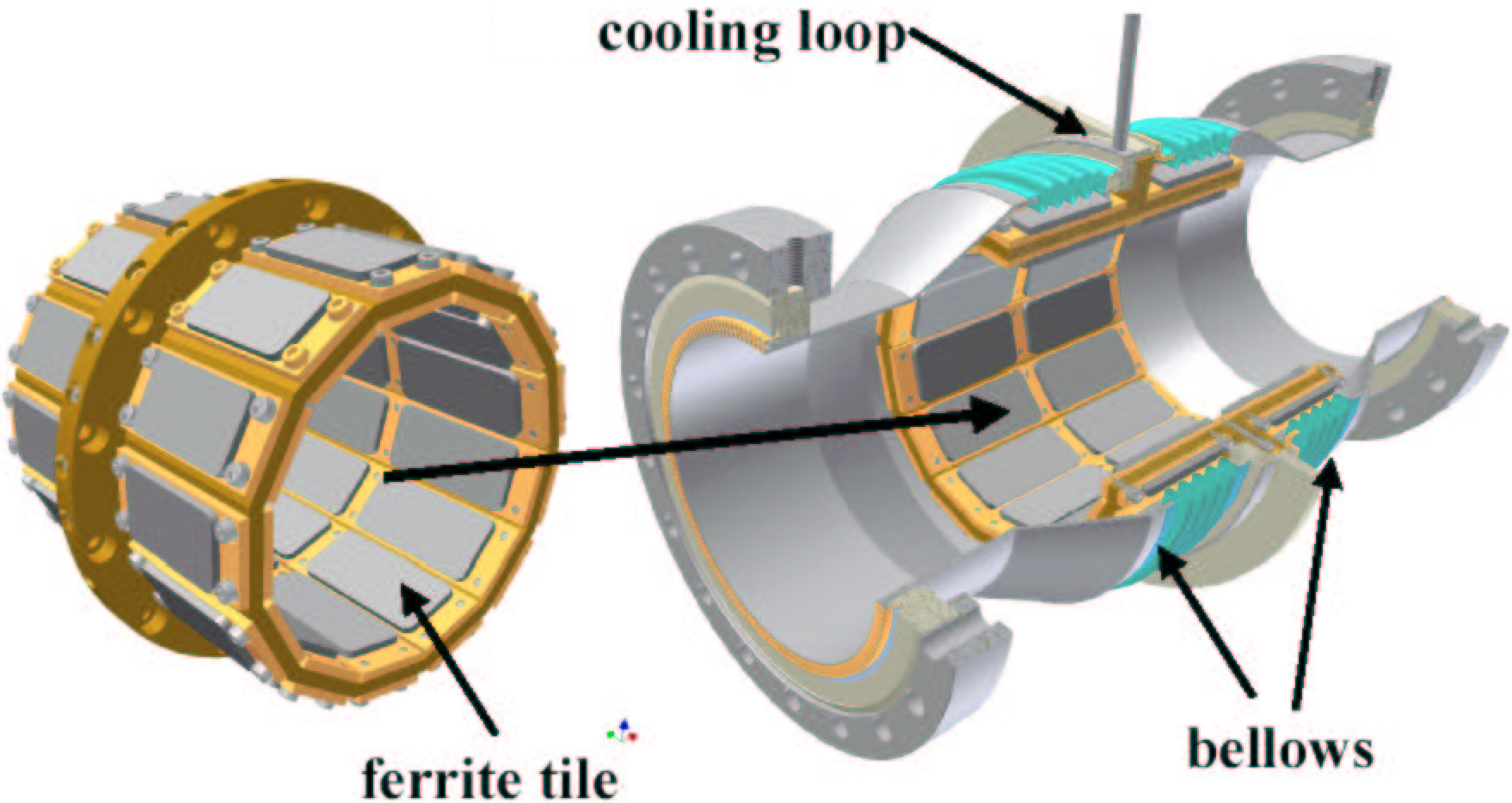
Ferrite shielded bellows



The temperature dependent absorption is being studied up to 40GHz as a function of temperature.

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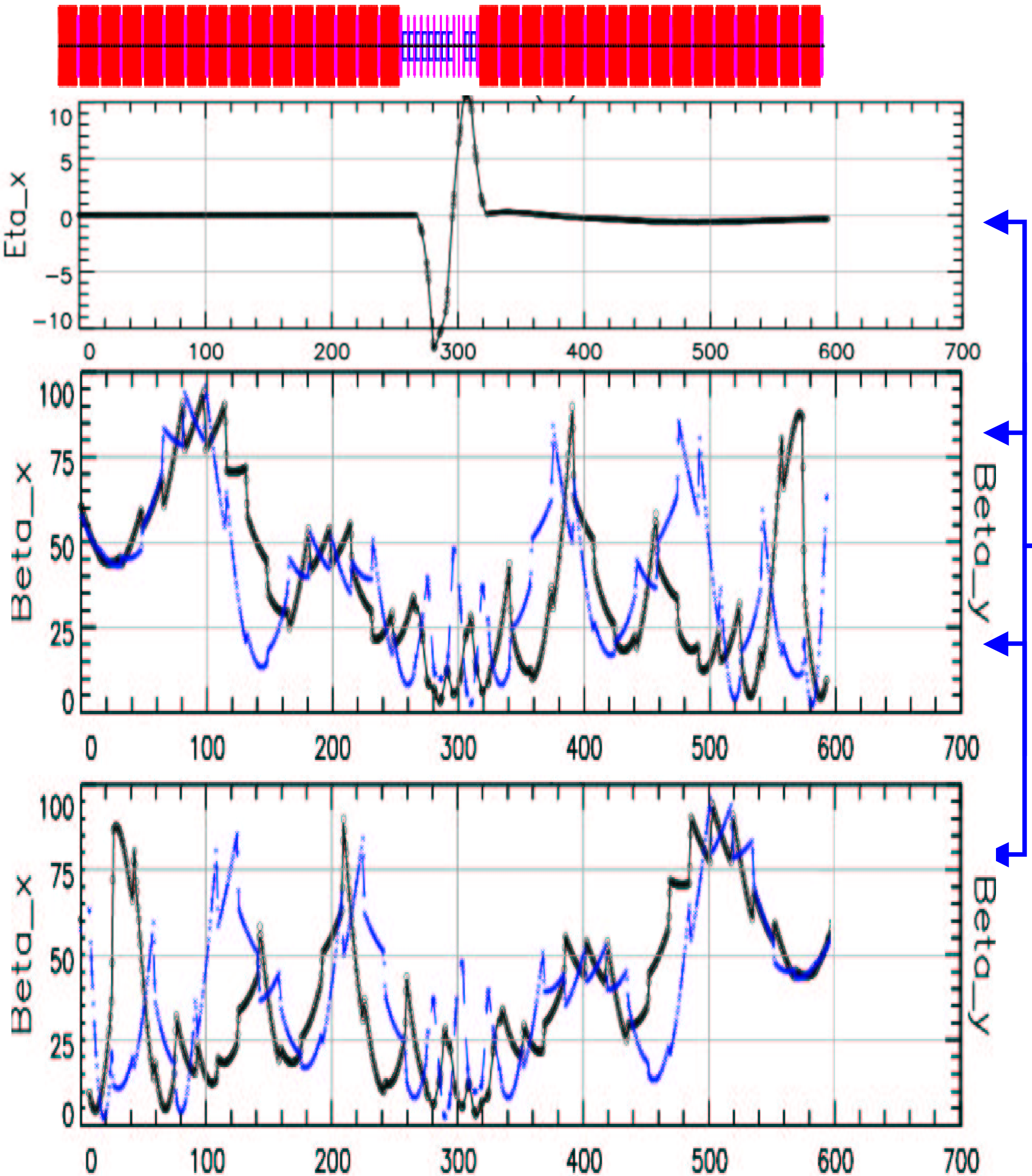
Linac optics



Optimize optics in the Linac for the accelerated and the decelerated energy.

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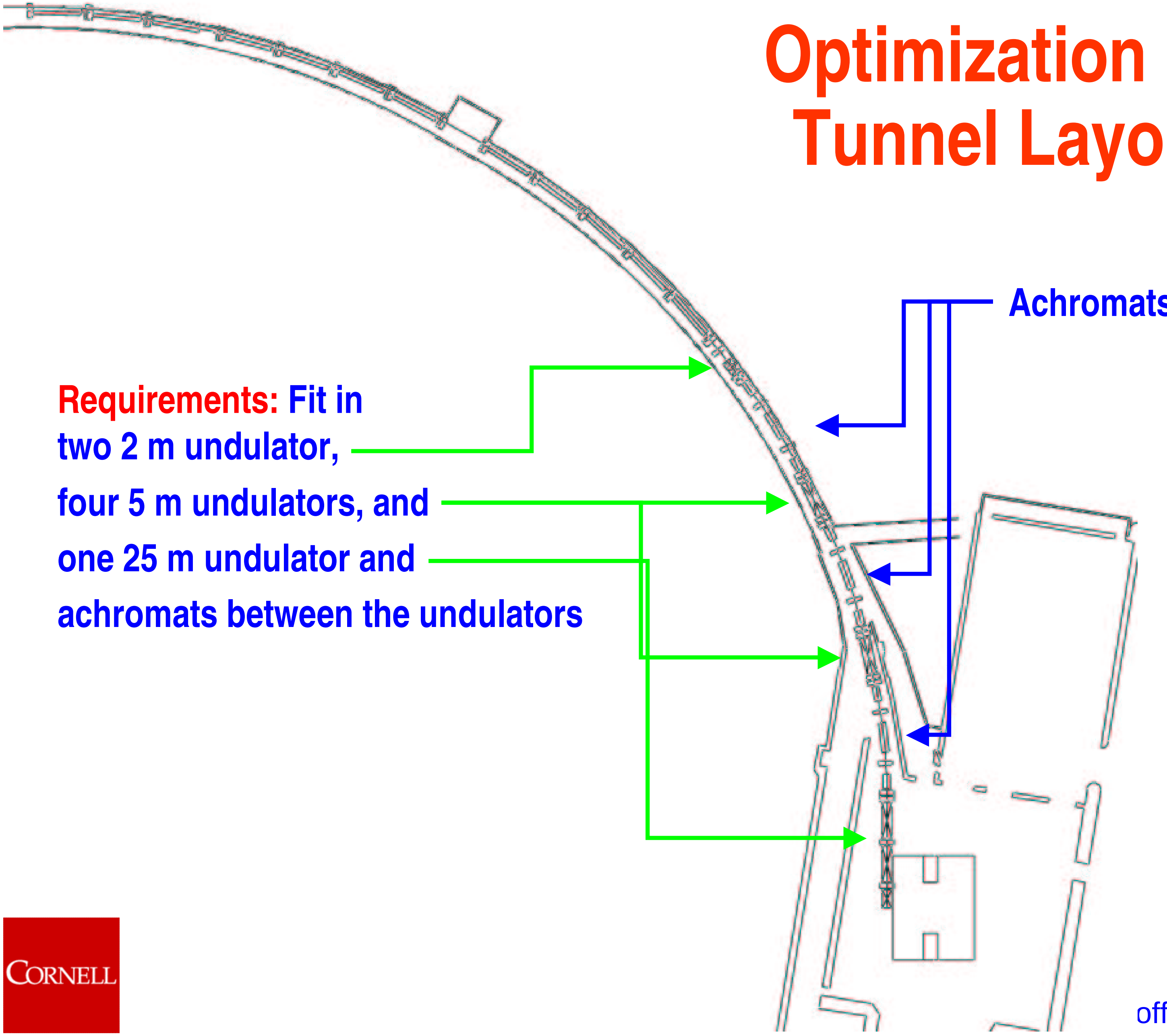
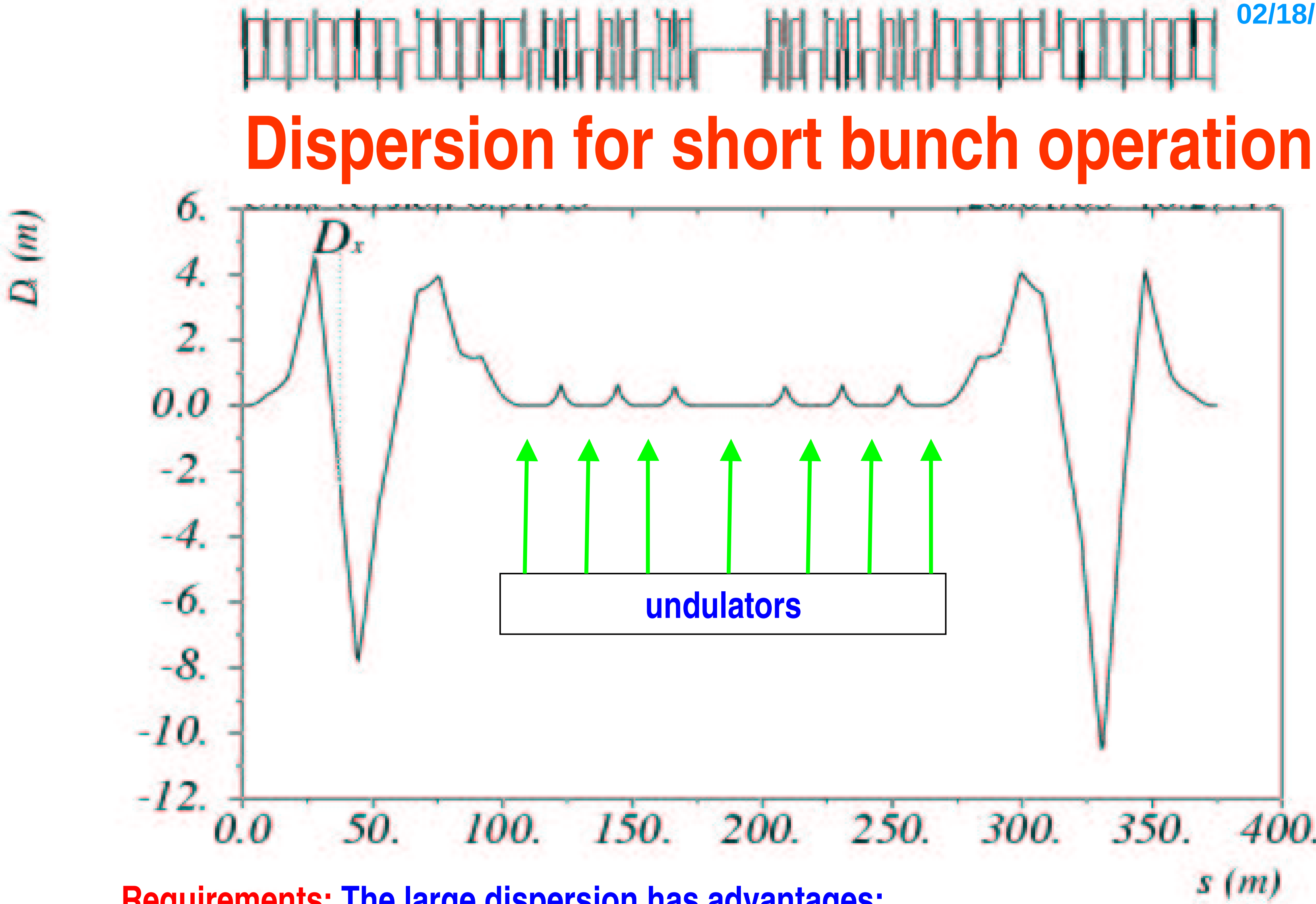
Optimization of Tunnel Layout



Dispersion for short bunch operation



Requirements: The large dispersion has advantages:

Can be used to manipulate R56, and with sextupoles also higher chromatic orders.

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Emittance with CSR and nonlinear optics

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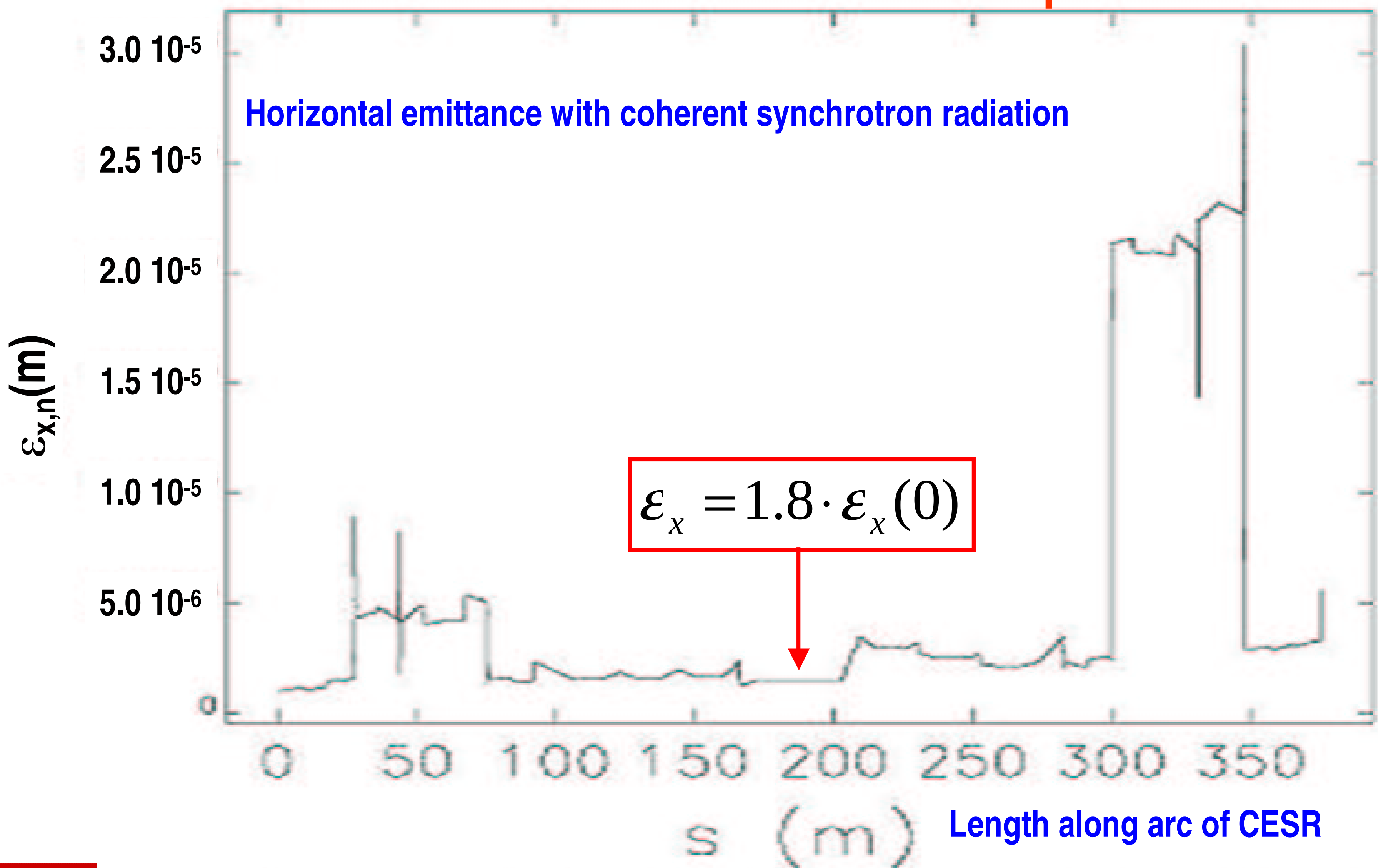

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Result: After suitable nonlinear bunch length manipulation, the emittance growth can be controlled in all undulators.

Conclusion

- Possibilities of extending the CESR tunnel to accommodate an ERL have been investigated.

- First and second order optics have been found for an ERL
  - which uses the current CESR tunnel and many of its components
  - which can be used to compress 2ps bunches to 100fs
  - which leads to less than a factor of 2 in transverse emittance increase due to CSR
  - Nearly all quadrupoles and sextupoles have a strength which can be achieved in CESR today
  - The BBU limit is at least as large 100 – 200mA

- This upgrade of CESR to an ERL light source would be a demonstration of an upgrade path that could then be open to many existing X-ray rings.

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