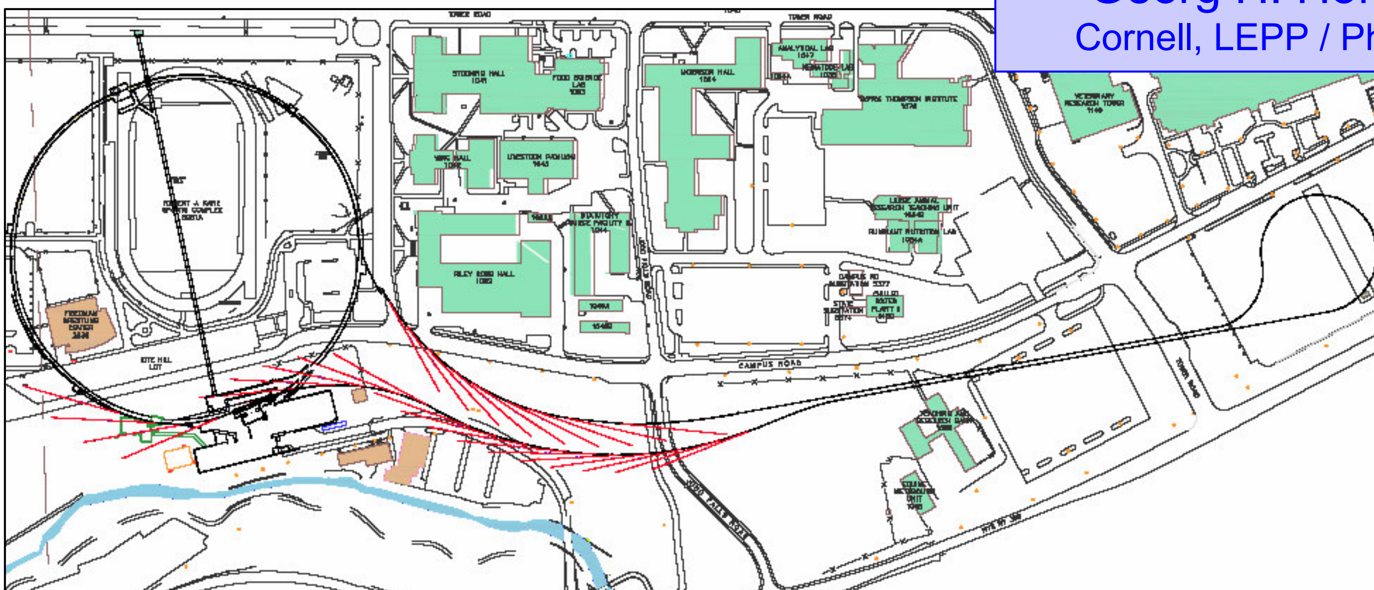
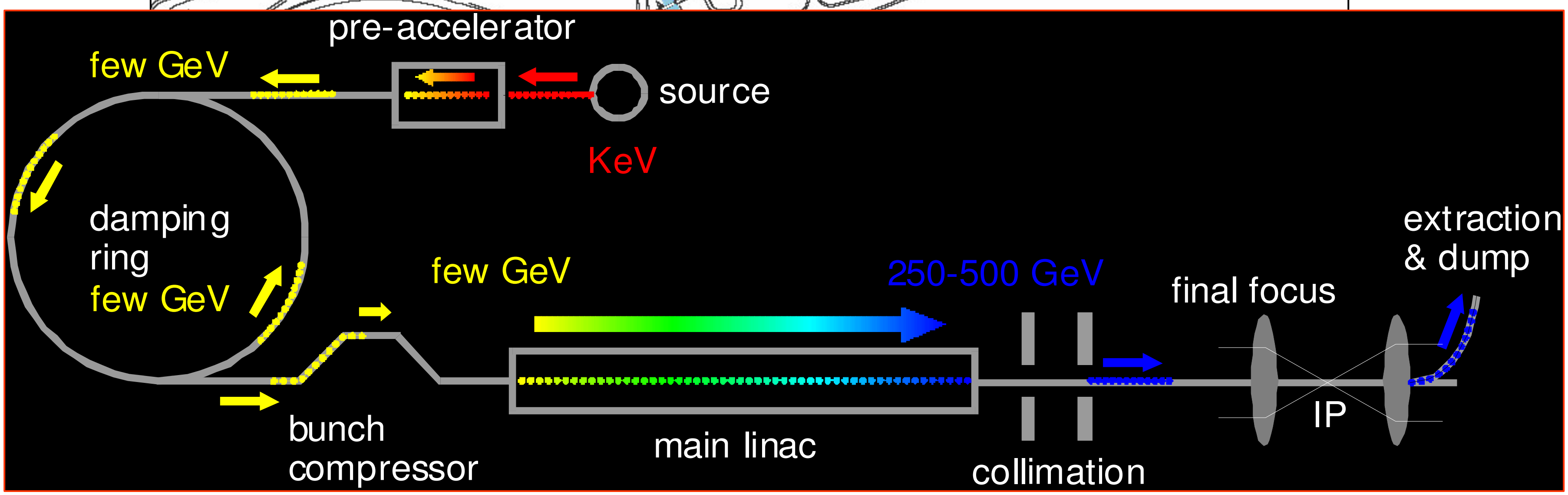
Future Accelerators: ERL and ILC

Georg H. Hoffstaetter
Cornell, LEPP / Physics Dep.

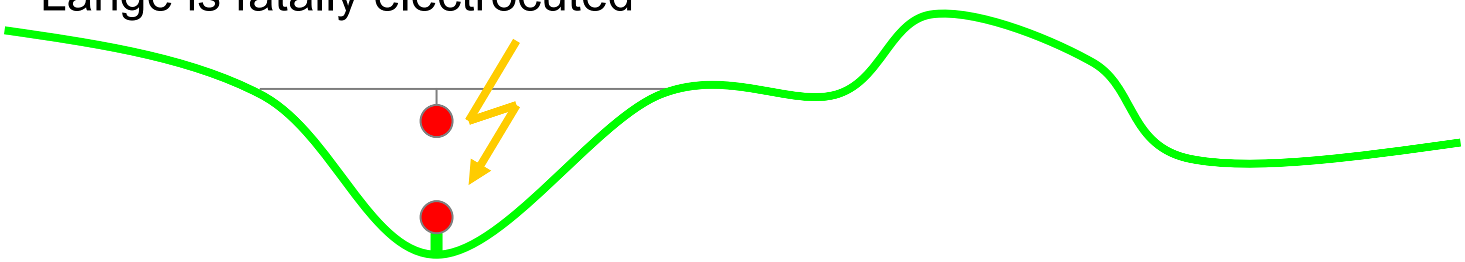




Accelerator Physics @ Cornell

CHESS & LEPP

- 1932: Brasch and Lange use potential from lightening, in the Swiss Alps, Lange is fatally electrocuted



- 1934: Livingston builds the **first Cyclotron away from Berkely** (2MeV protons) at Cornell (in room B54)
- 1949: Wilson et al. at Cornell are **first to store beam in a synchtotron** (later 300MeV, magnet of 80 Tons)
- 1954: Wilson et al. build **first synchrotron with strong focusing** for 1.1MeV electrons at Cornell, 4cm beam pipe height, only 16 Tons of magnets.
- 1965: **First paper on Linear colliders and ERLs**
- 1979: 5GeV electron positron collider CESR (designed for 8GeV)
- Currently:
  - CESR operation and optimization for the CLEO experiment
  - CESR operation and optimization for CHESS
  - ERL prototyping facility (ERL e-source and injector linac)
  - ERL and CESR upgrade to an ERL
  - ILC design, simulations, damping ring studies with CESR

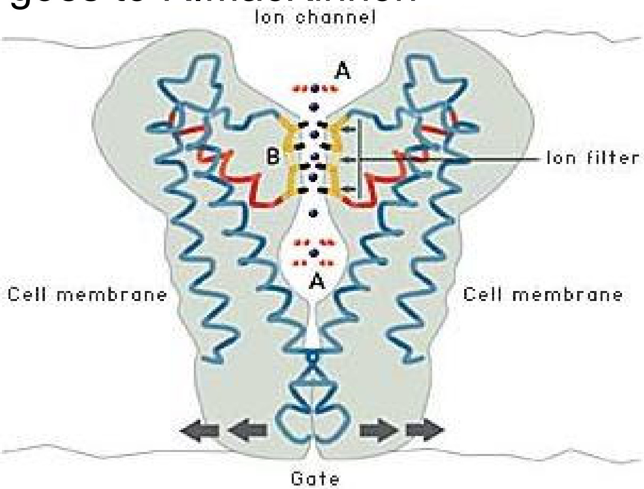
Synchrotron Radiation @ Cornell

CHESS & LEPP

- 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

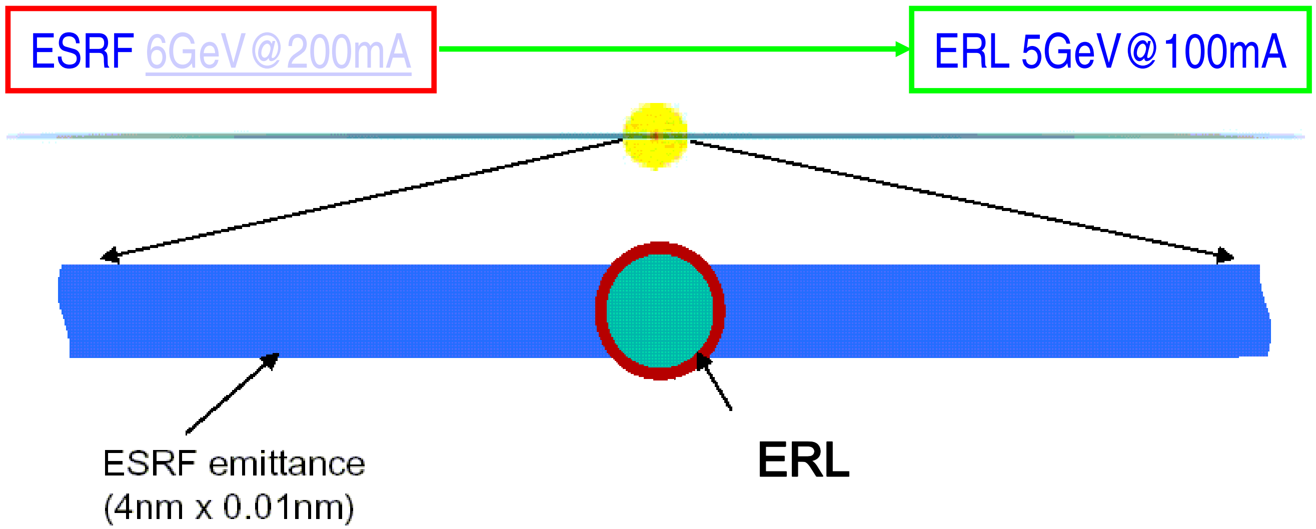


Roderick MacKinnon

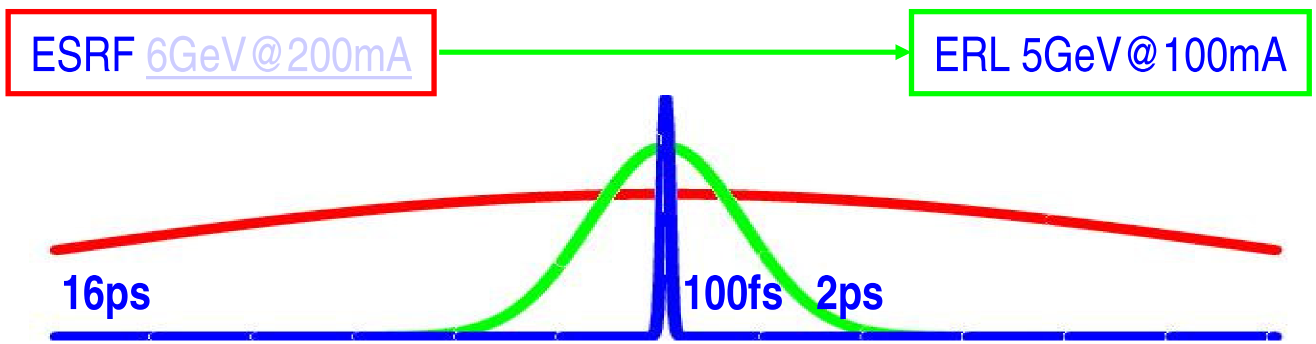
How good are ERL beam goals?

CHESS & LEPP

Transverse emittance reduction:



Bunch-legth reduction:

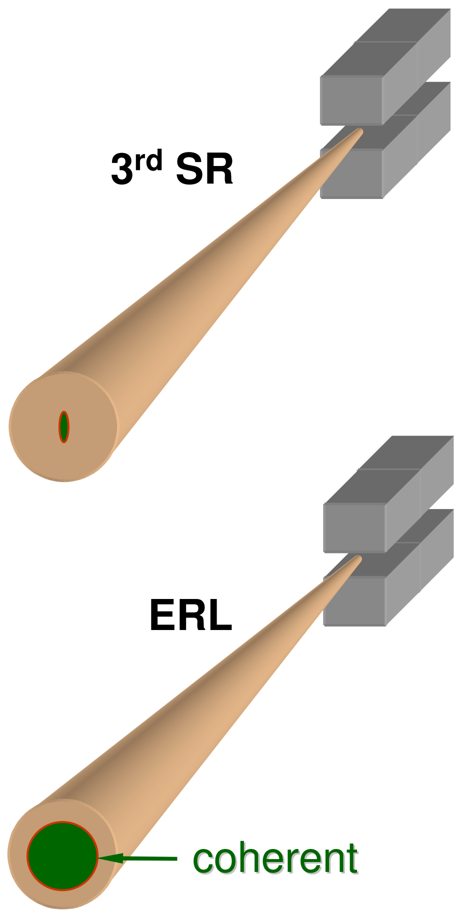


Smaller Beams and more Coherence

CHESS & LEPP

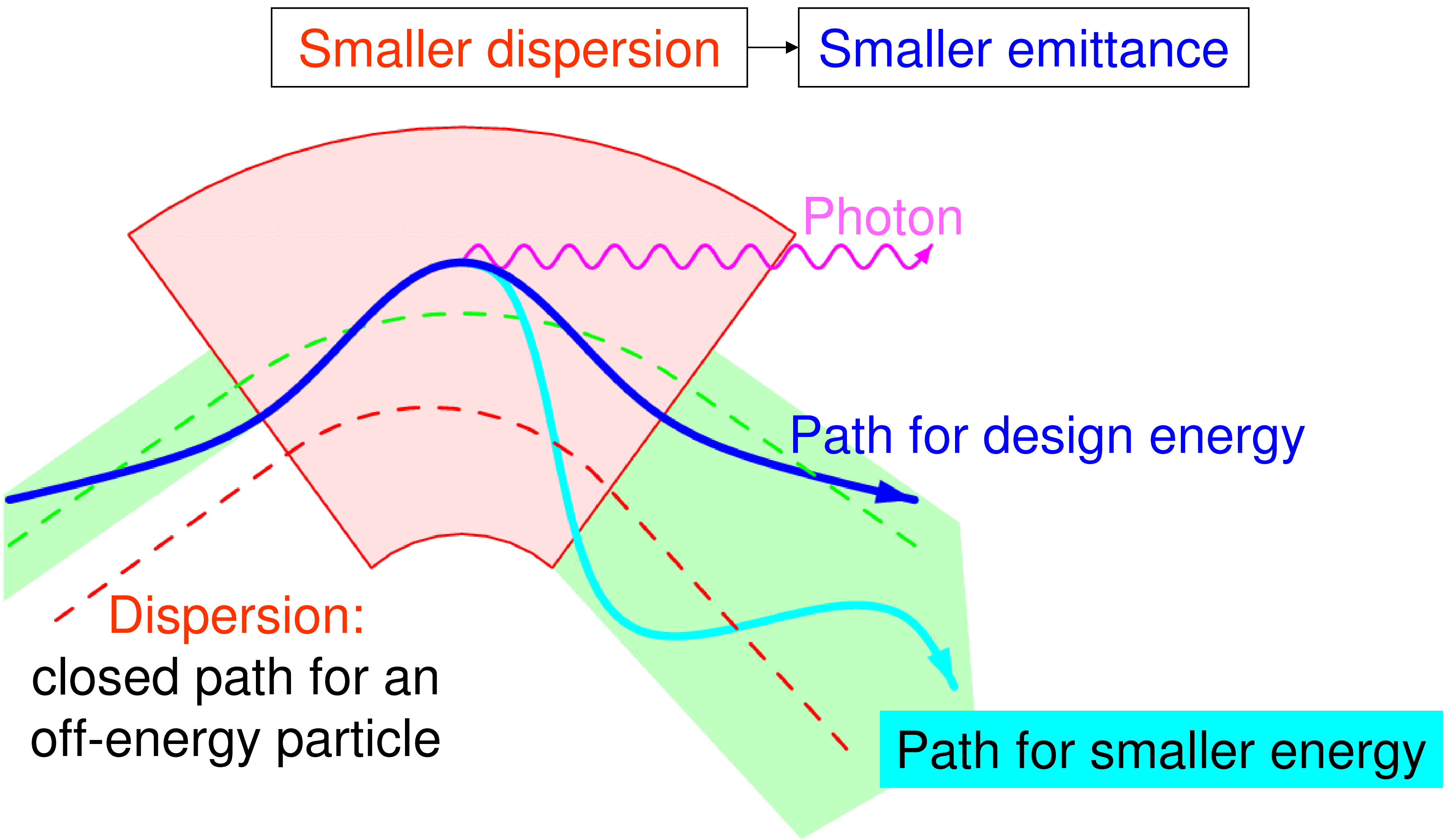
- Coherent x-ray diffraction imaging
- It would, in principle, allow atomic resolution imaging on non-crystalline materials.
- This type of experiments is completely limited by coherent flux.

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



Emittance Excitation

CHESS & LEPP



Pro and Con for an x-ray Linac

As compared to a ring, the beam properties are largely determined by the injector system:

- **The bunch length can be made much smaller than in a ring**
- **Smaller emittances**
- **Higher coherence fraction**

ESRF 6GeV@200mA → ERL 5GeV@100mA

Current of 100mA and energy of 5GeV leads to a beam power of 0.5GW !!!

The energy of the spent beam has to be recaptured for the new beam.

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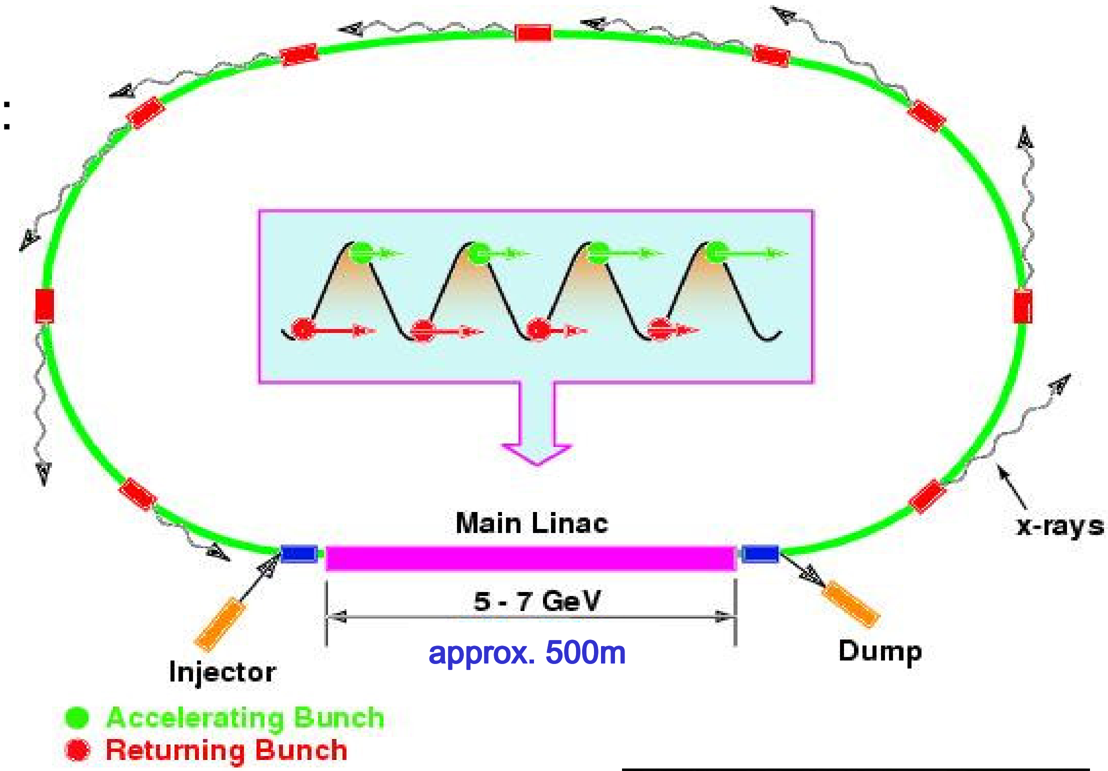
Principle of an X-ray ERL

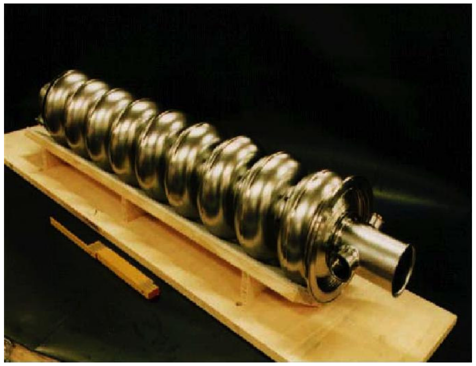
CHESS & LEPP

X-ray analysis with highest resolution in space and time:

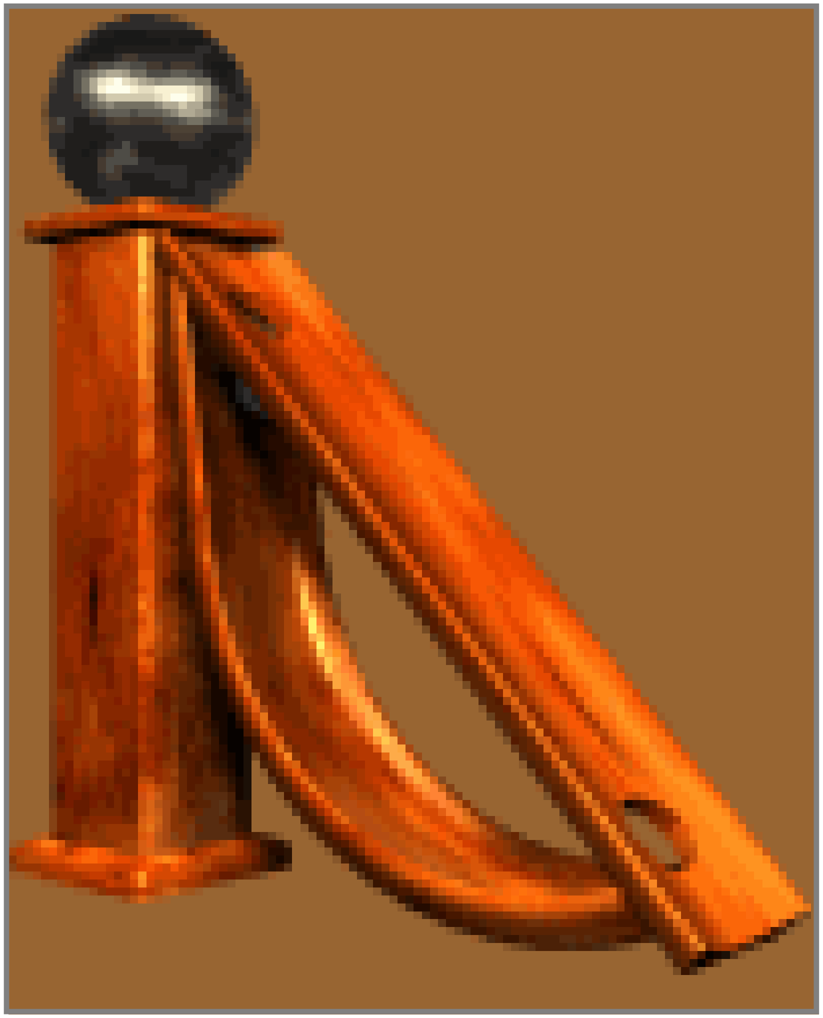


Challenges:

- Low emittance, high current creation
- Emittance preservation
- Beam stability at insertion devices
- Accelerator design
- Component properties, e.g. SRF



Accelerator Physics @ CESR



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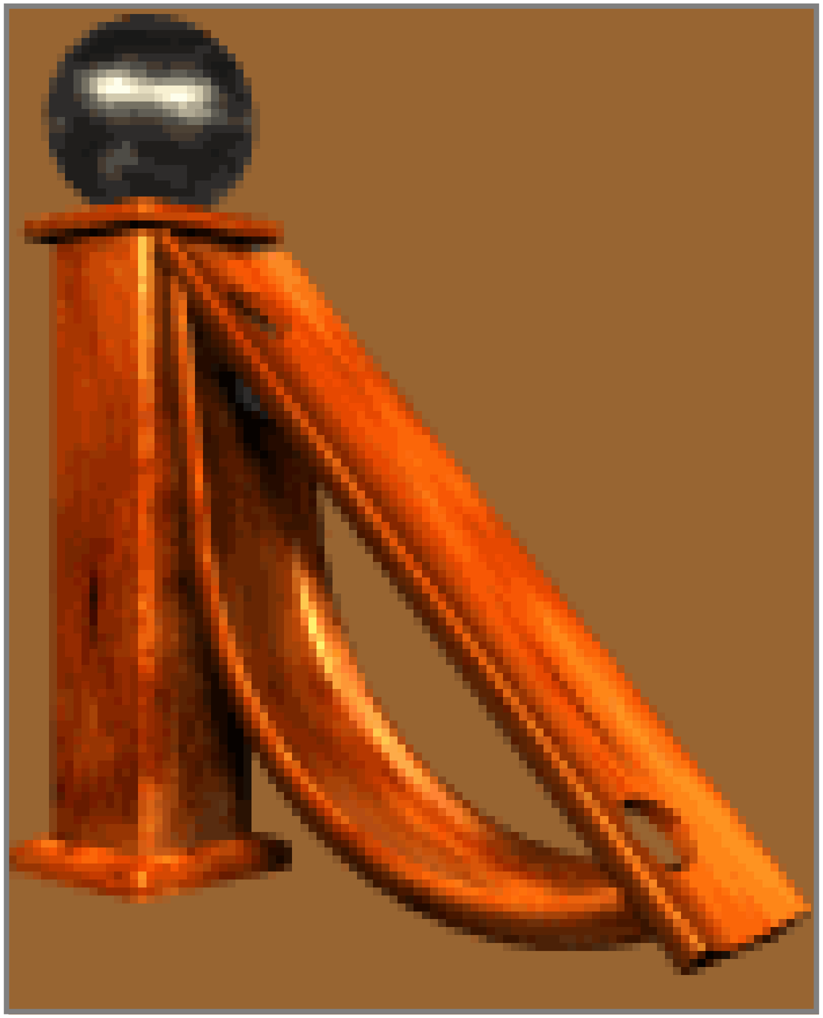
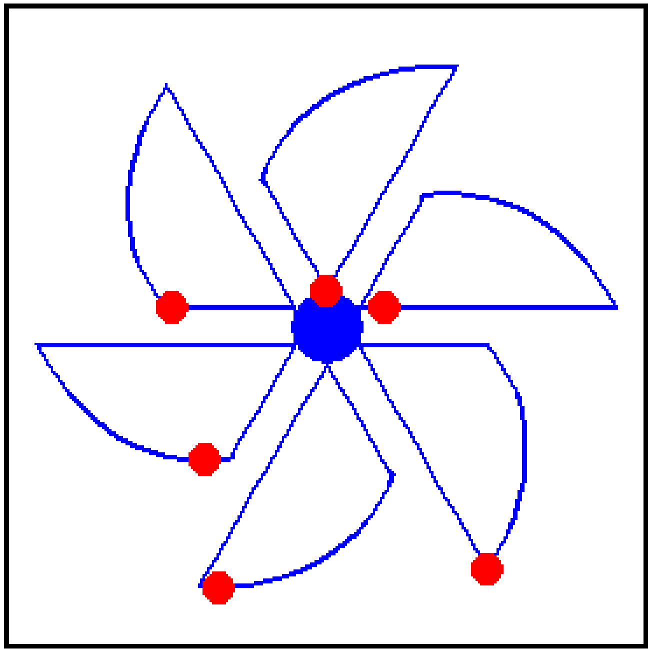
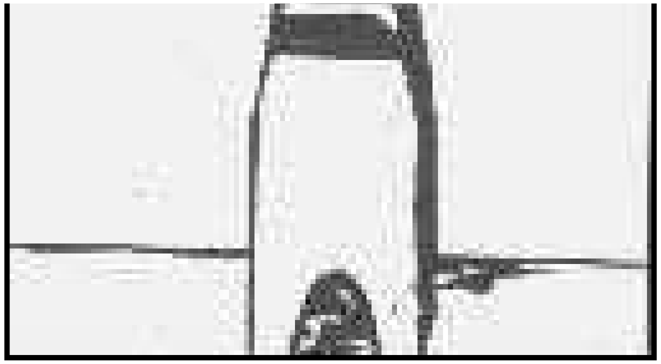
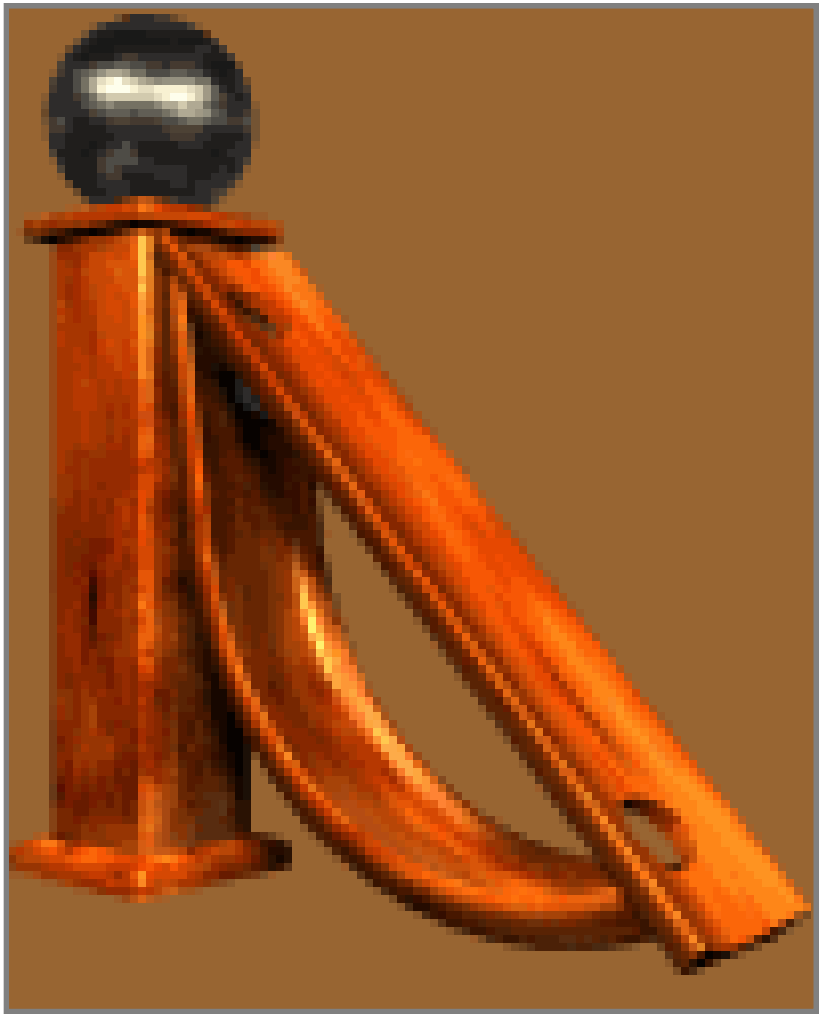


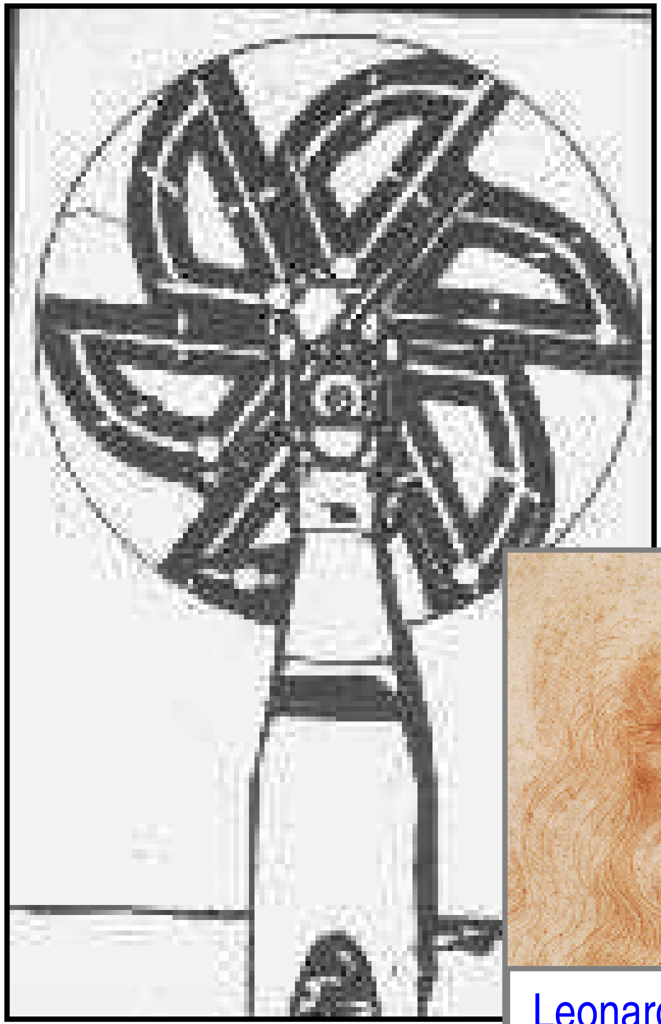




Accelerator Physics @ CESR

CHESS & LEPP

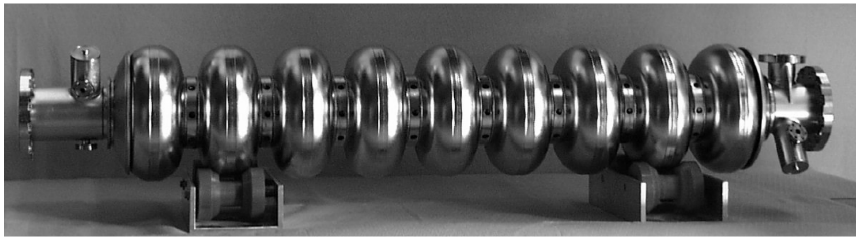




Leonardo da Vinci
(1452-1519)

Accelerator Physics @ CESR

CHESS & LEPP



$Q = 10^{10}$

$E = 20MV/m$

A bell with this Q would ring for a year.

- Very low wall losses.
- Therefore continuous operation is possible.
- Energy recovery becomes possible.

Normal conducting cavities

- Significant wall losses.
- Cannot operate continuously with appreciable fields.
- Energy recovery was therefore not possible.

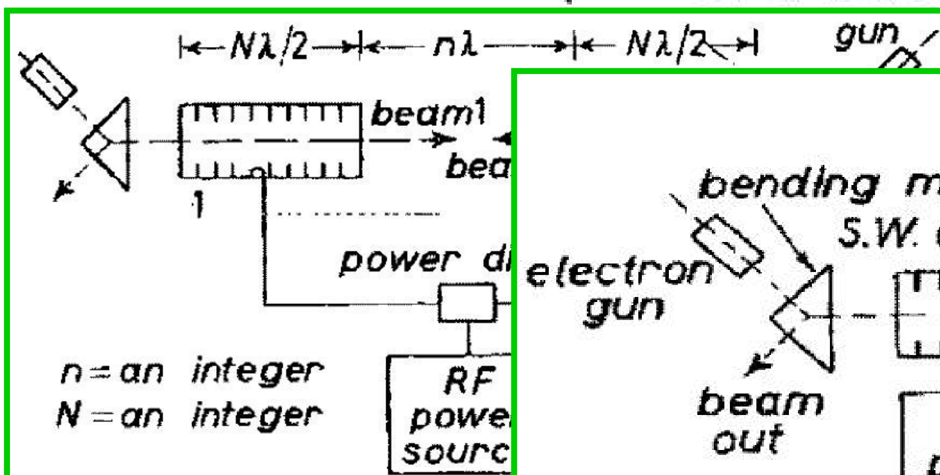
The ERL principle

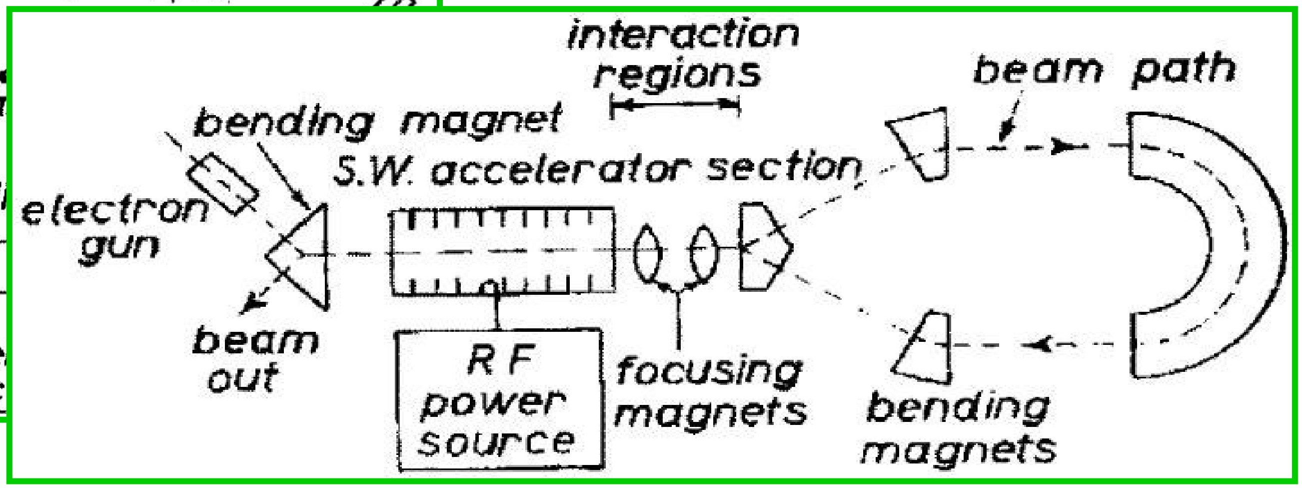
A Possible Apparatus for Electron Clashing-Beam Experiments (*).

M. TIGNER

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

(ricevuto il 2 Febbraio 1965)

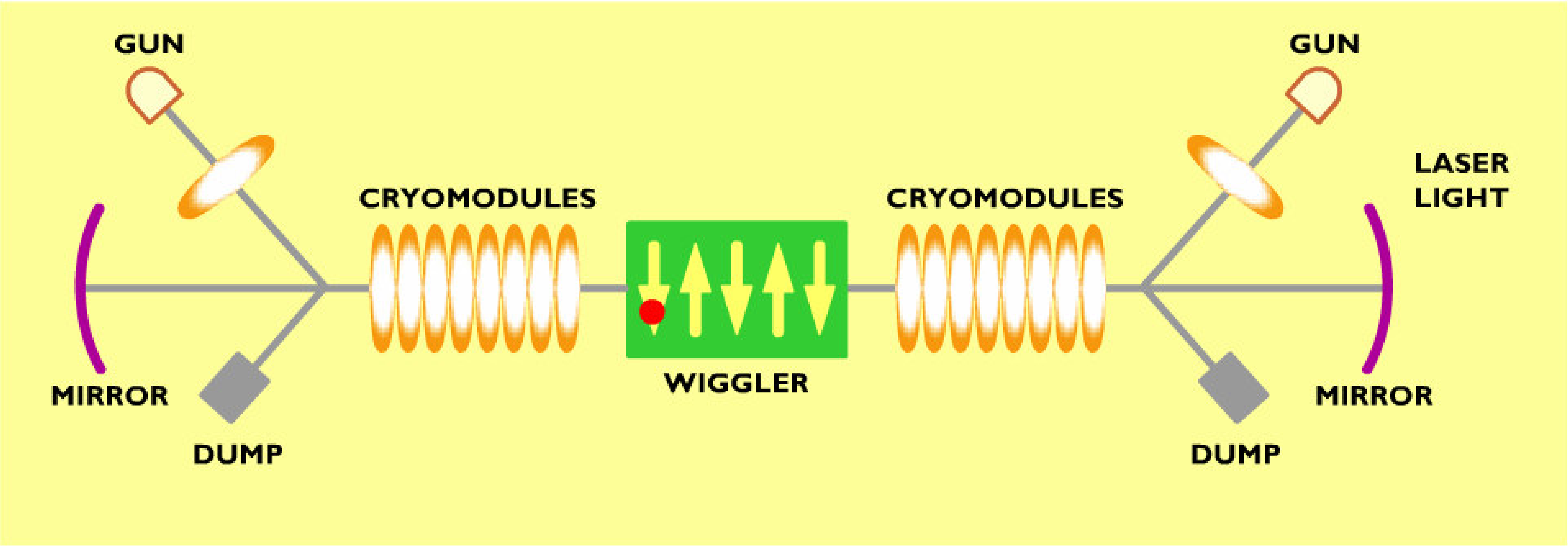




Energy recovery needs continuously fields in the RF structure

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

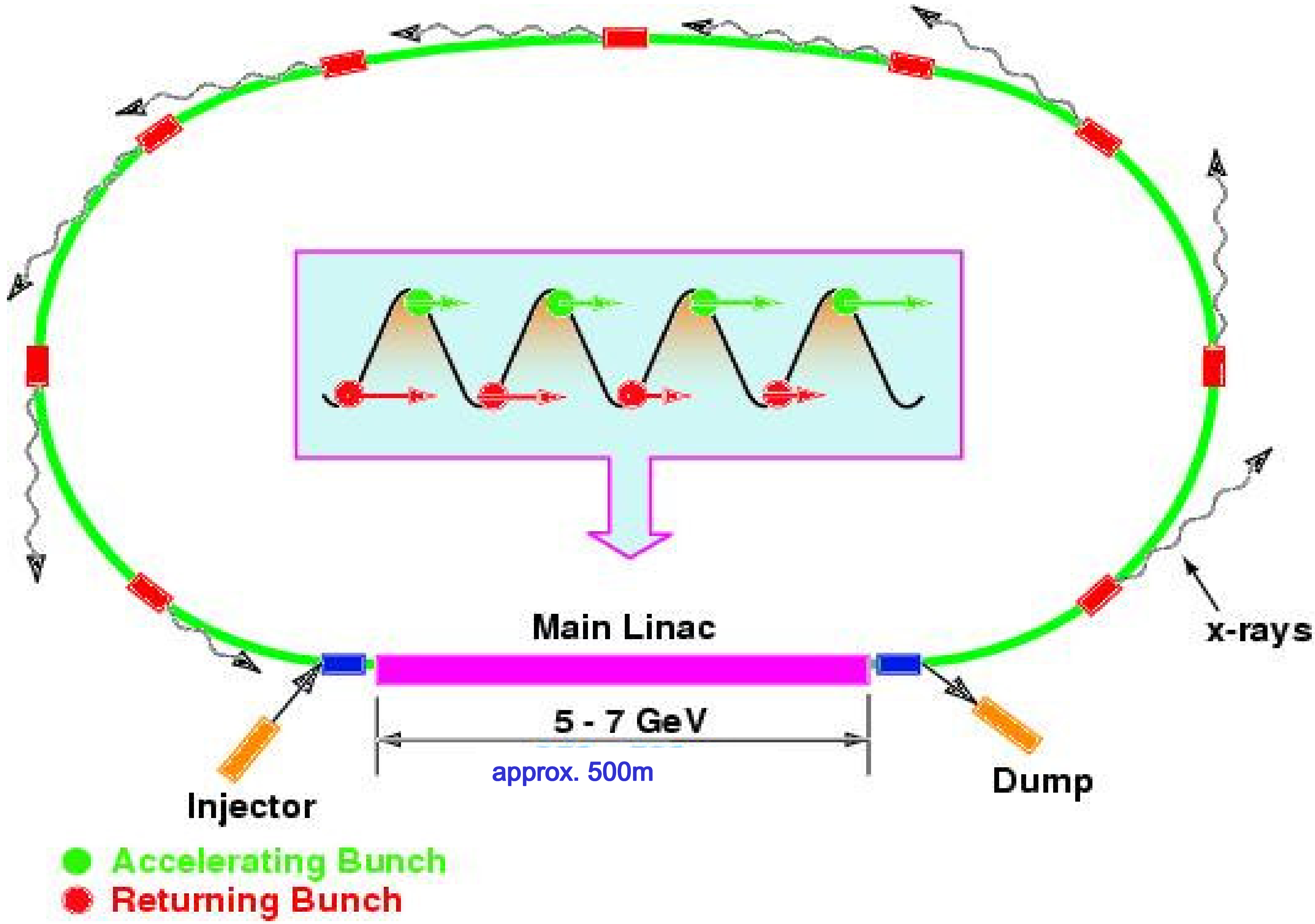
A push-pull ERL



Animation by Tom Oren

Layout options: Green field design

CHESS & LEPP



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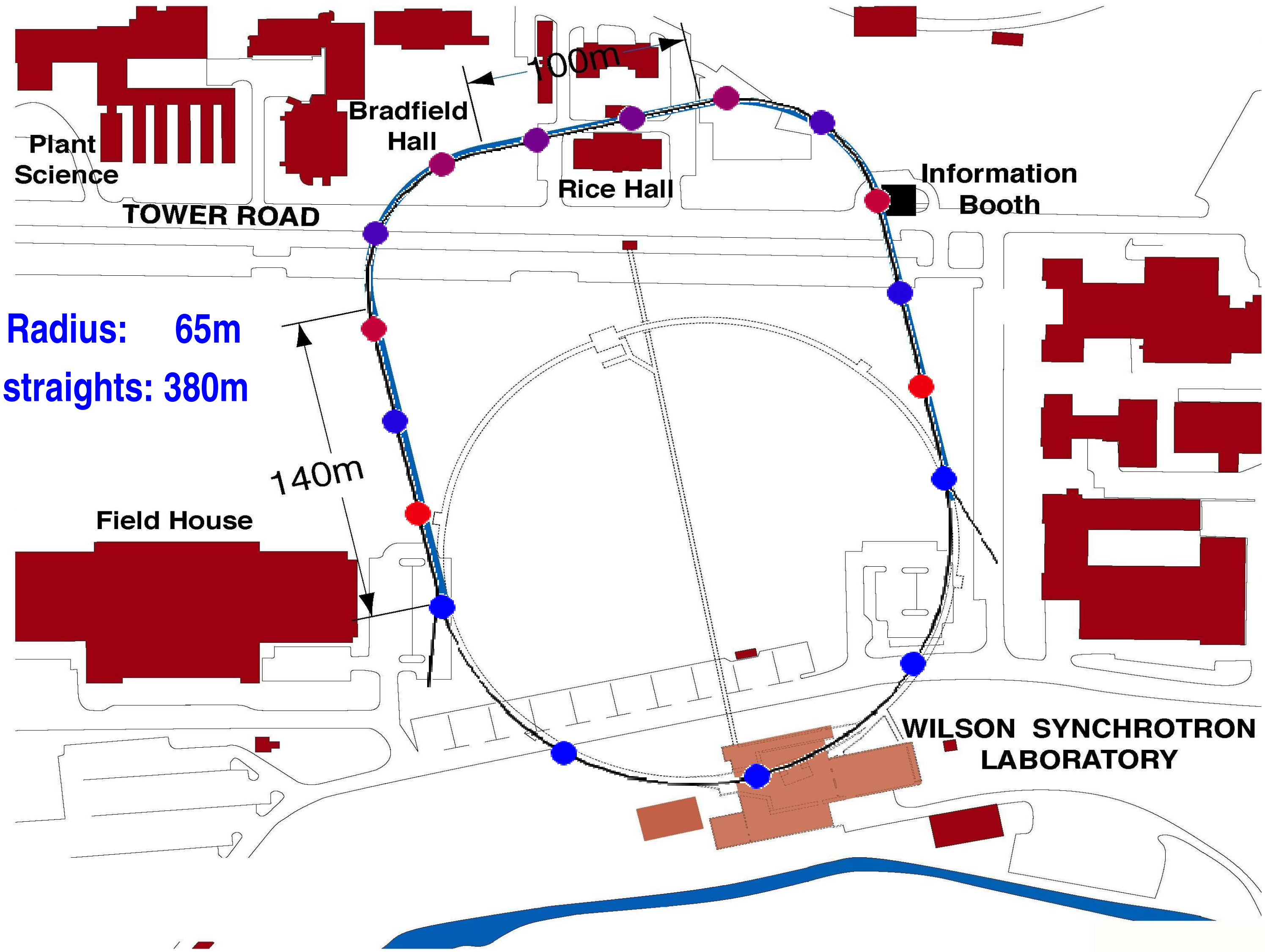
An ERL@CESR

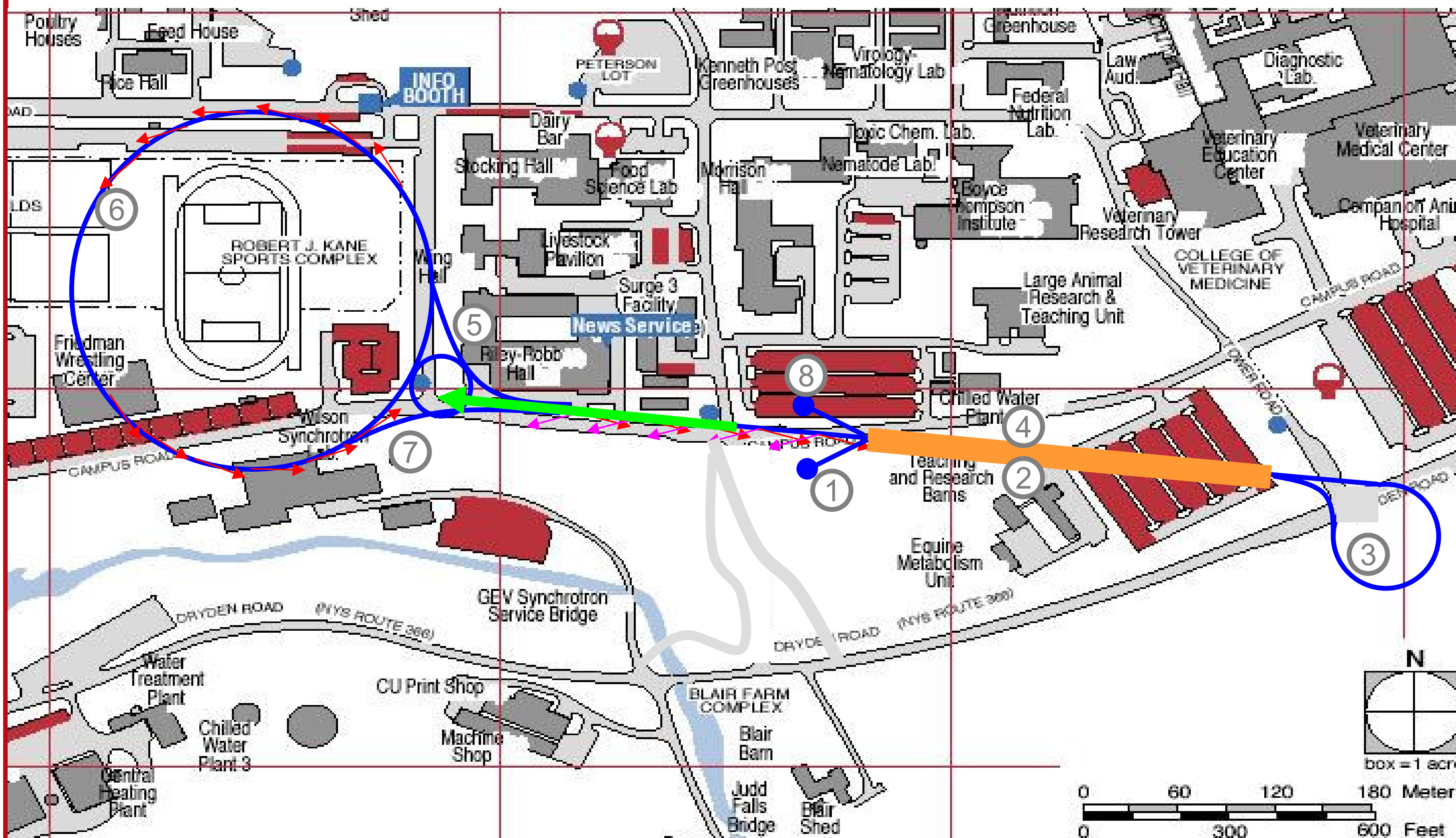
Bend Radius: 65m

Total straights: 380m



Smooth injection + commissioning loop

CHESS & LEPP

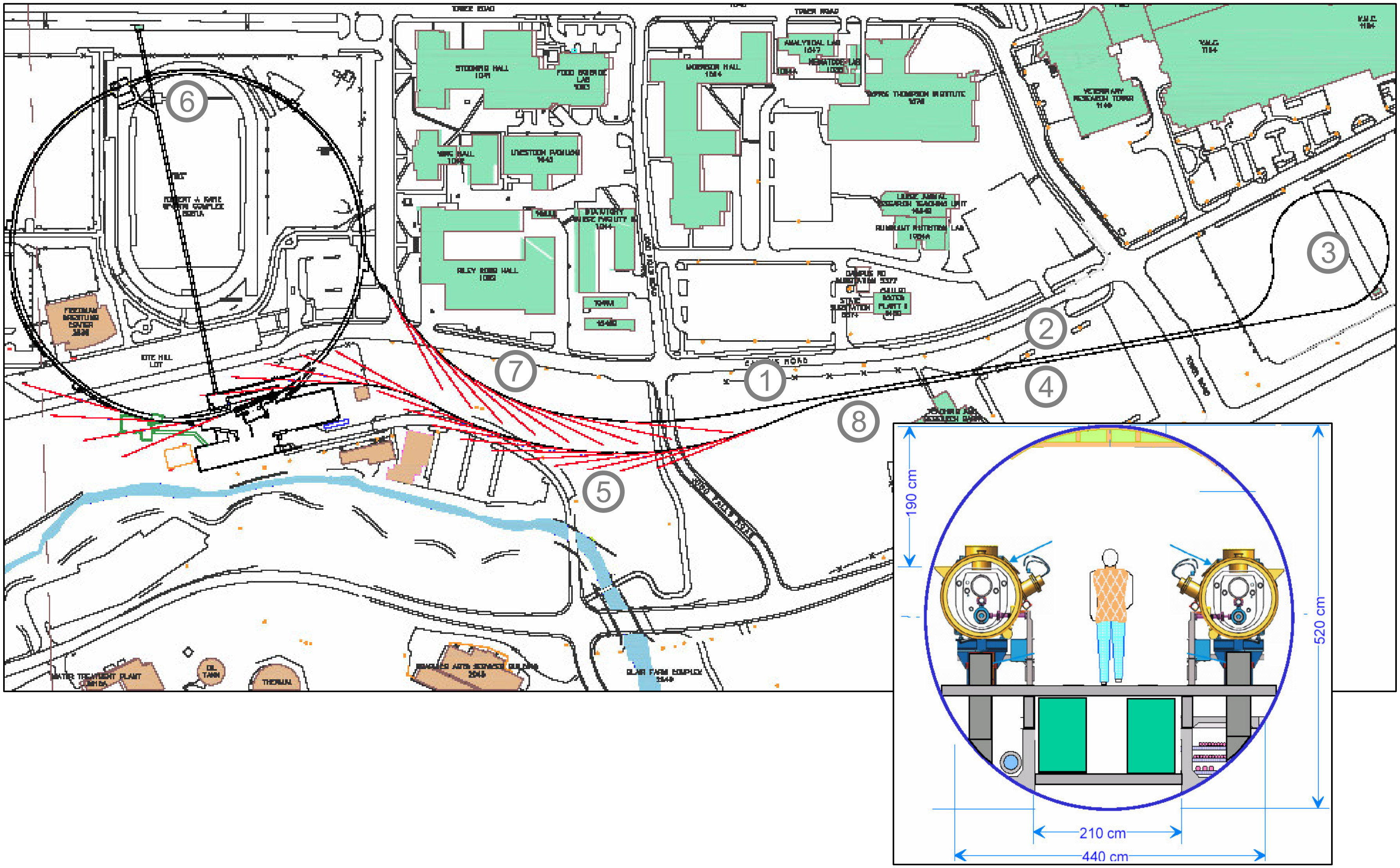


Advantages of ERL@CESR

- Operation of CESR and ERL test simultaneously.
- Use all of the CESR tunnel.
- Lots of space for undulators.
- Space for future upgrades, like an FEL.
- No basements of existing buildings to worry about.
- Only one tunnel for two linacs.
- Less competition, since other sights cannot offer upgrades.
- Example character for other existing light sources.

ERL@CESR design version 1.3

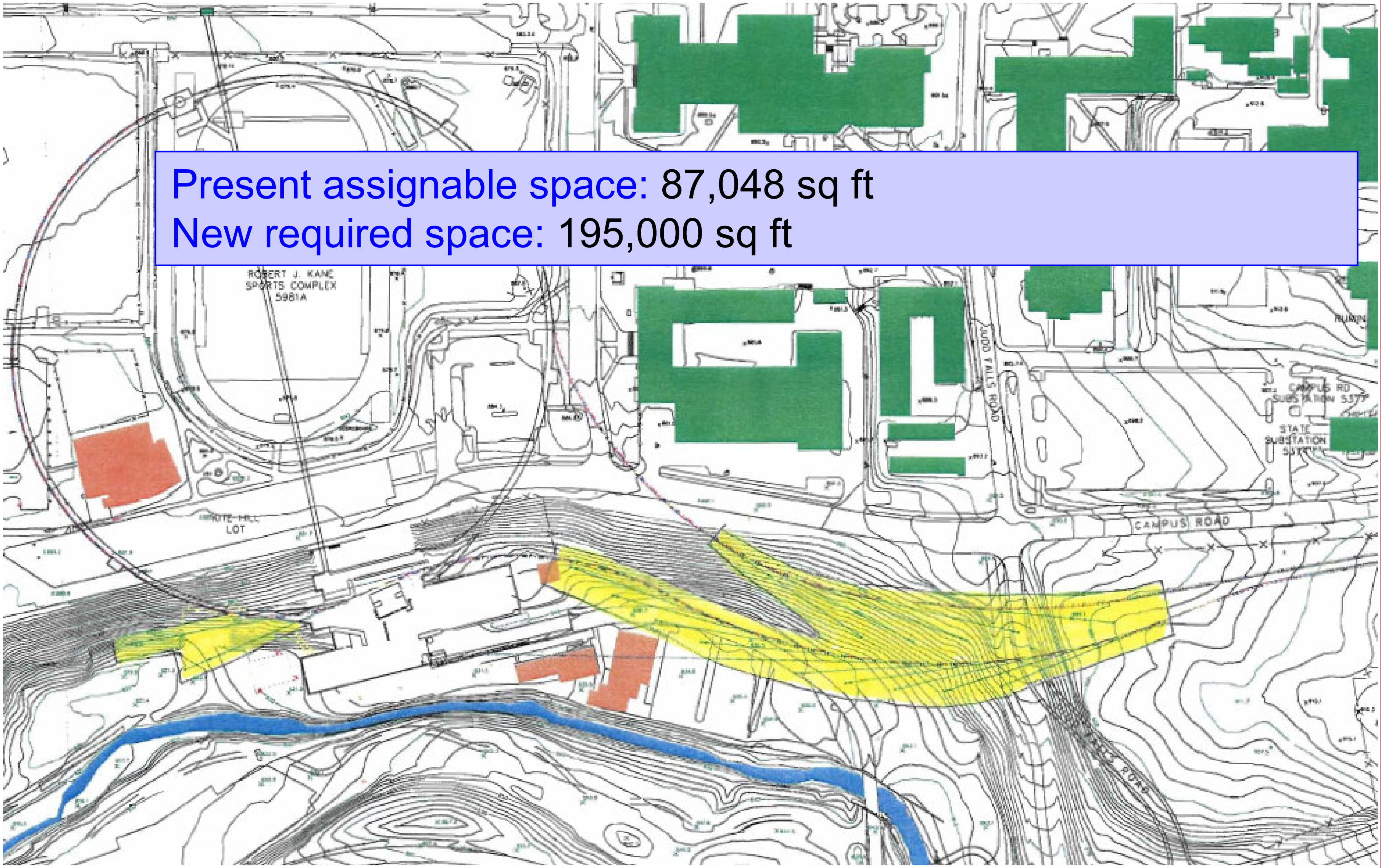
CHESS & LEPP



Space requirements

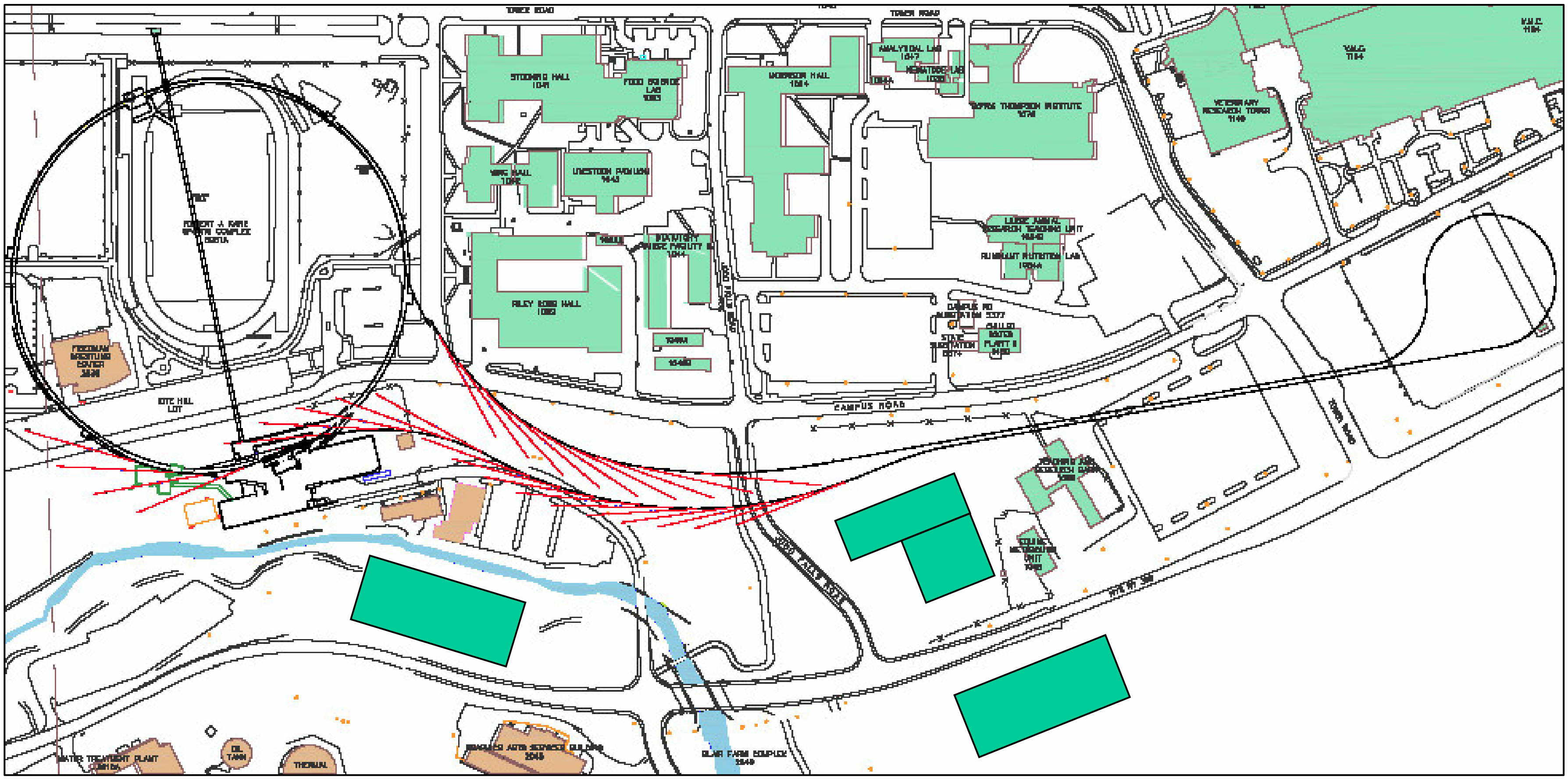
CHESS & LEPP

Present assignable space: 87,048 sq ft
New required space: 195,000 sq ft



Cryogenic building

Two designs: 25 X 55 X 7m and 35 X 65 X 12m



Beam requirement

CHESS & LEPP

Beam transport – Beam stabilization – Component damage

In undulators:

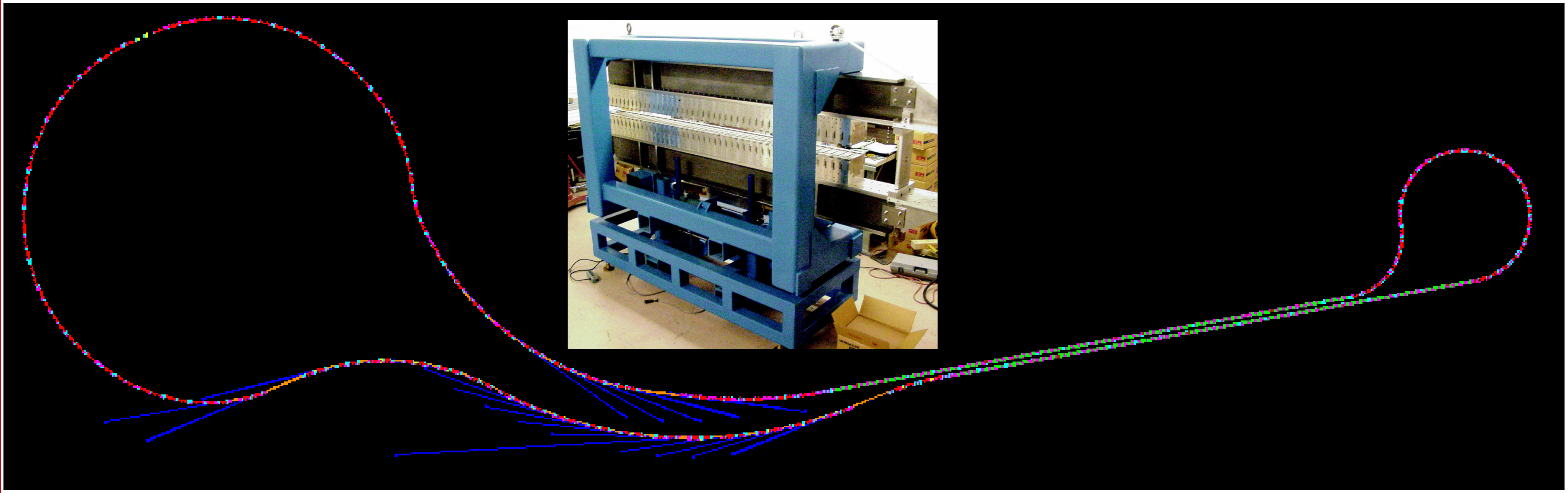
- Specified small emittances in 6D
- Specified high current
- Specified beam size and divergence
- Specified beam direction
- Limited radiation and particle loss background
- All of these stable at all times

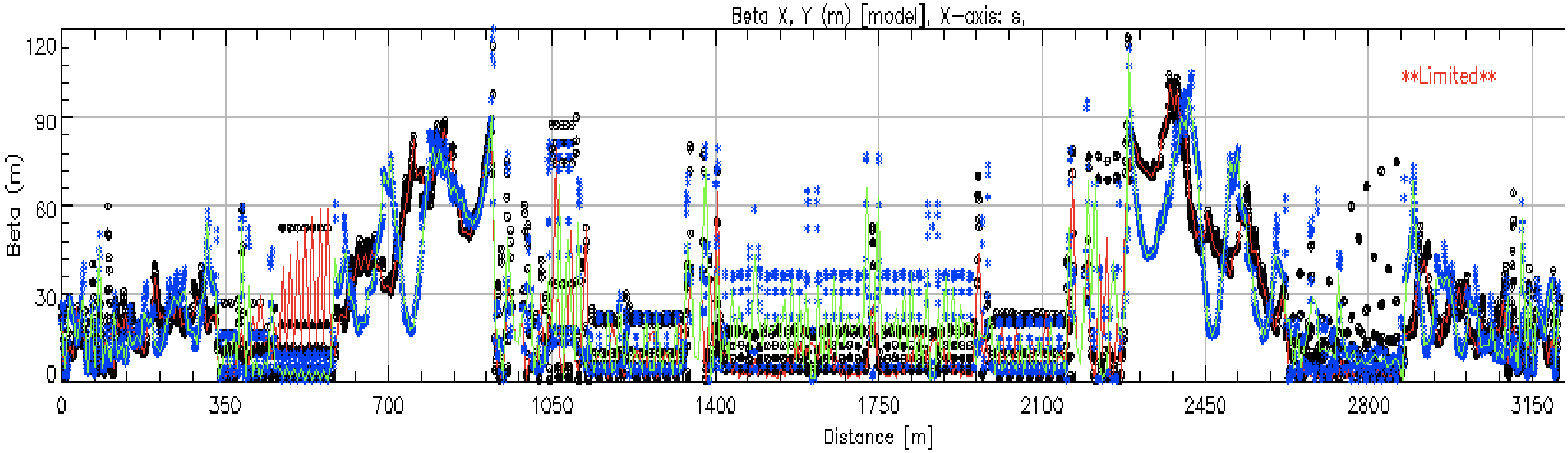
In all components:

- Limited HOM heating
- Limited synchrotron radiation heating
- Limited beam loss heating and radiation

Linear Optics (A – high brilliance)

CHESS & LEPP





Lasing at JLAB with the ERL-FEL

CHESS & LEPP

Wiggler gap

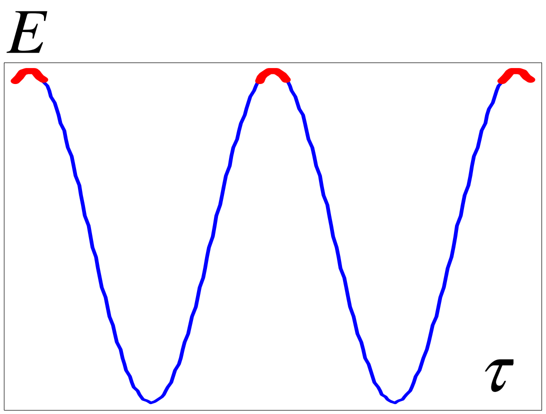
Hole Outcoupler

High Reflector

Beam in control room

CHESS & LEPP

Linear Optics (C – short pulse)



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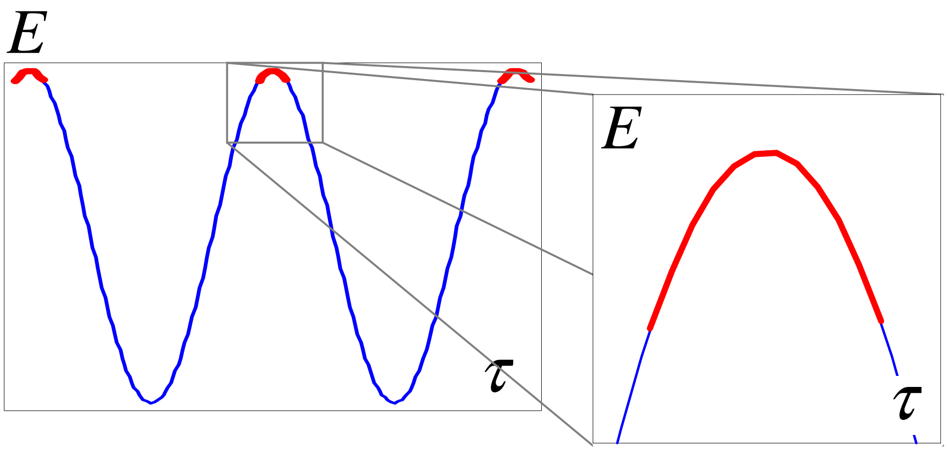
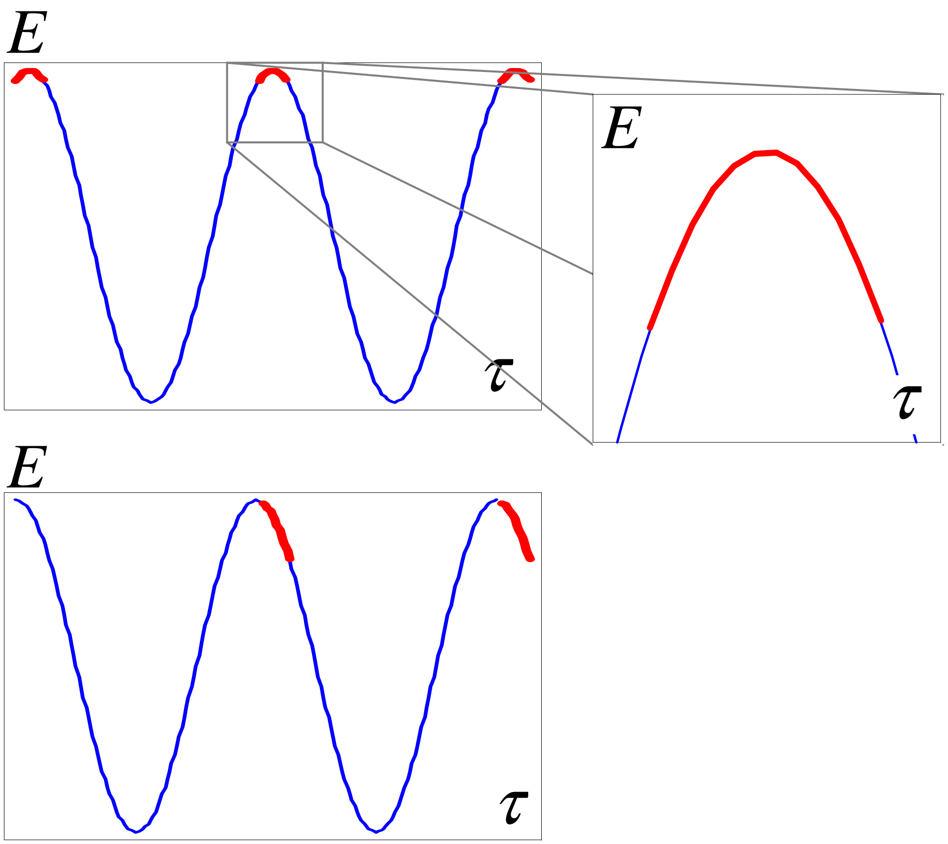


- On crest acceleration leads to long Bunches with small energy spread.

Linear Optics (C – short pulse)



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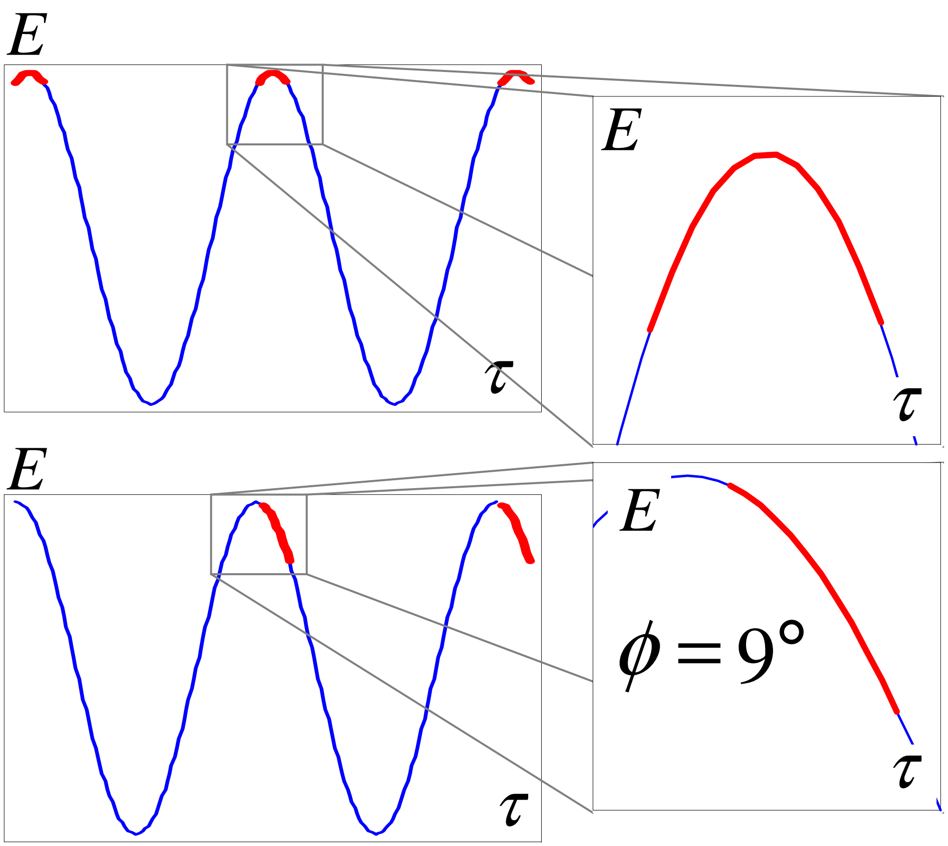

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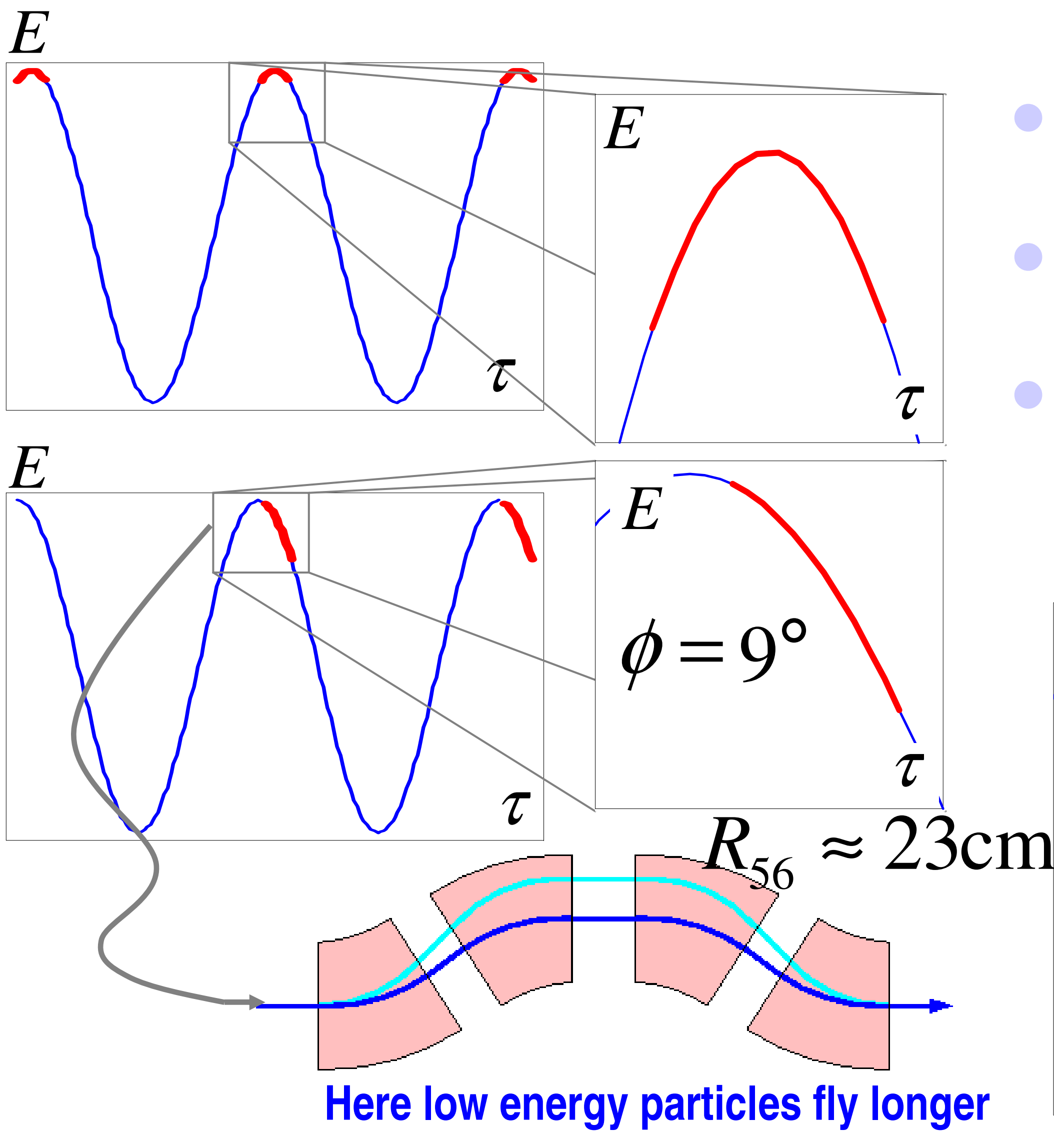
Linear Optics (C – short pulse)

CHESS & LEPP



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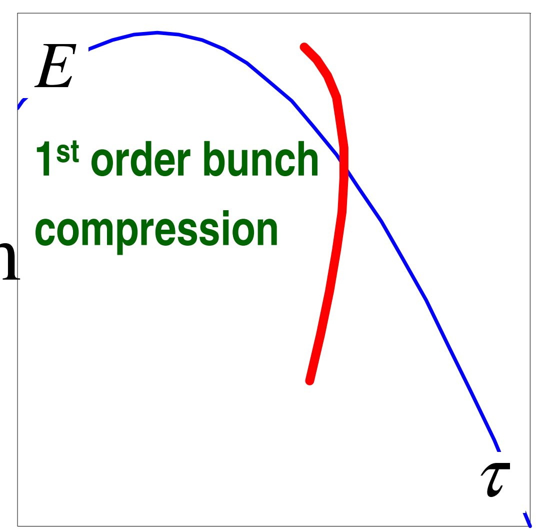
- The bunch length can be made even shorter by nonlinear optics



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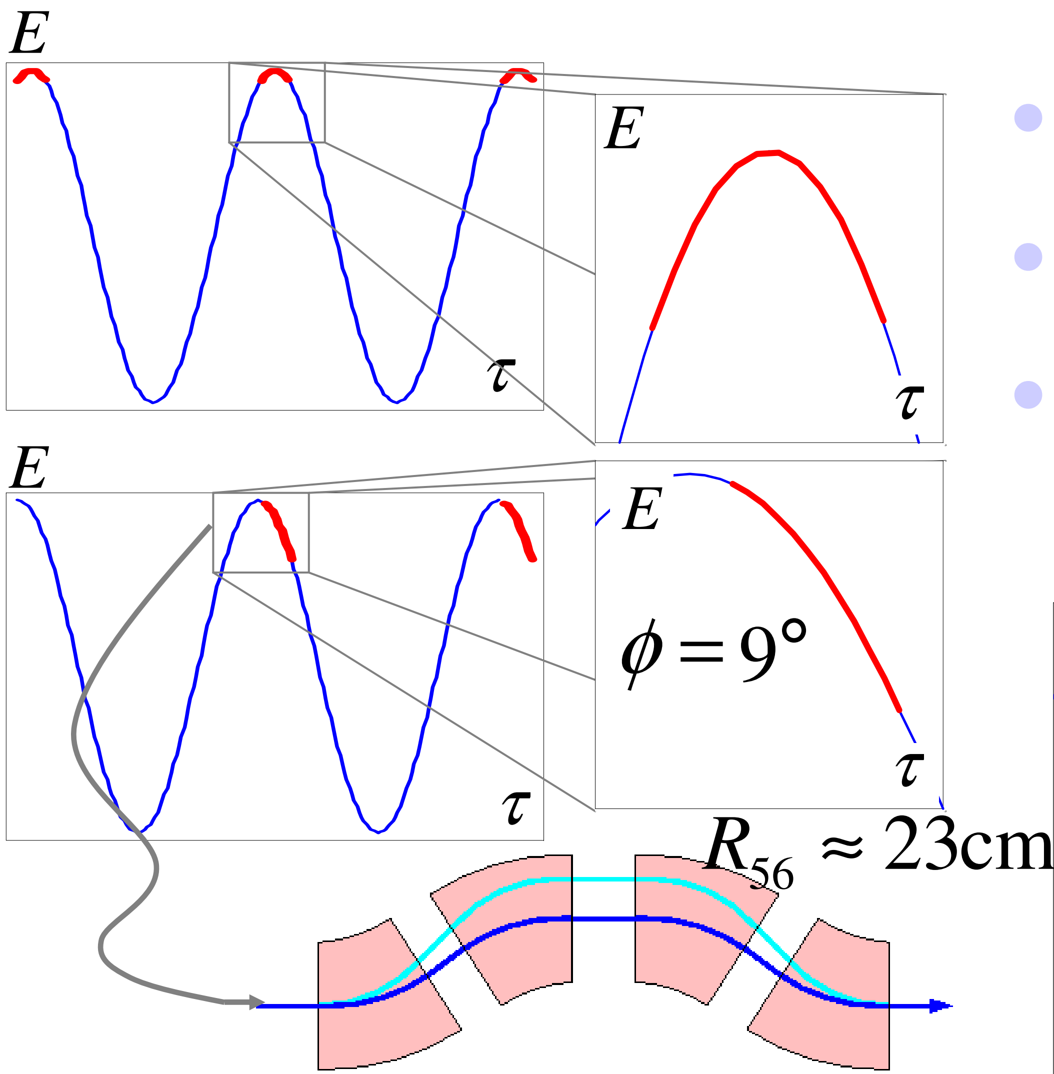

Here low energy particles fly longer

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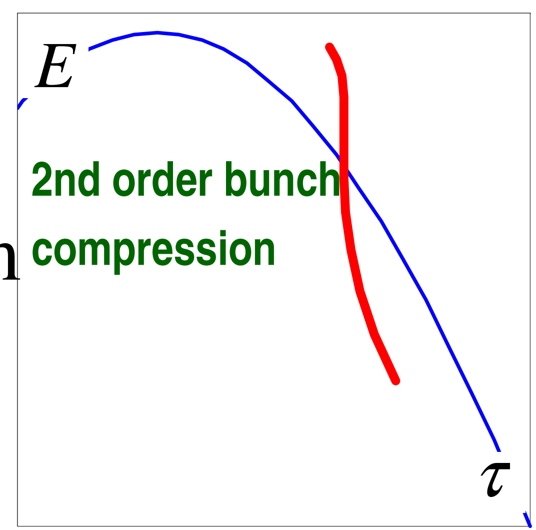

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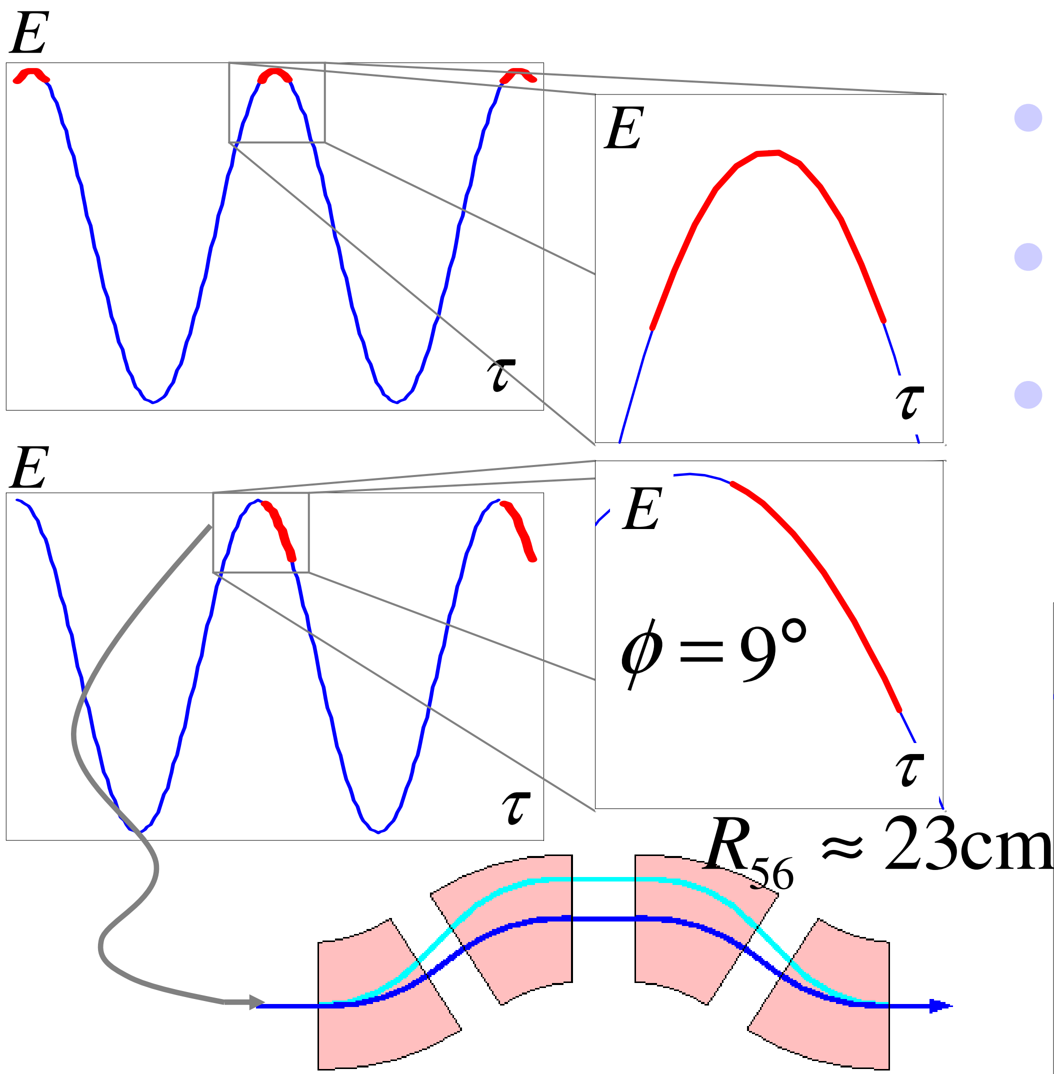

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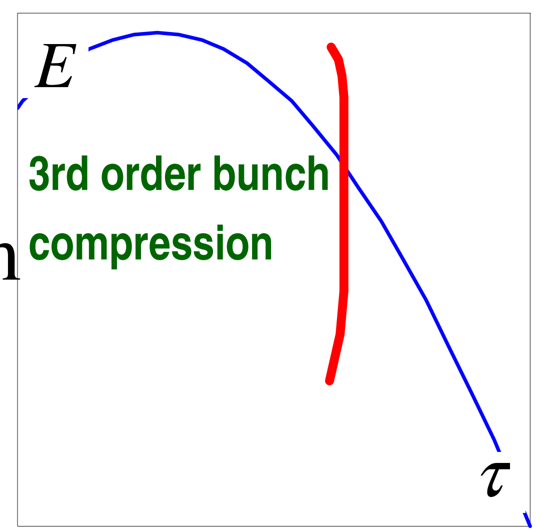
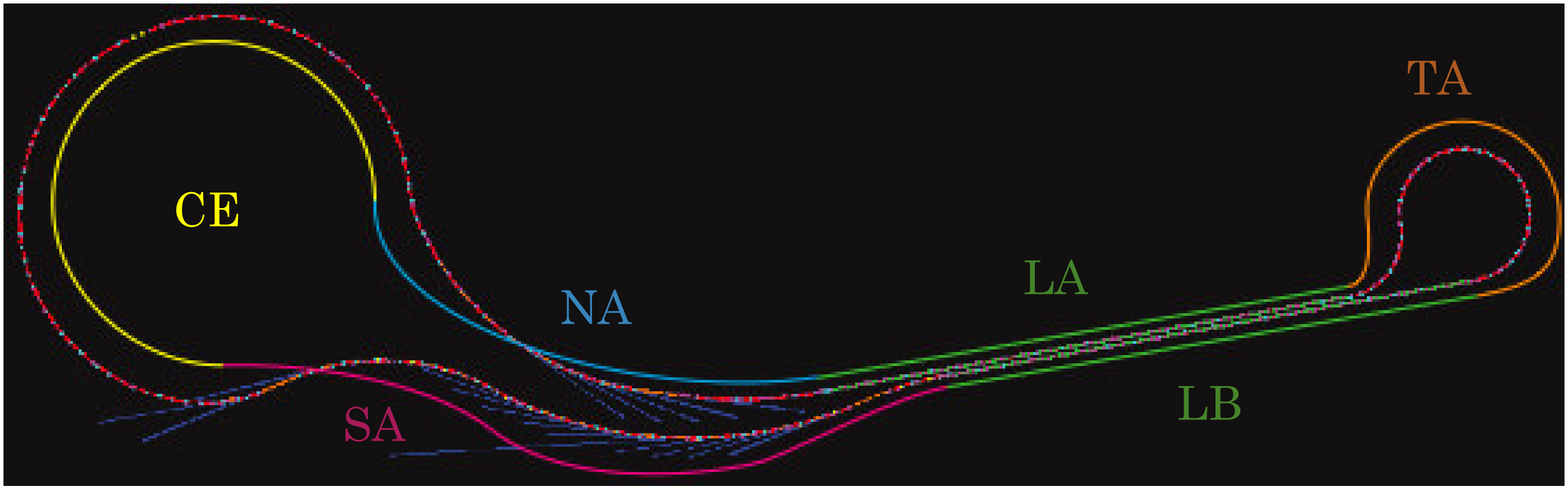


Incoherent Synchrotron Radiation (ISR)

CHESS & LEPP



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LB
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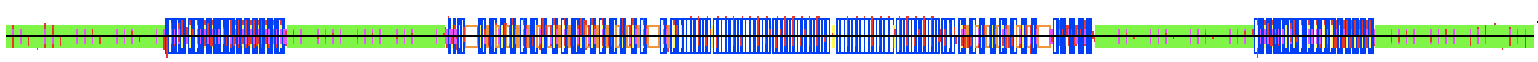
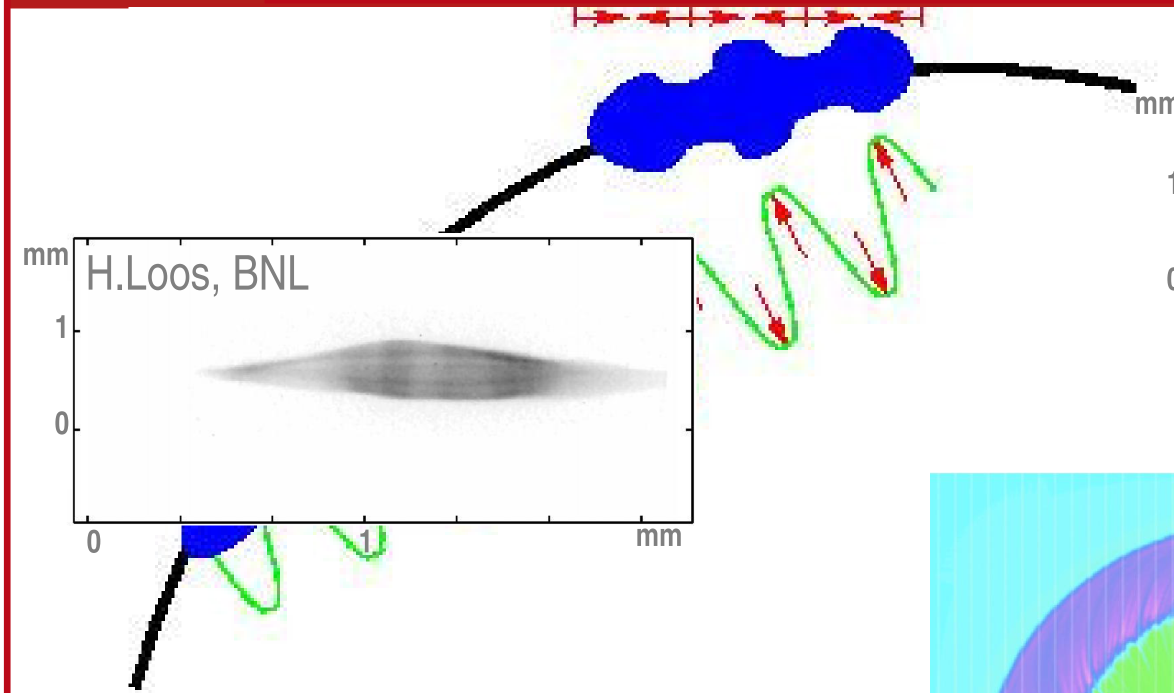
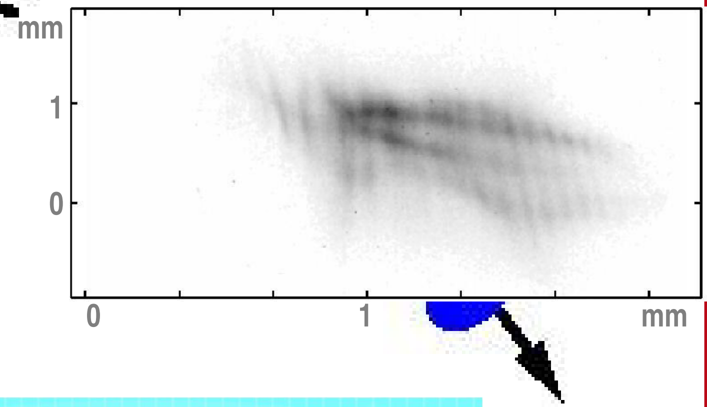
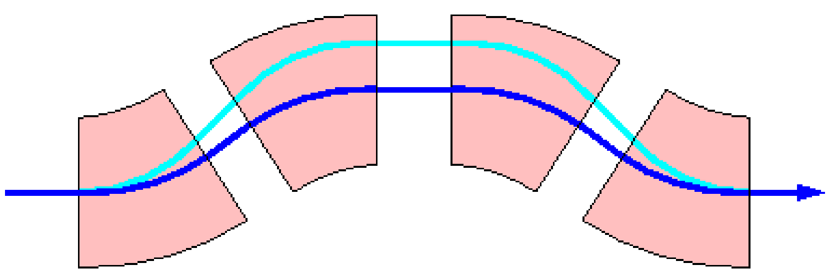


Coherent Synchrotron Radiation

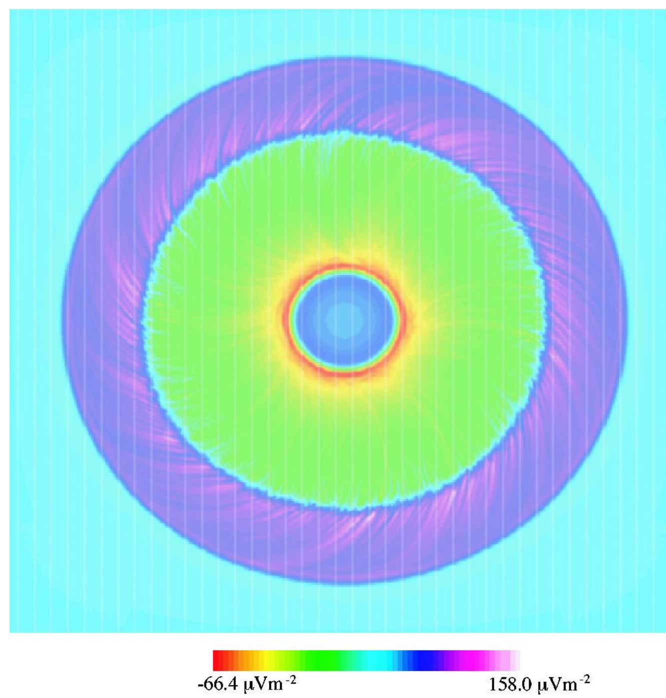
CHESS & LEPP







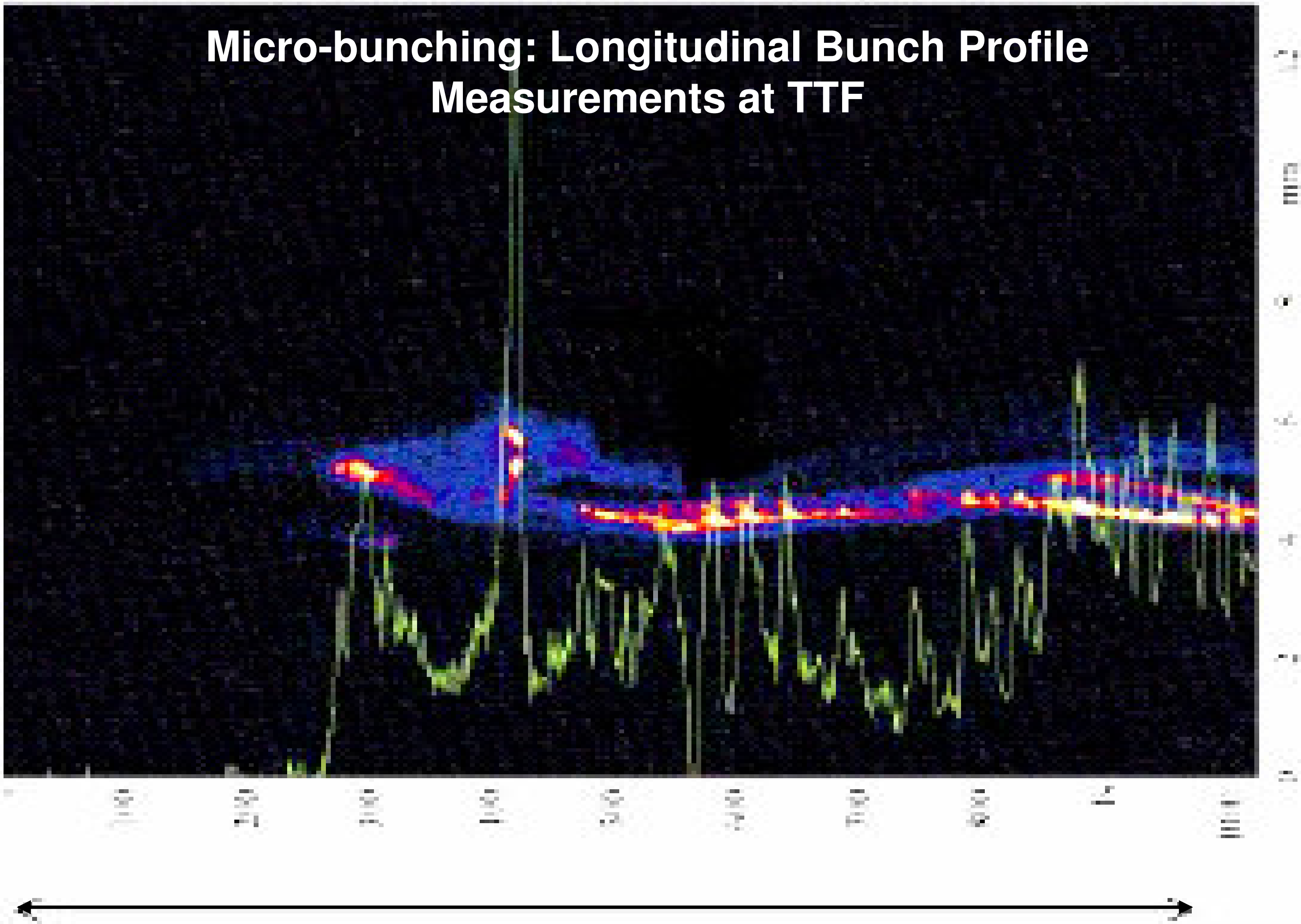
Bunch compressor in an ERL



courtesy Bjoern Schmekel

Microbunching due to CSR

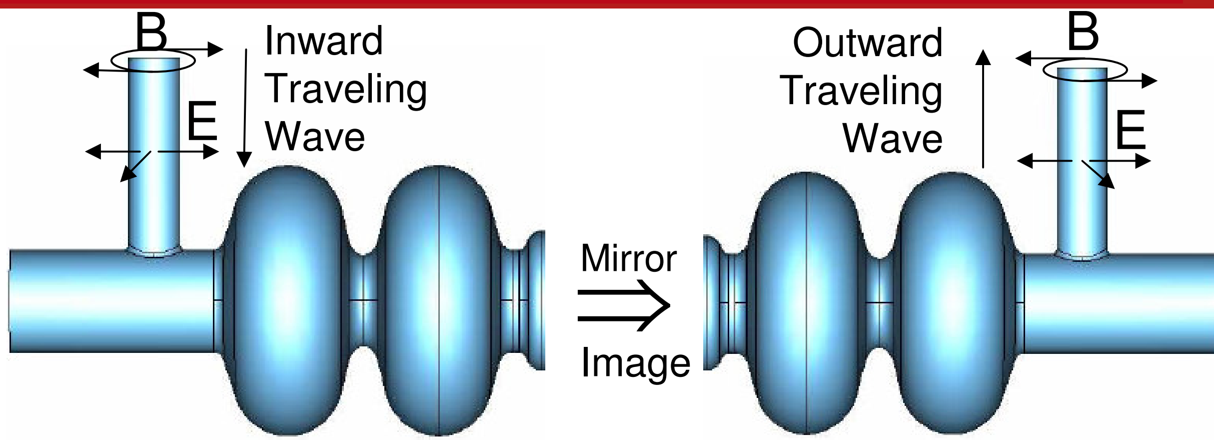
CHESS & LEPP



1 picosecond

Coupler kicks

CHESS & LEPP

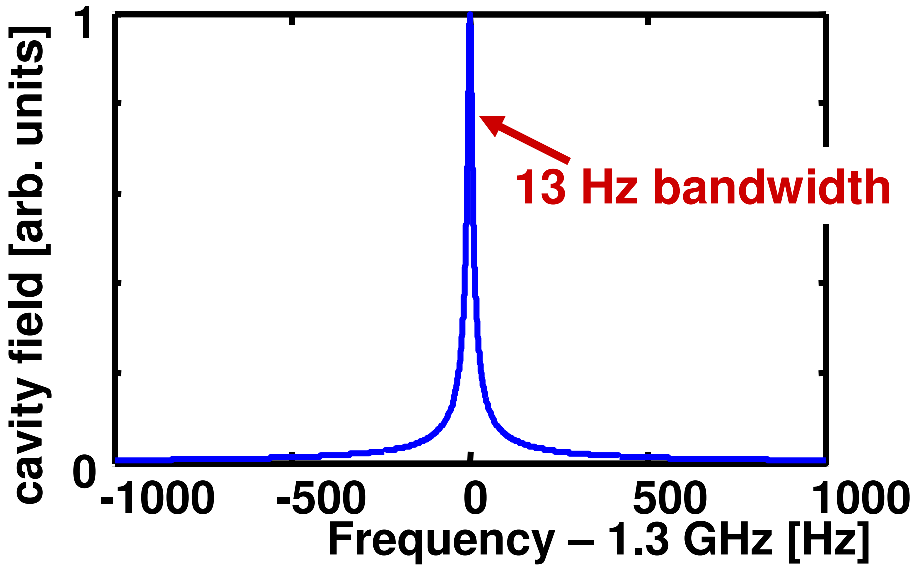


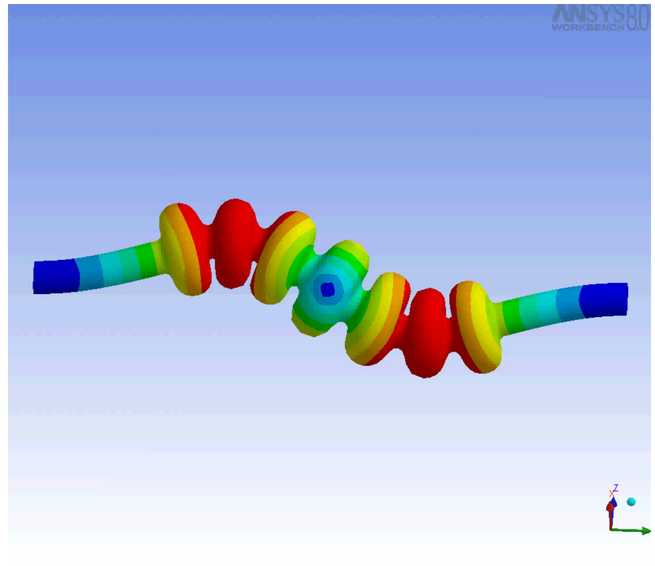
Q_{ext}	Position of Coupler	coupler_strength	coupler_phase (rad/2π)
2×10^7	entrance	1.0002857×10^{-4}	.32307
2×10^7	exit	1.0022857×10^{-4}	-.31351
1×10^8	entrance	1.00857×10^{-4}	.321436
1×10^8	exit	1.0277143×10^{-4}	-.31922

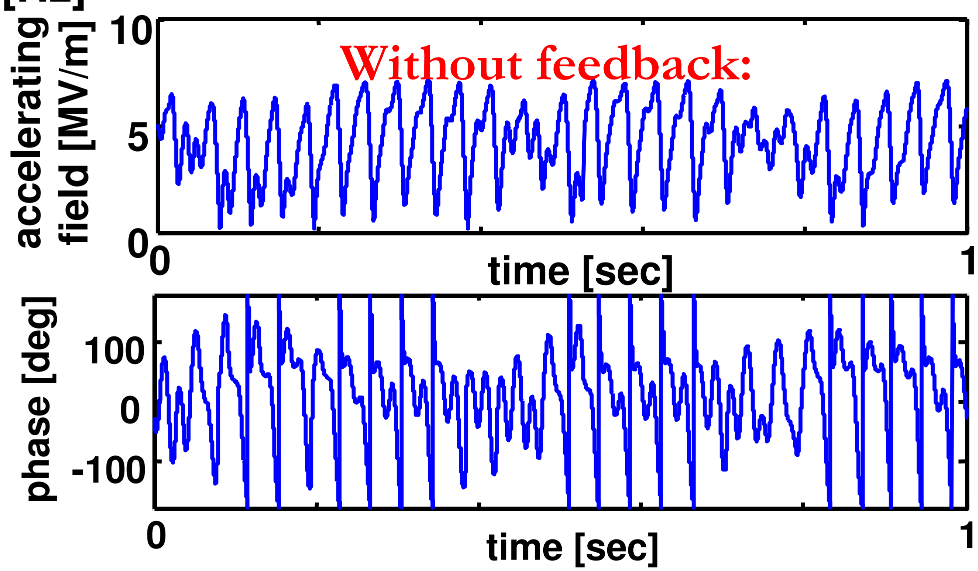
Emittance growth	Phase not minimized		Phase minimized	
	$Q_{ext} = 2 \times 10^7$	$Q_{ext} = 1 \times 10^8$	$Q_{ext} = 2 \times 10^7$	$Q_{ext} = 1 \times 10^8$
No Couplers	0.9%	0.9%	0.9%	0.9%
Onesided	1.39%	1.40%	0.97%	0.95%
Alternating Cavities	43.07%	43.92%	0.95%	0.93%
Alternating Cryomodules	1.13%	1.13%	0.96%	0.95%

Cavity control for SC linacs (ERL & ILC)

CHESS & LEPP

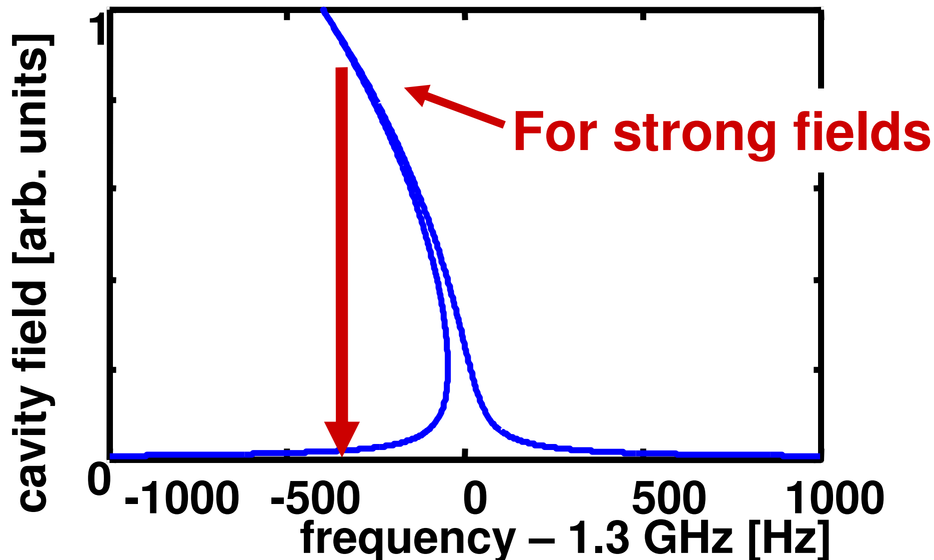


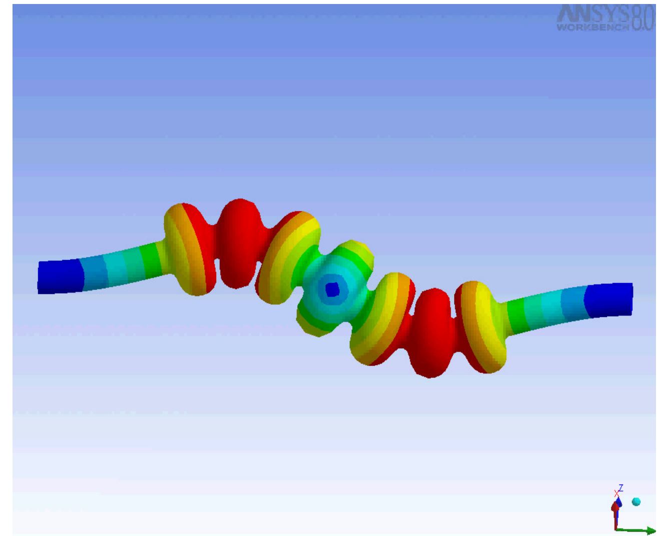




- Run cavity with lowest possible bandwidth for ERL.
- But frequency stabilization becomes very critical.

Cavity control for SC linacs (ERL & ILC)





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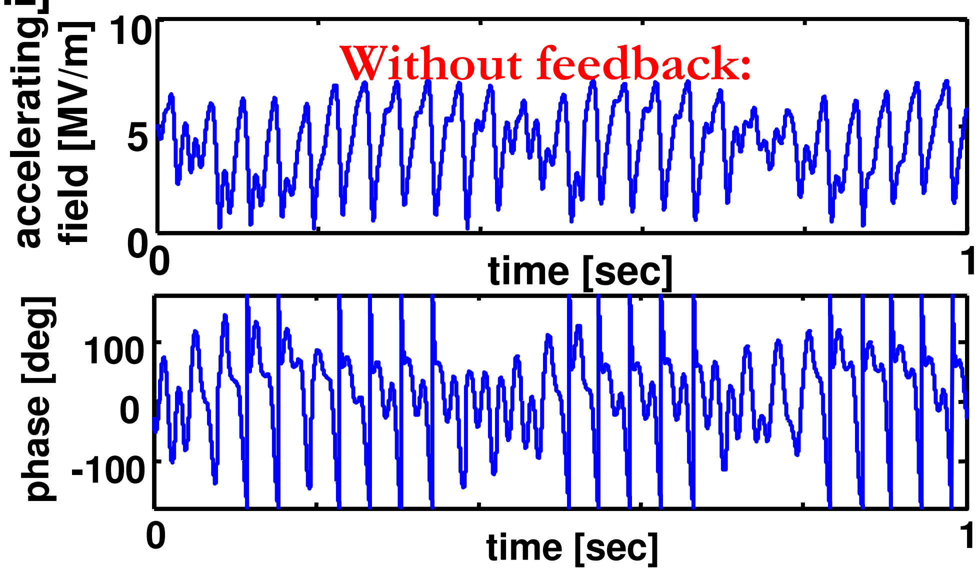
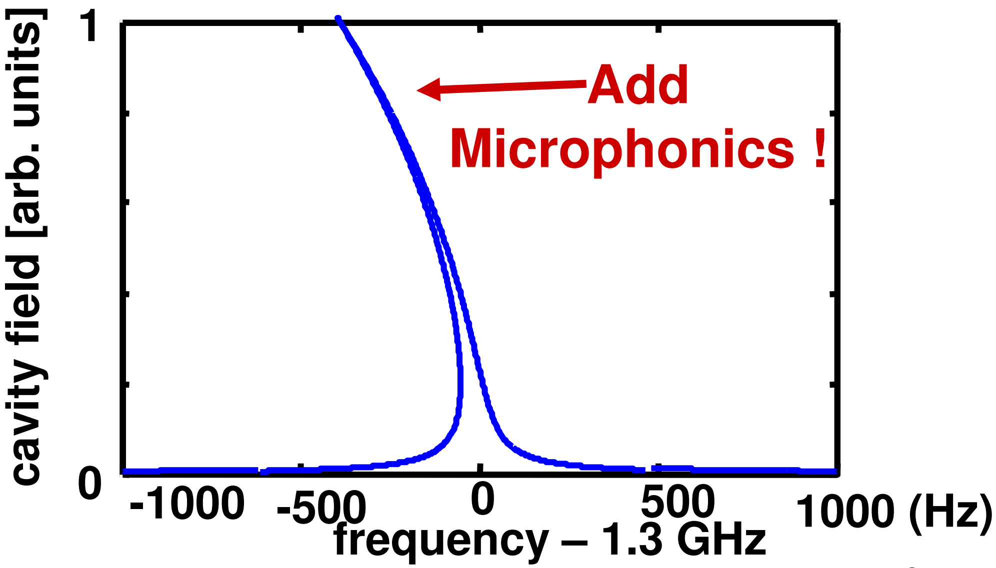
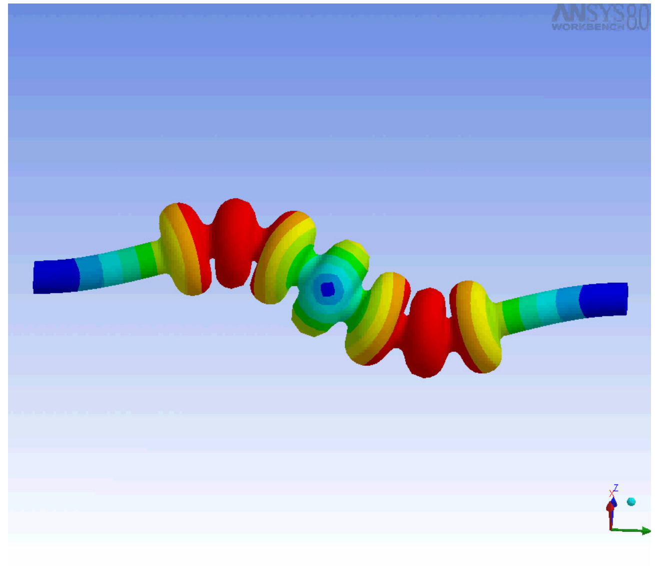
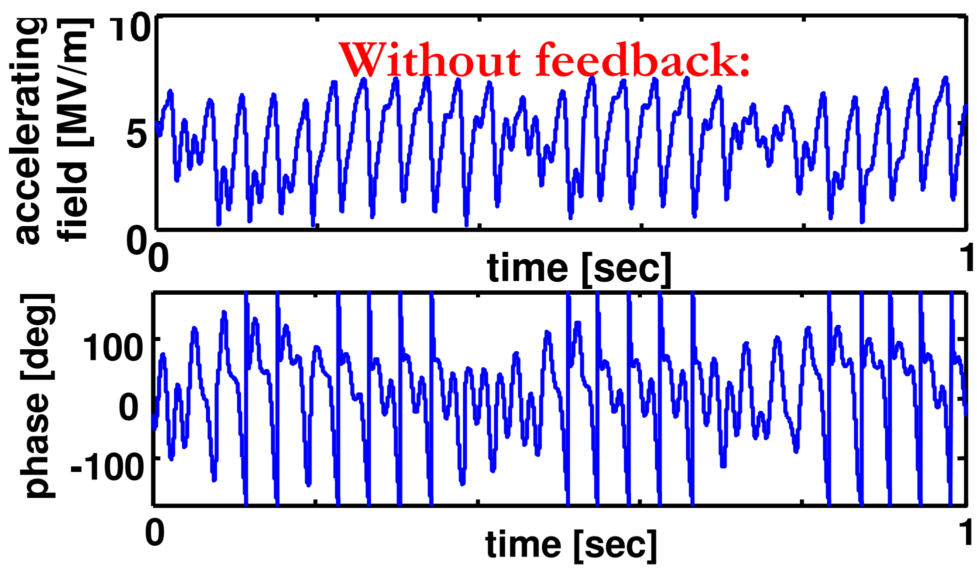


Cavity control for SC linacs (ERL & ILC)

CHESS & LEPP



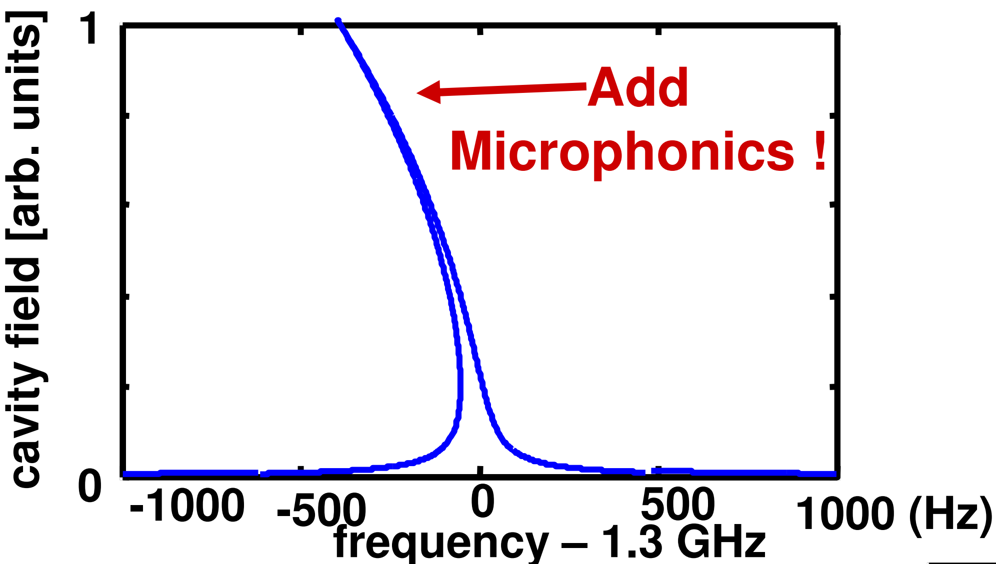


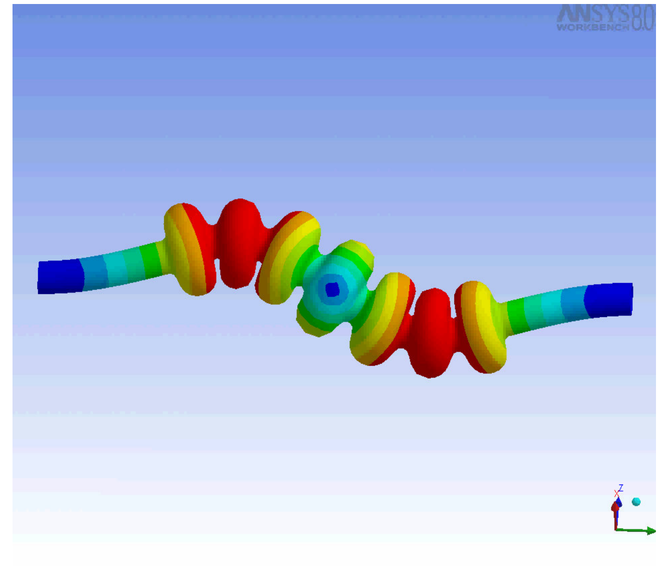


- Run cavity with lowest possible bandwidth for ERL.
- But frequency stabilization becomes very critical.

Cavity control for SC linacs (ERL & ILC)

CHESS & LEPP





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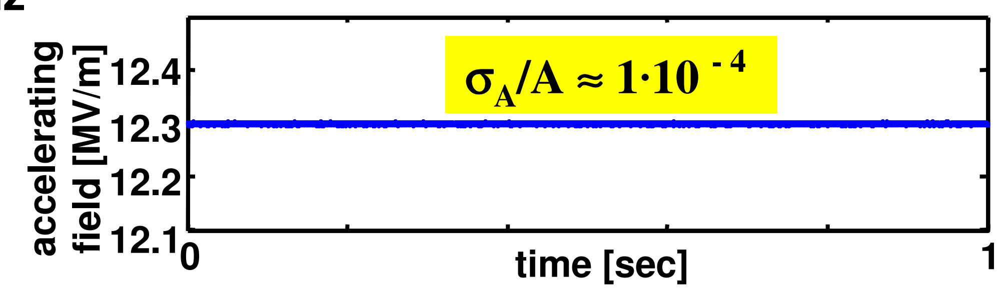
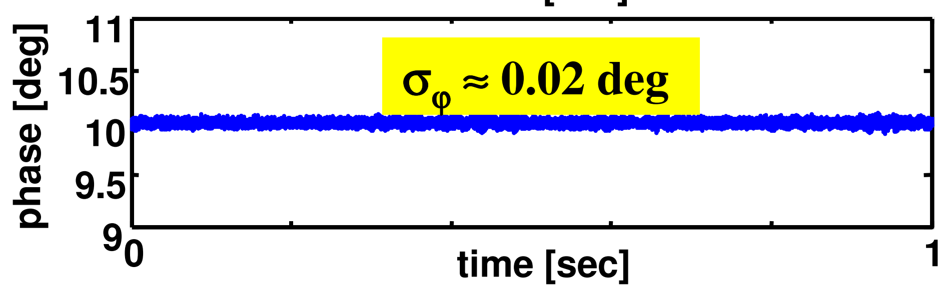
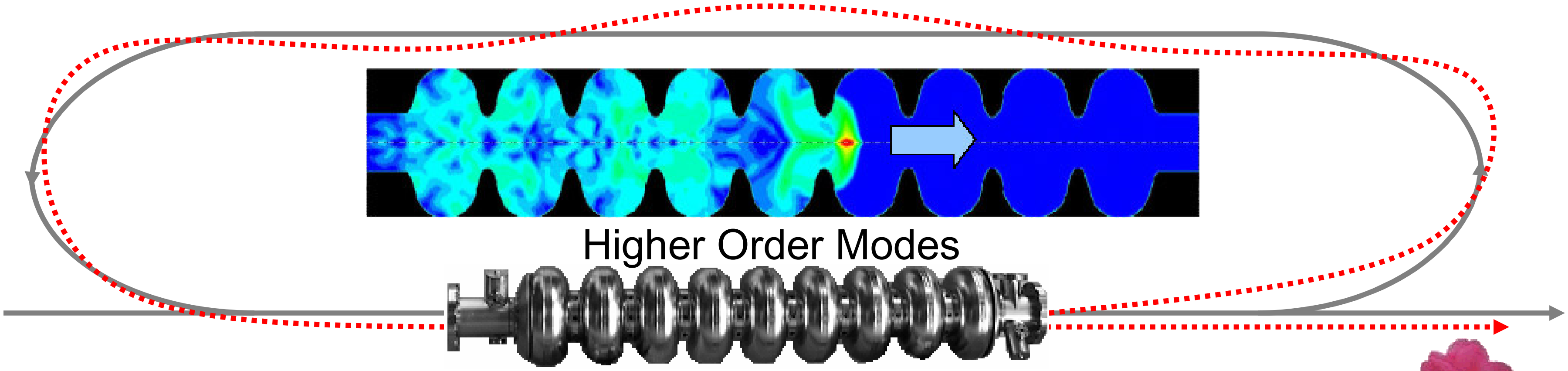




BBU: Collective Instabilities



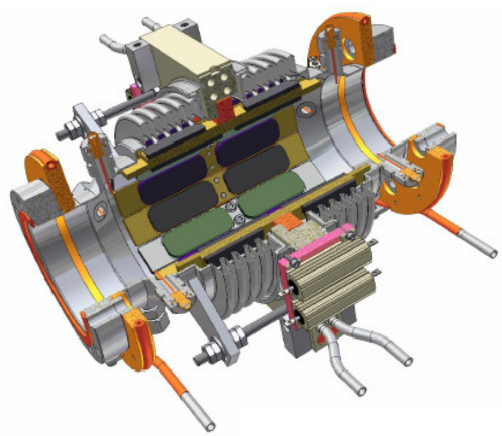
$$V_x(t) = T_{12}\,\tfrac{e}{c}\int_{-\infty}^{t} W_x(t-t')V_x(t'-t_r)I(t')dt'$$

- Similar instabilities would occur in the Linear Collider

HOM absorbers a la Cornell

CHESS & LEPP

From design

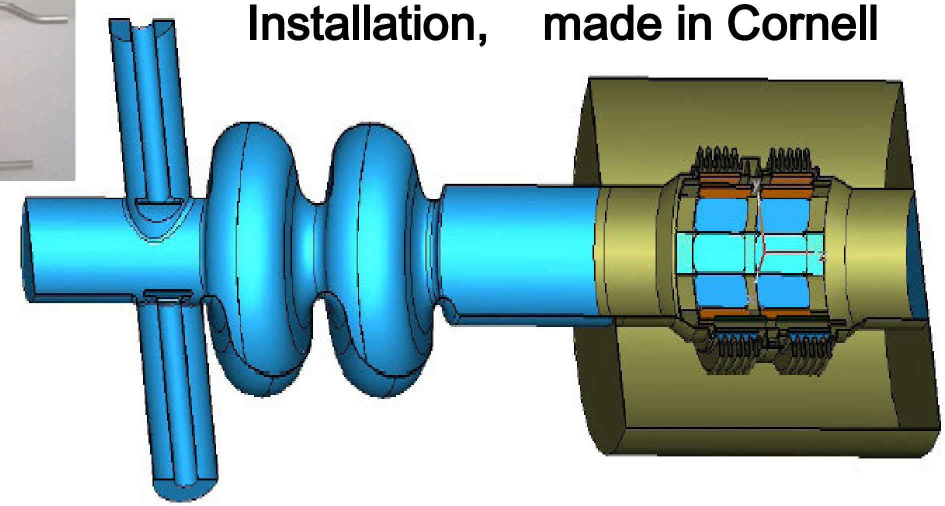


to production and

The Cornell-type HOM absorbers:

- first developed for CESR
- adopted internationally
- Refined for the ERL

Installation,   made in Cornell



HOM absorbers quickly reduce unwanted field components.

ERL student projects

CHESS & LEPP

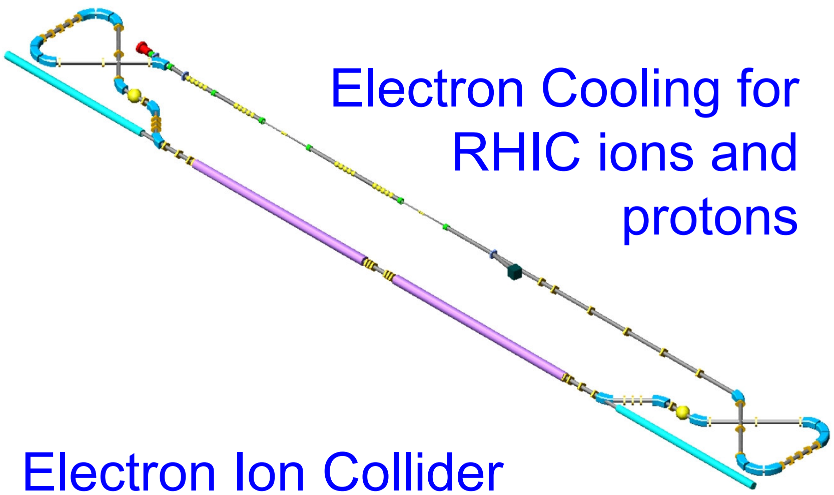
The ERL is a great chance for students to make real contributions:

- Accelerator layout and optimization (PhD student Chris Mayes)
- Beam stability and stabilization (PhD student Changsheng Song)
- Design of ion absorbers (PhD student Yi Xie)
- Beam disturbance by ions (HEP-PhD student Christian Spethmann)
- Couple kick beam dilution (Cornell undergrad Brandon Buckley)
- Characterization of optimal gun materials (Cornell undergrad Vaibav)
- Several other Cornell undergrads and REU students for injector controls, dump design, beam simulations, cavity design, …

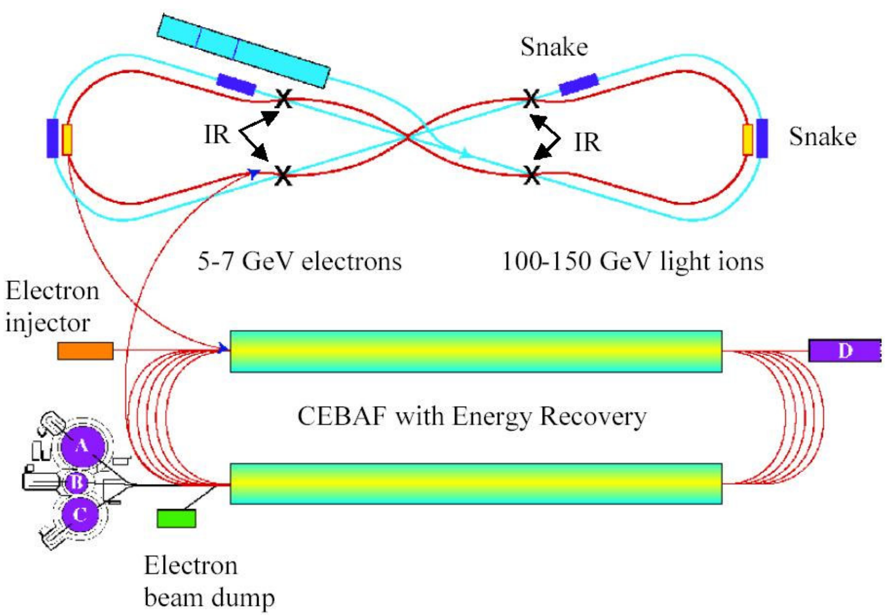
Non Light Source ERLs

CHESS & LEPP

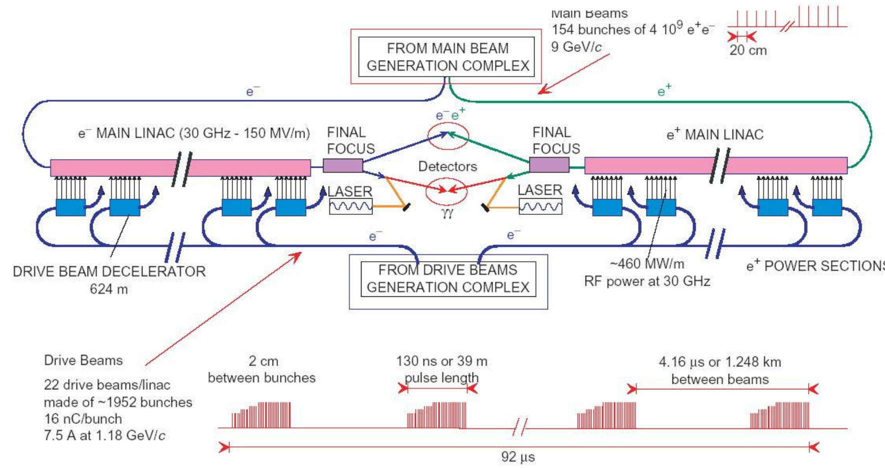
Electron Cooling for RHIC ions and protons



Electron Ion Collider



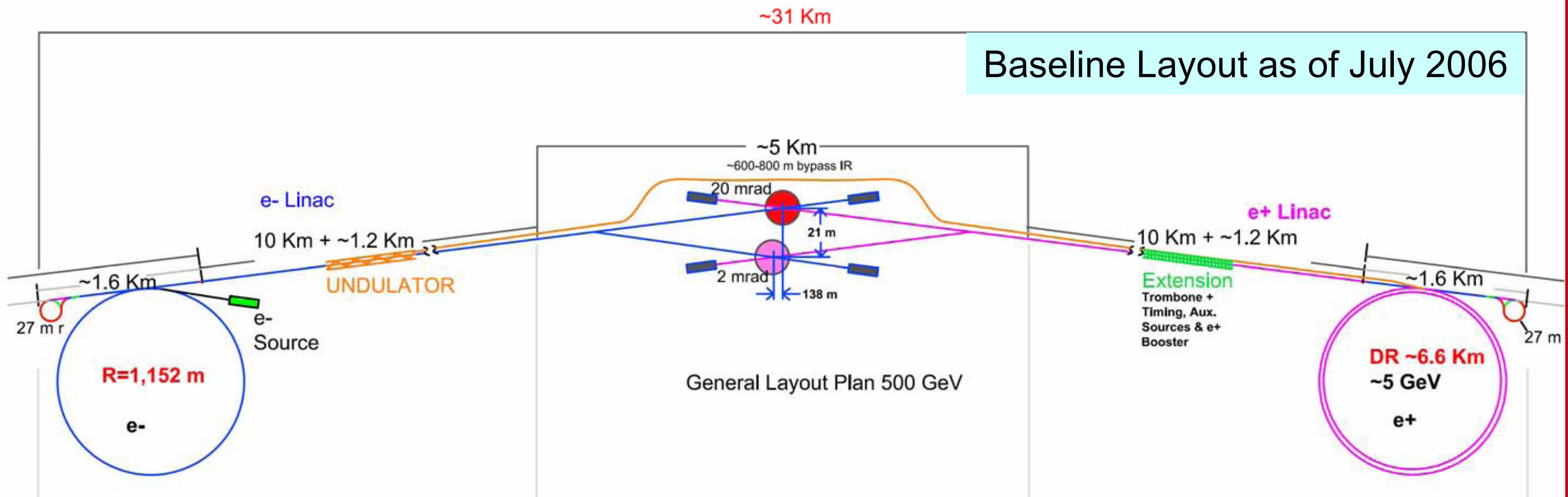
CLIC-like drive beam ERL



A low emittance RF source Could save the electron damping ring in a LC

The International Linear Collider (ILC)

CHESS & LEPP



- **Key Milestones**
  - **Costed Reference Design by the end of 2006**
  - **Technical Design by the end of 2009**
- **An R&D Program To…**
  - **Demonstrate the baseline design**
  - **Optimize cost and perfomance**
  - **Develop improvements to the baseline**
- **Ready in 2010 to propose construction**

See opening VLCW06 talk by B. Barish
http://vlcw06.triumf.ca/

ILC Accelerator R&D at Cornell

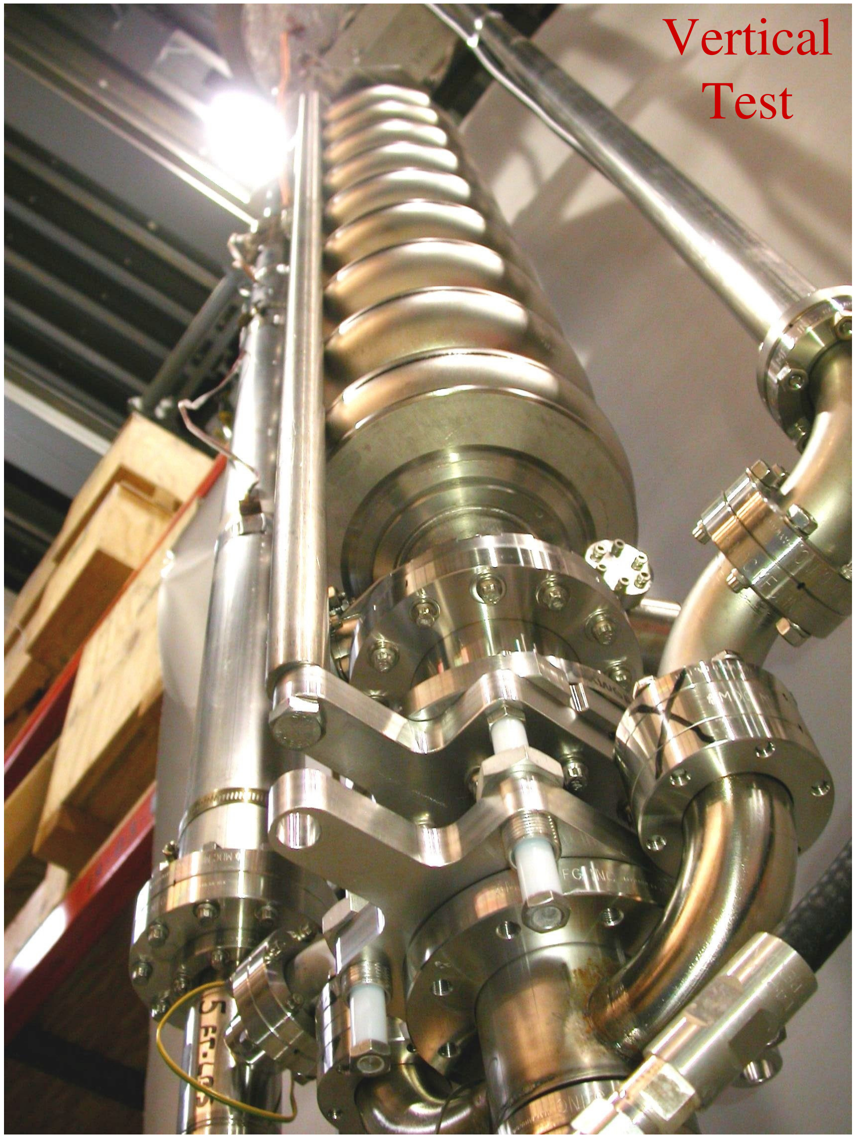
CHESS & LEPP

- Ring to Final Focus - Low Emittance Transport and BBA
- Helical Undulator for the Positron Source
- Superconducting RF
  - Facilities: BCP, EP, HPR, Cavity Test
  - Re-entrant cavity development
  - Basic R&D on Niobium Cavities
  - 650 MHz RF for Damping Rings
- Damping Rings
  - Simulation
  - Kickers
  - Wigglers
  - Instrumentation
  - CesrTF

Simulation Tools Based On BMAD
D. Sagan
http://www.lepp.cornell.edu/~dcs/bmad

ILC main linac 9-cell SRF cavities

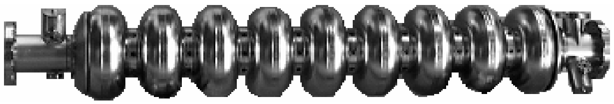
CHESS & LEPP



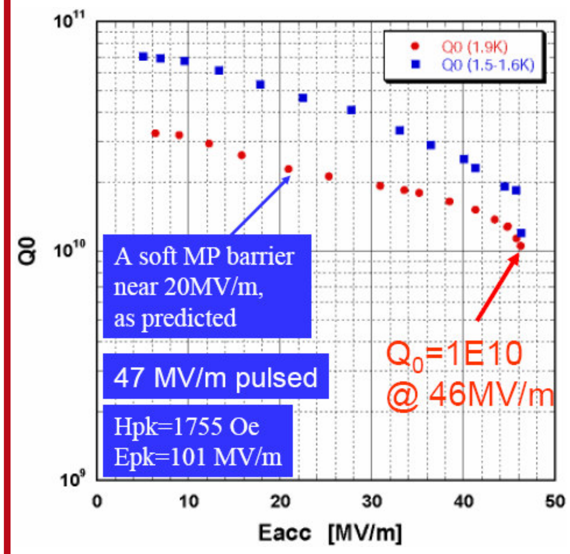
SRF & Solid State/Surface Physics

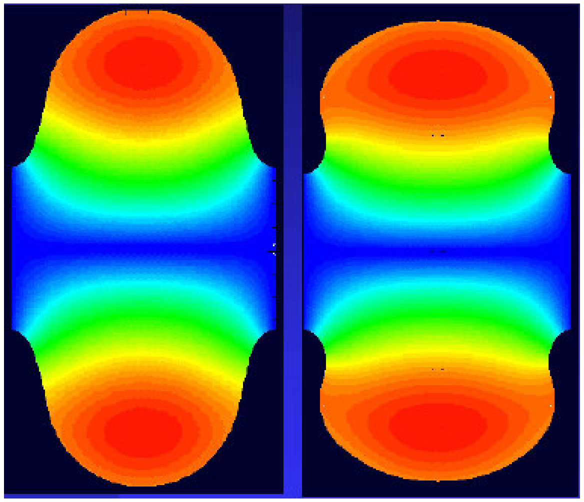
CHESS & LEPP

Research Subjects with Solid State Physics aspects:



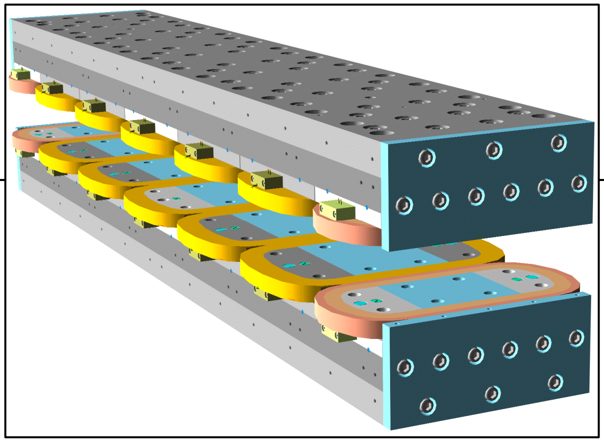
- Higher gradients in solid niobium cavities (ILC and ERL)
- Understand the dependence on Q on field (ILC and ERL)
- Alternate materials for superconducting cavities, e.g. Nb3Sn, Nb bonded to Cu, Nb on Cu,... (ILC, ERL, Muon accelerator)
- Improve breakdown characteristics of cavities to assure high duty factor operation (main ERL and ILC)





CesrTA Goals

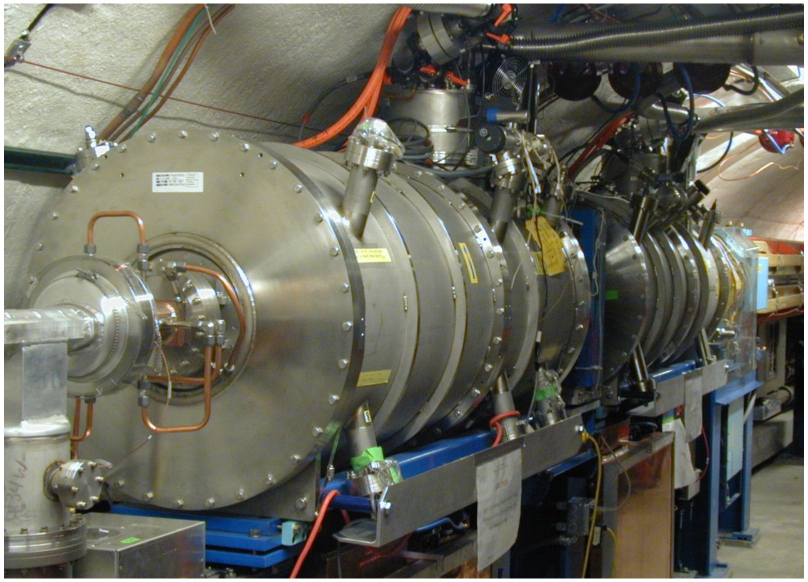
CHESS & LEPP

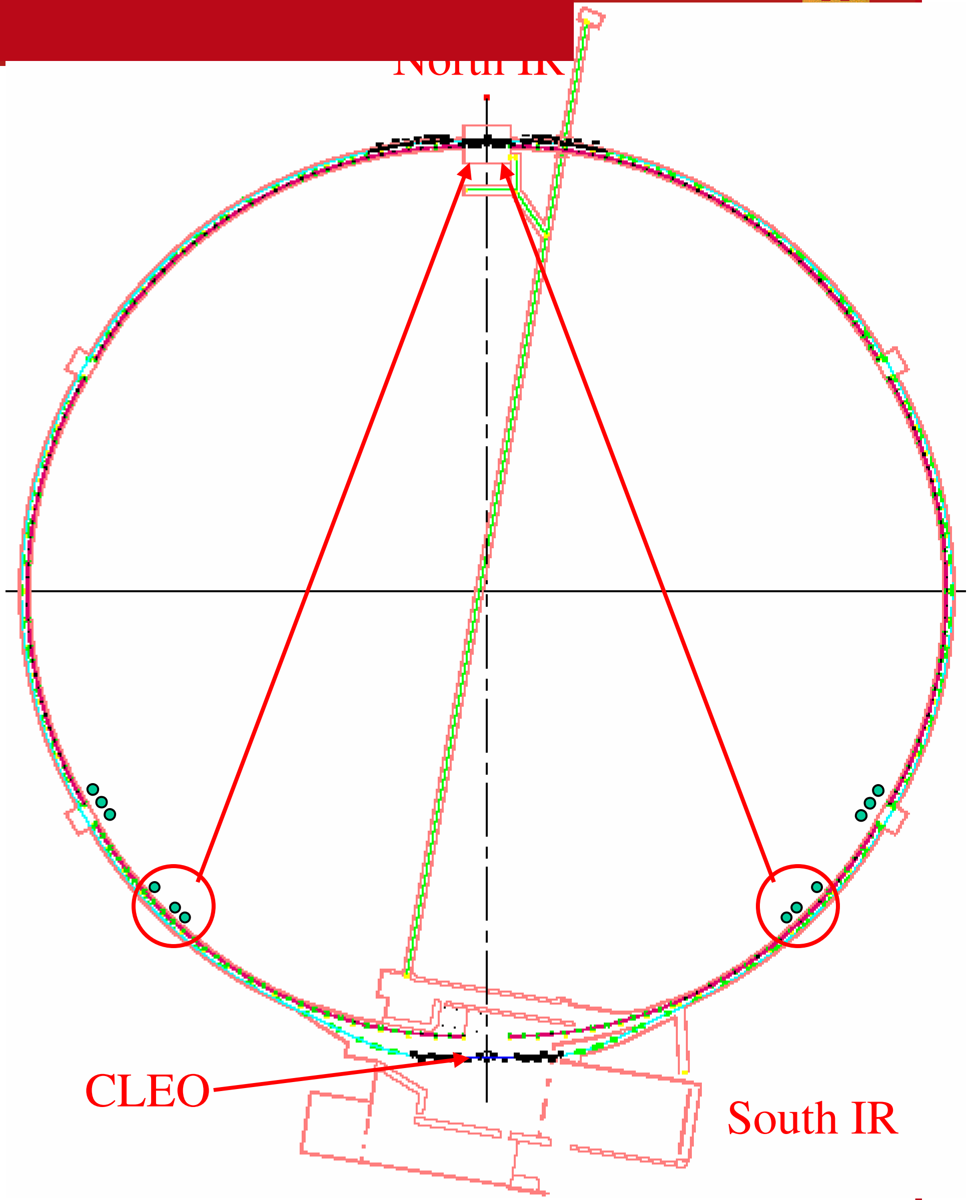


- **Primary Goals**
  - **Electron cloud measurements**
    - e^- cloud buildup in wigglers
    - e^- cloud mitigation in wigglers
    - Instability thresholds
    - Validate the ILC DR wiggler and vacuum chamber design (critical for the single 6 km positron ring option)
  - **Ultra-low emittance operations and beam dynamics**
    - Study emittance diluting effect of the e^- cloud on the e^+ beam
    - Detailed comparisons between electrons and positrons
    - Also look at fast-ion instability issues for electrons
    - Study alignment issues and emittance tuning methods
    - Emittance measurement techniques
  - **ILC DR hardware development and testing**
    - ILCDR wiggler prototype, wiggler vacuum chamber, 650 MHz SRF , kickers, alignment & survey techniques, instrumentation, *etc.*

CESR Modifications

- Move 6 wigglers from the CESR arcs to the North IR (zero dispersion region)
  - New cryogenic transfer line required
  - Zero dispersion regions can be created locally around the wigglers left in the arcs
- Make South IR available for insertion devices and instrumentation
- Instrumentation and feedback upgrades





Linear Collider @ Cornell

Subjects esp. suitable for Cornell:

- Low emittance electron sources (as ERL)
- Undulator based positron sources (from CESR undulator expert)
- Damping rings (have wigglers like CESR)
- Beam dynamics simulation and accelerator modeling (based on codes for CESR and ERL)
- Bunch compressors (similar to ERL)
- Many superconducting RF subjects (as ERL)
- Crab cavities for the collision region (as in LHC)