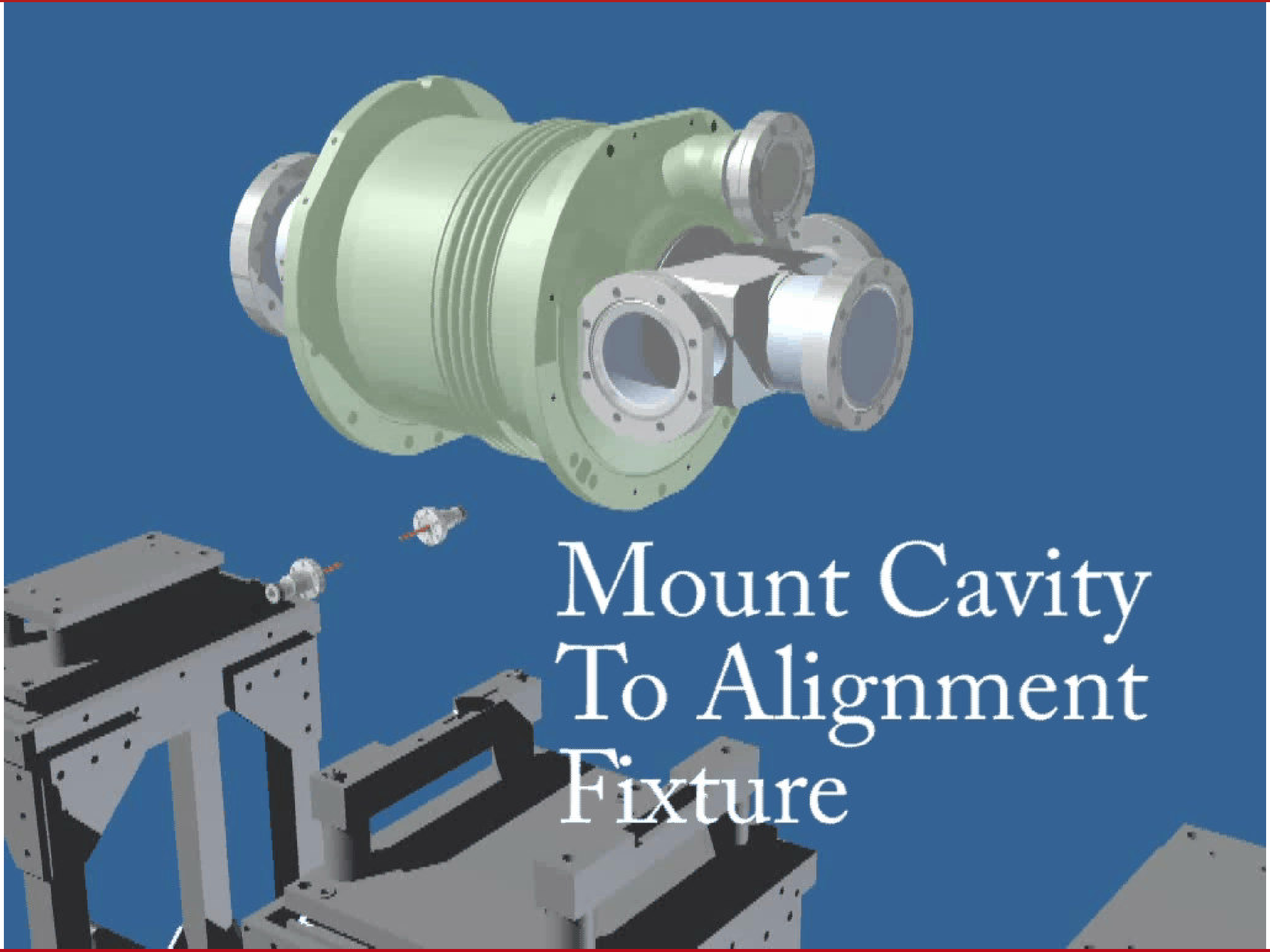
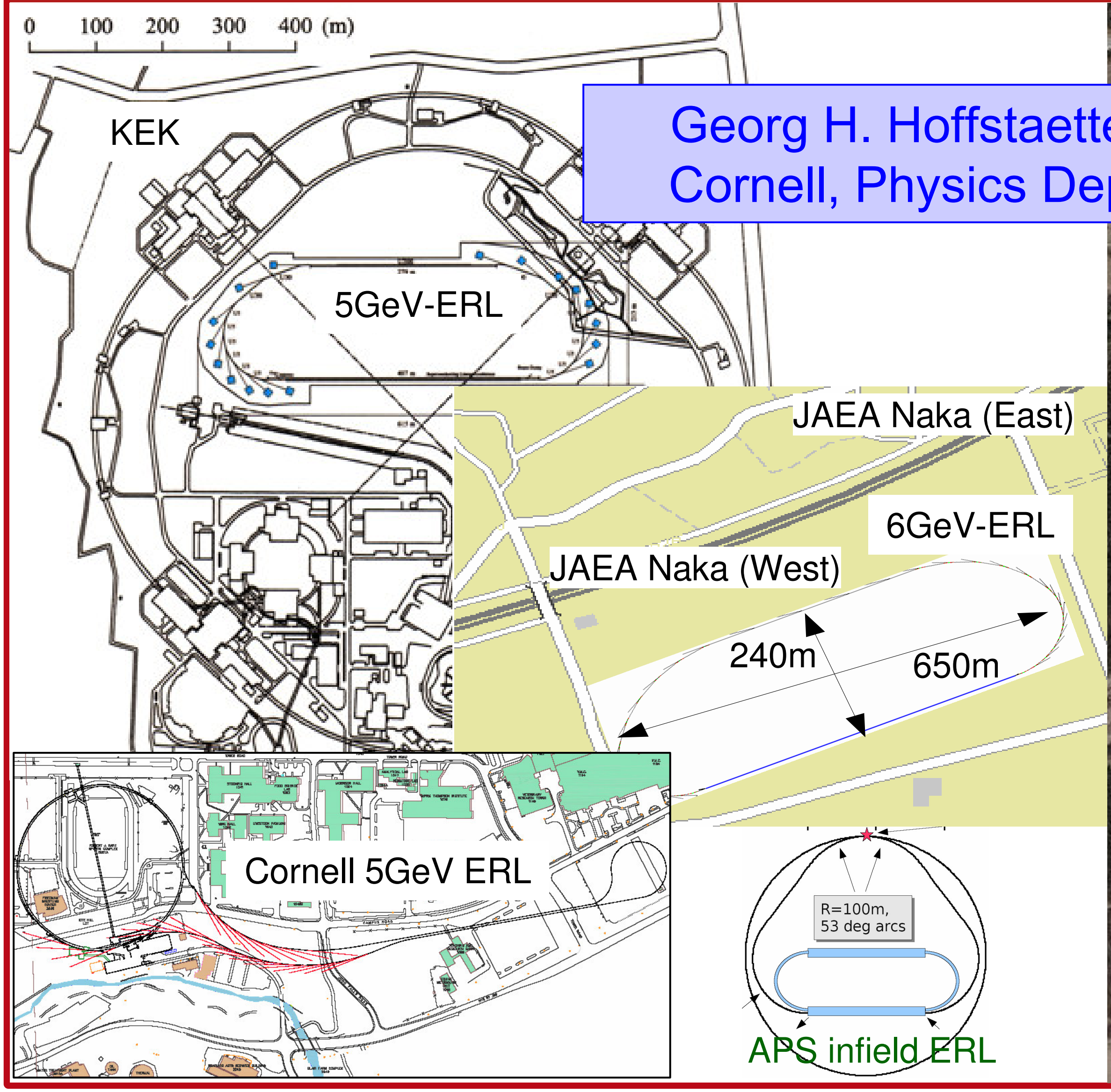
Assambly of ERL injector linac for ultra low emittances

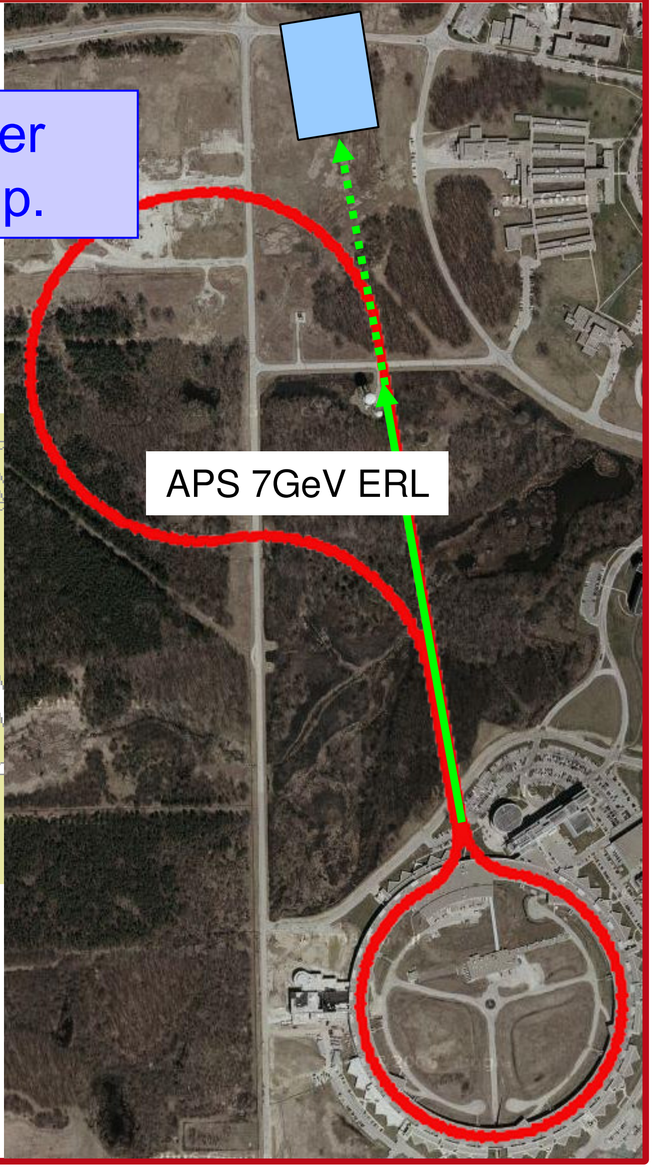


Injector assembly

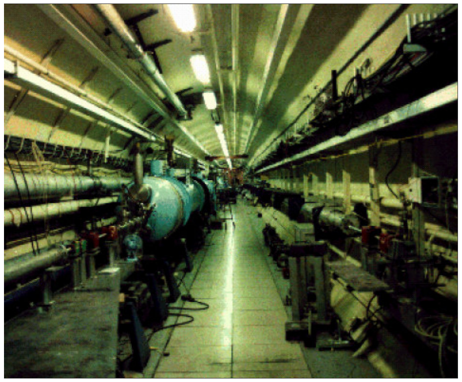
Energy Recovery Linacs as X-ray Sources

Georg H. Hoffstaetter
Cornell, Physics Dep.





Histroy of x-ray ERLs



1986: T. Smith et al.
Stanford SCA
NIM A 259 (1987) 1

1999: JLAB Demo-FEL

2002: JAERI FEL

2004: BNIP FEL

1965: M. Tigner
Nuovo Cimento
37 (1965) 1228

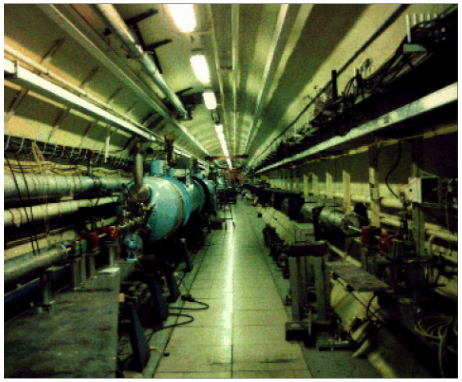
1990: A. Richter et al.
S-DALINAC, Darmstadt

Funding for:
2004: ERL-P
2004: BNL test ERL
2005: Cornell Phase 1a

Ideas on x-ray ERLs:
1998: MARS (BINP) APAC98, 6D015
2001: PERL (BNL) PAC01, WPAH075
2001: Cornell, PAC01, RPAH016
2002: Erlangen, EPAC 02, TUPLE012
2004: KEK/JAEA, EPAC04, MOPKF049
2006: Argonne / APS

Histroy of x-ray ERLs

CHESS & LEPP



1986: T. Smith et al.
Stanford SCA
NIM A 259 (1987) 1

1999: JLAB Demo-FEL

2002: JAERI FEL

2004: BNIP FEL

1965: M. Tigner
Nuovo Cimento
37 (1965) 1228

1990: A. Richter et al.
S-DALINAC, Darmstadt

Funding for:
2004: ERL-P
2004: BNL test ERL
2005: Cornell Phase 1a

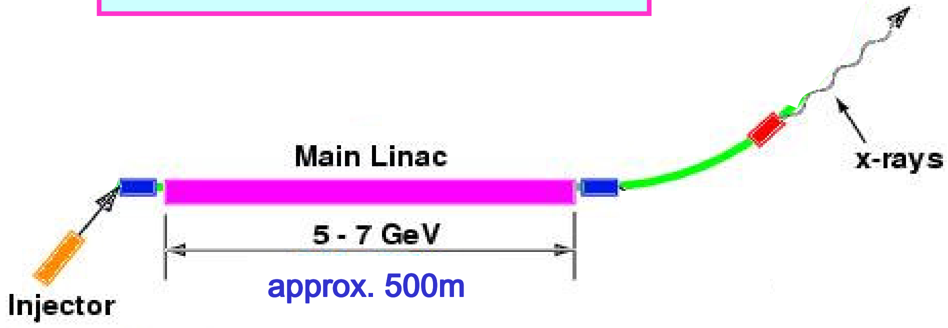
2001: Cornell, PAC01, RPAH016

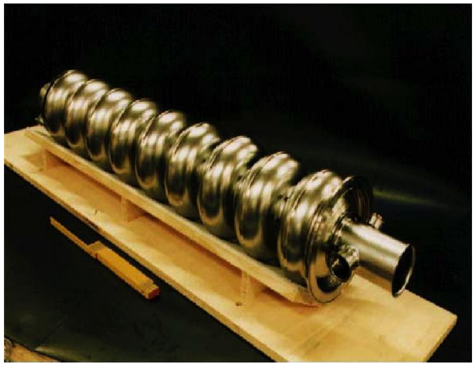
2004: KEK/JAEA, EPAC04, MOPKF049
2006: Argonne / APS

Principle of an X-ray ERL

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

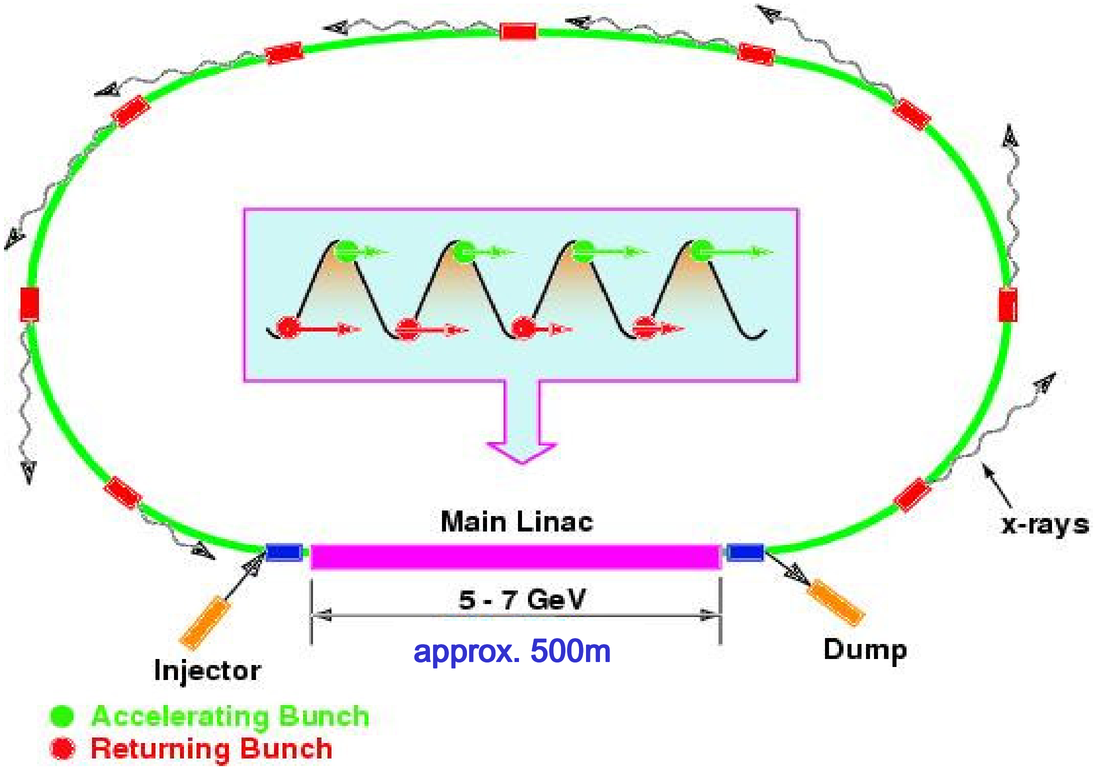
5GV*100mA = 0.5GW
(full size power plant!)

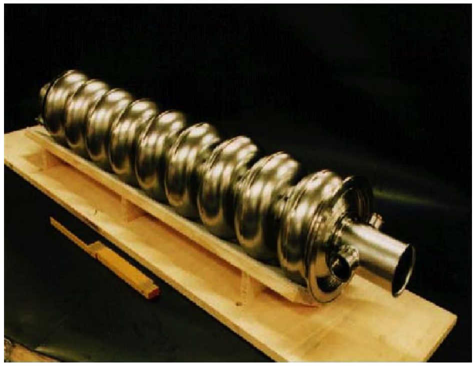




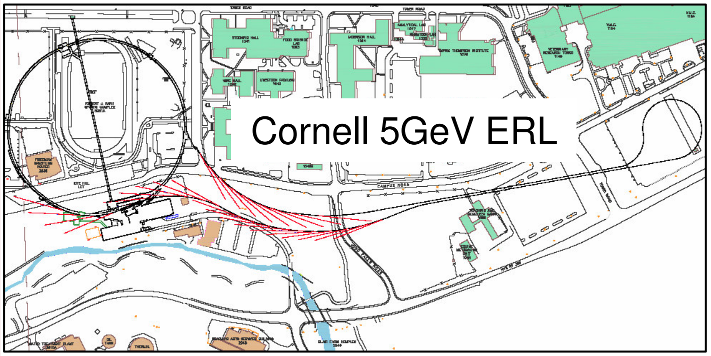
Principle of an X-ray ERL

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



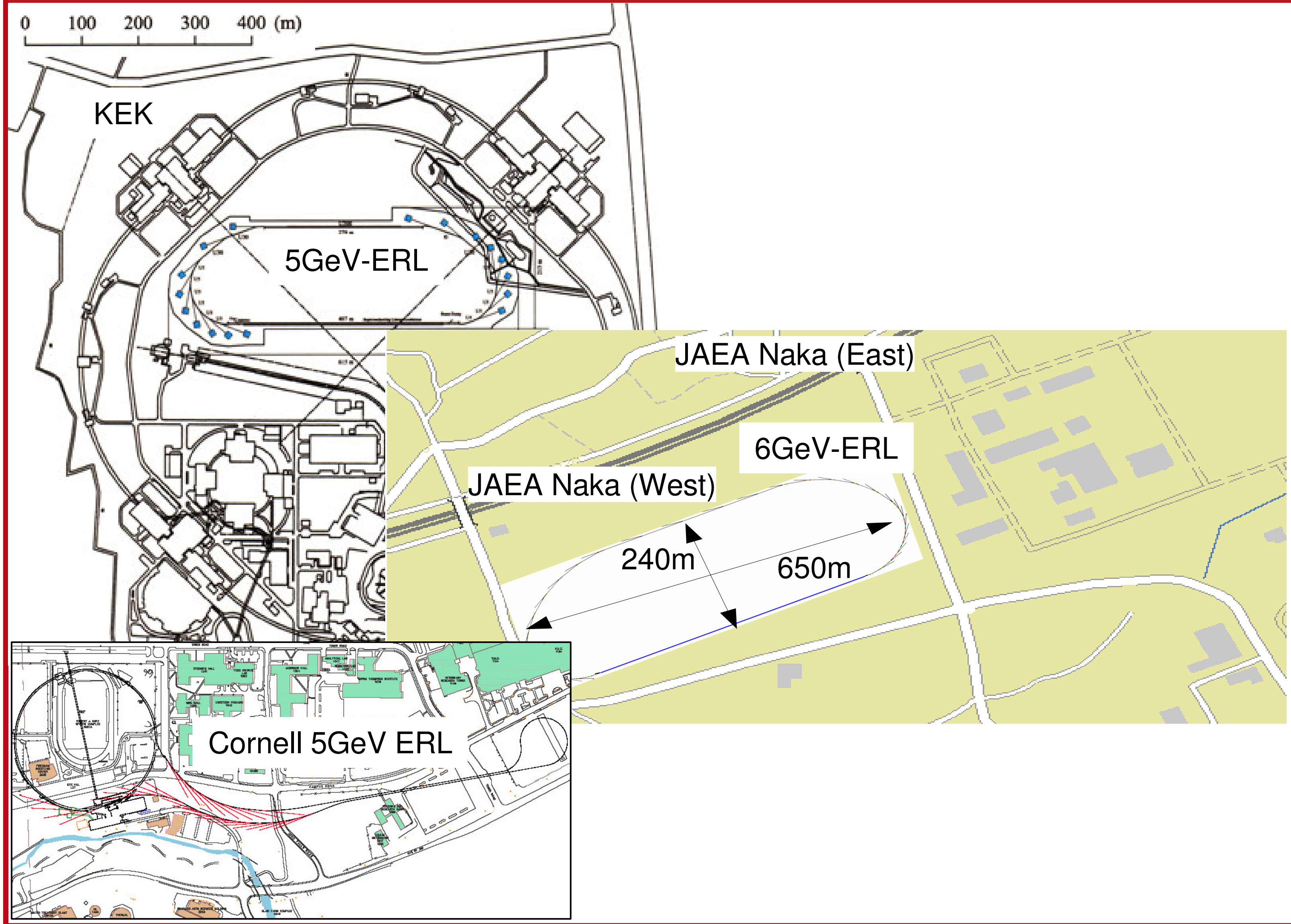


Cornell ERL

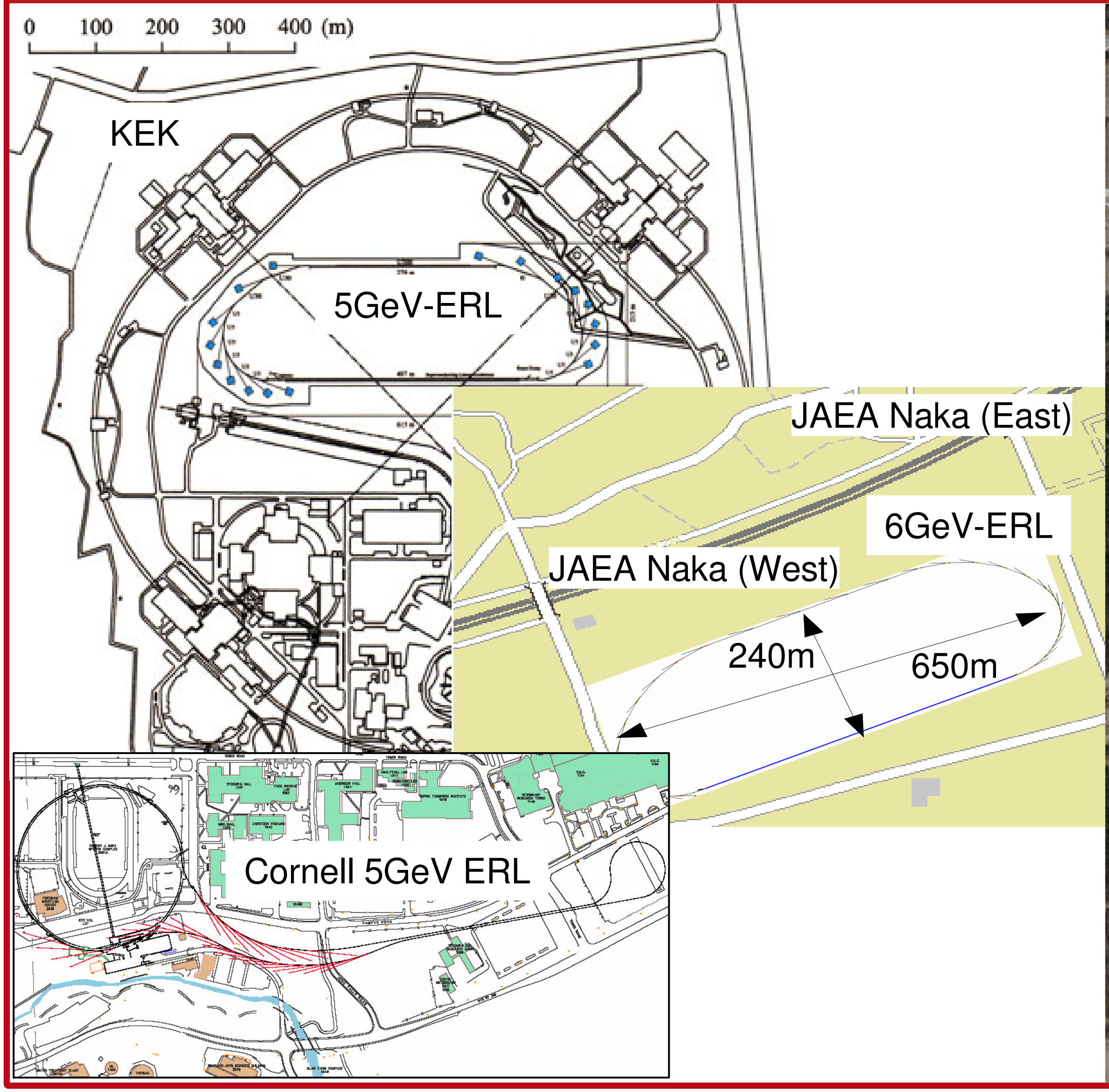


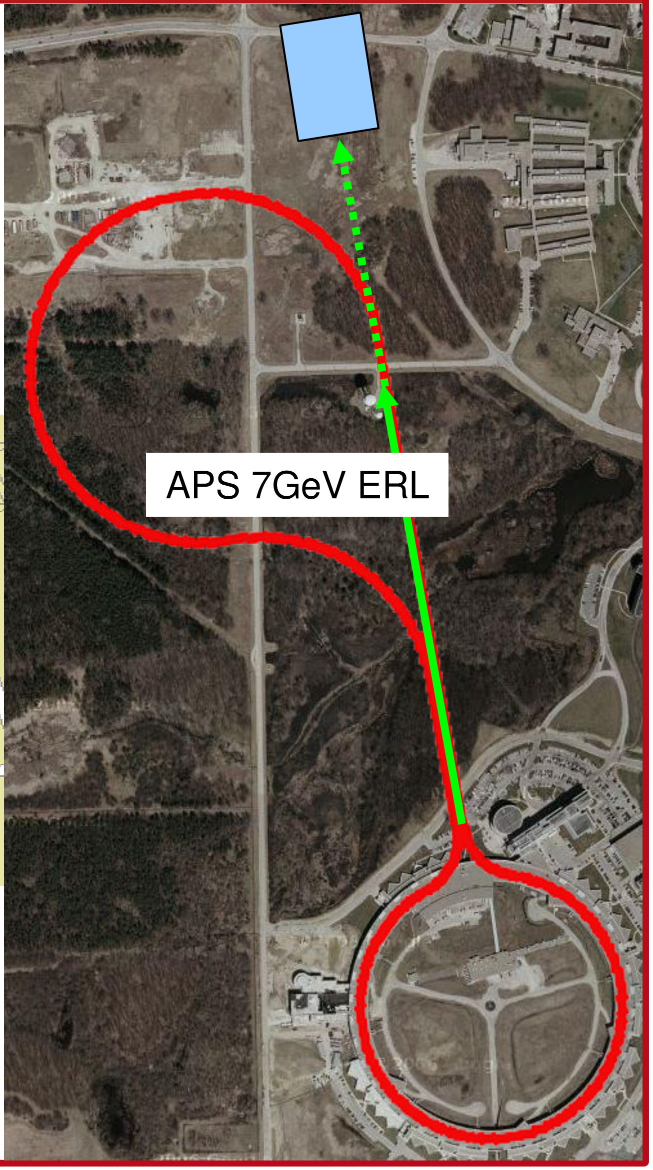
Cornell 5GeV ERL

Cornell / KEK / JAEA ERLs



Cornell / KEK / JAEA / APS ERLs

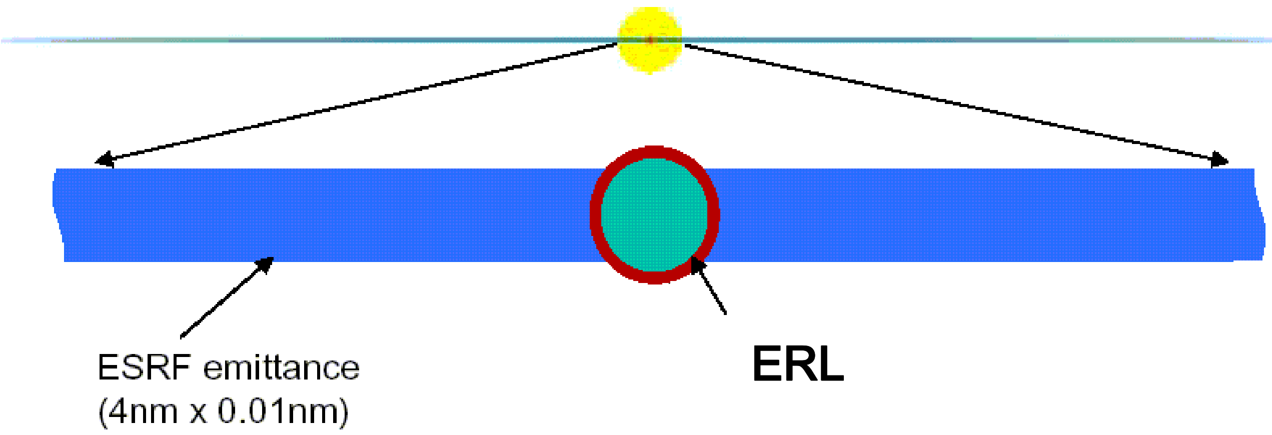




Advantages of ERL beams

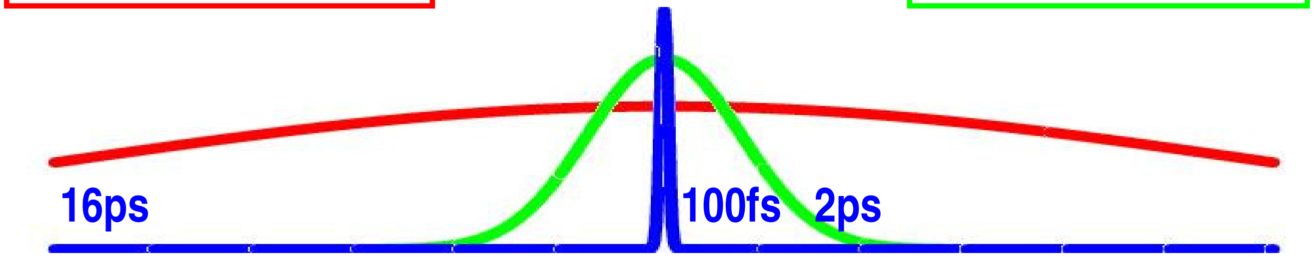
Transverse emittance reduction:

ESRF 6GeV@200mA → ERL 5GeV@100mA



Bunch-length reduction:

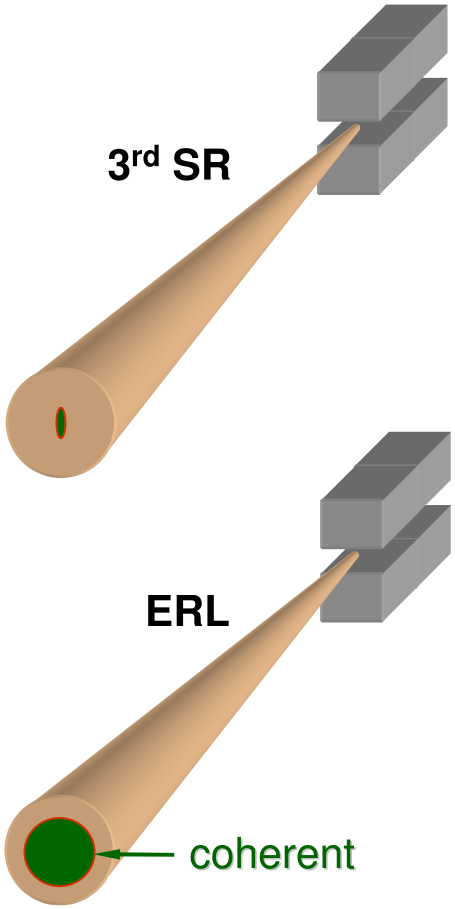
ESRF 6GeV@200mA → ERL 5GeV@100mA



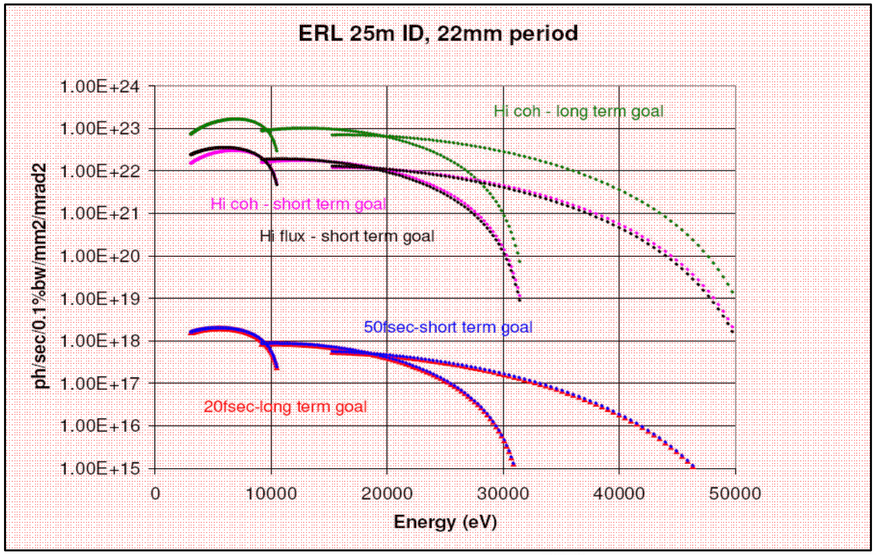
Smaller Beams and more Coherence

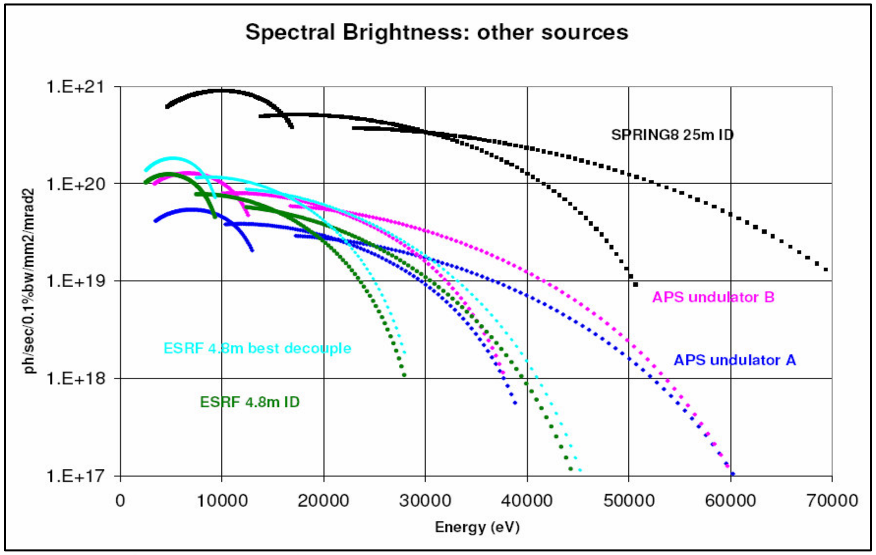
- Coherent x-ray diffraction imaging
- It would, in principle, allow atomic resolution imaging on non-crystalline materials.
- This type of experiments is completely limited by coherent flux.

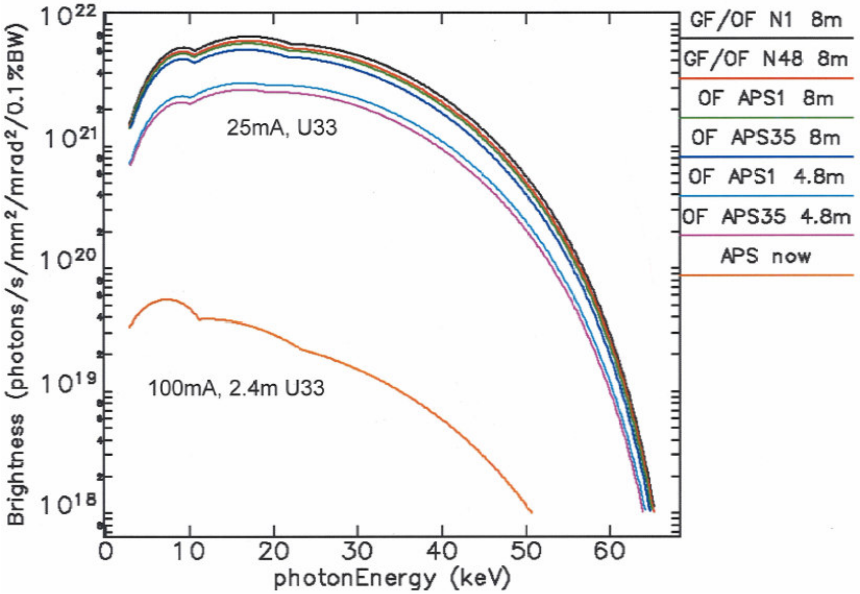
Factor 100 more coherent flux for ERL
for same x-rays, or provide coherence for
harder x-rays



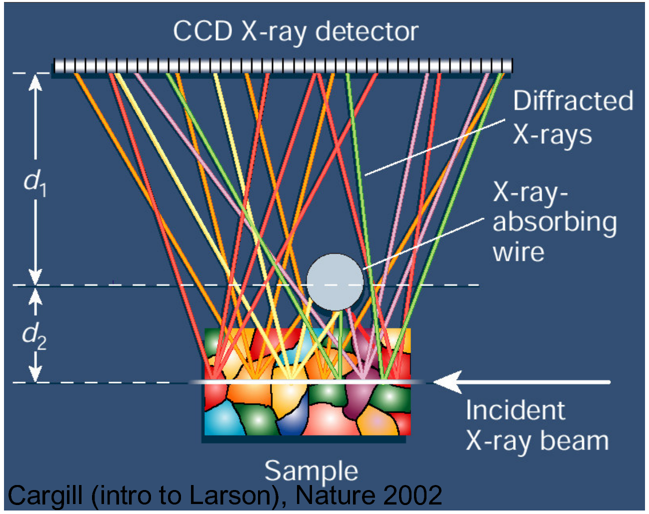
How large is the advantage of ERLs ?







Microprobe: higher resolution from narrower x-ray beams

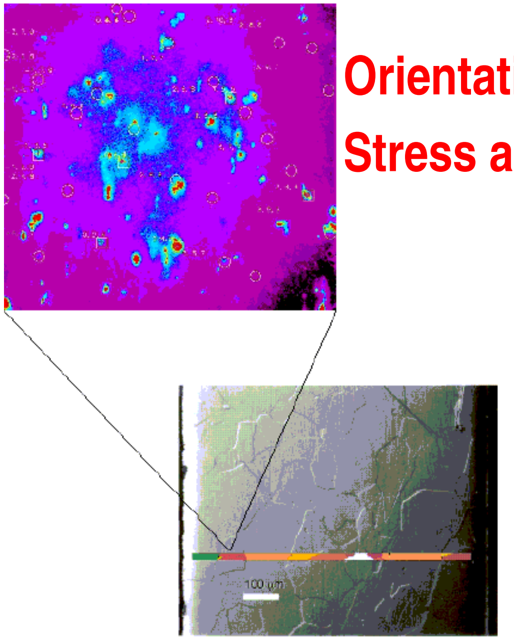


Cargill (intro to Larson), Nature 2002

Differential-Aperture X-ray Microscopy (DAXM)

- Smaller beams lead to better spatial resolution (currently sub μm)

ERL: smaller area



Orientation of crystals and

Stress and strain in crystals

Ben Larson (2000), ERL science workshop, Cornelll

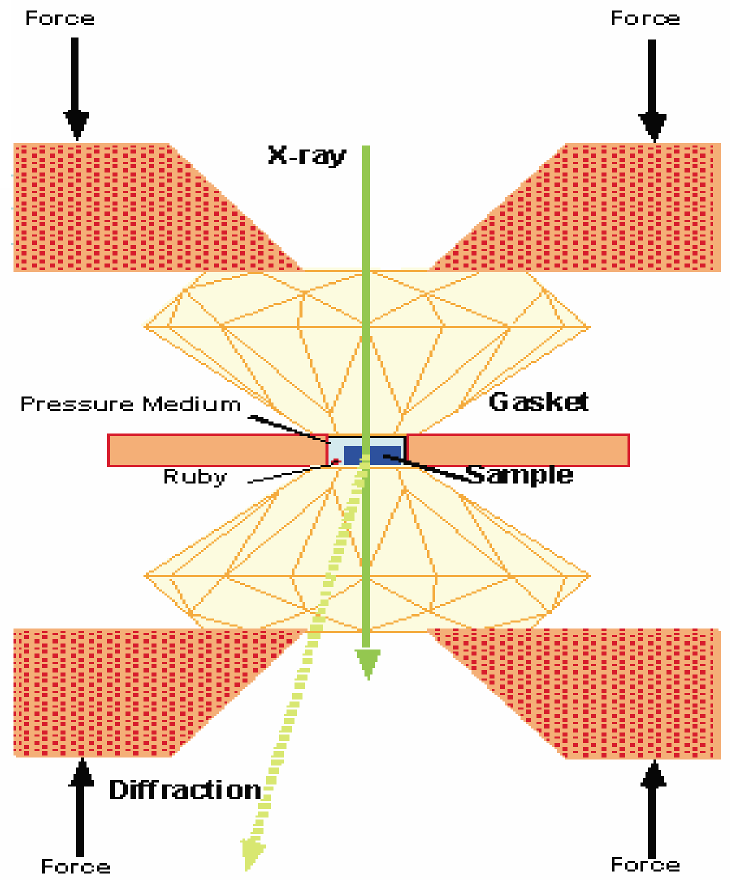
3-D Studies of Structure

High pressure: more flux through a small probe

High Pressure: Materials, Engineering, Geological and Space Sciences.
J. B. Parise, H.- K. Mao, and R. Hemley
at ERL Workshop (2000)

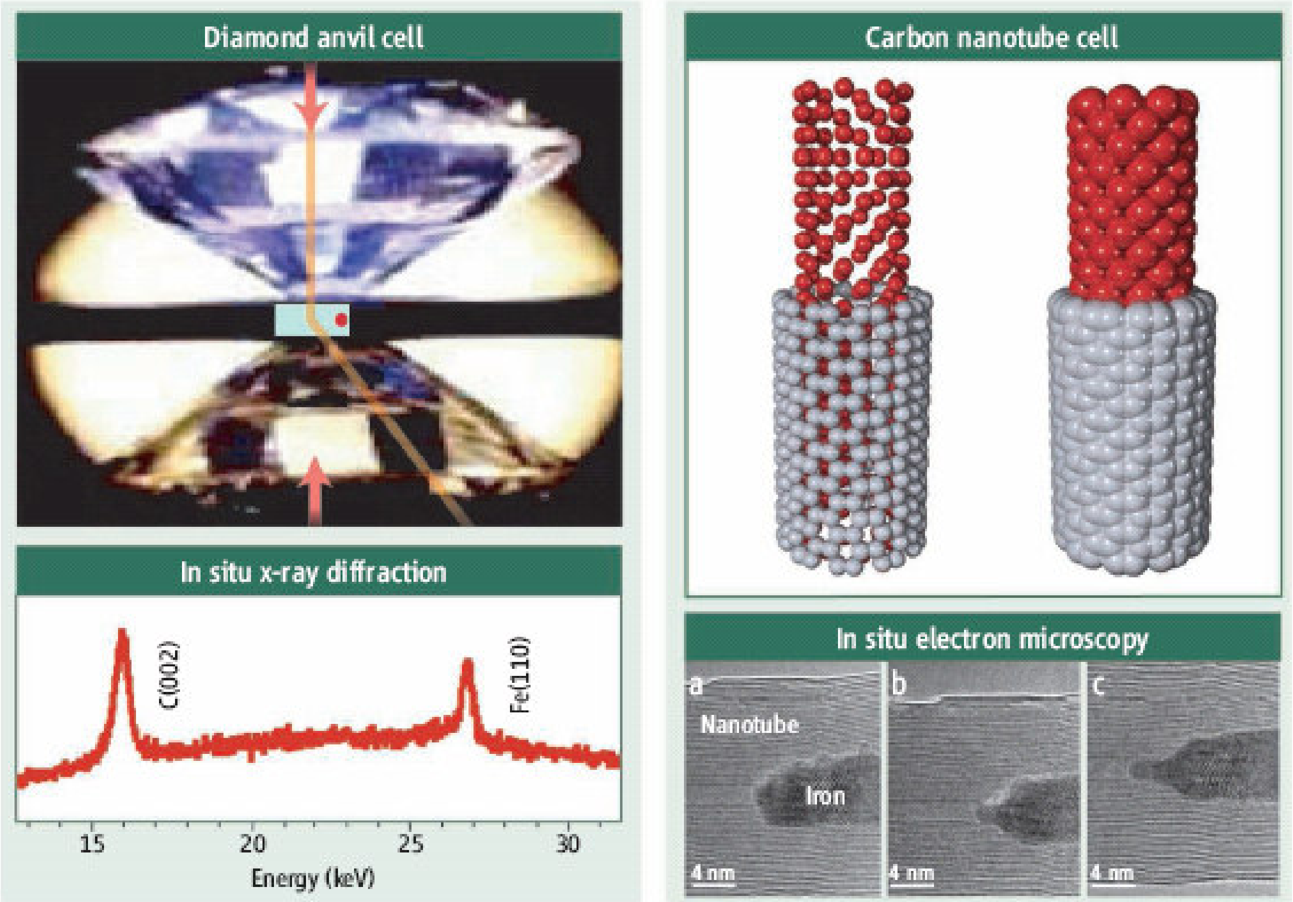
- HP experiments are brightness-limited. Time resolved experiments for plasticity, rheology measurements, phase transitions, etc. are especially photon starved.
- Higher P ⇒ smaller samples.
- No ideal pressurization medium

  ⇒ need to scan sample.
- Peak-to-background critical.
- ERL will greatly extend pressures and samples that can be studied.



Parise, Hemley & Mao

High pressure in carbon nanotubes



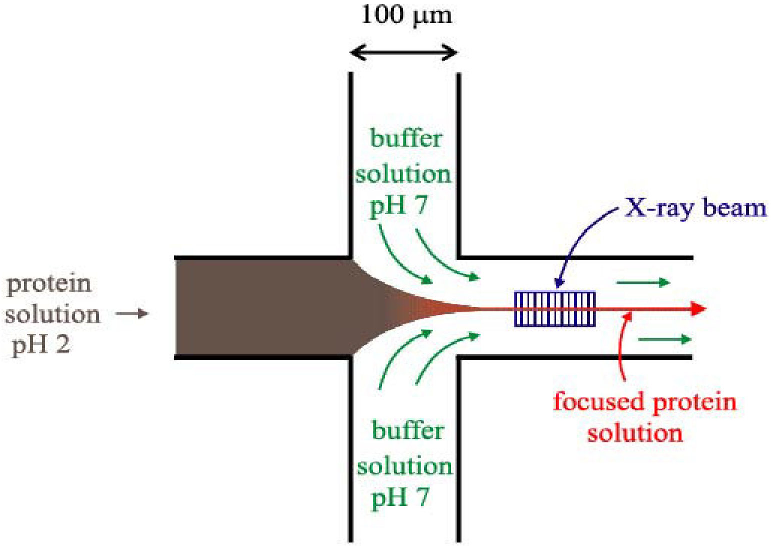
A matter of scale. **(Left)** A transparent diamond anvil cell allows in situ spectroscopic measurements of bulk samples. The red arrow represents an x-ray beam that is diffracted by the sample. **(Right)** A carbon nanotube self-compression cell enables in situ atomic-resolution snapshots at zero (a), intermediate (b), and high (~40 GPa) (c) pressure.

Wang &Zhao, *Science*, **312** (2006) 1149; Sun et al., *Science*, **312** (2006) 1199.

Bio and polymer science:
more flux through thin sheet probes

& LEPP

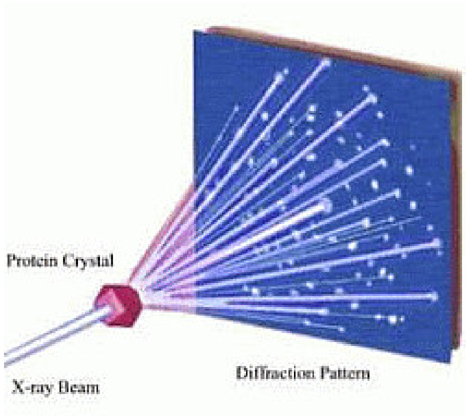
- Examples: folding/unfolding of proteins & RNA; assembly of fibers; polymer collapse upon solvent changes; conformational changes upon ligand binding; monomer/multimer association.
- Microfabricated laminar flow cells access microsecond equilibration mixing times.
- Data acquisition entirely limited by source brilliance. The ERL will extend time scales from present milliseconds to microseconds.

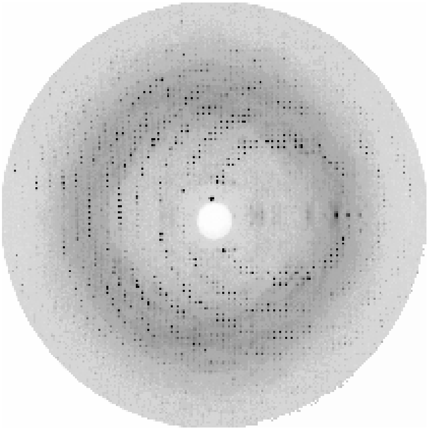


Thanks to Lois Pollack

Cornell Univ.

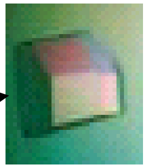
Structural biology: more flux through microcrystals





ERL enables new crystallographic method

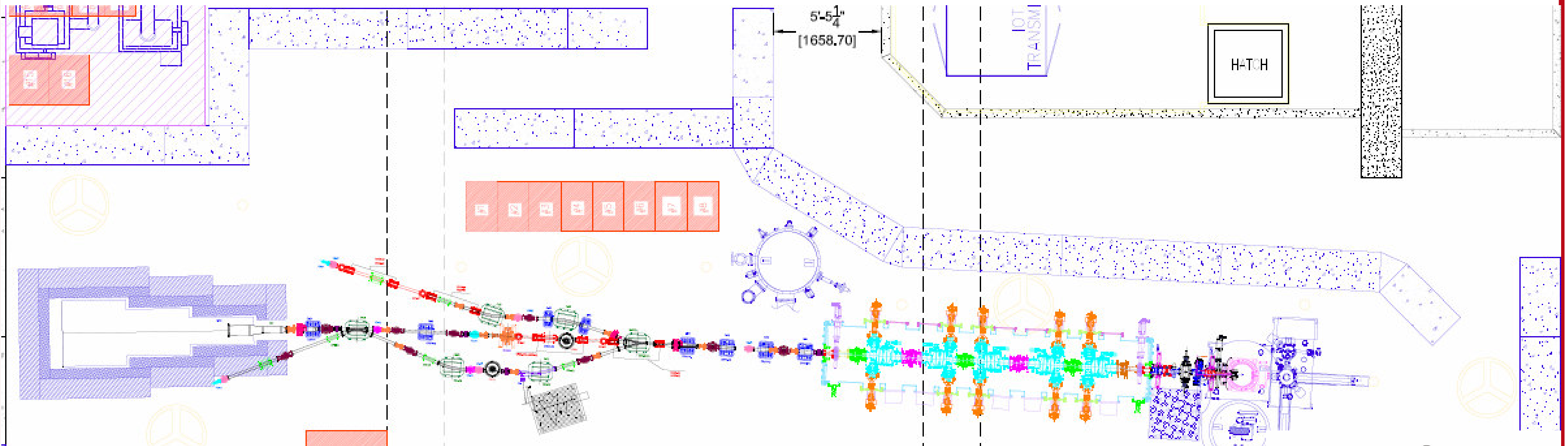
1. Obtaining good crystals is rate limiting. Easier to obtain microcrystals. Radiation limits crystals to >~(20µm)^3.
2. Single image sufficient to determine orientation matrix.
3. Plate microcrystals in random orientations onto ultrathin film support.
4. Scan film w/microbeam, recording diffraction images.
5. ERL microbeam intensity and low divergence allows this to be done with micron-sized crystals.



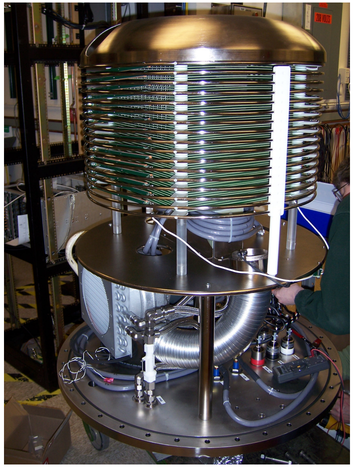
(1) Challenges for x-ray ERLs

- Production of low emittances + limiting emittance growth (WG1 / WG2)
  - Optics in the linac for very different energies (0.01 - 5GeV)
  - Limit coupler kicks / cavity misalignments
  - Limit optics errors and adjust fields to radiated energy
  - Low emittance growth optics similar to light sources

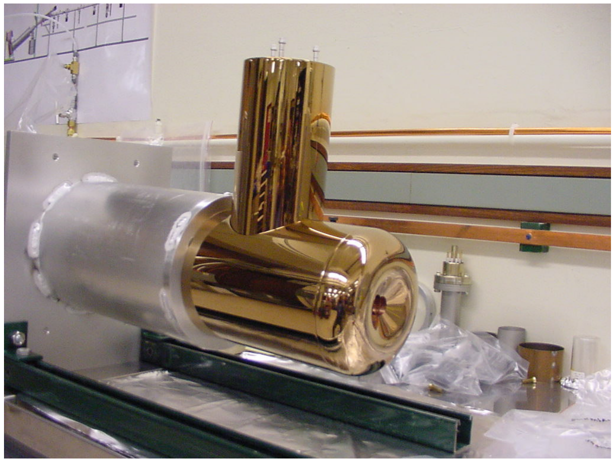
Cornell Injector prototype: Verification of beam production



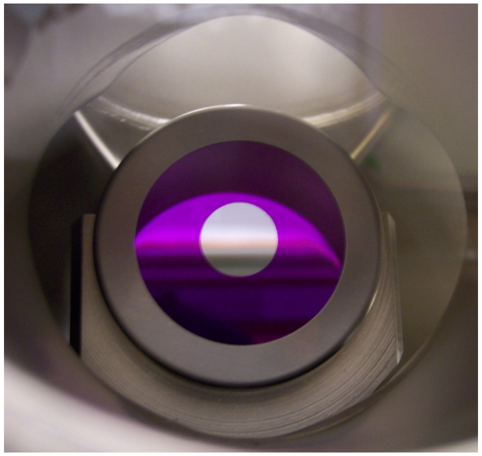
dump



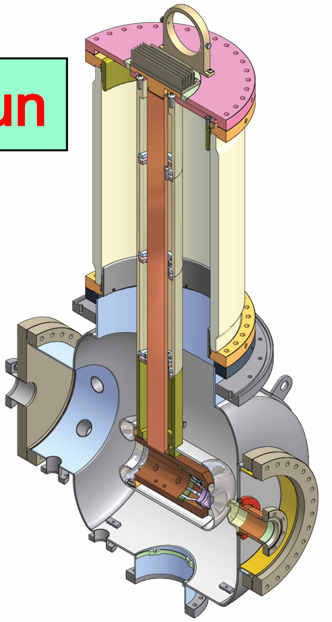
diagnostics



SC injector



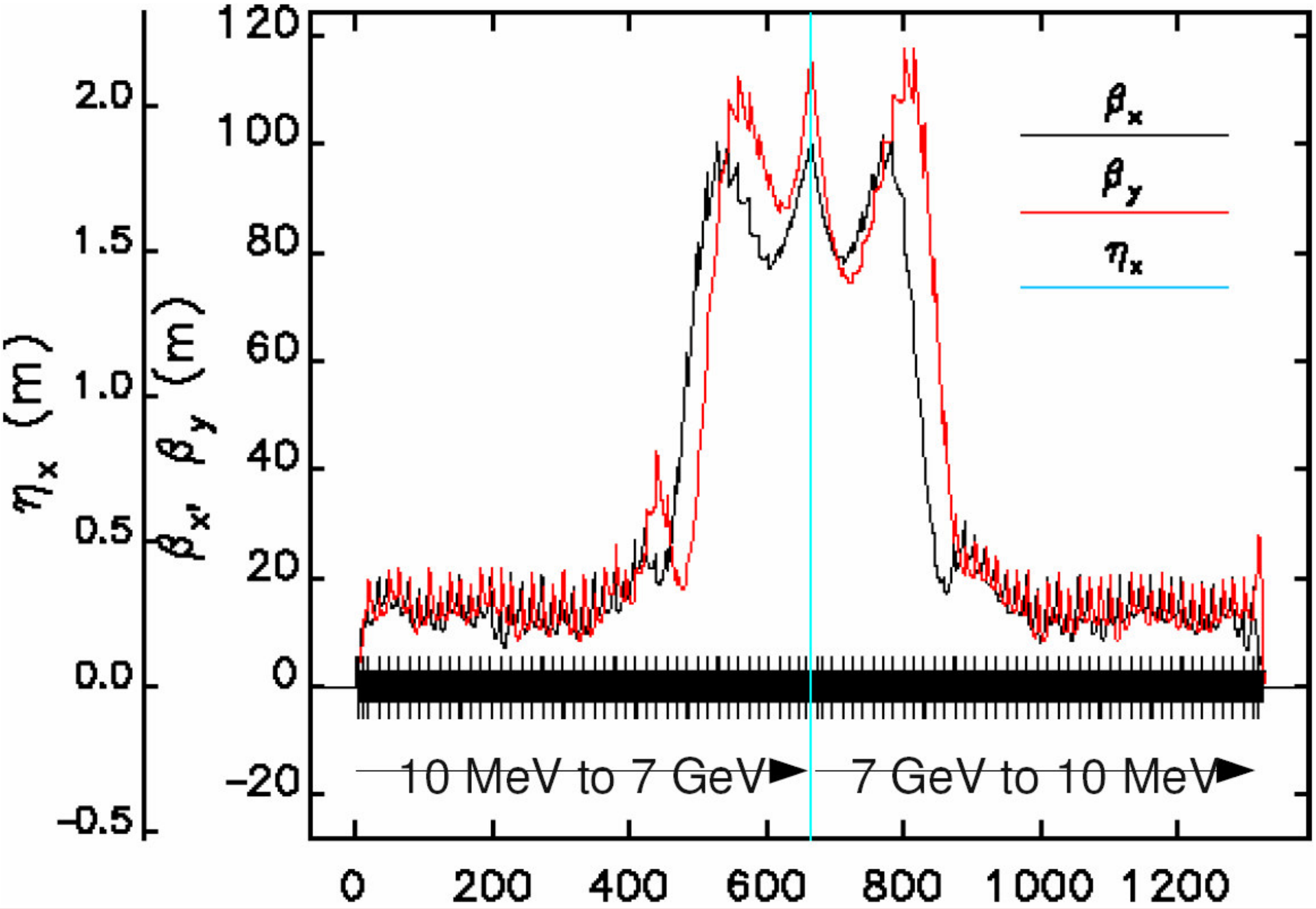
gun



Linac Optics for two very different energies

CHESS & LEPP

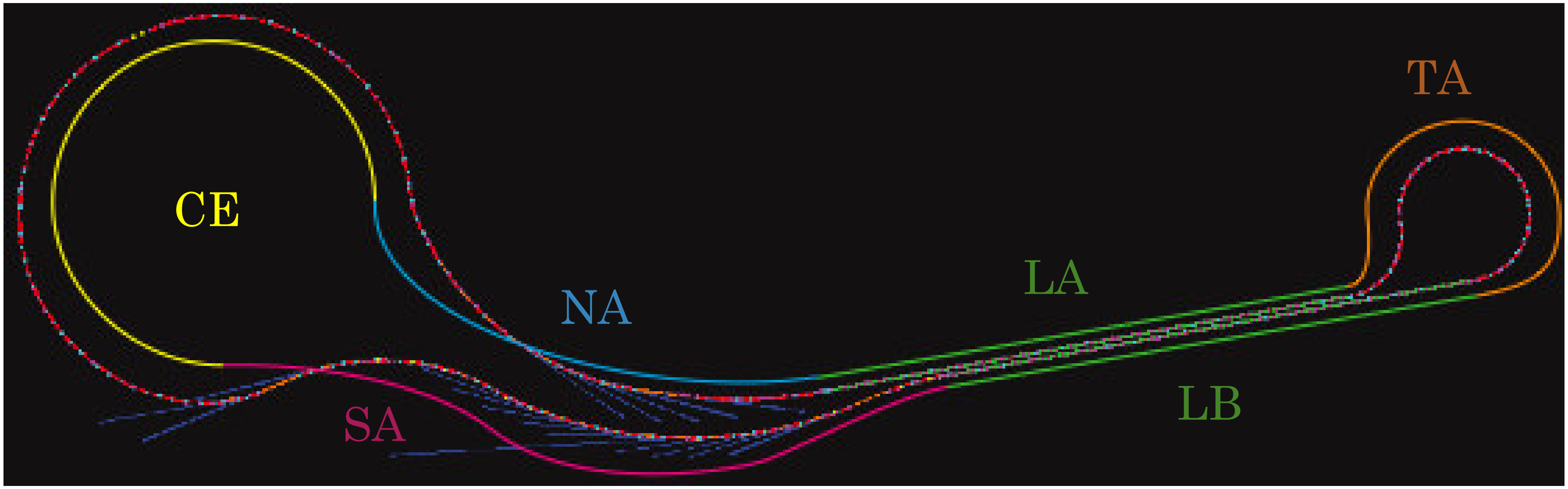
The high energy beam hardly reacts to the weak quads at the beginning of the linac



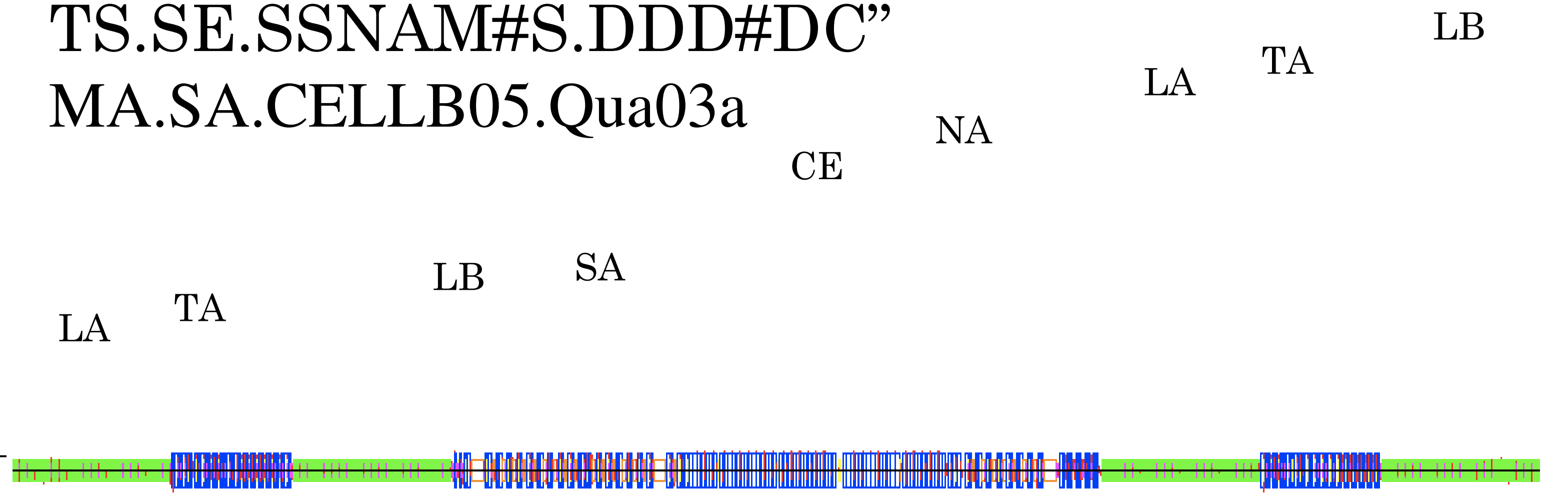
Example from the APS – ERL upgrade study

Incoherent Synchrotron Radiation (ISR)

CHESS & LEPP



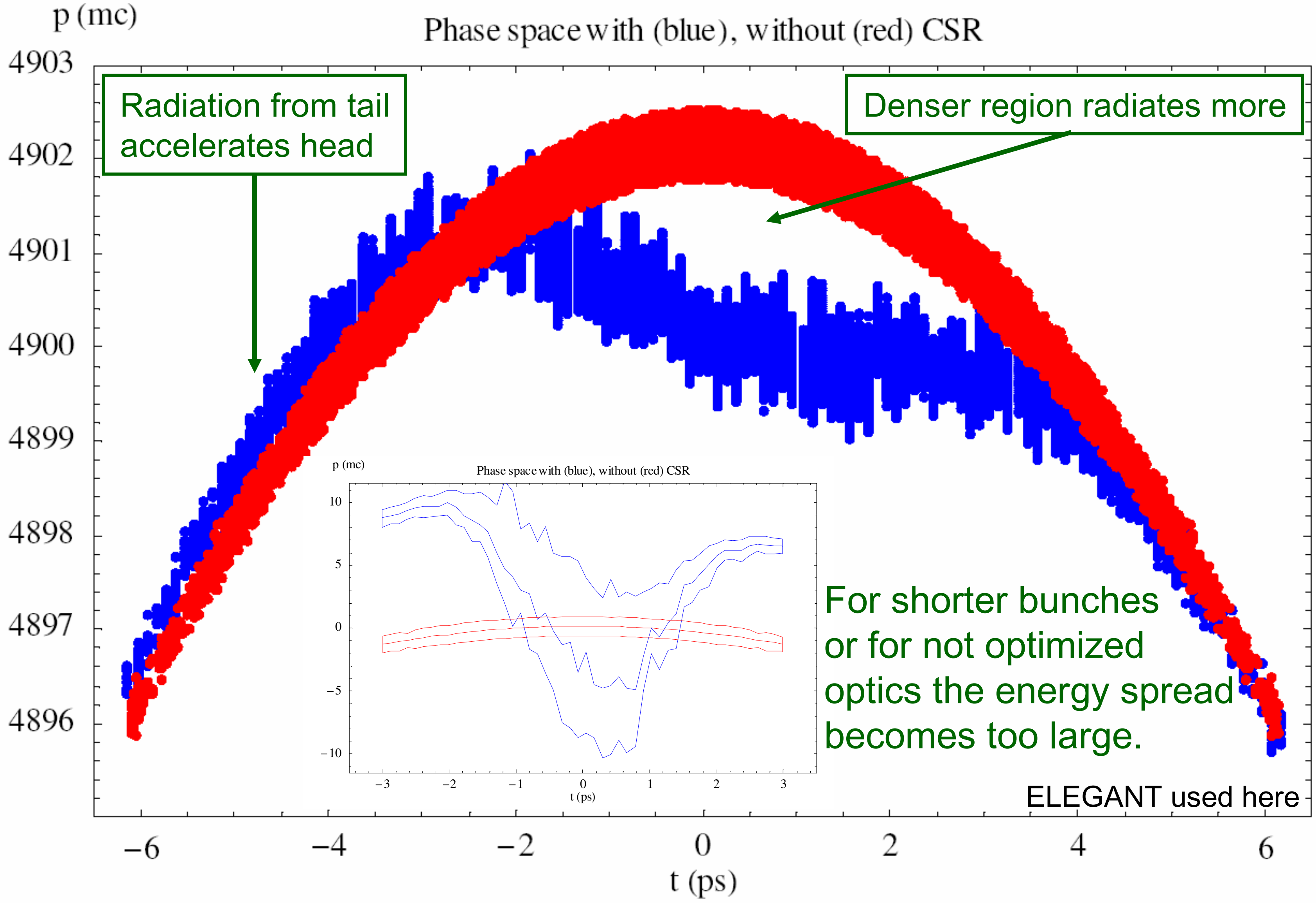
TS.SE.SSNAM#S.DDD#DC”
MA.SA.CELLB05.Qua03a



(2) Challenges for x-ray ERLs

- Limit energy spread after deceleration, e.g. 5GeV to 10MeV (WG2)
  - Accurate time of flight correction, including sextupoles
  - Limit energy spread from wake fields
  - Limit energy spread from intra beam scattering (IBS) and rest gas scattering
  - Limit energy spread from incoherent / coherent synchrotron radiation (ISR / CSR)

CSR in ERL bends



Radiation from tail accelerates head

Denser region radiates more

For shorter bunches or for not optimized optics the energy spread becomes too large.

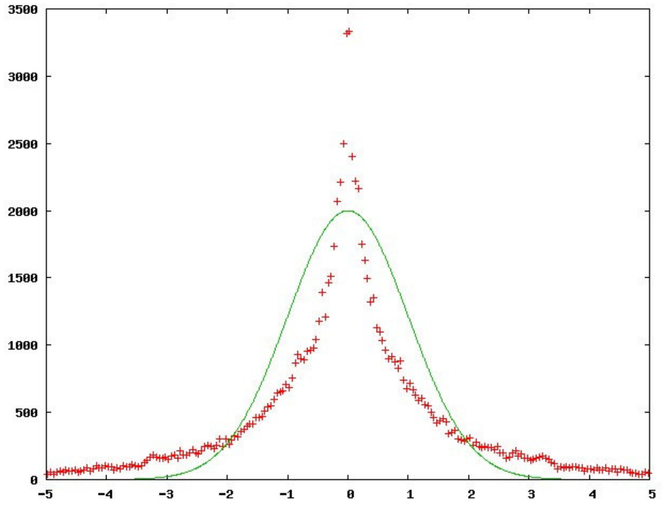
ELEGANT used here

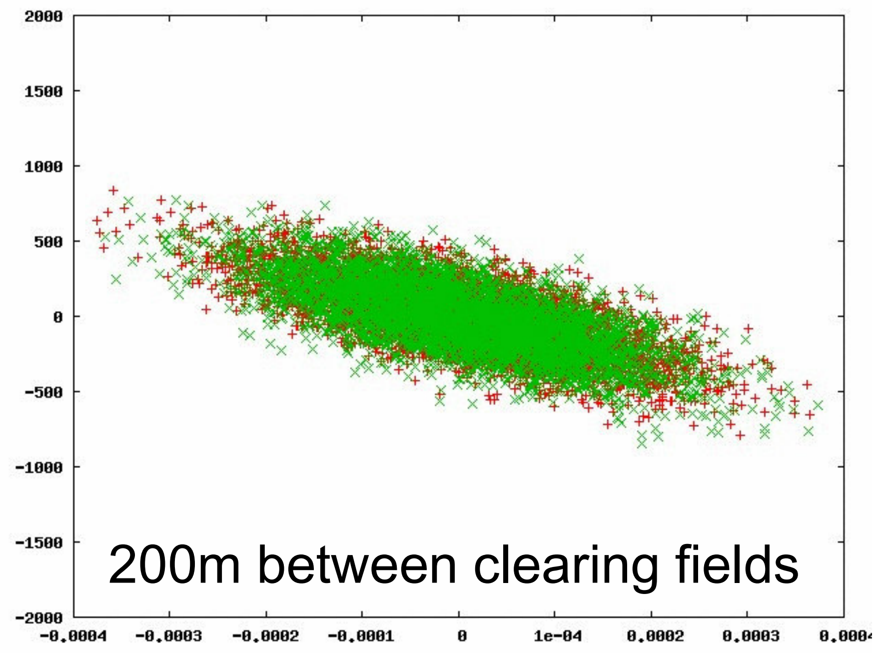
(3) Challenges for x-ray ERLs

- Beam loss concerns
  (WG2 / WG4)
  - Beam loss from IBS / Tourschek
  - Rest gas scattering
  - Disturbance from ions / ion removal
  - Halo development

CHESS & LEPP

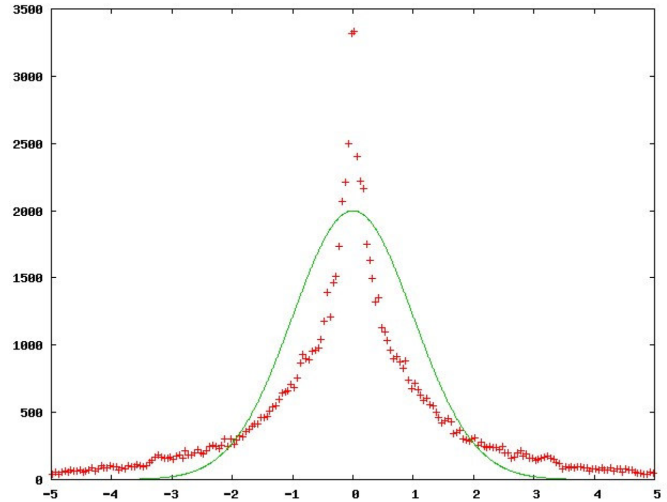
Ions in an ERL beam

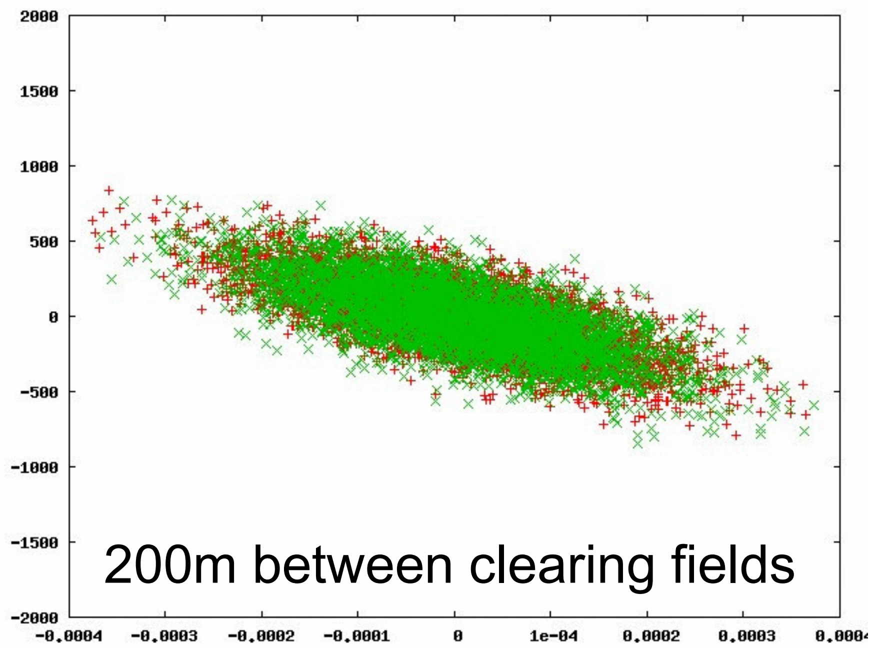




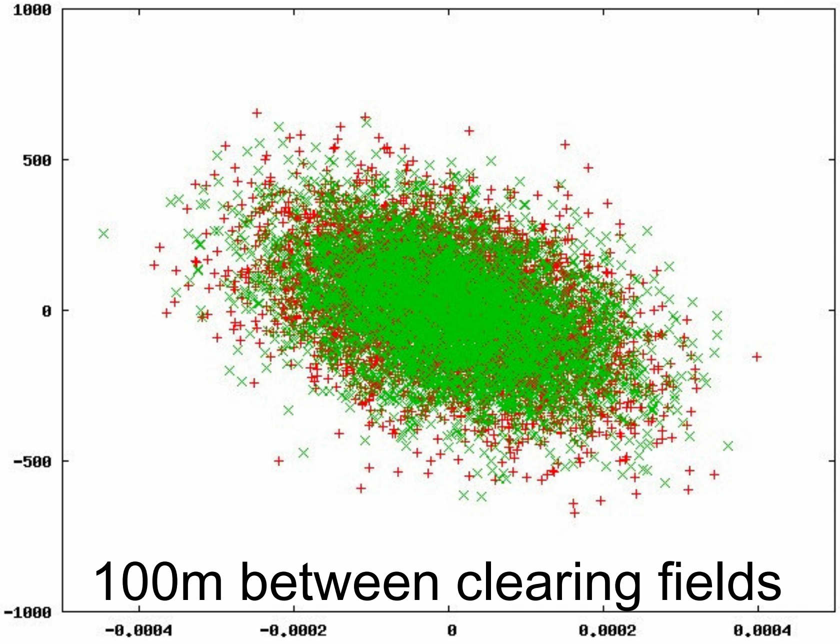
200m between clearing fields

Ions in an ERL beam





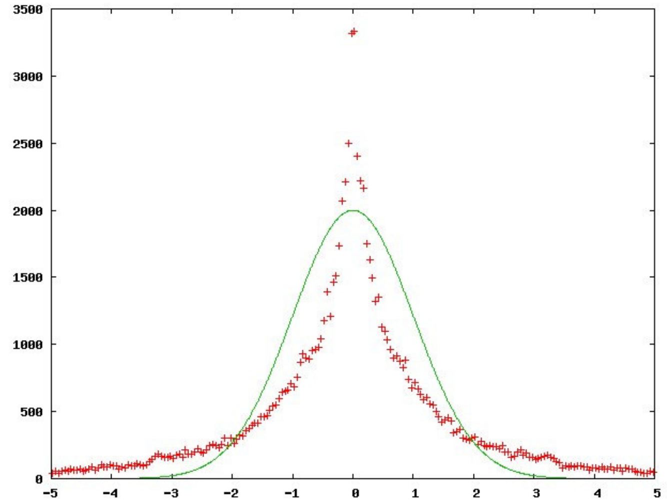
200m between clearing fields

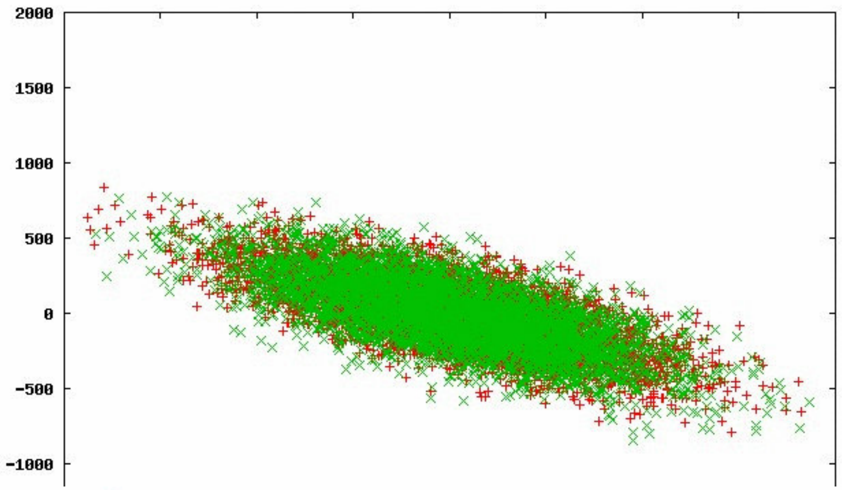


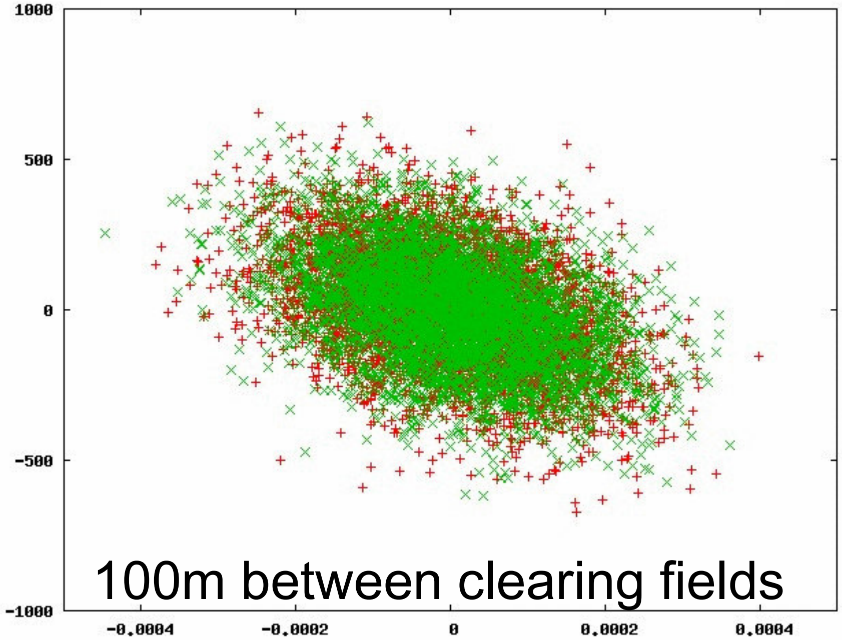
100m between clearing fields

Ions in an ERL beam

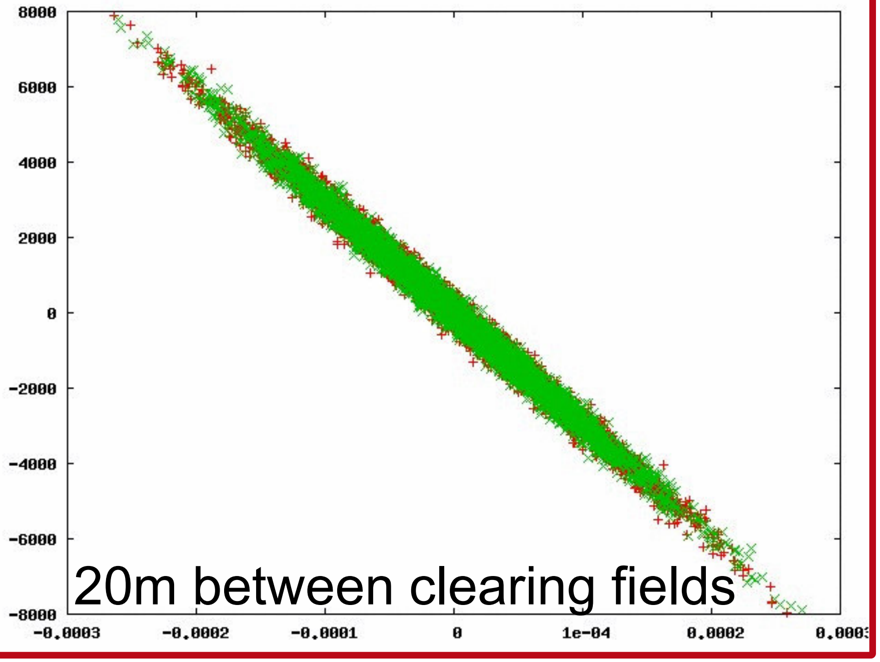
CHESS & LEPP







100m between clearing fields



20m between clearing fields

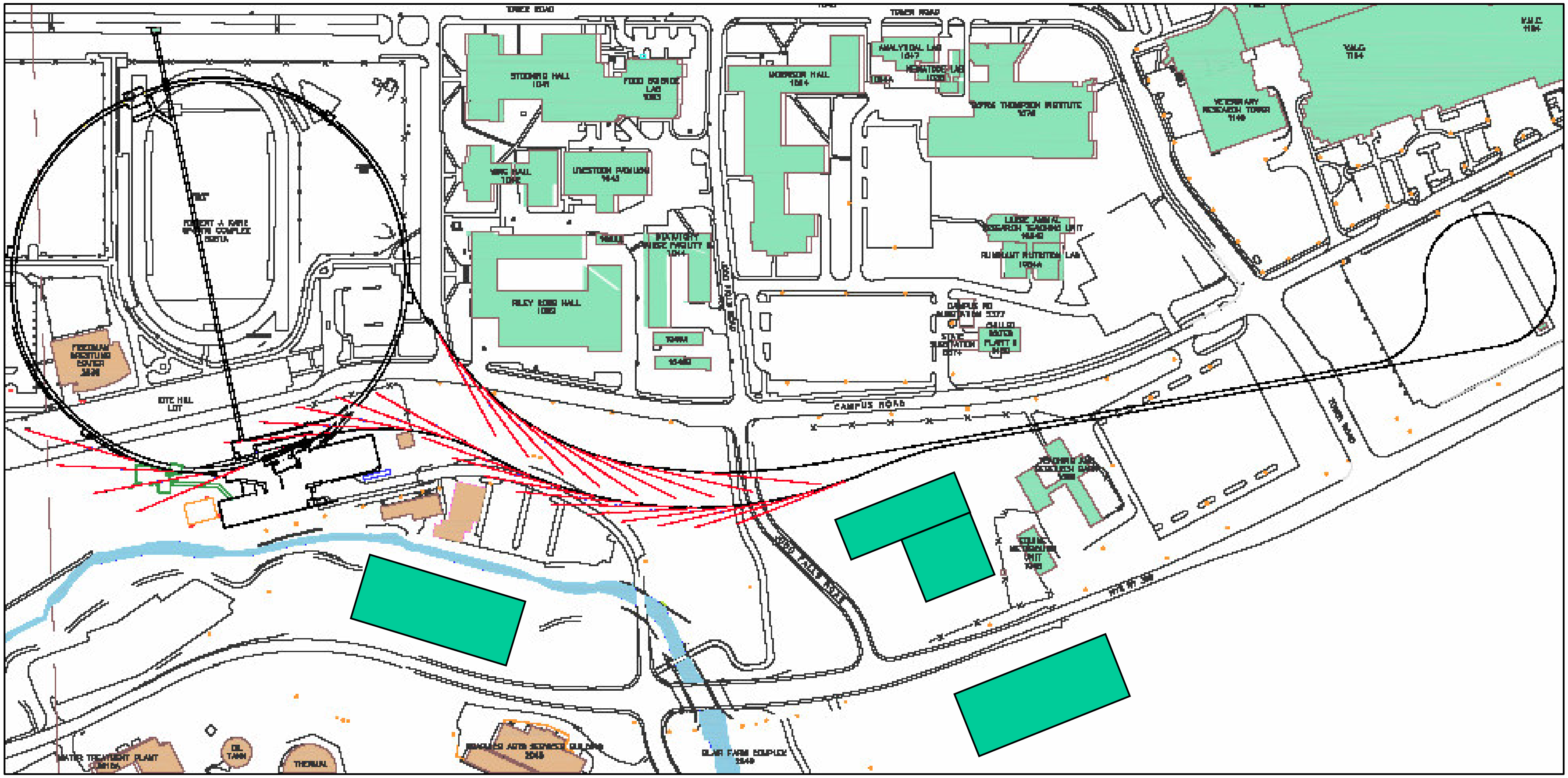
(4) Challenges for x-ray ERLs

- Superconducting RF challenges
  (WG 3)
  - Phase and amplitude control for very narrow frequency window (10^{-8})
  - Avoid heating / Higher order mode absorption
  - Limit cooling power

Cryogenic building

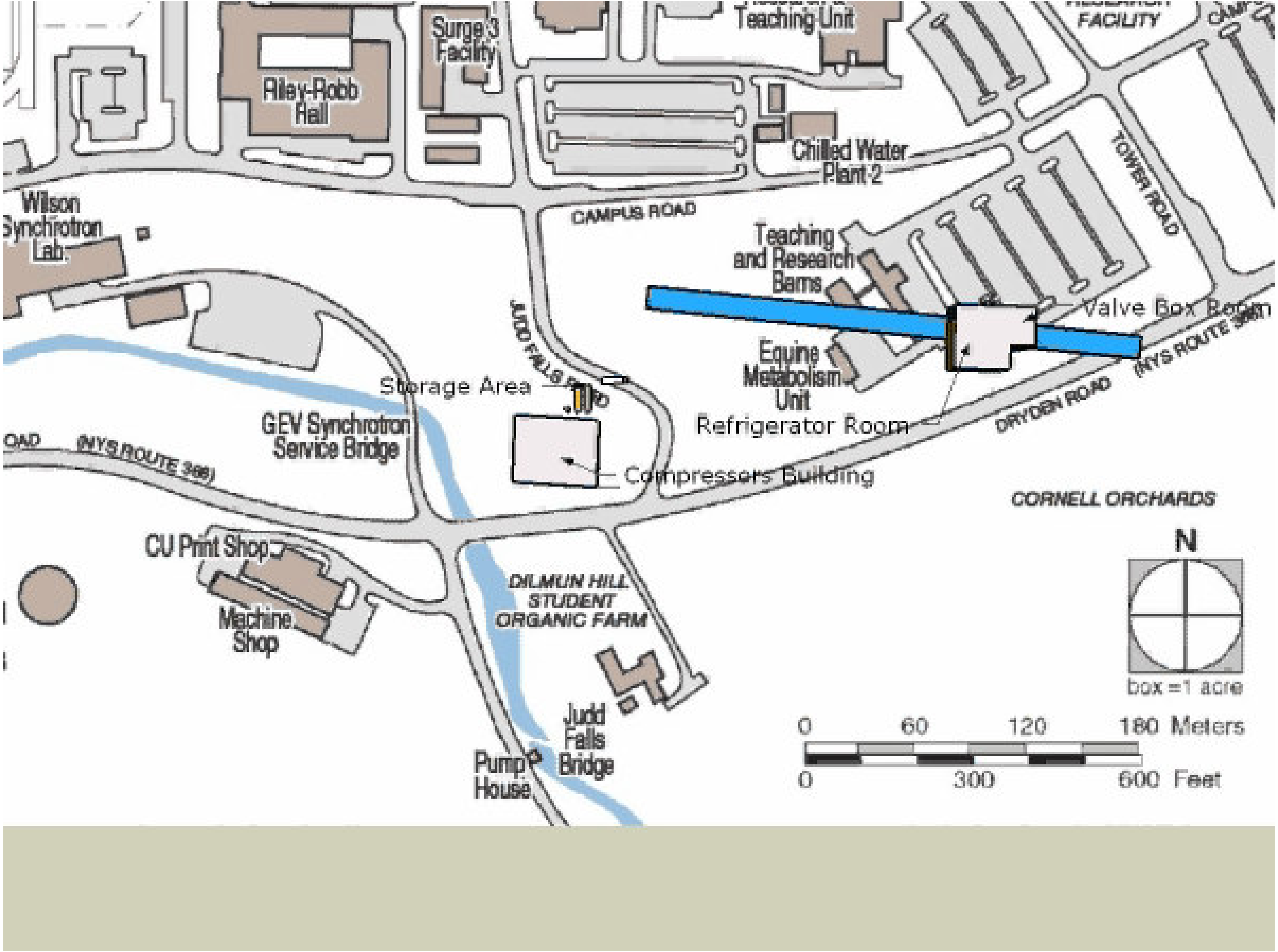
CHESS & LEPP

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



Cryogenic building

CHESS & LEPP



Challenges for x-ray ERLs

- Production of low emittances + limiting emittance growth (WG1 / WG2)
  - Limit coupler kicks / cavity misalignments
  - Limit optics errors and adjust fields to radiated energy
  - Low emittance growth optics similar to light sources
- Limit energy spread after deceleration, e.g. 5GeV to 10MeV (WG2)
  - Accurate time of flight correction, including sextupoles
  - Limit energy spread from wake fields
  - Limit energy spread from intra beam scattering (IBS) and rest gas scattering
  - Limit energy spread from incoherent / coherent synchrotron radiation (ISR / CSR)
- Manage user community
  - Running with different modes, bunch patterns, currents
- Beam stabilization – as stable as rings (WG4)
  - Limit beam breakup instability (BBU)
  - Limit beam jitter by feedback
  - Tolerances
- Beam loss concerns
  - Beam loss from IBS / Tourschek
  - Rest gas scattering
  - Disturbance from ions / ion removal
  - Halo development
- Superconducting RF challenges (WG 3)
  - Phase and amplitude control for very narrow frequency window (10^{-8})
  - Avoid heating / Higher order mode absorption
  - Limit cooling power