ERL Layout, Optics, Accelerator Physics

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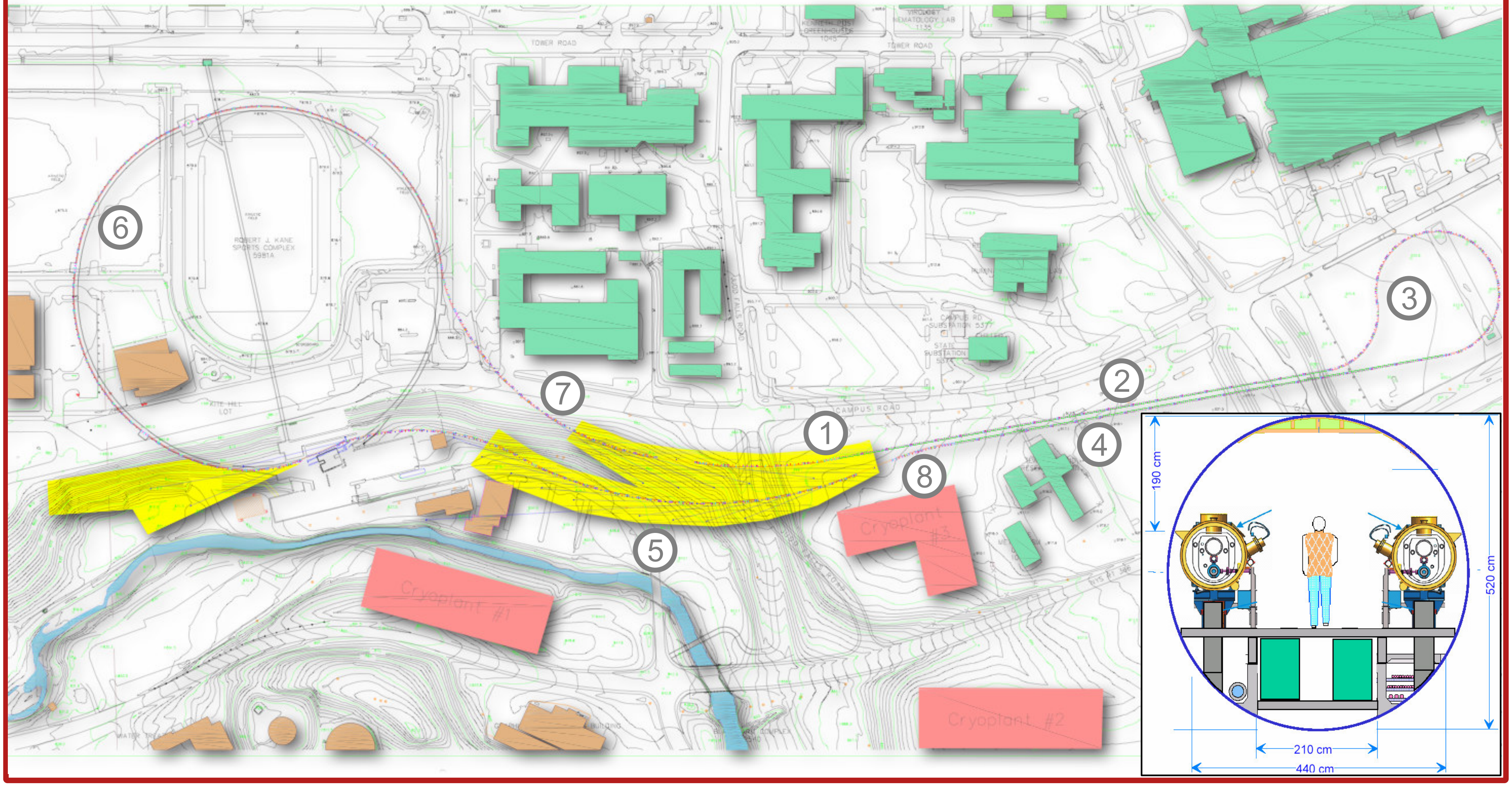
for the ERL design team



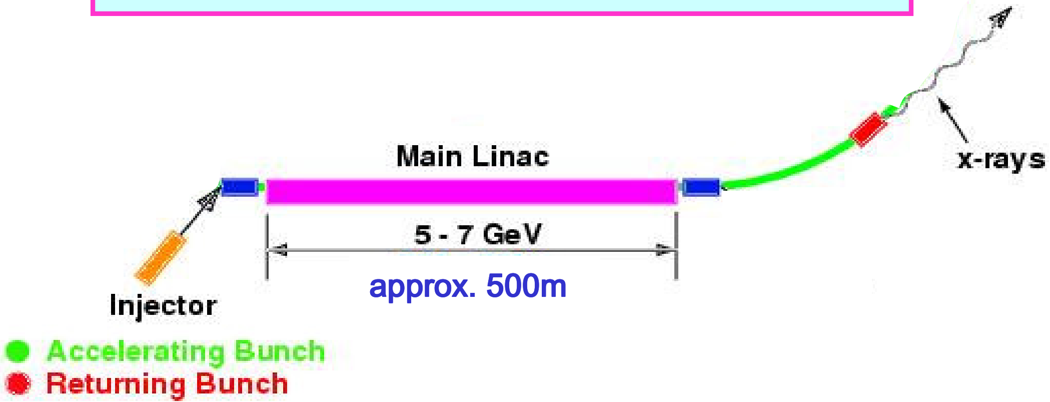
Talk overview

1. Introduction to x-ray ERLs
2. Layout
3. Optics
4. Emittance preservation
5. Beam stability
6. Background rates and machine protection
7. Concluding topics

Principle of an X-ray ERL

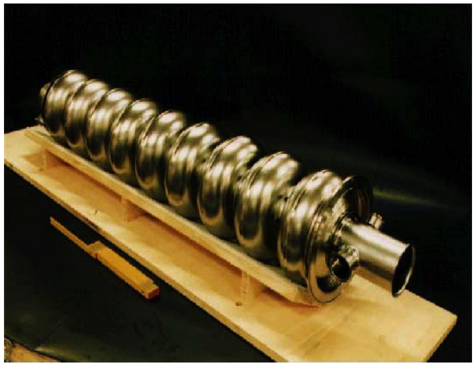
X-ray analysis with highest resolution in space and time:

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



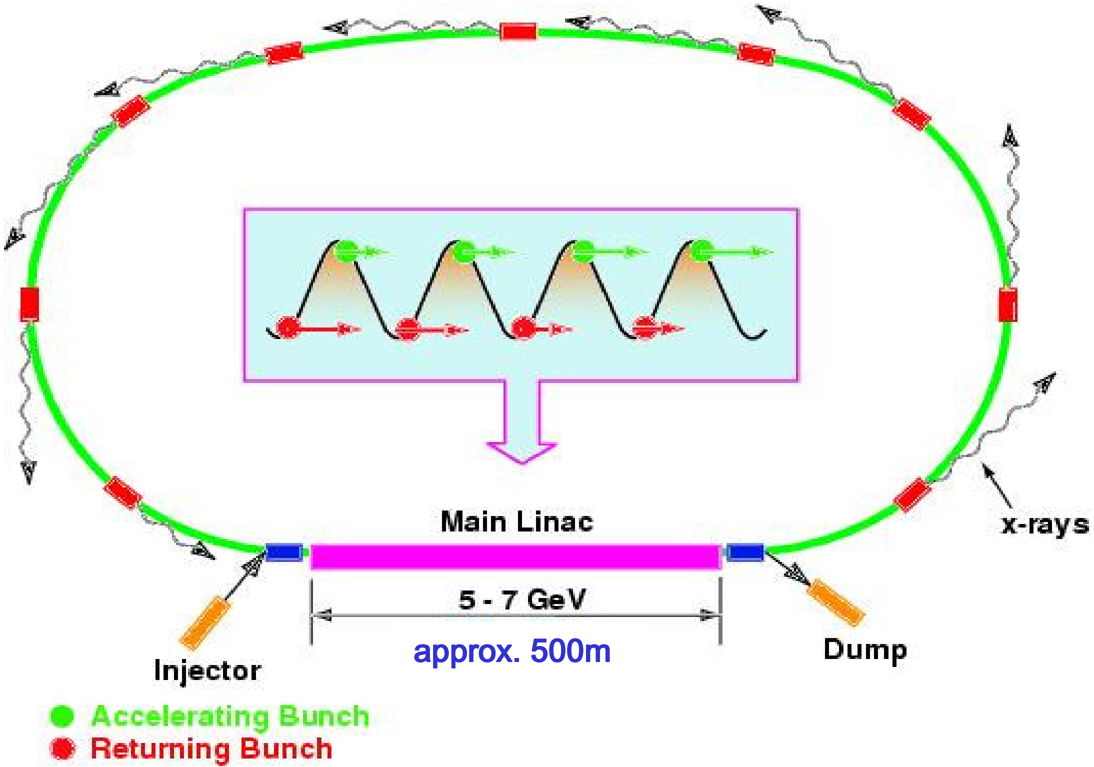
Challenges:

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



Principle of an X-ray ERL

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



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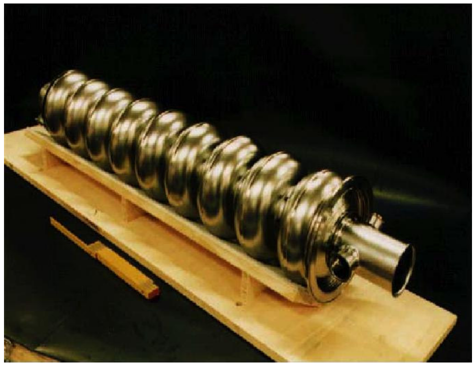


Flux comparison: ERL / state of the art

Comparison to

Friedrich Schotte, “Picosecond time-resolved x-ray crystallography: probing protein function in real time.” L=1.6m, lu=17mm, 45nC per bunch, 6GeV, st=150ps (for 35nC)

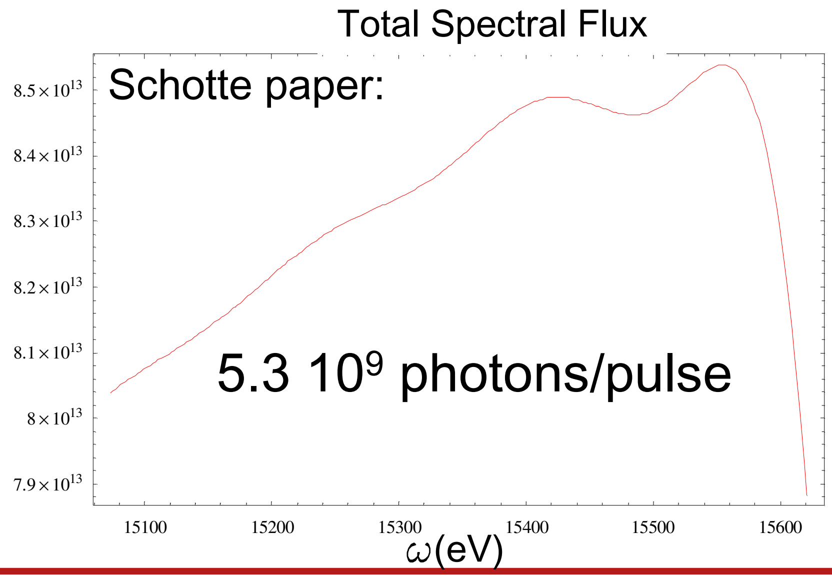
Claim: 10^{10} photons per pulse in 3.5% around l=0.79 Angstom

And other papers.

Conclusion:

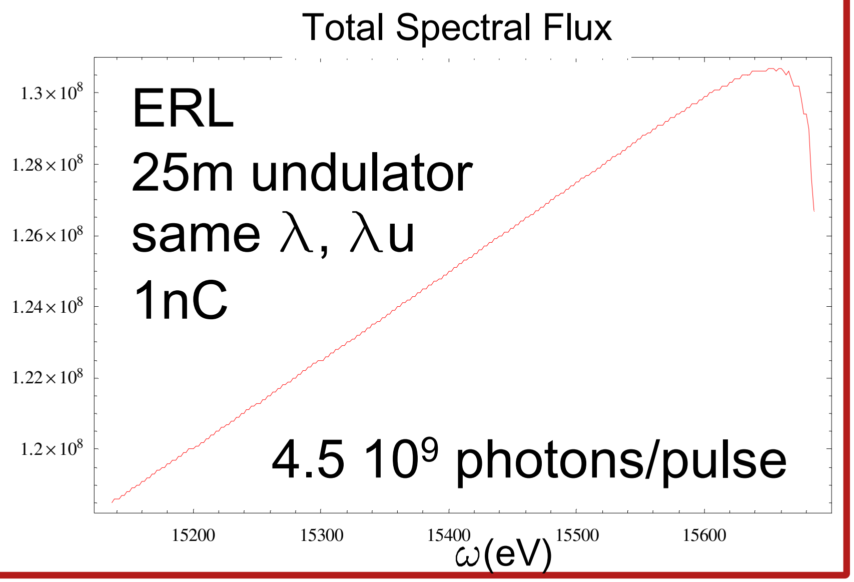
A 25m long undulator in the ERL that has the same K as existing short pulse (35ps) experiments has similar photons per pulse.

By locating the first harmonic peak at the desired energy and choosing the best energy window location around it, SPECTRA leads for a linear undulator to:



Schotte paper:

5.3 10^9 photons/pulse



ERL

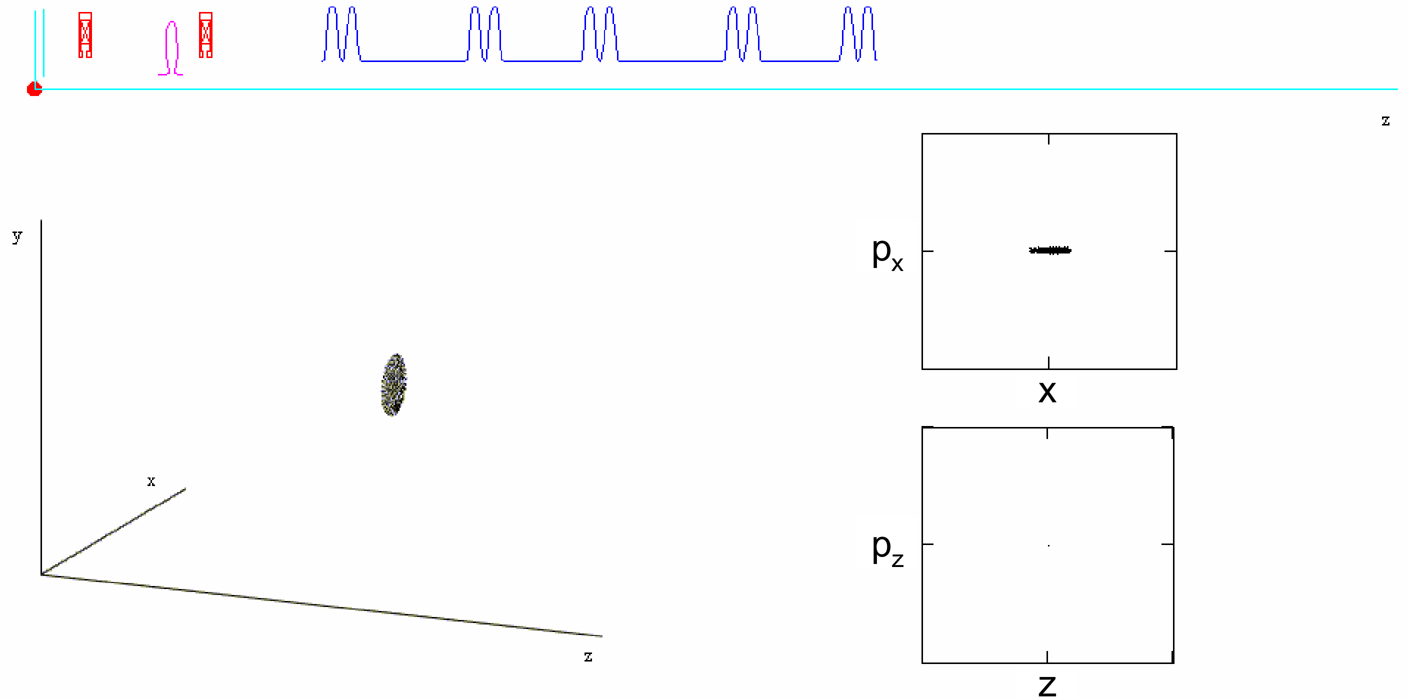
25m undulator

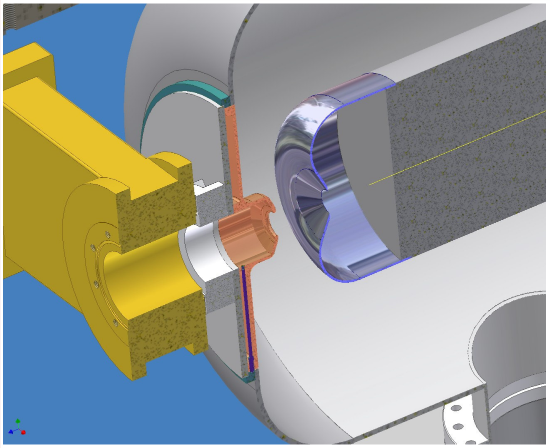
same λ, λu

1nC

4.5 10^9 photons/pulse

The injector: round beam optimization





DC source for high current & low emittances

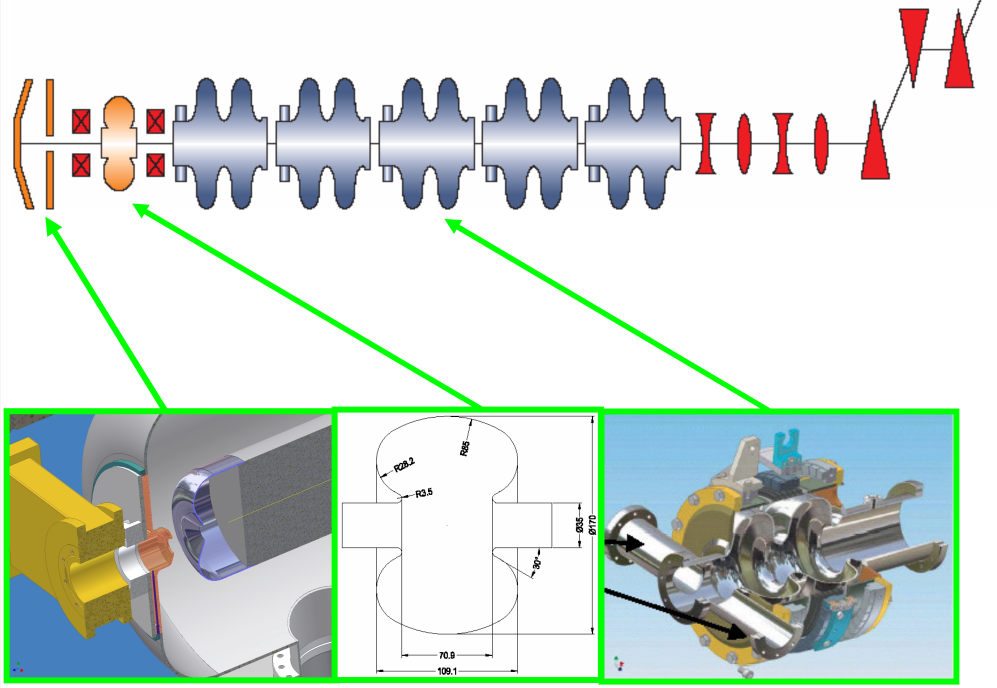
- Simulations show 10 times smaller emittances than previously thought possible, and 50 times smaller than standard.
- Gun development, coating for low field emission
- Photocathode development, neg. el. affinity GaAs, cooled
- Laser beam shaping

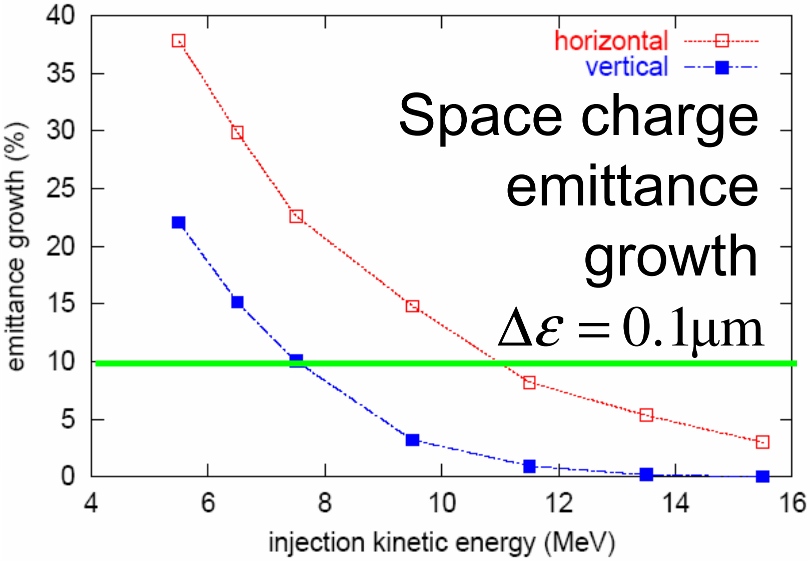
The injector optimization

HIGH BRIGHTNESS, HIGH CURRENT INJECTOR DESIGN FOR THE CORNELL ERL PROTOTYPE*

2003 Particle Accelerator Conference

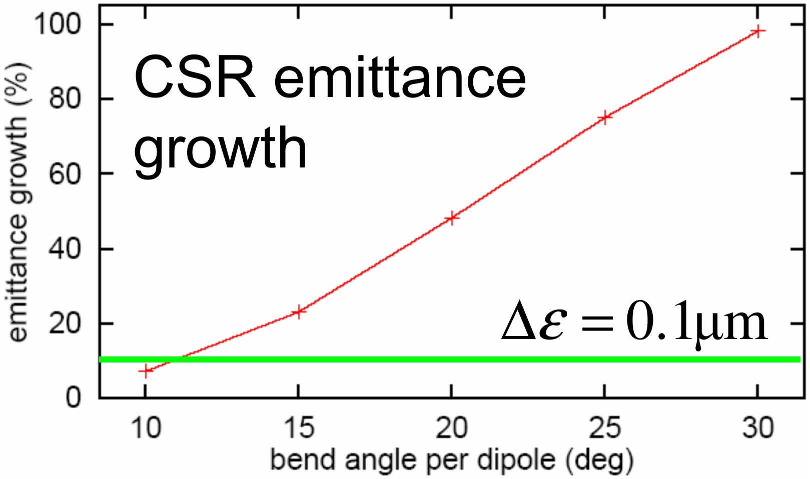
I.V. Bazarov† and C.K. Sinclair





Space charge emittance growth

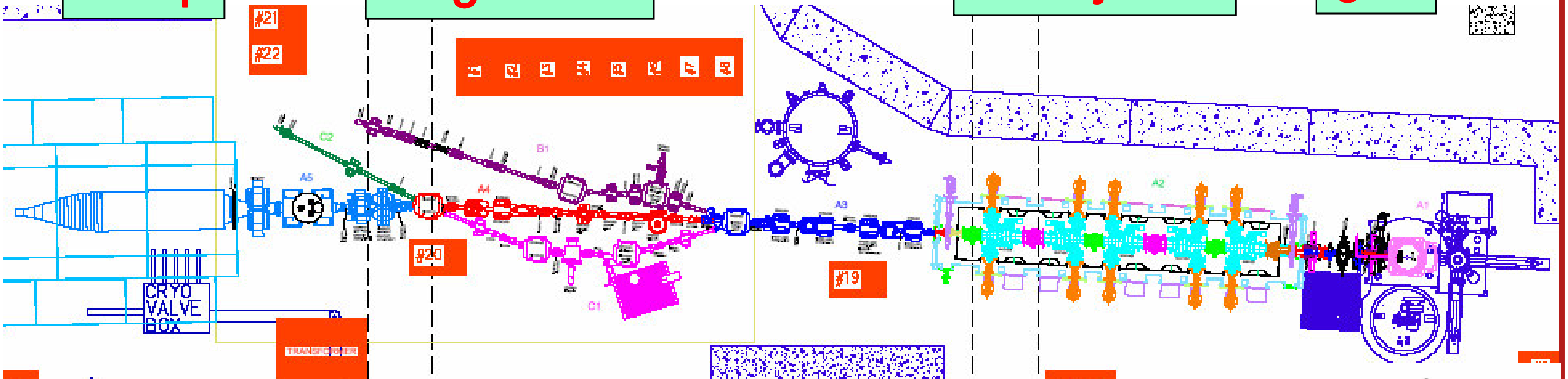
$\Delta\varepsilon = 0.1\mu\mathrm{m}$



CSR emittance growth

$\Delta\varepsilon = 0.1\mu\mathrm{m}$

Cornell Injector prototype: Verification of beam production



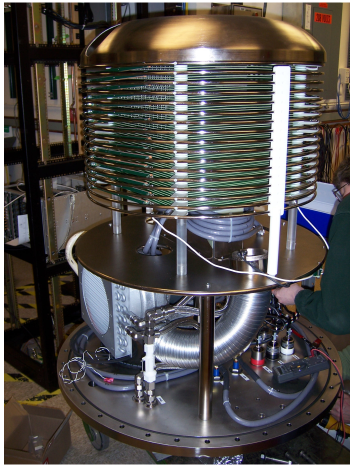
dump

diagnostics

SC injector

gun

Power sup.



Cathode

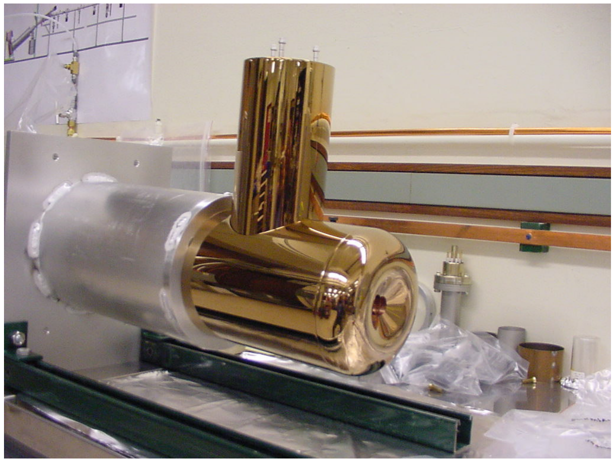
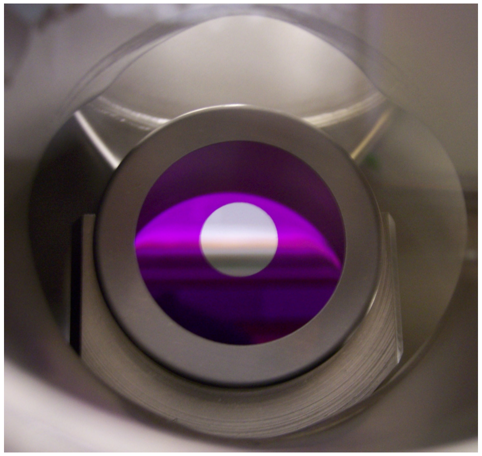
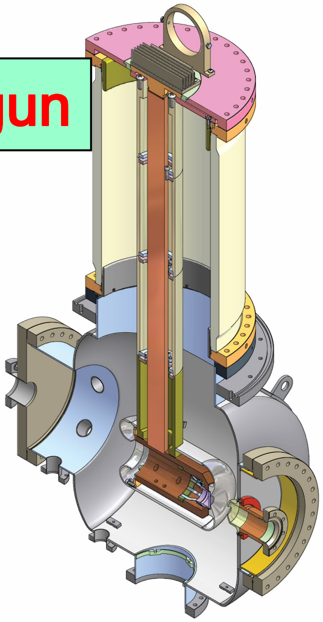


Photo emitter



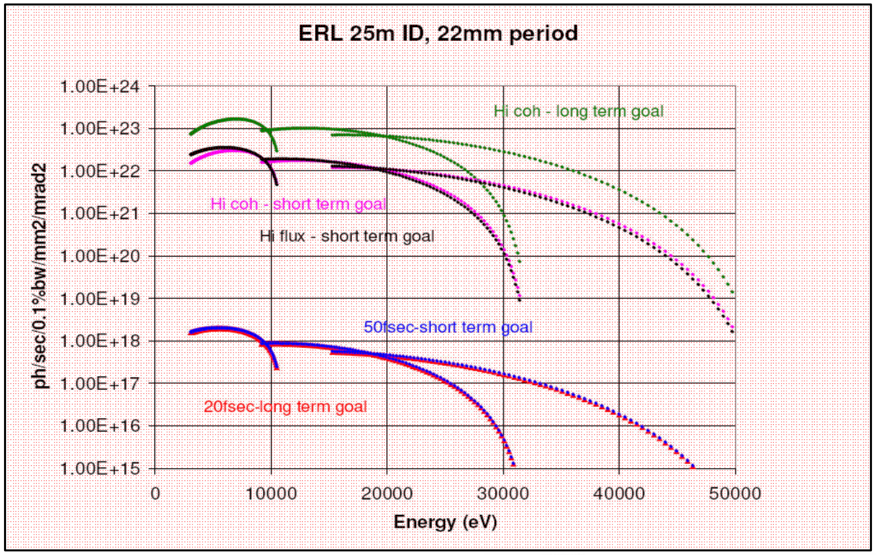
gun

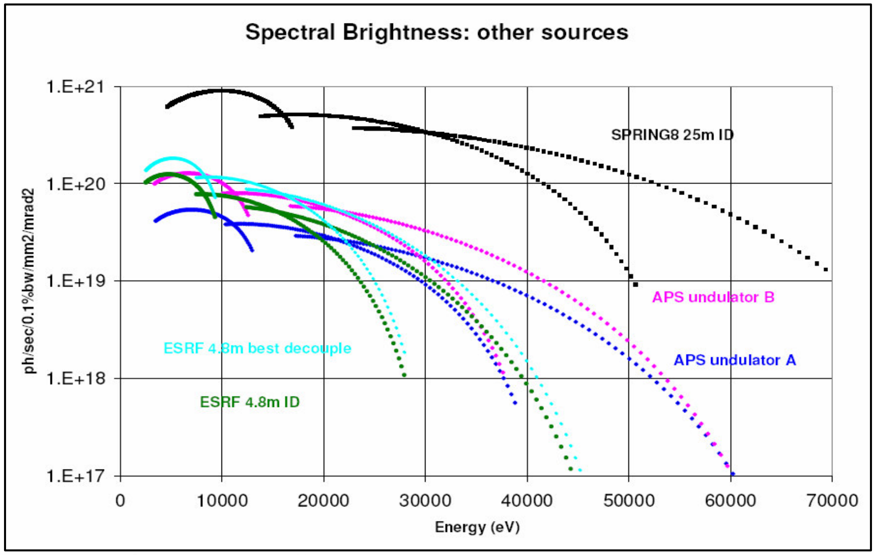


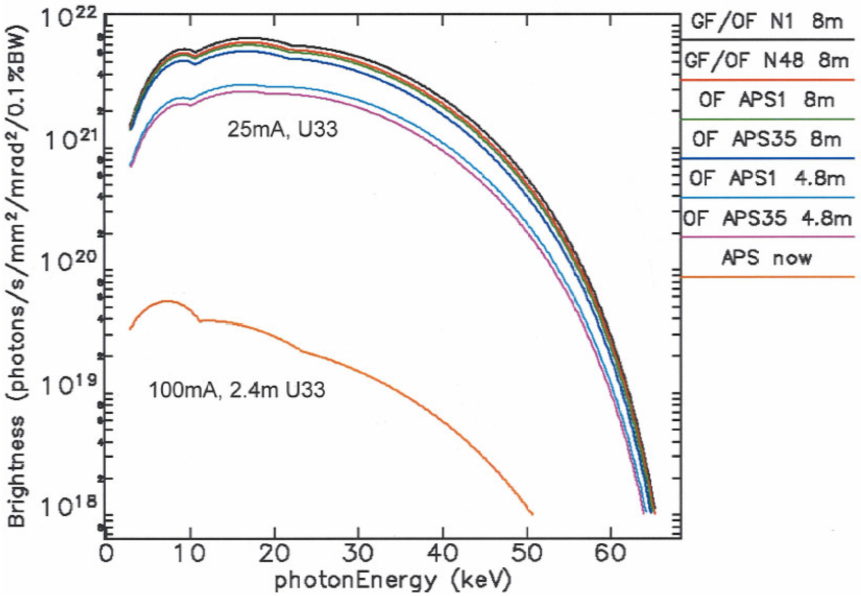
The injector: goals for the ERL

	Energy recovered modes			One pass	
Modes:	(A) Flux	(B) Coherence	(C) Short-Pulse	(D) High charge	Units
Energy	5	5	5	2.5	GeV
Current	100	25	100	0.1	mA
Bunch charge	77	19	77	1000	pC
Repetition rate	1300	1300	1300	0.1	MHz
Norm. emittance	0.3	0.08	1	5.0	mm mrad
Geom. emittance	31	8.2	103	1022	pm
Rms bunch length	2000	2000	100	50	fs
Relative energy spread	0.2	0.2	1	3	10^{-3}
Beam power	500	125	500	0.25	MW
Beam loss	< 1	< 1	< 1	<1	micro A

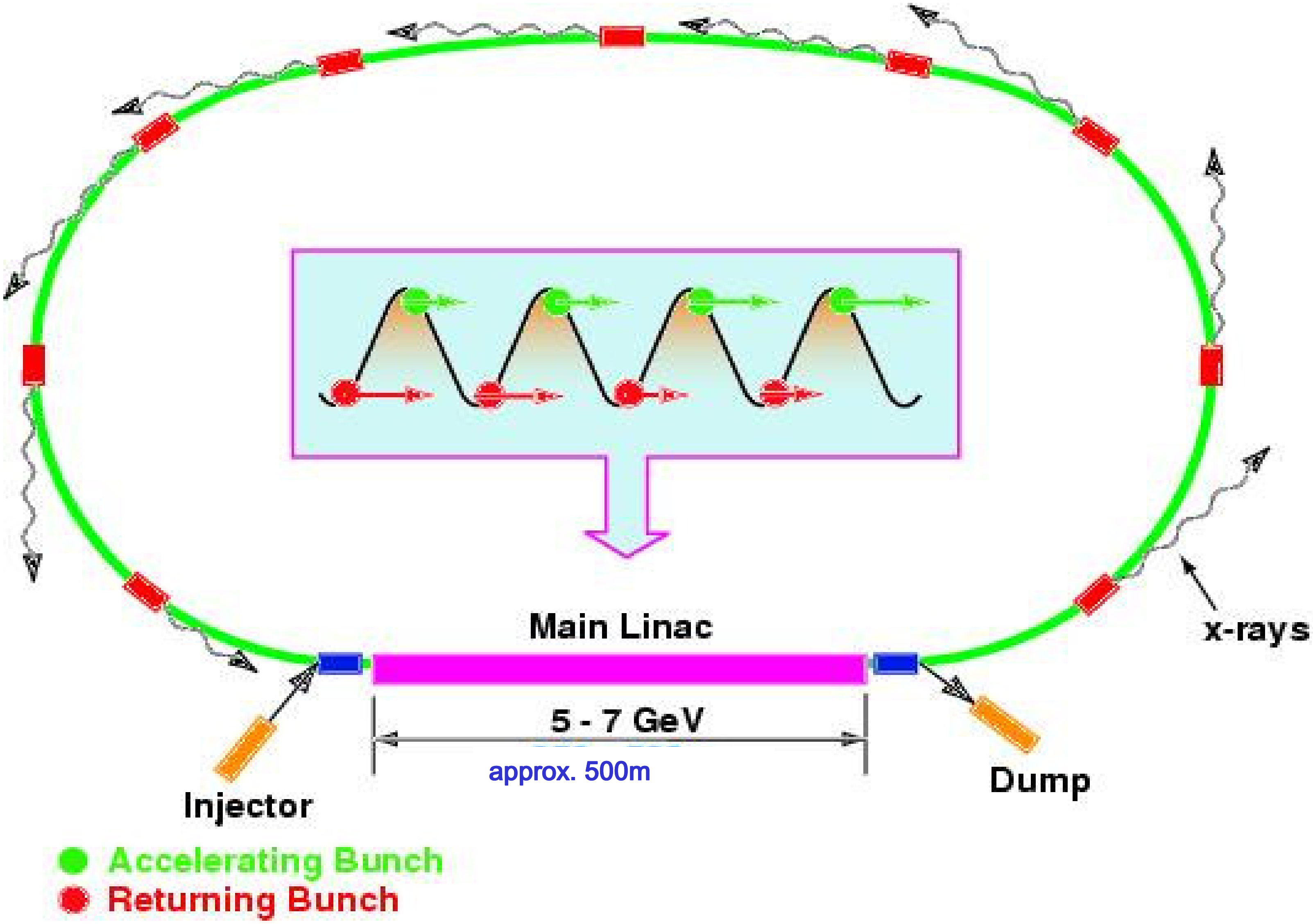
How large is the advantage of ERLs ?



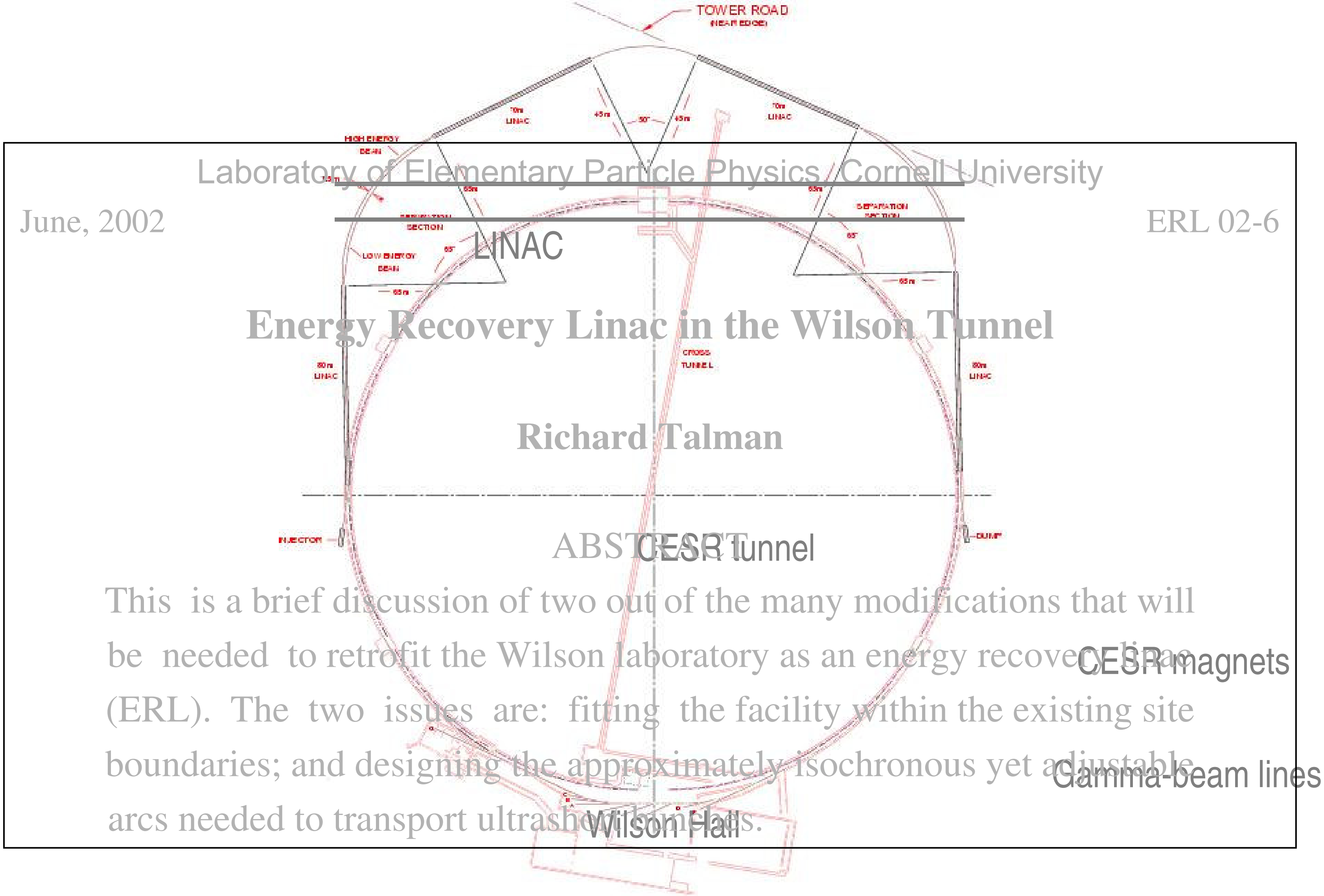




Layout options: Green field design



Layout options: CESR extension



Laboratory of Elementary Particle Physics, Cornell University

June, 2002

ERL 02-6

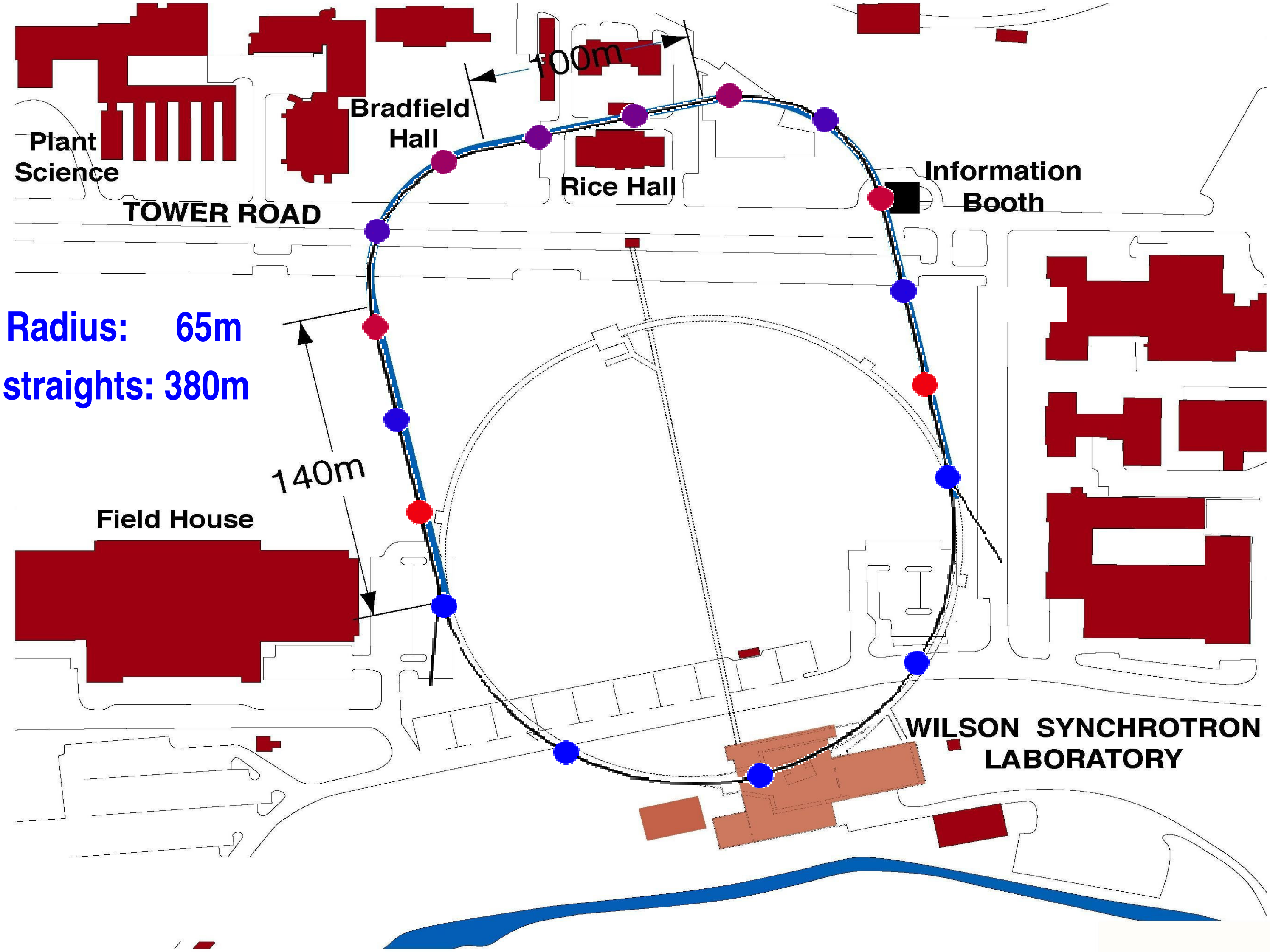
Energy Recovery Linac in the Wilson Tunnel

Richard Talman

ABSTRACT

This is a brief discussion of two out of the many modifications that will be needed to retrofit the Wilson laboratory as an energy recovery linac (ERL). The two issues are: fitting the facility within the existing site boundaries; and designing the approximately isochronous yet adjustable arcs needed to transport ultrashort bunches.

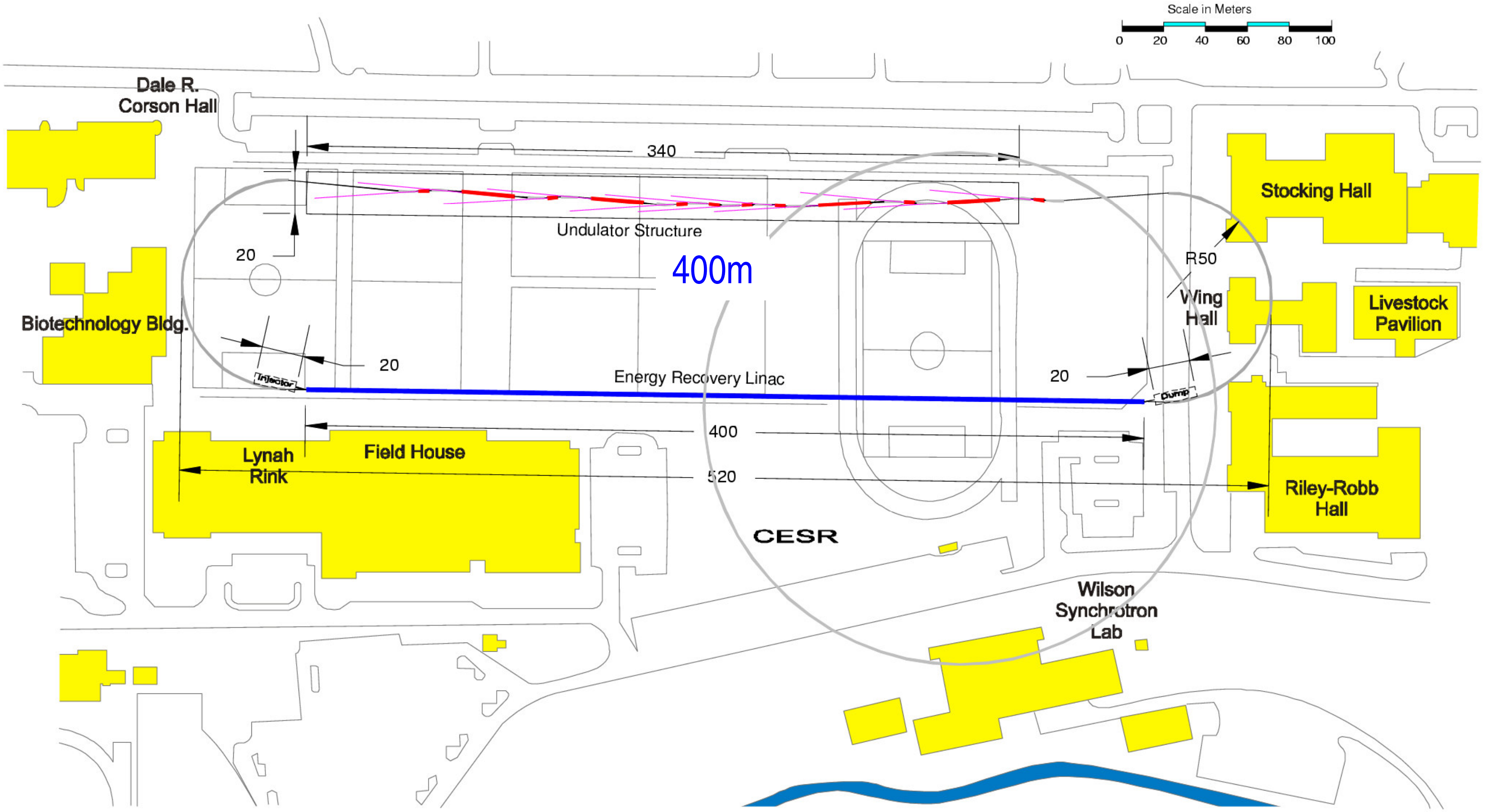
An ERL@CESR



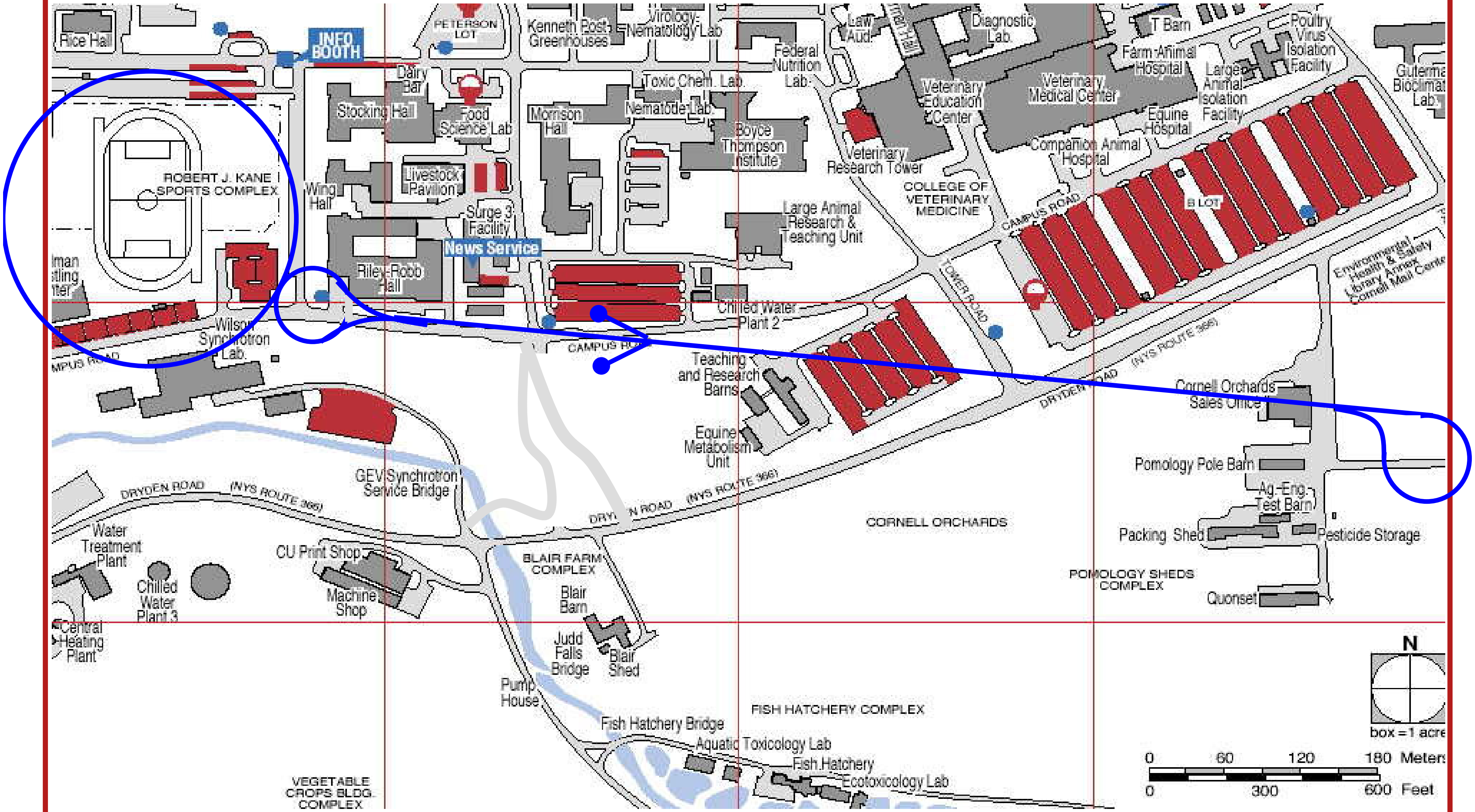
Bend Radius: 65m

Total straights: 380m

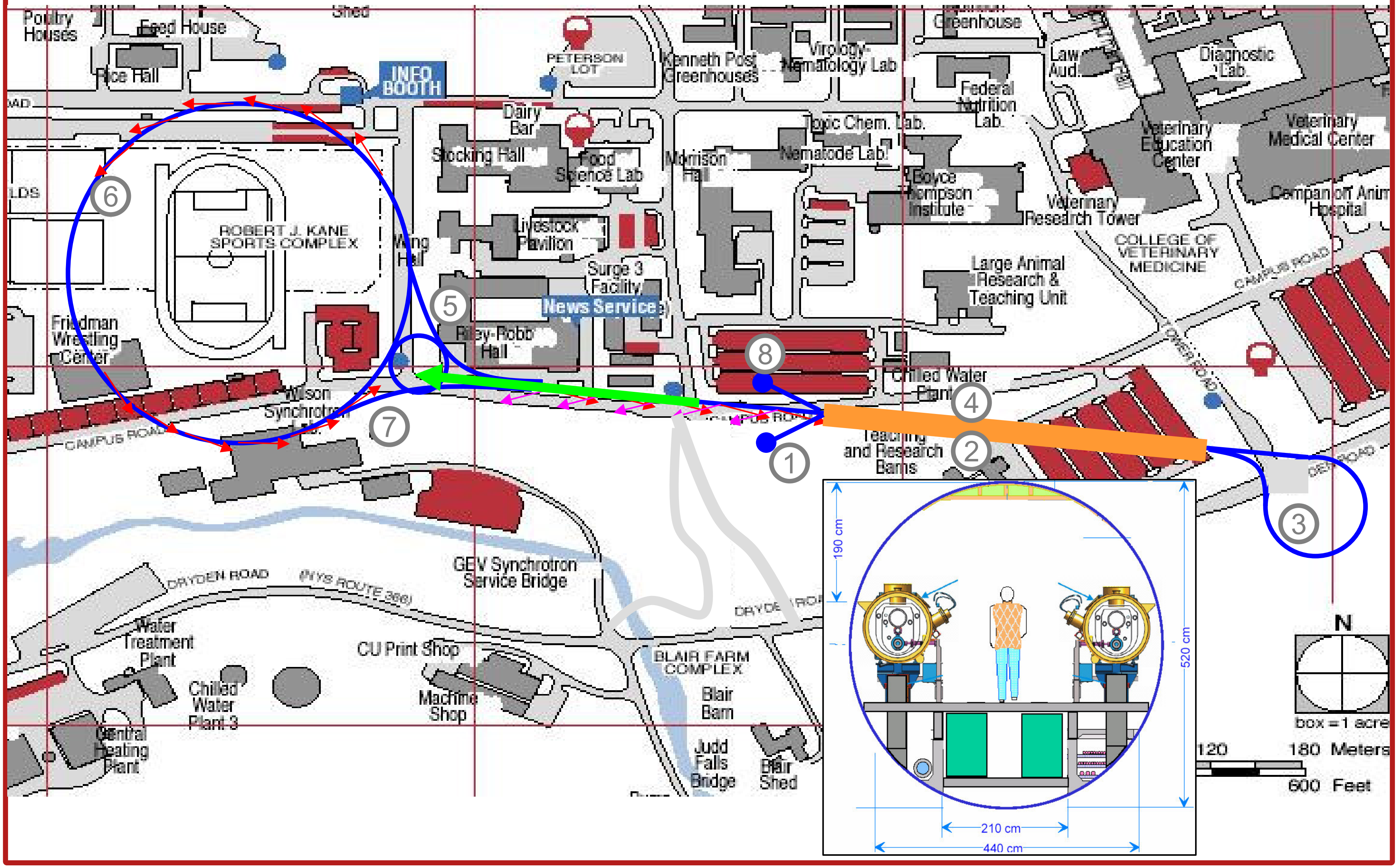
Green Alumni-Field design



ERL injection into CESR



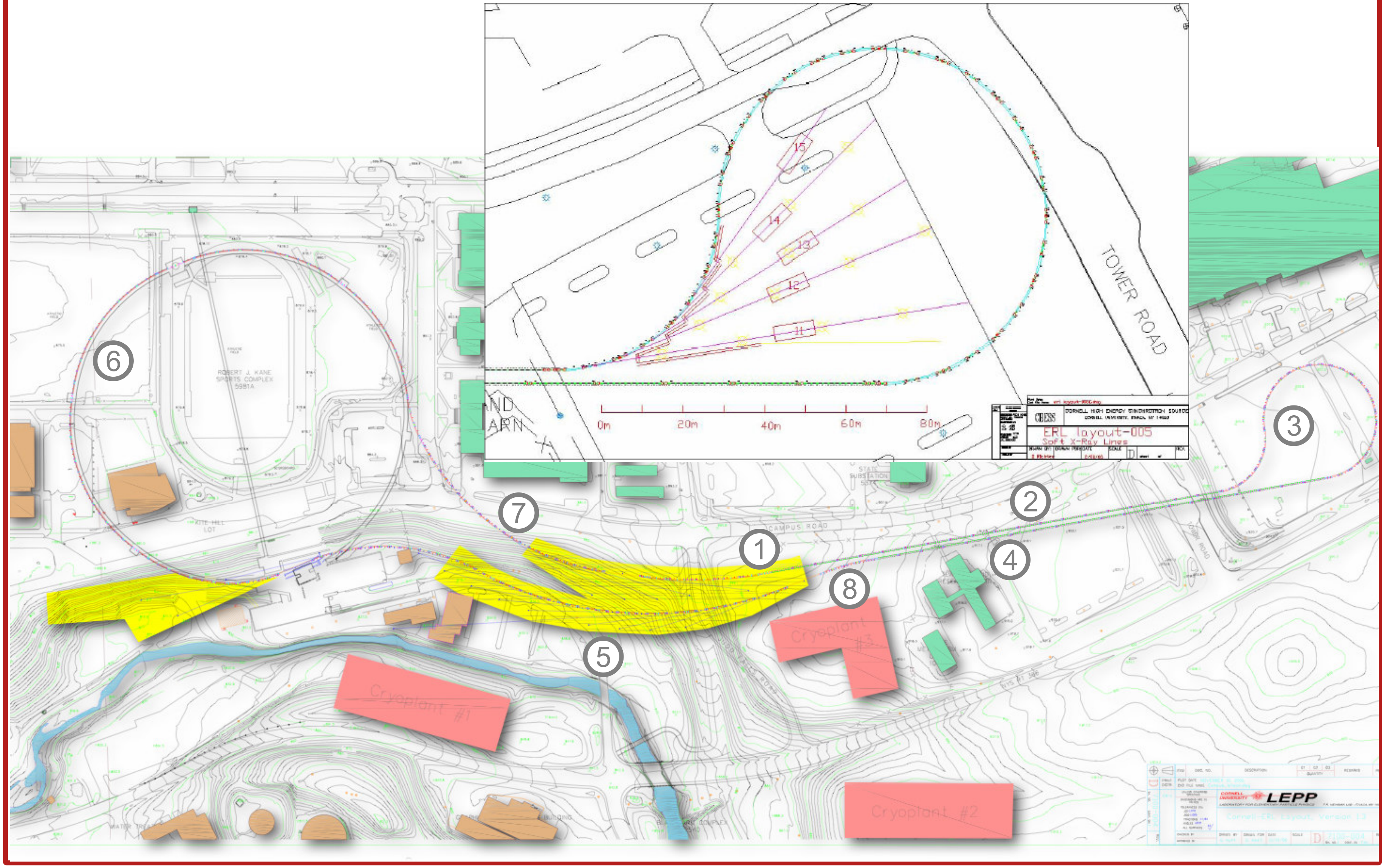
Smooth injection + commissioning loop



Advantages of ERL@CESR

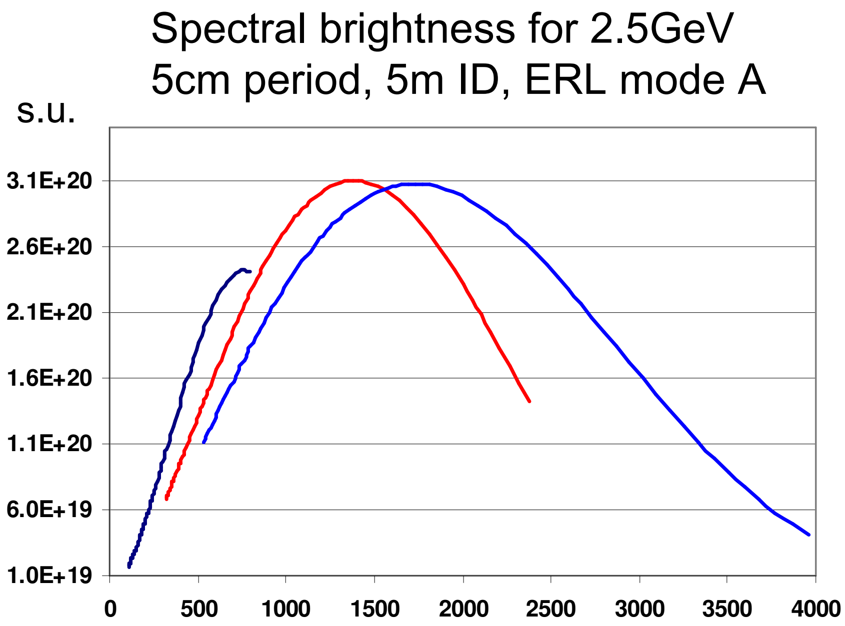
- Operation of CESR and ERL test simultaneously.
- Use all of the CESR tunnel.
- Lots of space for undulators.
- Space for future upgrades, like an FEL.
- No basements of existing buildings to worry about.
- Only one tunnel for two linacs.
- Less competition, since other sights cannot offer upgrades.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

Dog-bone design

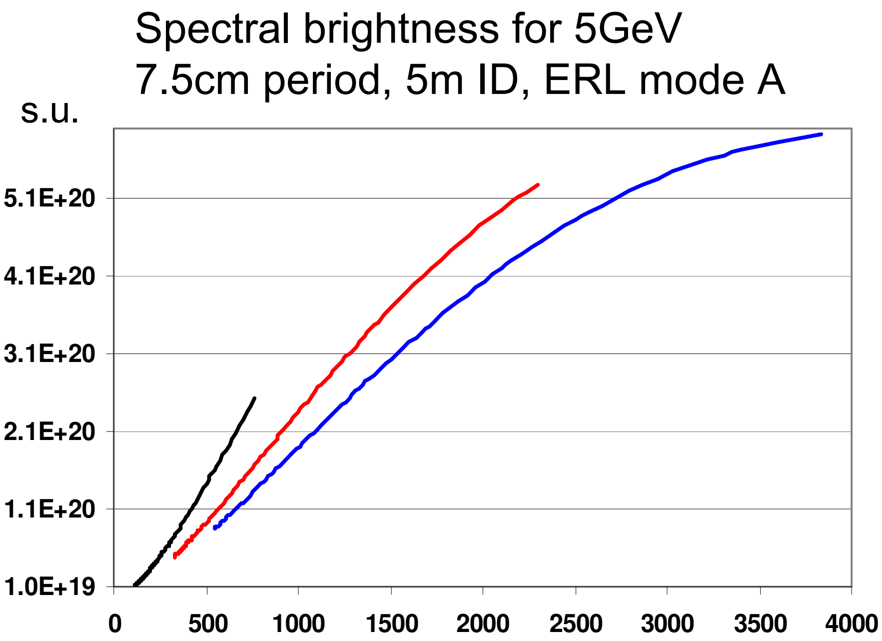


2.5 GeV soft x-ray beamlines ?

PPM ID tuning curves for $0.1 < E_{1,3,5} < 4$ KeV when gap ≥ ½ cm



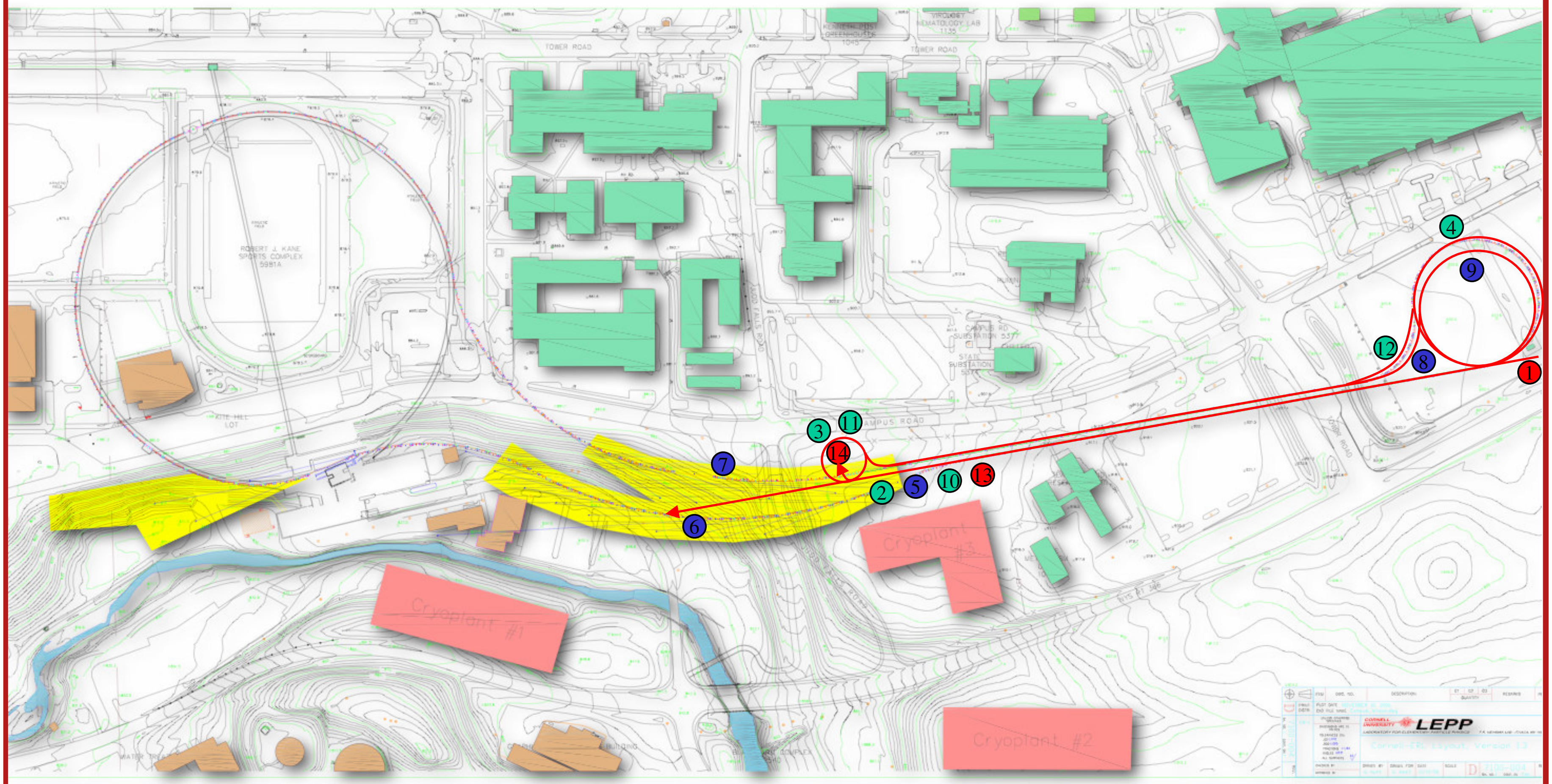
Spectral brightness for 2.5GeV
5cm period, 5m ID, ERL mode A



Spectral brightness for 5GeV
7.5cm period, 5m ID, ERL mode A

5GeV (66 periods/5m) device has ~ 2X brilliance of 2.5GEV,100 period ID

2-turn ERL operation



1: injector
2: acceleration to 2.5GeV
3: return to the East
4: 2.5GeV turnaround to the linac
5: acceleration to 5GeV
6: to x-ray beamlines
7: return through CESR
8: 5GeV beam separation
9: 5GeV turnaround to the linac
10: deceleration to 2.5GeV
11: return to East
12: 2.5GeV turnaround to linac
13: deceleration to 2.5GeV
14: dump at 10MeV

Conclusion of 2-turn ERL analysis

1) Beam dynamics could be controlled

Space-charge beam dynamics seems to be manageable

Emittance growth can be managed by appropriate return loop sizes

2) Risks remain:

More complicated RF control

Less overhead for BBU

Four beam positions need to be stabilized simultaneously

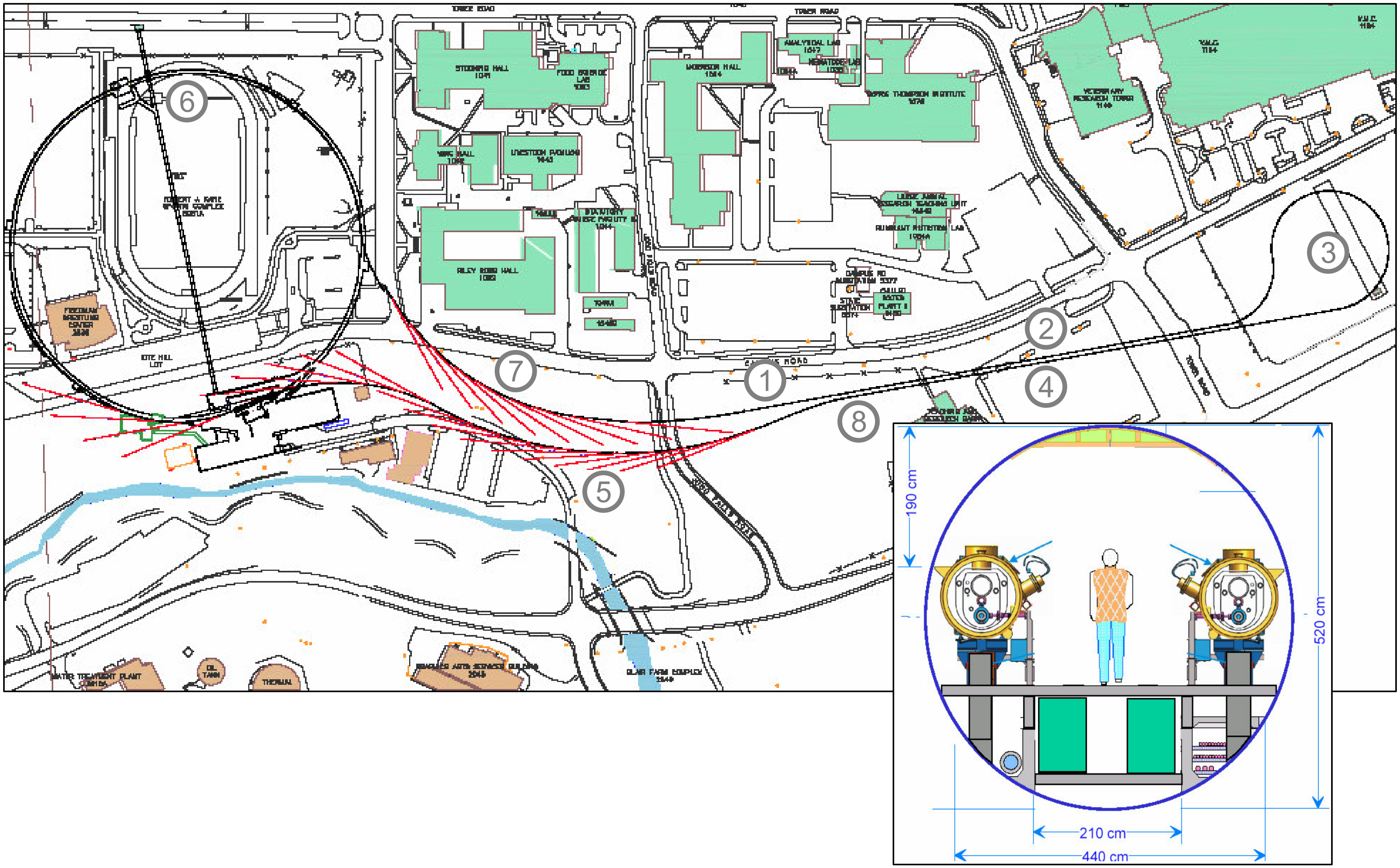
3) Cost savings:

In best of circumstances, 10 year cost savings would be around 6%

4) Conclusion

While 6% is a substantial cost saving, developing and proposing a 2 turn ERL does not seem reasonable at this time.

ERL@CESR design version 2.0



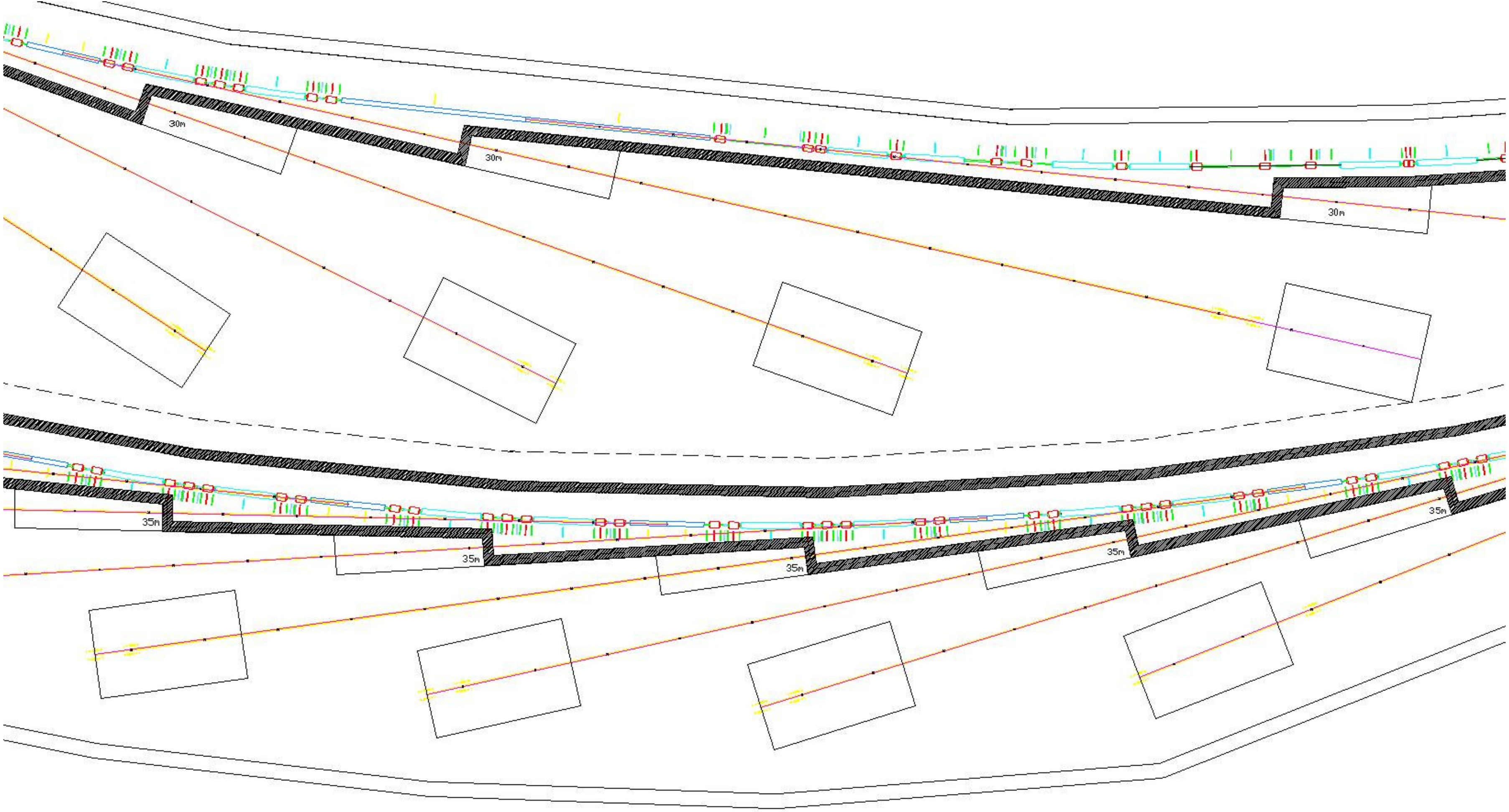
List of desired x-ray beamlines

5 GeV ERL: table of beamlines last changes: Sept. 04, 2006 by GH

#	Function	Application	ID	L(m)	β(m)	Mode	beam	E range	BL length
1	Inelastic Scattering	meV resolution	U	25	12	"		20<E_g(KeV)<30	70m
2	Diagnostic beamline	machine diagnostics	U	2.5	2.5	all modes	pink, mono	"	70m
3	Protein crystallography III	micro-focus	U	2.5	1.25	"	"	"	70m
4	Nanoprobe	1 nanometer beams	U*	2.5	0.5	Hi-Coh		1<E^*(Kev)<10	70m
5	microscope, nanoprobe	TXM, STXM	U	2.5	0.5	"	"	"	70m
6	phase contrast, topography	biomed, matscience	U	2.5	0.5	Hi Coh	mono	<25KeV	200m
7	coherent diffraction, XPCS	microscopy, dynamics		U	25	5.0	pink, mono	<25KeV	80m
8	Protein crystallography II	MAD	U	5.0	1.0	"	"	"	70m
9	SoftX microscope	biomaterials	heIU	5.0	2.5	Hi Flux	mono	<5KeV	70m
10	SoftX, XMCD, ARPES	mag/elect materials	heIU	5.0	2.5	"	vari-polariz	<5KeV	70m
11	High Energy Scattering	PDF, Compton, etc	U	5.0	2.5	"	high K & n	>100KeV	80m
12	Protein crystallography I	high throughput	U	5.0	2.5	Hi-flux	tuneable	<25KeV	70m
13	Materials science I	high pressure	U	5.0	2.5	Hi-flux		20<E(KeV)<40	70m
14	Materials science II	general application	U	5.0	2.5	"		5<E(KeV)<30	70m
15	Materials science III	resonant el&inelastic	U	5.0	2.5	"	ΔE(eV)<1	<25KeV	70m
16	GSAXS, XPCS, SAXS	polymers, liquids	U	5.0	2.5	"	pink & 1%bw	"	70m
17	ASAXS, micro-SAXS	catalys	U	5.0	2.5	"	"	"	70m
18	Femtosecond science	pump-probe, etc	U	25	5	Ultra-fast	timing	<25KeV	70m

Bends to accommodate hutches and mirrors

1st optics at 35m after center of undulator, outside shielding wall.
80m long x-ray beamlines.



Radiation in Arcs

Radiative effects in the linac loop:

1) Incoherent-radiation emittance growth
2) Incoherent-radiation energy spread
3) Power deposition
4) Power deposition per length of bend
5) Coherent-radiation emittance growth

For CESR arc:

1) Incoherent-radiation emittance growth:

$0.022\ 10^{-10}\ \mathrm{m}^2\ (E/5\mathrm{GeV})^5(\vartheta\ 180/\pi)^3\ F/\rho$

F=0.064 for min emit, 0.22 for achro, 1.3 for fodo

$F \times 4.8\ 10^{-12}\mathrm{m}$

2) Incoherent-radiation energy spread:

$9\ 10^{-4}\ \mathrm{m}\ (E/5\mathrm{GeV})^{7/2}/\rho$

$3.9\ 10^{-6}$

3) Power deposition

$5.5\mathrm{MW\ m}\ (E/5\mathrm{GeV})^4(I/100\mathrm{mA})/\rho$

17kW

4) Power deposition per length of bend

$5.5\mathrm{MW\ m}\ (E/5\mathrm{GeV})^4(I/100\mathrm{mA})/2\pi\rho^2$

130W/m [APS/10]

Designs for different power with achromats

Power per length:	as in CESR		as in APS	
	Folded linac	Single linac	Folded linac	Single linac
Bending radius (from P/L limit)	**20m**	**82m**	**6.5m**	**26m**
Number of bends (ε growth limit)	**27**	**55**	**40**	**81**
Length of bends	**4.6m**	**9m**	**1m**	**2m**
Total power	**17kW**	**67kW**	**53kW**	**212kW**
Energy spread	**3.8e-6**	**1.1e-5**	**1.2e-5**	**3.5e-5**

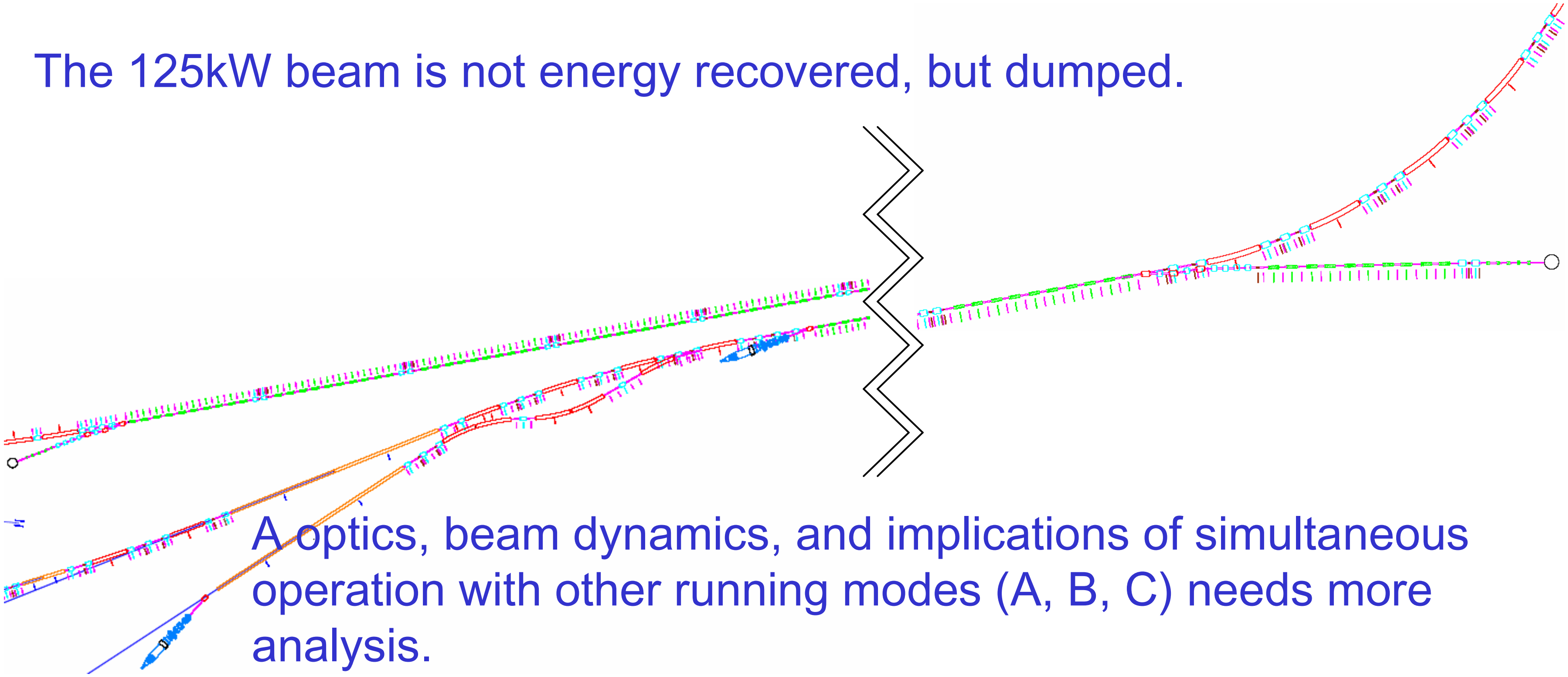
- Because each the TA has to be isochronous, it is simplest to make each cell isochronous.
- The dispersion is therefore not free to be varied for emittance minimization.
- Assuming achromats is therefore more suitable than assuming a minimal emittance lattice.

One pass, high charge mode (D)

A separate injector linac injects into the second 2.5GeV linac at 100kHz with up to 1nC per bunch.

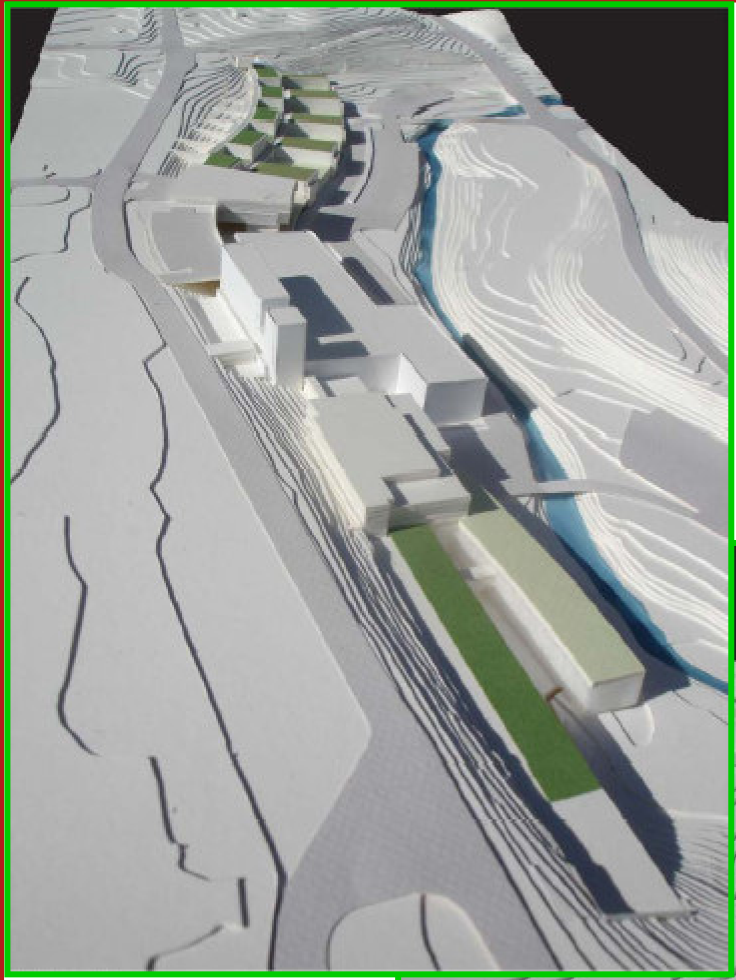
Two-stage bunch compression with 3rd-harmonic linearizer cavity at low energy produces bunches as short as 50fs.

The 125kW beam is not energy recovered, but dumped.



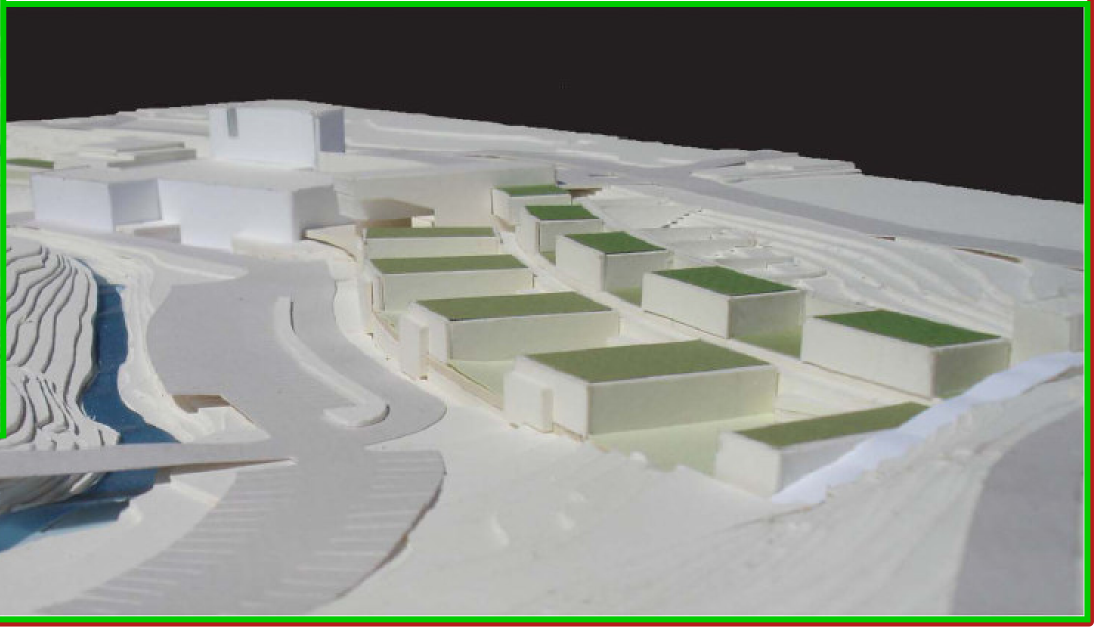
A optics, beam dynamics, and implications of simultaneous operation with other running modes (A, B, C) needs more analysis.

Conceptual building design



New floor space:
likely as large as existing Wilson lab.

Beamline location:
out of the hillside next to existing Wilson lab



Optics considerations

1. An optics in the linac is needed that works simultaneously for a 10MeV to 5GeV and for a 5GeV to 10MeV beam.

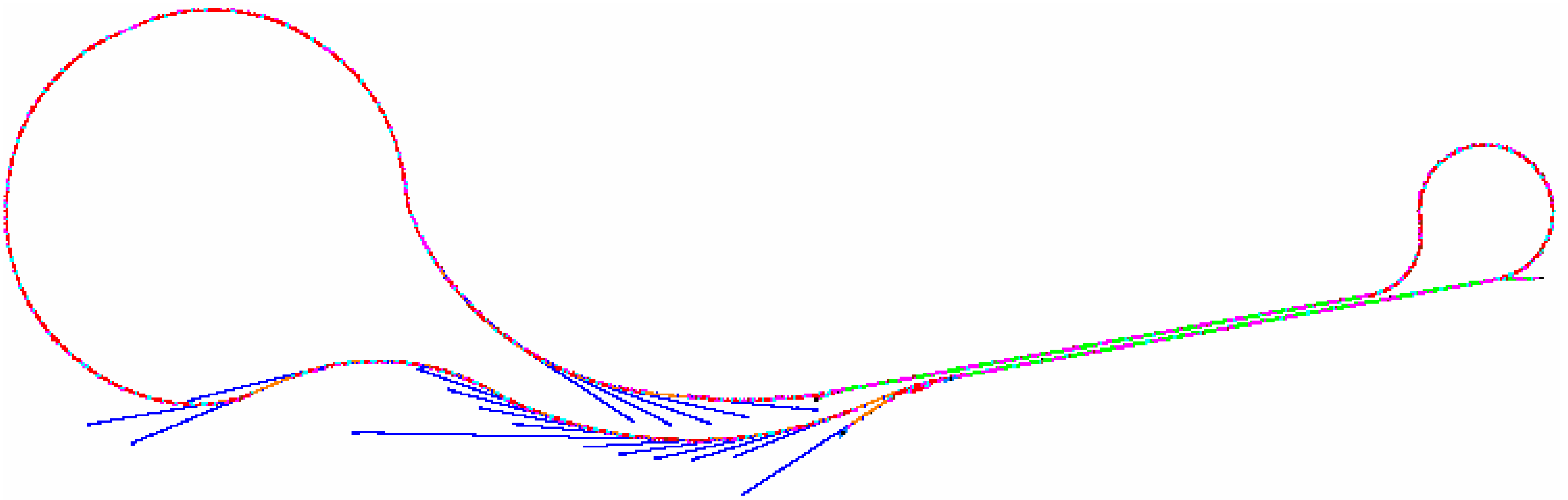
2. A low ISR emittance growth optics is needed in all bends. The optics is therefore similar to that of 3rd generation light sources, with similar (large) quadrupole strengths.

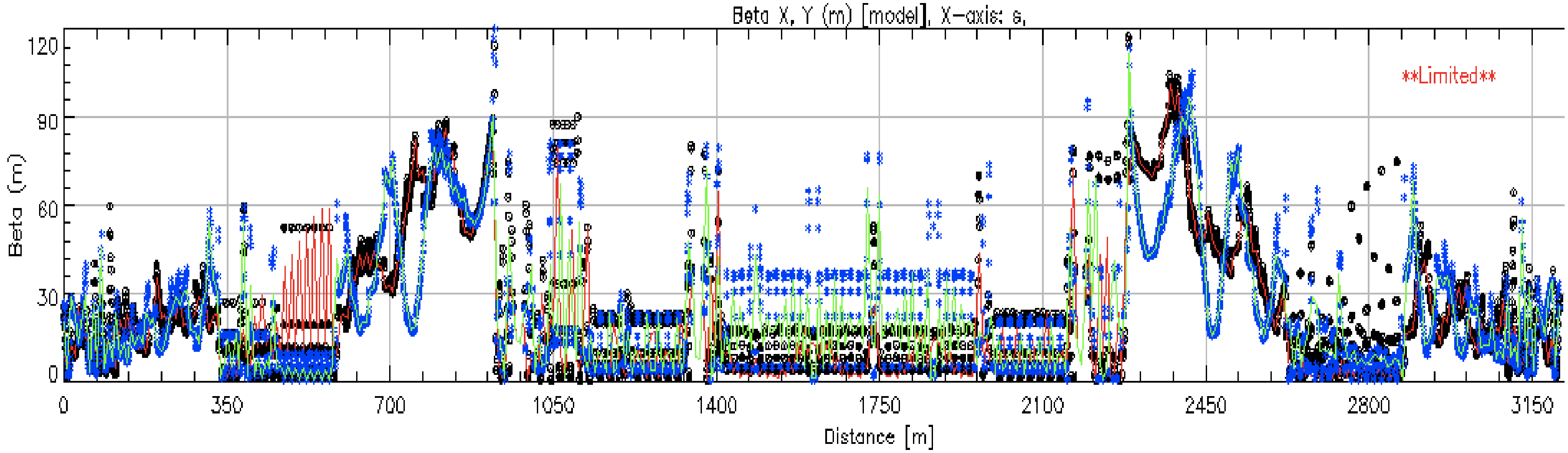
3. The beam size should be flexible in all undulators (and can be made flexible compared to 3rd generation sources.)

4. The first and second order dispersion in all undulators has to be 0. Sextupoles are therefore required.

5. The first and second order time of flight from the end of acceleration to the start of deceleration has to be 0.

Linear Optics (A – high brilliance)

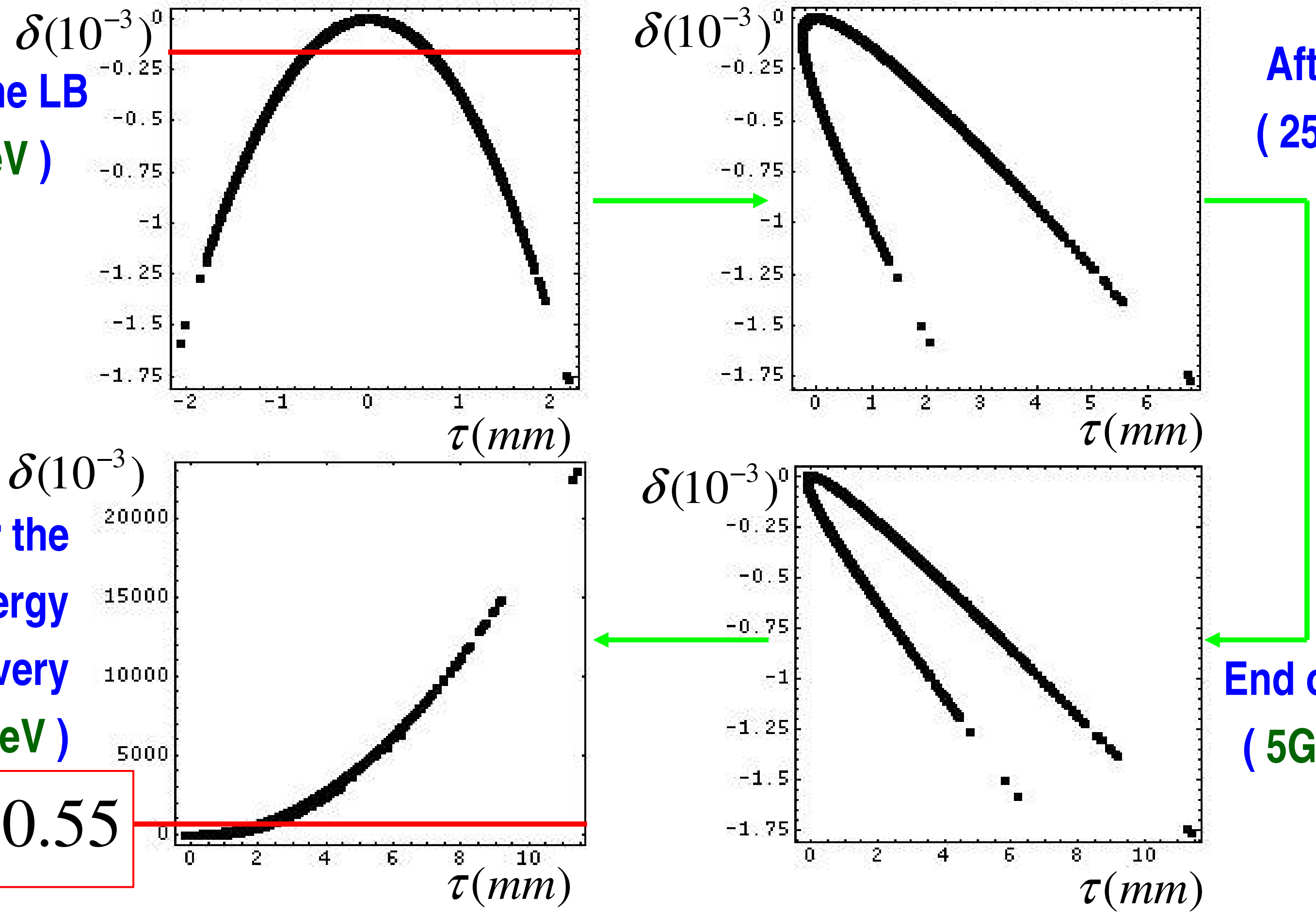




Time of flight considerations – Mode A,B

On crest acceleration (R56=5.2m)

$$\sigma_\tau = 600\mu m, \quad \sigma_\delta = \sigma(\tfrac{\Delta E}{E}) = 2\cdot 10^{-4}$$



After the LB
(5GeV)

After SA
(25m ID)

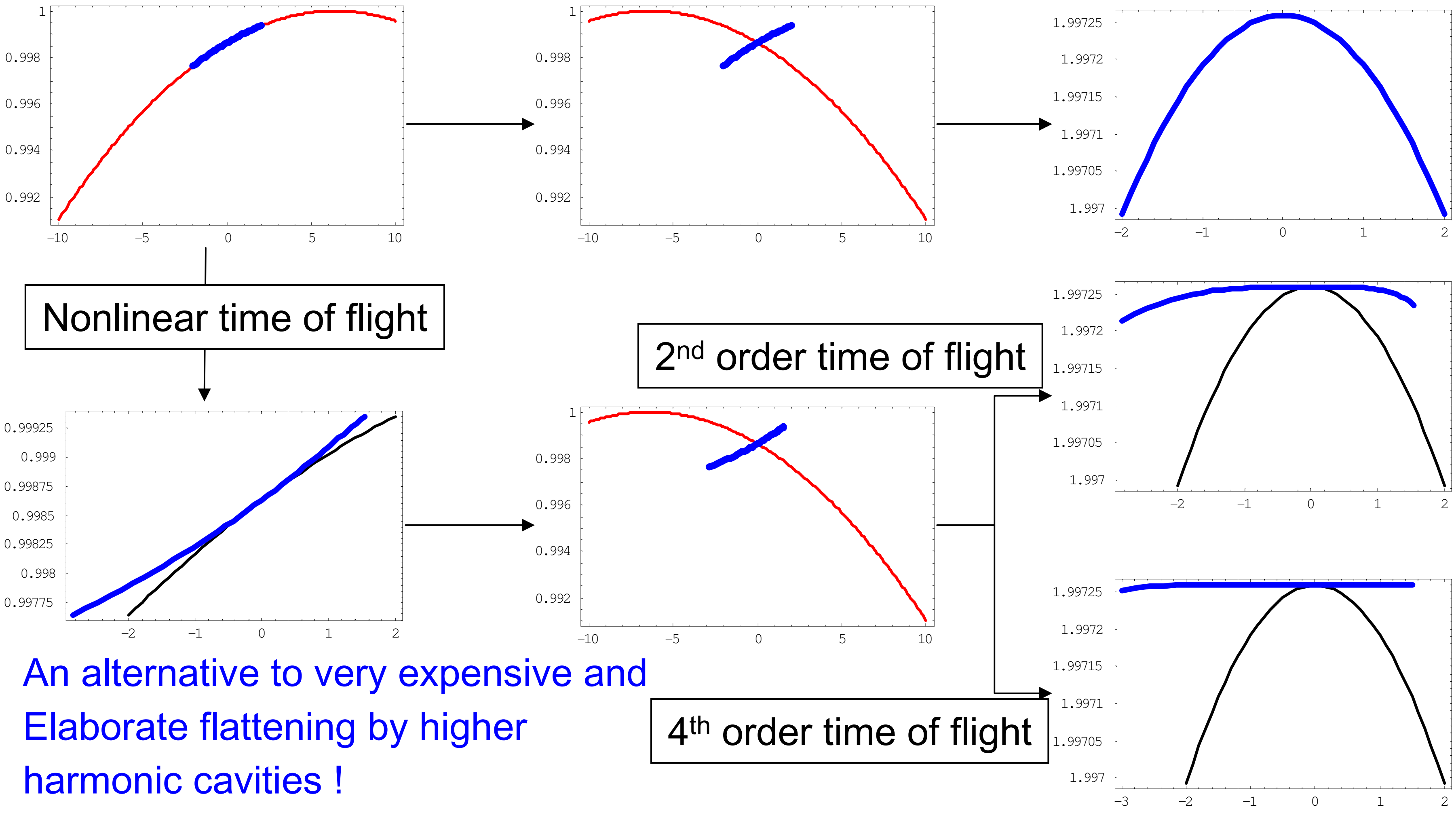
End of NA
(5GeV)

After the energy recovery
(10MeV)

$$\langle\delta\rangle = 0.55$$

Conclusion: A quite relaxed optics is sufficient for on crest acceleration with energy recovery.

Split Linac bunch flattening



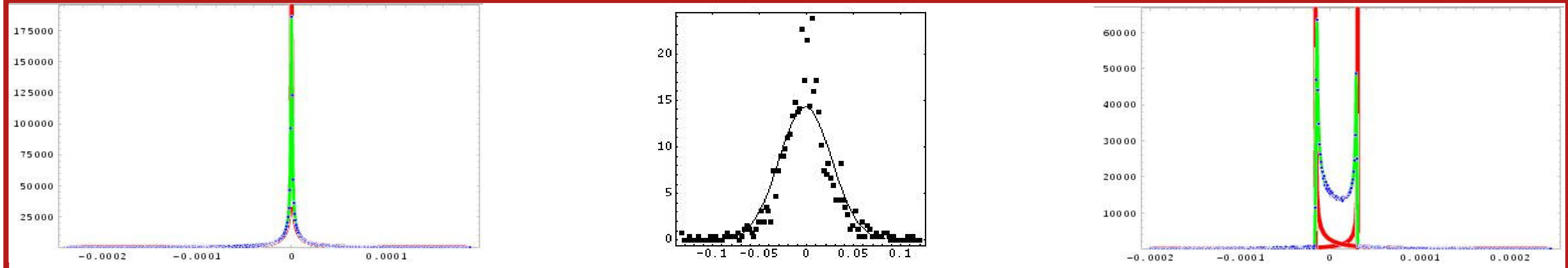
Nonlinear time of flight

2nd order time of flight

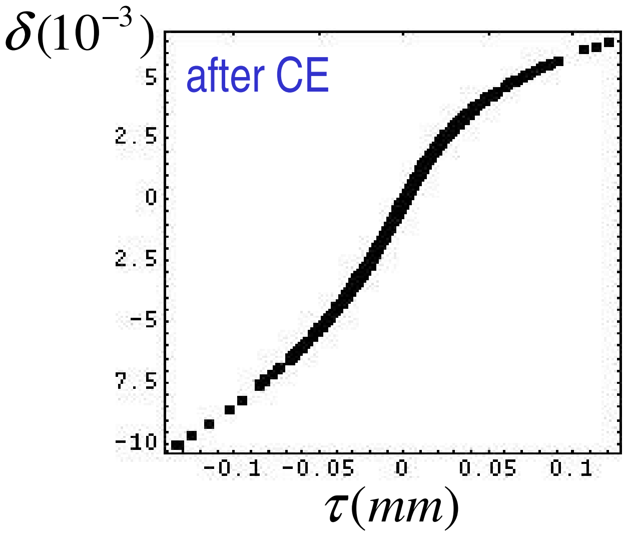
4th order time of flight

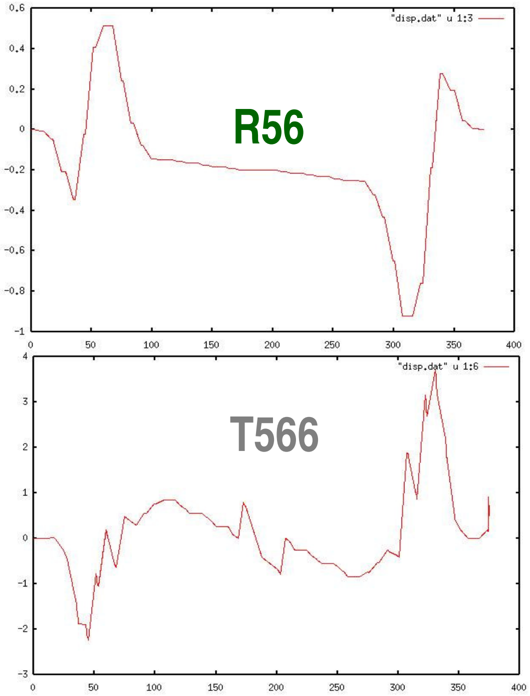
An alternative to very expensive and Elaborate flattening by higher harmonic cavities !

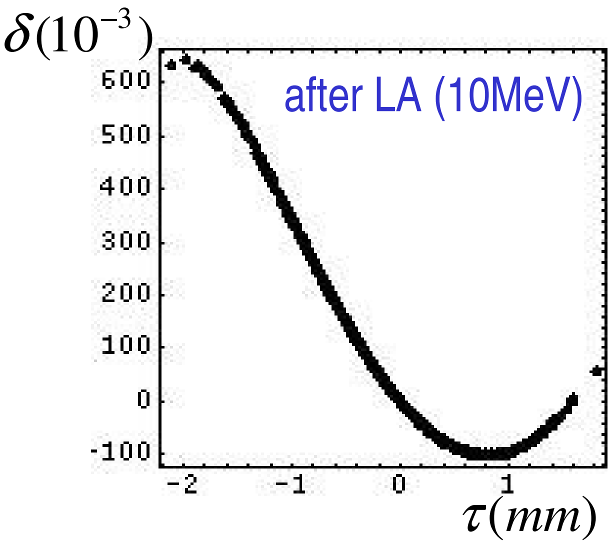
Nonlinear Optics (C – short pulse)



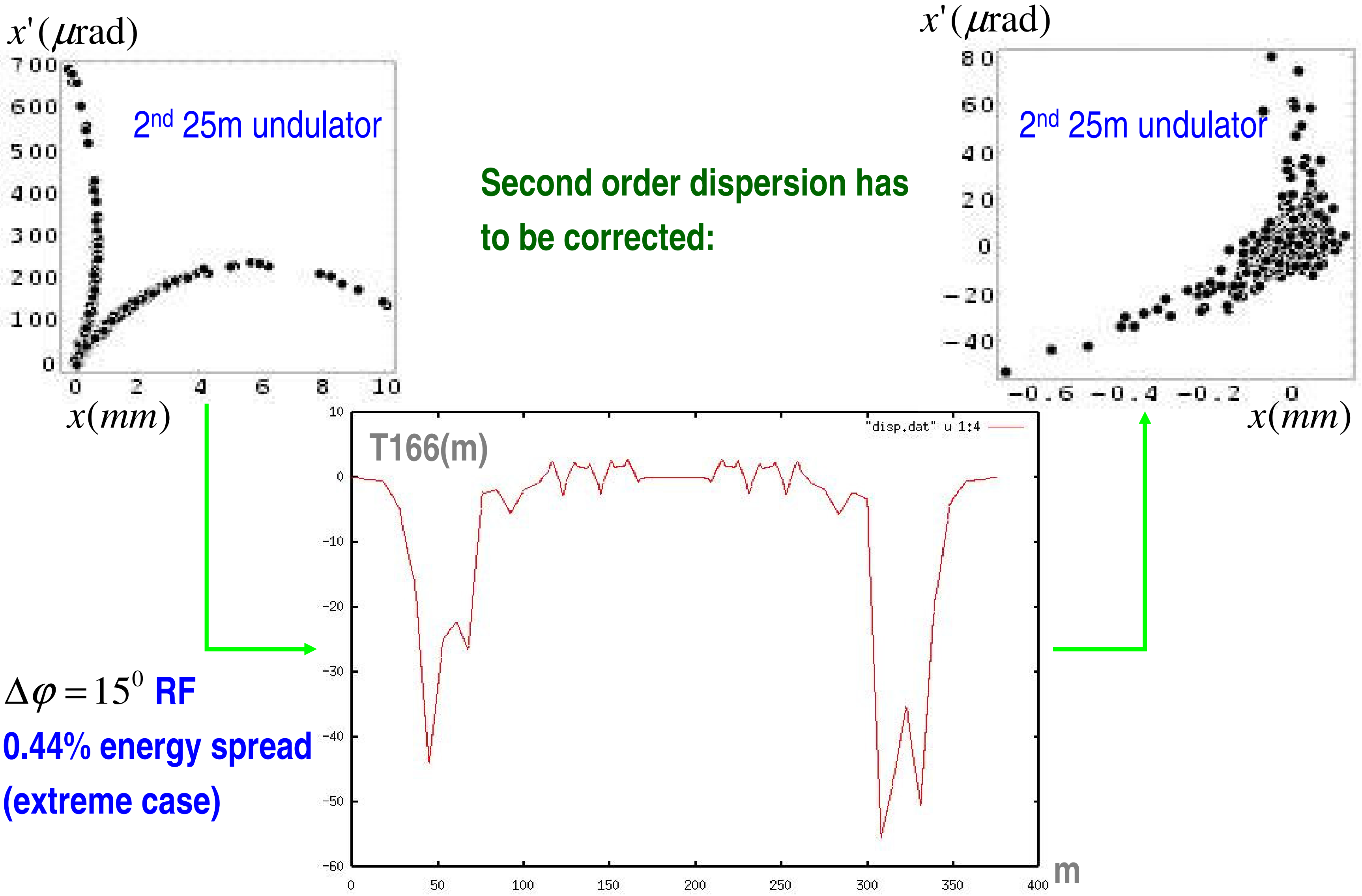
With second order optimization: 9^0 RF phase and undercompression at short pulse section, and separate optimization for energy recovery:







Transverse nonlinear optics



Second order dispersion has to be corrected:

$\Delta\varphi = 15^0$ **RF**

0.44% energy spread

(extreme case)

Conclusion

1) Working modes that take advantage of unique ERL capabilities have been defined:
A: high flux with large spectral brightness
B: optimal spectral brightness with reduced flux with
C: short pulses with high currents but low charge per bunch
D: short pulses with high charge per bunch but low current

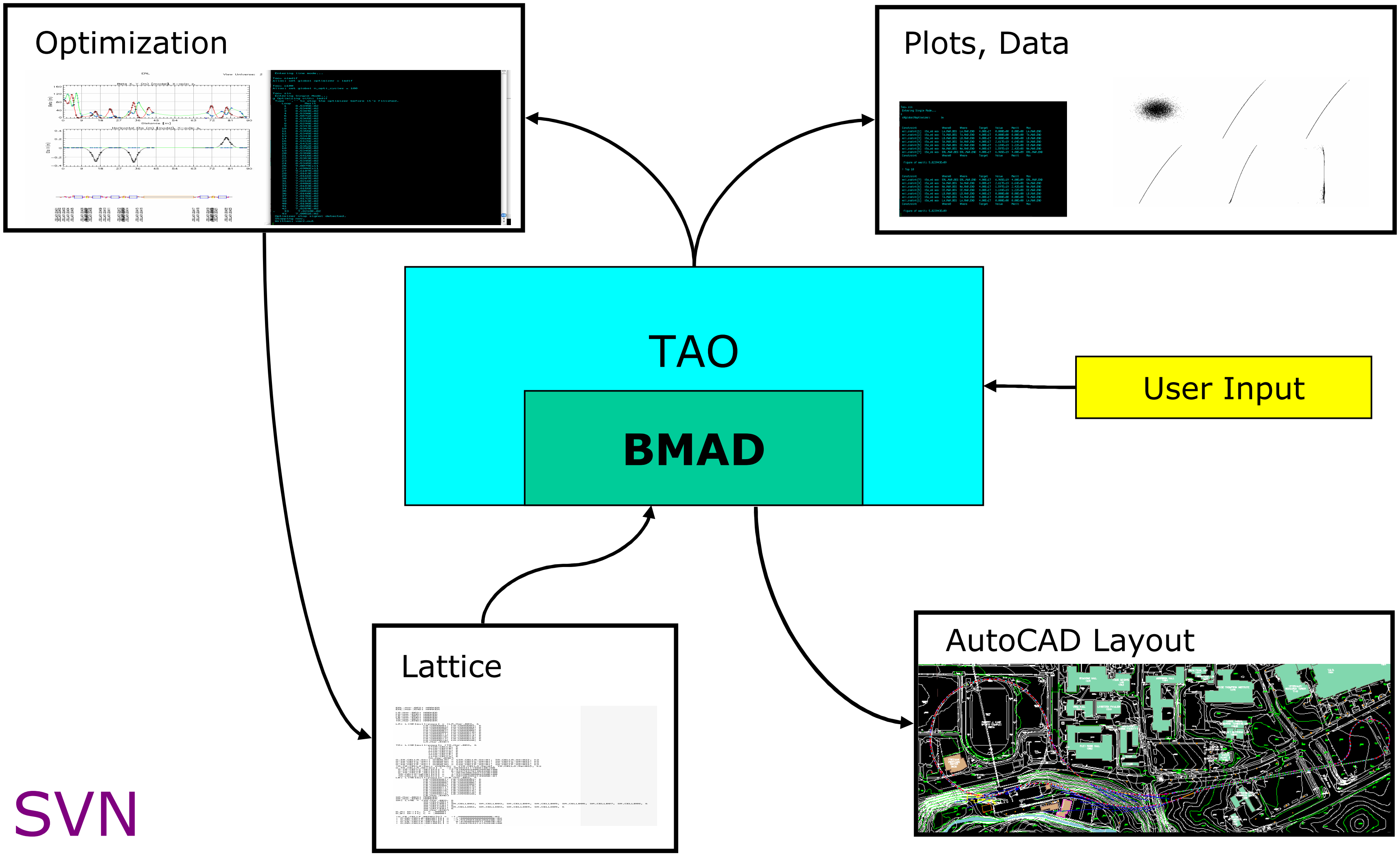
2) A layout has been defined that fits on the Cornell campus and extends Wilson lab and the CESR accelerator, and is compatible with x-ray beamline needs.

3) Optical requirements have been defined that go along with x-ray beamline considerations and allow running in the 4 working modes.

Accelerator Physics in the ERL

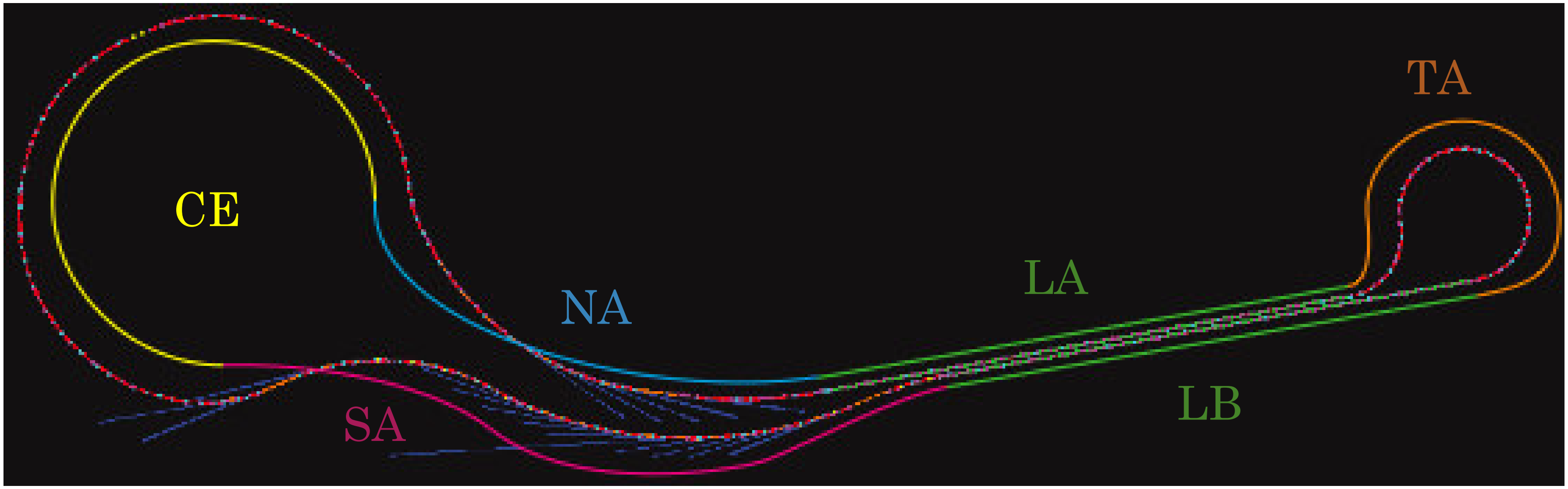
1. Introduction to x-ray ERLs
2. Layout
3. Optics
4. **Emittance preservation**
5. **Beam stability**
6. **Background rates and machine protection**
7. **Concluding topics**

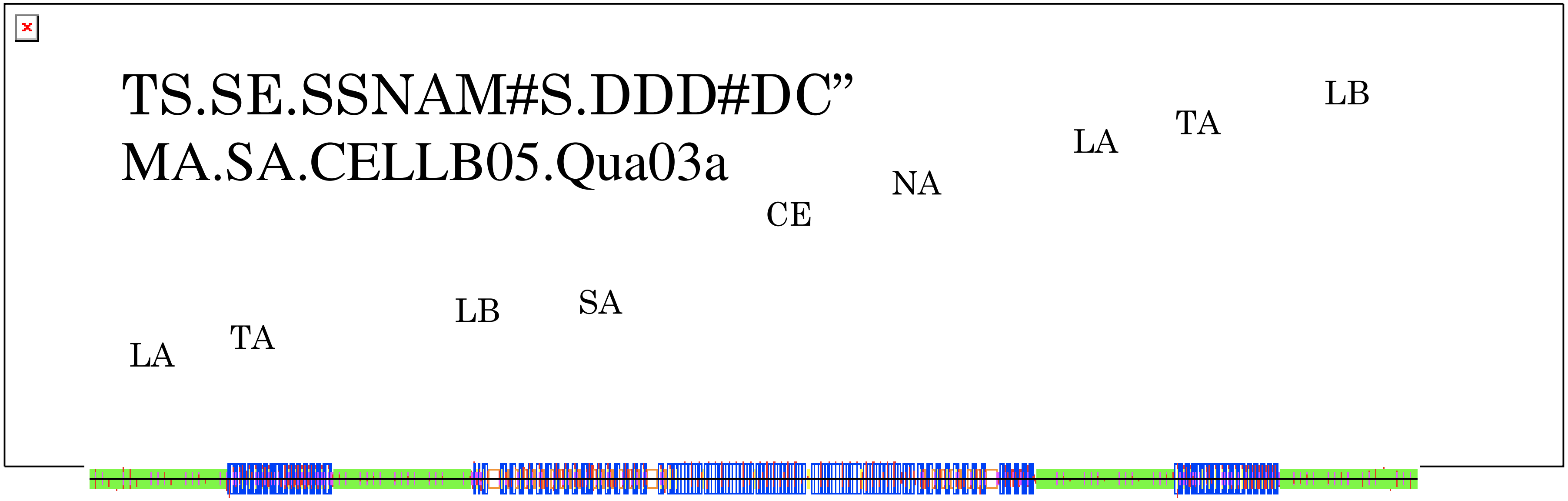
Software for many beam dynamics effects



SVN

Incoherent Synchrotron Radiation (ISR)





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CSR for the ERL turn around for 2ps bunches

High currents (up to 100mA)
Mode A: 2ps, 77pC bunches can go through the ERL without significant CSR.
Mode B: 2ps, 19pC bunches obviously also.
Mode C: Bunch compression to 100fs in the ERL is not prohibited by CSR.

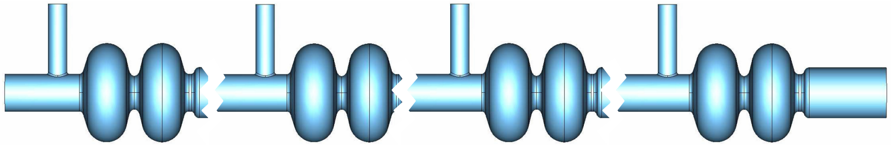
Bunch compression of larger bunch charges in the ERL is prohibited by CSR.
(Larger bunch charges also produce too much wake-field energy spread)
→Larger bunch charges are therefore not energy recovered, but dumped.

High Charges (1nC)
Mode D: 2.5GeV, 1nC, 50fs bunches are produced with one linac.

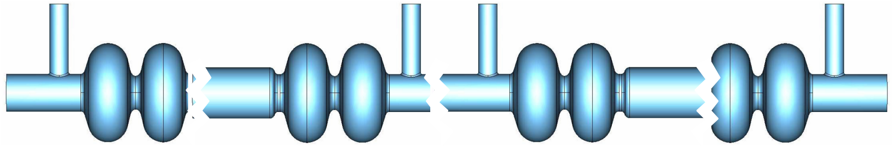
Extra-modes:
5GeV, 1nC, 2ps bunches can be produced without CSR problems in the TA.

5GeV, 1nC with less bunch length are prohibited by CSR without shielding.

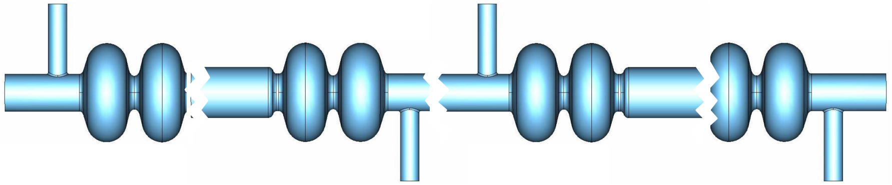
Coupler kicks



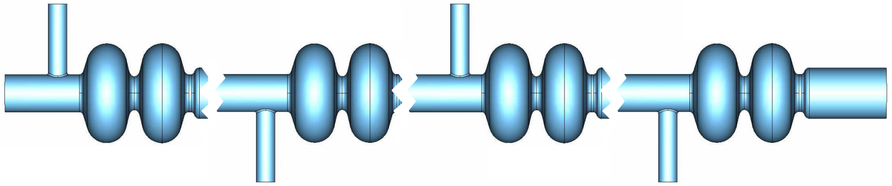
$$\Delta y' = 4\Delta y'_c,\ \Delta\varepsilon = 4\Delta\varepsilon_c$$



$$\Delta y' = 0,\ \Delta\varepsilon = 4\Delta\varepsilon_c$$



$$\Delta y' = 4\Delta y'_c,\ \Delta\varepsilon = 0$$

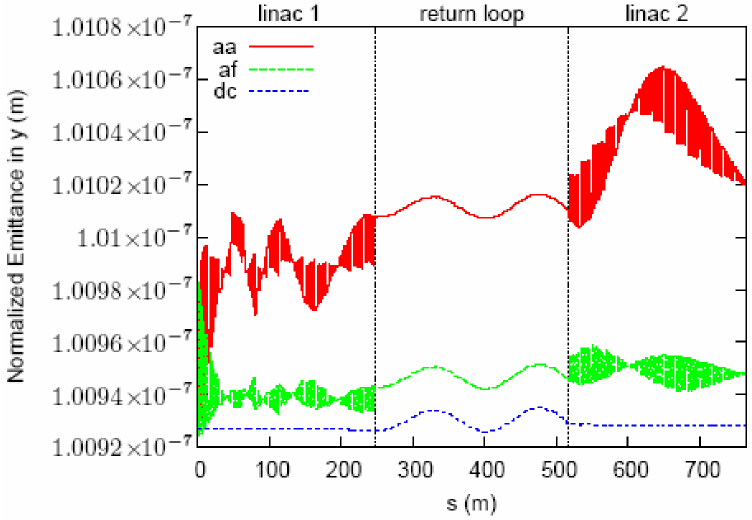


$$\Delta y' = 0,\ \Delta\varepsilon = 0$$

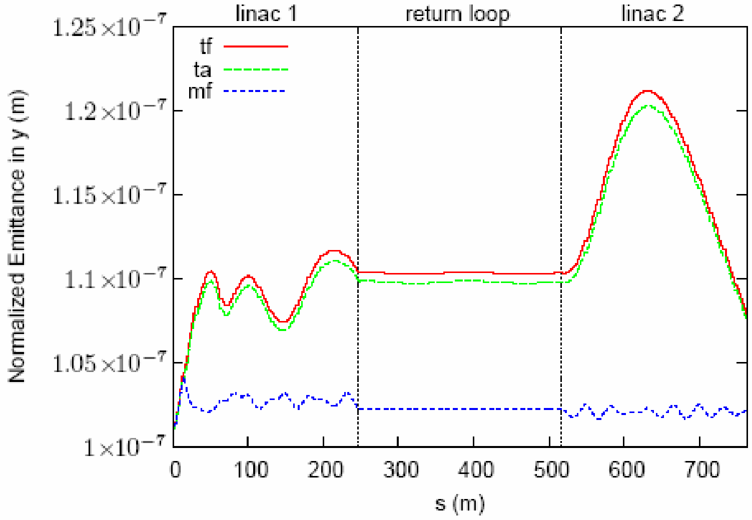
(even for all phases of the reflected wave)

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%

Coupler kicks

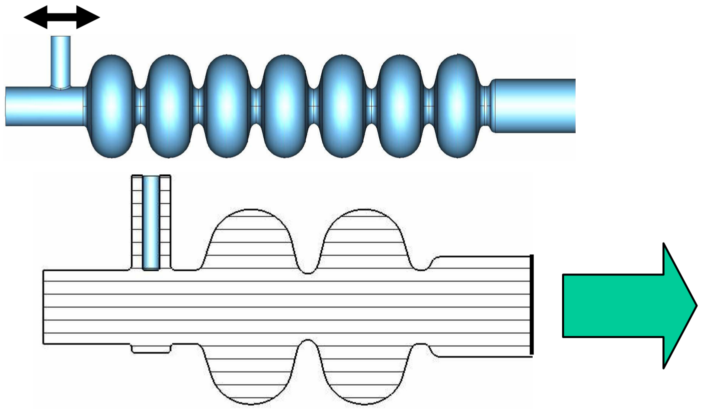


(c) Small emittance growth configurations, $Q_{ext} = 3.5\times10^8$



(d) Large emittance growth configurations, $Q_{ext} = 3.5\times10^8$

Coupler-kick compensation by optimized coupler placement: The coupler was moved from 4.5cm to 5.3cm off the first cell.



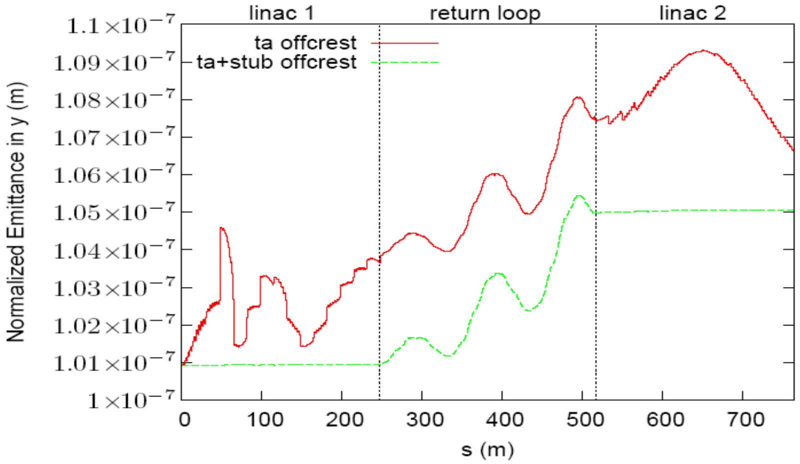


FIG. 8: Emittance growth with off crest operation with and without symmetrizing stub.

Ion focusing

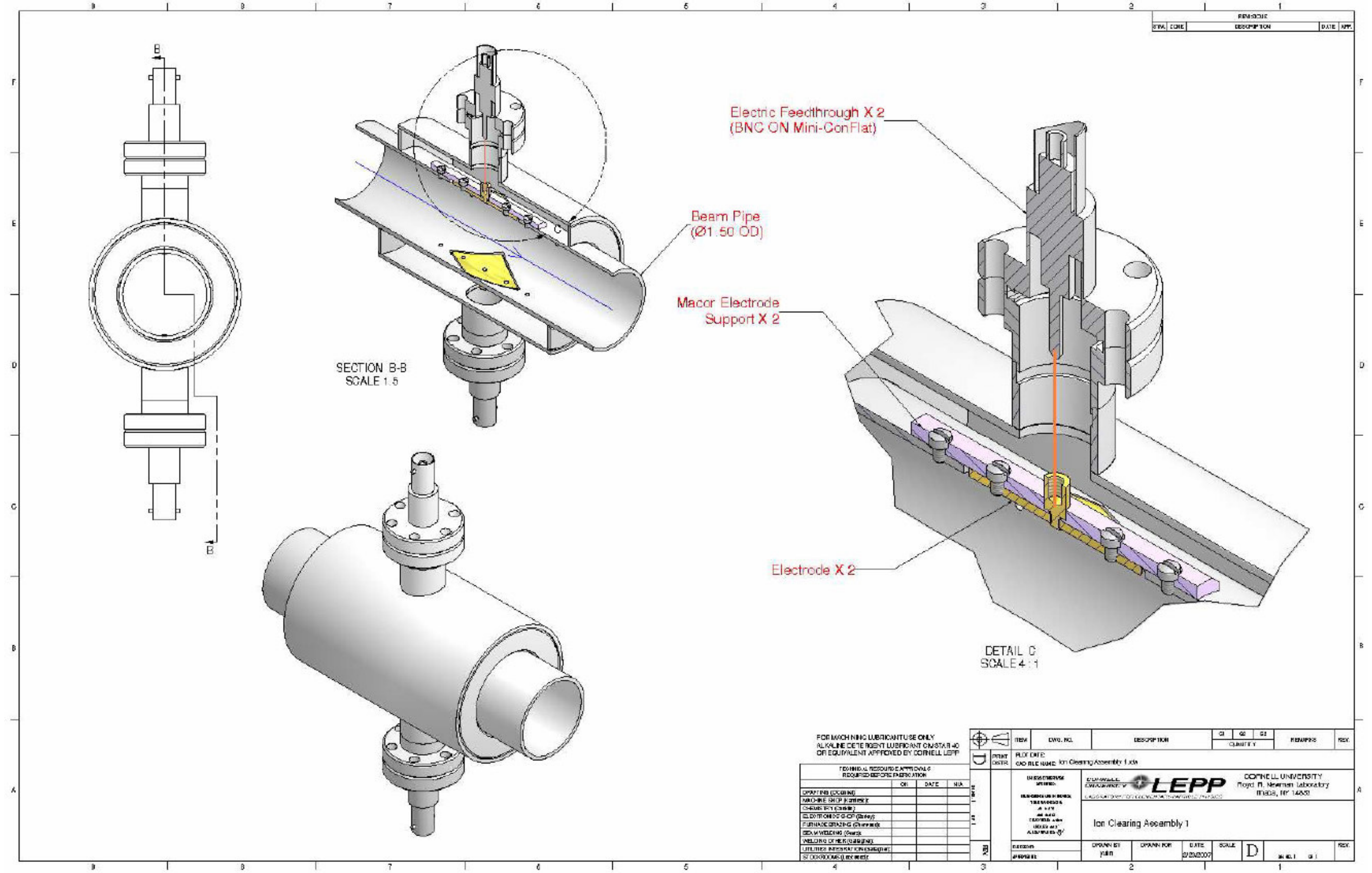
- Ion are quickly produced due to high beam density

Ion	σ_{col}, 10MeV	σ_{col}, 5GeV	τ_{col}, 5GeV
H_2	$2.0 \cdot 10^{-23}\mathrm{m}^2$	$3.1 \cdot 10^{-23}\mathrm{m}^2$	5.6s
CO	$1.0 \cdot 10^{-22}\mathrm{m}^2$	$1.9 \cdot 10^{-22}\mathrm{m}^2$	92.7s
CH_4	$1.2 \cdot 10^{-22}\mathrm{m}^2$	$2.0 \cdot 10^{-22}\mathrm{m}^2$	85.2s

- Ion accumulate in the beam potential. Since the beam is very narrow, ions produce an extremely steep potential – they have to be eliminated.

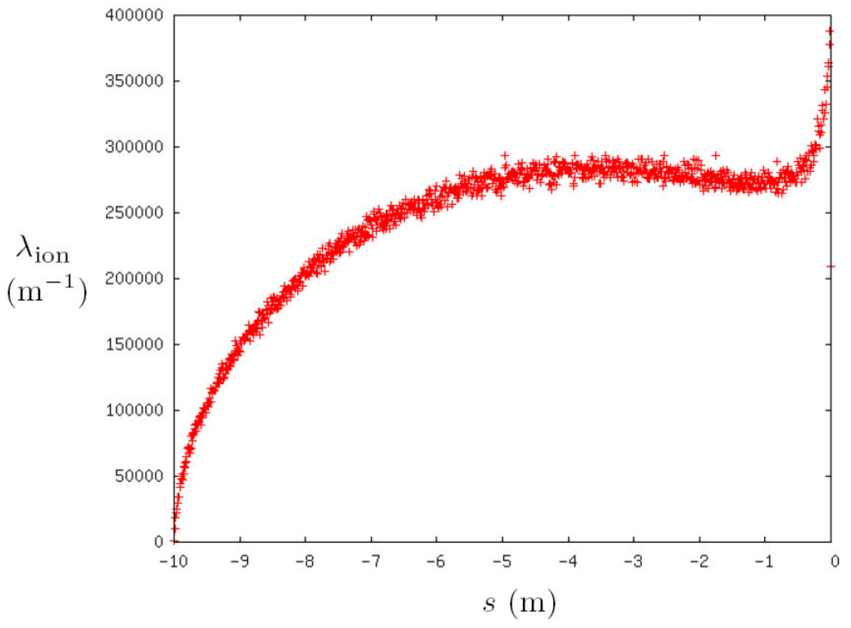
- Conventional ion clearing techniques:
  1) Long clearing gaps have transient RF effects in the ERL [2ms every 7ms].
  2) Short gaps have transient effects in injector and gun and produce more beam harmonics that excite HOMs [0.4 ms every 7ms].
  3) DC fields of about 150kV/m have to be applied to appropriate places of the along the accelerator, without disturbing the electron beam.
     But remnant ion density before clearing can still cause emittance growth.

Ion - clearing electrodes

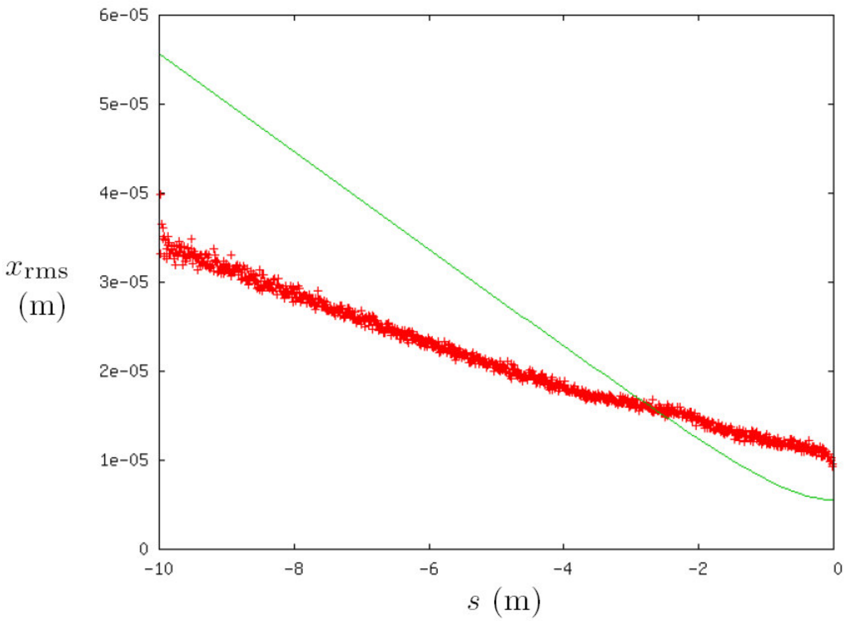


Equilibrium ion distributions

Plot of ion line density as a function of s:



Transverse distribution: rms values for ions and beam



- Longitudinal ion forces proportional to Twiss-a

  so ions created near minimum move slowly
- All ions pass through region near electrodes

$\Rightarrow$ sharp ion density peak near beam waist

- Ions oscillate through beam

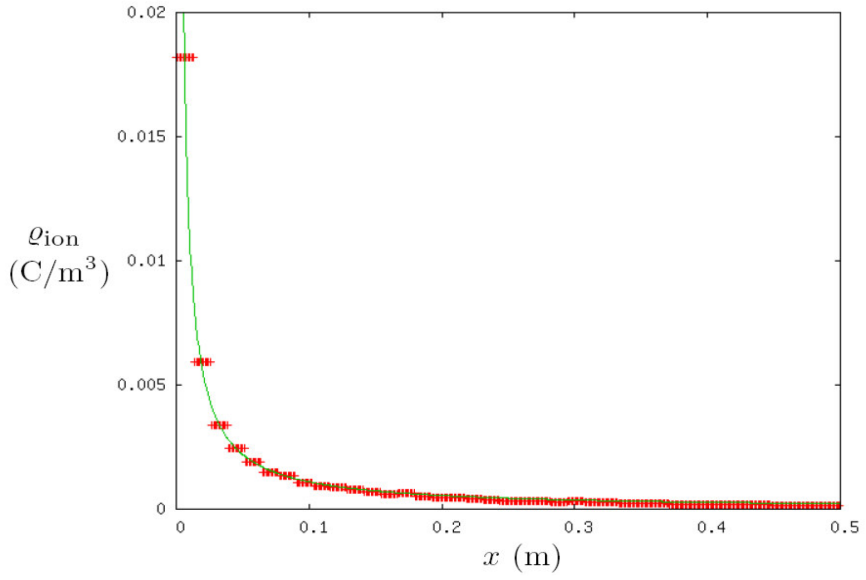
$\Rightarrow$ ion rms initially smaller than beam rms

- Beam contracts, ion action remains constant

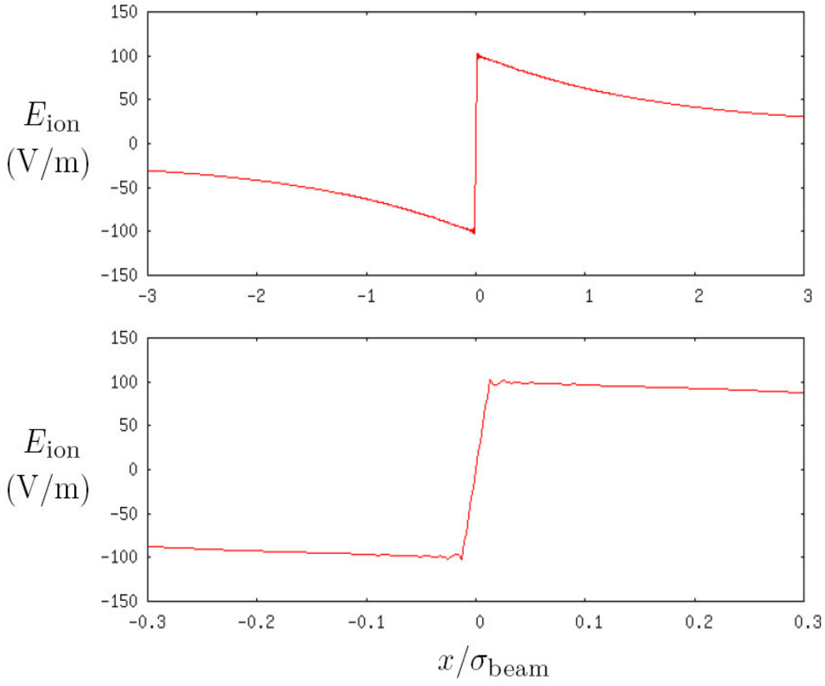
$\Rightarrow$ ion rms near electrode larger than beam rms

Forces from the ion distribution

Transverse charge density distribution:



Transverse ion electric field:



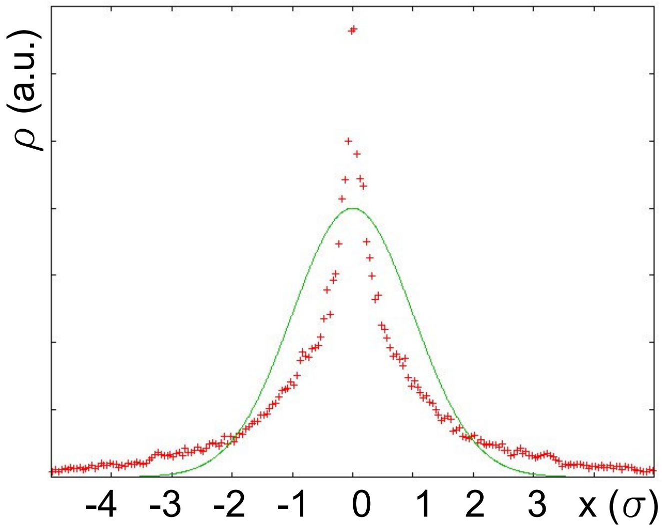
- Ions with all oscillation amplitudes contribute to center density

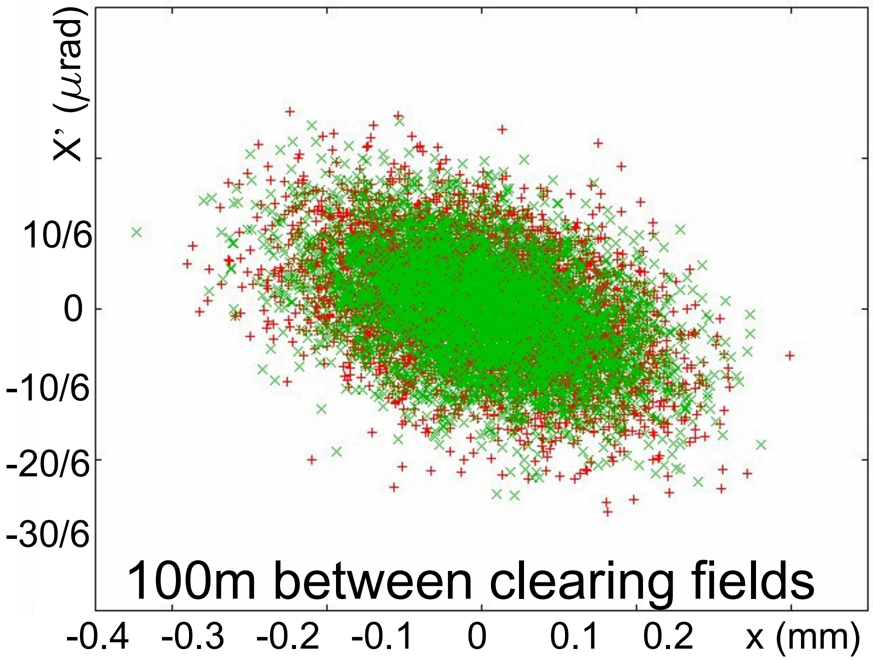
⇒ Ion charge density has 1/r peak at center of beam

- repulsive ion on ion forces are nevertheless many orders of magnitude weaker than electron on ion forces

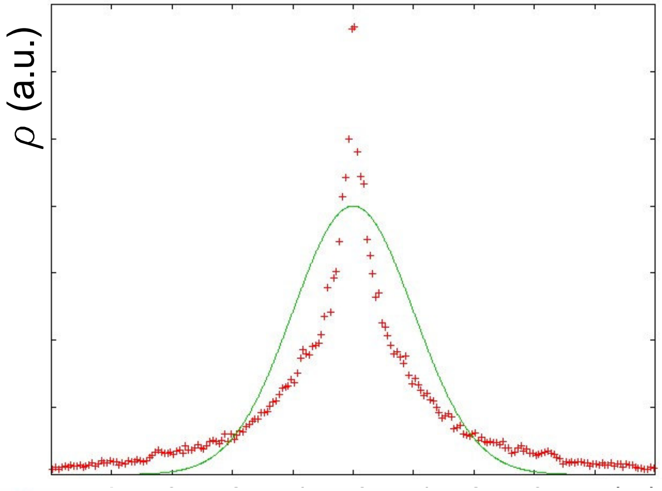
- Ion field approaches constant for r → 0
- Ion on electron fields in center damage beam

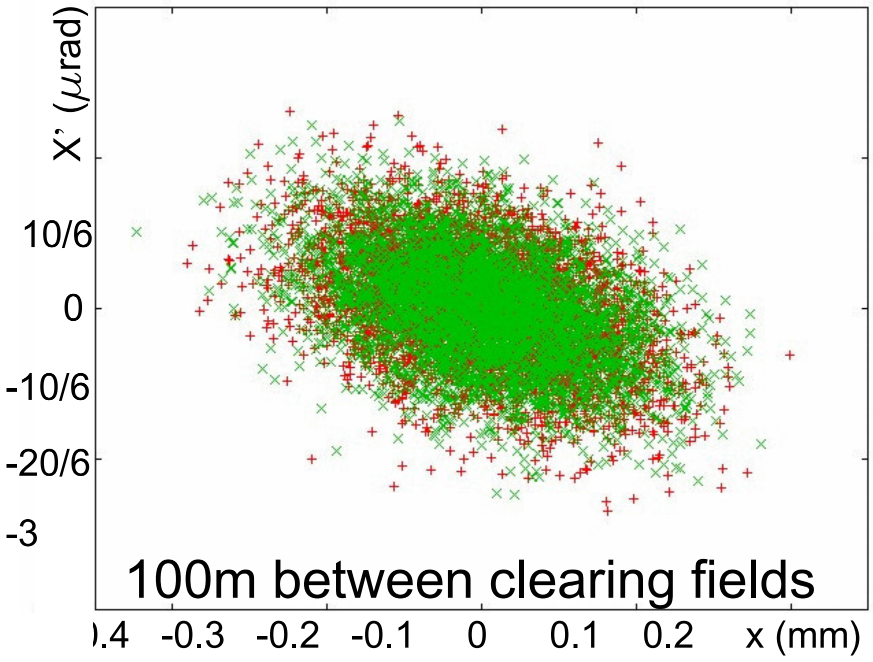
Ions in an ERL beam

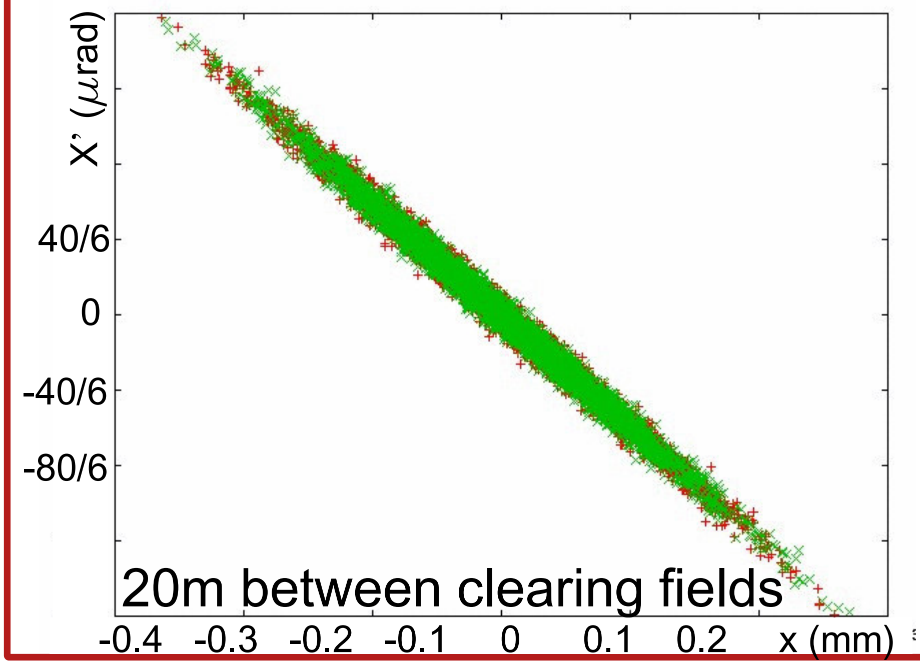




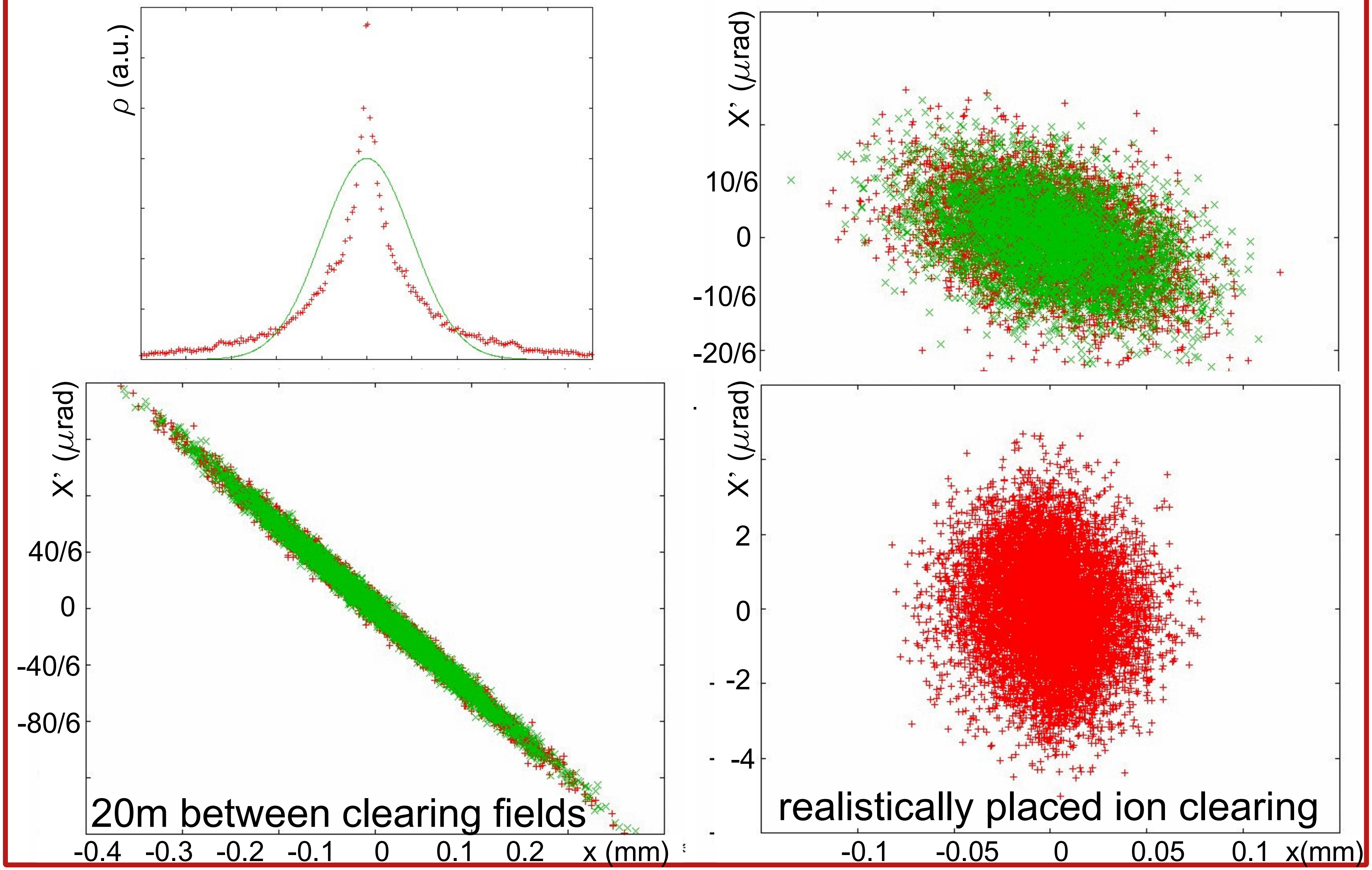
Ions in an ERL beam







Ions in an ERL beam



Short ion clearing gaps

To avoid nonlinear motion and emittance growth from the remnant ion density, we are looking into producing 0.4 μs ion clearing gaps every 7μs.

Gap kicker:

Due to space limitations, kickers after the gun (750kV) and after the injector (10MeV) both need about 1kV transverse strength, which seems very challenging.

(1) A kicker with comparable strength with 2% duty cycle was once sought for longitudinal feedback in CESR – without full success (ERL needs at least 6%).

(2) A kicker with comparable strength is needed for the ILC – which is already hard even though it is pulsed but needs to be cw for the ERL.

Gap in the DC-cathode laser:

(1) The response time of the power supply at full load is 1ms, leading to a voltage change of approximately 4×10^{-4} within 0.4μs.

(2) The low Q_{ext} of the injector linac leads to a voltage change of 1.3 10^{-2} within 0.4μs if no feed forward is applied. After acceleration this leads to an energy jitter of 3×10^{-5}.

➢ More study is needed, but this solution seems promising.

Power-supply stability

Uncorrelated dipole errors:

Random Seed ($\Delta B/B = 2 \times 10^{-7}$)	Worst Orbit Error (μm)
5	-3.5 (18%)

Correlated dipole errors:

$\Delta B/B$	+
10^{-3}	-1.46×10^{-1}(0.7%)

Uncorrelated quadrupole errors:

$\sigma(\Delta k1/k1)$	$\Delta\sigma_x/\sigma_x$	$\Delta\sigma_y/\sigma_y$
10^{-3}	10.6%	5.48%

Correlated dipole errors and uncorrelated quadrupole errors:

$\Delta B/B$	$\sigma(\Delta k1/k1)$	Orbit Error (μm)
10^{-4}	10^{-4}	1.50 (5.4%)

Orbit correction

- Orbit correction is complicated by having two beams in one beamline
  A) Close to injector and dump: the orbit of the high energy beam can hardly be influenced.
  B) TA: the orbits of two beams with same energy can not individually be influenced, but they should not have to be.

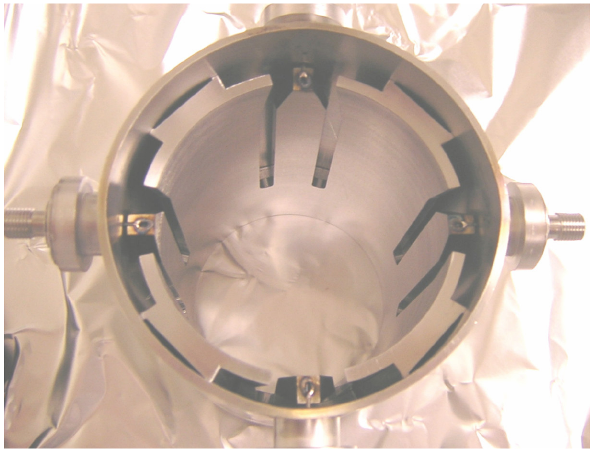
- The x-ray radiation from bends has to be shielded before or between cavities. Orbit errors could cause radiation past these shields.

- Orbit length correction (to about 150μm):
  Master oscillator correction (slow) and dispersive bump correction (fast)

BPMs for the Cornell ERL

Challenges:

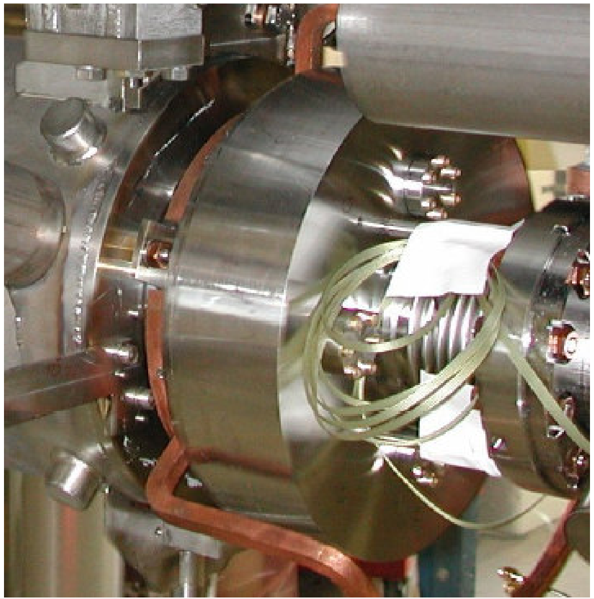
1) Two beams of different energy have to be measured simultaneously in much of the ERL
2) Tolerances of transverse motion are very stringent, 0.3μm in some places: **0.5μm at 10kHz and <0.1μm at 10Hz for 77pC, 1.3GHz**.
3) Wake-field heating and energy spread from wake fields has to be tolerable
4) BPMs have to work in 80K environment.



Possible solutions:

1) Read out a difference orbit at 1.3GHz and a sum orbit at 2.6GHz.
2) Buttons: ok
   Strip line: size for 1/6 of the rf wavelength
   Cavity BPM: needs a resonance at 1.3GHz and 2.6GHz.

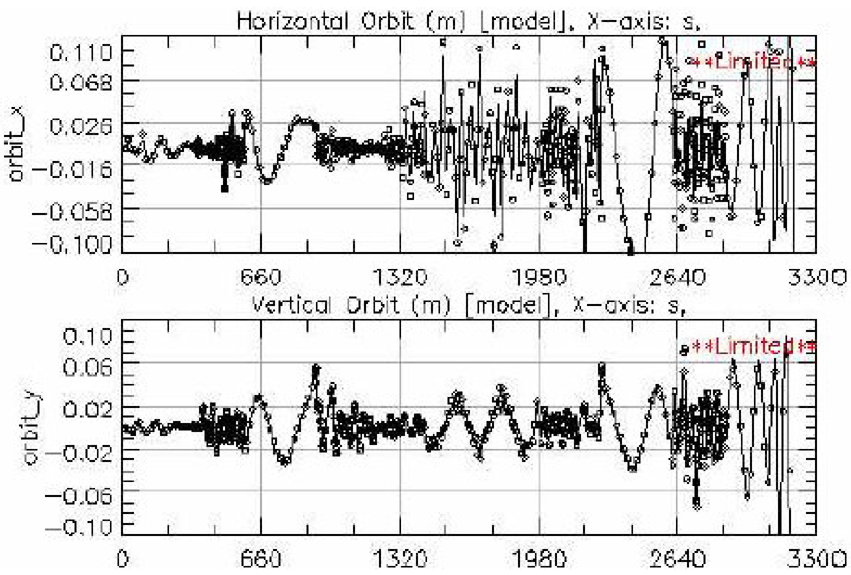
Strategy: Use buttons all around the ring and strip lines at a few critical places for low currents.



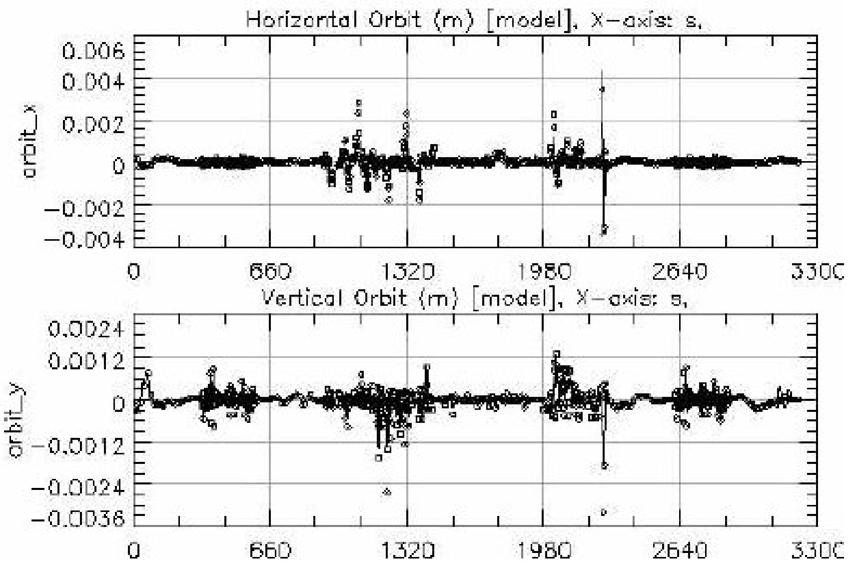
BPM and corrector placement

The orbit can be controlled with the placement of BPMs and correctors.

Uncorrected orbit for 0.3mm rms quadrupole misalignments:



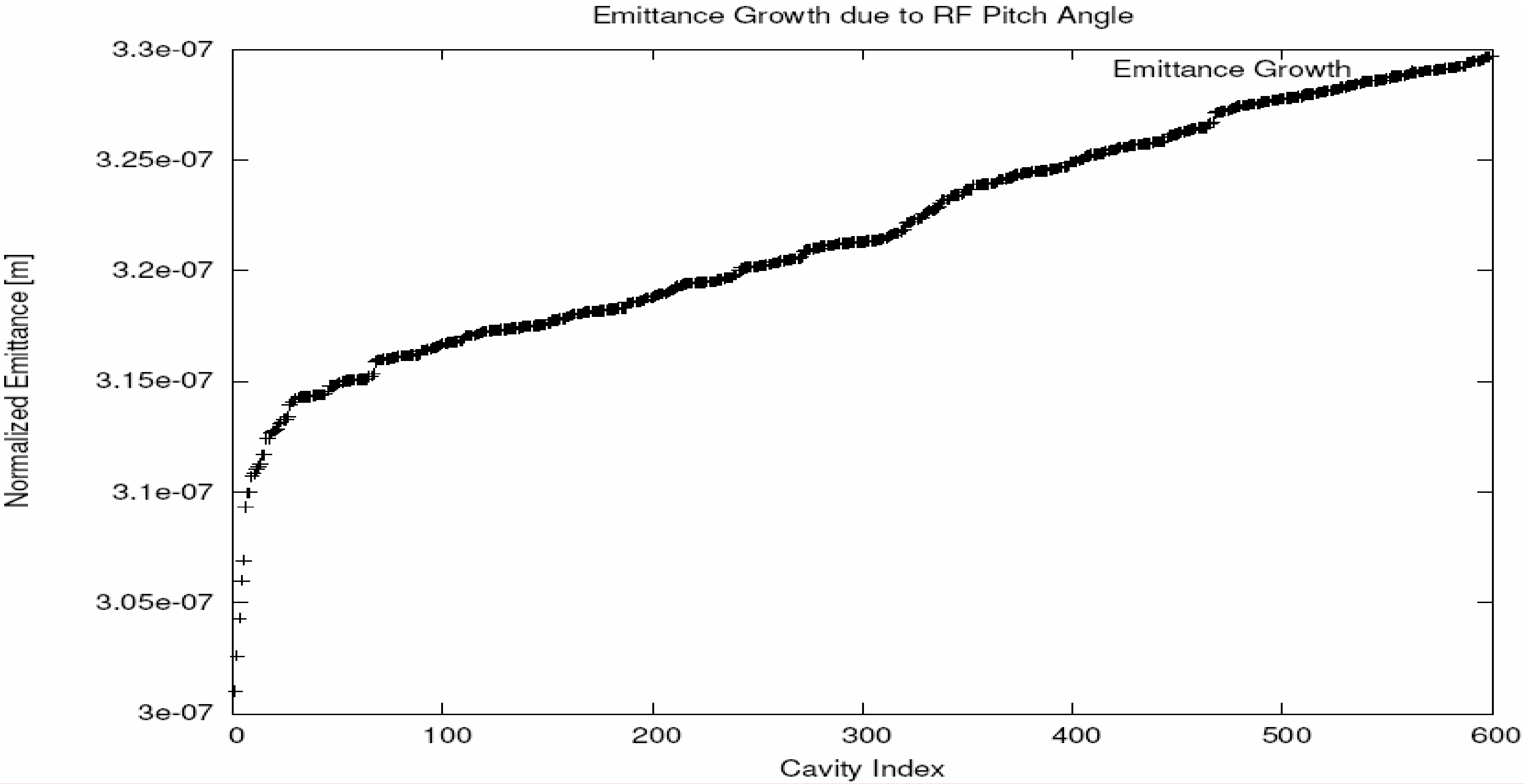
Corrected orbit for 0.3mm rms quadrupole misalignments:



Cavity-alignment tolerances

Tolerances that differ from 3rd generation light sources:

Cavity alignment: 1.5mrad for 9^0 off crest acceleration and
4.9mrad for on crest acceleration.

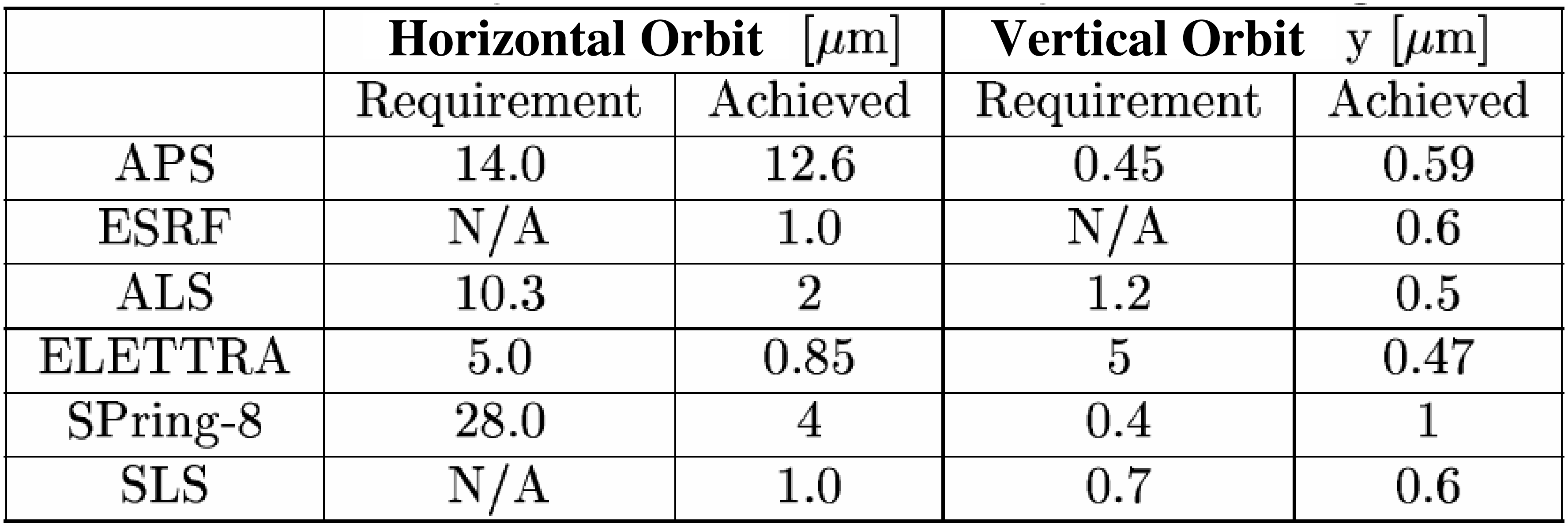


Alignment requirements

General comment about DC alignment requirements:

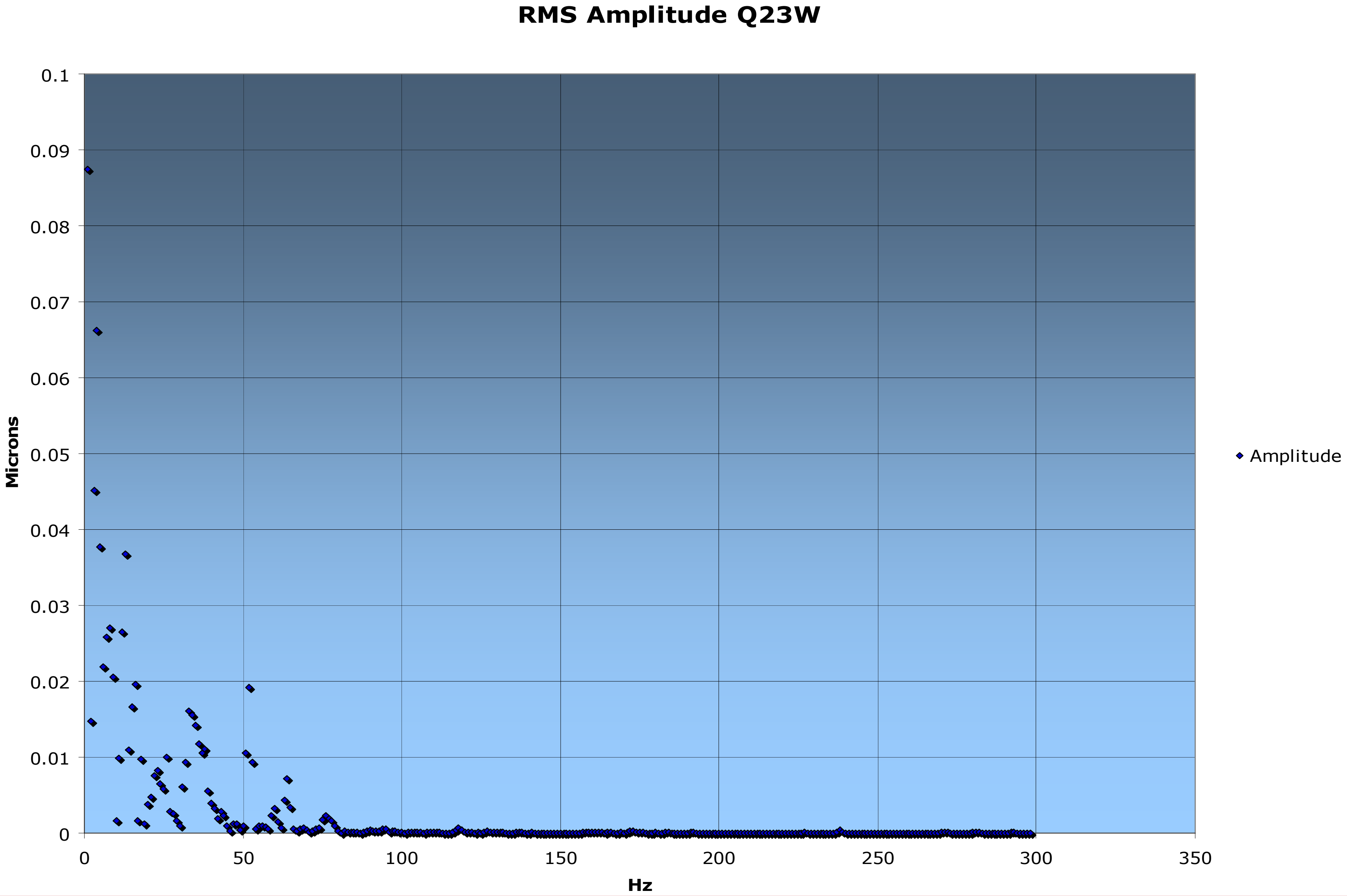
These are similar to that in ring light sources because the vertical beam size in such sources is as small and smaller than the vertical and horizontal size in the ERL.

Achieved orbit stability in 3rd generation light sources:

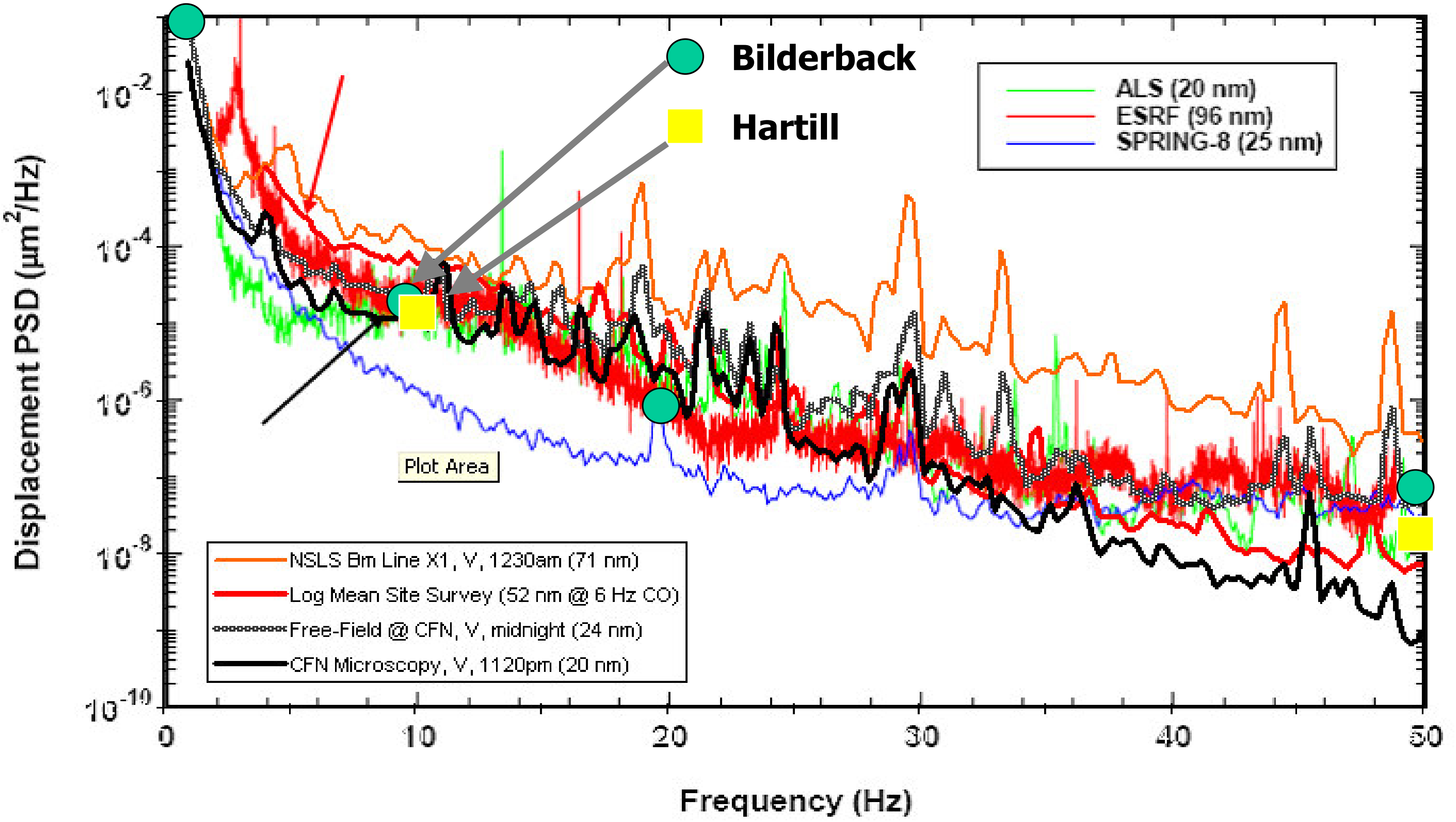


	Horizontal Orbit [μm]		**Vertical Orbit** y [μm]	
	Requirement	Achieved	Requirement	Achieved
APS	14.0	12.6	0.45	0.59
ESRF	N/A	1.0	N/A	0.6
ALS	10.3	2	1.2	0.5
ELETTRA	5.0	0.85	5	0.47
SPring-8	28.0	4	0.4	1
SLS	N/A	1.0	0.7	0.6

Vibrations of CESR elements



Vibration measurements


● Bilderback

■ Hartill

Transverse feedback considerations

Attenuation of Correction Through Beampipe:

- Freq ~ conductivity/(thickness)**2
- Use 1/e frequency => -8.5dB attenuation
- Assume 2mm wall thickness
- Copper: 270Hz
- Aluminum: 440Hz
- Stainless Steel: 14kHz

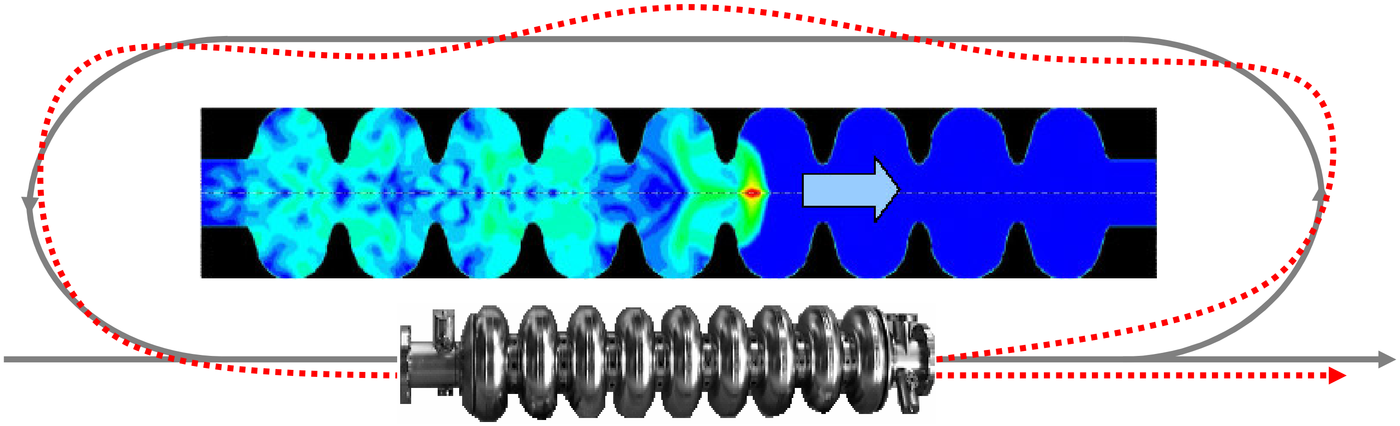
Position Feedback Corrector:

- Max kick required ~ 0.1mrad = B*Δs
- Let Δs be 0.1m, air core
- B = 166 gauss
- For example: 150 turns/coil, 10 amps => 180 gauss
- Resistance with #14 wire 0.92 Ω both coils => 9.2Volts DC
- L ~ 400 μH for both coils => LdI/dt ~ 1Volt at 100Hz

Vibration Measurements in CESR:

- Q23E < 0.1μm (Hartill)
- rms orbit errors are about 170 times the rms quad displacement.
- Laser/source vibrations? (have to be remove at source!).
- Cryostat/cryogen turbulence: Largest effect is on cavity tuning.

Beam instabilities => BBU



Beam breakup instability (BBU) in one dimension
originally a major concern for current limit, now:

400 identical cavities → **Current limited to 25 mA**

Random f_{HOM} with rms of 10MHz → **Current limited to 400 mA**

Polarized Cavities + x-y coupling → **2000 mA >> required 100 mA**

Experiments in collaboration with the JLAB-FEL team showed that BBU limiting techniques work for the 3 mA nominal threshold current of that accelerator.

Since BBU is limited, the current is limited by HOM heating

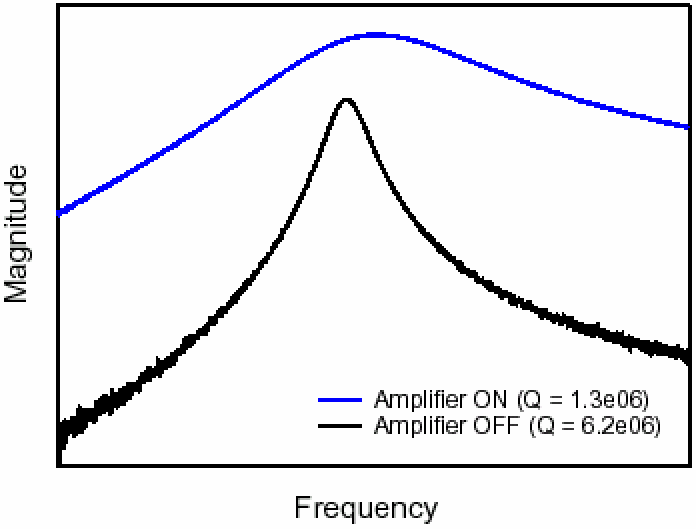
HOM with BBU: Starting from Noise

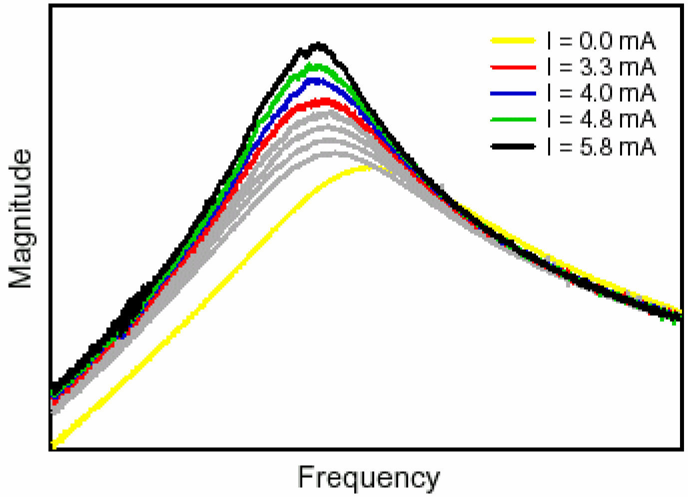
Recall… $I_{threshold} \propto \frac{1}{Q_{HOM}}$

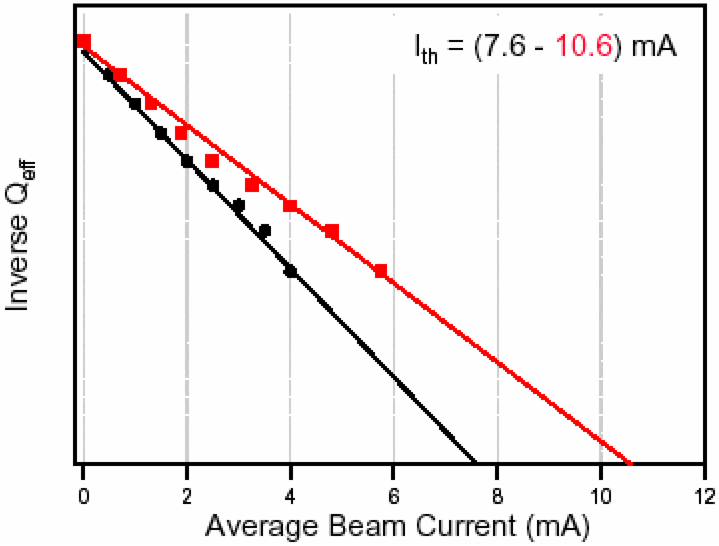
- Damping circuit easily reduced the *Q* of the 2106 MHz mode by a factor of 5

  (Above a factor of about 10, the system becomes sensitive to external disturbances)

- The threshold is increased accordingly: from 2 mA to ~10 mA

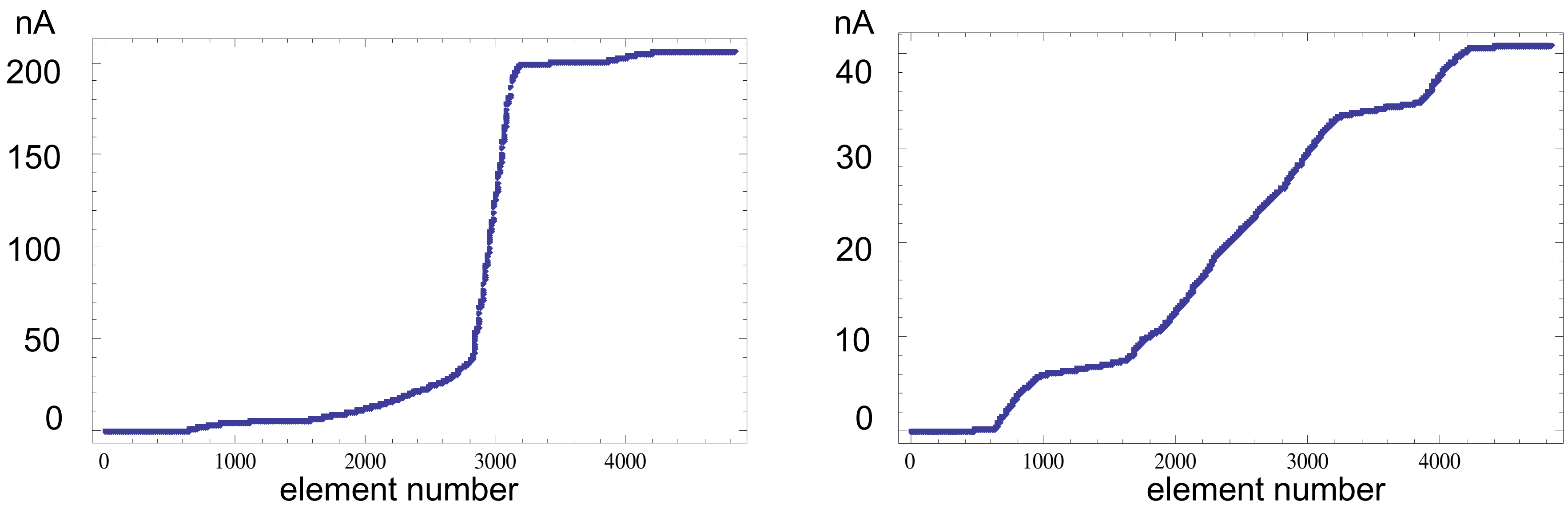


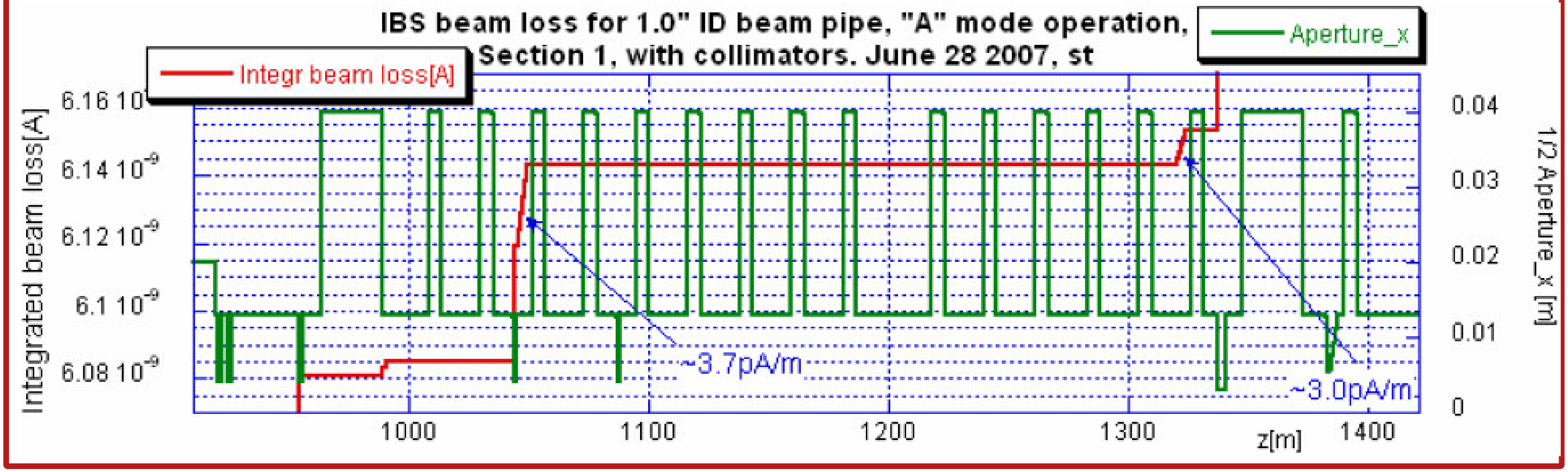




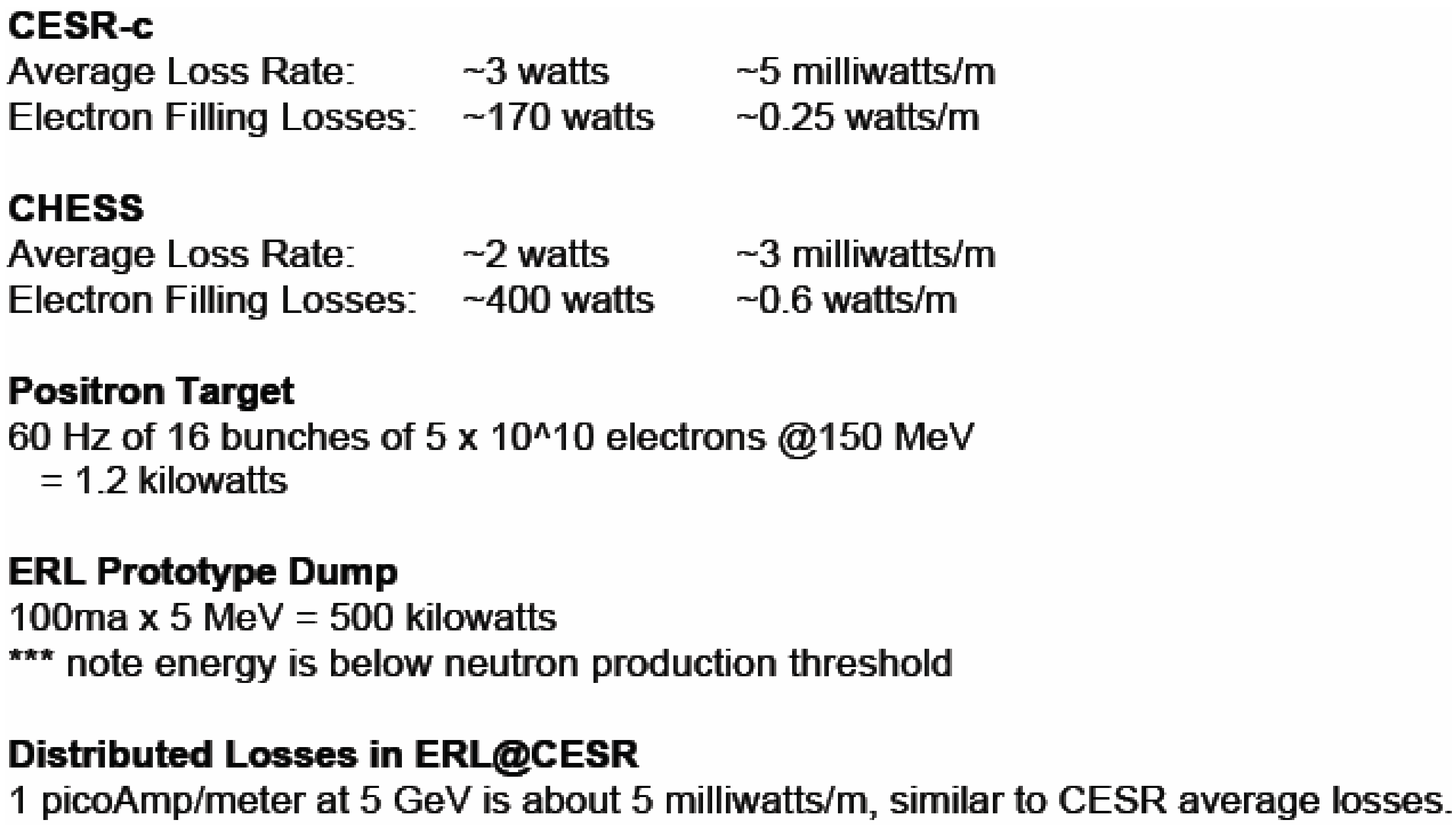
Scattering and background: IBS

CLASSE





Collimation of scattered electrons



CESR-c

Average Loss Rate:	~3 watts	~5 milliwatts/m
Electron Filling Losses:	~170 watts	~0.25 watts/m

CHESS

Average Loss Rate:	~2 watts	~3 milliwatts/m
Electron Filling Losses:	~400 watts	~0.6 watts/m

Positron Target

60 Hz of 16 bunches of 5 x 10^10 electrons @150 MeV
= 1.2 kilowatts

ERL Prototype Dump

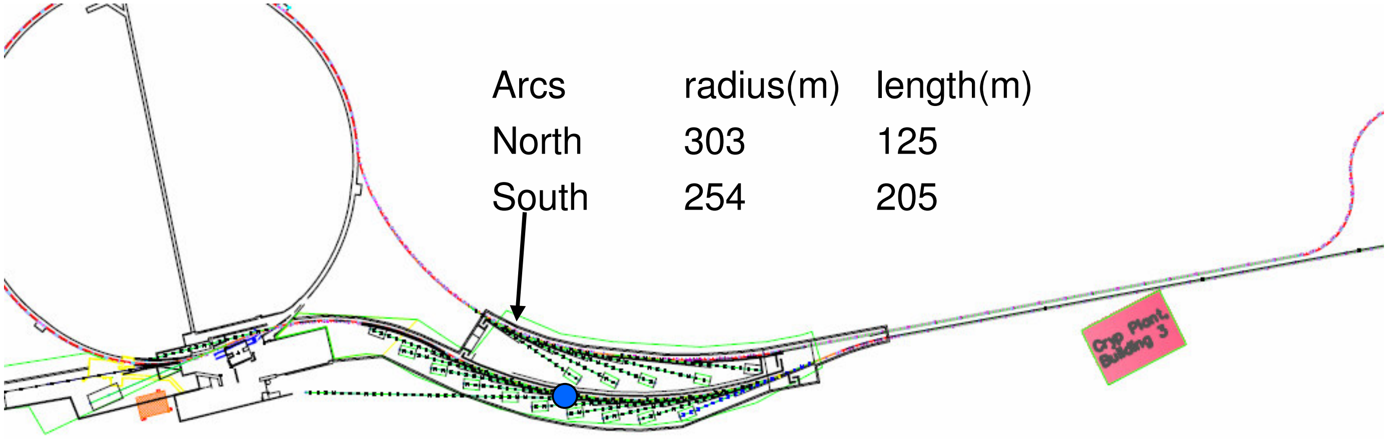
100ma x 5 MeV = 500 kilowatts
*** note energy is below neutron production threshold

Distributed Losses in ERL@CESR

1 picoAmp/meter at 5 GeV is about 5 milliwatts/m, similar to CESR average losses.

Accelerator research options

Estimate following H.J. Moe in APS-LS-141 & -272



Arcs	radius(m)	length(m)
North	303	125
South	254	205

Three contributions to background from continuous uniform e^- loss: Bremsstrahlung, giant resonance neutrons, & high-energy neutrons

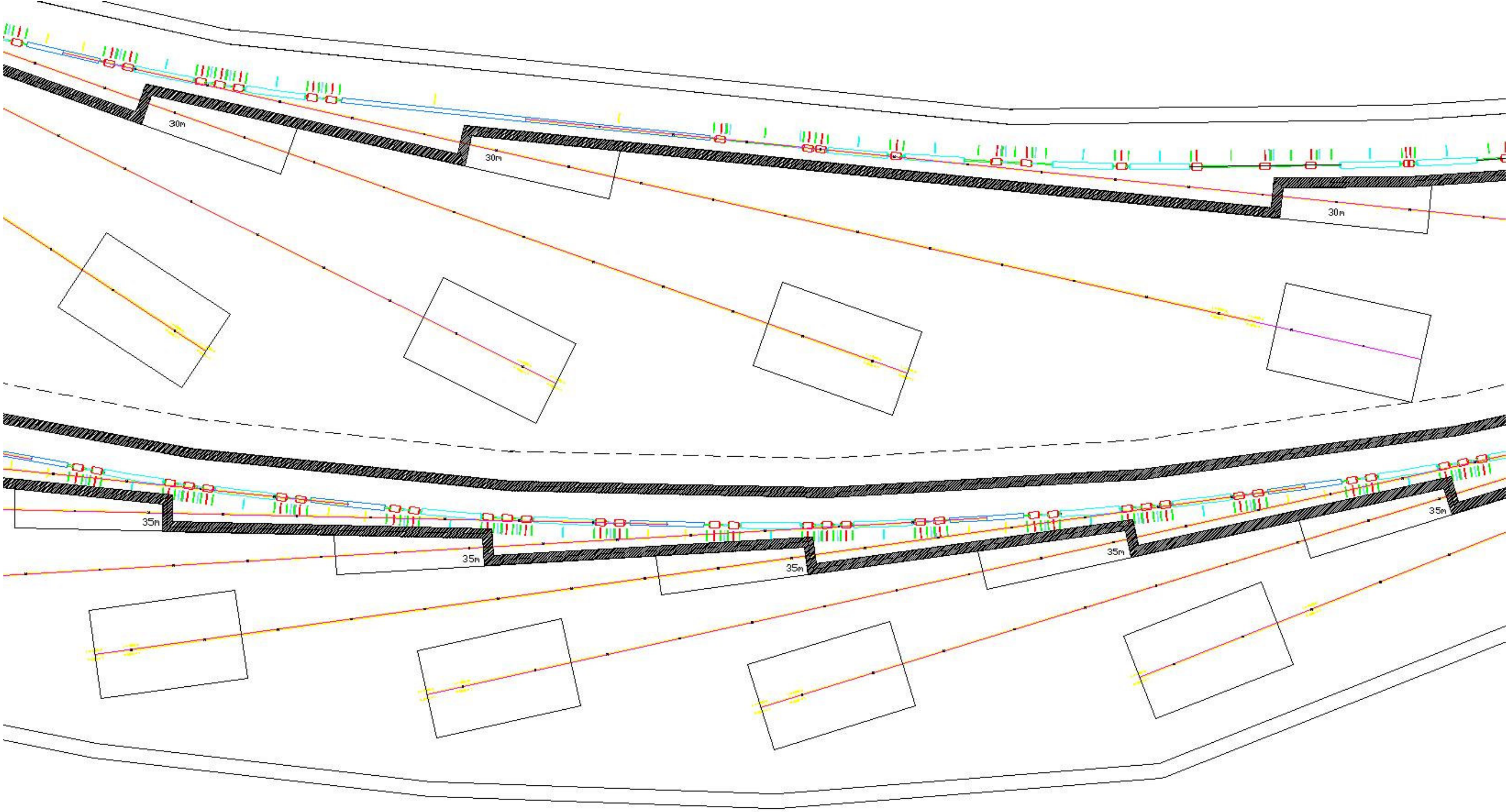
For average beam loss 1 pA/m over 205m southern arc, shield wall: for 2’ heavy concrete + 2” Pb→0.058mrem/hr just outside the wall, at arc center.

Moe’s estimate for APS (300mA,10 hour lifetime or 1/57 pA/m) → 80cm normal concrete wall limits dose to 8 mrem/yr @ 50m

Public: limit to less than 100mrem/year, occupational limit to less than 5000mrem/year

Shielding and x-ray optics

1st optics at 35m after center of undulator, outside shielding wall.
80m long x-ray beamlines.



Design of collimators

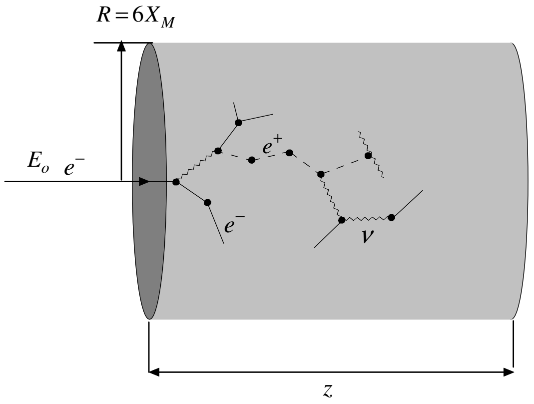
- Large collimators are needed that absorb several nA to protect the user region by limiting the loss per meter to less than 1pA/m.
- Smaller collimators are needed to protect individual undulators.

$$Ta: \quad Z=73 \quad A=181 \quad \rho=16.6\,g/cm^3 \quad E_o=5GeV \quad Critical\ Energy: E_c=11\,MeV \quad \left(\frac{dE}{dx}\right)_{rad}=\left(\frac{dE}{dx}\right)_{ion}$$

$$Moliere\ Length: \boldsymbol{X_M}=\left(\frac{21.2}{E_c\,(MeV)}\right)X_o=11\,g/cm^2=0.66\,cm$$

$$For\ 10^{-3}\ of\ total\ energy\ deposited\ z=1.2\lambda_l \quad where\ \lambda_l=\frac{325\cdot\ln(E_o)}{(\ln Z)^{1.3}}=417\ g/cm^2$$

$$z=500\,g/cm^2=30\,cm$$



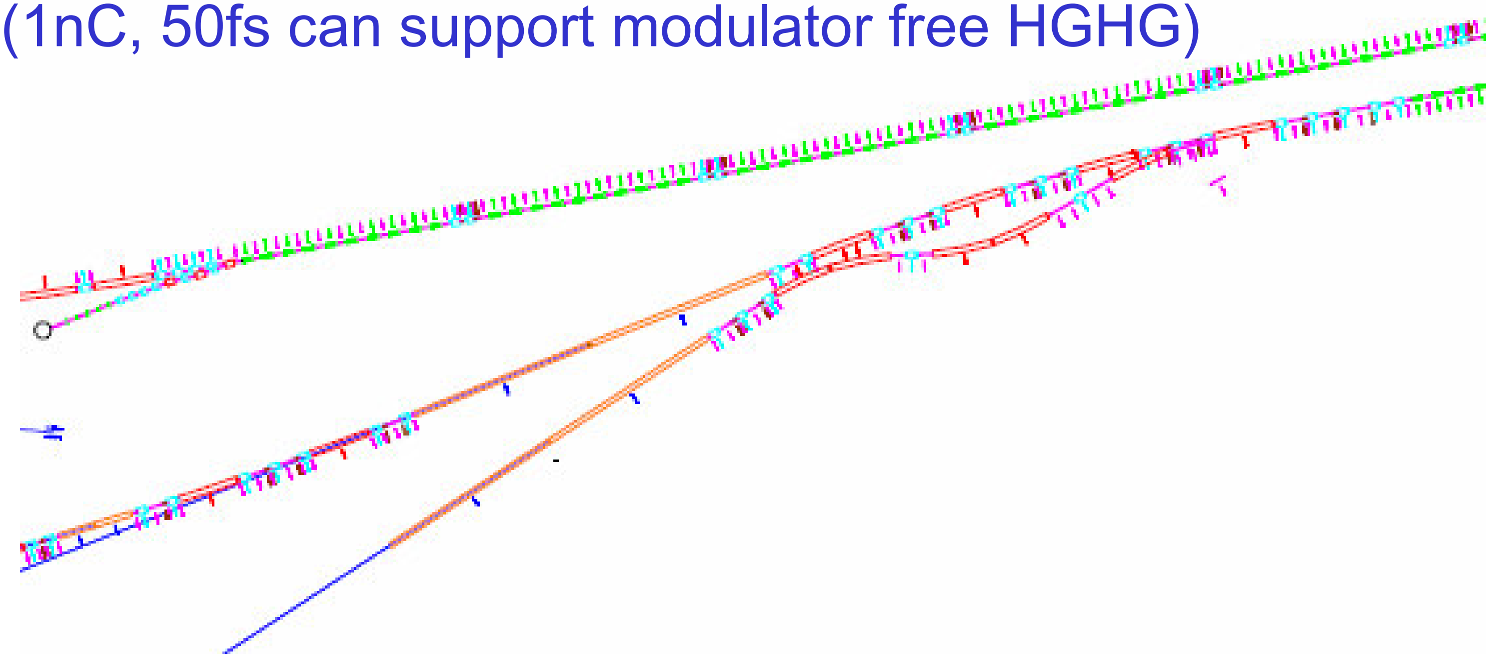
Tantalum cylinder of radius $6X_M$ *and length* z *should be a good start for more calculations, i.e. a cylinder 8 cm in diameter and 30 cm long.*

Reference: NCRP Report No. 144

Future accelerator developments

1) SASE FEL development in parallel with ERL operation (1nC, 50fs can support SASE amplification)

2) HGHG development in parallel with ERL operation
(1nC, 1ps can support radiator/modulator HGHG)
(1nC, 50fs can support modulator free HGHG)



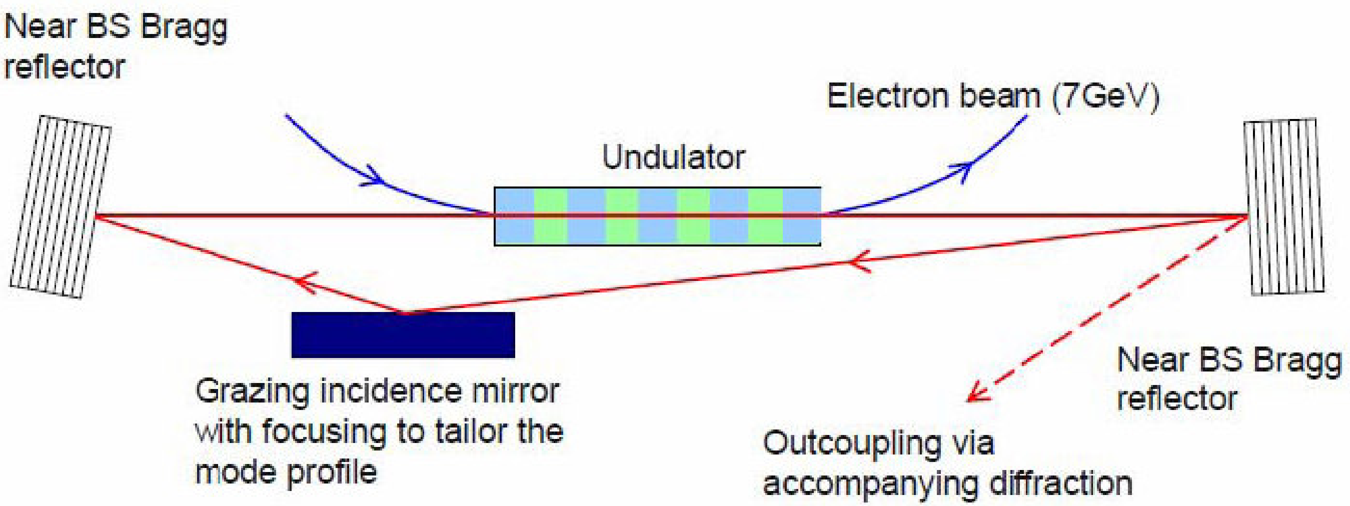
3) Development of higher current operation

Amplifier FEL operation

K-J. Kim

A Novel Concept for X-Ray Optical Cavity Using Near Backscattering & Accompanying Diffraction

(KJK & Shvyd'ko)



- Cornell-ERL parameters scaled to 7-GeV (19-60pC, 2ps, ε=6pm, ΔE/E=0.02%) → $\varepsilon < \lambda / 4\pi$ for 1Å
- FEL single-pass gain ~ 50% for 60pC, Lu=23m case.
- Energy spread of 0.05% (after FEL lasing) is acceptable for ERL operation.

From ERL07 Workshop

Conclusions and Contributors*

Injector parameters	Ivan Bazarov, Charlie Sinclair
User requirements for layout and beam parameters	Don Bilderback, Dana Richter
Layout, optics considerations, ISR, CSR	Chris Mayes
Coupler kicks	Brandon Buckley
Ion effects with clearing electrodes	Christian Spethmann, Yi Xie
Ion gap options	Bob Meller
Cavity alignments, orbit correction techniques, BBU	Changsheng Song
BPM solutions for 2 beams, ERL impedances	Mike Billing, Mark Palmer
Transverse orbit feedback considerations	Jerry Codner, Don Hartill , John Sikora
x-ray loads	Mike Forster
Gas and pressure profile	Yulin Li
Gas and Touschek scattering, beam halo, collimation	Sasha Temnykh, Mike Ehrlichmann
Radiation shielding	Ken Finkelstein, , Steve Gray, Val Kostroun
Code developments	Dave Sagan

Cornell has an experienced team of accelerator experts who have laid out an ERL for the Cornell campus that extends the CESR ring, and have defined working modes that accommodate all considered accelerator physics issues.

*** Several people contributed to more than one subject.**

Preconstruction Plans

1. Development of a multicell ERL cavity
2. Operation of two 7 cell cavities with beam
3. Long term operation of an ERL cavity in a test cryostat, if possible with beam
4. Design and construction of a complete main linac cryomodule with RF test
5. Diagnostics and instrumentation:
    (a) Electron and X-ray BPM's
    (b) feedback systems
    (c) longitudinal distribution function measurement
    (d) high-sensitivity emittance measurements
    (e) spectral brightness measurements
6. Ion removal electrode development including design and test
7. Measure CSR shielding function
8. Theoretical studies
    (a) Optics optimization, short, high charge bunch formation and transport
    (b) Orbit and optics correction, tolerances and feedback system design
    (c) Emittance growth via CSR in merger and ERL loop
    (d) longitudinal space charge through linac, ions
    (d) Ion instabilities
    (e) Beam loss, collimation, abort strategies
9. HOM studies of planned vacuum chamber components.
10. Electron source improvements