Summary of ERL WG

Conveners

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March 5, 2010.

Working Group Overview

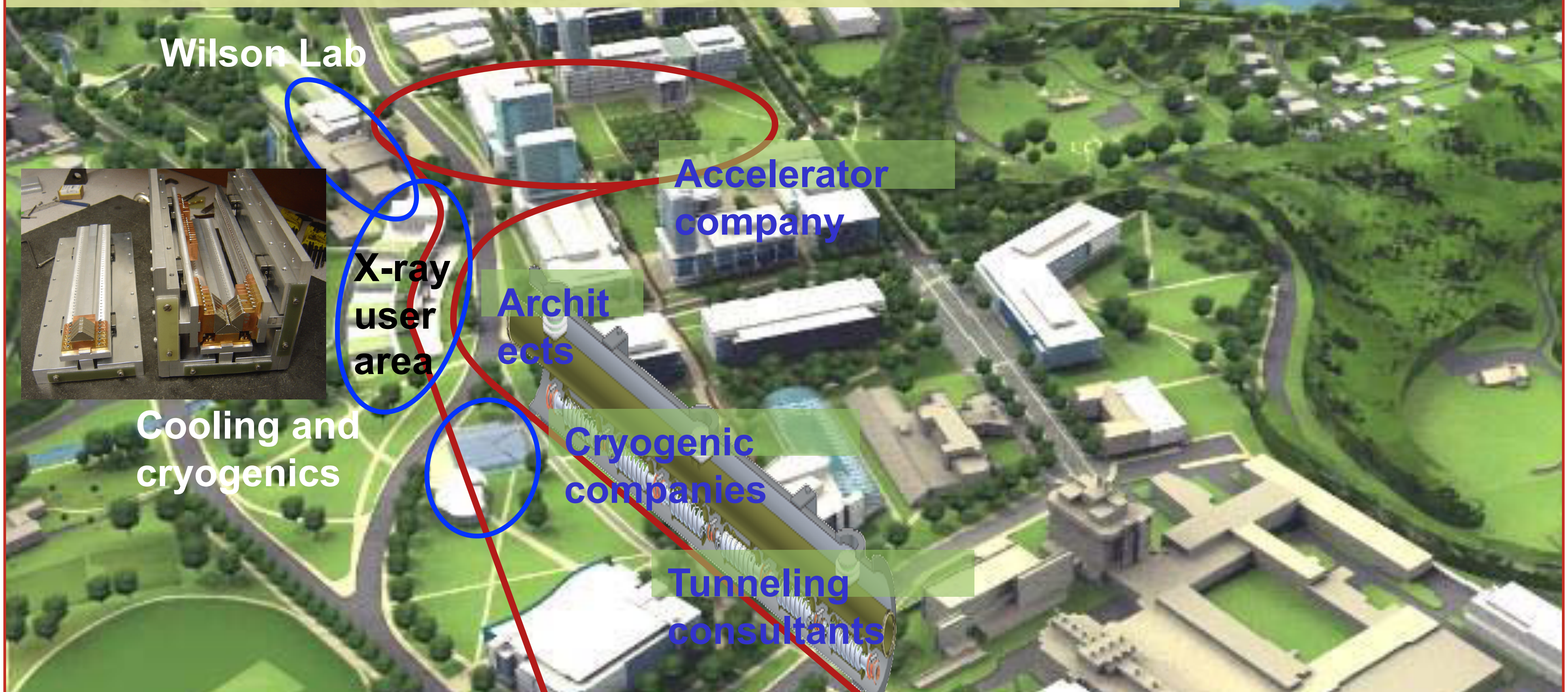
- Project Status Update
  - reports from 5 projects
- Performance & Operation modes
- High-rep. Guns (Joint Session with Gun WG)
- FEL in ERLs (Joint Session with FEL WG)
- Injector & SRF
- Miscellaneous Subjects

Status of Cornell's ERL Project

Working modes: current, emittances, energy spread, bunch length

A)	**100mA,**	**30/30pm,**	**2.e-4,**	**2ps**
B)	**25mA,**	**8/ 8pm,**	**2.e-4,**	**2ps**
C)	**25mA,**	**300/10pm,**	**2.e-3,**	**1ps in South, 100fs in North beamlines**

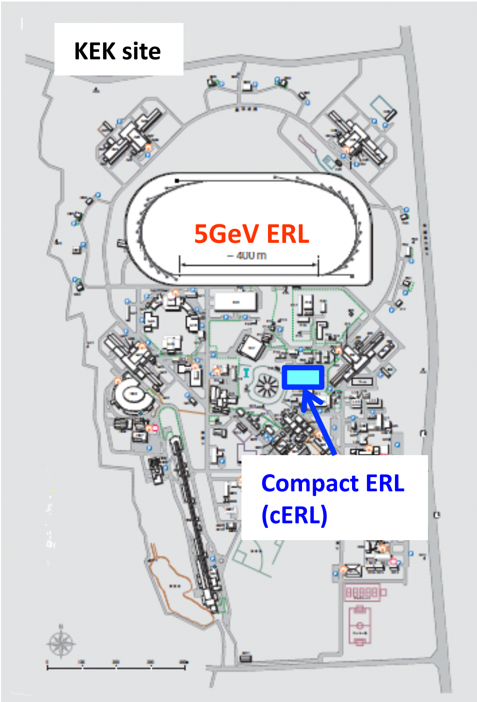
The option of large bunch charge (1nC) with low repetition rate (100kHz),
without energy recovery, up to 1nC for studying XFELO, HGHG FELs, etc.



Status of the ERL Project in Japan

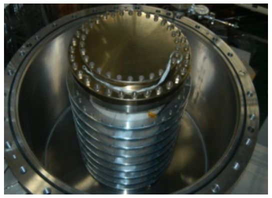
ERL Project

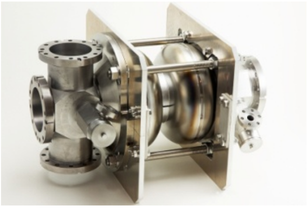
- Compact ERL (final version : 2 loop, 245 MeV, 100 mA)
- Two-loop 5-GeV ERL and 7.5-GeV XFEL-O



R&D on Key Components

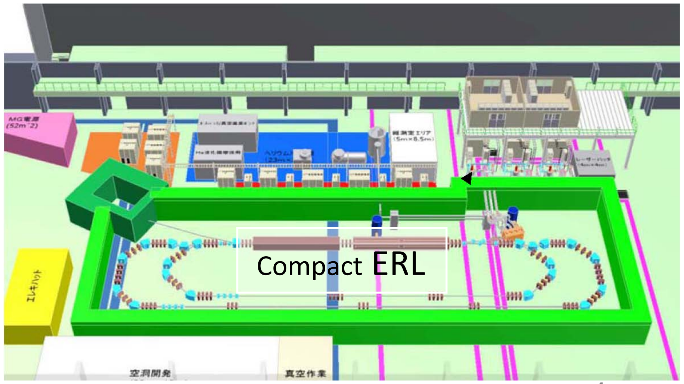
- 500-kV DC photocathode gun with a segmented insulator
- Test injector beamline and drive laser system
- SC cavities for both injector and main linacs





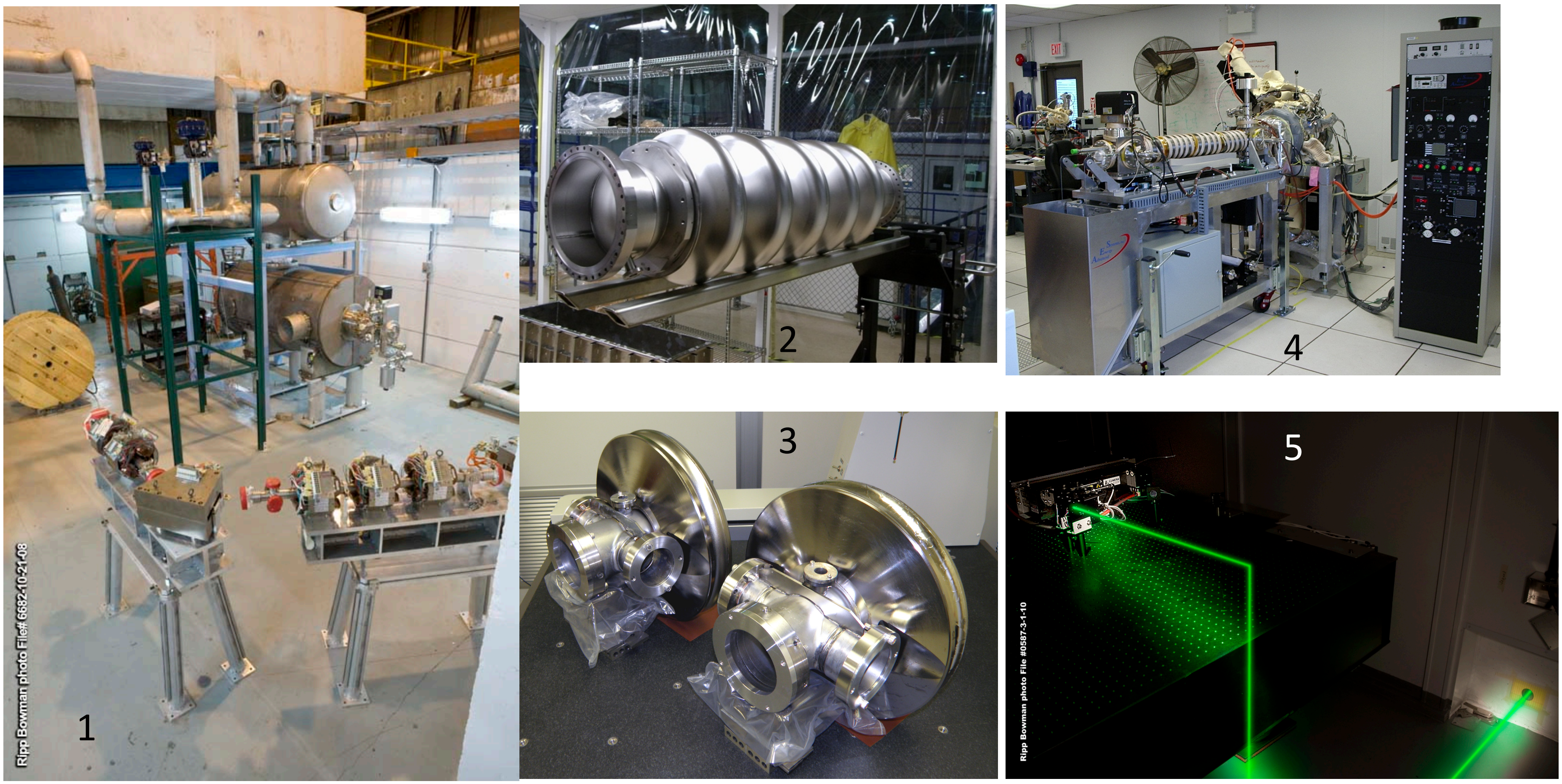
Compact ERL (cERL)

- Optics design and error effects of cERL studied
- East Counter Hall renewed as cERL building
- Commissioning (1 loop, 35MeV, 10mA) planned in FY2012



Status of the ERL Projects at BNL

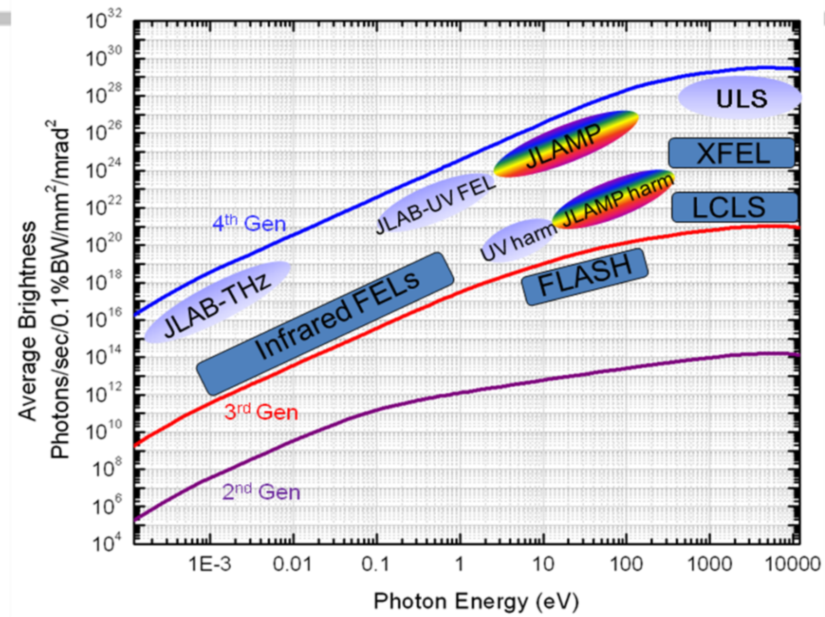
R&D ERL at BNL: 500 mA, 20 MeV, SRF injector, advanced state of construction

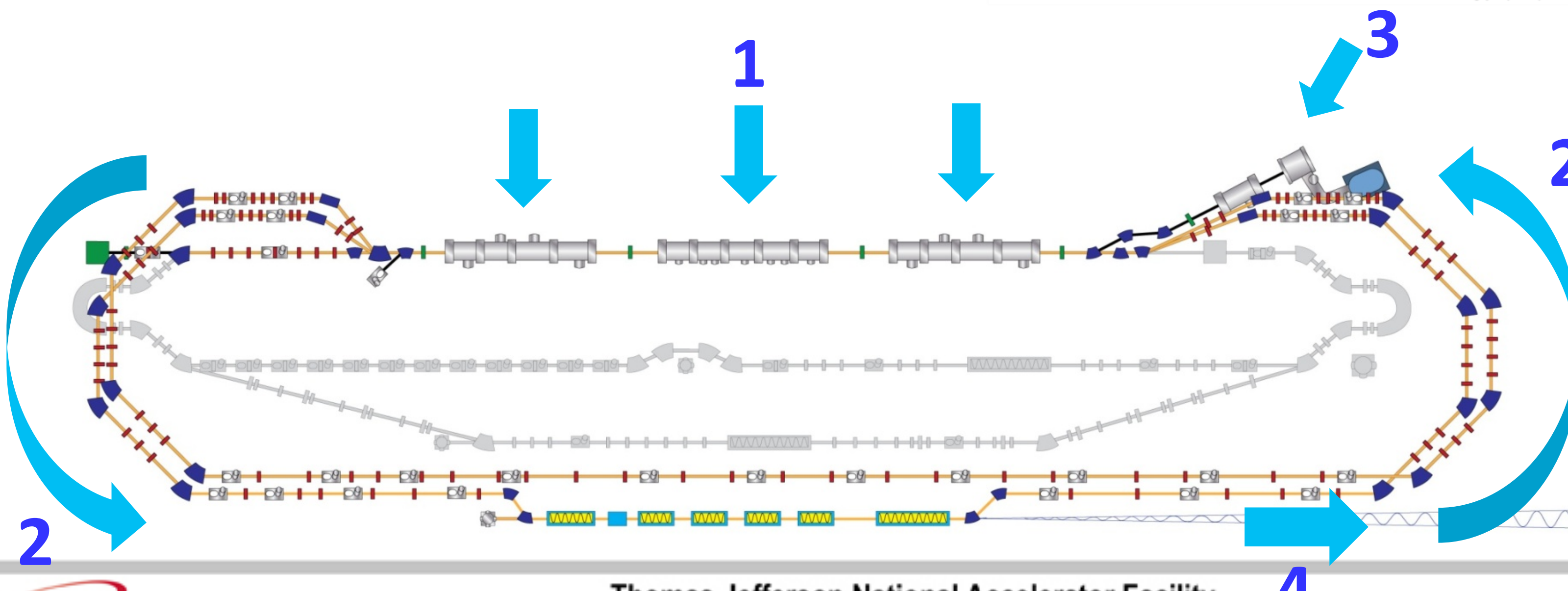


1. The ERL vault, showing the SRF cavity and some of the magnets. 2. The 704 MHz 5-cell 20 MeV cavity with single-mode properties. 3. The superconducting 2 MeV 500 mA guns. 4. The load-lock multialkaline photocathode system. 5. 6 watt green beam laser.

JLab Conversion to JLAMP

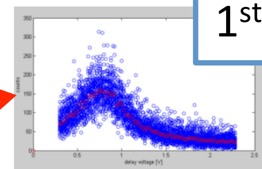
- 4 steps
- 600 MeV, 2 pass acceleration
- 200 pC, 1 mm mrad injector
- Up to 4.68 MHz CW repetition rate
- Recirculation and energy recovery
- 10 eV – 100 eV fundamental output, harmonics to 2nm
- Pulse widths down to 50 fs



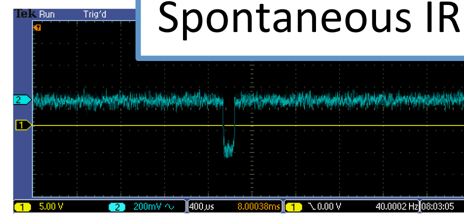


ALICE Project Status Update

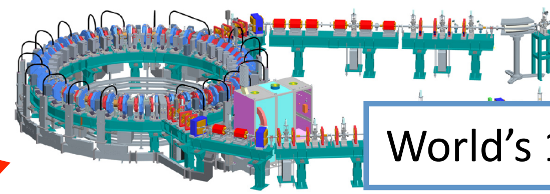
- Commissioning 2009/10
  - Achieved 1st THz in Diagnostics Room
  - 1st Compton Scattering
  - Characterisation of beam
  - Some RF conditioning & optimisation
- **FEL commissioning Feb 10**
- Future experiments
  - Accelerator science R&D
    - FEL lasing
    - EMMA etc...
  - Photon science R&D
    - THz tissue culture lab
    - IR and THz pump probe etc...
  - Technology development
    - International cryomodule
    - Gun upgrade etc......



1st Compton X-rays



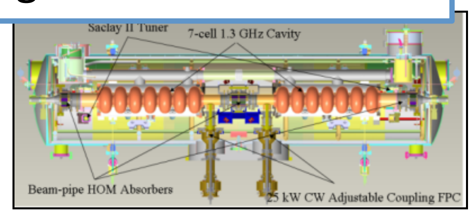
Spontaneous IR

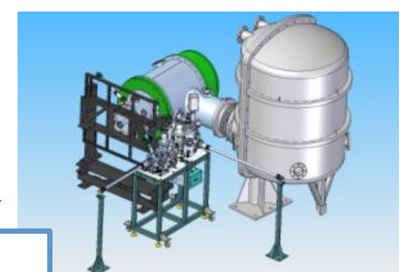


World's 1st ns-FFAG

Live tissue exp.

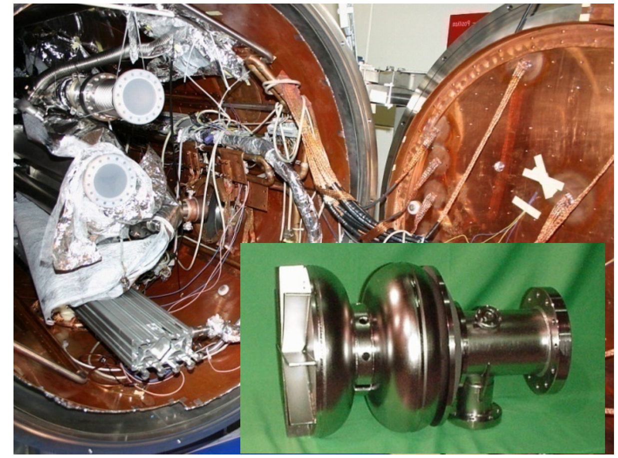
CW high current module





Load lock cathode exp.

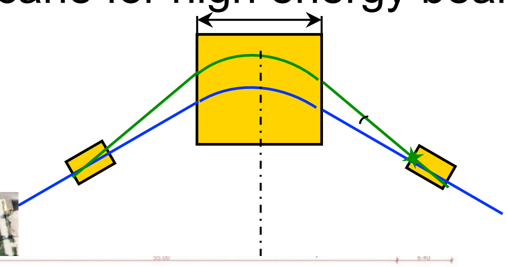
B*ERL*inPro: ERL demonstration facility @ Berlin-Adlershof



Goal: 1.3GeV, 100MeV, 100mA, small emittance, short bunches
Explore limits of ERL, show different operational modes

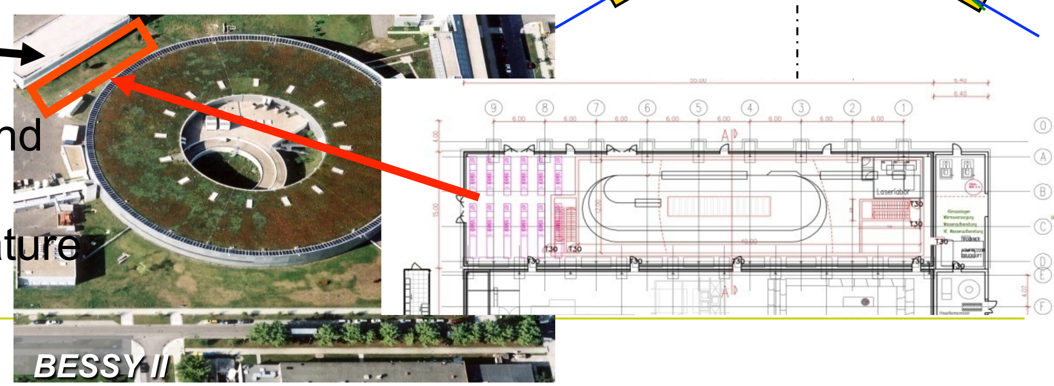
Gun: Funded, staged approach
Beam dynamics → Cathode infrastructure → High current

Merger: Studies show: C-chicane does the job
- –Higher order dispersion is an issue
- –Lower limit on bunch length after merger depends on current and energy spread
- –Emittance depends on bunch length: Remaining compression factors in recirculator < 10
- –Lambertson Magnet considered as last merger dipole: saves chicane for high energy beam



Path length control:
Most probably in arc, trajectory elongation in central dipole by outside deflection of the beam

Cryogenic plant



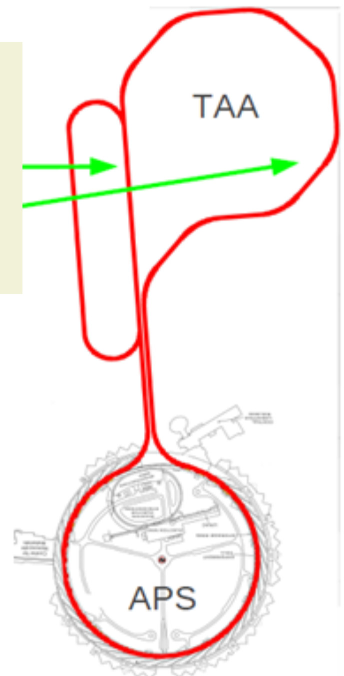
Too little space for shielding above ground
Consider construction underground
Benefit: reduced vibrations and temperature fluctuations at comparable costs

Comparison of APS-upgrade to ERL@APS

APS-upgrade may include
- 2ps X-ray by crab cavity
- short-period SC undulators
- long straights (7.7m)
- higher current (150 mA)
- lower coupling (8 pm)

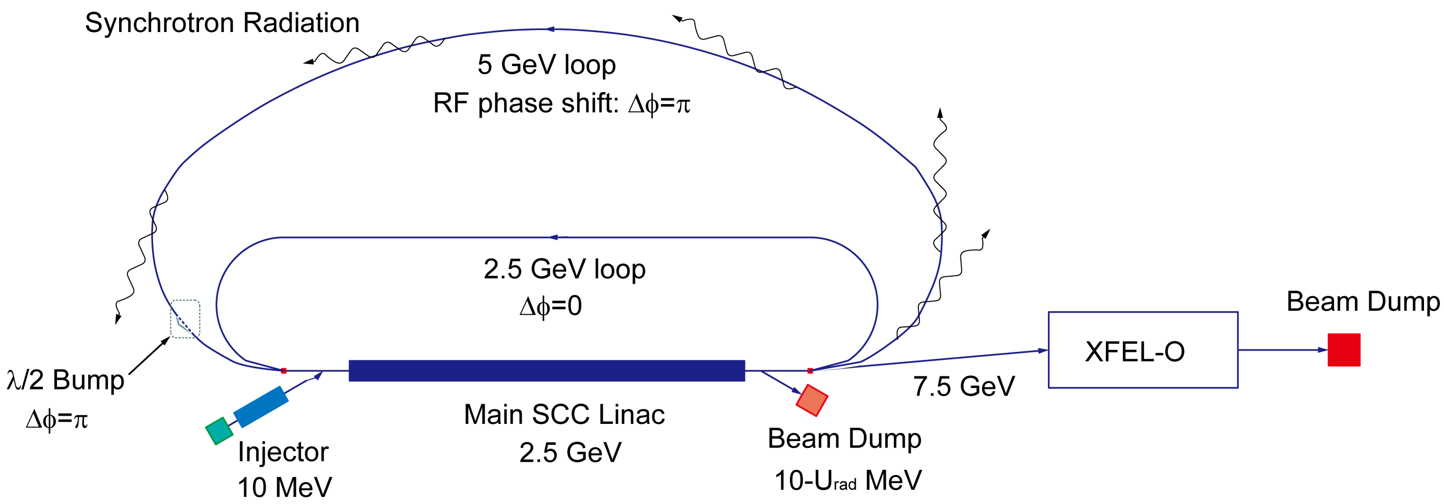
↔

ERL@APS
- 2-pass 7-GeV linac
- 50-m straights at TAA
- 0.1 mm-mrad, 25 mA



- APS-U is a cost-effective approach
  - shorter pulse, higher flux and brightness
  - relative low risk
- ERL@APS makes spectacular promises, but
  - multiple show-stoppers → significant R&D required
  - not much enthusiasm from APS users
- APS-U does nothing to preclude ERL@APS
- ANL also keeping XFELO and USR in mind

XFELO in ERL

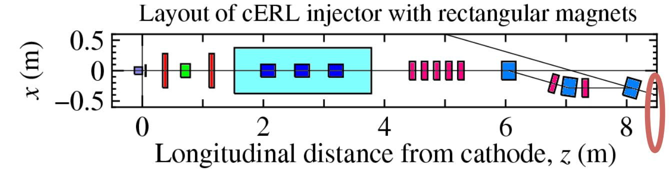


- Hard X-ray ERL can accommodate XFELO.
- 0.1nm-XFELO is feasibly realized at
  - 5-GeV ERL with velocity bunching
  - 7.5-GeV beam from a 2-loop 5-GeV ERL
- In the Japanese collaboration, XFELO is considered as a part of 5-GeV hard X-ray ERL.

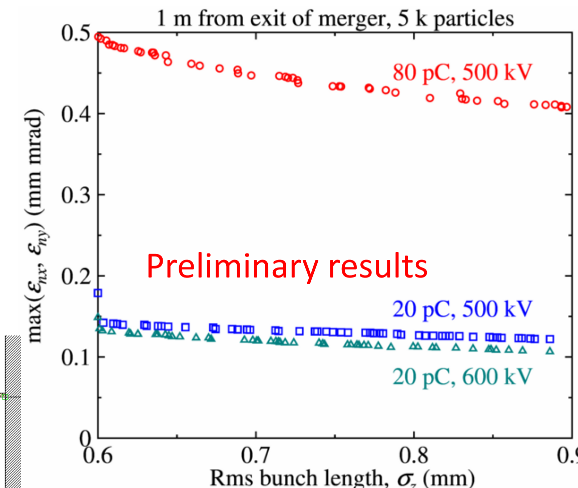
Studies of compact ERL injector in Japan

- Beam dynamics simulation for the compact ERL (cERL) has been carried out using 3D space charge particle tracking code.
  - For high current mode with 80 pC/bunch, we obtained the minimum emittance of 0.56 mm mrad with the bunch length of 0.63 mm. with the gun voltage of 500 kV.
  - For XFEL-O with 20 pC/bunch, so far, we have obtained the minimum emittance of 0.13 mm mrad with the bunch length of 0.6 mm and the gun voltage of 600 kV.
- To evaluate performance of the DC guns, we are developing the gun test beamline in the PF-AR south experimental hall, KEK.
- From the early part of March, we are going to start beam running in the gun test beamline using NPES3 200kV DC photo cathode gun.

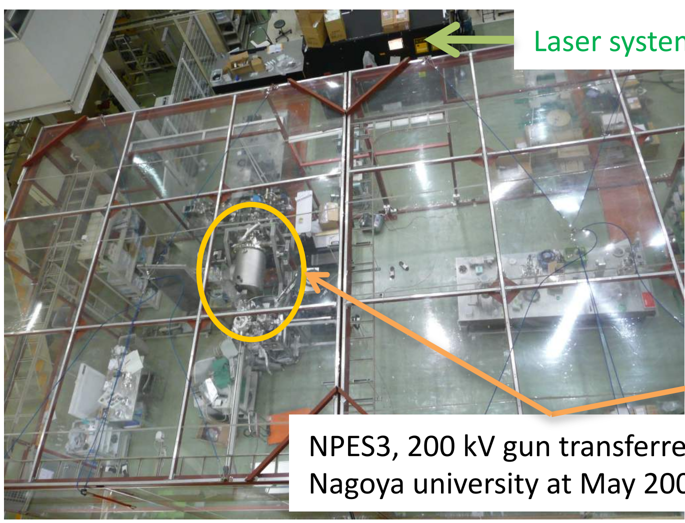
Layout of cERL injector beamline



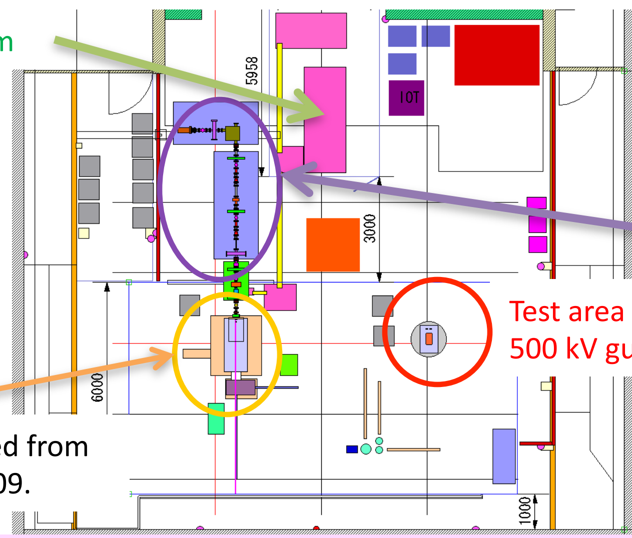
Bunch length vs. emittance



Gun test area in PF-AR south hall, KEK

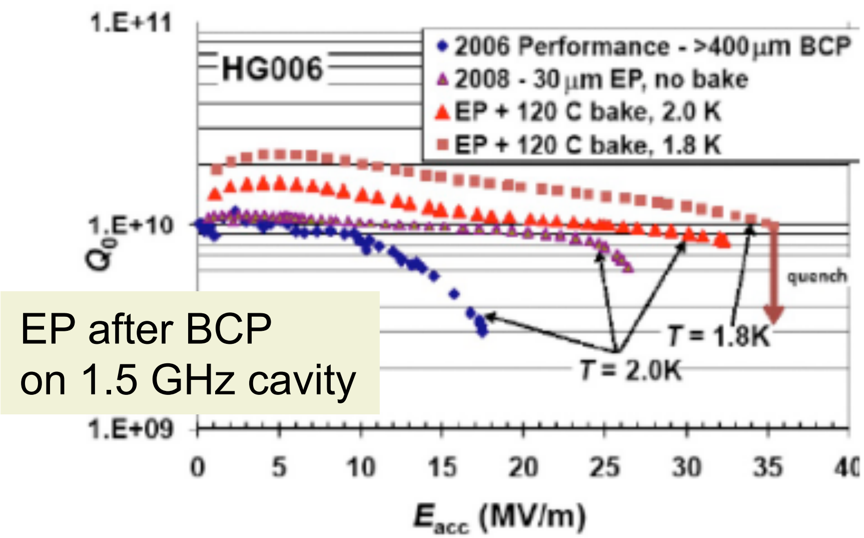


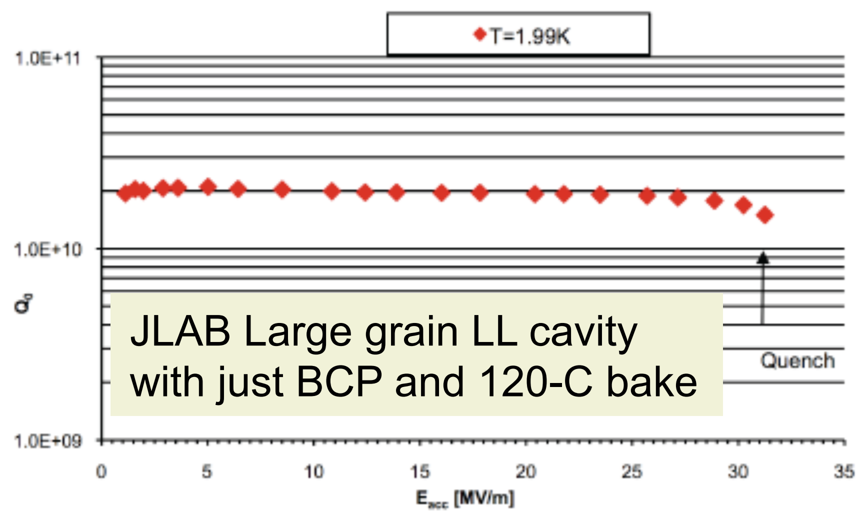
Layout of gun test beamline



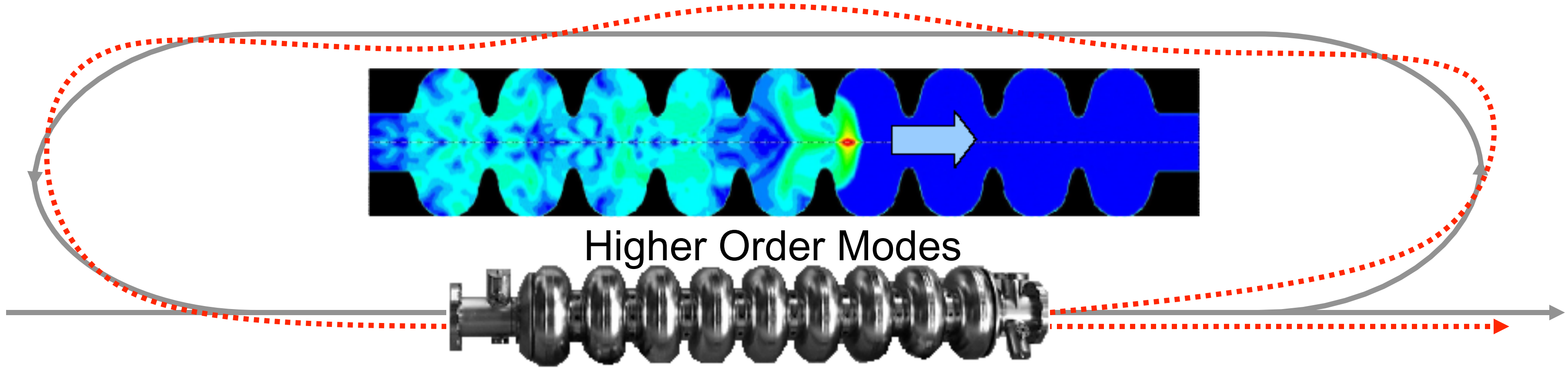
Update on CW SRF at JLAB

- CEBAF 12 GeV upgrade ramping up (10 CM's in 2 years)
- Cavity performance encouraging with EP or large grain
- better Q0 pulls down ERL cost
- JLAMP/FEL, SRF guns, high-current cavity.
- Large 2K cryogenic plant are getting more efficient





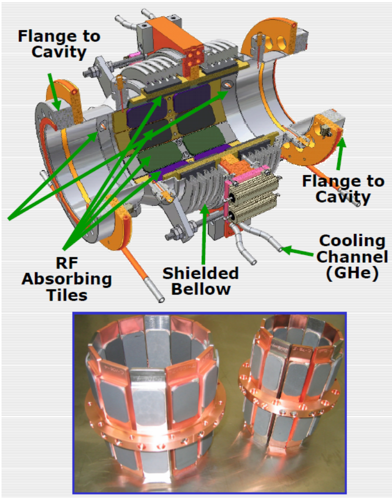
BBU: Collective Instabilities

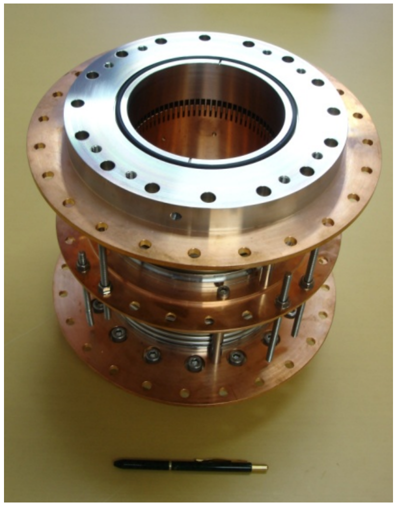


- Beam-Breakup instability is well understood and simulations corrspond to measurements at the JLAB ERL. BBU studies therefore do not require another test ERL.

- Cavity shapes can and have to be optimized so that the BBU threshold becomes insensitive to cavity construction errors.

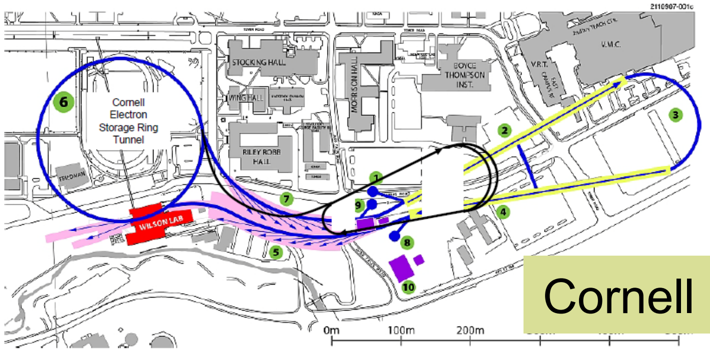
HOM Absorber

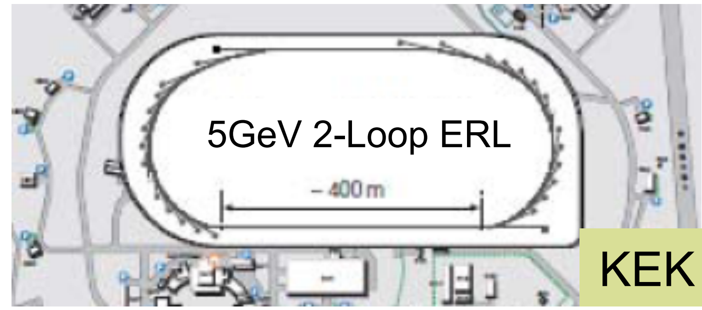




- Material of absorber
  - ferrite (New IB004-1) for KEK/JAEA main linac
  - Carbon nanotube for Cornell main linac
- Frequency range to be covered
  - We need to manage high-frequency component (>100GHz)
  - additional installation of XFEL-type HOM absorber may help
- Manufacturing
  - Study needed
  - Effects of thermal cycle and design to avoid cracking
  - hot isostatic press seems promising
- Magnetization
  - No problem, so far.
- Conductivity to avoid charge up
  - Carbon nanotube seems to be conductive in low temp.

2-Loop ERL Concerns: OK, Challenge





1. Space charge forces for superimposed beams and emittance growth.
2. Intra beam scattering between superimposed beams and halo/background creation.
3. Increasing Higher Order Mode (HOM) power for separated bunches.
4. More sophisticated Beam spectrum and RF control.
5. Tighter orbit and return time tolerances.
6. Limits of orbit corrections for 4 simultaneous beams.
7. Linac optics for 4 simultaneous beams.
8. Reduced Beam-Breakup (BBU) tolerances, esp. with cavity errors.
9. Reduced effectiveness of polarized cavities and coupled optics for fighting the BBU instability.
10. Impedance budget and increased energy spread.

Depending on environment, the challenges can be worth the potential savings or not.

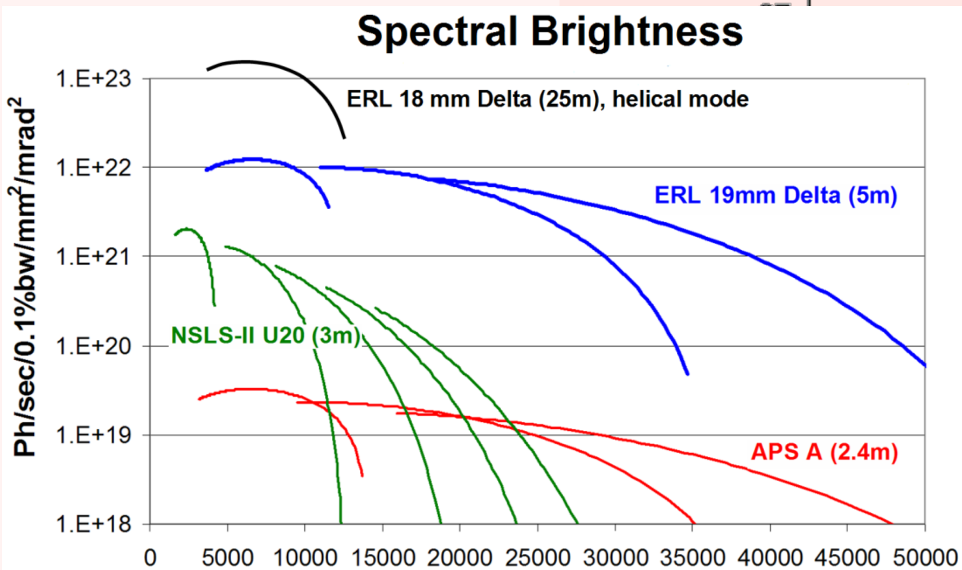
Cornell: increased tunnel and building needs for two turns make risk not worth taking.

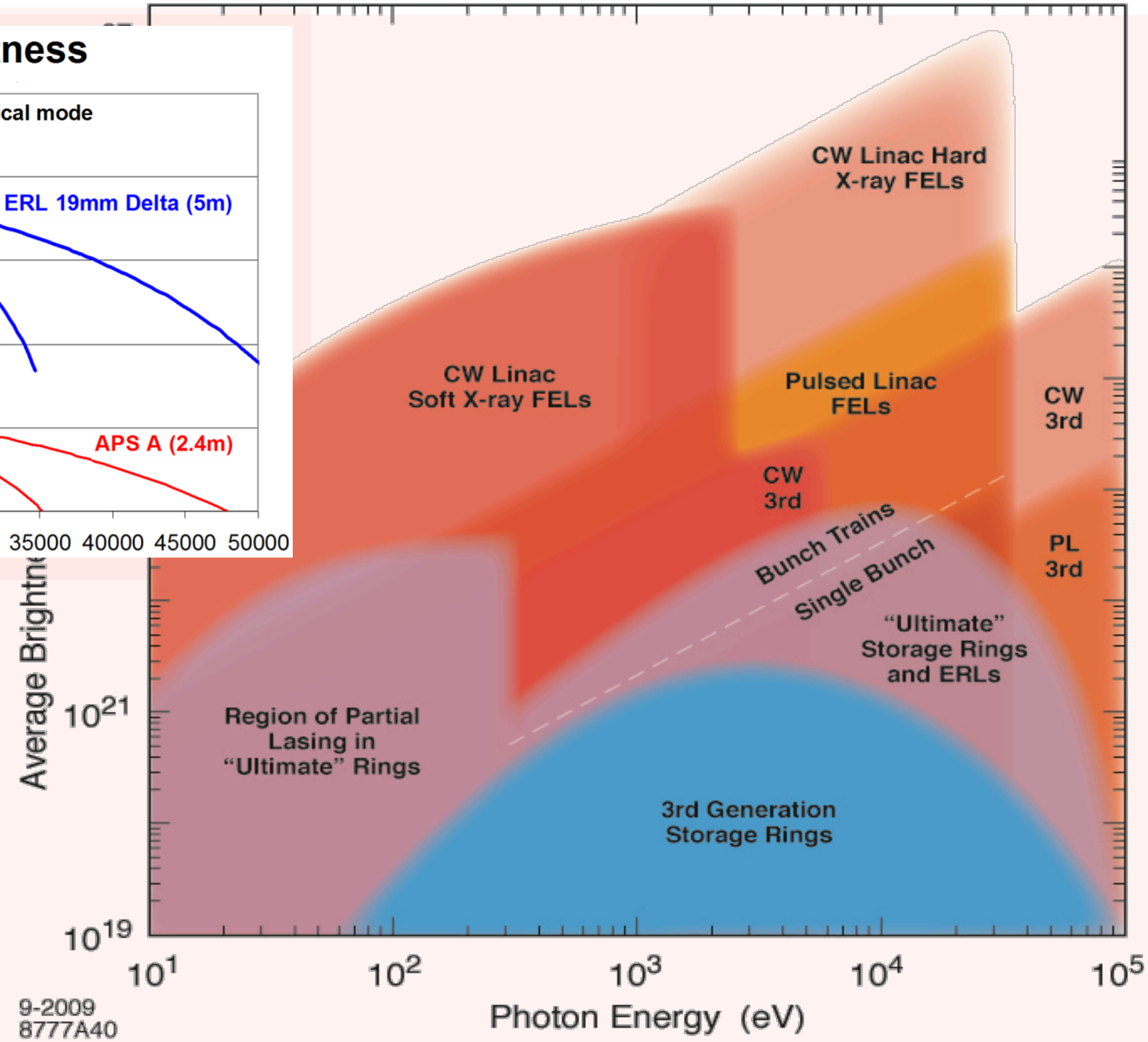
KEK: because of space limitations, a two turn ERL seems to have a benefit.

Operation Modes for Hard X-ray ERL (Cornell)

	Energy recovered modes			One pass	
Modes:	(A) Flux	(B) Coherence	(C) Short-Pulse	(D) High charge	Units
Energy	5	5	5	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	0.5	MW

Average Spectral Brightness for Hard X-ray ERL





Exceedingly large average spectral brightness is one large advantage for ERLs, but by far not the only one.

Summary of Advantages for ERLs

ERLs have unique capabilities and many advantages over rings:

a) Large currents for Linac quality beams

b) Continuous beams with flexible bunch structure

c) Small emittances for round beams

[similar transverse properties have recently been proposed for 3km long rings]

d) Openness to future improvements

[today's rings can also be improved, improvements bejond ring performances mentioned under c) may be harder to imagine]

e) Small energy spread

a) Variable Optics

b) Short bunches, synchronized and simultaneous with small emittances

The breadth of science and technology enabled is consequently very large and the ERL will be a resource for a very broad scientific community.

X-ray ERLs are at the beginning of a development sequence, whereas decades may have brought x-ray rings to the end of their development.

Operation Modes for Other Types of ERLs

Modes:	THz	Compton gamma	Compton x-ray	Seeding FEL
Energy	100MeV<E<1GeV	>300MeV	>25MeV for IR laser for 10keV	>2GeV HHG for Sxr >5GeV for selfseeding Hxr ?
Current	>1mA	>1mA	Large?	kA peak
Bunch charge		Cavity length as long as possible	As large as pos	As high as pos
Repetition rate	for 75MHz	Therefore as low as possible	As low as pos for given current	<1MHz if echo enhanced
Norm. emittance	$\gamma\lambda/4\pi$	$\lambda_{Laser}/4\pi$	$\gamma\lambda/4\pi$ for beam matching	
Geom. emittance	$\lambda/4\pi$	$\lambda_{Laser}/4\pi/\gamma$		
Rms bunch length	<100fs	< hourglass > Energy spread if applicable	< hourglass	Somewhat > 30fs +- 20fs jitter laser length
Relative energy spread	To recover	1.e-9, thus as small as possible or corresponding to emittance		Slice over 30fs seed as small as possible.

We appreciate all the contributions to the ERL WG, and the arrangement by WS Organizers.

ICFA have approved ERL-11 WS. See you at Tsukuba Japan in fall 2011.