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APS Upgrade - R&D Plans

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APS Upgrade R&D goal

Develop and test designs of novel accelerator systems that will deliver several orders of magnitude in brightness and coherent flux of x-rays

APS Upgrade main R&D topics

- *Beam dynamics of ultra-low emittance e-beam*
- *Next generation of RF systems*
- *Ultra-bright electron source*

Topics for ERL Beam Dynamics R&D

- *Ultra-low emittance: production and preservation with the required bunch charge*
  - Design gun and merger using evolutionary algorithms, targeting 0.1 micron emittance, 2~3 ps rms bunch length for 20 pC/bunch
    - Such performance not yet demonstrated even in simulation
  - Explore options for DC and rf guns, both normal and superconducting
- *Cost-effective configuration that preserves emittance*
  - Develop options for single- and multi-pass linacs in various configurations
  - Explore alternatives to complex TBA-based designs that sufficiently control both coherent and quantum radiation effects
- *Control of beam instabilities at 25~100 mA average current*
  - Apply standard codes to evaluate and improve lattices and cavities for resistance to beam break-up (BBU) instability
  - Model ion trapping and explore use of kickers to create bunch gaps
  - Develop integrated ELEGANT simulation that includes BBU, resistive wall, chamber wakes, detailed transport, etc.

ERL Beam Dynamics R&D

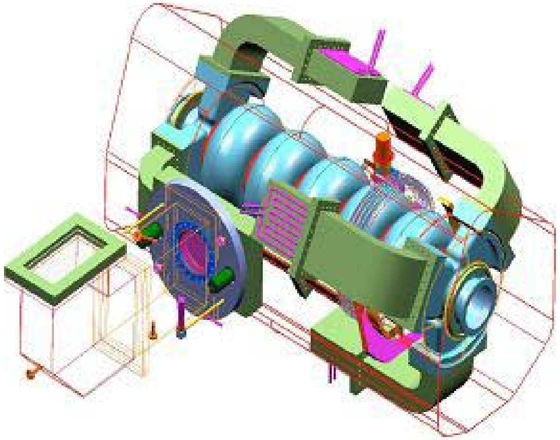
- *Beam loss level and its reduction and control*
  - beam halo generation and propagation, starting at the gun
  - modeling of beam loss and propagation of shower products
  - design of collimation and shielding
- *Integrated, start-to-end simulations are performed with errors and other practical issues included*
  - multiple, long, independently-controlled insertion devices combined with a very small beam emittance
  - lattice correction techniques that succeed at a level comparable to 3rd generation light sources
  - develop path length adjustment methods to maintain efficient energy recovery in the face of seasonal, tidal, and user-related changes.

Improving Cavity Quality Factor Q_0

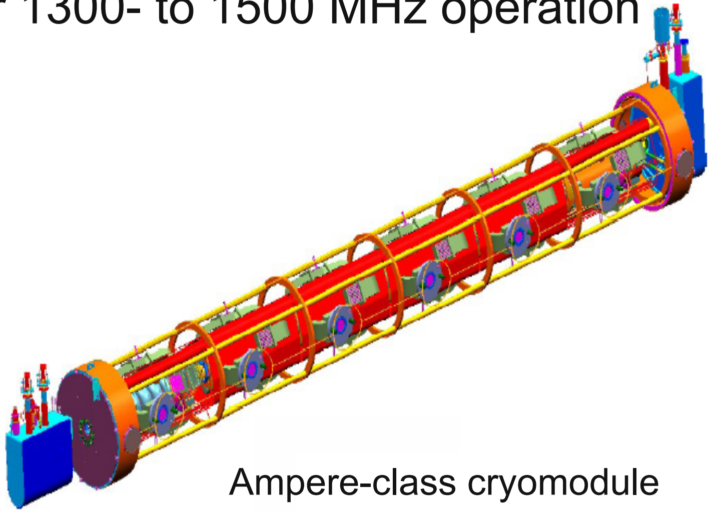
- *ERL requires continuous wave (CW) rf power*
- *Current state-of-the-art SRF: $Q_0 = 1\times10^{10}$ for multi-cell cavities; accelerating field gradient of ~ 18 MV/m at 2.0K*
- *ERL wall-plug power with a $Q_0 \sim 1\times10^{10}$, is on the order of tens of Mw*
- *R&D goal is to improve cavity quality factor by a factor of five, $Q_0 \sim 5\times10^{10}$*
  - Improving surface residual resistance (our goal is to obtain 1nΩ).
  - Exploring niobium cavity surface coating using atomic layer deposition (ALD)
  - Investigating other materials (e.g., Nb_3Sn)

Multi-cell Cavity and Cryomodule Design for CW Operation

- Optimizing a multi-cell cavity shape to achieve good accelerating gradient with high rf efficiency
- Optimizing a multi-cell cavity to reduce trapped higher-order-modes (HOMs) inside the cavity and to efficiently extract and absorb HOM power
- Designing cost-effective HOM power absorbers
- Investigate the design of an optimized and magnetically-shielded CW cryomodule to reduce the effect of microphonics and to maintain the cavities' high Q values
- Investigate the design of an adjustable fundamental power coupler with power handling capability of 100 to 150 kW (CW) for 1300- to 1500 MHz operation



Concept of a 5-cell SRF cavity optimized for high-current and good rf efficiency for CW operation.



Ampere-class cryomodule concept.

Cathode Development for ERL Injector

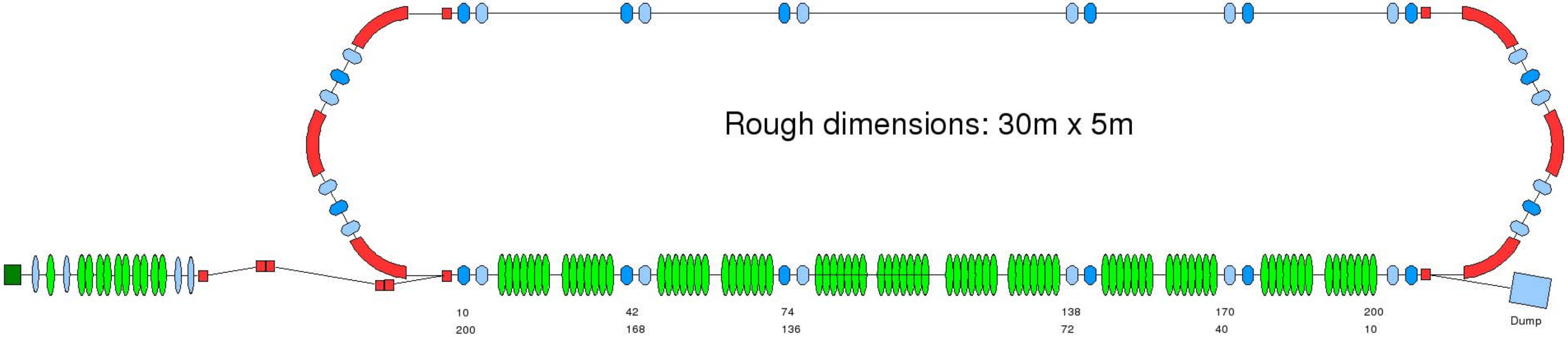
- *Challenge*
  - ERL requires electron source with an order of magnitude smaller emittance than that achieved in present injectors
  - Emittance requirement is on the order of the intrinsic emittance of a photocathode, which sets the lower limit of the achievable emittance

- *Approach*
  - Perform optimization study of laser-photocathode system to set boundaries on min. QE and max. intrinsic emittance
  - Systematically characterize the intrinsic emittance for a variety of cathodes using advanced surface analysis to measure the emission momentum distribution (ARPES) and spatially-resolved cathode composition and surface geometry (e.g., SEM, scanning Auger)

- *Complementary R&D*
  - Develop and test optimized gun designs for physics regime of ERL injector

Proposed ERL Test Facility

- *APS supports building a ~25 mA, ~200 MeV ERL test facility*
  - Test predictions related to beam quality and its preservation up to relativistic energies
  - Assess performance and reliability of rf cavities, dampers, and control systems in a realistic high-current environment
  - Investigate beam loss and collimation in an experimental setting
  - Develop high-precision, high-rate diagnostics
  - Address integration issues
- *APS is eager to be the host or a strong partner in this endeavor*

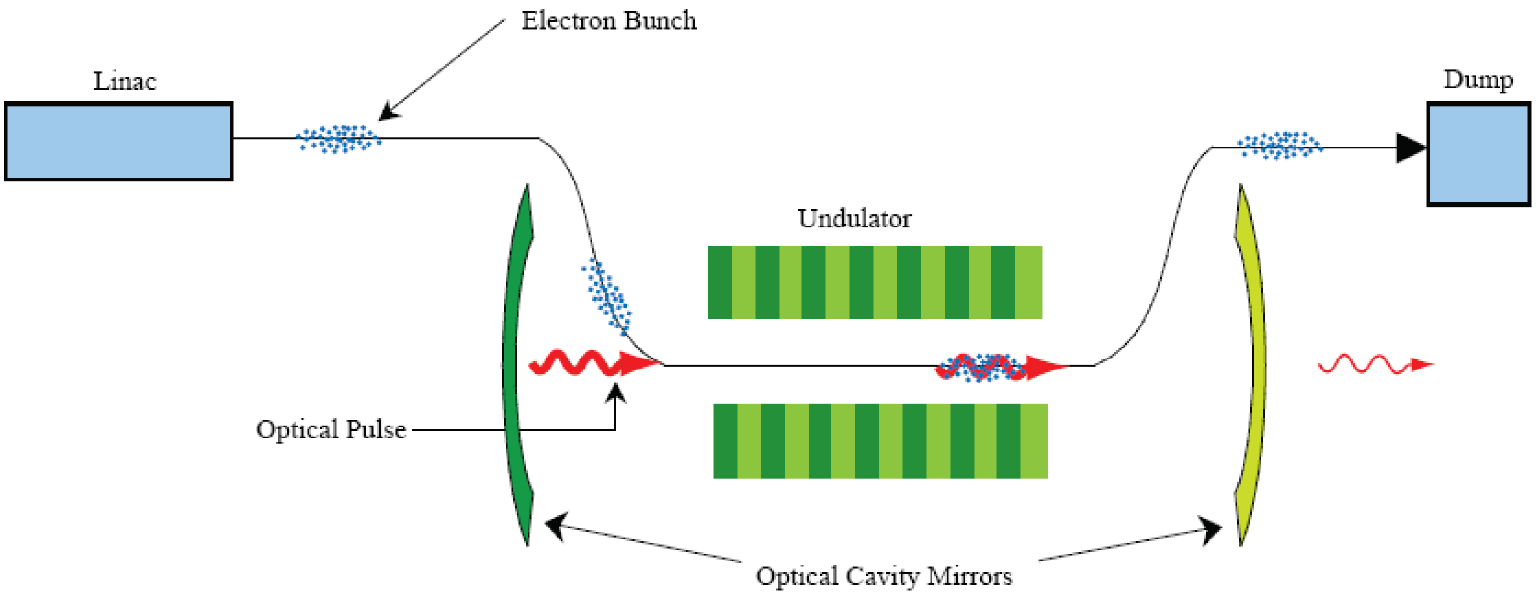


Rough dimensions: 30m x 5m

Feedback-Enhanced X-Ray Sources

- X-ray FEL Oscillator (XFEL-O) using Bragg reflector was first proposed by R. Collela and A. Luccio at the BNL FEL workshop in 1984
- This was also the time when a high-gain FEL(SASE) was proposed by R. Bonifacio, C. Pelegrini, and L. M. Narducci (the “r-paper”.)
- Feedback-enhanced x-ray sources using electron beams optimized for high-gain amplifiers have been studied recently:
  - Electron out-coupling scheme by B. Adams and G. Materlik (1996)
  - Regenerative amplifier using LCLS beam (Z. Huang& R. Ruth, 2006)
- XFEL-O with the beam parameters of Cornell ERL Coherent Mode scaled to 7 GeV was studied recently by K.-J.Kim and Y.Shvydko

Principles of an FEL Oscillator

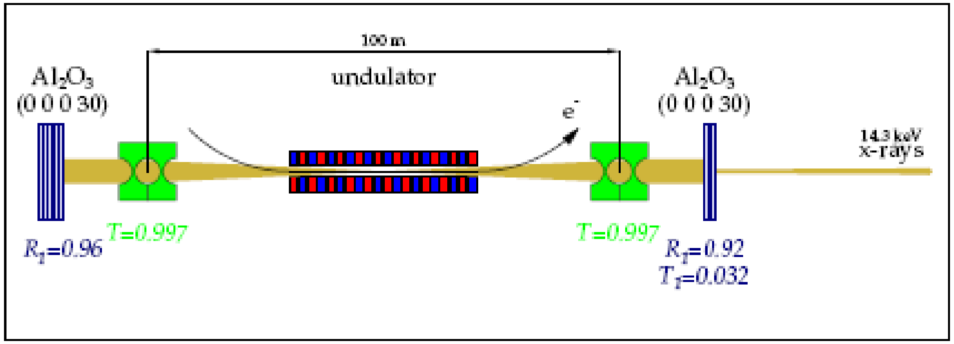


- Small signal gain G= $\Delta P_{intra}/P_{intra}$
  - Start-up: $(1+G_0)\ R_1\ R_2 > 1$ (R_1& R_2 : mirror reflectivity)
  - Saturation: $(1+G_{sat})\ R_1\ R_2 = 1$
- Synchronism
  - Spacing between electron bunches=2L/n (L: length of the cavity)

Options for XFEL-O Cavities (Y. Shvydko)

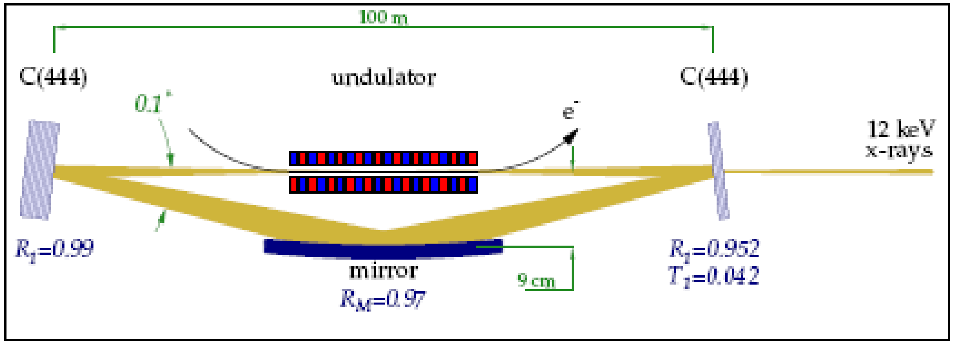
$Al_2O_3xAl_2O_3$ @14.3 keV

R_T=0.87, G_{sat}=15%, T=3%



CxCxmirror @12.4 keV

RT=0.91, G_{sat}=10%, T=4%



$Al_2O_3xAl_2O_3xSiO_2$@ 14.4125 keV

RT=0.82, G_{sat}=22 %, T=4%