Energy Recovery Linac

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RHIC

Goals for ERL R&D program

- RHIC II: Au-Au luminosity of 7×10^{27} $cm^{-2}sec^{-1}$, i.e. approximately 40 times the present design value [1]
- RHIC II: 10^{+}- fold boost in $\vec{p}$-$\vec{p}$ luminosity [1]
- eRHIC: potential for $\sim 10^{34}$ $cm^{-2}sec^{-1}$ per nucleon e-p collider [1]

✓ **ERLs (2) for Electron beam cooler of the gold ion beams**

✓ ERL for an FEL-driver of polarized electron gun

✓ 10-20 GeV ERL for eRHIC

✓ **ERL prototype to test the concept(s)**

[1] Twenty-Year Planning Study for the Relativistic Heavy Ion Collider Facility at Brookhaven National Laboratory BNL-71881-2003, INFORMAL REPORT, December 31, 2003, Upton, New York

Goals for ERLs

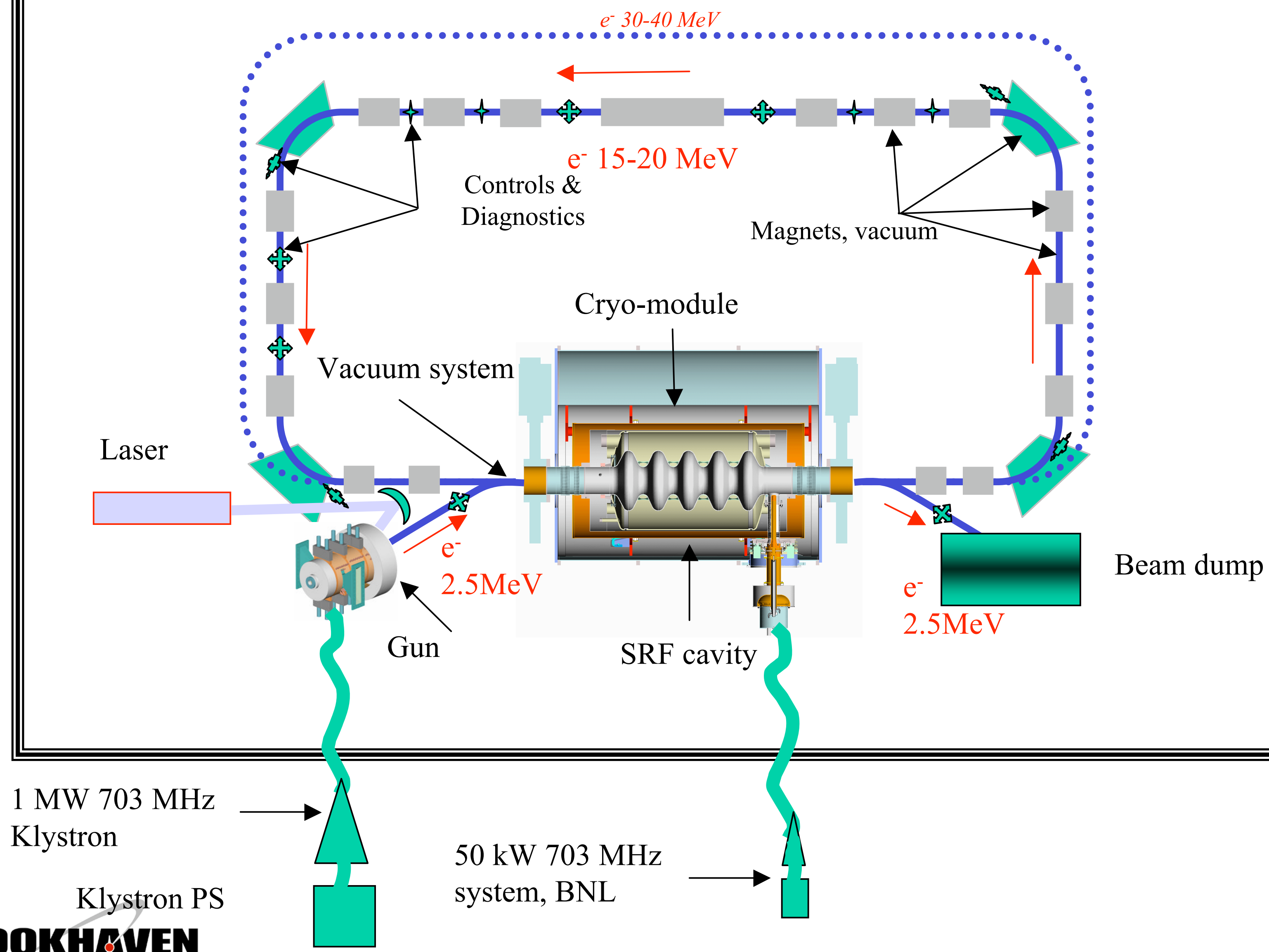
e-cooler

- Generate and accelerate bright ($\square_n < 50$ □mrad) intense (i.e. 100^+ mA) *magnetized* (i.e. with angular momentum) electron beam to the energy of 54.677 MeV
- **Cool the ion beam(s)**
- Decelerated the electron beam to few MeV and to recover its energy back into the RF field

prototype

- Generate and accelerate bright ($\square_n < 50$ □mrad) intense (i.e. 100^+ mA) electron beam with energy ~ 20-40 MeV
- Decelerated the electron beam to few MeV and to recover its energy back into the RF field
- **Test the concepts and stability criteria for very high current ERLs**

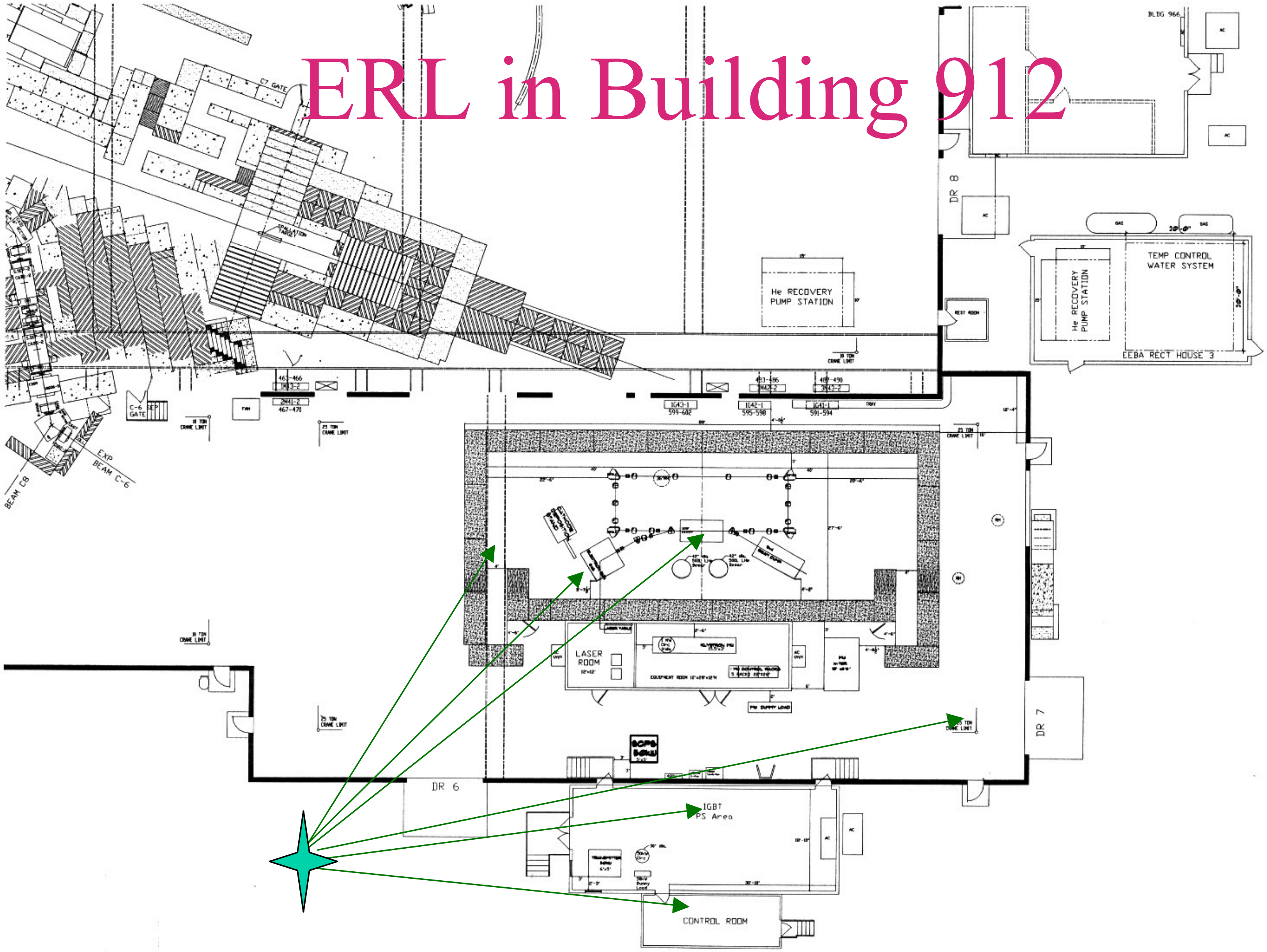
R & D item #1 - Bldg. 912



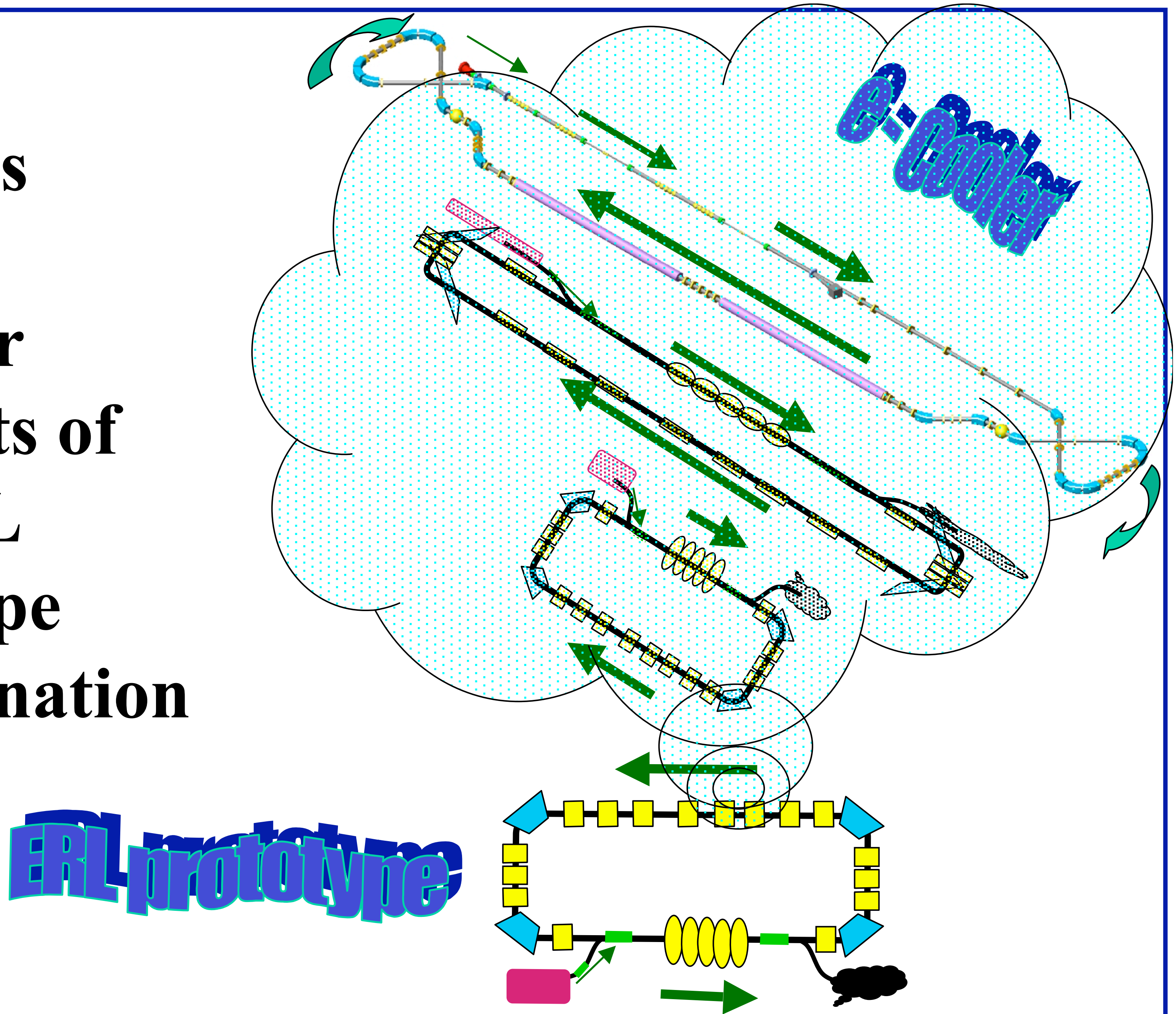
Beam parameters

ERL	e-Cooler	Prototype
ERL circumference [m]	~ 120	~ 20
Number of passes	1	1 to 2
Beam rep-rate [MHz]	9.38 -28.15	9.38 - ?
for tuning		1 Hz – 1 kHz
Beam energy [MeV]	54.677	20 - 40
Electrons per bunch (max)	10^{11}	10^{11}
Normalized emittance [μm rad]	~ 50	~ 50
RMS Bunch length [m]	0.03 – 0.2	0.05
Charge per bunch [nC]	10+	10+
Average e-beam current [A]	0.1+	0.01 – 0.1+
Efficiency of energy recovery	99.9…%	> 99.95%
Efficiency of current recovery	99.999….%	> 99.9995%

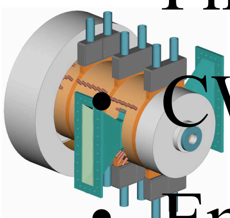
ERL in Building 912

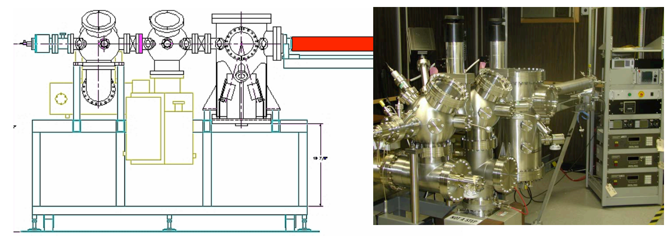


All key elements of the e-Cooler are parts of the ERL prototype + imagination

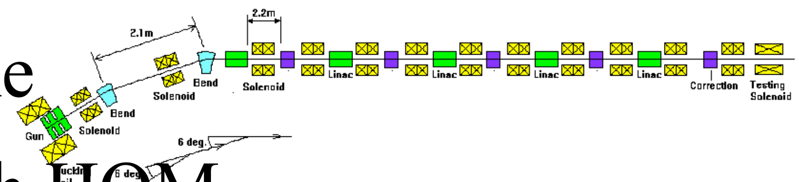


Main components of ERL

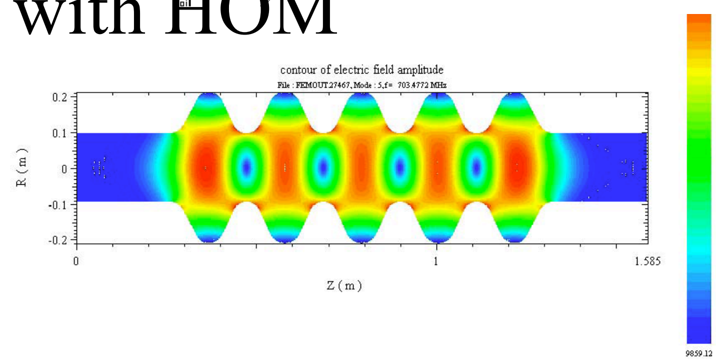




- Photocathode
- CW RF Gun - 2.5 MeV, 100 mA
- Emittance compensation scheme



- Superconducting RF cavity with HOM absorbers



- Beam-recovery loop
- Beam dump
- Cryogenic system
- Water & Power

Beam Diagnostics

- **6-D phase space tomography**

- Two high precision DCCTs: one at the entrance and other at the exit of re-circulator, for determining both re-circulated and lost currents
- Beam position monitors
- Fast Log-BMPs for beam break-up studies and the energy feed-back system
- Beam profile monitors – both Compton and Synchrotron radiation
- A good dozen of CCD cameras and monitors
- Energy spread measurement system
- 703 MHz lock-in amplifier for tracking the phase of e-beam
- Strip-lines, fast digital scope and
- Stroboscopic system or streak camera with psec resolution

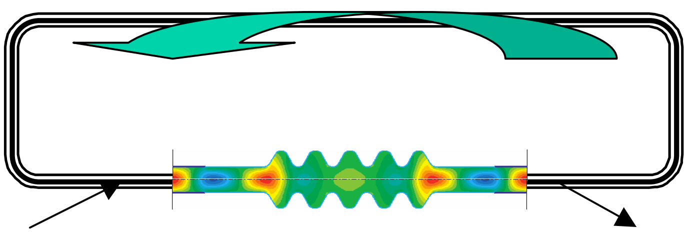
Main features of ERL

- Control of M12 for studying the transverse stability limits in both horizontal and vertical directions
- Control of longitudinal compaction factor for studying longitudinal dynamics

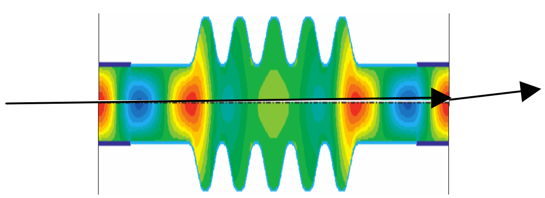
$$m_{12} = \sqrt{\beta_{1x}\beta_{2x}}\,\sin\Delta\psi_x$$

$$m_{34} = \sqrt{\beta_{1y}\beta_{2y}}\,\sin\Delta\psi_y$$

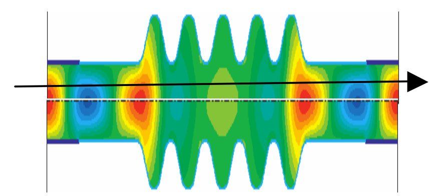
$$m_{56} = \oint \frac{D}{\rho}\,ds$$



$$\begin{pmatrix} x \\ x' \\ y \\ y' \\ c\Delta t \\ \Delta E/E \end{pmatrix}_{s2} = \begin{pmatrix} m11 & \mathbf{m12} & \ldots & \ldots. & \ldots & \eta_x \\ m21 & m22 & \ldots & \ldots & \ldots & \eta_x' \\ \ldots & \ldots & m33 & \mathbf{m34} & \ldots & \eta_y \\ \ldots & \ldots & m43 & m44 & \ldots & \eta_y' \\ \ldots & \ldots & \ldots & \ldots & m55 & \mathbf{m56} \\ \ldots & \ldots & \ldots & \ldots & \ldots & m66 \end{pmatrix} \cdot \begin{pmatrix} x \\ x' \\ y \\ y' \\ c\Delta t \\ \Delta E/E \end{pmatrix}_{s1}$$



$$\begin{pmatrix} \mathbf{x} \\ x' \end{pmatrix}_{return} = \begin{pmatrix} m11 & \mathbf{m12} \\ m21 & m22 \end{pmatrix} \cdot \begin{pmatrix} 0 \\ \mathbf{x'} \end{pmatrix}_{comming}$$



Excitation process of transverse HOM

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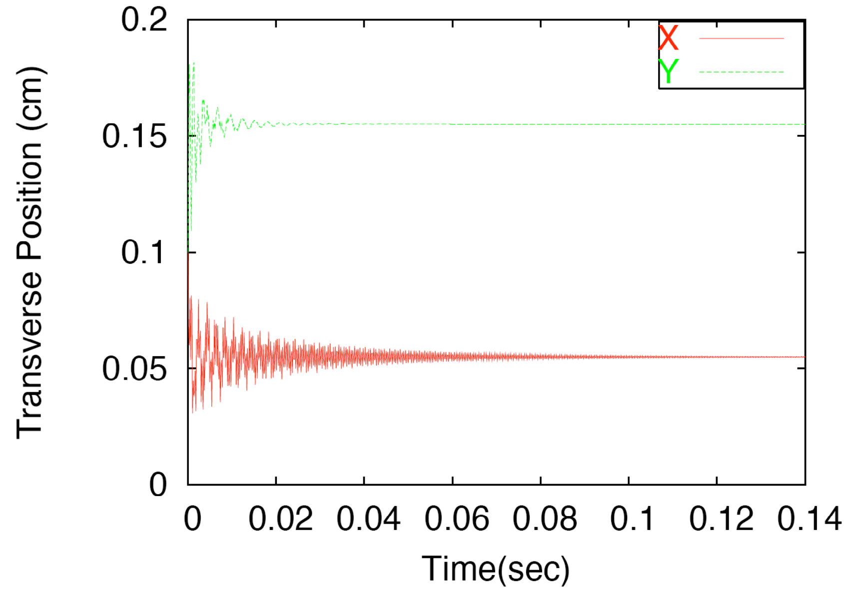
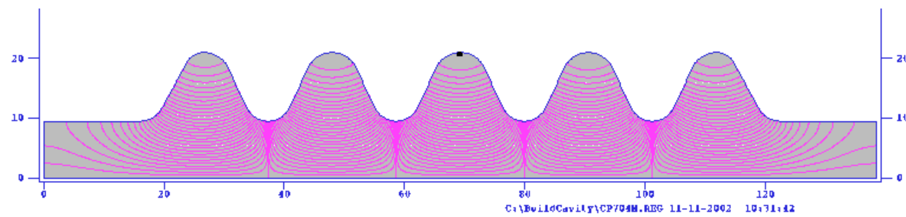
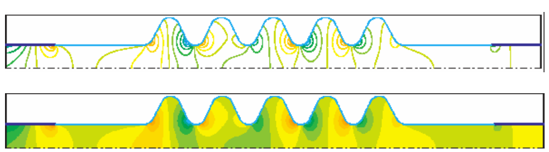
Stability of ERL

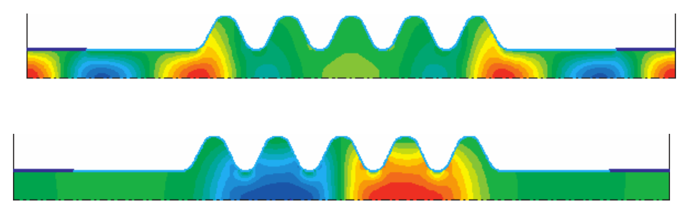
(details in next talk)

- TDBBU, MatTBBU give for ERL with this cavity stability limit: currents up to ~1.8 A (1,800 mA !) for a proper lattice
- We plan to increase M12 in order to measure the TBBU and to compare with predictions by TBBU









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Feed-backs

- <u>Required for SC RF</u>
  - phase and amplitude feed-back
  - Lorentz shift compensation
- Required for the beam stability
  - Beam energy feed-back
  - Time jitter feed-back
  - Transverse stability feed-back

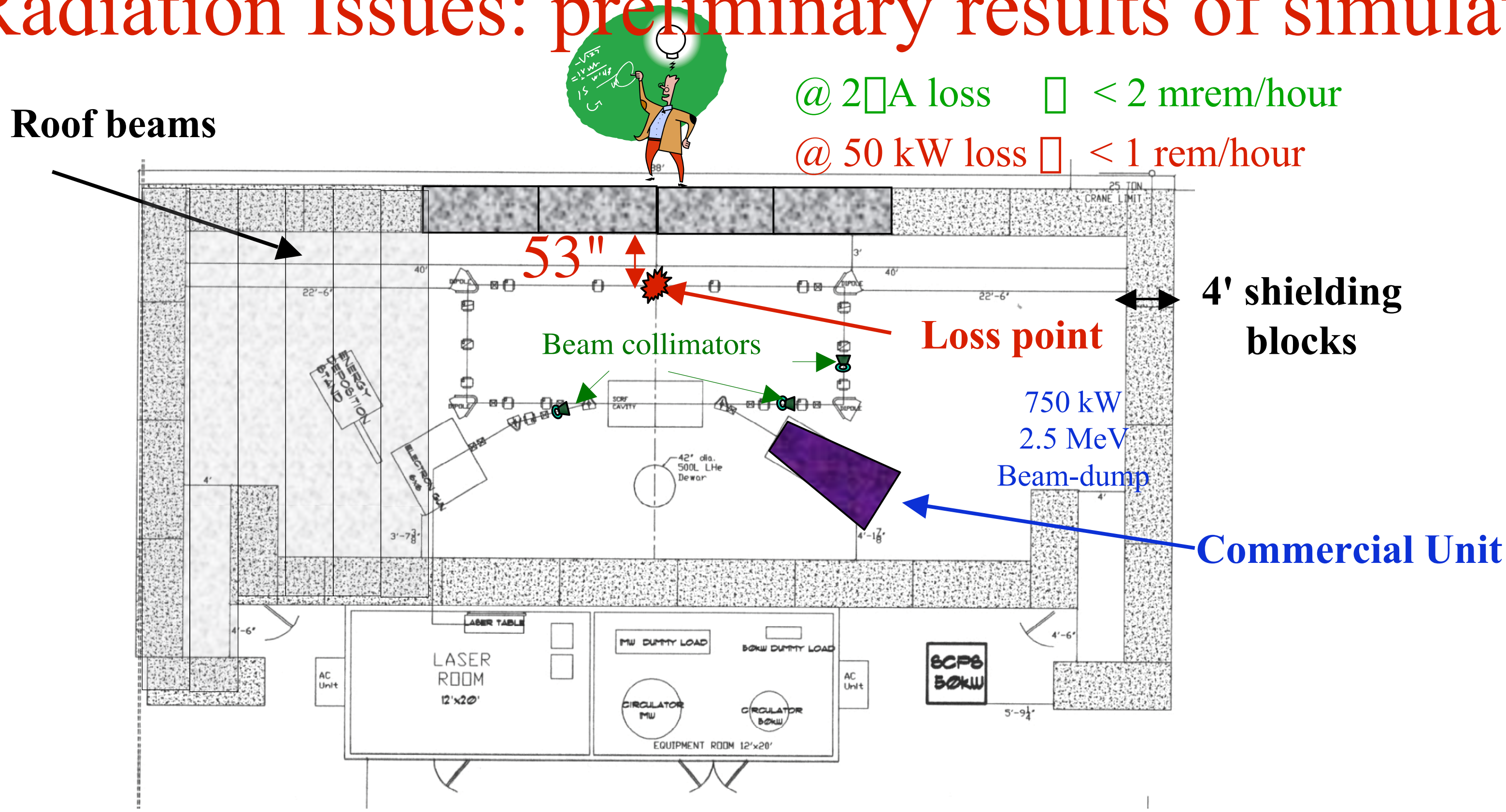
Modes of operation

- Main mode is CW (MHz)
  - Demonstrating the main e-cooler parameters
  - Very low losses
  - Only non-disruptive beam diagnostics
- Pulse and low rep-rate mode (Hz)
  - First day flag diagnostics
  - Moderate losses allowed
  - Disruptive beam diagnostics
  - Test and start-ups

Radiation Issues:

- Normal Mode - CW
  - Hundreds of kWs of 2.5 MeV e-beam in the beam dump
  - Losses of 1-2 A or less at 20-50 MeV
- Commissioning Mode
  - low rep-rate to not exceed the level of loss in the normal mode
- Worst credible case scenario
  - Potential loss of up-to 50 kW of 20-50 MeV e-beam
  - Potential for concentrated local losses

Radiation Issues: preliminary results of simulations



- CW mode, exaggerated but close to worst realistic case, 54 MeV electrons hit on locally a stainless beam-pipe of radius of 1.5", 53" away from the nearest wall.
- Most of radiation is in the form of electrons, γ-rays and X-rays
- Radiation dose due to photo-nuclear reaction is ~ 1/1000 of total dose

Radiation Issues

- Beam dumping at 2.5 MeV
  - Absence of induced radioactivity
  - Simpler commercial absorber
  - Possibility of the full current test of injector
- Radiation protection
- Passive
  - 4’ concrete shielding
  - Local absorbers and shielding
- Active
  - Two hard-wired Chipmunks
  - Machine feed-backs and interlocks

9.1.11.a General Guideline for C-A Radiation Access-Control System Classification and Application

ABCS –Access/Beam Control System;HFD-Hardwire, fail-safe, dual; HF-Hardwire, fail-safe; AFD-Active, fail-safe, dual; AF-Active, fail-safe; H-Hardwired; AD-Active, Dual; & A-Active

C-A Class Area Name with Access as per 10CFR835	Radiation Level (Allowed potential whole body dose with access)	Equivalent 30 GeV Large Beam Proton Fluence Rate,[a,b,c]	Access When Beam Enabled	Sweep/Reset Authority	Area Enclosure	C-A Class (Radiation Level) *C-A Class without Access*	Minimum ABCS *Additional ABCS at this Class Level*	Purpose of ABCS for Operational Class *Purpose of ABCS for Class*
Class I Very High Radiation Area -	>500 rad/hr [a]	$>3.9\times10^{9}$	Absolute Prohibition	MCR Operator or RSC Designate	Impregnable Enclosure, Dual Interlocked Gates	I *Not Applicable*	HFD *Not Applicable*	Preventing Access or Beam Enablement *Not Applicable*
Class II High Radiation Area-	<500 rad/hr >50 rem/hr	$<3.9\times10^{9}$ $>1.1\times10^{8}$	Special RCD Approved Procedure	RSC Designate	Fully Enclosed ,Dual Interlocked Gates	II *I*	HFD *Not Specified*	Controlling Access or Beam Enablement *Preventing exposure to these levels*
Class III High Radiation Area -	<50 rem/hr >5 rem/hr	$<1.1\times10^{8}$ $>1.1\times10^{7}$	RCD Technician Supervision	RSC Designate	Walls or Fences, Interlocked Gates	III *II* *I*	HF *AF* *HF*	Controlling Access or Beam Enablement *Preventing exposure to these levels* *Preventing exposure to these levels*
Class IV High Radiation Area	<5 rem/hr >0.1 rem/hr	$<1.1\times10^{7}$ $>2.3\times10^{5}$	Individual Authorized by the RSC	Individual User May Be Authorized by the RSC	Walls or Fences, Locked Gates	IV *III* *II* *I*	H *AF* *HF* *HFD*	Control Access or Beam Enablement *Preventing exposure to these levels* *Preventing exposure to these levels* *Preventing exposure to these levels*
Class V Radiation Area	<0.1 rem/hr >0.005 rem/hr	$<2.3\times10^{5}$ $>1.1\times10^{4}$	Radiation Worker or Visitor Escorted by Radiation Worker	When Required, Individual User Authorized by the RSC	Fences or, Ropes, Radiation Warning Signs Every 40 ft	V *IV* *III* *II, I*	A *A* *HF* *HFD*	Alarm on Excessive Radiation *Preventing exposure to these levels* *Preventing exposure to these levels* *Preventing exposure to these levels*
Class VI Controlled Area	<0.005 rem/hr >0.00005 rem/hr	$<1.1\times10^{4}$ $>1.1\times10^{2}$	GERT Trained Individual or Escorted Visitor	Not Required	Signs, Fences or, Ropes at Perimeter; Posted at Entrances	VI *V* *IV* *III* *II, & I*	A *A* *H* *HF* *HFD*	None *Preventing exposure to these levels* *Preventing exposure to these levels* *Preventing exposure to these levels* *Preventing exposure to these levels*

a See section 5.5 for procedures for small beam sizes.

b If the absorbed dose rate is 500 rad/hr or greater, the area is named a "Very High Radiation Area" as per 10CFR835.

c This is the fluence rate from a beam of 30-GeV hadrons with size greater than 1000 cm2. It corresponds to the dose rate listed in column two and was obtained by using equations in section 5.4

Milestones of the ERL prototype projects

Task Name	Start	Finish	2004 H1	2004 H2	2005 H1	2005 H2	2006 H1	2006 H2	2007 H1
e-CX/ERL Project	3-Feb-03	15-Mar-07							
Develop the 5-cell RF cavity shape	3-Feb-03	30-Nov-05							
Assemble SRF Cavity & Associated Components	3-Oct-05	4-Dec-05							
Electron Gun Procurement	3-Feb-03	6-Jan-06							
Photocathode System Procurement	3-Feb-03	23-Mar-06							
Assemble & Test of RF Gun & Associated Systems	2-Feb-04	4-Apr-06							
Design & Procurement of ERL Vacuum System	10-Jan-05	8-Mar-06							
Beam Dump Procurement	1-Oct-03	25-Aug-05							
Assemble Photocathode, RF Gun, Cavity & Beam I	24-Aug-05	25-Sep-06							
Design & Procurement of ERL Magnetic System	8-Jan-04	2-Nov-06							
ERL installation	26-Sep-06	15-Mar-07							
Building 912 Facility modifications for ERL	3-Feb-03	15-Feb-06							
ERL commissioning	1-Mar-07								

Conclusions

- The prototype ERL will demonstrate the main parameters of the e-beam required for e-cooling
- The prototype will also serve as a test bed for studying issues relevant for very high current ERLs
- Basic scheme is well understood
- Many more calculations and simulations
- Schedule seems to be reasonable