Recent SRF Developments for ERLs

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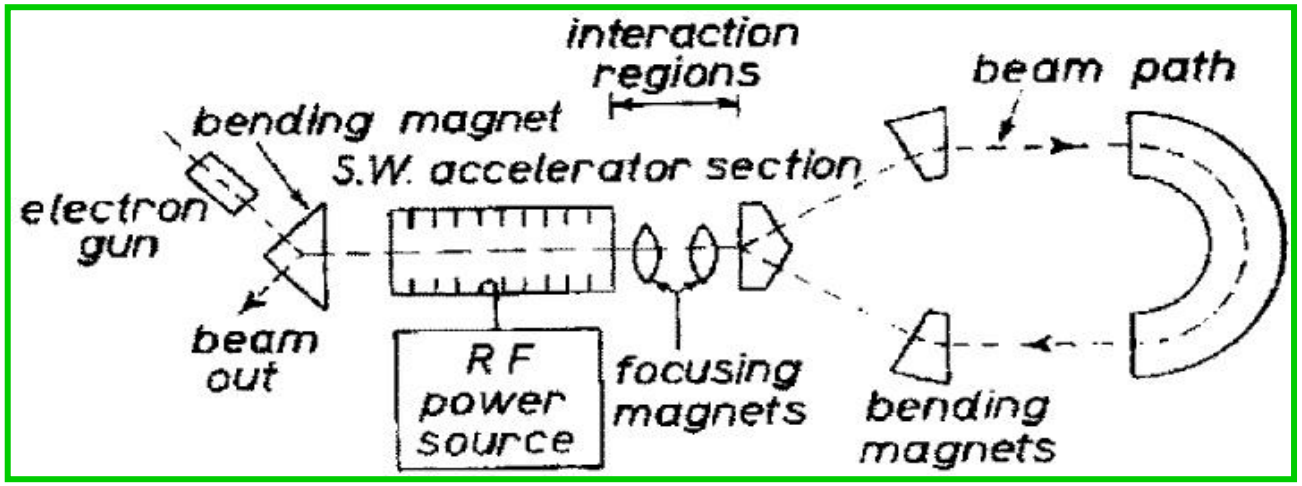
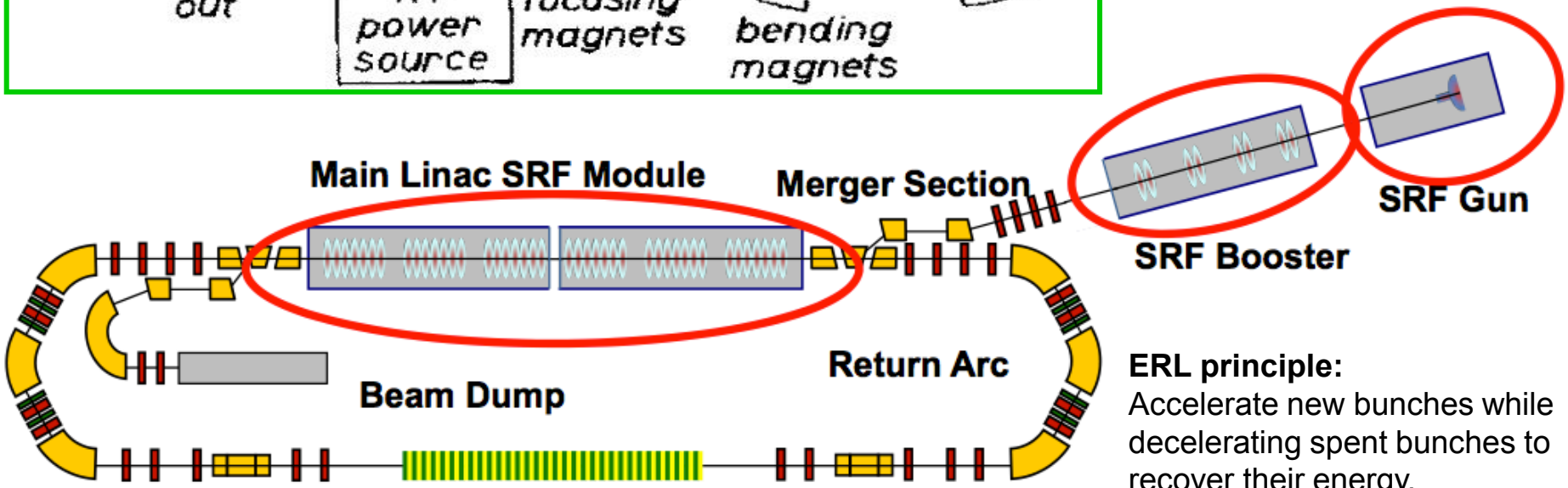


1st paper on ERL
Maury Tigner, 1965



Outline of HZB test ERL

ERL principle:
Accelerate new bunches while decelerating spent bunches to recover their energy.

Overview

Developments at:

Daresbury (ERL operation with commercial cryomodule, international cryomodule collaboration)

Helmholtz-Zentrum Berlin (SRF gun, test ERL loop plans with SRF)

KEK (ERL test loop plans with SRF, ERL-cavity R&D)

JLAB (ERL-FEL operation with 3 cryomodules, SRF gun)

BNL (Test ERL loop with SRF cavity, SRF gun)

Cornell (SRF injector, ERL cryomodule, SRF test with ERL beam, SRF gun simulations)

Intern. CW Cryomodule Collaboration
Host lab: Daresbury

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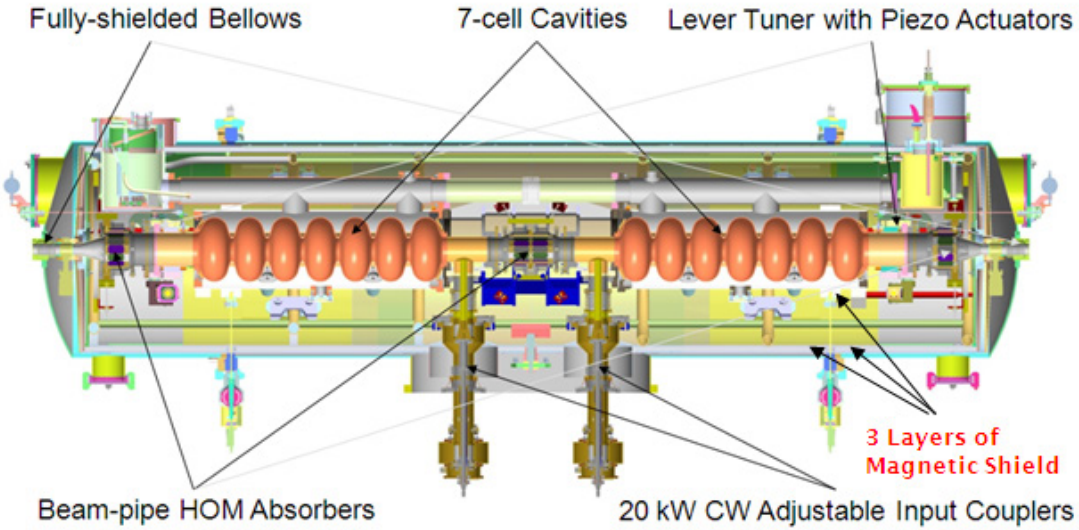
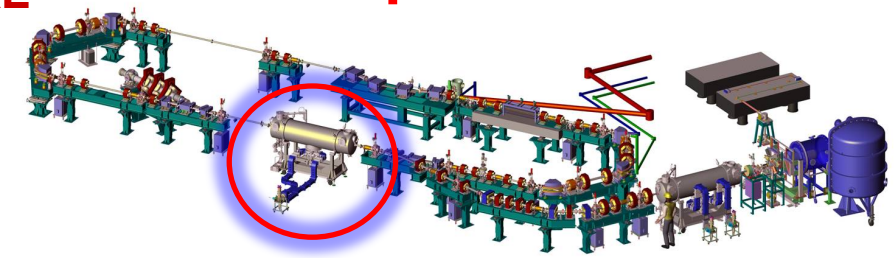


Parameter	Target
Frequency (GHz)	1.3
Cryomodule Length	3.6m
R/Q (Ω)	762
E_{acc} (MV/m)	>20
E_{pk}/E_{acc}	2.23
H_{pk}/E_{acc}	46.9
CM Energy Gain	>32MeV
Q_o	$>10^{10}$
Q_{ext}	$4x10^6$ - 10^8

- **Collaboration formulated in early 2005 to design and fabricate new CW cryomodule and validate with beam**
- **Dimensioned to fit on the ALICE ERL facility at Daresbury:**
  - **Same cryomodule footprint**
  - **Same cryo/RF interconnects**
  - **'Plug Compatible' with existing cryomodule**

See poster: TUPO013



Assembly preparations at Daresbury for the intern. CW cryomodule

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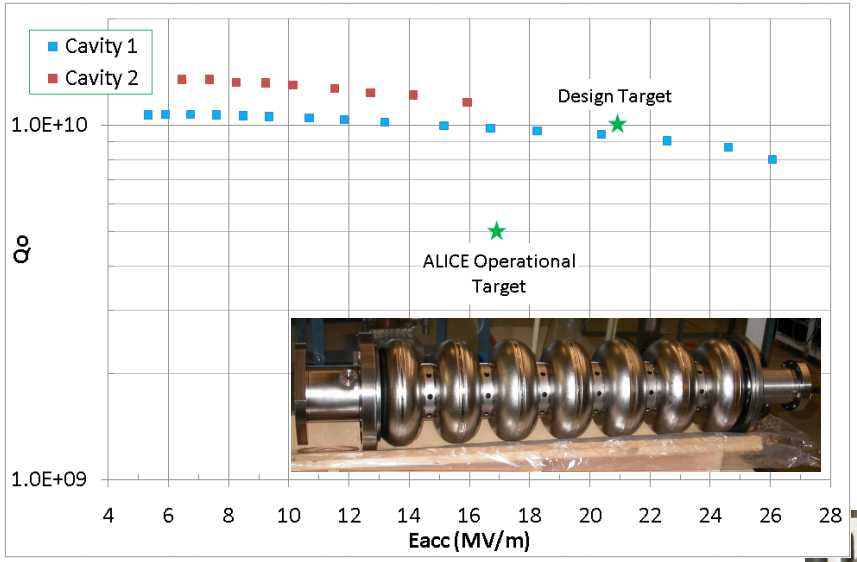
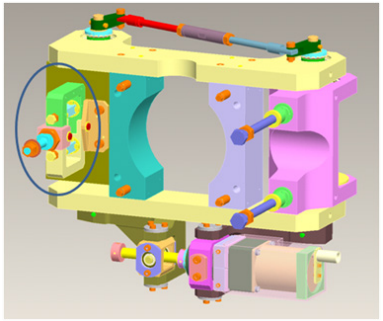
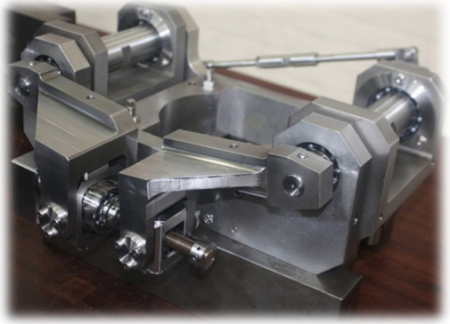
DESY superstructures modified, changed to optimised end groups by Cornell

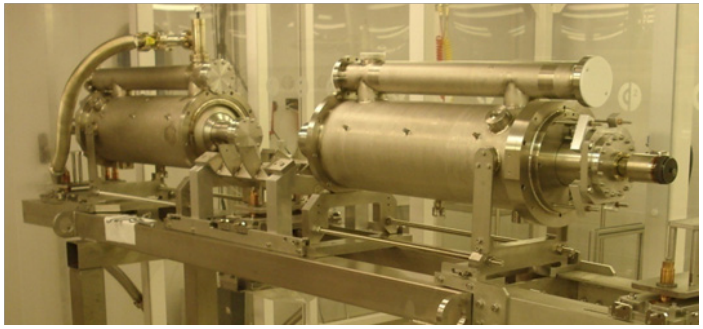


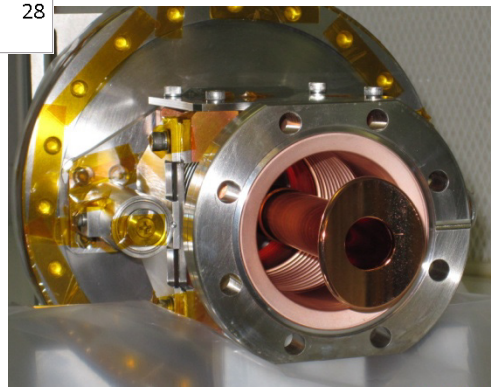
Modified Saclay-II tuner with wider aperture and low voltage piezo cartridges.

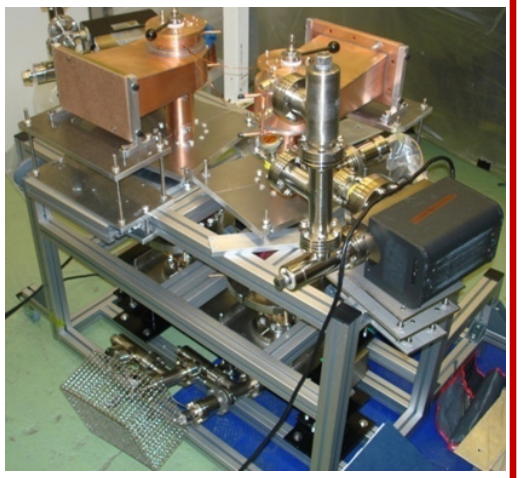




Modified Cornell ERL injector coupler with a shortened cold section.



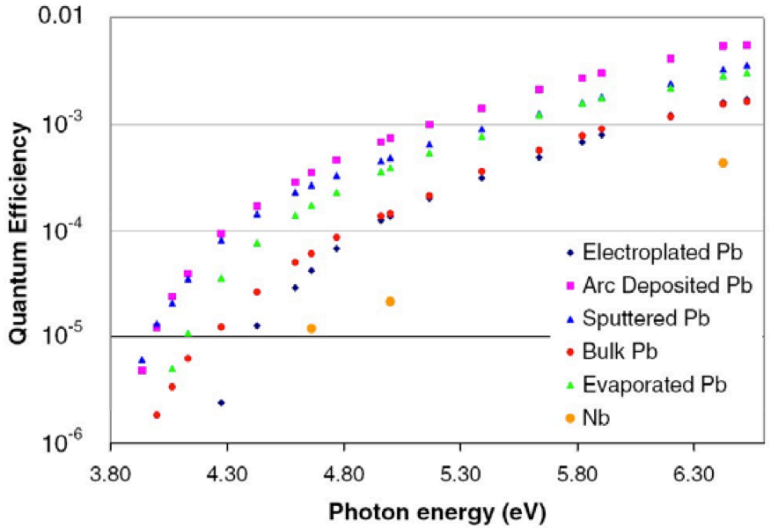




Cold couplers installed ⇒ awaiting HOM absorbers.
Cryomodule to be ready later this year.

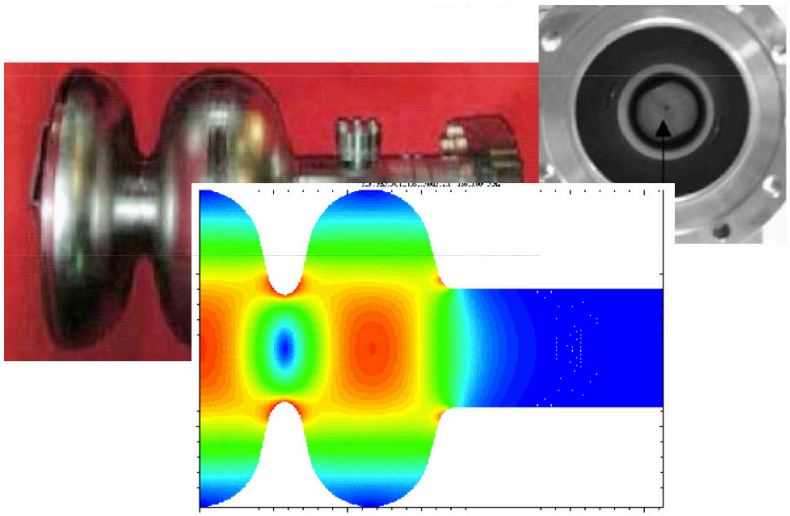
SRF Gun0 at the Helmoltz Zentrum Berlin

- Utilizes a thin Pb field on the backwall of cavity as photo-electron emitter
- Pb is also a superconductor of type I with Hc=8mT at 1.3GHz and 2K, and has QE at least one order of magnitude higher than Nb



J. Smedley et al., PRST-AB 11, 013502 (2008)

- Discussed first during CW source workshop in Sep 2008, sketched during ERL09 at Cornell and then agreed on in June 2009.
  - Jacek and HZB elevate cavity from sketch to engineering design
  - Peter Kneisel builds and tests a cavity ready for beam tests at HoBiCaT
  - Robert Nietubyc coats backwall of cavity with Pb film
  - HZB prepares HoBiCaT for beam tests
  - 1st beams in April 2011



Gun0 takes advantage of the work done by Jacek Sekutowicz and others for hybrid Nb/Pb gun cavities

Helmoltz Zentrum Berlin
Gun0 SRF properties

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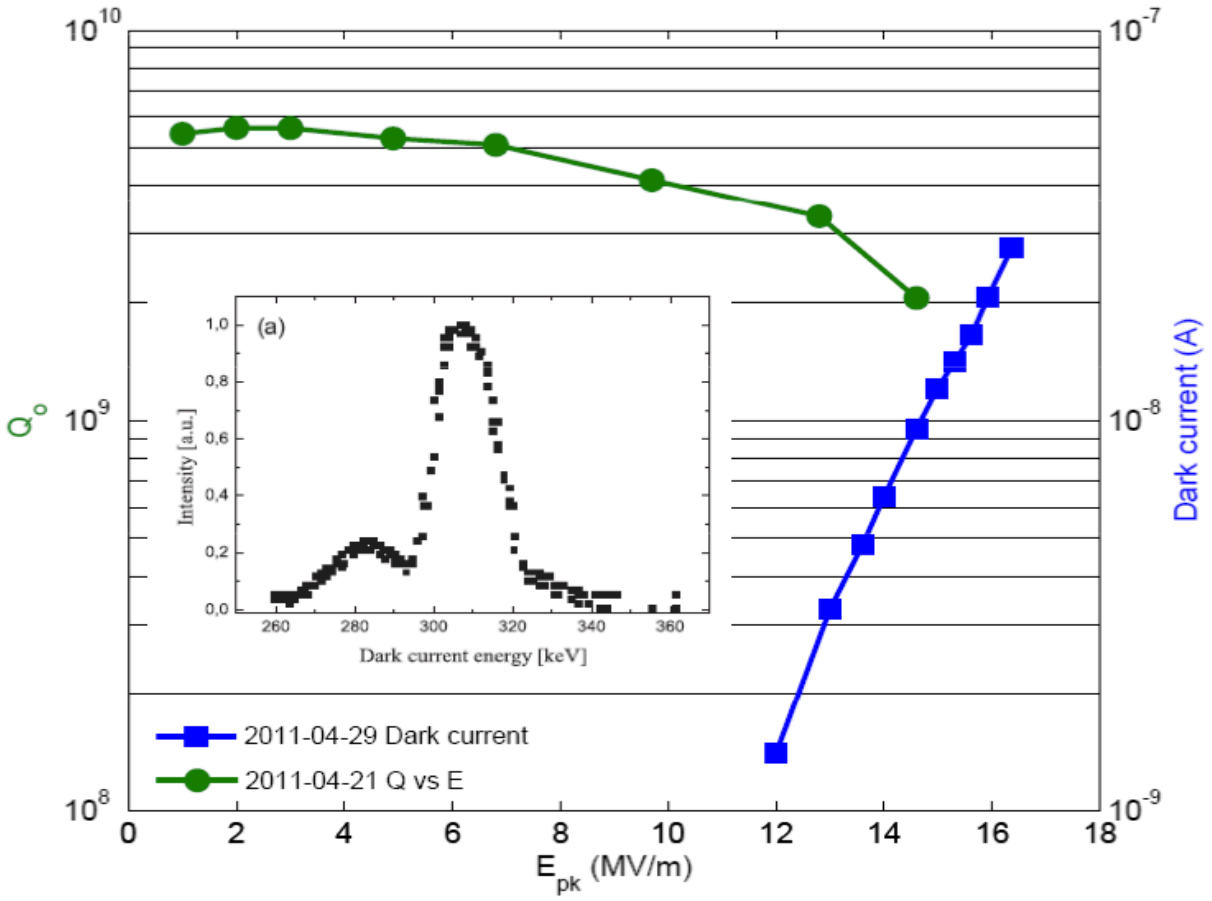
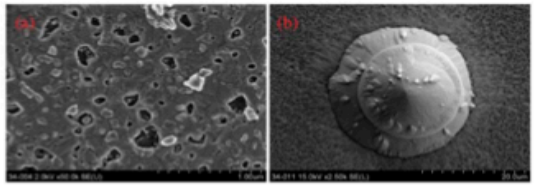
Q vs Epk and dark current measurements at HoBiCaT



R. Barday, T. Kamps, A. Neumann, S. Schubert et al Proc. of DIPAC 2011

- Qo slightly lower compared to last measurement at JLAB
- So far we set safety limit to 15 MV/m
- Dark current kicks in above 10 MV/m, increases exponentially → field emission from cathode spot?
- SEM/EDX reveal Pb droplets and flawed Pb film on Nb surface
- Energy spectrum of dark current suggests emission around 90 deg of RF



Helmoltz Zentrum Berlin
Gun0 beam tests

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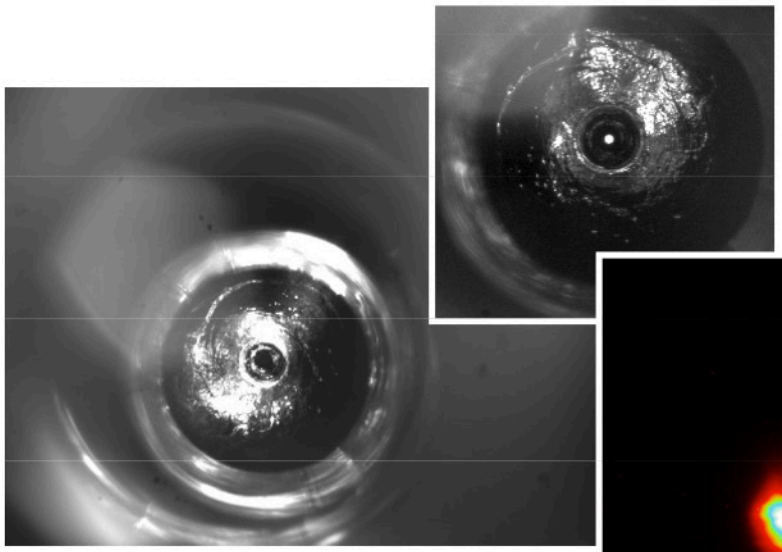
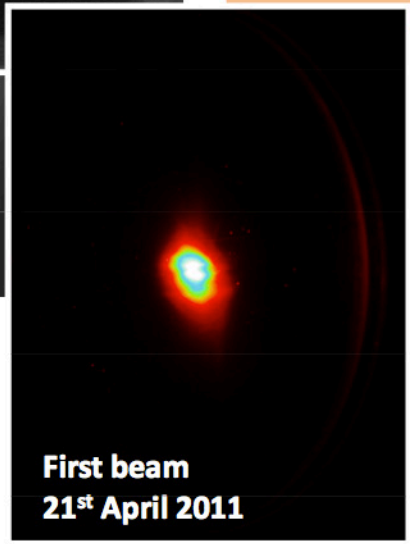
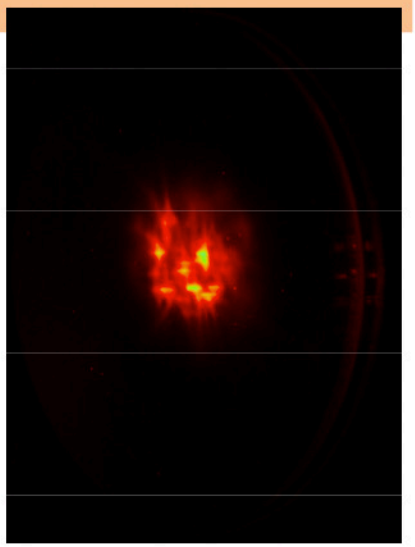
First beam of photoelectrons from Pb cathode generated and accelerated at 21st Aptil 2011, < 2 years after project approval



Switch on RF, adjust phase, steer and focus with solenoid
Measure QE of 1*10^(-5) at 260 nm
Next lasercleaning of cathode





Start with steering of laser beam spot on backwall of cavity

T. Kamps et al, Proc. of IPAC 2011 (planned)

I_{max} = 20nA for 8kHz
2ps long bunches

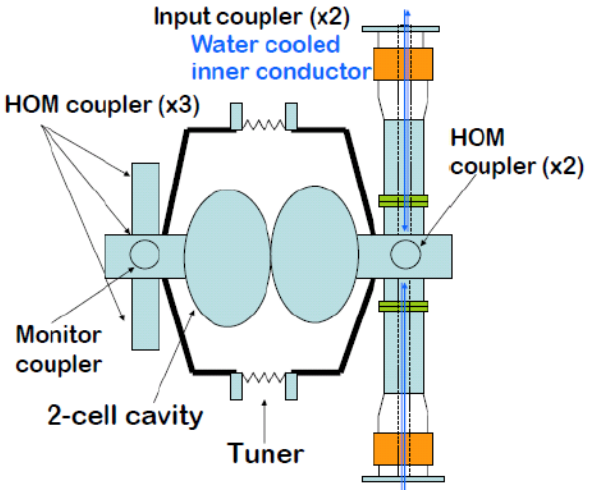
λ_{Laser} = 260nm, 4.76eV
QE of Pb = 6.5E-5
Can be > 5 X better

W_{tot} = 1mJ
W_{pulse} = 0.125μJ

q_{bunch} = 2.5pC

New 1.5cell at Jlab for 9/2011 with better coating

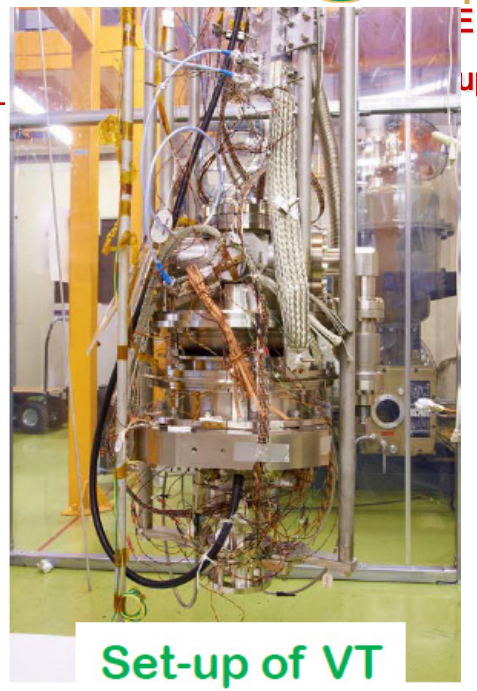
R&D of Injector for cERL test loop at KEK



	V_{acc} [MV]	P_{rf} [kW]
Cavity-1	1.5	10
Cavity-2	2.5	25
Cavity-3	2.5	25

(I_{beam} = 10 mA, P_{rf} /coupler)

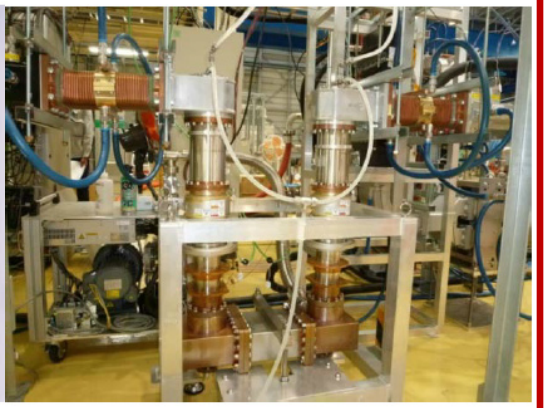
Three 2-cell cavities
with 5 HOM couplers



Set-up of VT

Six power couplers for double feed system

Six cw input couplers



High power test stand

- Each 2-cell cavity has 5 HOM couplers
- Vertical tests in progress
- Module assembling starts early 2012

R&D of main linac for cERL test loop at KEK

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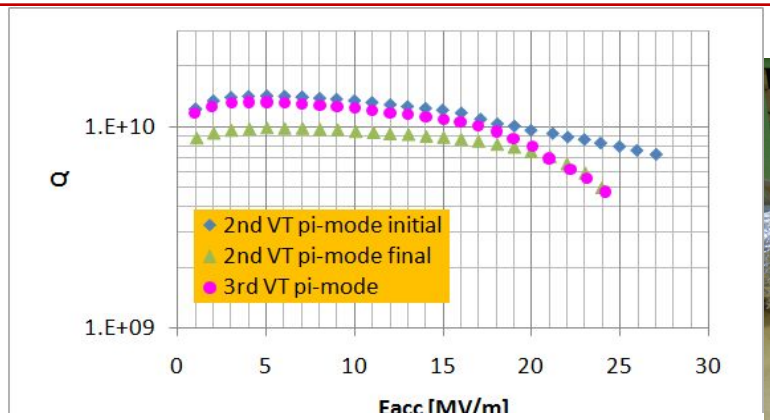
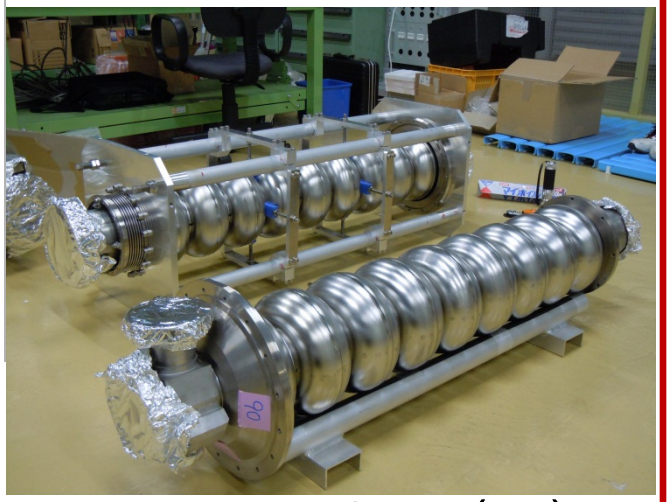
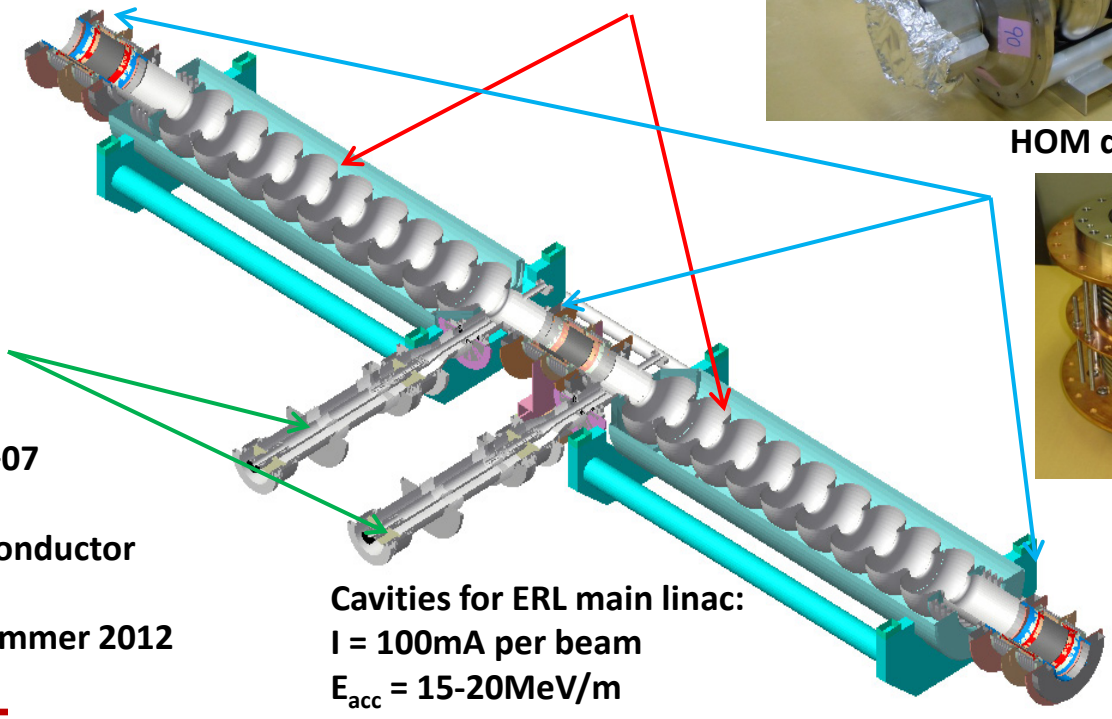


9-cell ERL cavities with fluted beam pipe



Power coupler (x 2)

HOM dampre (×3)



Power: CW of 20kW
Coupling: variable 1 to 4E+07
Ceramic: 99.7% Al2O3
Cooling: N2 gas for inner conductor
Impedance: 60Ω
Module assembly start: summer 2012

Cavities for ERL main linac:
I = 100mA per beam
E_{acc} = 15-20MeV/m

IB004 ferrite
Comb type RF shield
LN2 cooling
& 5K anchor flange
Power > 150W

JLAB SRF R&D for ERLs
1497 MHz high-current cryomodule

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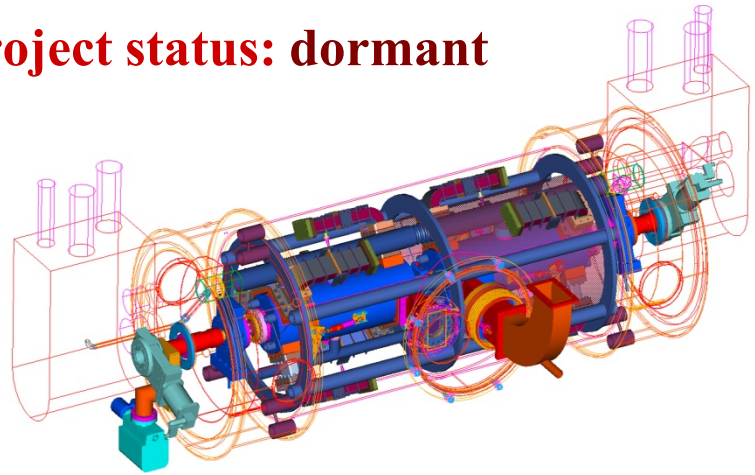
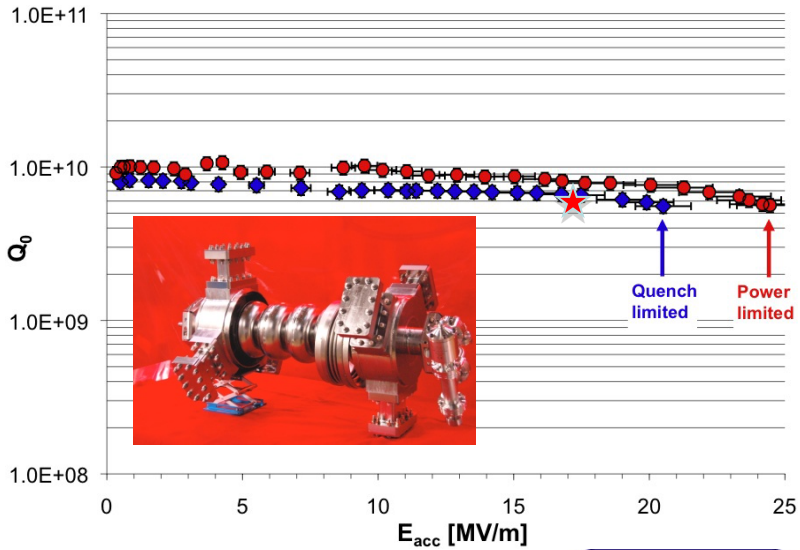
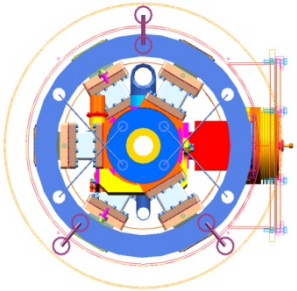
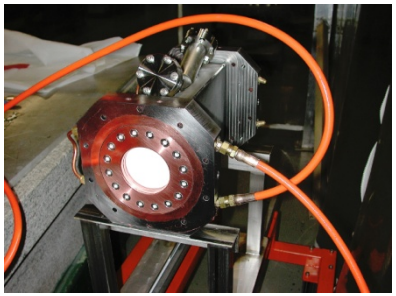
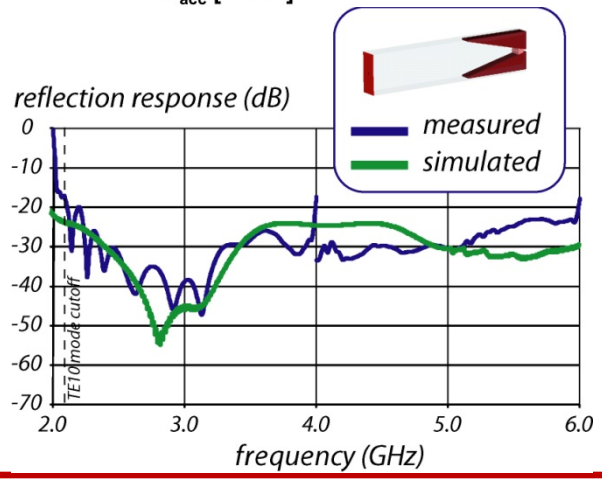
- High-current module concept for JLab ERL / injector upgrade
- 2 cavities built and qualified
- Window qualified to 60 kW
- HOM load concept developed
- Project status: dormant











JLAB SRF R&D for ERLs
748.5 MHz high-current cryomodule

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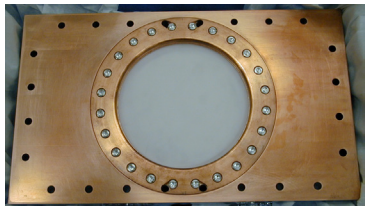
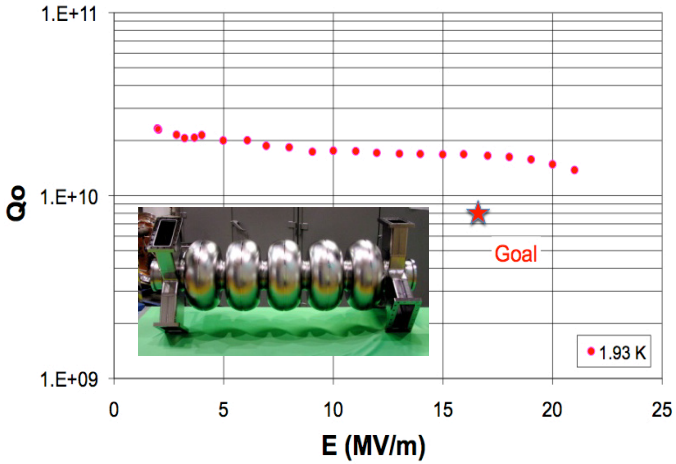
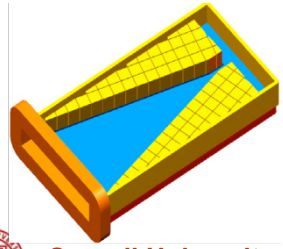
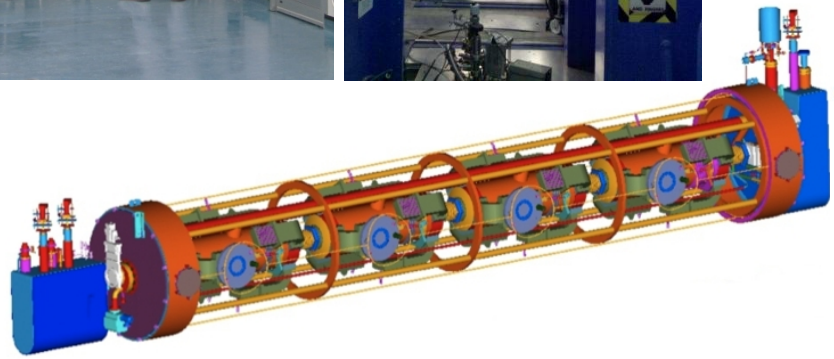
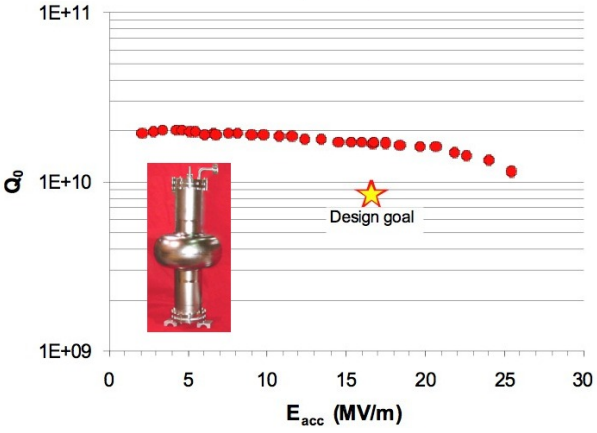
- Ampere-class module aimed at shipboard FELs
- One test each of single cell and 5-cell
- Window and HOM load concepts developed
- Project status: transferred to industry











Cornell University

5-cell SRF cavity with strong HOM damping for eRHIC at BNL

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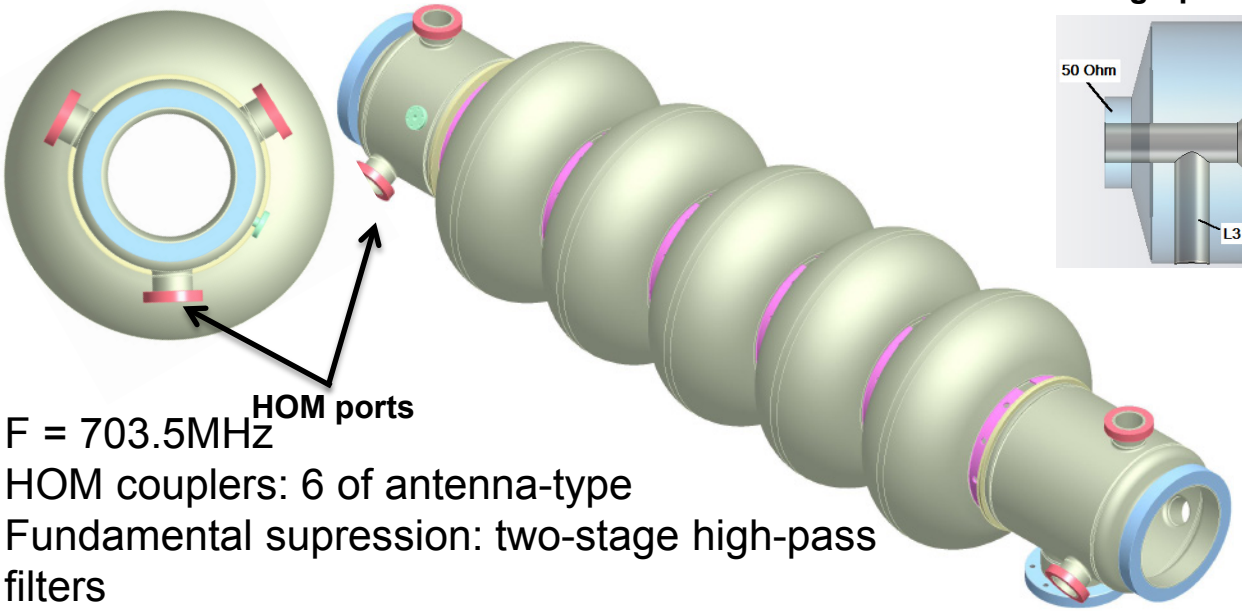
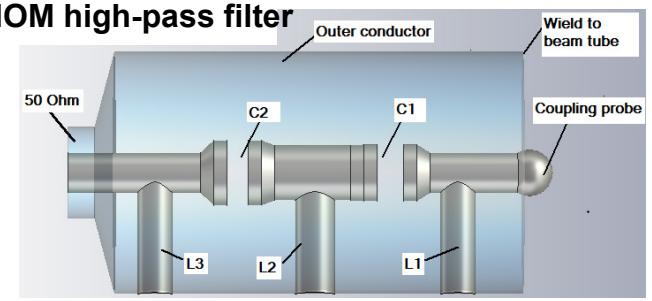
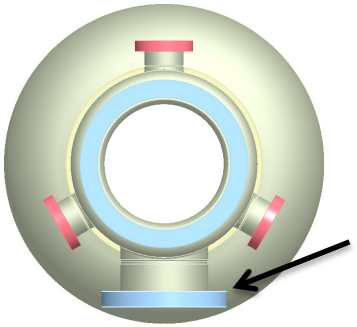


HOM high-pass filter





F = 703.5MHz

HOM couplers: 6 of antenna-type

Fundamental supression: two-stage high-pass filters

E_{acc} = 20 MV/m

N_{cav} = 240 for eRHIC

- A five-cell 703.5 MHz SRF cavity (BNL3) for high-current applications is under development at BNL.
- The cavity is optimized and designed for applications such as eRHIC and SPL.
- Three antenna-type HOM couplers will be attached to a large diameter beam pipes at each end of the cavity and will provide strong damping while maintaining good fill factor for the linac.
- A two-stage high-pass filter rejects fundamental frequency, allows propagation of HOMs toward an RF load.
- A copper model of the cavity is fabricated to study effectiveness of the HOM damping scheme. The niobium cavity is expected to be ready by the end of 2011 [**MOPO040, MOPO059**]

ERL test loop at BNL: 5cell SRF Cavity

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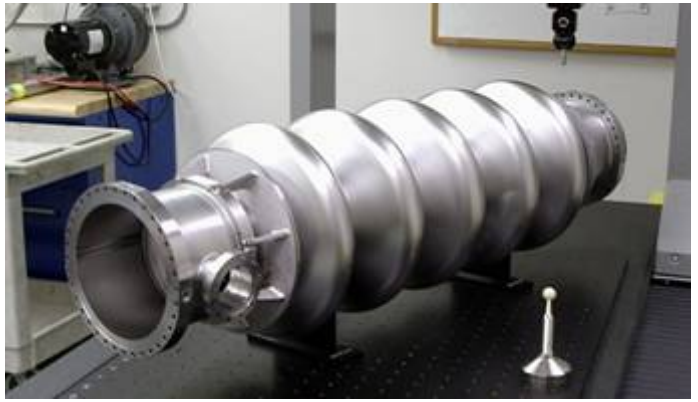
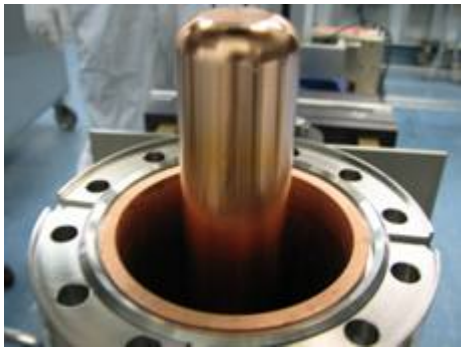
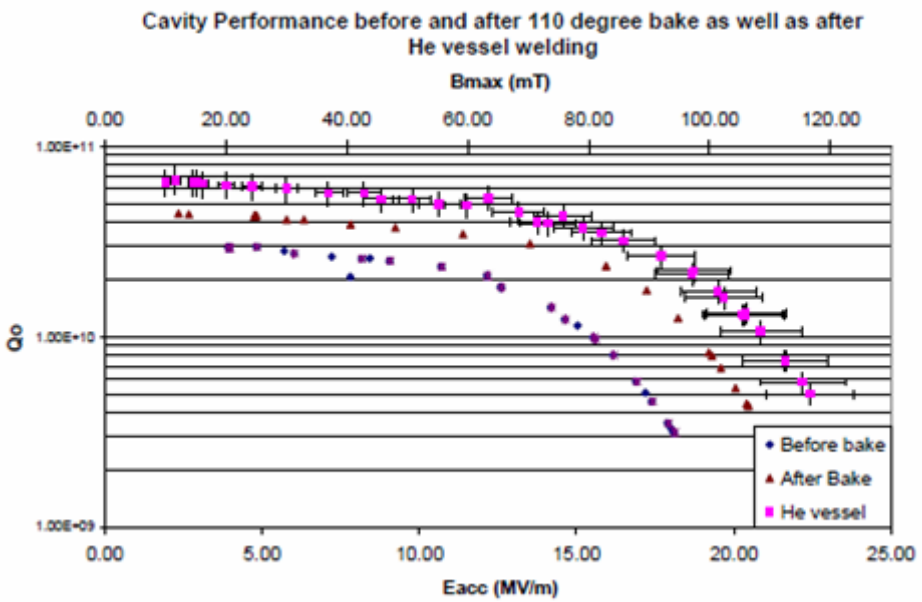
- 5 cell SRF cavity, 17 cm iris, 24 cm beampipe
- 703.75 MHz, 20 MV/m @ Q_o=1e^{10}
- No trapped HOMs
- Cavity is inherently stiff, so no additional stiffeners are needed
- Coaxial FPC for power delivery
- Ferrite Dampers for HOMs
- 5 K heat intercept on beampipe
- Mechanical Tuner with 100 kHz tuning range, piezo provides 9 kHz fast tuning







ERL SRF Gun at BNL

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Design Parameters	Units	Value
Frequency	MHz	703.75
Iris radius	cm	5
Equator Diameter	cm	37.9
Cavity length	cm	25
Beam kinetic energy	MeV	2
Peak electric field	MV/m	35.7
Peak magnetic field	A/m	58740 (73mT)
Stored energy	Joule	8.37
Ratio of Bmax/Emax	mT/(MV/m)	2.1075
Ratio of Emax/Eacc		1.3998
QRs (geometry factor)	Ω	111
R/Q	Ω	62
Qe (external Q)		37000
Power input	MW	1
Maximum current	mA	500
Emittance at 1.4 nC	μm rms normalized	1.4
Cathode recess	mm	1
Cathode spot size	mm diameter	5
Emission phase	Degrees	25
Longitudinal loss factor	V/pC	0.7
Transverse loss factor	V/pC/m	32

Two 704MHz SRF gun have been built

- Large grain gun will be used for continue mutipactoring studies
- Small grain is under hermetic string assembly in JLab. Will be installed and commissioning at ERL in fall 2011
- CsK_2Sb Photocathode lab produces and transports cathodes to gun.
- SRF gun will test diamond e-amplifier

Rebuilding and Improving the Cornell ERL Injector

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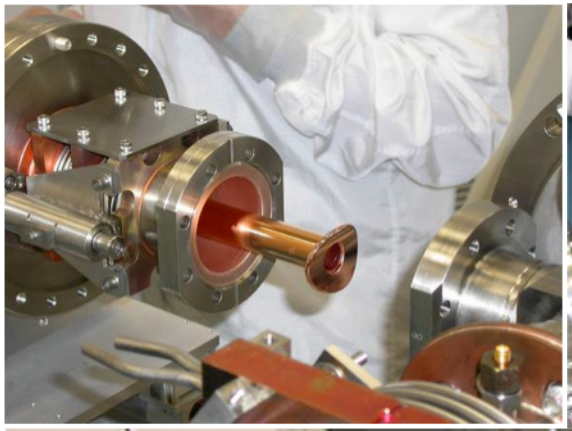
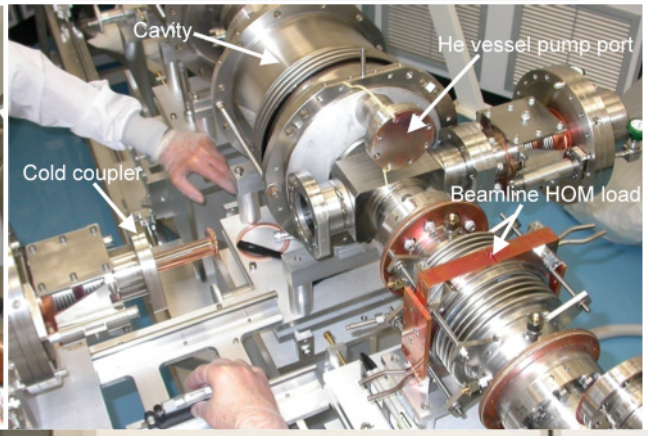
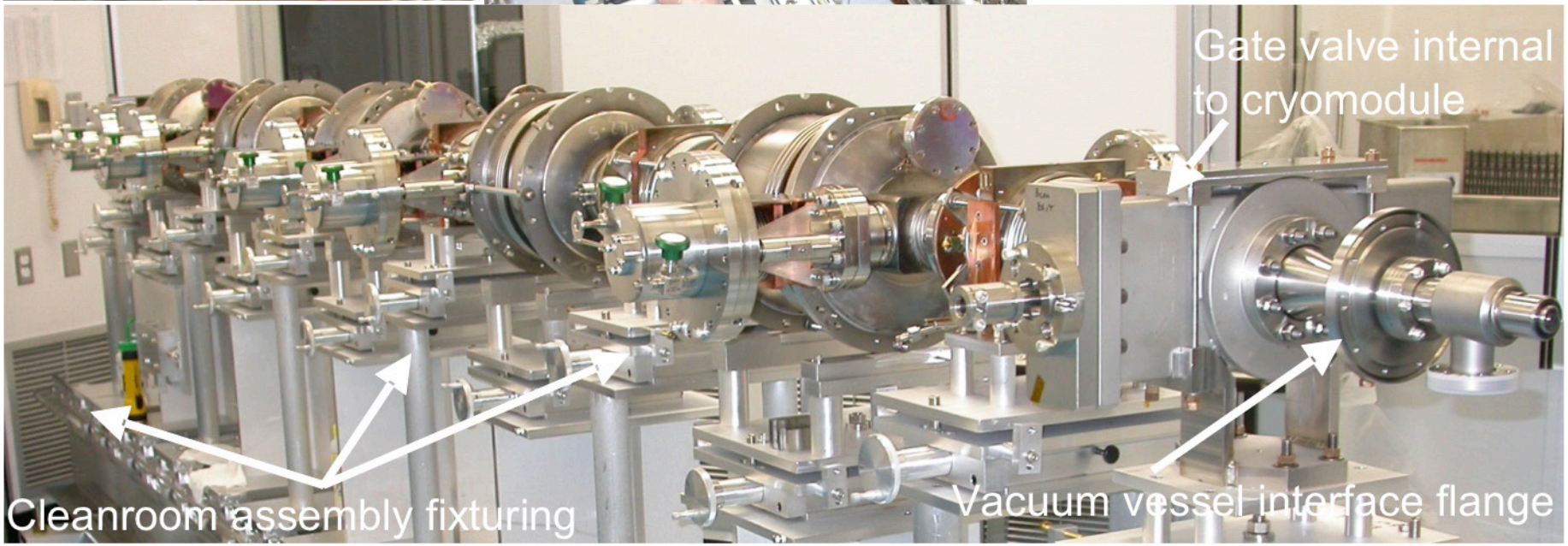
Attach cold couplers to beamline string





- Beam showed absorber plates charging up at 80K
- Removal of exposed absorber plates
- Installation of appropriate plates in shielded bellows region



Achieved milestones at Cornell's SRF ERL injector

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Peak DC-power supply voltage: 750kV
Peak DC-gun voltage: 440kV

Peak DC-beam current: 25mA
Peak bunched-beam current: 25mA

Peak charge per bunch: 200pC

Typical bunch length: 2ps

Smallest normalized thermal emittance: 0.25 mm mrad/mm radius
Smallest normalized emittance after gun at 80pC: 1.8 mm mrad
Smallest normalized emittance after injector at 80pC: 2.6 mm mrad

Largest SRF-injector cavity Q0: 1.e10
Largest injector-coupler power: 60kW
Largest SRF-cavity voltage: 13MV/m

ERL Phase1B funding: 2010-2014
Pre-construction and industrialization

CLASSE

SRF Group

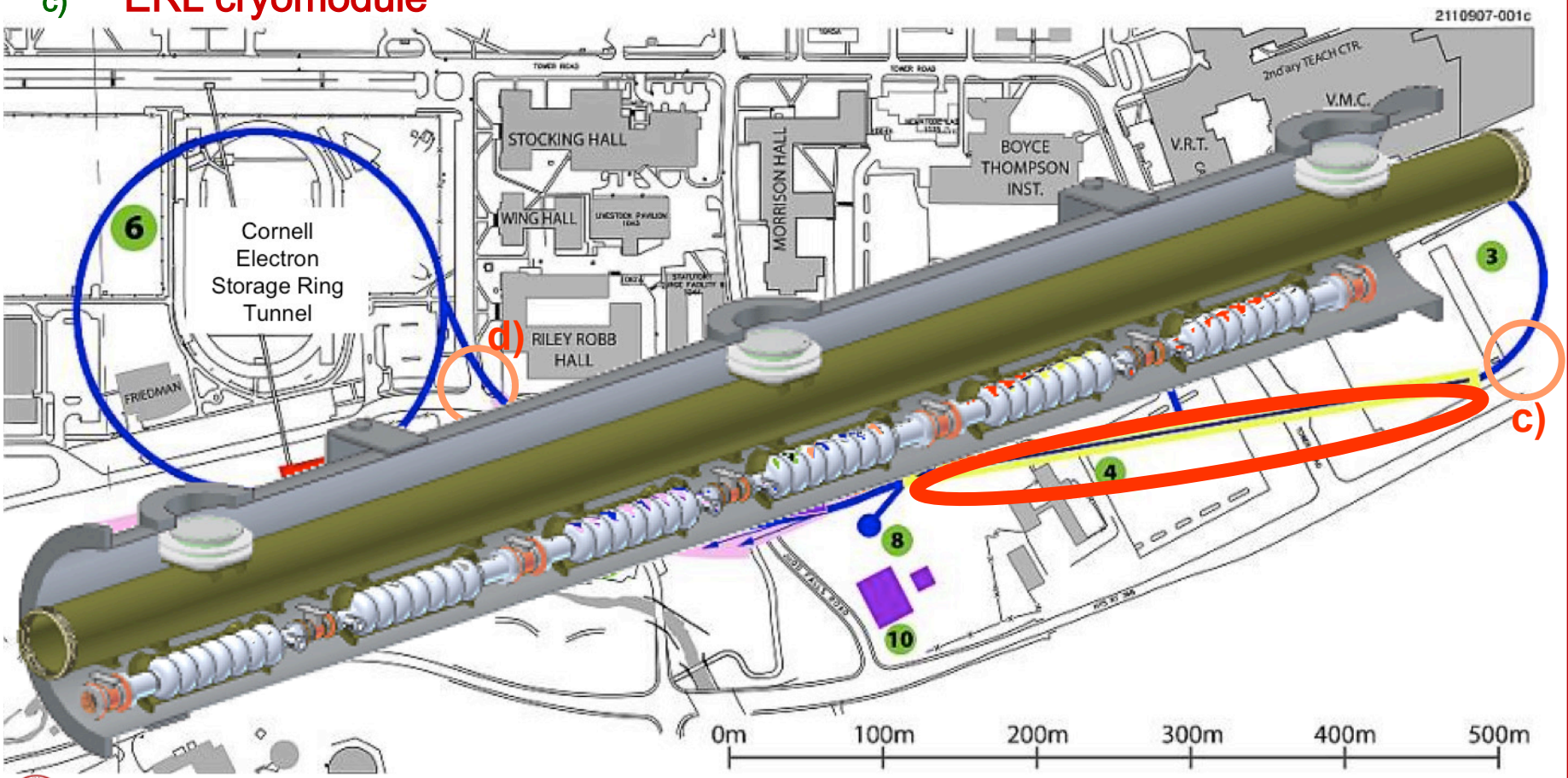
a) Continued Gun R&D

b) High-brightness beam physics

c) ERL cryomodule

d) ERL Undulators

e) Other X-ray beamline R&D



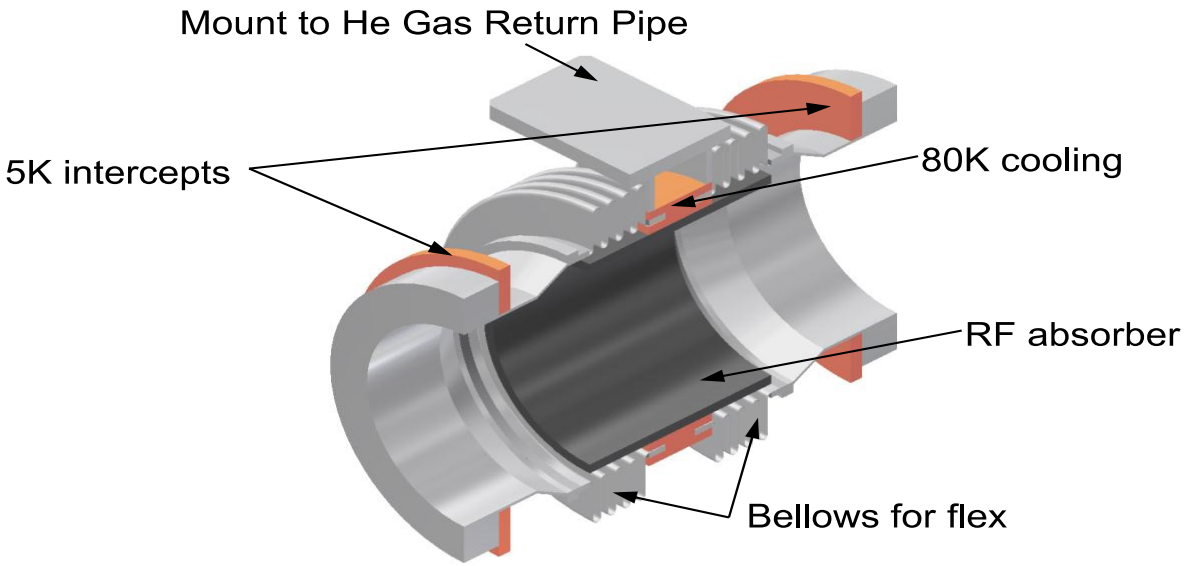
ERL Phase1B progress for SRF

CLASSE

SRF Group

- Engineering design of 7-cell cavity, dumbbells ready, v-test of 1st cavity in Sept.
- Engineering design of 8 HOM absorber, parts ready for bracing
- Engineering design and quote for SC quadrupole/corrector/BPM package

- Horizontal test to evaluate midfield Q in early 2012
- Horizontal test with beam for HOM measurements in 2013
  - Incorporate a full-circumference heat sink to allow >500W dissipation @ 80K
  - New beamline flanges, variations of the "Zero Impedance Flange"



END

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