Report from SRF2013: *The SRF World Today*

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16th International Conference on RF Superconductivity

SRF 2013 covered the latest advances in the science, technology, and applications of superconducting RF.

~390 participants from >35 institutions

The program:

- 10 tutorial talks in pre-series @ GANIL
  - http://pro.ganil-spiral2.eu/events/cw/srf2013/
- 62 invited review talks
  - https://indico.in2p3.fr/conferenceOtherViews.py?confId=8939
- ~350 contributed posters
  - All papers will appear soon on JaCOW
- 3 "hot-topic" discussion sessions

Report from SRF2013:

The SRF World Today

1. Status of SRF-based accelerator projects in the world - scale and quality in comparison with CEBAF, esp. 12 GeV
   John Mammosser

2. SRF cavity processing techniques - the latest standard and the emerging
   Ari Palczewski

3. SRF non-bulk materials - what is new and promising?
   Anne-Marie Valente-Feliciano

4. Nb high-Q pursuits - what is new, what is the best seen, what understanding and control is needed yet?
   Pashupati Dhakal

Status of Accelerator Based Projects SRF2013

Thomas Jefferson National Accelerator Facility is managed by
Jefferson Science Associates, LLC, for the U.S. Department of Energy's Office of Science

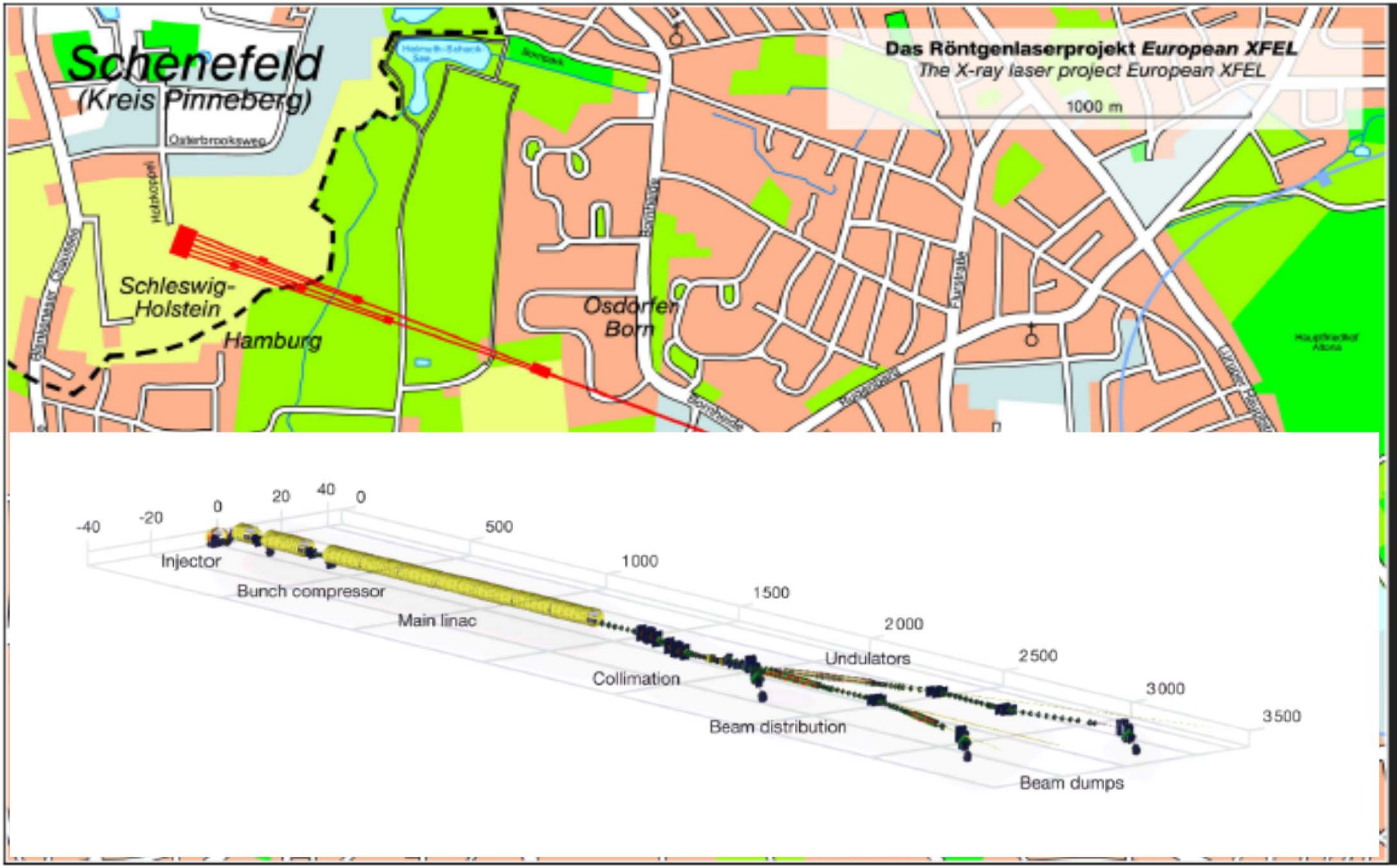
Jefferson Lab

Outline:

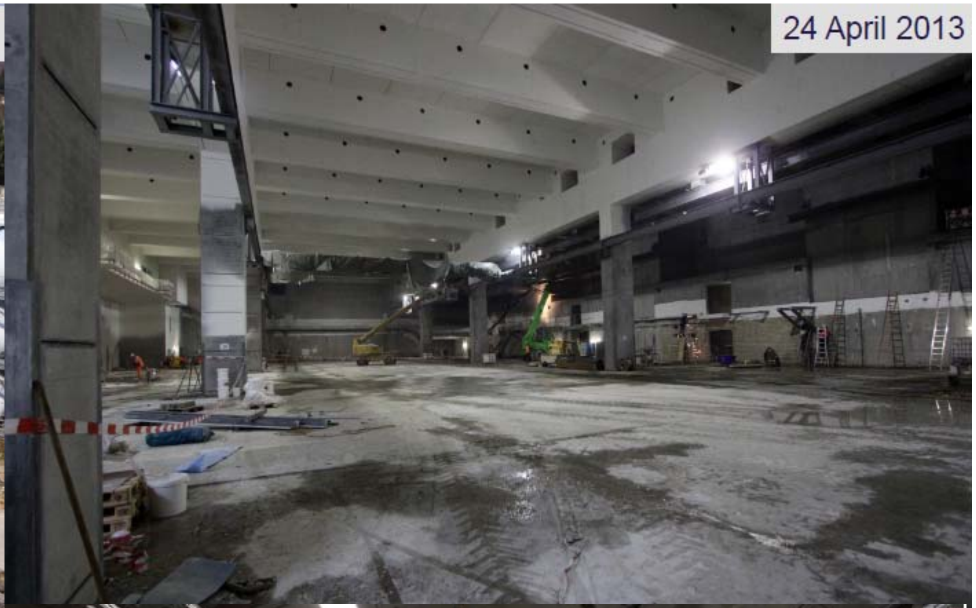
SRF Based Projects:

XFEL
FRIB
Cornell ERL
ADS China
ESS
Atlas Upgrade
IFMIF
Project X

XFEL-Europe


Schenefeld
(Kreis Pinneberg)
Schleswig-
Holstein
Hamburg
Osdorfer
Born
Das Röntgenlaserprojekt European XFEL
The X-ray laser project European XFEL
1000 m
Injector
Bunch compressor
Main linac
Collimation
Beam distribution
Undulators
Beam dumps
-40
-20
0
20
40
0
500
1000
1500
2000
2500
3000
3500

Civil Construction

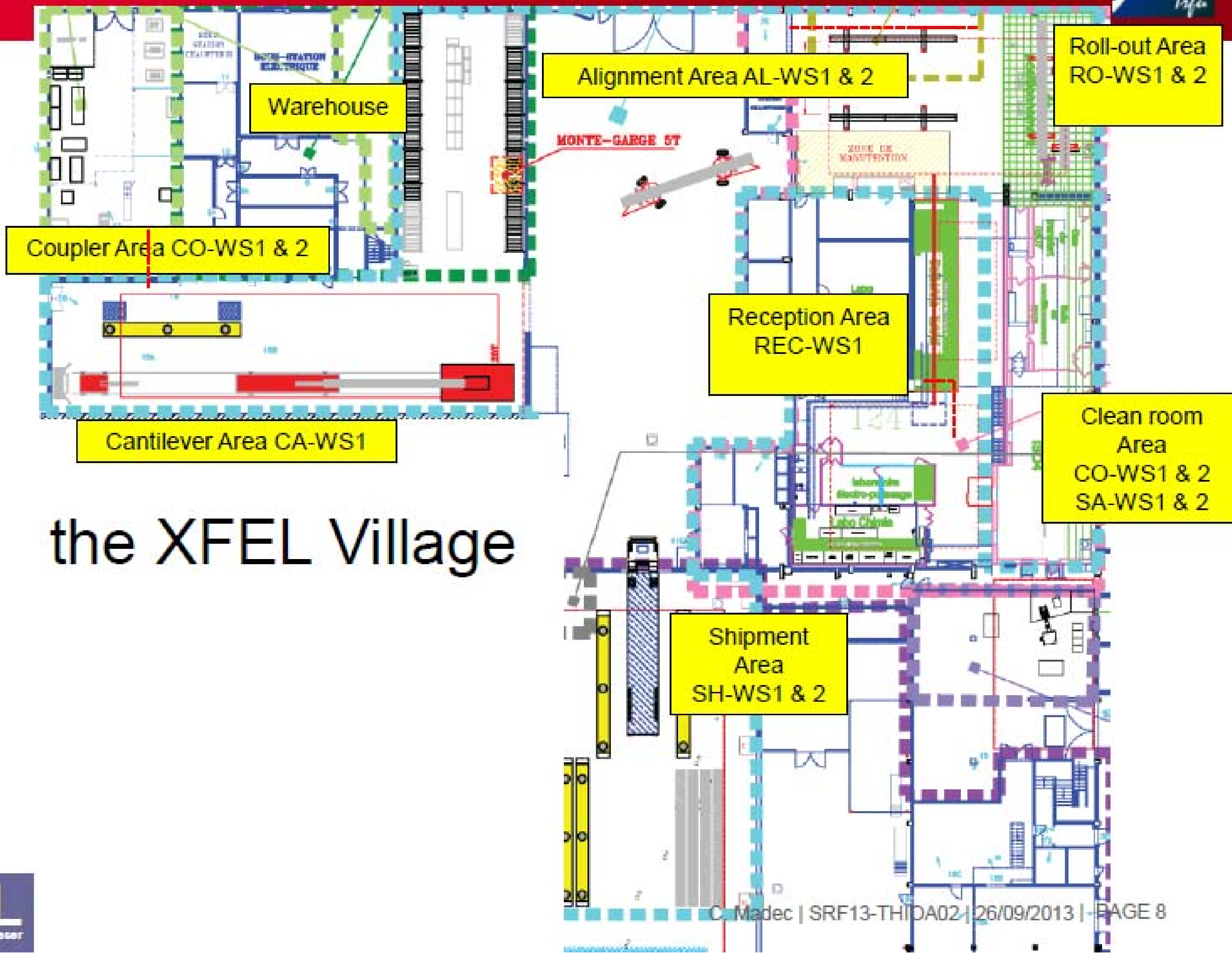


XFEL - DESY

- 220/640 Cavities fabricated, 111 delivered
- Rate 4/week ending in mid 2015
- Two Vendors both with new facilities for
  - EP
  - HPR
  - Cleanroom assembly
  - QA, RF and Mechanical
- Cavities delivered fully processed ready for testing in helium vessel
  - Only additional HPR necessary

Nb to Cavities, DESY

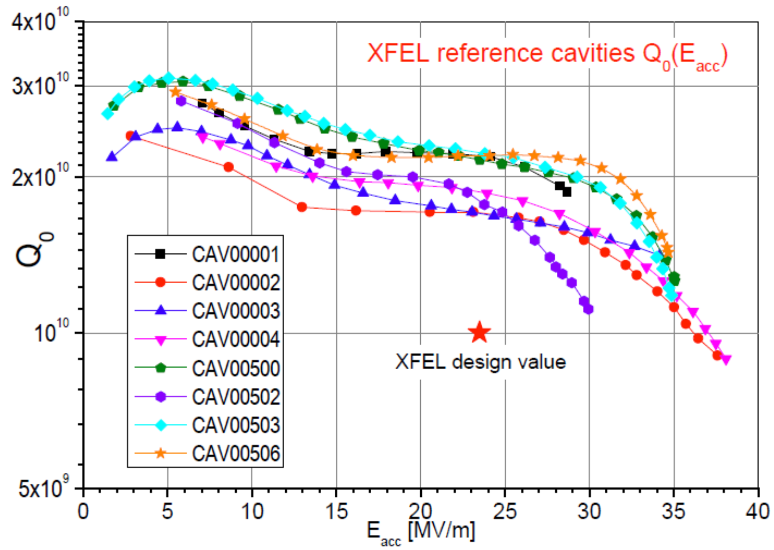
PHASE 2 : WORKSTATIONS IN ASSY HALLS



the XFEL Village

XFEL- Performance

4 RCVs of RI and 4 RCVs of E. Zanon: acceptance test successful



Prior surface treatment.

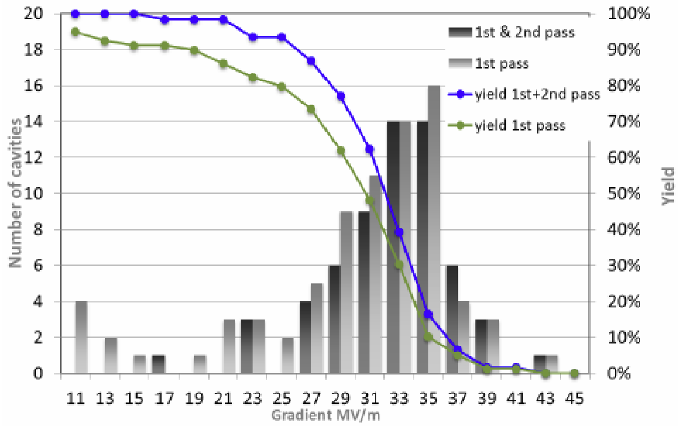
EP 110-140 µm (main EP), outside BCP, ethanol rinse, 800° C annealing, tuning

Final surface treatment - two alternative options

1. **Final EP of 40 µm, ethanol rinse, high pressure water rinsing (HPR) and 120° C bake**
2. **Final BCP of 10 µm (BCP Flash), HPR and 120° C bake.**

Integration of the helium tank, assembly of HOM, pick up and high Q antennas and shipment to DESY for 2K RF acceptance test

XFEL- Performance Comparison

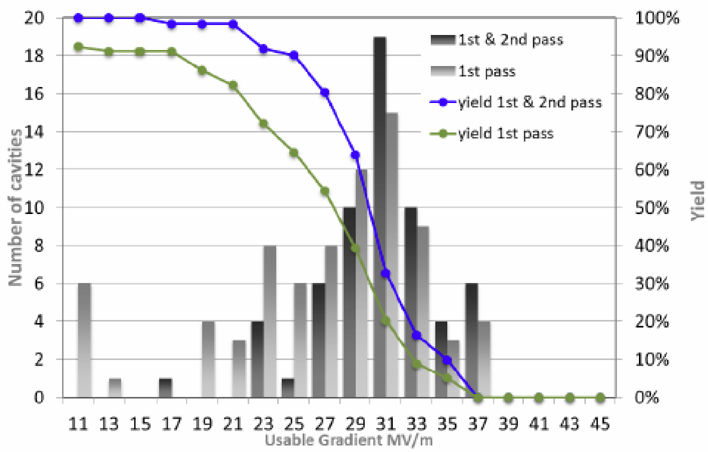


Average **maximum** gradient:

(30.9 ± 4.4) MV/m

EZ: (30.4 ± 4.5) MV/m

RI: (32.3 ± 4.1) MV/m

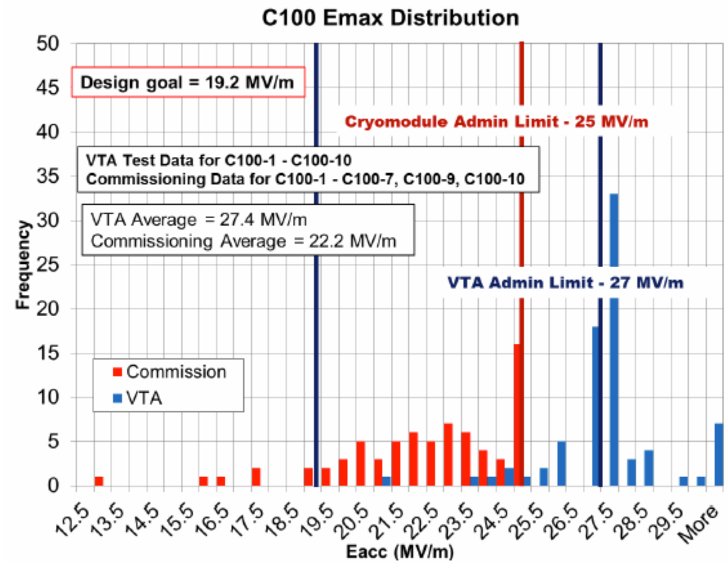


Average **usable** gradient:

(29.0 ± 3.9) MV/m

EZ: (28.4 ± 4.0) MV/m

RI: (30.6 ± 3.1) MV/m



Preliminary accounting for gradient reductions:

- Capping VTA Admin limit to 25 MV/m reduces VTA average to 24.9 MV/m
- Cryostat riser limits (50 – 60W per cavity) account for reductions in 21% of the cavities
- Assembly / Testing “events” account for reductions in ~5% of the cavities

- **Acceptance Criteria**:
  “…maximum gradient > 26 MV/m with an unloaded Q_0 of ≥ $1x10^{10}$ and a X-ray level lower than $1x10^{-2}$ mGy/min.”
  (with 26 MV/m to give 10% margin compared to 23.6 MV/m design gradient)

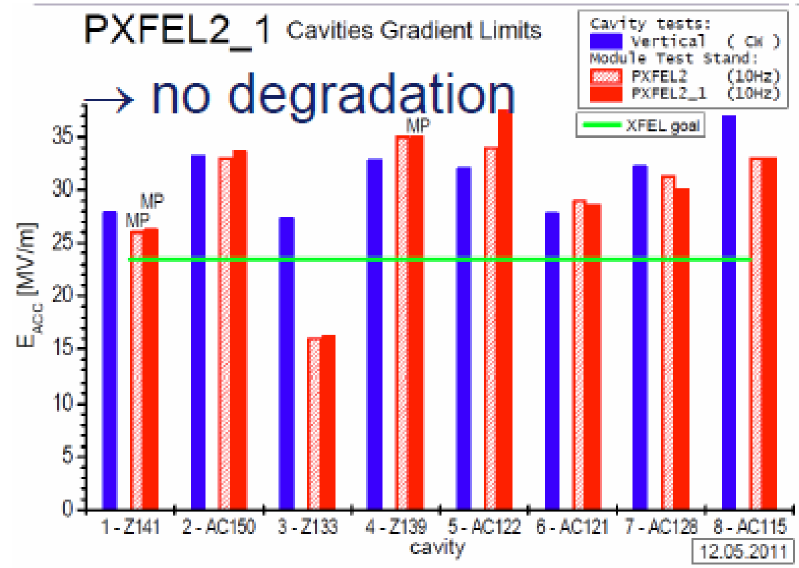
- If acceptance criteria **passed**
  => preparation for transport + string assembly
- If acceptance criteria is **not passed**
  => **re-treatment at DESY**
  (Reminder: **No performance guarantee by the vendors**, i.e. the risk of unexpected low gradient or field emission is with DESY)

- **“Usable Gradient”**: i) Quench
  ii) $Q_0 < 1x10^{10}$
  iii) radiation > $1x10^{-2}$ mGy/min

Performance Comparison Vertical Test

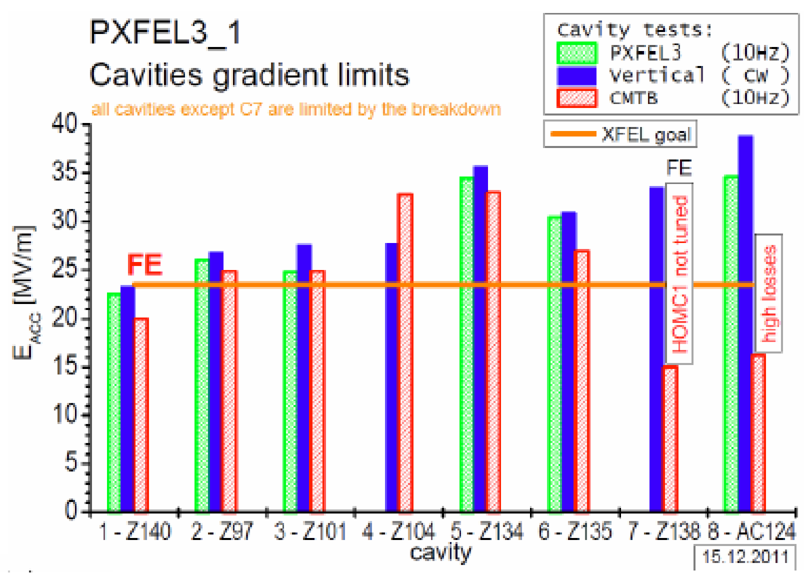
Vertical Test Performance Cavity Vendor	C100 2.07K (R1)	XFEL 2.0K (1/3-Ri/2/3 - Z)	C100 Yield	XFEL Yield
VTA Admin Limit	27.0/Rad /Pd/Quench	26.0/Rad /Qo/Quench		
Eacc (Avg Maximum)	27.4	28.1 ±7.8		
Qo (Low Field)	1.3E10	2.2e10		
Eacc (Usable)		29.0 ±3.9		
VTA Yield First Pass	62/86	50/79	72.1%	63.3%
VTA Yield Second Pass	18/21	13/17	85.7%	76.4%
No Success First and Second Pass	3/86	3/79	3.5%	3.8%

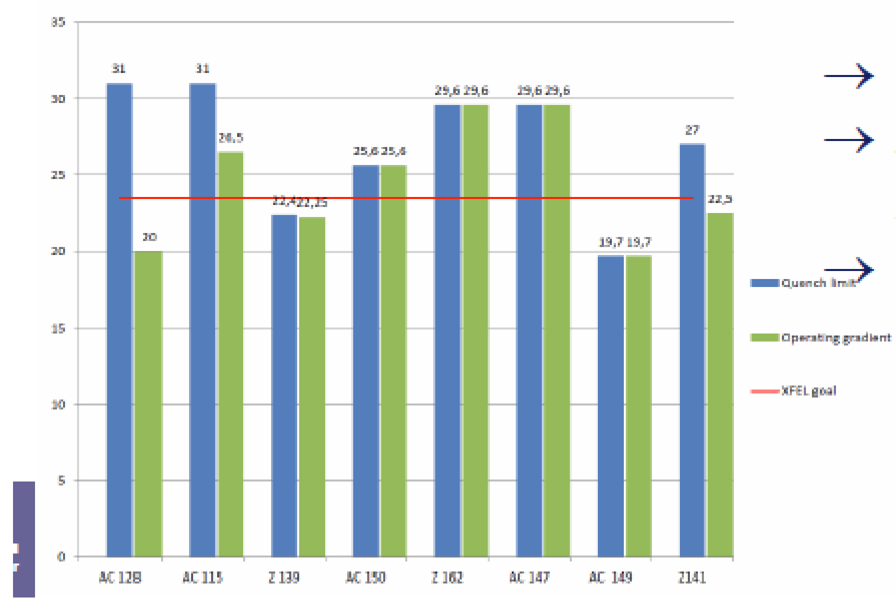
Performance Comparison Cryomodules



- Cryomodules are built at CEA by CEA staff
- 3 Modules fabricated to date PXFEL2-1, PXFEL3-1, PXFEL2-2

The team (~10 persons)

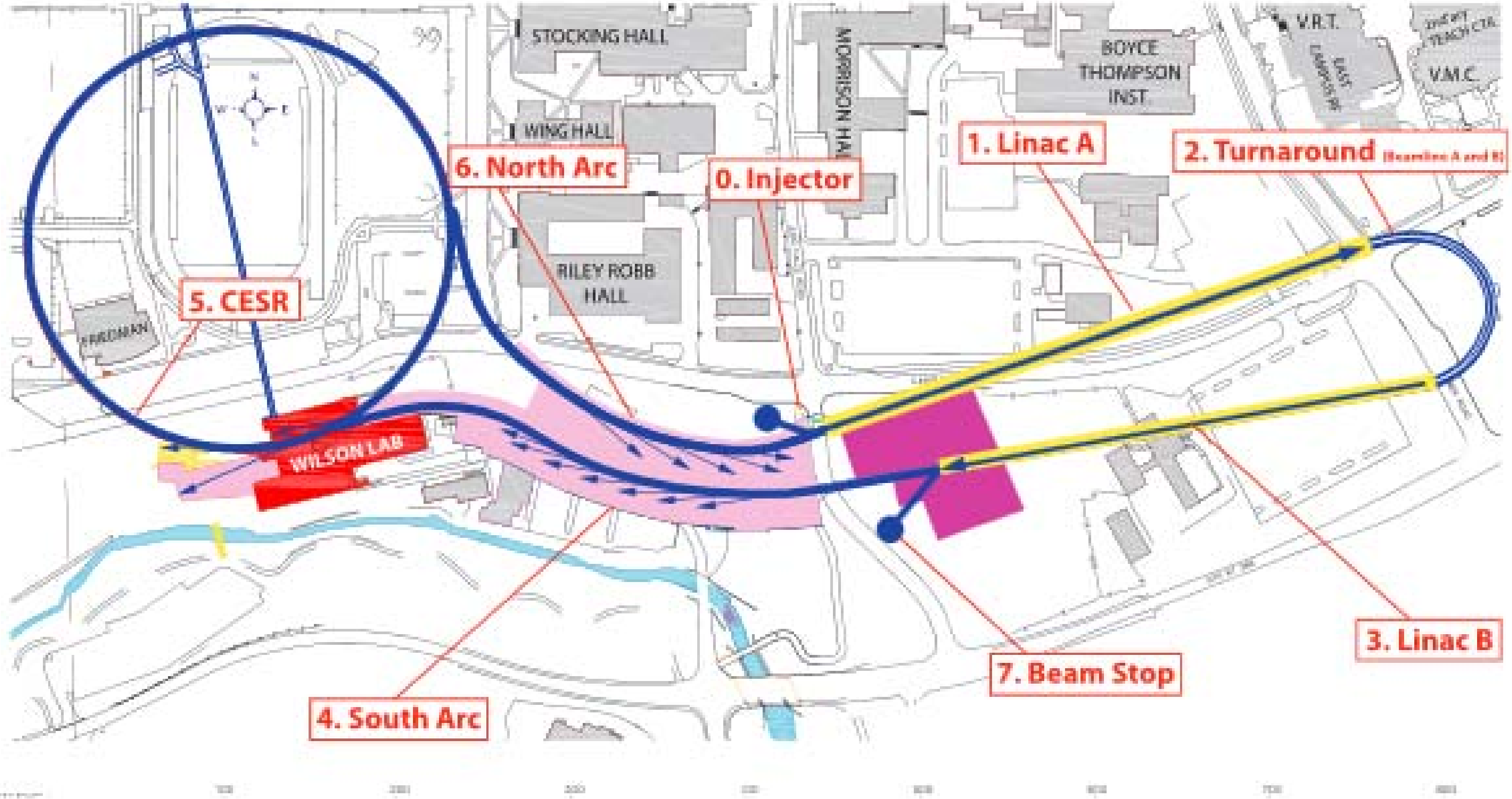




A closer look at two modules

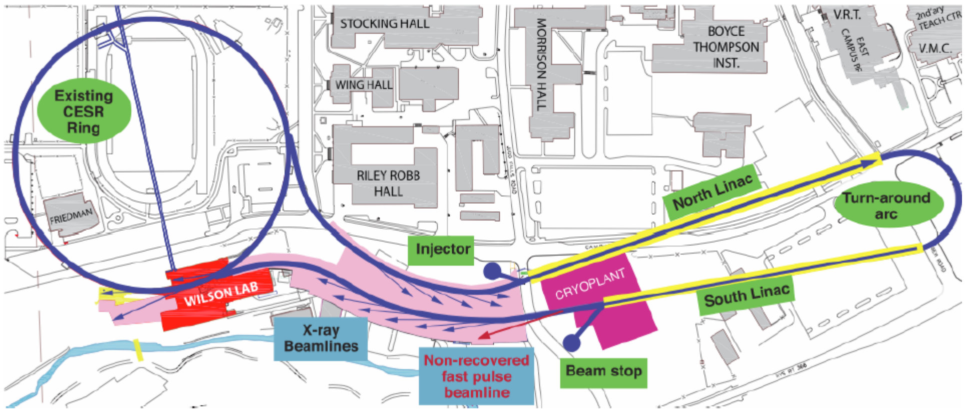
PXFEL2-1	cav1	cav2	cav3	cav4	cav5	cav6	cav7	cav8	Avg
Vertical test	**28**	**33**	**27**	**32.5**	**32**	**27**	**32**	**37**	**31.1**
DESY assembly	26	33	16	34.5	34	28.5	31	32	29.4
% change	-7.1	0.0	-40.7	-6.2	-6.3	-5.6	-3.1	-13.5	-5.8
CEA Assembly	26.2	33.5	16	34.5	37	28	29.5	32	29.6
% change	-6.4	+1.5	0.0	+6.2	+15.6	+3.7	-7.8	-13.5	-0.1
PXFEL3-1							HOM		
Vertical test	23.5	27	27.5	28	35.5	31	33	38	30.4
CEA Assembly	20	25	25	32.5	32.5	26.5	15.5	16	24.1
% change	-14.9	-7.4	-9.1	+16.1	-8.5	-14.5	-53.0	-57.9	-18.7

Cornell ERL

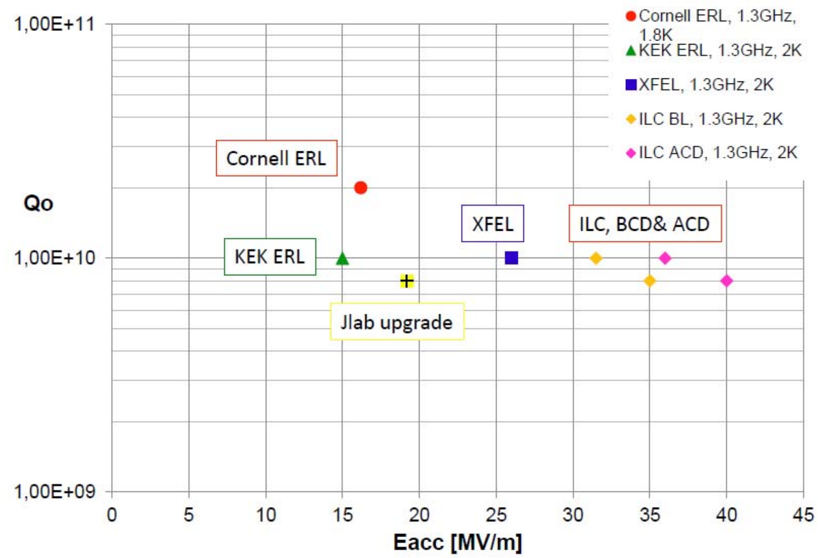

STOCKING HALL
MORRISON HALL
BOYCE THOMPSON INST.
V.R.T.
V.M.C.
WING HALL
RILEY ROBB HALL
WILSON LAB
1. Linac A
2. Turnaround
6. North Arc
0. Injector
5. CESR
3. Linac B
7. Beam Stop
4. South Arc

Cornell ERL

5 GeV, 100 mA CW beam , 8 pm emittance, 2 ps bunches



~200 W HOM power/cavity
CW operation, Q(1.8 K) = 2×10^{10} @ 16.2 MV/m

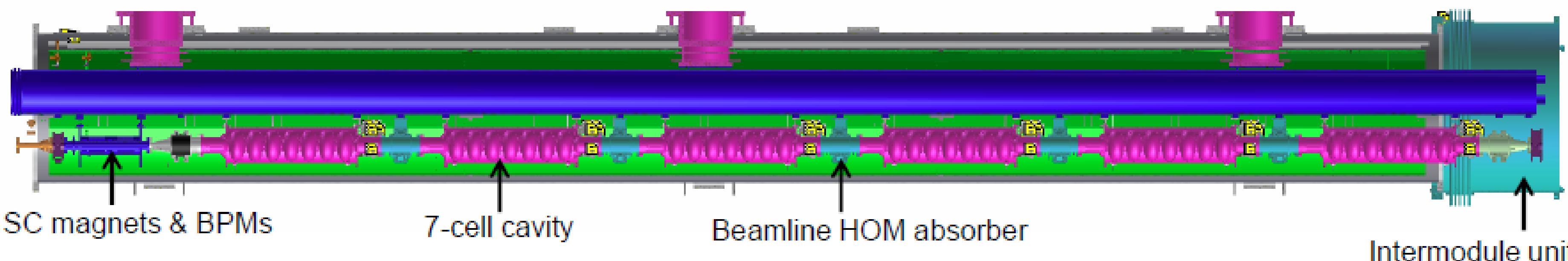


Total 64 cryomodules, each:

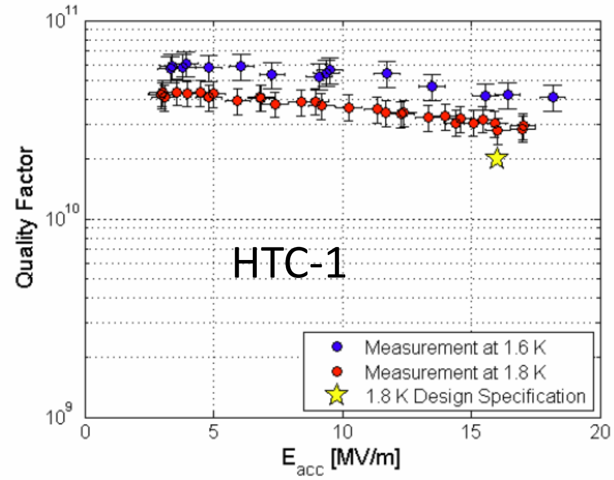
- six packages of 7-cell cavity/Coupler/tuner
- a SC magnets/BPMs package
- five regular HOMs/two taper HOMs

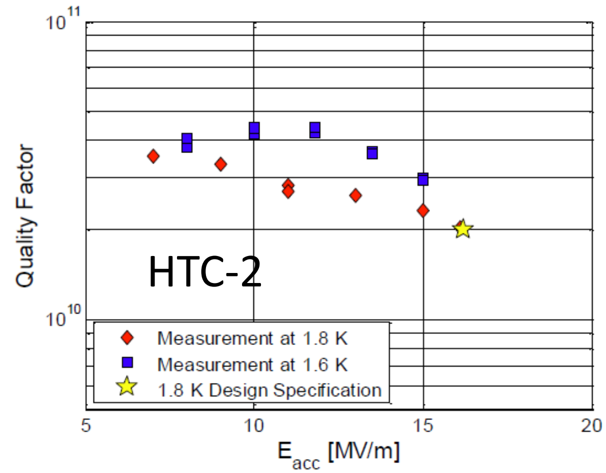
Linac B
285 m with 29 cryomodules

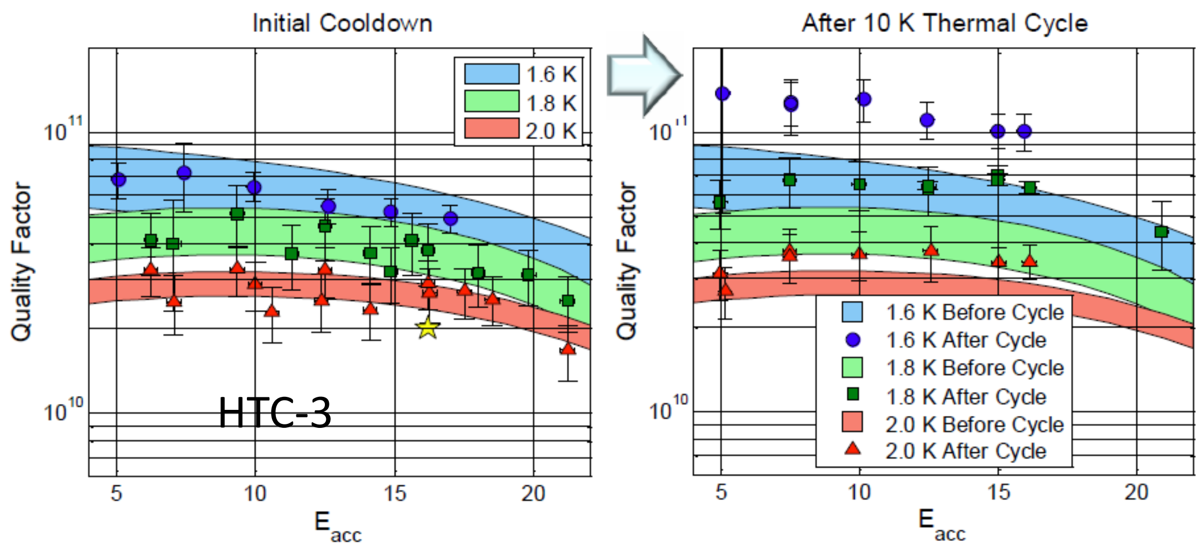
Staff- 45



Cornell Cryomodule Test Bed Results

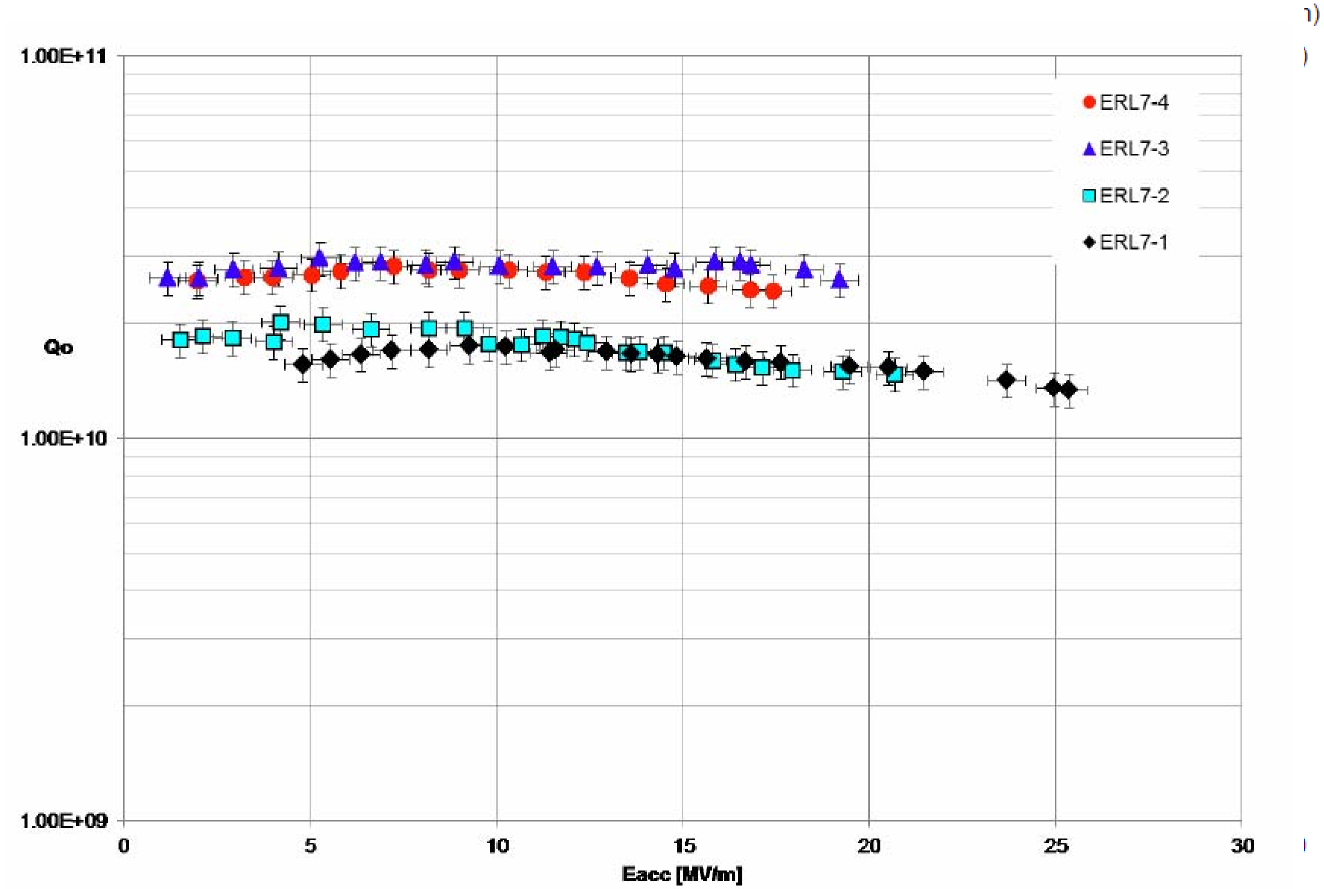




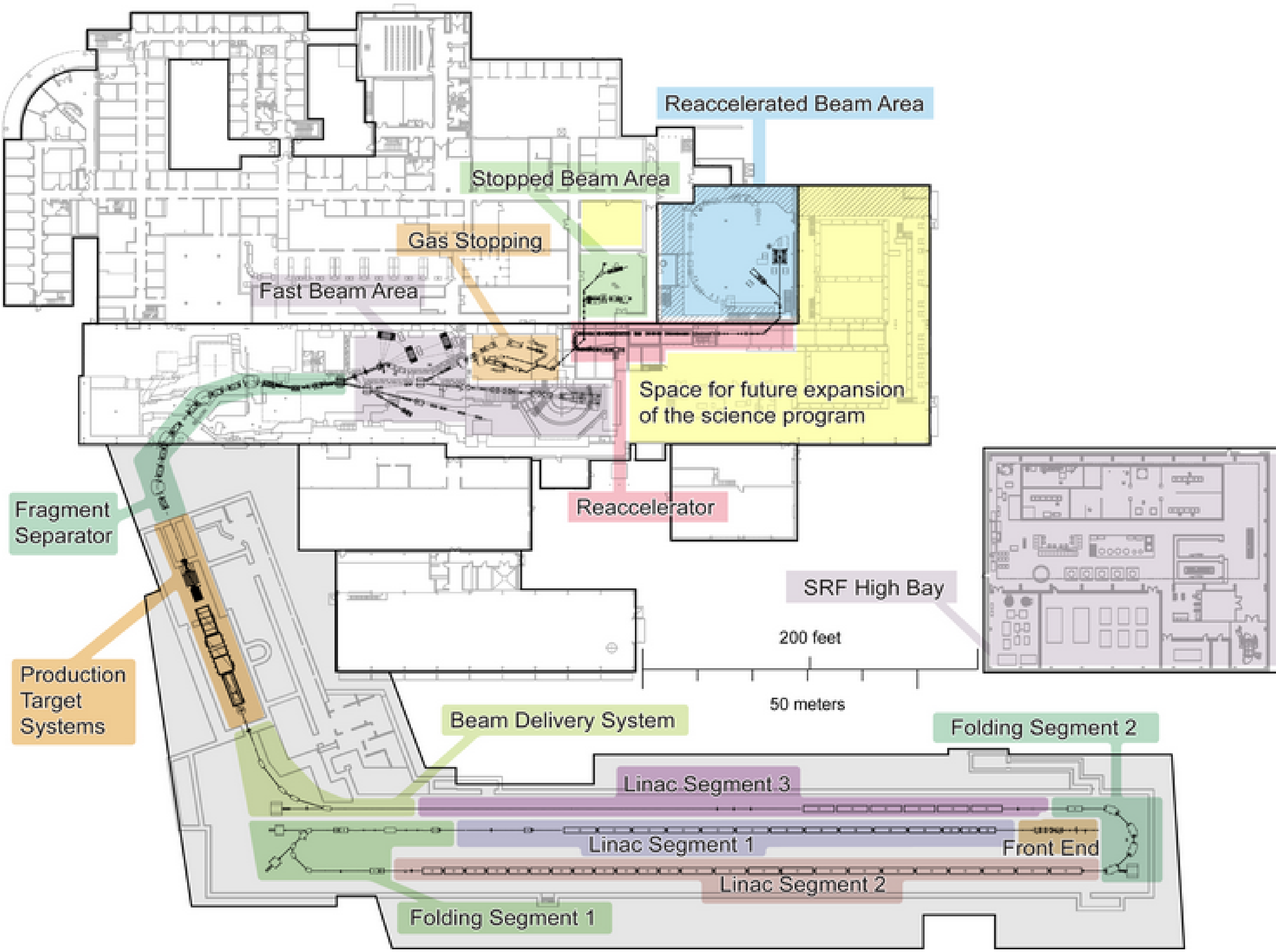


- HTC-1: Follow vertical assembly procedure as closely as possible
- HTC-2: Include side mounted, **high power RF input coupler**
- HTC-3: Full cryo-module assembly:high power RF input coupler and **beam line HOM loads**

Cornell Vertical Test Results



FRIB- MSU



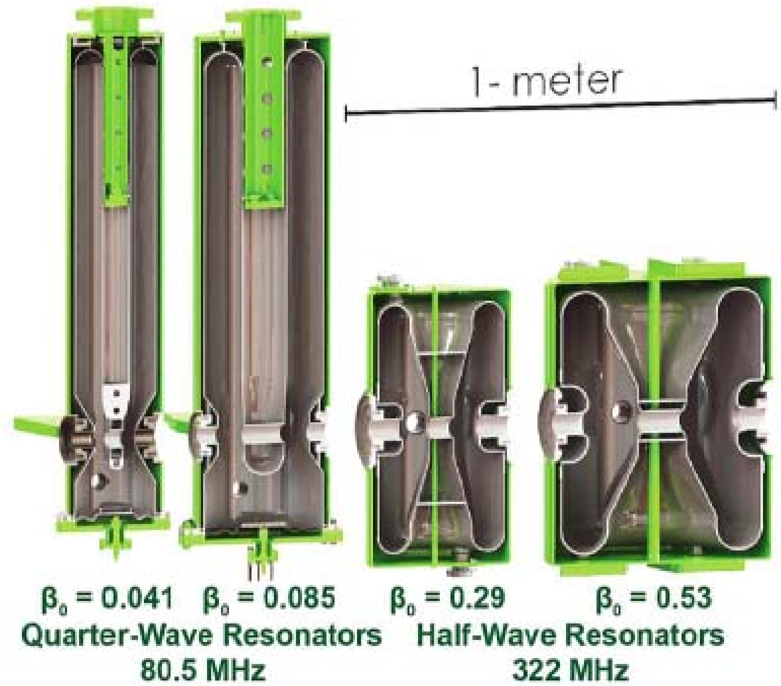
Reaccelerated Beam Area
Stopped Beam Area
Gas Stopping
Fast Beam Area
Space for future expansion of the science program
Fragment Separator
Reaccelerator
SRF High Bay
200 feet
50 meters
Production Target Systems
Beam Delivery System
Folding Segment 2
Linac Segment 3
Linac Segment 1
Front End
Linac Segment 2
Folding Segment 1

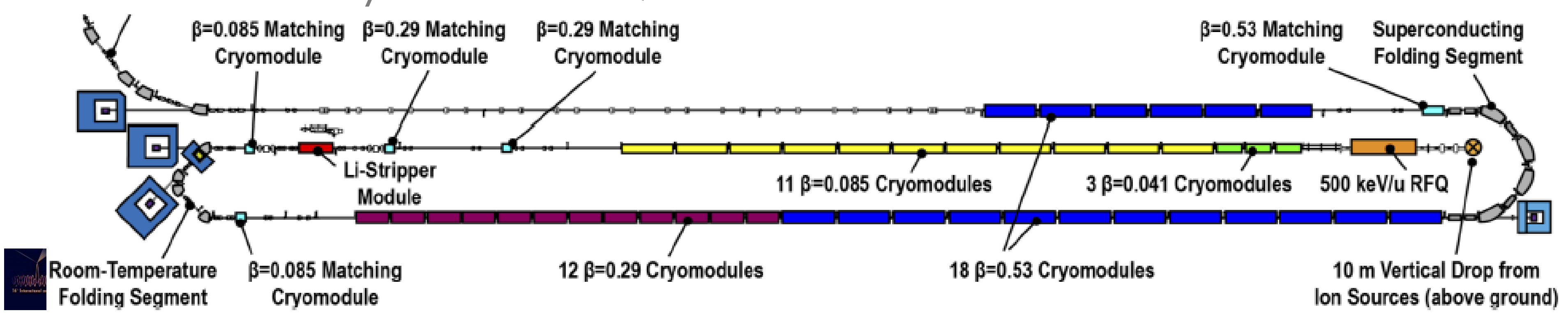
FRIB – Facility for Rare Isotope Beams

- 400 KW beam >200 MeV/u Oxygen to Uranium
- Currently at CD2-3A
- Start of civil construction April 2014
  - Total $ 730M, 180 employees
  - CD4 in 2020
- SRF Infrastructure at MSU
  - 27000 sq. ft. production facilities under construction
  - Complete in April 2014

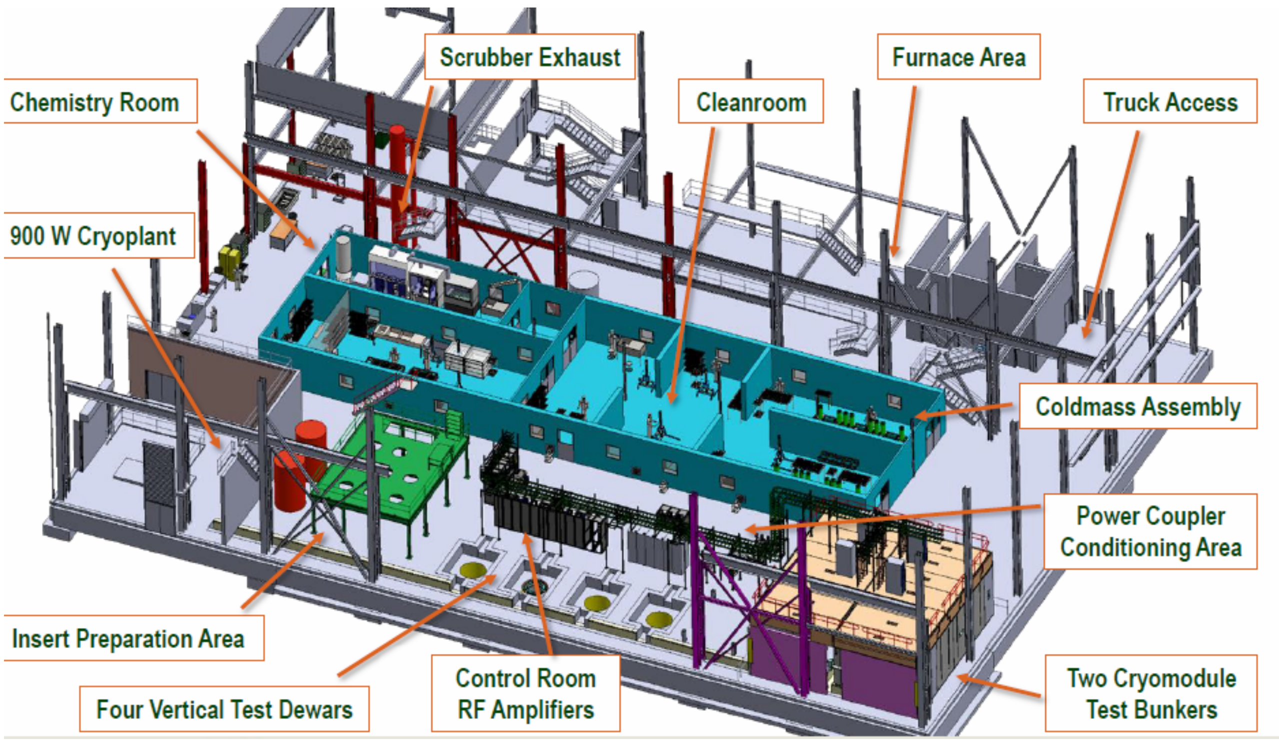
Production Required

- β – 0.041
  - 3 Cryomodules, 12 Cavities
- β- 0.085
  - 11 Cryomodules, 88 Cavities
- β- 0.29
  - 12 Cryomodules, 72 Cavities
- β- 0.53
  - 18 Cryomodules, 144

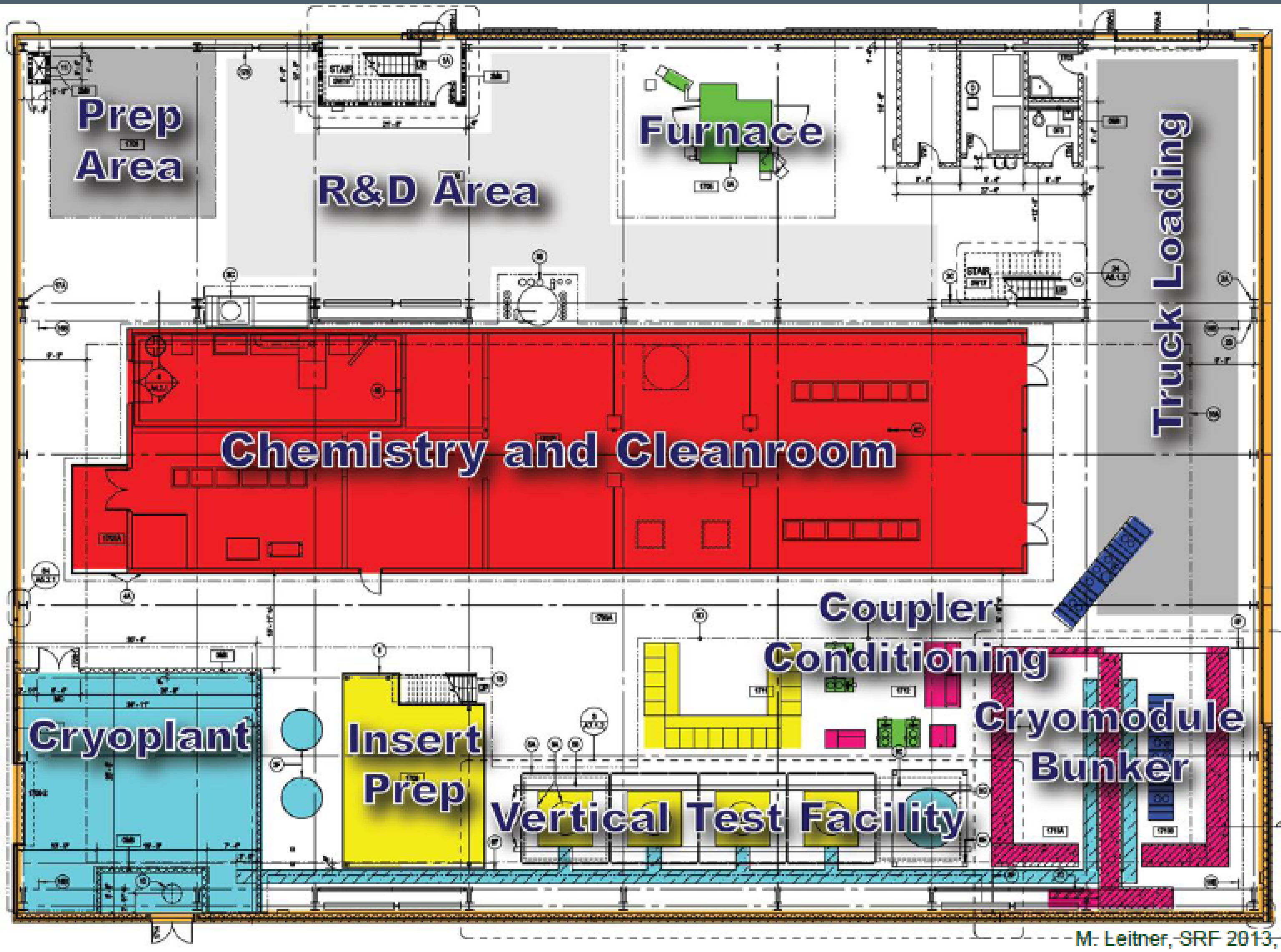





MSU SRF Facility Under Construction

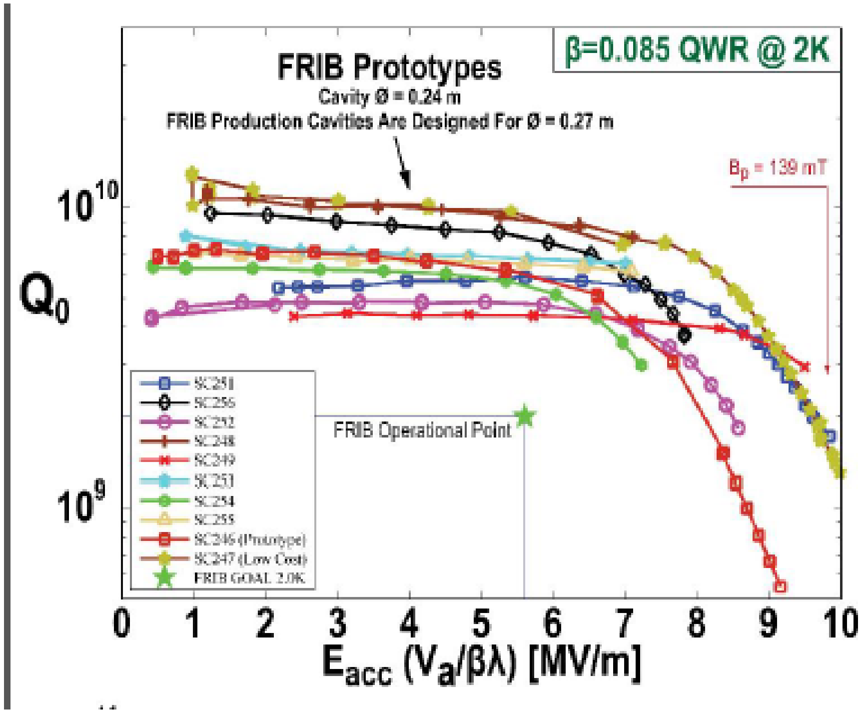

Scrubber Exhaust
Furnace Area
Chemistry Room
Cleanroom
Truck Access
900 W Cryoplant
Coldmass Assembly
Power Coupler
Conditioning Area
Insert Preparation Area
Four Vertical Test Dewars
Control Room
RF Amplifiers
Two Cryomodule
Test Bunkers

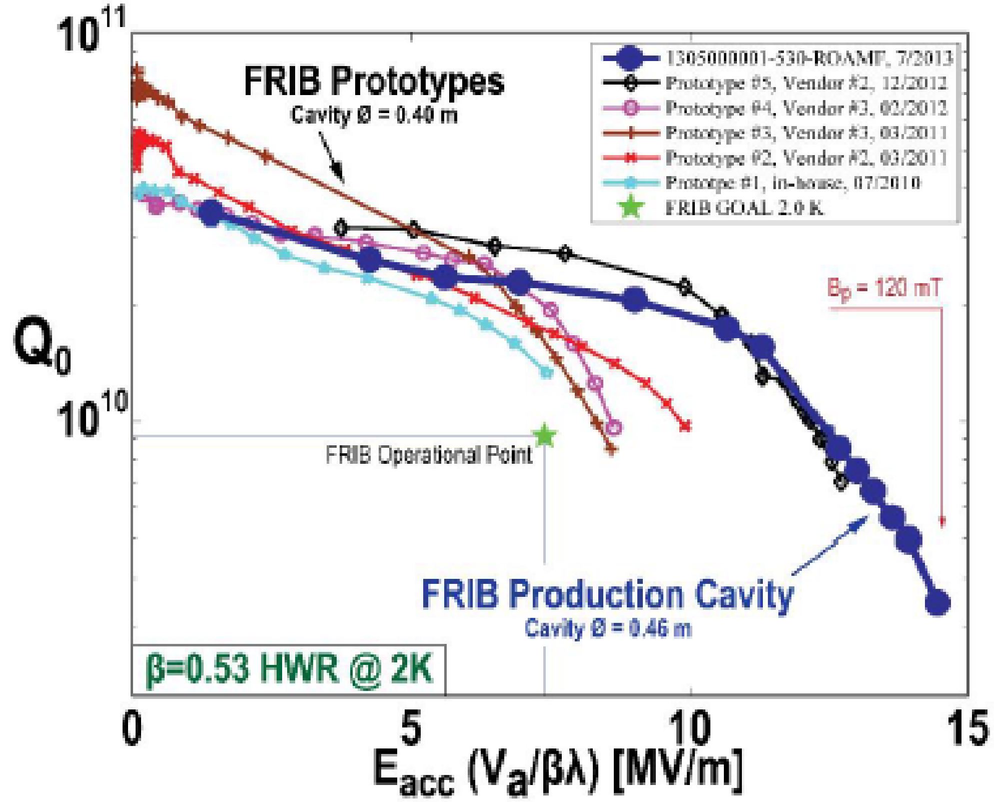
SRF Mass Production Will Occur In New MSU SRF Facility
27,000 sq. ft. SRF High Bay - Building Completion: April 2014



M. Leitner, SRF 2013, Slide 18

Performance

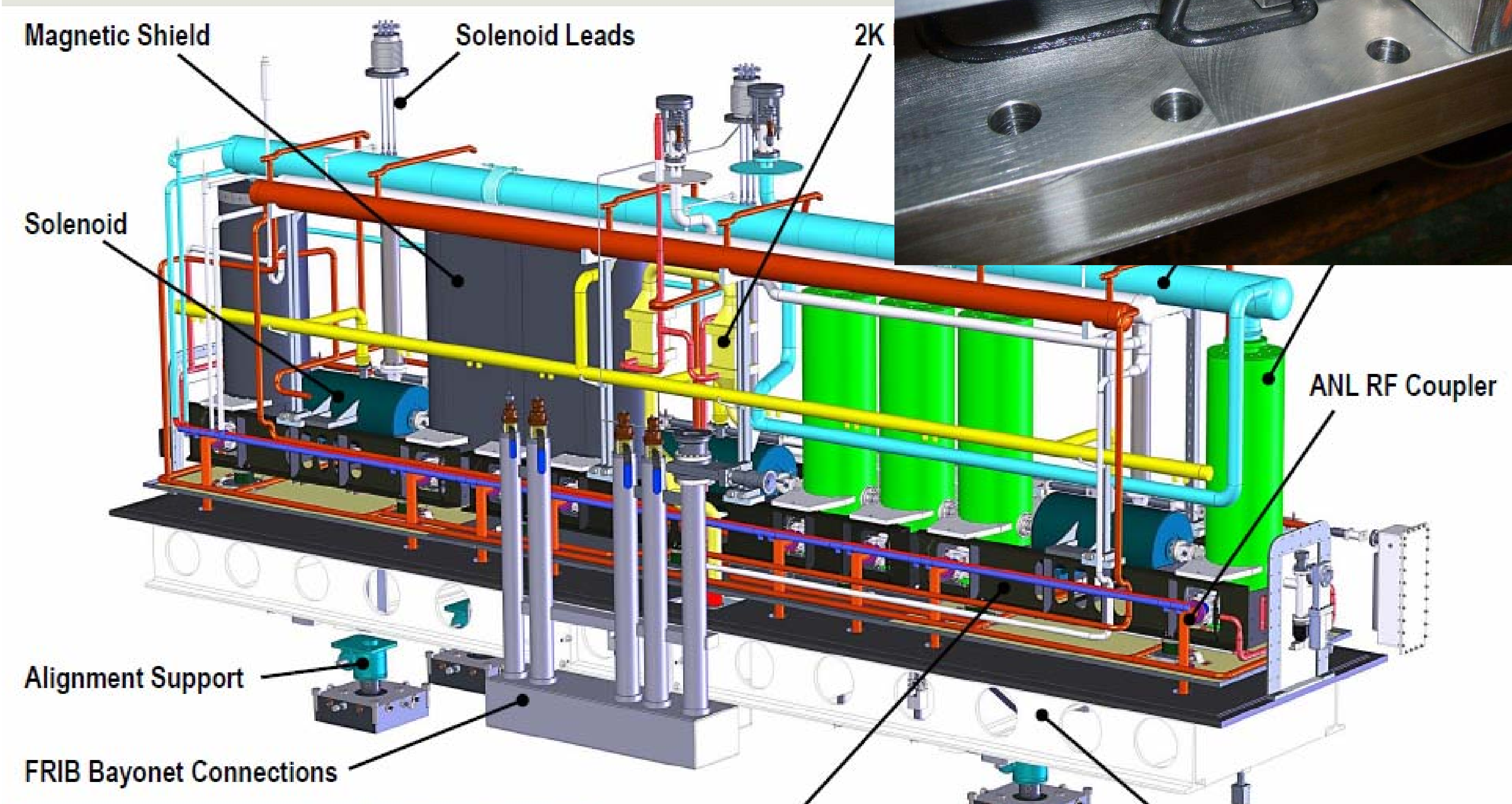




- 23 FRIB-relevant cavity prototypes have been successfully tested
  - 8 β=0.041 cavities, 11 β=0.085 cavities, 5 β=0.53 cavities

Cryomodule I

First FRIB-style Quarter Wave
Construction: Cavities Operate At



Projected Heat Load	Static	Dynamic
2 K	5.8 W	32.0 W
4.5 K	30.4 W	2.1 W
38/55 K	168.1 W	33.4 W

S. Miller: THIOA04

M. Leitner, SRF 2013, Slide 15

Cavity Production

- Production cavities are procured using a phased approach
  - 2 development cavities, undressed (no helium vessel) ⬅ CONFIRM FINAL DESIGN
  - 10 dressed pre-production cavities (with helium vessel) ⬅ CONFIRM PRODUCTION
  - Production cavities
- Production Cavities Fabrication Status:
  - First development cavities have been successfully fabricated and delivered
    - » β=0.53 Roark Welding & Engineering Co., Inc. (received and certified)
    - » β=0.29 Roark Welding & Engineering Co., Inc. (received)
    - » β=0.085 Pavac Industries, Inc. (delivery early 2014)
  - β=0.53 FRIB production contract placed for 144 cavities.
  - Rest of cavity production contracts will be placed by end of this year.

- FRIB project procured $13.2M of niobium material

Roadmap of ADS Project in China

Stage 1: Research facility

(~10 MWt, ~2023)

key technology R&D

Stage 2: Exp. facility

(~100 MW$_t$, ~2030)

Stage 3: Demo facility

(~1000 MW$_t$, ~2040)

"strategic Priority Research Program" of the Chinese Academy of Sciences

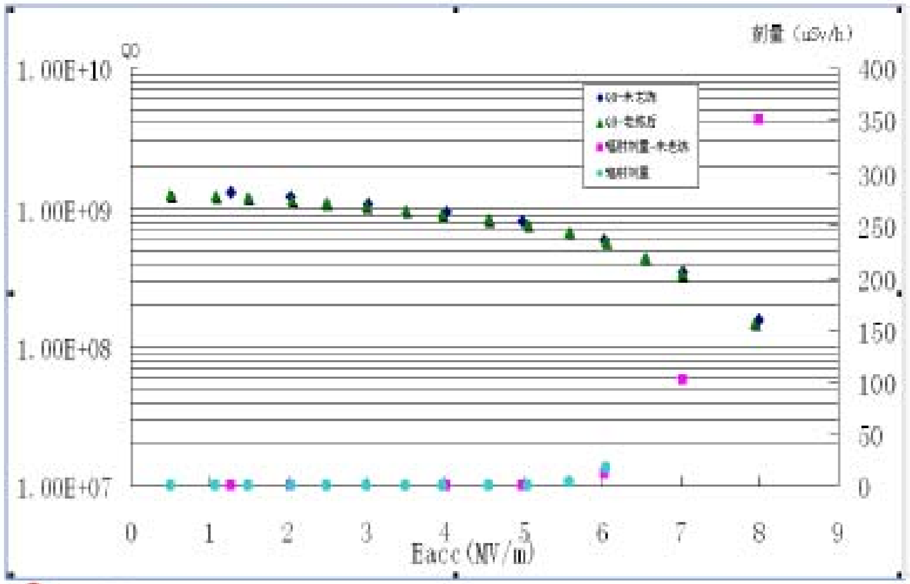
ADS China

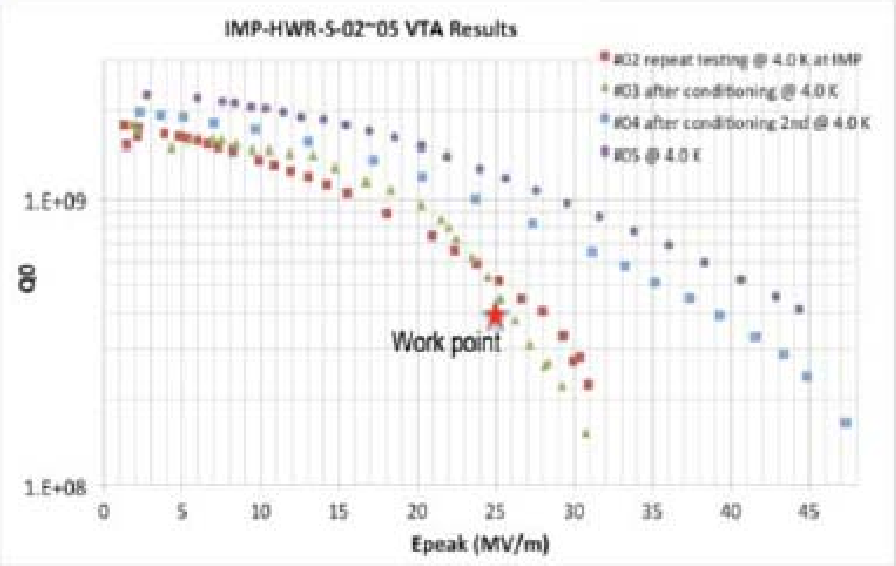
	Spoke 012	HWR 010	HWR 015	Spoke 021	Spoke 040	Ellip 063	Ellip 082	Unit
Freq.	325	162.5	162.5	325	325	650	650	MHz
βg	0.12	0.09	0.14	0.21	0.40	0.63	0.82	-
Aperture	35	40	40	50	50	100	100	mm
Uacc	0.82	0.78	1.82	1.64	2.86	10.26	15.63	MV
Epeak	32.5	25	32	24/31	25/32	29/38	28/36	MV/m
Bpeak	46	50	40	50/65	50/65	50/65	50/65	mT
Temp.	4.5	4.5	4.5	4.5	2	2	2	K
Ploss	10 (70nΩ)	10 (70nΩ)	15.5 (70nΩ)	16.8 (70nΩ)	6.5	21	39	W
Number	12	6	6	28	72	28	85	-

Operation At 4.5K injectors and possible 2K for rest
Bpk – 65mT

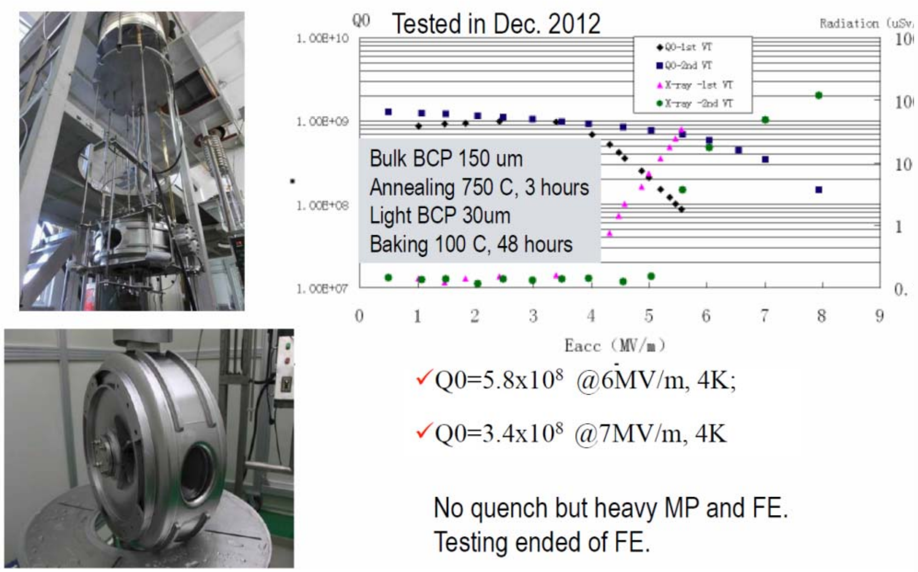
Prototyping on-going

Courtesy of IHEP

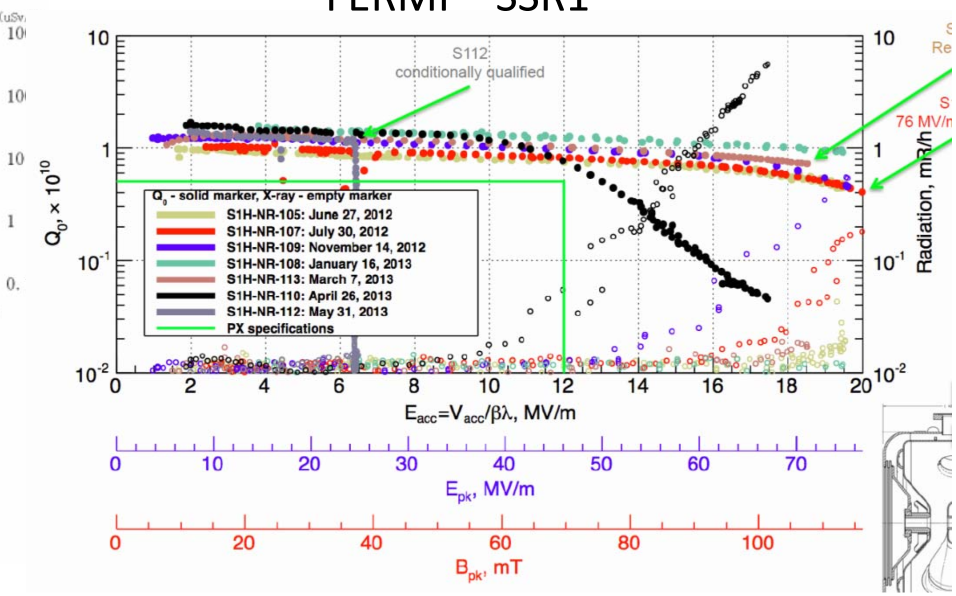


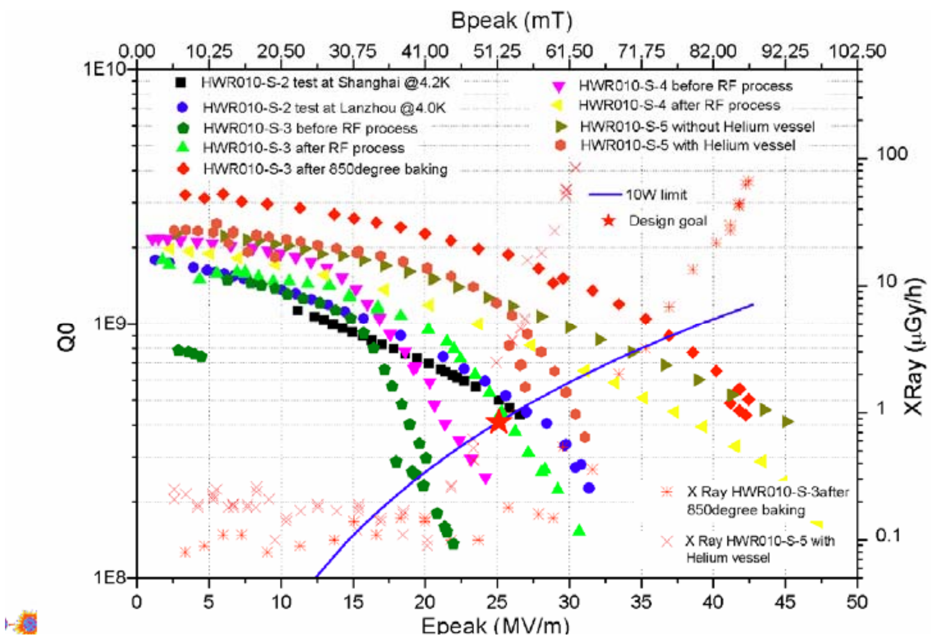


Performance Comparison

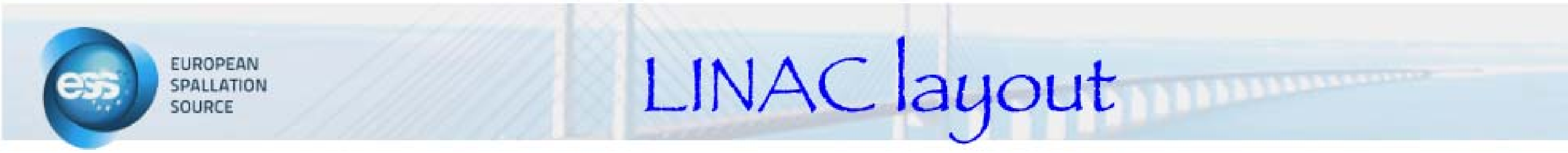


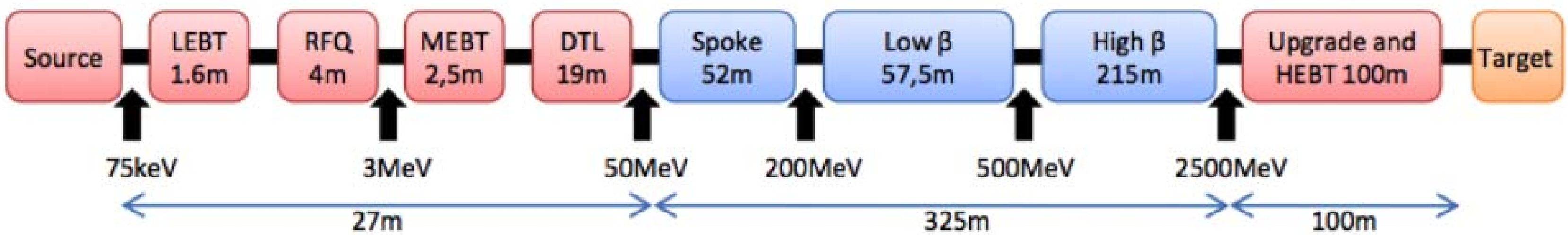
FERMI – SSR1





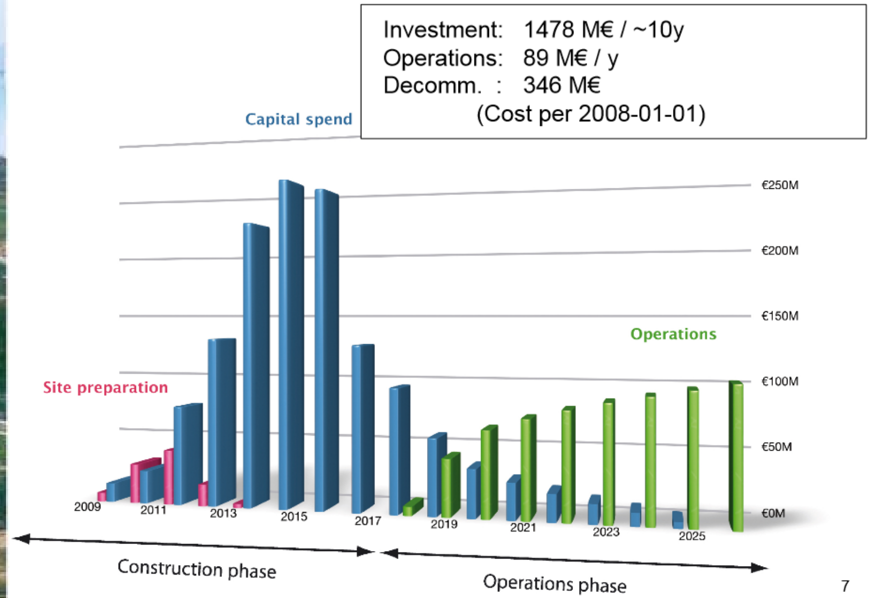
ESS





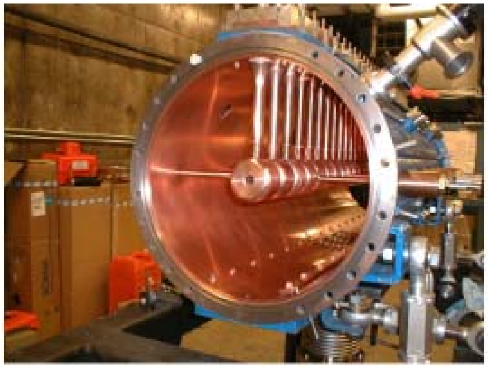
	Length (m)	Input Energy (MeV)	Frequency (MHz)	Geometric β	# of Sections	Temp (K)
RFQ	4	75×10^{-3}	352.2	--	1	≈ 300
DTL	19	3	352.2	--	3	≈ 300
Spoke	52	50	352.2	0.45	14 (3c)	≈ 2
Low Beta	57.5	200	704.4	0.63	10 (4c)	≈ 2
High Beta	215	500	704.4	0.75	19 (8c)	≈ 2
HEBT	100	2500	--	--	--	--

Lund, Sweden


Investment: 1478 M€ / ~10y
Operations: 89 M€ / y
Decomm. : 346 M€
(Cost per 2008-01-01)
Capital spend
Site preparation
Operations
€250M
€200M
€150M
€100M
€50M
€0M
2009
2011
2013
2015
2017
2019
2021
2023
2025
Construction phase
Operations phase

Linac R&D in progress

IPHI RFQ at CEA-Saclay



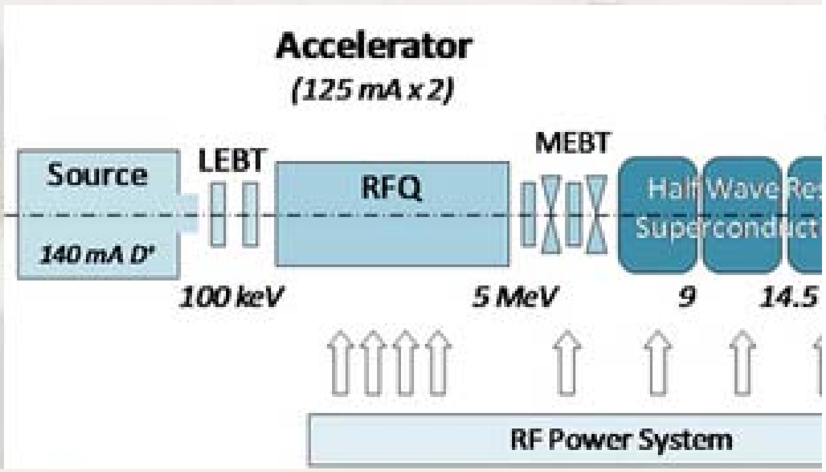
http://www.jpaw.com

SC triple spoke cavity, ANL

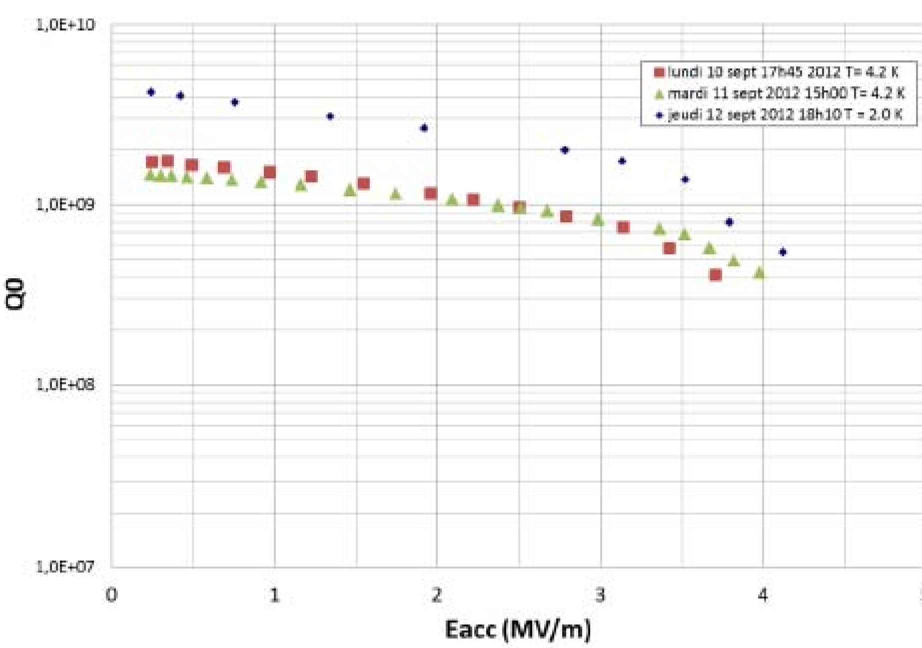
SC 5 cell cavity for 704 MHz, CEA and CNRS

IFMIF/EVEDA

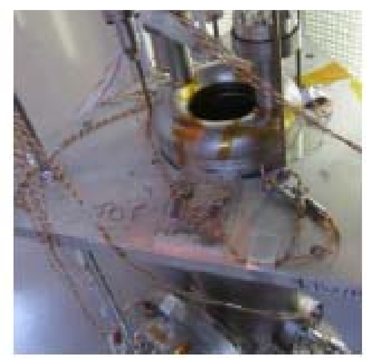
Two parallel 125 mA Deuteron beams at 40 MeV will coll
that within a few years will reach the expected displ
commercial nuclear fusion reactor.



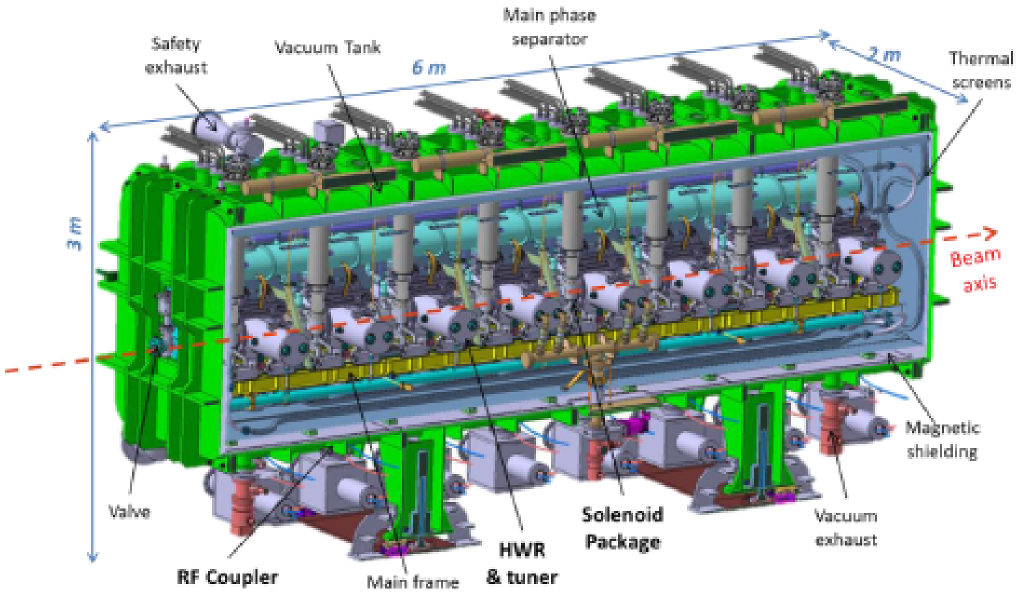
Primary Parameters	LIPAc	Units
Number of Linacs	1	
Duty factor	CW	
Ion type	D^+	
Beam intensity on target	125	mA
Beam kinetic energy on target	9	MeV
Beam Power on target	1.125	MW
RF Frequency	175	MHz
Target material	Cu*	
Total length	34.00	m
Injector length	5.05	m
RFQ length	9.81	m
MEBT (MS) length	2.35	m
SRF Linac length	4.64	m
Number of cryomodules	1	
HEBT total length	9.65	m



- Q_0 recovered
- Quench occurring on one HPR port



THE LIPAC CRYOMODULE

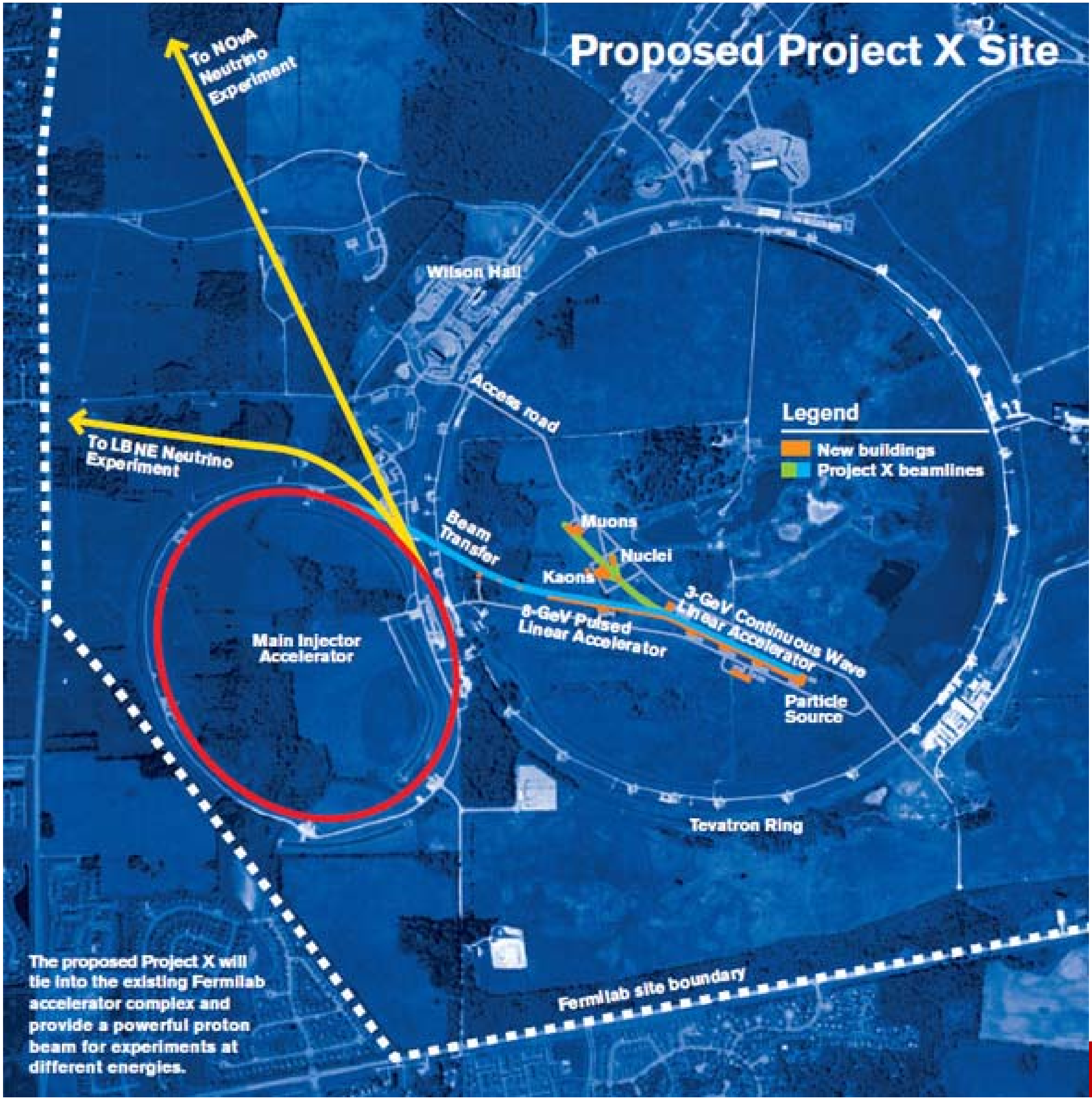


- 8 Half Wave Resonators (operating temperature 4.4 K)
- 8 RF Power Couplers
  - CW operation (70 kW max)
  - Vertical position
  - One room temperature window

See H. Jenhani, THP056

- 8 Superconducting Solenoid Packages
  - Focusing solenoid with shielding
  - H & V steerers
  - Cold BPM
- Cryostat

Target Values of complete Cryomodule	
Frequency	175 MHz
β value of the HWR	0.094
Accelerating field E_a	4.5 MV/m
Unloaded Quality factor Q_0 for R_s=20 nΩ at nominal field	1.4×10^9
Beam aperture HWR/SP	40 / 50 mm
Freq. range of HWR tuning syst	± 50 kHz
Freq. Resolution of tuners	200 Hz
Max. transmitted RF power by coupler in CW (for LIPAc)	70 kW
Max. reflected RF power in CW	20 kW
External quality factor Q_{ex}	6.3×10^4
Magnetic field B_z on axis max.	6 T
∫ B.dl on axis	1 T.m
Field at cavity flange	≤ 20 mT
CBPM position meas. Accuracy	0.25 mm
CBPM phase meas. accuracy	2 deg
Total Static/Dynamic Heat losses	18 / 120 W


Proposed Project X Site
To NOvA Neutrino Experiment
To LBNE Neutrino Experiment
Wilson Hall
Access road
Legend
New buildings
Project X beamlines
Beam Transfer
Muons
Nuclei
Kaons
3-GeV Continuous Wave Linear Accelerator
8-GeV Pulsed Linear Accelerator
Main Injector Accelerator
Particle Source
Tevatron Ring
Fermilab site boundary
The proposed Project X will tie into the existing Fermilab accelerator complex and provide a powerful proton beam for experiments at different energies.

Cavities Project -X

Project X Meeting 8/16/2011

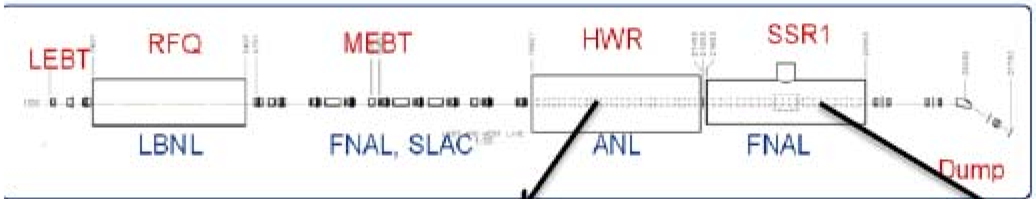
Cavity Types & Quantities

*Source: Vyacheslav Yakovlev

Section	Energy MeV	E_{acc} MV/m	B_{max} mT	Q @ 2K x10^9	Installed cavities	Processed Cavities
SSR0 (β_G=0.11)	2.5-11	9.0	66	6.5	18	22
SSR1 (β_G=0.22)	11-41	11.0	65	11	20	24
SSR2 (β_G=0.42)	41-179	10.0	69	13	44	53
650 MHz (β_G=0.61)	179 - 559	16.5	70	15	42	51
650 MHz (β_G=0.9)	559 - 3000	16.8	63	20	152	183
1300 MHz (β_G=1)	3000-8000	25	107	10	224	270

The PXIE demonstrator

- Front-end demonstrator PXIE is under construction (25 MeV, 1mA)
  - ✓ Goal = validate Project X concept & eliminate technical risks (compact lattice layout)
  - ✓ Beam operation planned between 2016 & 2018
  - ✓ Cavities under fabrication

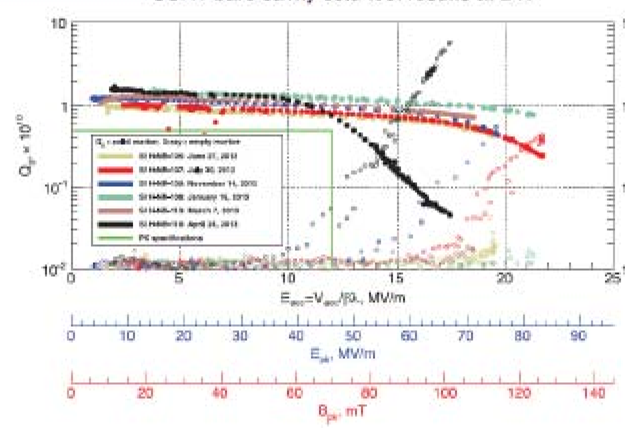


See P. Ostroumov MOP066

Cavity Type	HWR
Frequency	162.5 MHz
Optimal β	0.112
Effective Length	20.7 cm
Aperture	33 mm
E_{peak}/E_{acc}	4.7
B_{peak}/E_{acc}	5.0 mT/(MV/m)
G	48 Ω
R_{sh}/Q	272 Ω

See A.I. Sukhanov MOP014

SSR1 bare cavity cold test results at 2 K

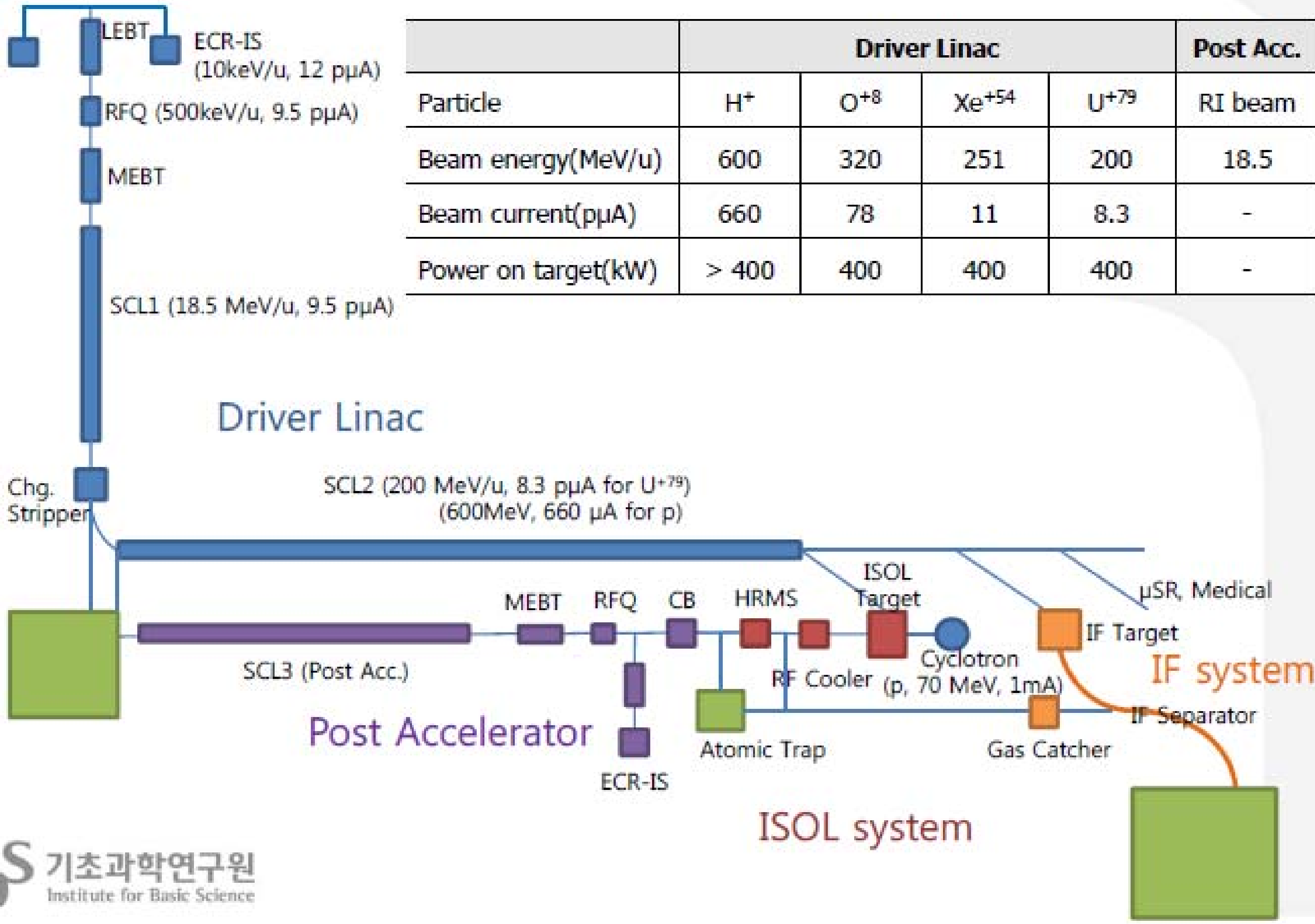


RAON - Korea

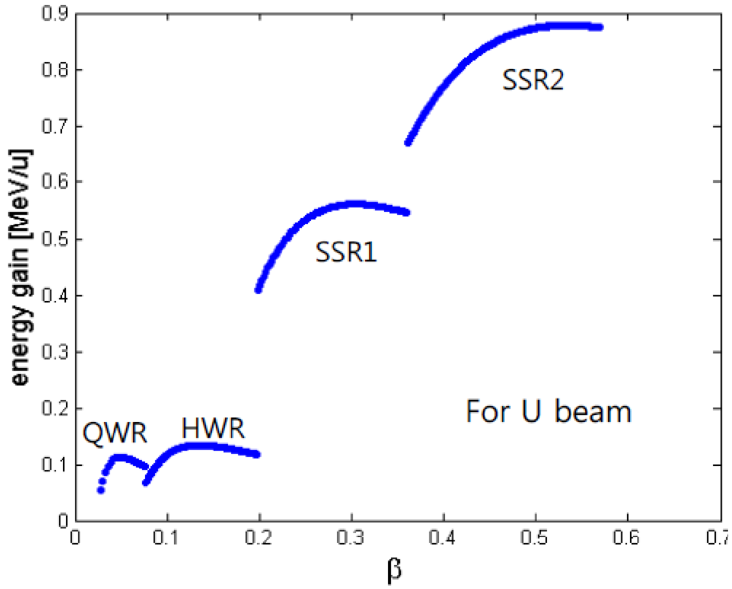
Seoul
Daejeon
Fushun
Shenyang
Tong Hua
Anshan
Dalian
Pyongyang
Qingdao
Vladivostok
Incheon
Daegu
Kwangju
Busan
대한민국
동해
서해
북한

Beam Parameters of RAON

	Driver Linac				Post Acc.	Cyclotron
Particle	H^{+}	O^{+8}	Xe^{+54}	U^{+79}	RI beam	proton
Beam energy(MeV/u)	600	320	251	200	18.5	70
Beam current(pμA)	660	78	11	8.3	-	1000
Power on target(kW)	> 400	400	400	400	-	70



SRF Cavities



RISP: 0.047, 0.120, 0.30, 0.51

Superconducting cavity

RAON

Parameters	Unit	QWR	HWR	SSR1	SSR2
β_g	-	0.047	0.12	0.30	0.51
F	MHz	81.25	162.5	325	325
Aperture	mm	40	40	50	50
QR_s	Ohm	21	42	94	112
R/Q	Ohm	468	310	246	296
V_{acc}	MV	1.05	1.52	2.22	4.20
E_{peak}/E_{acc}		5.6	5.0	4.4	3.9
B_{peak}/E_{acc}		9.3	8.2	6.3	7.2
$Q_{calc}/10^9$	-	2.1	4.1	9.2	10.5
Temp.	K	2	2	2	2

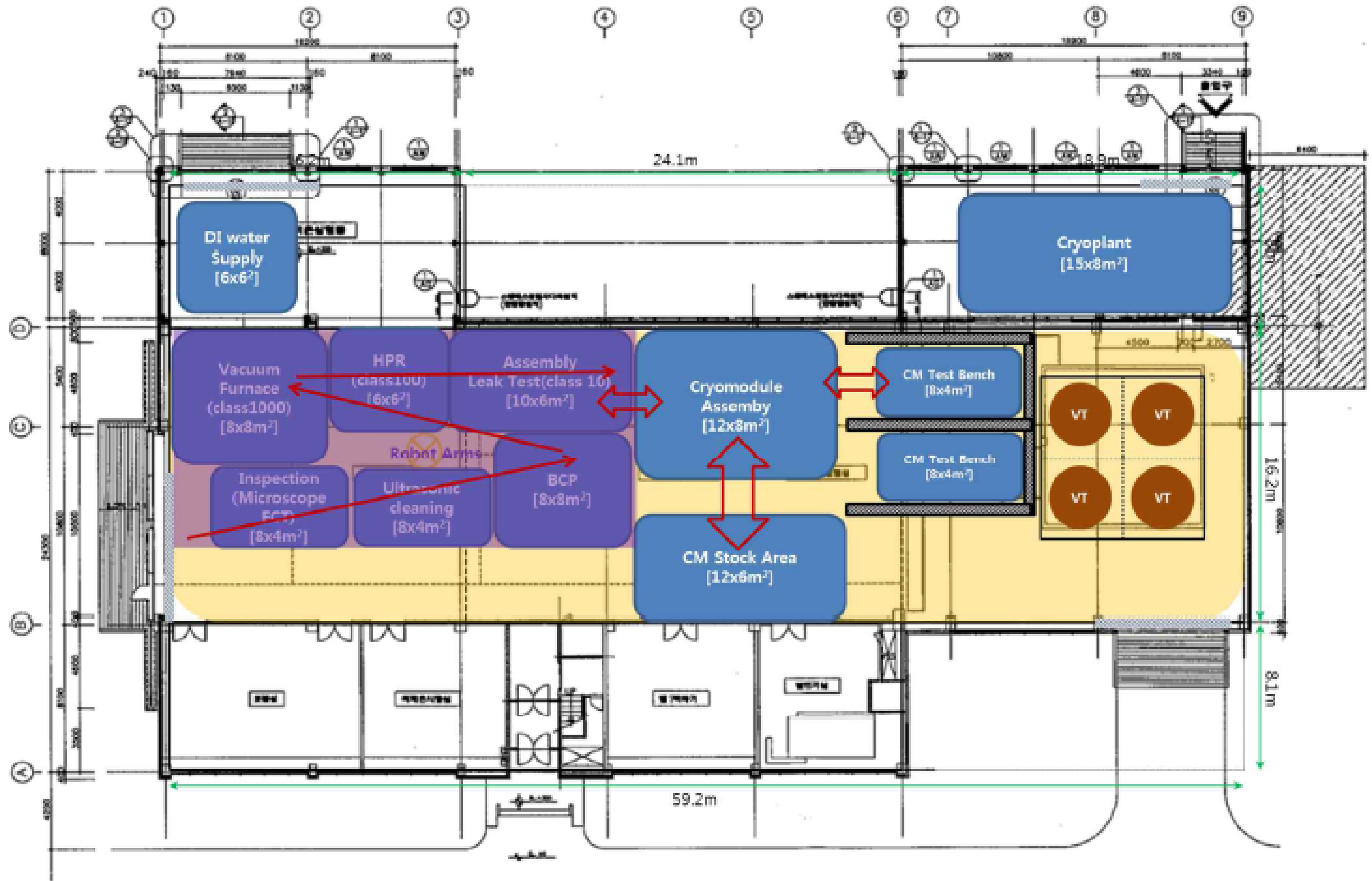
(Ep = 35MV/m)

ibS 기초과학연구원 Institute for Basic Science

16

RISP

SRF Test Facility Layout



Process Line   Moving line by trail/crane   Cleanroom   Total Area: 59.2 x 16.2m² ~ 960m²

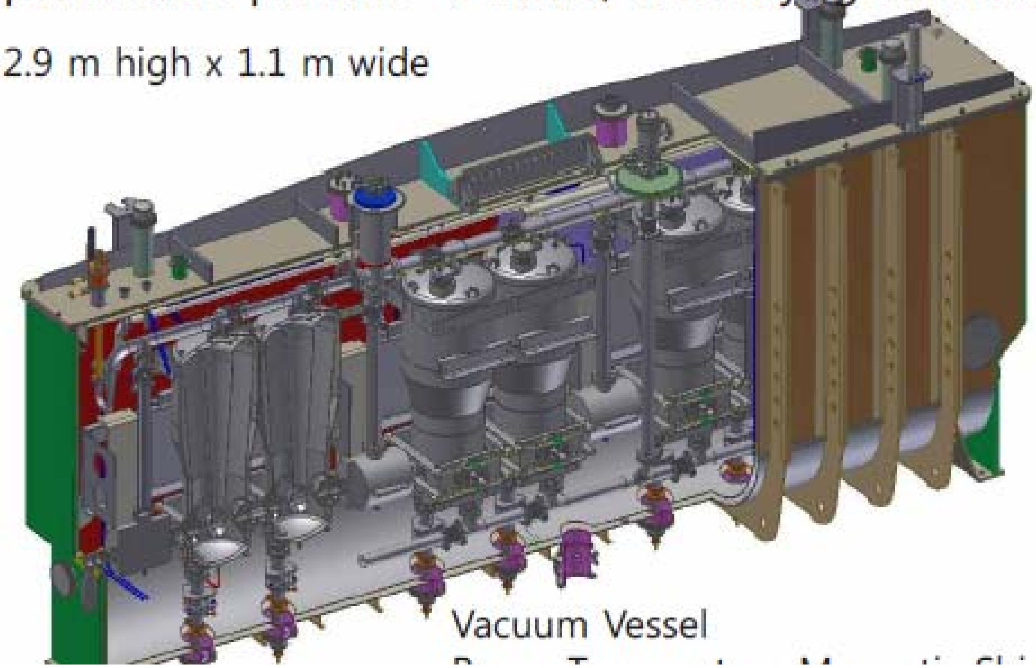
Atlas Upgrade, ANL

ANL ATLAS Intensity Upgrade Cryomodule

Courtesy of ANL

- Seven β = 0.077, 72.75 MHz quarter-wave cavities
- Four 9-Tesla superconducting solenoids
- Replaces 3 old cryomodules with split-ring cavities
- Total design voltage is 17.5 MV, expected 4.5K cryogenic load is 70 W
- Will be operated to provide ~20 MV, 4.5K cryogenic load is 85 W

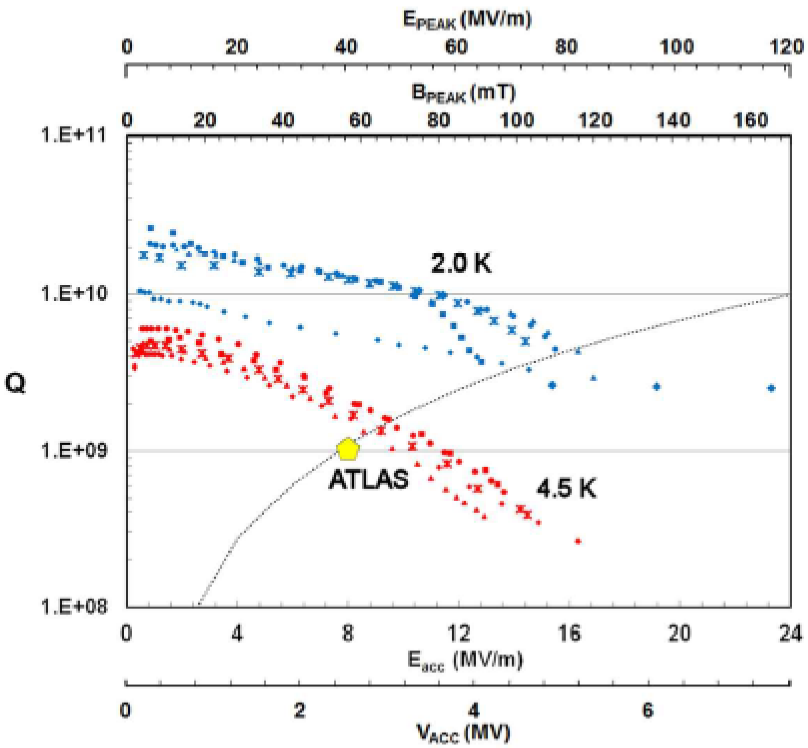
5.2 m long x 2.9 m high x 1.1 m wide



Cavity Results

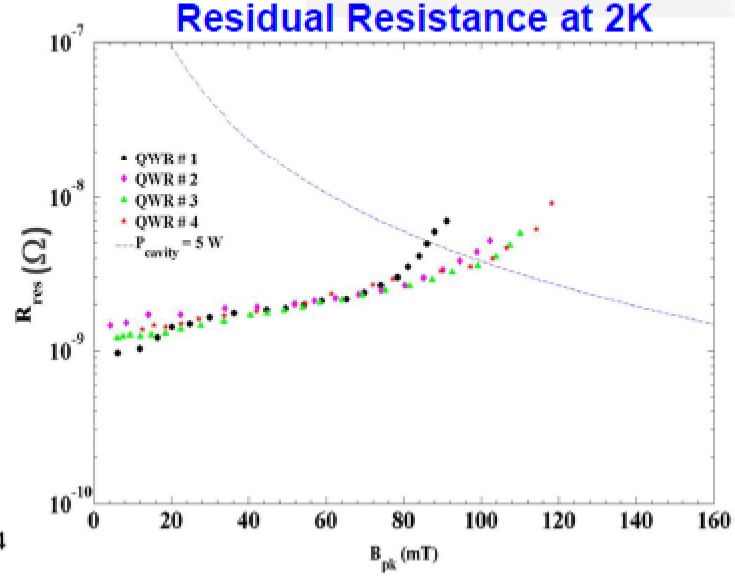
5 QWRs were tested in TC3

- Highly optimized EM design, conical shape, minimized ratio Bpeak/Eacc, Epeak/Eacc
- Only wire EDM is applied for machining of the Nb joints to be EB welded
- EP after all mechanical work including He vessel is completed



Courtesy of ANL

Residual Resistance at 2K

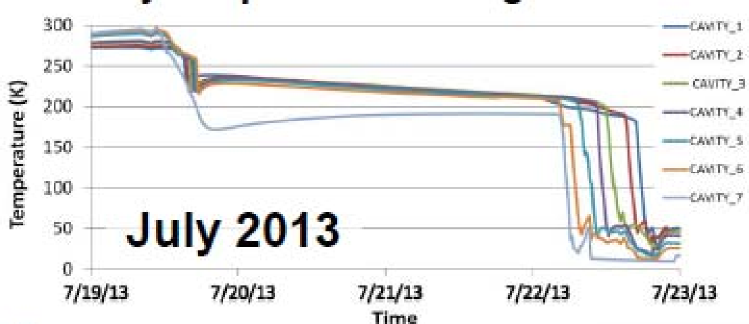


37

New Cryostat Design

Cavity String Assembly and Cooldown

Cavity temperature during 1st cool down



August 2013 (Test for 2 wks)

- All cavities $E_{ACC} \geq 10$ MV/m
- Tuners cycled through full range
- Low microphonics, +/- 2 Hz for periods of minutes up to days
- Solenoids aligned to 120 μm RMS

October 2013

- Need to place string in stand (above) and
- Replace pickup loops (too much coupling)
- Squeeze one cavity by +5 kHz

KEK - Activities

Purpose of fabrication of cavities on the KEK site

Development of a mass production technology in order to fabricate more than 16000 cavities within 3 to 5 years for ILC project

- Improvement of yield ratio = Stable quality
- Reduce the cost drastically
- Development of mass production technologies

Development on the KEK site

↓

Speed up the R&D

↓

Realization of ILC

Cooperation with STF

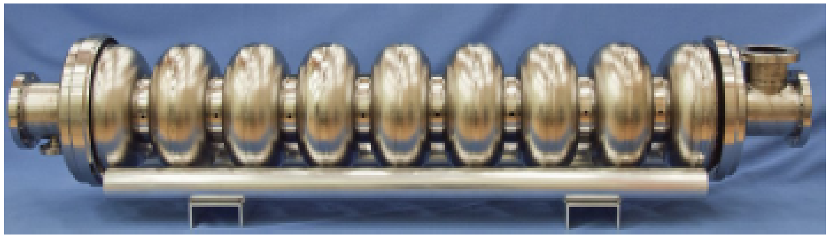
↕

Establish the Cavity Fabrication Facility

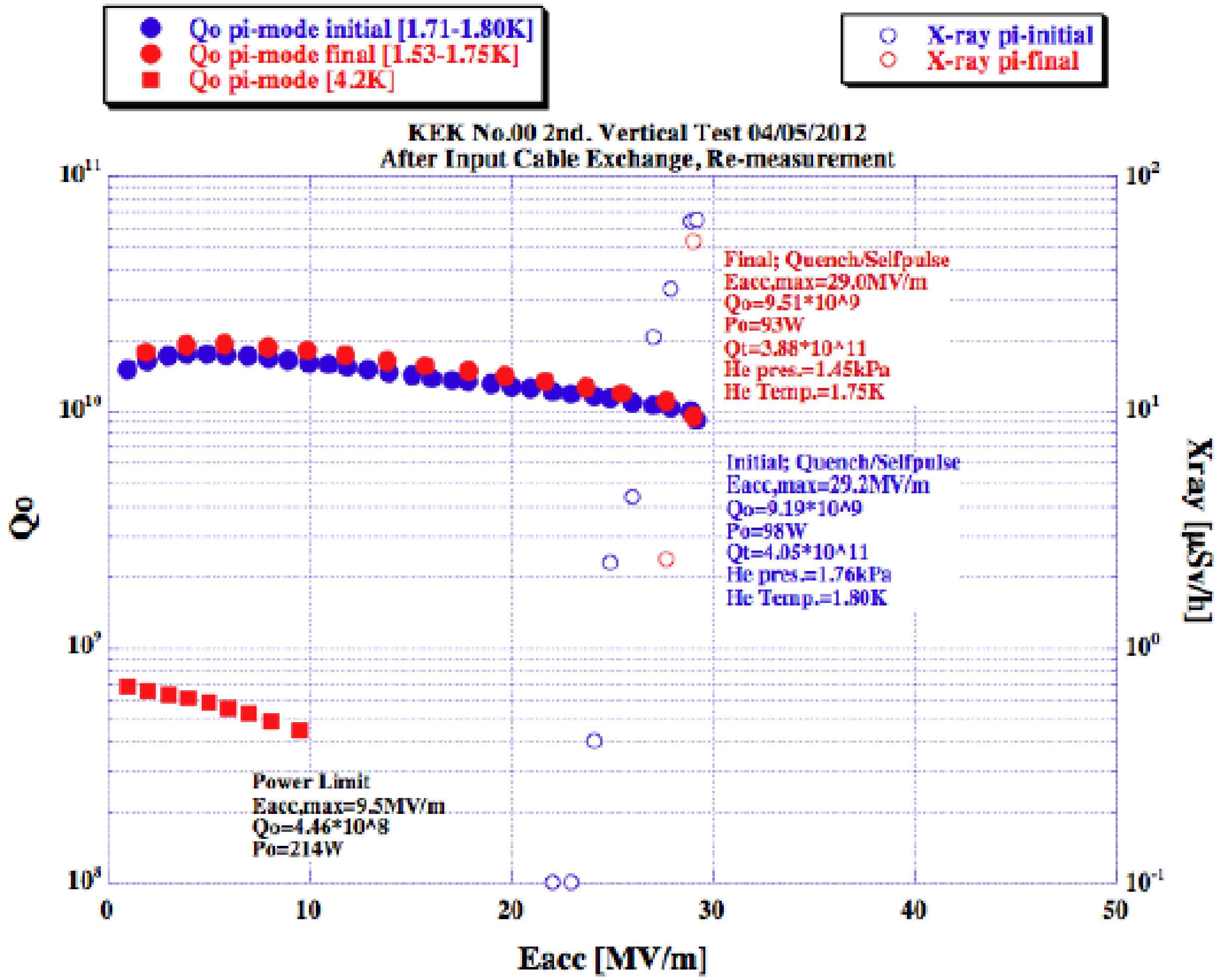
↕

Collaboration with many companies

Q-E curve of vertical test at STF



KEK-0 (First product)
Acceleration gradient attained 29 MV/m,
did not meet the ILC specification (31.5).

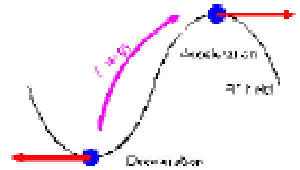


Compact ERL(cERL) at KEK

Current : 10-100mA
Emittance : 0.1-1 mm mrad
Bunch length :0.1-3ps

cERL parameters Red: initial case

Apparatus of cERL

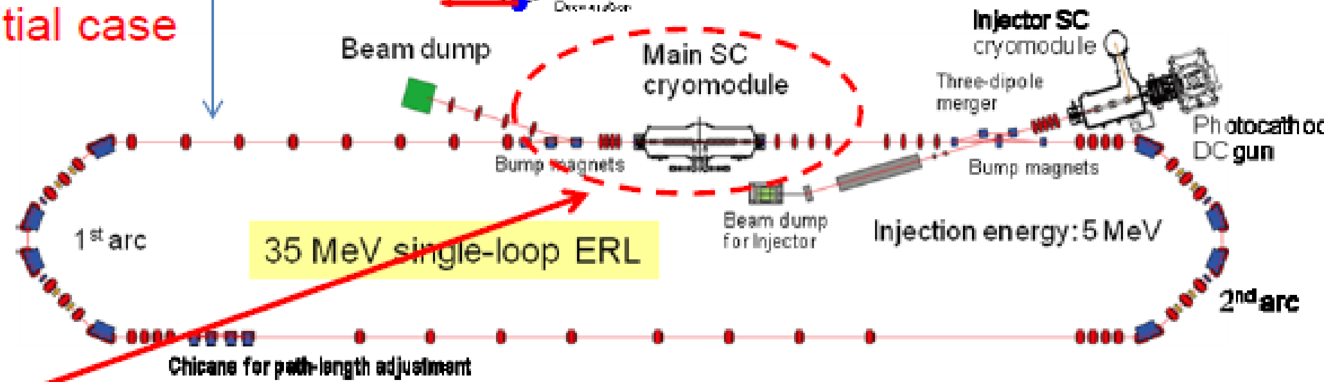


$$P_{loss} = \frac{V_c^2}{(R/Q)Q_0}$$

Ploss = 25W/m (15MV/m)

Requirements of cERL main linac

Frequency : 1.3 GHz
Gradient: 15MV/m
Q0: >1*10^10
Beam current : max 100mA
(100mA (in)+ 100mA(out))



ERL-model-2 cavity: 600mA can be circulated in design

H.Sakai et al., Proc. of ERL07 (2007). All HOMs damped to both end

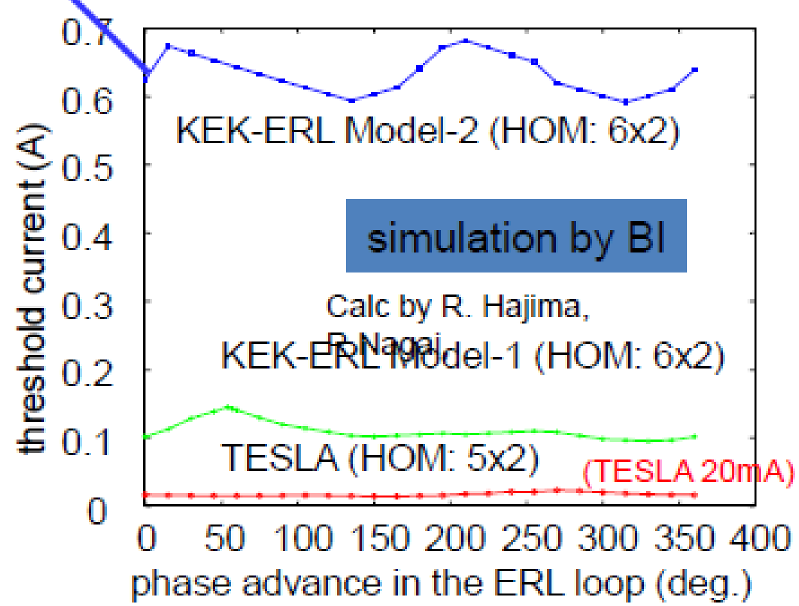
HOM-BBU calculation
(w/o HOM randamization)

Φ100 (SBP) Iris : φ80 Φ120 (LBP)

Parameters of cERL main linac

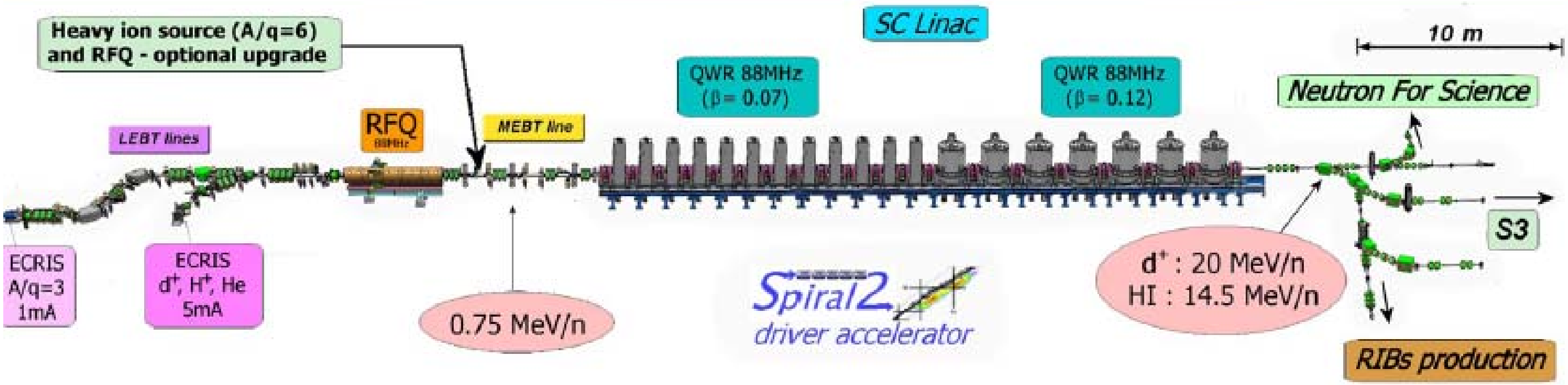
():TESLA cavity

Frequency	1300 MHz	Eacc	15-20MV/m
Q0	1e+10	Coupling	3.8 % (1.9%)
R_{sh}/Q	897 Ω (1007Ω)	$Q_o \times R_s$	289 Ω
E_p/E_{acc}	3.0 (2.0)	H_p/E_{acc}	42.5 Oe/(MV/m)



footnote

Accelerator Baseline Configuration Spiral2



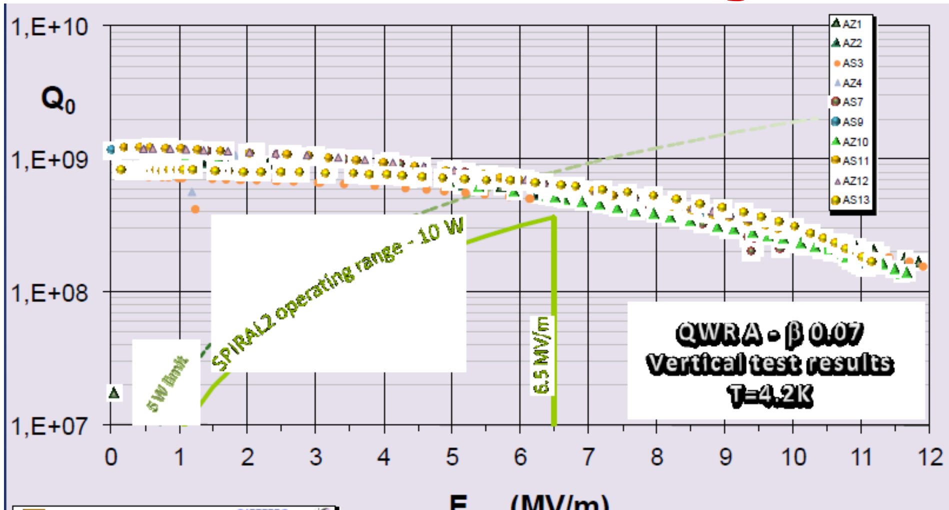
Particles	H^+	$^3He^{2+}$	D^+	Ions	
Q/A	1	2/3	1/2	1/3	1/6
I (mA) max.	5	5	5	1	1
W_O max. (MeV/A)	33	24	20	15	9
CW max. beam power (KW)	165	180	200	44	48

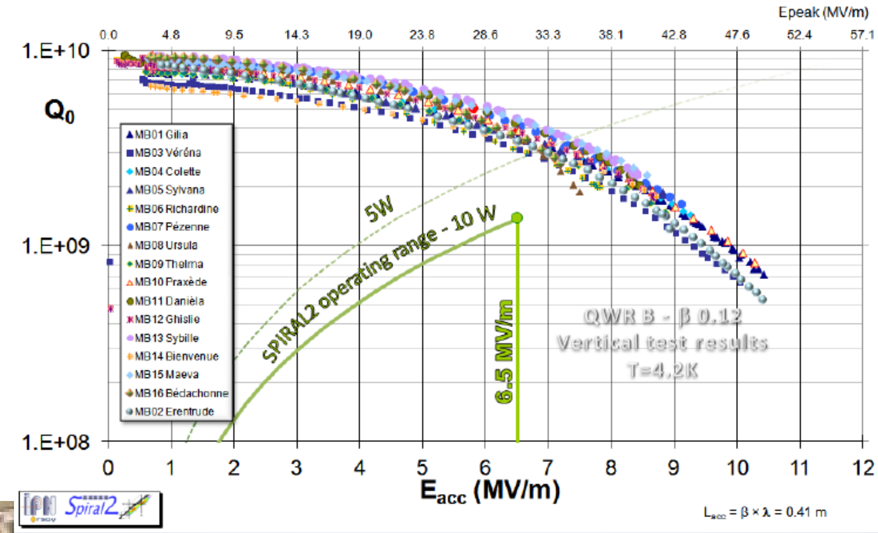
Total length: 65 m (without HE lines)

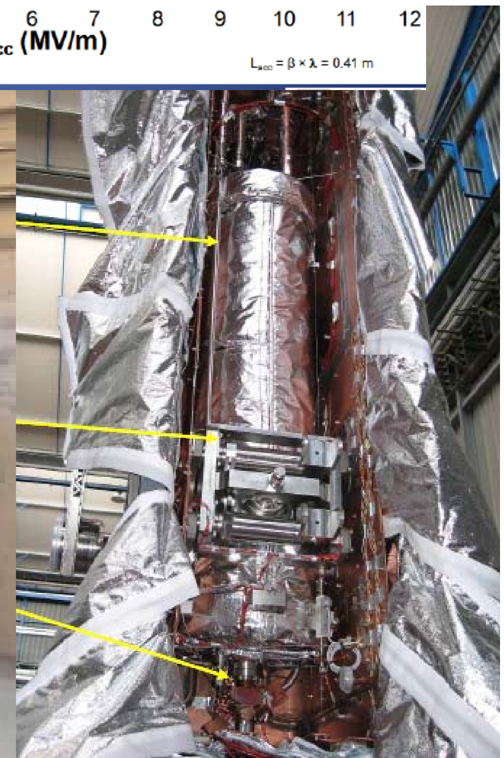
Slow (LEBT) and Fast Chopper (MEBT)
RFQ (1/1, 1/2, 1/3) & 3 re-bunchers

12 QWR beta 0.07 (12 cryomodules)
14 (+2) QWR beta 0.12 (7+1 cryomodules)
1.1 kW Helium Liquifier (4.5 K)
Room Temperature Quadrupoles
Solid State RF amplifiers (10 & 20 KW)
6.5 MV/m max $E_{acc} = V_{acc}/(\beta_{opt}\lambda)$ with $V_{acc} = \int E_z(z) e^{j\omega z/c} dz$

Cavity Performance







Report from SRF2013 Accelerator Seminar: The SRF World Today

SRF cavity processing techniques - the latest standard and the emerging

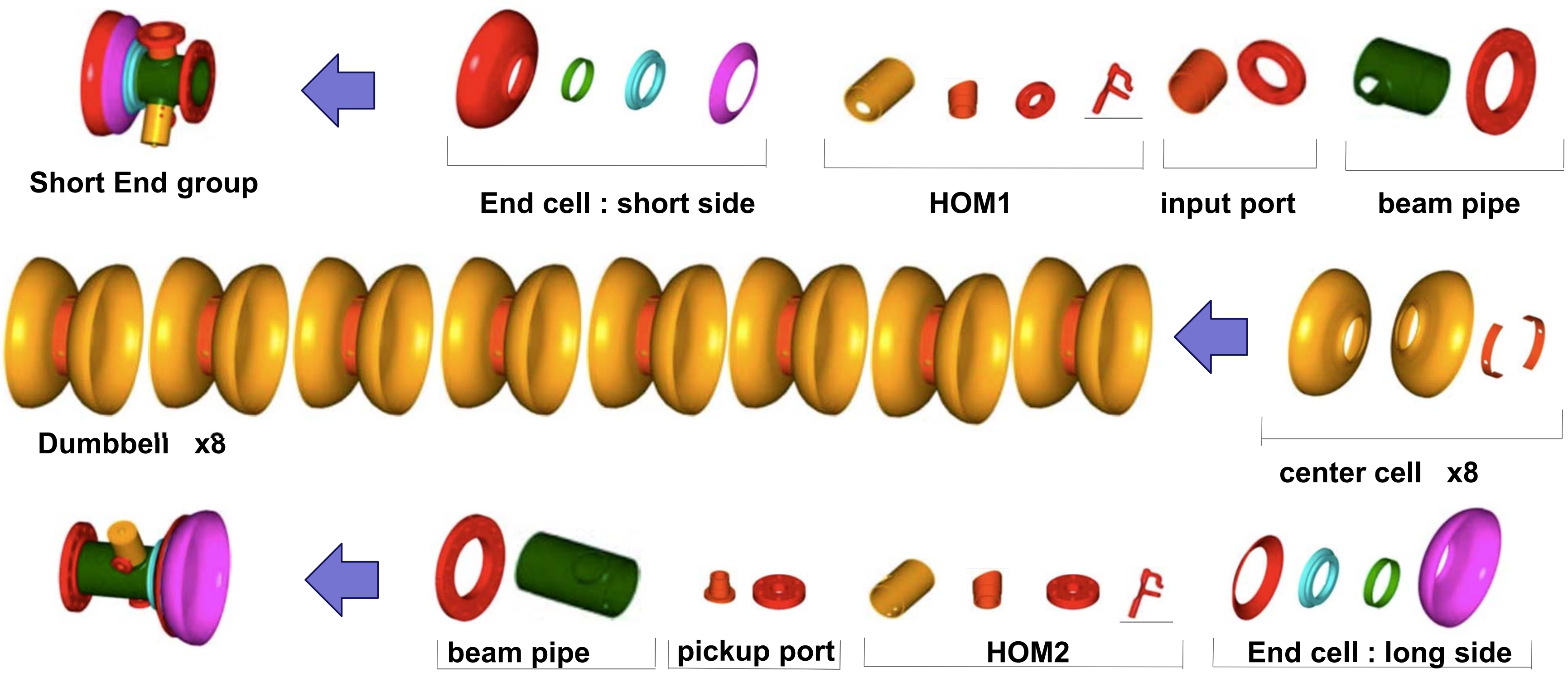
Ari D. Palczewski, SRF Scientists
Jefferson Lab, USA
10/17/2013

Highlights from SRF2013 - processing

- Review – how a cavity is made
- XFEL standard vs. C100 surface prep
- Cavity weld prep – chemistry and handling (informal discussions with industry and DESY)
- New welding – laser welding in Argon environment
- Standard horizontal Electo-polishing (EP)
- Alternative EP – Vertical EP (9 cell)
- Alternative EP - Bipolar EP (no HF)
- Alternative EP - ionic liquid EP (no HF)
- Alternative to bulk chemistry (and possible zero chemistry) – Centrifugal barrel polishing (CBP)

How Cavities Are Made

Niobium is cleaned, etched and electron beam welded



Graphic from Hitoshi Hyano

Cavity surface treatment standard (XFEL) vs. (C100)

Surface treatment after welding.

EP 110-140 µm (main EP), outside BCP, ethanol rinse, 800°C annealing 2 hrs.

Final surface treatment - two alternative options

1. **Final EP of 40 µm, ethanol rinse, high pressure water rinsing (HPR) and 120°C bake**
2. **Final BCP of 10 µm (BCP Flash), HPR and 120°C bake.**

vs.

Su

BC

Fi

Fi

No need for ethanol rinse because of low temperature (below 25C) from external water cooling) and no bulk EP – ethanol rinsing required for bulk EP at JLab to remove sulfur even at low temperatures

(New) Standard weld prep XFEL vs. JLAB

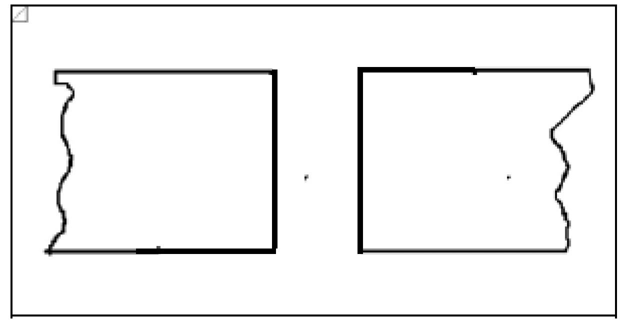
Machining prep

Iris and equator

Abandoned years ago by many labs because of weld pits from trapped particles, but has better tolerance for eccentricity and easier tooling

vs.

Iris and equator



cid etch/cleaning

HI ... 85%)
With mechanical stir plate agitation
5-20 µm
+DI water rinse to resistivity 16MΩ

•Buffered chemical polish
[BCP112]
HNO_3(65%)+HF(40%)+H_3PO_4(85%)]
Hand agitation
3-6µm
+ DI water triple rinse/ultrasonic in DI 10 min.

Weld assembly (XFEL) vs. JLab

•Dry in clean area with fully gowned personal with

Is the extra cost associated with this worth the money? Depending on DESY, Zanon or RI this is only done for high field regions welds.

machine (iso 6/7) with partially gowned personal

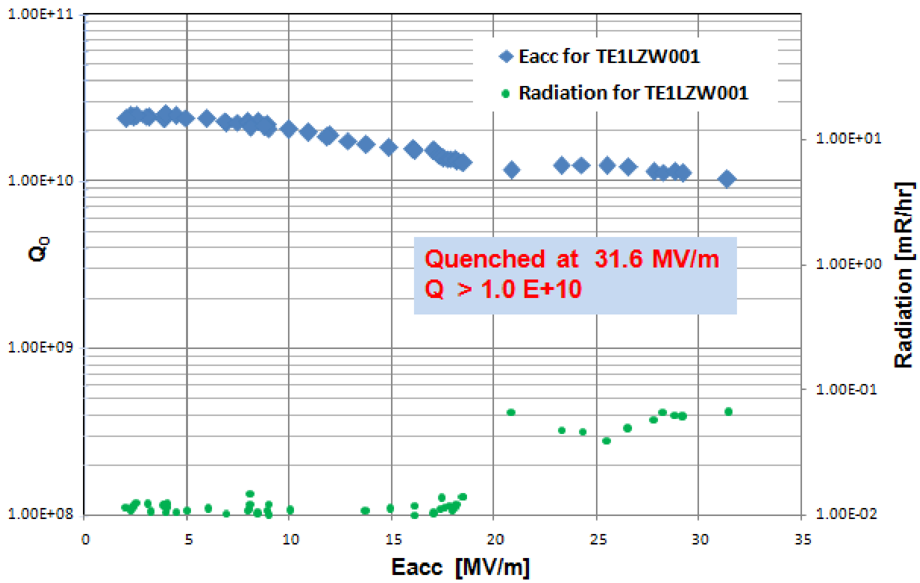
vs.

•Dry in iso 6 area with

Should JLab implement some of these standards? Should JLab consider interlocking weld prep which was abandoned years ago because of weld bubbles?

New welding (tested at FNAL) – Laser welding

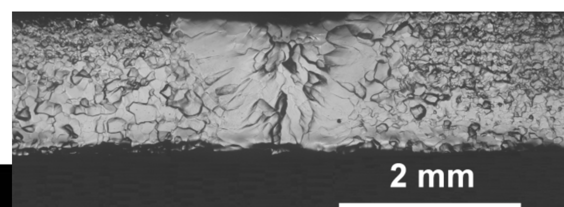
500W (avg.) Nd:YAG laser



Prashant Khare - RRCAT in India

31MV/m Q>1e10!
On first prototype

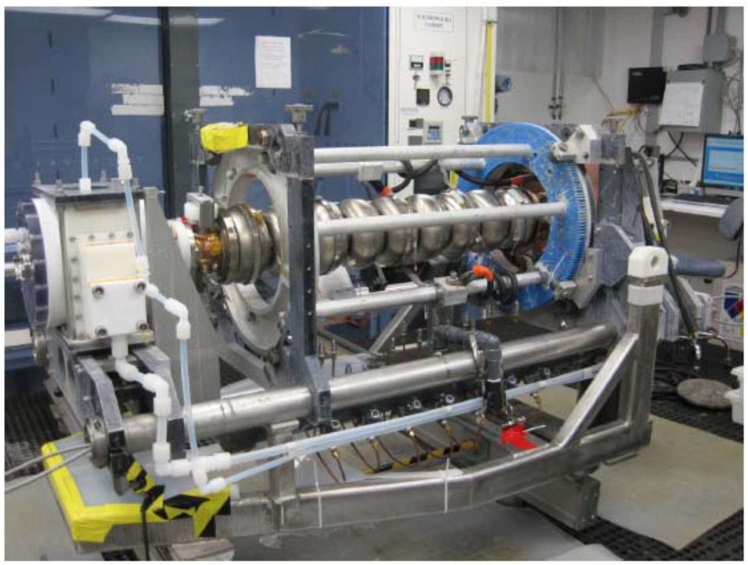
- Can be used with optical fiber to make all inside welds
- Promises – higher through-put, lower initial costs and lower operations costs, and can be done in non-vacuum environments



Electro-polish facilities

Horizontal EP

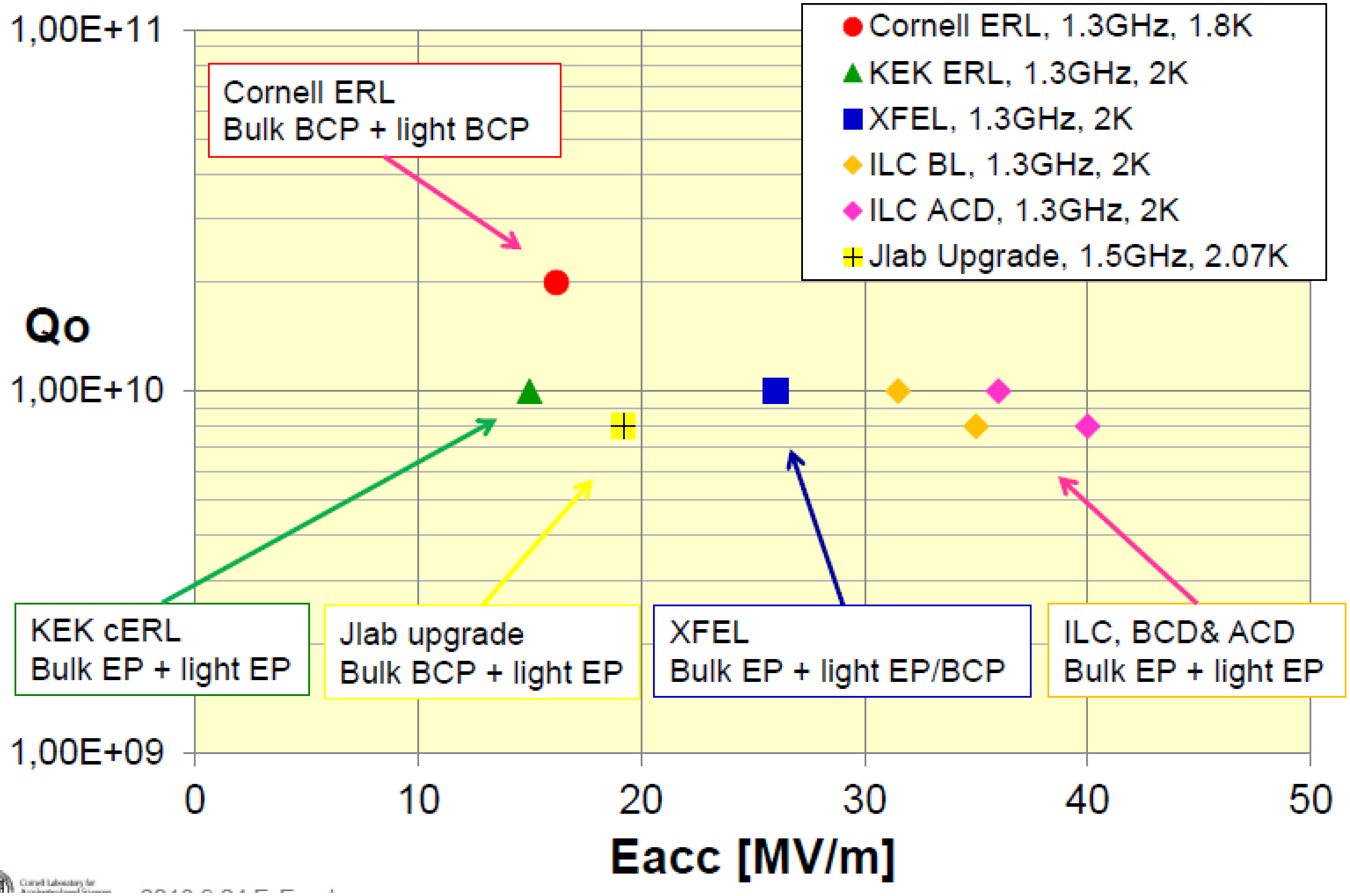
- Asia:KEK
- Euro:DESY, Zanon, RI
- USA: FNAL/ANL, JLab



Vertical EP

- Asia:KEK
- Euro:Saclay, INF
- USA: Cornell, JLab

Machine Specs that use EP (one BCP)



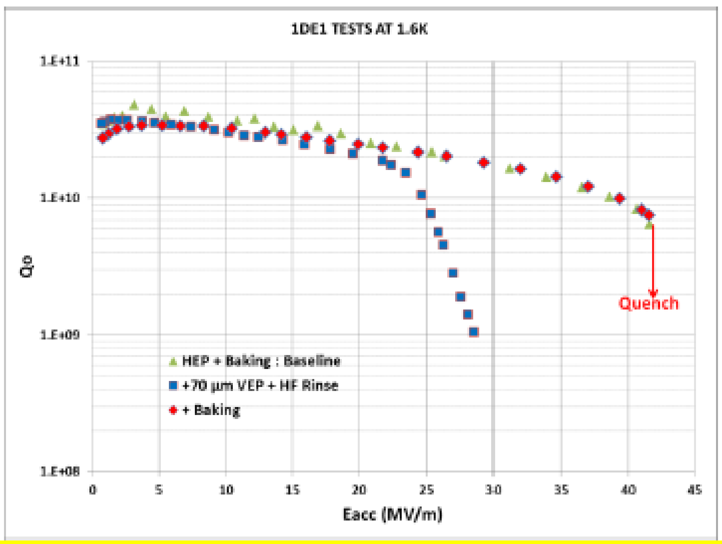
Non-standard EP – Vertical EP SACLAY (1-cell)

1DE1: Horizontal EP + 70 µm VEP

- Parameters: 6V & >24L/min
- Bright and smooth surface

- Performance before/after baking similar to HEP
- High gradient maintained after VEP

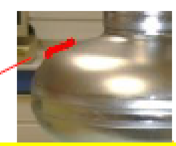
1DE1 after HEP + 70 µm VEP



Aspects to improve:

-Low removal rate at 19° C: 0.2µm/min

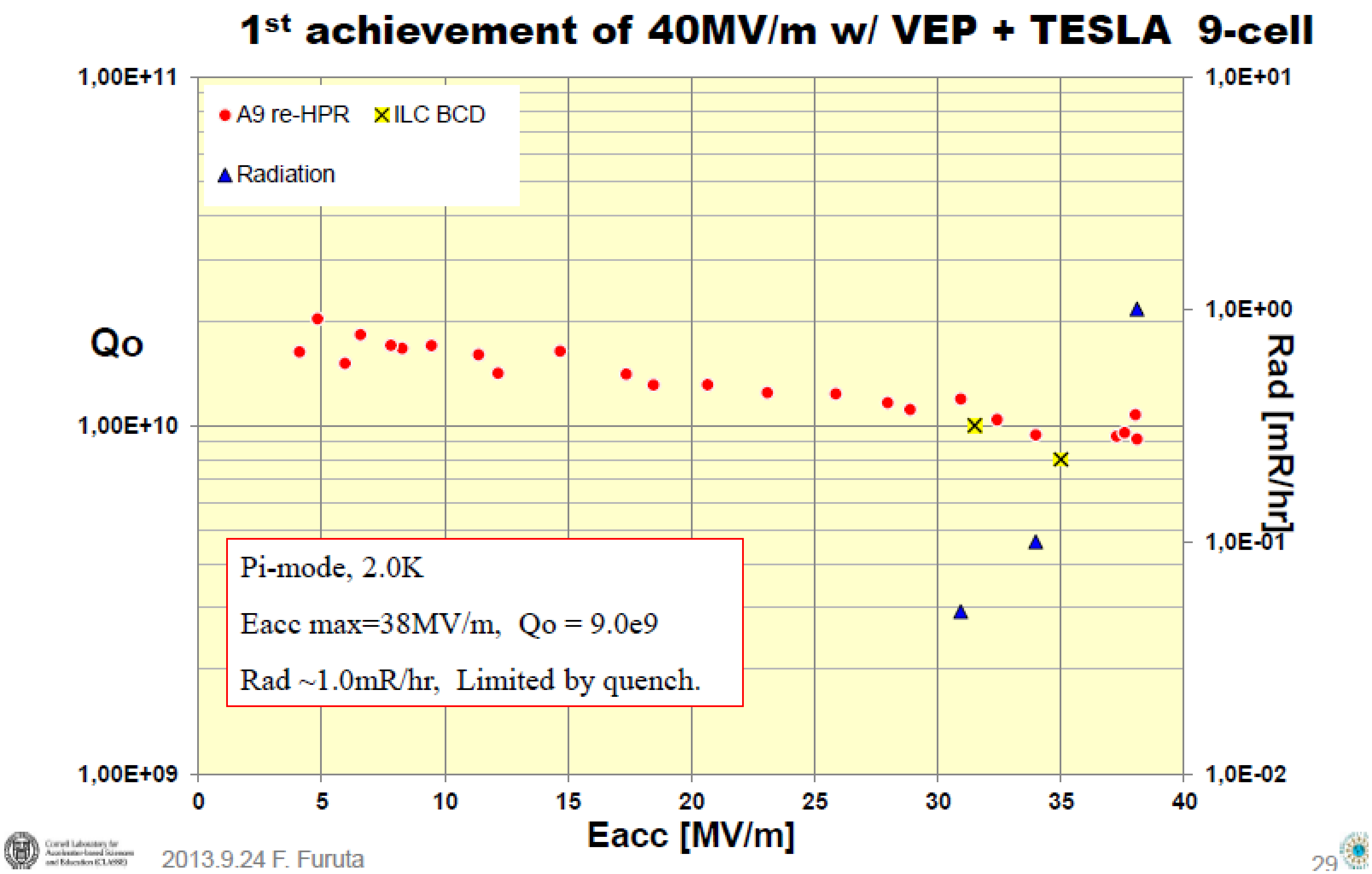
- asymmetry: removal rate higher in the upper part of the cell (x 3)



higher local

Presented by F. Eozénou, 1st LCC/ILC cavity group meeting, 2013

Non-standard EP – Vertical EP Cornell 9-cell



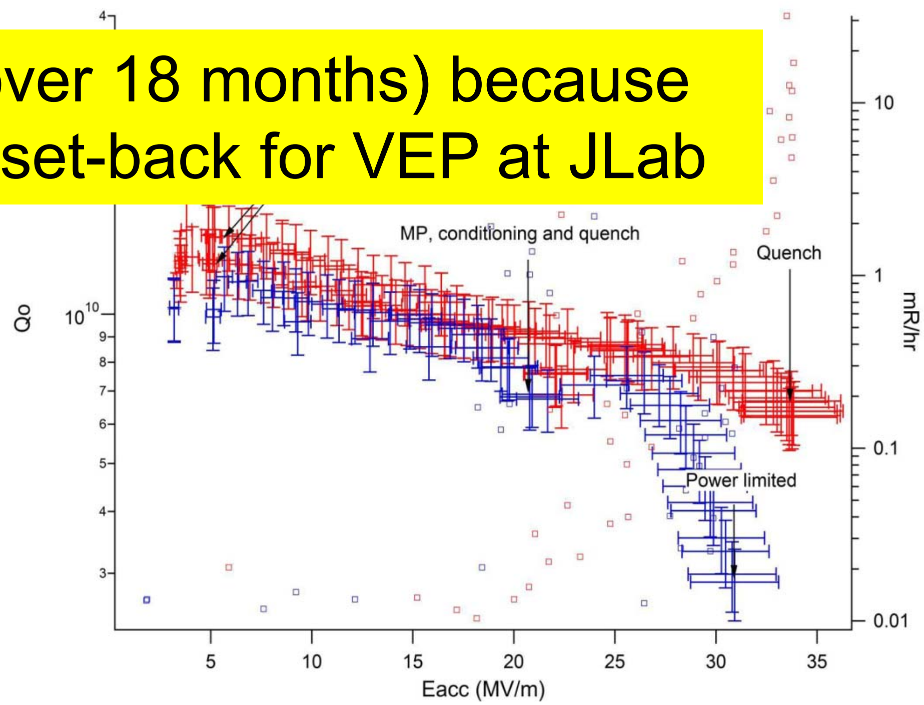
Non-standard EP – Vertical EP JLab

Development of an Integrated Cavity Processing (ICP) System: Pushing cavity processing technology

✓**Hydrophobic PTFE membrane proven to efficiently**
cathode ar
process.

Put on hold since 2012 (over 18 months) because of facilities move – major set-back for VEP at JLab

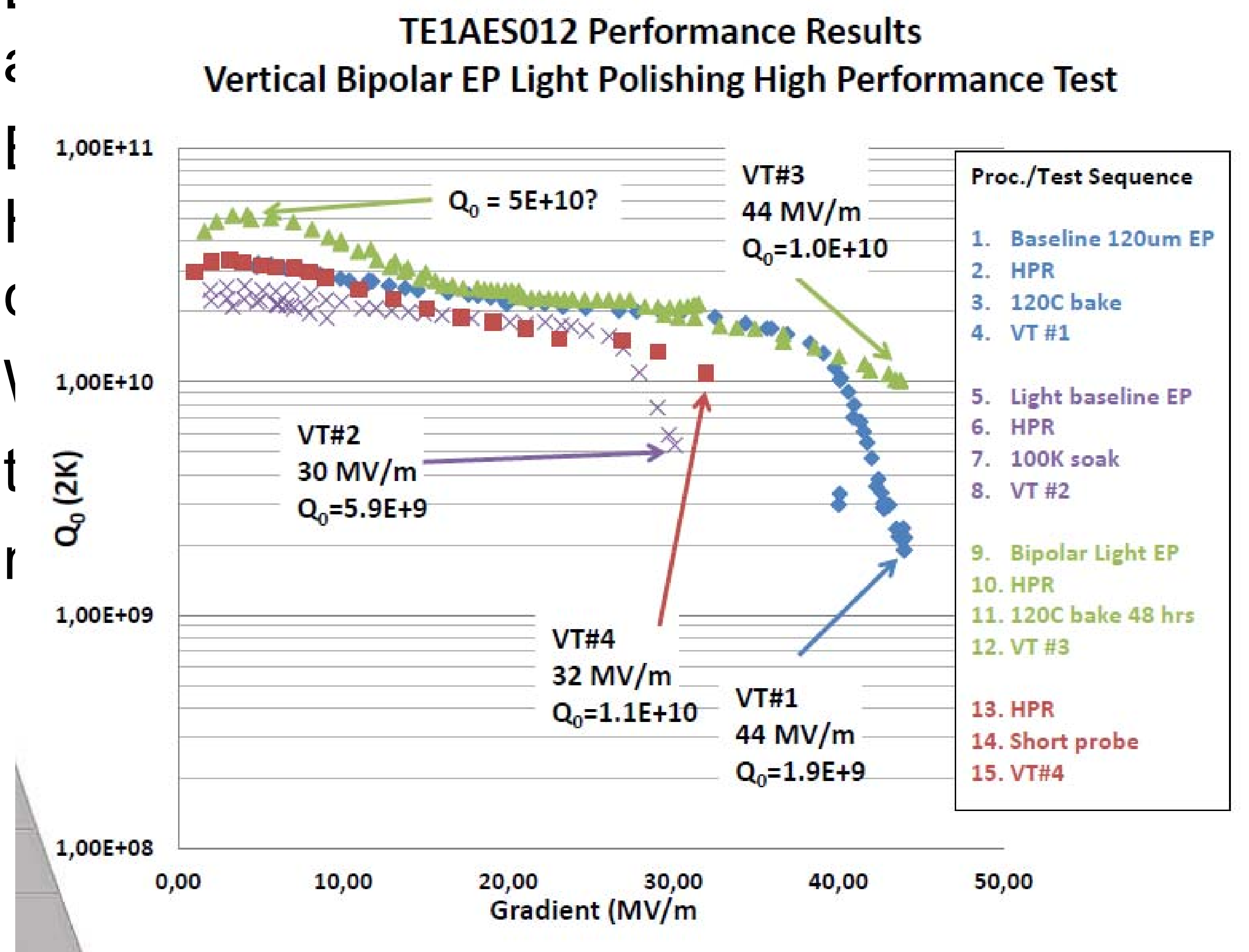
✓**Spline shaped cathode increases cathode surface area, flow inside of membrane-protected cathode transports hydrogen bubbles away.**

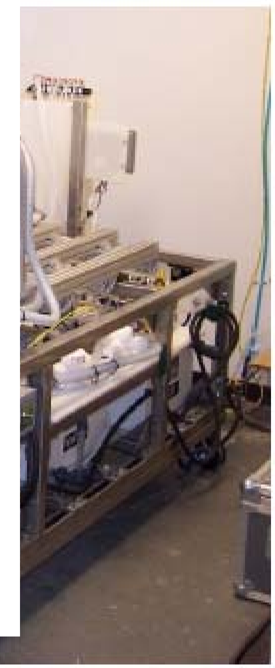


Jlab's CBP+VEP reaches 35MV/m - 2012

Non-standard EP - Bipolar EP

- HF) in
- %
-

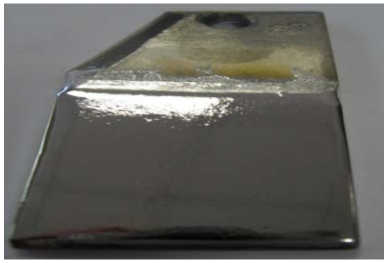




Allan Rowe - FNAL

Non-standard EP - IONIC LIQUID EP 6GHz

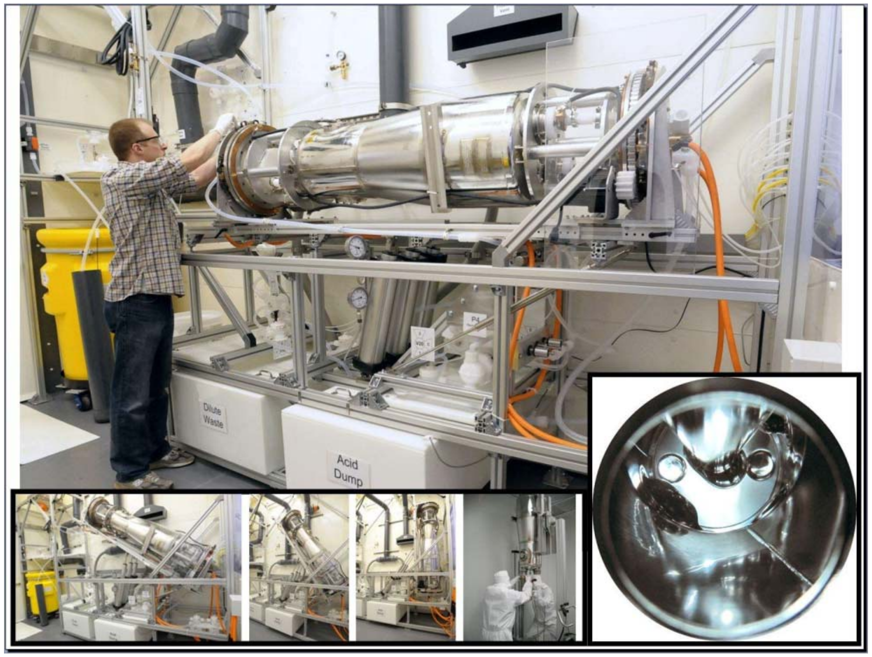
Choline Chloride:Urea (1:4) + 97 g/l Sulfamic
Temperature = >120C
Current density (A/cm2)=0.3
Niobium cathode



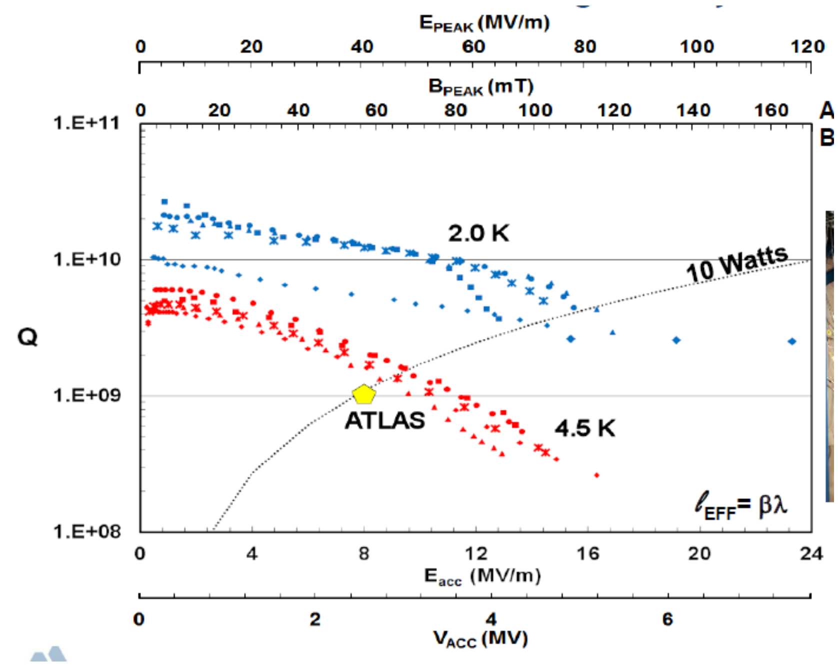
Promising but still needs a lot of work

V. Pastushenko @ INFN/LNL

Low beta cavities (spoke/quarter/half) - EP



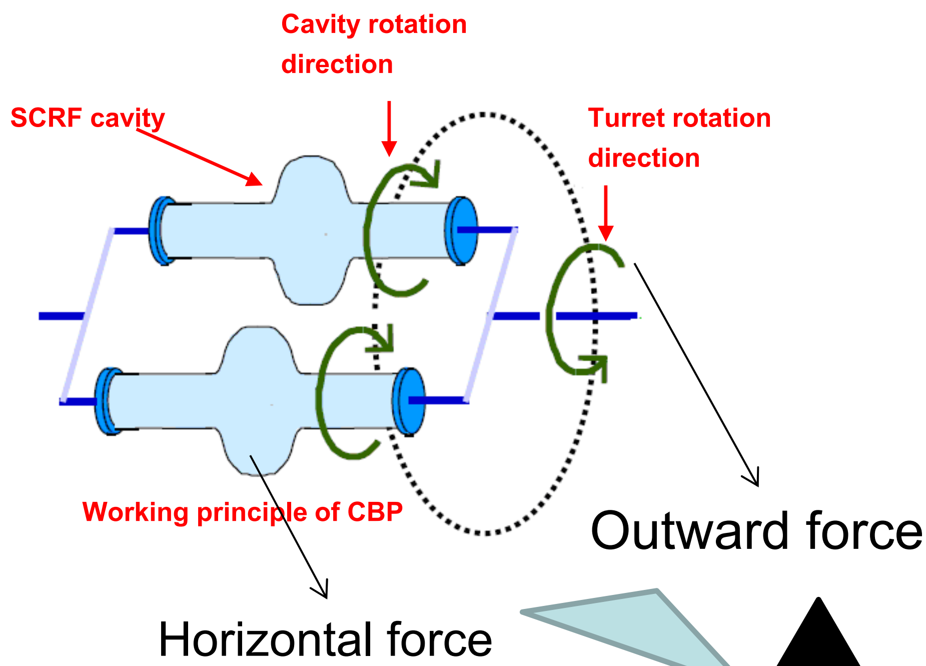
Quarter wave 72.75MHz
Quad cathode EP @ ANL

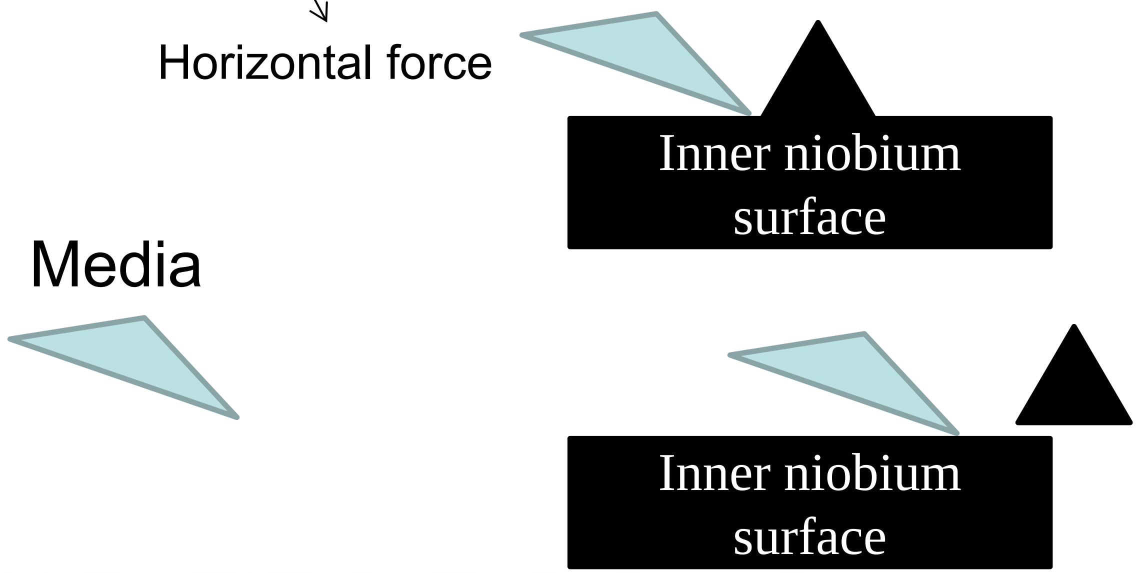


In the past most non-elliptical cavities were only chemically treated with BCP

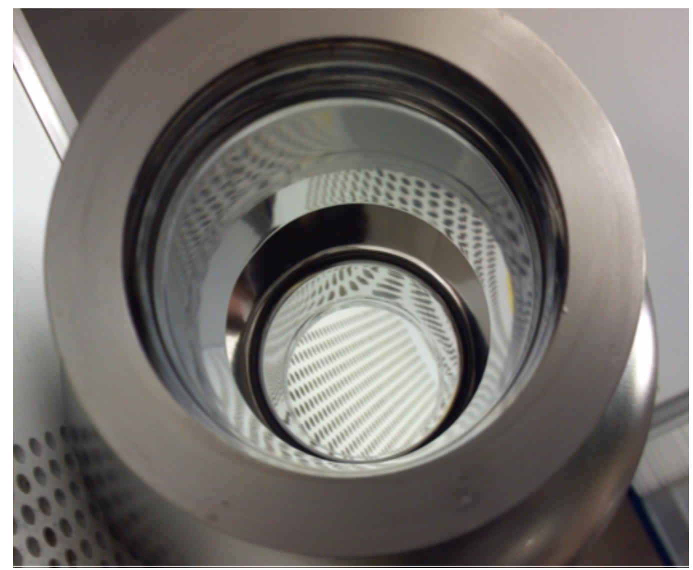
	72 MHz QWR	Really Good ILC 9-Cell
Peak Surface Magnetic Field	166 mT	175 mT
Peak Surface Electric Field	117 MV/m	84 MV/m

Alternative to bulk chemistry (CBP)





- •Fill cavity with abrasive median and usually a liquid
- •Hermitically seal the cavity - run in machine for a set time
- •Clean cavity (water rinse, ultrasonically clean, HPR ….)
- •Reduce media grit size and repeat
- •Light chemistry still needed at end
- •Creates uniform and hopefully defect free surfaces



Alternative to bulk chemistry (CBP)

Cavities CBP'ed in last 2 years JLAB

FNAL

•Nine Cell (TE

–7 different c

–ACC015, NR

–AC114 – Lar

–IHEP02 – La

•Single Cell (

–JL001, JL002

CAT001-CAT0

PAV007, PIPP

–1DE20, IHEP

–RICU001 (se

–CAT05 – Alu

•Coupon Cav

–TACAES001

cavity

es (Cu and Nb)

onate vibration)

ess muti-cell

5 fold increase of cavities process by CBP over the last two years from the two years prior – FNAL's CPB program is leading the way by a large margin JLab trailing in a distance second

RRCAT

•Multiple single cell

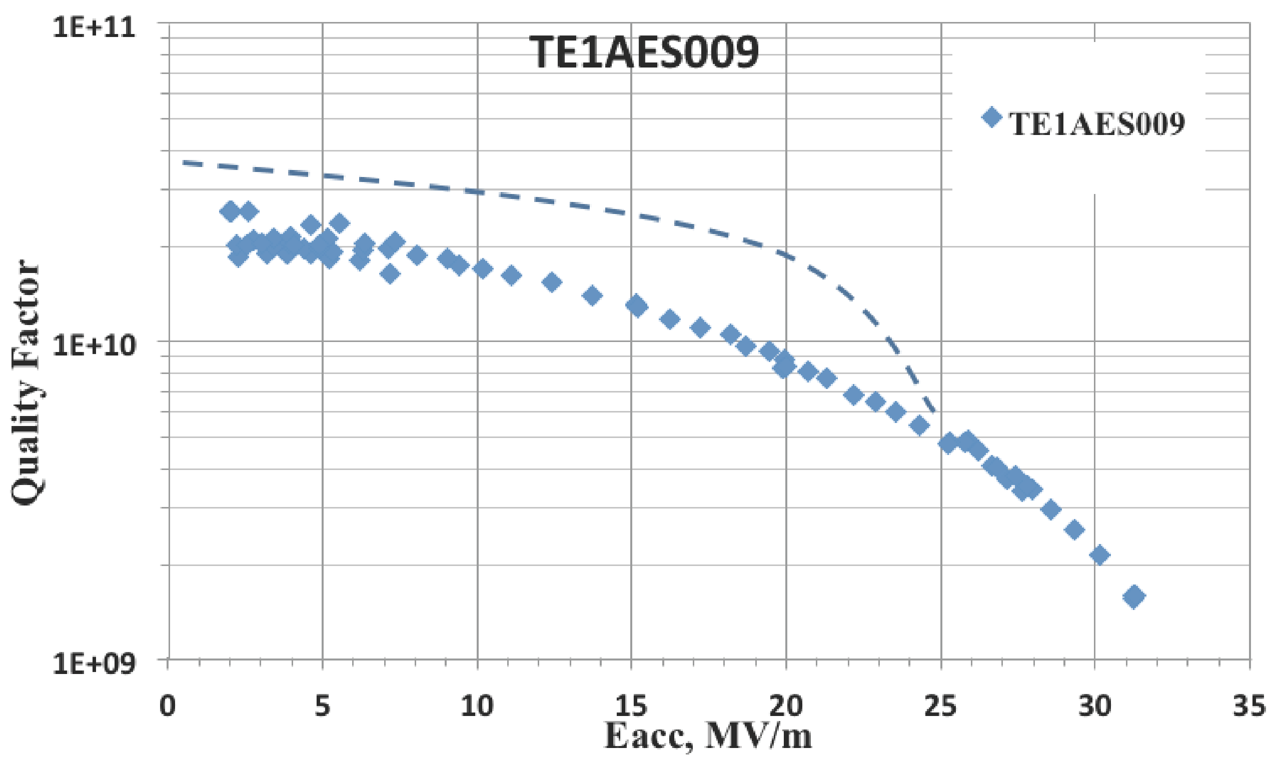
DESY

•Machine setup and beginning to process

(CBP) with zero post chemistry at FNAL

-See TUP030 (Grassellino/Cooper FNAL)
TE1AES009 – fine grain
4 step CBP + 800C heat treatment (with end caps)

-See TUP060 (Cooper et al. FNAL)
Large grain single cell
CBP final step with 800C does not effect surface on large grain
Q slope limited



High temperature heat treatment

See - Pashupati Dhakal

Nb high-Q pursuits - what is new, what is the best seen, what understanding/control is needed yet?

Report from SRF2013 Accelerator Seminar: The SRF World Today

SRF non-bulk materials - what is new and promising?

Oral session- Wednesday Sep, 25

Basic R&D New materials

Thin film deposition techniques

Multilayers, MgB_2 I

Multilayers, MgB_2 II

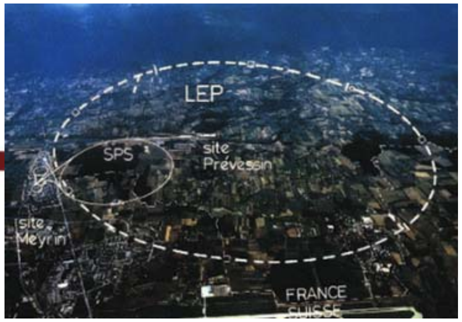
Poster session – Tuesday Sep, 24

Anne-Marie Valente-Feliciano

Jefferson Lab, USA

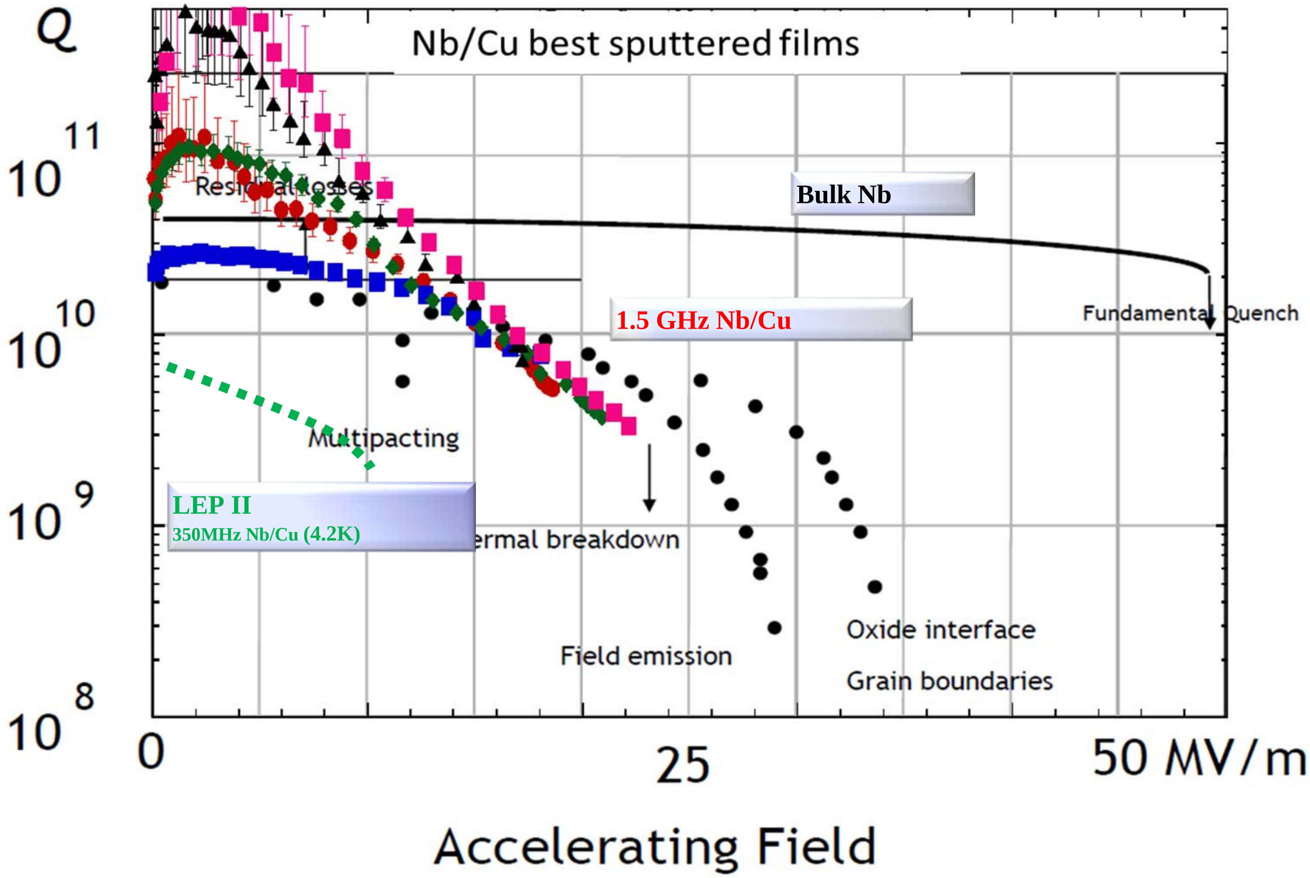
10/17/2013

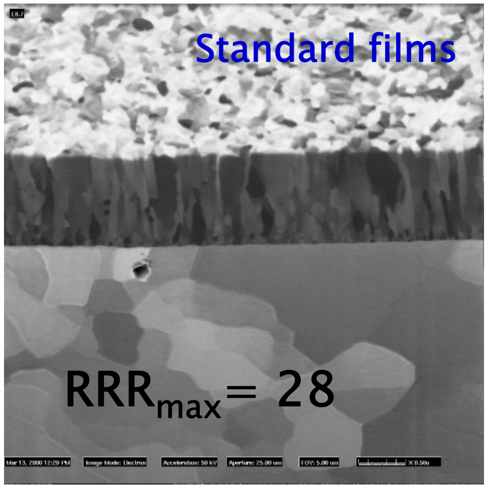
Background



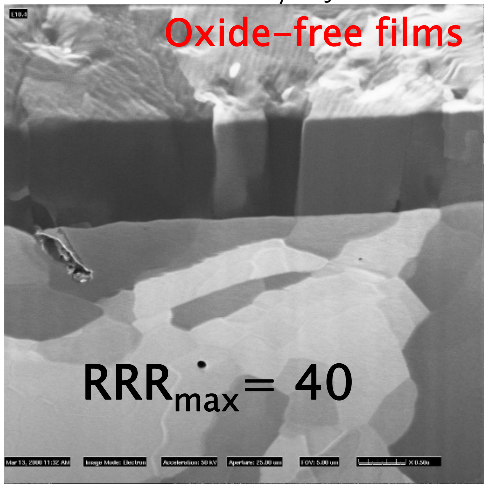
- CERN LEP 2   272 x 353MHz Nb/Cu 4-cell cavities   also LHC
- INFN Legnaro   52 x 160 MHZ Nb/Cu QWR

1.5 GHz Nb/Cu cavities, sputtered w/ Kr @ 1.7 K (Q_0=295/R_s)





Courtesy: P. Jacob - EMPA

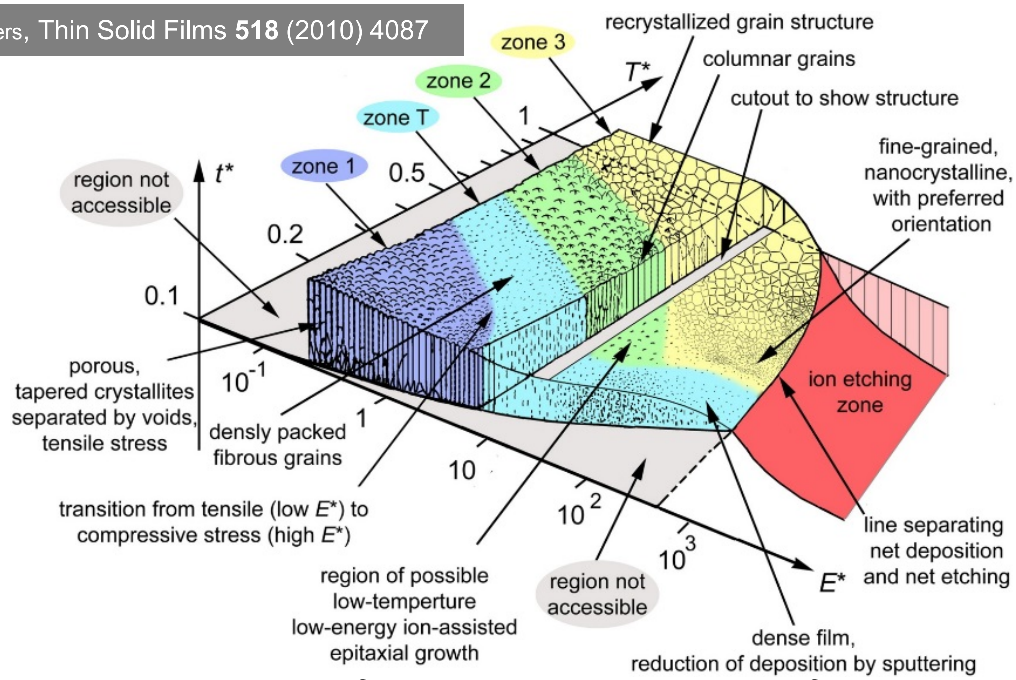


Energetic Condensation

Condensing (film-forming) species : hyper-thermal & low energies (>10 eV).

Generalized Structure Zone Diagram

A. Anders, Thin Solid Films **518** (2010) 4087

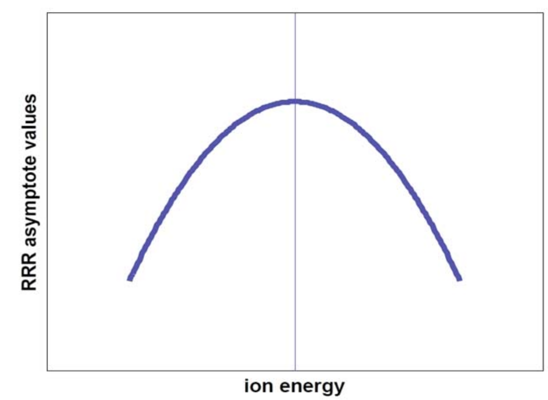


derived from Thornton's diagram for sputtering (1974)

Additional energy provided by fast particles arriving at a surface ⇒number of surface & sub-surface processes ⇒changes in the film growth process:

- ❑ residual gases desorbed from the substrate surface
- ❑ chemical bonds may be broken and defects created thus affecting nucleation processes & film adhesion
- ❑ enhanced mobility of surface atoms
- ❑ stopping of arriving ions under the surface

⇒ Changes in
- ❑ morphology
- ❑ microstructure
- ❑ stress



As a result of these fundamental changes, energetic condensation allows the possibility of controlling the following film properties:

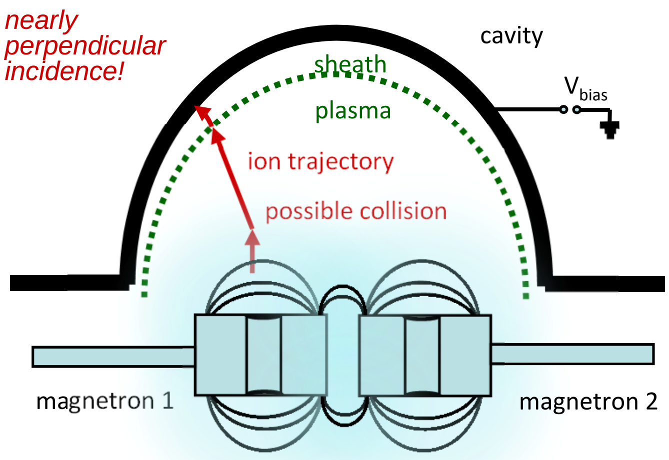
- ❑ Density of the film
- ❑ Film composition
- ❑ Crystal orientation may be controlled to give the possibility of low-temperature epitaxy

Thin film deposition techniques

High Impulse Power Magnetron Sputtering

CERN

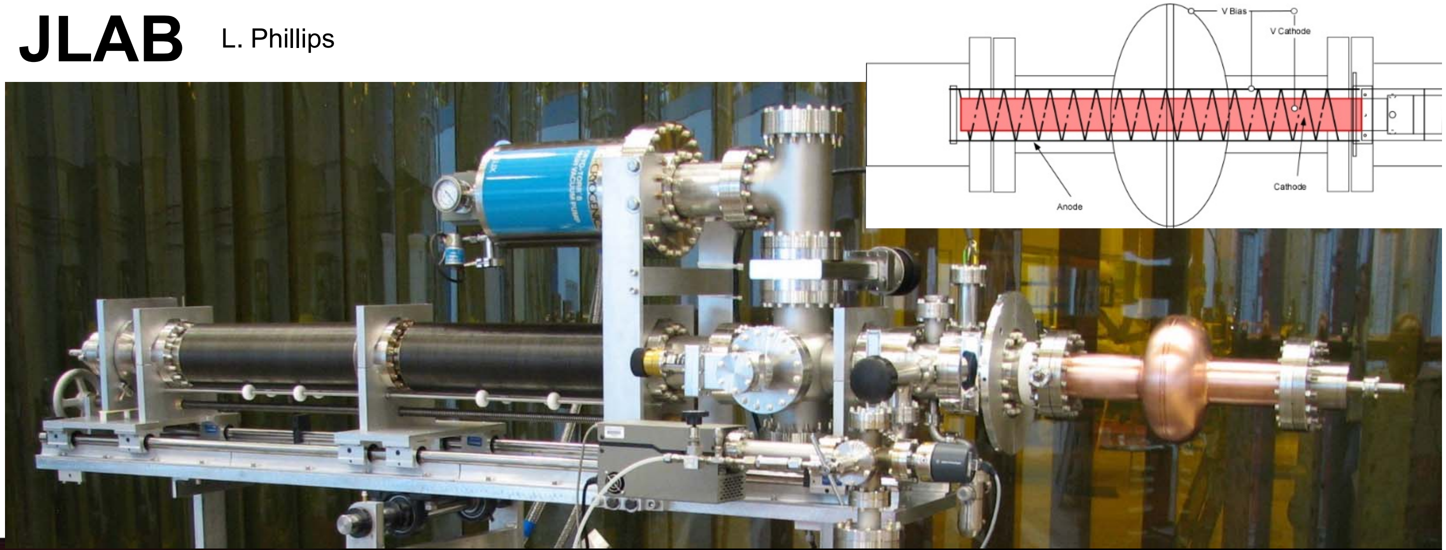
G. Terizziani, S. Calatroni



A. Anders, R. Mendleberg

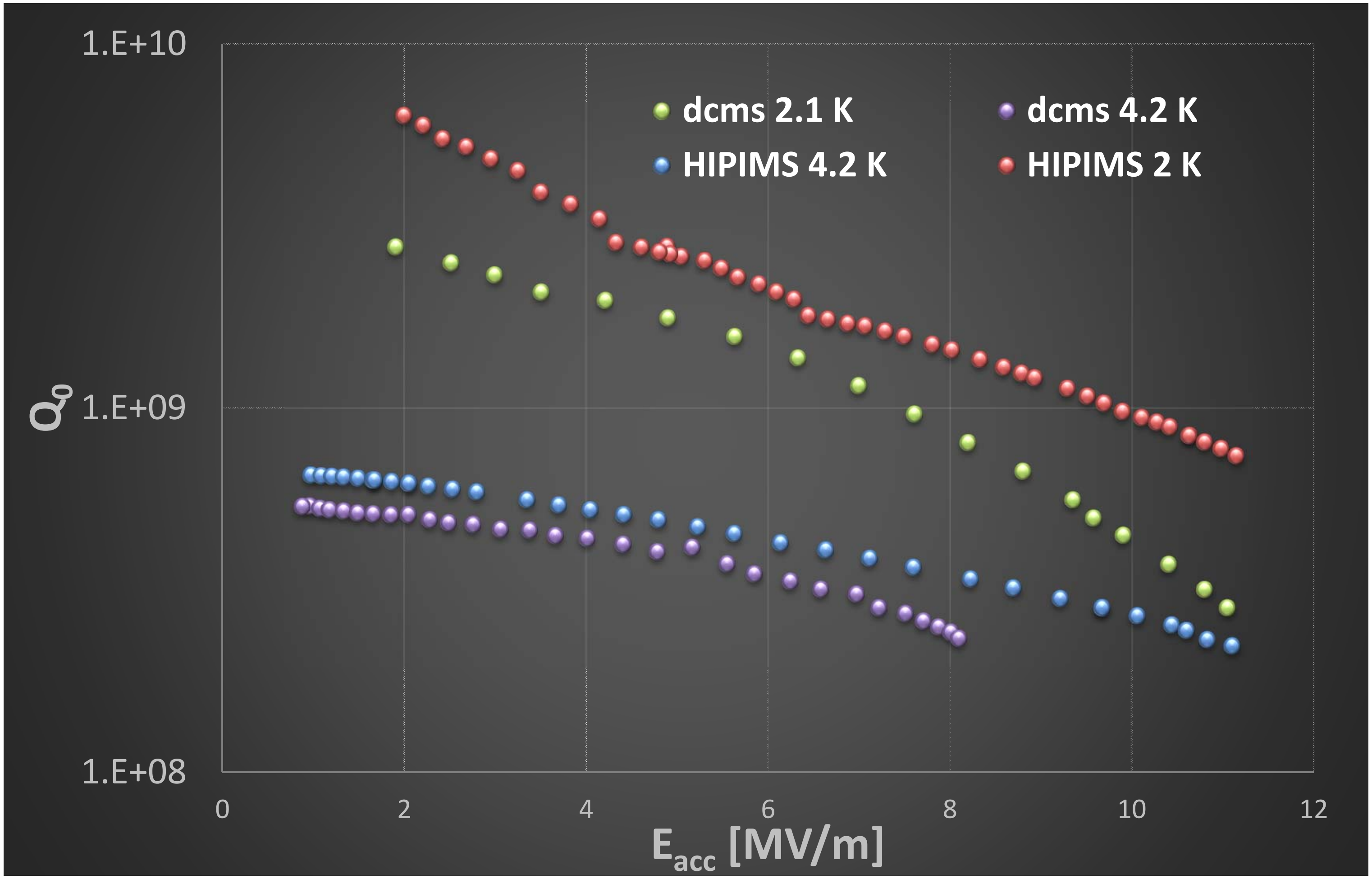
LBNL

JLAB L. Phillips



Thin film deposition techniques
High Impulse Power Magnetron Sputtering

Nb/Cu cavities produced at CERN both by DC cylindrical magnetron sputtering and cylindrical HiPIMS with Kr



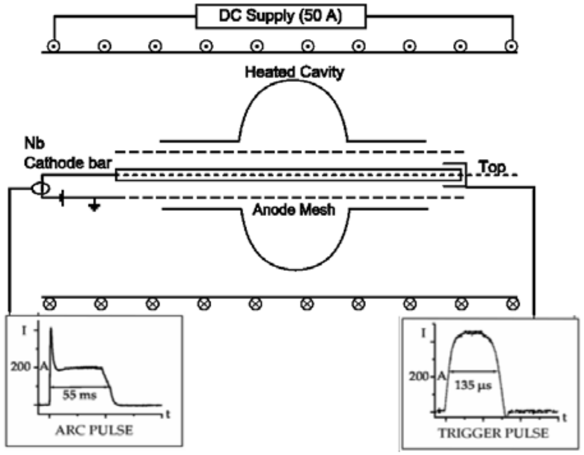
***Note:* - Substrate preparation is SUBU (by opposition to electropolishing for the best 1.5GHz DCMS Nb/Cu cavities to date)**

- Measurement at higher fields than 11MV/m prevented by interlock system due to radiation

Thin film deposition techniques

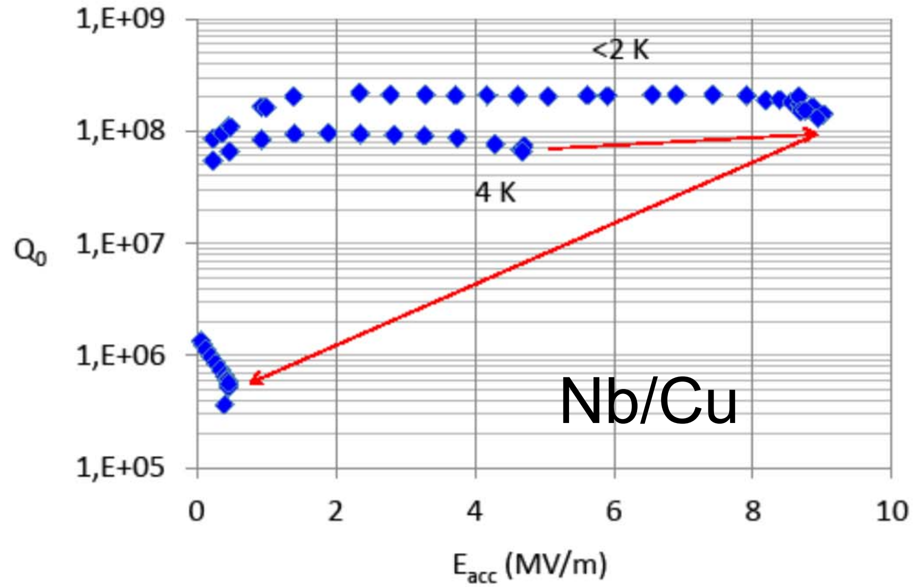
Other energetic condensation techniques: CED, ECR

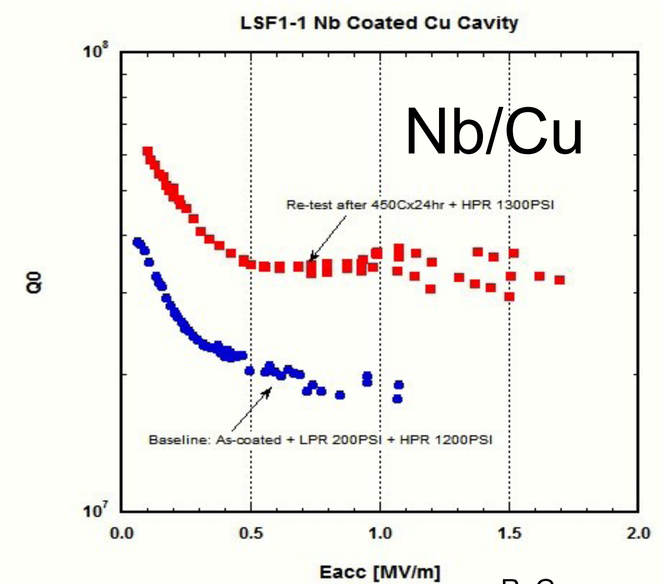
Co-axial Energetic Deposition (AASC Inc.) – collaboration with Jlab, ANL, LANL, CERN



K. Mahadevan

KEK06 hydro-formed copper cavity, CBP at FNAL (Cooper), coated at AASC, tested at LANL (Tajima, Haynes)





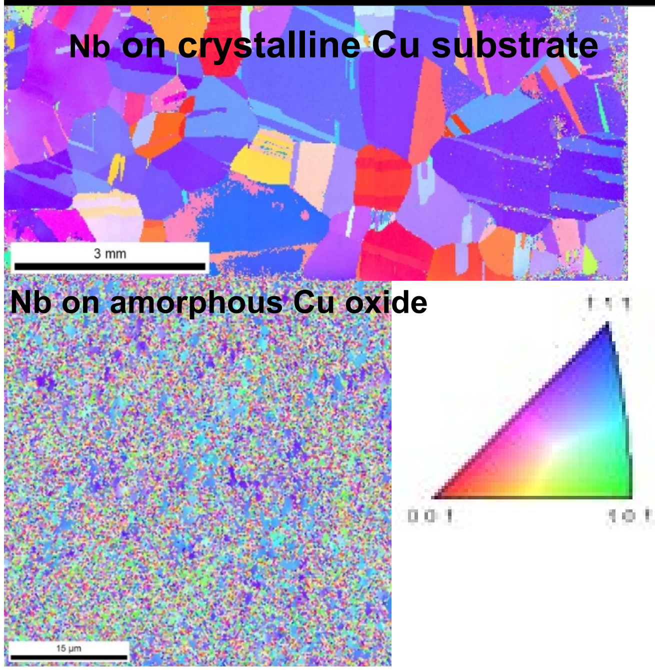
R. Geng

- The difference between 4K and 2K is smaller than expected: BCS resistance should be about 40x less if all the surfaces are Nb.
- This suggests that there are areas that are not coated well and lossy, which is causing the lower than expected Q_0

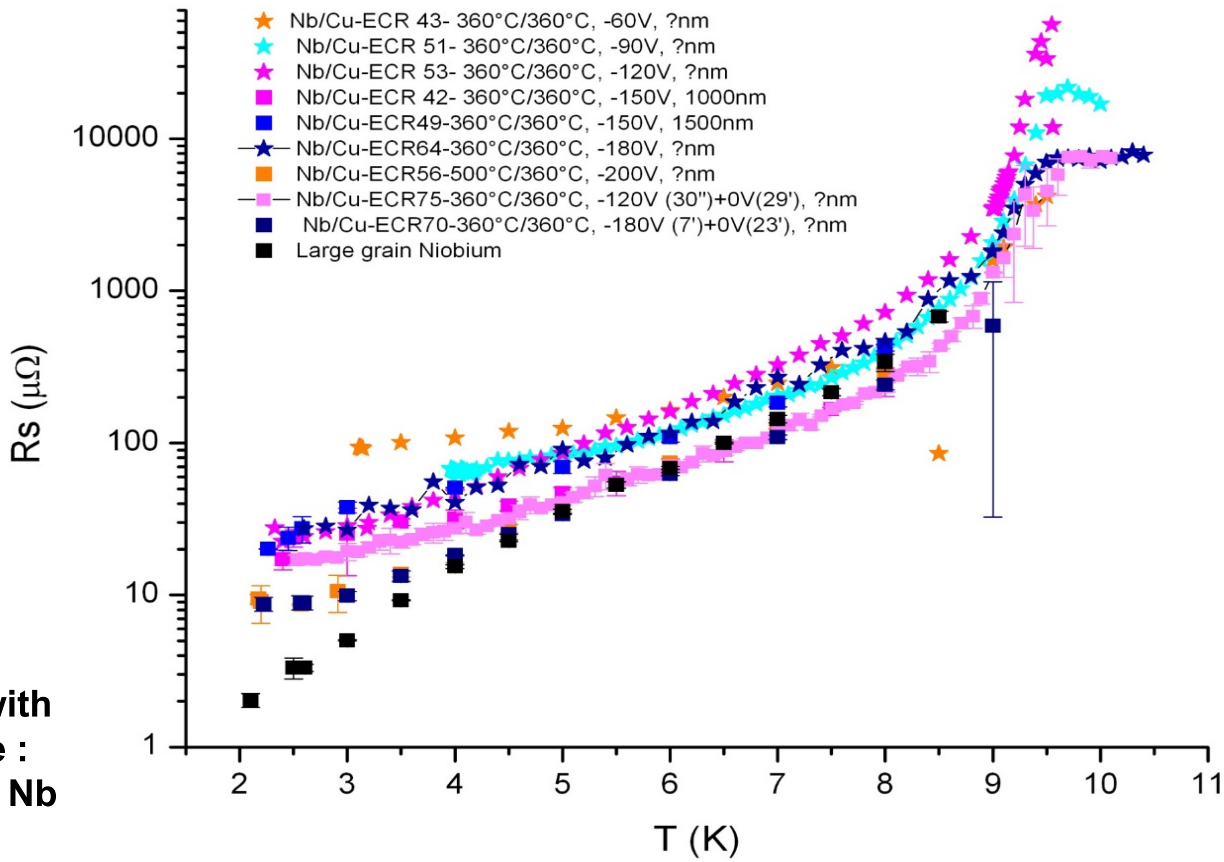
Good results on Nb/Cu samples (RRR:12-110)
Several attempts of Nb coating on both Cu and bulk Nb cavities.
Transition from flat samples to cavity coating is a challenge

Thin film deposition techniques

Other energetic condensation techniques: CED, ECR

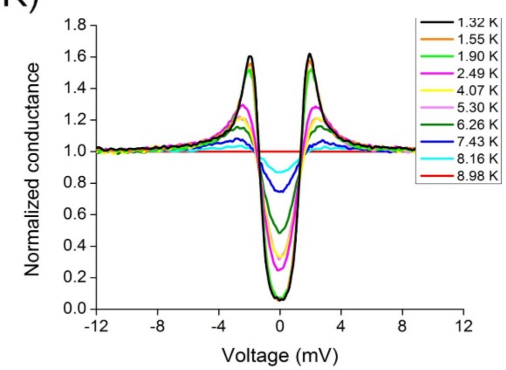


Energetic Deposition vis Electron Cyclotron Resonance - JLab



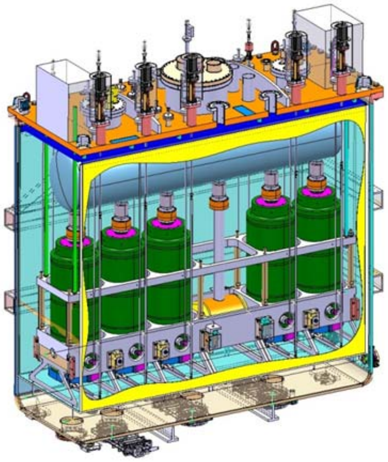
Tune thin film structure and quality with ion energy and substrate temperature : RRR values from single digits to bulk Nb values on a variety of substrates (on Cu: 5 – 300).

Gap measurements performed by PCT (point contact tunneling spectroscopy-ANL) show a superconducting gap (**1.56-1.62meV**) similar to bulk Nb ($\Delta_{\text{Nb bulk}}$ =1.55meV measured on the same setup) for hetero-epitaxial ECR Nb films on polycrystalline Cu.

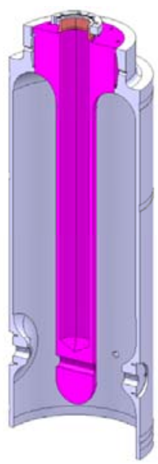


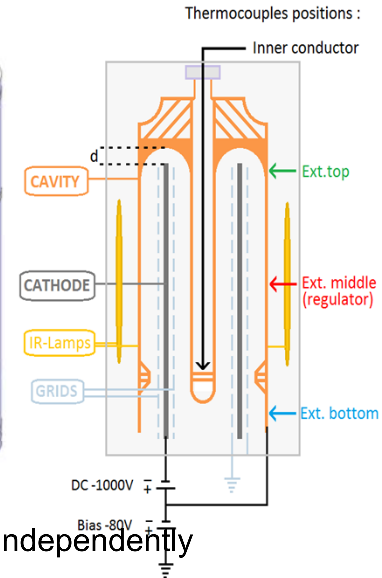
Thin film deposition techniques

Magnetron sputtering development for HIE-ISOLDE - CERN



W. Venturini et al.





Strong development program focused on bias diode sputtering method:

- Increasing baking and coating temperatures
- Increasing sputtering power (global deposition rate)
- Layered coatings
- Sputtering gas, venting gas
- Global film thickness
- Local film thickness

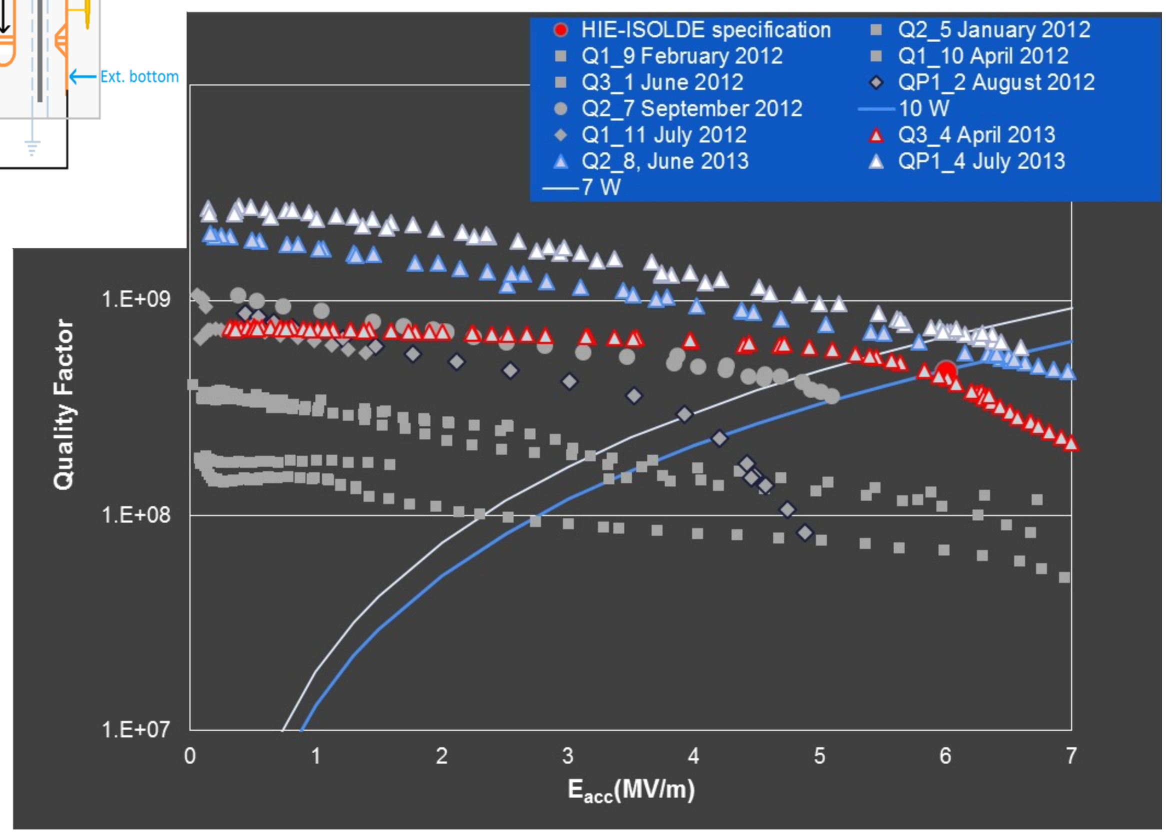
HIE-ISOLDE needs 39.6 MV from 32 independently phased QWR,
project schedules are always tight and physicists are waiting for the beam

Project oriented R&D, several parameters changed at a time

<u>HIE ISOLDE specifications recently met, (with 30% margin in power)</u>

We are on track to start series production for the first phase up to 5 MeV/u

R&D at INFN-LNL and at CERN continues with encouraging results, which could benefit phase II and phase III (low beta), and future machines



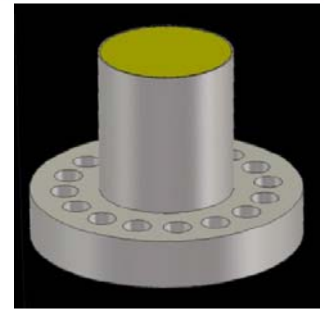
Measurement setups for materials beyond bulk Nb

Quadrupole resonator @ CERN

S. Aull et al.

- 400, 800, 1200 MHz
- Almost identical magnetic field configuration
- Ratio of *B*peak to *E*peak is proportional to *f*res
- *B*max ≈ 60 mT
- Temperatures 1.6 -12 K
- Reproducible measurements
- Upgrade design in collaboration with HZB, Berlin

Resolution for R_s measurement: 0.44nΩ@5mT

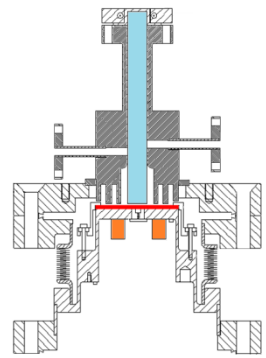


collaboration with Jlab for ECR Nb/Cu and ML/Nb measurements

SIC (TE011) cavity @ Jlab

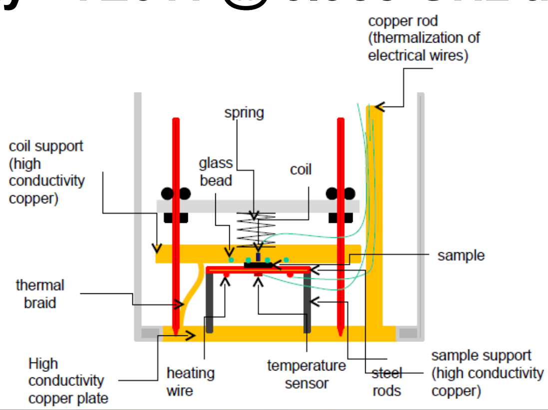
G. Eremeev et al.

- 7.5 GHz sapphire-loaded TE011
- Calorimetry
- *B*max ≈ 20 mT currently, improving to higher fields
- Temperatures 1.6 ~50 K
- λ measurements thru frequency shift (T)
- Reproducible measurements



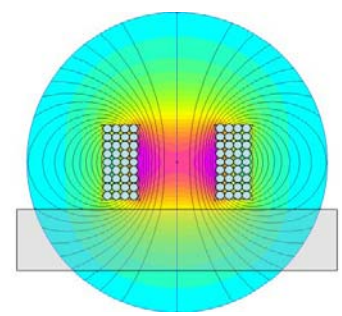
IPN Orsay/CEA Saclay –TE011 @ 3.988 GHz and magnetometry

C. Baumier, C. Antoine, G. Martinet…

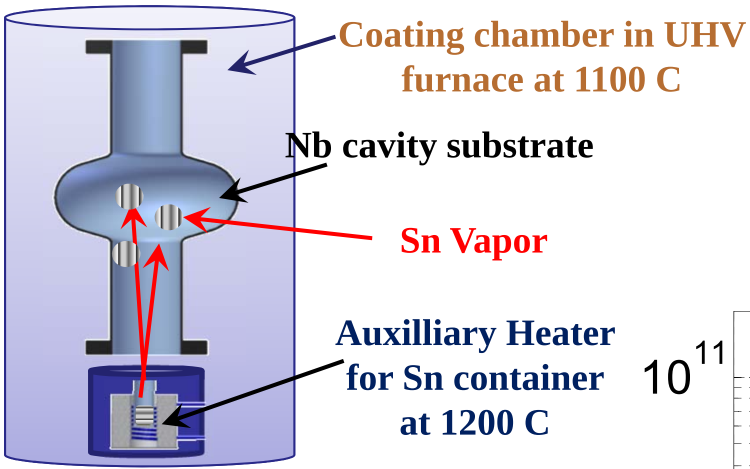


Fields up to 150mT, 2-40K

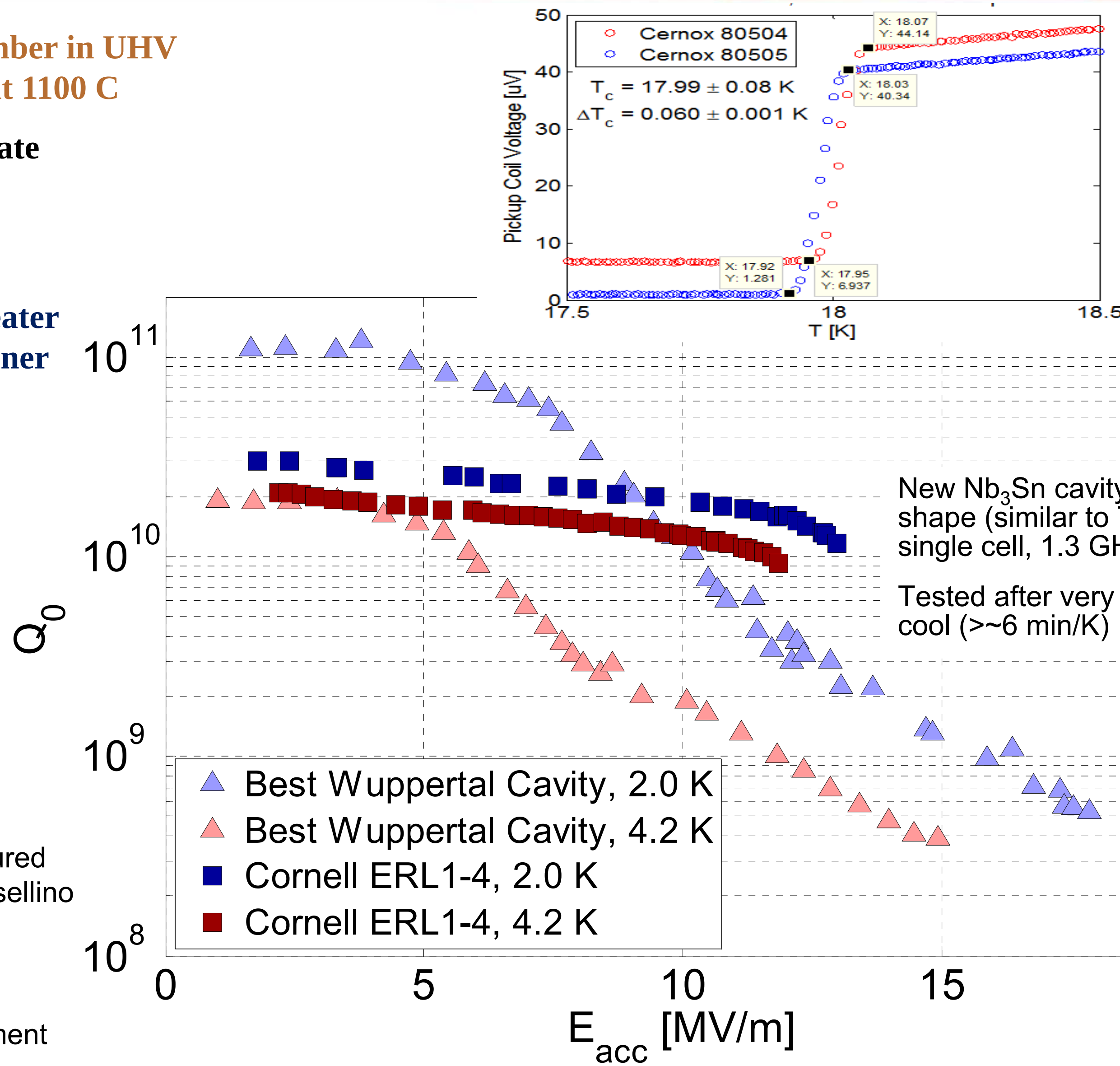
H_{c1} direct value
Perpendicular
Local
No border effect



Nb_3Sn @ Cornell



S. Posen, M. Lieppe



New Nb_3Sn cavity: ERL shape (similar to TESLA), single cell, 1.3 GHz

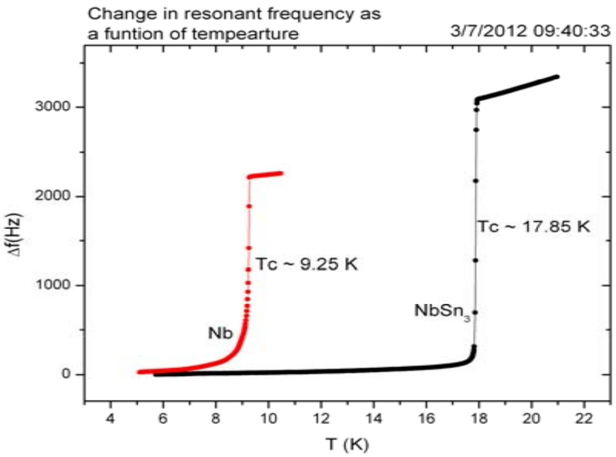
Tested after very slow cool (>~6 min/K)

B_{c1} of Nb_3Sn witness sample measured directly via muon-SR by Anna Grassellino et al.

B_{c1} ~ 20-30 mT

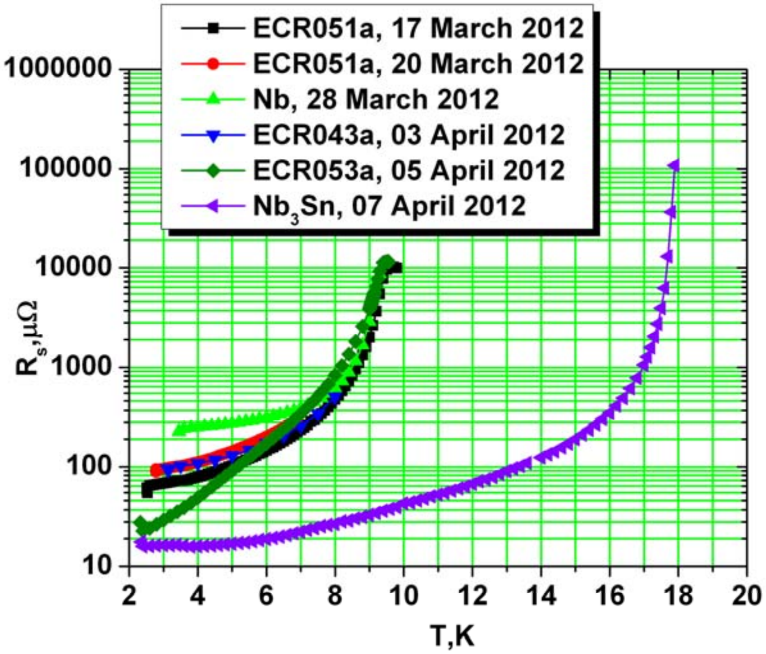
-> agrees well with cavity measurement

Nb_3Sn @ JLab



Transition temperature is ~ 17.85 K. The best of three samples shows very smooth surface with no residual tin contamination

G. Eremeev

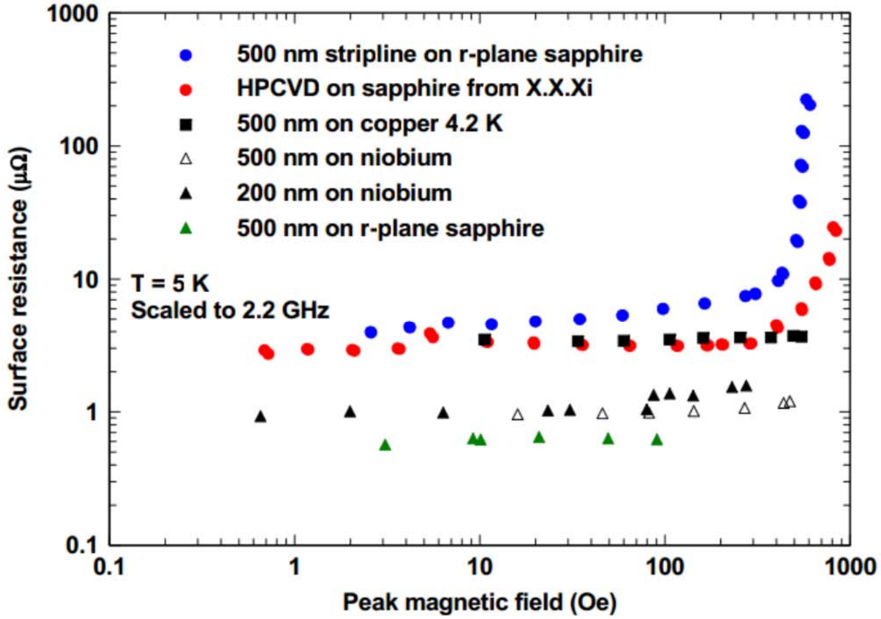


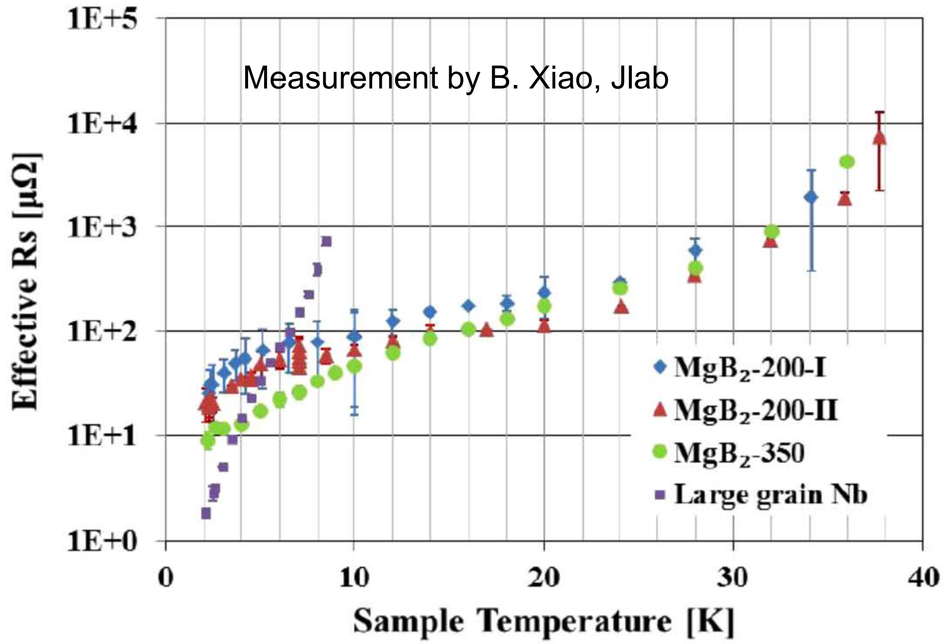
Recent measurements of surface resistance of several ECR films, bulk Nb sample, and Nb_3Sn sample as a function of temperature at 7.4 GHz.

- Preliminary studies with samples have been done. RF measurements on a sample indicated the transition temperature of 17.9 K and RF surface resistance of about 30 $\mu\Omega$ at 9 K and 7.4 GHz.
- The horizontal insert has been built and inserted in the furnace. The first furnace run has been done at 1200 °C for 2 hours.
- R&D furnace for Nb_3Sn development was ordered in October 2012, delivered in August 2013, and is being commissioned.

MgB_2- Hybrid Physical Chemical Vapor Deposition

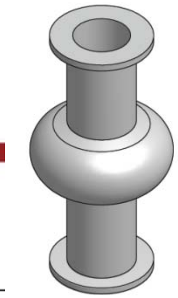
MgB2 thin film samples especially prepared by HPCVD have shown excellent properties relevant to SRF applications, which warrants the coating of practical-size cavities and study the performance as a cavity.



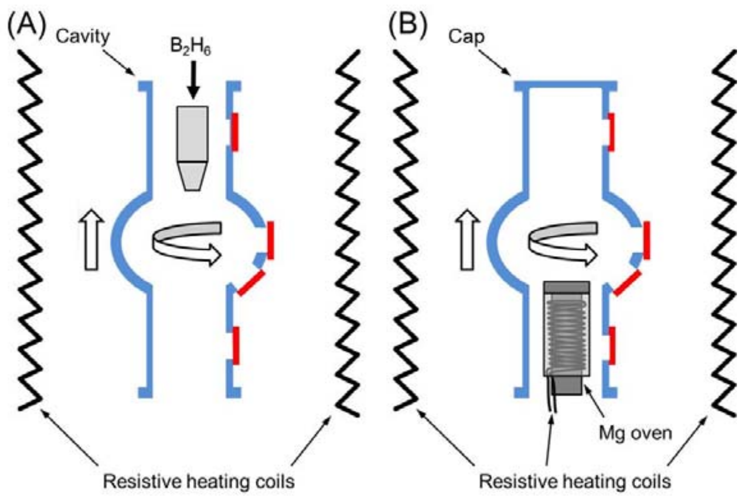


LANL is implementing a cavity coating system based on HPCVD
Challenges in reproducing the results from Temple University

MgB_2



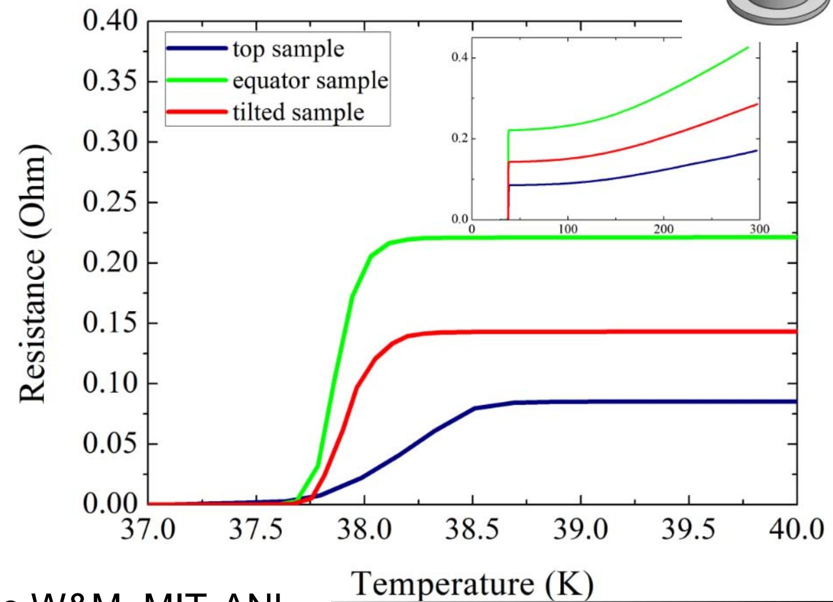
- A boron film was deposited first (A) and then annealed in Mg vapor (B).
- The process is being optimized.
- The top three films show T_c above 37 K with a RRR of 2.



<u>Two-step depositions on dummy cavity</u>

HPCVD- Temple University

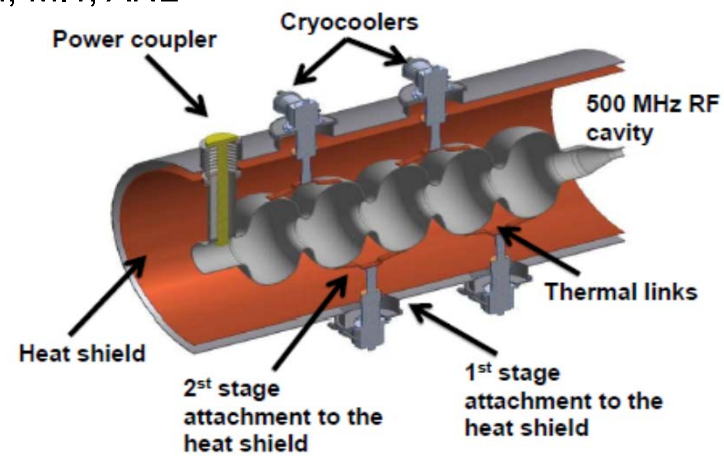
X. Xi et al.



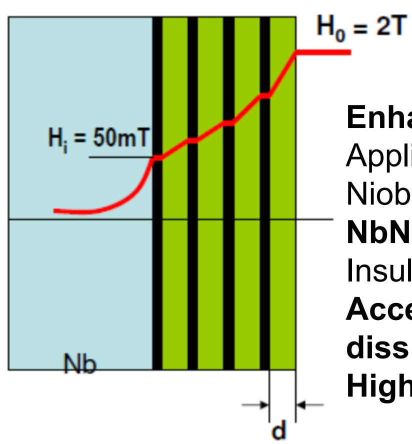
Collaboration with Jlab, College W&M, MIT, ANL

Cavity and cryomodule concept - ANL A. Nassiri et al.

- superconducting Nb CW cavity designs require about 20 to 60 W at 4 K
- MgB2 films can achieve similar surface resistance at 8 -12 K.
- It makes is possible to use cryocooolers for heat removal.
- The cryomodule without liquid cryogens is considerably simplified. No liquid filling ports or internal piping, liquid reservoirs, or internal gas piping is required. Cryocoolers.
- Ideally, a high thermal conductivity material like copper would be best for the cavity.
- The thermal conductivity of Nb is about 200 W/mK, so even Nb would be usable as a substrate if MgB2 cannot be deposited on copper.

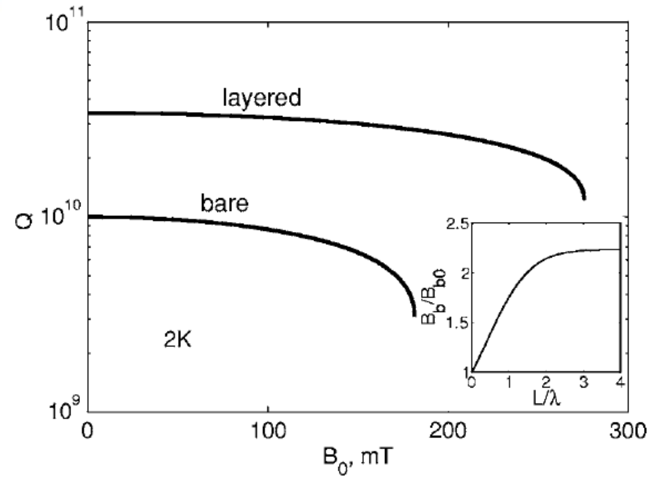


Multilayers – the Model



[1] A. Gurevich, App. Phys. Lett. 88, 012511 (2006)
[2] A. Gurevich, SRF Materials Workshop (2007).

Enhancement of H_{C1} for**Thin SC films with d< λ** (1)
Applied field is reduce by each layer.
Niobium surface screening: allows higher field in the cavity
NbN thin film : higher TC → higher Q0
Insulating layer prevents Josephson coupling between layers
Accelerating field can be increased without high field dissipation
High H_{C1}→no vortex in the layer



Work from Cornell - S. Posen et al.

Evaluation of the thermodynamic potential G(x) of single vortex as function of its position across the SIS structure and evaluation of HSH from evaluation of the vortex entry energy barrier in the London theory
SIS multilayer films have B_{c1}= 0 & rely on energy barrier as the bulk does
SIS B_{sh} is very close to bulk B_{sh}
Small potential gain but very difficult to fabricate
•May not be superior for SRF applications—they are useful in DC applications
•$B_{c1}$is not a limit for cavities made from small-ξ superconductors! No need for B_{c1} enhancement!
•Strong optimism for bulk films

See reply from A. Gurevich in ArXiv

Work from KEK (Kubo et al.)

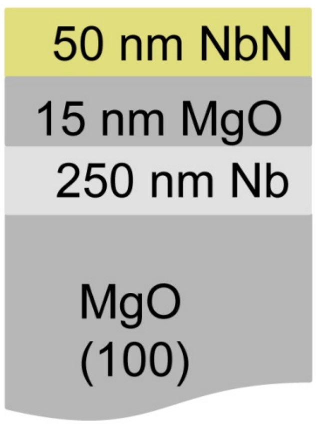
Formulation derived from Maxwell equation and London equation to describe the RF electromagnetic field attenuation for the multilayer coating model
Some SC material may be more suitable than others and thickness is critical

Proof of principle is necessary … now more than ever…

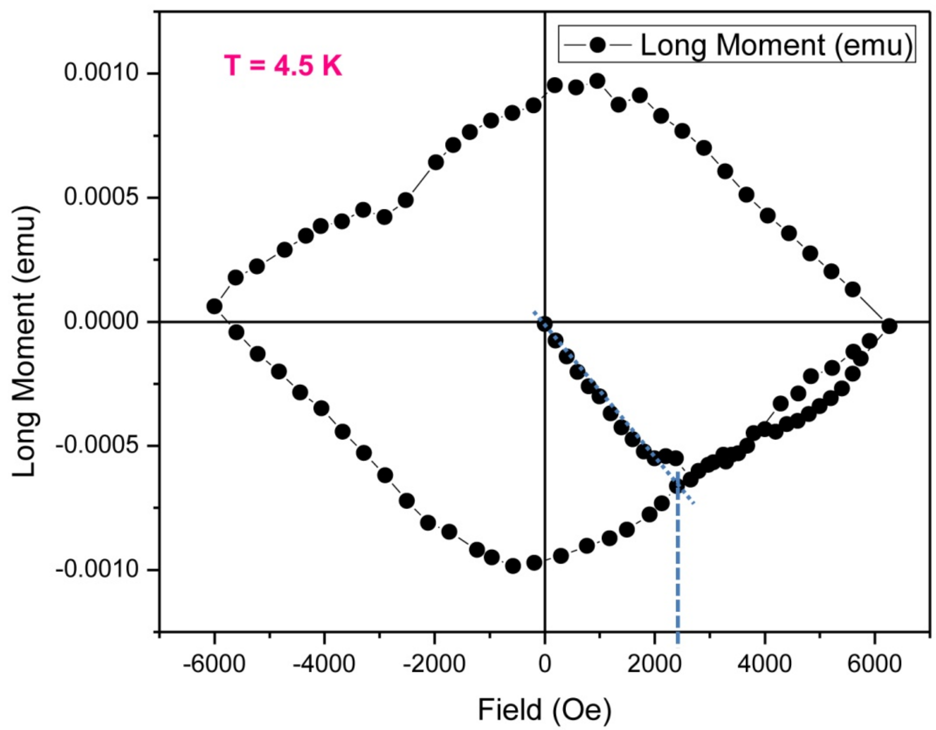
Multilayers –based on NbN

College William & Mary

"Magnetic Shielding Larger than the Lower Critical Field of Niobium in Multilayers" W. M. Roach, D. B. Beringer, Z. Li, C. Clavero, and R. A. Lukaszew, *IEEE Trans. Appl. Supercond.* **23**, 8600203 (2013).



R.A. Lukaszew et al.



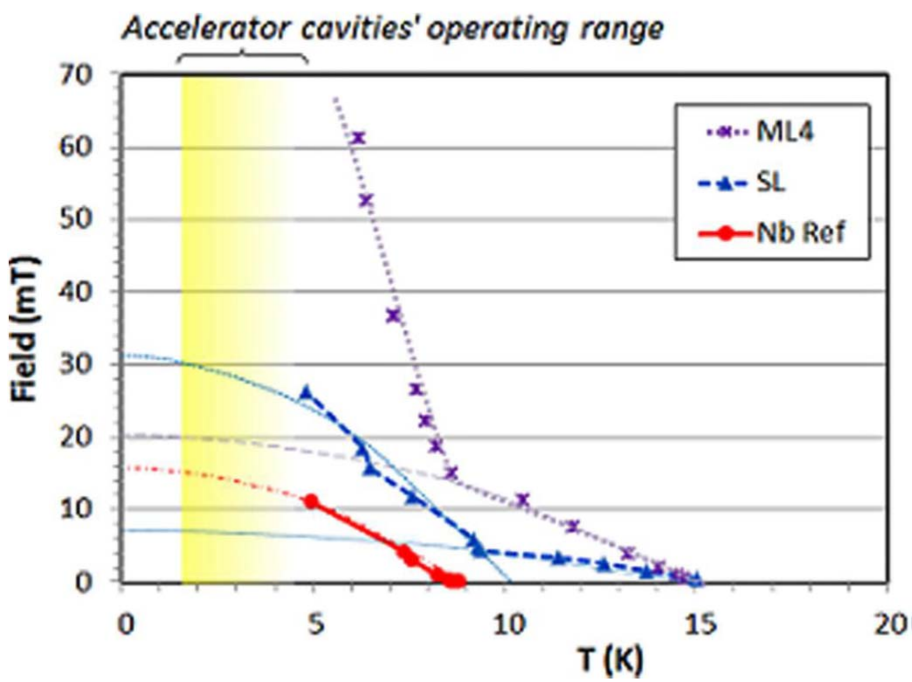
By tailoring thin film growth parameters, and also using SQUID magnetometry we were able to demonstrate shielding beyond the critical field of Nb also using NbN-based trilayers.

$H_{c1\text{-NbN-based-Multilayer}} \sim 220$ mT!

$H_{c1\text{-bulk Nb}} = 170$ mT

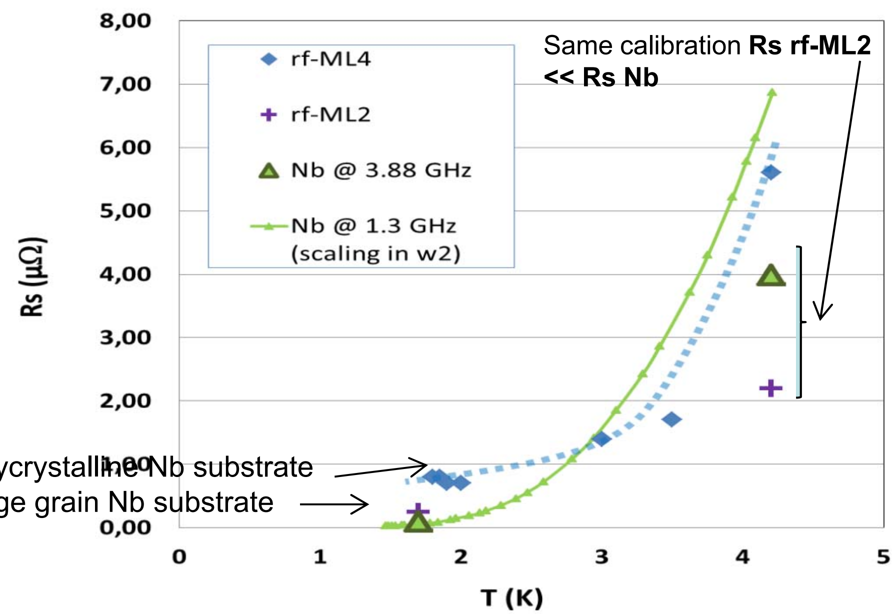
Multilayers –based on NbN

CEA Saclay – Molecular Beam Epitaxy



C. Baumier et al.

Strong indication that R_{BCS} is improved with ML
Could probably be improved with the use of thicker layers (complete screening)
Very promising preliminary results



Effective screening of the surface, prevents early vortex penetration
–**RBCS is improved with the use of higher TC SC**
–Rres is not dramatically degraded compared to Nb
–Room for improvement: better understanding of interaction with substrate needed

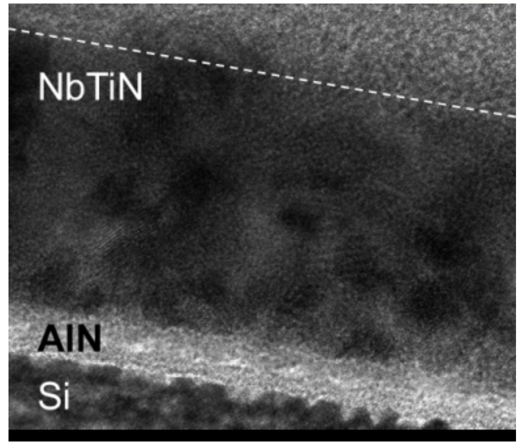
Multilayers-based on NbTiN

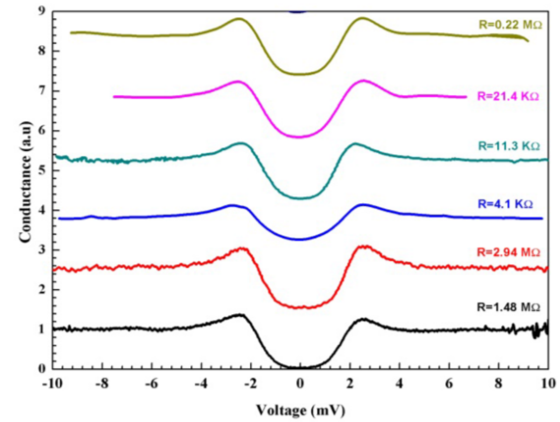
NbTiN/AlN by ALD - ANL

Explore via ALD various Sc materials : Nb1-xTixN, TiN, MoN, NbSi, NbC, NbCN
And insulators: MgO, Al_2O_3, AlN…
Collaboration with Jlab

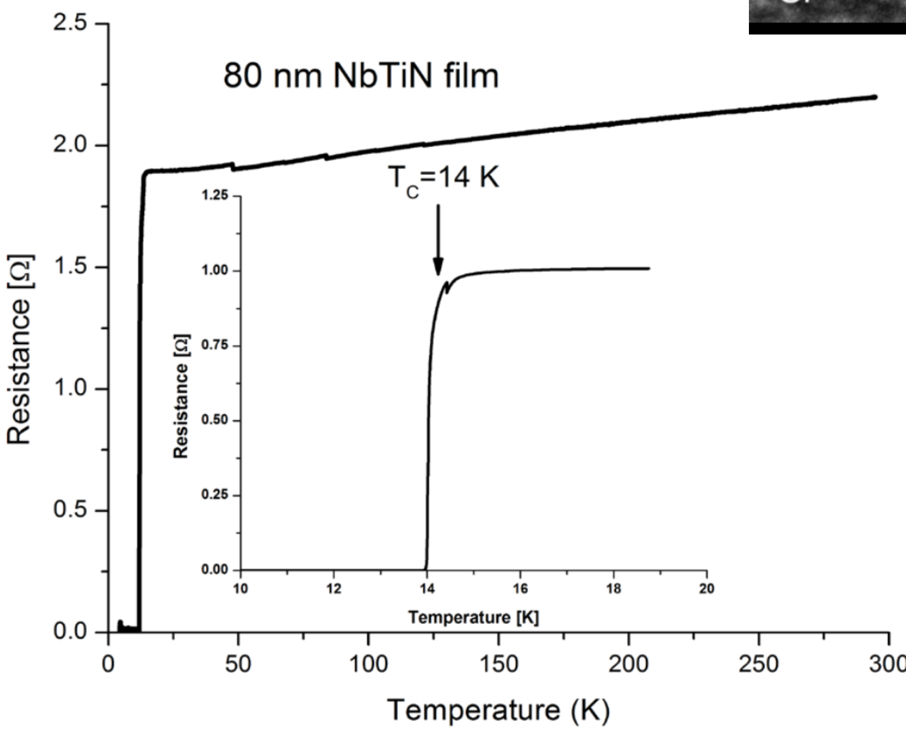
(NbF5, TiCl4) + NH3
(NbCl5, TiCl4) + Zn + NH3

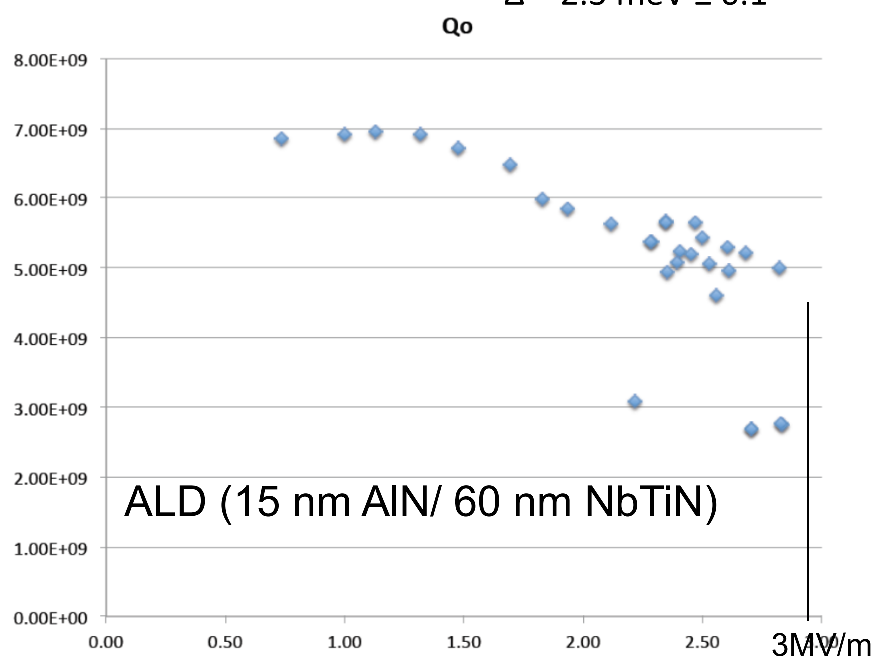
T. Proslier et al.





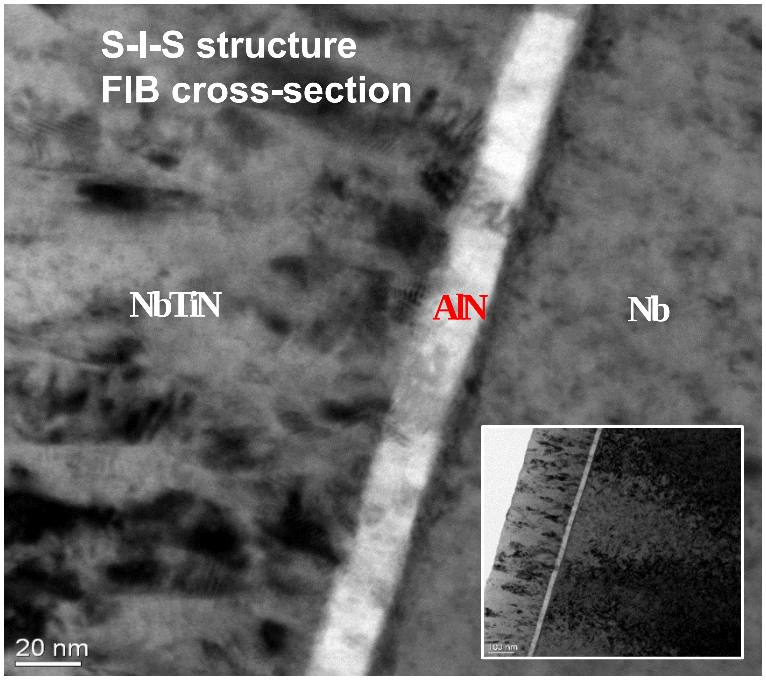
Δ = 2.3 meV ± 0.1



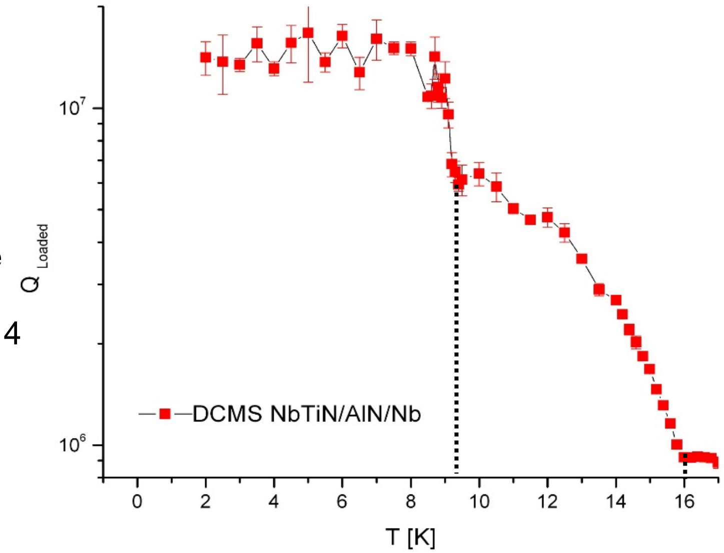


Multilayers-based on NbTiN

NbTiN/AlN by Sputtering-JLab

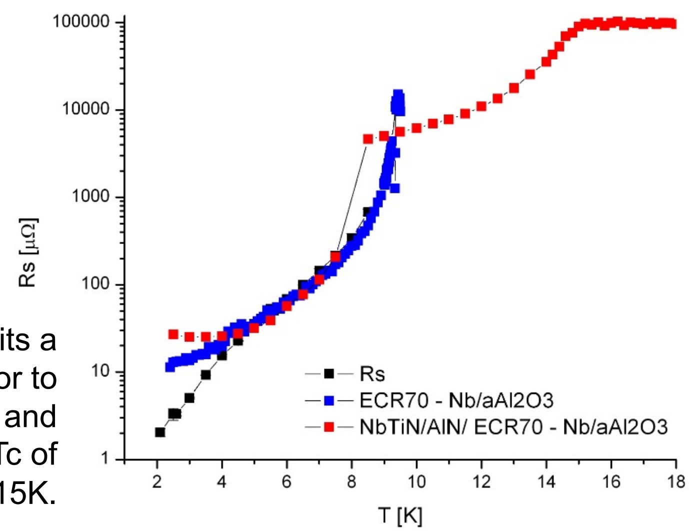


SIS structures based on NbTiN and AlN have been coated at 450°C in-situ on bulk Nb and Nb/a-Al_2O_3 substrates after a 24h-bake at 600°C. The samples are then annealed at 450°C for 4 hours.



The SIS structure coated on the Nb exhibits a T_c for the NbTiN of 16K . RF measurements are on going [6] .

The SIS structure coated on the ECR Nb/(11-20)Al_2O_3 film exhibits a suppressed Tc for the Nb film compared to the measurement prior to the SIS coating. This is most likely due to the Nb oxide reduction and oxygen diffusion during the bake at 600˚C. The NbTiN has a Tc of about 15K.



Multilayers-based on MgB_2

Enhancement of H_{c1} in thin MgB_2 films

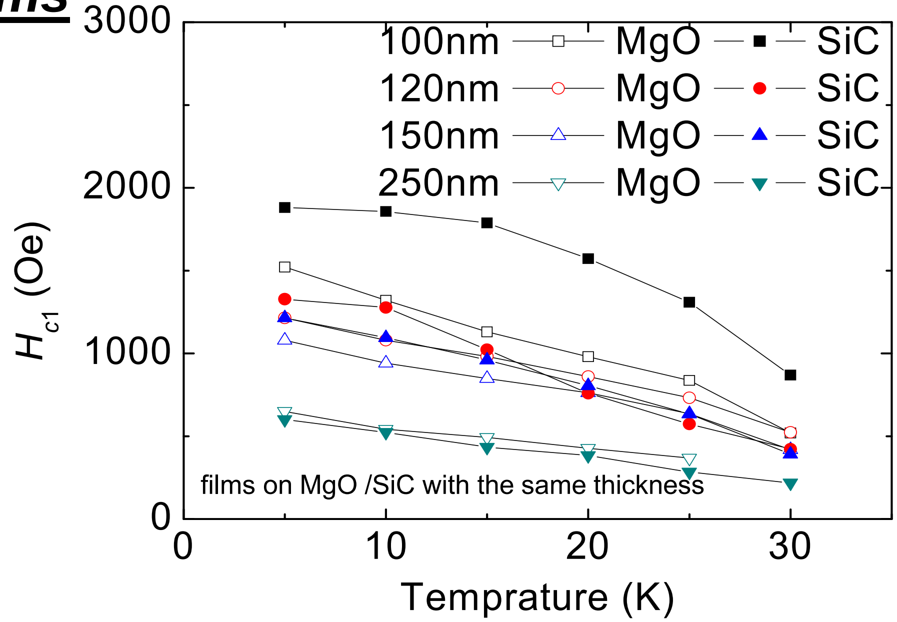
Temple University

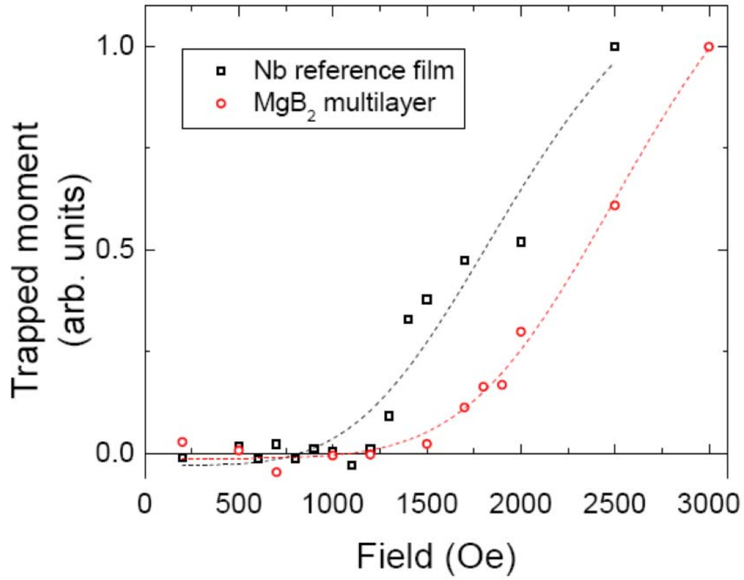
X. Xi et al.

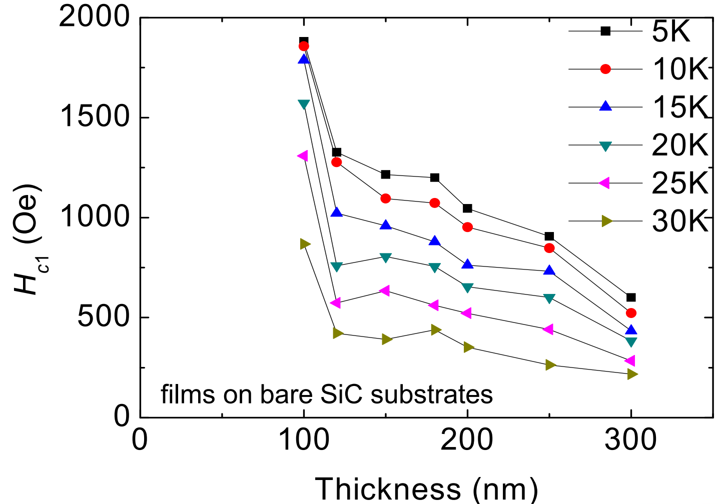
collaboration with W&M,Jlab, MIT…

- 2 group of samples were studied:
  - Single crystalline thin films on SiC(0001) substrate
  - Polycrystalline thin films on amorphous MgO layer on SiC(0001)

- H_{c1}(5K) is enhanced when the film thickness decreases, for films on both single crystal SiC substrate and polycrystalline MgO films.
- H_{c1}(5K) ~ 2000 Oe in 100nm-thick MgB_2 film.



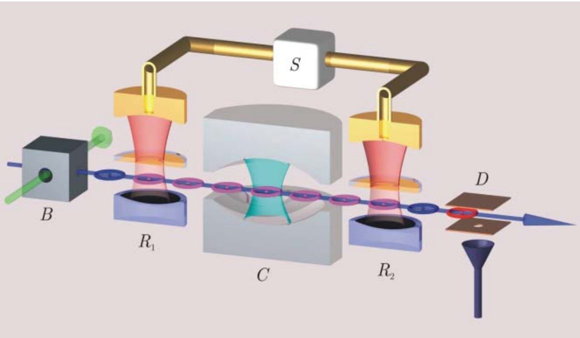




Beyond bulk Nb material

- In depth sample studies. Quality samples produced.
- First results with multilayers show some field enhancement
- Undisputable proof of principle for the S-I-S multilayer structure concept needed
- Progress towards cavity coating both for Nb films and multilayers in most institutions involved
- Significant synergy between all the institutions active in the field of materials beyond bulk Nb:

Jlab closely collaborates with College William & Mary, ANL, LBNL, MIT, AASC Inc., Temple university, CERN on the development of Nb films and S-I-S Multilayer structures



Key note talk:"Quantum Measurement with "Trapped" Microwave Photons in a SRF Cavity"- M. Brune – S. Harouche Team (2012 Nobel Prize Laureat), Laboratoire Kassler-Brossel

Collaboration with JLab for ECR Nb based torroidal mirrors

Report from SRF2013 Accelerator Seminar: The SRF World Today

Nb high-Q pursuits - what is new, what is the best seen, what understanding/control is needed yet?

Pashupati Dhakal
Jefferson Lab, USA
10/17/2013

R&D on SRF

- Driven by Project Need
  - * CW applications
  - * Pulse applications
  - * High current
  - * 4.2 K applications
- Conventional R&D
  - * Maximize E_{acc} and Q_0
  - * Search for alternative materials
  - * Process improvement

Overall goal : Minimize construction and operation cost with reliable and efficient SRF cavities

Quality Factor and Surface Resistance

Quality Factor (Q_0) = G/ R_s

G = Geometry factor (shape dependent)

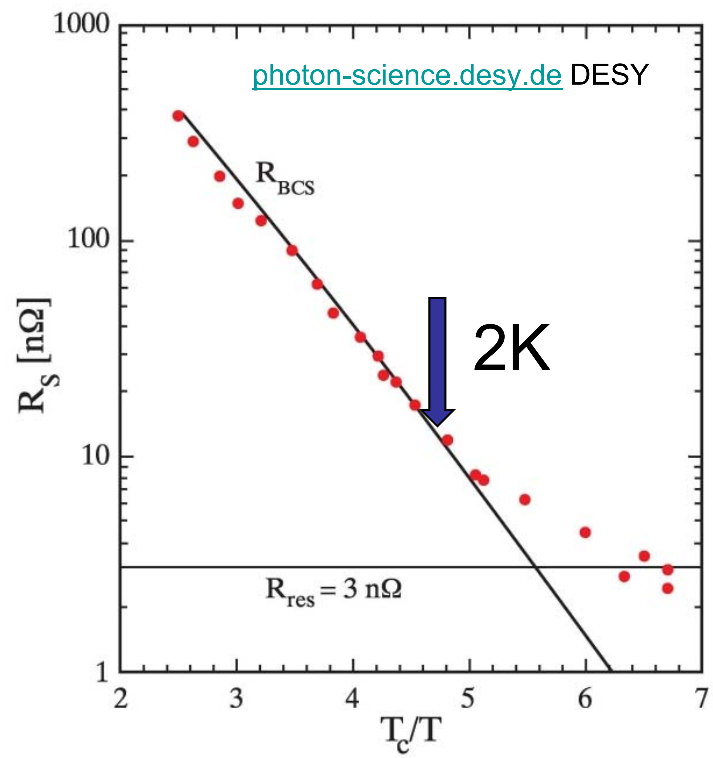
$$R_s = R_{res} + R_{BCS}(f, T, \Delta, \lambda_L, \xi_0, l)$$

Possible sources of R_{res}

- Trapped magnetic field
- Normal conducting precipitates
- Grain boundaries, dislocations
- Interface losses
- Subgap states

Remedies:

- High treatment heat treatments
- Magnetic shielding
- ---

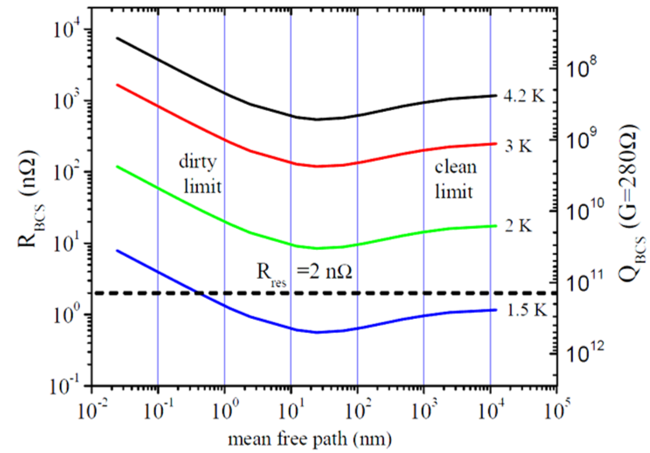


At temperature below 2K, R_s is dominated by R_{res}

Quality Factor and Surface Resistance

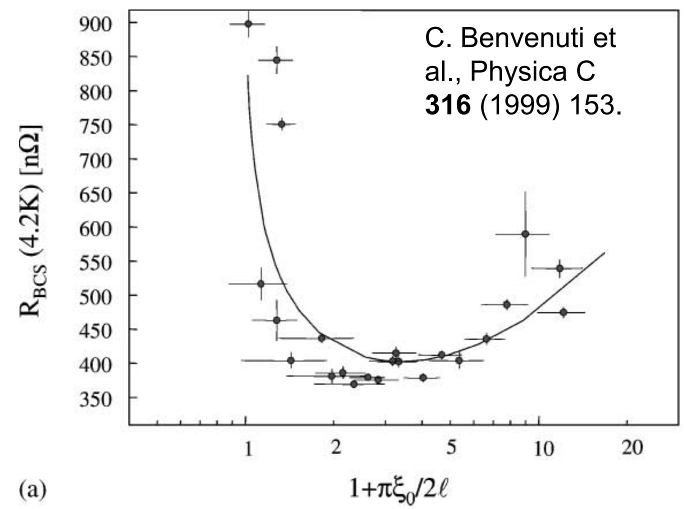
BCS surface resistance results from the interaction between the RF electric field within the penetration depth and thermally activated electrons in a superconductor.

$$R_{BCS}(f, T, \Delta, \lambda_L, \xi_0, l) = (Af^2/T)\, e^{-\Delta/k_B T}$$



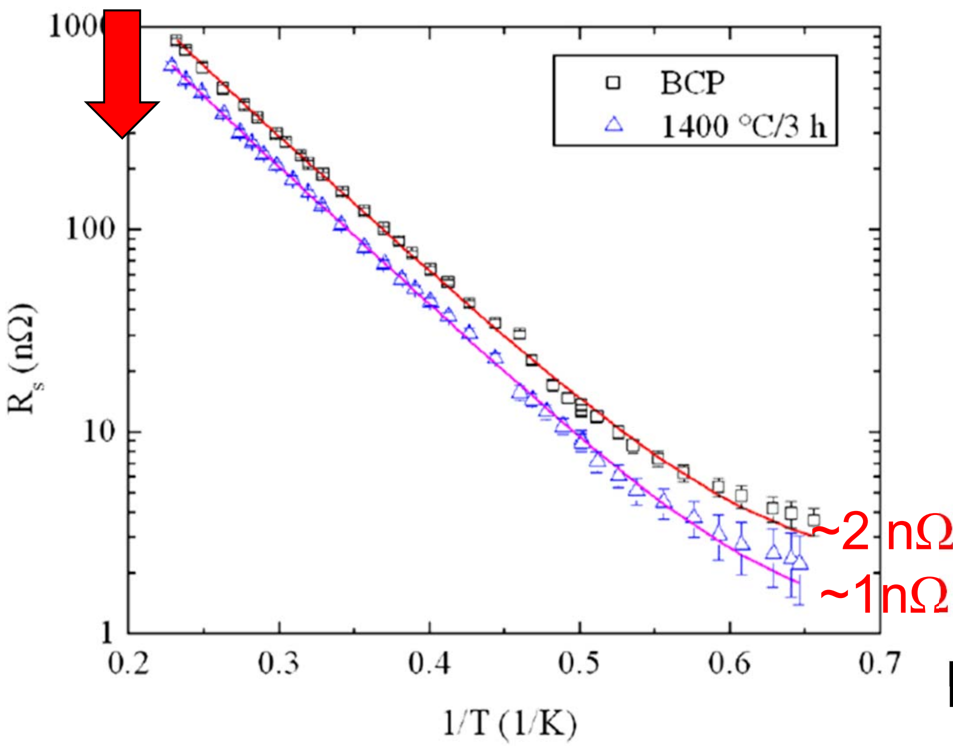
Minimizing BCS Resistance

- Lower frequency
- Higher T_c superconductors
- Higher energy gap
- Optimal electronic mean free path



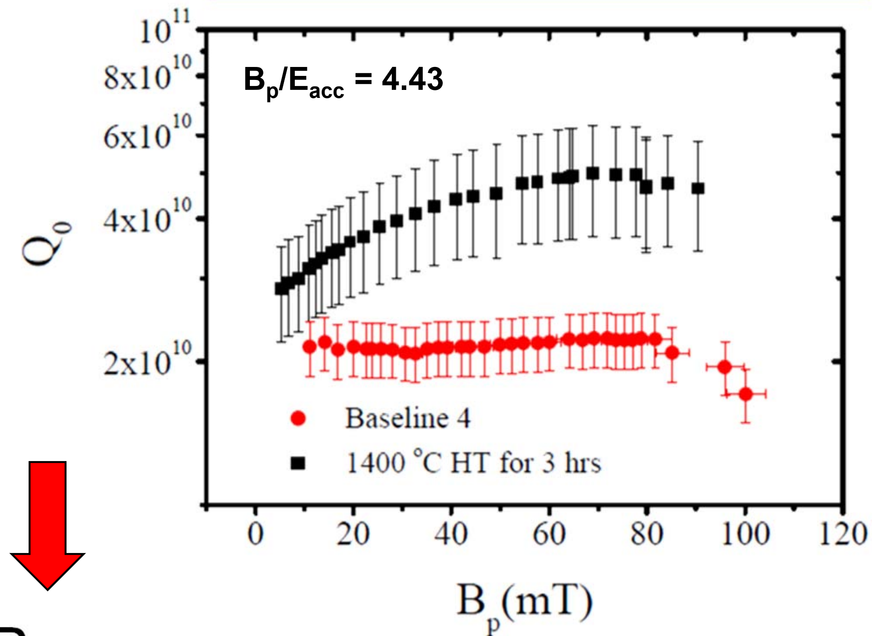
High Temperature Treatment Results

Reduction in R_{BCS}



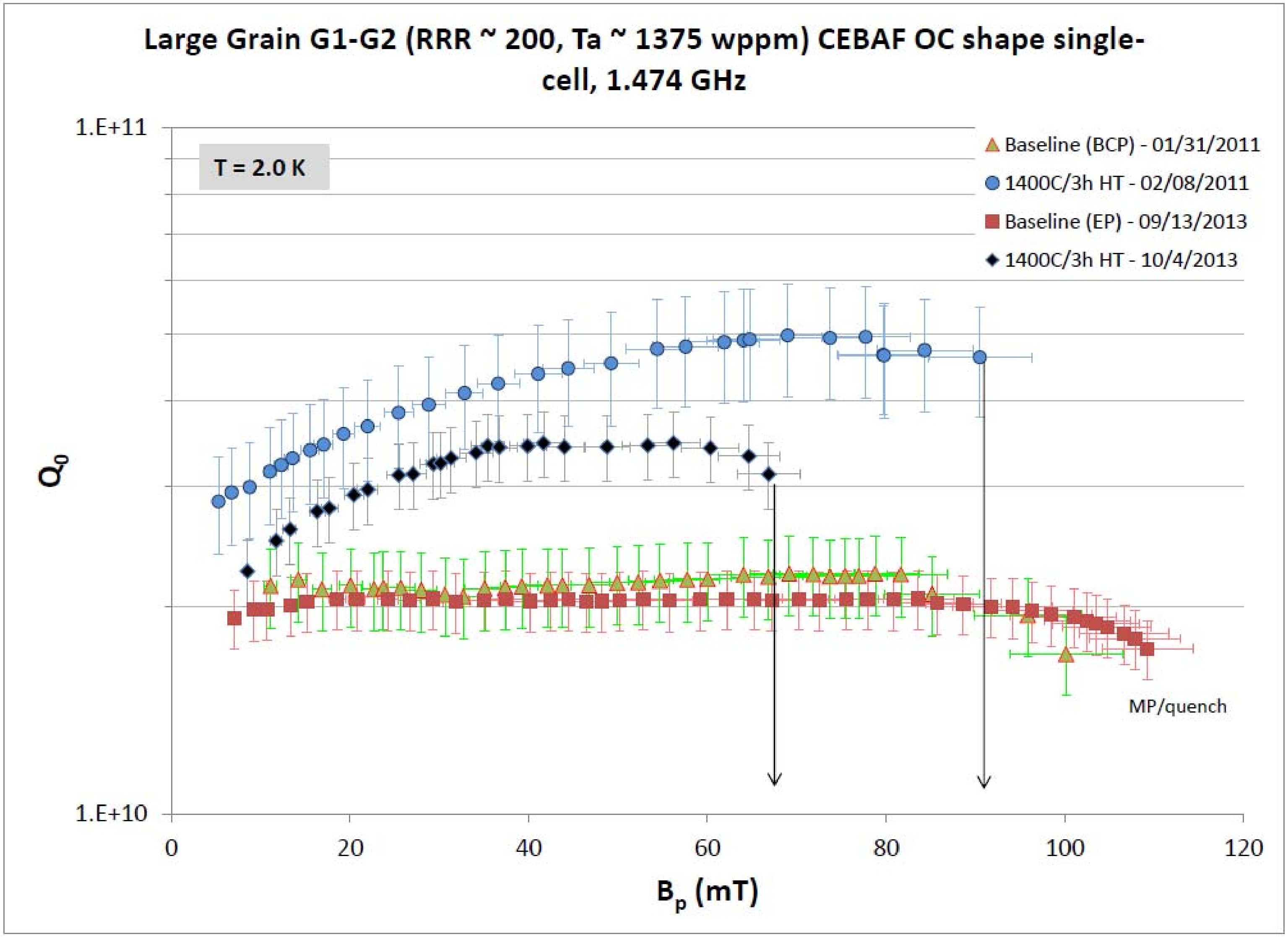
R_{res}

4.6x10^{10} @ 20 MV/m



P. Dhakal et al., Phys. Rev. ST Accel. Beams **16**, 042001 (2013)

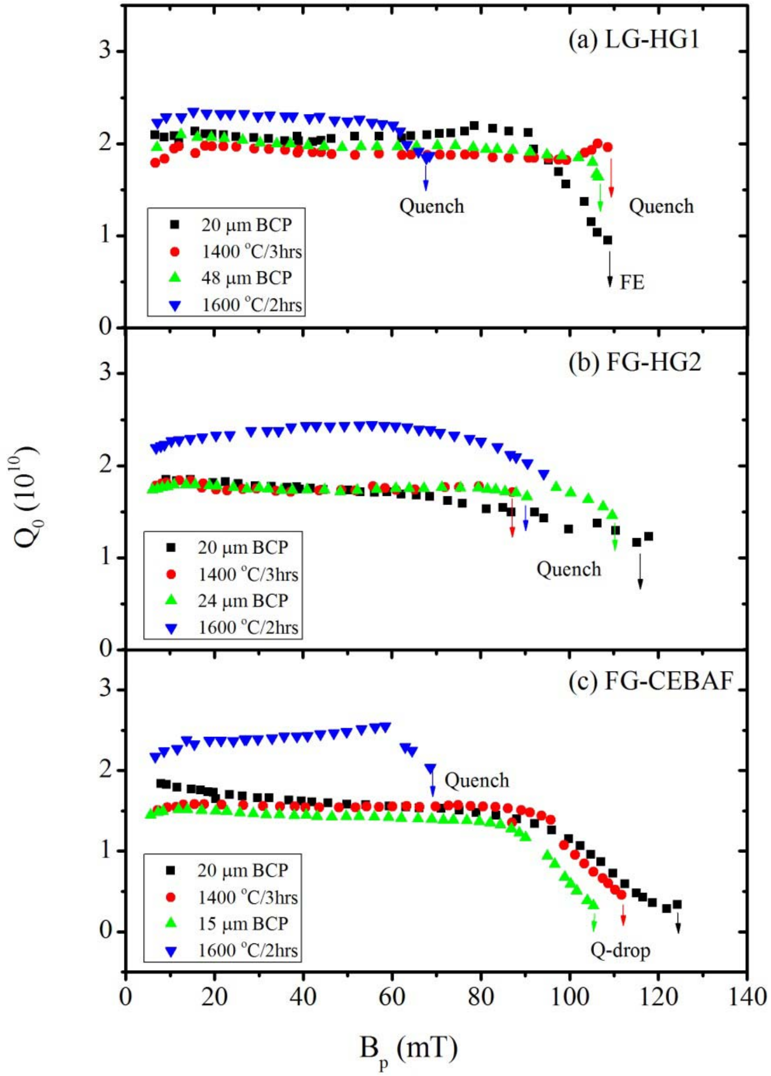
Extended Q-rise



SRF 13

HT results for “All Nb Cavity”

- **3 “all Nb” cavities (2 LG and 1 FG) are heat treated up to 1600 C**
- **Improvement in Q in medium field range up to ~70%**
- **No extended Q-rise**

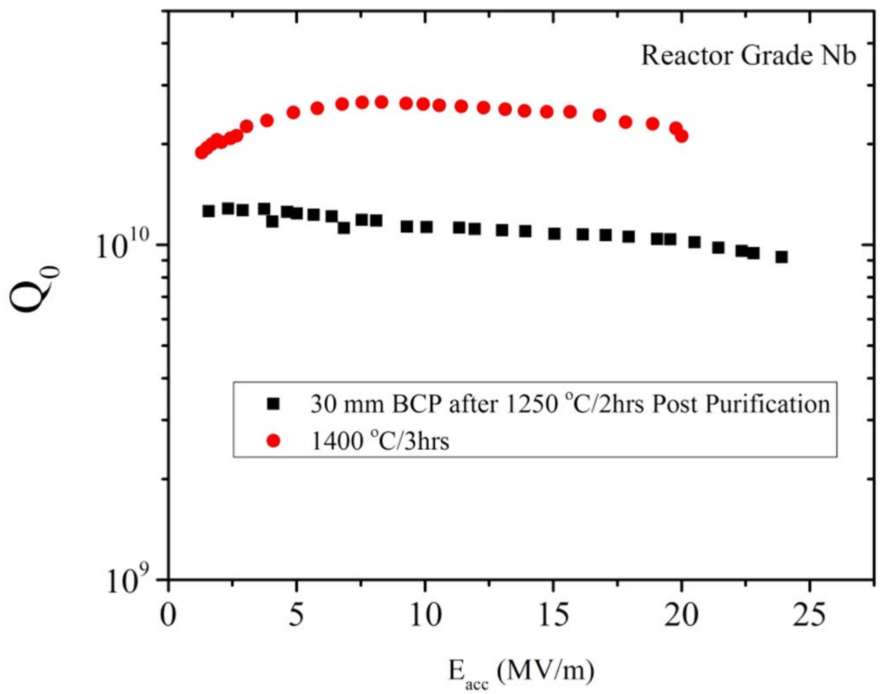


P. Dhakal et al, TUIOC04, SRF 13

HT results for Reactor Grade Nb

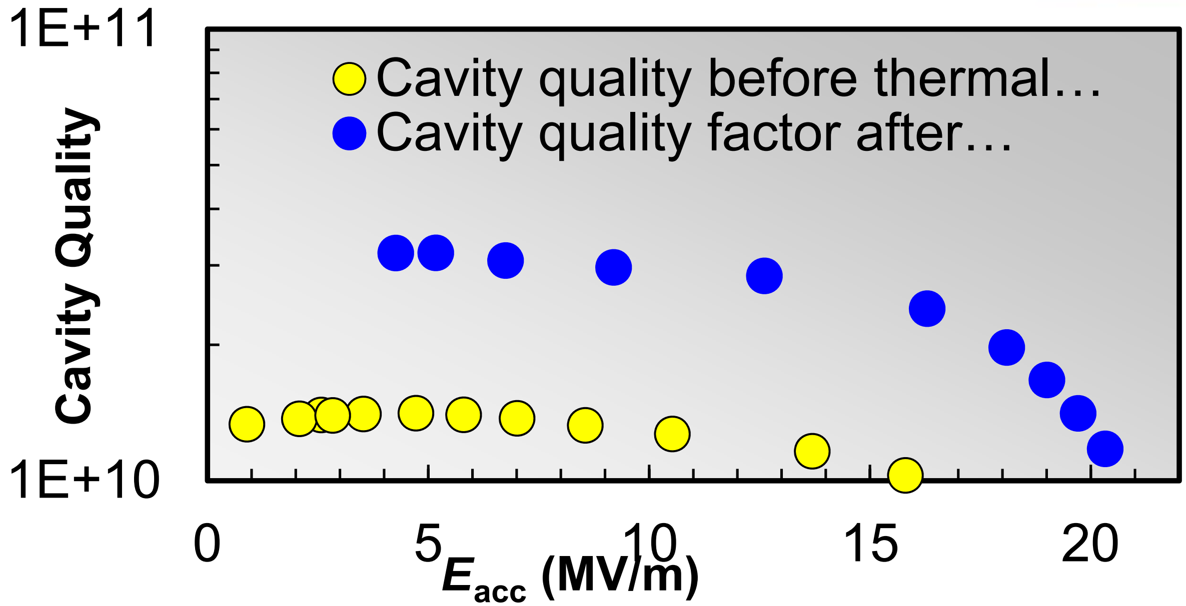
P. Dhakal et al, TUIOC04, SRF 13

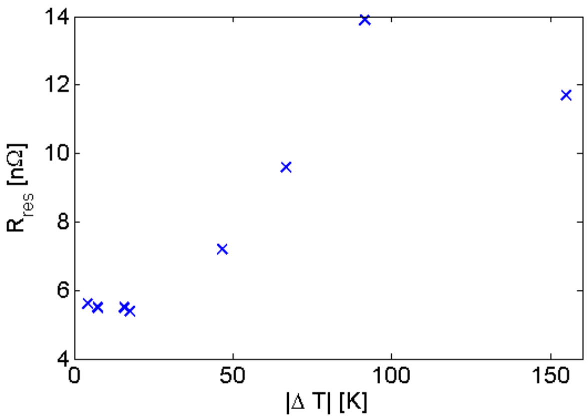
- **RRR ~ 40**
- **Extended Q- rise up to 35 mT with factor of 2 improvement in Q at 20 MV/m**
- **Cavity was purified in the presence of Ti and surface removal of ~30 μm before the baseline test**

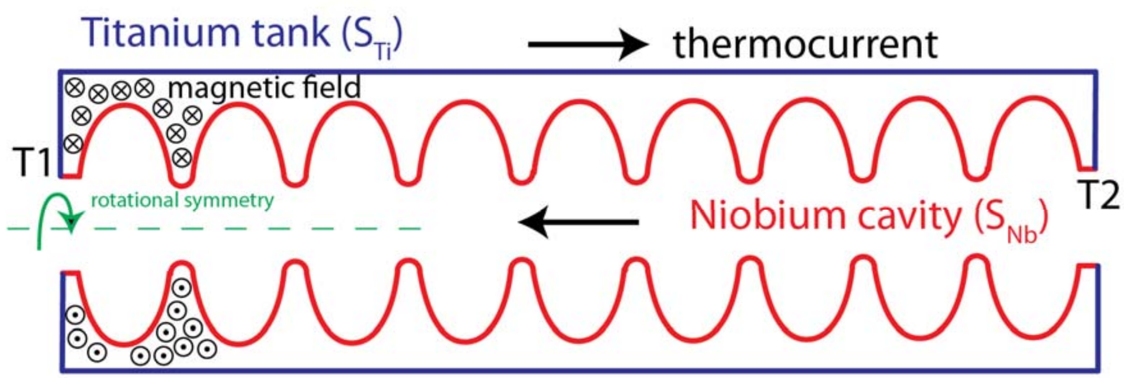


Note: In early 80's those high Q cavities are made from reactor grade and heat treated at very high temperatures.

Thermal Cycling @ HZB







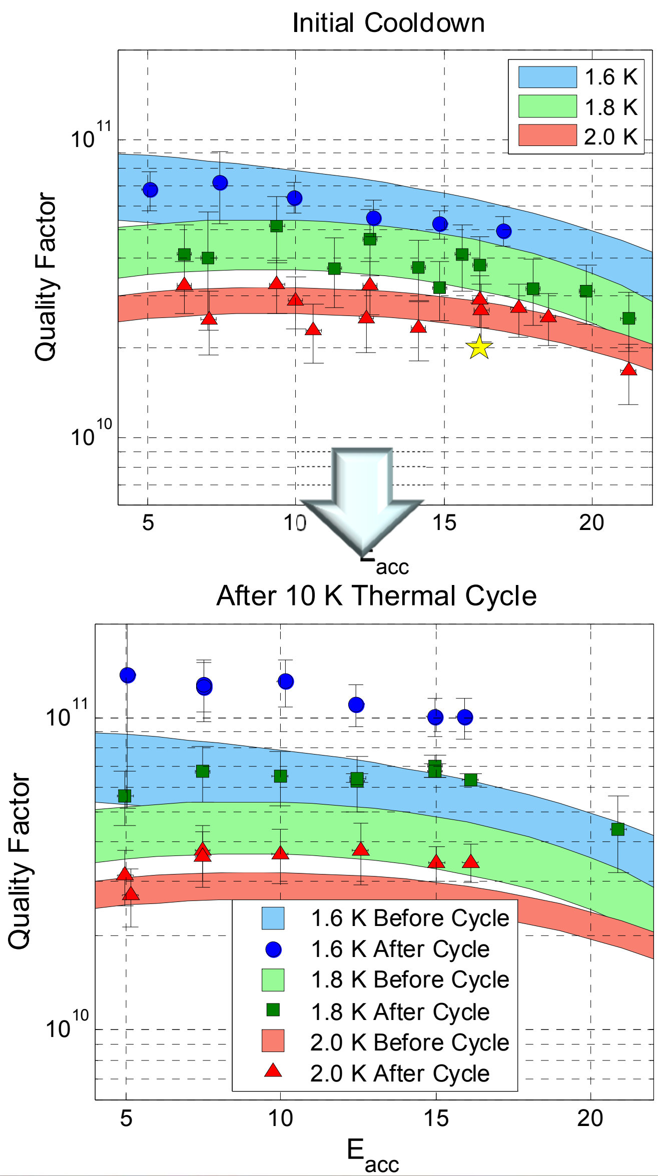
$$U_{thermo} = (S_{Niobium} - S_{Titanium}) \cdot \Delta T$$

The temperature gradient across the cavity need to be minimized

Oliver Kugeler
Julia Vogt

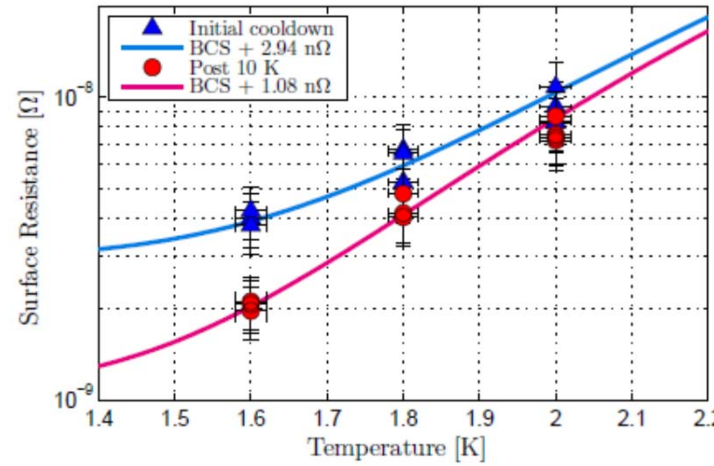
High Q Cavities for the Cornell ERL

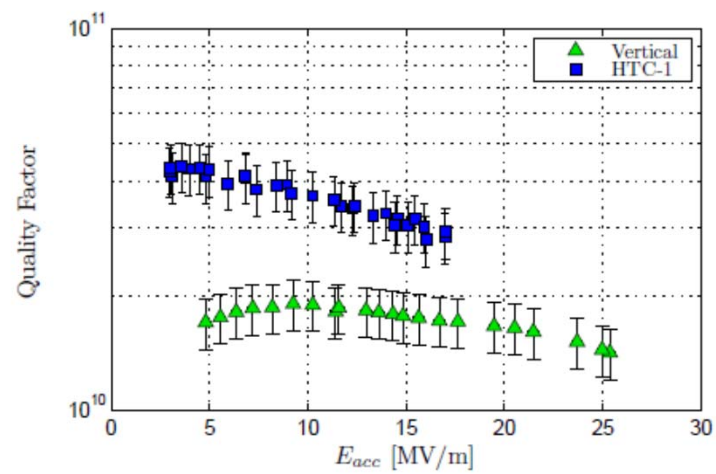
Ralf Eichhorn



Initial Cool down
at 16.2 MV/m
Q(2.0 K) = 2.5 x 10^{10}
Q(1.8 K) = 3.5 x 10^{10}
Q(1.6 K) = 5.0 x 10^{10}

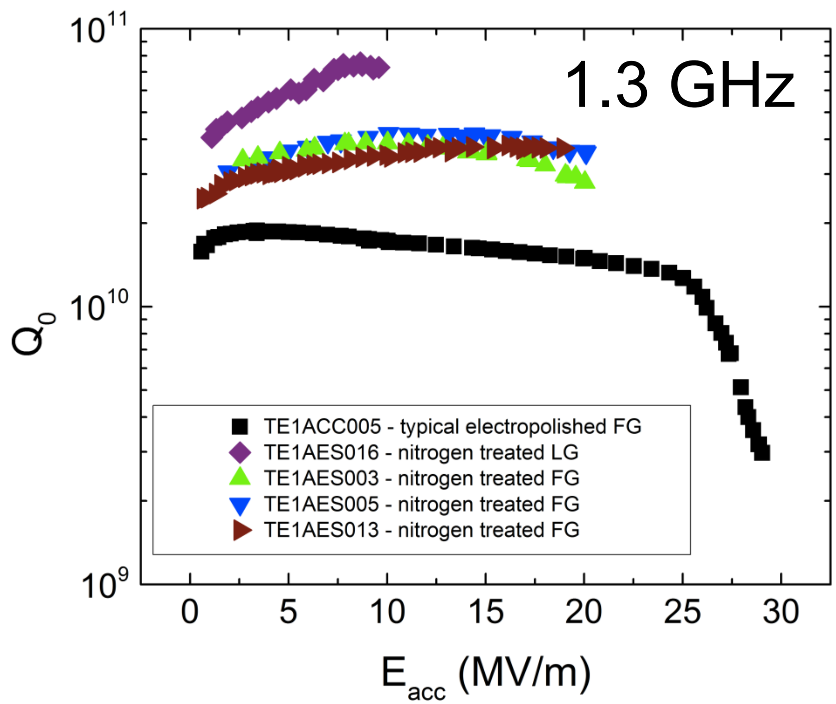
10 K thermal cycle
at 16.2 MV/m
Q(2.0 K) = 3.5 x 10^{10}
Q(1.8 K) = 6.0 x 10^{10}
Q(1.6 K) = 10.0 x 10^{10}

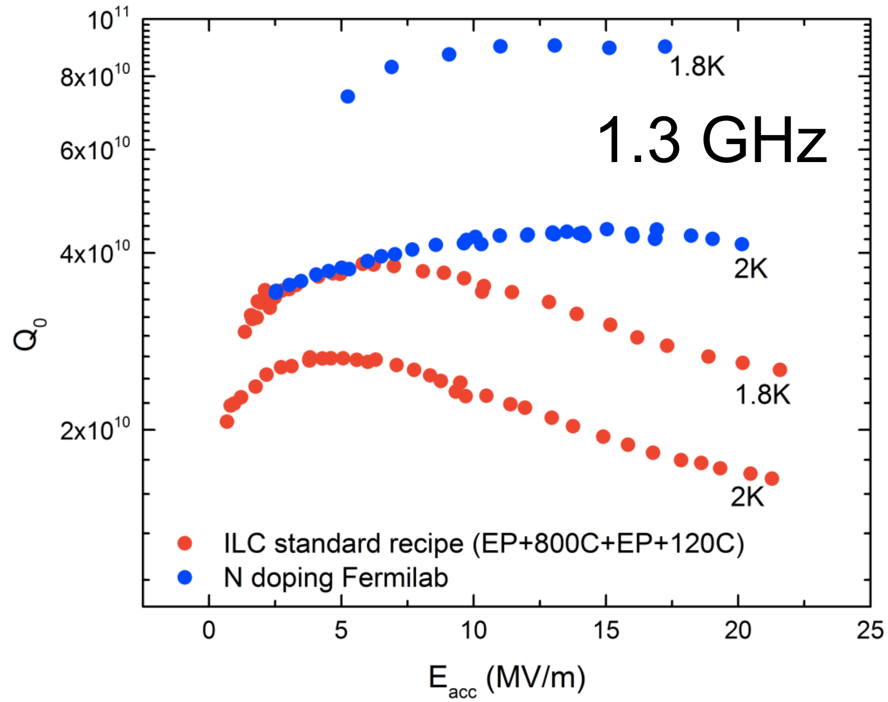




Fermi Lab Nitrogen Doping

Fermi Lab started to inject gas in furnace during HT after the initial encouraging results from JLAB

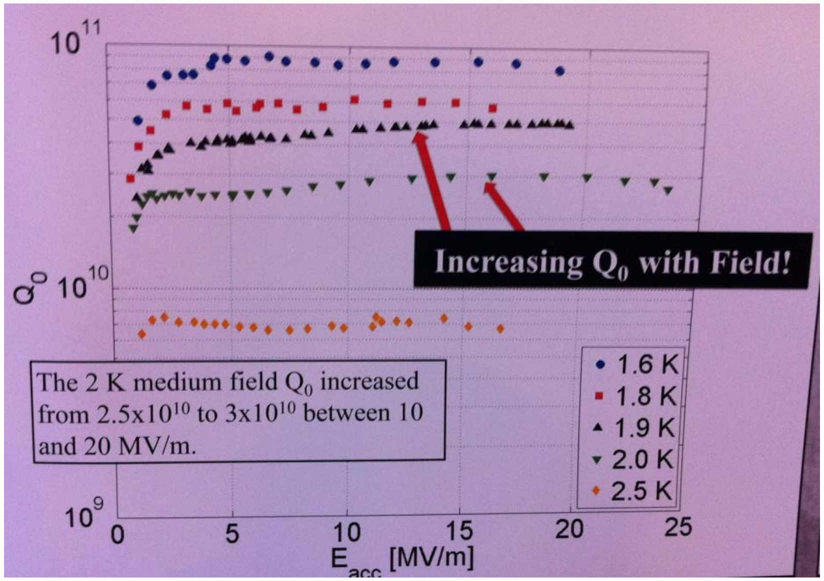


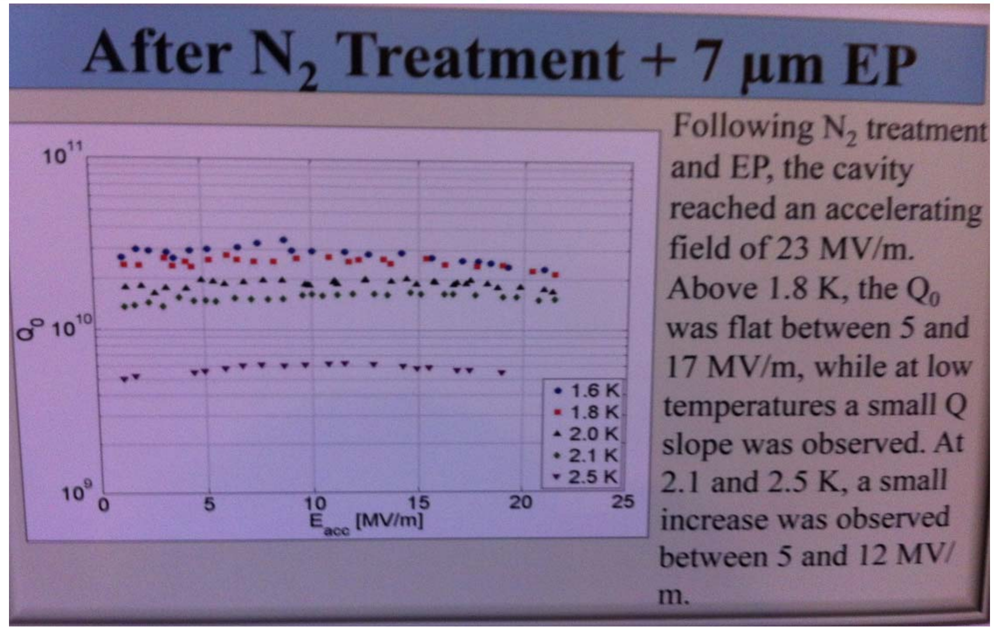


Low field Q-rise similar to that observed at JLAB

Anna Grassellino

Cornell Experience with Nb doping

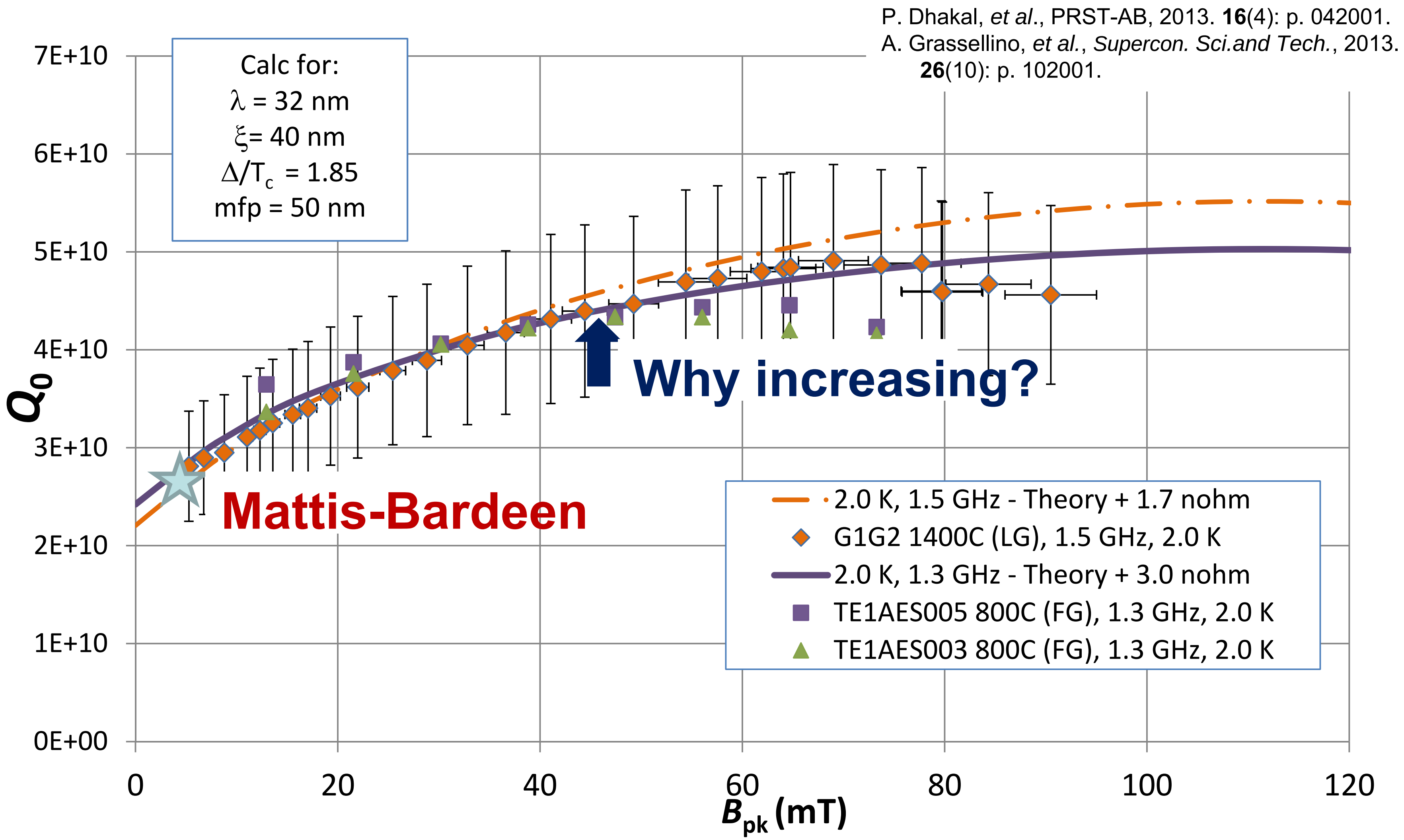




- Rapid low field Q-rise and tend to saturate at high field
- No clear evidence on how much material should be removed after baking cavity in the presence of N_2

Poster from Cornell

Theoretical Buzz on Q-rise

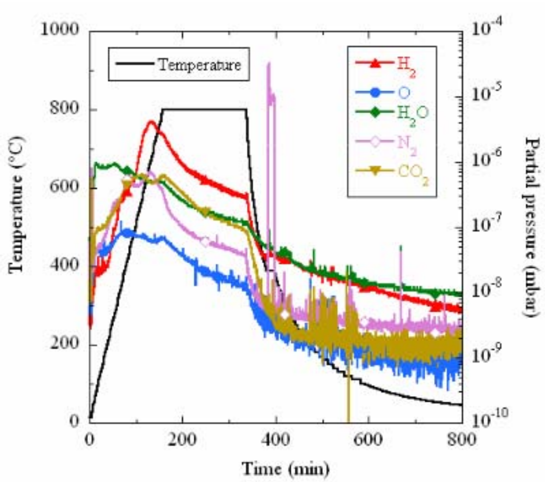


B. Xiao and C. Reece

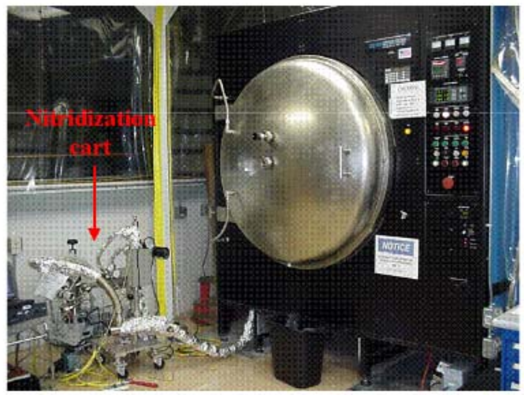
JLAB Status in High Q

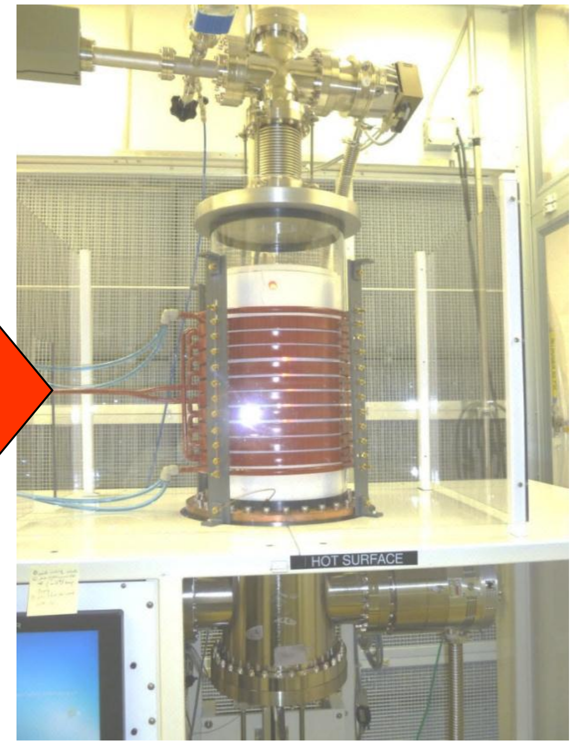
N_2 treatment procedure

- UHV Heat treatment at 800 °C/3h
- Rapid cooling to 400 °C, admit ~ 5×10^{-6} Torr N_2 for 15 min
- Cool to 120 °C and hold for 12 h (optional)
- No chemical etching afterwards!!! Just degreasing and HPR



G. Ciovati et al. 2010





Induction Furnace

Dedicated furnace with controlled gas injection system

Dhakal et al, Rev. Sci. Instrum. ***83****, 065105 (2012)*

JLAB Status in High Q

- So far the heat treatment are focused on temperature as a parameter (800-1600 □C)
- Studies showed the Ti doping in SRF cavities, cause the extended Q-rise
- Sample studies with point contact tunneling, magnetizations and AC susceptibility are underway
- Nitridation in cavities with optimal partial pressure of nitrogen, eliminating final chemistry.

High Q Status

- Search for high Q is an ultimate goal for the future CW accelerators
- Current research is mostly Trial and Error, and lack the physics based research
- Samples studies from the cavity cut out as well as from coupons to understand the loss mechanism is necessary.
- The high Q has been observed in contaminated surface. The role of contaminant in Nb as well as its interactions with other interstitial impurities (H, O, N, C), dislocations and vacancies need to be understood
- The universal theoretical model that fits all Q-rise, Q-slope and Q-drop is still lacking. The current model by Xiao et al explain the extended Q-rise

Conclusions

- Several research lab are pursuing high Q research in both R&D SRF cavities as well as cryomodules.
- Doping in the SRF cavities seem to increase quality factor, however the mechanism hasn't been understood.
- Controlled experiments as well as the sample studies are needed.