LINAC14 報告

2014.9.24

阪井寛志

Linac14の会場

場所はスイスジュネーブ

会場はCICG
(Centre International de
Conferences Geneve)
というところ。

会場の中は大きく国際会議場の
机は一人一人が質問できるような
マイクが付いていた。

発表全体

発表全体の私の印象：下の赤部分が超伝導空洞を使った実験およびprojectの口頭発表。全体の約半数を占めている（linacの参加者に聞いたところこんなに多いのは初めてとのこと）。特にproton&ionビームでのCW加速のために超伝導空洞を使った計画の話が多かった。今回は電子加速の超伝導空洞を使った関係の話と最近のtopicについて再度話していく。（下記青四角部＋α）詳しくはhttps://oraweb.cern.ch/pls/linac2014/TOC.htm

Monday, 1 Sept.

M01	Chair: Roland Garoby
08:00	Registration
09:00	Welcome
09:30	Linear Collider Studies / Steinar Stapnes
10:00	Commissioning of the Low Energy Part of Linac4 / Alessandra Lombardi
10:30	coffee break
M02	Chair: Yoshishige Yamazaki
11:00	Early Commissioning and Operation in 12 GeV CEBAF + Future Upgrade Plan / Michael Spata
11:30	Optimizing RF Linacs as Drivers for Inverse Compton Sources the ELI-NP Case / Cristina Vaccarezza
11:50	Generation and Acceleration of Low Emittance, High Current Electron Beams for Super-KEKB / Mitsuhiro Yoshida
12:10	Current Status of PAL-XFEL / In Soo Ko
12:30	lunch break
M03	Chair: Alexander Alexandrov
14:00	Status of Superconducting Electron Linac Driver for Rare Ion Beam Production at TRIUMF / Robert Laxdal
14:20	Single-Knob Beam Line for Transverse Emittance Partitioning / Chen Xiao
14:40	Model and Beam Based Setup Procedures for a High Power Hadron Superconducting Linac / Andrei Shishlo
MOPL	Chair: Deepak Raparia
15:00	Oral posters
16:00 - 18:00	Poster session
15:00	CERN Technology Transfer Programme: Accelerating Science &

Tuesday, 2 Sept.

TU1	Chair: Yong Ho Chin
08:30	Status of Swiss FEL / Hans-Heinrich Braun
09:00	R&D Efforts for ERLs / Ralf Eichhorn
09:30	The MAX IV Linac /
09:50	The New LCLS-II Project Status and Challenges / John Galayda
10:10	High Power Industrial Accelerator ILU-14 for E-beam and X-ray Processing / Alexander Bryazgin
10:30	coffee break
TU2	Chair: Milorad Popovic
11:00	C-ADS Linac R&D Progress / Hongwei Zhao
11:30	Beam Commissioning of the 100 MeV KOMAK Linac / Yong-Sub Cho
11:50	Commissioning of Energy Upgrade Linac of J-PARC / Kazuo Hasegawa
12:10	Linac Construction Status of CSNS Project / Sheng Wang
12:30	lunch break
TU3	Chair: Graeme Burt
14:00	Large Scale Testing of SRF Cavities and Modules / Jacek Swierblewski
14:20	Breakthrough Technology for Very High Quality Factors in SCRF Cavities /
14:40	Nb3Sn - Present Status and Potential as an Alternative SRF Material / Sam Posen
TUPL	Chair: Subrata Nath
15:00	Oral posters
16:00 - 18:00	Poster session

Wednesday, 3 Sept.

WE1	Chair: Robert Laxdal
08:30	Construction and RF Conditioning of the Cell-Coupled Drift Tube Linac (CCDTL) for Linac4 at CERN / Alexey Tribendis
8:50	New Applications of High Gradient RF Linacs / Alexej Grudiev
9:10	New Xband and Above High Gradient Linacs / Sami Tantawi
09:30	Phase Locked Magnetrons for Accelerators / Amos Dexter
09:50	High Power RF Sources for the ESS RF Systems / Morten Jensen
10:10	Low Level RF for SRF Accelerators / Julien Branlard
10:30	coffee break
WE2	Chair: Alberto Facco
11:00	Chopping High Intensity Ion Beams at FRANZ / Christoph Wiesner
11:20	Acceleration of mA CW Proton Beams in SARAF Phase-I / Arik Kreisel
11:40	Status of RAON Heavy Ion Accelerator Project / Hyung Jin Kim
12:00	CW Heavy Ion Accelerator with Adjustable Energy for Material Science / Sergey Kutsaev
12:20 - 22:00	Outing

Thursday, 4 Sept.

TH1	Chair: Patrick Bertrand
08:30	Cost Optimized Design of High Power Linacs / Mohammad Eshraqi
09:00	Superconducting RF Development for FRIB at MSU / Kenji Saito
09:30	Status of the HIE ISOLDE Linac / Walter Venturini Delsolaro
09:50	Superconducting Cavities and Cryomodules for Proton and Deuteron Linacs / Guillaume Devanz
10:10	An 800 MeV Superconducting Linac to Support Megawatt Proton Operations at Fermilab / Valeri Lebedev
10:30	coffee break
TH2	Chair: Maurizio Vretenar
11:00	Cryogenic Plants for SRF Linacs / Dana Arenius
11:20	SPIRAL2 Cryomodule Production Result and Analyses / Pierre-Emmanuel Bernaudin
11:40	Results from the LCLS X-band Transverse Deflector with fs Longitudinal Resolution / Yuantao Ding
12:00	Student prizes (10 min) + Student poster talk (20 min)
12:30	lunch break
TH3	Chair: Alexey Tribendis
14:00	SPIRAL2 Bunch Extension Monitor / Roman Revenko
14:20	Allison Scanner Emittance Diagnostic Development at TRIUMF / Aurelia Laxdal
14:40	Operation Experience with CW High Gradient and High QL Cryomodules / Curt Hovater
THPL	Chair: Hans Weise
15:00	Oral posters
16:00 - 18:00	Poster session
19:00	Banquet

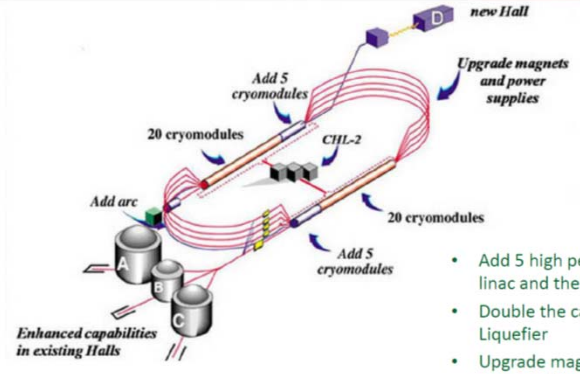
Friday, 5 Sept.

FR1	Chair: Lars Groening
08:30	Demonstration of a Cascaded IFEL / Erik Hemsing
08:50	Challenges toward Attosecond and Zeptosecond XFELs / Takashi Tanaka
09:10	RF Guns for FELs / Frank Stephan
09:30	Production of Energetic Ion Beams Using High Intensity Lasers / Zulfikar Najmudin
09:50	The Muon Accelerator Program Research Effort / Mark Palmer
10:10	AWAKE: Advanced Proton Driven Plasma Wakefield Acceleration Experiment at CERN / Edda Gschwendtner
10:30	coffee break
FR2	Chair: Frank Gerigk
11:00	Positive Trends in Radiation Risk Assessment and Consequent Opportunities for Linac Applications / Yehoshua Socol
11:30	Proton and Carbon Linacs for Hadron Therapy / Ugo Amaldi
12:00	Prospects for Accelerator Driven Thorium Reactors / Jean-Pierre Revol
12:30	Closing remarks
13:00 - 17:00	CERN tours

Early Commissioning Experience and Future Plans for 12 GeV CEBAF (1)

Michael Spata (Center for The Advanced Studies of Accelerators)

Scope of the 12 GeV Upgrade



JlabのCEBAF：12GeVの
upgradeがおわり、
いよいよビーム運転開始。

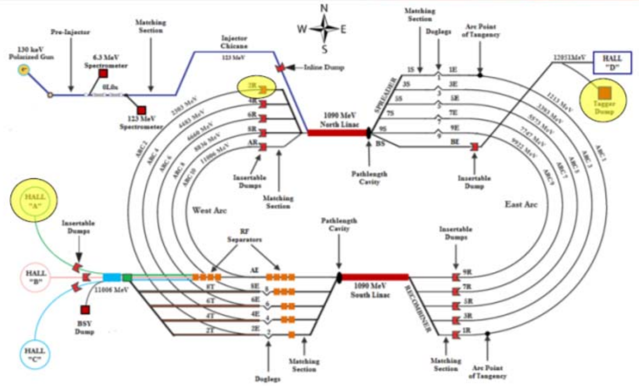
- Add 5 high performance cryomdules in each linac and their associated LLRF Systems
- Double the capacity of the Central Helium Liquefier
- Upgrade magnets and power supplies for recirculation arcs
- Upgrade Extraction, Instrumentation and Diagnostics, and Safety Systems
- Add new beamlines for Arc 10 and Hall D
- Add new experimental Hall D and upgrade existing Halls

Cryomodule Commissioning

- Between May and November of last year 415 cavities were recommssioned in advance of beam operations.
  - Measured:
    - ✓ Maximum accelerating gradient
    - ✓ Cavity Q_0s
    - ✓ Field emission survey

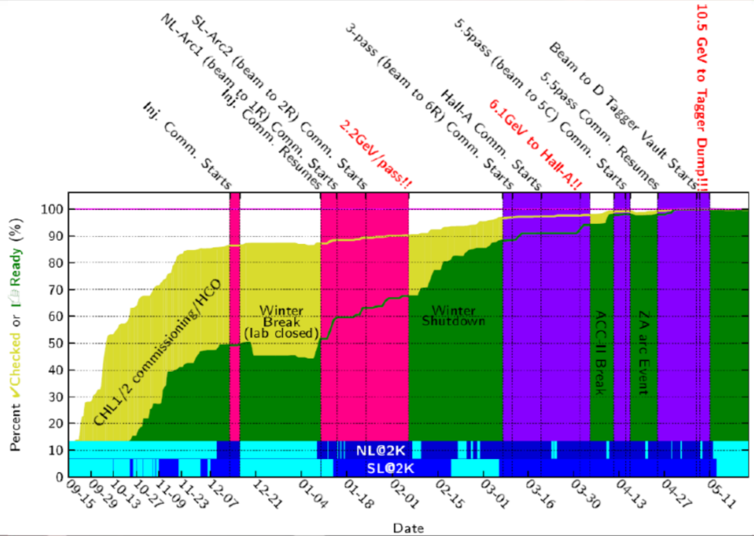
Linac	Type	Ncav	<Gmax> (MV/m)	<Q_0@Gmax >
NL	C20	120	8.61	$3.91x10^9$
NL	C50	40	11.72	$3.74x10^9$
NL	C100	40	20.86	$8.11x10^9$
SL	C20	110	9.09	$4.33x10^9$
SL	C50	47	11.55	$3.81x10^9$
SL	C100	40	19.77	$7.44x10^9$

Commissioning Milestones



- Three main goals for the November 2013 – May 2014 run period:
  - Deliver 2.2 GeV Beam to the 2R dump.
  - Deliver greater than 6 GeV beam to Hall A and run first CW beam of the 12 GeV era to an experimental Hall.
  - Deliver greater than 10 GeV in 5.5 passes to Hall D.

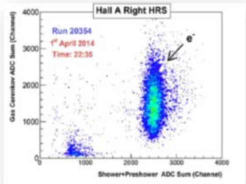
Timeline of Commissioning Progress



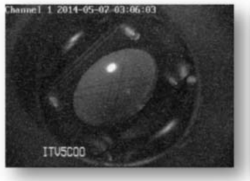
Early Commissioning Experience and Future Plans for 12 GeV CEBAF (2)

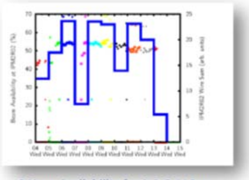
Commissioning Milestones

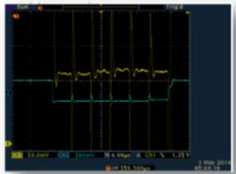

2.2 GeV Beam on ARC 2 Viewer



First data from Scattered Electrons in Hall A


10.5 GeV Beam to Hall D Ramp


8 Hour Availability for 2.2 GeV Run


Six Beams in the NL for the First Time


10.5 GeV Beam to Hall D Tagger Dump

Optimizing the SRF Performance

Run Period	Dates	Max. 5.5pass Energy	Trip Downtime Goal (% - min/hr)
ACC-III	Fall2014	11 GeV	<20% <12
ACC-IV	Spring2015	11 GeV	<17% <10
Phy-I	Fall2015	12 GeV	<20% <12
Phy-II	Spring2016	12 GeV	<17% <10
Phy-III	Fall2016	12 GeV	<13% <8
Phy-IV	Spring2017	12 GeV	<12% <7
Phy-V	Fall2017	12 GeV	<10% <6
Phy-VI	Spring2018	12 GeV	<10% <6
Ultimate		12 GeV	<5% <3

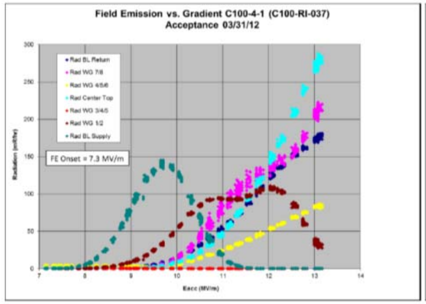
Multiple options for reaching the availability goals over time:

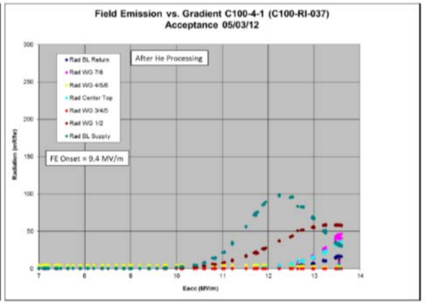
- Improve C20 trip models, maximize gradient/minimize trip rate.
- C50 program, one C50 refurbishment is in progress.
- Build more C100s.
- In-situ Helium Processing to reduce field emission.

Helium Processing

Helium Processing of a C100 Cryomodule:

- Introduce helium gas into cavity vacuum space.
- Run RF to clean cavity surfaces.
- Warm up and pump down to remove residual gas.
- Improves high-field Q, reduces x-ray production and greatly reduces incidence of arcing at the cold ceramic window.





Future Run Plans

Fall 2014 Run

- Restore 5.5 pass beam to the Hall D Tagger vault.
- Deliver CW electron beam to Hall D Tagger and first photon beam to Hall D for detector checkout.
- Commission the 499 MHz RF Separators and extraction beamlines.
- Refine beam tuning procedures.
- Study synchrotron radiation induced emittance growth in the upper passes.
- Parasitic support of an early Physics run in Hall A and Hall B.

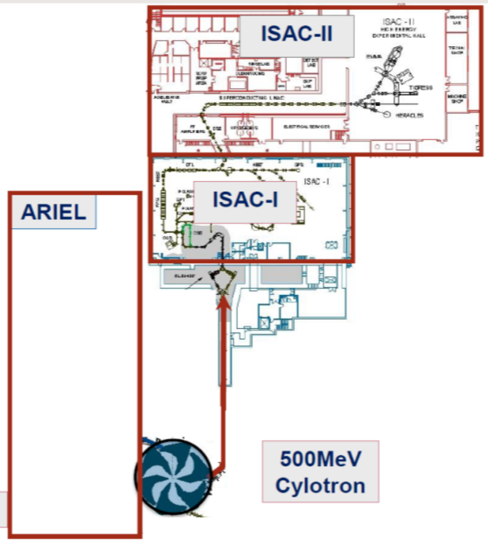
CW運転は大変だがTripを減らしていくのが課題。まずはHe processingでfield emissionのonsetを上げることをするが、C100のperformanceはいいので、C20,C50をC100にいずれ入れ替えることも、検討中。

Status of Superconducting Electron Linac Driver for Rare Ion Beam Production at TRIUMF (1)

Bob Laxdal, TRIUMF

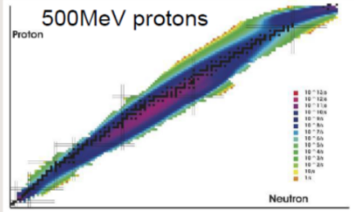
ARIEL Project (2010-2020)

- ISAC: World class ISOL facility for the production and acceleration of rare isotope beams (RIB)
- Presently utilize one driver beam at 500MeV and 50kW to create RIBs for ISAC
- Now adding ARIEL to allow up to three simultaneous RIB beams
- ~~Add e-Linac (50MeV 10mA cw - 1.3GHz SC linac) as a second~~ driver to create RIBs via photofission
- Add a second driver beam from the cyclotron

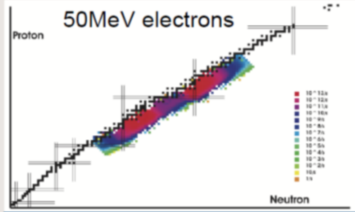


Why electrons? Why 50MeV?

- the electron linac is a strong complement to the existing proton cyclotron
  - Photofission yields high production of many neutron rich species but with relatively low isobaric contamination with respect to proton induced spallation
  - An energy of 50MeV is sufficient to saturate photo-fission production – fits the site footprint and project budget



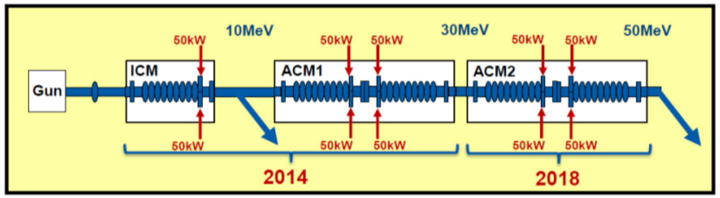
Calculated in-target production for 10 μA, 500 MeV protons incident on a 25 g/cm2 UCx target



Calculated in-target production for 10 mA, 50 MeV electrons incident on a Hg converter and 15 g/cm2 UCx target

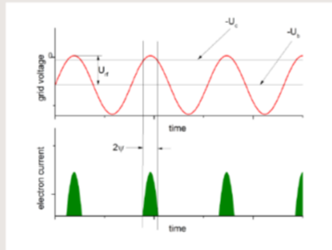
E-Linac Specifications

- The ARIEL E-Linac specification – dominated by rf beam loading
  - 10mA cw at 50MeV - 0.5 MW of beam power
  - Choose five cavities 100kW of beam loaded rf power per cavity
  - two couplers per cavity each rated for 50kW operation
  - Means 10MV energy gain per cavity
- Linac divided into three cryomodules
  - one Injector cryomodule (ICM) with one cavity
  - two Accelerator crymodules (ACM1, ACM2) with two cavities each
  - Installation is staged - Phase I – includes ICM and ACM1 for a required 25MeV/100kW demonstration by end of 2014

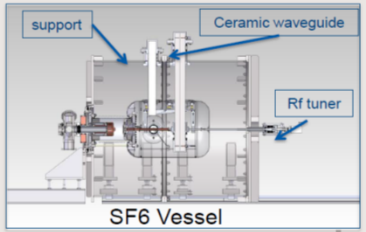


Electron Gun

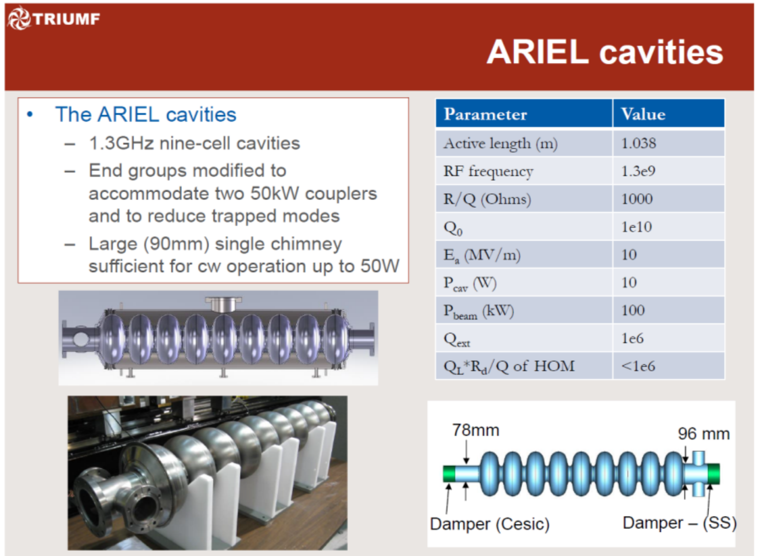
- Thermionic 300kV DC gun – cathode has a grid with DC supressing voltage and rf modulation that produces electron bunches at rf frequency
- Gun installed inside an SF6 vessel
- Rf delivered to the grid via a ceramic waveguide

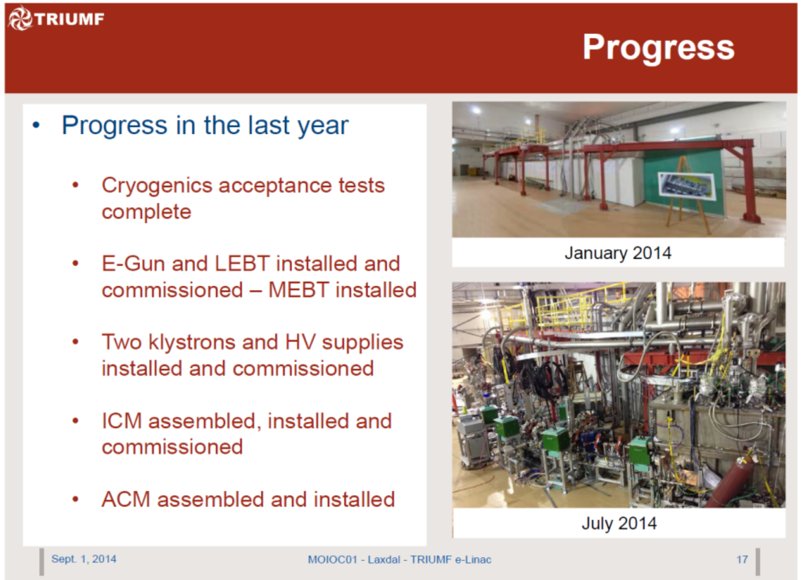


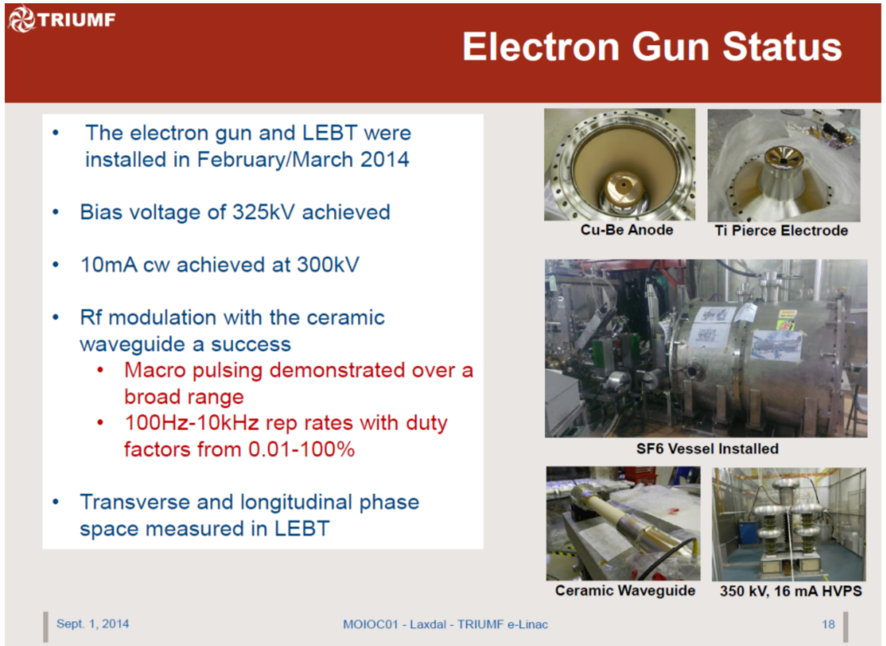
Parameter	Value
RF frequency	650MHz
Pulse length	$\pm16^0$ (137ps)
Average current	10mA
Charge/bunch	15.4pC
Kinetic energy	300keV
Normalized emittance	5μm
Duty factor	0.01 to 100%

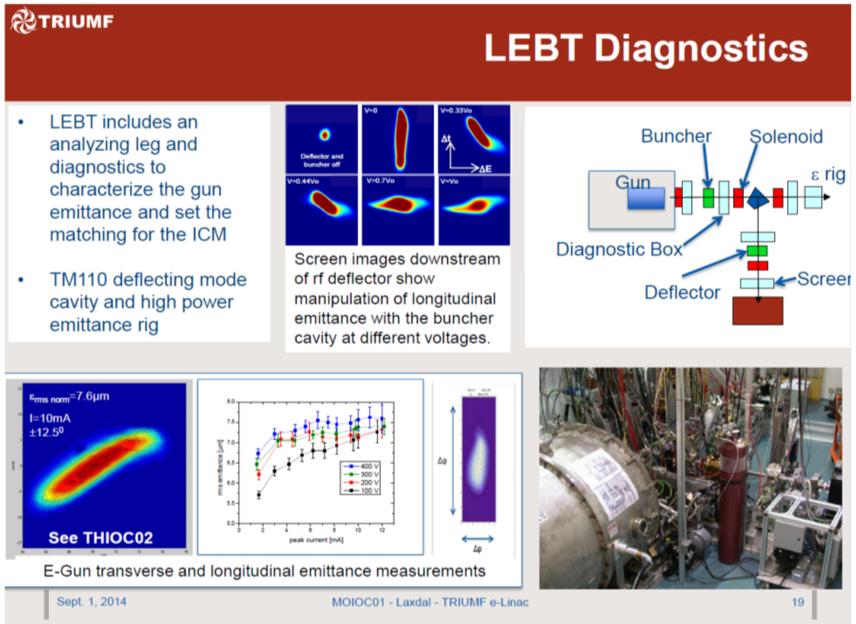


Status of Superconducting Electron Linac Driver for Rare Ion Beam Production at TRIUMF (2)



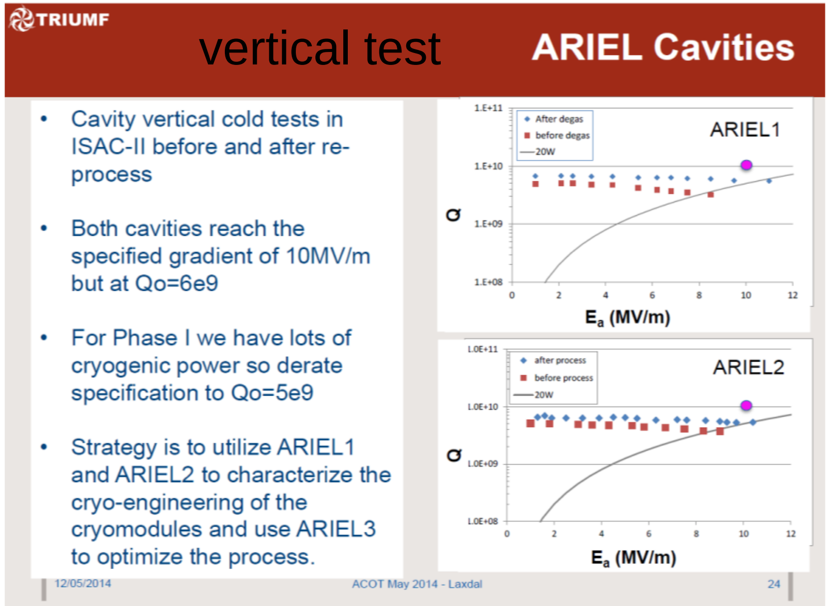


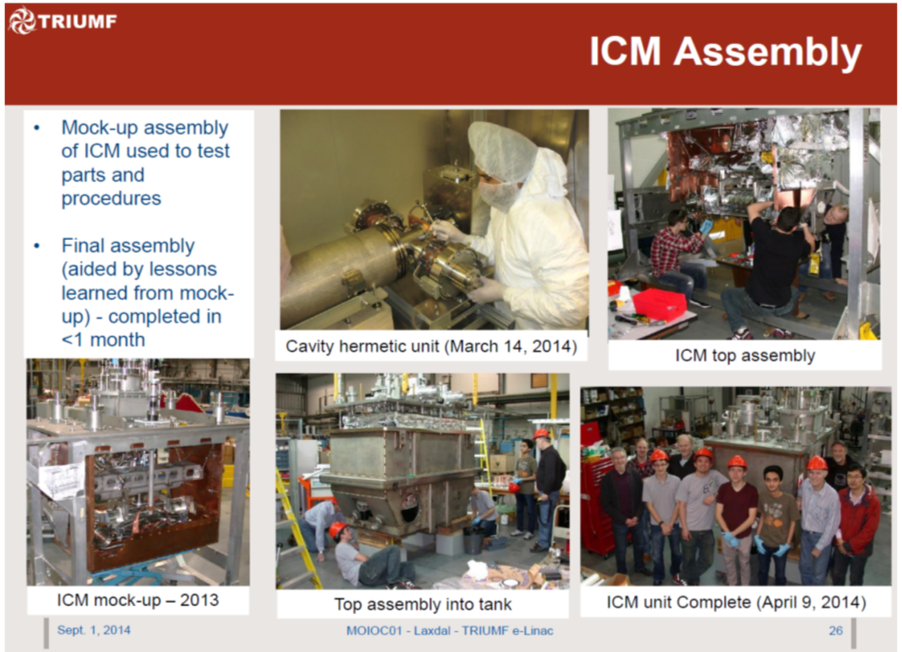


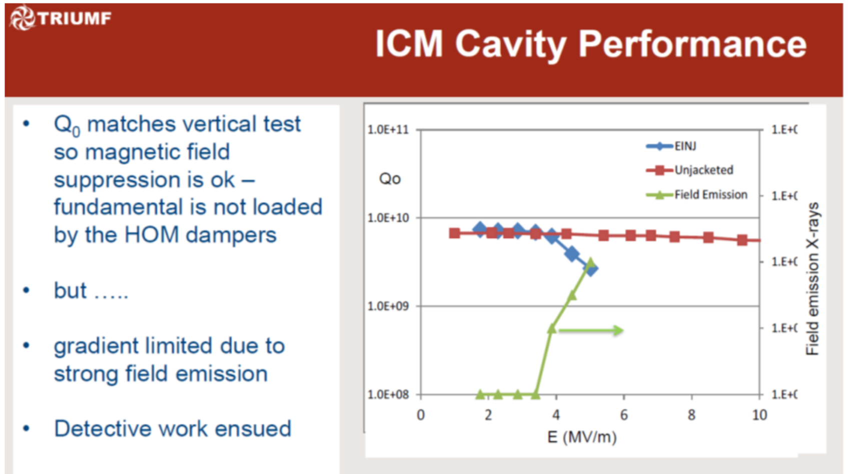


電子銃は325kVまで印加。7.6mm mrad@10mAをテストベンチにて確認。

Status of Superconducting Electron Linac Driver for Rare Ion Beam Production at TRIUMF (3)







VTで<1*10^10で9セル空洞2つを作成したが、そのうちARIEL1をjacket化してモジュールに組み込んだところ、3MV/mからfield emissionで劣化。開けたところ、SSのHOM damperが接触し、金属の粉が見られた。

R&D Efforts for ERLs (1)
Ralf Eichhorn Cornell University

Cornell以外ではBNLとKEKがメインでERLのR&Dが進んでいる感じ。ほかはBerlin、Mainz Univ.、あとCERNの計画の紹介があった。

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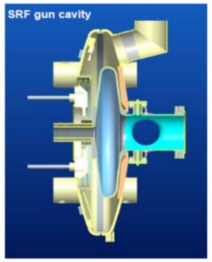
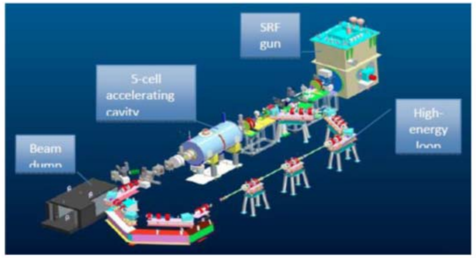
R&D ERL facility at BNL





- An ampere class 20 MeV superconducting ERL (R&D ERL) is under commissioning at BNL.
- This facility enables testing of concepts relevant for high-energy coherent electron cooling, electron-ion colliders, and high repetition rate Free Electron Lasers.
- The machine consists of an SRF photoemission injector, an SRF accelerating cryomodule, a recirculating loop, and a beam dump.

Courtesy of: Sergey Belomestnykh

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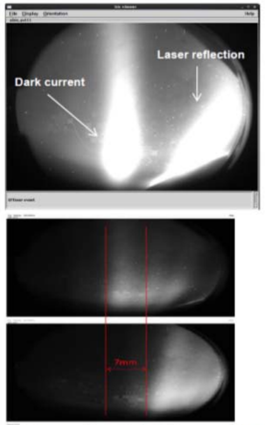
First beam commissioning at BNL



Dark current image taken at beam profile monitor during energy measurement at gun voltage settings 1.2 MV. Corrector current top 0.5 A, bottom 1 A. 7mm shift due to 0.5 A corrector change corresponds to beam energy of 1.2 MeV

- For the first beam test, a Cs3Sb cathode was fabricated and QE has been measured at 0.25% in the deposition chamber.
- During the cathode insertion into the gun and initial start of RF power, there were several instances of vacuum spiking to 1e-8 Torr range. These significantly reduced QE of the cathode to the level, where it became impossible to measure the photoemission current.
- However, a dark current was observed on a YAG screen and measured by the Faraday cup (1.4 uA at a cathode field of 15 MV/m). Gun has been running with 40 msec pulses with 1 second interval during the dark current measurements. Measurements of the dark current energy agree with RF gun voltage calibration.
- The low power beam testing will continue in September after some improvements are mad to the cathode deposition chamber and transport cart.
- The ERL 1 MW beam dump is installed. Extraction line magnets vacuum components are installed as well. We plan to start the gun to beam dump test later this fall.
- After the recirculation loop is complete, we will be able to demonstrate energy recovery with high charge per bunch and high beam current. These experiments are planned for 2015.

Courtesy of: Sergey Belomestnykh

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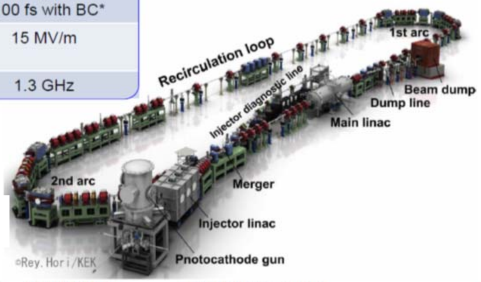
Compact ERL @ KEK

Design Parameters of cERL	
Maximum beam energy	35 MeV (upgradable to 125 MeV)
Injector energy	5 MeV (10 MeV in future)
Beam current (initial goal) (long-term goal)	10 mA 100 mA
Normalized emittance @bunch charge	0.3 mm·mrad @7.7 pC 1 mm·mrad @77 pC
Bunch length (rms)	1 - 3 ps ~100 fs with BC*
Accelerating gradient (main linac)	15 MV/m
RF frequency	1.3 GHz

*BC : bunch compression

Purpose of the Compact ERL

- To demonstrate the generation and recirculation of ultra-low emittance beams
- To demonstrate reliable operations of our ERL components (photocathode gun, SC cavities, ...)
- Initial goal: 1 mm·mrad @7.7pC/bunch(10mA)



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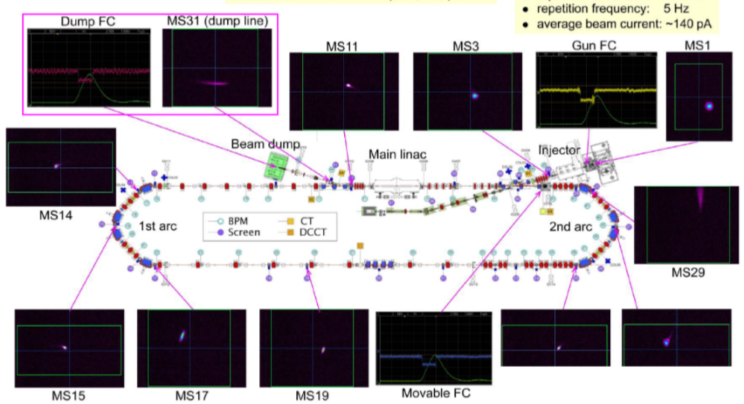
Beam Recirculation & Energy Recovery

Beam was successfully transported to the beam dump in Feb. 6, 2014.

Beam energy
- Injector: 2.9 MeV
- Recirculation loop: 19.9 MeV

Acceleration parameters
- Gun voltage: 390 kV Buncher: OFF
- Injector cavities: E_{acc} = (3.3, 3.3, 3.1) MV/m
- Main-Linac cavities: Vc = (8.57, 8.57) MV

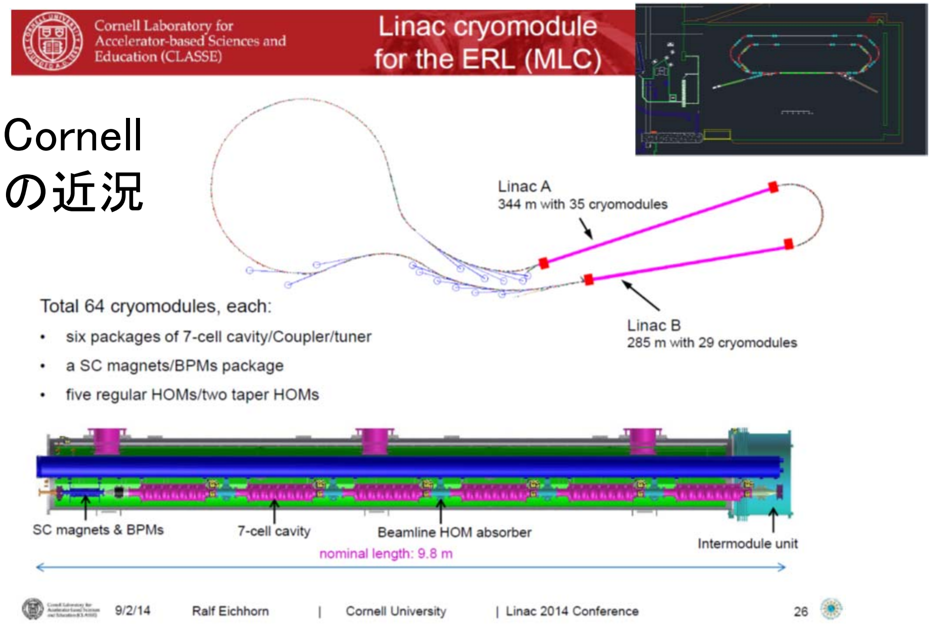
Beam parameters
- peak current: ~24 μA
- macropulse width: 1.2 μs
- repetition of bunches: 1.3 GHz
- repetition frequency: 5 Hz
- average beam current: ~140 pA

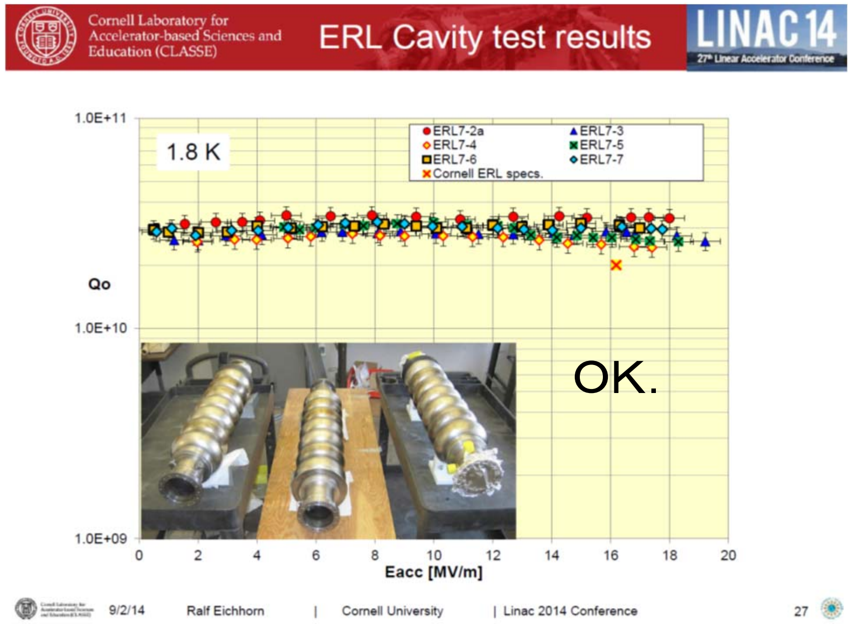


R&D Efforts for ERLs (2)

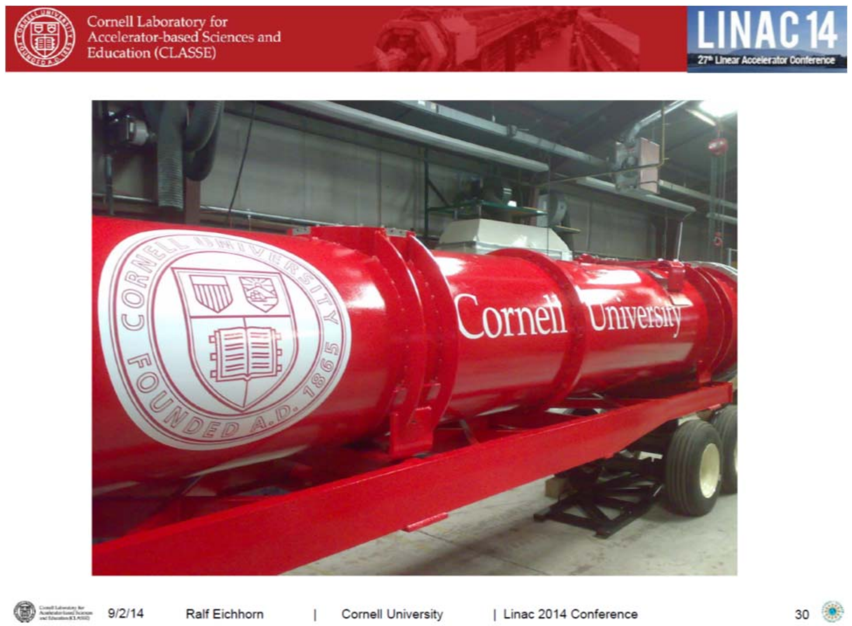
Cornellではinjectorビームテストは2013年以降行っていない75mAがmax。現在は7cell6空洞入りのモジュールの組立をメインい行っている。3空洞のモジュールの組立まで終了。

Cornell
の近況





OK.



The first beam recirculation and beam tuning in the Compact ERL at KEK
Shogo Sakanaka (presenter Hiroshi Sakai)

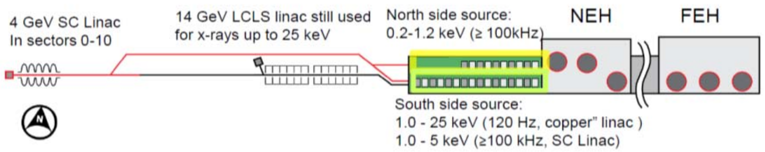
ちなみに坂中さんの代わりにcERLに関しては私からporter oralにて発表。内容が単純だったのがむしろ皆さんにシンプル（それでも5分ギリギリでしたが） に聞こえたようでした。PosterにてBNL、Jlab、Cornell、他からCongratulationを頂いた。詳細を聞きに（特にエネルギー回収の図）やtwo beamの調整の仕方、 High chargeのときの様子などを色々興味深く聞いてきた。 あと、今後どうするのかという質問もあり、high charge＆high current (100uA)と同時に 利用でCompton X-rayをやるということをいうと100uAはステキだという言葉と同時にやはり、他（どこか忘れた）からは加速器だけの運転だけっていうのはだめで 利用がないとだめだねというニュアンスのことも言われた。

The New LCLS-II Project: Status and Challenges

John N. Galayda

A New LCLS-II Project Redesigned in Response to BESAC

Accelerator	Superconducting linac: 4 GeV
Undulators in existing LCLS-I Tunnel	New variable gap (north) New variable gap (south), replaces existing fixed-gap und.
Instruments	Re-purpose existing instruments (instrument and detector upgrades needed to fully exploit)



2014年４月にKEKにTorとM.C Rossが発表した内容からの進展はN2 dopingの空洞関係がメイン。(後に示す。)

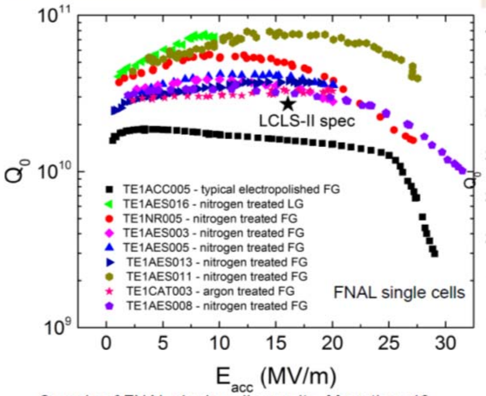
Fermilab-developed ‘gas-doping’ process →

- *A. Grassellino, et al., “New insights on the physics of RF surface resistance”, TUIOA03, 2013 SRF Conference, Paris, France*
- A cavity processing recipe that results in high quality factors (>3E10) at operating gradients between 10 and 20 MV/m.
- Starting 2/2014, Fermilab has led a “Qo for LCLS-II” program in collaboration with Cornell and JLab.
- The primary goal is to develop a reliable and industrially compatible processing recipe to achieve an average Q0 of 2.7E10 at 16 MV/m in a practical cryomodule; minimum 1.5E10.
- To reach this goal, the collaborating institutions processed and tested single-cell and 9-cell 1.3 GHz cavities in a successive optimization cycle.
- The deliverable is industrial capability and cost-effective production yield.
  - Supporting the cryoplant design choices

LCLS-IIの空洞の要求receipeにHigh Qが入っている。

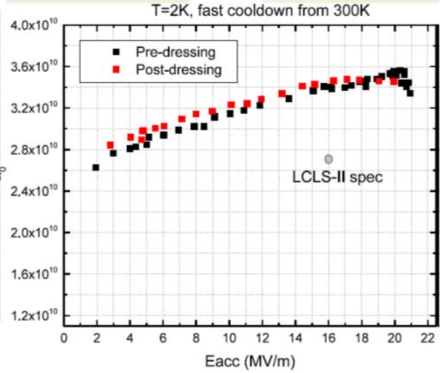
２つの方法（後述）

Nitrogen Doping to enable 4 GeV linac, 4 kW Cryoplant
A Breakthrough for CW linac performance



Sample of FNAL single cells results. More than 40 cavities have been nitrogen treated so far systematically producing 2-4 times higher Q than with standard surface processing techniques.

N2 doping



First high Q dressed cavity preserving identical performance pre-post dressing

N2 cav Fast cooling (jacketつき)

High Q0 R&D program making rapid progress

High Q0 testing done at 3 labs: Fermilab (from 2012), JLab, and Cornell

MOPP054
Continuous-wave horizontal tests of dressed 1.3 GHz SRF cavities for LCLS-II
A. Hocker, et al.

TUIOC02
Breakthrough technology for very high quality factors in SCRF cavities
A. Romanenko

TUPP138
Analysis of New High-Q0 SRF Cavity Tests by Nitrogen Gas Doping at Jefferson Lab
C.E. Reece

High Q0 Program 9 cell results – ***inclusive*** (through August 5)		
	Q0	E_acc (MV/m)
Average	3.14E+10	18.3
Number of 9 cell tests		Number of test cavities
22		11

Includes 2 horizontal tests (and one dressed-cavity VTS)
Only one vertical test Q0 below 2.3E10

次に続く

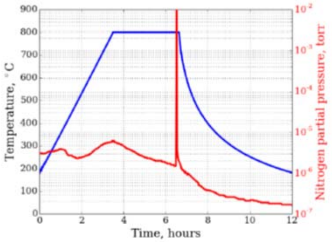
Breakthrough Technology for Very High Quality Factors in SRF Cavities (1)

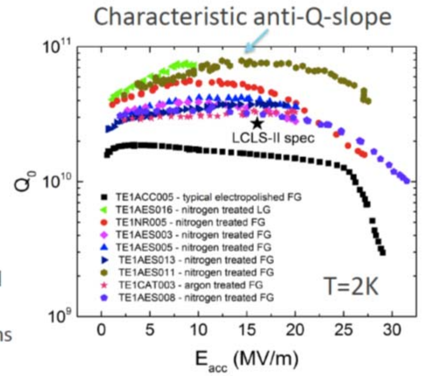
Alexander Romanenko

まずは①N2 doping

先ほどのLCLS-IIのQ0のベースを作ったbreakthroughについて2つ紹介。

Breakthrough in quality factor: nitrogen doping



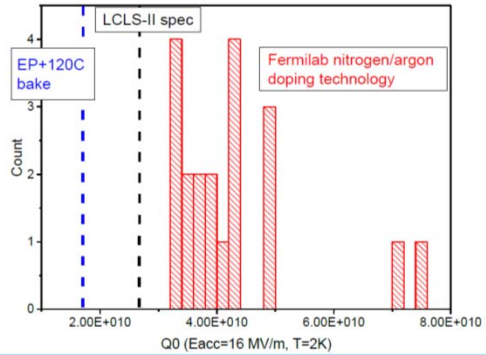


- Injection of small nitrogen partial pressure at the end of 800C degassing followed by several ums of EP-> drastic increase in Q
- Reproduced on tens of 1- and 9-cell cavities at FNAL

A. Grassellino et al, 2013 Supercond. Sci. Technol. **26** 102001 (Rapid Communication)

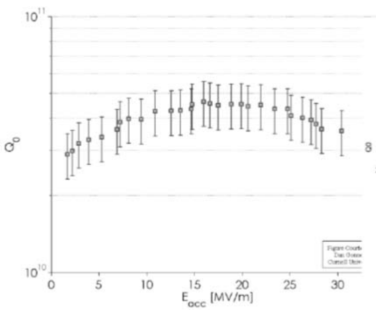
Doping is easily reproducible process

	N total	Mean	Standard Deviation	Minimum	Median	Maximum
Q0	20	**4.3e10**	1.2e10	3.2e10	**4.0e10**	7.4e10

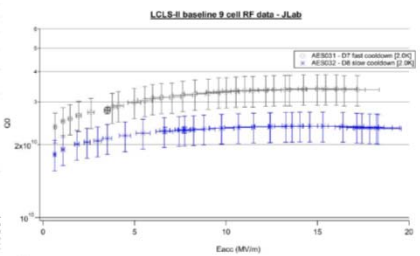


Obtained Q several times above state-of-the-art

Reproduced at other labs in 1- and 9-cells

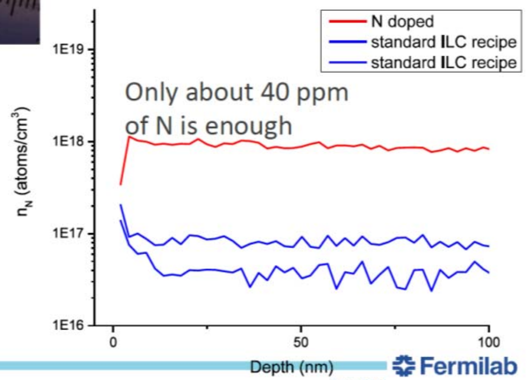


Cornell



JLab

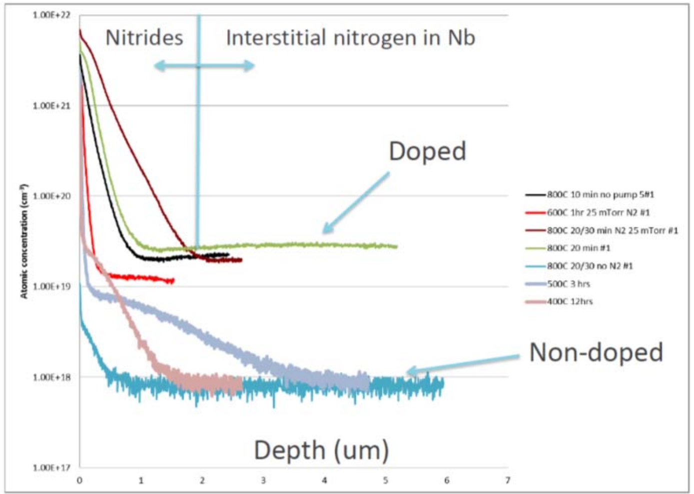
Cutouts from N doped cavities - SIMS



Breakthrough Technology for Very High Quality Factors in SRF Cavities (2)

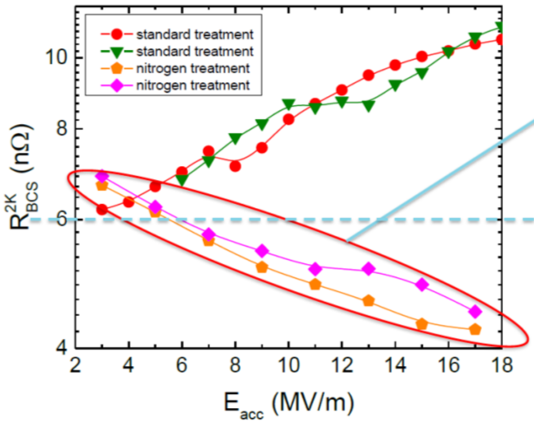
①N2 doping続き

What does N treatment do? N depth profiles by SIMS



Physics – origin of the effect

$R_s(T) = R_{BCS}(T) + R_{residual}$



Anti-Q-slope emerges from the BCS surface resistance decreasing with field

This is what Mattis-Bardeen theory predicted to be the lowest possible surface resistance for Nb -> we breached it!

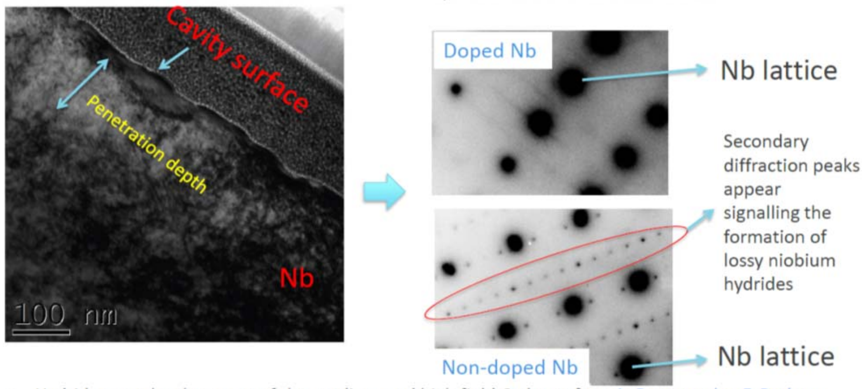
A. Grassellino et al, 2013 Supercond. Sci. Technol. **26** 102001 (Rapid Communication)
A. Romanenko and A. Grassellino, Appl. Phys. Lett. **102**, 252603 (2013)

Nanostructural studies provide first clues

Y. Trenikhina (IIT/FNAL), A. Romanenko – to be published

TEM on FIB-prepared cutouts

Electron diffraction patterns from the penetration depth taken at 94K reveal the difference



- Hydrides may be the cause of the medium and high field Q slopes [see A. Romanenko, F. Barkov, L. D. Cooley, A. Grassellino, 2013 Supercond. Sci. Technol. 26 035003]
- Nitrogen doping may fully trap hydrogen => only intrinsic Nb behavior is then manifested?

Some possible mechanisms for intrinsic Nb behavior leading to increasing Q with field

- Momentum of Cooper pairs changes the DoS
  - B. P. Xiao et al, Physica C **490** (2013) 26-31
- Quasiparticle energy distribution deviates from thermal equilibrium
  - P. J. de Visser et al, Phys. Rev. Lett. **112**, 047004 (2014)
- Time-dependent DoS
  - A. Gurevich, Phys. Rev. Lett. 113, 087001 (2014)

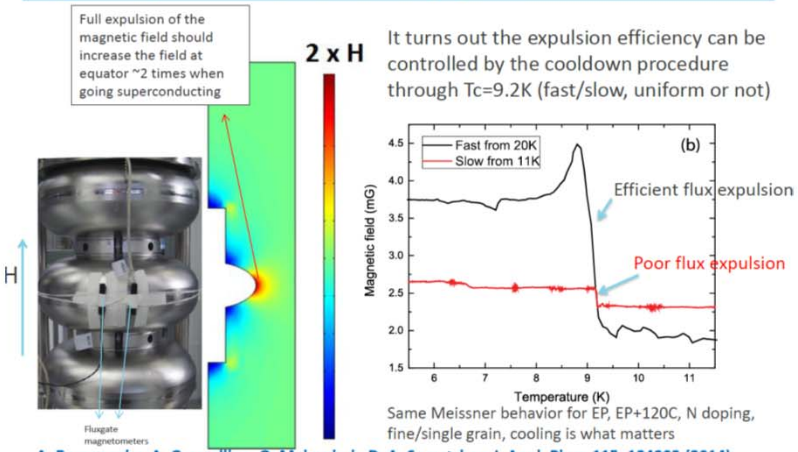
N2 dopすることで空洞内面までN2 richになる。そのせいかわからないが、Niobium hydrideがなくなり、Rresのロス成分が少なくなる。但し、まだ詳細は分かっていない。→ KEKでもN2 dopingをやるべし。

Breakthrough Technology for Very High Quality Factors in SRF Cavities (3)

②fast cooling

cooldown rate and thermal gradients around Tc drastically affect the Meissner effect and can be used to achieve ultra-low residual resistances even in high ambient fields

Magnetic probes reveal the new physics

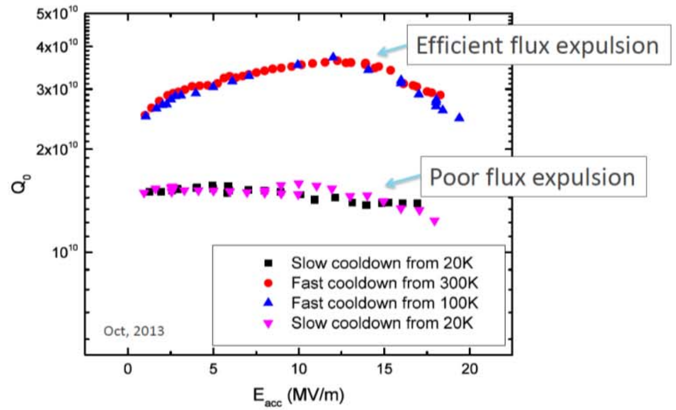


A. Romanenko, A. Grassellino, O. Melnychuk, D. A. Sergatskov, J. Appl. Phys. 115, 184903 (2014)

Fermilab

14 Alexander Romanenko | LINAC'2014 2 Sep 2014

Bare N doped 9-cell in vertical test



Fermilab

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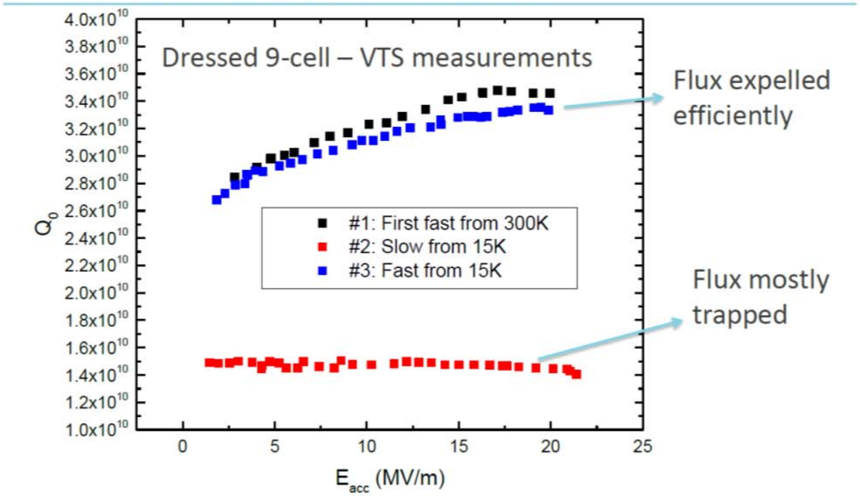
Bare/dressed cavities behave identical



Thermal currents are present but have no effect

Fermilab

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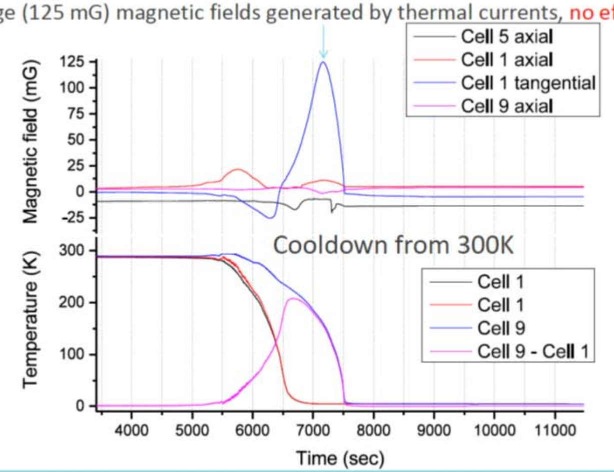
No effect of thermal currents in VTS of dressed cavities

Large (125 mG) magnetic fields generated by thermal currents, no effect on Q



Fermilab

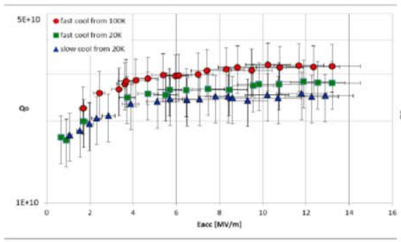
Alexander Romanenko | LINAC'2014 2 Sep 2014

2013年８月に報告したTTC-CW meetingではジャケットと空洞の異材(Nb,Ti)によりthermal currentが流れるため、温度差をつけないようにslow coolingすることでHigh Qが可能とHZBの結果は示していたが、Fermiではむしろfast coolingによりHigh-QをVTで達成している。

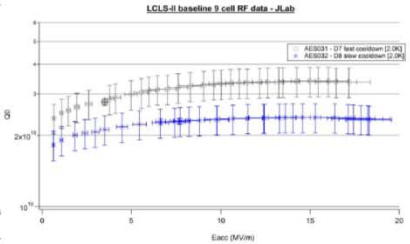
Breakthrough Technology for Very High Quality Factors in SRF Cavities (4)

②fast cooling続き

Confirmed at Cornell and Jlab – VTS and HTS



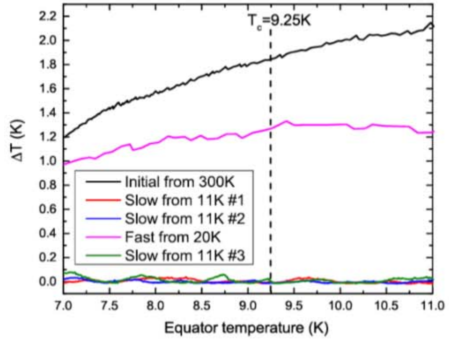
Cornell HTS measurements of the Fermilab N-doped 9-cell [See MOPP018]



JLab VTS data on a 9-cell [See TUPP138]

Possible mechanism #1

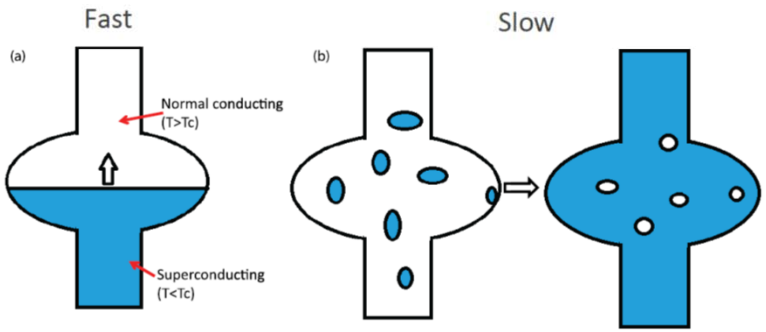
- Thermal gradient at the superconducting/normal conducting boundary is aiding the flux expulsion => the higher dT/dx the better (fast and from higher temperature preferred)
- See [**J. Appl. Phys. 115, 184903 (2014)**] for details



Example of thermal difference across the 1-cell cavity

Possible mechanism #2

- See [**J. Appl. Phys. 115, 184903 (2014)**] for details



For this mechanism uniformity is "bad" -> leads to islands

Conclusions

- We have two new breakthroughs increasing the Q
  - Nitrogen doping
    - Doped cavities become even more efficient at higher fields
  - Efficient flux expulsion
    - Opens up the route to minimize the residual resistance even in poorly shielded realistic environment
      - May allow to relax the specs on magnetic shielding
- Exciting time in SRF
  - We will follow the science of these discoveries further and see where it leads us

Slow coolingの方が磁束をtrapしやすいという説明。ほんまか？いずれにせよこの2つでQ0が上がる可能性は開けて今SRFは面白いという結論。

Nb3Sn – Present Status and Potential as an Alternative SRF Material

S. Posen and M. Liepe, Cornell University

SRF New materialの最近の進展の１例（わかる範囲で）

Potential of Nb_3Sn

Cornell University

Increase in Q_0 via N-doping

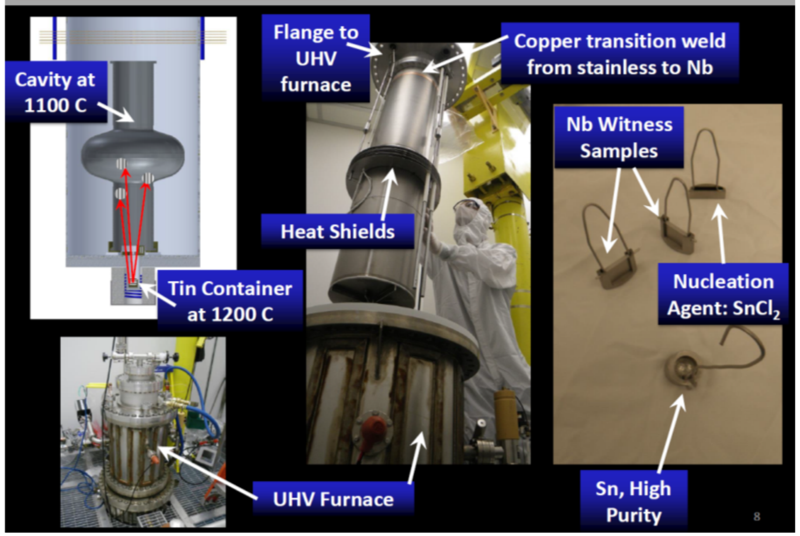
$\eta_{4.2\,K} / \eta_{2.0\,K} \approx 3.6$, simpler cryoplant

	Niobium	Nb_3Sn
Critical Temperature T_c	9 K	18 K
Q_0 at 4.2 K	6 x 10^8	6 x 10^{10}
Q_0 at 2.0 K	4-8 x 10^{10} ~~3 x 10^{10}~~	>10^{11}
Max. gradient E_{acc} (theory)	50 MV/m	100 MV/m

Approximate E_{acc} and Q_0 given for 1.3 GHz TeSLA or 1.5 GHz CEBAF cavities with R_{res} small

Halve # of cavities to reach energy?

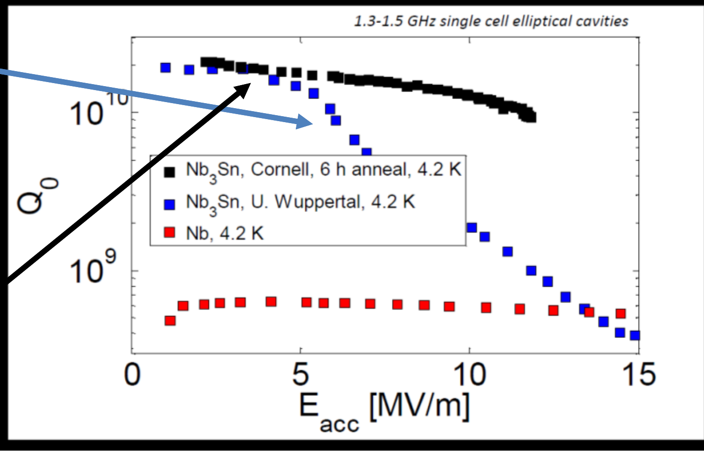
Cornell Coating Chamber



Pioneering work at Siemens AG, U. Wuppertal, K.F. Karlsruhe, SLAC, Cornell U., Jefferson Lab , and CERN
- U. Wuppertal: (1990年代??)
  – Very small Rs values in Nb3Sn cavities
  – Strong Q-slope, cause uncertain

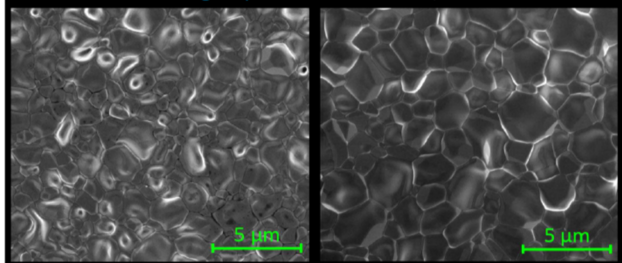
4.2 K Comparison Curves

Cornell University



6 hours annealing after Sn coating @Cornell

- Found could grow grains by factor of ~2 while maintaining desired stoichiometry by modifying Wuppertal recipe
  – Extra annealing step: Furnace at 1100 C, but tin heater off



No annealing step, average grain size ~1 μm *Anneal 6 hours, average grain size ~2 μm*

Lossはcrystal間のboundaryで起こっていた可能性が高いので、annealして結晶の大きさを増やした。

Annealingにより今までQ slopeが見られたのがなくなった。
4.2Kで1*10^10@10MV/m。--> Nb3Sn promising material

LARGE SCALE TESTING OF SRF CAVITIES AND MODULES (1)

Jacek Swierblewski

Euro−XFELの現状

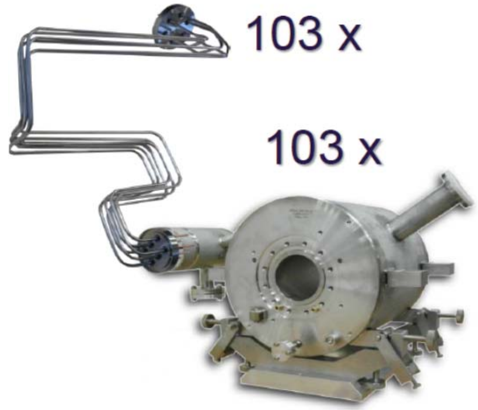
For Cavities and Cryomodules tests are involved :
AMTF Technical Coordinator
18 engineers
24 technicians

840 x

103 x

103 x

103 x



Accelerator Module Test Facility – AMTF Hall

Location: DESY campus at Hamburg

- Two cryostats
- Preparation area for cavities (6 Inserts)
- Three test stands for cryomodules

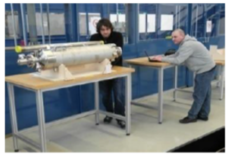
LARGE SCALE TESTING OF SRF CAVITIES AND MODULES (2)

European XFEL

Cavity Testing

Preparation and assembling

8

Main tasks:
- Incoming checks
- Assembling Cavity to the Insert
- Connecting Cavity to the vacuum line (in cleanroom conditions)
- Tuning of Fundamental Mode Rejection Filters of both HOM couplers + Cables connection
- Leak check of the Cavity
- Transport of the Insert to the cryostat + vacuum connection



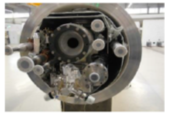

European XFEL

Cryomodule testing

Preparation and assembling

9





Main tasks:
- Unload the cryomodule from the truck
- Incoming checks
- Load the cryomodule to the movable support
- Assembling Cryomodule at the test stand
- Connecting Cryomodule beam line to the test stand under clean room conditions
- Leak check of beam line interconnections and mass spectroscopy of the beam line
- Connecting of the waveguides
- Connecting of all electrical cables
- Connect of all cryomodule process pipes to the test stands
- Leak check of cryomodule vessel (ISO-VAC)
- Leak check of cryomodule cryogenic lines
- Assembly and isolating thermal shields
- Pumping down of isolation vacuum



European XFEL

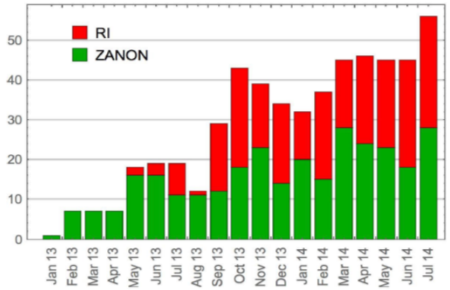
Cavity Testing

Vertical acceptance tests (Status Jul 31, 2014)

12

- Analysis of vertical acceptance tests includes
  - Series Cavities + "ILC HiGrade"-Cavities
  - NO infrastructure commissioning tests

- So far delivered: 404 cavities
- Total RF tested: 382 cavities



Average:
> 9 tests per week
since Oct 2013
(full operation of AMTF)

European XFEL

Cavity Testing

Vertical RF test conditions + acceptance criteria

13

- **Cavity "full equipped" refers to**
  - Dressed with He-tank (except of "HiGrade" cavities)
  - Equipped with fixed High Q-antenna, Pick-up and two HOM-antennas
- Only Q(E)-measurement at 2K + fundamental mode frequencies
  - All cavities checked for Q-disease by parking at 100K

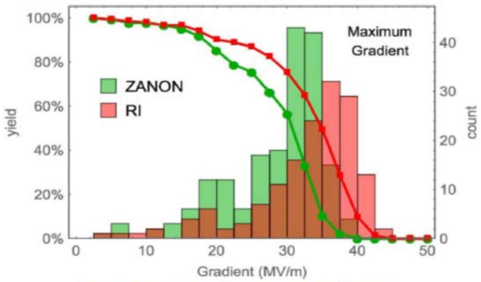
- Definition of **usable gradient**:
  - Gradient of Quench or
  - Gradient at Unloaded $Q_0 < 1 \times 10^{10}$ or
  - Gradient at X-ray level: upper detector > 1×10^{-2} mGy/min; lower detector > 0.12 mGy/min (empirical limit from FLASH cavities for different detector locations)
- **Acceptance criteria:**
  - OLD: Usable gradient **>26 MV/m** (10% margin for 23.6 MV/m design gradient)
  - NEW: Usable gradient **>20 MV/m** (after analysis of retreatment results for optimized number of tests and energy gain

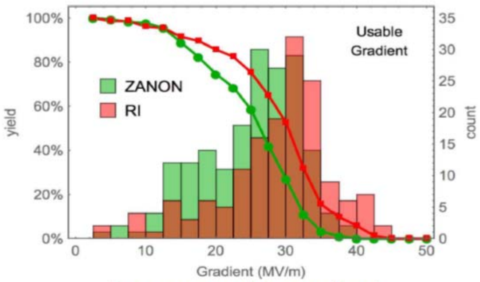
LARGE SCALE TESTING OF SRF CAVITIES AND MODULES (3)

European XFEL | Cavity Testing | VT results

Yield of gradients: "As received"

- Yield of usable and maximum gradient of **339 cavities "as received"** (EZ: 185; RI:154)





Average **maximum** gradient:
(30.4 ± 7.6) MV/m
EZ: (28.4 ± 7.1) MV/m
RI: (32.4 ± 7.6) MV/m

given errors are standard deviation

Average **usable** gradient:
(26.6 ± 7.6) MV/m
EZ: (24.8 ± 7.0) MV/m
RI: (28.6 ± 7.9) MV/m

Detailed vertical test analysis see **Poster THPP021**

RIの方ができがよい？

European XFEL | Cryomodule testing | Cryomodule (7つのmodule、8x7=56空洞

Summary of results

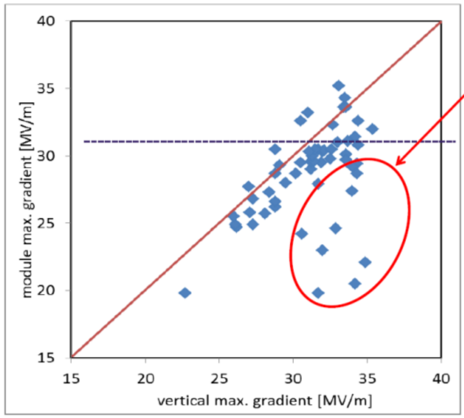
	average max. gradient **module** [MV/m]	average max. gradient **vertical** [MV/m]	Average operational gradient **module** [MV/m]	Average usable gradient **vertical** [MV/m]
XM-2	27.2	28.1	24.5	26.5
XM-1	28.2	30.8	25.1	29.4
XM1	30.3	32.5	27.6	29
XM2	27.7	32.7	25.5	28.6
XM3	30.4	32.0	28.8	29.3
XM4	28.6	33.3	23.8	30.5
XM5	27.8	28.9	24.9	26.9

All results above XFEL specs. 23.6 MV/m

European XFEL | Cryomodule testing

Vertical vs. module performance

- Comparison of maximum vertical vs. module gradient



Few cavities show significant performance reduction

From individual max. gradient

to operational module gradient:

~20% reduction

20%の空洞がcrymodule testではVTより低いgradientでlimitしている。原因は解析中。

European XFEL

Summary

- In total 840 cavities and 103 cryomodules are foreseen to test
- Testing of the cavities established, 382 tested - Status Jul 31, 2014
- Testing of the cryomodules started, 7 cryomodules tested - Status Jul 31, 2014
- Cavity and Cryomodule testing and all work flows at AMTF are well established
- Cavities and Cryomodules acceptance test performance are in average above specification
- Testing in large scale requires development of many test procedures, software improvements and trainings. It is also a big logistic challenge. This have been succeed with help of DESY experts.

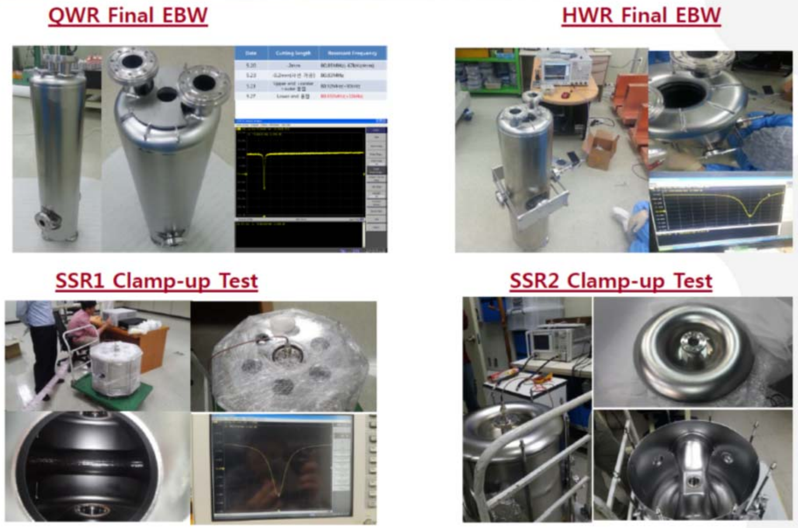
382個までtestが終了。Module testでは56個の空洞テストまで終了。引き続き、空洞の量産の体制を組んで840個の空洞まで行っていくという感じであった。空洞劣化時の原因の解析がまだ追いついていない印象（DESY側はわかっているのかもしれないが？）。あと、縦測定時の空洞の平均は26.6±7.6MV/mといいのだが、なぜ低い方まで裾のが広がっているのかというのが私の見た感じの印象であった。

Proton & ion beam

SUPERCONDUCTING CAVITIES AND CRYOMODULES FOR PROTON AND DEUTERON LINACS
（ESS：スウェーデン、SPIRAL2：フランス、IFMIF：）
Superconducting RF Development forFRIB at MSU （米、ミシガン）
China ADS Linac R&D Progress（中国）
Status of the RAON Heavy Ion Accelerator Project （韓国）
などなど

超伝導空洞を使ったproton ionの**<u>CW beam</u>**<u>の計画</u>がどんどんapproveされている。これに合わせて、特に中国、韓国などは空洞生産に合わせた表面処理、クリーンルーム組立場所のinfraの設備が急ピッチで作られている感じがした。（勢いがある。）
→日本からは、理研（和光）の方々がRIBFの延長で超伝導空洞を使った計画を立てていたが、現状超伝導空洞linacでapproveされた計画がなく、ここらへんが後手に回っている。FRIBが完成すればビーム強度では圧倒的に負ける。

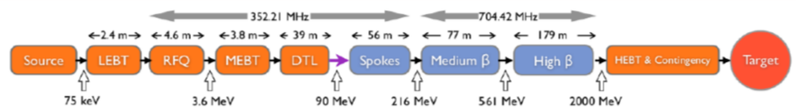
RAON計画 SC Cavity Prototyping



Prototype superconducting cavities are fabricated through domestic vendors.

これらの計画に合わせてspoke空洞などの製作が急速に進められている。

ESS - SRF LINAC



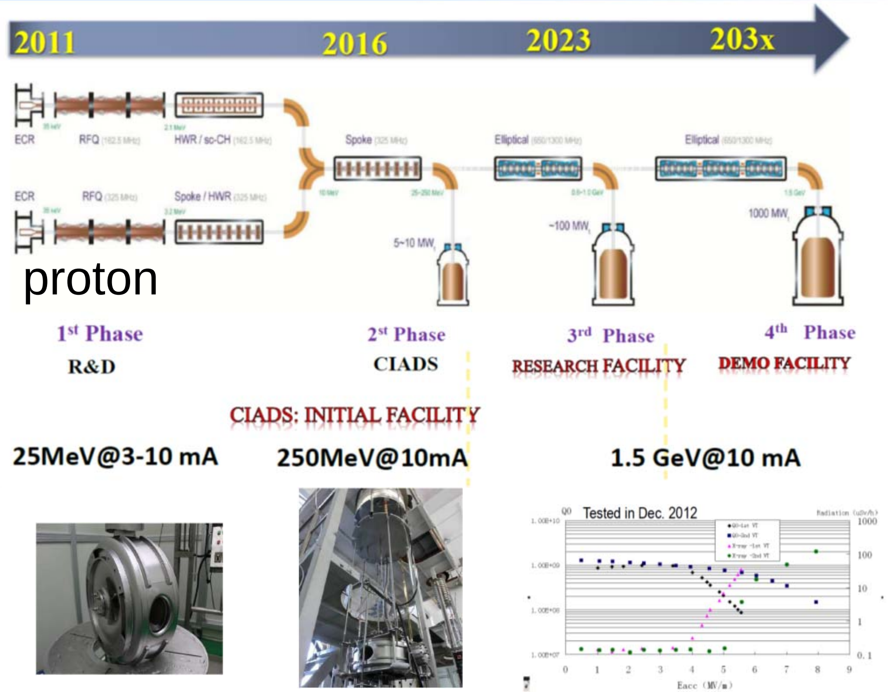
Requirements	Spoke	Medium	High
Frequency (MHz)	352.21	704.42	704.42
Geometric beta	0.50	0.67	0.86
Nominal Accelerating gradient (MV/m)	9.0	16.7	19.9
Epk (MV/m)	39	45	45
Bpk/Eacc (mT/MV/m)	<8.75	4.79	4.3
Epk/Eacc	<4.38	2.36	2.2
Iris diameter (mm)	50	94	120
RF peak power (kW)	335	1100	1100
G (Ω)	130	196.63	241
Max R/Q (Ω)	427	394	477
Qext	$2.85\ 10^{5}$	$7.5\ 10^{5}$	$7.6\ 10^{5}$
Q0 at nominal gradient	$1.5\ 10^{9}$	$> 5\ 10^{9}$	$> 5\ 10^{9}$

See M. Eshraqi THIOA01

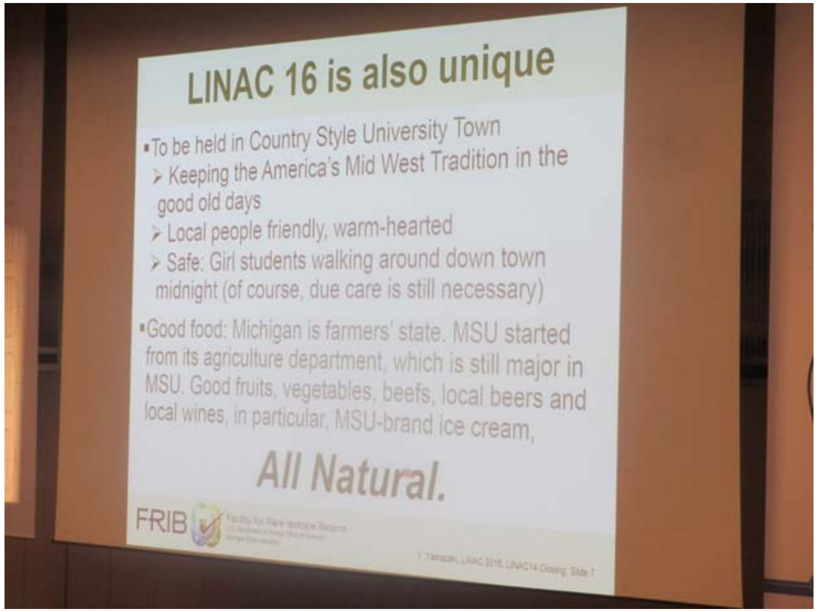
Beam power (MW)	5
beam current (mA)	62.5
Linac energy (GeV)	2
Beam pulse length (ms)	2.86
Repetition rate (Hz)	14

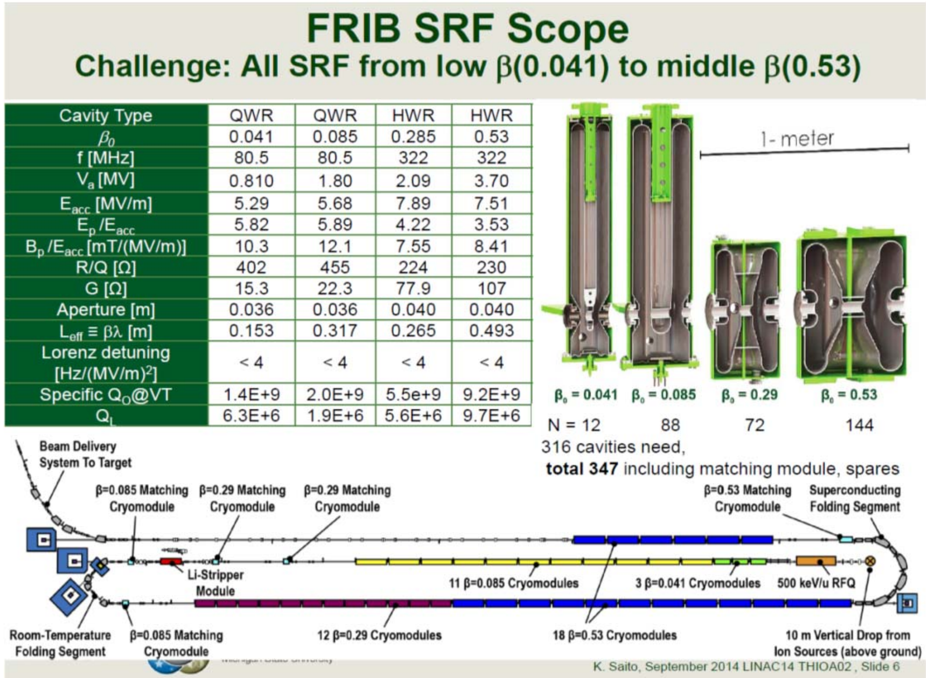
	Num. of CMs	Num. of cavities
Spoke	13	26
6-cell medium β	9	36
5-cell high β	21	84

China ADS Roadmap



次(LINAC16)はFRIB





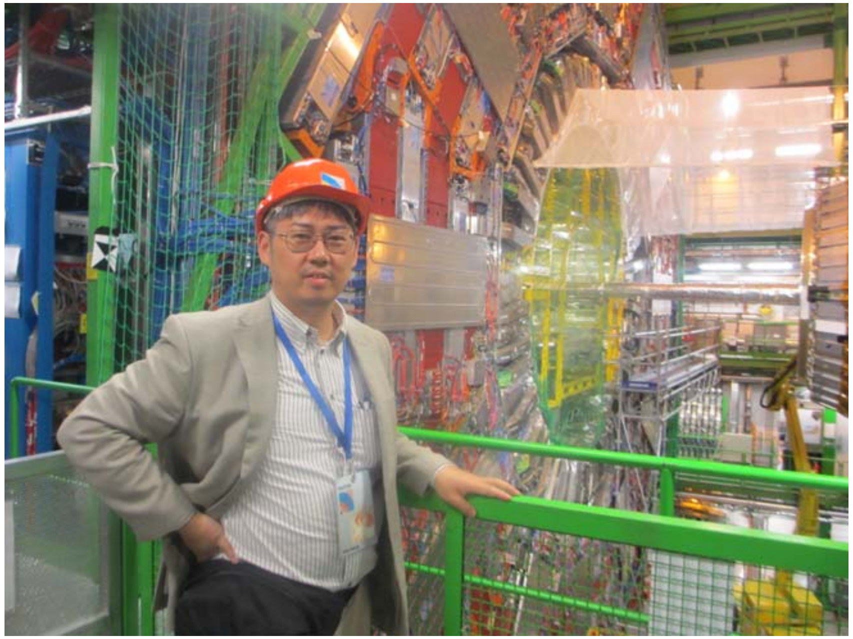
Cavity Type	QWR	QWR	HWR	HWR
β_0	0.041	0.085	0.285	0.53
f [MHz]	80.5	80.5	322	322
V_a [MV]	0.810	1.80	2.09	3.70
E_{acc} [MV/m]	5.29	5.68	7.89	7.51
E_p/E_{acc}	5.82	5.89	4.22	3.53
B_p/E_{acc} [mT/(MV/m)]	10.3	12.1	7.55	8.41
R/Q [Ω]	402	455	224	230
G [Ω]	15.3	22.3	77.9	107
Aperture [m]	0.036	0.036	0.040	0.040
$L_{eff} \equiv \beta\lambda$ [m]	0.153	0.317	0.265	0.493
Lorenz detuning [Hz/(MV/m)^2]	< 4	< 4	< 4	< 4
Specific Q_0@VT	1.4E+9	2.0E+9	5.5e+9	9.2E+9
Q_L	6.3E+6	1.9E+6	5.6E+6	9.7E+6

（ざっくりとした）まとめ

- Linacに参加したのは実は初めてだが、前回に比べて、圧倒的に超伝導空洞を使ったlinacの話がoral、posterを含めて大半を占めていたようだ。
- 電子ビーム加速ではFELなどはC-bandなどを使ったSwiss-FEL計画などで常伝導空洞の計画が進んで建設が進んでいる。またSuper-KEKBのRF Gunの話でhigh chargeの低エミッタンスビーム生成の話があった。それに対し、CW beamでの加速のLCLS-IIやCEBAFのビーム運転やERLの話などでCW加速の方向での報告などがポスターを含めて多かった。またレーザー加速などの話も出てきた感じであった。ILC関係は超伝導の加速というより、CERNの人が話したせいもあるが、全体のoverview＋CLICの話という何か漠然とした話であったのが、少し残念であった。
- Ion、protonビームは日本はJ-PARCの話がACS加速空洞により進んだという話が大きなtopicであったが、海外では多数の国がCWビーム加速を目指した、超伝導空洞の開発が圧倒的であった。
- SRFの個々の開発もHigh-Q0の研究で面白ん段階になってきたと感じた。
- Linacの究極の目的であるCW linacがいよいよ色々なところで進んできたという印象である。
- 日本からの参加はKEK以外では、Spring-8、理研(播磨）、理研（和光）、広島大、東北大、日本大、M社、T社、、、、。KEK以外での超伝導空洞製作で裾野を広げないといけないなどという話を私とは色々話がでた。（ここら辺は個人的な関係で話しました。）

Thank you

CLIC見学：alignmentは10um程度



LHCのCMSの見学：周長27km。
でかい。すごい。
人数は1500人程度で作成。大きな加速器はできんことはないという印象は持った。
ILCをやる人は一度見学しておくべき。