Science Reports
- Accelerators -

TRIUMF-KEK Scientific Symposium
December 14-15, 2017
Seiya Yamaguchi

Collaboration on Accelerator Technologies between TRIUMF and KEK

i. Superconducting RF

ii. Superconducting magnet & cryogenics

iii. Beam physics

iv. Target Technology

v. Medical Application, BNCT

vi. Medical isotope production

Parallel Sessions, Accelerators

i	1	Superconducting RF accelerator	S. Michizono	KEK
	2	Superconducting RF research at TRIUMF	R. Laxdal	TRIUMF
ii	3	Activity on Superconducting Magnet R&D for Accelerators	T. Ogitsu	KEK
	4	Multi-National Partnership Project MNPP-02	J. Urakawa	KEK
iii	5	ARIEL target station and target ion source technology	J. Lassen	TRIUMF
iv	6	Beam physics	R. Baartman	TRIUMF
v	7	Accelerator for BNCT	T. Sugimura	KEK
vi	8	Medical isotope production at TRIUMF	C. Höhr	TRIUMF
	9	Medical isotopes research at KEK	S. Michizono	KEK
		Discussion on collaboration	All	

i Superconducting RF

i	1	Superconducting RF accelerator	S. Michizono	KEK
	2	Superconducting RF research at TRIUMF	R. Laxdal	TRIUMF

Background

- SRF cavities are one of the key components for advanced accelerators such as ILC(electron, pulse), ISAC II (heavy ion, CW) and ARIEL (electron). Faction of cost (ILC) is coming from SRF cavities.

Objective

- increase the performance and reduce the cost of SRF part.

Status

- R&D on material (Nb) optimization, N2-doping, infusion for High-Q, High-G
- VEP R&D
- R&D on low-beta cavities

Superconducting RF accelerator

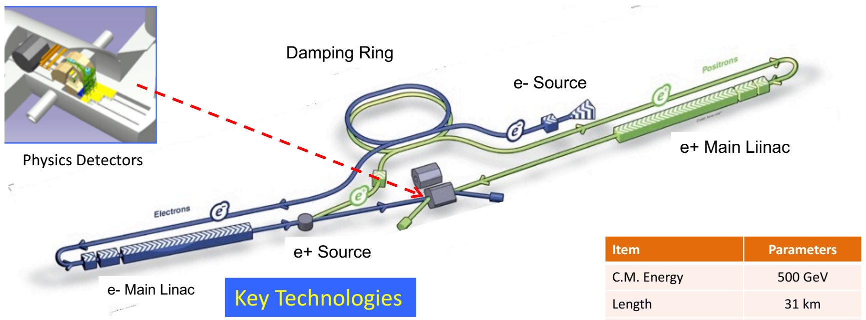
KEK

Shin MICHIZONO

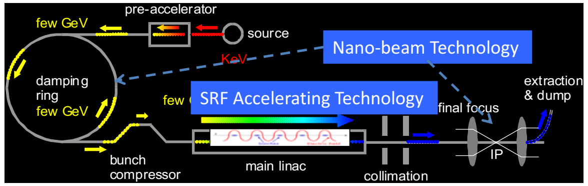
- *The ILC*
- *Cavity fabrication facility CFF*
- *Superconducting RF R&D at STF*
- *ILC cost reduction SRF R&D*
- *Low- beta SRF activities*

Michizono

ILC Acc. Design Overview (in TDR)



Key Technologies



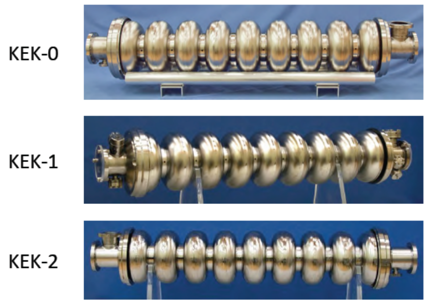
Item	Parameters
C.M. Energy	500 GeV
Length	31 km
Luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA (in pulse)
Beam size (y) at FF	5.9 nm
SRF Cavity G. Q_0	31.5 MV/m Q_0 = 1x10^{10}

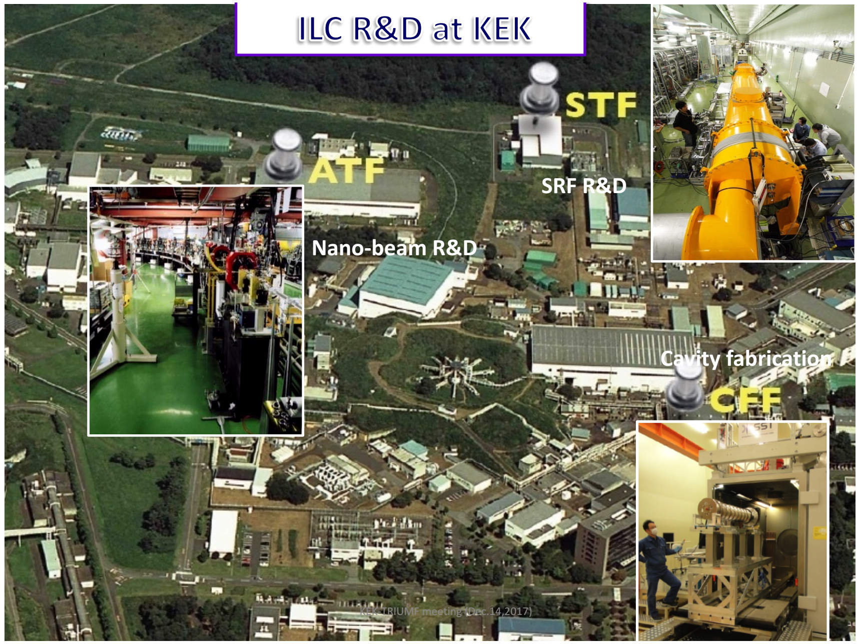
17)

Present status of production

July 2011 Construction of Cavity Fabrication Facility (CFF) is finished.
Feb. 2012 The first cavity named KEK-0 was fabricated in CFF, and its acceleration gradient attained 29 MV/m.
Mar. 2014 The second cavity named KEK-1 was finished, and its acceleration gradient attained 36 MV/m.
April 2014 5 R&D cavities (1-cell & 3-cell) were fabricated, to June 2015
Feb. 2016 The third cavity named KEK-2 was finished, and its acceleration gradient attained 38 MV/m.
April 2016 Fabrication of new R&D cavities and the fourth cavity named KEK-3 are ongoing.

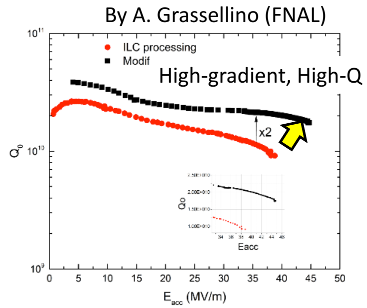
Opening of CFF





A-2. SRF cavity fabrication for high gradient and high Q (with a new surface process provided by Fermilab)

- High Q cavity enables the decrease in number of cryogenics leading to the cost reduction.
- FNAL researcher (A. Grassellino) found the new cavity preparation recipe having high Q and high gradient.
- Demonstrate N2-infusion (High-gradient and High-Q) technology with 9-cell-cavities.

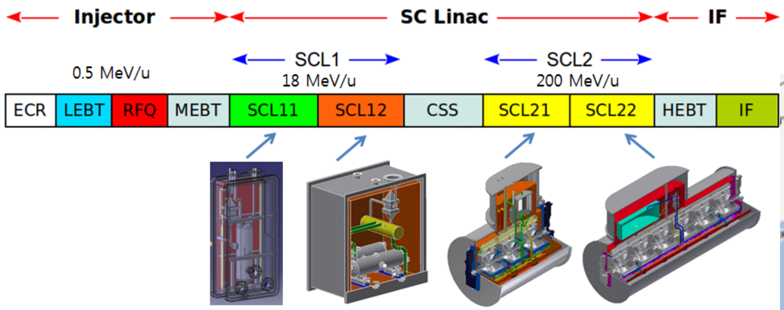


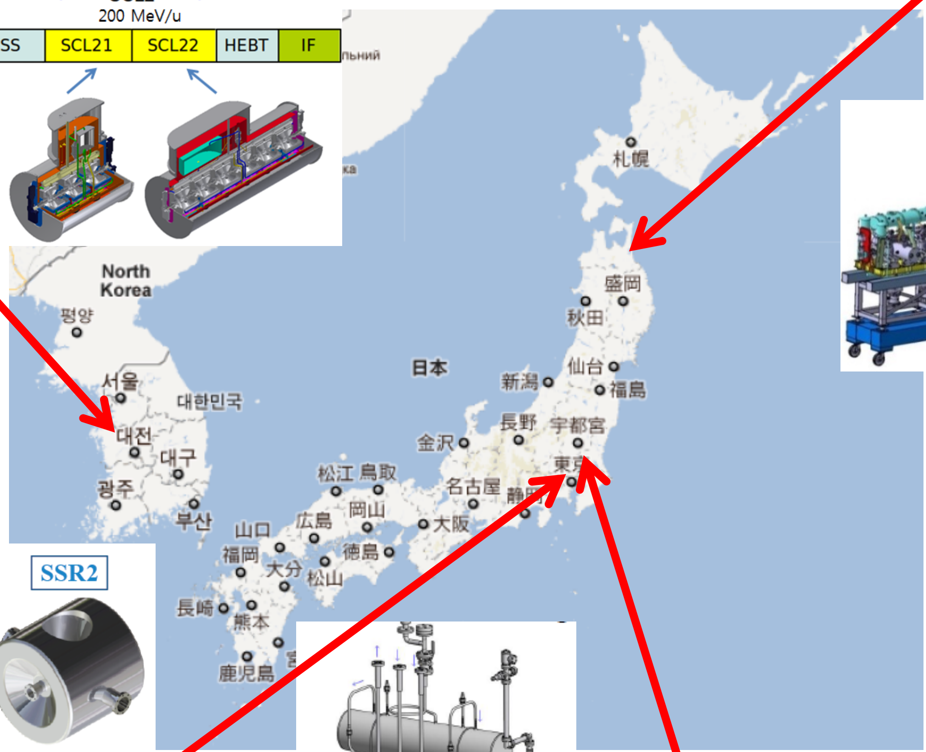
neeting (Dec.14,2017) 11

- **ILC needs 16,000 SRF cavities.**
- **KEK has ILC related facilities, ATF, STF, CFF**
- **In-house production of 9-cell SRF cavities at CFF.**
- **Trying to demonstrate N2-infusion -> High-Q, High-G**

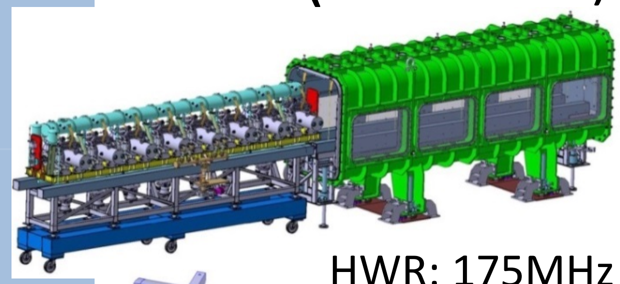
Michizono

Superconducting Ions Accelerators in Japan/Korea

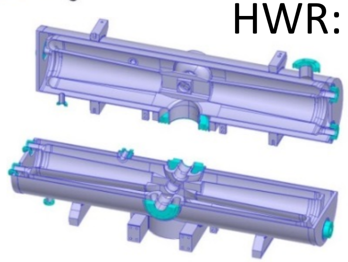




QST/Rokkasho
IFMIF (deuterons)



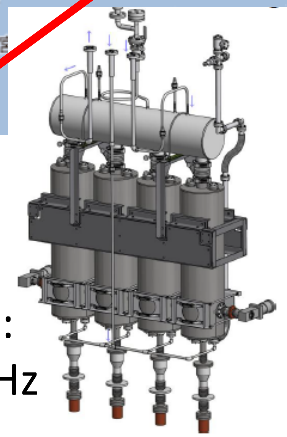
HWR: 175MHz



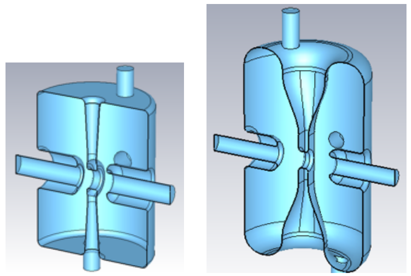
IBS/Daejeon
RISP-RAON
(heavy ions)

RIKEN/Wako
SC-Linac
(heavy ions)

QWR: 75MHz



KEK/Tsukuba
SC Proton Driver
(protons)



HWR: 325MHz

From Eiji KAKO (KEK)

TRIUMF

Canada's national laboratory
for particle and nuclear physics
and accelerator-based science

Superconducting RF research at TRIUMF

Bob Laxdal, TRIUMF

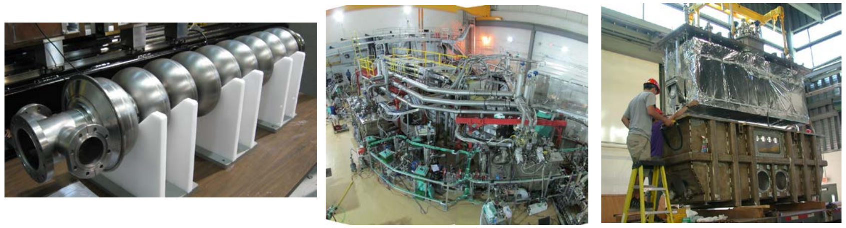
KEK Symposium, Dec. 14, 2017

Laxdal

TRIUMF — SRF Accelerators

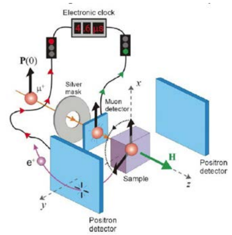
40MV ISAC-II SRF heavy ion linac @ 106MHz - operational since 2006

30MV ARIEL SRF 10mA electron linac @ 1.3GHz – first beam 2014



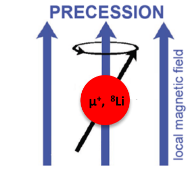
TRIUMF — Material Science Probes at TRIUMF – muSR and β-NMR

- TRIUMF has two world class material science probes in muSR and betaNMR – utilize the beta decay of a beam of polarized muons or 8Li ions respectively as probes of local magnetism
- TRIUMF muSR samples near surface fields (100µm) and betaNMR samples surface fields (0->200nm)



Method

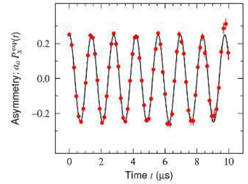
Imbedded probes decay with emitted positrons or electrons correlated with direction of spin. Spin precession dependent on the magnetic field of the imbedded probe



$$\mu^+ \rightarrow e^+ + \nu_e + \overline{\nu}_\mu$$

$$^8\mathrm{Li} \rightarrow e^- + \nu_e + ^8\mathrm{Be}$$

Atomic lighthouse



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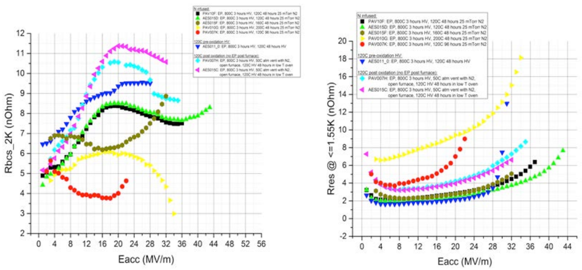
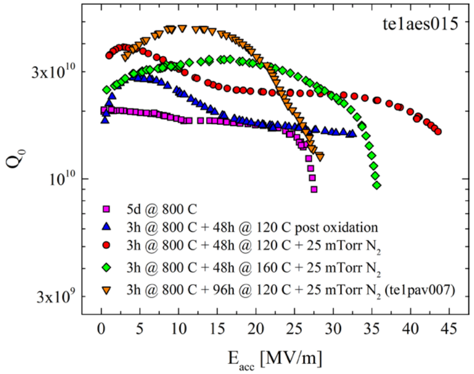
TRIUMF — Room for optimization and understanding

- Variations in the infusion process produce significant variations in the performance
- need to fine tune the duration and Temp to create right concentration and depth to reach highest fields with no Q-slope



Grassellino et al, TTC Saclay

Grassellino et al, TTC Saclay

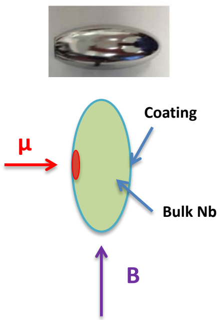


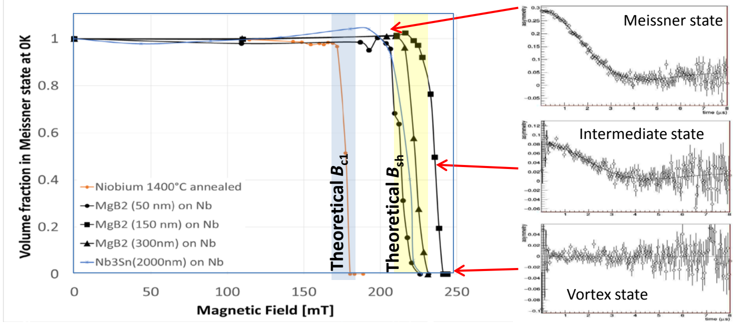
Laxdal, KEK symposium, Dec 2017 12

TRIUMF — Fundamental studies - field of first flux entry with muSR

Findings: A layer of a higher T_c material on niobium can enhance the field of first entry by about 40% from a field consistent with H_{c1} to a field consistent with H_{sh}.

This enhancement does not depend on material or thickness suggesting that superheating is indeed induced in niobium by the overlayer - consistent with `surface layer' hypothesis





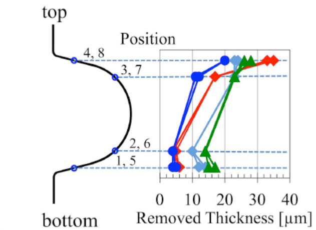
T. Junginger, R. Laxdal, W. Wasserman, *Superheating in coated niobium*, SUST, DOI: 10.1088/1361-6668/aa8e3a, 2017

- **SRF Accelerators - ISAC II (heavy ion), ARIEL (e-linac)**
- **Material Science Probes at TRIUMF - muSR and β-NMR**
- **Experiments for HQ cav. —> 120C Bake, N2-Doping, N2-infusion.**
- **Fundamental studies -> physics of these treatment**

Laxdal

TRIUMF — D'Sonoqua – Vertical EP Development

- TRIUMF SRF is developing vertical EP with teflon stirrers to augment doping effort – collaboration with Tamao Shishido
- Japan has the `Ninja' (Marui Galvanizing Co) – Canada has D'Sonoqua – the wild women of the woods – stealer of children yet bringer of wealth



paddles

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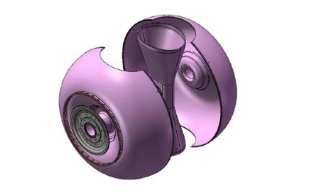
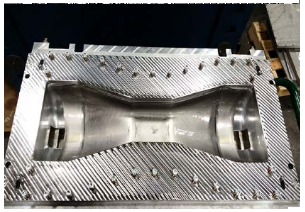
TRIUMF — SRF/RF Work for Others

- Design and fabrication of two single spoke resonators (SSRs) – 325MHz β=0.3 – for RISP (Korea)
- Cavity is designed to suppress high field multipacting - early tests confirm this – we are now degassing the cavity before the next cold test
- TRIUMF Machine Shop and SRF team successfully formed Nb parts - developed local fabricators for brazing and spinning
- Also designing SSR tuner and coupler for RISP

SSR1 spokes + fixture





SSR1 cavity - RISP

Laxdal, KEK symposium, Dec 2017

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TRIUMF — SRF Student Program

- TRIUMF offers a graduate students program in Accelerator Physics and Engineering
- One course per year taught at UBC by TRIUMF research scientists
- Five PhD students in SRF studies to date:

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6

- **VEP (collaboration with Tamao)**
- **Low-β cavity (Work for Others)**
- **Student Program**

Laxdal

ii Superconducting magnet and cryogenics

ii	3	Activity on Superconducting Magnet R&D for Accelerators	T. Ogitsu	KEK
	4	Multi-National Partnership Project MNPP-02	J. Urakawa	KEK

Background

- high-field (~ 6-7 T), high radiation-resistant magnet is required (J-PARC, HL-LHC)
- very low-vibration cryogenics system is needed (KAGRA)

Objective

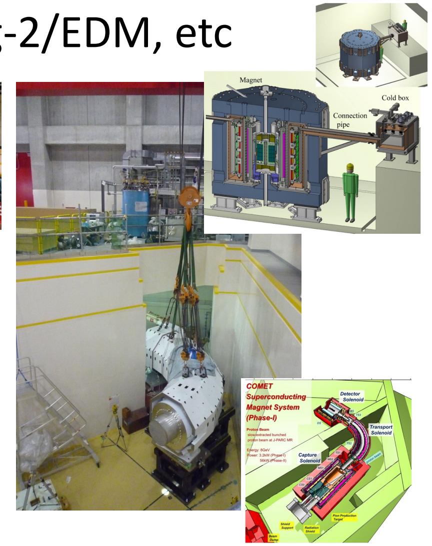
- develop novel superconducting magnet / cryogenic system
- construct a framework of international partnership (MNPP) for promotion of novel superconducting magnet technologies

Novel superconducting magnet technologies towards the applications in future high-intensity accelerators

Toru Ogitsu

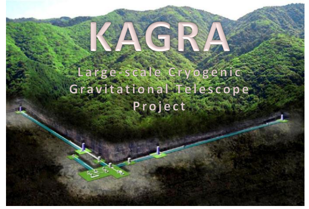
KEK, Cryogenics Science Center

On going projects at J-PARC: MUSE, COMET, g-2/EDM, etc

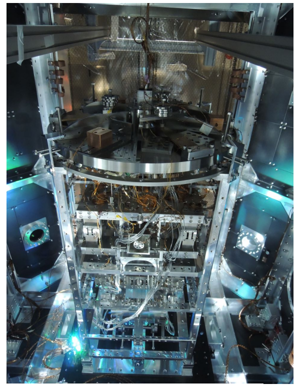


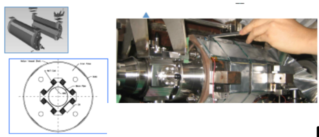
- Just constructed
  - MUSE MUON beam line solenoids
    - SC magnet under high radiation environment
- Under construction
  - COMET
    - SC magnet under high radiation environment with high field ~6 T
    - Radiation resistant materials
- Under Development
  - g-2/EDM
    - High accuracy superconducting solenoid

On going project: KAGRA



- Under construction: since 2010
  - Very low vibration cryogenics

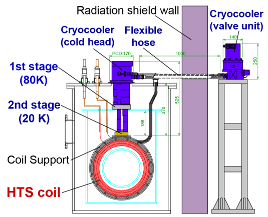




Pure Al heat conduction technology
Spin out: ILC Q-Mag

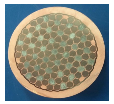
R&D for Future

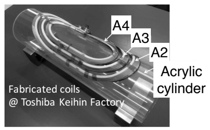
- Radiation Resistant Superconducting Magnet
  - HTS based

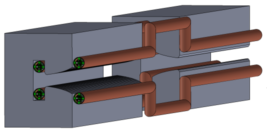


R&D of Ceramic Coating

- SC Accelerator Magnet with Advanced Conductor
  - High Jc Nb_3Sn conductor
    - CERN collaboration
  - HTS accelerator magnet
    - Company & University collaboratior
  - High-efficiency superconducting magnet



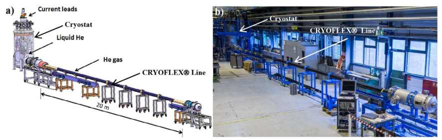




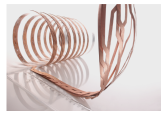
Multinational Lab

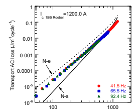
Promote R&D for Radiation Resistance Superconducting Magnets with Advanced Superconductors

- KEK (JP)
- TRIUMF (CA)
- CERN (CH): A. Ballarino MgB_2 Transmission Line



- Robinson Research Institute Victoria University of Wellington (NZ)
- Kyoto Univ. (JP)





- **On-going projects: MUSE・COMET(high-rad.environment), g-2(high accuracy) / KAGRA (low vibration cryogenics)**
- **Future R&D: Advanced conductor (HTS, Nb3Sn)**
- **MN-Lab: KEK-TRIUMF-CERN-VUOW-Kyoto U.**

Multi-National Partnership Project MNPP-02

Title of the project:
Novel superconducting magnet technologies towards the applications in future high-intensity accelerators

Proposed by
Toru Ogitsu (Project Manager)
KEK, Cryogenics Science Center

Aim:

1. Low electric power consumption
2. Insusceptibility to large heat load
3. Low yield of radioactive materials
4. Low construction cost of the system including cryogenics

Possible Applications:

1. Accelerator Ring or Beam Line (High efficiency magnets)
2. Muon Beam Line (High efficiency muon production solenoids)
3. Future Hadron Collider (High field magnets for high radiation environments)
4. Neutrino Super Beam (DC horn or high field solenoid)

Cryogenics Science Center

Research Administration Department, International Cooperation Office
Multi-national Partnership Laboratory Coordinator
Junji Urakawa

Concept of Multi-National Partnership Laboratory (MNPL)
Institution-based Partnership of World Accelerator Laboratories

Categories of KEK experiments

Joint Usage Experiments **For examples: Belle II, T2K**

1) **Invite application for experiments using KEK facilities.**
2) **Form collaboration.**
3) **Apply proposal.**
4) **Judge by Program Advisory Committee (PAC).**
5) **KEK user registration**

International Joint Research (New MNPP has to make many bilateral MoU with the explanation regarding the project)

- **KEK takes initiatives to form international joint research programs using KEK facilities or improving/creating facilities.**
- **Based on agreements (MoU) between KEK and participating Institutes (bilateral MoU or Appendix or simple agreement)**
- **Call it "MNP-Project"**

Purpose of MNPL:

- **Offers a framework to coordinate the MNP-Projects and to support the participating researchers from abroad.**
- **Integrates the bilateral cooperation to form a unified framework for partnership.** 4

iii 5 ARIEL target station and target ion source technology J. Lassen TRIUMF

TRIUMF

1

ARIEL Target Station and Target Ion Source Technology

TRIUMF-KEK Symposium 2017

Jens Lassen
Alexander Gottberg

2017-12-09

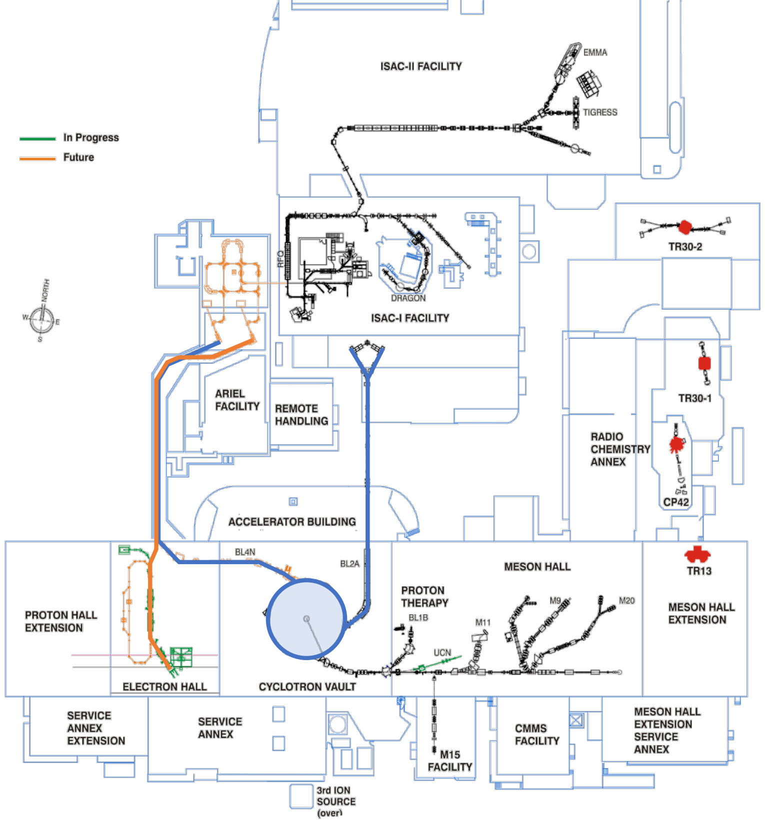
Discovery, accelerated

ISAC (currently):

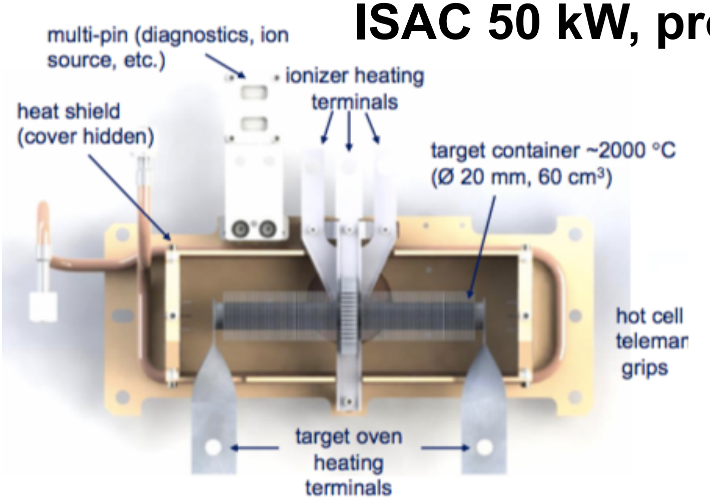
- 480 MeV, ≤100 μA protons from main cyclotron
- 50 kW is highest-power ISOL target worldwide
- Two target stations (ITE, ITW), alternating operation
- Approx. 5 weeks operation per target
- Target exchange approx. 5 weeks
- Routine target materials: UC_x, SiC, TaC, Ta, NiO, Nb, ZrC, TiC

ARIEL (in development / under construction):

- 480 MeV, ≤100 μA protons from main cyclotron onto APTW
- ≤ 50 MeV, ≤10 mA electrons from e-linac onto AETE
- 100 kW electron beam on ISOL target is fully unprecedented
- Two independent target stations
- RIB beam through beam transport and CANREB system to ISAC experiments
- Optimized design based on lessons learnt and new technology

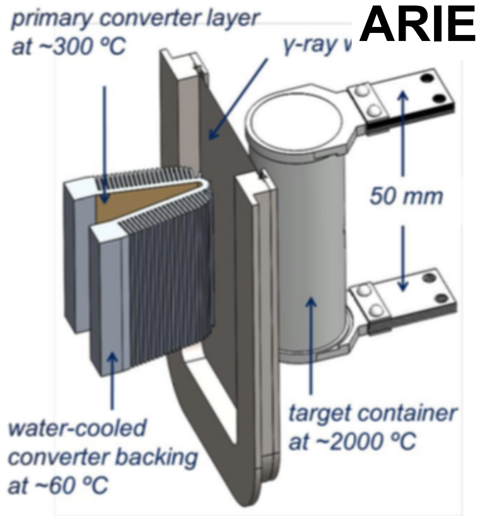


ISAC 50 kW, protons



ARIEL 100 kW, electrons

(in development/ under construction)



Requirements, Strategy and Technical challenges for High-Power Target system.

Lassen

iv Beam physics

iv 6 Beam physics	R. Baartman TRIUMF 14:55

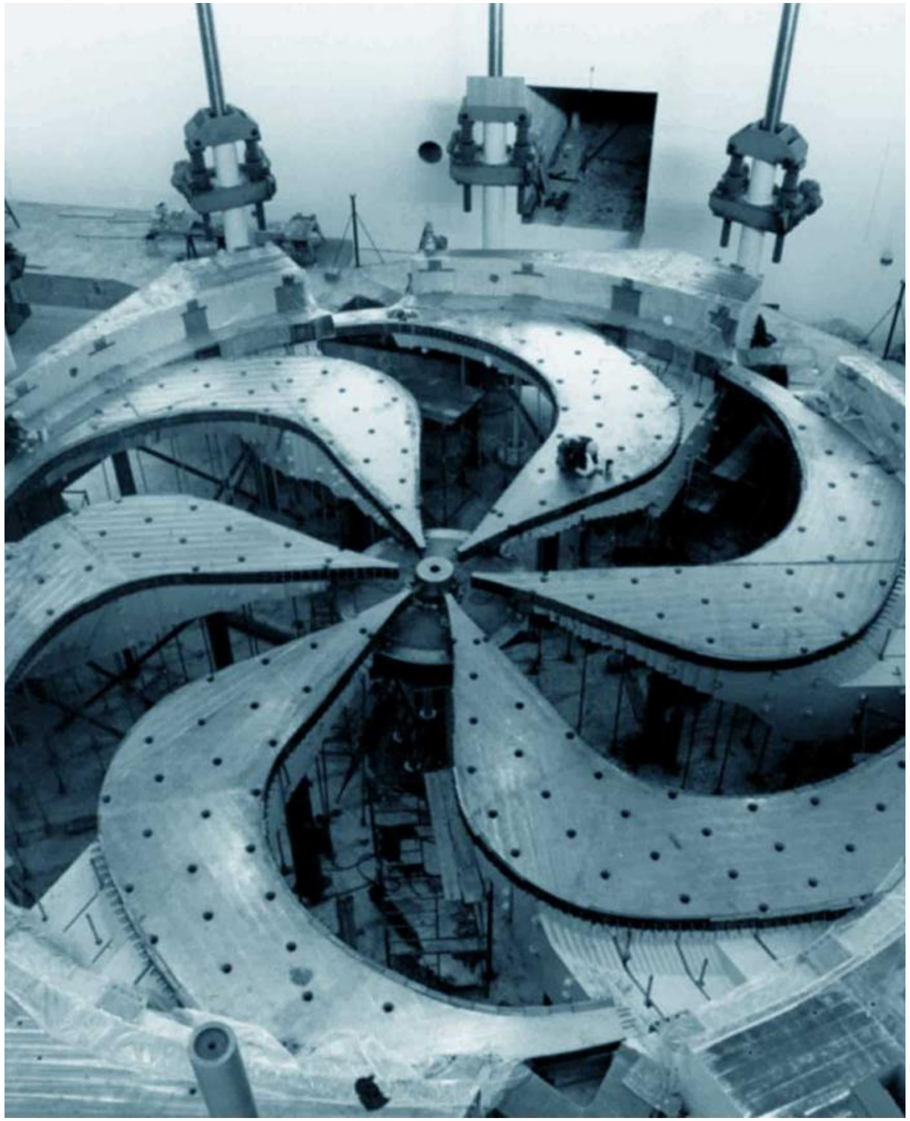
TRIUMF

Beam Physics Activities

Rick Baartman

Accelerator Division

2017-12-09



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Discovery, accelerated

Beam physics related issues

Web-based Control Room Applications at TRIUMF

Towards end-to-end envelope simulations with TRANSOPTR: Database & Code development

TRIUMF Cyclotron Simulations with Space Charge

Resonance Compensation, Cyclotron

LHC Beam-Beam Effect Studies for HL Upgrade: DA Scans

Permanent Magnet Lens

BL4N Proton Collimation Study

CANREB HRS – Dipoles

CANREB HRS – Automatic Multipole Tuning Technique

Shimmed Electrodes (and Magnets)

EBIT modelling in TRANSOPTR (for CANREB) v 7 Accelerator for BNCT T. Sugimura KEK

Background

- **worldwide rapid increase of cancer patients.**
- **availability of nuclear reactors for BNCT is very low.**

Objective

- **Develop accelerator(linac)-based BNCT system in Japan.**

Status

- **required beam power (2 kW) is almost achieved.**
- **Issue:stability of accelerator, robustness of target.**

Accerelator for BNCT

2017.12.14　KEK-TRIUMF COLLABORATION MEETING

KEK　TAKASHI SUGIMURA

Contents

- Preface
- What is BNCT
- Requirements for accelerator
- Key points of iBNCT project 1,2,3,4
- What has achieved in iBNCT
- Summary

vi Medical isotope research

vi	8	Medical isotope production at TRIUMF	C. Höhr	TRIUMF
	9	Medical isotopes research at KEK	S. Michizono	KEK

Background

- **large demand of medical isotope.**
  ex. ^{99m}Tc (0.6 million procedures/year in Japan)
- **availability of nuclear reactors is very low.**

Objective

- **Develop accelerator for medical isotope production.**
- **Domestic production of ^{99m}Tc using accelerator. (Japan)**

Status

- **TRIUMF:PET(^{11}C, ^{18}F, ^{68}Ga,etc.), SPECT(^{99m}Tc), α-emitter(^{225}Ac)**
  routine production or experiments
- **KEK:conceptual design of accelerator for ^{99m}Tc production.**
  issue:target, handling of radioactivity

TRIUMF

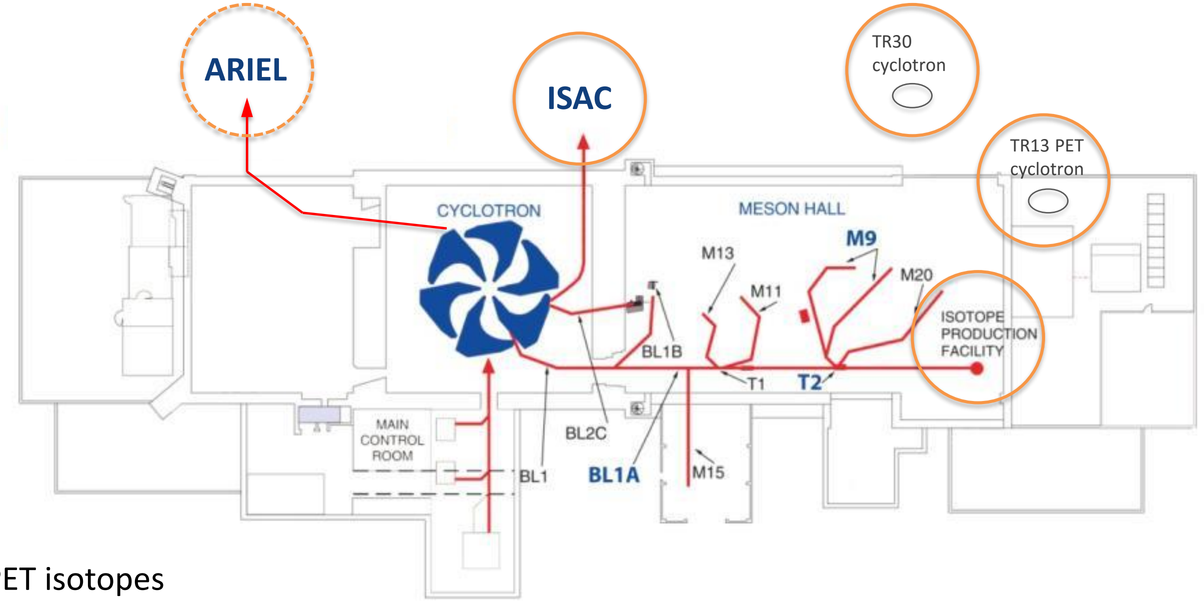
Canada's National Laboratory for Particle and Nuclear Physics

Medical isotope production at TRIUMF - from imaging to treatment

Cornelia Hoehr
Research Scientist, Life Sciences

TRIUMF

Beamlines and Production Sites at TRIUMF



- PET isotopes
- SPECT isotope
- α emitters

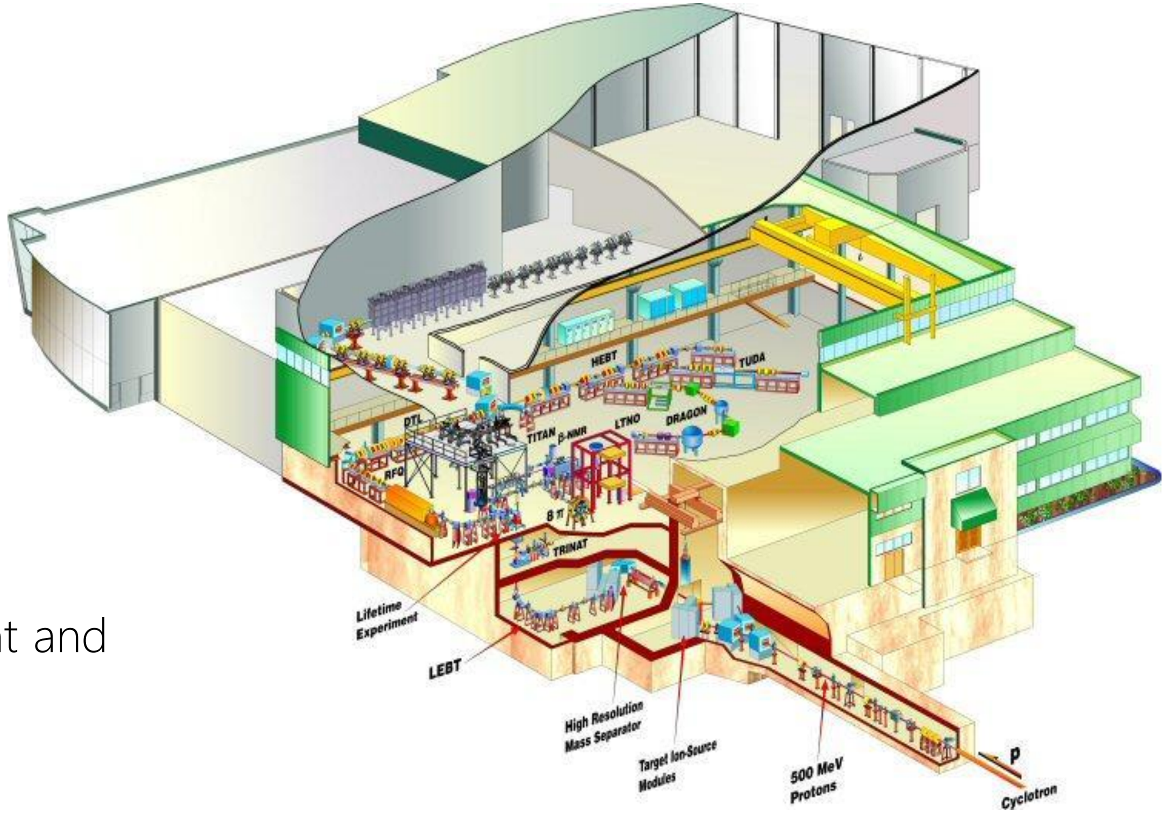
TRIUMF Isotope Accelerator Program (ISAC): 50 kW ISOL Facility

Isotope production using TRIUMF's
500 MeV infrastructure

1) ISAC – ISOL (Research, Feasibility)
Low activity (kBq to MBq), high purity

2) 500 MeV – IPF (BL1A)
Intermediate activity (MBq), spallation
- Routine, independent production

3) ARIEL/H^+
High activity (GBq), spallation
- Enable radiopharmaceutical development and clinical trials



- **Three facilities, ISAC, IPF and ARIEL**
- **Status**
- **ARIEL Parasitic Target Station**

Experiments underway

Medical isotopes research at KEK

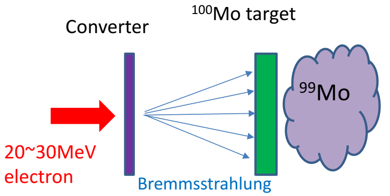
KEK

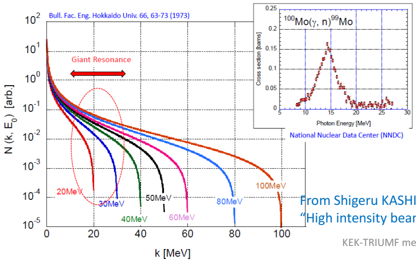
Shin MICHIZONO

- *^{99}Mo and its application*
- *SRF linac (CW/pulse)*
- *Specification of SRF accelerator*
- *SRF components for ^{99}Mo*

^{99}Mo generation by electron accelerator

- Utilize the gamma ray generated by the electron beam irradiation to the converter.
- Typical energy of the gamma ray contributing to the reaction ^{100}Mo(γ,n)^{99}Mo is 10～20MeV
- Electron with the energy of 20～30MeV is required for this reaction.
- Beam current of 1mA～10mA
- Beam quality (emittance) is not important as long as the electron is irradiated to the





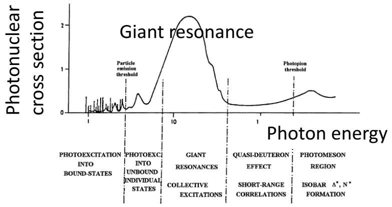


Fig. 1. Total photonuclear cross section as a function of the photon energy k [17].

Nucl Instr Meth B 155 (1999) 373

From Shigeru KASHIWAGI (U. Tohoku)
"High intensity beam and its application" (in Japanese)

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Requirements of the accelerator for ^{99}Mo production

～10mA(CW) electron beam
20～30MV acceleration

※ 10mA(CW) beam

Essential accelerator components
- ☐ High current DC electron gun
- ☐ Superconducing cavity operated at 10～15MV/m
- ☐ High power RF input coupler

Key points for the accelerator
- Beam loading (beam current x accelerating voltage)
  - ➢ Max. rf power for CW input coupler is ~ a few 10 kW
  - ➢ Number of cavities, cavity gradients are limited by the input coupler.
- Cyrogenics
  - ➢ High Q cavity leads to low cryogenic load
  - ➢ Higher gradient operation results in the higher cryogenic load (load is proportional to (voltage)^2)

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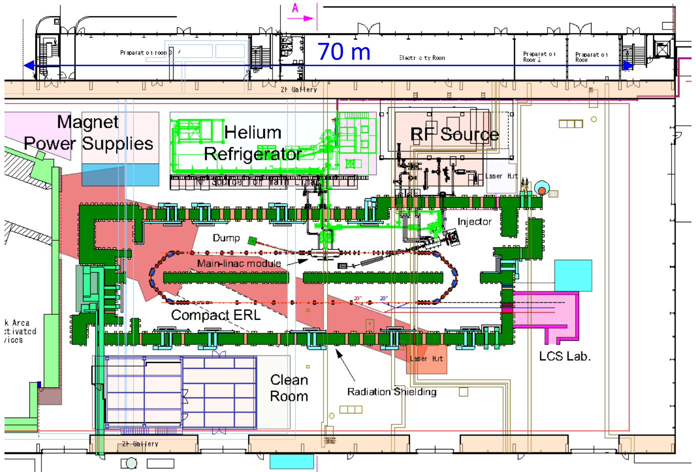
Compact ERL

Proto type of the 3 GeV high current ERL

Parameters of the Compact ERL

	Parameters
Beam energy	35 - 200 MeV
Injection energy	5 - 10 MeV
Average current	10 - 100 mA
Acc. gradient (main linac)	15 MV/m
Normalized emittance	0.1 - 1 mm·mrad
Bunch length (rms)	1 - 3 ps (usual) ~ 100 fs (with B.C.)
RF frequency	1.3 GHz

※ red numbers are parameters for initial stage



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- **Generation of ^{99}Mo by e$^-$ accelerator**
- **SC or NC / CW or pulse**
- **Requirements of accelerator for ^{99}Mo production**
- **cERL -> candidate of the accelerator for the demo. of ^{99}Mo product.**

Michizono

Parallel Sessions, Accelerators

i	1	Superconducting RF accelerator	S. Michizono	KEK
	2	Superconducting RF research at TRIUMF	R. Laxdal	TRIUMF
ii	3	Activity on Superconducting Magnet R&D for Accelerators	T. Ogitsu	KEK
	4	Multi-National Partnership Project MNPP-02	J. Urakawa	KEK
iii	5	ARIEL target station and target ion source technology	J. Lassen	TRIUMF
iv	6	Beam physics	R. Baartman	TRIUMF
v	7	Accelerator for BNCT	T. Sugimura	KEK
vi	8	Medical isotope production at TRIUMF	C. Höhr	TRIUMF
	9	Medical isotopes research at KEK	S. Michizono	KEK
		Discussion on collaboration	All	

Thank you for your attention.