Reports on Parallel Sessions
- Accelerators -

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

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
		break		
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	

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*

Summary

- *Cavity fabrication facility (CFF) has fabricated various SRF cavities for the ILC.*
- *Superconducting RF R&D has been carried out at STF and 8 cavity vector sum worked well.*
- *ILC cost reduction SRF R&D started from 2016. New Nb material and HighQ-HighG processing (N-infusion) R&Ds are ongoing.*
- *Low- beta SRF design, fabrication and evaluation works have been carried out with RIKEN, IFMIF and RISP (Korea).*

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

SRF at TRIUMF

- SRF at TRIUMF began in 2000 with cavity and infrastructure development in support of the ISAC-II heavy ion linac.
- SRF department supports
  - Internal projects
    - ISAC-II heavy ion linac, ARIEL e-Linac,
  - Student education
    - Fundamental and technical SRF
  - External collaborations (FRIB, KEK, IMP, CERN, RISP, FNAL, VECC, Cornell)

- **Vertical EP Development**
- **Fundamental Studies using muSR and beta-NMR**
- **SRF Dipole Cavity (650 MHz), Low-beta cavity for RISP**

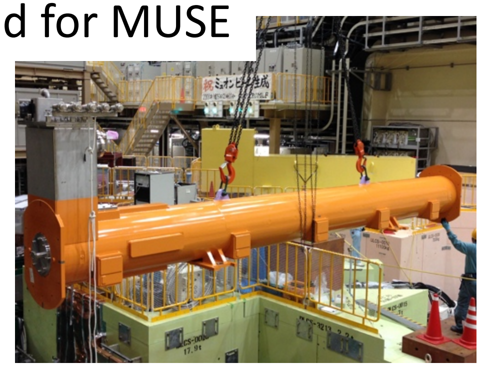
Novel superconducting magnet technologies towards the applications in future high-intensity accelerators

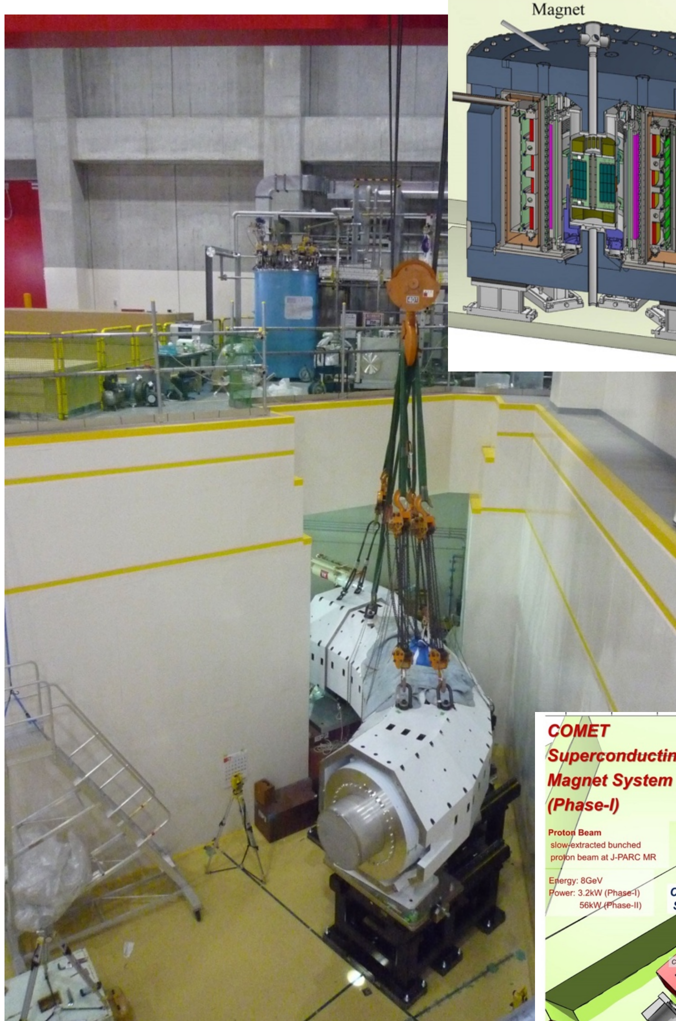
Toru Ogitsu

KEK, Cryogenics Science Center

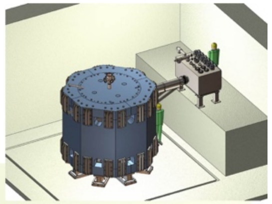
On going projects at J-PARC: MUSE, COMET, g-2/EDM, etc

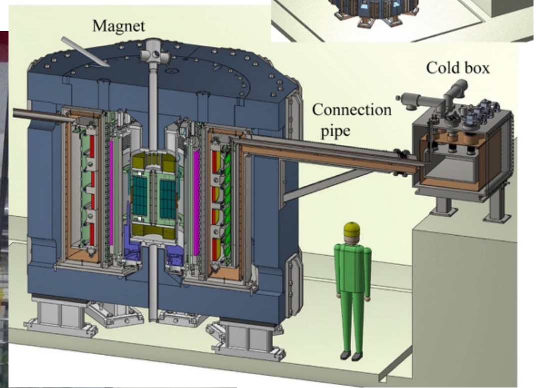
SC solenoid for MUSE

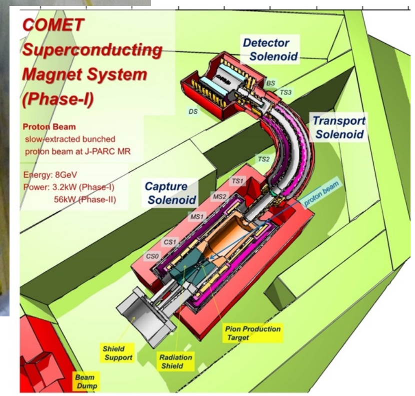




g-2/EDM





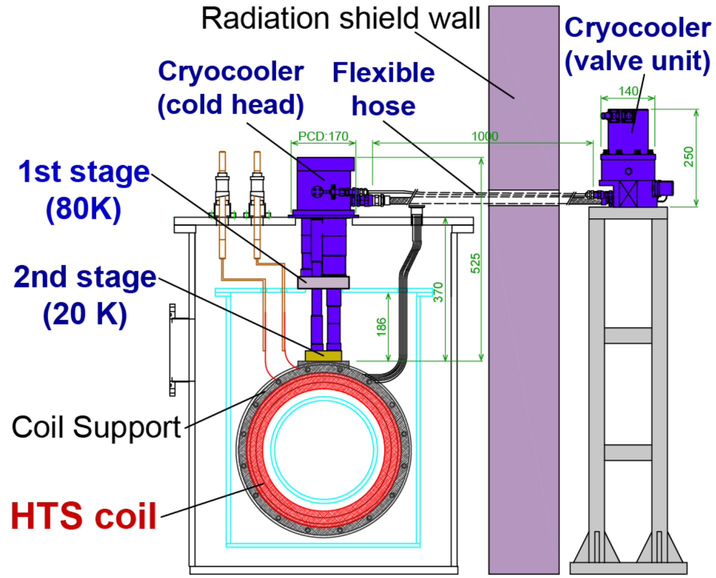


- Just constructed
  - MUSE MUON beam line solenoids
    - SC magnet under high radiation environment
- Under construction
  - COMET
    - SC magnet under high radiation environment with high field ~6 T
    - Radiation resistant materials
- Under Development
  - g-2/EDM
    - High accuracy superconducting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

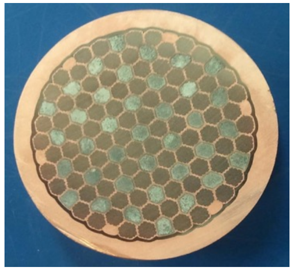
R&D for Future

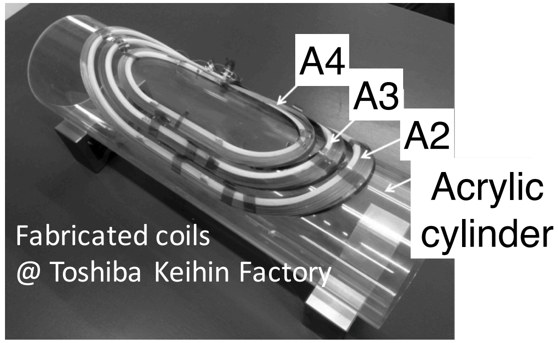
- Radiation Resistant Superconducting Magnet
  - HTS based

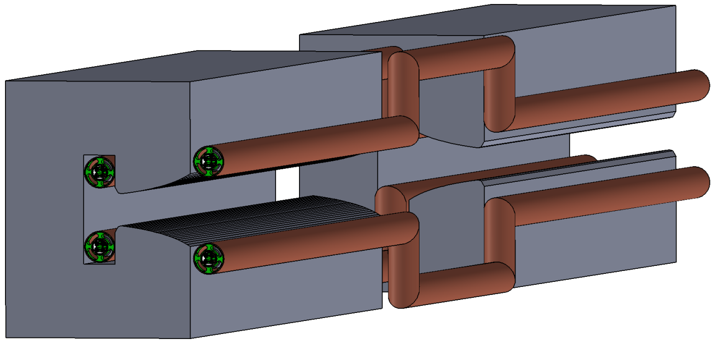
R&D of Ceramic Coating



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

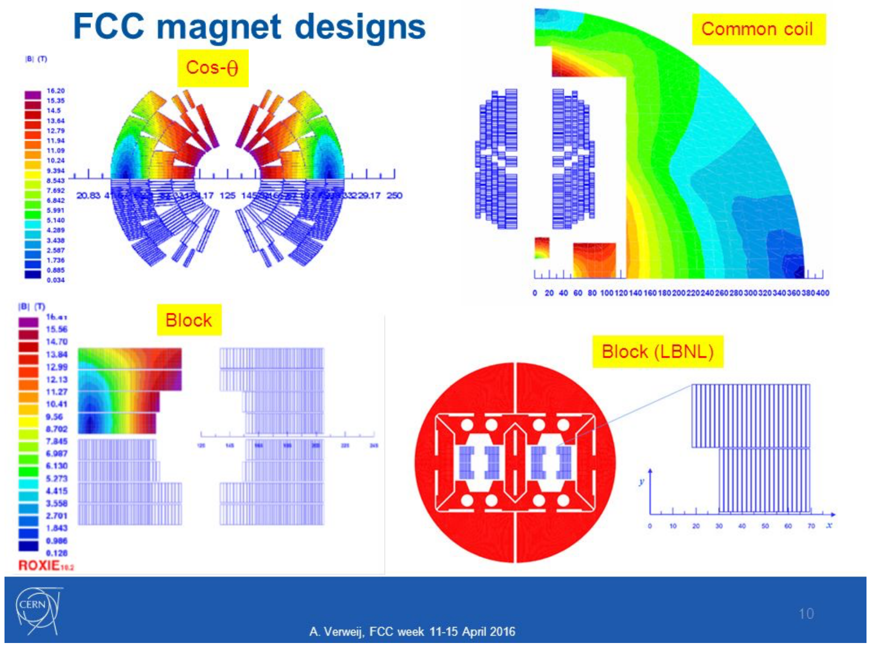


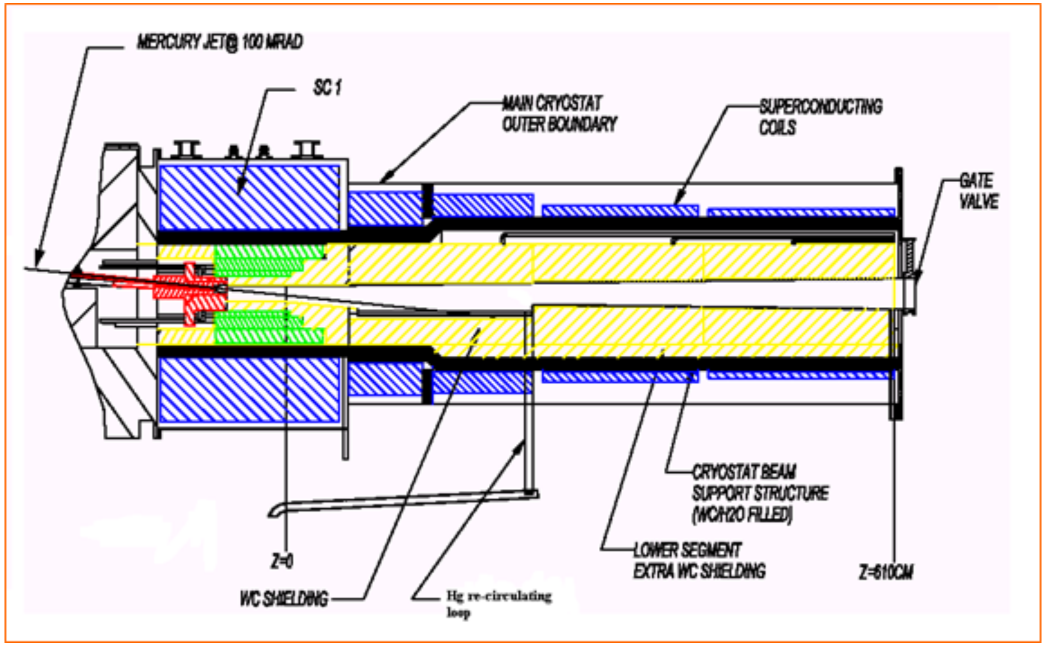




Further Future

- High Field(>10 T) Magnets for High Radiation Environments (~100 MGy)
  - High field magnets for future hadron collider (IR, etc)
  - High field solenoid for neutrino super beam





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:

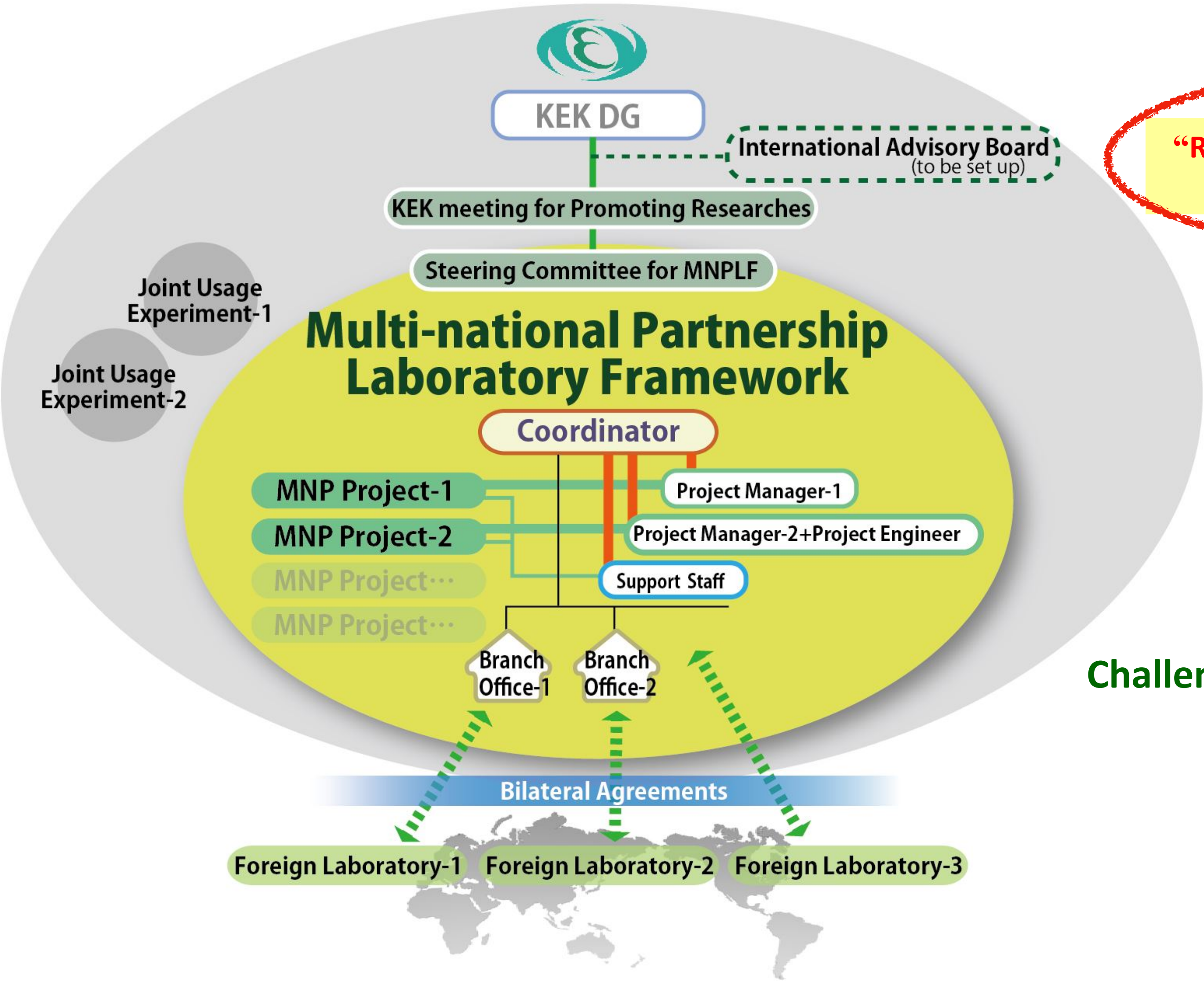
1. Accelerator Ring or Beam Line (High efficiency magnets)
2. Muon Beam Line (High efficiency muon production solenoids)
3. Future Hadron Collider (High field magnets for high radiation environments)
4. Neutrino Super Beam (DC horn or high field solenoid)

Cryogenics Science Center

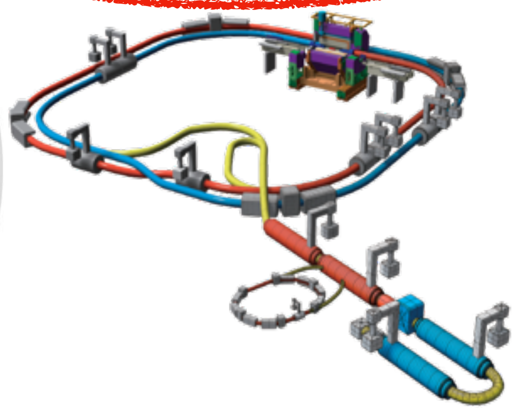
Research Administration Department, International Cooperation Office
Multi-national Partnership Laboratory Coordinator
Junji Urakawa

HL Accelerator Project (MNPP-01) , SC MG Project (MNPP-02)

Activity of Multi-National Partnership Laboratory (MNPL) at KEK and its Approved Project (MNPP-01+MNPP-02)



"R&D for high luminosity colliders" Project (MNPP-01)



Challenge to highest luminosity at SuperKEKB

$2\times10^{34} \Rightarrow 8\times10^{35}$

2

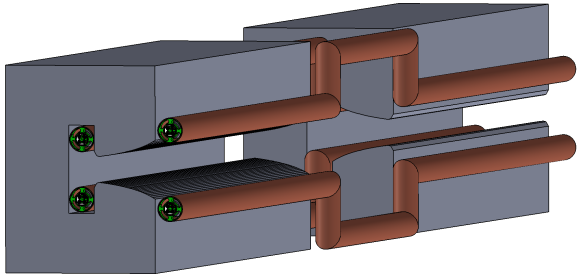
R&D Plan

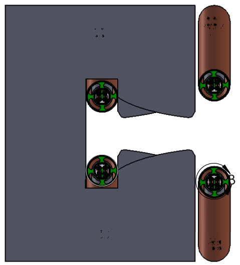
1. High Efficiency Superferric Magnet R&D – MgB_2 with Helium Gas Cooling
2. HTS Solenoid for High Radiation Environments – YBCO with Conduction Cooling
3. HTS Magnets for Higher Radiation – YBCO with Helium Gas Cooling
4. HTS High Field Magnets for High Radiation – YBCO with Liquid Helium Cooling

High Efficiency Superferric Magnet R&D

Use transmission Line Technology

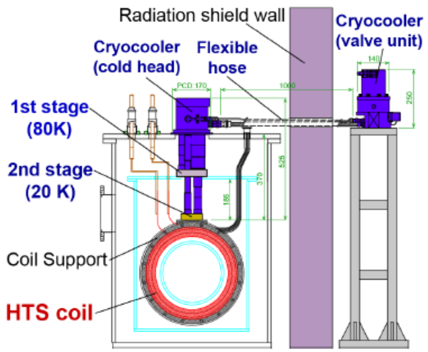
- MgB_2 with 20K
- Forced Flow Helium Gas Cooling

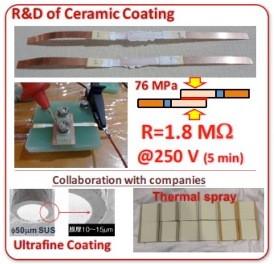


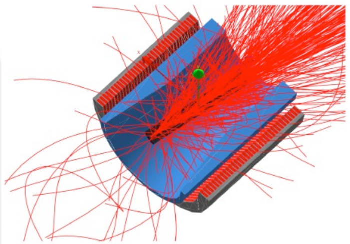


HTS Magnets for High Radiation Environments

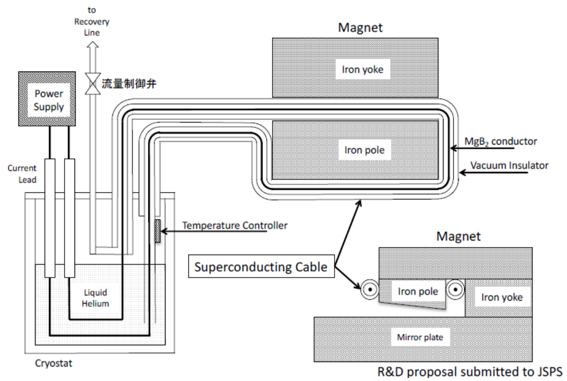
Computational model study indicates HTS magnets can sustain very high radiation environments.







Experimental plan and Mini-model magnet proposal



ARIEL Target Station and Target Ion Source Technology

TRIUMF-KEK Symposium 2017

Jens Lassen

Alexander Gottberg

2017-12-09

1

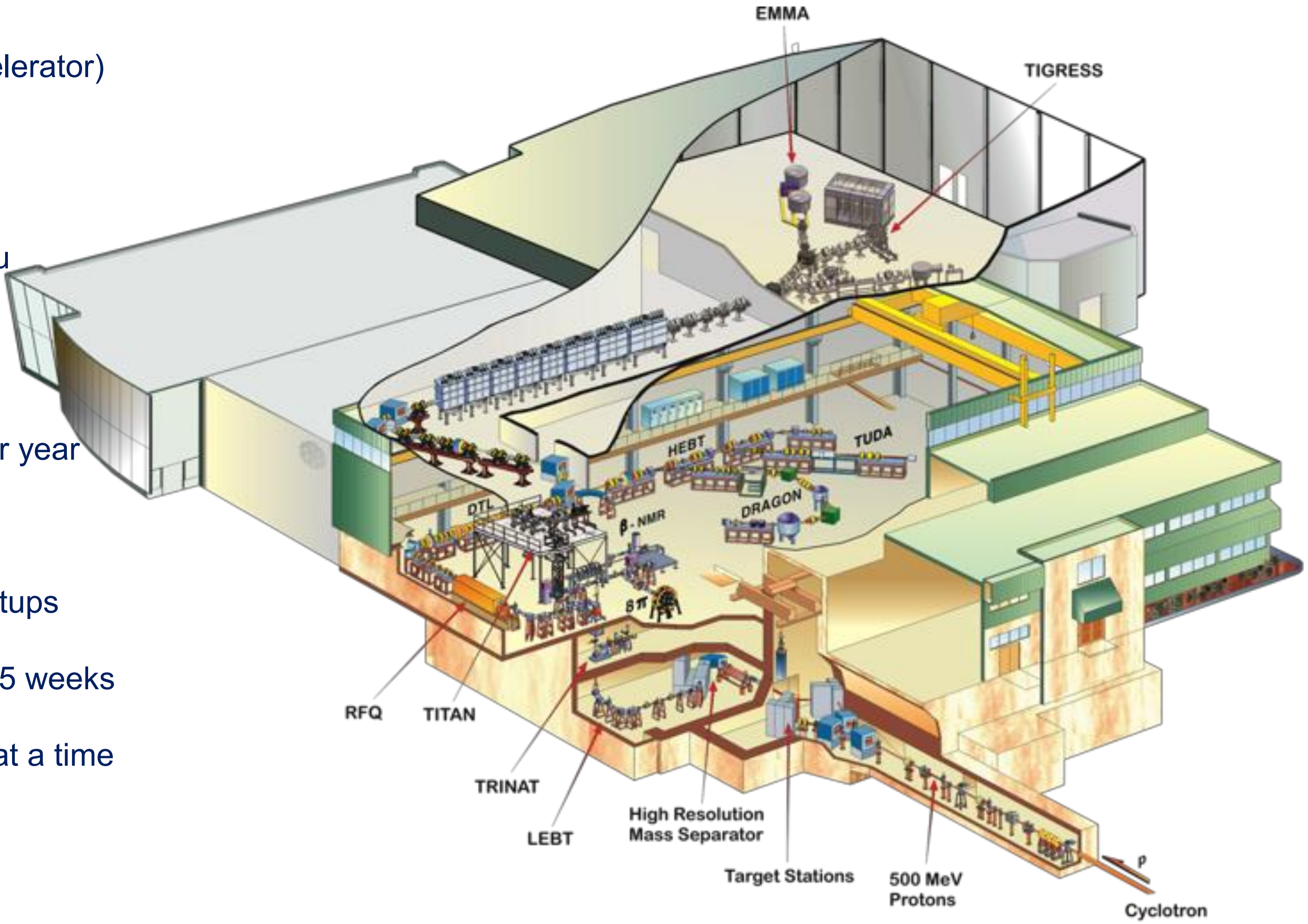
Discovery, accelerated

The ISAC Facility   50 kW proton

ISAC (Isotope Separator and Accelerator)

ISAC I:
- Low energy: 50 keV
- Medium Energy: up to 1.8 MeV/u

ISAC II:
- Up to 16 MeV/u
- Approx. 2500 h of RIB beam per year
- 700 isotopes extracted
- State-of-the art experimental setups
- Target exchange every approx. 5 weeks
- Operation of one target station at a time



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ARIEL Target Infrastructure - Overview

100 kW electron

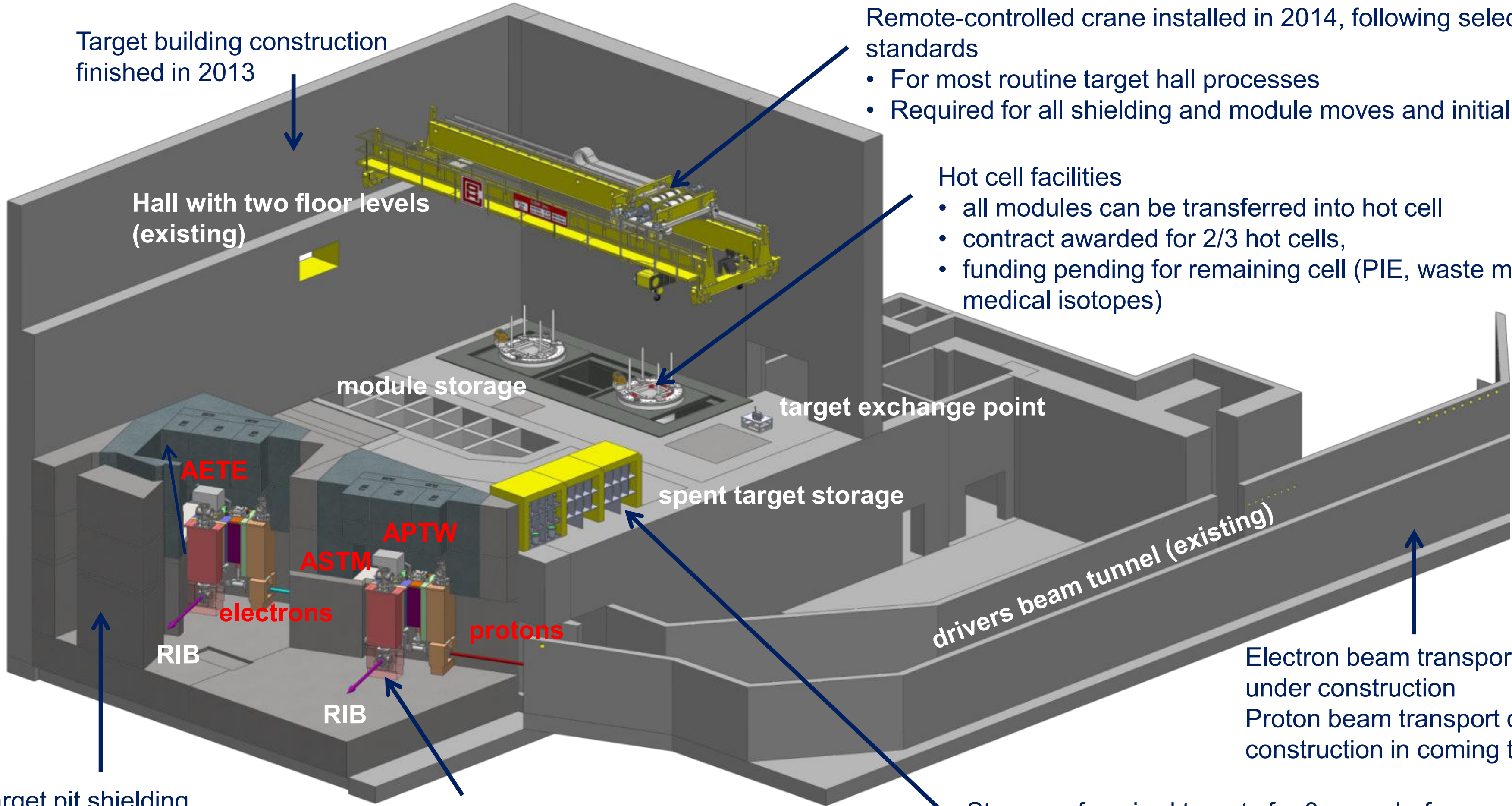
Target building construction finished in 2013

Remote-controlled crane installed in 2014, following selected nuclear standards

- For most routine target hall processes
- Required for all shielding and module moves and initial installation

Hot cell facilities

- all modules can be transferred into hot cell
- contract awarded for 2/3 hot cells,
- funding pending for remaining cell (PIE, waste management, medical isotopes)



Electron beam transport to target station under construction
Proton beam transport design complete, construction in coming two years

Target pit shielding concept validated through FLUKA simulations

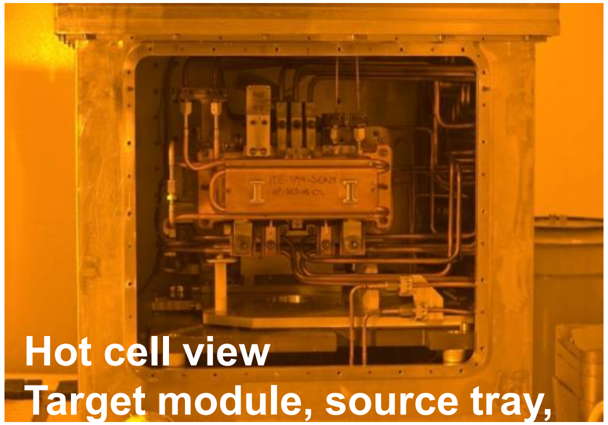
beam-critical components with life-time < 30 years: modular and serviceable in hot cell facility

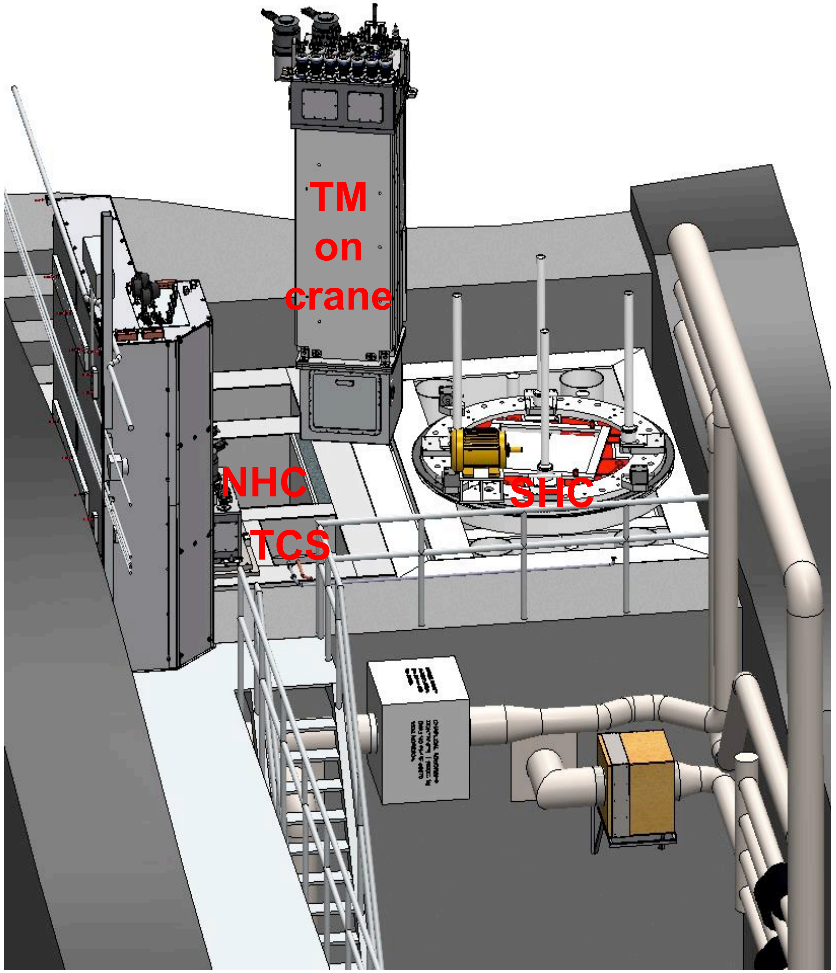
Storage of expired targets for 3 years before shipment to CNL (as for ISAC targets)

7

ISAC Remote Handling Infrastructure

- 20 t redundant nuclear crane
- Beam and target infrastructure modular on 2m steel shield plugs
- α/β/ɣ hot cell target exchange (SHC)
- α/β/ɣ hot cell for module maintenance (NHC, under construction)
- Shielded target vault for initial radioactive decay before shipment
- Remote module storage area
- Safe module parking with rotating module flange for safe landing of modules in case of crane rotation failure (under construction)





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Technical Challenges

- **Lifetime**
- **Cooling system**
- **Radiation resistance**
- **Maintainability**
- **Hermeticity**
- **Remote Handling**
- **Minimization of mass and radioactive inventory after irradiation**

These are common issues for high-power targets.
KEK would like to learn a lot from TRIUMF's experience.

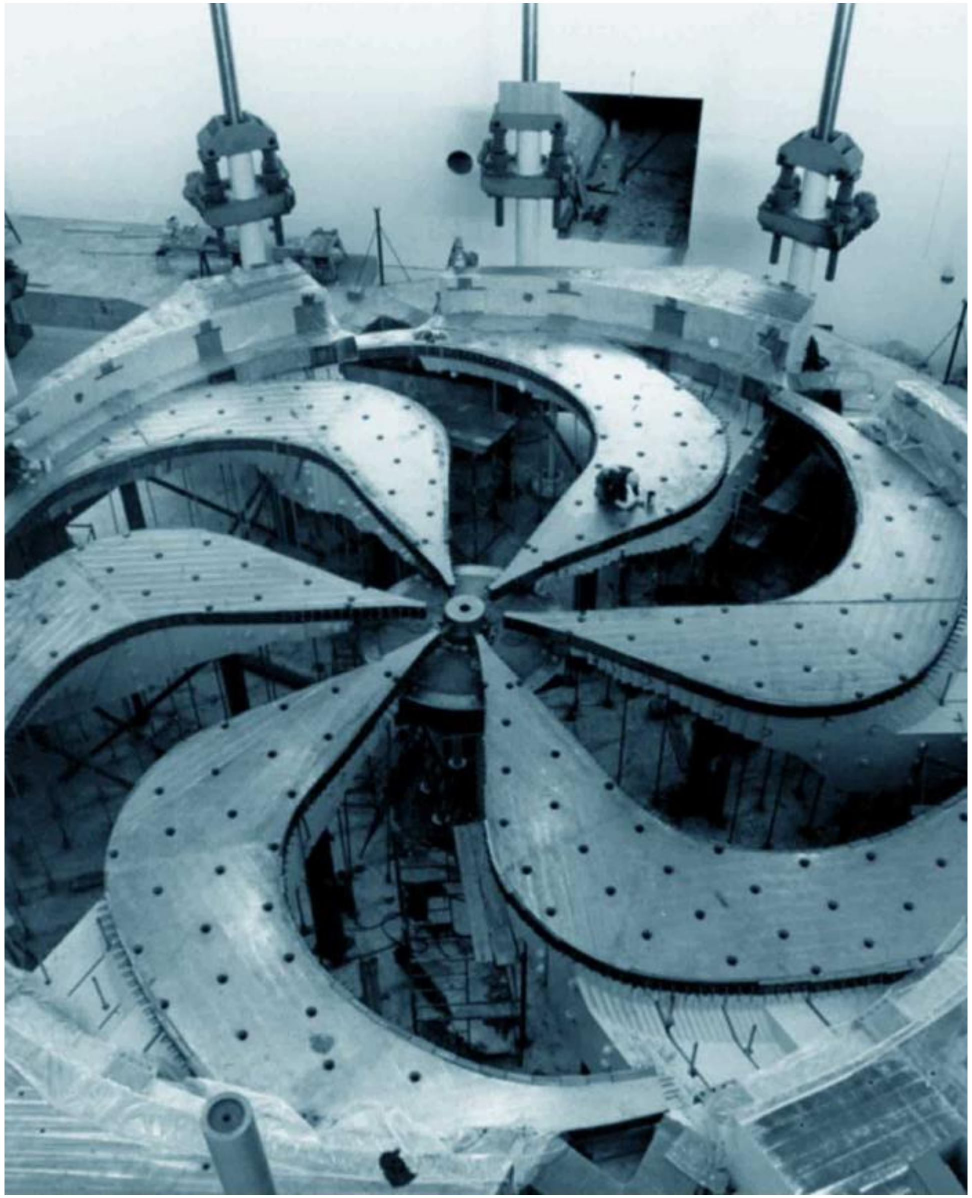
TRIUMF

Beam Physics Activities

Rick Baartman

Accelerator Division

2017-12-11



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Discovery, accelerated

--Carla Barquest, Thomas Planche, various co-op students.

Web-based Control Room Applications at TRIUMF

(IPAC18 abstract)

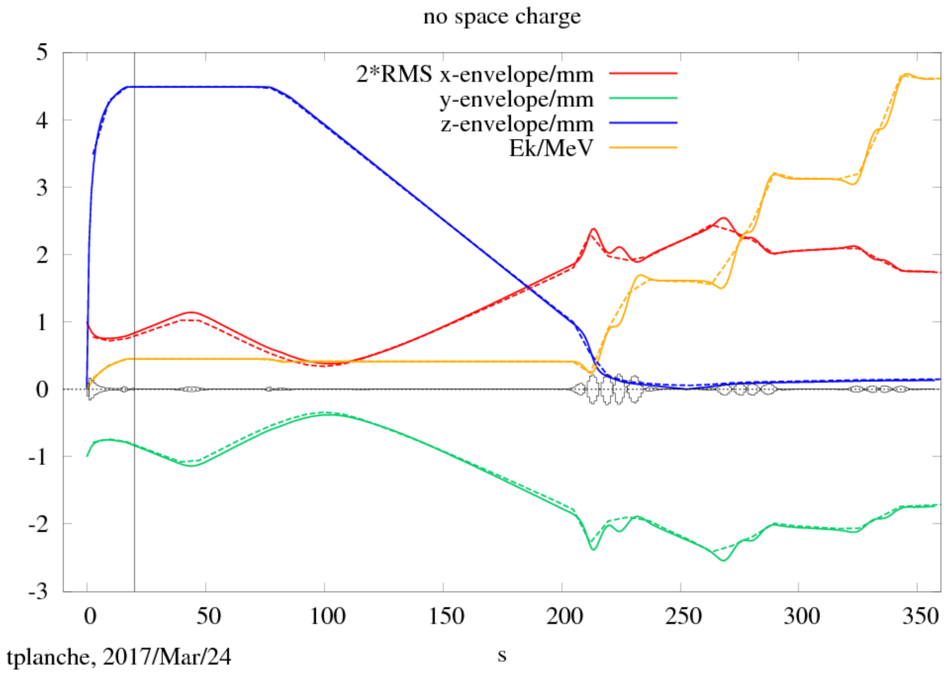
High level applications in accelerator facilities are programs that interface with control systems and beam physics models. These tools range from real-time diagnostic visualizations to post-processing data analysis. **At TRIUMF, the concept of web-based high level applications has been adopted to advance the capabilities of these applications and facilitate operations.** This **online model** takes advantage of three key features: server-based continuous integration, an open-source code base, and a centralized middleware layer. Continuous integration of server-based applications allows for easy deployment and maintenance. Open-source applications eliminate the dependence on licensed software. A centralized middleware layer allows a single application to work for many different accelerator configurations. Some motivating examples of deployed web-based high level applications are presented, demonstrating this online approach to be an effective method for deploying high level applications for use in the control room and beyond.

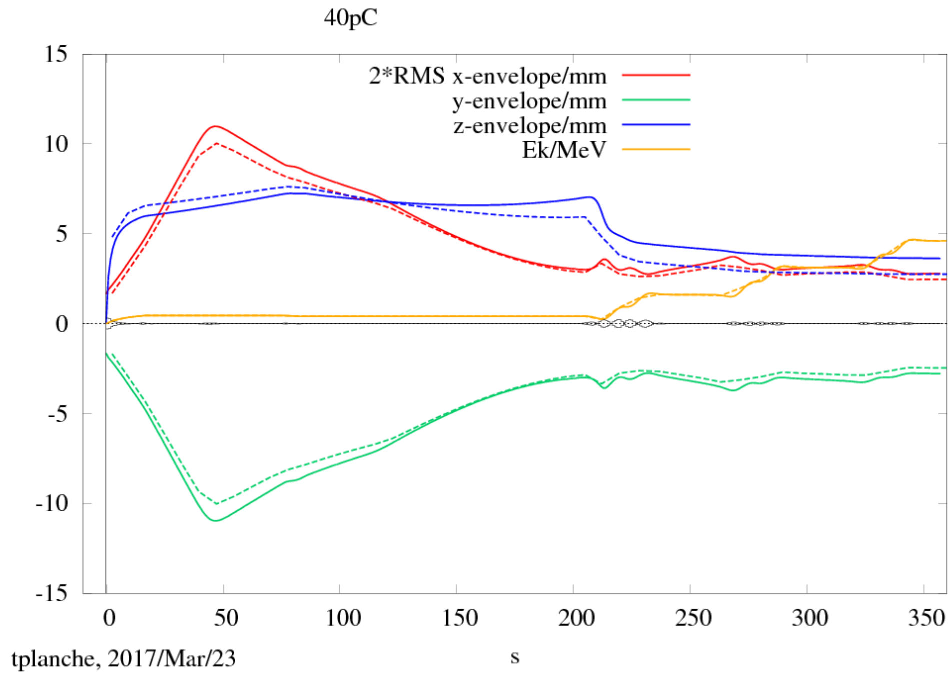
TL;DR: Use Higher level tools to reduce tuning time.

beam envelope browser-based app

KEK cERL (visit by Thomas Planche, March 2017)

TRANSOPTR envelope calculation (solid) versus
GPT multiparticle model (dashed)
GPT is ~10000 times slower.





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

--Baartman, Olivier Shelbaya

This will include all linacs, bunchers, beam transport. Olivier is gathering the ISAC data to add to our database.
But: We did not have code for RFQ. →

Other participants: Spencer Kiy, Tiffany Angus, Stephanie Raedel

RFQ Hamiltonian and F-Matrix

With the distance along the reference trajectory s as the independent variable, the Hamiltonian is

$$H(x, P_x, y, P_y, t, E; s) = -\sqrt{\left(\frac{E - q\Phi}{c}\right)^2 - m^2c^2 - P_x^2 - P_y^2}$$

$$\Phi(x, y, s, t) = \frac{1}{2}V_0\left[A_{1,0}\cos(ks)\left(\frac{1}{4}k^2\left(x^2+y^2\right)+1\right) + A_{0,1}\left(x^2-y^2\right)\right]\sin\left(\omega t+\theta\right)$$

Transformed to the reference trajectory, $z = -\beta c\Delta t$, $P_z = \Delta E/(\beta c)$.

Notation: $\beta,\ \gamma,\ P = \beta\gamma mc$ are usual relativistic parameters of the reference particle.

$$\boldsymbol{\sigma}' = \mathbf{F}\boldsymbol{\sigma} + \boldsymbol{\sigma}\mathbf{F}^T$$

This is the **envelope equation**. For the full 6D case, it represents 21 equations. (Because σ is symmetric.) The **F**-Matrix:

$$\mathbf{F} = \begin{pmatrix} 0 & \frac{1}{P} & 0 & 0 & 0 & 0 \\ -\mathcal{A}_+ & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{P} & 0 & 0 \\ 0 & 0 & -\mathcal{A}_- & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \mathcal{B} & \frac{1}{\gamma^2 P} \\ 0 & 0 & 0 & 0 & -\mathcal{C} & -\mathcal{B} \end{pmatrix}$$

where

$$\mathcal{A}_\pm = \frac{qV_0\sin\left(\omega t_0+\theta\right)\left[k^2A_{10}\cos(ks) \pm 4A_{01}\right]}{4\beta c},$$

$$\mathcal{B} = \frac{qV_0A_{10}\left[k\sin(ks)\sin\left(\omega t_0+\theta\right) + (\omega/(\beta c))\cos(ks)\cos\left(\omega t_0+\theta\right)\right]}{2\beta^2\gamma^3 mc^2},$$

$$\mathcal{C} = \frac{qV_0(\omega/(\beta c))^2A_{10}\cos(ks)\left[qV_0A_{10}/(\beta^2\gamma^3mc^2)\cos(ks)\cos^2\left(\omega t_0+\theta\right) - 2\sin\left(\omega t_0+\theta\right)\right]}{4\beta c}$$

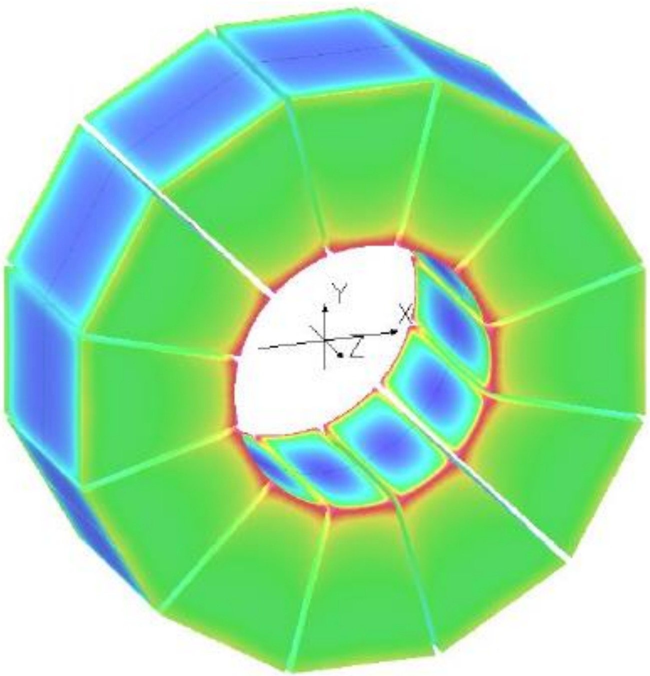
Series expansion of Hamiltonian:

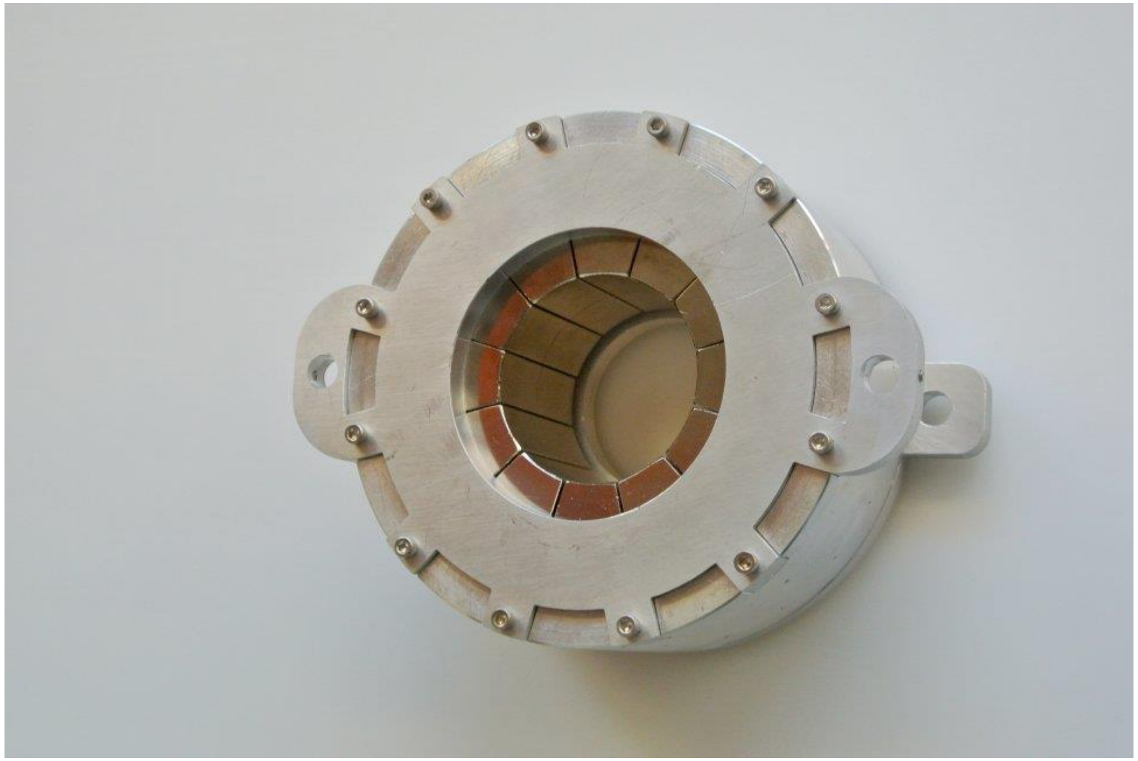
$$H(x, P_x, y, P_y, z, P_z) = -P + \frac{P_x^2}{2P} + \frac{P_y^2}{2P} + \frac{P_z^2}{2\gamma^2 P} + \frac{\mathcal{A}_+}{2}x^2 + \frac{\mathcal{A}_-}{2}y^2 + \frac{\mathcal{C}}{2}z^2 + \mathcal{B}\,zP_z$$

Permanent Magnet Lens

– Baartman, Planche, (Jayamanna/Minato/Lovera)

Simulated and built a new type of permanent magnet lens (like Iwashita, but single). To be used to create higher brightness H- beams.



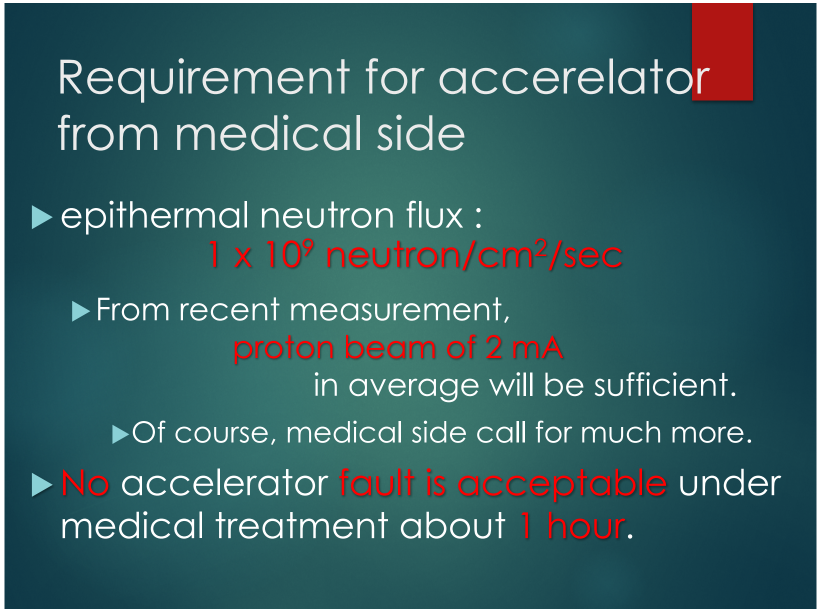


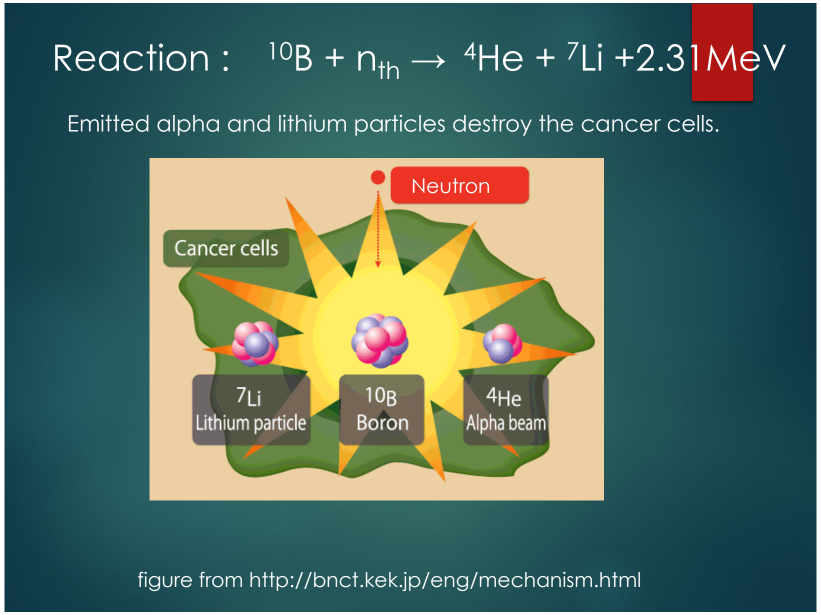
Axial Magnetic Field Lens with Permanent Magnet

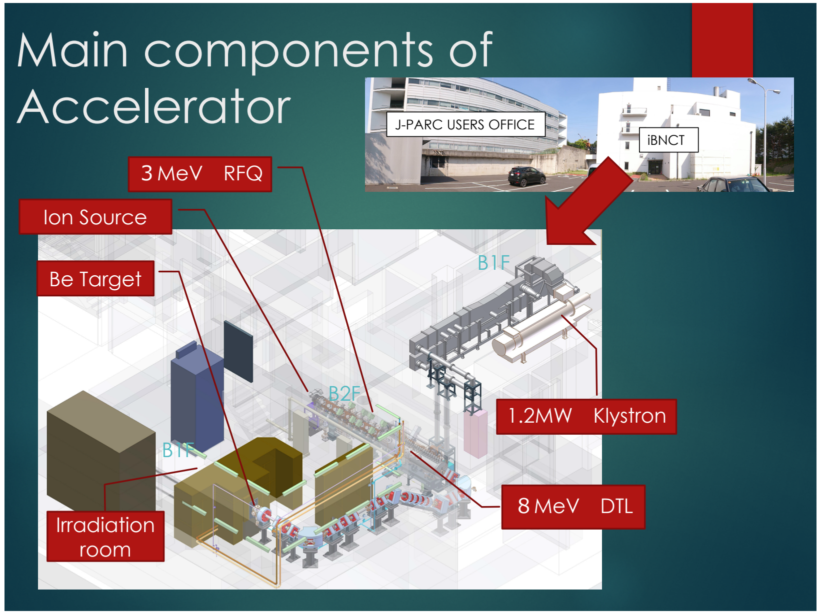
(PAC'93)

Yoshihisa Iwashita
Accelerator Laboratory
Nuclear Science Research Facility
Institute for Chemical Research, Kyoto University
Gokanosho Uji, Kyoto 611, JAPAN

- **Axial Magnet Field Lens with Permanent Magnet collaboration with Iwashita (Kyoto U.)**







- **Principle of BNCT**
- **Requirements for accelerator from medical side**

Key points of iBNCT 1

We call our BNCT project as "iBNCT".
"i" stands for Ibaraki prefecture, where KEK established.

- Hospital-use equipment.
- compact footprint about 100 m^2.

Key points of iBNCT 2

- The RF design of the RFQ and the DTL is based on the J-PARC Linac to reduce development work.
    - note: The duty factor of the iBNCT is much higher (20%) compared with that of J-PARC (1.25%).

Key points of iBNCT 3

come along with Key points 1

- One klystron feeds both of an RFQ and a DTL.
- Allowing a large temperature difference (ΔT) up to 10 degree Celsius between inlet and outlet cooling water of RF cavities, cooling water system shrinks in size.
    - It's a big challenge.

Key points of iBNCT 4

- There are some choices for an accelerator based BNCT.
    - Linac, cyclotron, electrostatic accelerator,,,
    - 8MeV, 30 MeV,,,,
    - Li target(solid or liquid), Be target,
- iBNCT selected 8MeV linac with Be target.
    - Low residual activity is essential in a hospital.

These selections characterize iBNCT.

Key points:

- **Hospital use -> Size**
- **Duty -> Cooling**
- **2Cav.- 1Kly.**
- **8 MeV Be target**

Summary

- Introduced BNCT
- iBNCT accelerator:
  - Small foot print suitable for hospital-use.
  - RF Cavity design is based on J-PARC LINAC.
  - Feeding two different cavities from one klystron.
  - Allowing large ΔT of cooling water for cavities to shrink cooling system in size.
  - 8MeV linac with Be target.
- iBNCT achieved average current of 1 mA and thermal neutron flux of 5.3×10^{8} neutron/cm^2/sec .
- We are still in a half of the way there.

TRIUMF

Canada's National Laboratory for Particle and Nuclear Physics

Medical isotope production at TRIUMF - from imaging to treatment

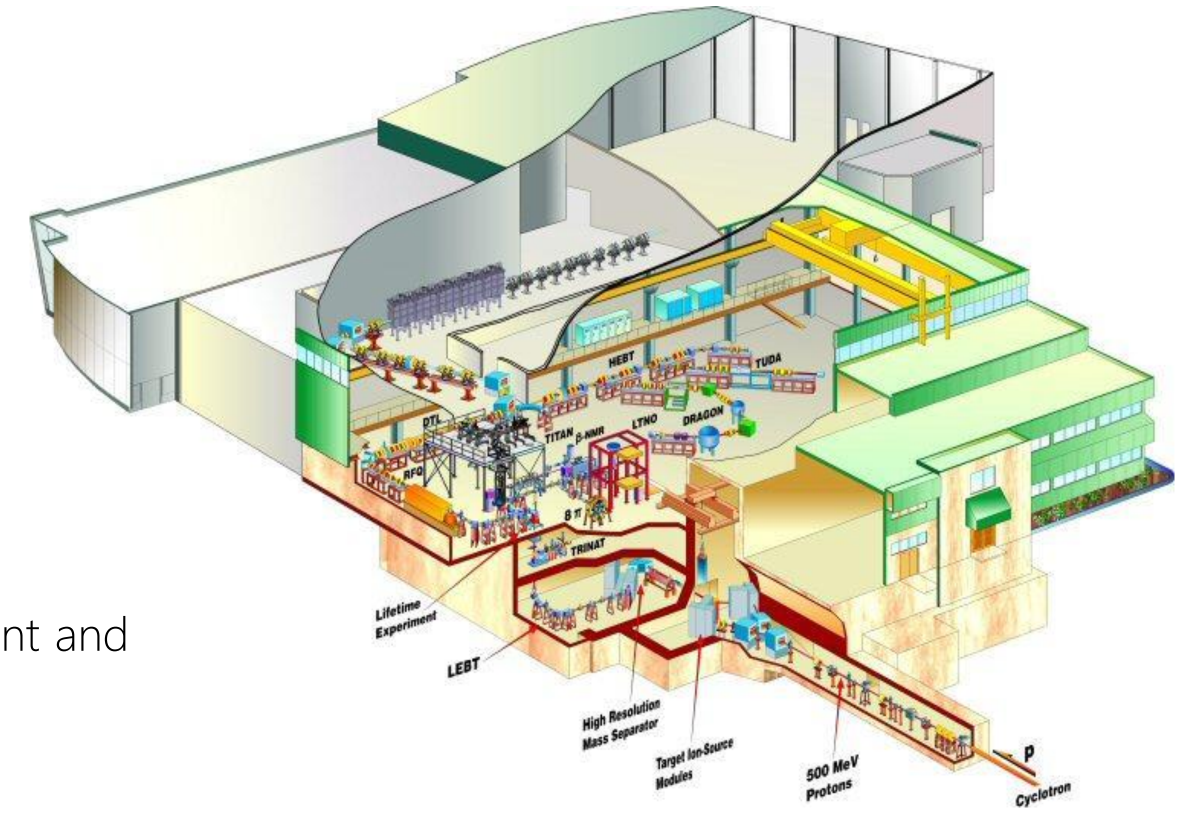
Cornelia Hoehr
Research Scientist, Life Sciences

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



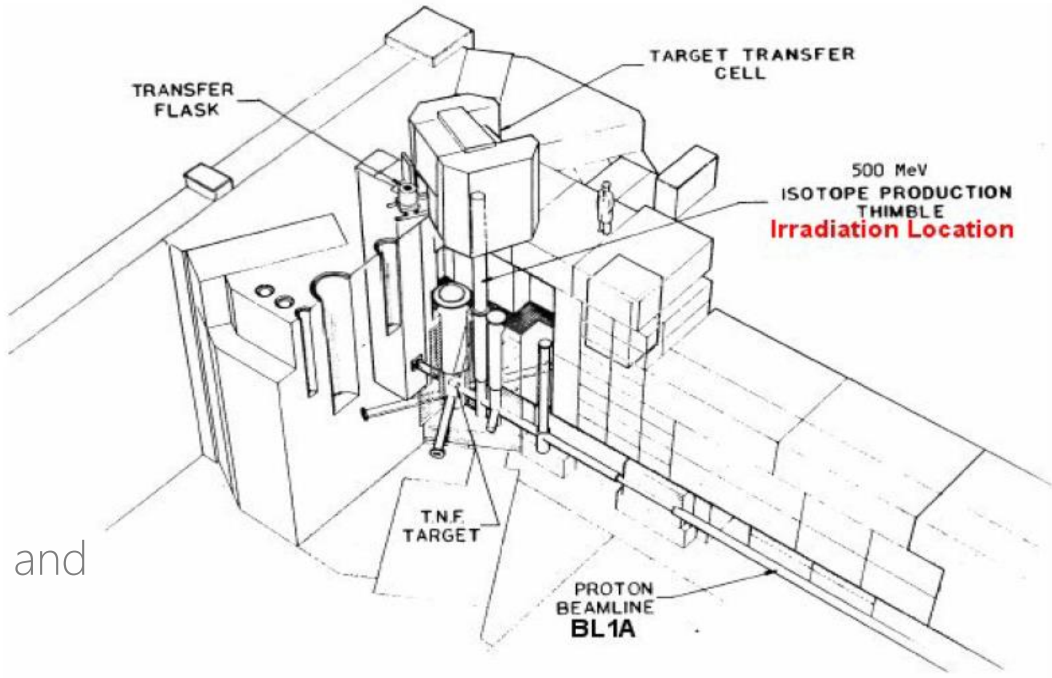
Experiments underway

Isotope production using TRIUMF's 500 MeV infrastructure

1) ISAC - ISOL
Low activity (kBq to MBq), high purity
- Feasibility chemistry, radiolabeling

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



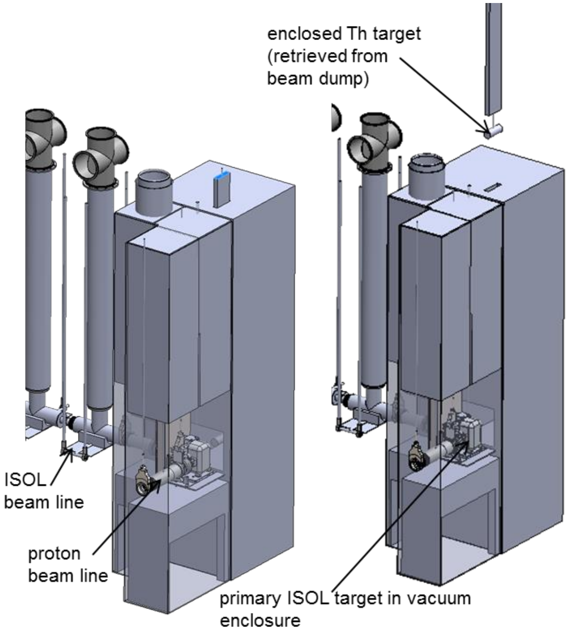
500 MeV Isotope Production Facility

Isotope production using TRIUMF's 500 MeV infrastructure

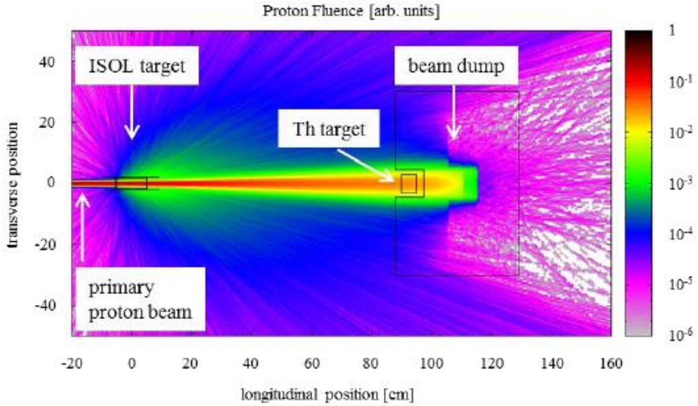
1) ISAC - ISOL
Low activity (kBq to MBq), high purity
- Actinide targets
- Feasibility chemistry, radiolabeling

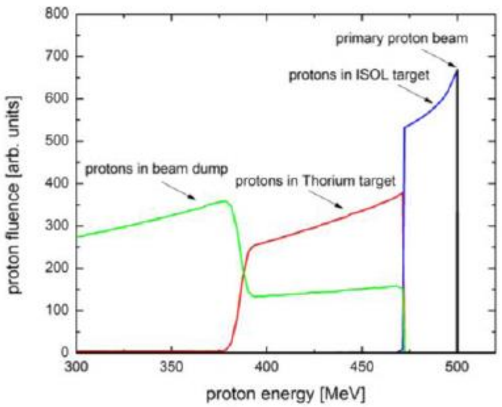
2) 500 MeV – IPF (BL1A)
Intermediate activity (MBq), spallation
- Routine, independent production

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



- 400 mCi (15 GBq) ^{225}Ac per target (FLUKA; A. Gottberg)
- Irradiation schedule decoupled from science target
- ARIEL Proton Station commissioning scheduled for 2021
- \$9.8M for infrastructure





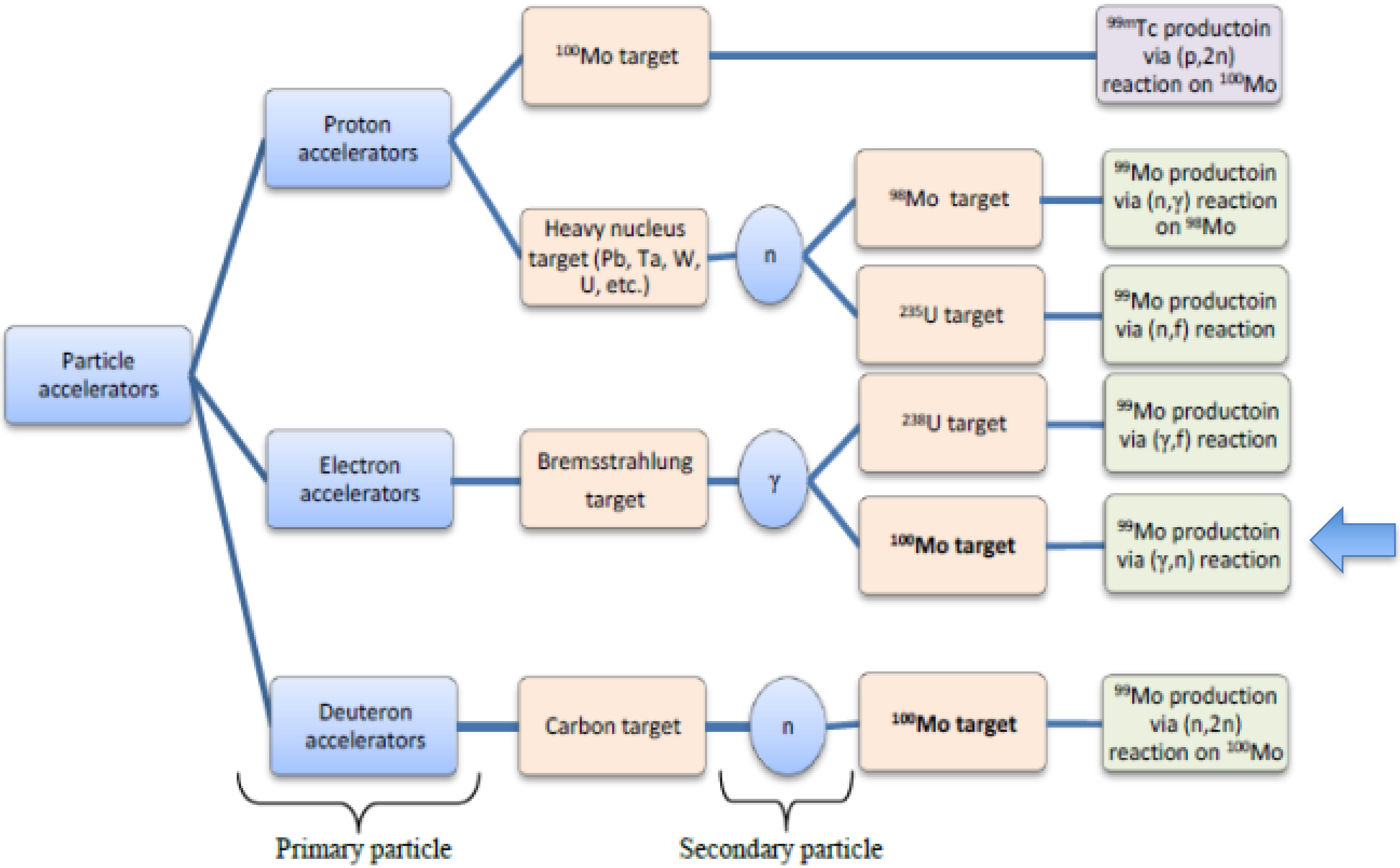
Medical isotopes research at KEK

KEK

Shin MICHIZONO

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

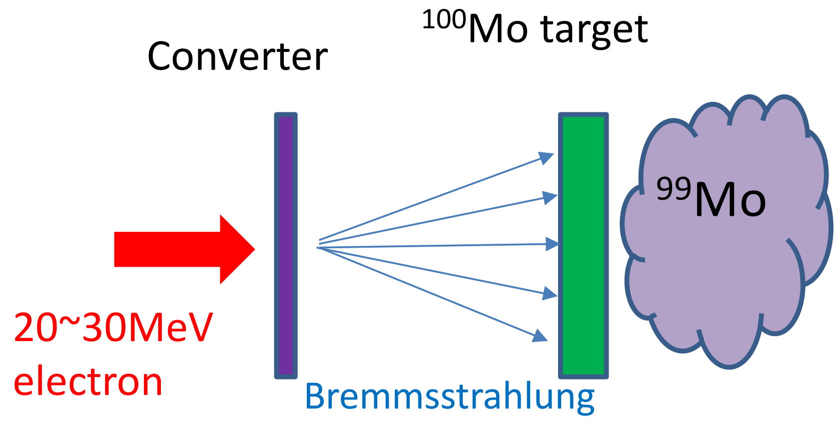
Accelerator driven ^{99}Mo production



The Supply of Medical Radioisotopes - Nuclear Energy Agency
NUCLEAR ENERGY AGENCY ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT,2010

^{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



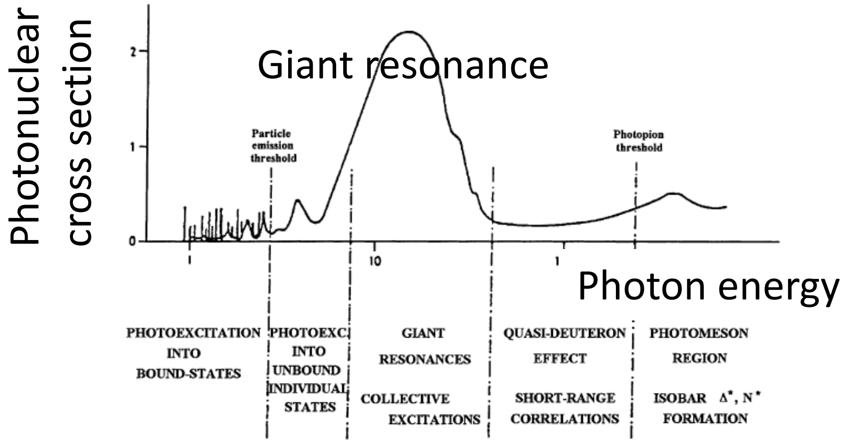
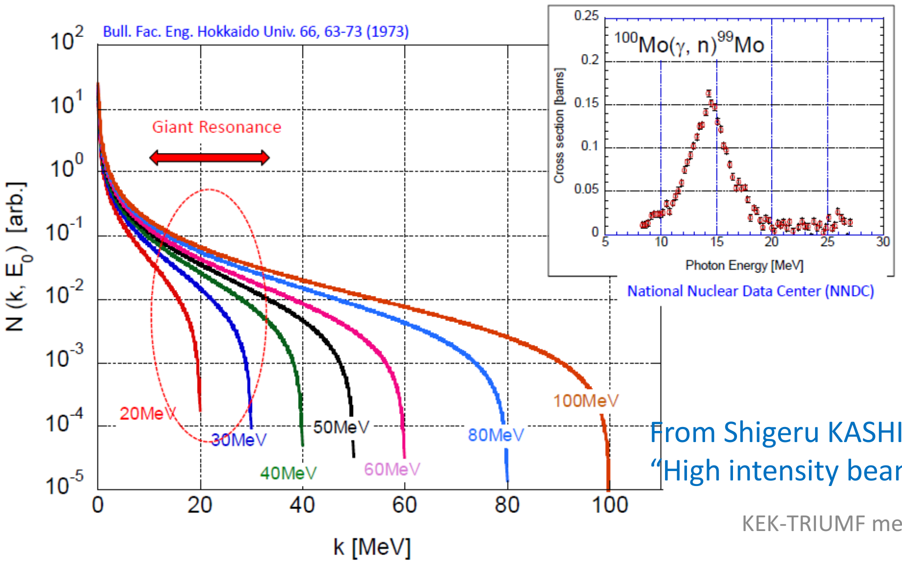


Fig. 1. Total photonuclear cross section as a function of the photon energy k [17].

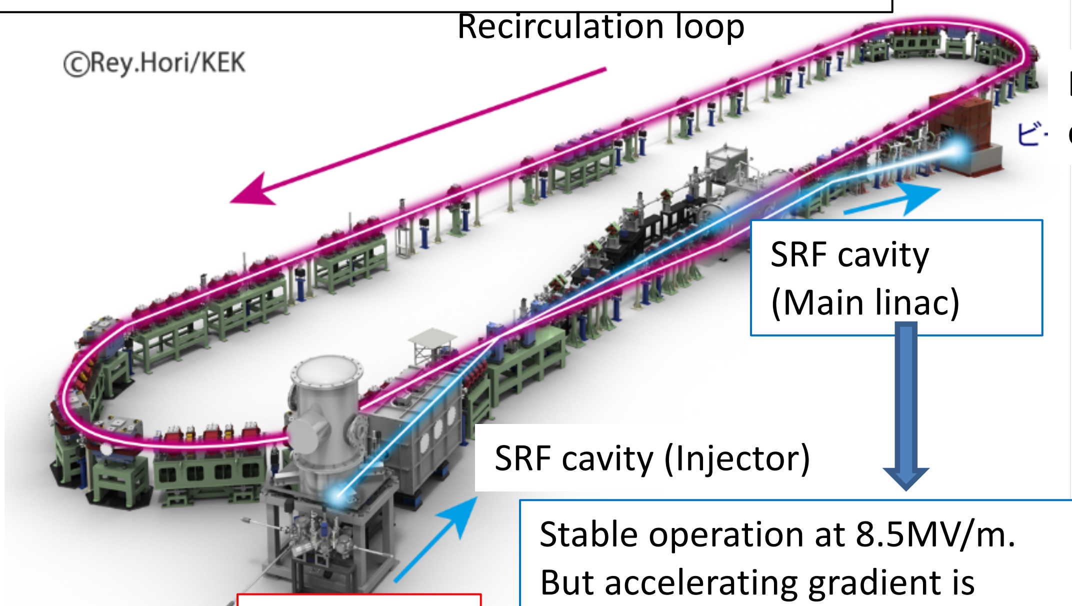
Nucl Instr Meth B 155 (1999) 373



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

Operation experience at cERL

Start beam operation from 2014/Jan. Energy recovery successful. 20MeV, ~1mA at present



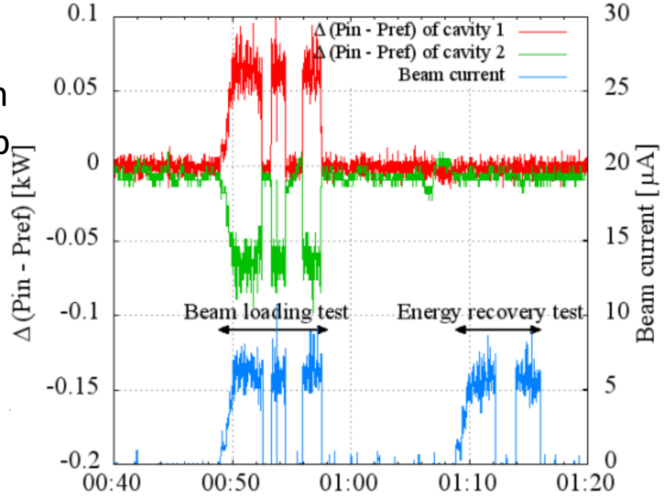
Very stable operation at 390kV. Plan to upgrade to 500kV.
At present 1mA operation.
10mA near future.

Stable operation at 8.5MV/m. But accelerating gradient is limited by field emission.

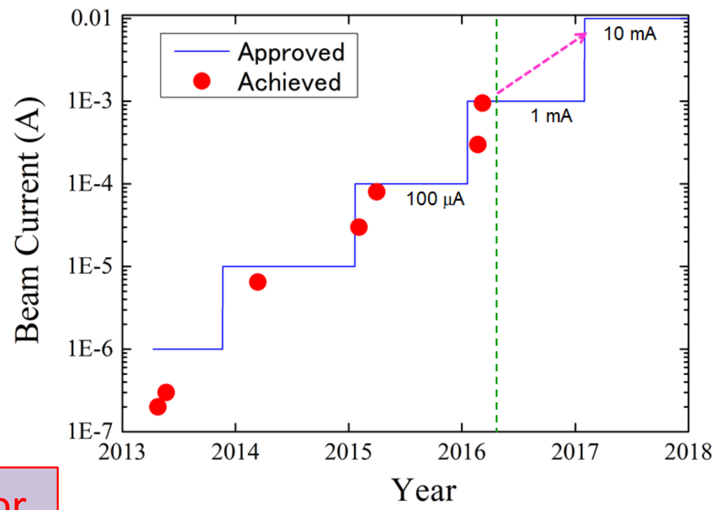
Energy recovery of
E_beam(MeV)xI_beam(mA)

Given power to
beam acceleration
= Obtained power from
beam decceleration

Successful energy recovery



Upgrade of beam current
(S. Sakanaka)



Stably operated at 1mA. Can be operated at 10mA at the injector

Summary

- Mo-99/Tc-99m is widely used for the medical inspection.
- These are 100% imported and most of them are produced by using the nuclear reactors now.
- For the stable supply, we propose the production of Mo-99 by SRF accelerator.
- The 10mA ~30MeV electron beam might supply the large amount of Mo-99 in Japan.
- The SRF technology (developed for EXFEL, ILC, cERL,…) looks matured to satisfy these requirements.
- R&D for conversion target and sample preparation (Mo-100/Mo-99) will be necessary.

Collaboration Items between TRIUMF-KEK (1)

	Collaboration items
SC	• SRF technologies: cavity (cost, performance, material), cryomodule L-band elliptical (ILC, ARIEL), low-beta (ISAC, ADS, IFMIF, etc.) • R&D on radiation-resistant high-field SC magnet in the framework of MNPP
target	• material, cooling, vacuum, maintainability, etc. • target/extraction/separation for medical isotope production (small or mid-size target). (BNCT ->patent?) • KEK would like to learn a lot from TRIUMF’s experience.

Collaboration Items between TRIUMF-KEK (2)

	Collaboration items
beam physics	• optimization of beam transport to minimize beam loss at high current/high power accelerators ARIEL, (c)ERL, (BNCT) • Permanent Magnet Lens for 25keV H- transport
medical application	• cyclotron based BNCT (?) • technologies for medical isotope production
control	• high-level (intelligent) application of control system • Beam-based tuning

Thank you for your attention.