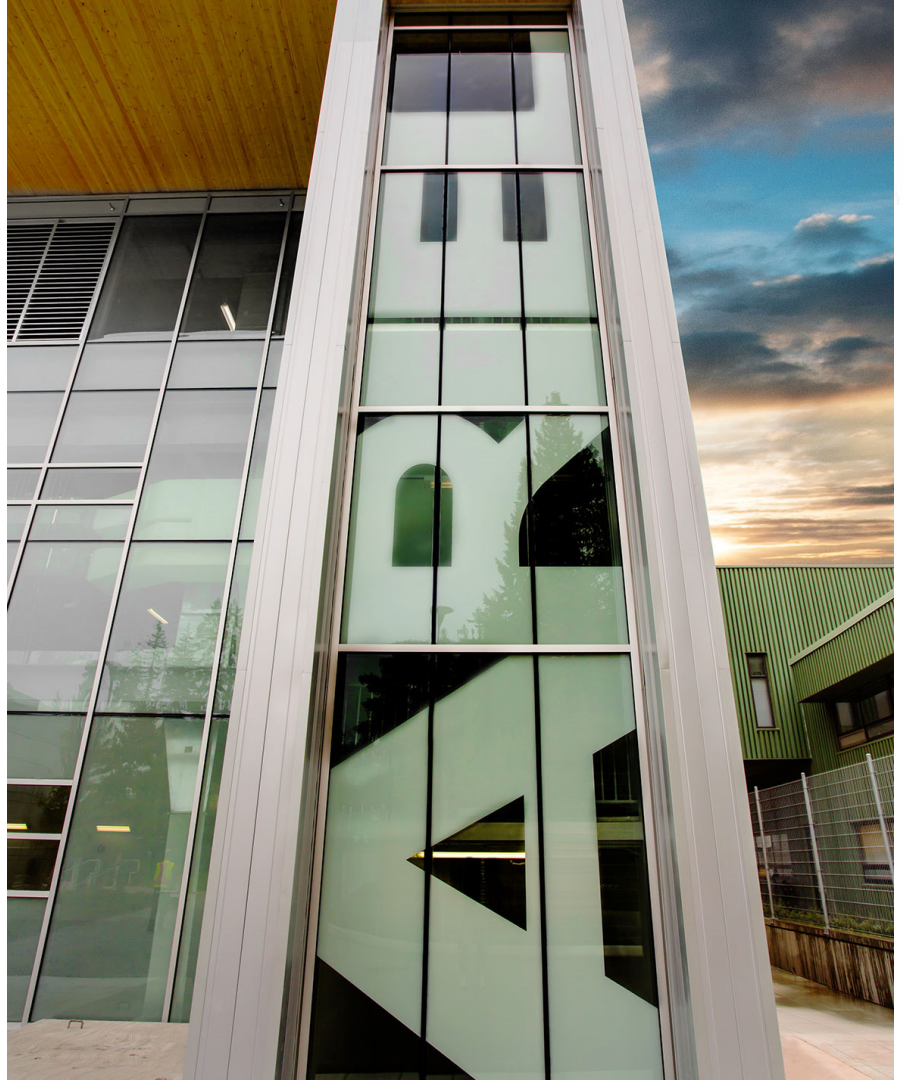




# TRIUMF in the ARIEL Era

IPAC 2018

Jonathan Bagger  
Director



Discovery,  
accelerated



# TRIUMF

**50** anniversary  
anniversaire

[www.triumf50.com](http://www.triumf50.com)



A woman with long brown hair, wearing a dark grey cardigan and a patterned skirt, is kneeling on a yellow table in a laboratory. She is focused on adjusting a cylindrical metal component with a pink handle. The table is covered with various tools and components, including a screwdriver and another pink-handled tool. In the background, other people are visible, some wearing lab coats, and the environment is brightly lit with yellow walls.

TRIUMF is Canada's  
particle accelerator centre



 **TRIUMF**

GOVERNMENT OF - GOUVERNEMENT DU  
**CANADA**

OTTAWA  
COMPTROLLER OF THE TREASURY  
CONTRÔLEUR DU TRÉSOR

NEGOTIABLE WITHOUT CHARGE AT ANY BANK IN CANADA  
PAYABLE AU PAIR PAR TOUTE BANQUE AU CANADA

TO THE RECEIVER GENERAL OF CANADA, OTTAWA  
AU RECEVEUR GÉNÉRAL DU CANADA, OTTAWA

PAY TO THE ORDER OF - PAYEZ À L'ORDRE DE  
UNIVERSITY OF BRITISH COLUMBIA

291-0023511

APR 1967

\$\*\*650,000.00

*[Handwritten Signature]*

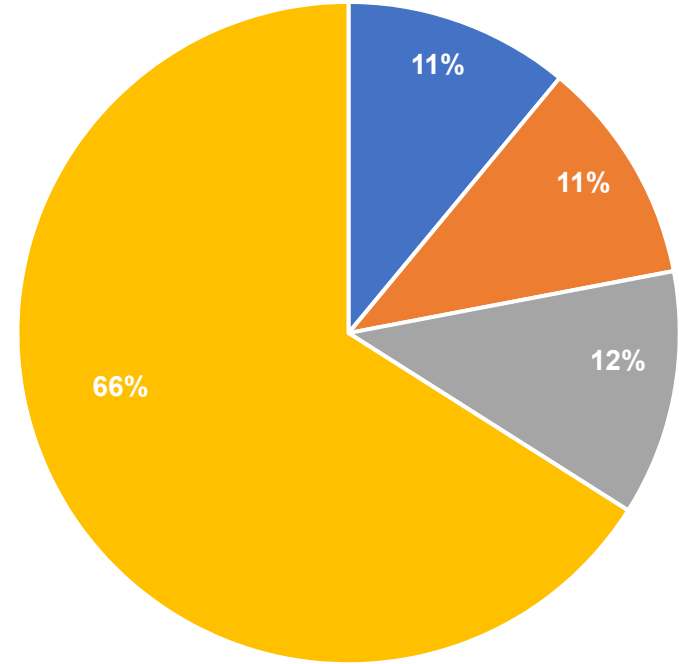
APR 1967

2910023511

TRIUMF's first cheque

**FY17/18:**

**\$95.2M Total Funding**



**TRIUMF Revenue by Source (2015-2020)**

■ Private Sector ■ Capital ■ Sponsored Research ■ Core Operations



THE UNIVERSITY  
OF BRITISH COLUMBIA



SIMON FRASER UNIVERSITY



University  
of Victoria

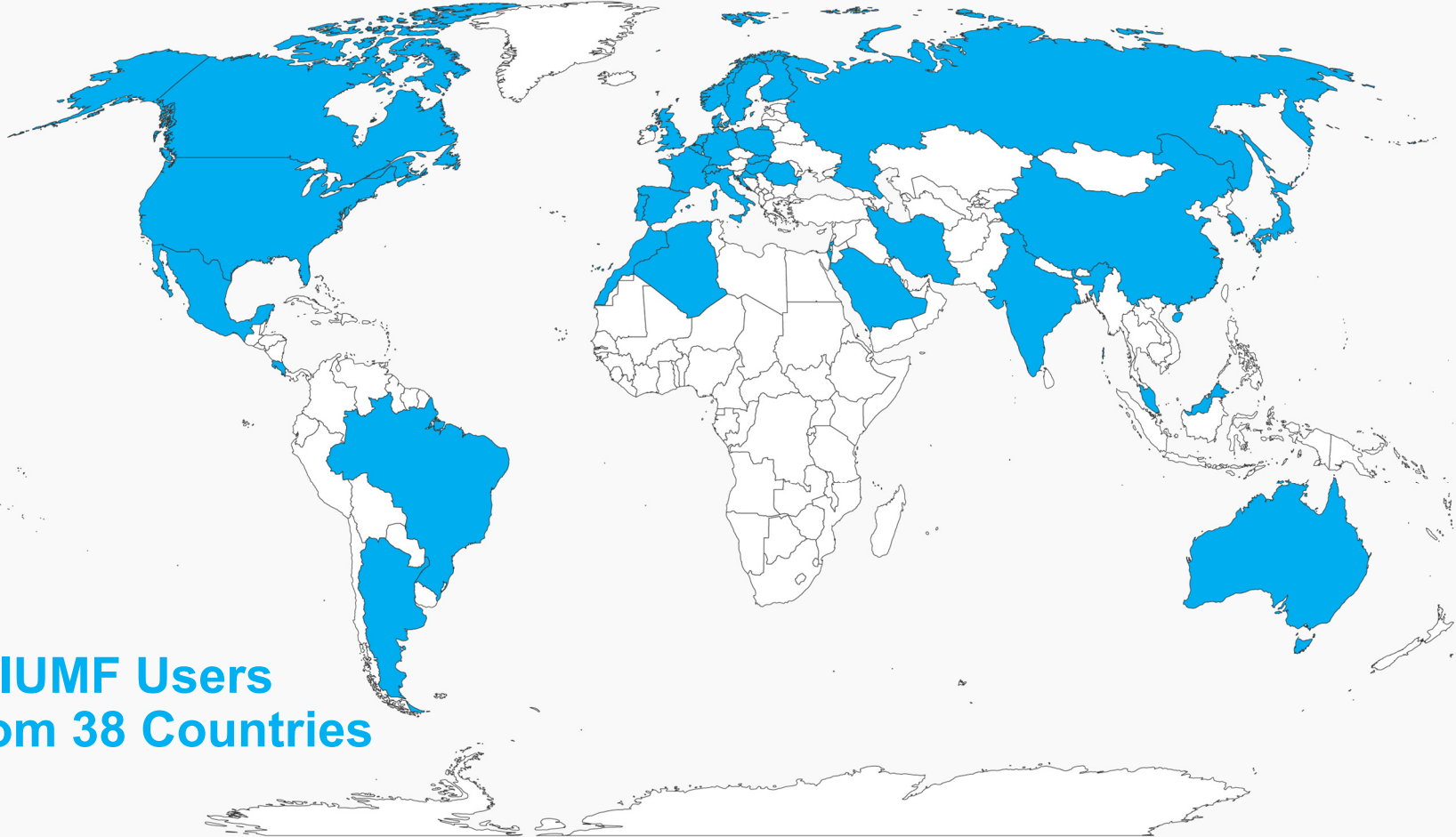
Tri-University Meson Facility

## 20 Member Universities

University of Alberta  
University of British Columbia  
University of Calgary  
Carleton University  
University of Guelph  
University of Manitoba  
McGill University  
McMaster University  
Université de Montréal  
University of Northern  
British Columbia  
Queen's University  
University of Regina  
Saint Mary's University  
Université de Sherbrooke  
Simon Fraser University  
University of Toronto  
University of Victoria  
Western University  
University of Winnipeg  
York University

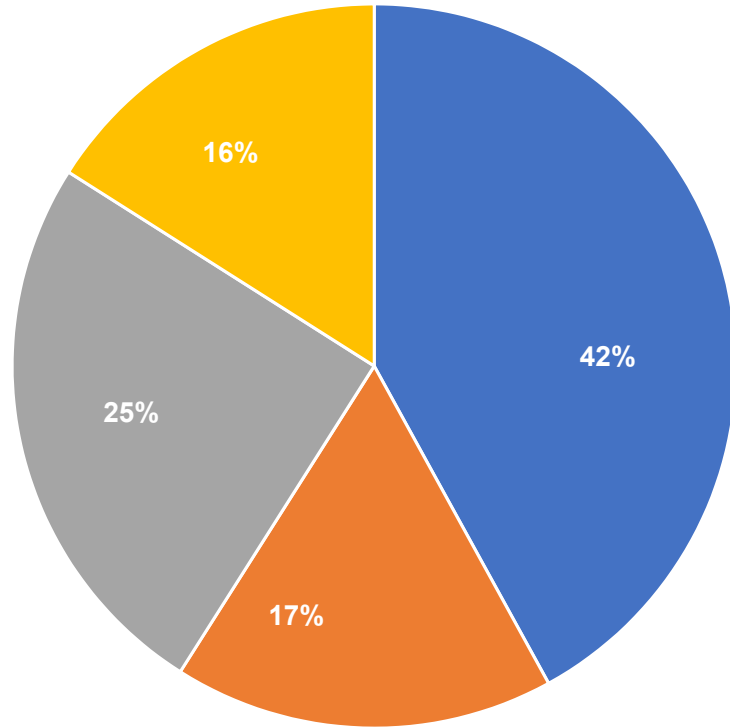


**TRIUMF Users  
From 38 Countries**



**FY17/18:**

**875 Scientific  
Users and Visitors  
By Origin**



■ Canada ■ Asia ■ Americas ■ Europe

# 50+

international  
agreements



CERN  
*Europe*



KEK / J-PARC  
*Japan*



VECC  
*India*



Helmholtz Association  
Centres  
*Germany*



Department of Energy  
Laboratories  
*USA*

HEEDE

CAP. 50 TONS

Meson Facility



Dark Matter  
& Cosmology

Electronics  
Radiation Testing

Molecular &  
Materials Science

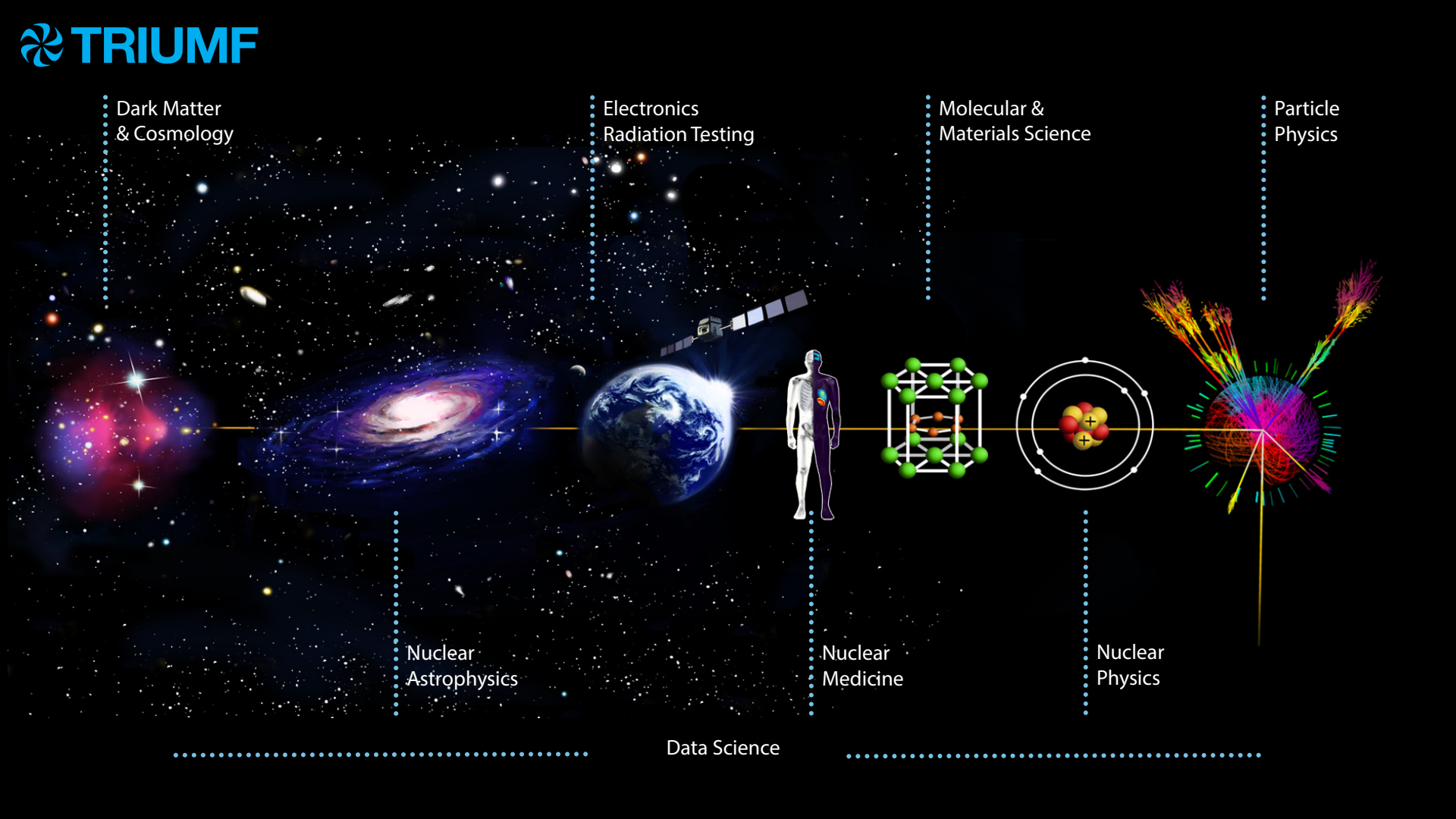
Particle  
Physics

Nuclear  
Astrophysics

Nuclear  
Medicine

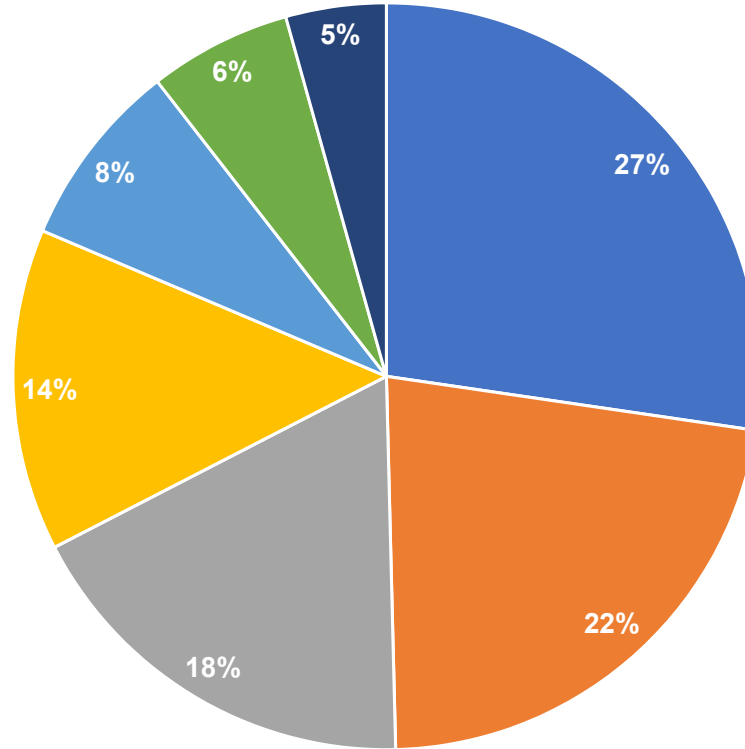
Nuclear  
Physics

Data Science



**FY17/18:**

**875 Scientific  
Users and Visitors  
By Field**



■ Nuclear Physics

■ Irradiation Services

■ Materials Science

■ Particle Physics

■ Life Sciences

■ Theory

■ Accelerator



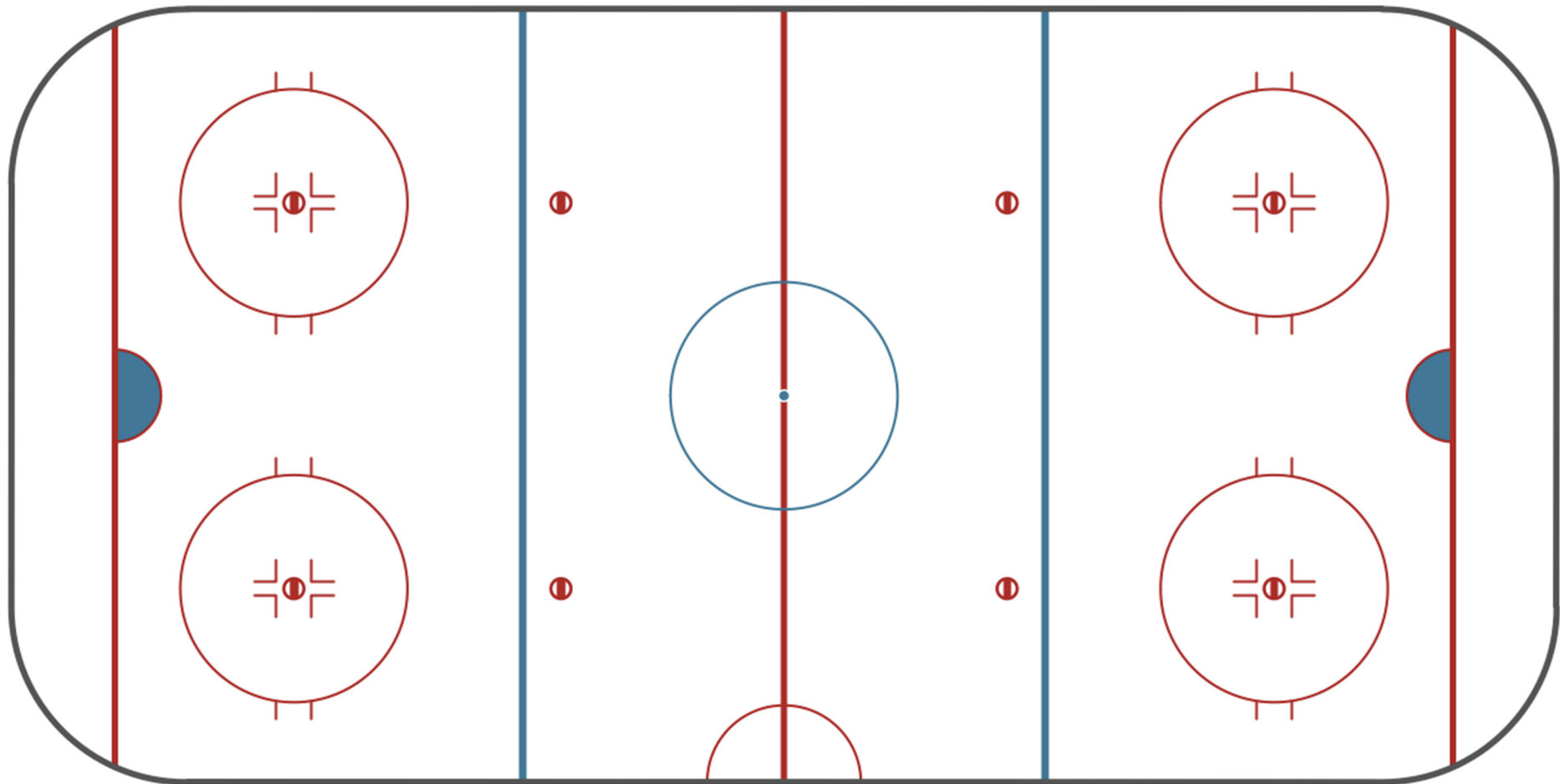
**TRIUMF**

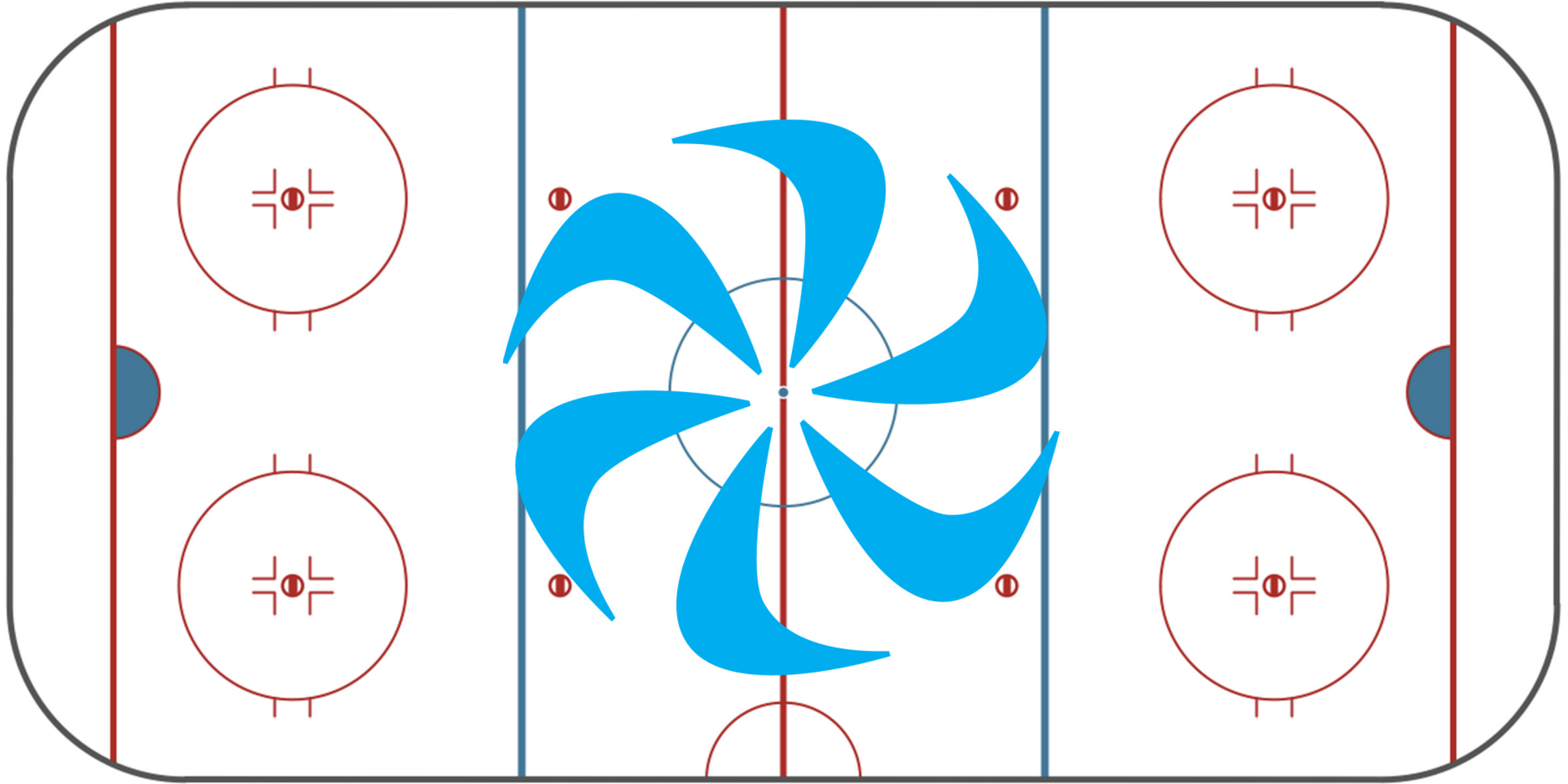
**PAST AND PRESENT**

A black and white aerial photograph of the TRIUMF 520 MeV H- Cyclotron. The image shows a large, complex, circular structure with multiple curved, metallic sections. A large group of people, including men and women in various work clothes and hard hats, are posing on the structure. The people are distributed across the different levels and sections of the cyclotron, some sitting on the curved surfaces and others standing. The overall scene is a historical record of the project's completion. The text "The Heart of TRIUMF: 520 MeV H- Cyclotron" is overlaid in white on the left side of the image. Below it, the text "IEEE Historical Engineering Milestone" is also overlaid in white.

# The Heart of TRIUMF: 520 MeV H- Cyclotron

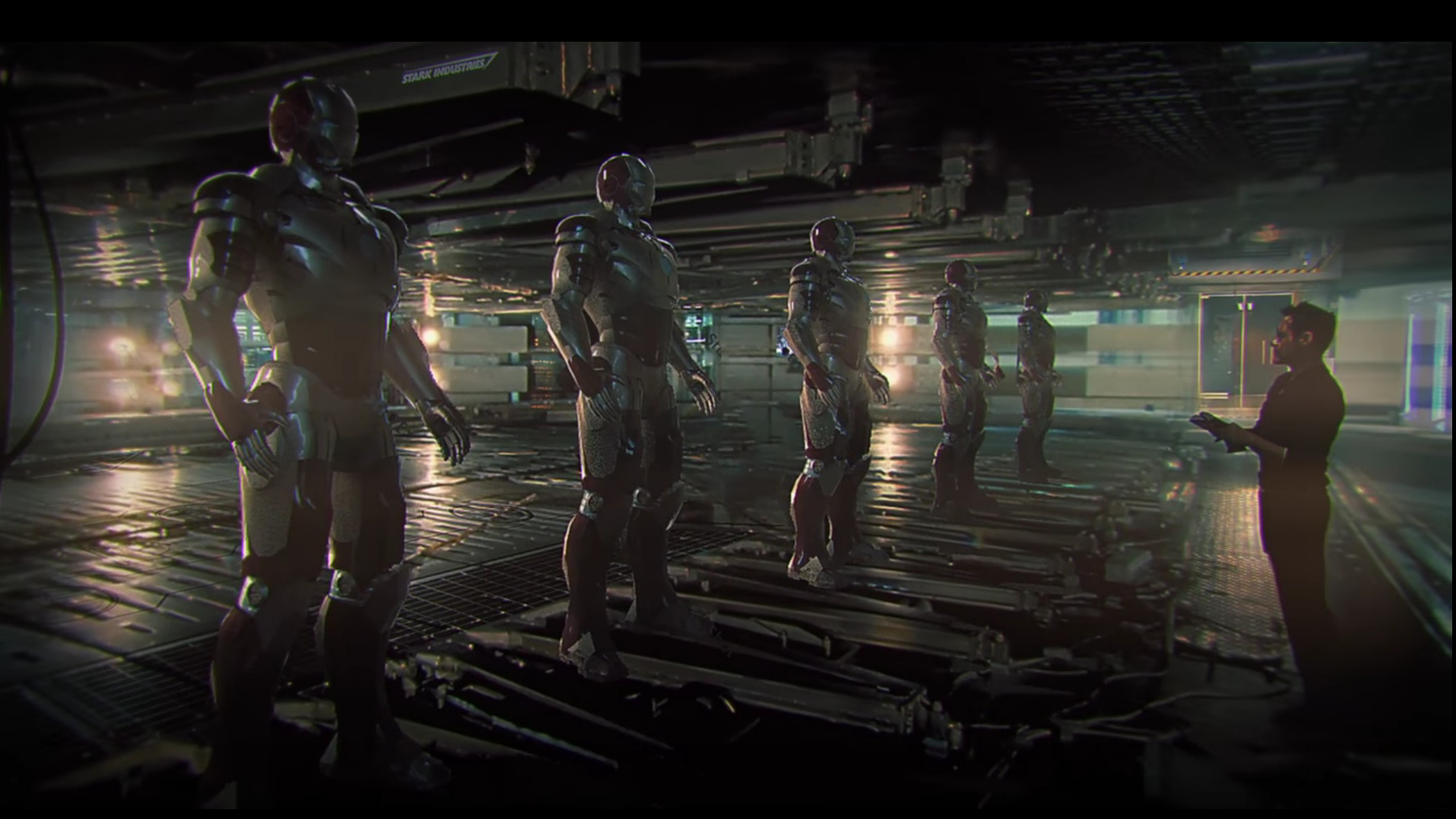
IEEE Historical Engineering Milestone



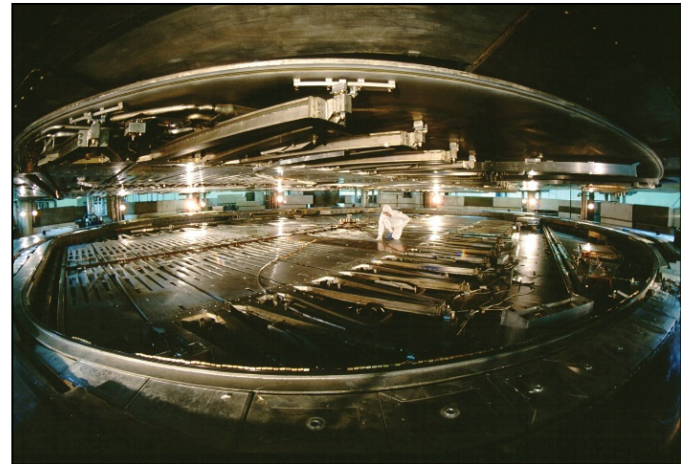
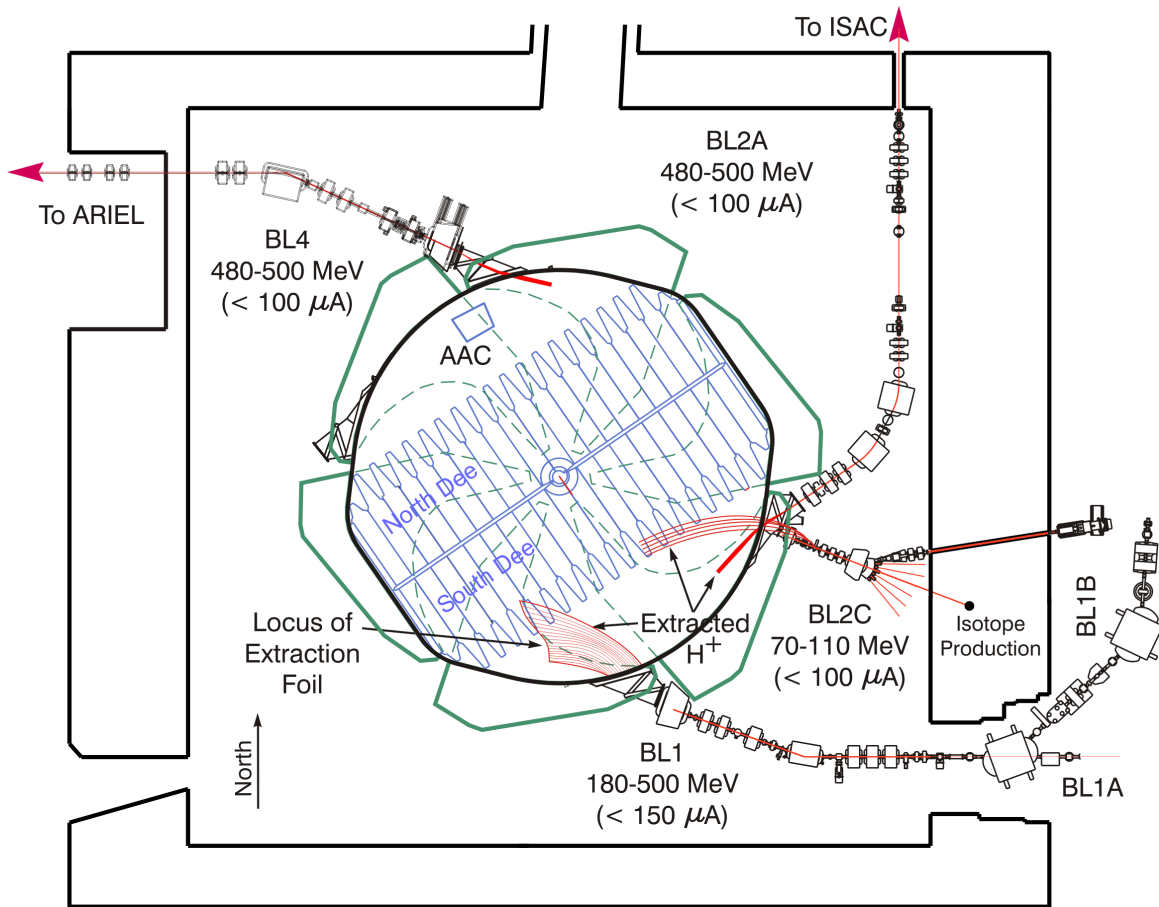


MARVEL STUDIOS

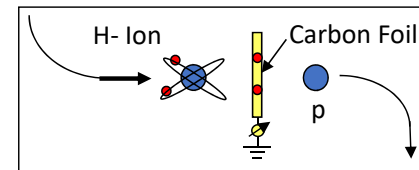
**AVENGERS**  
INFINITY WAR



# Cyclotron



## H<sup>-</sup> extraction



Prime Minister Pierre Trudeau  
TRIUMF Director Reg Richardson

February 9, 1976



# Cyclotron

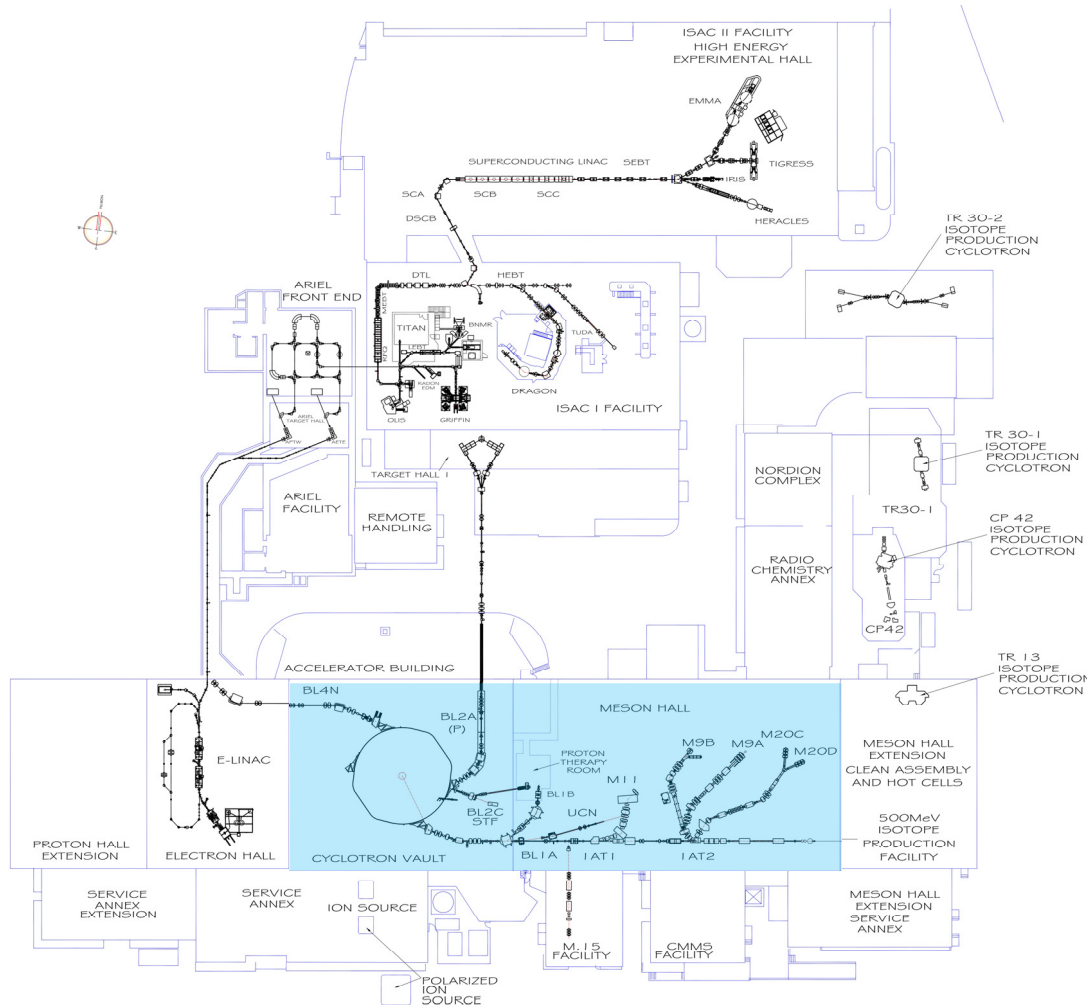
- Beamline 1A
  - Materials Science  $\mu$ SR
  - Ultra Cold Neutron Facility
  - Isotope Production
- Beamline 1B
  - Irradiation Services
- Beamline 2A
  - ISAC I Facility
  - ISAC II Facility
- Beamline 2C
  - Isotope Production
  - Proton Therapy

The 520 MeV cyclotron drives much of TRIUMF's multi-user, multi-disciplinary program

Present performance is limited to 300  $\mu$ A

BL Capacity	Routine
▪ BL1A (150 $\mu$ A)	(120 $\mu$ A)
▪ BL2A (100 $\mu$ A)	(70 $\mu$ A)
▪ BL2C (100 $\mu$ A)	(95 $\mu$ A)
▪ BL4A (100 $\mu$ A)	Future

# TRIUMF Site



## ■ Beamlines 1A, 1B, 2C

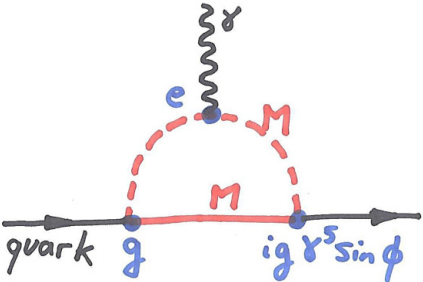
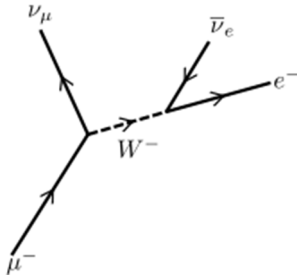
- Materials Science  $\mu$ SR
- Ultra Cold Neutron Facility
- Isotope Production
- Irradiation Services
- Proton Therapy



# Beamlines 1A, 1B, 2C

- These beamlines support a host of activities, from the very fundamental to the truly applied

- Materials Science  $\mu$ SR
- Ultra Cold Neutron Facility
- Isotope Production
- Irradiation Services
- Proton Therapy



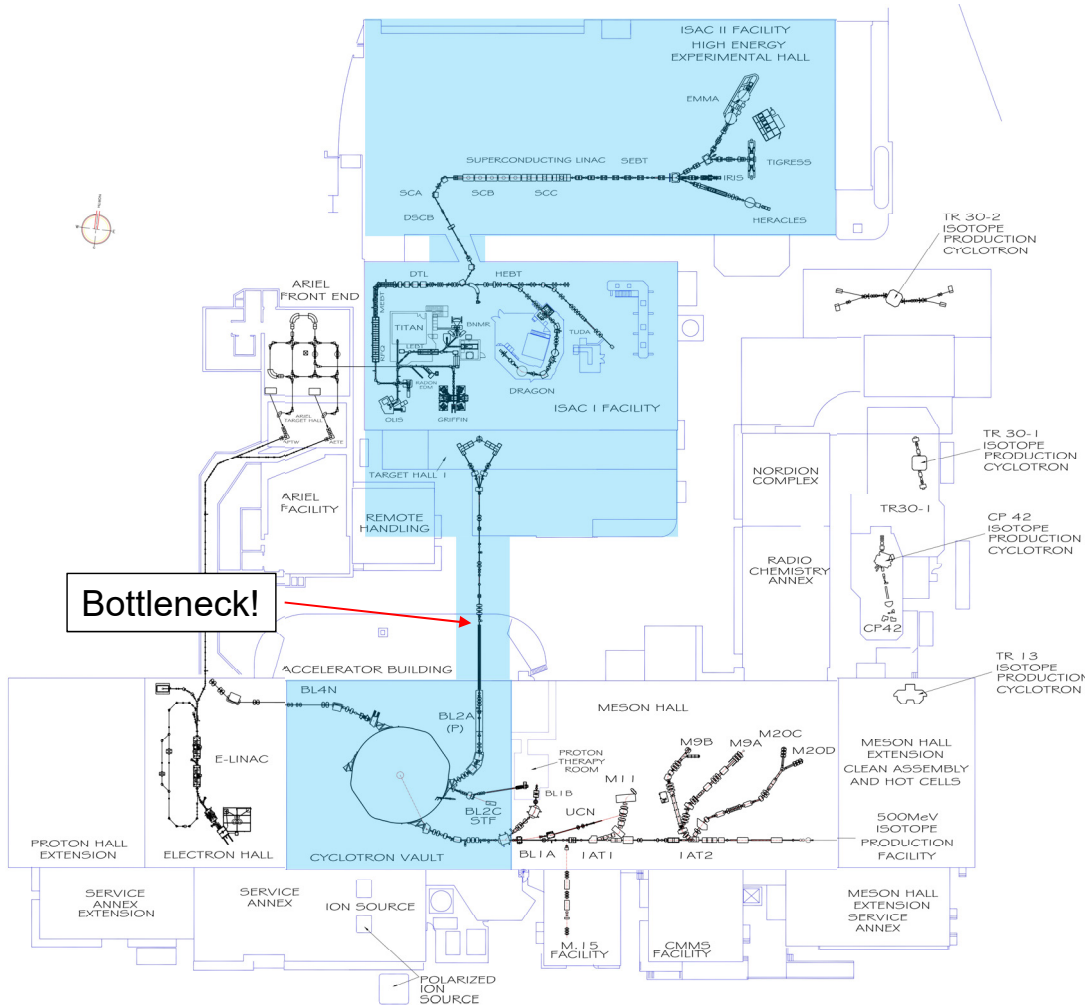
nordion

Japanese Prime Minister Toshiki Kaifu



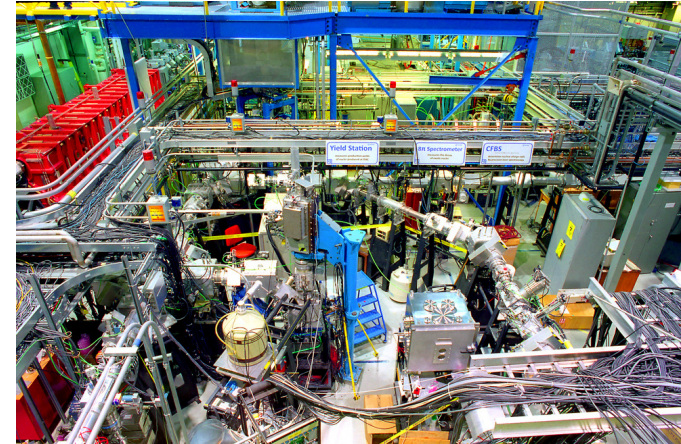
September 8, 1989

# TRIUMF Site

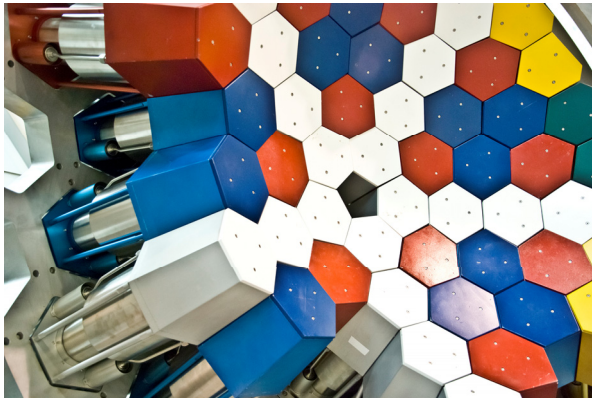


## ■ Beamline 2A

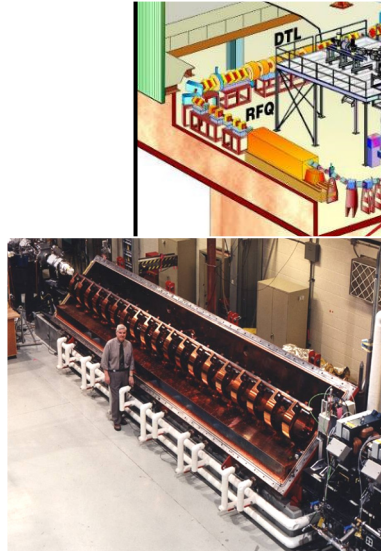
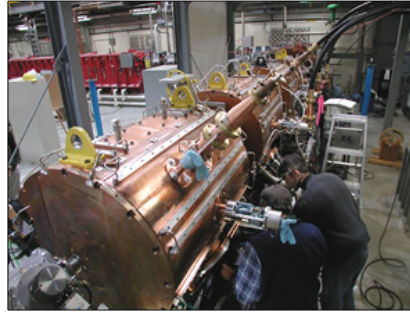
- ISAC I Facility
- ISAC II Facility
  - Nuclear Astrophysics
  - Nuclear Structure
  - Electroweak Physics
  - Materials Science  $\beta$ NMR
  - Life Science  $\beta$ NMR



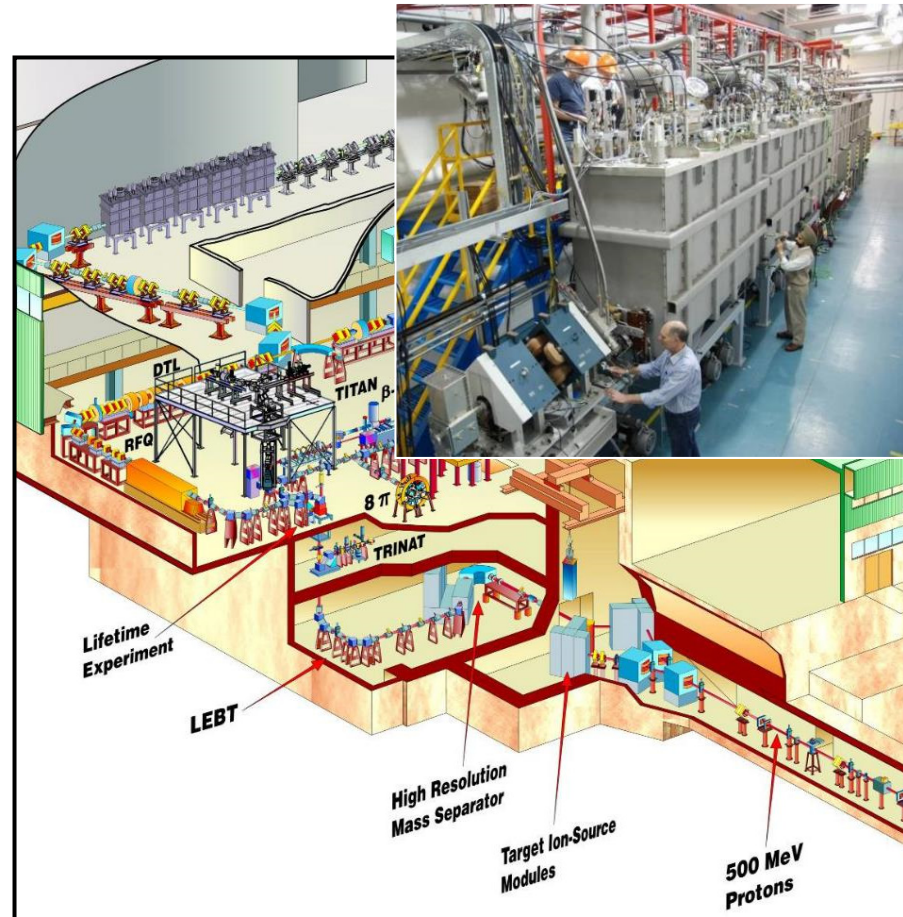
- This beamline drives ISAC I and II, Rare Isotope Beam (RIB) Facilities that are at the core of TRIUMF's on-site activities, with applications ranging from nuclear physics to the life and materials sciences
  - Nuclear Astrophysics
  - Nuclear Structure
  - Electroweak Physics
  - Materials Science  $\beta$ NMR
  - Life Science  $\beta$ NMR



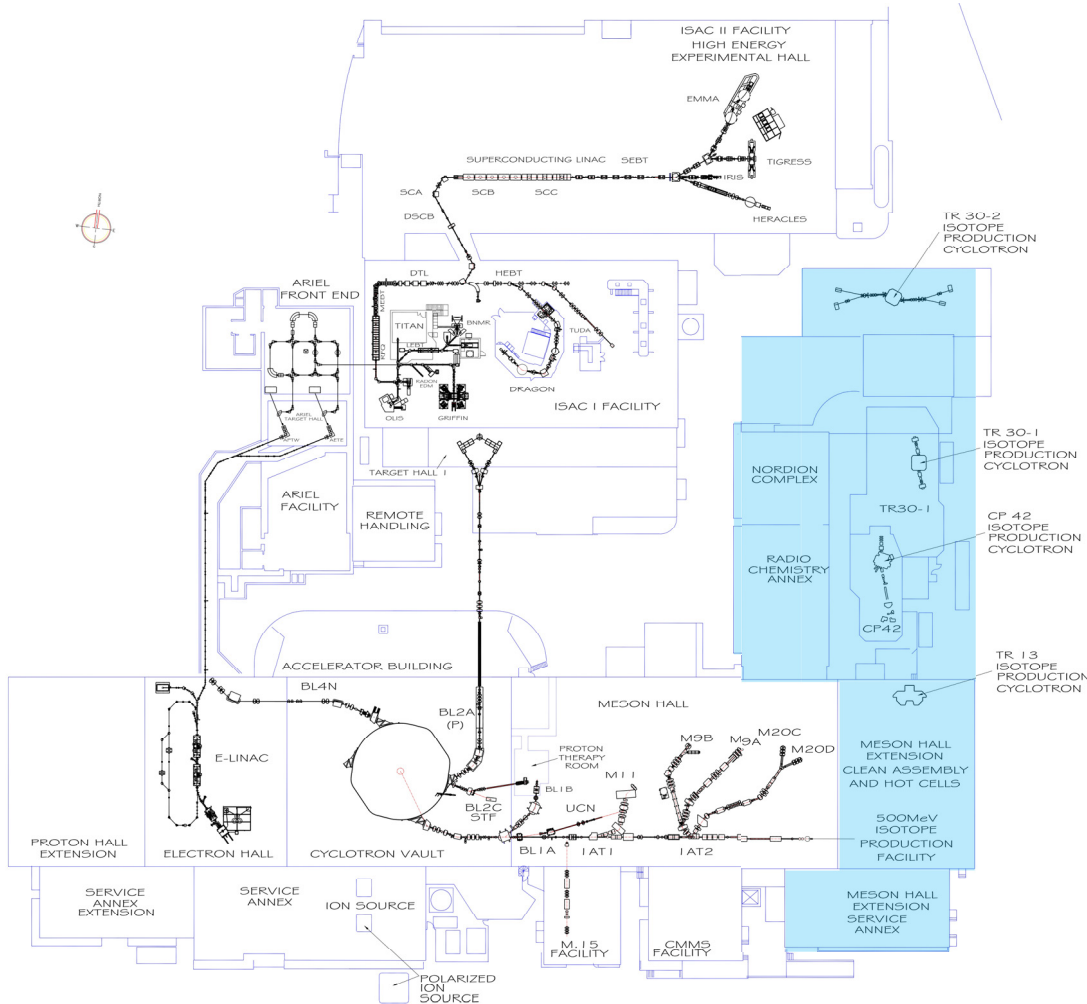
- “Low Energy” Radio Frequency Quadrupole (RFQ) normal conducting at 35.36 MHz
  - 8m long CW split ring structure
  - 150 keV/u
  - $3 \leq A/q \leq 30$
  - High quality transverse and longitudinal emittance
- “Medium Energy” Drift Tube Linac (DTL) normal conducting at 106.08 MHz
  - Separated functions
  - Variable energy machine
  - $150 \text{ keV/u} \leq E \leq 1.8 \text{ MeV/u}$
  - $2 \leq A/q \leq 7$



- “High Energy” Superconducting Linac at 106.1 and 141.4 MHz
  - Superconducting Linac using Quarter Wave Resonators (QWR) with  $\beta = 0.057, 0.071, 0.11$
  - Maximum energy range
    - 6.5 MeV/u ( $A/q=6$ )
    - 16.5 MeV/u ( $A/q=2$ )
  - Cryomodules with 4, 6 and 8 QWR and one 9T SC solenoid



# TRIUMF Site



## ■ Nuclear Medicine

- Five  $H^-$  medical cyclotrons
  - Isotope production
- Radiochemistry
  - Nordion
    - 2M doses annually
  - UBC
    - Centre for Brain Health





Queen Elizabeth II



March 8, 1983

- Nuclear Medicine continues to offer real benefits to real people. For example
  - A TRIUMF-led consortium developed a method to produce Tc-99m directly on medical cyclotrons
  - The method is clean, green and locally sourced – eliminating reliance on nuclear reactors and the fragile global supply chain
  - A TRIUMF spin-off company, ARTMS Products, is commercializing the technology
  - ARTMS technologies are being sold as OEM equipment on GE cyclotrons. The company has just received US\$3M in venture funding



43

(97.9072)

Tc

Technetium  
(Kr)4d<sup>5</sup>5s<sup>2</sup>

Governor General David Johnston



February 17, 2015

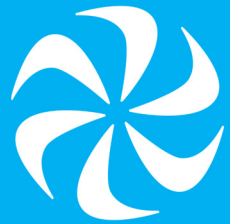


Since 1968, TRIUMF has delivered  
50 years of science and innovation  
for Canada

CYC ON  
SLIA ON  
SLIA ON  
SLIA ON

Cyclotron  
www.triumf.ca/cyclotron  
1-877-944-6888

TRI-2



**TRIUMF**

**FUTURE**

ARIEL

IAMI

TRIUMF INNOVATIONS

**TRIUMF INNOVATIONS**



**TRIUMF**  
INNOVATIONS

---

**The interface bridging  
TRIUMF with the  
business world.  
TRIUMF Innovations  
links cutting-edge  
science and technology  
to tangible business  
opportunities by:**

---

- 1** Connecting TRIUMF's researchers and technologies to the world via industry partnerships, licensing agreements, and start-up companies
- 2** Providing a pathway for businesses to access TRIUMF infrastructure and expertise
- 3** Developing business opportunities for technologies developed within the TRIUMF network
- 4** Training the next generation of science-driven entrepreneurs

Since 2010,  
TRIUMF has  
launched five  
spin-off  
companies  
spanning a  
wide range of  
sectors

**ARTMS Products**  
Life Sciences



Novel medical cyclotron technology enabling production of world's most-used imaging isotopes, propelled by \$3M in venture financing and an international customer base that includes GE Healthcare

**CRM**  
**Geotomography**  
Mining & Security



Advanced detector technology that can detect ore bodies and other materials without the need for physical inspection

**Frontier Sonde**  
Oil & Gas



Well-logging tool that uses neutron probes to detect residual oil deposits

**IKOMED**  
Medical Devices



Microshutters that reduce radiation exposure during medical procedures

**Micromatter**  
Advanced  
Manufacturing

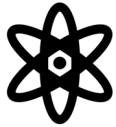


Specialized foils and calibration standards for research and industrial applications

**IAMI:  
Institute for Advanced  
Medical Isotopes**



## IAMI is a multidisciplinary R&D facility that will work across five areas



Medical isotope  
production



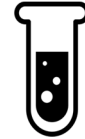
Cancer therapies



Accelerated drug  
development



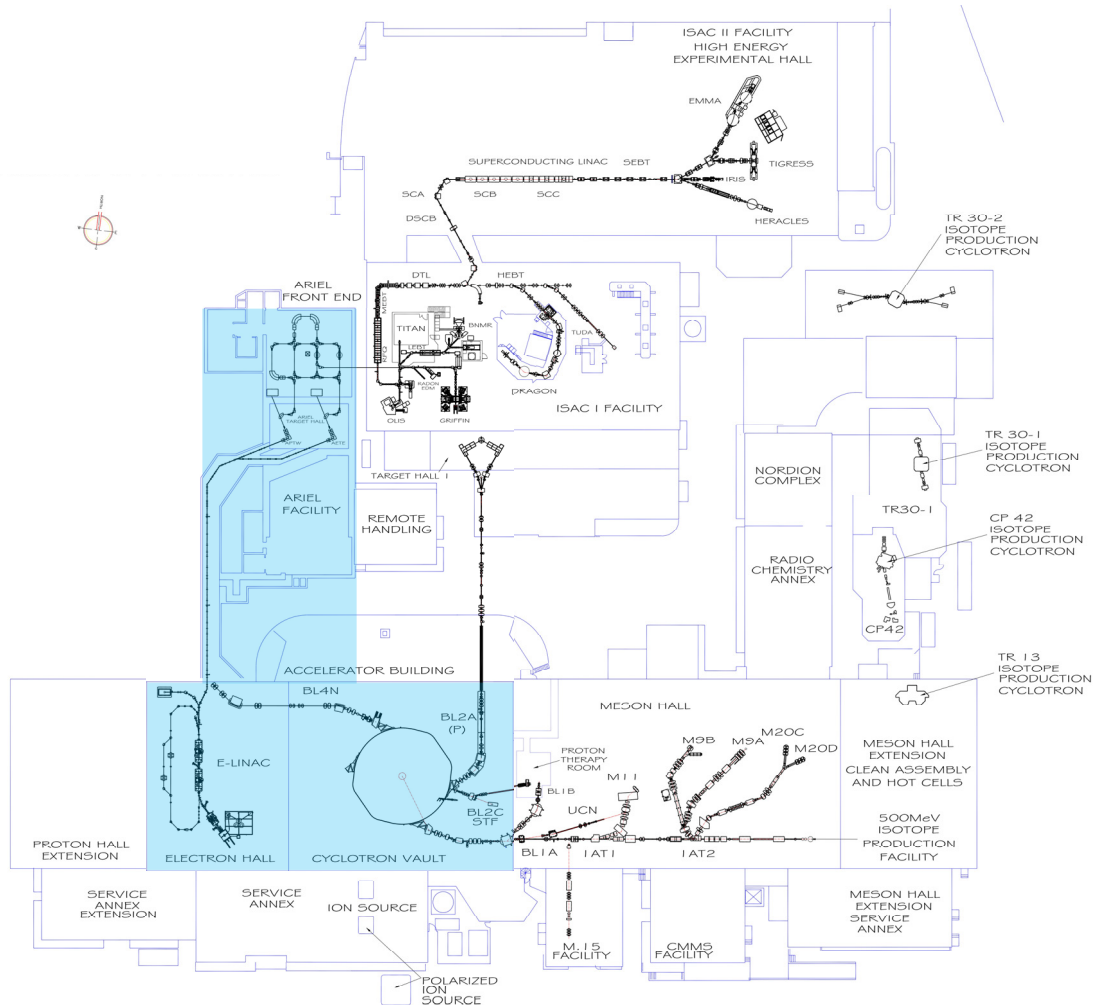
Clinical imaging



Radiopharmaceutical  
development

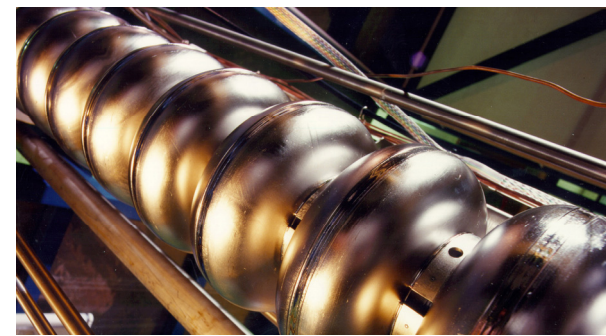
**ARIEL:  
Advanced Rare Isotope  
Laboratory**

# TRIUMF Site



## ■ ARIEL

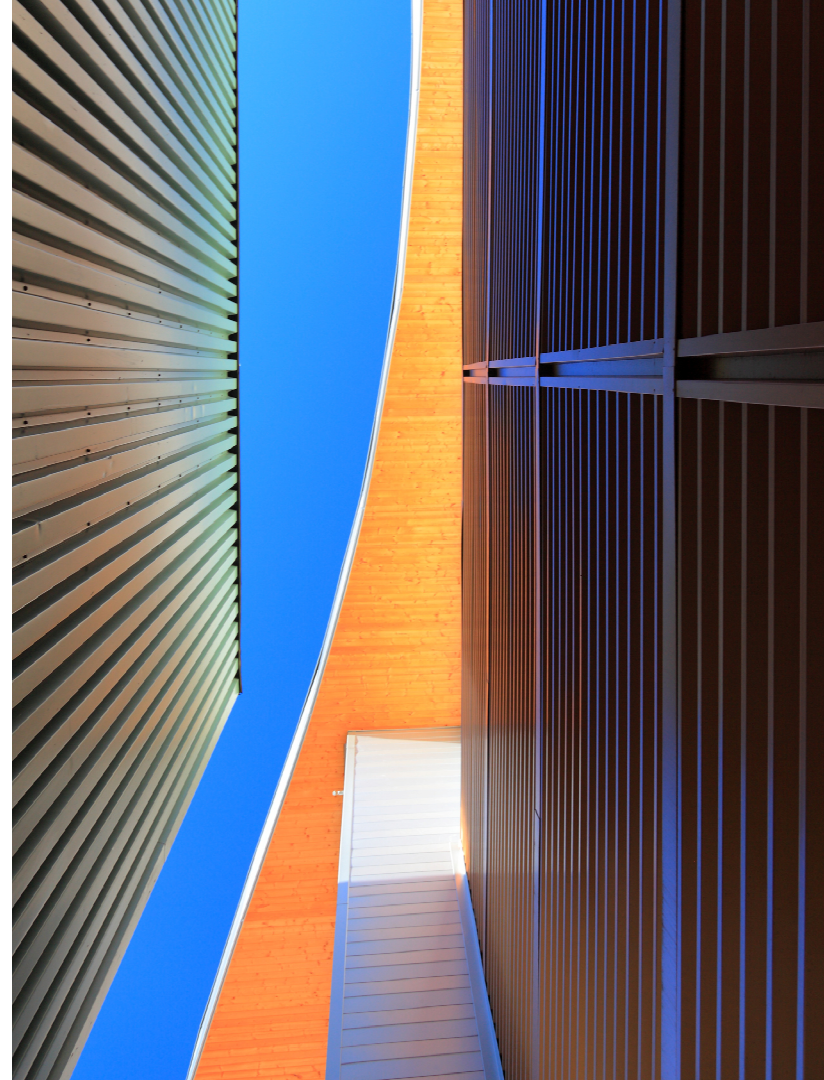
- Multi-user, multi-disciplinary RIB Facility
- Intense, clean RIB beams into ISAC experiments
  - New 35 MeV superconducting electron CW linac
  - New 100 kW electron beamline and target station
  - New 50 kW proton beamline and target station



## STATUS:

- 35 MeV superconducting linac with 9-cell TESLA-type elliptical cavities, made in Canada. 11 MV/m demonstrated
  - Being commissioned
- New RIB transport system, ISAC-ISAC and ARIEL-ISAC, including new high resolution separator (HRS) and new charge breeding system (RFQ cooler-EBIS-Nier spectrometer)
  - Being installed
- New electron and proton target ion sources, beamlines, and hot cell infrastructure. Electrons to 100 kW
  - Being designed and tested

FIRST OPERATIONS IN 2019!







**Superconducting Acceleration**  
Featuring Superconducting RF (SRF)  
Technology - Made in the US

SRF provides the most efficient way to accelerate particles to high energies. It is used in the most advanced accelerators, including the Large Hadron Collider (LHC) at CERN, the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, and the Superconducting Super Collider (SSC) at Texas Tech University.

**RF Acceleration**  
SRF provides the most efficient way to accelerate particles to high energies. It is used in the most advanced accelerators, including the Large Hadron Collider (LHC) at CERN, the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, and the Superconducting Super Collider (SSC) at Texas Tech University.

**Cavity Fabrication**  
SRF provides the most efficient way to accelerate particles to high energies. It is used in the most advanced accelerators, including the Large Hadron Collider (LHC) at CERN, the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, and the Superconducting Super Collider (SSC) at Texas Tech University.

E-Linac

# RIB Transport – Installation underway!



Italian President Sergio Mattarella



July 10, 2017

## WHY ARE WE EXCITED?

- ARIEL will more than triple TRIUMF's capacity to produce Rare Isotope Beams. 9,000 hours/year!
- Two new beamlines
  - Will allow efficient use of our existing experimental infrastructure
  - Will allow more time for long-duration experiments
  - Will allow for new uses in life and materials sciences
- New electron linac
  - Will produce new isotopes via photofission
- New production system
  - Will provide intense, clean high-mass beams

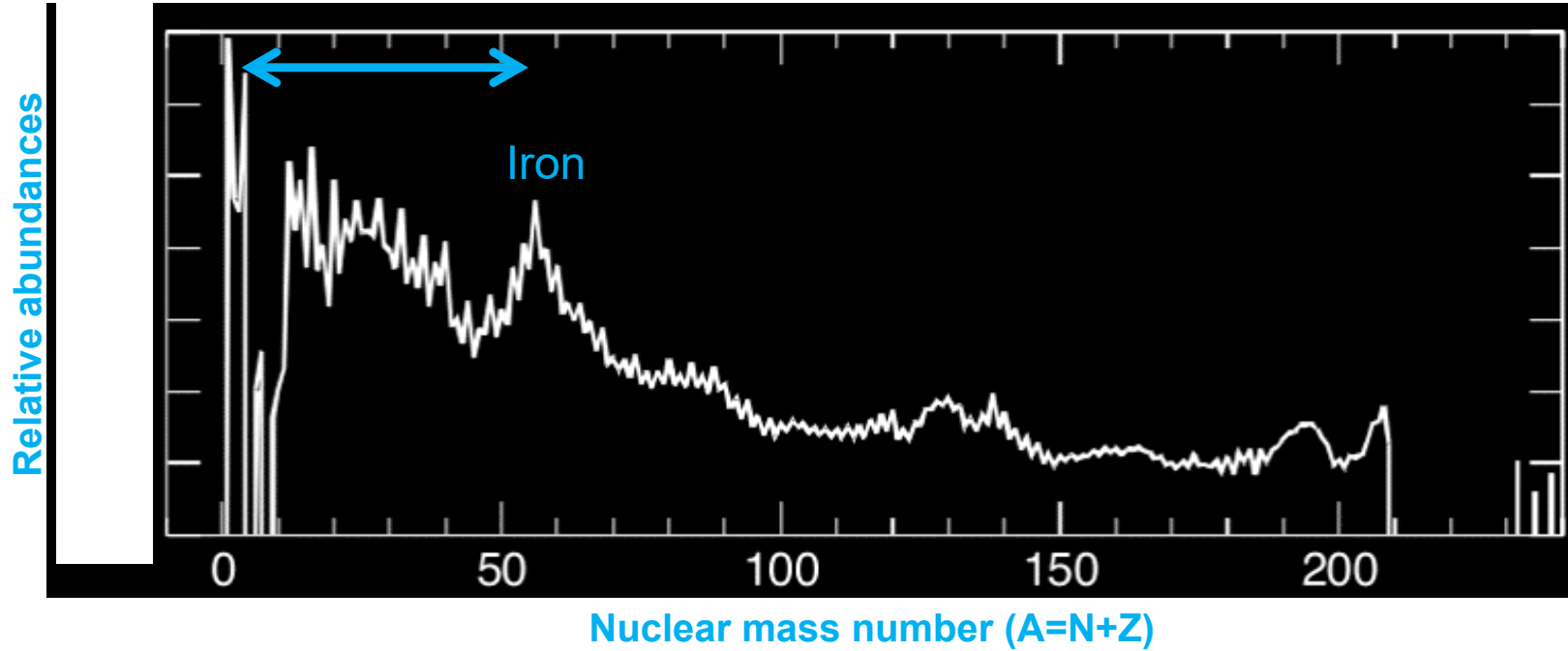


**WHY DOES IT MATTER?**

**ARIEL WILL HELP ANSWER THE BIG QUESTION:**

**What is the astrophysical origin of the heavy elements?**

## Stellar Burning



**WHY DOES IT MATTER?**

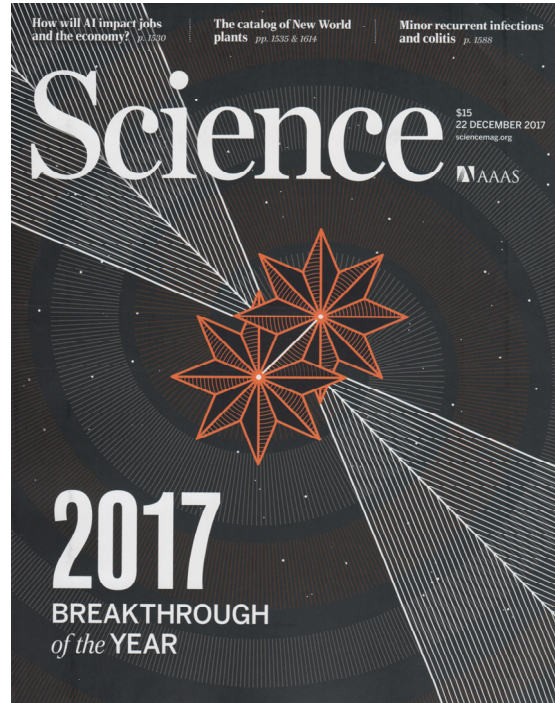


August 17, 2017



# LIGO

This is  
TRIUMF's  
moment!

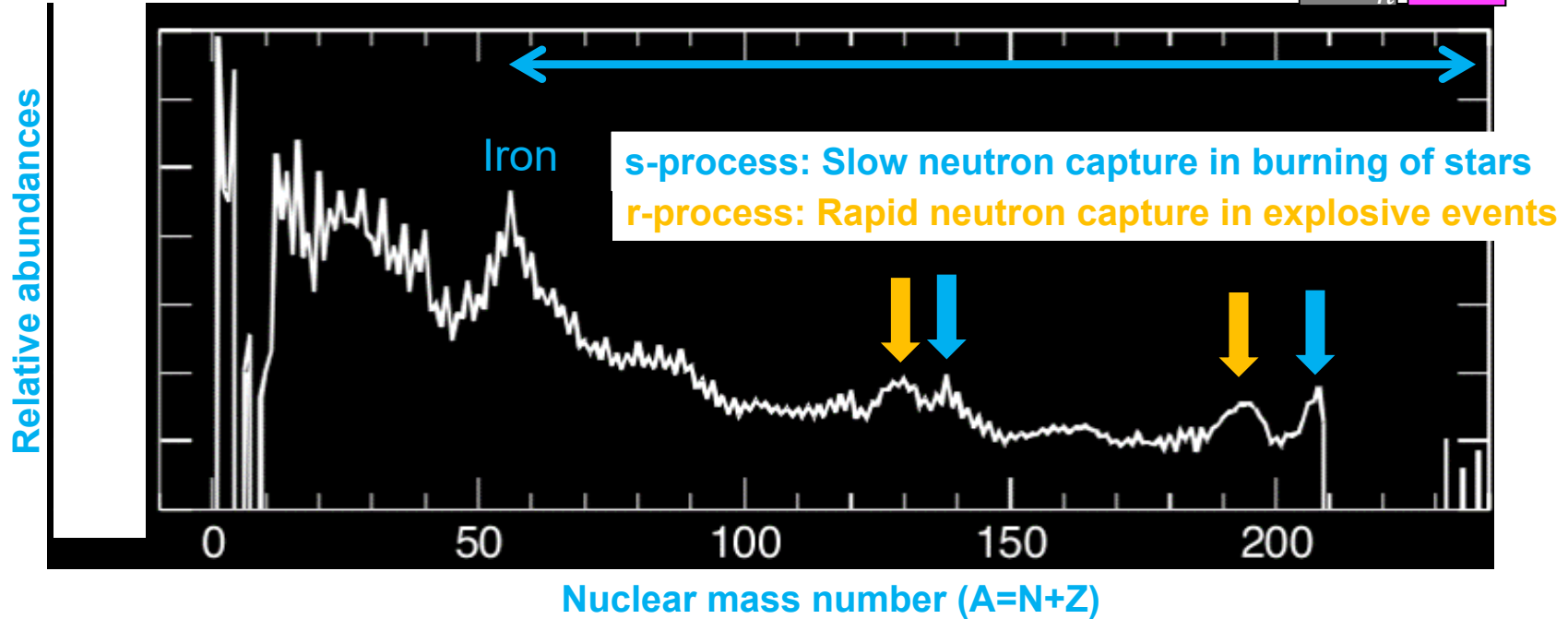
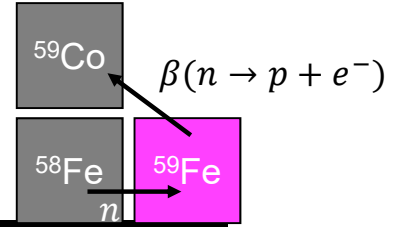


LIGO is opening the era of multi-messenger astronomy

ARIEL will expand and deepen our understanding of nuclear physics by stress testing with exotic isotopes

Together, they will help us understand the origin of the heavy elements

## Neutron Capture Processes



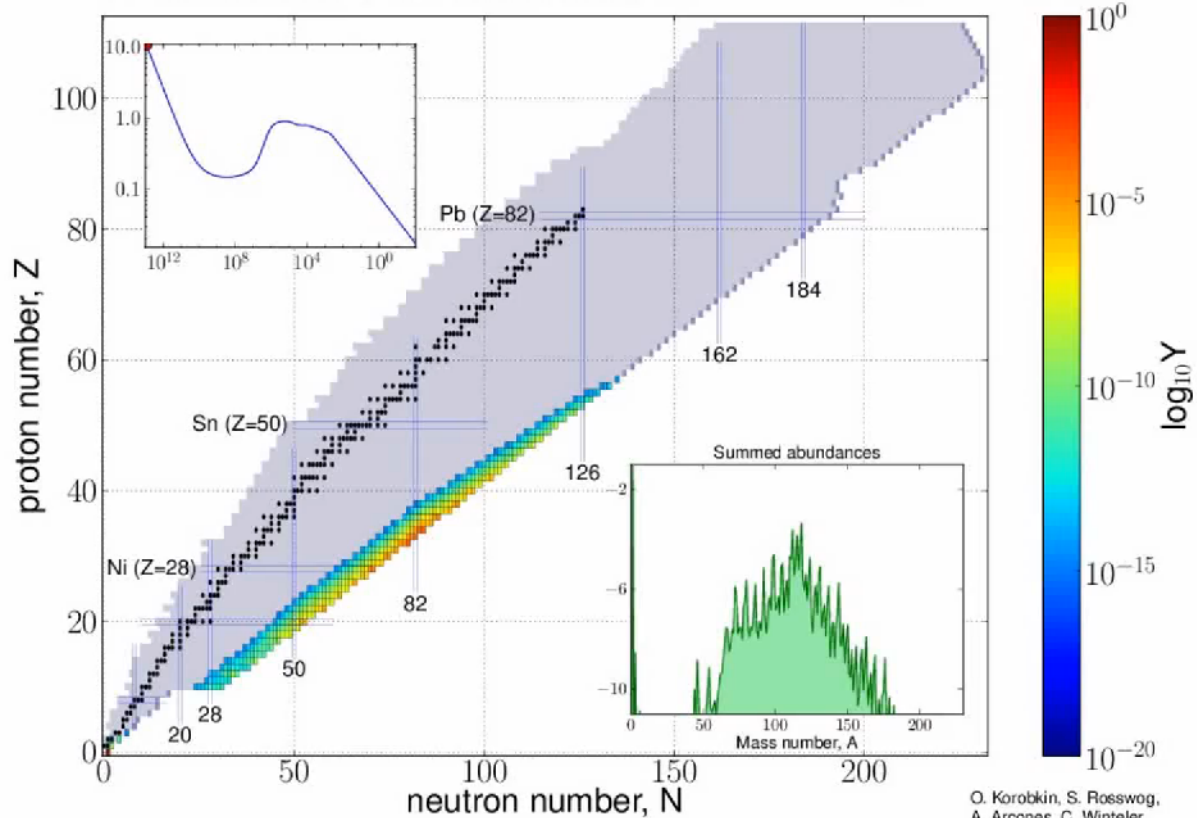
Relative abundances

Iron

s-process: Slow neutron capture in burning of stars  
r-process: Rapid neutron capture in explosive events

Nuclear mass number (A=N+Z)

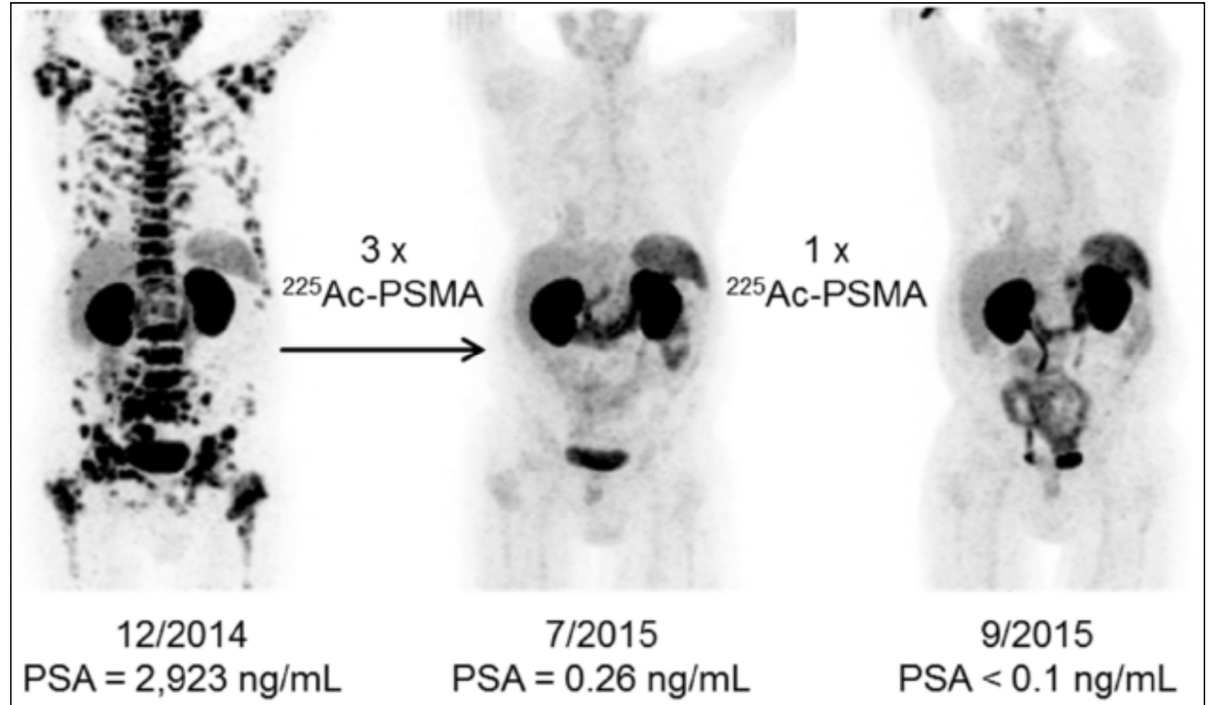
$t : 0.00\text{e}+00 \text{ s} / T : 10.96 \text{ GK} / \rho_b : 8.71\text{e}+12 \text{ g/cm}^3$



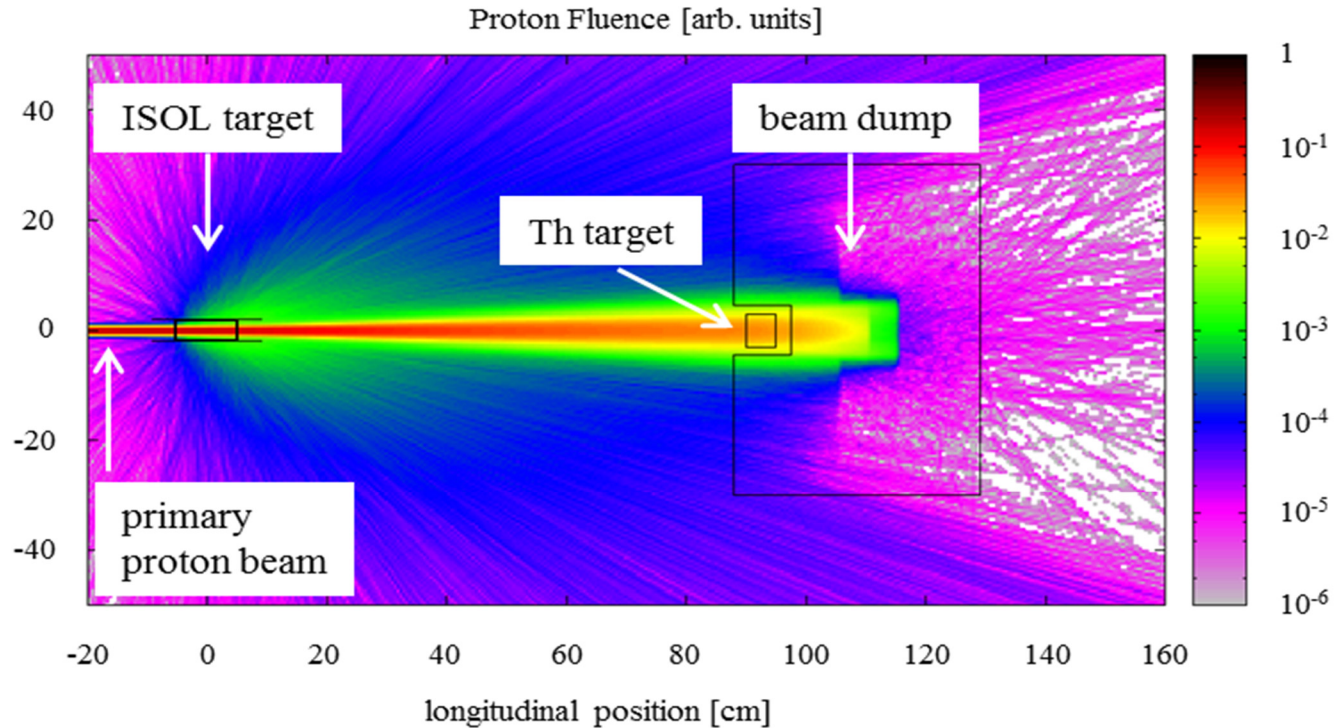
## WHY DOES IT MATTER?

ARIEL will also open exciting new opportunities in the Life Sciences and Nuclear Medicine

Prostate cancer patient before and after treatment with  $^{225}\text{Ac}$ -PSMA



ARIEL will make  $^{225}\text{Ac}$  symbiotically with nuclear physics experiments





**TRIUMF**

**50** anniversary  
anniversaire

# Science Week 2018

July 16 – July 20

This year, will include

- 50th Alumni Event
- 50th Science Symposium
- ARIEL Science Workshop
- TRIUMF User's Group Annual General Meeting

## Daily Highlights:

Monday, July 16 <sup>th</sup>	Tuesday, July 17 <sup>th</sup>	Wednesday, July 18 <sup>th</sup>	Thursday, July 19 <sup>th</sup>
<ul style="list-style-type: none"><li>• 50th Anniversary Alumni Event</li></ul>	<ul style="list-style-type: none"><li>• 50th Anniversary Science Symposium and Celebration</li></ul>	<ul style="list-style-type: none"><li>• ARIEL Science Workshop</li></ul>	<ul style="list-style-type: none"><li>• TRIUMF User's Group Annual Meeting</li></ul>

Governor General Julie Payette



March 22, 2018