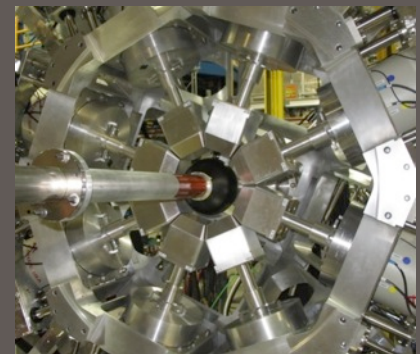
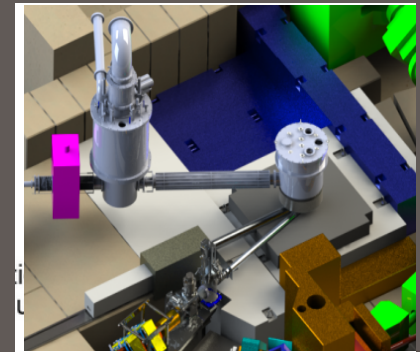
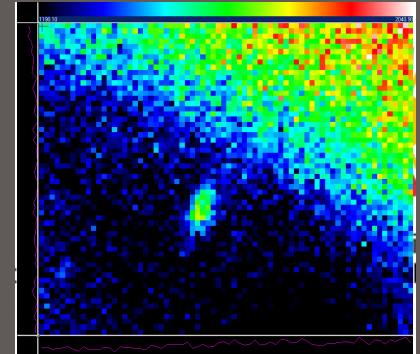


Advanced Instrumentation at TRIUMF

June 16, 2015

Reiner Kruecken | Science Division Head | TRIUMF
Professor | University of British Columbia



Accelerating science for Canada
Un accélérateur de la démarche scientifique canadienne

Owned and operated as a joint venture by a consortium of Canadian universities via a contribution through the National Research Council Canada
Propriété d'un consortium d'universités canadiennes, géré en co-entreprise à partir d'une contribution administrée par le Conseil national de recherches Canada

- Introduction to TRIUMF
- Accelerator and Experimental Facilities
- Isotopes for Science and Medicine
 - Example Instrumentation (w/ focus on light)
- Particle Physics Facilities
- Conclusions

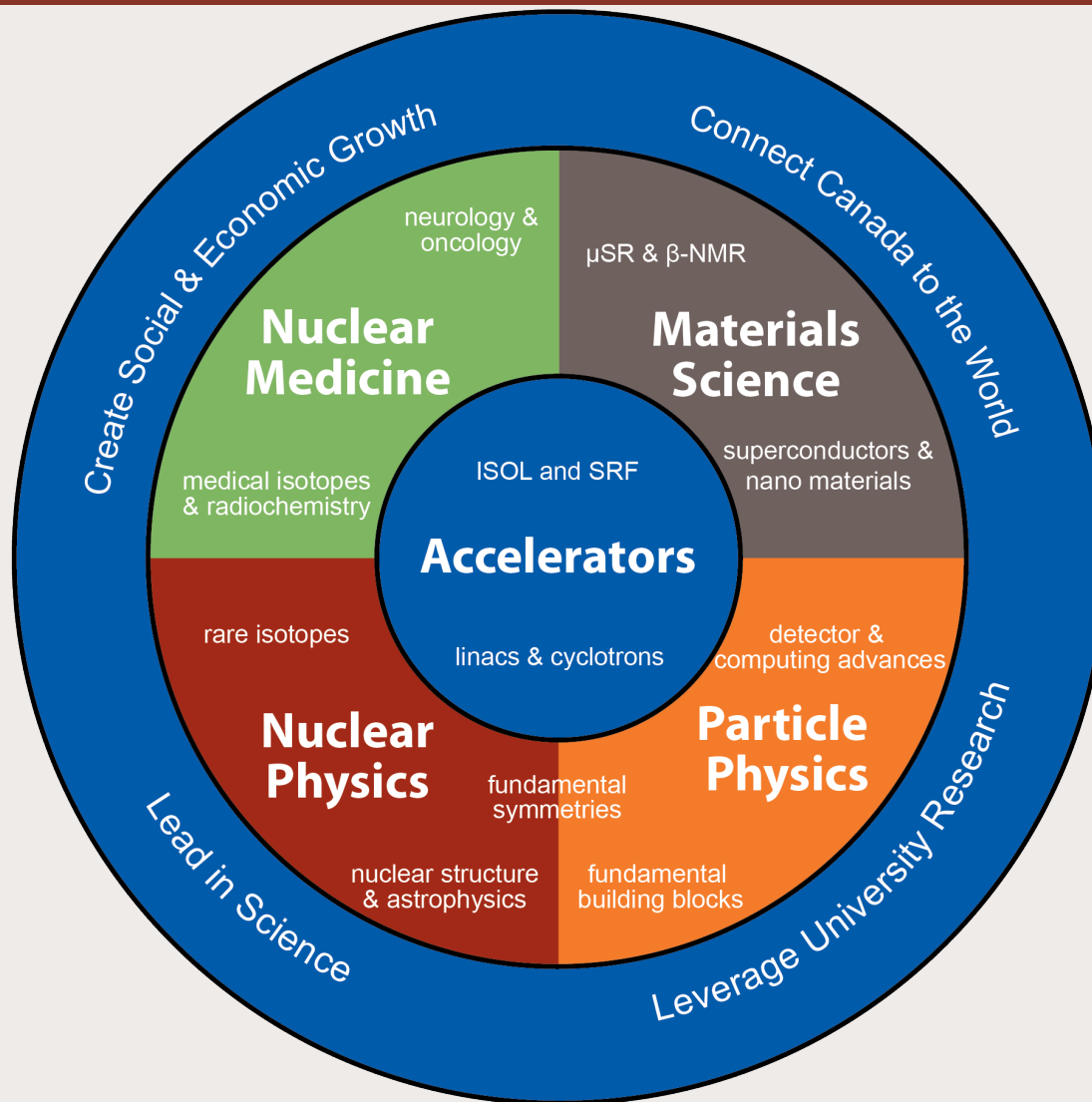


A National Laboratory



**TRIUMF is owned & operated by a consortium of 19 universities
Founded 47 years ago in Vancouver**

TRIUMF Research Program & Vision



TRIUMF Laboratory

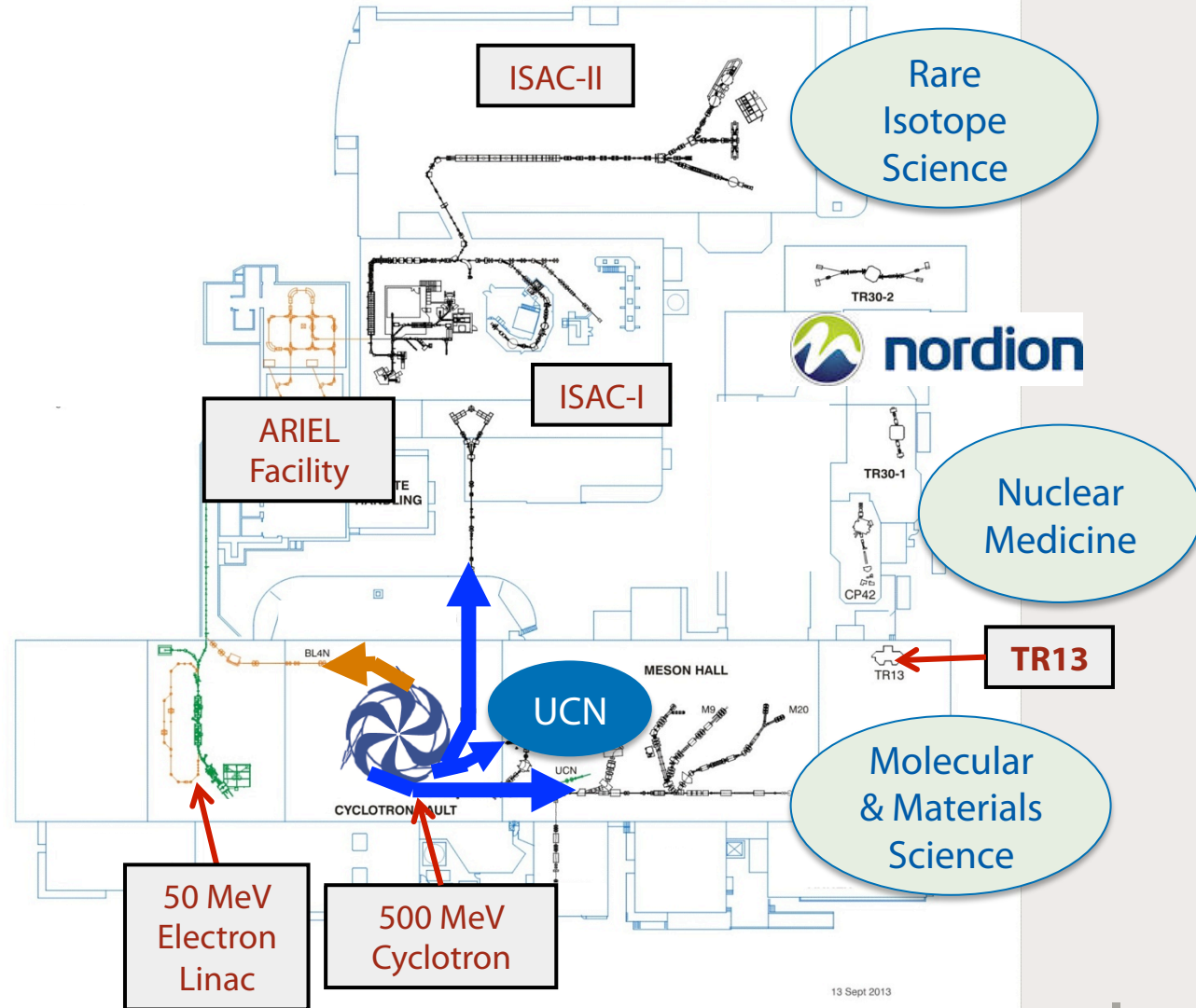
TRIUMF Accelerator Complex

Original 520 MeV,
350 μ A, H⁻ cyclotron

4 medical isotope
cyclotrons

ISAC 50kW ISOL
facility

New ARIEL e-linac
(10mA, 50 MeV)

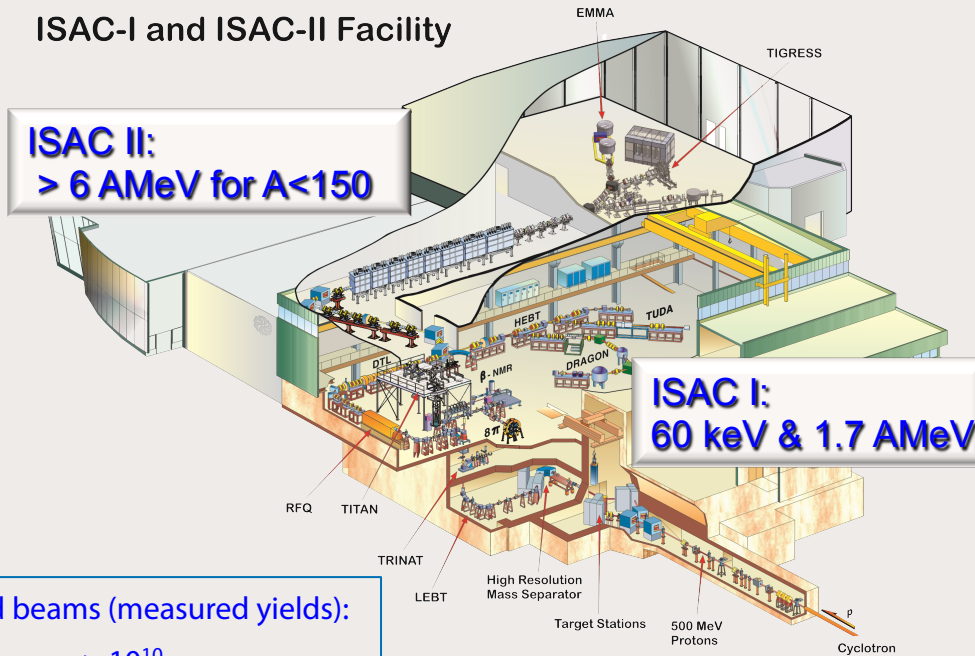


13 Sept 2013

Isotope Separator and Accelerator (ISAC)

ISOL facility with highest primary beam intensity
(100 μ A, 480 MeV protons)

ISAC-I and ISAC-II Facility



Programs in

- Nuclear Structure & Reactions
- Nuclear Astrophysics
- Fundamental Symmetries
- Material Science
- Nuclear Medicine

Selected beams (measured yields):

^{26}Al	> 10^{10} pps
$^{37,38}\text{mK}$	> 10^9 pps
$^{211-213}\text{Fr}$	> 10^9 pps
^{225}Ra	> 10^8 pps
^{103}Rb	3 pps

Select accelerated RIBs:

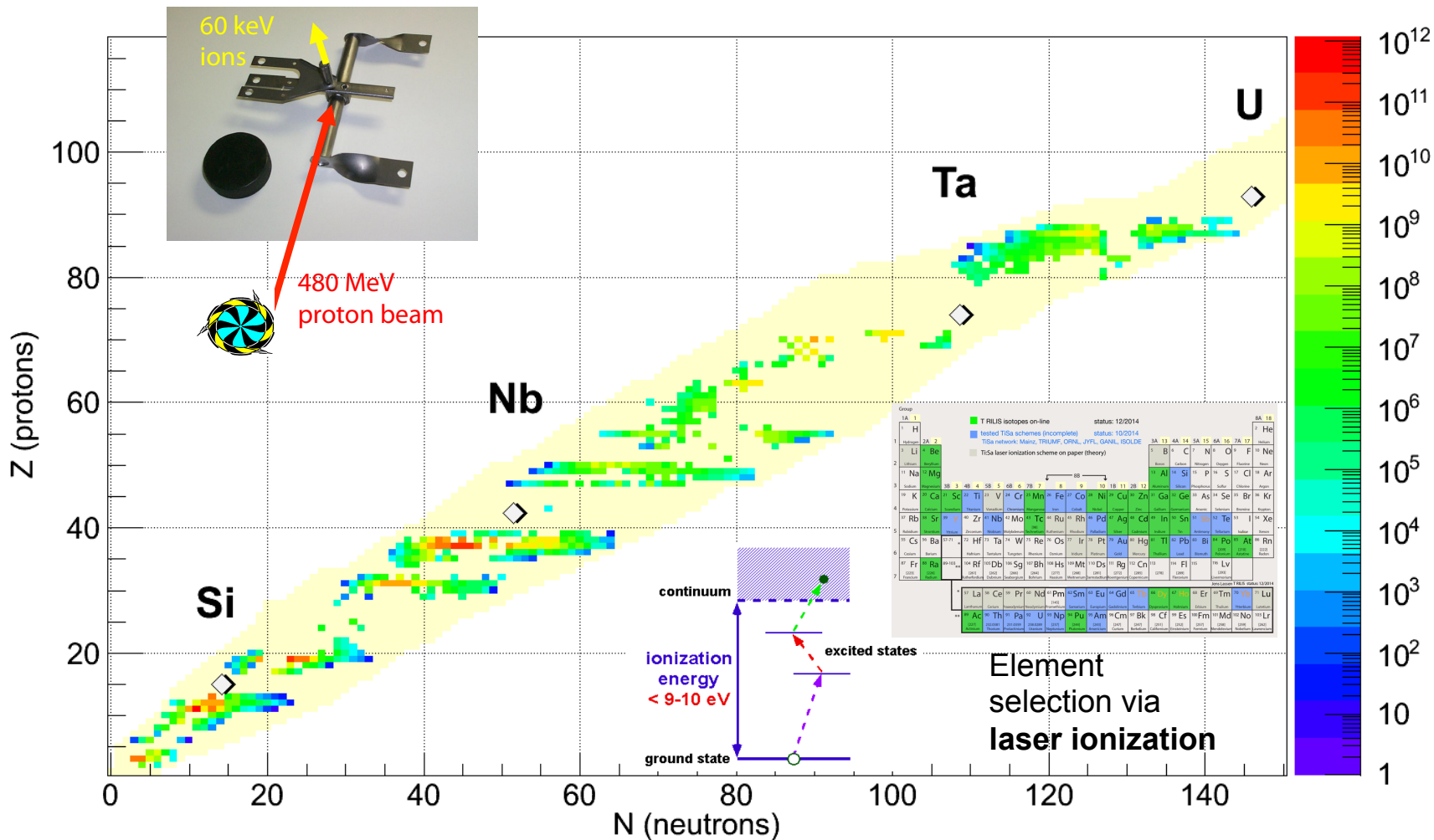
$^{95}\text{Sr}^{15+}$	10^7 pps
$^{11}\text{Li}^+$	3×10^3 pps
$^{11}\text{Be}^+$	10^5 pps



- ~3500 RIB hours / yr
- 600 user community, 2/3 international (~ 120 U.S. users)
- Factor 2-2.5 oversubscribed
- ~ 2 year backlog
- Complementary capabilities to in-flight facilities like FRIB

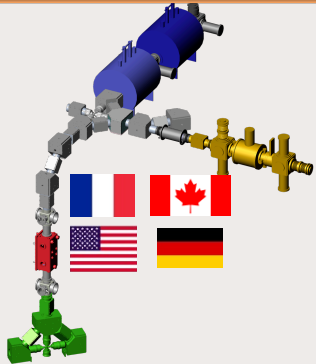
Measured ISAC RIB Intensities

Yield Chart of Nuclides

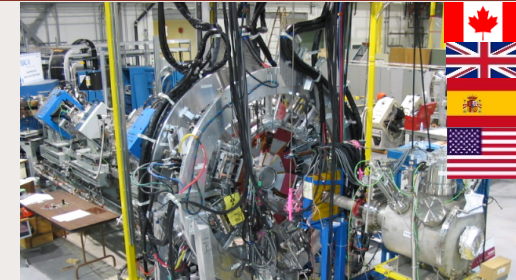


ISAC Experimental Facilities

TITAN Penning Trap facility



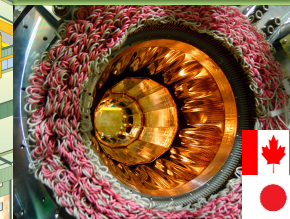
EMMA recoil mass analyzer



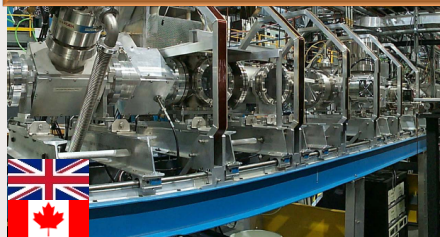
TIGRESS in-beam gamma-ray spectrometer

- Nuclear Structure
- Nuclear Astrophysics
- Fundam. Symmetries
- Materials Science

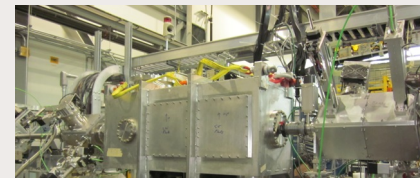
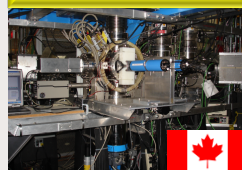
MTV Mott scatt. drift chamber



Laser polarizer line

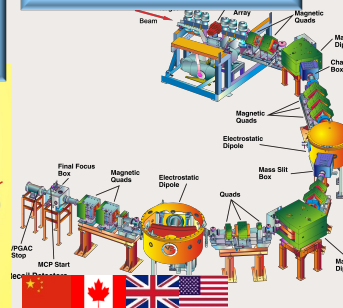


β NMR/NQR

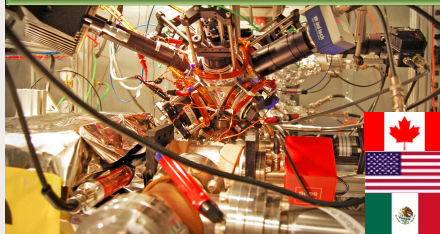


IRIS solid hydrogen reaction set-up

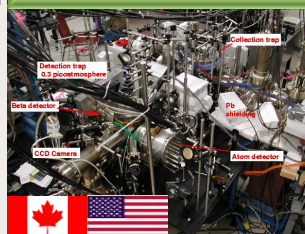
DRAGON recoil separator



Francium trapping facility



TRINAT magneto optical trap



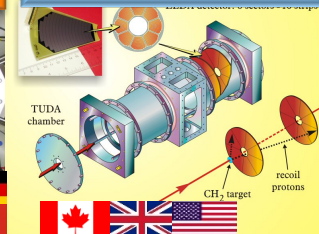
DESCANT neutr. det.



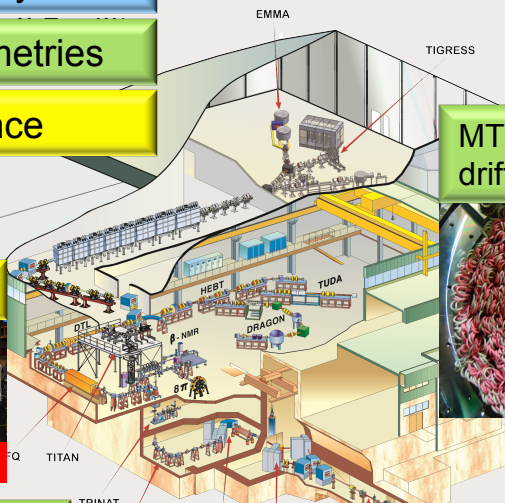
GRIFFIN decay spectrometer



TUDA reaction setup



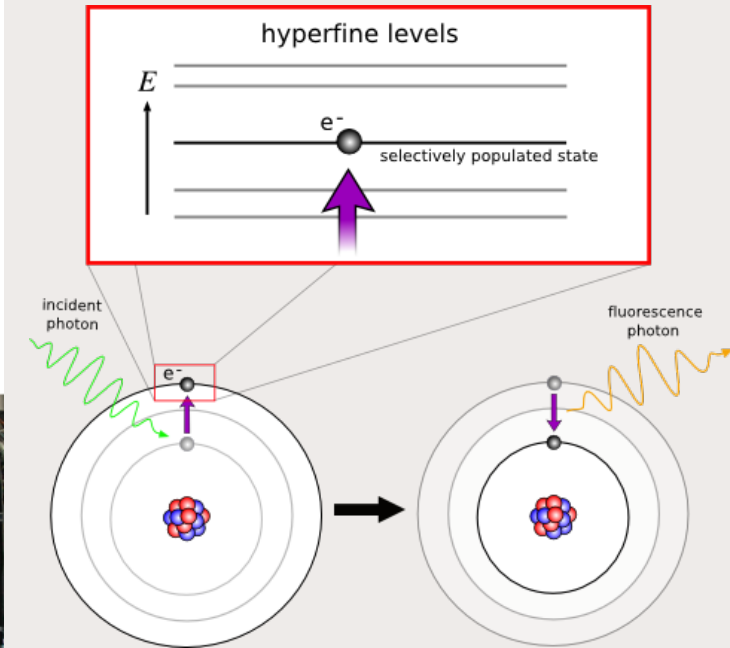
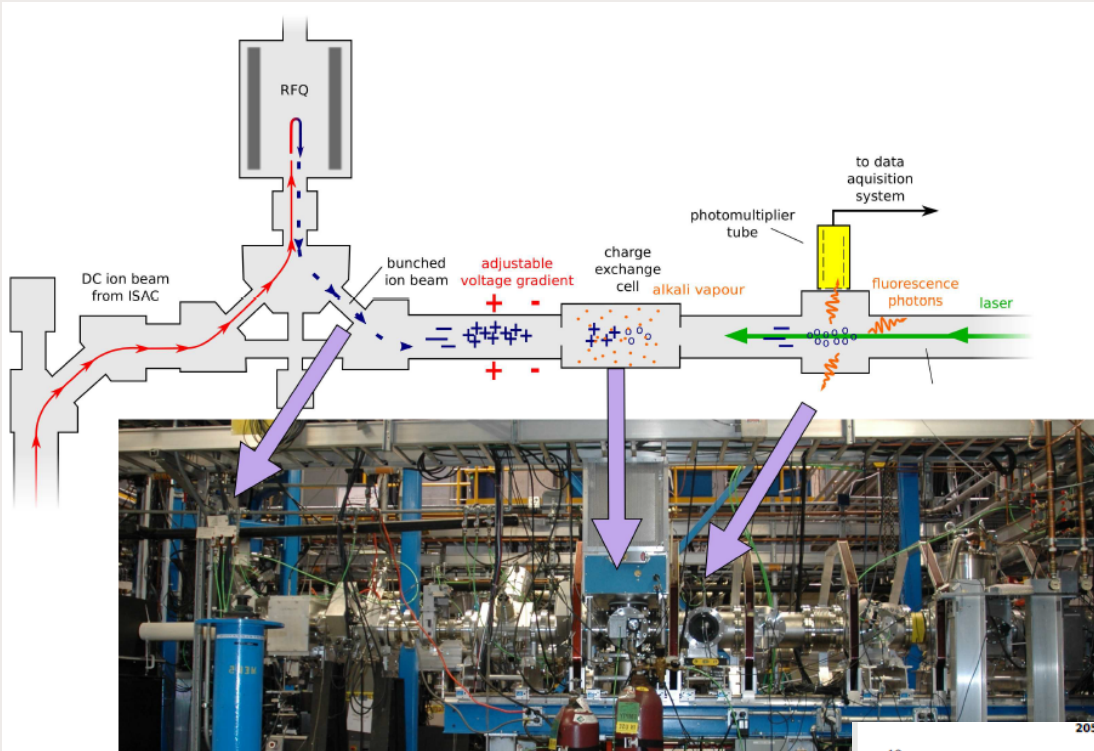
TITAN



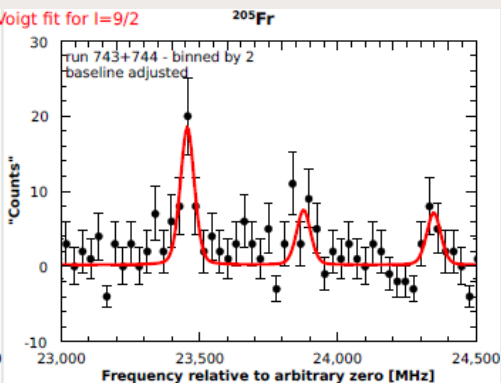
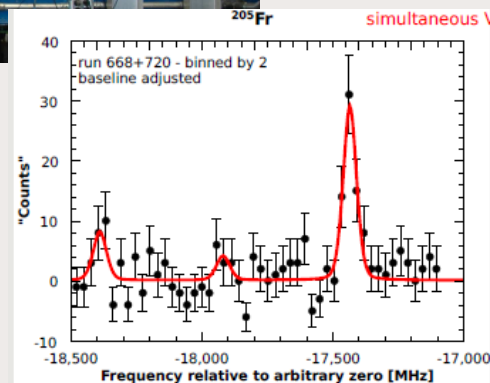
Major thrust: Isotopes for Science and Medicine

- Isotopes for developing a standard model for nuclear physics;
- Isotopes to determine how and where the heavy elements were produced in the universe;
- Isotopes as laboratories to search for new forces in nature;
- Isotopes as probes of magnetism at interfaces and surfaces of new functional materials; and
- Isotopes for molecular imaging of diseases and treatment of cancer.

Collinear Laser Spectroscopy



First ever laser spectroscopy of ^{205}Fr
 A. Voss et al., PRL 111, 122501 (2013)
 Informs about ground state spin & nuclear size



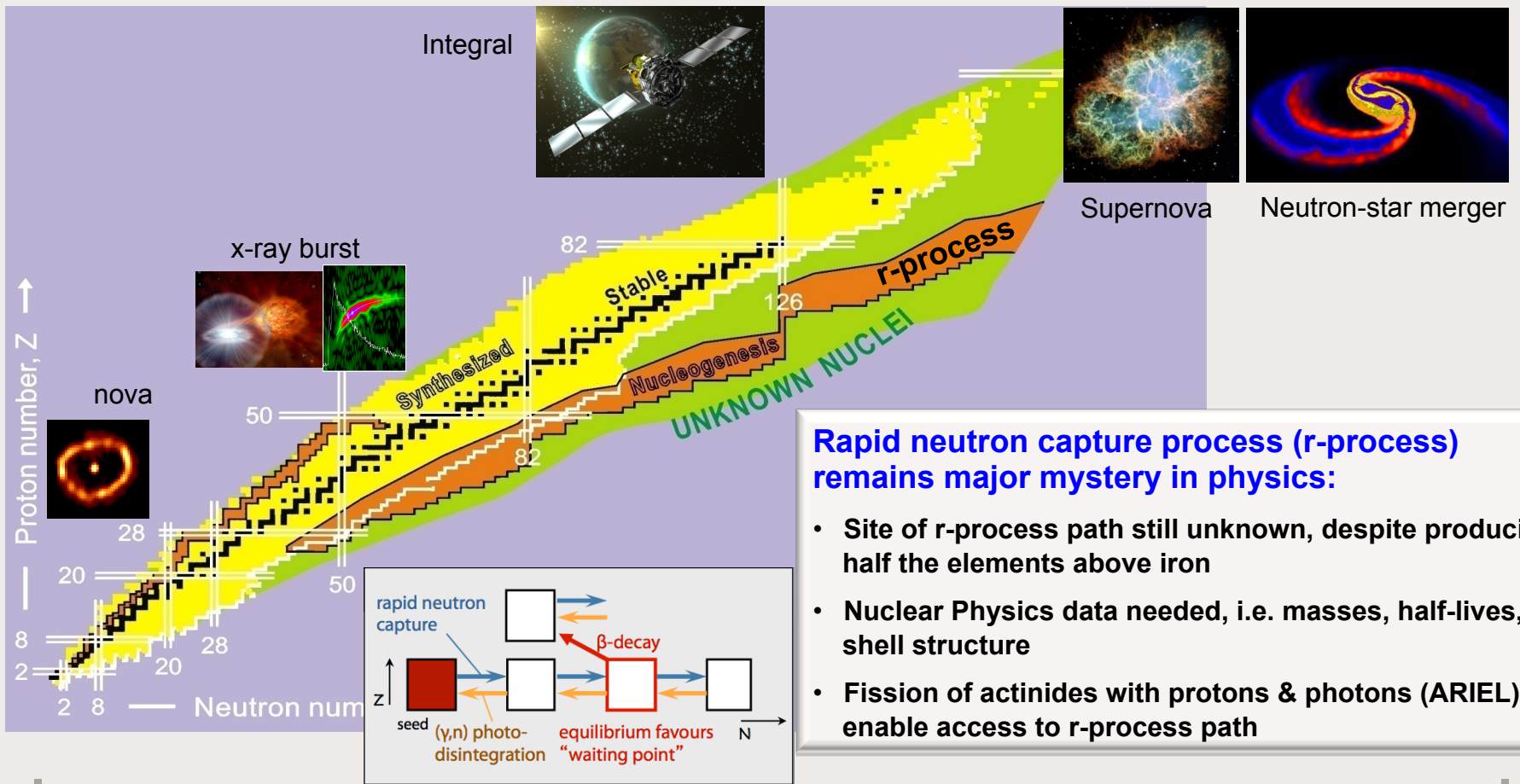
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Nuclear Astrophysics at TRIUMF

ISAC program has concentrated on directly measuring reactions in proton-rich outflows in novae, x-ray bursters, core collapse supernovae

→ determine production/destruction of cosmic gamma ray emitters: ^{18}F , ^{22}Na , ^{26}Al , ^{44}Ti



Rapid neutron capture process (r-process) remains major mystery in physics:

- Site of r-process path still unknown, despite producing half the elements above iron
- Nuclear Physics data needed, i.e. masses, half-lives, shell structure
- Fission of actinides with protons & photons (ARIEL) enable access to r-process path

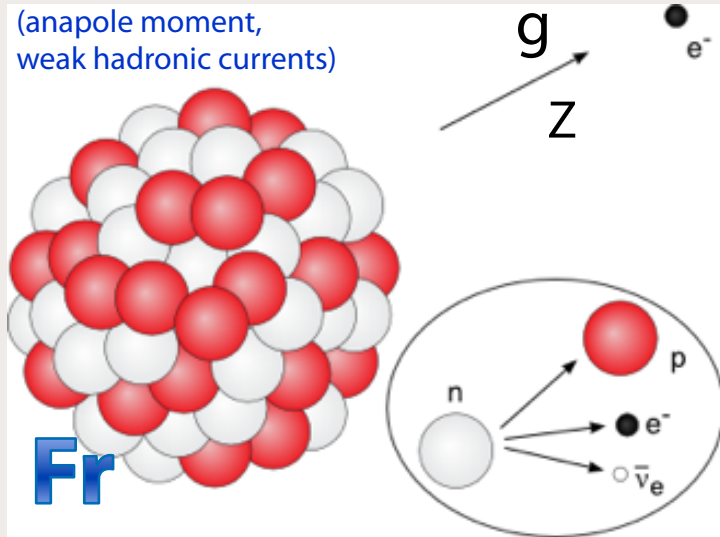
Major thrust: Isotopes for Science and Medicine

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Francium Atomic Parity Violation Program

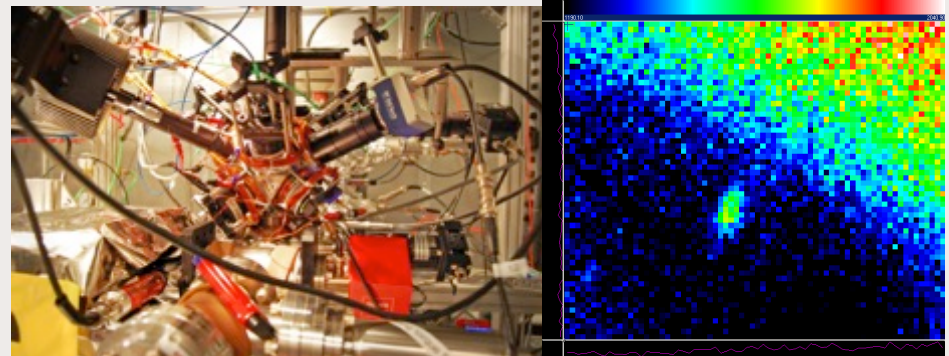
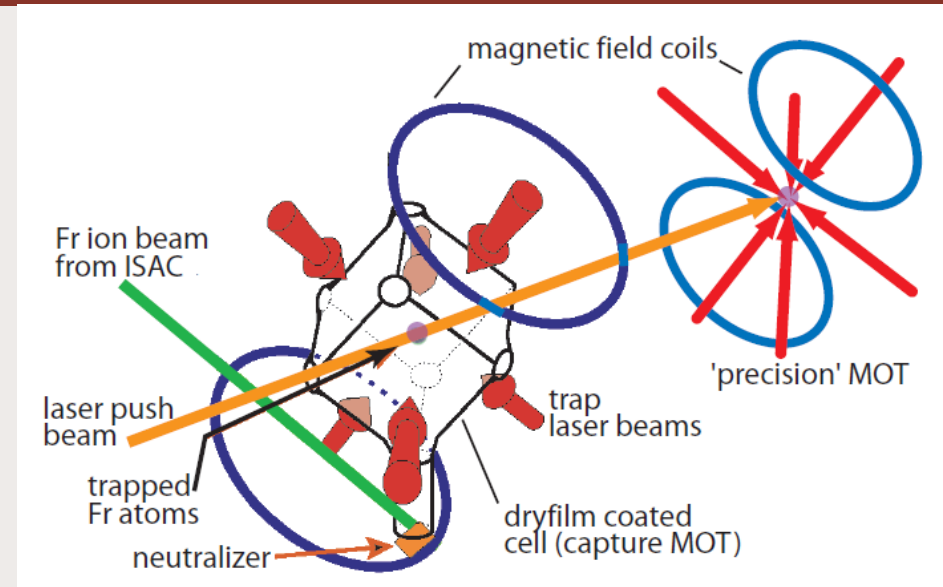
Atomic Parity Violation

(anapole moment,
weak hadronic currents)



Sensitive probe of weak interaction
between electron and quarks

Search for Physics Beyond the
Standard Model of Particle Physics



Successful Francium trapping of $^{207,209,221}\text{Fr}$
in new Magneto Optical Trap (MOT)

Major thrust: Isotopes for Science and Medicine

- Isotopes for developing a standard model for nuclear physics;
- Isotopes to determine how and where the heavy elements were produced in the universe;
- Isotopes as laboratories to search for new forces in nature;
- **Isotopes as probes of magnetism at interfaces and surfaces of new functional materials; and**
- Isotopes for molecular imaging of diseases and treatment of cancer.

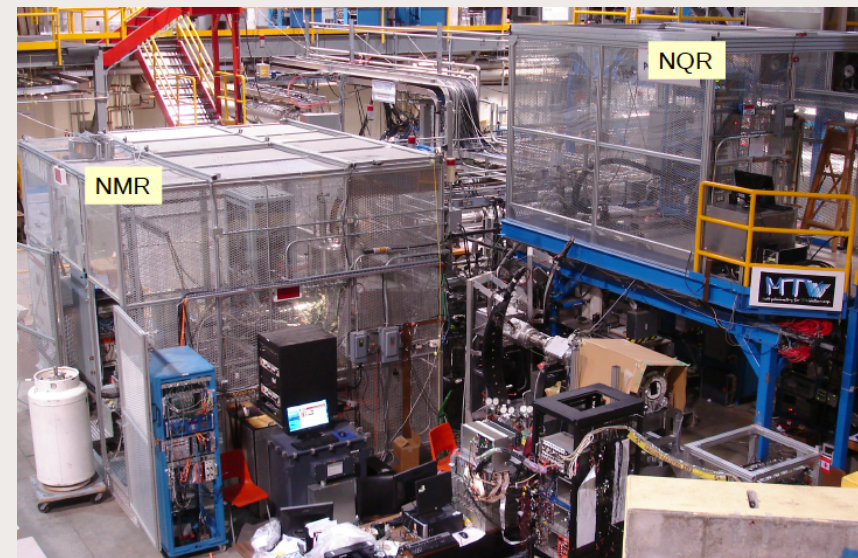
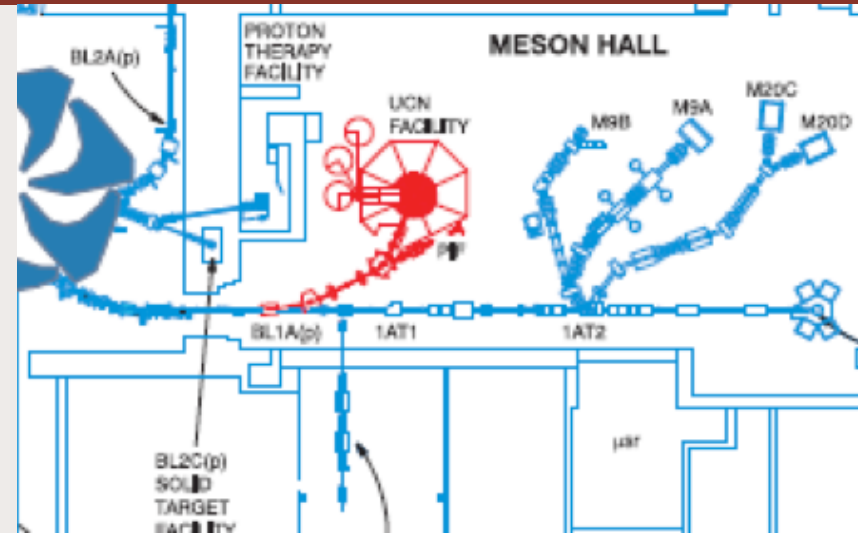
Centre for Molecular and Material Science

Muon Spin Rotation (MuSR)

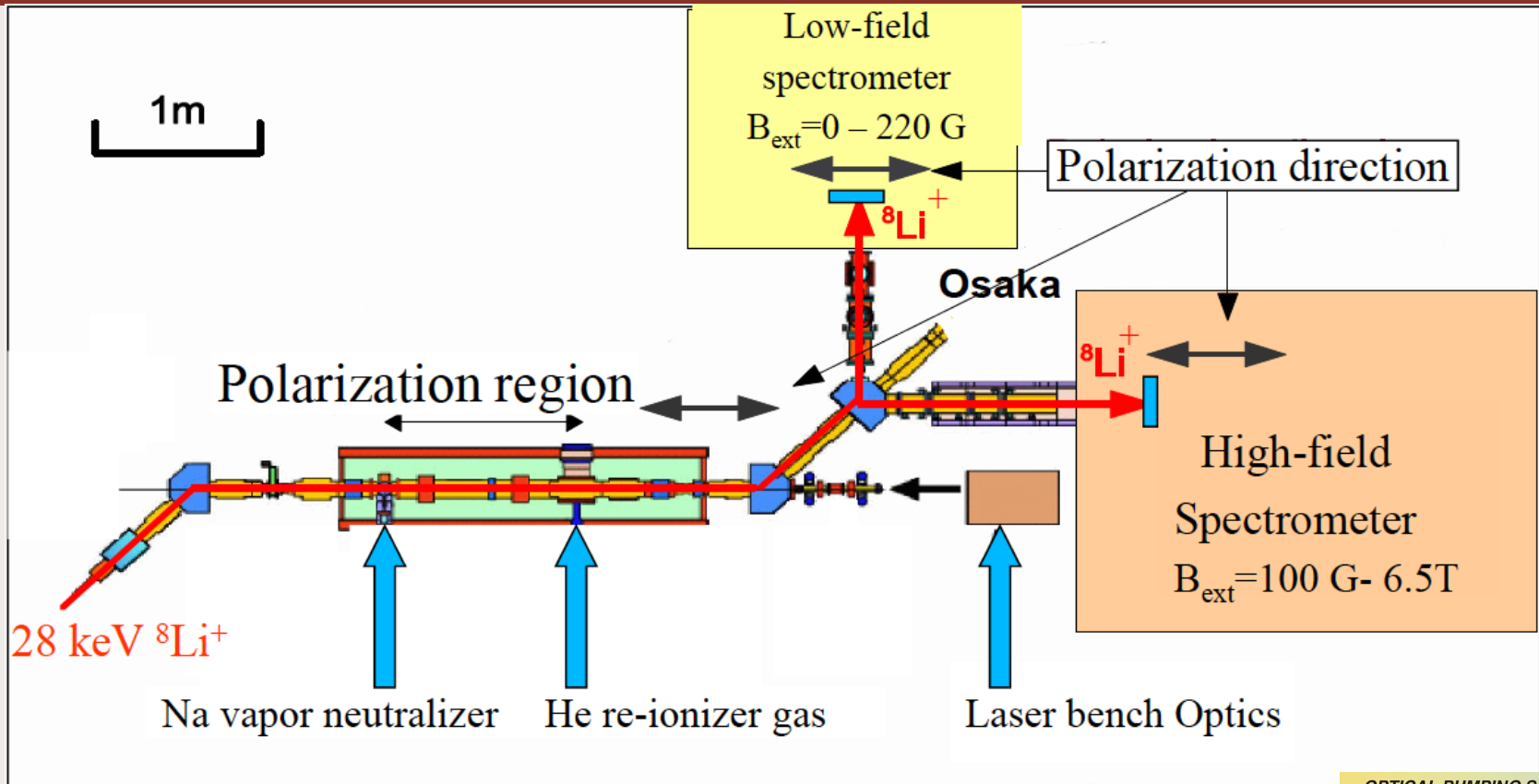
- Muon as Probe of Bulk Magnetism
 - New superconductors
 - New semiconductors
 - Lithium diffusion in battery materials
- Muonium Chemistry
 - Hydrogen atom kinetics
- Muoniated Free Radicals
 - Gen IV reactor chemistry

betaNMR

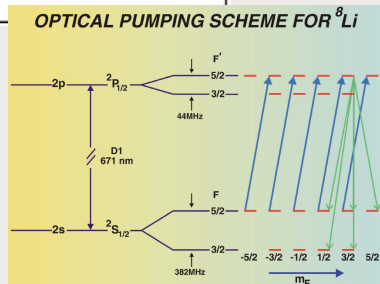
- Magnetic Properties of
 - at interfaces
 - on surfaces
 - in thin films
- Nanometer Depth Resolution



Depth Controlled BetaNMR with spin-polarized ^8Li



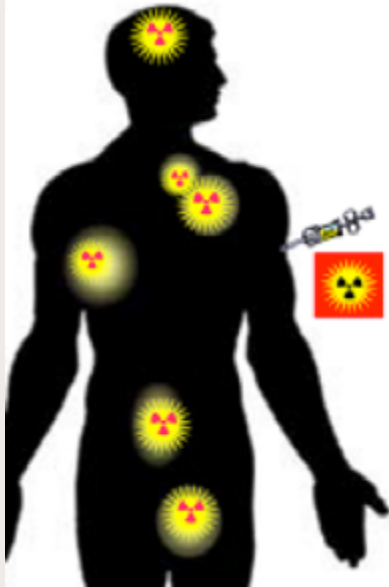
- Optical pumping with a tuned laser is used to achieve $\sim 70\%$ of spin polarization.
- Electrostatic deceleration is used to control the depth of the implanted ions (2-500nm)



Major thrust: Isotopes for Science and Medicine

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- Isotopes as probes of magnetism at interfaces and surfaces of new functional materials; and
- **Isotopes for molecular imaging of diseases and treatment of cancer.**

Isotopes for Medical Application: Tumor Treatment and Imaging



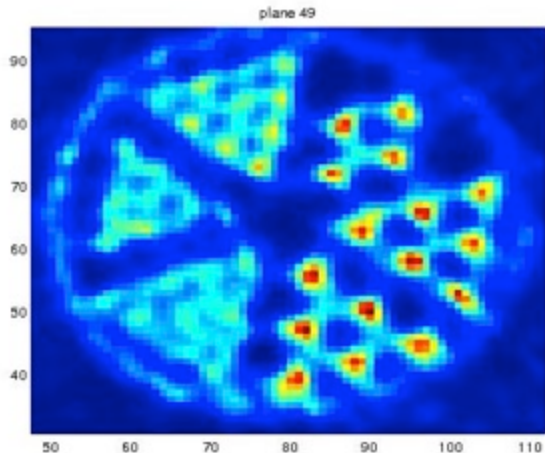
Alpha emitting isotopes:
powerful way for direct tumor treatment

Clustered DNA damage due to
'heavy particle' stopping power, short range.

^{211}At particularly well suited

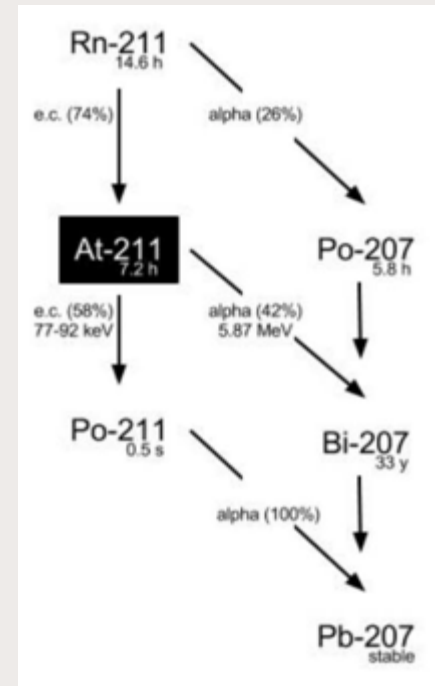
**Gamma-emitting ^{209}At can be used
to test functionality via imaging**

First image ^{209}At with ISAC isotopes

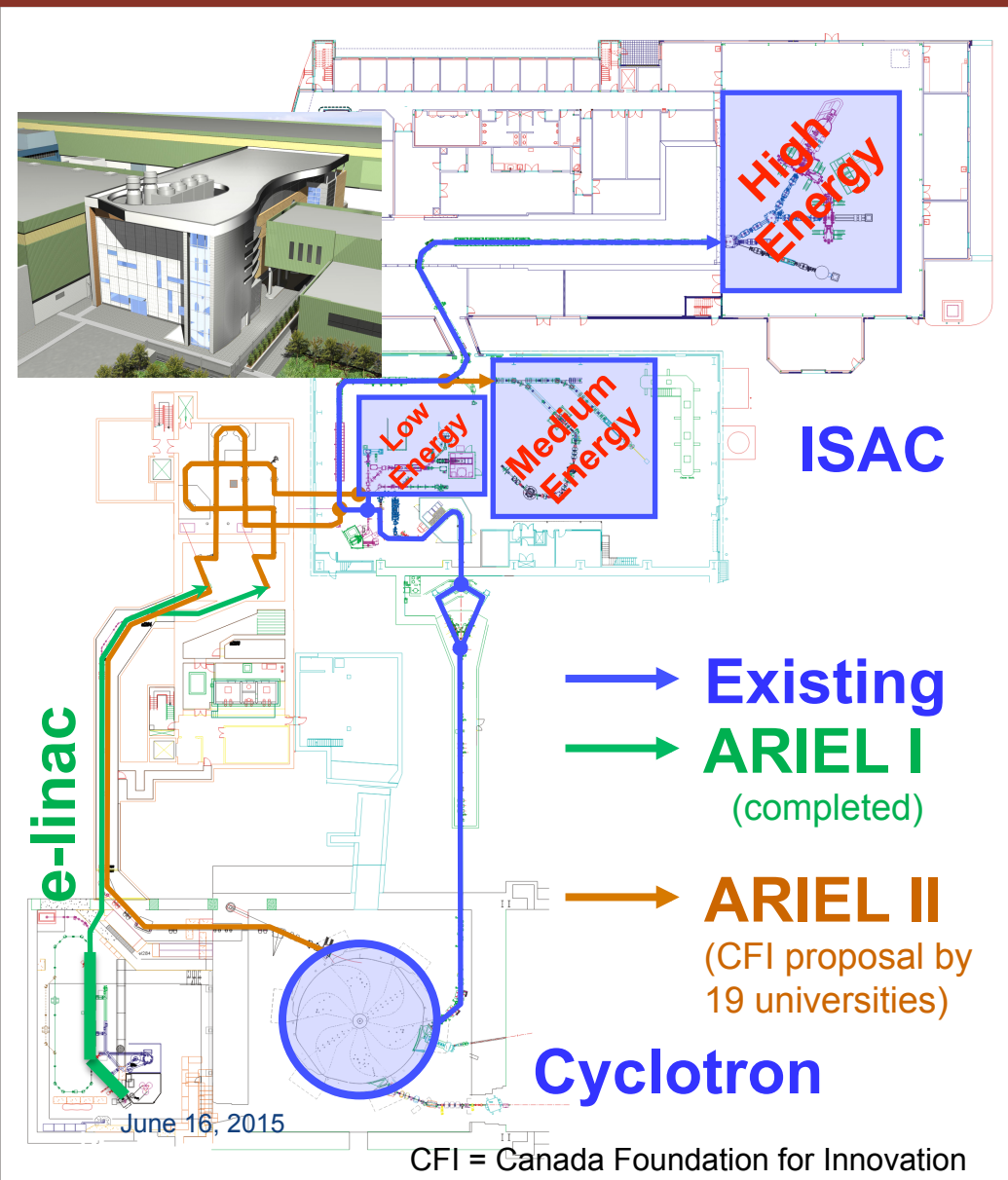


^{211}At is generated via
 ^{211}Rn at ISAC & ARIEL via
proton induced spallation

Another isotope of interest for
target alpha therapy is ^{225}Ac
also produced at ISAC & ARIEL



The Advanced Rare Isotope Laboratory (ARIEL)



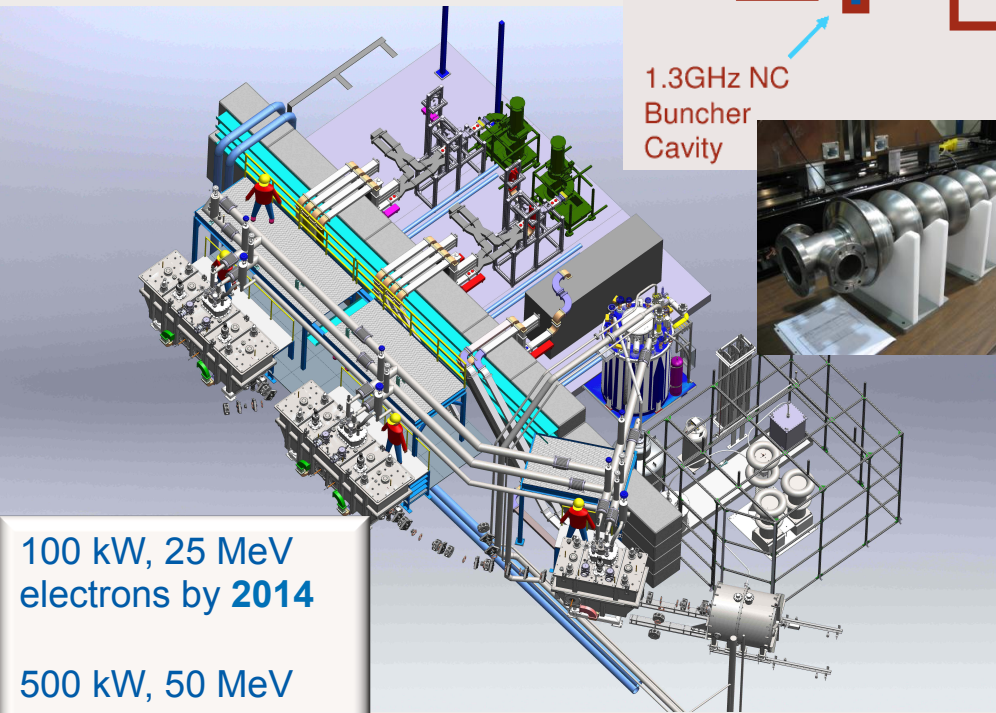
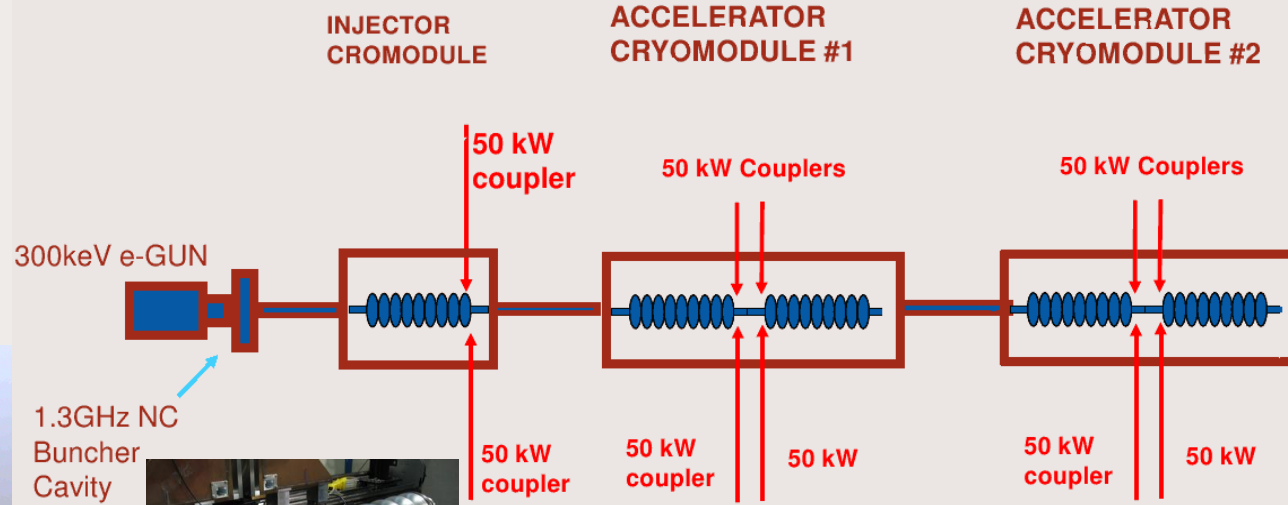
TRIUMF's flagship project:
➔ Isotopes for Science & Medicine

Expanding Canadian capabilities

- three simultaneous beams
- more "time" for science
- more and new isotopes
- more national & international users
- phased implementation
- interleave science with construction
- compete with the best in the world

e-linac: MW-class Superconducting Electron Accelerator

Kinetic energy (MeV)	50
Average current (mA)	10
Duty Factor	100%
Beam Power (MW)	0.5



100 kW, 25 MeV electrons by 2014

500 kW, 50 MeV electrons by ~2020

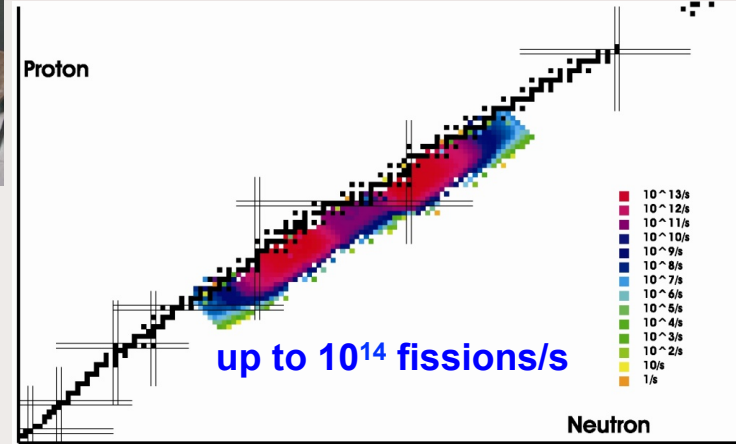


Photo-fission products using 50 MeV 10 mA electrons onto Hg convertor & UC_x target.

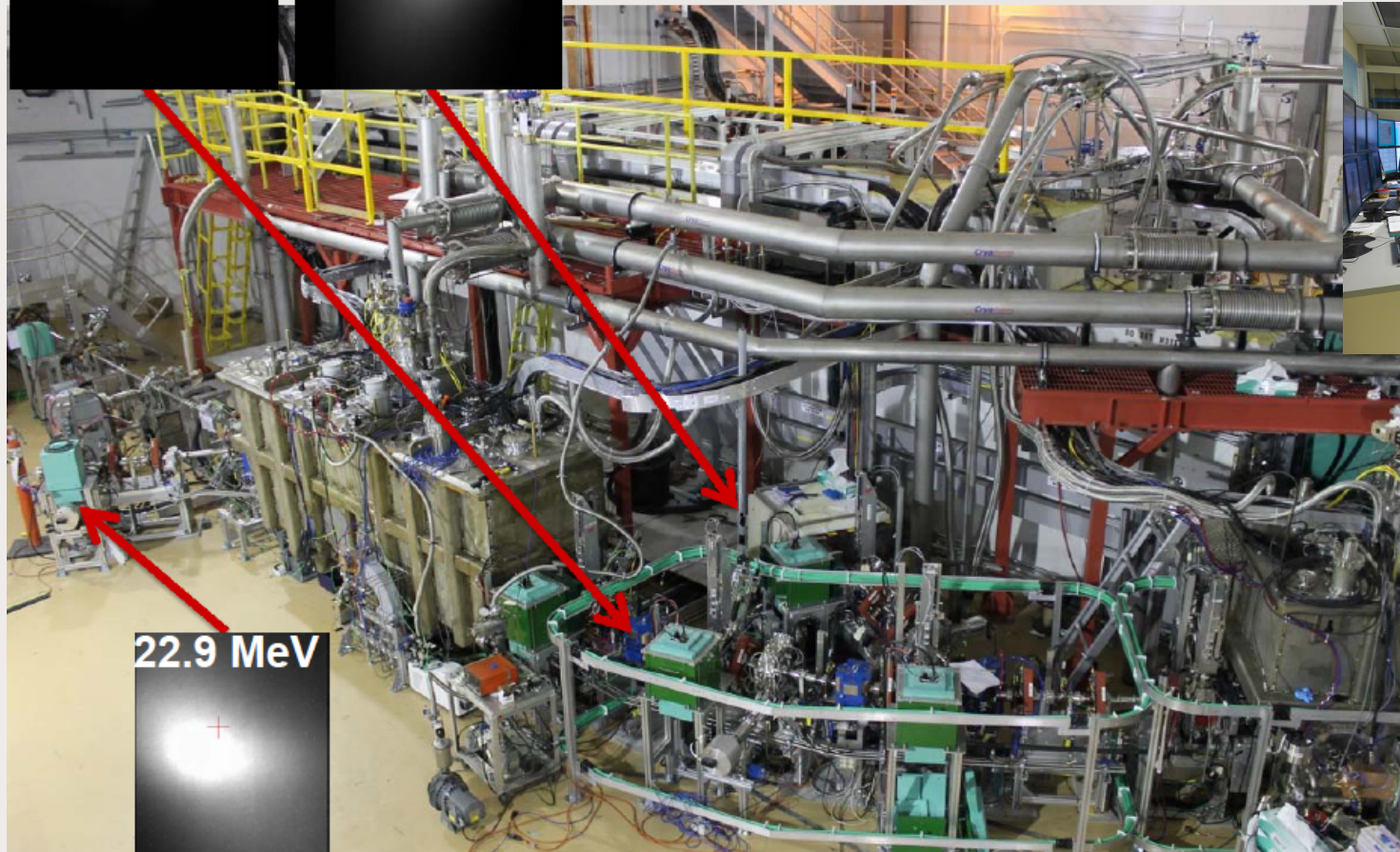
ARIEL e-Linac: on-time, on budget

Sept. 30, 2014

10.6 MeV

10.6 MeV

e-Linac accelerator commissioning

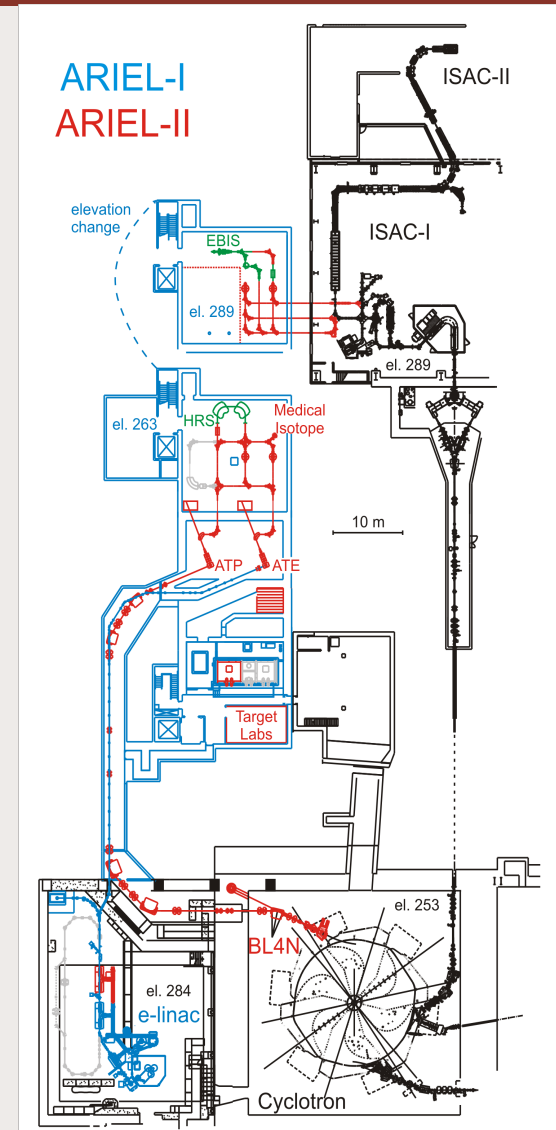


22.9 MeV

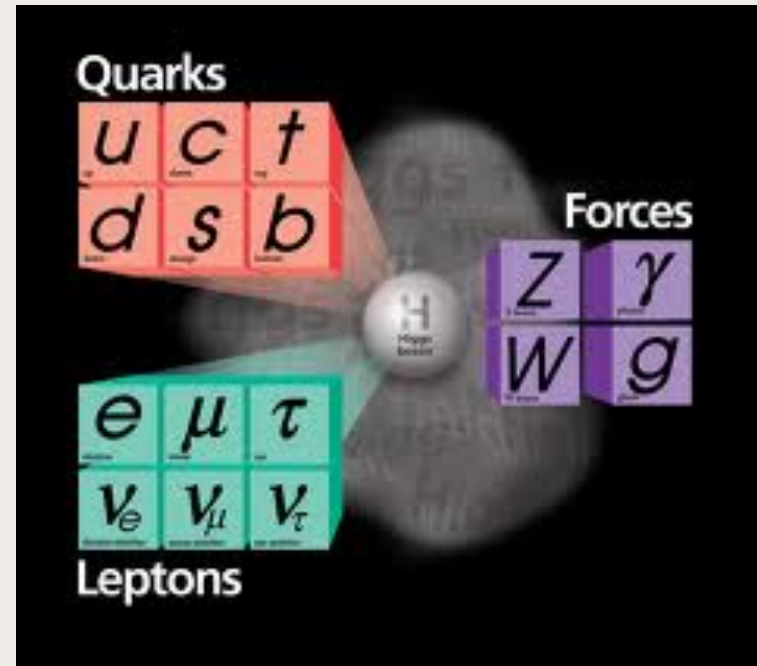
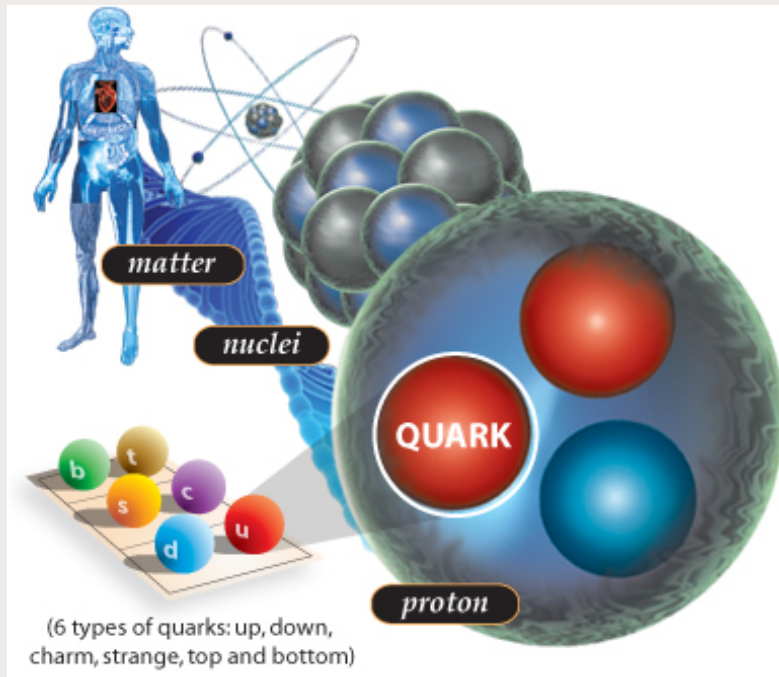


ARIEL: A staged Project

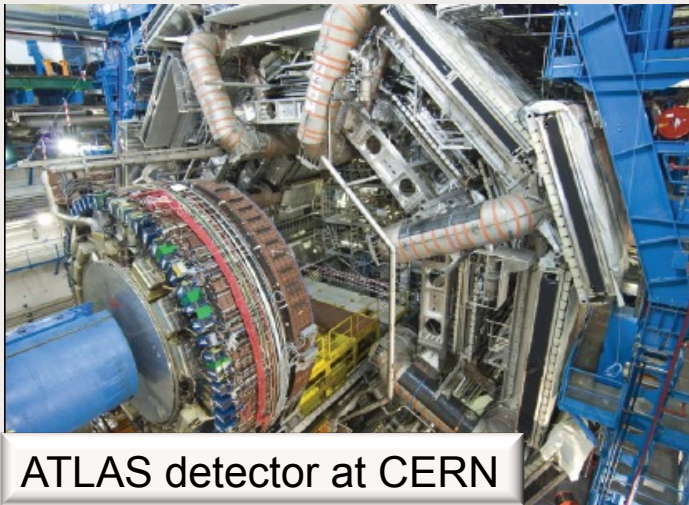
- **ARIEL-I (2010-2014): (CFI, UVic et al.)**
 - Civil construction for full ARIEL scope
 - Electron linac up to 25 MeV, 100 kW
- **CANREB (2014-2019): (CFI, SMU, UoM)**
 - High Resolution Mass Separator
 - EBIS Charge breeder
- **ARIEL-II (2016-2021): (CFI, UVic et al.)**
 - Completion and scientific utilization of ARIEL facility
 - RIB targets & delivery infrastructure
 - New proton beamline
 - Full power electron linac (500kW)
 - Phased approach to bring science online
 - CFI approved project (C\$34M)



Particle Physics Facilities



ATLAS Tier – 1 Centre



ATLAS detector at CERN



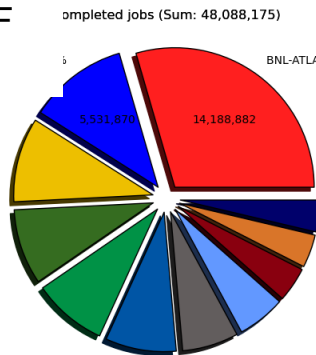
7.8 PB disk
8.8 PB tape
4830 cores
90 servers

ATLAS Tier 1 at TRIUMF

Urgent, large simulations for Higgs analysis in summer 2012 were done at TRIUMF

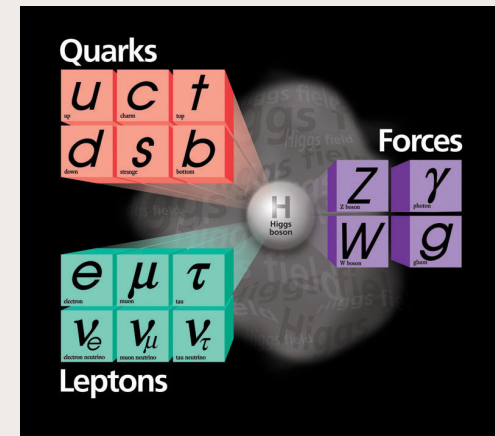
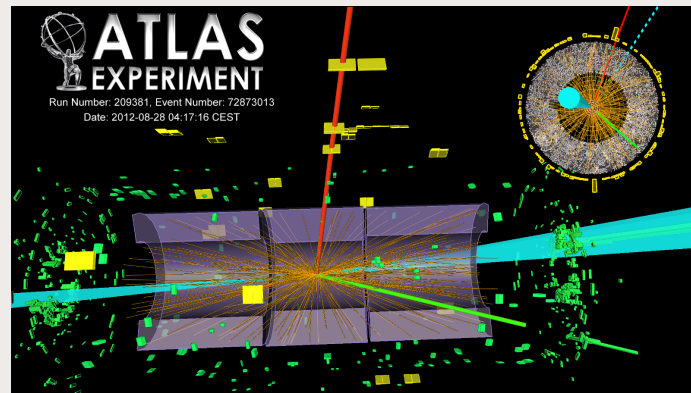
Highest availability of 10 Tier-1 centers worldwide

TRIUMF 11% BNL-ATLAS - 2 30%



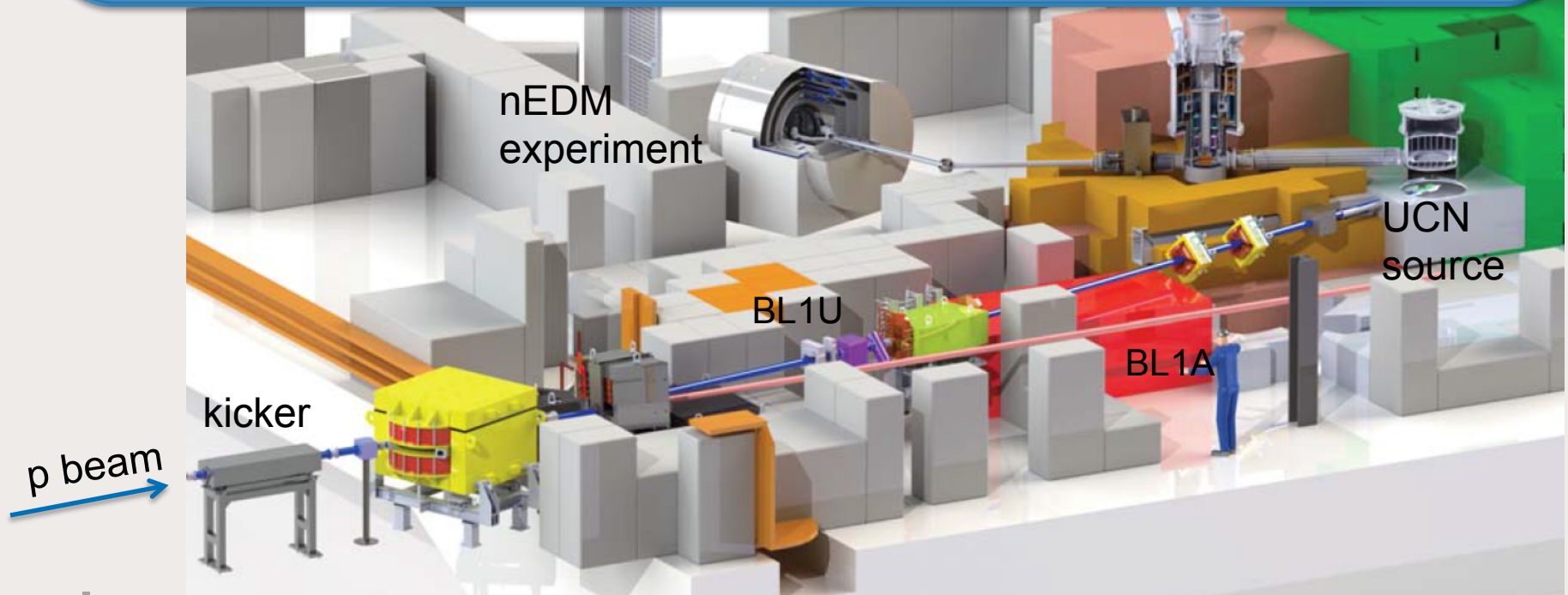
BNL-ATLAS - 29.51% (14,188,882)	TRIUMF-LCG2 - 11.50% (5,531,870)	FZK-LCG2 - 9.78% (4,704,336)
RAI-LCG2 - 8.76% (4,213,444)	INFN-FT1 - 8.01% (4,142,692)	IN2P3-CC - 8.23% (3,956,436)
TRIUMF-LCG2 - 6.51% (3,131,253)	NSF-T1 - 5.58% (2,681,780)	PK - 4.01% (1,929,622)
NIKHEF-ELPROD - 3.82% (1,838,334)	SARA-MATRIX - 3.68% (1,769,326)	

June 16, 2015



Future Ultra Cold Neutron Facility

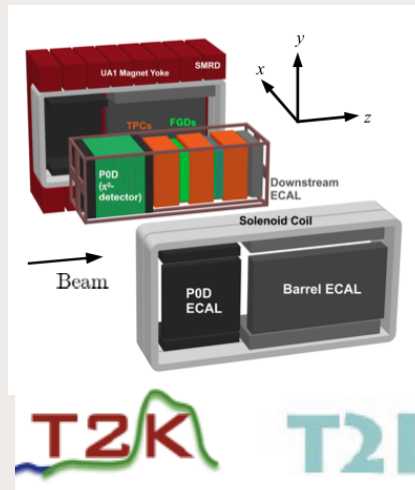
- Japan-Canada collaboration (KEK, RCNP, Winnipeg, Manitoba, UBC, SFU, TRIUMF)
- 40 μA protons on spallation neutron target
- He-II source concept developed and being tested at RCNP
- Small room temperature EDM apparatus with dual co-magnetometer
- Installation of new beam line and source at TRIUMF 2014-16
- **Goal: 3000 UCN/cm³ in EDM cell, 10^{-28} e·cm sensitivity by ~2020**



TRIUMF's role in the Canadian and international community

TRIUMF & international projects:

- Scientific Leadership
- Unique capabilities and infrastructures
- Detector design and construction
 - T2K near detector TPC, FGD
 - Qweak
 - ALPHA2 cryostat
- Electronics & DAQ development
 - T2K, DEAP, GRIFFIN, MIDAS DAQ



Detector facilities



Large Clean Room (e.g. T2K)

June 16, 2015

Detector integration



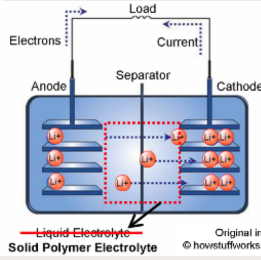
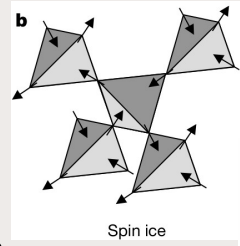
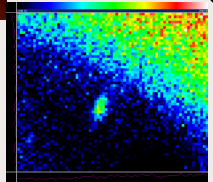
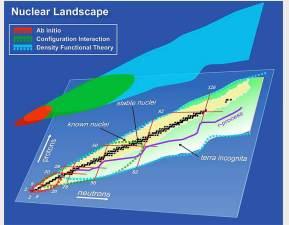
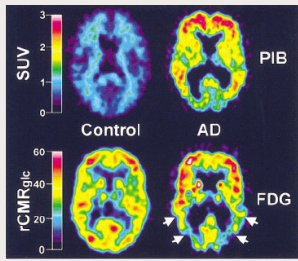
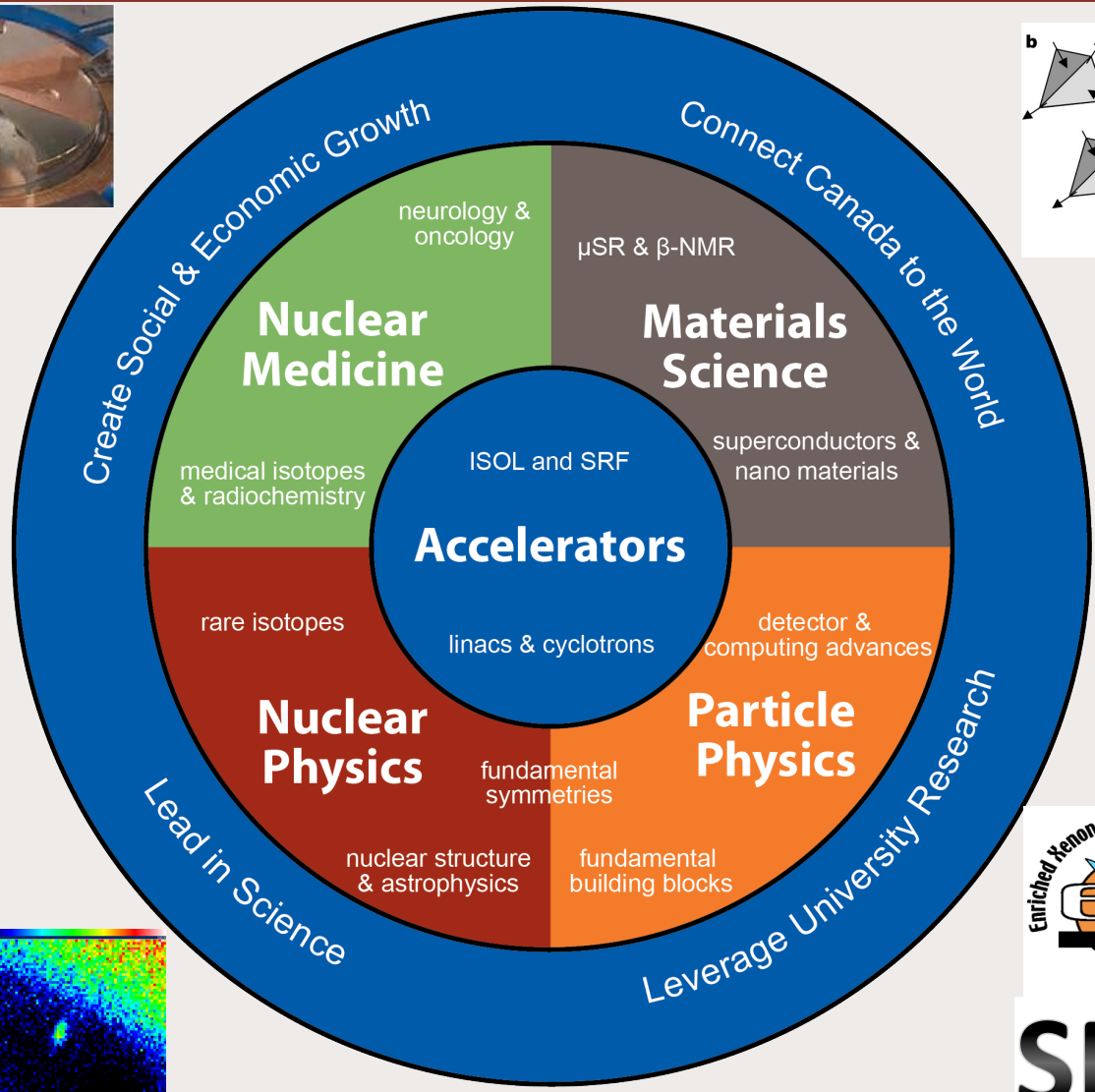
Kruecken - CAP 2015

Electronics Development



DEAP readout

TRIUMF Research Program & Vision



Thank you!

Merci

TRIUMF: Alberta | British Columbia |
 Calgary | Carleton | Guelph | Manitoba |
 McGill | McMaster | Montréal | Northern
 British Columbia | Queen's | Regina |
 Saint Mary's | Simon Fraser | Toronto |
 Victoria | Western | Winnipeg | York

