Advanced Instrumentation at TRIUMF

June 16, 2015

Reiner Kruecken | Science Division Head | TRIUMF
Professor | University of British Columbia
• Introduction to TRIUMF
• Accelerator and Experimental Facilities
• Isotopes for Science and Medicine
  • Example Instrumentation (w/ focus on light)
• Particle Physics Facilities
• Conclusions
TRIUMF is owned & operated by a consortium of 19 universities
Founded 47 years ago in Vancouver
TRIUMF
Accelerator Complex

Original 520 MeV, 350μA, H⁻ cyclotron

4 medical isotope cyclotrons

ISAC 50kW ISOL facility

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

TRIUMF Laboratory
Isotope Separator and Accelerator (ISAC)

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

Programs in
• Nuclear Structure & Reactions
• Nuclear Astrophysics
• Fundamental Symmetries
• Material Science
• Nuclear Medicine

ISAC-I and ISAC-II Facility

ISAC II: > 6 AMeV for A<150

ISAC I: 60 keV & 1.7 AMeV

Selected beams (measured yields):
- \(^{26}\text{Al} \quad > 10^{10}\) pps
- \(^{37,38}\text{mK} \quad > 10^9\) pps
- \(^{211,213}\text{Fr} \quad > 10^9\) pps
- \(^{225}\text{Ra} \quad > 10^8\) pps
- \(^{103}\text{Rb} \quad 3\) pps

Select accelerated RIBs:
- \(^{95}\text{Sr}^{15+} \quad 10^7\) pps
- \(^{11}\text{Li}^+ \quad 3 \times 10^3\) pps
- \(^{11}\text{Be}^+ \quad 10^5\) 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

June 16, 2015

Kruecken - CAP 2015
Measured ISAC RIB Intensities

Yield Chart of Nuclides

Element selection via laser ionization

Si

Nb

Ta

U

continuum

ionization energy < 9-10 eV

ground state

excited states

60 keV ions

480 MeV proton beam

June 16, 2015

Kruecken - CAP 2015
ISAC Experimental Facilities

- TITAN Penning Trap facility
- Nuclear Structure
- Nuclear Astrophysics
- Fundam. Symmetries
- Materials Science
- EMMA recoil mass analyzer
- TRINAT magneto optical trap
- DESCANT neutr. det.
- GRIFFIN decay spectrometer
- TUDA reaction setup
- Laser polarizer line
- Francium trapping facility
- MTV Mott scatt. drift chamber
- IRIS solid hydrogen reaction set-up
- DRAGON recoil separator
- TIGRESS in-beam gamma-ray spectrometer

Nuclear Structure
Nuclear Astrophysics
Fundam. Symmetries
Materials Science

June 16, 2015
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.
First ever laser spectroscopy of $^{205}$Fr
A. Voss et al., PRL 111, 122501 (2013)

Informs about ground state spin & nuclear size
New GRIFFIN Facility at TRIUMF
Sensitive Decay Spectroscopy

Initial operation since fall 2014. First 4 experiments in 2015

- Custom designed high-performance digital readout electronics (U. Montreal, TRIUMF)
- Implantation of radioisotope in tape followed by observation of decay radiation
- Specialized detector systems for **gammas**, betas, neutrons, conversion electrons

HPGe: 16 Clovers
Detect gamma rays and determines branching ratios, multipolarities and mixing ratios
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.
Supernova

x-ray burst

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

- 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.
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 $^{207,209,221}$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.
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 $^8\text{Li}$

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

28 keV $^8\text{Li}^+$

Low-field spectrometer
$B_{\text{ext}}=0 - 220 \text{ G}$

Polarization direction

High-field Spectrometer
$B_{\text{ext}}=100 \text{ G} - 6.5 \text{T}$

Na vapor neutralizer  He re-ionizer gas  Laser bench Optics
• 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.
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.

211At particularly well suited

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

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

Another isotope of interest for
target alpha therapy is 225Ac
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

Existing
 Existing ARIEL I
(completed)

ARIEL II
(CFI proposal by 19 universities)

CFI = Canada Foundation for Innovation

June 16, 2015
e-linac: MW-class Superconducting Electron Accelerator

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

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

100 kW, 25 MeV electrons by 2014
500 kW, 50 MeV electrons by ~2020
ARIEL e-Linac: on-time, on budget

e-Linac accelerator commissioning

Sept. 30, 2014
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

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

Highest availability of 10 Tier-1 centers worldwide

ATLAS Tier 1 at TRIUMF

<table>
<thead>
<tr>
<th>TRIUMF</th>
<th>BNL</th>
</tr>
</thead>
<tbody>
<tr>
<td>11%</td>
<td>30%</td>
</tr>
</tbody>
</table>

7.8 PB disk
8.8 PB tape
4830 cores
90 servers
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/cm$^3$ 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)

**Detector integration**

**Electronics Development**

- DEAP readout
TRIUMF Research Program & Vision

- Nuclear Medicine: medical isotopes & radiochemistry, neurology & oncology
- Materials Science: ISOL and SRF, superconductors & nano materials, detector & computing advances
- Nuclear Physics: rare isotopes, fundamental symmetries, nuclear structure & astrophysics
- Particle Physics: fundamental building blocks

Create Social & Economic Growth
Connect Canada to the World
Lead in Science
Leverage University Research

June 16, 2015
Kruecken - CAP 2015
Thank you!

Merci