TRIUMF

Canada's National Laboratory for
Particle and Nuclear Physics

The science program at ISAC and ARIEL, selected highlights

Jens Dilling
Associate Laboratory Director TRIUMF
- Physical Sciences Division

December 2 2015

ISOLDE workshop CERN

TRIUMF: Canada's National Laboratory

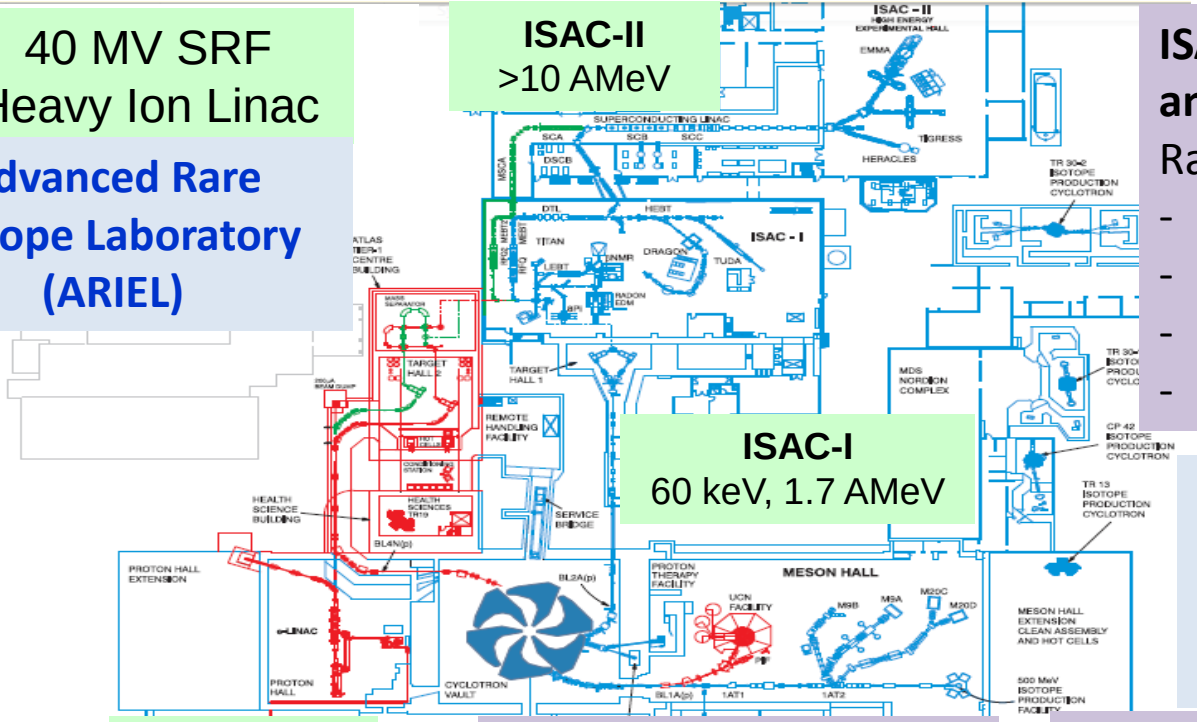
TRIUMF was founded in 1968 and has delivered nearly 50 years of accelerator-based science and innovation for Canada, and is engaging the World.

TRIUMF's accelerator complex

40 MV SRF
Heavy Ion Linac

Advanced Rare Isotope Laboratory (ARIEL)

ISAC-II
>10 AMeV



ISAC-I
60 keV, 1.7 AMeV

ISAC (Isotope Separator and ACcelerator)
Rare Isotope Facility
- Nuclear Structure
- Nuclear Astrophysics
- Fund. Symmetries
- CMMS (βNMR)

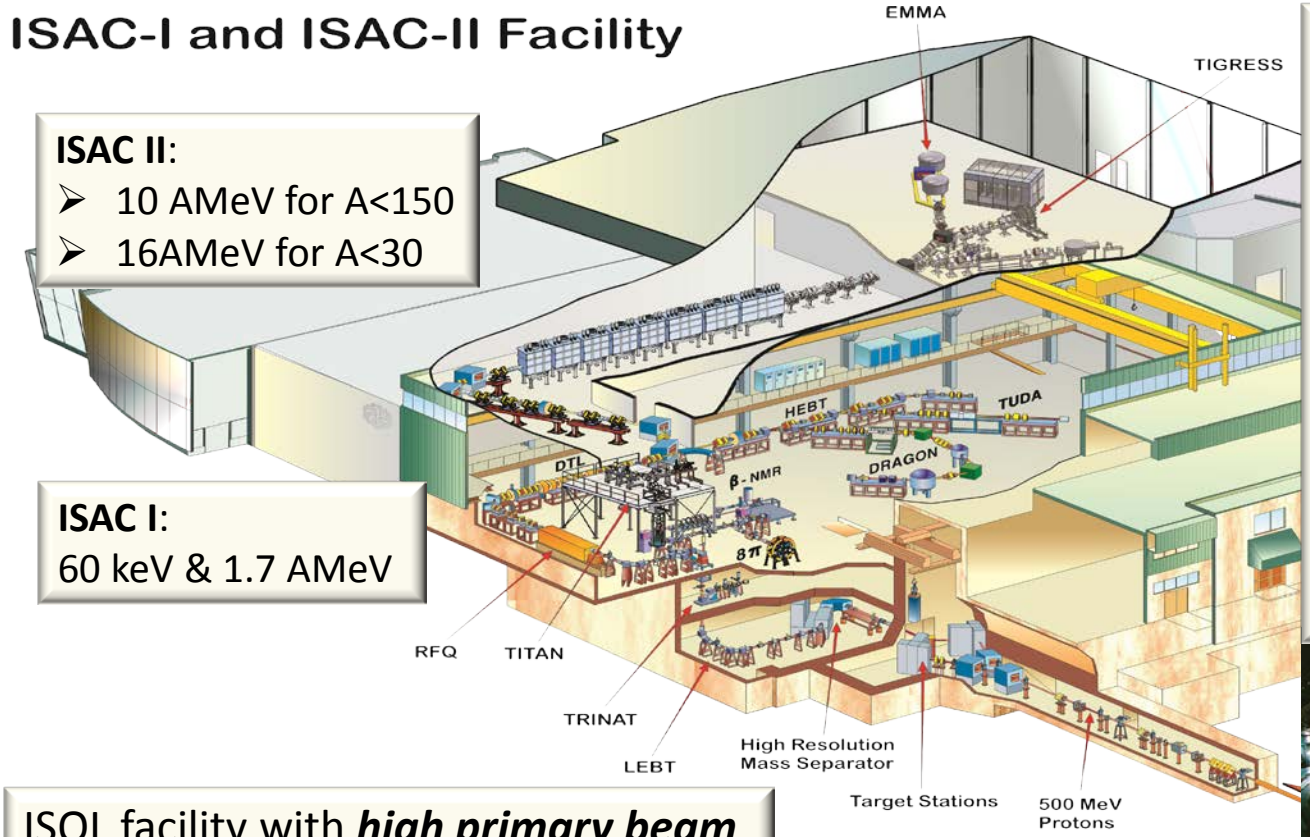
Nordion
commercial medical isotope production
3 cyclotrons

Cyclotron
500 MeV
350 μA

Particle Physics
Pienu
Ultra Cold Neutrons

CMMS
Centre for Molecular and Material Science (μSR)

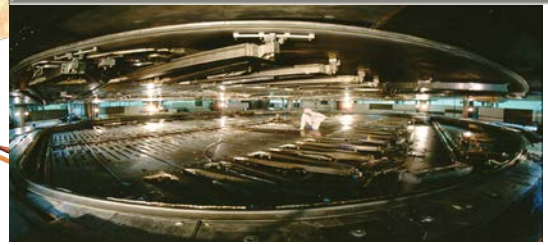
ISAC rare isotope facility



ISAC II:
- 10 AMeV for A<150
- 16AMeV for A<30

ISAC I:
60 keV & 1.7 AMeV

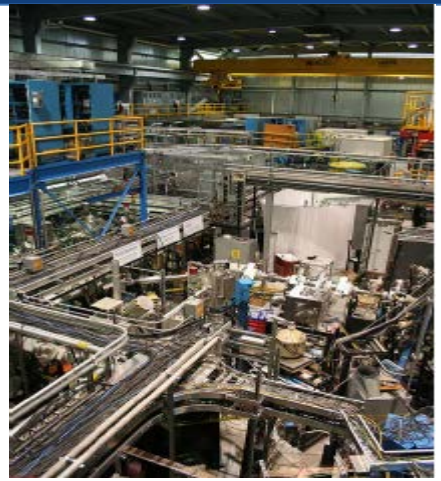
Programs in
- Nuclear Structure & Dynamics
- Nuclear Astrophysics
- Electroweak Interaction Studies
- Material Science
- 16 permanent experiments

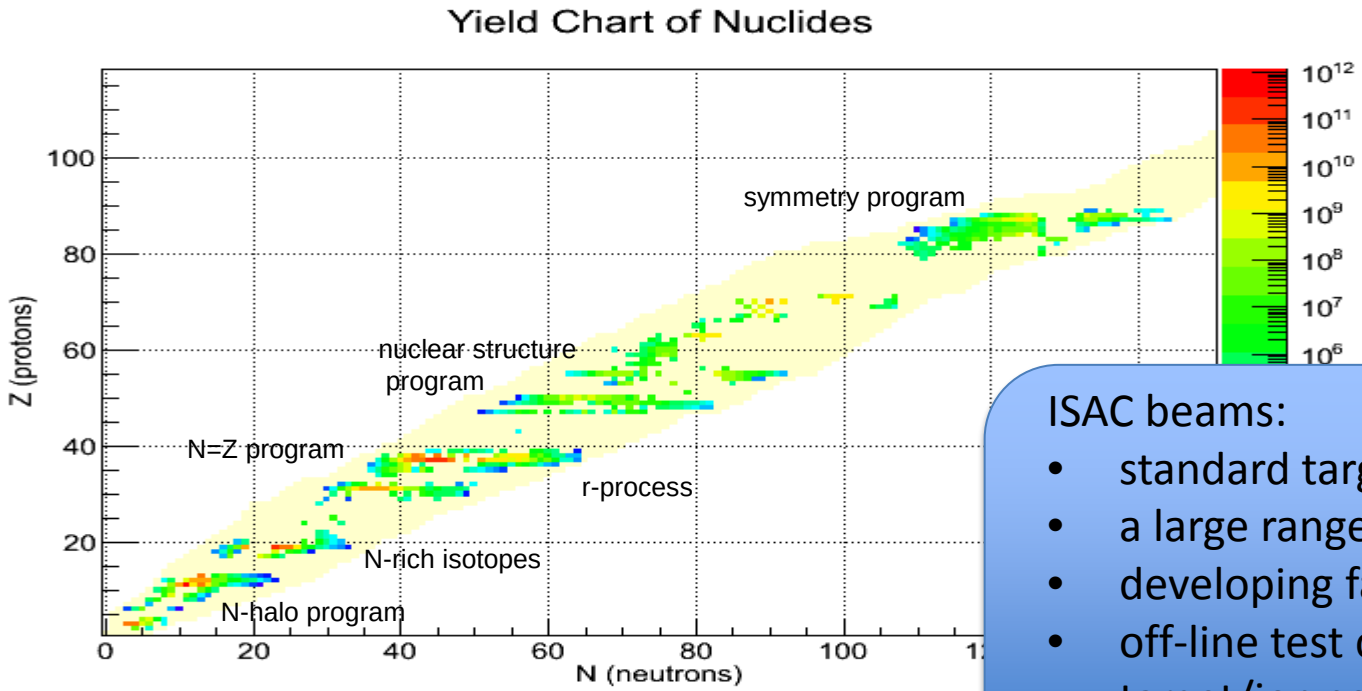


ISOL facility with ***high primary beam intensity*** (100 μA, 500 MeV, p)

TRIUMF

Isotopes delivered at ISAC





ISAC beams:

- standard targets and new R&D
- a large range of ion sources
- developing fast proton rotation
- off-line test capabilities
- target/ion source system operational for ~4-6 weeks

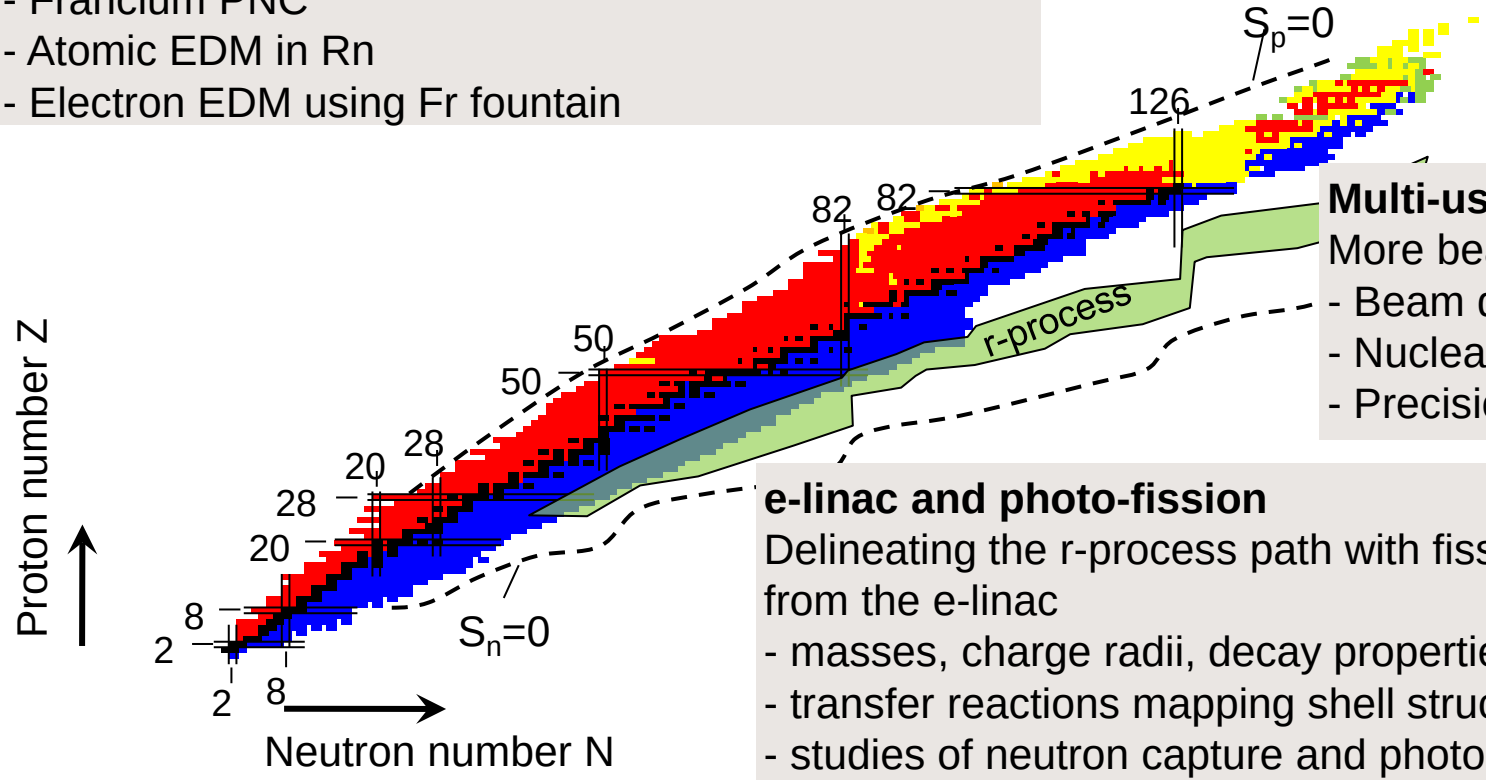
F. Ames, P. Bricault, J. Lassen, P. Kunz

The **A**dvanced **R**are **I**sotop**E** **L**aboratory will triple TRIUMF's isotope beam capacity

- Uses state-of-the-art, made-in-Canada super-conducting RF accelerator technology; targets are designed to allow medical isotopes to be extracted alongside the experimental program
- Represents ~$100 million investment by federal and provincial governments; supported by 19 university partners from across Canada
- Project to occur in two phases: ARIEL-I completed in Fall 2014; ARIEL-II funded by Canada Foundation of Innovation in May 2015

Actinide proton beam-line:
High intensity, clean beams for electroweak precision experiments using hundreds of days of beam per year
- Francium PNC
- Atomic EDM in Rn
- Electron EDM using Fr fountain

TRIUMF ARIEL
ADVANCED RARE ISOTOPE LABORATORY



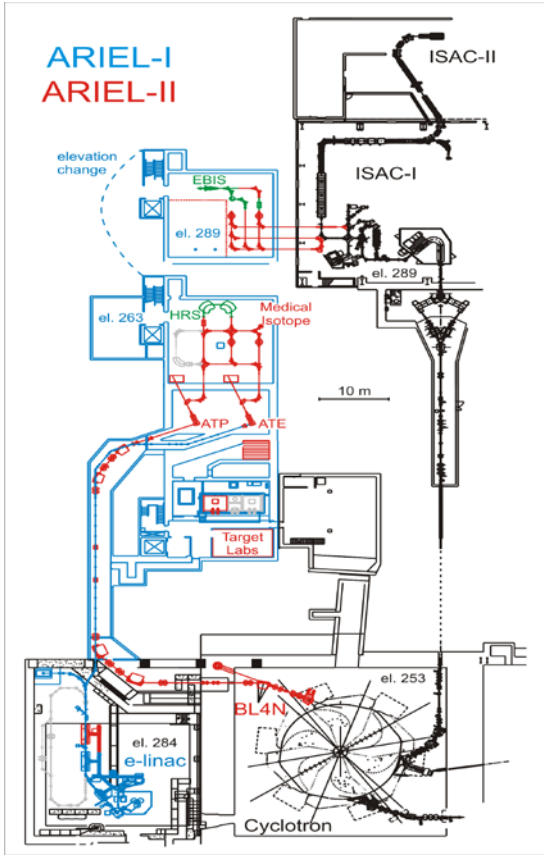
Multi-user operations:
More beam time for
- Beam development
- Nuclear astrophysics
- Precision experiments

e-linac and photo-fission
Delineating the r-process path with fission fragment beams from the e-linac
- masses, charge radii, decay properties
- transfer reactions mapping shell structure
- studies of neutron capture and photo dissociation rates

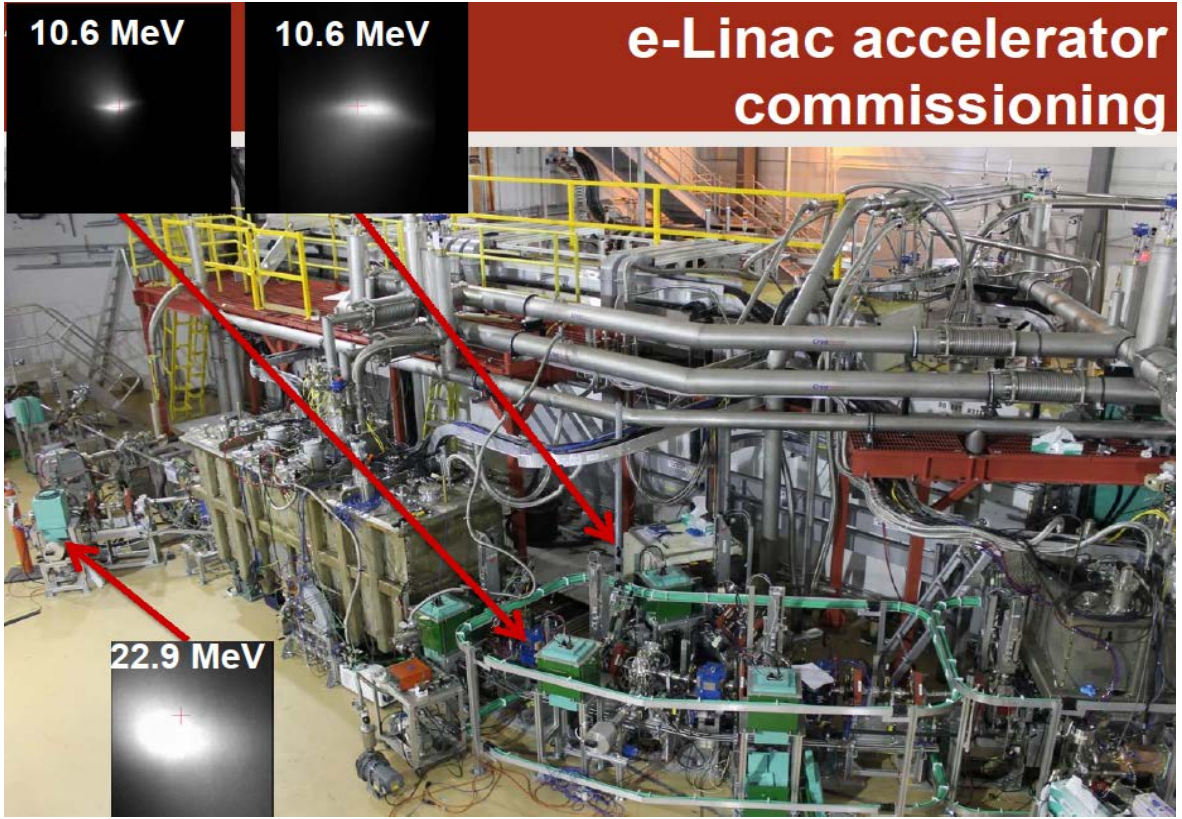
ARIEL: A two-stage Project

- **ARIEL-I** (2010-2014):
  - Civil construction to encompass objectives of both ARIEL-I & II
  - Electron linac up to 25 MeV, 50 kW

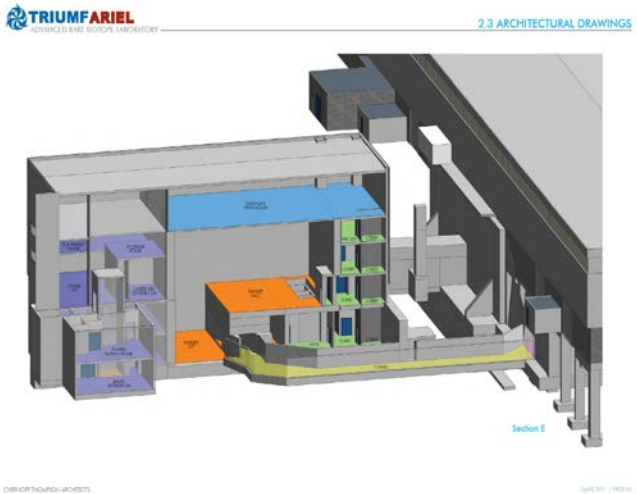
- **ARIEL-II** (2016-2021):
  - Completion and scientific utilization of the ARIEL facility
    - RIB targets & delivery infrastructure
    - New proton beamline
    - High power electron linac (36 MeV, 100kW)
  - Phased approach to bring science online
  - Fully funded



ARIEL e-Linac: completed and operational



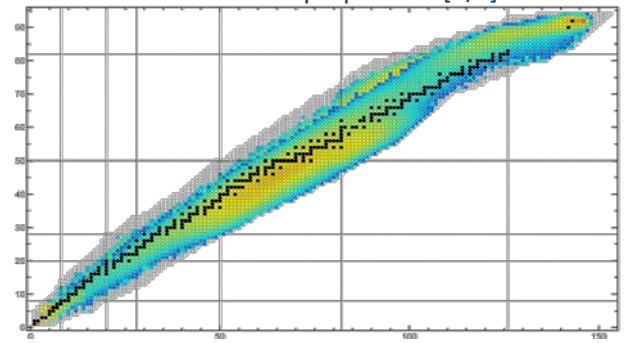
Sept. 30, 2014



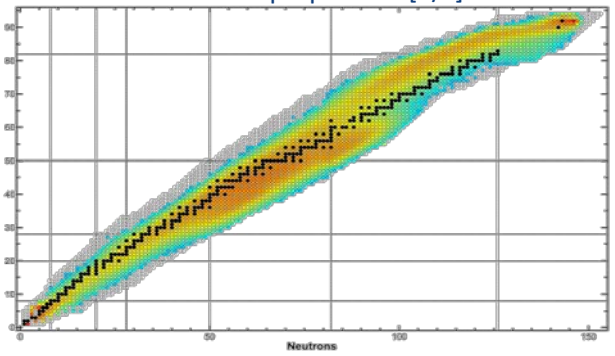
ARIEL target developments

Production of Radioisotopes from of $^{238}UC_x$ for ISOL

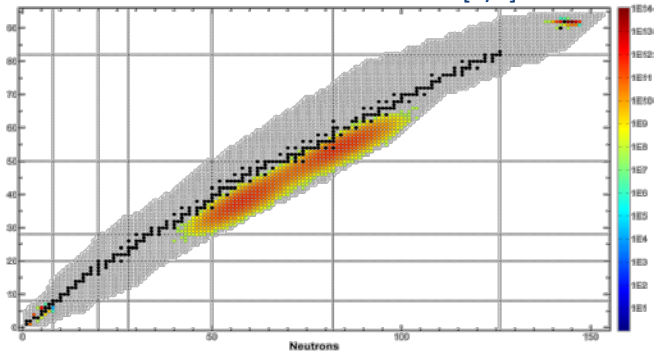
500 MeV x 10 µA protons [1/s]

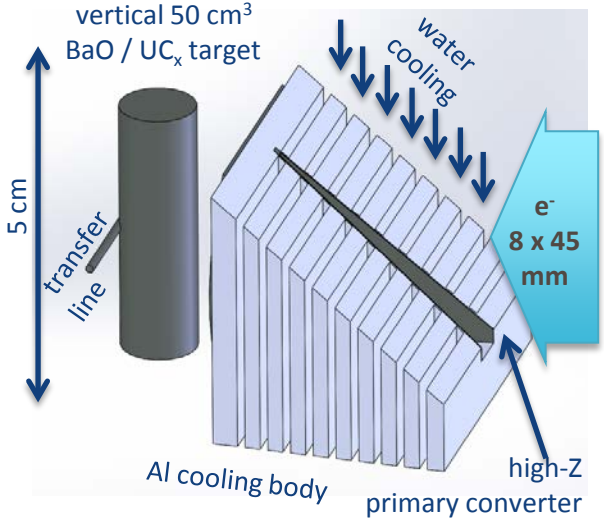


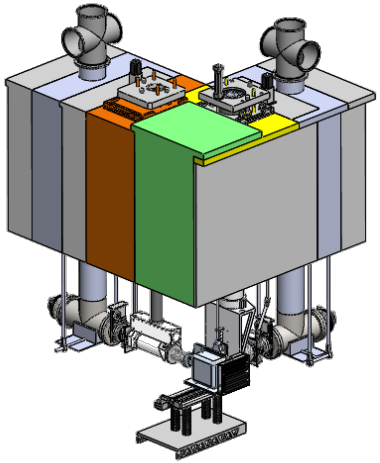
1.4 GeV x 2 µA protons [1/s]



50 MeV x 10 mA electrons [1/s]



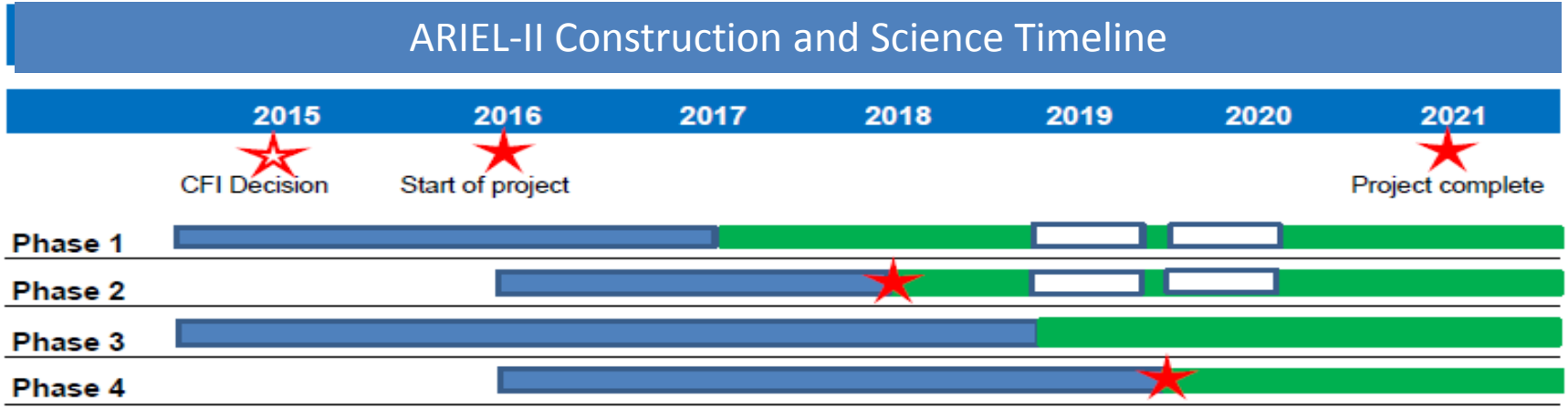




- **Significant target developments for photo-fission targets with $^{238}UC_x$**
- **New target removal and exchange concept considered.**
- **Collaboration with ISOL labs, including ISOLDE.**

A. Gottberg, P. Bricault

ARIEL-II Schedule – Science Phases



Phase	Will deliver isotopes for....
1	Materials science with β-NMR + light beams for Fund. Symm. (^{8}Li)
2	Photo-fission of uranium from e-Linac
3	Purified accelerated high mass beams (CANREB), Medical isotopes for imaging & treatment
4	Fundamental Symmetries w/ new proton beamline (BL4N) ❖ **Three simultaneous rare isotope beams delivered to users**

Current ISAC operation: Science highlights

Science highlights from this year:

ISAC I, low energy:

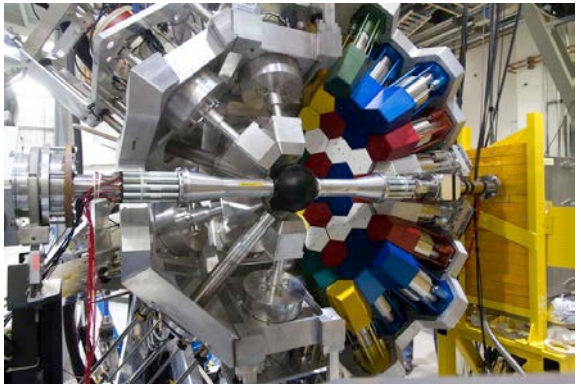
- **GRIFFIN Cd isotopes**
- **Collinear laser spectroscopy**
- **Fundamental Symmetry program with FRANCIUM**

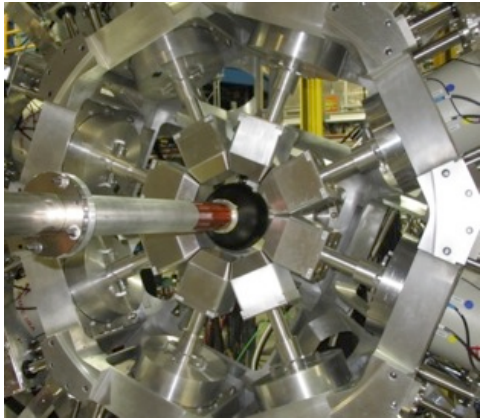
ISAC II, post-accelerated beam:

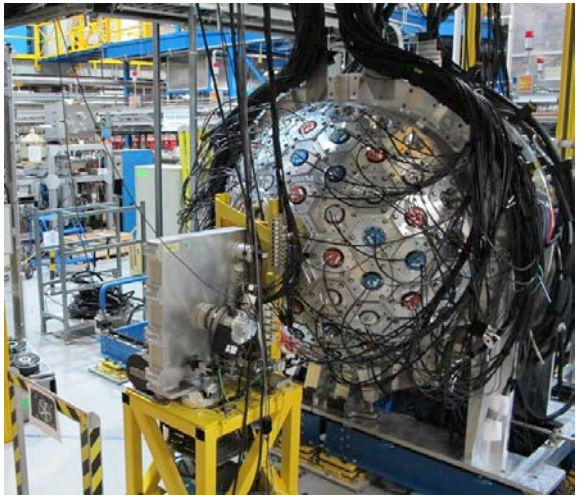
- **Nuclear astrophysics with DRAGON and TUDA**

ISAC II, accelerated beam:

- **TIGRESS and SPICE**
- **Cluster studies with TUDA II**

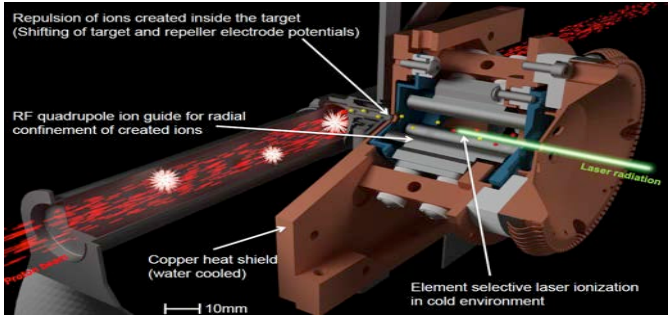


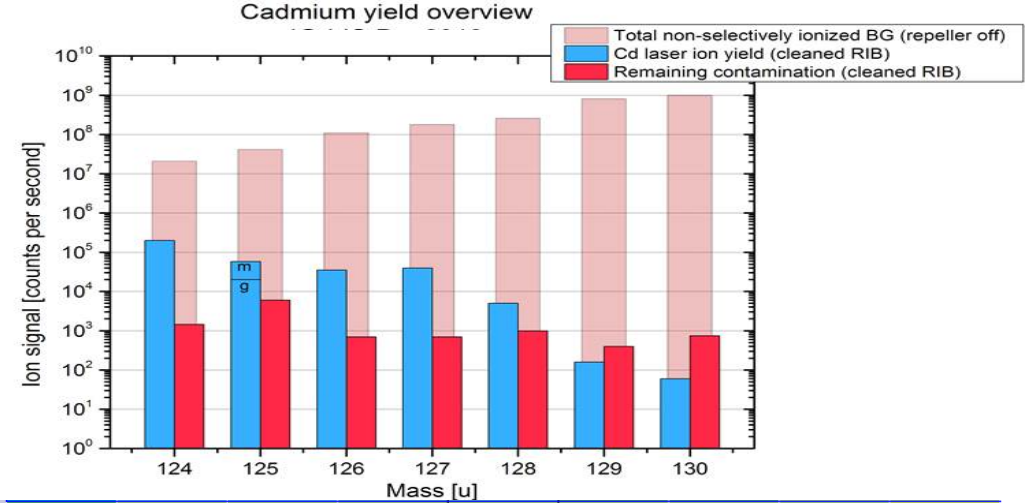




GRIFFIN Cd spectroscopy, beam production

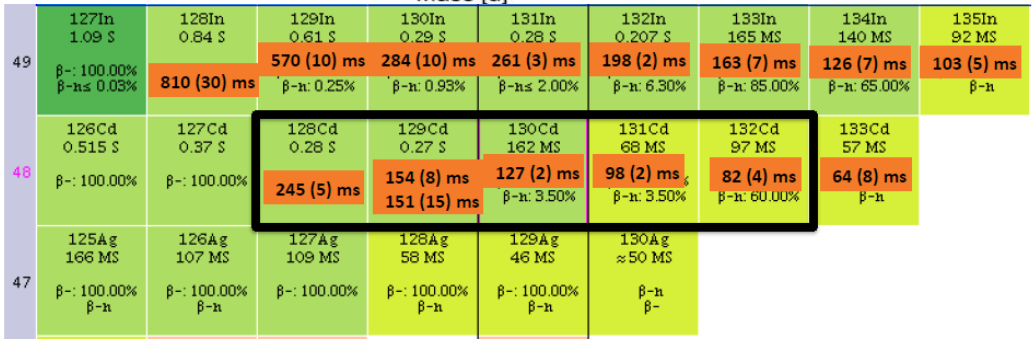
- Uranium carbide target, requires **IG-LIS** (Ion Guide- laser Ion Source): suppression of surface-ionized species (In, Cs, Ba) by factor 10^5-10^6
- IG-LIS beam development





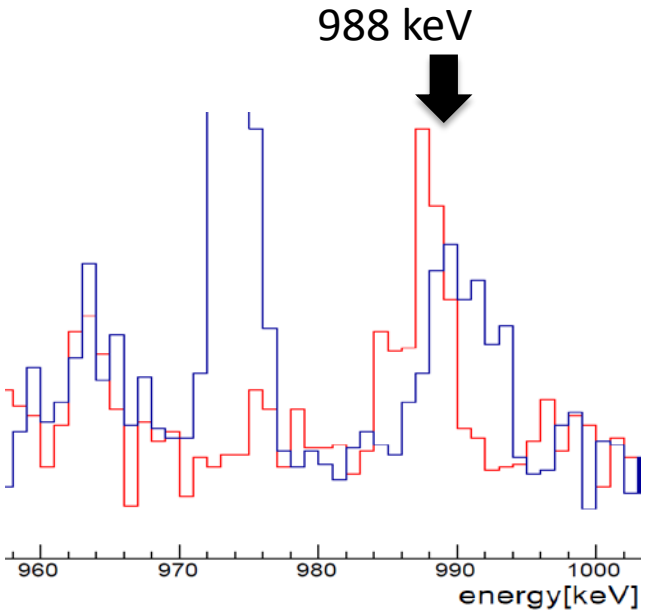
^{128}Cd: 4040 pps
^{129}Cd: 237 pps
^{130}Cd: 60 pps
^{131}Cd: 3 - 15 pps
^{132}Cd: 0.15 - 0.75 pps

Measured:
1067 pps
122 pps
16-29 pps
~0.8 pps
~0.1 pps



^{131,132}Cd β-decay

GRIFFIN: large HPGe detector array (16 clover)
Lowest yield ever measured with 8π or GRIFFIN!



red: ^{131}Cd decay
doublet with 985 keV ? Preliminary.

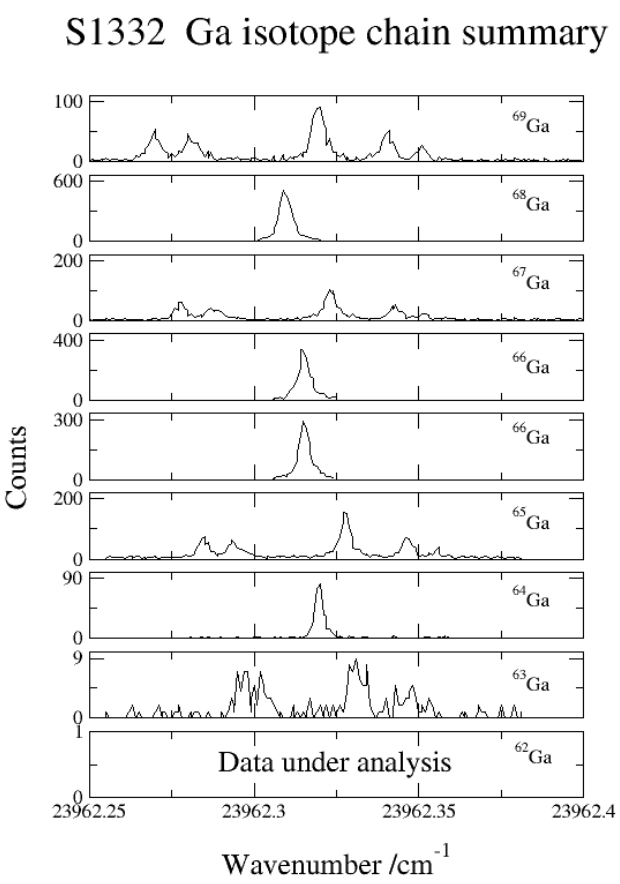
blue: ^{132}Cd decay
doublet with 992.6 keV (^{132}Sn decay)

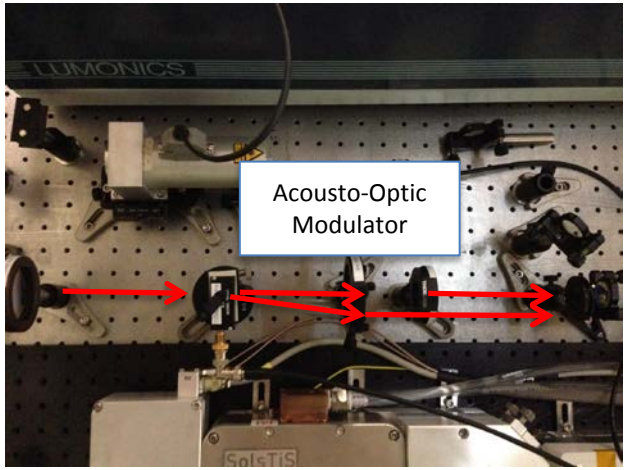
- Confirmed observation of 988 keV transition ☺
- Statistics too low for observation of low-energy M1 transitions
- Analysis on-going (PhD work N. Bernier)

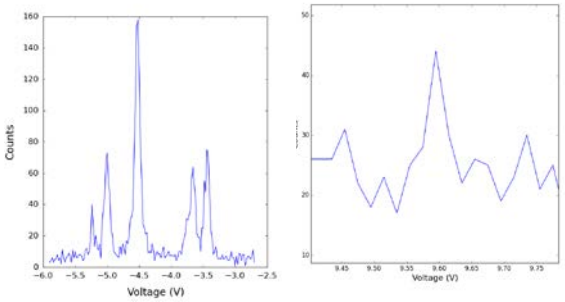
I. Dillmann & GRIFFIN Collaboration

TRIUMF, Guelph, SFU, St Mary's, Colorado School of Mines, Madrid, Orsay, UNA Mexico & the GRIFFIN Collaboration

Laser spectroscopy: Ga and the CKM







^{65}Ga

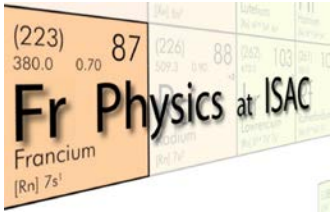
^{62}Ga

Collinear laser spectroscopy:
Cooled and bunched beams
& development of a new technique for ISAC:

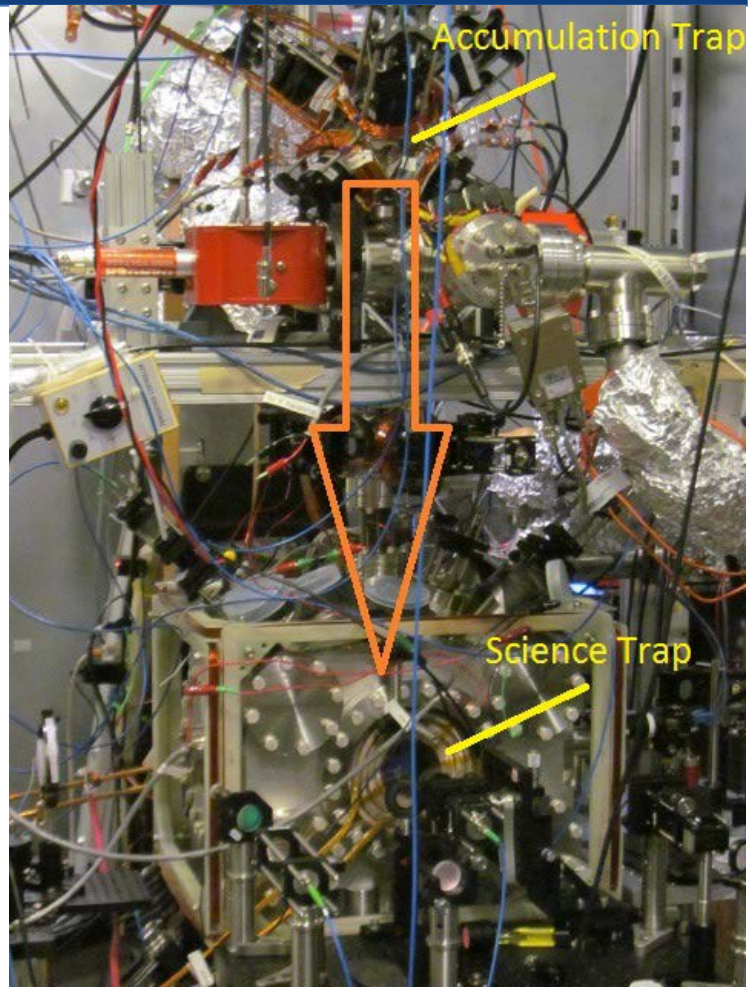
- Chopping and switching technique.
- Increased sensitivity
- Re-gained efficiency

M. Pearson, T. Proctor
& Collinear Laser Collaboration
TRIUMF, McGill, Manchester, Liverpool, Jyvaskyla

Parity Violation Experiments with Fr



- Radioactive Fr - laser trap for precision measurements
- Two chambers: upper accumulation trap, lower science trap
- Ions neutralized and collected on thin Y/Zr foil
- Science chamber contains parity violation measurement apparatus for optical and anapole measurements
- Zhang, J. et al., PRL **115**, 042501 (2015).
- Recent improvements of neutralisation efficiency



^{26}Al production and destruction in stars

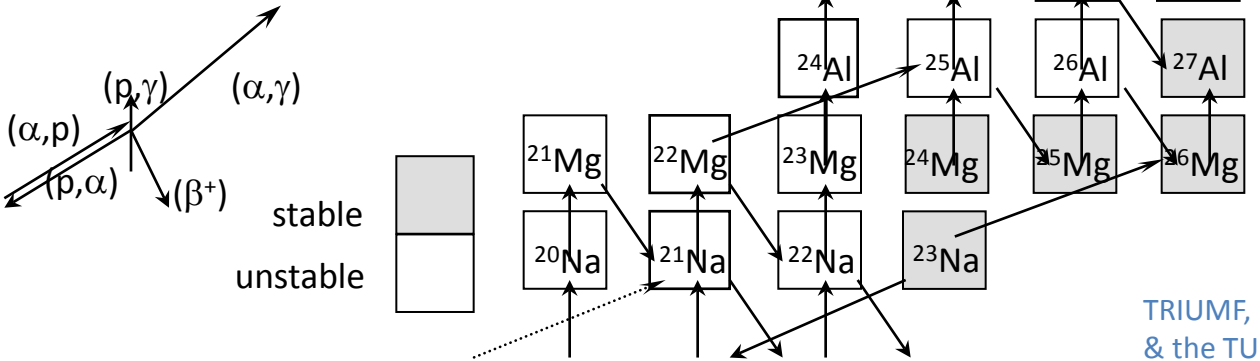
TUDA: Tomlinson et al. PRL 115, 052702 (2015)

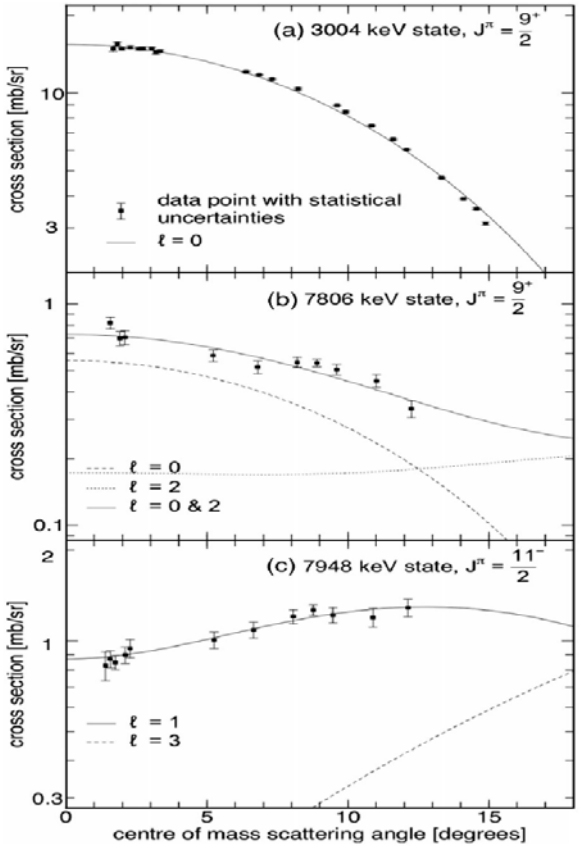
Inverse kinematics study of ^{23}Na(α,p)^{26}Mg for E_{cm}= 1.28–3.15 MeV:

- Important reaction for the production of Al isotopes in the convective burning shell of massive stars

TUDA: Margerin et al. PRL 115, 062701 (2015)

- constraining strengths of key astrophysical resonances in the ^{26g}Al(p,γ)^{27}Si reaction
- results indicate that the resonance at E_r=127 keV in ^{27}Si determines the entire ^{26g}Al(p,γ)^{27}Si reaction rate over almost the complete temperature range of Wolf-Rayet and AGB stars.



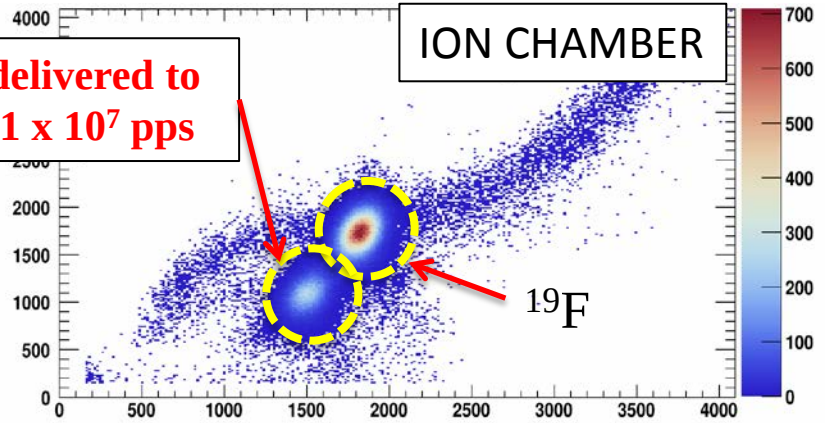


TRIUMF, Edinburgh, York, Surrey, Colorado S of Mines & the TUDA Collaboration

DRAGON: $^{19}Ne(p,\gamma)^{20}Na$ Reaction

Beams of ^{19}Ne delivered to DRAGON at ~ 1 x 10^7 pps

ION CHAMBER



$^{15}O(\alpha,\gamma)^{19}Ne(p,\gamma)^{20}Na$ represents main breakout sequence in X-ray bursts and hence, governs recurrence rate.

Strength of resonance determined for 1st time

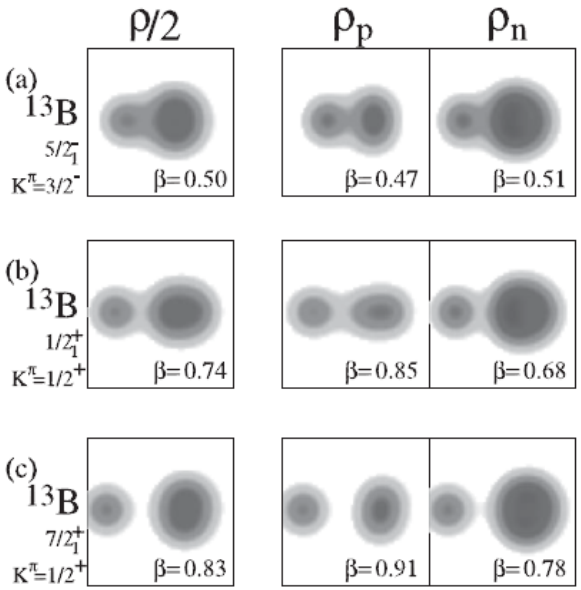
MCP vs. SEPARATOR TOF

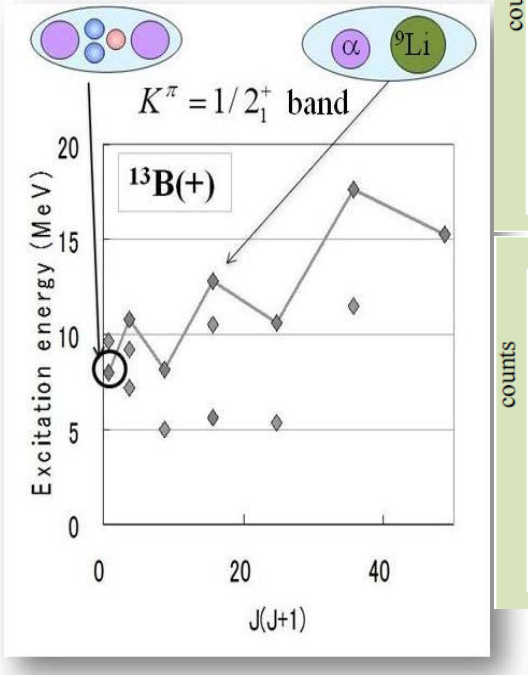
Location of resonance determined for 1st time

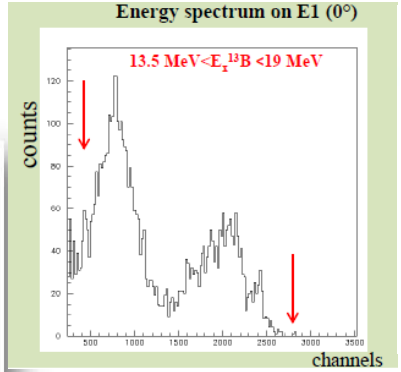
TRIUMF, McMaster, York, Surrey, Politecnia de Catalunya, Notre Dame, Colorado School of Mines, Michigan State U. & the DRAGON collaboration

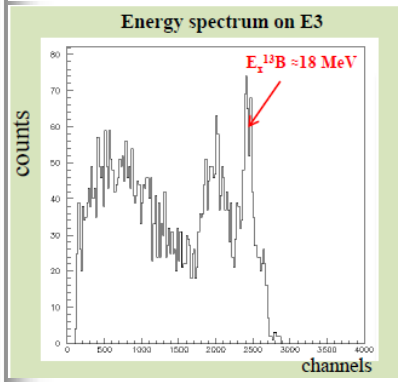
TUDA experiments at ISAC II

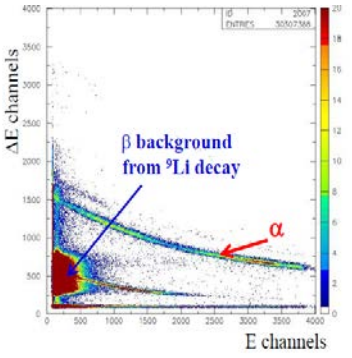
STUDY OF ^{9,11}LI-α CLUSTER STATES IN ^{13,15}B USING THE RESONANCE SCATTERING METHOD

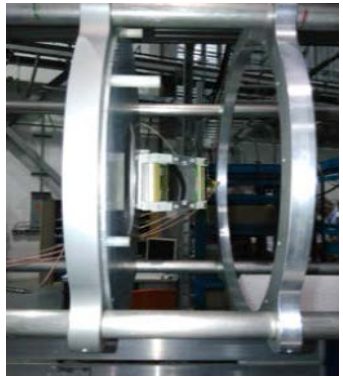








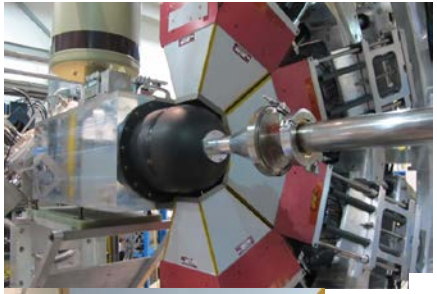


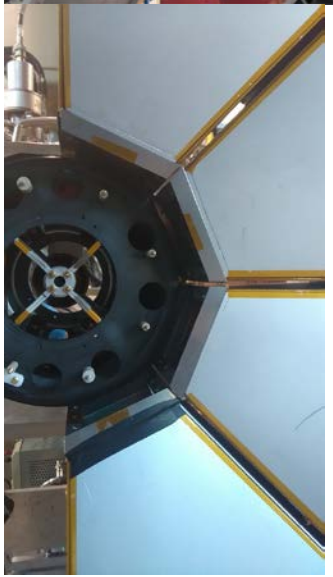


AMD predictions: e.g.Y. Kanada En'yo et al. Prog.Theor.Phys.120 (2008) 917

TRIUMF, Catania, INFN Sud, Madrid, Zagreb, Edinburgh & the TUDA Collaboration

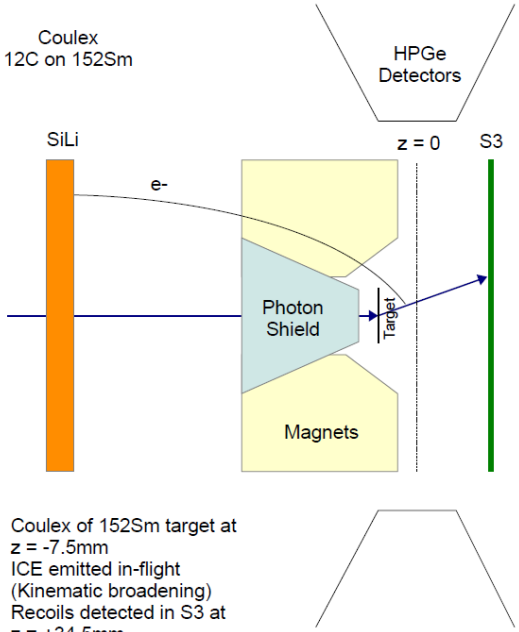
TIGRESS and SPICE detector at ISAC II





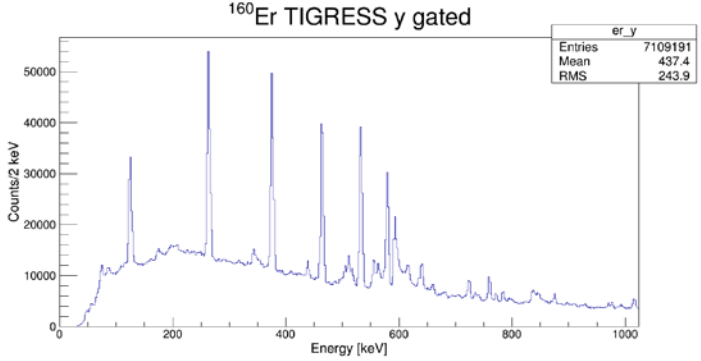
TIGRESS: large segmented HPGe detector array

SPICE: secondary electron spectrometer, fully integrated



- Coulex of 152Sm target at z = -7.5mm
- ICE emitted in-flight (Kinematic broadening)
- Recoils detected in S3 at z = +34.5mm

- 68 MeV 12 C beam,
- 4mg/cm2 152Sm,
- 13.5h 1.6*108 pps
- 4% of data
- 152Sm(12C,4n)160Er
- In beam resolution @300 keV is ~11keV



TRIUMF, Guelph, SFU, St Mary's, Colorado School of Mines & the TIGRESS Collaboration

Summary and conclusions

ISAC is currently running at full capacity, adjusted to ARIEL needs. ARIEL will come on-line in 2017. ISAC science highlights (nuclear physics, many preliminary)

- Gamma and beta spectroscopy at low energy
- Laser spectroscopy, and laser traps
- Nuclear astrophysics at post-accelerated beam (DRAGON and TUDA)
- Nuclear structure at ISAC II, with TUDA and TIGRESS

- TRIUMF is focusing in 2016 on beam delivery (mostly low energy and post accelerated beams, some for ISAC II). Driving ARIEL phases forward.
- New developments include:
  - new charge breeding EBIS (Max Planck Heidelberg)
  - Proton beam rotation on target for high power densities
  - Molecular beams,…
  - ARIEL target developments, HR separator

- TRIUMF is the North American ISOL facility and provides excellent science opportunities, including opportunities for collaboration, both for experiments and developments.

TRIUMF

Canada's national laboratory for particle and nuclear physics

Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

Thank you!
Merci!

Also my colleagues for material.

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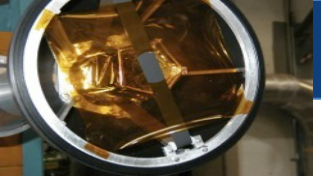
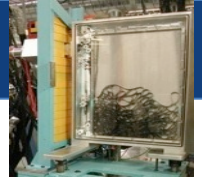
TRIUMF: Alberta | British Columbia | Calgary | Carleton | Guelph | McGill | Manitoba | McMaster | Montréal | Northern British Columbia | Queen's | Regina | Saint Mary's | Simon Fraser | Toronto | Victoria | Western | Winnipeg | York

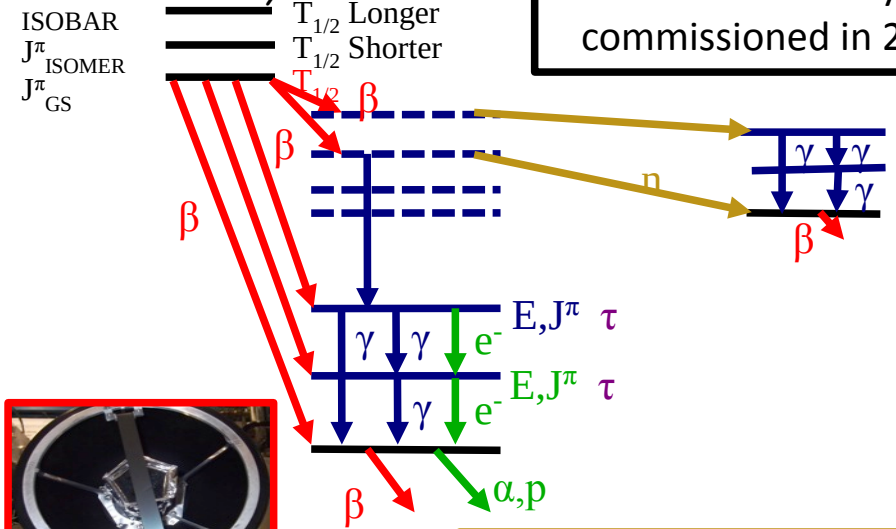
extra



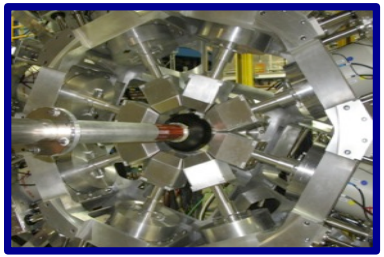


Fast, in-vacuum tape system

Enhances decay of interest



Initial operation in fall 2014. Fully commissioned in 2015

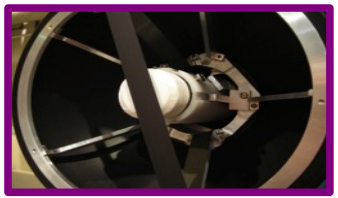


HPGe: 16 Clovers

Detect gamma rays and determines branching ratios, multipolarities and mixing ratios

$LaBr_3$: 8 $LaBr_3$

Fast-timing of photons to measure level lifetimes



Zero-Degree Fast scintillator

Fast-timing signal for betas

SCEPTAR: 10+10 plastic scintillators

Detects beta decays and determines branching ratios

DESCANT Neutron array

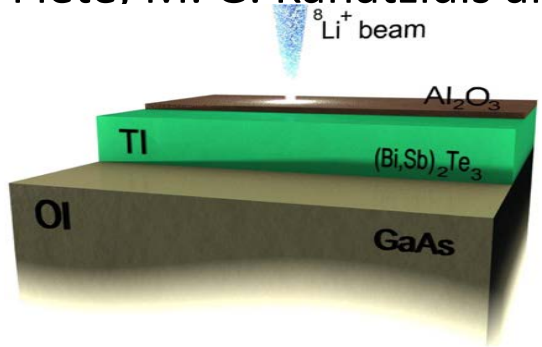
Detects neutrons to measure beta-delayed neutron branching ratios

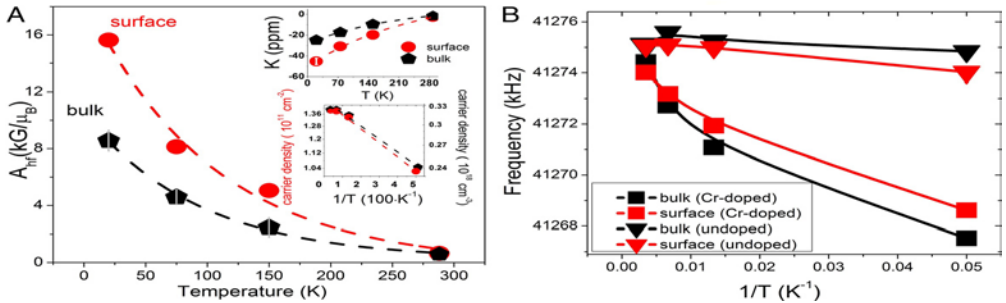
PACES: 5 Cooled Si(Li)s

Detects Internal Conversion Electrons and alphas/protons

Proceedings of the National Academy of Sciences, **112**, E3645 (2015)

D. Koumoulis, G. D. Morris, L. He, X. Kou, D. King, D. Wang, M. D. Hossain, K. L. Wang, G. A. Fiete. M. G. Kanatzidis and L. S. Bouchard





βNMR was used to directly visualize topological insulators (TIs) in a depth-resolved manner and report on their electronic and magnetic properties. There is a substantial change in the hyperfine coupling constant and the Knight shift between the surface and bulk of the TI.

ARIEL will allow ~ 15 weeks/a of operation of the β-NMR experiments

- 2015: controlled growth, add a few new groups, currently ~5 weeks/a, average ~60 -12h shifts per year, corresponds to ~ 95 shifts/ for of β-NMR and β-NQR at ISAC, eliminated user-fees
- 2016: manage expectations, new β-NMR capabilities for liquid samples (Banting-fellow proposal to NSERC), attract possible new users & increase awareness of β-NMR features, battery workshop (ISOSIM)
- 2017: evaluate increase of annual time at ISAC consummate with support and EEC recommendations, New-materials workshop at TRIUMF
- 2018: attracting new users, reach out to facilities in US, Asia and Europe, TRIUMF summer school with hands-on training
- 2019: ARIEL β-NMR becomes available, total annual beam time ramps up to 15 weeks/a