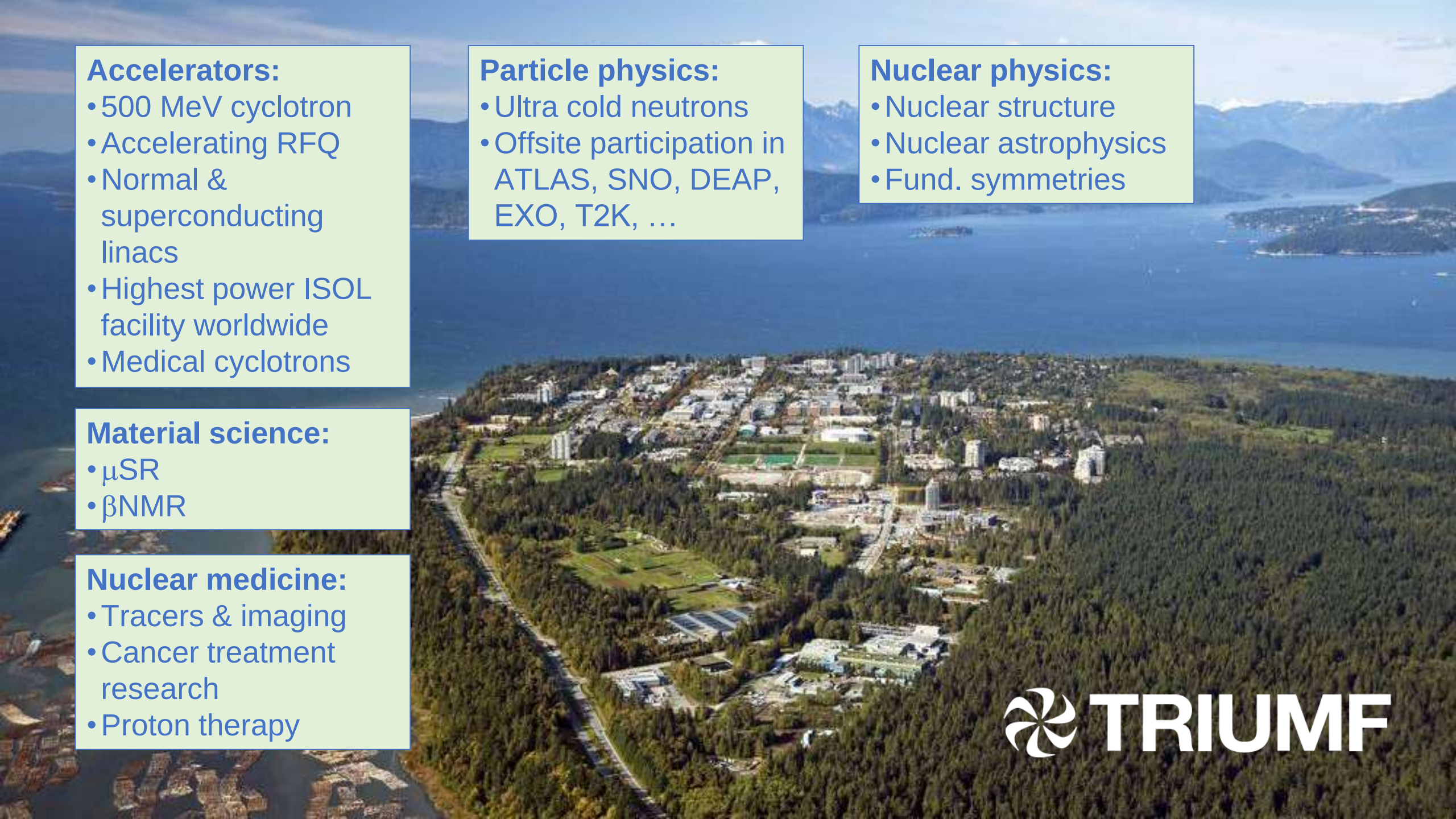
TRIUMF

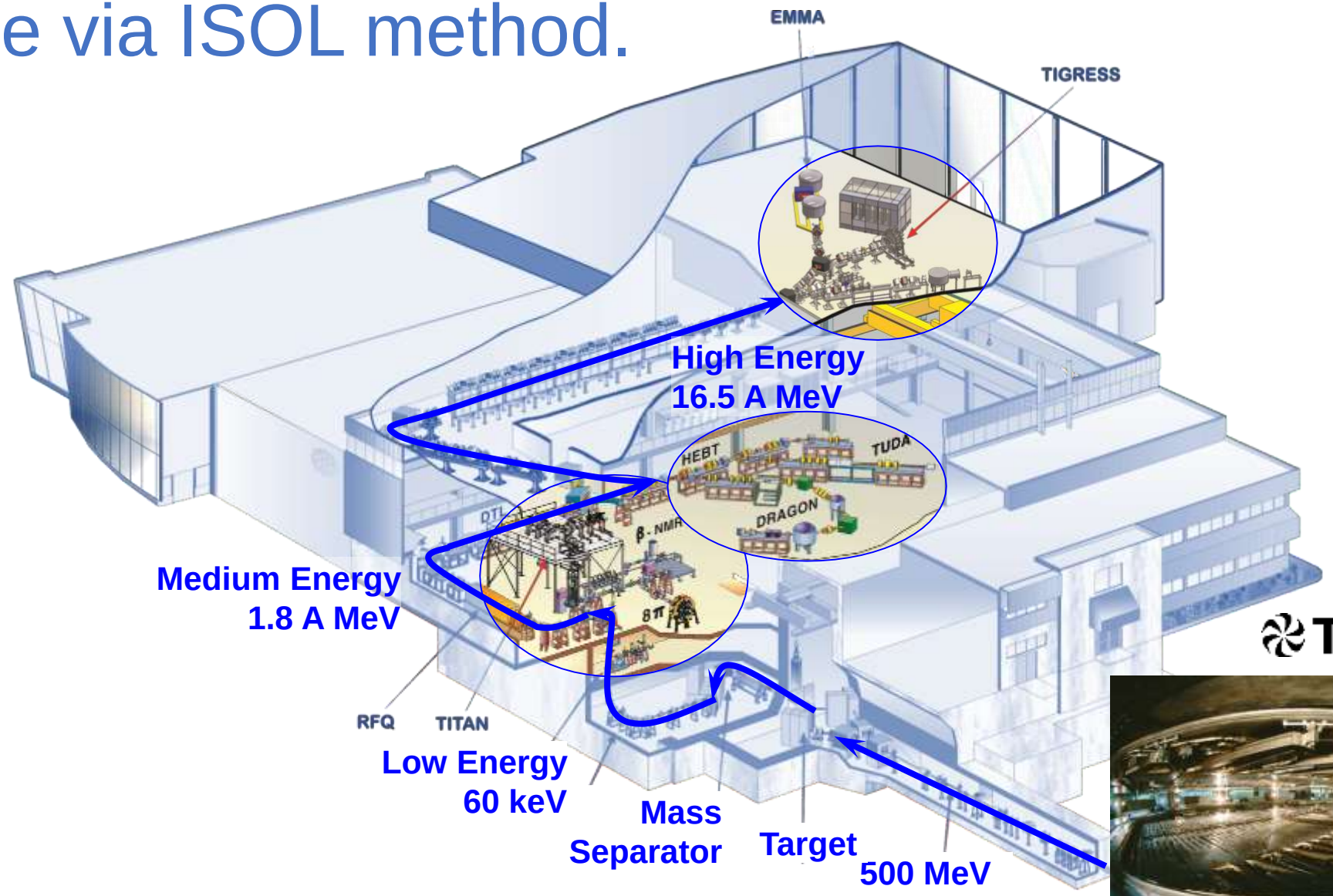
Recent Results from ISAC-TRIUMF

Ania Kwiatkowski
Research Scientist, TRIUMF
Adjunct Professor, U. Victoria

NuSTAR Collaboration Meeting
1 March 2019


Accelerators:
• 500 MeV cyclotron
• Accelerating RFQ
• Normal & superconducting linacs
• Highest power ISOL facility worldwide
• Medical cyclotrons
Particle physics:
• Ultra cold neutrons
• Offsite participation in ATLAS, SNO, DEAP, EXO, T2K, …
Nuclear physics:
• Nuclear structure
• Nuclear astrophysics
• Fund. symmetries
Material science:
• μSR
• βNMR
Nuclear medicine:
• Tracers & imaging
• Cancer treatment research
• Proton therapy
TRIUMF

Radioactive beam is made via ISOL method.



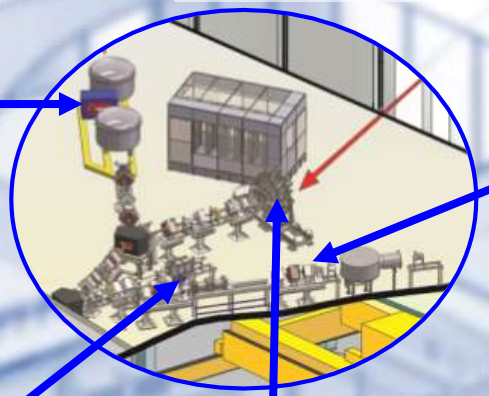
TRIUMF

Nuclear Astrophysics
Fundamental Interactions
Nuclear Structure & Dynamics

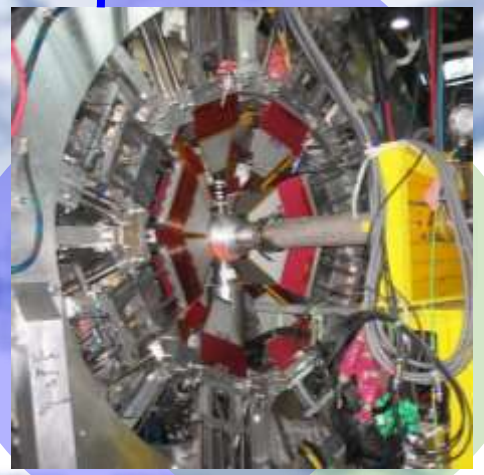
High-energy RIB
10-17 A MeV

EMMA
Mass analyzer
for reactions

TUDA
Scattering array
Direct reactions



IRIS
Solid hydrogen target
Transfer reactions



TIGRESS
In-flight γ-ray spectroscopy
+ ancillary det./tech.

BAMBINO
DESCANT
DSL
SHARC
SPICE
TIP

Nuclear Astrophysics
Fundamental Interactions
Nuclear Structure & Dynamics

Medium-energy RIB for astro, 0.15-1.8 A MeV

DRAGON
Gas target
Recoil spectrometer

TUDA
Charged-particle
reactions

UNIVERSITY OF SURREY
UNIVERSITY of York
THE UNIVERSITY of EDINBURGH
COLORADO SCHOOL OF MINES
McMaster University
UNBC UNIVERSITY OF NORTHERN BRITISH COLUMBIA

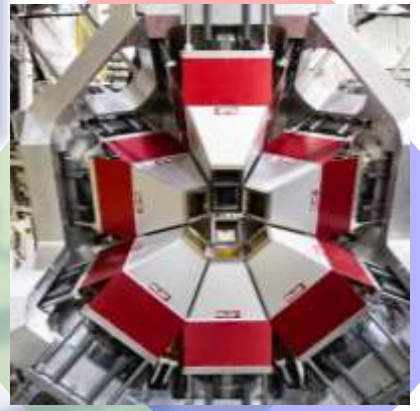
Low-energy RIB, ≤60 keV, for g.s. properties

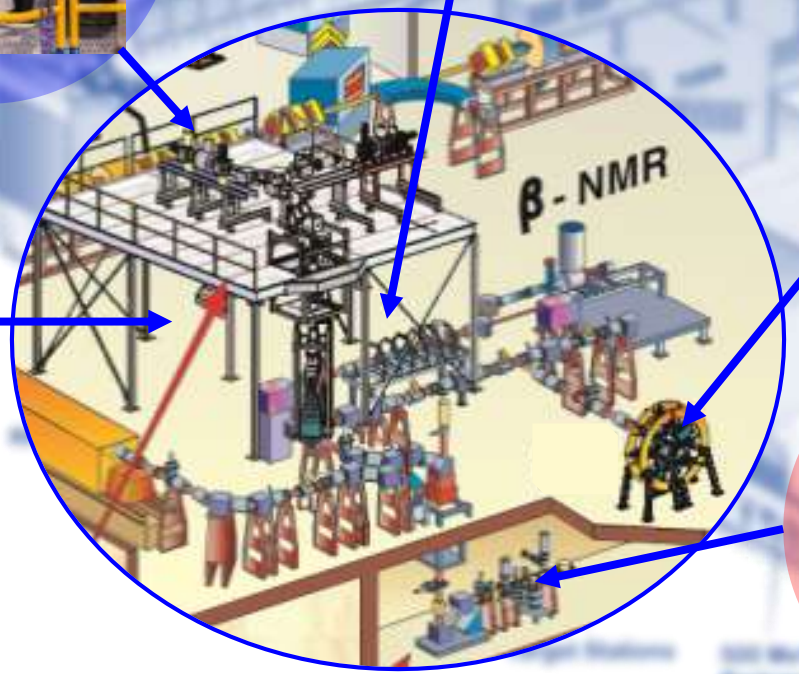
Nuclear Astrophysics
Fundamental Interactions
Nuclear Structure & Dynamics

Laser Spectroscopy
Isotopic shifts
Charge radii

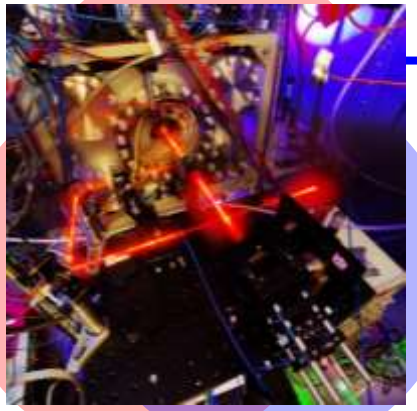
TITAN
Masses & Q-values
In-trap γ-ray spec.

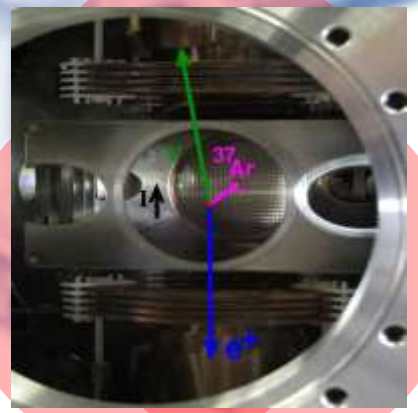
GRIFFIN
Decay spectroscopy
+ ancillary detectors





Francium
Isotopic shifts
PNC hunt





TRINAT
β-ν correlations

DESCANT
GPS

Research Highlights

Nuclear Astrophysics
Nuclear Structure & Dynamics
Fundamental Interactions

- Most precise $T_{1/2}$ of a superallowed β emitter, ^{10}C, γ-ray spec, PRL 2017
- Nuclear force revealed through inelastic proton scattering, IRIS + theory, PRL 2017
- Best relative β-asymmetry measurement, TRINAT, PRL 2018
- 1st direct $^{38}K(p,\gamma)$ refines novae nucleosynthesis, DRAGON, PRL 2018
- Benchmark nuclear models with masses at N=32, TITAN + theory, PRL 2018
- 1st heavy-mass transfer reaction @ ISAC on shape co-existence, TIGRESS, PLB 2018
- Precision tests of *ab initio* theory through CoulEx, TIGRESS, PLB 2018
- New resonance in ^{20}Mg, IRIS + theory, PRC 2019

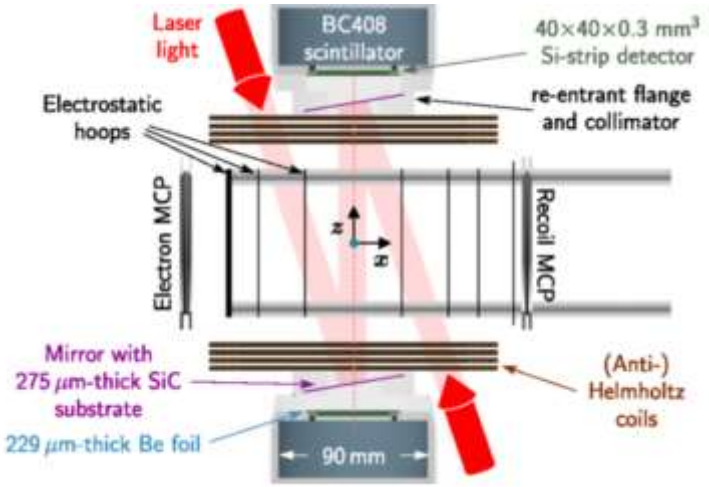
Image: https://stfc.ukri.org/stfc/includes/themes/MuraSTFC/assets/legacy/2009%20npap%20report.pdf

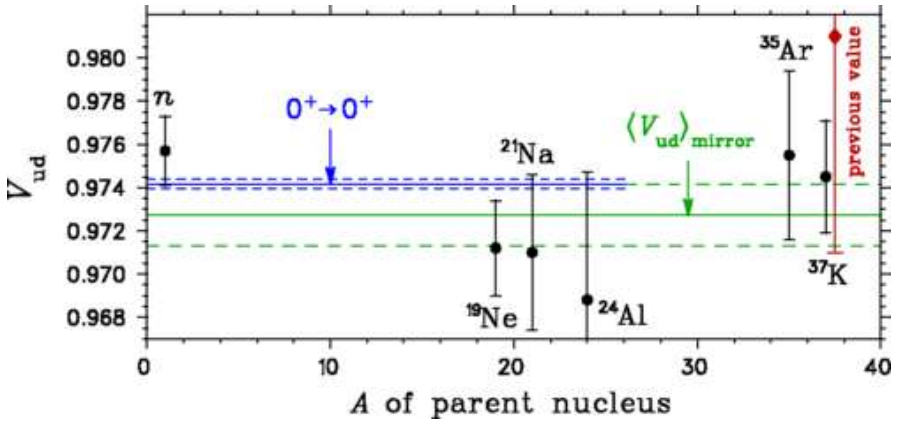
TRINAT performs best relative β-asymmetry measurement in a nucleus or the neutron.

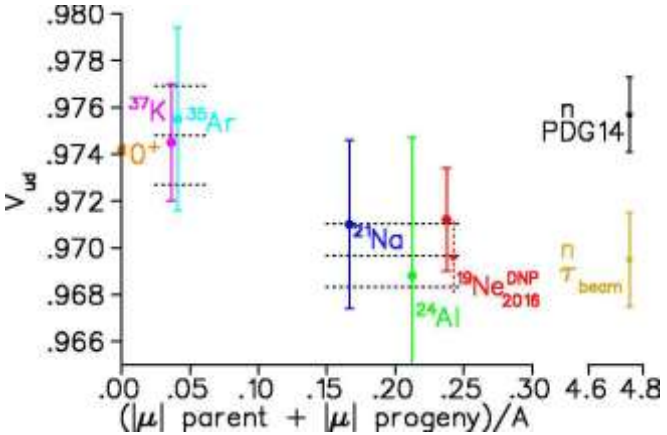
Precision Measurement of the β Asymmetry in Spin-Polarized ^{37}K Decay

B. Fenker, A. Gorelov, D. Melconian, J. A. Behr, M. Anholm, D. Ashery, R. S. Behling, I. Cohen, I. Craiciu, G. Gwinner, J. McNeil, M. Mehlman, K. Olchanski, P. D. Shidling, S. Smale, and C. L. Warner
Phys. Rev. Lett. **120**, 062502 – Published 8 February 2018

- Improves CVC for I > ½ and value of V_{ud} by a factor of 4
- V_{ud} as a function nuclear magnetism
- Places limits on the mass of hypothetical W_R coupling to right-handed ν's





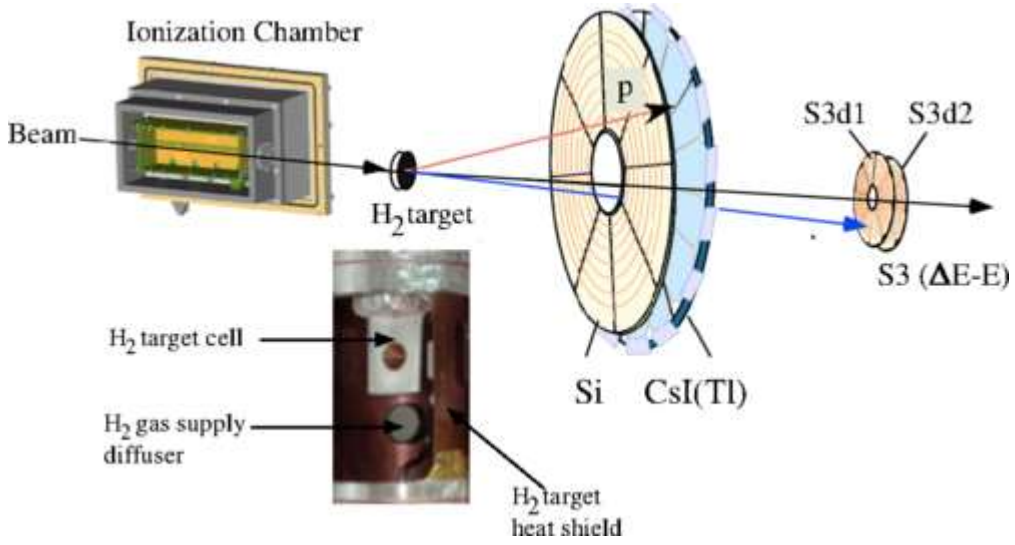


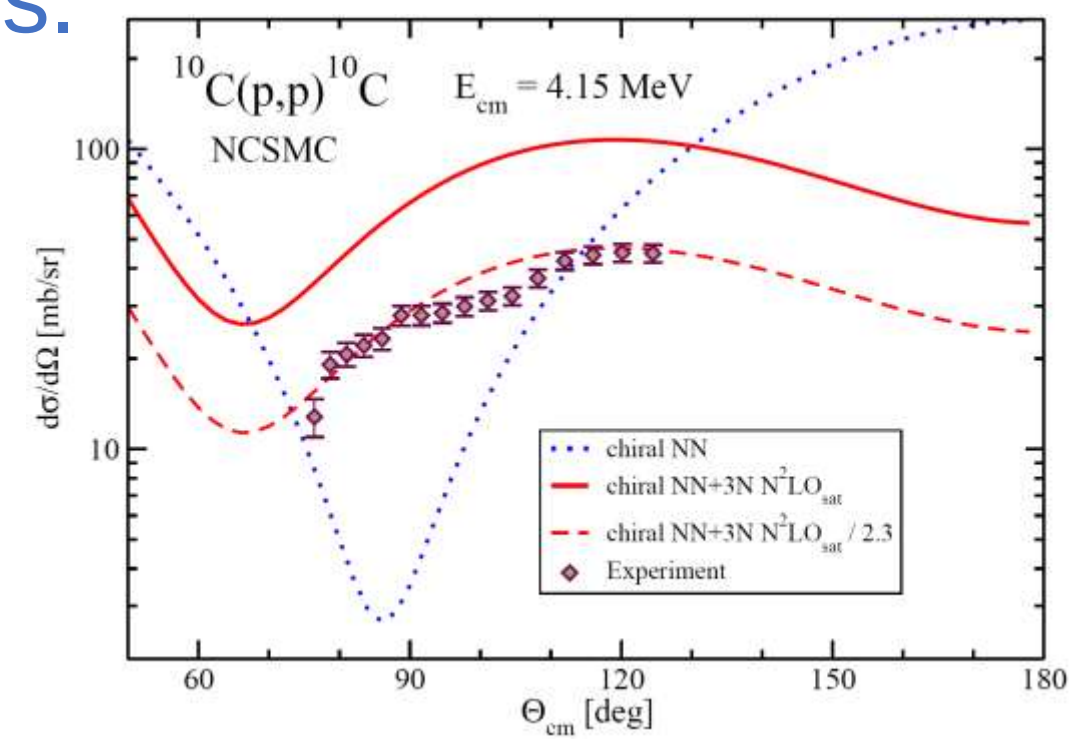
^{10}C(p,p) scattering at IRIS reveals the magnitude of 3N forces.

Selected for a Viewpoint in *Physics*
PRL 118, 262502 (2017) PHYSICAL REVIEW LETTERS week ending 30 JUNE 2017

Nuclear Force Imprints Revealed on the Elastic Scattering of Protons with ^{10}C

A. Kumar,[1] R. Kanungo,[1*] A. Calci,[2] P. Navrátil,[2†] A. Sanetullaev,[1,2] M. Alcorta,[2] V. Bildstein,[3] G. Christian,[2] B. Davids,[2] J. Dohet-Eraly,[2,4] J. Fallis,[2] A. T. Gallant,[2] G. Hackman,[2] B. Hadinia,[3] G. Hupin,[5,6] S. Ishimoto,[7] R. Krücken,[2,8] A. T. Laffoley,[3] J. Lighthall,[2] D. Miller,[2] S. Quaglioni,[9] J. S. Randhawa,[1] E. T. Rand,[3] A. Rojas,[2] R. Roth,[10] A. Shotter,[11] J. Tanaka,[12] I. Tanihata,[12,13] and C. Unsworth[2]





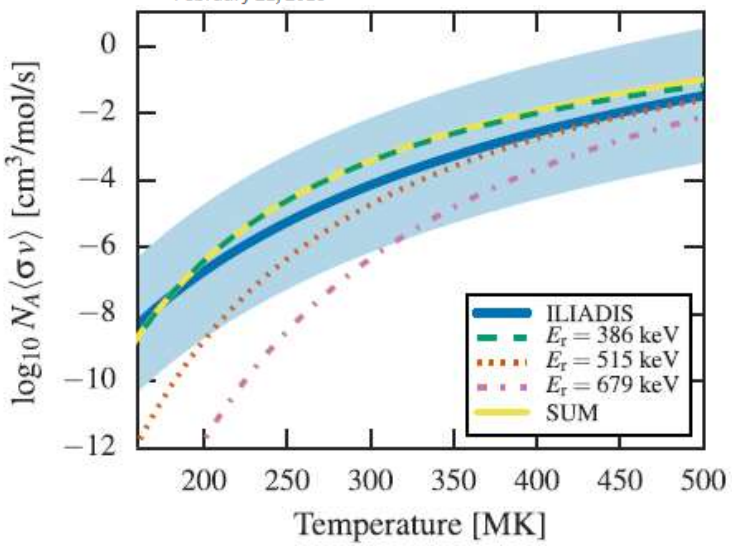
- Spectroscopic properties like phase shifts and interference good probes of nuclear force
- 3-body forces achieve qualitative agreement and correct order of magnitude.

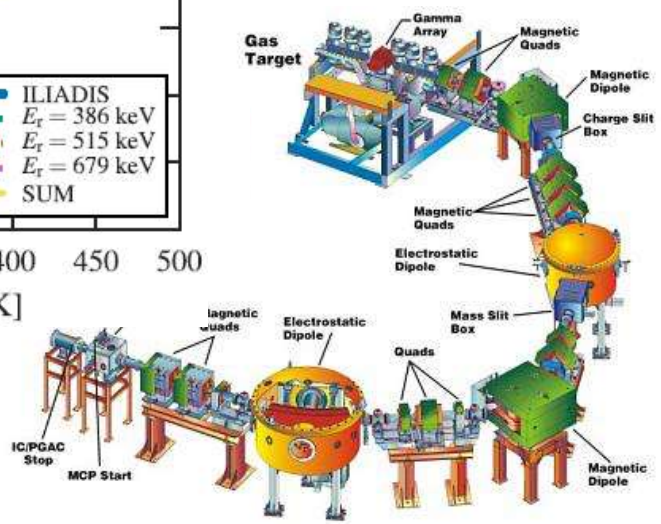
First direct $^{38}K(p,\gamma)$ reaction measurement confronts astronomical abundance observations from novae.

Physics ABOUT BROWSE PRESS COLLECTIONS

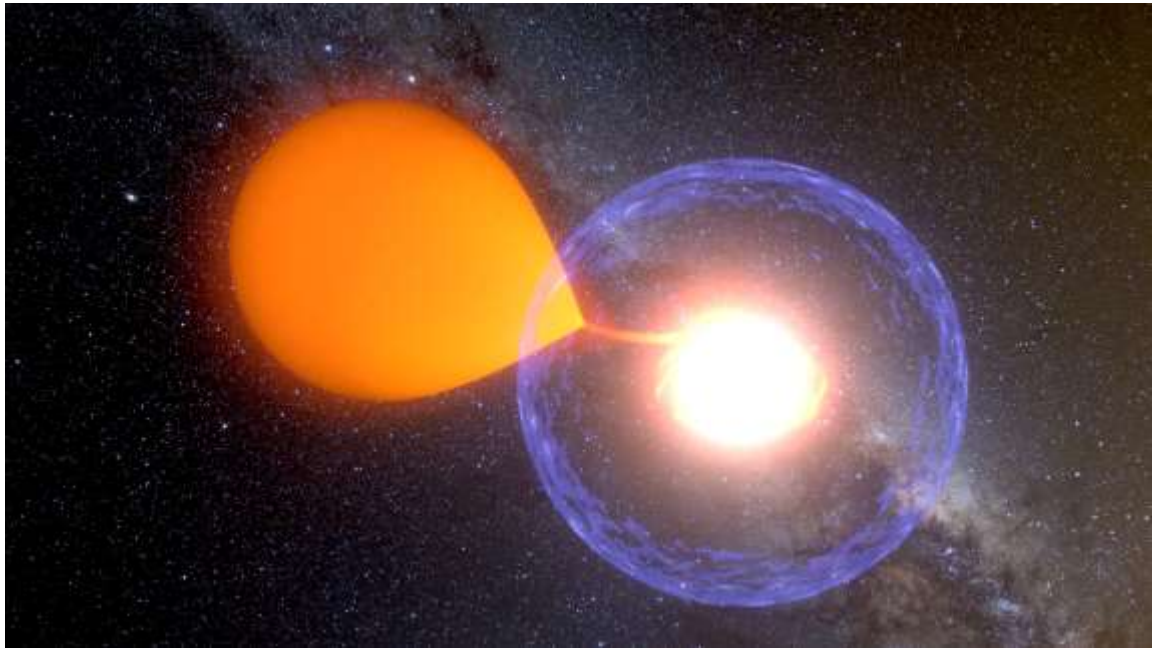
Synopsis: Intel on Stellar Element Production from Accelerator Data

February 21, 2018

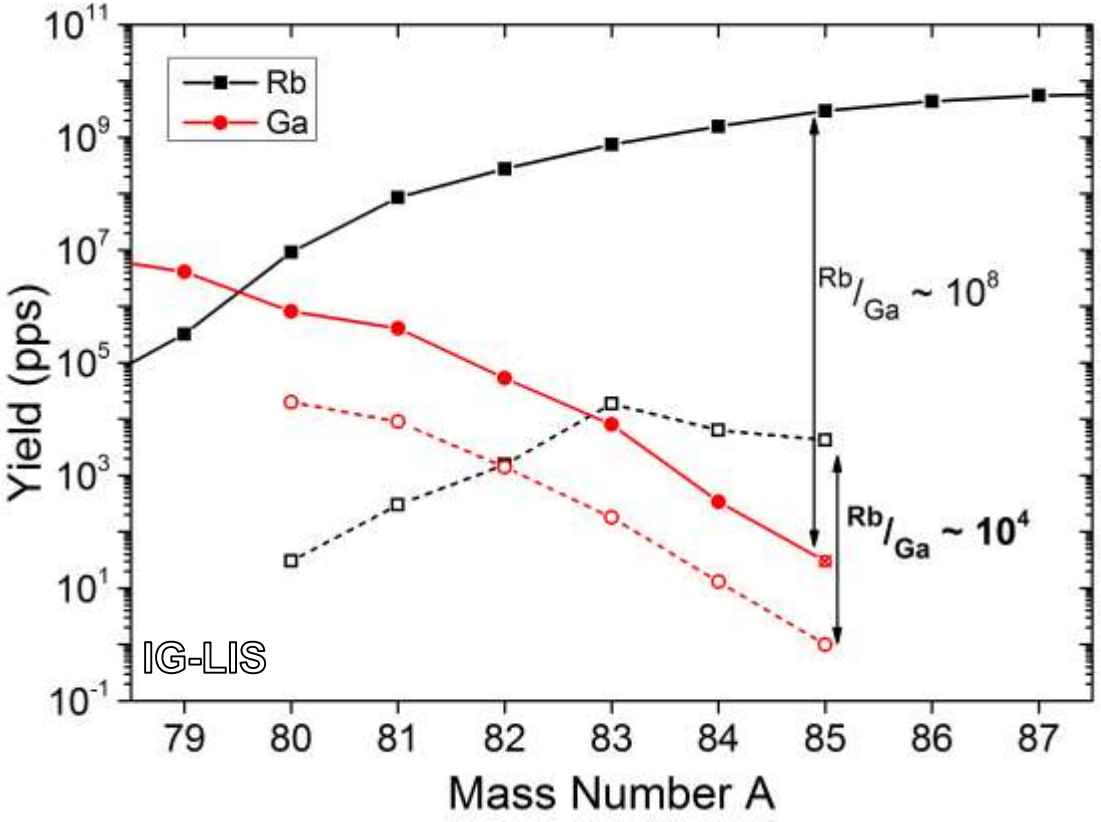




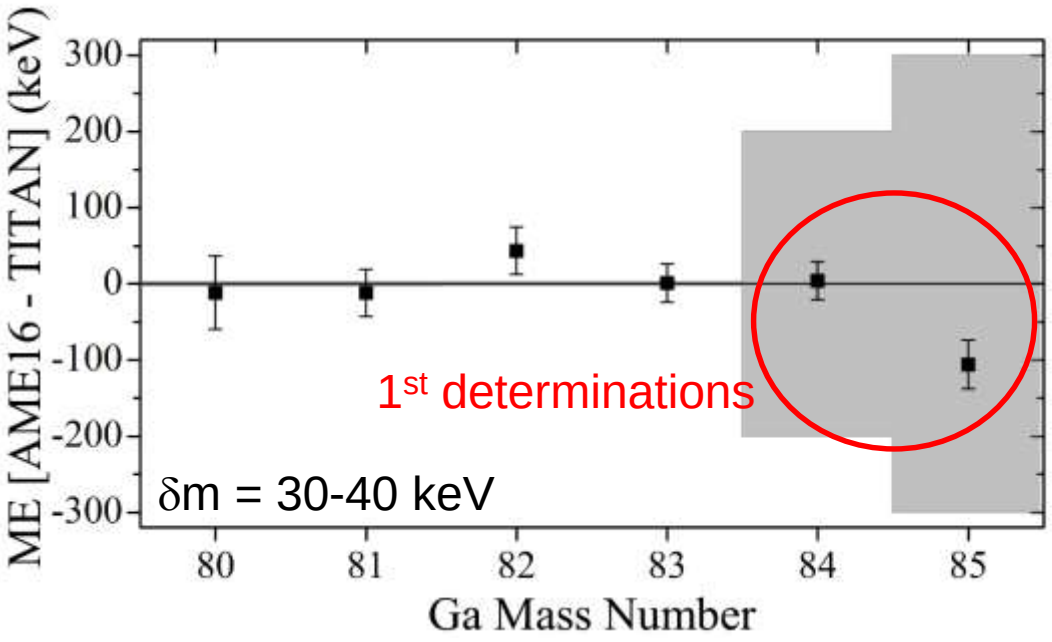
- Important for K, Ar, Ca abundances
- Reduced astrophysical uncertainties from factor 10 000 to ~40
- Technical achievement: highest mass RIB radiative capture measurement



TITAN's MR-TOF is well suited for r-process studies, such as n-rich Ga isotopes.

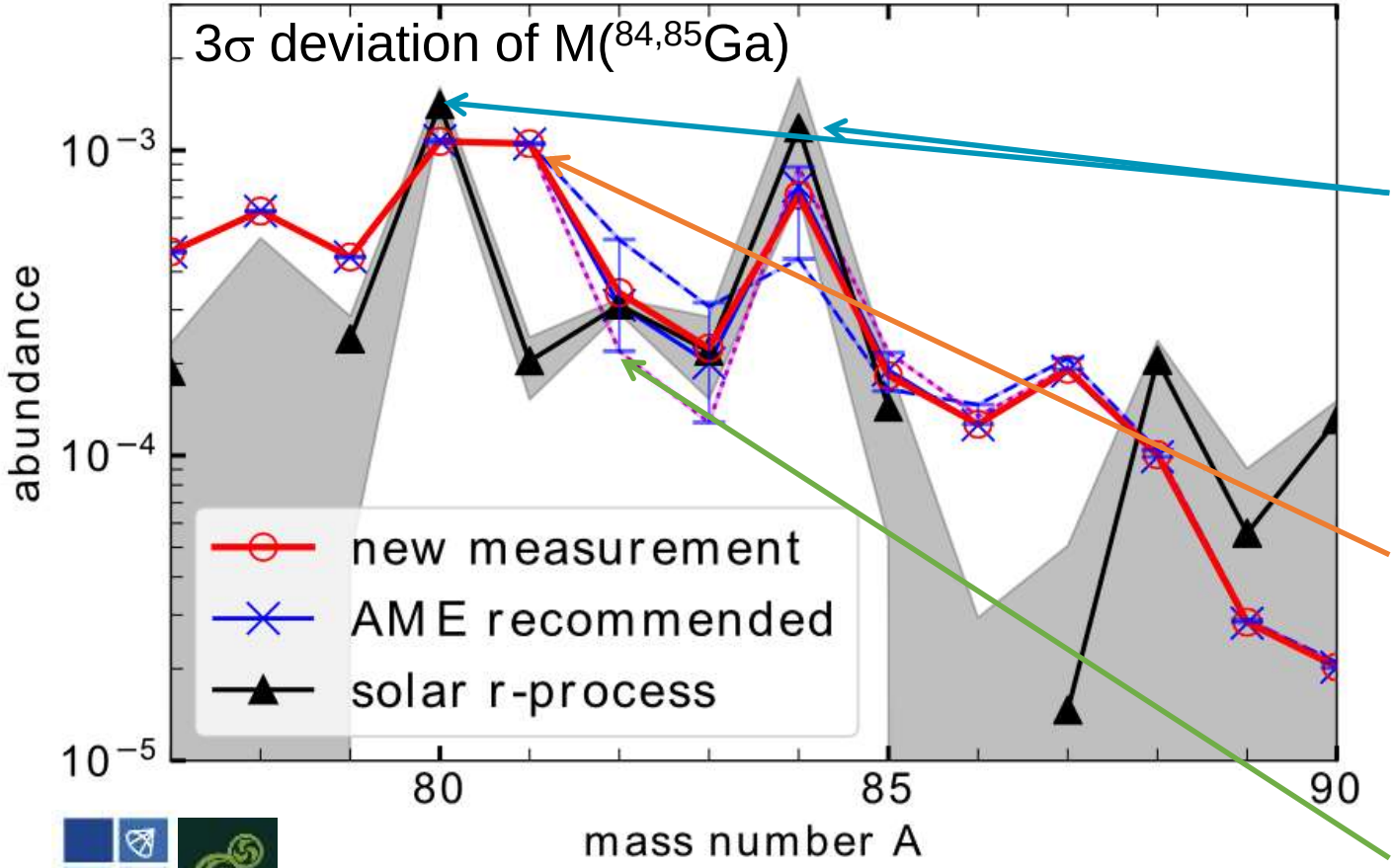


Used in combination with ISAC's IG-LIS ion source, which reduces rates of all surface-ionized ions



M.P. Reiter *et al.*, submitted to PRL

Measurements of ^{84,85}Ga primarily affect calculated final abundances for A=82-85.



Expansion timescale: 7ms
Entropy: 10kB /baryon
Starting temperature: 6GK
Electron-per-baryon ratios: Y_e = 0.35-0.38

A=80,84 abundance maxima

- A=80 due to magic N=50
- ^{84}Kr is produced by βn decay ^{85}Ga at freeze out due to βn decay ^{84}Ga & late time n capture

over production at A=81

- uncertainties in βn decay of ^{82}Zn
- ^{83,84}Zn masses needed

^{82}Se produced only by r-process

- used as reference
- uncertainty significantly reduced

TITAN finishes several developments for improved mass-measurement capabilities.

MR-TOF:

- Integrated & commissioned → faster measurements, superior purification

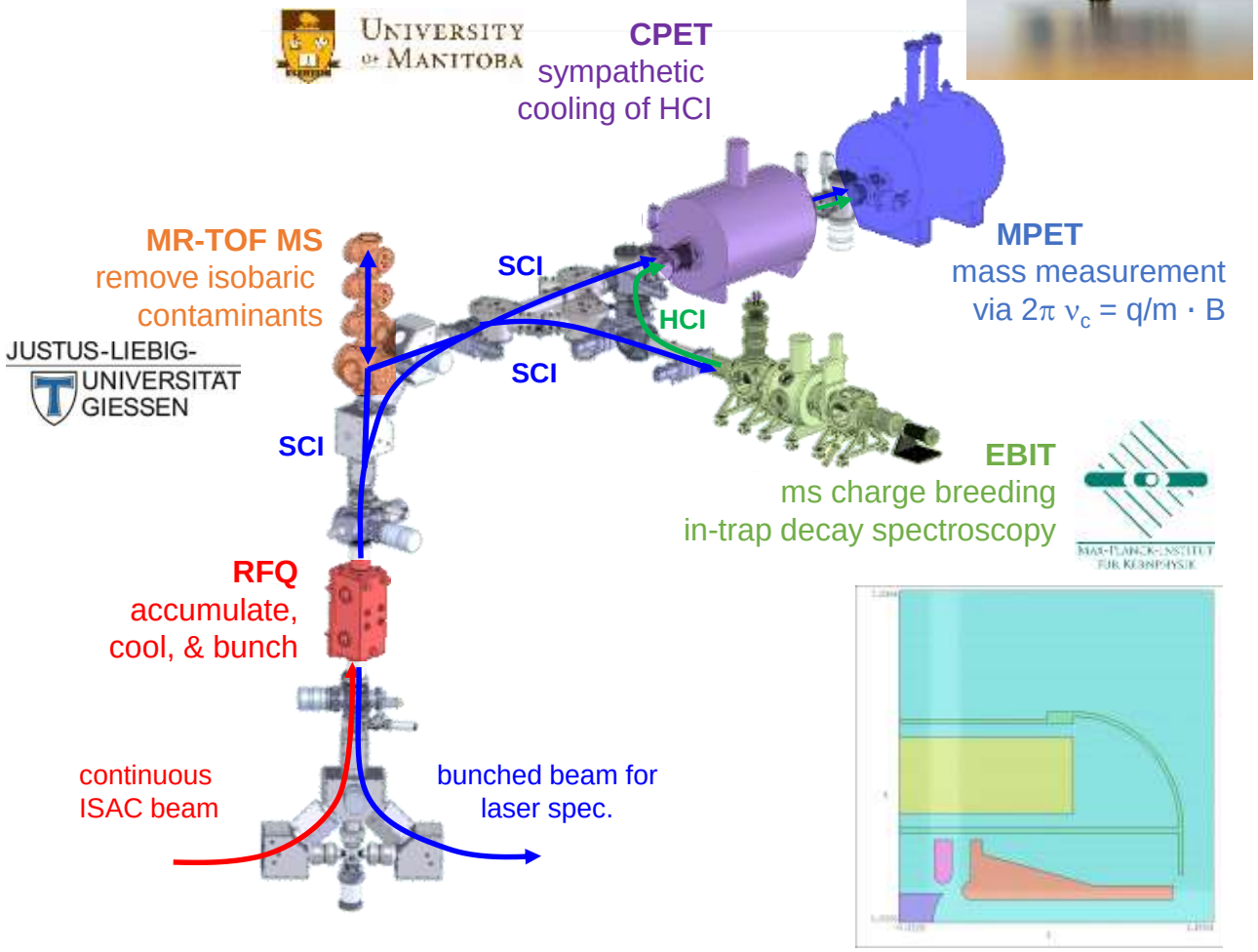
MPET

- PI-ICR underway → higher res. power & precision
- Cryogenic upgrade completed May 2019 → higher charge states & precision

$$\frac{\delta m}{m} \propto \frac{m}{q} \text{ for TOF-ICR}$$

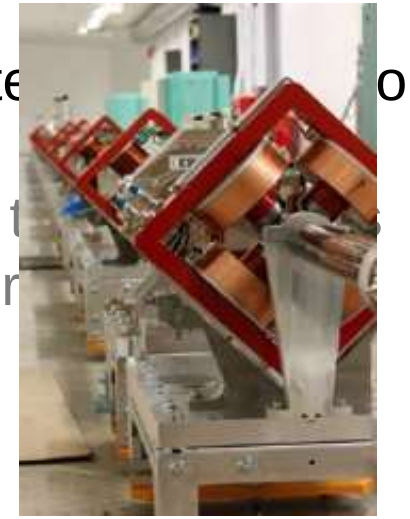
EBIT:

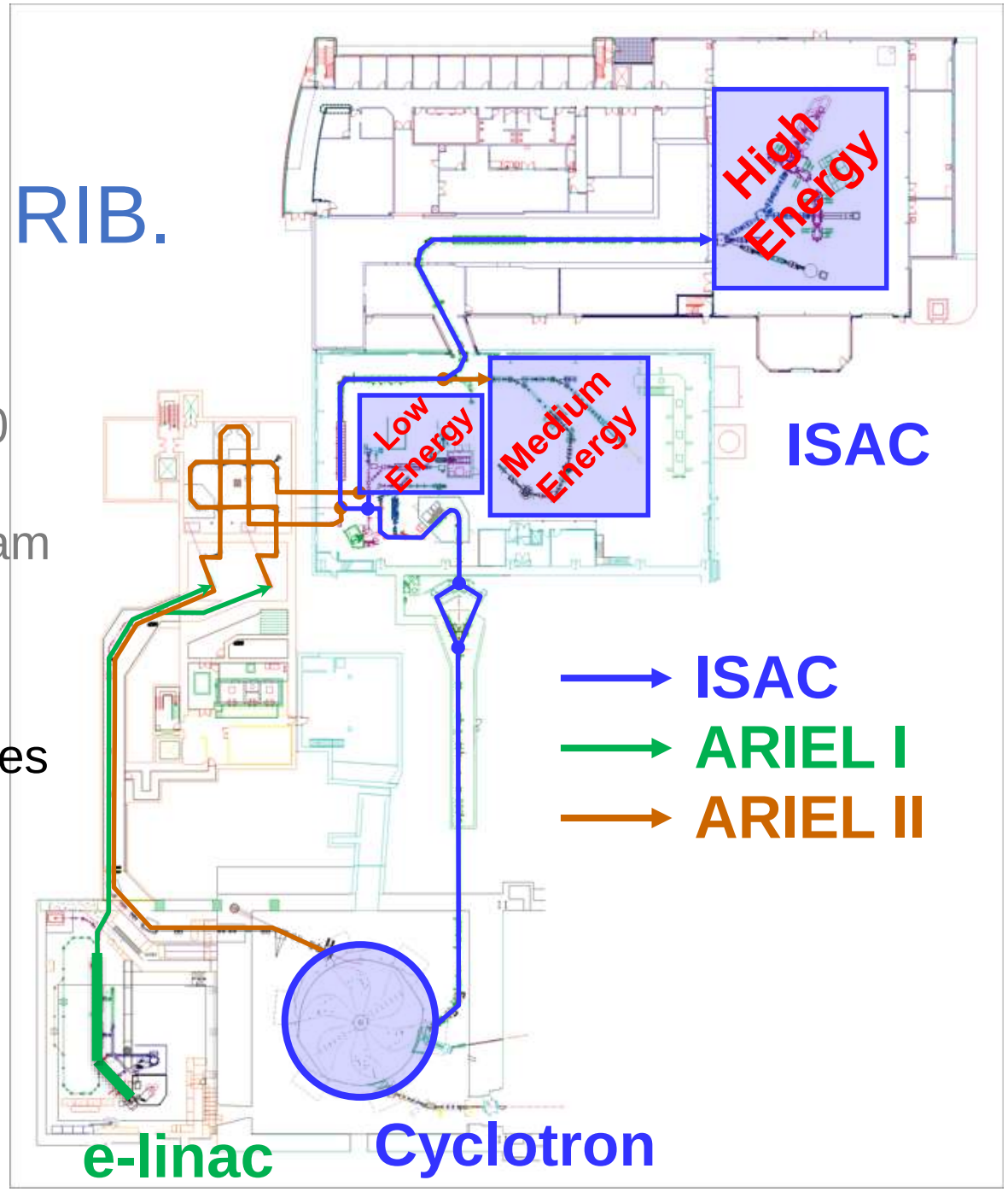
- HV upgraded for 65 keV e beams → higher charge states & precision
- New e gun



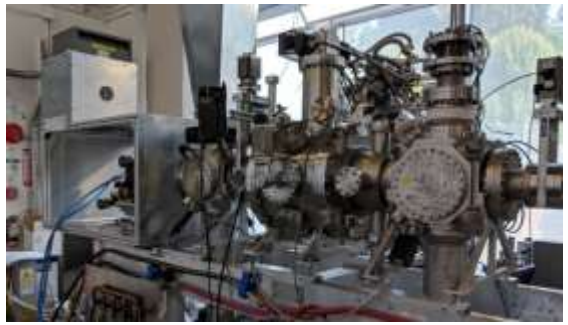
Advanced Rare IsotopE Laboratory (ARIEL) triples RIB.

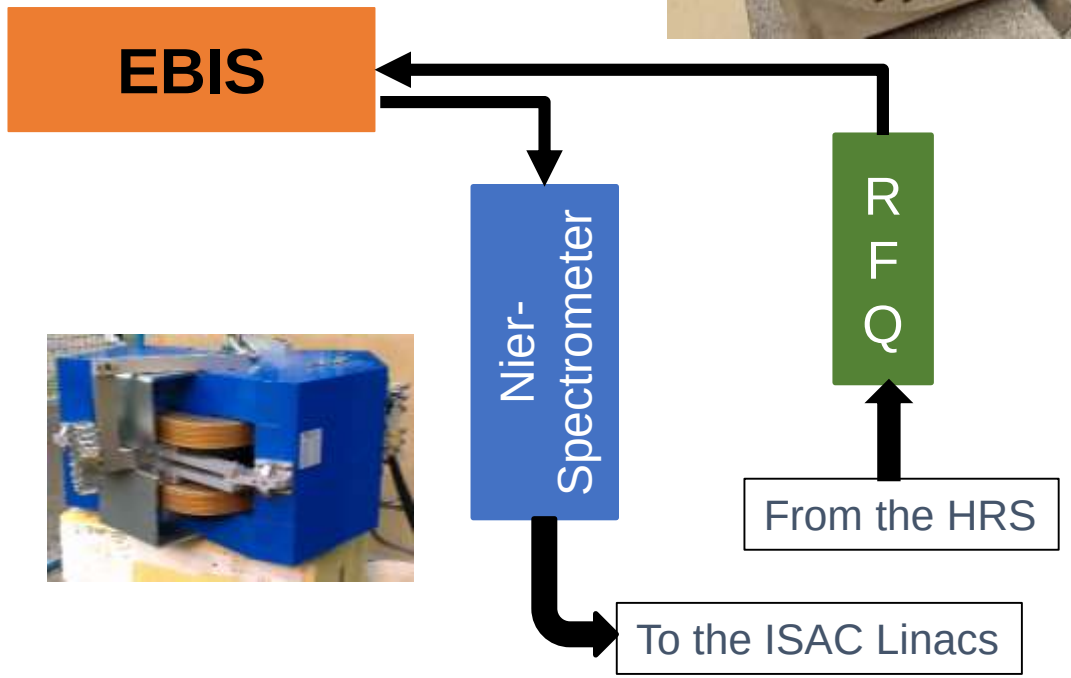
- AETE: ≤100 kW, 35 MeV, electrons
- APTW / ITE / ITW: ≤50 kW, 500 MeV, ≤100 μA protons
- 2 low energy beams + 1 higher-energy beam
- > 9000 hours of RIB per year





CANREB is the unique beam preparation system for high-quality ARIEL beams.





CANadian Rare Isotope facility with Electron Beam ion source

- High Resolution mass Separator (HRS) M/ΔM = 20,000 for RIB beams
- Gas-filled Radio Frequency Quadrupole (RFQ) for cooling & bunching
- Electron beam ion source (EBIS) charge state breeder with shortest breeding time (10 ms) and highest rep rate (100 Hz)!
- Will enable the high mass acceleration with cleaner beam!

CANREB
Nier Spectrometer
Yield Station

ISAC-TRIUMF: nuclear structure,

- neutron halos
- evolution of nuclear shells
- collectivity
- shape coexistence

nuclear astrophysics,

- origin of elements
- connecting structure & solar abundances
- structure of neutron stars

& fundamental symmetries studies

- high-precision, low-energy probes
- complementary to high-energy physics scale

in preparation for the ARIEL.

- 3x RIB (2 ISOL, 1 induced fission)

Discovery,
accelerated