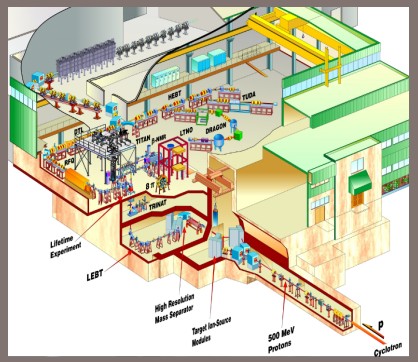
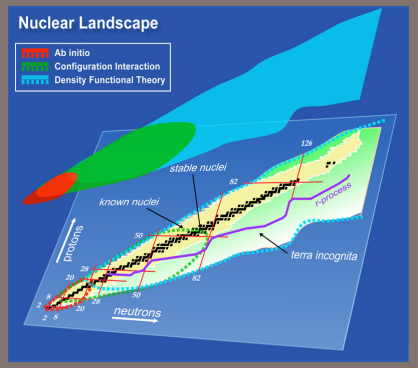
TRIUMF

Canada's National Laboratory for Particle and Nuclear Physics
Laboratoire national canadien pour la recherche en physique nucléaire
et en physique des particules

TRIUMF's rare isotope program





Aug. 17, 2012

Reiner Krücken | Science Division Head | TRIUMF
Professor of Physics | University of British Columbia

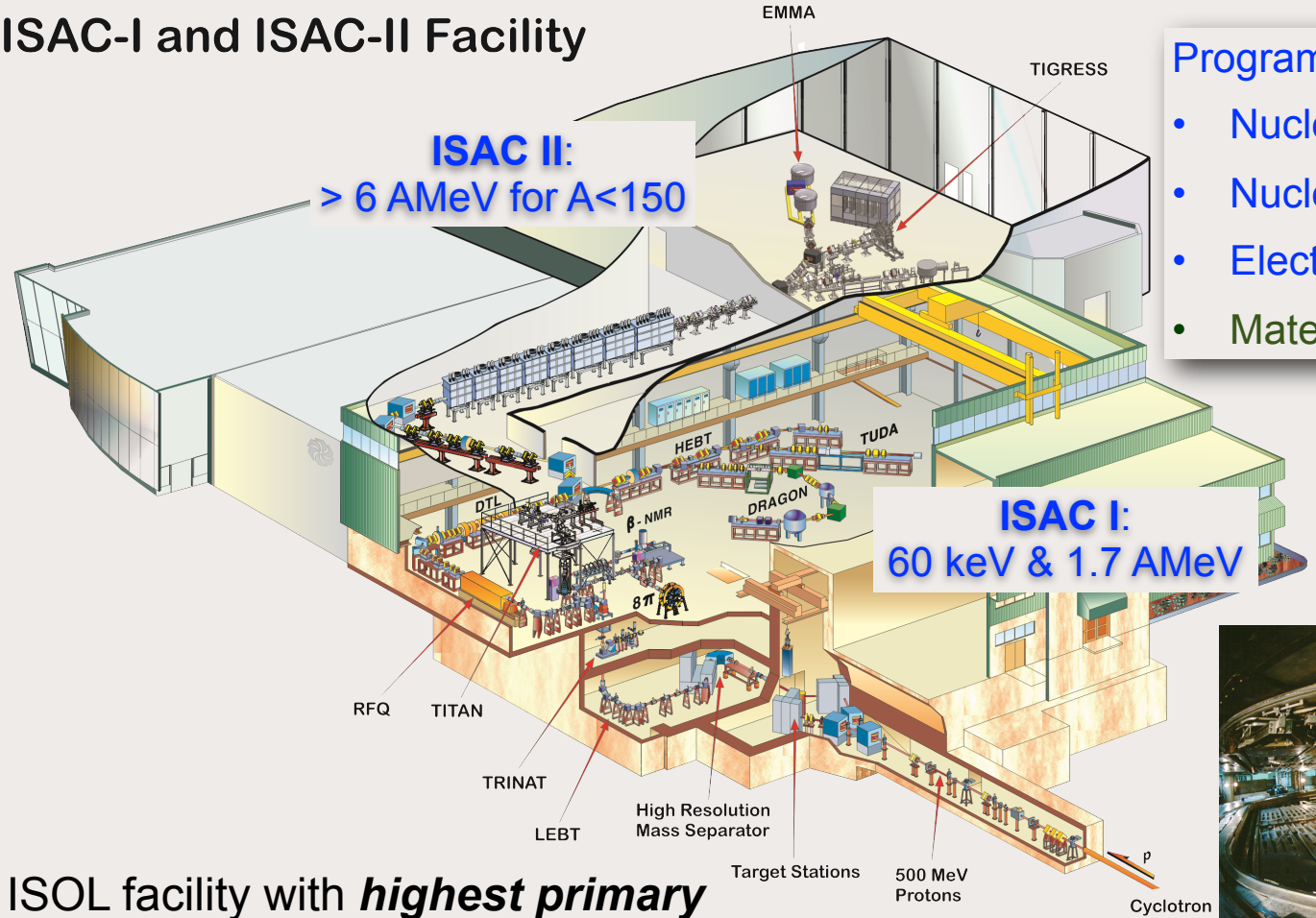
Probing the structure and origins of matter

Advancing isotopes for science and medicine

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

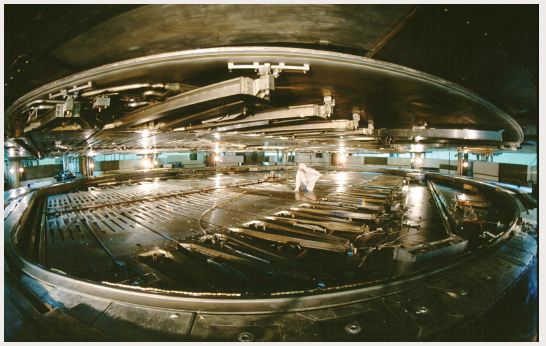
ISAC rare isotope facility

ISAC-I and ISAC-II Facility



Programs in

- Nuclear Structure & Dynamics
- Nuclear Astrophysics
- Electroweak Interaction Studies
- Material Science

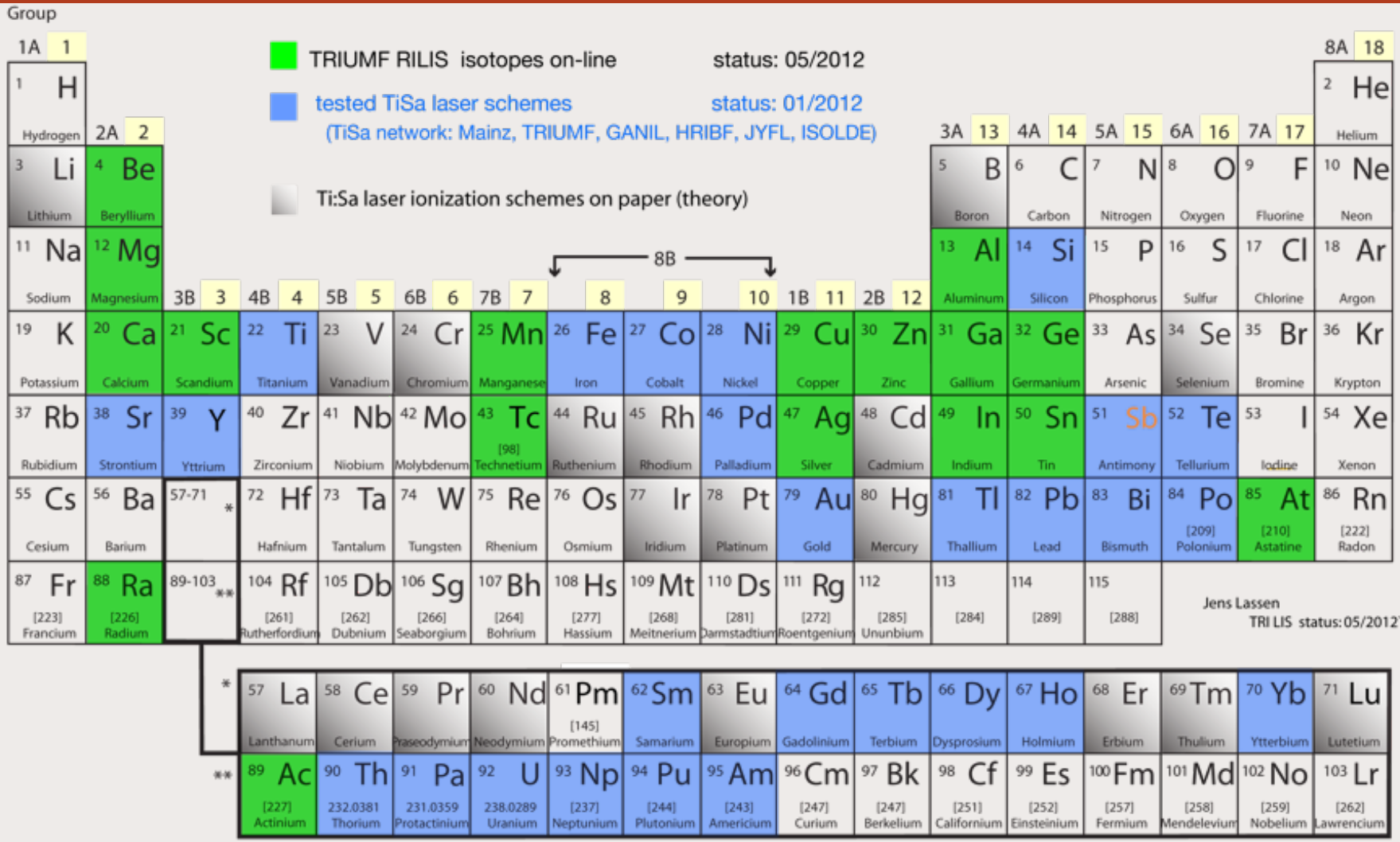


ISOL facility with ***highest primary beam intensity*** (100 μA, 500 MeV, p)

target materials: Si, Ti, Zr, Nb, Ta, U

TRIUMF

TRILIS beams

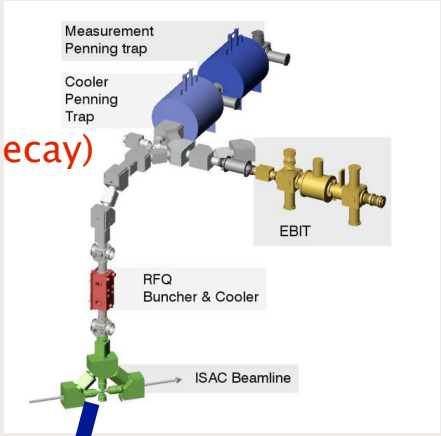


J. Lassen et al.

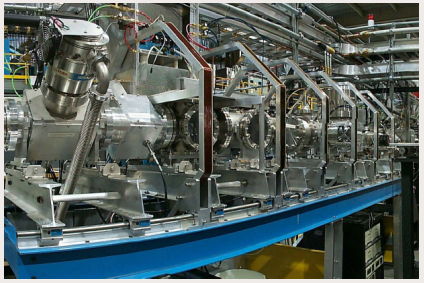
ISAC experimental areas

Low energy
< 60 keV

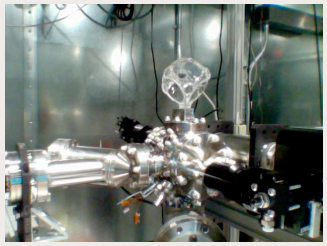
TITAN
Penning Traps
(masses, in-trap decay)

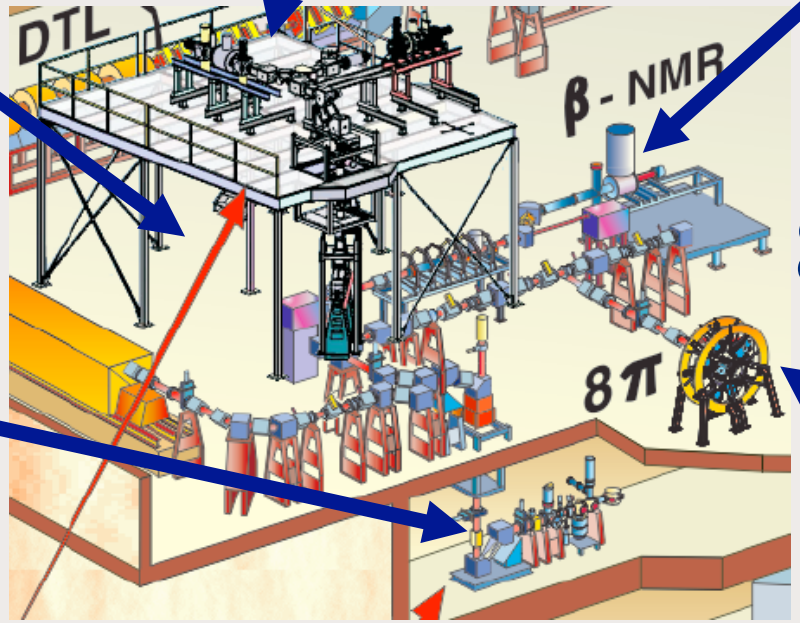


Polarizer beamline
Laser spectroscopy, MTV,
betaNMR (material science)

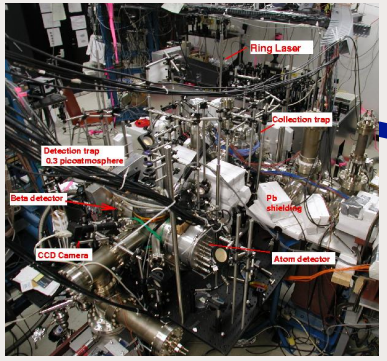


FRANCIUM MOT
(PNC, anapole moment)

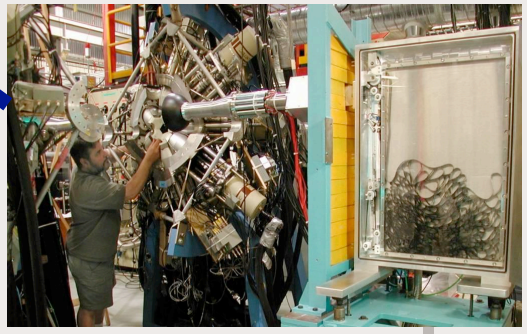




TRINAT
Neutral Atom Trap
(βν-neutrino correlations)



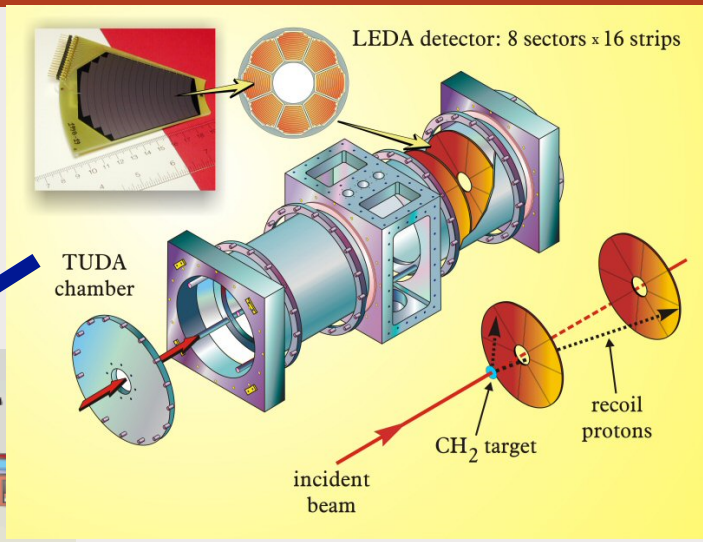
8π
Gamma & Electron
spectrometer
(decay spectroscopy
superallowed decays)

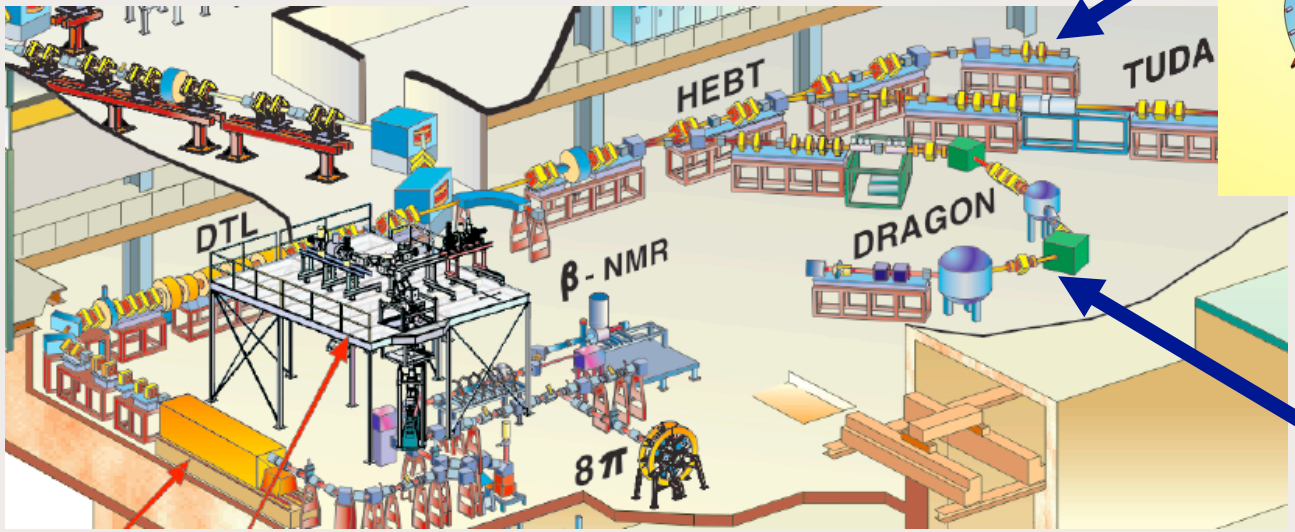


ISAC experimental areas

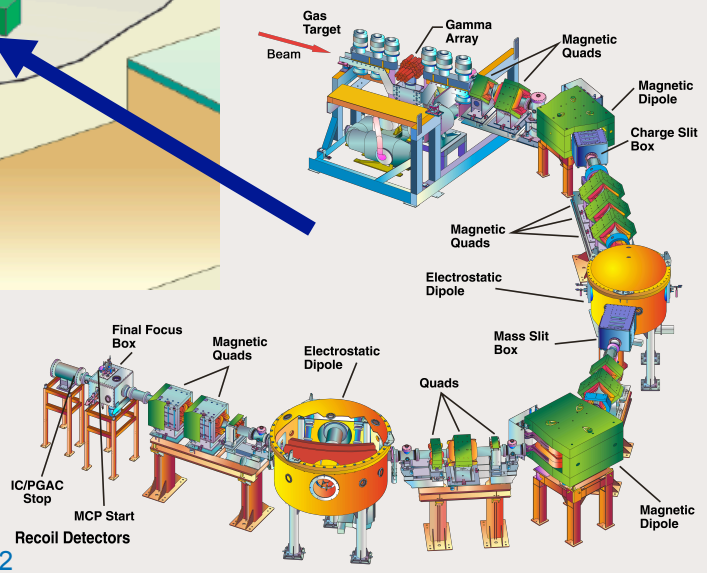
medium energy
~ 0.15 -1.7 AMeV

TUDA
Astrophysical charged particle reactions





DRAGON
Astrophysical capture reactions

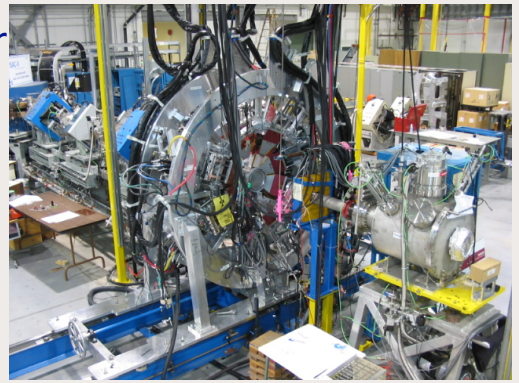


ISAC experimental areas

high energy
> 6 AMeV for A < 150

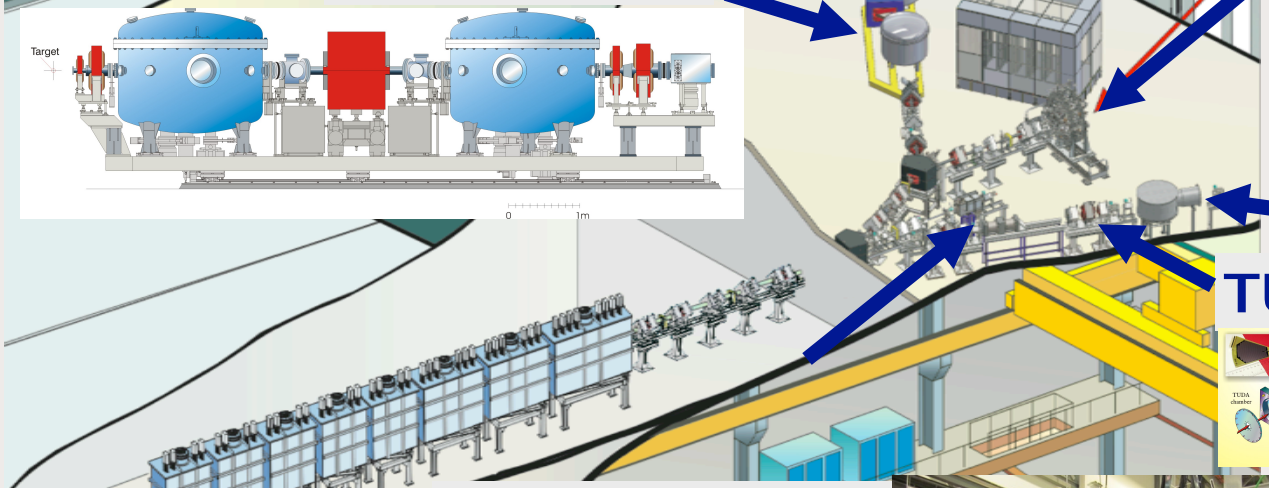
TIGRESS + auxiliary detectors

12 clover γ-ray spectrometer
in-beam spectroscopy
nuclear reactions

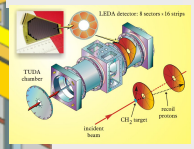


EMMA

Mass analyzer for
nuclear reactions

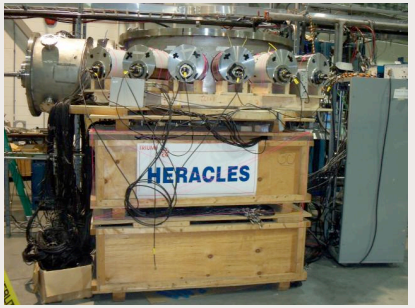


TUDA



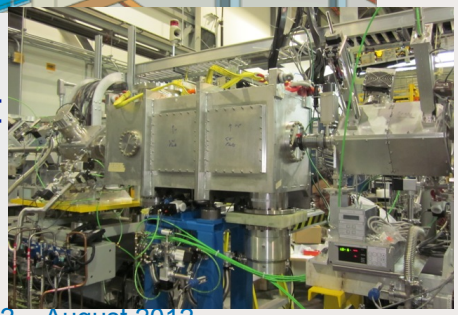
HERACLES

fragmentation of
light beams, EOS



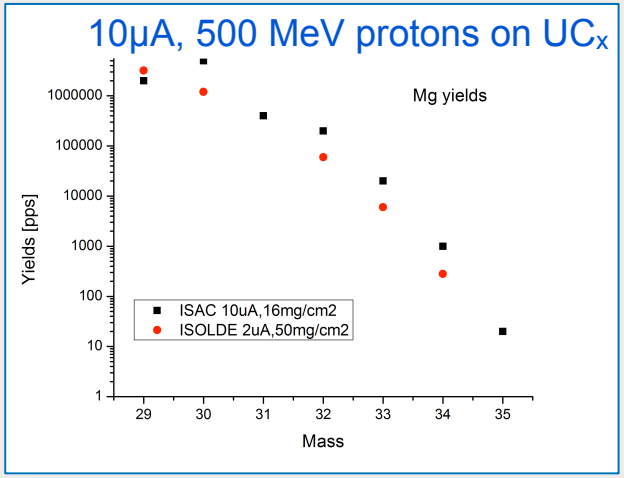
IRIS

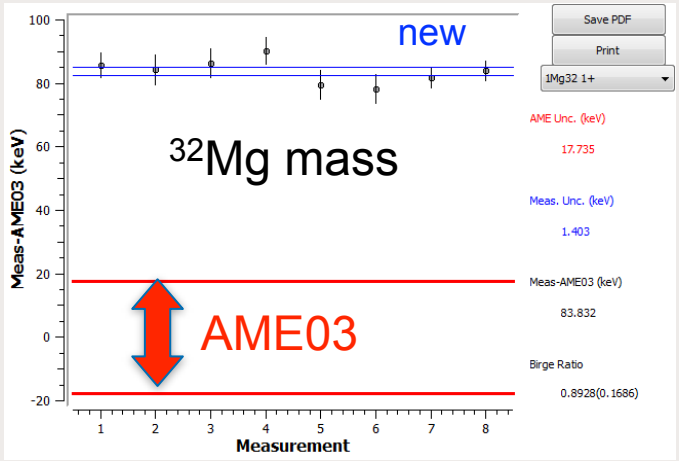
Solid hydrogen target
for direct nuclear
reactions

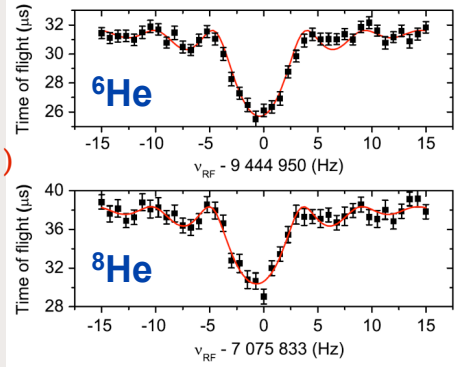


Nuclear Structure Highlights

- precision mass measurements at TITAN
  - masses of 2-neutron halo ^{6}He and 4-neutron halo ^{8}He (Brodeur, PRL2012)
  - masses of ^{9}Li, ^{9}Be: isobaric mass multiplet equation for A=9 (Brodeur, PRL2012)
  - mass cartography of the island of inversion: $^{30-34}$Mg, $^{29-31}$Na, ^{29,32}Al

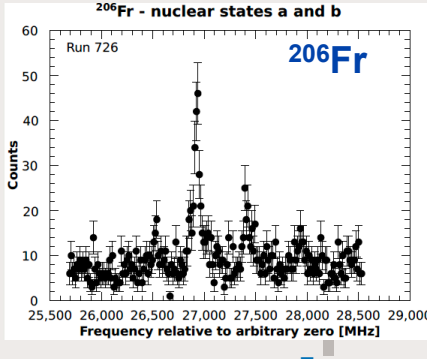






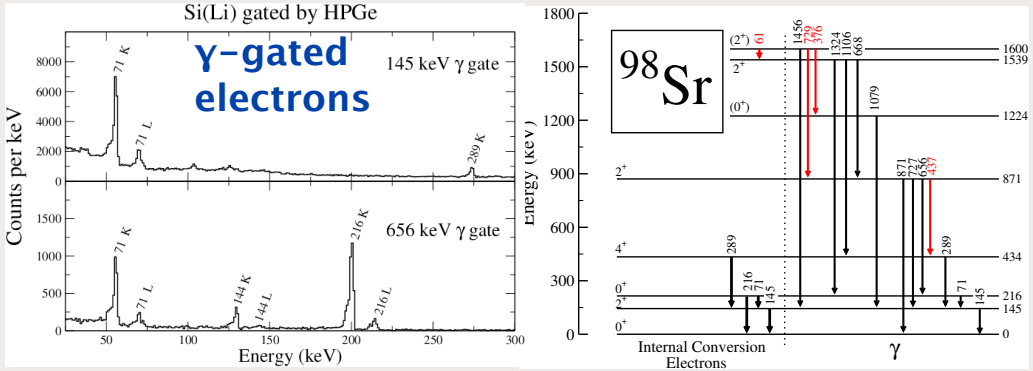
  - probing shell evolution and 3N-forces in neutron-rich Ca, K (talk by A. Gallant, PRL2012)
  - masses of neutron-rich Rb and Sr isotopes near the r-process (V. Simon, PRC2012)

- utilizing polarized beams
  - collinear laser spectroscopy of Rb, At, Fr: atomic structure, spins, charge radii
  - β-decay spectroscopy in ^{28,30}Mg using spin-polarized ^{28,30}Na (talk by A. Odahara, Kura et al., PRC2012)

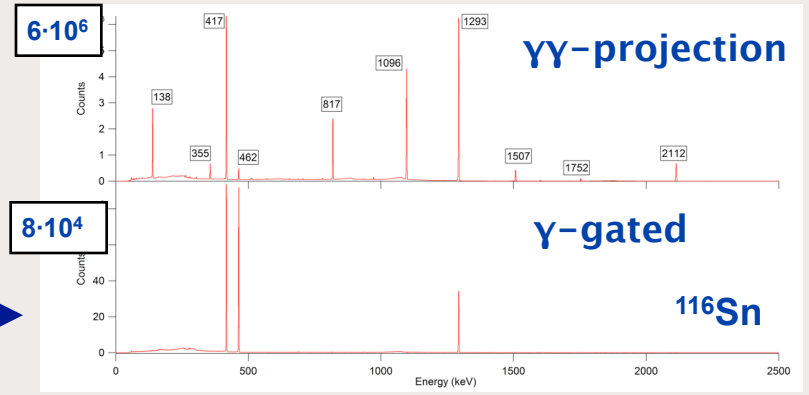


Nuclear Structure Highlights

- β-decay studies w/ 8π using γ-rays & conversion-electrons
  - shape evolution in ^{96,98,100,102}Sr (posters by P. Bender, Z. Wang)

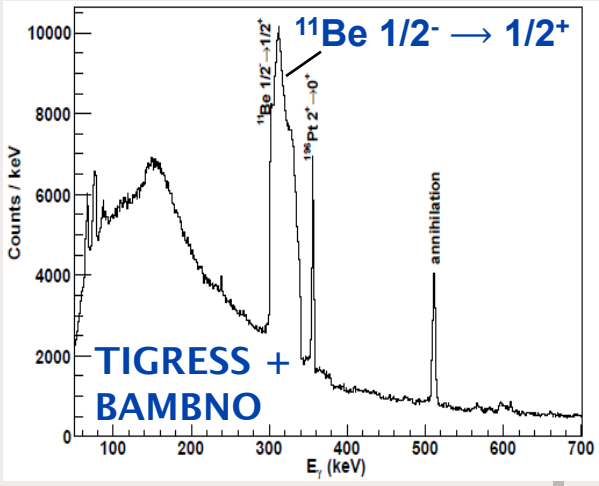


  - shape coexistence in ^{116}Sn (poster by D. Cross)

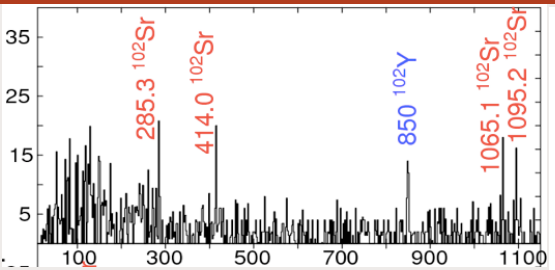


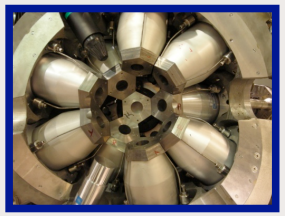
  - investigation of multiphonon states in ^{110}Cd (poster by A. Diaz Varela)

- in beam gamma-ray spectroscopy w/ TIGRESS
  - Coulomb excitation of ^{10}Be – testing ab-initio theory
  - inelastic excitation and breakup of halo nucleus ^{11}Be
    - ➜ E1 strength below and above the threshold (poster by E. Kwan)

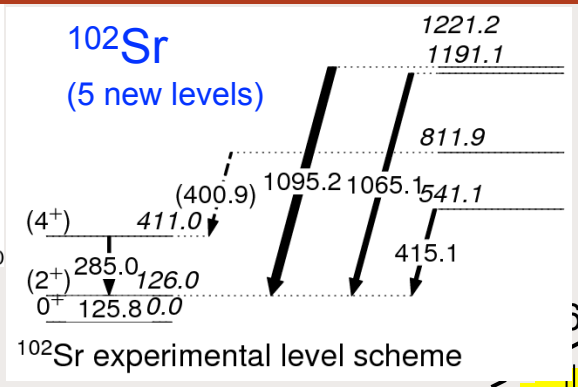


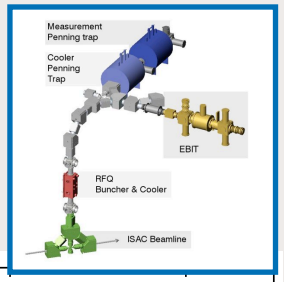
Towards the r-process path: 10 μA 500MeV protons on 16 mg/cm² UC_x

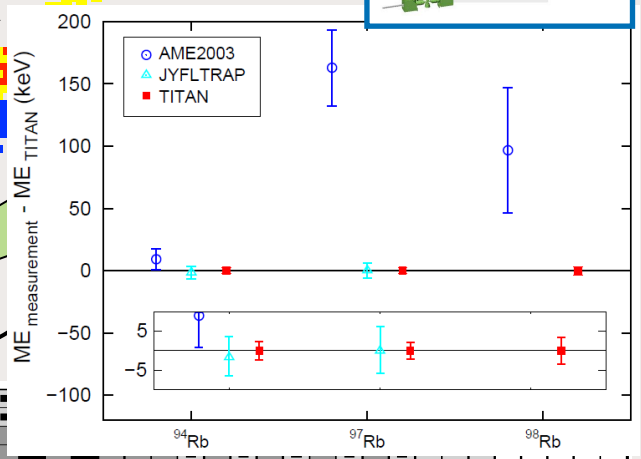


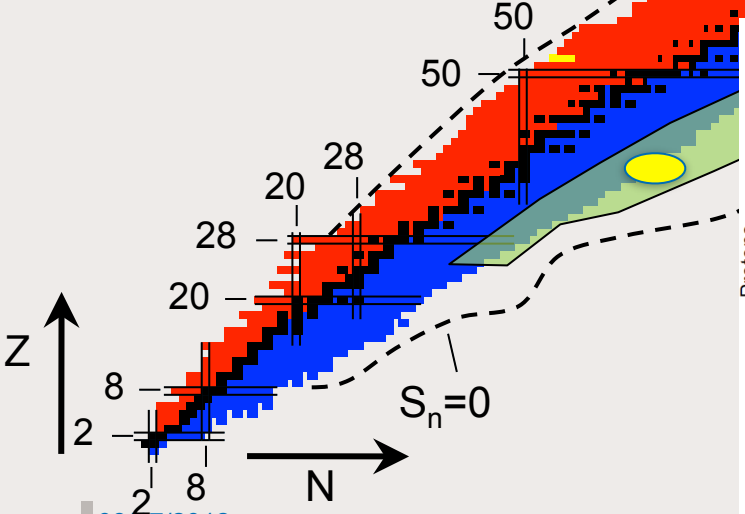


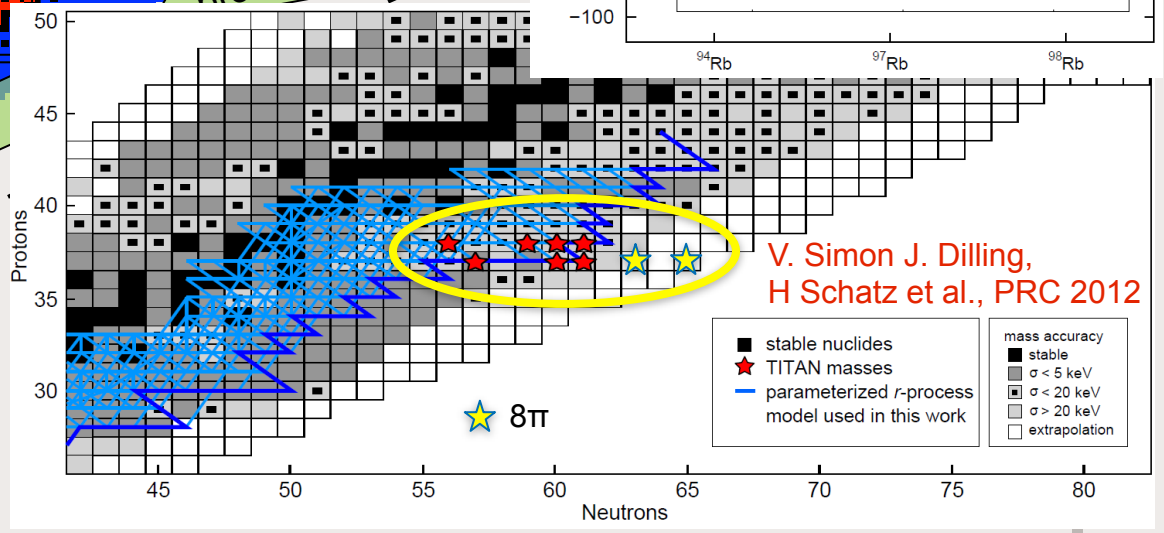
Z. Wang, poster











Nuclear Astrophysics at TRIUMF

DRAGON & TUDA are world-class facilities to directly measure 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

Recent results:

^{18}F(p,α)^{15}O (**TUDA**):
C.E. Beer, PRC 2010

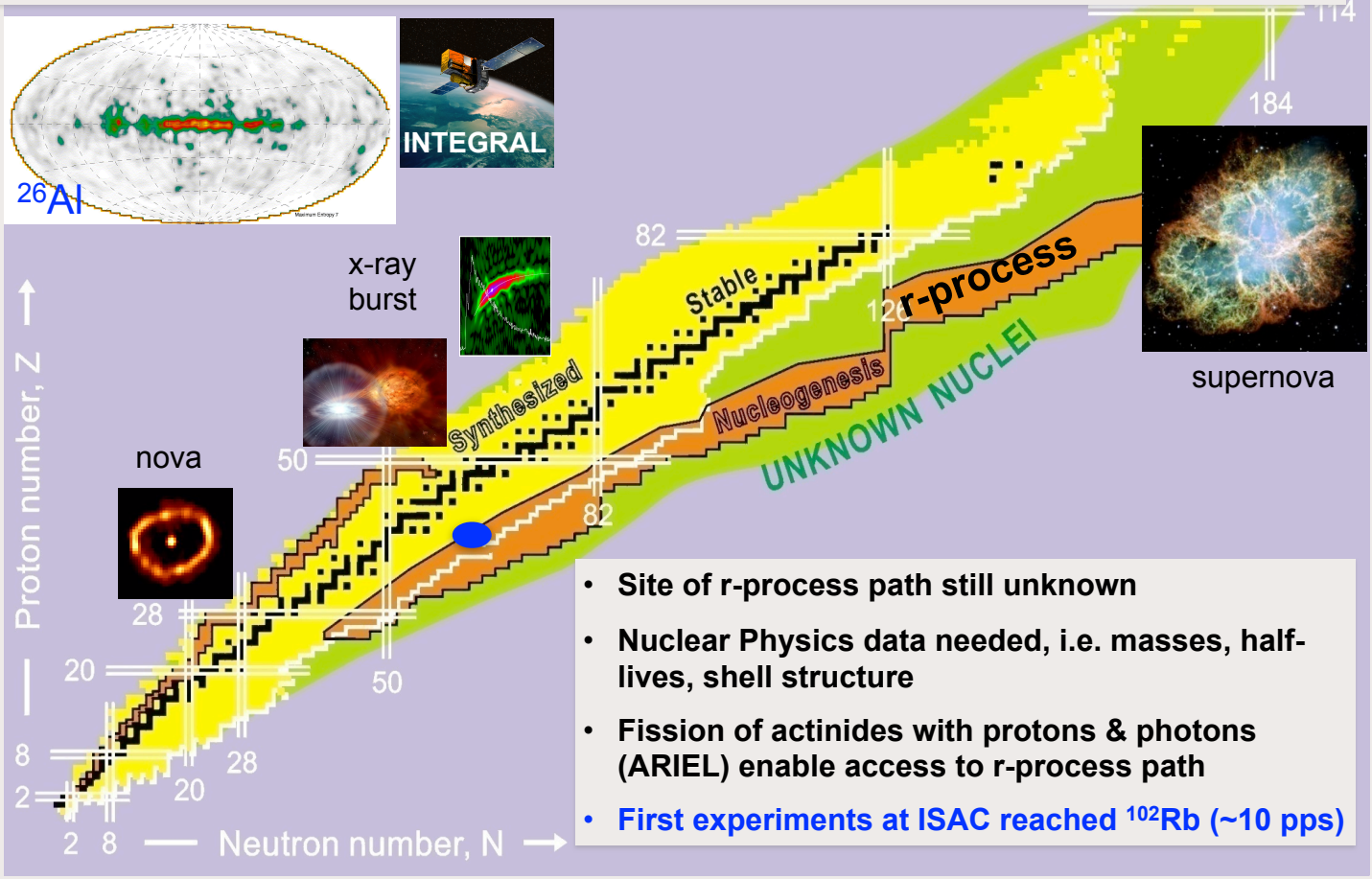
^{22}Na(p,γ)^{23}Mg (**U. Wash**):
A.L. Sallaska, PRL'10, PRC'11

^{23}Mg(p,γ)^{24}Al (**DRAGON**)
L. Erikson, PRC 2010

^{21}Na(p,α)^{18}Ne (**TUDA**)
P.J.C. Salter, PRL 2012

^{18}F(p, γ)^{19}Ne (**DRAGON**)
^{26m}Al(p,γ)^{27}Si (**DRAGON**)
^{26}Al(d,p)^{27}Al (**TUDA**)

stable beam experiments:
^{33}S(p, γ)^{34}Cl, ^{17}O(p, γ)^{18}F (Hager, PRC'12), ^{3}He(α, γ)^{7}Be



- **Site of r-process path still unknown**
- **Nuclear Physics data needed, i.e. masses, half-lives, shell structure**
- **Fission of actinides with protons & photons (ARIEL) enable access to r-process path**
- **First experiments at ISAC reached ^{102}Rb (~10 pps)**

Fundamental Symmetries

Tests of CKM unitarity & CVC hypothesis

- **mass measurement of $^{74}Rb^{8+}$** with TITAN (Ettenauer et al., PRL2011)
- **charge radius of ^{74}Rb** from collinear laser spectroscopy (Mane et al., PRL2011)
- **branching-ratio measurement w/ 8π:**

  ^{74}Rb (x 3 improved), **^{26m}Al** (Finley et al., PRL2011, PRC2012)
- **half-life measurement w/ 8π:**

  ^{14}O (poster by A.T. Laffoley), **^{19}Ne** (Triambak et al. PRL 2012)

Francium PNC program

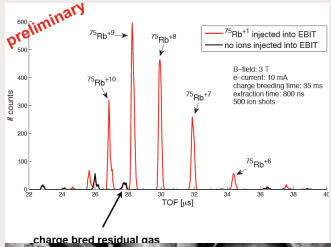
- utilize **10μA of 500 MeV protons on UC_x** target
- Successful Fr yield measurements, **hyperfine spectroscopy of ^{205}Fr**
- MOT trap currently under commissioning

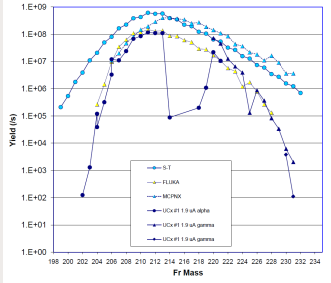
Towards EDM experiments

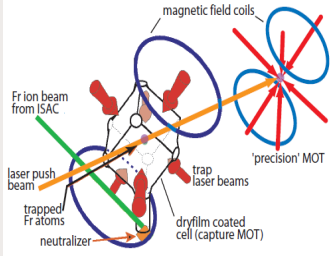
- **Laser ionization and spectroscopy of At** ➔ towards atomic EDM in Rn
- LoI for Fr fountain experiment ➔ towards electron EDM experiment

TITAN-EC branching ratio measurements for double beta decay

- in-trap EC/β decay of ^{116}In inside TITAN-EBIT w/ Si(Li) detectors
  (poster by C. Andreoiu)



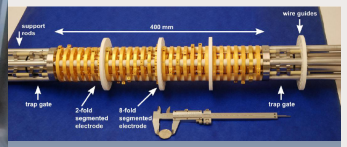


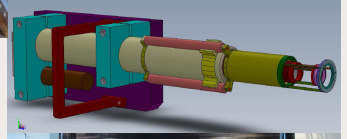


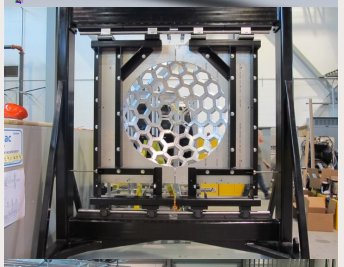
ISAC experiment projects

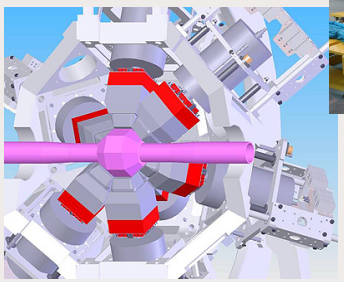
- IRIS solid hydrogen target
  - charge particle spectroscopy station, commissioned
- TITAN CPET
  - higher precision masses using cooled ions (2012)
- TIP Plunger for TIGRESS + CsI Ball (poster P. Voss)
  - lifetimes of excited states, CsI for charged particles (2012/13)
- DESCANT
  - neutron detector array for TIGRESS and GRIFFIN (2013)
- SPICE (poster S. Ketelhut)
  - in-beam electron conversion spectrometer (2012)
- EMMA
  - Mass analyzer for ISAC-II reaction program (2013)
- GRIFFIN (poster A. Garnsworthy)
  - gamma-ray array, 300x 8π γγ-eff. - (2015)

+ Proposals for campaigns w/ 3Hen, VANDLE, Super-ORRUBA



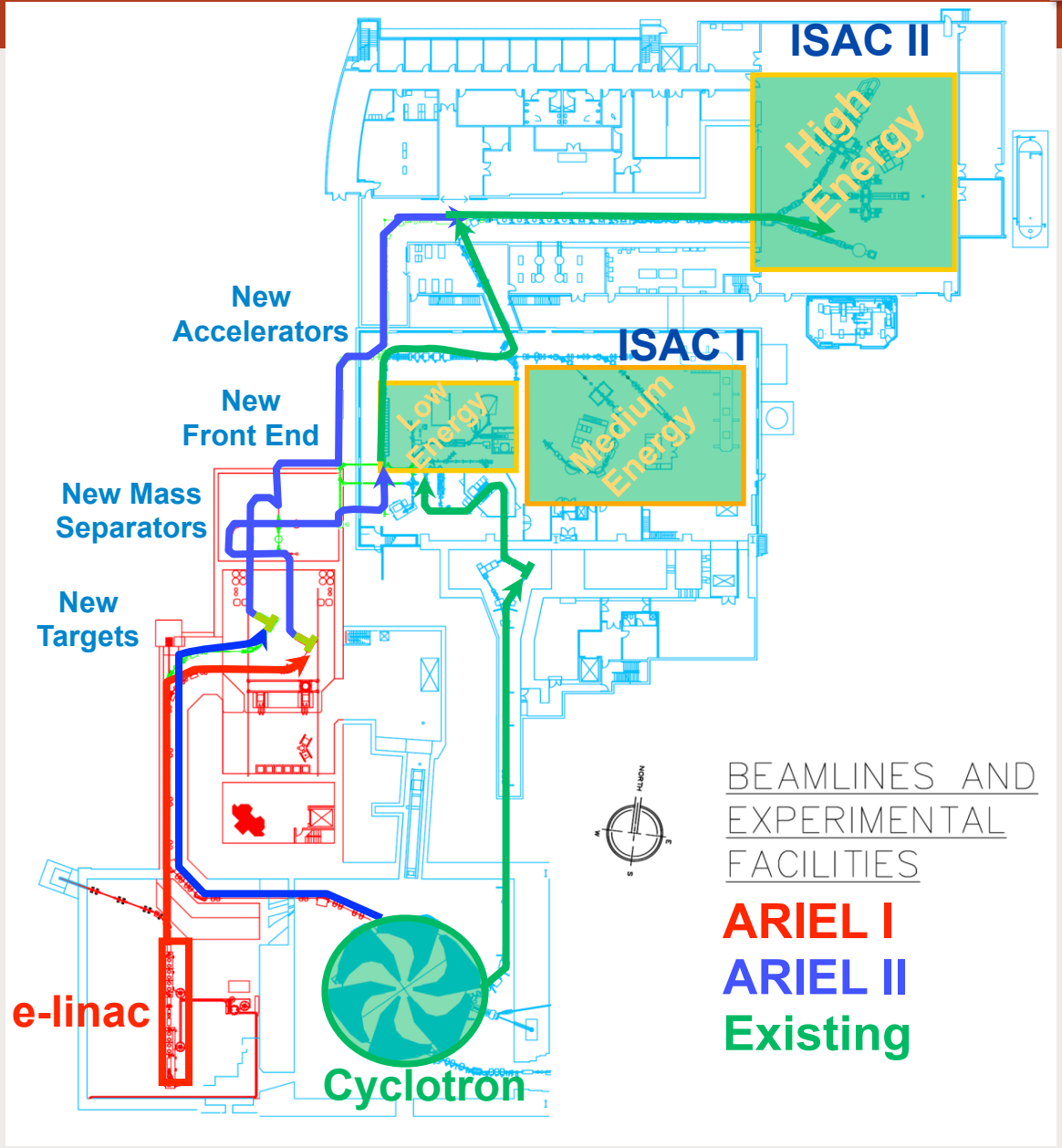






TRIUMF

Advanced Rare Isotope Laboratory



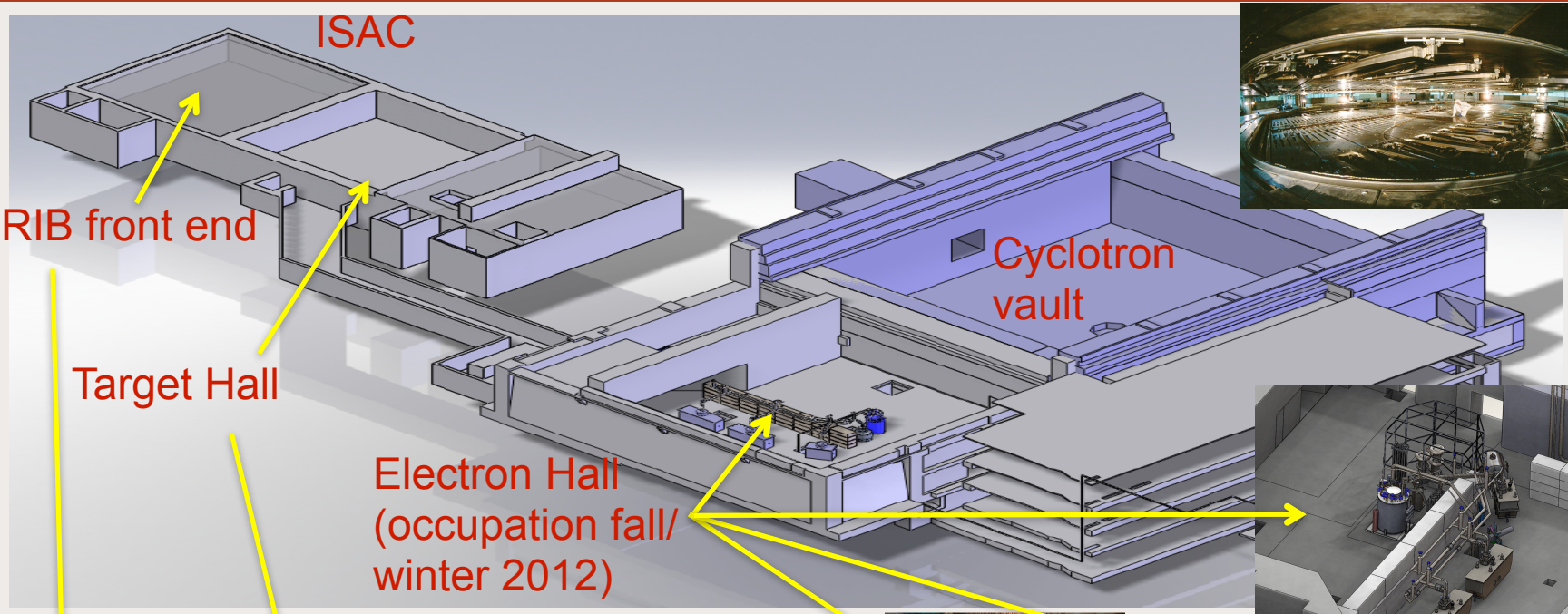
Substantially expand RIB program with:

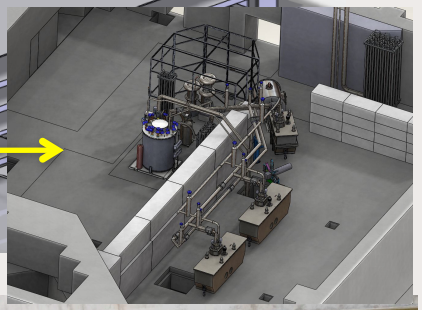
- three simultaneous beams
- increased number of hours delivered per year
- new beam species
- increased beam development capabilities

Implementation:

- Complementary electron linac driver for photo-fission
- New target stations and front end
- New proton beamline
- Staged installation

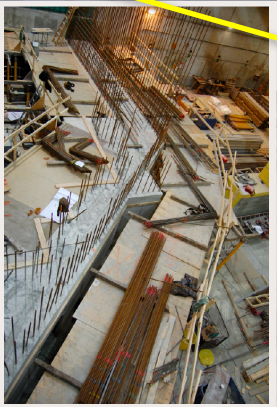
ARIEL construction



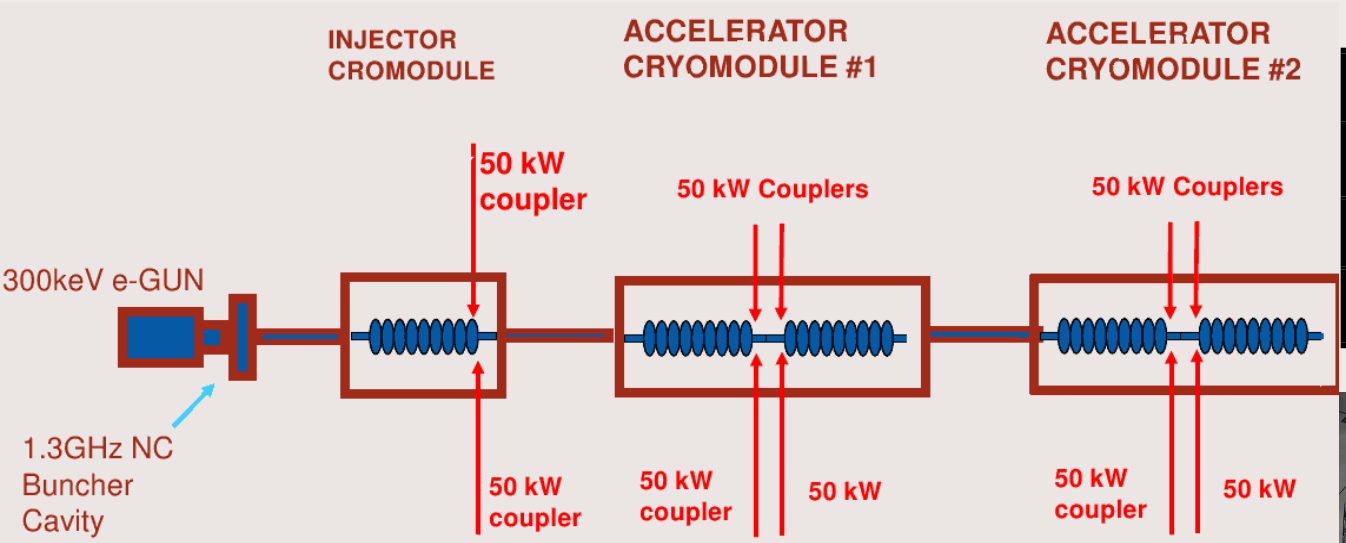


(occupation spring 2013)

tunnel breakthrough



e-Linac: MW-class Superconducting Electron Accelerator at TRIUMF



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

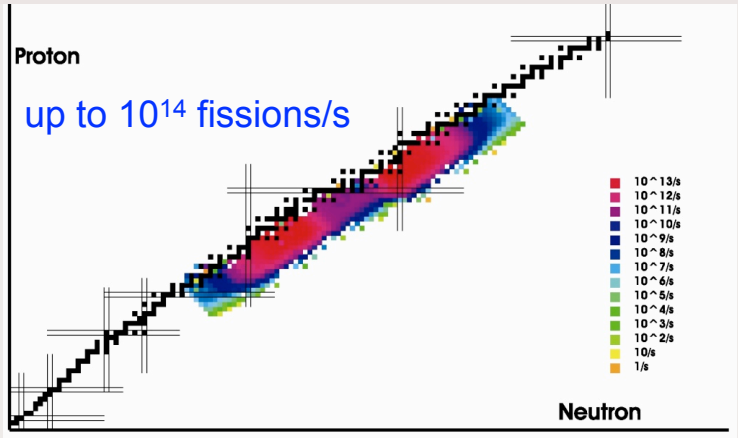
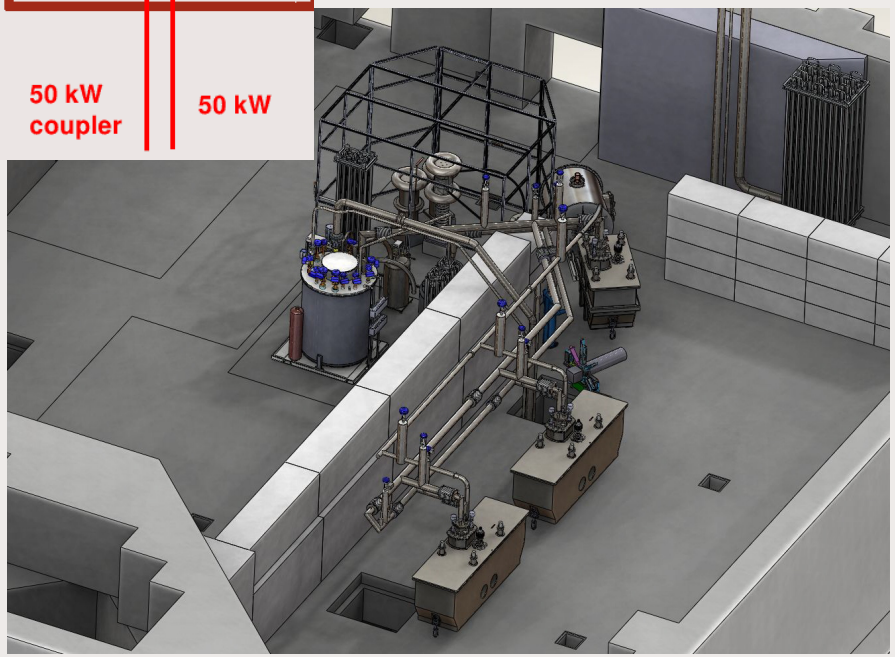
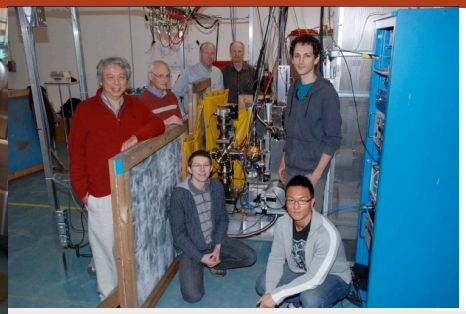
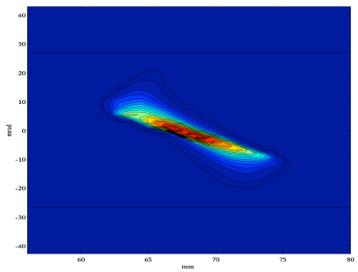


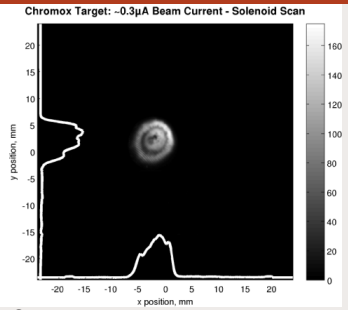
Photo-fission products using 50 MeV 10 mA electrons on to Hg convertor & UC_x target.



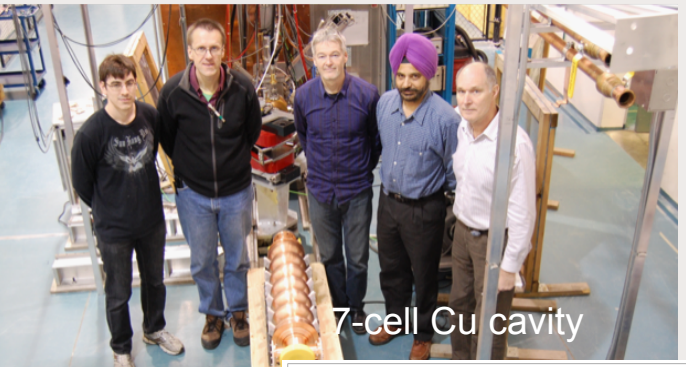
e-LINAC developments

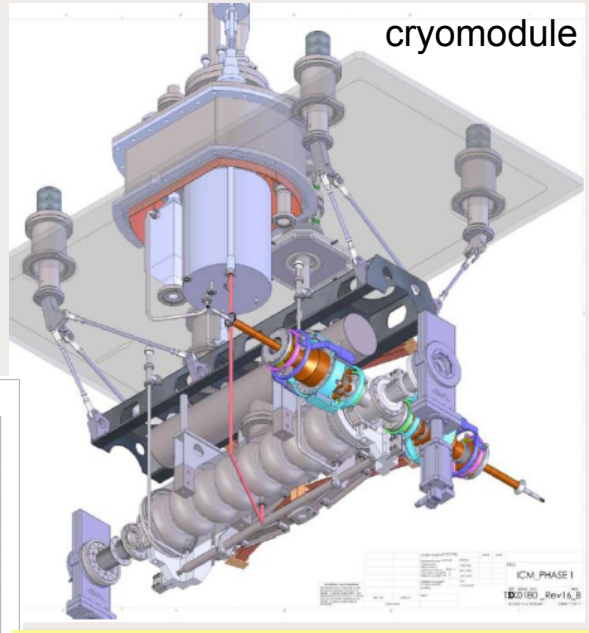


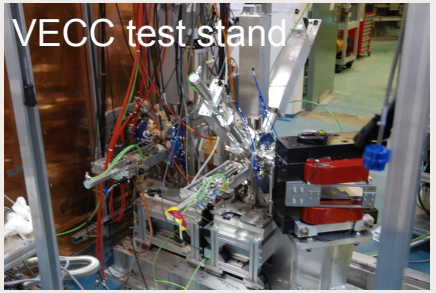




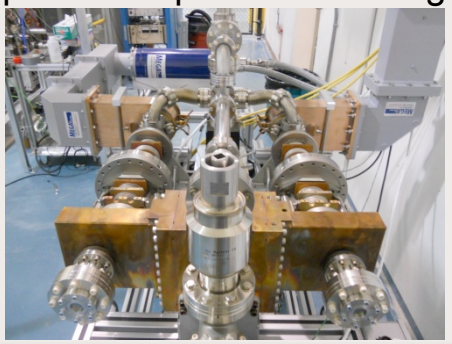
emittance scan of e-gun

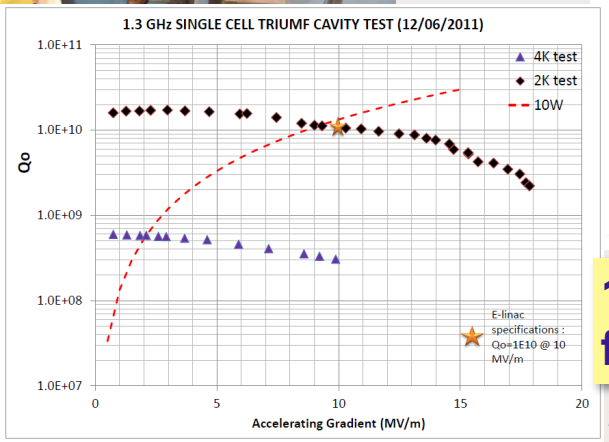






power coupler conditioning



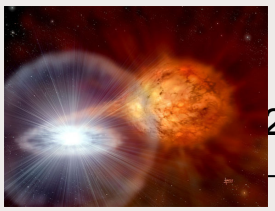


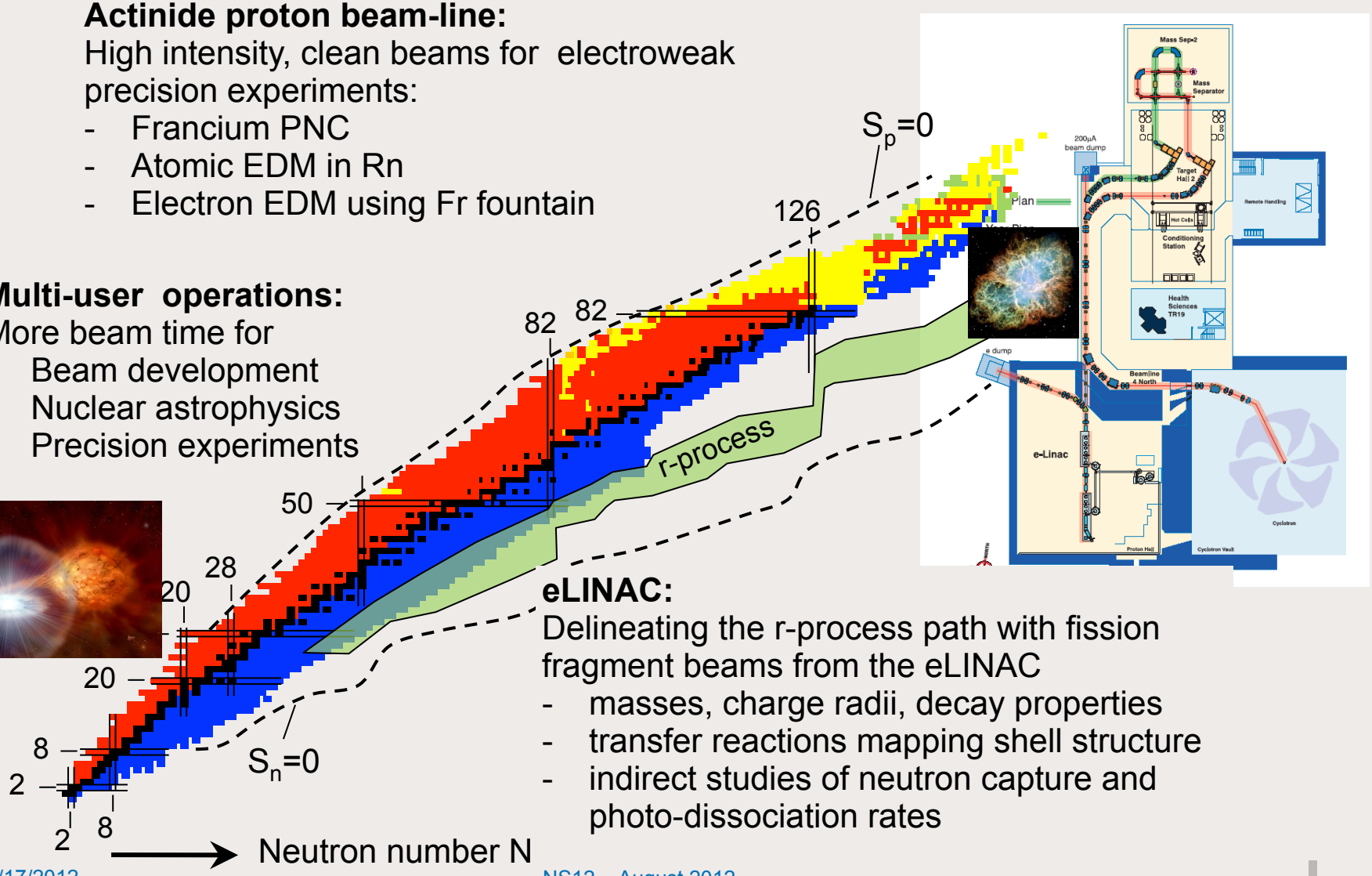
100 kW operation starting 2014
first science: ^{8}Li photo-production for βNMR

Science enabled by ARIEL

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

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





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

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!

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Nuclear Structure 2014 in Vancouver