Gamma-ray spectroscopy at TRIUMF-ISAC: recent results, perspectives and future opportunities

Zhimin Wang | Postdoctoral Research Fellow | **TRIUMF & SFU**
On behalf of the 8pi & TIGRESS collaboration

Nuclear Structure Physics with Advanced Gamma-Detector Arrays
10-12 June 2013
Palazzo del Bo', Padova, Italy

Accelerating Science for Canada
Un accélérateur de la démarche scientifique canadienne

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Outline

- TRIUMF-ISAC
- TIGRESS: S1297, Investigating halo states with the $^{11}Be(p,d)^{10}Be^*$ transfer reaction at 10 MeV per nucleon, F. Sarazin (Colorado School of Mines)
- 8pi: S1337, Decay properties of neutron-rich Rb nuclei relevant to r-process nucleosynthesis, Z.-M. Wang and A. Garnsworthy (TRIUMF & SFU)
- Undergoing developments: GRIFFIN, ARIEL
- Conclusions

TRIUMF

Canada's national laboratory for particle and nuclear physics

Vancouver, BC, Canada

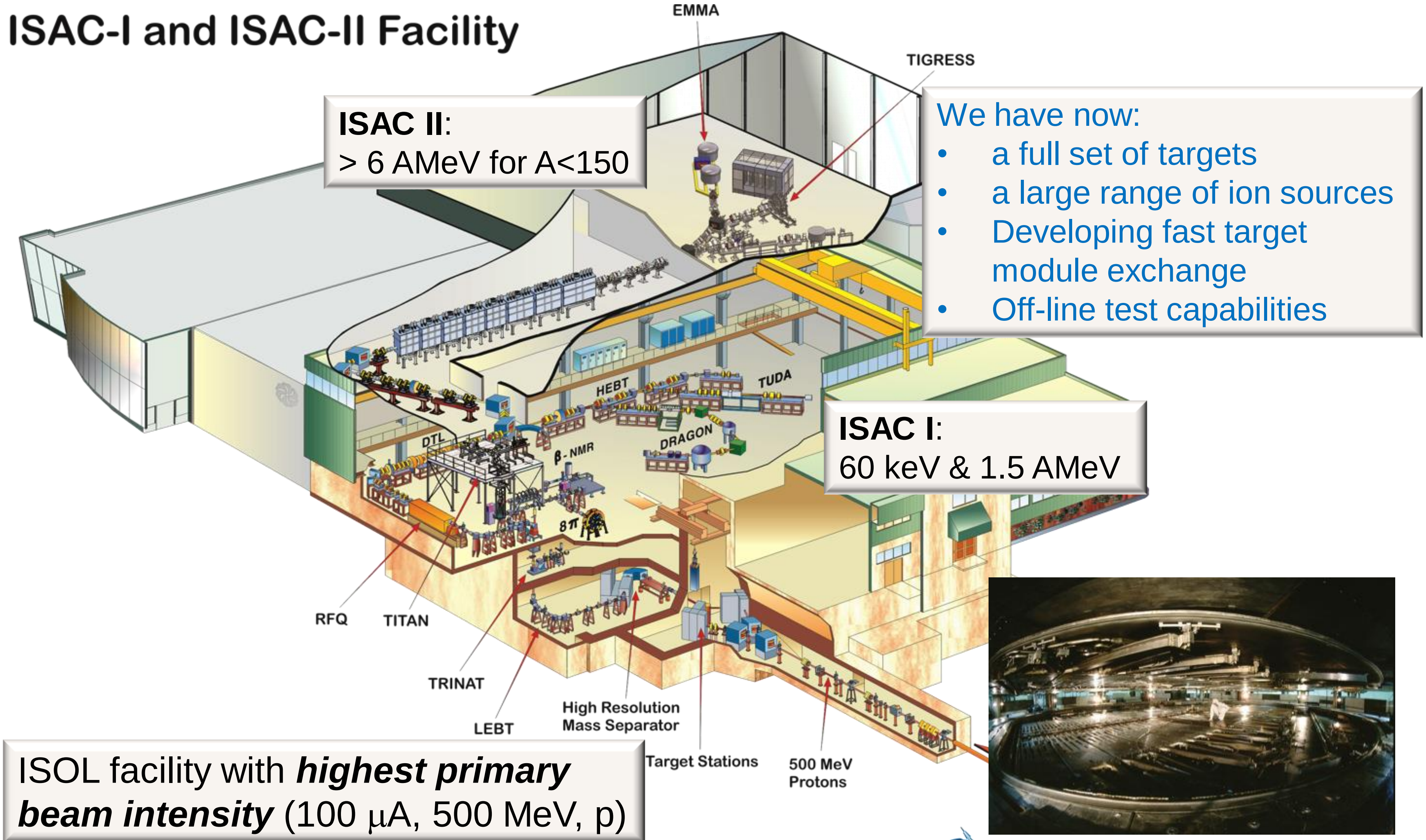
Founded in 1969

~350 staff
~150 students, postdocs and scientists

Large cyclotron

Research in **nuclear physics,** particle physics, nuclear medicine, materials science

Isotope Separator and ACcelerator (ISAC)



ISAC II:
> 6 AMeV for A<150

We have now:

- a full set of targets
- a large range of ion sources
- Developing fast target module exchange
- Off-line test capabilities

ISAC I:
60 keV & 1.5 AMeV

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

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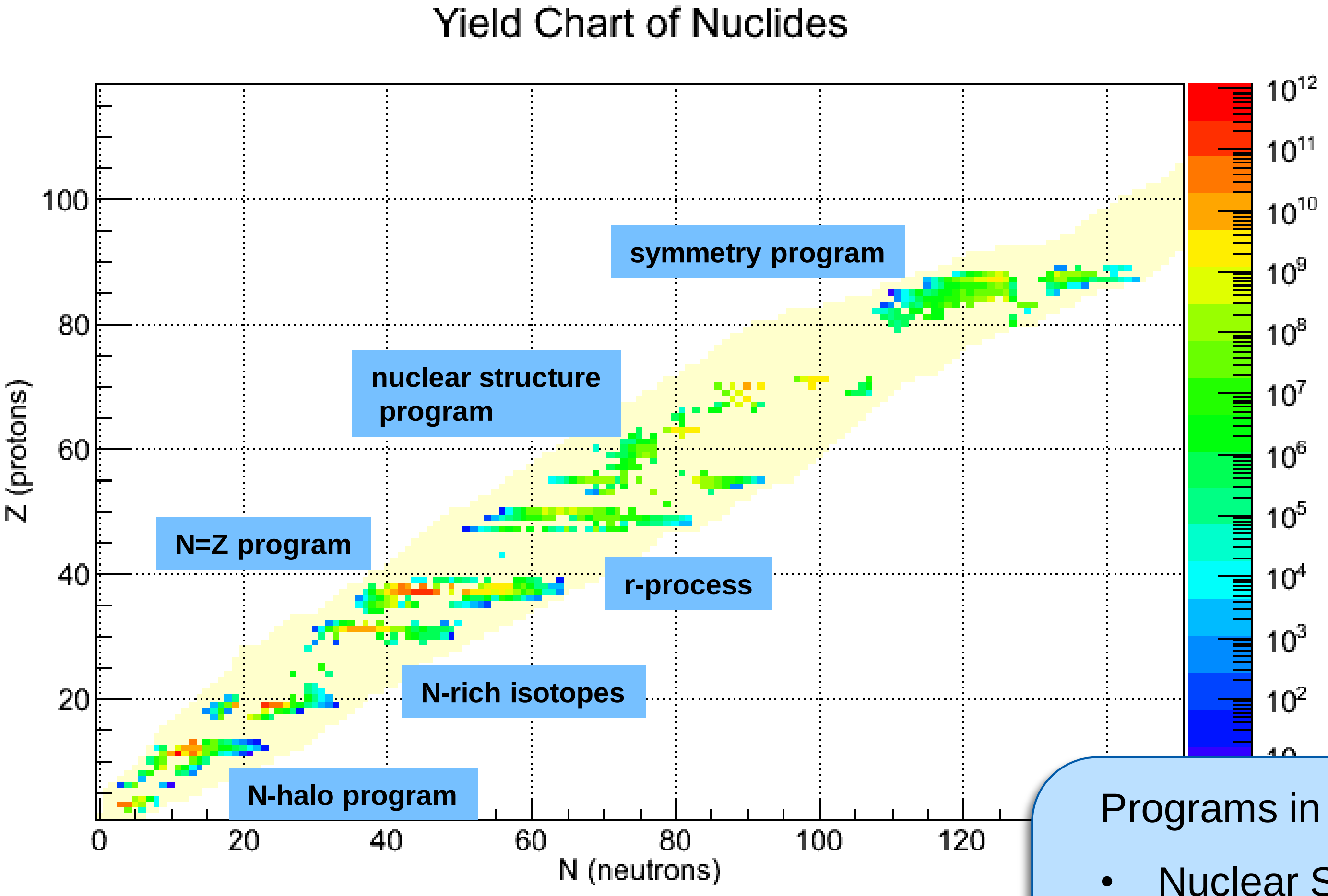
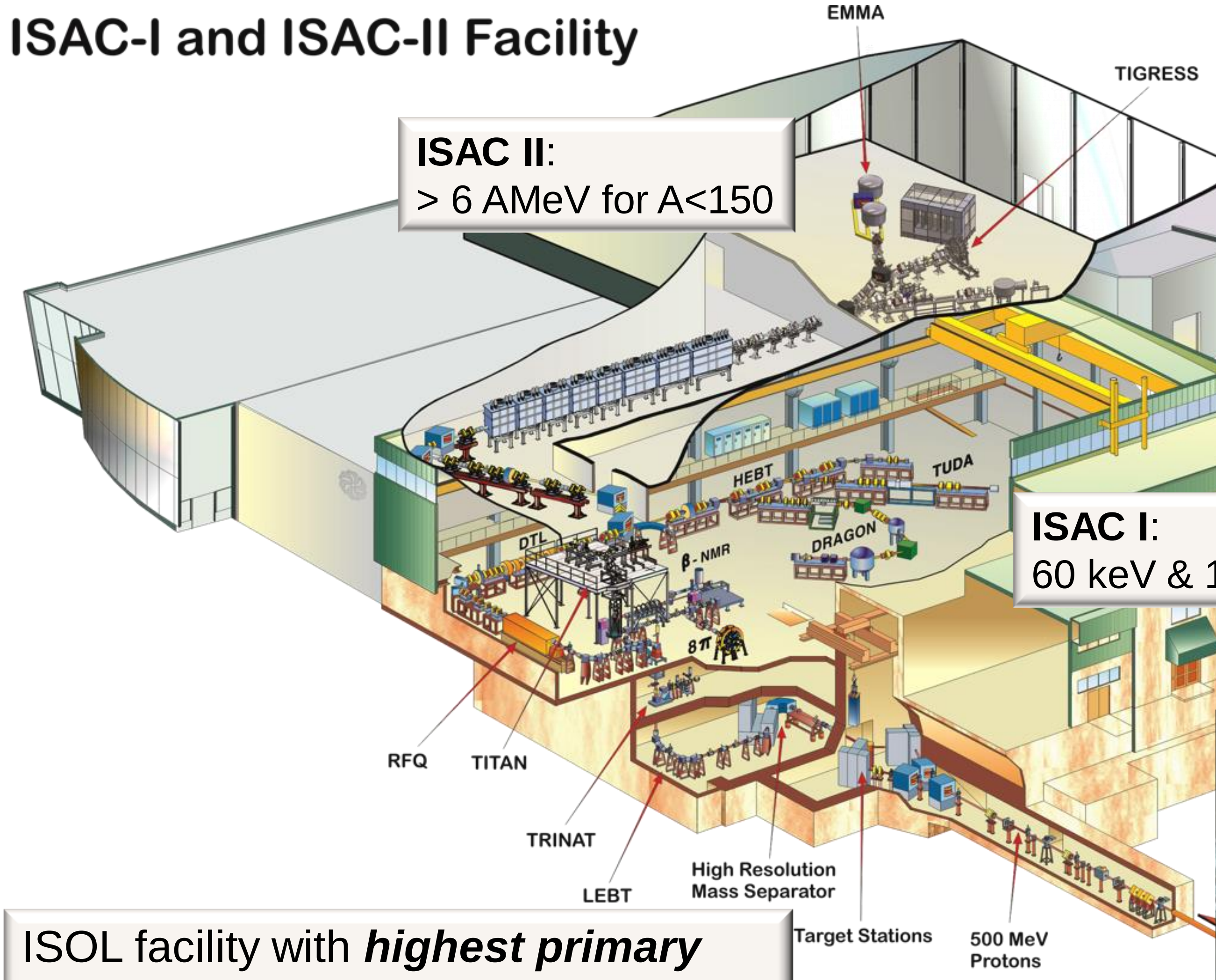


Isotopes delivered at ISAC

Programs in

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

Isotope Separator and Accelerator (ISAC)



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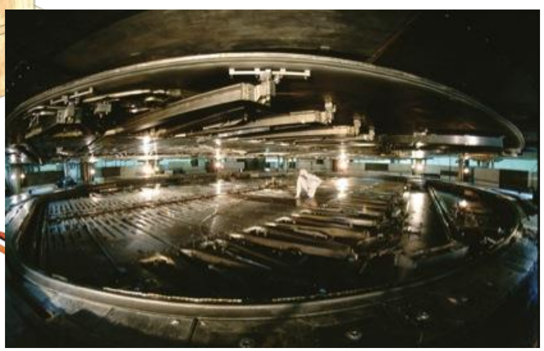

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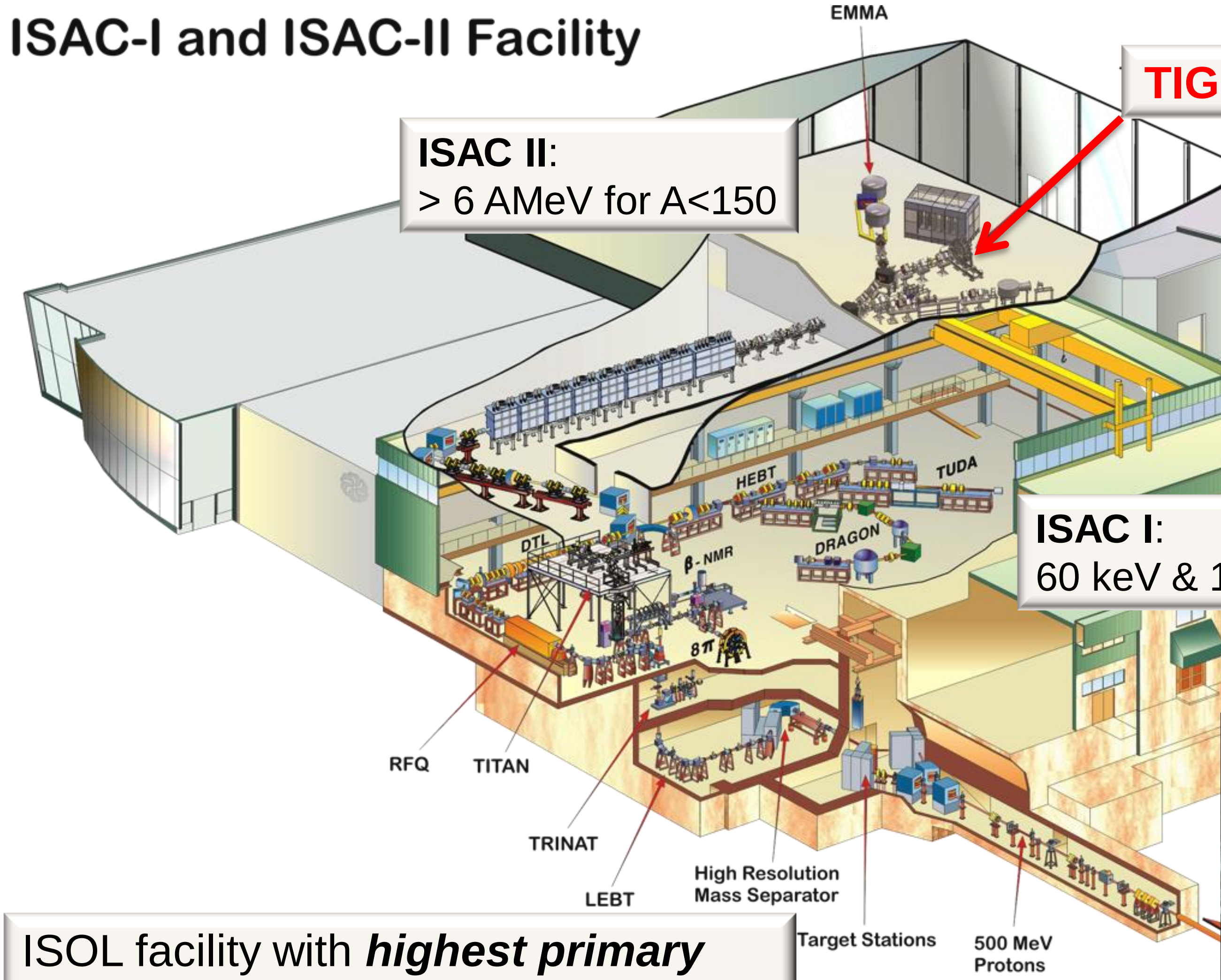

TIGRESS

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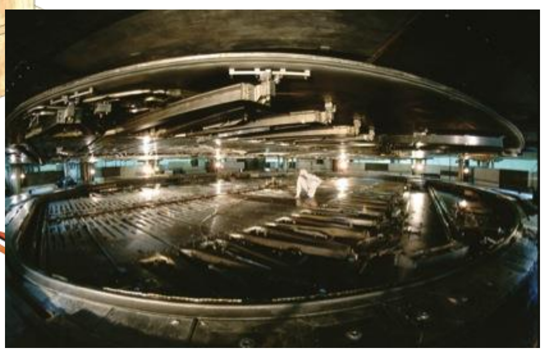
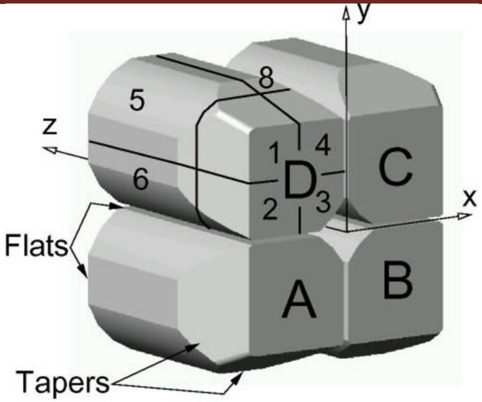
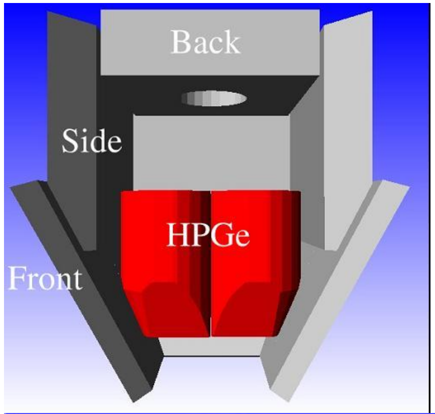
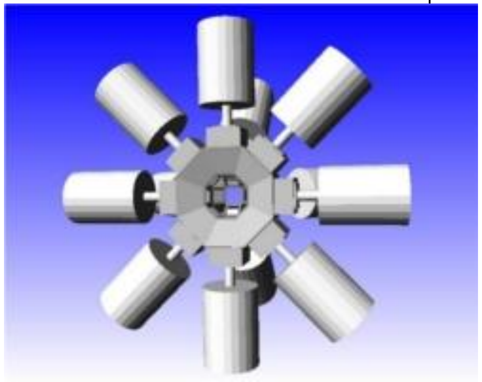


TIGRESS

TRIUMF ISAC Gamma-Ray Escape Suppressed Spectrometer



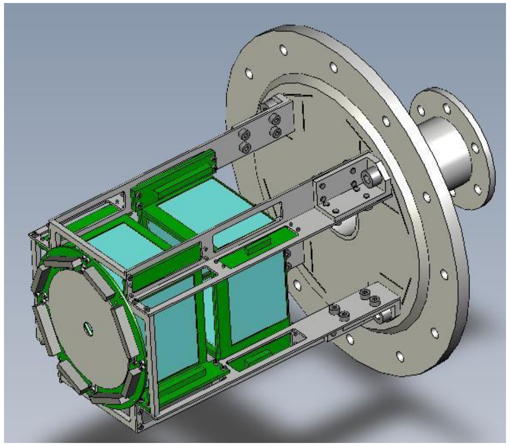


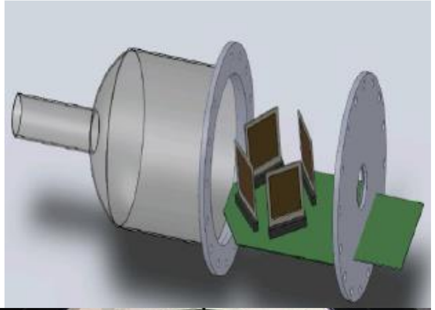


- High detection efficiency, especially at higher gamma-ray energies
- High spectral quality (Crystal segmentation and full Suppression shields)
- Full digital electronics
- BAMBINO S3 CD detectors, SHARC Silicon barrel and customized Si detectors
- Optimized for sensitive gamma-ray spectroscopy with accelerated radioactive beams

Coming online in near future:

- DESCANT - Neutron detector array
- SPICE – In-beam e^- spectrometer
- CsI Ball – for use with TIP (plunger)
- EMMA – ElectroMagnetic Mass Analyzer





TIGRESS

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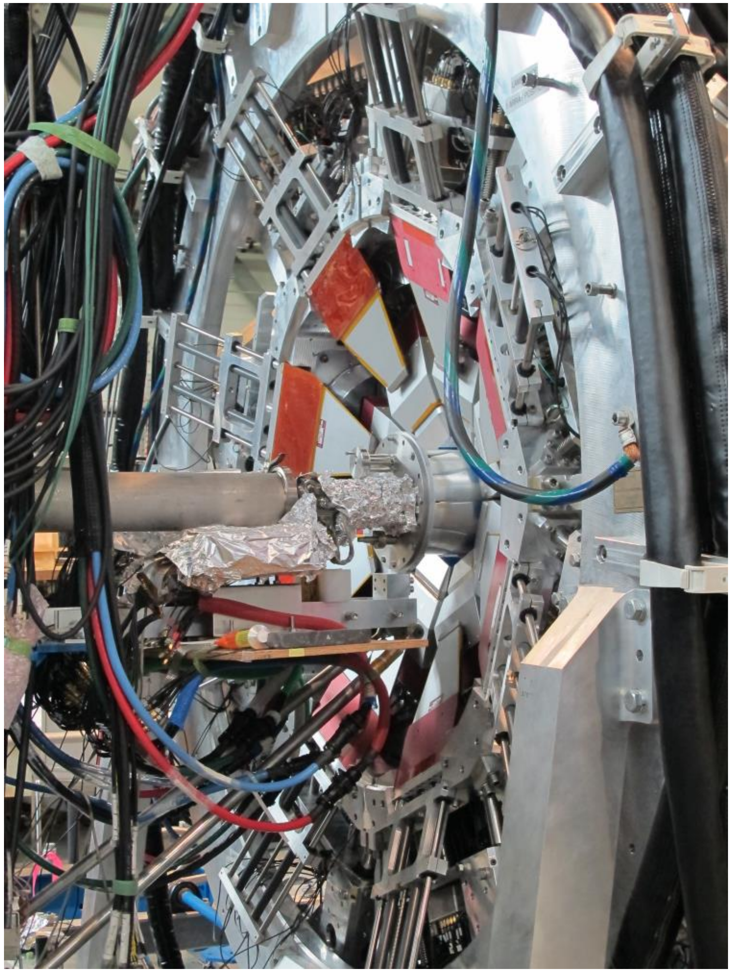
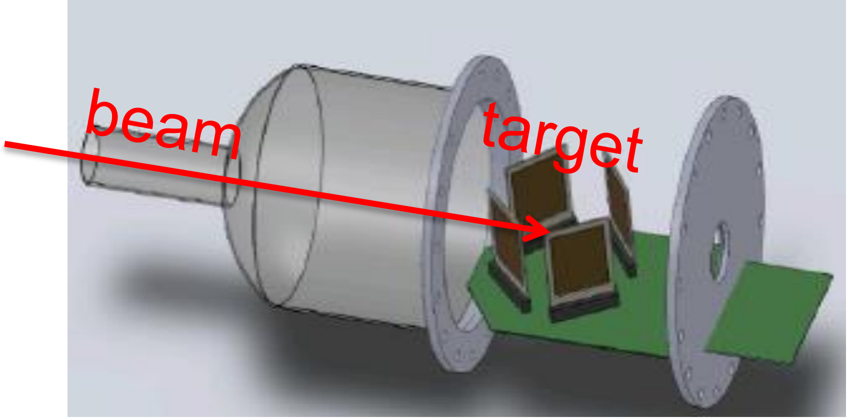


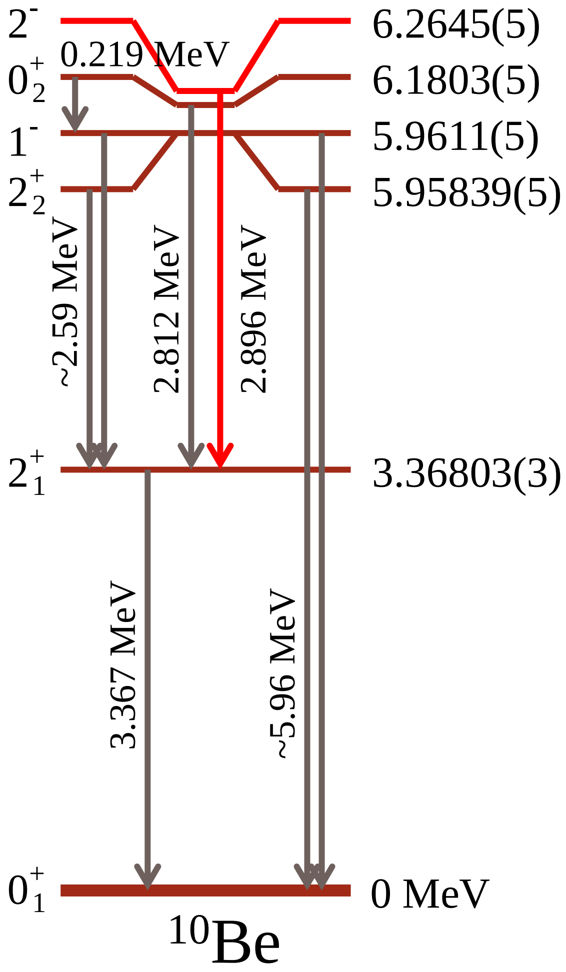
Recent campaign on halo structure:

S1202(M.J.G. Borge, J.J. Gomez-Camacho, I. Martel, O. Tengblad): ^{11}Be Coulex, near Coulomb barrier energy, exploring halo effects in the scattering of ^{11}Be on heavy targets

S1297 (F. Sarazin): p(^{11}Be,^{10}Be)d transfer reaction at 10MeV/u, investigating halo states in ^{11}Be,^{10}Be



Study of halo features in ^{10}Be and ^{11}Be using ^{11}Be(p,d) at 10MeV/u at TRIUMF ISAC-II



two halo state studies

- **^{11}Be is a one-neutron halo nucleus**
  - Simplified picture:
    - ^{10}Be(gs) core + one neutron in $2s_{1/2}$
  - More accurate:
    - ^{10}Be(gs) $\otimes \nu s_{1/2}$ + ^{10}Be(2^+) $\otimes \nu d_{(3/2,5/2)}$ (84% / 16%)

→ Continue the study of the ^{11}Be halo

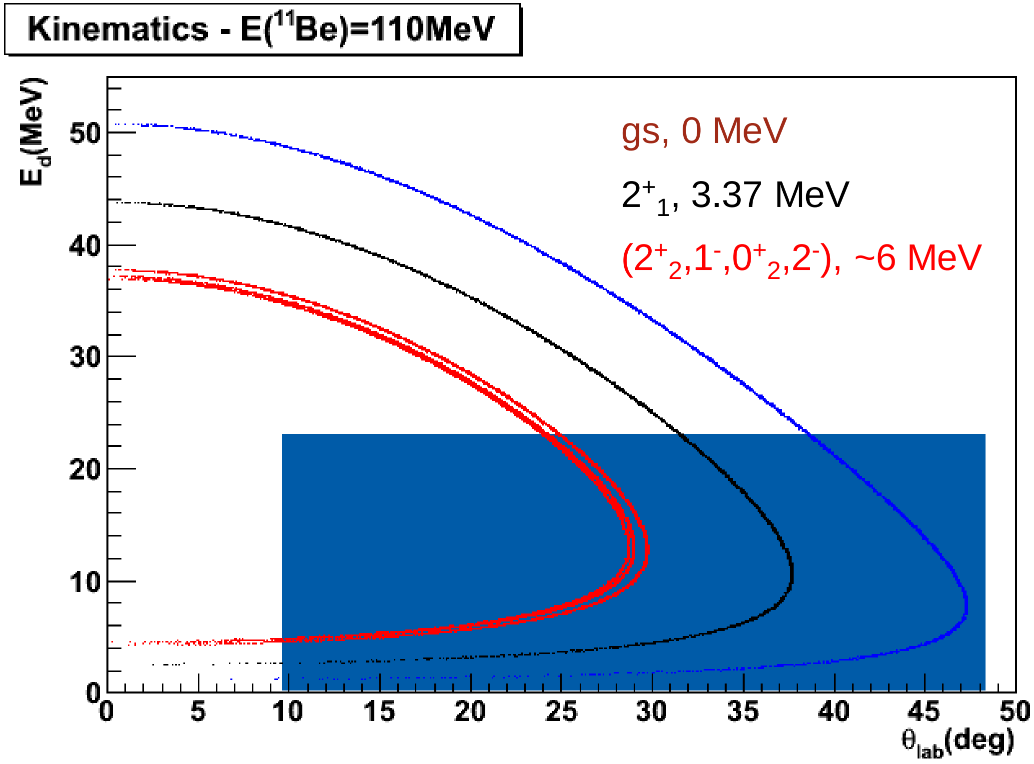
- **^{10}Be (2^-, 6.263MeV) is a suspected one-neutron halo excited state**
  - 0.55MeV below the ^{9}Be+n threshold
  - (Tentative) structure:
    - ^{9}Be(gs, $3/2^-$) + one neutron in $2s_{1/2}$ (the ^{11}Be halo neutron)

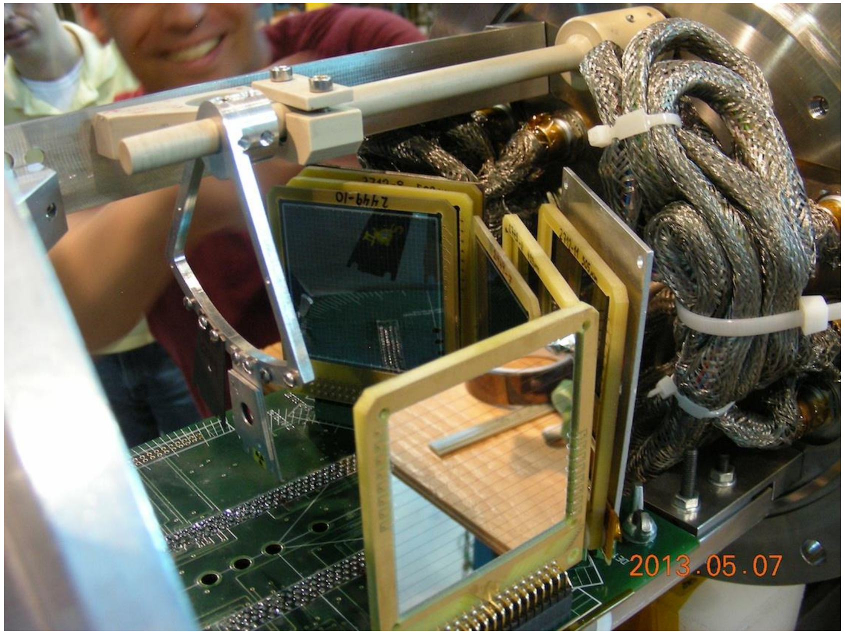
→ Confirm the halo nature of the 2^- state

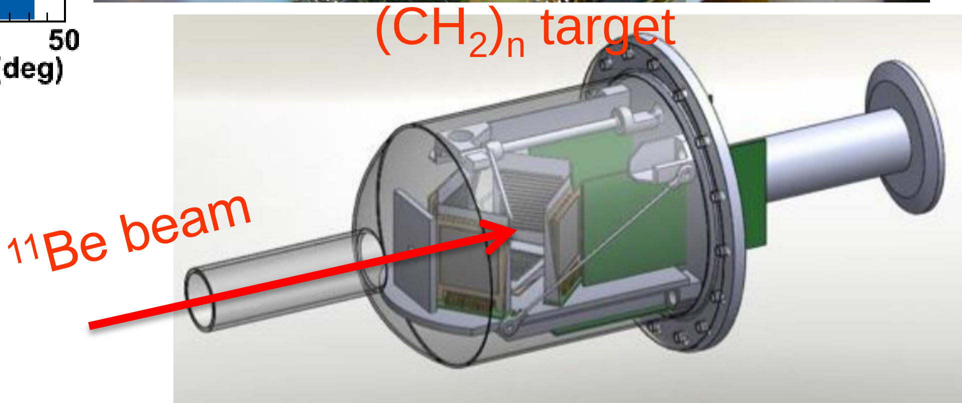
Jim Al-Khalili, et al, PRC74, 034312 (2006)

Kinematics, Si setup and experiment

TIGRESS will resolve the multiple states at ~6 MeV



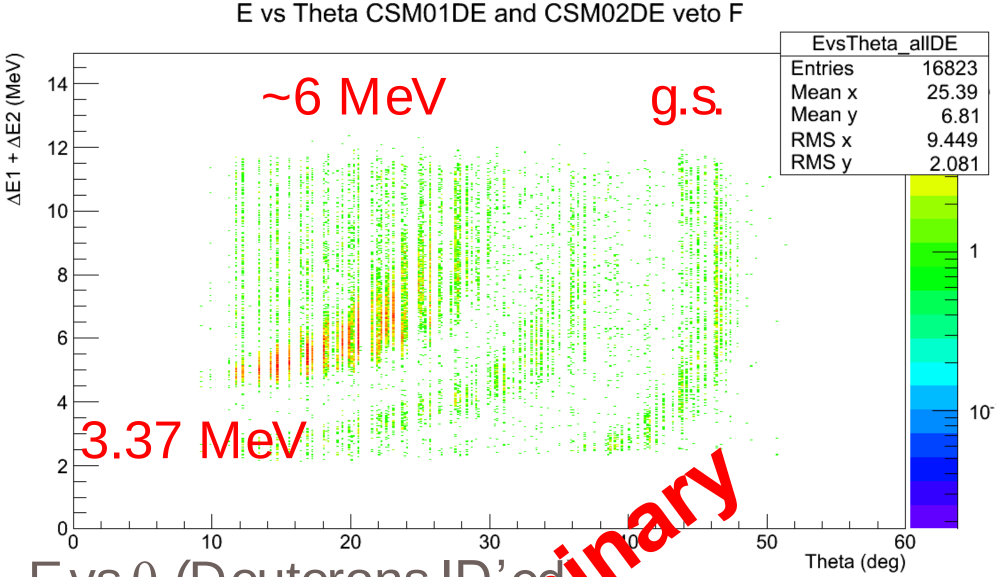




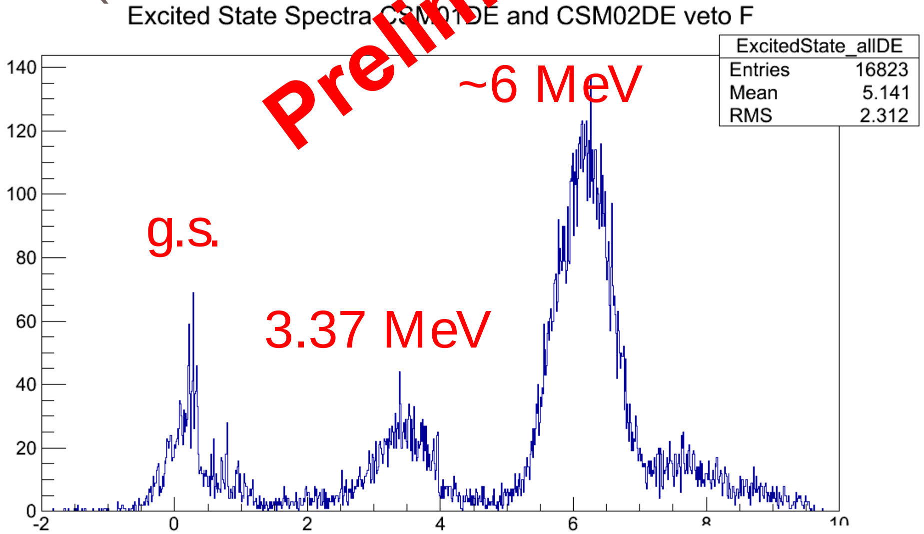
638 μg/cm^2 $(CH_2)_n$ target

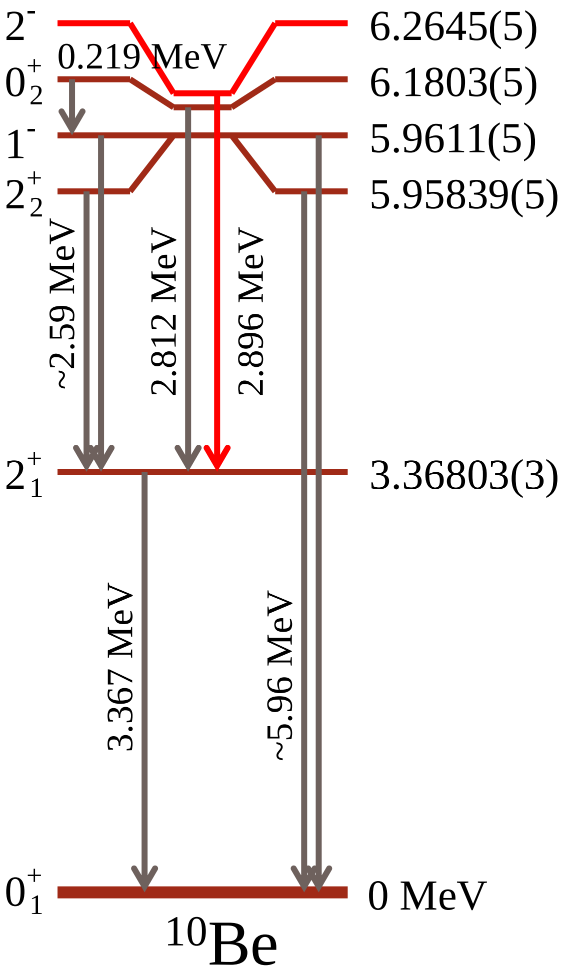
^{11}Be(p,d)@110MeV, ~ 2x10^{5}pps

Preliminary results: charged particles



E vs θ (Deuterons ID'ed)

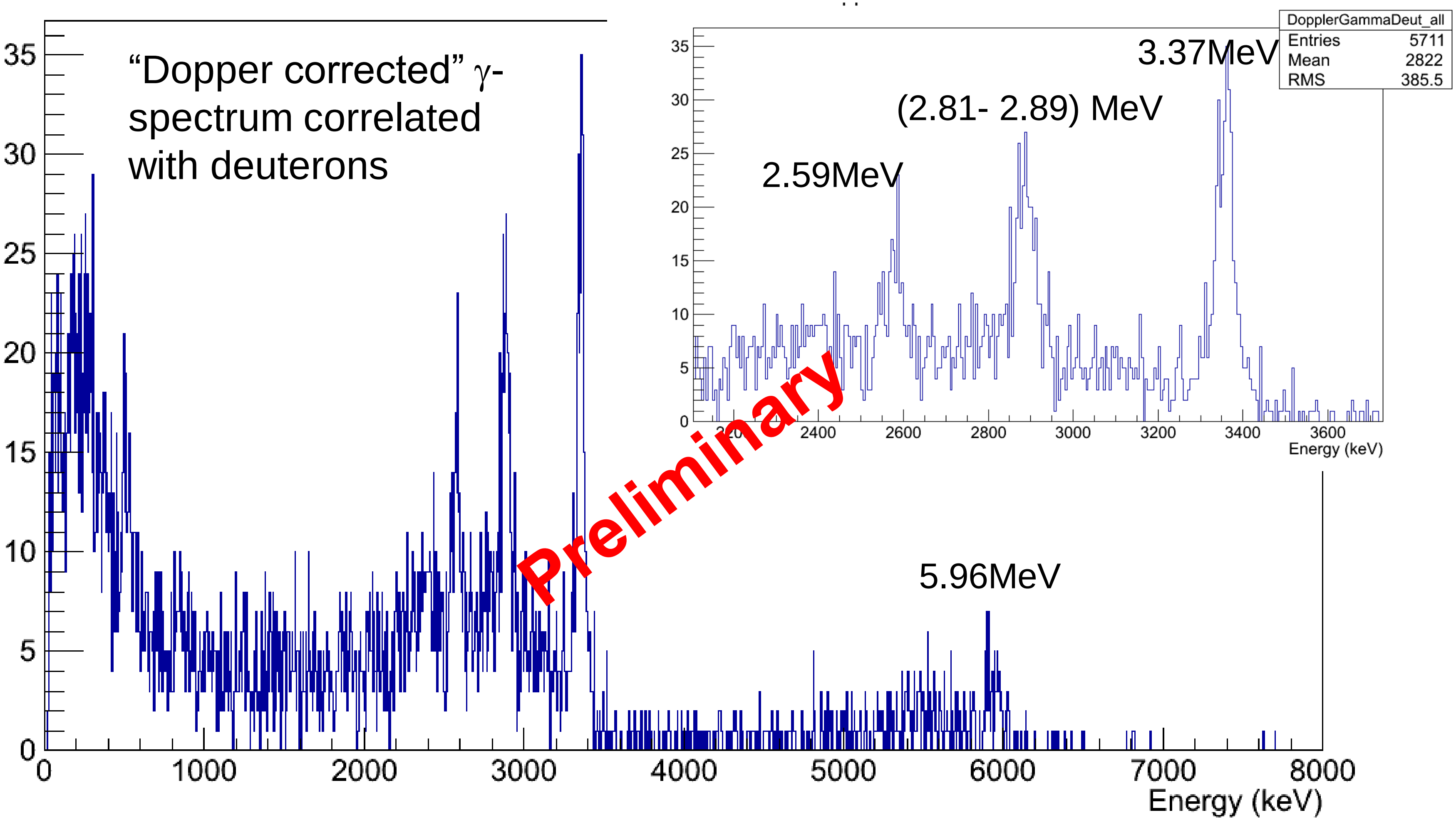




Frederic Sarazin, Keri Kuhn (Colorado School of Mines)

Preliminary results: gammas

2.89 MeV ɣ-ray: evidence that the 2$^-$ state "ex. halo state" is strongly populated in ^{11}Be(p,d)



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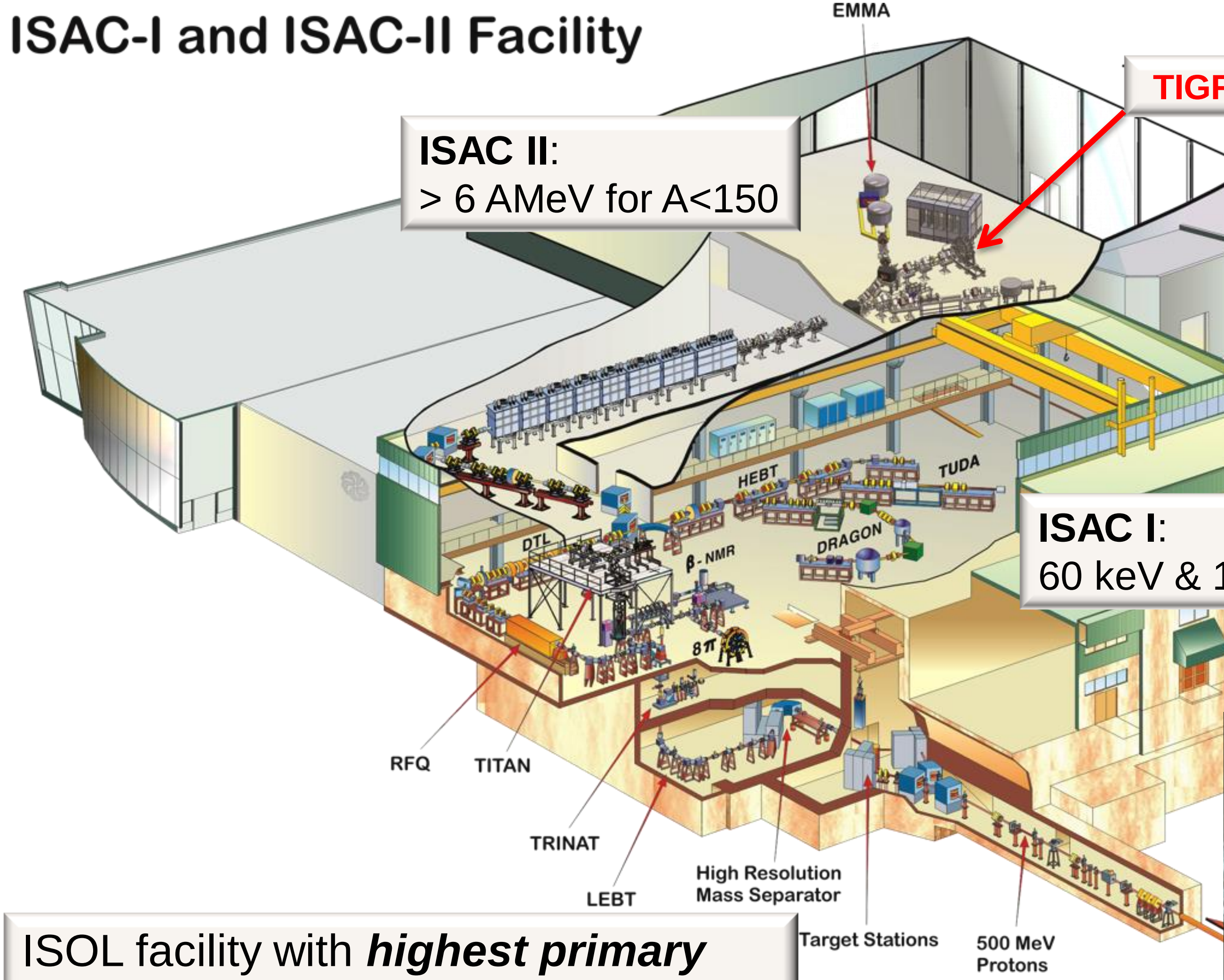

TIGRESS

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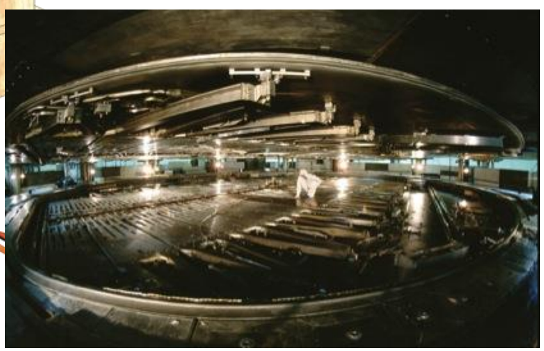

ISOL facility with ***highest primary beam intensity*** (100 μA, 500 MeV, p)

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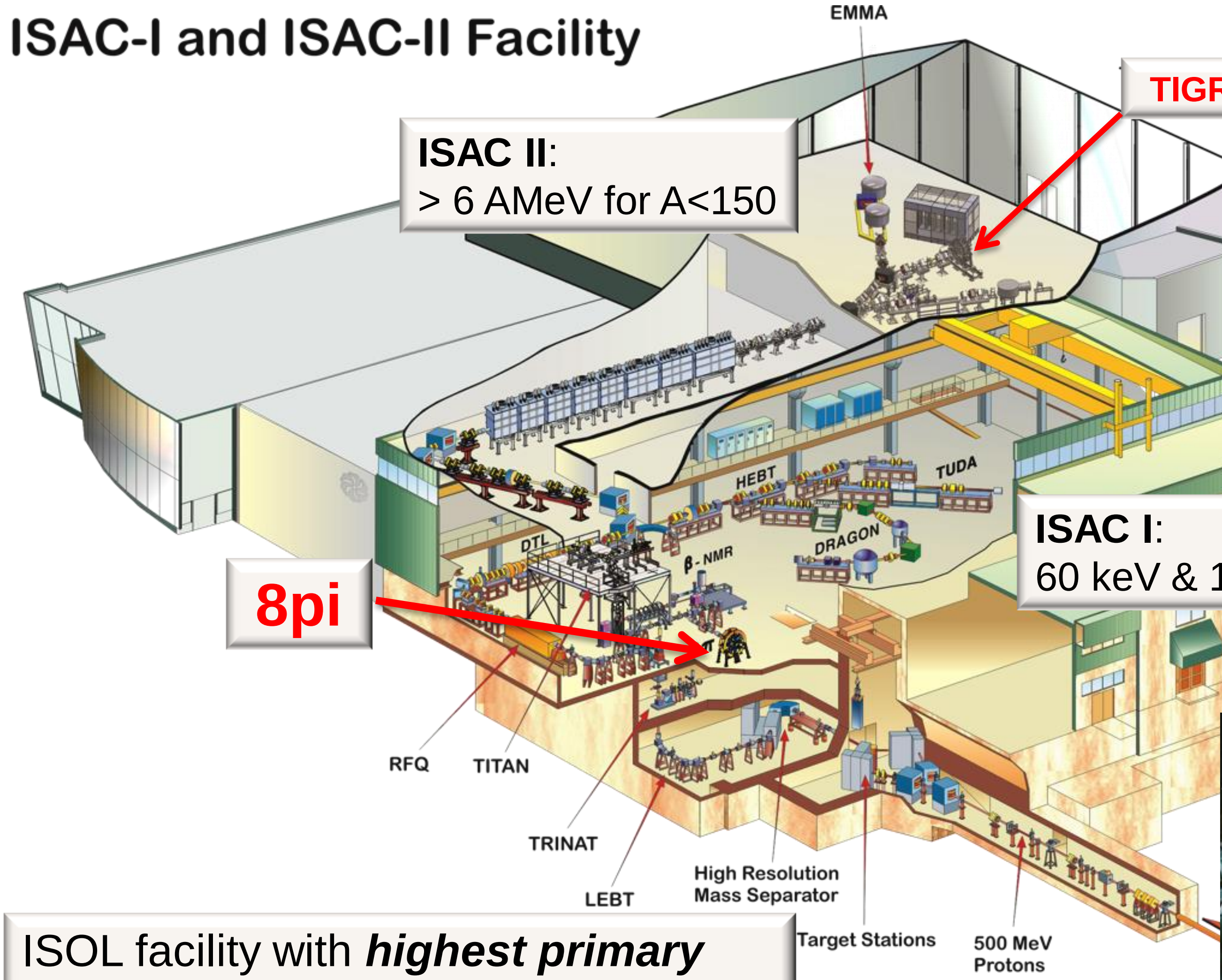

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TIGRESS

8pi

ISAC I:
60 keV & 1.5 AMeV

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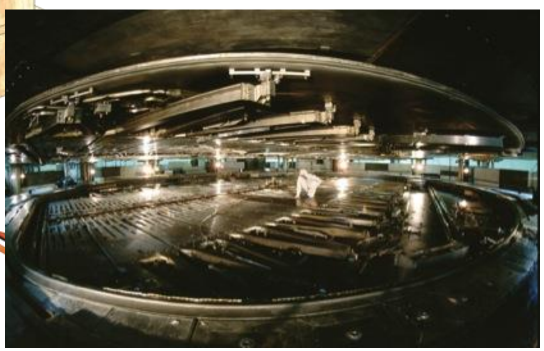
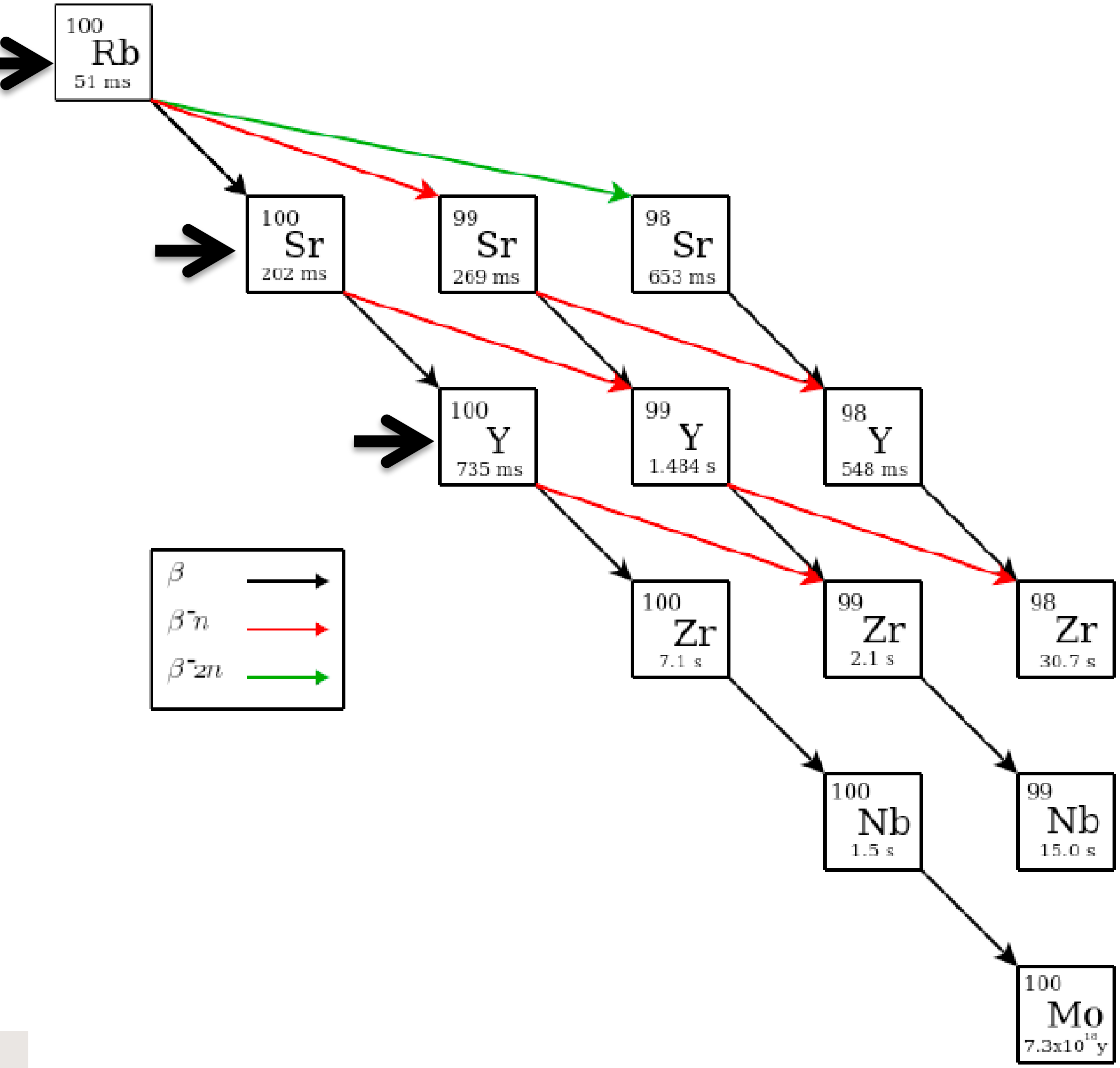


Isobaric cocktail beam

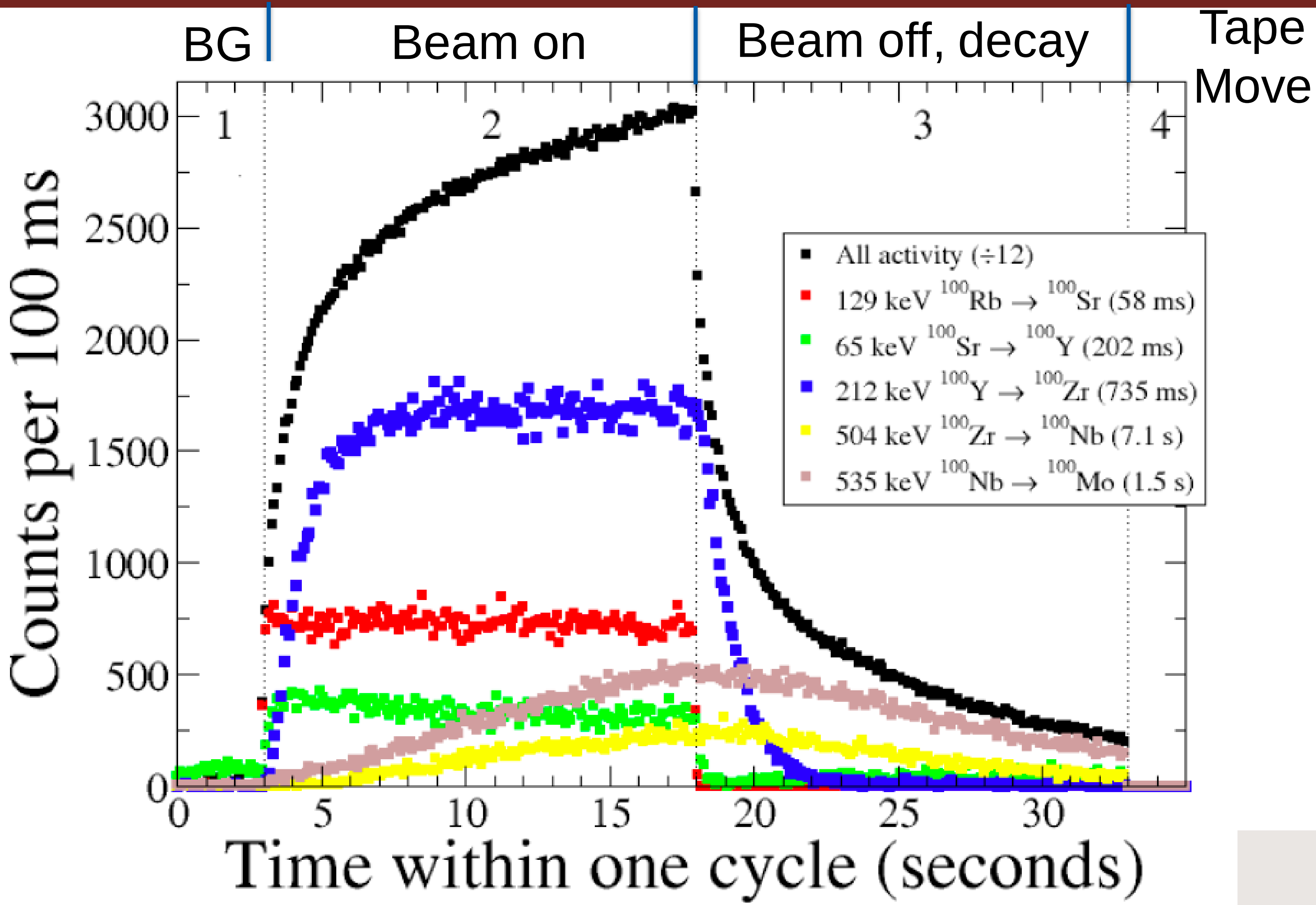


Multiple running modes:

Continuous tape movement: clean spectra by reducing long live decays

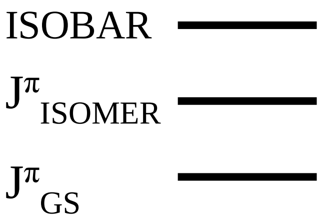
Cycling mode: beam-on, beam-off, capable of decay half-life measurement, attribute gamma rays to nucleus

Time Profile of Individual Gamma Rays



The 8pi Spectrometer at TRIUMF

Sensitive Decay Spectroscopy



ISOBAR

J^{π}_{ISOMER}

J^{π}_{GS}

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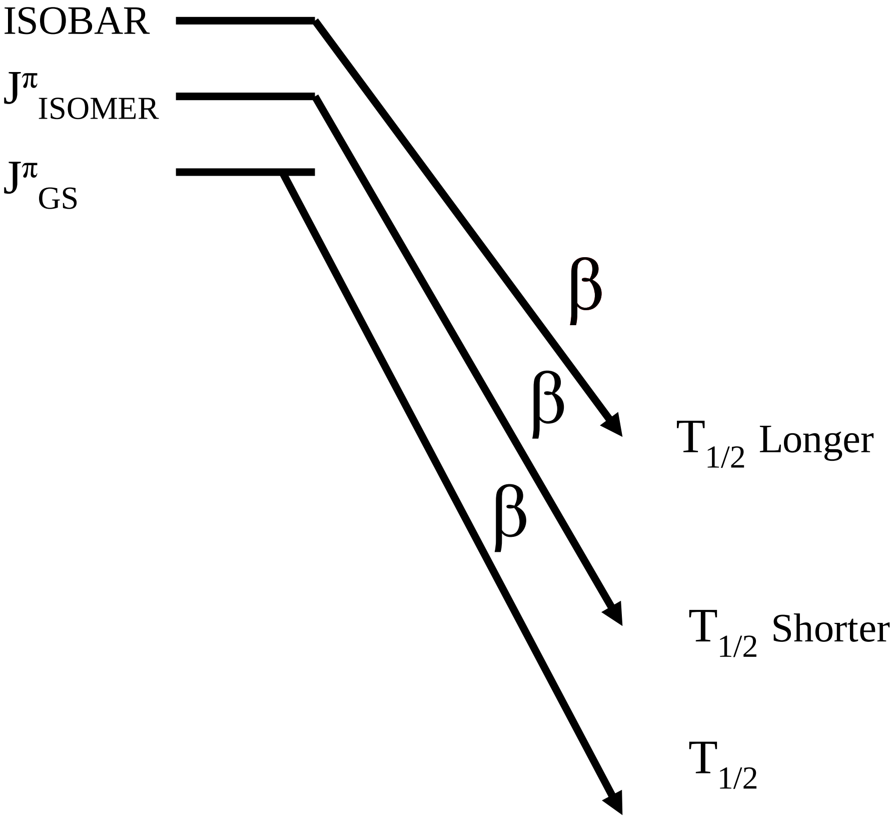
Sensitive Decay Spectroscopy

Fast, in-vacuum tape system

Enhances decay of interest



ISOBAR

J^{π}_{ISOMER}

J^{π}_{GS}

β

β

β

$T_{1/2}$ Longer

$T_{1/2}$ Shorter

$T_{1/2}$

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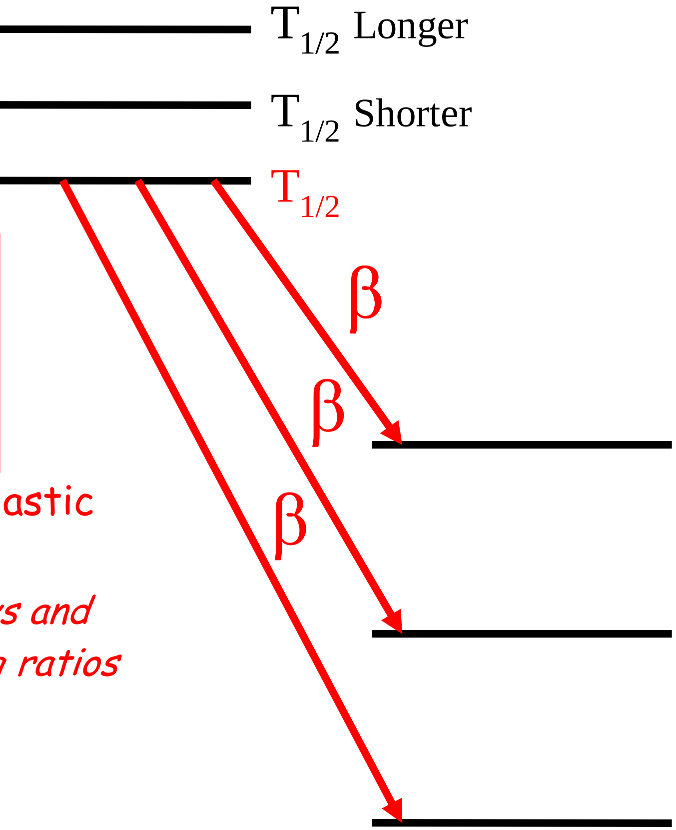
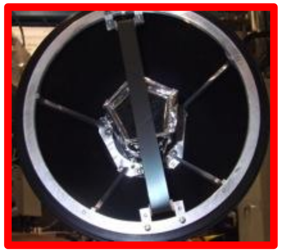


ISOBAR — $T_{1/2}$ Longer

J^{π}_{ISOMER} — $T_{1/2}$ Shorter

J^{π}_{GS} — $T_{1/2}$



SCEPTAR: 10+10 plastic scintillators

Detects beta decays and determines branching ratios

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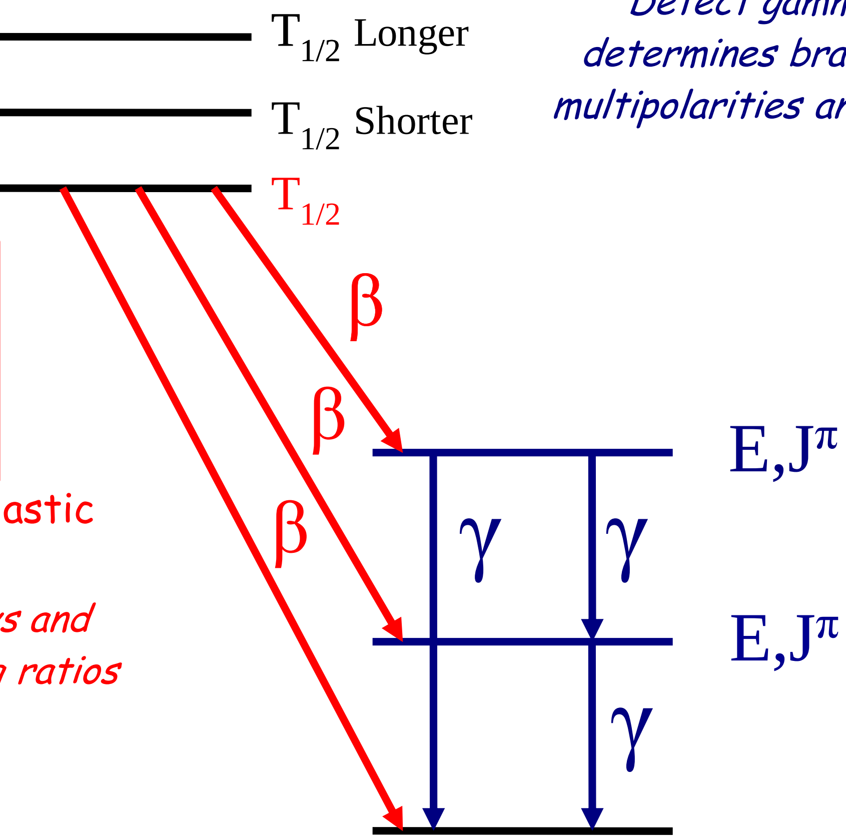
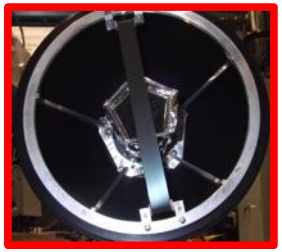




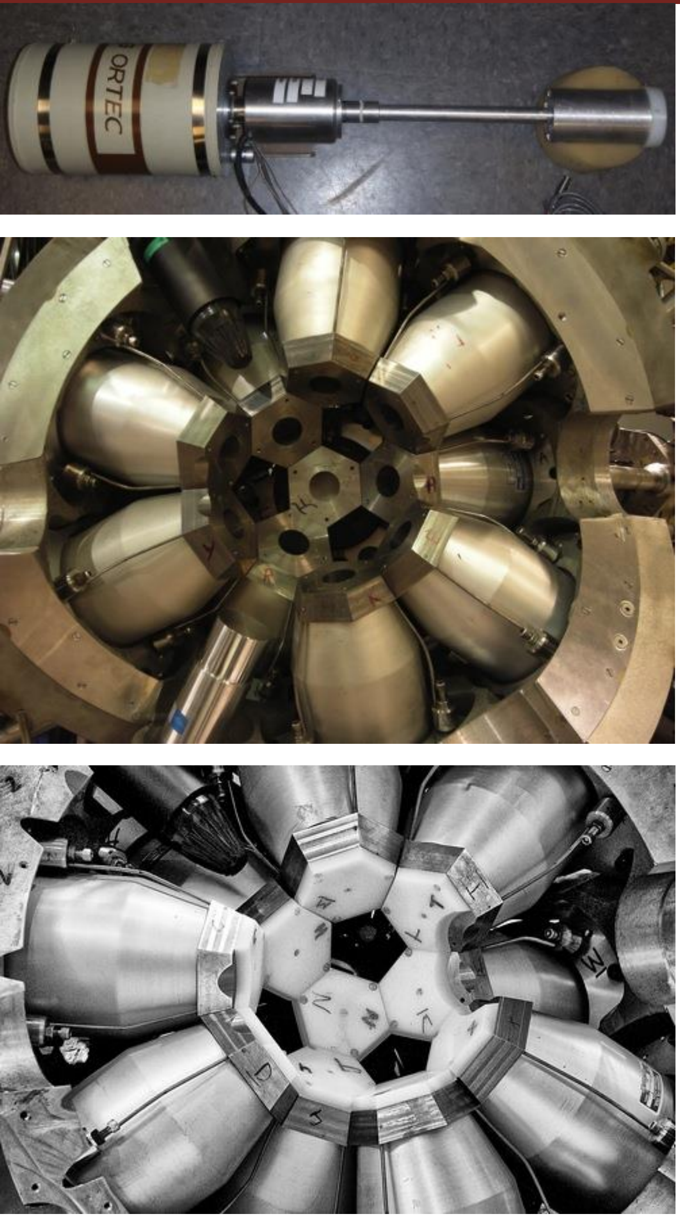
SCEPTAR: 10+10 plastic scintillators

Detects beta decays and determines branching ratios

8pi Ge: 20 Compton-Suppressed HpGe

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

8pi HPGe Detectors



Twenty Compton-Suppressed coaxial HPGe

Each has 20% relative efficiency, ~1% array total

1.8-2.2keV FWHM at 1.3MeV

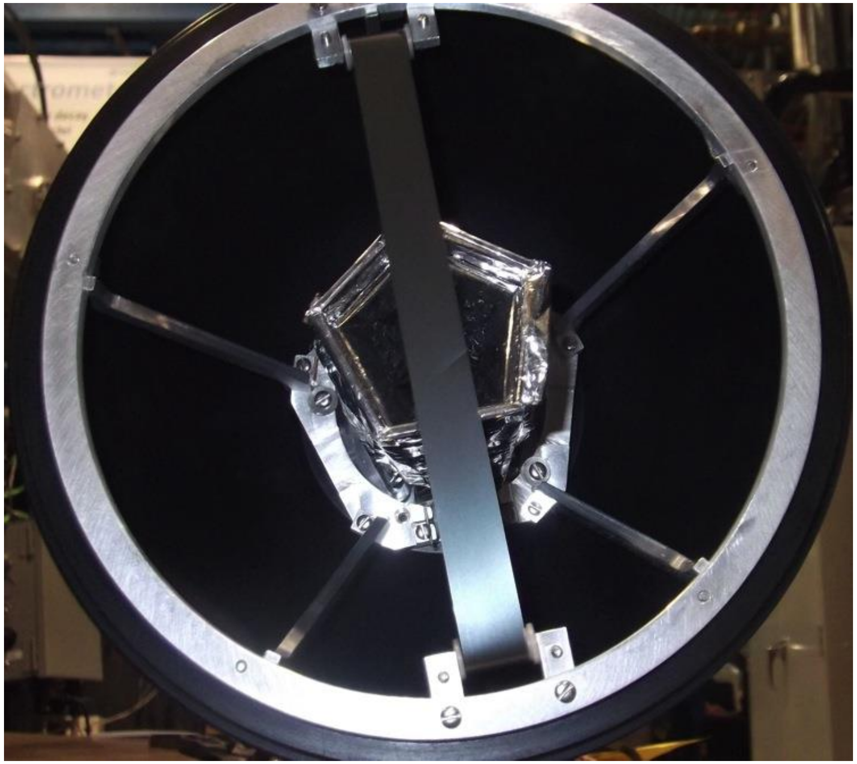
Thin Be front windows and delrin vacuum chamber to increase low-energy efficiency

Delrin absorbers to reduce Bremsstrahlung photons from high-energy beta particles

Icosahedron hexagonal arrangement for angular distribution measurements

TRIUMF

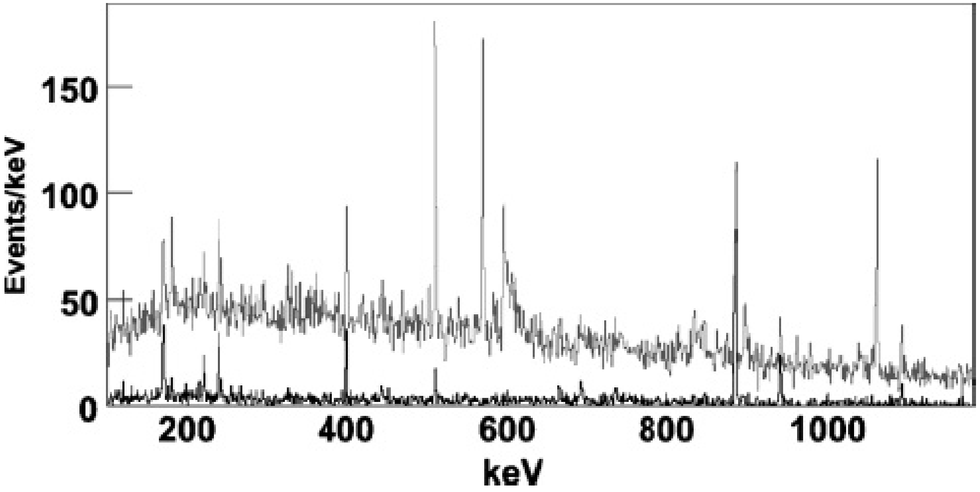
SCEPTAR
SCintillating Electron-Positron Tagging ARray



-Two hemispheres of 10 plastic scintillators

-Detect beta particles with ~80% solid angle coverage

-One-to-one correspondence with the HpGe



C.M. Mattoon *et al.*, PRC75, 017302 (2007)

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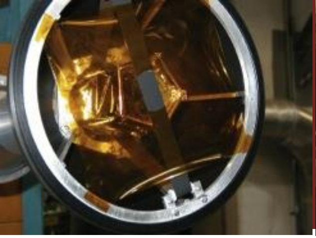
Sensitive Decay Spectroscopy

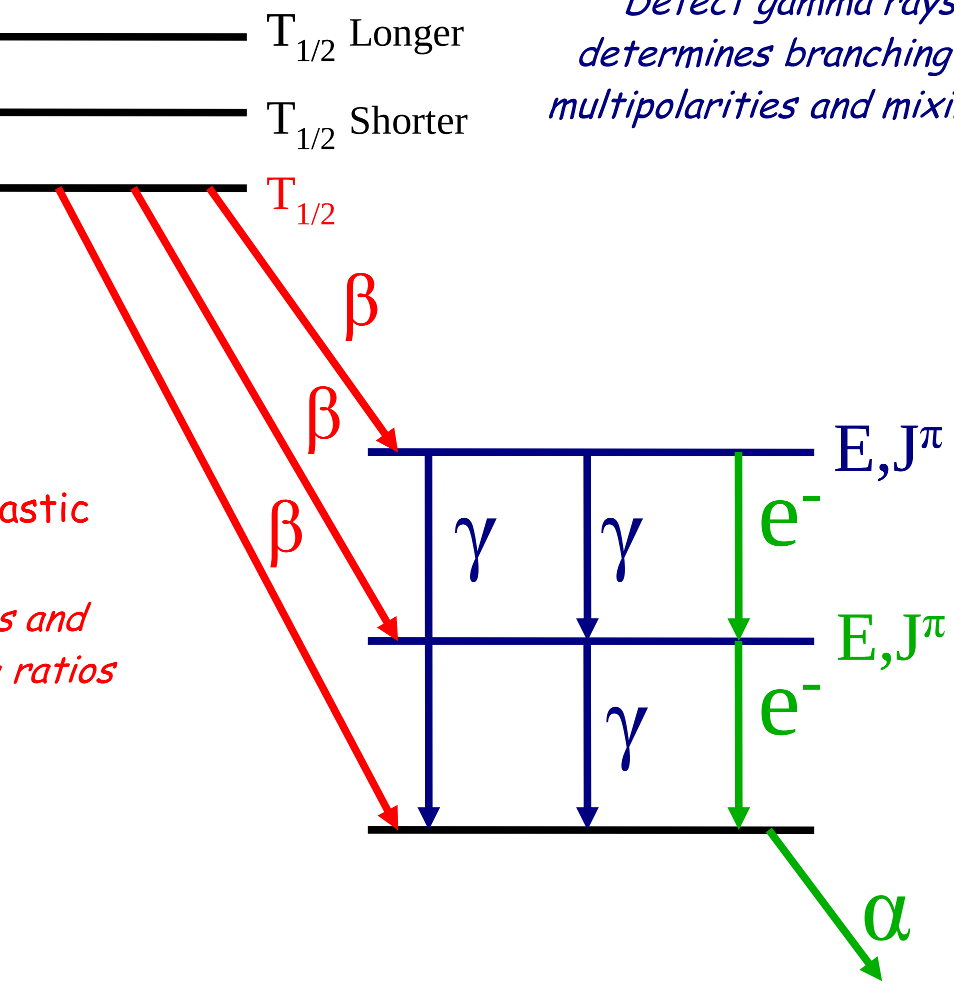


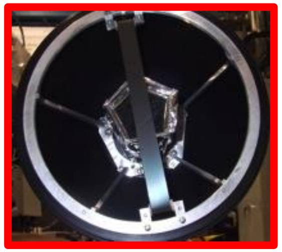
Fast, in-vacuum tape system

Enhances decay of interest

8pi Ge: 20 Compton-Suppressed HpGe

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





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Detects beta decays and determines branching ratios

PACES: 5 Cooled Si(Li)s

Detects Internal Conversion Electrons and alphas/protons

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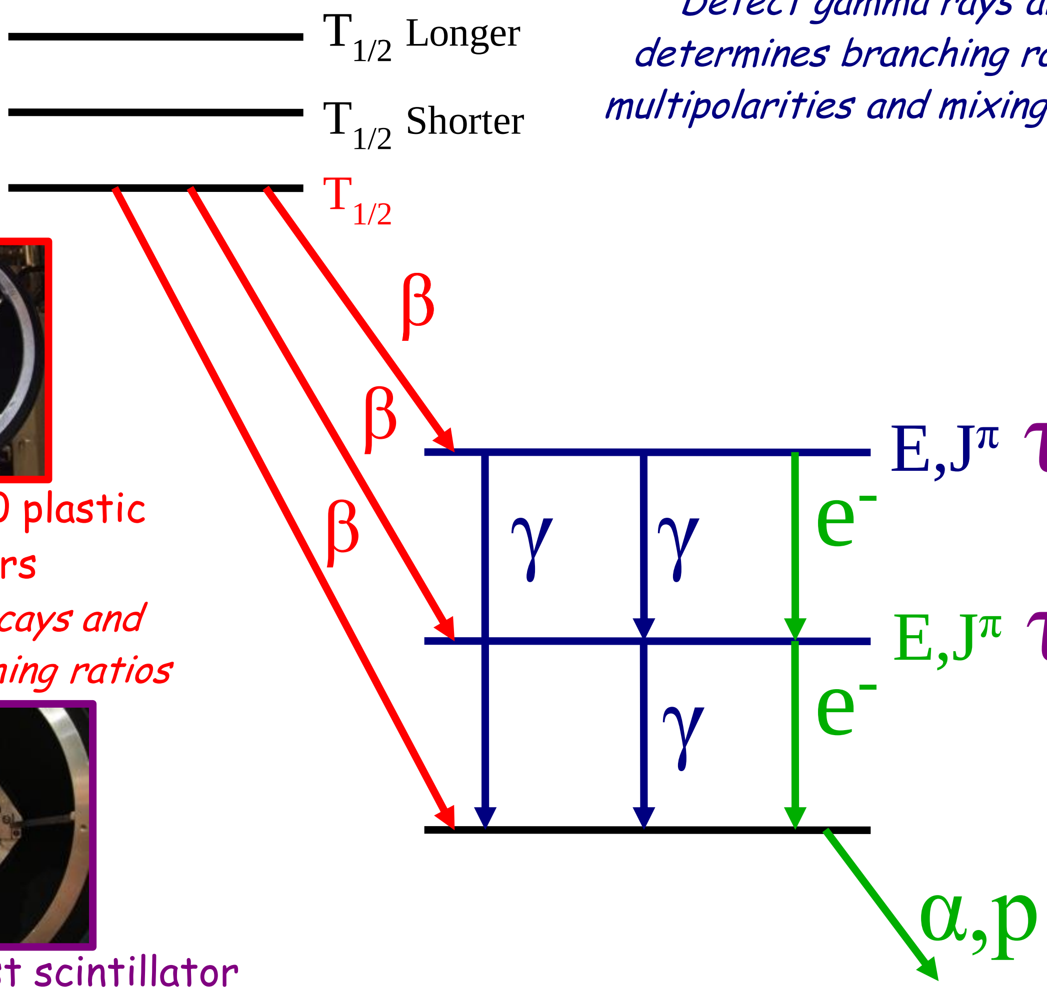

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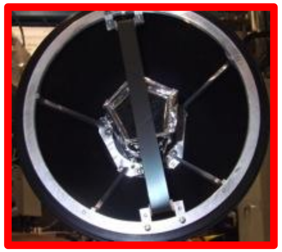
J^π_{ISOMER} — $T_{1/2}$ Shorter

J^π_{GS} — $T_{1/2}$

DANTE: 10 $BaF_2/LaBr_3$

Fast-timing of photons to measure level lifetimes



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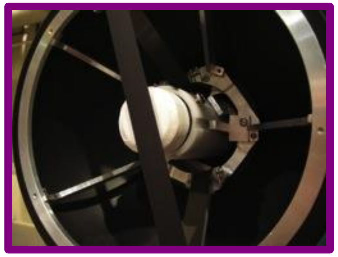

Zero-Degree Fast scintillator

Fast-timing signal for betas

PACES: 5 Cooled Si(Li)s

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The 8pi Spectrometer at TRIUMF

Sensitive Decay Spectroscopy

Fast, in-vacuum tape system

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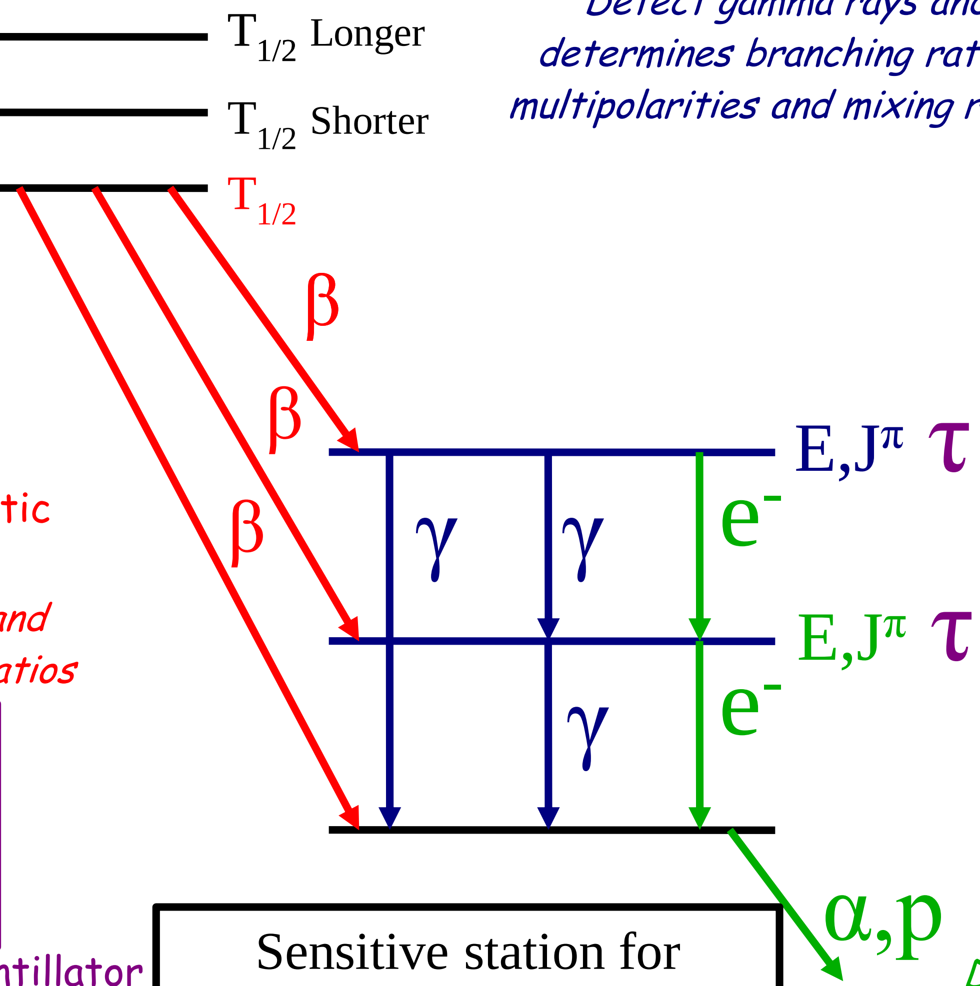

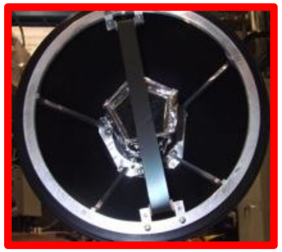

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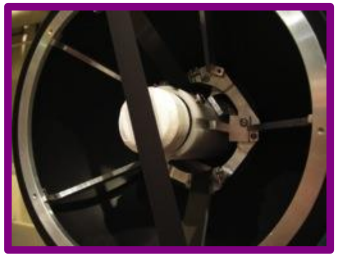


Zero-Degree Fast scintillator

Fast-timing signal for betas

Sensitive station for studying radioactive decay

8pi Ge: 20 Compton-Suppressed HpGe

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

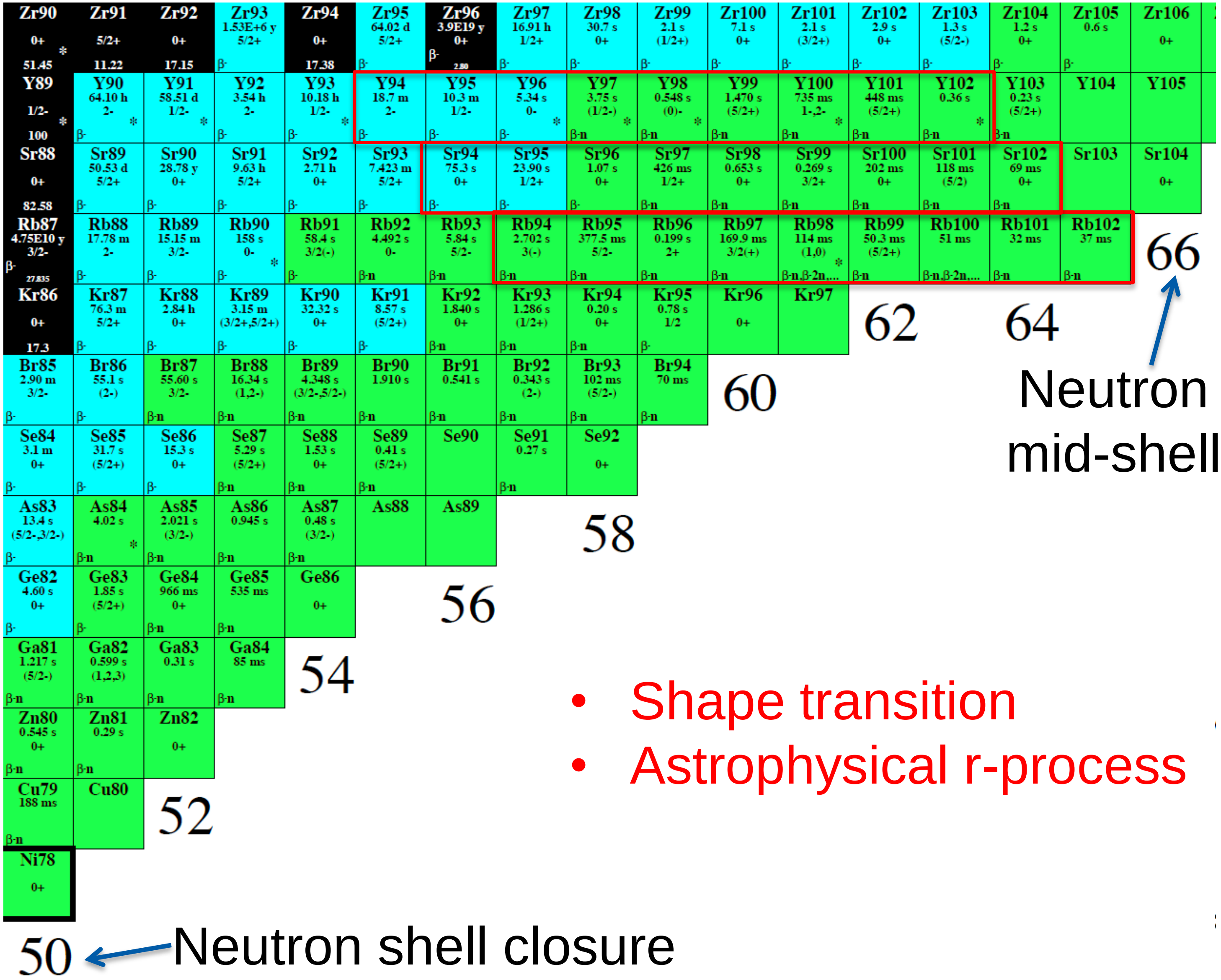
DANTE: 10 BaF_2/$LaBr_3$

Fast-timing of photons to measure level lifetimes

PACES: 5 Cooled Si(Li)s

Detects Internal Conversion Electrons and alphas/protons

Neutron-Rich Isotopes from UCx Target



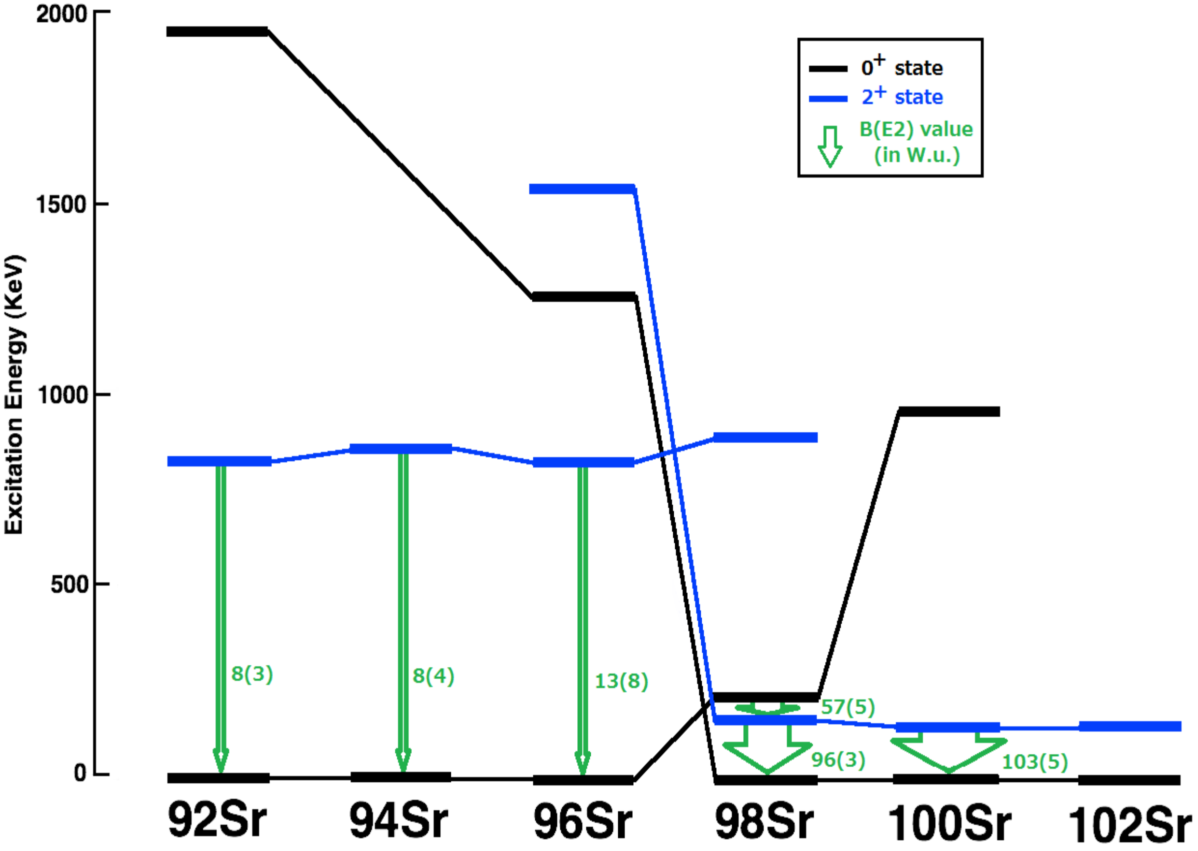
Z=40	Zr90 0+ * 51.45	Zr91 5/2+ 11.22	Zr92 0+ 17.15	Zr93 1.53E+6 y 5/2+ β-	Zr94 0+ 17.38	Zr95 64.02 d 5/2+ β-	Zr96 3.9E19 y 0+ β- 2.80	Zr97 16.91 h 1/2+ β-	Zr98 30.7 s 0+ β-	Zr99 2.1 s (1/2+) β-	Zr100 7.1 s 0+ β-	Zr101 2.1 s (3/2+) β-	Zr102 2.9 s 0+ β-	Zr103 1.3 s (5/2-) β-	Zr104 1.2 s 0+ β-	Zr105 0.6 s β-	Zr106 0+
Z=39	Y89 1/2- * 100	Y90 64.10 h 2- * β-	Y91 58.51 d 1/2- * β-	Y92 3.54 h 2- β-	Y93 10.18 h 1/2- * β-	Y94 18.7 m 2- β-	Y95 10.3 m 1/2- β-	Y96 5.34 s 0- * β-	Y97 3.75 s (1/2-) * β-n	Y98 0.548 s (0)- * β-n	Y99 1.470 s (5/2+) β-n	Y100 735 ms 1-,2- * β-n	Y101 448 ms (5/2+) β-n	Y102 0.36 s * β-n	Y103 0.23 s (5/2+) β-n	Y104	Y105
Z=38	Sr88 0+ 82.58	Sr89 50.53 d 5/2+ β-	Sr90 28.78 y 0+ β-	Sr91 9.63 h 5/2+ β-	Sr92 2.71 h 0+ β-	Sr93 7.423 m 5/2+ β-	Sr94 75.3 s 0+ β-	Sr95 23.90 s 1/2+ β-	Sr96 1.07 s 0+ β-	Sr97 426 ms 1/2+ β-n	Sr98 0.653 s 0+ β-n	Sr99 0.269 s 3/2+ β-n	Sr100 202 ms 0+ β-n	Sr101 118 ms (5/2) β-n	Sr102 69 ms 0+ β-n	Sr103	Sr104 0+
Z=37	Rb87 4.75E10 y 3/2- β- 27.835	Rb88 17.78 m 2- β-	Rb89 15.15 m 3/2- β-	Rb90 158 s 0- * β-	Rb91 58.4 s 3/2(-) β-	Rb92 4.492 s 0- β-n	Rb93 5.84 s 5/2- β-n	Rb94 2.702 s 3(-) β-n	Rb95 377.5 ms 5/2- β-n	Rb96 0.199 s 2+ β-n	Rb97 169.9 ms 3/2(+) β-n	Rb98 114 ms (1,0) * β-n,β-2n,...	Rb99 50.3 ms (5/2+) β-n	Rb100 51 ms β-n,β-2n,...	Rb101 32 ms β-n	Rb102 37 ms β-n	
	Kr86 0+ 17.3	Kr87 76.3 m 5/2+ β-	Kr88 2.84 h 0+ β-	Kr89 3.15 m (3/2+,5/2+) β-	Kr90 32.32 s 0+ β-	Kr91 8.57 s (5/2+) β-	Kr92 1.840 s 0+ β-n	Kr93 1.286 s (1/2+) β-n	Kr94 0.20 s 0+ β-n	Kr95 0.78 s 1/2 β-	Kr96 0+	Kr97					
	Br85 2.90 m 3/2- β-	Br86 55.1 s (2-) β-	Br87 55.60 s 3/2- β-n	Br88 16.34 s (1,2-) β-n	Br89 4.348 s (3/2-,5/2-) β-n	Br90 1.910 s β-n	Br91 0.541 s β-n	Br92 0.343 s (2-) β-n	Br93 102 ms (5/2-) β-n	Br94 70 ms β-n							
	Se84 3.1 m 0+ β-	Se85 31.7 s (5/2+) β-	Se86 15.3 s 0+ β-	Se87 5.29 s (5/2+) β-n	Se88 1.53 s 0+ β-n	Se89 0.41 s (5/2+) β-n	Se90	Se91 0.27 s β-n	Se92 0+								
	As83 13.4 s (5/2-,3/2-) β-	As84 4.02 s * β-n	As85 2.021 s (3/2-) β-n	As86 0.945 s β-n	As87 0.48 s (3/2-) β-n	As88	As89										
	Ge82 4.60 s 0+ β-	Ge83 1.85 s (5/2+) β-	Ge84 966 ms 0+ β-n	Ge85 535 ms β-n	Ge86 0+												
	Ga81 1.217 s (5/2-) β-n	Ga82 0.599 s (1,2,3) β-n	Ga83 0.31 s β-n	Ga84 85 ms β-n													
	Zn80 0.545 s 0+ β-n	Zn81 0.29 s β-n	Zn82 0+														
	Cu79 188 ms β-n	Cu80															
Z=28	Ni78 0+																

Neutron mid-shell

Neutron shell closure

- Shape transition
- Astrophysical r-process

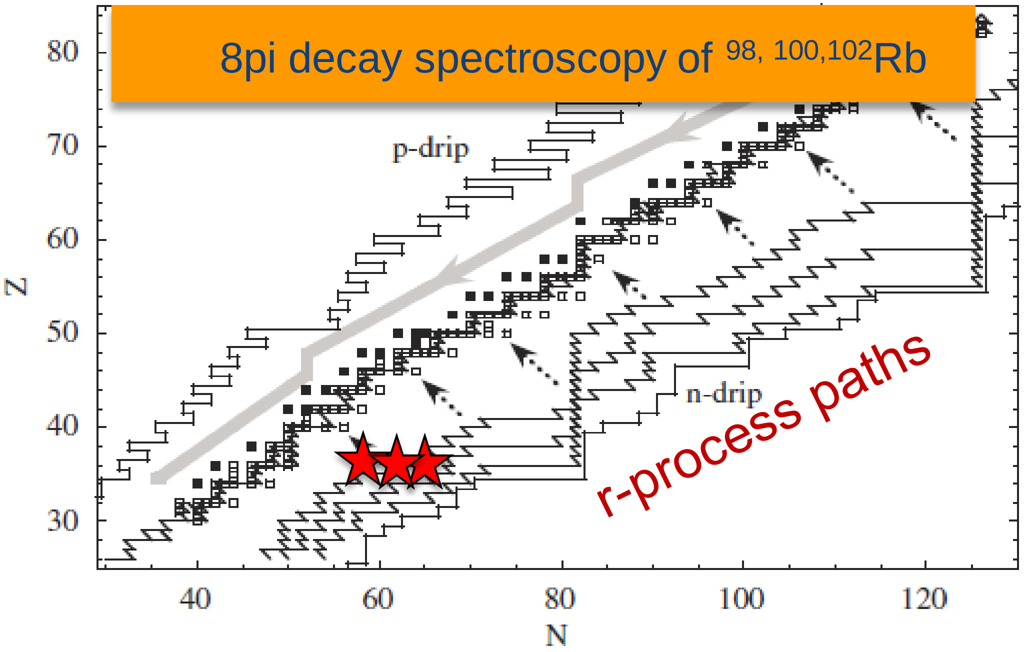
Decay of ^{102}Rb(S1337): Motivations on nuclear structure



^{92,94,96,98,100}Sr, ENSDF, ^{102}Sr, G. Lhersonneau et al., Z. Phys. A351, 357 (1995)

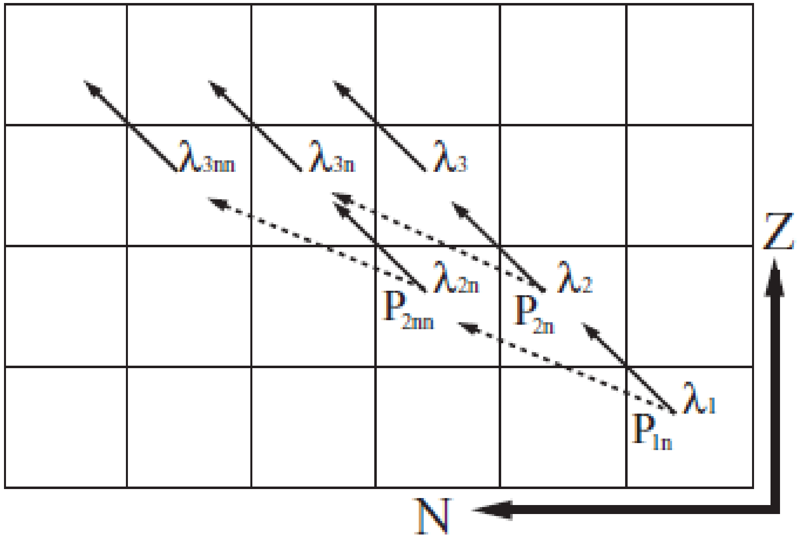
- Shape transition and coexistence in neutron-rich Sr.
- Extend nuclear structure knowledge at extreme isospin nuclei ^{101,102}Sr, $E(4^+)/E(2^+)$, $T_{1/2}$ of 2_1^+.
- γ-e⁻ coincident measurements can address E0 $(0_1^+ \text{->} 0_{g.s.}^+)$ shape transition strength.

Decay of ^{102}Rb(1337): Motivations on nuclear astrophysics



8pi decay spectroscopy of $^{98, 100,102}$Rb

r-process paths



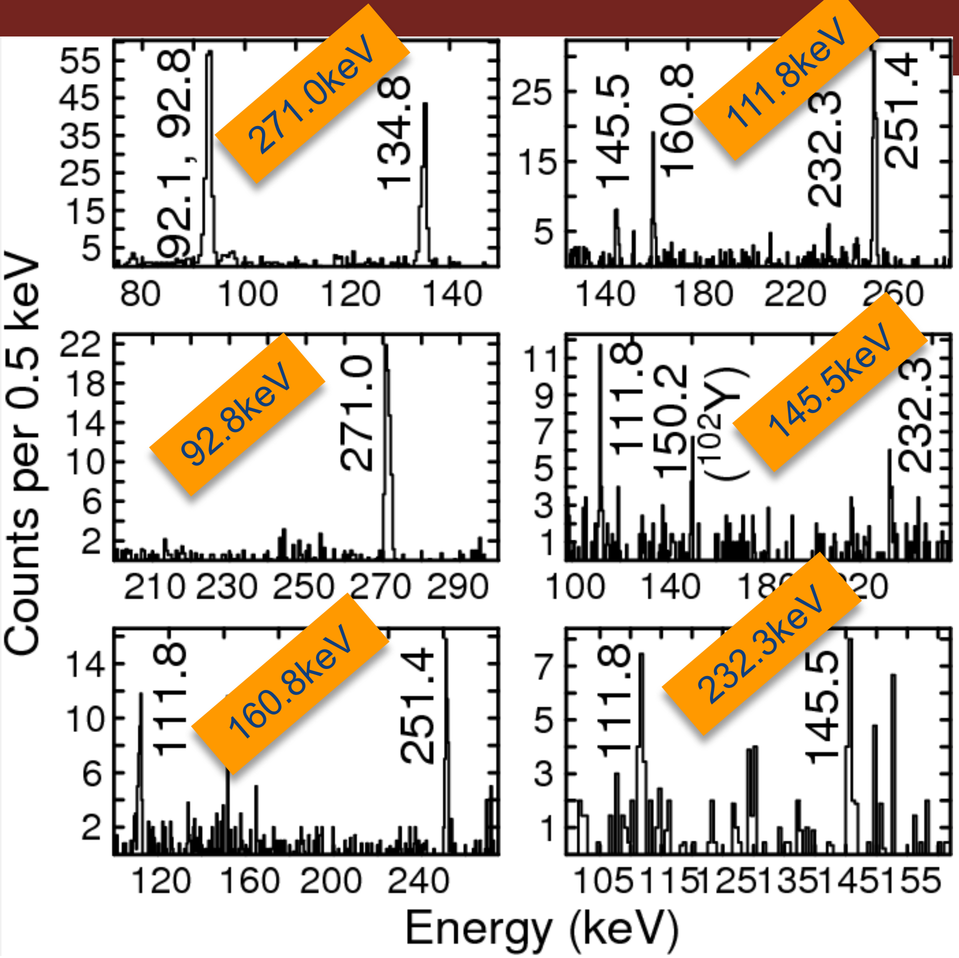
M. Arnould et al., Phys. Rep. **450** 97 (2007)

- Element abundance is determined by stellar conditions as well as *β*-decay half-life and *β*-delayed neutron emission branching ratio.
- The discrepancy in $T_{1/2}$ between theoretical predictions and experimental data leads to difficulties of r-process flow calculations.

S. Nishimura et al, PRL 106, 052502 (2011)

- Decay properties of ^{98,100,102}Rb are important for theoretical models.

Decay of ^{102}Rb: Results



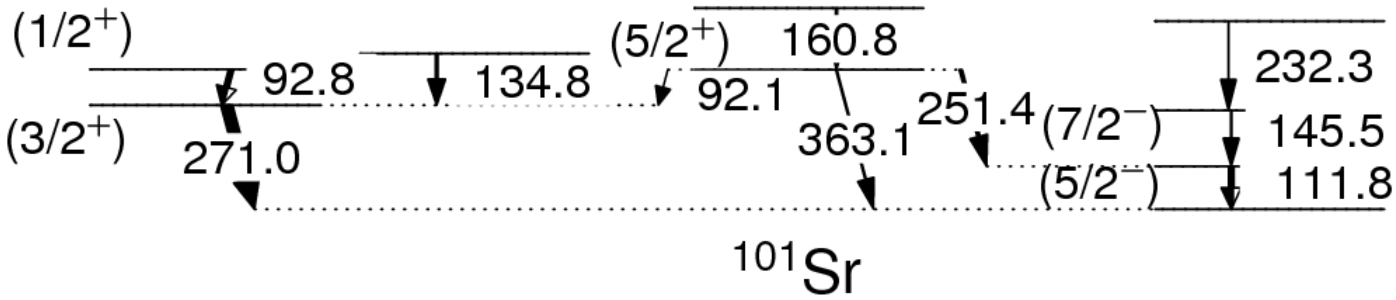
~6.5pps ^{102}Rb beam vs $\beta\gamma\gamma$ coincidence measurement

- ^{101}Sr populated in β-delayed neutron emission
- Level scheme consistent with previous beta-decay study

Lhersonneau *et al.*, Z. Phys. A 351, 357 (1995)

- Level scheme is extended by adding 134.8, 145.5 and 160.8 keV transitions

^{102}Rb ➔ ^{101}Sr



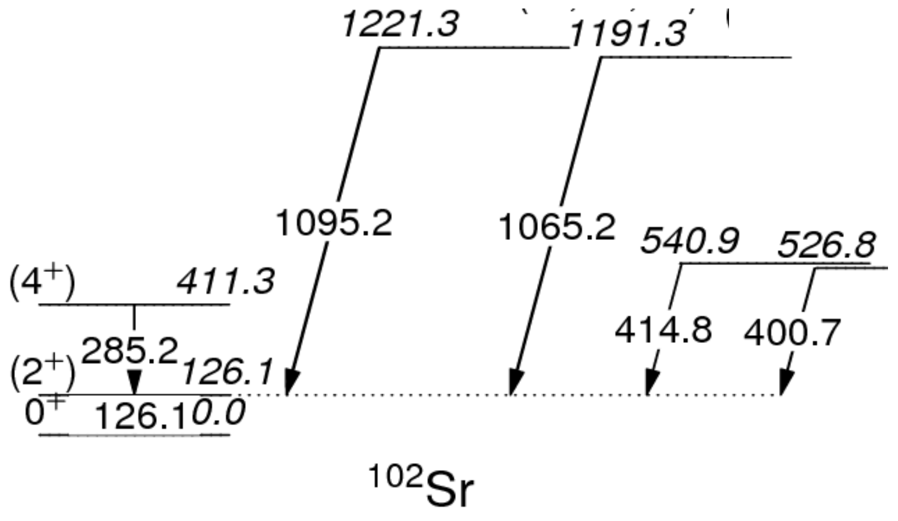
Decay of ^{102}Rb: Results

^{102}Sr populated in β-decay

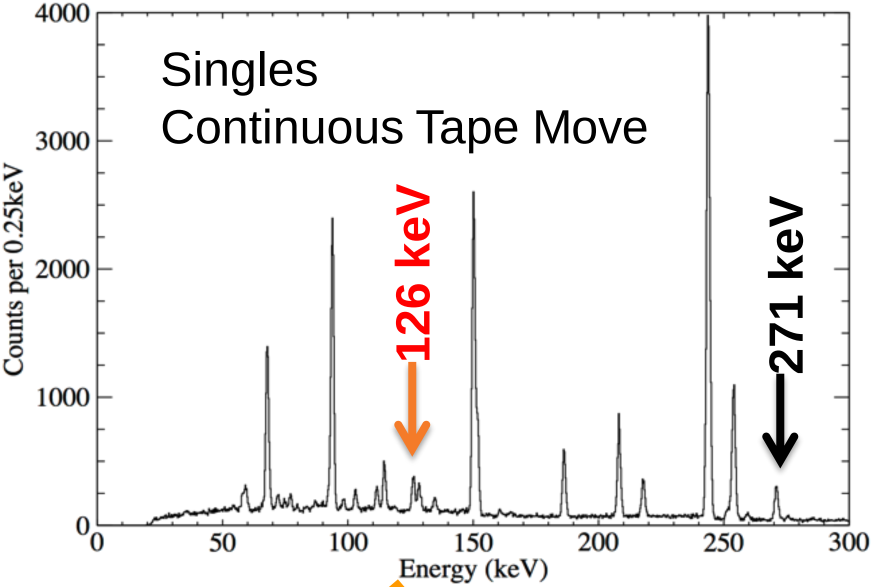
Previously only 126 keV known

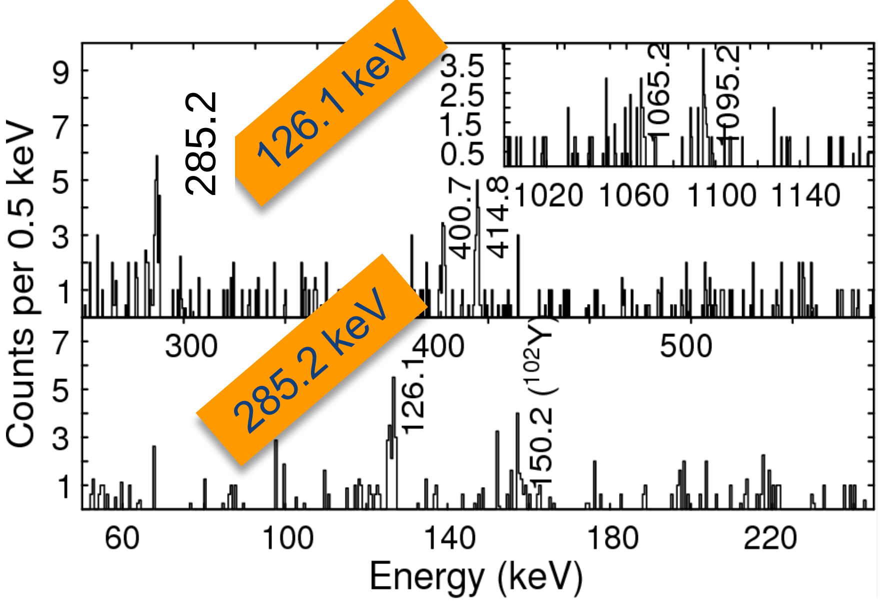
Lhersonneau *et al.*, Z. Phys. A 351, 357 (1995).

Extend the level scheme and more…



^{102}Rb → ^{102}Sr

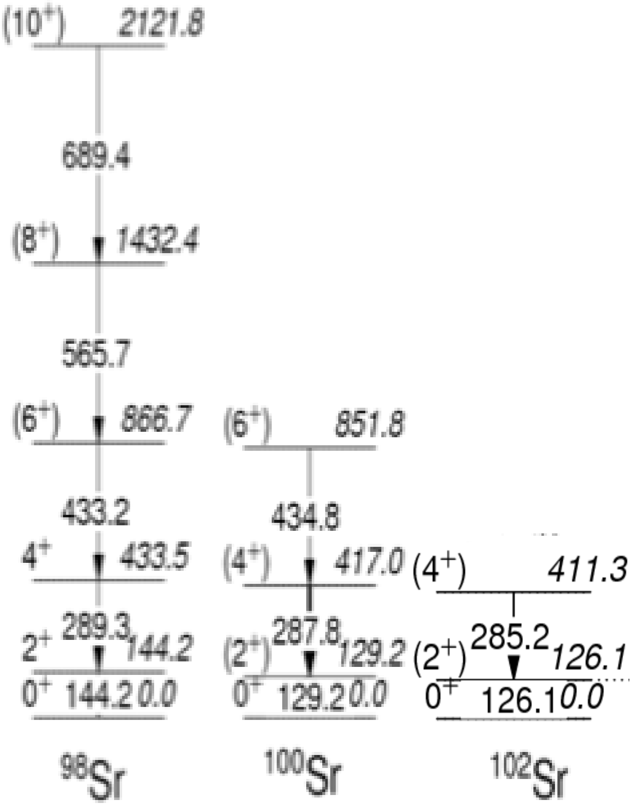


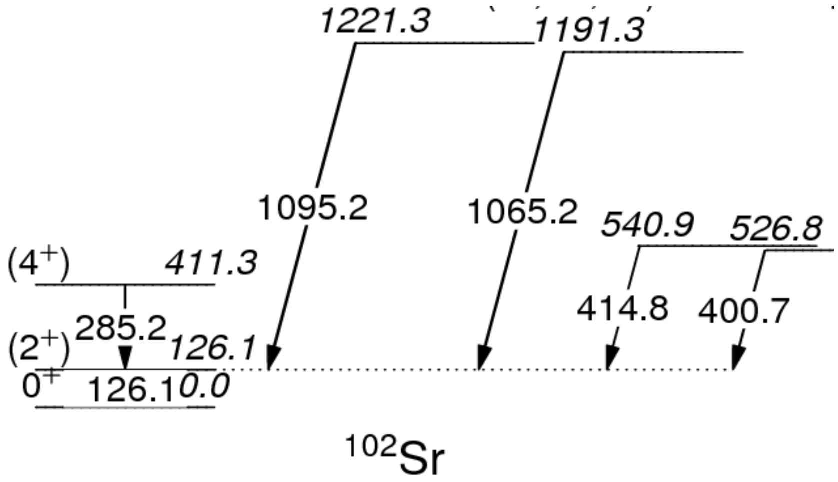


Decay of ^{102}Rb: Results

^{102}Rb GS $J^{\pi}=(3^{+},4^{-})$ from sys, 3^{+} supported by beta-branching ratio, 45(8)% to (2^{+})

Saturation of deformation towards N=66 mid-shell, down-sloping intruding orbitals, especially $h_{11/2}$



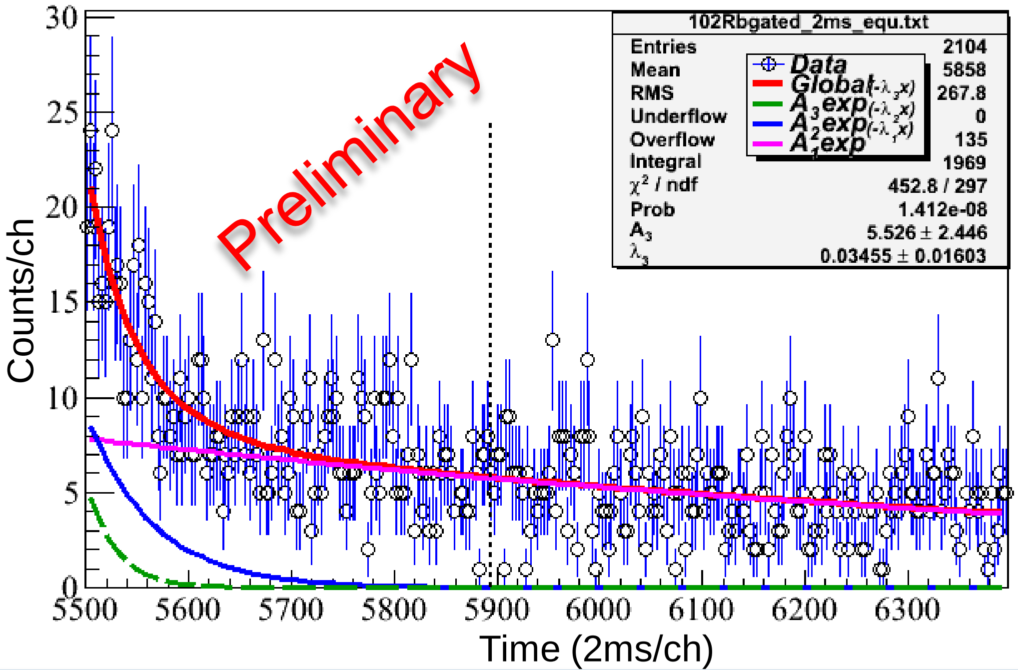


^{102}Rb ➔ ^{102}Sr

	$^{98}Sr_{60}$	$^{100}Sr_{62}$	$^{102}Sr_{64}$
$E(4^{+})/E(2^{+})$	3.01	3.23	3.26
β_2	0.408(6)	0.423(12)	~0.4

S. Raman et al., At. Data and Nucl. Data Tables 78, 1 (2001)

Decay of ^{102}Rb



Time profile of 112, 126 and 271 keV ɣ ray

$T_{1/2}$ = 40 (+35–13) ms

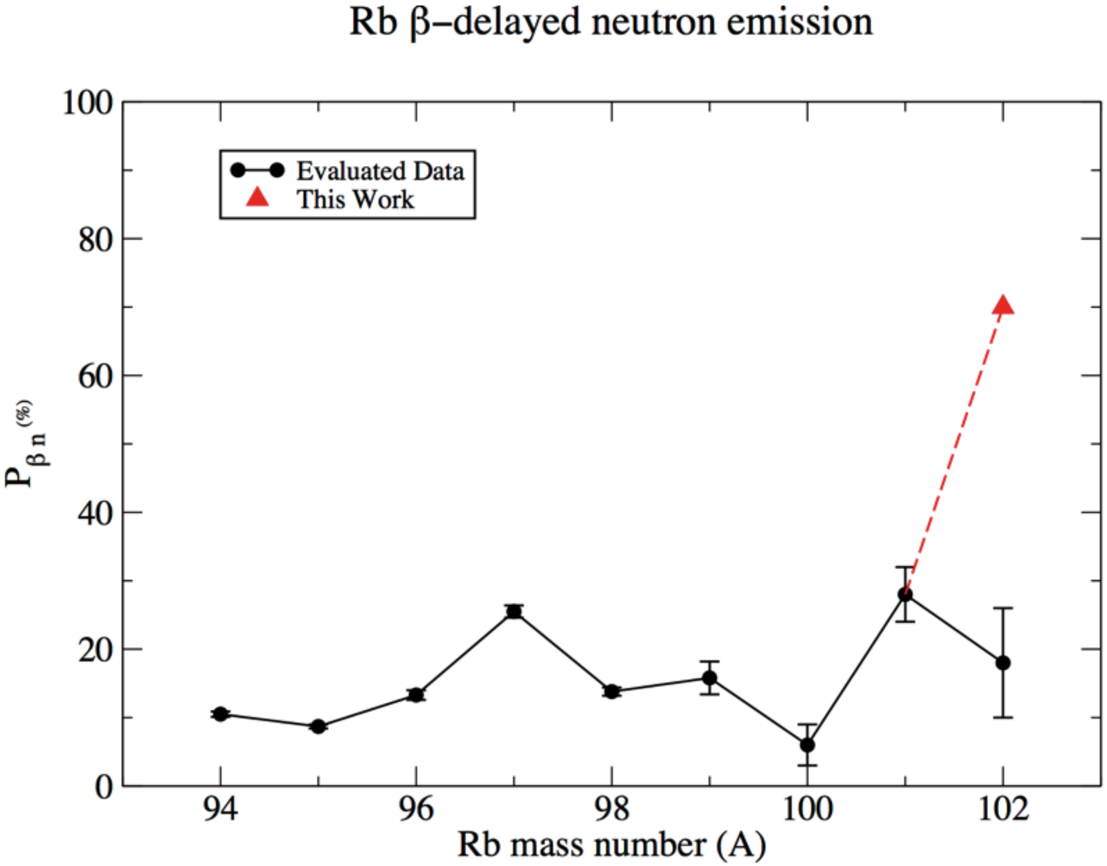
37 (3) ms
G. Lhersonneau *et al.*, Z. Phys. A 351, 357 (1995)
35 (+15-8) ms
S. Nishimura, *et al.*, PRL106, 052502 (2011)

Beta-Delayed Neutron Branching Ratio:
I(^{101}Sr) / I(^{101}Sr + ^{102}Sr) = 54% is lower limit from this data with 50% feeding to GS of ^{102}Sr. If use 0% to GS, then Pn=70%

The systematic shows the neutron branching ratio to g. s. decrease with $Q_{\beta n}$ value increase.
K.-L. Kratz, *et al.*, Z. Phys. A306, 3, 239(1982)

Previous was 18 (8)% B. Pfeiffer *et al.*, Proc. ICDNP, Birmingham, D.R. Weaver, Ed., p.75 (1987)
FRDM+QRPA: 19.7% P. Moller *et al.*, Atom. Data and Nucl. Data Tables 66, 131 (1997)

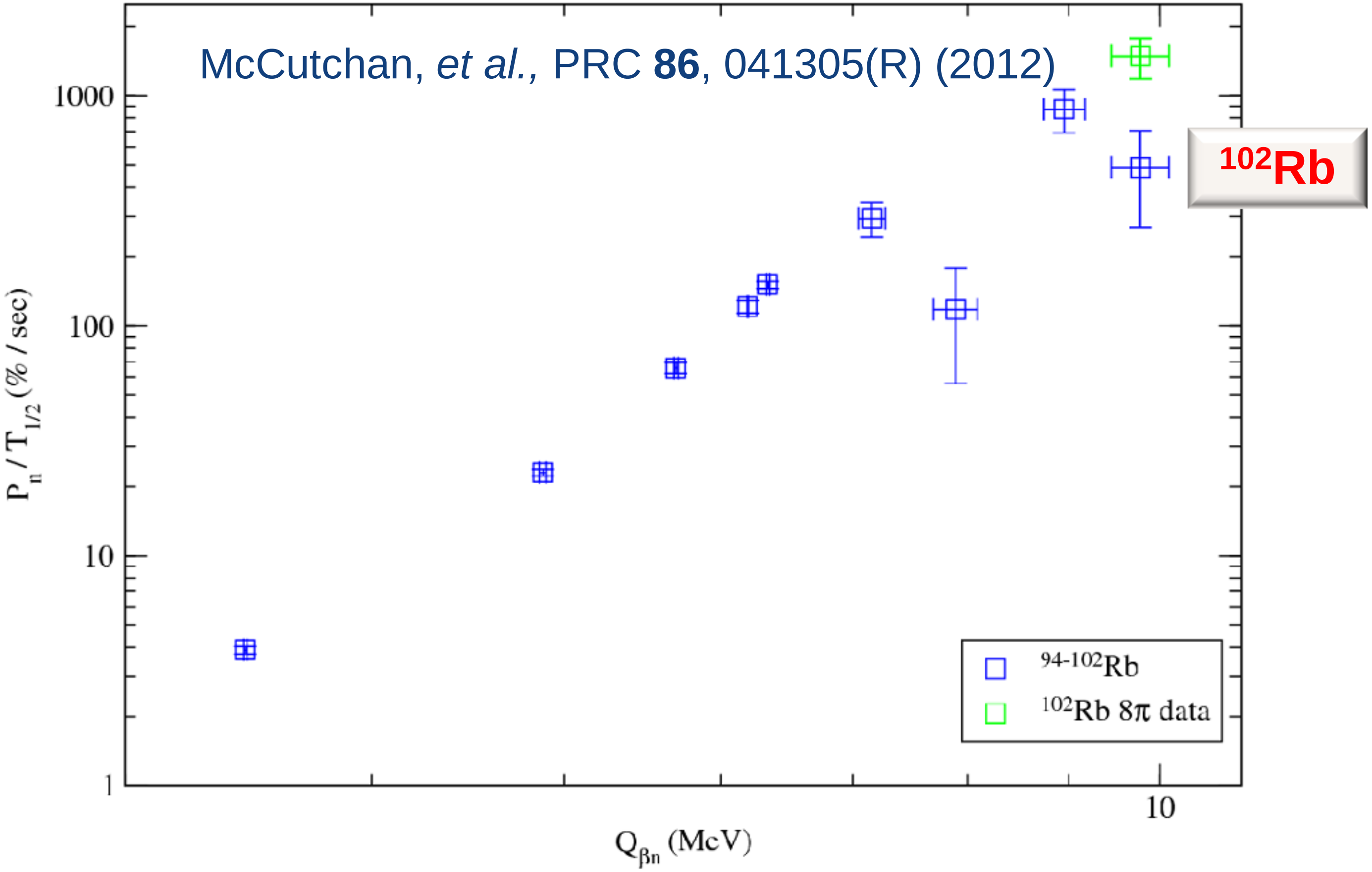
Beta Delayed Neutron Branching Ratio



Implications for r-process. Decay back to stability affected by Pn. If ^{102}Rb value so large, what about others in this region?

Motivates beta-neutron-gamma measurements:
DESCANT, VANDLE, 3HEN

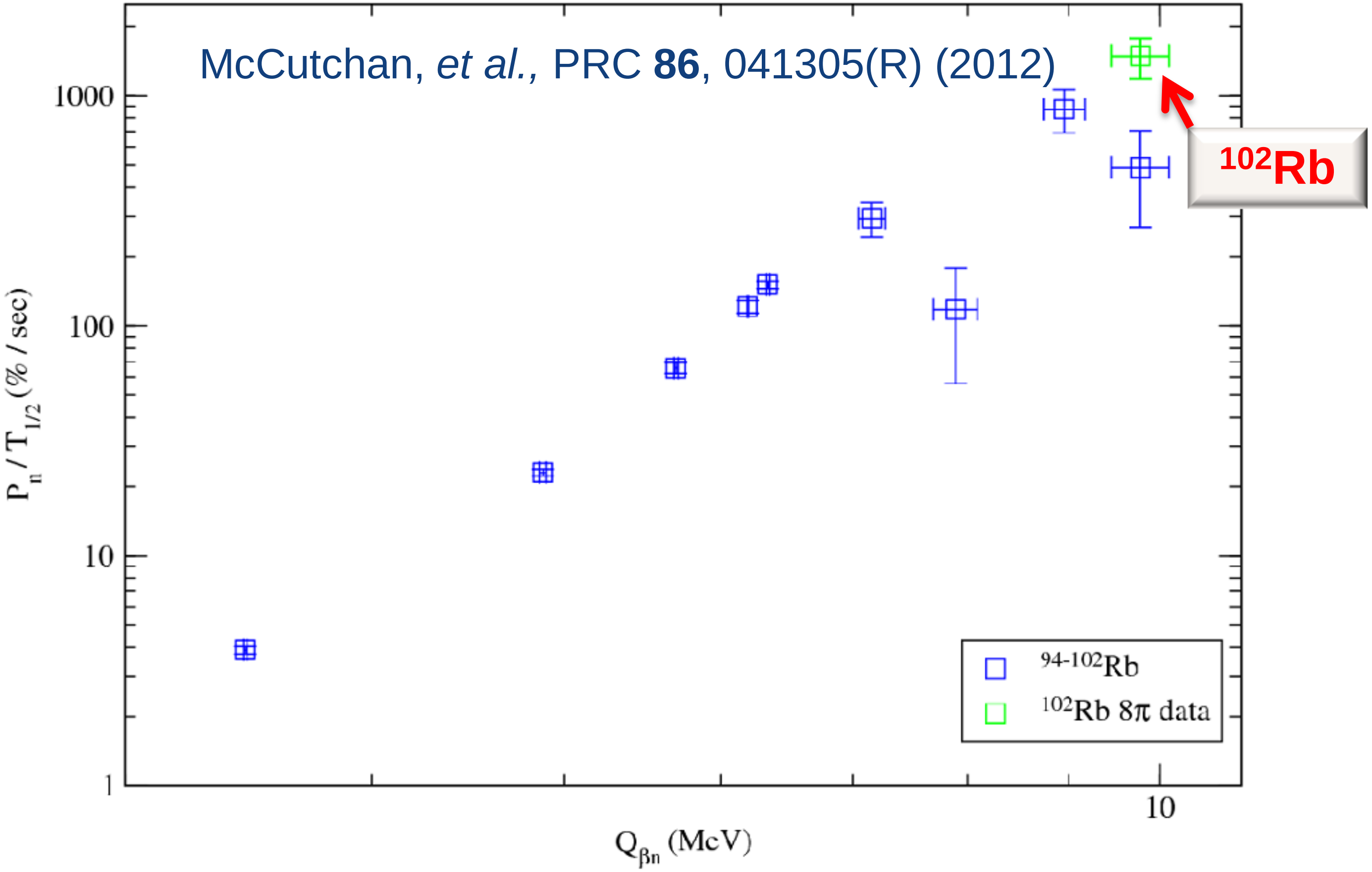
Beta Delayed Neutron Branching Ratio



Implications for r-process. Decay back to stability affected by Pn. If ^{102}Rb value so large, what about others in this region?

Motivates beta-neutron-gamma measurements:
DESCANT, VANDLE, 3HEN

Beta Delayed Neutron Branching Ratio



McCutchan, *et al.*, PRC **86**, 041305(R) (2012)

^{102}Rb

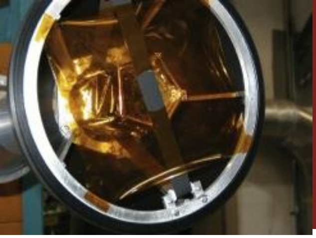
Implications for r-process. Decay back to stability affected by P_n. If ^{102}Rb value so large, what about others in this region?

Motivates beta-neutron-gamma measurements:
DESCANT, VANDLE, 3HEN

Future GRIFFIN at TRIUMF

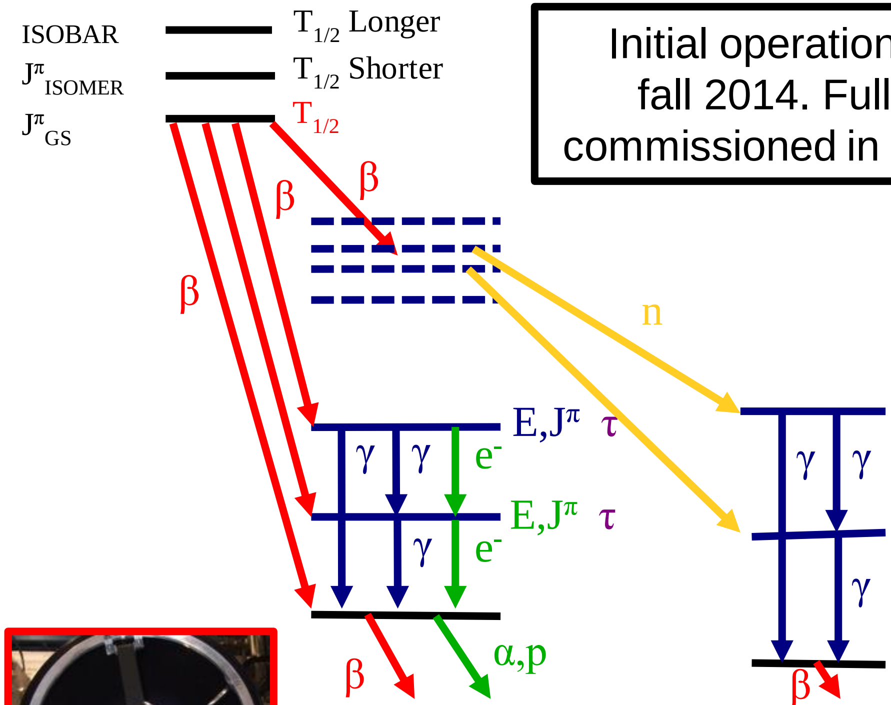
Sensitive Decay Spectroscopy

GRIFFIN



Fast, in-vacuum tape system

Enhances decay of interest



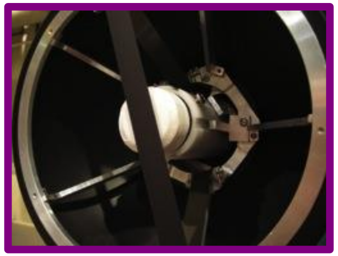
Initial operation in fall 2014. Fully commissioned in 2015

HPGe: 16 Clovers

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

DANTE: 8 Compton-Suppressed $LaBr_3$

Fast-timing of photons to measure level lifetimes

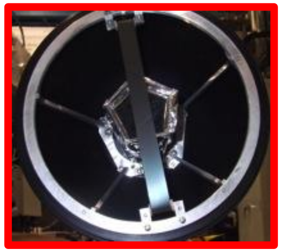


Zero-Degree Fast scintillator

Fast-timing signal for betas

PACES: 5 Cooled Si(Li)s

Detects Internal Conversion Electrons and alphas/protons



SCEPTAR: 10+10 plastic scintillators

Detects beta decays and determines branching ratios

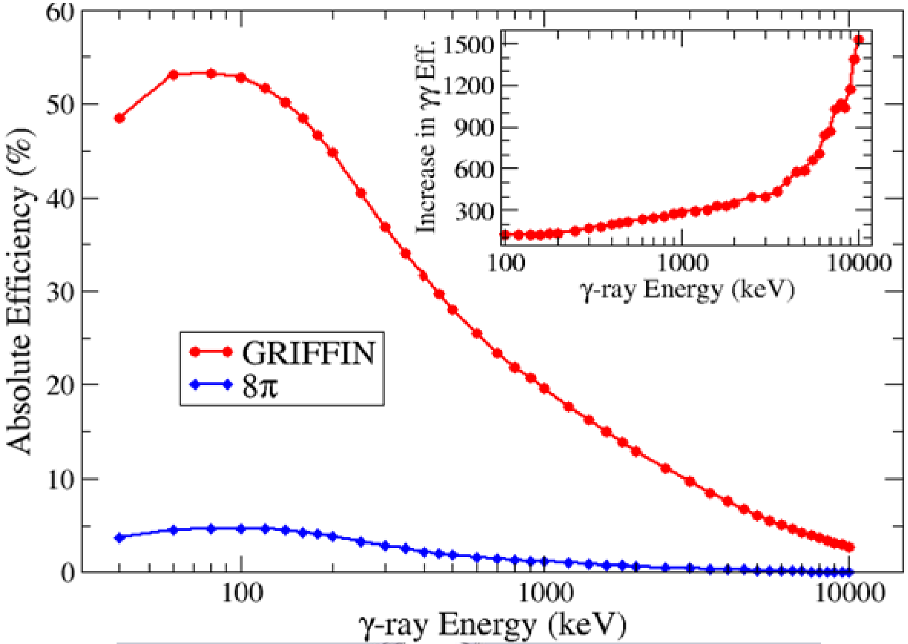
DESCANT: 70 deuterated scintillators

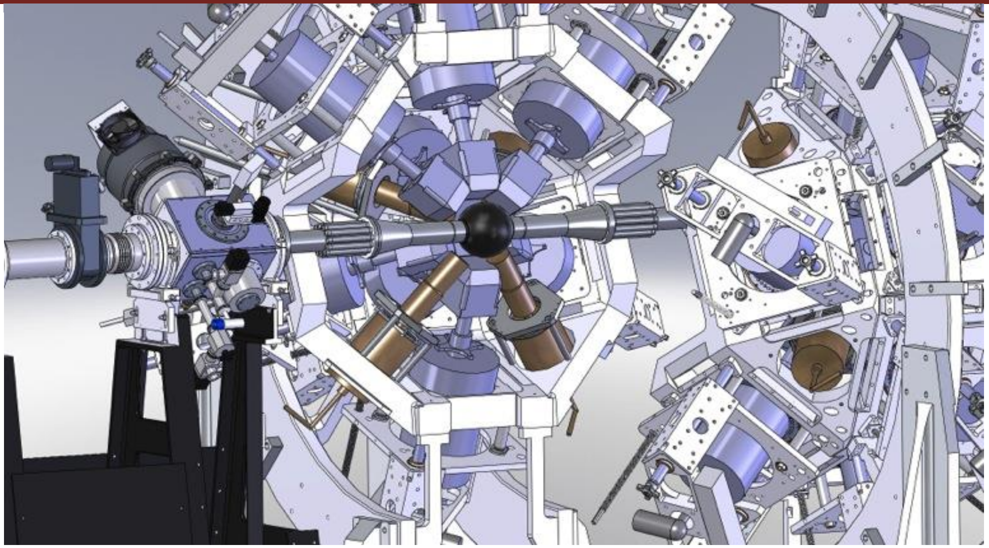
Detects neutrons to measure beta-delayed neutron branching ratios

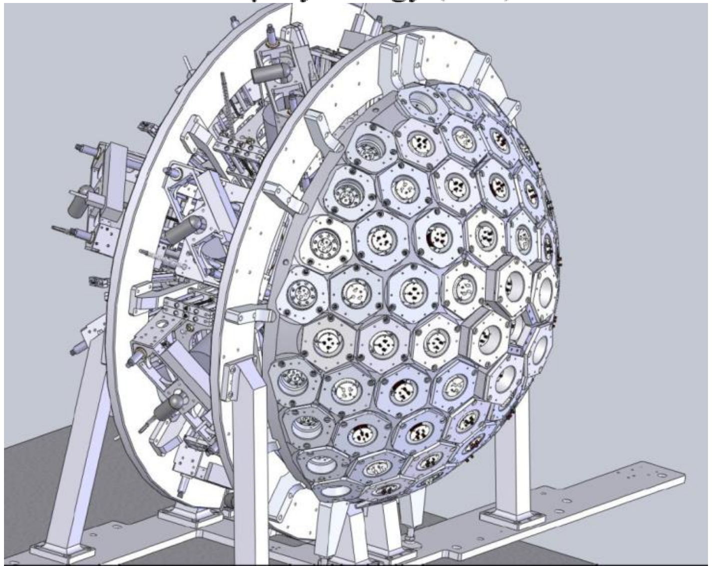
TRIUMF

GRIFFIN

Gamma-Ray Infrastructure For Fundamental Investigations of Nuclei



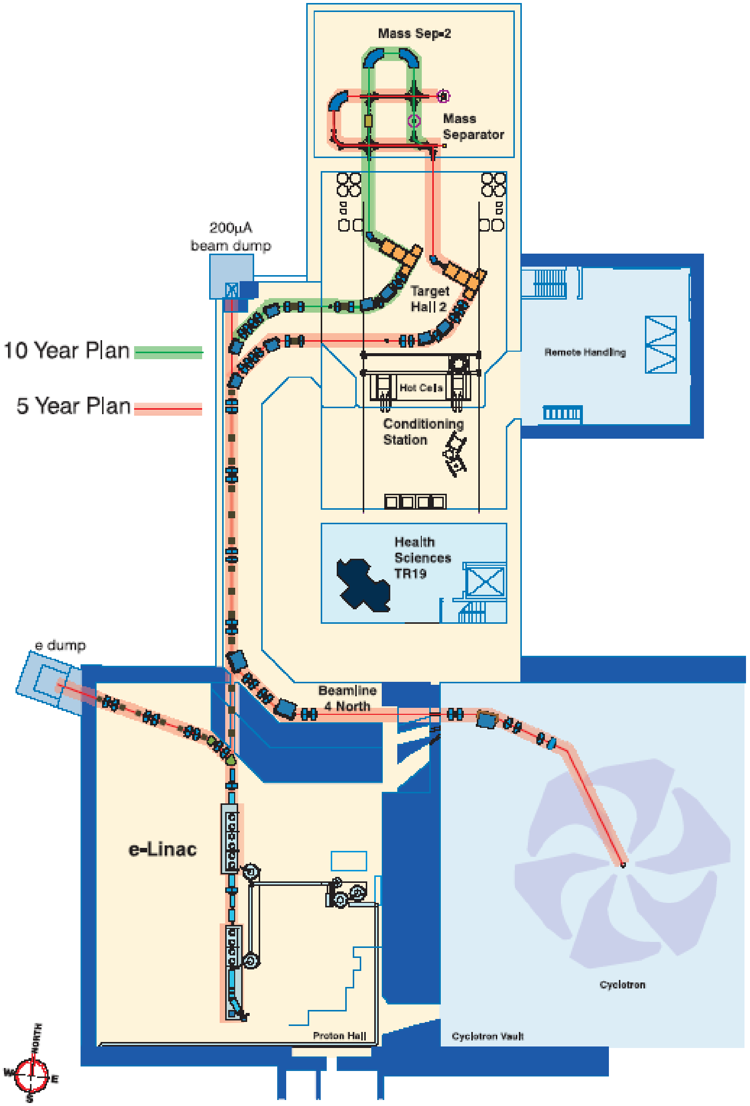




Single = ×17 @ 1.3MeV, ×300 fold increase in γ and γγ efficiencies

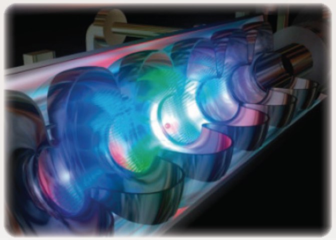
- DESCANT: 70 element neutron array formed of deuterated benzene scintillators, 15~20%
- Fast digital electronics, high precision clock and high throughput DAQ

Advanced Rare Isotope Laboratory



TRIUMF **ARIEL**

ADVANCED RARE ISOTOPE LABORATORY



ARIEL is a new underground beam tunnel surrounding a next-generation linear accelerator – an e-linac, led by the University of Victoria. The project will allow TRIUMF to develop technology to advance Canada's supply of critical medical isotopes, capitalize on existing investments, and broaden its research capabilities in particle physics, nuclear physics, nuclear medicine, and materials science.

Conclusions

- Wide program of study utilizing Radioactive Ion Beams at TRIUMF-ISAC

- TIGRESS is a powerful tool to study halo structures

- 8pi has been exploring neutron-rich nuclei produced from actinide target

- GRIFFIN facility extends opportunities for radioactive decay studies

- New ARIEL infrastructure expands the capabilities of ISAC

Acknowledgements

TRIUMF

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SFU SIMON FRASER UNIVERSITY THINKING OF THE WORLD

C. Andreoiu, A.S. Chester, D. Cross, J. Pore, P. Voss

COLORADO SCHOOL OF MINES EARTH ▲ ENERGY ▲ ENVIRONMENT

R. Braid, K. Kuhn, P.O'Malley, F. Sarazin

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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 | Winnipeg | York

Canada
British Columbia
The Best Place on Earth
Canada Foundation for Innovation
Fondation canadienne pour l'innovation
CIHR IRSC
NRC·CNRC From Discovery to Innovation...
NSERC CRSNG
Western Economic Diversification Canada
Diversification de l'économie de l'Ouest Canada
Natural Resources Canada
Ressources naturelles Canada

BC Cancer Agency
D-Pace
CINP ICPN
Institute of Particle Physics
GE imagination at work Canada
nordion
Selkirk College
cpdc Centre for Probe Development and Commercialization
AAPS Advanced Applied Physics Solutions
LAWSON Health Research Institute
Positron Emission Tomography Imaging at The University of British Columbia
Pacific Parkinson's Research Institute

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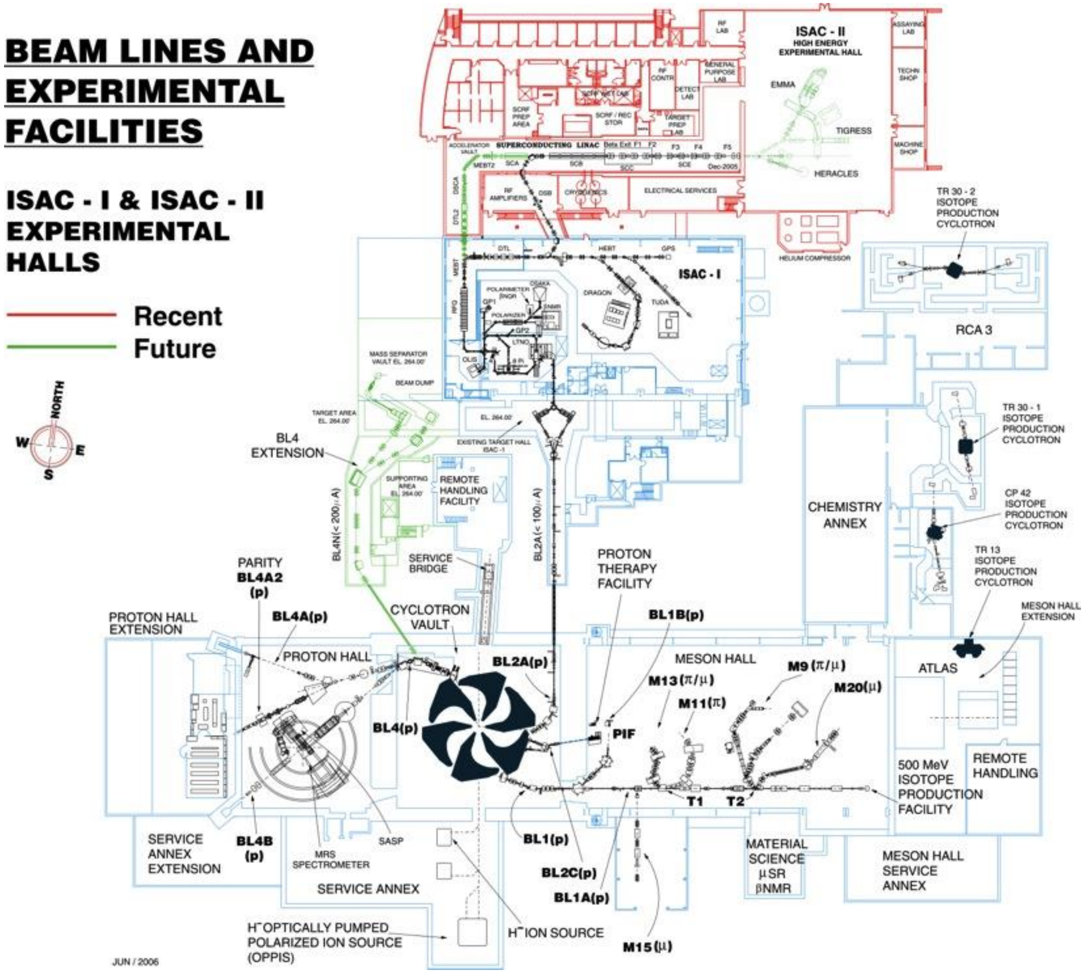
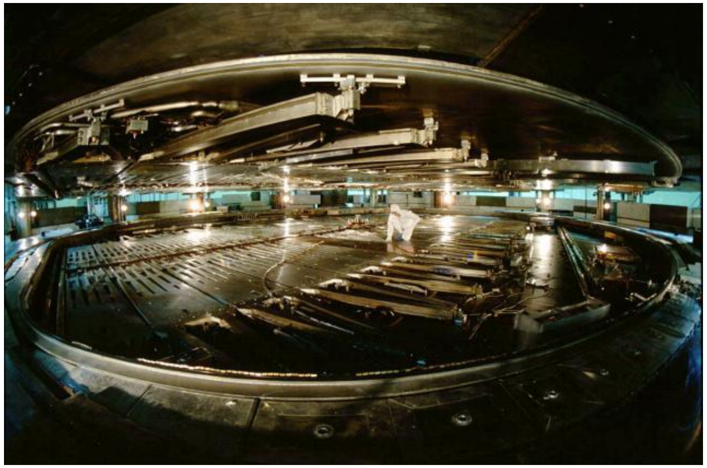
Propriété d'un consortium d'universités canadiennes, géré en co-entreprise à partir d'une contribution administrée par le Conseil national de recherches Canada

ISAC
Isotope Separator and ACcelerator



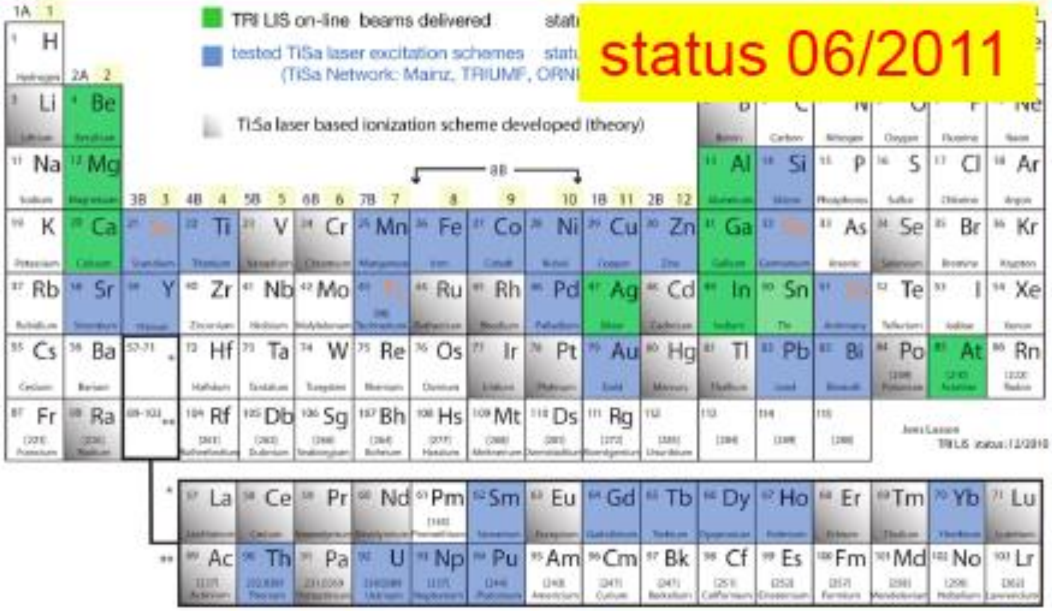


Cyclotron Driver: <100 µA, 500MeV protons, 50kW beam power

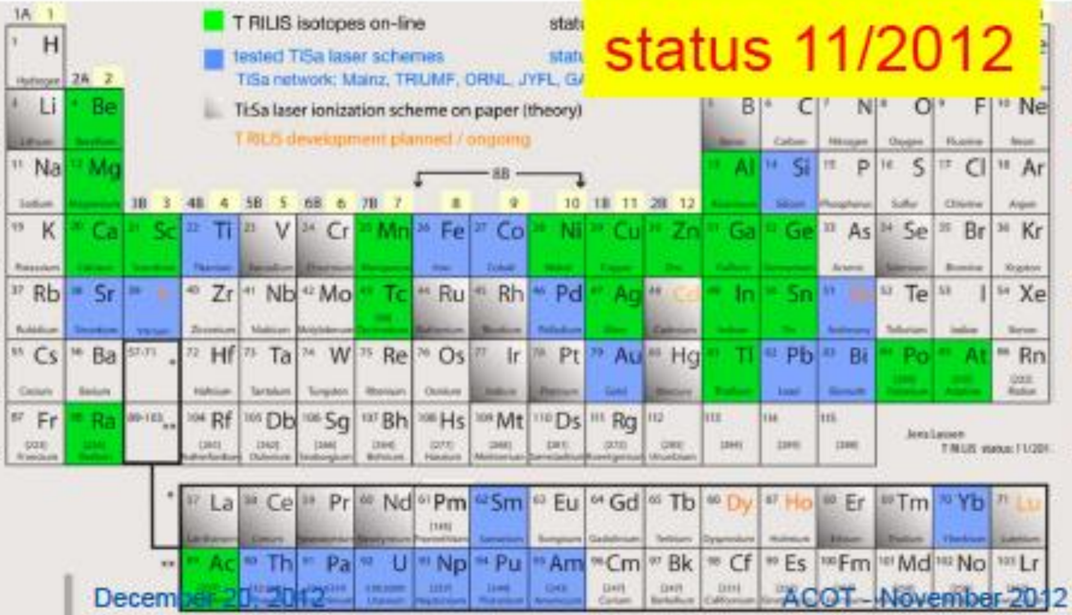
SiC, Nb, ZrC, Ta, UC Targets
Surface, FEBIAD, TRILIS ion sources, ~1/2000 Mass resolution

ISAC-I Low-Energy <60keV
ISAC-I Medium E <1.5MeV/u
ISAC-II SC LINAC <10MeV/u

Ti:Sa RILIS (T RILIS): progress 2012 – plans 2013



status 06/2011



status 11/2012

2010: Full complement of TiSa lasers LIS @ ITW & ITE -> full scheduling flexibility

2011: Full off-line development capabilities
1st schedule with 50%$^+$ TRILIS shifts

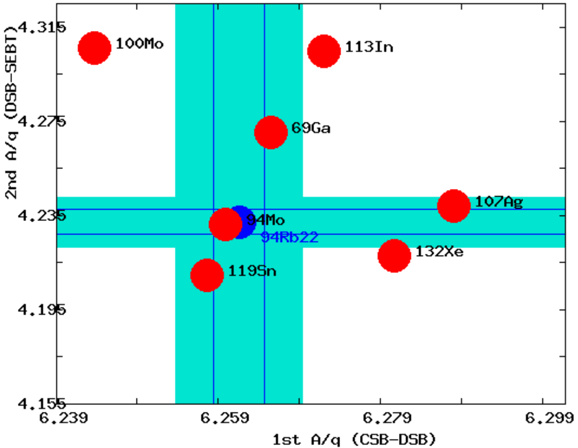
2012: 10 new T RILIS beams:

- on-line development & delivery: Sc, Mn, Ni, Cu, Zn, Ge, Tl, Po, Ra, Ac
- off-line “ion guide – LIS” (RFQ-LIS)
- laser spectroscopy At (S1237), Ac

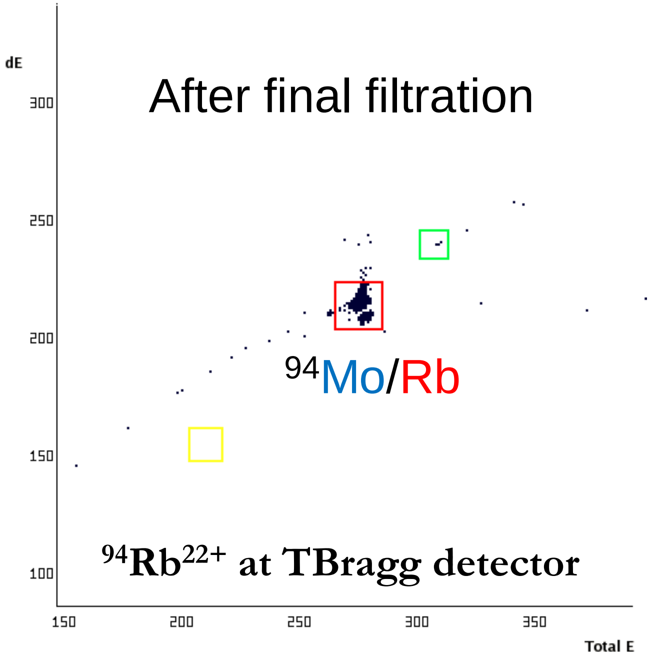
2013: T RILIS plans:
IG-LIS: $^{198-218}$At, $^{124-132}$**Cd**, ^{36}Ca, ^{20,23}Mg, $^{22-25}$Al
T RILIS post irradiation ^{163}**Ho**, ^{163}**Dy**

Yield database: http://www.triumf.info/facility/research_fac/yield.php

High Mass Task Force

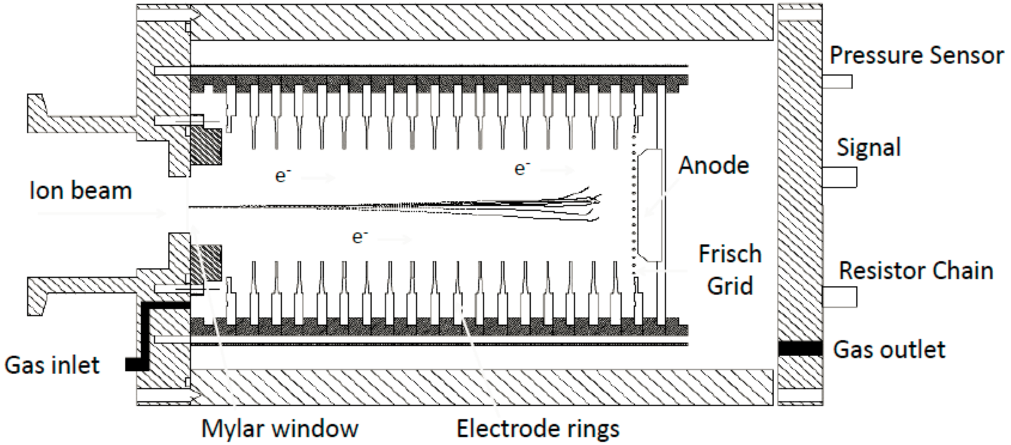


- Charge-State Booster Page



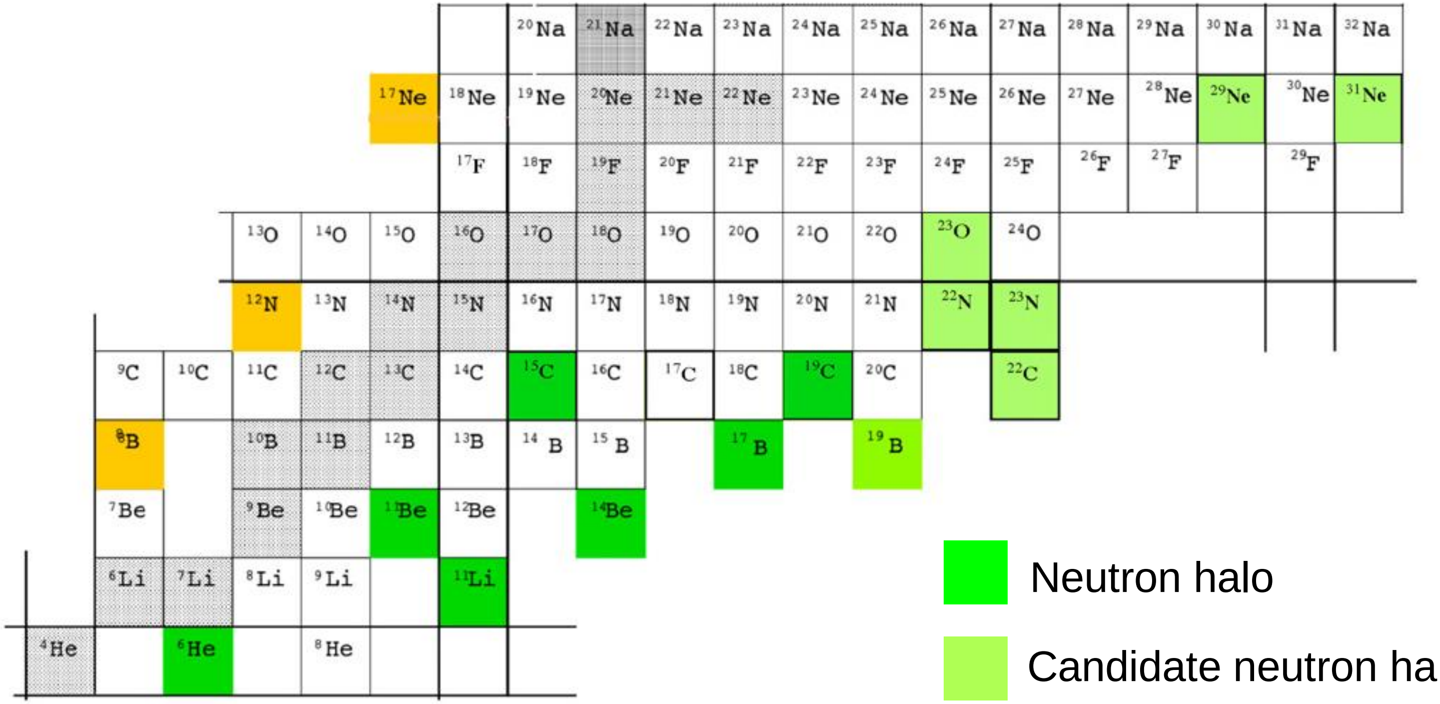
$^{94}Rb^{22+}$ at TBragg detector

- *“To develop hardware and techniques to deliver beams with A/q>30 from the CSB to high energy users.”*
- Charge State Breeder upgrade: conquer 3<A/q<6 limitation of DTL & SC-LINAC
- Clean isobar contamination by phase filtration
- Tbragg gaseous detector as an online beam diagnostic tool



Proposed CANREB:
HRS ~1/20000, EBIS, Cooler

Halo nuclei



							^{20}Na	^{21}Na	^{22}Na	^{23}Na	^{24}Na	^{25}Na	^{26}Na	^{27}Na	^{28}Na	^{29}Na	^{30}Na	^{31}Na	^{32}Na
					^{17}Ne	^{18}Ne	^{19}Ne	^{20}Ne	^{21}Ne	^{22}Ne	^{23}Ne	^{24}Ne	^{25}Ne	^{26}Ne	^{27}Ne	^{28}Ne	^{29}Ne	^{30}Ne	^{31}Ne
						^{17}F	^{18}F	^{19}F	^{20}F	^{21}F	^{22}F	^{23}F	^{24}F	^{25}F	^{26}F	^{27}F		^{29}F	
			^{13}O	^{14}O	^{15}O	^{16}O	^{17}O	^{18}O	^{19}O	^{20}O	^{21}O	^{22}O	^{23}O	^{24}O					
			^{12}N	^{13}N	^{14}N	^{15}N	^{16}N	^{17}N	^{18}N	^{19}N	^{20}N	^{21}N	^{22}N	^{23}N					
	^{9}C	^{10}C	^{11}C	^{12}C	^{13}C	^{14}C	^{15}C	^{16}C	^{17}C	^{18}C	^{19}C	^{20}C		^{22}C					
	^{8}B		^{10}B	^{11}B	^{12}B	^{13}B	^{14}B	^{15}B		^{17}B		^{19}B							
	^{7}Be		^{9}Be	^{10}Be	^{11}Be	^{12}Be		^{14}Be											
	^{6}Li	^{7}Li	^{8}Li	^{9}Li		^{11}Li													
^{4}He		^{6}He		^{8}He															

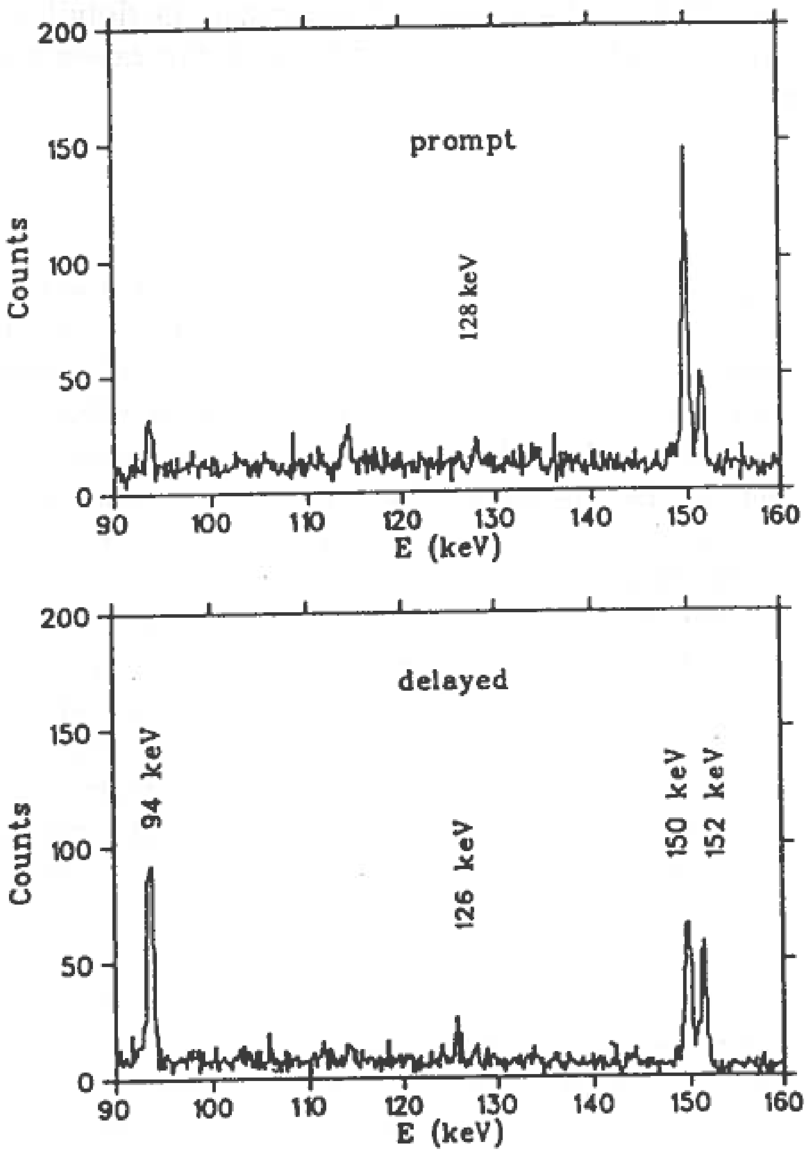
🟩 Neutron halo

🟩 Candidate neutron halo

🟧 Proton halo

From: I.Tanihata et al., Progress in Particle and Nuclear Physics 68 (2013) 215

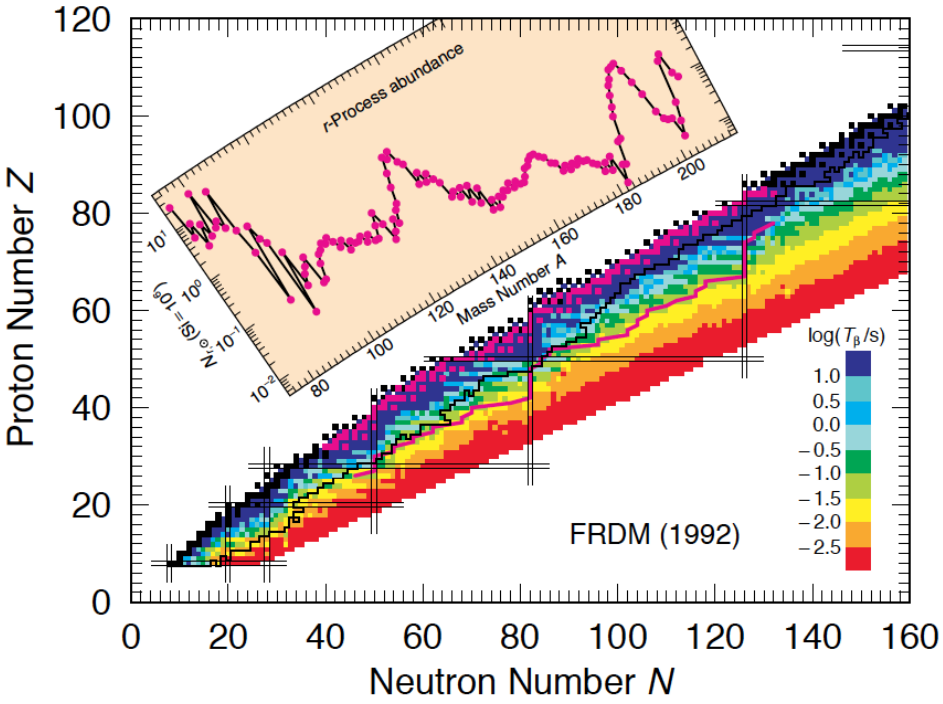
Previous study on 102Rb decay



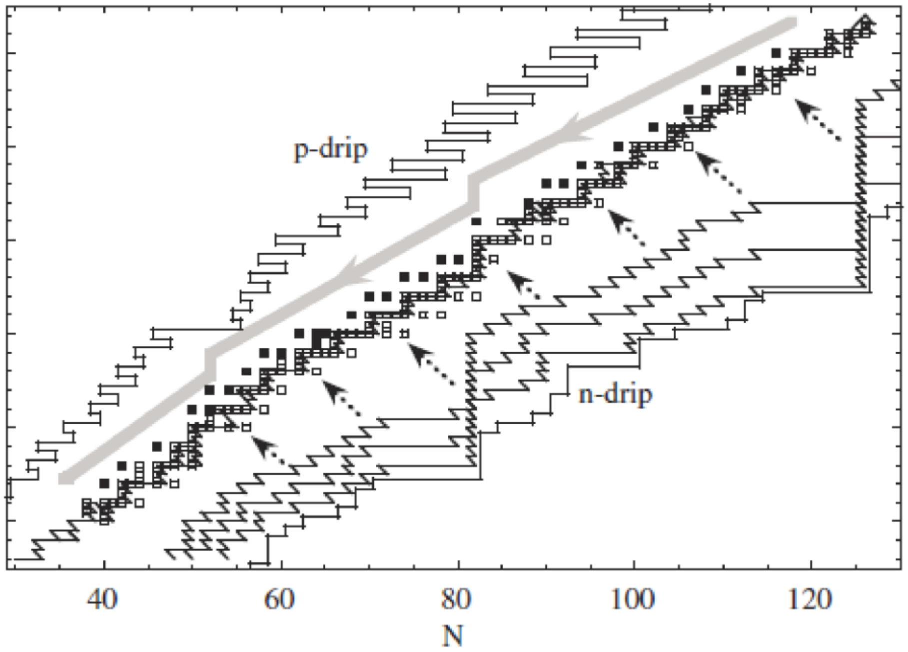
Lhersonneau *et al.*, Z. Phys. A 351, 357 (1995).

126 keV 2+ state
3.0 (12) ns half-life
B(E2) around 209.6 W.u.

Astrophysical r-process

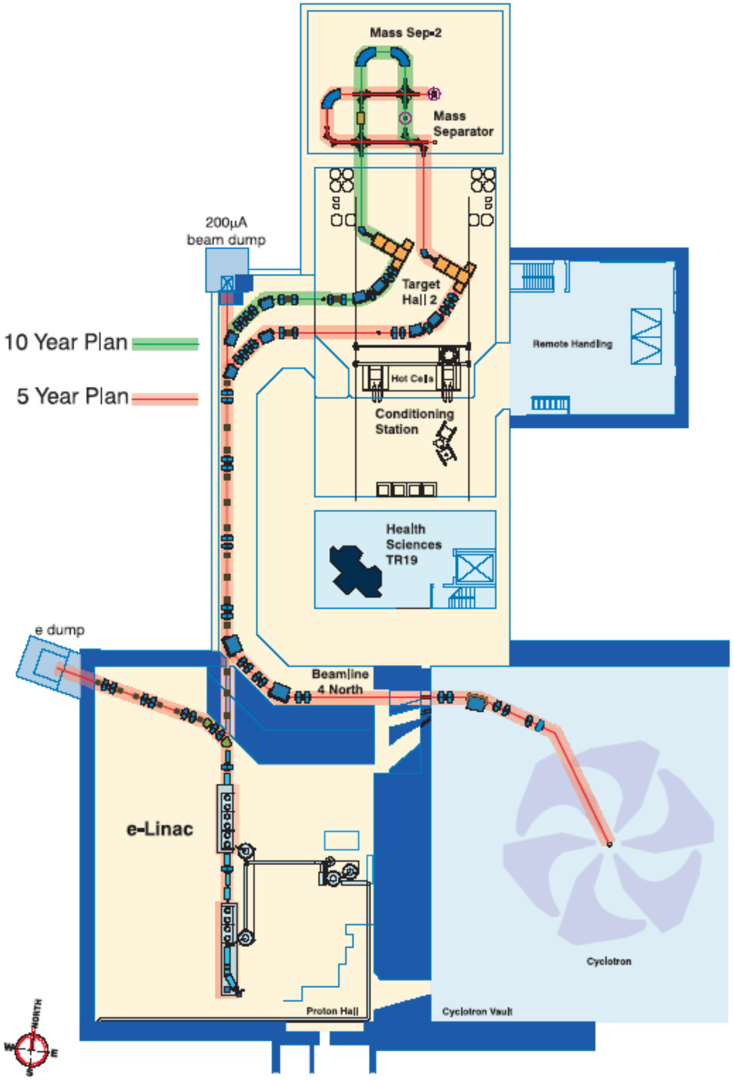


Moller et al., Atom. Data and Nucl. Data Tables 66, 131 (1997).



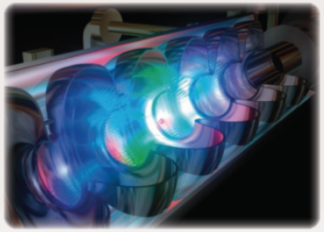
Arnould et al., Physics Reports 450, 97 (2007).

Advanced Rare Isotope Laboratory



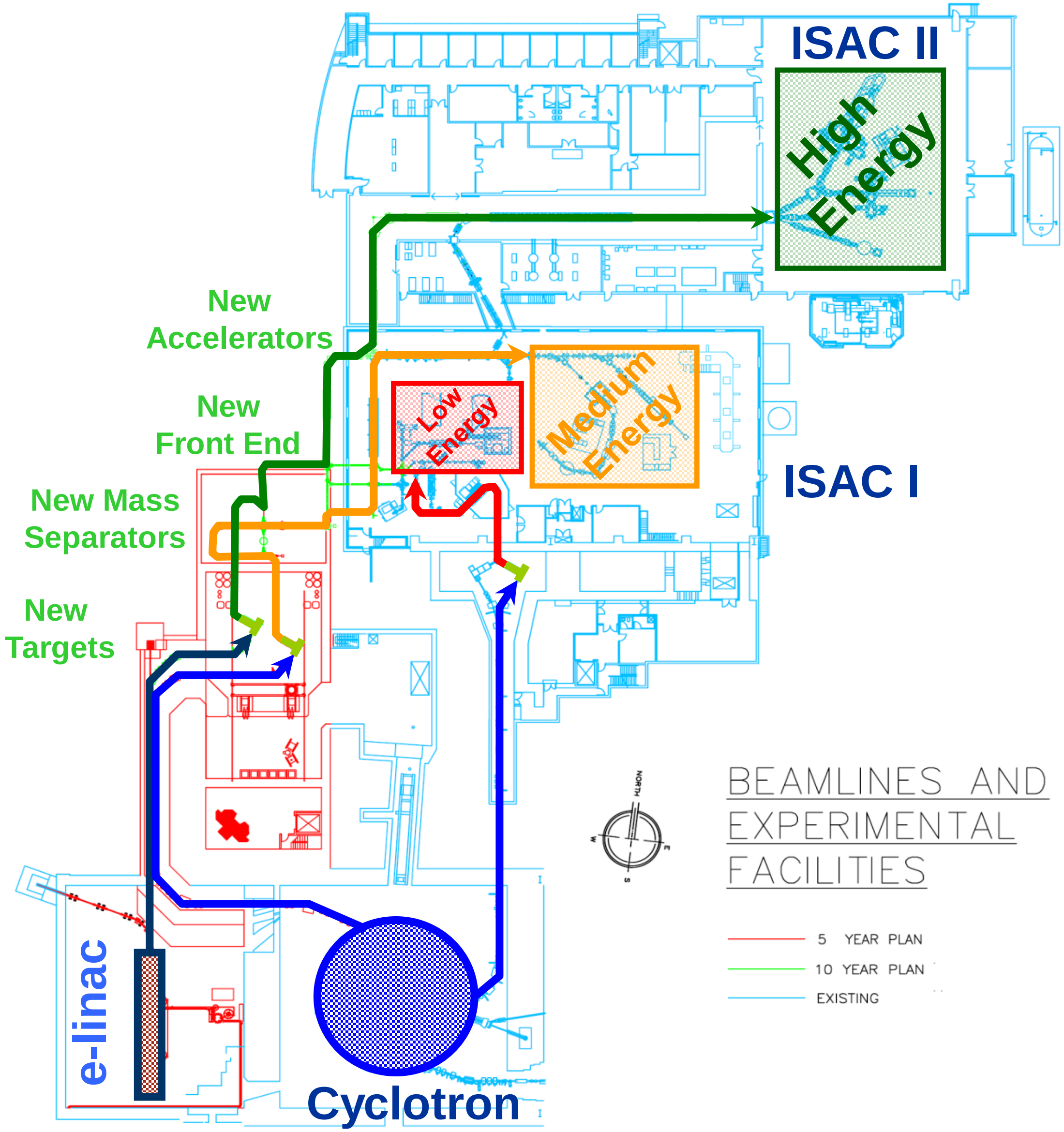
ARIEL

ADVANCED RARE ISOTOPE LABORATORY



ARIEL is a new underground beam tunnel surrounding a next-generation linear accelerator – an e-linac, led by the University of Victoria. The project will allow TRIUMF to develop technology to advance Canada's supply of critical medical isotopes, capitalize on existing investments, and broaden its research capabilities in particle physics, nuclear physics, nuclear medicine, and materials science.

ARIEL Project – Master Plan



- Expand RIB program with:
  - three simultaneous beams
  - increased number of hours delivered per year
  - new beam species
  - enable long beam times (nucl. astro, fund. symm.)
  - increased beam development capabilities
- New electron linac driver for photo-fission
- New proton beamline
- New target stations and front end
- staged installation

ARIEL science reach

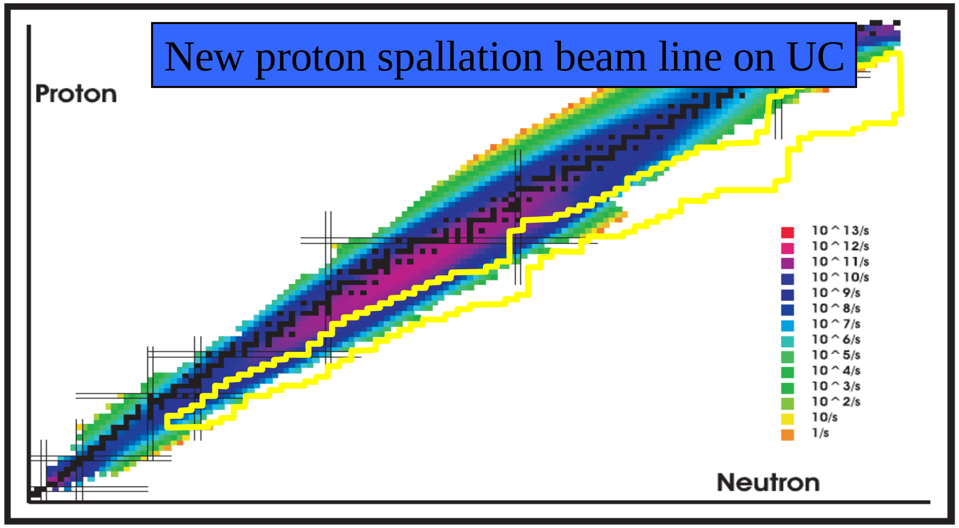
Experiments at the r-process path:

- masses, $T_{1/2}$, P_n
- (d,p), (t,p) reactions
  - → single particle structure
  - → pairing correlations
  - → (n,γ)
- decay spectroscopy

100 kW, 25 MeV e-beam:

➔ ~ 10^{13} fissions/sec

$2 \cdot 10^{10}$ ^{132}Sn/sec (in target)



New proton spallation beam line on UC

Figure 7: Production yield in target assuming a 10 μA proton beam onto a 25 g/cm^2 UC_x target using FLUKA.

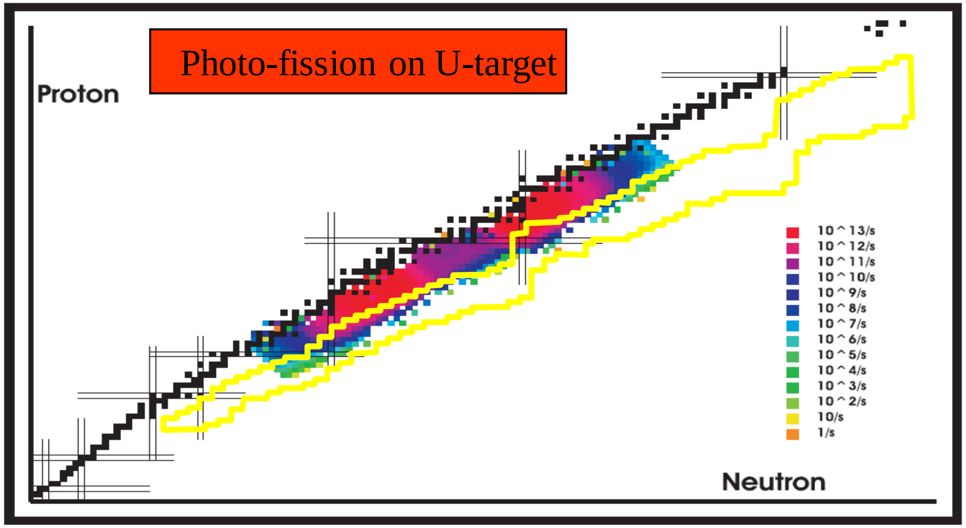
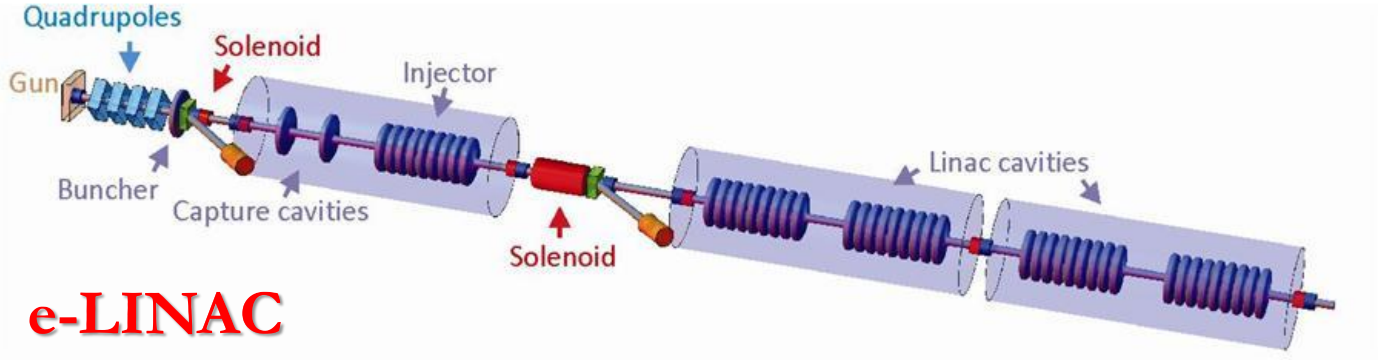


Photo-fission on U-target

Figure 8: Production in target assuming $4.6x10^{13}$ photo-fission induced into a 15 g/cm^2 UC_x target.

ARIEL Building

- The ARIEL tower crane was dismantled, building should be complete this summer.
- Under constructing of the new electron linac (e-Linac)



100 kW, 25 MeV electrons by **2014**

500 kW, 50 MeV electrons by **2017**