ATLAS

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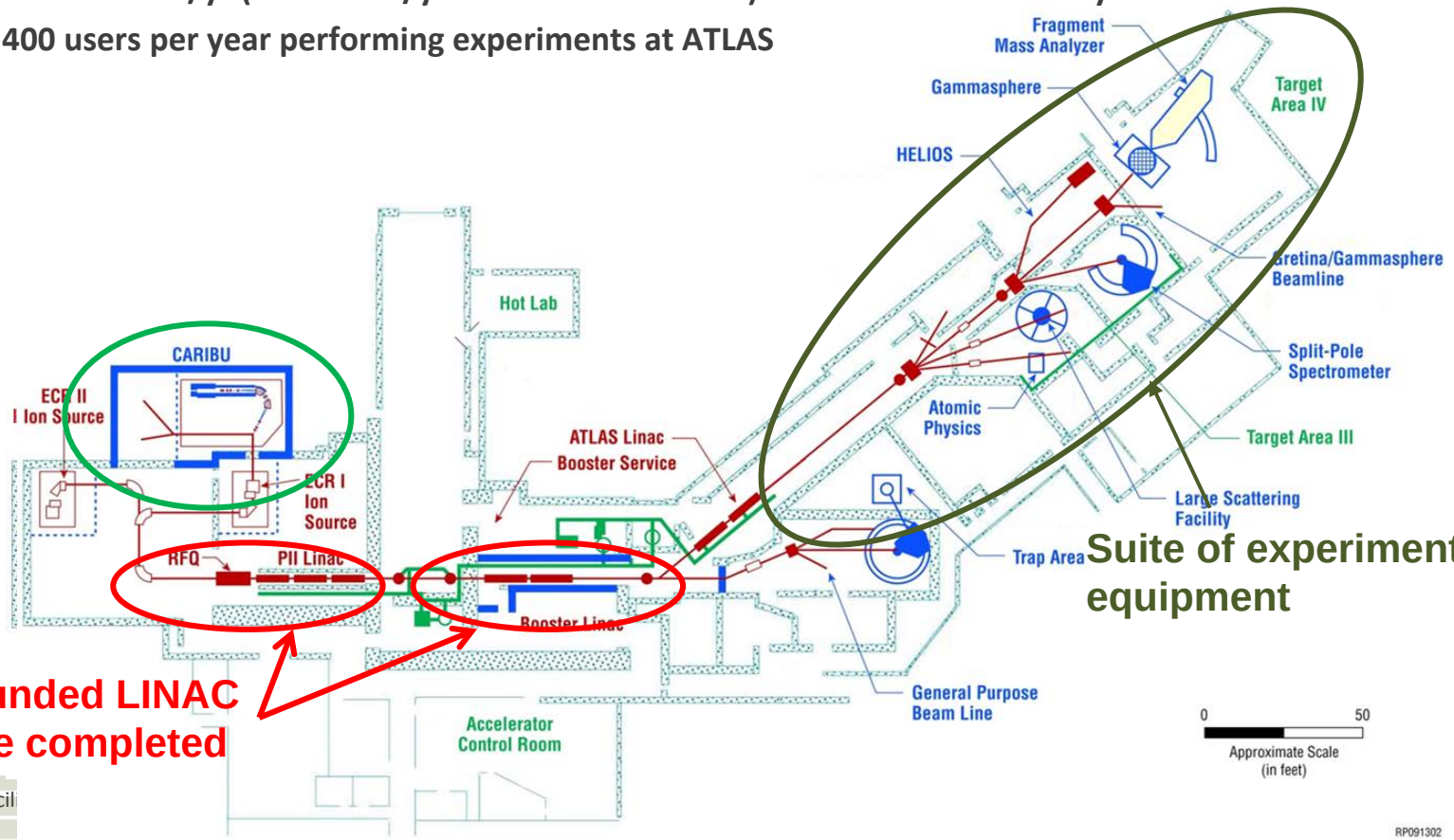
Argonne National Laboratory
&
University of Chicago

Presentation to the Low Energy Community Meeting

East Lansing, August 22, 2015

ATLAS facility

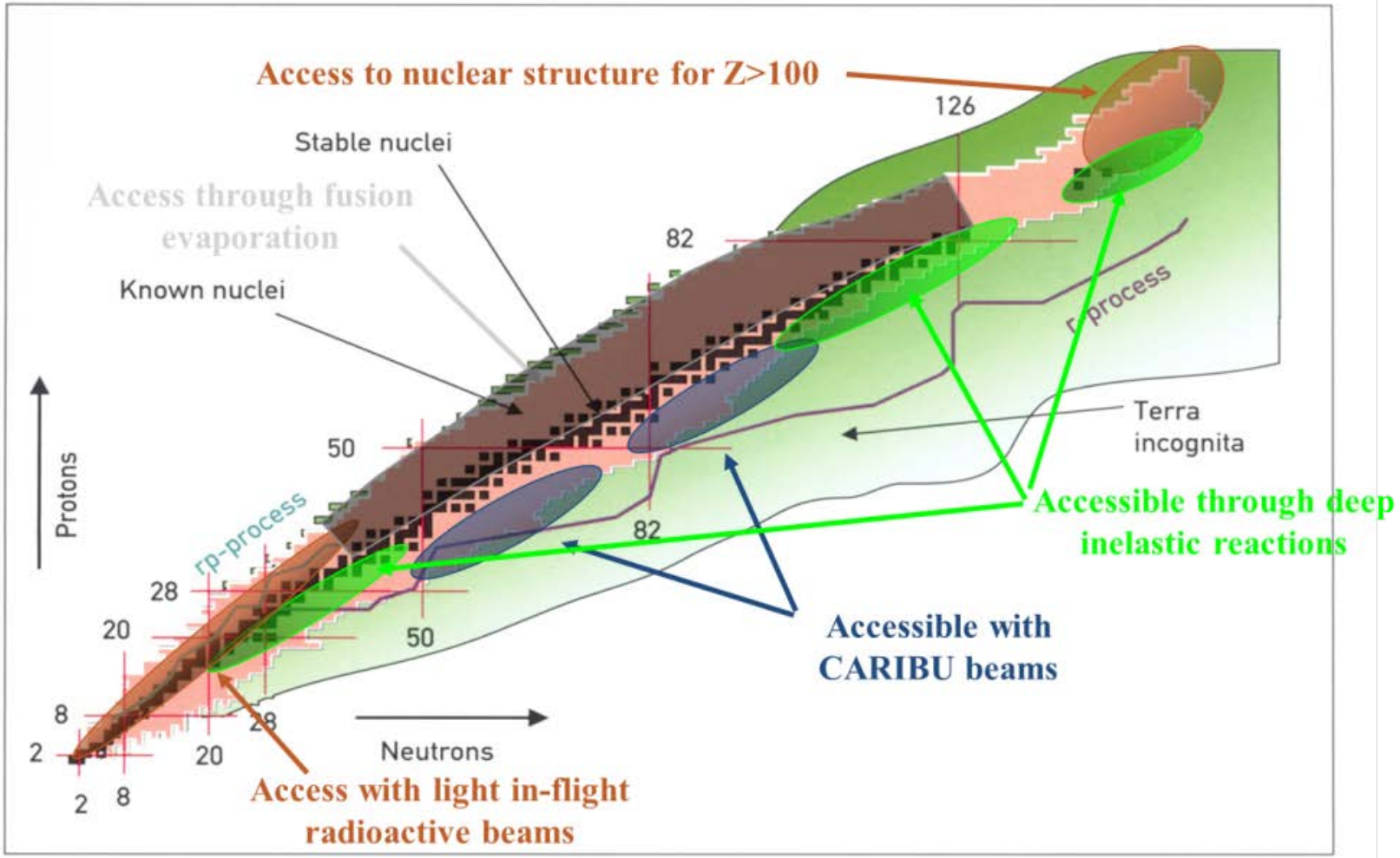
- Stable beams at high intensity and energy up to 10-20 MeV/u
- Light in-flight radioactive beams
  - *light beams, no chemical limitations, close to stability, acceptable beam properties*
- CARIBU beams
  - *heavy n-rich from Cf fission, no chemical limitations, low intensity, ATLAS beam quality, energies up to 15 MeV/u*
- State-of-the-art instrumentation for Coulomb barrier and low-energy experiments
- Operating 5000-6000 hrs/yr (+ 2000 hrs/yr CARIBU stand alone) at about 95% efficiency
  - About 400 users per year performing experiments at ATLAS



Suite of experimental equipment

ARRA funded LINAC upgrade completed

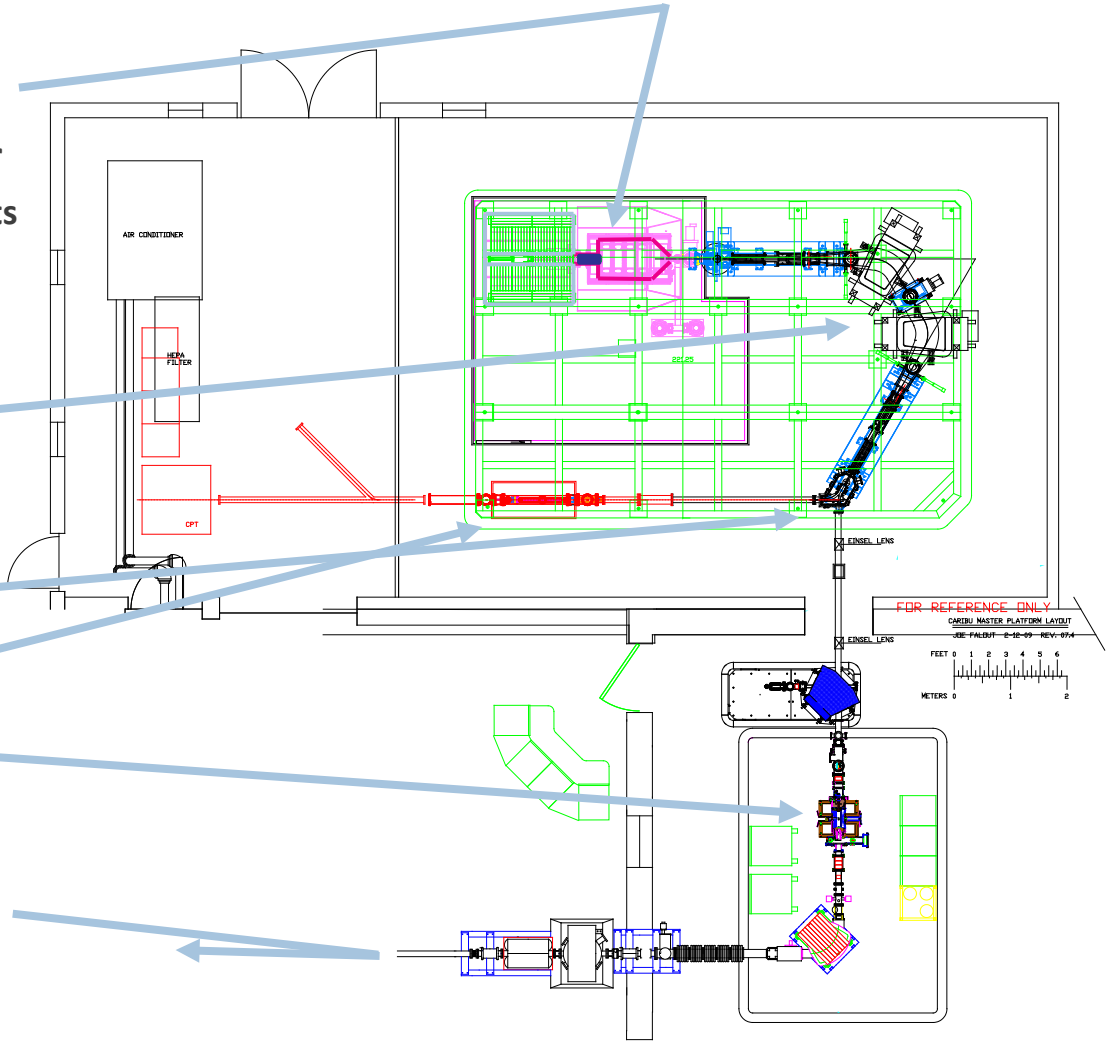
ATLAS: broad isotope reach through various reaction mechanisms



Neutron-rich beam source for ATLAS: CARIBU "front end" layout

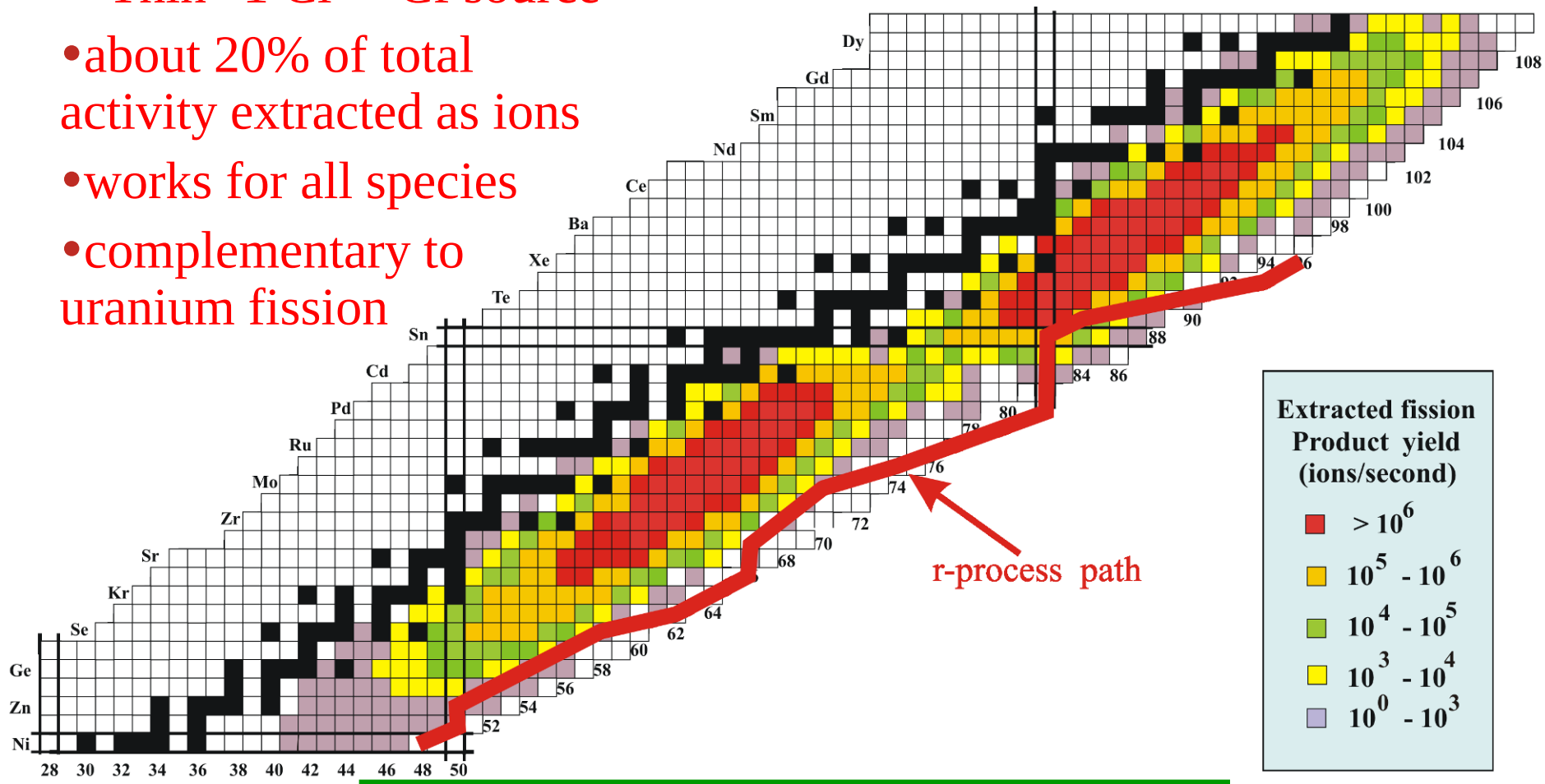
Main components of CARIBU

- **PRODUCTION**: "ion source" is ^{252}Cf source inside gas catcher
  - Thermalizes fission fragments
  - Extracts all species quickly
  - Forms low emittance beam
- **SELECTION**: Isobar separator
  - Purifies beam
- **DELIVERY**: beamlines and preparation
  - Switchyard
  - Low-energy buncher and beamlines
  - Charge breeder to Increase charge state for post-acceleration
  - Post-accelerator ATLAS and weak-beam diagnostics



Expected isotope yield distribution at low energy (50 keV)

- "Thin" 1 Ci ^{252}Cf source
- about 20% of total activity extracted as ions
- works for all species
- complementary to uranium fission

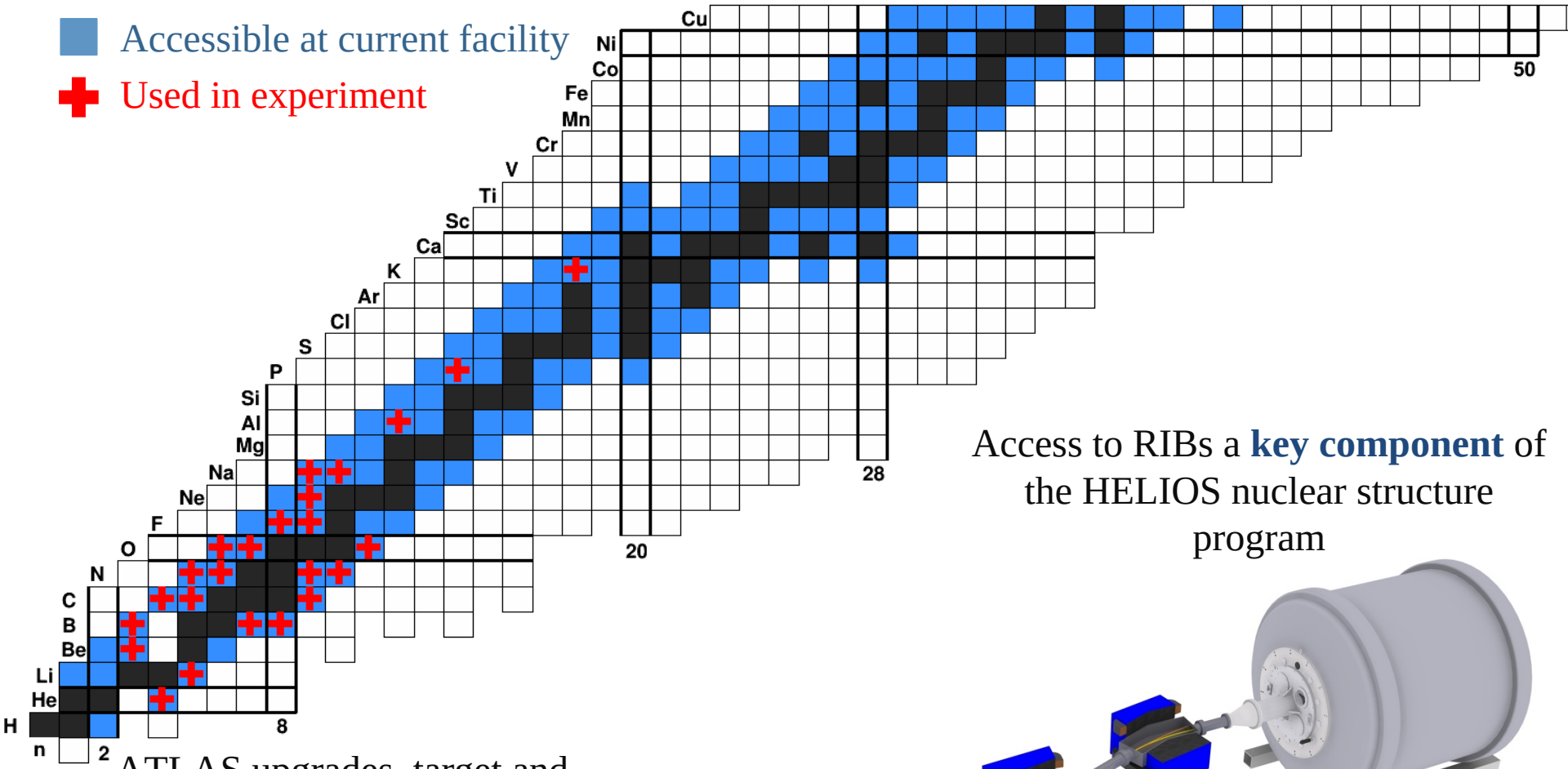


> than 500 neutron-rich species extracted at > 1/s

In-flight radioactive beams at ATLAS

Accessible at current facility

Used in experiment



Access to RIBs a **key component** of the HELIOS nuclear structure program

ATLAS upgrades, target and reaction techniques, will increase reach until arrival of the new in-flight separator **AIRIS**

ATLAS beams

- **Stable beams (protons to Uranium)**
  - up to 10 pμA, limited by ion source performance and radiation safety
  - Pulse separation of 82 ns or n X 82 ns with n=1, 2, 3, …
  - Pulse timing down to ~100 ps
  - Energy range from ~ 0.5 MeV/u up to 10-20 MeV/u depending on mass

Unique capabilities worldwide + coupled to unique instruments

- **CARIBU beams have similar properties …. but much lower intensity**
  - All species, even the most refractory, are extracted efficiently

Most of the CARIBU beams (species and energy) are not available anywhere else.

- **In-flight radioactive beams: all light species, close to stability, but some compromises between beam properties, intensity and purity**

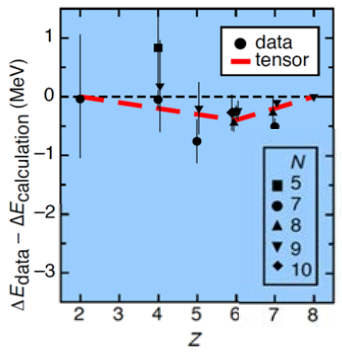
A few other facilities worldwide can produce these beams but none have the ATLAS experimental equipment suite (e.g. HELIOS).

Main research thrusts: Nuclear structure

Single-particle structure and collective property studies at ATLAS

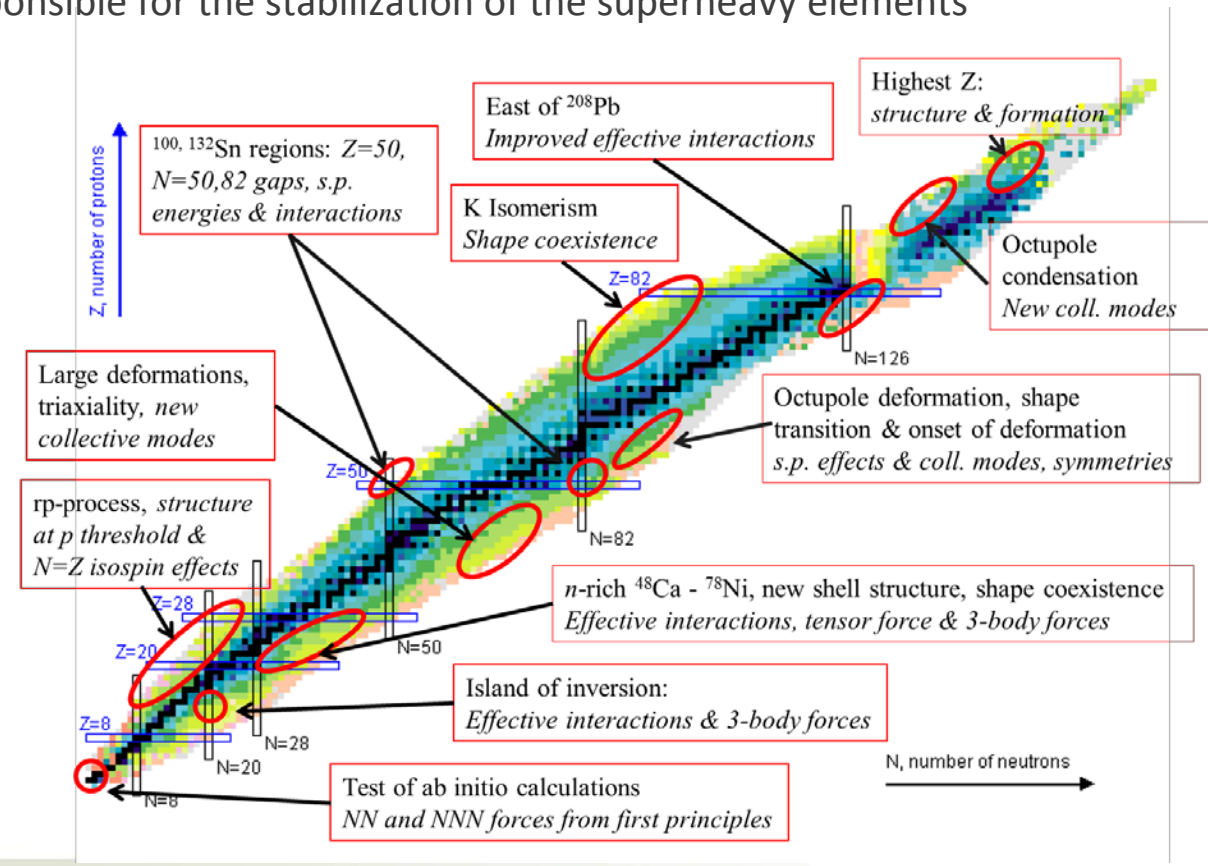
High level goal is to develop a comprehensive description of nuclei. This is done through the study of

- Structure of the lightest nuclei, improved tests of the ab-initio calculations
- Evolution of single-particle structure with isospin (tensor force, shell gaps, …)
- Collectivity in new regions of the nuclear landscape
- Evolution of the orbitals responsible for the stabilization of the superheavy elements

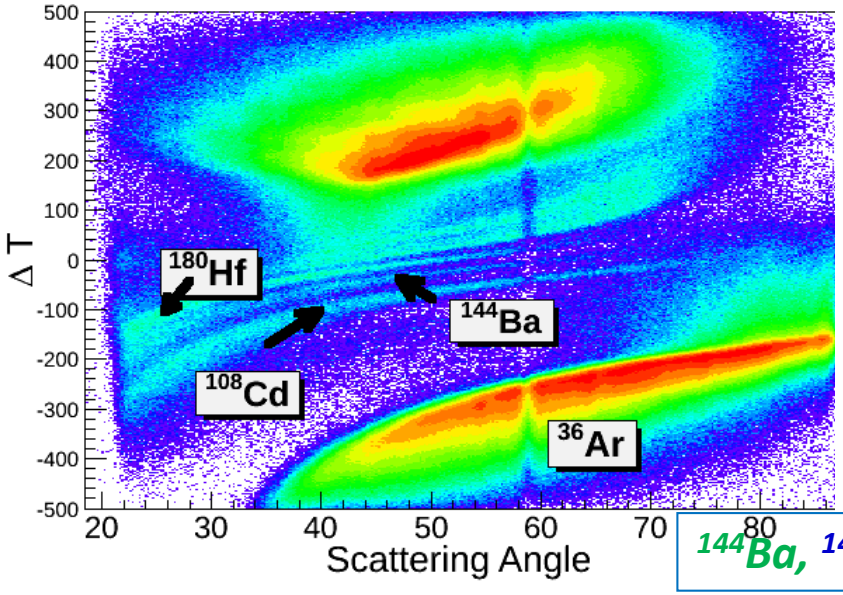


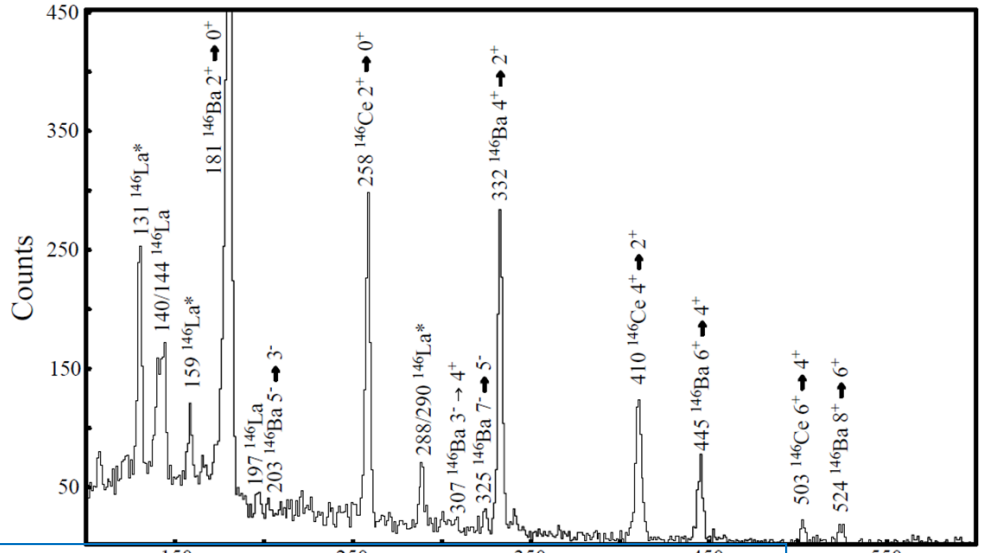
- Marriage of ***in-flight beams*** and ***HELIOS***
- Addressed ***selected*** key issues
- ***New insights*** into global behavior of centroids

Back *et al.*, PRL **104**, 132501 (2010)	^{13}B
Wuosmaa *et al.*, PRL **105**, 132501 (2010)	^{16}C
Lighthall *et al.*, NIM **A580**, 1290 (2010)	—
Hoffman *et al.*, PRC **85**, 054318 (2012)	^{20}O
Bedoor *et al.*, PRC **88**, 011304(R) (2013)	^{14}B
Hoffman *et al.*, PRC **88**, 044317 (2013)	^{18}N
Hoffman *et al.*, PRC **89**, 061305(R) (2014)	—



Coulomb excitation of CARIBU beams with GRETINA/CHICO2





^{144}Ba, ^{146}Ba, ^{142}Cs, ^{110}Ru, ^{100}Zr, ^{98}Zr, ^{98m}Y, ^{106}Mo

650-MeV ^{144}Ba + ^{208}Pb (1mg/cm^2) GRETINA + CHICO2 + CARIBU/ATLAS expt.

Rochester – LLNL – LBL- ORNL – Liverpool – Scotland – Ohio U – Tennessee – Georgia IT – Richmond - ANU –Washington – Toronto - Saclay – IHL Warsaw – GANIL – TU Darmstadt – Oslo – Notre Dame - ANL collab.

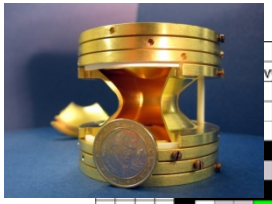
- GRETINA + CHICO2 provide excellent Doppler reconstruction
- charge breeder + upgraded ATLAS provide post-acceleration with ~10% total efficiency and exquisite beam properties

Main research thrusts: Nuclear astrophysics

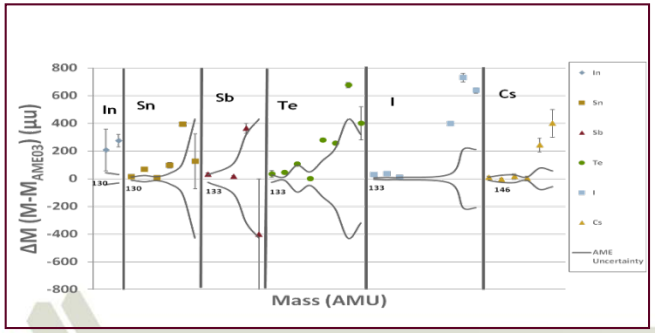
Understanding nucleosynthesis processes in the cosmos

- High level goal is the understanding of the production of the elements in the cosmos through studies of the nuclear physics input to
  - rp-, αp- and νp- process nucleosynthesis (reaction rates, masses, important spectroscopic information)
  - r-process path (masses, lifetimes, beta-delayed neutrons, surrogate reactions)
  - sub-barrier fusion hindrance, break out from CNO cycle, important quiescent reactions, ...

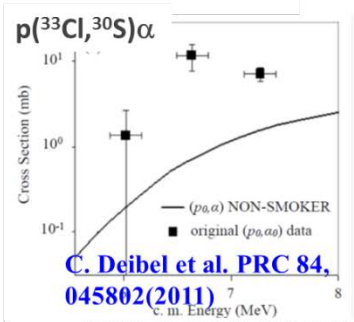
n-rich masses for r-process



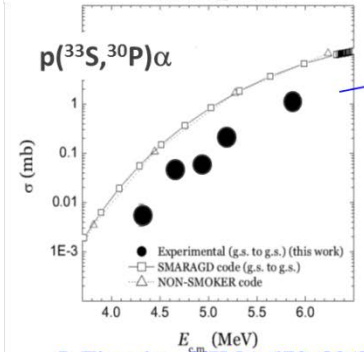
J. Van Schelt *et al.*, Phys. Rev. C **85**, 045805 (2012)
J. Van Schelt *et al.*, Phys. Rev. Lett. **111**,061102 (2013)



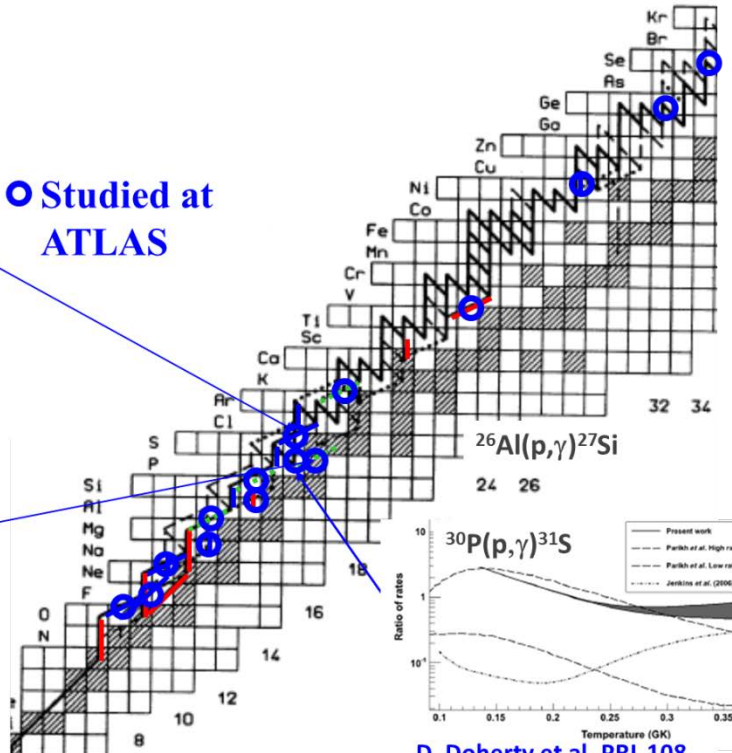
reactions for rp-process



C. Deibel et al. PRC 84, 045802(2011)



J. Figueira, NIMA 670, 32(2012)



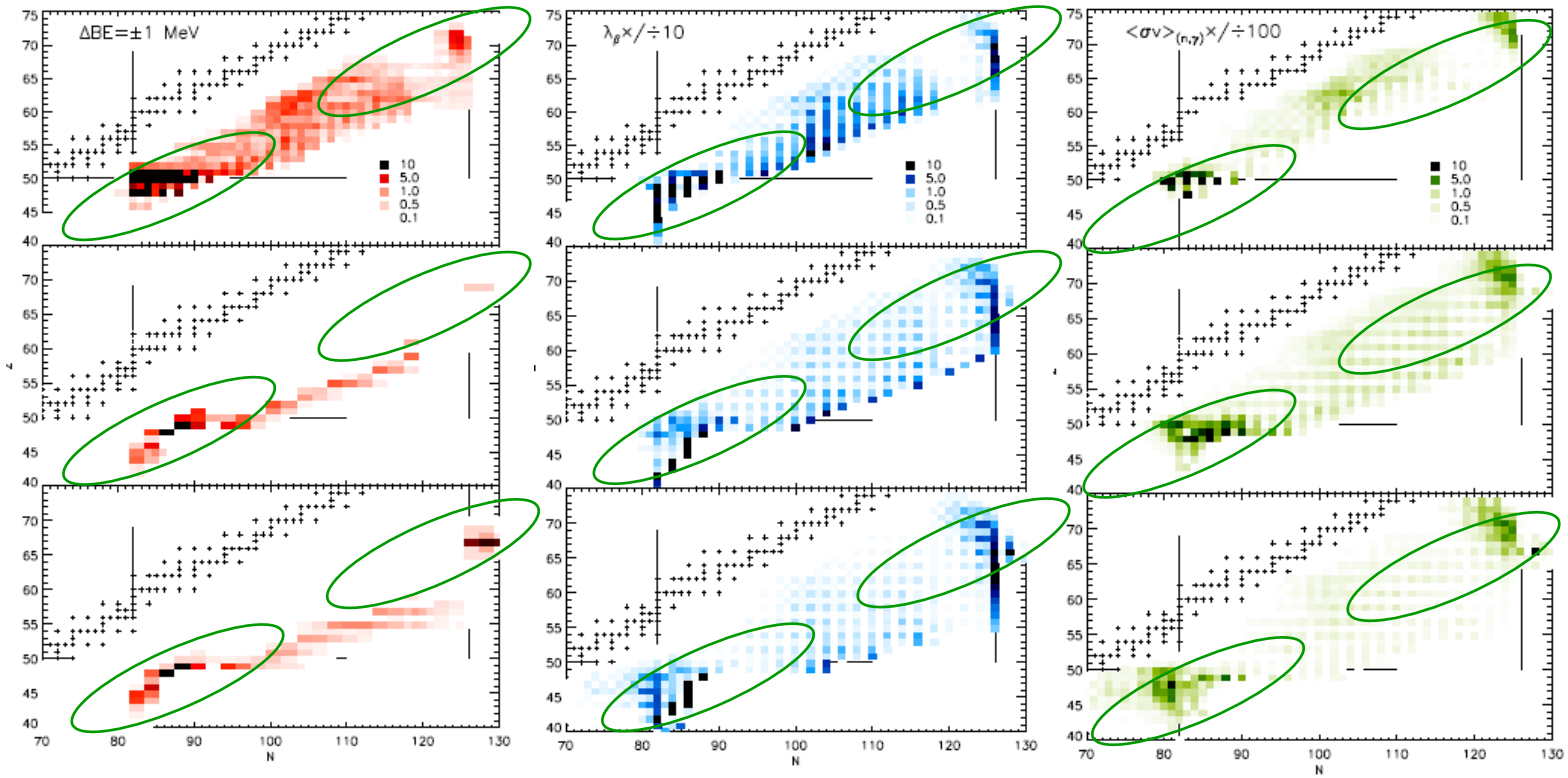
D. Doherty et al. PRL 108, 262502(2012)

R-process sensitivity to nuclear physics input

Hot r-process

Supernova neutrino-driven wind cold r-process

Neutron-star merger cold r-process



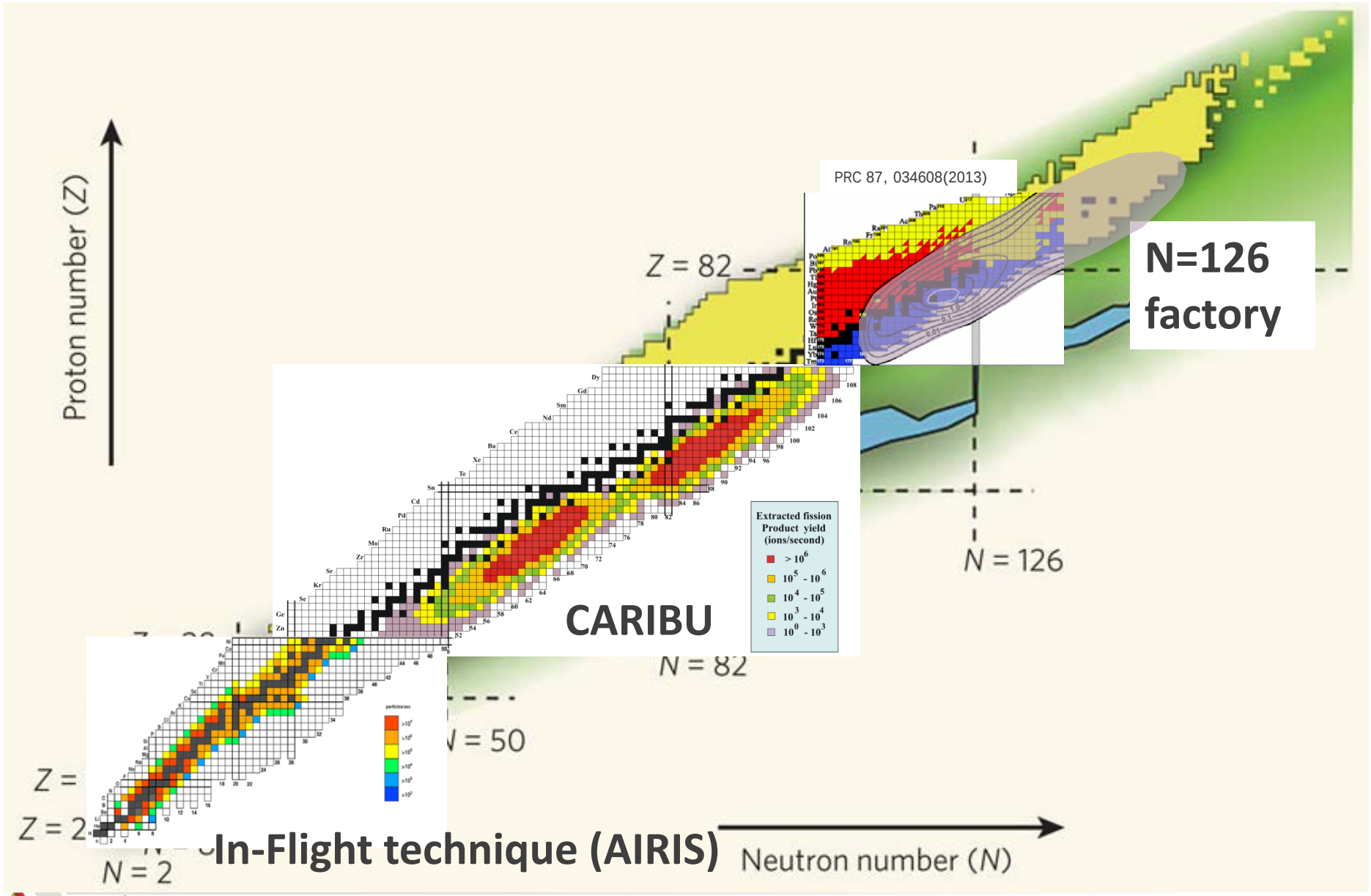
binding energy | neutron-capture rate | lifetime

From R. Surman, M. Mumpower et al, arXiv:1039.0059v1

Clear regions of interest for most scenarii … need to make them accessible experimentally

Main research thrusts: Nuclear astrophysics

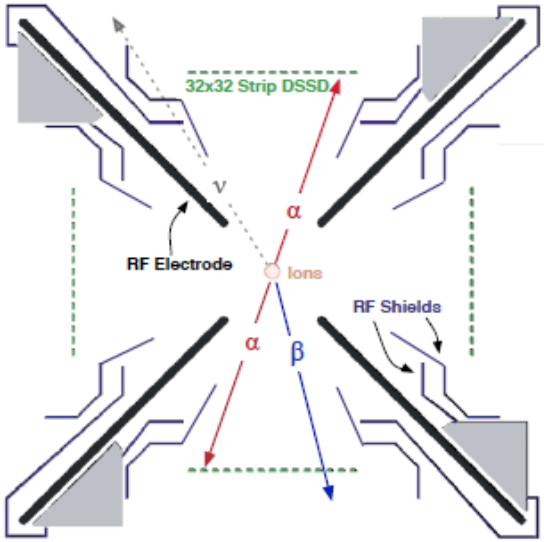
Accessing new regions for r-process and rp-process measurements

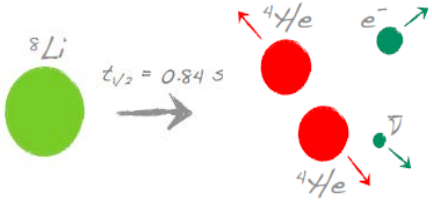


Main research thrusts: Fundamental Interactions

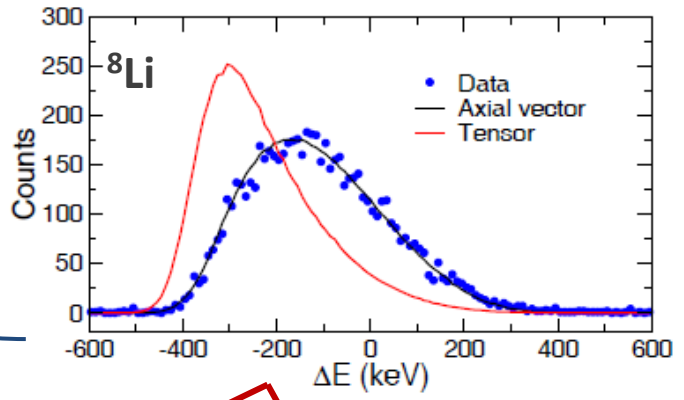
Search for tensor and second-class currents via beta-neutrino correlation

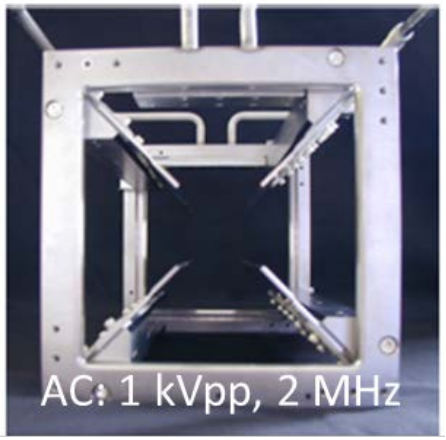
- Using new technologies (ion traps and ion manipulation techniques) to improve searches for physics beyond the Standard Model



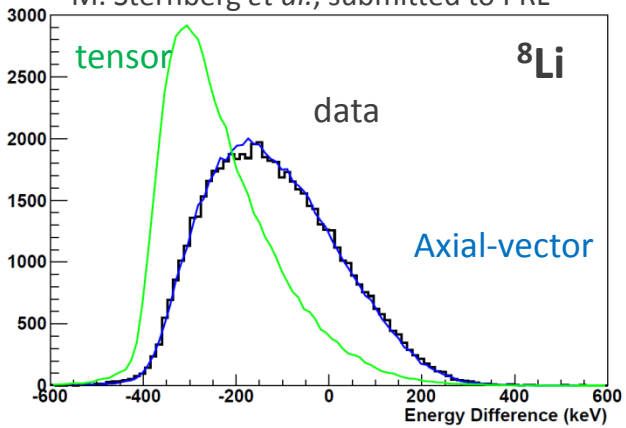


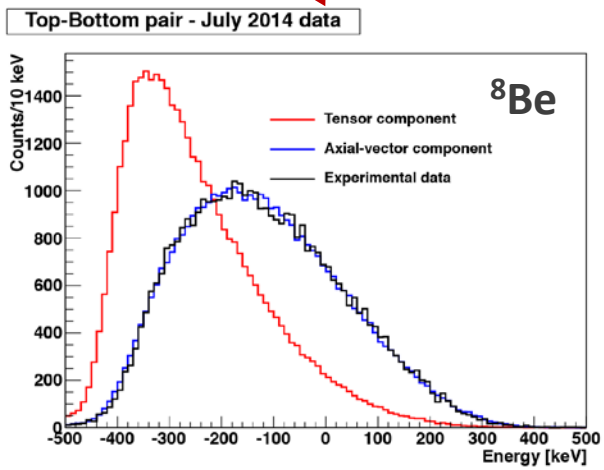
L. Gang *et al.*, PRL **110**, 092502 (2013)





2012 correlation data and fits
M. Sternberg *et al.*, submitted to PRL





Main research thrusts: Applications

Combining basic and applied research: AMS and beta-delayed neutron measurements

R.M. Yee *et al.*, PRL **110**, 092501 (2013)

Half-lives of astrophysical important nuclei measured at ATLAS with AMS:

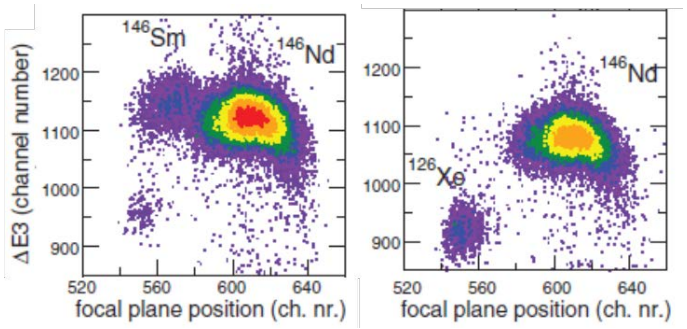
^{60}Fe: W. Kutschera et al. (NIMB 85, 430(1984))

^{44}Ti: I. Ahmad et al. (PRL 80, 2550 (1998))

^{146}Sm: A Shorter ^{146}Sm Half-Life Measured and Implications for ^{146}Sm-^{142}Nd Chronology in the Solar System

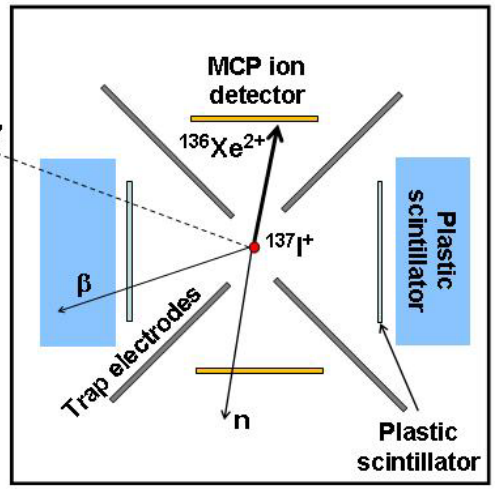
N. Kinoshita,[1] M. Paul,[2*] Y. Kashiv,[3*] P. Collon,[3] C. M. Deibel,[4,5] B. DiGiovine,[4] J. P. Greene,[4] D. J. Henderson,[4] C. L. Jiang,[4] S. T. Marley,[4] T. Nakanishi,[6] R. C. Pardo,[4] K. E. Rehm,[4] D. Robertson,[3] R. Scott,[4] C. Schmitt,[3] X. D. Tang,[3] R. Vondrasek,[4] A. Yokoyama[6]

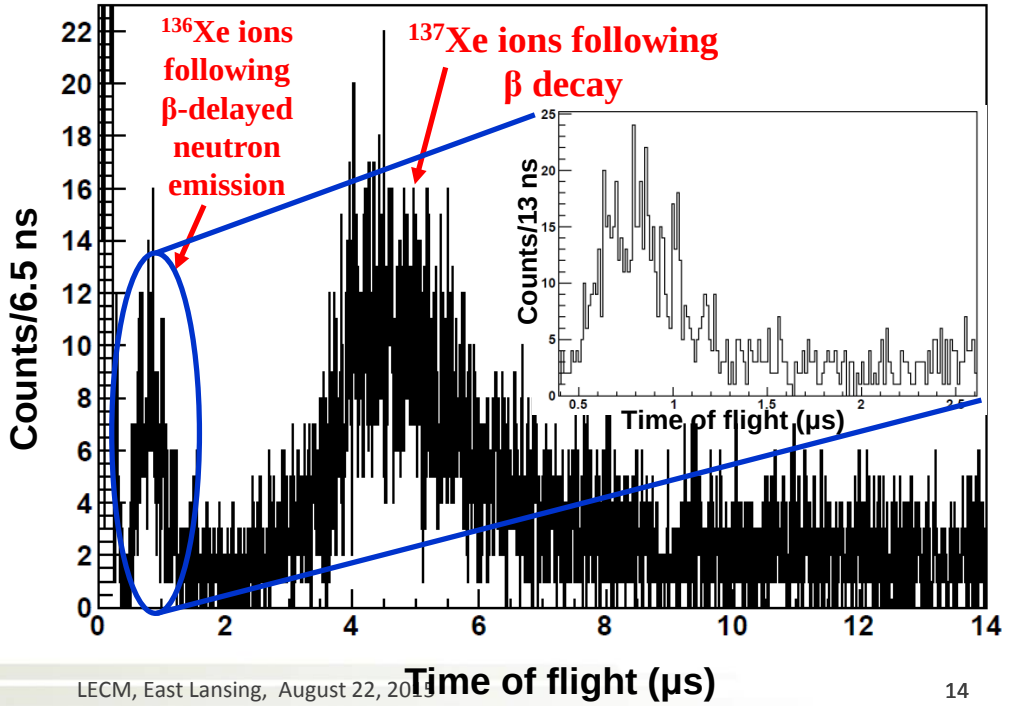
Science **335**, 1614 (2012)



Accelerator Mass Spectrometry (AMS) technique now used at ATLAS (MANTRA) to measure neutron-capture cross-section for heavy actinides

- **Let ion decay at rest from center of ion trap (Paul trap)**
- **Surround ion trap (Paul trap) with plastic scintillators (to detect β's) and MCPs (to detect decay recoils)**
- **β-delayed neutron decay produces recoil detected by TOF with MCP**



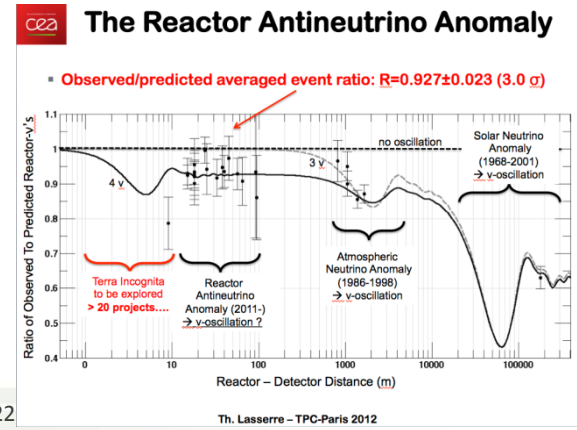


Interest in the applications' program is large and growing rapidly, particularly for neutron-rich nuclei

- Decay data of relevance to Advanced Fuel Cycle applications (emphasis on reactor decay heat calculations)

- Decay and reaction data of interest to national security applications

- Nuclear data necessary for the advancement of other fields (e.g. reactor anti-neutrino anomaly)

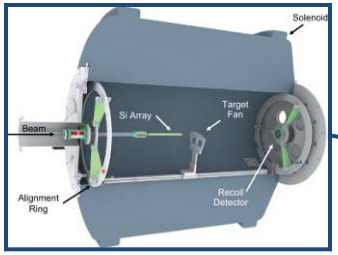


Main tools enabling the physics: ATLAS suite of experimental equipment

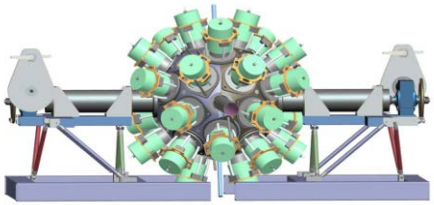
CPT mass spectrometer

X-array

HELIOS spectrometer

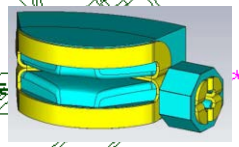


GRETINA

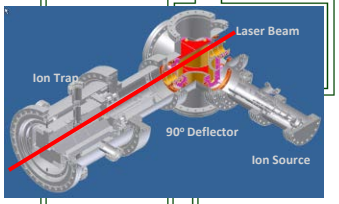


FMA

AGFA

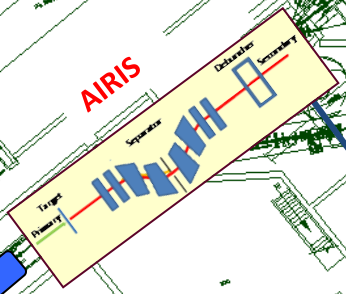


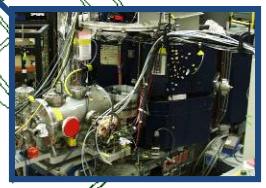
Laser Lab



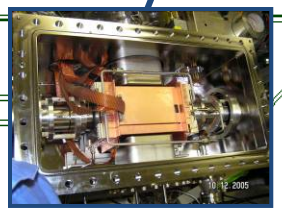
CARIBU

AIRIS

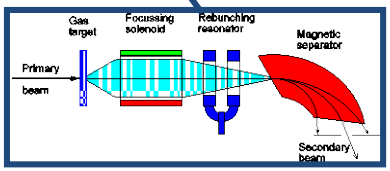




Si-array (Ludwig) and Enge spectrometer



Beta decay Paul trap



In-flight RIBs production

+ outside instruments: GRETINA, CHICO-II, HERCULES, GODDESS, VANDLE, …

Continued push forward for ATLAS

- Increasing efficiency with which programs are run
  - Pushing back beam limitations
    - Stable beams → higher intensity
    - In-flight radioactive beams → higher intensity, purity, and accessible to more experimental areas
    - CARIBU beams → higher intensity, purity
  - Pushing back rate limitations for essentially all experiments, including Gammasphere
  - Gaining higher efficiency for weak channels
  - Gaining access to other regions of the nuclear chart
  - Providing more beam hours

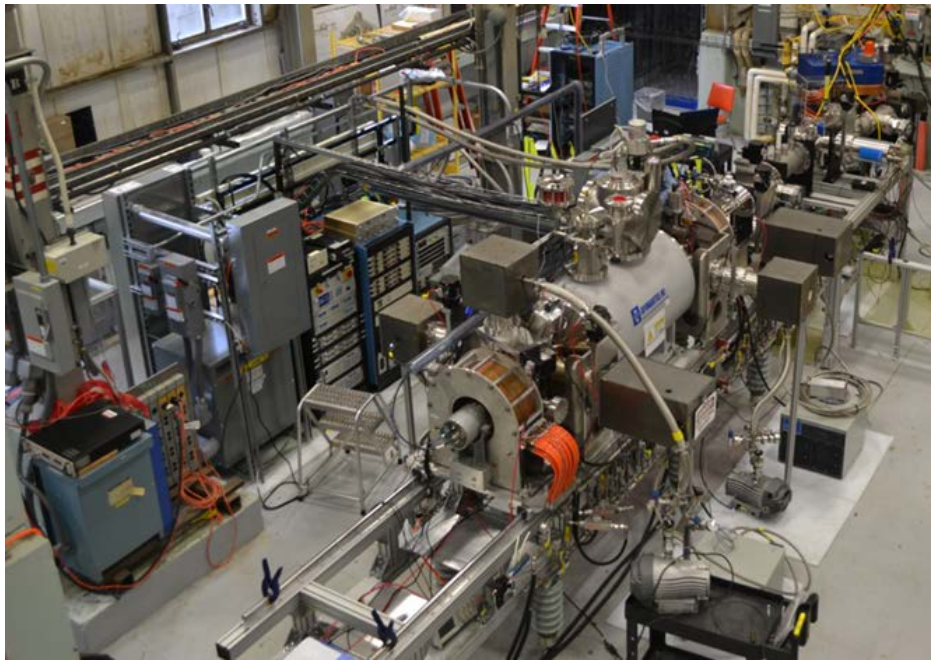
- Recent/current/possible upgrades addressing main limitations
  - ARRA funded intensity and efficiency upgrade of ATLAS (X10 in intensity) (FY13-14)
  - Digital Gammasphere (X4-12 in rate capabilities) (FY13-14)
  - EBIS charge breeder and larger low-energy experimental area for CARIBU (X 3 in intensity and higher purity) (FY14-15)
  - AGFA (X10 in acceptance for superheavies) (FY14-16)
  - AIRIS: New recoil separator for in-flight program (>100 in intensity and higher purity) (FY15-17)
  - Multi-user upgrade (FY16-20) ← ~ $ 2-3 M

within baseline funding

EBIS charge breeder upgrade

- Removing stable beam contamination of reaccelerated beams from ECR charge breeder
  - Concept developed and demonstrated by accelerator R&D group
  - Provides two important gains versus ECR charge breeding at CARIBU
    - Higher charge breeding efficiency demonstrated for pulse injection operation (ANL tests at BNL EBIS … and now operating off-line at ANL)
    - UHV system leads to stable beam background suppression

Factor 2-3 gain in intensity and large suppression of stable beam contaminants for reaccelerated CARIBU beams



ECR charge breeder removal and EBIS installation started as first GRETINA campaign ended

June 2015 – ECR in place

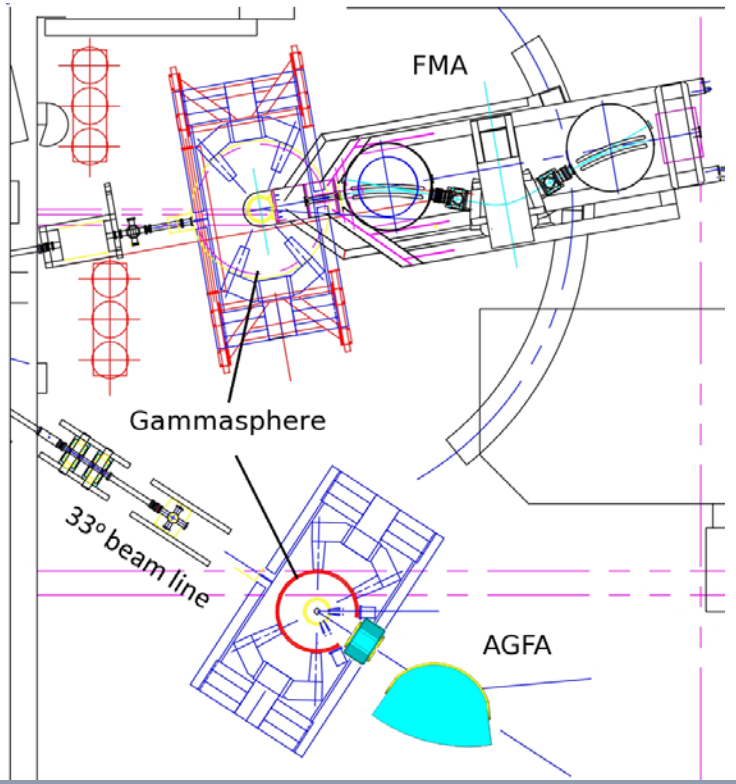
July 2015 – ECR removed

August 2015 – ECR HV platform removed, EBIS HV platform being installed

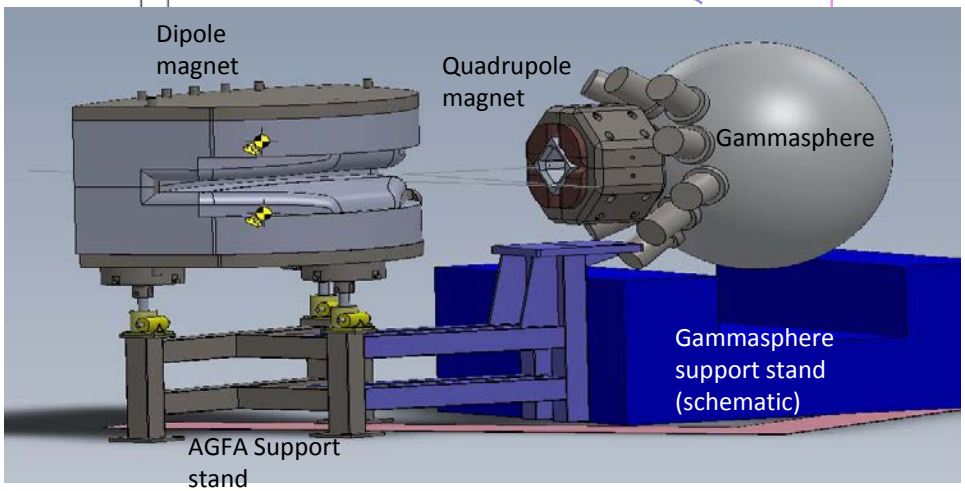
AGFA: Argonne Gas-Filled Analyzer

Purpose:

- High efficiency separation
  - Gammasphere at target position
  - Evaporation residues
    - Super-heavy nuclei
    - ~^{100}Sn region
    - Spectroscopy at the p drip line
  - Deep-inelastic products
    - N-rich nuclei e.g. N~126
  - General purpose use



Cost: $1755k (incl. contingency)

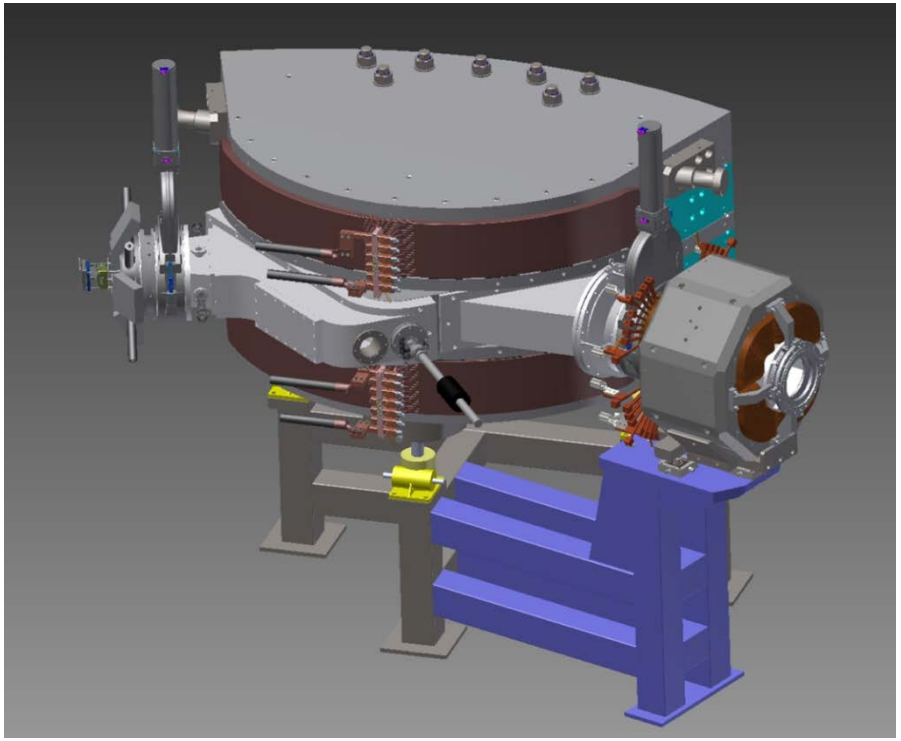


AGFA: 50-95% Efficiency

FMA: Less efficiency, m/q measurement

Cost status – under budget

(Aug.18/2015 AGFA review)



Status as of June 30, 2015

(Last quarterly report to DOE)

- Costed and committed: $520k
- Estimate to complete: $740k
- Estimated total cost: $1,261k

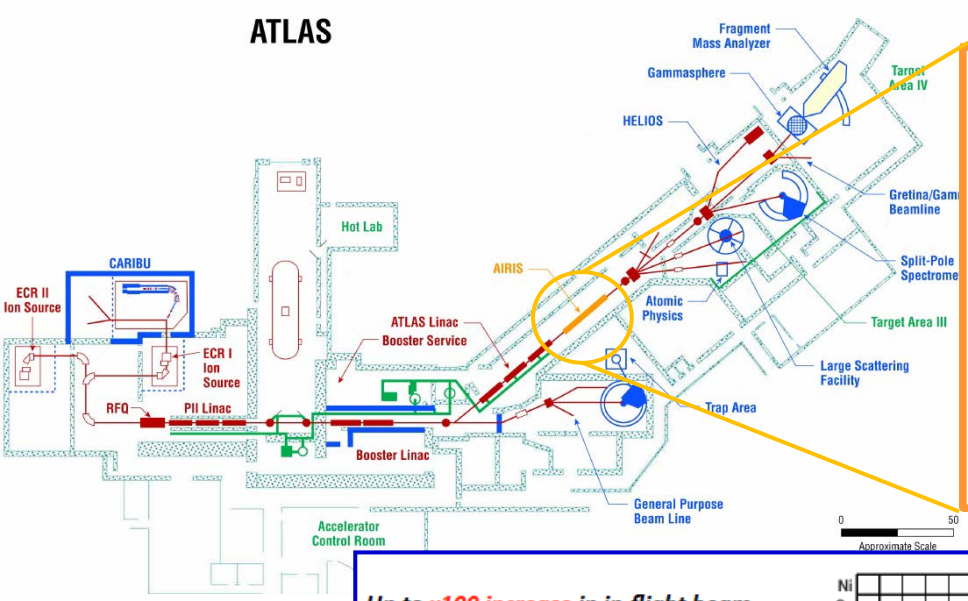
- Total baseline cost: $1,755k
- Baseline contingency: $372k
- Remaining contingency: $346k (Management + some WBS level 3 items)
- Rem. cont. + savings: $493k

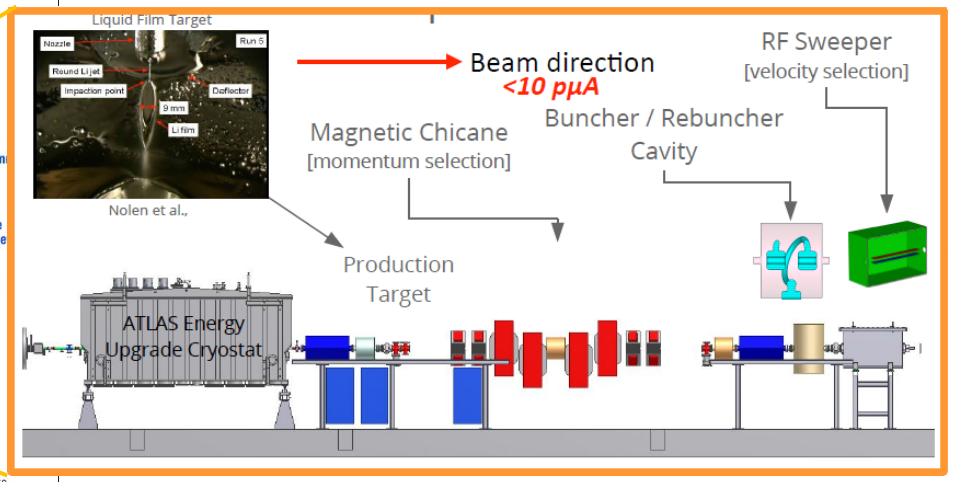
Schedule Milestones – on time

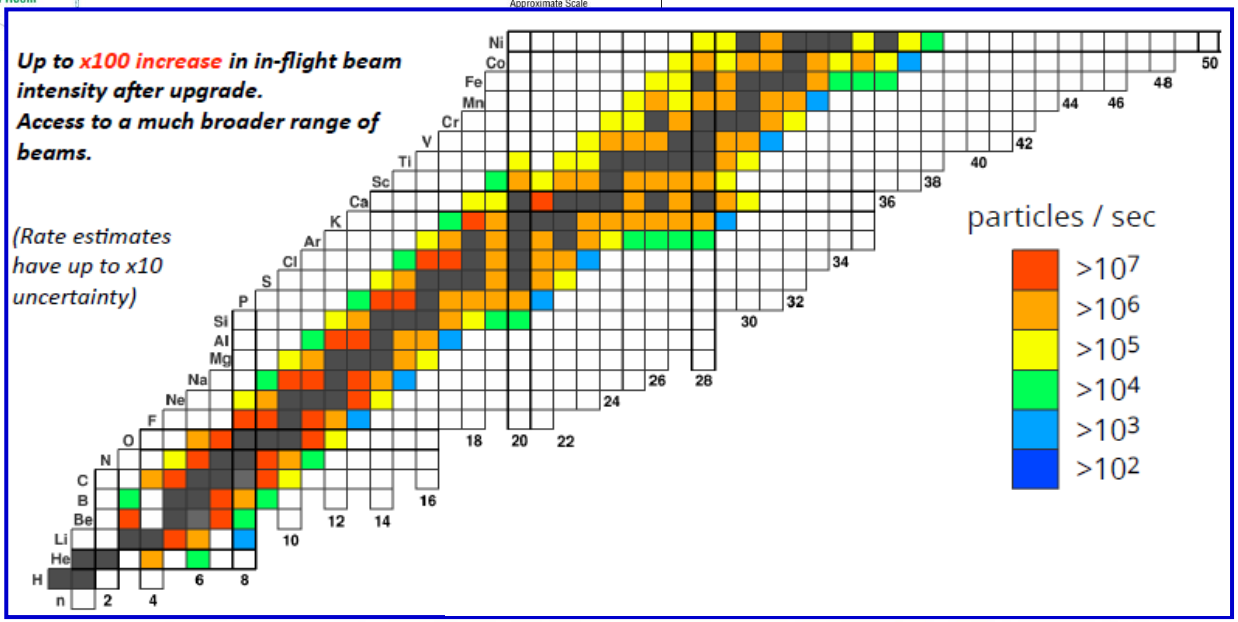
(Aug.18/2015 AGFA review)

WBS Number	Control Milestone Name	Baseline Date	Actual/ Forecast Date
1.1.2	Submit PMP	Jul 2014	Jul 2014
1.2.4	Quad steel bid package submitted	Oct 2014	Aug 2014
1.3.4	Dipole steel bid package submitted	Jan 2015	Aug 2014
1.2.12	Quad coil bid package submitted	Apr 2015	Aug 2014
1.3.10	Dipole coil bid package submitted	Oct 2015	Aug 2014
1.7.5	Support stand delivery	Jan 2016	Dec 2015
1.2.7	Quad steel delivery	Apr 2016	Feb 2016
1.3.6	Dipole steel delivery	Jul 2016	Feb 2016
1.10.1	AGFA installed and surveyed	Oct 2016	Oct 2016
1.5.7	Power supplies connected	Jan 2017	Jan 2017
1.12.1	Commissioning completed	Apr 2017	Apr 2017

AIRIS upgrade to the ATLAS facility

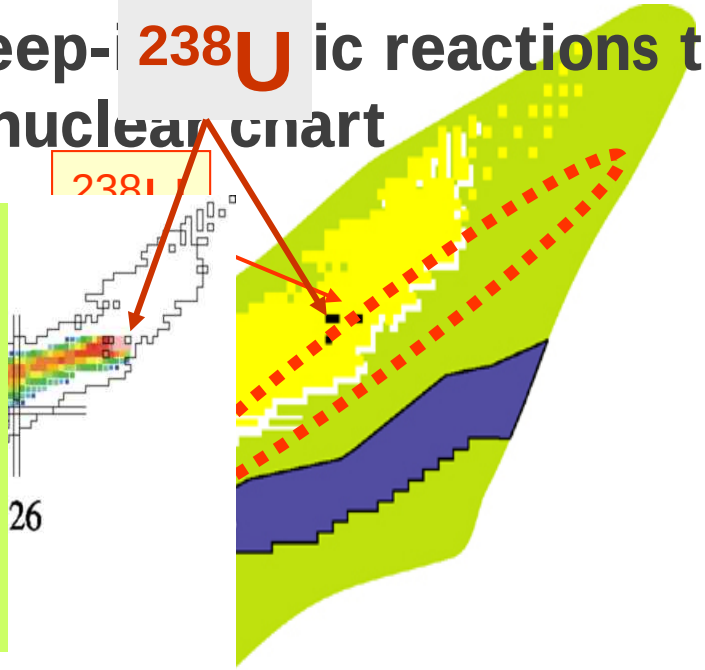






Accessing new regions: deep-inelastic reactions to reach the

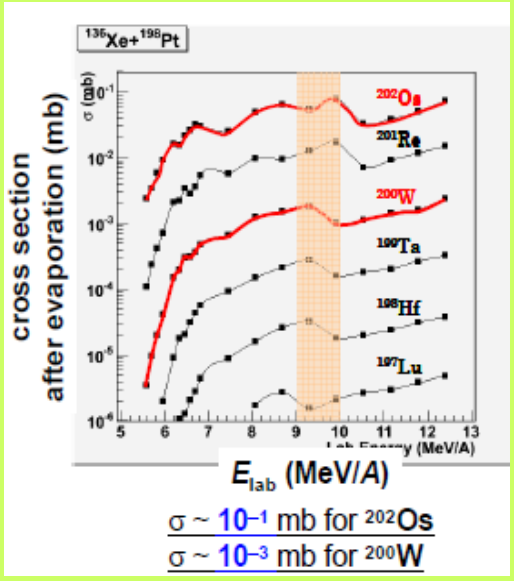
1 GeV/u ^{238}U + ^{1}H
Armbruster et al.



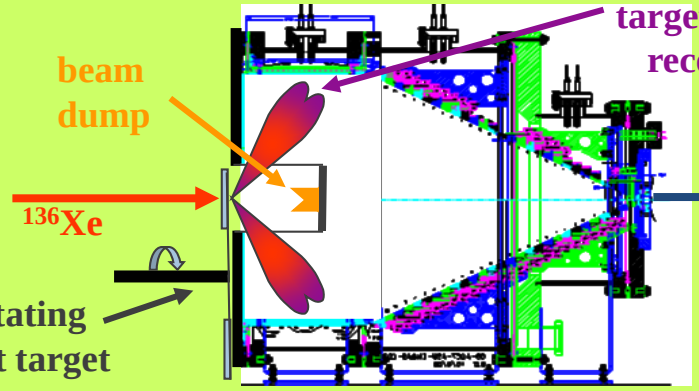
The Science:

- nuclear shell structure at the extremes
- r-process: second abundance peak, fission recycling and termination
- fission barriers of neutron-rich nuclei and symmetry energy
- connection of hot-fusion SHE island and mainland

Production through deep-inelastic reactions



Efficient thermalization, extraction and separation through a CARIBU like large gas catcher and separator



ATLAS multi-user upgrade: filling the gap, enabling new science

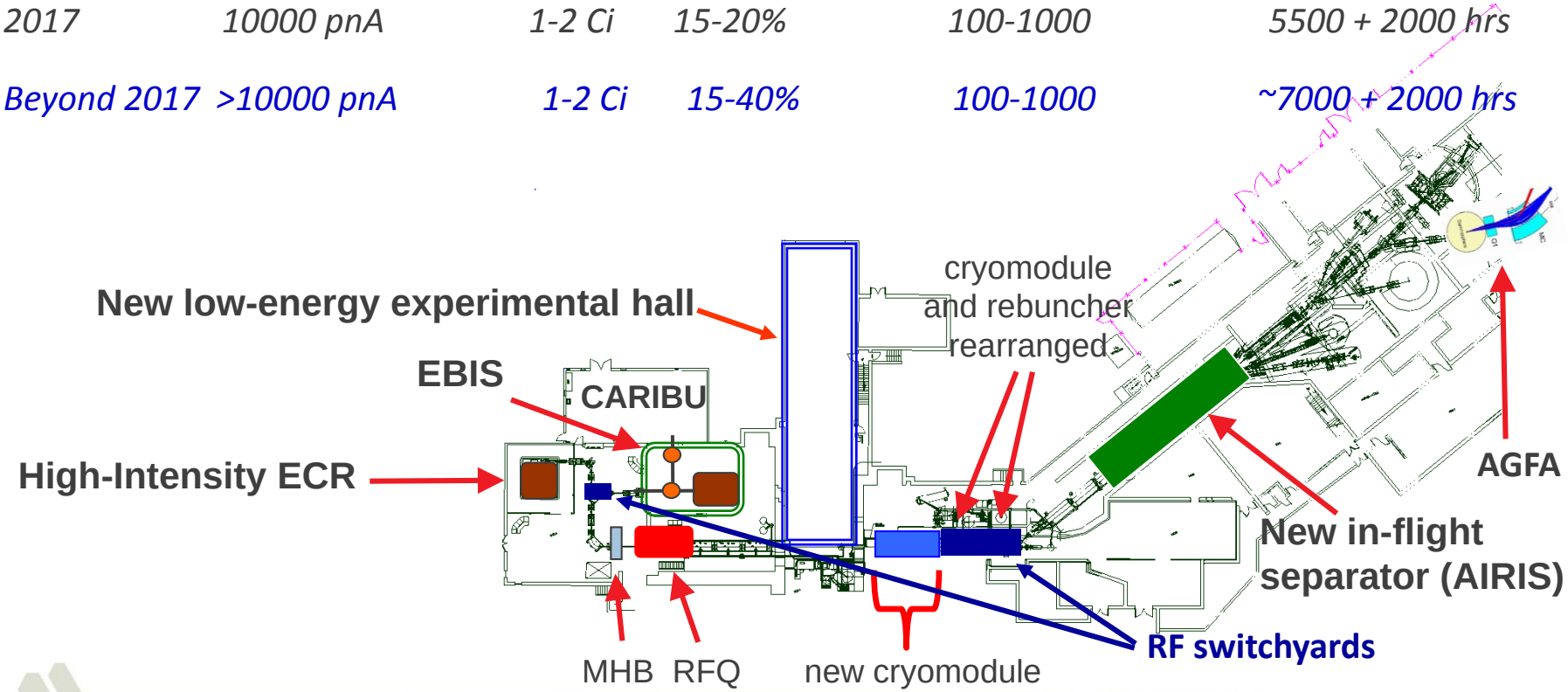
- Beamtime availability for low-energy community is under increasing pressure
  - The low-energy community lost HRIBF and Yale (~ 4000-6000 hrs/yr) … and the 88" cyclotron
  - Facilities outside the US (GSI, GANIL, RIKEN, ISOLDE) also have limited capabilities in coming years
- Further pressure on available beamtime to users from
  - Move to longer experiments with weak beams or low cross-section channels
  - ATLAS PAC oversubscribed by factor of ~ 3
- Specific characteristics of ATLAS and CARIBU can provide a cost efficient way to remedy this situation
  - With the EBIS breeder, the full CARIBU reaccelerated beam will be pulsed with a duty cycle of ~ 1%, leaving the accelerator "idle" for ~99% of the time.
  - The ATLAS linac can accelerate simultaneously ions with similar charge-to-mass ratio within 10% or so as shown in the multiple-charge-state acceleration performed at ANL to demonstrate the original RIA/FRIB accelerator concept

ATLAS could be modified to simultaneously accelerate two beams … providing full fledged multi-user capability (2 simultaneous users)

- **One full intensity CARIBU beam using 10-100 μs 30 times per second**
  - **Could accelerate 2 charge states to essentially double available intensity**
- **One ATLAS stable beam utilizing the remaining ~99% of the time**
  - **Available at the full intensity provided by the source**

ATLAS layout: 2012 -> 2014 -> 2016 ->2017 -> 2020

	Stable beam	CARIBU		in-flight beams	beam hrs
	I_{max}	source	reacc. eff.	relative yield	ATLAS+CARIBU low-E hrs
2012	200-500 pnA	0.3 Ci	3%	1	5500 + 2000 hrs
2014	10000 pnA	1 Ci *	8%	10	5500 + 2000 hrs
2016	10000 pnA	1-2 Ci	15-20%	10	5500 + 2000 hrs
2017	10000 pnA	1-2 Ci	15-20%	100-1000	5500 + 2000 hrs
Beyond 2017	>10000 pnA	1-2 Ci	15-40%	100-1000	~7000 + 2000 hrs



Status

- ATLAS is the DOE low-energy nuclear physics national user facility
  - Running reliably and logging in a large number of operating hours
  - Doing great science
  - Adding new capabilities
    - CARIBU
    - Intensity upgrade
  - Improving its suite of experimental equipment
    - HELIOS, digital Gammasphere and DSSD, X-array
    - AGFA, AIRIS, N=126 factory, laser lab, beta-delayed neutron trap

- Providing unique capabilities to a broad user community
  - unique experiments with stable beams
  - exploring the path and bridging the gap to the reaccelerated beam program at FRIB

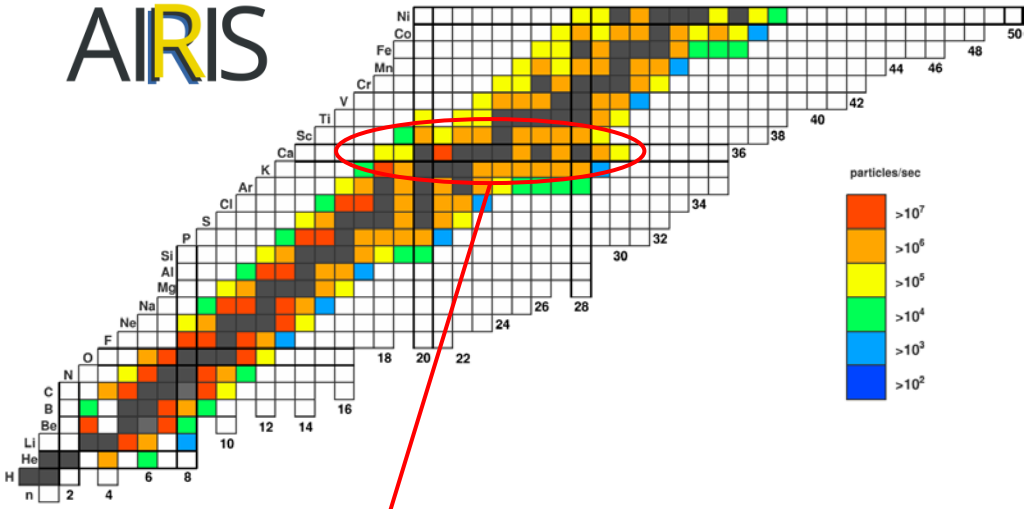
- Evolving to keep up with (and anticipate) the needs of the community and keep its central role in low-energy nuclear physics

Backup slides

Main research thrusts: Nuclear structure

Single-particle transfer program with Helios at ATLAS in coming years

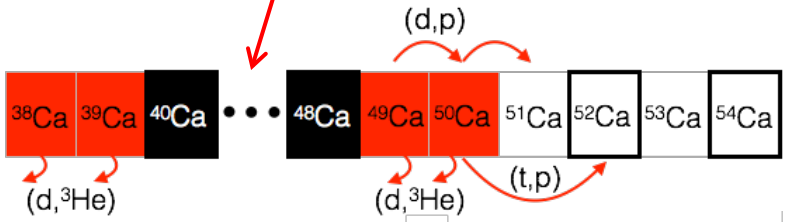
AIRIS

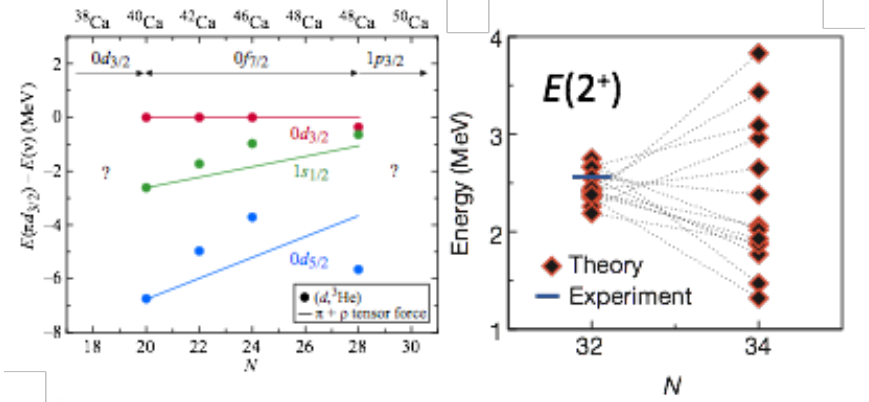


CARIBU

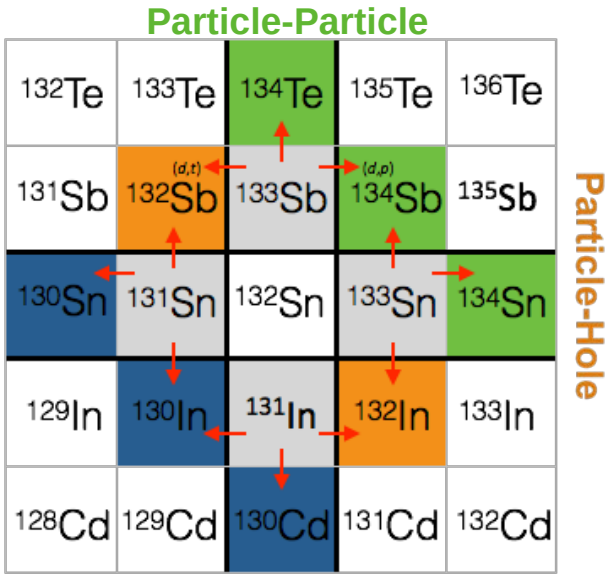
FWHM < 100 keV

Kay et al PRC **84**, 024325 (2011)





Steppenbeck *et al.*, Nature 502, 207 (2013)



Beams