ATLAS

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Presentation to the NSAC committee

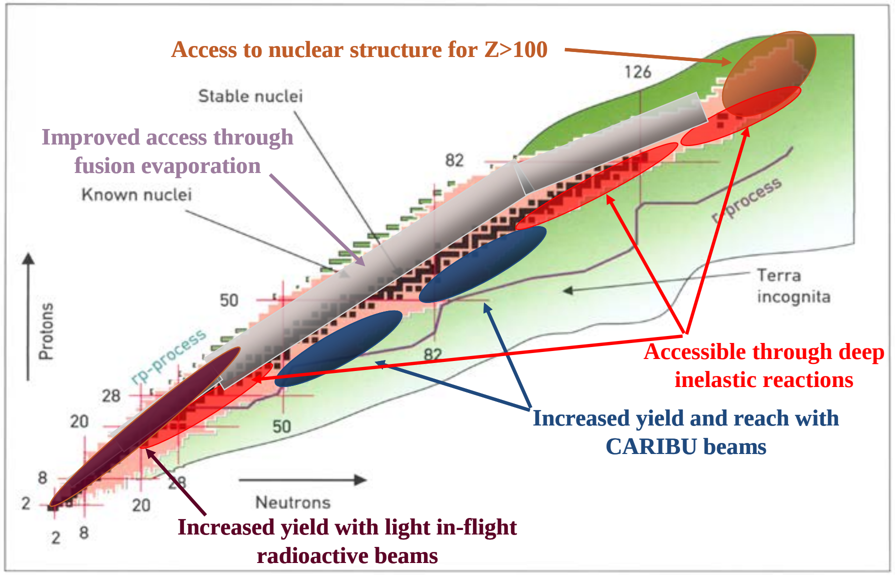
Rockville, November 17, 2014

ATLAS Role and Goals

- ***ATLAS is the DOE low energy nuclear physics national user facility***
- It provide beams and facilities enabling world leading research at around Coulomb barrier energy, answering key questions in the fields of:
  - nuclear structure
  - nuclear astrophysics
  - low-energy tests of the Standard Model
  - applications of low-energy nuclear physics

Research goals are guided by the Nuclear Science Long-Range plan, the relevant DOE performance milestones and the ATLAS Strategic plan.

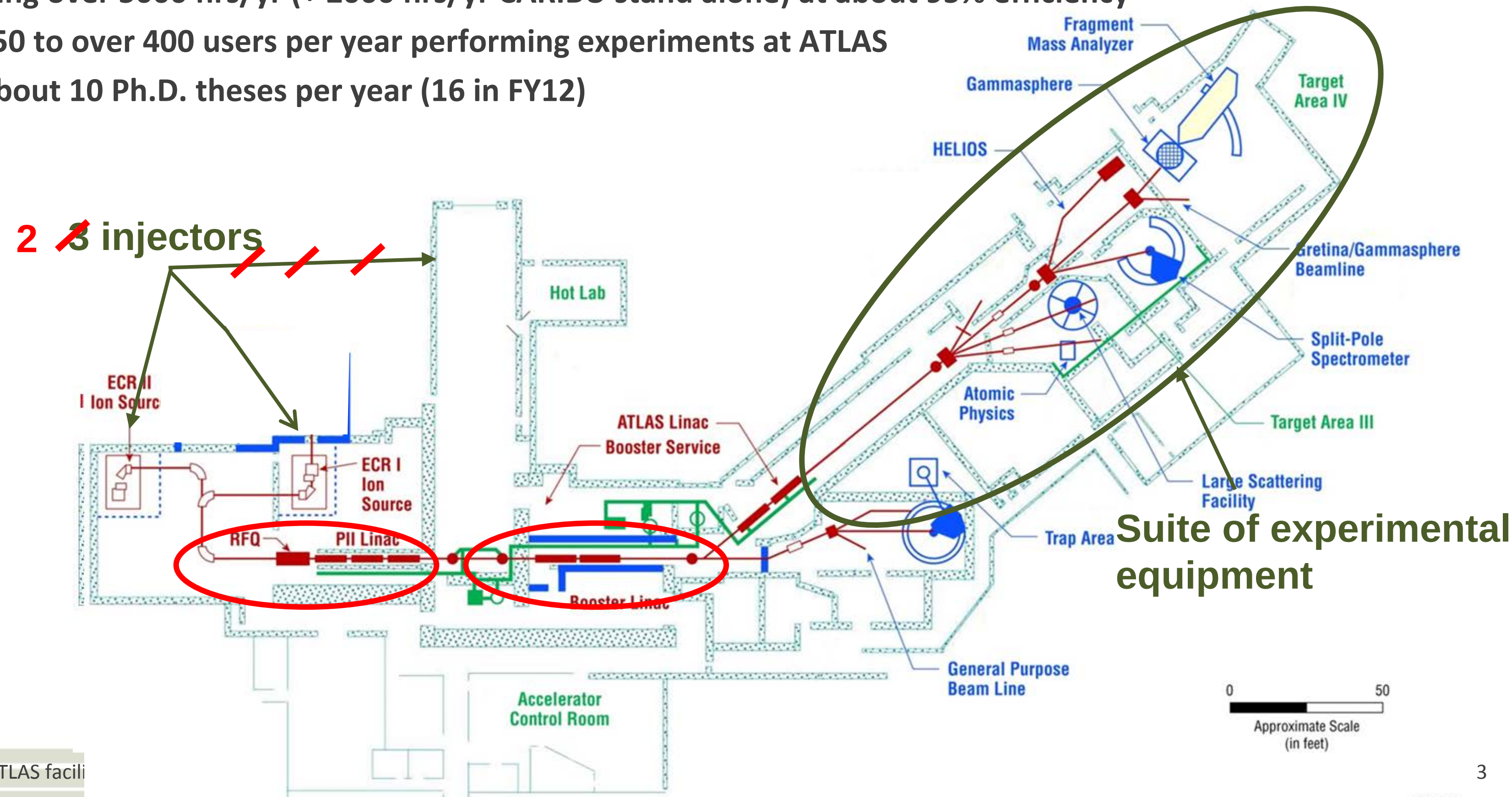
- This is done through:
  - providing beamtime for research programs
    - Any stable beam from proton to uranium
    - some in-flight radioactive beams
    - Low-energy and reaccelerated CARIBU beams
  - developing new capabilities to address evolving needs of the field
    - new experimental equipment
    - new accelerator capabilities (accelerator R&D group)



- ATLAS is interacting strongly with the community to ensure that it fulfills the needs of its users and evolves to continue doing so in the future. This includes developing capabilities and expertise that will be important for the physics program (focused mainly on reaccelerated beams) at FRIB and positioning ATLAS for its expected role as the high-intensity stable beam facility in the FRIB era.

ATLAS facility

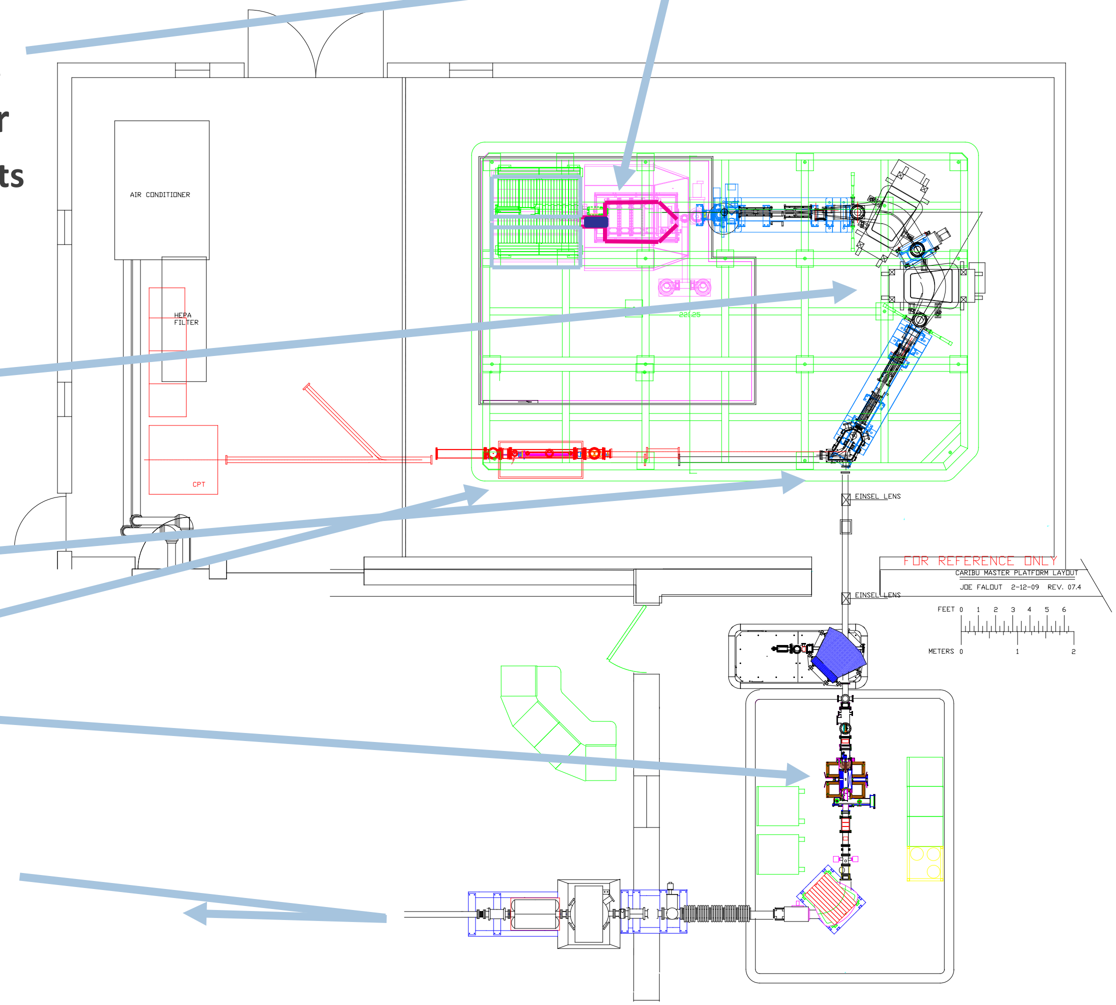
- Stable beams at high intensity and energy up to 10-20 MeV/u
- Light in-flight radioactive beams
  - *light beams, no chemical limitations, close to stability, acceptable beam properties*
- CARIBU beams
  - *heavy n-rich from Cf fission, no chemical limitations, low intensity, ATLAS beam quality, energies up to 15 MeV/u*
- State-of-the-art instrumentation for Coulomb barrier and low-energy experiments
- Operating over 5000 hrs/yr (+ 2000 hrs/yr CARIBU stand alone) at about 95% efficiency
  - 350 to over 400 users per year performing experiments at ATLAS
  - About 10 Ph.D. theses per year (16 in FY12)



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

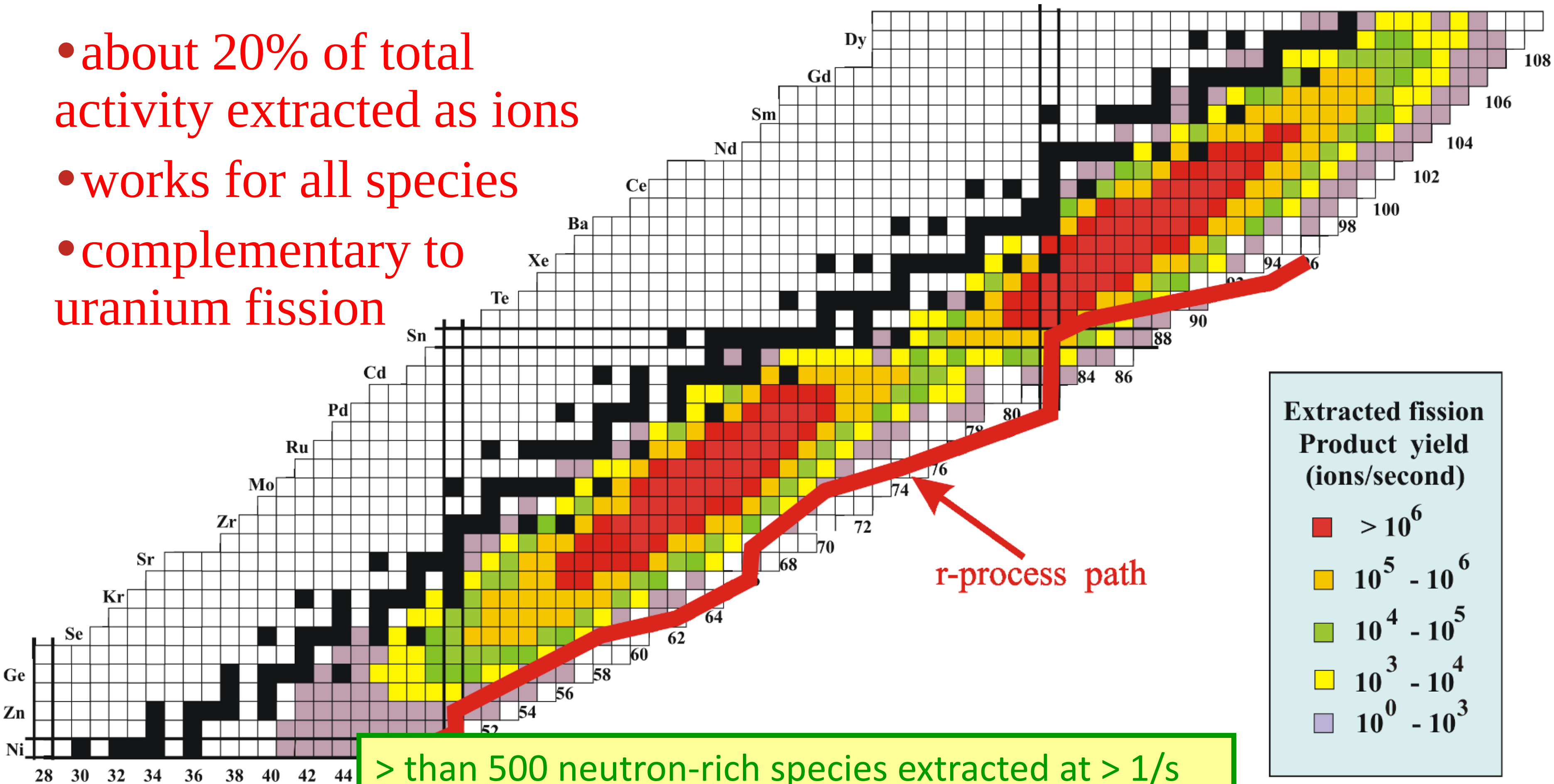
Main components of CARIBU

- **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



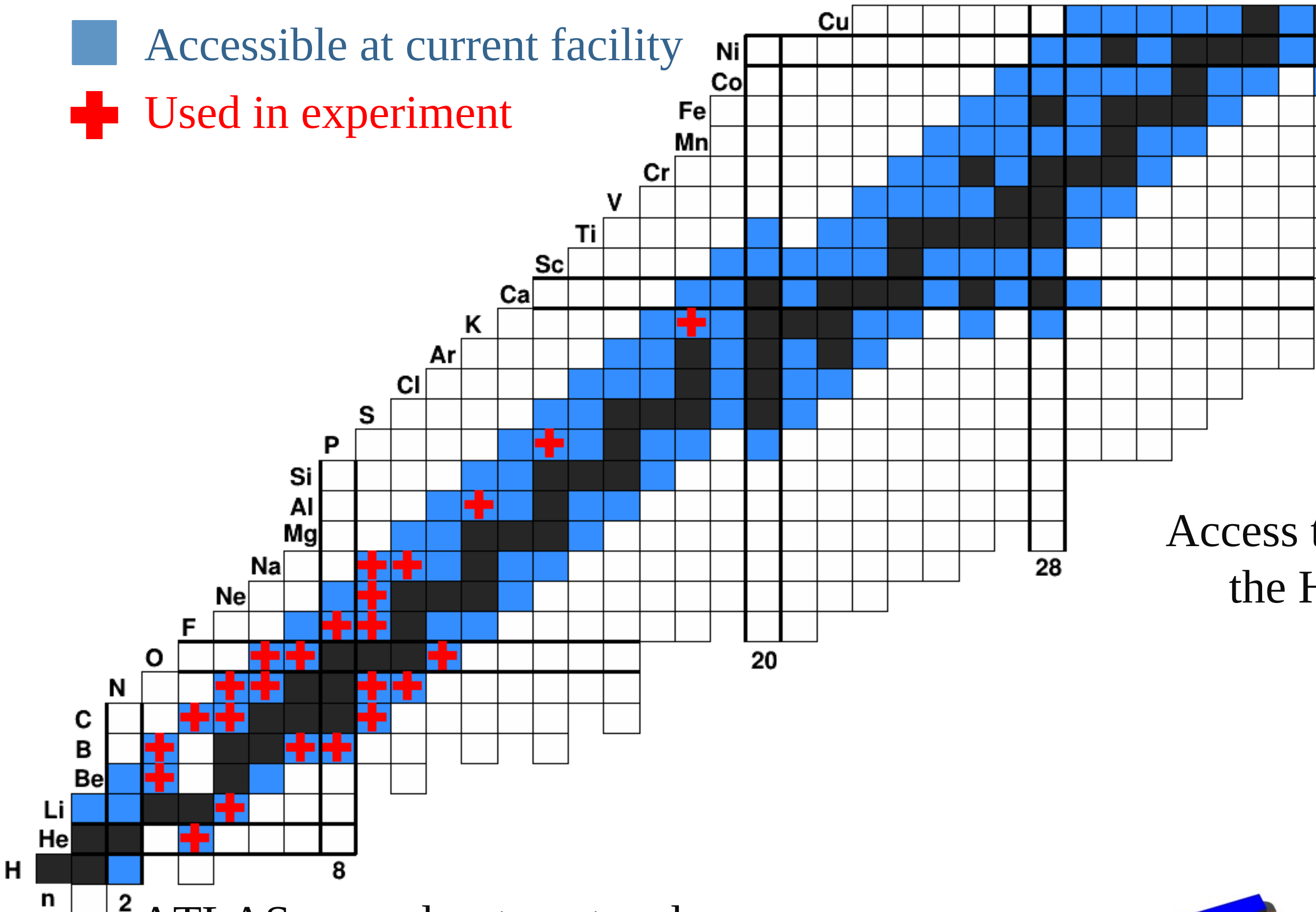
> than 500 neutron-rich species extracted at > 1/s

> than 150 different neutron-rich species have been used for experiments at CARIBU already

In-flight radioactive beams at ATLAS

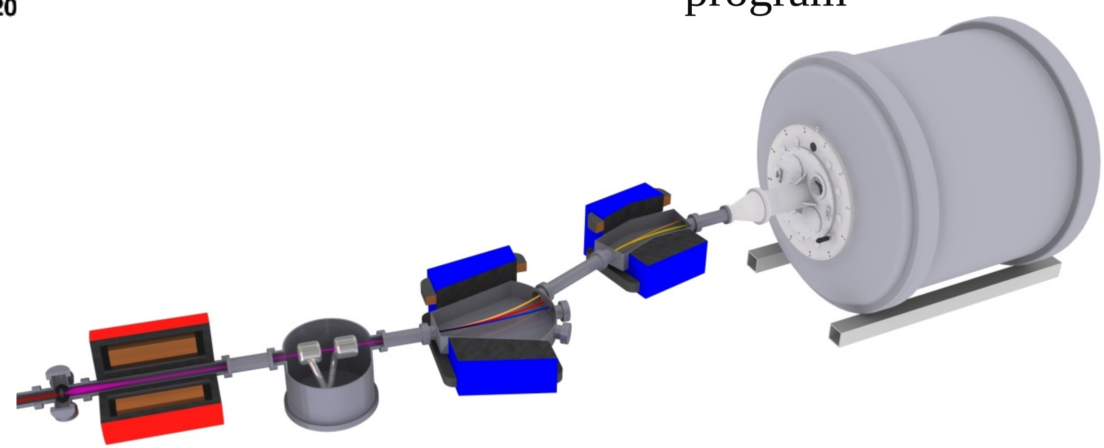
Accessible at current facility

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. This will remain so at least until FRIB turns on.

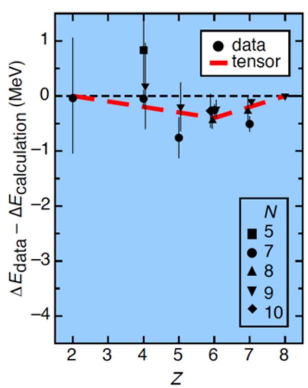
- **In-flight radioactive beams: all light species, close to stability, but compromise between beam properties, intensity and purity**

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

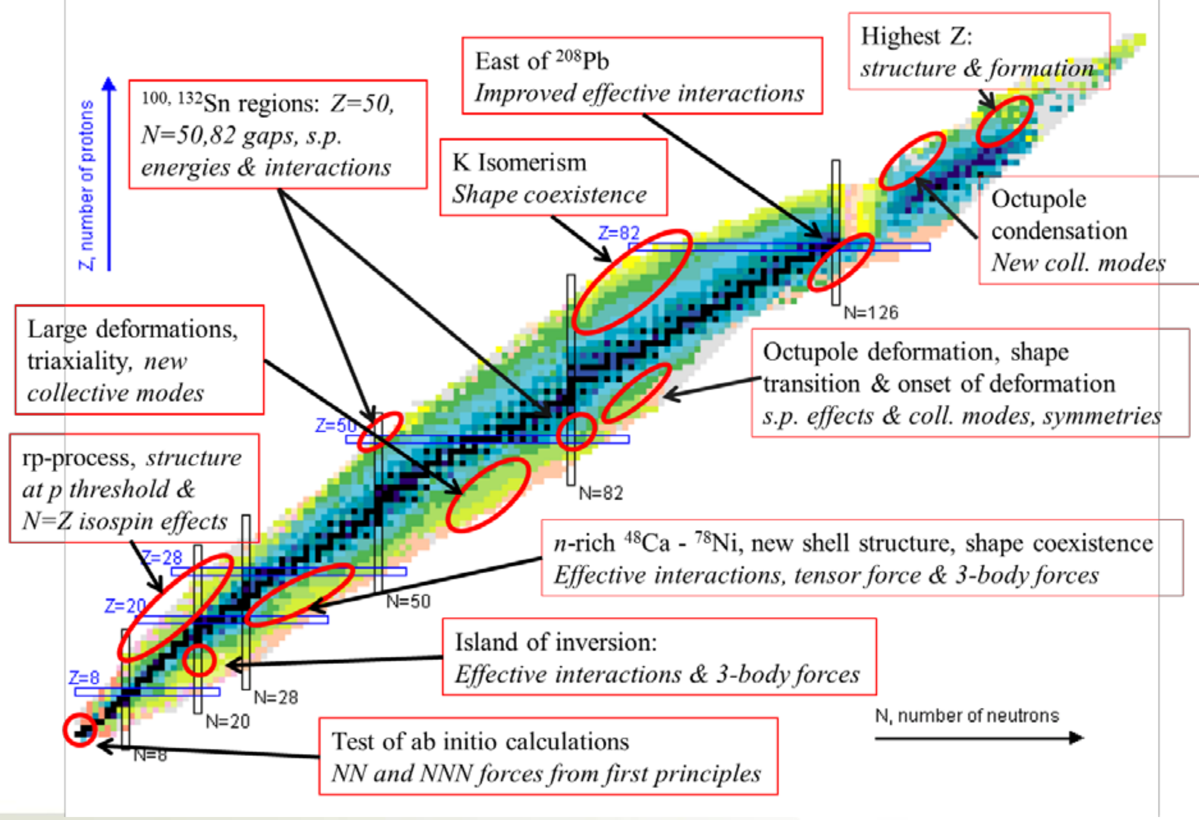
High level goal is to develop a comprehensive description of nuclei. This is done through the study of

- 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

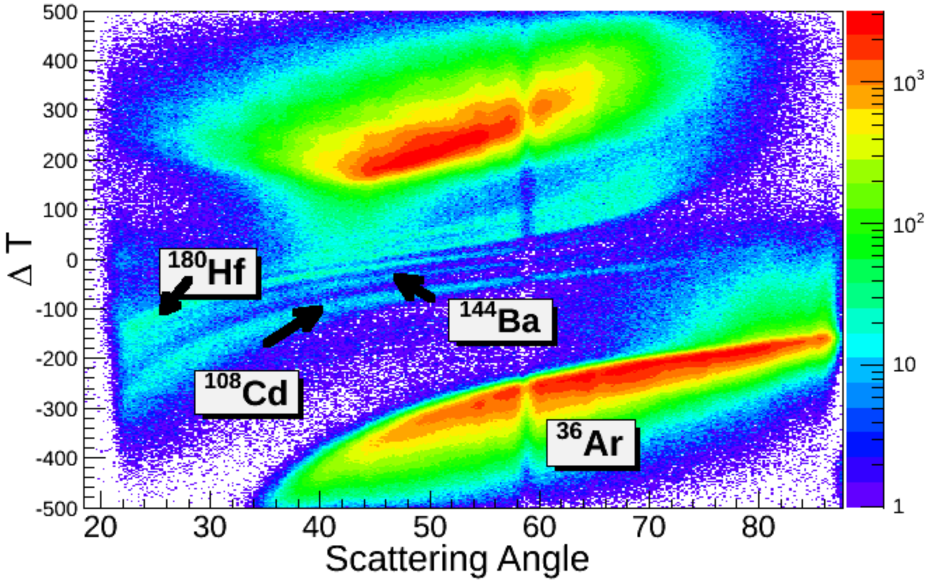


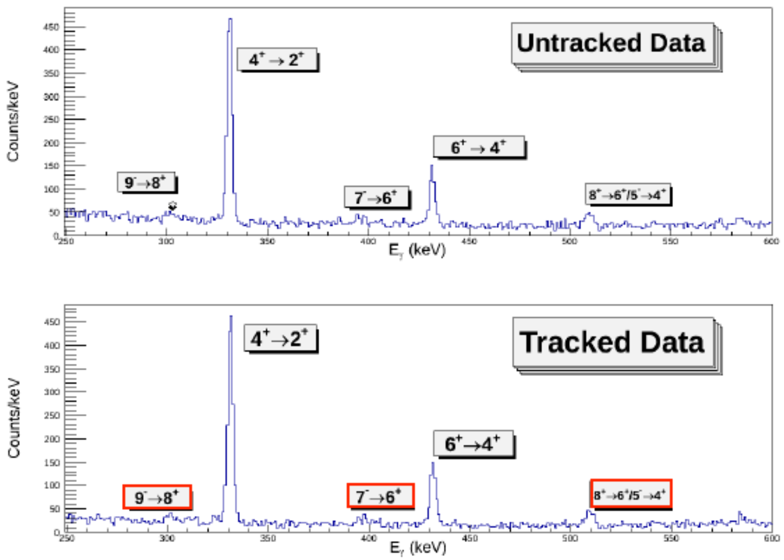
- Marriage of ***in-flight beams*** and ***HELIOS***
- Addressed ***selected*** key issues
- ***New insights*** into global behavior of centroids

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 ^{144}Ba from CARIBU with GRETINA/CHICO2





(*Analysis preliminary*)

S. Zhu (analysis) (2014) [ANL, LLNL, etc]

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

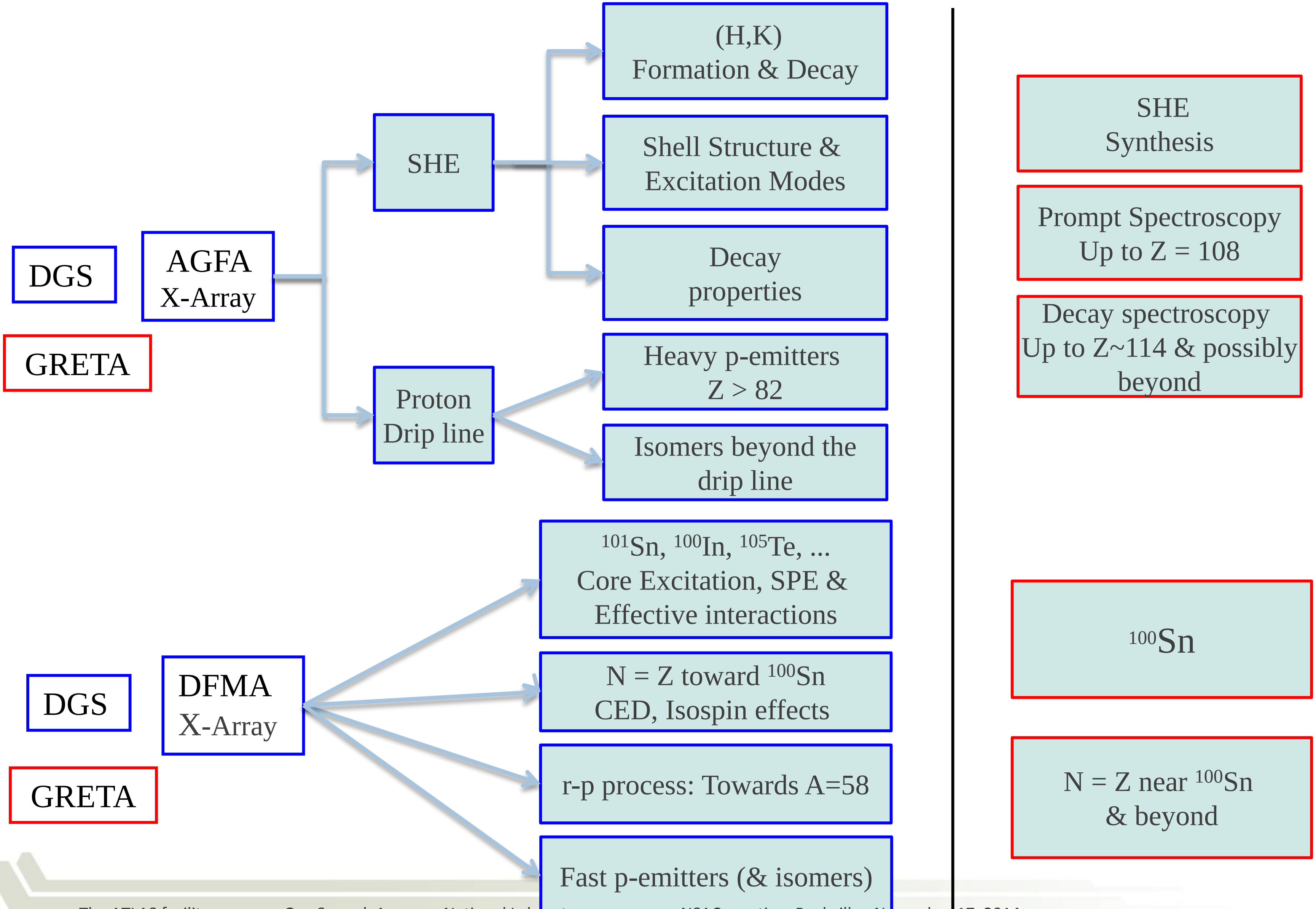
Rochester – LLNL – LBL – Liverpool – Scotland – Ohio U -ANL collab.

- 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 structure

s.p. structure and collective properties via gamma-ray studies at ATLAS in coming years

Instrumentation | 5 Year Goals | Beyond 5 years



Main research thrusts: Nuclear structure

s.p. structure and collective properties via gamma-ray studies at ATLAS in coming years

Instrumentation	5 Year Goals	Beyond 5 years

DGS X-Array

- DIC
- N~126 with Gas Catcher

GRETA

AGFA

Structure of n-rich nuclei In-beam & Decay

Structure of nuclei close to r-process line

Pt, Pb, Bi,.. N ~ 126 spectroscopy

Structure at largest N/Z smallest Xsection

CARIBU

DGS X-Array

CHICO

GRETA

AIRIS

A~110

Coulex

Triaxiality

Shape as a function of spin

Decay

Complete low spin structure

A~146

Coulex

Collective Modes Coexistence

Onset of Deformation

Decay

New Symmetries

Structure at largest N/Z

*Stable beams mostly

Hyperdeformation *

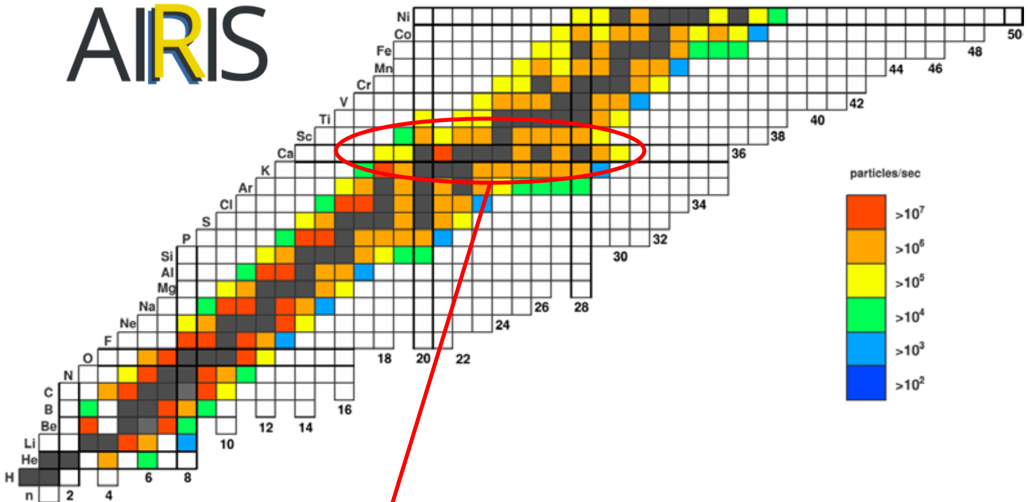
Other exotic modes (Jacobi shapes ...) *

Quasi Continuum *

Main research thrusts: Nuclear structure

Single-particle transfer program at ATLAS in coming years

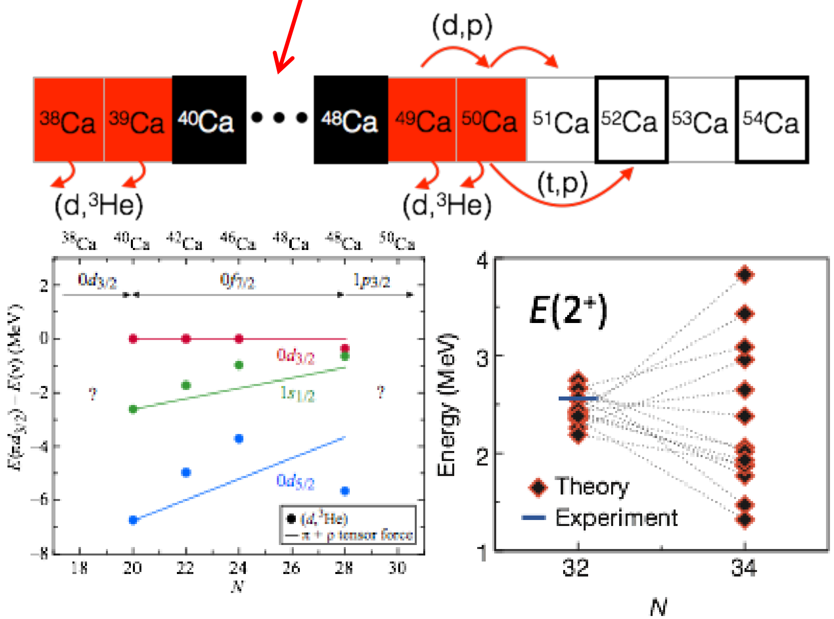
AIRIS



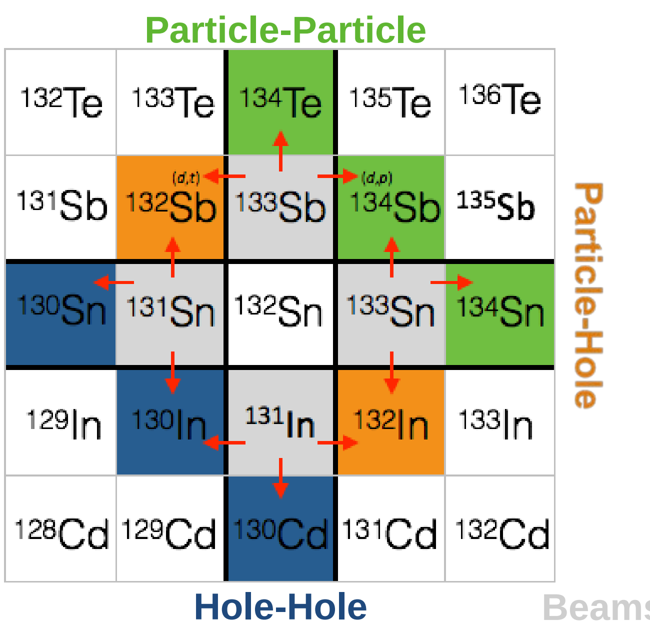
CARIBU

FWHM < 100 keV

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



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

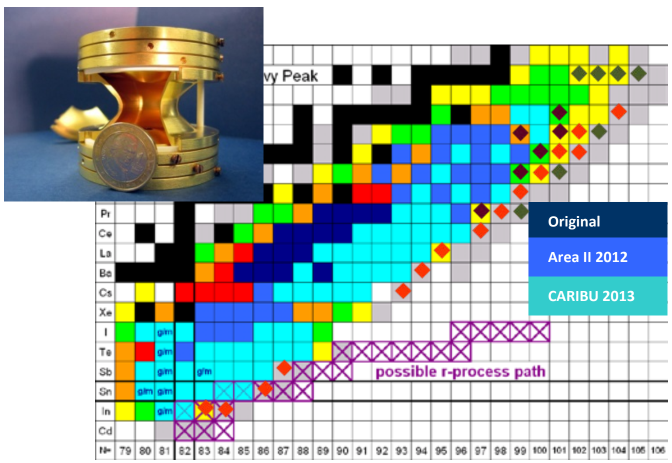


Main research thrusts: Nuclear astrophysics

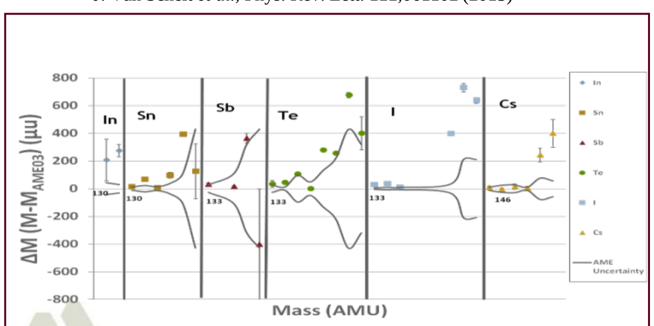
Understanding nucleosynthesis processes in the cosmos

- 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, ...

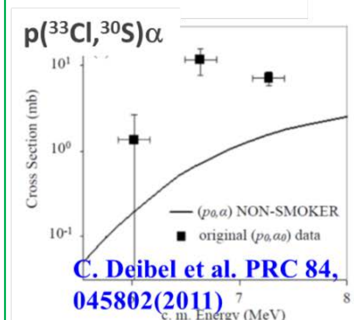
n-rich masses for r-process



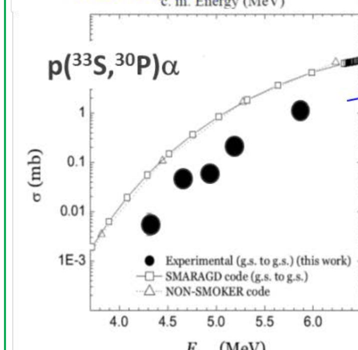
J. Van Schelt *et al.*, Phys. Rev. C **85**, 045805 (2012)
J. Van Schelt *et al.*, Phys. Rev. Lett. **111**,061102 (2013)



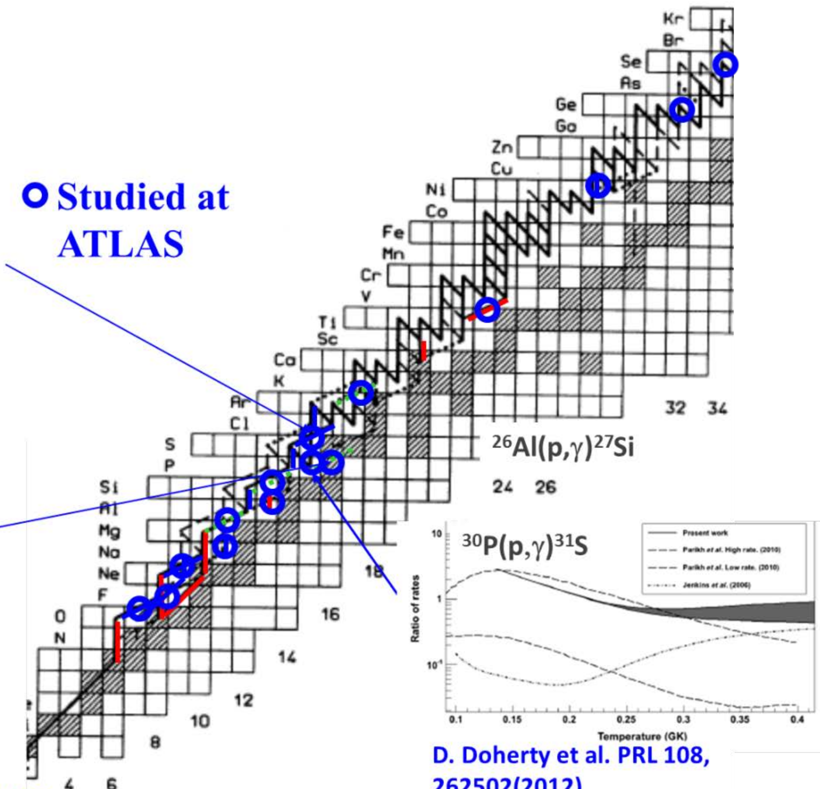
reactions for rp-process



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



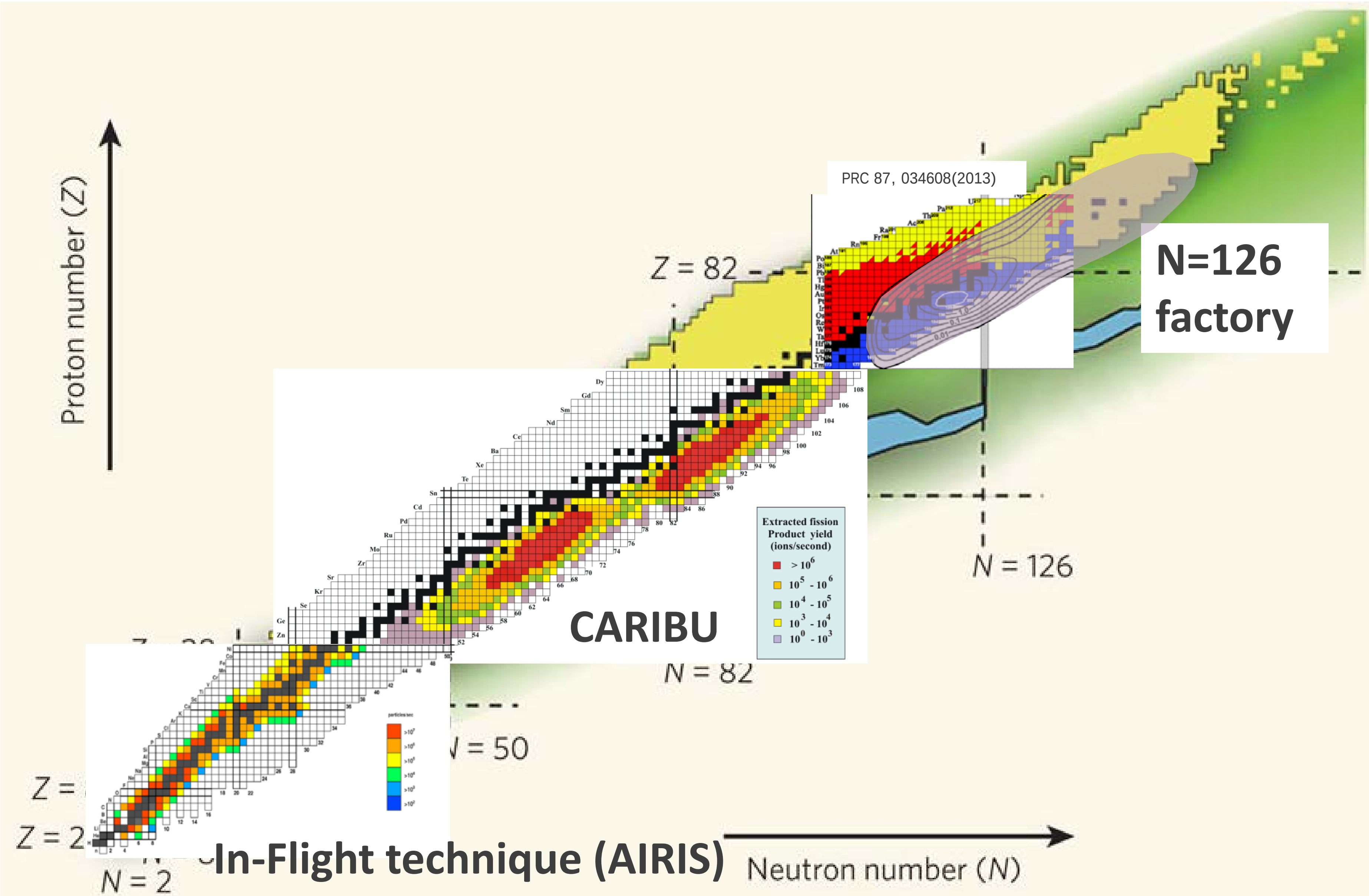
J. Figueira, NIMA 670, 32(2012)



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

Main research thrusts: Nuclear astrophysics

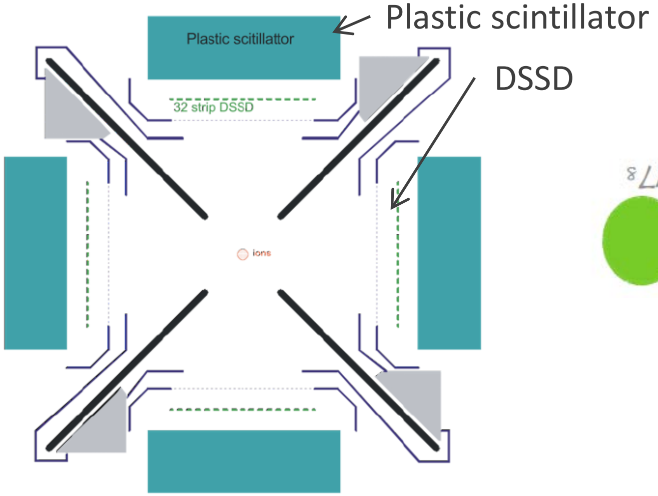
Accessing new regions for r-process and rp-process measurements in coming years



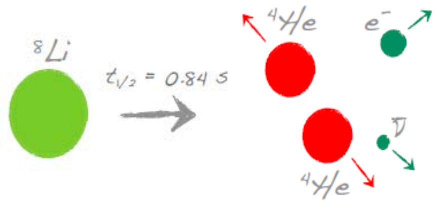
Main research thrusts: Fundamental Interactions

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

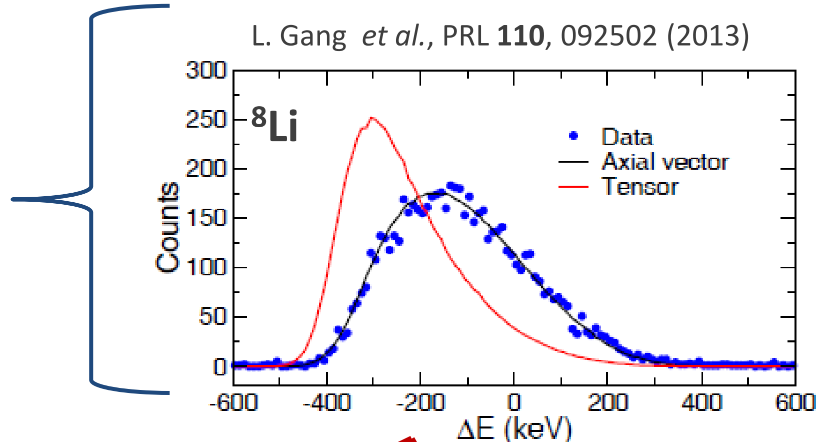
- Using new technologies (ion traps and ion manipulation techniques) to improve searches for physics beyond the Standard Model

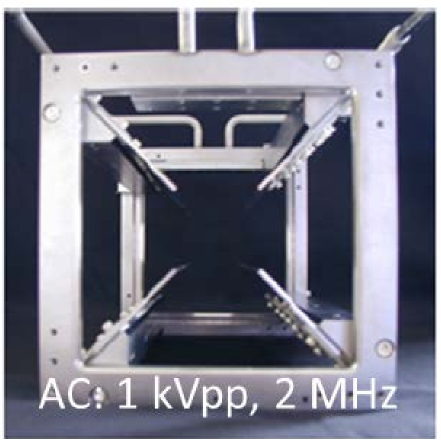


Detector System

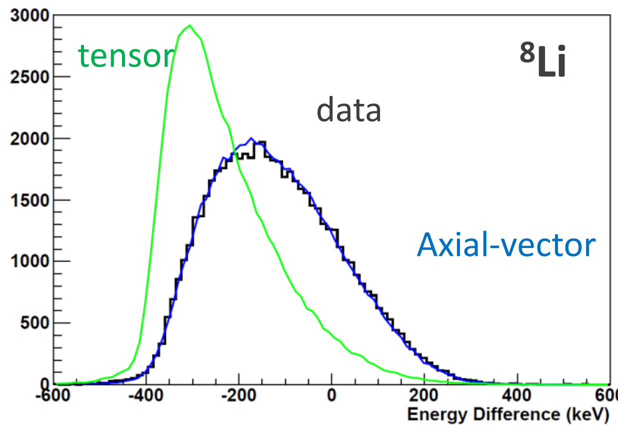


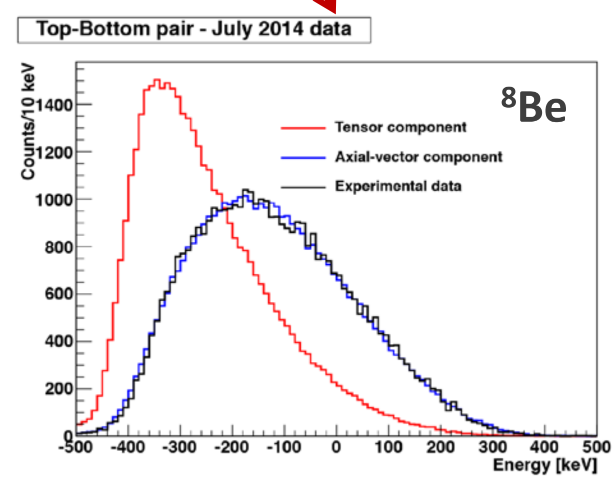
L. Gang *et al.*, PRL **110**, 092502 (2013)





2011 correlation data and fits





Main research thrusts: Applications

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

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

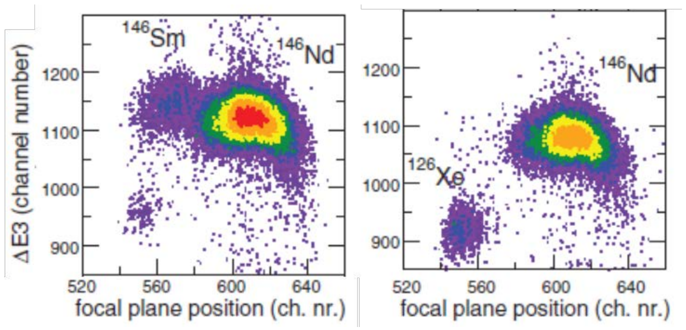
^{60}Fe: W. Kutschera et al. (NIMB 85, 430(1984))

^{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]

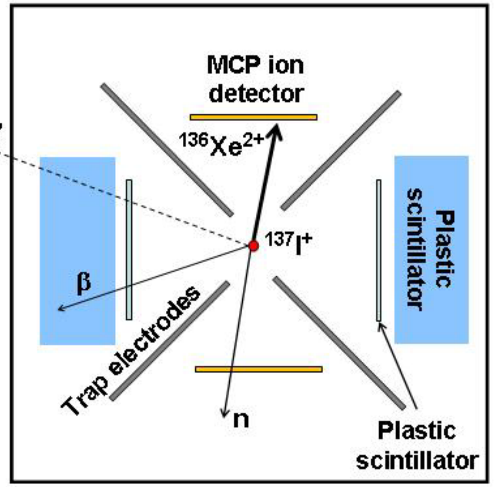
Science **335**, 1614 (2012)

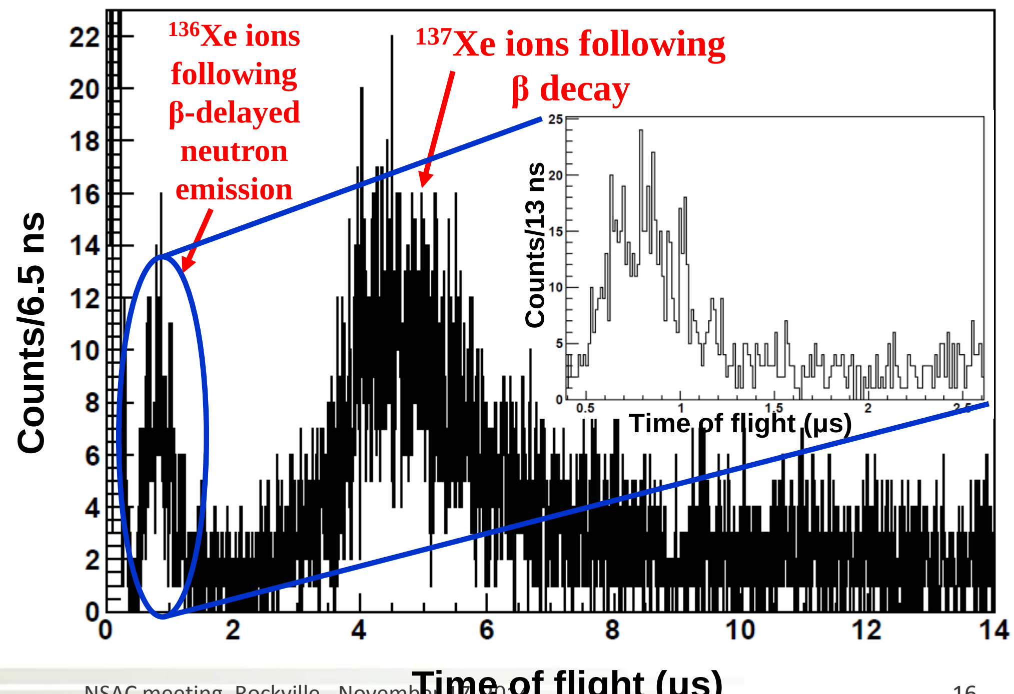


Accelerator Mass Spectrometry (AMS) technique now used at ATLAS (MANTRA) to measure neutron-capture cross-section for heavy actinides

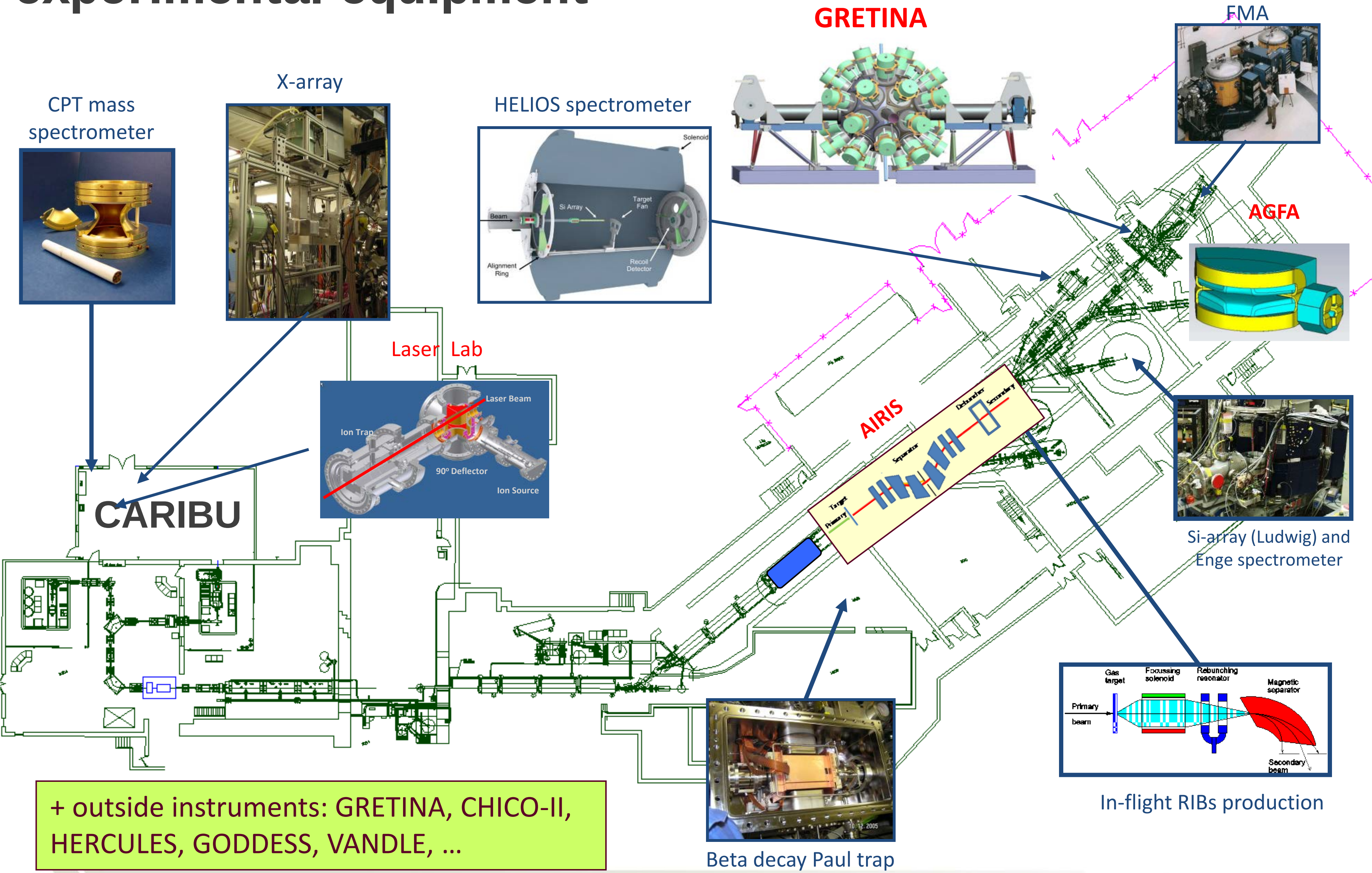
R.M. Yee *et al.*, PRL **110**, 092501 (2013)

- **Let ion decay from rest at 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**





Main tools enabling the physics: ATLAS suite of experimental equipment



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

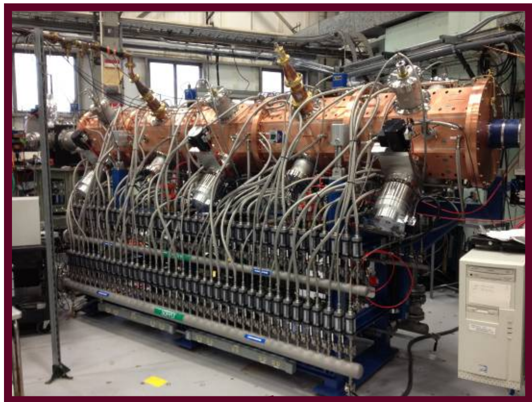
Current push forward for ATLAS

- 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

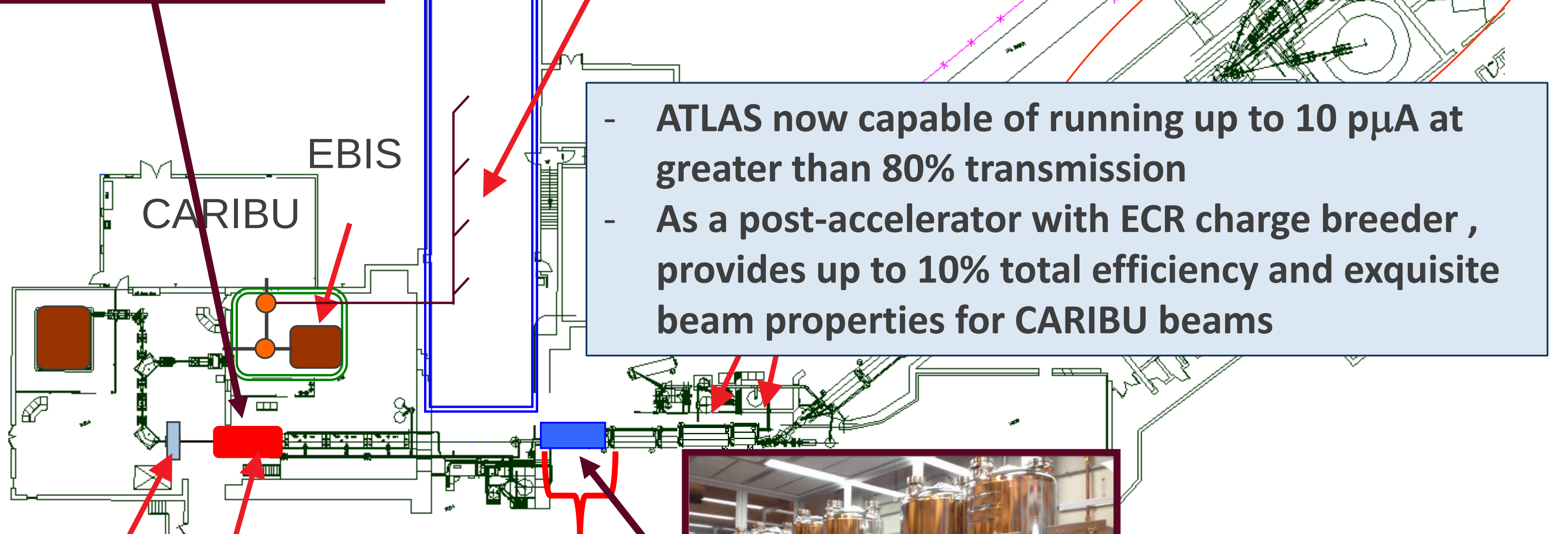
- Recent/current/possible upgrades addressing main limitations
  - ARRA funded intensity and efficiency upgrade of ATLAS (X10 in intensity) (FY13-14)
  - Digital Gammasphere (X4-12 in rate capabilities) (FY13-14)
  - EBIS charge breeder and larger low-energy experimental area for CARIBU (X 3 in intensity 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) ← Roughly $2 M

within baseline funding

ATLAS layout after recent upgrades



Novel design from Accelerator R&D group

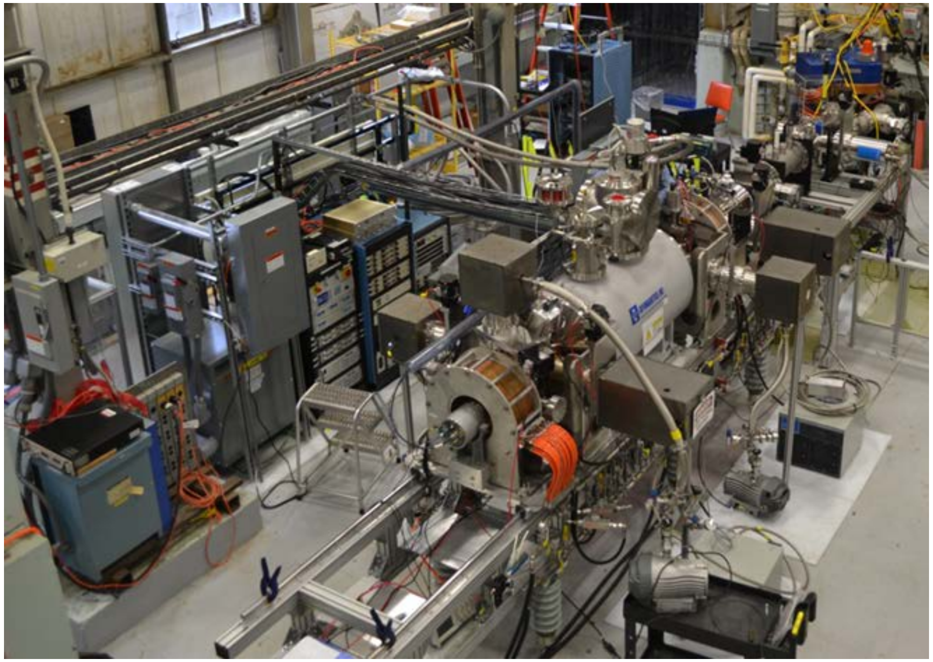


- ATLAS now capable of running up to 10 pμA at greater than 80% transmission
- As a post-accelerator with ECR charge breeder , provides up to 10% total efficiency and exquisite beam properties for CARIBU beams

World record performance

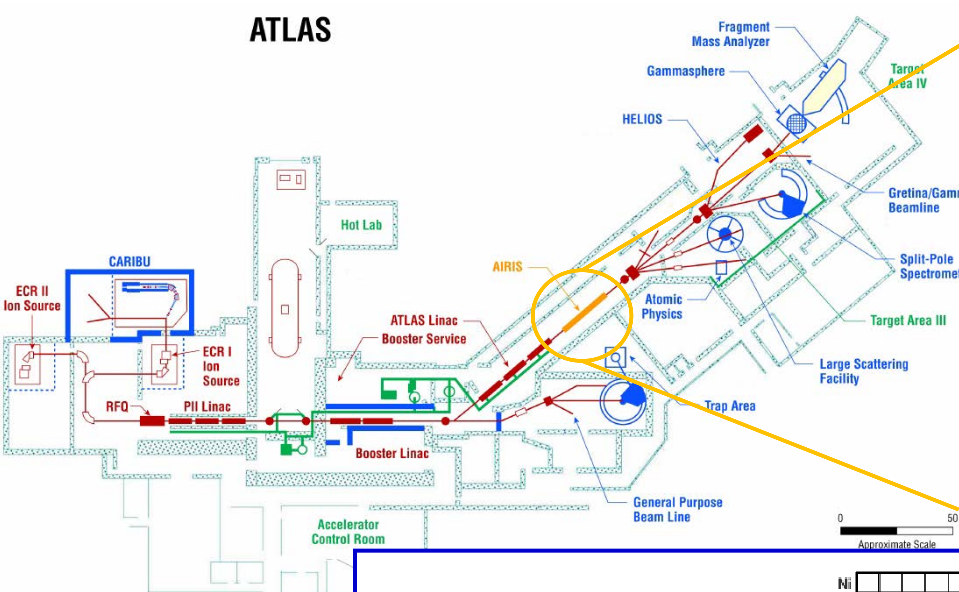
EBIS charge breeder upgrade

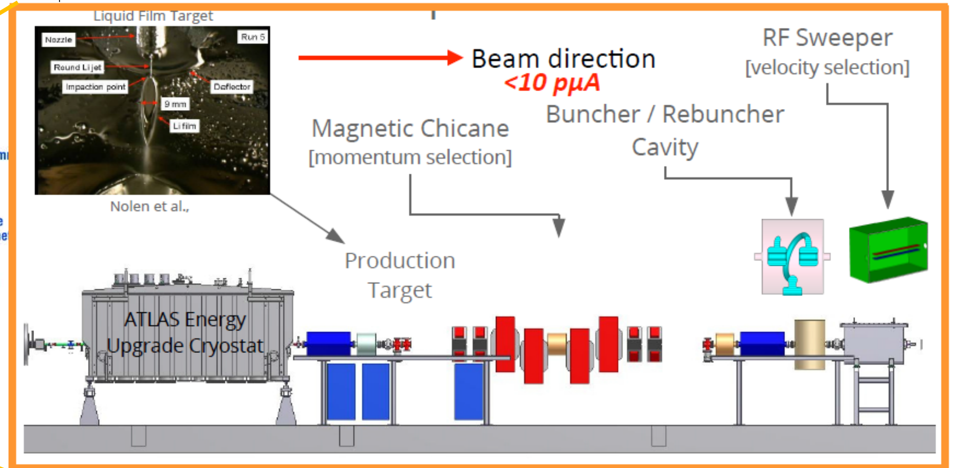
- Removing stable beam contamination of reaccelerated beams from ECR charge breeder
  - Concept developed and demonstrated by accelerator R&D group
  - Provides two important gains versus ECR charge breeding at CARIBU
    - Higher charge breeding efficiency demonstrated for pulse injection operation (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

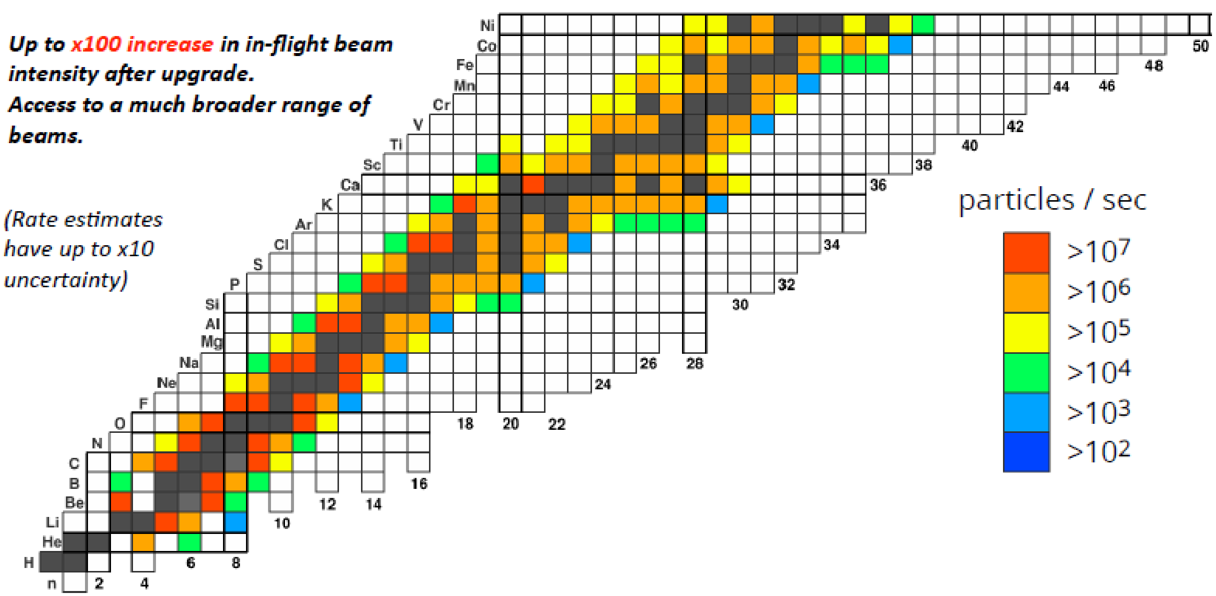
AIRIS upgrade to the ATLAS facility





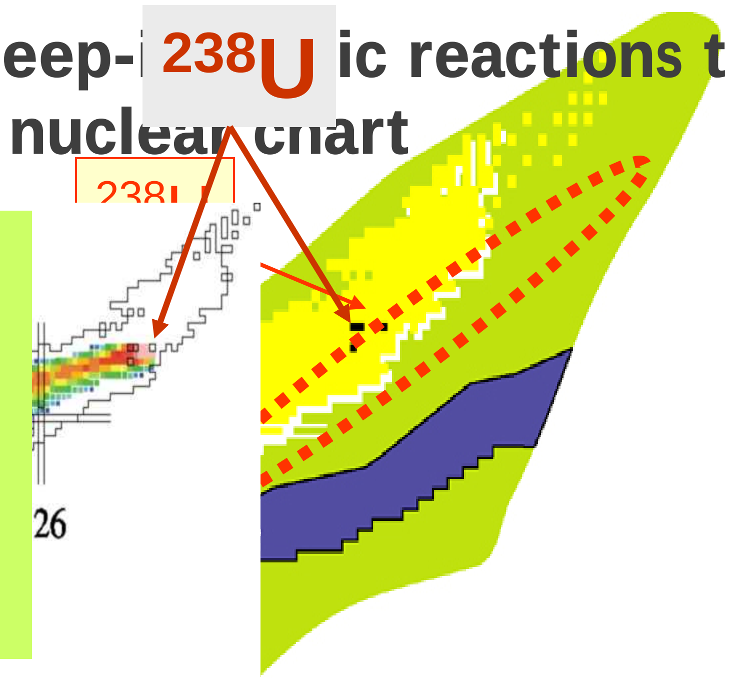
Up to x100 increase in in-flight beam intensity after upgrade.
Access to a much broader range of beams.

(Rate estimates have up to x10 uncertainty)



Accessing new regions: deep-inelastic reactions to reach the … of the nuclear chart

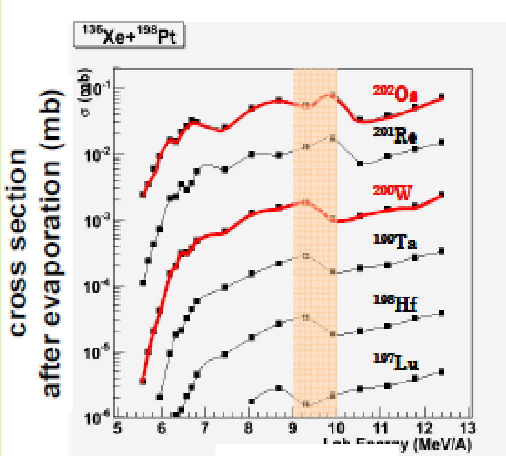
1 GeV/u ^{238}U + ^{1}H
Armbruster et al.



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

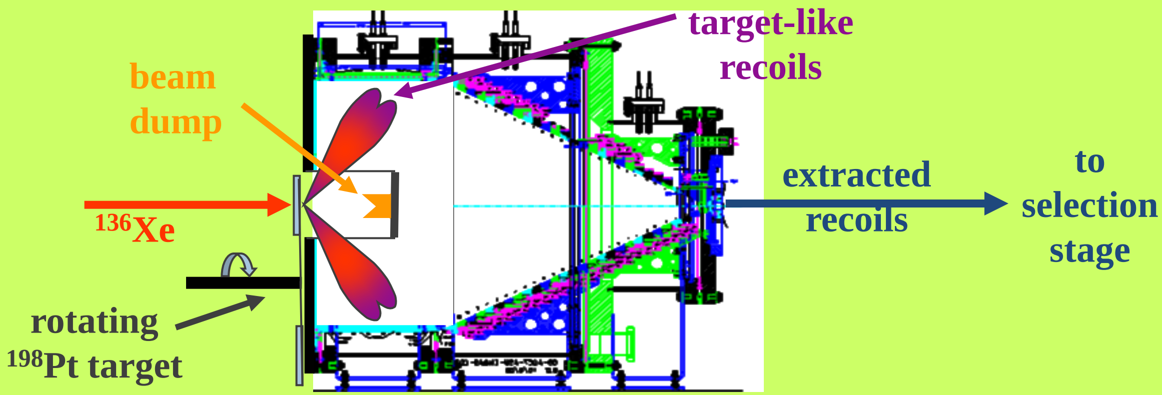
Production through deep-inelastic reactions



E_{lab} (MeV/A)

σ ~ 10^{-1} mb for ^{202}Os
σ ~ 10^{-3} mb for ^{200}W

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



ATLAS multi-user upgrade … filling the gap

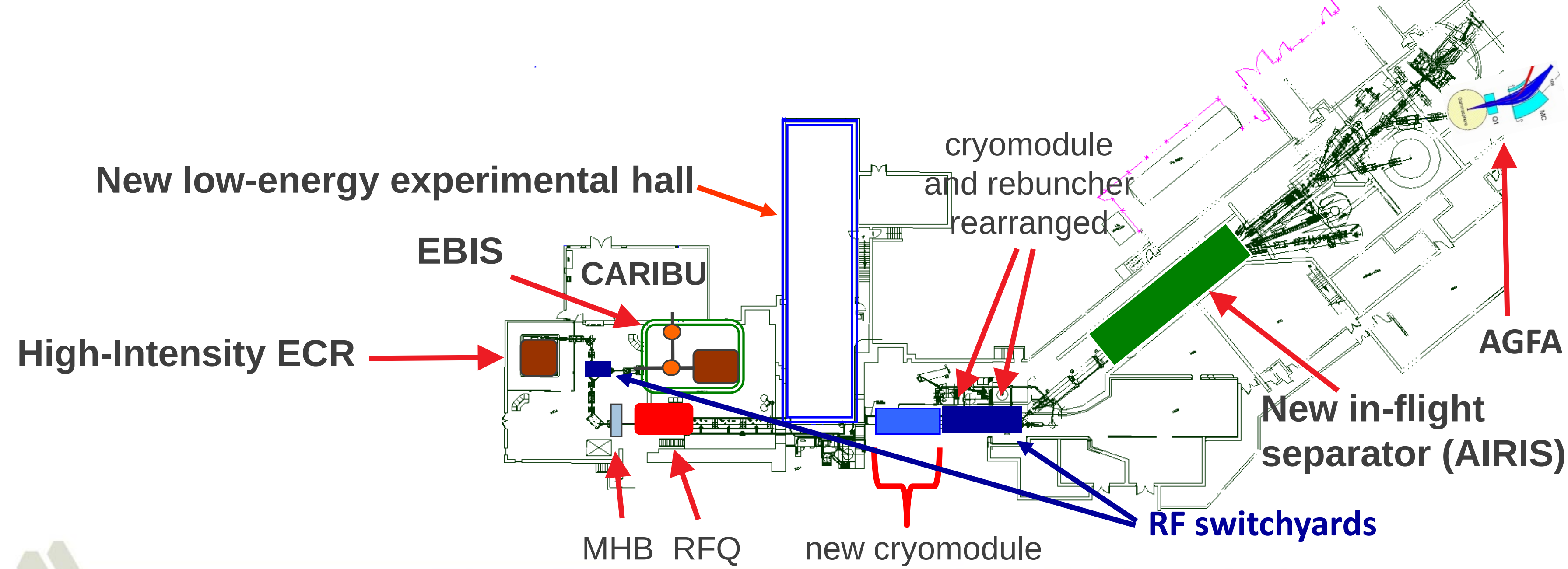
- Beamtime availability for low-energy community is under increasing pressure
  - In last few years, the low-energy community lost HRIBF and Yale (~ 4000-6000 hrs/yr)
  - Facilities outside the US (GSI, GANIL, RIKEN, ISOLDE) also have limited capabilities in coming years
- Further pressure on available 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 of charge-to-mass ratio over a range of 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 -> 2015 ->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*
2015	*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*



ATLAS role in 2024

- Two main users facility needed to accommodate the physics goals of the low-energy nuclear physics community in the US
  - FRIB: single user radioactive beam facility with the furthest reach from stability
  - ATLAS: unique high-intensity stable beam facility for low cross section and high precision experiments closer to stability

- ATLAS high-intensity stable beam facility main capabilities
  - Highest intensity stable beam (> 10 pμA) facility at the Coulomb barrier energy
    - Suite of experimental equipment capable of using this highest intensity
    - Large amount of beamtime to perform experiments with lowest cross-section
  - Limited capabilities for radioactive beams close to stability
    - Perform important niche radioactive beam experiments close to stability that
      - Can be performed effectively without the full FRIB reach/capabilities
      - Require more beamtime than will be available at FRIB
  - Development and testing of new equipment for low-energy and reaccelerated beams
  - Applications

- Community can address its full physics program with these two complementary world leading facilities

Status

- ATLAS is the DOE low-energy nuclear physics national user facility
  - Running reliably and logging in a large number of operating hours
  - Host to a broad science program
  - 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
  - access to unique reaccelerated beams allows community to explore the path and bridge 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 material

Operation of ATLAS/CARIBU

- Very lean and efficient operation
  - Minimal staff required for reliable 24/7 operation
  - Many support groups are groups of two (ECR ion sources, control systems, cryogenics, …)
  - Not only maintains facility but also continuously improves its capabilities

- Over 5500 hours (+ 2000 hours of low-energy CARIBU) of operation per year
  - Total cost of ~ $17 M/yr
  - breakdown:
    - $9.97 M/yr for ATLAS operation
    - $0.77 M/yr AIP funding
    - $0.41 M/yr ATLAS equipment
    - $5.04 M/yr experimental support
    - $1.34 M/yr experimental equipment

- This includes operation and maintenance of the facility, plus some continuous improvements to its capabilities to continue meeting the evolving needs of the community

AGFA: Argonne Gas-Filled Analyzer

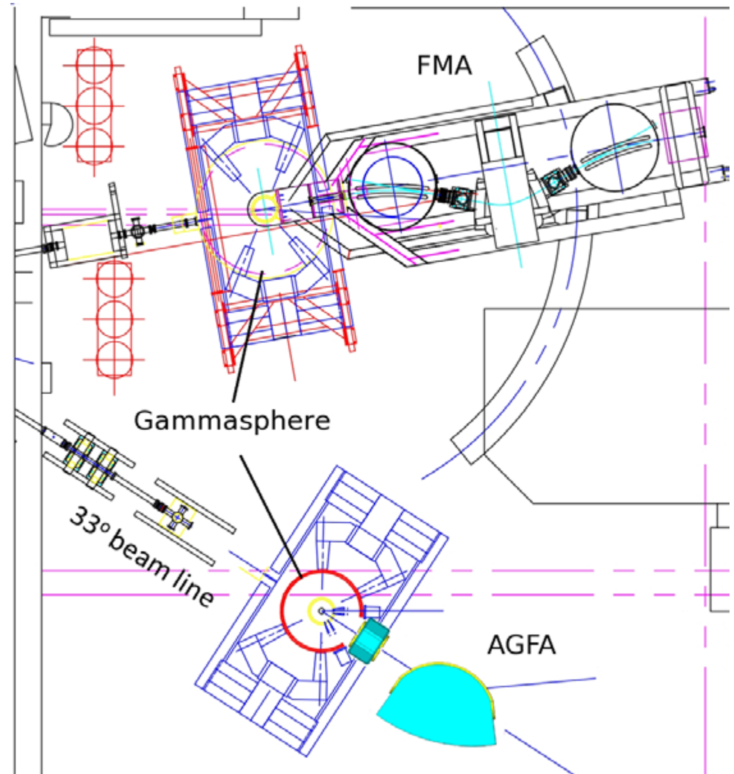
Purpose:

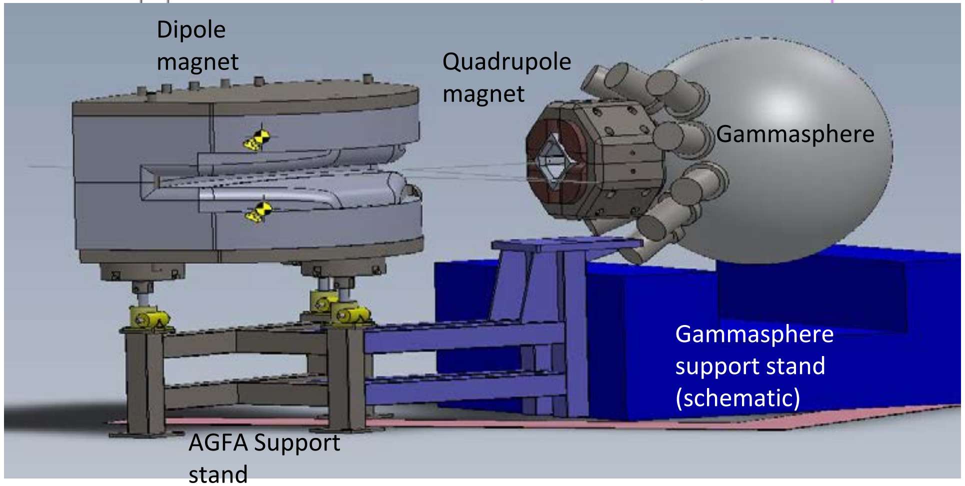
- High efficiency separation
  - Gammasphere at target position
  - Evaporation residues
    - Super-heavy nuclei
    - ~^{100}Sn region
    - Spectroscopy at the p drip line
  - Deep-inelastic products
    - N-rich nuclei e.g. N~126
  - General purpose use

Status:

- DOE go ahead July 2013
- Management plan submitted Sept 2013
- ***Procurement of magnets ongoing***
- Planned completion Q2 FY2016

Cost: $1755k (incl. contingency)





AGFA: 50-95% Efficiency

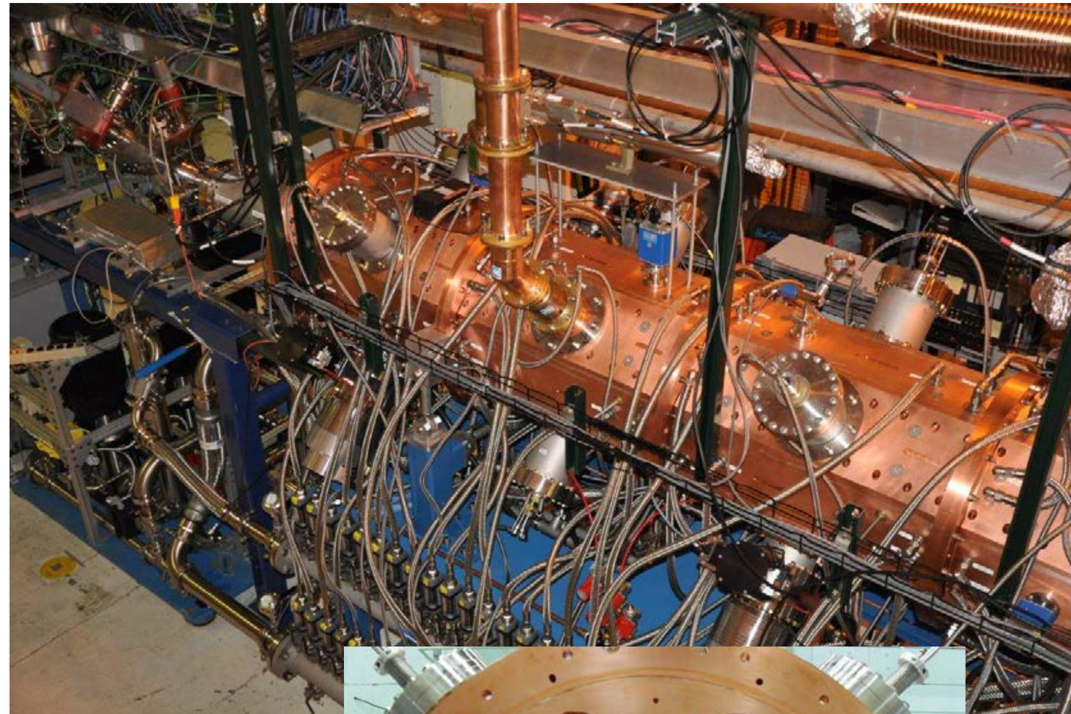
FMA: Less efficiency, m/q measurement

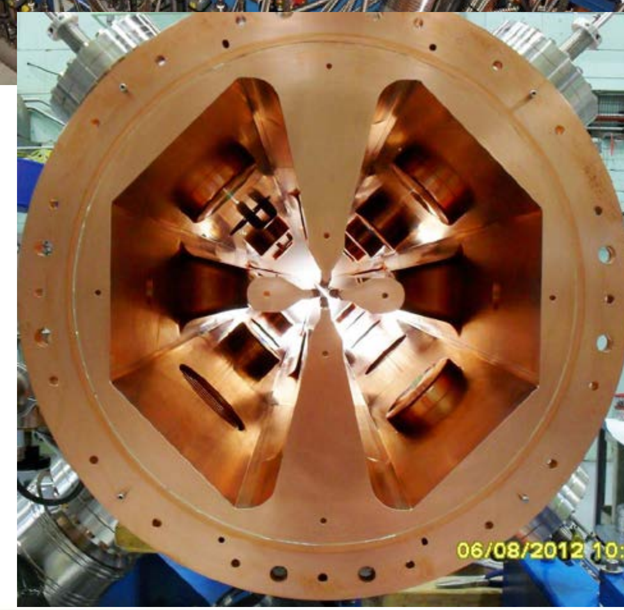
ATLAS Efficiency & Intensity Upgrade: New RFQ Accelerator

Project: RFQ Construction & installation, beam line reconfiguration, & cryomodule reconfiguration

Performance:

1. RFQ WORKS – CW!!
2. Excellent transmission
   a) 40%-60% →80% through PII
   b) Up to 100% PII → Target
3. Operation at ~95% of full power
   → m/q ~7 acceleration achieved





RFQ has been in routine operation since January, 2013.

ATLAS Efficiency & Intensity Upgrade: Replacement of First Booster Cryostat Module & Liquid Helium Upgrade