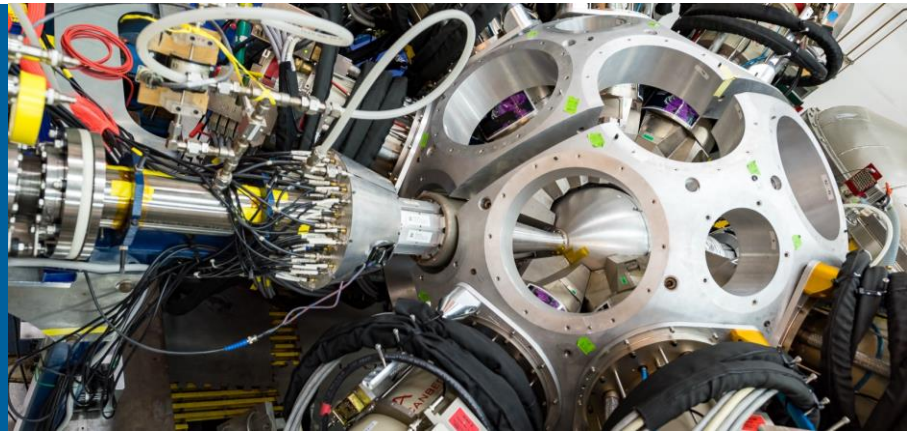
Argonne NATIONAL LABORATORY

ATLAS/CARIBU STATUS AND PLANS



GUY SAVARD
Director of ATLAS

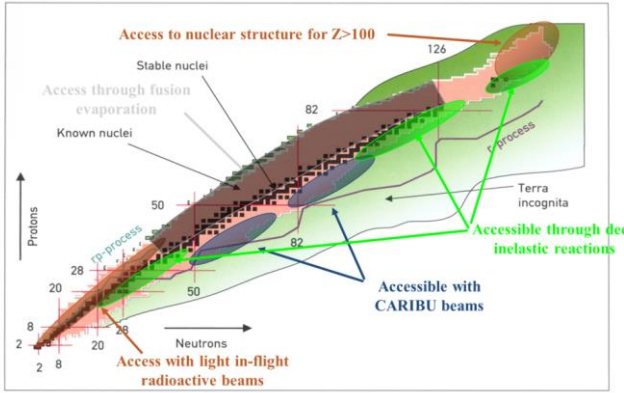
11/14/2022
Argonne National Laboratory

ATLAS

- ***ATLAS is the DOE nuclear physics stable beam 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
  - low-energy tests of the Standard Model
  - nuclear astrophysics
  - applications of low-energy nuclear physics

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

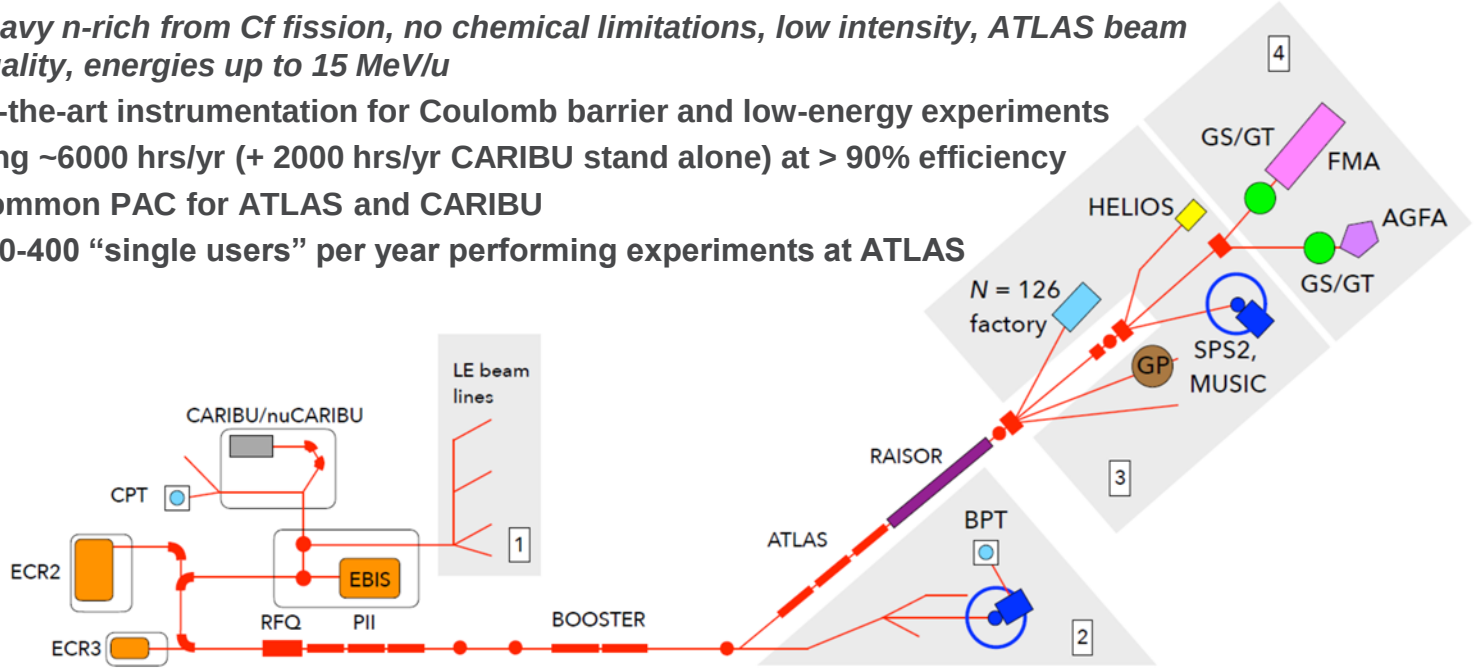
- This is done through:
  - providing beamtime for research programs
    - any stable beam from proton to uranium
    - some in-flight radioactive beams
    - low-energy and reaccelerated CARIBU beams
  - developing new experimental equipment and accelerator capabilities to address evolving needs of the field



- A plan for how ATLAS can best continue serving the community was developed in collaboration with the user community and is being implemented in steps. It presents a coherent accelerator and experimental equipment upgrade path to offer new opportunities to the community now and in the coming FRIB era. It will provide higher intensity beams (new ECR, nuCARIBU), more beam time (AMUU) and access to new regions (N=126 factory).

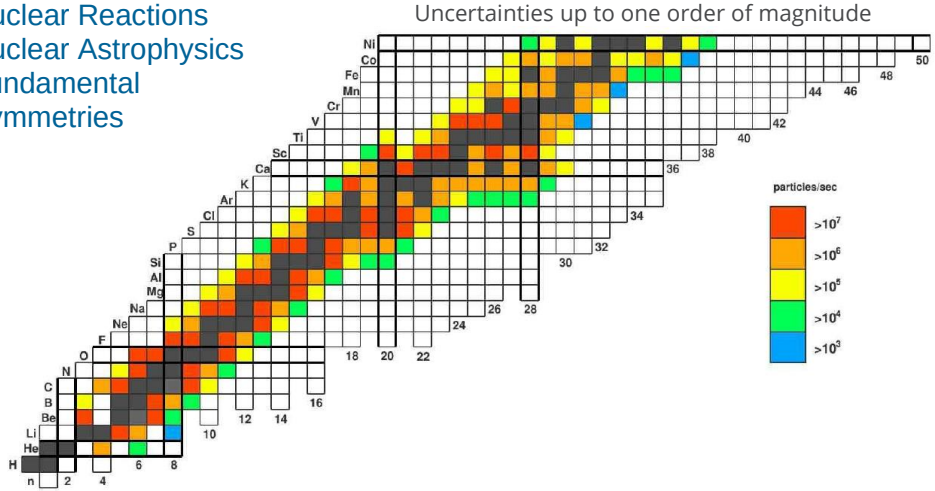
ATLAS/CARIBU FACILITY

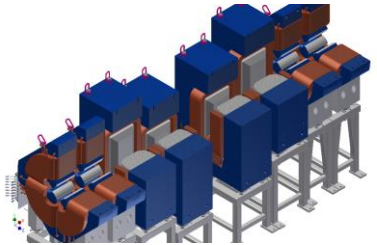
- ATLAS is the **DOE National User Facility** for low-energy stable beam physics
- Stable beams at **high intensity** and energy up to 10-20 MeV/u
- Light in-flight radioactive beams with **RAISOR**
  - *light beams, no chemical limitations, close to stability, acceptable beam properties*
- **CARIBU 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 ~6000 hrs/yr (+ 2000 hrs/yr CARIBU stand alone) at > 90% efficiency
  - Common PAC for ATLAS and CARIBU
  - 300-400 “single users” per year performing experiments at ATLAS

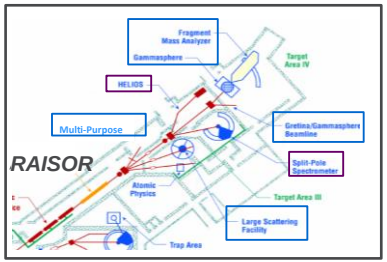


LIGHT IN-FLIGHT RADIOACTIVE BEAMS WITH RAISOR

Collective Nuclei
Pairing in Nuclei
Single-Particle Structure
Nuclear Reactions
Nuclear Astrophysics
Fundamental Symmetries





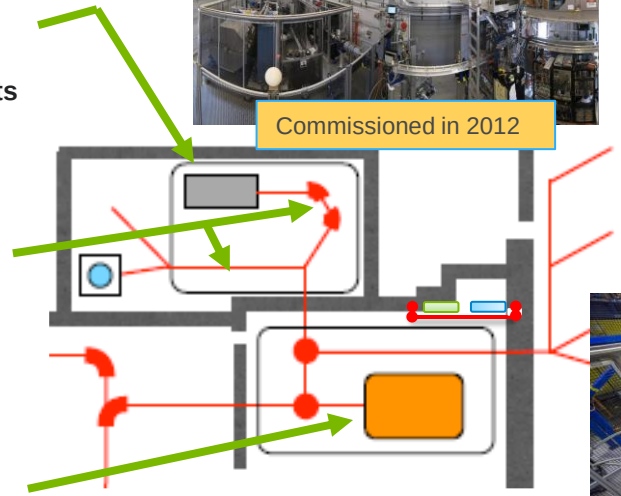


- Increased intensities, purities, & reach for ATLAS in-flight beams
- Momentum selection (magnetic chicane) followed by velocity selection (RF sweeper) → A/q selection
- Accessibility to more experimental areas

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 and MR-TOF
  - Purifies beam
- **DELIVERY**: beamlines and preparation
  - Low-energy buncher and beamlines
  - Charge breeder to Increase charge state for post-acceleration
  - Post-accelerator ATLAS and weak-beam diagnostics



Commissioned in 2012

Commissioned in 2020

Commissioned in 2017

ATLAS BEAMS

- **Stable beams (protons to Uranium) + some long-lived beams**
  - up to 5 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

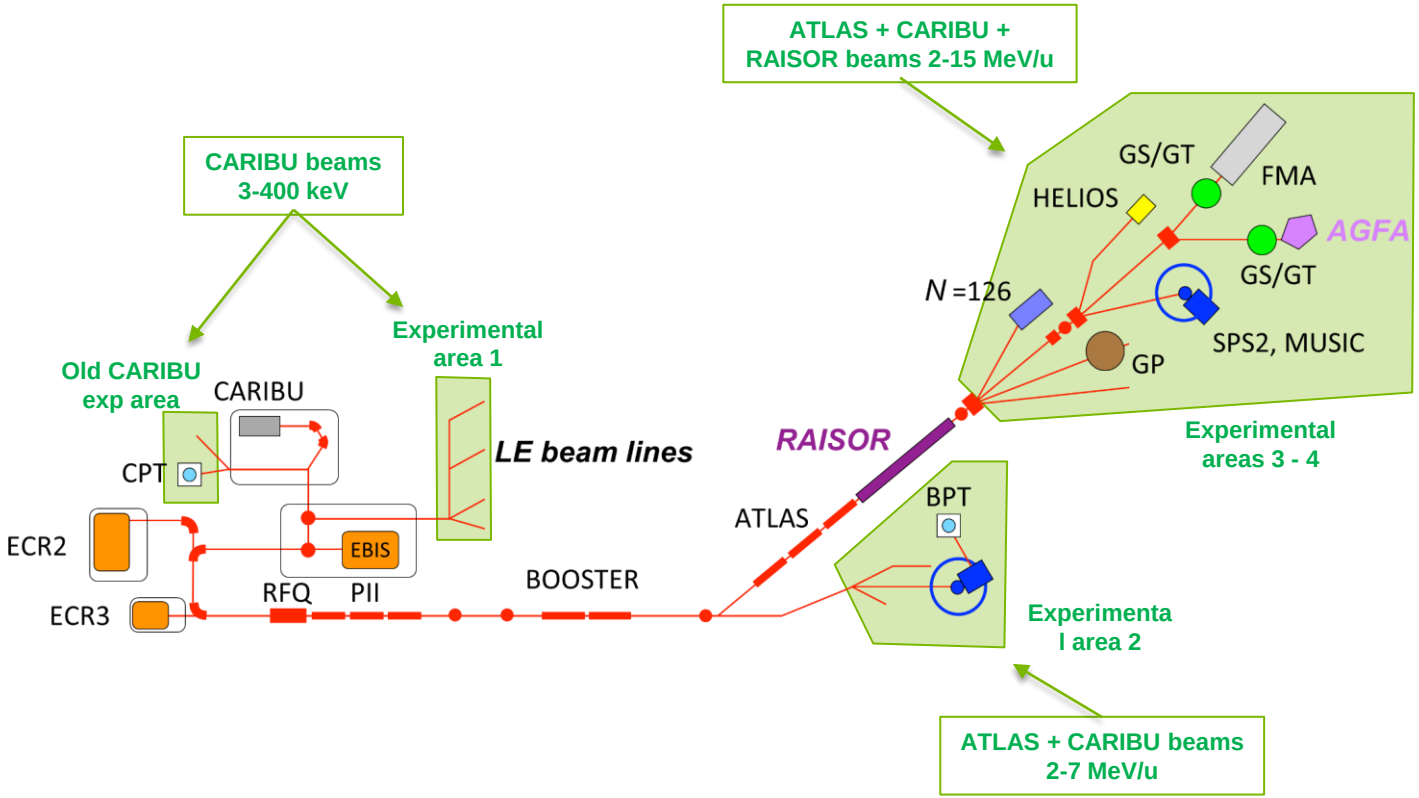
- **CARIBU beams have similar properties …. but much lower intensity**
  - All species, even the most refractory, are extracted efficiently
  - Reaccelerated CARIBU beam up to ~ 10 MeV/u, essentially free of stable beam contamination

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

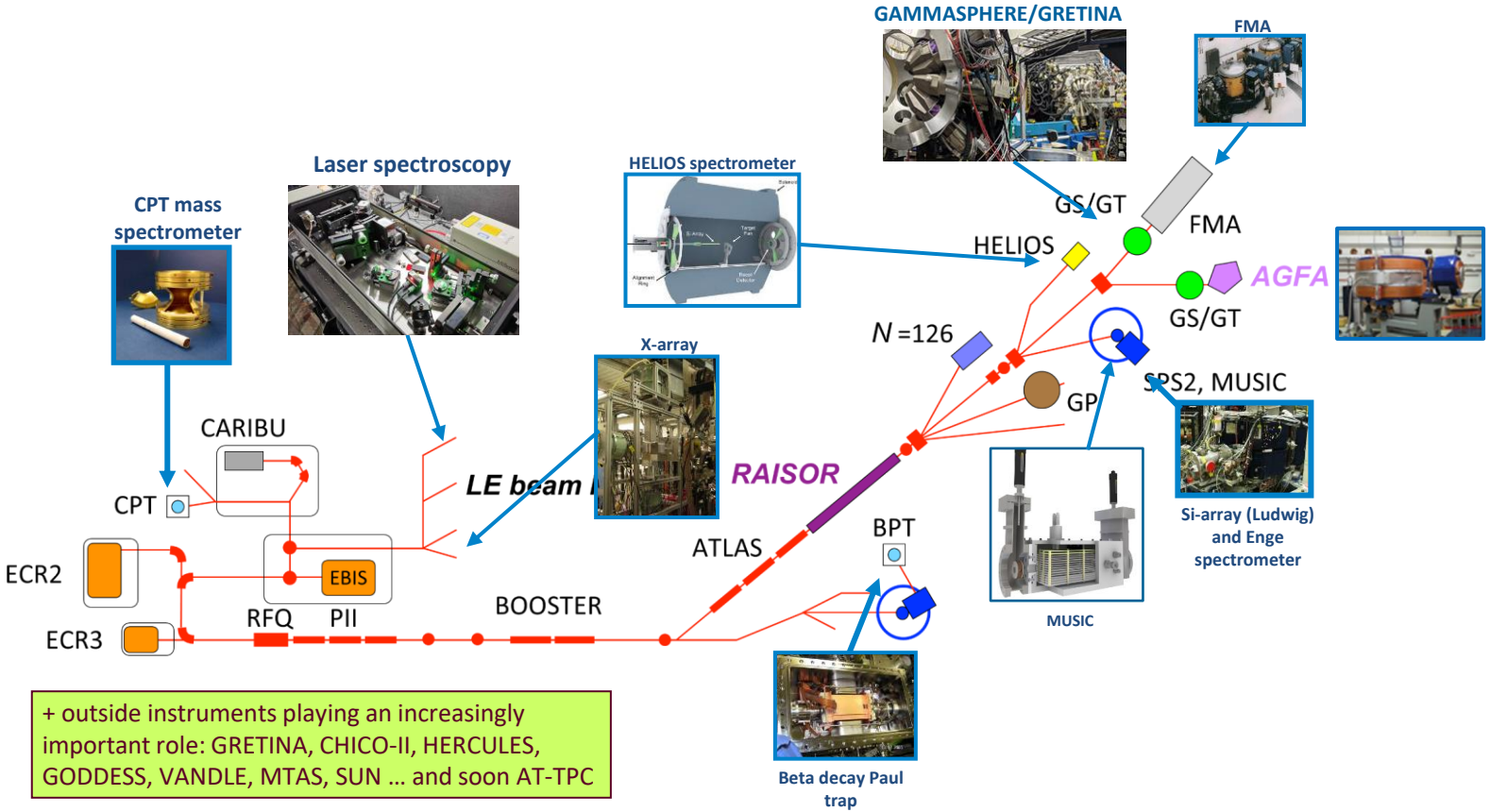
- **In-flight radioactive beams from RAISOR: all light species, close to stability, energy up to 10-20 MeV/u, but some compromises between beam properties, intensity and purity**

No other facilities worldwide can produce a number of these beams at these energies and they are perfectly suited to the ATLAS experimental equipment suite (e.g. HELIOS)

LAYOUT OF ATLAS FACILITY



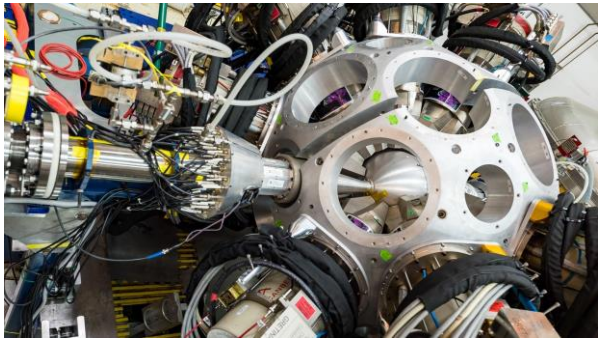
DISTRIBUTION OF EXPERIMENTAL EQUIPMENT



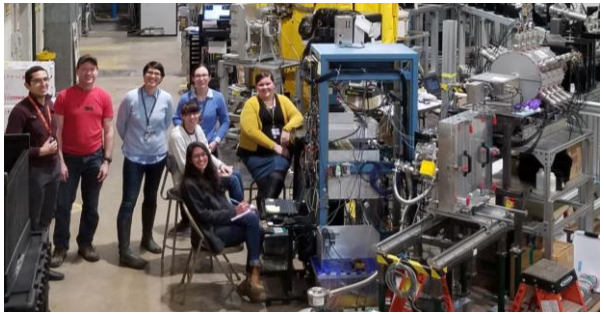
+ outside instruments playing an increasingly important role: GRETINA, CHICO-II, HERCULES, GODDESS, VANDLE, MTAS, SUN … and soon AT-TPC

NEW AND IMPROVED EQUIPMENT CAPABILITIES

Significant impact of community devices

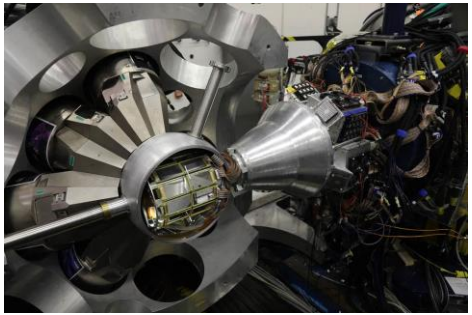


CHICO2 + GRETINA



SUN

- Local equipment continually improved for higher efficiency and rate capability
- Extended stays by state-of-the-art community devices for focused physics campaigns
- Versatile DAQ infrastructure to merge signals from visiting devices with local equipment



ORRUBA/GODDESS + GRETINA

MTAS

Maximizing the return on community investment: for example, 2021/2022 GRETINA campaign of 30 experiments employing 6 different ancillary detectors (~60% of beamtime during campaign)

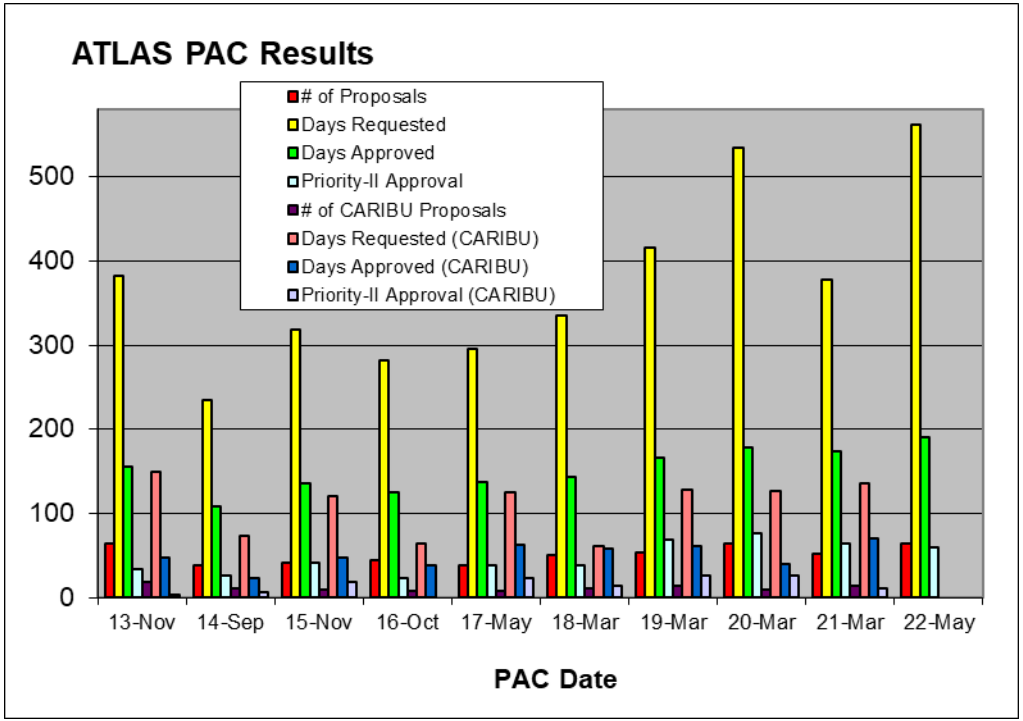
ATLAS FACILITY PERFORMANCE

Operating Statistics								
Machine Operation ATLAS	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023 (proj.)
Research Hours (on Target)	4953	4318	4497	5377	3640	4071	4808	4850
Beam Study Hours	352	310	255	296	203	394	643	350
Tuning/Restore	855	840	995	1100	685	1018	975	800
Total Delivered Hours	**6160**	**5468**	**5747**	**6773**	**4528**	**5483**	**6426**	**6000**
Unscheduled failure hours	433	452	612	594	206	675	363	450
Total Scheduled Hours	6593	5920	6359	7367	4734	6158	6789	6450
Availability (%)	94.4	92.4	90.4	91.9	95.6	89.0	94.7	93.0
CARIBU								
Research Hours	2820	2260	652	1068	862	1328	2264	1700
Beam Study Hours	464	204	240	296	138	264	232	300
Total Delivered Hours	3284	2464	892	1332	1000	1592	2496	2000

ATLAS+CARIBU delivered hours	**8980**	**7728**	**6399**	**7841**	**5390**	**6811**	**8690**

- FY20: operating hours reduced due to COVID-19 shutdown for 3 months followed by restart at 5 days/wk without outside users
- FY21: targeted 5350 hours for ATLAS due to budget reduction and to allow removal of 109 MHz cryostat
- FY22: targeted 5900 hours for ATLAS due to reduced budget and to allow reinstallation of 109 MHz cryostat
- FY23 – FY28 : plan for ~6000 delivered hours for ATLAS in FY23 assuming president's request and returning to > 6000 hours/year starting in FY24

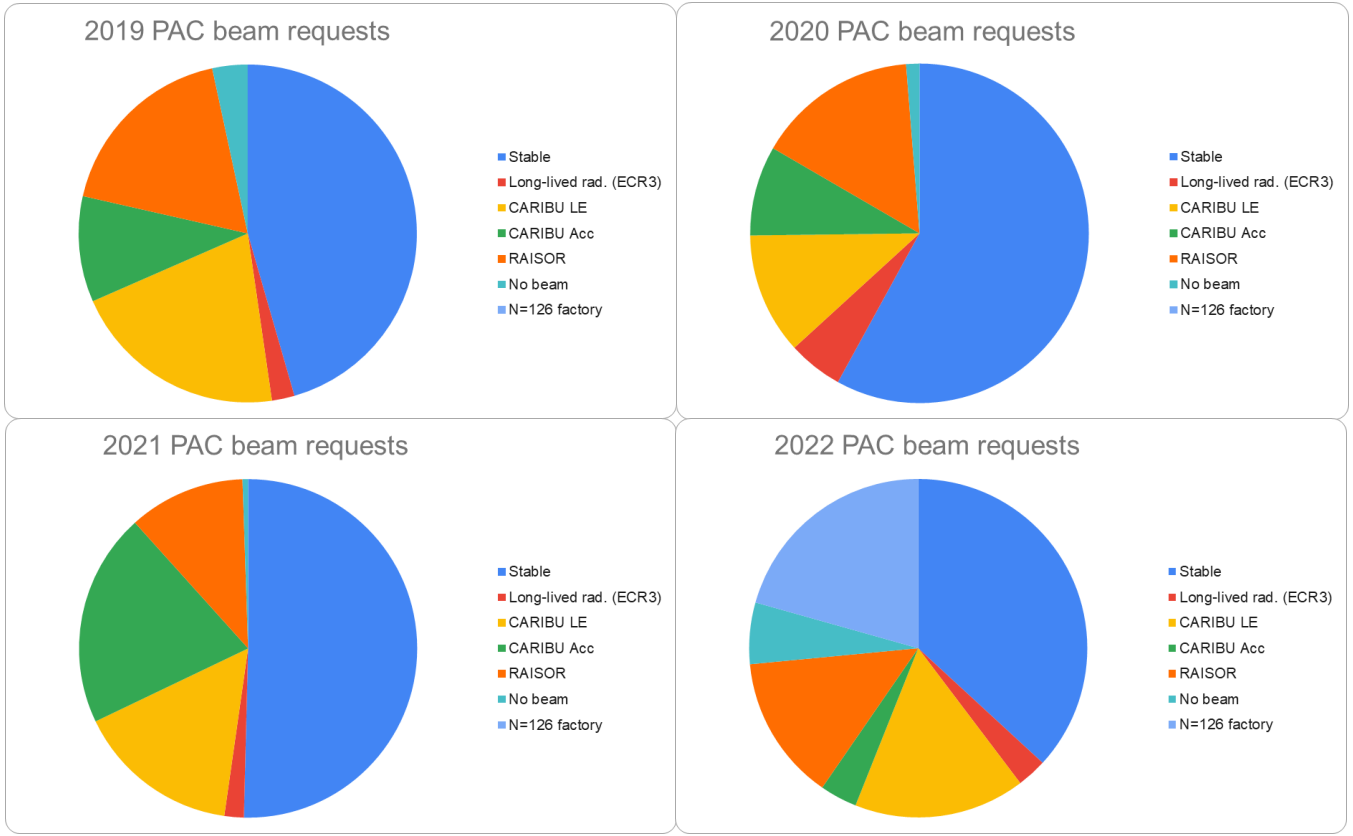
PAC STATISTICS



PAC Statistics:

- Trends persist, i.e., high number of proposals & oversubscription by a factor of ~3
- Continue to operate with priority I & II modes to optimize efficiency of program
- keep enough backlog to allow additional needed flexibility in scheduling
- Last PAC meeting: May 2022 … record number of days requested

TYPE OF BEAMS REQUESTED BY USERS



OPTIMIZATION OF THE ATLAS PROGRAM TAKES THE FOLLOWING ELEMENTS INTO ACCOUNT:

•ATLAS is the low-energy national user facility focusing on experiments with stable beams. ATLAS has an inherent responsibility to make stable ion beams available to the national community.

•The priorities expressed in the (previous) NSAC Long Range Plan, the performance measures as well as the scientific goals of the field, make it imperative that opportunities with unique radioactive beams at ATLAS continue to be pursued with high priority when identified as being important science by the community and endorsed by the Program Advisory Committee.

•Beyond the ramp up phase of FRIB, ATLAS will address the needs of the low-energy community both as the only stable beam user facility and as a complement to FRIB in specific areas of rare isotope science.

•A balance between the effective operation of ATLAS and the development of new accelerator capabilities and new instrumentation remains an essential consideration of the program.

ATLAS FLAGSHIP PROGRAMS NOW AND IN COMING 5-10 YEARS

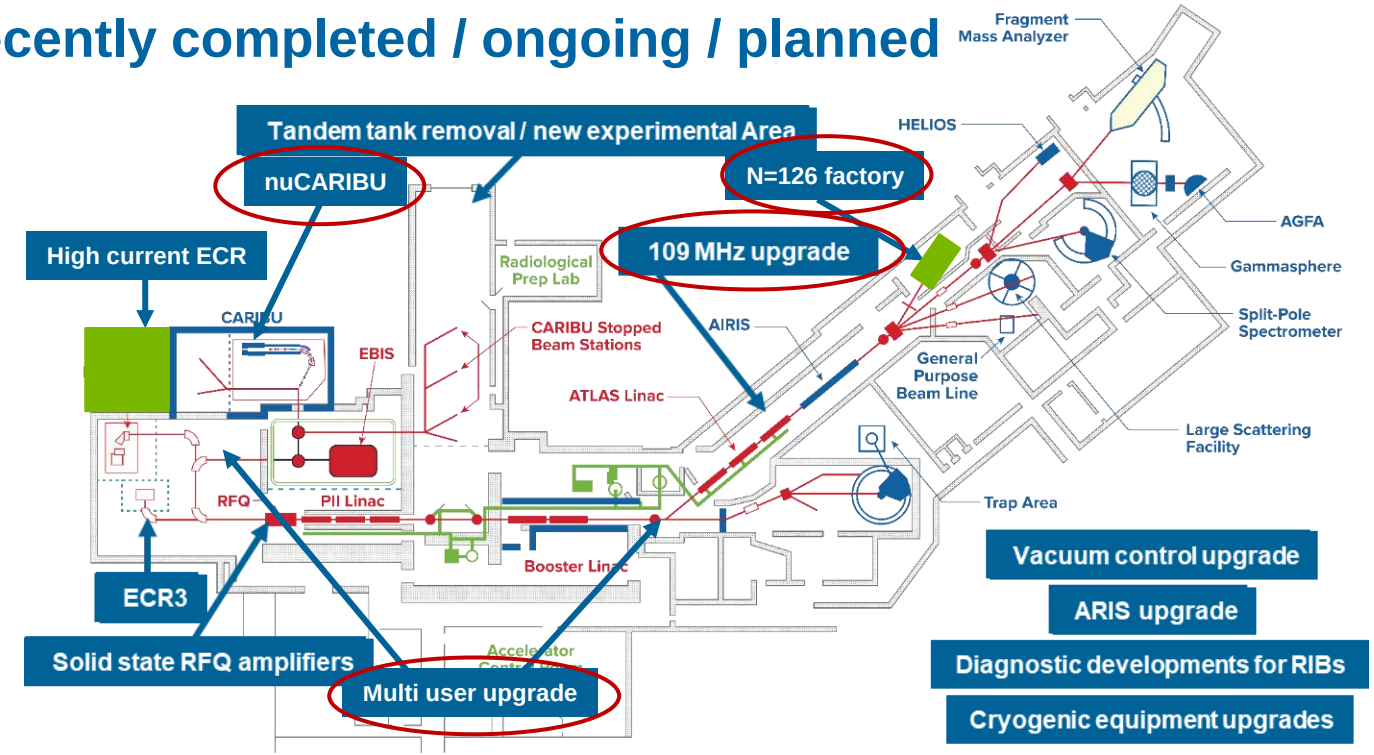
- Study of evolution of single-particle structure from light to medium mass nuclei (RAISOR + HELIOS + AT-TPC + AMUU)
- Study of the structure of nuclei with Z>100 (AGFA + Gammasphere + AMUU)
- Study of shape coexistence/transition in n-rich nuclei via Coulomb excitation (Gammasphere/GRETINA + nuCARIBU + AMUU)
- Definitive study around ^{132}Sn in terms of effective interactions (HELIOS+nuCARIBU+AMUU)
- Measurements of (α,n) reactions affecting the weak r-process (CARIBU/nuCARIBU + MUSIC + AMUU)
- Measurement of mass and decay properties of neutron-rich nuclei close to the r-process path, especially around N=82, rare-earth and N=126 peaks (CARIBU/nuCARIBU+low-E area+ N=126 factory+AMUU)
- Searches for possible extensions of the Standard Model by improving by one order of magnitude limits on scalar, tensor and right-handed components to the electro-weak interaction (RAISOR + CRES + AMUU)
- Studies of the antineutrino spectra in abundant fission products to determine the origin of the apparent reactor antineutrino anomaly (CARIBU/nuCARIBU + CRES)
- Decay properties of neutron-rich isotopes of importance for accurate modeling of kinetics and decay heat in novel nuclear fuel cycles and for stockpile stewardship (CARIBU/nuCARIBU + low-E area)

MAIN INITIATIVES BEING FOLLOWED TO ADDRESS THESE SCIENTIFIC OPPORTUNITIES

- Take advantage of the significant new capabilities in last few years: AGFA, RAISOR, EBIS and the low-background experimental area for CARIBU
- Move forward with the development and implementation of the ATLAS multi-user upgrade to allow ATLAS to address the large oversubscription of the facility by providing more research hours to its user community
- Expand the range and intensity of unstable neutron-rich beams available from ATLAS with the CARIBU upgrade by implementing the nuCARIBU upgrade
- Provide first access to the north-east region of the chart of nuclei near ^{208}Pb through the completion of the N=126 factory
- Extend the energy range of ATLAS for high-intensity stable beams, primarily for in-flight production of exotic beams with RAISOR and the N=126 factory
- Maintain an infrastructure capable of sustaining and improving the ATLAS experimental equipment and developing or adapting other detectors designed by the community for use at ATLAS.

ATLAS UPGRADE OVERVIEW

Recently completed / ongoing / planned



ACCELERATOR UPGRADES

- New solid-state amplifier for ATLAS RFQ
  - 96 1 kW transistors coupled by coaxial combiners
  - Design brings redundancy that eliminates single point of failure
  - Operational and used for all beams since April 2022
  - Essentially no downtime due to RFQ since

- 109 MHz refurbishment and new hardware
  - Cryostat removed during the May 2021 shutdown
  - Mods performed over the following 6 months
  - Cryostat reinstalled in June 2022
  - Will provide an increase of 8MV, 12MV → 20MV

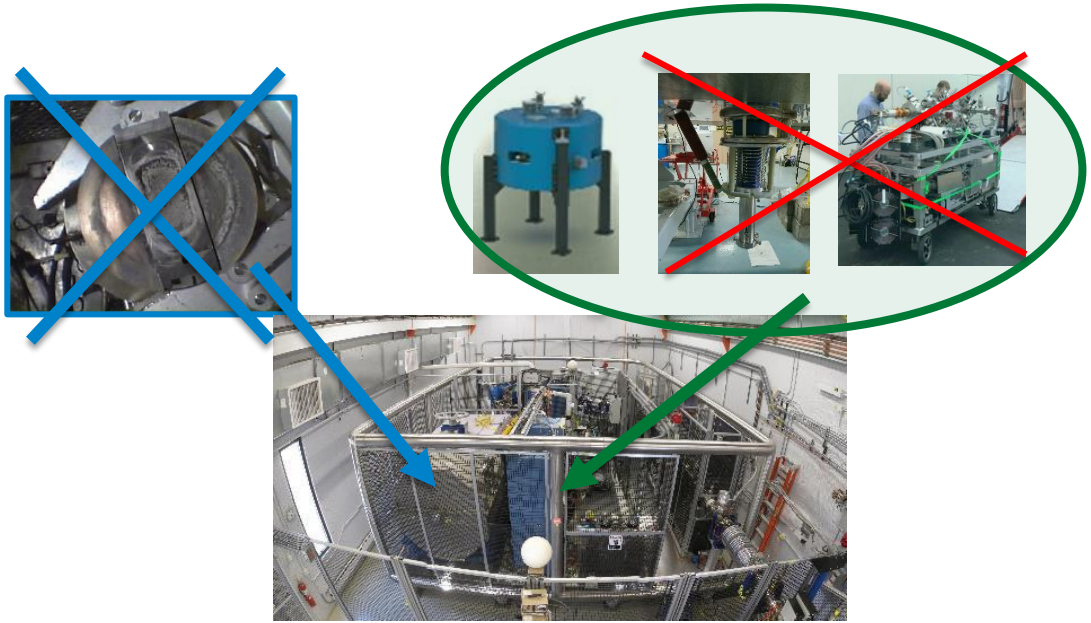
Cryostat accelerating gradient

Status	Voltage [MV]
Current (de-rate)	10-12
After cleaning	14.5
Additional resonator	16.5
Overcoming VCX limit	20

Net gain of roughly 1.4 MeV/u for mid to heavy mass beams

NEUTRON GENERATOR UPGRADE TO CARIBU

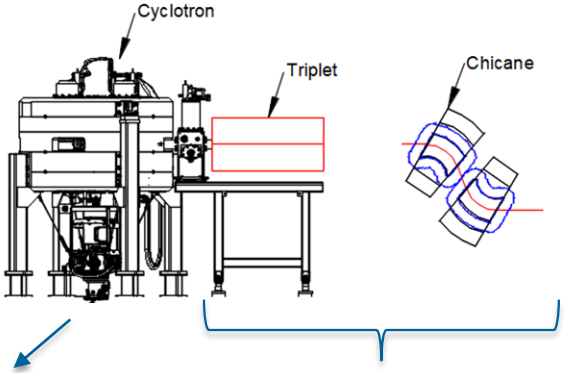
- Replace ^{252}Cf source by neutron-induced fission on actinide foils
  - More reliable source of fission products
  - Operationally easier to maintain and operate
  - Gain an order of magnitude in overall fission rate … i.e. ~ 10^9 fission/sec vs current few 10^7 fission/sec
  - Higher fission yield feeding in the ^{132}Sn region or above ^{78}Ni region



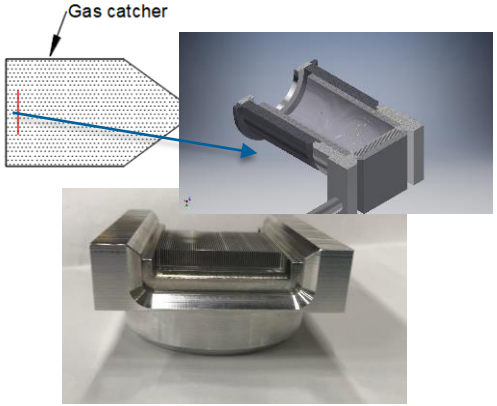
NUCARIBU PROGRESS

Neutron generator

- *Cyclotron passed factory acceptance test*
- *Has been delivered to Argonne on Jan 31 2022*



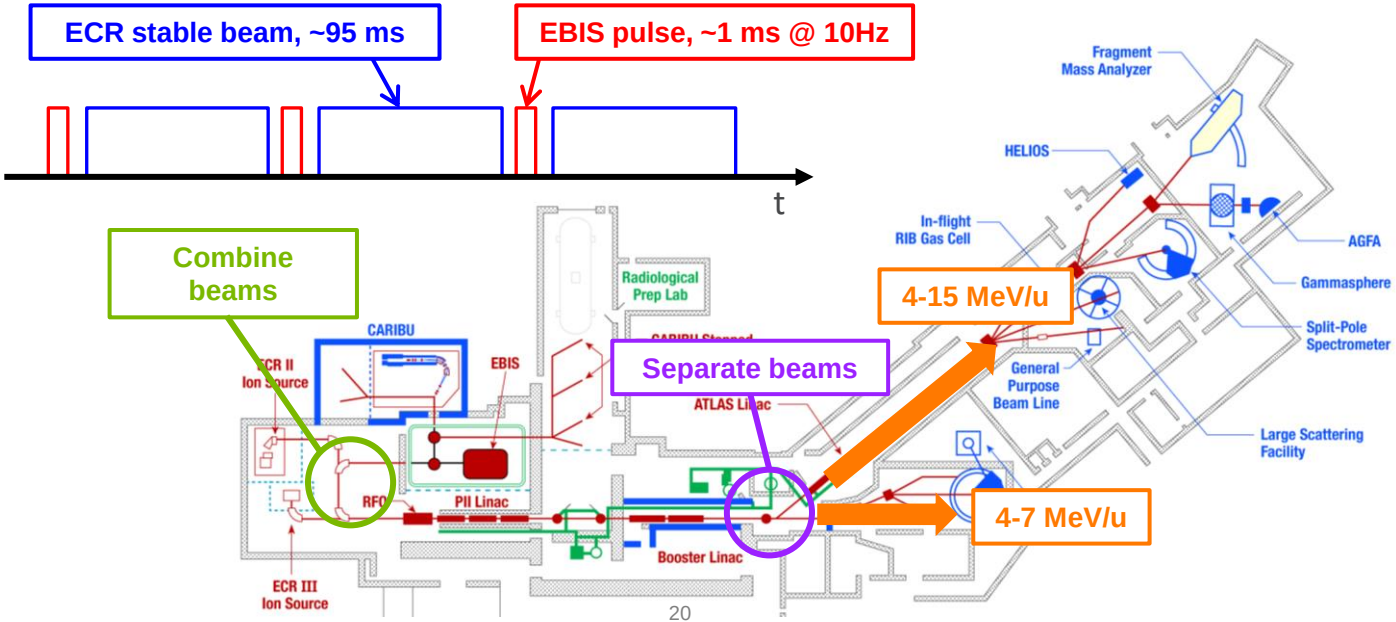
- *Beam transport system design completed*
- *Solicitation period for triplet and magnetic chicane closed on Feb 14 2022*
- *Scheduled Nov 2022 delivery*



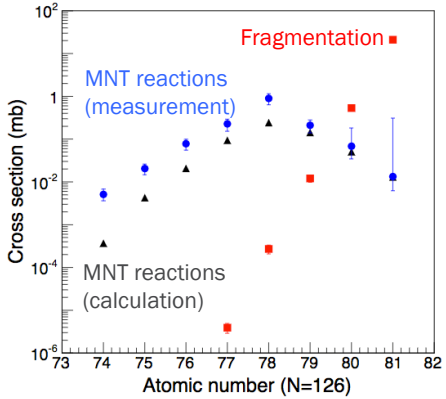
- *Concept developed for high power heat removal*
- *Prototype built and being tested*

KEY COMPONENT: ATLAS MULTI-USER UPGRADE

- EBIS beams represents 1-3% duty factor
- Combine pulsed EBIS beam with stable ECR beam
  - Address high demand on facility
  - Enable long duration experiments
  - Maximize efficient accelerator usage



NEW CAPABILITY: N=126 FACTORY … MULTI-NUCLEON TRANSFER VERSUS FRAGMENTATION FOR NEUTRON-RICH HEAVY ISOTOPES

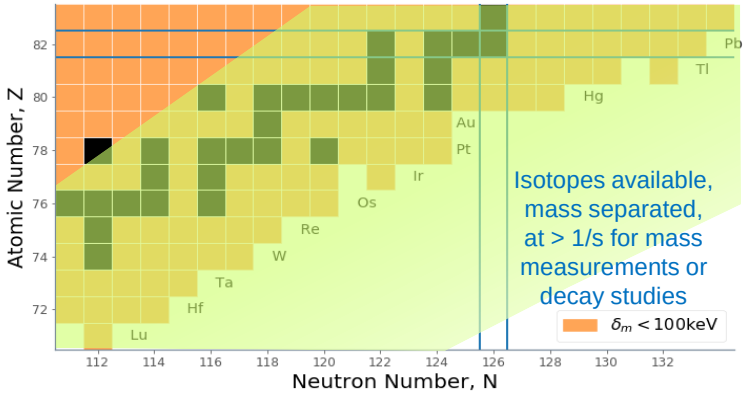


Hirayama *et al*., EPJ Web Conferences **109,** 08001 (2016)

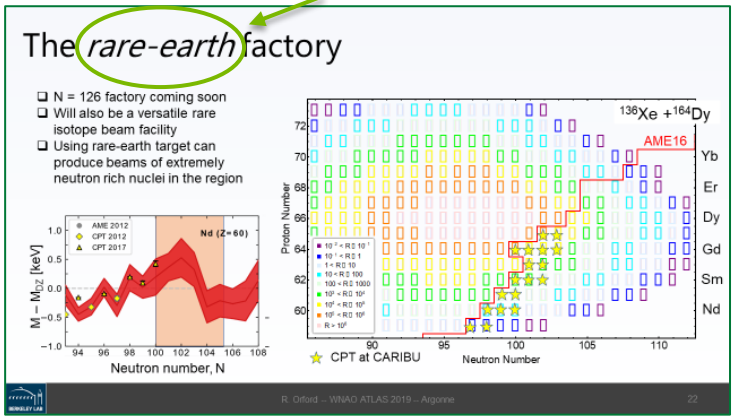
^{208}Pb + ^{9}Be at 1 GeV/u (best fragmentation reaction cross-sections for N = 126)

versus

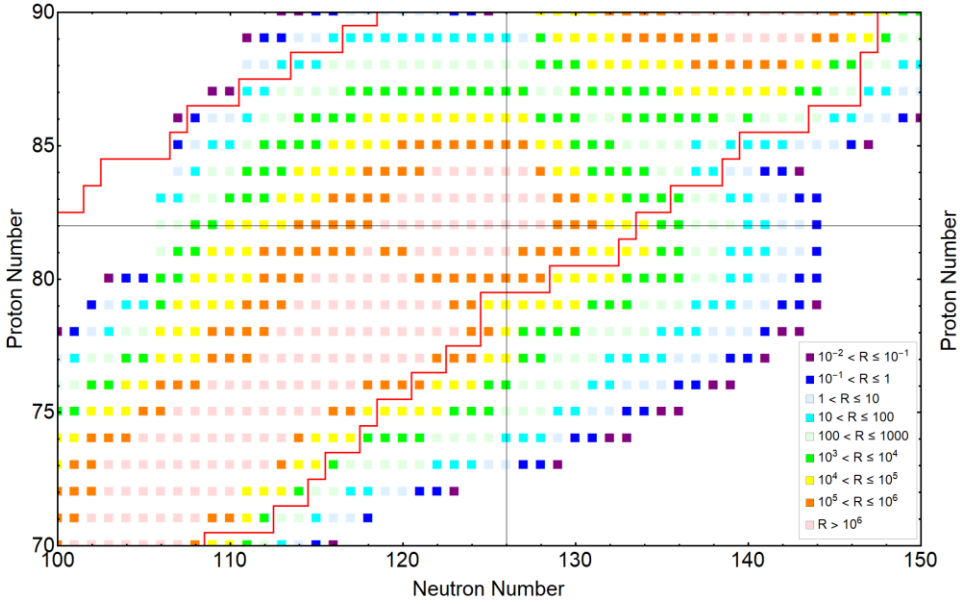
^{136}Xe + ^{198}Pt at 10 MeV/u (best multi-nucleon transfer (MNT) reaction)

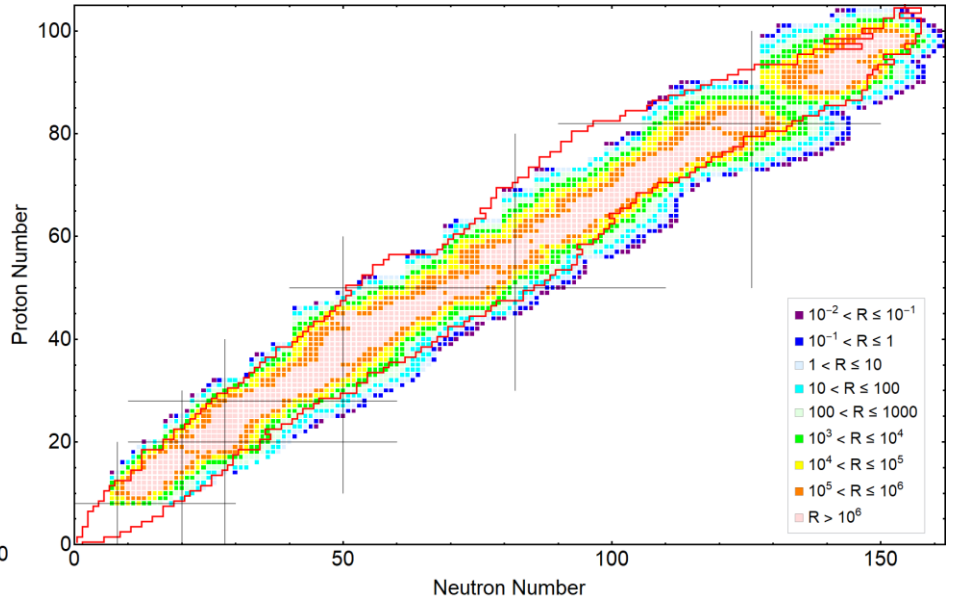


N=126 and much more … slide from our users



REACH OF THE N=126 FACTORY … FOR N-RICH NUCLEI

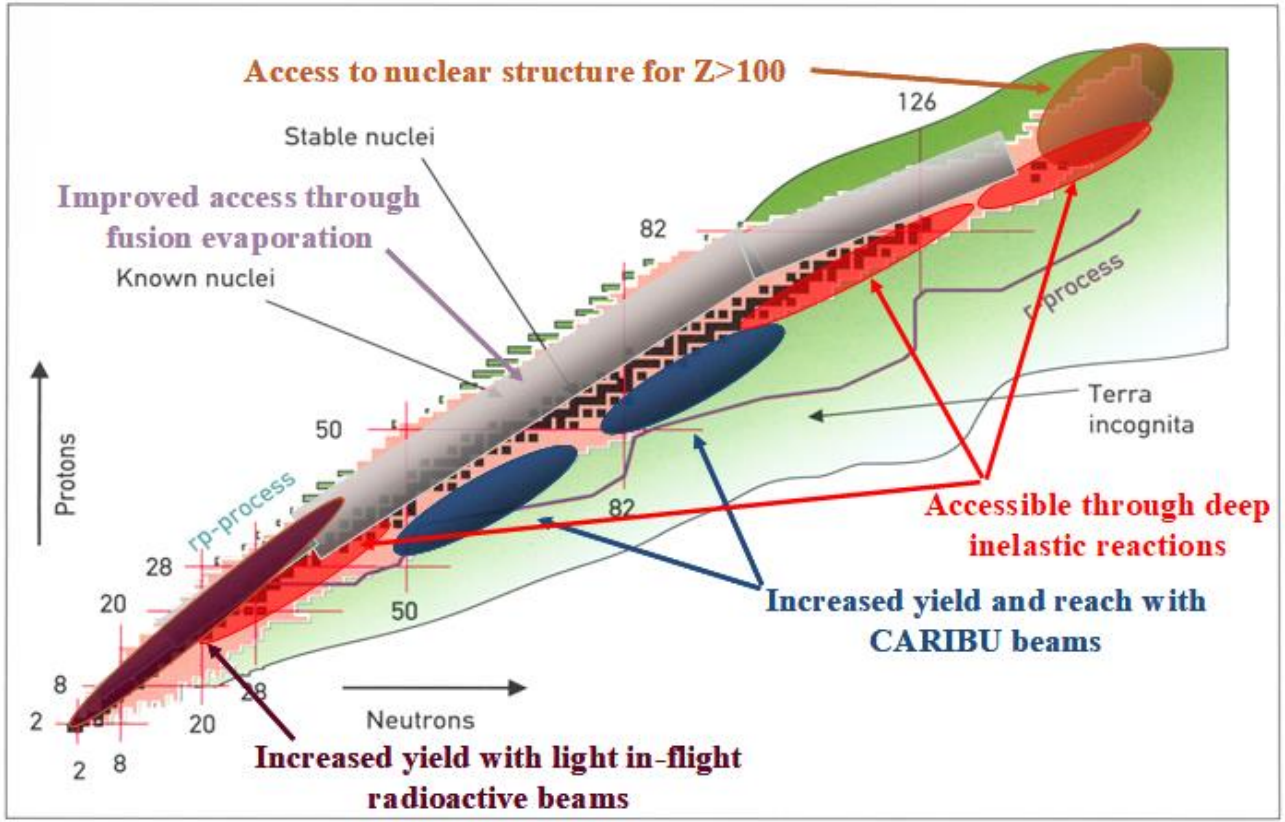




Courtesy of Biying Liu

- Red line is limit of known masses
- Reaction ^{136}Xe + target … with 10 mg/cm^2 target and > 1% abundance isotopes
- For very heavy, limit target thickness to 50 mCi activity

PHYSICS REACH OF ATLAS



OUTLOOK

- ATLAS is the DOE nuclear physics stable beam national user facility
  - Running reliably, logging in a large number of operating hours and completing upgrades needed to keep it at the forefront of the field
  - Accomplishing its current science goals
  - Demand for beamtime is increasing

- ATLAS, with the help of the community, has developed a coherent upgrade program to add accelerator and experimental capabilities that build on each other to provide new capabilities to better address the community's evolving science goals, now and in the FRIB era.

This program, aligned to the (previous) nuclear physics LRP, highlighted in the 2018 ATLAS long range plan, and approved by the ATLAS user's community, enables ATLAS and its user community to fulfill their expected flagship programs for the coming decade.

- ATLAS has put in place key elements (RAISOR, AGFA, EBIS, CARIBU low-energy experimental area, GAMMASPHERE upgrade) of this plan while continuing to provide operating hours and world leading capabilities to its users. ATLAS is currently putting in place the remaining elements of this plan with the construction of nuCARIBU, the N=126 factory and the AMUU, uniquely positioning ATLAS to serve the nuclear physics community in the coming decade.

SUPPLEMENTARY MATERIAL