ATLAS 25^{th} Anniversary Celebration

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ATLAS Upgrade Plans - Science

Guy Savard

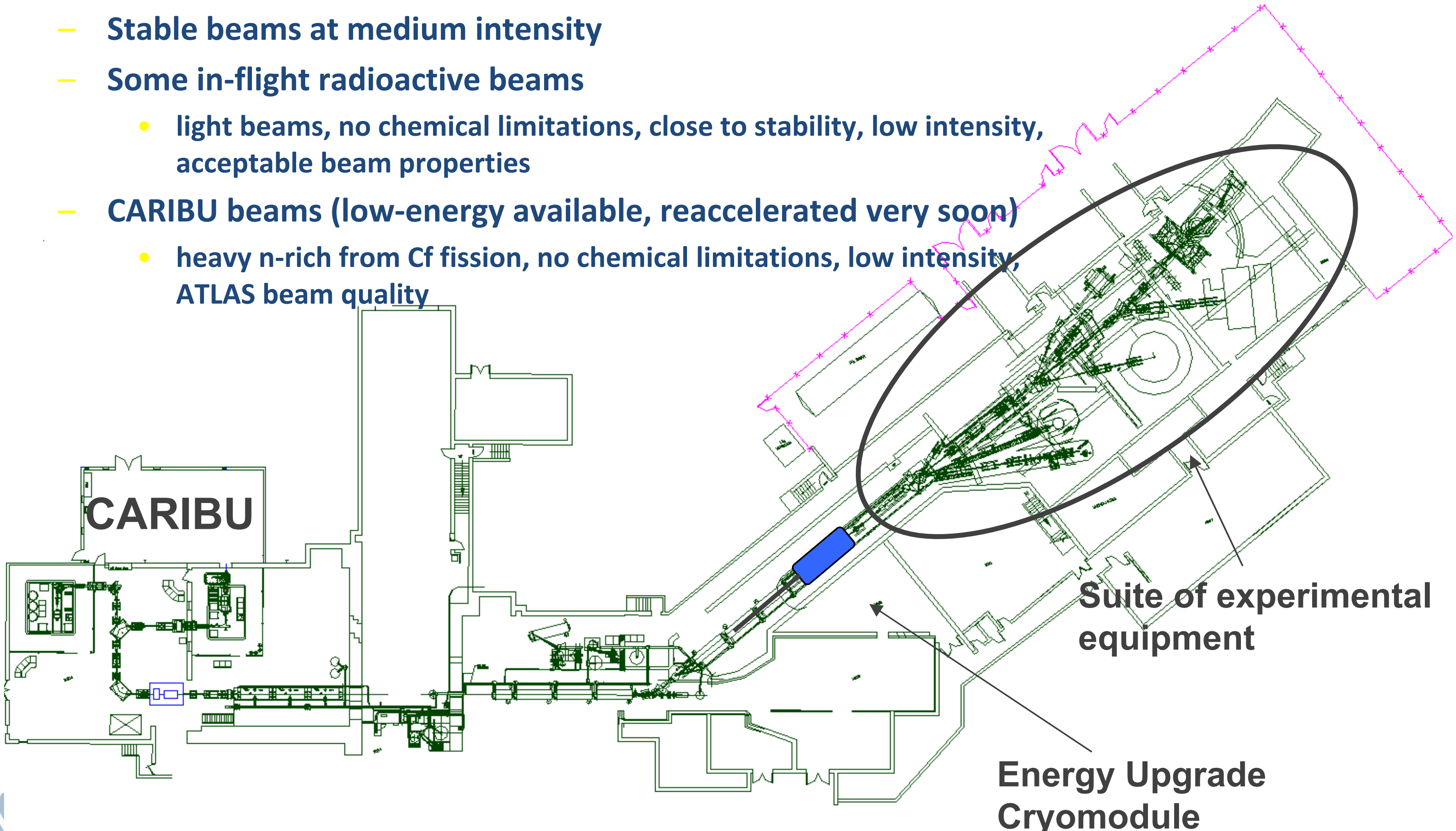
Argonne National Laboratory
and
University of Chicago

Outline

- Overview of ATLAS near future program
- Longer term physics program needs and role in community
- Proposed upgrade stages and physics capabilities

ATLAS now and near future

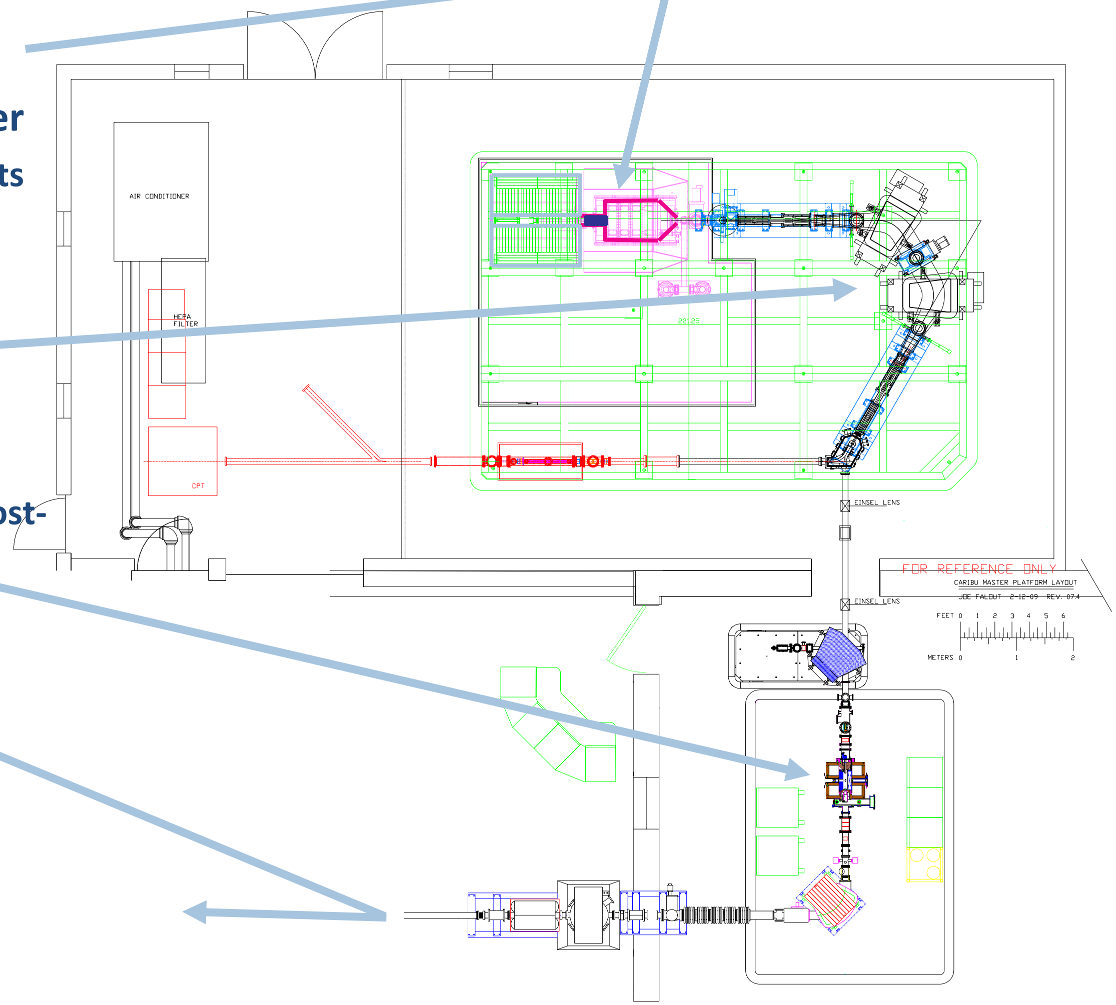
- ATLAS has served the low-energy community well
  - more than 100000 hrs of beam on target
- Capabilities have steadily increased. It now offers its users:
  - Stable beams at medium intensity
  - Some in-flight radioactive beams
    - light beams, no chemical limitations, close to stability, low intensity, acceptable beam properties
  - CARIBU beams (low-energy available, reaccelerated very soon)
    - heavy n-rich from Cf fission, no chemical limitations, low intensity, ATLAS beam quality



CARIBU: neutron-rich “front end” for ATLAS

Main components of CARIBU

- “ion source” is ^{252}Cf source inside gas catcher / RFQ cooler
  - Thermalizes fission fragments
  - Extracts all species quickly
  - Forms low emittance beam
- Isobar separator
  - Purifies beam
- Charge breeder
  - Increases charge state for post-acceleration
- Post-accelerator
  - ATLAS with energy upgrade



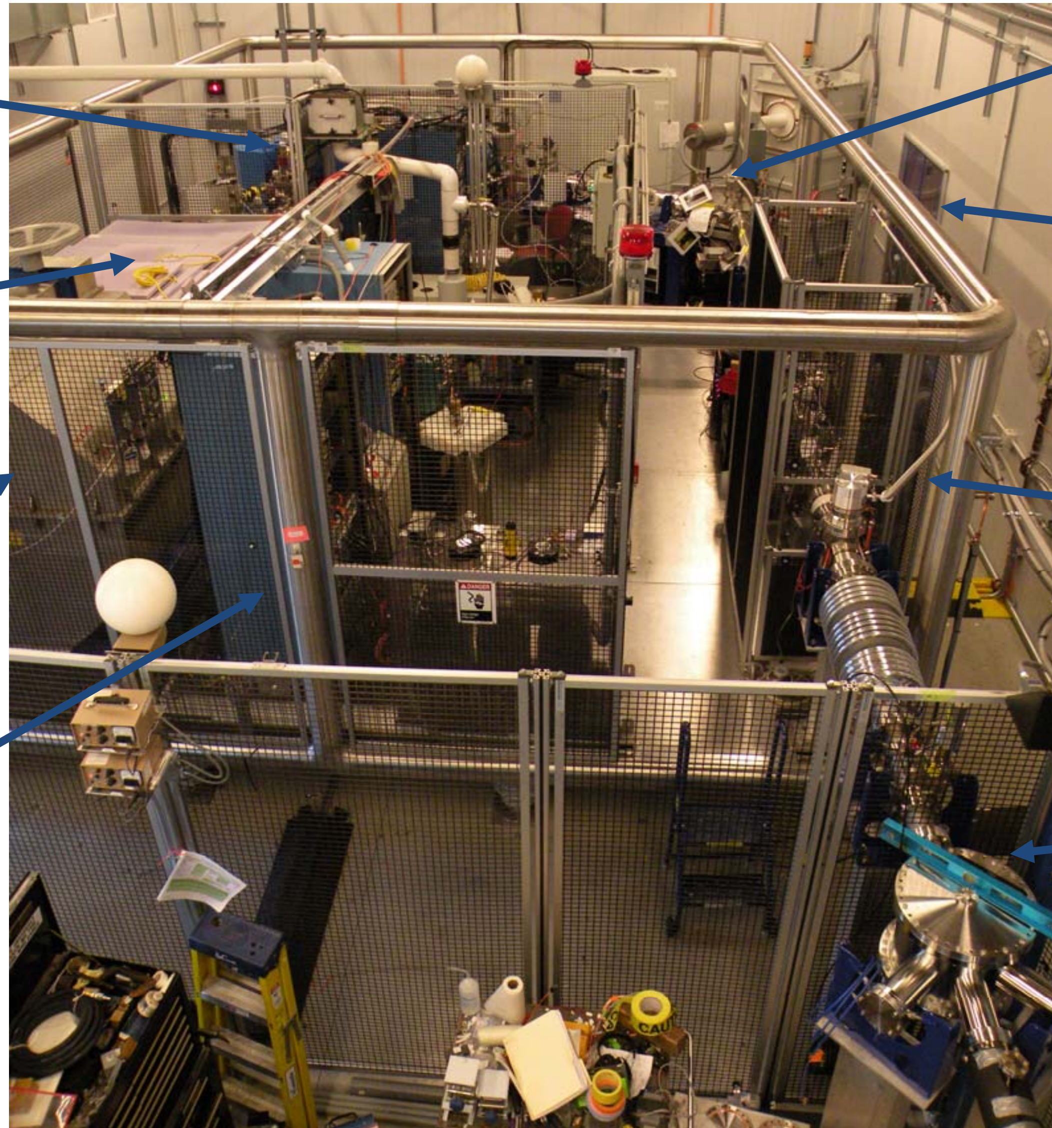
CARIBU front end

isobar separator

gas catcher

source transport cask

HV platform



switchyard

beamline to ECR breeder

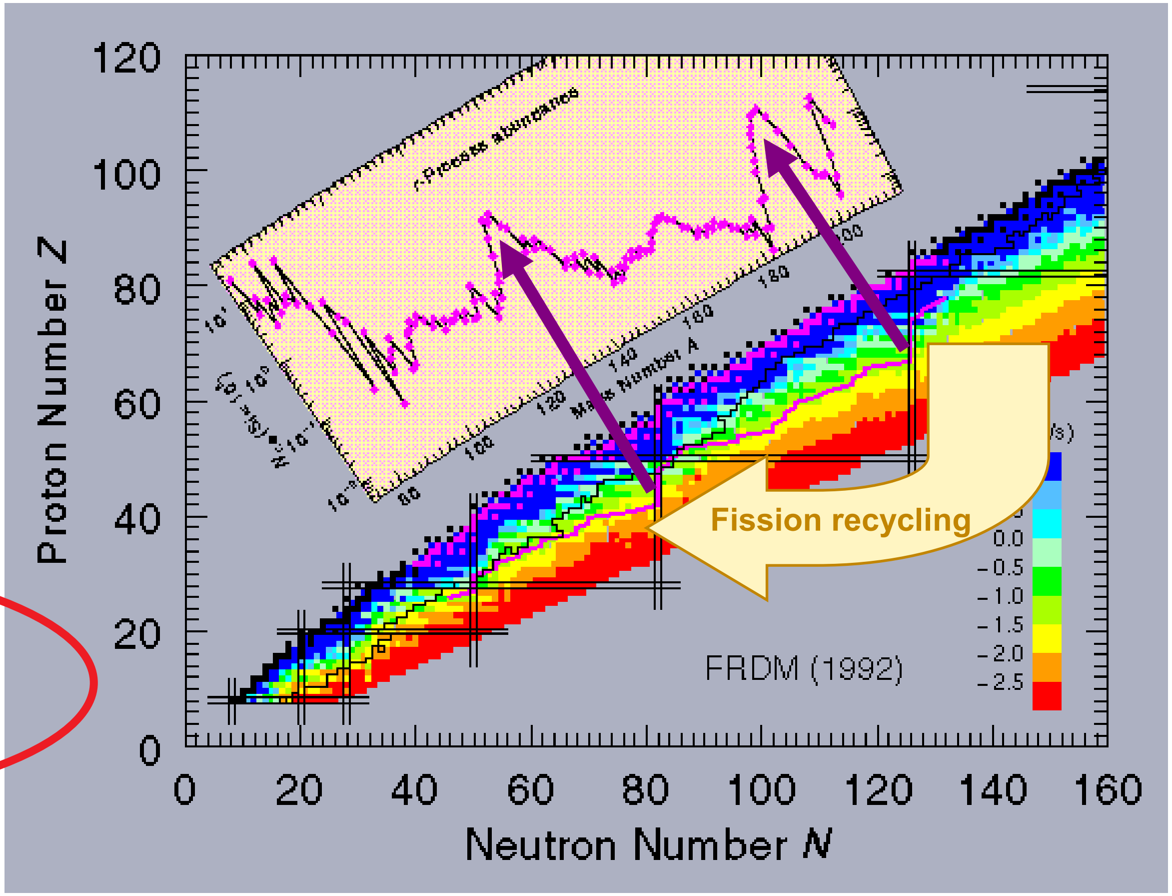
RFQ buncher

low-energy beamline

Astrophysics: the r-process path

r-process:

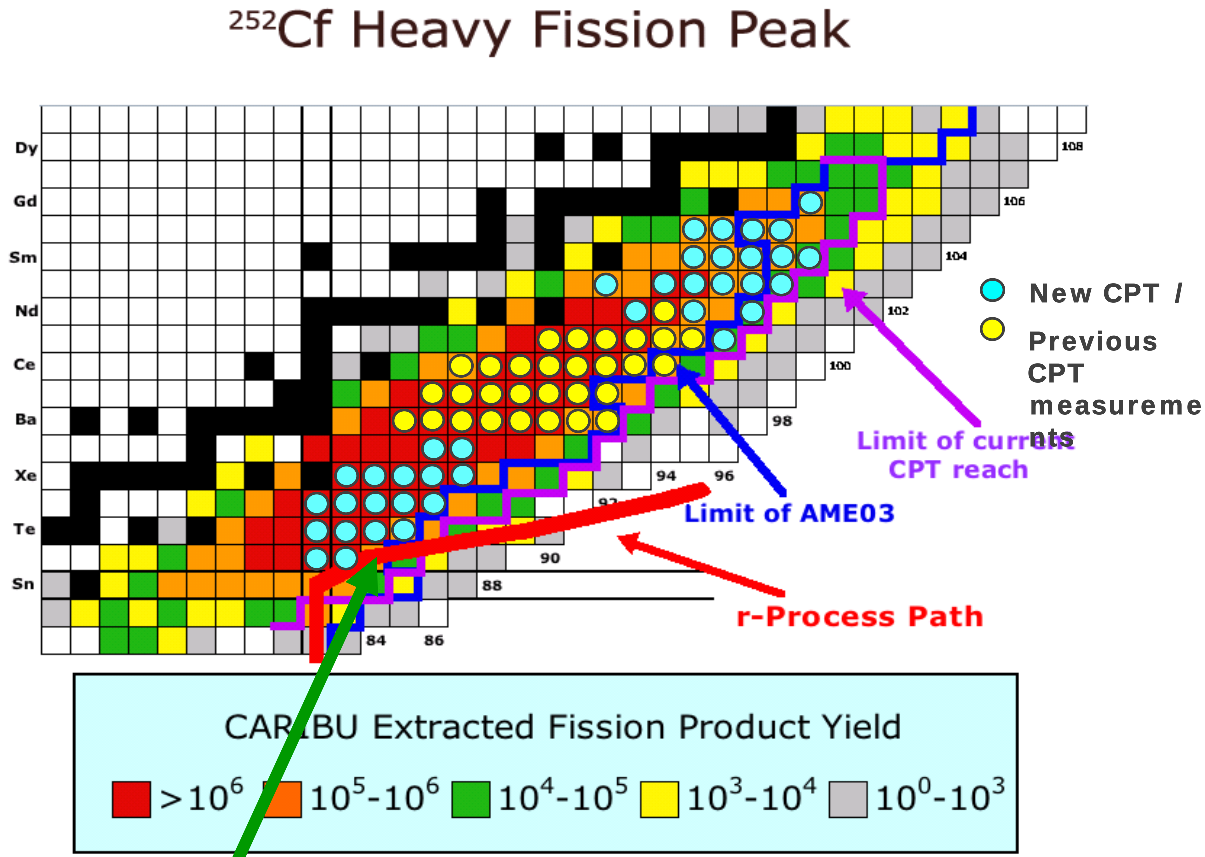
- Process known to exist
- Exact site unknown
- Path critically depends on nuclear properties of neutron-rich nuclei:
  - mass
  - lifetime
  - β-delayed neutrons
  - fissionability



Efficient techniques exist to obtain this information but the required beams were missing in most of this region of the chart of nuclides.

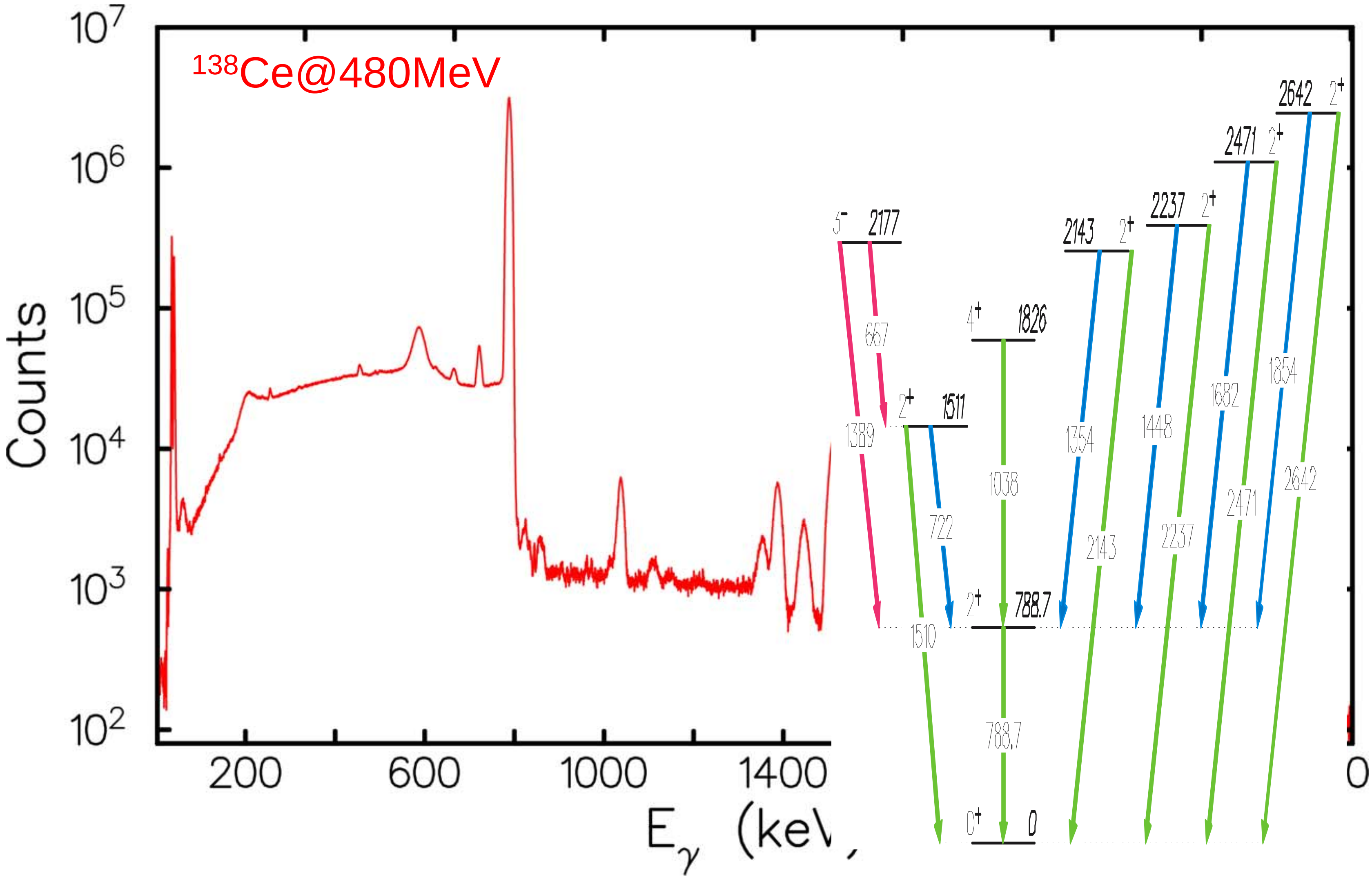
Mass measurements on neutron-rich isotopes

- Continuation of CPT program
- Greatly benefits from even the weaker CARIBU source
  - Requires > 0.1 ion/s
- All marked nuclei accessible with 100 mCi source currently installed
- CPT spectrometer moved to CARIBU, ready to start measurements
- CPT spectrometer will spend 12-18 months at CARIBU … measure > 150 n-rich nuclei

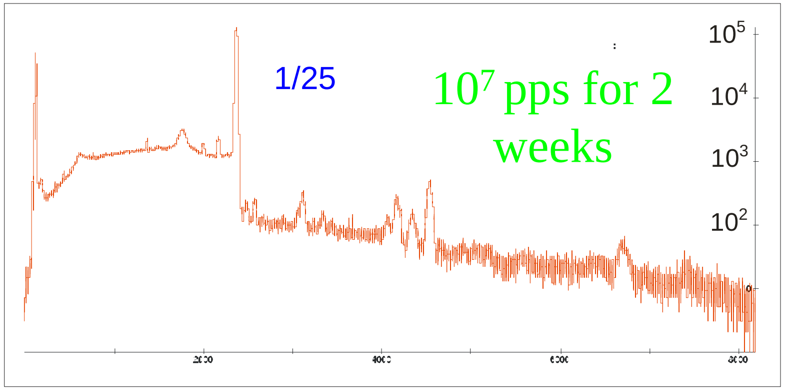


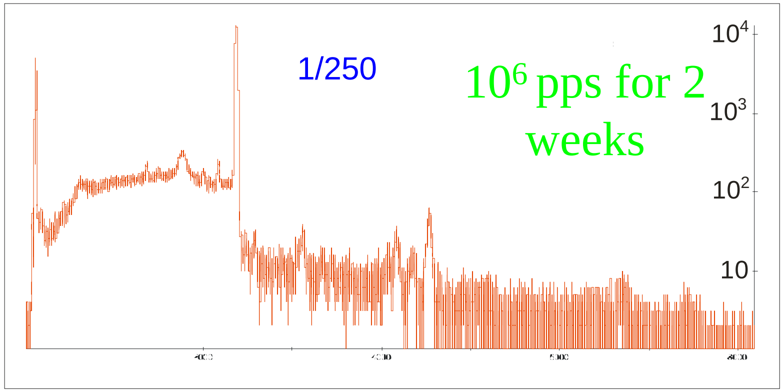
Extracted yield measured at CARIBU presently is 4 orders of magnitude higher than that used for these CPT measurements on n-rich isotopes

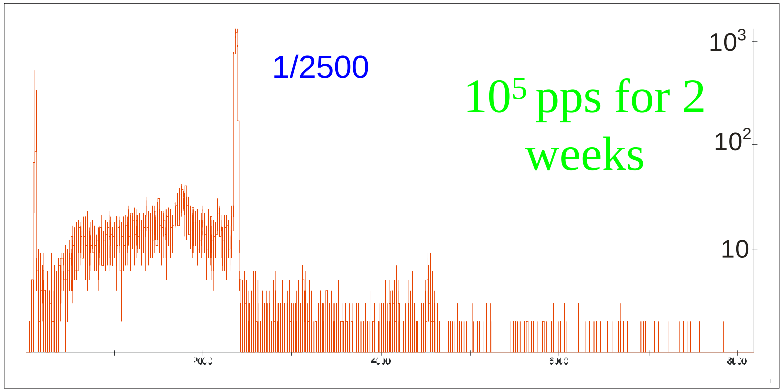
GSFMA 155 (February 2005)
Background subtracted, Doppler corrected spectrum



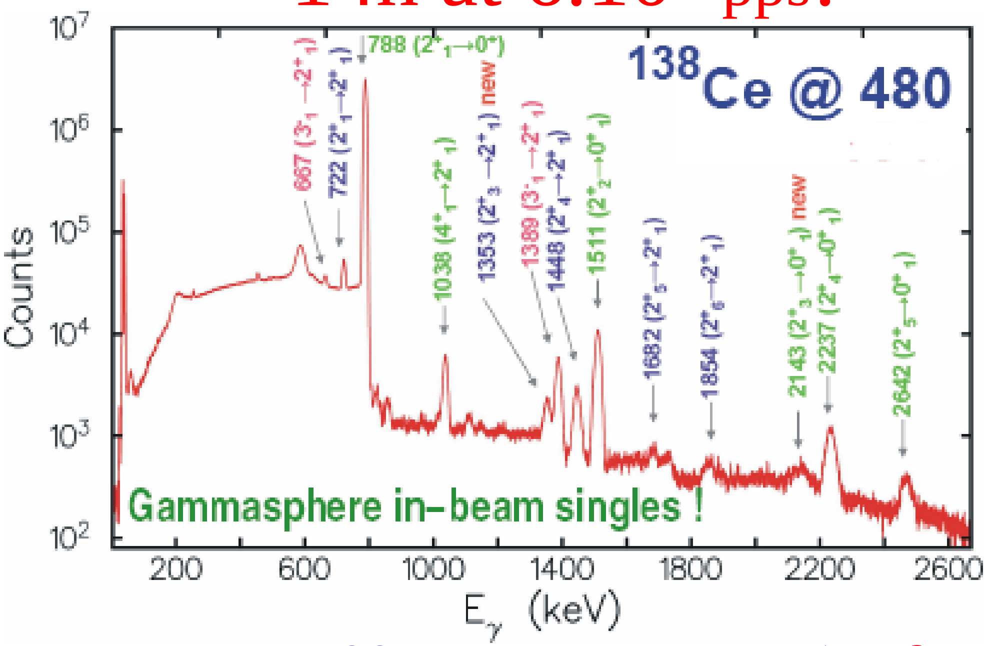
How much beam do we need with Gammasphere?







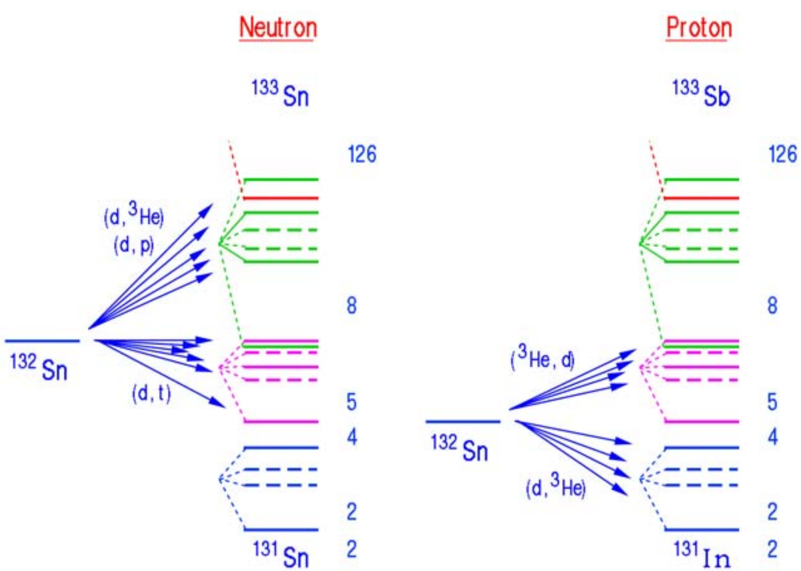
14h at 6.10^9 pps!

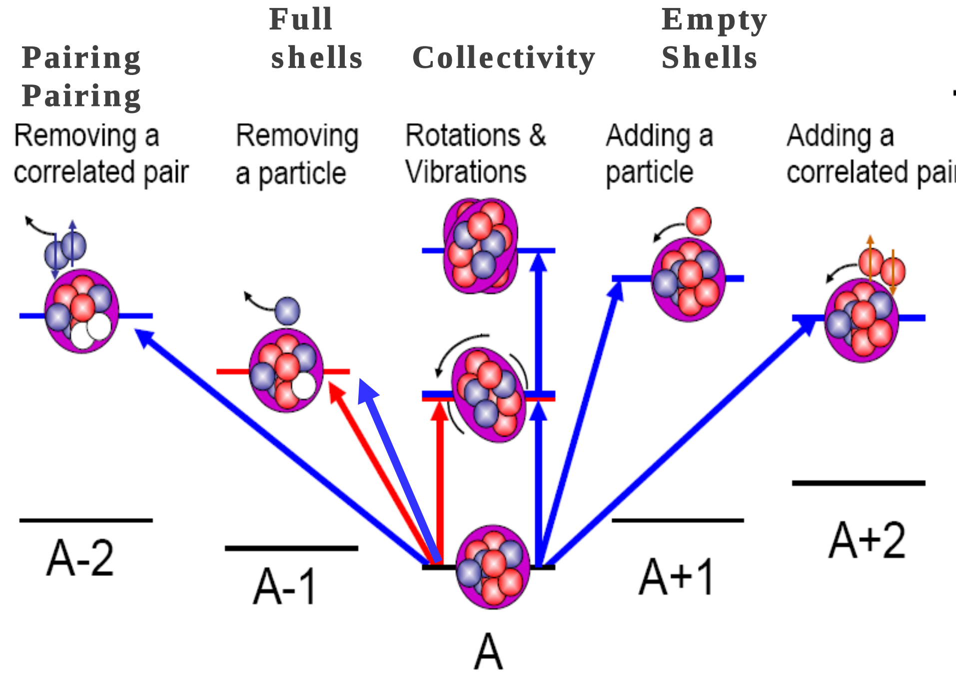


- **To get B(E2) of first 2+ state, we need ≥ 10^2 pps**
- **To identify excited 2^+ state (beyond the 2^+_1) in vibrational nucleus (B(E2)~1Wu) with Gammasphere for 2 weeks beam time we need ~10^5 pps.**
- **For complete spectroscopy, 10^6-10^7 pps is needed**

Nucleon transfer – knock-out

- Changes in shell structure with *single-nucleon transfer* and *knockout* reactions
  - Occupied and non-occupied states by nucleon transfer
  - Occupied states in knock-out





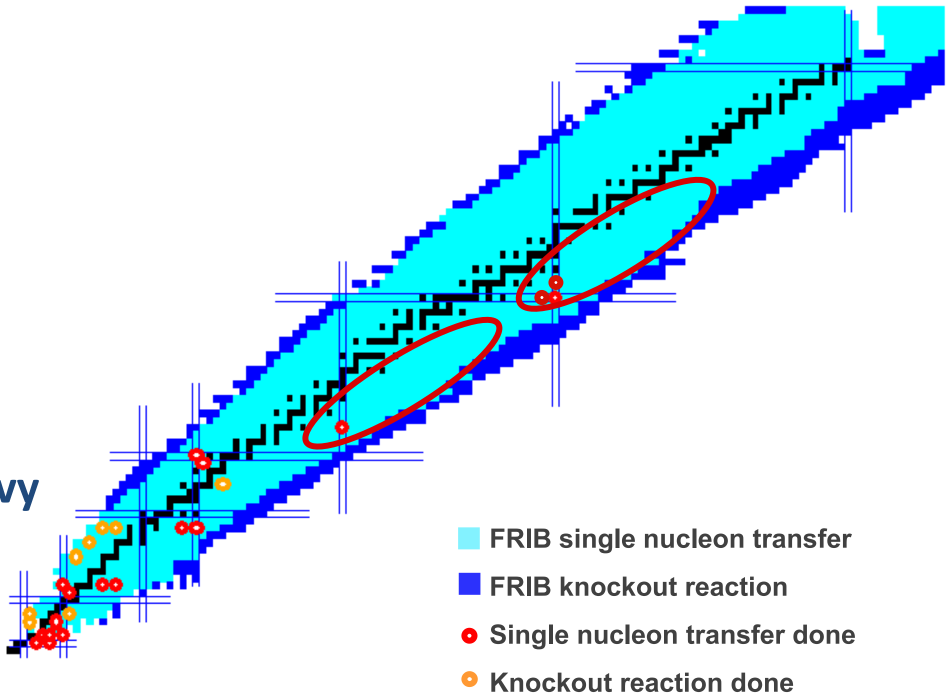
Tools used:

reaccelerated beams (5-15 MeV/u)

fast beams (>50 MeV/u)

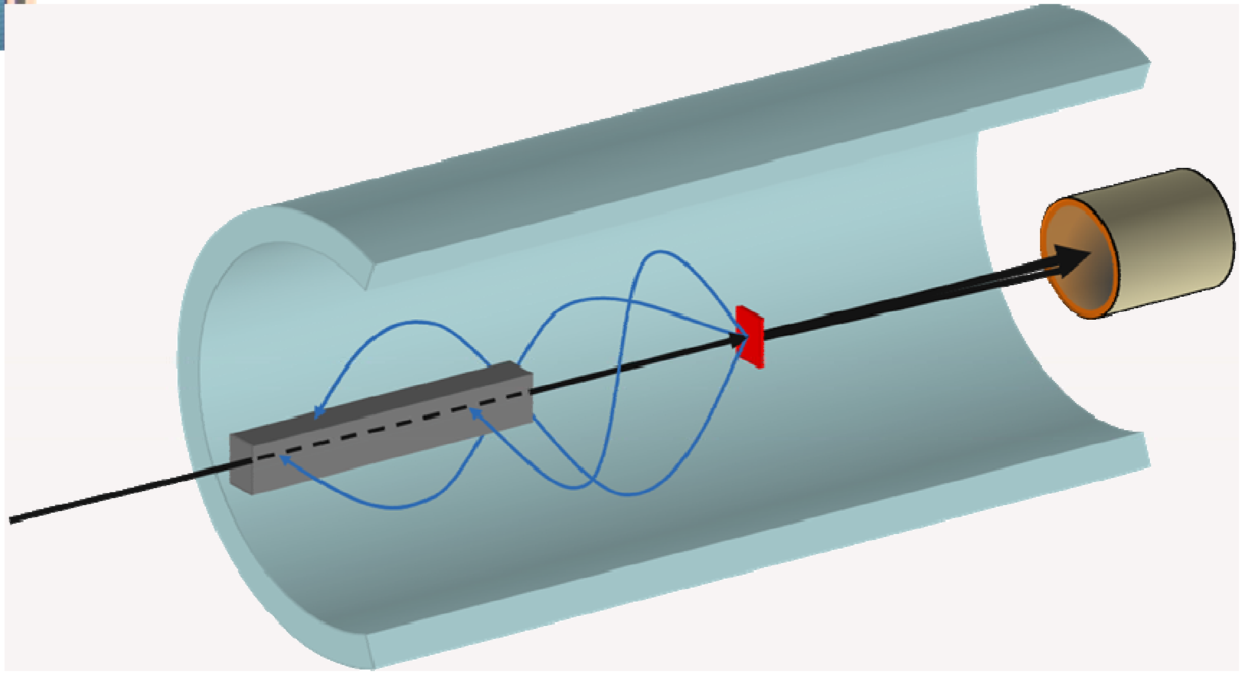
Opening the Radioactive Nuclei Landscape to Precise Structure Information

- Very few unstable nuclei have been studied by single nucleon transfer at low energy or knockout
  - mostly in the very light nuclei where the density of states is low
- In a decade, FRIB will provide the capabilities to extend these precision studies
  - detailed spectroscopic information over most of the chart with low-energy reactions
  - key input on the most exotic nuclei at higher energy
- In the intervening years, CARIBU will enable the initial exploration of the heavy neutron-rich region using precision low-energy transfer reactions and help developing and testing the required techniques

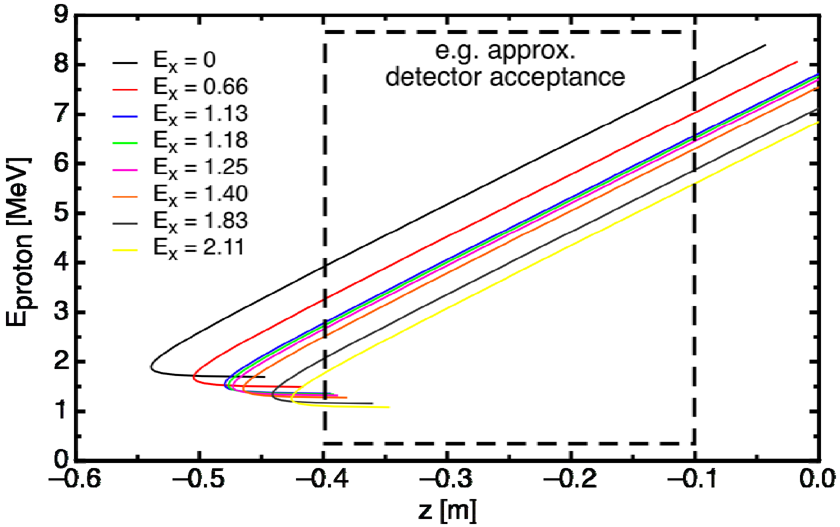


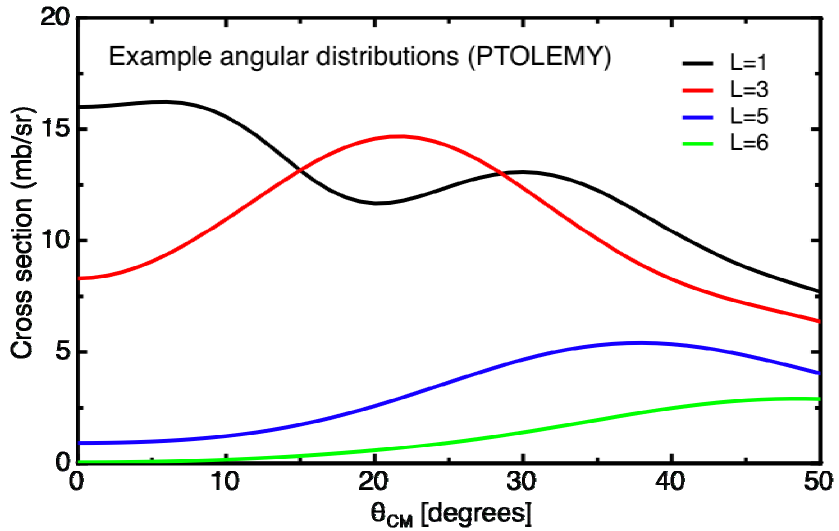
Synergy between improvement in instrumentation and CARIBU: HELIOS solenoid for Transfer Studies

HELIOS solenoid operational at ANL



Single-neutron transfer on N=82: CARIBU→ATLAS→HELIOS





- *d(^{134}Te,p)^{135}Te @ 8 MeV/u*
- *Q value = 1.115 MeV, B = 2T*
- *Clearly identify low-ℓ transfer (1,3) from angular distributions*
- *Isobaric contaminants low (factor 10 lower), recoil detector not crucial*
- *Expect ~1×10^4 ^{134}Te per second (with 80 mCi source) on 200 μgcm^{-2} CD_2 target with (d,p) cross sections of ~1-15 mb/sr*
- *Current array ~50% 'dead' area, however, ~6 days beam should yield >1000 cts per state.*

Disclaimer about planning for the future

It is difficult and can be hazardous.

"Prediction is very difficult, especially about the future."

Niels Bohr … Danish Physicist

"It's tough to make predictions, especially about the future."

Yogi Berra …. American Philosopher

It can be very useful.

"If you don't know where you are going, you might wind up someplace else."

Yogi Berra … important American Philosopher

The future can change, you have to adapt.

"In theory there is no difference between theory and practice. In practice there is."

Yogi Berra … great American Philosopher

"The future ain't what it used to be."

Yogi Berra … outstanding American Philosopher

If all else fails ….

"I never said most of the things I said."

Yogi Berra … possibly greatest American Philosopher ever

Process followed to determine the optimum path for ATLAS' future

- ATLAS program and capabilities are continually evolving to try to better fulfill the evolving needs of the user community … but a recent important shift in the landscape and an unexpected funding opportunity required and helped ATLAS to adjust to a new role.

- Path forward delineated with user community input to determine
  - How will the field evolve in the next decade?
    - Which subfields have important new issues popping up?
    - Which subfields have answers in sight and will wrap up?
    - How should role of ATLAS evolve over next decade?
    - What new capabilities are required to address future challenges?

- Came to the solution being implemented by
  - Summarizing the interests and needs
  - Capitalizing on existing expertise and facility
  - Looking for paths that kept ATLAS in a leadership position until FRIB comes along (timescale important) while leading to a useful role for the community in the FRIB era

The new landscape for the field: what is coming to a town near us

---- FRIB ----

- At full power
  - Fast beams
  - Reaccelerated beams at a few % of that
- Starts operating ~ 2017-19
  - ~ 1% of full power
- Reach full power in 5 years
  - ~ 2023
- Other first rate facilities are required to
  - prepare the landscape and keep the community engaged until that point
  - provide complementary capabilities once FRIB is operating

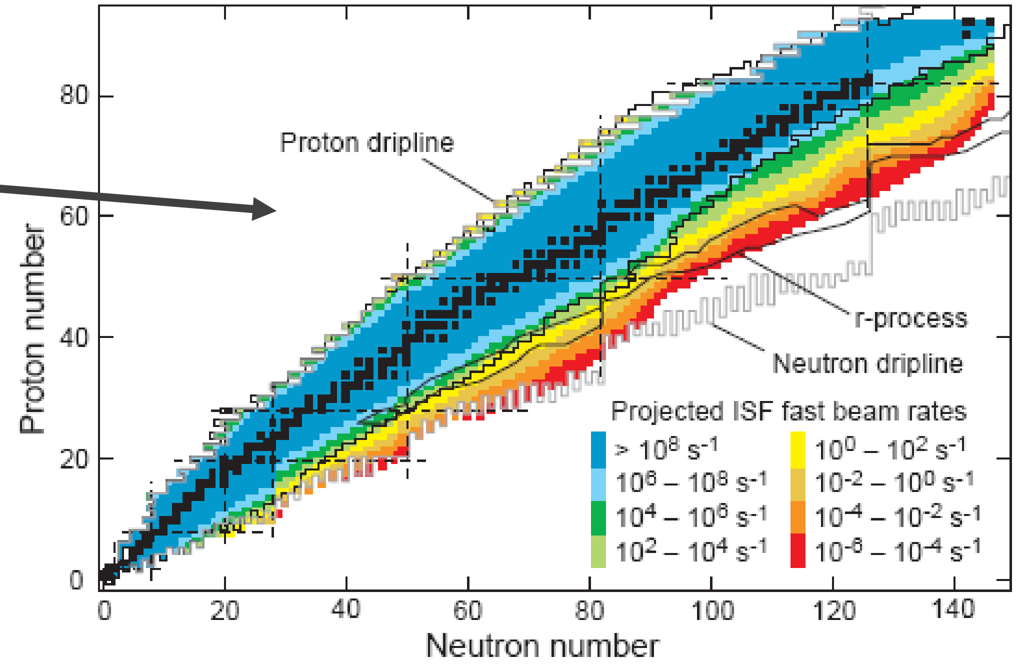


Figure 1.12: Scientific reach of the ISF. Shown are the intensities after the fragment separator calculated for in-flight production and separation, based on the proposed fragment separator and assuming the availability of 200 MeV driver beams with 400 kW beam power for all stable elements. It should be noted that predictions for isotopes very far from stability represent extrapolations into the unknown and have, therefore, uncertainties that can be as large as one or two orders of magnitude.

Broad vision of ATLAS scientific future (1)

- ATLAS in 1 to 5 years (CARIBU discovery phase):
  - CARIBU beams offer exciting new science opportunities … collect the low-hanging fruits
  - Best of stable beam components flourish in new evolved program (includes in-flight RIBs)
  - Continued equipment investments
  - Preparation for 5-10 years program
  - Participation into the R&D and physics preparation for FRIB

Broad vision of ATLAS scientific future (2)

- ATLAS in 5 to 10 years (pre-FRIB turn-on phase):
  - Higher intensity stable beams and improved equipment to pursue natural extensions of the running programs and new avenues
  - Higher intensity (reaccelerated) neutron-rich beams from CARIBU to extend precision experiments further from stability

- ATLAS in 10 years and more (FRIB era):
  - High intensity stable beam facility fulfilling needs of community
  - Selected programs with high impact, complementary to FRIB and capitalizing on developments in the field
  - Contribution to the FRIB physics effort

Expected main lines of investigations for nuclear structure program at ATLAS in next decade

- Neutron-rich region … where the field is moving, where we expect changes
  - ATLAS is uniquely positioned with CARIBU and its suite of experimental equipment
    - Single particle structure …more detailed/further out (HELIOS with more n-rich RIBs)
    - Collective properties (Coulex at Gammasphere/FMA, Gretina)
    - Ground-state properties (decay station, CPT, laser)
  - n-rich nuclides outside fission peaks also available for limited studies via deep inelastic reactions
- Superheavy elements research
    - Shell evolution and fission barrier moving up from Z~100 to Z~103-108 (Gas-Filled Separator)
    - More n-rich isotopes (deep inelastic and gas-filled magnet)
- Neutron-deficient region
    - Spectroscopy around ^{100}Sn (FMA+Digital DSSD, Digital Gammasphere)
    - Beta decay studies around N=Z line (FMA+Digital DSSD)
    - Structure of the lightest nuclei (HELIOS + in-flight separator)
    - Exotic phenomena (Digital Gammasphere, FMA+)
    - Gamma spectroscopy after secondary reactions

Critical capabilities for this program are higher intensity reaccelerated neutron-rich beams, higher intensity stable isotope beams over full ATLAS energy range, improved instrumentation

Expected main lines of investigations for nuclear astrophysics program at ATLAS over the next decade

- **r-process**
  - Masses, spins, lifetimes, beta-delayed neutrons on r-process path, not just close to it (decay station, CPT)
    - Main interest is in regions responsible for the abundance peaks
      - N=50 and N=82 regions (CARIBU + CPT & decay station)
      - N=126 region (deep inelastic + CPT & decay station)
  - Particle transfer reaction, similar goals to nuclear structure + n-capture surrogate reactions, on very n-rich nuclei (HELIOS with more n-rich RIBs)

- **rp-, αp-, νp-, CNO, …**
  - reactions with HELIOS on more exotic (mostly close to N=Z line) and higher intensity RIBs (HELIOS + in-flight separator)
  - Mass measurements past N=Z line (CPT+)

Critical capabilities for this program are higher intensity stable beams over full ATLAS energy range, improved instrumentation

Expected main lines of investigation for fundamental interactions program at ATLAS over next decade

- Search for nuclear electric dipole moment
  - EDM in octupole deformed nuclei
    - Continue with strongest source of ^{225}Ra and similar nuclei (>10^8/s)

- Search for currents beyond V-A
    - Angular correlation in beta decay in optical traps (^{6}He, ^{18}Ne, …)
    - Angular correlation in beta decay in ion traps (light nuclei)

Higher intensity stable isotope beams, improved instrumentation

- Searches for new physics
    - Opportunities in double beta decay experiments, dark matter searches, neutrino physics

Individual opportunities, some overlap with low-energy nuclear physics technologies (CPT, decay work), unlikely to become a major ATLAS program

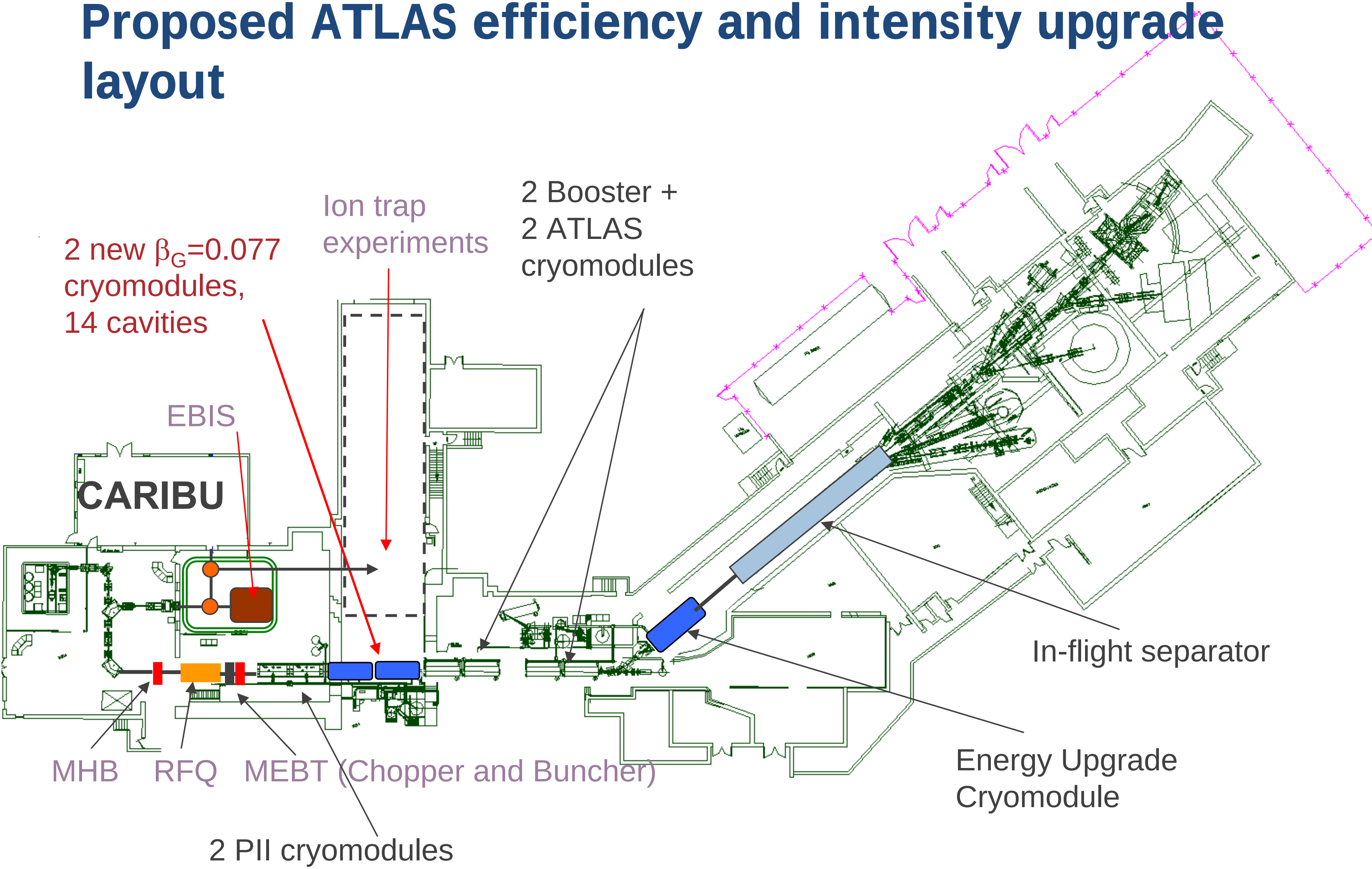
Moving ahead … general considerations

- Physics program at ATLAS will remain aligned with the priorities of the field.
- Many components of the future program are natural extensions to the current program.
- The required new capabilities to perform the various components of this program have a large technical overlap. Maximum benefit from the accelerator upgrades is obtained with attached experimental equipment upgrades.
- To have the maximum impact for the community, the programs must have time to get good science out before FRIB
    - <5 years to implement
    - >5 years to use
- The community needs access to beamtime and so extended downtime during much of the upgrades should be avoided

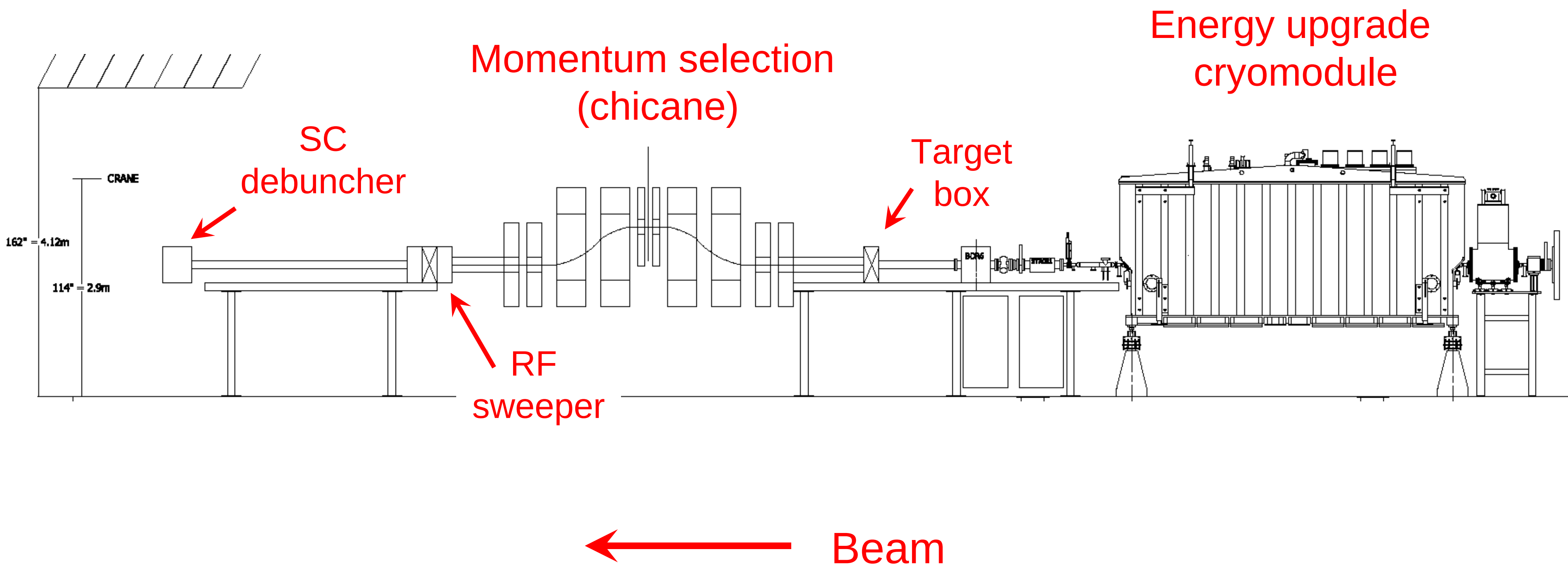
Moving ahead … maximizing physics overlap within a reasonable cost envelope

- Proposed upgrade path will
  - Increase intensity of stable beams from ATLAS by factor >10
    - Add an RFQ and reconfigure buncher and part of PII, add two new cryostats, rearrange rest of linac
  - Increase intensity of CARIBU reaccelerated beams by about 5
    - Only two options for this are bigger source or higher efficiency charge breeding/reacceleration
      - Stronger source has many difficulties associated to it
      - Replace ECR breeder by RF buncher and EBIS breeder, plus modifications to front end of linac above
  - Increase intensity of in-flight beams by >100
    - 10 times more primary beam, new high power gas targets, and new in-flight separator
  - Upgrade experimental equipment for selected programs

Proposed ATLAS efficiency and intensity upgrade layout



Conceptual layout of in-flight recoil separator



- Angular acceptance of ± 50 mrad in both x and y, a momentum acceptance of ± 5% and a maximum rigidity of 1.5 Tm
- Combination of magnetic chicane and RF sweeper provide rough mass selection
- SC debuncher reduces energy spread of selected secondary beam

Physics capabilities versus upgraded accelerator and experimental equipment capabilities (nuclear structure)

	Phase 1		PHASE 2			
Research area	Acc. upgrade	EBIS upgrade	Acc. upgrade	In-flight separator	Equipment upgrades	comments
Single particle structure of n-rich nuclei form CARIBU	Yes	Yes	---	---	HELIOS detector	~ 10 times faster data taking more reach access to weaker levels
Collective properties of n-rich nuclei from CARIBU	Yes	Yes	---	---		~ 5 times faster data taking more diverse information
Spectroscopy around 100Sn	Yes	---	---	---	Digital DSSD + GS	Other options are available here
Superheavy element research	Yes	---	Yes	---	Gas-filled separator	Shell evolution and fission barrier up to ~ 108
Beta-decay studies around N=Z	Yes	---			Digital DSSD	
Gamma-ray spectroscopy after secondary reactions	yes	---	yes	yes		Removes rate limitations of GS

Physics capabilities versus upgraded accelerator and experimental equipment capabilities (nuclear astrophysics and weak interaction)

	Phase 1		PHASE 2			
Research area	Acc. upgrade	EBIS upgrade	Acc. upgrade	In-flight separator	Equipment upgrades	comments
Surrogate n-capture in r-process region	Yes	Yes	---	---	HELIOS detector	▪~ 10 times faster data taking ▪more cases possible
Masses and decay studies along N=126	Yes	---	Yes	---	CPT back at ATLAS	▪Unique access to this region until FRIB
Reactions for rp-, νp-, αp-processes and CNO cycle	Yes	---	Yes	Yes	Helios detector	▪Higher intensity and more exotic beams
Mass measurements past N=Z lines for astrophysics	Yes	---	---	---	CPT back at ATLAS	▪Higher selection in CPT injection line

	Phase 1		PHASE 2			
Research area	Acc. upgrade	EBIS upgrade	Acc. upgrade	In-flight separator	Equipment upgrades	comments
Search for current beyond V-A	Yes	---	Yes	Yes		▪More candidate available at higher intensity

What new physics possibilities are enabled?

- Addresses the community's main nuclear structure goals
  - Even higher intensity n-rich beams would be nice … FRIB will come in at the right time

- Considerably improves ATLAS' nuclear astrophysics program and keeps it competitive until FRIB

- Gives access to new and larger amount of isotopes for fundamental interactions studies

- Positions the Physics Division and the ATLAS users community for a leading user role in reaccelerated beam physics at FRIB

Improved capabilities with ATLAS upgrade