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Science with the ATLAS Efficiency and Intensity Upgrade

Guy Savard

Argonne National Laboratory
and
University of Chicago

U.S. Department of Energy
THE UNIVERSITY OF CHICAGO
Office of Science
U.S. DEPARTMENT OF ENERGY
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Outline

- **Evolving landscape for low-energy nuclear physics**
- **Self-assessment of ATLAS present and near future program**
- **Process followed to evaluate near and longer term physics program needs and role in community**
- **Option proposed**
  - **Physics**
  - **Machine**
  - **Instrumentation**

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

---- FRIB ----

- **At full power**
  - **Fast beams**
  - **Reaccelerated beams at a few % of that**
- **Starts operating ~ 2017-18**
  - **~ 1% of full power**
- **Reach full power**
  - **~ 2020-2021**
- **Other first rate facilities are required to**
  - **prepare the landscape (lots of physics to be done until FRIB) and keep the community engaged until that point**
  - **provide complementary capabilities once FRIB is operating**

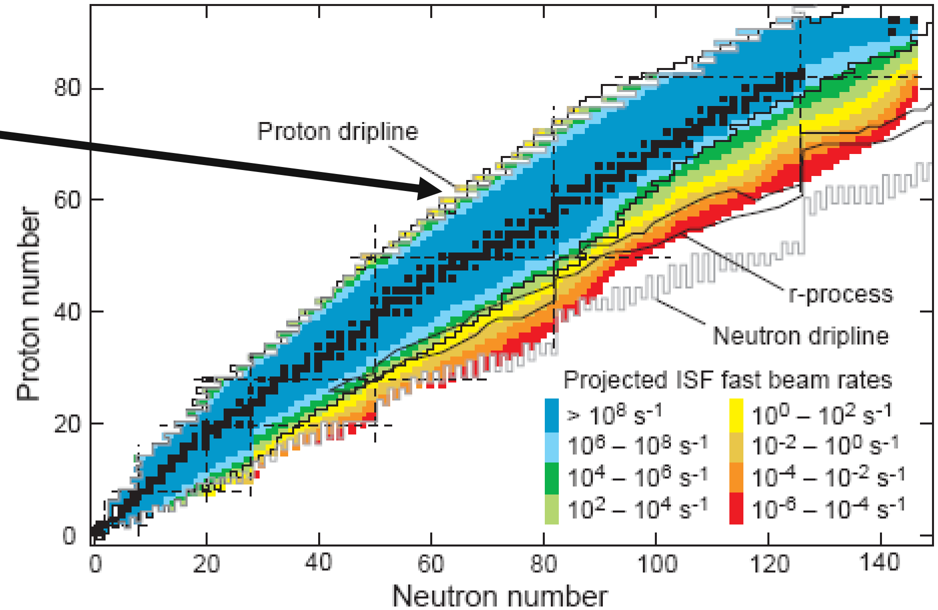
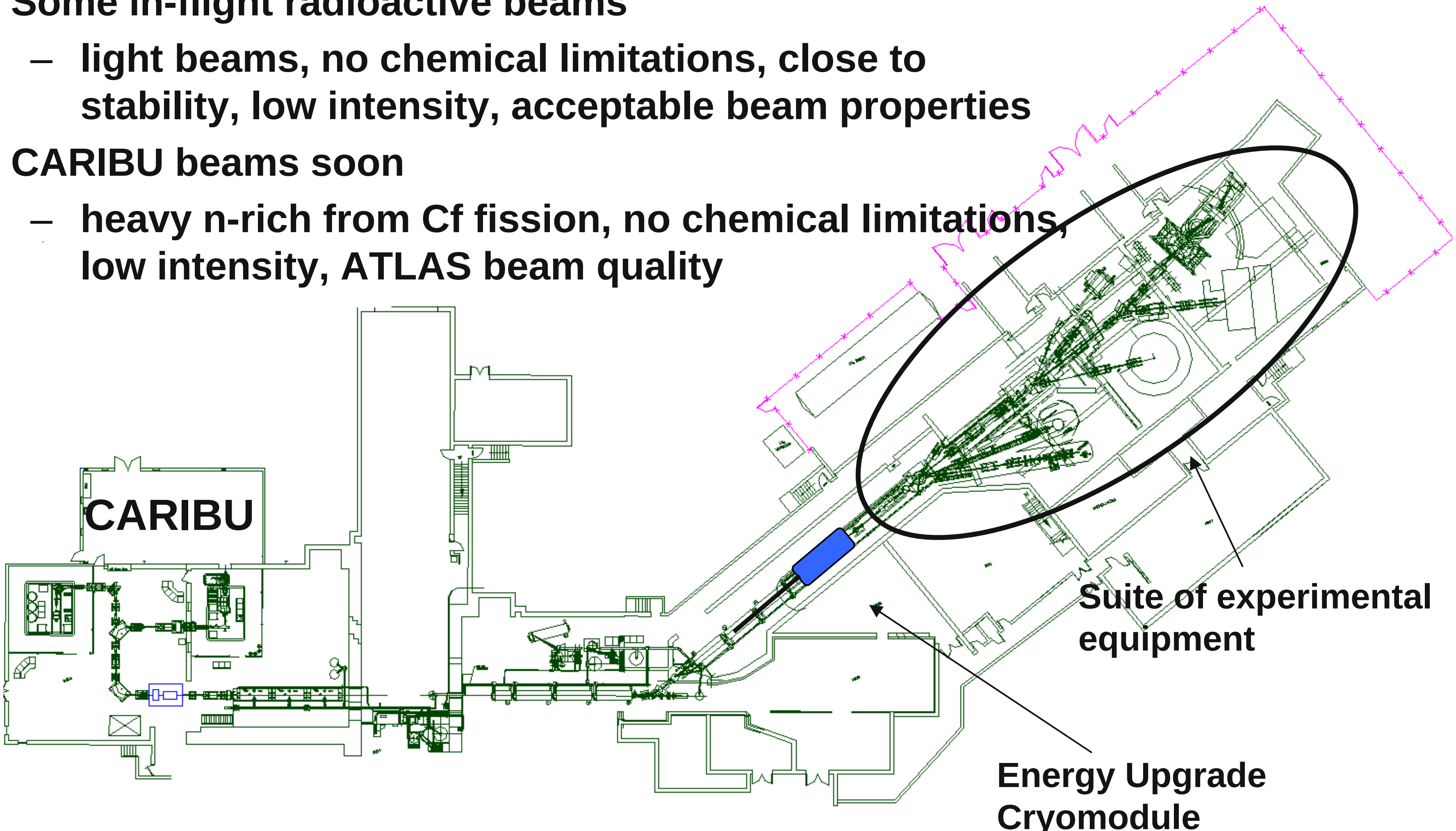


Figure 1.12: Scientific reach of the ISF. Shown are the intensities after the fragment separator calculated for in-flight production and separation, based on the proposed fragment separator and assuming the availability of 200 MeV driver beams with 400 kW beam power for all stable elements. It should 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.

ATLAS now and very near future

- 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 soon
  - heavy n-rich from Cf fission, no chemical limitations, low intensity, ATLAS beam quality



CARIBU Yields for Representative Species versus time

Expected ^{252}Cf fission source strength:

- **2.5 mCi** **End of summer 2009**
- **80 mCi** **Fall 2009**
- **1 Ci source** **2010 - …**

Isotope	Half-life (s)	Low-Energy Beam Yield (s^{-1})	Accelerated Beam Yield (s^{-1})
^{104}Zr	1.2	1.5×10^{3} / 4.8×10^{4} / 6.0×10^{5}	5.3×10^{1} / 1.7×10^{3} / 2.1×10^{4}
^{143}Ba	14.3	3.0×10^{4} / 9.6×10^{5} / 1.2×10^{7}	1.1×10^{3} / 3.4×10^{4} / 4.3×10^{5}
^{145}Ba	4.0	1.4×10^{4} / 4.4×10^{5} / 5.5×10^{6}	5.0×10^{2} / 1.6×10^{4} / 2.0×10^{5}
^{130}Sn	222.	2.5×10^{3} / 7.8×10^{4} / 9.8×10^{5}	9.0×10^{1} / 2.9×10^{3} / 3.6×10^{4}
^{132}Sn	40.	9.3×10^{2} / 3.0×10^{4} / 3.7×10^{5}	3.5×10^{1} / 1.1×10^{3} / 1.4×10^{4}
^{138}Xe	846.	2.5×10^{4} / 7.8×10^{5} / 9.8×10^{6}	1.8×10^{3} / 5.8×10^{4} / 7.2×10^{5}
^{110}Mo	2.8	1.6×10^{2} / 5.0×10^{3} / 6.2×10^{4}	5.8×10^{0} / 1.8×10^{2} / 2.3×10^{3}
^{111}Mo	0.5	8.3×10^{0} / 2.6×10^{2} / 3.3×10^{3}	0.3×10^{0} / 9.6×10^{0} / 1.2×10^{2}

Self-assessment of ATLAS present and future (1)

- **ATLAS program now**
  - **Machine runs well, though constrained by limited funds and manpower**
  - **It hosts a solid and diversified physics program, leading the NP office facilities in many aspects**
  - **It serves a strong users community**
  - **Equipment investments have been at an inadequate level due to continuing resolutions**

- **ATLAS in 1 to 5 years (CARIBU discovery phase):**
  - **CARIBU beams offer new science opportunities**
  - **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**

Self-assessment of ATLAS present and 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 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**

Process being followed to find the best option for our future

- **December 2008 brought an important shift in the landscape, ATLAS had to adjust to find its new role**
- **Opportunities provided by ARRA … required fast response**
- **The physicists in the field (local and user community) are the expert, they know the field and can provide the best guidance as to where it is going**
- **Ask the experts (the locals, the users executive committee and the full users community)**
  - **How they believe what they are working on will evolve in the next decade? New important issues popping up or answer is in sight and subfield will wrap up.**
  - **What they believe will be interesting in 5-10 years?**
  - **What they would like to work on in 5-10 years? What capabilities and equipment is needed?**
  - **What should the role of ATLAS be in the future on the national and international landscape? Is there one?**
- **Came to the proposed solution, for the community to iterate upon, by**
  - **Summarizing the interests and needs**
  - **Capitalize on existing expertise and facility**
  - **Looking for paths that put ATLAS in a leadership position until FRIB comes along (timescale important) while leading to a useful role for the community in the FRIB era**

This is an ongoing process. Community input is critical to guide it.

Examples of possible components of an ATLAS physics program in 5-10 years: … nuclear structure

- Neutron-rich region (came in at #1 in the feedback gathered so far)
  - where the field is moving, where we expect changes
    - *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)*
- Neutron-deficient region
    - *Spectroscopy around ^{100}Sn (FMA+Digital DSSD, Digital Gammasphere)*
    - *Beta decay studies around N=Z line (FMA+Digital DSSD)*
    - *Exotic phenomena (Digital Gammasphere, FMA+)*
    - *Gamma spectroscopy after secondary reactions*
- Superheavy
    - *Shell evolution and fission barrier moving up from Z~100 to Z~103-108 (Gas-Filled Spectrometer)*
    - *More n-rich isotopes (???)*

Higher intensity beams, similar energy range, improved instrumentation

Examples of possible components of an ATLAS physics program in 5-10 years: … nuclear astrophysics

- **r-process**
  - ***Masses, spins, lifetimes, beta-delayed neutrons on r-process path, not just close to it (decay station, CPT)***
  - ***Particle transfer reaction, similar goals to nuclear structure and n-capture, on very n-rich (HELIOS with more n-rich RIBs)***

- **rp-, αp-, νp-, CNO, …**
  - ***reactions with HELIOS on more exotic and higher intensity RIBs (mostly close to N=Z)***
  - ***Mass measurements past N=Z line (CPT+)***
  - ***very high intensity, low energy, light stable beams with a recoil spectrometer***

Higher intensity beams, similar energy range, improved instrumentation

Examples of possible components of an ATLAS physics program in 5-10 years: … fundamental interactions

- **EDM**
  - **EDM in octupole deformed nuclei**
    - ***Need a stronger source of ^{225}Ra and similar nuclei (>10^8/s)***

No currently planned facility improves significantly over sources

- **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 beams, similar energy range, 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, unlikely to become a major ATLAS program

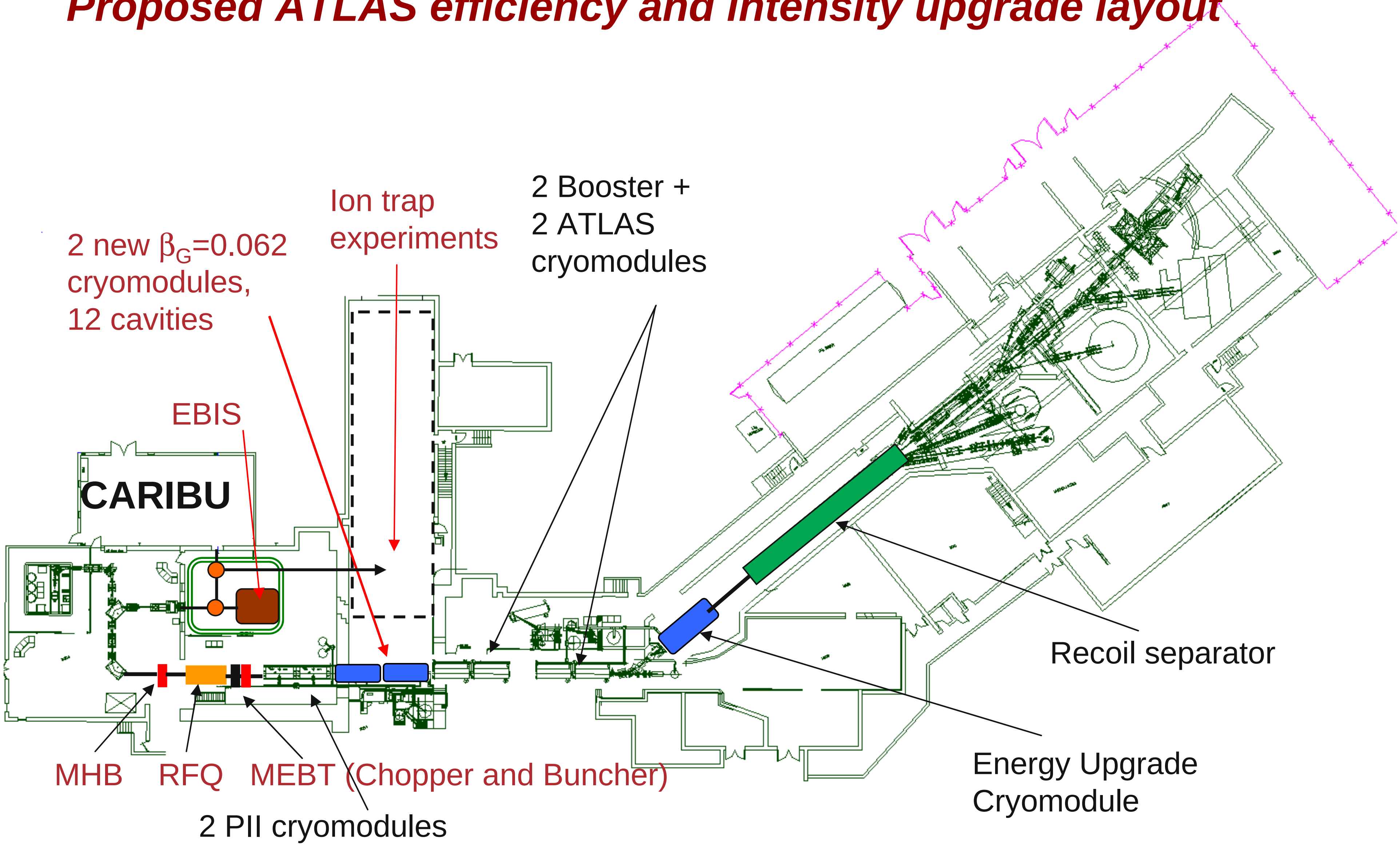
So how do we proceed? …general considerations

- **General findings**
  - **Many subfields of study important at ATLAS right now have interesting future ramifications**
    - ***Good: shows field is still interesting and offers new opportunities***
  - **For most subfields, upgrades to the accelerator are only fully used if improvements in experimental equipments are attached to them**
- **To have the maximum impact for the community, we must have time to get good science out of an ATLAS upgrade before FRIB is fully operational**
    - ***<5 years to implement***
    - ***>5 years to use***
- **We should avoid extended downtime during much of the upgrades**

How do we proceed? … maximize physics overlap within reasonable cost envelope

- **Proposed upgrade path should**
  - **Increase intensity of stable beams from ATLAS by factor >10**
    - ***Replace buncher and part of PII by new buncher, RFQ and two new cryostats, rearrange rest of linac***
  - **Increase intensity of CARIBU reaccelerated beams by > 5-10**
    - ***Only two options for this are bigger source or higher efficiency charge breeding/reacceleration***
      - **Higher 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 separation spectrometer***
  - **Funds for new and upgraded experimental equipment**

Proposed ATLAS efficiency and intensity upgrade layout



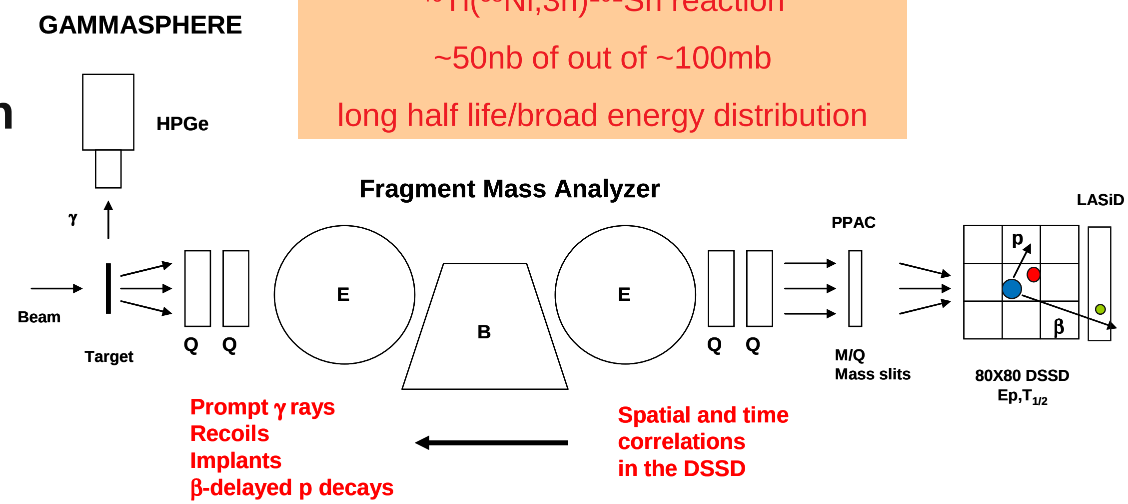
Single particle structure around ^{100}Sn

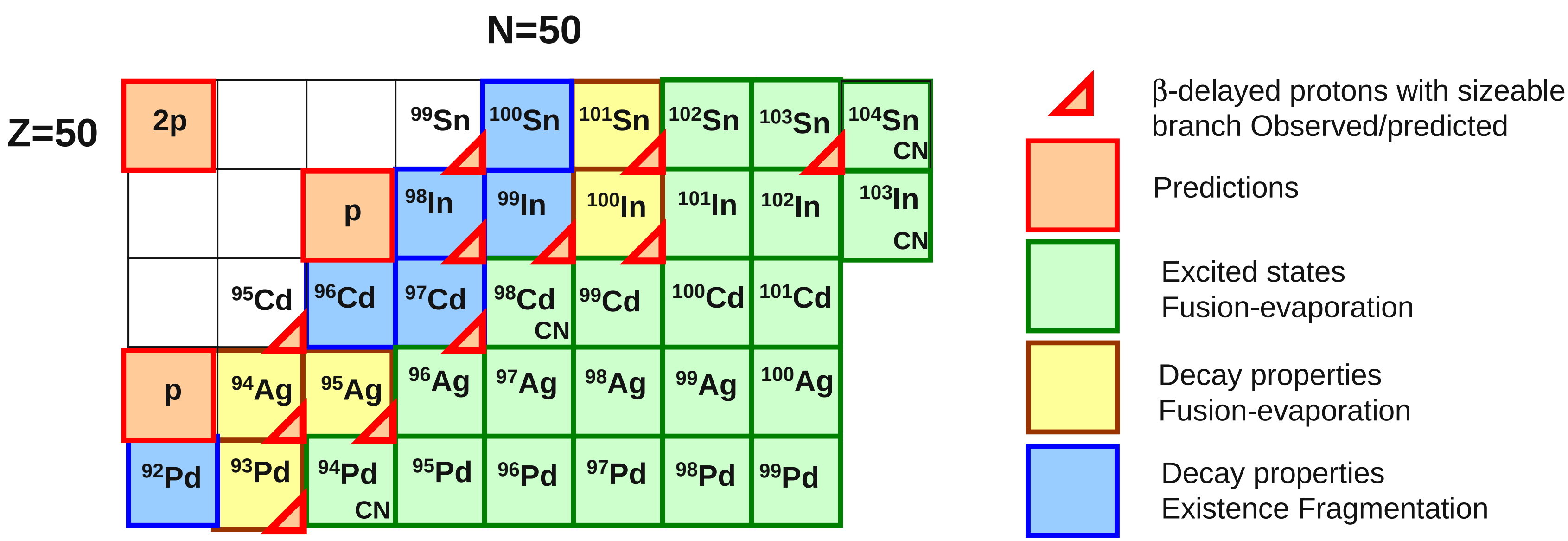
- **Recent observation of excited state in ^{101}Sn through beta-delayed proton tagging**
- **Same type of tag could be used for other nuclei around ^{100}Sn with increased production**

^{46}Ti(^{58}Ni,3n)^{101}Sn reaction

~50nb of out of ~100mb

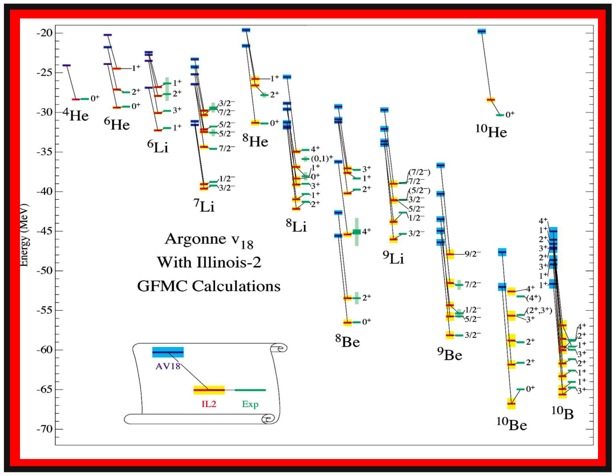
long half life/broad energy distribution





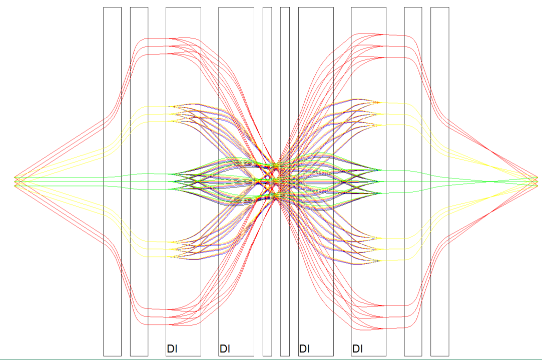
Two orders of magnitude intensity gain on in-flight beams

- **Existing system limited by**
  - **Production → primary beam intensity and targets**
  - **Poor transmission (measured transmission for ^{17}F was 0.3%)**
  - **Limited selectivity**
- **Upgrade will provide**
  - **X10 in primary beam**
  - **> X10 in transmission with better selectivity**
- **Enables**
  - **better experiments with existing beams**
    - **Structure of light nuclei to test GFMC**
      - ***^{6}He(d,p)^{7}He***
      - ***^{8}Li(d,^{3}He)^{7}He***
    - **Astrophysical reaction rates**
    - **Higher production for fundamental interaction studies**
  - **Experiments with beams one (or few) neutron further away from stability**
    - **These beams were too weak with the present system, with the upgrade, they become usable**



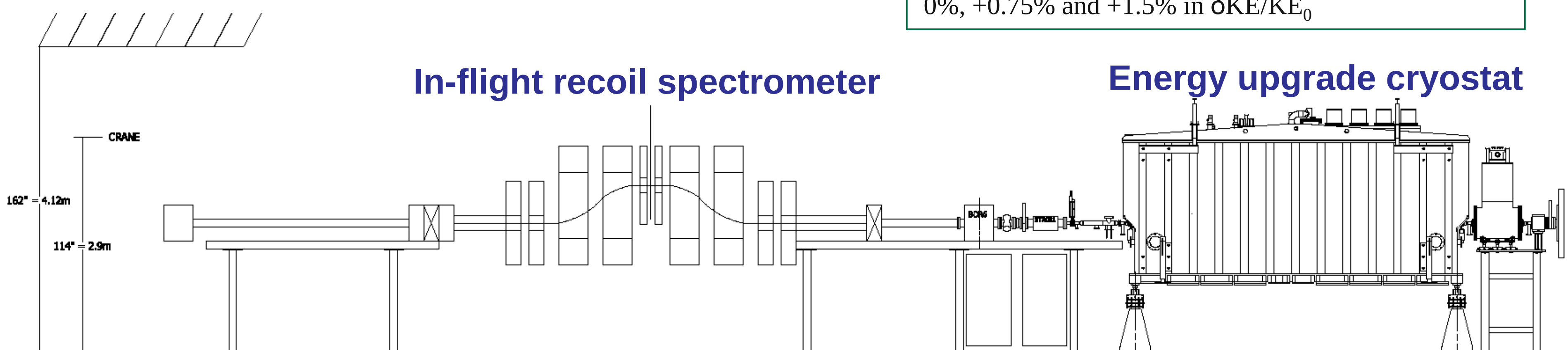
Proposed compact in-flight recoil spectrometer for ATLAS

- **similar to the present in-flight system, but with higher acceptance and better rejection of beam tails:**
  - **Momentum selection of reaction products via an achromatic, magnetic chicane**
  - **RF sweeper to suppress low energy beam tails**
  - **Superconducting debuncher to compress reaction product energy spread**



$^{33}S+p \rightarrow {}^{33}Cl+n$

- Recoils at 10 MeV/u
- $B\rho(^{33}Cl^{17+})=0.88Tm$
- ^{33}Cl charge state=17+ (70% yield)
- $\delta\Phi = \delta\theta = +/- 50mrad$ for ^{33}Cl
- $\delta X=+/- 2.5mm$ and $\delta Y= +/- 2.5mm$
- $\delta KE/KE_0= +/- 1.50\%$; $\delta q=\pm 1$
- Different colors represent rays with -1.5%, -0.75%, 0%, +0.75% and +1.5% in $\delta KE/KE_0$

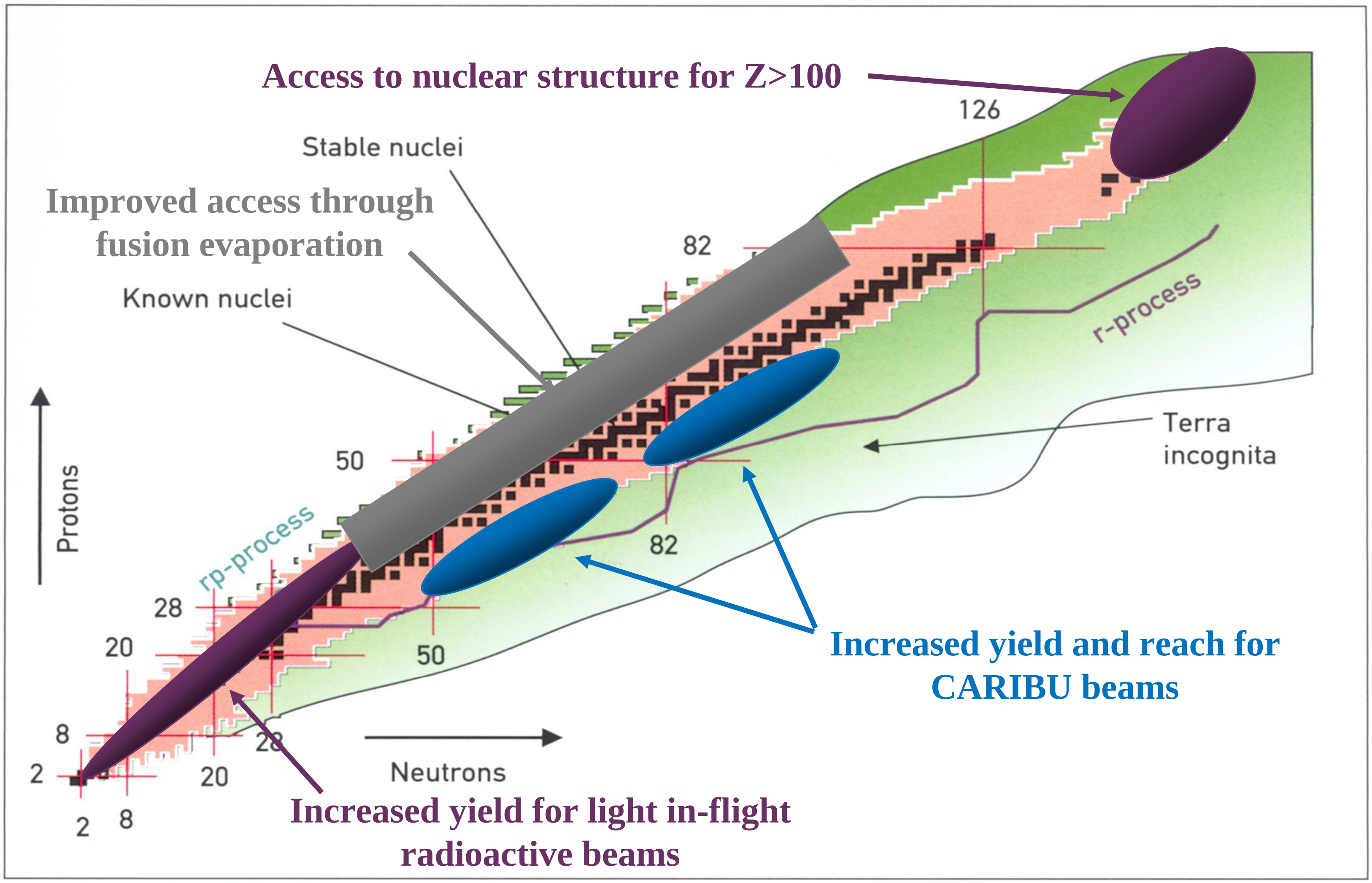


Manikonda & Nolen

Imcreased intensity for reaccelerated neutron-rich beams from CARIBU

- **All experiments can be performed faster**
- **All experiments have extended reach**
  - **roughly one neutron further away from stability**
  - **roughly one higher or lower Z at the limits of the distribution**
- **Some key nuclei (e.g. ^{130}Cd) become accessible as reaccelerated beams**
- **Large extension of the nuclei that can be studied via transfer reactions and of the details accessible**
- **New type of experiments, such as fusion evaporation reaction with these beams, become possible.**

Improved capabilities with ATLAS upgrade



What new physics possibilities would be enabled by the proposed upgrades?

- **Addresses the main nuclear structure goals presented**
  - **Even higher intensity n-rich beams would be nice … FRIB will come in at the right time**
- **Considerably improves the nuclear astrophysics program and keeps it competitive until FRIB**
- **Gives access to some of the fundamental interactions studies**
  - **Next generation EDM is not there, need a full blown ISOL facility for that, 10X ISAC … outside the present FRIB scope**
- **Positions the ATLAS users community for a leading user role in reaccelerated physics at FRIB**

Some instances where 100pnA could be used for in-beam spectroscopy

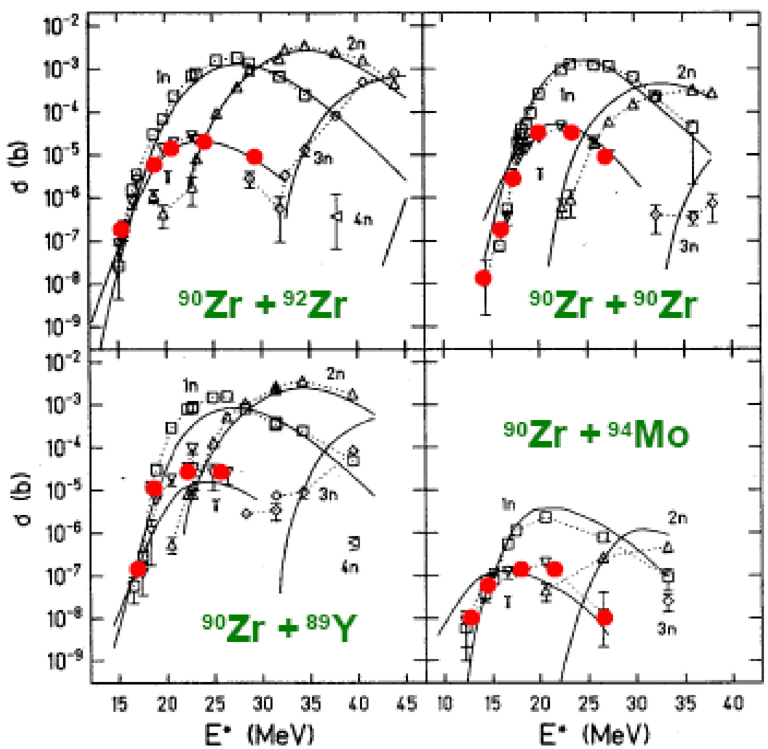
COLD FUSION IN SYMMETRIC ^{90}Zr-INDUCED REACTIONS

J.G. KELLER, K.-H. SCHMIDT, F.P. HESSBERGER, G. MÜNZENBERG and W. REISDORF

Gesellschaft für Schwerionenforschung, Darmstadt, Federal Republic of Germany

H.-G. CLERC and C.-C. SAHM

Institut für Kernphysik, Technische Hochschule Darmstadt, Federal Republic of Germany

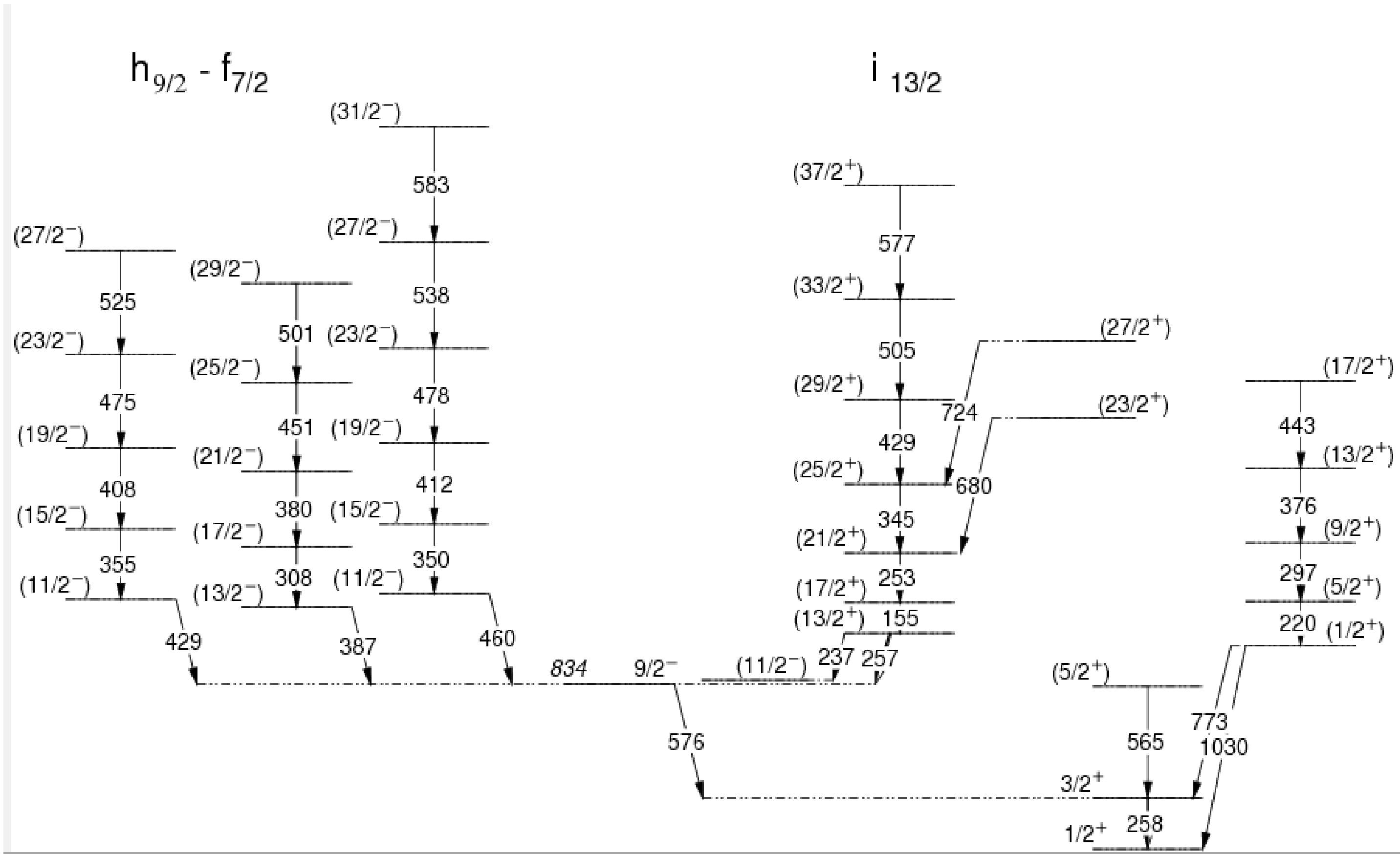


Advantages of near-Coulomb barrier reactions

Due to large, negative Q-value, the compound system is left with relatively low excitation energy when using bombarding energies near the Coulomb barrier.

- **Minimizes** fission probability.
- **Minimizes** fragmentation of reaction channel (1 and 2 particle evaporation).
- **Allows**:
  - More beam on target.
  - Less restrictive gating.

$^{92}Mo(^{90}Zr,1p)^{181}Tl$ – (σ ~ 15μb)



With 30pnA of ^{91}Zr on target, Ge single rate in Gammasphere at 5k.
With 300pnA Ge single rate at 50k, increase data rate by 10x.

Re-visit In-beam Studies at the Proton Drip-line

- 3-4 times increase with Digital Gammasphere.
- 3-4 times increase with a gas-filled separator
- Intensity upgrade should expand our studies to nuclei above Z=82 using symmetric reactions.
- We should realize > 10x increase in statistics.