ReA upgrade

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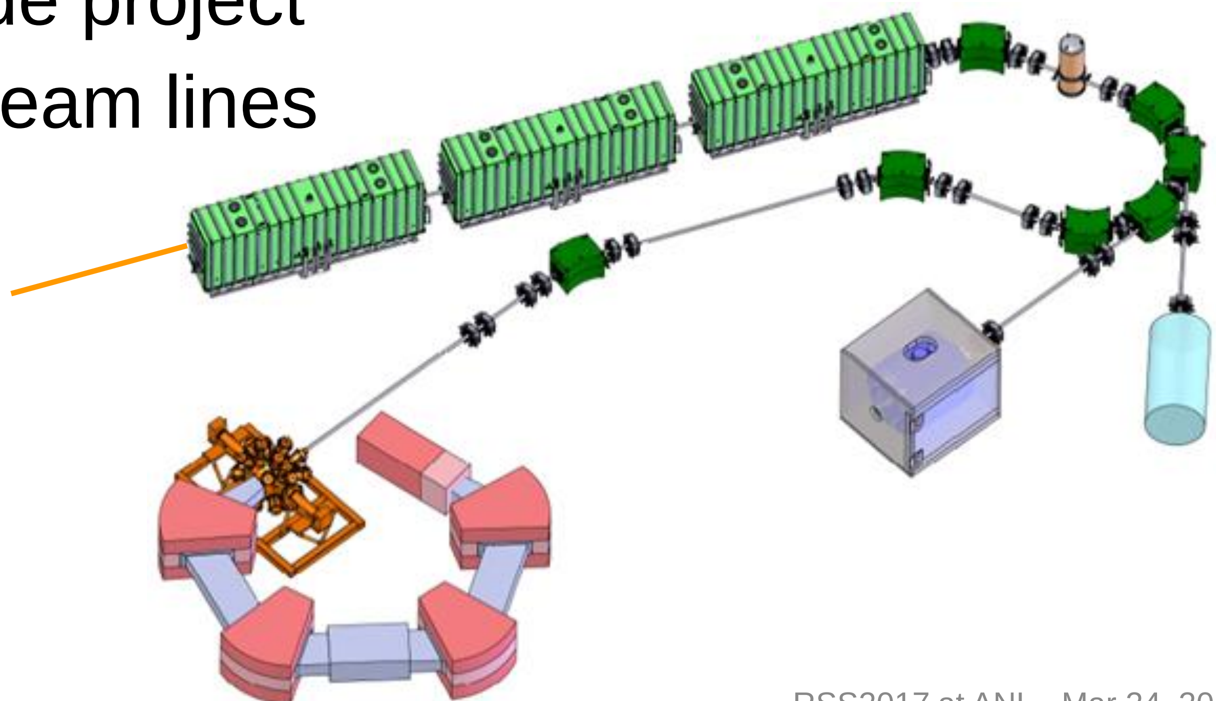
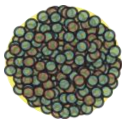
Outline

- Physics motivation for ReA science at NSCL and toward FRIB
- ReA Accelerator Facility Overview (past and present)
  - ReA3 complete and operational in 2015
- ReA energy upgrade project
  - ReA6 area and beam lines



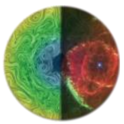
Overarching questions and science drivers for FRIB



How does subatomic matter organize itself and what phenomena emerge?

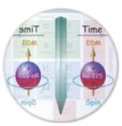
- Testing Nuclear Structure Concepts (2.4)
- Probing the modification of shell structure (2.1, 2.2, 2.3)
- Pairing and superfluidity (3.3)
- The evolution of collective motion in complex nuclei (3.1, 3.2, 3.4)
- Production and properties of the heaviest nuclei (4.1, 4.2)
- Probing neutron skins (2.4)

section # in ReA energy upgrade whitepaper



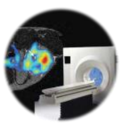
How did visible matter come into being and how does it evolve?

- The origin of the heaviest elements (5.2)
- Explosive nucleosynthesis (5.1)
- Composition of neutron stars (4.3)



Are the fundamental interactions that are basic to the structure of matter fully understood?

- Test of fundamental symmetries with rare isotopes (6.1)



How can the knowledge and technological progress provided by nuclear physics best be used to benefit society?

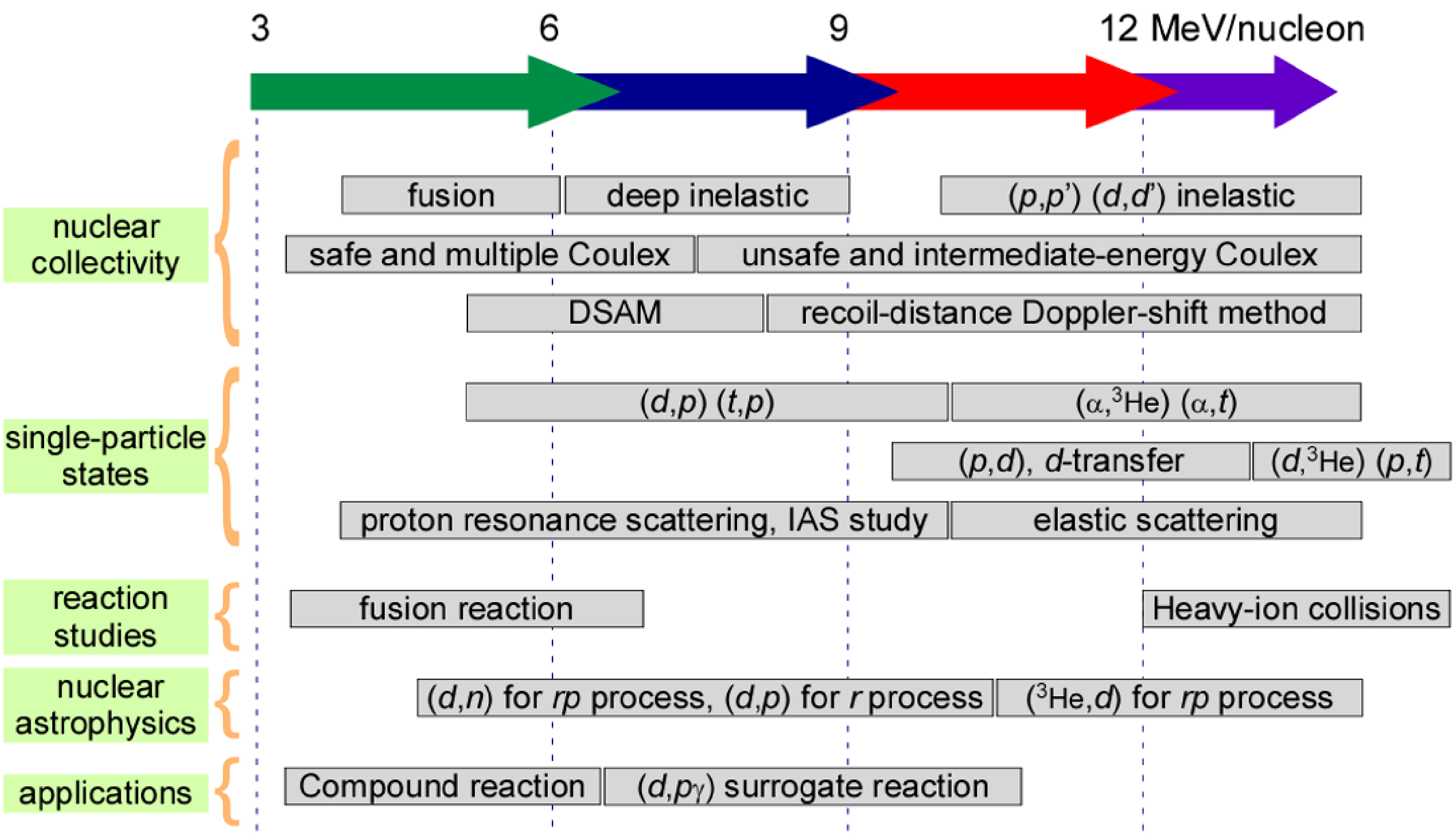
- Applications for the benefit of stockpile stewardship, materials science, medical research, and nuclear reactors (7.1, 7.2, 7.3)

Exploring the Heart of Matter, NRC (2013)
reaffirmed by Long Range Plan (2015)

ReA energy and key reactions

The ReA energy upgrade will provide unique beams to:

- facilitate reaction studies with well-established probes, mapping out the evolution of structural phenomena throughout the nuclear chart



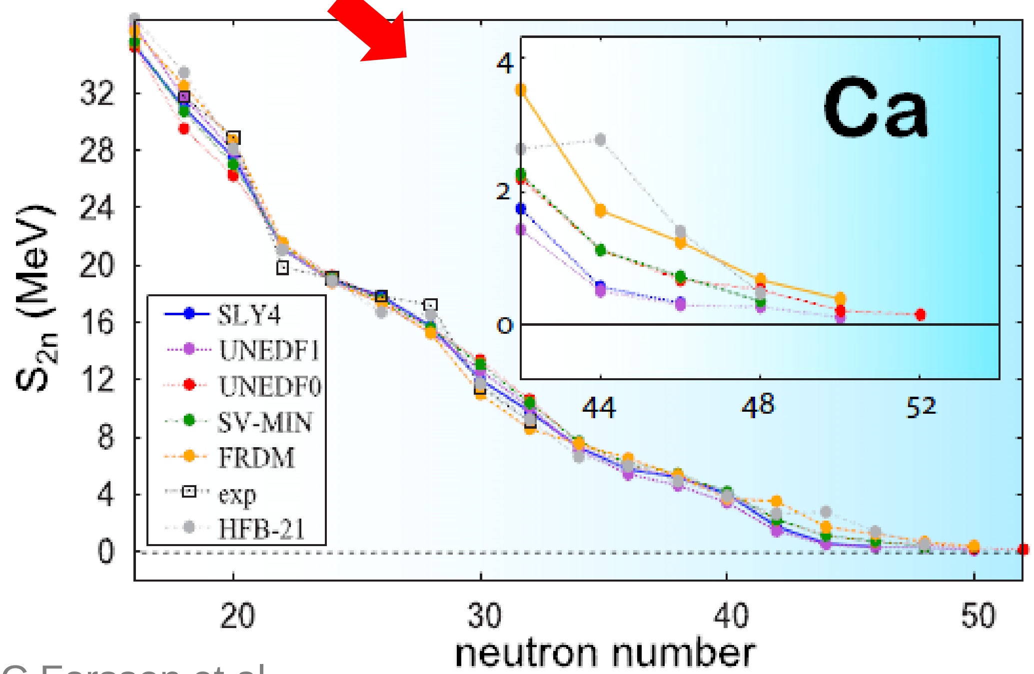
Beyond ReA3: Single-particle states

ReA experiments can characterize shell structure on the microscopic level, refining modern structure theory that incorporates realistic two- and three-body forces and continuum effects → predictions for very exotic nuclei

Evolution toward ^{60}Ca and ^{70}Ca

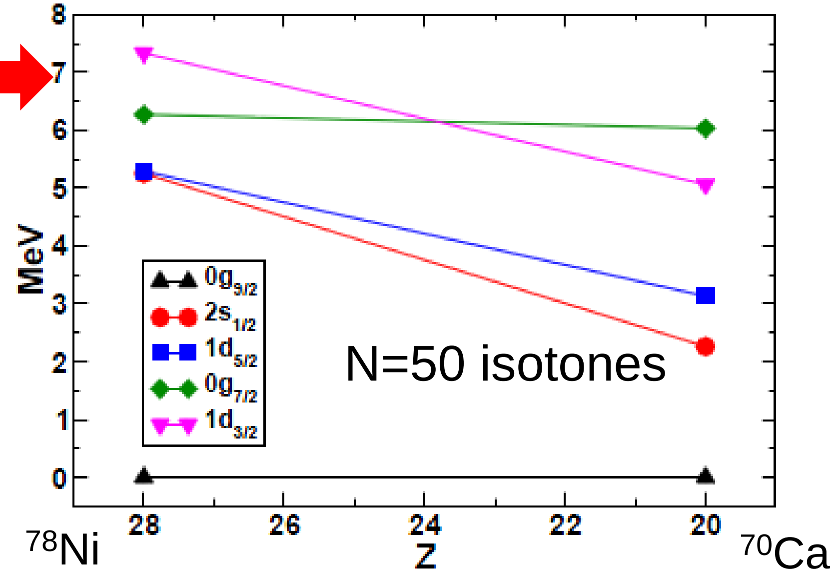
along Z=20 isotopes

along N=50 isotones



C.Forssen et al., Phys, Scr. T152, 014022 (2013)

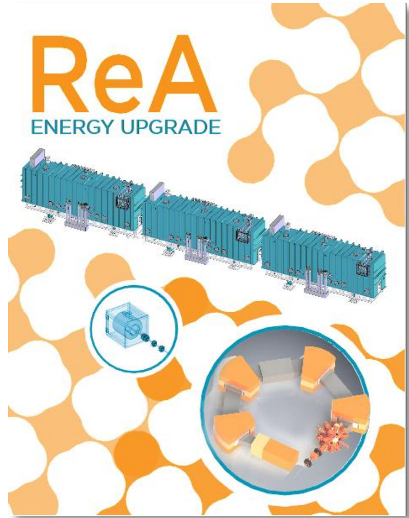
F.Nowacki et al., arXiv:1605.05103v1 Phys.Rev.Lett. 117, 272501 (2016)



Studies with better suited probes, e.g. (α,t) (α,^{3}He), for heavier systems above A=100

ReA energy upgrade whitepaper

- The ReA energy upgrade whitepaper was compiled based on input from the low-energy community and initiated at the **ReA3 upgrade workshop** held on August 20, 2015 (>70 registered participants).

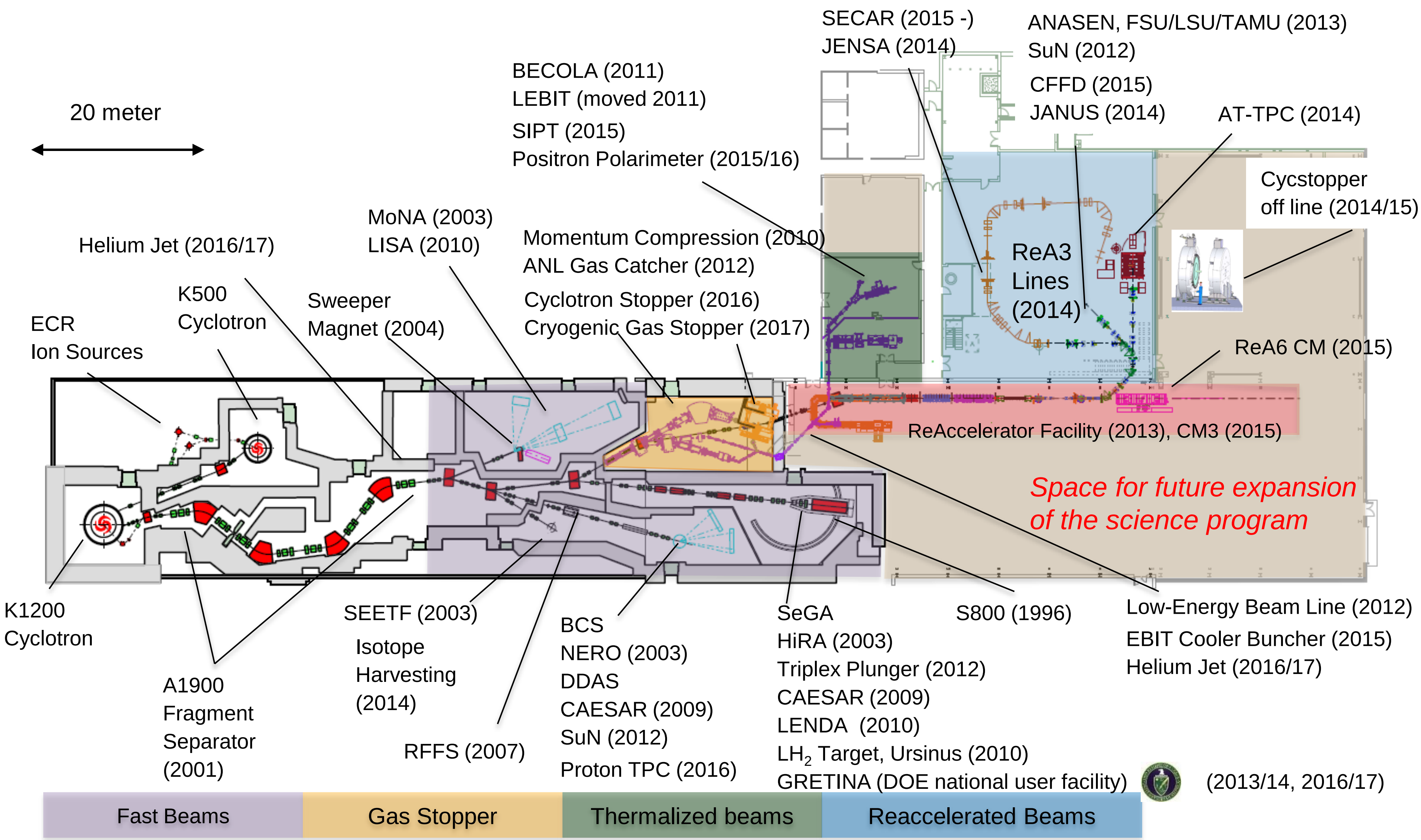


- The ReA energy upgrade whitepaper is available at 2016.lecmeeting.org/ReA_energy%20upgrade_whitepaper.pdf
- The ReA energy upgrade working group conveners are: A.Wuosmaa (U. of Connecticut), G.Rogachev (Texas A&M), B.Kay (ANL), and H.Iwasaki (NSCL/MSU). The ReA WG will work closely with other WGs for detectors and spectrometers.

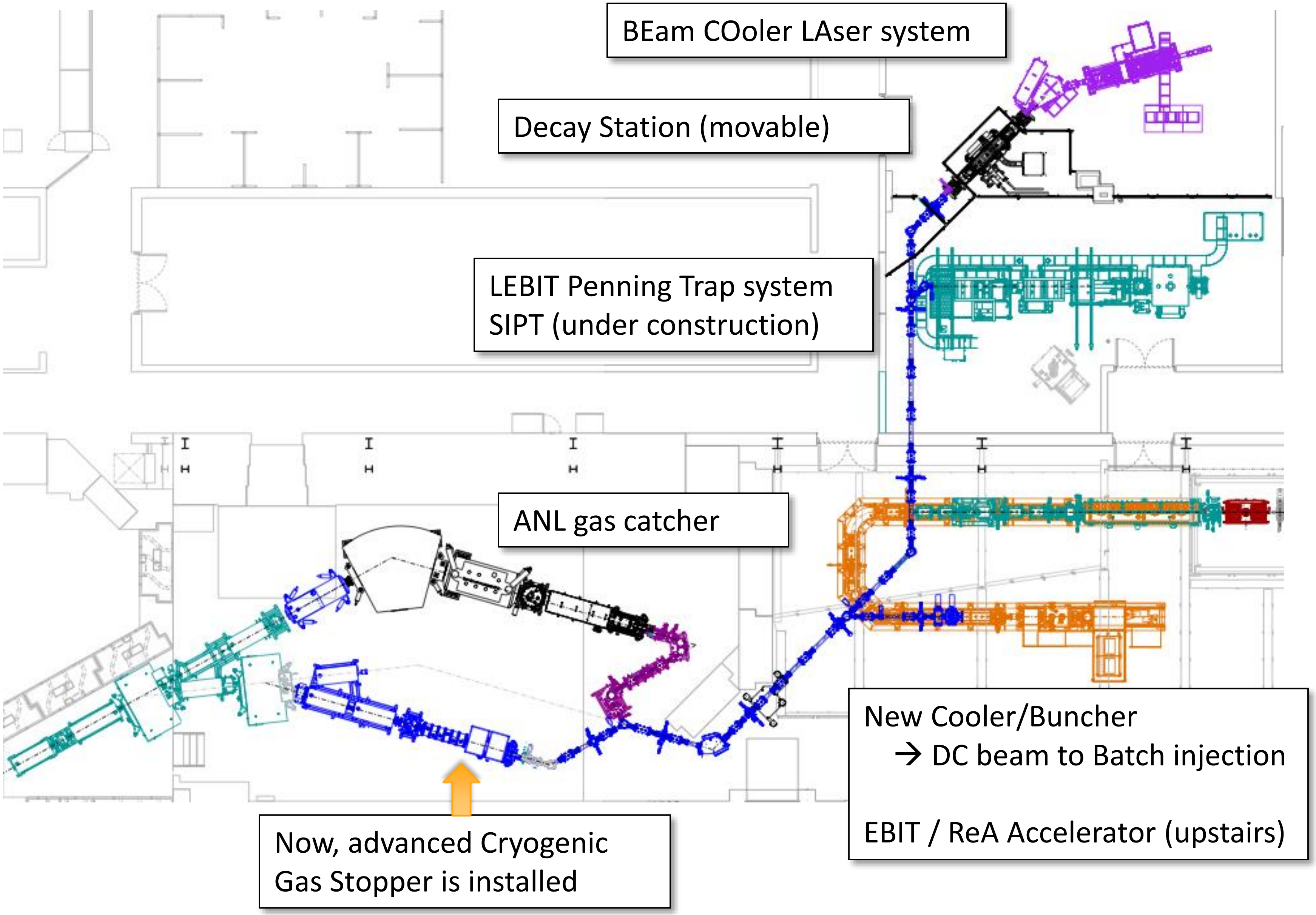
ReA

Past, present and future

Facility Layout & Major Equipment at NSCL

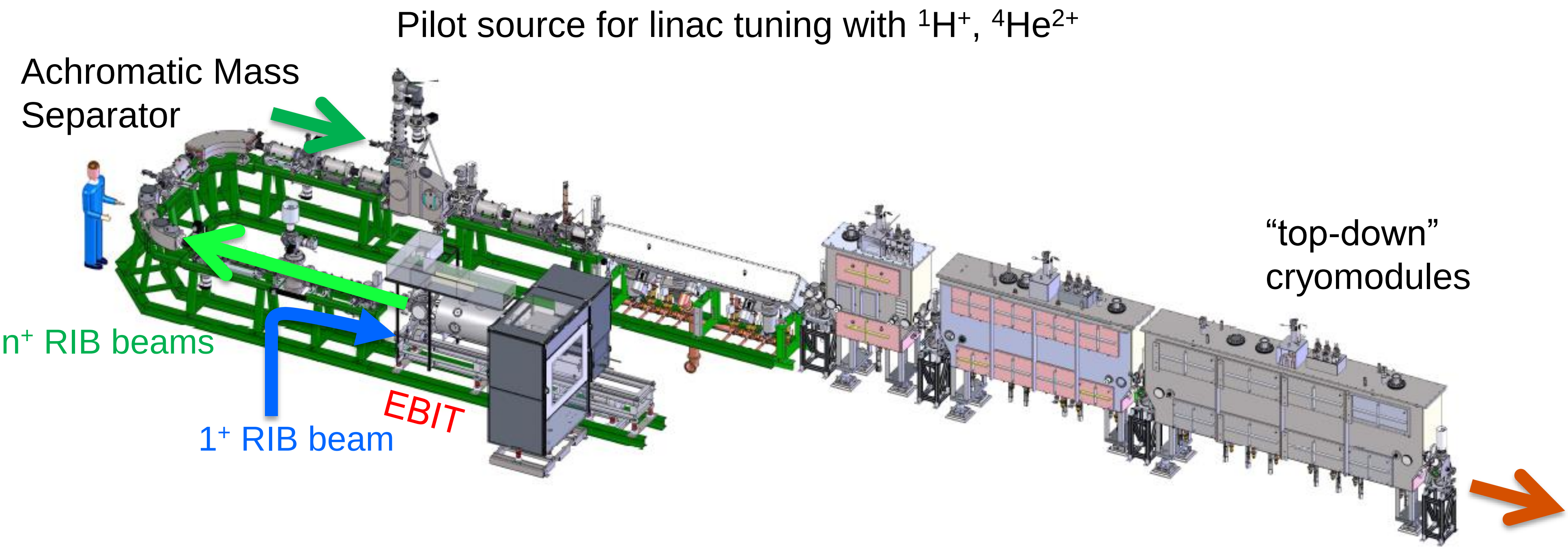


Present Thermalized Beam Area for ReA and Precision Experiments



Georg Bollen, Kasey Lund, Antonio Villari

ReA3 Accelerator
with original cryostat designs

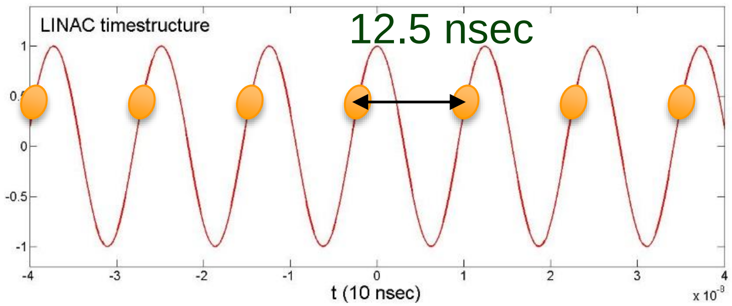


- First RIB delivered in Aug/13 ($^{37}K^{17+}$) then EBIT failed with ~18 mo. Downtime

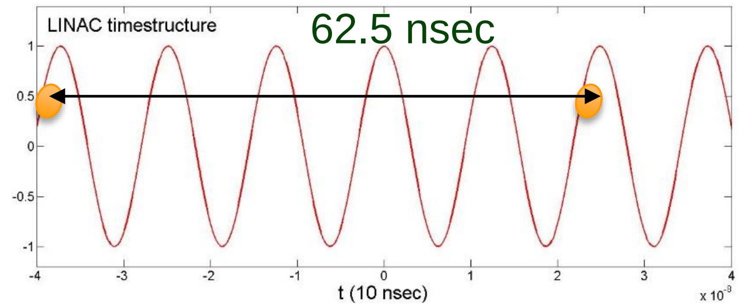
  ReA3 operational in 2015
- Prebuncher before the RFQ for some pulse control (manipulate intensity in buckets)
- The ReAccelerator developments and commissioning are supported by the Accelerator Physics faculty and with matrixed high-level support from FRIB

Capability Enhancements for the ReAccelerator:
EBIT And LINAC Time Structure To Address User Needs

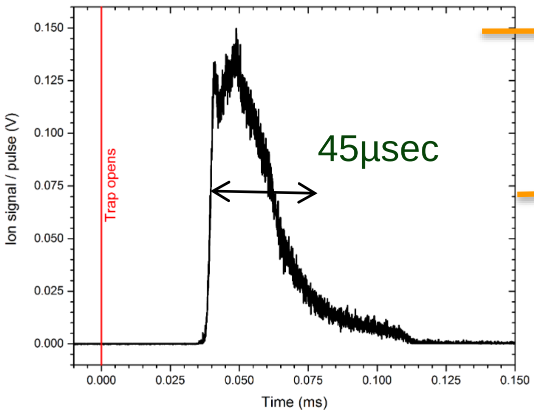
LINAC Time scale, 80.5 MHz
1.5-2 ns beam bunch every 12.5 ns
ToF can be too short for experiments

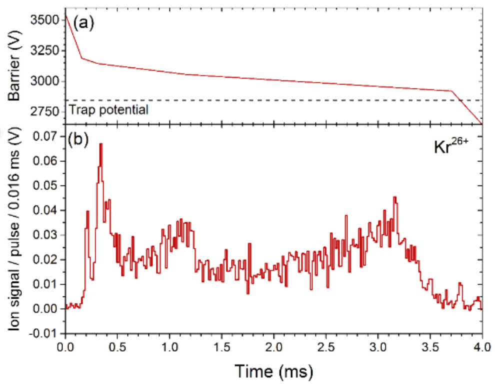


With low frequency prebuncher, 16 MHz
1.5-2 ns beam bunch every 62.5 ns
M. Syphers & D. Alt



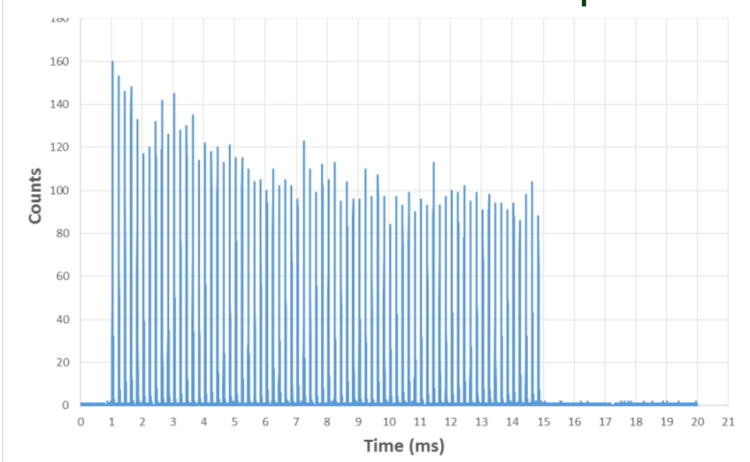
Natural ion pulse from the EBIT
gives high instantaneous rate





Good: open trap slowly to
release the ions over few ms

Better: pulse trap to release the
ions over tens of ms A.Lapierre



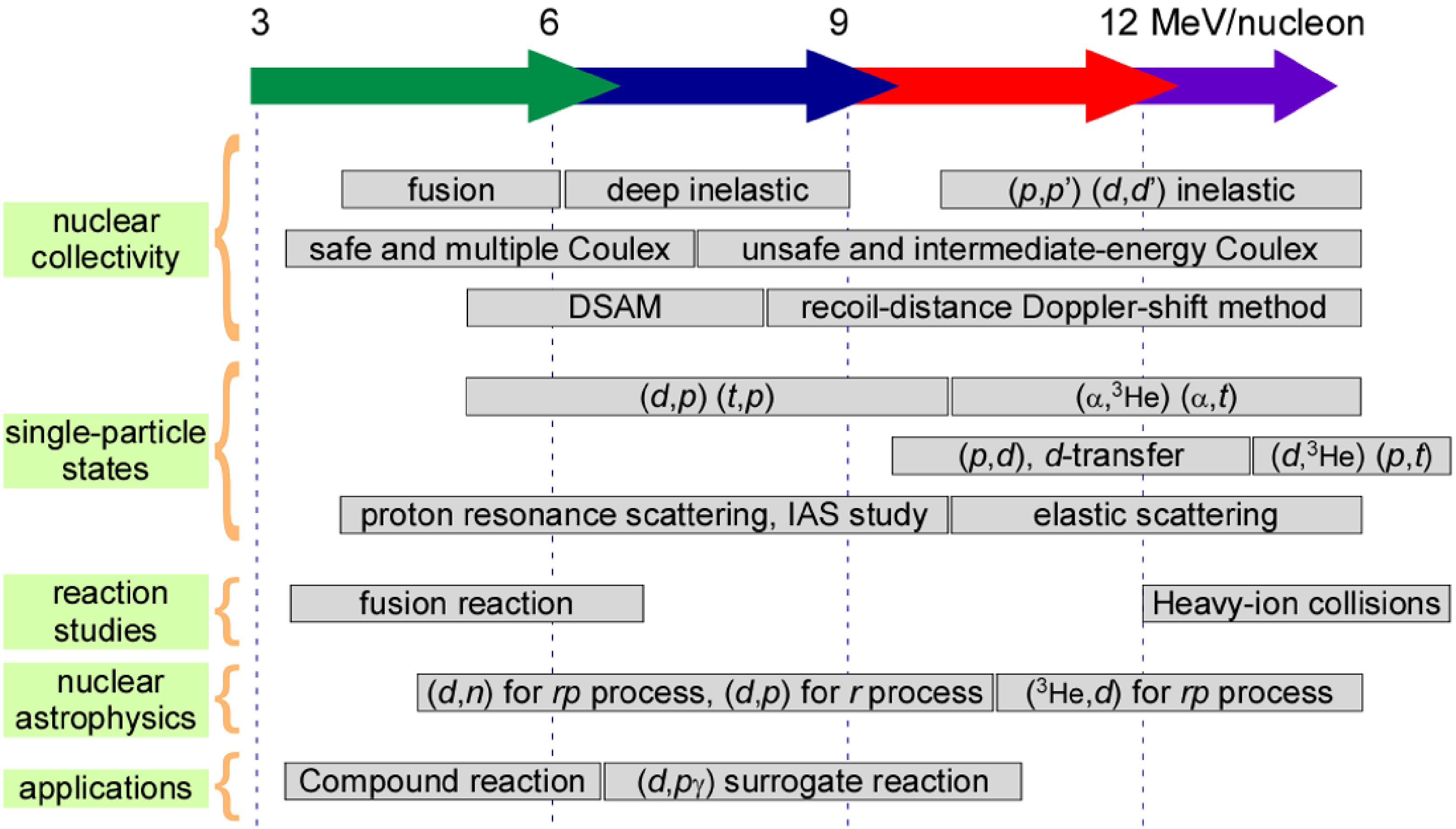
ReA

near

Past, present and future

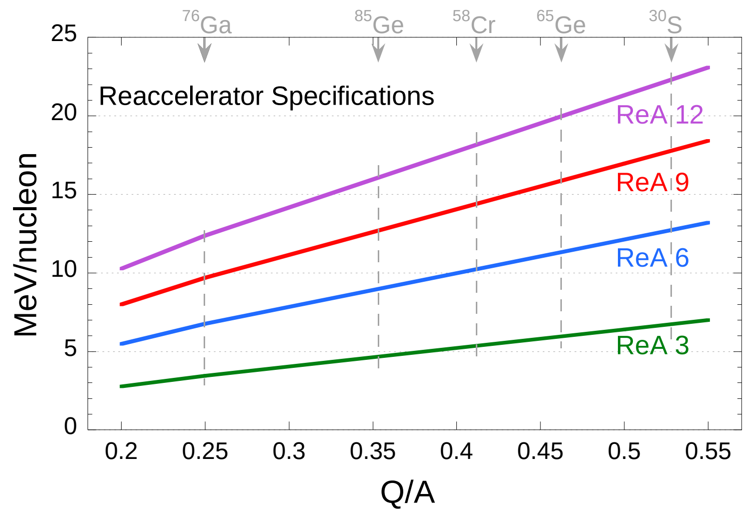
From Coulomb barrier energies up to 12 MeV/nucleon

- **ReA3** – best suited for reaction studies of astrophysical interest
- **ReA6 and beyond**
  - – safe/multiple Coulomb excitation – nuclear collectivity
  - direct transfer reactions – shell evolution

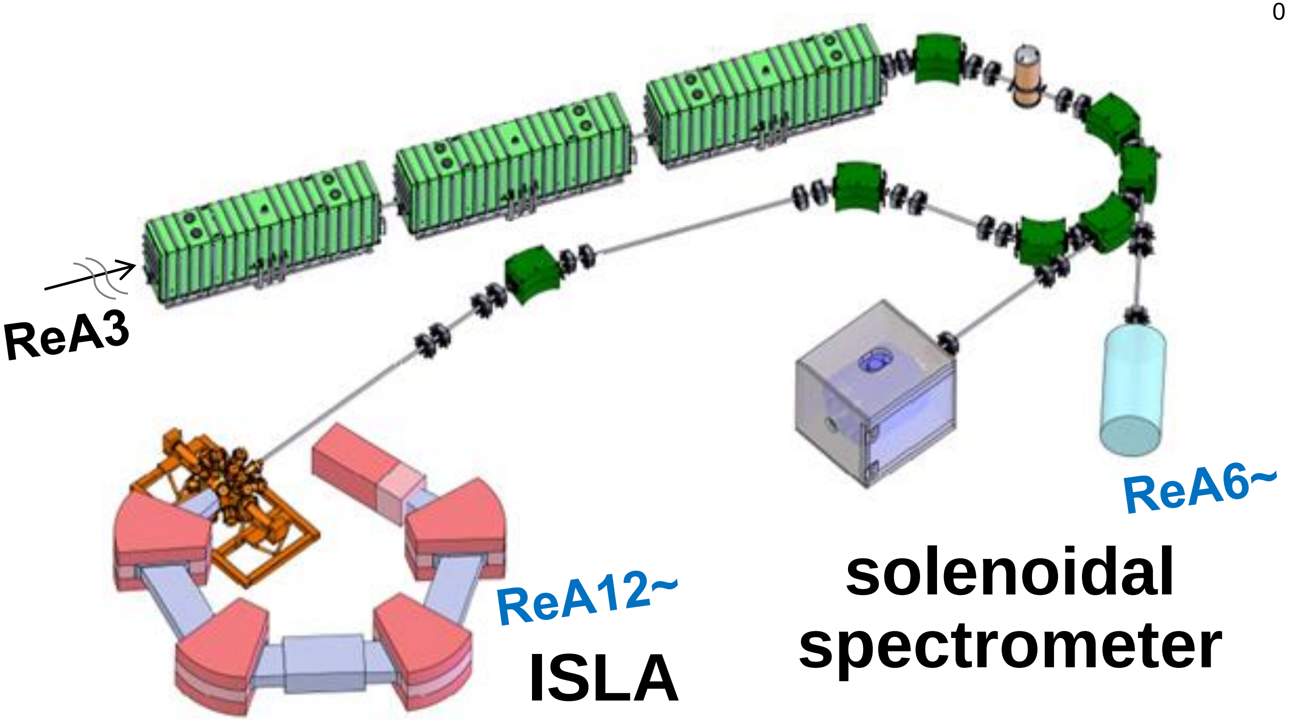


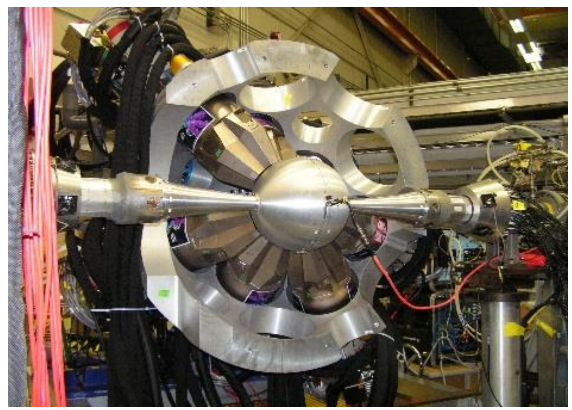
A vision of →ReA6→ReA9→ReA12

- The ReA energy upgrade will be realized by adding up to three cryomodules. ReAX provides at least X MeV/nucleon for neutron-rich beams with Q/A=0.25



- Start with at least two beam lines (space for many more exists):
  for **solenoidal spectrometer**
  and general-purpose beam line



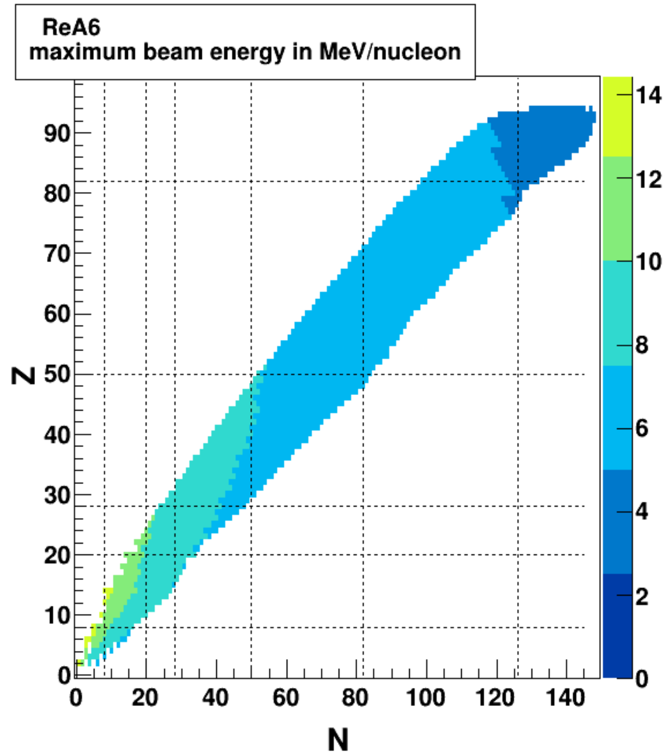


GRETINA/GRETA

ReA6: An important step for nuclear science

One cryomodule (ReA6) capable of accelerating ions with a charge-to-mass ratio of Q/A=0.25 up to 6 MeV/nucleon and Q/A=0.5 beyond 9 MeV/nucleon **will allow forefront science programs to be initiated at NSCL**

- ❑ Collectivity in medium-mass and heavy neutron-rich nuclei
- ❑ Single-particle states in proton-rich or light exotic nuclei
- ❑ Pair transfer via (*t*,*p*), (^{3}He,*p*)
- ❑ Mechanism for fusion-evaporation reactions
- ❑ Indirect studies for nuclear reaction rates relevant for astrophysics (*rp* process)



Users can perform measurements with ReA beams using powerful existing equipment and techniques

to take immediate advantage of the unique scientific capabilities

- ❑ GRETINA/GRETA
- ❑ Solenoidal spectrometer (AT-TPC/HELIOS)
- ❑ Various types of Si-arrays and TPC
- ❑ Coincident Fission Fragment detector, etc

ReA6 Phase-1 Tested

- The prototype contains two β = 0.085 cavities and one superconducting focusing solenoid, built to validate both the unique bottom-up assembly of the cold mass and the FRIB cryogenic cooling system.

- A FRIB-style cryoline was also constructed and connected to the cryomodule.
- The device was installed in a concrete shielded area in the position that would be used later for operation with beam but NOT connected to the ReA3 beamline.
- The tests were completed in May/2015 and were very successful.
- This not only validates the FRIB cryomodule design but is the first step in a cost-effective path towards ReA12 ...

ReA6 – layout plan

A new experimental area with a beam delivery system.

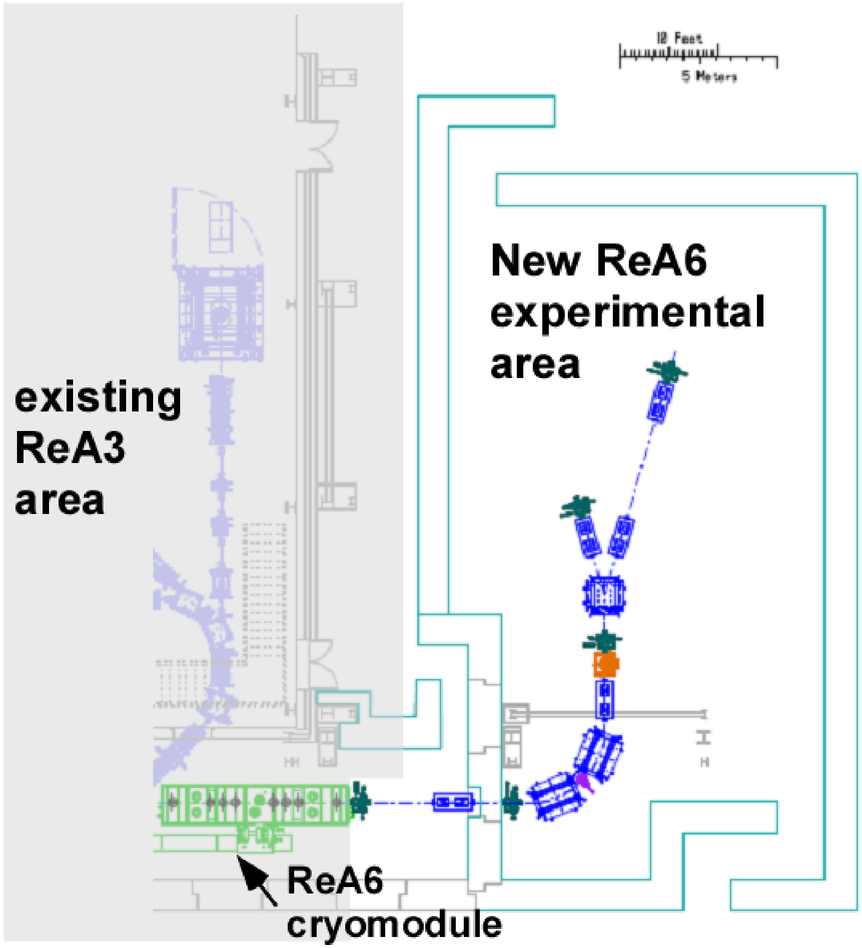
- maximum rigidity 2.2 Tm

- two beam lines to accommodate two large-scale experimental systems at the same time

  ReA solenoidal spectrometer
  GRETINA, ANASEN, ORRUBA, Indiana system, etc

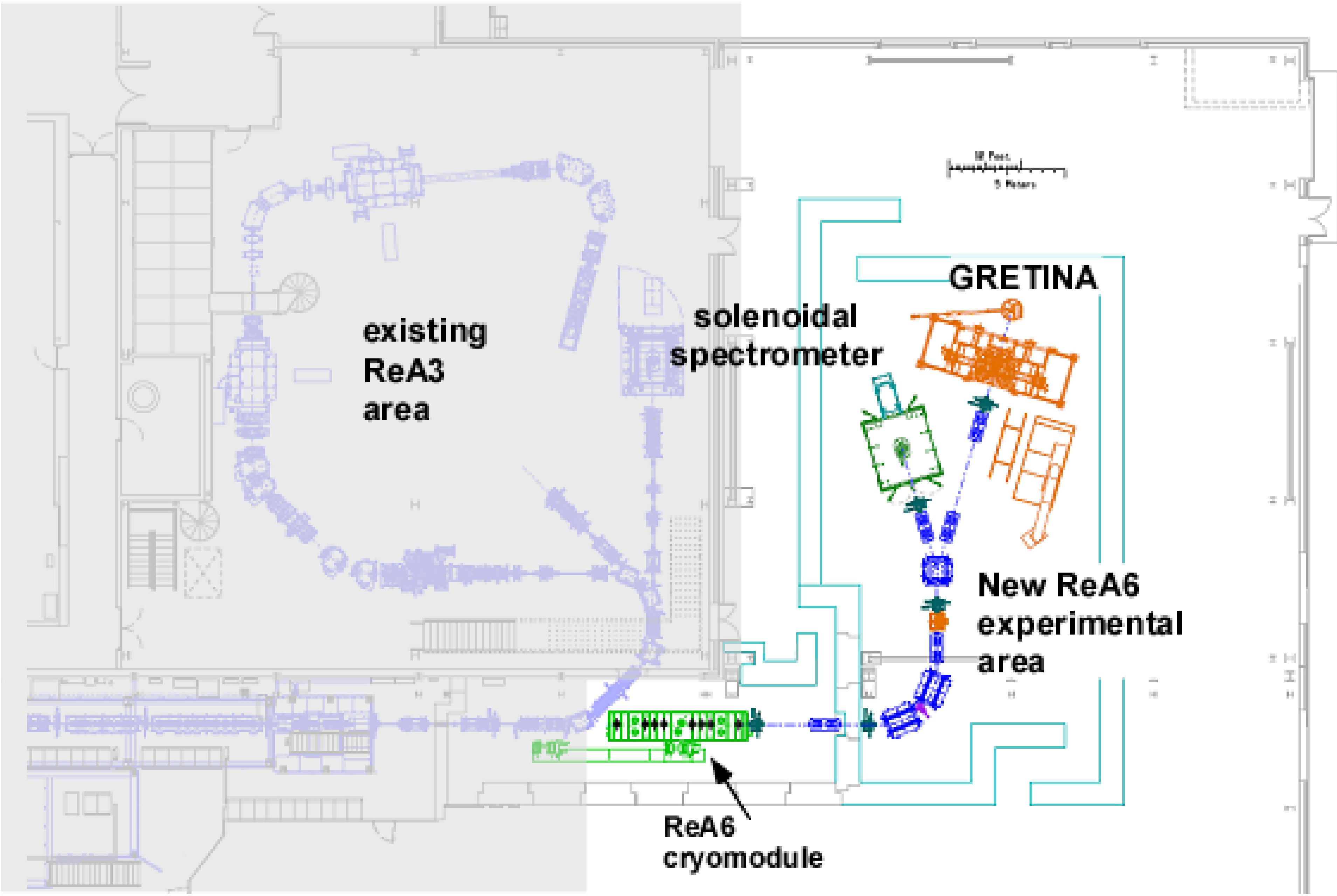
- cost-effective system based on existing superconducting magnets + new three quadrupole doublets (with existing design)

- concrete shielding to define ReA6 experimental area



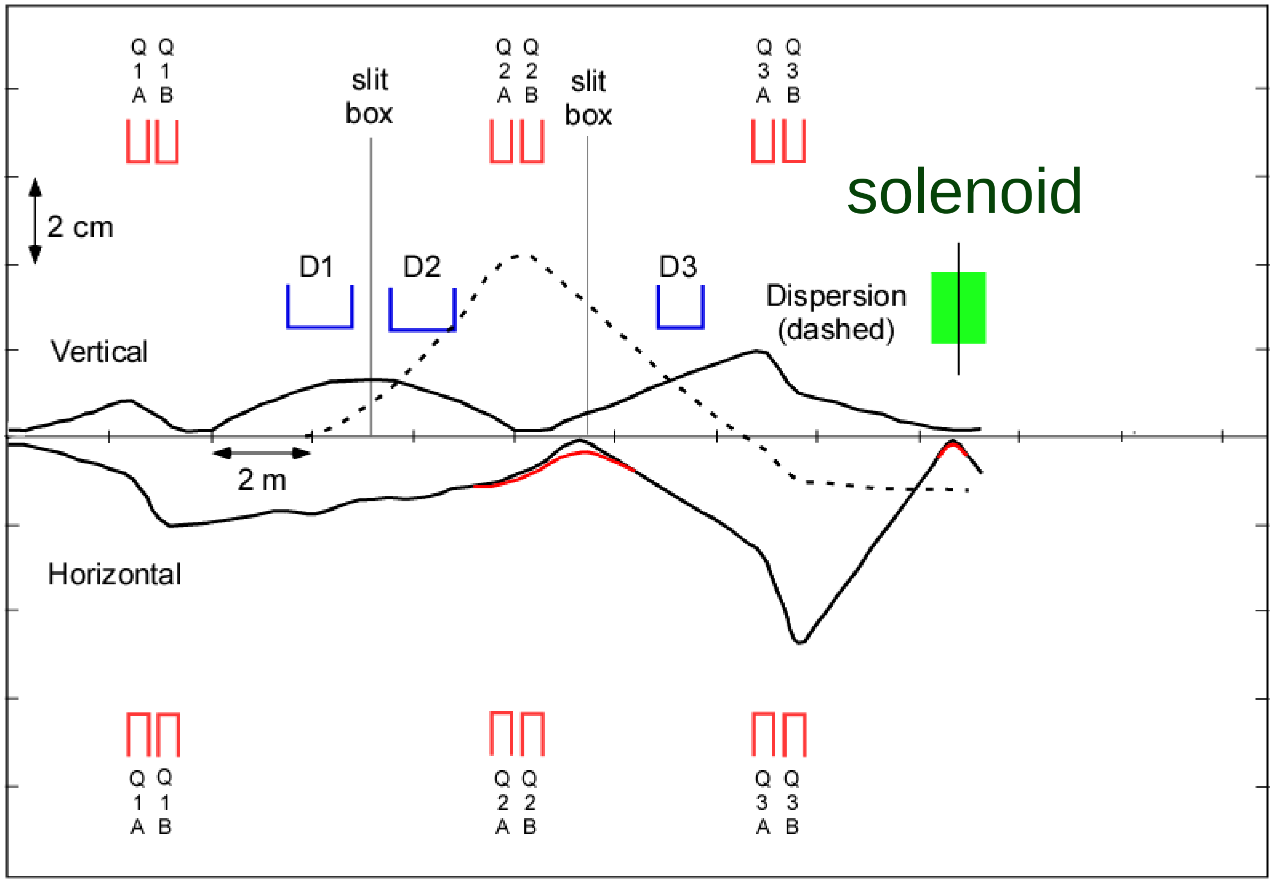
Need feedback from this workshop

ReA6 – layout plan



1st order optics calculation (west line)

First-order optics calculations were performed for the relatively simple beam line (quadrupole doublet QQ – two dipoles – QQ – bending dipole – QQ (or QQ QQ for east) – experimental stations)



Marc Hausmann

Resolving power
R = 1/2700

Initial beam emittance (from ReA6)
5 π mm mrad

Beam spot sizes
~ 1mm (FWHM)

Need field map information for RSS

Summary

The ReA energy upgrade will provide unique beams to facilitate reaction studies with well-established probes, mapping out the evolution of structural phenomena, including nuclear shell and shapes

- ReA3 is working well, is reliable and gives satisfaction
- The efficiency of the system is compatible with the present technology but further developments of advanced equipment are ongoing first to improve the overall efficiency of the system
- Plan for ReA6 upgrade is developed and presented.

❑ **To take an immediate advantage, it is important to have ReA6 before FRIB begins operation. There is a tremendous opportunity for forefront science at NSCL.**

❑ **ReA solenoidal spectrometer is a key device for science programs in nuclear structure and reactions at ReA6 and beyond.**