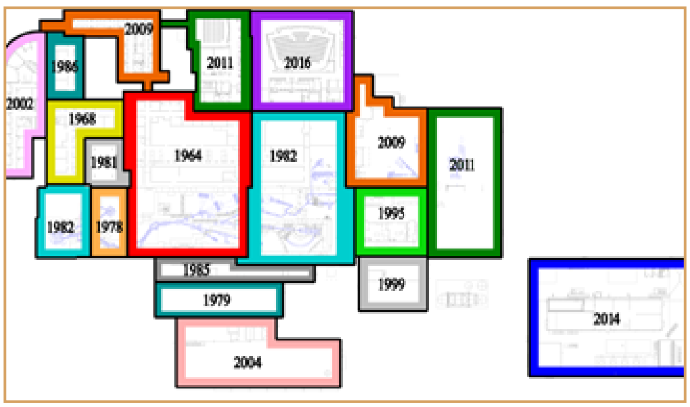
NSCL Tour Location Script

Revised October 2018 | INTRA.NSCL.MSU.EDU > OUTREACH

Tour Guidelines

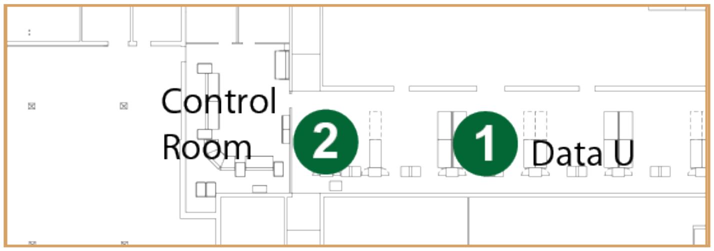
1. Only take visitors in areas that have been surveyed (proved by a copy of the safety survey) and are not currently secured or blocked by a warning sign.
2. Try to orient your group to where the beam is entering (and leaving?) when you enter a vault, since they can get turned around easily (laminated maps are recommended for you to use as reference).
3. This script is developed by the Outreach coordinator with information from staff, and must be approved by a faculty member or division director.
4. More info is available on the tour wiki (Intra Enterprise > Employee Information > Resources for Tour guides) .
5. *Information for higher-level tours is in red italics (also useful for answering general public questions).*
6. ***Information is this script is for Public Tour guests. Information for non-public tours is in a separate document.***



General points of interest

Things to point out when it's appropriate and when you need more info to fill in a stop.

- We build large machines to study tiny particles to understand giant stars.
- Note changes in floor and wall colors, indicating that we've added on to the building (12 additions since 1964, FRIB is #13).
- The electronics: designed to do high-speed, high-volume data acquisition. Most built right here in the lab.
- Pipes around the building carry cooling water (Low-Conductivity Water, or LCW, reduces corrosion in copper equipment) and liquid nitrogen (LN). We consume 3000 gallons (12000 liters) of liquid nitrogen every week, costing only 26 cents per gallon (7 cents/liter). We make liquid helium on-site in a 15 kW cryoplant.
- Power supplies and power cables: when power fails, we are backed up by East Lansing or on-site generators. MSU power plant gives us priority when power returns. We consume 3 MW, equivalent to 6,000 houses, spending about $2 million per year on electricity *(from Andreas)*
- Ethernet cables: carry commands/feedback to/from the control room experimental data to Data-U.
- Walls: The concrete blocks are stacked around equipment to prevent radiation from escaping. All are at least 6 feet thick, *based on calculations that show 200 MeV neutrons produced would still result in less than 10 mRem exposure per year even if we ran experiments 24/7*. The wall blocks are not mortared together so they can be easily removed and re-stacked (like big LEGOs), completely changing the layout of the laboratory as needed! Science and technology change quickly, so the laboratory can change to accommodate new technology or techniques.
- Vault doors: let a volunteer close one partway, show how they must hold the button to close (safety feature!). The open button only needs to be pushed momentarily. The doors are solid concrete, about as thick as the walls to contain the radiation. When they close fully, switches at the top are tripped to inform the operators in the control room that the vault is sealed.
- The vault-seal alarm: in order to run beam in a vault, hit the red button that informs everyone to GET OUT with lights and sound (music from Close Encounters of the Third Kind), then you seal the door. Unsealing the door automatically cuts off the beam to that vault.
- The sticky mats: in the unlikely event of a radioactive spill, some will be tracked onto the mats. Health physicists scan them periodically and can tell where the spill occurred and where it was tracked. Can then identify the person with a hot shoe and contain the problem. You can say that no activity has left the controlled areas since you've been here at the lab.
- The 40-ton crane (yellow bridge) that can travel the length of the room. The crane could lift one Apatosaurus (Brontosaurus) plus 2 Tyrannosaurs. The vaults are built of concrete blocks with concrete beams (10+ tons) for roofs. As tall as the room is, it goes as deep under your feet (at ground level) as well.
- Noise in the vaults is usually vacuum pumps like the "roughing pumps" found on the floors next to beamlines. The one in the yellow cage in the Transfer Hall is a diffusion pump. We need to remove the atmosphere from the beam line so the air molecules don't interfere with the motion of the beam nuclei. Pressures are commonly one-billionth of an atmosphere (*10^{-6} Torr*) or lower.
- Even when running, the radiation levels are small. You are far more likely to be hurt in a car accident that by radiation in our lab. NSCL does not exceed regulatory radiation exposure limits *(from Andreas)*. Industrial hazards (falling, tripping, etc.) are more common.
- Magnet quenching: there are failsafes/pressure release valves to protect superconductors from an uncontrolled switch to normal conduction. In the event of a large release of boiled-off LN, the Oxygen Deficiency alarms in each vault will alert staff if percentage goes below 19.5%.
- The black disks (occasionally covered by red caps) on the walls in the research area serve as known points in space, and are used with a laser surveyor to position equipment. They serve as the lab's "GPS".



Stops 1 and 2: The control room and Data-U

Safety

- Do not take tour groups inside the control room - observe through the windows in the hallway. You can refer to the vault map mounted above those windows.
- If there are users in the Data-U, avoid disturbing them and give your speech in a different section.

The Data-U (1)

- Data-U sometimes contains the complex electronics required to rapidly collect, process and store data, but most equipment is located remotely and computer-controlled.
- Researchers (users) are in here 24 hours a day during their experiment, observing data coming to one of the computer banks from whichever detector they're using.
- NSCL serves over 1300 users from over 50 countries.
- The racks of electronics are connected to the vaults with many cables so experimenters can make changes without having to stop the beam and open the vault door. There is one Data-U matched to each vault.
- Could discuss the cost to operate (effectively $5000/hr), which is not required of the user but comes from NSF.
- Anyone in the user community can propose an experiment, and those proposals are reviewed by a committee (PAC) featuring some of the nation's top nuclear scientists. (Note: NSCL representatives on that committee are non-voting) The PAC selects the most critical and achievable research and approves beam time. They can only accept about 1/3 of the proposals (~40 experiments/year)!
- Running an experiment requires that you apply for beamtime, set up about one month in advance, have group monitoring in Data-U for length of experiment (average 120 hours), then spend months analyzing the data with the goal of publishing, and writing Ph.D. dissertations.
- Beam time is free to the user, but they must "pay back" by publishing their results, adding to human knowledge.
- The floor tiles can be lifted up (using the suction cup or handle cutout) to show visitors how the raised floor is used to transport air conditioning and run cables underneath the computer equipment.

Approved: Daniel Bazin 1/9/17

The Control Room (2)

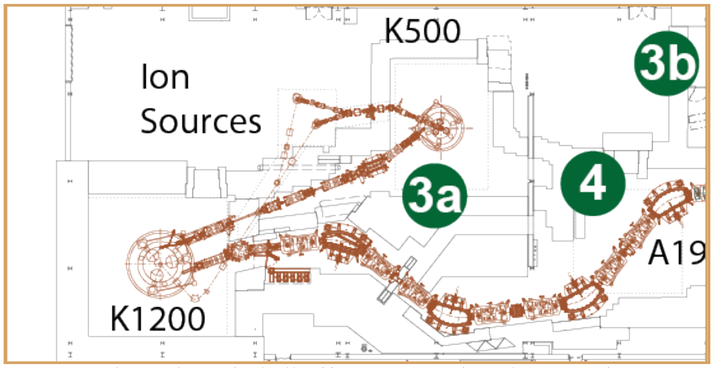
- While the NSCL is running the experimental program, operators are here 24 hours a day monitoring systems and maintaining beam output. We generally have three shifts, like a "nucleus factory"! We run experiments ~4000 hours per year, with maintenance shutdowns and tests making up the remainder of the year. Operating the cyclotrons is done remotely from the control room. Operators maintain the beam by "tuning" devices to produce quality beams that satisfy the users' needs.

1. ***An example beam current (for O-16): 625 billion particles per second ~ 100 pnA ~ 0.2 kW.***

- Explain how some monitors show video from various points in the beam where operators can insert a fluorescent screen to "see" the beam (bright spot) in real time while adjusting its position, size, and shape. This works on the same principle as old TV picture tubes.
- The majority of software used by our operators to control the facility is developed here at NSCL and runs on standard PCs running Windows Operating system. Operators can adjust settings and turn devices on and off, with the click of a mouse, typing a new value or by adjusting hardware knobs. These computers are connected to thousands of sensors for diagnostics.
- Hallway displays detail the current experiment, accelerated isotope, selected isotope, availability (reliability), vaults security status, etc. Our lab's availability is generally > 90%, which is great for a lab our size.
- Operators typically have a bachelor's or masters degree in physics or engineering, and also possess skills in fields such as programming, maintenance, fabrication and electronics to name a few. When NSCL is not running experiments, we are performing maintenance and upgrades, where the additional skills of the operators are put to use.
- Operators are highly-skilled and trained. In many cases they are the only people with working knowledge of how to control and repair a particular piece of equipment. It takes ~9 months to qualify as an operator-in-charge.
- Operating the cyclotron controls is similar to a pilot flying (operating) a 747. Just as a pilot is not an expert in aeronautics, operators are not experts in particle physics. Both however, need to have a deep understanding of all the systems at their disposal and the confidence to operate those systems successfully.

1. ***Over 30,000 settings and readings of equipment are recorded constantly throughout the day by the NSCL's control system.***

Approved: Andreas Stolz 10/18



Stops 3a (K500) and 3b (hallway outside when vault sealed/magnet on)

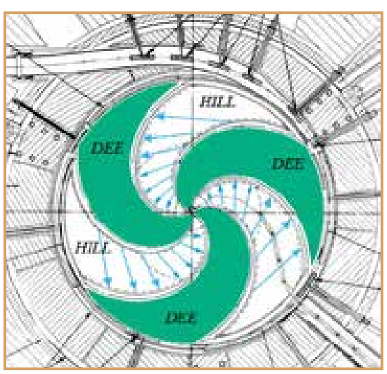
Safety

- Watch out for low ceilings and protruding objects.
- Assume objects on benches or yellow mat are radioactive, keep a distance away and never touch.
- When K500 magnet is on, do not approach door or walk down adjacent hallway! There is a yellow light by the door from the atrium and near the control room hallway.
- Do not pass the ion sources nor enter the K1200 with public tours, due to concerns about x-ray radiation.

K500 Cyclotron (3a)

- World's first superconducting cyclotron
- 10 feet (over 3 meters) wide, 5 stories tall

1. Dees/Pole tips (look like "fan blades") at the center are electrical poles, which are charged and discharged millions of times per second up to 60-65 kV. The electric field produced is used to accelerate the ions through attraction/repulsion. *The frequency can be adjusted to suit the beam by changing the length of the resonator cavities, depending upon on the magnetic field and charge/mass ratio of the nuclei. 23 MHz is one example frequency.* The copper pillars (resonators, attached to dees) extending below and above the cyclotron *are "tuned" by moving a short to the desired RF frequency*. The nuclei inside orbit almost exactly 250 times before leaving at their maximum velocity (0.15 c, 30000 miles/sec, 45 million m/s). The dee shape promotes beam focussing in the vertical direction.



Top-down blueprint of cyclotron interior

2. A "helium can" contains 20 miles (32 km) of superconducting wire in coils bathed in liquid helium, like many of the magnets we use to steer the beam. The coil generates a strong enough magnetic field (3-5 Tesla) to keep fast-moving nuclei in an orbit. *The magnets typically run at 600-700 amps, depending on the beam (Q/A) to ensure proper path. The two coils shape the field to compensate for relativistic mass of the nuclei.*

- The liquid helium is insulated with layers of liquid nitrogen shields and vacuum. Cold He gasses are returned to cryogenics plant for reliquefaction.

1. *Many of the objects sticking out on the beam plane are probes (to measure the internal conditions), electric extraction elements (deflectors: E1, E2…) or magnetic extraction elements (mag channels: M1…), used to adjust fields inside the cyclotron and extract the beam.*

Approved: Jon Bonofiglio 1/26/17

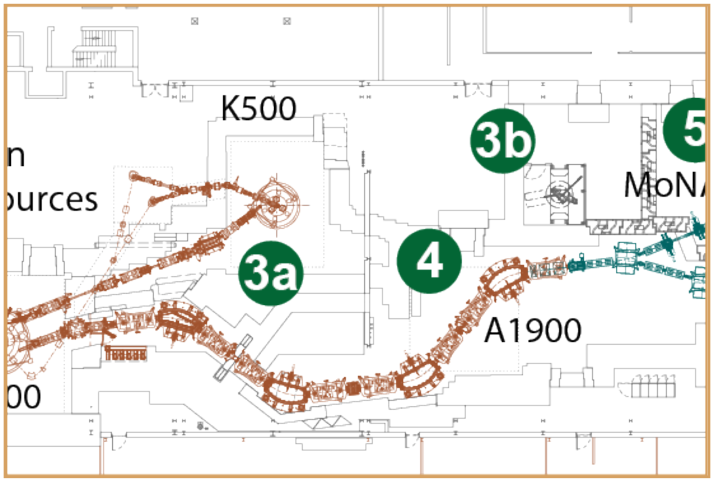
K1200 Cyclotron (not accessible)

- 14 feet (over 4 meters) wide, 5 stories tall, superconducting wire extends 38 miles (61 km), dees charge 140 kV.
- Was the worlds highest-energy cyclotron from 1988 until 2009, when RIKEN's Superconducting Ring Cyclotron began operations.

1. Coupled with K500 in 2001, dramatically increasing NSCL capabilities. *Entering ions pass through a "stripper foil" which removes nearly all electrons. Injection requires a ratio of charge states (k1200/k500) of 2.3-2.7.* Stripped ions travel up to two miles inside the K1200, exit at up to half the speed of light (*100-150 MeV/nucleon,* 93000 miles/s, 150 million m/s, about 4 times around the Earth per second), then smash into a beryllium foil target.
2. Travel time is 20-25 μs in K500, 30-40 μs in K1200.

Hallway outside (3b)

- Use when the cyclotrons are sealed or magnets are on.
- Indicate where the K500 and K1200 are, and if the A1900 is closed, point out the directions of the target and fragment separator. Describe the process of acceleration from ion source > K500 > K1200 > target (normally a chunk of beryllium) > A1900.
- Can point out the high bay visible up the stairs - almost the entire tour is inside one 450-foot-long (130+ meters) room, with all the equipment housed in concrete vaults to contain the radiation.
- This is a good place to show the systems involved: power supplies (blue cabinets), cooling pipes, control cables, concrete walls, operation of door to A1900 (if it's open).



Stop 4: the A1900 Fragment Separator

Safety

- Do not enter if magnetic field (yellow light above door) is on.
- Keep pacemakers/implants away from dipoles/quadrupoles.
- Always have visitors stay an arm's length away from the dipoles (grey magnets)
- Don't go beyond area inside north door.

Transfer Hall/ A1900 Fragment Separator (4)

- The A1900 Fragment Separator serves to filter out particles that are NOT the isotope we want to study. In essence, the A1900 is two magnetic spectrometers (four dipole magnets) in a row. It has high acceptance and high-efficiency transmission of specific isotopes.

1. The target is generally a piece of beryllium, *which is preferred because it doesn't have a large electron density (only 4 per nucleus) and thus the electrons have less effect on the charged beam passing through. Its low density also allows us to use a thicker foil, which is better for heat dissipation (plus, the melting point of beryllium is 1287 Celsius). The foil is about 1"x2", though the beam spot is only about 1 mm wide. The foils do wear out, as over an average experiment it is possible for every atom in it to be struck by a beam nucleus! Some experiments use more than one target to avoid damaging targets by beam interaction.*

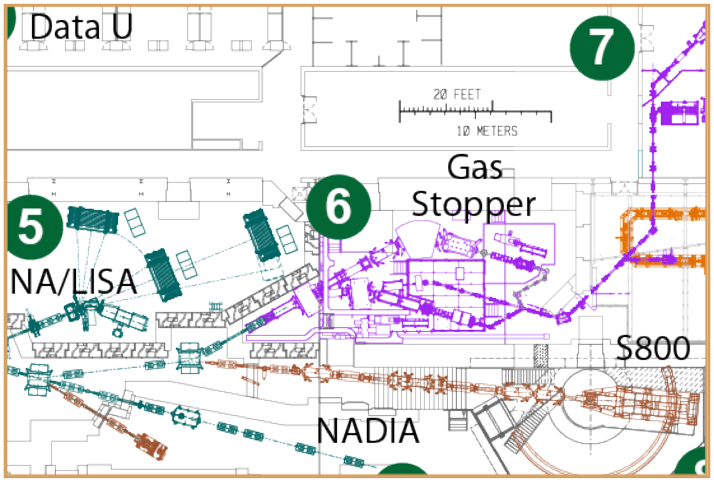
1. The A1900 is about 35 meters (115 feet) long. It is composed of four large dipole magnets (gray, pic on the right) that act on isotopes like prisms act on different colors of light, bending and spreading the beam particles *according to their ratio of momentum (mass x velocity) over charge.* Only some particles make it around the corner (a 45-degree turn) into the next beam pipe. Quadrupole magnets (green barrels), *arranged in eight "triplets" (groups of three),* focus the continuing beam like a lens focuses light.

- Rare isotope beam intensity is key! It is imperative that the A1900 preserve as many of the desired isotope as possible while efficiently eliminating the vast majority of other isotopes from the beam. As nuclei pass through the separator, it can select one nucleus from a million billion others. It's like finding one specific person on a million Earths.
- There is a windowed box and camera looking in at a point on the beam line where operators can lower a fluorescent screen and establish where the beam is, size, shape, etc. During the process of "tuning", this provides visual confirmation. The window is there so people can see the slit drives in motion.

1. *"Tuning" to find a particular isotope is done with silicon PIN detectors (identifies element), Parallel Plate Avalanche Counters (PPACs) (measures position/angle of fragments), and a plastic scintillator (measures time-of-flight and particle energy). The combination of all this information allows one to determine the mass and charge (element) for every exiting particle.*

Approved: Andreas Stolz 10/18

The gray dipole (left) separates isotopes, the green quadrupole triplet (center) focuses the beam to prevent loss of nuclei, and the metal box (center right) offers a place to "observe" the beam.



Stop 6: N4 vault, featuring the Beam Stoppers.

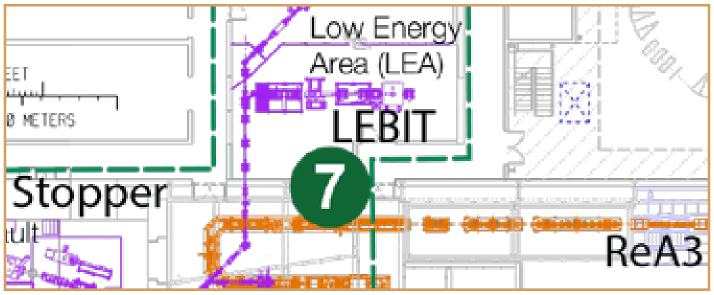
Safety

- This room is often actively under construction, be aware of personnel, equipment and materials!
- Red light indicates that the HV platform is energized - OK if you don't proceed past the door from the north hallway.
- Yellow light indicates magnetic field is on - do not bring visitors into the vault!
- This room is normally blocked off - if you want to stop here, you will likely have to stand outside.
- Tour guides have permission to bypass the strap across the door, replacing it when done. Stay on the platform!

N4 Vault: Stopped beam area (6)

1. Some experiments require a low-energy beam to perform a precise measurement. This vault is where beam nuclei can be slowed down to velocities similar to the molecules in air and then sent on for an experiment or reacceleration.
2. *Note that gas stoppers reduce incoming nuclei to "thermal energies", equivalent to the speeds of particles moving in room-temperature air. This is still hundreds of meters per second!*
3. Three beam lines *(AA, AB, AC)* are installed in the room with different capabilities to slow down and collect the fast beams for further experimentation. Stopped nuclei and reaccelerated beams offer new experiments at NSCL!
4. Stopping the rare isotopes allows researchers to make more careful measurements (e.g. measuring their mass - you wouldn't try to weigh yourself by driving over the scale at 70 mph! Alternatively: it's hard to weigh a cat when it won't stop moving.)
5. What you can see are magnets – the gas stoppers themselves are blocked from view. There are 2 gas cells:
6. *A new linear gas cell is temporarily installed on the large beam line on the north (left) side of the room. In the longer term the gas cell will be moved to smaller beam line on the south side. The ions slow down by passing through metal plates a few mm thick and then go into 50-75 torr of 99.9999% helium gas (which is difficult to ionize, a benefit). Escaping helium gives the stopped ions a final push out of the 1.3 mm hole. 5% extraction efficiency is representative of normal operating conditions. The minimum extraction time: 63 ms.*
7. *The room has two enclosed high voltage areas, red lights indicate when the HV is active.* The platform is at 30 kV potential, which also pushes stopped ions out to the D-line. and *over the relatively long distances to the new precision measurements area and the reaccelerator.*
8. Slowing down the fast ions with helium gas can be compared to slowing down a speeding bullet as it flies through a giant cloud of flying gnats. Every collision takes a tiny energy and eventually after billions and billions of collision the bullet will stop.
9. The Advanced Cryogenic gas cell has the advantage of fewer reactions with impurities. *It sses RF surfing, and has a faster extraction/shorter drift time (~10 ms?). It should have higher efficiency (>5%).* You can just see it over the magnets. *After a dipole separates nuclei by energy, the resulting beam is momentum-compressed by a wedge.*
10. Another beamline will be constructed in the center of the room to collect certain ions that can be easily extracted from a hot metal. These ions do not require the helium gas and the system is much smaller.
11. After the ions nearly come to rest, the low-energy beam of ions will be passed out of the vault in the beam line that exits the room in the far (south east) corner of the room.

For Approval: Chandana Sumithrarachchi



Stop 7: Stopped Beams area, featuring the Low-Energy Beam Ion Trap (LEBIT) and BEam COoler and LAser Spectroscopy station (BECOLA)

Safety

- View LEBIT by looking in the window on the southern door facing the East High Bay (near "7" on the map)
- For VIPs, take <5 people in at once, stay close to the door, and do not test the magnetic field with a wrench.

Low Energy area (Precision Measurements)

(7) Low-Energy Beam Ion Trap (LEBIT)

1. LEBIT has a superconducting magnet (gray barrel with spartan "S" and helmet), note the yellow light on top indicating strong magnetic field) where previously-slowed *and bunched* nuclei are trapped in a circular orbit.
2. You can measure their mass by measuring the frequency of their orbit (like RPM) inside the magnetic *(+electrostatic = Penning)* trap: heavy ions are slower. *Typical frequencies measured are 1-10 MHz. Cyclotron frequency is a simple calculation:* $\omega_c = qB/m$ *(cyclotron frequency is equal to charge*field/mass)*
3. *The mass is measured by probing the ions' specific (cyclotron) frequency with a radio frequency electric field, seeking the resonant frequency that will eject it from the trap. This technique works best for single trapped ions.*

- LEBIT can measure the mass of a nucleus to one part in 100 million; equivalent to weighing an entire jumbo jet and telling how much change is in a passenger's pocket.

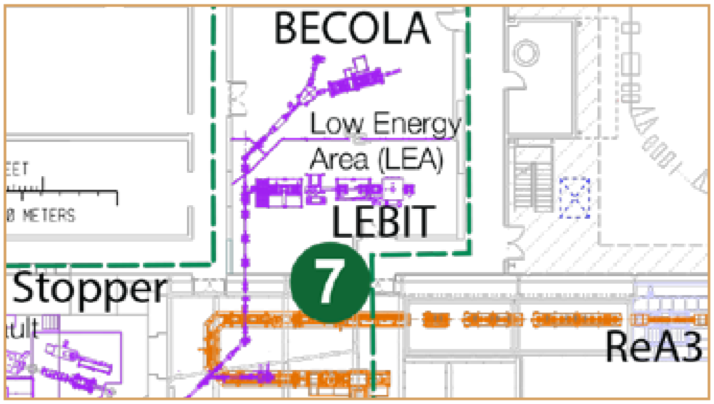
1. *Short-lived isotopes with half lives down to the millisecond range can be addressed. Stopping in the helium gas cell takes 10-100 ms. Cooling/bunching the beam (converting a continuous beam of nuclei to bunches) takes 5-30 ms. Time spent measuring in Penning trap takes between a few milliseconds to a few seconds.*
2. *World record for precisely measuring mass of short-lived isotope with a Penning Trap at TRIUMF like LEBIT: Lithium-11 (half life of 10 ms)!*
3. *Mass measurement results can have implications for astrophysics, the r-process path, nuclear structure and fundamental interactions.*

4. It's the strongest magnet you'll probably ever see (9.4 T, 94000 gauss, about 200,000 times the strength of the Earth's magnetic field), and it's always on (note yellow light above it), but it's well shielded. NOTE: you can feel the field near where the beamline enters the barrel, so beware! *LEBIT's superconducting wire coil carries a little less than 100 amps.*
5. Once NSCL staff got the current running in the superconducting coil inside, they unplugged it. The current is still going! It's superconducting, so there's no reason for the current to stop as long as the niobium wire is kept cold. LEBIT can operate for several thousand years before recharging. It is essentially the best battery you'll ever see. *(note: the penning trap is not kept cold - it has a separate LN2 shield)*

- Helium and nitrogen gas pressure release valves allow vaporized LHe and LN_2 to escape. Oxygen sensors in the room tell you if too much nitrogen is escaping (because N_2 displaces oxygen and creeps along the floor, making it hazardous). Any ice on the LN_2 pipes is just humidity in the air freezing onto the cold surface.

1. *The entire LEBIT beam line has been reconfigured and is floated up to 60 kV to match the new gas stopping stations (see the red insulators on the magnet stands). The previous gas cell was at ground potential and only fed LEBIT. After showing that rare isotopes produced via projectile fragmentation can be thermalized and used for precision mass measurements, the new gas stopping stations feed LEBIT, BECOLA, and ReA3.*
2. *We've recently added a 7 T magnet to the beam line, but you can't see it from the doors. This houses the new Single Ion Penning Trap (SIPT) which uses a different detection technique. Essentially it picks up the signal from asingle trapped ion on the trap electrodes. To detect this tiny signal a superconducting resonant circuit is used, so the trap and detection electronics are cooled to liquid helium temperature (~4K). SIPT will enable us to measure isotopes that are delivered at the rate of one per day, or less, drastically improving the reach of the high-precision mass measurement program.*
3. *Someone may ask why don't you just use SIPT for every measurement, but it's best suited for high-impact cases. The measurement method isn't as flexible as our original trap. Rhe original trap can move from mass 20 to 200 in a couple of seconds with simple adjustment. Using SIPT we have to change out the resonator circuit if we want to significantly change the mass range we're looking at.*

Approved: Ryan Ringle 10/18



Stop 7: Low Energy Precision Experiments area, featuring the Low-Energy Beam Ion Trap (LEBIT) and BEam COoler and LAser Spectroscopy facility (BECOLA)

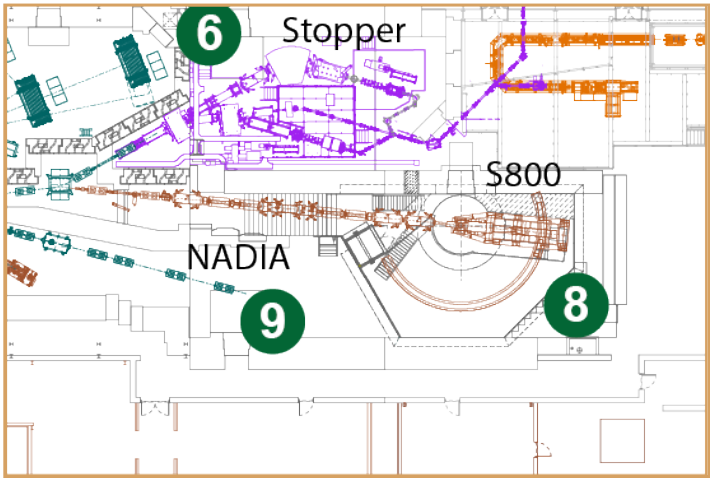
Safety

- Through the window by the main hallway, your group can see BECOLA, SuN, and the d-line extension. For VIPs, take <5 people in at once, stay close to the door, and do not test the magnetic field with a wrench.

Low Energy Area (7) BEam COoler LAser Spectroscopy facility (BECOLA)

1. BECOLA stands for BEam COoler and LAser spectroscopy. Experiments in BECOLA shoot laser light into very "cold" beams of nuclei to study the nuclear structure and fundamental symmetries. Depending on its electron configuration, an element reacts to a certain color of laser light and fluoresces as a response.
2. *The color of the laser light to which the atom reacts varies depending on elements (each element has a "fingerprint" spectrum) and even within among isotopes of elements there is subtle variation of the light color absorbed. It is the slight changes of light color/energy necessary for the atom's reaction that the experimenter in BECOLA study to deduce information about nuclear structure and fundamental symmetries. BECOLA can detect light wavelength change of 0.00001%.*
3. BECOLA can measure nuclear structure information such as the "size" of a nucleus; a charge radius. BECOLA can measure a nuclear radius of a few femto-meter (0.000000000000001 m), and can distinguish variation of radius among isotopes, which is even hundreds of times smaller than the radius itself.
4. ***Beams from NSCL gas stopper are delivered to the BECOLA beam cooler/buncher. The cooler/buncher is a device that improves the quality of a rare isotope beam from the gas stopper, meaning it emits beams with a small energy spread, small divergence, small diameter and so forth.***
5. ***The laser system consists of a 15 W green laser to pump a Ti:Sapphire ring laser (~2 W, 700-1000 nm). The light from the Ti:S laser can be frequency doubled to generate second-harmonic light (~250 mW, 350 – 500 nm).*** An optical fiber is used for laser light transport from the laser room to BECOLA beam line by about 25 m. Laser light is introduced into beam line through a laser window on the 2-way bend using optic components on the breadboard by the bend.
6. ***Resulting fluorescence is collected using a fluorescence detection system. The heart of the system is an ellipsoidal mirror. The laser light and beam passes one of the focal point of the ellipse. The fluorescence emitted at the focal point is re-focused at the other focal point, where a fluorescence detector is placed. This is a similar concept to a parabolic antenna for satellite TV. It's an efficient fluorescence detector thanks to the ellipsoidal mirror.***
7. ***The fluorescence detection system is turned on only when there are beam bunches from the cooler/buncher, in order to increase signal to noise ratio. The technique makes it possible for experimenters to perform measurements with incoming ion beam rates as low as ~ 100 ions per second, which enlarges the accessible number of nuclei in the nuclear chart.***
8. ***Experimenters can also produce polarized beam (all spins are pointing at the same direction) using optical pumping technique with circularly polarized laser light. The bike rim coils along the beam line produce magnetic field to maintain the polarization. The polarized beam is required for the beta-particle-detecting nuclear magnetic resonance (β NMR) technique, which has much higher sensitivity than the conventional NMR due to the polarization and beta particle detection. The technique may be applied to rates as low as ~ 100 ions per second as well.***
9. ***Within BECOLA facility there is a Penning Ionization Gauge (PIG) offline ion source. The PIG source is a discharge sputtering source and can generate many stable isotopes including refractory elements (transition metals). Experimenters can use beams produced at the PIG source offline to develop best suited laser excitation schemes for spectroscopy that will be used in online experiments at BECOLA.***

Approved: Kei Minamisono 10/18



Stop 8: S3 vault, featuring the S800 Spectrograph.

Safety

- Don't lean over the rail!
- It is recommended to not take groups downstairs for safety and comfort purposes; however, if you do, advise them to watch their step carefully because it is steep. They must be wearing proper shoes. The downstairs is not usually surveyed either!
- Notify visitors who don't like heights that they can wait off the catwalk.

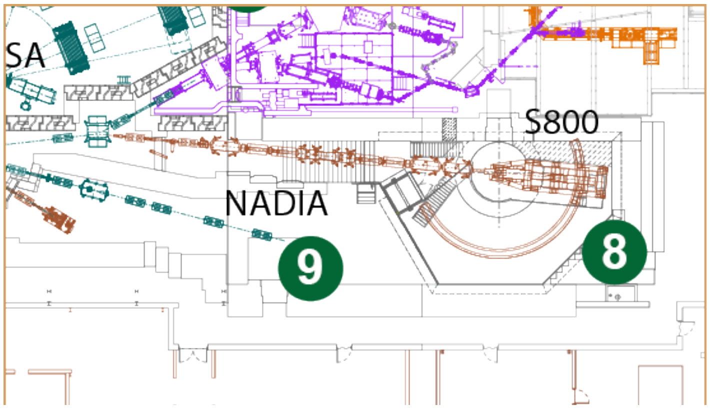
S3 Vault: S800 Spectrograph (8)

1. The S800 spectrograph is three stories high, 300 tons, designed to detect fragments coming from a collision between the rare isotope beam and a thin foil target. The basic idea of the S800 is that it allows the measurement of the velocity and angles of the fragments with great accuracy. *The S800 combines two key factors to achieve its performance:*
2. *High resolution (at best 0.01% of the particle's energy), meaning it is capable of distinguishing between two particles of only slightly different energies. This is equivalent to 0.005% of the velocity… for example, measuring the velocity of a car at about 50 mph, one could determine the speed to within 13.2 feet (4 meters) per hour, or 0.04 inches (1 mm) per second.*
3. *Large acceptance, meaning it collects and measures inside a large momentum range (~5% of the central energy) and angular range of the particles after they have reacted with the target.*

- The S800 acts much like the A1900 in that its two brown dipole magnets filter out many products and allow only the fragments of interest to reach the white detector box at top. By establishing the identity of those particles, their energies, and their trajectories, researchers can model what the rare isotopes were like before the collision: the structure of the nucleus.

1. *Particles are detected (tracked) in 2 focal plane detectors placed inside the detector box. The position in each detector is determined, and from those two positions, the angle of the track. The angle and position in the focal plane are then used to calculate (raytrace) the velocity and angles of the particles just after the collision. The detector box contains a scintillator used to time the particle (TOF, mass), and measure the amount of energy lost in material, an ion chamber to also measure delta-E (proton number), and hodoscope to measure particle energy. From that information, the particle type (charge & mass) can be determined.*
2. *Using another detector around the collision point (target) at the bottom, one can correlate the gathered information with the detected particles at the top to get more information. The Segmented Germanium Array (SeGA), GRETINA, HiRA and LENDA have been employed there to collect gamma rays, neutrons, or charged particles from nuclei that are excited in the reaction.*
3. October 2016: work done on S800 + GRETINA shows Si-34 is a "bubble" nucleus, no protons in center!
4. Because the S800 Spectrograph is so versatile, over one-third of the experiments performed at NSCL use it!
5. To check different scattering angles of post-collision fragments, the S800 can rotate over 150°, although this is rarely used nowadays; *the particles in the beam are usually much heavier than those in the target and thus tend to continue their forward-directed motion without being deflected much.*

Approved: Jorge Pereira Conca 10/18



Stop 9: the Modular Neutron Array (MoNA) and Large multi-Institutional Scintillator Array (LISA) (coming soon)

Safety

- Do not approach red magnet if yellow light is on.
- Photomultiplier Tubes (PMTs) on MoNA bars receive high voltage.

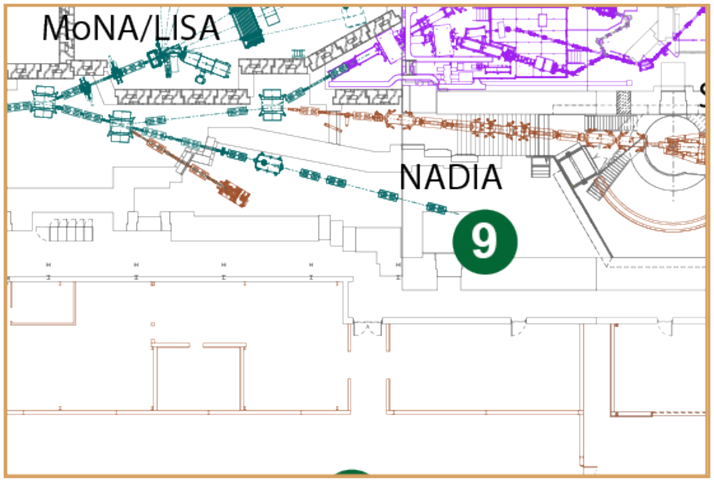
S2 Vault: Modular Neutron Array (MoNA) and Large multi-Institutional Scintillator Array (LISA) (9)

- MoNAand LISA: were designed at NSCL and built by undergrads from a collaboration of many colleges and universities (funded by $2 million from NSF), and members of that collaboration come to NSCL each year to conduct experiments. College-level students can do world-leading research while in school!

1. Operation: after secondary collision between rare isotopes and a target, the sweeper magnet diverts all charged particles from the beam into the attached detector box, allowing just neutrons to bombard MoNA and LISA. Note that the neutrons pass right through a metal plate and through the air - while nuclei require a vacuum for transport, neutrons rarely interact with matter because they are neutral. 6-foot walls of concrete are required to contain the neutrons.
2. Each bar of plastic scintillator (like acrylic glass) is wrapped in a black covering so that no light can enter. Neutrons can pass right through, *the only way they interact with the material is if they scatter off a nuclear core of an atom (which is tiny compared to the size of the atom). The plastic is hydrogen-rich because when neutrons his a proton (H nucleus), their similar mass makes for a large effect. If this happens, the scattered nucleus will* cause emission of light, which travels to the ends of the bar where photo-multipliers (like night vision goggles) amplify it (up to 30 million times) for detection.
3. *These photo-multipliers also detect when the light arrives very precisely, so the position of the light emission along the bar can be determined within a few centimeters by measuring the time difference of the signals at the left and the right end. This time difference has to be known to less than a nanosecond (billionth of a second). Additional spatial tracking of neutrons comes from identification of which bar gave the signal (16 per stack, 9 stacks deep for both MoNA and LISA). Each neutron might provide multiple "hits" in the detector.*
4. *The 576 signals from the bars feed into the Field Programmable Gate Arrays electronics modules in back. The FPGA-based trigger logic needs to tell the neutrons from about 200-400 counts/second of background cosmic ray events, which is done by detecting the neutrons in coincidence with charged particles arriving in the detector box by the sweeper magnet.*
5. From the measured parameters we can calculate where neutrons hit, what direction they were travelling, and how fast. Information from MoNA-LISA can be used to reconstruct a picture of the interior of rare neutron-rich nuclei, providing a deeper understanding of their structure *and, ultimately, answers to astrophysical questions because rare neutron-rich nuclei play a key role in the synthesis of the heavy elements and help drive tremendous stellar explosions, like supernovae and x-ray bursts.*

- When not detecting neutrons from a beam, MoNA-LISA is still counting cosmic rays, which is useful data.
- The total length of all cables for MoNA is 5 miles (8 km), and LISA's cables stretch 7 miles (11 km). With the large number of detector modules, cabling is a significant cost with each cable costing about $50. The cabling weighs about 1 ton.
- MoNA-LISA was used to discover di-neutron decay of oxygen-26 and beryllium-14.
- The kind of research opportunities at NSCL afforded by MoNA-LISA is a major reason we have the #1 nuclear science graduate program in the country!

Approved: Thomas Baumann 10/18



Stop 9: S2 vault, featuring the RF Kicker, Neutron Walls, occasionally Miniball/HiRA and/or SeGA

Safety

- Stay on the platform inside the door.
- Watch for items on the floor.

S2 Vault (9)

Radio Frequency Fragment Separator (RF Kicker)

1. (by Ana Becerril) The Radio Frequency Fragment Separator in S2 (a.k.a. RF-Kicker) is a velocity filter that separates proton-rich ions (very far from stability) that cannot be purified using the A1900 Separator alone. *The RF-Kicker uses a time varying vertical electric field to induce a transverse deflection on the beam depending on the velocity of the different species, i.e. it gives a little kick to the unwanted isotopes (which are then stopped with a set of vertical slits), and lets only the desired fragments through the detection system.*
2. The RF Kicker decreases the contamination in our secondary beam by several orders of magnitude without affecting the intensity of the fragment of interest. *Beam purity is crucial to allow β-ion correlations in decay studies, and also to prevent overloading of our detectors.*

Approved: Daniel Bazin 1/9/17

Miniball and HiRA (8 or 9)

1. ***NOTE: Miniball and/or HiRA are only set up for one month out of the year, and sometimes in S3 instead of S2... often, there will be no detector at the end of this vault's beamline.***

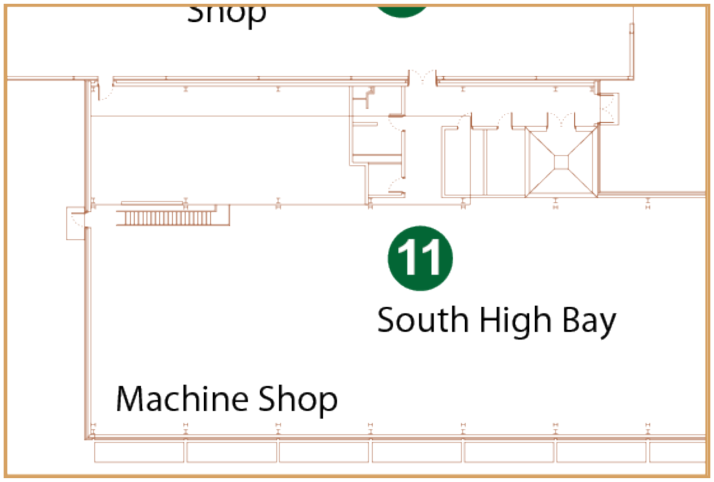
- Detectors are placed in a vacuum vessel and evacuated down to 10^{-6} Torr. Beam enters the vessel and strikes a target at the center of the miniball. The collision releases many protons, neutrons, and fragments.

1. The miniball is made of about 100 CsI crystals surrounding the target so they can pick up particles released in almost any direction. This lets researchers determine the violence of the collisions. (Less violent collisions give out fewer particles. In very violent collisions, the colliding nuclei disintegrate.)
2. HiRA is made up of several "telescopes" designed to pick up the charged particles *that pass through its matrix of silicon strips. The strips form pixels of less than tenth of an inch square.* From the position, the experimenters can deduce the angles of the emitted particles. HiRA is a state of the art detector which can measure the charge, mass, energy, and position of a particle to very high resolution.

- The neutron walls (like MoNA, but using liquid scintillator) detect the neutrons striking them from the fragmented nuclei. These walls are special because they can distinguish light specifically generated by neutrons.

1. Combining information from walls and detector in the vessel allows researchers to reconstruct the directions and energies of most particles especially the protons and neutrons from the collision. The information can then be used to work backwards and learn more about the properties of the colliding regions between two heavy nuclei. We use the results of the experiment to learn about astrophysical objects such as neutron stars because the colliding region simulates the matter in these objects.

Approved: Betty Tsang 2/25/11



Stops 10 and 11: Machine Shop and South High Bay.

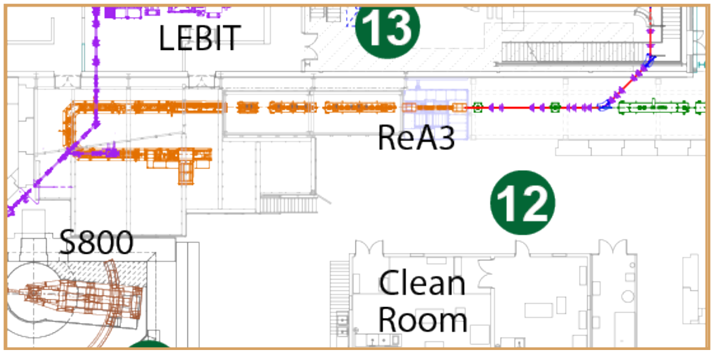
Safety

- If you must enter the Machine Shop (a very rare occurrence), do not cross the barrier wall without eye protection. Ensure all visitors have them on before passing the “warning” sign!
- In the South High Bay, everyone must wear a hard hat if the crane is running (yellow light flashing)!
- In the South High Bay, keep your group within 30 feet of the entryway to avoid most hazards.

Machine Shop (11)

1. The Machine Shop: The shop contains Computerized Numerical Control (CNC) Machines, many are mills and have automatic tool changers. Another CNC, the Haas machining center with rotary table capable of traveling 150” x 72” x 36” is housed in the South High Bay. There are several manual machines as well.
2. • Our machine shop staff consists of 7 full time journeyman machinists and one full-time trades assistant to purchase material and prepare stock for manufacturing.
3. Machinists undergo continuous education in CAD/CAM upgrades and have a total of >200 years experience among them. The manufacturing staff is rounded out by six qualified welders who support fabrication and cryogenics assembly.
4. Common materials worked in the shop: copper, steel, stainless steel, aluminum, titanium, niobium
5. The Machine shop provides service from 6am - 4:30pm on weekdays, and occasionally weekends when needed.
6. The Machine shop and Welding shop support all of NSCL and our outside users. Our shop is directly connected with our design department and receives all of our part files electronically. What this means is all tool and cutter paths are generated directly off from the designer’s solid part model. This method of manufacturing virtually eliminates any discrepancy between a designed part and the finished parts. Much of NSCL’s equipment was designed and built right here since it has a very specific purpose! We are always building replacement and prototype parts.

Approved: Ken Plath 1/26/16



Stop 12: East High Bay, featuring ReA3 and Clean Room.

Safety

- Hard hats must be worn if crane is in operation.
- Watch for objects on floor.
- Do not take visitors upstairs.

East High Bay (12) Clean Room

1. The cleanroom is where NSCL builds equipment that must meet very high cleanliness specifications in order to operate at high accelerating voltages. *The cleanroom is separated into two rooms of different classes, a Class 100 and Class 10,000. "Class" refers to a measure of the cleanliness of the room. To certify a Class 100, there must be less than 100, 0.5 µm particles, per cubic foot of area. In comparison, the East High Bay measures at over 350,000, 0.5 µm particles, per cubic foot.* Occupants of the cleanroom are required to wear "bunny suits" to keep body contaminates from escaping into the clean environment.

1.) The components being prepared and assembled here are the vacuum chambers, beam pipes, and diagnostic devices that are being installed in the FRIB beamline. To ensure proper operation of the accelerator, it's critically important that these components be free of particulate contamination (hair, dust, lint), and oils or films that can spoil the vacuum and impair the function of sensitive devices.

2.) Many components prepared in this cleanroom are installed adjacent to superconducting coldmasses, the "engine" of the new FRIB linear accelerator. These coldmasses (prepared in another cleanroom elsewhere) contain "cavities" made of niobium, a metal used for its superconducting properties. The cavities are energized with large electric fields (millions of volts) on the internal surfaces to accelerate ions. Any dust or surface contamination in the vacuum system can result in sparking and performance degradation, which is why our cleanrooms and clean assembly processes are so important!

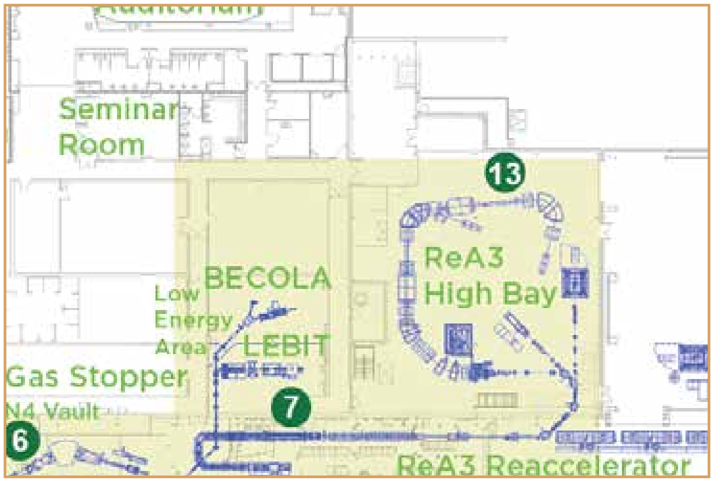
Approved: Ian Malloch 10/18

ReA3 (12)

- Some experiments can't be done while the nuclei are travelling at half the speed of light. This upgrade lets us stop the beams (in the gas stopper), ionize them (strip them of electrons to high charge states in EBIT, the Electron Beam Ion Trap), and reaccelerate them to about 8% of the speed of light. This is approximately the speed of nuclei you'd find in a star, so this reaccelerated beam lets you do nuclear astrophysics experiments that reproduce nuclear reactions found in stars. ReA3 makes NSCL the only facility of our kind (fast-beam fragmentation) with this capability. Researchers have been asking to do this type of experiment, and want to come here.
- ReA3 provides a world-unique science capability requested by users!
- First experiments with rare-isotope beams began in September 2015.

1. *The ReA3 accelerator is made of 15 superconducting cavities made of pure niobium. These next-generation accelerators are of a brand-new design, developed in collaboration with some other labs around the country, and we've built the first ones ever. As nuclei pass through, the center part is charged to +/- one million volts, shooting the nuclei out the other side. There are different sizes/shapes of cavities, all operating at 80.5 MHz, each optimized to operate at either 4.1% or 8.5% of the speed of light.*
2. *The cavities are in cryomodules (cold boxes) behind the green lead shielding.*
3. *Resulting beam energies from ReA3 will be variable and relatively low (from 0.3 MeV/u to 6 MeV/u), 3.2 MeV/u (8% of c), appropriate for astrophysics-type experiments. By comparison, the cyclotrons accelerate nuclei up to 140 MeV/u (50% of c) and FRIB will achieve 200 MeV/u for uranium beam (57% of c).*
4. *FRIB uses similar cavity technology, incoporating 300 cavities in 4 designs to make up the 400-yard-long accelerator.*

Approved: Antonio Villari 10/18



Stop 13: ReA12 High Bay and ReA3 High Bay/Low Energy Experimental Area, featuring parts the AT-TPC.

Safety

- Hard hats must be worn if crane is in operation.
- Watch for objects on floor.
- Do not take visitors upstairs.
- Stay outside glass partition.

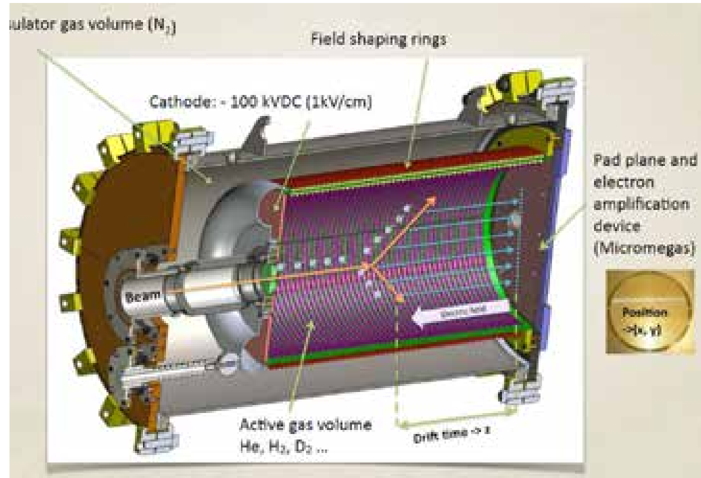
ReA12 High Bay

1. This addition to the Experimental area (you can see the walls are a different color than by ReA3) will allow the reaccelerator to be extended and bring rare isotope beams up to and beyond 12 MeV/u. This energy is analogous to that expected in a supernova, and high enough to overcome electric repulsion between nuclei (Coulomb barrier), thus allows for more transfer reaction experiments.

ReA3 High Bay (13)

1. The AT-TPC magnet (white cylinder) and yoke (green box) are currently in place, and the 10,000 channel electronics fully operational
2. The magnet was originally constructed to serve as part of an MRI, but was repurposed for a nuclear detector (which MRIs were invented to be) at TRIUMF in Vancouver, then donated to NSCL.

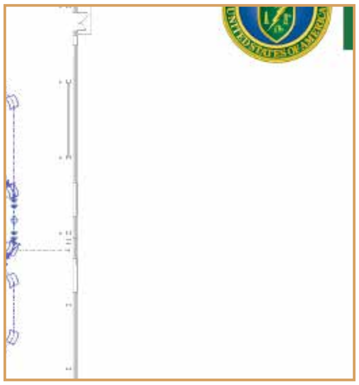
1. The AT-TPC is a large gas volume located inside the magnetic field of the detector. Secondary beam particles will enter the detector through a thin window. If they interact with the active target helium gas (by a nuclear reaction) the resulting charged products will leave an ionization track. The electrons of the ionization track drift to the anode and are amplified (Micro Mesh Gas Amplifier). The ionization track is read out via a high granularity micropattern by 10,000 electronic channels on the back of the detector.
2. The location, amount, and time of the current read lets this detector track individual particles in three dimensions. This detector will be used, among other things, for the study of nuclear structure far from stability and for the study of reactions of astrophysical interest either by (d,p) or (^{3}He,d) transfer reactions.



Cutaway view of AT-TPC internals.

1. *(from the NSCL website) The AT-TPC combines time projection and active target functionality in a single device thus allowing measurements of rare processes that require high detection efficiency and large acceptance. Low momentum transfer reactions (such as quasi-elastic scattering) that are traditionally difficult to measure due to the very low recoil energy (down to hundreds of keV) can be observed by using low pressure. As the name implies, the AT-TPC will operate in two different modes. In the active target mode, the AT-TPC counter gas acts as both a target and detector, allowing investigations of fusion, isobaric analog states, cluster structure of light nuclei and transfer reactions to be conducted without significant loss in resolution due to the thickness of the target. The high efficiency and low threshold of the AT-TPC will allow investigations of fission and giant resonances with fast fragmentation rare isotope beams. Operating the AT-TPC in the detector mode, the reaction products created in collisions between isospin asymmetric heavy ions will allow the density dependence of the symmetry energy term of the nuclear equation of state to be explored. To accommodate this range in experimental programs the AT-TPC is designed to be portable to allow the chamber to be installed at a variety of NSCL beam lines, including the new reaccelerator area.*

Approved: Wolfgang Mittig 10/18



LENDA (near AT-TPC in ReA3 High Bay 12/16/15)

LENDA (sometimes 13, will move)

1. The Low-Energy Neutron Detector Array (LENDA) is used for detecting neutrons with velocities ranging from 2000-20000 miles/s, which is actually not very fast from the point of view of a nuclear scientist. It can be used in a variety of experiments at NSCL, but the main use thus far has been in experiments at the S800 spectrometer that aim to understand processes that take place in exploding stars (supernovae) or that involve neutrinos, which are very weakly interacting particles that can help us learn about fundamental properties of matter and forces.
2. In the experiments at the S800, beams of rare isotopes are injected onto a target (usually a cryogenic target of liquid Hydrogen), and the neutrons from reactions taking place at the target are detected in LENDA. Heavy beam-like fragments are detected in the S800, with the goal of tagging specific reaction channels.

Approved: Remco Zegers 10/18

JENSA (13)

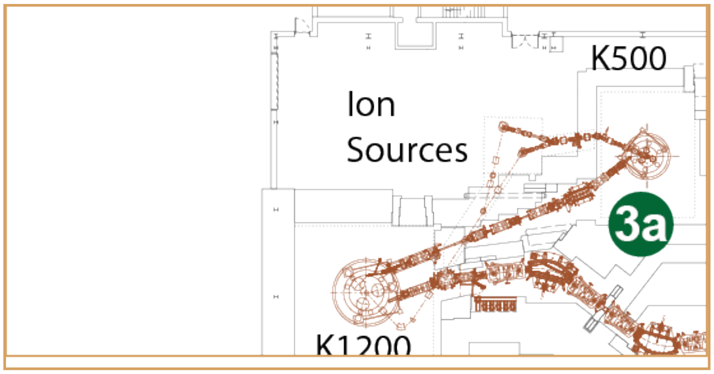
- Jet Experiments in Nuclear Structure and Astrophysics
- Designed by Colorado School of Mines and ORNL, funded by DOE and JINA, see jensajet.org for a complete list of collaborators. Current collaboration is led by Kelly Chipps from ORNL.
- One of the goals of JENSA experiments is to measure directly astrophysical reactions of radioactive nuclei with hydrogen or helium at the same collision energy that particles have inside stellar explosions such as X-ray bursts and Novae when temperatures reach 10^8 - 10^9 degrees.
- The radioactive beam hits a 4mm stream of gas (the gas jet), and reaction products such as protons or helium nuclei are detected by surrounding Si detectors
- For reactions that emit only gamma-rays we will need a gamma ray detection array that is currently under construction and the SECAR recoil separator.
- World's densest He gas jet with 10^19 nuclei per cm^2.
- Jet inlet pressure maintained by large compressor is up to 40 Atmospheres.
- The connection to the high vacuum beamlines without any windows is accomplished with a series of differential pumping stages where large pumps bring the pressure stepwise down to high vacuum. These pumping stages are connected with small apertures to restrict gas flow.
- All gas is recirculated in a closed system so we can use expensive gases like ^{3}He (filling the system is about $100k)

Approved - Hendrik Schatz 1/8/17

SECAR (13)

- SEparator for CApture Reactions
- the goal of SECAR is to directly measure astrophysical reactions where a radioactive nucleus captures either a proton or a helium nucleus, and a gamma ray is emitted.
- SECAR will be sensitive to measure extremely weak reactions that are important to understand X-ray bursts, Novae, Supernovae, Supermassive Stars, and other more exotic astrophysical phenomena.
- SECAR is coupled with JENSA, where the radioactive beam passes through a gas jet. Both the unreacted beam and the occasional heavier nucleus produced by a capture reaction in the target are entering SECAR. The purpose of SECAR is to separate the beam from the capture reaction product, which can then be counted in detectors at the end of SECAR. SECAR is expected to detect reactions that occur with rates a slow as one per day.
- SECAR consists of four separation stages - a first stage that separates charge states using dipole magnets, 2 stages that use a Velocity Filter each to separate by velocity, and a final dipole stage for additional cleanup.
- SECAR Velocity Filters will have electrodes with up to +-250 kV creating an electric field that is perpendicular to a dipole magnetic field. Both fields bend particles horizontally in opposite directions and the forces cancel for the desired velocity.
- All magnets are room temperature magnets
- SECAR is designed by JINA-CEE scientists at Notre Dame, built by a collaboration with funding from DOE Office of Science and the National Science Foundation.
- The first elements arrived in 2017. Project completion is planned for the end of 2021, though managed to an earlier completion date.

Approved: Hendrik Schatz 10/18



Ion Sources, including SuSI (near 3a).

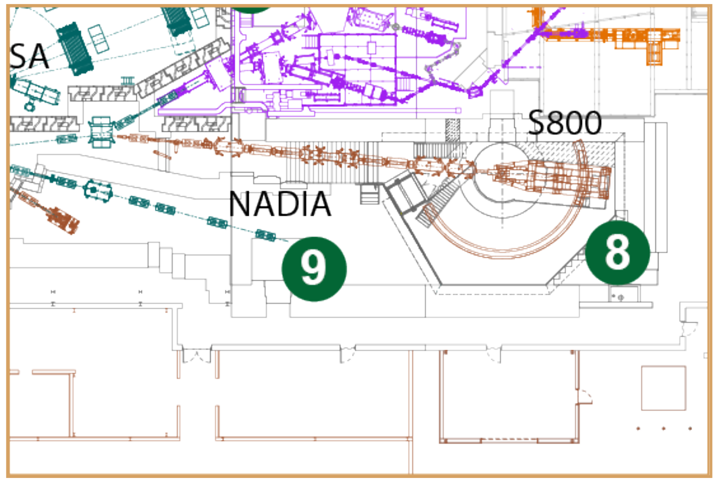
Safety

- Yellow light in hallway by Atrium door indicates that the magnet is on. Do not approach ECR area or K1200.
- Tours should not enter this area without approval.

Superconducting Source for Ions (SuSI) (near 3a)

1. *Accelerators only work on charged particles; therefore, the stable nuclei we accelerate must be slightly ionized so they have a net positive charge. The acceleration depends on the voltage times the charge, so depending on their charge, the ions produced will leave the ion source going a little less than 1000 km/s.*
2. *If accelerating a metallic element, it will be heated in a little oven (from 200°C for selenium to 2000°C for uranium) to produce a vapor, and the gas is injected into a magnetic bottle. SuSI's magnetic field (up to 2.5 T) is far higher than our other ion sources (Artemis about 1.5 T).*
3. *Inside, the neutral atoms are bombarded with electrons from a plasma (heated by microwaves to energy several times the ionization energy of bound electrons) to knock electrons away from the atom, creating an ionized state.*
4. *The goal is to have a large number of ions in the same ionized state (e.g. 3+ for oxygen), though the ion source produces many different states (typical distribution is 6-7 charge states). There is a trade-off between confining ions to reach higher charge states but sourcing less current vs. delivering high current of a lower charge state. The plasma is optimized to produce most nuclei in a specific charge state. The first magnetic dipole along the extraction line selects only one charge state to pass through… so only some of the produced ions can be used.*
5. *The ions are extracted by an electric field of 25-30 kV and sent to the K500 cyclotron. Primary beam currents range from 175 pnA (O-16) to 0.2 pnA (U-238)*

Approved: Guillaume Machicoane 10/18



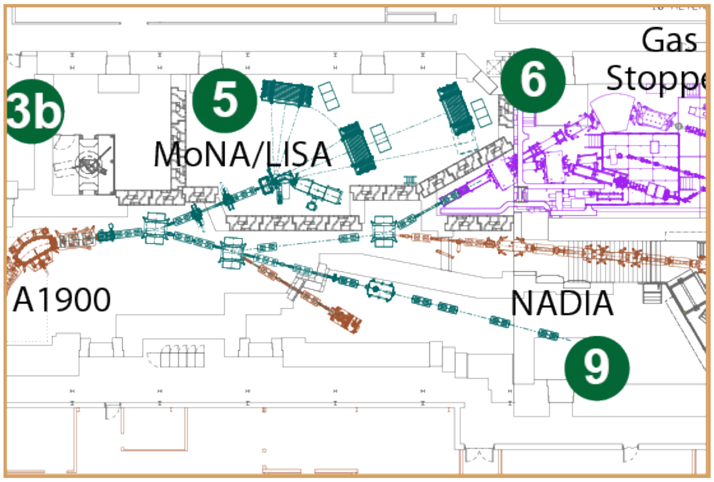
The Segmented Germanium Array (SeGA) could be placed in either the bottom of S3 (stop 8) or in S2 (stop 9).

Segmented Germanium Array (usually 8 or 9 or 13)

- After the nucleus is excited, it will often de-excite by emitting energy in the form of high-energy light: gamma rays. With arrays of gamma-ray detectors, this light can be collected to learn about the properties of that rare nucleus. The detectors at the NSCL are unique for detecting gamma rays from very rare nuclei that travel at very high velocities.

1. *The segmented germanium array (SeGA) allows "high-resolution" in-beam γ-ray spectroscopy of intermediate-energy beams from the Coupled Cyclotrons. Each of the eighteen detectors in the array is a single-crystal 75% relative-efficiency germanium counter with the outer surface electronically divided into 32 segments. By using the segment information, the interaction of the γ-ray can be localized within the detector, therefore reducing the uncertainty in the Doppler correction due to the finite opening angle of the detector. A detector frame is available and allows the detectors to be placed at several distances, so the experimentalist can decide on the compromise between efficiency and resolution for their particular needs. The standard configuration is 18 detectors at 20 cm, which gives an approximate 3% photo peak efficiency at 1.3 MeV with about 2% in-beam energy resolution. The detectors are also available for stopped beam experiments such as β-delayed γ-ray decay studies.* (from NSCL website)

Approved: Dirk Weisshaar 10/18

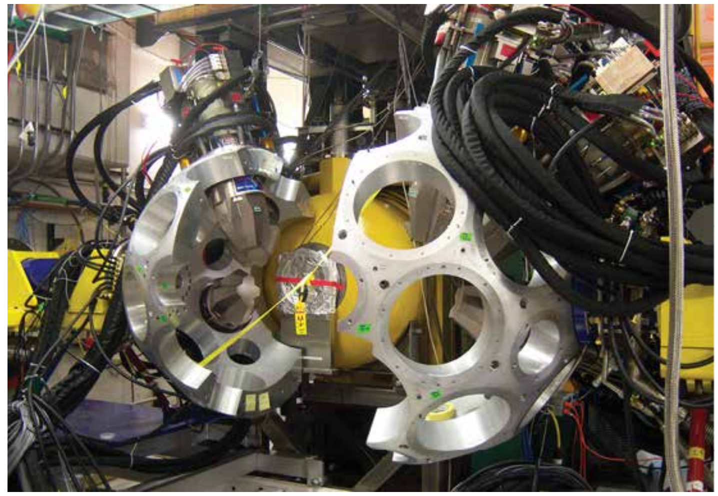


CAESAR could be placed in either by the sweeper magnet in N2 (stop 5) or in S2 (stop 9).

CAESium iodide ARray (CAESAR) (usually 5 or 9)

1. *(from NSCL website)* The structure of rare isotopes has been found to be significantly different from that of stable ones and new results continue to surprise researchers. Many NSCL experiments react a beam of a rare isotope with stable targets *at >0.3 c to elucidate its structure.* The photons emitted during and after the reaction provide invaluable information on the energy levels of the exotic nuclei and allow detailed studies of their properties.
2. CAESAR is a very efficient detector that is tuned to collect and measure these photons. *It consists of 192 individual CsI(Na) scintillation crystals that cover 95% of the solid-angle surrounding the target. The large number of detector elements is needed since the photons emitted by moving nuclei are subject to the well-known Doppler phenomena that can only be corrected if the relative direction of emission is known. Each individual CAESAR detector that responds to a photon has a specific angle relative to the beam direction that is used in the Doppler reconstruction to calculate the spectrum of emitted photons in the rest frame of the moving nucleus. CAESAR was successfully commissioned in May 2009.*

Approved: Dirk Weisshaar 10/18



Gamma-Ray Energy Tracking IN Array (GRETINA) (usually 9)

1. *(from NSCL website)* A collaboration of scientists from Lawrence Berkeley National Laboratory, Argonne National Laboratory, NSCL, Oak Ridge National Laboratory, and Washington University has designed and constructed a new type of gamma-ray detector to study the structure and properties of atomic nuclei. *Construction started in June 2005 and was completed in March 2011. The detector is built from large crystals of hyper-pure germanium and will be the first detector to use the recently developed concept of gamma-ray energy tracking. GRETINA consists of 28 highly segmented coaxial germanium crystals. Each crystal is segmented into 36 electrically isolated elements and four crystals are combined in a single cryostat to form a quad-crystal module.* There are 12 modules in total. The modules are designed to fit a close-packed spherical geometry that will cover one quarter of a sphere.
2. GRETINA is a national resource that will move from laboratory to laboratory. NSCL has hosted GRETINA for several experimental campaigns, while at other times it was housed at Argonne.

Approved: Dirk Weisshaar 10/18

K500 model in lounge near Seminar Room

K500 wooden model (near Seminar)

- The K500 was designed long before Computer Aided Design (CAD) was available. A wooden model was constructed first to ensure that the parts would fit correctly!
- It is a full-scale model of the interior that shows all of the critical elements (listed below)

1. Hills (high magnetic field regions that together with the valleys provides "flutter" for focusing the beam)
2. Valleys (low magnetic field region where the Dees are)
3. ***Trim coils to make the magnetic field isochronous (the particles stay in phase with the accelerating electric field)***
4. ***Hill liner (copper) that keeps the RF contained in the beam chamber***
5. ***Beam probe track (aluminum) – resides inside of a Dee and follows the shape of the Dee. It provides a way to carry a camera or beam current monitor to observe the beam as it moves out in radius (i.e., higher energy)***

Approved - Al Zeller 10/27/14

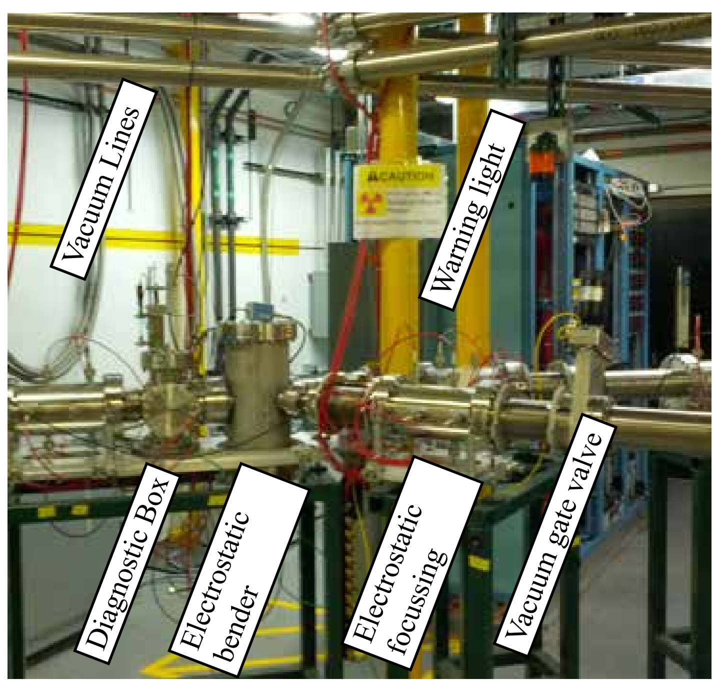
D-line (north of S3 Vault)

- This is a good place to point out the complexity of transporting a beam of nuclei.
- The electrostatic bender (which appears in several places along the line – all are one design to be more efficient) is able to divert the beam 45 degrees. It can take the place of a larger and more expensive magnetic dipole because the beam energy is low (slow velocity).
- ***The 61-degree dipole magnet (blue, left of the picture) serves to select isotopes of interest like a mass spectrometer, since there can be impurities in the beam when it leaves the gas stopper.***
- The electrostatic focusing elements (quad doublet) serve the same purpose as quadrupole magnets in other places; however, they use adjustable potentials (+/- 6 kV) to confine the beam.

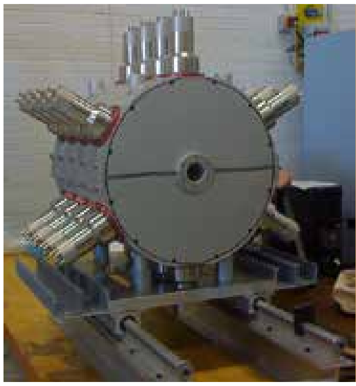
The D-line for transporting beam from the gas stoppers to the low-energy area or reaccelerator.

- The diagnostic boxes let the operators know about the beam characteristics so they can adjust other elements accordingly. ***They use Faraday cups (conductors that measure beam current), silicon detectors (to detect electrons from decay), microchannel plates (MCP, provides beam image) and collimator jaws (works with dipole magnet to select mass of interest from the beam).***
- The vacuum lines allow the pumps in the right corner to evacuate the whole D-line.
- The vacuum gate valves break the beam line into several vacuum sections to allow localized maintenance.
- Safety - if the orange warning light is ON, the D-line may be carrying radioactive beam. However, there is no danger to visitors and it is OK to stop here!

Approved: Kasey Lund 10/18



NSCL Tour Location Script



K500 model in lounge near Seminar Room

The cycstropper currently resides in the ReA12 High Bay.

Summing NaI (SuN) detector (7)

- *(from Artemis Spyrou's website)* SuN is a γ-ray detector. It is made of sodium-iodide ***NaI(Tl)*** scintillator material which has a very high efficiency in detecting γ-rays. The source of radiation can be placed inside the borehole of SuN, at its geometric center, and in this case the solid angle coverage is about 98%. SuN is the main instrument the Spyrou group uses for experiments at NSCL. They use it to detect γ rays coming from studies of astrophysical reactions or from the β decay of exotic radioactive nuclei.
- ***(from the SuN Group website) An example of the "summing technique": if a proton is captured to an excited state of a target nucleus, the created system will deexcite emitting a gamma radiation. The emitted gamma cascade might be complicated with many level transitions. Some gamma detector register various transitions as separate peaks and the resulting spectrum might be complex and difficult to analyze.***
- ***When a large-volume detector, like SuN, completely surrounds the target, then the energy coming from all gammas in a gamma-cascade can be summed. As a result, the detection of the final product is simplified because each excitation energy that is populated will give only one peak. Typically, the time window for summing the energy in the different parts of SuN is 300 ns.***

Approved: Artemis Spyrou 10/18

Cycstopper (5)

1. A large gas-filled reverse cyclotron (AKA cyclotron stopper) has been constructed in the ReA12 high bay and will be installed in the N2 vault in the near future.
2. The device is about the size of the K1200 cyclotron, because it has to capture ions accelerated with that machine. ***Similar to the K1200, it uses a sectored magnet with a maximum magnetic field strength of 2.6 T. Contrary to the K1200, it does not use RF dees to change the ions' energy but relies on solid degraders and buffer gas inside a central chamber to stop the ions.***
3. The cyclotron stopper will be used to slow down light ions that cannot be collected efficiently in the more compact (~1m long) linear gas cells in N4. Light ions are expected to travel up to 200 meters inside. Fast ions circle in the magnetic field and spiral towards the center as they lose kinetic energy through collisions with the gas.
4. ***RF-based ion guides, so-called ion carpets and an ion conveyor, are used to center and extract the stopped ions. Prof. Morrissey's and Bollen's research groups have been developing RF-based ion guiding techniques over many years and used them to prepare beams for the low-energy experimental program (LEBIT, BECOLA) and ReA.***
5. ***The central chamber can be cooled to liquid-nitrogen temperature to improve cleanliness of the extracted beams.***
6. ***The cyclotron stopper can be biased up to 60kV to deliver the stopped ions as a low-energy beam (note the large green insulators).***
7. Magnet facts: the steel yoke weighs about 170 tons and it stands 14 feet tall. The floor in N2 has been reinforced with micropilings to support the cyc-stopper's weight. The magnet has its own cryo-refrigerators to provide liquid helium to its two super-conducting coils, facilitating HV operation. One side of the cyclotron stopper moves on rails and opens for access to the stopping chamber.
8. Low-energy ion transport tests with RF ion guides have been successful in the ReA12 area with the magnet energized. Stopping energetic ions will be tested in N2.

Approved: Stefan Schwarz 10/18