### Section 1.2 Notes (see slides in same section)

This material is taken from various nuclear accelerator home pages on the World-Wide-Web.

# 1 Electron accelerator: CEBAF at Newport News, Virginia http://www.jlab.org/

CEBAF is an acronym for Continuous Electron Beam Accelerator Facility. Completed Fall 1994. Premier high-energy electron accelerator for nuclear physics experiments in US. Uses superconducting cavities for electron acceleration and delivers 6-GeV high-intensity continuous (i.e. 100% duty factor) electron beam. Particularly useful for coincidence studies. CEBAF studies elastic and inelastic nuclear form factors, single-nucleon density distributions, hadron resonance production and propagation in nuclei, fundamental form factor measurements, parity violation, hypernuclear physics, quark substructure.

# 2 Relativistic Heavy-Ion Collider (RHIC) at Brookhaven National Laboratory http://www.bnl.gov/rhic/

The Relativistic Heavy Ion Collider (RHIC) is located on Long Island, New York, at Brookhaven National Laboratory. The RHIC ring is an underground almost circular tunnel 3.8 kilometers in circumference. Heavy ions are pre-accelerated by the AGS and then injected into the RHIC ring via a beam transfer line. RHIC is capable of accelerating heavy ions such as <sup>197</sup>Au+<sup>197</sup>Au in opposite directions through the ring at a collider beam kinetic energy of 100 GeV per nucleon; this beam energy is equivalent to 20,000 GeV per nucleon in the fixed-target reference frame! The counterrotating beams intersect in six interaction regions. The huge number of produced particles are measured using the STAR and PHENIX detectors. The main purpose of RHIC is to study global properties of nuclear matter under extreme conditions of temperature and density. The primary physics goal of RHIC is to search for the quark-gluon plasma phase transition of nuclear matter, a phase of matter that existed (according to Big Bang Cosmology) during the first millionth of a second after the Big Bang.

## 3 Low-energy heavy-ion accelerators

#### 3.1 HRIBF at Oak Ridge National Laboratory http://www.phy.ornl.gov/hribf/

HRIBF is an acronym for the Holifield Radioactive Ion Beam Facility located at the Oak Ridge National Laboratory (ORNL). HRIBF is operated as a National User Facility for the U.S. Department of Energy, producing high quality beams of short-lived, radioactive nuclei for studies of exotic nuclei and astrophysics research. These nuclei are produced when intense beams of light ions from the Oak Ridge Isochronous Cyclotron (ORIC) strike highly refractory targets. The radioactive isotopes diffuse out of the production target and are ionized, formed into a beam and mass selected. This technique of radioactive ion beam production is known as the isotope separator on-line (ISOL)

technique. The radioactive ion beam is then injected into the 25-MV Tandem, the world's highest voltage electrostatic accelerator.

Nuclear structure research at HRIBF provides insight into the nature of the force that clusters protons and neutrons into a nucleus. HRIBF tests the limits of nuclear stability using intense beams above the Coulomb barrier and new techniques for detecting the shortest-lived proton-rich nuclei. These nuclei have exotic decay modes such as one- and two-proton emission.

HRIBF produces beams of radioactive nuclei with a wide range of easily variable energies and intensities sufficient to allow some of the first direct measurements of the nuclear reactions that power novae, X-ray bursts, and other stellar explosions. HRIBF's unique combination of highquality radioactive beams with experimental equipment optimized for astrophysics has enabled high-precision measurements of stellar reactions with radioactive beams.

#### 3.2 ATLAS at Argonne National Laboratory http://www.phy.anl.gov/atlas/index.html

ATLAS is an acronym for Argonne Tandem-Linac Accelerator System; it represents the world's first superconducting linear accelerator for heavy ions at energies in the vicinity of the Coulomb barrier. The full range of all stable ions can be produced in ECR ion sources, accelerated to energies of 7-17 MeV per nucleon and delivered to one of several target stations. About 20% of the beam-time is used to generate secondary radioactive beams. These beams are used mostly to study nuclear reactions of astrophysical interest and for nuclear structure investigations. Users of ATLAS take advantage of the existing experimental equipment such as, for example, the Canadian Penning Trap (CPT), the Fragment Mass Analyzer (FMA), the magnetic spectrograph and Gammasphere.

Specific issued being addressed are 1) the quantum structure of nuclei, 2) nuclear shapes, 3) exotic decay modes, 4) masses of exotic nuclei, 5) fundamental interactions, 6) nuclear reactions of astrophysical importance, 7) properties of the heaviest nuclei and 8) accelerator mass spectrometry. At present, the Californium Rare Ion Breeder Upgrade, CARIBU, is being built. This facility will provide for the acceleration of neutron-rich fission fragments from a one Curie 252Cf source to study neutron-rich nuclei, particularly those of relevance for the astrophysical rapid neutron capture process responsible for the production of a large fraction of the heavy elements in the Universe. A novel superconducting solenoid spectrometer, HELIOS, which is ideal for the study of the structure of these neutron-rich species, is under construction and an energy upgrade of ATLAS is also under way.

# 4 Intermediate-energy heavy-ion accelerator: NSCL at Michigan State University http://www.nscl.msu.edu/

The National Superconducting Cyclotron Laboratory (NSCL) operates two coupled cyclotrons: In 1981 the world's first superconducting cyclotron (K500) was operated at the NSCL. It was followed in 1988 by a larger cyclotron (K1200) of similar design. These two cyclotrons are now used in a coupled mode, in which the beam from the first machine is further accelerated in the second one. The K500 is 10 feet in diameter, and the magnet is 7 feet, 2 inches tall, with a magnetic field that can be tuned between 3 and 5 tesla (60,000 to 100,000 times the earth's magnetic field). The K1200 is 14 feet, 7 inches in diameter, and the magnet is 9 feet, 7 inches tall.

In the coupled system, the K500 cyclotron accelerates ions of low charge state from the ion source to an energy suitable for injection into the K1200 (less than 20 MeV/nucleon). When injected into

the K1200, the ions pass through a thin foil and lose many electrons, typically emerging with a charge 2.5 times larger. The accelerating high voltage, acting on this higher charge, can boost the ions to a higher energy. For example, uranium can be accelerated to 90 MeV/nucleon, while the limit with the K1200 alone is about 25 MeV/nucleon. The coupling of the two cyclotrons greatly increases the beam intensity and makes it possible to explore very rare exotic isotopes.