

Teachers Day at the Particle Accelerator Conference in 2005



The Spallation Neutron Source

N.R. Holtkamp

Oak Ridge National Laboratory

Accelerator Systems Division Director for the SNS

Mai 18th, 2005

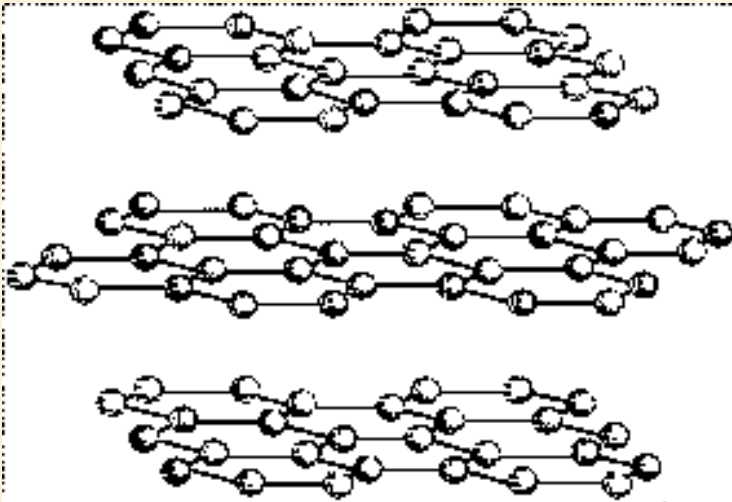
Knoxville, TN

Materials define the ages of civilization

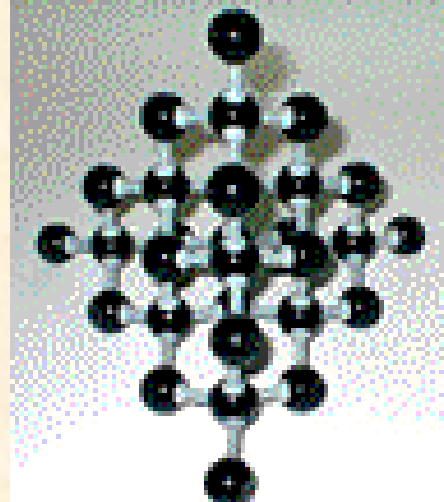
- Stone Age – Bronze Age – Iron Age
- The modern era has seen iron advance to steel
 - Achieved by trial and error starting with Excalibur
- More recently we've moved to silicon
- All of these are actually relatively “simple” materials
 - Increasingly we are trying to master very complex materials
 - Polymers
 - Proteins
 - Nanomaterials
 - Superconductors
- Understanding complicated materials requires sophisticated scientific tools

Structure determines properties

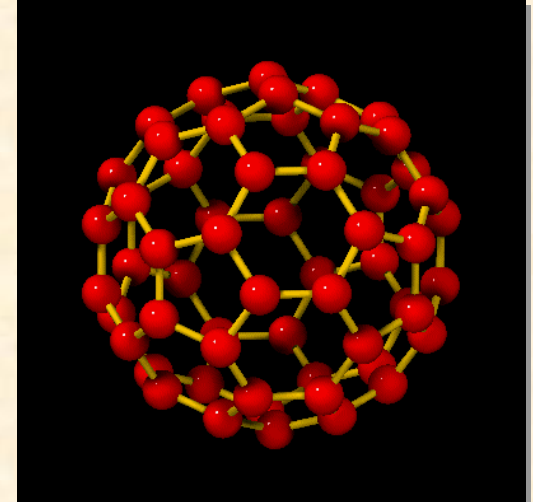
Three forms of carbon – very different materials



Graphite



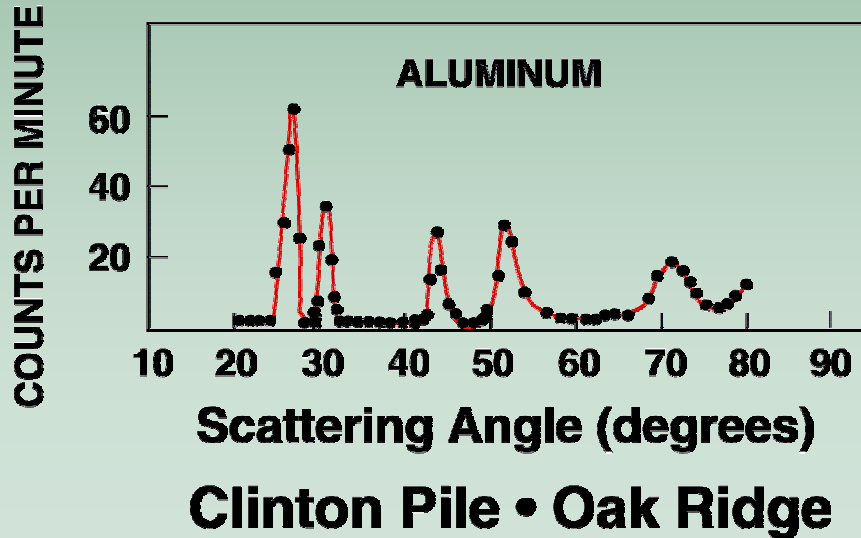
Diamond



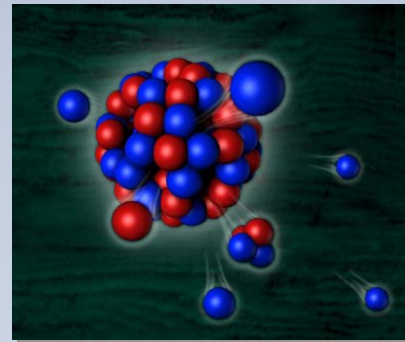
Buckyballs

Neutrons and neutron sources *Continued*

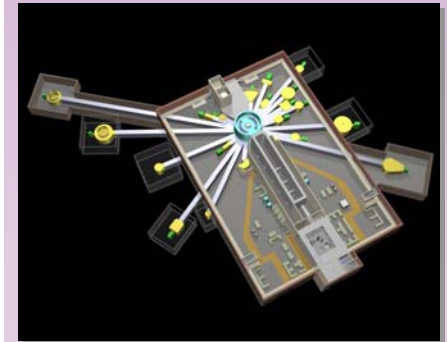
The application of slow neutron scattering to the study of condensed matter had its birth in the work of Wollan and Shull (1948) on neutron powder diffraction



The neutron is a weakly interacting, non-perturbing probe with simple, well-understood coupling to atoms and spins

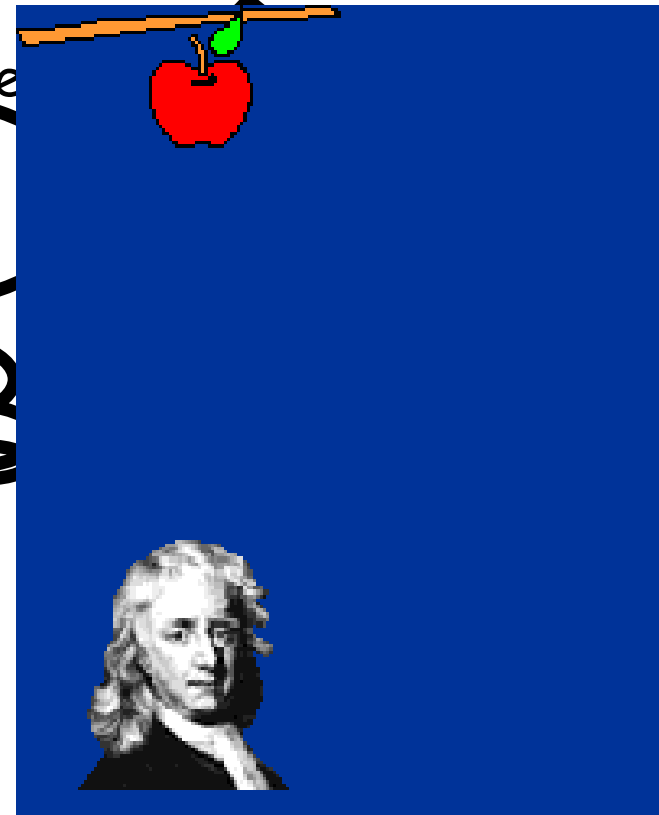


The scattering experiment tells you about the sample, not the probe



Newton's First Law and the concept of force!

Every object continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it.

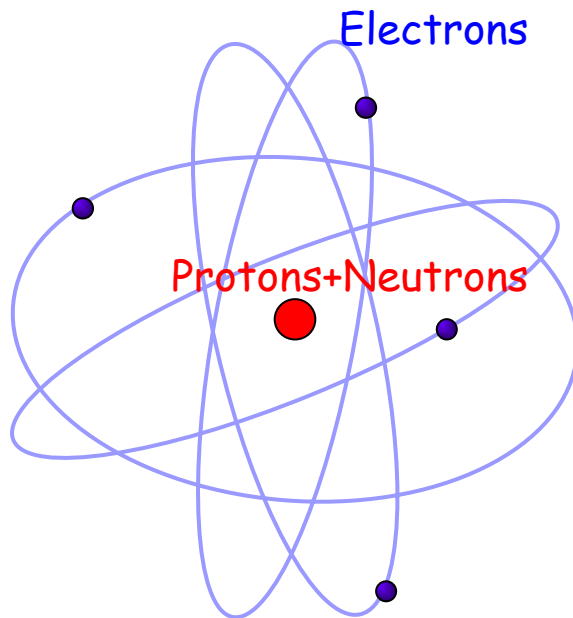


Electricity and Magnetism



- Electrons have a negative charge
- Protons have a positive charge
- Neutrons have no charge

- Opposite charges attract
- Like charges repel



Rutherford, 1912

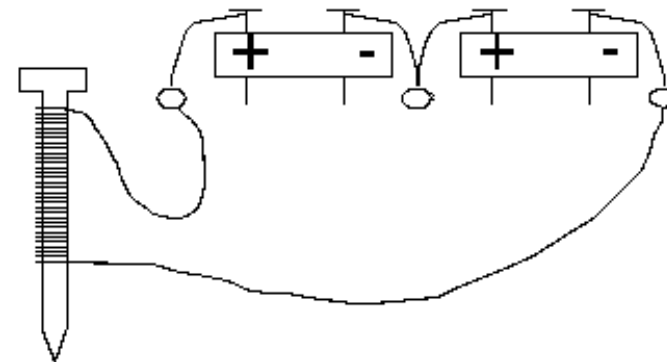
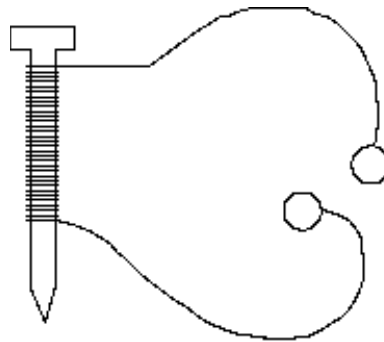


Moving charges, currents, and electromagnets

- If charges move they represent a current
- Currents can transport energy
- Currents can produce magnetic fields
- Magnetic fields can change the direction of moving charges

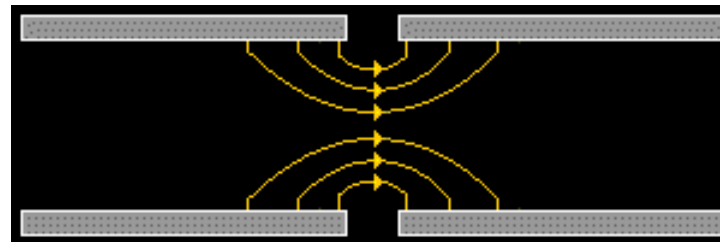
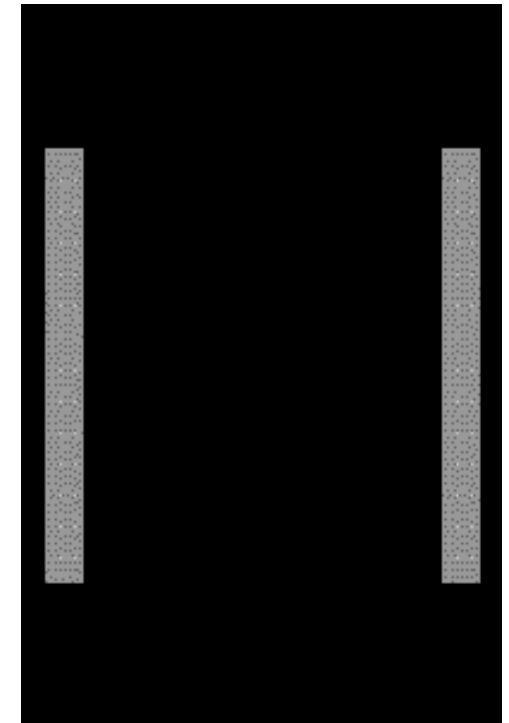
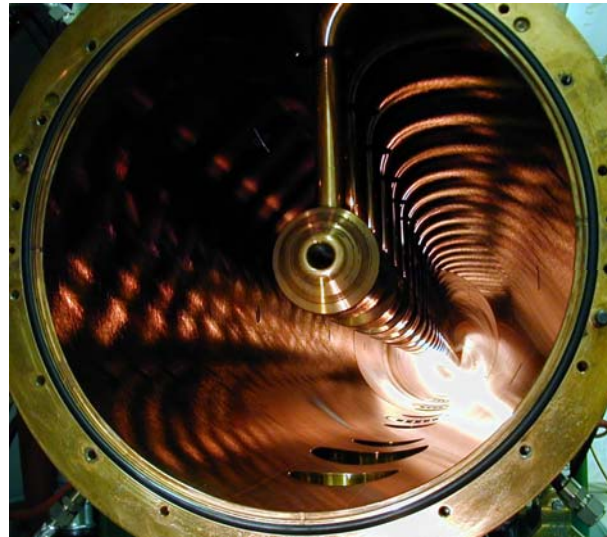
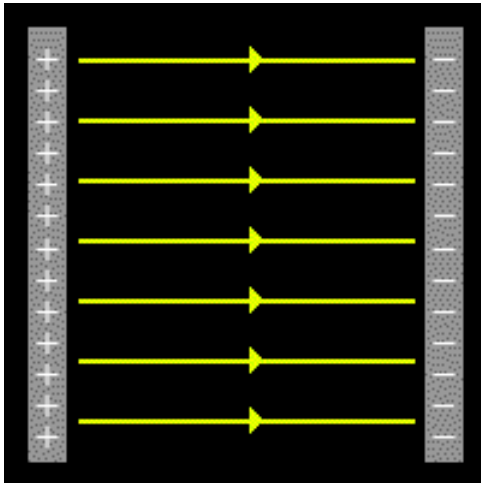


What happens if
a compass comes close?



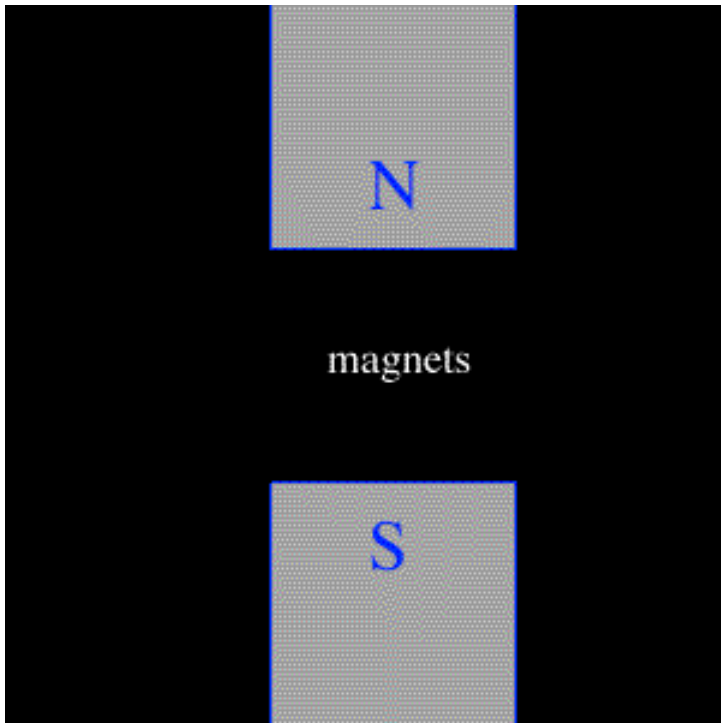
Force and Acceleration: Electric Fields

- An electric field will impose a force on charge, and the charge will be accelerated along the direction of the force !!!



Force and Acceleration: Magnetic Fields

- In a magnetic field a moving charge will be accelerated perpendicular:
 - To the direction of motion
 - To the direction of the magnetic field

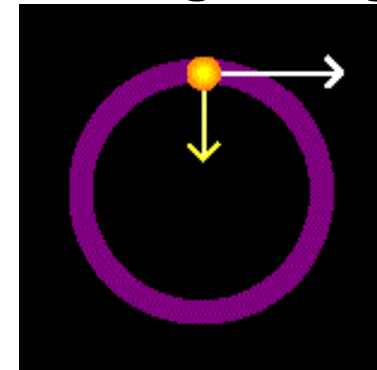


TOP VIEW

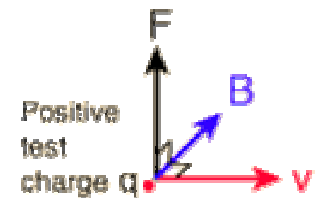


Charged Particle

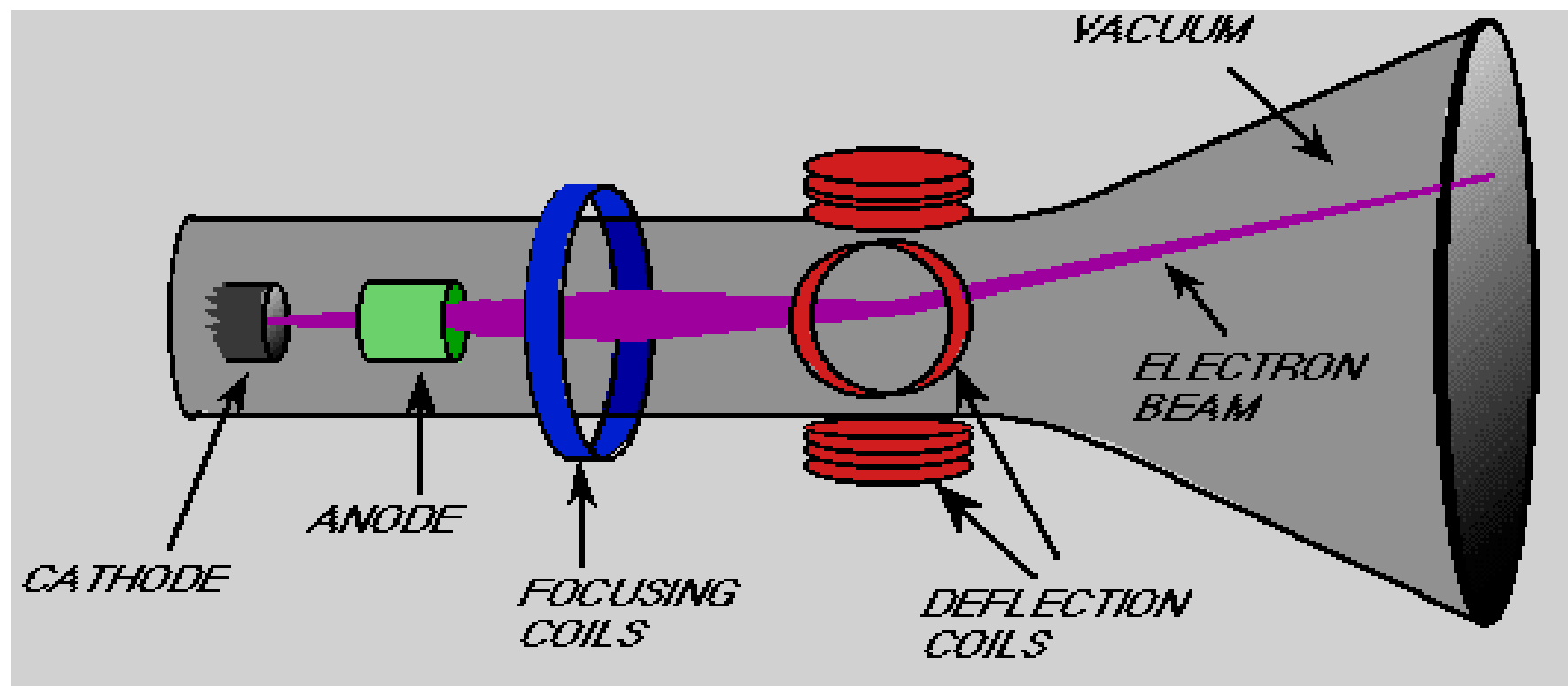
Storage Ring

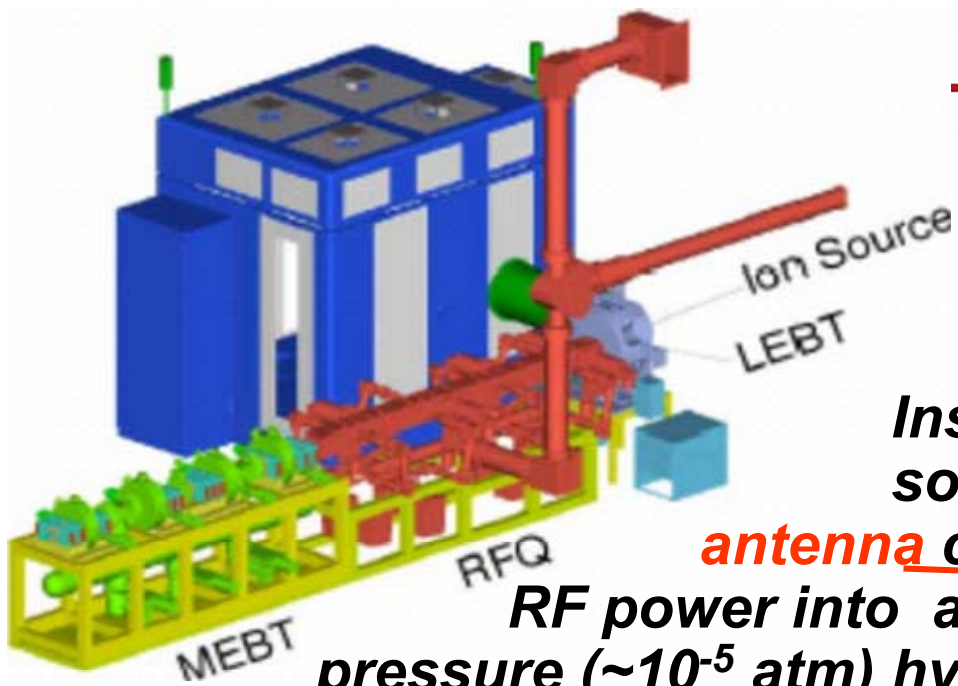


$$\vec{F} = q\vec{v} \times \vec{B}$$

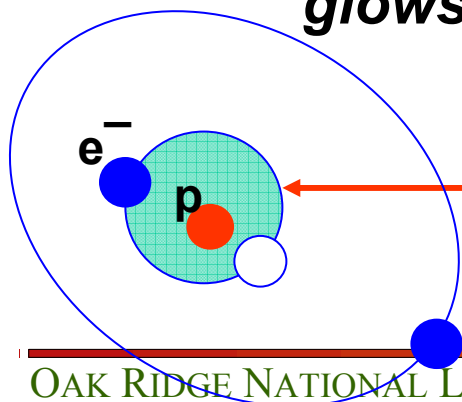
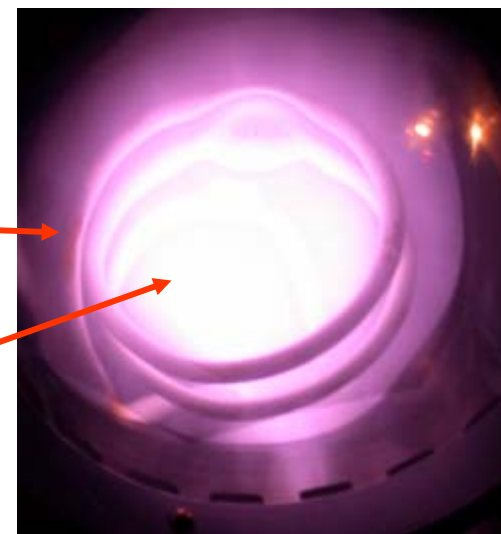


The Simplest DC Electron Accelerator at Home





Inside the ion source the **antenna** couples RF power into a low pressure ($\sim 10^{-5}$ atm) hydrogen gas. The partially ionized gas (**plasma**) glows like a fluorescence light.



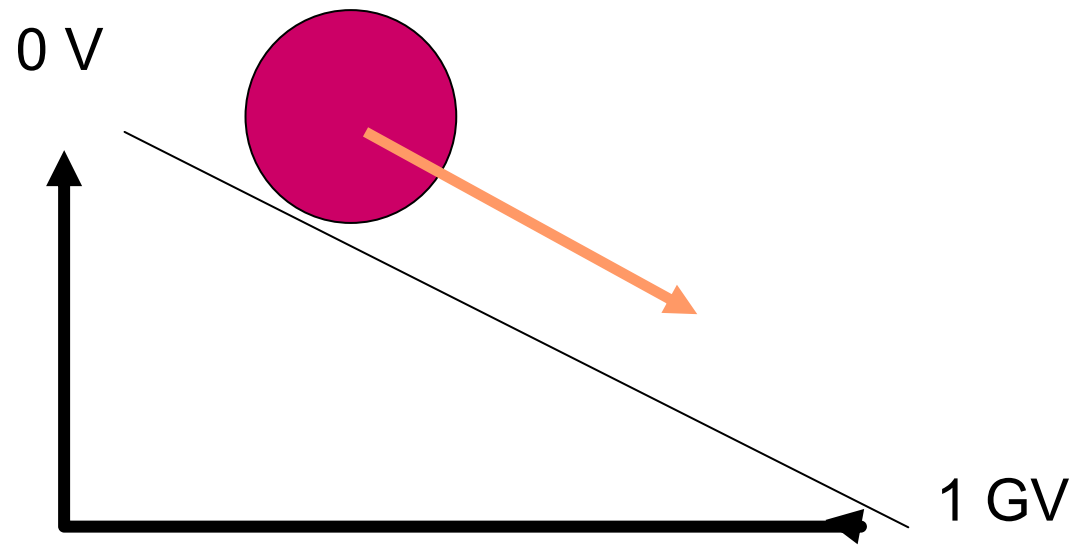
Low energy ions, electrons, **atoms**, and excited molecules drift through a magnetic field towards the exit aperture where some of them form negative Hydrogen ions.

How do we accelerate many charged particles???



- SNS:
 - $1000 \times 1000 \times 10 \times 100 \text{ V} = 1000 \times 1 \text{ Million Volt (MV)}$
 - 1 Giga Volt

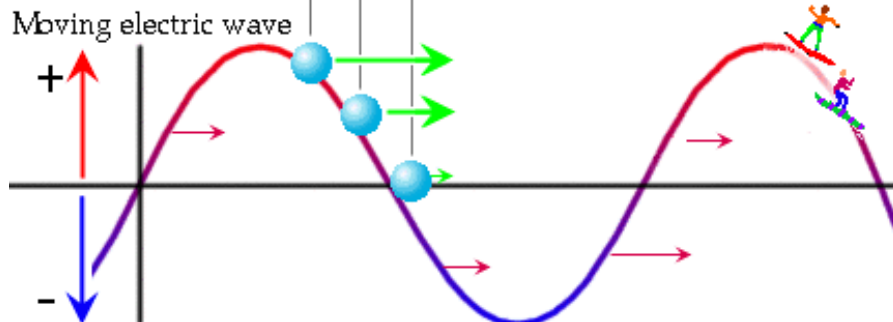
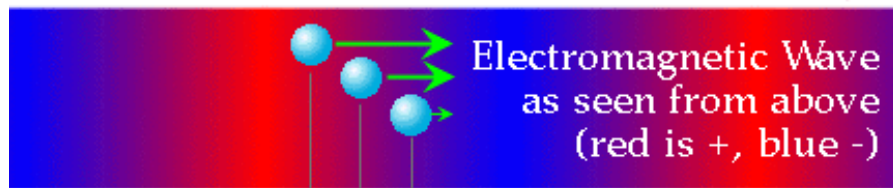
We could use 1 GV DC Voltage??



Or we could be smarter

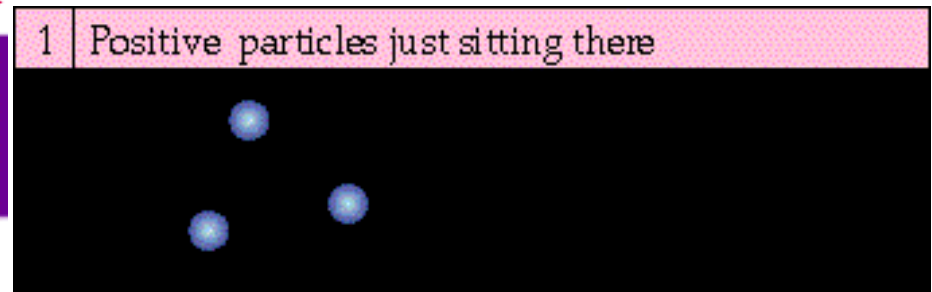
- Riding on a wave is acceleration
- Will show later how we do that !!!

Electromagnetic wave is traveling, pushing particles along with it



Positively charged particles (●) close to the crest of the E-M wave experience the most force forward; those closer to the center experience less of a force. The result is that the particles tend to move together with the wave.

1 Positive particles just sitting there



SNS has a 300 meter long
evacuated tube where we
do this !!!!

The Spallation Neutron Source Partnership



Description	Accelerator	
Project Support	75.6	
Front-End Systems	28.8	28.8
Linac Systems	315.9	315.9
Ring & Transfer System	142.0	142.0
Target Systems	108.2	
Instrument Systems	63.3	
Conventional Facilities	378.9	
Integrated Control Syst	59.7	59.7
BAC	1,164.4	
Contingency	28.3	
TEC	1,192.7	
R&D	100.0	80.0
Pre-Operations	119.0	95.2
TPC	1,411.7	713.6

SNS-ORNL Accelerator systems: ~167 M\$



99-06976F/arb

At peak: ~500 People worked on the construction of the SNS accelerator



Oak Ridge, TN
35° 49' N , 83° 59' W

Spring 1999



Spring 2000



Spring 2001



Spring 2002



Spring 2003



Spring 2004



OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

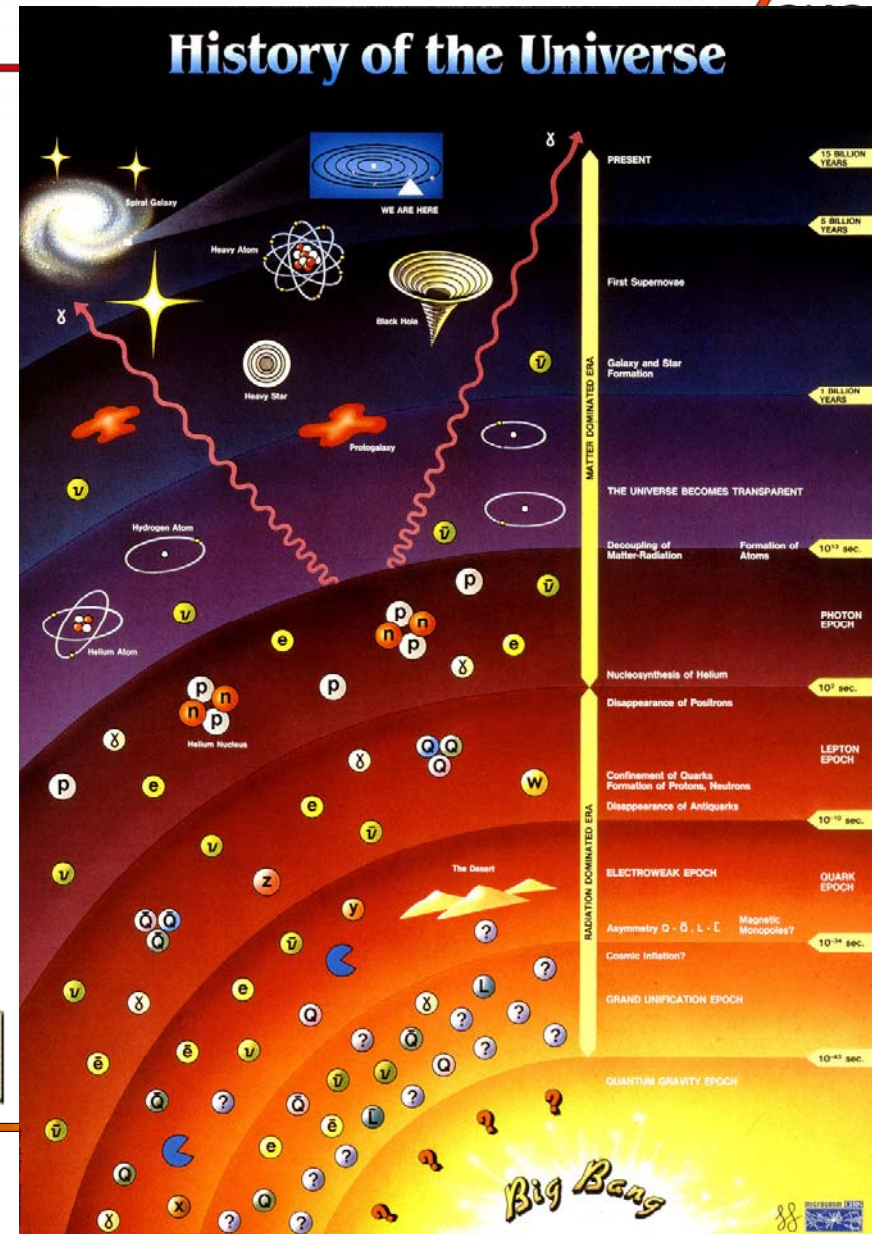
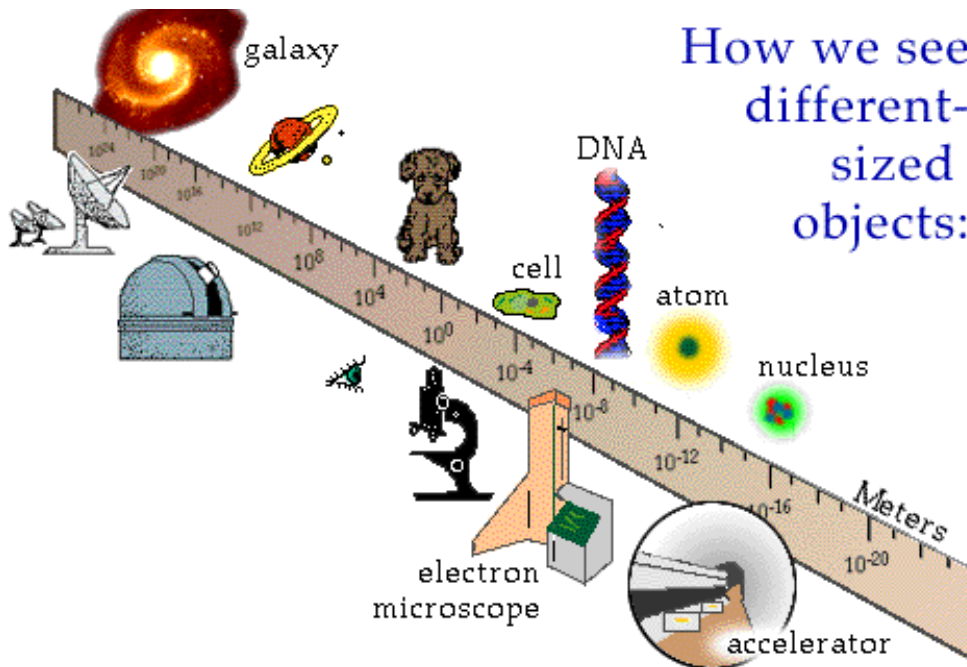


Spring 2005



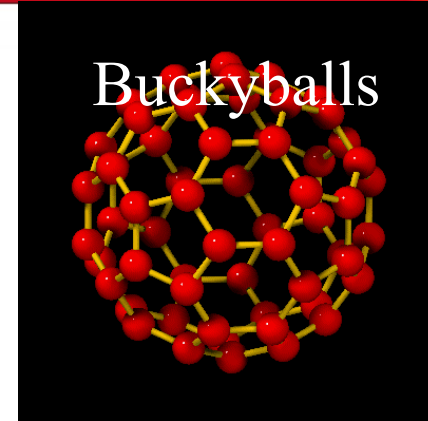
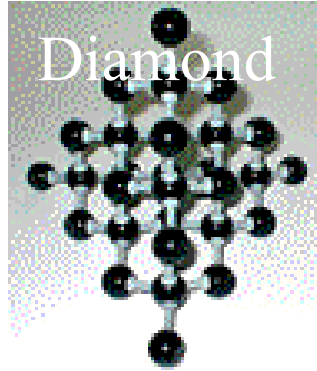
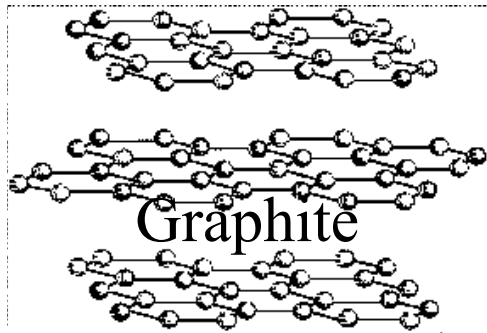
A Sense of Scale

- Next thing: Get a feeling for **time** or **scale** or is it the **same**?: Or why do we built SNS

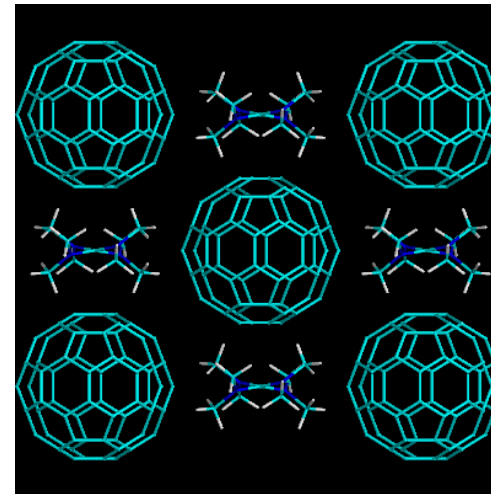
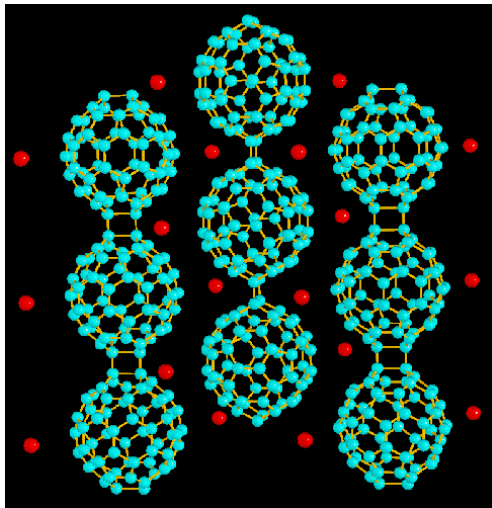


Structure Determines Properties

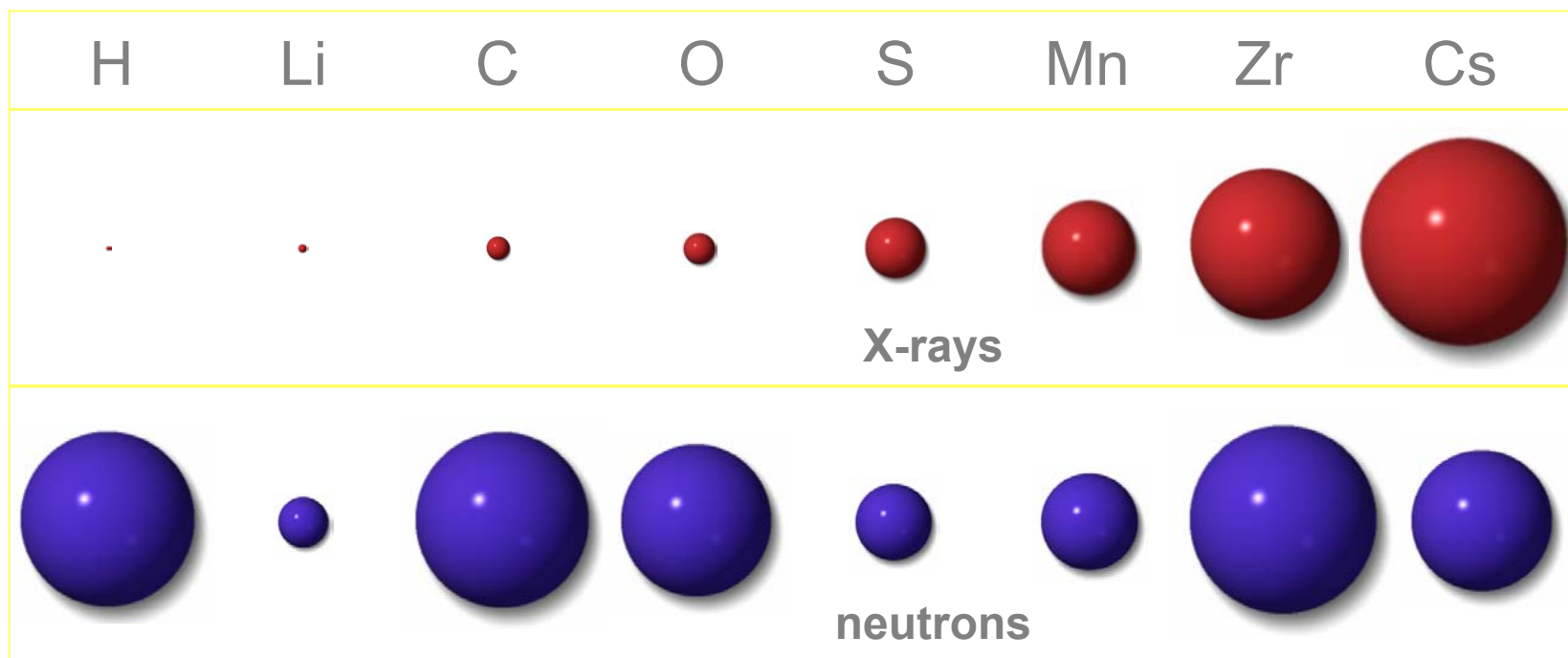
3 forms of Carbon - very different materials



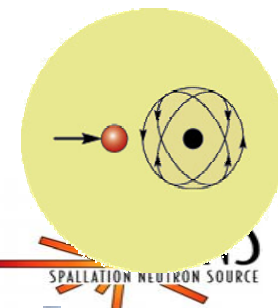
- Superconductors or organic ferromagnets



Neutrons see the Nuclei



Neutrons see the Nuclei

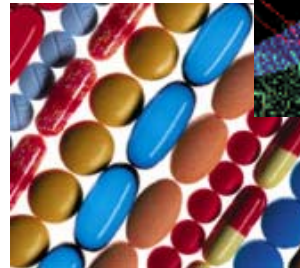
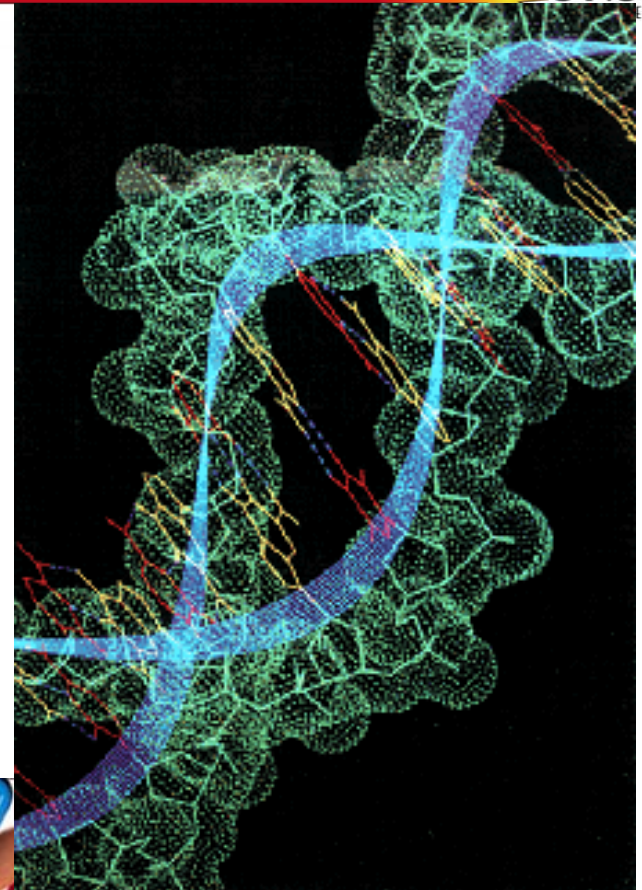


Better performance of complex fluids.

Biology and Neutron Scattering: >95 % of the Body is Water!



- The Human genome project will tell you what sequence the DNA's represent
- Neutron and X-Ray scattering will tell how they function
- Neutrons are very good, because they are sensitive to hydrogen
- New medicine will be developed

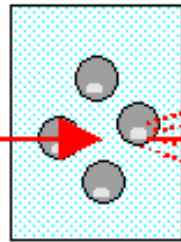


How does it work?

Light or
Neutrons

Neutrons: $\lambda = 5 \div 20 \text{ \AA}$

Light: $\lambda = 4500 \div 6500 \text{ \AA}$



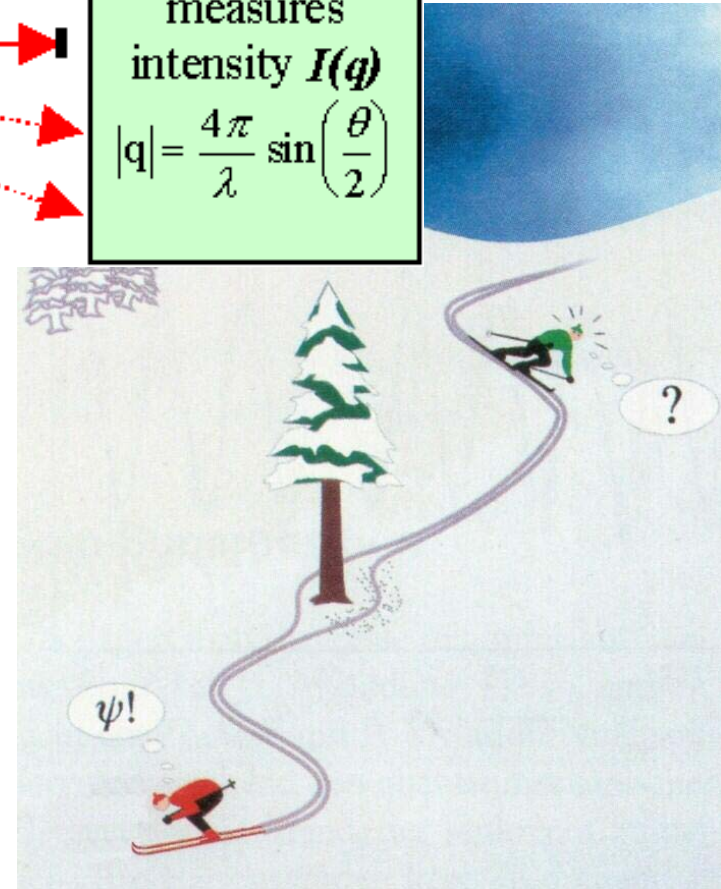
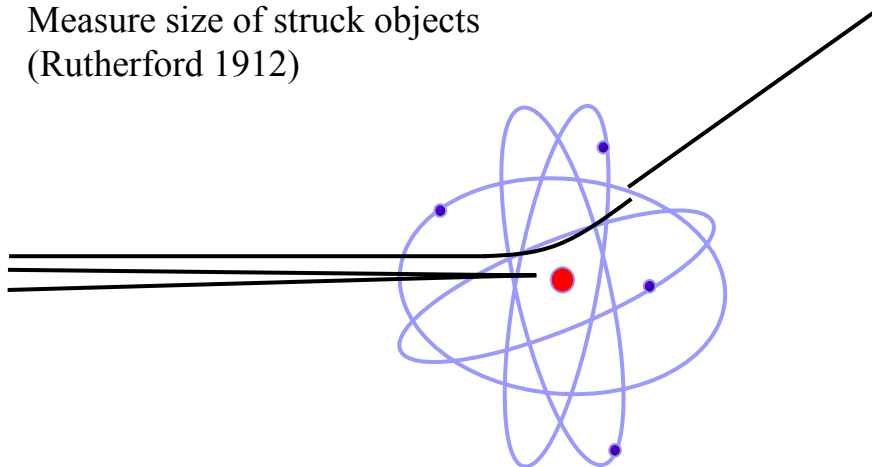
Proteins: $R = 10 \div 50 \text{ \AA}$

Detector
measures
intensity $I(\mathbf{q})$

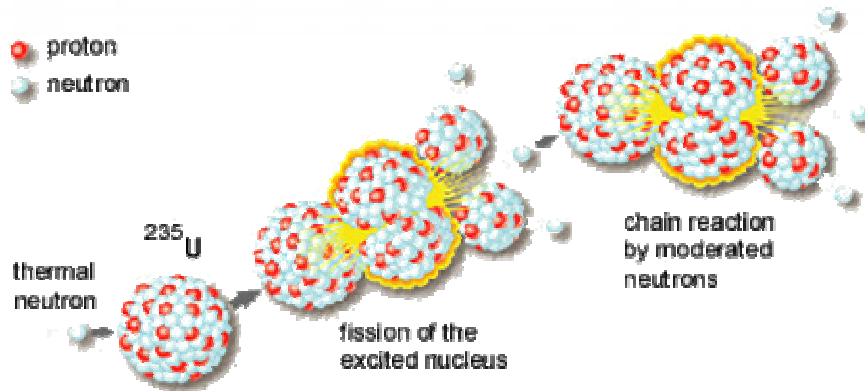
$$|\mathbf{q}| = \frac{4\pi}{\lambda} \sin\left(\frac{\theta}{2}\right)$$

$$\lambda = h/p = h/\sqrt{2 \cdot m_N \cdot E} \quad \text{De Broglie}$$

Measure size of struck objects
(Rutherford 1912)

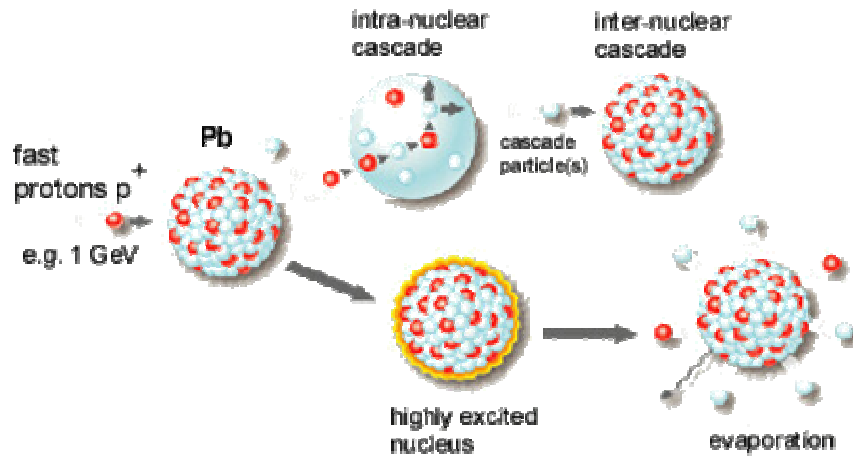


Spallation-Evaporation Production of Neutrons and Why to use heavy metal target



Fission

- chain reaction
- continuous flow
- 1 neutron/fission



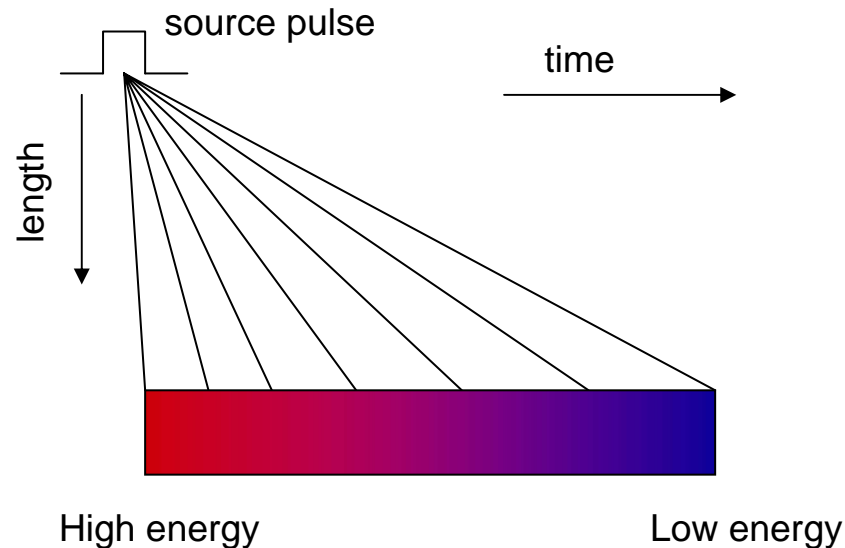
Spallation

- no chain reaction
- pulsed operation
- 30 neutrons/proton

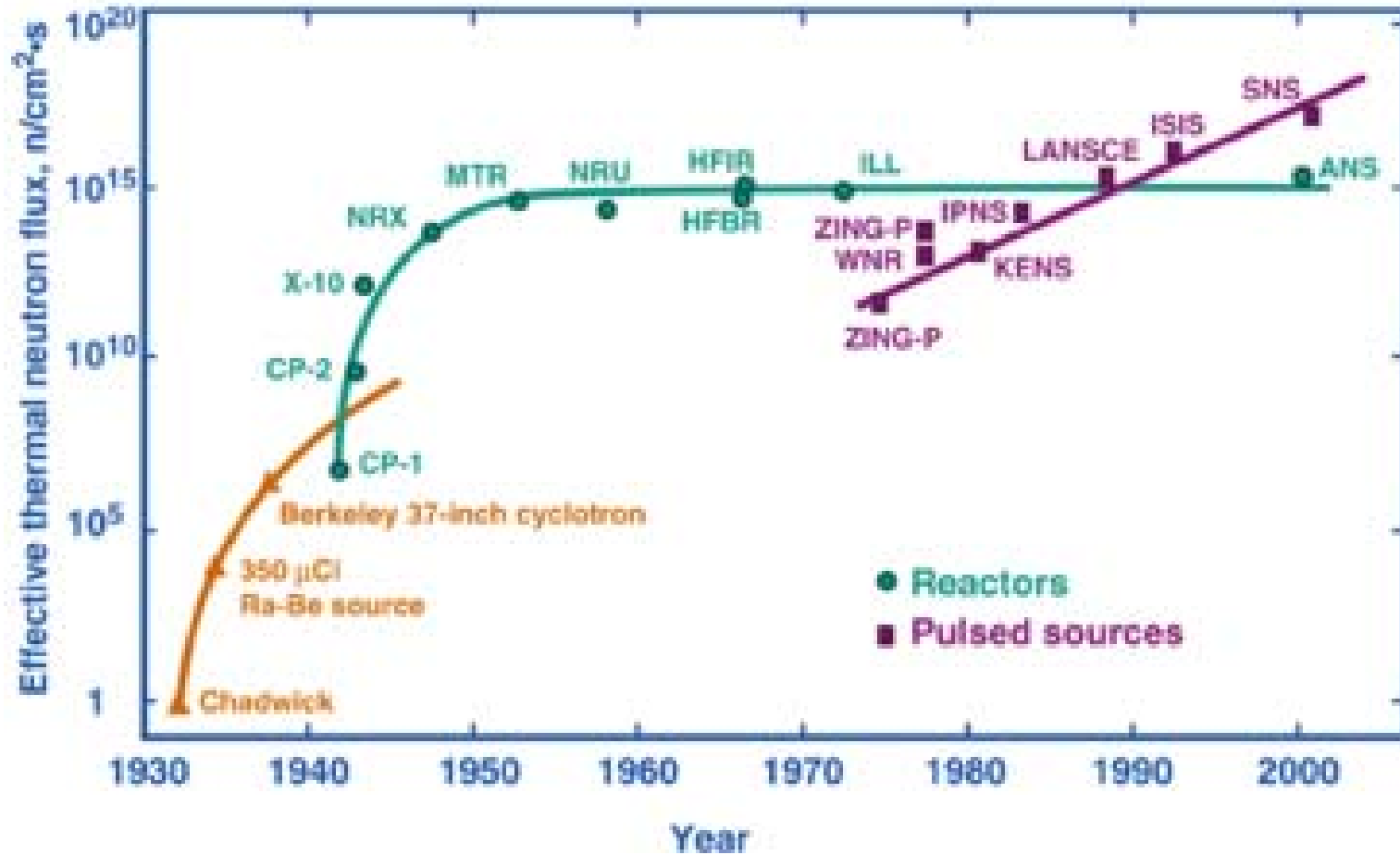
Why a pulsed source?



- Arrival time of neutrons at a sample is directly related to the energy (and wavelength) of the neutrons
 - Can either use this information to get spectral information, or filter out most of the signal to gather data at a particular wavelength
- Create separation in arrival time, i.e. energy or wavelength resolution, by extending length of neutron beam line



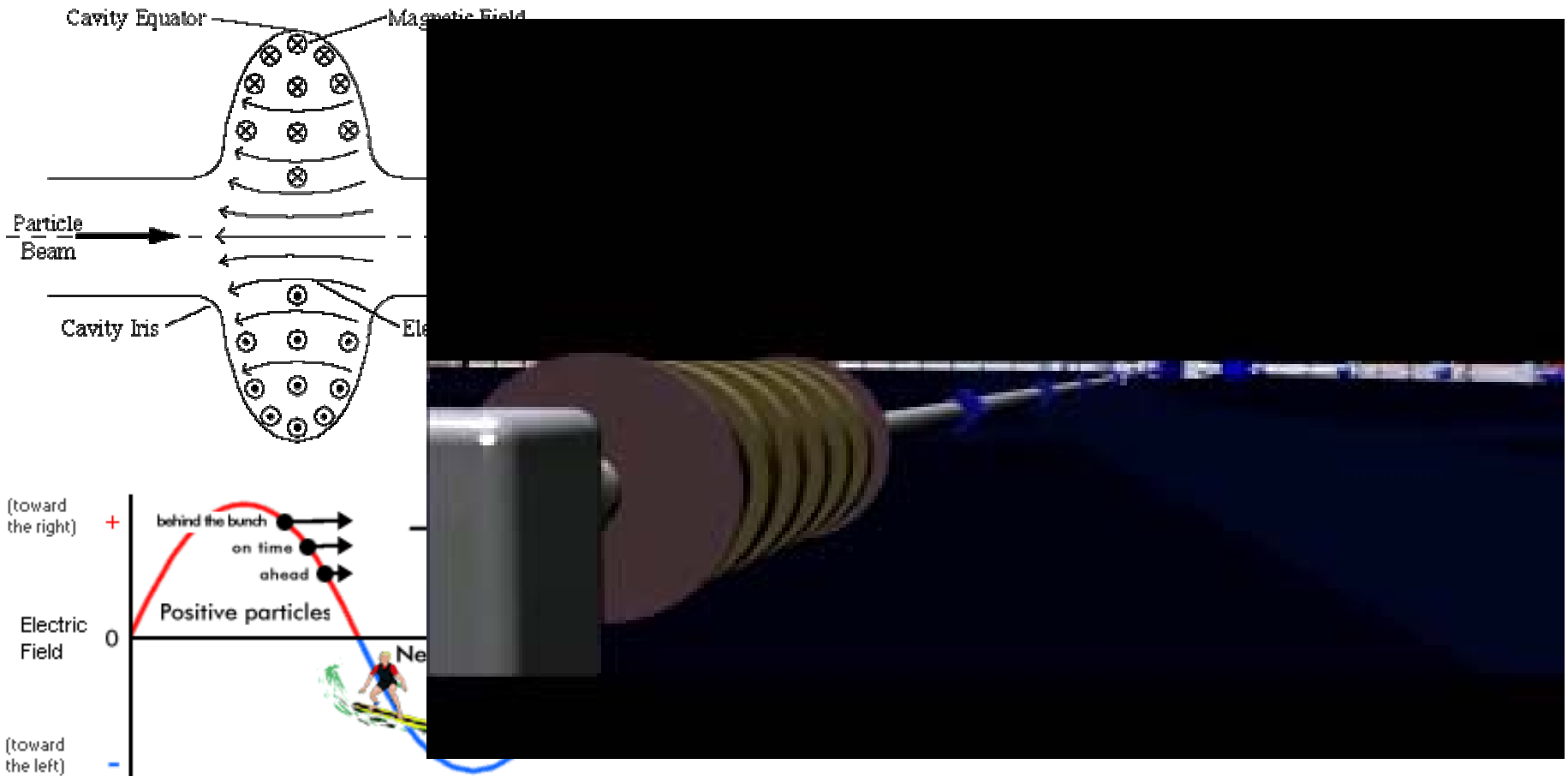
SNS will be World-Class! (being the best...)



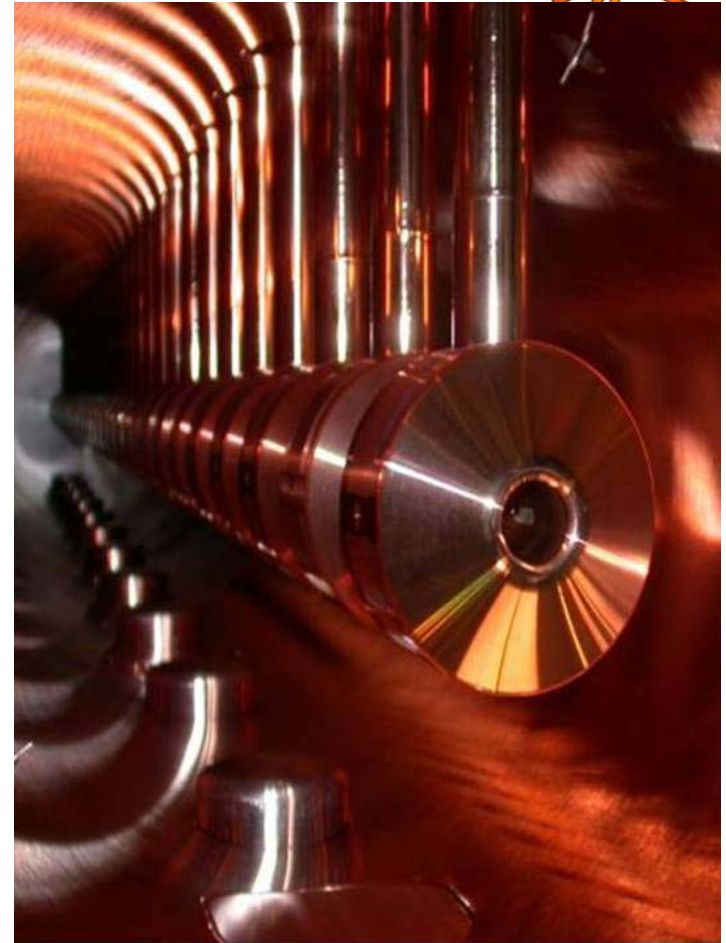
97-3924E uc/djr

RF Acceleration for the SNS

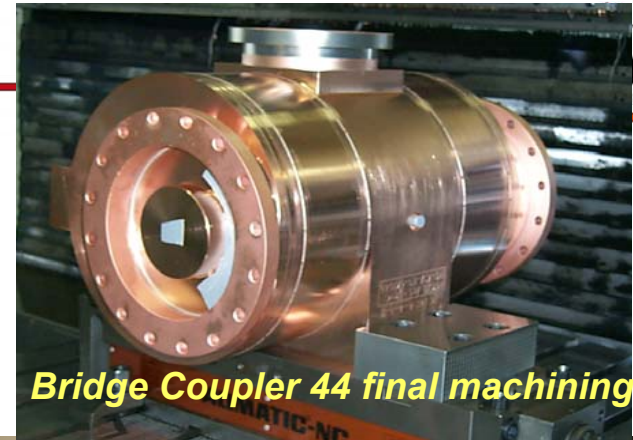
- How to efficiently accelerator H^- ions / charged particles?



Drift Tube Linac



Coupled-Cavity Linac



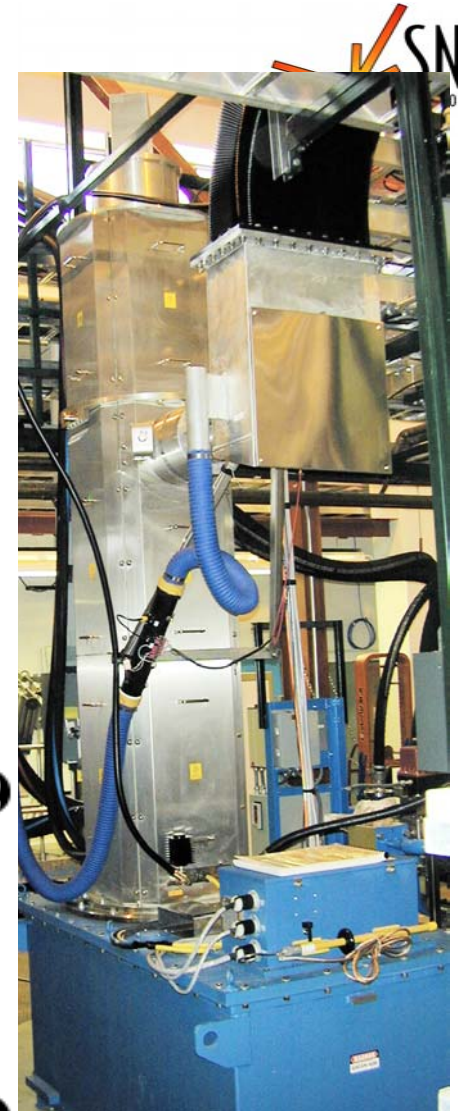
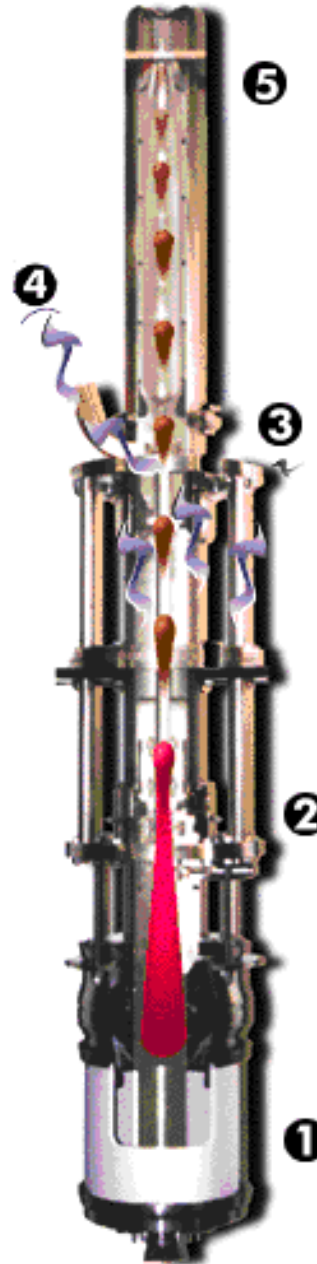
Bridge Coupler 44 final machining



Installation Complete August 2004

Major Components of the SNS High Power RF System

- Radio frequency is the heart of the accelerator
- So how do we make it (or: what happens in a microwave oven?)



High-Power RF Installation



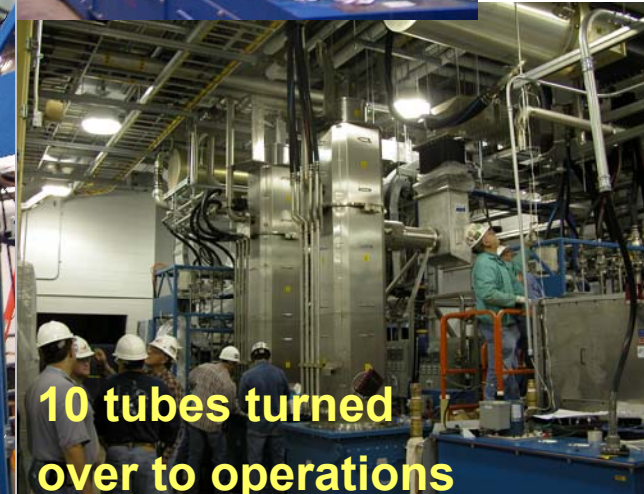
- High-Power RF System (klystrons, waveguide, power supplies, ...) supplied by LANL



81 klystrons out of 81
for sc linac in place



4 CCL 5 MW
Klystron

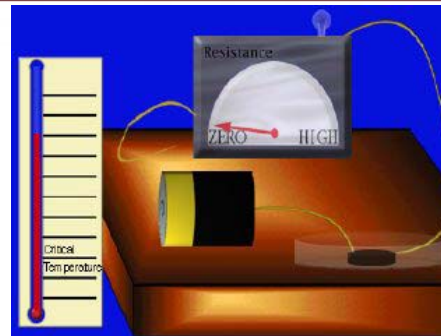
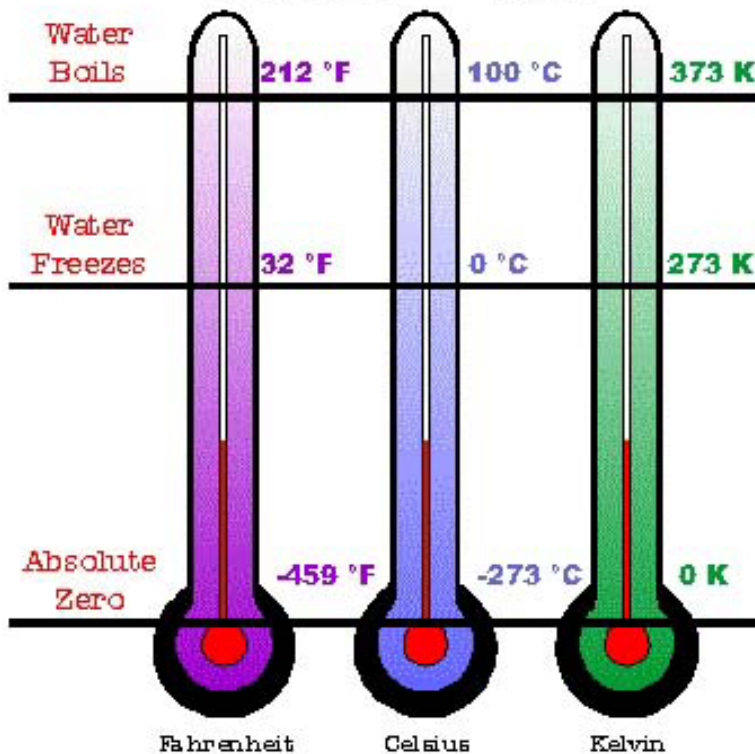


10 tubes turned
over to operations

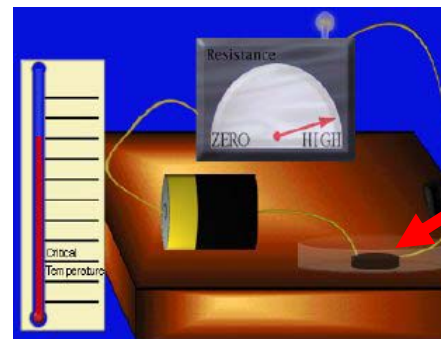
Superconductivity

Absolute Zero

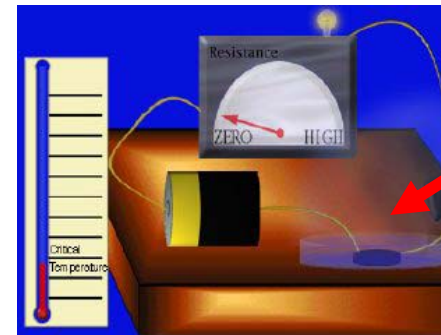
Thermometers compare Fahrenheit, Celsius and Kelvin scales.



Current 0



Current on,
Resistance is high



Current on,
Resistance very low,
After cooled down

Cavity Preparation

BCP 1:1:1 or 1:1:2
~120 μ m removed

~1hr HPR

Assembly in
clean room
(class 100)

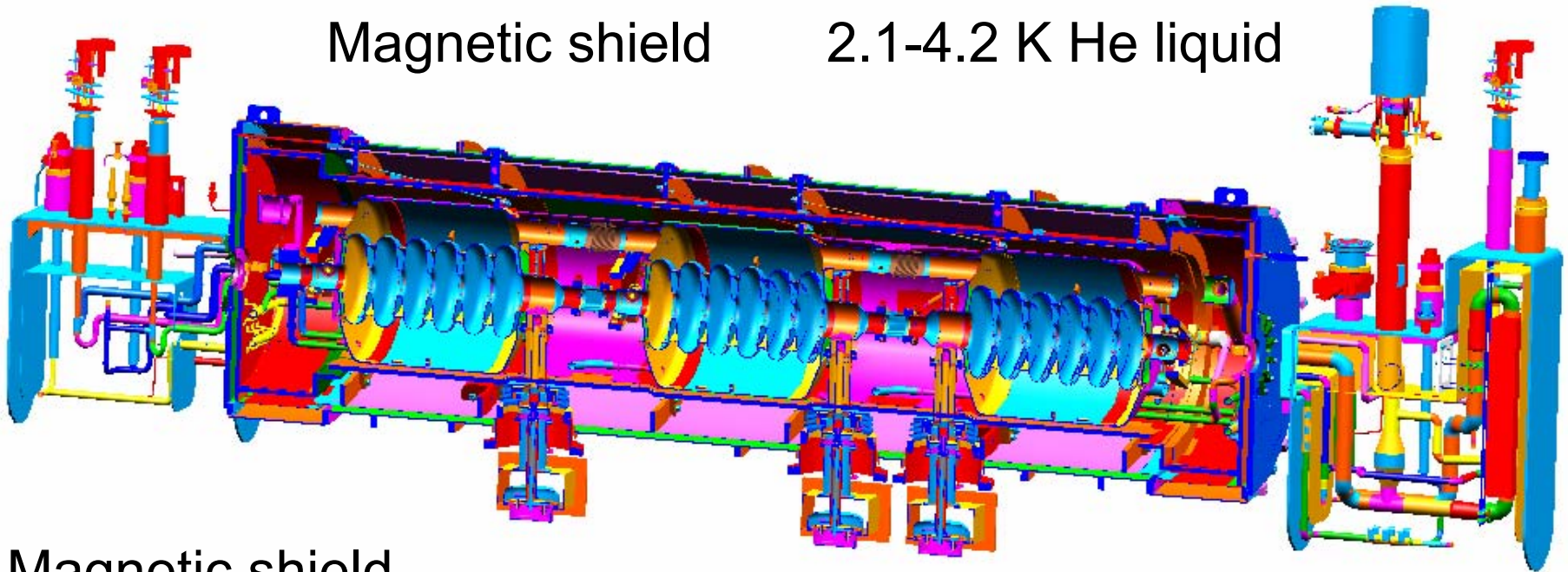
Dewar
insertion



Medium Beta Cryomodule Internal Structure

Magnetic shield

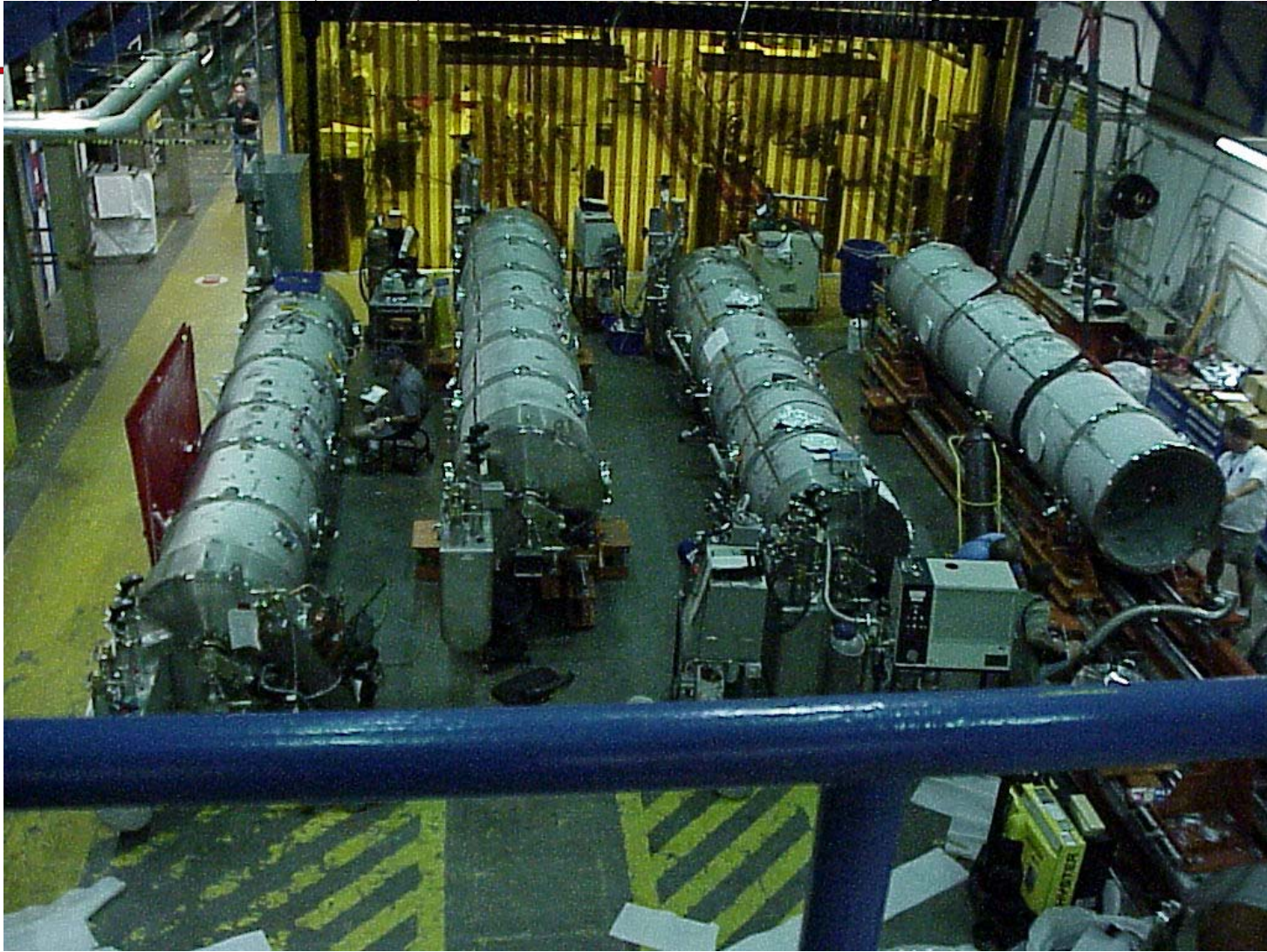
2.1-4.2 K He liquid



Magnetic shield

Thermal shield at 50 K

Cryomodules H1, H3, & H5 thru H8 Sep 04



Status of Superconducting Linac



- SCL accelerates beam from 187 to 1000 MeV
- Jefferson Lab is building 23 cryomodules with 81 SC cavities

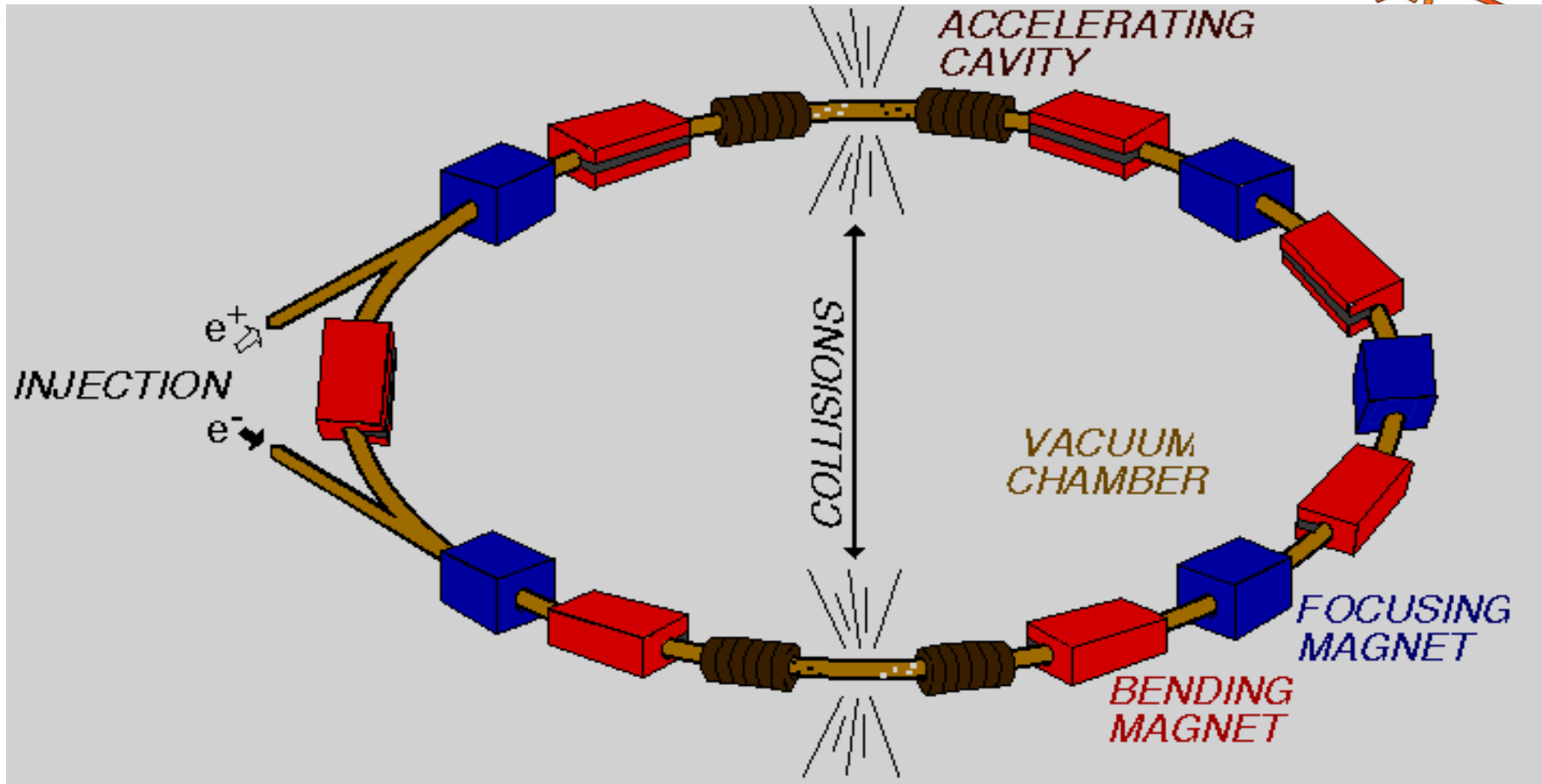


Cavities are assembled into strings

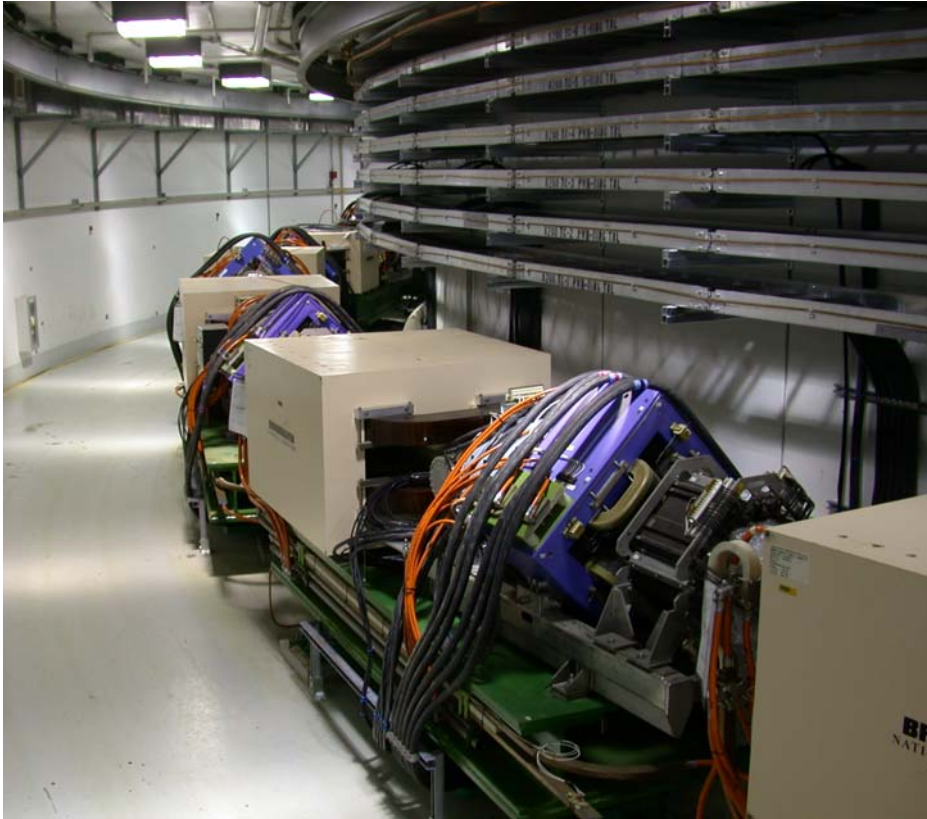


High beta cavity

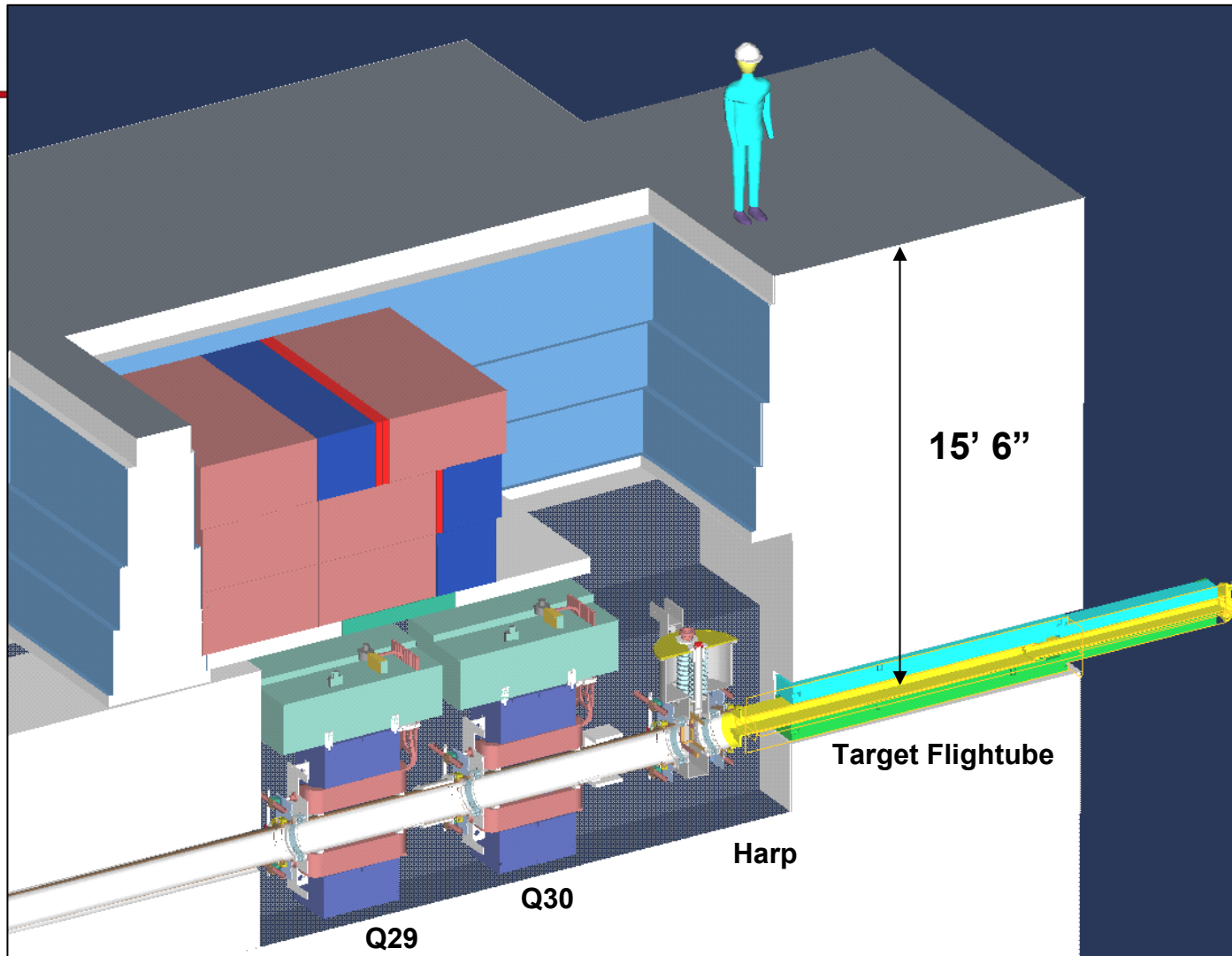
The SNS Storage Ring



RTBT Installation Progress

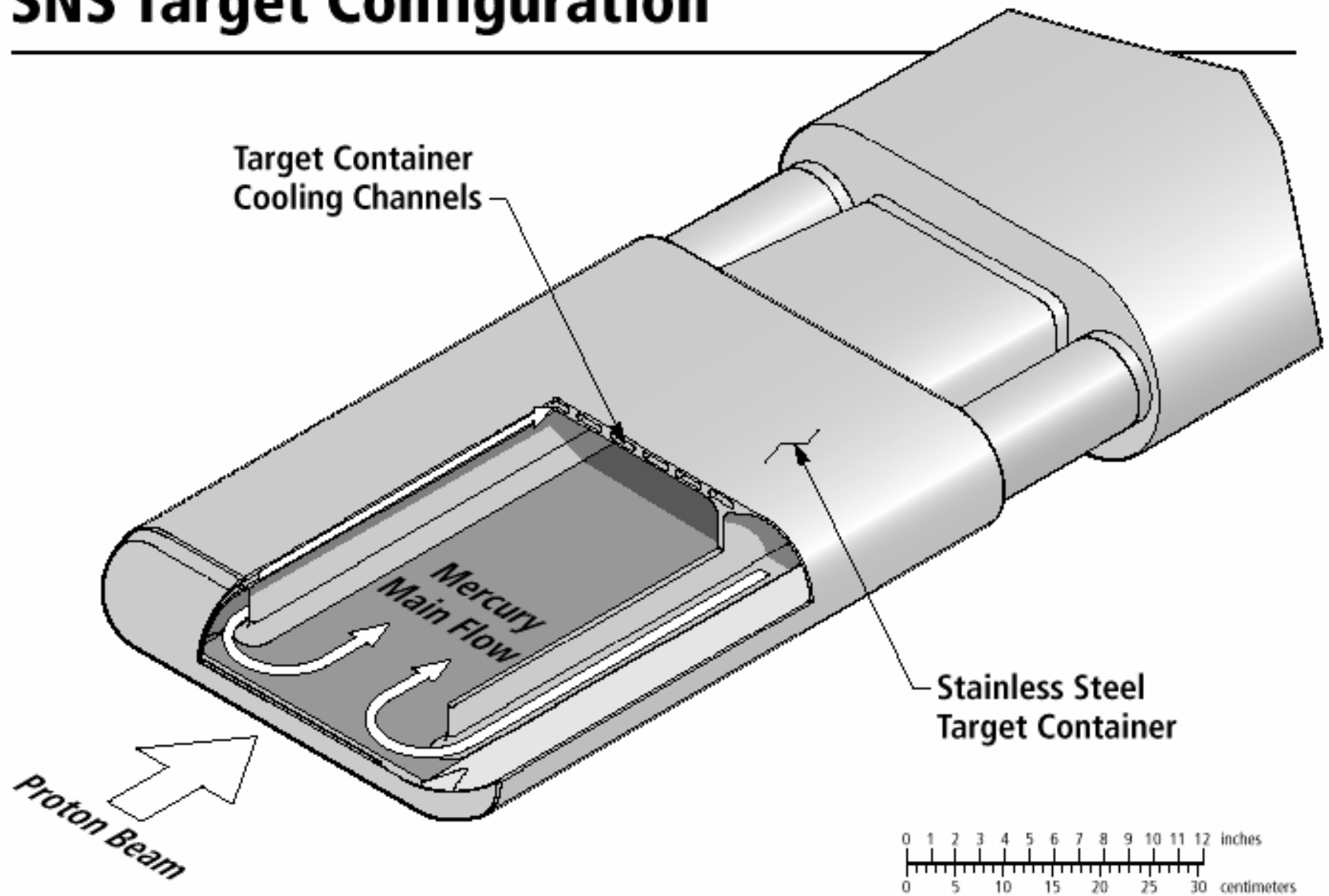


RTBT/Target Interface

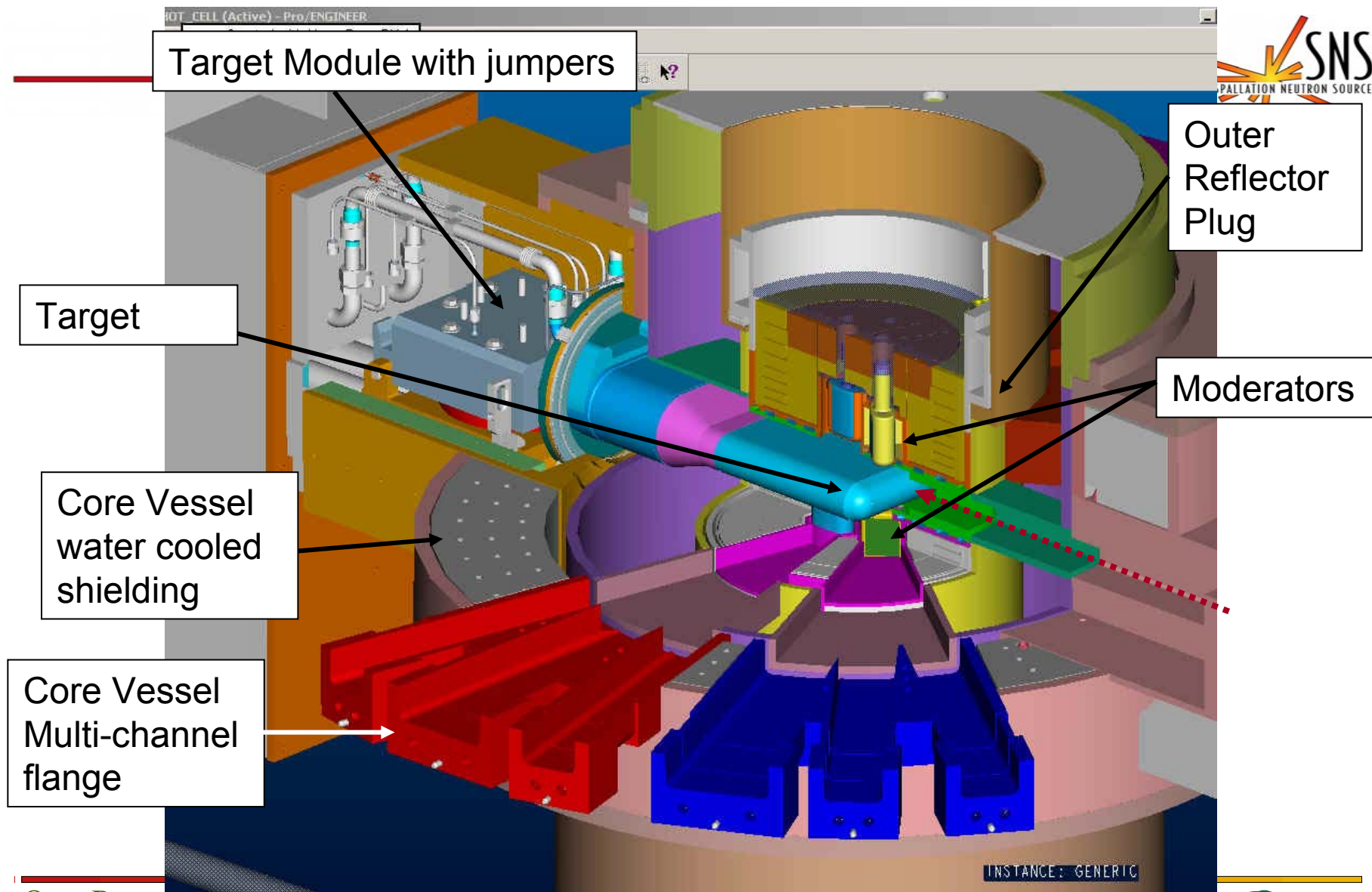


Section through RTBT/Target Flight-tube Interface

SNS Target Configuration



Target Region Within Core Vessel



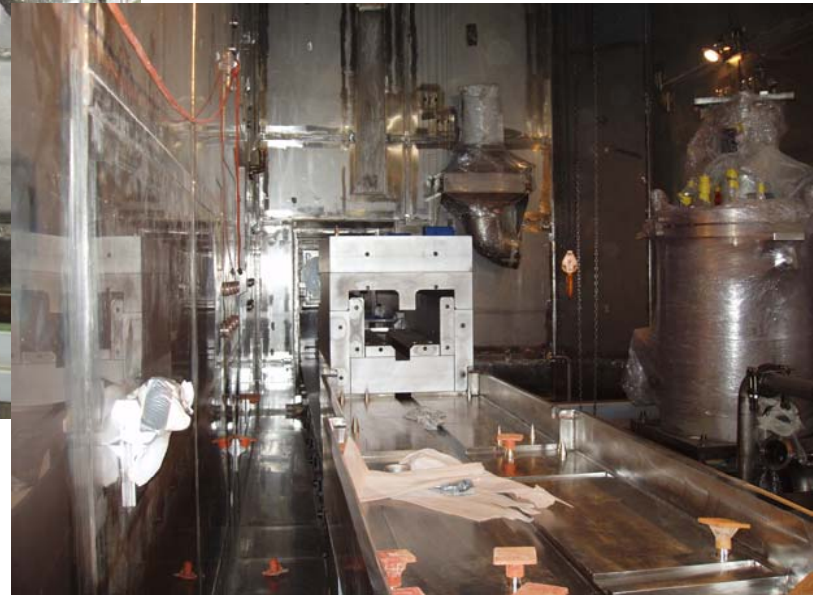
Target Service Bay Installation



- Target is transitioning from civil construction to installation



- GC installation of target systems in Target Service Bay completed in Jan. 05
- Outer Reflector Plug in place – Jan. 05



Seventeen instruments now formally approved

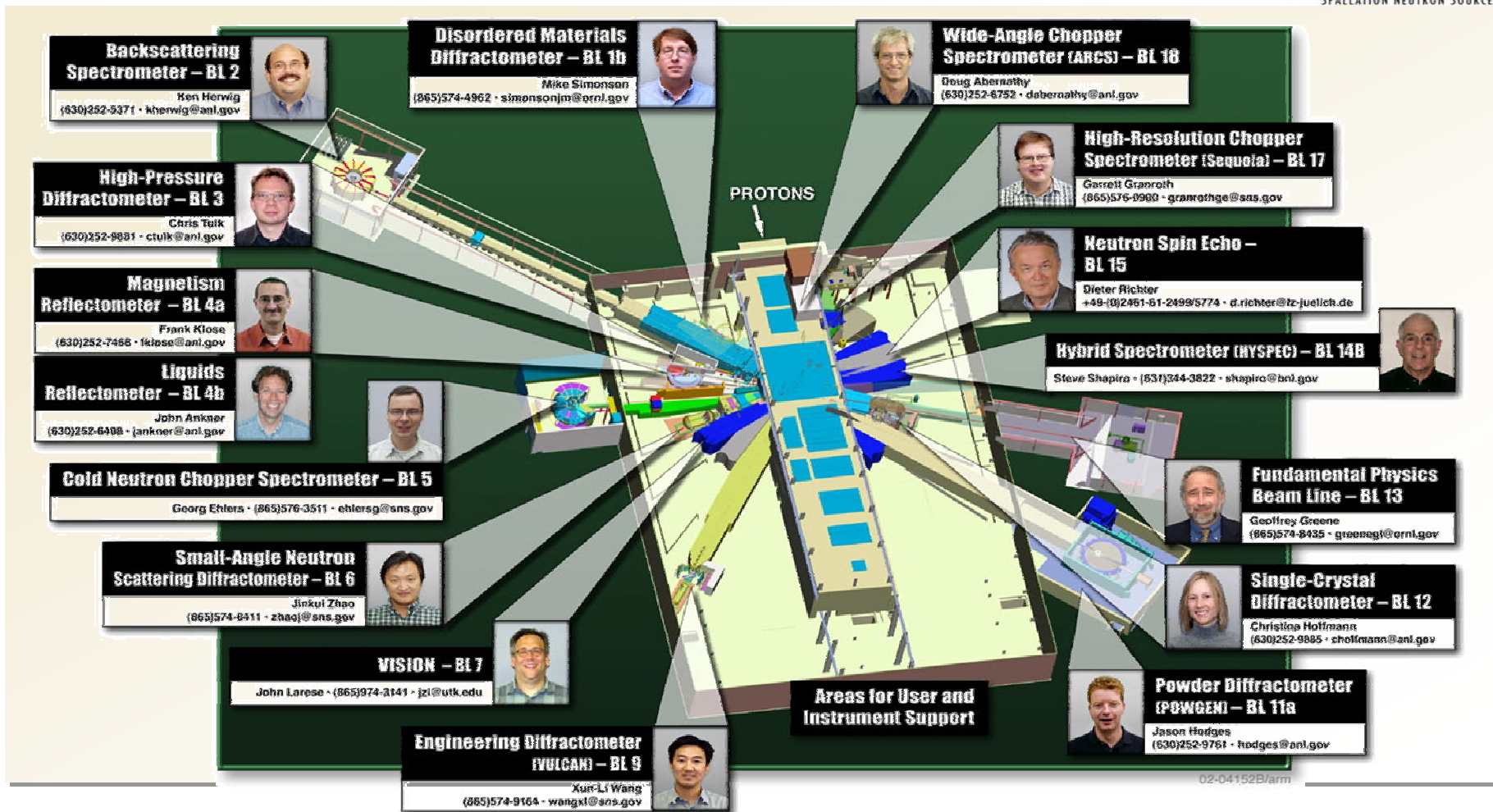


Diagram illustrating the layout of the Spallation Neutron Source (SNS) instrument hall, showing 17 approved instruments and their respective beam lines. The central beam line is labeled "PROTONS".

- Backscattering Spectrometer – BL 2**
Ken Herwig
(630)252-8371 • kherwig@anl.gov
- Disordered Materials Diffractometer – BL 1b**
Mike Simonson
(865)574-4962 • simonsonjm@ornl.gov
- Wide-Angle Chopper Spectrometer (ARCS) – BL 18**
Doug Abernathy
(630)252-6752 • daberathy@anl.gov
- High-Resolution Chopper Spectrometer (Sequela) – BL 17**
Garrett Granroth
(865)576-0900 • granrothge@sns.gov
- High-Pressure Diffractometer – BL 3**
Chris Tulk
(630)252-8881 • ctulk@anl.gov
- Neutron Spin Echo – BL 15**
Dieter Richter
+49-(0)2461-61-2498/5774 • d.richter@tz-juelich.de
- Magnetism Reflectometer – BL 4a**
Frank Klose
(630)252-7456 • fklose@anl.gov
- Hybrid Spectrometer (HYSPEC) – BL 14B**
Steve Shapiro • (631)344-3822 • shapiro@bnl.gov
- Liquids Reflectometer – BL 4b**
John Ankoer
(630)252-6400 • jankoer@anl.gov
- Fundamental Physics Beam Line – BL 13**
Geoffrey Greene
(865)574-8435 • greenejl@ornl.gov
- Cold Neutron Chopper Spectrometer – BL 5**
Georg Ehlers • (865)576-3511 • ehlersg@sns.gov
- Single-Crystal Diffractometer – BL 12**
Christina Hoffmann
(630)252-9885 • choffmann@anl.gov
- Small-Angle Neutron Scattering Diffractometer – BL 6**
Jinkui Zhao
(865)574-8411 • zhaoj@sns.gov
- VISION – BL 7**
John Larese • (865)974-3141 • jzl@utk.edu
- Powder Diffractometer (POWGEN) – BL 11a**
Jason Hodges
(630)252-9761 • hodges@anl.gov
- Engineering Diffractometer (VULCAN) – BL 9**
Xun-Li Wang
(865)574-9164 • wangxl@sns.gov
- Areas for User and Instrument Support**

02-04152B/arm

SNS

Contact



- For more information about the Spallation Neutron Source Project,
 - Use the SNS public web-site address: <http://www.sns.gov/>
 - Email: snsprojectoffice@sns.gov