Real Accelerators: a facility overview

the nuts and bolts…and gaskets and resistors

United States Particle Accelerator School – Accelerator Fundamentals

Old Dominion University/Hampton VA

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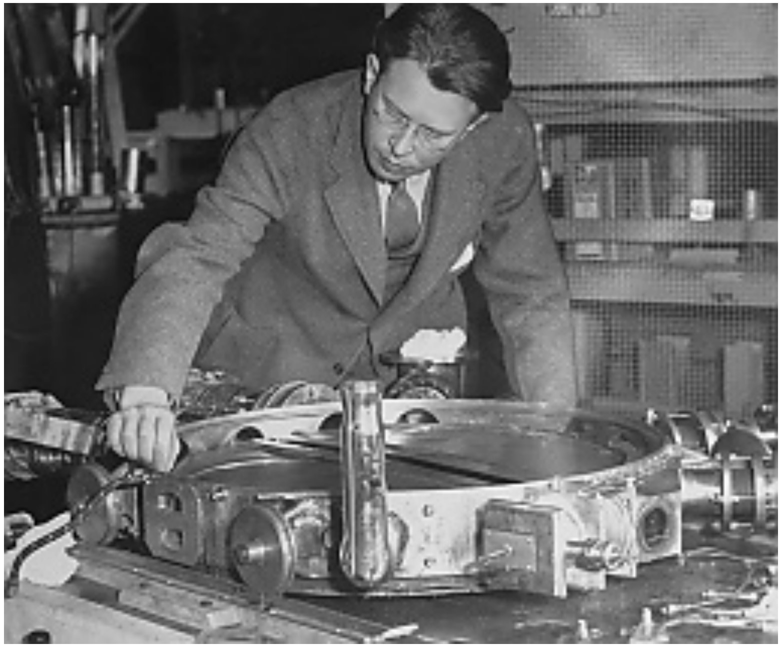
Introduction

- ‘Scratch the surface’ overview
- What goes into making a real working accelerator
- Perspective of ‘big’ machines
- Principles applicable to all types of accelerators
- Interactive

Scale

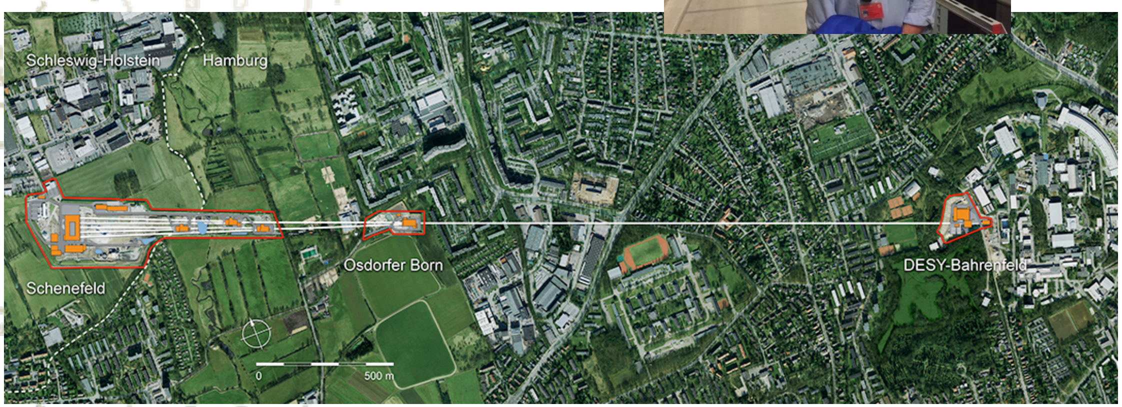
- Table top

E. O. Lawrence
early cyclotron 'dees'
Berkley, California USA

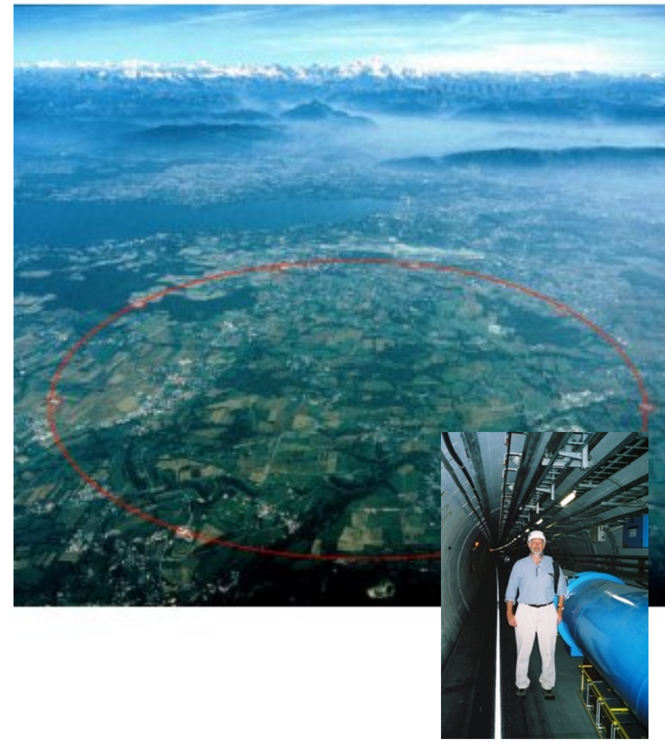


Scale

- Big machines



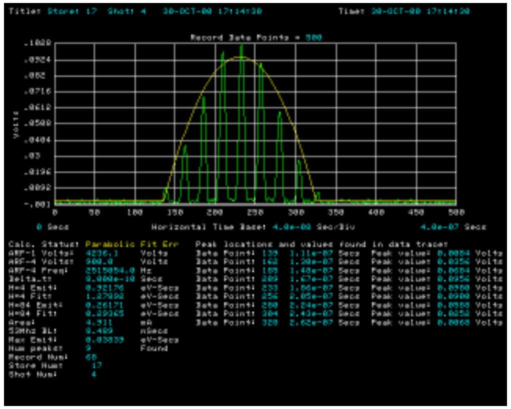
European XFEL – 3.4 kilometers
DESY Hamburg, Germany



LHC – 27 kilometers
CERN Geneva, Switzerland

What makes up an Accelerator?

- Two primary components
  - Magnet system
    - Keep the beam on course
    - Keep the beam focused
  - Radiofrequency system
    - Impart energy to the particle beam
      - Acceleration
      - Maintain beam’s energy (synchrotron light)
      - Maintain structure (collider, storage ring)

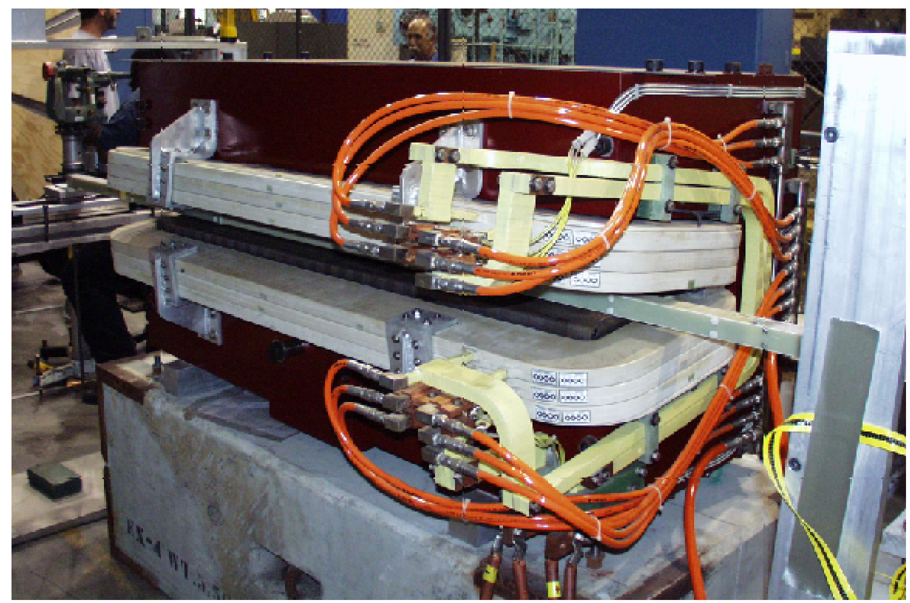


Magnets

- Electromagnets
  - Conventional
    - Water or air-cooled
    - Copper or aluminum coils
    - Iron shapes and contains the field
  - Superconducting
    - Liquid helium cooled
    - Higher fields > higher energies
    - Ramp slowly – eddy currents
    - Coil placement critical to field
- Permanent

Magnets

- Gradient or ‘Combined function’
  - Steering and focusing by a single element



Magnets

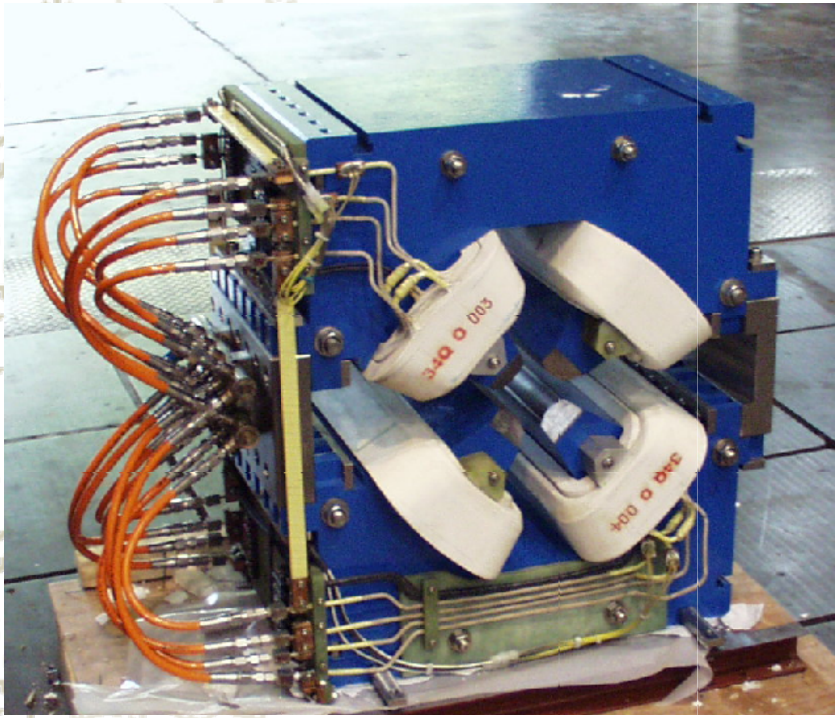
- Separated function
  - Focusing and bending are done by separate elements
    - Quadrupole for focusing
    - Dipole for bending

Magnets

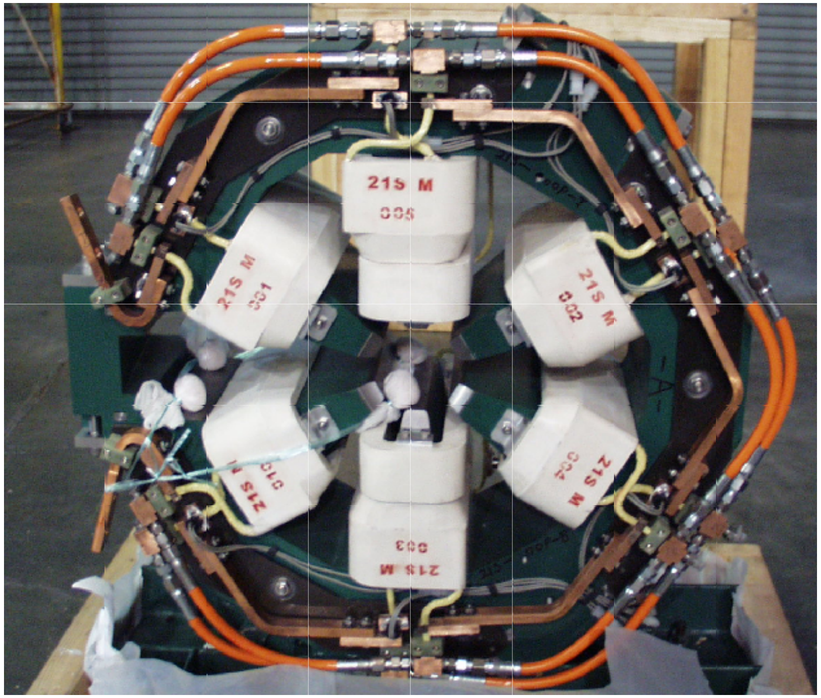
- Flavors
  - Dipoles
  - Quadrupoles
  - Correctors
    - ‘trim’ dipoles
    - (skew) quadrupoles
    - sextupoles
    - even higher order
    - Special purpose
      - Injection/Extraction
      - Light sources

Magnets

- Flavors



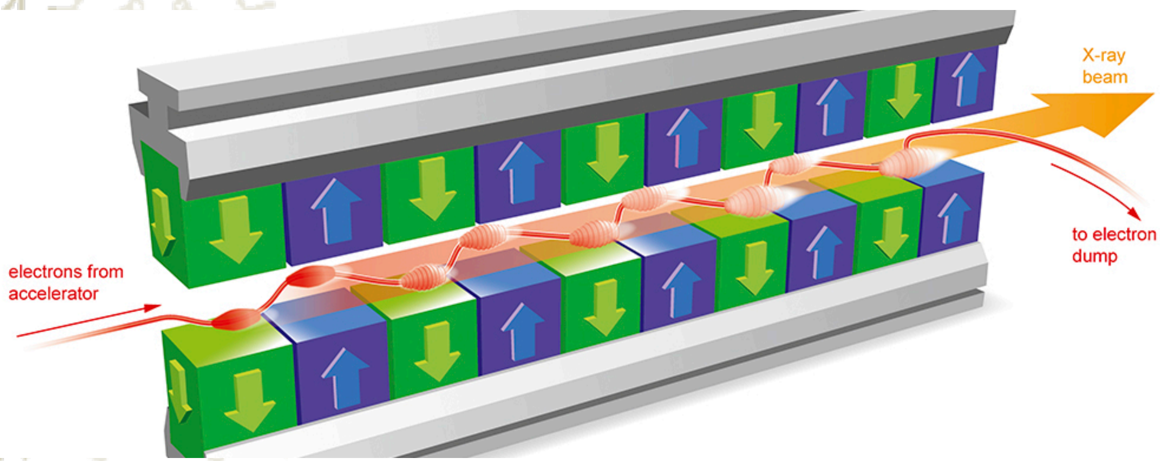
Quadrupole

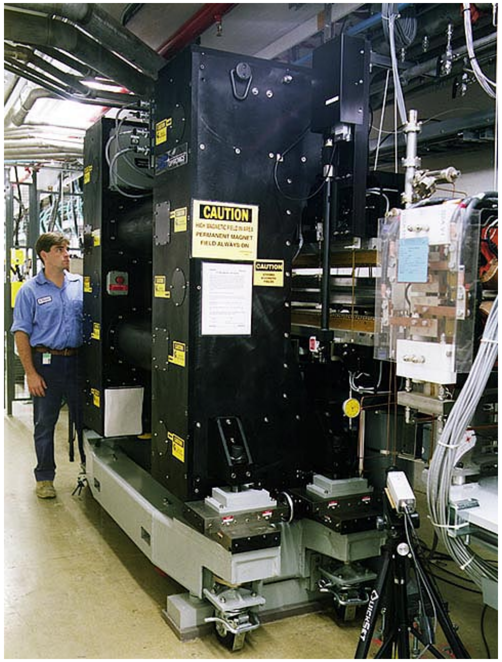


Sextupole

Magnets

- Flavors
  – Undulator/Wiggler

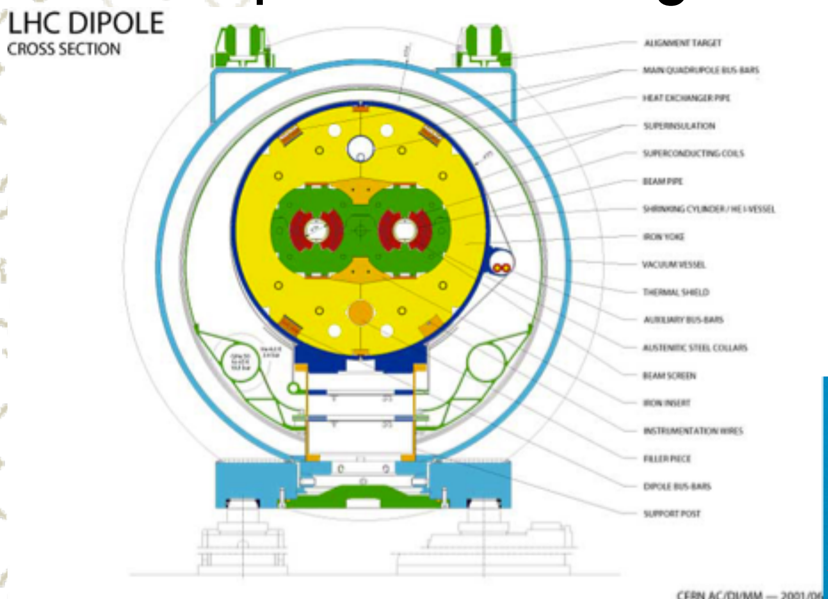


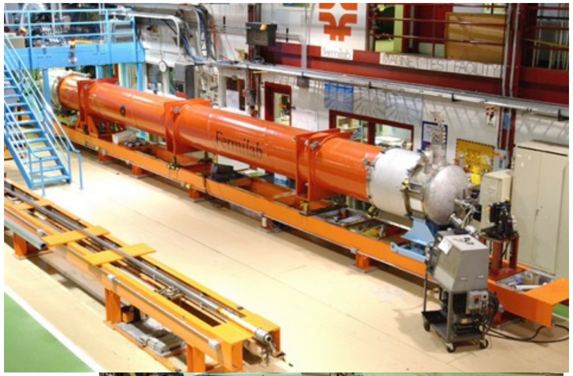


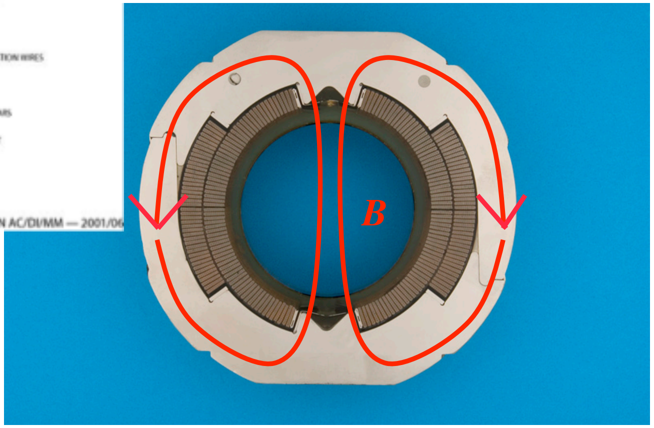
Can be permanent, electro-, some now superconducting

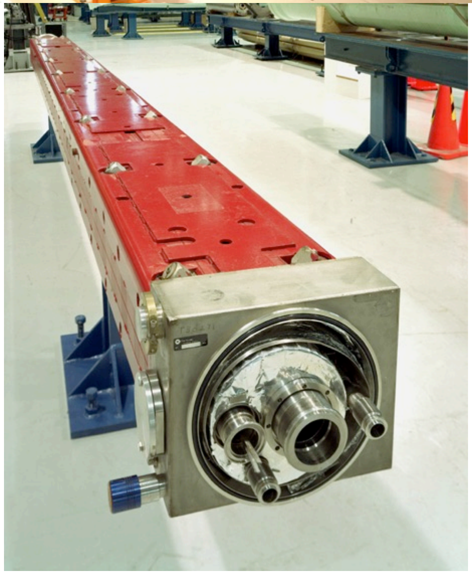
Magnets

- Superconducting



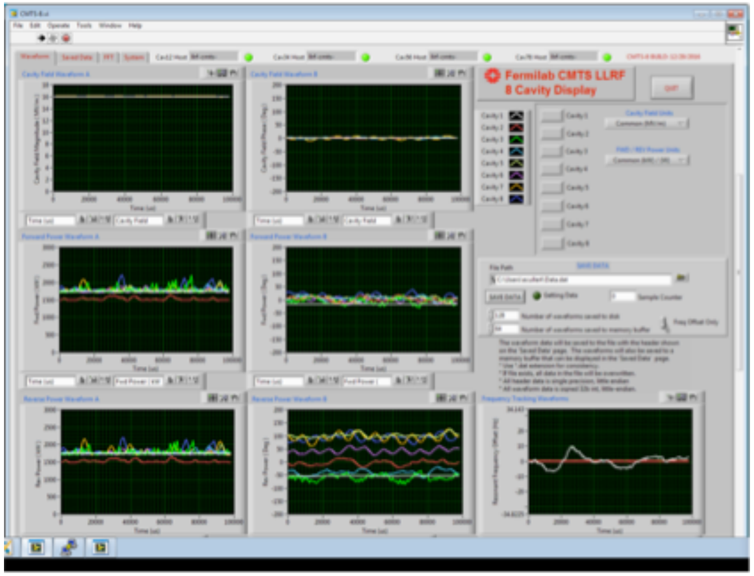






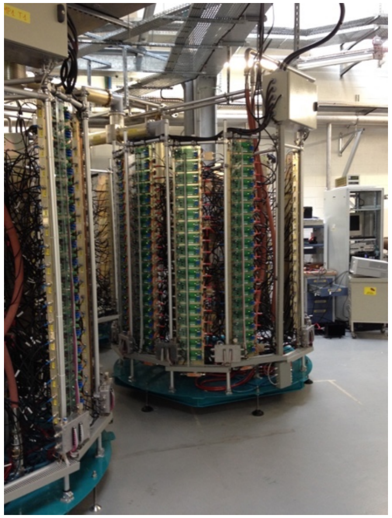
Radiofrequency systems

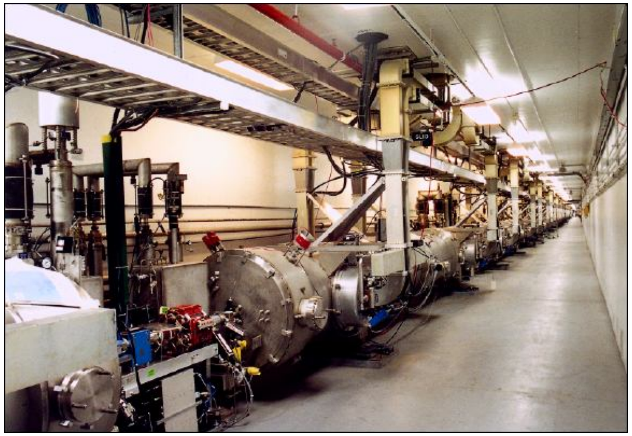
- Low level
  - Frequency
  - Amplitude (voltage)
  - Feed forward & feedback
    - frequency, amplitude, phase
    - slow, fast
    - beam



Radiofrequency systems

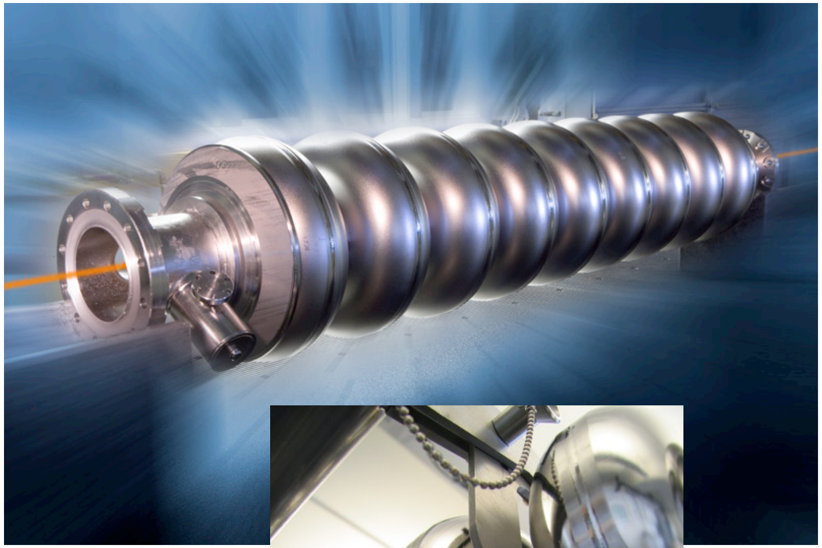
- High level
  - Amplification
  - Tubes, solid state, klystron
  - RF distribution
  - Accelerating cavities





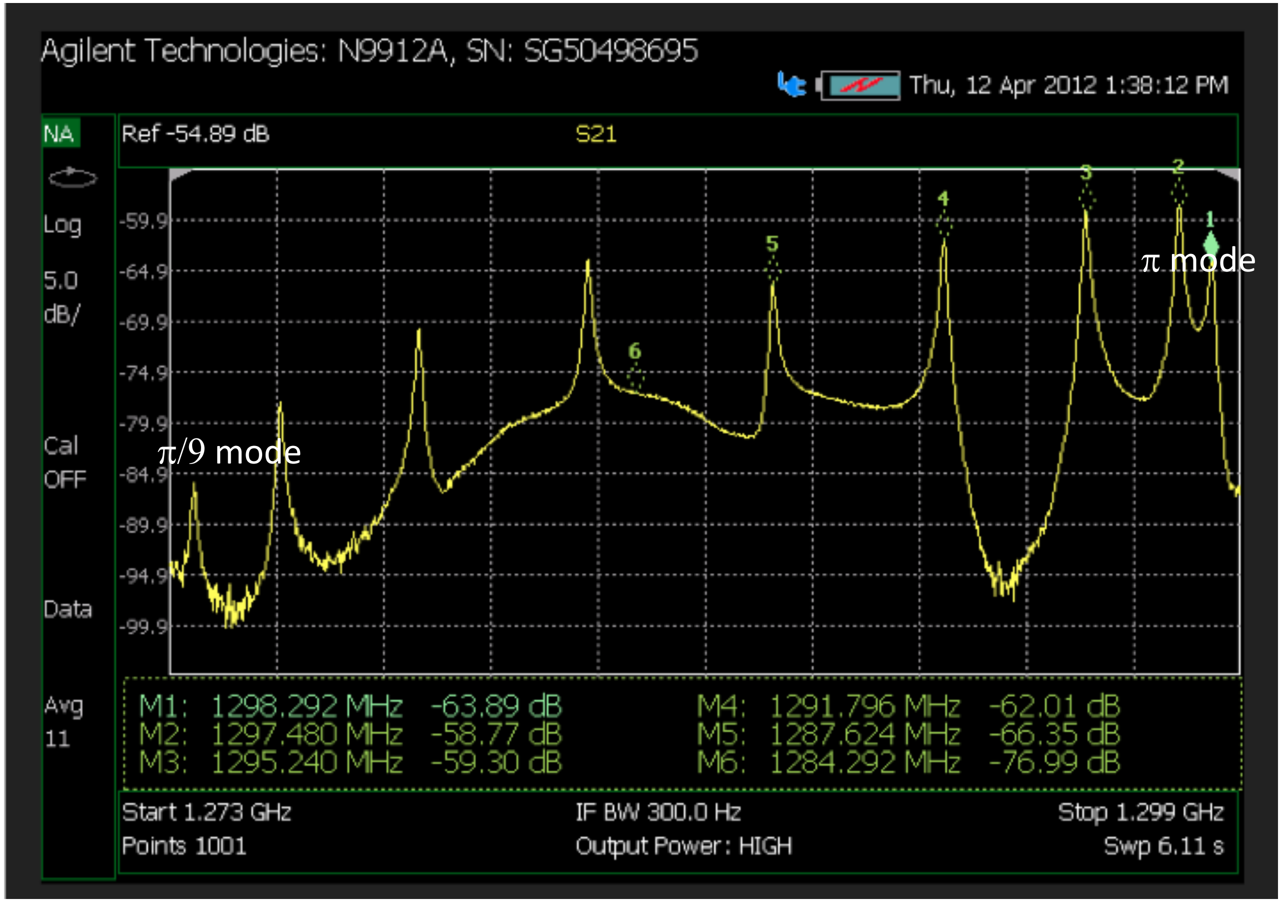
Radiofrequency systems - Superconducting

- Cavities typically made of high purity Niobium
  - (Z = 41)
- • Operate at ~2 Kelvin
- • Generate accelerating gradients ~35 MV/m.
- Q ~10^{10}
- complicated fabrication
- maturing technology
- variety of shapes & frequencies



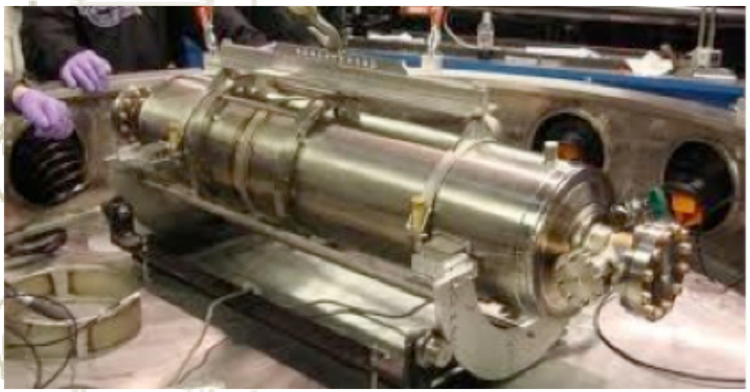
Radiofrequency systems - Superconducting

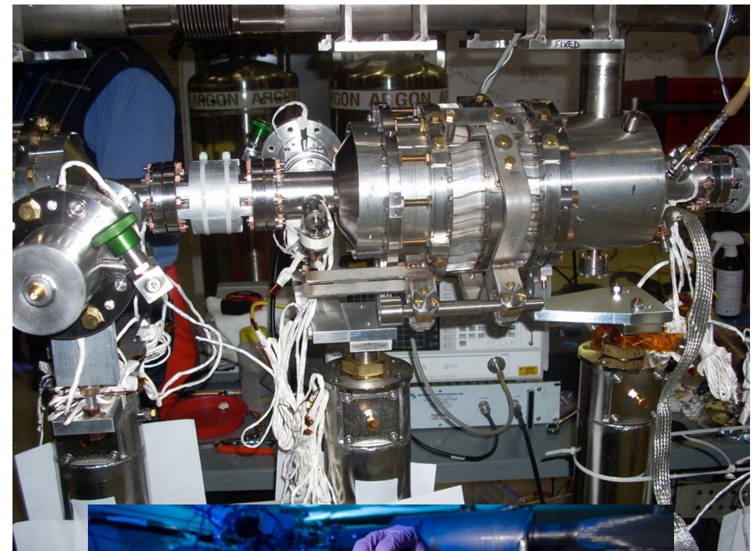
- Tesla style 1.3 GHz 9-cell cavity frequency spectrum (room temperature)



Radiofrequency systems - Superconducting

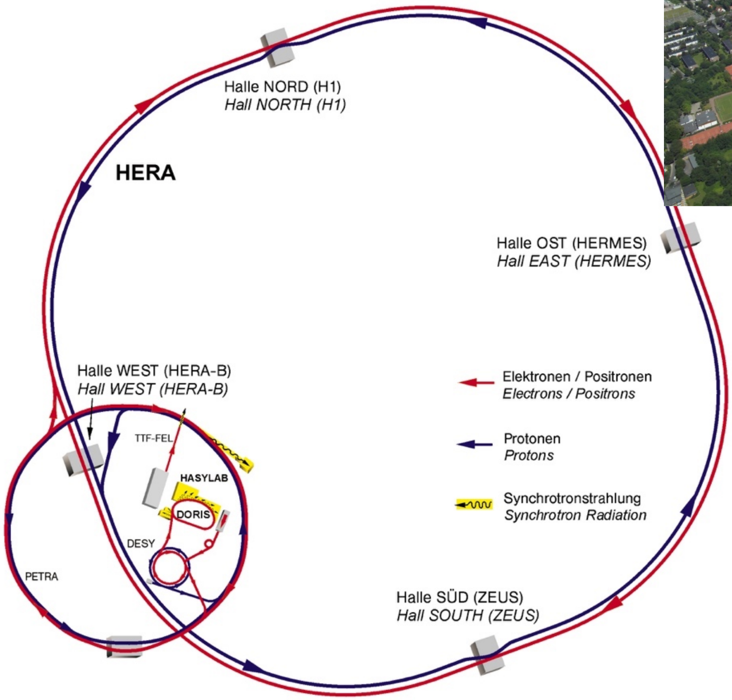
- Not ‘just’ a cavity



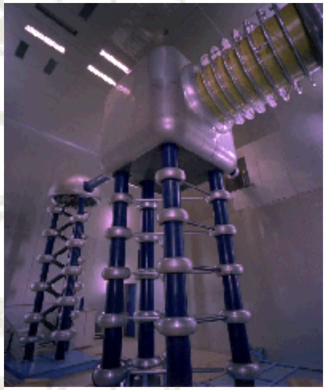


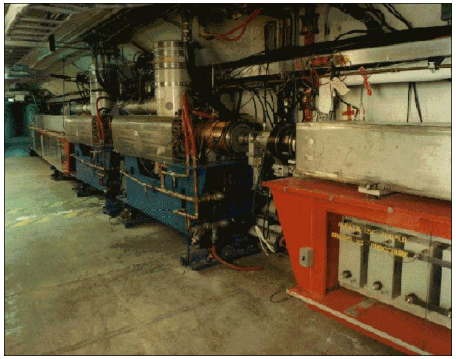
Piecing the machine together

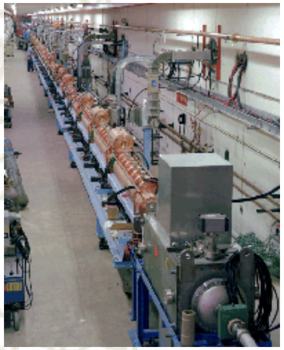
- Cascade of accelerators
  - Different technologies are more efficient in different energy regimes
    - Ion sources
    - Injectors
    - Collectors
    - Transfer lines
    - End accelerator

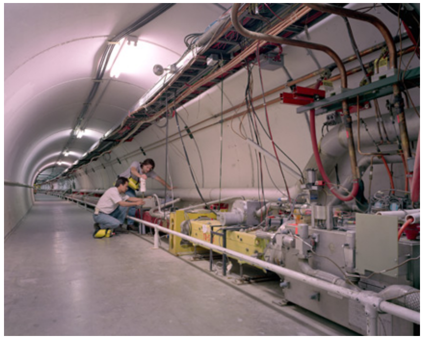


Piecing the machine together









Piecing the machine together

- Power
  - Accelerators require lots of it!
  - Stable and reliable source

Piecing the machine together

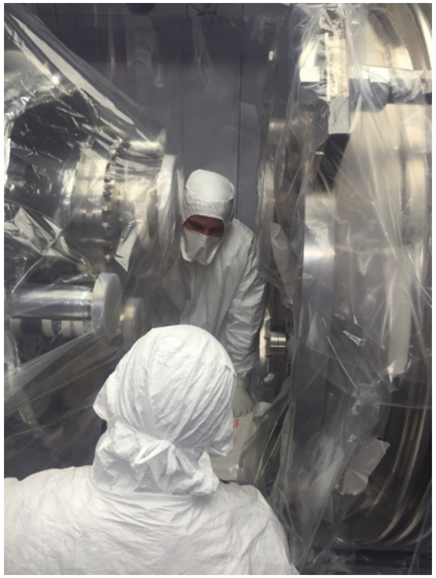
- Power
  - Magnets connected in series
    - Distribution
    - Regulation/feedback loops
    - Current changes through a component leads to changes in beam behavior (never better…)

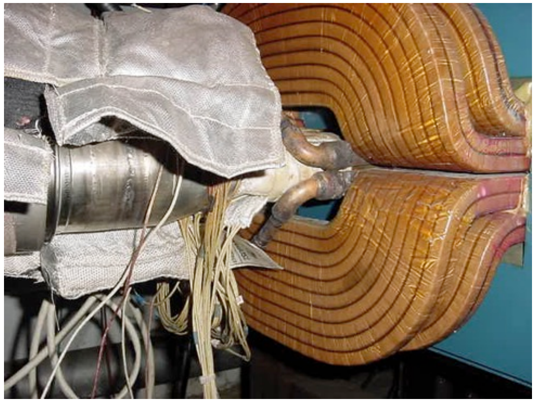
Piecing the machine together

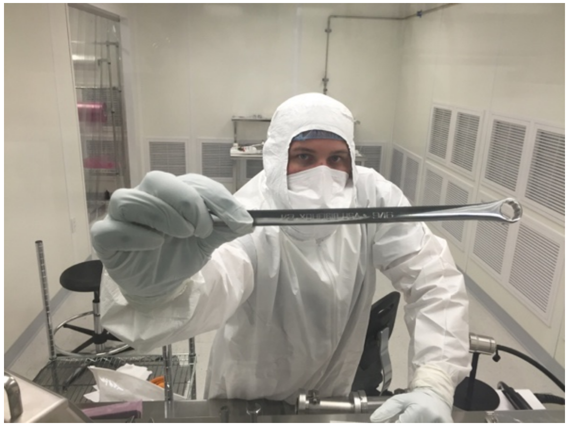
- Contain the beam in a pipe
- Vacuum
  - Particles travel a long way while being accelerated/in storage
  - Scattering by air can lead to reduced beam quality
    - emittance growth
    - energy loss

Piecing the machine together

- Vacuum
  - Quality: at least 10^{-7} mbar for circular machines
  - Distributed pumping
  - Ion pumps, TSP's, cryo pumping
  - Leak checking
  - Pick the correct materials and seals
  - Meticulous cleaning beforehand
  - UHV: bake the chamber in place
  - SRF: clean room assembly





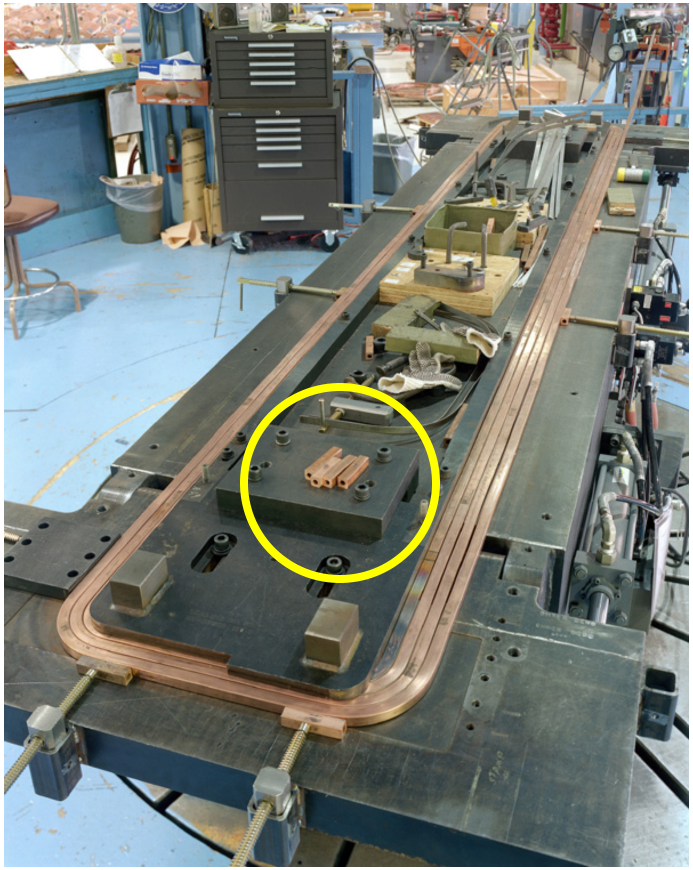


Piecing the machine together

- Cooling
  - Virtually every component requires some sort of external cooling, electronics, too
  - Water and air are the most common media, but also
    - Glycol,
  - Superconducting components require cryogens
    - liquid helium at ≤4 Kelvin most common
  - Coolant should be in as direct contact with heat load as possible (best thermal transfer)

Piecing the machine together

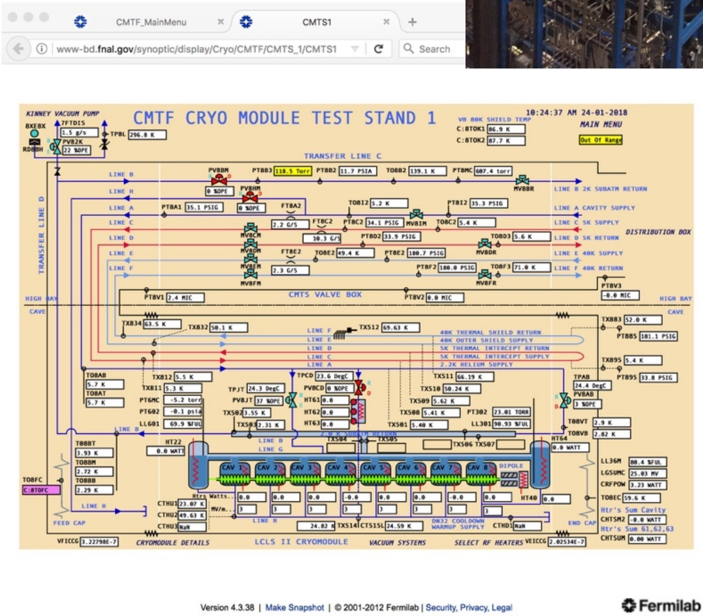
- Water Cooling
  - Conventional magnet coils, klystrons, too, typically have a coolant orifice through middle of conductor
  - Closed loop - Control the chemistry
    - Water must be low conductivity (deionized) since water & current flow together
    - Remove the dissolved oxygen
    - Minimize particulates – small orifices
    - Regulate the pressure & temperature



Piecing the machine together

- Cryogenic Cooling
  - Superconducting coils or cavities bathed in liquid helium between 1.8 and 4.6K
  - Lots of refrigeration (significant power use)
  - Low heat loss
  - cryostats are super "thermos" bottles

equivalent to ~20,000 household refrigerators

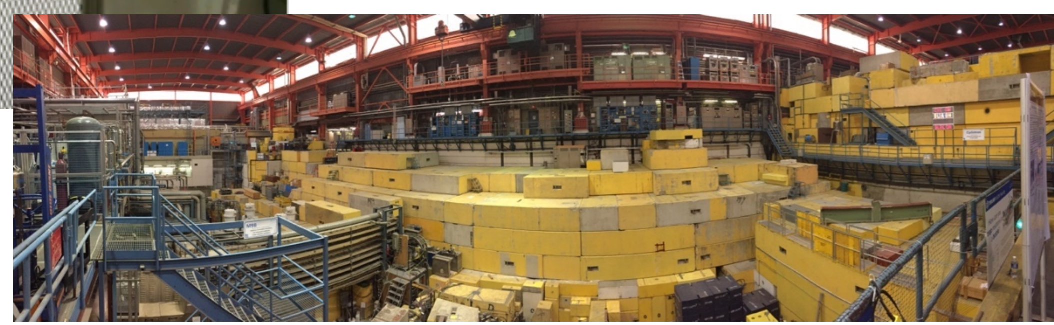


Piecing the machine together

- Cryogenic Cooling
  - 8-cavity superconducting RF module: 2 Kelvin
  - Lots of refrigeration (significant power use)
  - Heat loss ~ 10’s of watts
  - Modules are also super “thermos” bottles

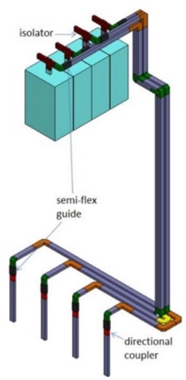
Piecing the machine together

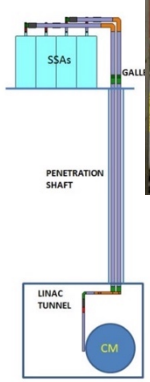
- Enclosure
  - Electrical and Radiation hazards when operating
  - Personnel protection
  - Dump the beam in a safe place



Piecing the machine together

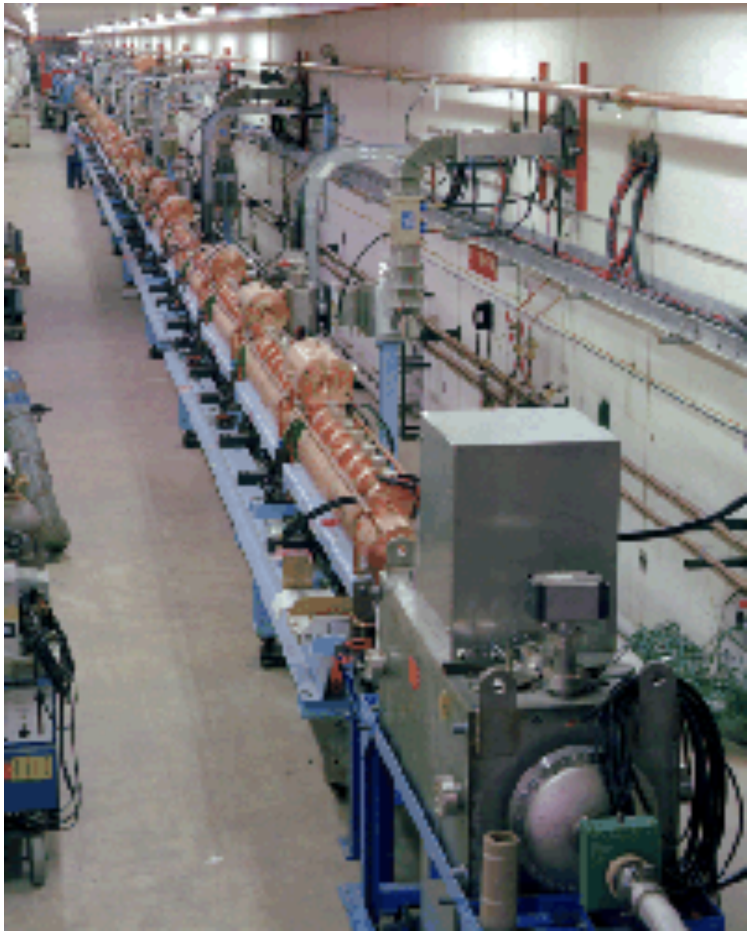
- Equipment housing
  – Want power supplies and other interface equipment as close as possible, but accessible





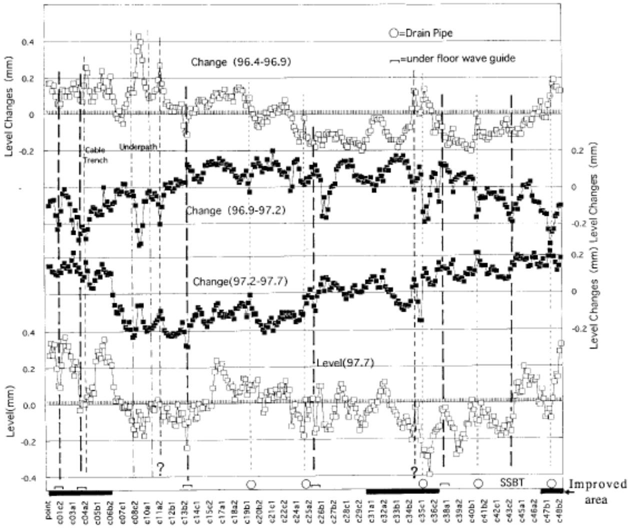
Keeping it all together / Making it work

- Alignment
  - Keep it in line!
    - Tevatron 150 to 800 GeV in 30 seconds
    - $\tau_0 = 21\mu s$
    - C ~4 miles
    - > 1.4 million miles traveled during acceleration alone



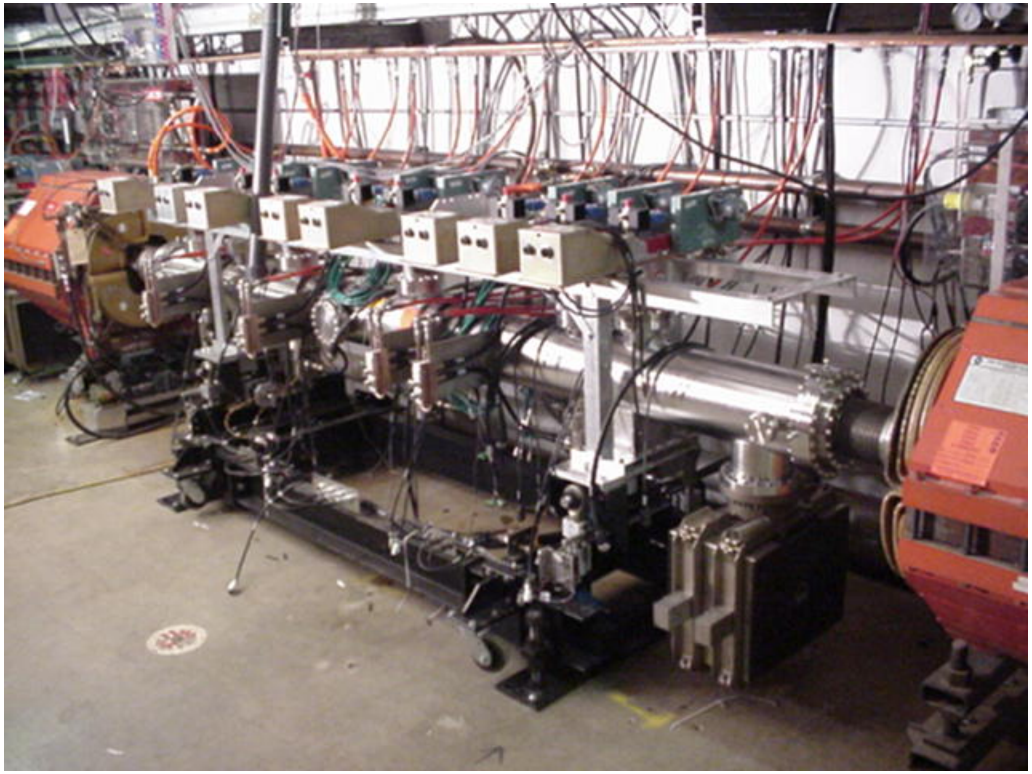
Keeping it all together / Making it work

- Alignment
  - Where is it?
    - Position of components with respect to each other
    - Macro-positioning



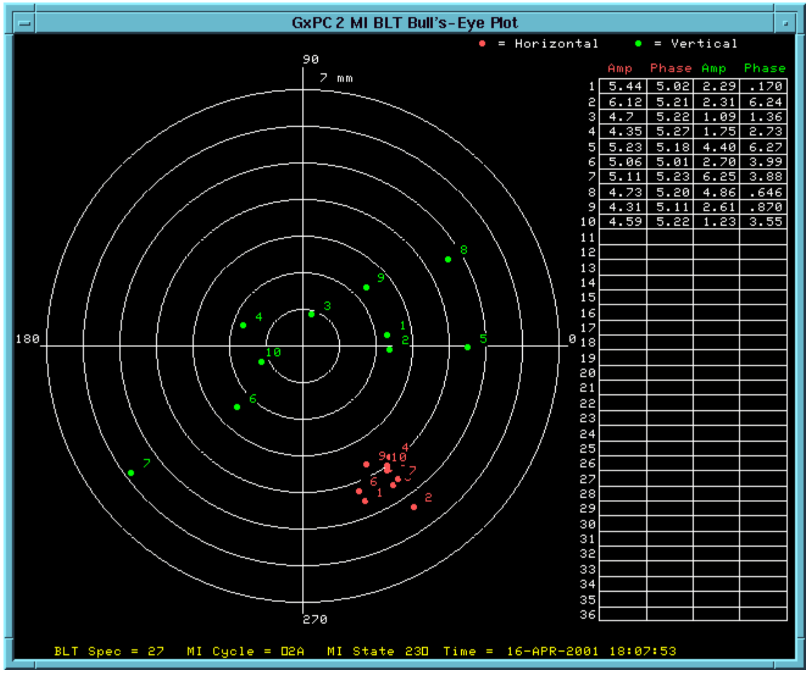
Keeping it all together / Making it work

- Alignment
  - Move it
    - Reference system
    - Fixturing
    - Component stands
    - Remote positioning



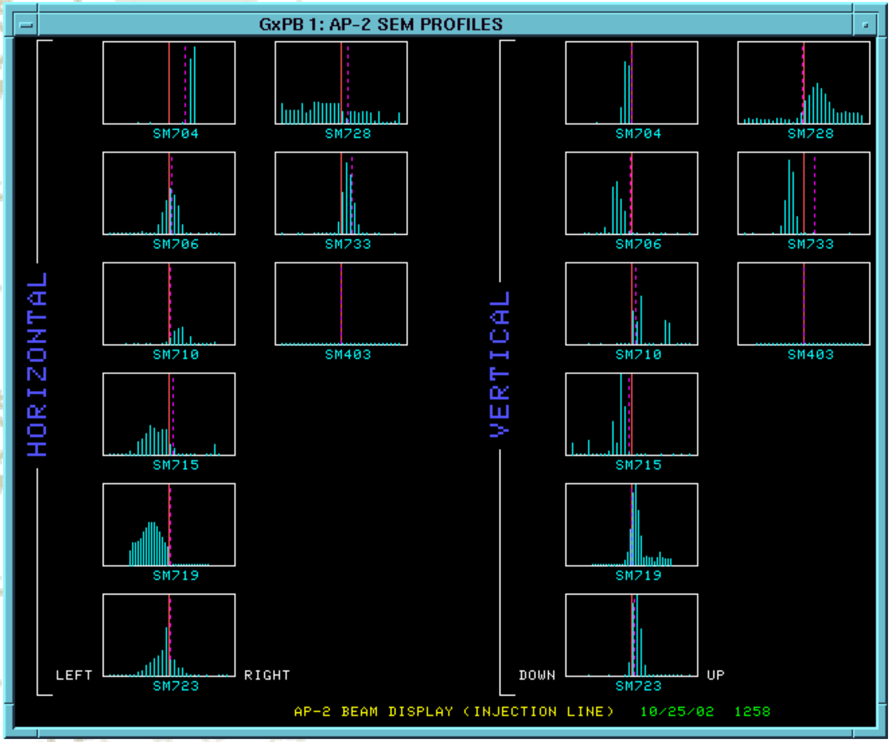
Keeping it all together / Making it work

- Diagnostics
  - Where's the beam, what does it look like, how many particles?
    - Beam Position Monitor
    - Beam Loss Monitor
    - Profile Monitor/Wire scanner
    - Schottky detector
    - Toroid
    - Resistive Wall Monitor
    - Damper
    - …

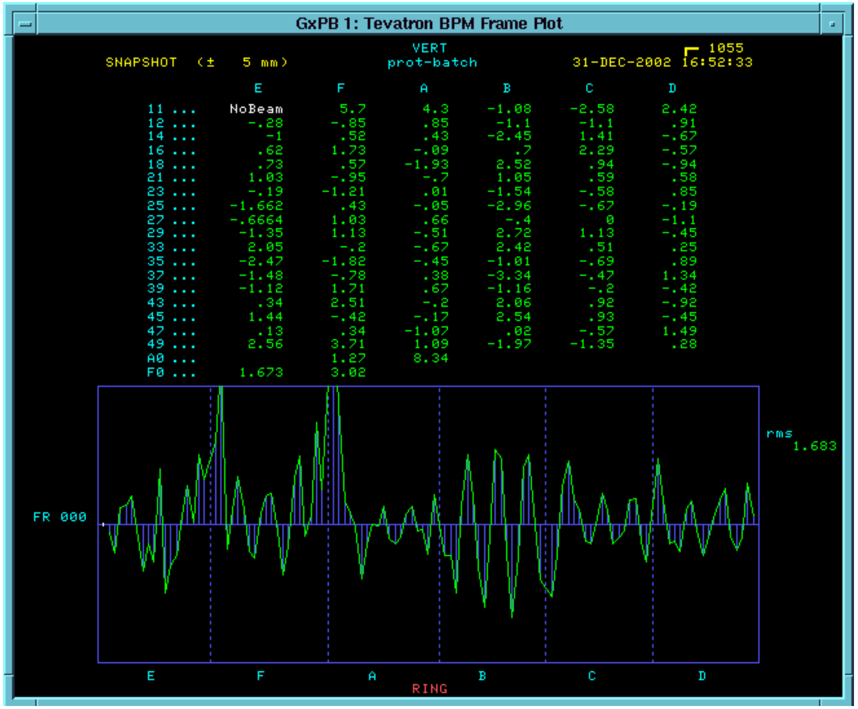


Keeping it all together / Making it work

- Diagnostics



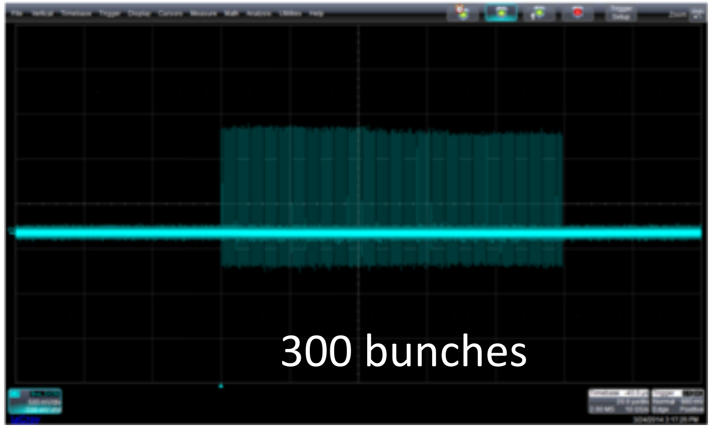
Beam profiles

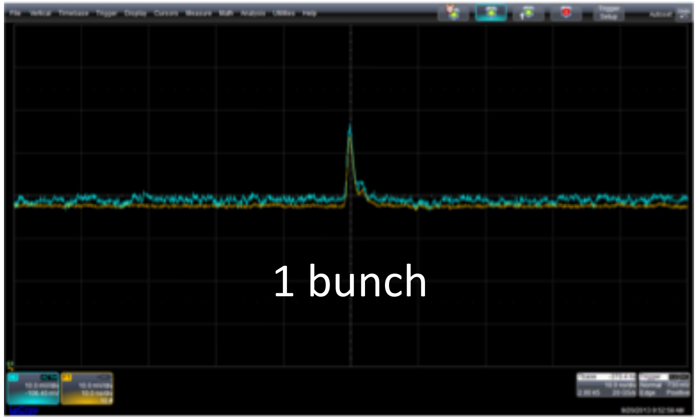


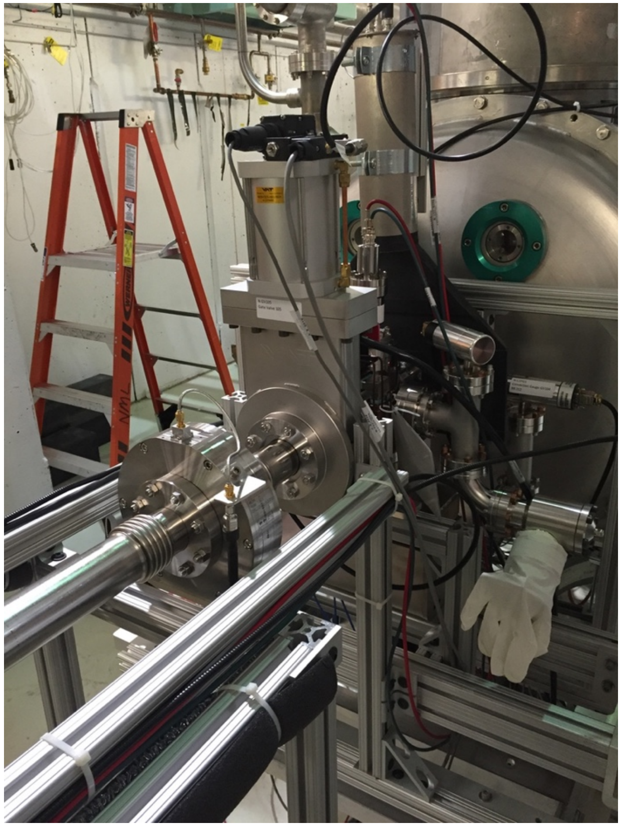
Orbit (BPM's)

Keeping it all together / Making it work

- Diagnostics
  - (Resistive) Wall current monitor





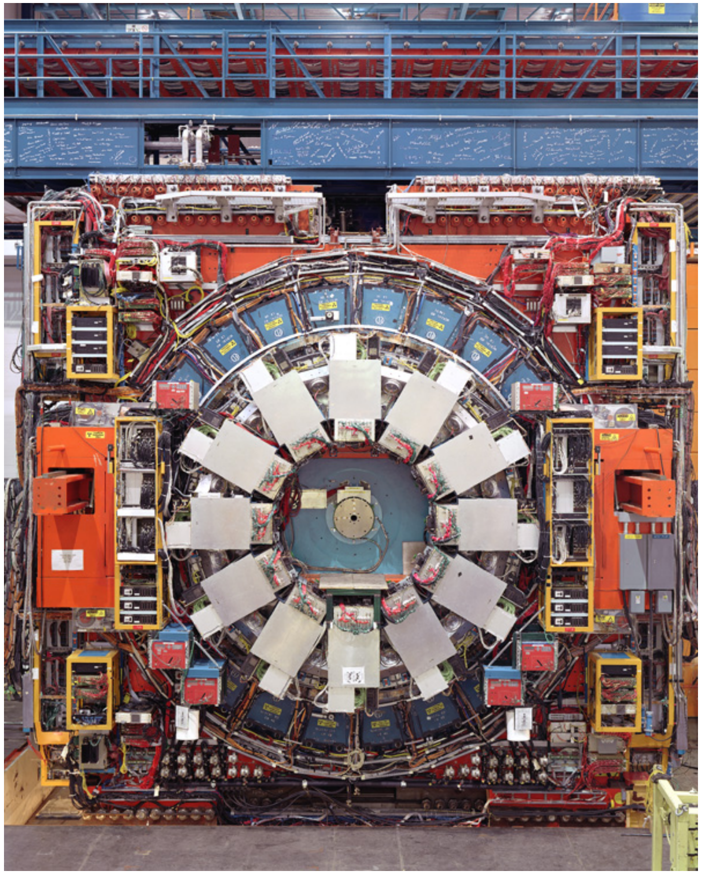


Keeping it all together / Making it work

- Controls system
  - Monitor and Control
  - Timing
  - Fast response
  - Beam removal
  - Coordination
  - Human interface

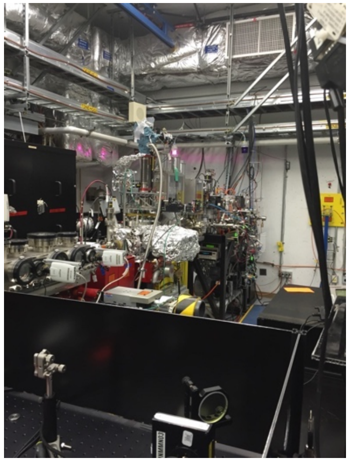
Where does the beam go?

- Experiments / End Users
  - Internal to machine
    - Interaction regions
    - Beam quality/size



Where does the beam go?

- Experiments / End Users
  - External
    - Rate, energy, size, and location to deliver beam
      - Single-turn
      - Resonant extraction
      - Synchrotron light



Resources

- People are the most important component
- Other resources
  - Books
  - Schools
  - Workshops, conferences
  - Web

Thanks