PHYS 3446 – Lecture #18

Monday, Nov. 7, 2016

Dr. Jae Yu

- Particle Accelerators
  - Electro-static Accelerators
  - Cyclotron Accelerators
  - Synchrotron Accelerators
- Elementary Particle Properties
  - Forces and their relative magnitudes
  - Elementary particles

Announcements

- Quiz #3
  - Beginning of the class Wednesday, Nov. 9
  - Covers 6.1 through what we finish today!
  - Bring your calculators
    - No phone or computers allowed
  - Bring your own handwritten formula sheet
    - Front and back of a letter size sheet
    - No word definitions, no derivations, no reaction equations
- Reading assignments: 9.6 and 9.7

Homework #9

1. End of chapter problems 9.1, 9.2 and 9.3
2. Due for these assignments is next Monday, Nov. 14

Physics Department
The University of Texas at Arlington
COLLOQUIUM

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Solar Wind Induced Atmospheric Erosion at Mars

Dr. Yingjuan Ma
UCLA

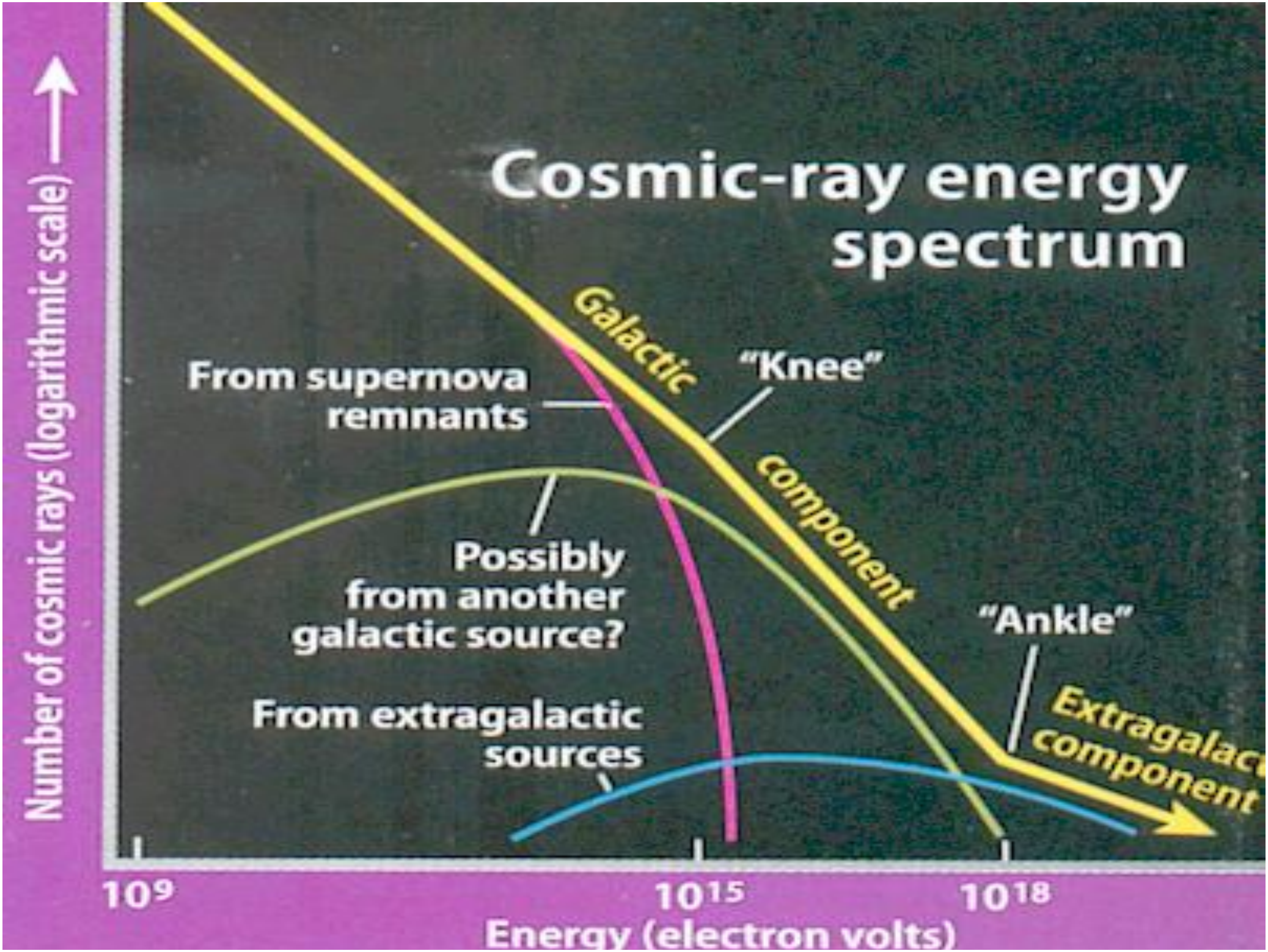
Wednesday November 9, 2016
4:00 Room 100 Science Hall

Modern Mars atmosphere is thin, cold and dry. However, there is considerable evidence that Mars' climate has changed greatly during the planet's history. Solar wind induced atmospheric erosion is one candidate for causing the long-term variations of the Mars atmosphere. Mars has only localized crustal magnetic fields, so the solar wind plasma flow interacts directly with the Mars atmosphere/ionosphere system. Such an interaction generates induced current in the ionosphere, modifies the magnetic field environment around Mars and more importantly, causes the erosion of the Mars atmosphere. Here we use a 3D time-dependent multi-species single-fluid MHD model to study the plasma environment of Mars and quantify the ion loss rate. The effects of the crustal magnetic fields are discussed based on model results and their comparison with MGS (Mars Global Surveyor) magnetometer observations. Two event studies of MAVEN (Mars Atmosphere and Volatile Evolution) mission are also presented, one for quiet solar wind condition and the other for a strong ICME impact in March 2015. The ongoing MAVEN mission was designed to study the upper atmosphere, ionosphere, and magnetosphere of Mars, the response to solar and solar-wind input, and the ability of atmospheric molecules and atoms to escape to space. Through detailed comparisons between the model results and the relevant plasma observations from MAVEN, we find that the time-dependent global MHD model is able to reproduce the main features of the plasma environment around Mars for both quiet and disturbed solar wind conditions. Model results suggest that the total ion escape rate was enhanced by an order of magnitude during the ICME event. Given the likely prevalence of ICME-like conditions earlier in the solar system history, ion loss during solar events in ancient times could have contributed significantly to the long-term evolution of the Mars atmosphere.

Refreshments will be served at 3:30 p.m. in the Physics Library

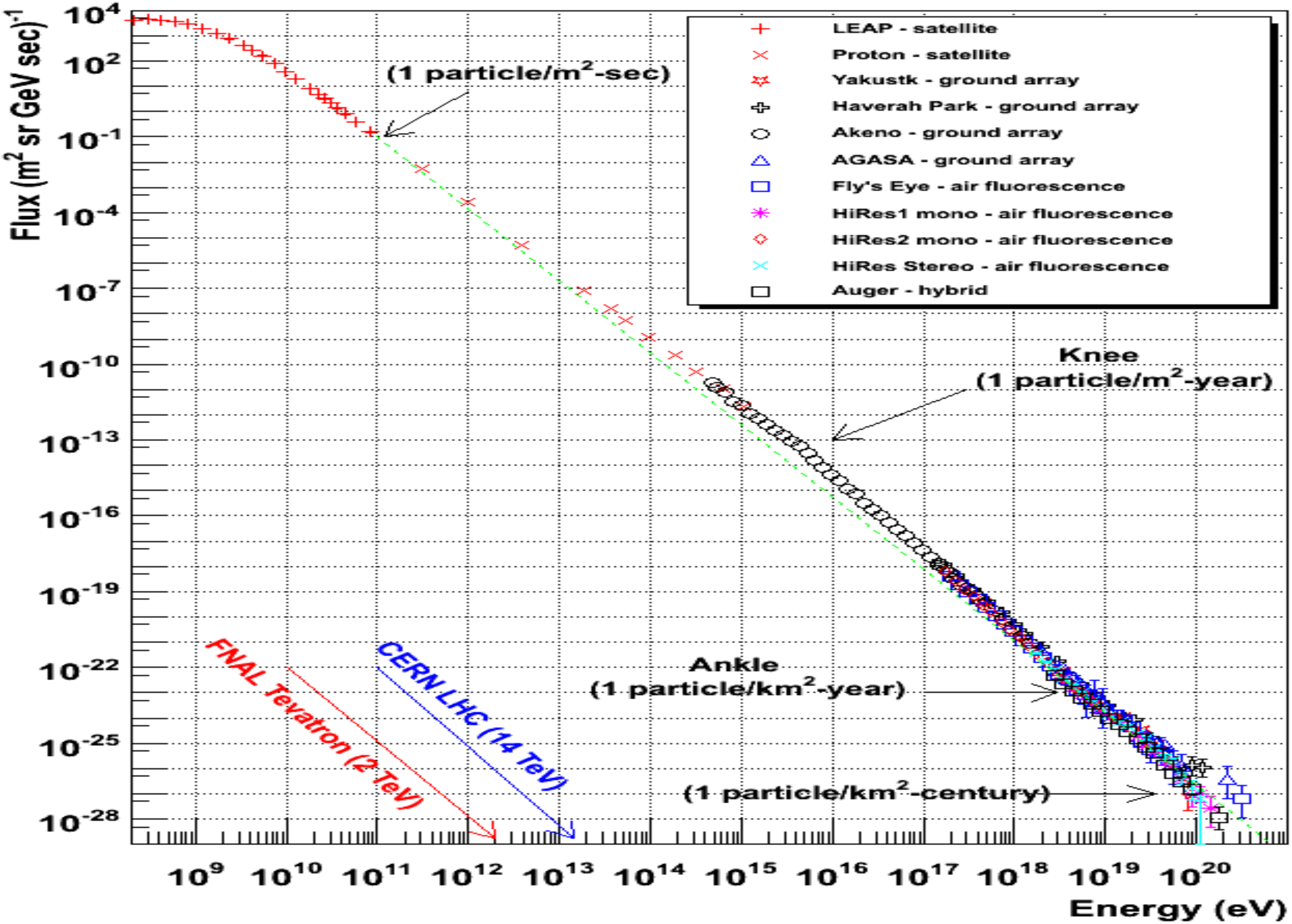
Particle Accelerators

- How can one obtain high energy particles?
  - Cosmic ray ➔ Sometimes we observe 1000TeV cosmic rays



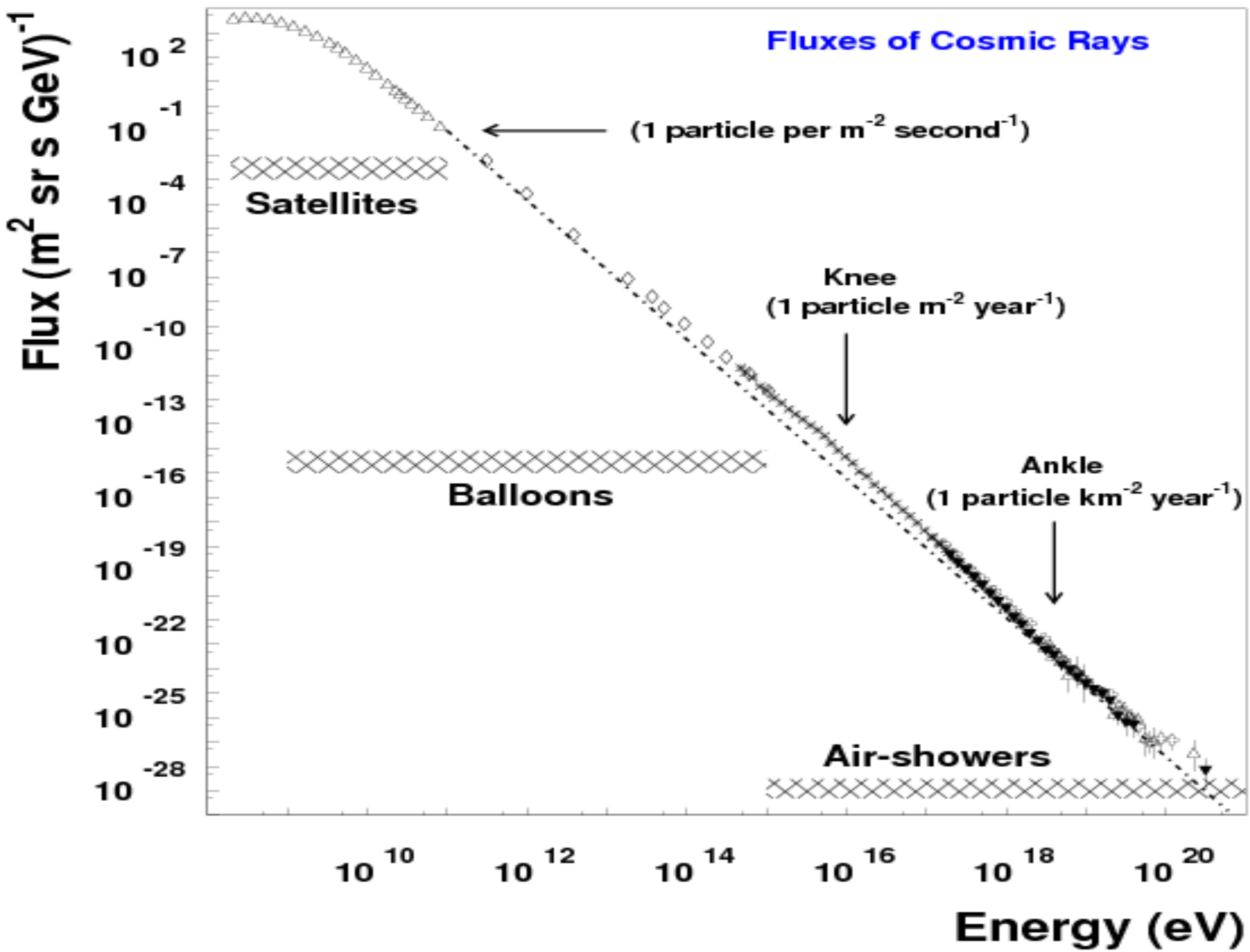
Cosmic-ray energy spectrum
Number of cosmic rays (logarithmic scale)
Galactic component
"Knee"
From supernova remnants
Possibly from another galactic source?
From extragalactic sources
"Ankle"
Extragalact component
10^9
10^15
10^18
Energy (electron volts)

Cosmic Ray Spectra of Various Experiments



Particle Accelerators

- How can one obtain high energy particles?
  - Cosmic ray → Sometimes we observe 1000TeV cosmic rays
    - Low flux and cannot control the energy too well


Fluxes of Cosmic Rays
Flux (m^2 sr s GeV)$^{-1}$
10^2
10^{-1}
10^{-4}
10^{-7}
10^{-10}
10^{-13}
10^{-16}
10^{-19}
10^{-22}
10^{-25}
10^{-28}
(1 particle per m^{-2} second^{-1})
Satellites
Knee
(1 particle m^{-2} year^{-1})
Balloons
Ankle
(1 particle km^{-2} year^{-1})
Air-showers
10^{10}
10^{12}
10^{14}
10^{16}
10^{18}
10^{20}
Energy (eV)

Particle Accelerators

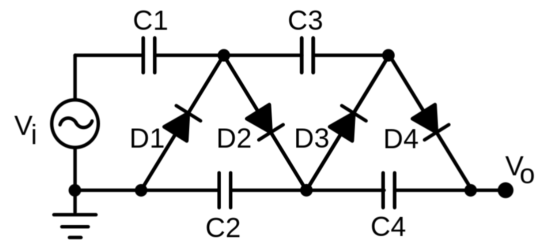
- How can one obtain high energy particles?
  - Cosmic ray → Sometimes we observe 1000TeV cosmic rays
    - Low flux and cannot control the energy too well
- Need to look into small distances to probe the fundamental constituents with full control of particle energies and fluxes
  - Particle accelerators
- Accelerators need not only to accelerate particles but also to
  - Track them
  - Maneuver them
  - Constrain their motions to within the distance of order 1μm
- Why?
  - Must correct particles' paths and momenta to increase fluxes and control momenta better

Particle Accelerators

- Depending on what the main goals of physics are, one needs different kinds of accelerator experiments
- Fixed target experiments: Probe the nature of the nucleons ➔ Structure functions
  - Results also can be used for producing secondary particles for further accelerations ➔ Tevatron anti-proton production
- Collider experiments: Probe the interactions between fundamental constituents
  - Hadron colliders: Wide kinematic range and high discovery potential
    - Proton-anti-proton: TeVatron at Fermilab, $Sp\bar{p}S$ at CERN
    - Proton-Proton: Large Hadron Collider at CERN (started operating in 2010)
  - Lepton colliders: Very narrow kinematic reach, so it is used for precision measurements
    - Electron-positron: LEP at CERN, Petra at DESY, PEP at SLAC, Tristan at KEK, ILC in the future
    - Muon-anti-muon: Conceptual accelerator in the far future
  - Lepton-hadron colliders: HERA at DESY

Electrostatic Accelerators: Cockcroft-Walton

- Cockcroft-Walton Accelerator – invented in 1932
  - Pass ions through sets of aligned DC electrodes consist of arrays of capacitors and diodes at successively increasing fixed potentials
  - Consists of ion source (hydrogen gas) and a target with the electrodes arranged in between
  - Acceleration Procedure
    - Electrons are either added or striped off of an atom
    - Ions of charge q then get accelerated through series of electrodes, gaining kinetic energy of T=qV through every set of electrodes



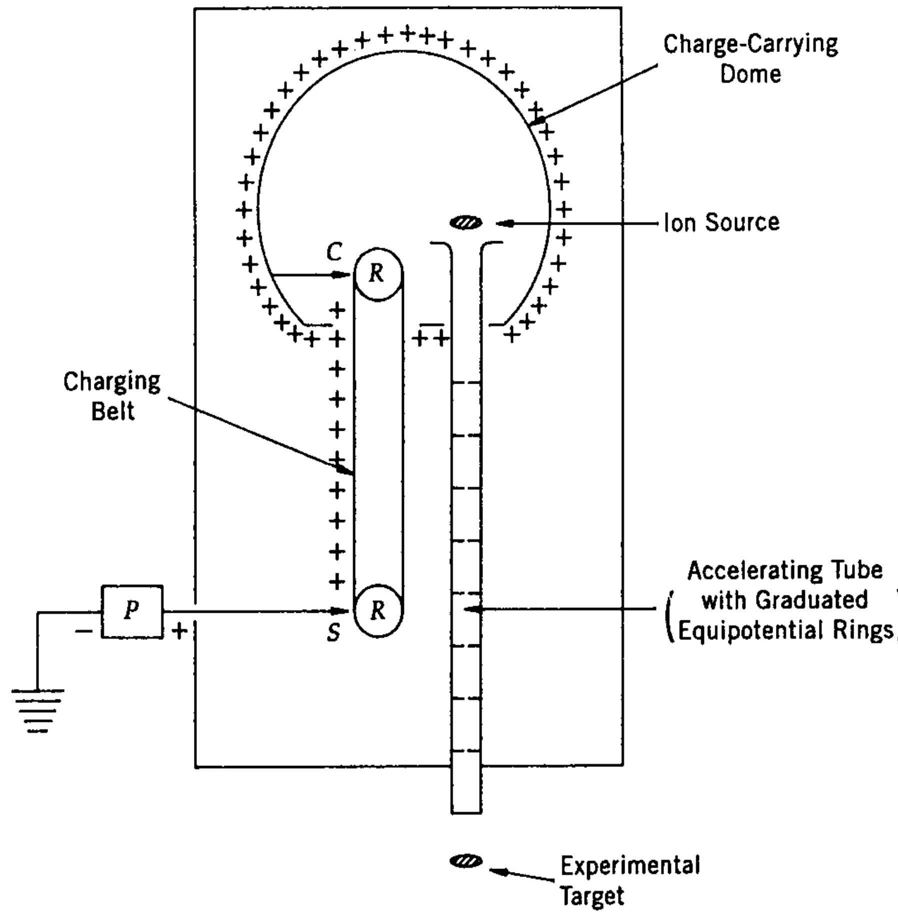
- Limited to about 1MeV acceleration due to voltage breakdown and discharge beyond the voltage of 1MV.
- Available commercially and also used as the first step high current injector (to ~1mA).

Electrostatic Accelerators: Van de Graaff

- Energies of particles through DC accelerators are proportional to the applied voltage
- Robert Van de Graaff invented a clever mechanism to increase HV in 1929
  - The charge on any conductor resides on its outermost surface
  - If a conductor carrying additional charge touches another conductor that envelops it, all of its charges will transfer to the outer conductor increasing the charge on it and thereby increase the HV

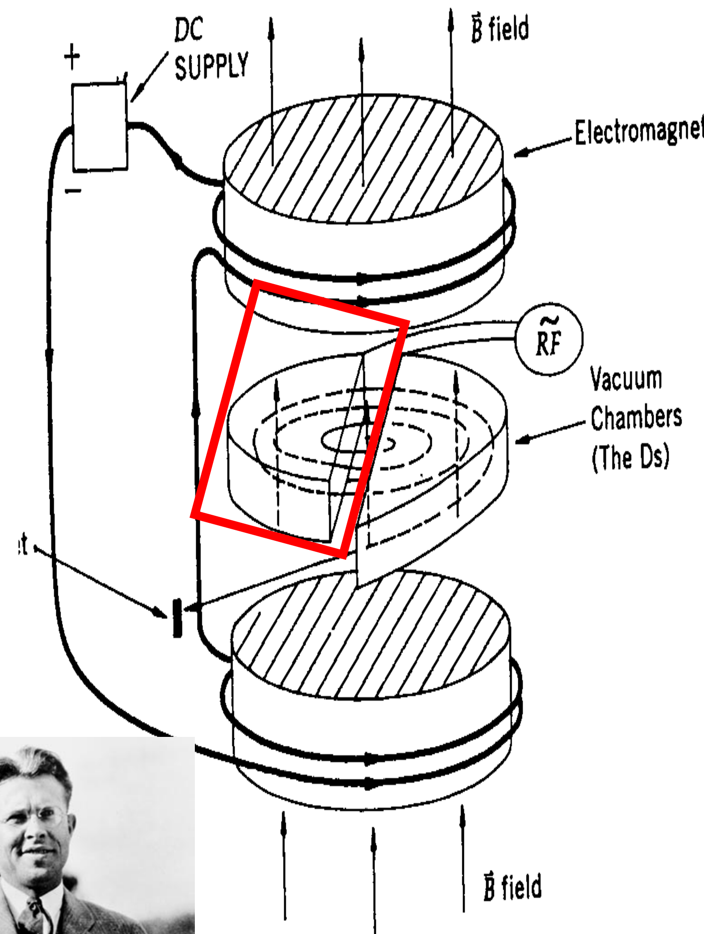
Electrostatic Accelerators: Van de Graaff

- Sprayer adds positive charge to the conveyor belt at corona points
- The charge is carried on an insulating conveyor belt
- The charges get transferred to the dome via the collector
- The ions in the source then gets accelerated to about 12MeV
- Tandem Van de Graff can accelerate particles up to 25 MeV
- This acceleration normally occurs in high pressure gas (~15atm) that has very high breakdown voltage



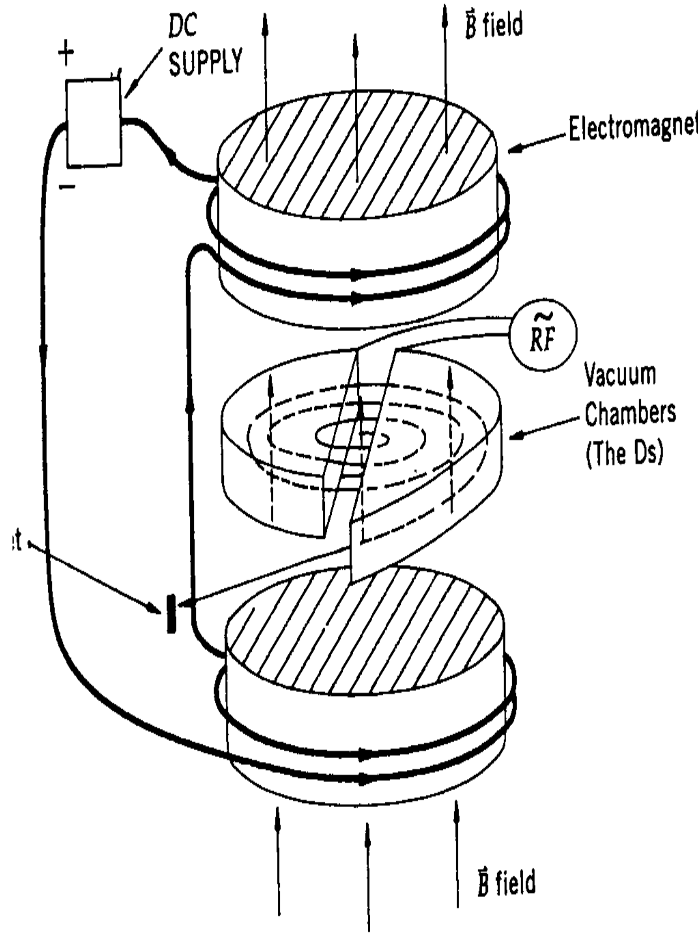
Resonance Accelerators: Cyclotron

- Fixed voltage machines have intrinsic limitations in their energy due to breakdown
- Machines using resonance principles can accelerate particles in higher energies
- Cyclotron invented by Ernest Lawrence 1934 is the simplest one
  - Awarded Nobel Prize 1939
- Accelerator consists of
  - Two hallow D shaped metal chambers connected to alternating HV source
  - The entire system is placed under strong magnetic field



Resonance Accelerators: Cyclotron

- While the D's are connected to HV sources, there is no electric field inside the chamber due to Faraday effect
- Strong alternating electric field exists only in the gap between the D's
- An ion source is placed in the gap
- The path is circular due to the perpendicular magnetic field
- Ion does not feel any acceleration inside a D but gets bent due to magnetic field
- When the particle exits a D, the direction of voltage can be changed and the ion gets accelerated before entering into the D on the other side
- If the frequency of the alternating voltage is just right, the charged particle gets accelerated continuously until it is extracted



Resonance Accelerators: Cyclotron

- For a non-relativistic motion, the frequency appropriate for alternating voltage can be calculated from the fact that the magnetic force provides the centripetal acceleration for a circular orbit

$$m\frac{v^2}{r} = qvB \quad \Rightarrow \quad \frac{v}{r} = \frac{qB}{m} = \omega$$

- In a constant angular speed, ω=v/r. The frequency of the motion is

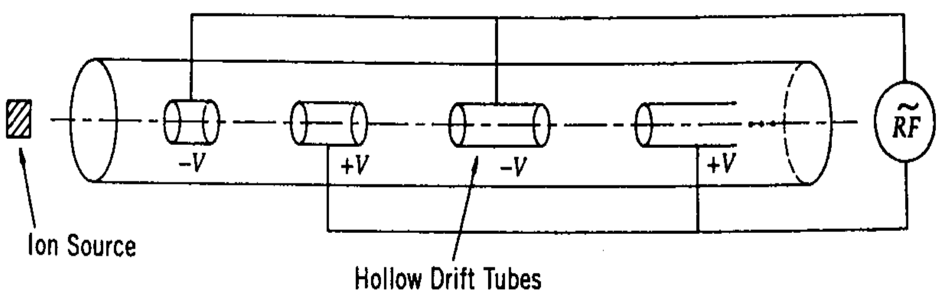
$$f = \frac{\varpi}{2\pi} = \frac{qB}{2\pi m} = \frac{1}{2\pi}\left(\frac{q}{m}\right)B$$

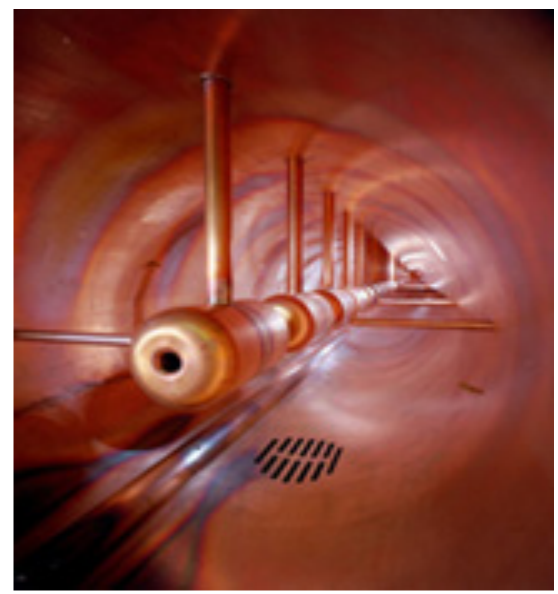
- Thus, to continue accelerate the particle the electric field should alternate in this frequency, **cyclotron resonance frequency**
- The maximum kinetic energy achievable for an cyclotron with radius R is

$$T_{max} = \frac{1}{2}mv^2_{\max} = \frac{1}{2}m\omega^2 R^2 = \frac{(qBR)^2}{2m}$$

Resonance Accelerators: Linear Accelerator

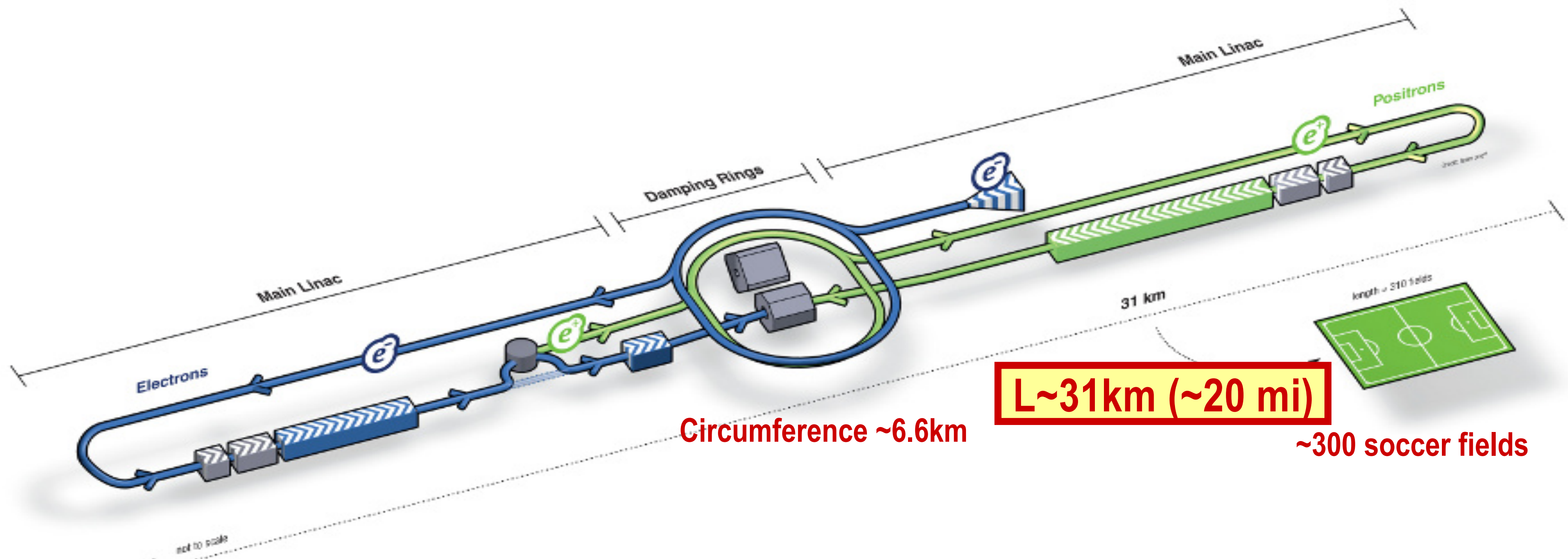
- Accelerates particles along a linear path using the resonance principle
  - Method invented by Leo Szilard and patented by Rolf Widerøe in 1929
- A series of metal tubes are located in a vacuum vessel and connected successively to alternating terminals of radio frequency oscillator
- The directions of the electric fields changes before the particles exits the given tube
- The tube length needs to get longer as the particle gets accelerated to keep up with the phase
- These accelerators are used for accelerating light particles to very high energies





Future Linear Collider

- Has been in the works since late 1990's
- An electron-positron collider on a straight line for precision measurements
- 10~15 years from now (In Dec. 2011, Japanese PM announced that they would bid for a LC in Japan and reaffirmed by the new PM in 2013)
- Takes 10 years to build a detector



Synchroton Accelerators

- For very energetic particles, the relativistic effect must be taken into account
- For relativistic energies, the equation of motion of a charge q under magnetic field B is $$m\gamma\frac{d\vec{v}}{dt}=m\gamma\vec{r}\times\vec{\omega}=q\frac{\vec{v}\times\vec{B}}{c}$$
- For v ~ c, the resonance frequency (ν) becomes $$\nu=\frac{\varpi}{2\pi}=\frac{1}{2\pi}\left(\frac{q}{m}\right)\frac{1}{\gamma}\frac{B}{c}$$
- Thus for high energies, either B or ν should increase
- Machines with constant B but variable ν are called synchro-cyclotrons
- Machines with variable B independent of the change of ν is called synchrotrons

Synchroton Accelerators

- Electron synchrotrons, B varies while ν is held constant
- Proton synchrotrons, both B and ν varies
- For v ~ c, the frequency of motion can be expressed

$$\nu = \frac{1}{2\pi}\frac{\mathrm{v}}{R} \approx \frac{c}{2\pi R}$$

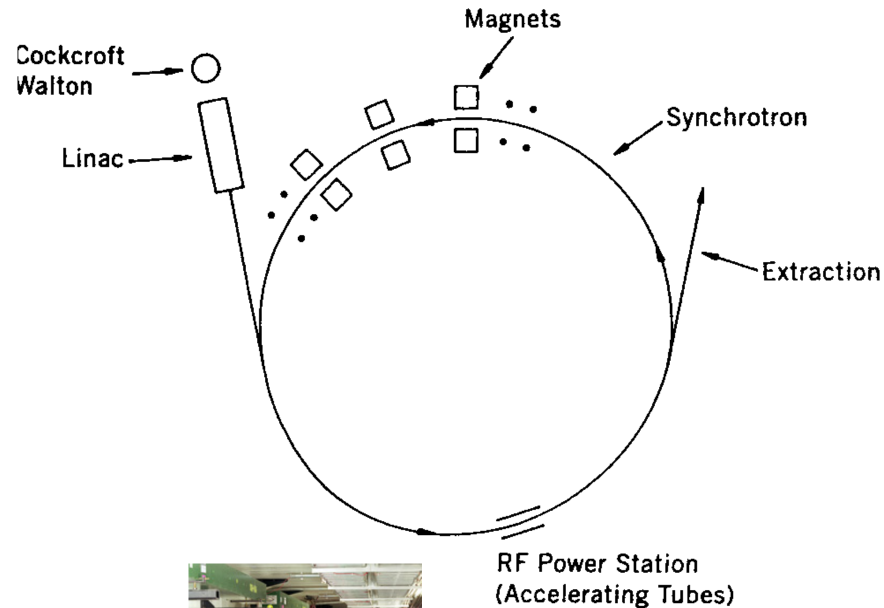
- For an electron

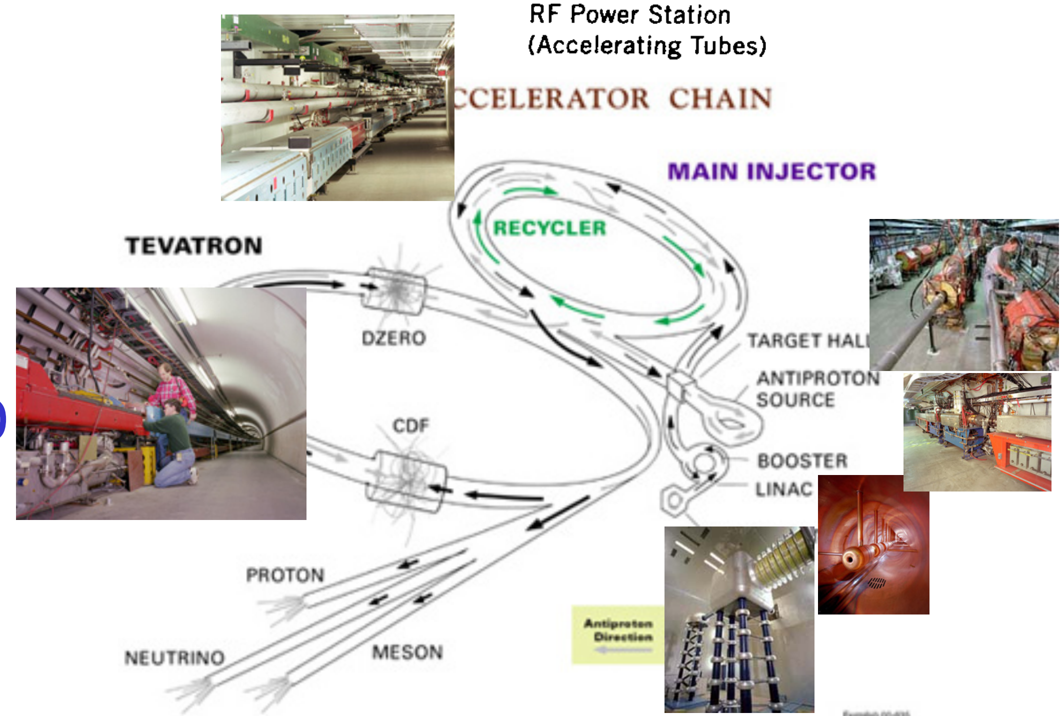
$$R(m) = \frac{pc}{qB} \approx \frac{p\left(GeV/c\right)}{0.3B\left(Tesla\right)}$$

- For magnetic field strength of 2Tesla, one needs radius of 50m to accelerate an electron to 30GeV/c.

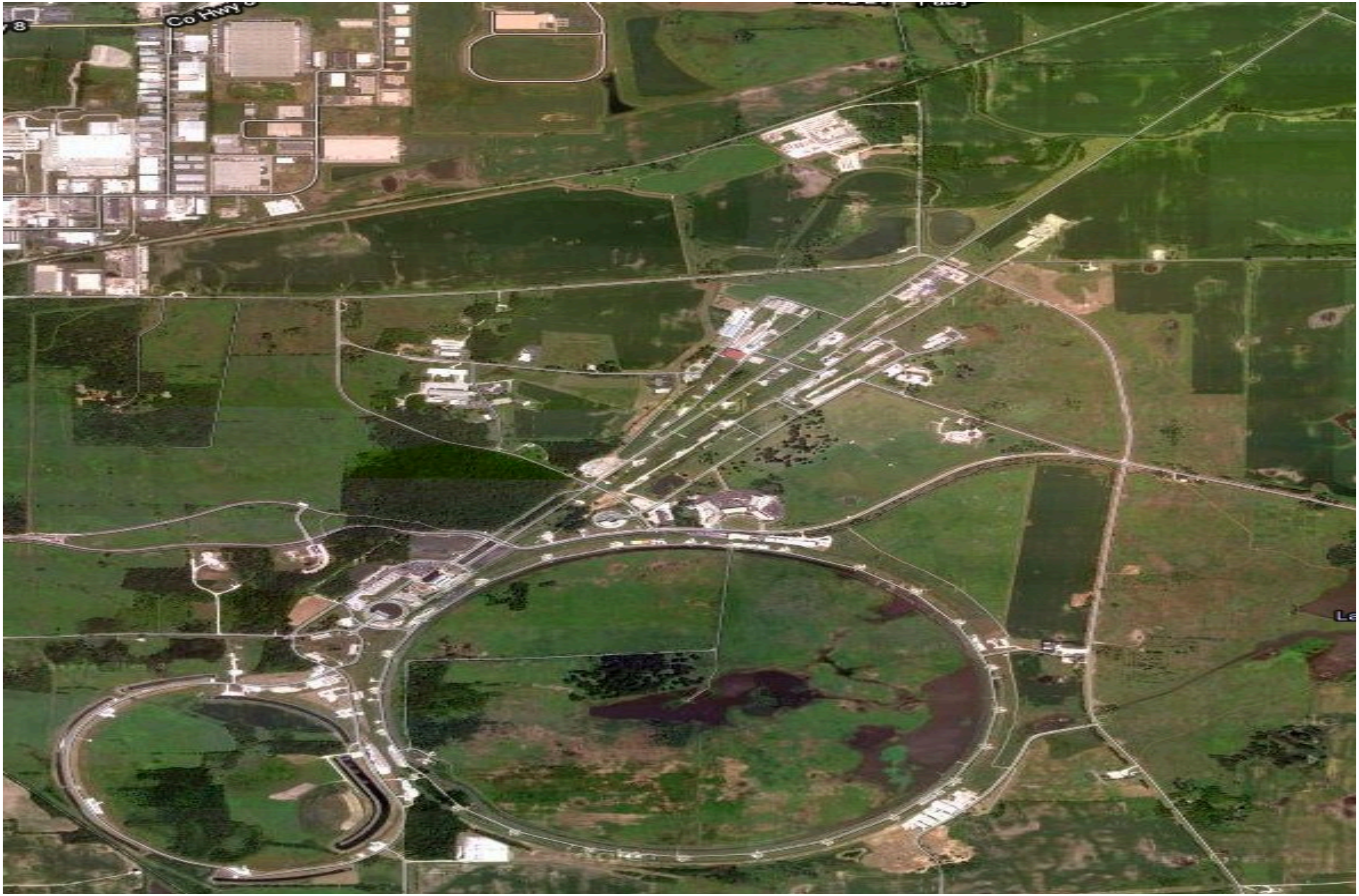
Synchroton Accelerators

- Synchrotons use magnets arranged in a ring-like fashion.
- Multiple stages of accelerations are needed before reaching over GeV ranges of energies
- RF power stations are located through the ring to pump electric energies into the particles

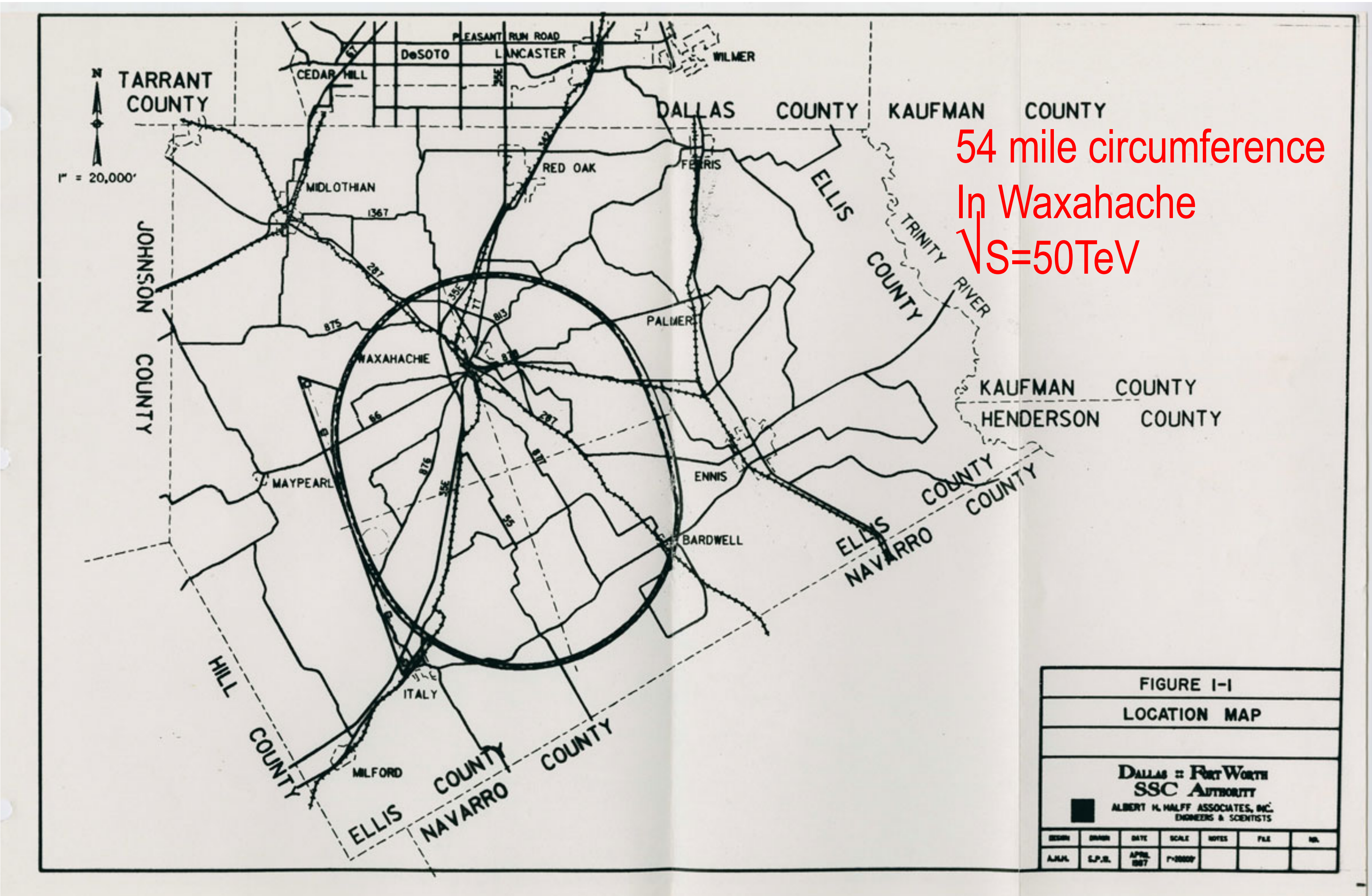




Aerial View of Fermilab Acc. Complex



Rough Regional Map of the SSC



54 mile circumference

In Waxahache

$\sqrt{S}$=50TeV