Fermilab
An Introduction

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Fermi National Accelerator Laboratory

June 7, 2011

Summer Student Lecture Series

U.S. DEPARTMENT OF ENERGY

Fermilab

Outline

What is the universe made of?

How Fermilab became a great laboratory

Particle physics with colliding beams and fixed targets

The Frontiers: FNAL, LHC

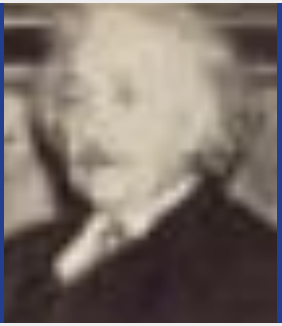
The Future: Project X and the Physics Frontiers

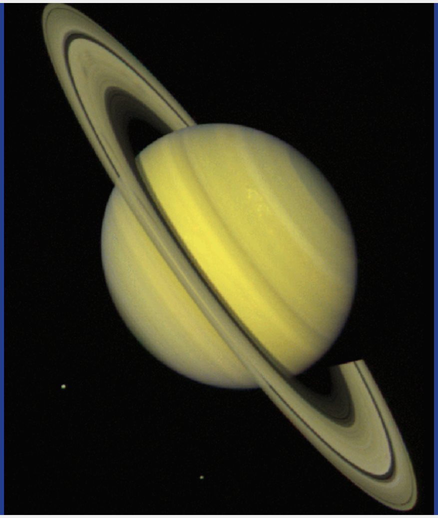
What is the Universe made of?

What are the smallest things we can study?










Great Moments in Physics

1687	Newton formulates the Law of Gravitation
1787	Coulomb formulates the Law of Electrostatic Attraction and Repulsion
1803	Dalton's Atomic Theory
1865	Maxwell's Equations of Electromagnetism
1870	Periodic Table of the Elements
1897	J. J. Thomson discovers the "electron"
1911	Rutherford shows that the atom has a nucleus or center, where the positive charge and most of the mass is concentrated.
1914	Rutherford discovers the "proton"
1926	Schrödinger Equation- Quantum Mechanics
1926 -1930	Quantitative understanding of atomic structure and the emission and absorption of light by atoms.
1932	Chadwick discovers the neutron (neutral component of the nucleus)

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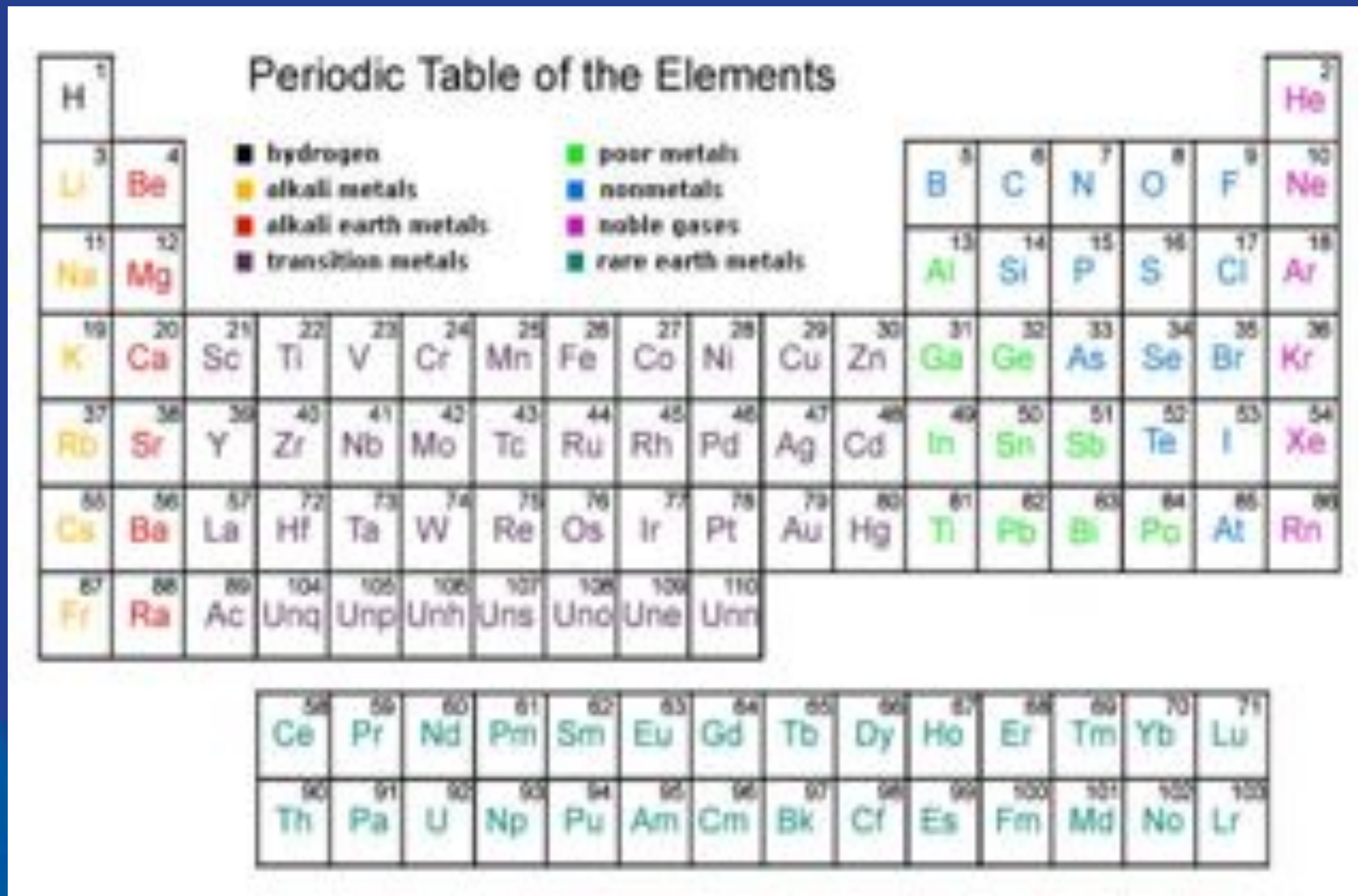
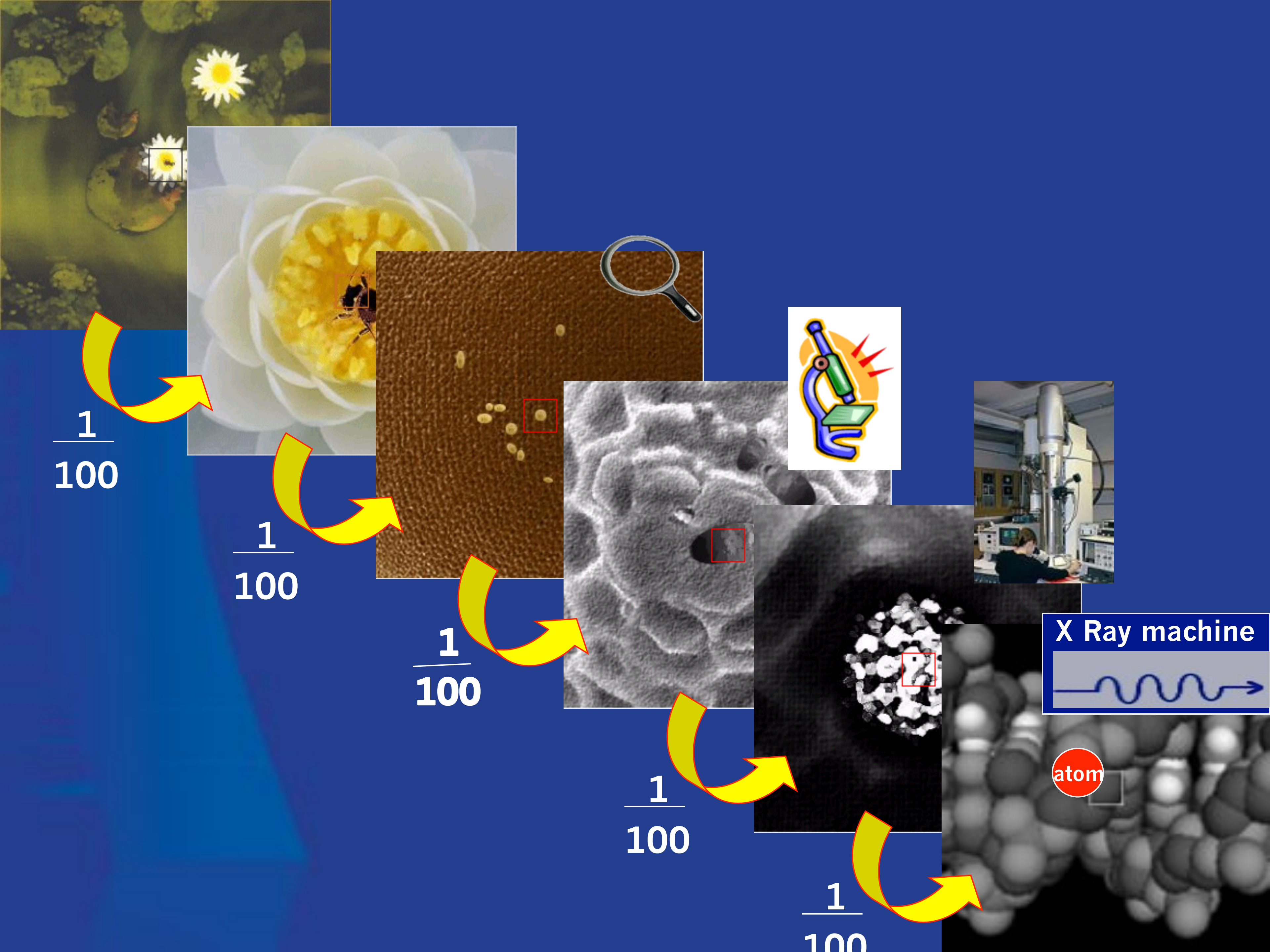
Atoms



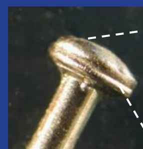
This arises because atoms have substructure



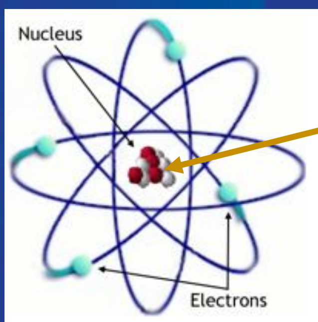
1/100
1/100
1/100
1/100
X Ray machine
atom
1

How tiny is tiny? Protons and the tinier quarks inside them:

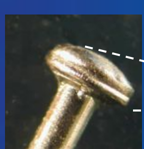
Magnify a pinhead to the size of the Earth:



Then an atom is about the size of a house:



NOT SO BIG!



… and the nucleus the size of a pinhead in that house!

…and we measure quarks 10,000 times smaller than that pinhead!

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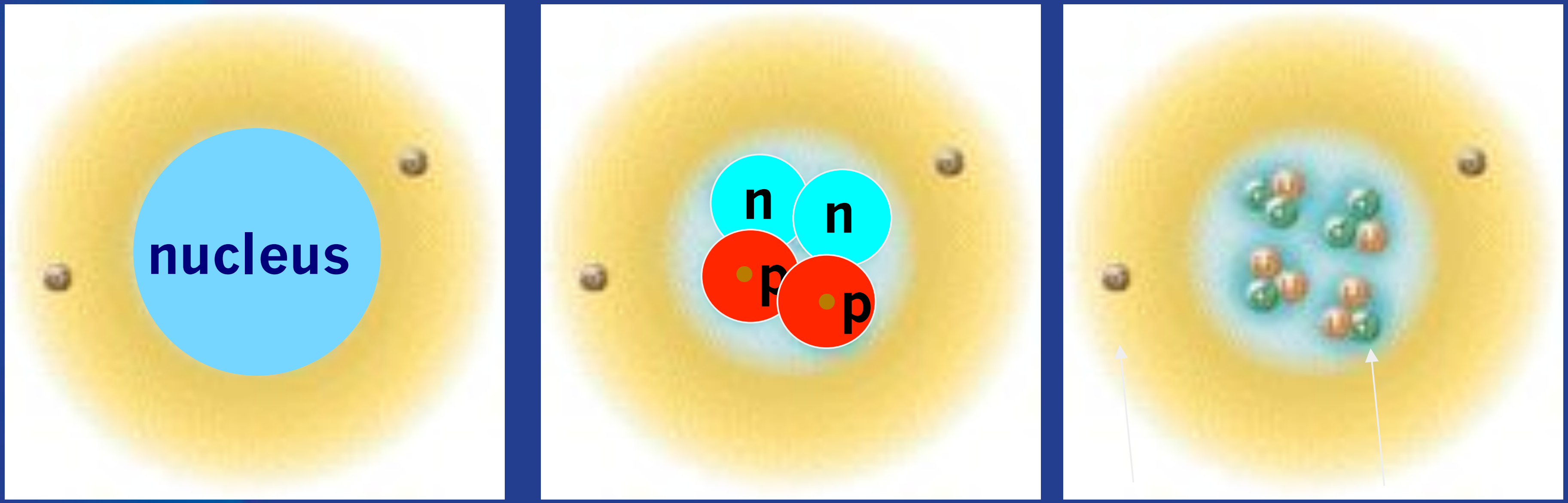
Everything that we can see is made of electrons, and smaller particles.

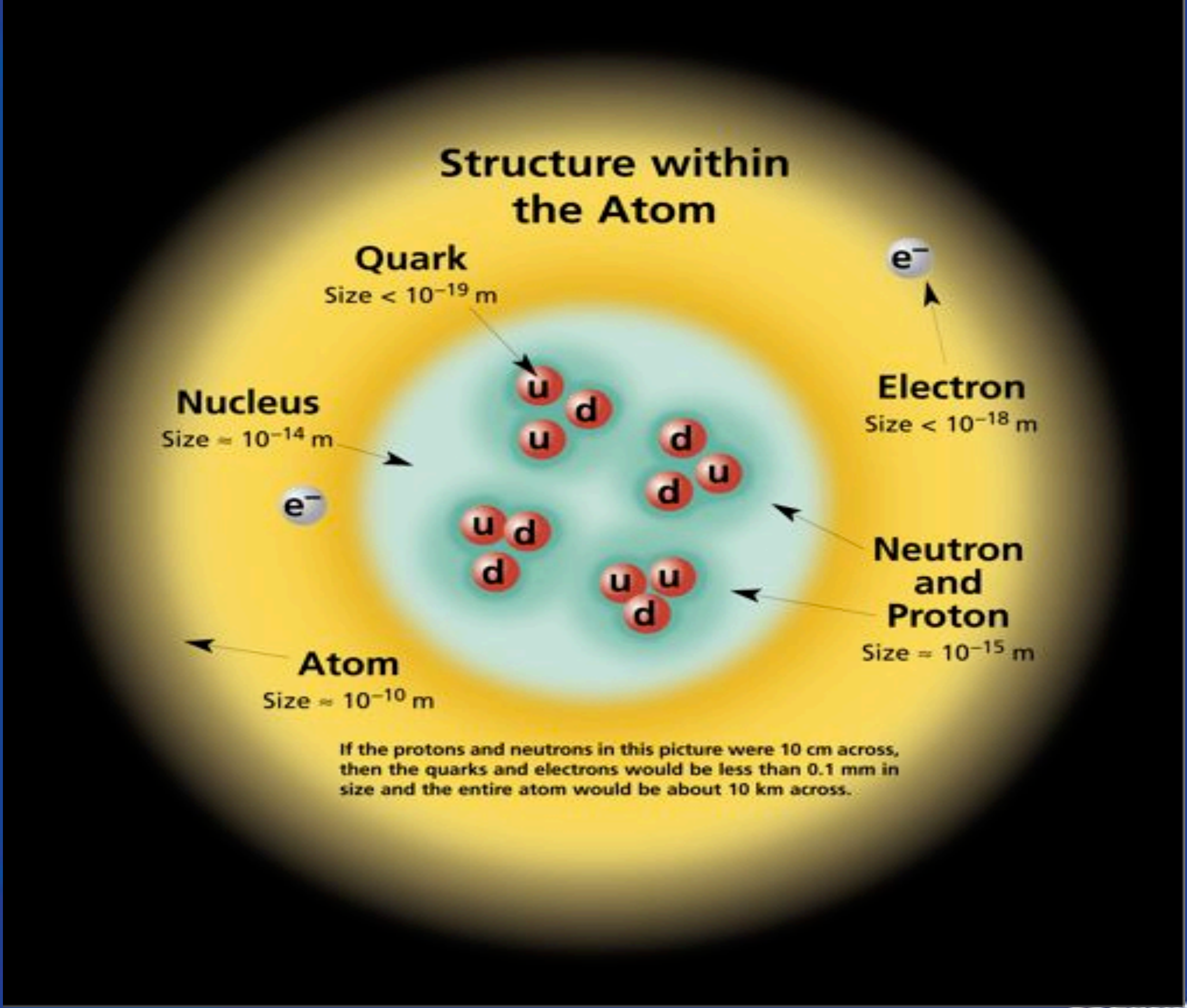


Electron **Quark**

0.0000000000000000001 m

nano nano meter

higher beam particle energy = smaller size you can see


Structure within the Atom
Quark
Size < 10−19 m
e−
Electron
Size < 10−18 m
Nucleus
Size ≈ 10−14 m
u
d
e−
Neutron and Proton
Size ≈ 10−15 m
Atom
Size ≈ 10−10 m
If the protons and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

How Fermilab became a great laboratory

Fermi National Accelerator Laboratory advances the understanding of the fundamental nature of matter and energy by providing leadership and resources for qualified researchers to conduct basic research at the frontiers of high energy physics and related disciplines.

Fermilab measures the properties of matter

A little history

Accelerators act like microscopes

The First Accelerators

Lawrence and Livingston began developing this 4.5-inch cyclotron in 1929-30.

Livingston (left) and Lawrence with the magnet of the 27-inch cyclotron, operating in 1932 at 3.6 MeV.

Courtesy: Adrienne Kolb, Fermilab

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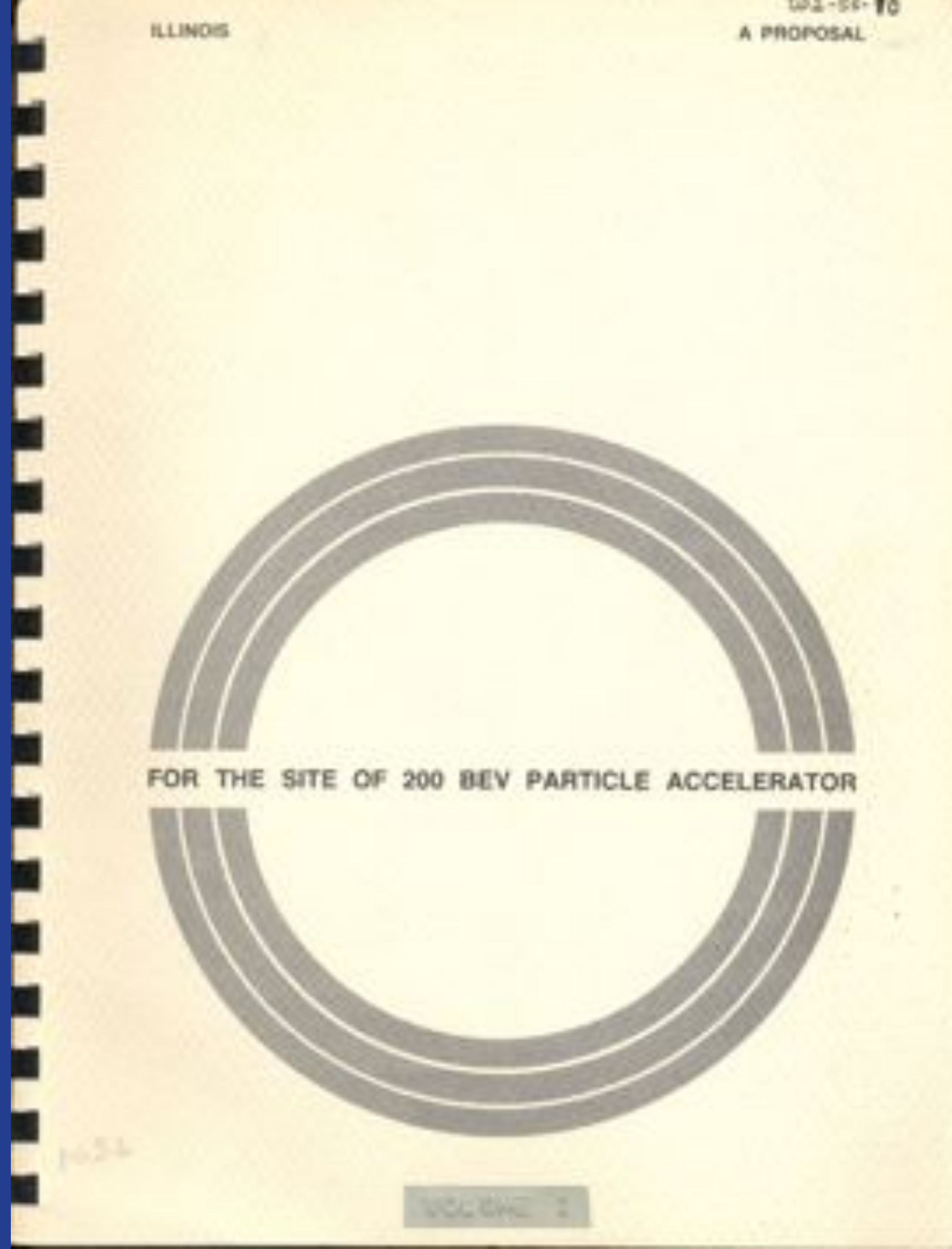
Accelerators

Ernest Lawrence
(1901 - 1958)

Illinois Proposal for 200 BeV Accelerator 1965



Courtesy: Adrienne Kolb, Fermilab

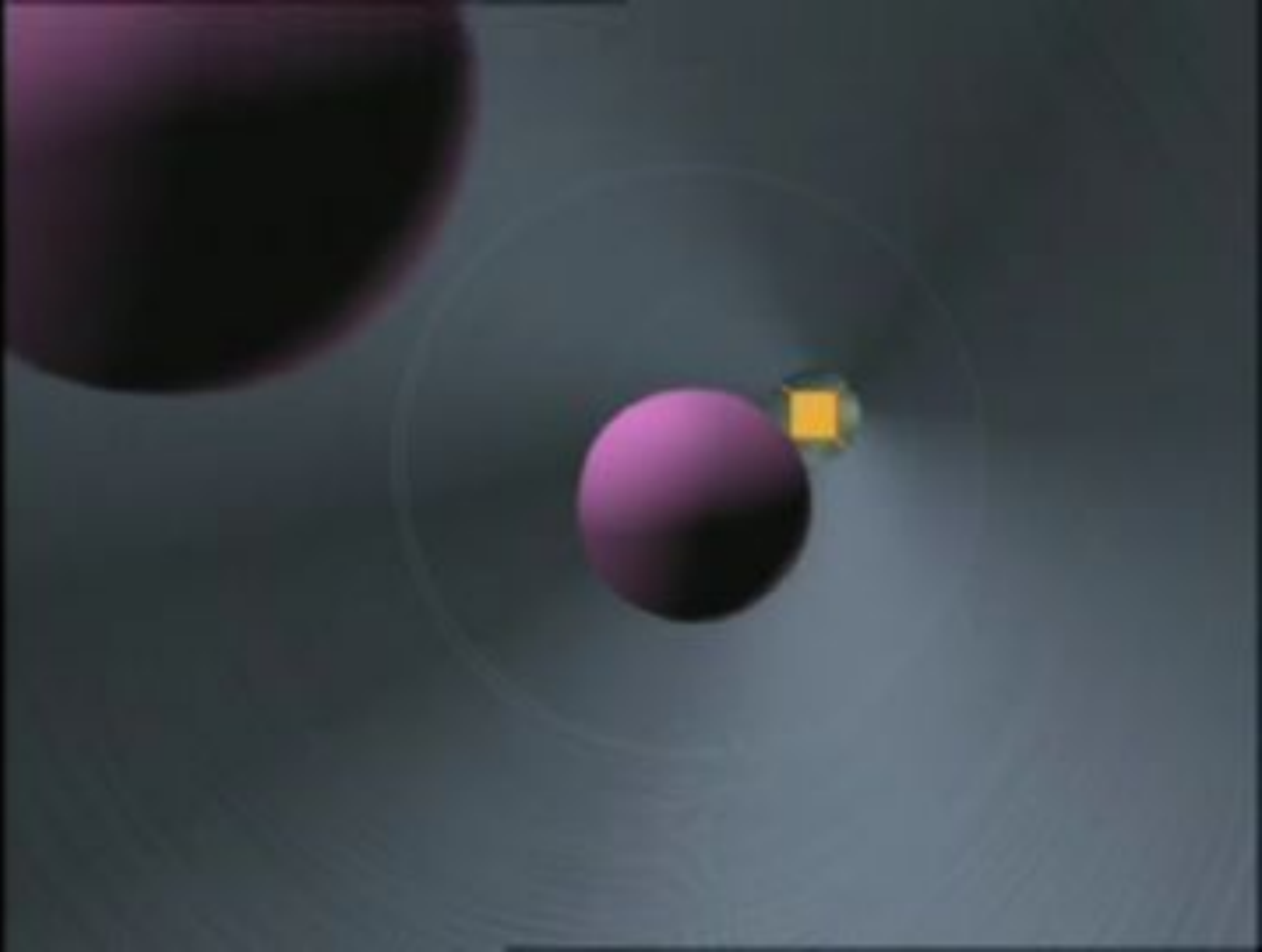
200 GeV March 1, 1972

Wilson toasts the NAL staff

The Weston Site

Courtesy: Adrienne Kolb, Fermilab

Fermilab, 1977

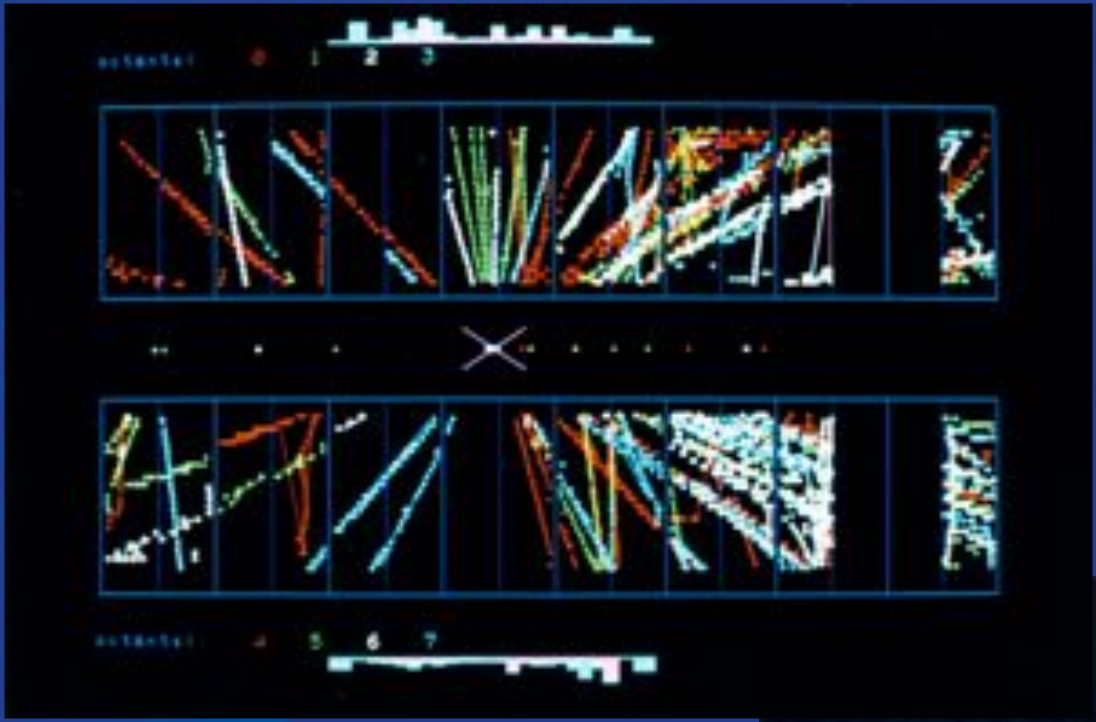


Before electronic data analysis, individuals visually examined photographs of Bubble Chamber particle interactions.

Lincoln University, 1946

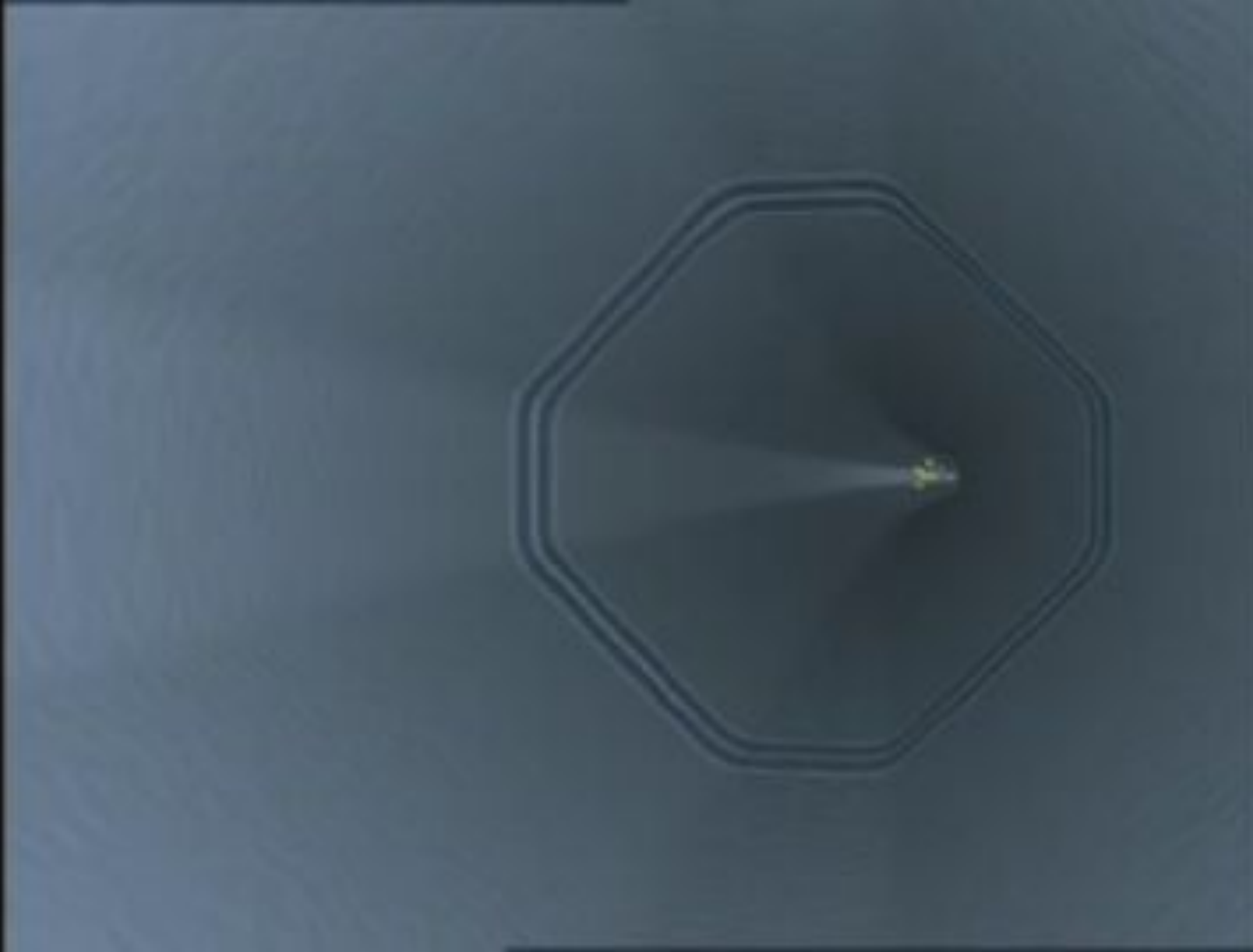
Courtesy: Leo Baeck Institute, New York & The Albert Einstein Estate

- Energy Doubler/Saver

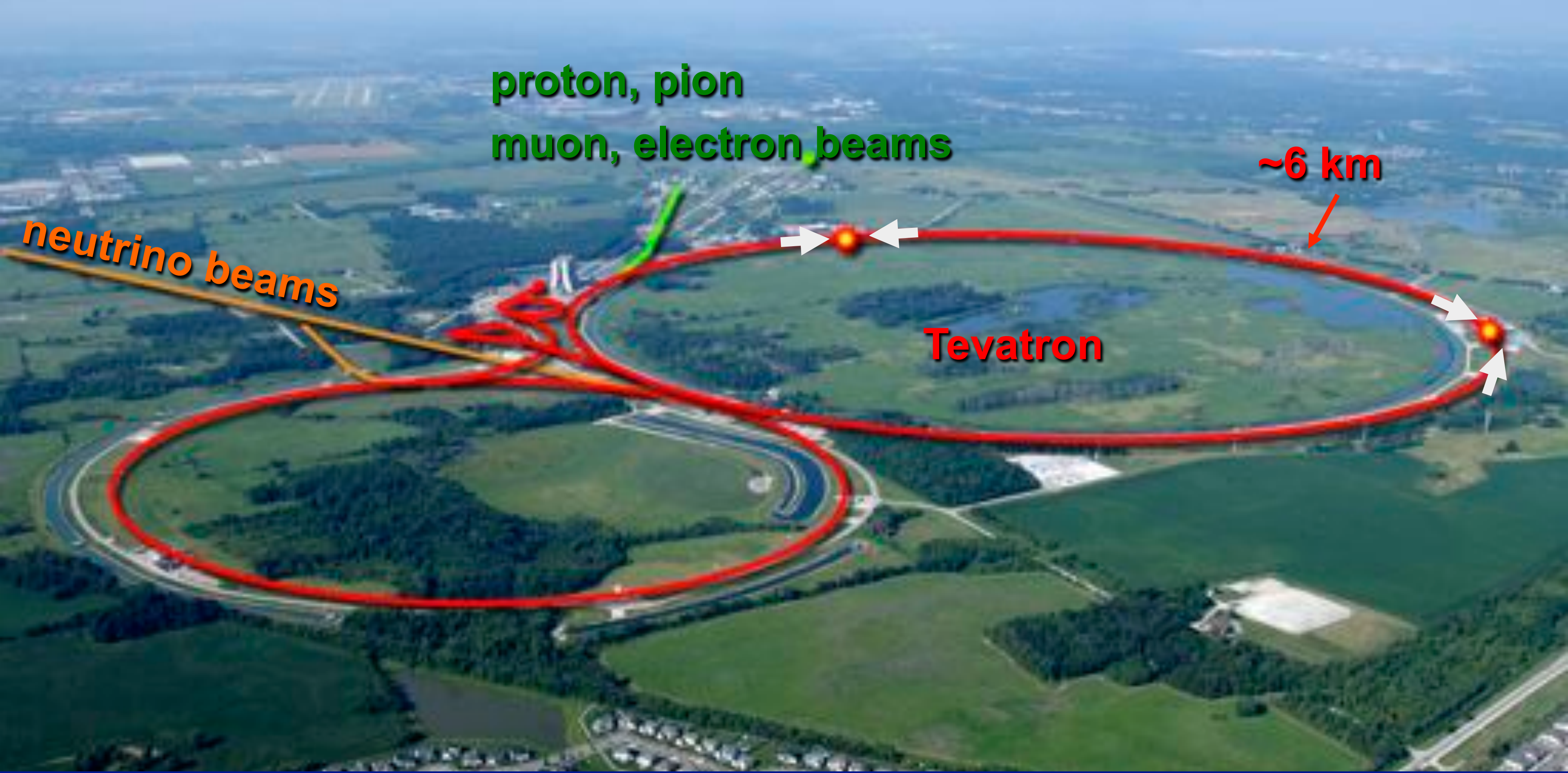


First Collisions
October 13, 1985

Dedication of the
Tevatron Collider
October 11, 1985



Accelerators are like Super Microscopes.



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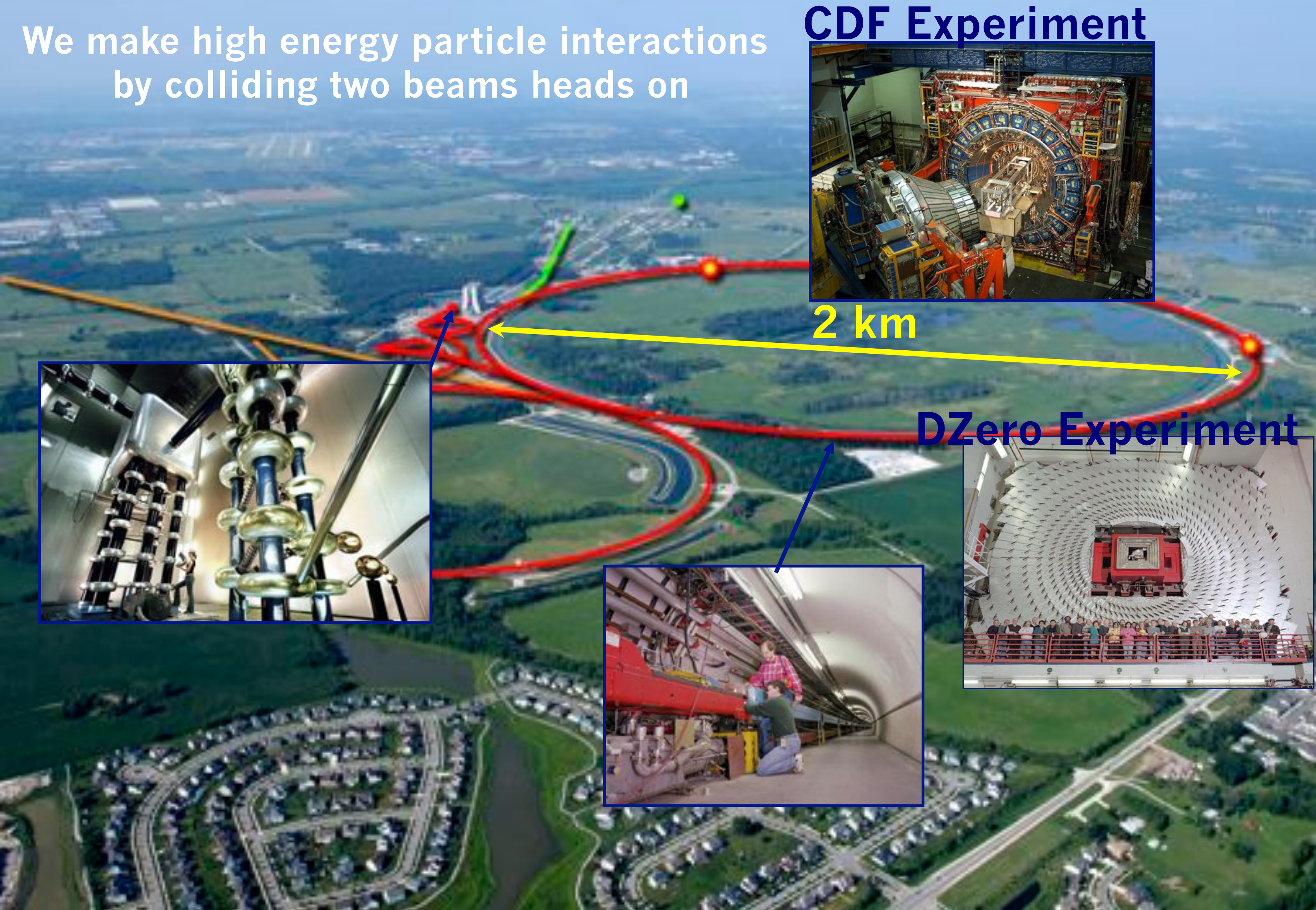
World's 2nd Highest Energy Accelerator

World's Highest Intensity Neutrino Beams

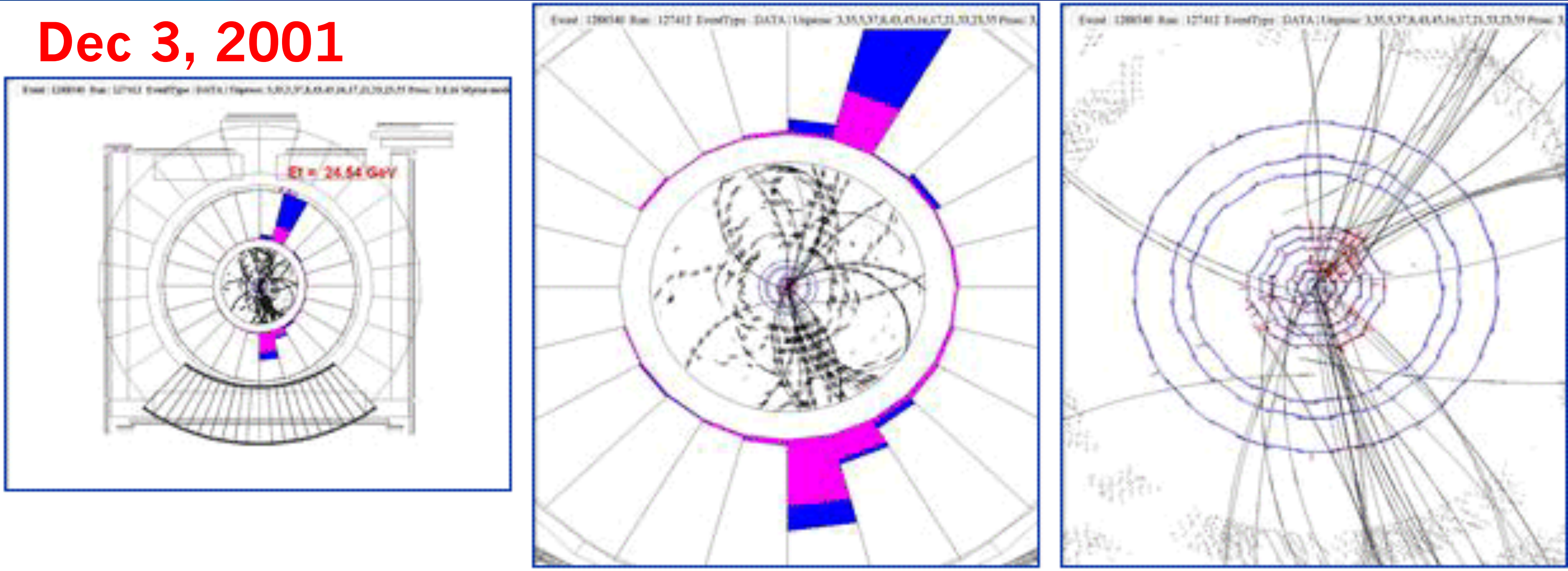
Accelerators – powerful tools for particle physics

We make high energy particle interactions by colliding two beams heads on



An Event Picture

Dec 3, 2001



End view of the entire CDF detector

Close-up showing tracks + energy

Close-up showing tracks with hits in the silicon system

Courtesy: William Wester, CDF

Physics Drivers

1940's	Basic Nuclear Structures Studies	Cyclotrons
	Nuclear Structure	
	-QED	
1950's-60's	Particle and Particle Properties	Synchrotrons
1960's-70's	Substructure	
	-QCD	
1980's-2000	Finishing the Standard Model	Lepton Colliders
		SSC, TeV
2000-----	Search for new particles	LHC, TeV
	Symmetries and New Matter Types	

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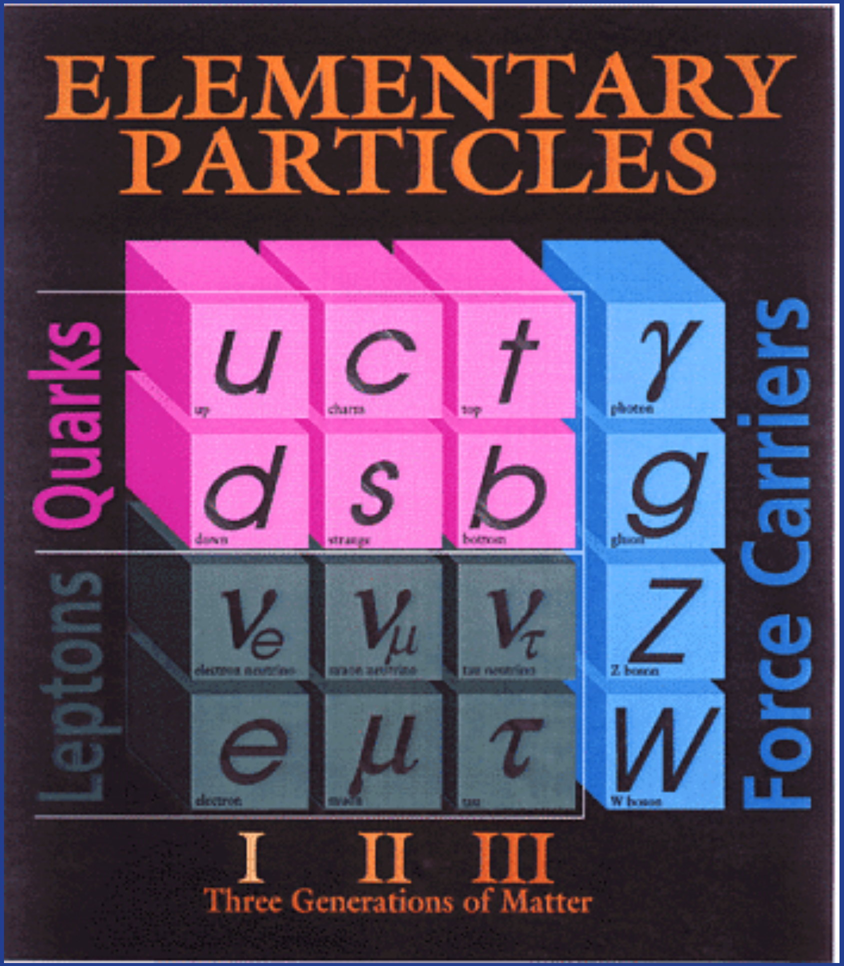
Particles

- **Discoveries**
  - top quark 1995
  - bottom quark 1977
  - ν_t (tau neutrino) 2000
  - direct CP violation 1999
  - (with CERN)

- **Some critical measurements**
  - *t* and *W* mass 1998
  - QCD at highest energies 1988
  - proton structure 1984-95
  - charm lifetimes 1985-95



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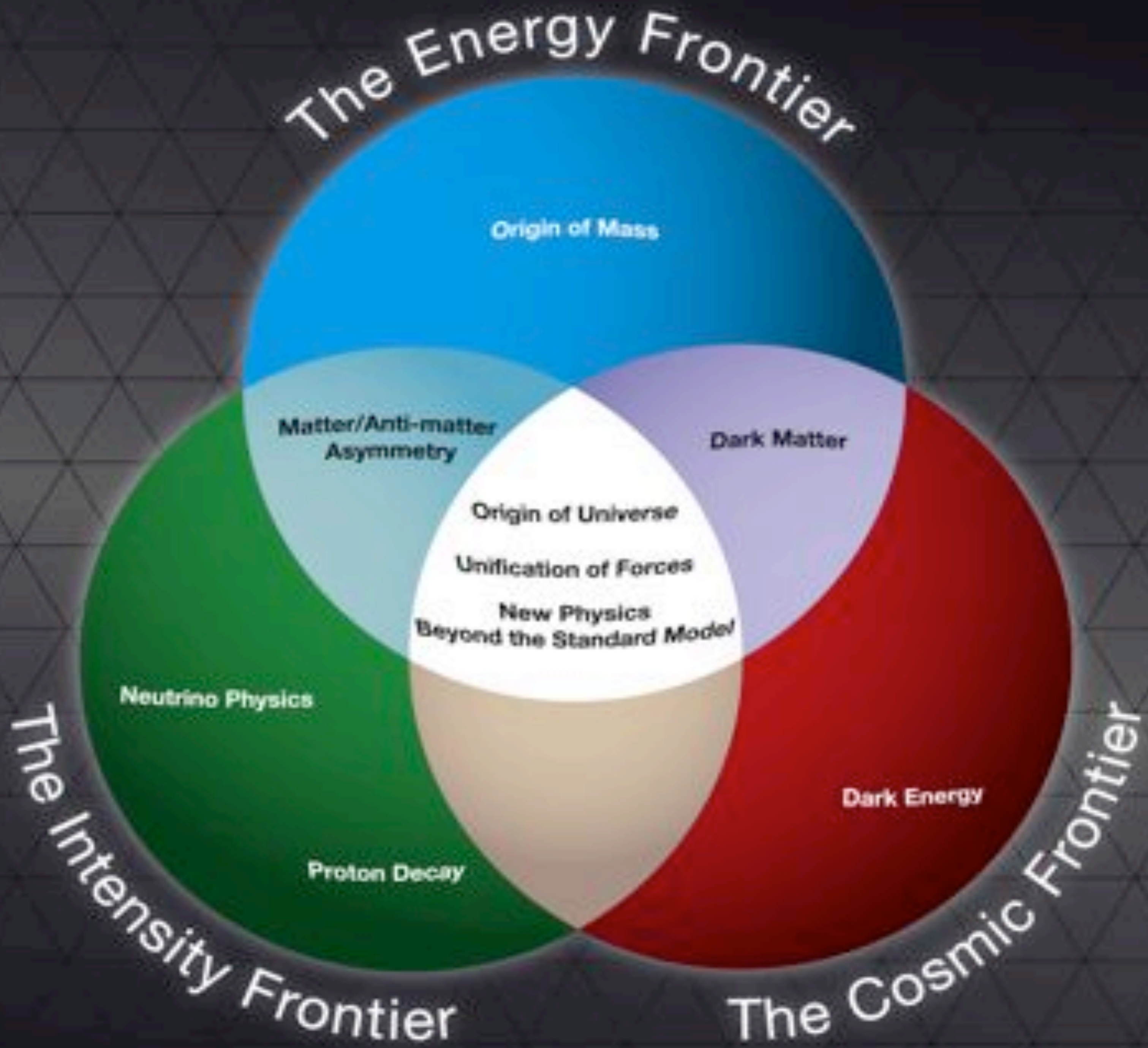
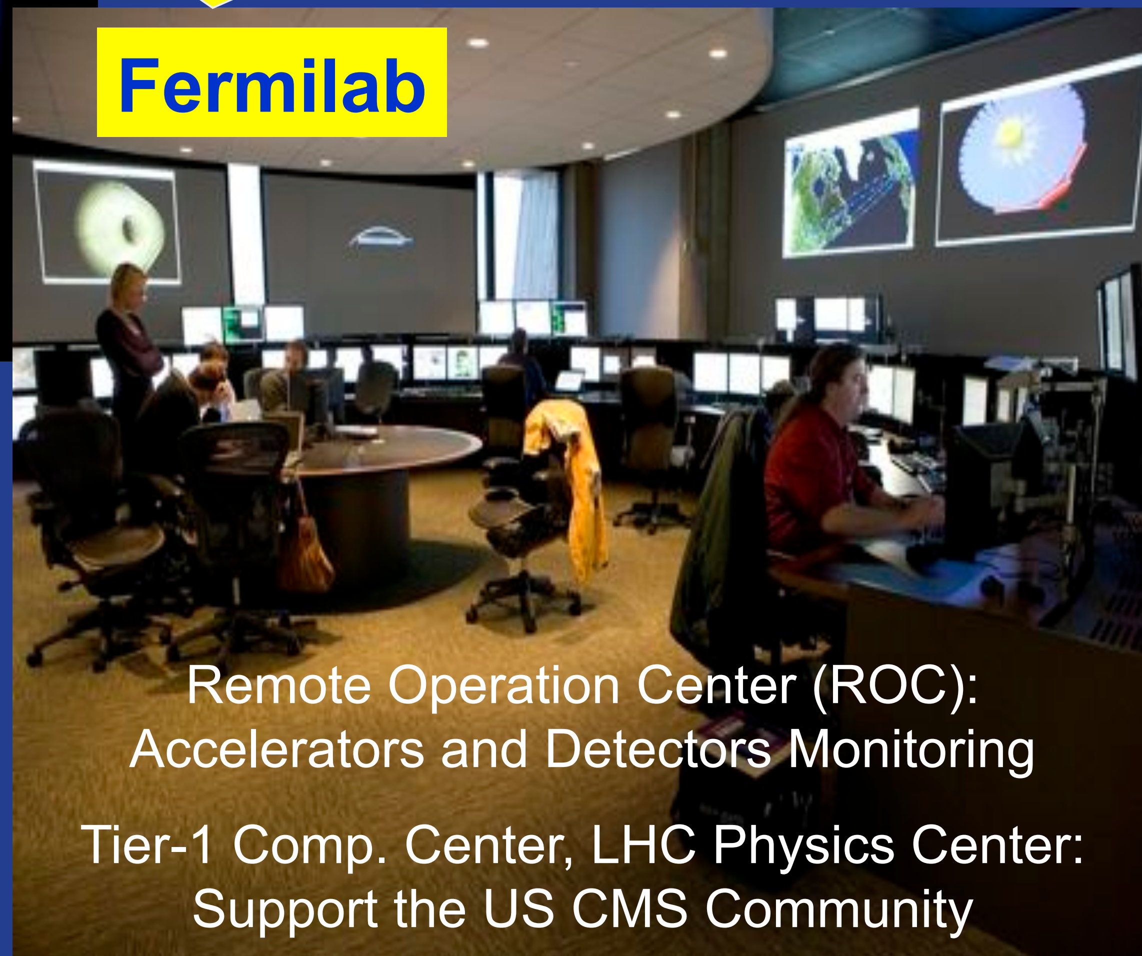
P5


The Energy Frontier
Origin of Mass
Matter/Anti-matter
Asymmetry
Dark Matter
Origin of Universe
Unification of Forces
New Physics
Beyond the Standard Model
Neutrino Physics
Proton Decay
Dark Energy
The Intensity Frontier
The Cosmic Frontier

The Energy Frontier: LHC and the Tevatron

- Energy difference of a factor of ~ 7 in the future
- Search for elusive particles and tests
- Train new scientists
- Develop new techniques, machines, and detectors at high energies

The Energy Frontier: CMS

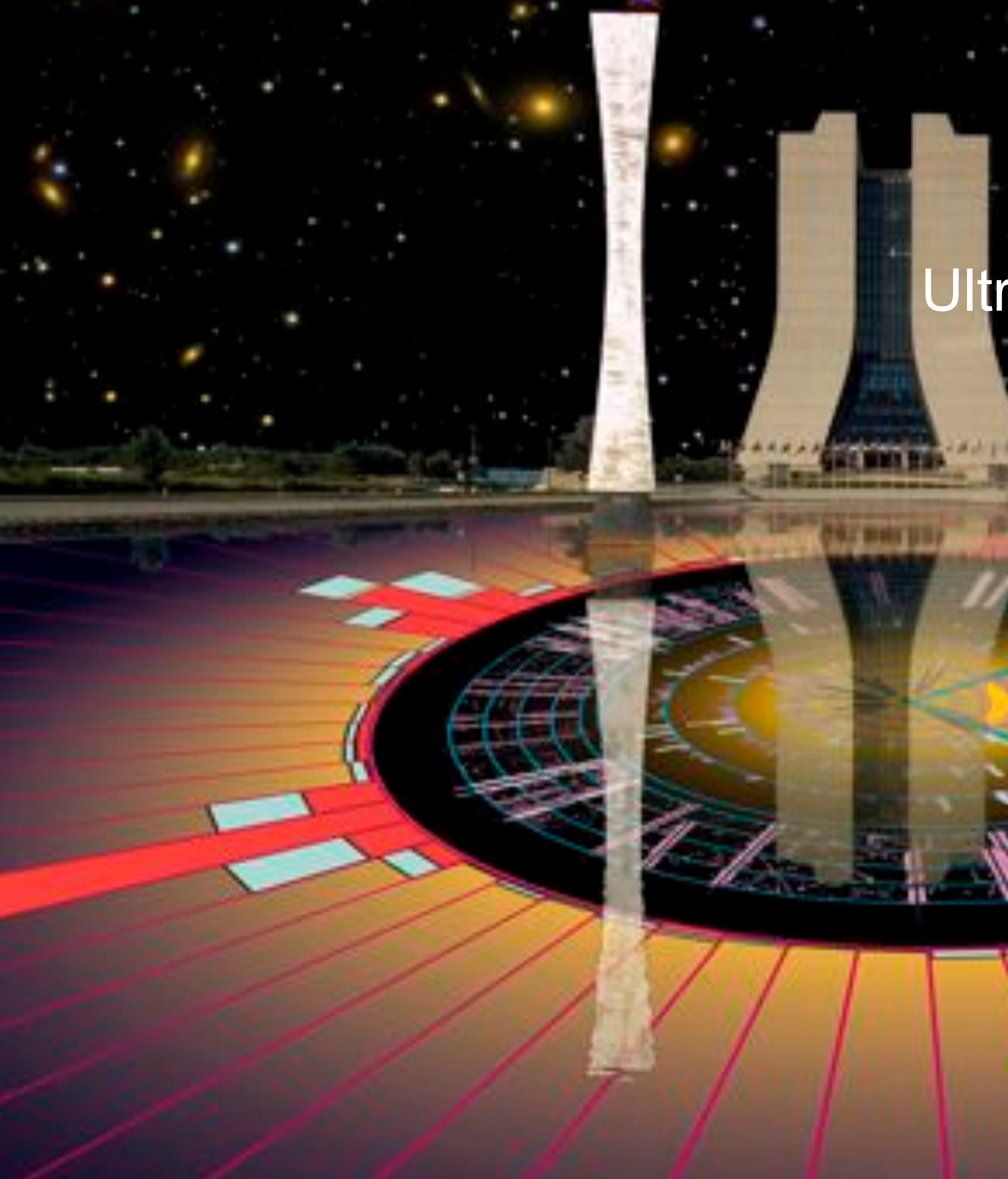


The Cosmic Frontier: Quarks to Cosmos

Dark Matter

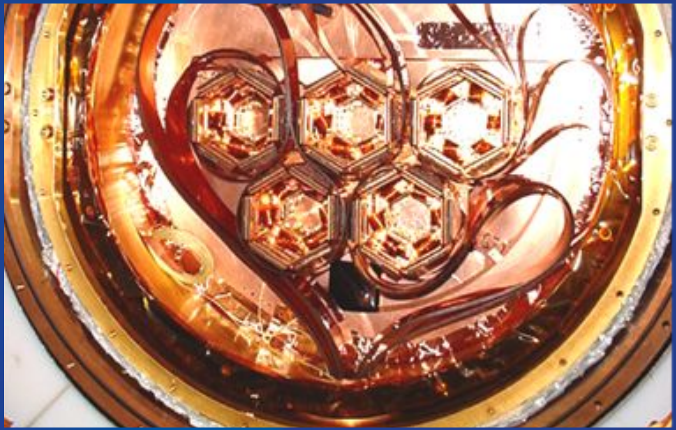
Dark Energy

Ultra High Energy Cosmic Rays

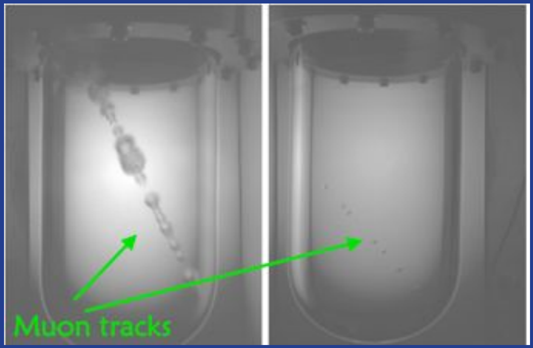


Underground Dark Matter Detectors

CDMS
Low temperature crystals



4 kg → 15 kg



2 kg / 1 liter

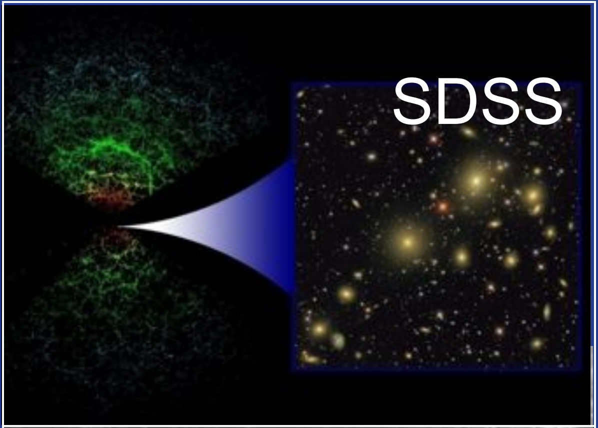
COUPP
Room temperature bubble chamber

Probing Dark Energy

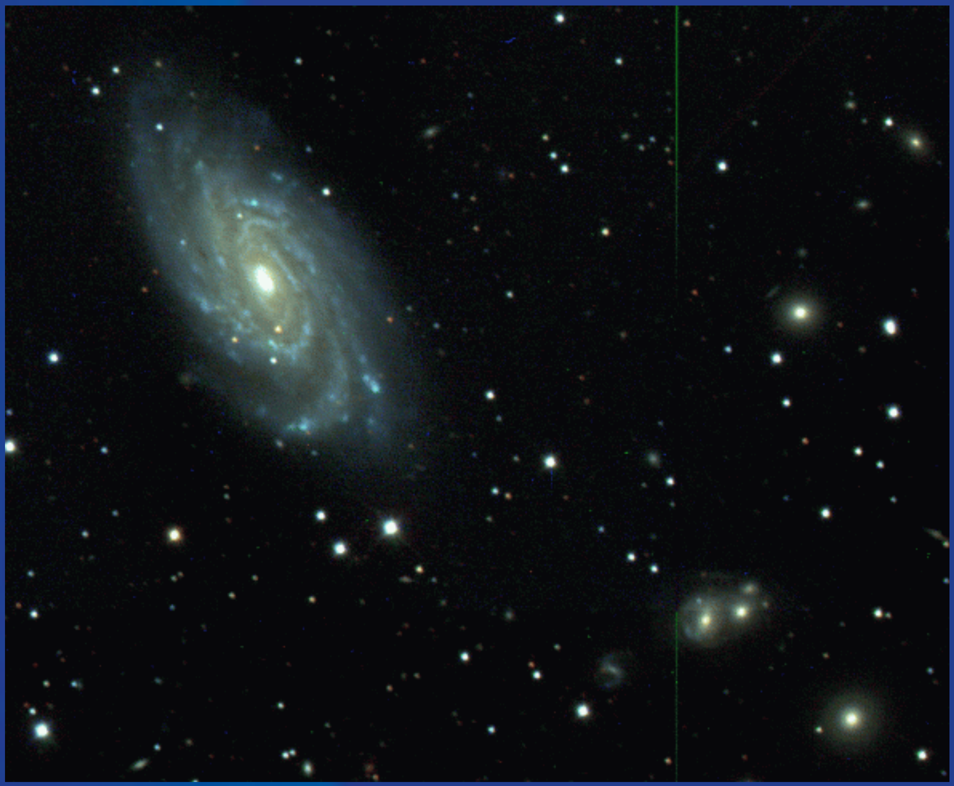
1. SDSS (Sloan Digital Sky Survey)
   - 2.5 meter telescope in New Mexico
   - Ranks as the facility with the highest impact on astronomy for the 3rd year in a row.
   - Power spectrum of galaxies constrain dark energy density parameter.

2. DES (Dark Energy Survey)
   - 4 meter telescope in Chile
   - DES Camera: CD-3a on Apr. 29, 2008
   - CD-3b on Oct. 24, 2008
   - Operation: 2011 – 2016

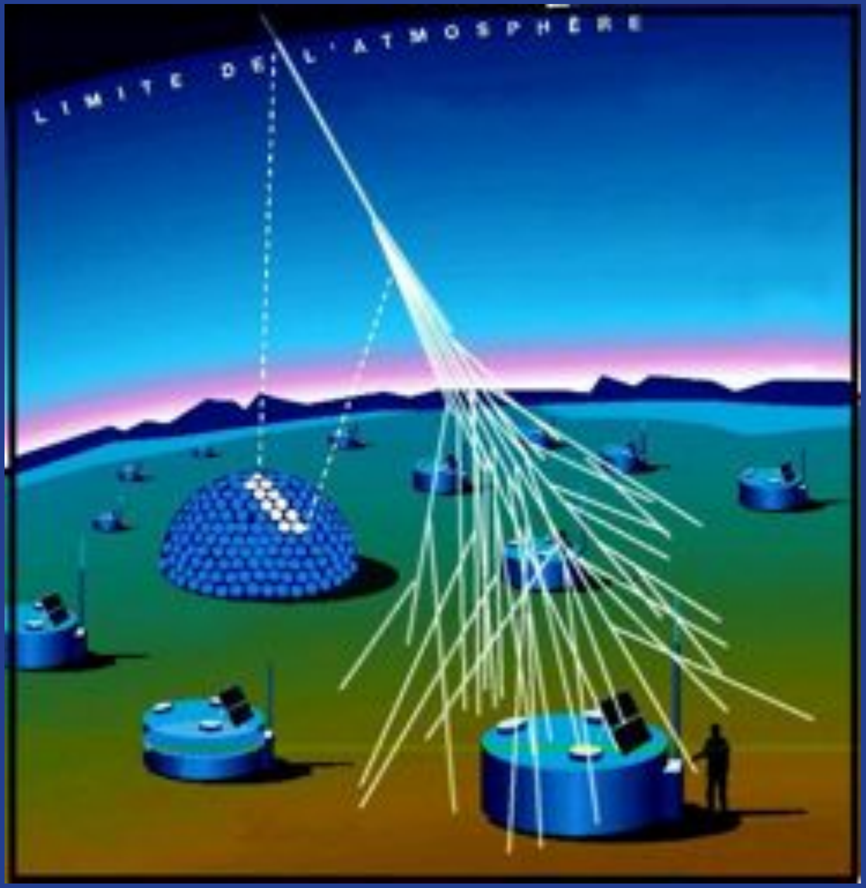
3. JDEM (Joint Dark Energy Mission)
   - Space telescope
   - Fermilab Goal: Science Operation Center



Outer Space
Astrophysics



Sloan Digital Sky Survey



Pierre Auger Observatory

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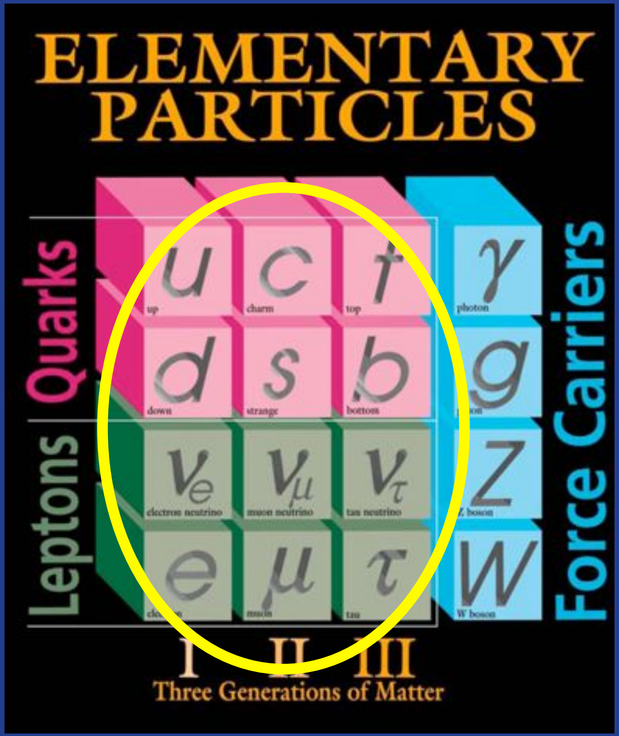
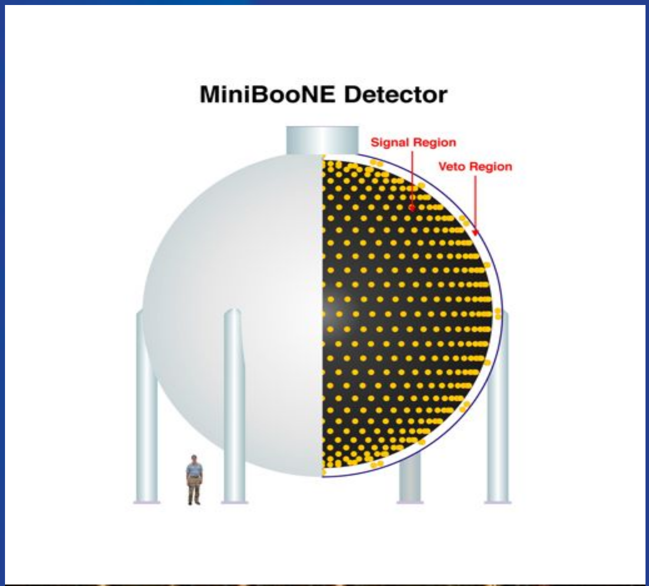
The Intensity Frontier



Physics of Flavor

- Flavor phenomena
  - Essential to shaping physics beyond the SM.
- SM is incomplete:
  - Neutrino Masses (flavor)
    - The only new physics seen so far in the laboratory
  - Baryon Asymmetry of the Universe (flavor)
  - Dark Matter
  - Dark Energy

Intensity Frontier: neutrinos now



- **Neutrinos:**

**The enigmatic neutrinos are among the most abundant of the tiny particles that make up our universe.
To understand the universe, must understand neutrinos.**

Behavior is so different from other particles.

Opening a "new" window

Unknowns: θ_{13}, $\nu = \bar{\nu}$, mass ordering, CP violation

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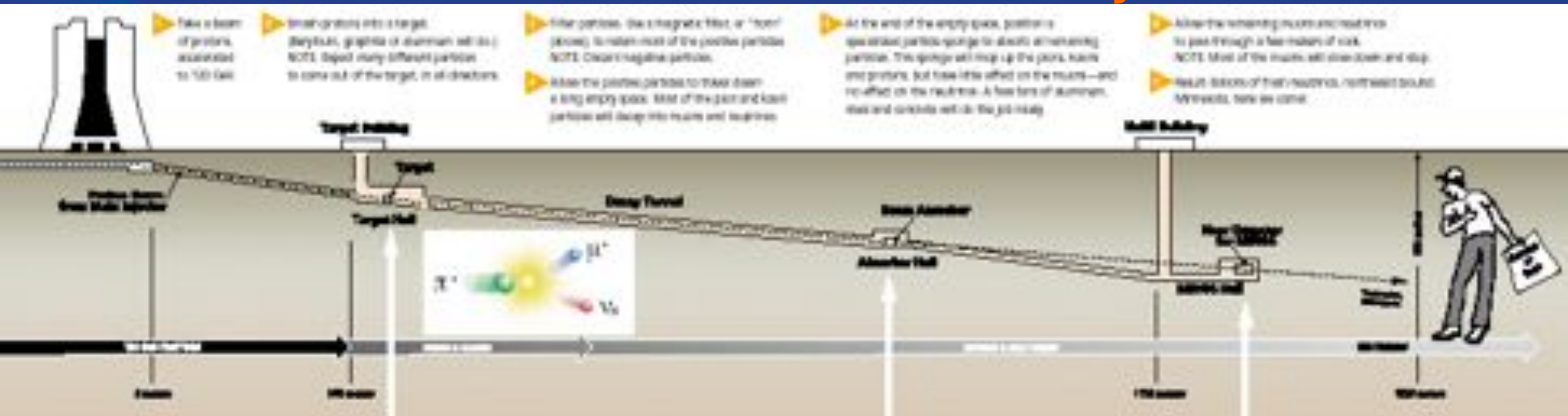
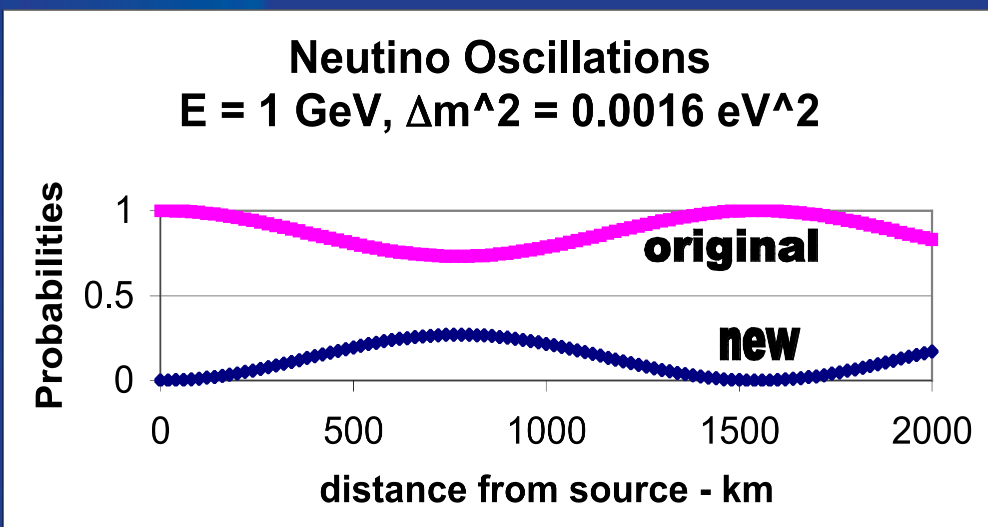
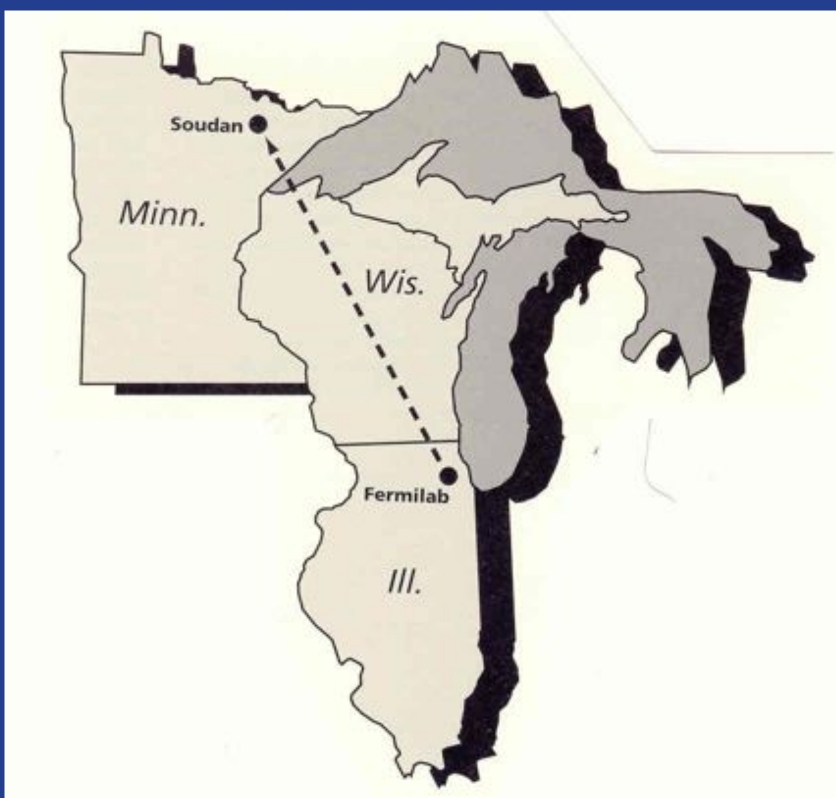
The Intensity Frontier


NOvA Near Detector
MINOS Far Detector
Ontario
Minnesota
Wisconsin
Iowa
Milwaukee
Michigan
Fermilab
Chicago
© 2007 Europa Technologies
Image © 2007 TerraMetrics
Image © 2007 NASA
168 km
Google
Pointer 43°34'32.84" N 89°04'55.60" W elev 271 m
Streaming 100%
Eye alt 545.86 km

NUMI – Neutrinos at the Main Injector



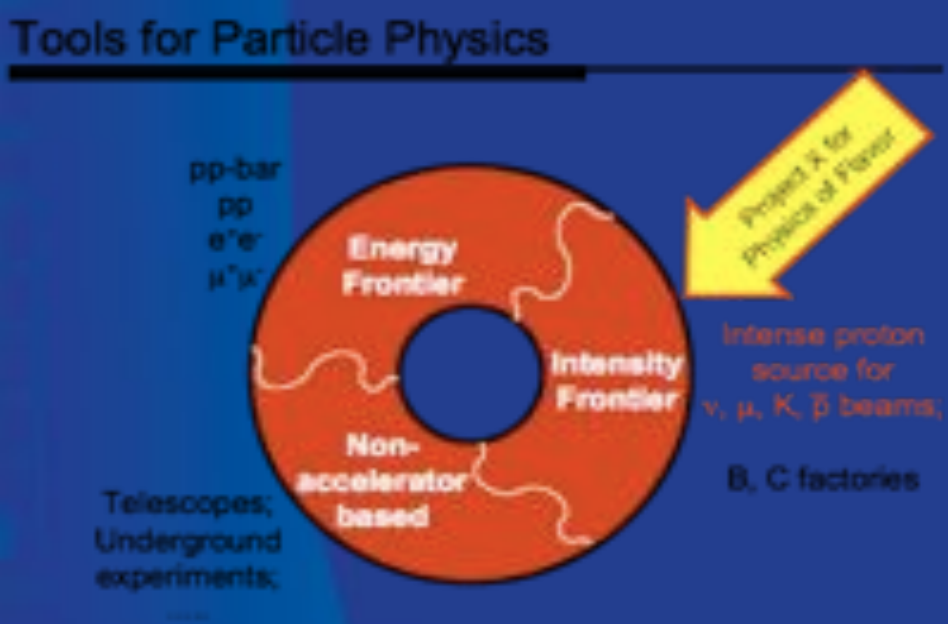




735 km long beam, right through the earth! 10 km deep

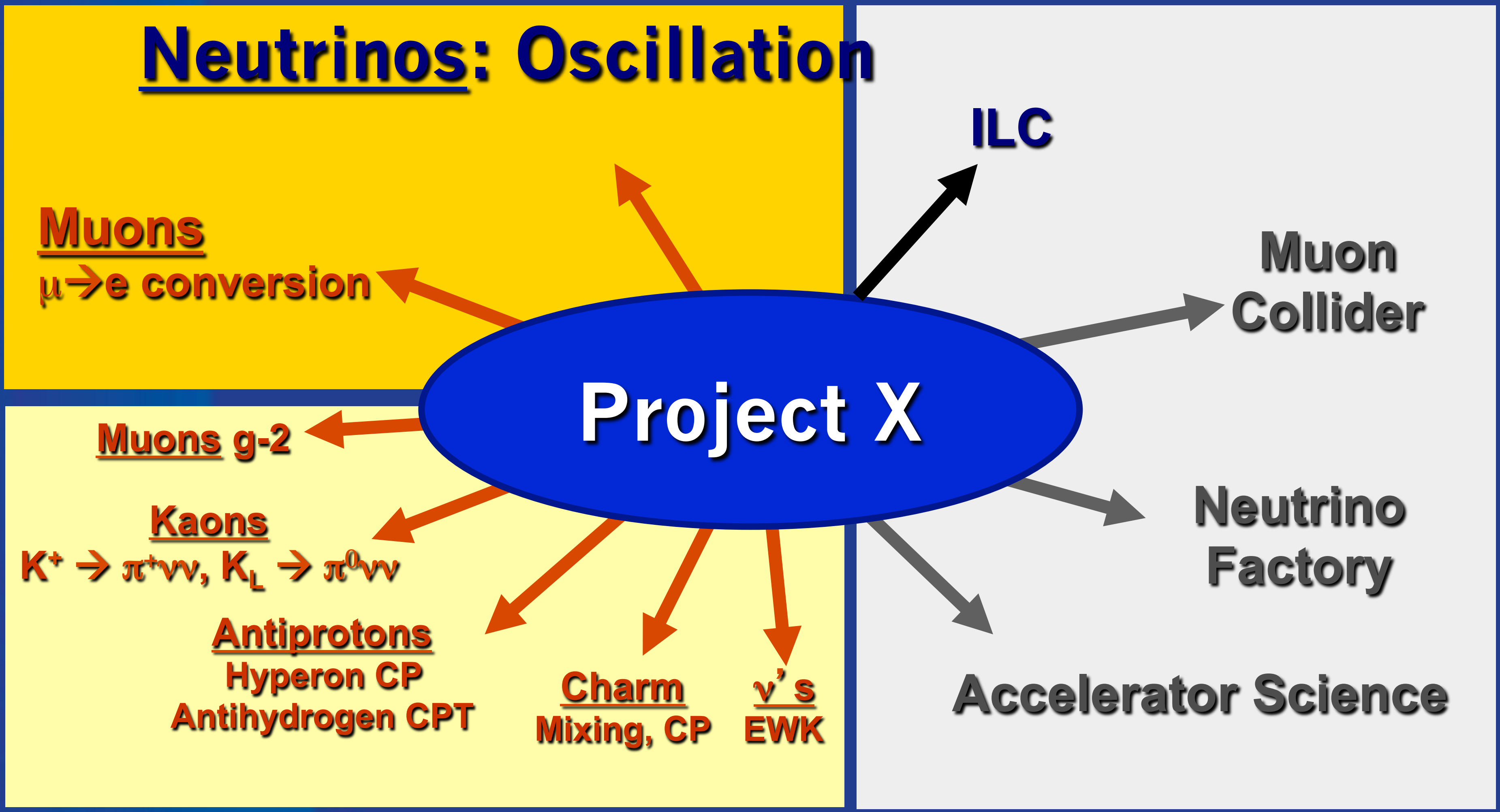
Future Planning for Fermilab

Why Project X?



- FNAL Booster cannot provide sufficient intensity for the Intensity Frontier Program: neutrinos, muons, kaons,...

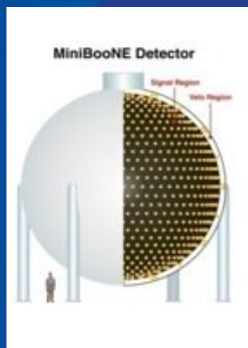
Opportunities with Project X

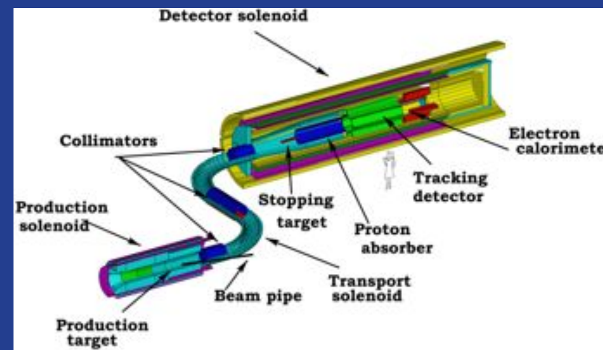


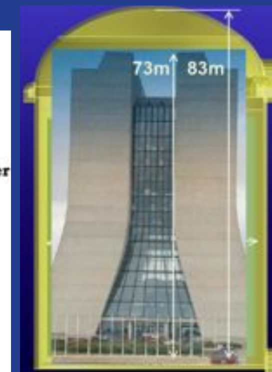
US HEP community and International Partners

Project X

Present plan: intensity frontier

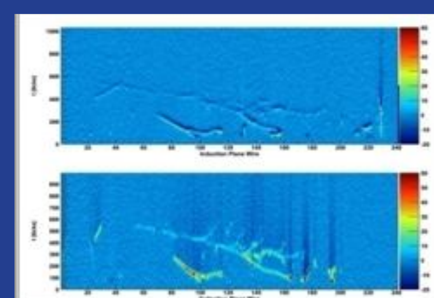


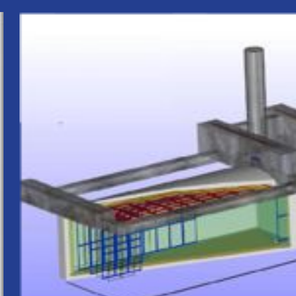




MINOS MiniBooNE MINERvA SeaQuest	NOvA MicroBooNE g-2? SeaQuest	LBNE Mu2e	Project X+LBNE μ, K, nuclear, … ν Factory ??

Now 2013 2016 2019 2022





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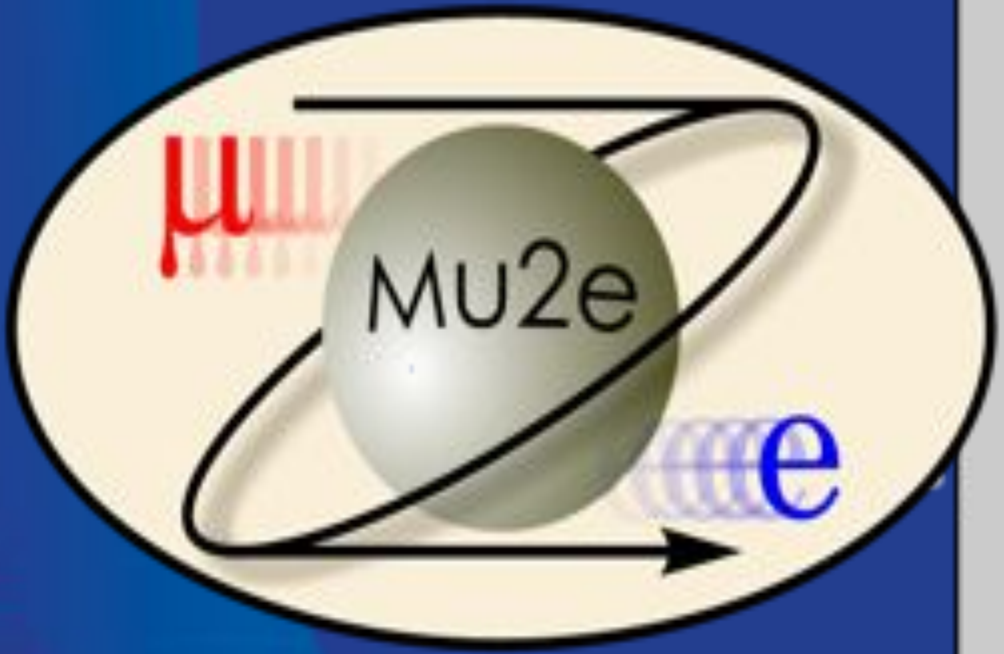
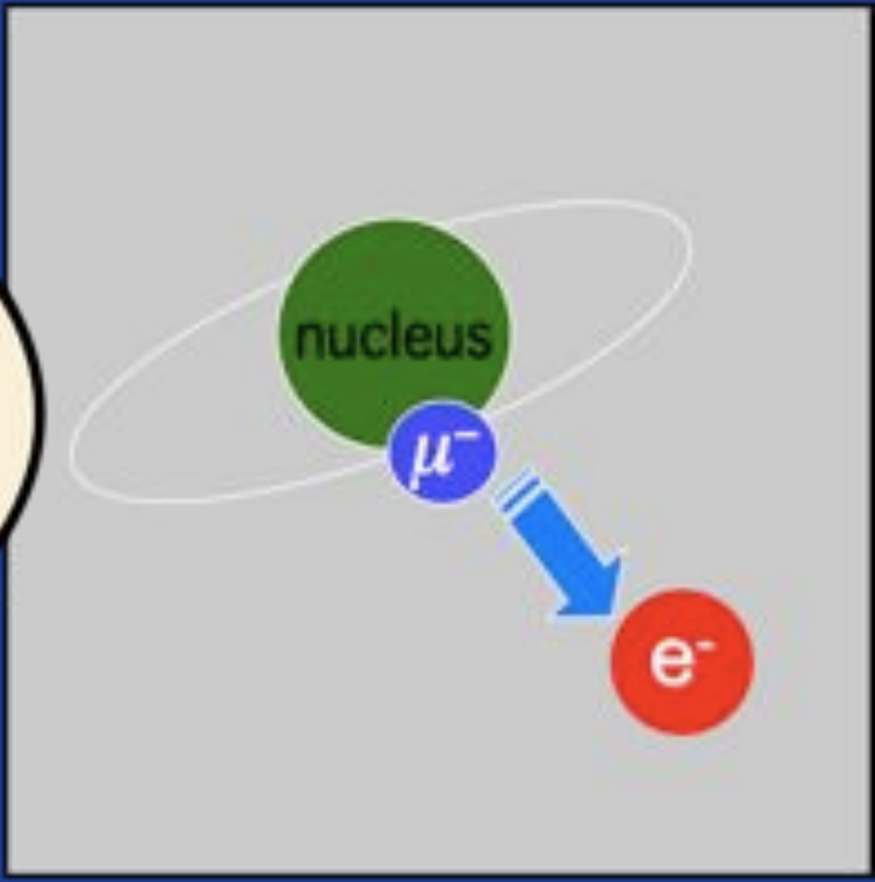
Muon to Electron Conversion

$$\mu^- N \rightarrow e^- N$$





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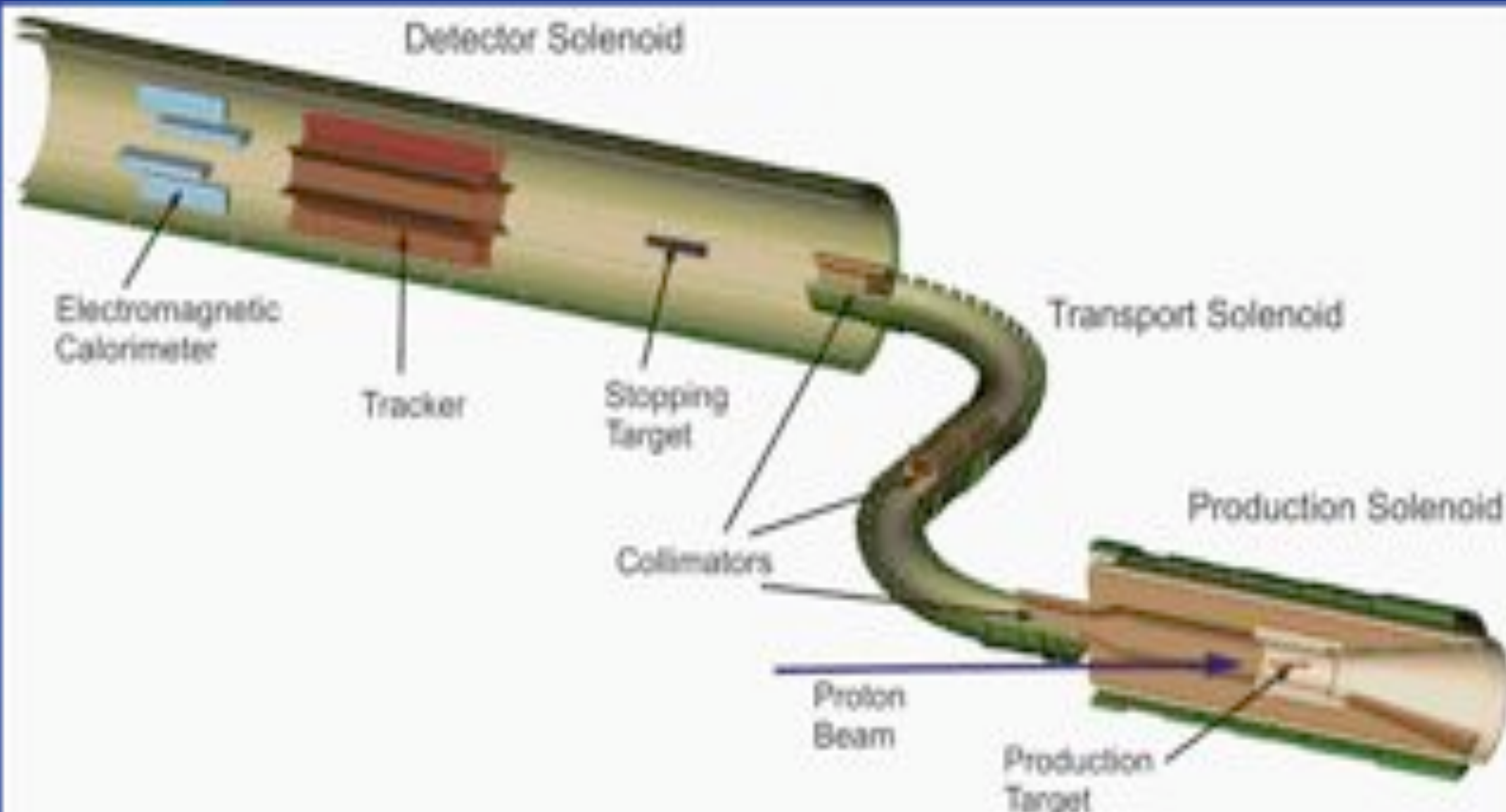
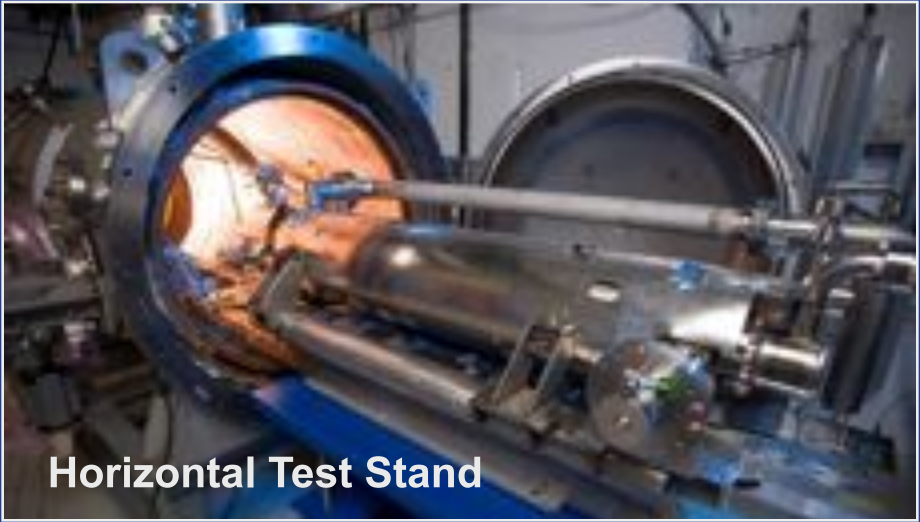
Detector and Solenoid

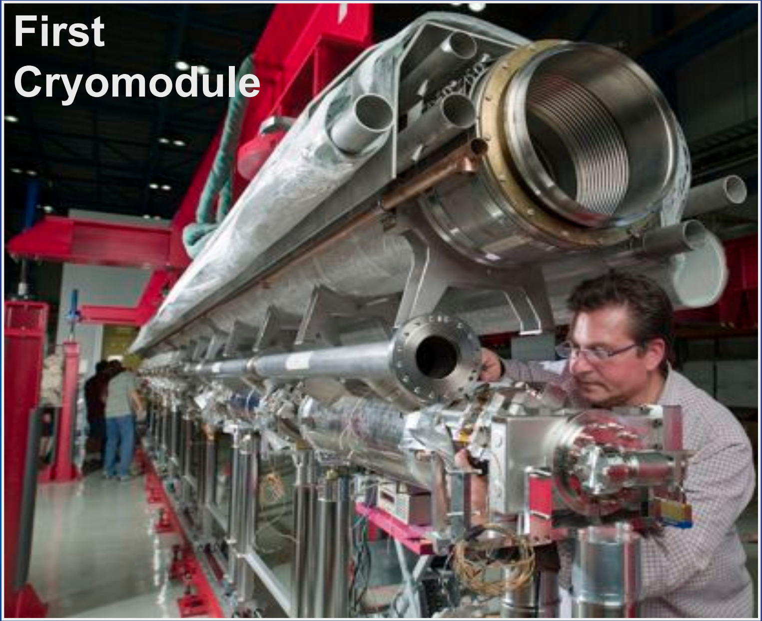



Muon Collider
Conceptual Layout
Fermilab Site

SCRF Tech: Broadly Applicable

at Fermilab





DISCOVERY

- Extracting and understanding a phenomena for the first time!
- Leading to answers and often more questions
- Usually a piece of a puzzle that took some time to ascertain
- Often connecting many separate fields of study
- Enjoyment!

Conclusions

We continue to smash the nuclei that make up our universe and everyday we learn something new!

The Frontiers may merge at some point so

We Should Go Boldly into the Next Frontier