Fermilab

Operated by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

An Introduction to

Fermi National Accelerator Laboratory

Herman B. White

Summer Student Lecture Series

May 27, 2014

OUTLINE

What is the universe made of?

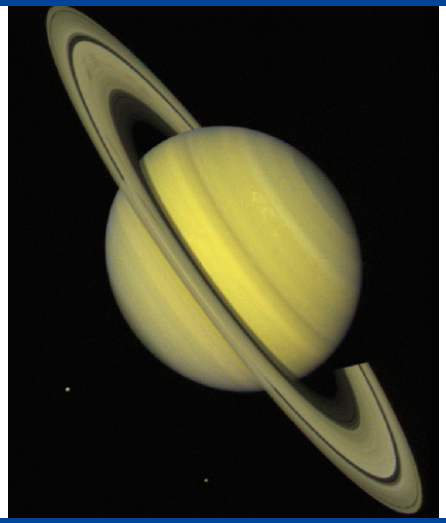
How Fermilab became a great laboratory

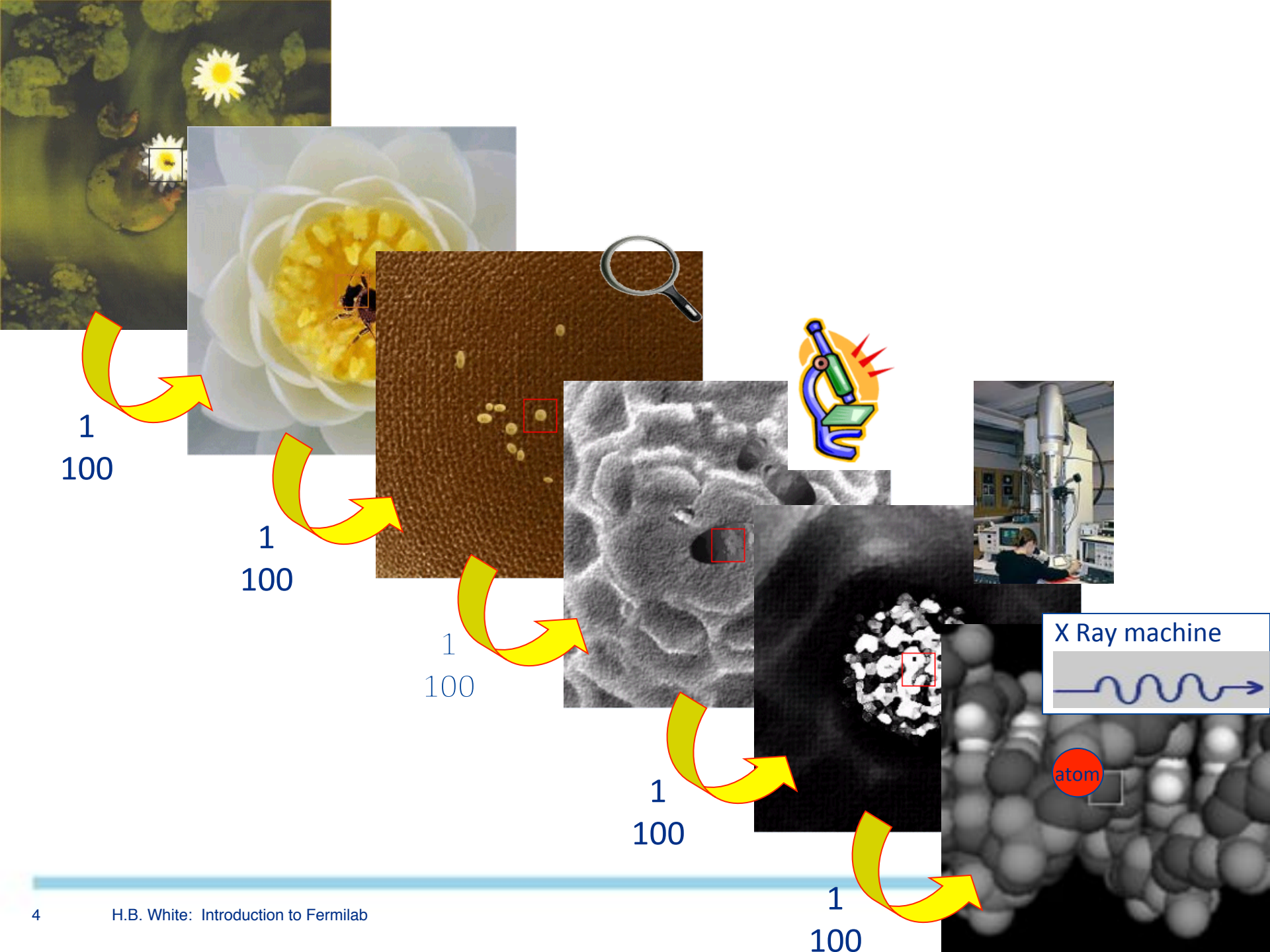
Particle physics on the Prairie

The new Frontiers: FNAL, LHC

The Future: New and Improved Physics Frontiers

What is the Universe made of?
What are the smallest things we can study?




1
100
1
100
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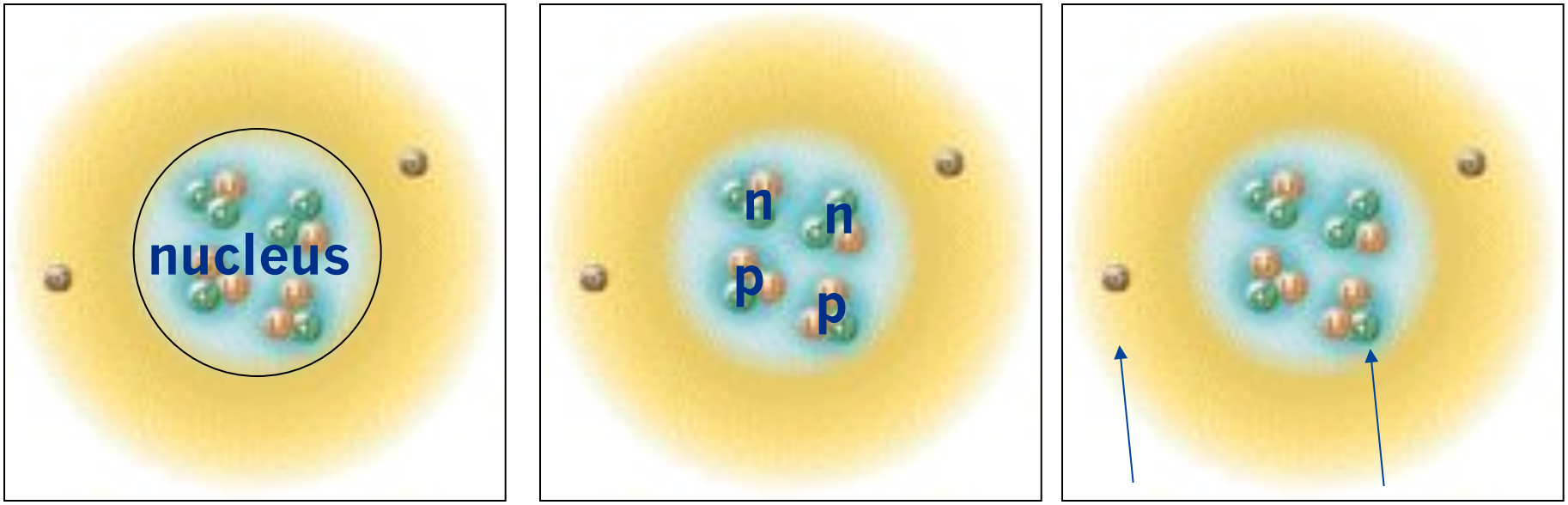
X Ray machine
atom

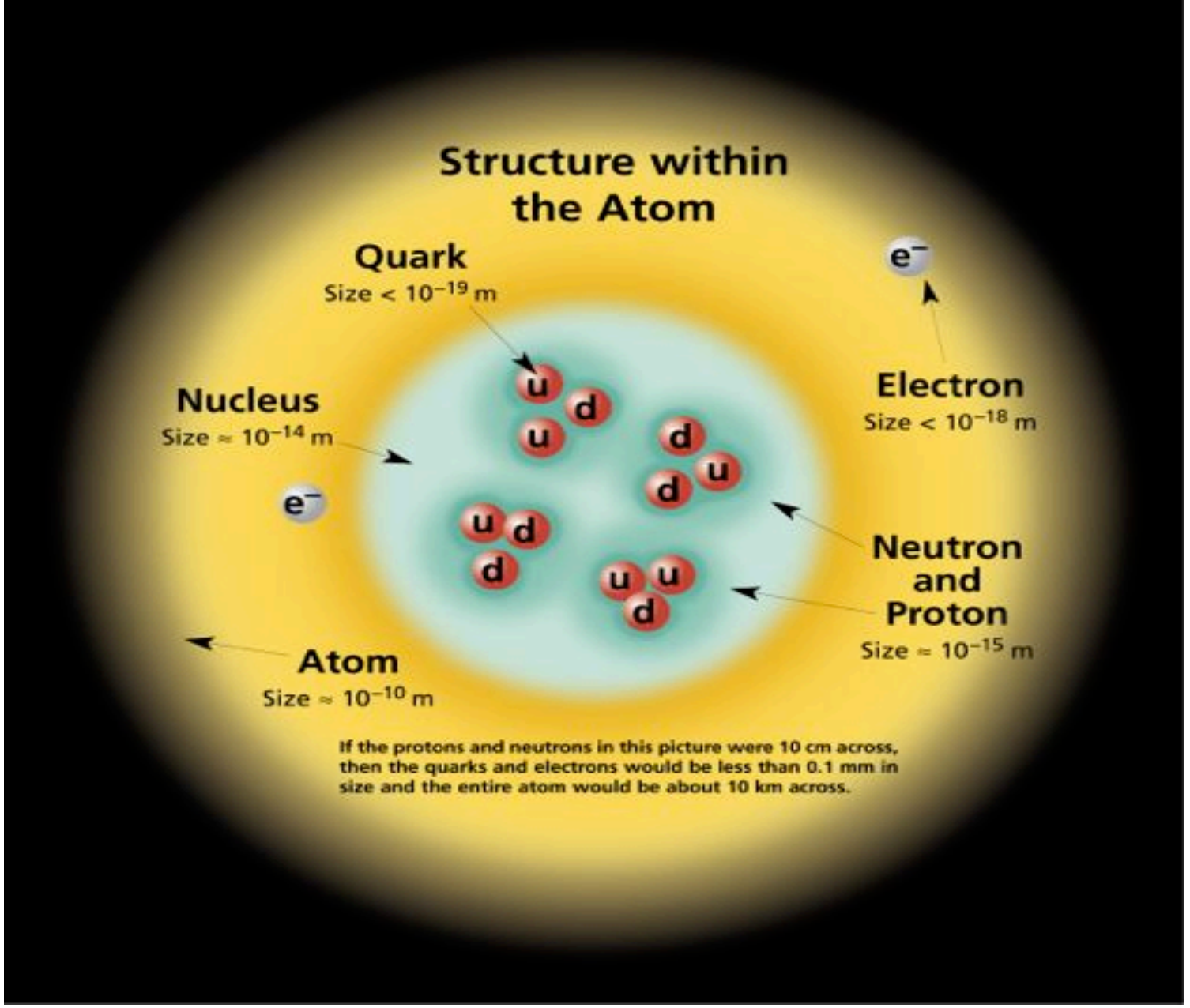
Everything that we can see is made of electrons, and smaller particles.



Electron **Quark**

0.00000000000000001 m
nano nano meter

higher beam particle energy = smaller size you can see


Structure within the Atom
Quark
Size < 10^{-19} m
Nucleus
Size ≈ 10^{-14} m
Electron
Size < 10^{-18} m
Neutron and Proton
Size ≈ 10^{-15} m
Atom
Size ≈ 10^{-10} m
e⁻
u
d
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.

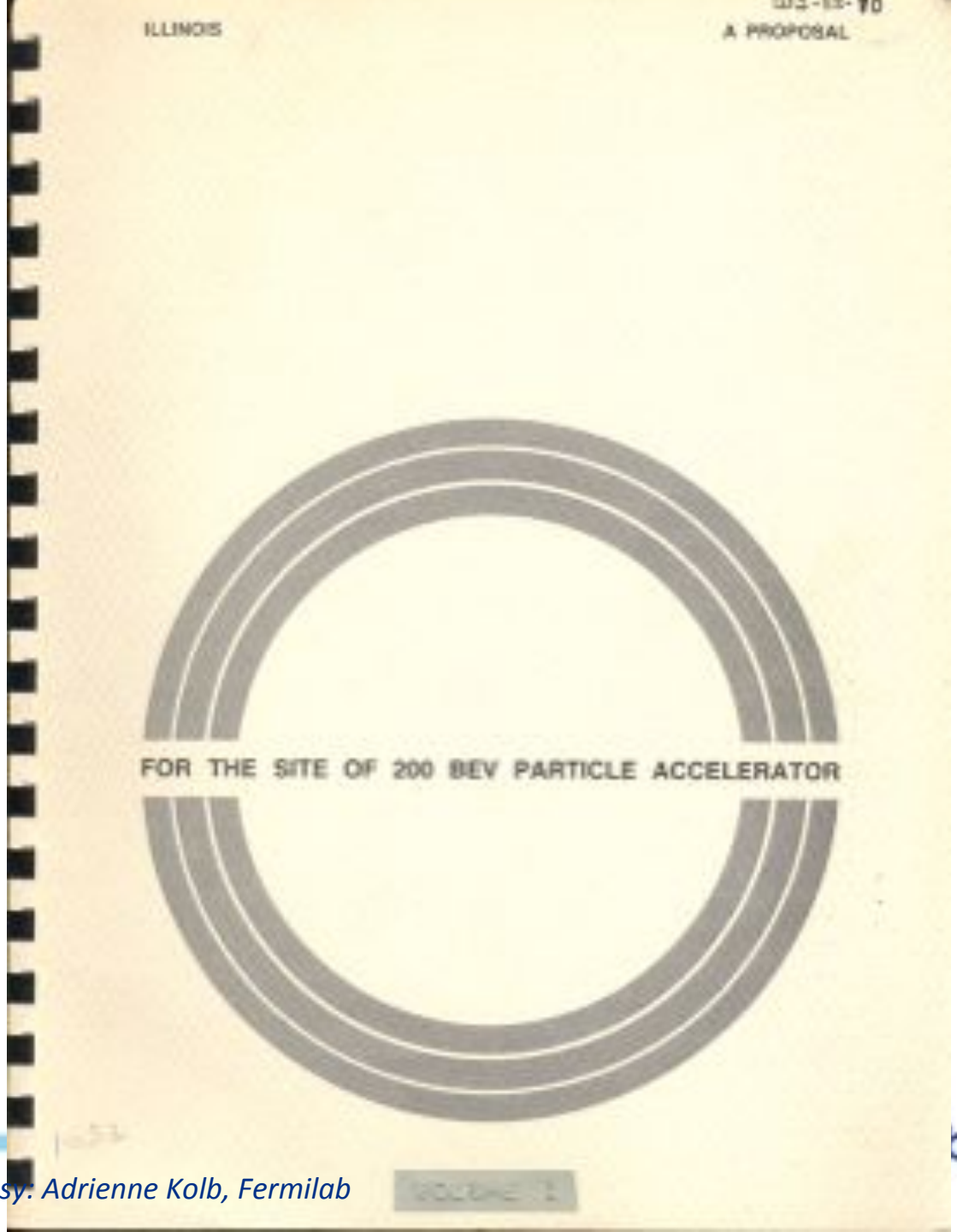
Courtesy: Adrienne Kolb, Fermilab

Accelerators

Ernest Lawrence
1901 - 1958

Fermilab

Illinois Proposal for 200 BeV Accelerator 1965



Courtesy: Adrienne Kolb, Fermilab

200 GeV March 1, 1972

Wilson toasts the NAL staff

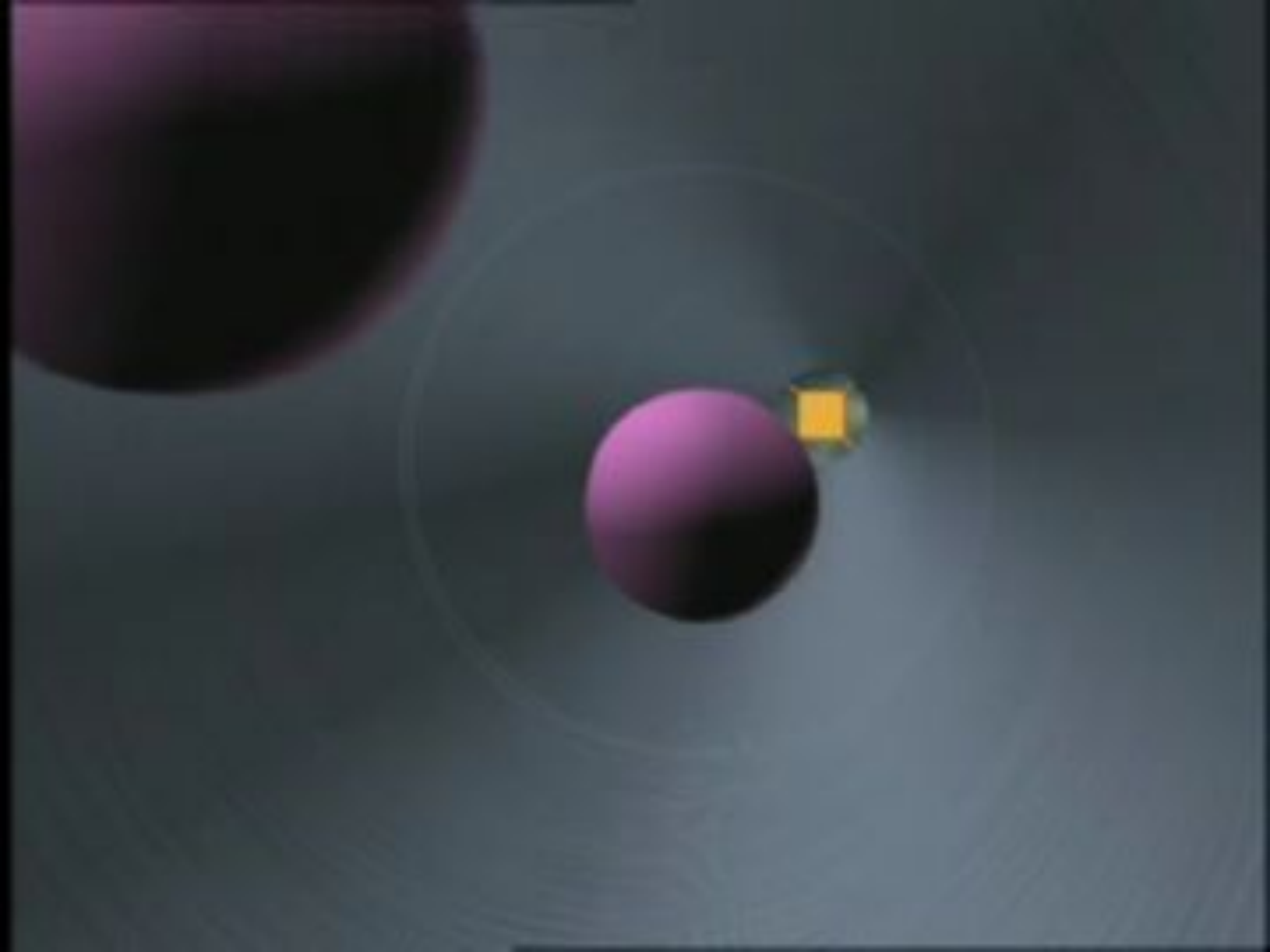
The Weston Site

Courtesy: Adrienne Kolb, Fermilab

Reconstructing Weston

Courtesy: Adrienne Kolb, Fermilab

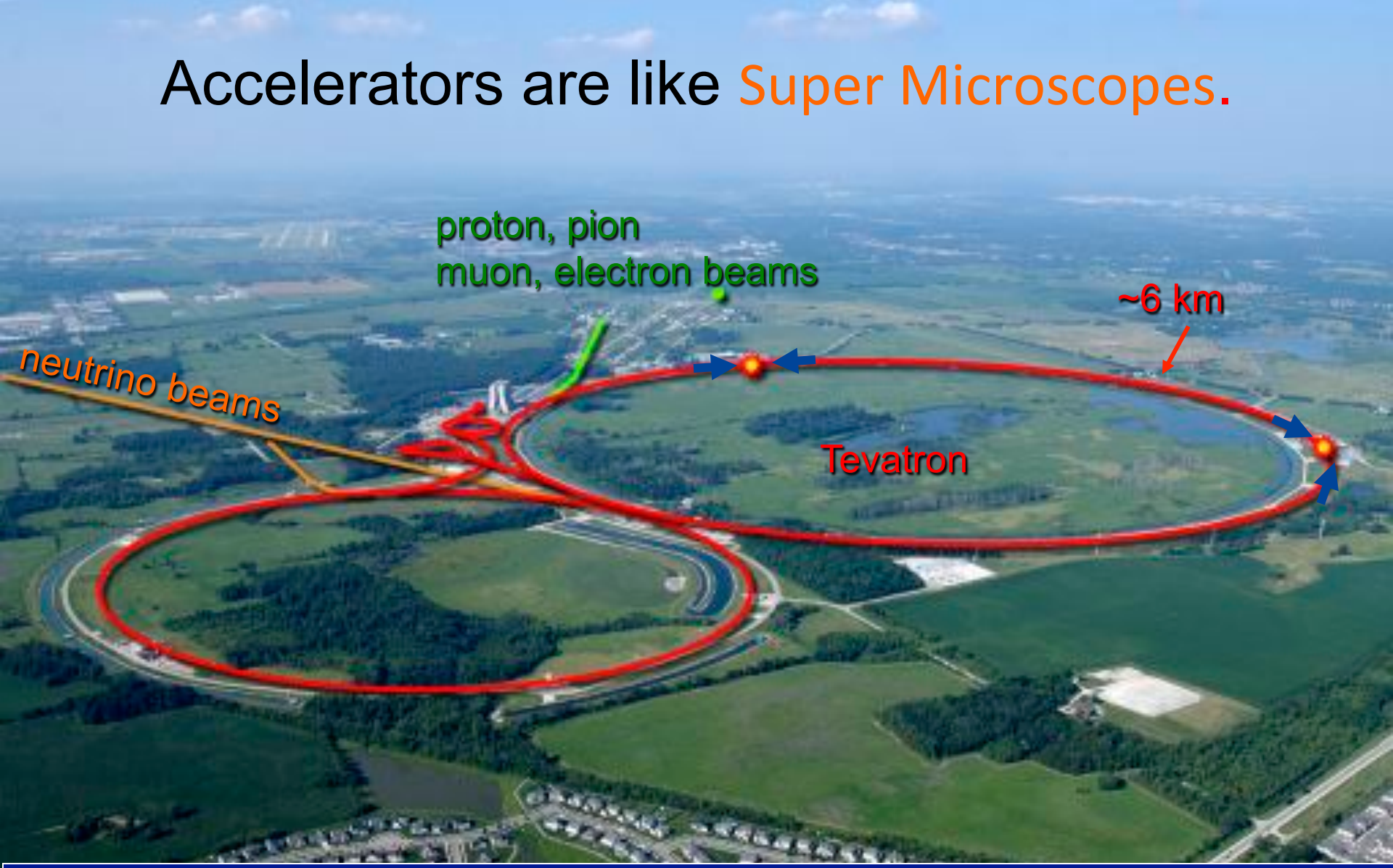
Fermilab, 1977



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

Energy Doubler/Saver

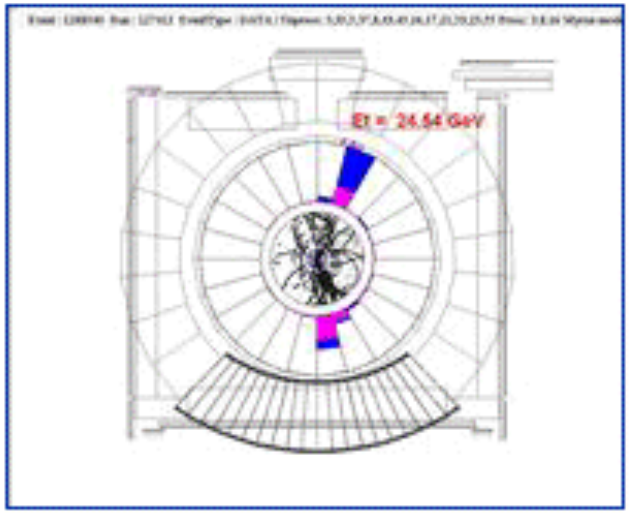
Accelerators are like Super Microscopes.

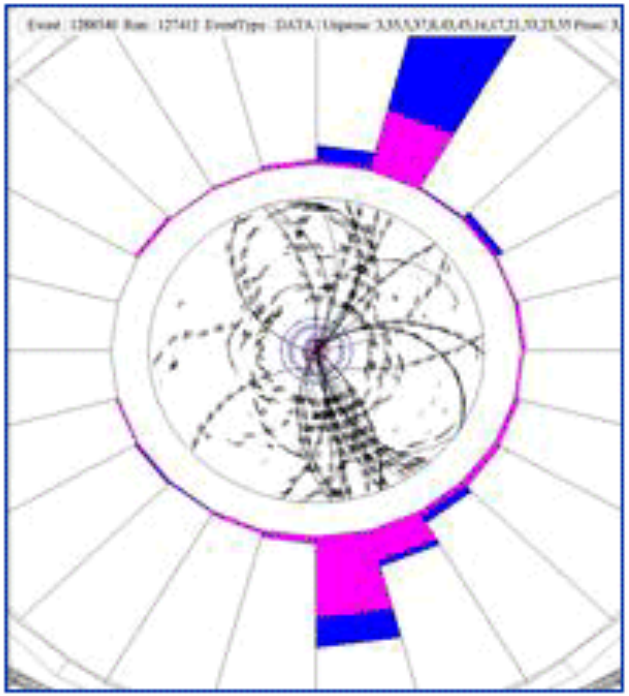


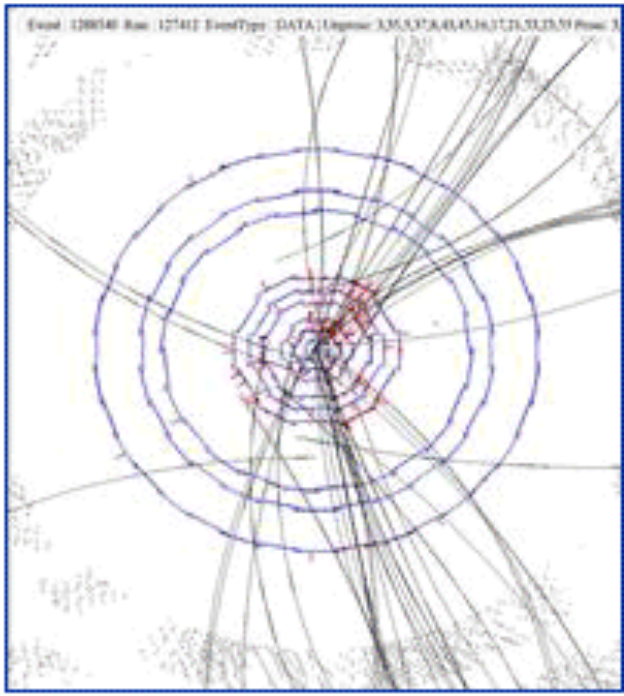
Fermilab
World's 2nd Highest Energy Accelerator
World's Highest Intensity Neutrino Beams

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

Fermilab

Physics Drivers

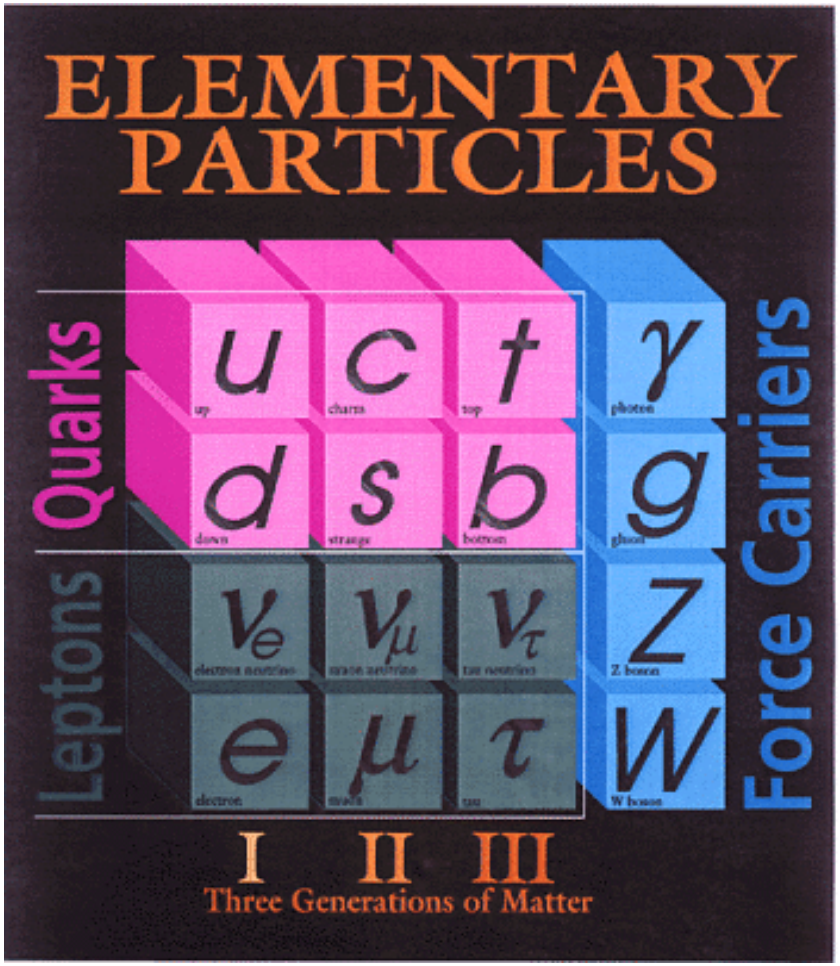
1940's	Basic Nuclear Structures Studies	Cyclotrons
	Nuclear Structure	
	-QED	
1950's-60's	Particle and Particle Properties	Synchrotrons
1960's-70's	Substructure	
	-QCD	
1980's-2000	Finishing the Standard Model	Lepton Colliders
		SSC, TeV
2000-----	Search for new particles	LHC, TeV
	Symmetries and New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

Fermilab

Particles

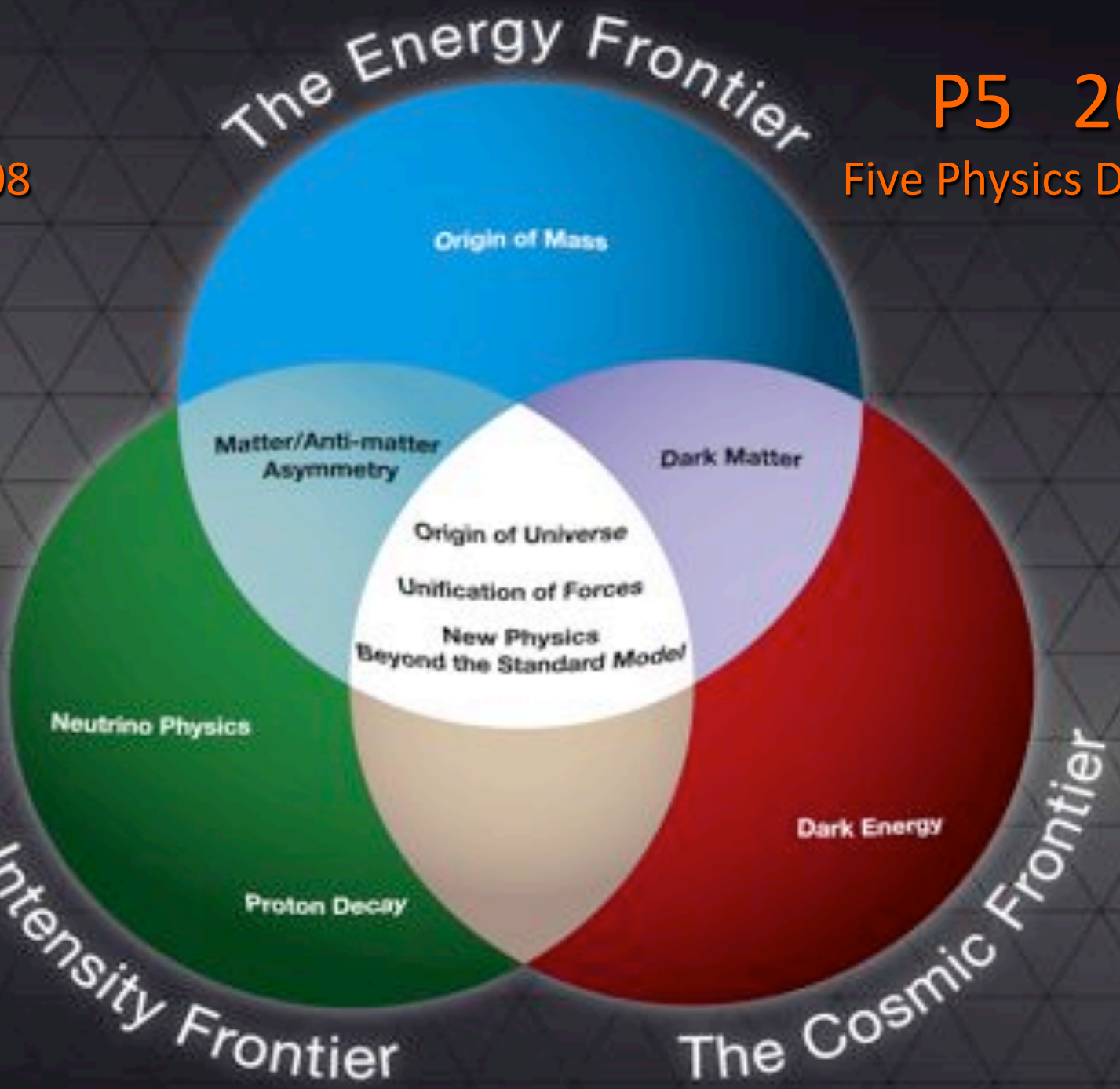
- **Discoveries**
  - top quark 1995
  - bottom quark 1977
  - ν_t (tau neutrino) 2000
  - direct CP violation 1999
  - (with CERN)

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



P5
Circa 2008

P5 2013
Five Physics Drivers



Snowmass 2013

P5 May 2014

Science Drivers

Higgs boson

Neutrino Mass

Dark Matter

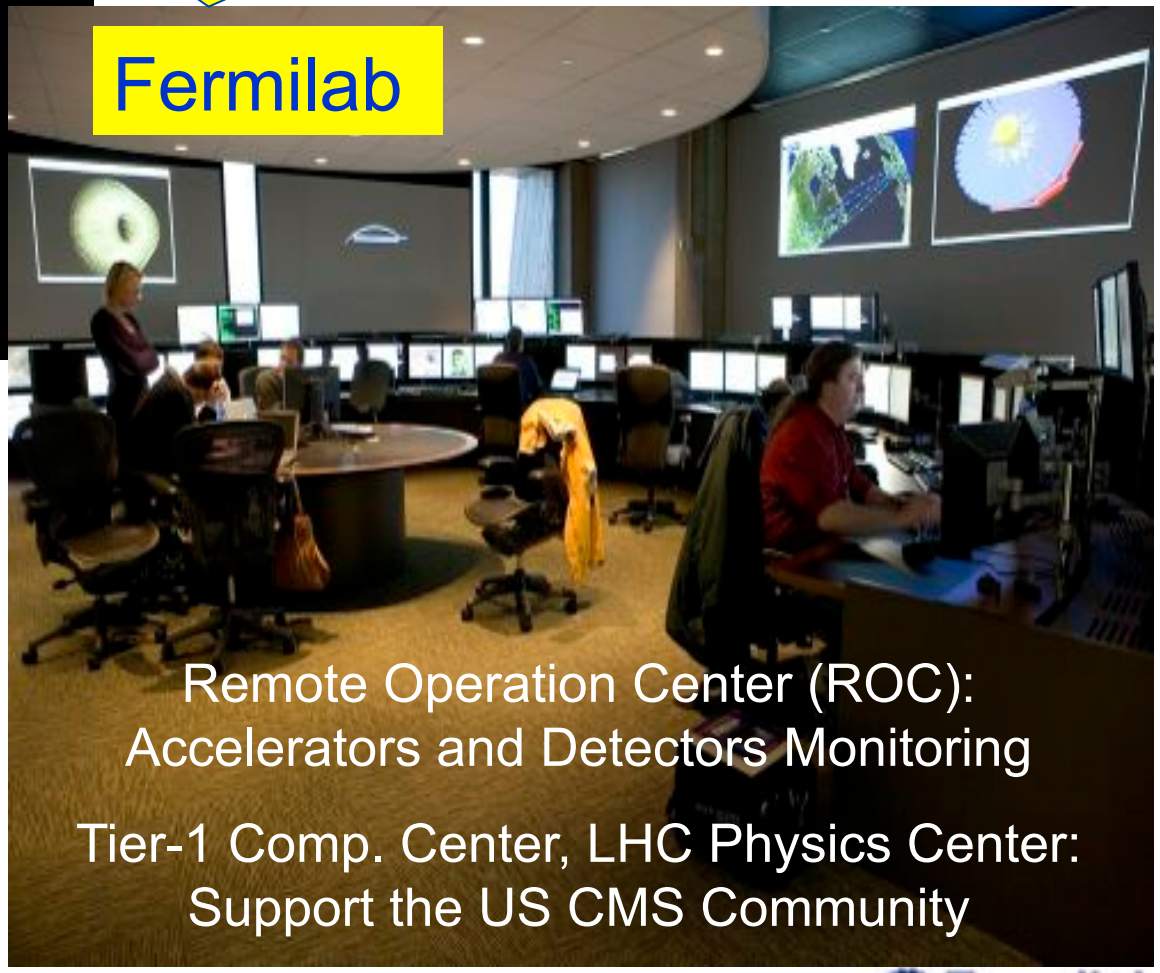
Cosmic acceleration :dark energy and inflation

Explore the unknown: new particles, interactions, and physical principles

The New Frontiers: LHC and the Tevatron ,+

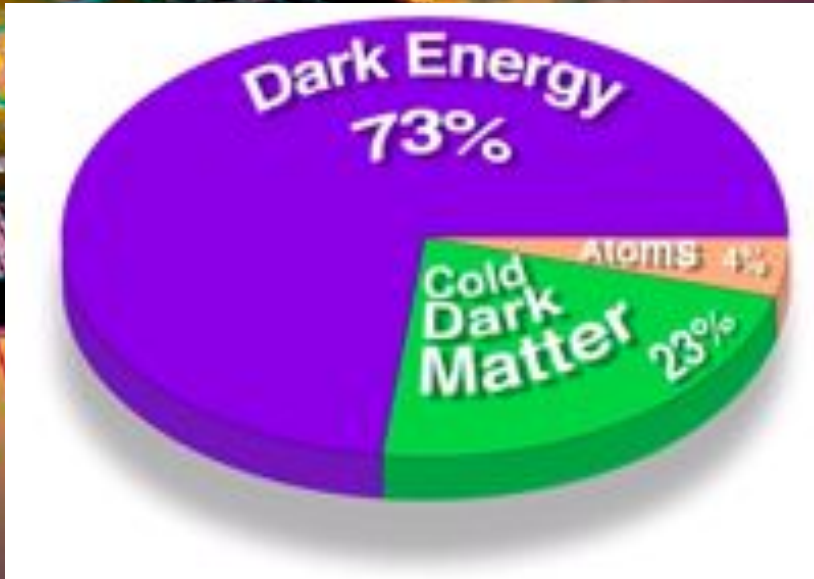
- Energy difference of a factor of ~ 7 in the future
- Search for elusive particles and tests
- Train new scientists
- Develop new techniques, machines, and detectors at high energies
- Discovering and studying the Higgs

The Energy Frontier: CMS



The Cosmic Frontier: Quarks to Cosmos

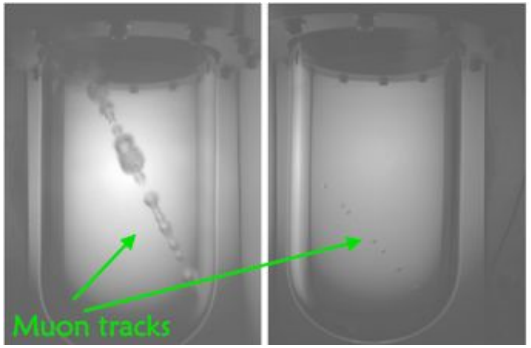
Dark Matter
Dark Energy
Ultra High Energy Cosmic Rays



Underground Dark Matter Detectors

CDMS
Low temperature crystals

4 kg → 15 kg



2 kg / 1 liter

COUPP
Room temperature bubble chamber

Probing Dark Energy

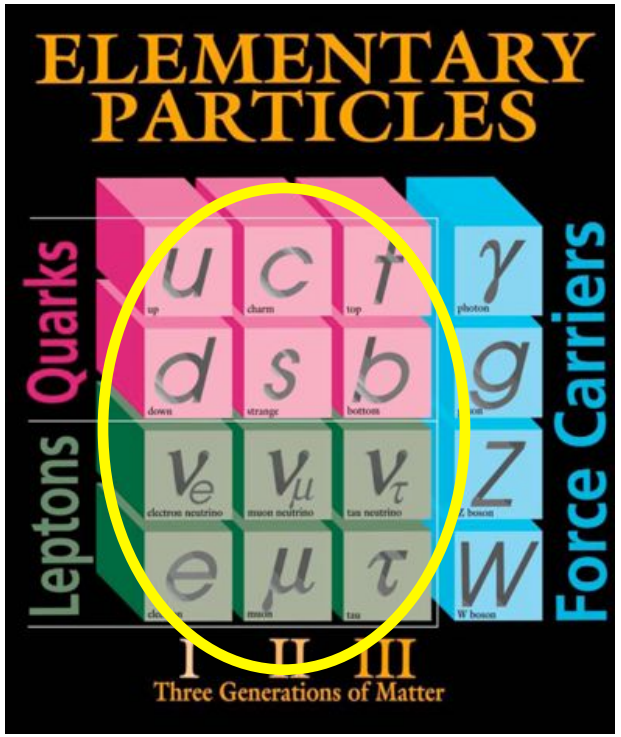
1. SDSS (Sloan Digital Sky Survey)
   - 2.5 meter telescope in New Mexico
   - Ranks as the facility with the highest impact on astronomy for the 3rd year in a row.
   - Power spectrum of galaxies constrain dark energy density parameter.

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
   - Possible Goal: Science Operation Center

The Intensity Frontier

Physics of Flavor

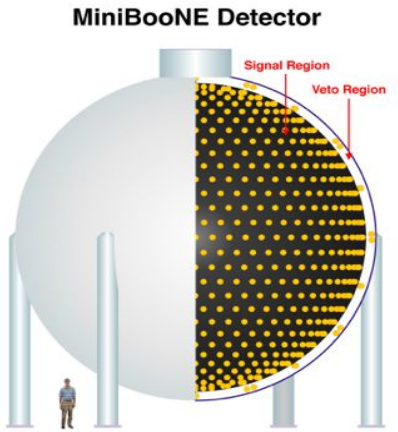


- Flavor phenomena
  - Essential to shaping physics beyond the SM.

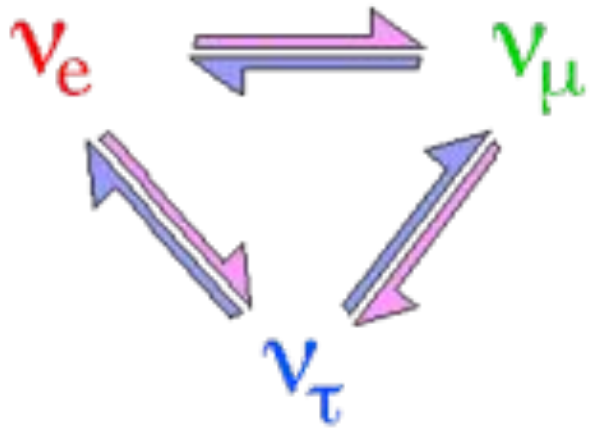
- SM is incomplete:
  - Neutrino Masses (flavor)
    - Exciting new physics seen in the laboratory
  - Baryon Asymmetry of the Universe (flavor)
  - Dark Matter
  - Dark Energy

Courtesy : Fermilab Strategic Plan

Intensity Frontier: Neutrinos now



Neutrinos:



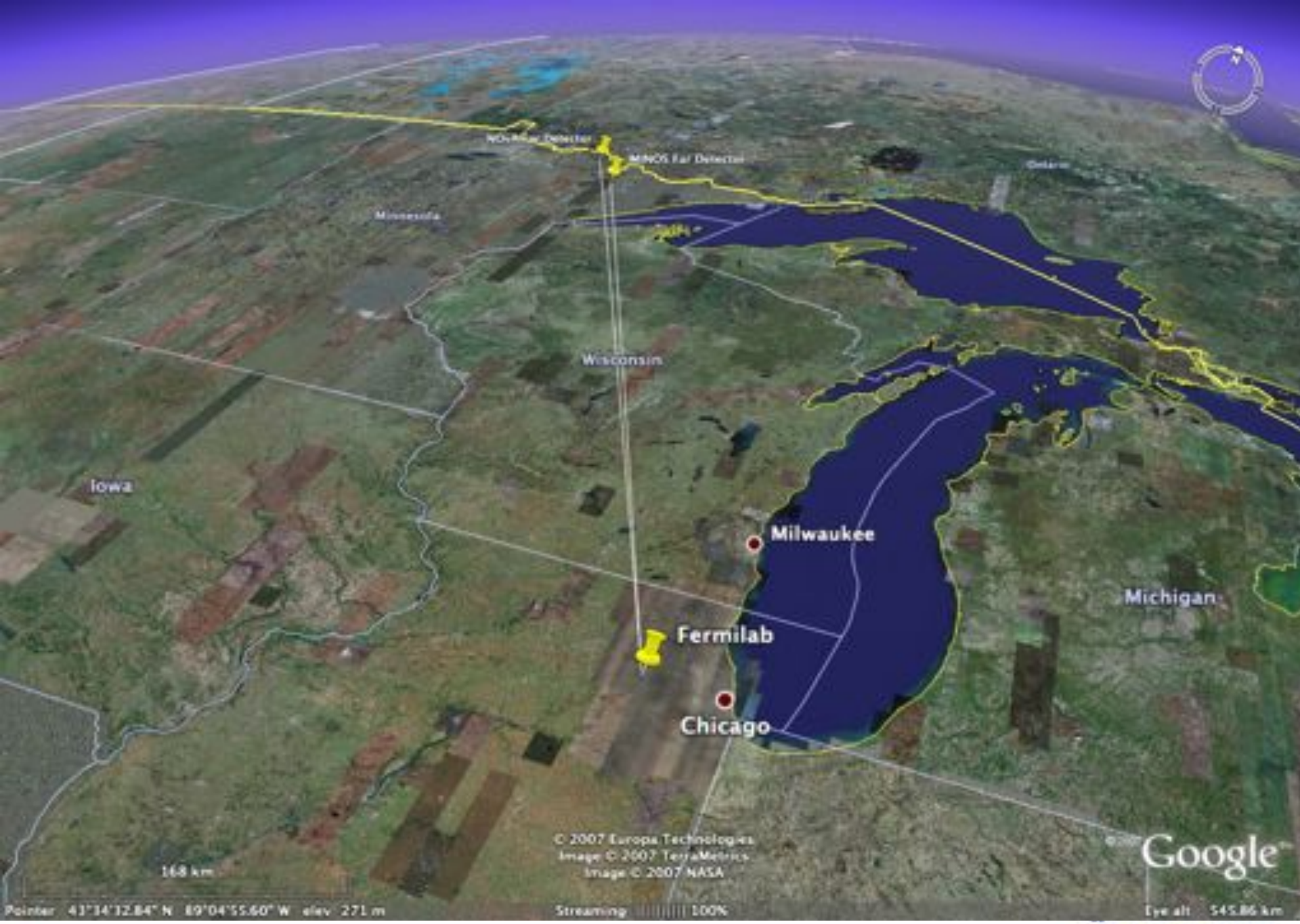
The elusive neutrinos are among the most abundant of the tiny particles that make up our universe.
To understand the universe, one must understand neutrinos.

Their behavior is different from other particles.

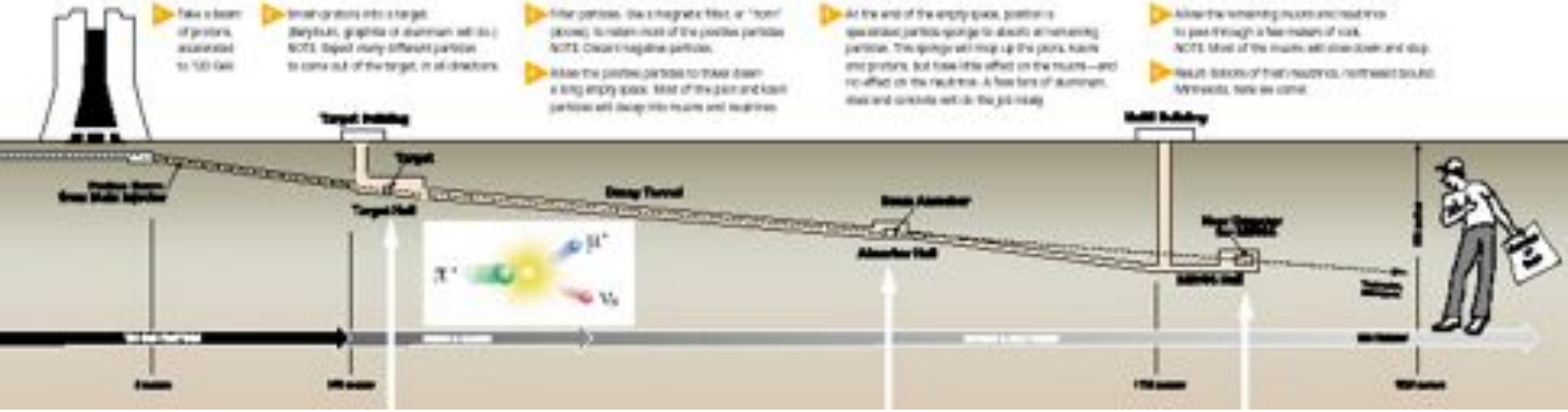
Opening a "new" window

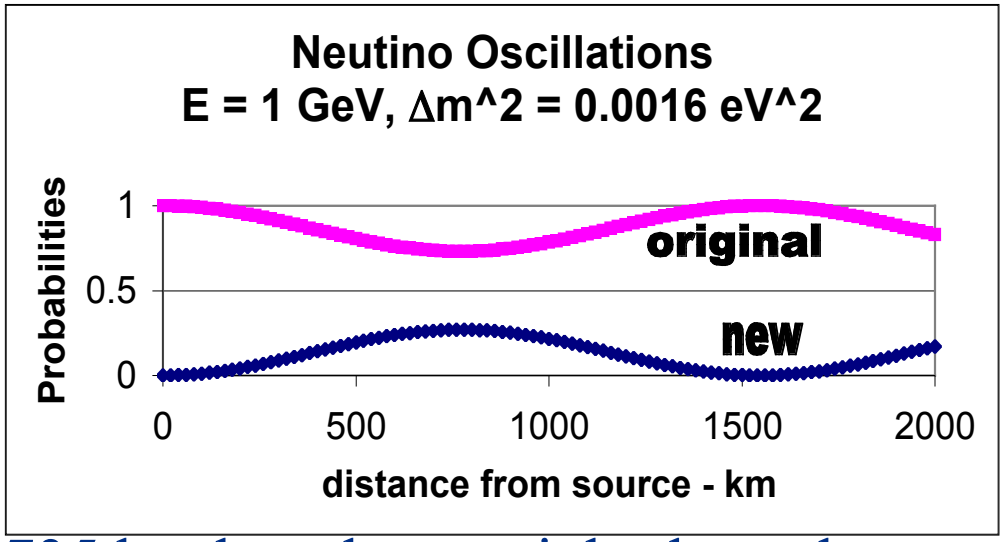
New and future info: θ_{13}, $\bar{\nu} = \nu$, mass ordering, CP violation

The Intensity Frontier

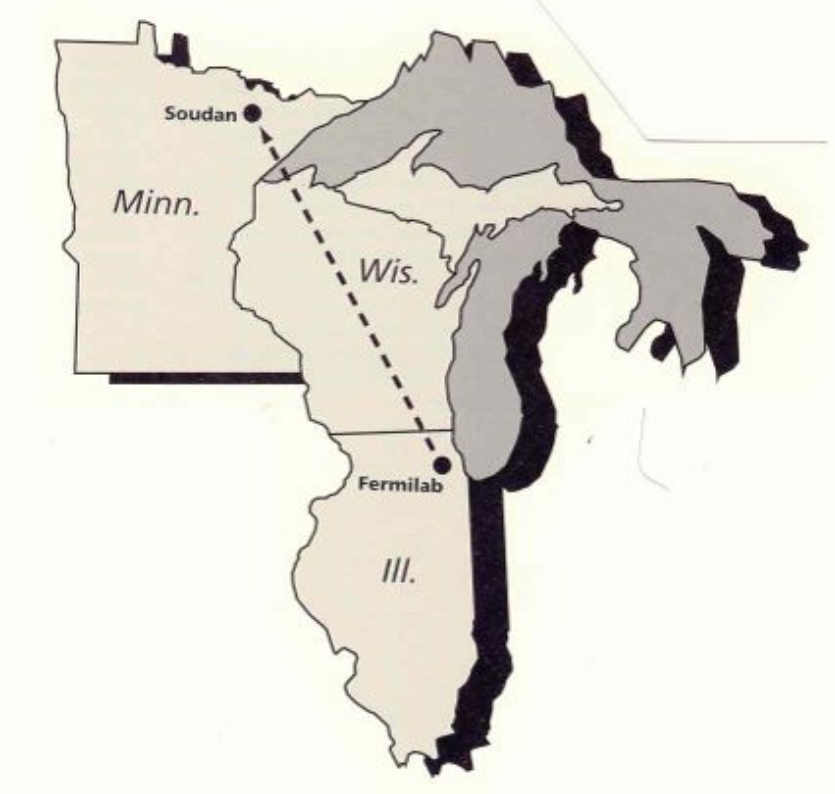

MINOS Far Detector
Minnesota
Wisconsin
Iowa
Milwaukee
Michigan
Fermilab
Chicago
© 2007 Europa Technologies
Image © 2007 TerraMetrics
Image © 2007 NASA
Google
168 km
Pointer 41°34'12.84" N 89°04'55.60" W elev 271 m
Streaming 100%
Eye alt 545.86 km

NUMI – Neutrinos at the Main Injector

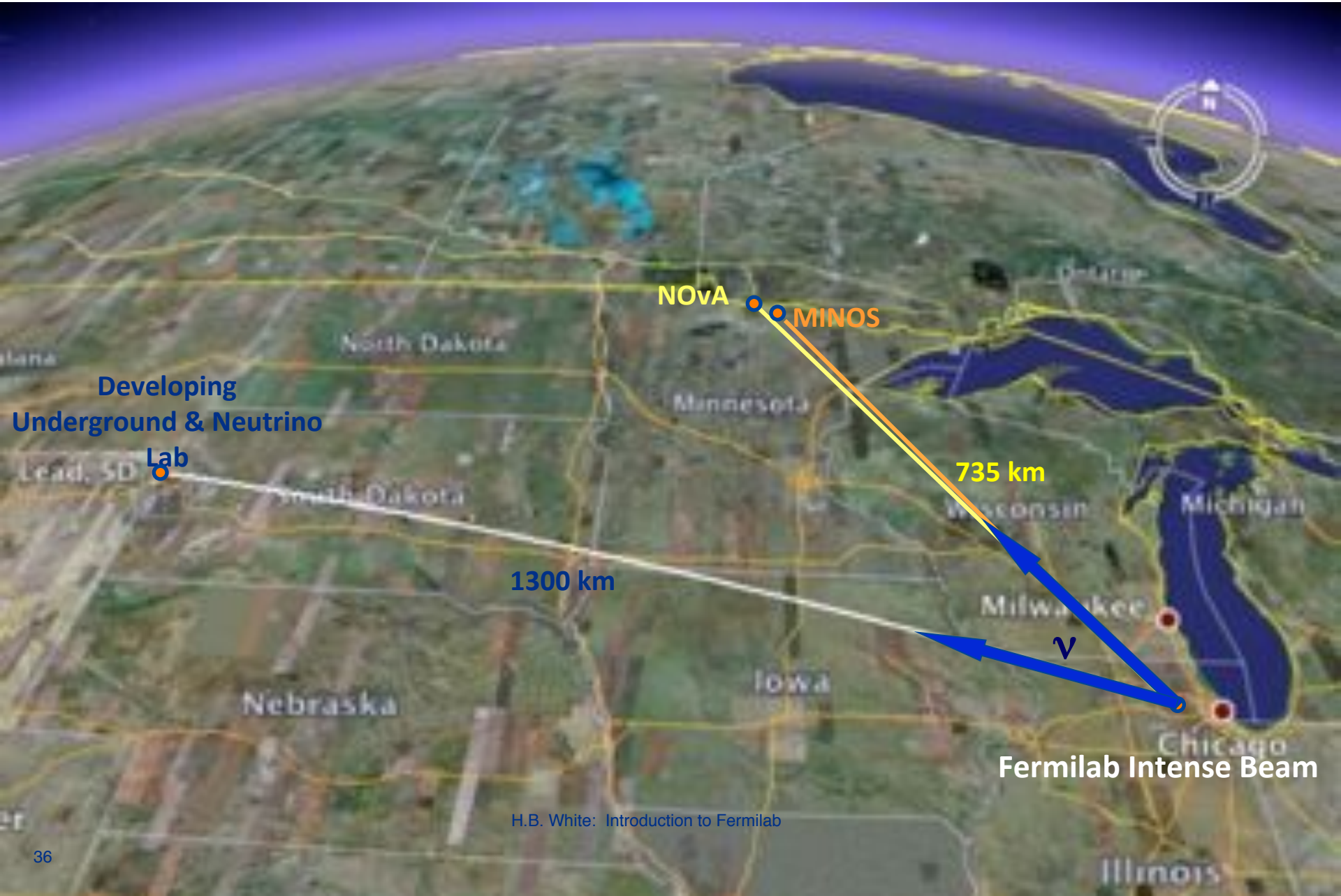


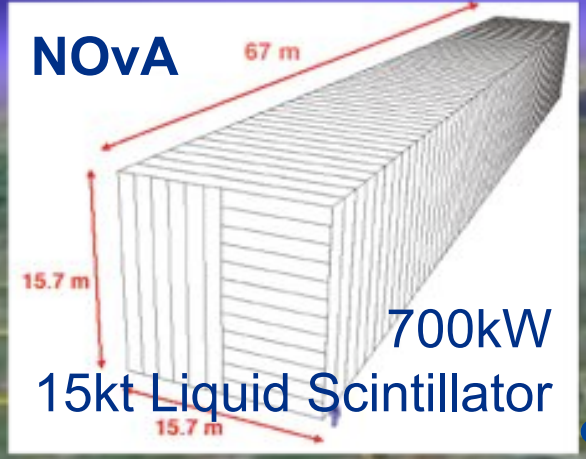


735 km long beam, right through the earth! 10 km deep



Future Planning for Fermilab





Proposed
Underground Lab.

735 km
2.5 msec

1300 km

MiniBooNE
SciBooNE
MicroBooNE
MINOS
NOvA
MINERvA

~100 kton Liquid Ar TPC

MicroBooNE: ~100 ton Detector

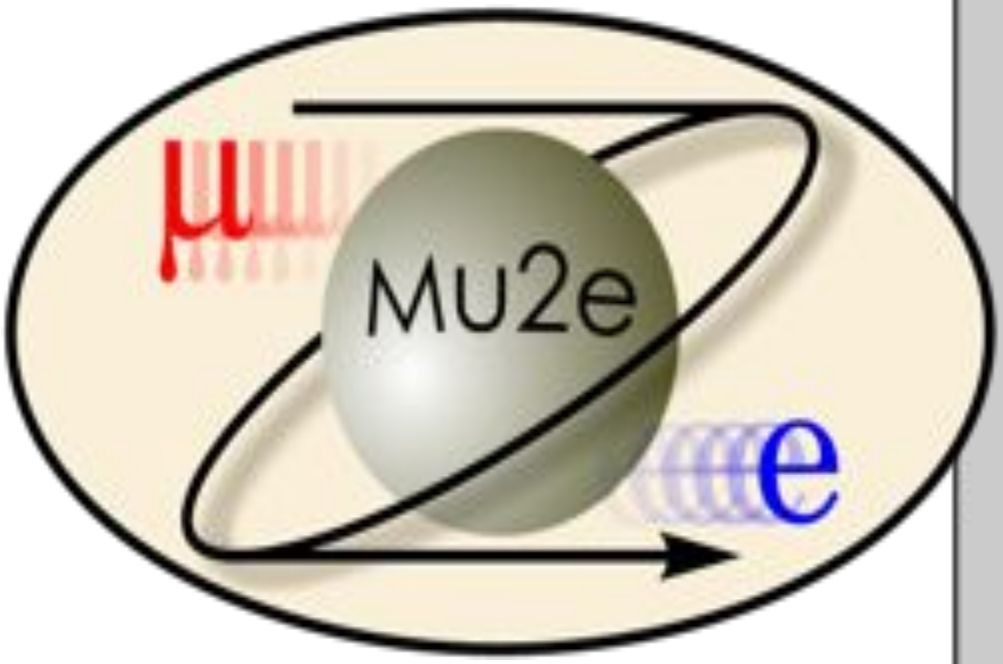
matter – antimatter asymmetry with neutrinos

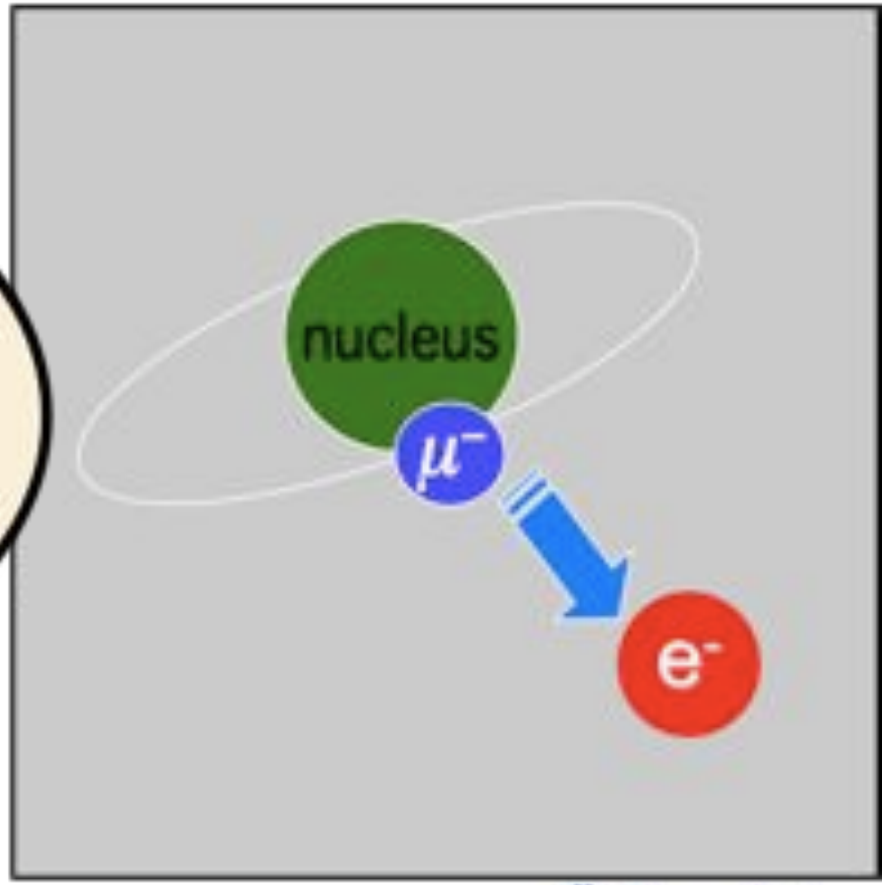
Proton decay

Supernovae

Muon to Electron Conversion

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





Overview Of Processes

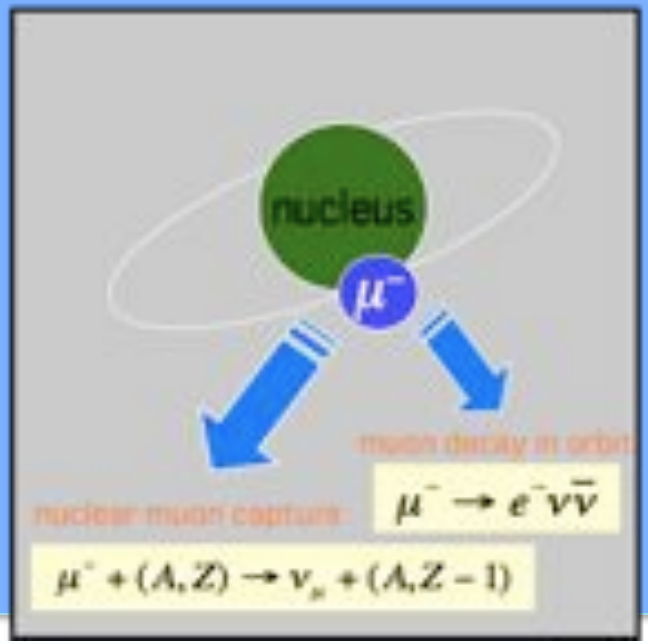
μ^- stops in thin Al foil

the Bohr radius is ~ 20 fm, so the μ^- sees the nucleus

μ^- in 1s state

Al Nucleus
~4 fm

muon capture, muon "falls into" nucleus: ***normalization***

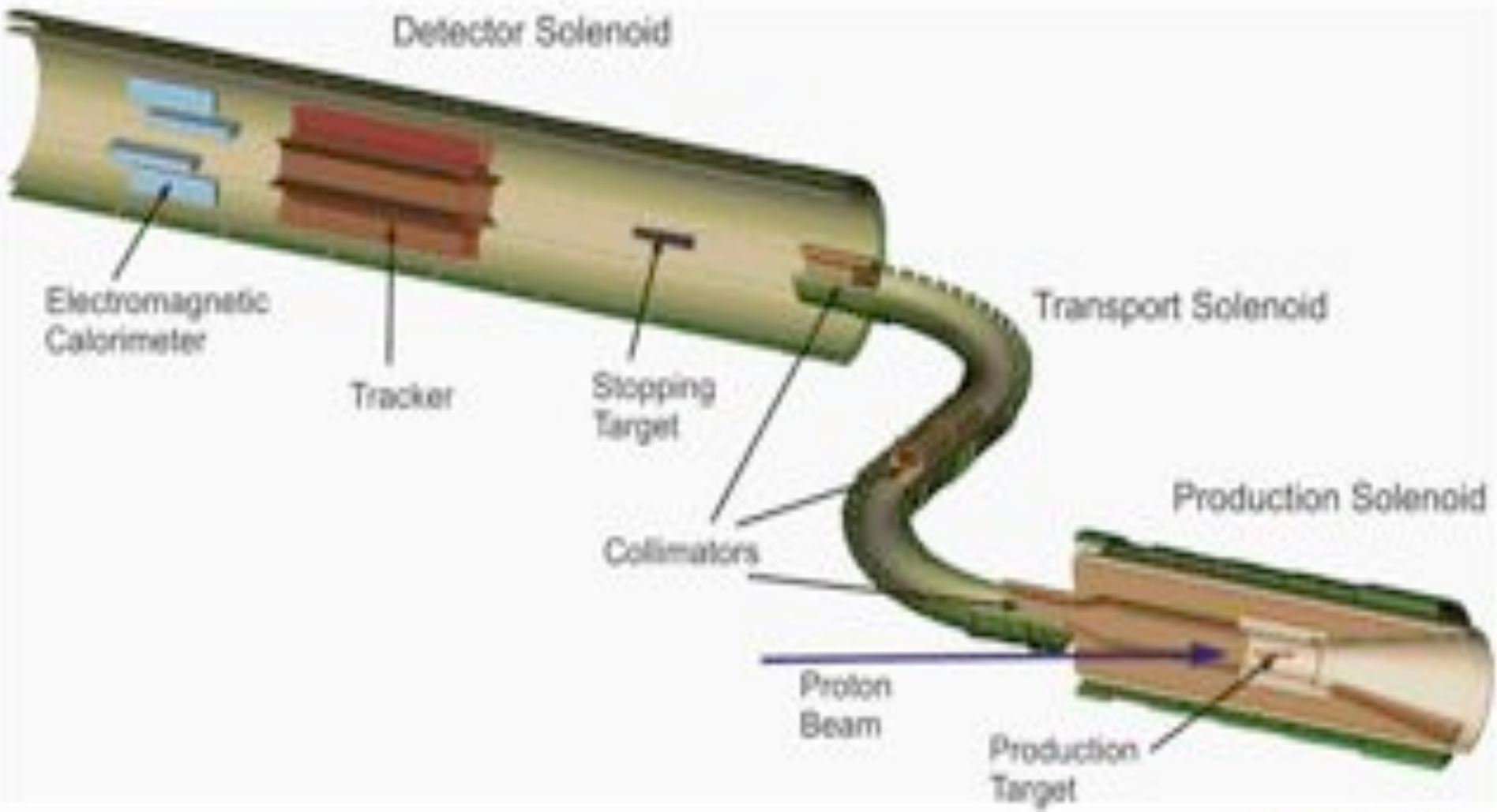


60% capture
40% decay

Decay in Orbit: ***background***

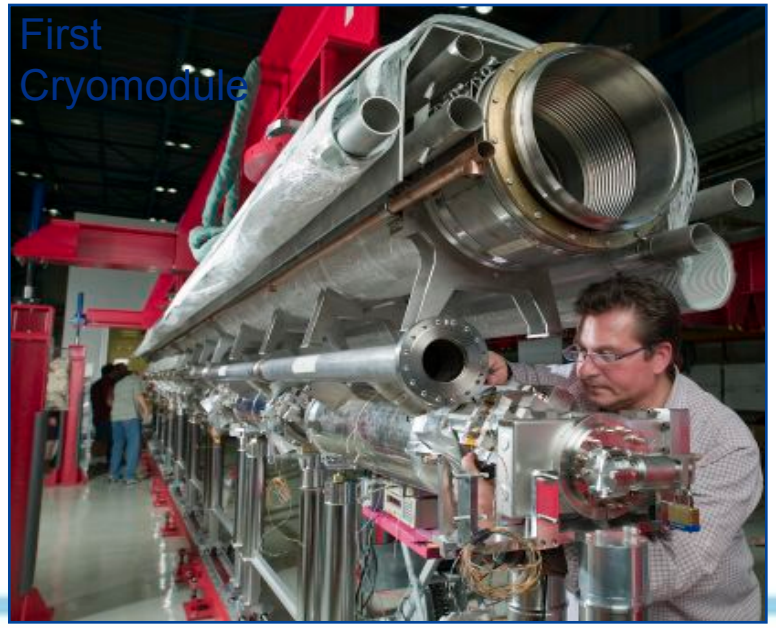
Fermilab

DETECTOR AND SOLENOID



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!

Join Us And Enjoy The Excitement!!