Particle Physics and Fermilab

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Fermilab and the University of Chicago

African School of Physics
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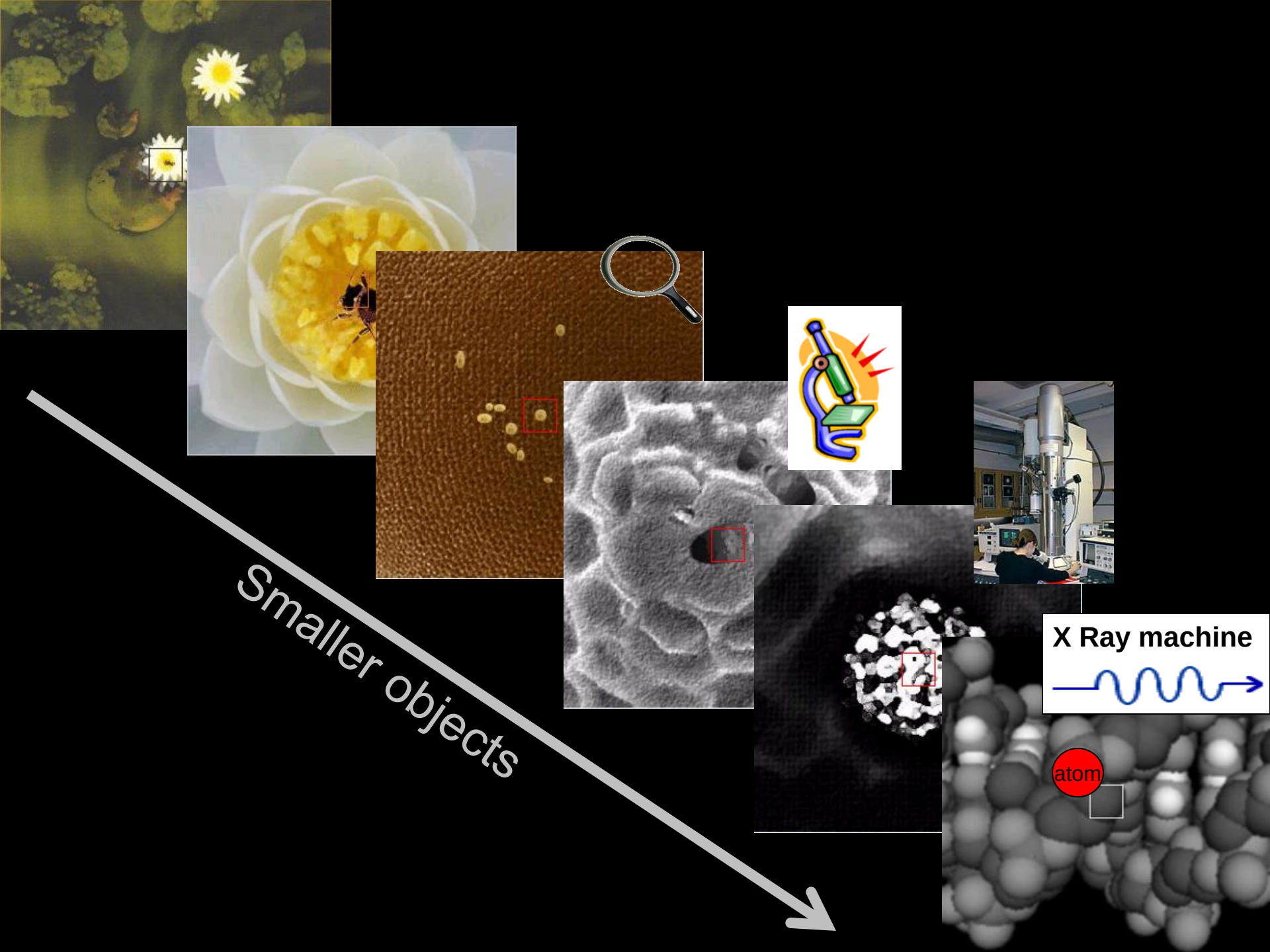
Hello from Chicago

What is the world made of?
What holds the world together?
Where did we come from?

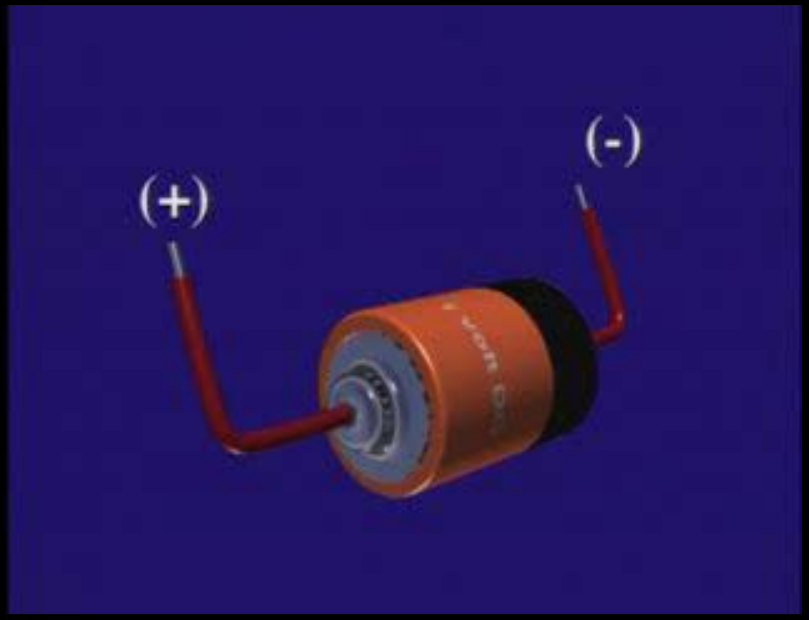
Tools ?

the smallest things in the world
interactions (forces) between them
the Universe's past, present, and future

Particle Physics: physics where
small and big things meet,
inner and outer space meet


Smaller objects
X Ray machine
atom

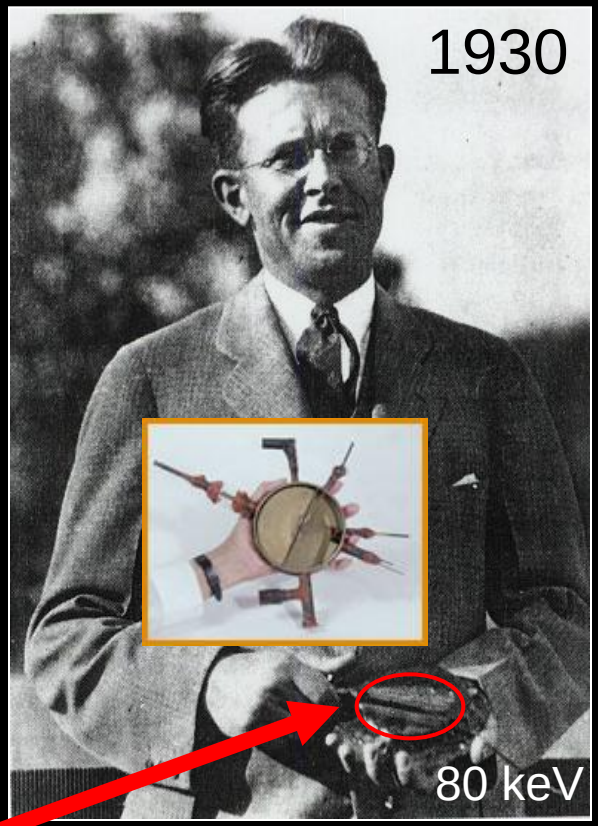
Accelerators



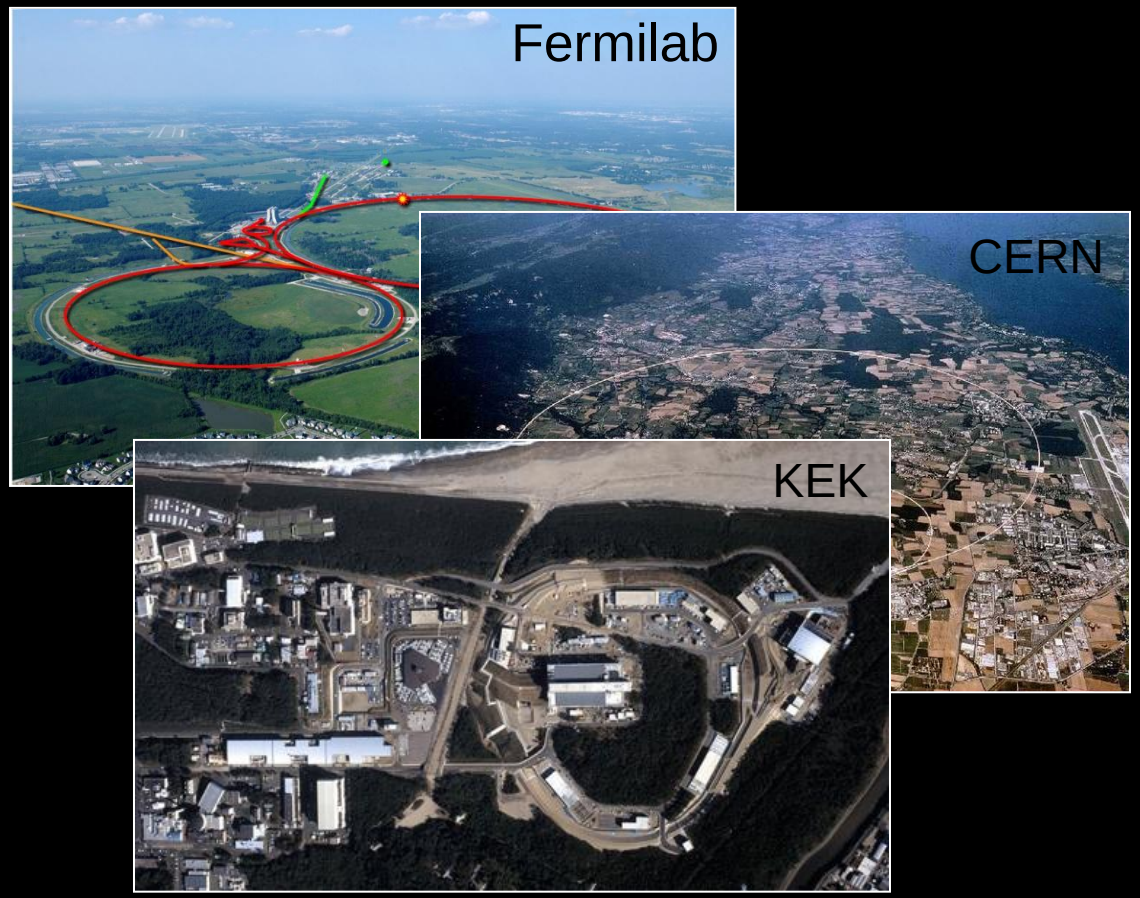
1 eV (electron Volt)
1 electron in 1 Volt battery

GeV (billion eV)
TeV (trillion eV)

Many generations of particle accelerators:
each generation built on the accomplishments of the previous ones
raising the level of technology ever higher



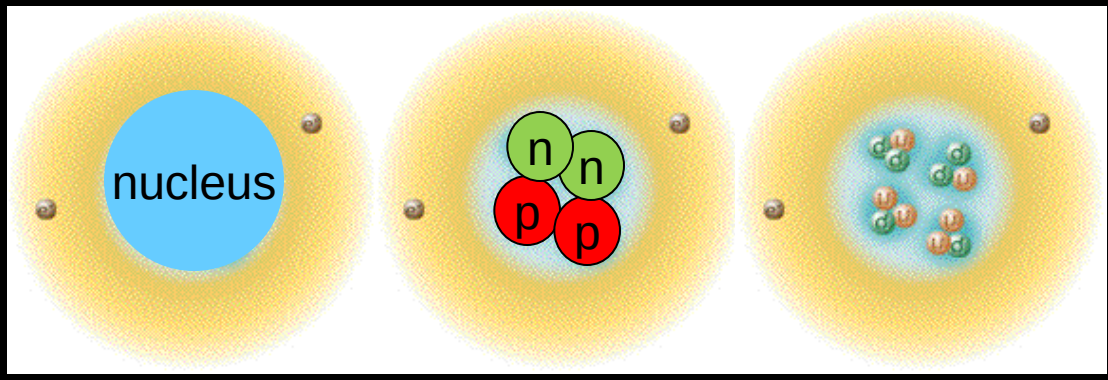
Ernest Lawrence
(1901 - 1958)



Accelerators are Ultimate Microscopes.

(higher energy beam particle = better resolution / small objects)

What is the world made of?



up quark, down quark, electron

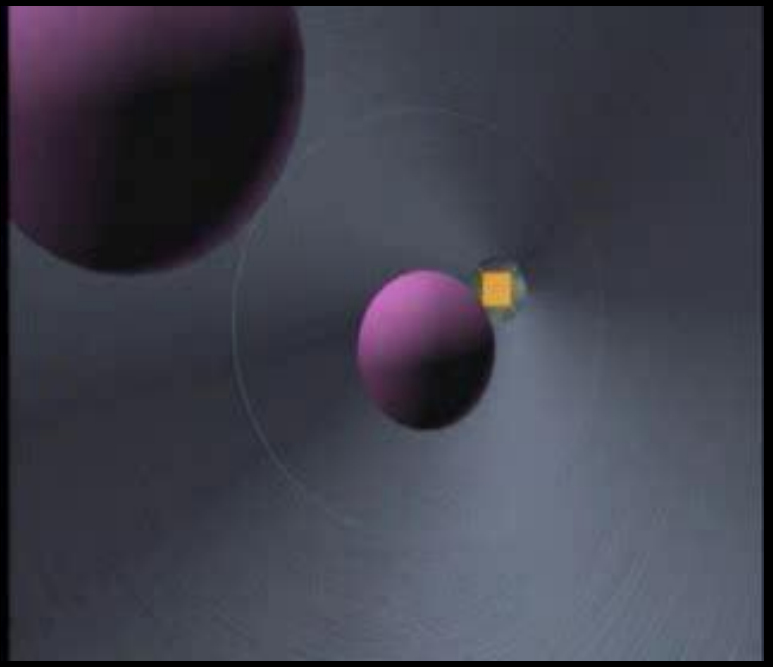
10^{-18} m

nana nano meter

What holds the world together?

Accelerators are like Time Machines.

because they make particles last seen
in the earliest moments of the universe.



neutrinos
muons
kaons
….

anti particles

Accelerators are like Time Machines.

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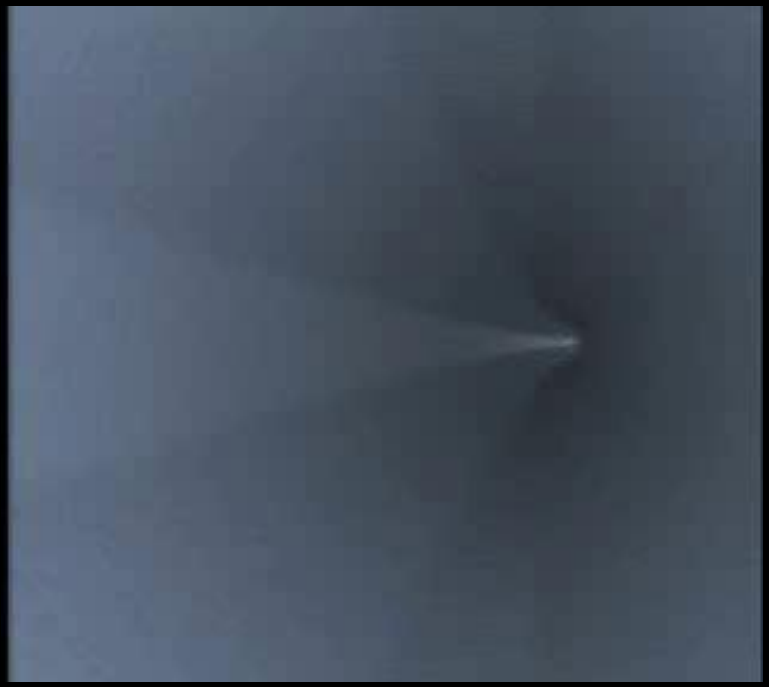

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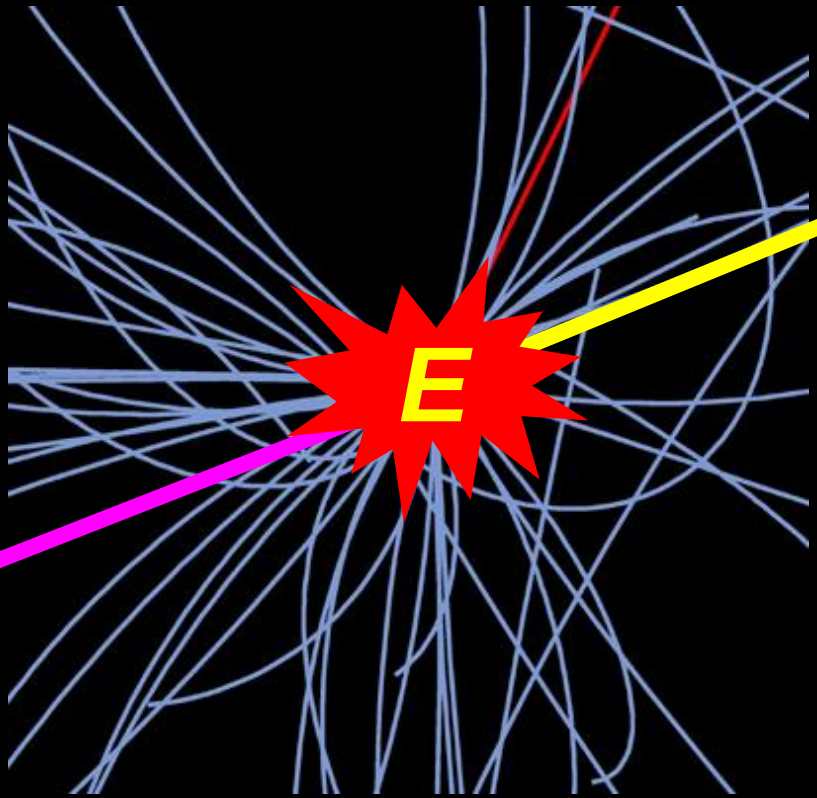
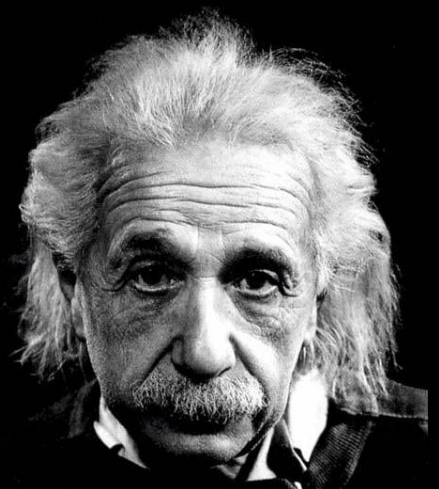


anti particle

particle

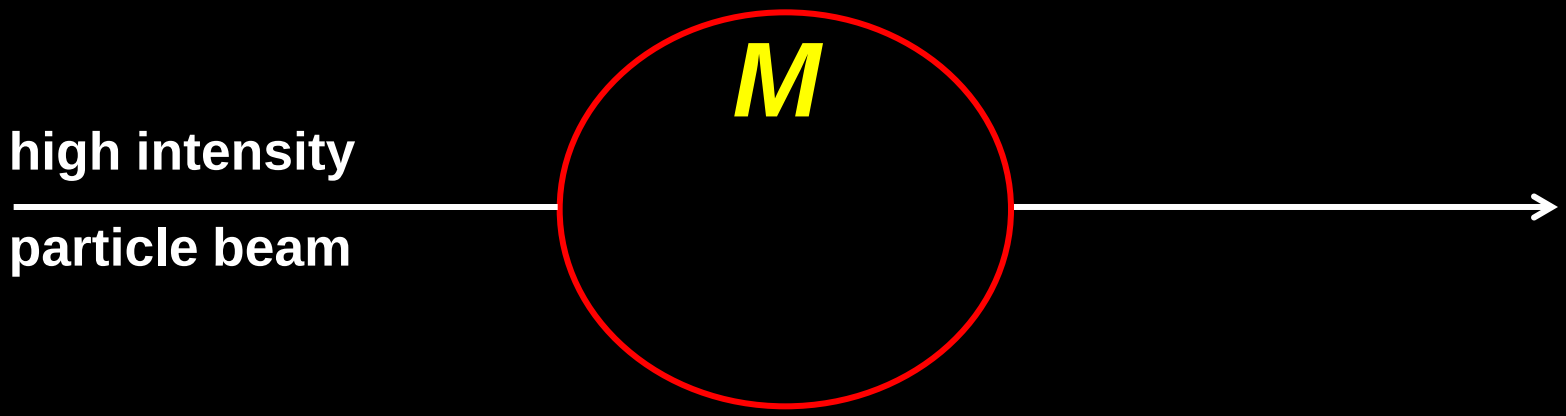


$E = Mc^2$

Accelerators are like Time Machines.

because they make particles last seen
in the earliest moments of the universe.

$$E = Mc^2$$



Quantum Fluctuation

Accelerators are like Time Machines.

because they make particles last seen
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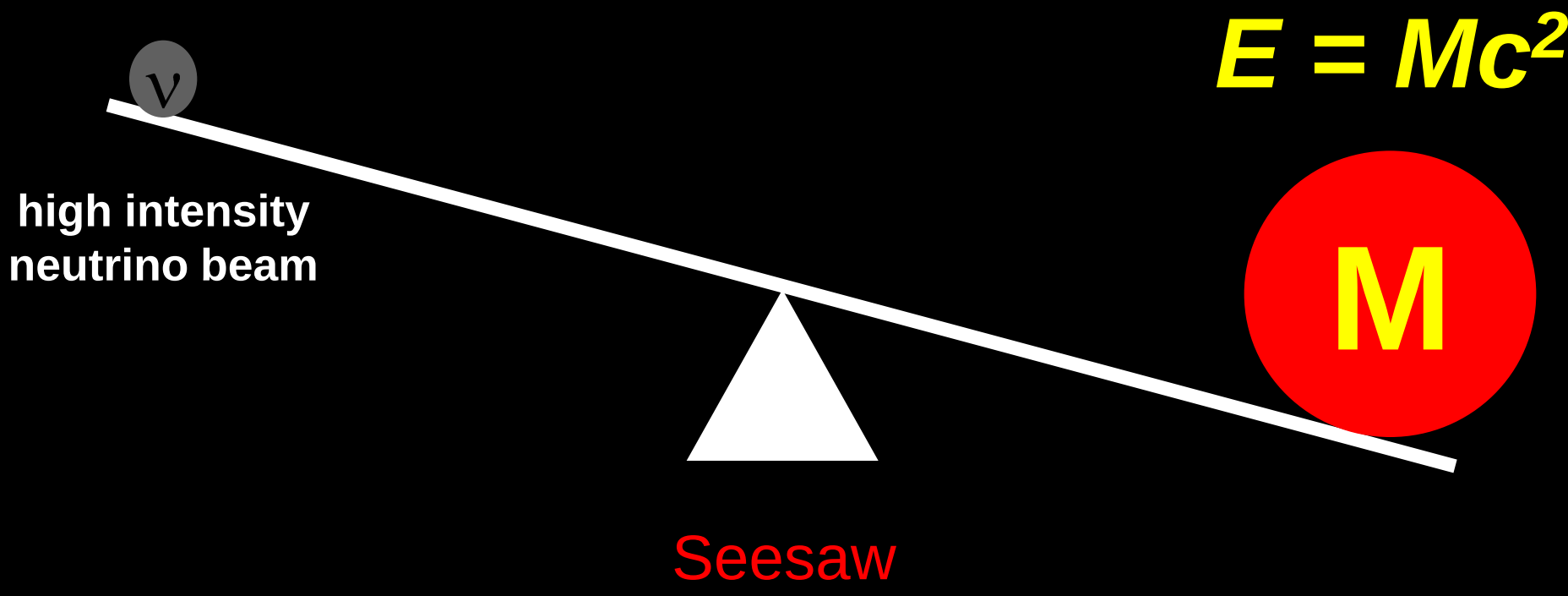
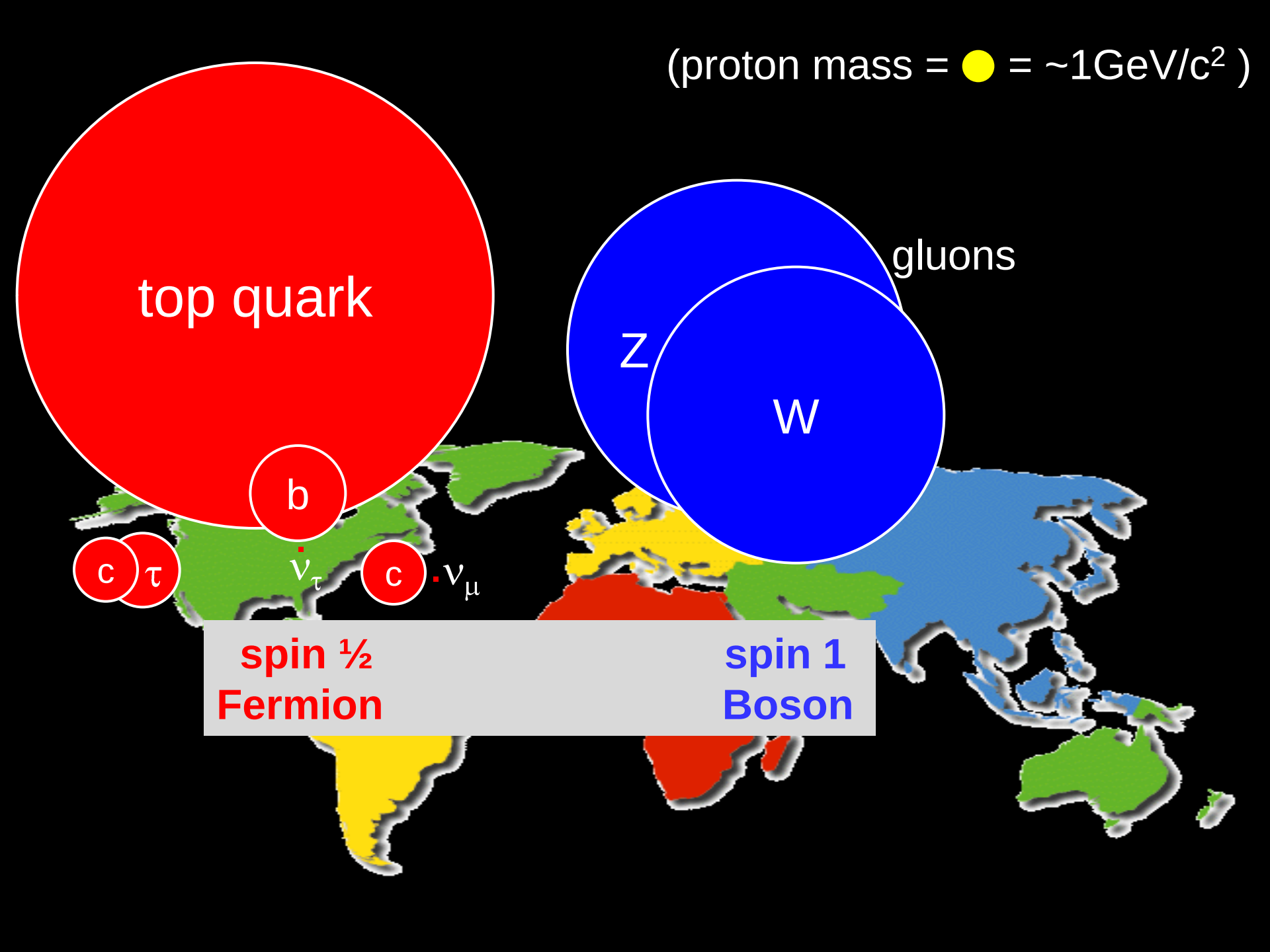
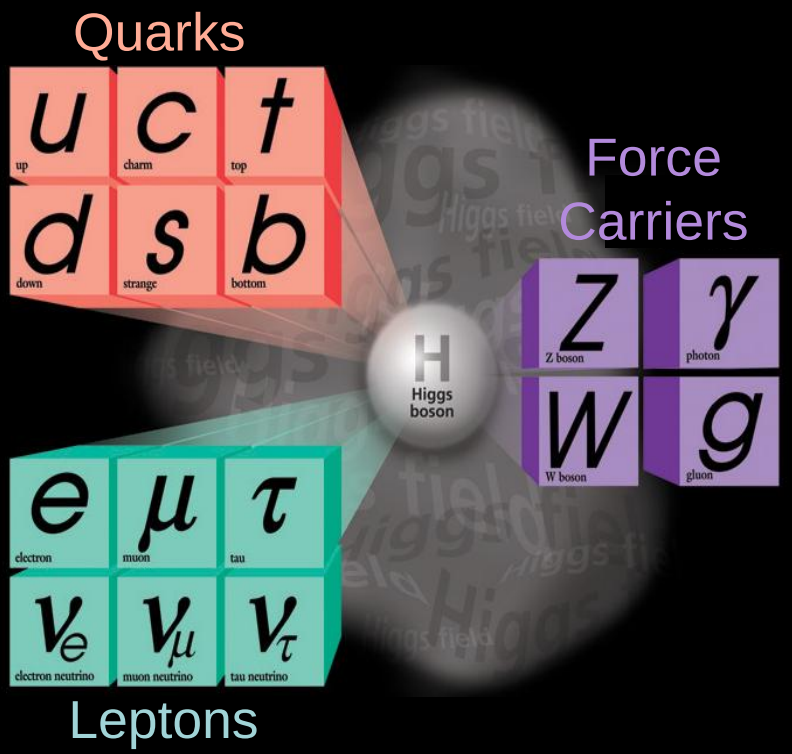



(proton mass = ● = ~1GeV/c²)
top quark
b
c
τ
ν_τ
c
ν_μ
gluons
Z
W
spin ½
Fermion
spin 1
Boson

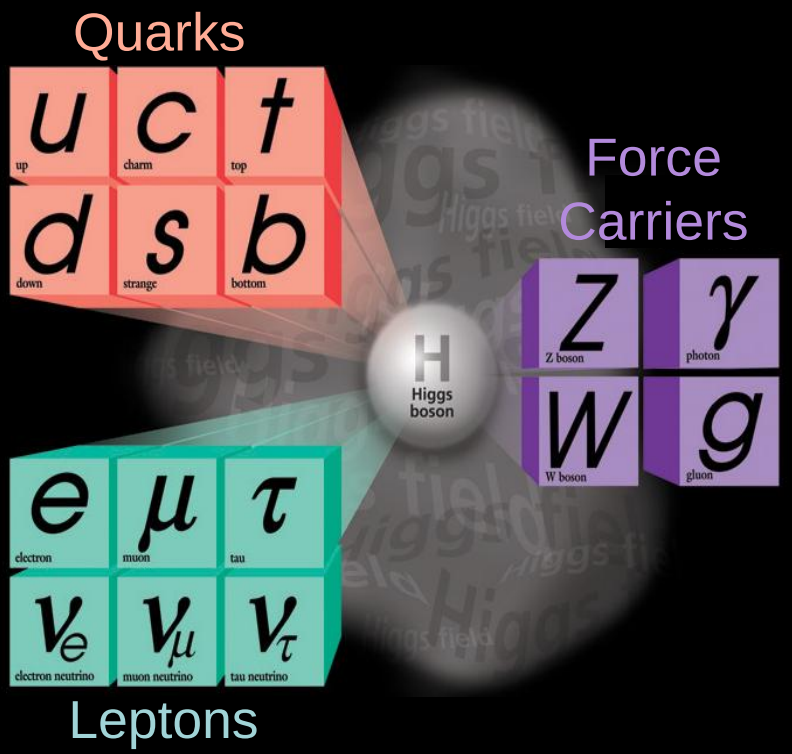
The triumphs……

- The present theory is a remarkable intellectual construction
- Particle experiments done at the laboratory beautifully fits in this framework



……. and the mysteries

- Why?
- Why?
- Why?
- …



……. and the mysteries

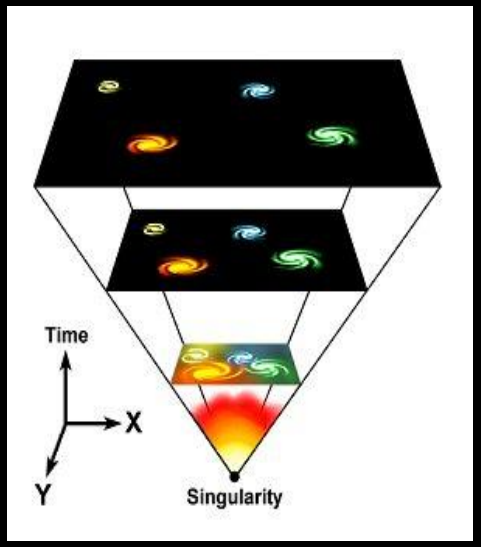
- Where did all antimatter go?

……. and the mysteries

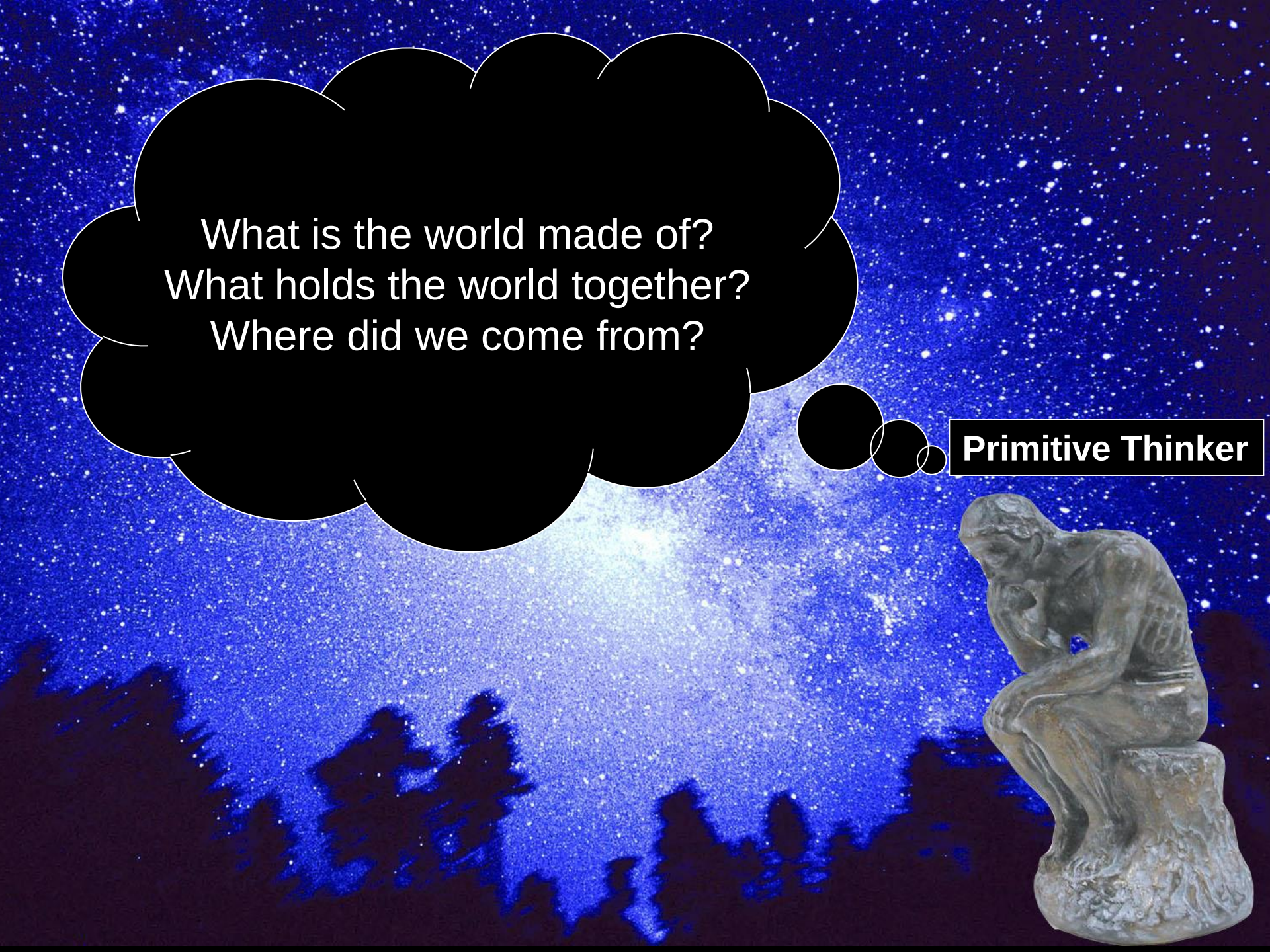
- What is dark matter?

……. and the mysteries

- Expanding the universe



- Accelerating the universe
- What is dark energy?

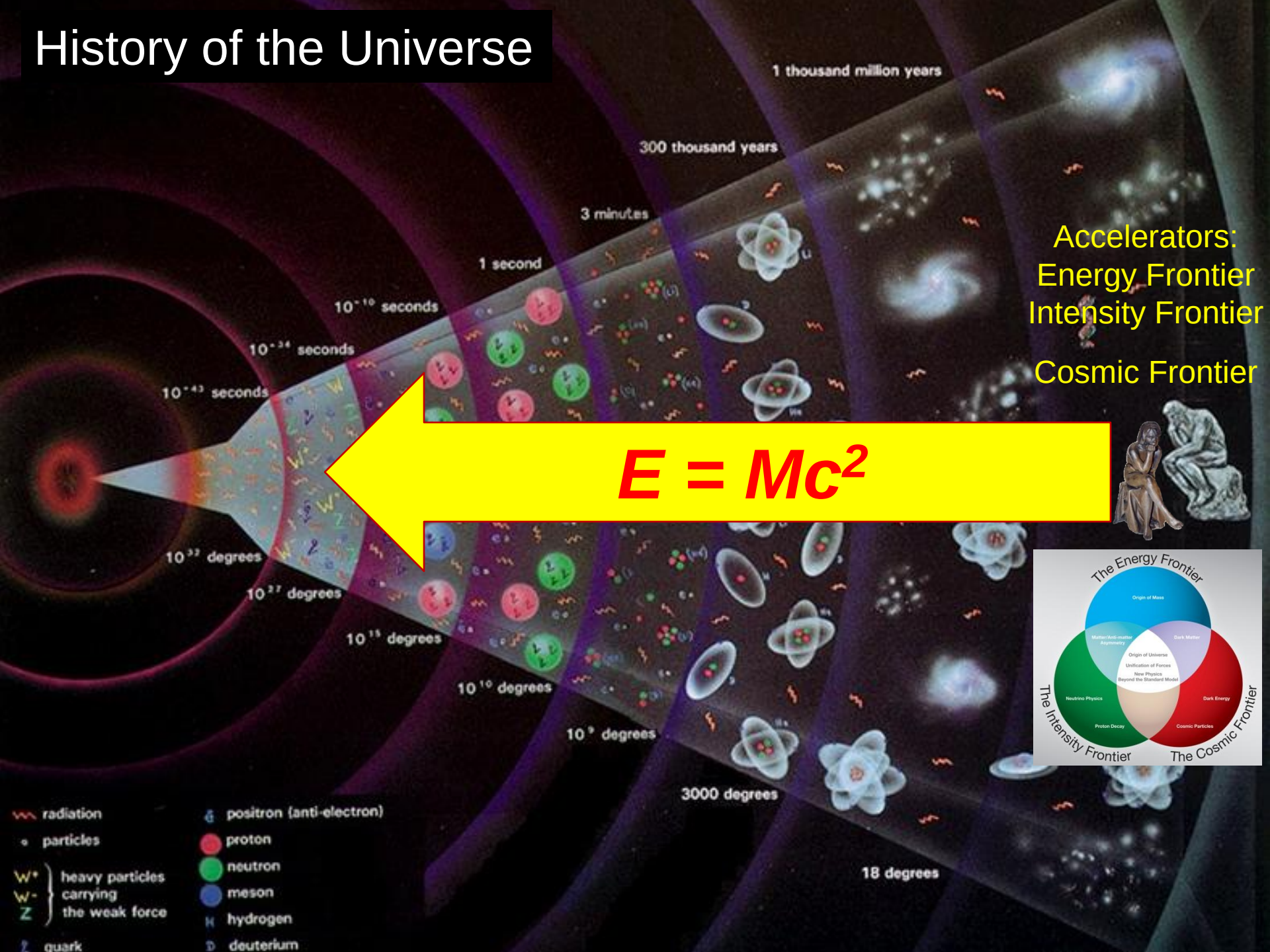

What is the world made of?
What holds the world together?
Where did we come from?
Primitive Thinker

21st Century Questions in Particle Physics

- What is the origin of mass for fundamental particles?
- Why are there so many kinds of particles?
- Do all the forces become one?
- Are there extra dimensions of space?
- What are neutrinos telling us?
- Do charged leptons change from one kind to another?
- Do protons decay?
- Are there undiscovered principles of nature:
  new symmetries, new physical laws?
- What happened to the antimatter?
- What is dark matter?
- How can we solve the mystery of dark energy?
- How did the universe come to be?

Evolved Thinker

History of the Universe

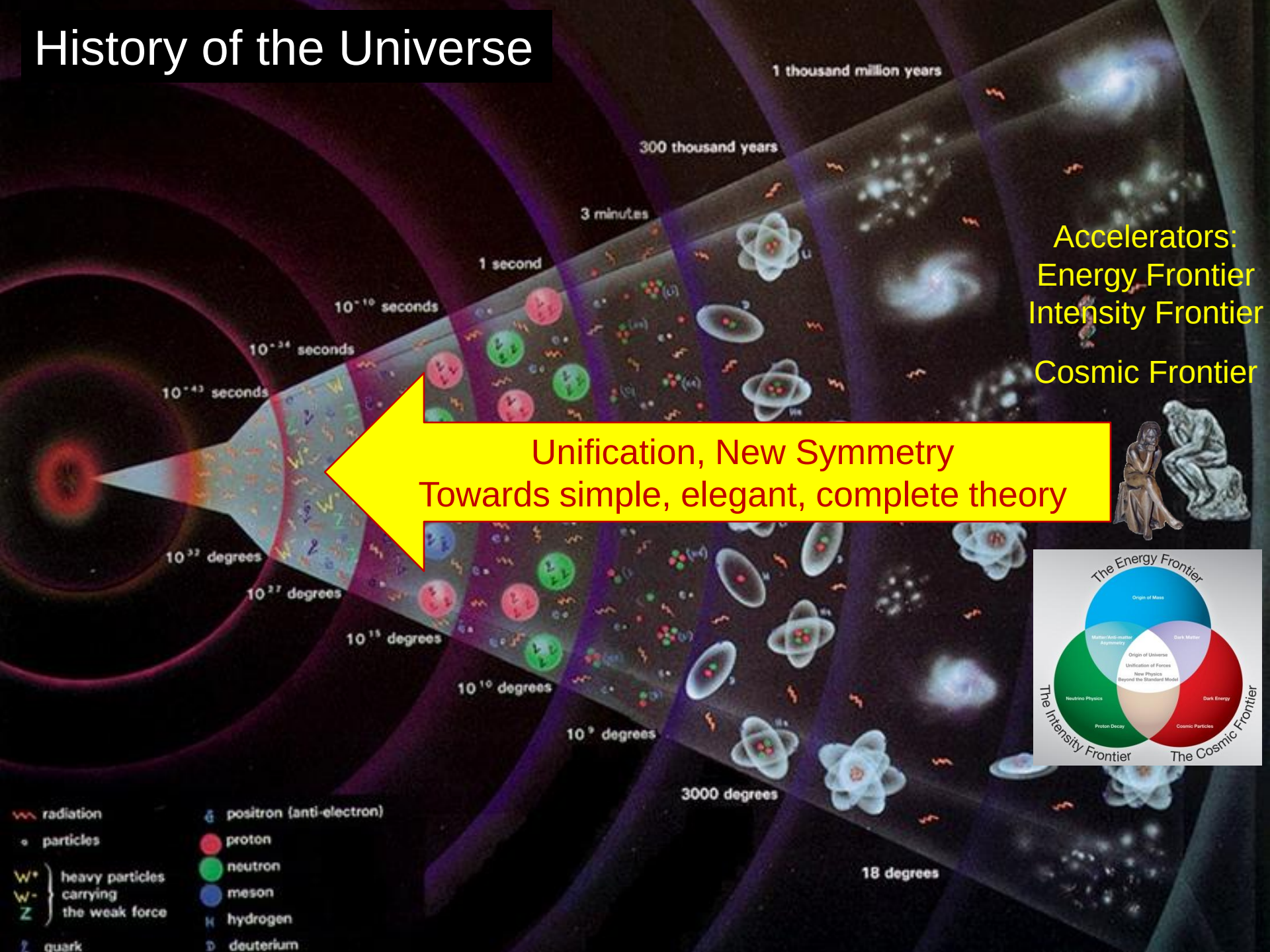


$E = Mc^2$

Accelerators:
Energy Frontier
Intensity Frontier

Cosmic Frontier

History of the Universe

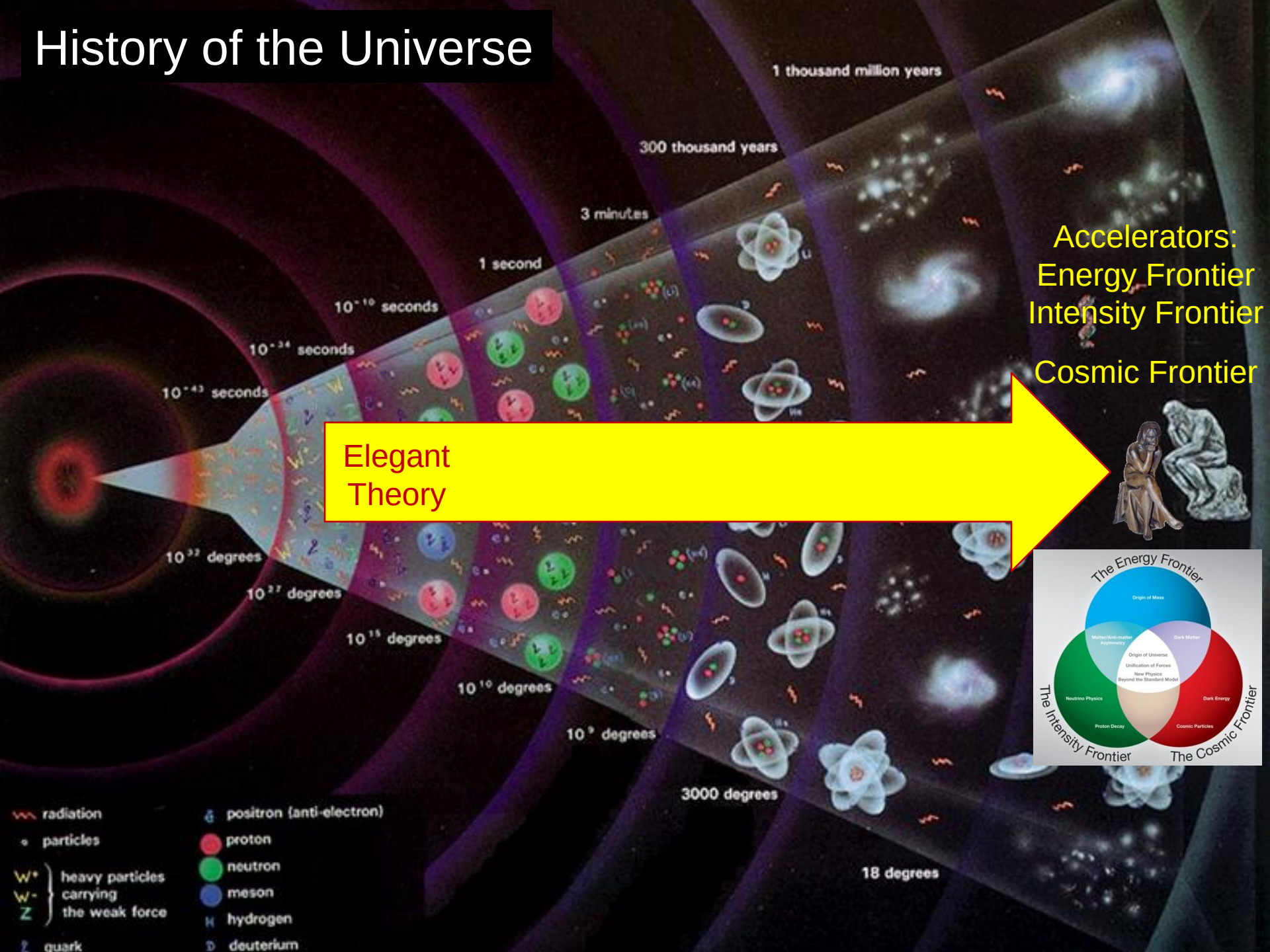


Accelerators:
Energy Frontier
Intensity Frontier

Cosmic Frontier

Unification, New Symmetry
Towards simple, elegant, complete theory

History of the Universe



Elegant Theory

Accelerators:
Energy Frontier
Intensity Frontier

Cosmic Frontier

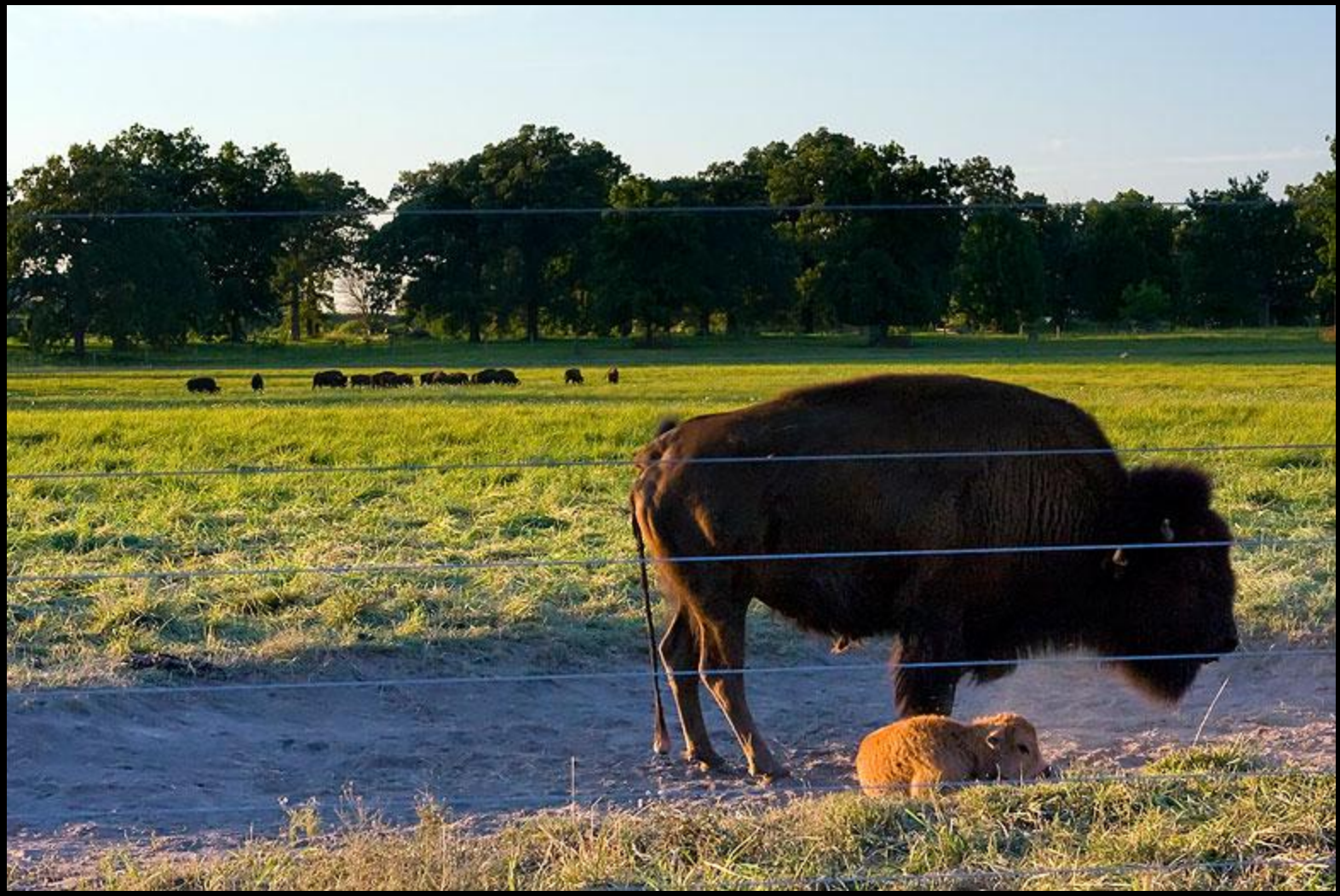
Fermilab today

- 1900 employees
- 2300 users (~1/2 from abroad)
- 6800 acres, park-like site

A herd of American bison, symbolizing Fermillab's presence on the frontiers of particle physics and the connection to its prairie origins

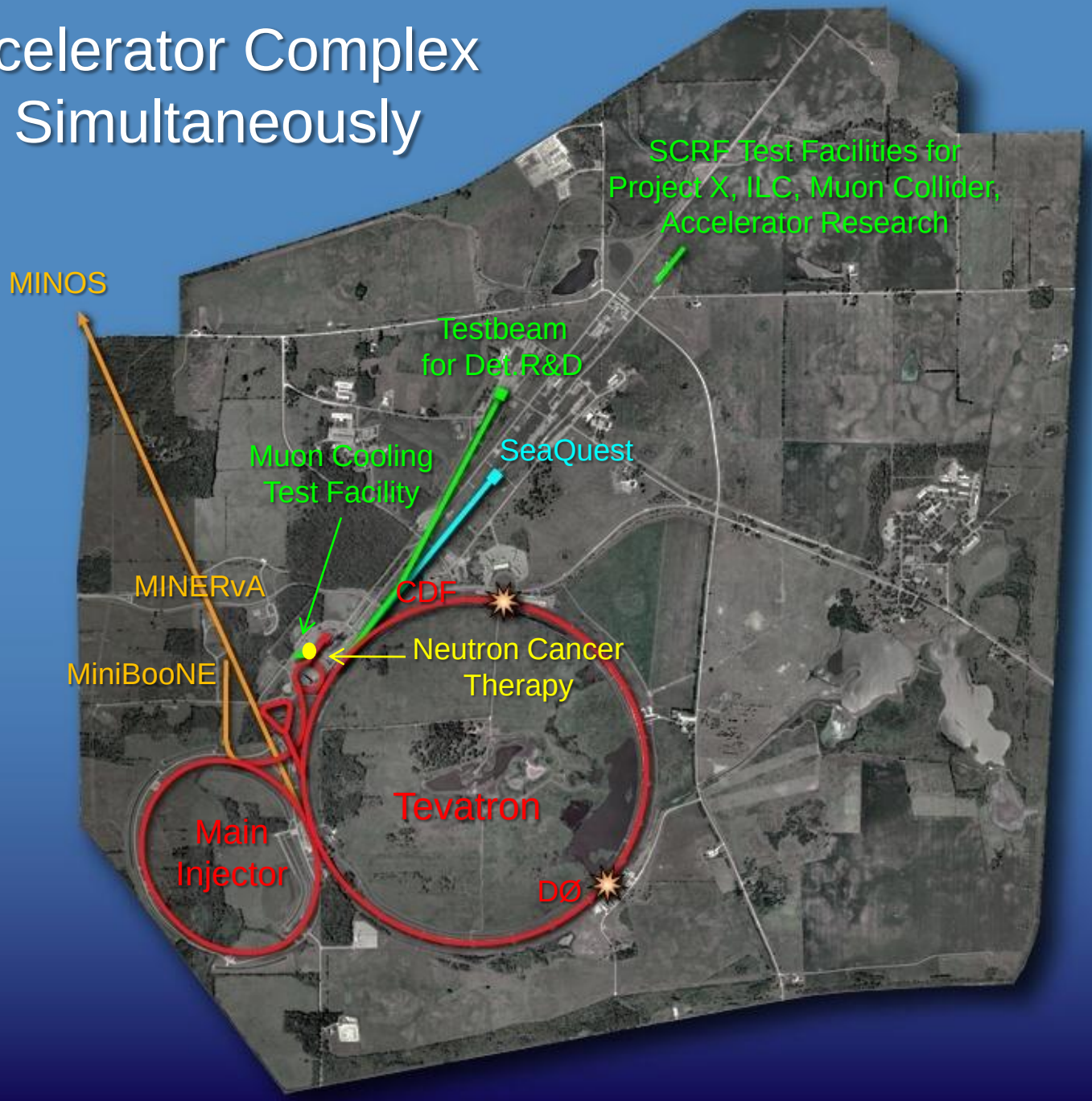
Now at Fermilab

Now at Fermilab



Tour of Accelerator Complex at Fermilab

Fermilab Accelerator Complex Operating Simultaneously



Cockroft-Walton

Linac

Booster

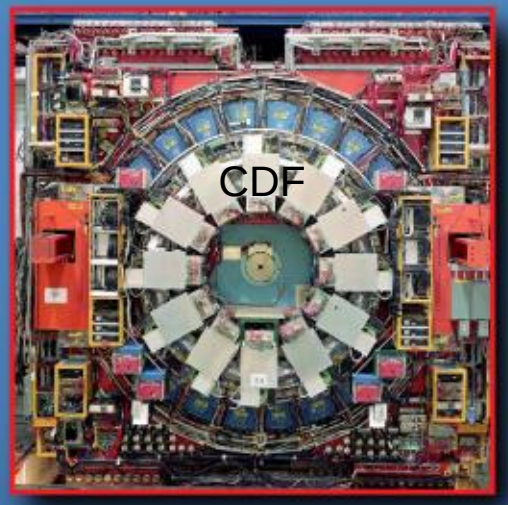
Main Injector

Tevatron

Antiproton

Tevatron

CDF and DZero



Energy Frontier Accelerators

Tevatron

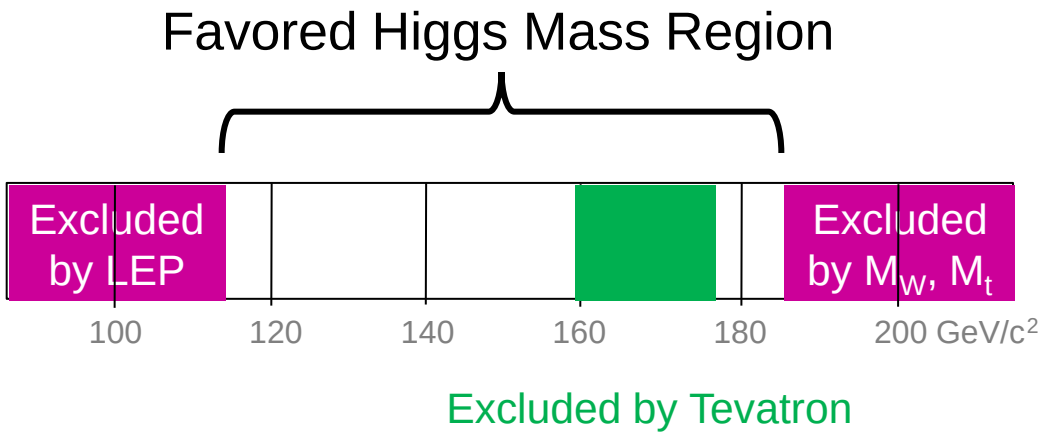
LHC

Lepton Collider

(energy to be determined)

(technology, site to be determined)

Origin of Mass



Proton mass ~ 1 GeV/c^2

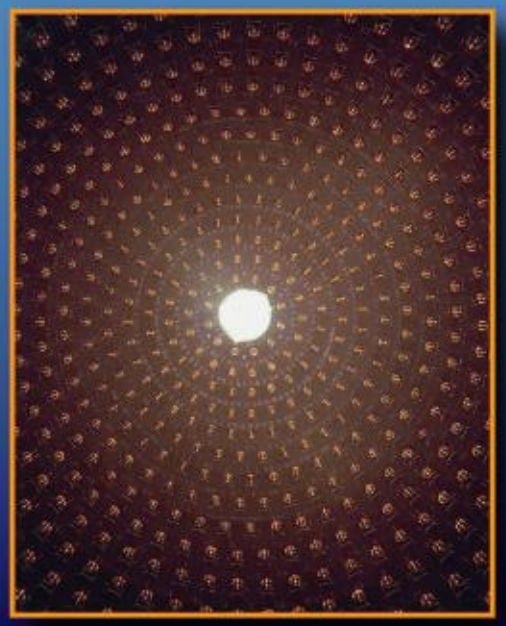
Top quark mass ~ 172 GeV/c^2

ν's from Main Injector

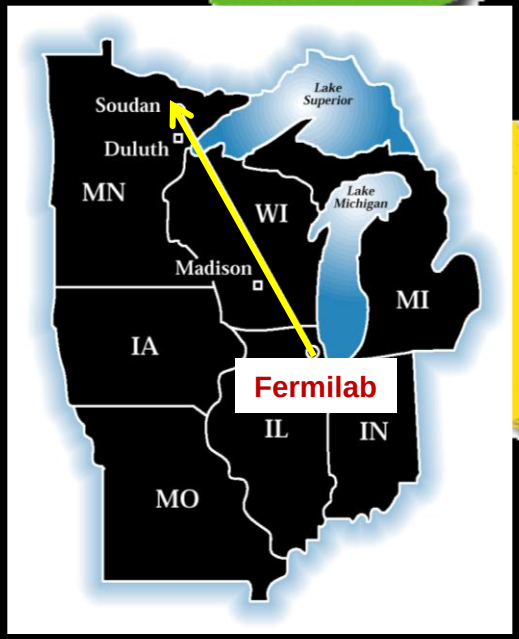
MINOS
MINERvA

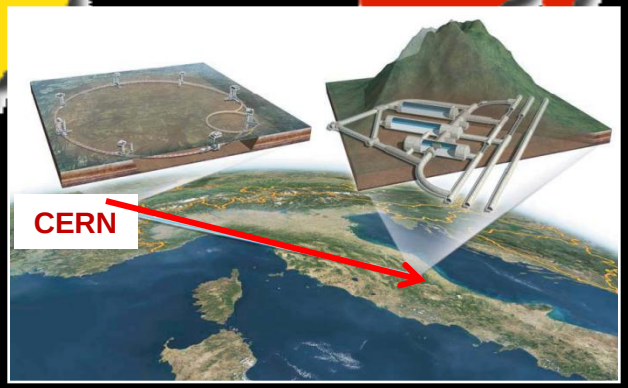
ν's from Booster

MiniBooNE



Accelerator-Based Neutrinos



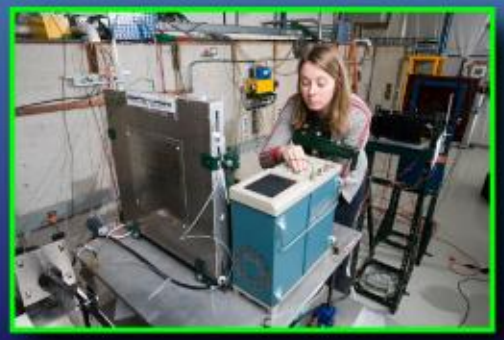


Fermilab → Soudan (735km)
Fermilab → Ash river(810km)

CERN → Gran Sasso (732km)

J-PARC → Kamioka (295km)

Beam for Detector Development



Test Facility for Accelerator Development

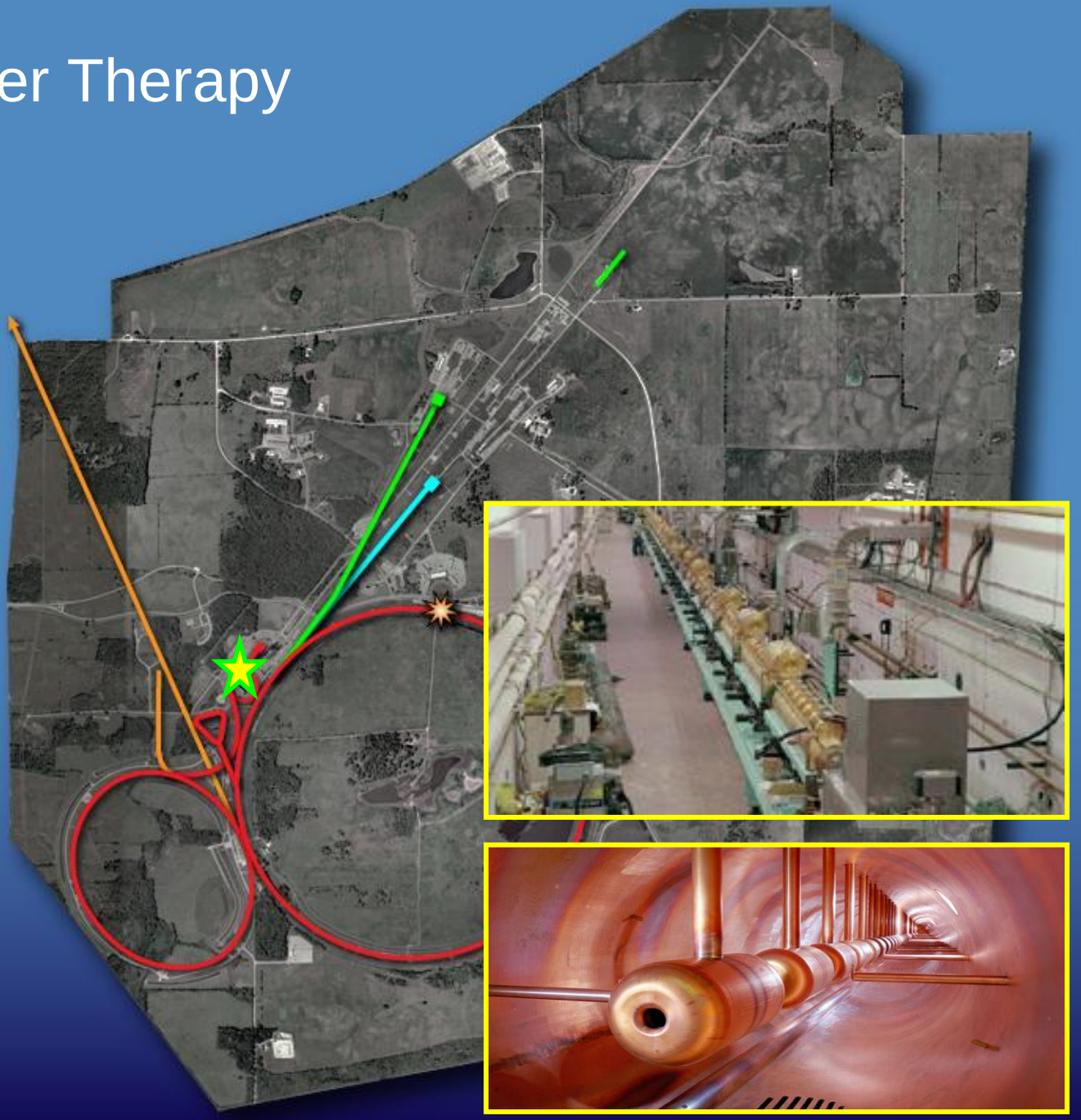
Super Conducting RF Technology

Test Facility for
Muon Cooling

Proton

SeaQuest

Neutron Cancer Therapy

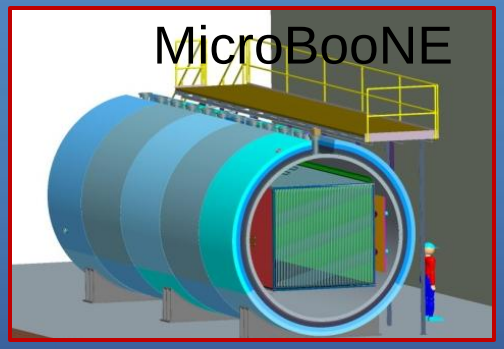


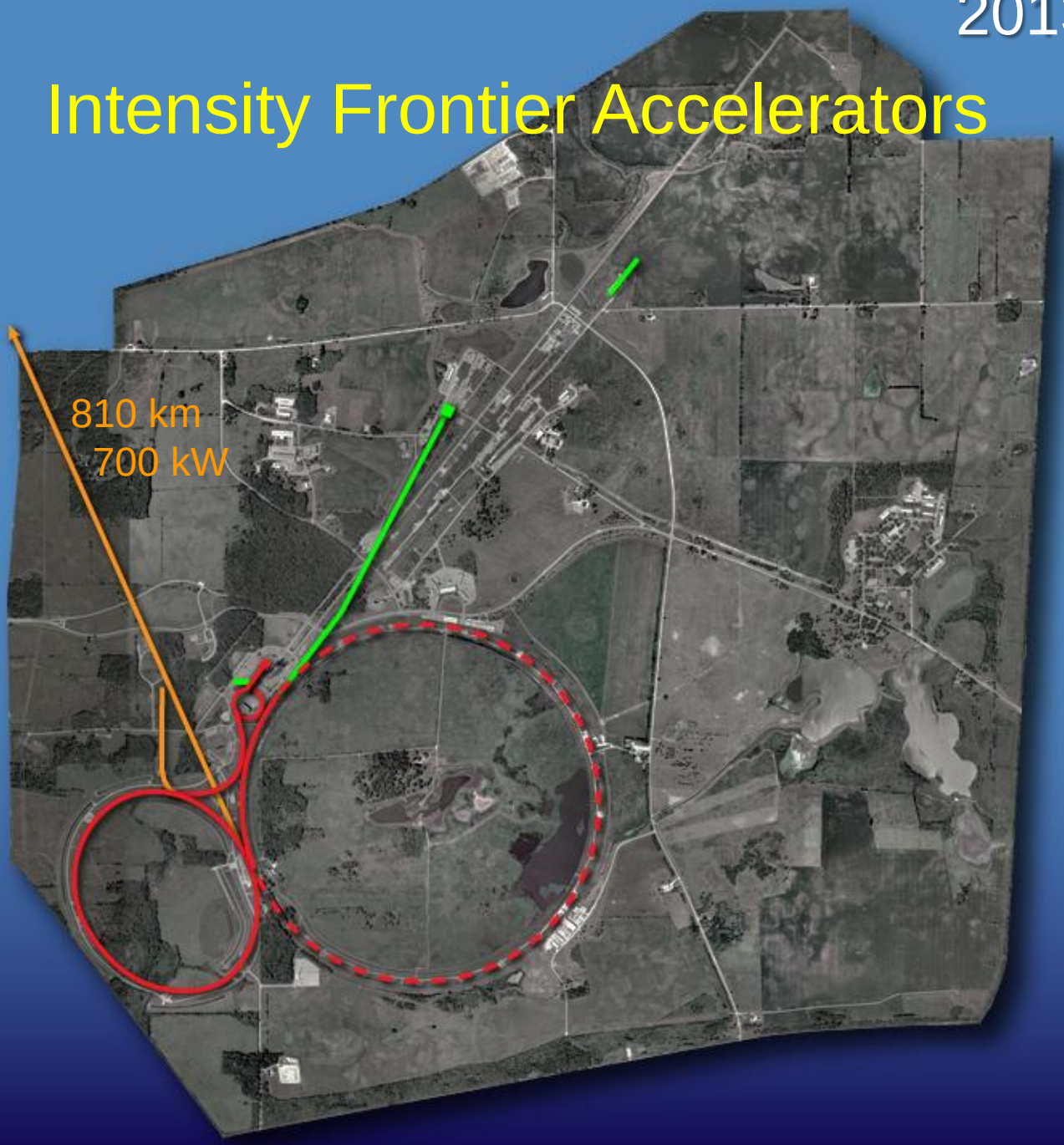
Patient treatments since 1976

2013

Intensity Frontier Accelerators

Neutrinos
NOvA
MINERvA
MicroBooNE

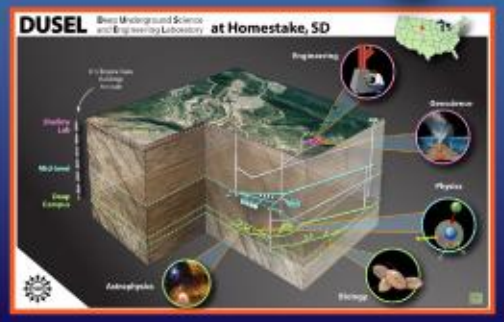


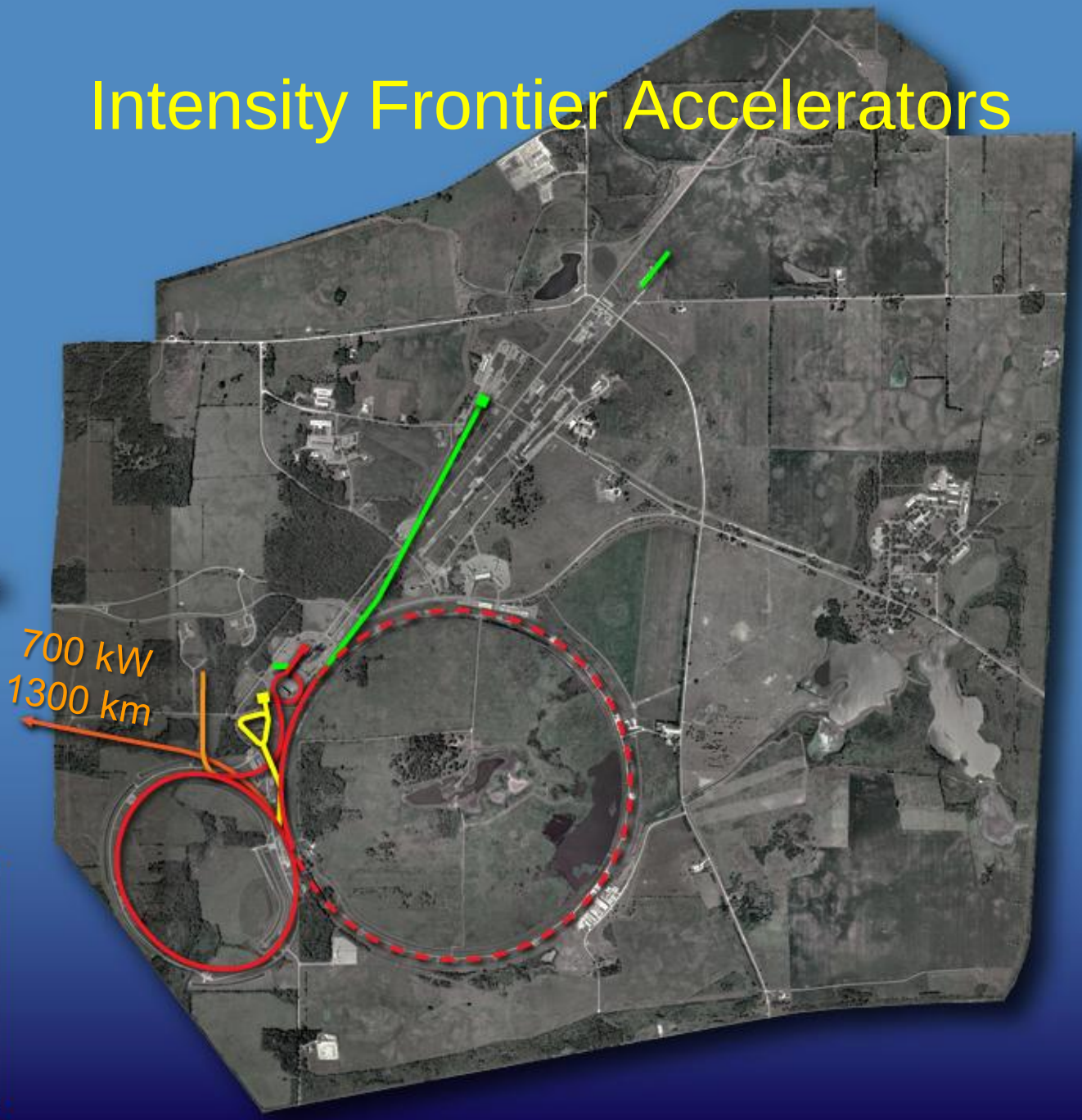


Intensity Frontier Accelerators

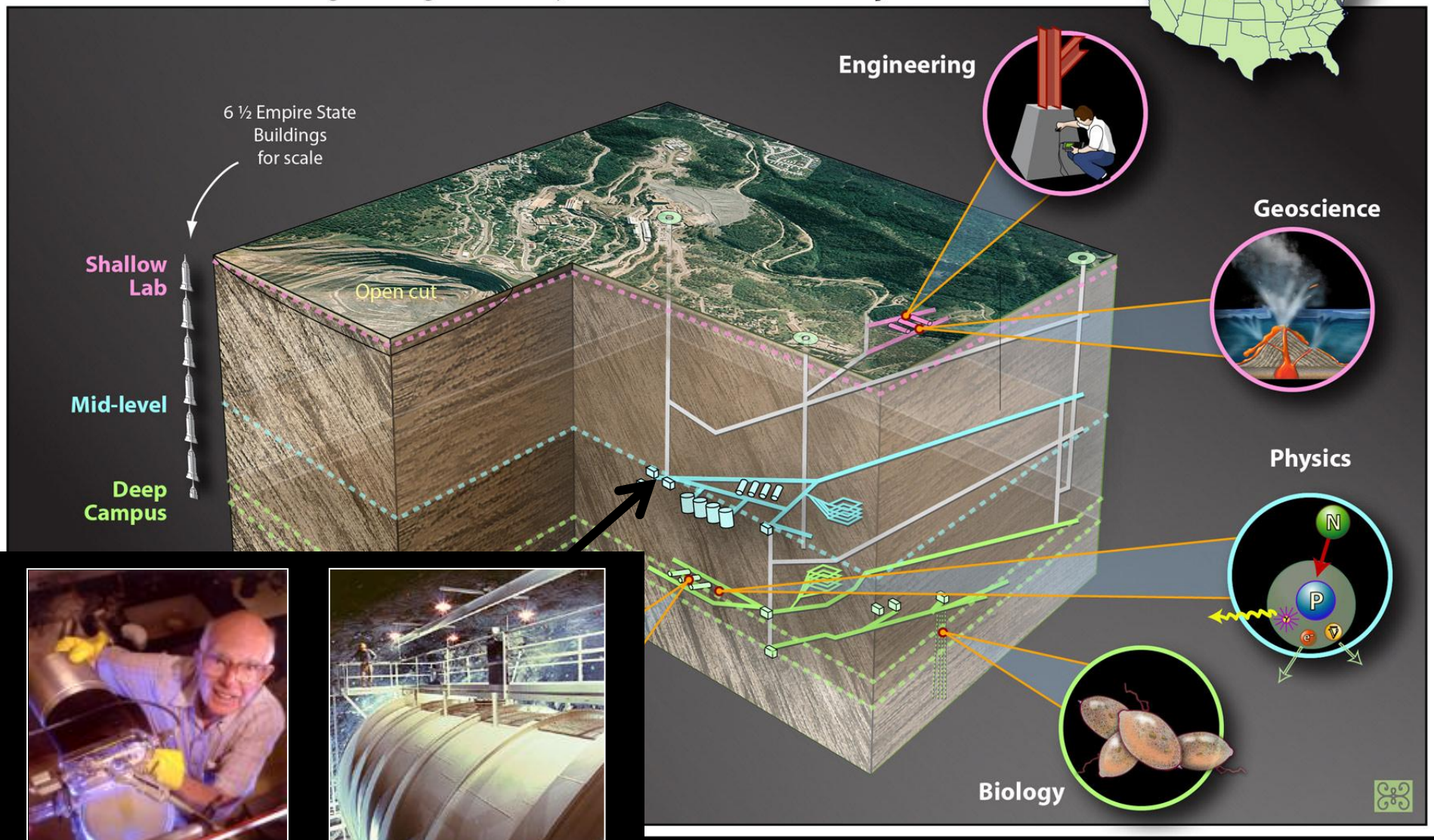
<u>Neutrinos</u>
neutrinos to DUSEL
(proton decay)

<u>Muons</u>
muon → electron

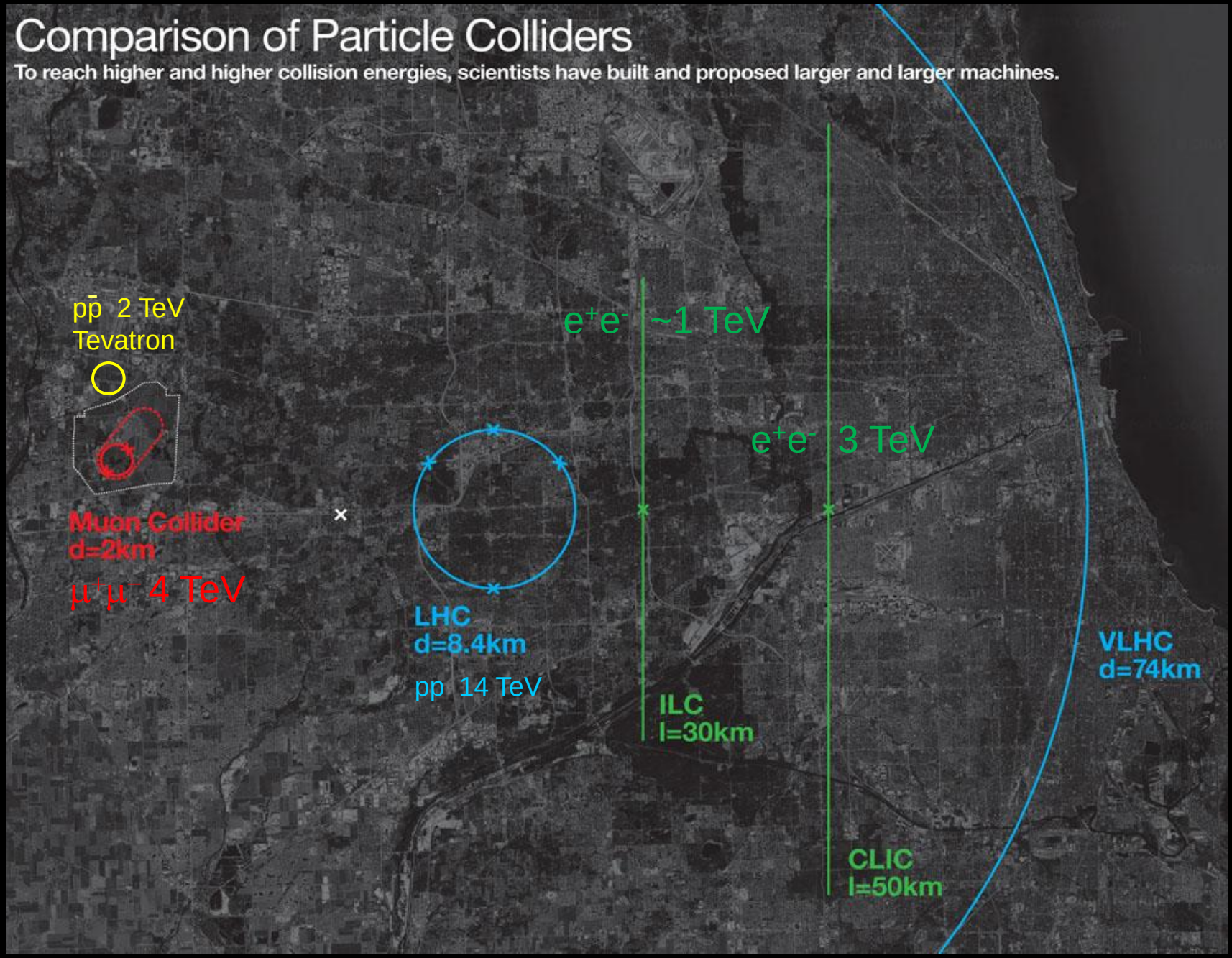




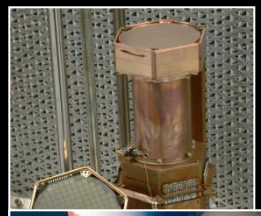
DUSEL Deep Underground Science and Engineering Laboratory at Homestake, SD

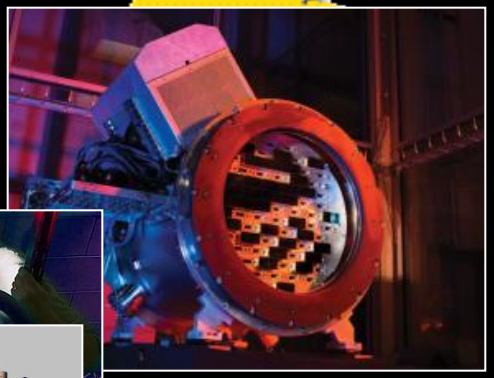


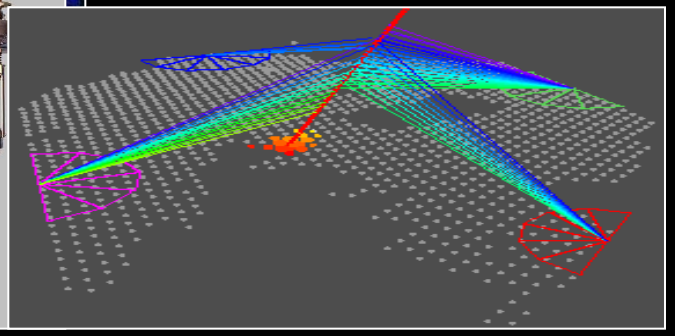
Ray Davis's Experiment


Comparison of Particle Colliders
To reach higher and higher collision energies, scientists have built and proposed larger and larger machines.
p$\bar{p}$ 2 TeV
Tevatron
Muon Collider
d=2km
$\mu^+\mu^-$ 4 TeV
LHC
d=8.4km
pp 14 TeV
e^+e^- ~1 TeV
ILC
l=30km
e^+e^- 3 TeV
CLIC
l=50km
VLHC
d=74km

Cosmic Frontier: Dark Matter & Dark Energy

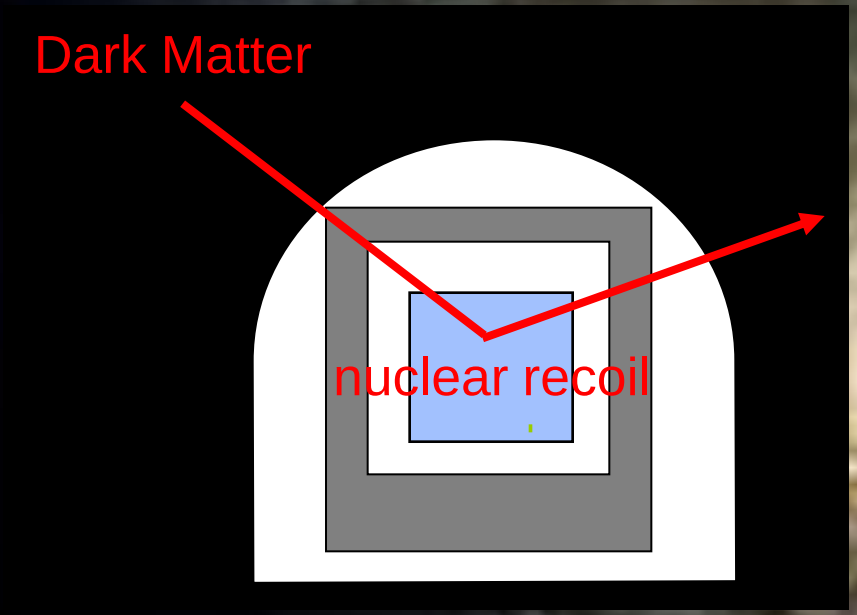




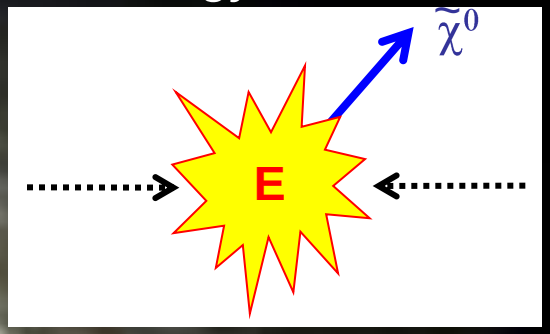


Cosmic Frontier: Dark Matter

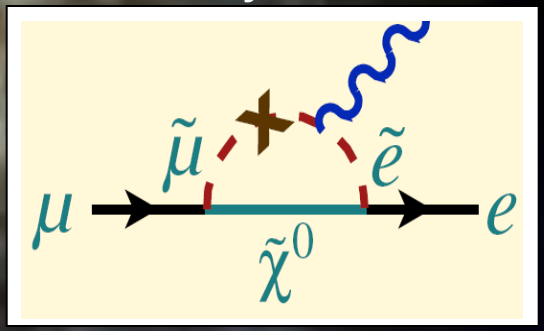
Underground experiments may detect Dark Matter candidates.



Energy Frontier



Intensity Frontier

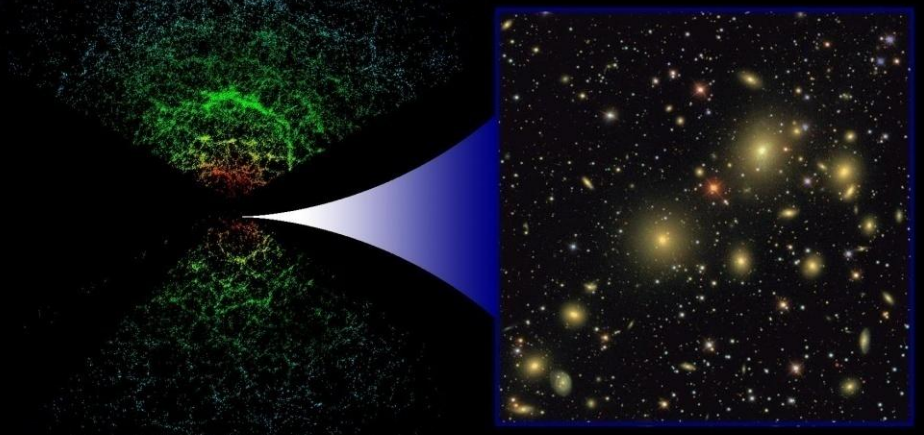


Accelerators can produce dark matter in the laboratory and understand exactly what it is.

Interplay: Energy – Intensity – Cosmic Frontiers

Cosmic Frontier: Dark Energy

Telescopes (ground, space)



Sloan Digital Sky Survey (SDSS)

Dark Energy Survey (DES)

Joint Dark Energy Mission (JDEM)

What are accelerators used for?

Today, 30,000 accelerators are in operation around world

- Discovery science
- Materials research / manufacturing

- National security

- Energy and the environment
- Medical sciences

International Fellow

- Two students from African universities
  - Research at Fermilab
  - Fermilab scientists will supervise them
  - Duration: up to 2 years for each student

- http://www.fnal.gov/pub/forphysicists/fellowships/international/index.html

Have a wonderful school!

Young-Kee Kim
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