

# ***The New Frontier on the Great Plains:***

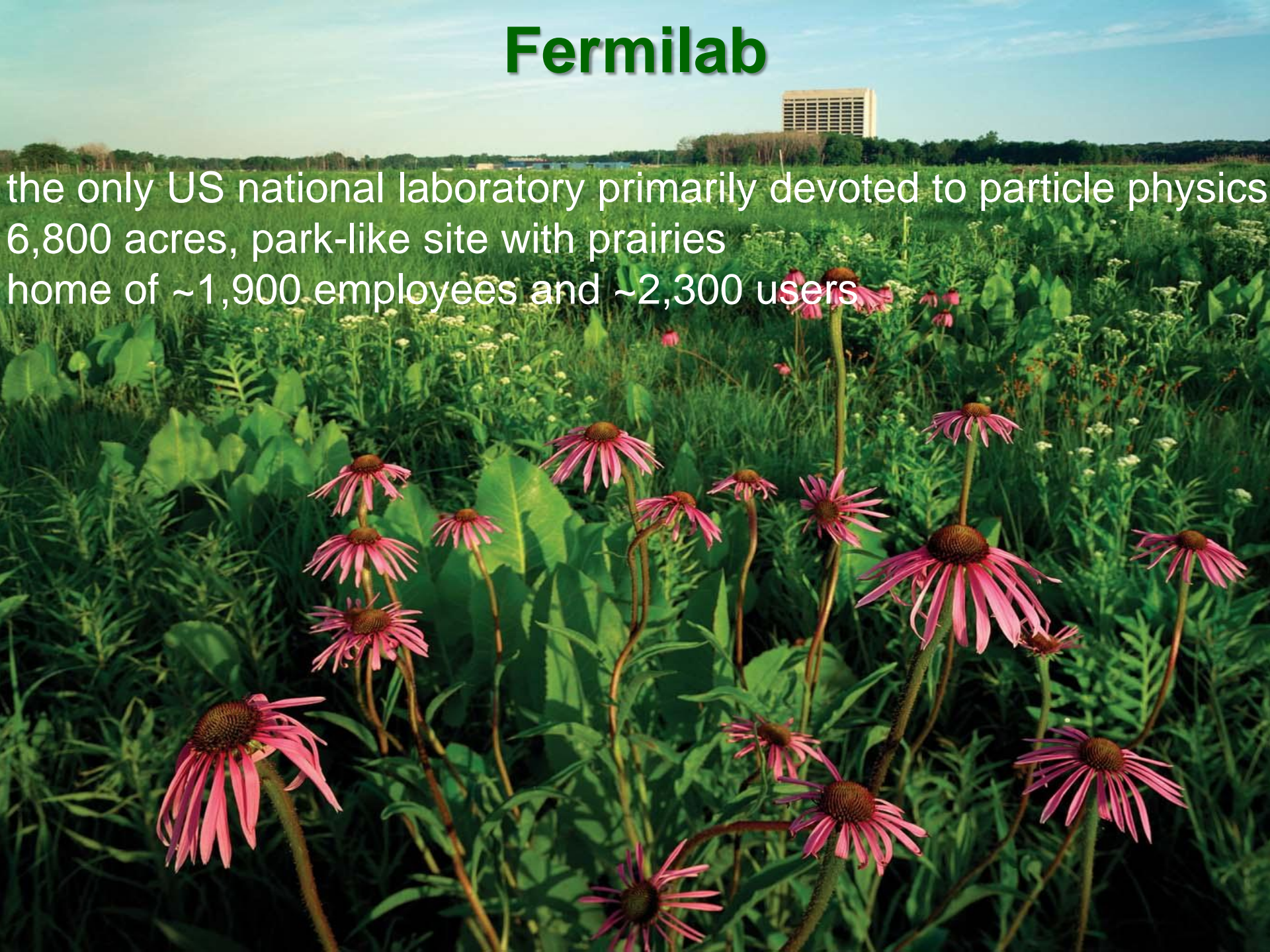
*Fermilab and the future of particle physics*

*Young-Kee Kim  
Deputy Director, Fermilab*

*Physics for Everyone:  
a non-technical lecture series about Fermilab science and culture  
November 16, 2011*

# Fermilab

the only US national laboratory primarily devoted to particle physics  
6,800 acres, park-like site with prairies  
home of ~1,900 employees and ~2,300 users.





the only US na  
6,800 acres, p  
home of ~1,90



particle physics



A herd of American bison,  
symbolizing

Fermilab's presence on the frontiers of particle physics  
and the connection to its prairie origins



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

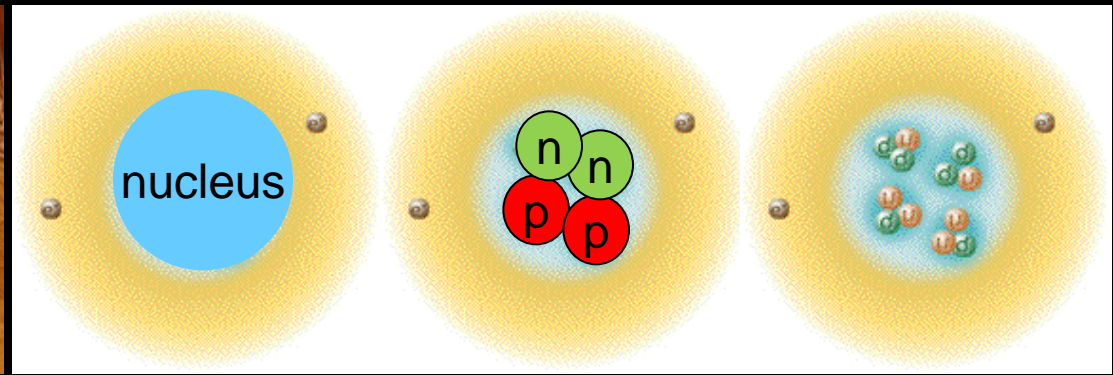


# Accelerators are **Ultimate Microscopes**.

What is the world made of?



up, down quarks, electrons



Gravitational force

Electromagnetic force

Weak and Strong forces



What holds it together?





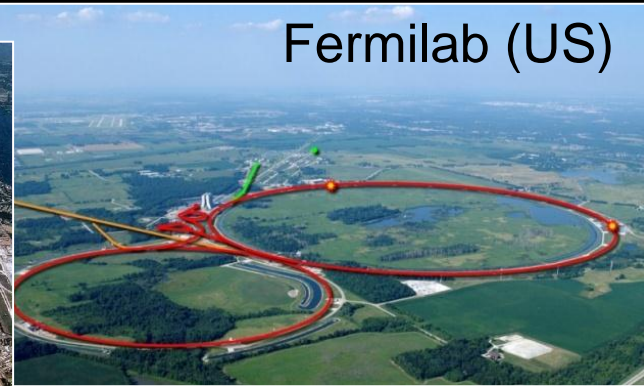
1930

## Today's accelerators for particle physics

CERN (Europe)



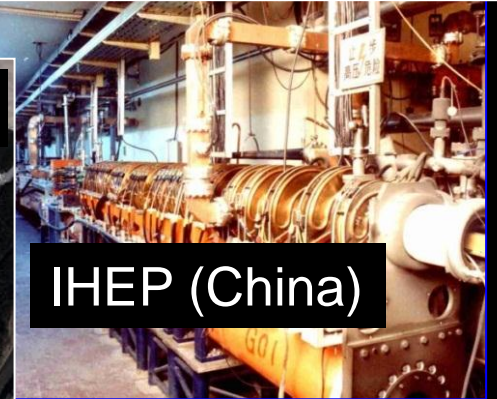
Fermilab (US)



KEK/J-PARC (Japan)



IHEP (China)



Ernest Lawrence  
(1901-1958)

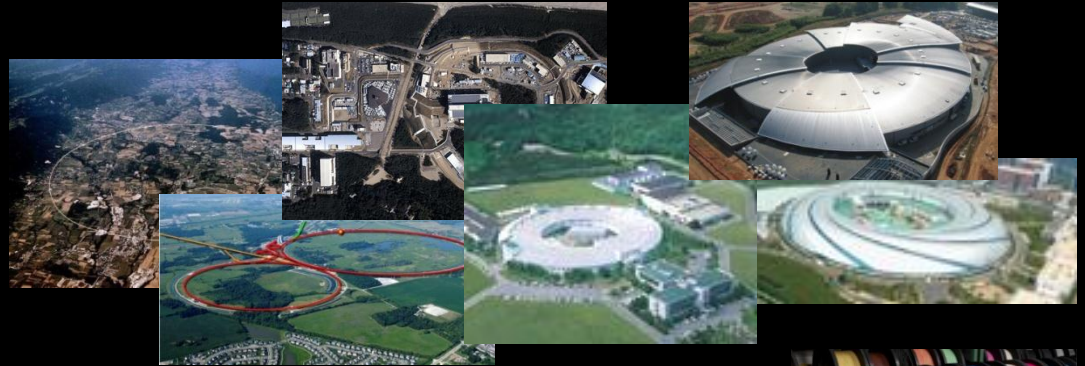


# Accelerators at Fermilab



Today, ~30,000 accelerators are in operation around world

- Discovery science



- Manufacturing and material science

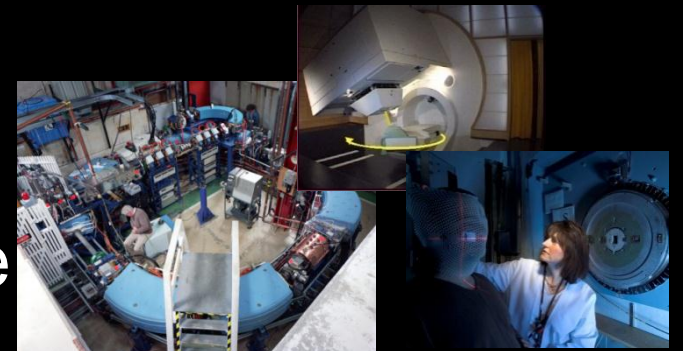


- National security



- Energy and the environment

- Medical treatments and science





# Fermilab and Industry Partnerships

## Proton Cancer Therapy



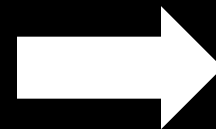
Loma Linda Proton Therapy  
and Treatment Center

World's 1<sup>st</sup> proton accelerator  
built specifically for proton therapy

Designed and built at Fermilab



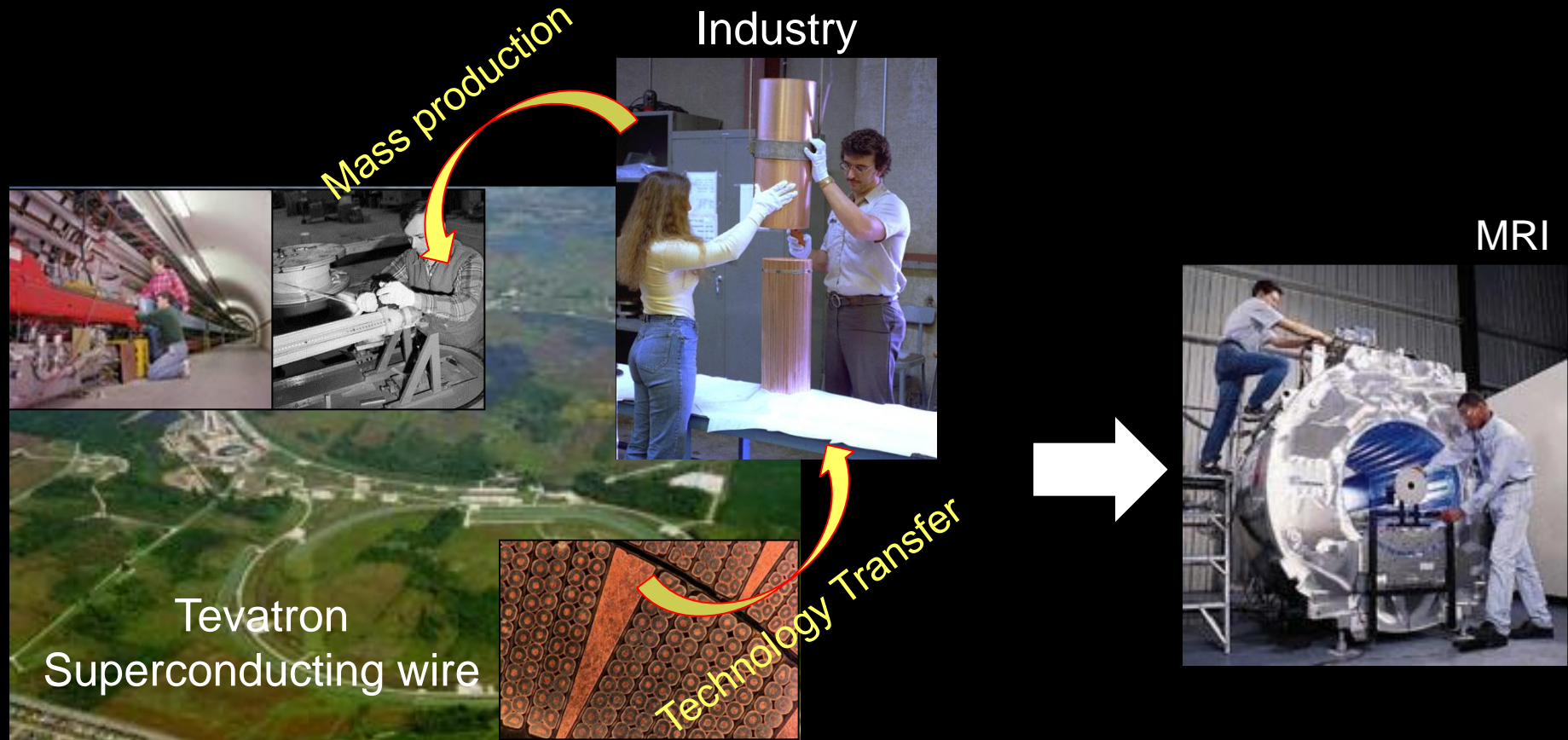
Technology  
Demonstration



Industry

# Fermilab and Industry Partnerships

Tevatron Superconducting Wire → MRI





# Illinois Accelerator Research Center

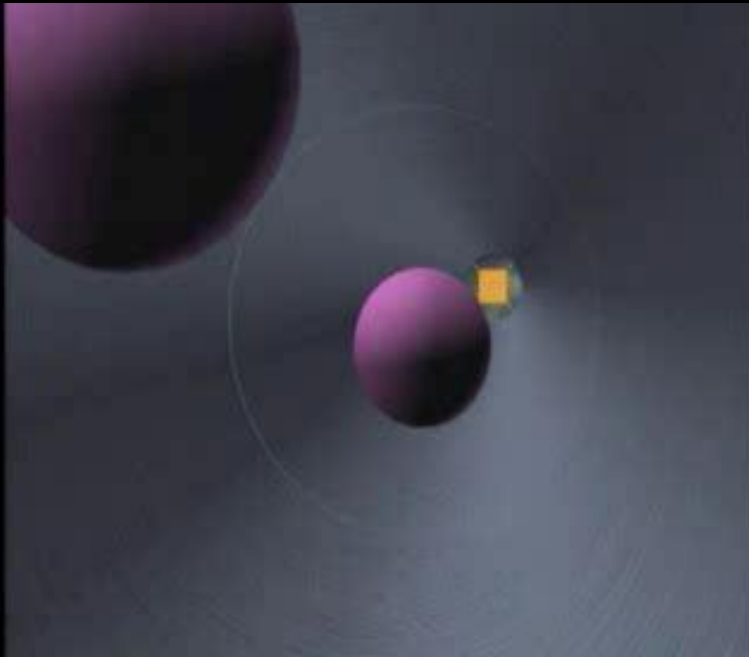
Construction of IARC (2011 – 2013)  
Groundbreaking on Dec. 16, 2011



Accelerator science, technology, education, partnerships with industry

# Accelerators are like **Time Machines**.

They make particles last seen  
in the earliest moments of the universe.



kaons

pions

neutrinos

muons

....

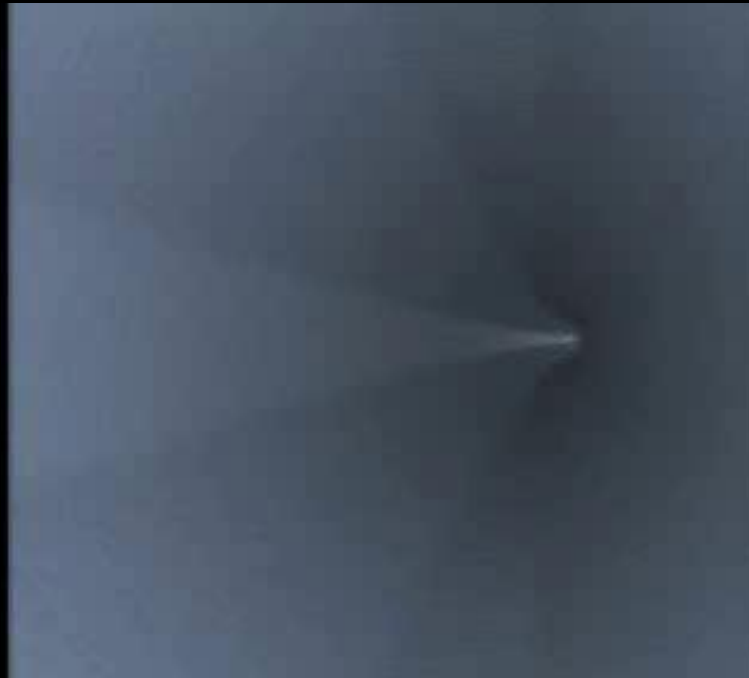
**anti protons**

.....



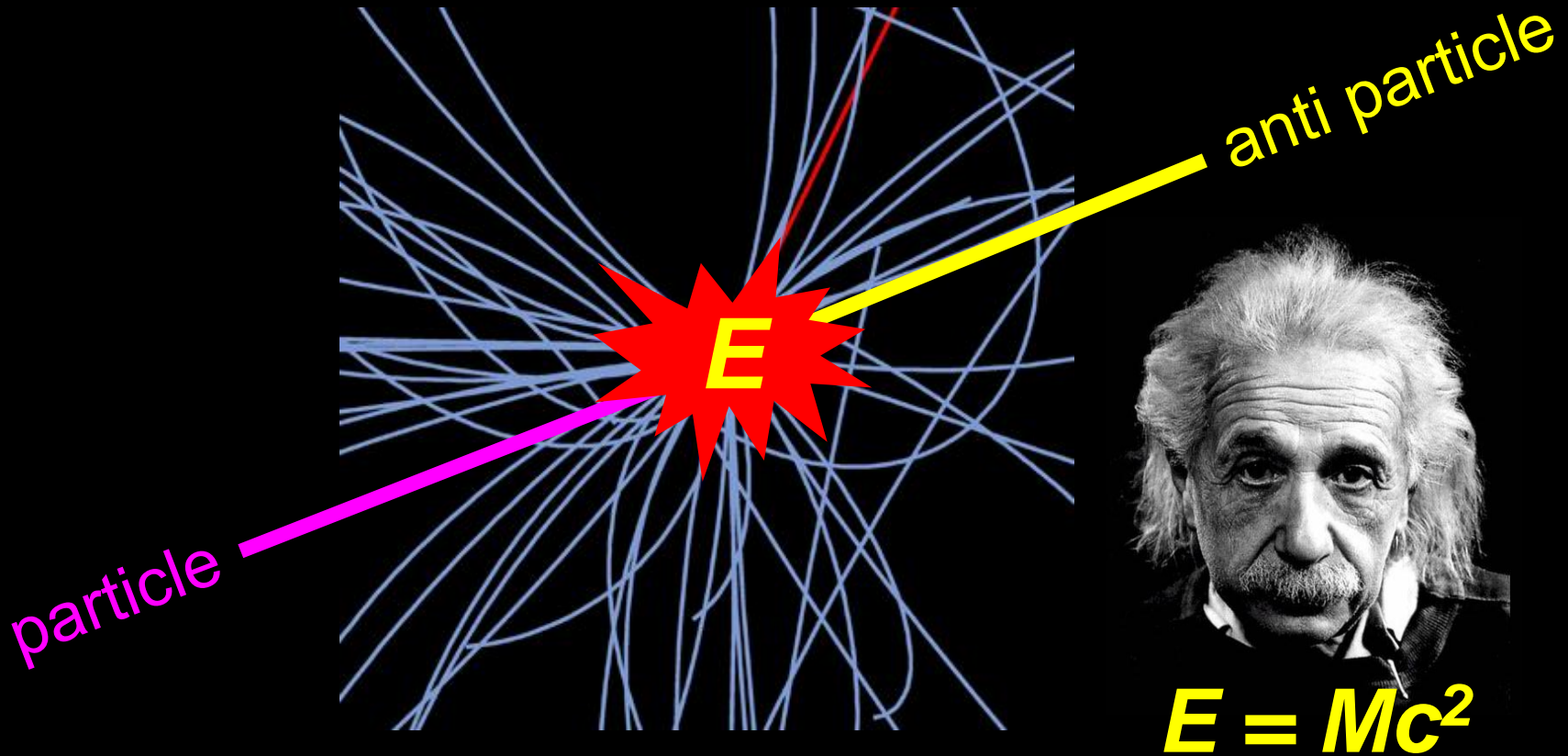
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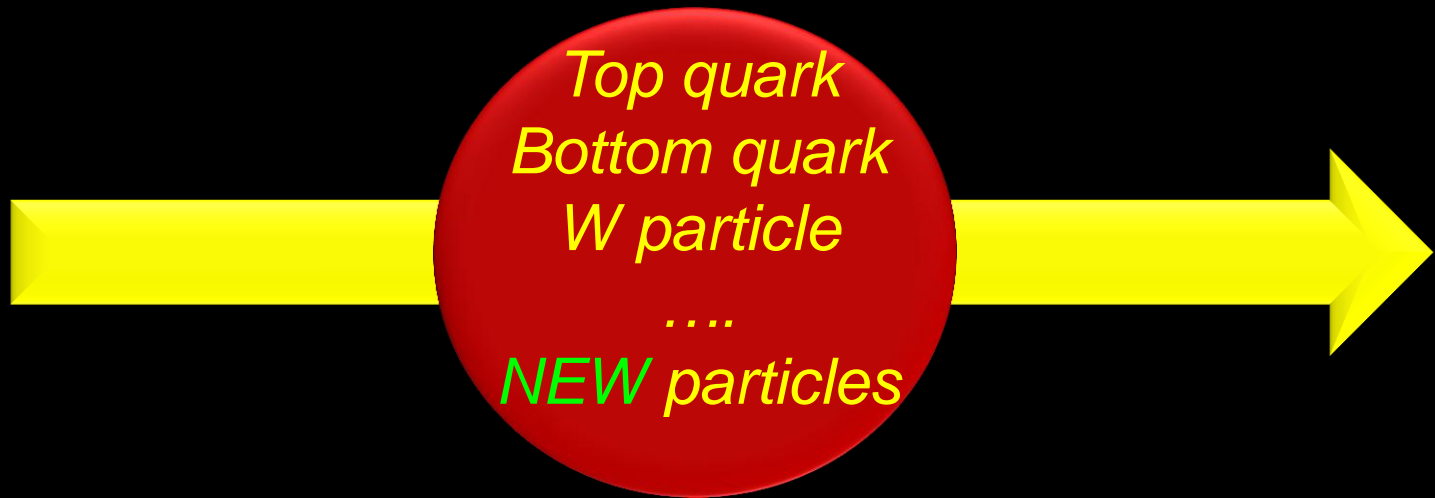
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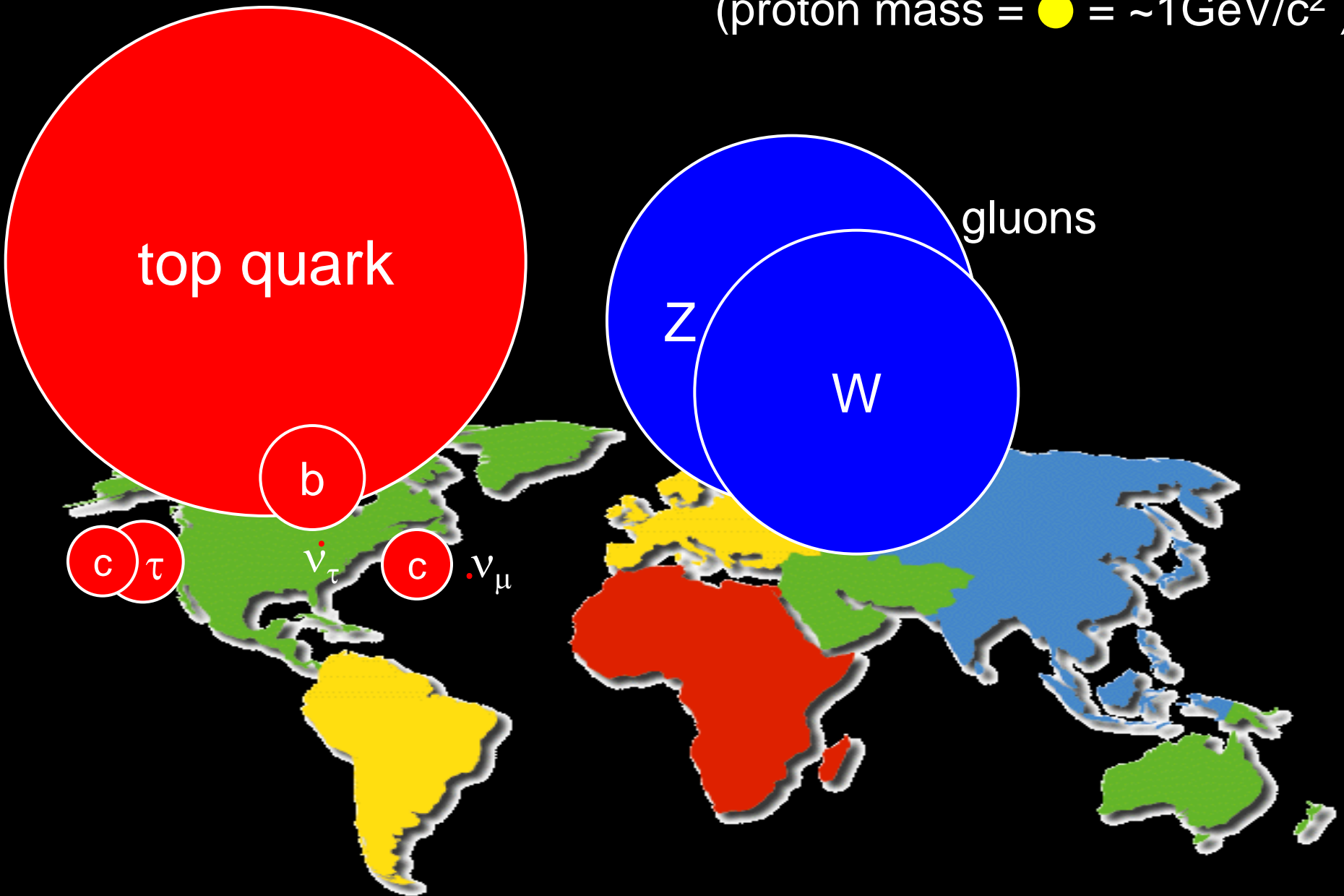


Discover the nature of these particles and **NEW** particles



by intense beams  
of neutrinos, muons, kaons and nuclei

(proton mass = ● =  $\sim 1\text{GeV}/c^2$  )





# Accomplishment of the 19<sup>th</sup> Century

## Periodic Table of Elements

IA																	VIIIA
1 H 1.0079																	2 He 4.0026
3 Li 6.941	4 Be 9.0122															10 Ne 20.179	
11 Na 22.990	12 Mg 24.305															17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.08	21 Sc 44.956	22 Ti 47.90	23 V 50.941	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.71	29 Cu 63.546	30 Zn 65.38	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.22	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.4	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.30
55 Cs 132.91	56 Ba 137.33	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.4	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04		
87 Fr (223)	88 Ra (226)	89 Ac (227)	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np 237.05	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (254)	100 Fm (257)	101 Md (258)	102 No (259)		

Alkali Metals

Alkaline Earth Metals

Transition Metals

Other Metals

Nonmetals

Noble Gases

Inner Transition Metals

GI Gaseous State

LI Liquid State

SI Solid State

SY Synthetically Prepared

IIIB

IVB

VB

VIB

VII B

VIII B

IB

IIB

IIIA

IVA

VA

VIA

VIIA

VIIIA

Lanthanide Series

Actinide Series

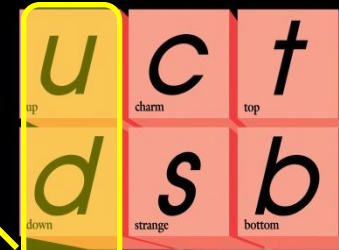
\*Name Not Officially Assigned

# Accomplishment of the 20<sup>th</sup> Century

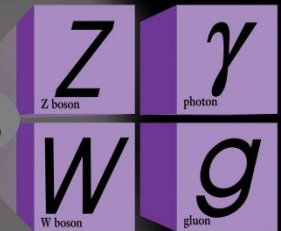
## Table of Elementary Particles

### Standard Model

#### Quarks



#### Forces



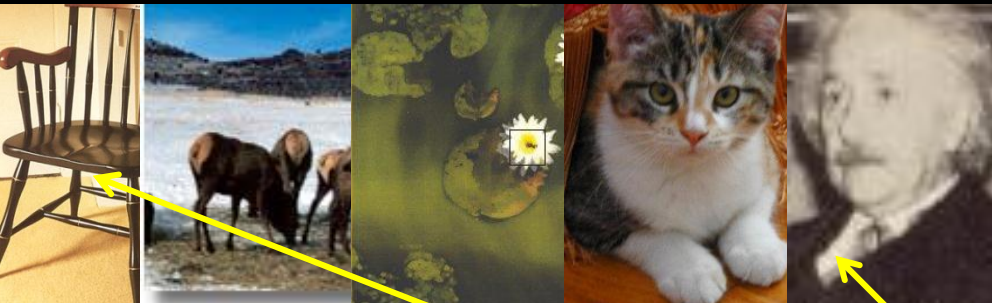
#### Higgs



#### Leptons

# Accomplishment of the 20<sup>th</sup> Century

## Table of Elementary Particles Standard Model



### Quarks

$u$ up	$c$ charm	$t$ top
$d$ down	$s$ strange	$b$ bottom

### Forces

$Z$ Z boson	$\gamma$ photon
$W$ W boson	$g$ gluon

Higgs

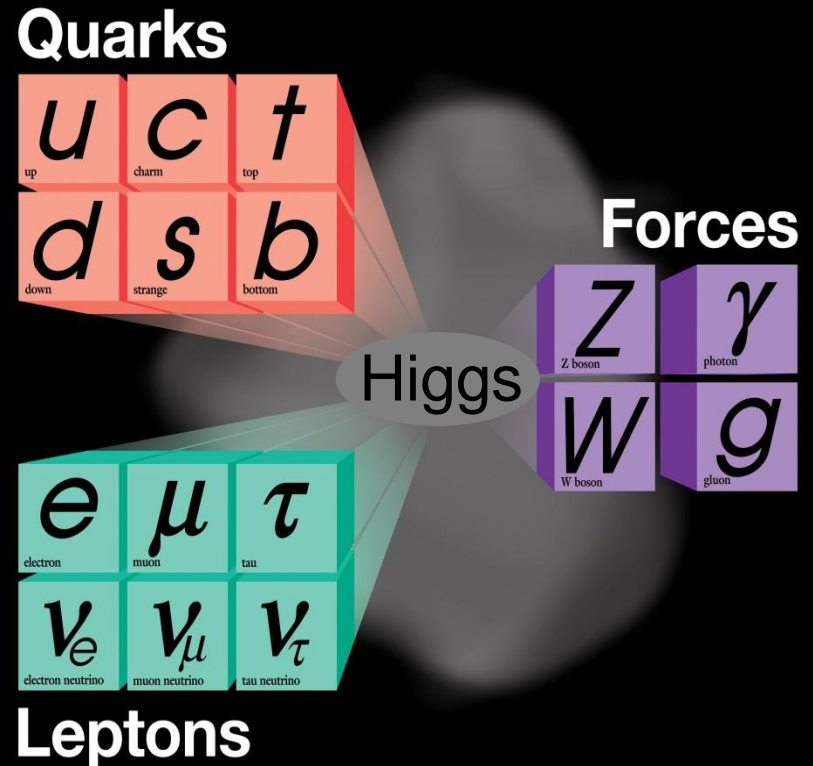
$e$ electron	$\mu$ muon	$\tau$ tau
$\nu_e$ electron neutrino	$\nu_\mu$ muon neutrino	$\nu_\tau$ tau neutrino

### Leptons



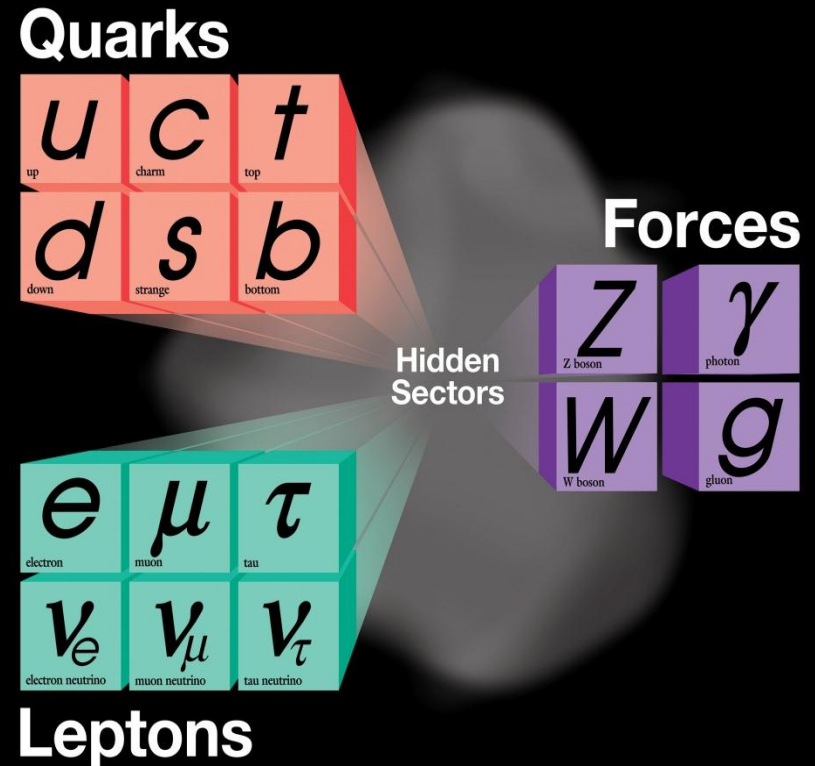
# The triumphs.....

- The present theory is a remarkable intellectual construction
- Particle experimental results beautifully fit in this framework



# ..... and the mysteries

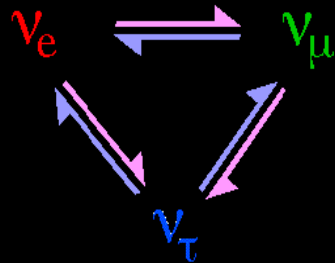
- Origin of mass?
- Why so many kinds of particles? Why three families?
- Do all forces become one?



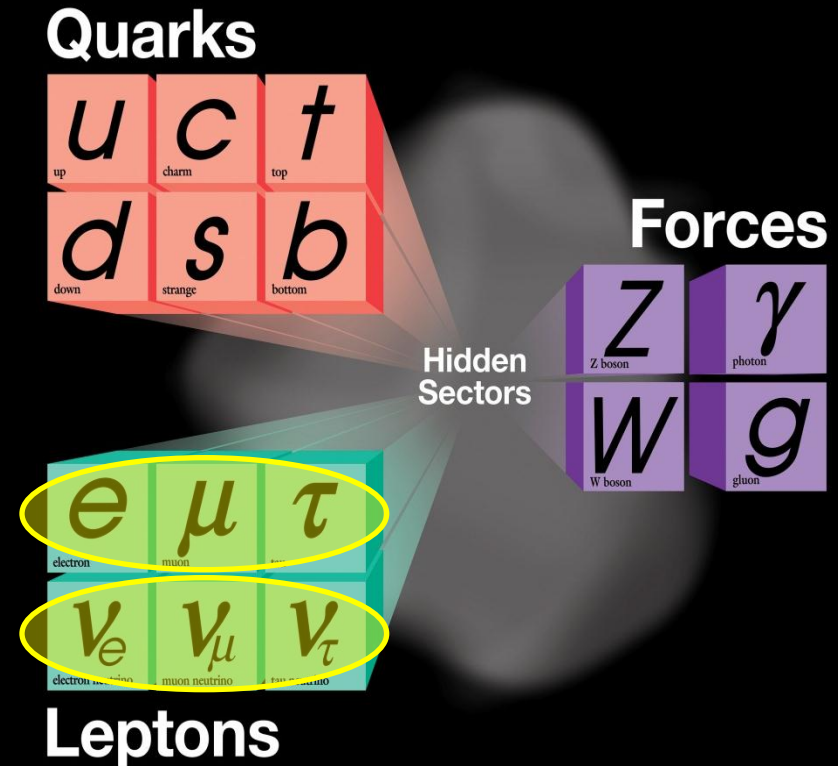
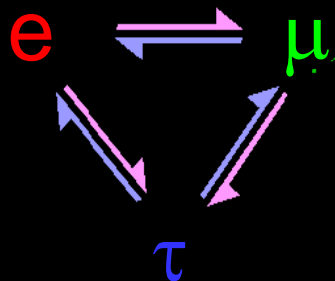


# ..... and the mysteries

- What do neutrinos tell us?

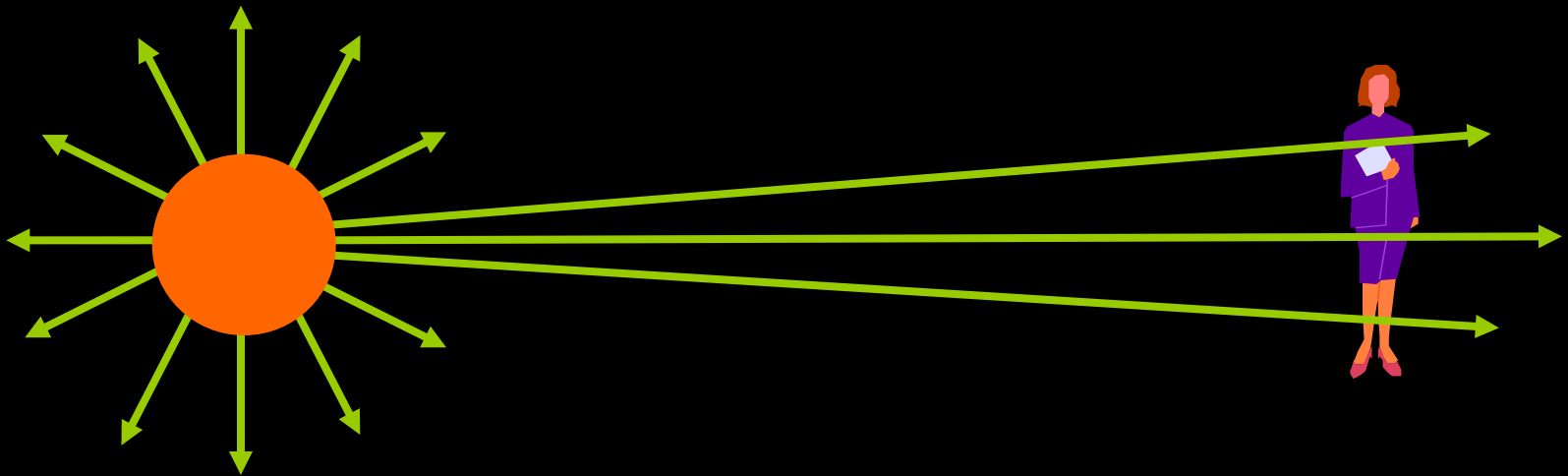


- Will charged leptons change from one kind to another?



# Neutrinos are under our skin

~100 trillion neutrinos zip through each person every second.



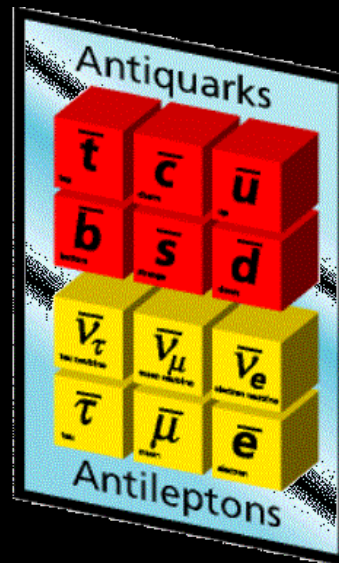
One billion neutrinos for each proton or electron in the universe

If we wish to understand the universe,  
we must understand neutrinos



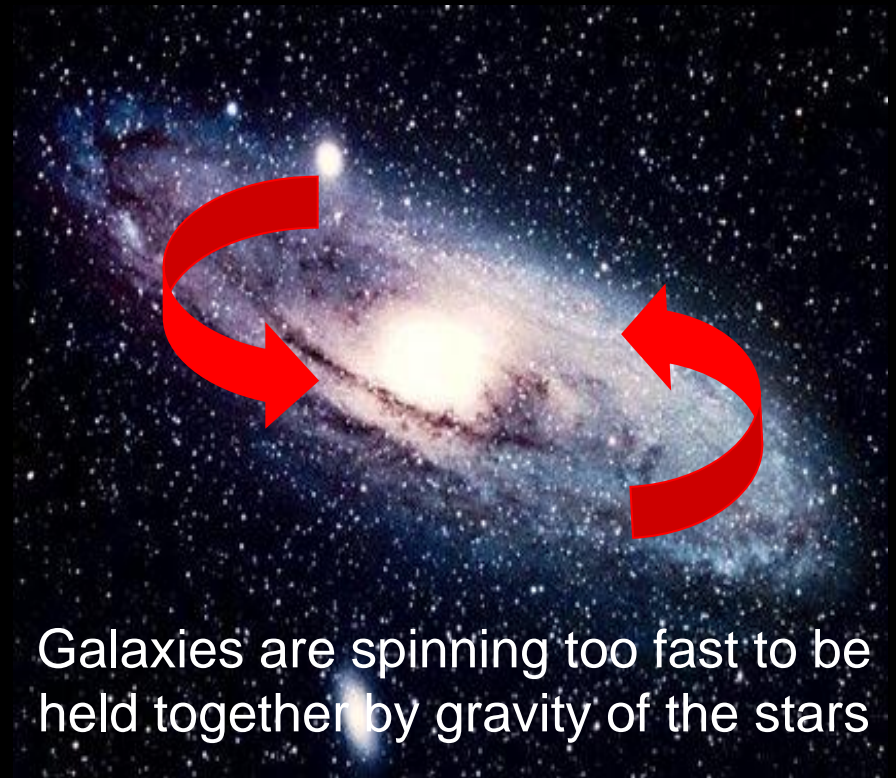
..... and the mysteries

Where did all antimatter go?



# ..... and the mysteries

- What is dark matter?
- It is everywhere, it is five times more abundant than matter.



Galaxies are spinning too fast to be held together by gravity of the stars

# ..... and the mysteries

- Not only is the universe expanding, it is accelerating.
- What is dark energy?  
Not a clue!





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

**Primitive Thinker**





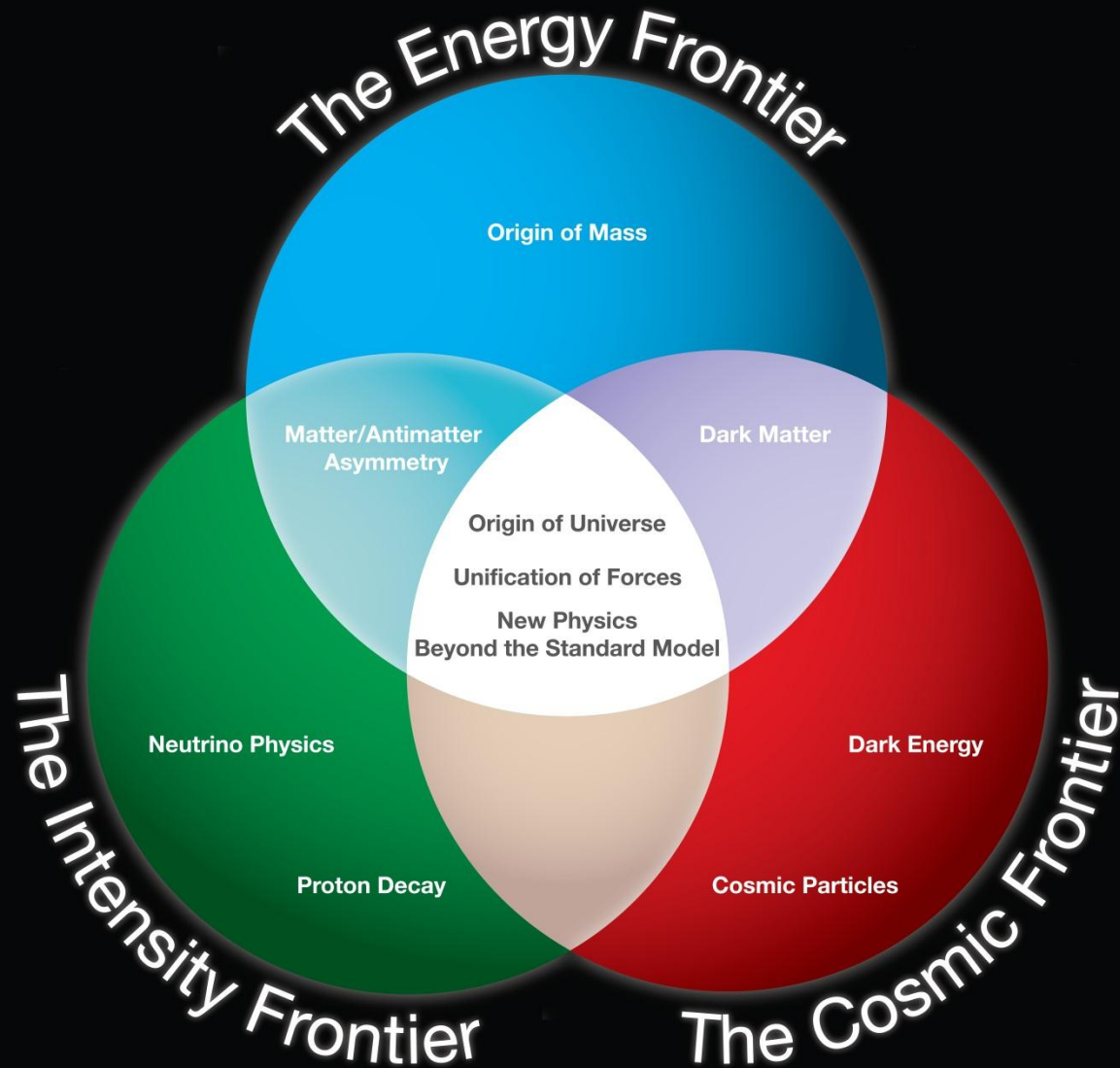
# 21<sup>st</sup> Century Questions in Particle Physics

- Origin of mass?
- Why so many kinds of particles?
- Do all forces become one?
- What do neutrinos tell us?
- What happened to antimatter?
- What is dark matter?
- Mystery of dark energy?
- .....

**Evolved Thinker**

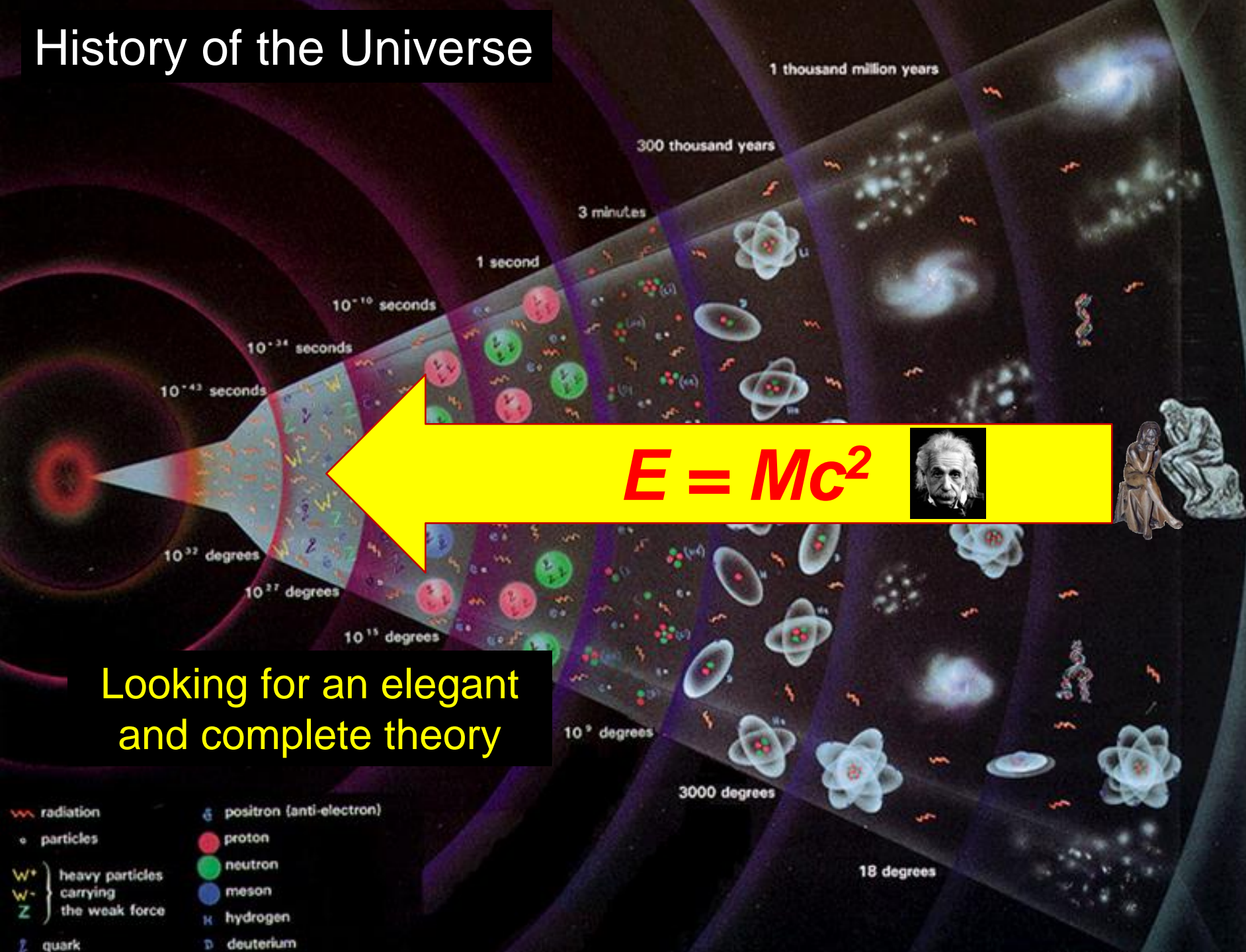


# Tools for the Future



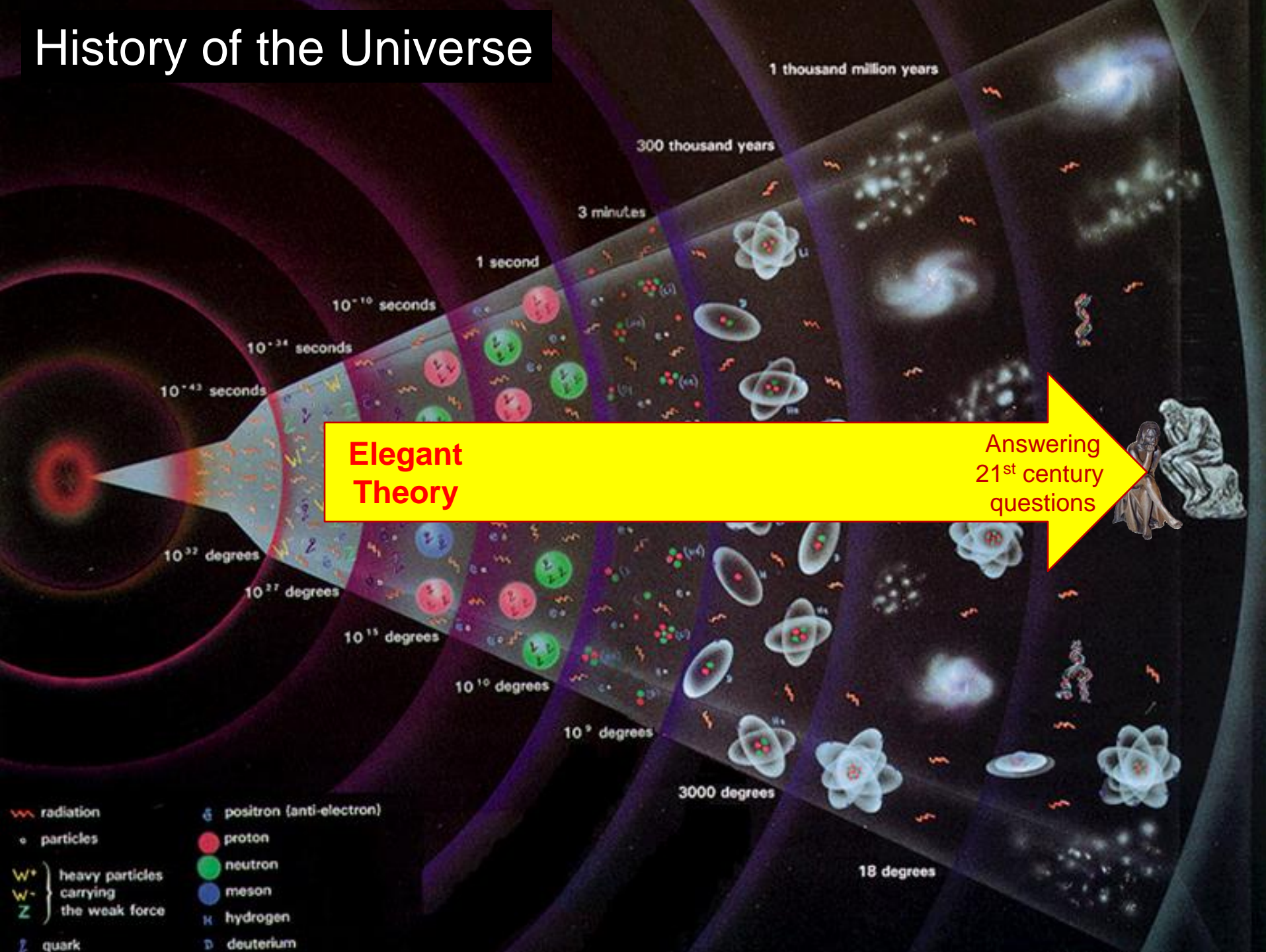


# History of the Universe





# History of the Universe



# Current Experimental Programs at Fermilab (Collaborative Efforts)

## Energy Frontier: 27 countries



## Intensity Frontier: 17 countries



## Cosmic Frontier: 24 countries

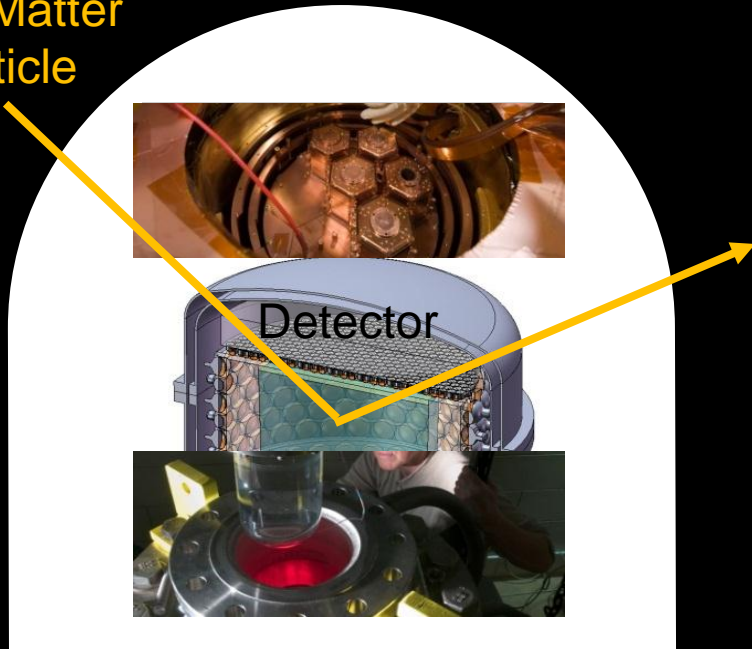




# Cosmic Frontier

## Dark Matter Detector

Dark Matter Particle



## Dark Energy Camera



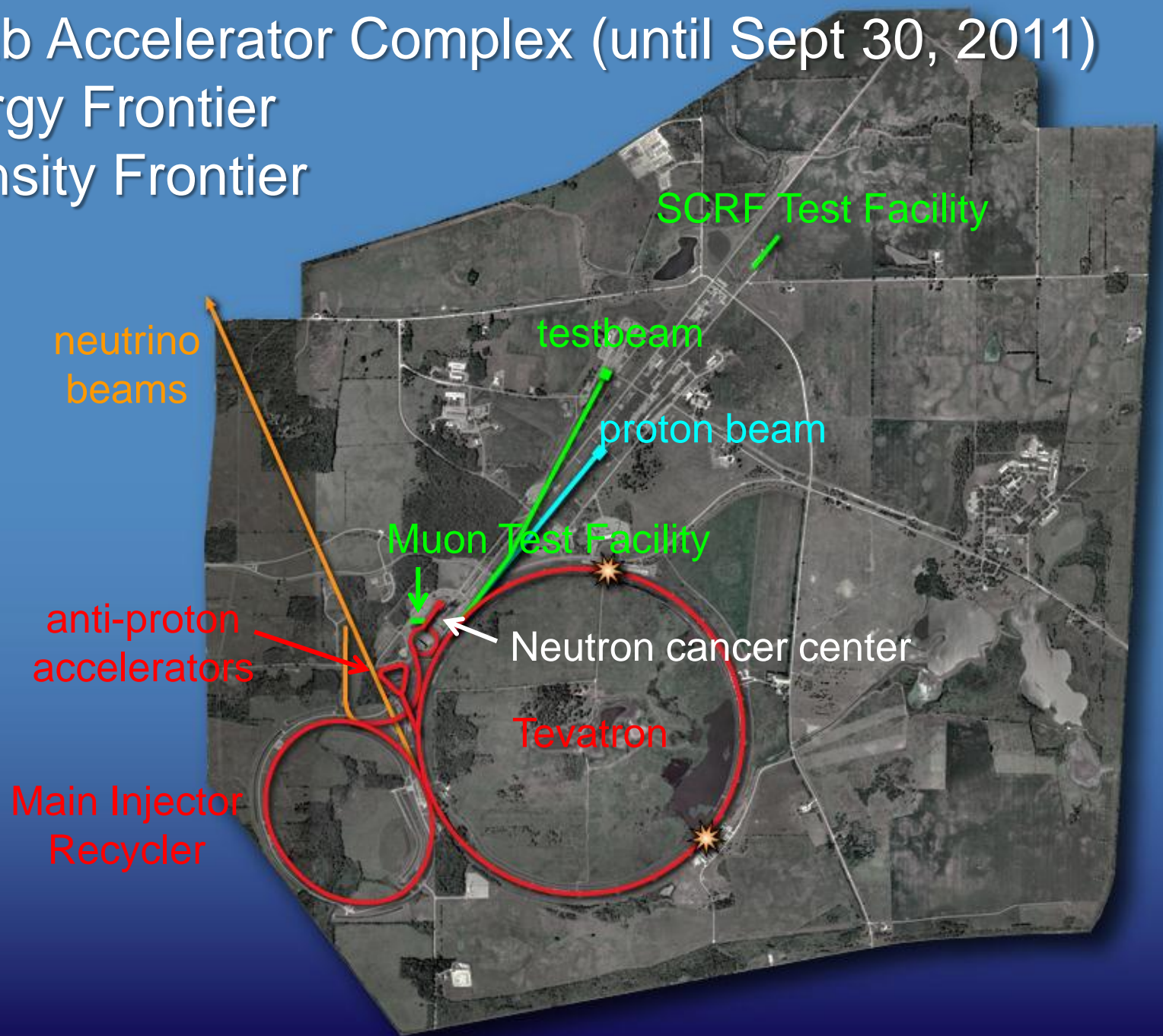
570-Megapixel digital camera

Detectors in underground facilities

Exploring Highest Cosmic Ray Particles  
Exploring Quantum Space-time

# Fermilab Accelerator Complex (until Sept 30, 2011)

- Energy Frontier
- Intensity Frontier



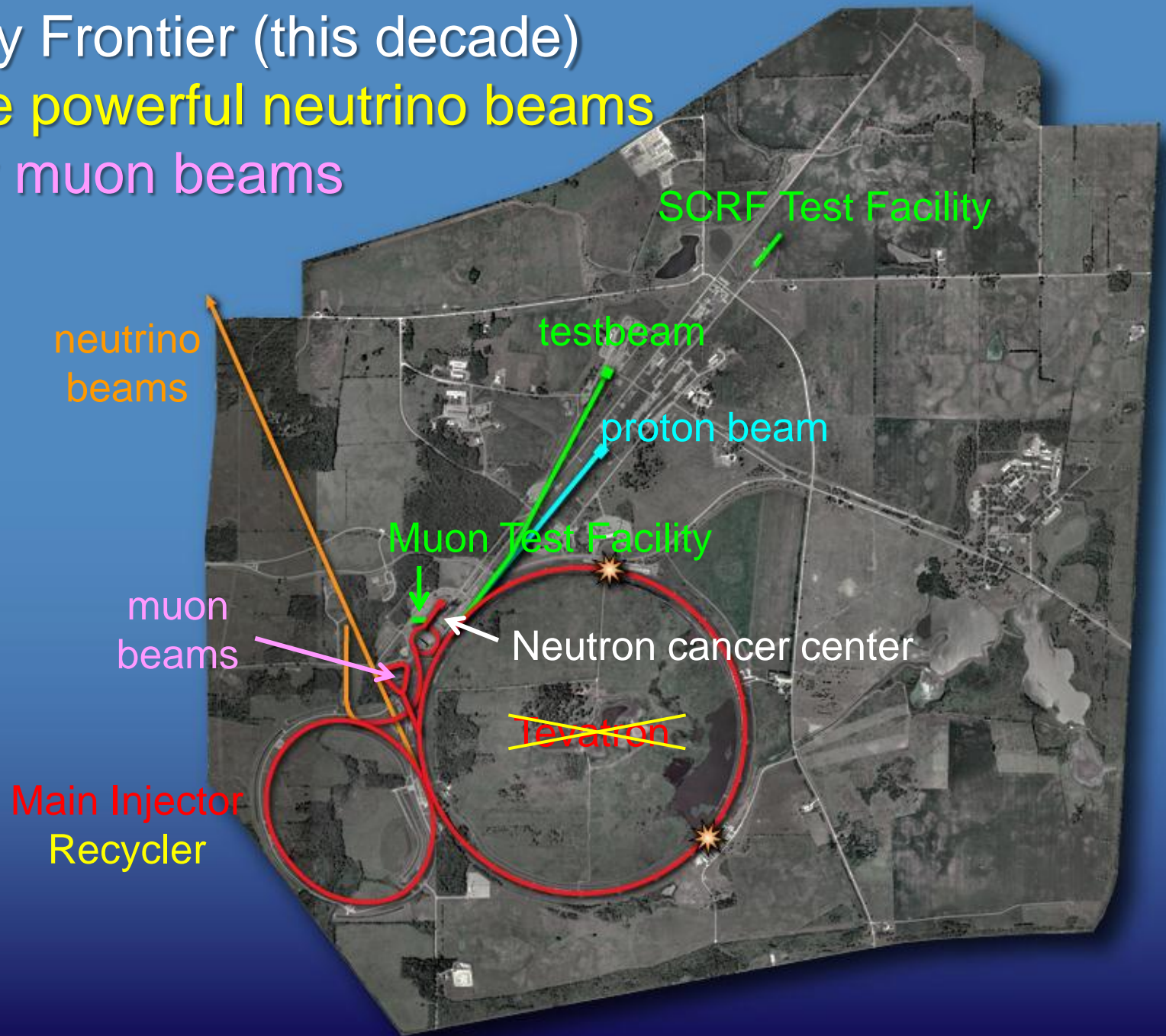
# Energy Frontier: Fermilab and LHC





# Intensity Frontier (this decade)

- More powerful neutrino beams
- New muon beams





# Intensity Frontier probes

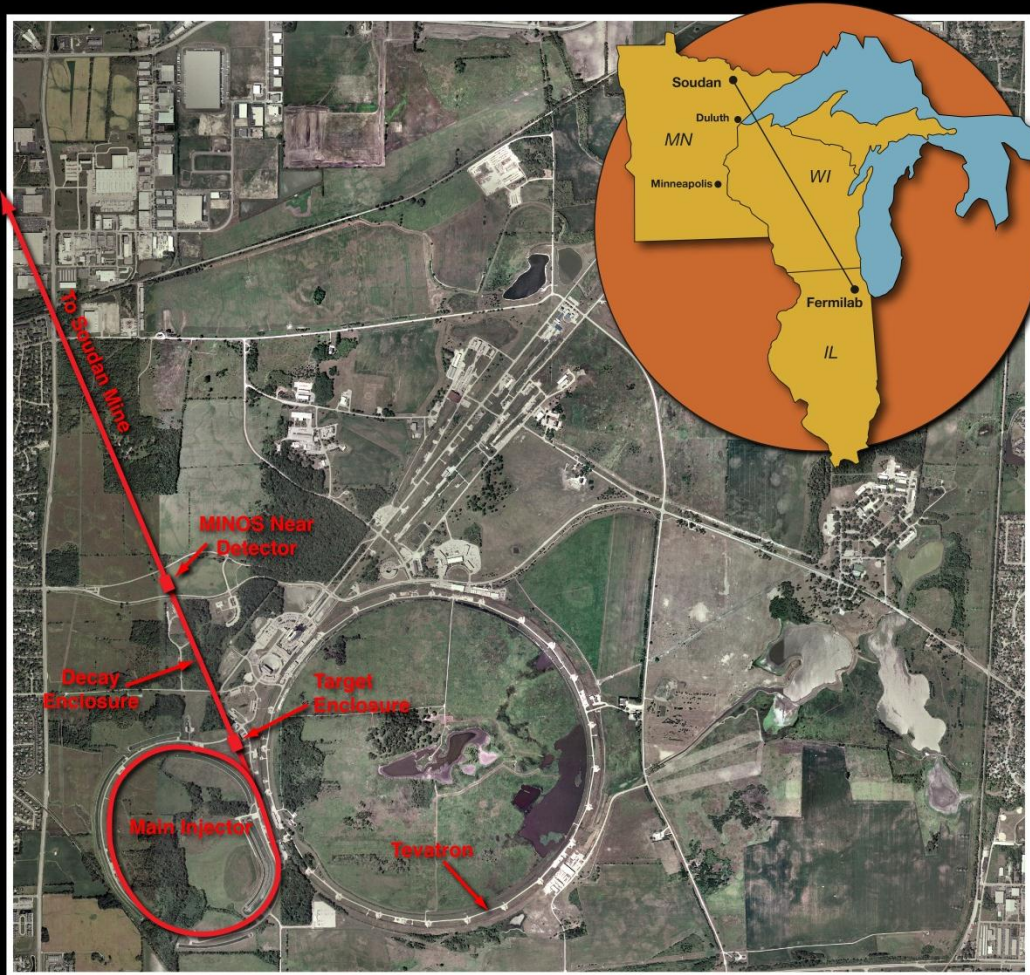
- Origin of mass?
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- .....

**Evolved Thinker**





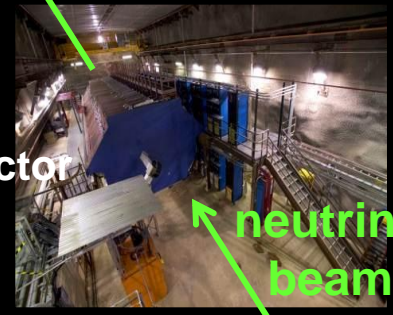
# Intensity Frontier: Neutrino Experiments (now)



**MINOS (Soudan Mine)**



**MINOS detector  
at Fermilab**

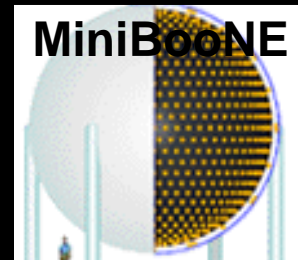


**neutrino  
beam**



**MINERvA**

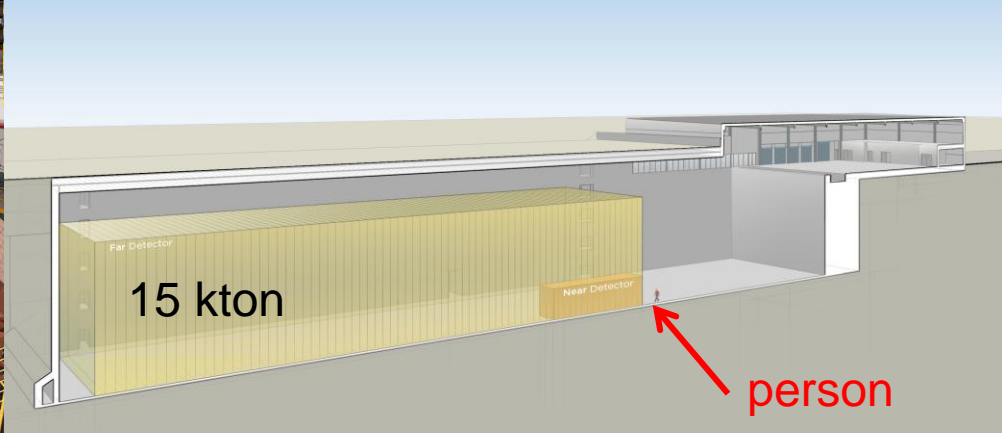
**MiniBooNE**



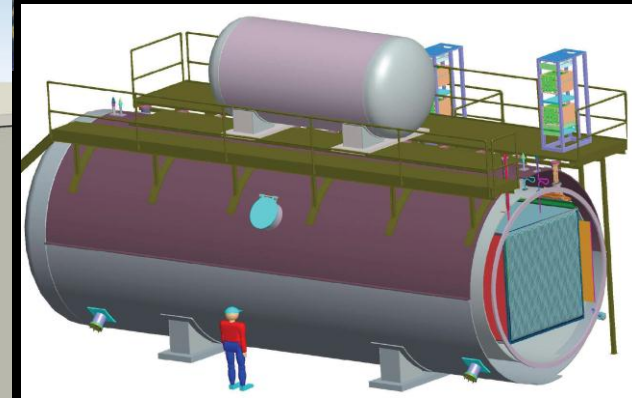


# Intensity Frontier (this decade) new generation neutrino detectors

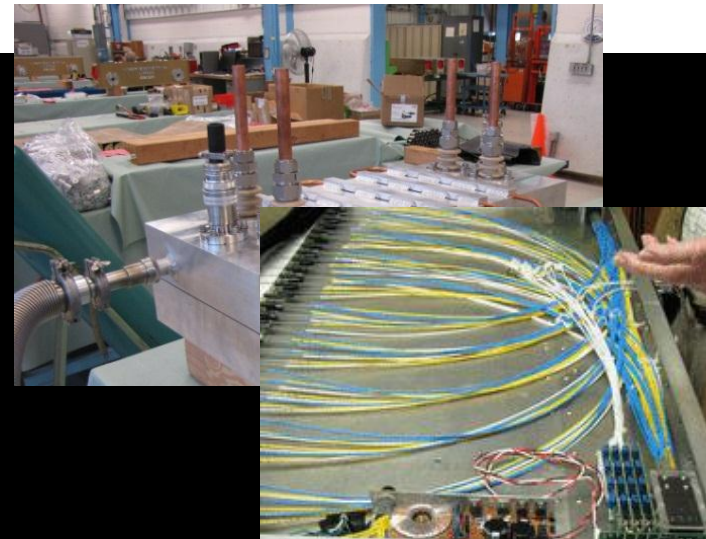
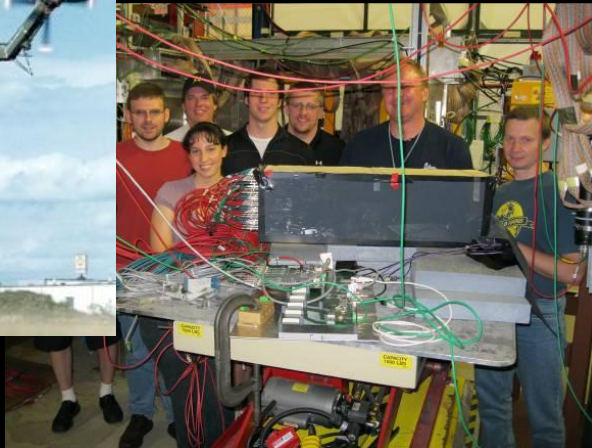
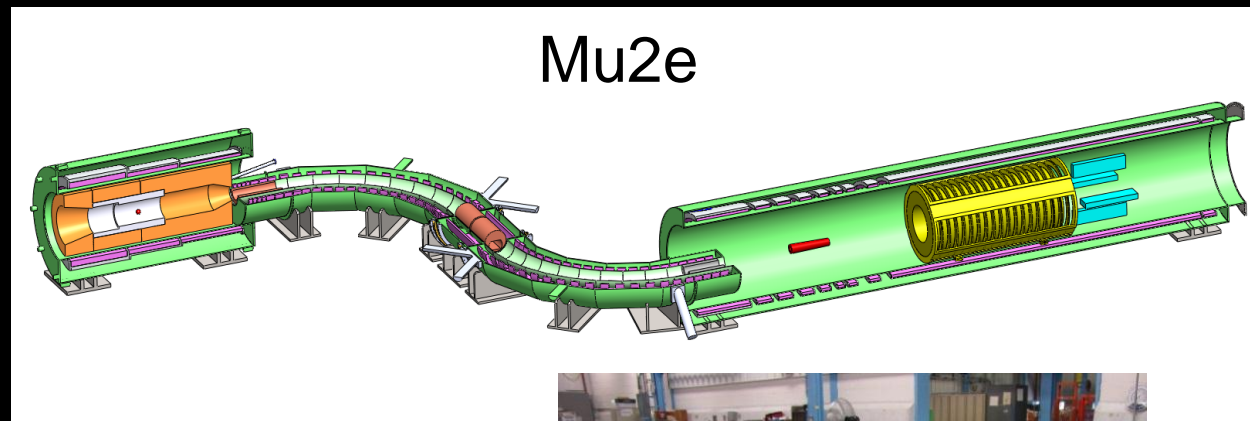
NOvA under construction  
Minnesota site & Fermilab site



MicroBooNE  
under construction  
Fermilab site



# Intensity Frontier (this decade) new muon experiments at Fermilab



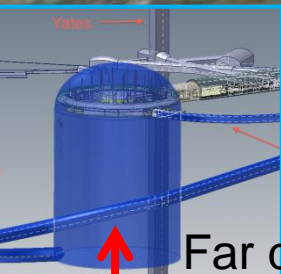
# Intensity Frontier: Developing programs for 2020s and beyond

**LBNE**  
(Long Baseline Neutrino Experiment)

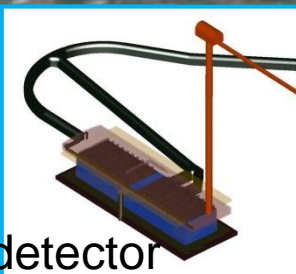
**Project X**



# Long Baseline Neutrino Experiment



Far detector

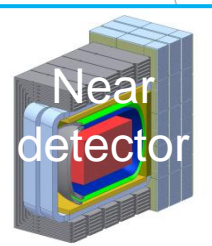
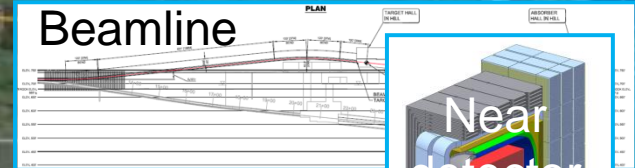


NOvA  
MINOS

1300 km  
808 miles

735 km  
450 miles

Beamline



Near detector

Collaboration: 318 members  
58 institutions (6 US labs) and 5 countries (India, Italy, Japan, UK, US)  
Continues to grow!





**Soul Mate**

Lead, SD

South Dakota

Minnesota

Ontario

Wisconsin

Michigan

Milwaukee

Iowa

Nebraska

Kansas

Image NASA

© 2008 Tele Atlas

Image © 2008 TerraMetrics

© 2008 Europa Technologies

Google

Pointer 43°03'56.44" N 95°10'42.53" W Streaming 100%

Eye alt 1108.62 km



# Project X

will be the world's most powerful proton source

will make the world's most powerful beams of neutrinos, muons, kaons and nuclei to explore new physics in unprecedented breadth and depth



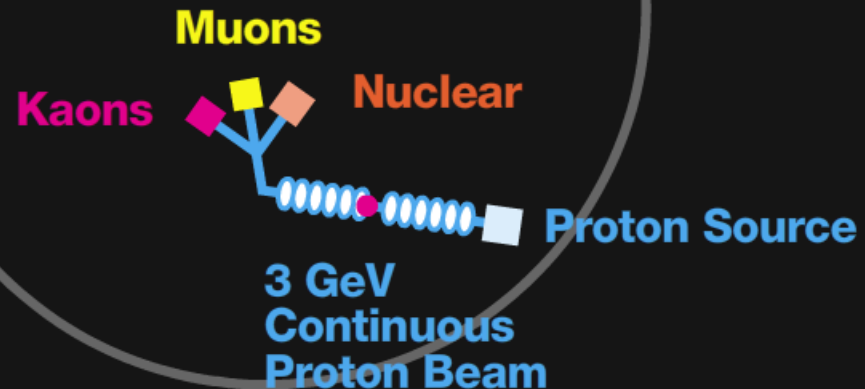
will establish a versatile technical foundation for future accelerators



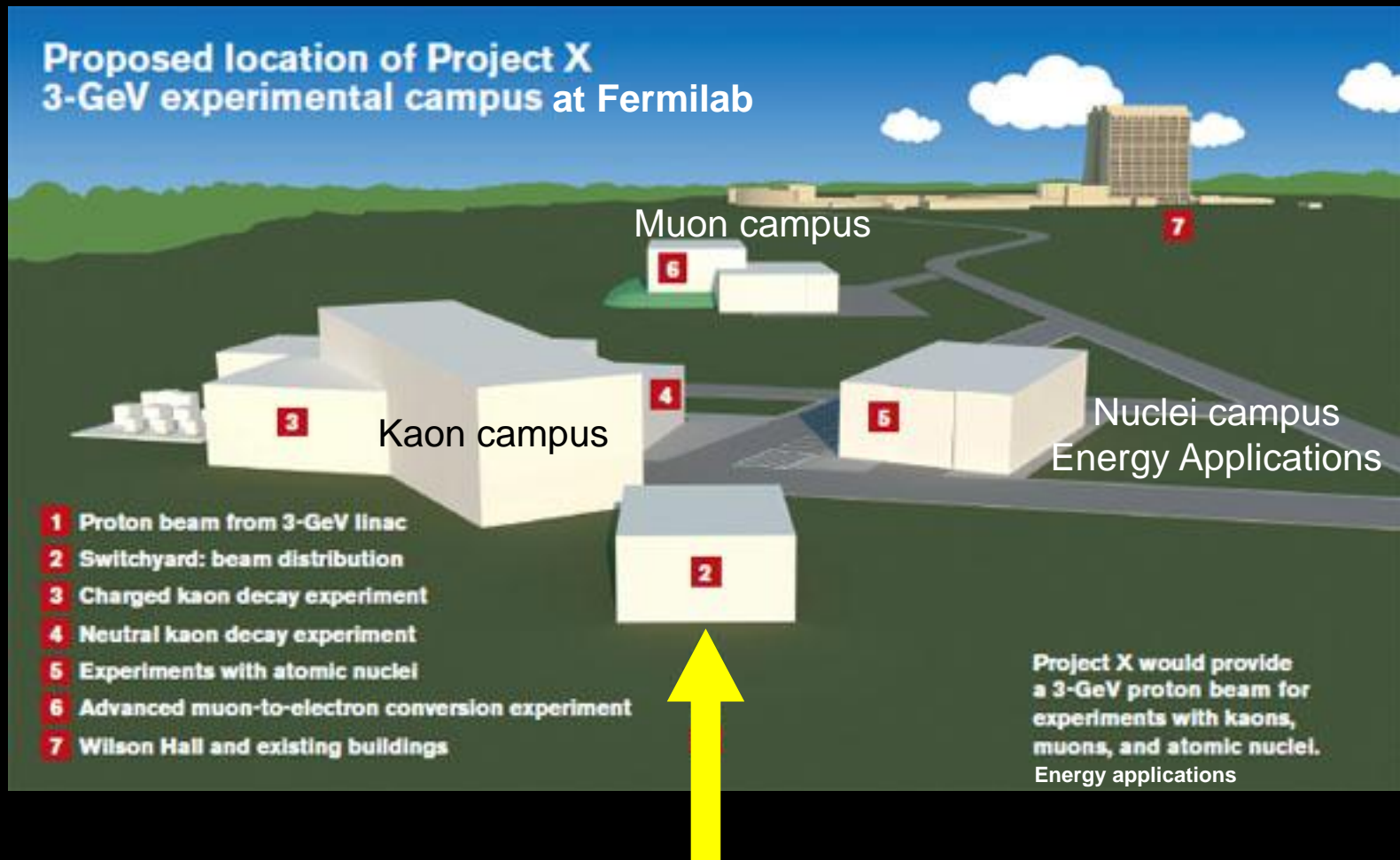
# Project X: Low-energy Program

Highest-intensity proton accelerator in the world

## Proposed Experimental Areas



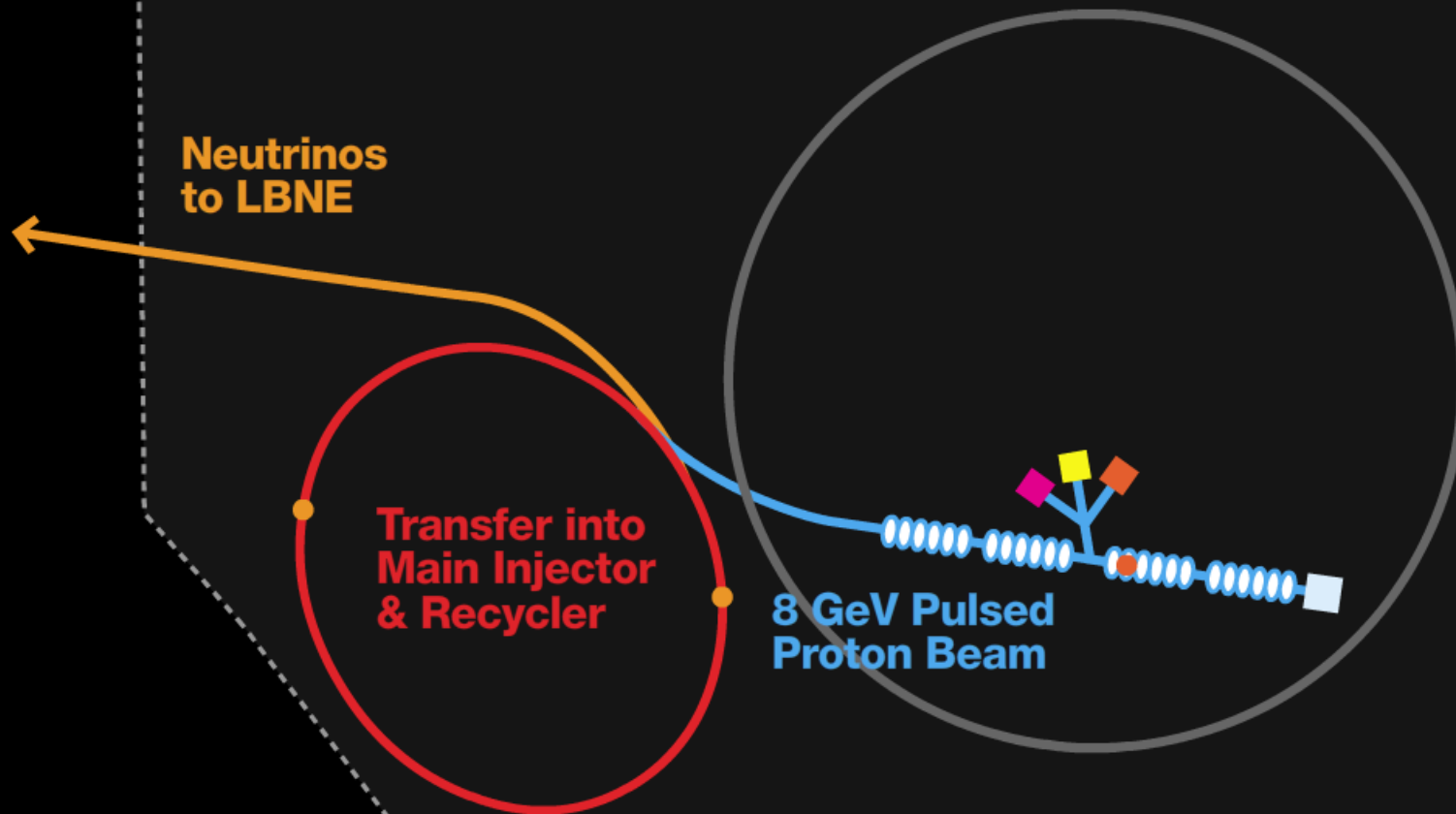
## Proposed location of Project X 3-GeV experimental campus at Fermilab



3 GeV, 3 MW Proton beam

# Project X: High-energy Program

More beam for high-intensity neutrino experiments





# Vision of Fermilab

- Fermilab is going after the most exciting questions in particle physics, the most interesting questions about the nature and future of our universe.
- Fermilab continues to operate most of its existing accelerators with enhanced capabilities and next generation experiments (2010s)
- Fermilab will build new accelerators and experiments for the future (2020s and beyond)

The Great Plains were once a frontier  
for the expanding United States.



It is now a frontier  
for expanding our knowledge of the universe.