Hunting for the Stuff of Stuff

Jerry Gilfoyle

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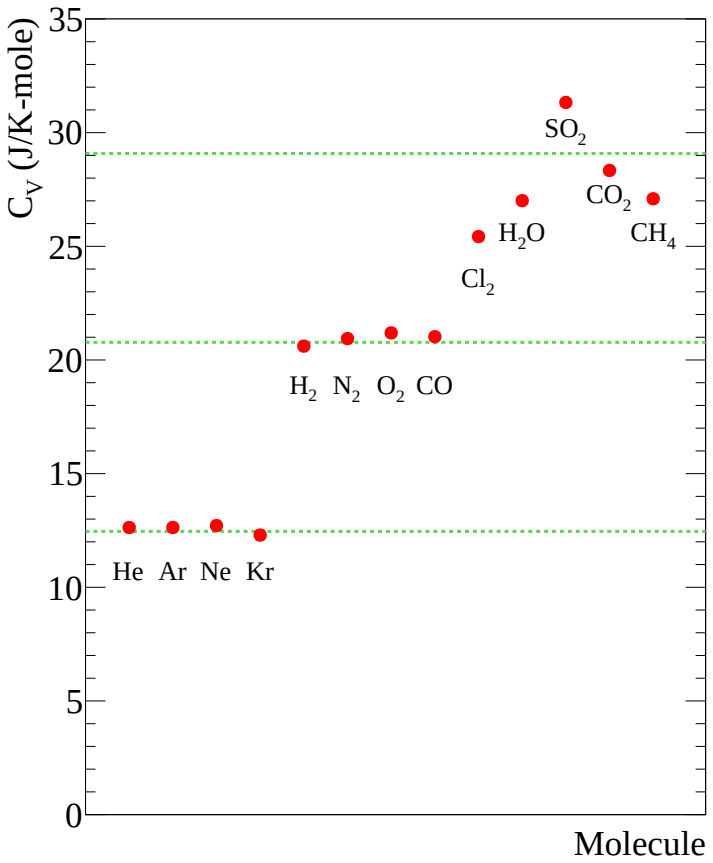
"The Periodic Table"

- How Do We Know Atoms and Other Subatomic Particles Exist?
- How (and What) Do We Learn at Jefferson Lab?
- How (and What) Do We Learn at the LHC?
- Why Should You Care?

Liquid Nitrogen and Balloons

- More than a century ago it was not yet known if atoms and molecules were real physical objects.
- Ludwig Boltzmann developed the kinetic theory of gases.
- Accurately described the thermal properties of gases (for some molecules).



$$\frac{7}{2}R = \frac{7}{2}N_A k_B$$

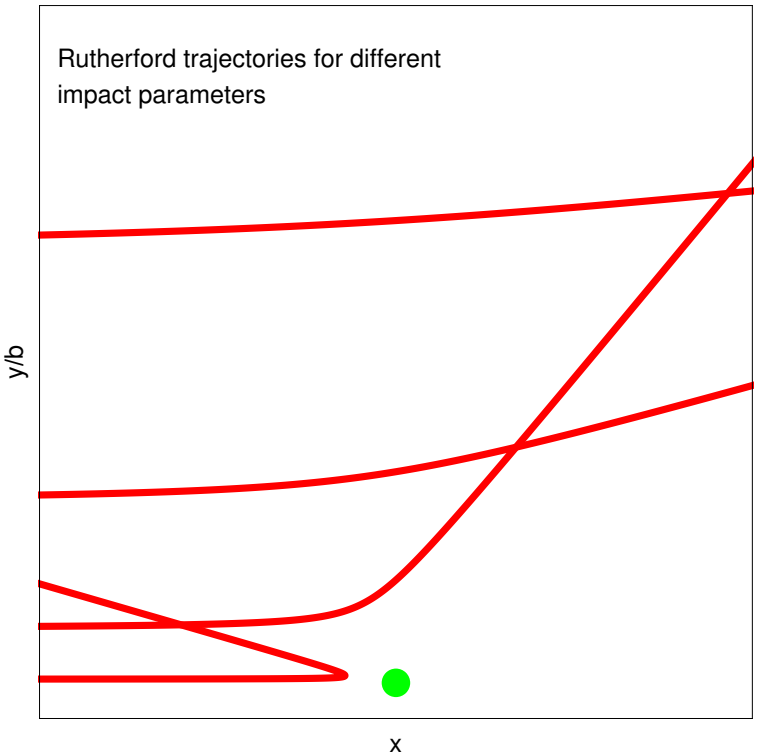
$$\frac{5}{2}R = \frac{5}{2}N_A k_B$$

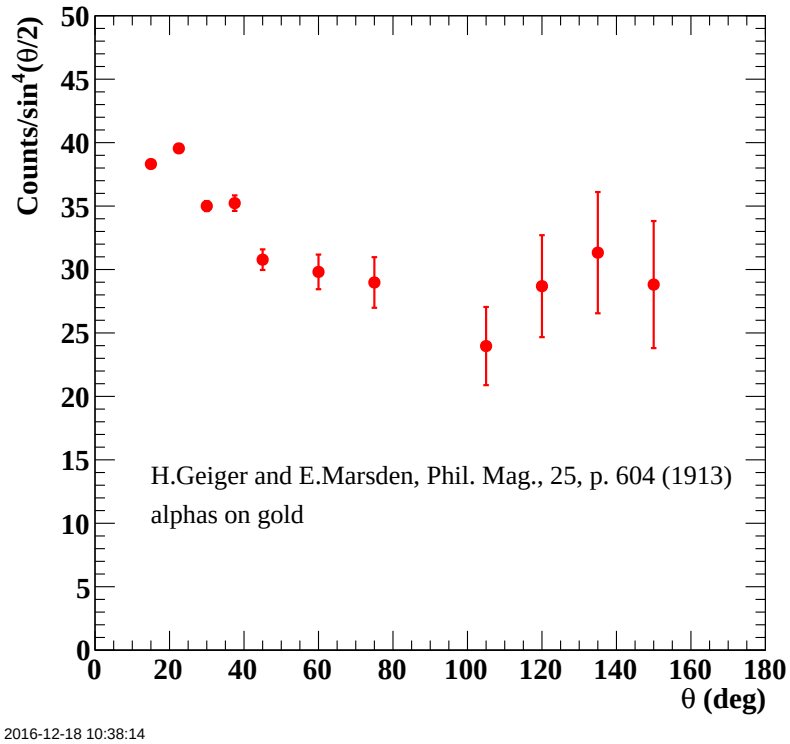
$$\frac{3}{2}R = \frac{3}{2}N_A k_B$$

Atoms are $\approx 10^{-10}$ m across.

Then We Found the Insides of the Atoms

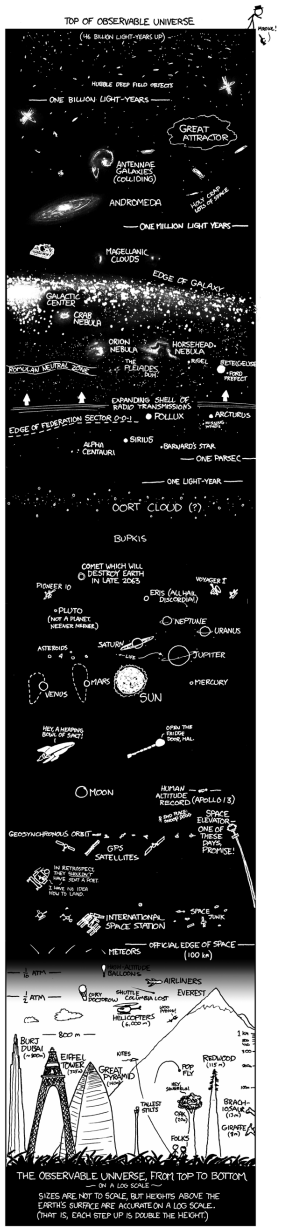
- In 1914 Rutherford discovers the core of the atom.
- The nucleus is 100,000 times smaller than the atom.



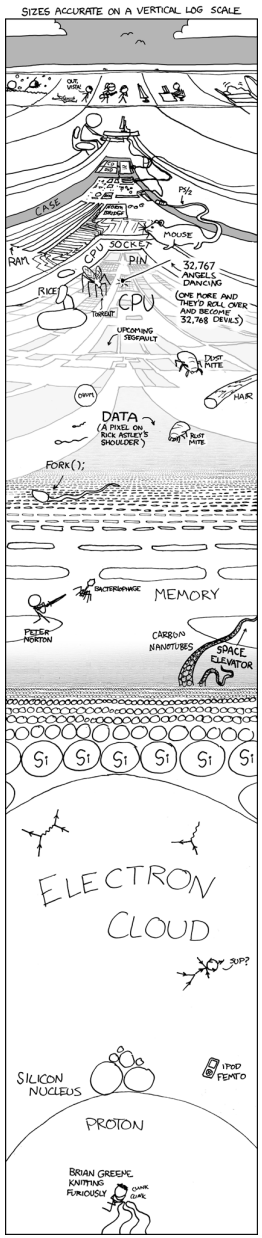


- Rutherford establishes scattering experiments as a crucial technique to illuminate the interior of atom and nuclei.

The Sizes of Things



Height



Depth

Our understanding of nature now extends from the edge of the visible universe 13.7 light-years away ($\approx 10^{25}$ m) down to 10^{-17} m at Jefferson Lab and 10^{-19} m at the LHC.

We're about as far away from the edge of the visible universe as we are from the insides of the nucleus.

What Do We Know About the Structure of Matter?

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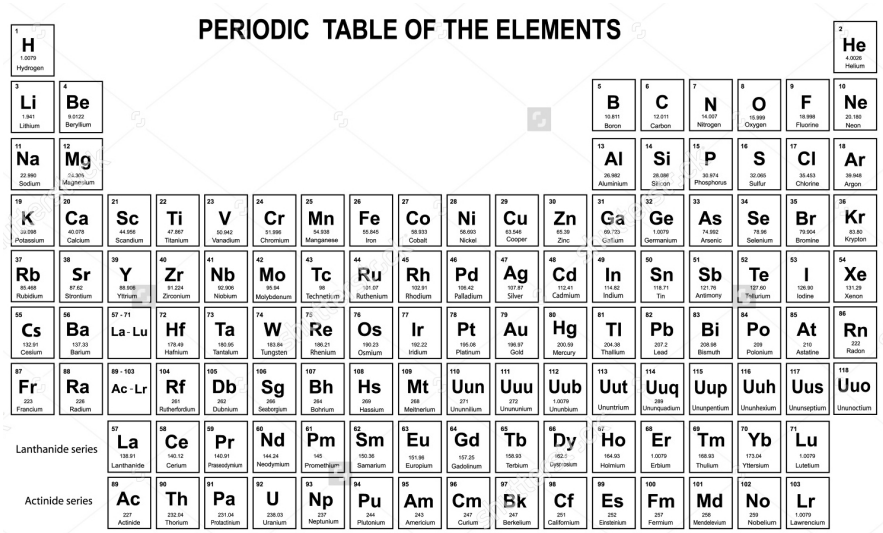
  $\rightarrow$ Table of Elements (TOE)



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- The current TOE!
  $\rightarrow$ quarks and leptons.

FERMIONS matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin =1/2

Flavor	Mass GeV/c^2	Electric charge
ν_L lightest neutrino*	$(0-2)\times10^{-9}$	0
e electron	0.000511	–1
ν_M middle neutrino*	$(0.009-2)\times10^{-9}$	0
μ muon	0.106	–1
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τ tau	1.777	–1

Quarks spin =1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.002	2/3
d down	0.005	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	173	2/3
b bottom	4.2	–1/3

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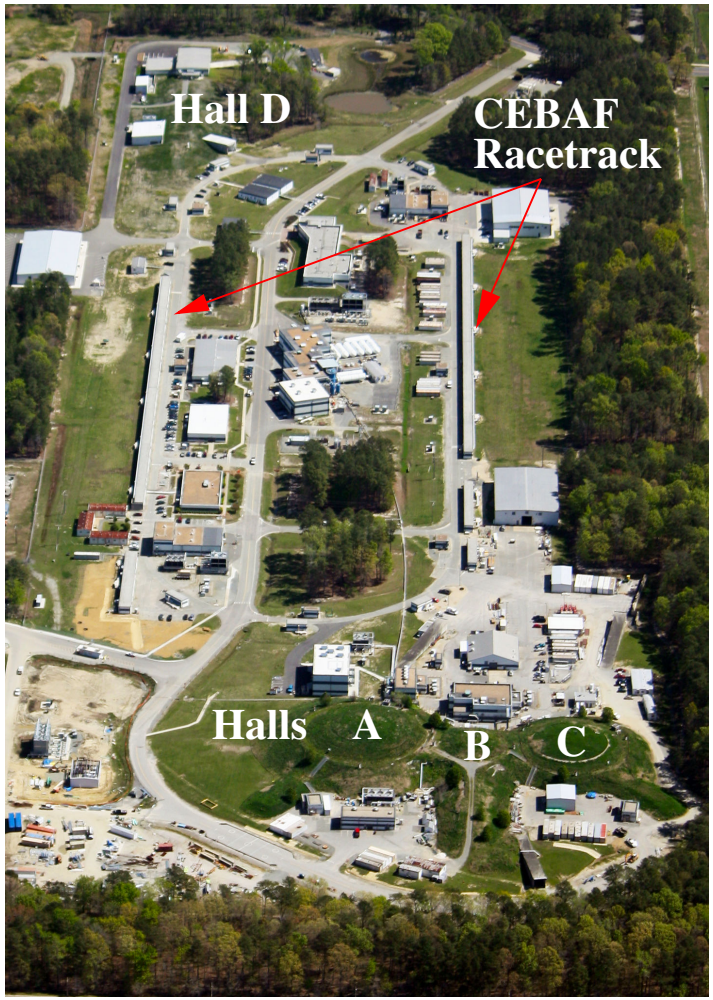
- Worldwide effort to unravel QCD in nuclei.

How Do We Turn on the Lights Inside a Nucleus?

- Build the newest US national lab Jefferson Lab (JLab) in Newport News, VA
- The accelerator CEBAF is a mile-long, racetrack-shaped, superconducting linear accelerator.
- Rapidly varying electric fields push electrons to 12 GeV.
- Electron beam distributed to four halls and strike stationary targets.
- It's a big electron microscope to image quarks and gluons inside nuclei.
- Unique combination of precision beams and sophisticated targets.



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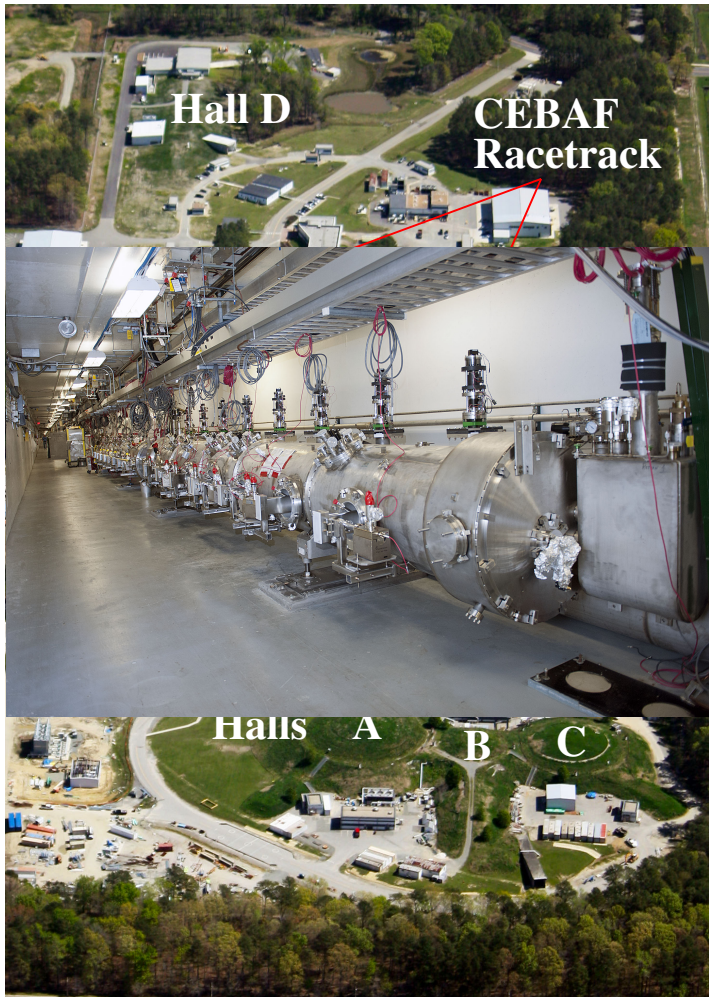

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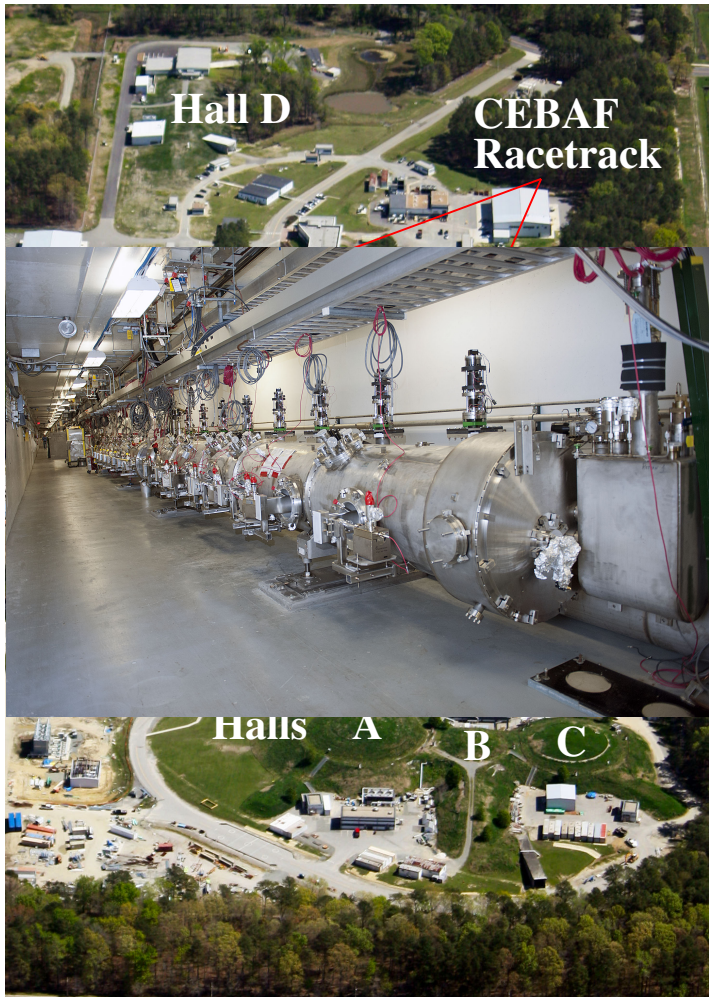
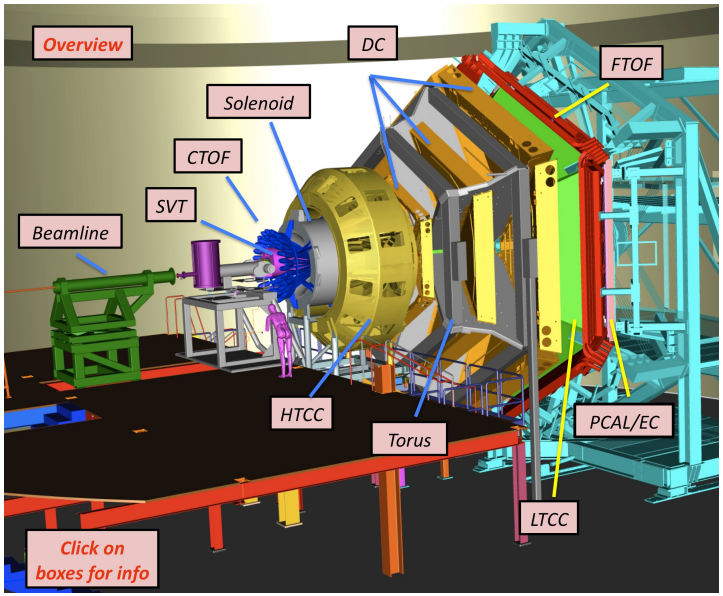
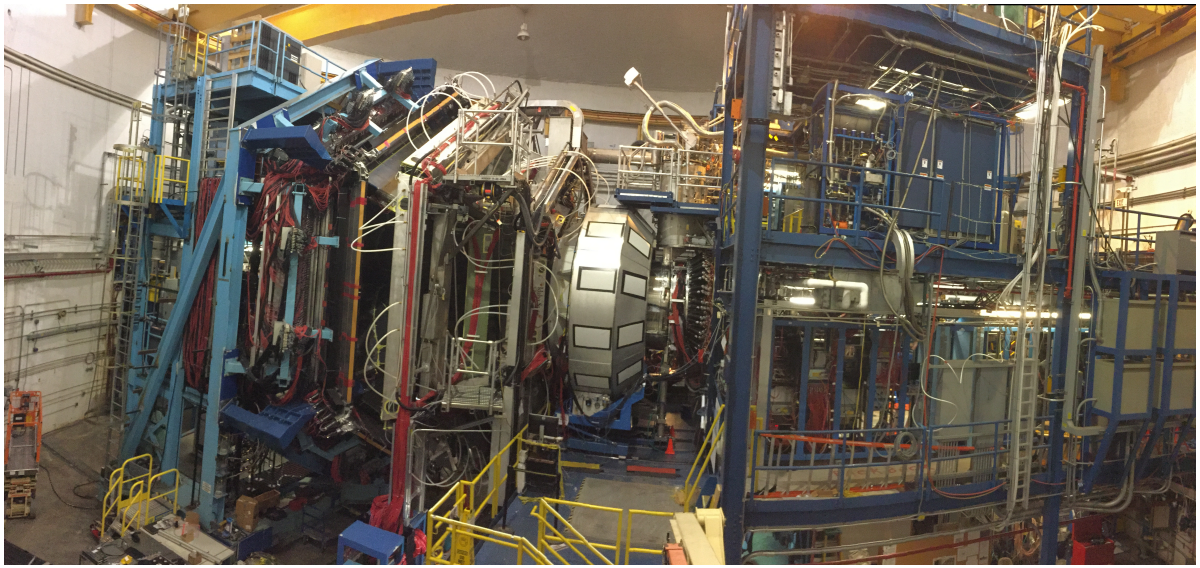
It's a QCD laboratory!



How Do We See Quarks?

- Build a large (3-story, 45-ton) particle detector called CLAS12 in Hall B.
- Many layers measure the debris from electron-target collisions.
- Over 100,000 readouts in $\approx$ 40 layers.
- Large magnet bends charged particles to measure 4-momenta of the debris.
- Will write 5-10 TByte to disk each day.





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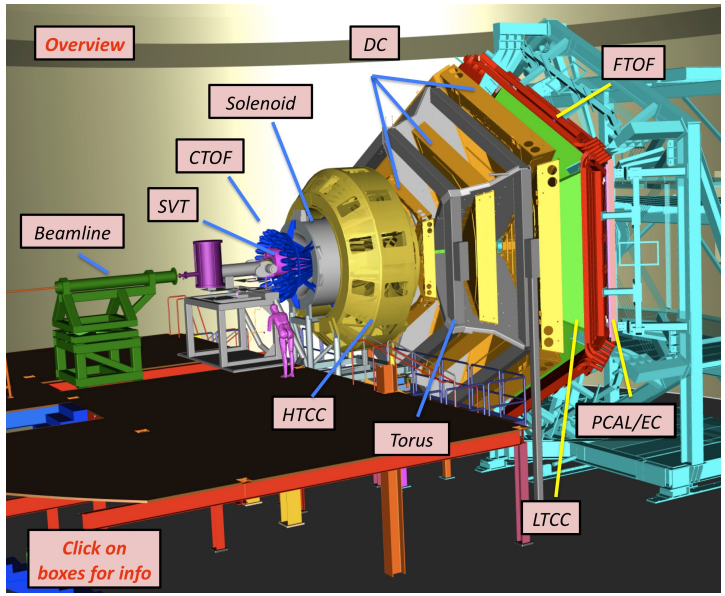
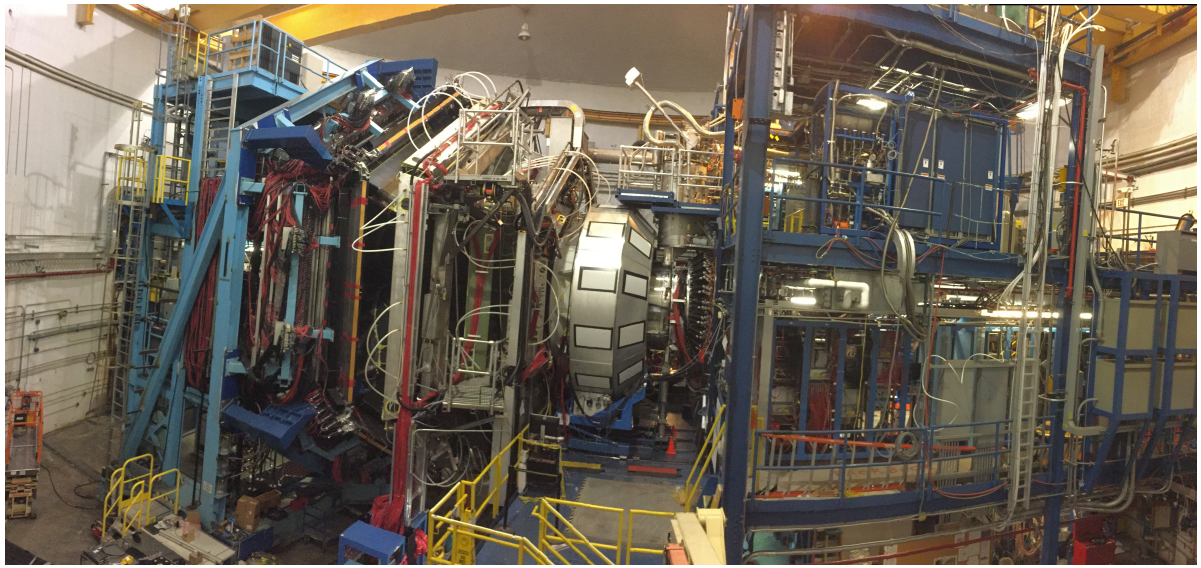


First production data spring, 2018!



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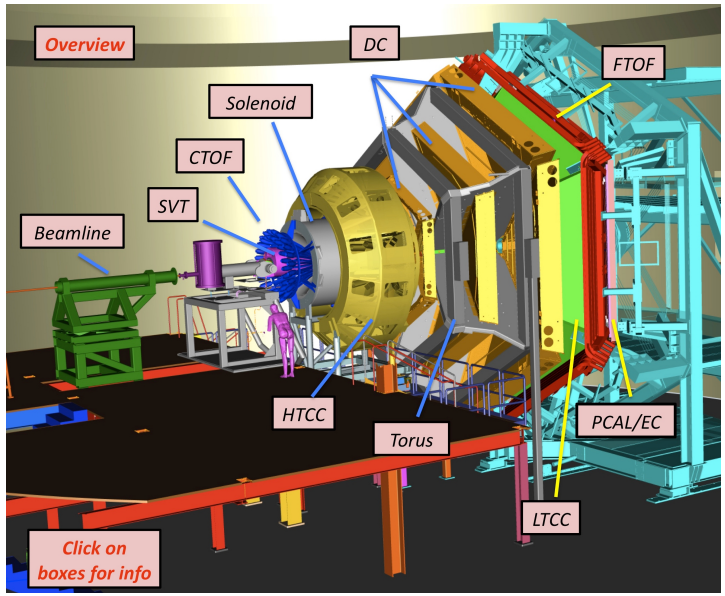

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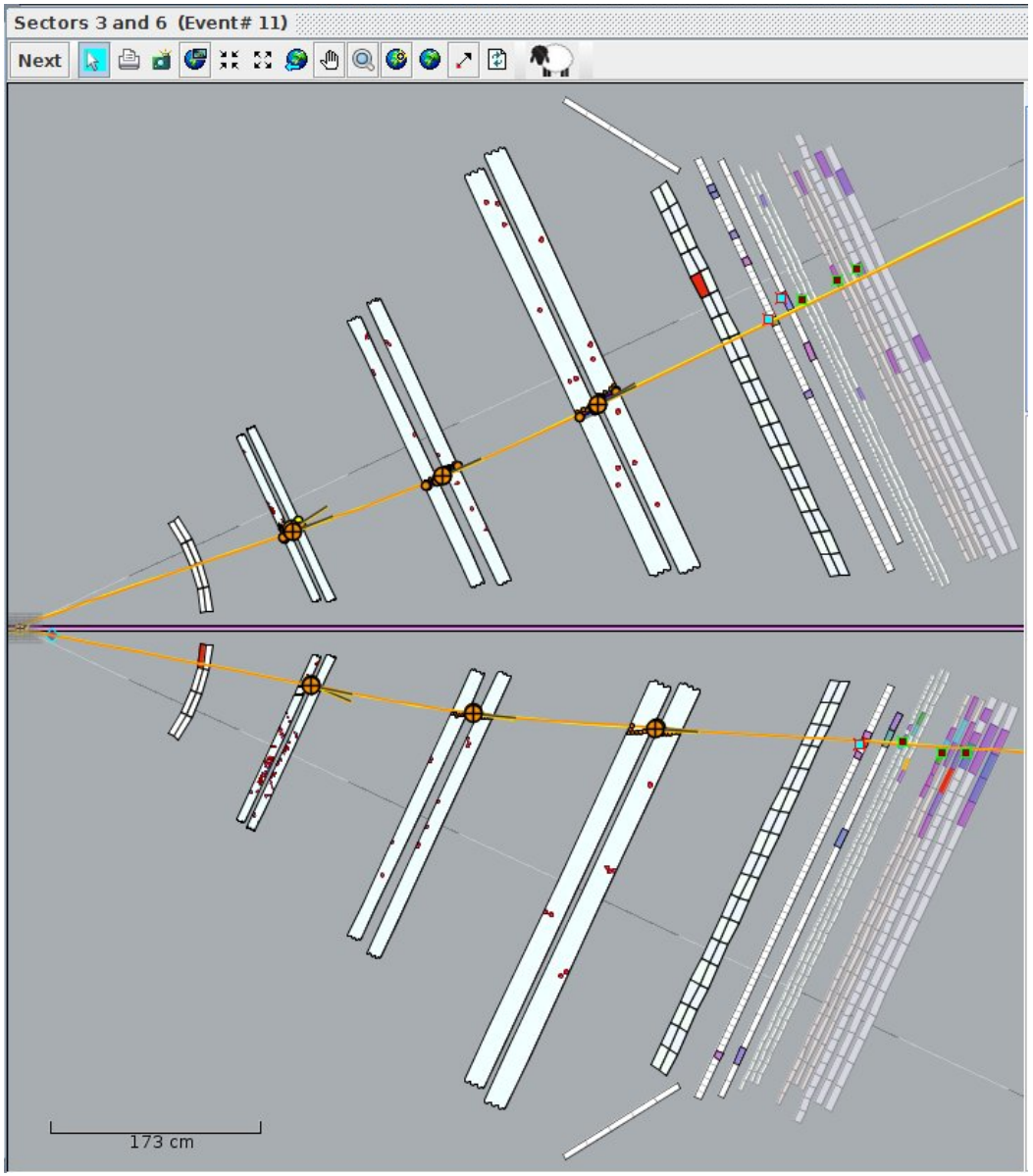
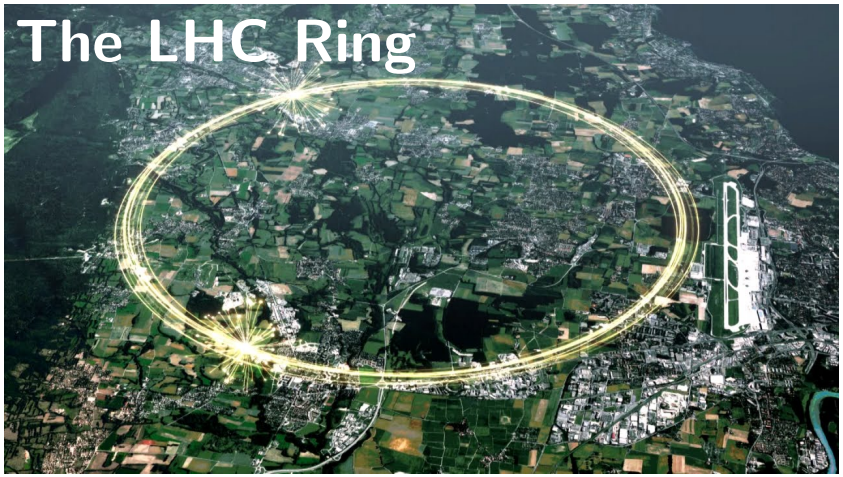
What Do They Look Like?



Event display of a CLAS12 collision $ep \rightarrow e'\pi^+$. The particle tracks bend in the toroidal magnetic field and leave a trail of electronic signals behind.

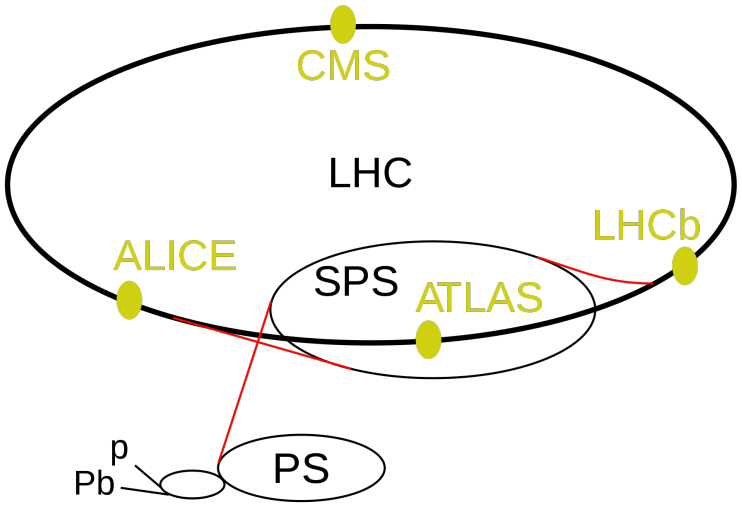
What Is Beyond the Standard Model?

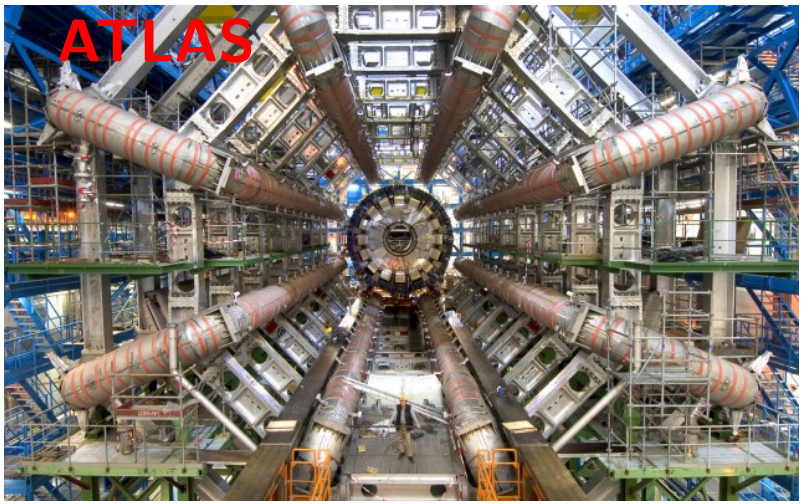
- The Standard Model describes two of the three fundamental forces (electromagnetic weak and strong interactions, but not gravity).
- Developed in the second half of the 20th century it is the most successful scientific theory ever.
- The discovery of the Higgs boson is made in 2012.
- 2013 Nobel for Higgs and Englert.
- Evidence is accumulating pointing to new physics that does NOT fit into the theory.



Neutrino Mass
Gravitons
New Particles
Dark Matter
Extra Dimensions
SUSY
Matter/Anti–Matter
Dark Energy
muon magnetic dipole
Neutrino Oscillations

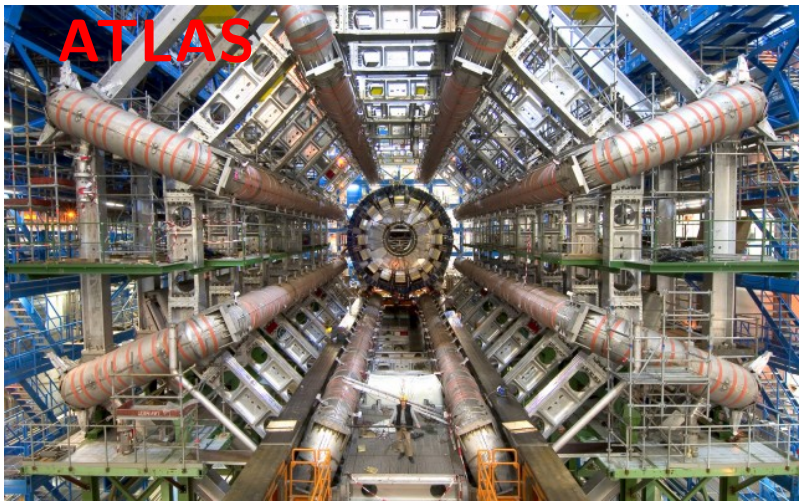
How Do We Look Beyond the Standard Model?





- The LHC is a ring about 16 miles around and buried undergound.
- Two proton beams (and heavier nuclei) circulate in opposite directions at energies of $\approx 7\ \mathrm{TeV}$.
- The beams are made to cross each other and collide creating a spray of debris.
- Large detectors with many layers of gas, plastic, silicon and other materials capture traces of the debris' passage.
- Large computing farms reconstruct the collisions.

How Do We Look Beyond the Standard Model?



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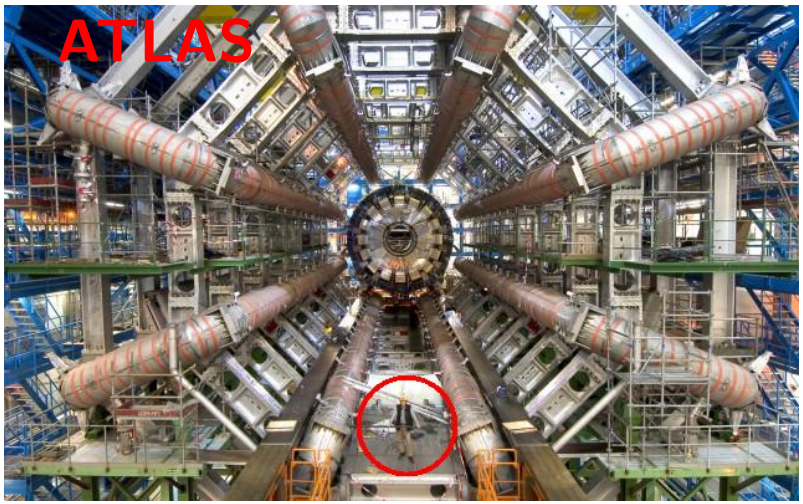

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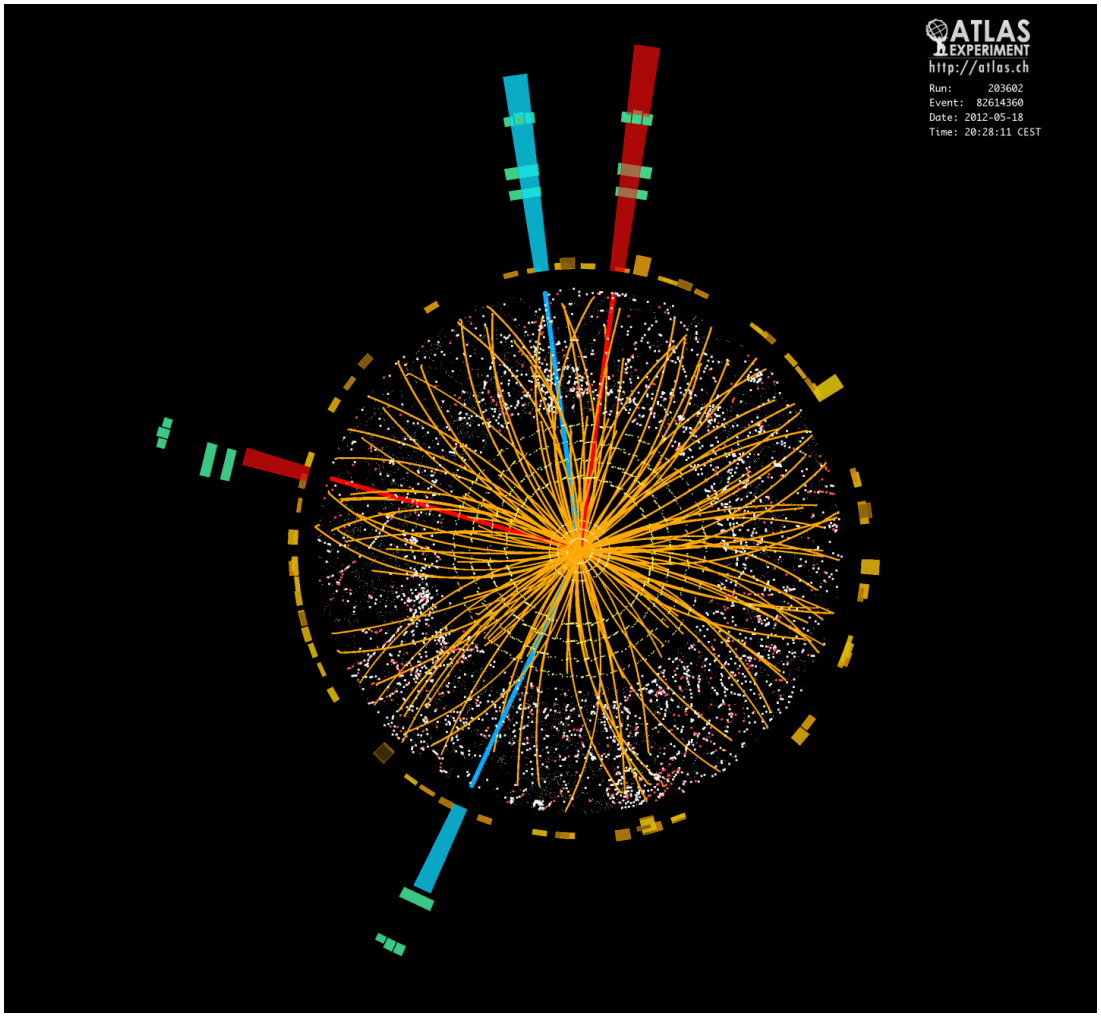
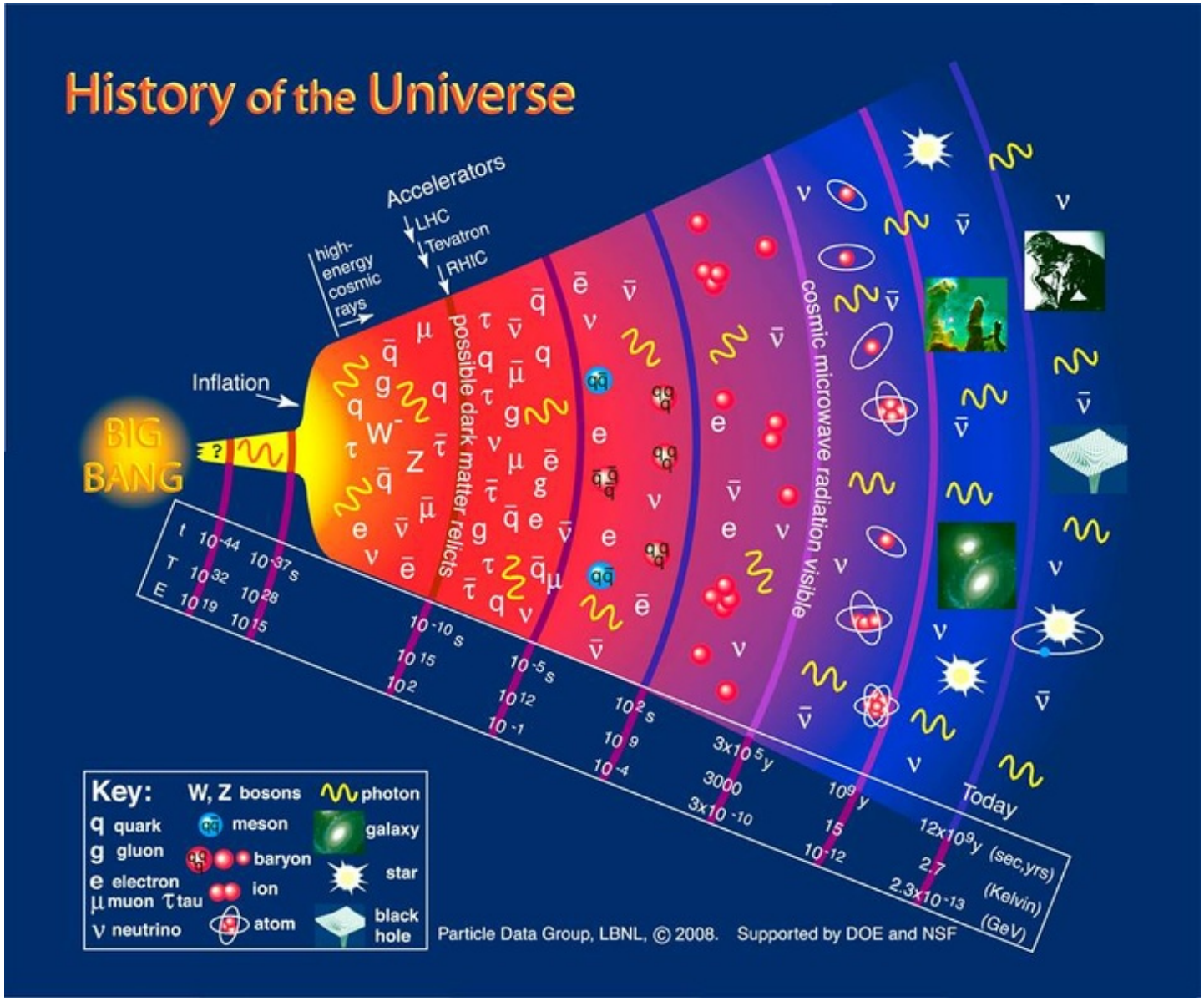
What Do We See?



Event display of a $H \rightarrow 4e$ candidate event with mass 124.5 (124.6) GeV. The tracks and clusters of the two electron pairs are colored red and blue, respectively.

A Connection Between the LHC and Jefferson Lab



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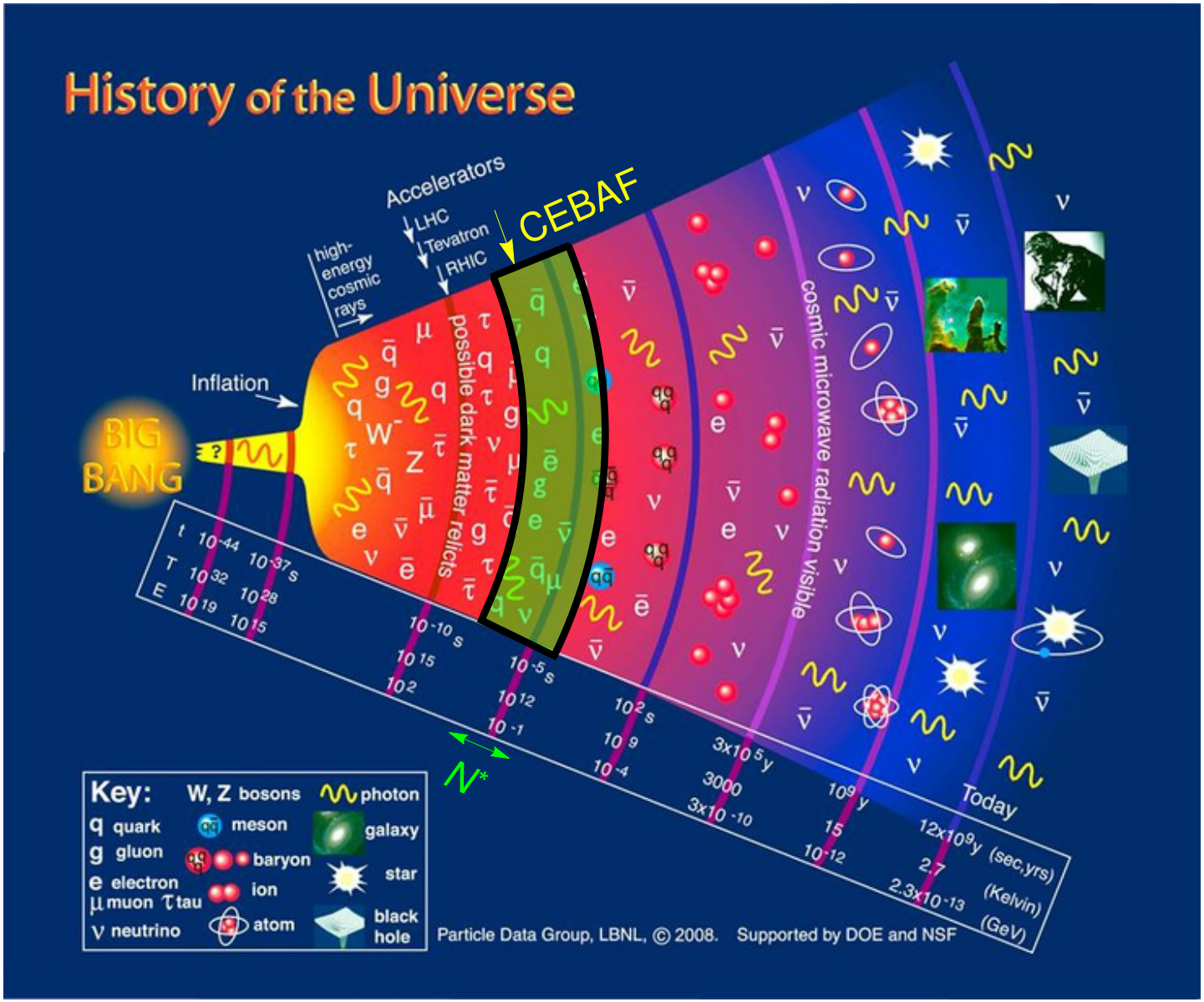

What I would do at the LHC.

- Visit the accelerator control room.
- Go down into the accelerator tunnel.
- Visit the detector counting houses.
- Go down into the detector halls especially any that have been partially dismantled for maintenance.
- Ask lots of questions.
- I hear the food in the cafeteria is good.

Why Should You Pay For It (basic science, that is)?

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1. **Over the last 100 years at least 50% of the growth in our standard of living is due to technological change.**

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Questioner to Franklin:	Sir, what's the use of flying in the air?
Ben Franklin's answer:	Sir, what's the use of a newborn baby?

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