PHYS 3446 – Lecture #1

Monday, Aug. 29, 2006

Dr. Jae Yu

1. Who am I?
2. Class time and location
3. Information and communication sources
4. Class specifications and style
5. Class plans
   - Syllabus
   - Special semester projects
6. Lab
7. Evaluation Policy
8. This class…

Who am I?

- Name: Dr. Jaehoon Yu (You can call me **Dr. Yu**)
- Office: Rm 342, Chemistry and Physics Building
- Extension: x22814, E-mail: *jaehoonyu@uta.edu*
- My profession: High Energy Particle Physics (HEP)
  - Collide particles (protons on anti-protons or electrons on anti-electrons, positrons) at the energies equivalent to 10,000 Trillion degrees
  - To understand
    - Fundamental constituents of matter
    - Forces between the constituents (gravitational, electro-magnetic, weak and strong forces)
    - Origin of Mass
    - Search for Dark Matter and Making of Dark Matter Beams
    - Creation of Universe (**Big Bang** Theory)
  - A pure scientific research activity
    - Direct use of the fundamental laws we find may take longer than we want but
    - Indirect product of research contribute to every day lives; eg. WWW
  - Why do we do with this?
    - Make our everyday lives better to help us live well as an integral part of the universe

We always wonder…

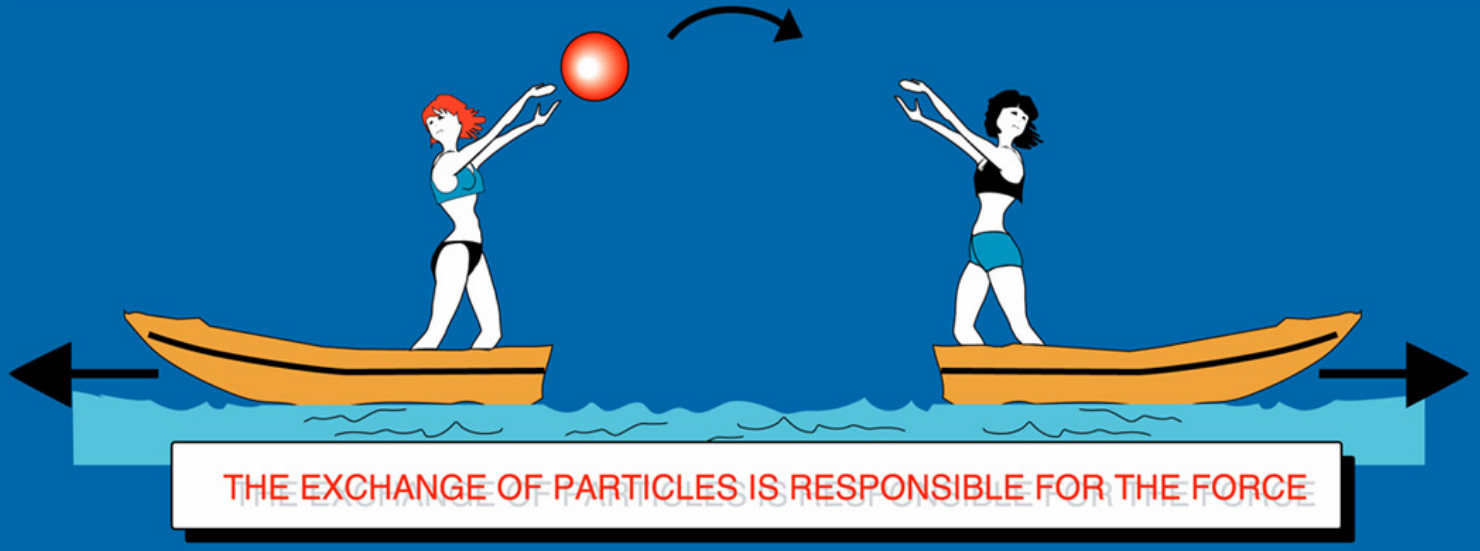
- What makes up the universe?
- How does the universe work?
- What holds the universe together?
- How can we live in the universe well?
- Where do we all come from?

High Energy Physics

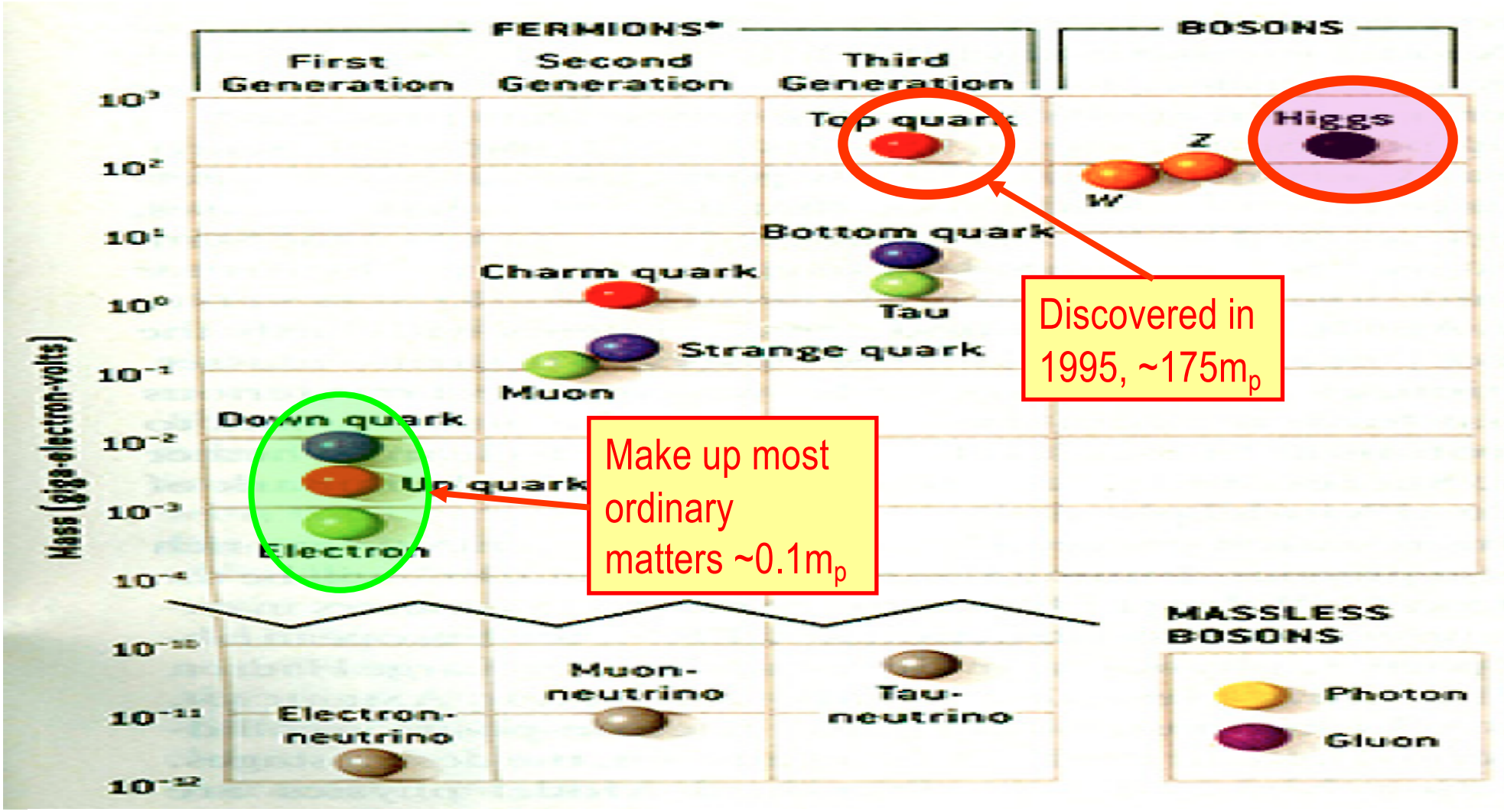
- Definition: A field of physics that pursues understanding the fundamental constituents of matter and basic principles of interactions between them.
- Known interactions (forces):
  - Gravitational Force
  - Electromagnetic Force
  - Weak Nuclear Force
  - Strong Nuclear Force
- Current theory: The Standard Model of Particle Physics

The forces in Nature

TYPE	INTENSITY OF FORCES (DECREASING ORDER)	BINDING PARTICLE (FIELD QUANTUM)	OCCURS IN :
STRONG NUCLEAR FORCE	~ 1	GLUONS (NO MASS)	ATOMIC NUCLEUS
ELECTRO -MAGNETIC FORCE	~ 10^{-3}	PHOTONS (NO MASS)	ATOMIC SHELL ELECTROTECHNIQUE
WEAK NUCLEAR FORCE	~ 10^{-5}	BOSONS Z^{o} , W^{+} , W^{-} (HEAVY)	RADIOACTIVE BETA DESINTEGRATION
GRAVITATION	~ 10^{-38}	GRAVITONS (?)	HEAVENLY BODIES



HEP and the Standard Model

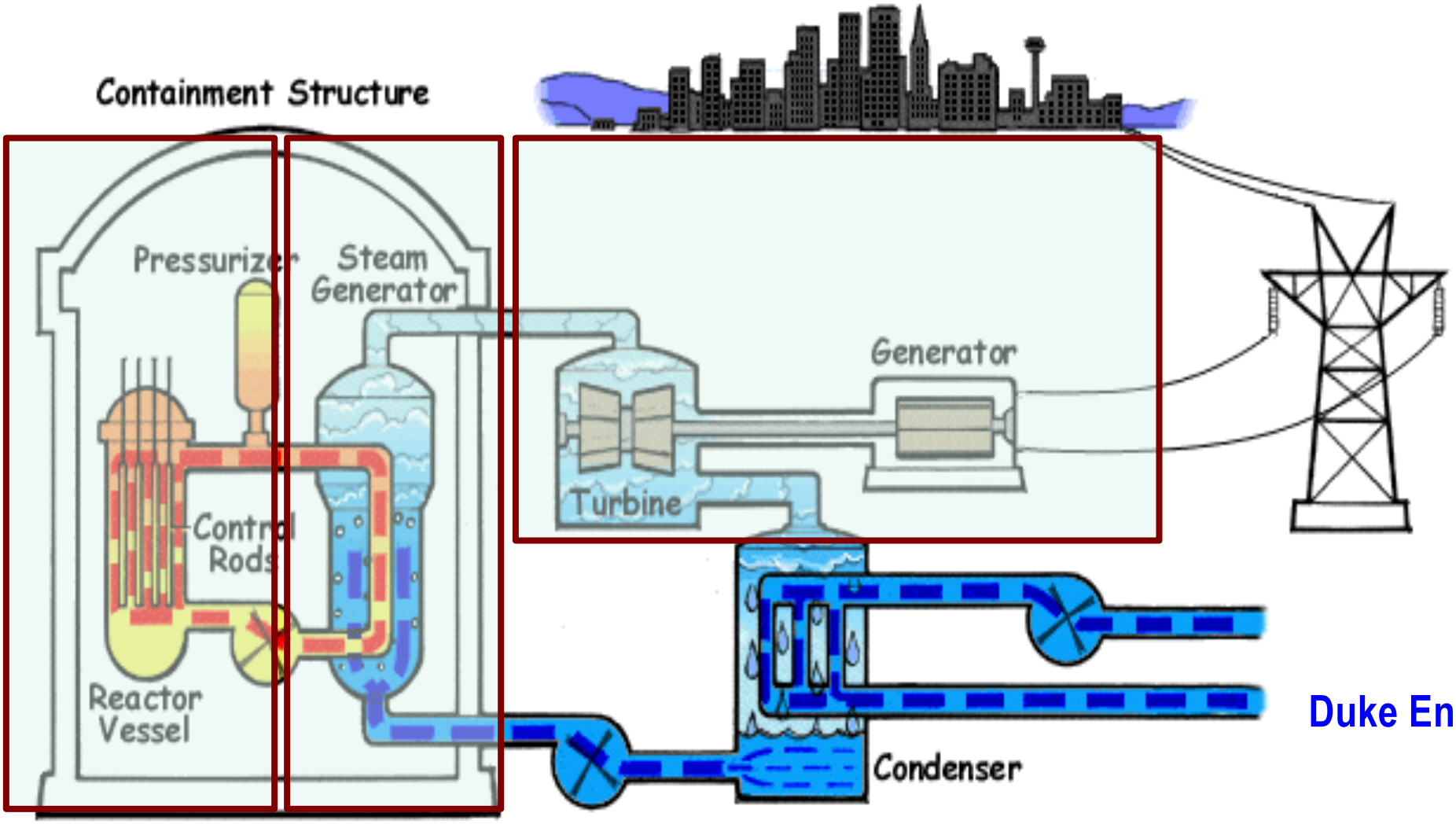


- Total of 16 particles (12+4 force mediators) make up all the visible matter in the universe! ➔ Simple and elegant!!!
- Tested to a precision of 1 part per million!

So what's the problem?

- Why is the mass range so large ($0.1m_p$ – $175\ m_p$)?
- Is the new particle we've discovered really the Higgs particle?
- Why is the matter in the universe made only of particles?
- Neutrinos have mass!! What are the mixing parameters, particle-anti particle asymmetry and mass ordering?
- Why are there only four apparent forces?
  - Were they all unified at the Big Bang?

How does a nuclear power plant work?



Duke Energy

My 1000 year dream: Skip the whole thing!

Make electricity directly from nuclear force!

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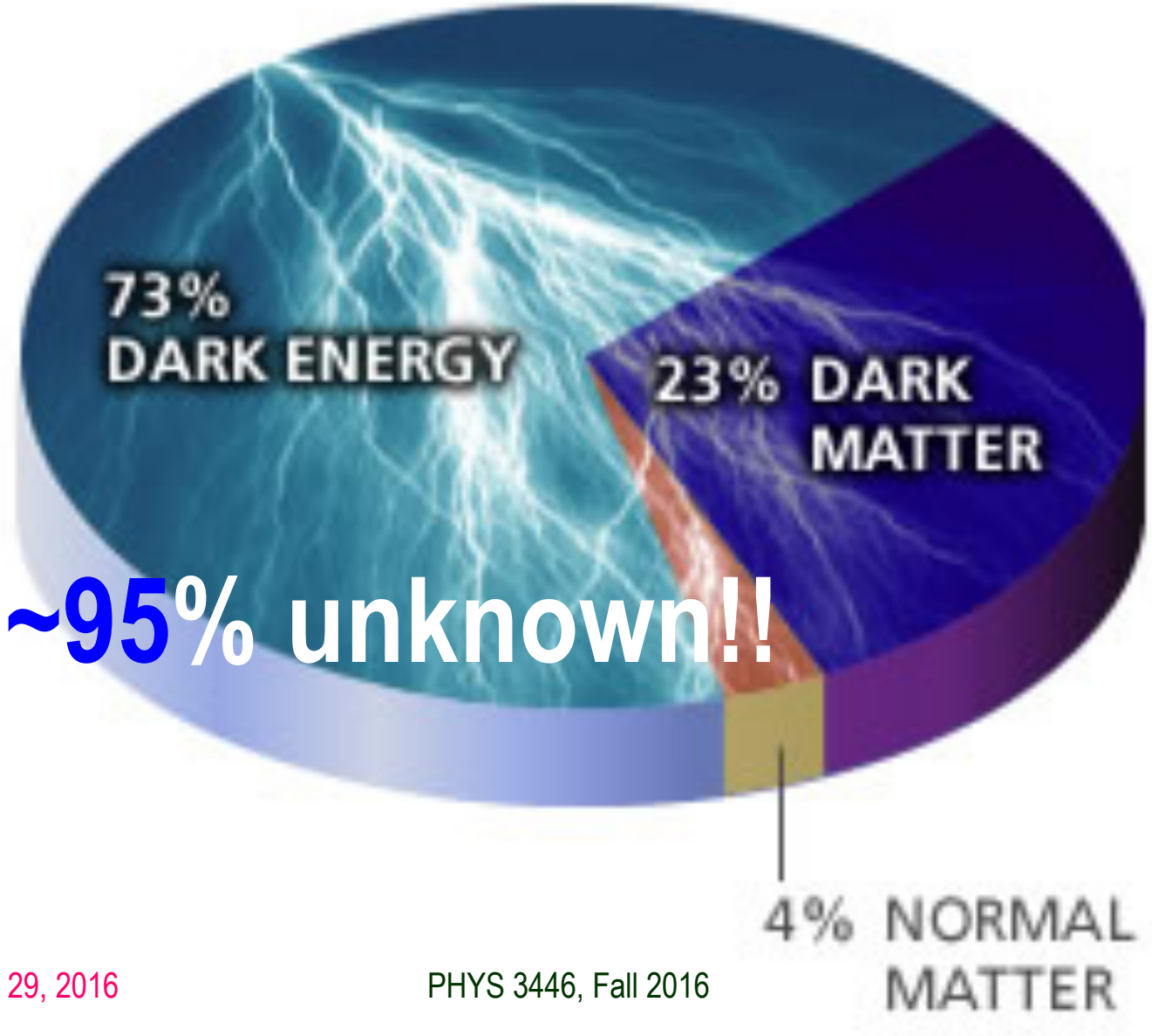
- Is the picture we present the real thing?

What makes up the universe?



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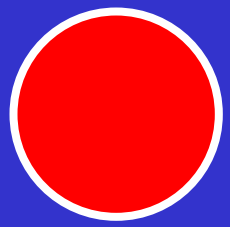
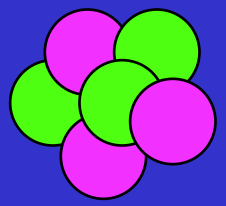
- Why are there only four apparent forces?
  - Were they all unified at the Big Bang?
- Is the picture we present the real thing?
  - What makes up the remaining ~95% of the universe?
- Are there any other particles we don't know of?
  - Big deal for the new LHC Run!
- Where do we all come from?
- How can we live well in the universe as an integral partner?

Accelerators are Powerful Microscopes.

They make high energy particle beams
that allow us to see small things.



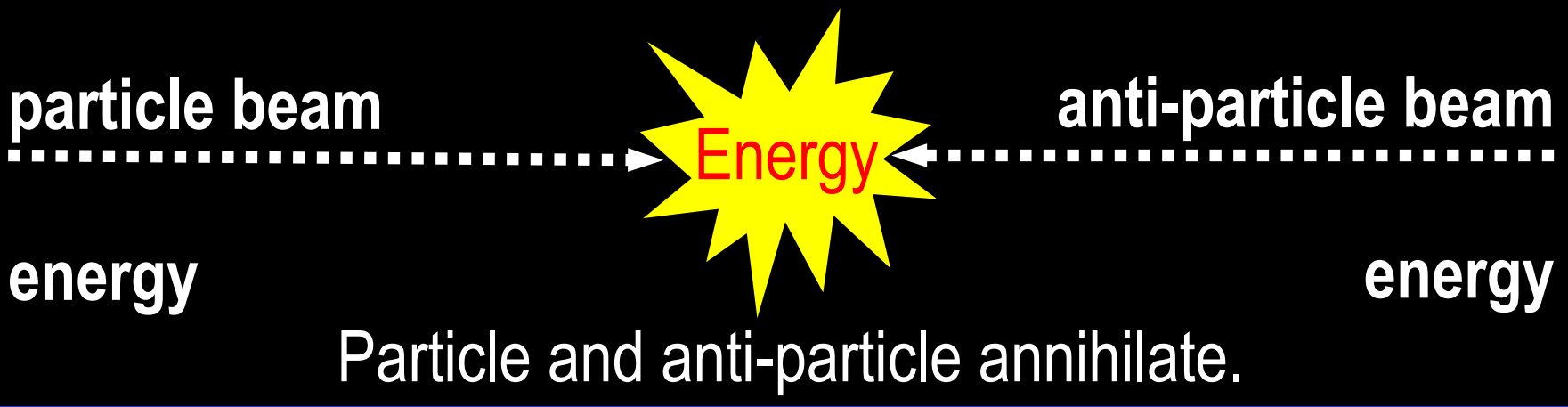
seen by
low energy beam
(poorer resolution)



seen by
high energy beam
(better resolution)

Accelerators are also Time Machines.

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



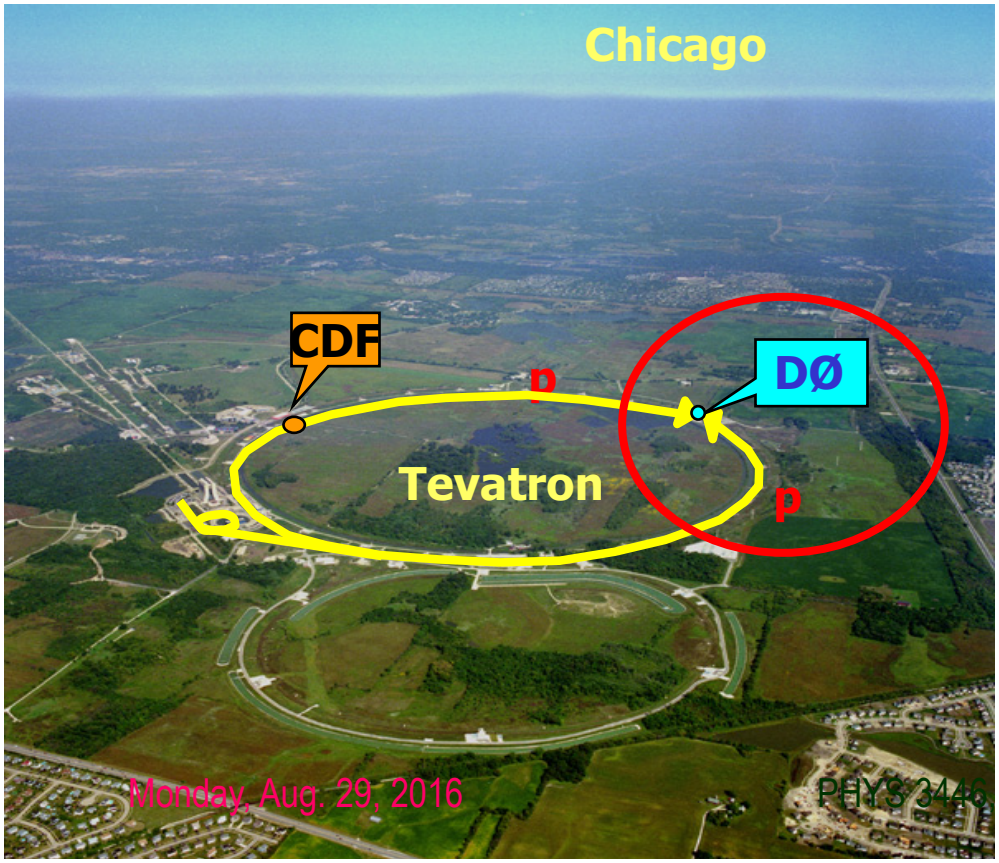
$$E = mc^2$$

What are the roles of particle accelerators?

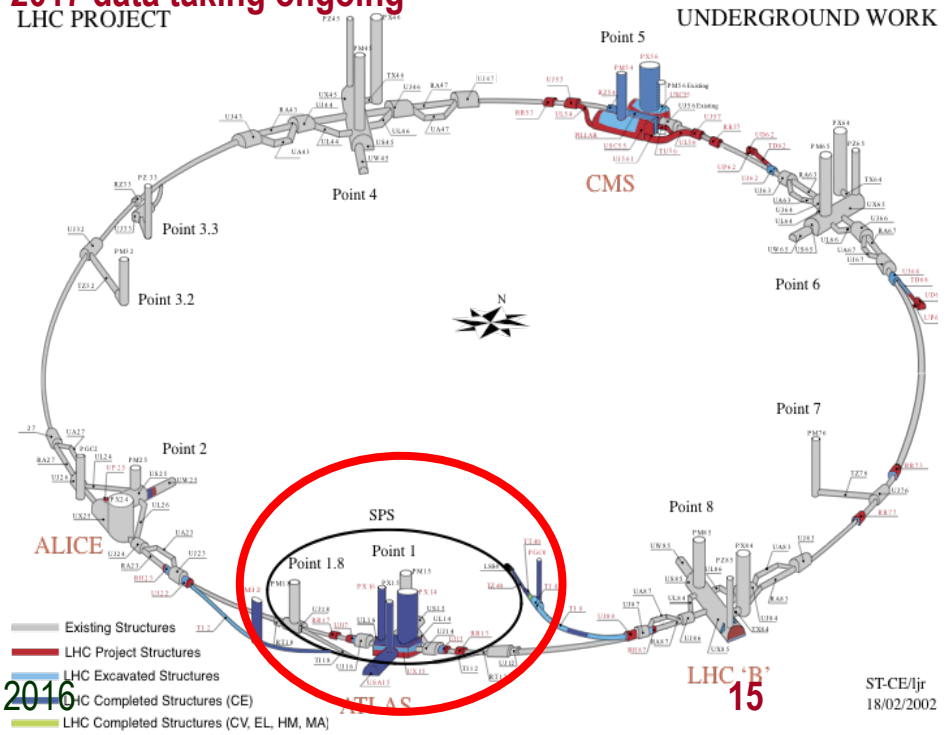
- Smash particles together
- Act as microscopes and time machines
  - The higher the energy, the smaller object to be seen
  - Particles that only existed at the time of the creation of the universe can be made
- Two method of accelerator based experiments:
  - Collider Experiments: $p\bar{p}$, pp, e^+e^-, ep
  - Fixed Target Experiments: Particles on a target
  - Each can look for different things

Fermilab Tevatron and LHC at CERN

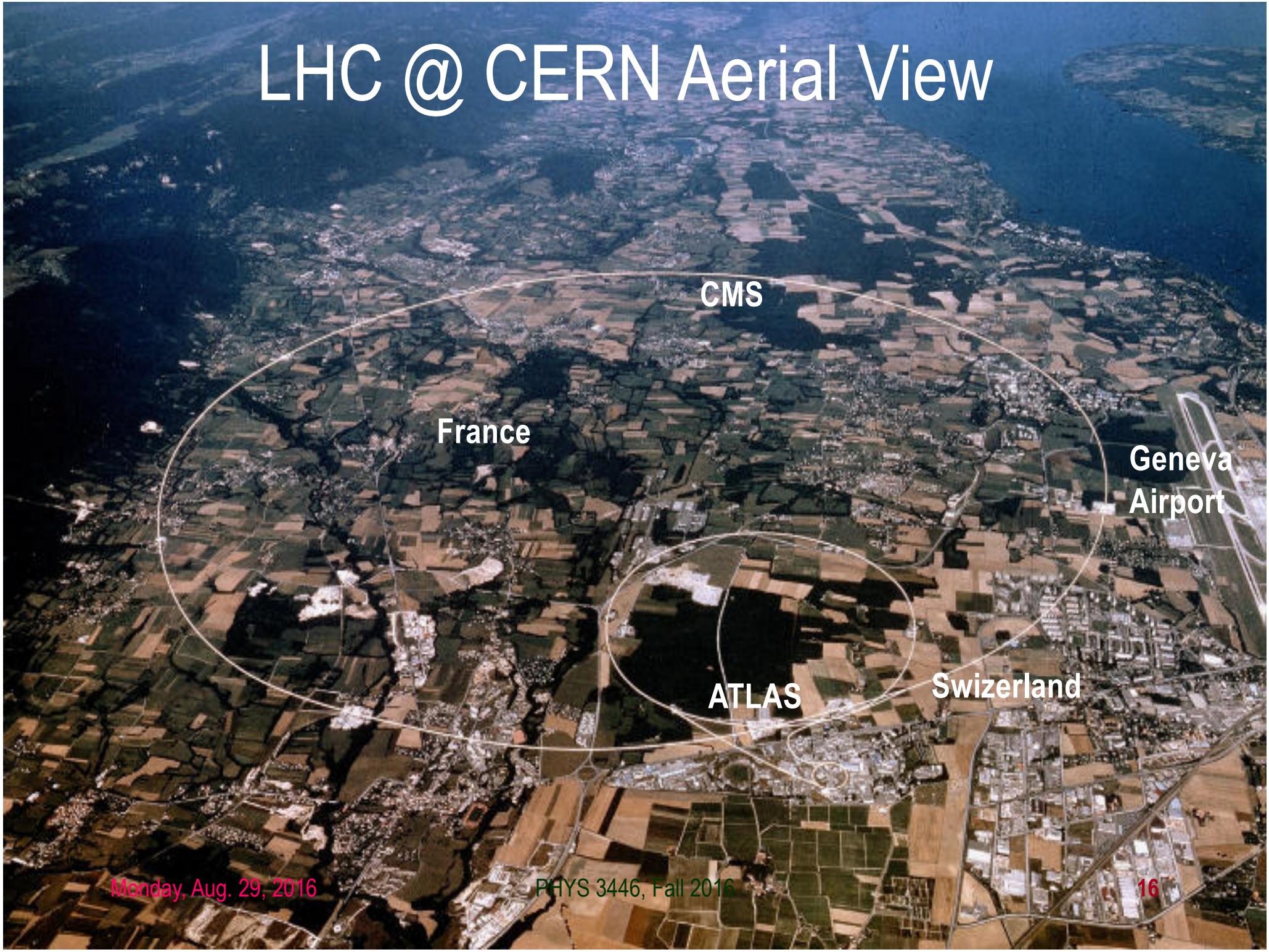
- World's Highest Energy proton-anti-proton collider
  - 4km (2.5mi) circumference
  - E_{cm}=1.96 TeV (=6.3x10^{-7}J/p➔ 13M Joules on the area smaller than 10^{-4}m^2)
  - Equivalent to the kinetic energy of a 20t truck at the speed 130km/hr
    - ~100,000 times the energy density at the ground 0 of the Hiroshima atom bomb
  - **Tevatron was shut down in 2011**
  - **Vibrant other programs running, including the search for dark matter with beams!!**



- World's Highest Energy p-p collider
  - 27km (17mi) circumference, 100m (300ft) underground
  - Design E_{cm}=14 TeV (=44x10^{-7}J/p➔ 362M Joules on the area smaller than 10^{-4}m^2)
  - ➢ Equivalent to the kinetic energy of a B727 (80tons) at the speed 310km/hr
    - ➢ ~3M times the energy density at the ground 0 of the Hiroshima atom bomb
- **Large amount of data accumulated in 2010 – 2013**
- **Beam returned 2015 after a 2 yr shutdown**
- **2017 data taking ongoing**

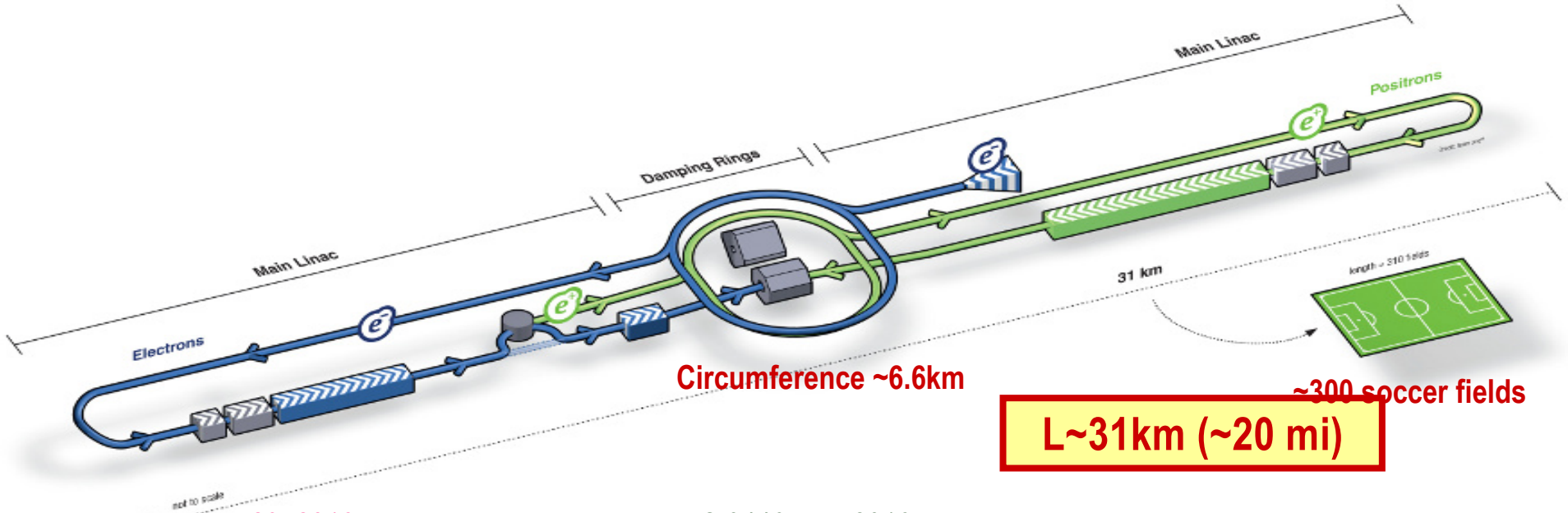


LHC @ CERN Aerial View

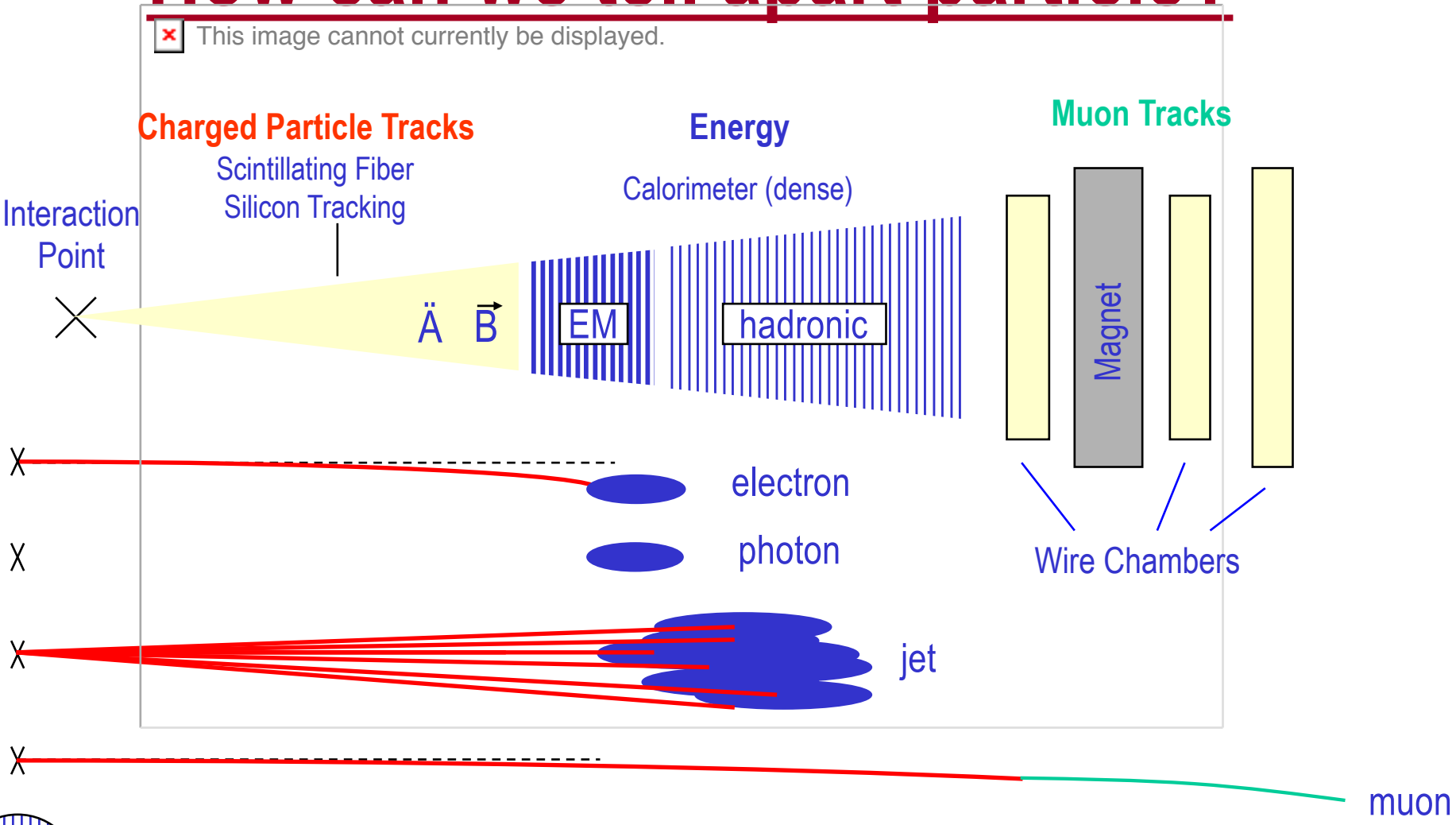


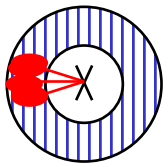
What's next? Future Linear Collider

- Now that we have found a new boson, precision measurement of the particle's properties becomes important
- An electron-positron collider on a straight line for precision measurements
- 10~15 years from now (In Dec. 2011, Japanese PM announced that they would bid for a LC in Japan and reaffirmed by the new PM in 2013)
- Takes 10 years to build a detector



How can we tell apart particle?

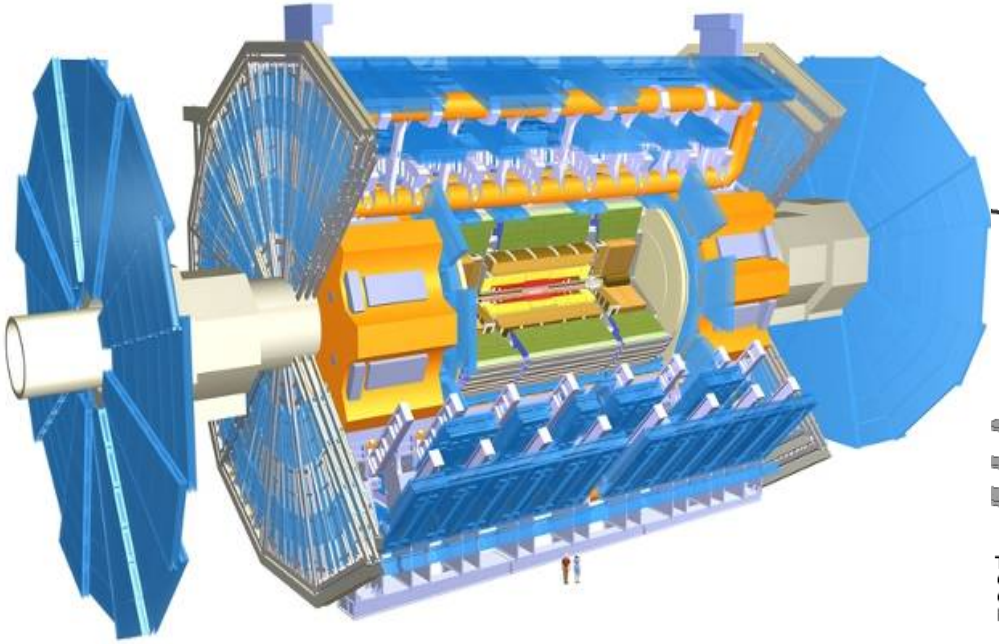


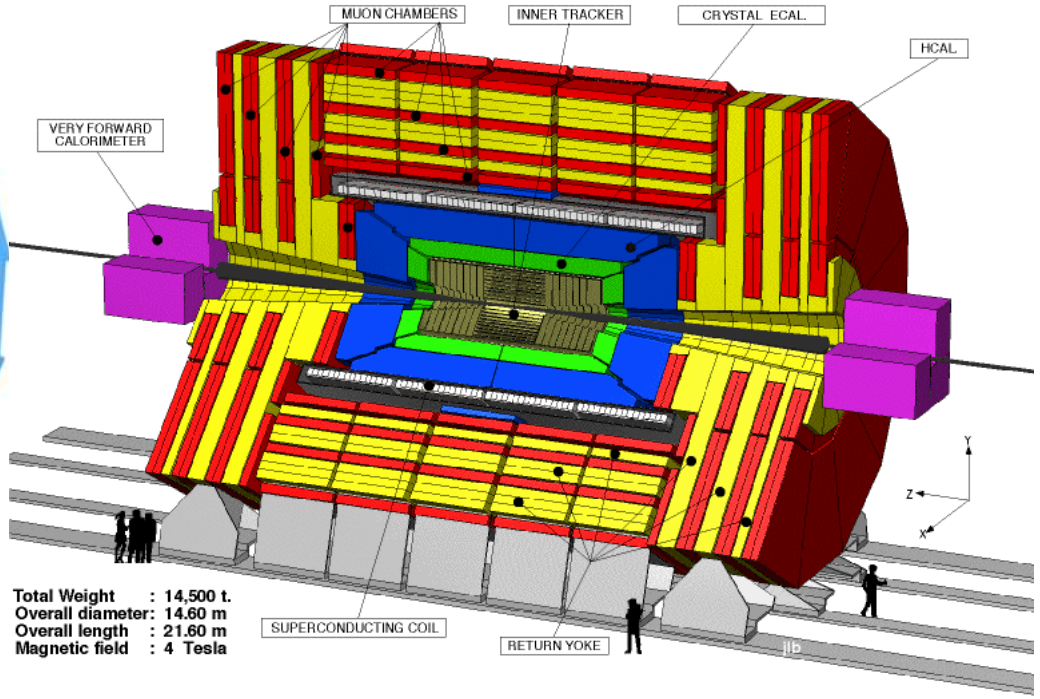


neutrino -- or any non-interacting particle
missing transverse momentum

We know x,y starting momenta is zero, but along the z axis it is not, so many of our measurements are in the xy plane, or transverse

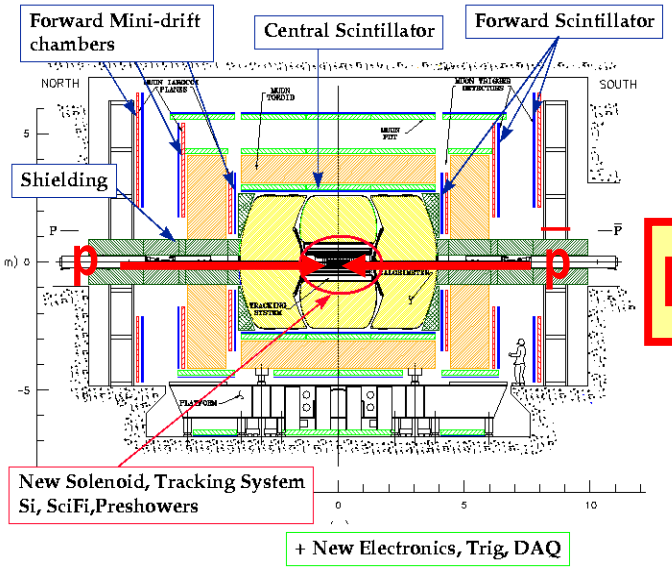
The ATLAS and CMS Detectors





- **Weighs 7000 tons and ~10 story tall**
- Records **200 – 400 collisions/second (out of 50million)**
- Records approximately **350** MB/second
- Records ~2 PB per year ➔ **200*Printed material of the US Lib. of Congress**

200x



Digital data

Data Reconstruction

What's the symmetry?

- Where is the head of the table?
- Without a broken symmetry, one cannot tell directional information!!

A broken symmetry

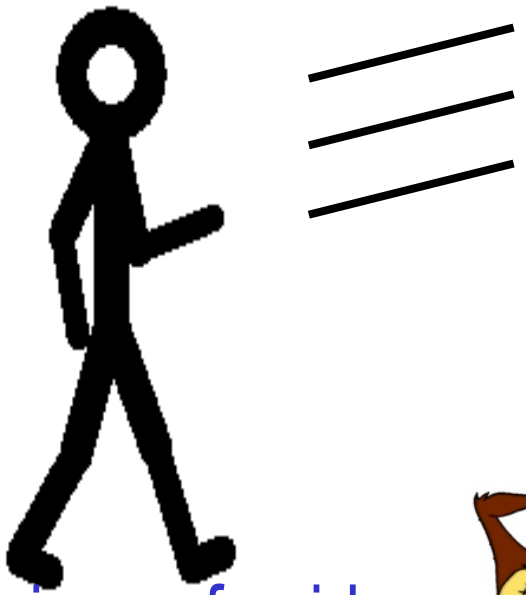
What is the Higgs and What does it do?

- When there is perfect symmetry, one cannot tell directions!
- Only when symmetry is broken, can one tell directions
- Higgs field works to break the perfect symmetry and gives mass to all fundamental particles
- Sometimes, this field spontaneously generates a particle, the Higgs particle
- So the Higgs particle is the evidence of the existence of the Higgs field!

So how does Higgs Field work again?

- Person in space ➔ no symmetry breaking

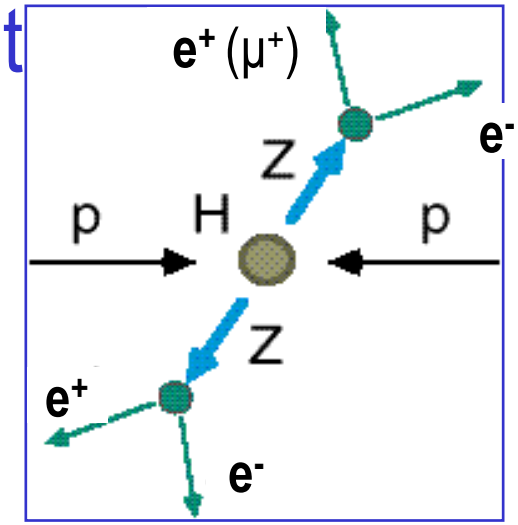
- Person in air ➔ symmetry can be broken
- Sometimes, you get



Just like the tornado is a piece of evidence of the existence of air, Higgs particle is a piece of evidence of Higgs mechanism

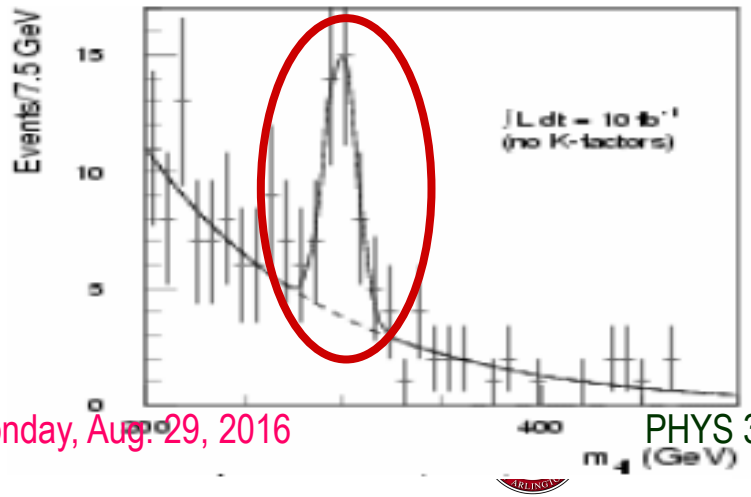
How do we look for the Higgs?

1. Identify Higgs candidate event

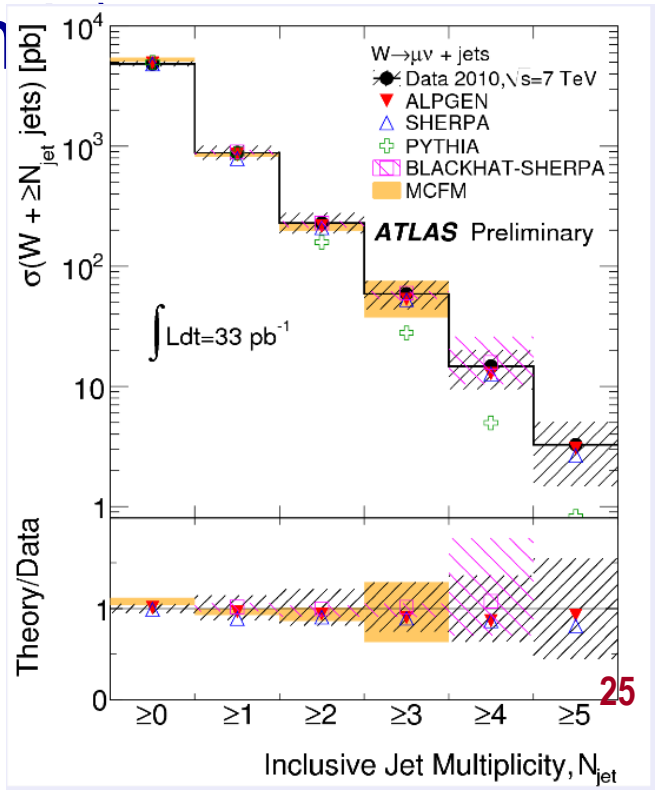


2. Understand fakes (backgroun

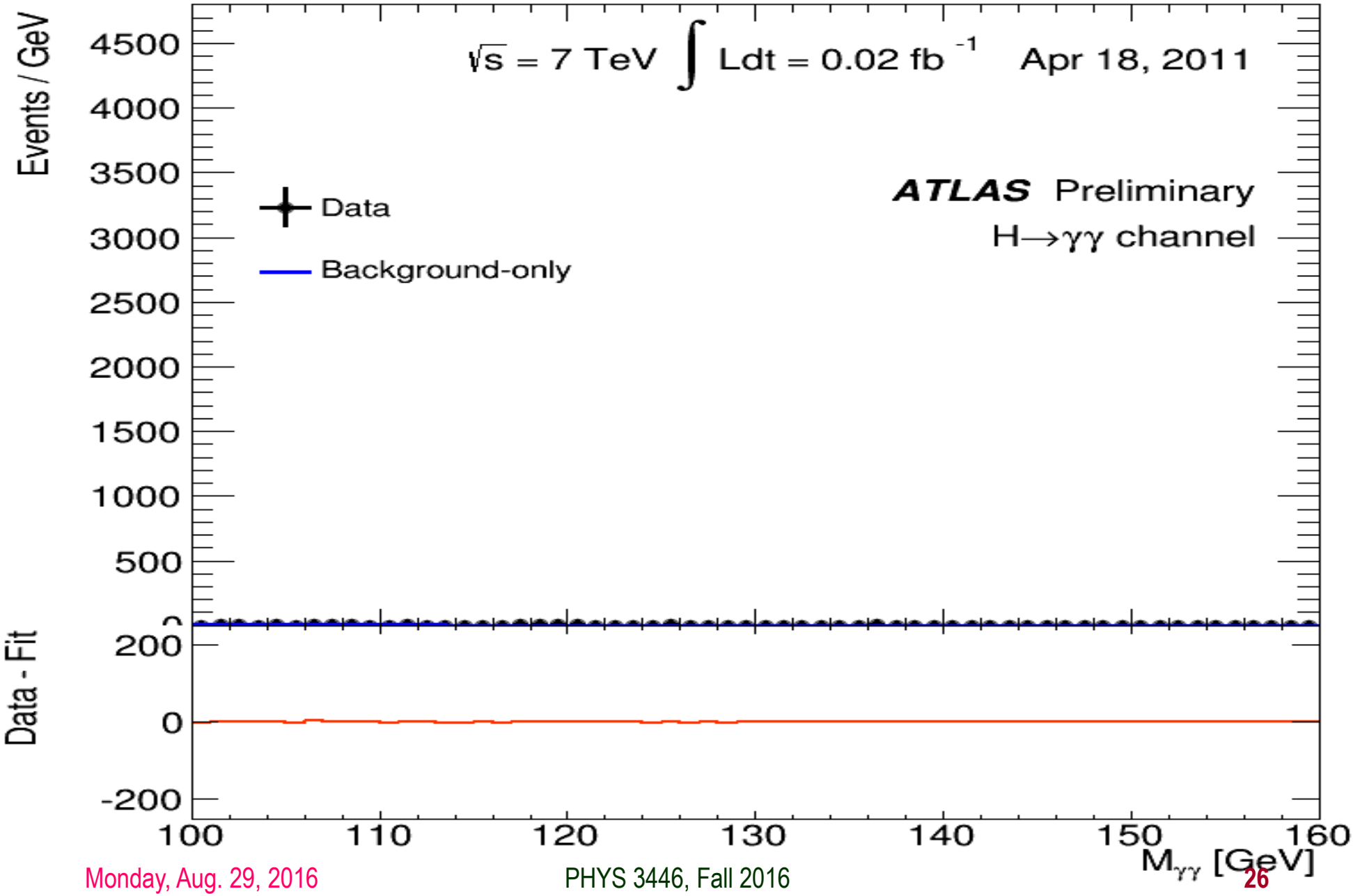
3. Look for a bump!!



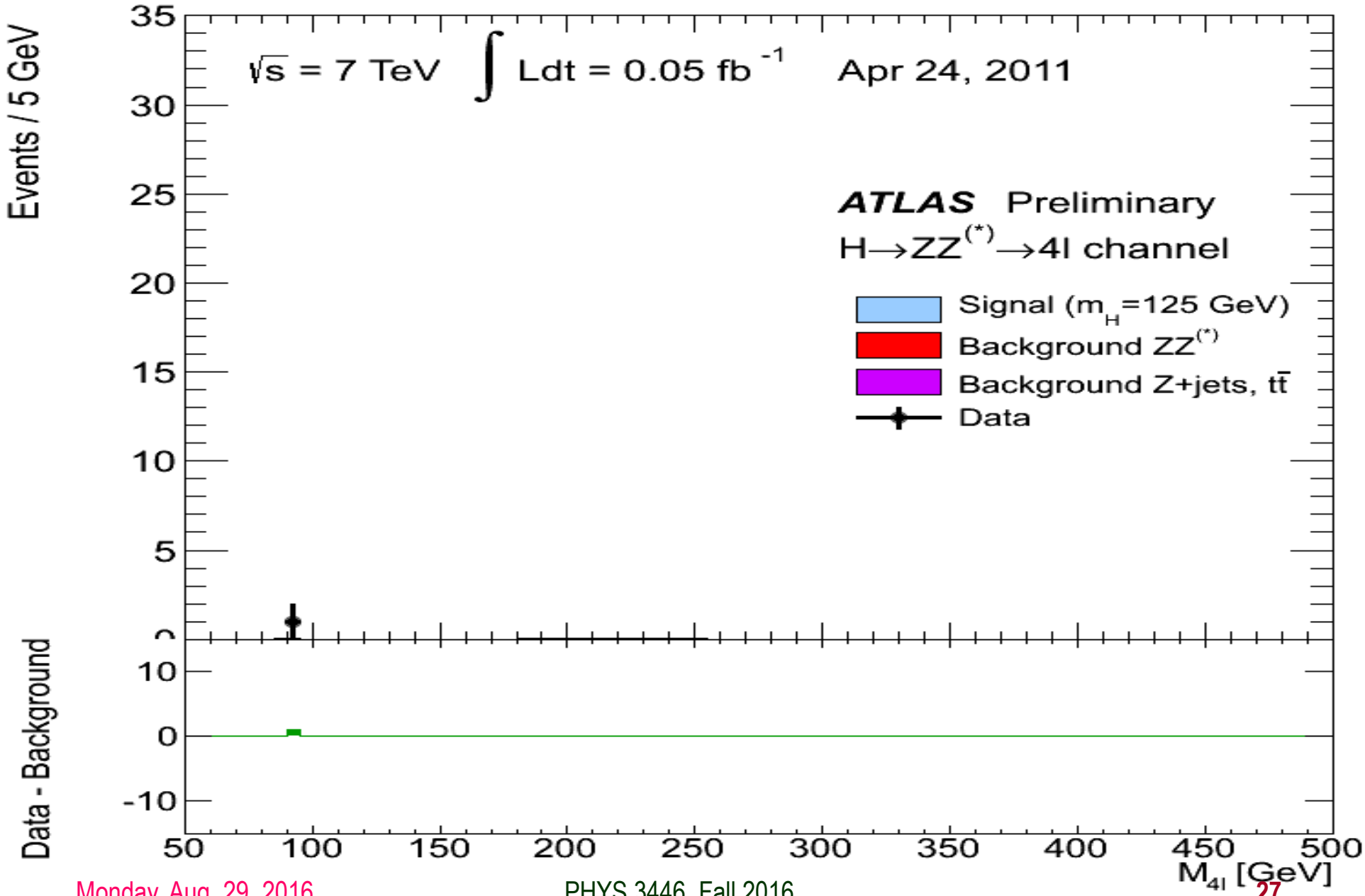
ely critical



What did statistics do for Higgs?



How about this?



So have we seen the Higgs particle?

- The statistical significance of the finding is way over 7 standard deviations

Statistical Significance Table

zσ	Percentage within CI	Percentage outside CI	Fraction outside CI
0.674 490σ	50%	50%	1 / 2
0.994 458σ	68%	32%	1 / 3.125
1σ	68.268 9492%	31.731 0508%	1 / 3.151 4872
1.281 552σ	80%	20%	1 / 5
1.644 854σ	90%	10%	1 / 10
1.959 964σ	95%	5%	1 / 20
2σ	95.449 9736%	4.550 0264%	1 / 21.977 895
2.575 829σ	99%	1%	1 / 100
3σ	99.730 0204%	0.269 9796%	1 / 370.398
3.290 527σ	99.9%	0.1%	1 / 1,000
3.890 592σ	99.99%	0.01%	1 / 10,000
4σ	99.993 666%	0.006 334%	1 / 15,787
4.417 173σ	99.999%	0.001%	1 / 100,000
4.891 638σ	99.9999%	0.0001%	1 / 1,000,000
5σ	99.999 942 6697%	0.000 057 3303%	1 / 1,744,278
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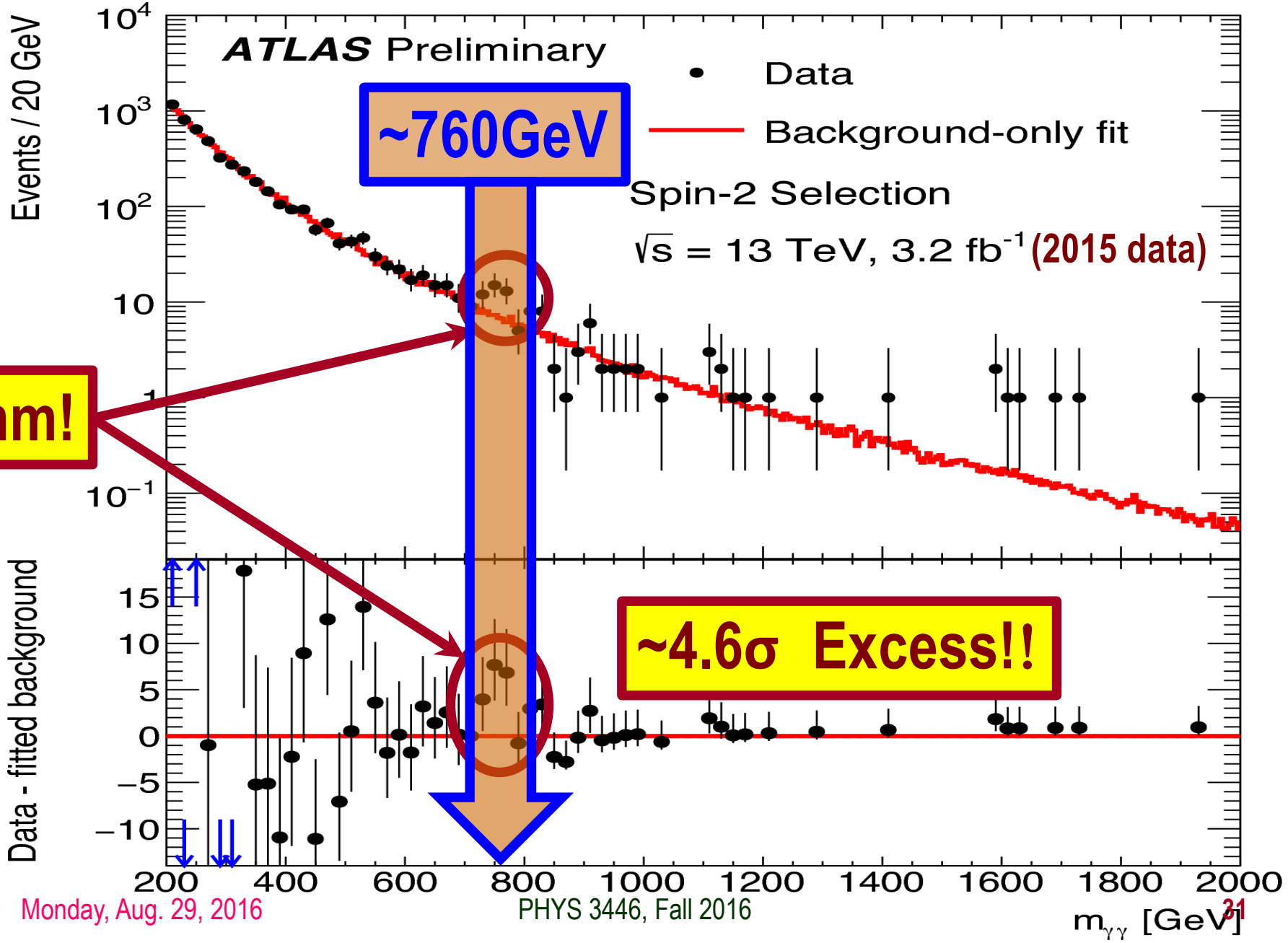
6.466 951σ	99.999 999 99%	0.000 000 01%	1 / 10,000,000,000
6.806 502σ	99.999 999 999%	0.000 000 001%	1 / 100,000,000,000
7σ	99.999 999 999 7440%	0.000 000 000 256%	1 / 390,682,215,445

So have we seen the Higgs particle?

- The statistical significance of the finding is much bigger than seven standard deviations
  - Level of significance: much better than 99.999 999 999 7% (eleven 9s!!)
  - We could be wrong once if we do the same experiment 391,000,000,000 times (will take ~13,000 years even if each experiment takes 1s!!)
- So did we find the Higgs particle?
  - We have discovered the heaviest new boson we've seen thus far
  - It has many properties consistent with the Standard Model Higgs particle
    - It quacks like a duck and walks like a duck but…
  - We do not have enough data to precisely measure all the properties – mass, lifetime, the rate at which this particle decays to certain other particles, etc – to definitively determine its nature
- Precision measurements and searches in new channels ongoing

A hint of something new?



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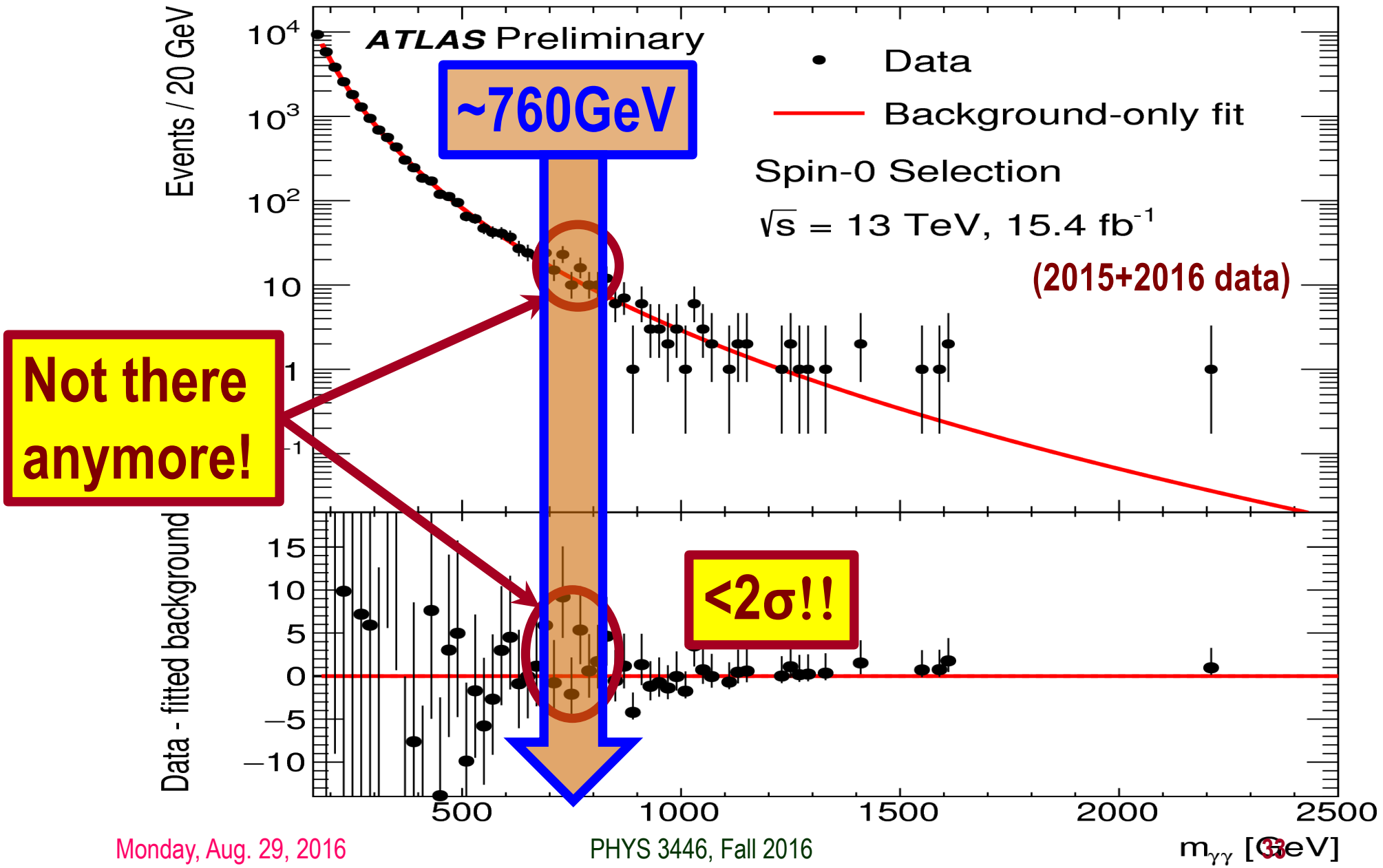
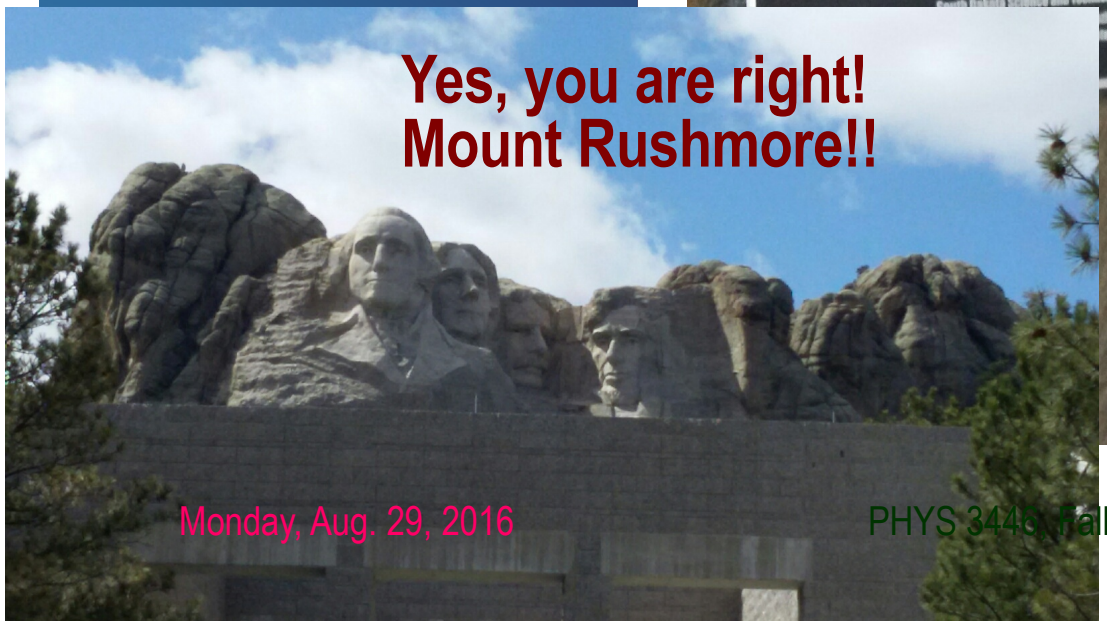
Not good enough yet!!

Disappeared after x4 data!!



The Next Big Thing - DUNE Experiment

- Stands for Deep Under Ground Neutrino Experiment
- The flagship long baseline (1300km) ν experiment
  - 1500m underground in South Dakota

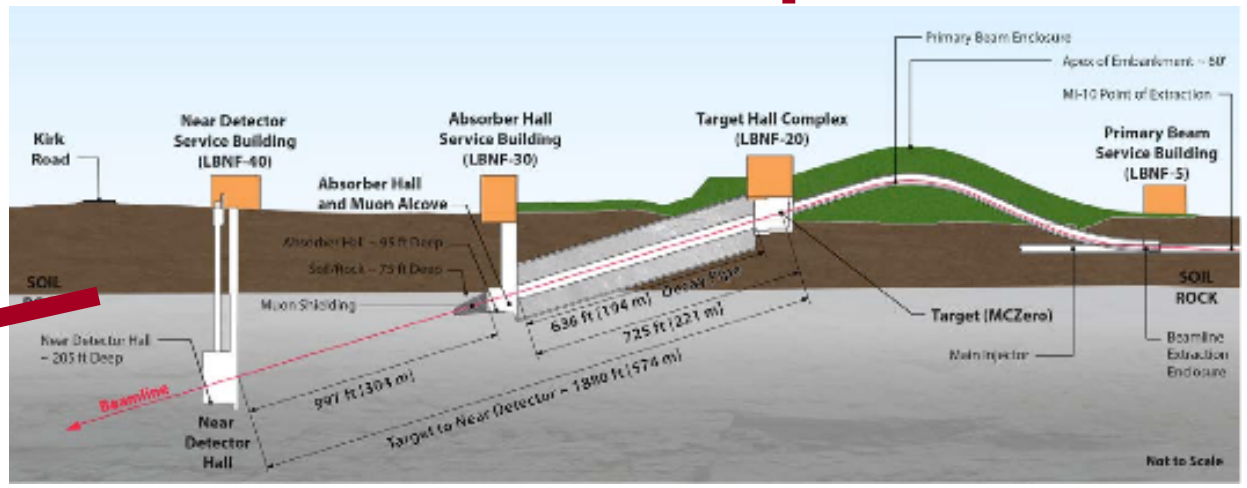


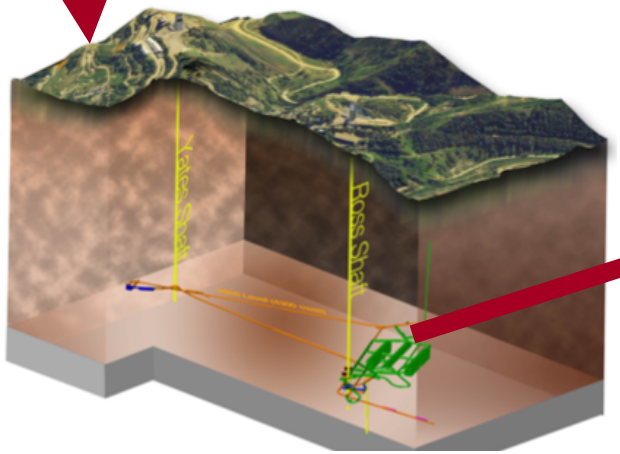
- Nobel Winning Neutrino Discovery by Ray Davis in 1960's
- Many Dark Matter experiments in progress
- New DUNE area to be excavated shortly

Dark Matter Searches at Fermilab

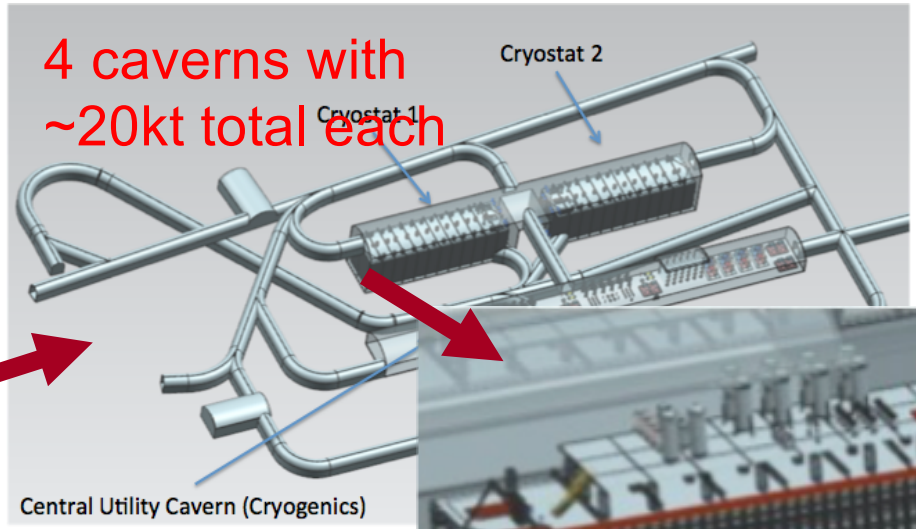
- Fermi National Accelerator Laboratory is turning into a lab with very high intensity accelerator program
- UTA group is part of three experiments
  - Long Baseline Neutrino Experiment (LBNE), an $850M flagship experiment, with data expected in 2025
    - High flux secondary beam and a near detector enables searches for DM
    - In addition to precision measurements of key neutrino param..
    - UTA playing very significant role in this experiment
- A rich physics program for the next 20 – 30 years!!
- If we see DM, we could use this to make DM Beam??

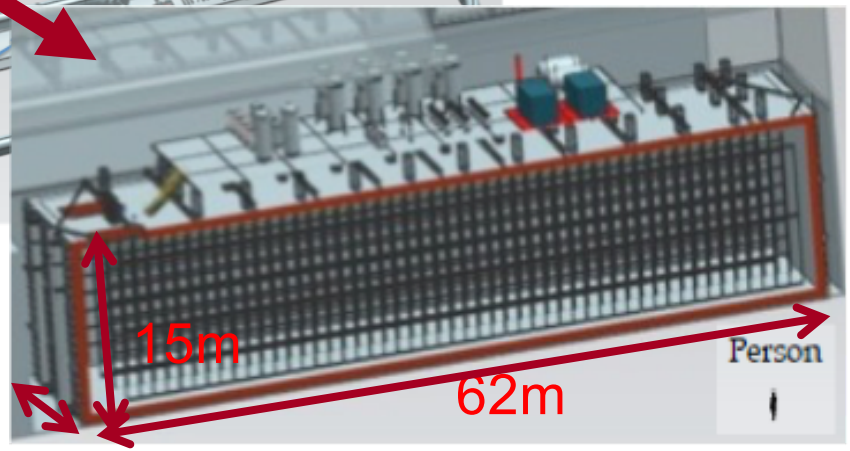
The Components of the DUNE Experiment





1500m underground



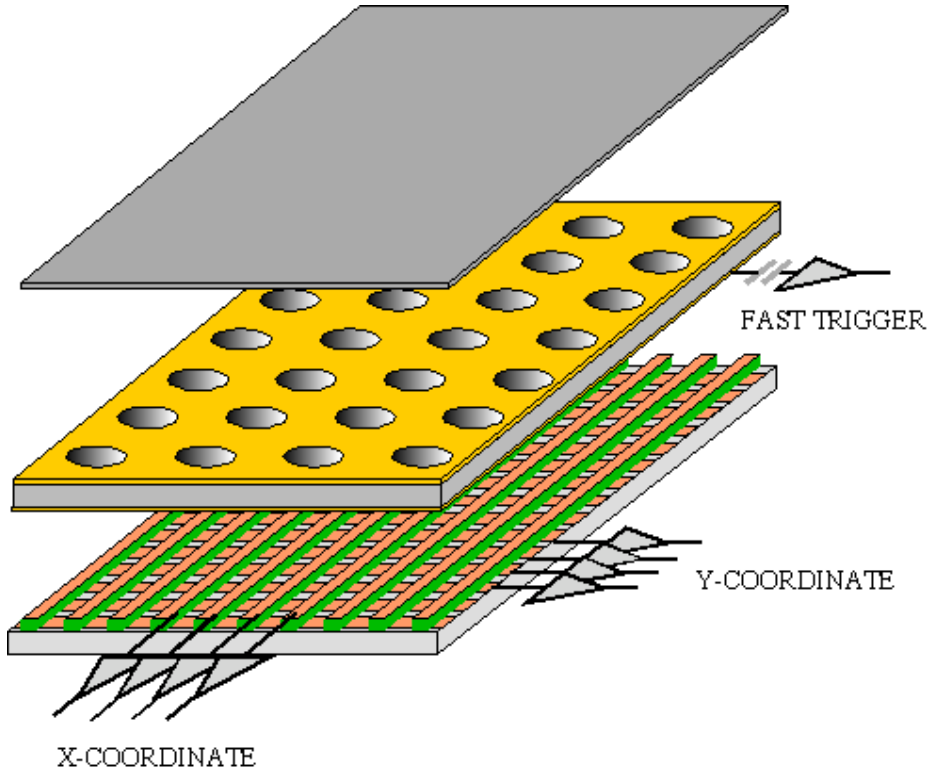


How BIG?

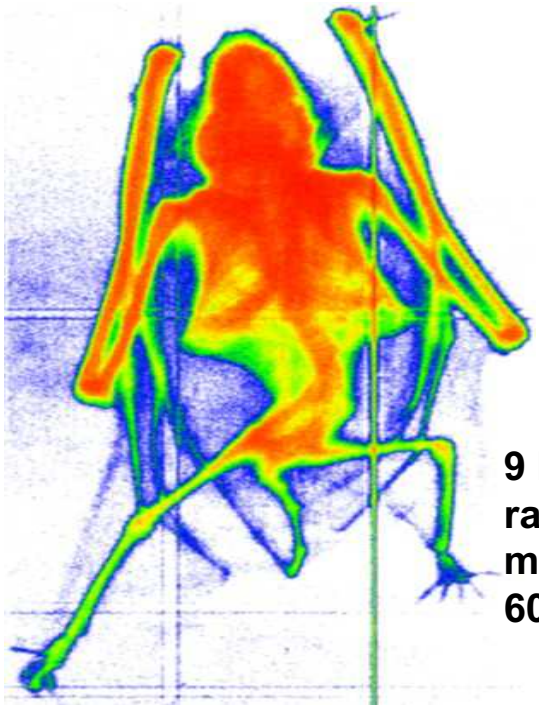
This is just for a 3mx1mx1m (42t) active volume baby prototype!!

GEM Application Potential

Using the lower GEM signal, the readout can be self-triggered with energy discrimination:



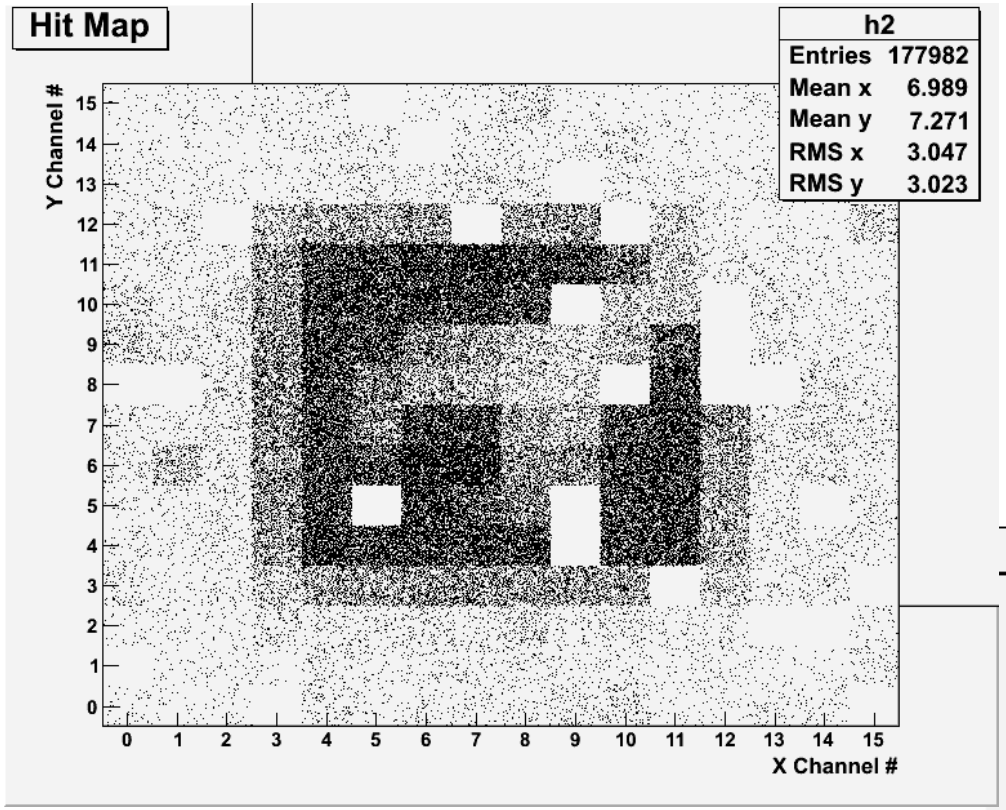
FAST X-RAY IMAGING

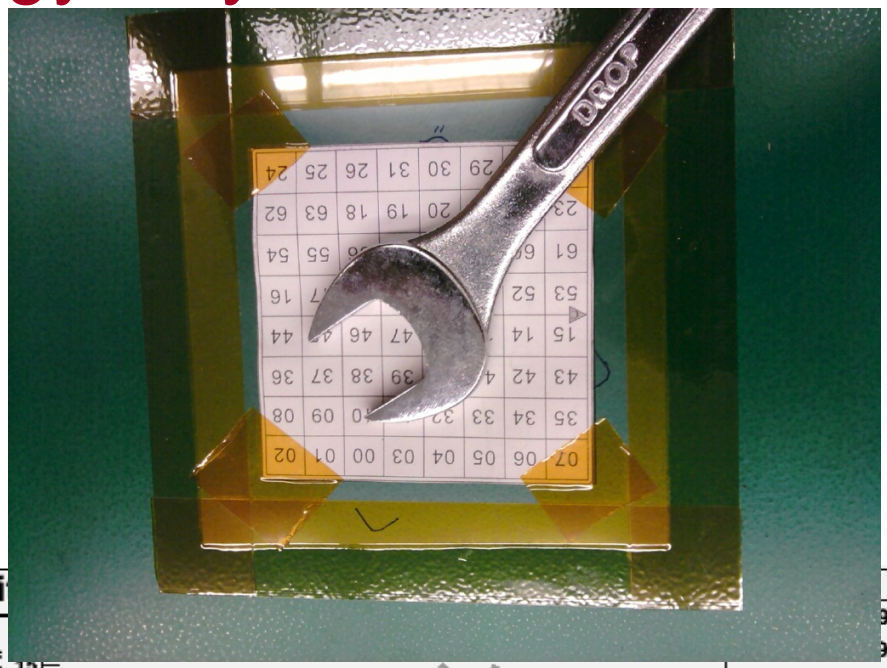


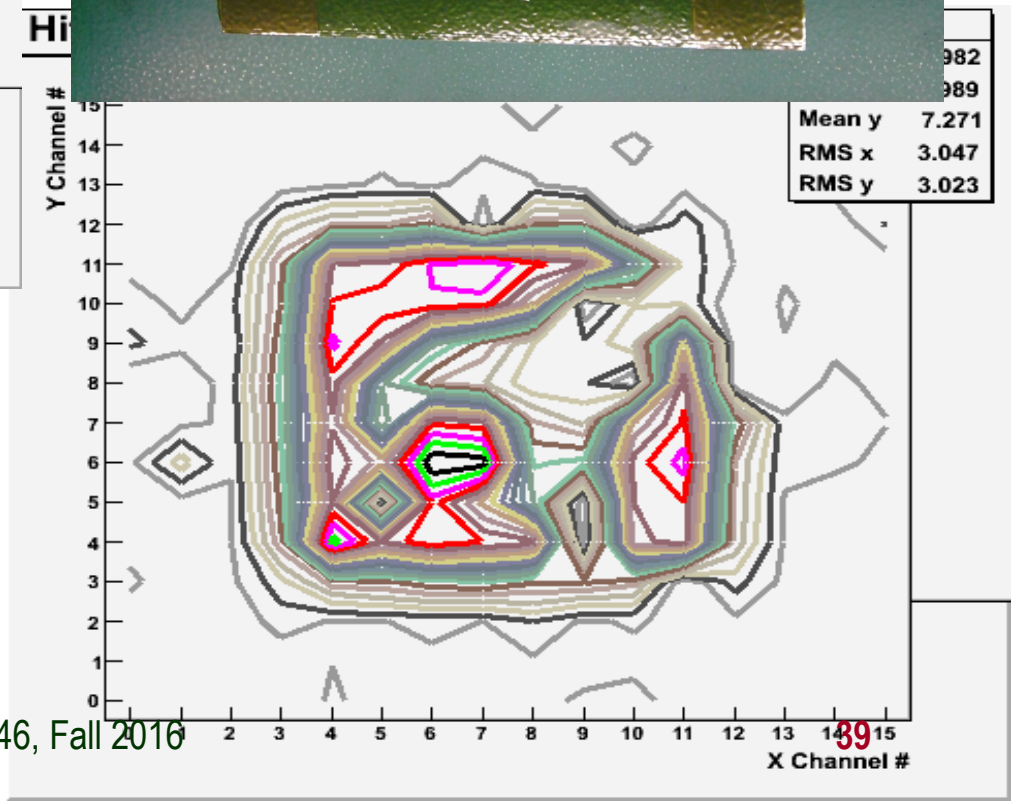
9 keV absorption radiography of a small mammal (image size ~ 60 x 30 mm^2)

A. Bressan et al,
Nucl. Instr. and Meth. A 425(1999)254
F. Sauli, Nucl. Instr. and Meth.A 461(2001)47

Bi-product of High Energy Physics Research







Can you see what the object is?
(GEM Detector X-ray Image)


And in not too distant future, we could do ...

Discovery of the God Particle in 2012