PHYS 3313 – Section 001
Lecture #2

Monday, Jan. 26, 2015
Dr. Jaehoon Yu

- Higgs and Dark Matter
- What do you expect to learn in this course?
- Classical Physics
- Concept of Waves and Particles
- Conservation Laws and Fundamental Forces
- Atomic Theory of Matter
- Unsolved Questions of 1895 and the New Horizon

Announcements

- Quiz #1 on appendices 3, 5, 6 and
  - Beginning of the class
  - Wednesday, Jan. 28
- Special colloquium at 4pm tomorrow
  - In SH101: Dr. James Siegrist of US Department of Energy
  - Special triple extra credit

Special Project #1

1. Compute the electric force between the two protons separate the farthest in an intact U^{238} nucleus. Use the actual size of the U^{238} nucleus. (10 points)
2. Compute the gravitational force between the two protons separate the farthest in an intact U^{238} nucleus. (10 points)
3. Express the electric force in #1 above in terms of the gravitational force in #2. (5 points)

- You must look up the mass of the proton, actual size of the U^{238} nucleus, etc, and clearly write them on your project report
- You MUST have your own, independent answers to the above three questions even if you worked together with others. All those who share the answers will get 0 credit if copied.
- Due for the submission is Monday, Feb. 2!

What is the Higgs and What does it do?

- When there is perfect symmetry, one cannot tell directions!

What? What's the symmetry?

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

A broken symmetry

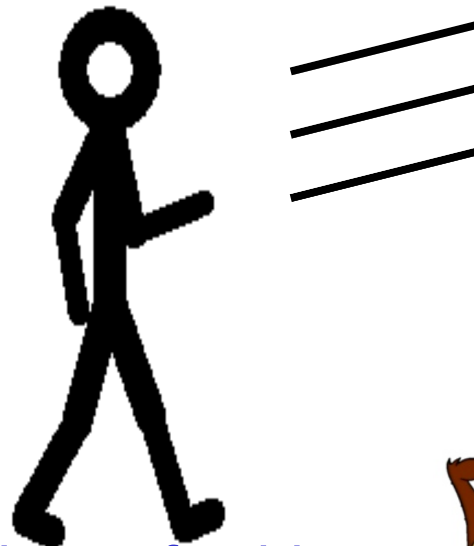
What is the Higgs and What does it do?

- 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

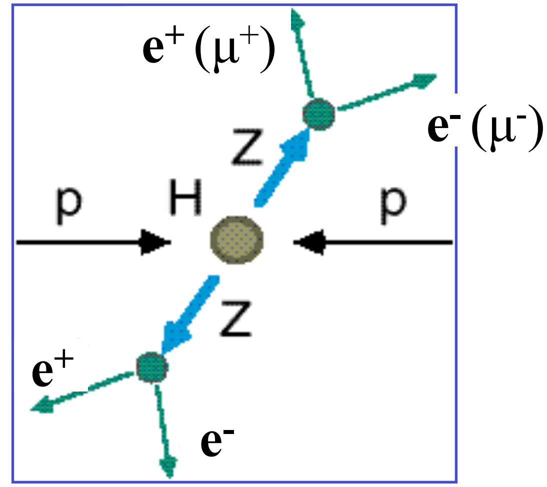
- Person in air ➔ symmetry can be broken
- Sometimes, you get



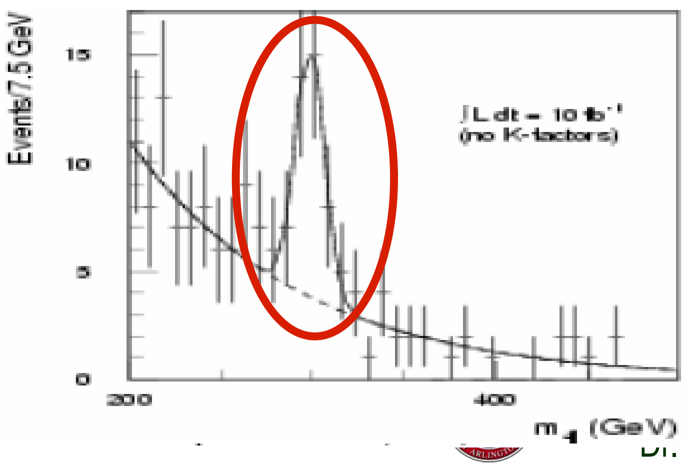
Just like a tornado is a piece of evidence of the existence of air, Higgs particle is a piece of evidence of Higgs mechanism

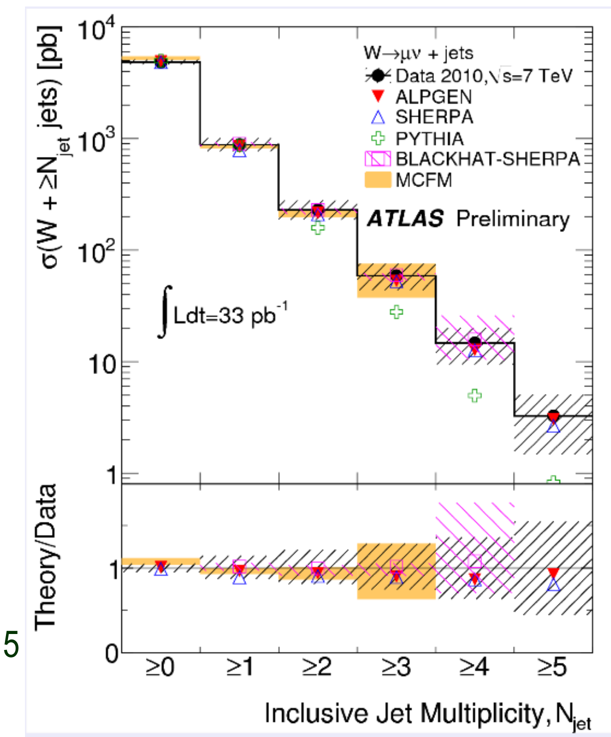
How do we look for the Higgs?

- Identify Higgs candidate events

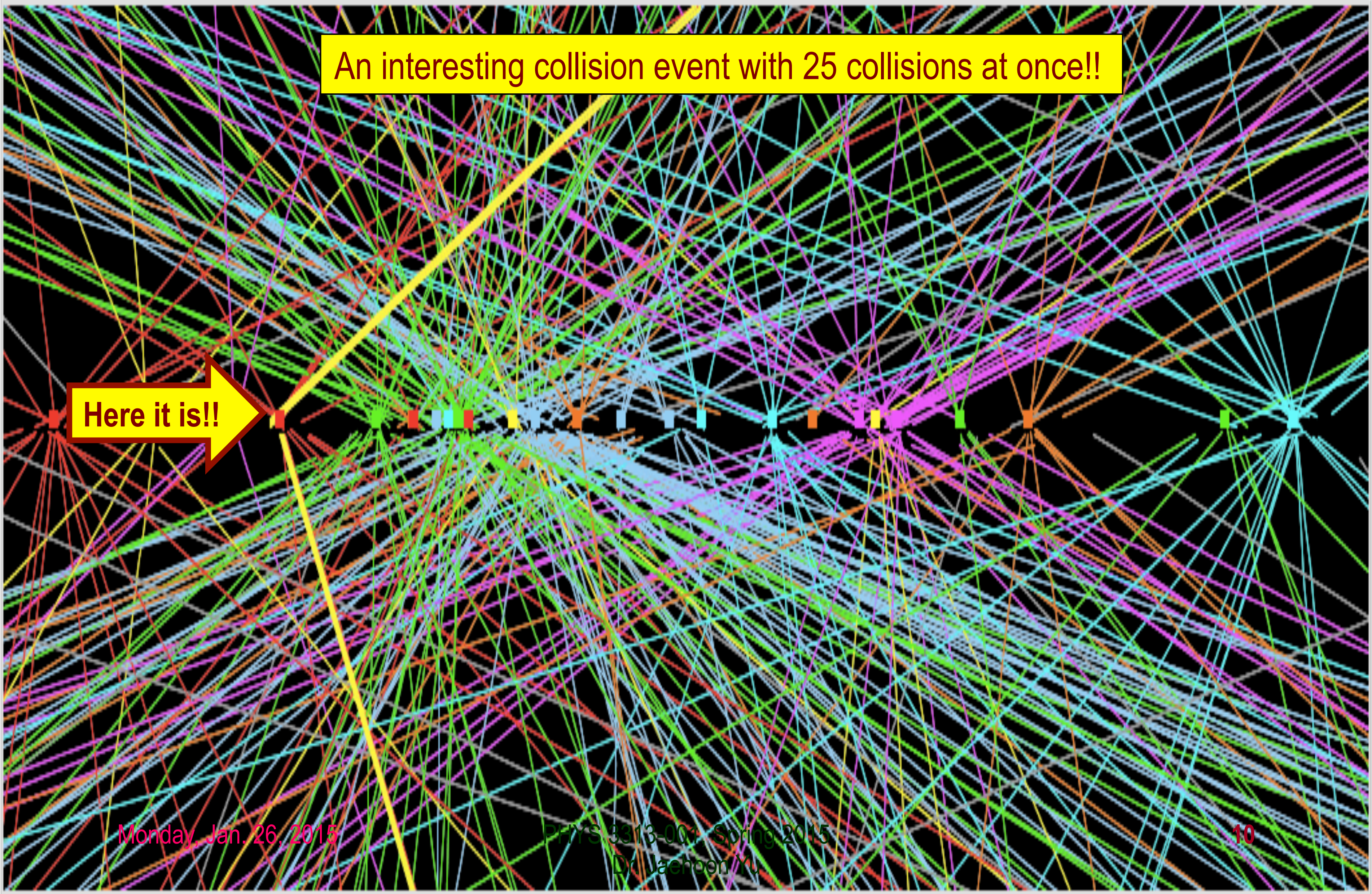


- Understand fakes (backgrounds)
- Look for a bump!!
  - Large amount of data absolutely critical

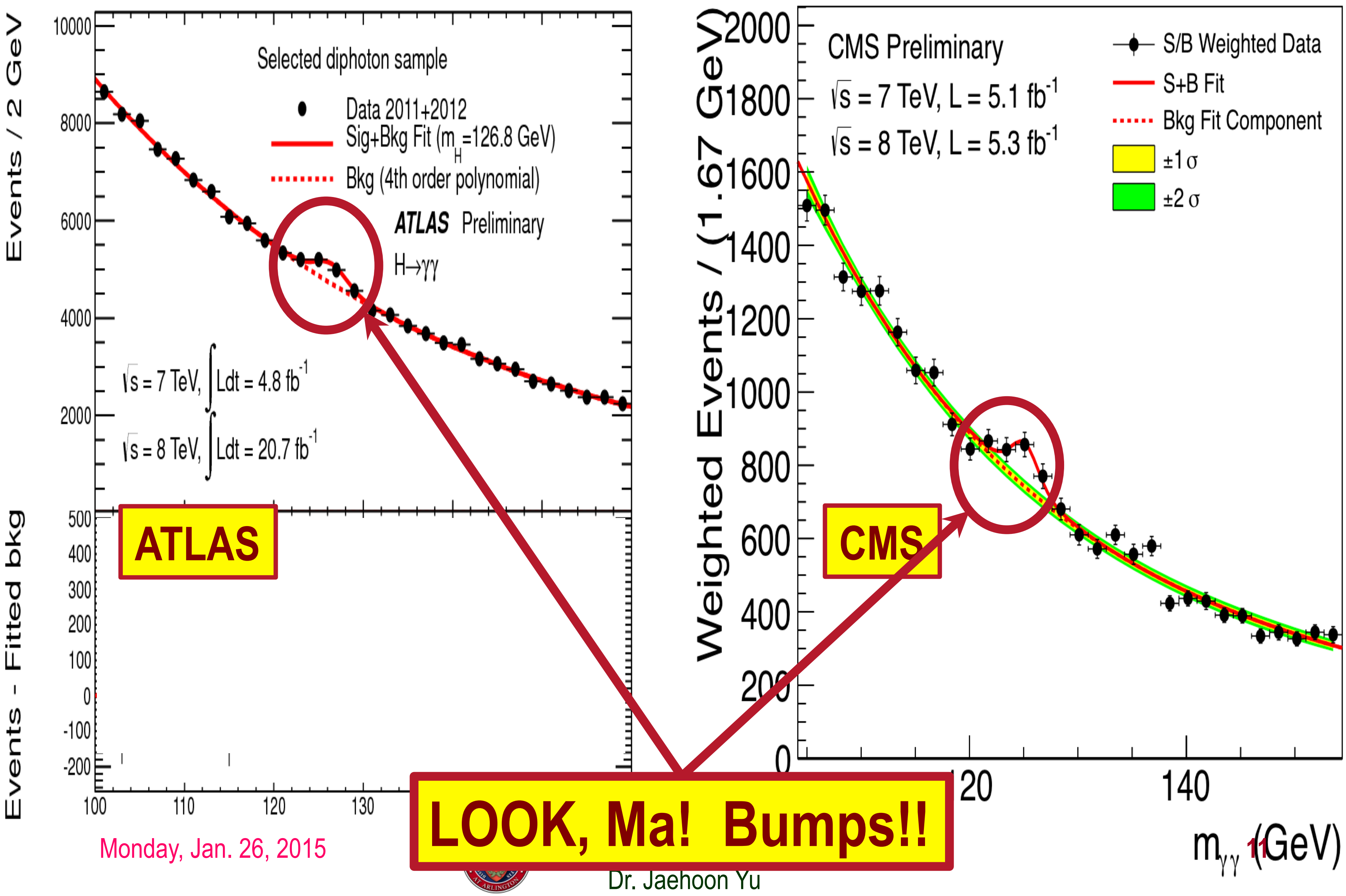




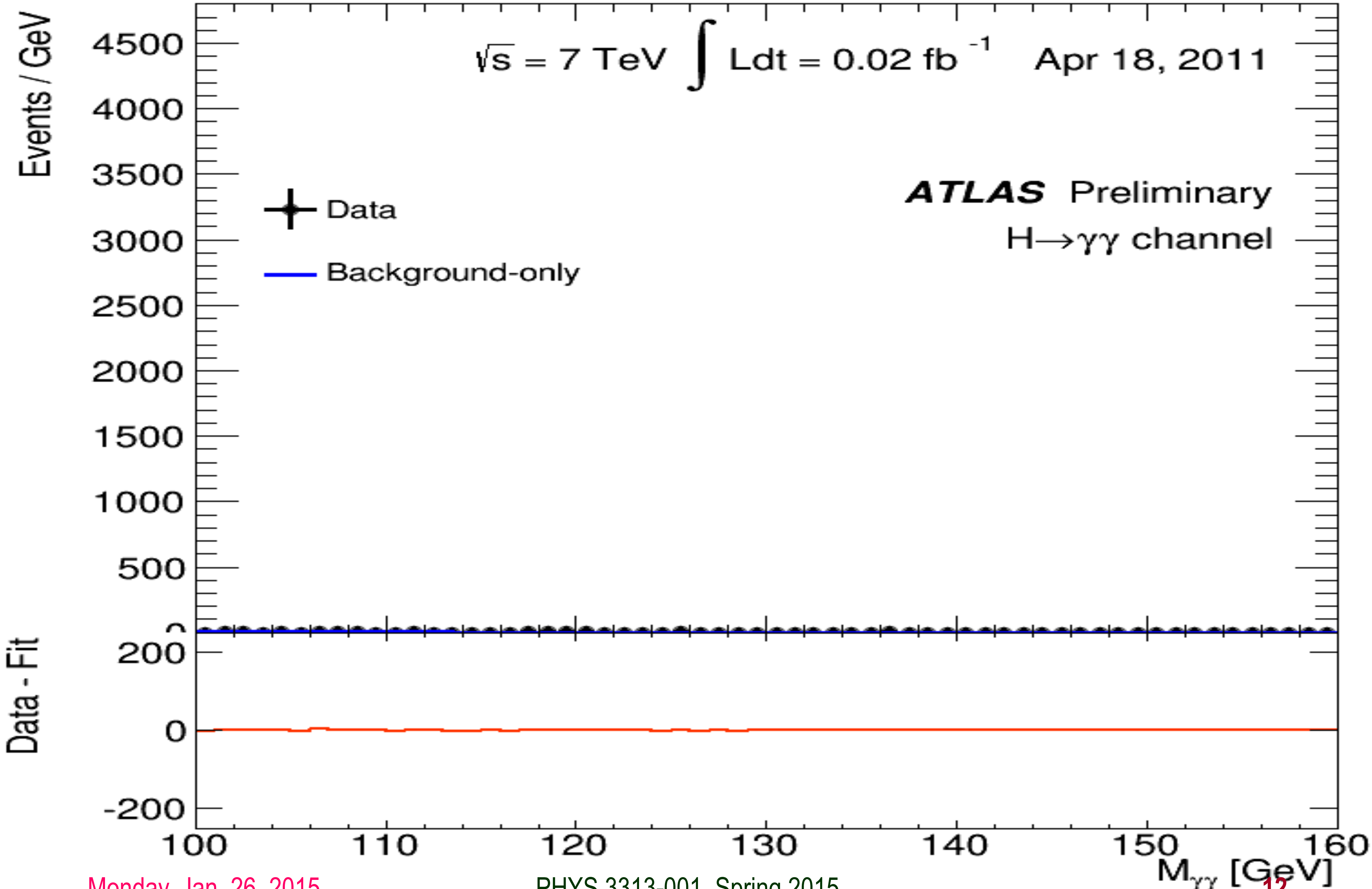
Challenges? No problem!



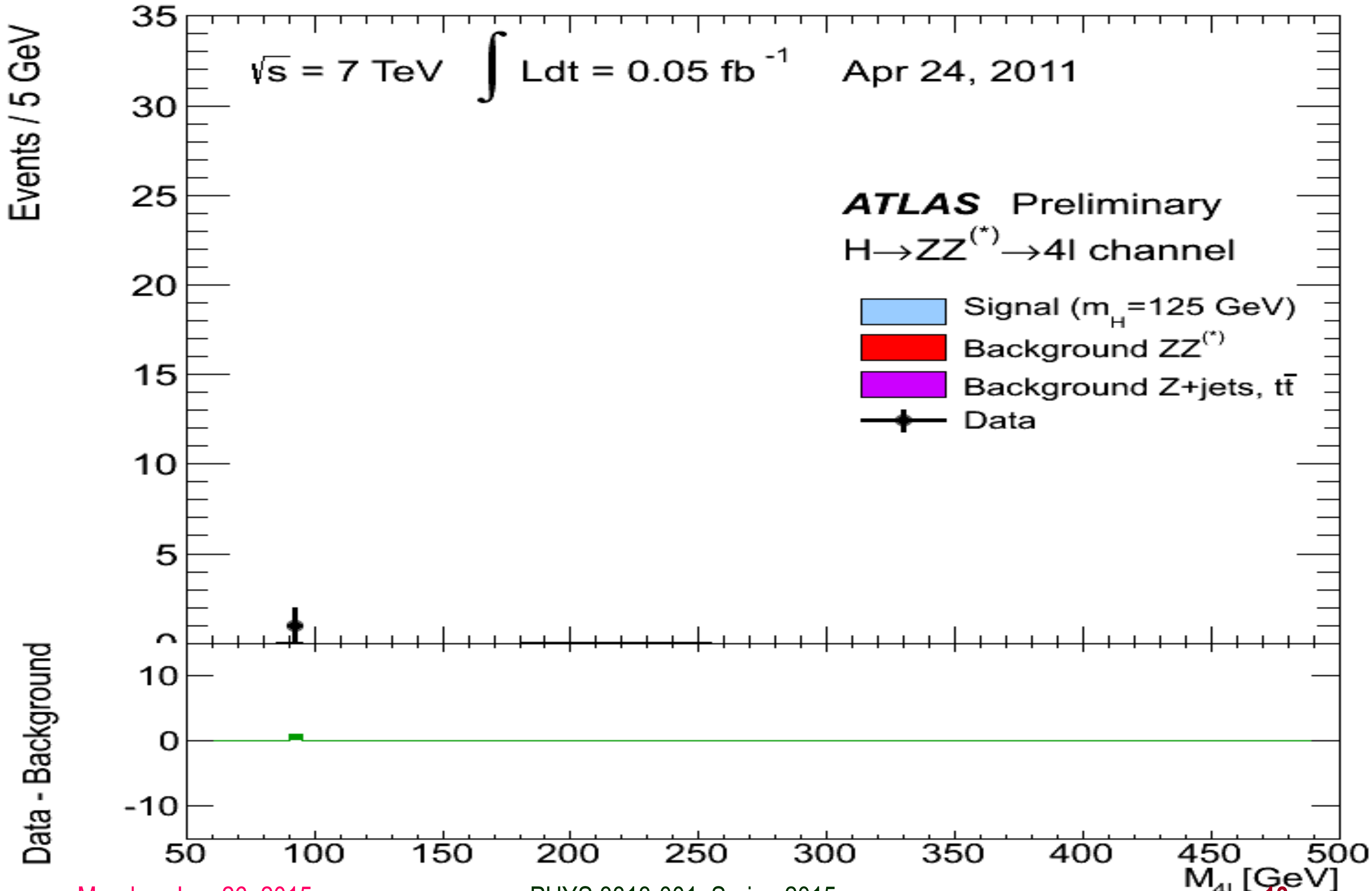
ATLAS and CMS Mass Bump Plots (**H→γγ**)



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

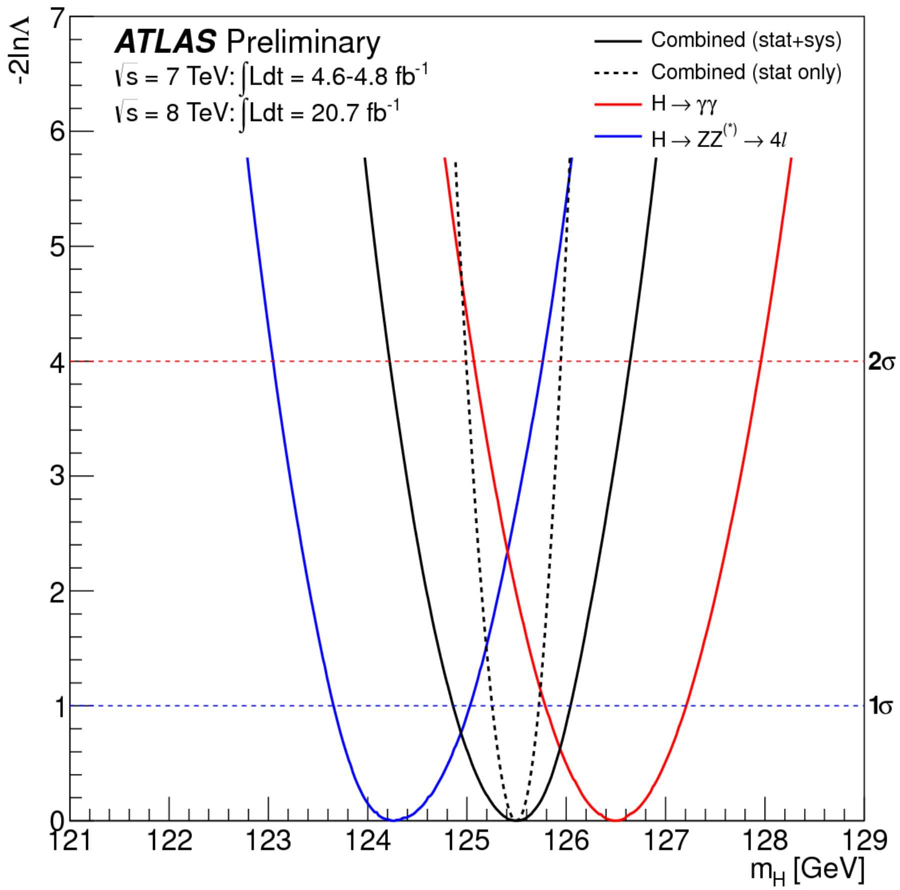
Statistical Significance Table

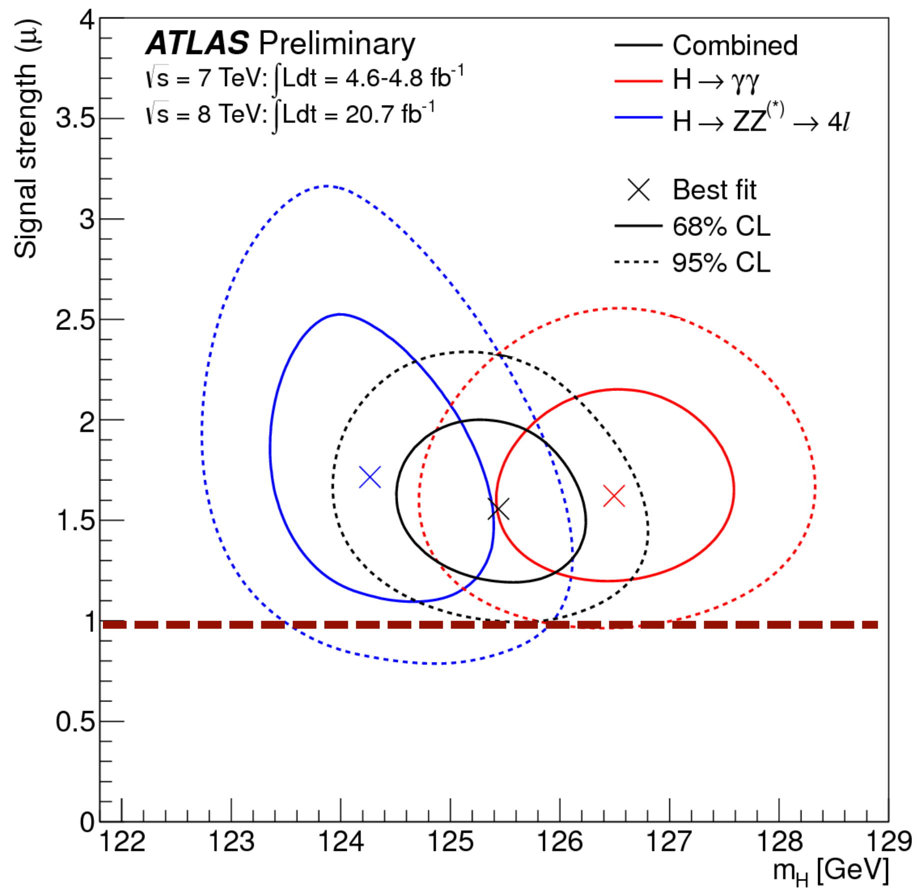
zσ	Percentage within CI	Percentage outside CI	Fraction outside CI
0.674 490σ	50%	50%	1 / 2
0.994 458σ	68%	32%	1 / 3.125
1σ	68.268 9492%	31.731 0508%	1 / 3.151 4872
1.281 552σ	80%	20%	1 / 5
1.644 854σ	90%	10%	1 / 10
1.959 964σ	95%	5%	1 / 20
2σ	95.449 9736%	4.550 0264%	1 / 21.977 895
2.575 829σ	99%	1%	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
5.326 724σ	99.999 99%	0.000 01%	1 / 10,000,000
5.730 729σ	99.999 999%	0.000 001%	1 / 100,000,000
6σ	99.999 999 8027%	0.000 000 1973%	1 / 506,797,346
6.109 410σ	99.999 9999%	0.000 0001%	1 / 1,000,000,000
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

An Interesting Property Measurement





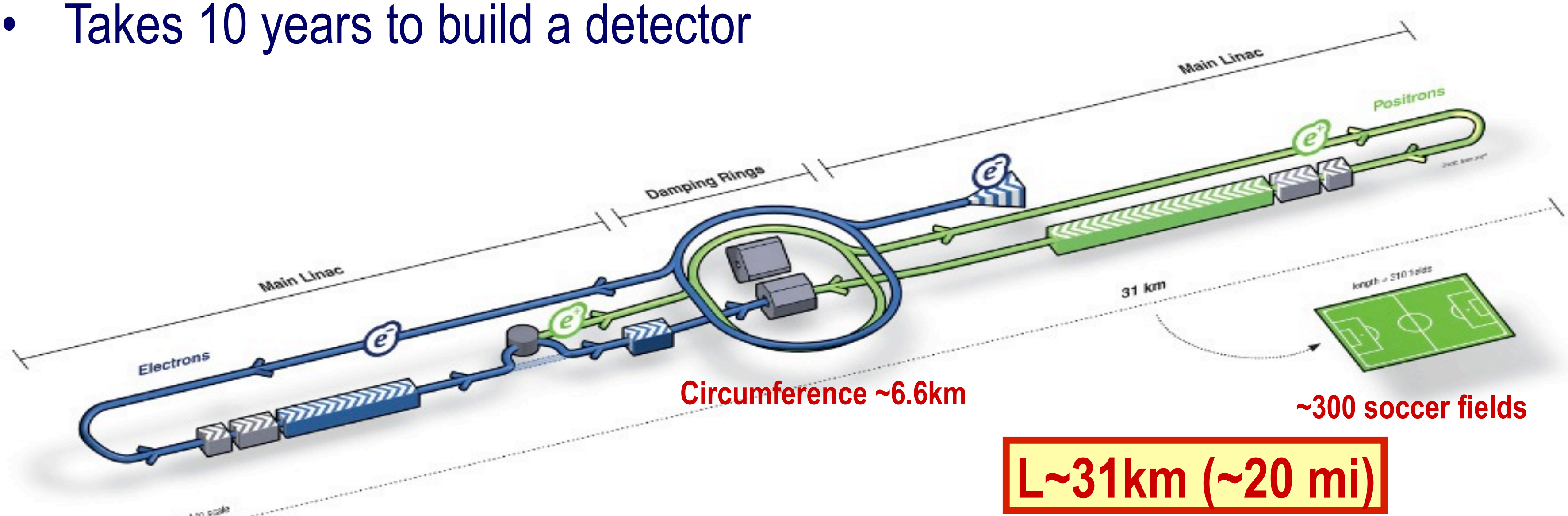
- Masses from H→γγ and H→ZZ→4l differ by 2 GeV at about 1.5σ
- H→γγ differ from SM by about 2σ and H→ZZ→4l by about 1σ

Long Term LHC Plans

- 2012 run ended with a total of ~20fb^{-1}
  - Combined with 2011 run (5.6fb^{-1}), a total of over 25fb^{-1}
- 2013 – 2014: shutdown (LS1) ongoing to go to the design energy (13 – 14TeV) at high inst. Luminosity
- 2015 – 2017: $\sqrt{s}$=13 – 14TeV, L~10^{34}, ~100fb^{-1}
- 2018: Shut-down (LS2)
- 2019 – 2021: $\sqrt{s}$~=13 – 14TeV, L~2×10^{34}, ~300fb^{-1}
- 2022 – 2023: Shut-down (LS3)
- 2023 – 2030(?): $\sqrt{s}$=13 – 14TeV, L~5×10^{34} (HL-LHC), ~3000fb^{-1}

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)
  - Our Japanese colleagues have declared that they will bid for building ILC
  - Japan announced the selection of the site for the ILC in Aug. 2013!!
- Takes 10 years to build a detector



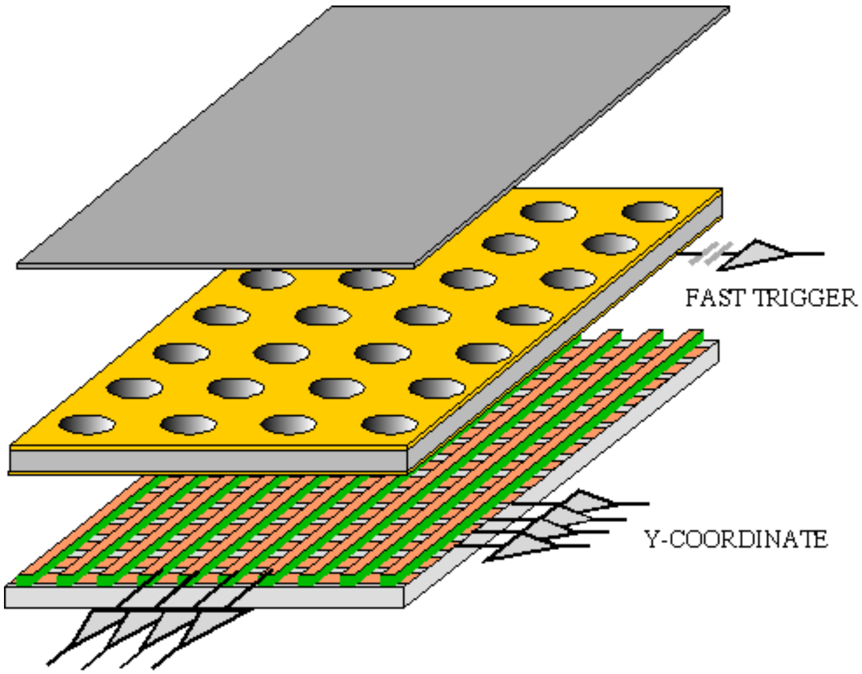
Circumference ~6.6km

~300 soccer fields

L~31km (~20 mi)

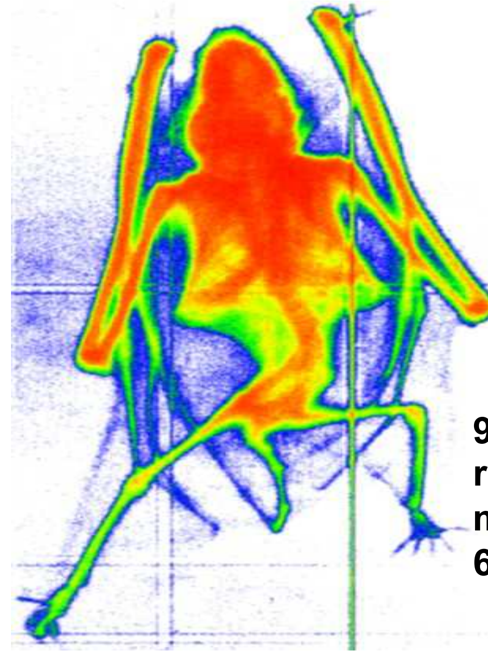
GEM Application Potential

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



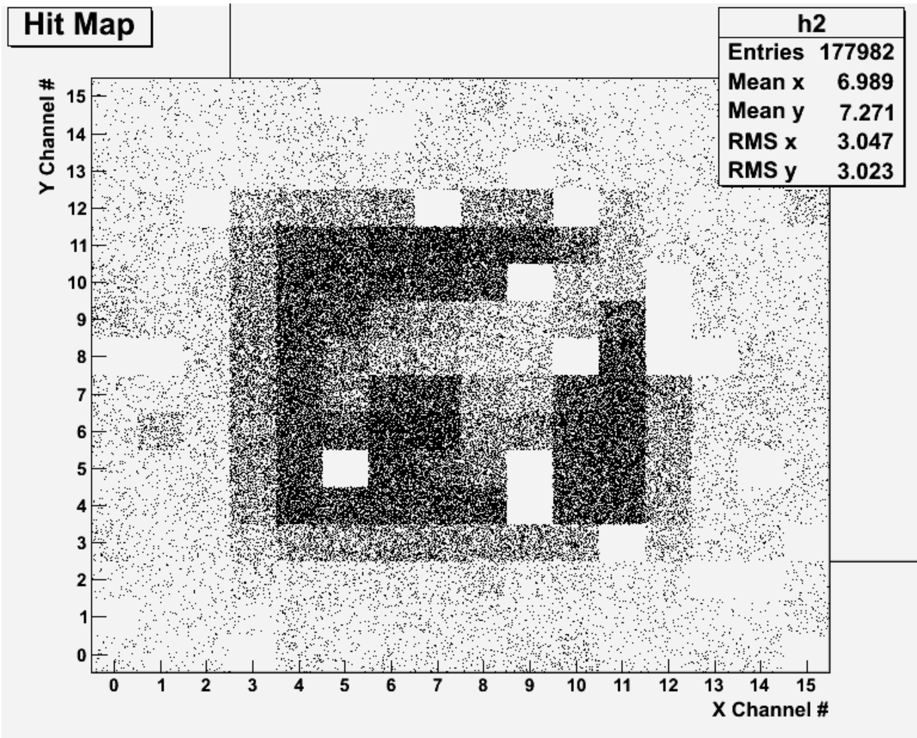
A. Bressan et al, Nucl. Instr. and Meth. A 425(1999)254
F. Sauli, Nucl. Instr. and Meth.A 461(2001)47

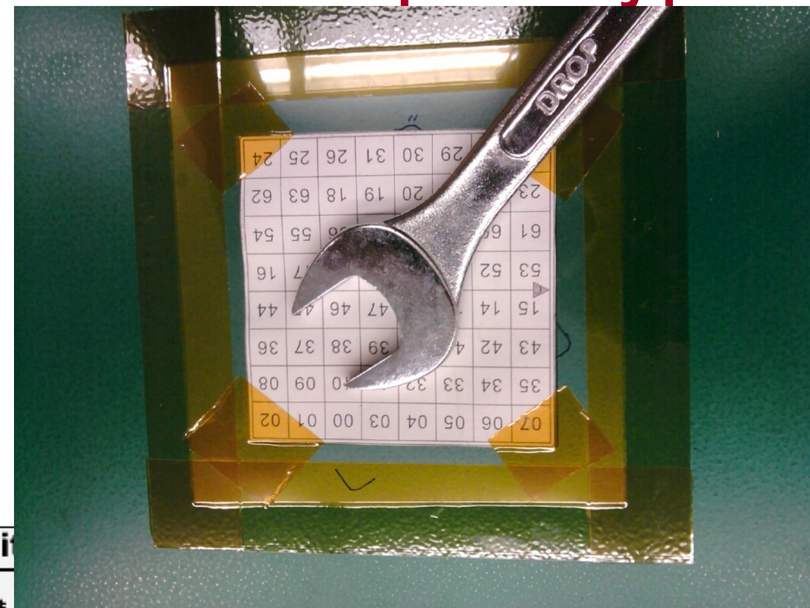
FAST X-RAY IMAGING

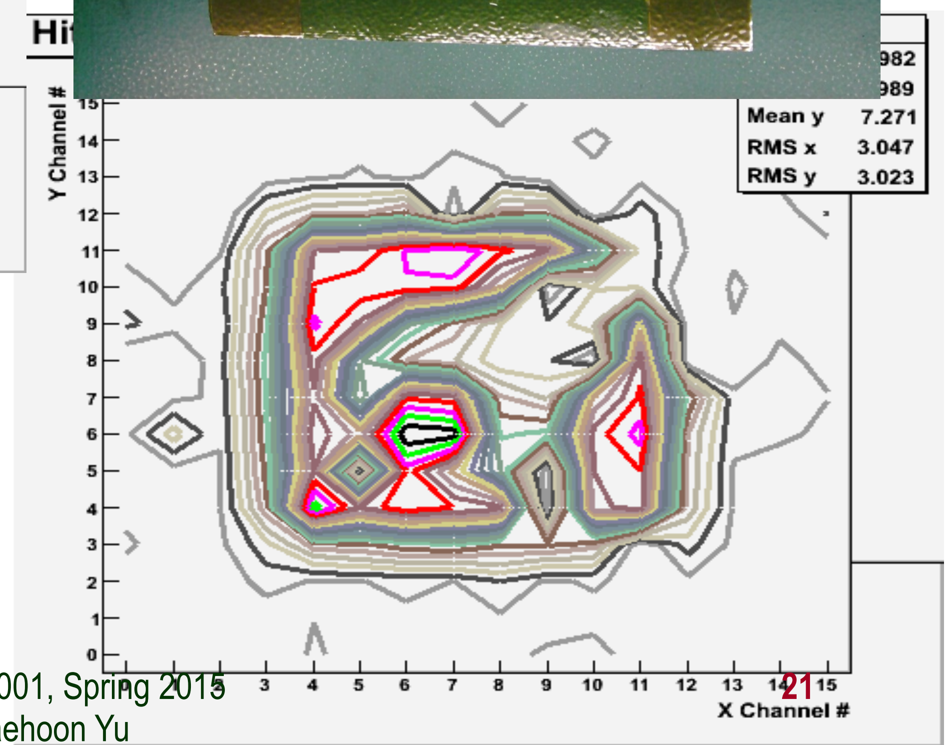


9 keV absorption radiography of a small mammal (image size ~ 60 x 30 mm^2)

X-ray Image of an object with a prototype





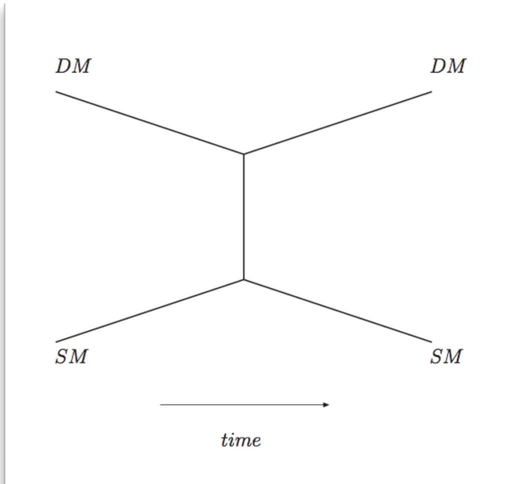


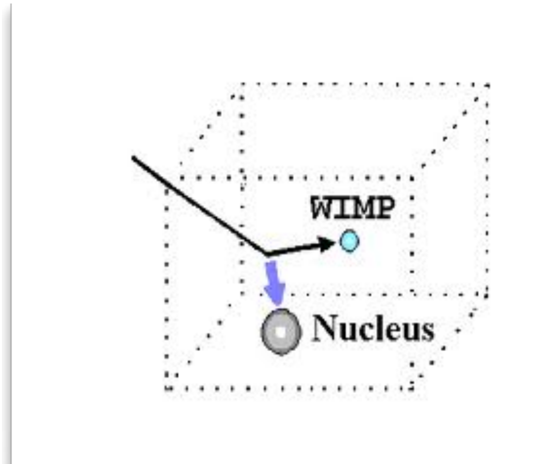
Can you see what the object is?

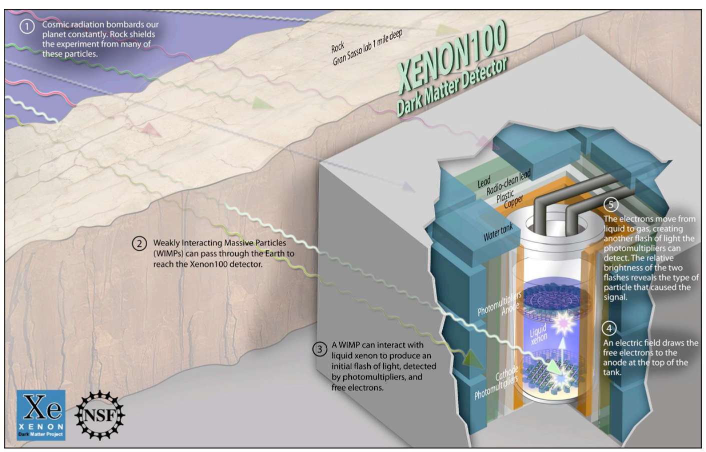
And in not too distant future, we could do ...

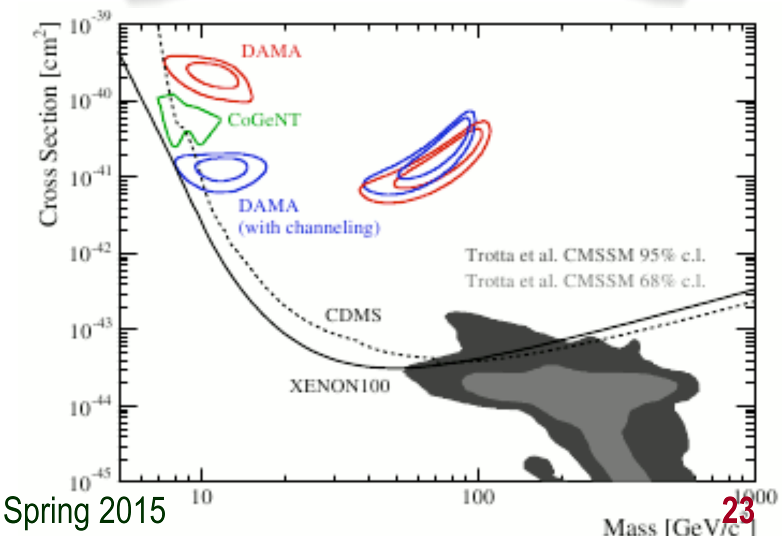
Dark Metter Search Motivation

- Now that the Higgs particle, a part of only 5% of the universe, is seen
- It is time for us to look into the 95% of the universe!!



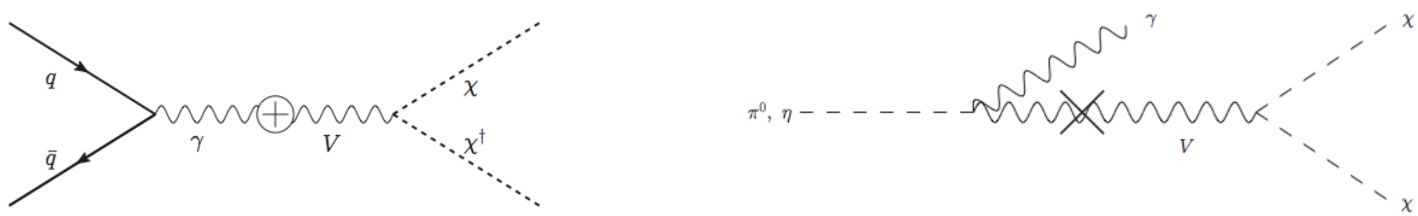




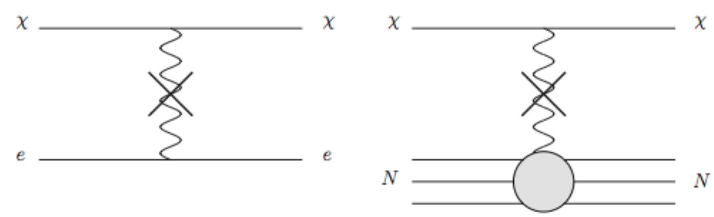


Light DM Production at High Intensity Accelerator

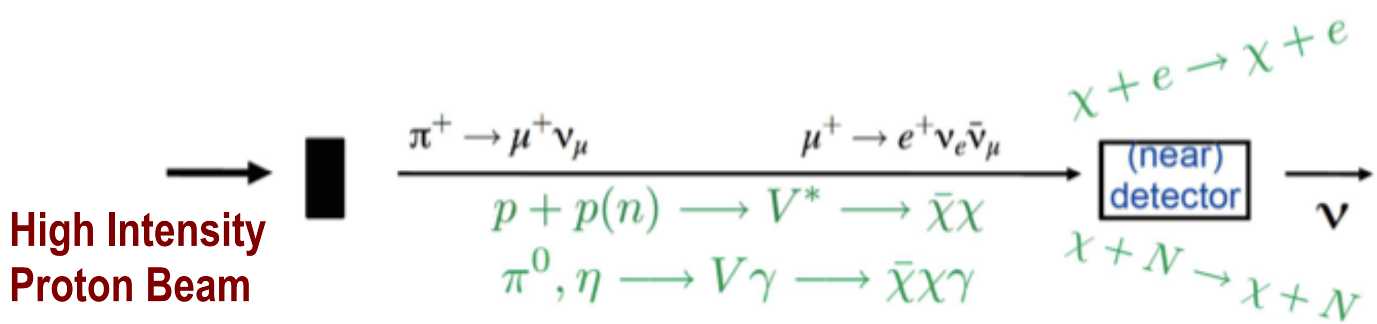
- Production of DM:



- Detection of DM:



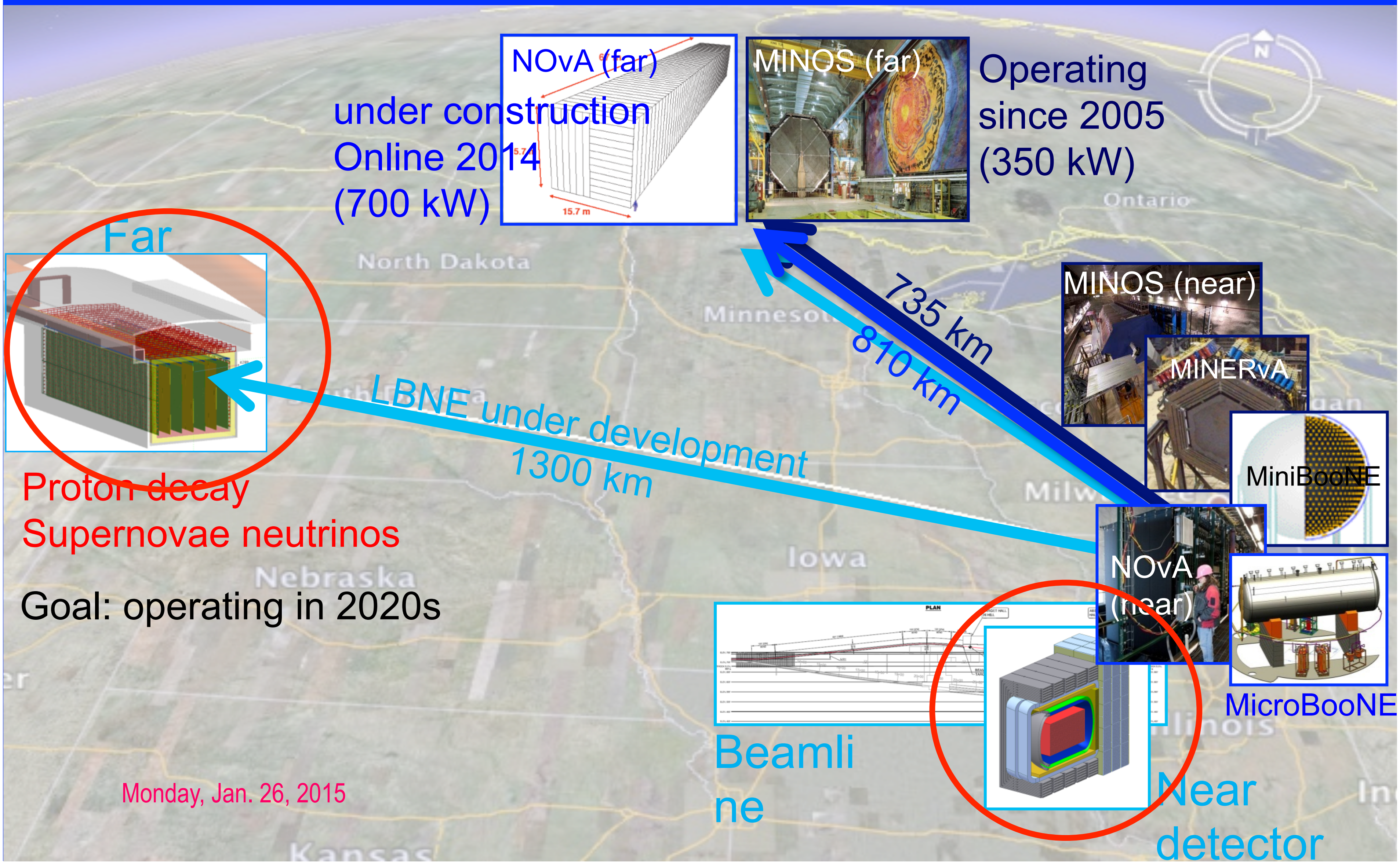
- How does a DM event look in an experiment?:



Search for Dark Matter at an Accelerator

- Fermi National Accelerator Laboratory is turning into a lab with very high intensity accelerator program

Intensity Frontier at Fermilab: Neutrinos



LBNE Neutrino Beam Assembly

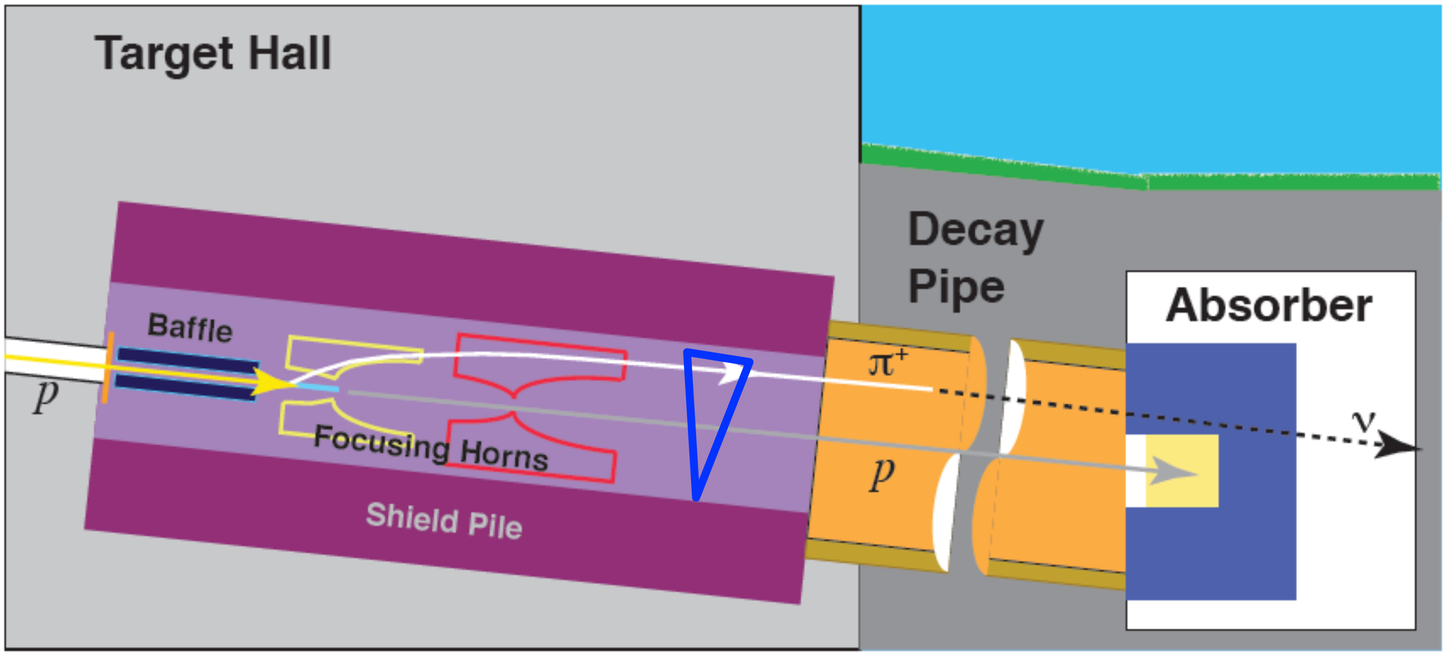
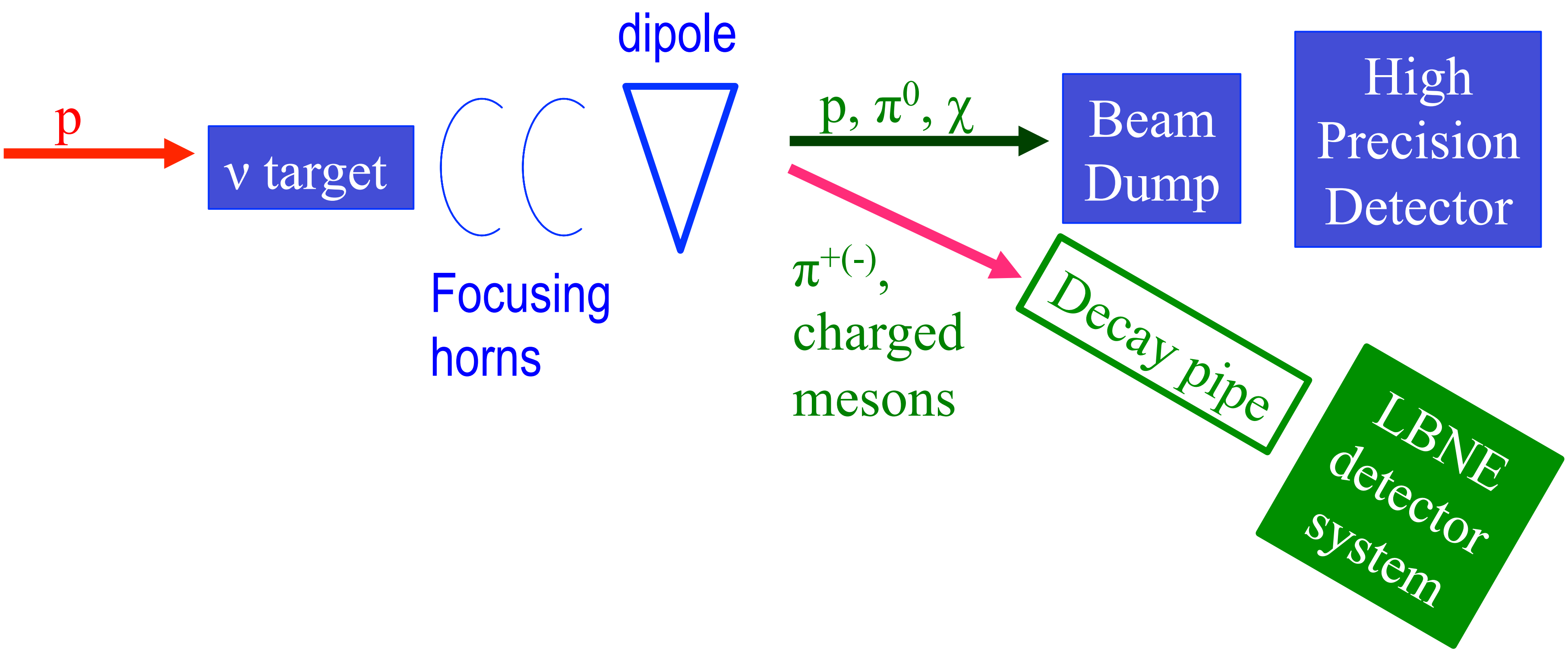


Figure 3–1: A cartoon of the neutrino beamline showing the major components of the neutrino beam. From left to right, the beam window, horn-protection baffle, target, the two toroidal focusing horns, decay pipe and absorber. The air volume surrounding the components between the window and the decay pipe is called the target "chase". The target chase and rooms for ancillary equipment (power supplies, cooling, air recirculation and so on) is included in the area called the target complex (not pictured).

Doubly Sign-selected Horn System (DSHS)

- Add a dipole after the mesons are fully focused with the 2nd horn



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 four experiments
  - E Long Baseline Neutrino Facility (ELBNF), an $1,3B 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??

So what?

- Linear collider and advanced detectors are being developed for future precision measurements of Higgs and other newly discovered particles
- The new frontier will give us a change to look for dark matter at an accelerator and other paradigm changing phenomena
- Outcome and the bi-product of HEP research improves our daily lives directly and indirectly
  - WWW came from HEP
  - GEM will make a large screen low dosage X-ray imaging possible
- Many technological advances happened through the last 100 years & will happen through the coming 100 yrs
- Continued and sufficient investments to forefront scientific endeavor is essential for the future!

What do we want to learn in this class?

- The physics that provided fundamentals to the technical progress for us
- Learn concepts of quantum theory for microscopic phenomena and relativity for phenomena with high speed
- Learn physical principles that we still exploit
- Learn skills to express observations and measurements in mathematical language
- Learn skills to research literatures and express your research in systematic manner in writing
- Build up confidence in your physics abilities and to take on any challenges laid in front of you!!

Most importantly, let us have a lot of FUN!!

In this course, you will learn…

- Concepts and derivation of many of the modern physics
  - History at the beginning of the new era
  - Special relativity
  - Quantum theory
  - Atomic physics
  - Condensed Matter physics
  - Nuclear physics
  - Particle Physics
- Focus on learning about the concepts with less complicated math
  - You will learn some Quantum calculations and understand the concept of probabilities
- Expectation at the end of the semester: You will be able to understand what fundamental physics provides the bases for the current technology

Why do Physics?

Exp. $\{$
- To understand nature through experimental observations and measurements (**Research**)

Theory $\{$
- Establish limited number of fundamental laws, usually with mathematical expressions
- Predict the nature's course

$\Rightarrow$ Theory and Experiment work hand-in-hand

$\Rightarrow$ Theory works generally under restricted conditions

$\Rightarrow$ Discrepancies between experimental measurements and theory are good for improvements

$\Rightarrow$ Improves our everyday lives, even though some laws can take a while till we see them amongst us

Brief History of Physics

- AD 18th century:
  - Newton's Classical Mechanics: A theory of mechanics based on observations and measurements, concepts of many kinematic parameters, including forces
    - First unification of forces – planetary forces and forces on the Earth
- AD 19th Century:
  - Electricity, Magnetism, and Thermodynamics
- Late AD 19th and early 20th century (Modern Physics Era, after 1895)
  - Physicists thought everything was done and nothing new could be discovered

State of Minds in late 19th Century

- **Albert A. Michelson, 1894**

  The more important fundamental laws and facts of physical science have all been discovered, and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote. Our future discoveries must be looked for in the sixth place of decimals!

- **William Thompson (Lord Kelvin), 1900**

  There is nothing new to be discovered in physics now. All that remains is more and more precise measurement.

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  - Physicists thought everything was done and nothing new could be discovered
  - Concept of atoms did not quite exist
  - There were only handful of problems not well understood late 19th century became the basis for new discoveries in 20th century
  - That culminates in understanding of phenomena in microscopic scale and extremely high speed approaching the speed of light
  - Einstein's theory of relativity: Generalized theory of space, time, and energy (mechanics)
  - Quantum Mechanics: Theory of atomic phenomena