PHYS 1441 – Section 001
Lecture #1

Monday, June 3, 2019

Dr. Jaehoon Yu

- Who am I?
- How is this class organized?
- What is Physics?
- What do we want from this class?
- Brief history of physics
- Standards and units

Today's homework is homework #1, due 11pm, this Wednesday, June 5!!

Announcements

- Plea to you: Please turn off all your electronic devices, including cell-phones and all types of computers before the start of all classes!
- Reading assignment #1: Read and follow through all sections in appendix A by tomorrow, June 4
  - A-1 through A-7
- There will be a quiz on this and what we have learned on Ch. 21 on this Wednesday, June 5.

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
    - Fundamental 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 endeavor
    - 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 in the first place?
    - Make everyday lives better to help the whole humanity live well as an integral part of the universe

We always wonder…

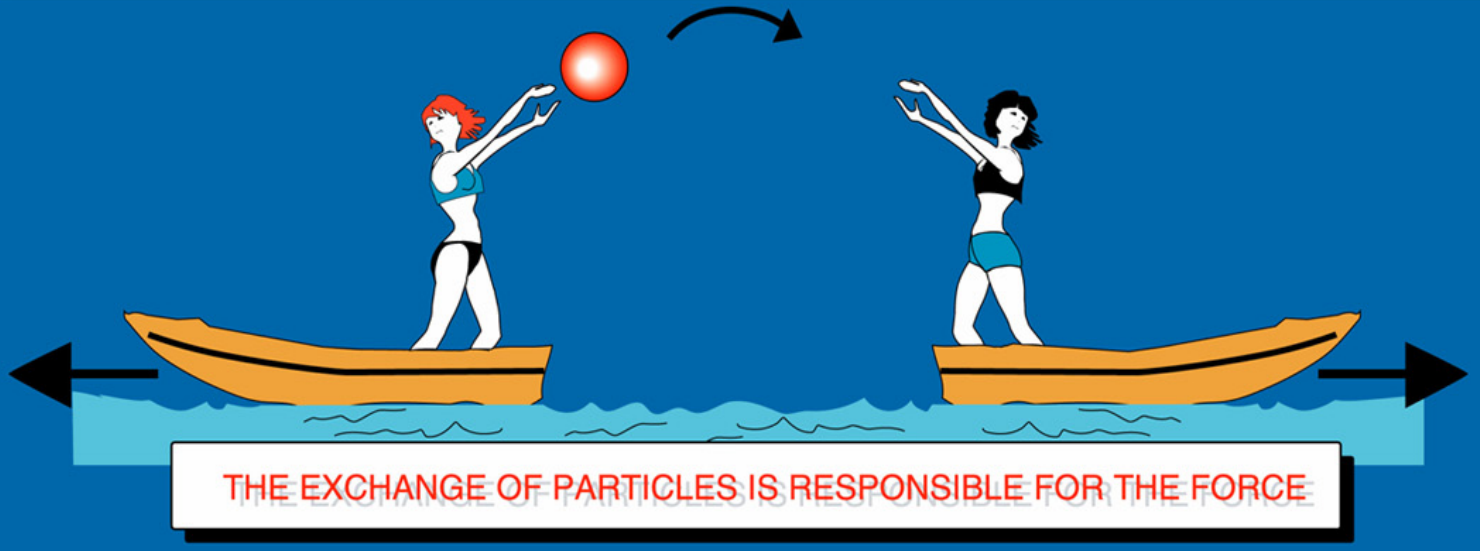
- What makes up the universe?
- How does the universe work?
- What holds the universe together?
- How can we live in the universe well?
- Where do we all come from?

High Energy Physics

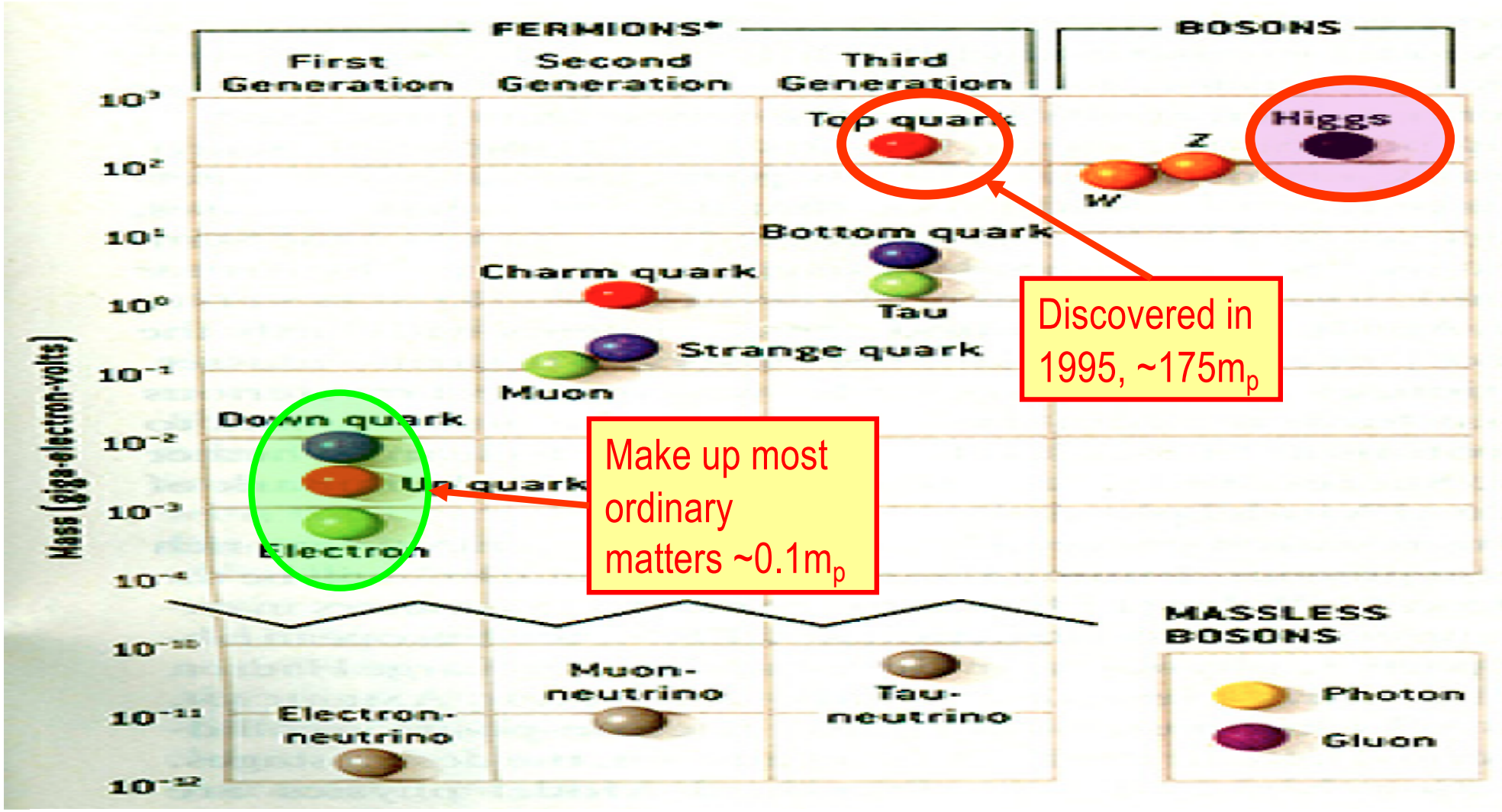
- Definition: A field of physics that pursues understanding the fundamental constituents of matter and basic principles of interactions between them.
- Known interactions (forces):
  - Gravitational Force
  - Electromagnetic Force
  - Weak Nuclear Force
  - Strong Nuclear Force
- Current theory: The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

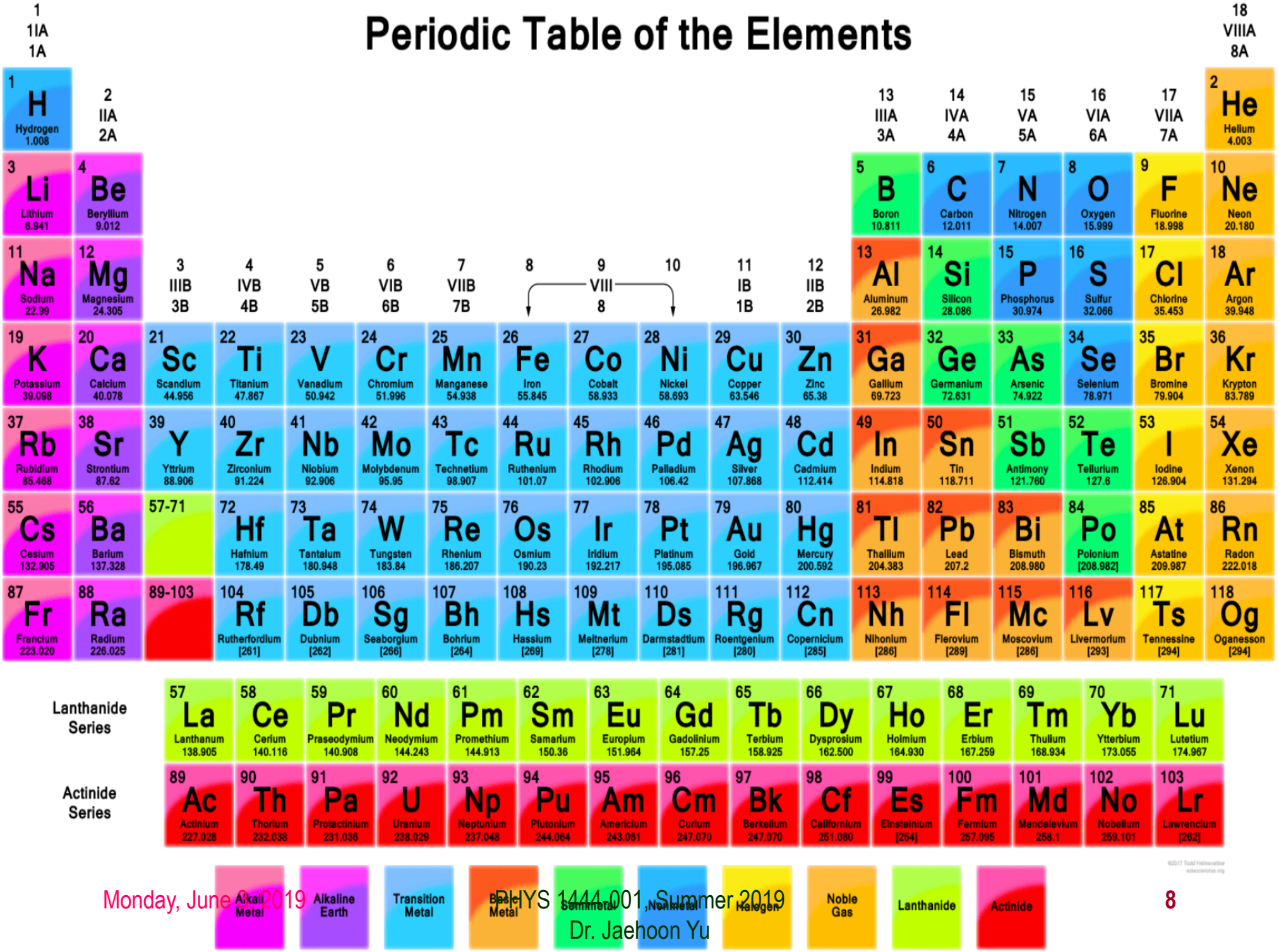


HEP and the Standard Model



- 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!

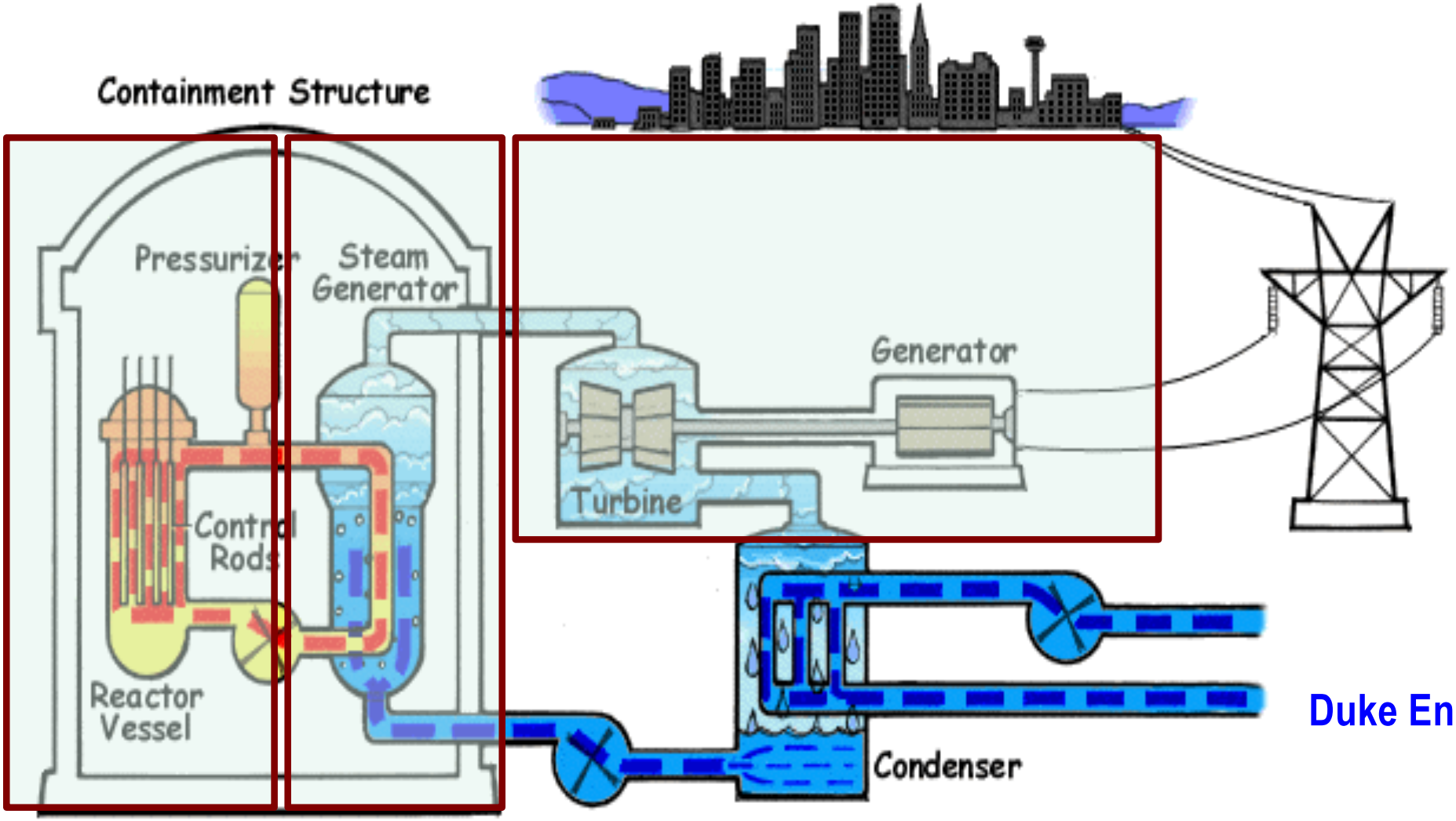
Periodic Table of the Elements



What are some issues in HEP?

- Why is the mass range so large ($0.1m_p$ – $175\ m_p$)?
- Is the particle discovered at the LHC really the Higgs particle?
- Why is the matter in the universe made only of particles?
- Neutrinos have mass!! (**OMG!! The SM is broken!!!**)
  - What are the mixing parameters, particle-anti particle asymmetry and the neutrino 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

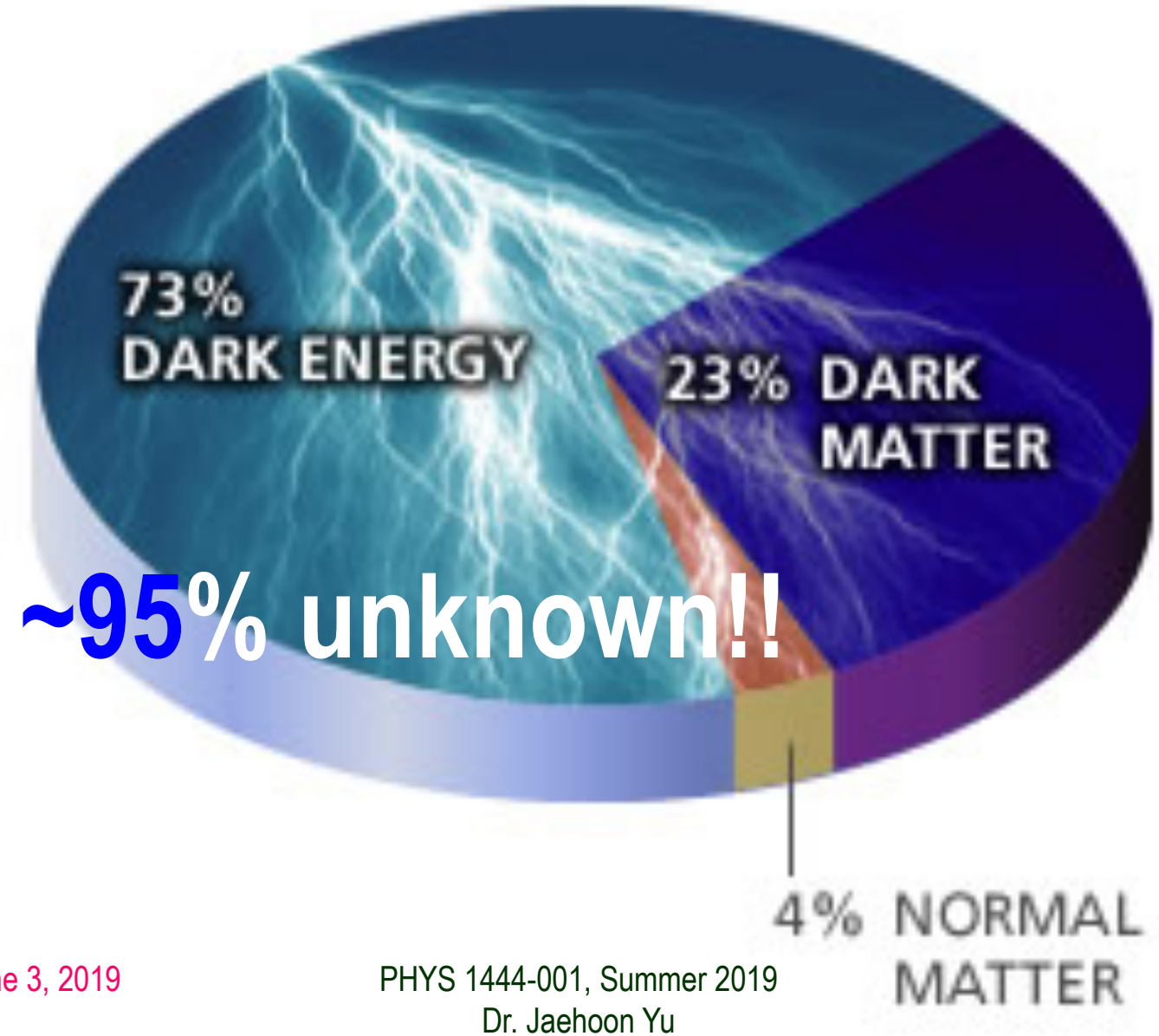
My 1000 year dream: Skip the whole thing!

Make electricity directly from nuclear force!

So what's the problem?

- Why is the mass range so large ($0.1m_p$ – $175\ m_p$)?
- Is the particle we 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?
- Is the picture we present the real thing?

What makes up the universe?



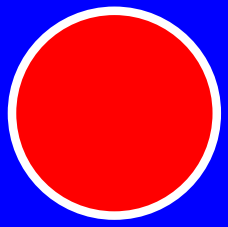
~95% unknown!!

So what's the problem?

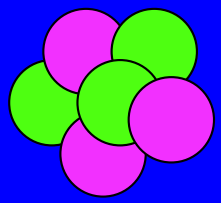
- Why is the mass range so large ($0.1m_p$ – $175\ m_p$)?
- Is the particle we discovered really the Higgs particle?
- Why is the matter in the universe made only of particles?
- Neutrinos have mass!! What are the mixing parameters, particle-anti particle asymmetry and mass ordering?
- Why are there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

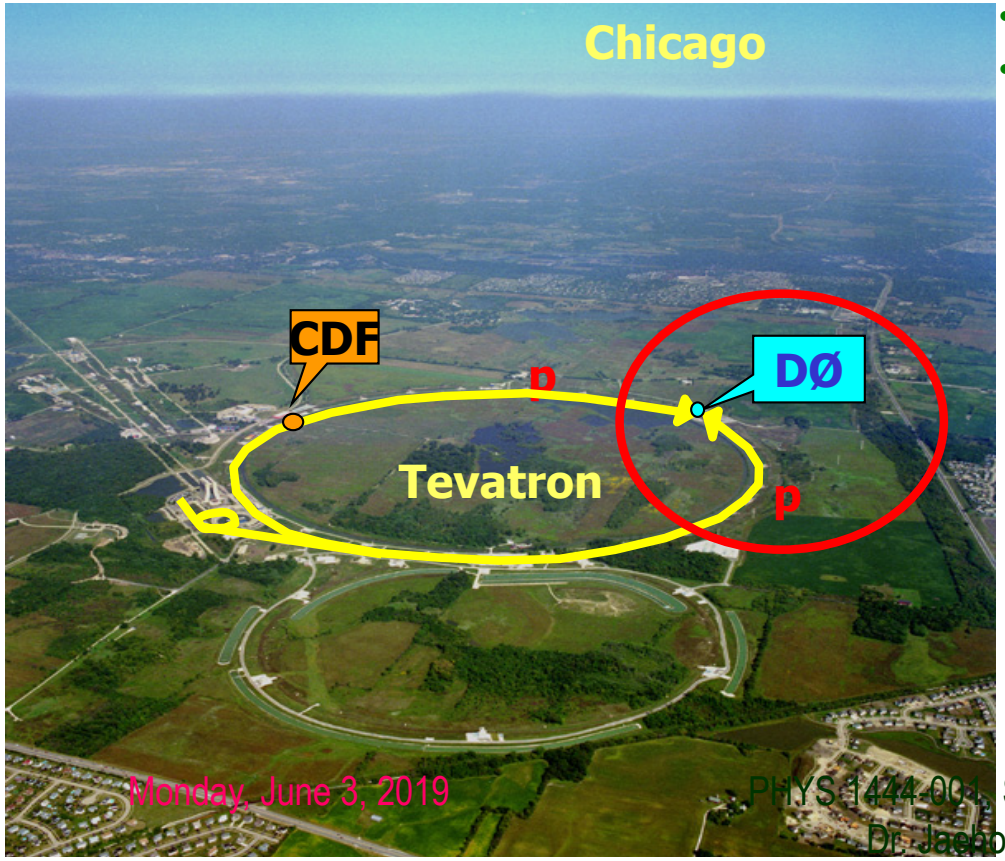
They make particles last seen
in the earliest moments of the universe.

Particle and anti-particle annihilate.

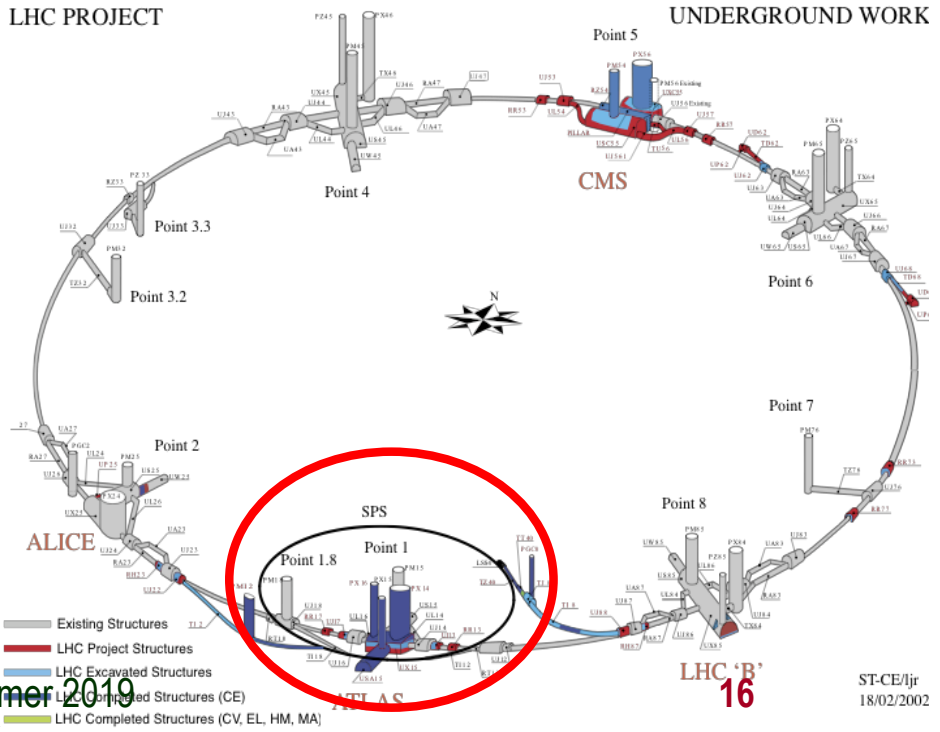
$$E = mc^2$$

Fermilab Tevatron and LHC at CERN

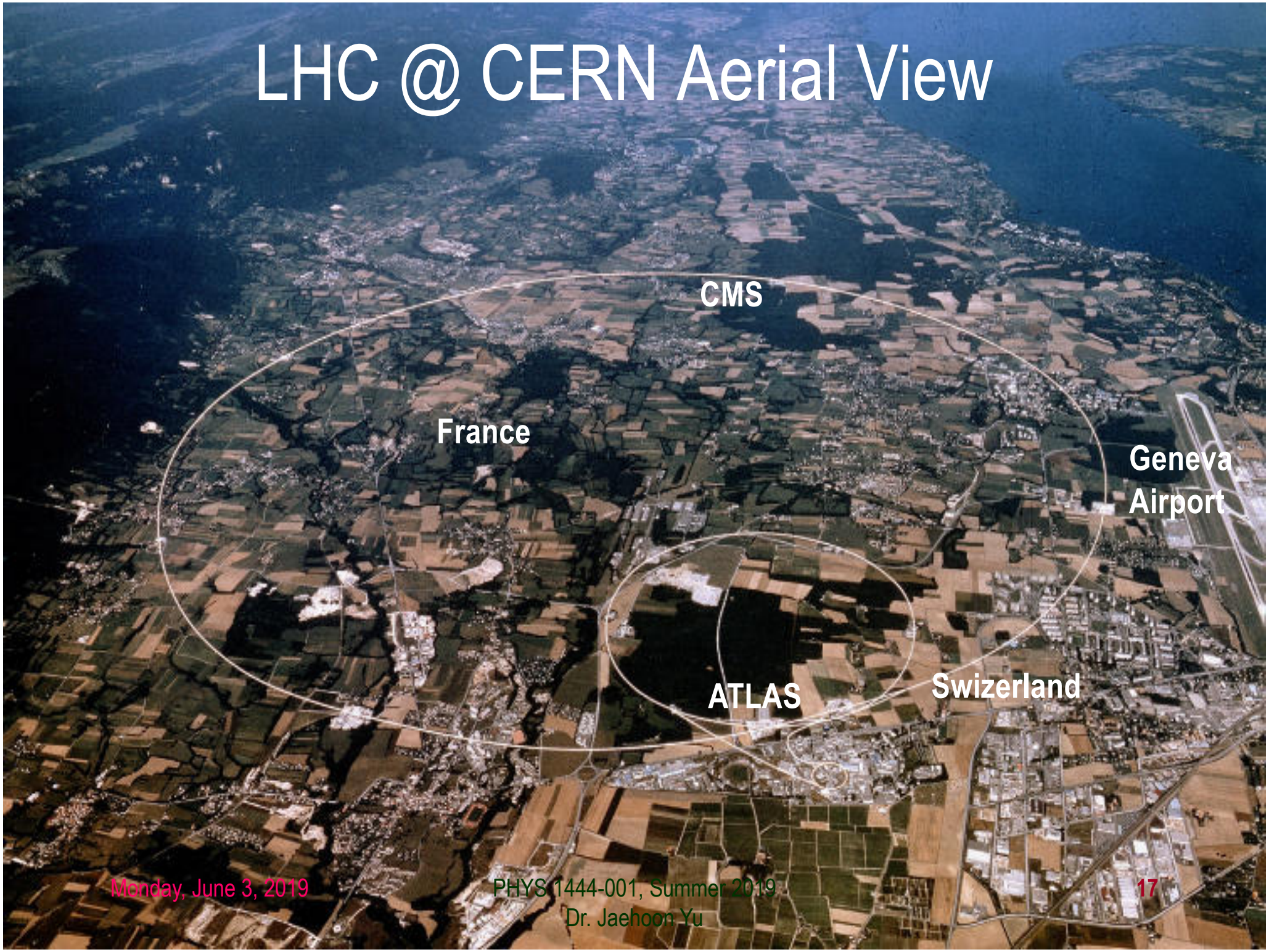
- World's Highest Energy proton-anti-proton collider
  - 4km (2.5mi) circumference
  - E_{cm}=1.96 TeV (=6.3x10^{-7}J/p➔ 13M Joules on the area smaller than 10^{-4}m^2)
  - Equivalent to the kinetic energy of a 20t truck at the speed 130km/hr
    - ~100,000 times the energy density at the ground 0 of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



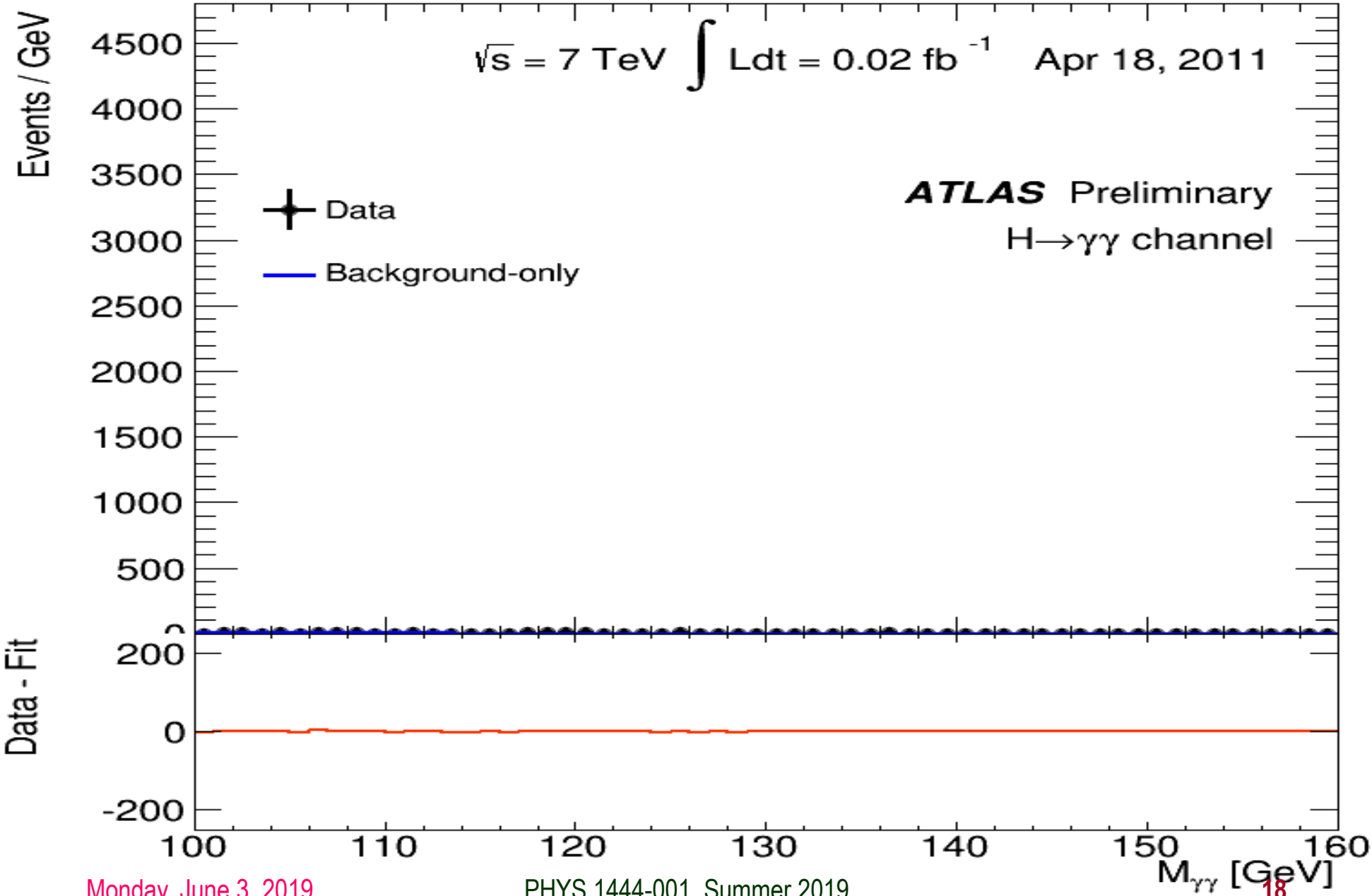
- World's Highest Energy p-p collider
  - 27km (17mi) circumference, 100m (300ft) underground
  - Design E_{cm}=14 TeV (=44x10^{-7}J/p➔ 362M Joules on the area smaller than 10^{-4}m^2)
  - ➢ Equivalent to the kinetic energy of a B727 (80tons) at the speed 310km/hr
    - ➢ ~3M times the energy density at the ground 0 of the Hiroshima atom bomb
- **Discovered a new heavy particle that looks Higgs in 2012**
- **Search for new particles has been ongoing!!**
- **Shut down for two years begun for high stat. upgrade!**



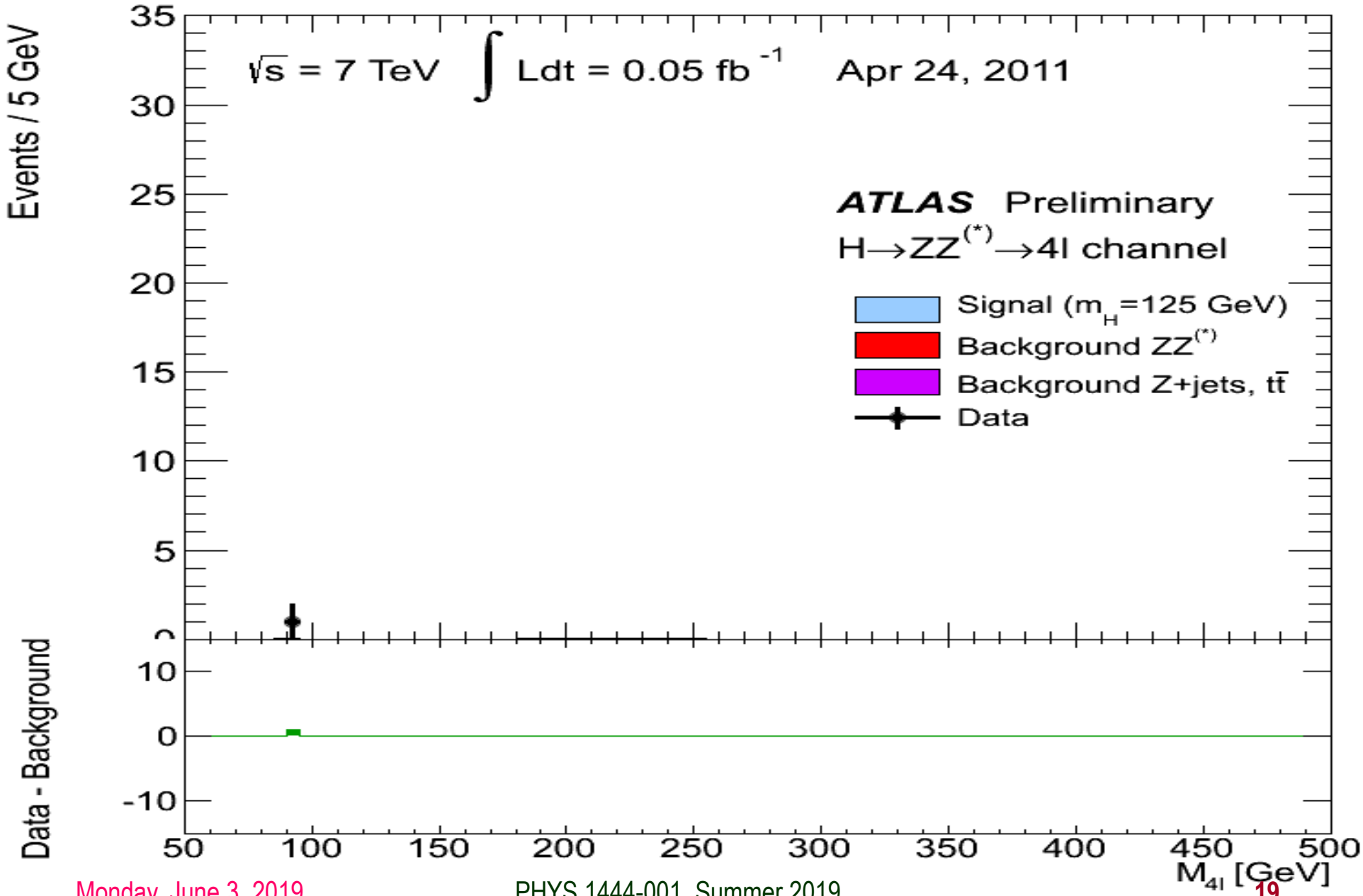
LHC @ CERN Aerial View



What did statistics do for Higgs?



How about this?



Discovery of the God Particle in 2012

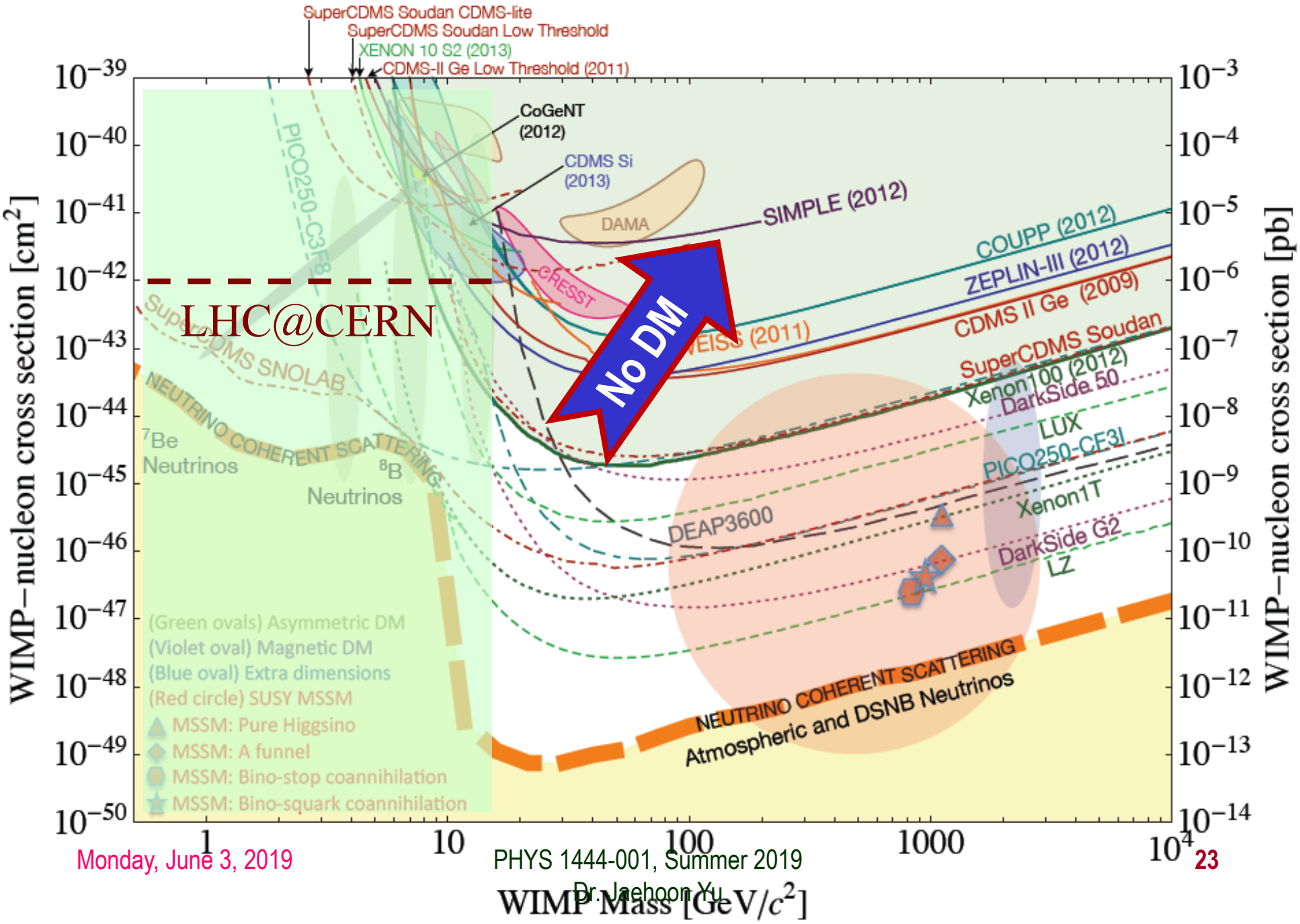
Fermilab Neutrino Program

- Fermilab is building high intensity proton beam based neutrino physics facility (LBNF – Long Baseline Neutrino Facility)
  - Precision neutrino oscillation properties
    - Mass Hierarchy, CP phase, etc
    - Supernova detection
  - Physics beyond Standard Model
  - Search for sterile neutrinos, dark matter, etc
- Require capable ND and large mass underground FD w/ a capability for low energy detection, good position resolution, timing resolution and good particle ID
- Also a short-baseline neutrino program

Light DM Production at High Intensity Accelerator

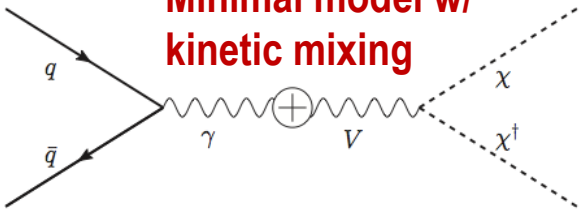
- The Higgs particle, a part of only 5% of the universe, may've been seen
- The remaining 95% of the universe must explored further!!

Dark Matter Search Motivation

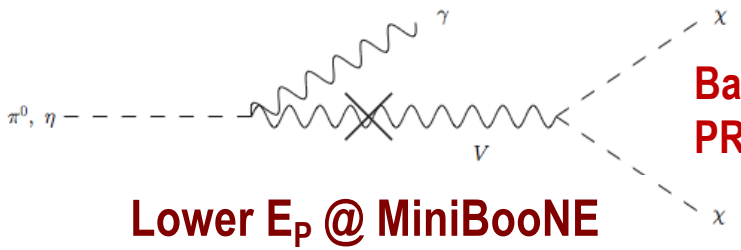


Light DM Production at High Intensity Accelerator

- The Higgs particle, a part of only 5% of the universe, may've been seen
- The remaining 95% of the universe must be explored further!



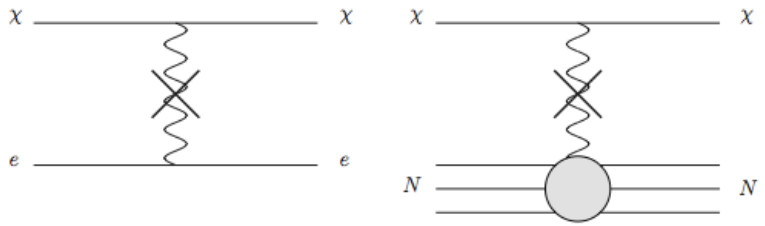
Higher E_P @ DUNE



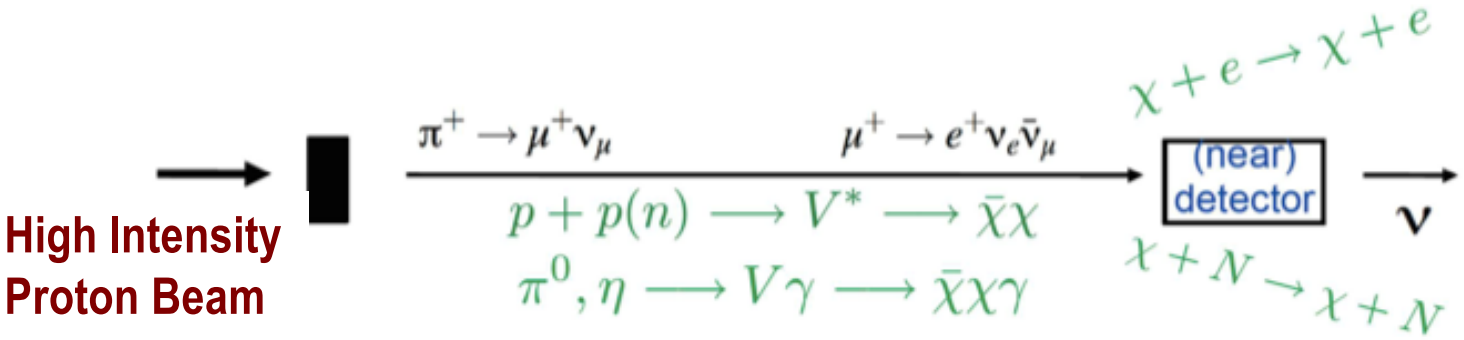
Battell *et al.*, PRD80, 095024

Lower E_P @ MiniBooNE

- Detection of DM (elastic):

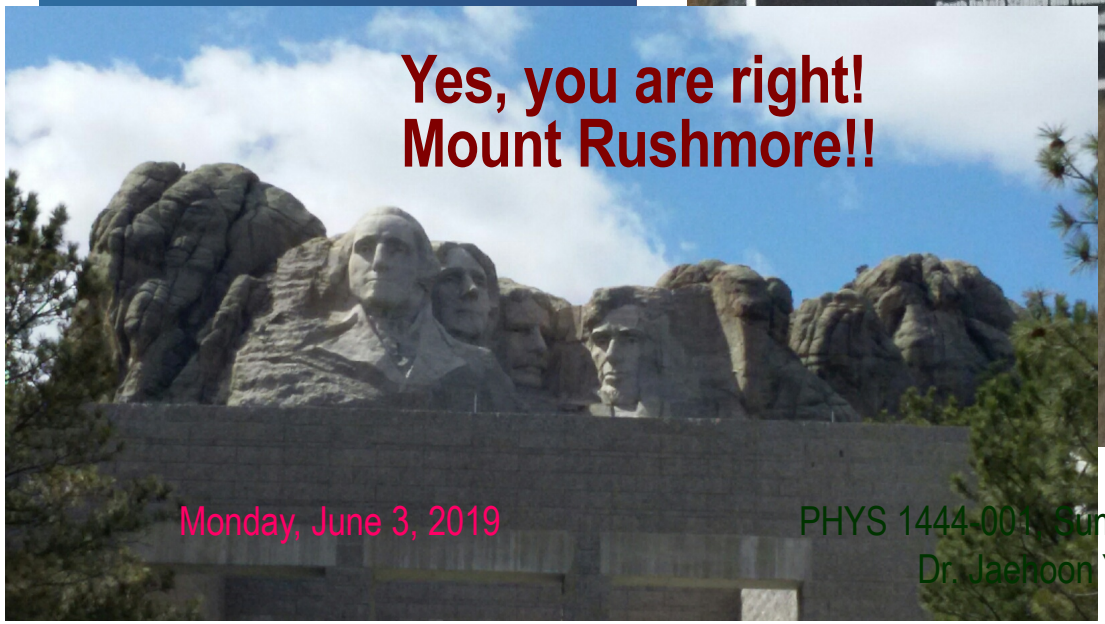


- How does a DM event look in an experiment?:



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

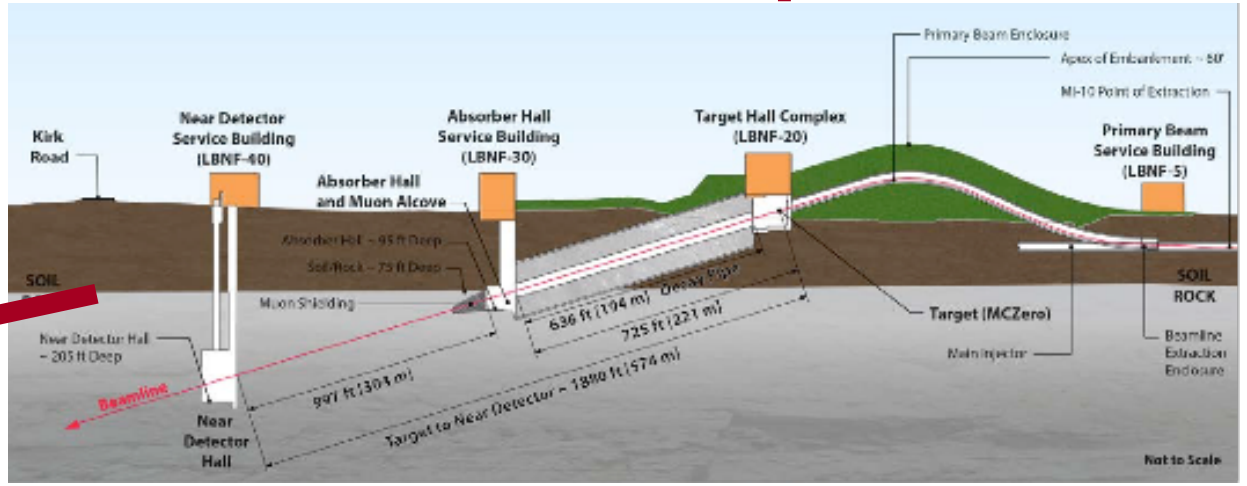


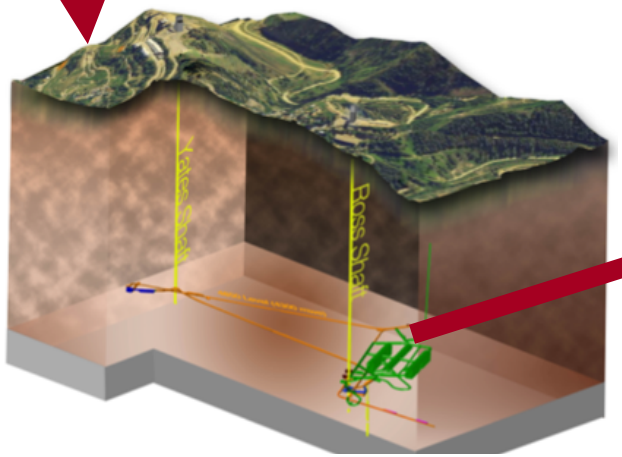
- Nobel Winning Neutrino Discovery by Ray Davis in 1960's
- Many Dark Matter experiments in progress
- New DUNE area to be excavated shortly

The Next Big Thing - DUNE Experiment

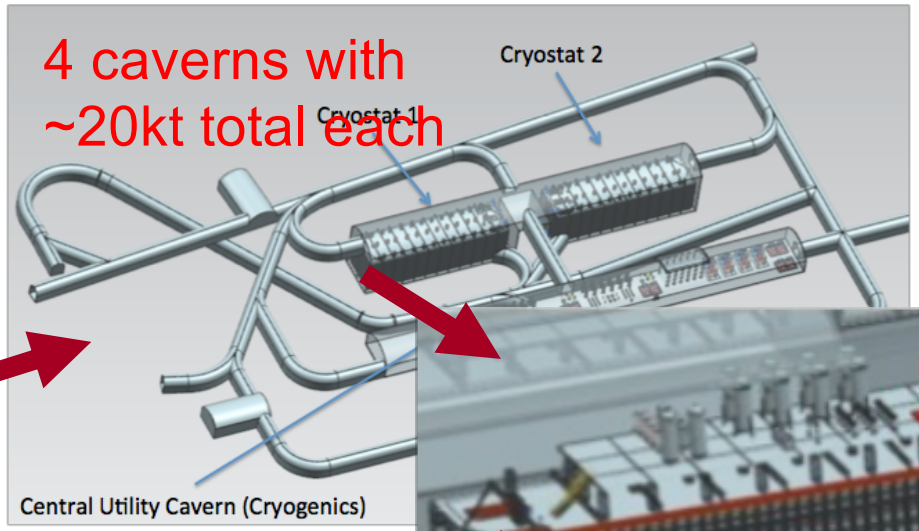
- Stands for Deep Under Ground Neutrino Experiment
- The flagship long baseline (1300km -800mi) ν experiment
  - 1500m underground in an old South Dakota gold mine
- With very high intensity proton beams (1.2MW → 2.4MW!)
  - Result in large number of neutrinos
  - A great potential for DM & other physics beyond the Standard Model
  - Food for thoughts! How many 100GeV protons per second do these beam powers correspond to?
- Large mass (~80kt! total) LAr Detector at SURF
- Powerful near detector
- Was born March 2015! A two year old baby!
  - Combination of two large proposals – LBNE (US) and LBNO (EU)
- 1020 collaborators from ~174 institutes in 30 countries

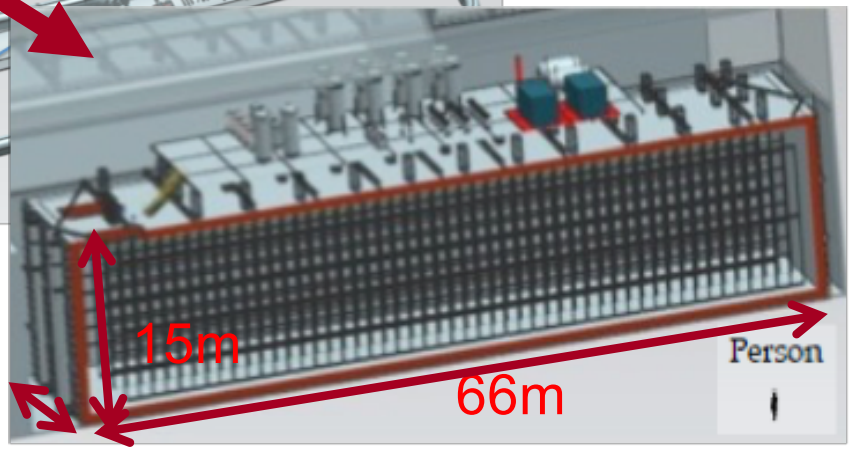
The Components of the DUNE Experiment





1500m underground



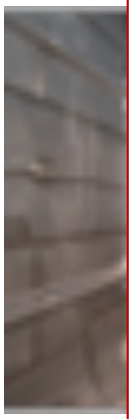


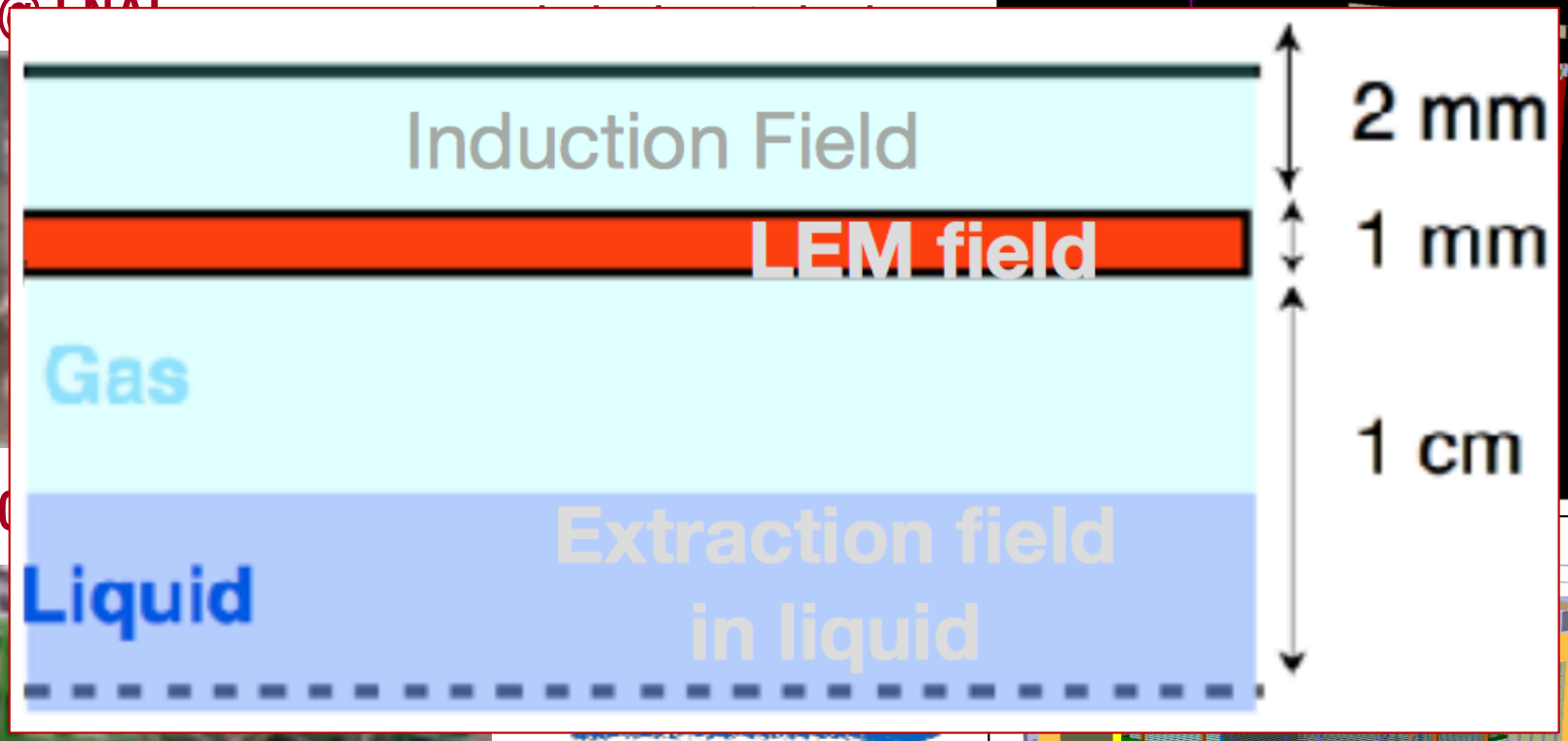
15m

Prototyping the DUNE Experiment

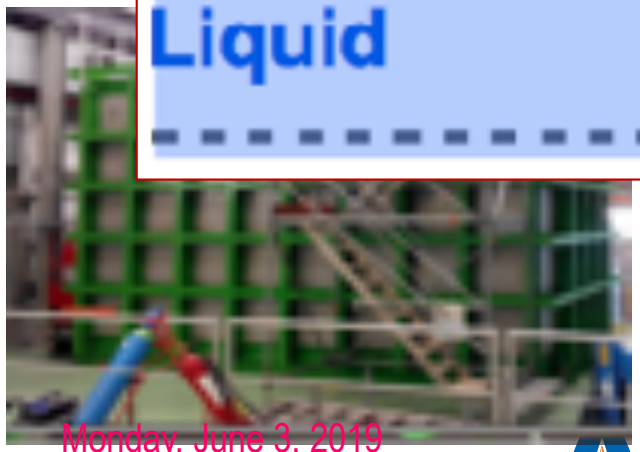
- Building four 10kt active volume LAr Detectors very challenging!
- Need to understand many aspects of the detector technology
- Two full scale prototype detectors under construction at CERN – SP and DP

35T @ FNAL

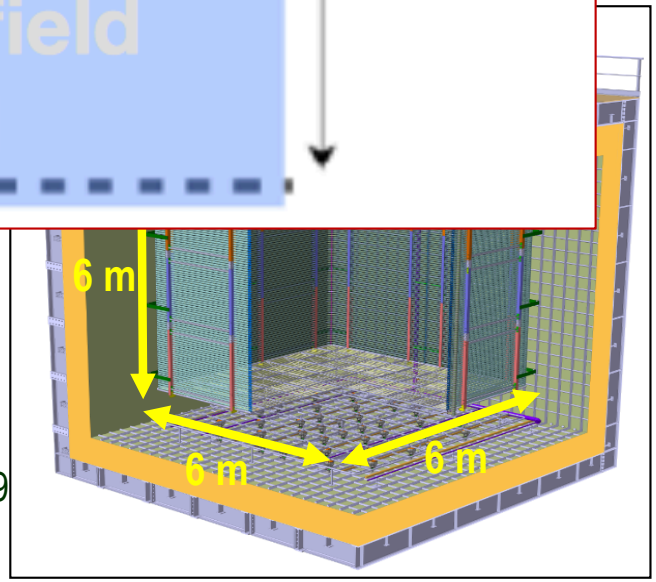




WA10

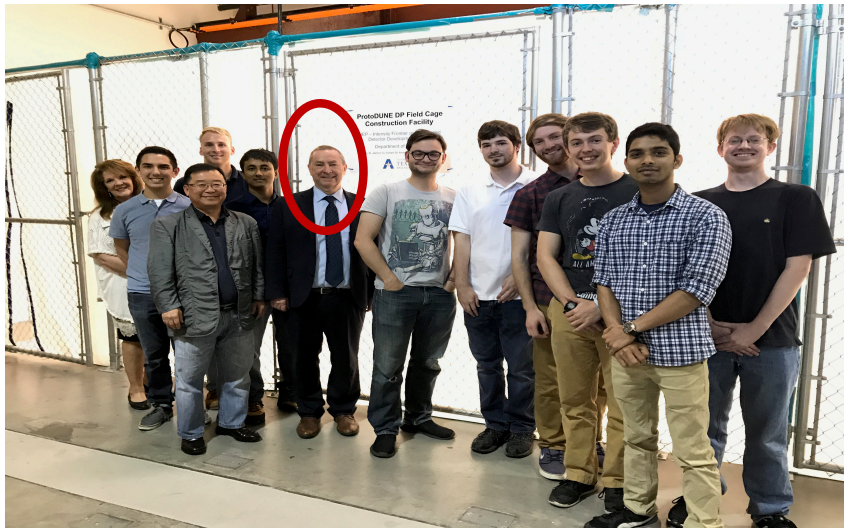


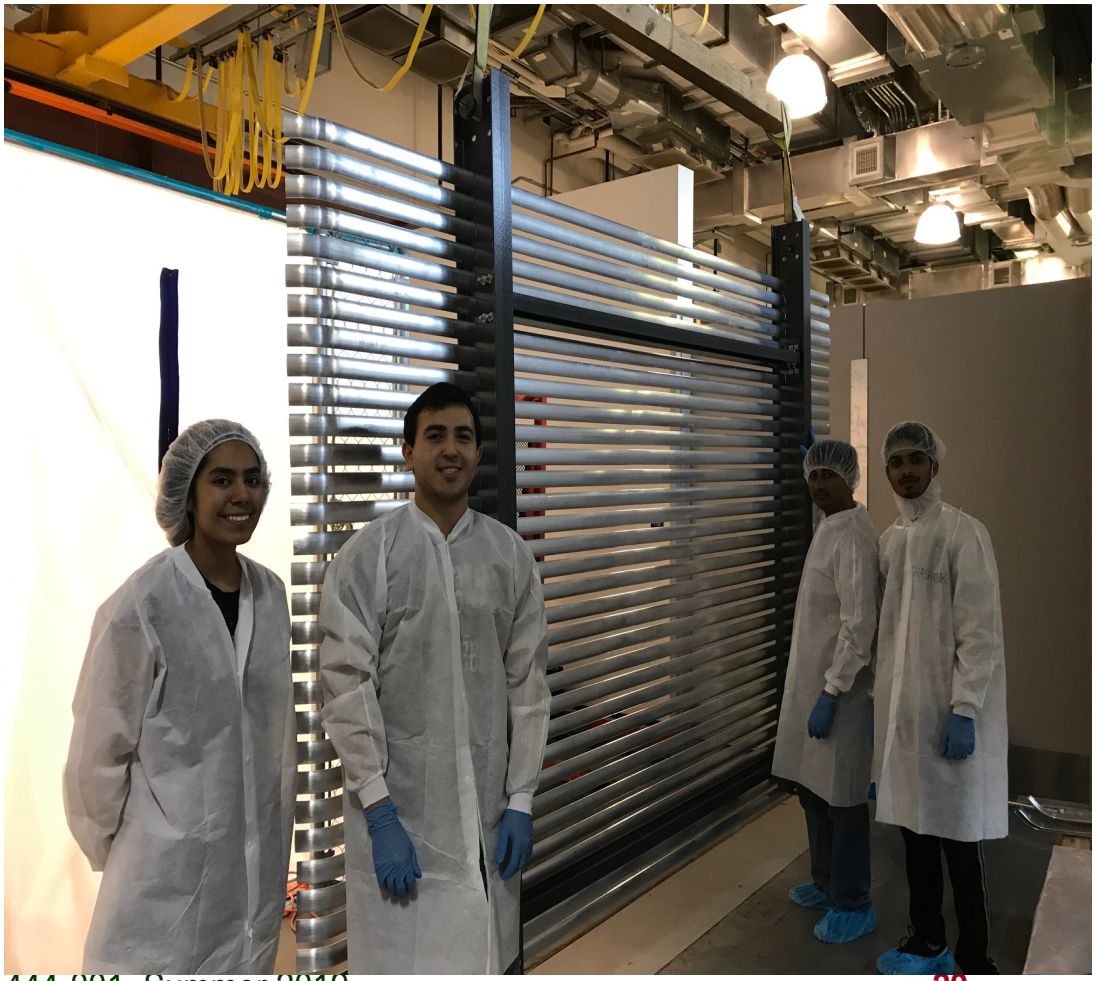
protoDUNE DP@CERN
6mx6mx6m Active



Field Cage Construction!!

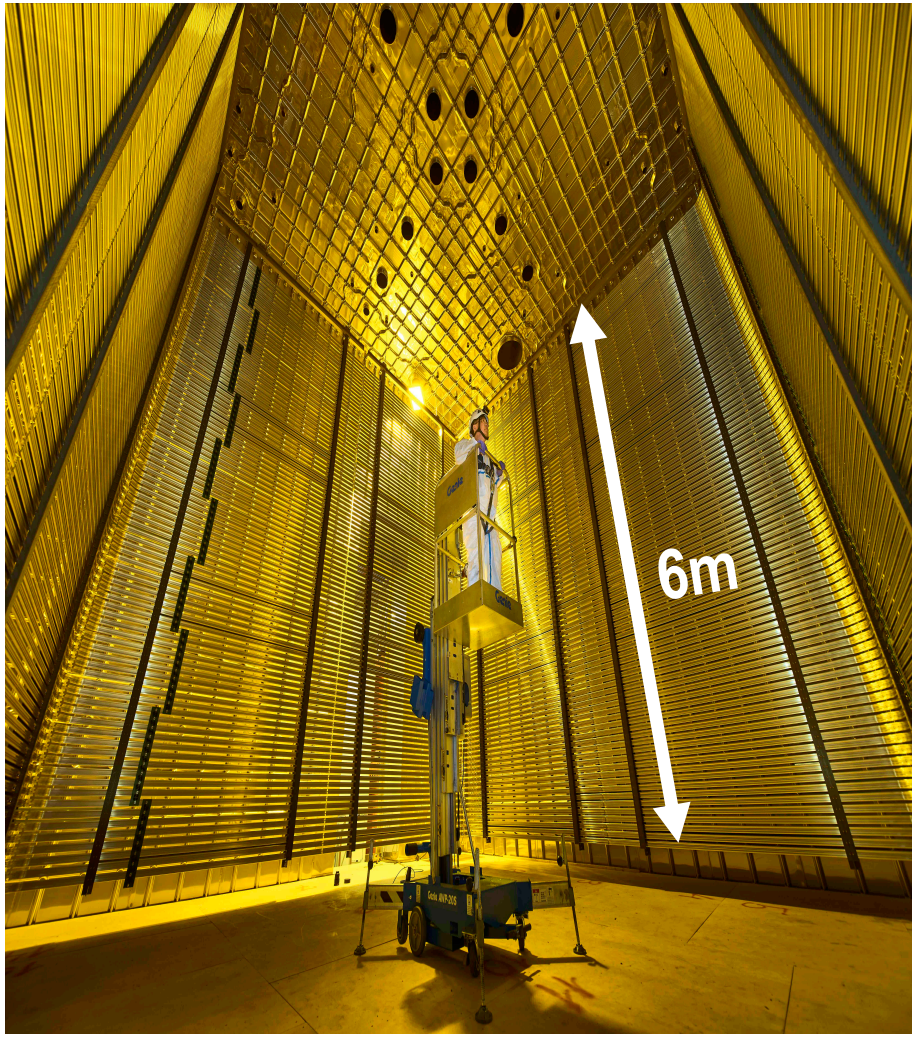
- Field cage provides a uniform electric field for the ionization electrons to drift toward the collection plane
- Modularized design ➔ UTA responsible for ProtoDUNE DP FC

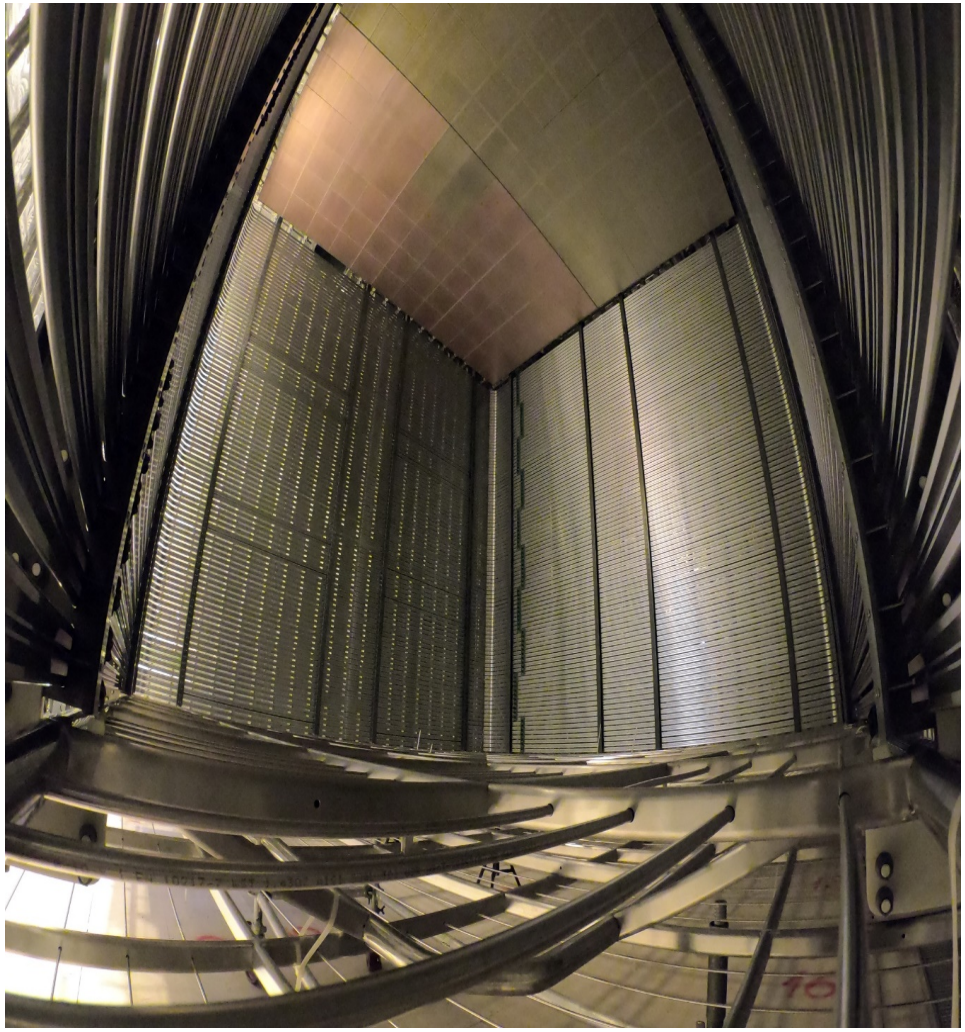




ProtoDUNE DP Detector

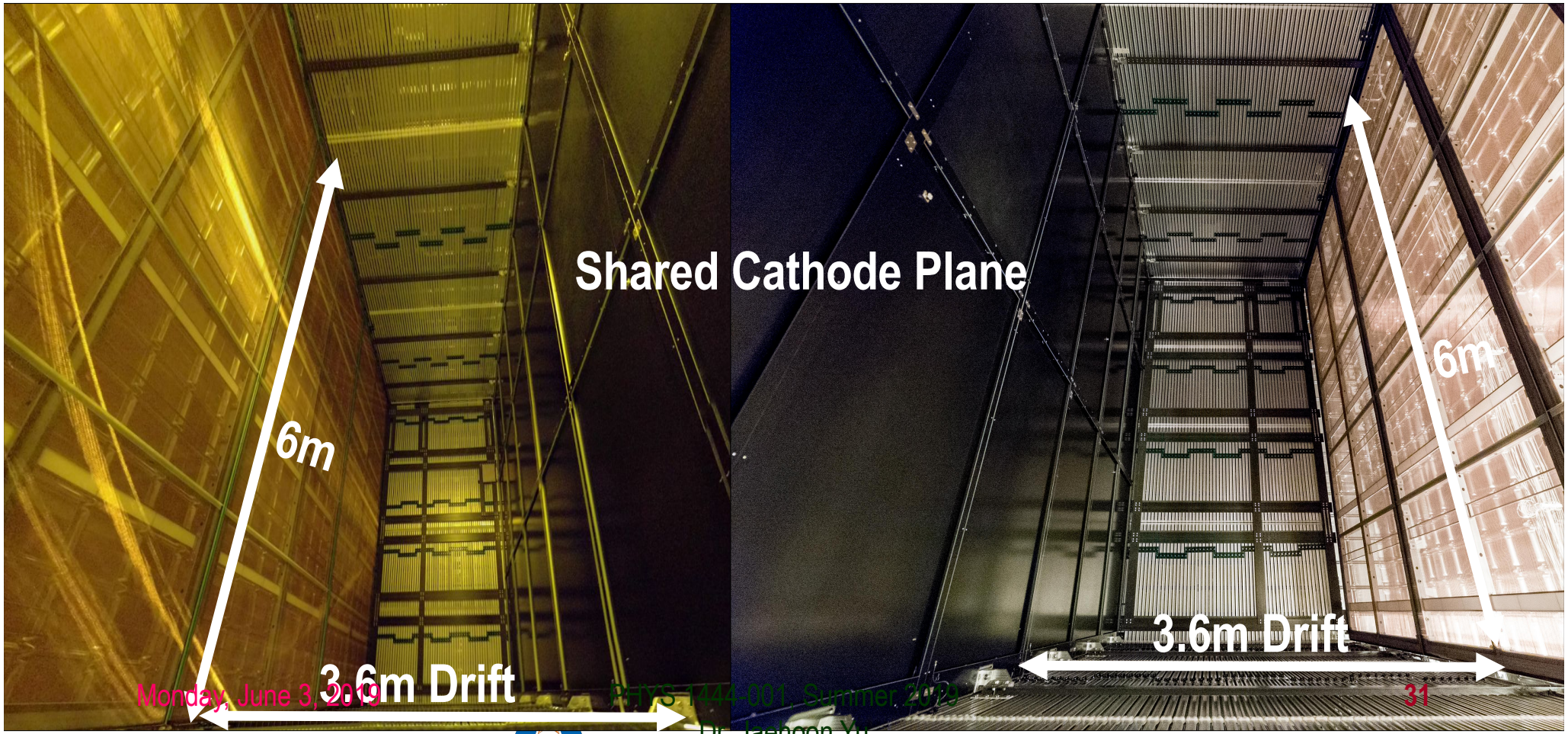
- Cryostat welded shut last week!!
- Gas Ar purge, cooldown and fill to complete for data in mid Aug.



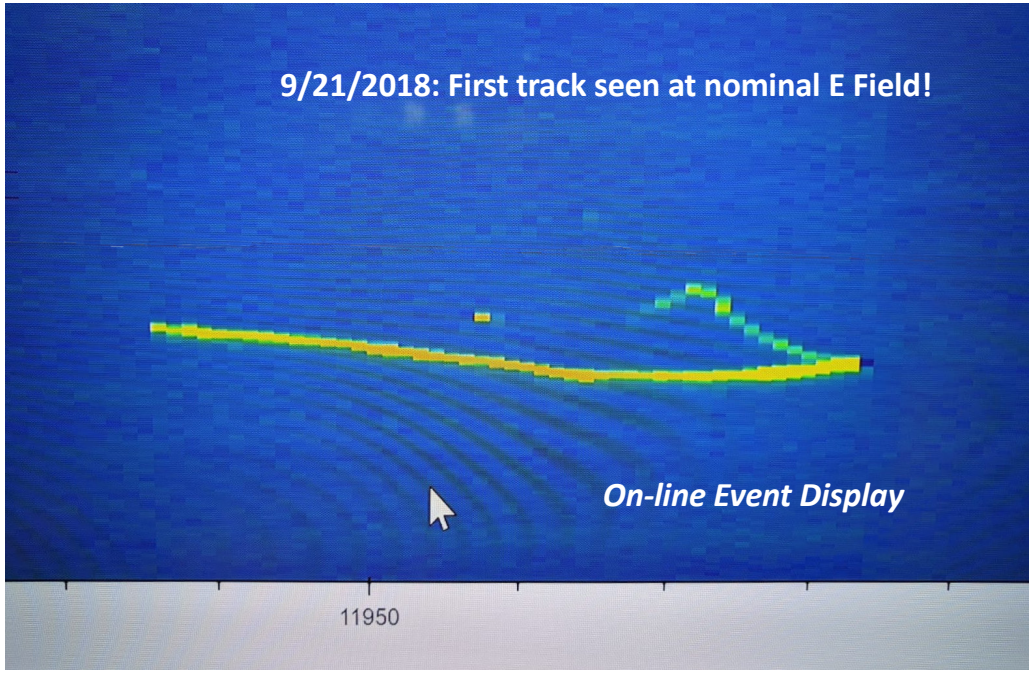


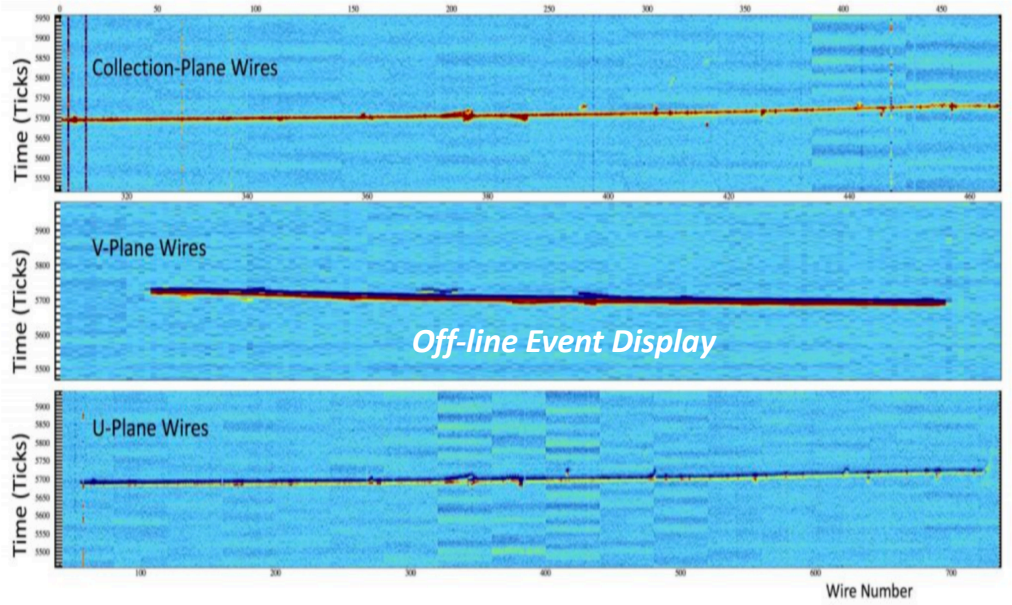
Status of ProtoDUNE Single Phase

- Detector completed and the cryostat shut end of June, 2018
  - LAr filling completed on Sept. 13, 2018
  - TPC's activated and taking data since Sept. 21
    - Observed cosmic tracks as soon as the TPC turned on close to the operational HV
    - LAr purity is **>6ms**, **99.7%** of the channels alive!, gain **uniform within 5%** across
  - Beam data taking stopped on Nov. 15, 2018
  - Cosmic data taking continues throughout the 2 year CERN beam shutdown

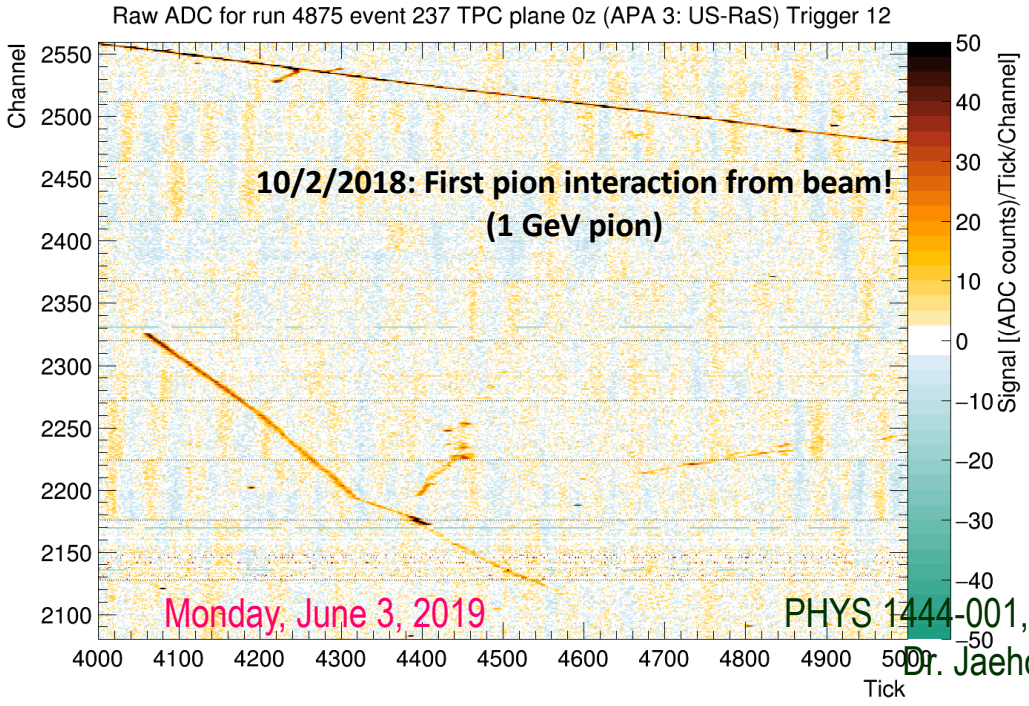


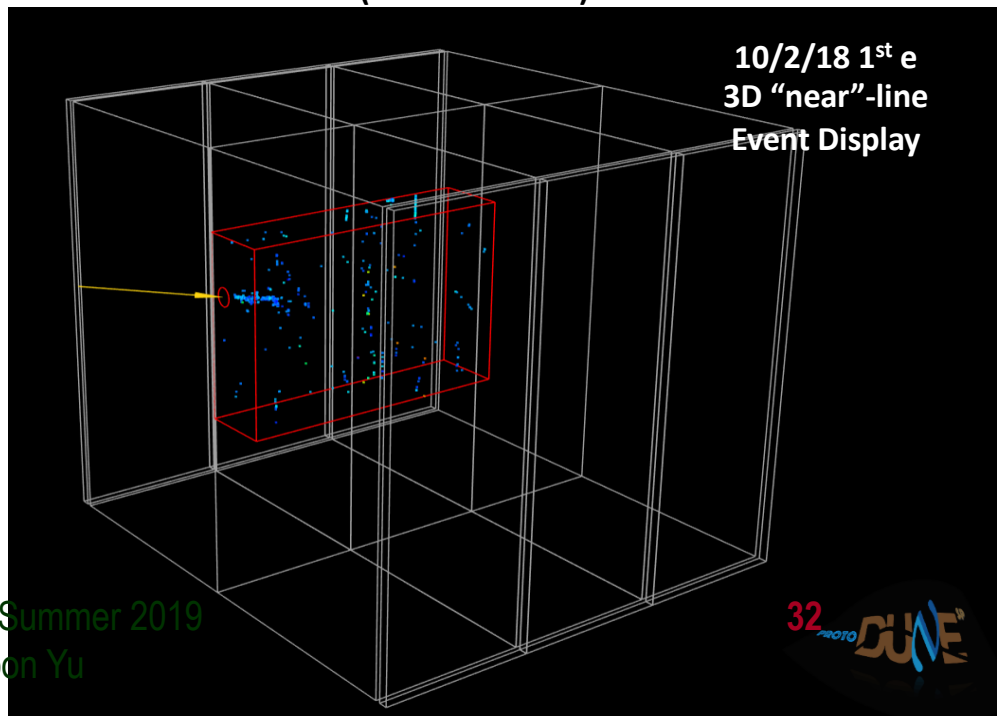
ProtoDUNE SP First Events



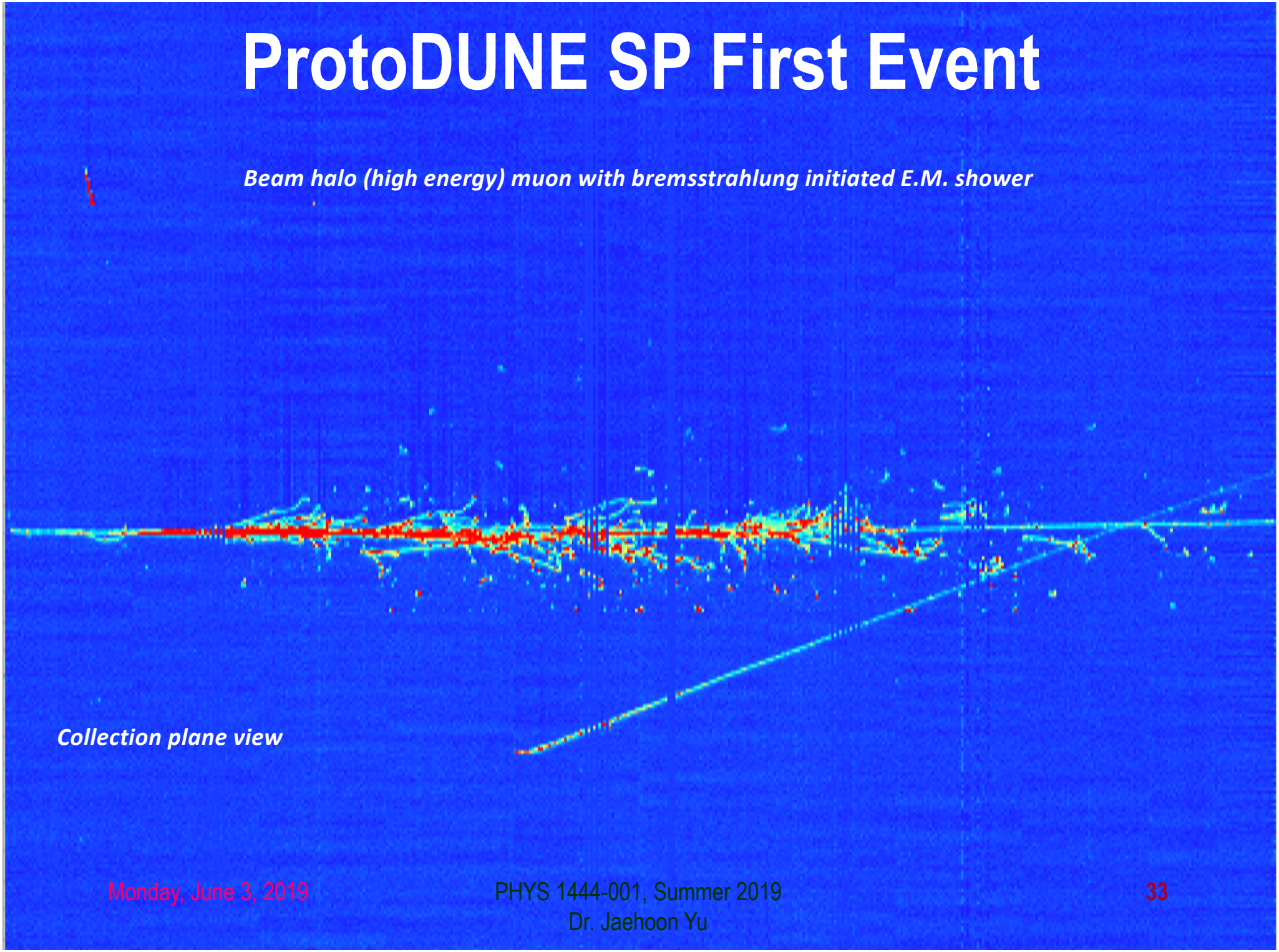


10/2/2018: First event seen from beam!
(1 GeV electron)



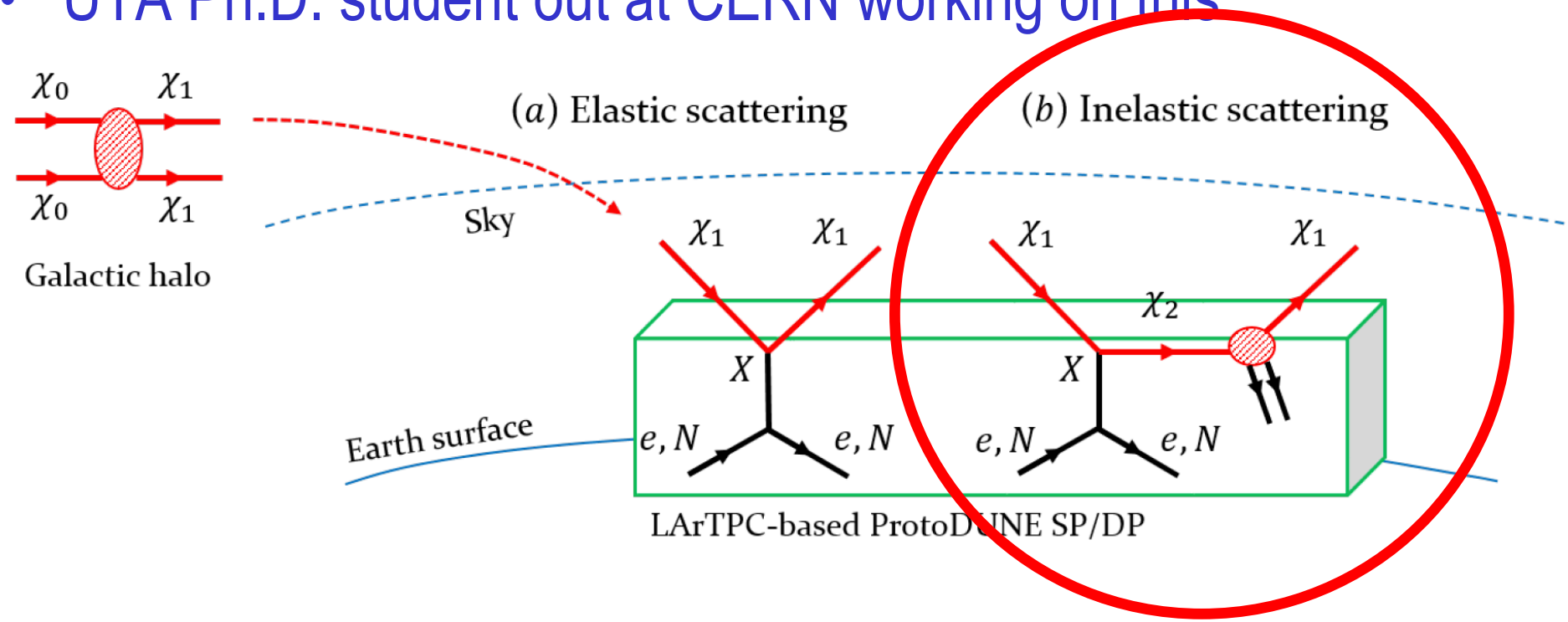


ProtoDUNE SP First Event

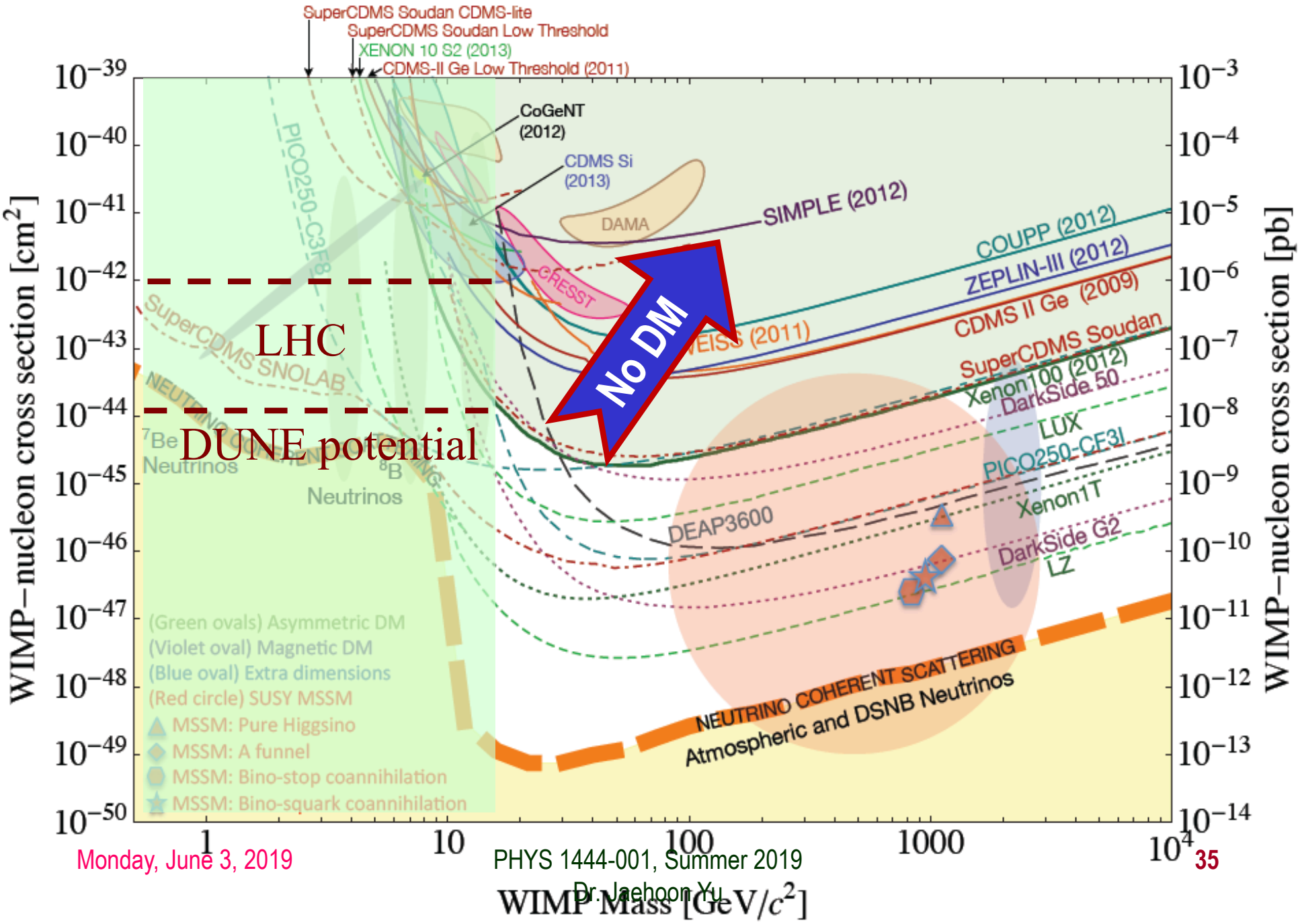


Intermediate Physics w/ ProtoDUNE?

- ProtoDUNE detectors have active volume of over 600t total
- Potential for searching for relativistic Boosted Dark Matter in its inelastic scattering in the detector ➔ Distinct signature of e/p + e^+e^- pair final states helps over the anticipated large background on the surface
- UTA Ph.D. student out at CERN working on this

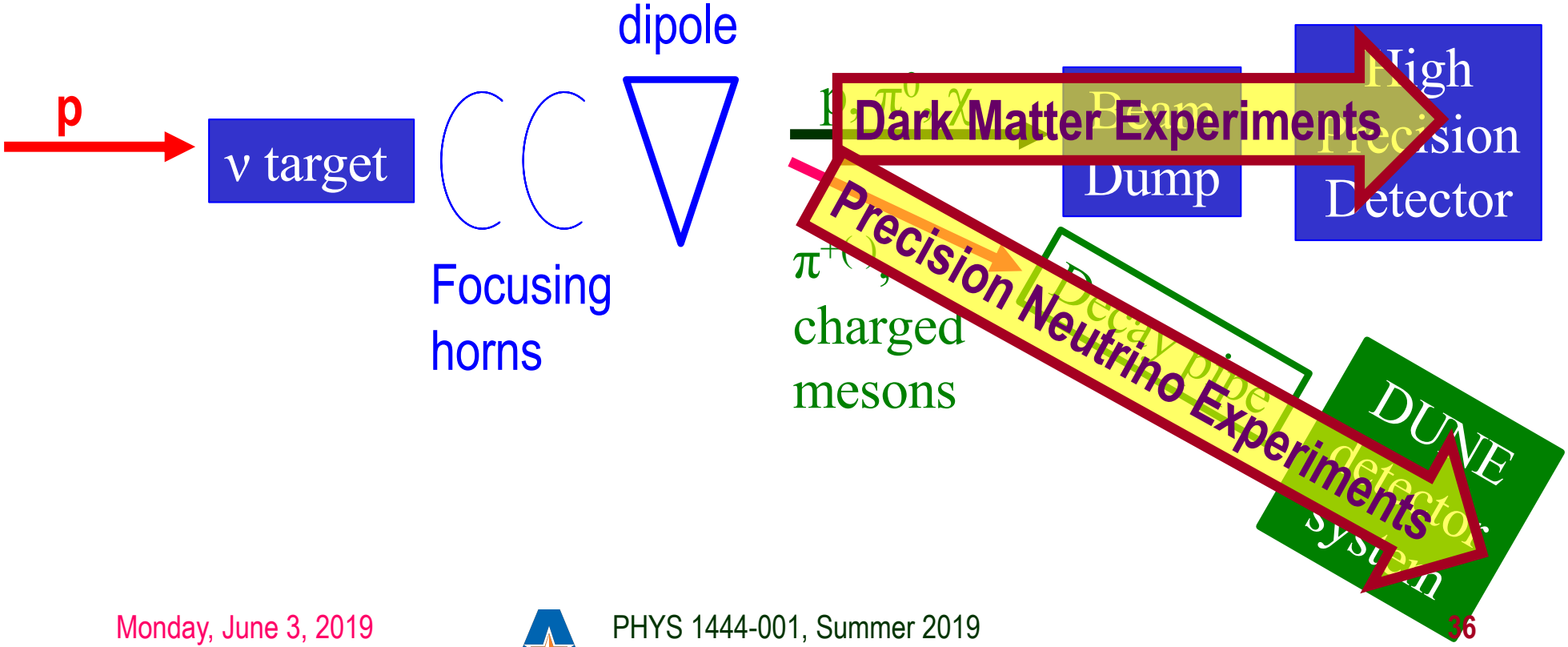


Dark Matter Search Motivation



Smart Dark Matter Beam Line!!

- A system that uses a string of magnets
- We can have a beamline that separates neutrinos and anti-neutrinos from DM's
- Give parent particles of ν's a magnetic kick to do this separation
- Add a dipole after the mesons are fully focused with the 2nd horn

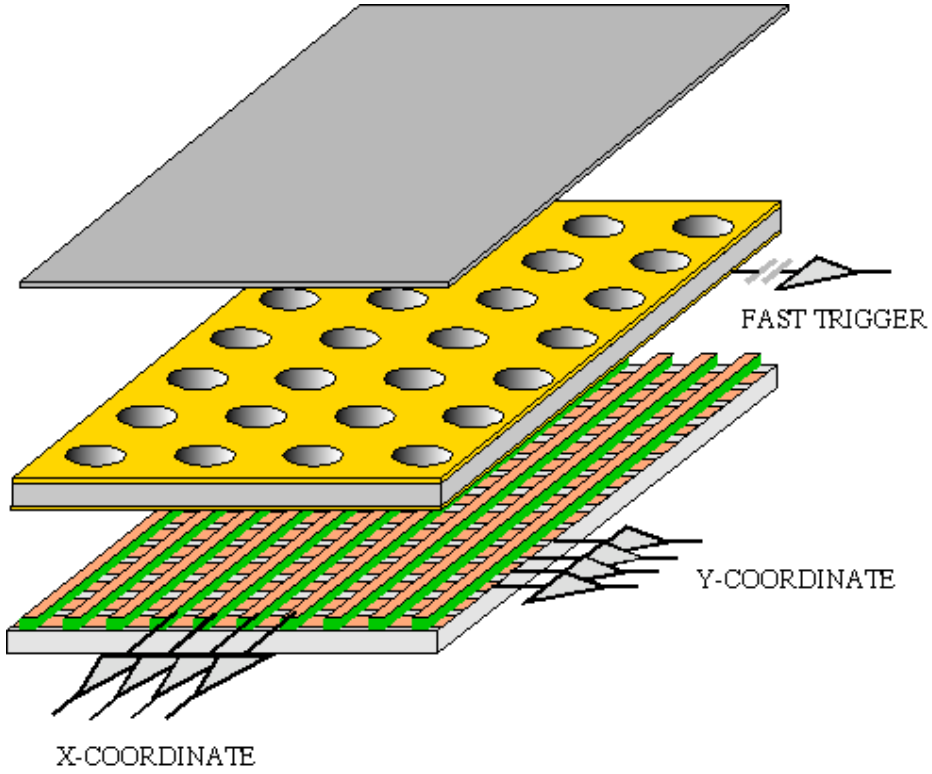


Dark Matter Searches at Fermilab

- Fermilab is turning into a lab with very high intensity accelerator program
- UTA group is part of three experiments
  - Deep Underground Neutrino Experiment (DUNE), a $1.3B US flagship experiment, with data expected in 2026
    - 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??

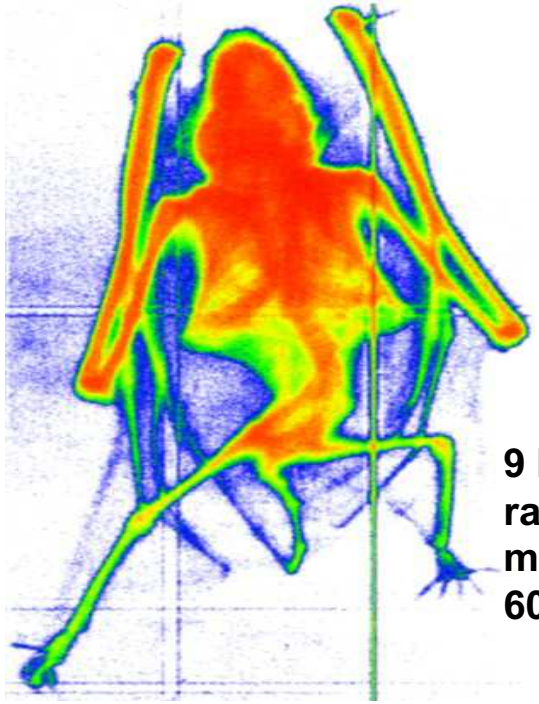
GEM Application Potential

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



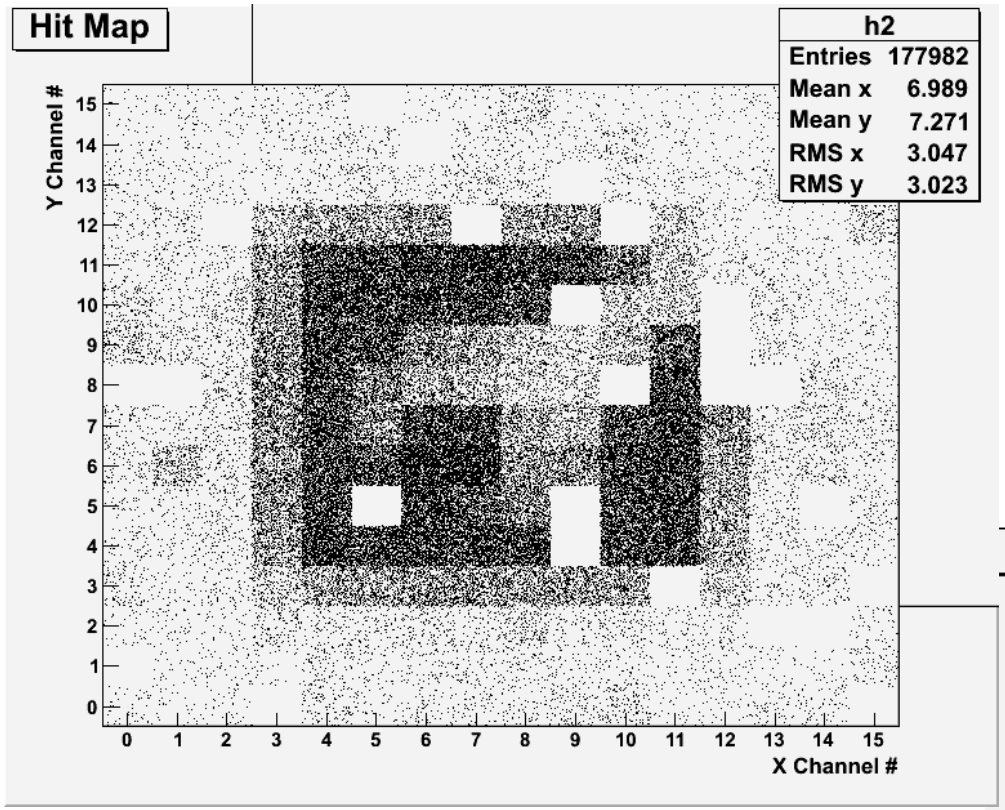
A. Bressan et al,
Nucl. Instr. and Meth. A 425(1999)254
F. Sauli, Nucl. Instr. and Meth.A 461(2001)47

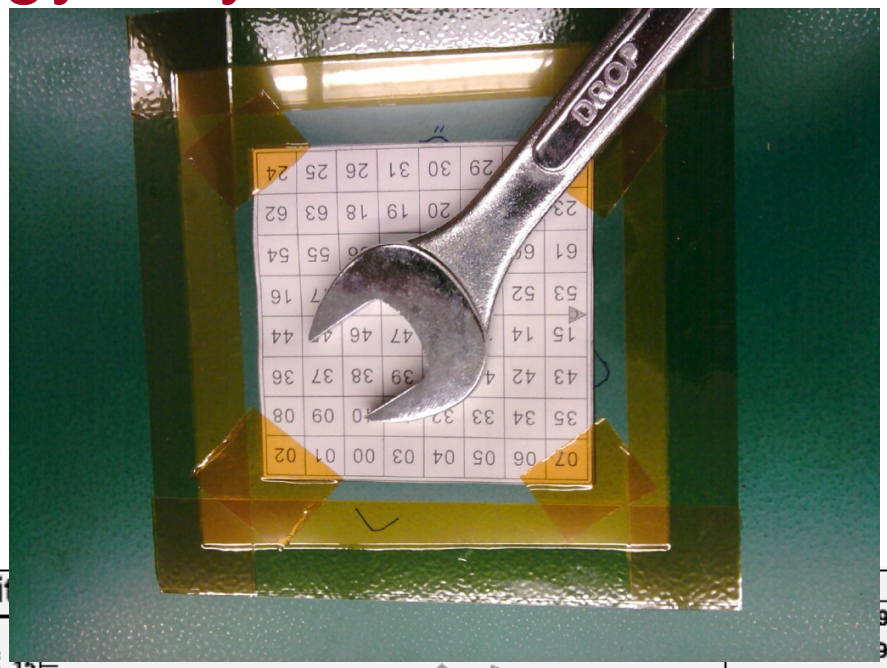
FAST X-RAY IMAGING

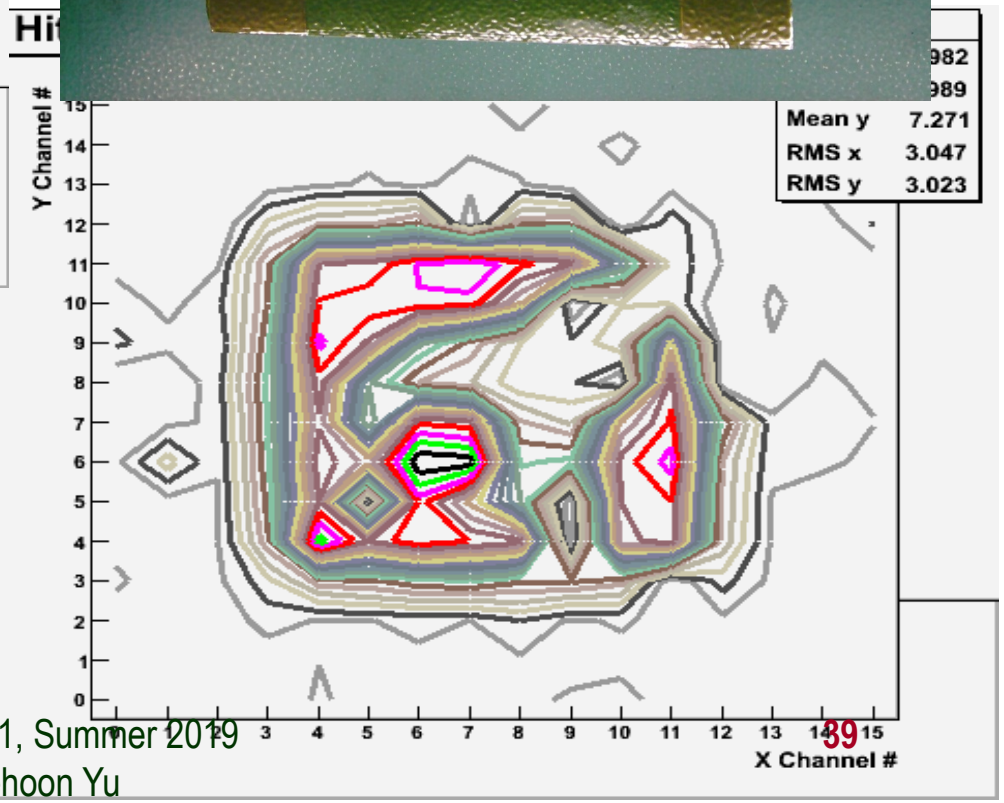


9 keV absorption radiography of a small mammal (image size ~ 60 x 30 mm^2)

Bi-product of High Energy Physics Research





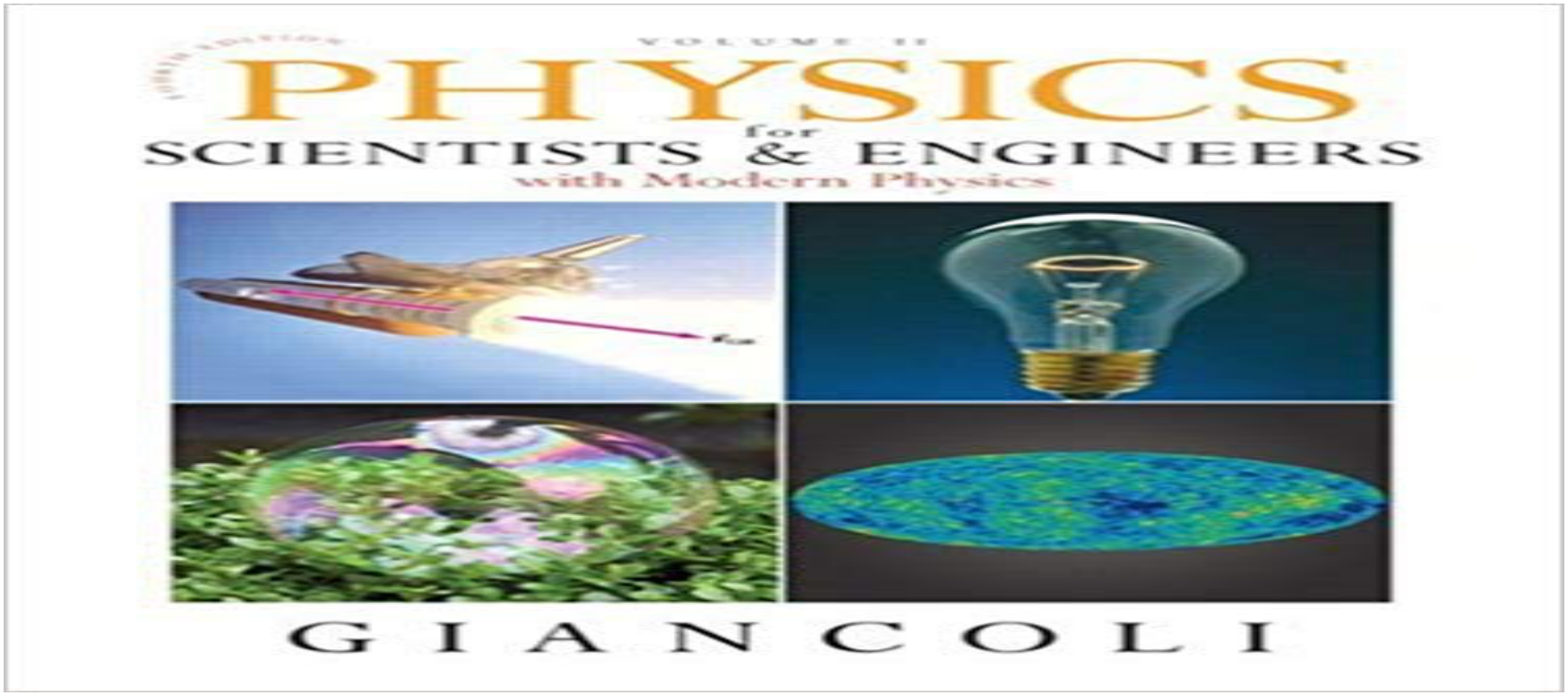


Can you see what the object is?
(GEM Detector X-ray Image)


And in not too distant future, we could do …

Textbook

- Title: Physics for Scientists and Engineers with Modern Physics
  - 4th edition
- Authors: D.C. Giancoli
- ISBN13: 978-0132273596
- ISBN10: 9780132273596



Information & Communication Source

- Course web page: http://www-hep.uta.edu/~yu/teaching/summer19-1444-001/summer19-1444-001.html
  - Contact information & Class Schedule
  - Syllabus
  - Homework
  - Holidays and Exam days
  - Evaluation Policy
  - Class Style & Communication
  - Other information
- Primary communication tool is e-mail: Make sure that your e-mail at the time of course registration is the one you most often read!!
- Office Hours for Dr. Yu: 12:30 – 1:30pm, M-Th or by appointments

Evaluation Policy

- Homework: 25%!!!
- Exams
  - Final Comprehensive Exam (7/3/19): 23%
  - Mid-term Comprehensive Exam (6/18/19): 20%
  - One better of the two term Exams (6/10/19 and 6/26/19): 12%
  - Missing an exam is not permissible unless pre-approved
    - No makeup test
    - You will get an F if you miss any of the exams without a prior approval no matter how well you've been doing in class!
- Lab score: 10%
- Pop-quizzes: 10%

100%

- Extra credits: 10% of the total
  - Random attendances
  - Strong participation in the class discussions
  - Special projects (BIGGGGG!!!)
  - Planetarium shows and Other many opportunities
- Grading will be done on a sliding scale

Homework

- Solving homework problems is the only way to comprehend class material ➔ 2 homeworks per week
- An electronic homework system has been setup for you
  - Details are in the material distributed today and on the web
  - https://quest.cns.utexas.edu/student/courses/list
  - Choose the course **PHYS1444-Summer19**, unique number **44019**
  - Download homeworks, solve the problems and submit them online
  - Multiple unsuccessful tries will deduct points
  - Roster will close at 11pm this Wednesday, June 5
  - You need a UT e-ID (NOT the UTA NetID): Go and apply at the URL https://idmanager.its.utexas.edu/eid_self_help/?createEID&qwicap-page-id=EA027EFF7E2DA39E if you don't have one.
- Each homework carries the same weight
- Home work problems will be slightly ahead of the class and tough!
- **No** homework will be dropped from the final grade!!
- Home work will constitute **25% of the total** ➔ A good way of keeping your grades high
- Strongly encouraged to collaborate ➔ Does not mean you can copy

Attendances and Class Style

- Attendances:
  - Will be taken randomly
  - Will be used for extra credits
- Class style:
  - Lectures will be on electronic media
    - The lecture notes will be posted on the web **AFTER** each class
  - Will be mixed with traditional methods
  - Active participation through questions and discussions are **STRONGLY** encouraged ➔ Extra credit….
  - Communication between you and me is extremely important
    - If you have problems, please do not hesitate talking to me

Lab and Physics Clinic

- Physics Labs: Begins Wednesday, June 5
  - Important to understand physical principles through experiments
  - 10% of the grade
  - Prelab questions can be obtained at www.uta.edu/physics/labs
  - Lab syllabus is available in your assigned lab rooms.
- Physics Clinic:
  - Free service
  - They provide general help on physics, including help solving homework problems
    - Do not expect solutions of the problem from them!
    - Do not expect them to tell you whether your answers are correct!
    - It is your responsibility to make sure that you have done everything correctly!
  - 11am – 6pm, Mon – Thu in SH 007
  - This service begins today!
  - Please take full advantage of this service!!

Extra credit

- 10% addition to the total
  - Could boost a B to A, C to B or D to C
- What constitute for extra credit?
  - Special projects (biggest!!)
  - Random attendances
  - Strong participation in the class discussions
  - Watch the valid planetarium shows
  - Many other opportunities

Valid Planetarium Shows

- Regular running show schedule: https://www.uta.edu/planetarium/shows/schedule.php
- Valid shows (some need special arrangements)
  - Black Holes and Phantom of the Universe (Count up to 2 times!!)
  - Astronaut; Bad Astronomy; Back to the Moon for Good; From Earth to the Universe; Experience the Aurora; IBEX; Ice Worlds; Magnificent Sun
  - Mayan Prophecies; MicroCosm; Nano Cam; Stars of the Pharaohs; TimeSpace, Two Small Pieces of Glass; Unseen Universe; Violent Universe; Out there
- How to submit for extra credit?
  - Obtain the ticket stub that is signed and dated by the planetarium star lecturer at the show
  - Collect the ticket stubs
  - Tape one edge of all of the ticket stubs on a sheet of paper with your name and ID written on it
  - Submit the sheet at the end of the semester at the final exam

What can you expect from this class?

- All A's?
  - This would be really nice, wouldn't it?
  - But if it is too easy it is not fulfilling or meaningful….
- This class is not going to be a stroll in the park!!
- You will earn your grade in this class.
  - You will need to put in sufficient time and sincere efforts
  - Exams and quizzes will be tough!!
    - Sometimes problems might not look exactly like what you learned in the class
    - Show your work! Just putting the right answer for free response problems does not work!
- But you have a great control (up to 45%) of your grade in your hands
  - Homework is 25% of the total grade!!
    - Means you will have many homework problems
      - Sometimes much more than any other classes
      - Some homework problems will be something that you have yet to learn in class
      - Exam problems will be easier than homework problems but the same principles!!
  - Lab 10%
  - Extra credit 10%
- I will work with you so that your efforts are properly rewarded

What do we want to learn in this class?

- Physics is everywhere around you.
- Skills to understand the fundamental principles that surrounds you in everyday lives…
- Skills to identify what laws of physics applies to what phenomena and use them appropriately
- Understand the impact of physical laws and apply them
- Learn skills to think, research and analyze observations.
- Learn skills to express observations and measurements in mathematical language
- Learn skills to express your research in a systematic manner in writing
- But most importantly the confidence in your physics ability and to take on any challenges laid in front of you!!

Eve more importantly, let us have a lot of FUN!!

Specifically, in this course, you will learn…

- Concept of Electricity and Magnetism
- Electric charge and magnetic poles
- Electric and Magnetic Forces and fields
- Electric and magnetic potential and energies
- Propagation of electric and magnetic fields
- Relationship between electro-magnetic forces and light
- Behaviors of light and optics
- Special relativity and quantum theories

How to study for this course?

- Keep up with the class for comprehensive understanding of materials
  - Come to the class and participate in the discussions and problems solving sessions
  - Follow through lecture notes
  - Work out example problems in the book yourself without looking at the solution
  - Have many tons of fun in the class, asking lots of questions!!!!!
- Keep up with the homework to put the last nail on the coffin
  - One can always input the answers as you solve problems. Do NOT wait till you are done with all the problems.
  - Form a study group and discuss how to solve problems with your friends, then work the problems out yourselves!
- Prepare for upcoming classes
  - Read the textbook for the material to be covered in the next class
- The extra mile
  - Work out additional problems in the back of the book starting the easiest problems to harder ones

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

⇒Theory and Experiment work hand-in-hand

⇒Discrepancies between experimental measurements and theory are good for improvements

⇒The general principles formulated through theory is used to improve 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
- AD 19th Century:
  - Electricity, Magnetism, and Thermodynamics
- Late AD 19th and early 20th century (Modern Physics Era)
  - Einstein's theory of relativity: Generalized theory of space, time, and energy (mechanics)
  - Quantum Mechanics: Theory of atomic phenomena
- Physics has come very far, very fast, and is still progressing, yet we've got a long way to go
  - What is matter made of?
  - How do matters get mass?
  - How and why do matters interact with each other?
  - How is universe created?

Models, Theories and Laws

- Models: An analogy or a mental image of a phenomena in terms of something we are familiar with
  - Thinking light as waves, behaving just like water waves
  - Often provide insights for new experiments and ideas
- Theories: More systematically improved version of models
  - Can provide quantitative predictions that are testable and more precise
- Laws: Certain concise but general statements about how nature behaves
  - Energy conservation
  - The statement must be found experimentally valid to become a law
- Principles: Less general statements of how nature behaves
  - Has some level of arbitrariness

Uncertainties

- Physical measurements have limited precision, however good they are, due to:

Stat.{ – Number of measurements

Syst.{ – Quality of instruments (meter stick vs micro-meter)
– Experience of the person doing measurements
– Etc

- In many cases, uncertainties are more important and difficult to estimate than the central (or mean) values

Significant Figures

- Denote the precision of the measured values
  - The number 80 implies precision of +/- 1, between 79 and 81
    - If you are sure to +/-0.1, the number should be written 80.0
  - Significant figures: non-zero numbers or zeros that are not place-holders
    - 34, 34.2, 0.001, 34.100
      - 34 has two significant digits
      - 34.2 has 3
      - 0.001 has one because the 0's before 1 are place holders to position "."
      - 34.100 has 5, because the 0's after 1 indicate that the numbers in these digits are indeed 0's.
    - When there are many 0's, use scientific notation for simplicity:
      - $31400000=3.14\text{x}10^{7}$
      - $0.00012=1.2\text{x}10^{-4}$

Significant Figures

- Operational rules:
  - Addition or subtraction: Keep the **smallest number of decimal place** in the result, independent of the number of significant digits: 12.001+ 3333.1= 3345.1
  - Multiplication or Division: Keep the **smallest number of significant digits** in the result: 12.001 x 3.1 = 37, because the smallest significant figures is ?.

What does this mean? **The worst precision determines the precision the overall operation!!**

In English? **Can't get any better than the worst of the measurements!**