PHYS 3313 – Section 001
Lecture #1

Monday, Jan. 14, 2019

Dr. Jaehoon Yu

- Research and Study Group Assignment
- Who am I?
- From Higgs to Dark Matter!!
- Class Information
- What do we want from this class?
- What is Physics?
- Brief history of modern physics

Announcements

- Plea to you: Please turn off your cell-phones, iPads, game consoles and computers in the class
- Reading assignment #1: Read and follow through appendices 3, 5, 6 and 7 by Monday, Jan. 21
  - There will be a quiz next Wednesday, Jan. 23, on these reading assignments
- Physics colloquium
  - 4:00pm Wednesdays

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…

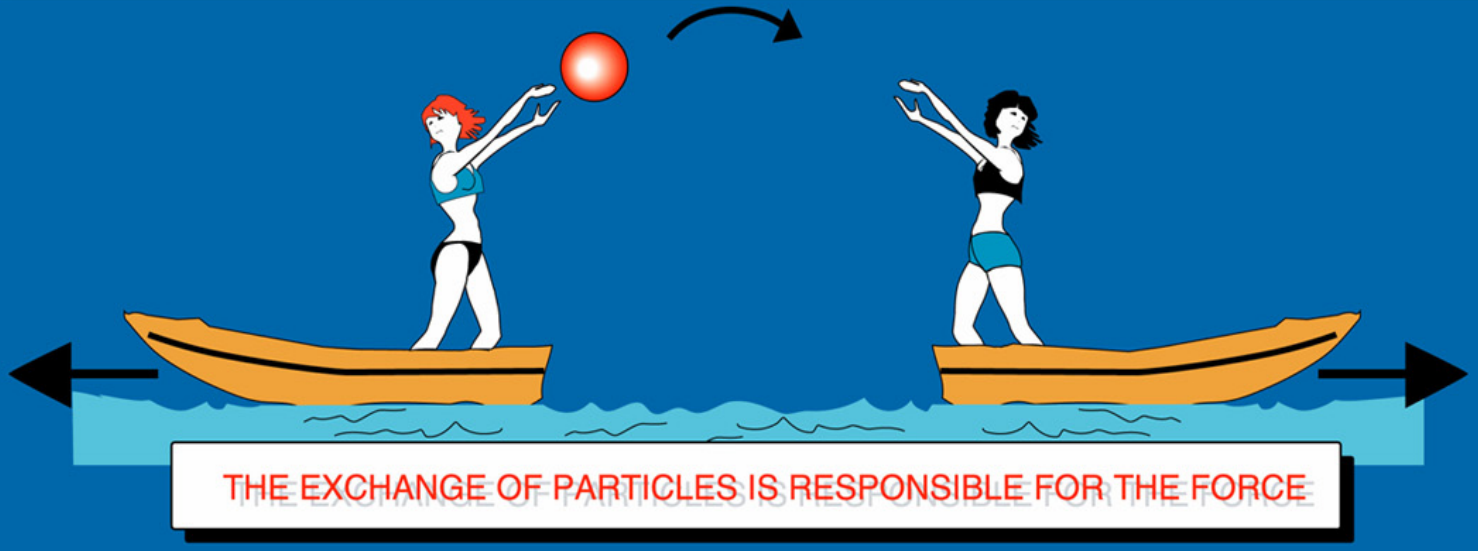
- What makes up the universe?
- How does the universe work?
- What holds the universe together?
- How can we live in the universe well?
- Where do we all come from?

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!

Periodic Table of the Elements

1 1IA 1A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8	9 VIII 8	10	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.99	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.789
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.294
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [278]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [280]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [286]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]

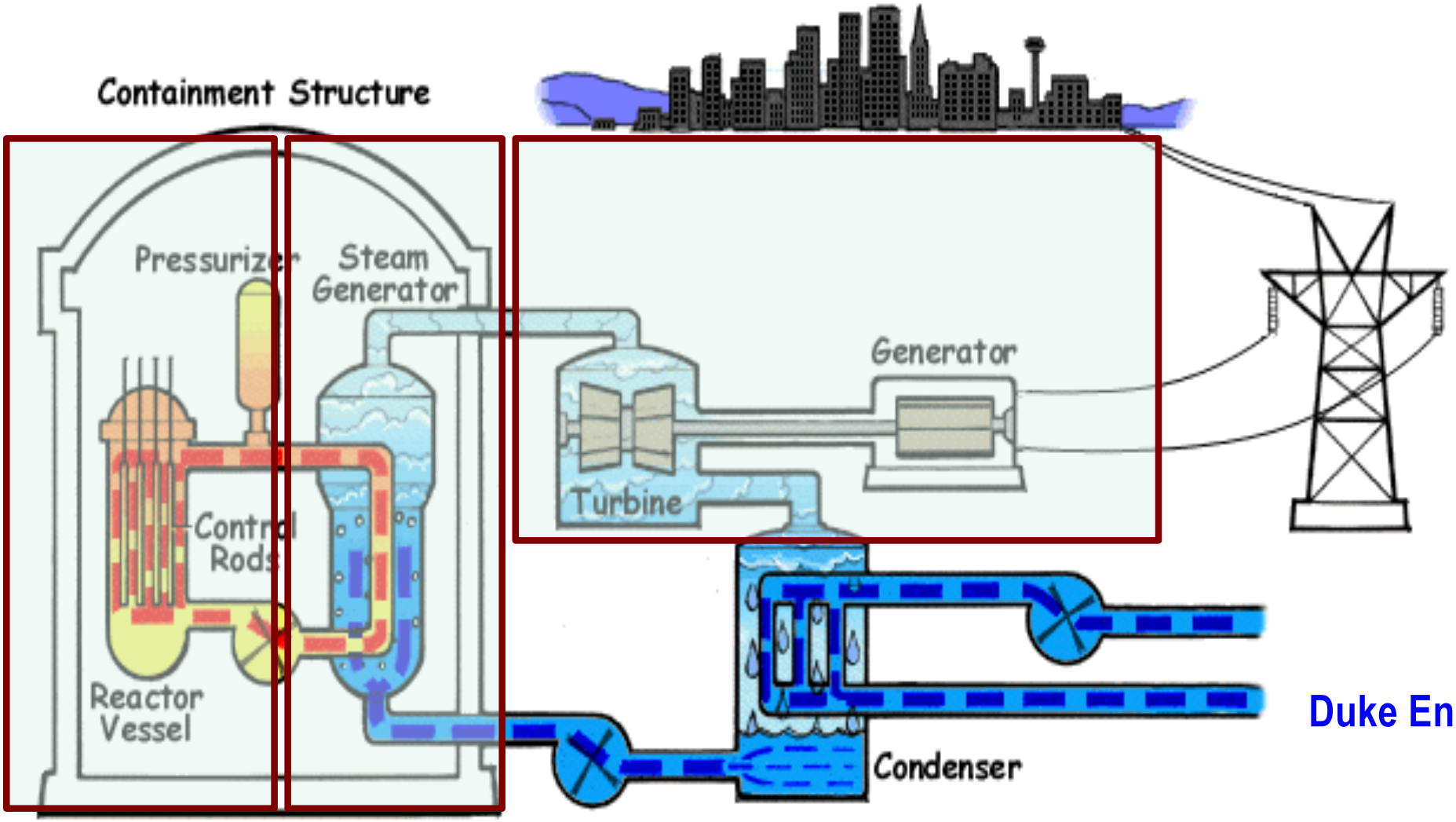
Lanthanide Series	57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.243	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.055	71 Lu Lutetium 174.967
Actinide Series	89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]

Alkali Metal | Alkaline Earth | Transition Metal | Basic Metal | Semimetal | Nonmetal | Halogen | Noble Gas | Lanthanide | Actinide

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?

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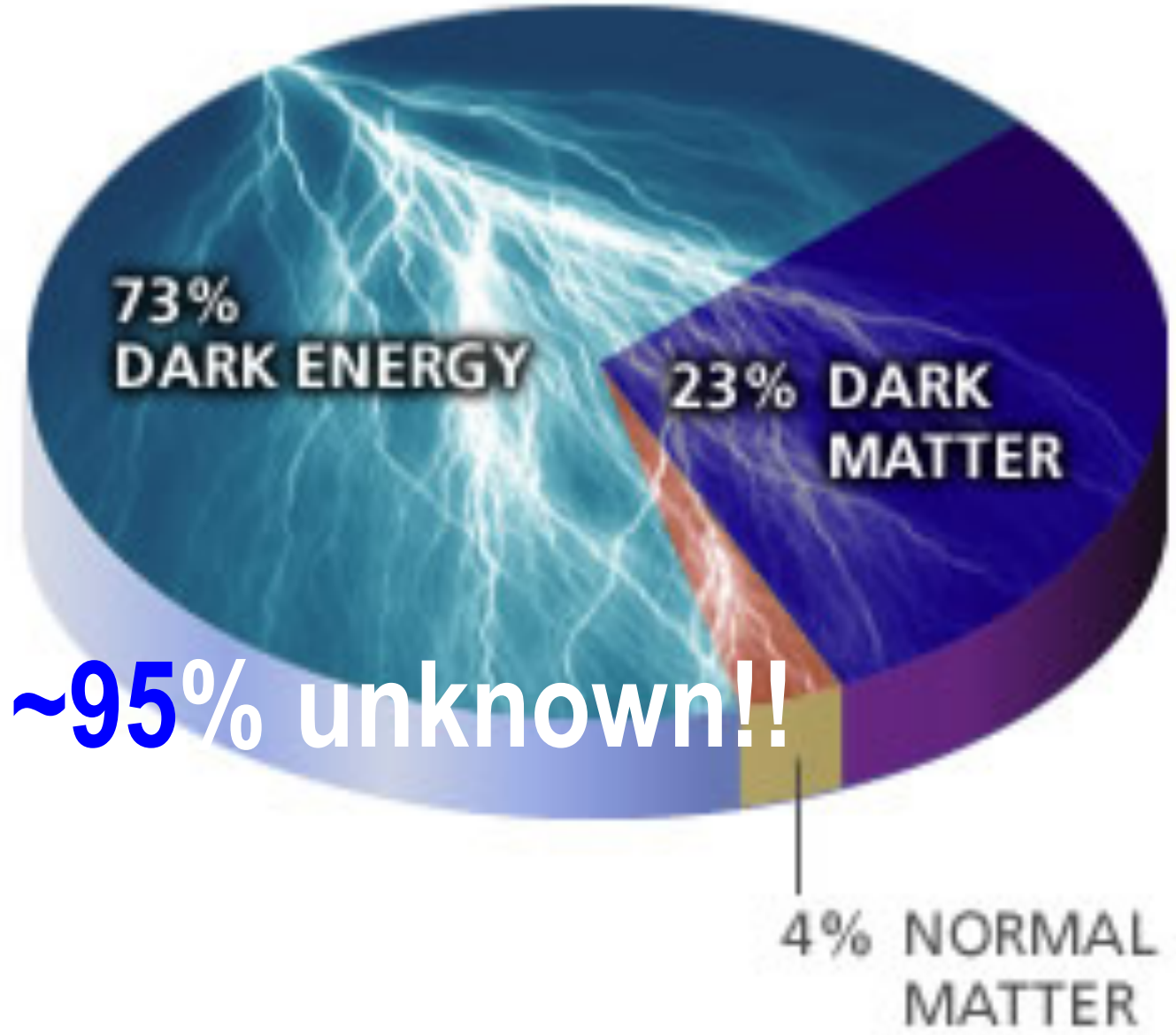
- Is the picture we present the real thing?

What makes up the universe?



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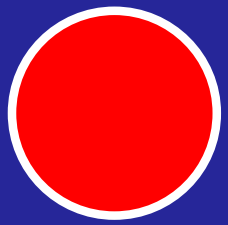
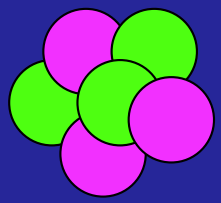
- Why are there only four apparent forces?
  - Were they all unified at the Big Bang?
- Is the picture we present the real thing?
  - What makes up the remaining ~95% of the universe?
- Are there any other particles we don't know of?
  - Big deal for the new LHC Run!
- Where do we all come from?
- How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

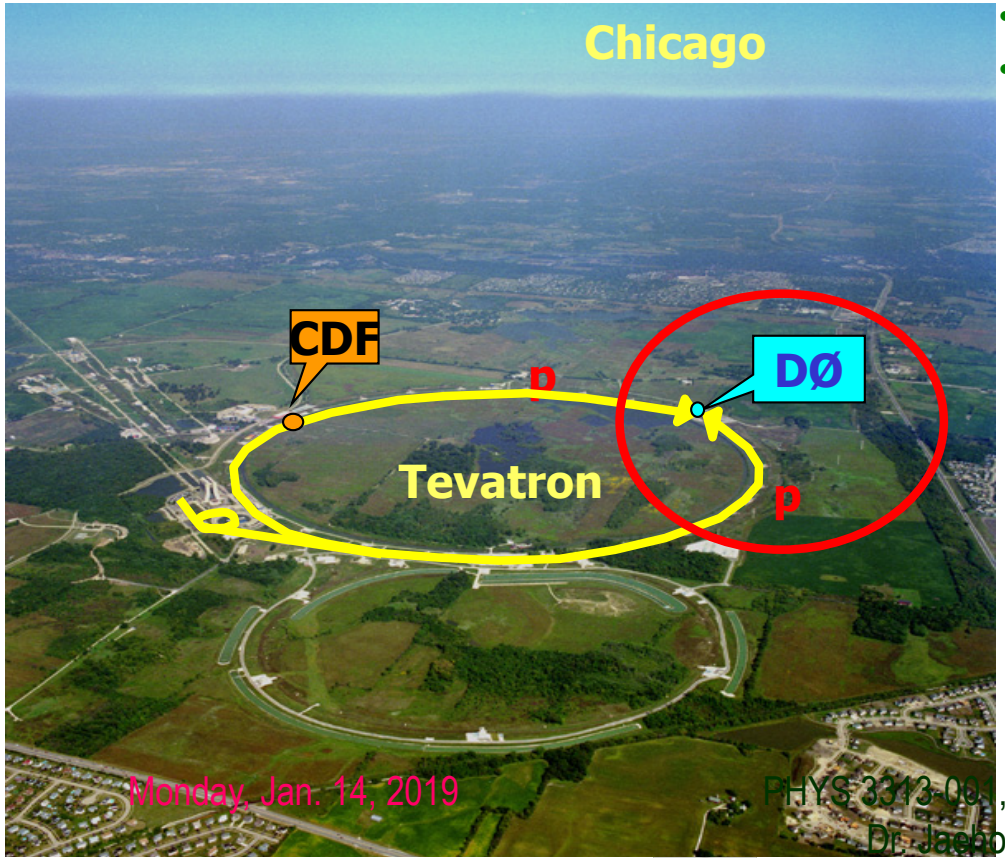
They make particles last seen
in the earliest moments of the universe.

Particle and anti-particle annihilate.

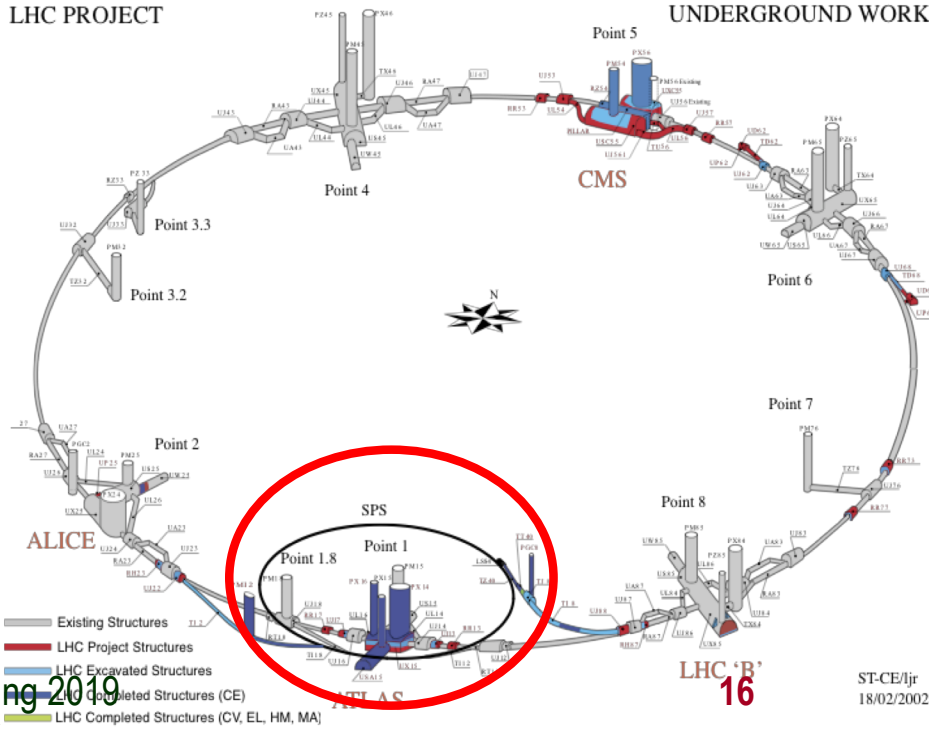
$$E = mc^2$$

Fermilab Tevatron and LHC at CERN

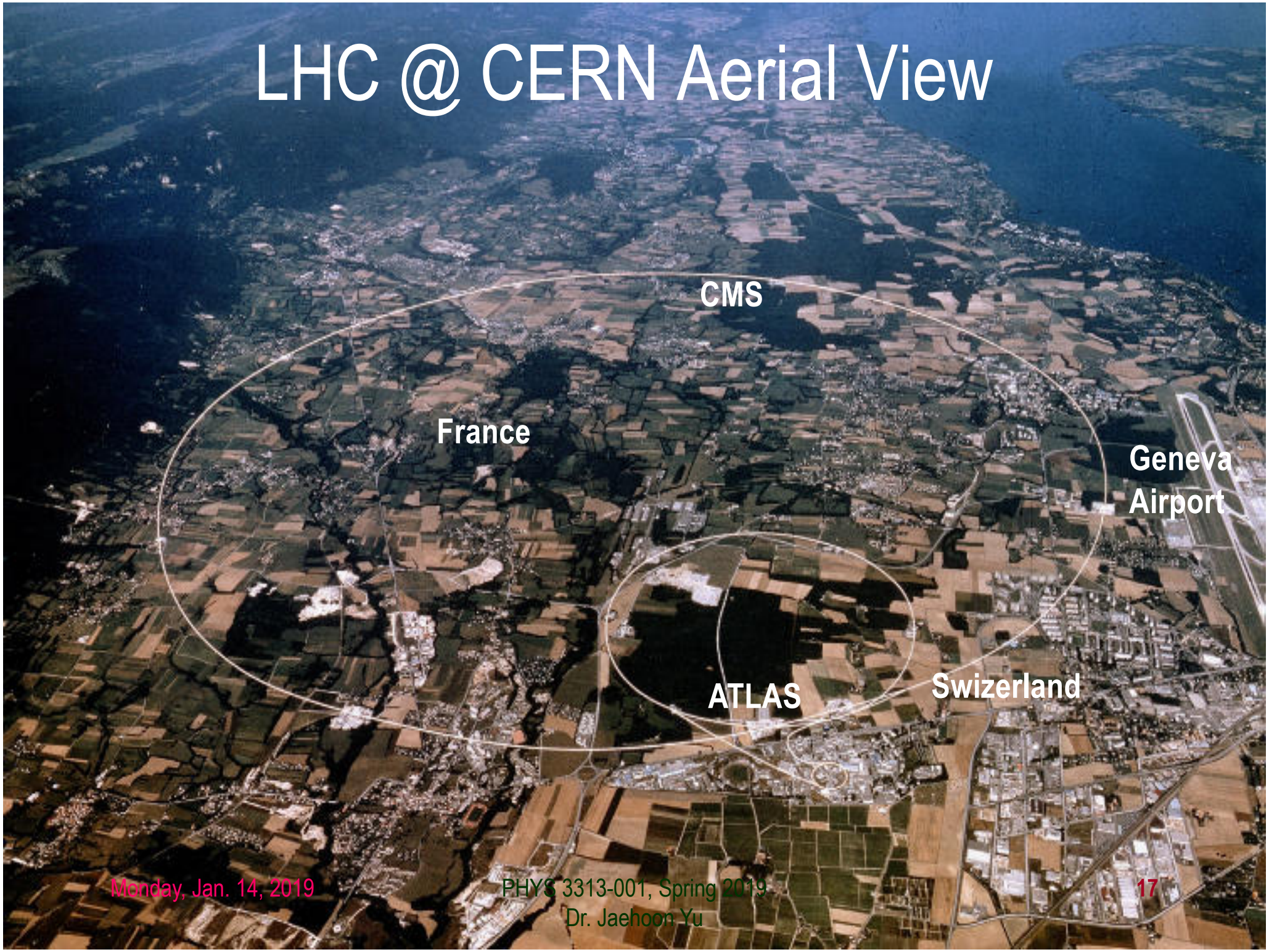
- World's Highest Energy proton-anti-proton collider
  - 4km (2.5mi) circumference
  - E_{cm}=1.96 TeV (=6.3x10^{-7}J/p➔ 13M Joules on the area smaller than $10^{-4}m^2$)
  - Equivalent to the kinetic energy of a 20t truck at the speed 130km/hr
    - ~100,000 times the energy density at the ground 0 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!!**



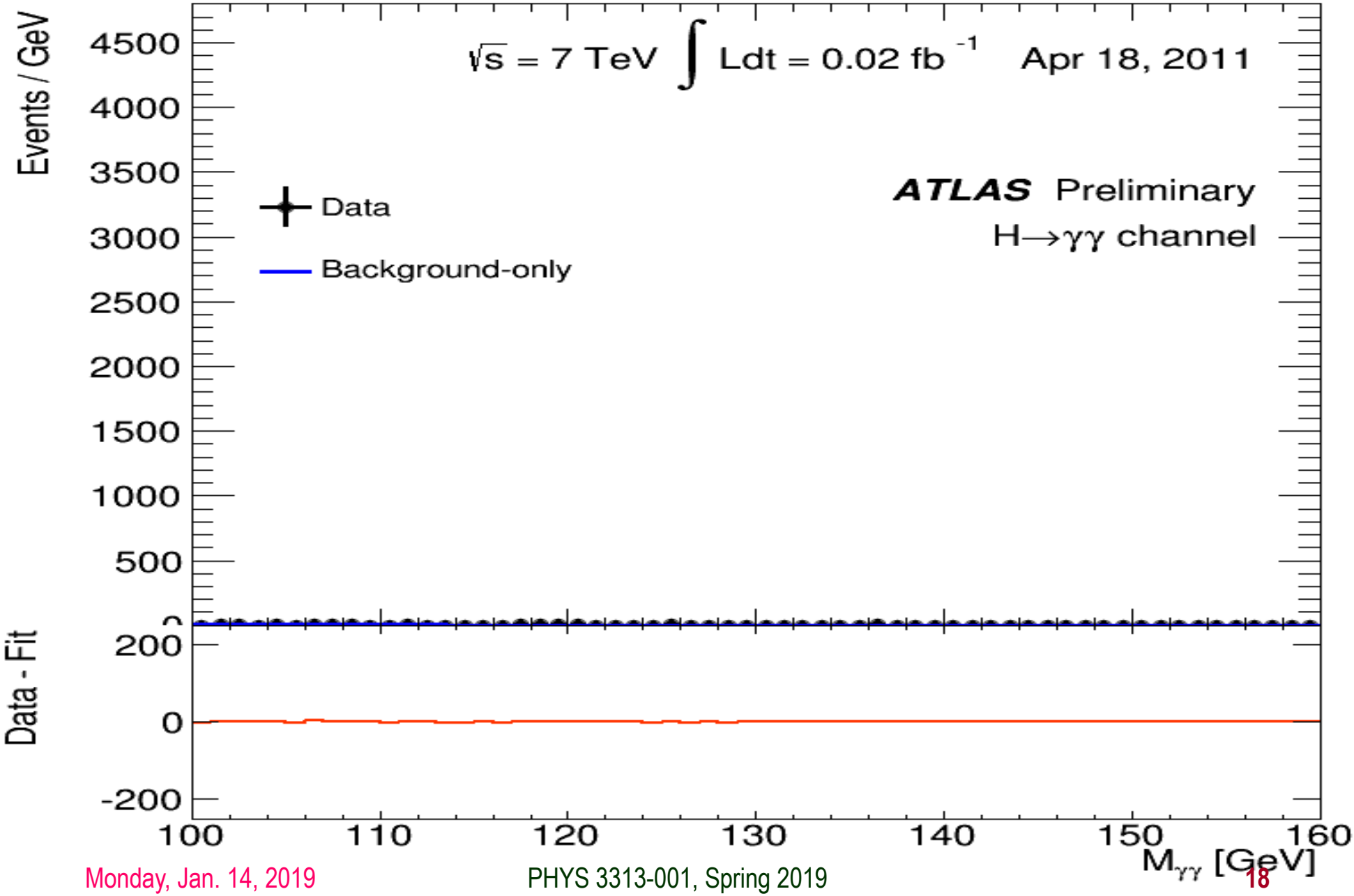
- World's Highest Energy p-p collider
  - 27km (17mi) circumference, 100m (300ft) underground
  - Design E_{cm}=14 TeV (=44x10^{-7}J/p➔ 362M Joules on the area smaller than $10^{-4}m^2$)
  - ➢ Equivalent to the kinetic energy of a B727 (80tons) at the speed 310km/hr
    - ➢ ~3M times the energy density 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?



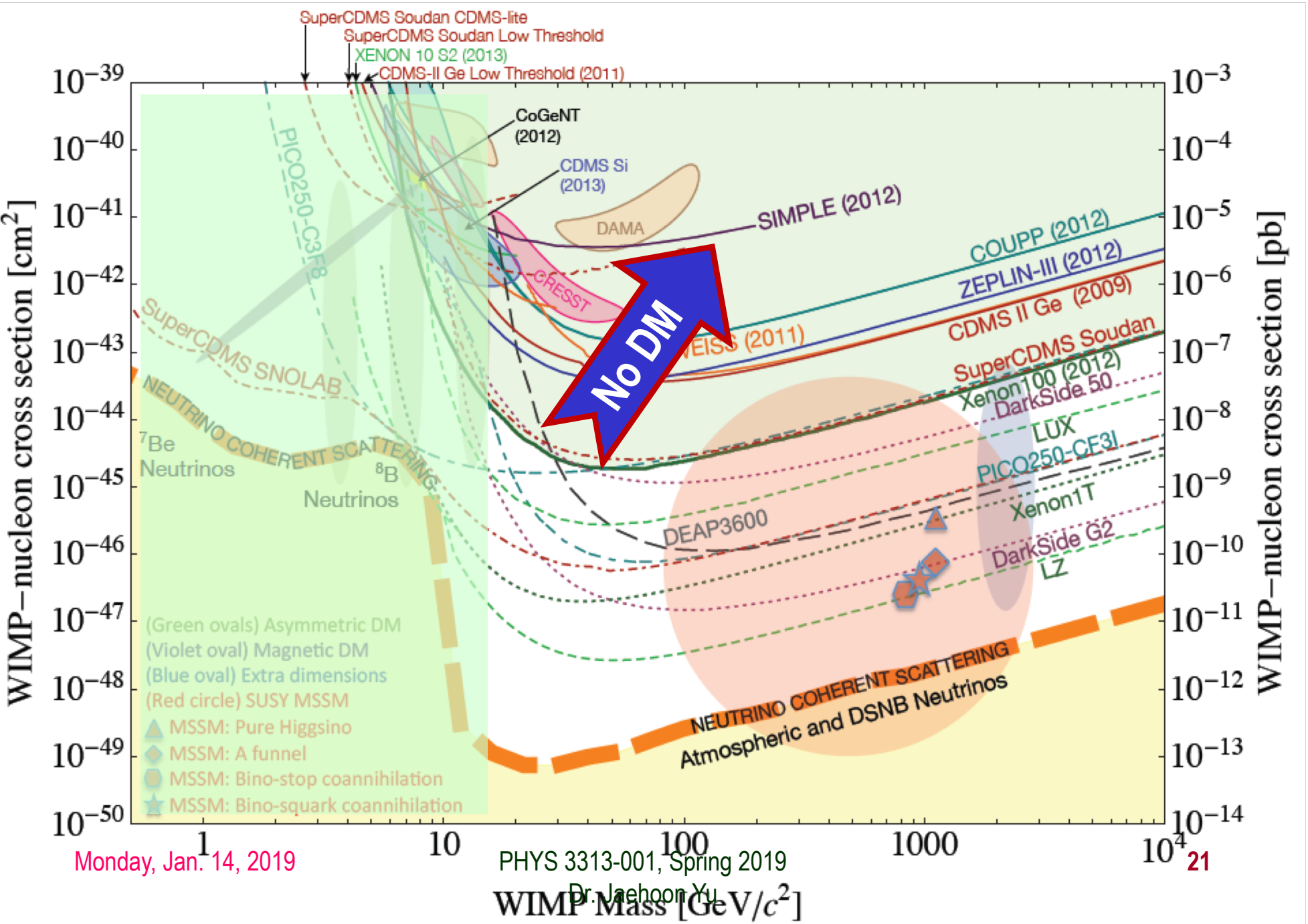
Fermilab Neutrino Program

- 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



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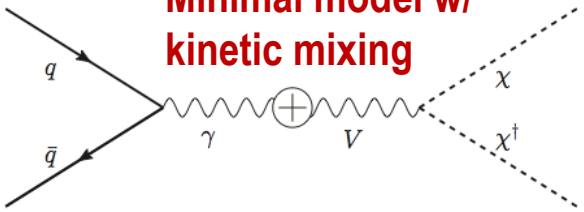
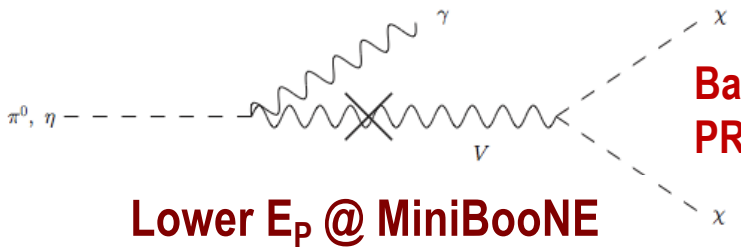


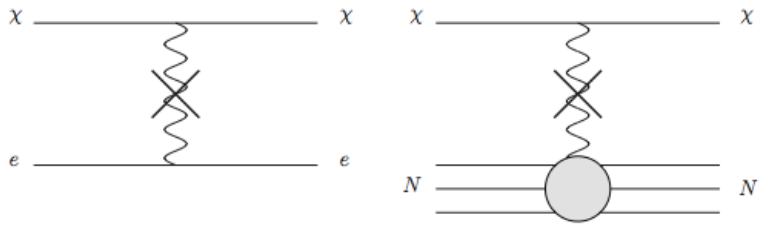
Higher E_P @ DUNE



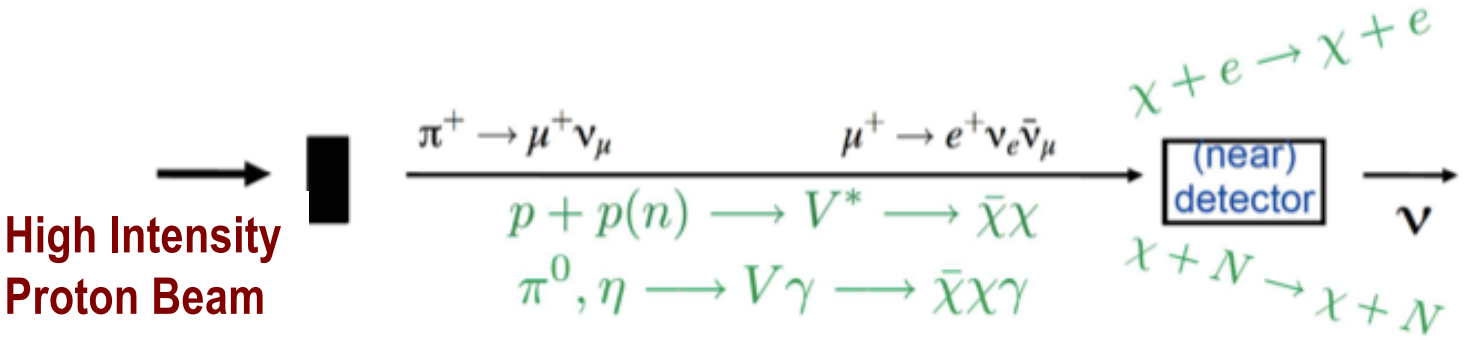
Battell *et al.*, PRD80, 095024

Lower E_P @ MiniBooNE

- Detection of DM (elastic):

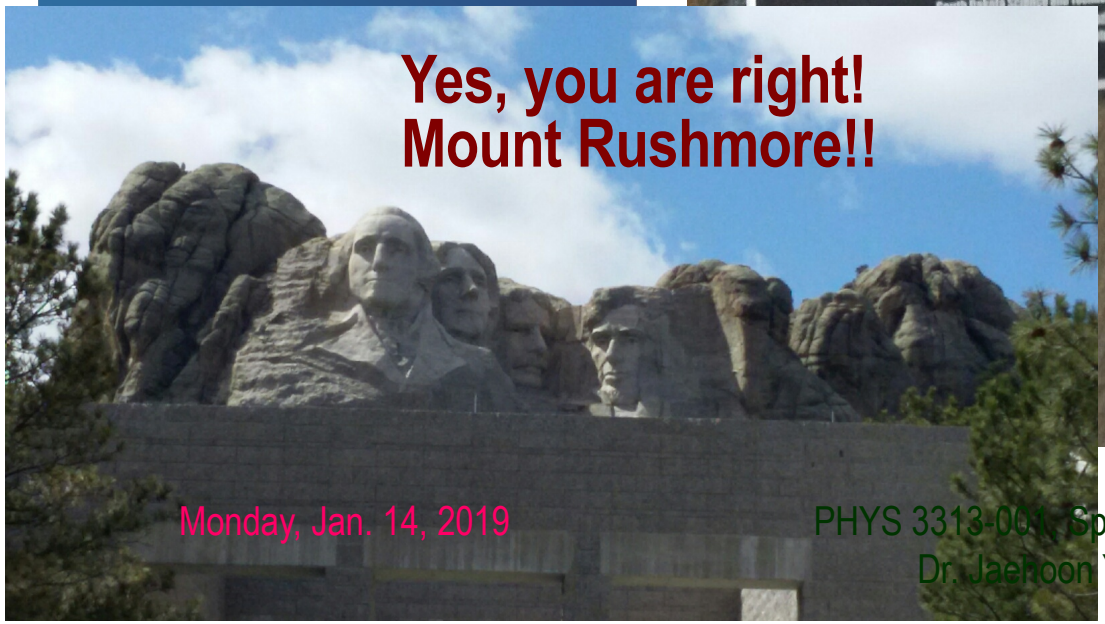


- How does a DM event look in an experiment?:



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

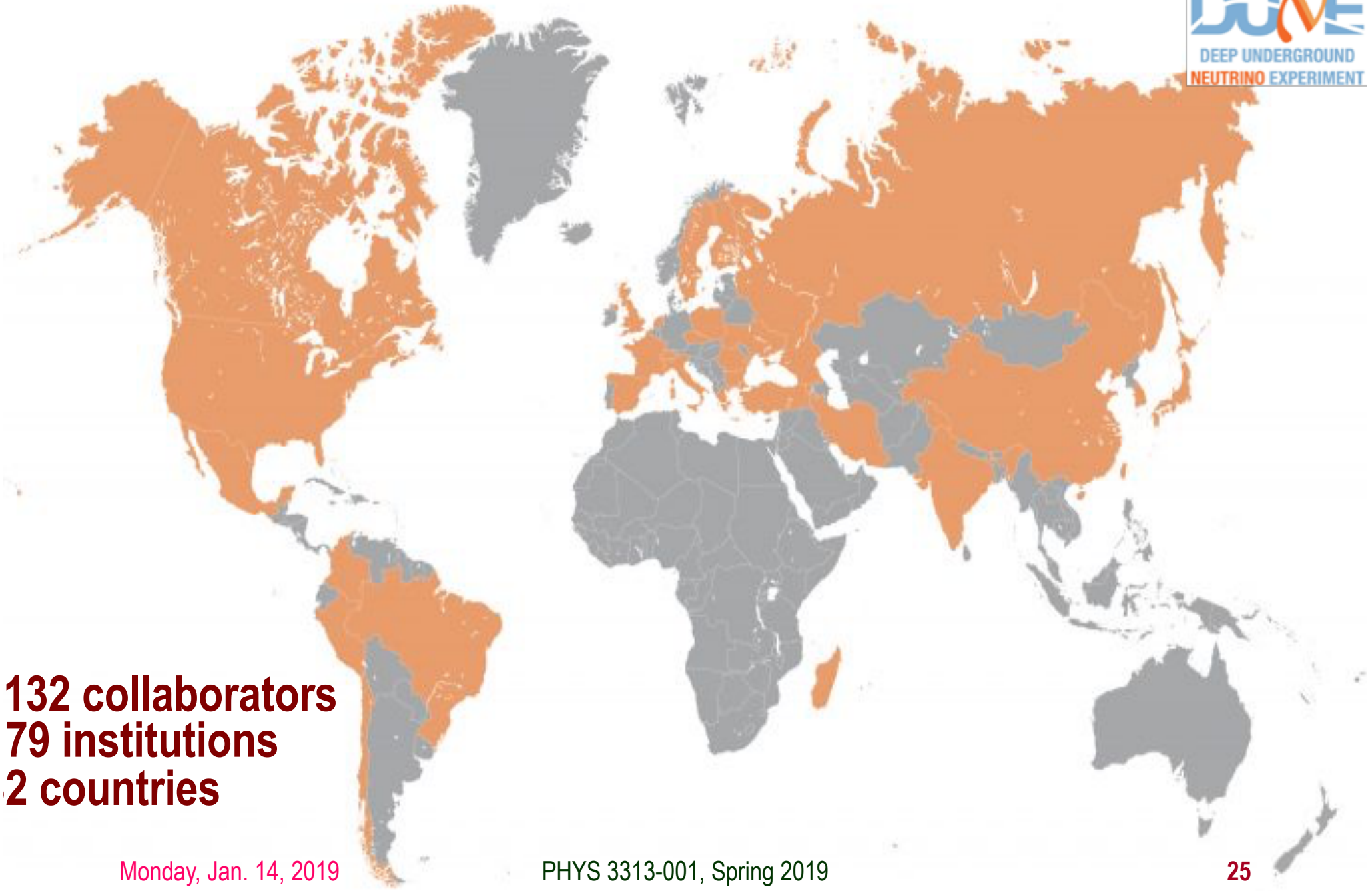


- Nobel Winning Neutrino Discovery by Ray Davis in 1960's
- Many Dark Matter experiments in progress
- New DUNE area to be excavated shortly

The Next Big Thing - DUNE Experiment

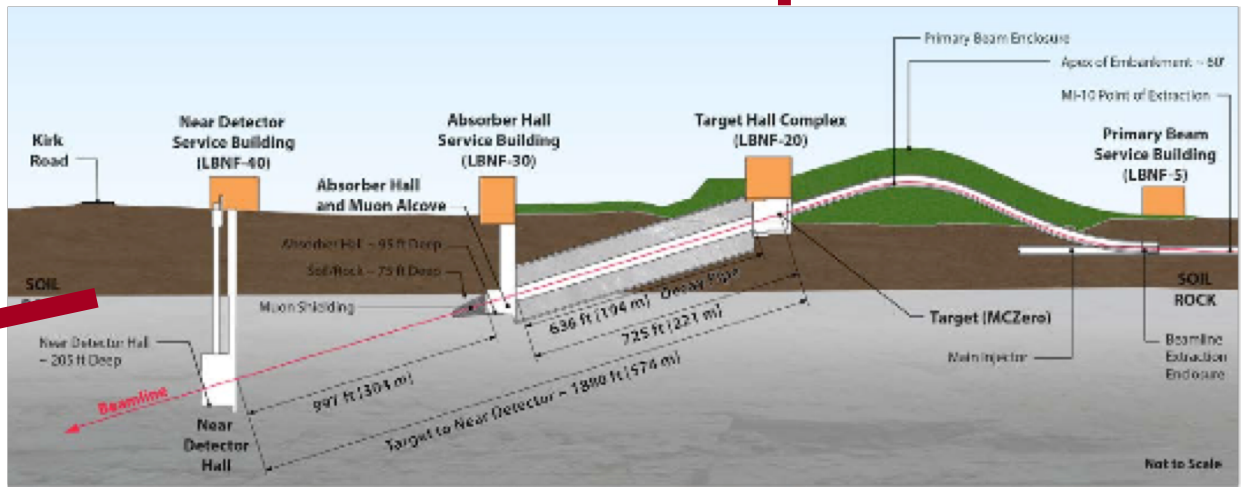
- Stands for Deep Under Ground Neutrino Experiment
- The flagship long baseline (1300km) ν experiment
  - 1500m underground in an old South Dakota gold mine
- With very high intensity proton beams (1.2MW → 2.4MW!)
  - Result in large number of neutrinos
  - A great potential for DM & other physics beyond the Standard Model
  - Food for thoughts! How many 100GeV protons per second do these beam powers correspond to?
- Large mass (~80kt! total) LAr TPC at SURF
- Powerful near detector
- Was born in March 2015! A four year old toddler!
  - Combination of two large proposals – LBNE (US) and LBNO (EU)
- 1132 collaborators from ~179 institutes in 32 countries

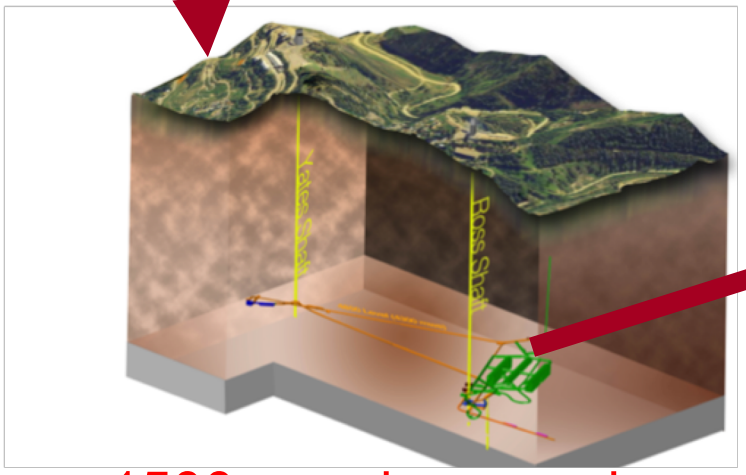
The Map of the DUNE Experiment



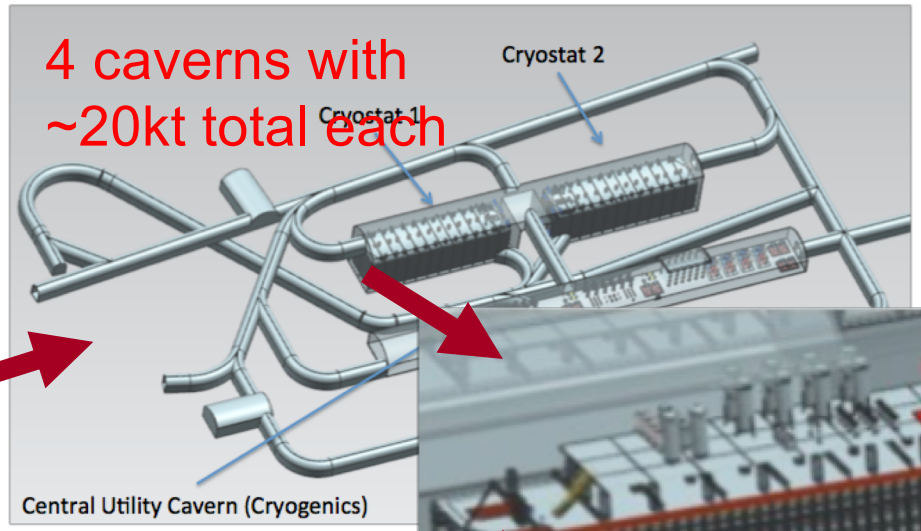
132 collaborators
79 institutions
2 countries

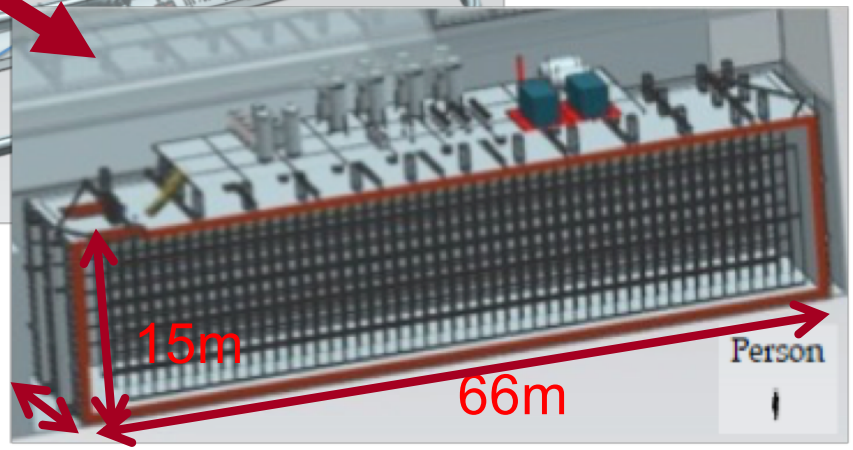
The Components of the DUNE Experiment





1500m underground



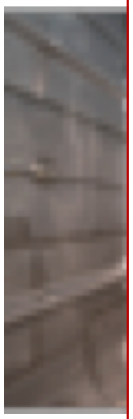


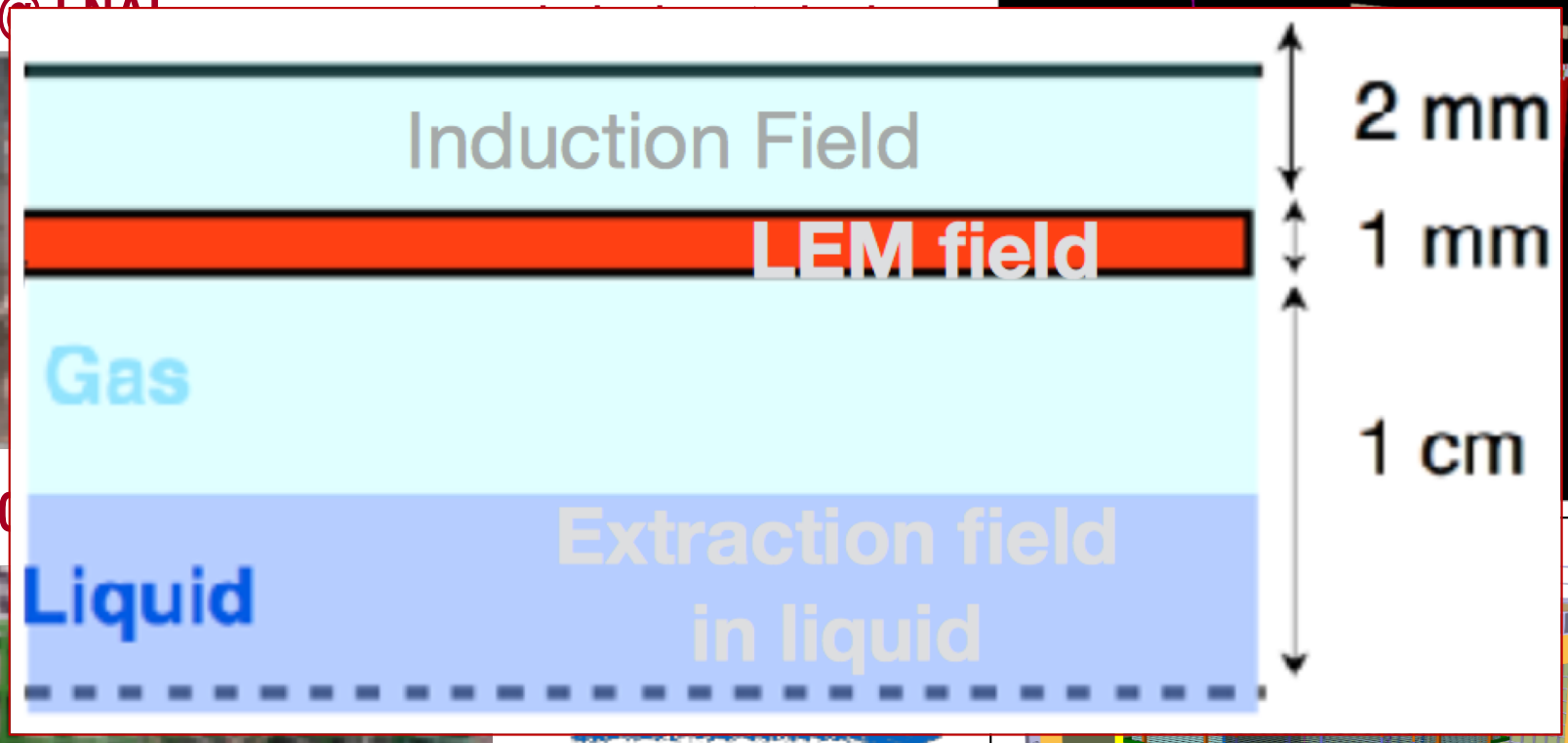
15m

Prototyping the DUNE Experiment

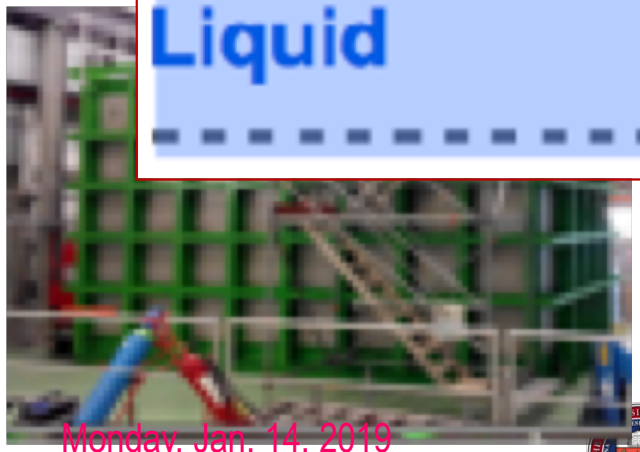
- Building four 10kt active volume LAr Detectors very challenging!
- Need to understand many aspects of the detector technology
- Two full scale prototype detectors under construction at CERN – SP and DP

35T @ FNAL

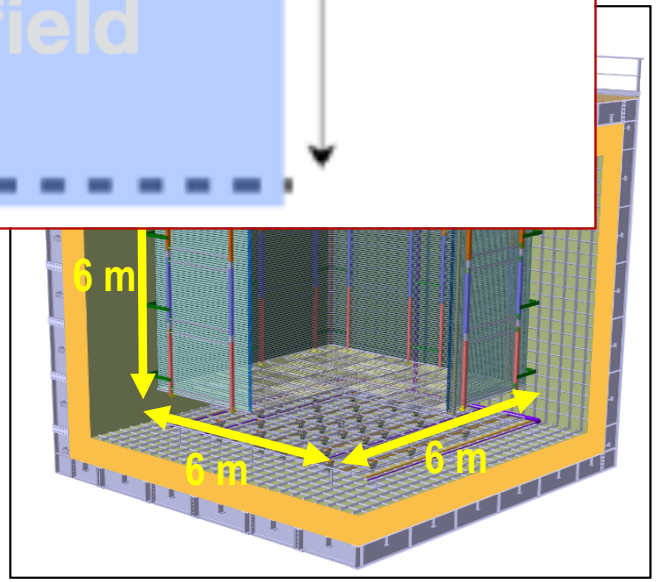


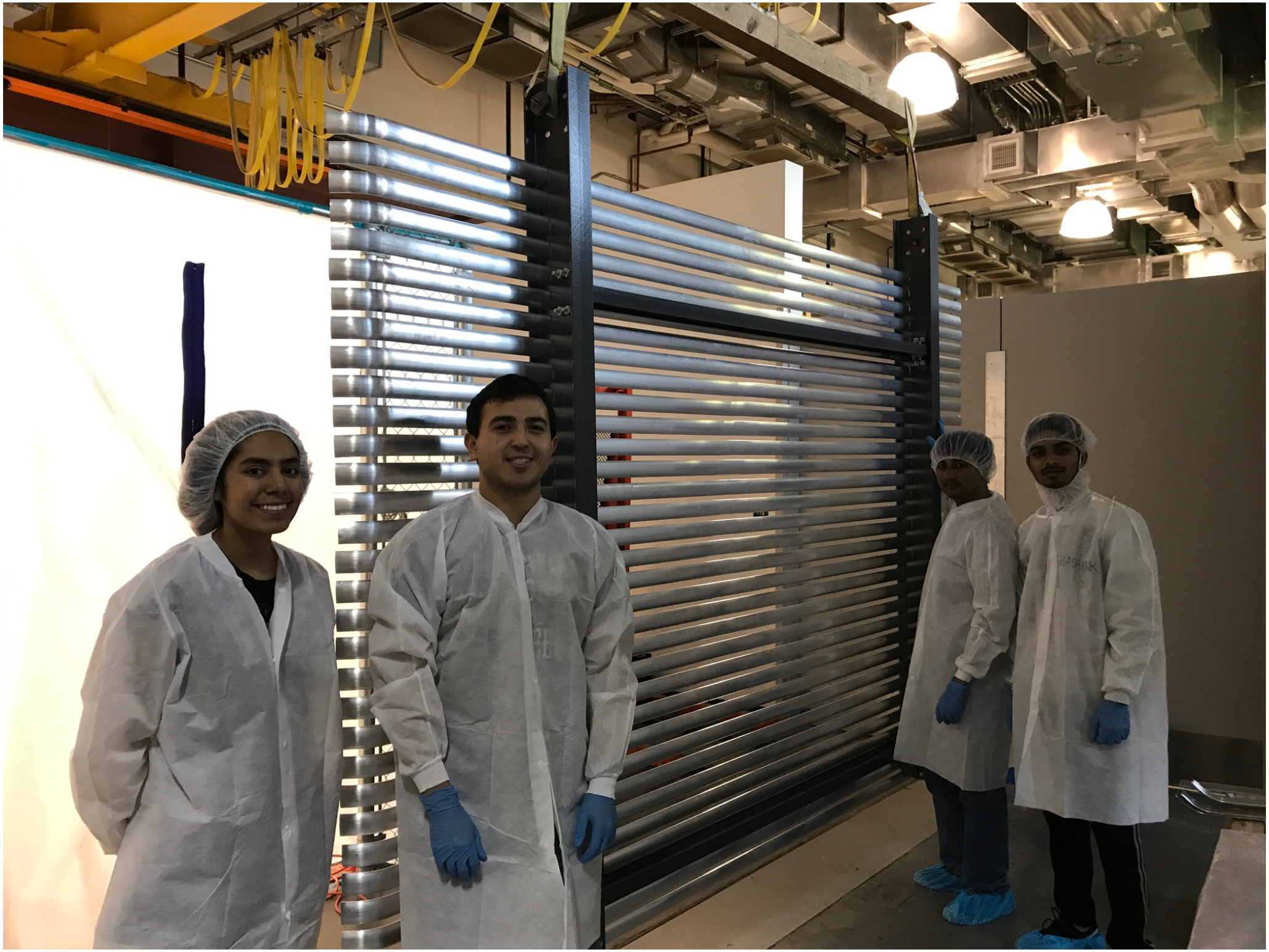


WA10



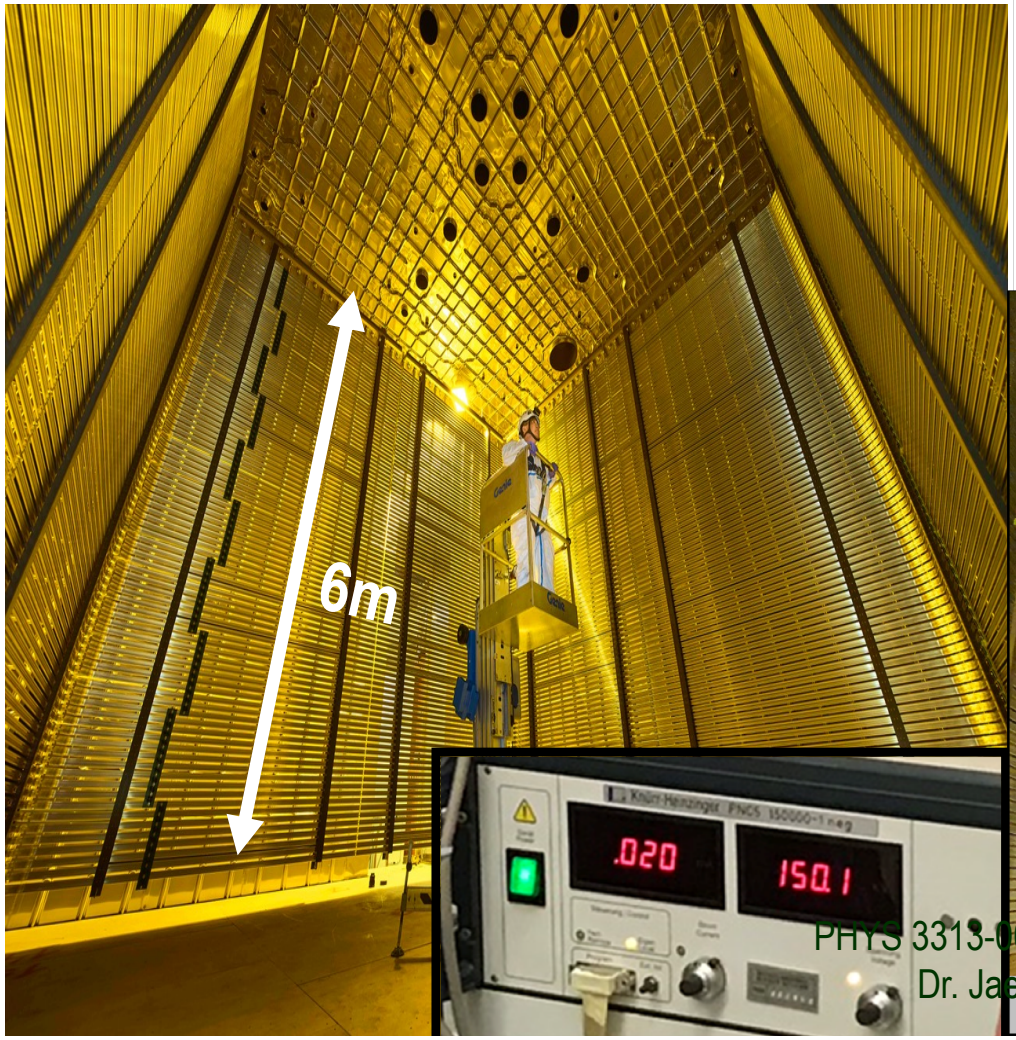
protoDUNE DP@CERN
6mx6mx6m Active

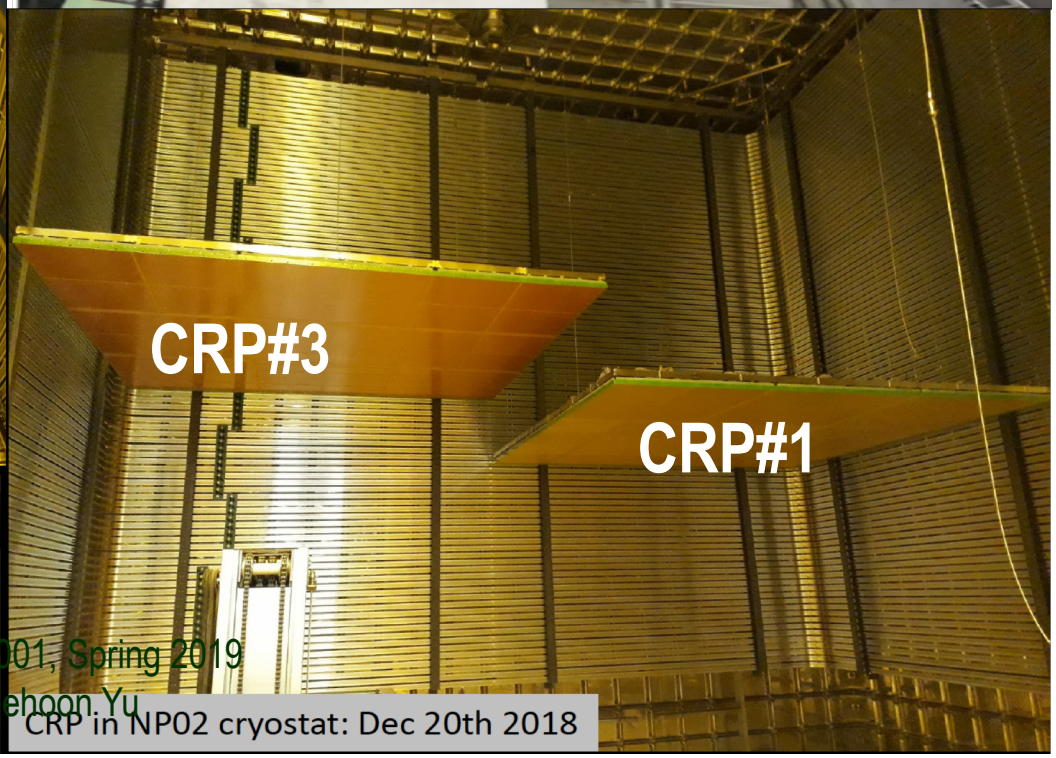




Status of ProtoDUNE Dual Phase

- Field cage completed and tested at 150kV in air & the charge readout plane (CRP) assembly and installation in progress (3 ready, 2 installed)
  - Complete the installation of the 3mx3m CRP's, cathode and PDS and close the cryostat Spring 2019
  - Complete purge and fill by July 2019
  - Ready for cosmic data summer 2019

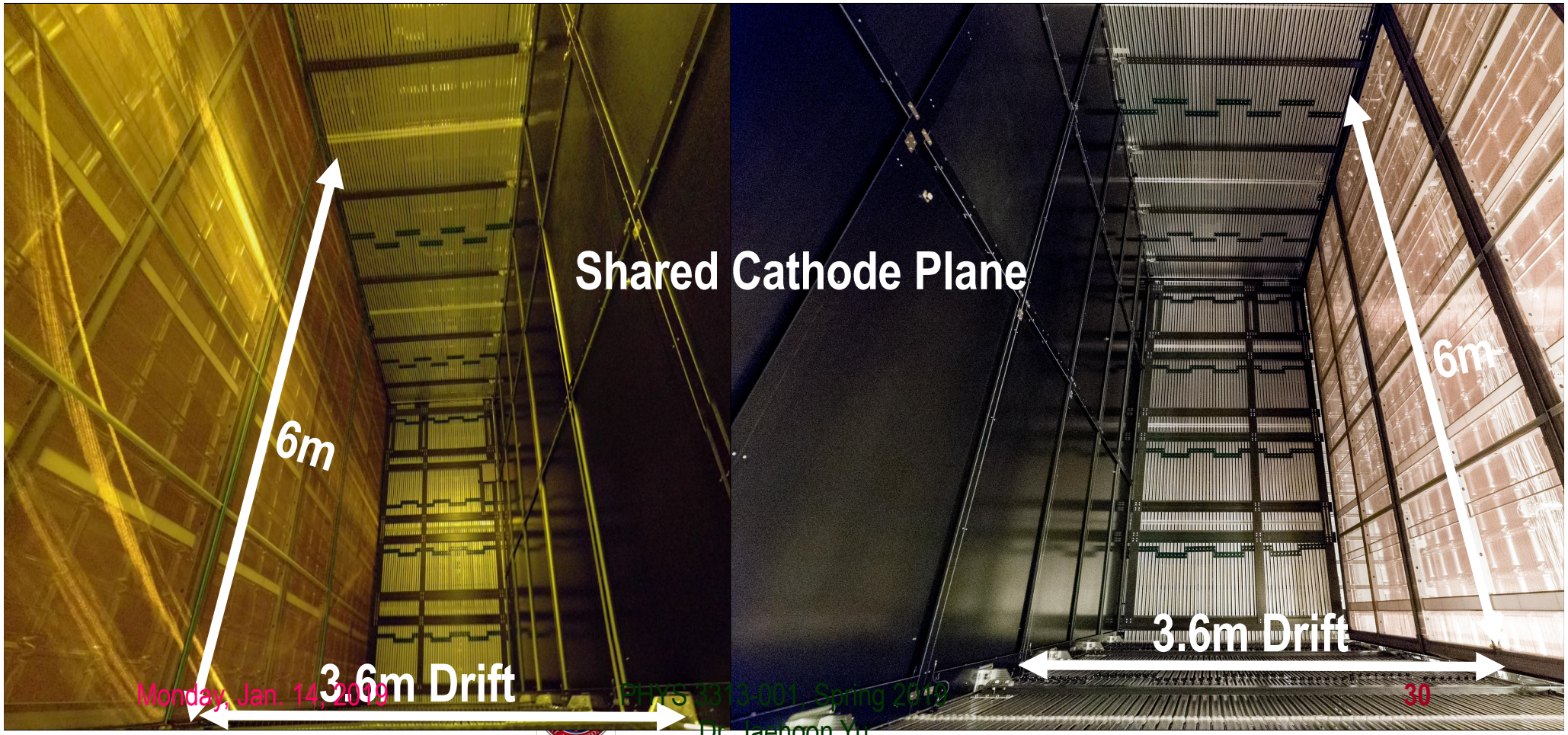




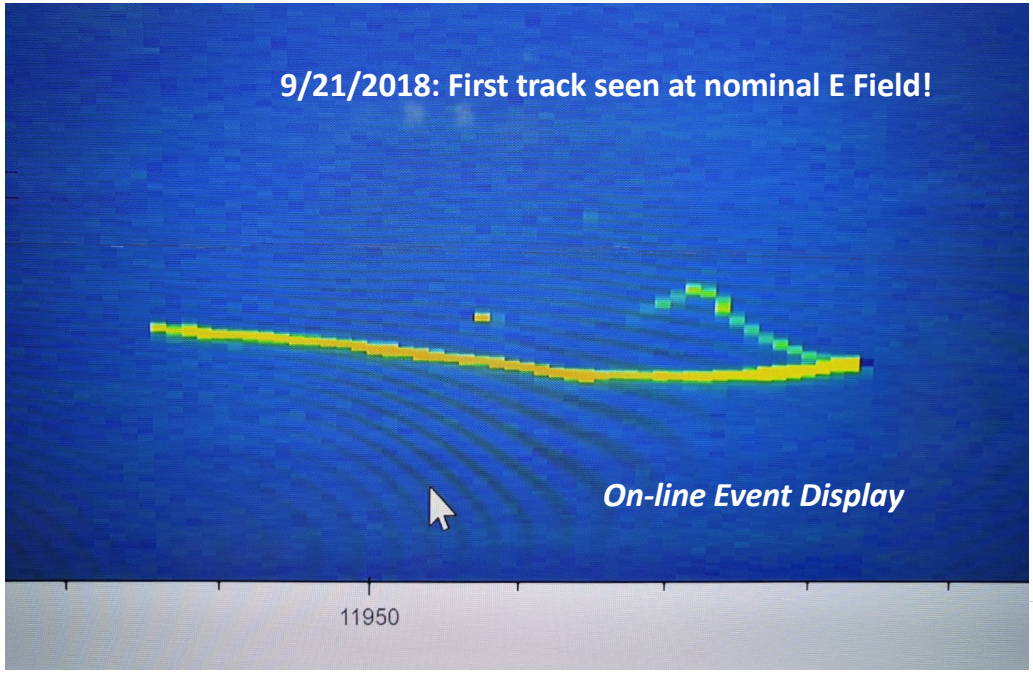
CRP in NP02 cryostat: Dec 20th 2018

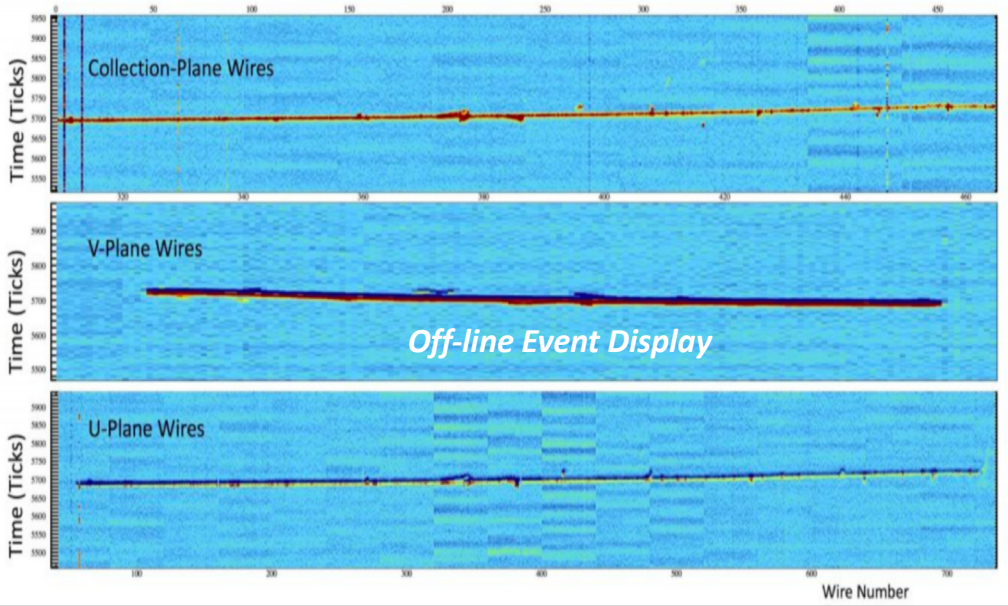
Status of ProtoDUNE Single Phase

- Detector completed and the cryostat shut end of June
  - LAr filling completed on Sept. 13
  - 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
  - Cosmic data taking continues throughout the 2 year CERN beam shutdown

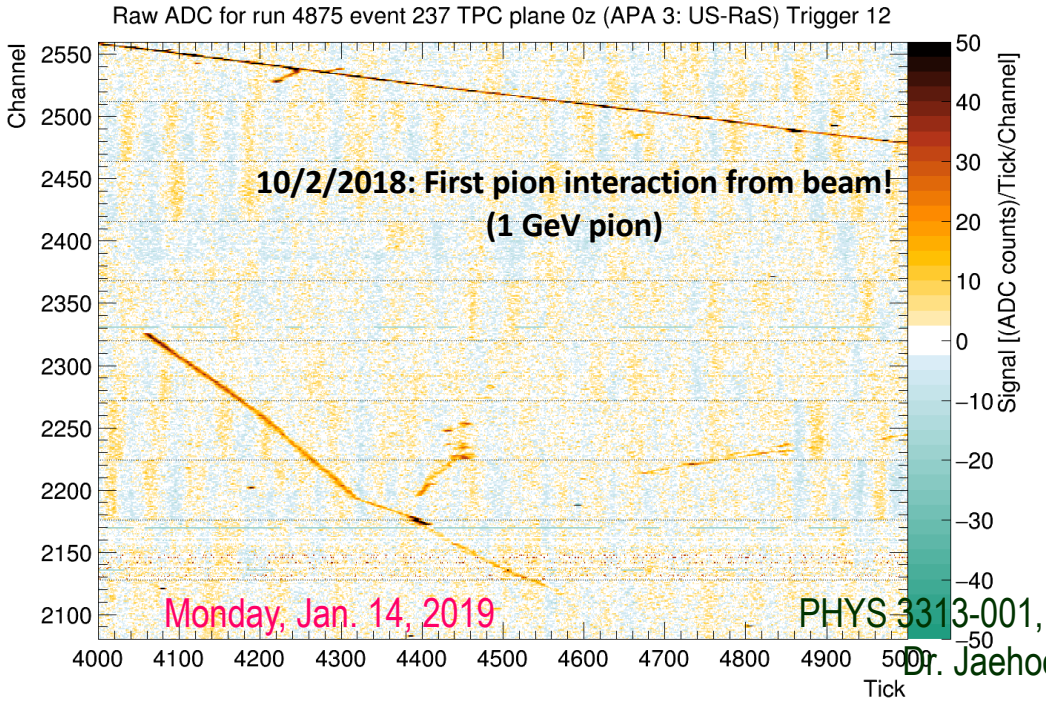


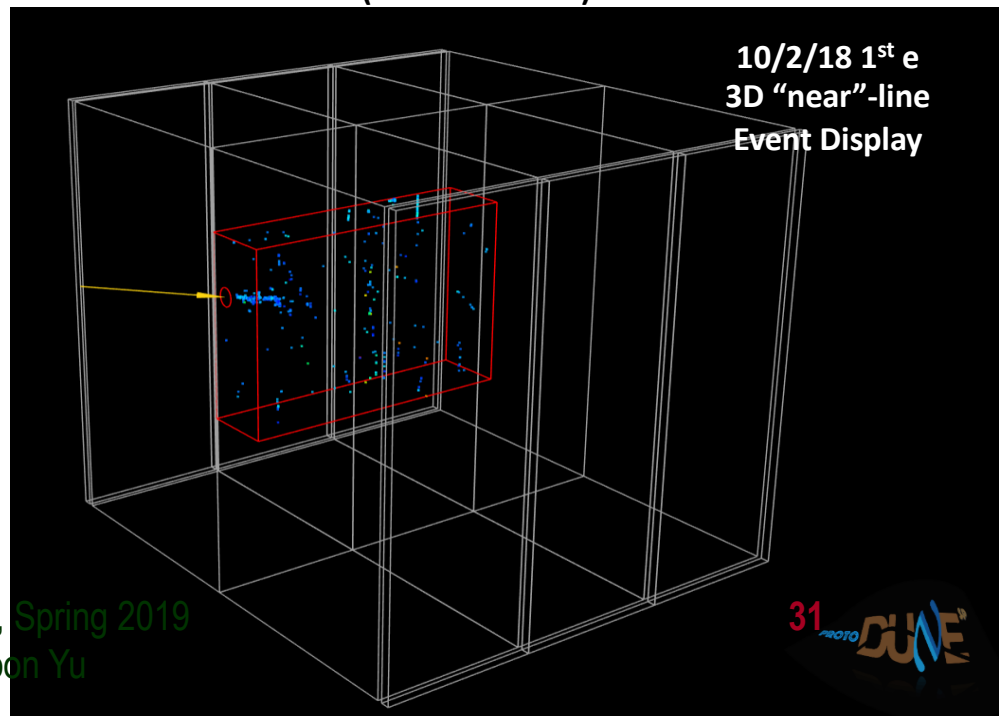
ProtoDUNE SP First Events



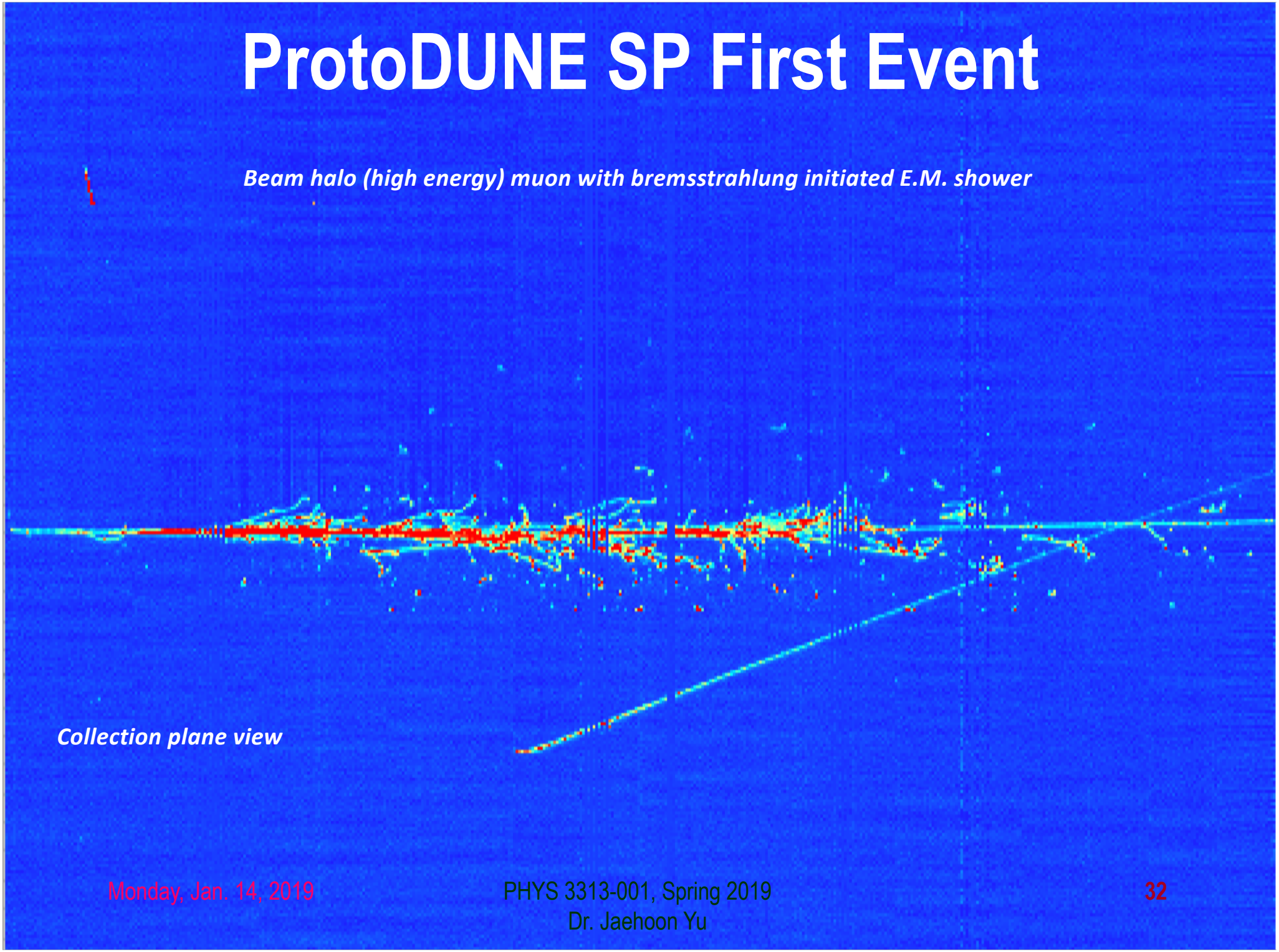


10/2/2018: First event seen from beam!
(1 GeV electron)



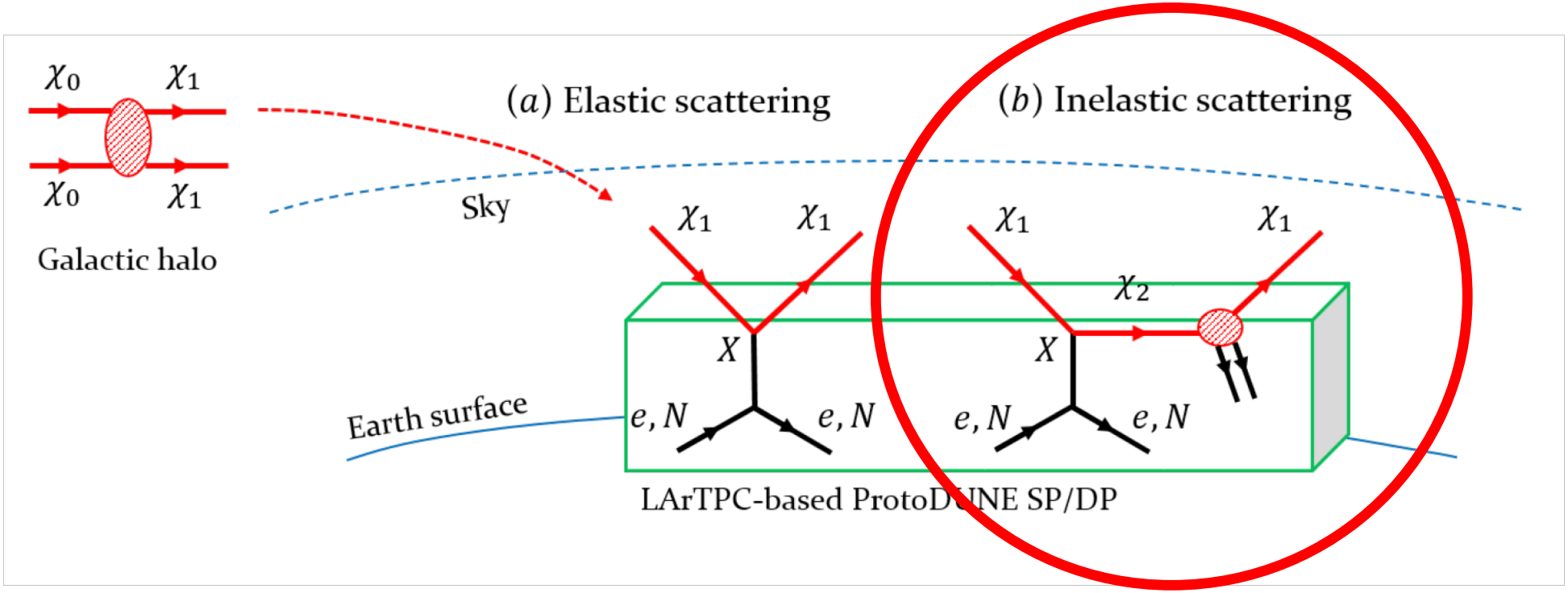


ProtoDUNE SP First Event

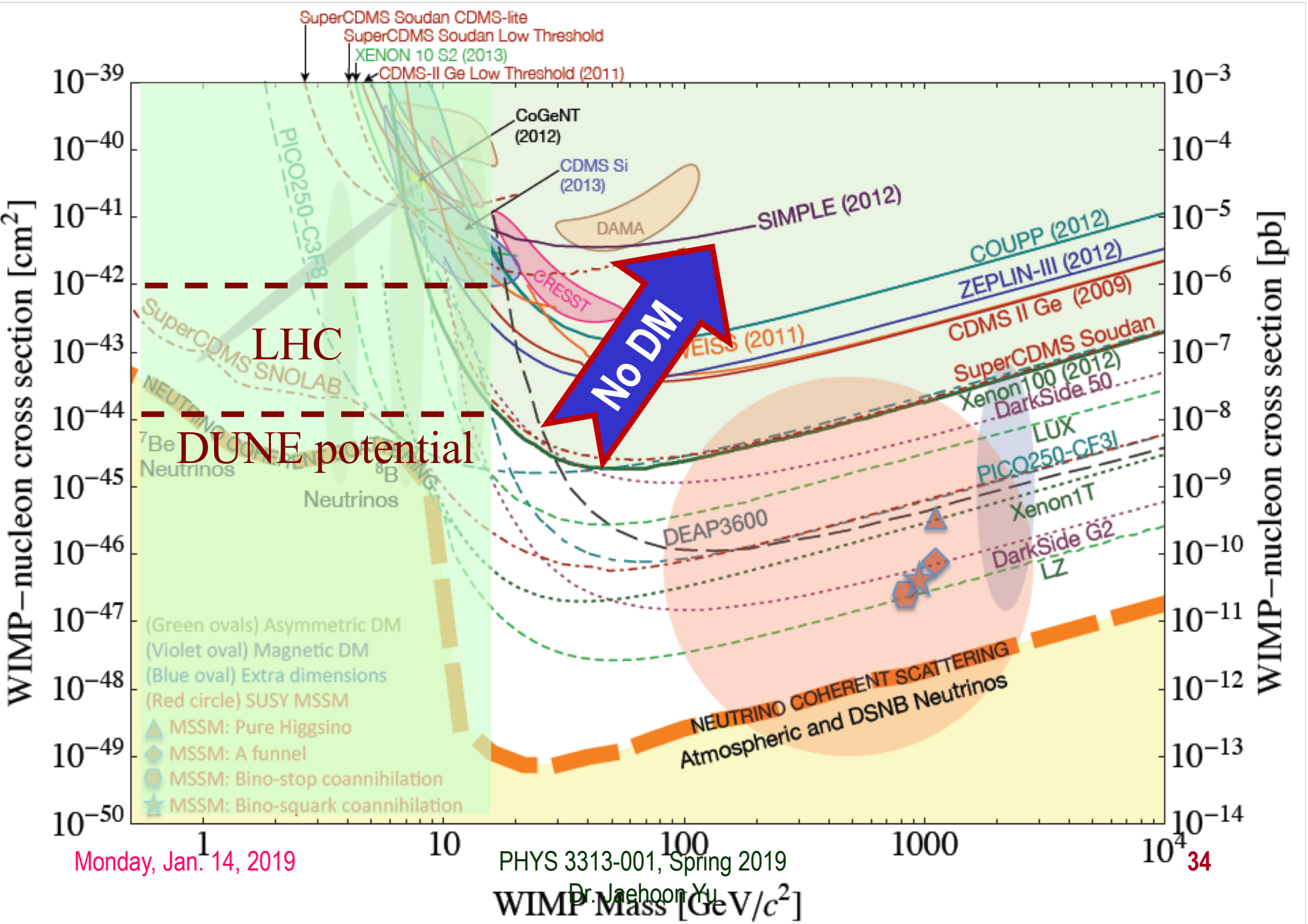


Intermediate Physics w/ ProtoDUNE?

- 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 3 lepton + missing energy final states helps over the anticipated large background on the surface

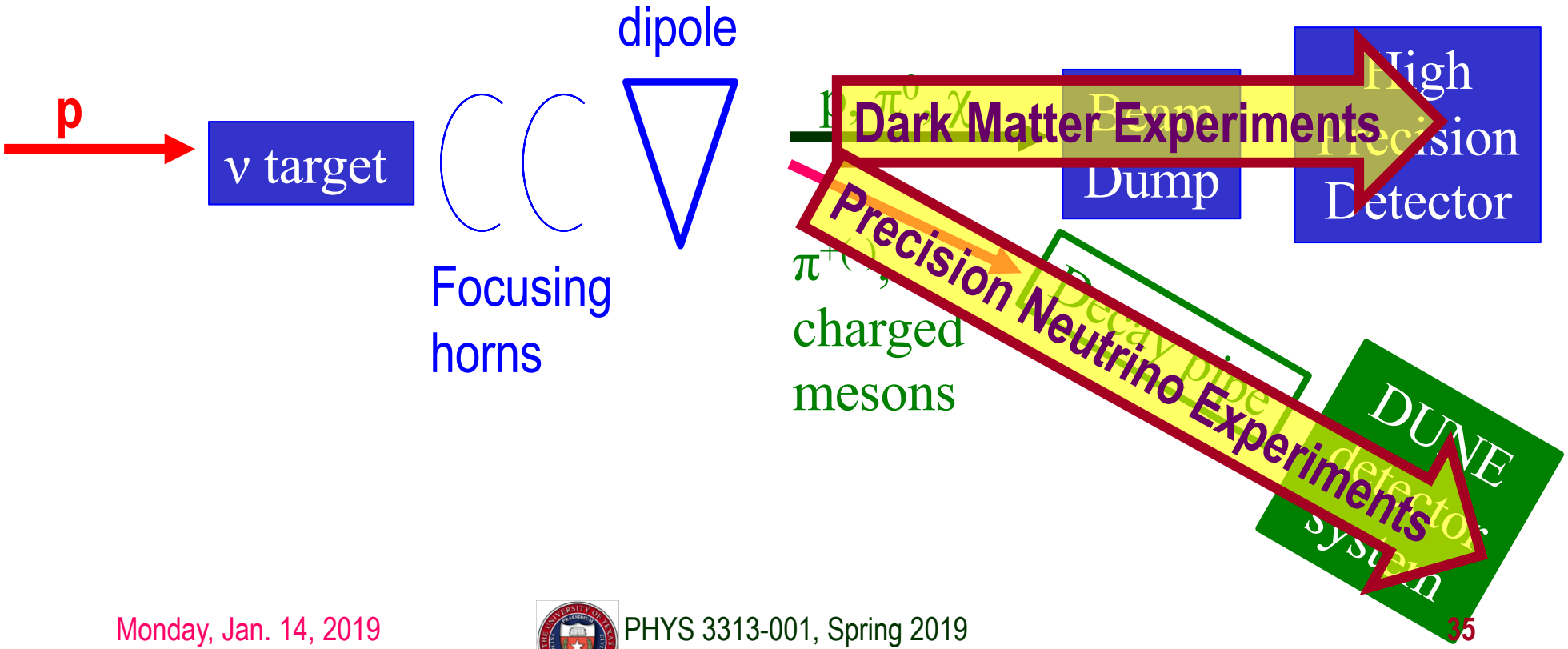


Dark Matter Search Motivation



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

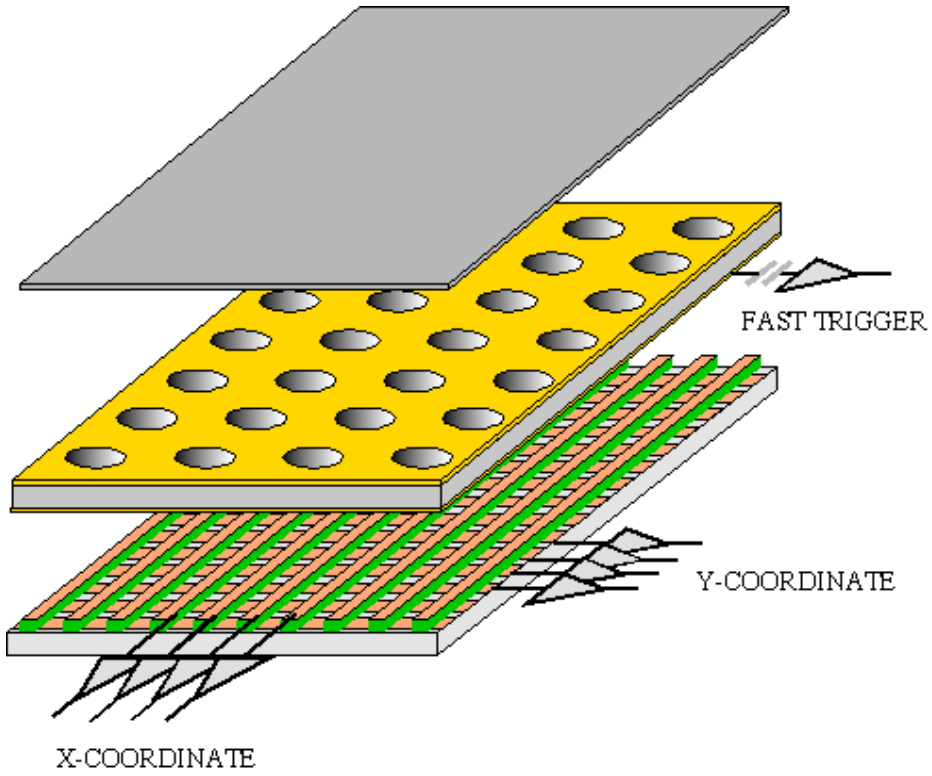


Dark Matter Searches at Fermilab

- 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??

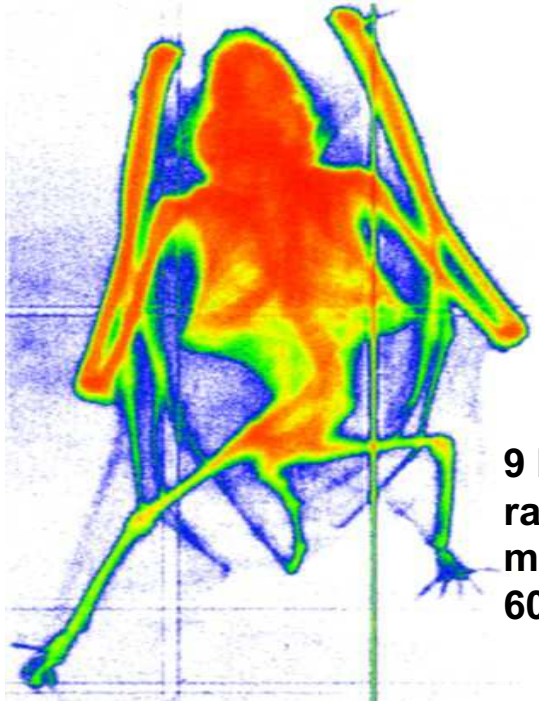
GEM Application Potential

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



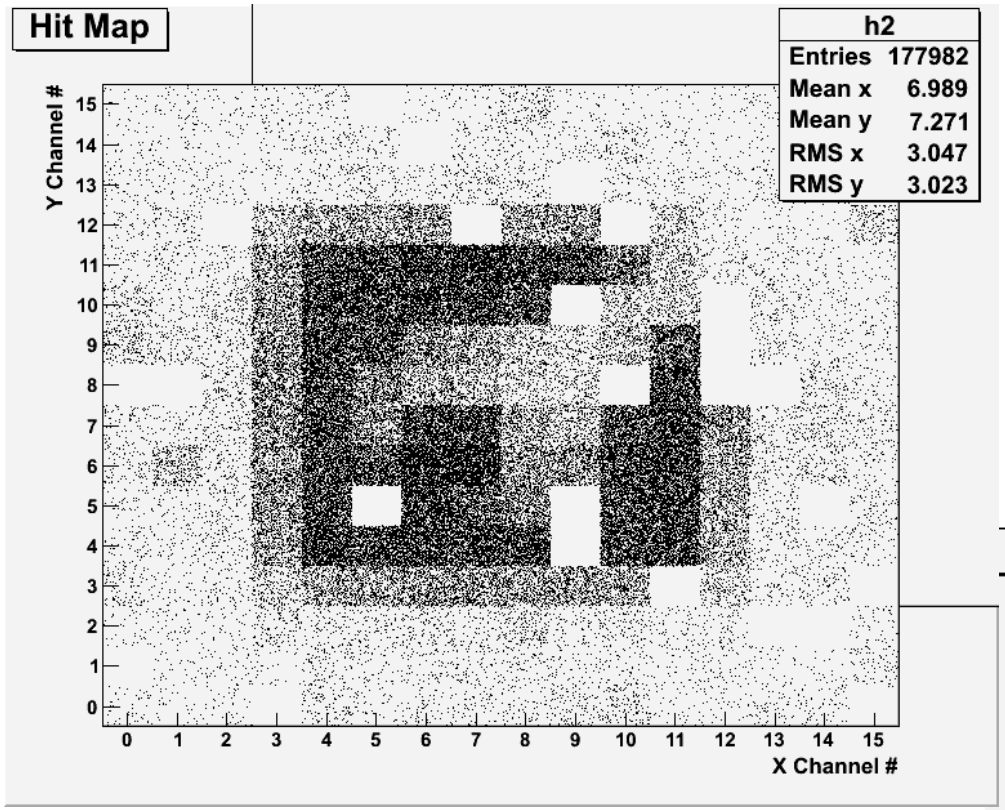
A. Bressan et al,
Nucl. Instr. and Meth. A 425(1999)254
F. Sauli, Nucl. Instr. and Meth.A 461(2001)47

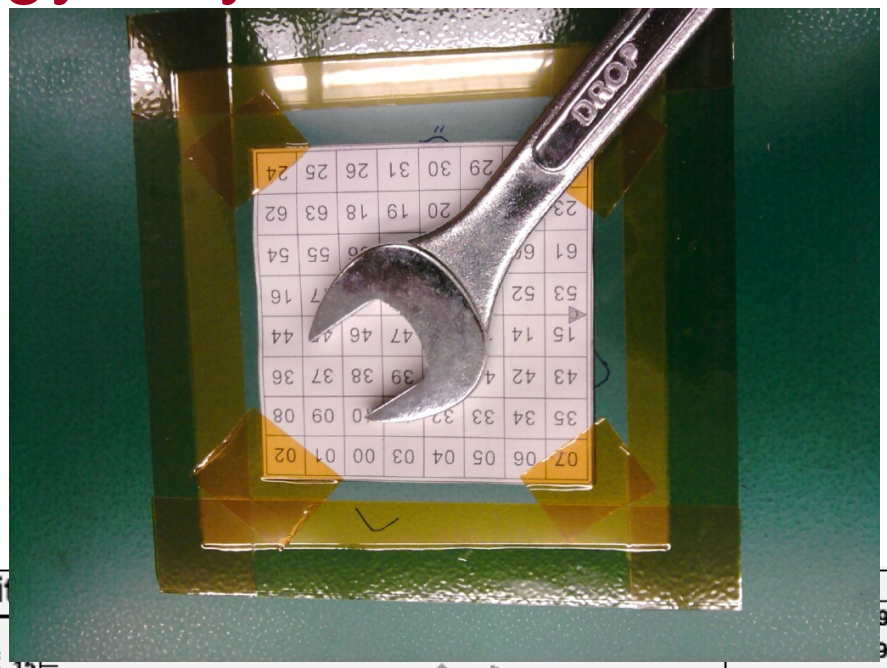
FAST X-RAY IMAGING

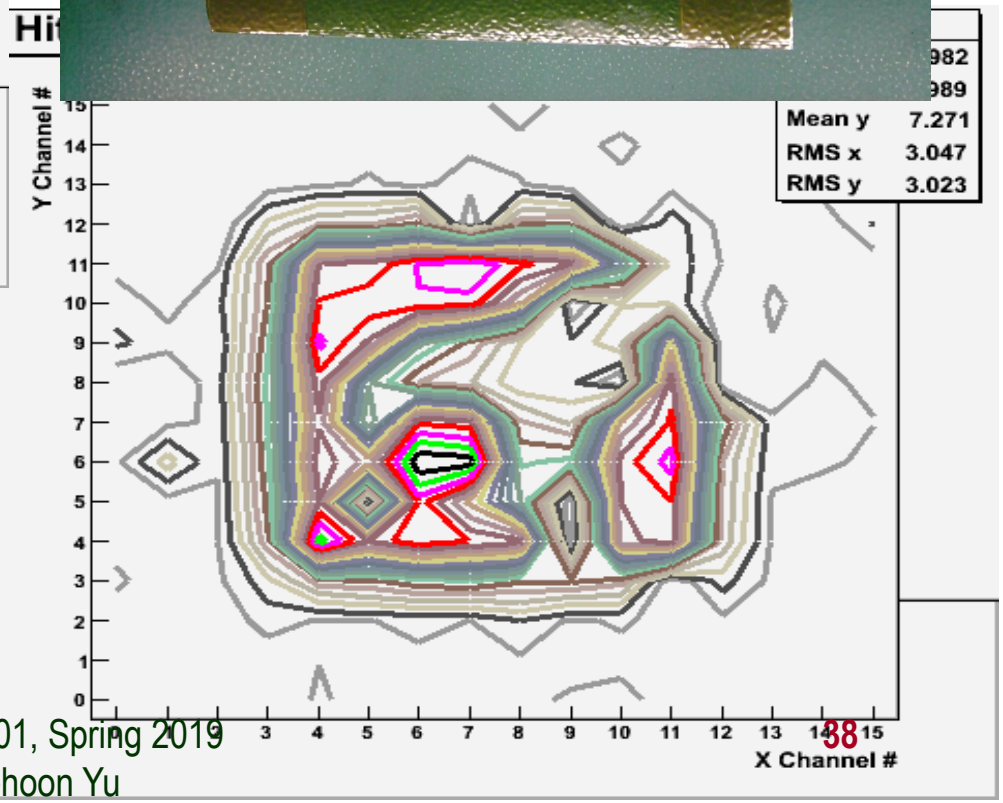


9 keV absorption radiography of a small mammal (image size ~ 60 x 30 mm^2)

Bi-product of High Energy Physics Research







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

Textbook

- Title: Modern Physics for Scientists and Engineers
  - 4th edition
- Authors: S.T. Thornton and A. Rex
- ISBN: 978-1-133-10372-1