High Throughput Grid Computing
and High Energy Particle Physics
and My 1000 Year Dreams

ASP Colloquium Series 2020

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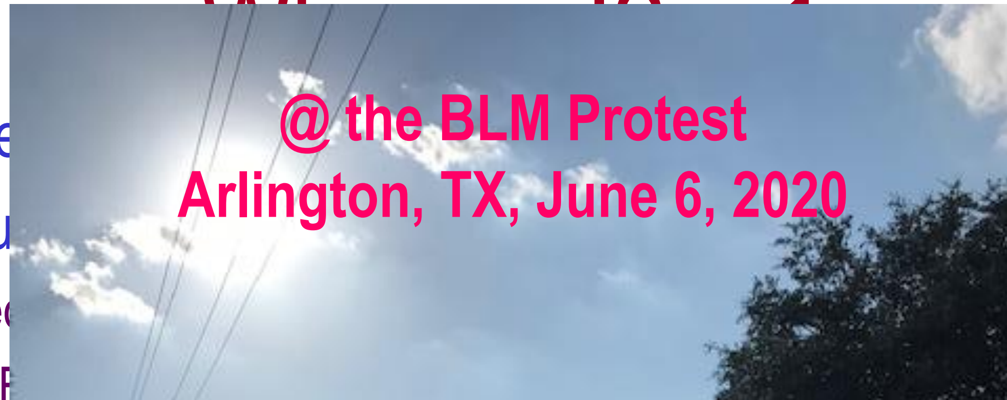
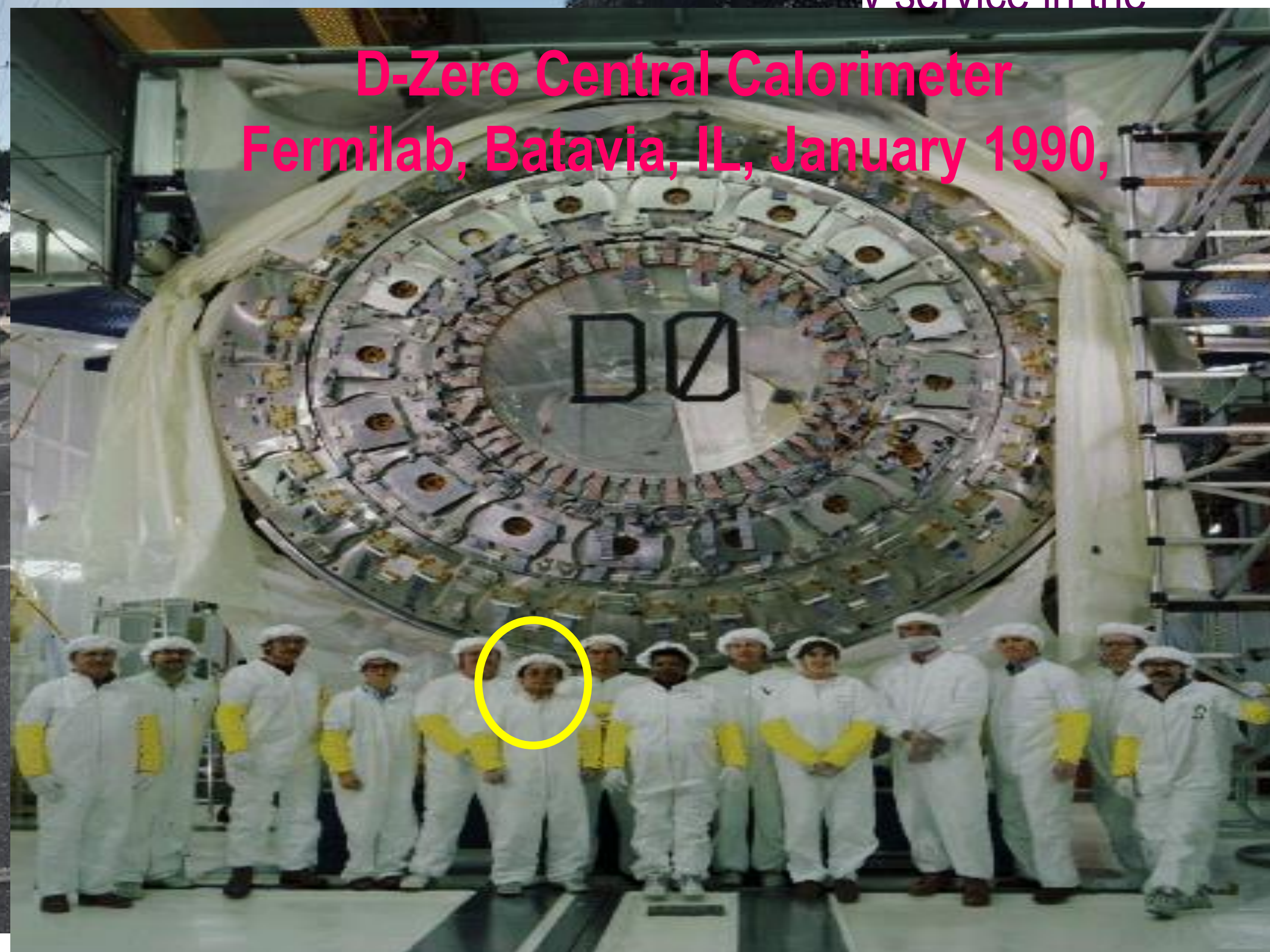
University of Texas at Arlington

Outline

- Introductions
- The problem
- A solution using the Computing Grid
- Performance of the Grid
- Conclusions

- My full name
- Lived in Sou ... atorship
  - I take free ... ery seriously
  - Obtained E ... y service in the Korean Ar
- Joined the P ... obtained Ph
  - Ph.D. thes ... prototyping ... data analy
  - All my 3 ch
- 1st postdoc a ... postdoc at F ... building the
- Fermilab sta

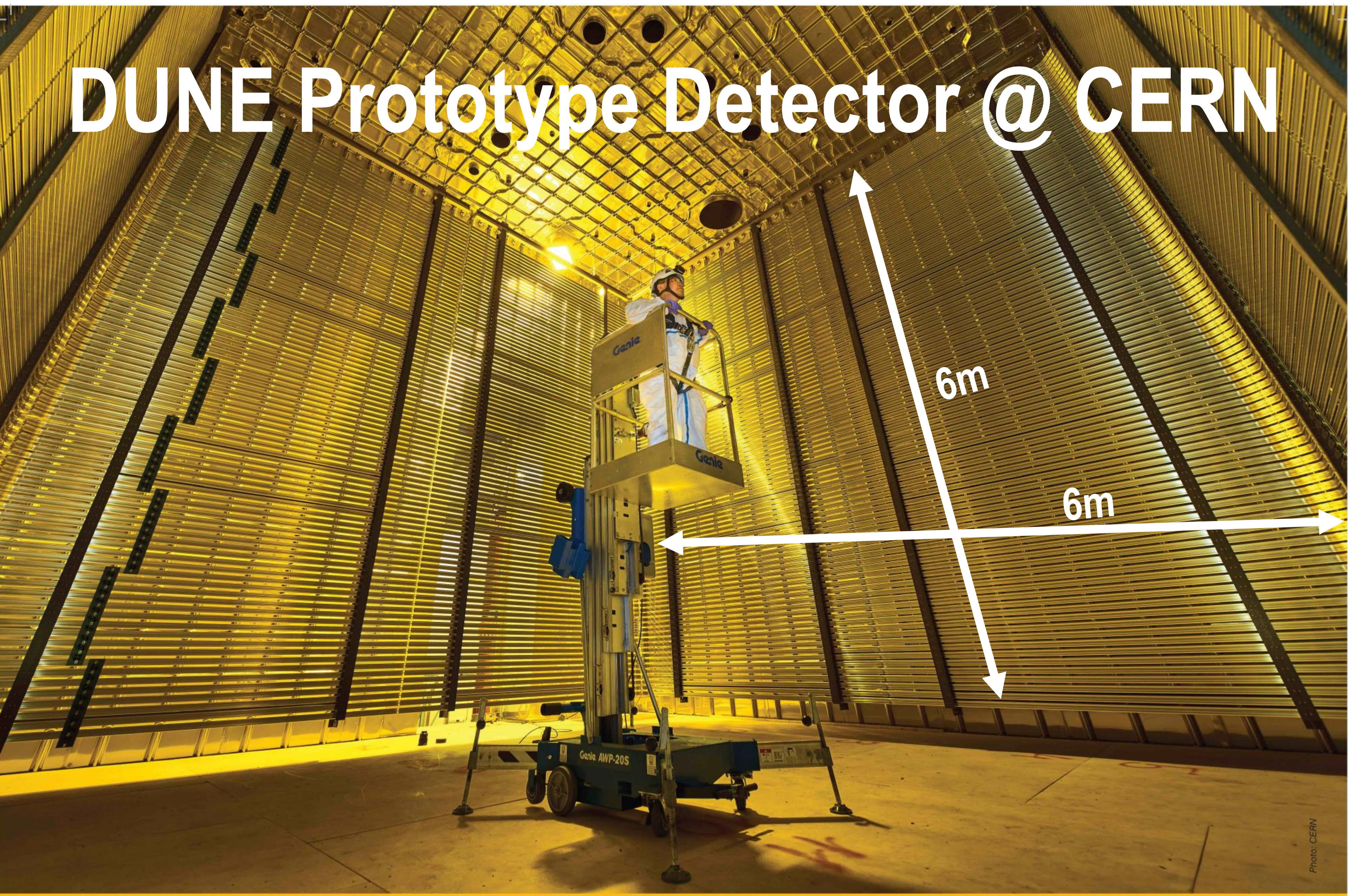




Who am I? – 2

- Professor at U. Texas Arlington (2001 – present)

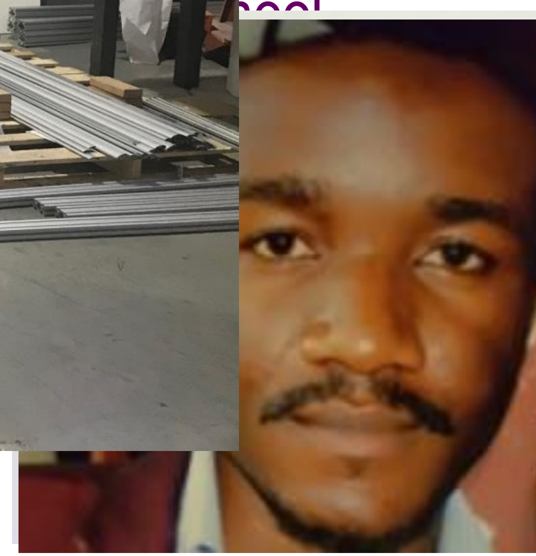
DUNE Prototype Detector @ CERN



How am I related to ASP?

- Organized the 1st high-performance computing program in ASP201
  - Secu
- Serving ... ber
  - Conti ... s with US NSF
  - Arran ... ool
- Worked
  - Last I
    - Qu
  - Brigh
    - Manager at Blicma since Apr. 2016

In March 2020 w/ his wife and the newborn son!!



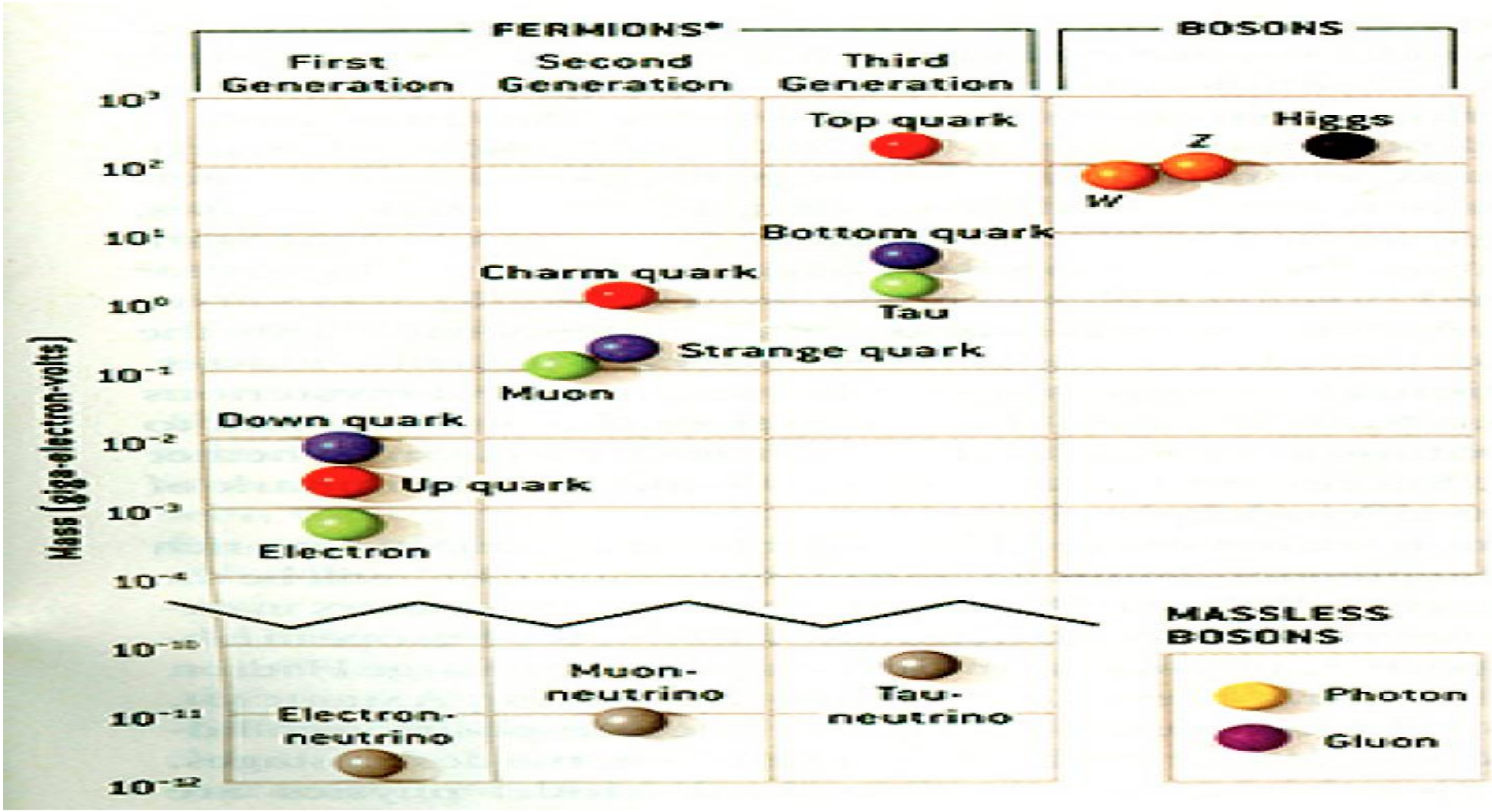
We always wonder…

- What makes up the universe?
- How does the universe work?
- Where do we all come from?

High Energy Physics

- Definition: A subfield 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 (SU3xSU2XU1)

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!!!

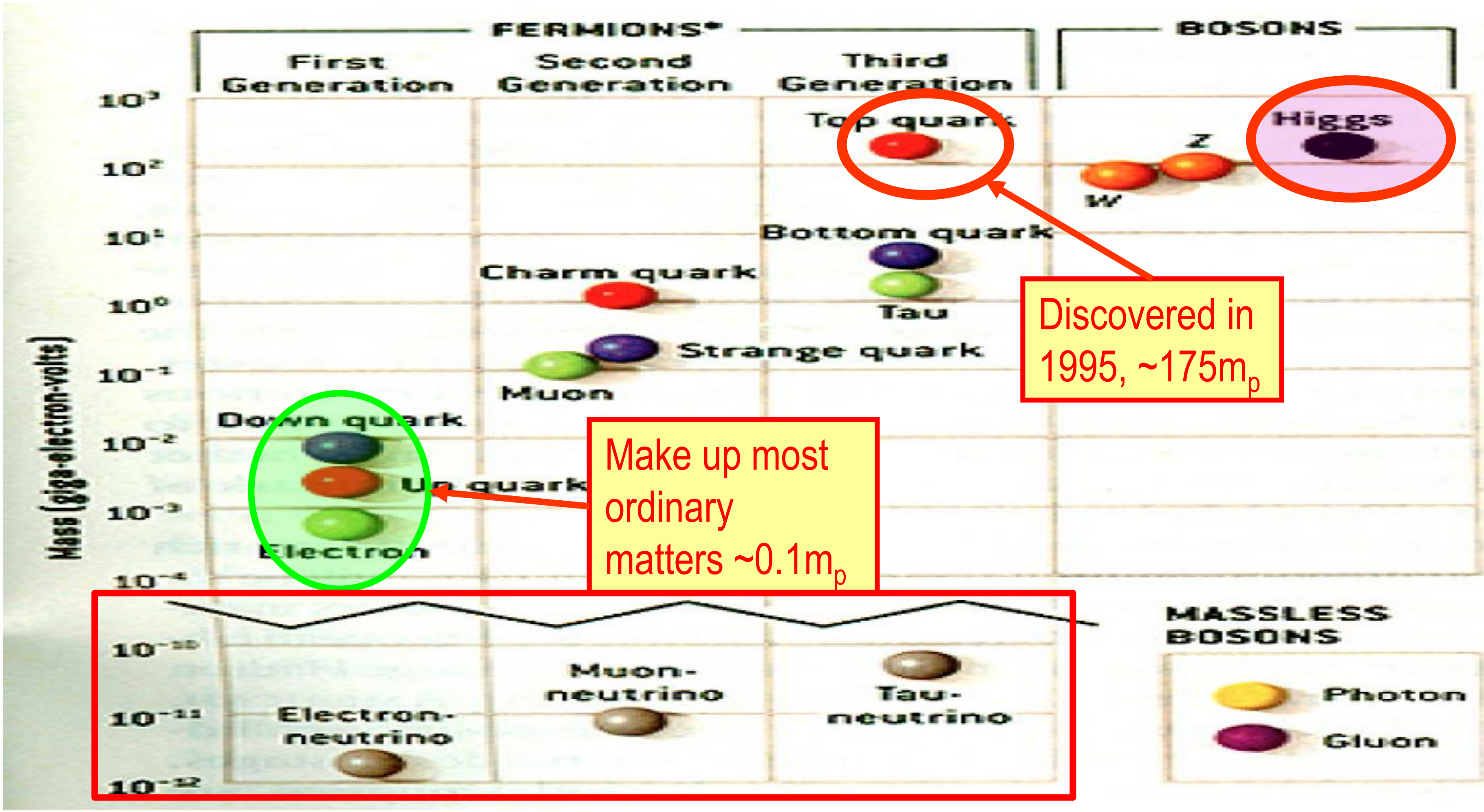
Periodic Table of the Elements

1 1IA 1A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8	9 VIII 8	10 VIII 8	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

HEP and the Standard Model



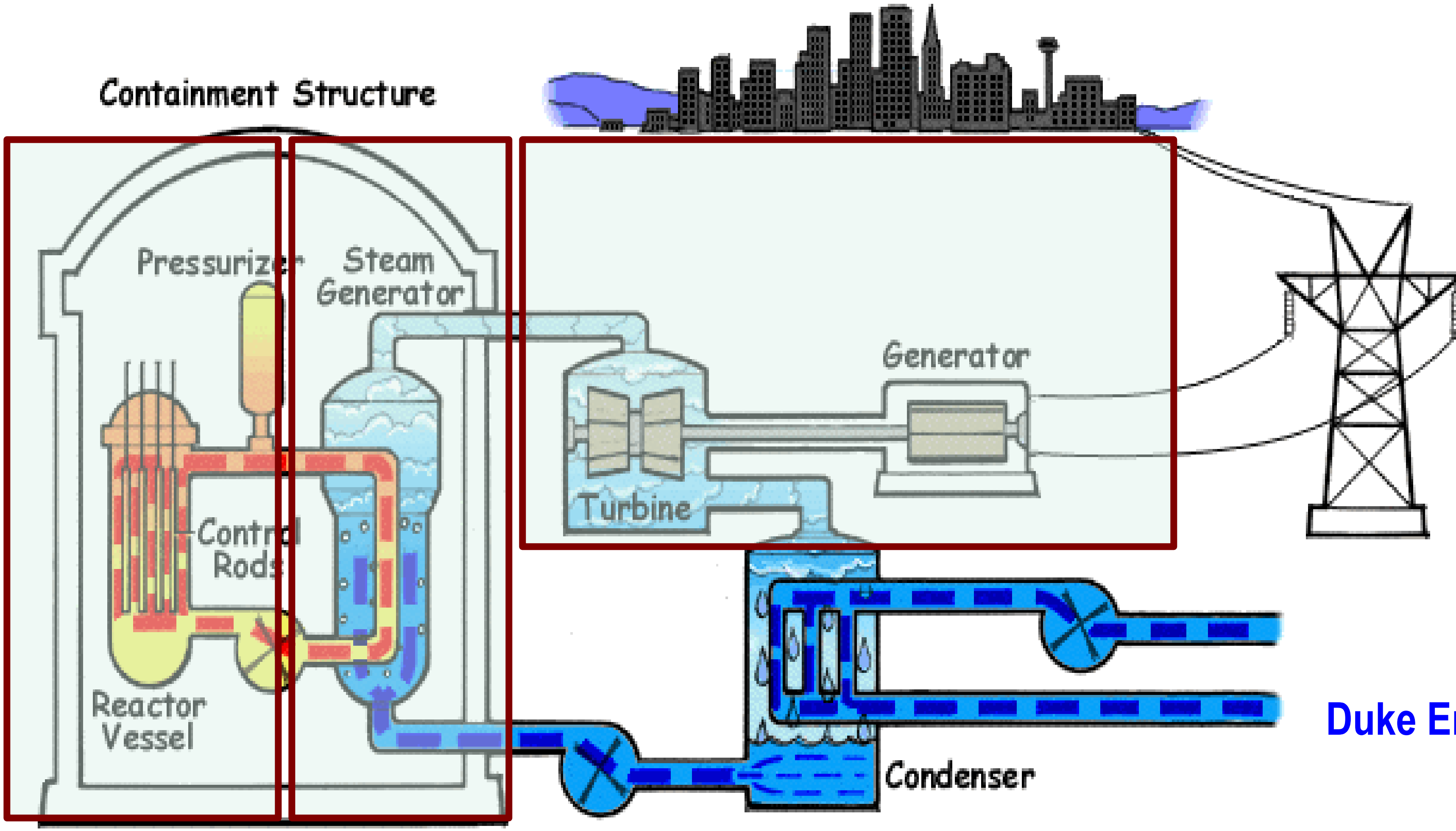
- Total of 16 particles (12+4 force mediators) make up all the visible matter in the universe! ➔ Simple and elegant!!!
- Tested to a precision of 1 part per million!

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?

Me!

How does a nuclear power plant work?



Duke Energy

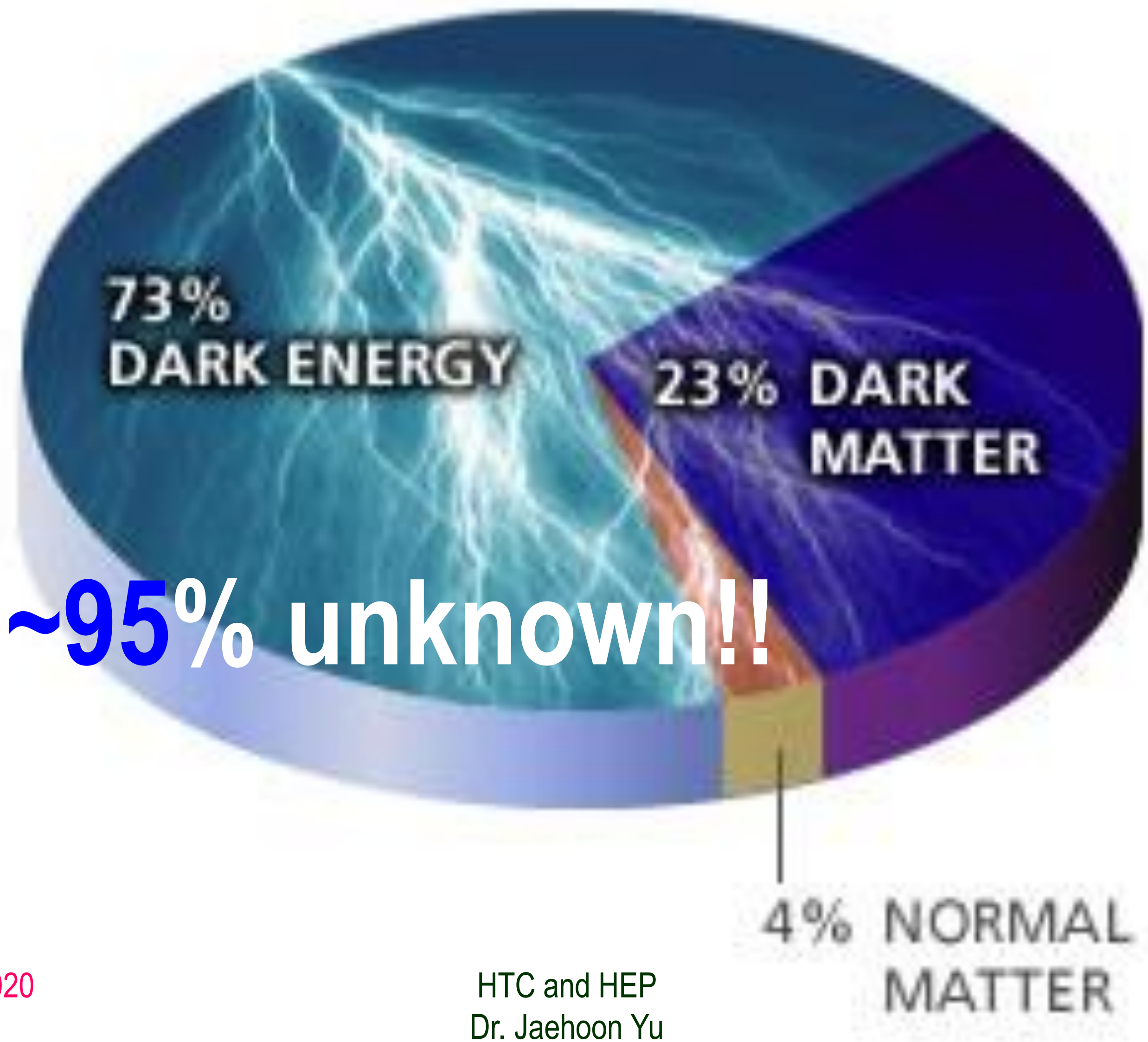
My 1000 year dream: Skip the whole thing!

Make electricity directly from nuclear forces!

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?



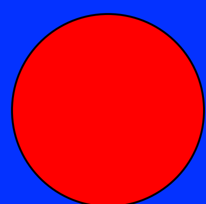
~95% unknown!!

So what's the problem?

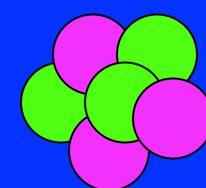
- Why is the mass range so large ($0.1m_p$ – $175\ m_p$)?
- Is the particle we discovered really the Higgs particle?
- Why is the matter in the universe made only of particles?
- Neutrinos have mass!! What are the mixing parameters, particle-anti particle asymmetry and mass ordering?
- Why are there 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 and in the new experiment in the US!
- 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.



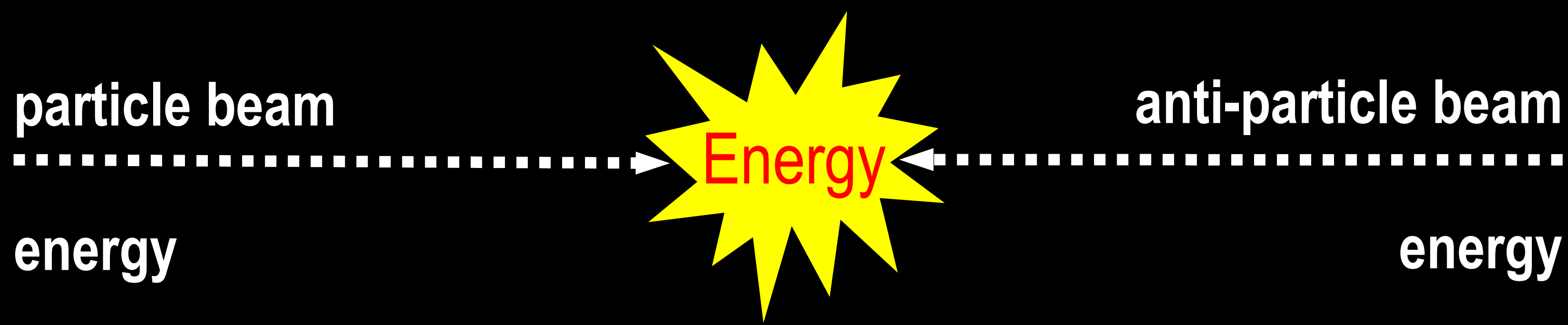
seen by
low energy beam
(poorer resolution)



seen by
high energy beam
(better resolution)

Accelerators are also Time Machines.

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

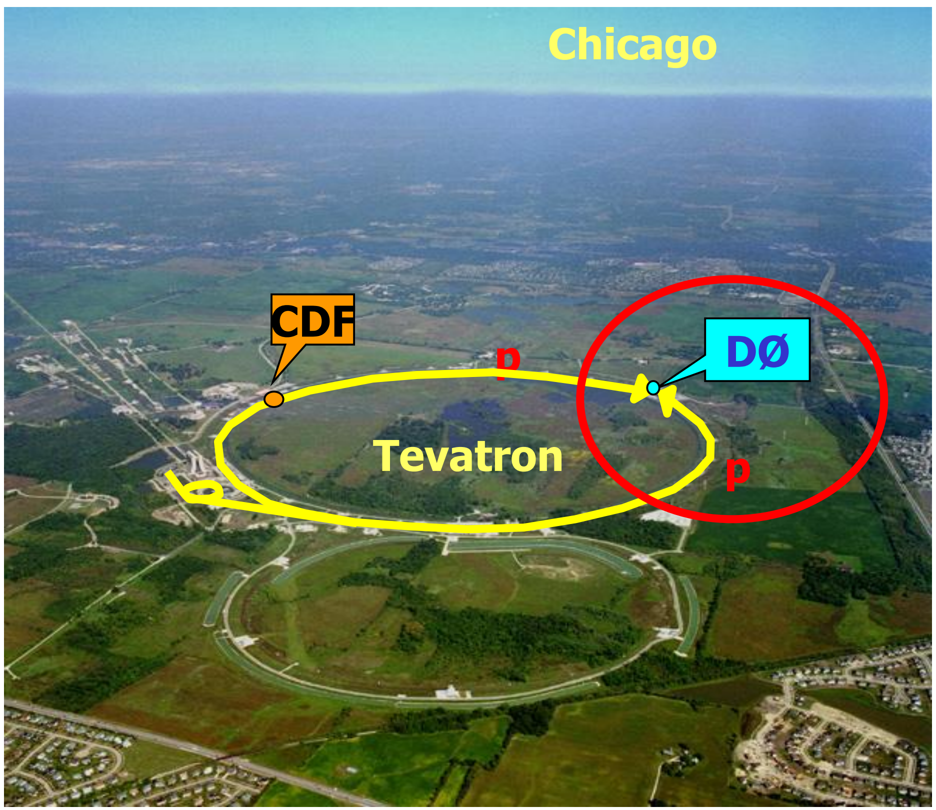


Particle and anti-particle annihilate.

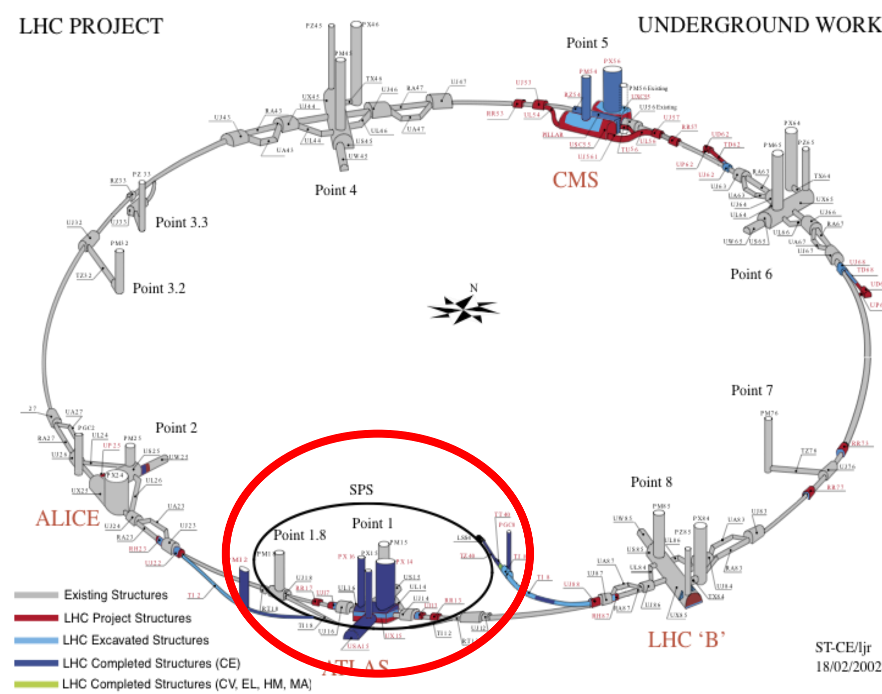
$$E = mc^2$$

Fermilab Tevatron and LHC at CERN

- World's Highest Energy proton-anti-proton collider
  - 4km (2.5mi) circumference
  - E_{cm}=2 TeV (=6.3×10^{-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!!**

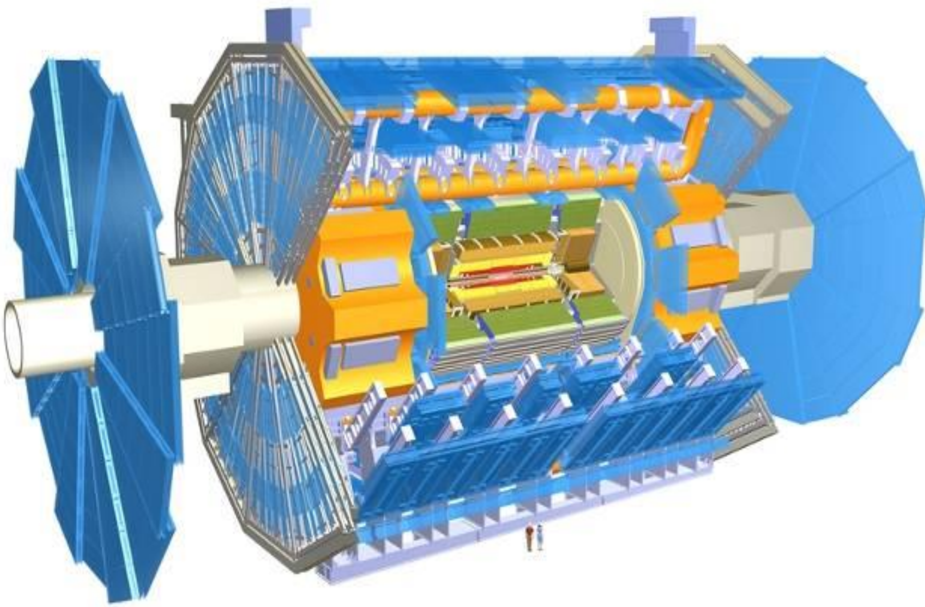


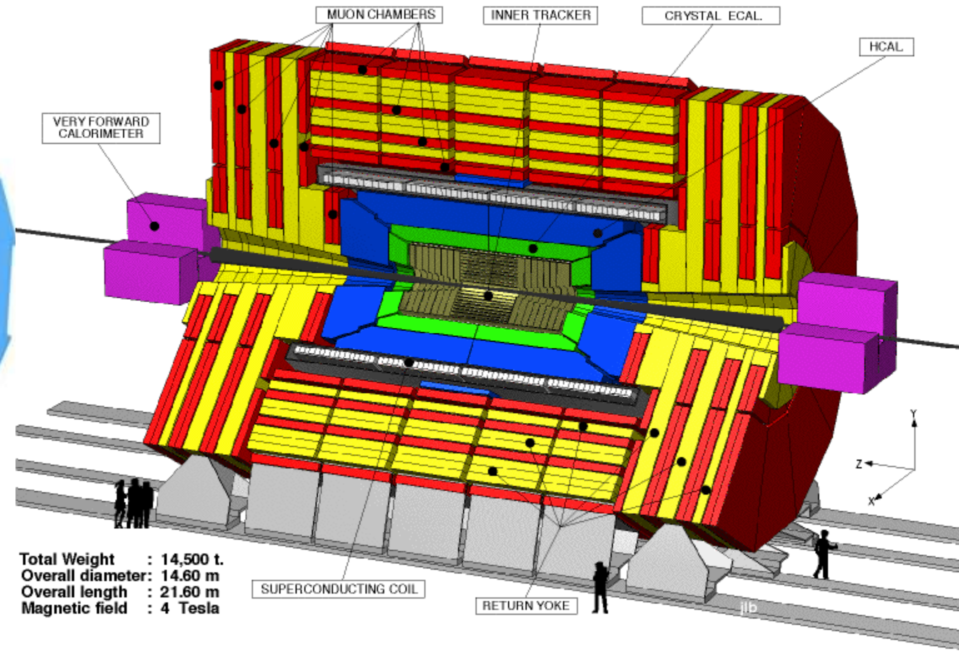
- World's Highest Energy p-p collider
  - 27km (17mi) circumference, 100m (300ft) underground
  - Design E_{cm}=14 TeV (=44×10^{-7}J/p➔ 362M Joules on the area smaller than $10^{-4}m^2$)
  - ➢ Equivalent to the kinetic energy of a B727 (80tons) at the speed 310km/hr
    - ➢ ~3M times the energy density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



LHC @ CERN Aerial View

The ATLAS and CMS Detectors



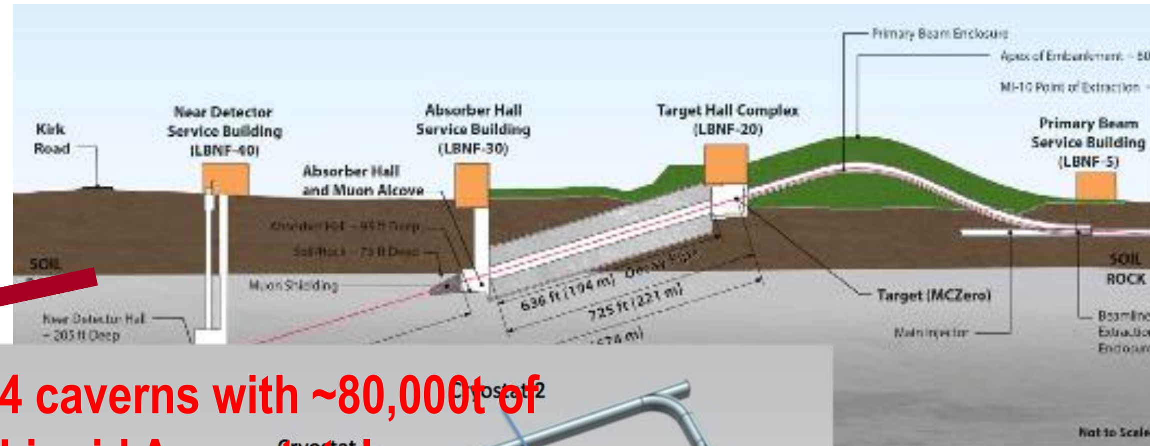


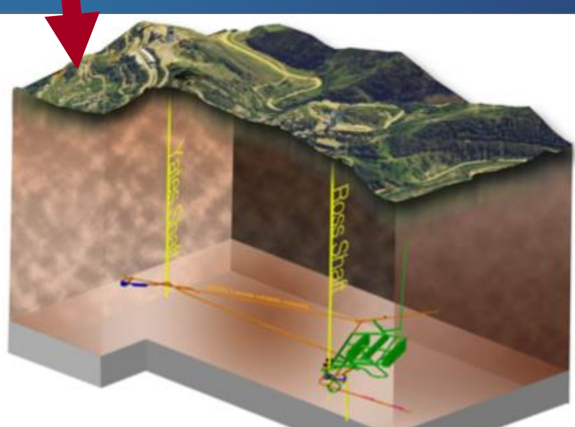
- **Weighs 7000 tons and ~10 story tall**
- Records **200 – 400 collisions/second (out of 50million)**
- Records approximately **350** MB/second
- Records ~2 PB per year ➔ **200*Printed material of the US Lib. of Congress**

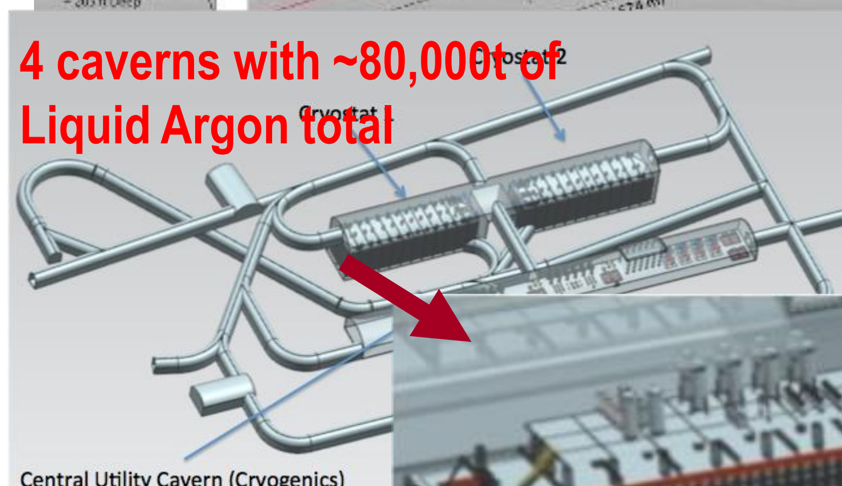
200x

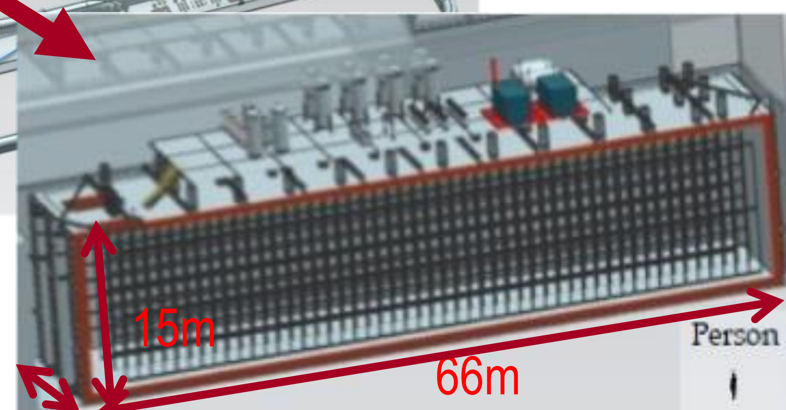
The Next Big Thing - DUNE

- Stands for Deep Under Ground Neutrino Experiment
- The $1.5B US flagship long baseline (1300km) ν experiment
  - 1500m underground in South Dakota



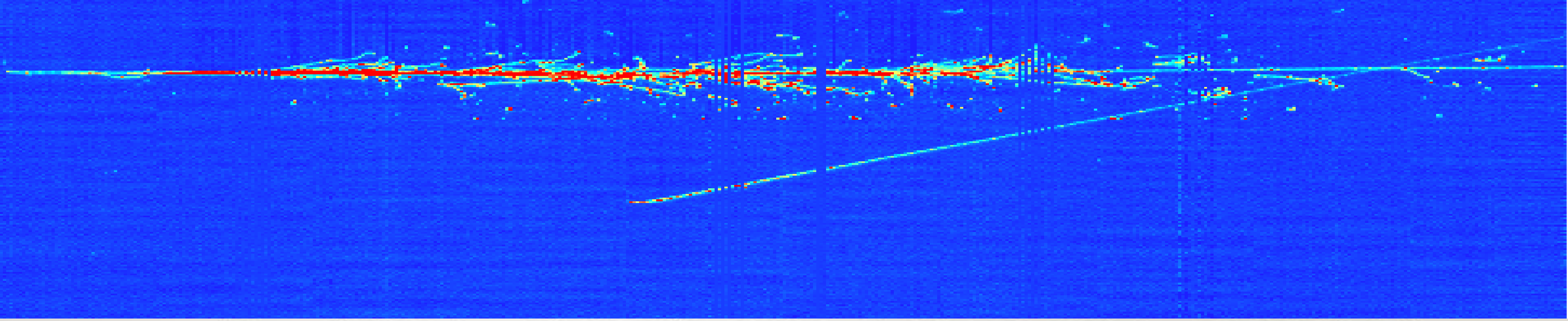


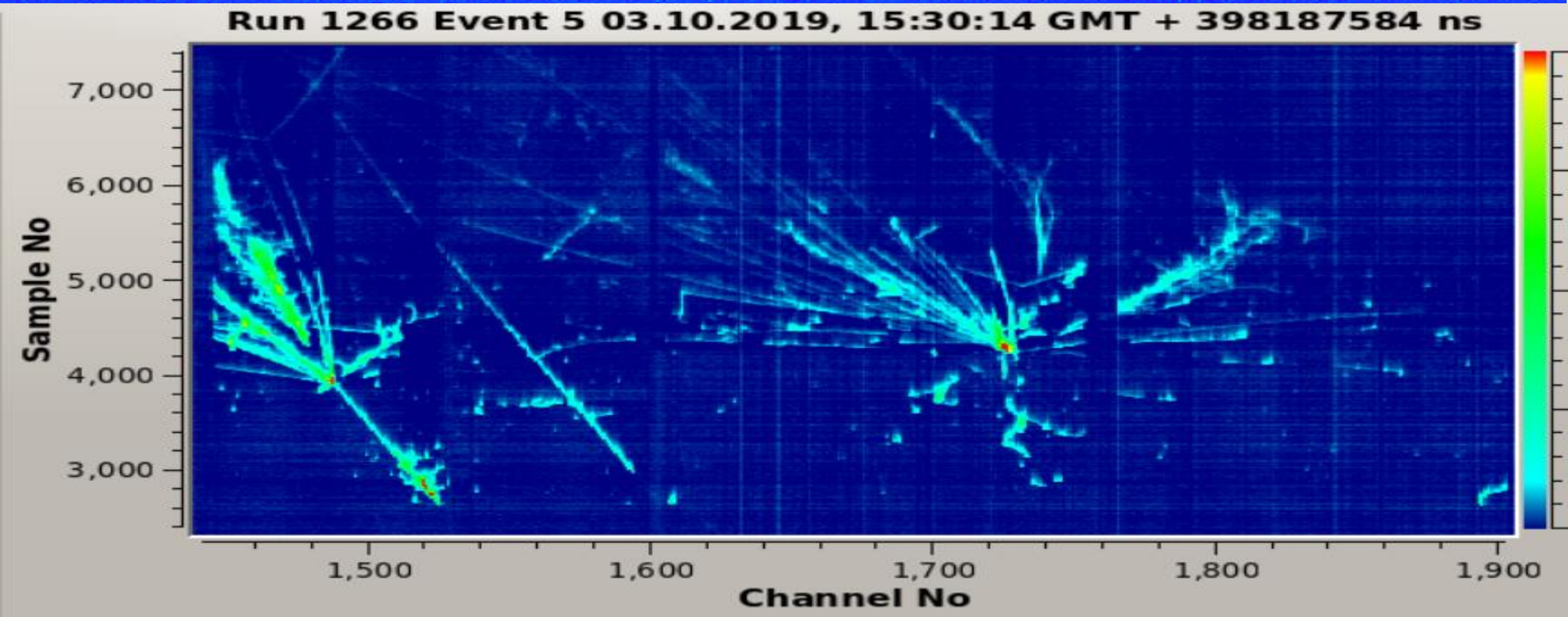


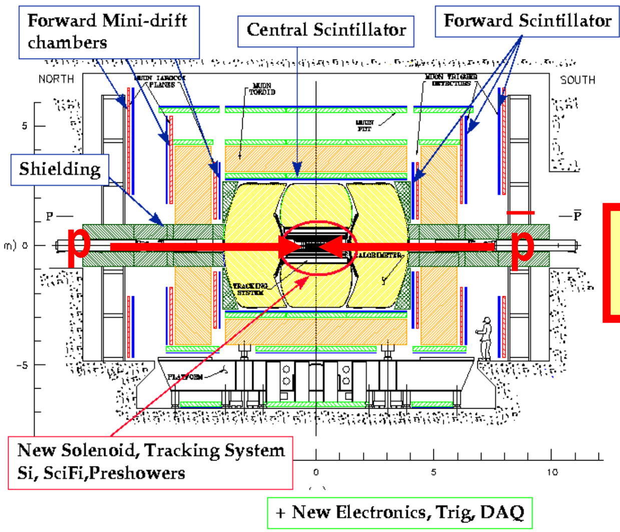


ProtoDUNE Event

Beam halo (high energy) muon with bremsstrahlung initiated E.M. shower







Digital data

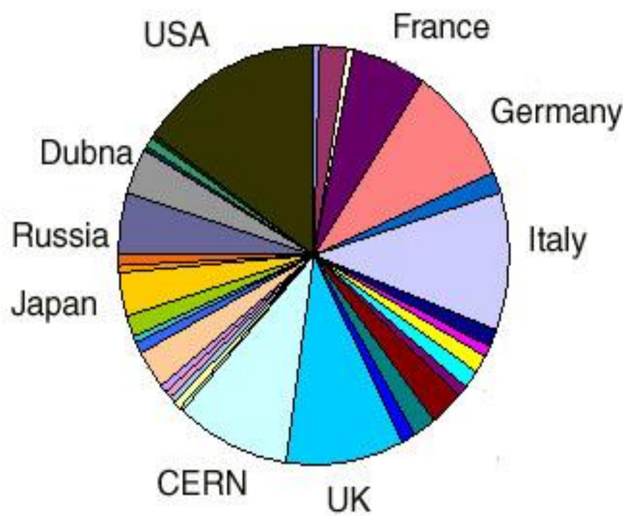
Data Reconstruction

The Problem

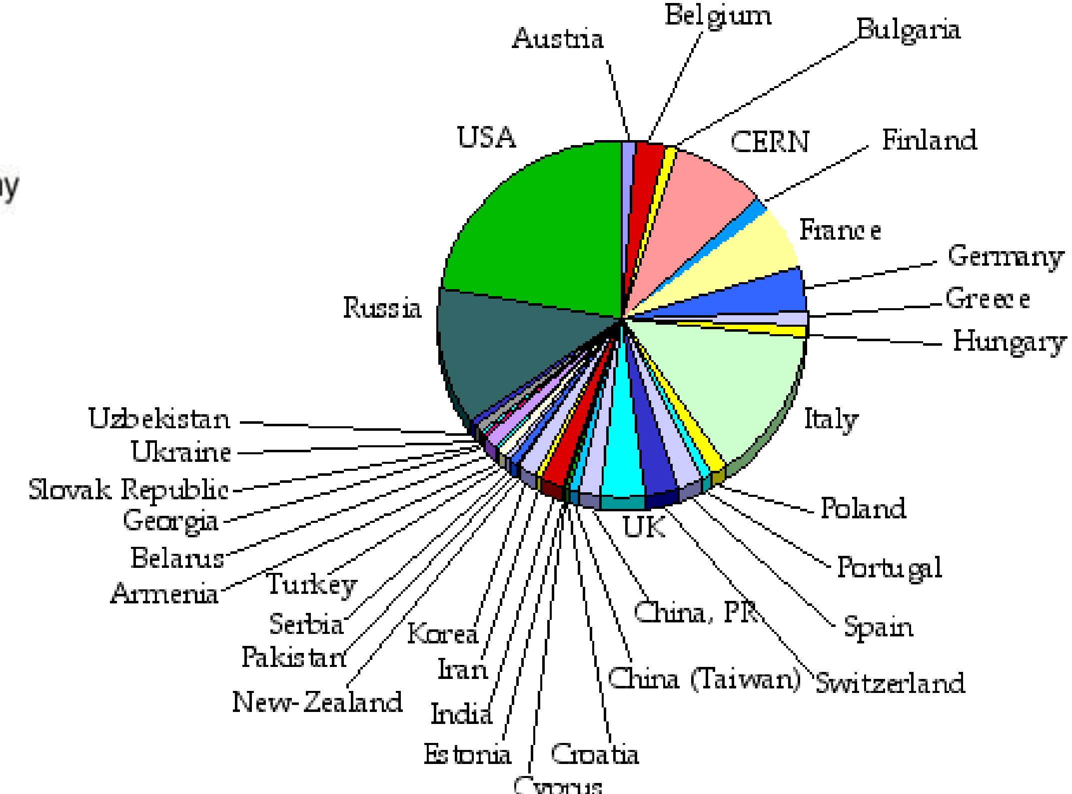
- Detectors are complicated and large ➔ Need large number of collaborators
  - They are scattered all over the world!

LHC Collaborations

ATLAS



CMS



ATLAS+CMS 6000 Physicists and Engineers
Over 60 Countries, 250 Institutions

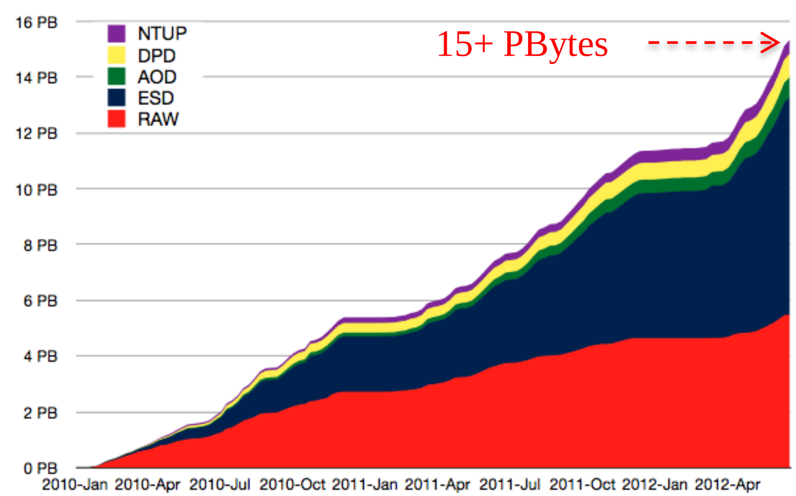
The Map of the DUNE Experiment

1106 collaborators
184 institutions
31 countries

The Problem

- Detectors are complicated and large → Need large number of collaborators
  - They are scattered all over the world!
  - How do we get them communicate quickly and efficiently?
  - How do we leverage collaborators' capabilities?
  - How do we utilize all the computing resources?
- Data size is large ~ 10 PB per year for raw data only
  - Entire data set 15+PB on disc
  - Where and how to store the la
  - How do we allow collaborators to access data in an efficient fa

ATLAS Data at CERN 2010-Jun 2012

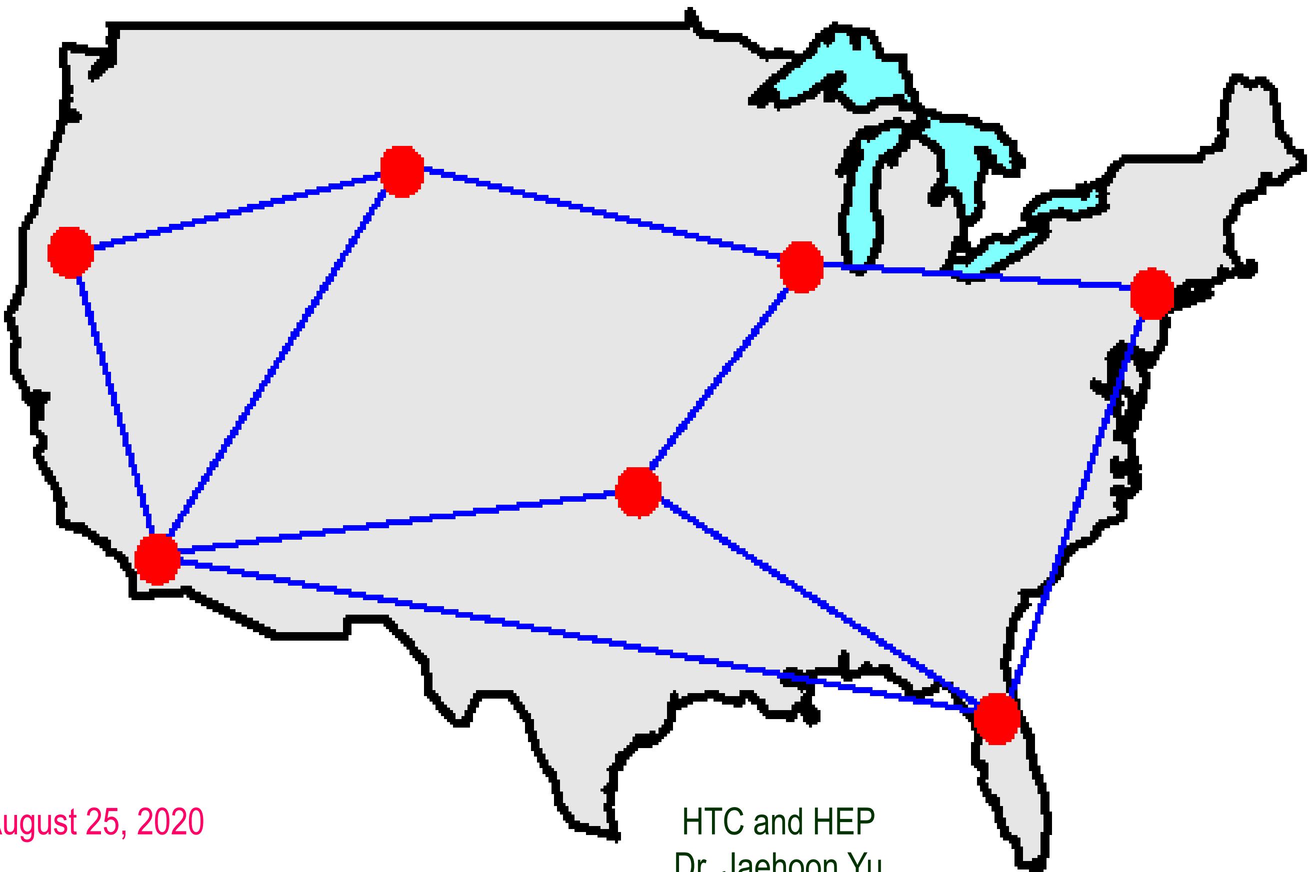


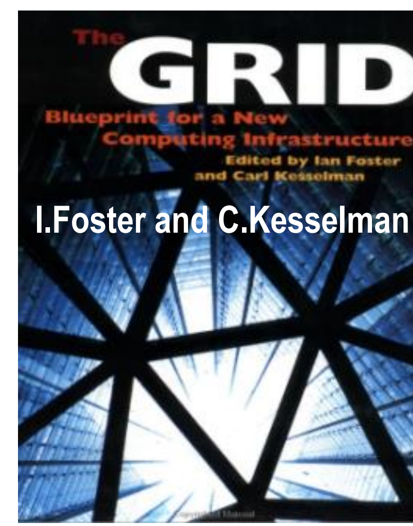
The Problem, cont'd

- How do we allow people's analysis jobs to access data and make progress rapidly and securely?
  - What is the most efficient way to get jobs' requirements matched with resources?
  - Should jobs go to data or data go to jobs?
  - What level of security should there be?
- How do we allow experiments to reconstruct data and generate the large amount of simulated events quickly?
  - How do we garner the necessary compute and storage resources effectively and efficiently?
  - What network capabilities do we need in the world?
- How do we get people to analyze at their desktops?

What is a Computing Grid?

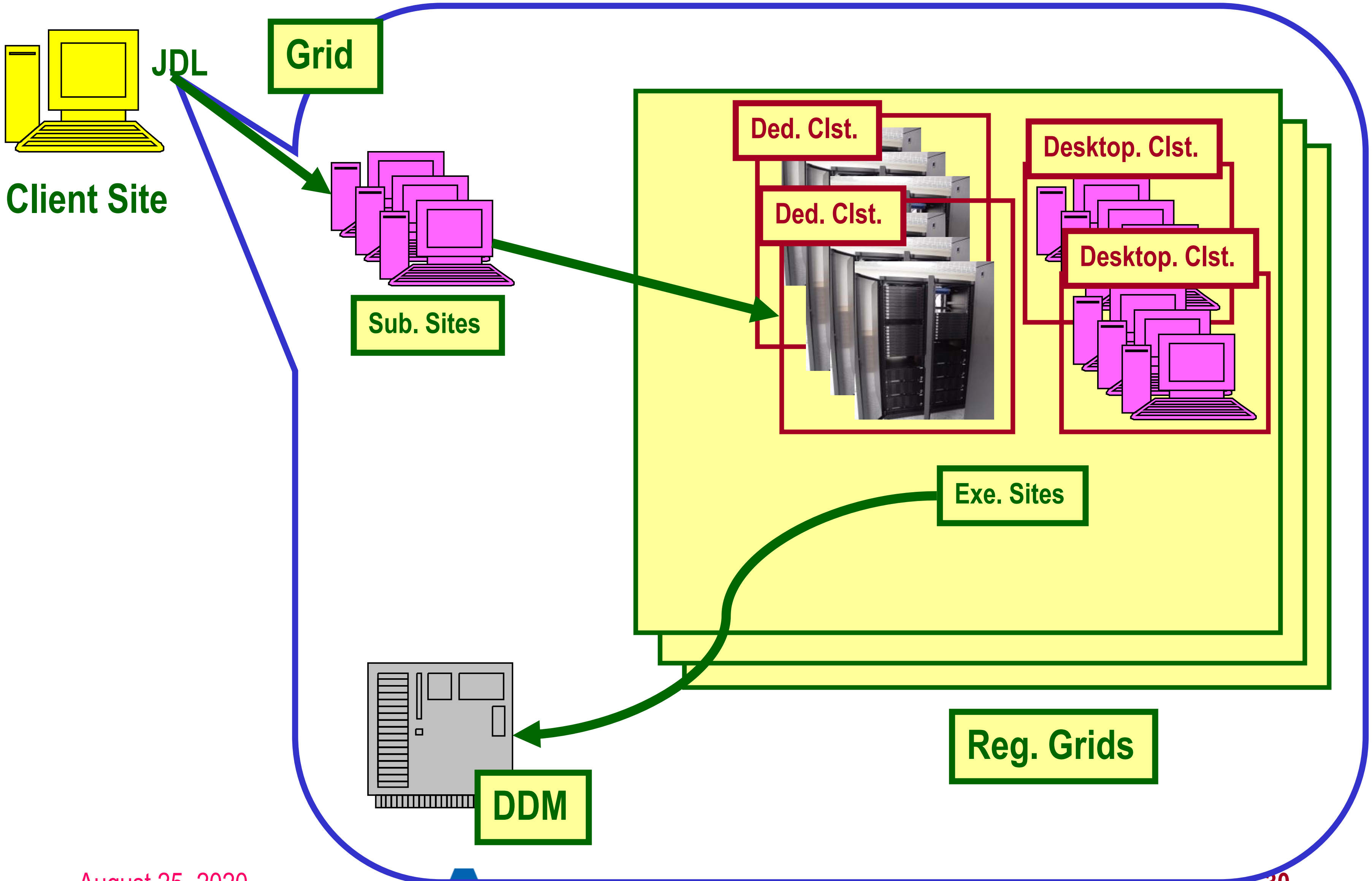
- Grid, the definition: Geographically distributed computing resources configured for a coordinated use
- Physical resources & good network provide hardware capability
- The "Middleware" software ties them together



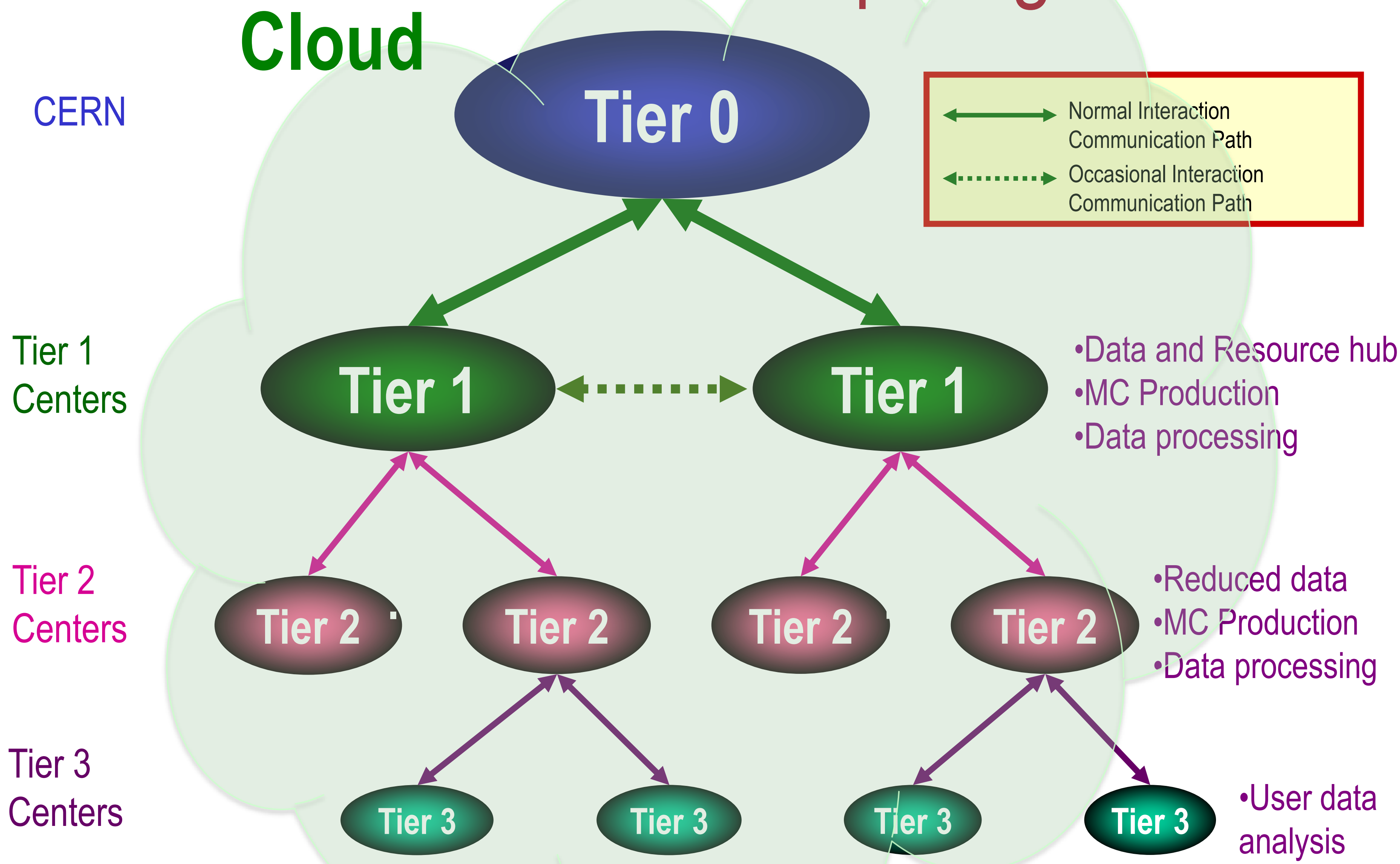


I.Foster and C.Kesselman

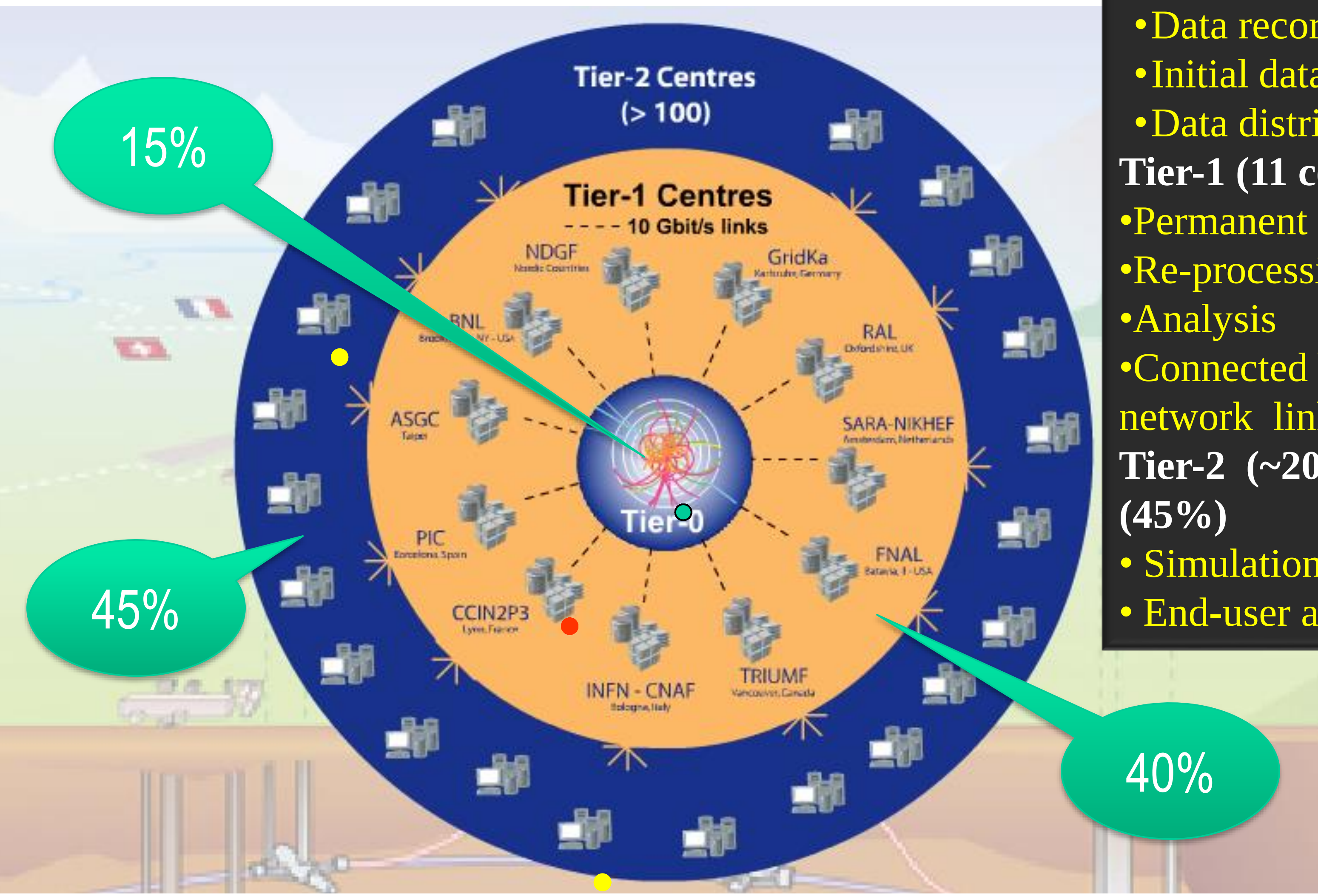
How does a computing Grid work?



Initial Idea of HEP Computing Model



Implemented ATLAS Grid Structure



Tier-0 (CERN): (15%)
- Data recording
- Initial data reconstruction
- Data distribution

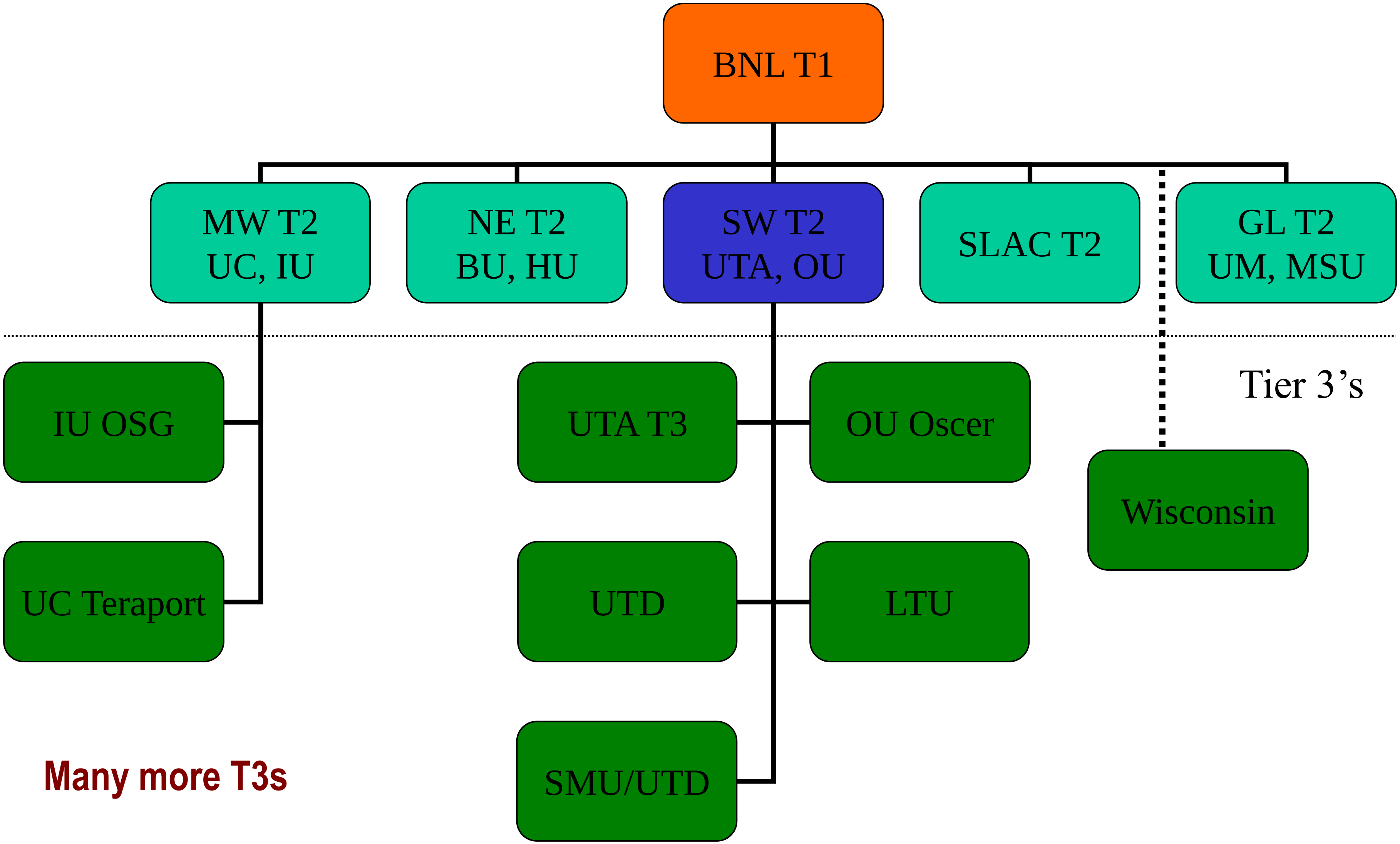
Tier-1 (11 centres): (40%)
- Permanent storage
- Re-processing
- Analysis
- Connected by direct 10 Gb/s network links

Tier-2 (~200 centres): (45%)
- Simulation
- End-user analysis

NORDUGRID Grid Solution for Wide Area Computing and Data Handling

Open Science Grid

Tiered Example – US Cloud



ATLAS Production and Distributed Analysis System, Panda

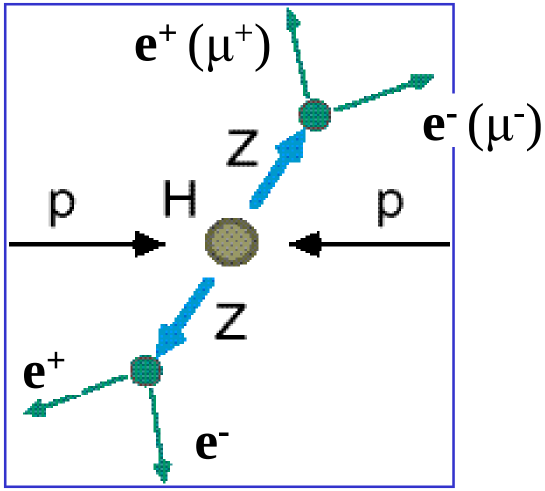
- Designed for analysis as well as production
- Works with OSG, EGEE/LCG and others
- A single task queue and pilots
  - Apache-based Central Server
  - Pilots retrieve jobs from the server as soon as CPU is available low latency
- Highly automated with an integrated monitoring system
- Requires low operation manpower
- Integrated with ATLAS Distributed Data Management (DDM) system
- Not exclusively ATLAS and has spread throughout many different entities in various disciplines

How to look for rare particles?

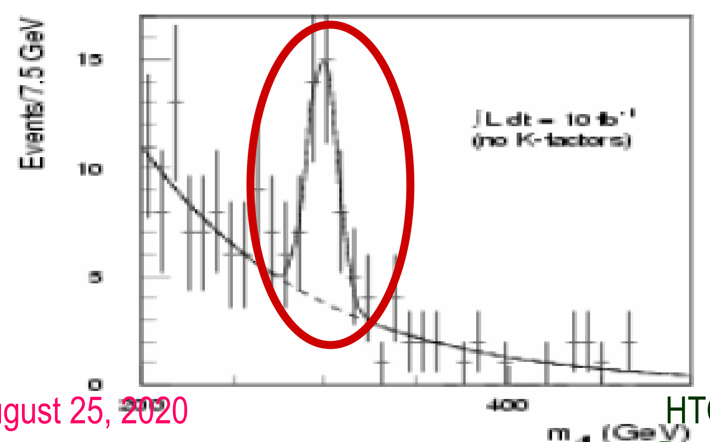
- Many of these rate particle are so heavy they decay into other lighter particles instantaneously
- When one searches for a new particle, one looks for the easiest way to get at them
- Of many signatures of the rare particle final states, some are much easier to find ➔e.g. for the Standard Model Higgs particle
  - $H \rightarrow \gamma\gamma$
  - $H \rightarrow ZZ^* \rightarrow 4e, 4\mu, 2e2\mu, 2e2\nu$ and $2\mu2\nu$
  - $H \rightarrow WW^* \rightarrow 2e2\nu$ and $2\mu2\nu$
  - And many more complicated signatures

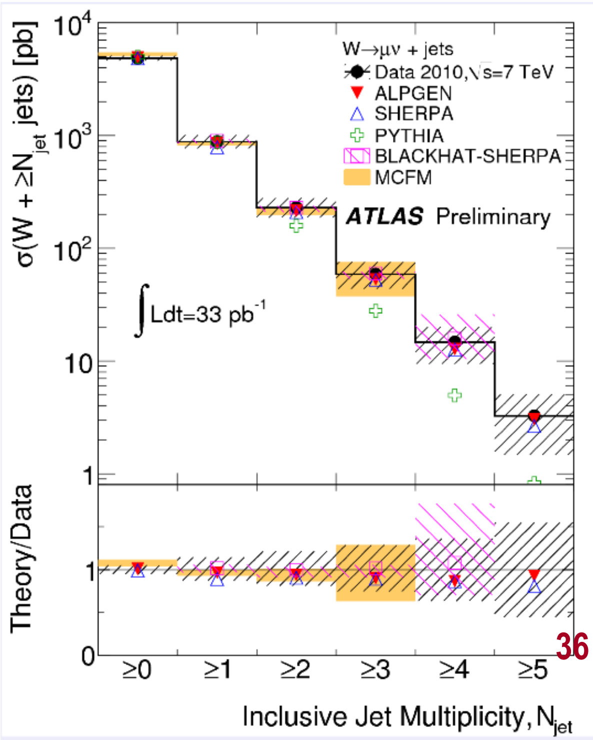
How do we look for a rare particle?

1. Identify Higgs candidate events

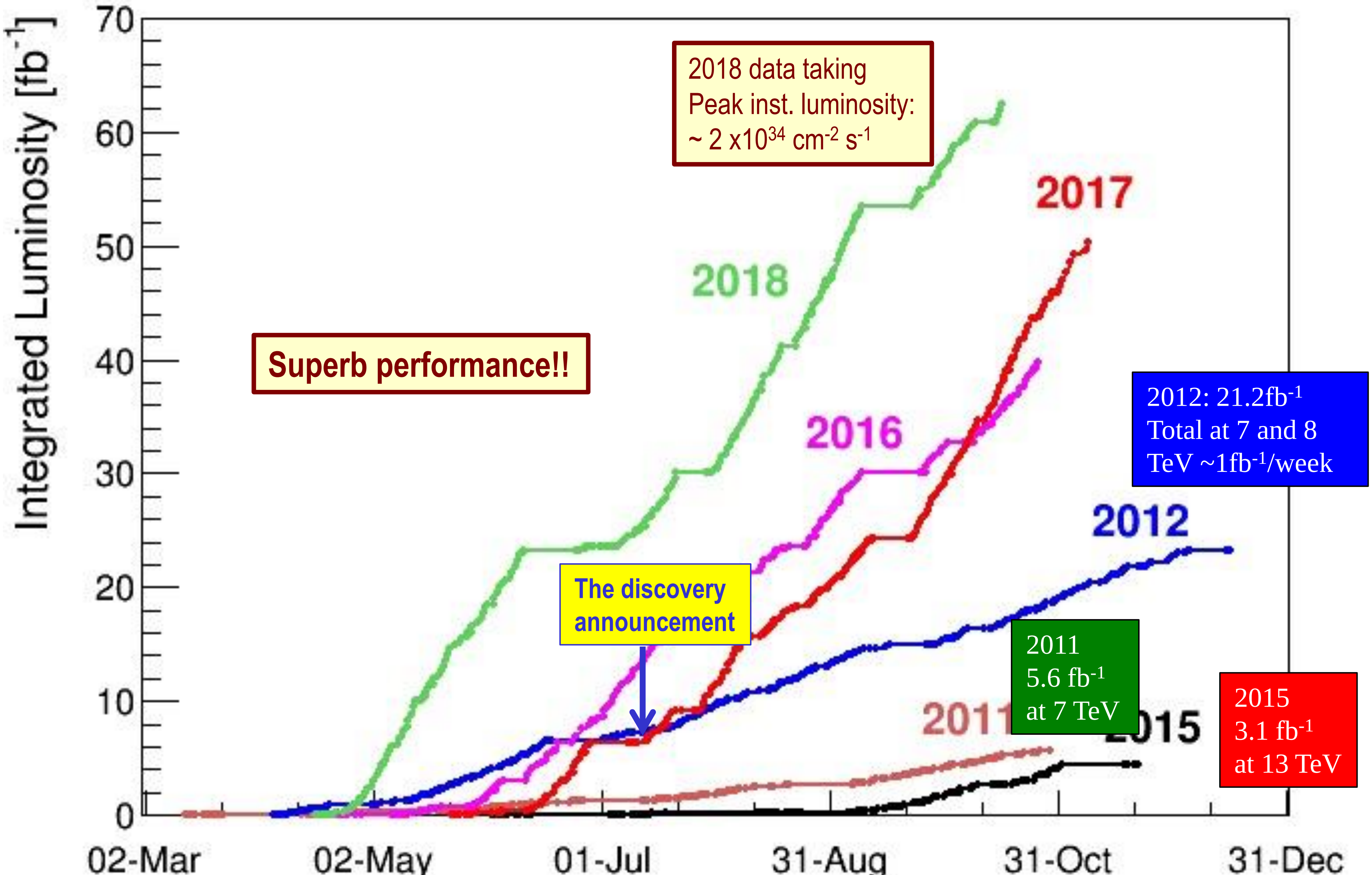


2. Understand fakes (backgrounds)
3. Look for a bump!!
   - Large amount of data absolutely critical

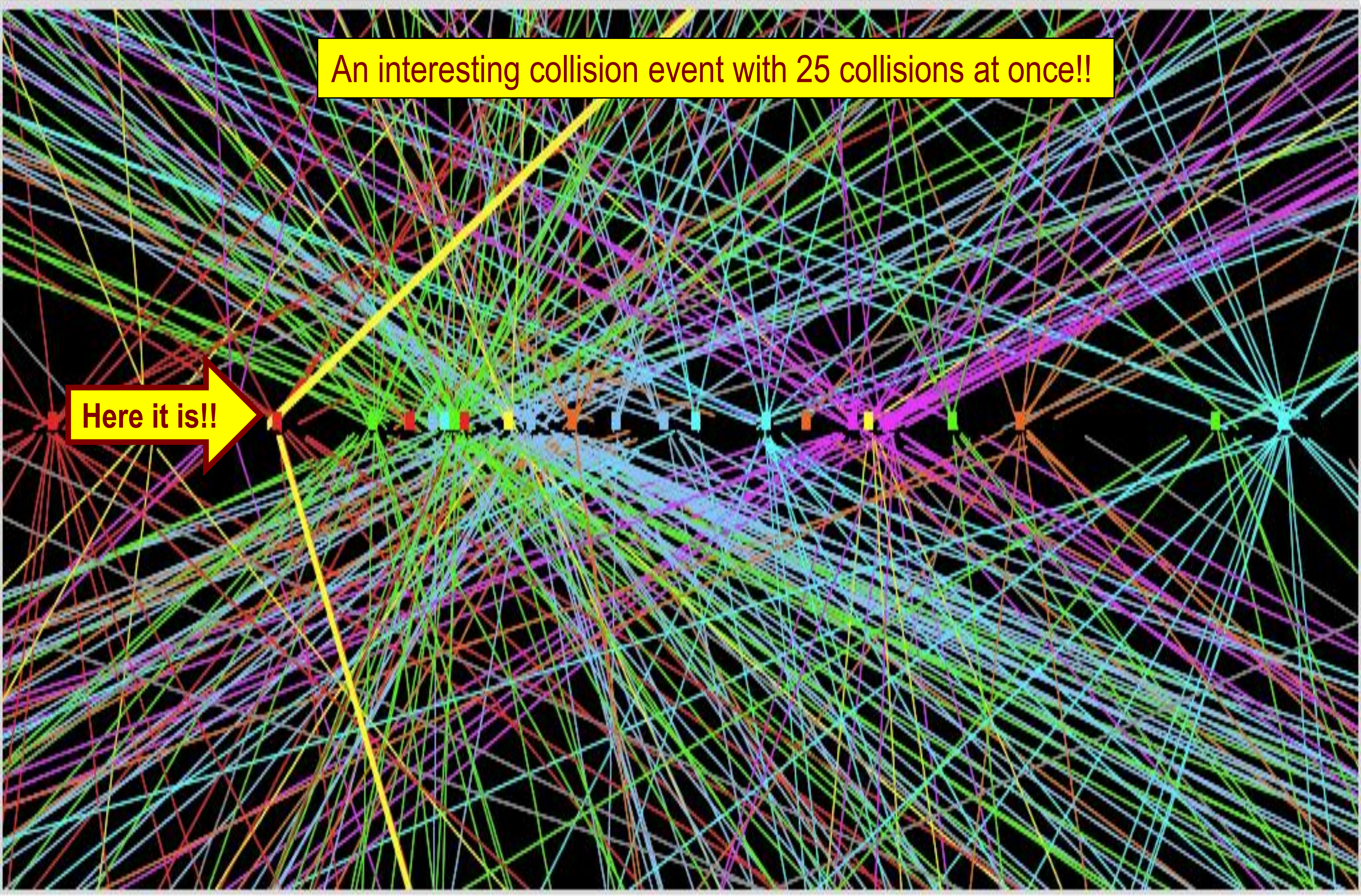




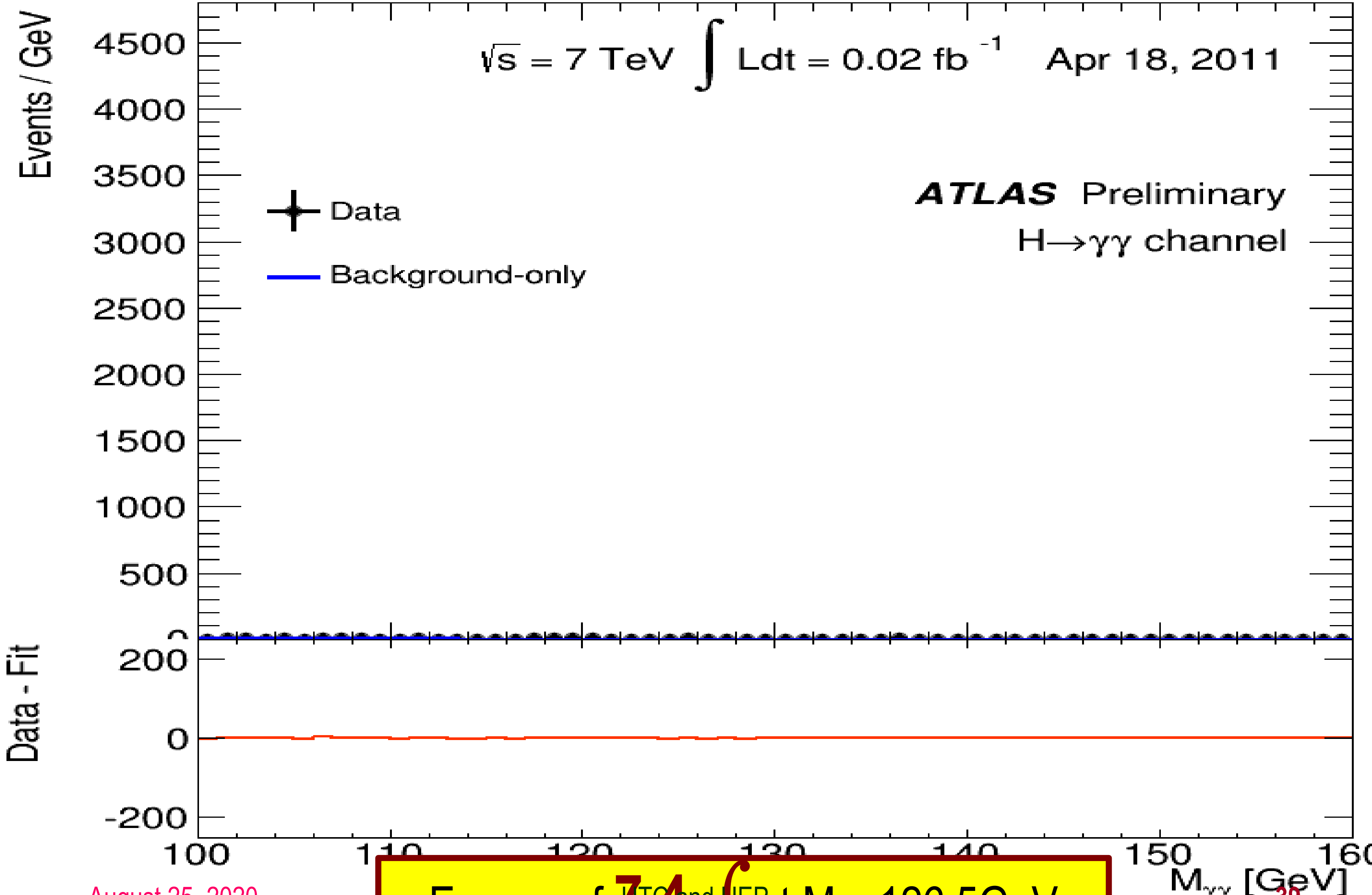
Amount of LHC Data



Challenges? No problem!

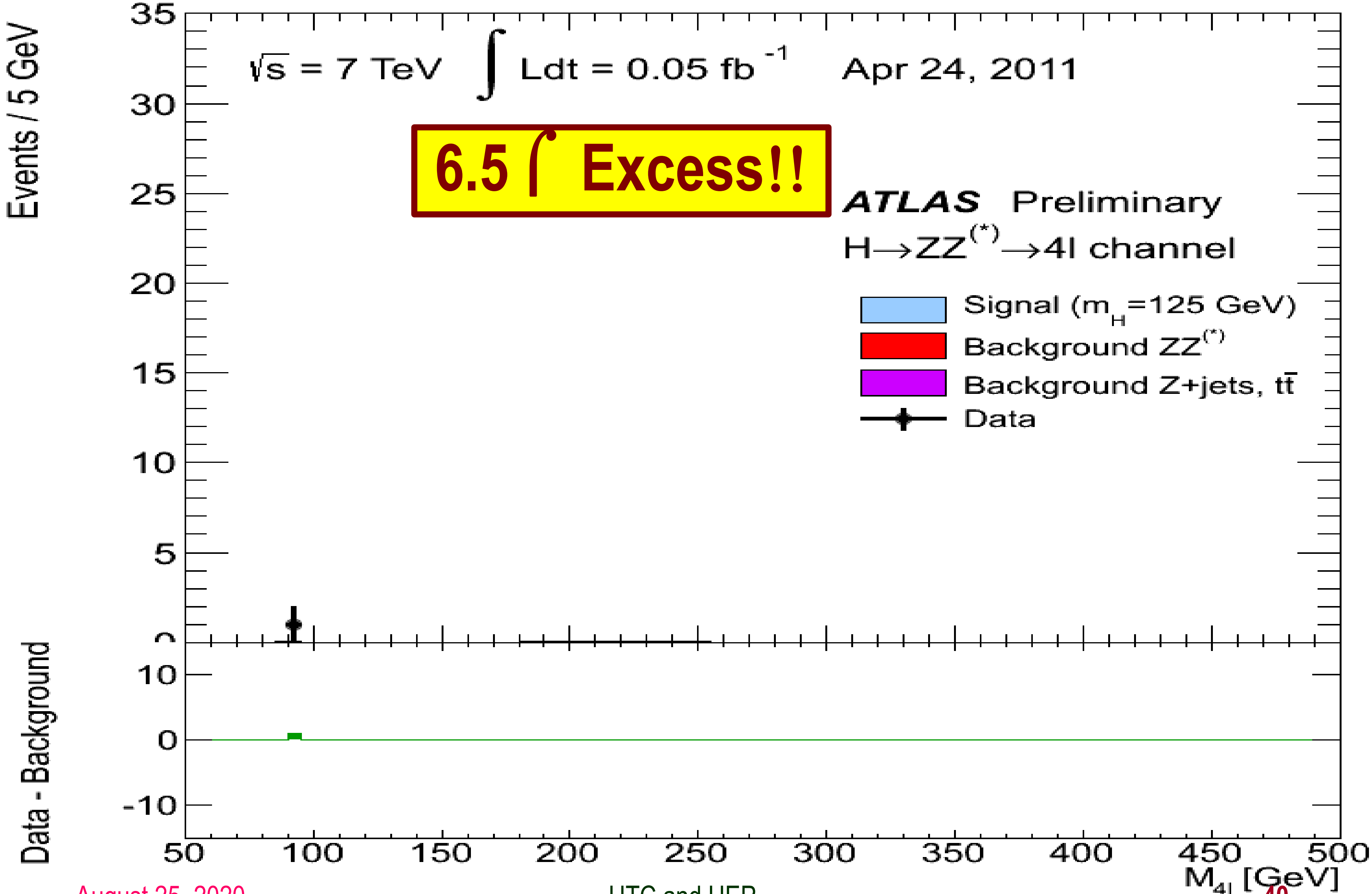


What did statistics do for Higgs→ γγ?

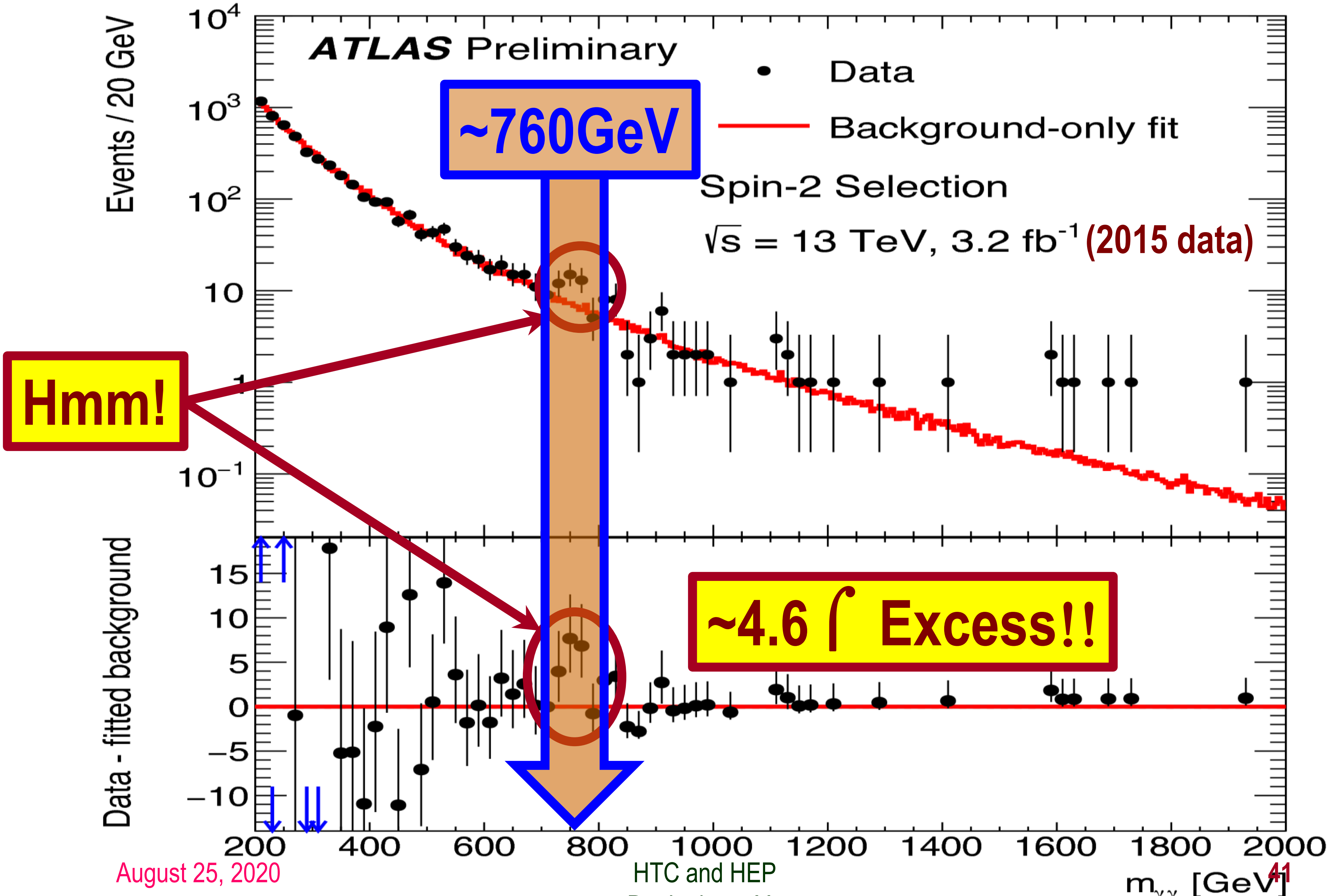


Excess of 7.4 σ at M_H=126.5GeV

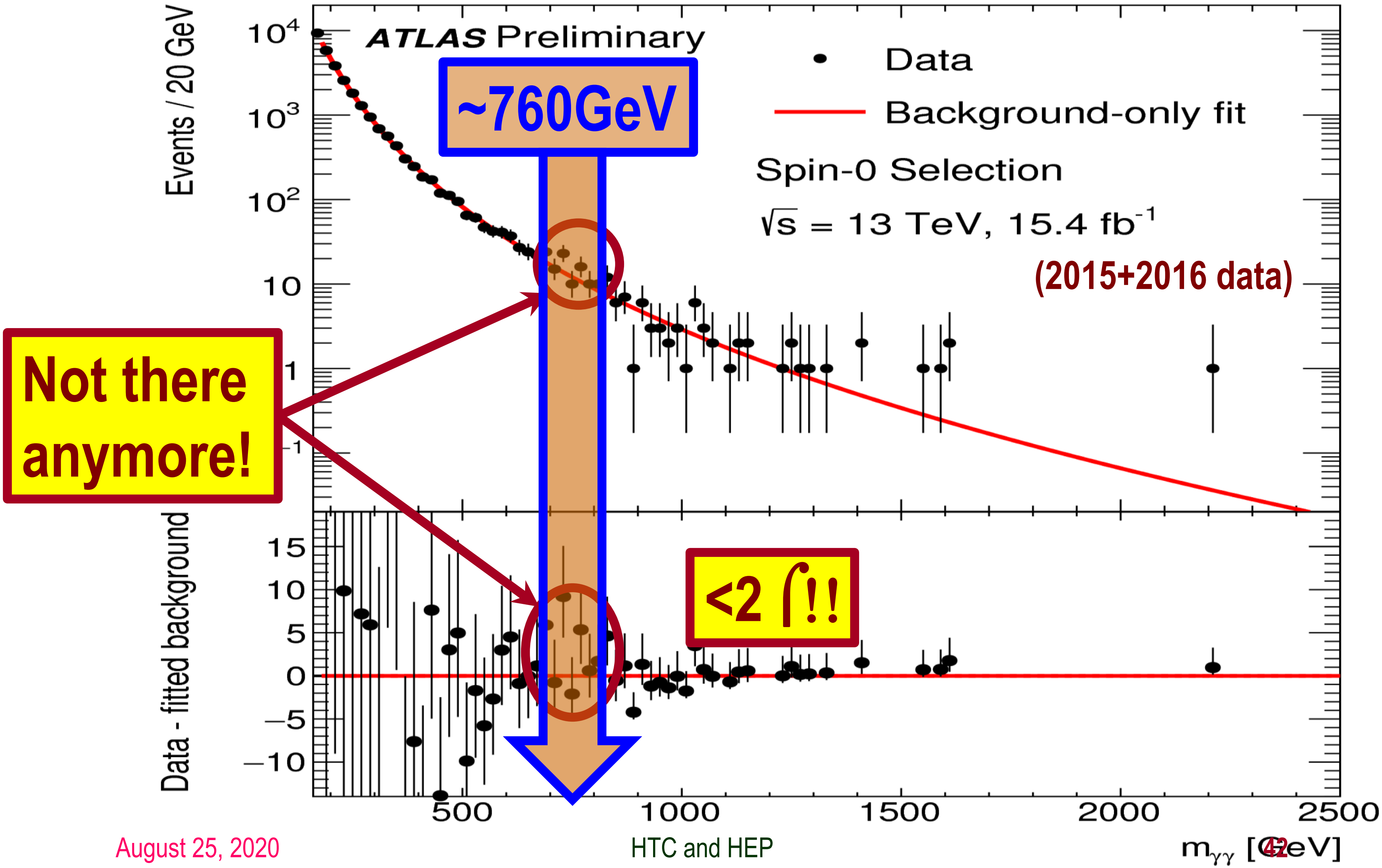
ATLAS Mass Bump Plot (**H→4l**)?



A hint of something new?

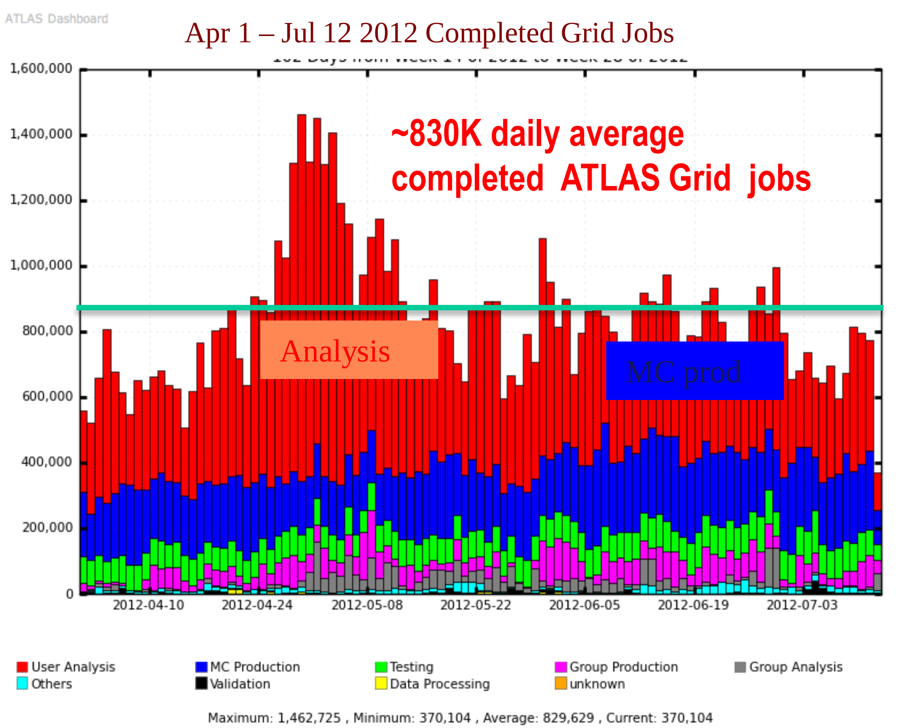


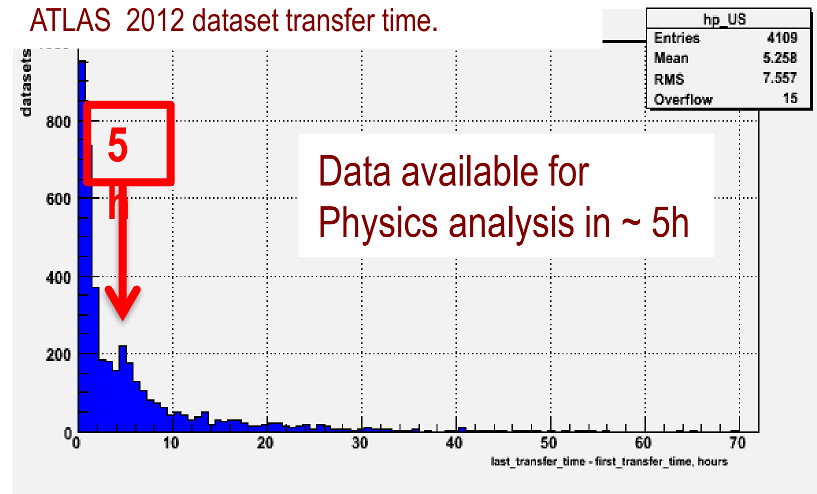
Disappeared after x4 data!!

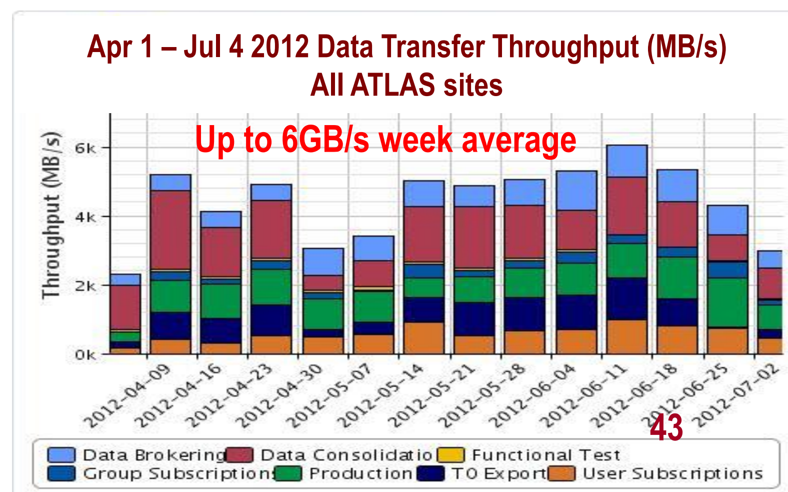


Performance of the Grid for LHC

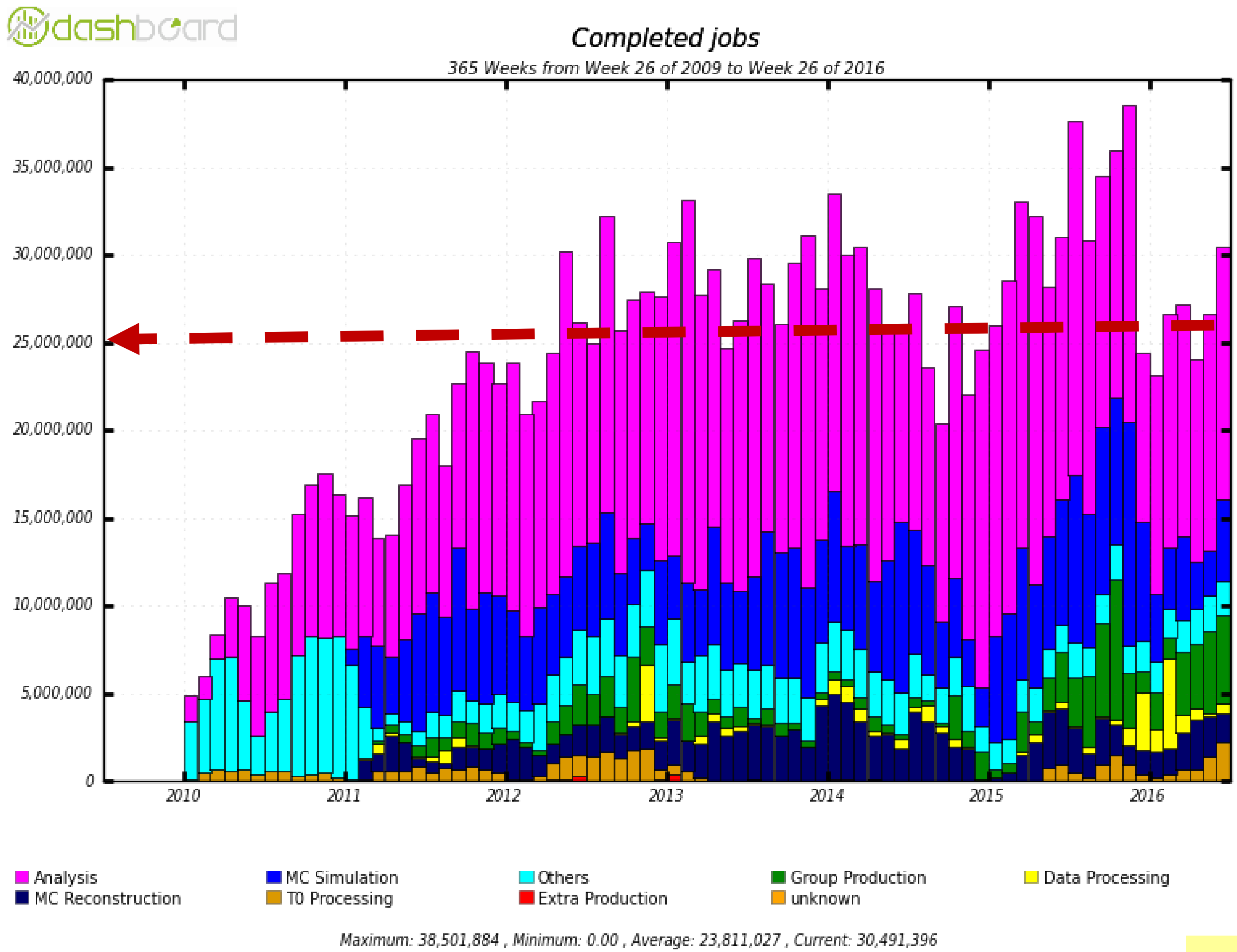
- ATLAS Distributed Computing on the Grid : 10 Tier-1s + CERN + ~70 Tier-2s +…(more than 80 Production sites)
- High volume, high throughput process through fast network!!







PanDA Performance

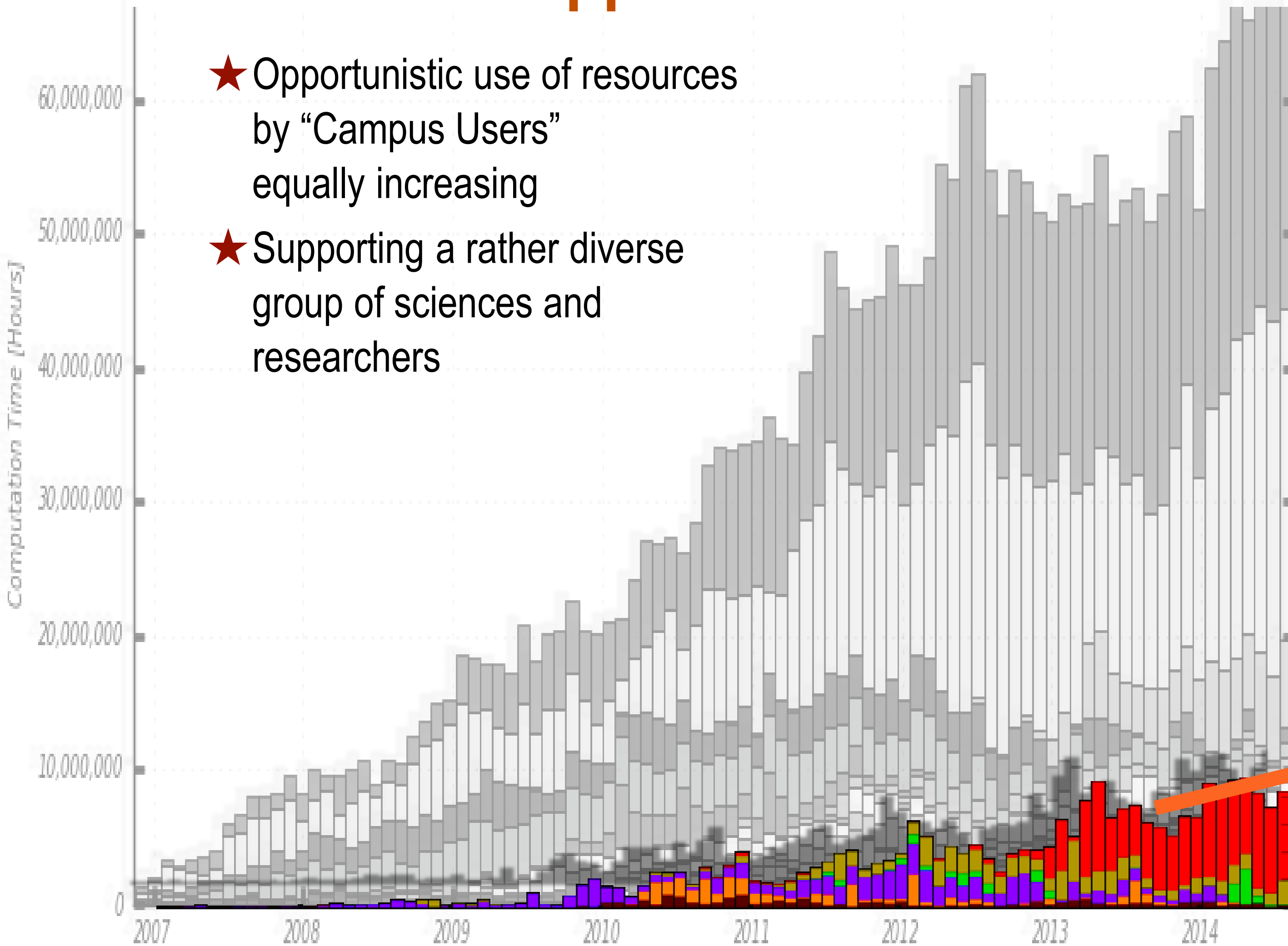


Current scale – 25M jobs completed every month at >hundred sites

Kaushik De

First exascale system in HEP – 1.2 Exabytes processed early in the LHC run

Growing Use of “Owned” and of “Opportunistic” Resources



- ★ Opportunistic use of resources by “Campus Users” equally increasing
- ★ Supporting a rather diverse group of sciences and researchers

Opportunistic Use?

>90M CPU hours opportunistic use past 12 Months

Lotha

Resources Accessible via PanDA

LCG WLCG Worldwide LHC Computing Grid

Many Others

egi

NORDUGRID Grid Solution for Wide Area Computing and Data Handling

Open Science Grid

nectar

NERSC

НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ ЦЕНТР «КУРЧАТОВСКИЙ ИНСТИТУТ»

amazon web services™ EC2

OLCF Oak Ridge Leadership Computing Facility

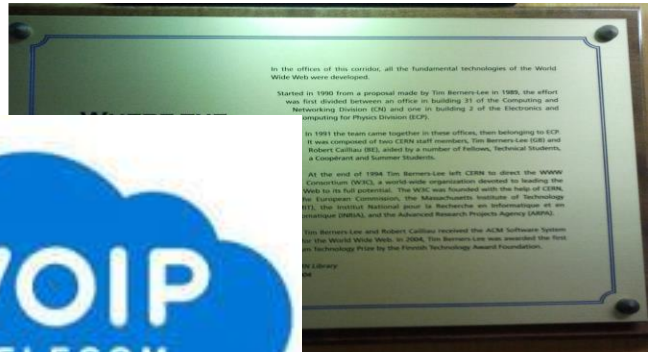
FutureGrid an XSEDE resource provider

Google Cloud Platform

About 250,000 job slots used continuously 24x7x365

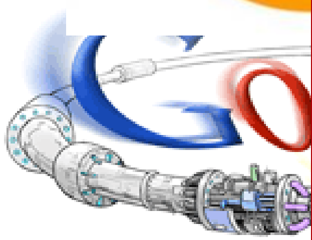
Now the commercial world picked up..

Early 90’s



19

1998



2004

006

Many private entities fully utilized the internet communication we’ve developed to multi-trillion dollar venture!!

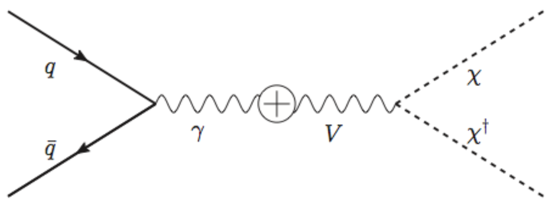
Now the concept of cloud being picked up, though not exactly the same idea behind it…

So why is HEP relevant to me?

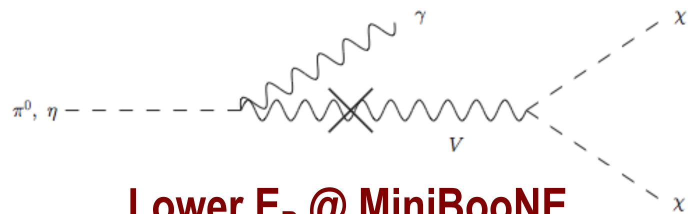
- HEP explores the most fundamental nature of the Universe!
- Discoveries will realize our 1000 year dreams
- The discovery of the dark matter and making of dark matter beams will take us to the next Quantum level

Light DM Production at High Intensity Accelerator

- Now the Higgs particle, a part of only 5% of the universe, may've been seen
- It is time for us to look into the 95% of the universe using high intensity beams, like 1.2 – 2.3MW beams at Fermilab in the US!

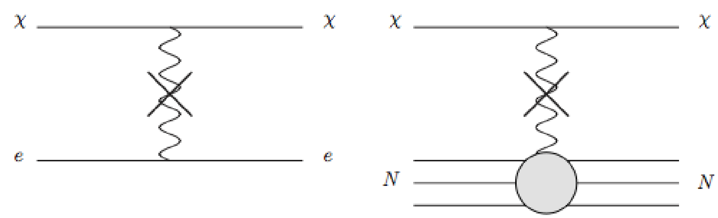


Higher E_P @ LBNE



Lower E_P @ MiniBooNE

- Detection of DM:

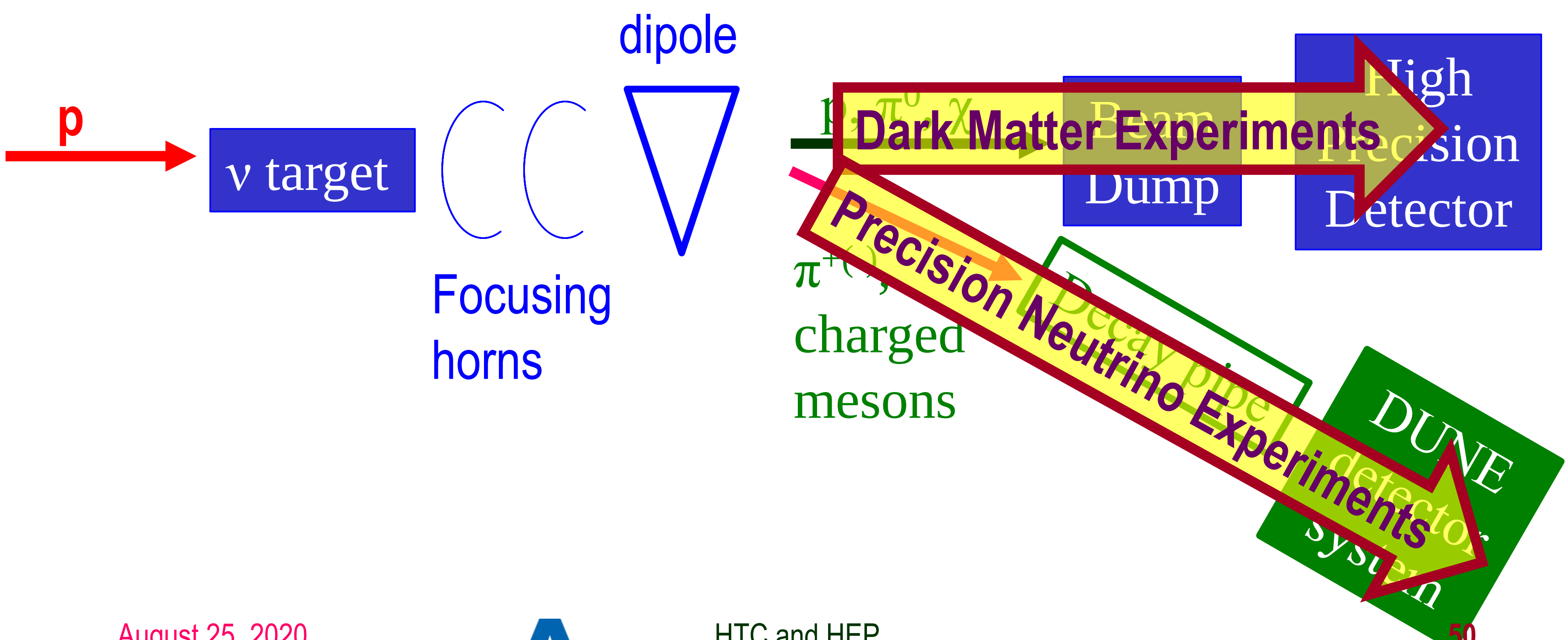


- How does a DM event look in an experiment?:

High Intensity Proton Beam

Smart Dark Matter Beam Line!!

- Now the Higgs particle, a part of only 5% of the universe, may've been seen ➔ Time to look for and study the 95% of the universe
- We can have a beamline that separates neutrinos and anti-neutrinos from DM's ➔ Use a string of magnets
- 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



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- Outcome and bi-products of HEP research improves our daily lives directly and indirectly
  - WWW came from HEP


WHERE THE
WEB
WAS BORN

So why is HEP relevant to me?

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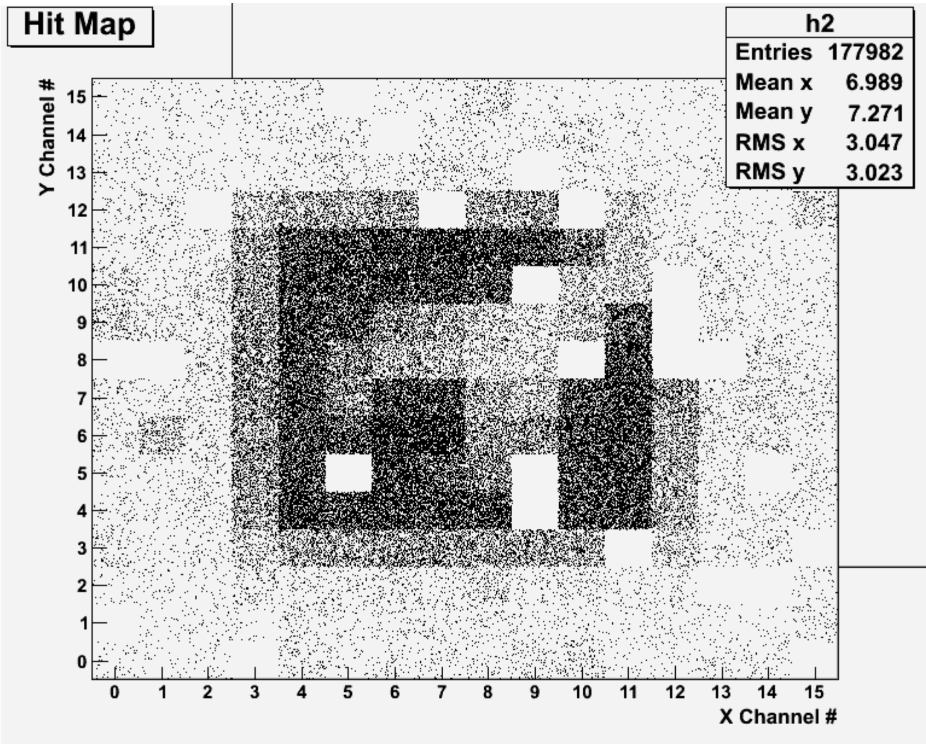
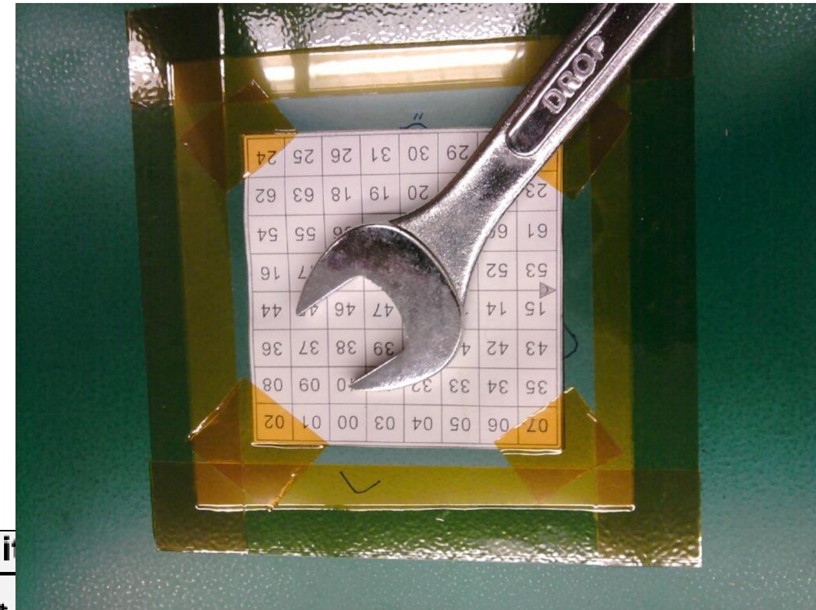
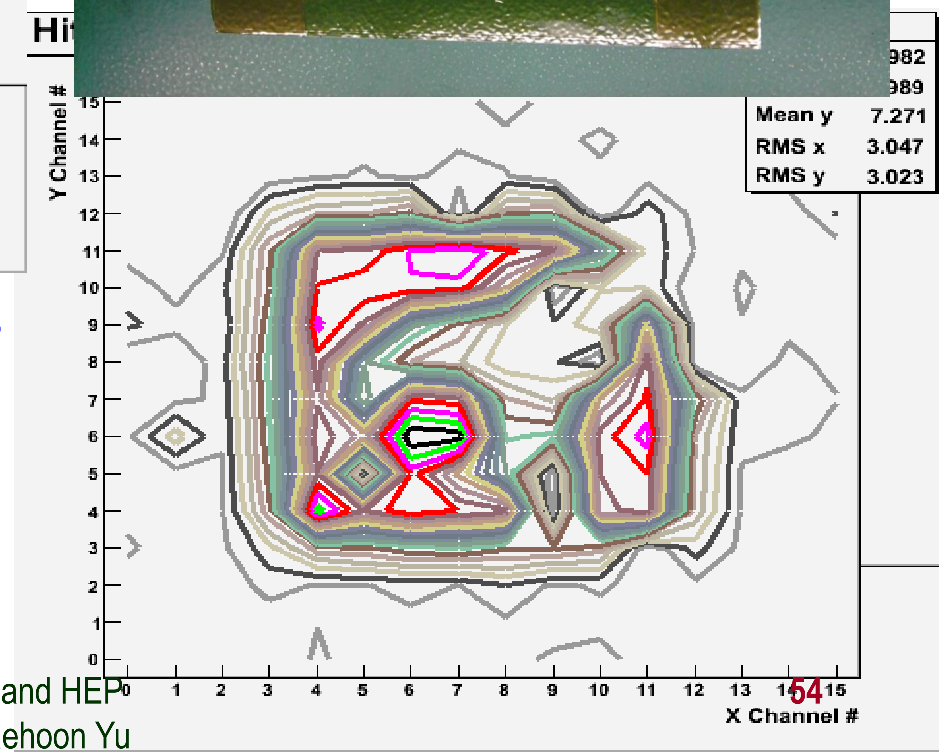
- Discoveries will realize our 1000 year dreams
- The discovery of the dark matter and making of dark matter beams will take us to the next Quantum level
- Outcome and bi-products of HEP research improves our daily lives directly and indirectly
  - WWW came from HEP
  - Advanced detector technologies like GEM will make a large screen low dosage X-ray imaging possible

Bi-product of High Energy Physics Research







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

So are we done with the grid?

- LHC has performed extremely well!
- The data size will increase by 10 fold or more in HLLHC
  - Computing will be under even more stress
- Grid computing infrastructure has served well thus far
  - 1500 ATLAS users process PBs of data & billions of jobs
- High Intensity Experiments, like DUNE, could record as much or even larger amount of data than the LHC
- Identified limits in databases scalability, CPU resources, storage utilization, etc, are being addressed
- Planning for HEP and utilize quantum computing and Machine learning technologies

Conclusions

- In the quest for the origin of the universe, High Energy Physics
  - Uses accelerators to look into extremely small distances
  - Uses large detectors to explore nature and unveil secrets of universe
  - Uses large number of computers to process data in a timely fashion
  - Large amount of data gets accumulated ➔ computing grid performed marvelously for expeditious data analyses
- HEP is an exciting endeavor in understanding the universe
- Physics analyses at one's own desktop using computing grid sitting behind has happened!!
- Computing grid needed for other disciplines with large data sets
- Computing grid now outside of HEP into everyday lives
- A true computing grid is revolutionizing everyday lives ….

Let’s all dream,

not just for tomorrow,

not just for the next year,

but for 1000 years into the future for the whole humanity!!

FFT: Number of beam particles per sec?

- What is the number of particles per second for an accelerator facility that can provide:
  - P MW of total beam power
  - of charged particles of energy E GeV?

$$N_p\left(/\sec; E\ GeV; P\ MW\right) = P/E \cdot 6.3 \times 10^{15}\left(particles/\sec\right)$$

  - What is the number of protons per second for 120GeV beams at 1.2MW?

$$N_p\left(/\sec; 120\ GeV; 1.2\ MW\right) = \frac{1.2}{120} \cdot 6.3 \times 10^{15}\left(particles/\sec\right)$$
$$= 6.3 \times 10^{13}\left(particles/\sec\right)$$

  - What is the beam current? $I = N_p \cdot 1.6 \times 10^{-19}$

$$= 1.2 \times 10^{-5}\left(C/\sec\right) = 12\,mA$$