High Throughput Computing and Its Impact on the Society
High Energy Particle Physics

The African School of Fundamental Physics 2021

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Outline

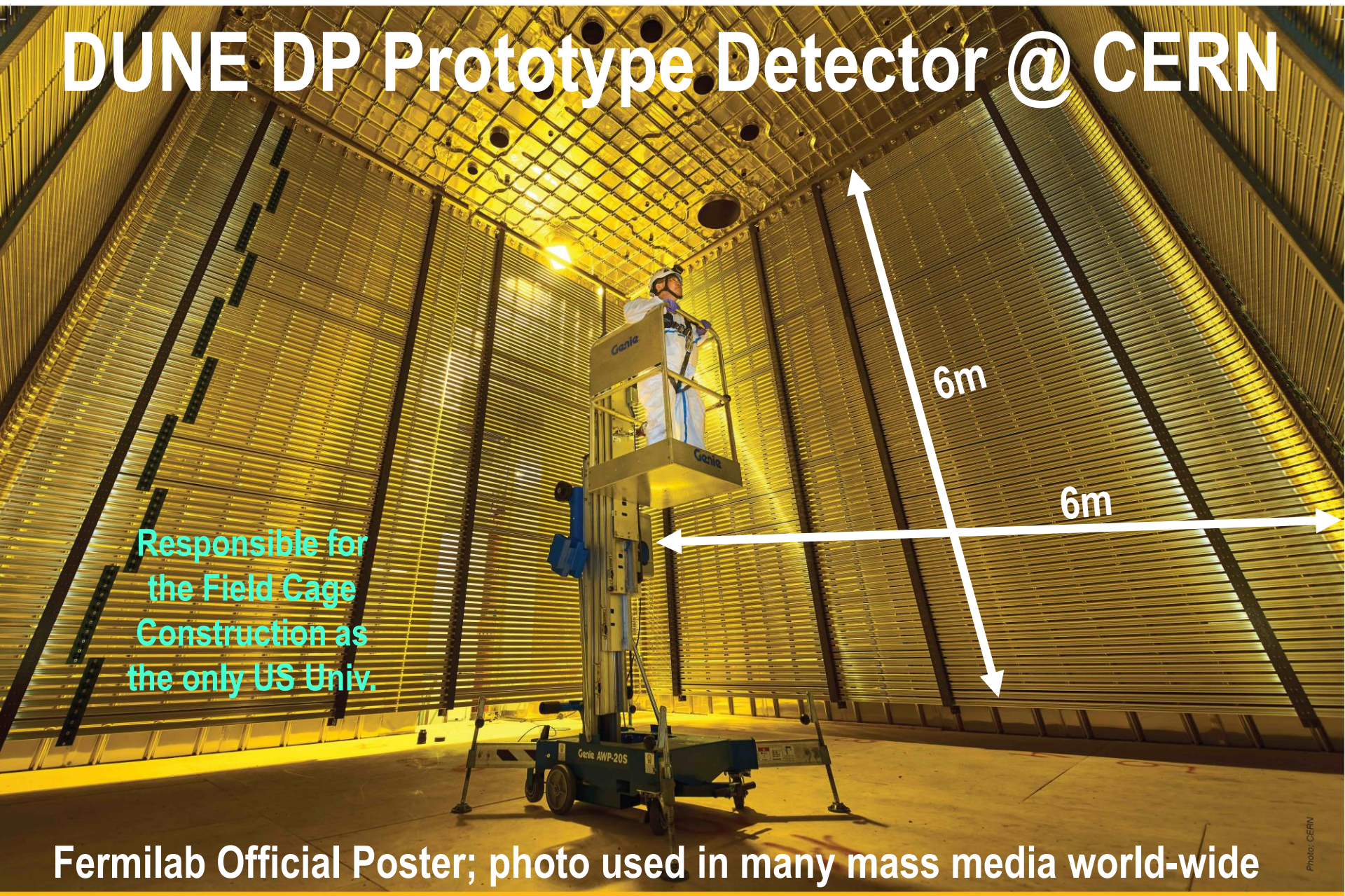
- Who am I and how am I related to ASP?
- Introduction
- The problem
- A solution using the Computing Grid
- What HTC did for a Nobel winning discovery
- Conclusions

- My full name
- Lived in Sout … orship"S"
  - I take freed … ery seriously
  - Obtained B … service in the Korean Arr
- Joined the P … obtained Ph.
  - Ph.D. thesi … prototyping … data analys
  - All my 3 ch
- 1st postdoc a … postdoc at F … building the d
- Fermilab staf

Who am I? – 2

- Professor at U. Texas Arlington (2001 – present)
  - Led the design and implementation of D-Zero computing grid
    - Led the group on discovery of Higgs in WW final states
  - Led International Linear Collider detector R&D beam testing
  - Joined ATLAS @ LHC 2005 and led the grid computing user services
  - Led a subgroup in LHC Higgs Cross section working group
  - Contributed to 2012 Higgs discovery (see the TV interview) and the subsequent precision property measurements
  - Moved to neutrino experiment and created and leading the Beyond the Standard Model physics group from 2013 (1st ever in the community!)
  - Constructed a prototype DUNE field cage (2018) for Prototype @CERN
  - To construct half the field cage for first 17,000t modules
  - Leading the conceptual design of the 2nd 17,000t module HV system

DUNE DP Prototype Detector @ CERN



Fermilab Official Poster; photo used in many mass media world-wide

How am I related to ASP?

- Organized the 1st high-performance computing program in ASP20
  - Secu
- Serving
  - Cont
  - Arran
- Workin
  - Dr. L
    ATLA
    - Q
  - Brigh
    - Has been working as software engineer at US Air
  - Mohammed Abdelrazek (a 2020 ASP grad) ➔ G

What is High Energy Physics (HEP)?

- The elevator talk: A subfield of physics that seeks to understand what makes up the universe and what the fundamental forces between them are
- Known forces (interactions):
  - Gravitational Force
  - Electromagnetic Force
  - Weak Nuclear Force
  - Strong Nuclear Force
- Current theory: The Standard Model of Particle Physics (SU3xSU2XU1)
- Most importantly: Ask yourselves why, what and how?

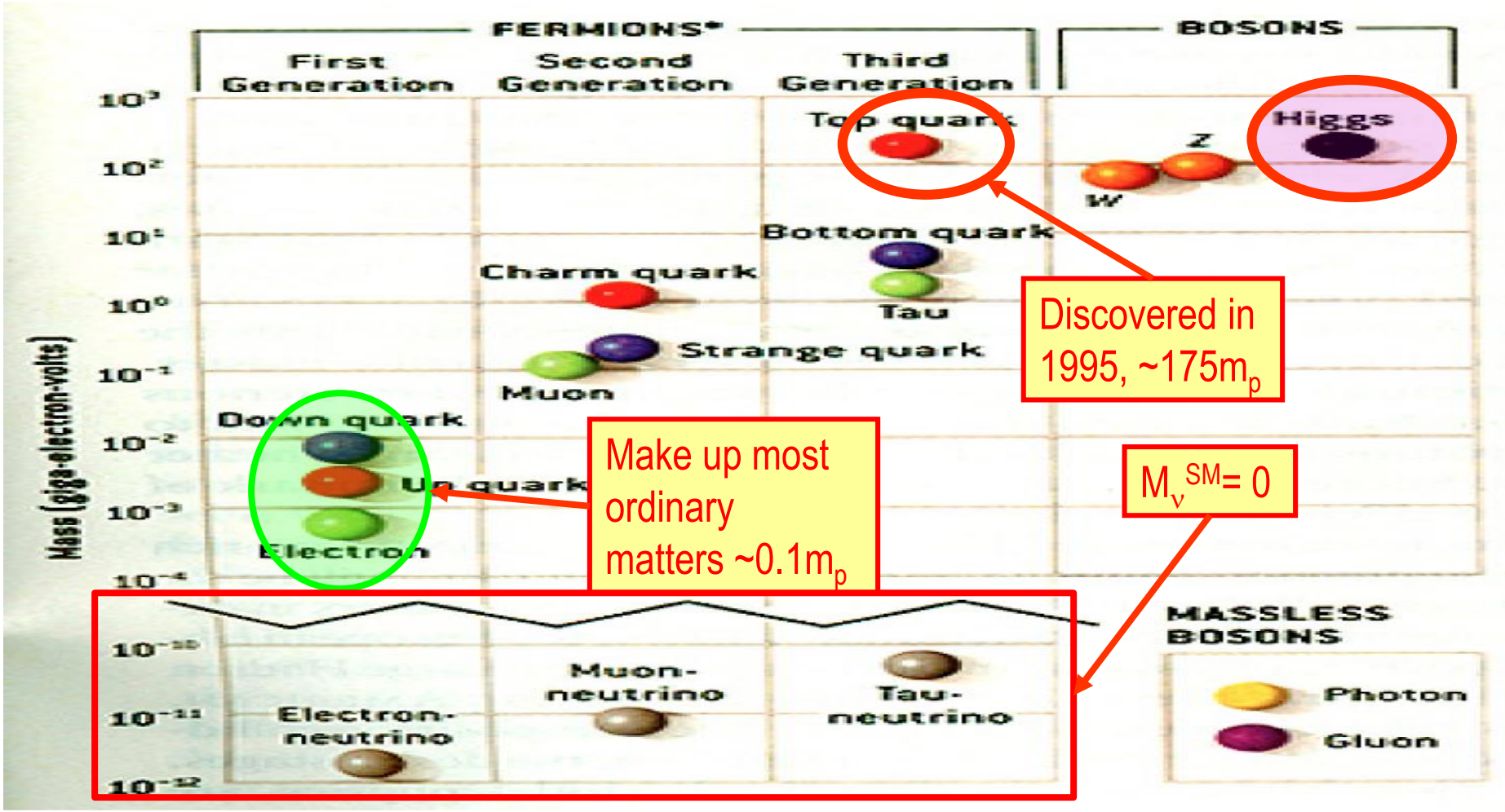
Periodic Table of the Elements

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

HEP and the Standard Model

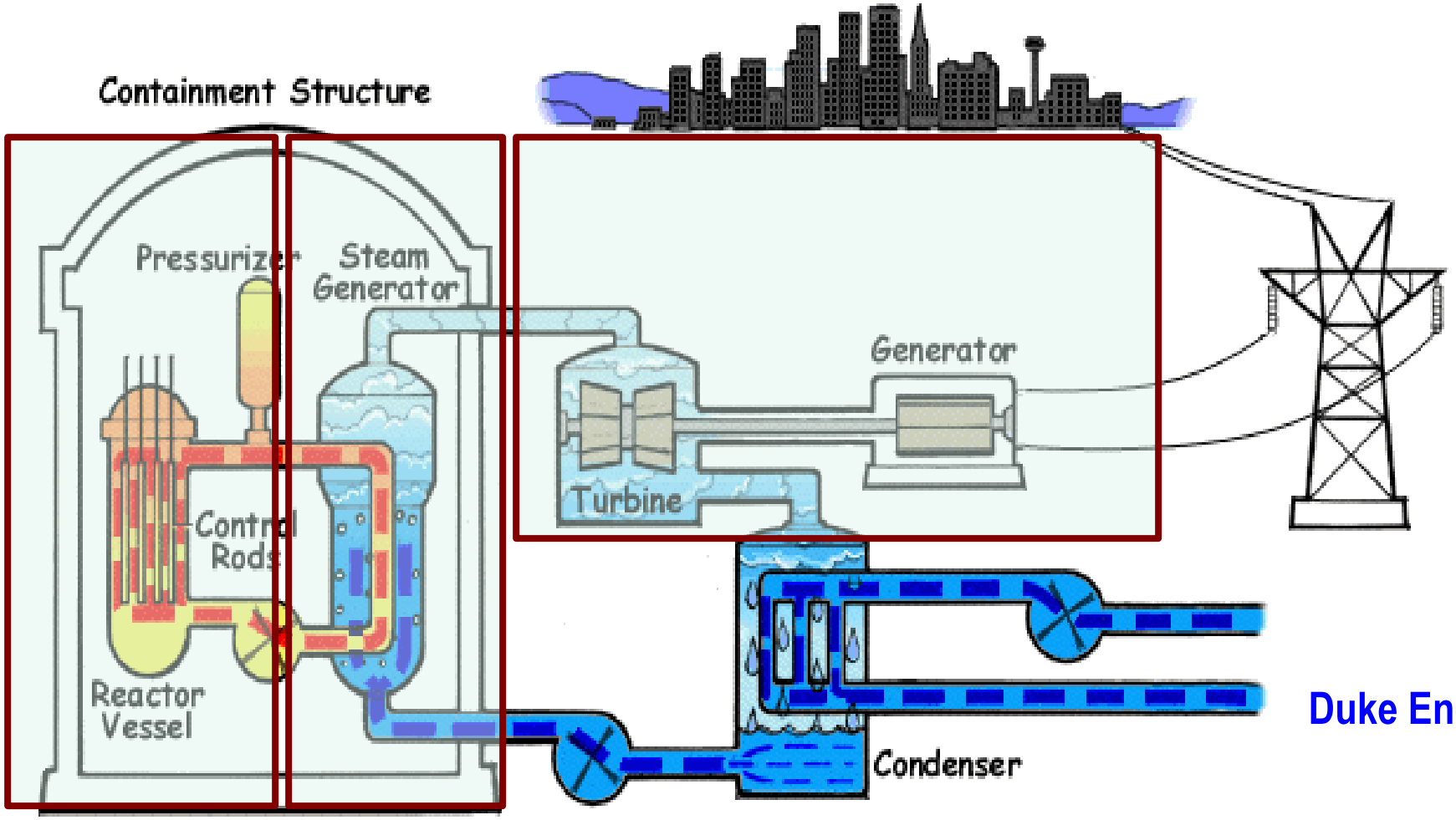


- Total of 16 particles (12+4 force mediators) make up all the visible matter in the universe! ➔ Simple and elegant!!!
- Tested to a precision of 1 part per million!

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 properties, such as the masses, of neutrinos?
  - Are there the particle-anti particle asymmetry in neutrinos?
- Why are there only four apparent forces?
  - Were they all unified at the Big Bang?
  - Ask a what question here!

How does a nuclear power plant work?



Duke Energy

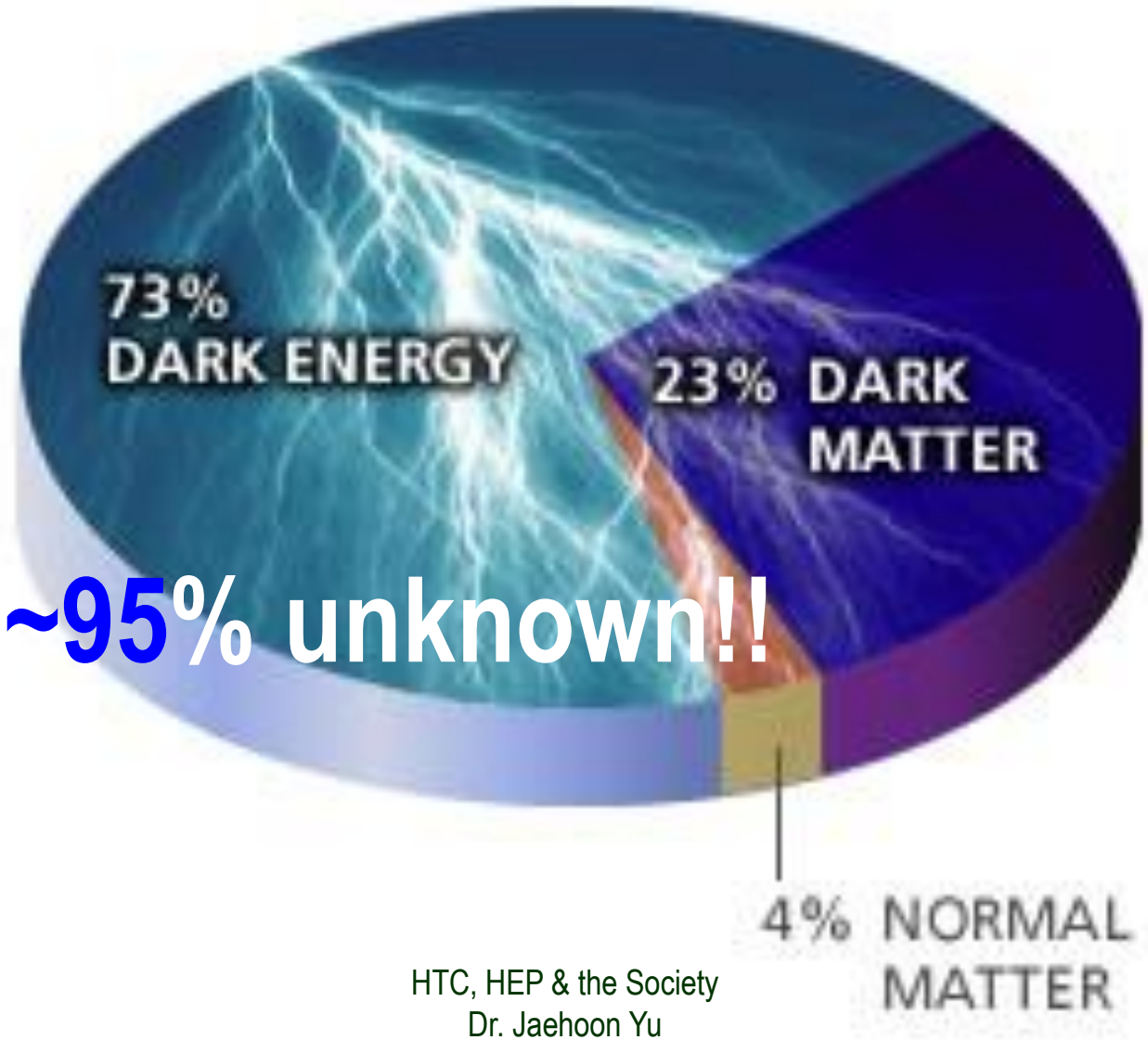
My 1000 year dream: Skip the whole thing!

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 of the universe we present the real thing?

What makes up the universe?



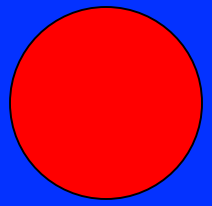
~95% unknown!!

So what's the problem?

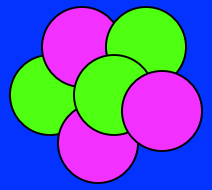
- Why is the mass range so large ($0.1m_p$ – $175\ m_p$)?
- Is the particle we discovered really the Higgs particle?
- Why is the matter in the universe made only of particles?
- Neutrinos have mass!! What are the mixing parameters, particle-anti particle asymmetry and mass ordering?
- Why are there only four apparent forces?
  - Were they all unified at the Big Bang?
- Is the picture of the universe we present the real thing?
- Are there any other particles we don't know of?
  - Big deal for the new LHC Run that started now and in the new experiments starting up 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.

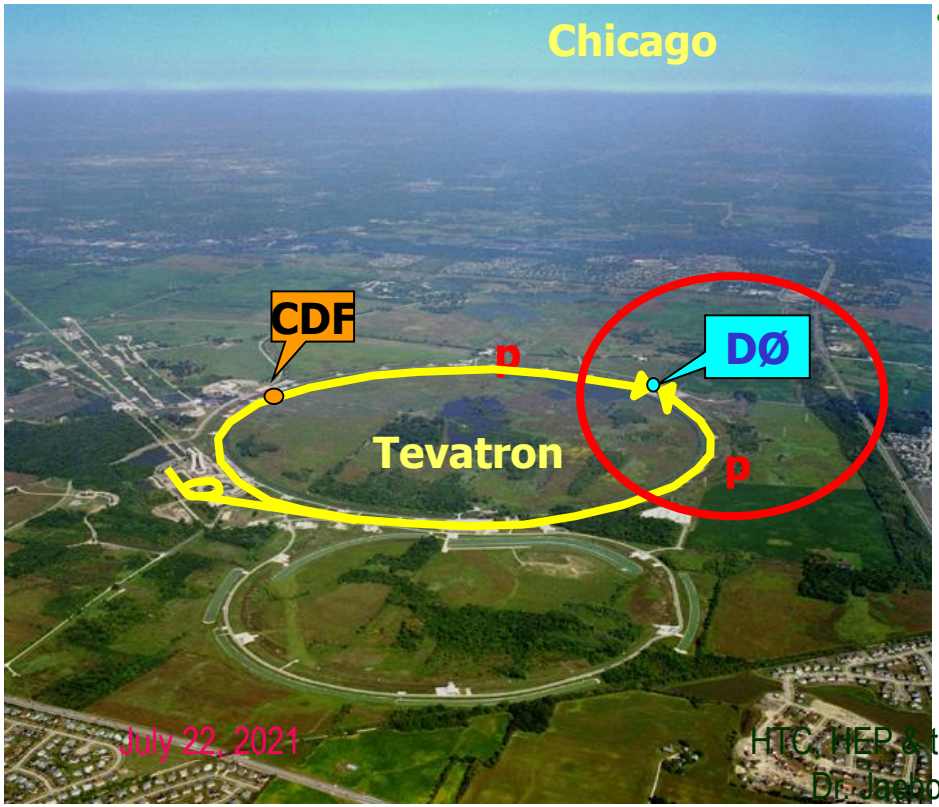
They make particles last seen
in the earliest moments of the universe.

Particle and anti-particle annihilate.

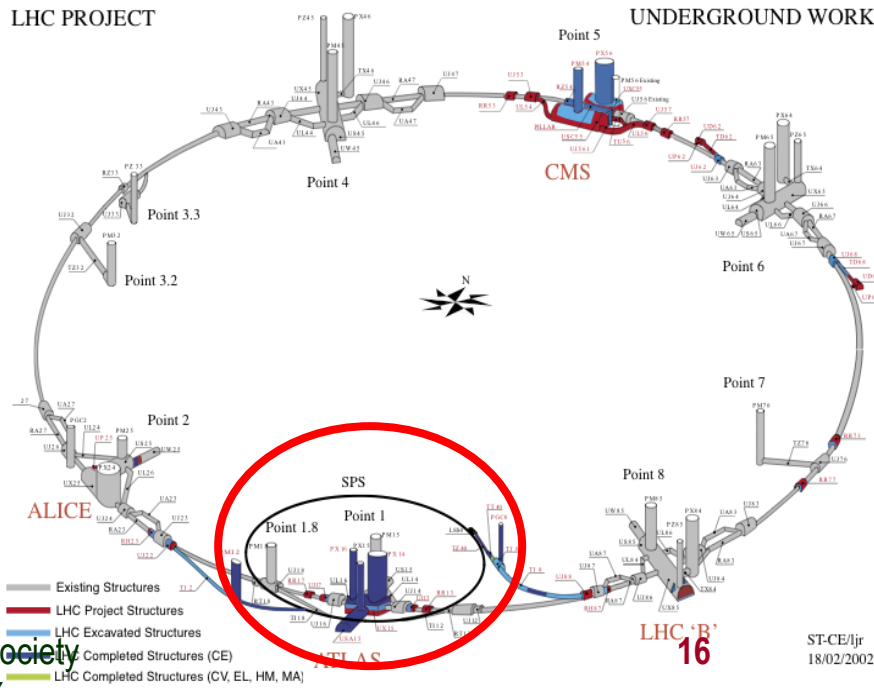
$$E = mc^2$$

Fermilab Tevatron and LHC at CERN

- World's Highest Energy proton-anti-proton collider
  - 4km (2.5mi) circumference
  - E_{cm}=2 TeV (=6.3x10^{-7}J/p➔ 13M Joules on the area smaller than 10^{-4}m^2)
  - Same as the KE of a 20t truck w/ 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!!**

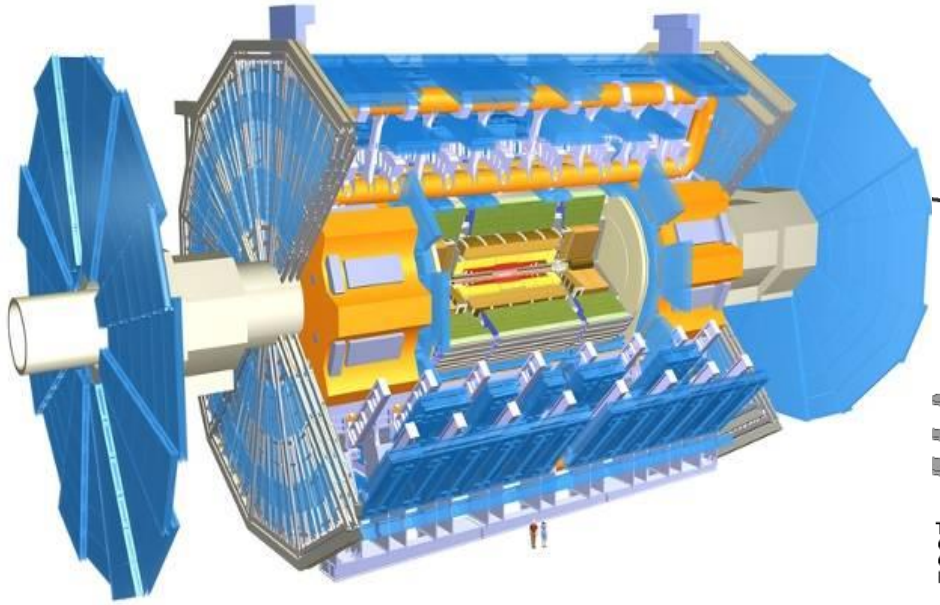


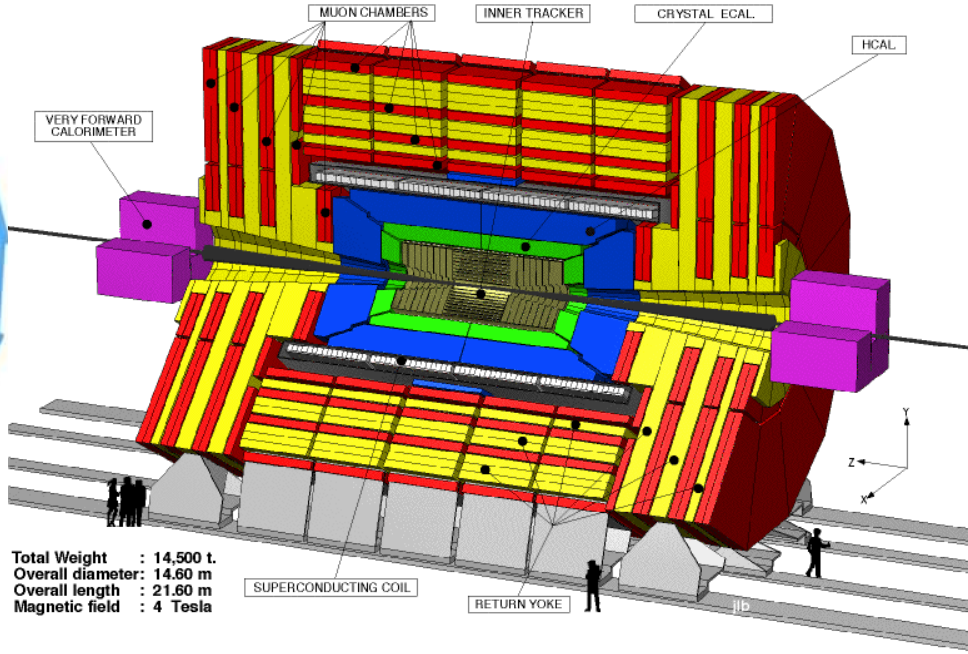
- World's Highest Energy p-p collider
  - 27km (17mi) circumference, 100m (300ft) underground
  - Design E_{cm}=14 TeV (=44x10^{-7}J/p➔ 362M Joules on the area smaller than 10^{-4}m^2)
  - ➢ KE of a B727 (80t) w/ speed 310km/hr
    - ➢ ~3M times the energy density at the ground 0 of the Hiroshima atom bomb
- **Discovered a new heavy particle that looks Higgs in 2012**
- **Search for new particles has been ongoing!!**
- **The LHC started back up early 2021 at high intensity**



LHC @ CERN Aerial View

The ATLAS and CMS Detectors



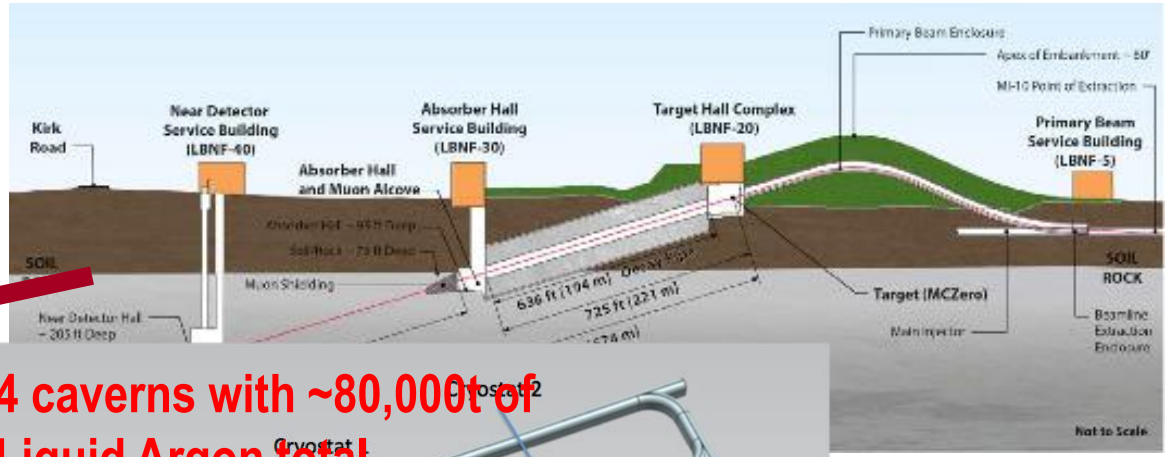


- **Weighs 7000 tons and ~10 story tall**
- Records **200 – 400 collisions/second (out of 50million)**
- Records approximately **350** MB/second
- Records >2 PB per year ➔ **200*Printed material of the US Lib. of Congress**

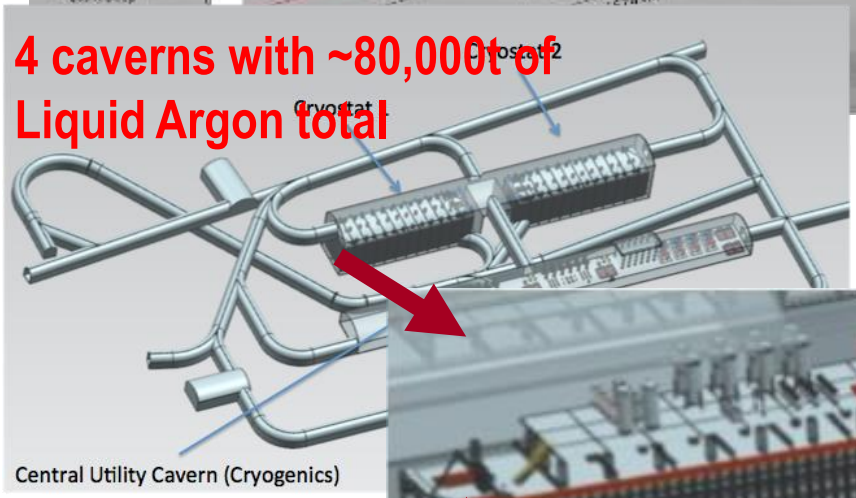
200x

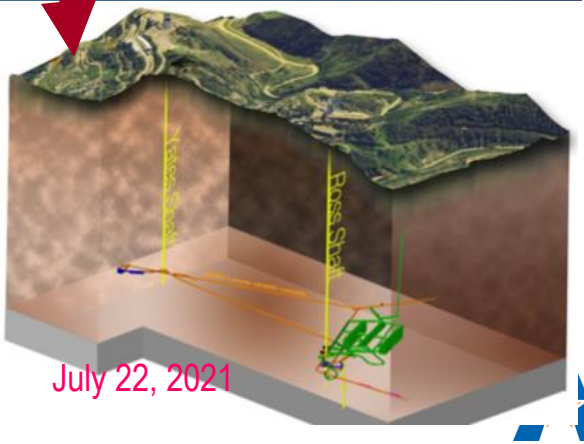
The Next Big Thing - DUNE

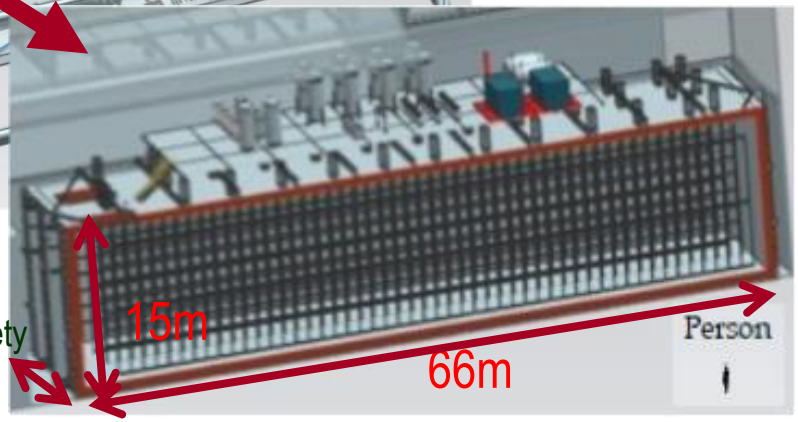
- Stands for Deep Under Ground Neutrino Experiment
- The $2.3B US flagship long baseline (1300km) experiment
  - 1500m underground in South Dakota



4 caverns with ~80,000t of Liquid Argon total

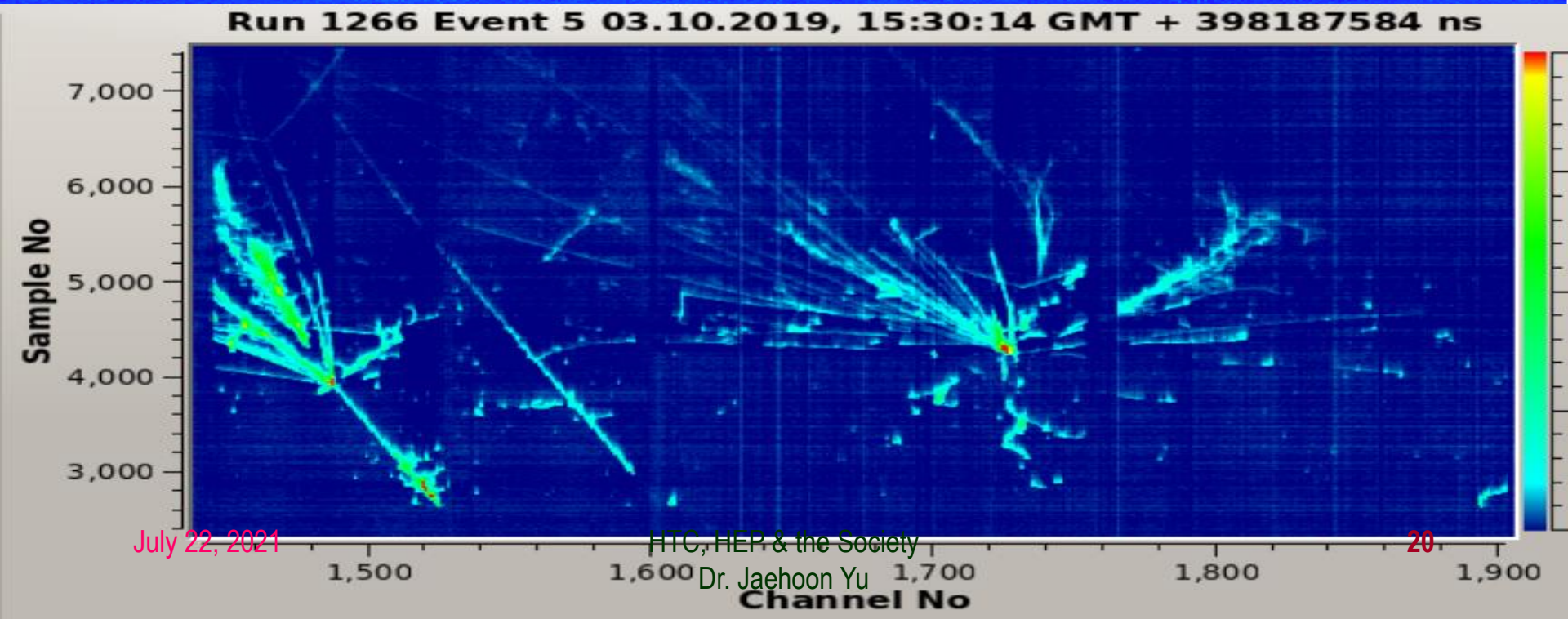


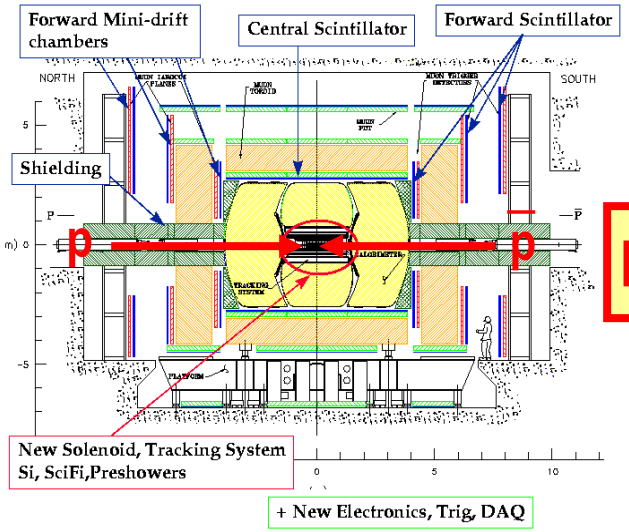




ProtoDUNE Event

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





Digital data

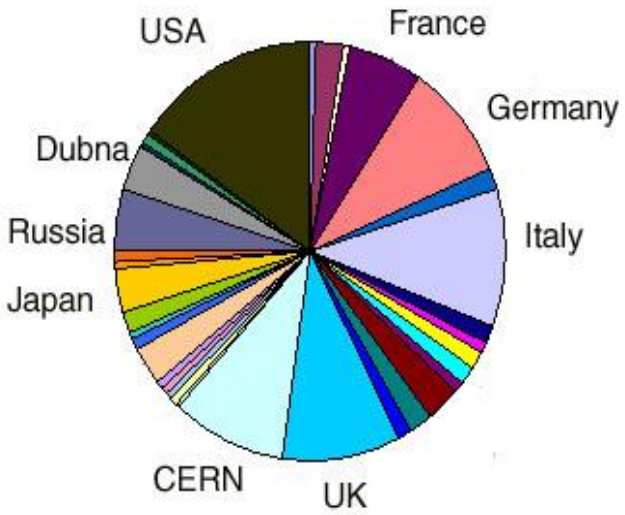
Data Reconstruction

The Problem

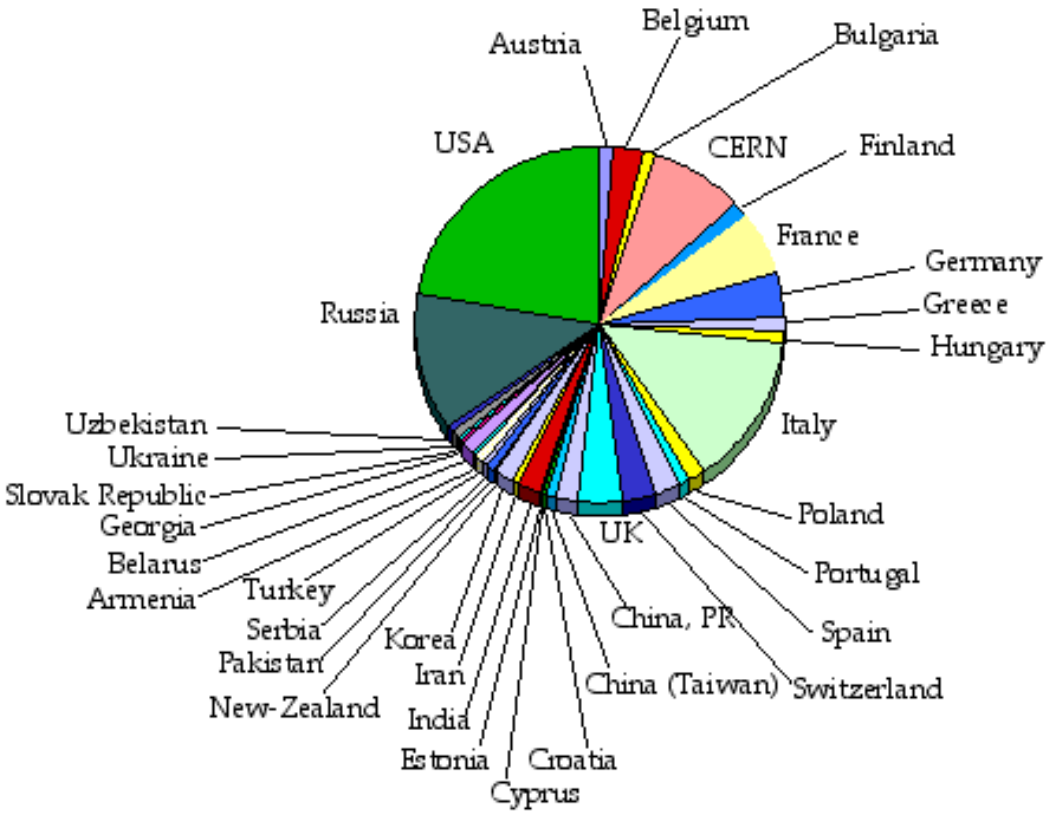
- Detectors are complicated and large ➔ Need large number of collaborators
  - They are scattered all over the world!

LHC Collaborations

ATLAS



CMS



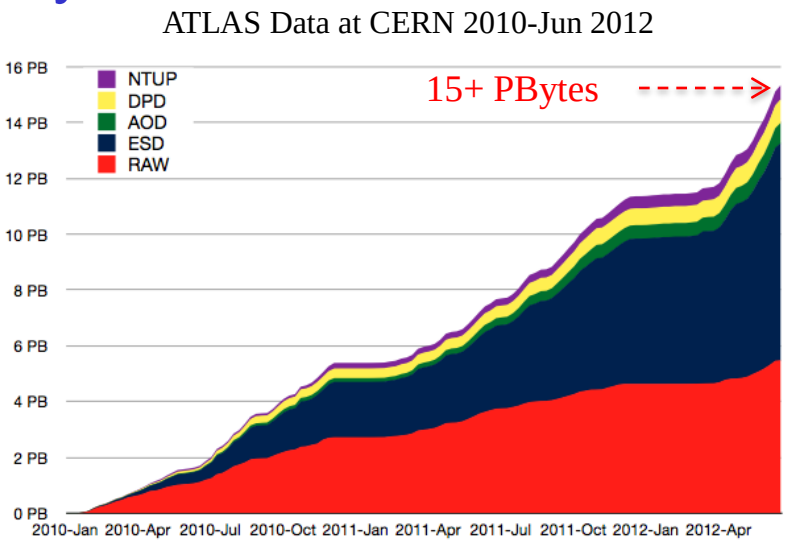
ATLAS+CMS over 6000 Physicists and Engineers
Over 60 Countries, 250 Institutions

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 efficiently 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

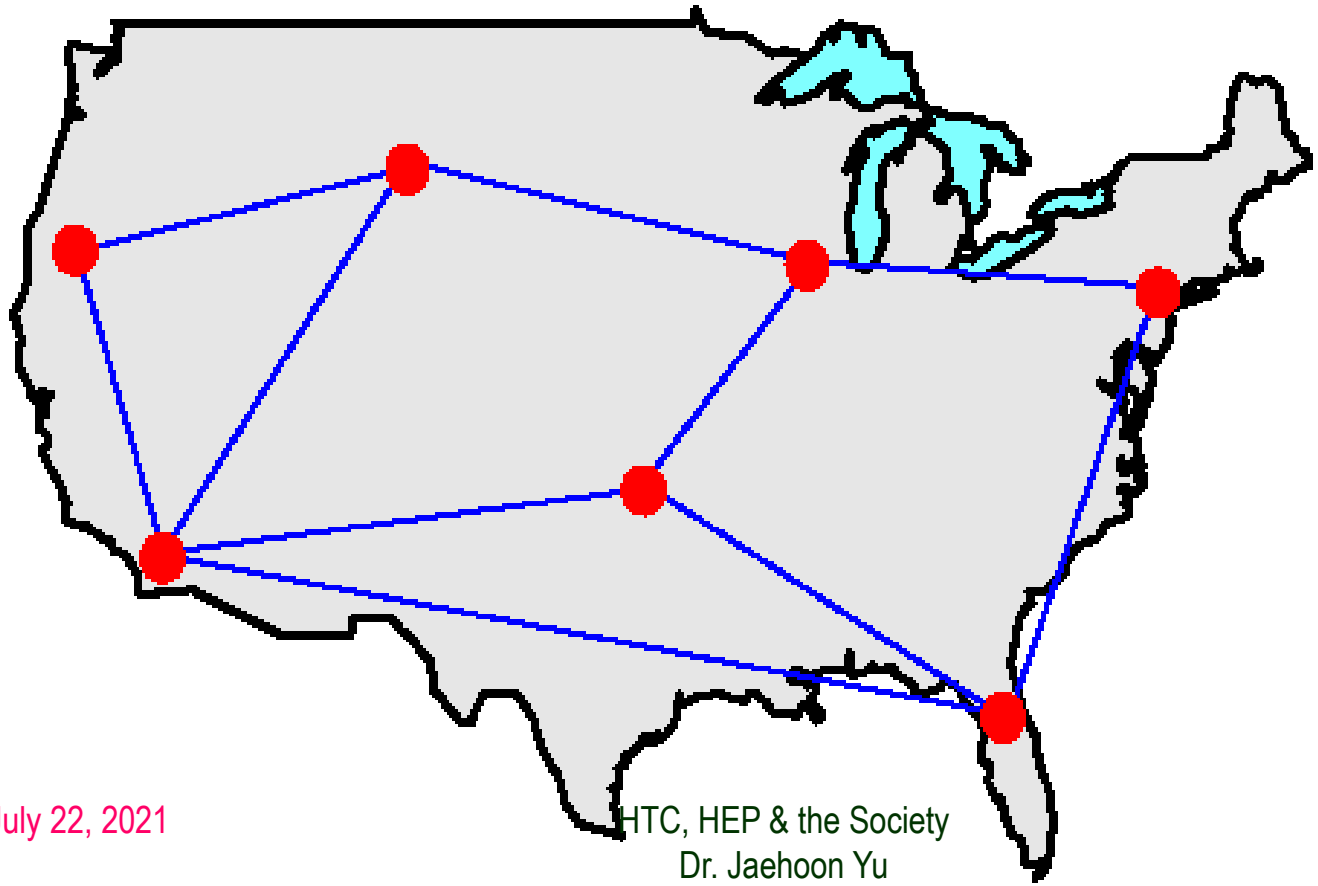


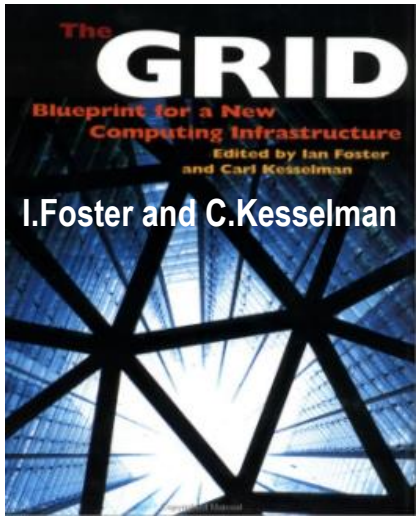
The Problem, cont'd

- 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?

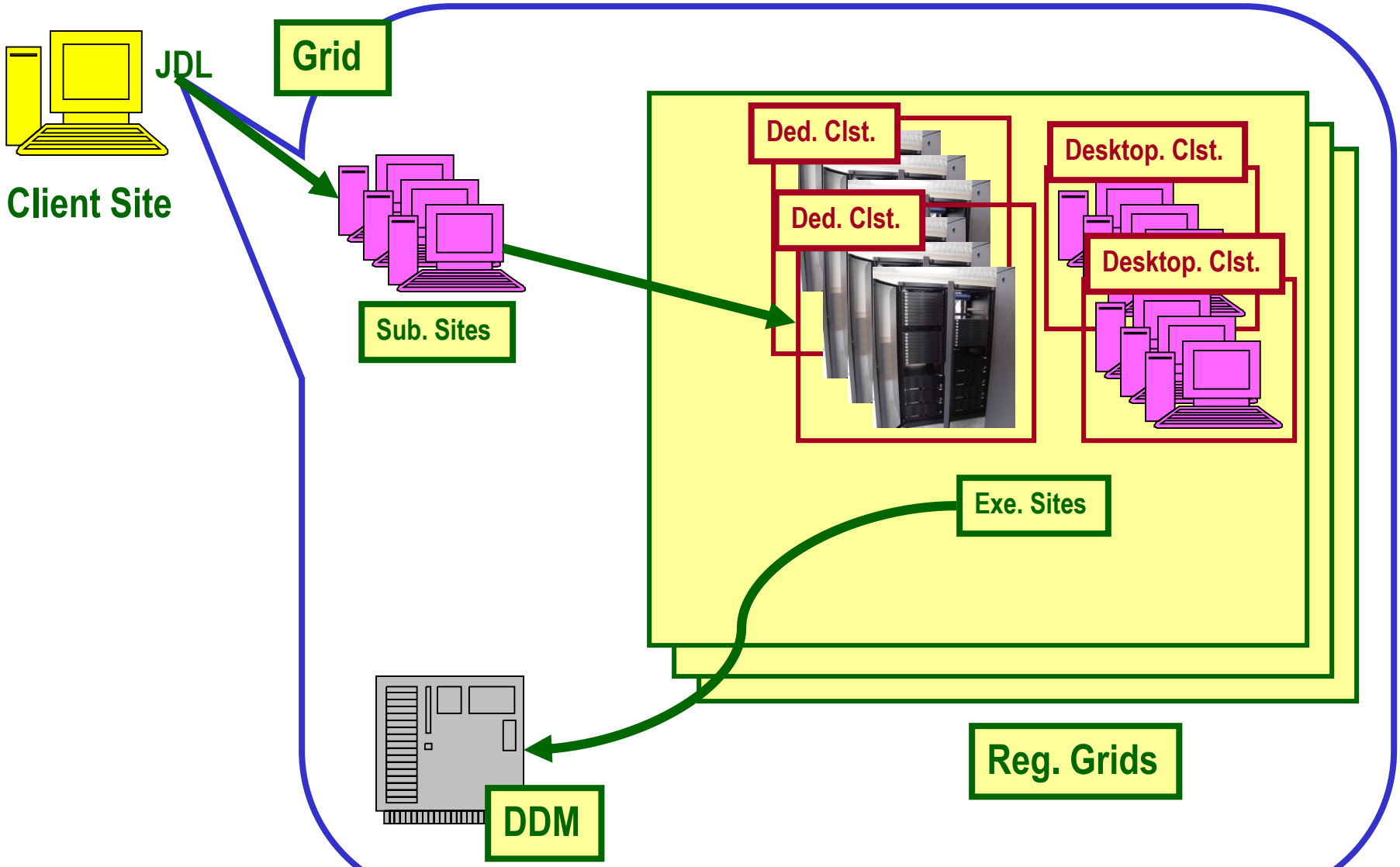
What is a Computing Grid?

- 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

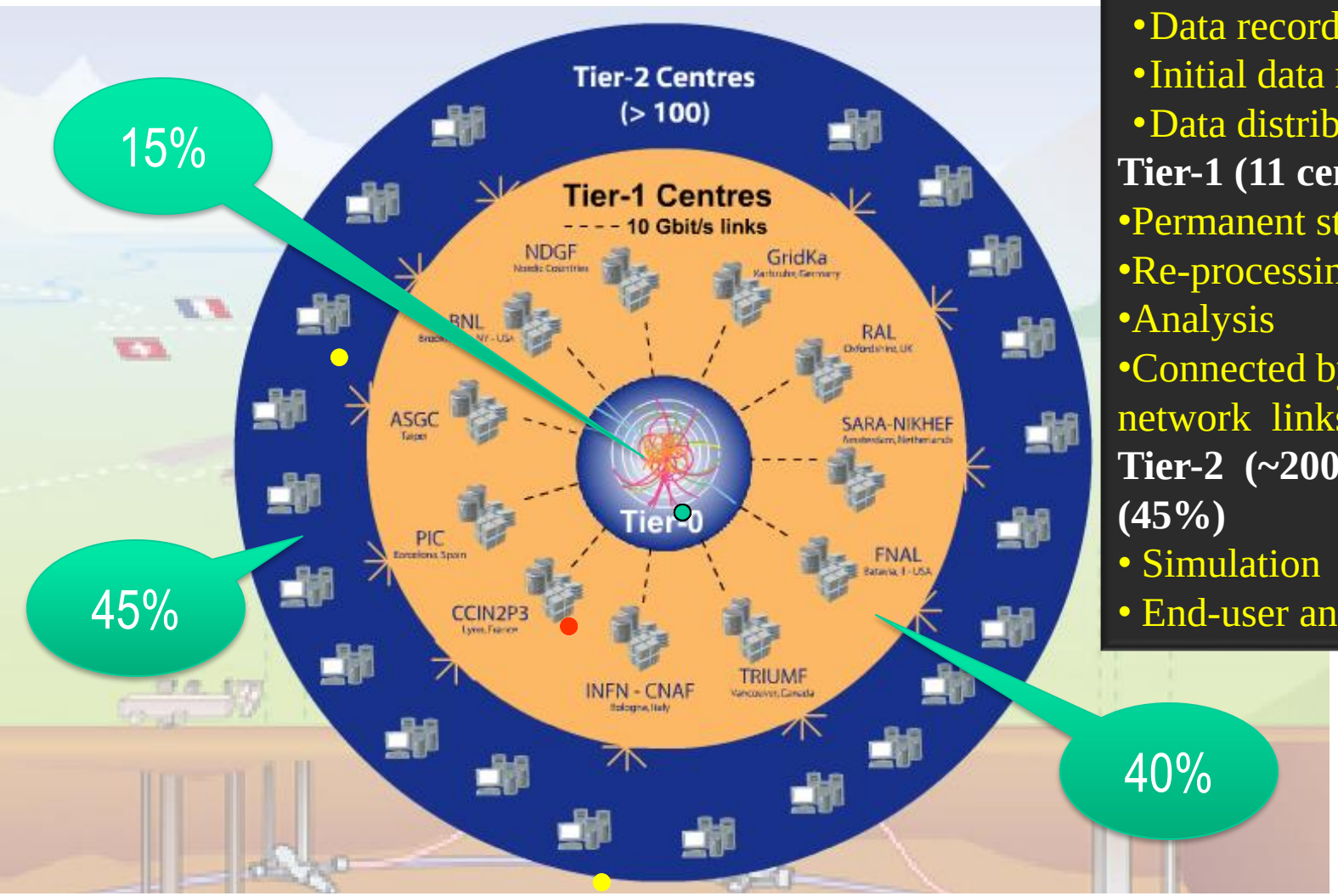




How does a computing Grid work?



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

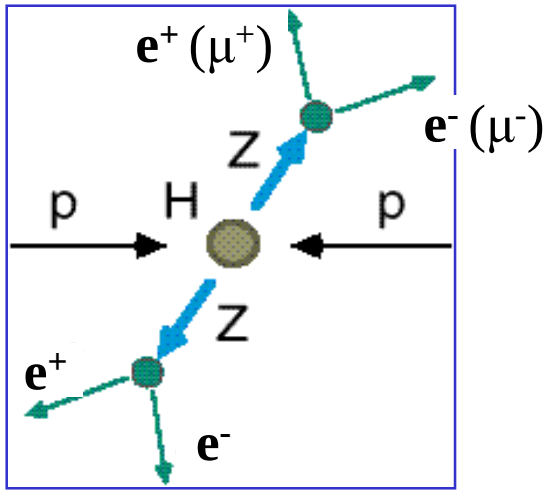
Open Science Grid

How to look for rare particles?

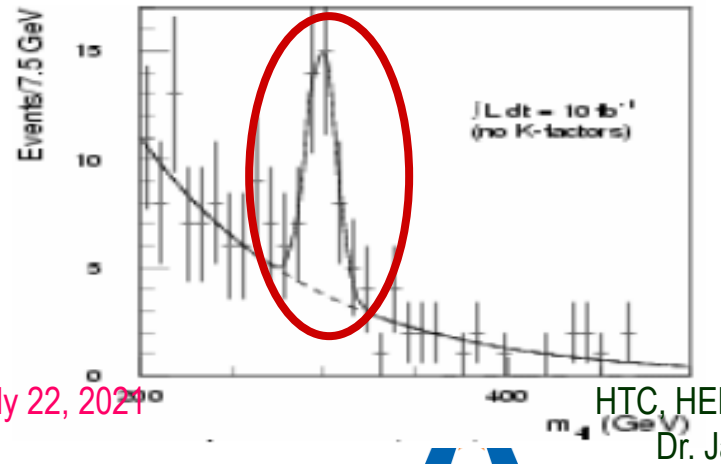
- Many of these rate particle are so heavy they decay into other lighter particles instantaneously
- When one searches for a new particle, one looks for the easiest way to get at them
- Of many signatures of the rare particle final states, some are much easier to find ➔e.g. for the Standard Model Higgs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

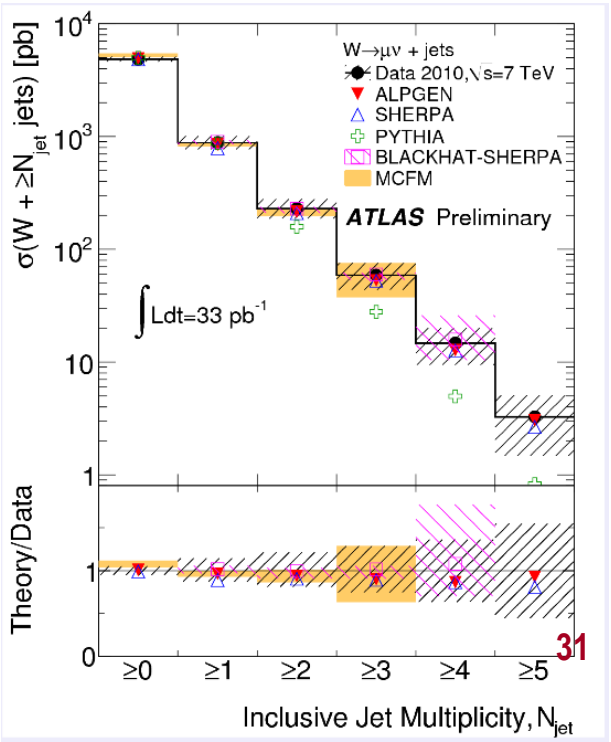
How do we look for a rare particle?

1. Identify Higgs candidate events

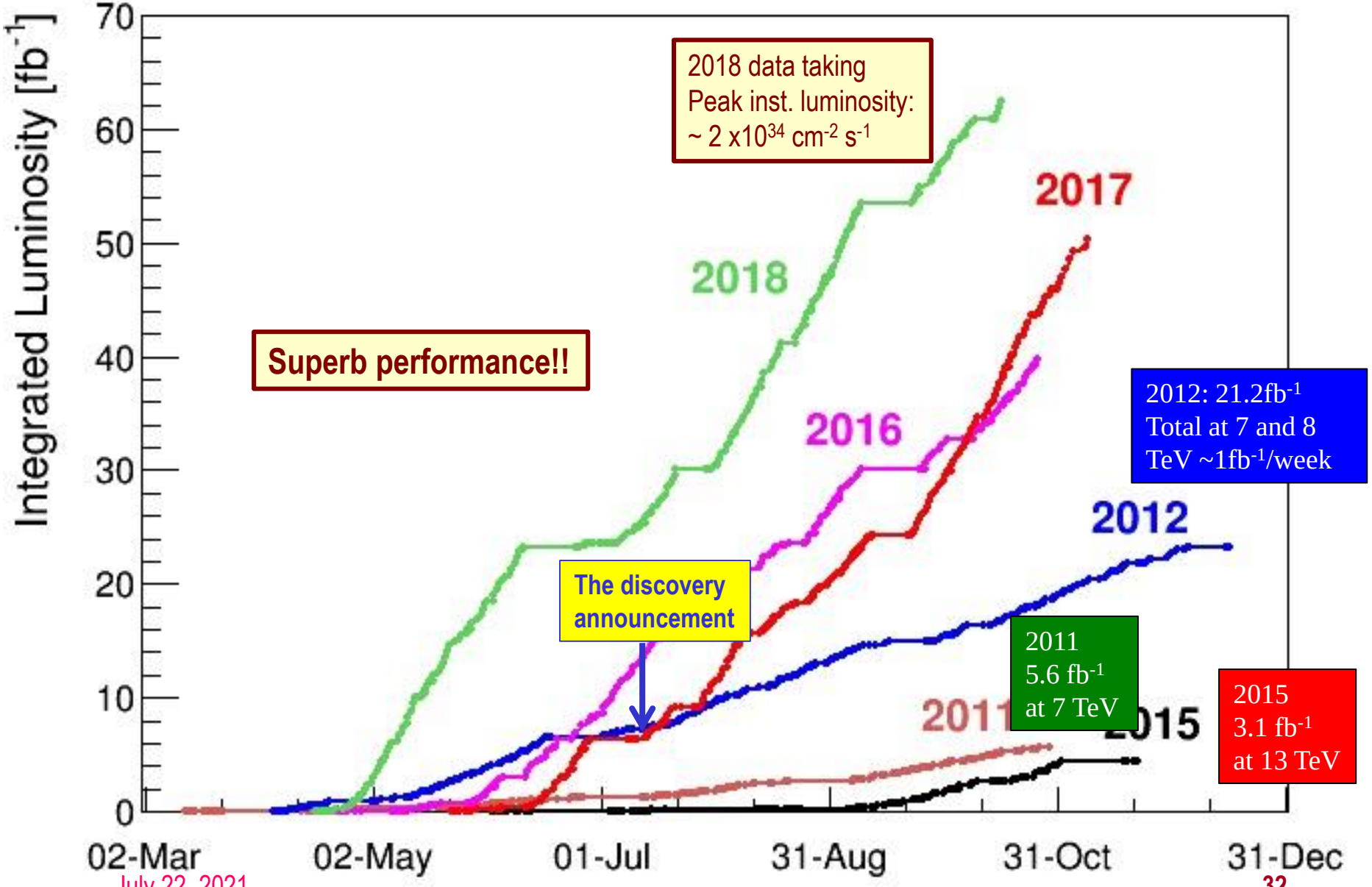


2. Understand fakes (backgrounds)
3. Look for a bump!!
   - Large amount of data absolutely critical

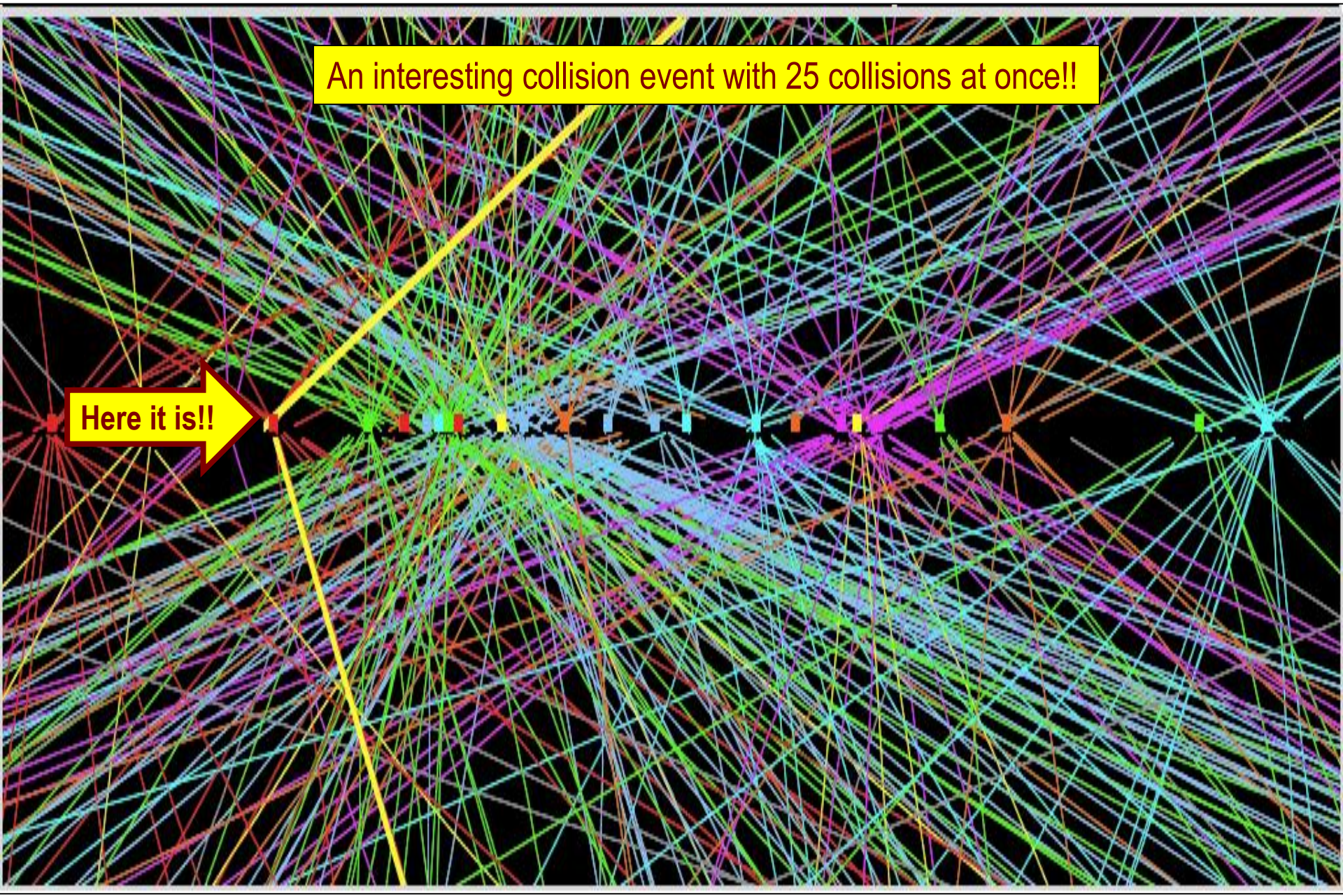




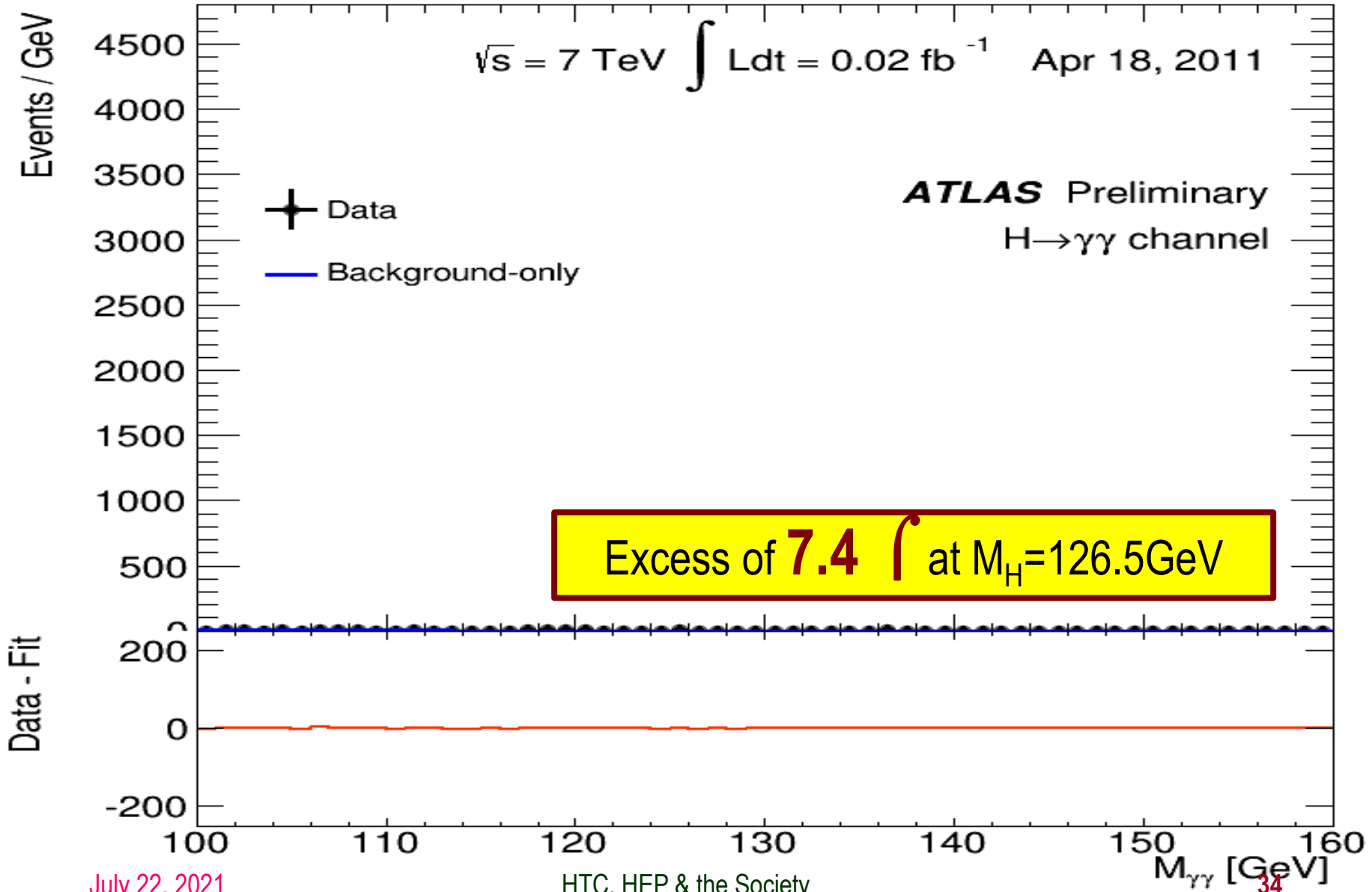
Amount of the LHC Data



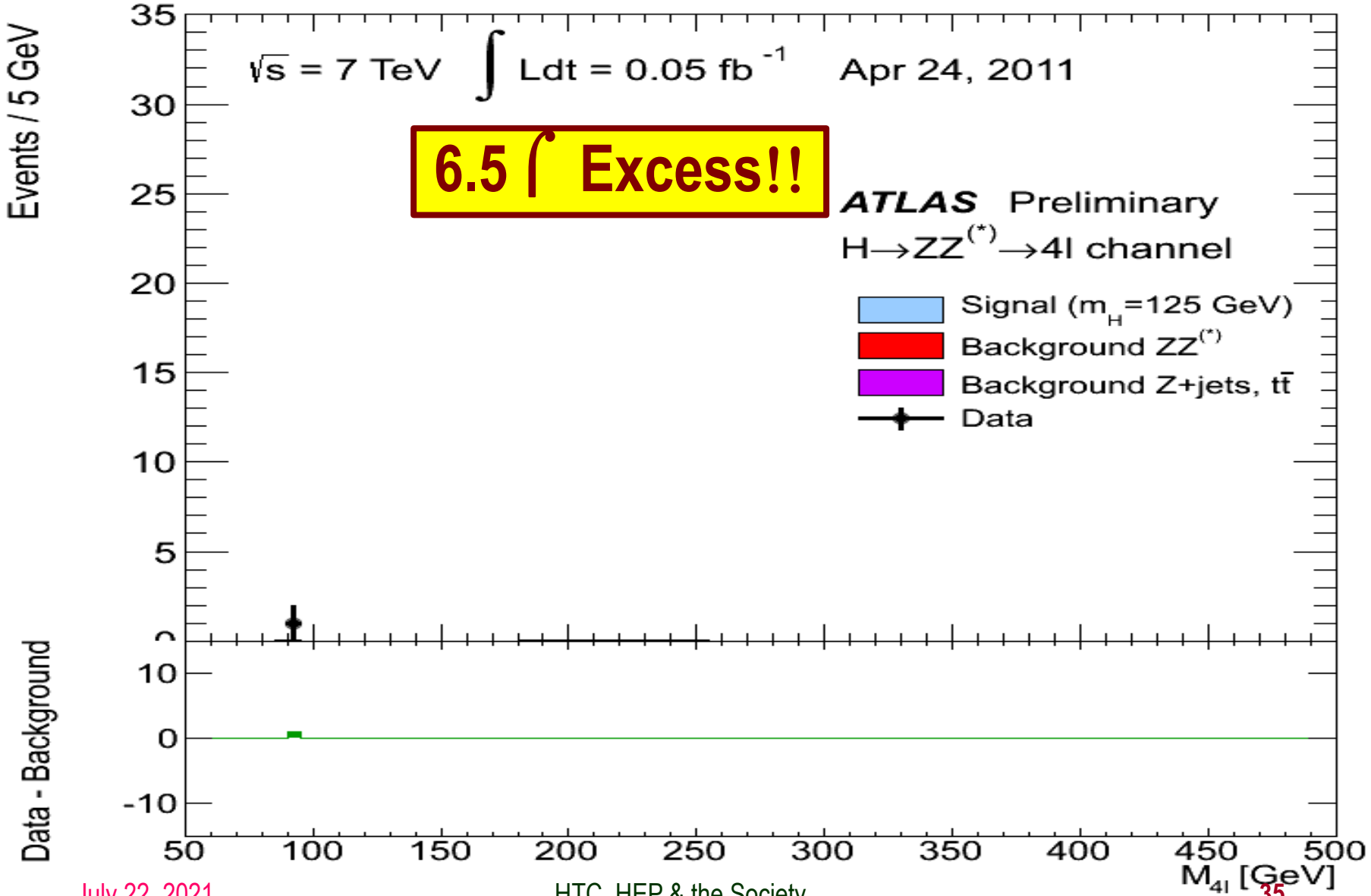
Challenges? No problem!



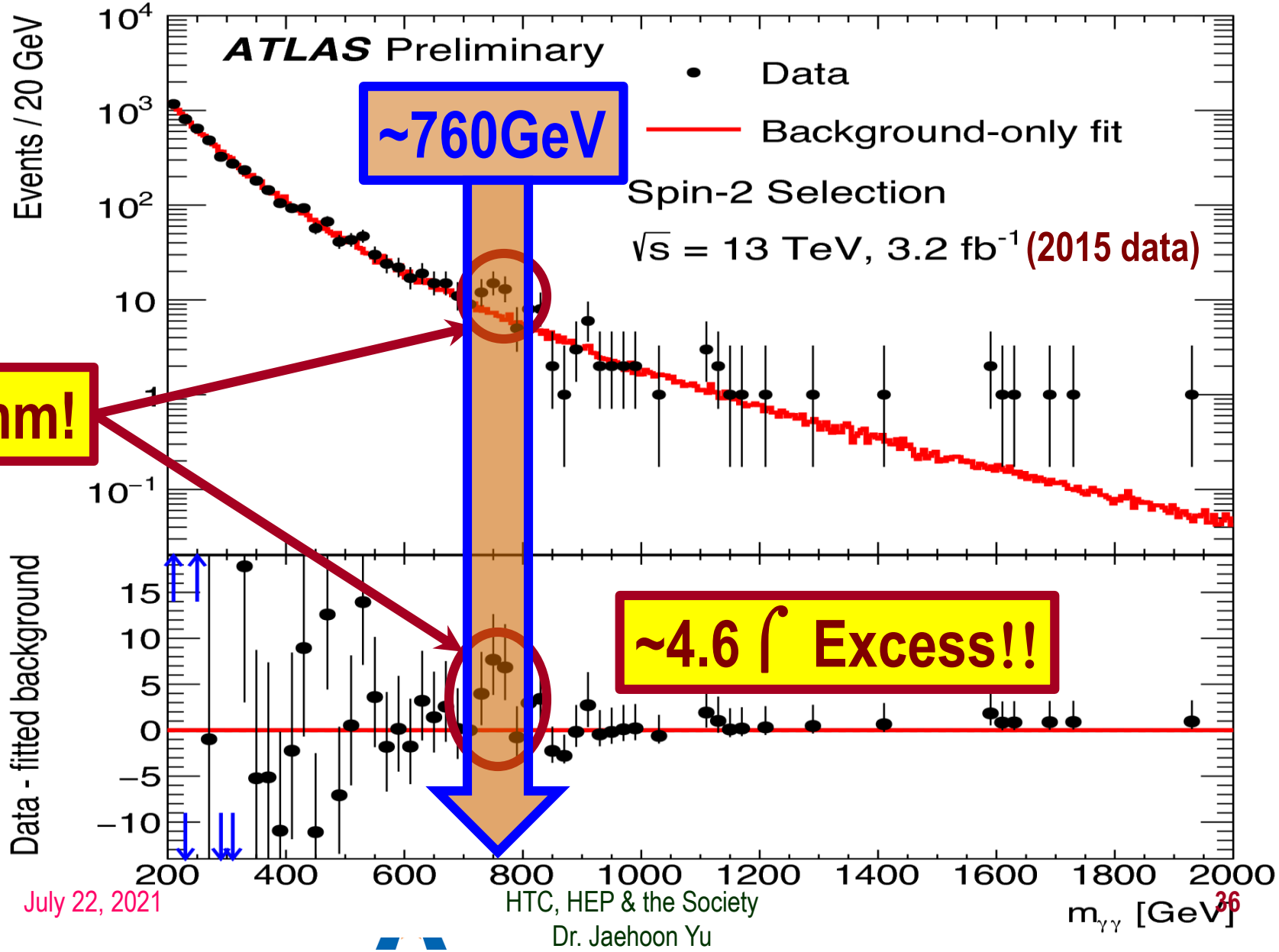
What did statistics do for Higgs→ γγ?



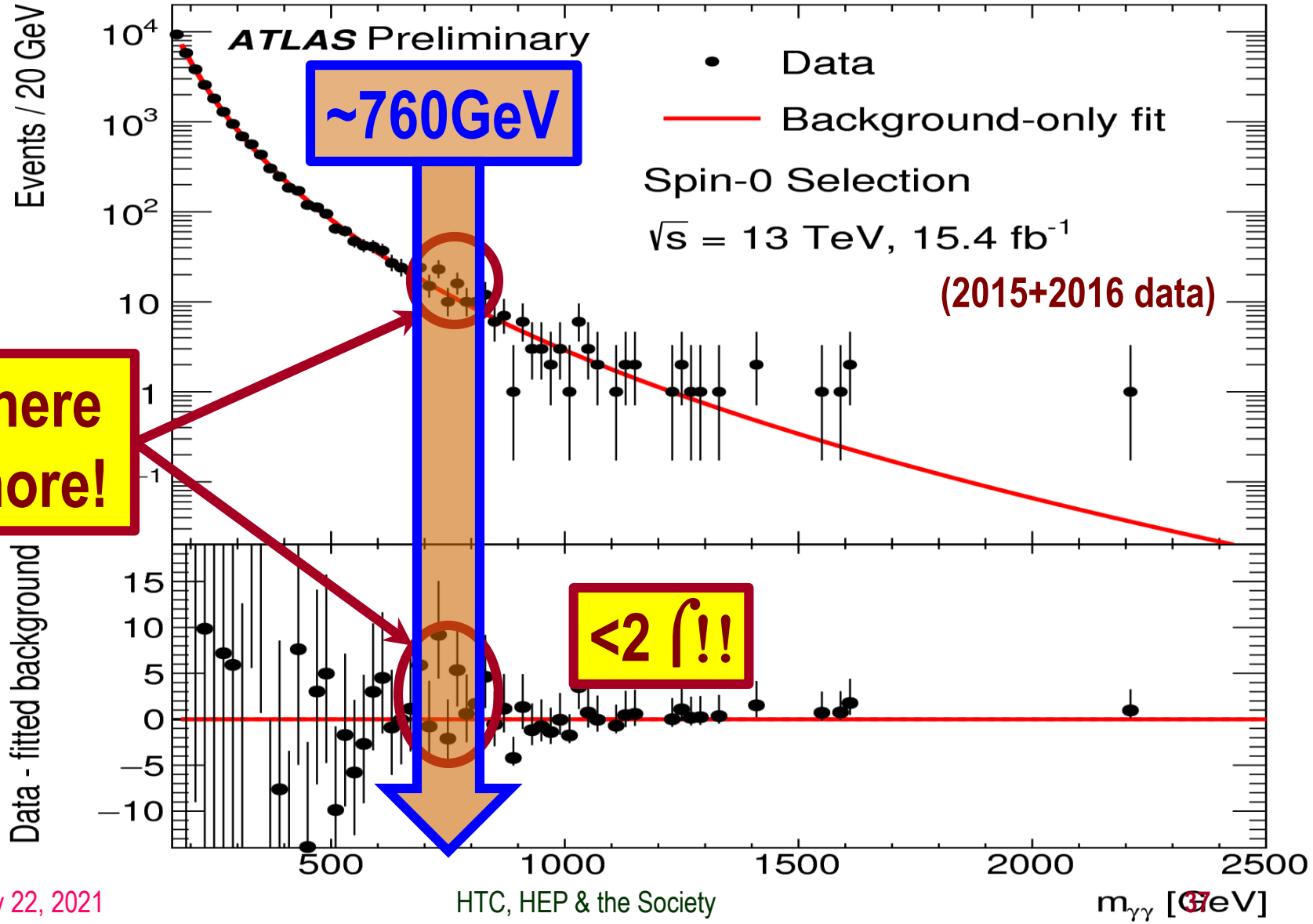
ATLAS Mass Bump Plot (H→4l)?



A hint of something new?

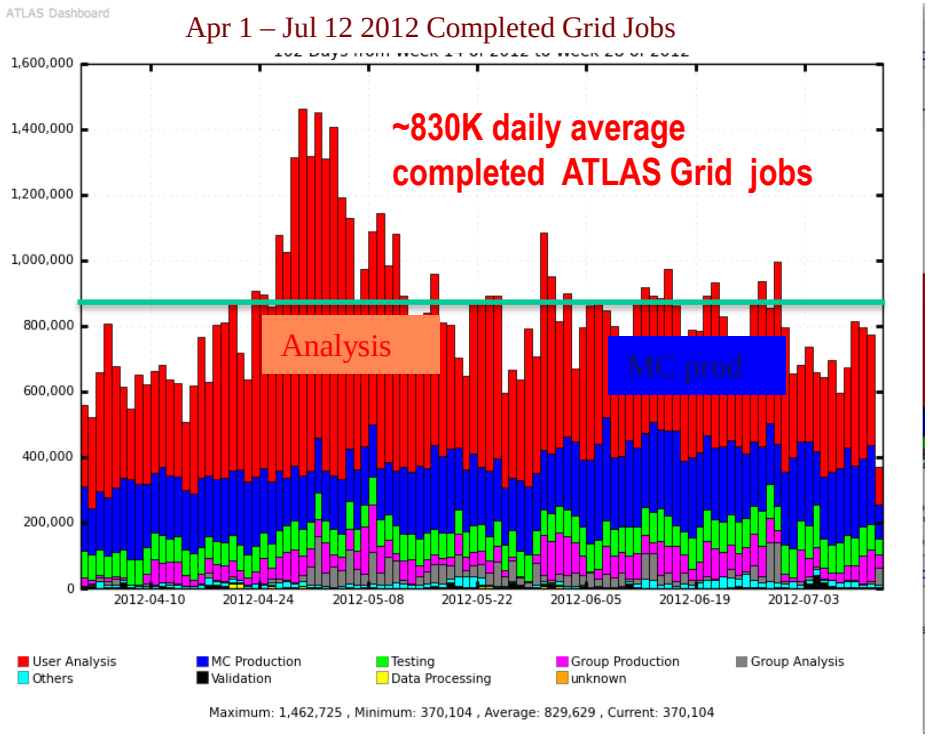


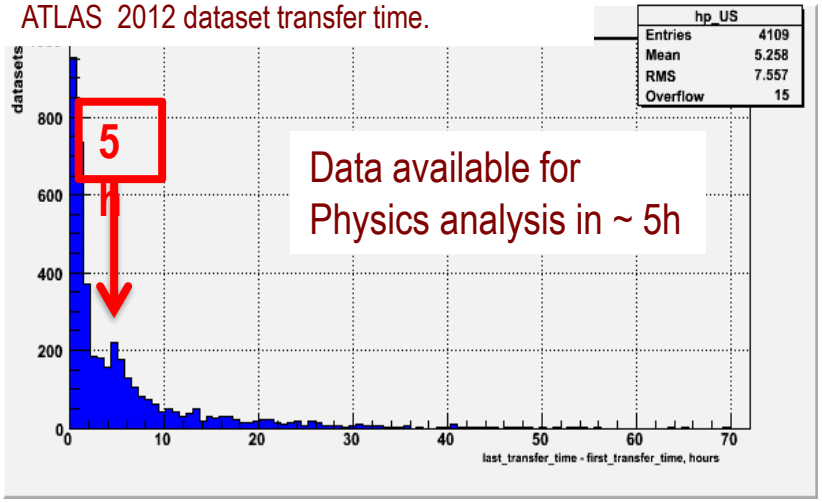
Disappeared after x4 data!!

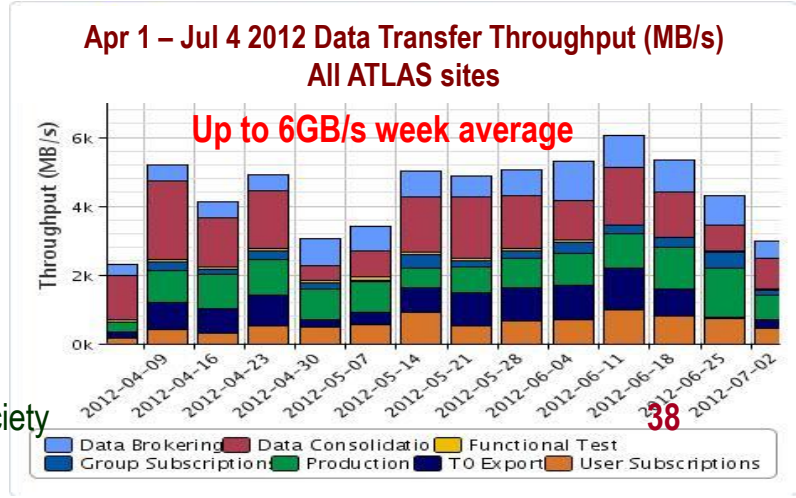


Performance of the Grid for LHC

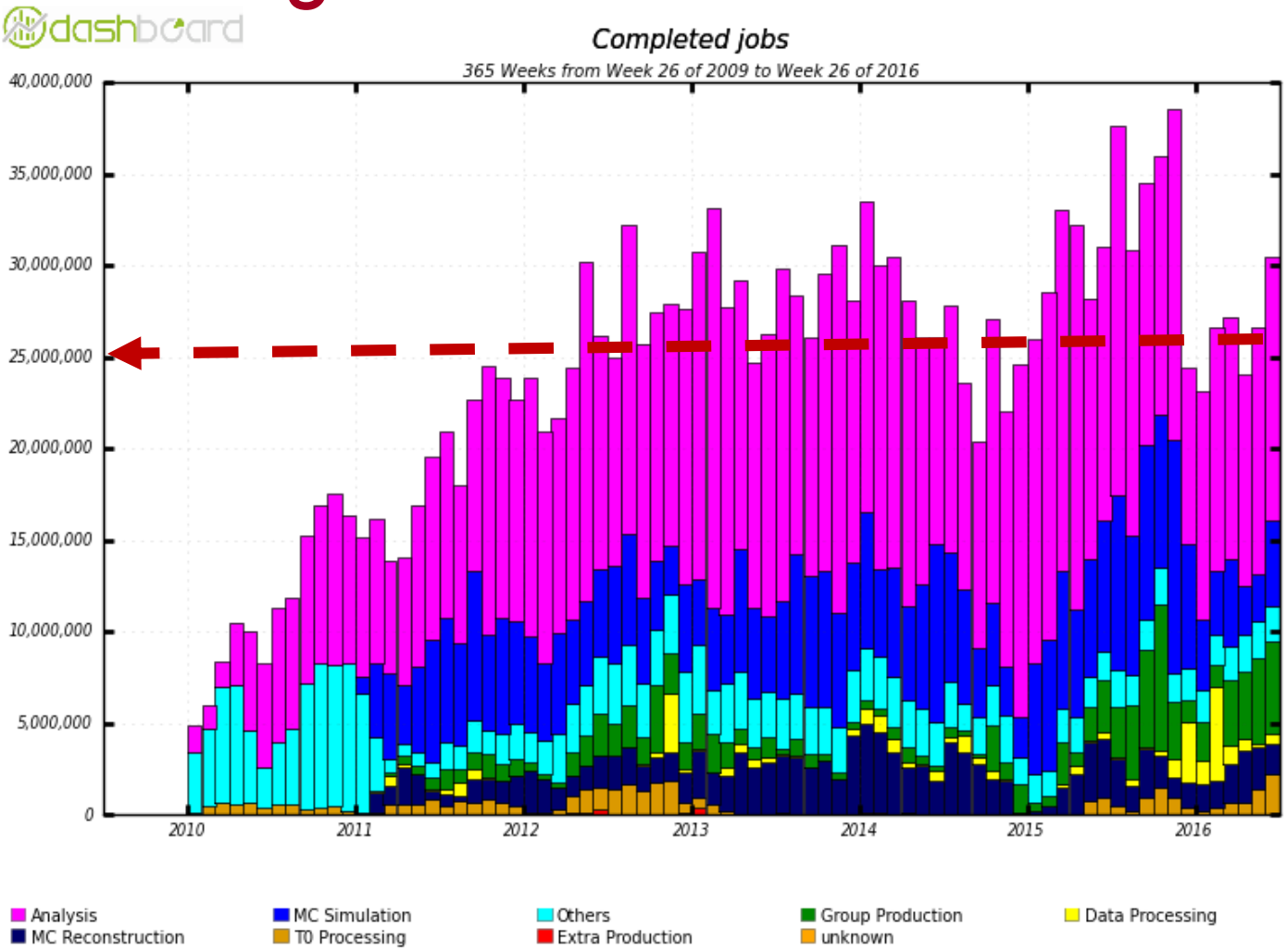
- ATLAS Distributed Computing on the Grid : 10 Tier-1s + CERN + ~70 Tier-2s +…(more than 80 Production sites)
- High volume, high throughput process through fast network!!







Data Management Software Performance



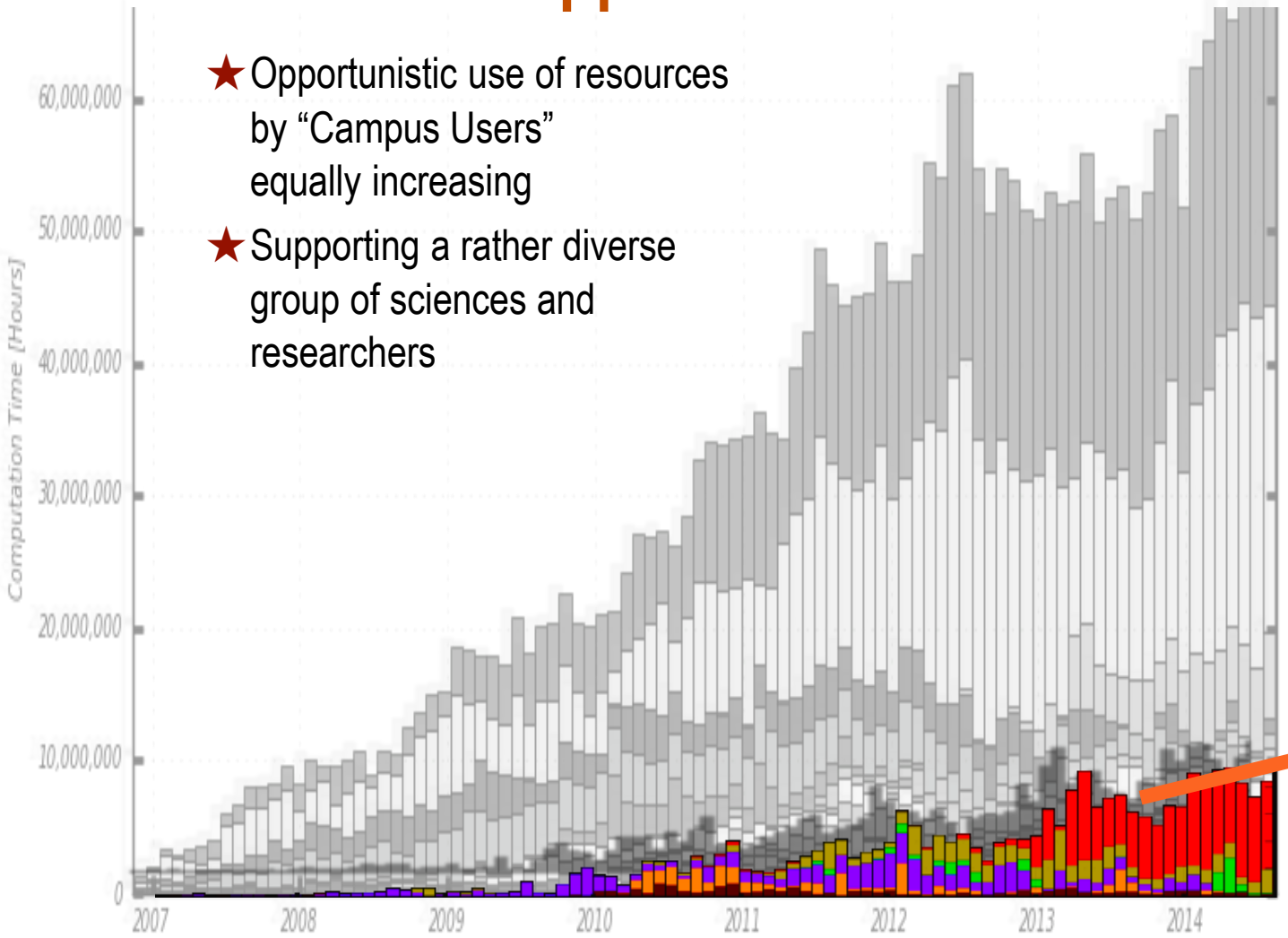
Current scale – 25M jobs completed every month at >hundred sites

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

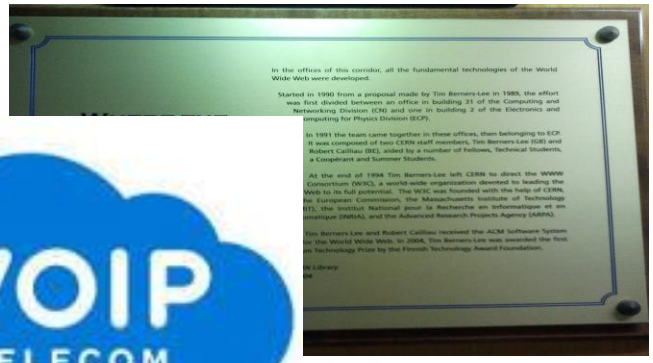


Opportunistic Use?

>90M CPU hours opportunistic use past 12 Months

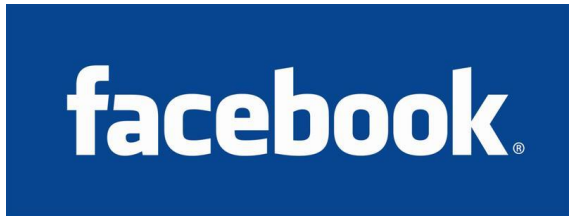
Lotha

The commercial world picked up..



Early 90's

2004



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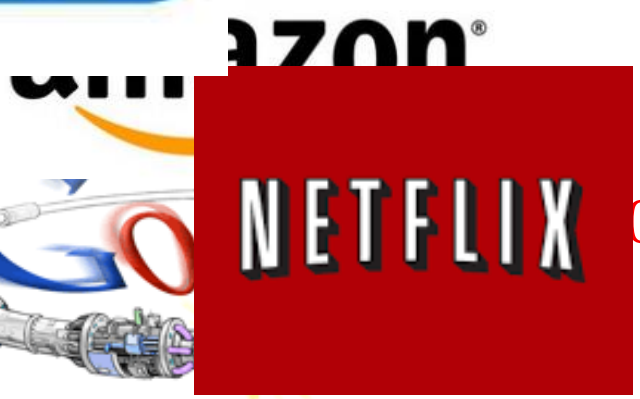

1998

006

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

The concept of cloud and the HTC turned into a new area of study, the Data Science!!

So why is HEP relevant to me?

- HEP explores the most fundamental nature of the Universe!
- The discovery of the dark matter and making of dark matter beams will take us to the next Quantum level
- Discoveries will realize our 1000 year dreams
- Outcome and bi-products of HEP research improves our daily lives directly and indirectly
  - WWW came from HEP


WHERE THE
WEB
WAS BORN

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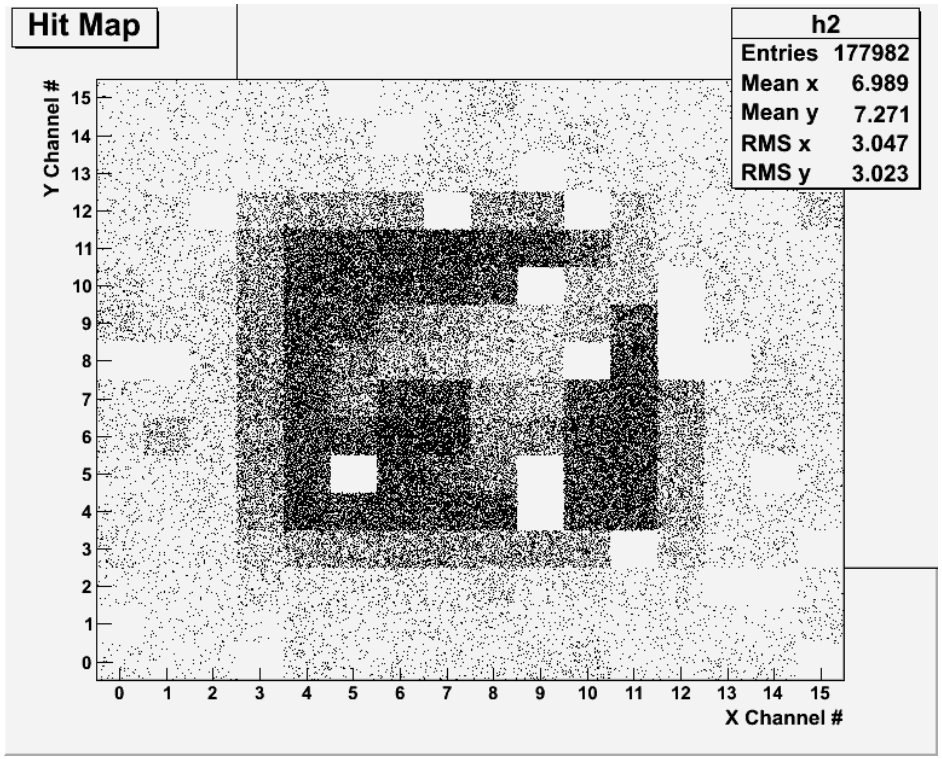
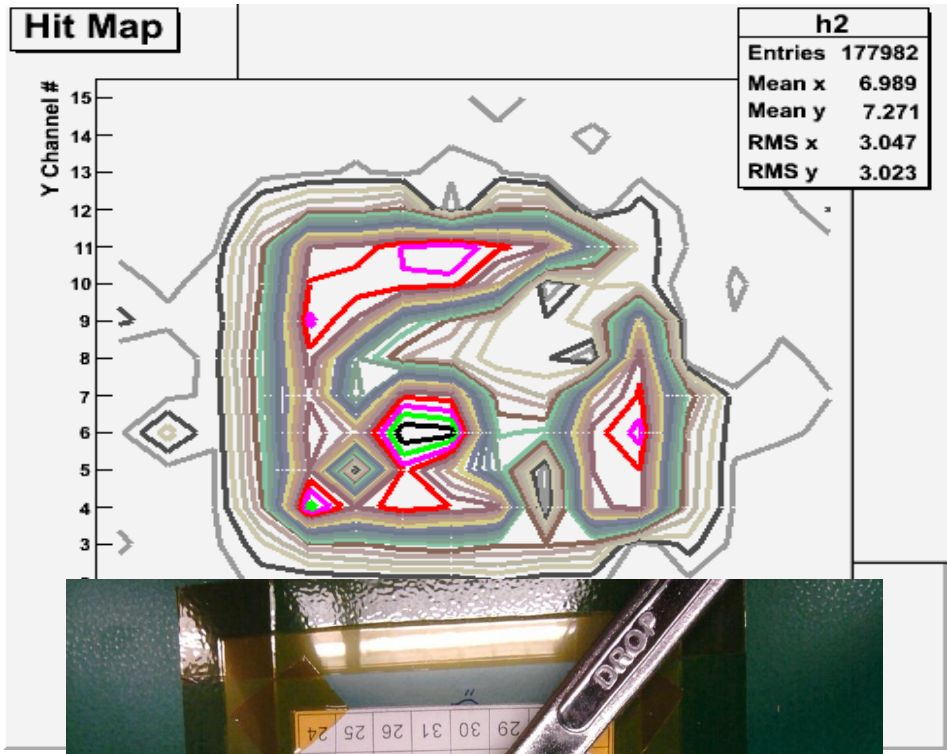
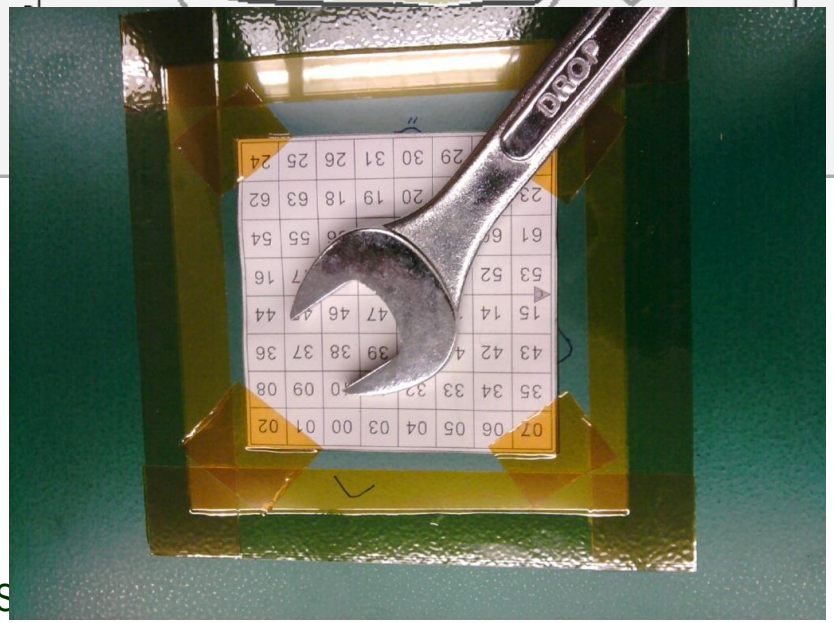
  - Advanced detector technologies like GEM will make a large screen low dosage X-ray imaging possible

Bi-product of High Energy Physics Research







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

So are we done with the HTC?

- LHC has performed extremely well!
- The data size will increase by over 10 fold in HLLHC
  - Computing will be stressed even further!!
- Grid computing infrastructure has served well thus far
  - LHC users process PBs of data & billions of jobs
- High Intensity Experiments, such as DUNE will record even larger amount of data than the LHC
- Identified limits in databases scalability, CPU resources, storage utilization, etc, are being addressed
- Utilization of quantum computing and machine learning technologies actively sought

Conclusions

- HEP is an exciting endeavor in understanding the universe
- 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
- Physics analyses at one's own desktop using computing grid sitting behind has happened!!
- Computing grid used in other disciplines with large data sets
- Computing grid fully integrated into everyday lives
  - The pandemic accelerated this process
- A true computing grid is revolutionizing everyday lives ….

HEP's Impacts to the Society?

- WWW and other advanced computing technologies from HEP greatly reduced the physical distances between us
  - Help freeing oppressed people and protecting their freedom
  - Keeping people from being imprisoned by their physical limitations or even by a pandemic
- HTC generates petrillions (=1000 trillions) dollars of economy
- Data science becomes a major area of education
  - Helps recording and analyzing enormous data in the COVID-19 fight
- All these technologies that can do good things, however, are instead harmful if used by those lack humanity and fundamental human decency
  - See how spreading misinformation hurts the very humanity we care!!
- Be a good person first with a heart toward the good of humanity

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?

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

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

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

  - What is the beam current? $I=N_p\times 1.6\times 10^{-19}$
$$=1.2\times 10^{-5}\left(C/\text{sec}\right)=12\,mA$$