

# COMPUTING IN PARTICLE PHYSICS

The coexistence of particle physics and computing.

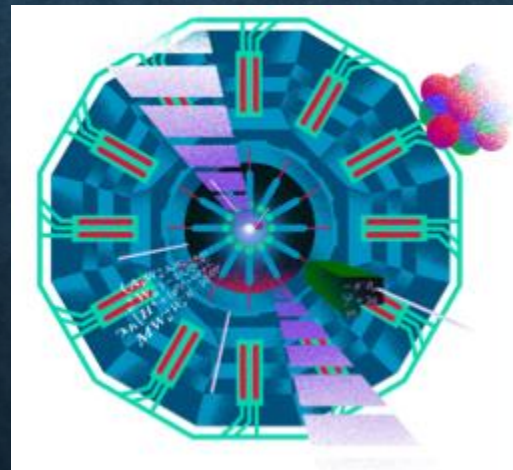
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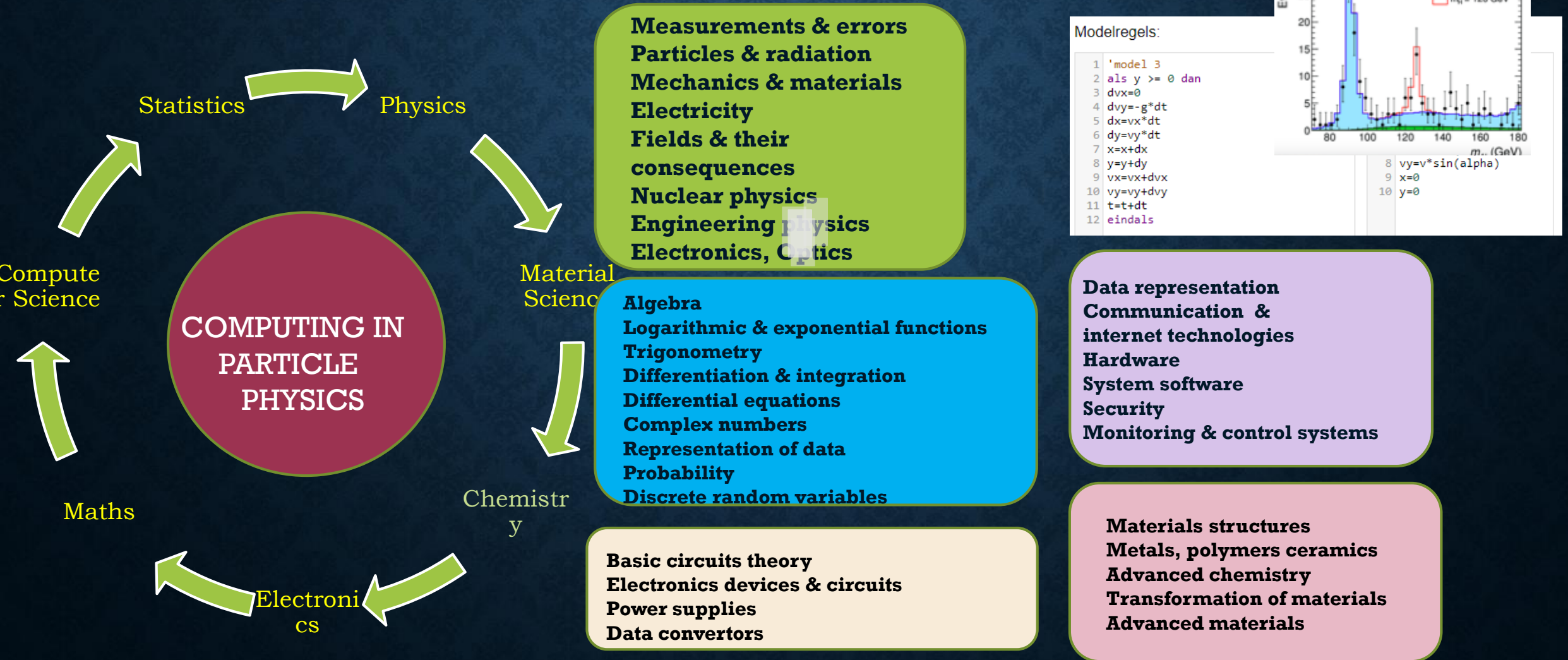
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# CURRICULUM & CLASSROOM CONNECTIONS



**Measurements & errors**  
**Particles & radiation**  
**Mechanics & materials**  
**Electricity**  
**Fields & their consequences**  
**Nuclear physics**  
**Engineering physics**  
**Electronics, Optics**

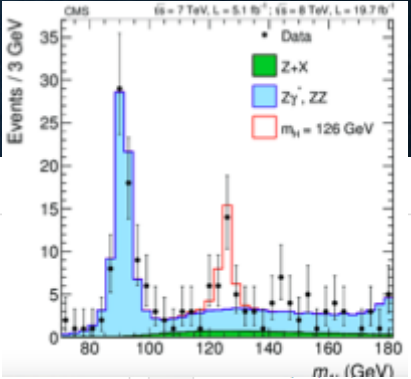
**Algebra**  
**Logarithmic & exponential functions**  
**Trigonometry**  
**Differentiation & integration**  
**Differential equations**  
**Complex numbers**  
**Representation of data**  
**Probability**  
**Discrete random variables**

**Basic circuits theory**  
**Electronics devices & circuits**  
**Power supplies**  
**Data convertors**

Modelregels:

```

1 'model 3
2 als y >= 0 dan
3 dvx=0
4 dvy=-g*dt
5 dx=vx*dt
6 dy=vy*dt
7 x=x+dx
8 y=y+dy
9 vx=vx+dvx
10 vy=vy+dvy
11 t=t+dt
12 eindals
  
```



```

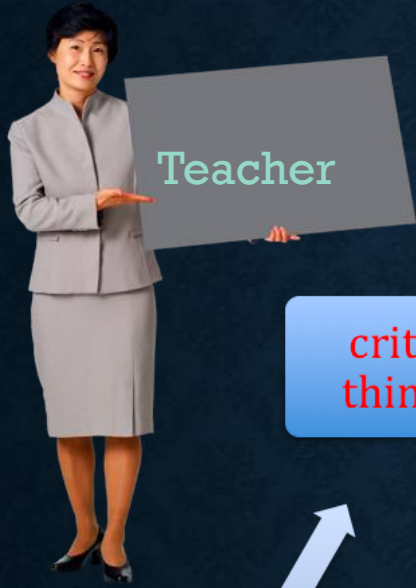
8 vy=v*sin(alpha)
9 x=0
10 y=0
  
```

**Data representation**  
**Communication & internet technologies**  
**Hardware**  
**System software**  
**Security**  
**Monitoring & control systems**

**Materials structures**  
**Metals, polymers ceramics**  
**Advanced chemistry**  
**Transformation of materials**  
**Advanced materials**



# CURRICULUM & CLASSROOM CONNECTIONS-



critical-thinking

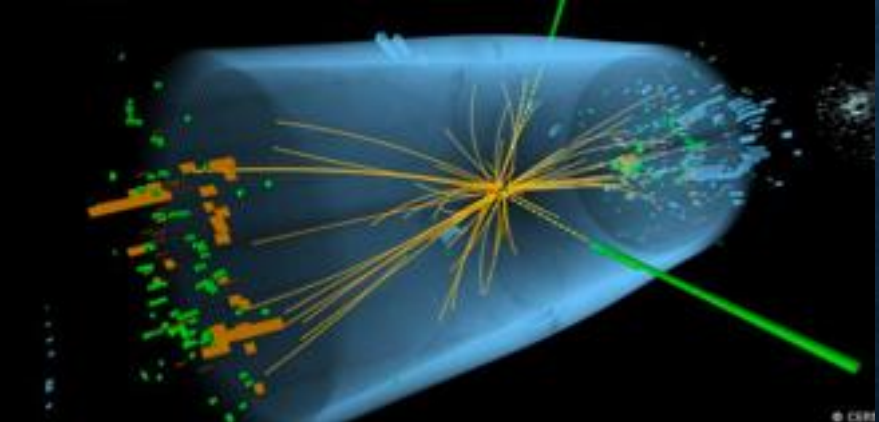
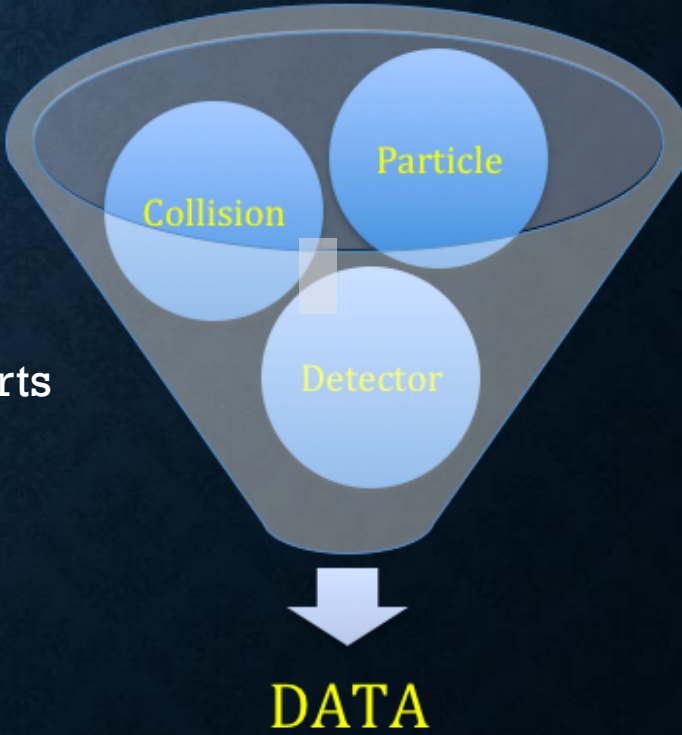


What skills does student need to have?

reflective

innovative

- domain knowledge
- problem solving
- data preparation
- data analysis & exploration
- creating dashboards & reports
- communication skills





# KEY IDEAS – LHC CONTROL SYSTEMS

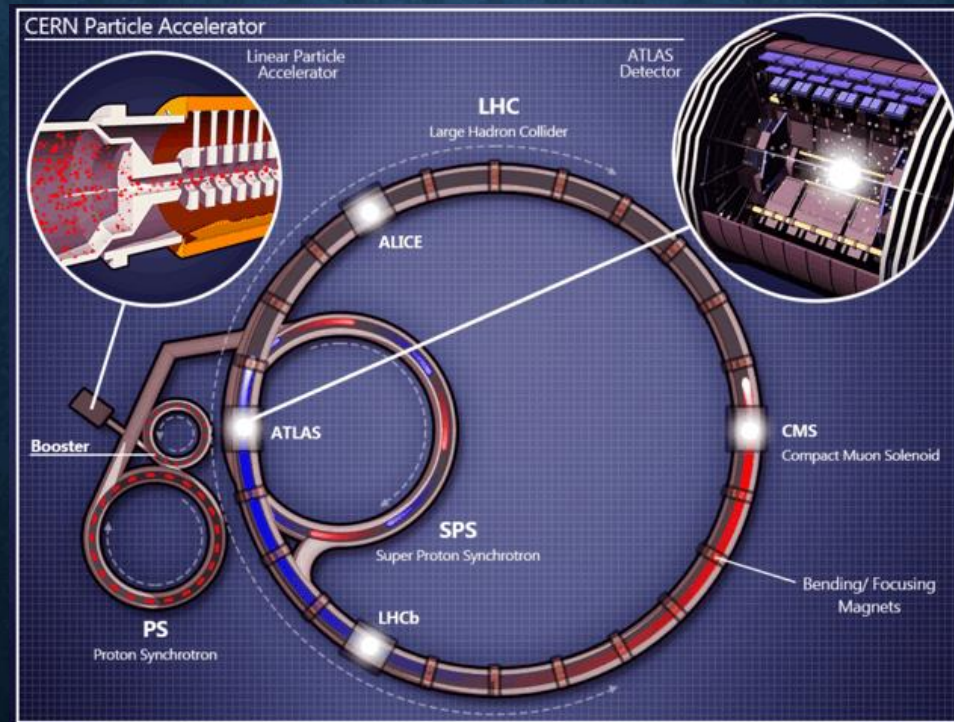
- Beam Injection
- Control
- Monitoring
- Feedback

LHC Beam  
Control

Collision Data  
Acquisition

Simulation

Data  
Processing &  
Storage





# KEY IDEAS – SIMULATION AND DATA SELECTION

- Simulation (Monte Carlo data)

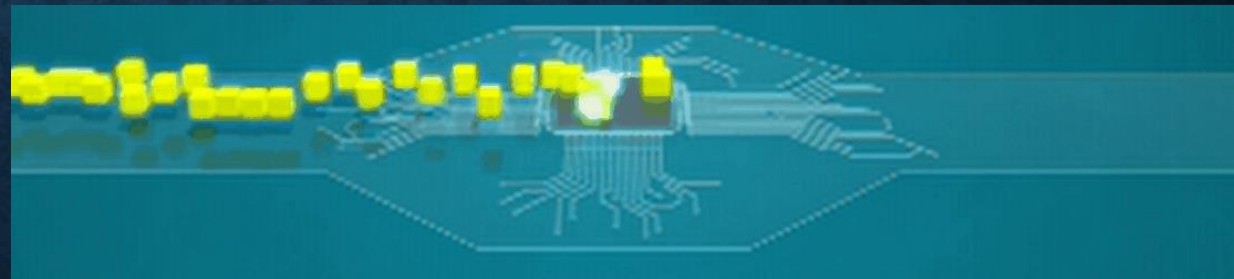
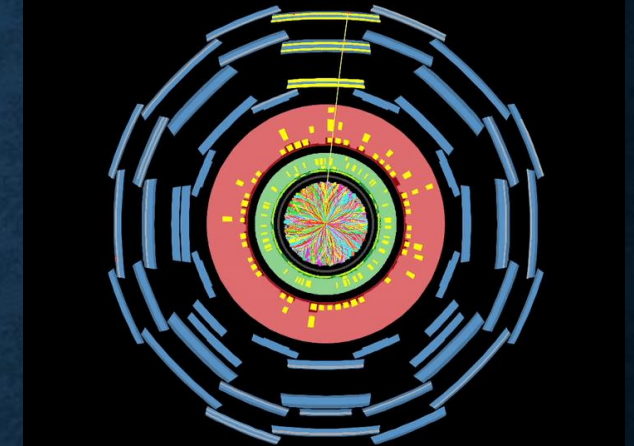
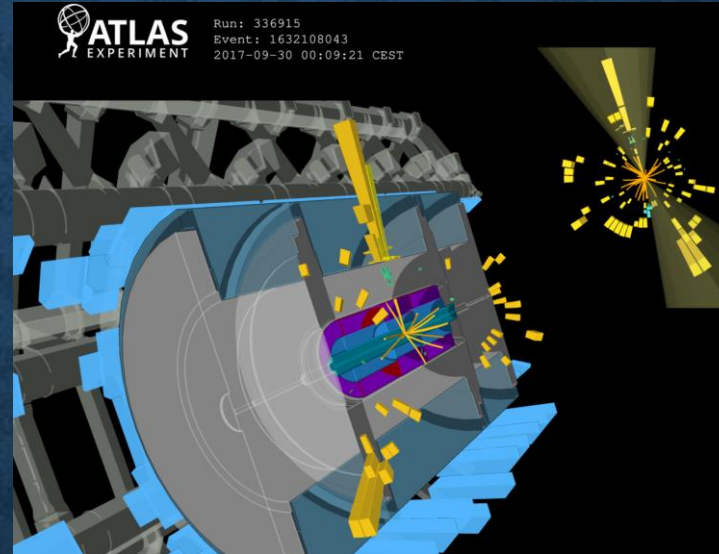
- Event generation
- Detector simulation
- Digitisation
- Reconstruction

- Data Selection

- Triggering
- “From hit to bit”

- The Future

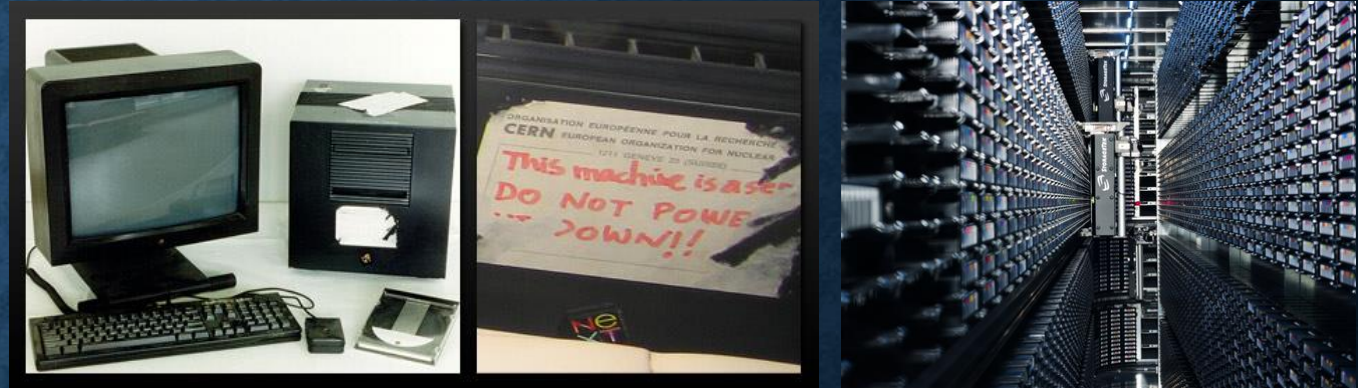
- Programmable FPGAs
- Quantum Computing (?)
- AI for data selection (the future)





# KEY IDEAS - DATA PROCESSING AND STORAGE

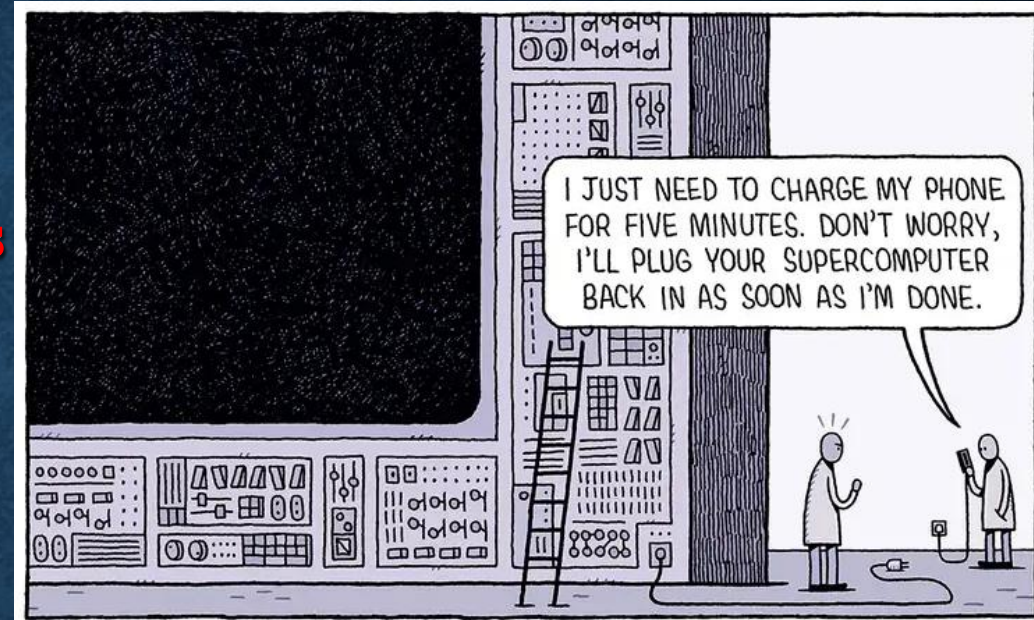
- History (creation of WWW)
- Funnelling to data centre (10Gb/s)
- Data storage
- Data Grid Processing
- Future
  - Bandwidth Solutions
  - Storage Solutions



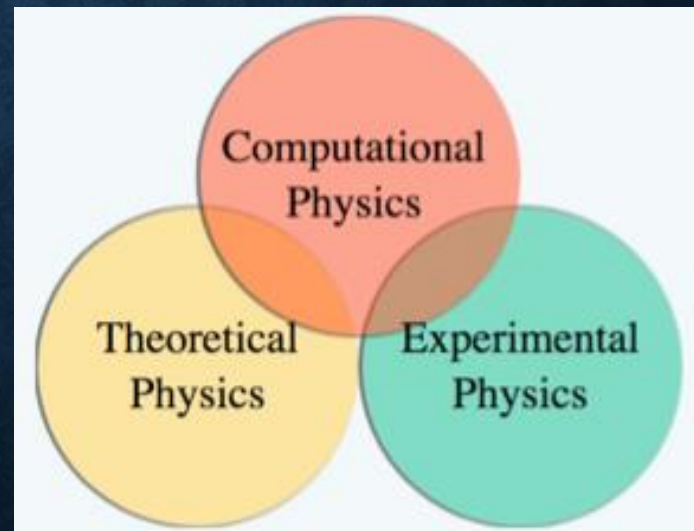


# POTENTIAL STUDENTS' CONCEPTIONS

- CERN needs supercomputers
- Have to be **really** good at physics, mathematics and/or programming to work in data analysis for CERN --> motivated though! :-)
- Only for boys
- Too complicated for regular students
- It has no relevance to our daily lives
- Difficult to deal with the errors
- Possibly not an engaging topic for some



TOM GAULD for NEW SCIENTIST





# POTENTIAL CHALLENGES

- Learning specific mathematical, physics, and/or computational skills
- Doing a Citizen Science type project
- Building a supercomputer with video processing chips from game computers

But...

...you could start with some easy calculations, so they get a feel for the amount of data produced at CERN!

*Just for position data with one detector you get: ~100 M channels: 27+ bits, every particle hits ~15 channels, ~500 particles per collision, and with 40 M collisions per second we get ~8,100,000 Mbps!*

*100 out of 40 M collisions, four detectors, ~300 days of operation per year: 300 Tb!*



# HELPFUL MATERIAL AND RESOURCES

- <https://op-webtools.web.cern.ch/vistar/vistars.php?usr=LIN>
- [https://scoollab.web.cern.ch/sites/default/files/Particle\\_v2/index.html](https://scoollab.web.cern.ch/sites/default/files/Particle_v2/index.html)



### Including "Masterclasses" – fully web-based

**CMS e-Lab**

High school students use cutting-edge tools to do scientific investigations.

At CERN near Geneva, Switzerland, the Large Hadron Collider (LHC) collides protons at the highest energies ever achieved in the laboratory to reveal new knowledge about matter and energy. Giant detectors make spatial measurements from the collisions. One of these detectors is CMS, the Compact Muon Solenoid.

Physicists working on CMS and its sister detector, ATLAS, first calibrated their experiments by rediscovering the particles of the Standard Model. They added to that picture in 2012 with the discovery of the Higgs boson, the long sought key to understanding the masses of fundamental particles. Yet physicists know that the Standard Model does not explain everything. The search for new physics continues beyond the Standard Model.

CMS e-Lab Student Home provides a guide with resources to create a research project, access to authentic CMS data and analysis tools for conducting their research, and steps to collaborate. The Teacher Home has learner objectives, assessment rubrics, manifests, management tools, and more.

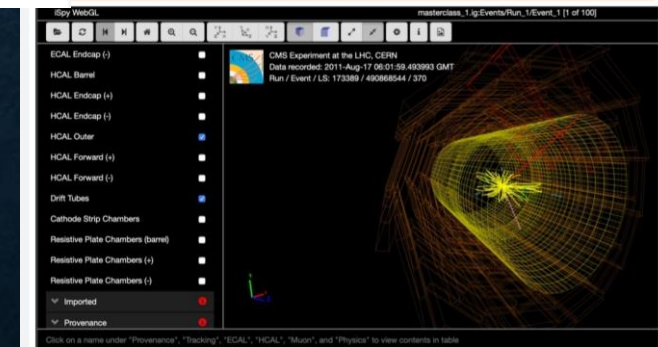
Join our learning community built around the CMS e-Lab and the QuarkNet CMS data thread as we probe the physics uncovered by CMS. What are the elementary constituents of matter? What are the fundamental forces that control their behavior at the most basic level?

Information common for all e-Labs  
Check out our online resources

http://www.i2u2.org/elab/cms/home/project.jsp

### Including "Masterclasses" – fully web-based

Understanding the structure of the proton (spoiler: it is NOT uudd!) just by looking at images!



<http://www.i2u2.org/elab/cms/ispy-webgl/>



# HELPFUL MATERIAL AND RESOURCES

- <http://opendata.cern.ch>
- <https://opendata-education.github.io>



And **you** can make measurements with CMS data!

**CMS OPEN DATA**  
Visualise particle collisions, play with high-level data, and build your own analysis tools

<http://opendata.cern.ch/docs/about-cms>

<https://cms.cern/interact-with-cms>

opendata

About CMS

The Compact Muon Solenoid (CMS) Experiment is one of the large particle detectors at CERN's Large Hadron Collider. The CMS Collaboration consists of more than 3000 scientists, engineers, technicians and students from 180+ institutes and universities from 40+ countries. You can find more information about the CMS detector design and software on the official CMS website.

You can find usage instructions and suggestions of CMS Open Data in two detailed guides:

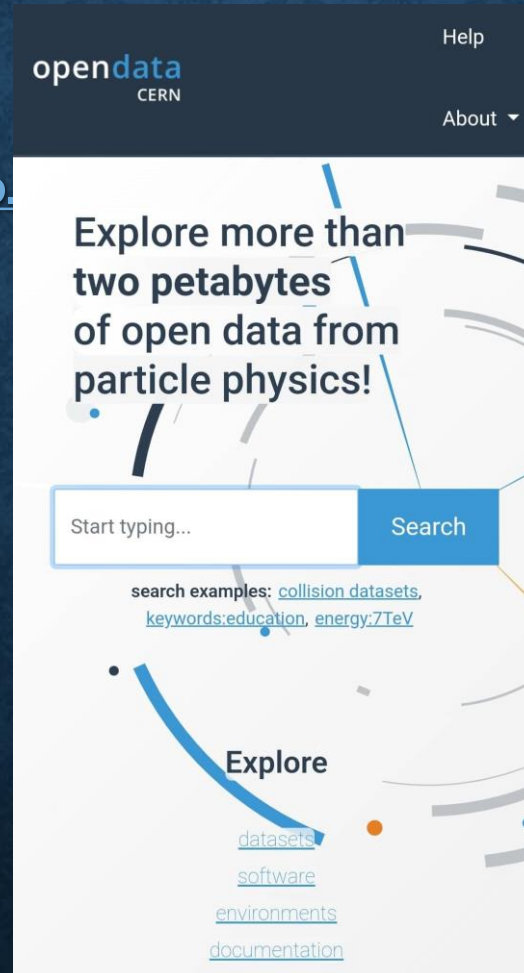
- Guide to education use of CMS Open Data
- Guide to research use of CMS Open Data

The page gives a brief overview of CMS Open Data contents:

1. CMS Data and analysis tools
2. Primary and simulated datasets
3. Datasets
4. Other CMS open data
5. Physics

**CMS Data and analysis tools**  
The following are provided through this portal:

- **Reconstructed datasets**
  - Primary datasets: full reconstructed collision data with no other selections. The data here are referred to as "reconstructed data". Reconstructed data from various sub-detectors are processed or "reconstructed" to provide coherent information about individual physics objects such as electrons or particle jets.
  - Simulation data (for data starting from 2011)
  - Examples of simulated datasets derived from the primary ones for use in different applications and analysis
- **Tools**
  - A downloadable Virtual Machine (VM) image with the CMS software environment through which the datasets can be accessed
  - An analysis example chain, reading the primary dataset and producing information derived data for the final analysis
  - Ready-to-use online applications, each as an online shape and simple programming software
  - Source code for the various examples and applications, available in the CMS software collection



opendata  
CERN

Help

About ▾

Explore more than two petabytes of open data from particle physics!

Start typing... Search

search examples: [collision datasets](#), [keywords:education](#), [energy:7TeV](#)

Explore

- [datasets](#)
- [software](#)
- [environments](#)
- [documentation](#)

## Open data in education

Materials

Open data ▾

Jupyter Notebook environment ▾

Making your own material ▾

Participate in development work

 Materials on GitHub

 YouTube channel



## Welcome to open data!

This is a collection of exercises that use open authentic data suitable for high school education to get familiar with programming and data processing. Interactive Jupyter Notebooks are used as the learning