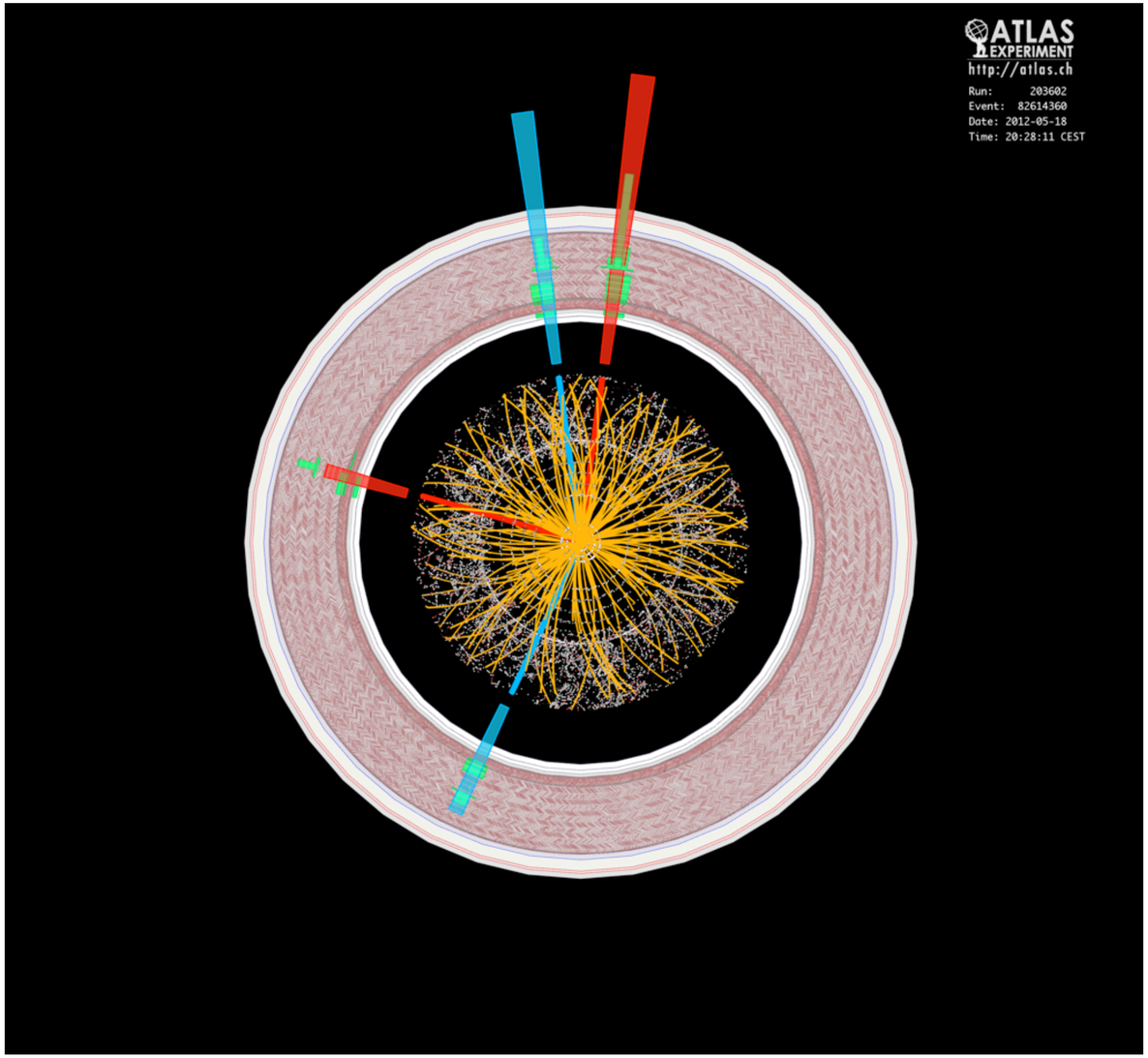

Big Bang, Big Data & Big Science

Andreas Salzburger  @SaltyBurger

Why listen to me?

Illustration:
B. KUSSIN

universität innsbruck

CERN

DESY.

CERN

2003
study of physics,
comparative literature

2003-2008
PhD @ CERN
University of Innsbruck

2008-2009
post-doc
Deutsches Elektronen
Synchrotron (Zeuthen)

2009-now
Marie Curie Fellow,
CERN Staff
CERN Senior Staff

Don't believe just because someone has a "title"

(argument by authority is never a good argument in my mind)

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2003

study of physics,
comparative literature

CERN

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CERN

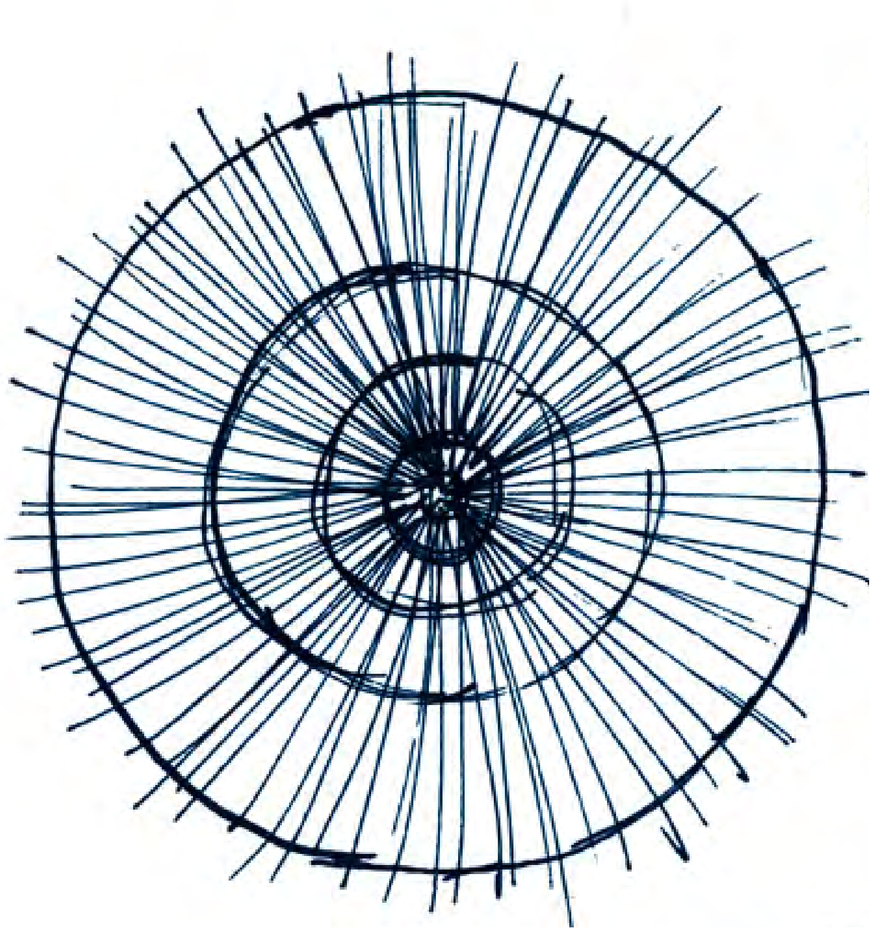
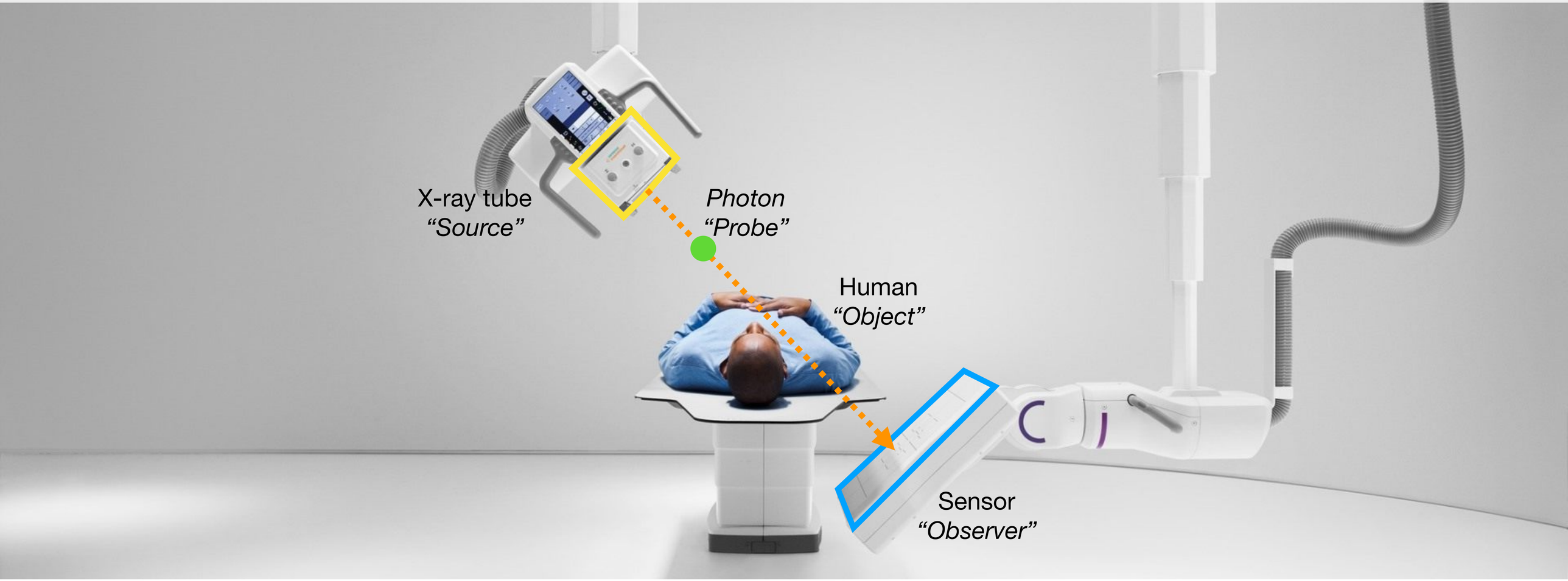


Illustration:
B. KUSSIN

A daily observation

[Image source]

A good microscope



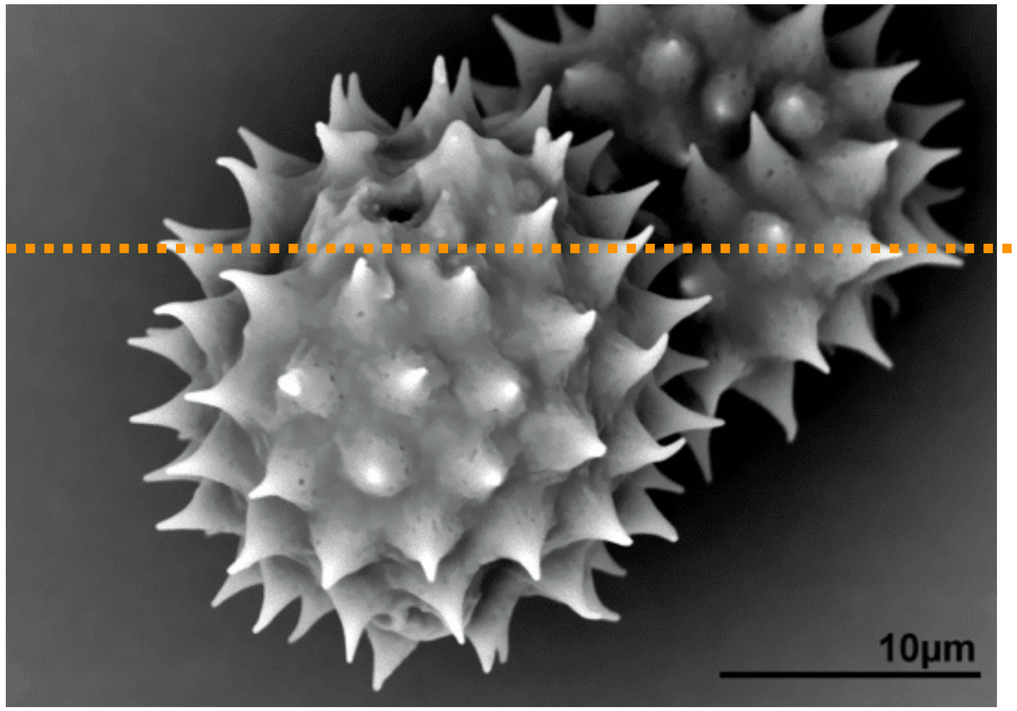
[Image Source: your own webpgage]

A very good microscope

Electron microscope Siemens, 1943

Cathode
“Source”

Electron
“Probe”

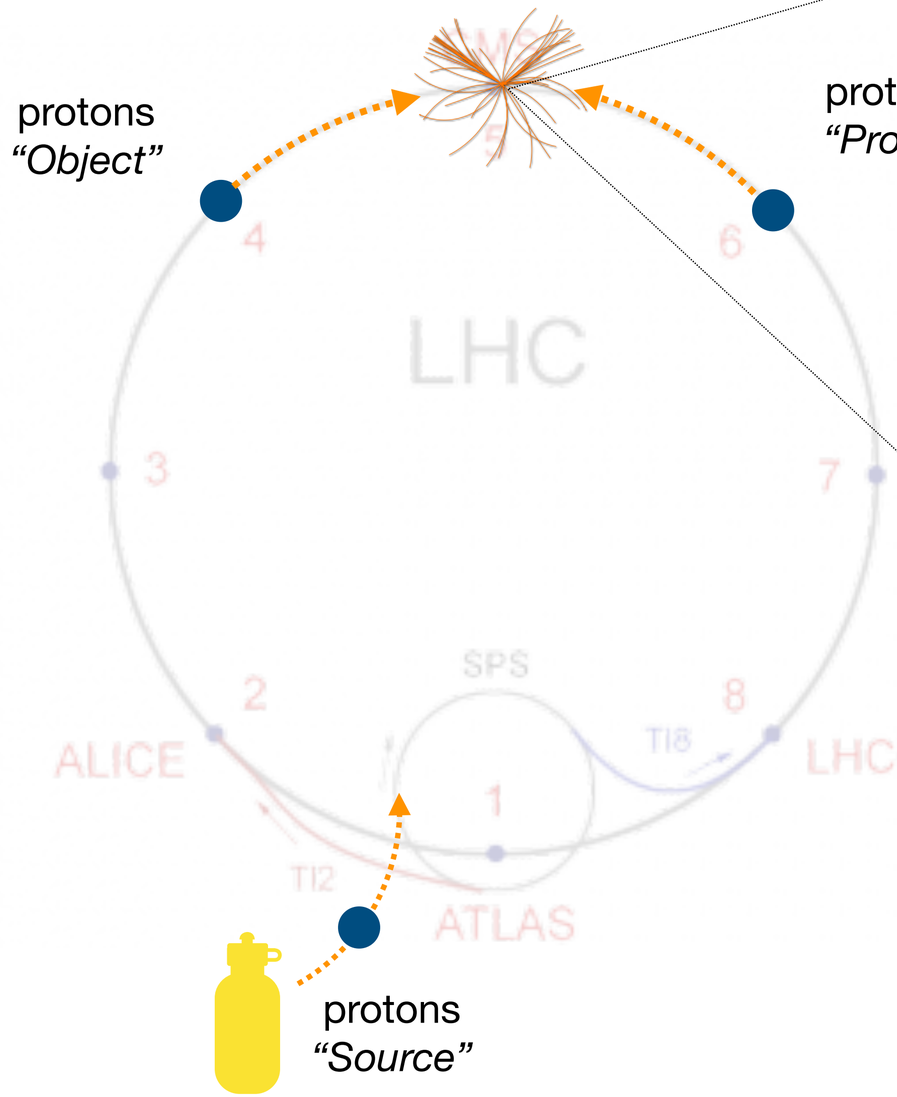


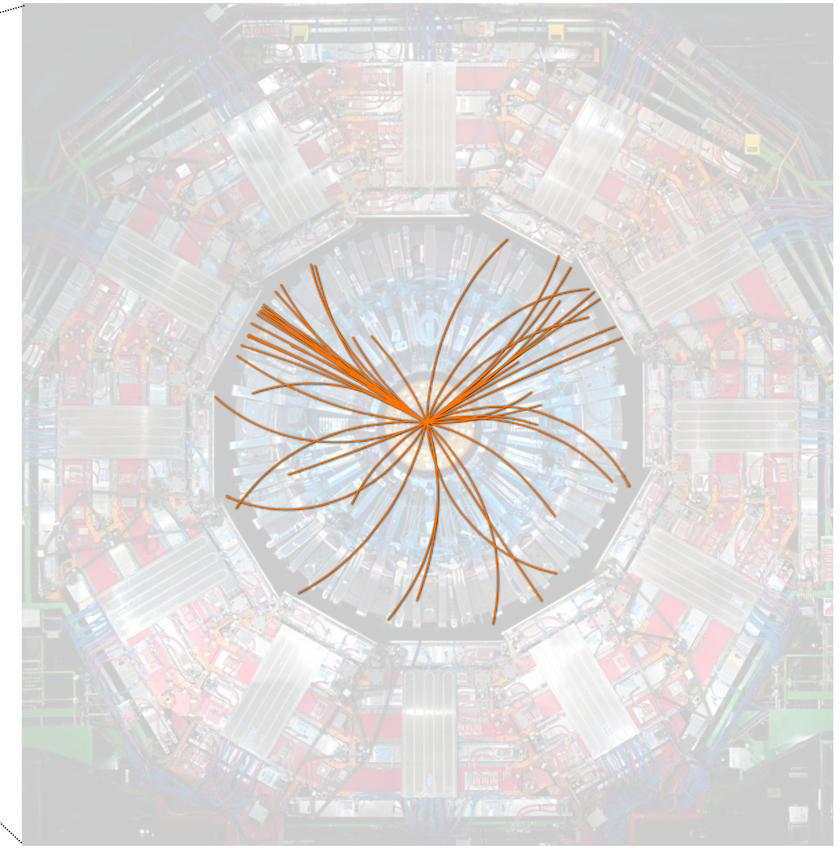
Pollen
“Object”

Detector
“Observer”

[Image source: EM]
[Image source: Pollen]

A very large microscope

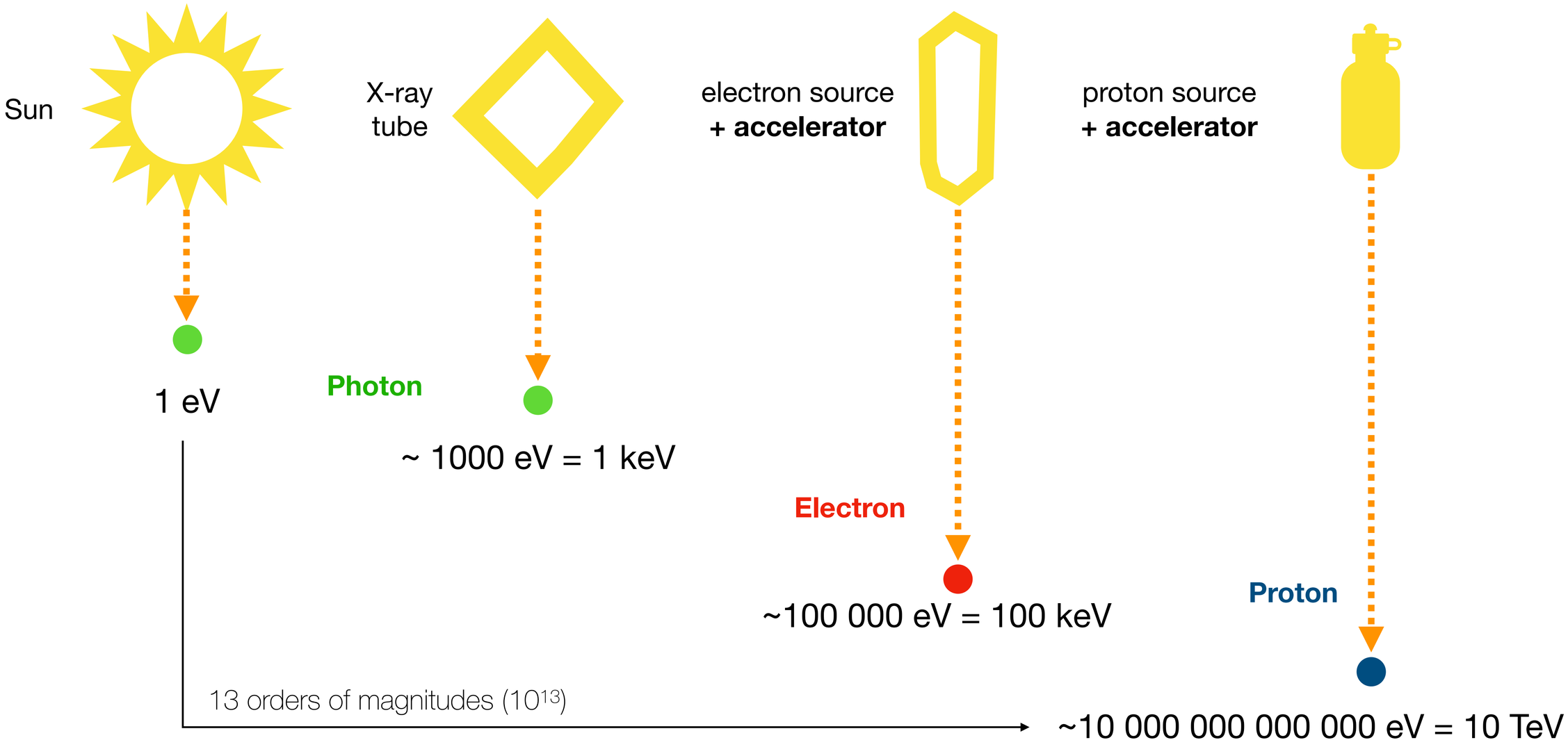




Detector
“Observer”

[Image source]

You see what you get



You get what you see

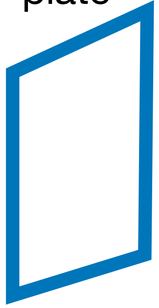
1 eV Photon

eye

1 keV Photon

photo plate

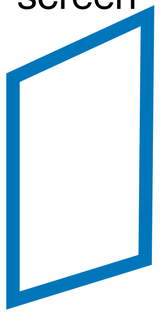
low energy sensor

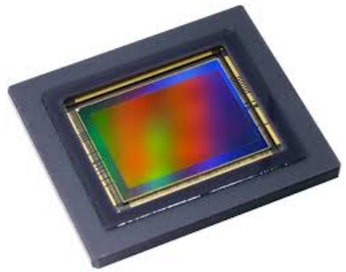


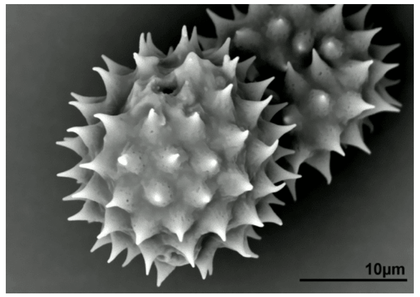
100 keV Electron

fluorescent screen

electron detector

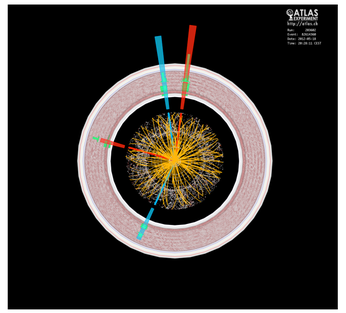


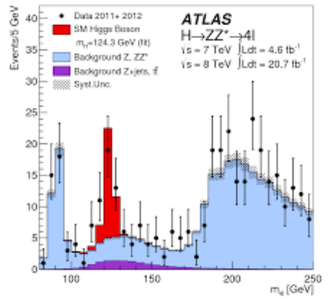




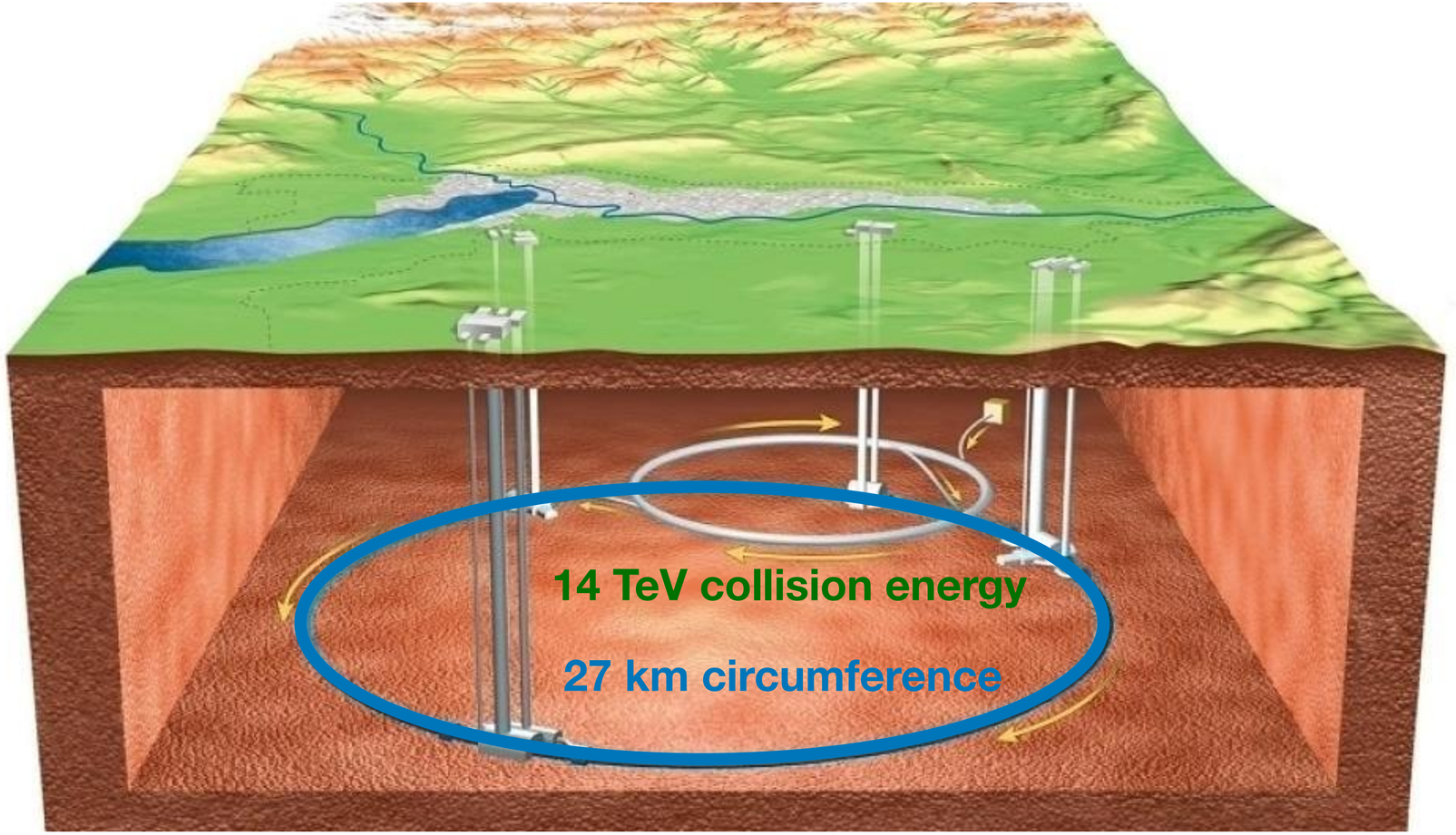
10 TeV Proton

particle detector





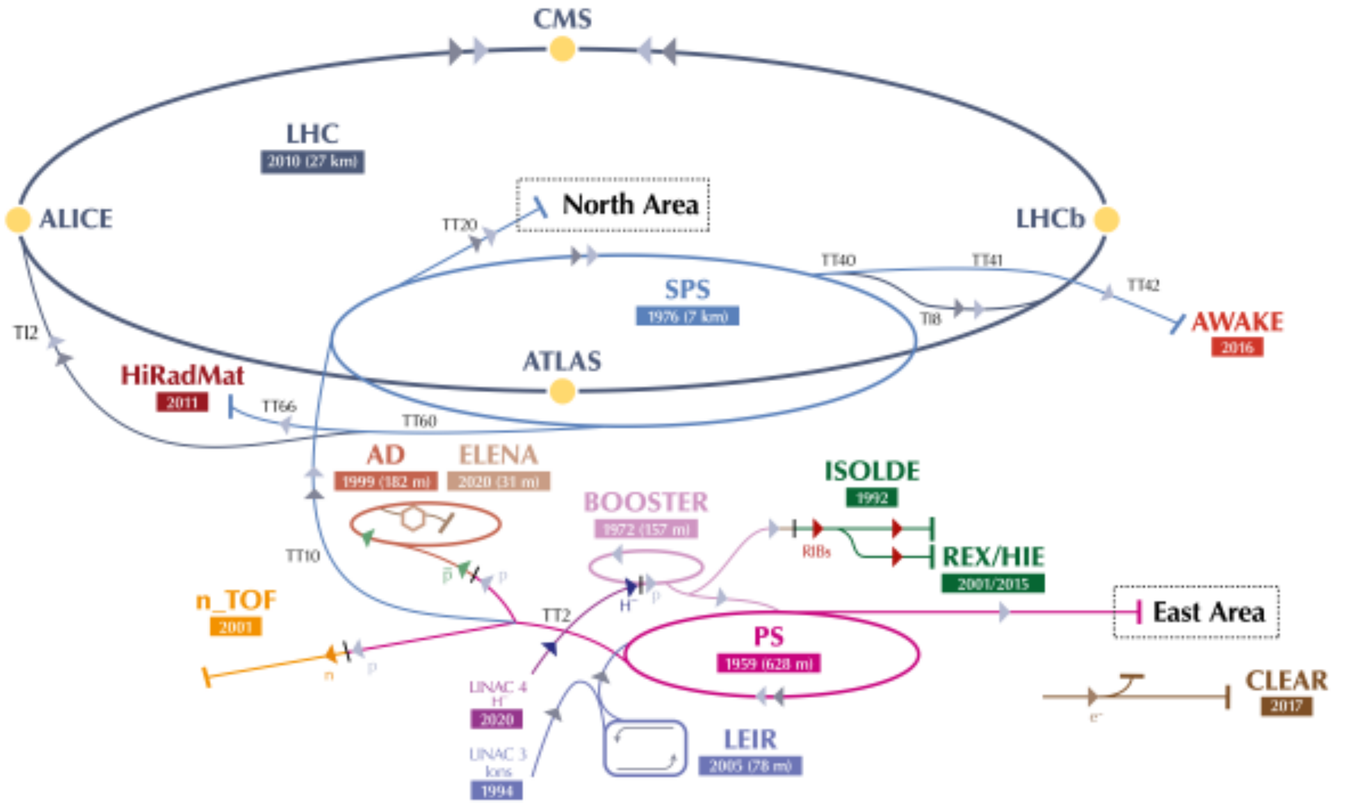
Our source: **L**arge **H**adron **C**ollider



100 m underground

40 millions/sec collision frequency

LHC accelerator

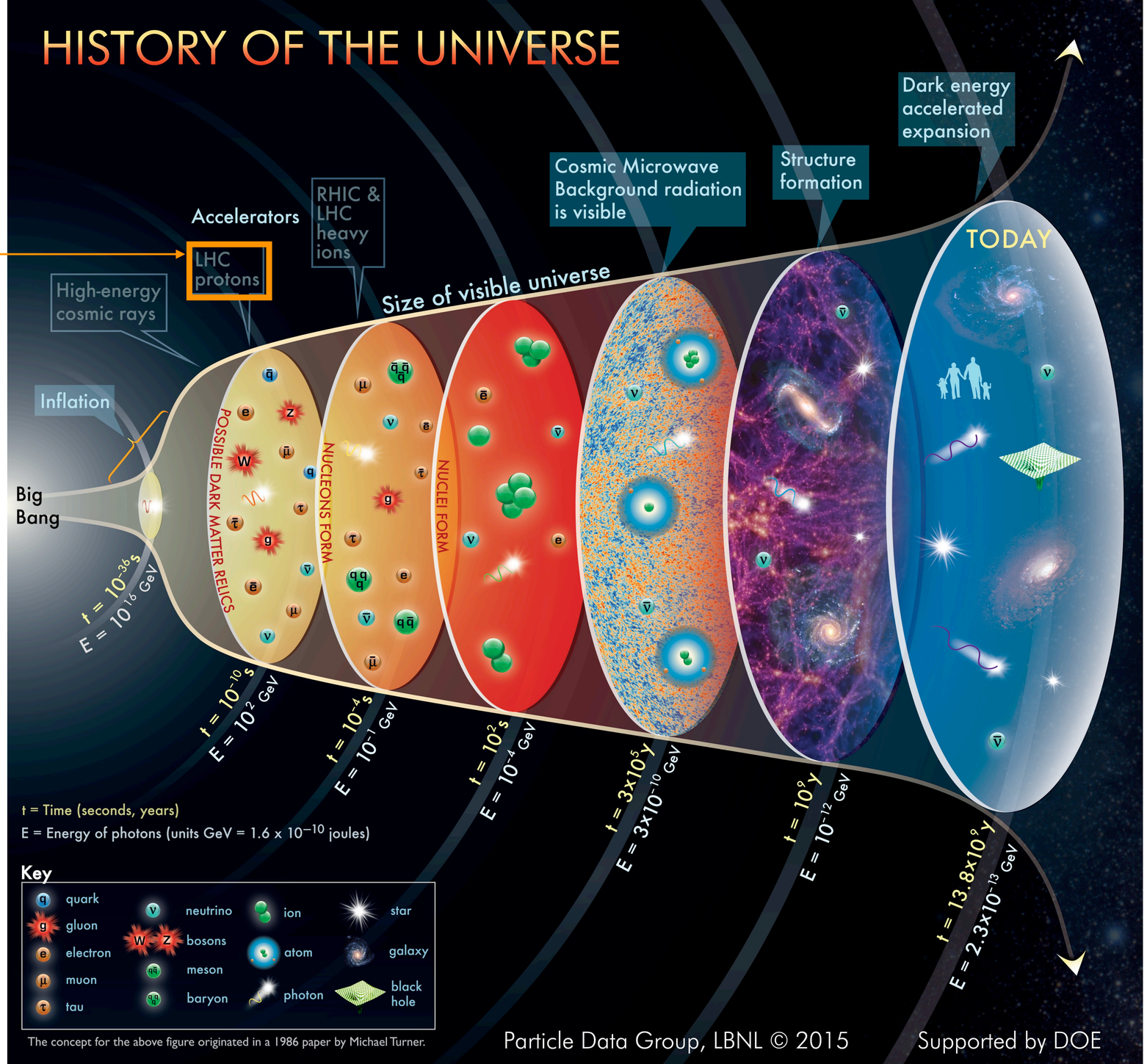


LHC - Large Hadron Collider // SPS - Super Proton Synchrotron // PS - Proton Synchrotron // AD - Antiproton Decelerator // CLEAR - CERN Linear Electron Accelerator for Research // AWAKE - Advanced WAKefield Experiment // ISOLDE - Isotope Separator OnLine // REX/HIE - Radioactive EXperiment/High Intensity and Energy ISOLDE // LEIR - Low Energy Ion Ring // LINAC - LINear ACcelerator // n_TOF - Neutrons Time Of Flight // HiRadMat - High-Radiation to Materials

Reach

allows us to investigate universe at an age of

10^{-10} s = 0.0000000001 s



…, but why ?

… to test this

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

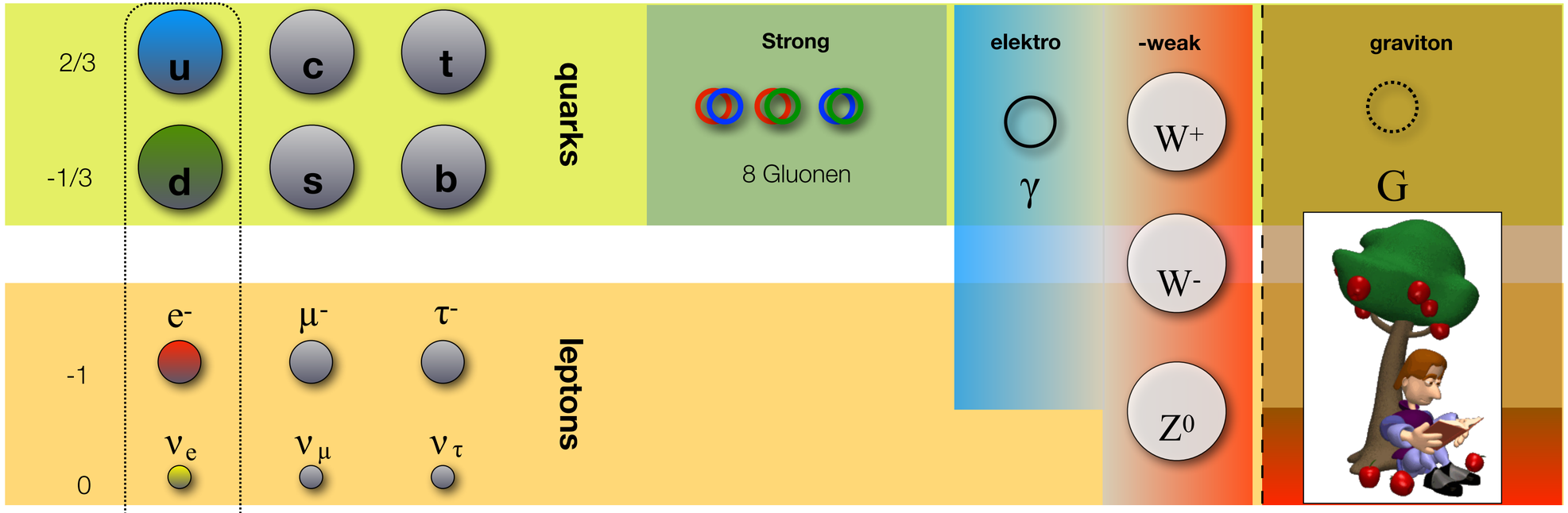
$$+ i \bar{\Psi} \not{D} \Psi + h.c.$$

$$+ \bar{\Psi}_i y_{ij} \Psi_j \phi + h.c.$$

$$+ |D_\mu \phi|^2 - V(\phi)$$

[Image Source]

Particles and mediators

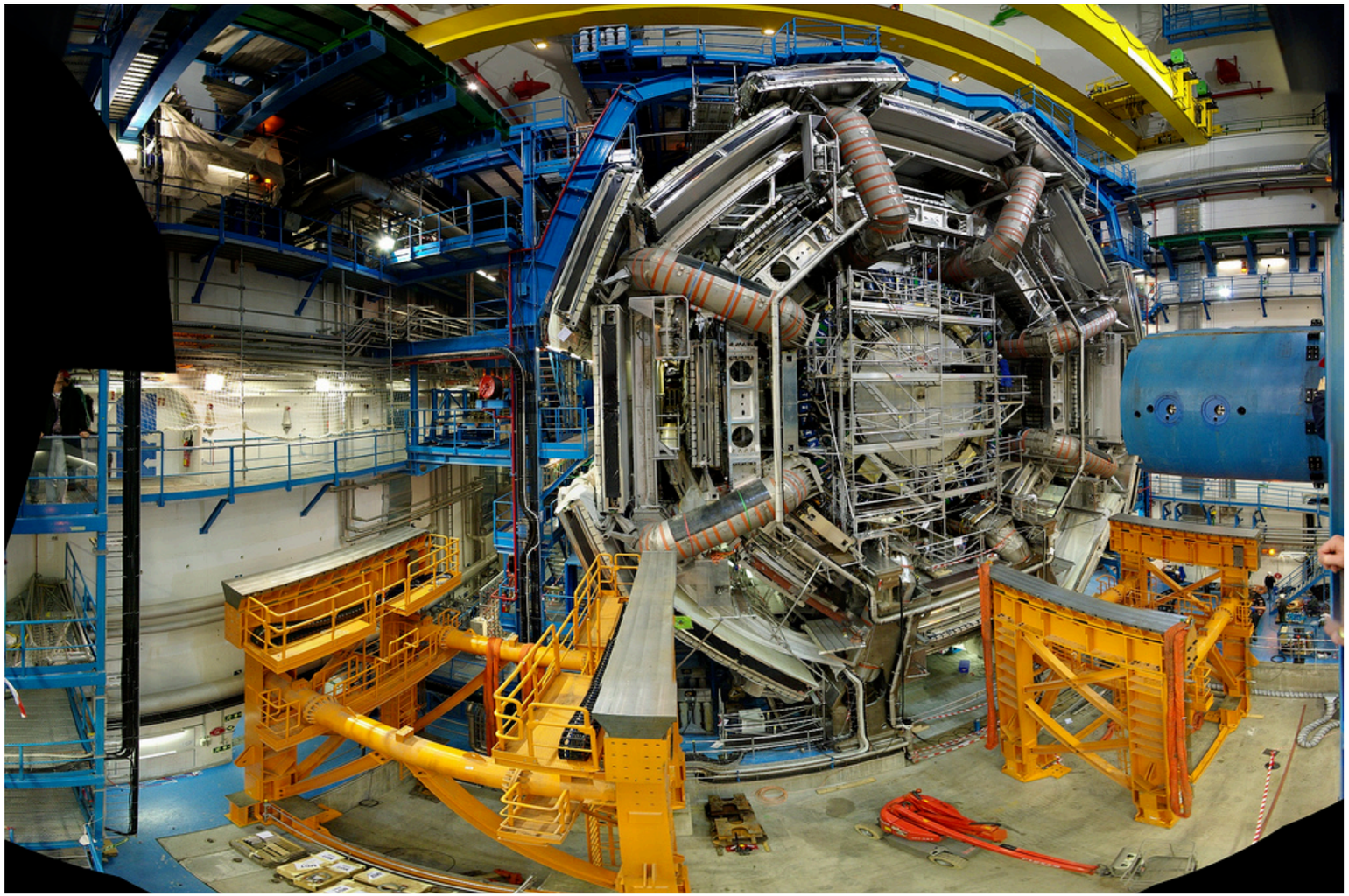


Fermions

Bosons

+ Higgs particle

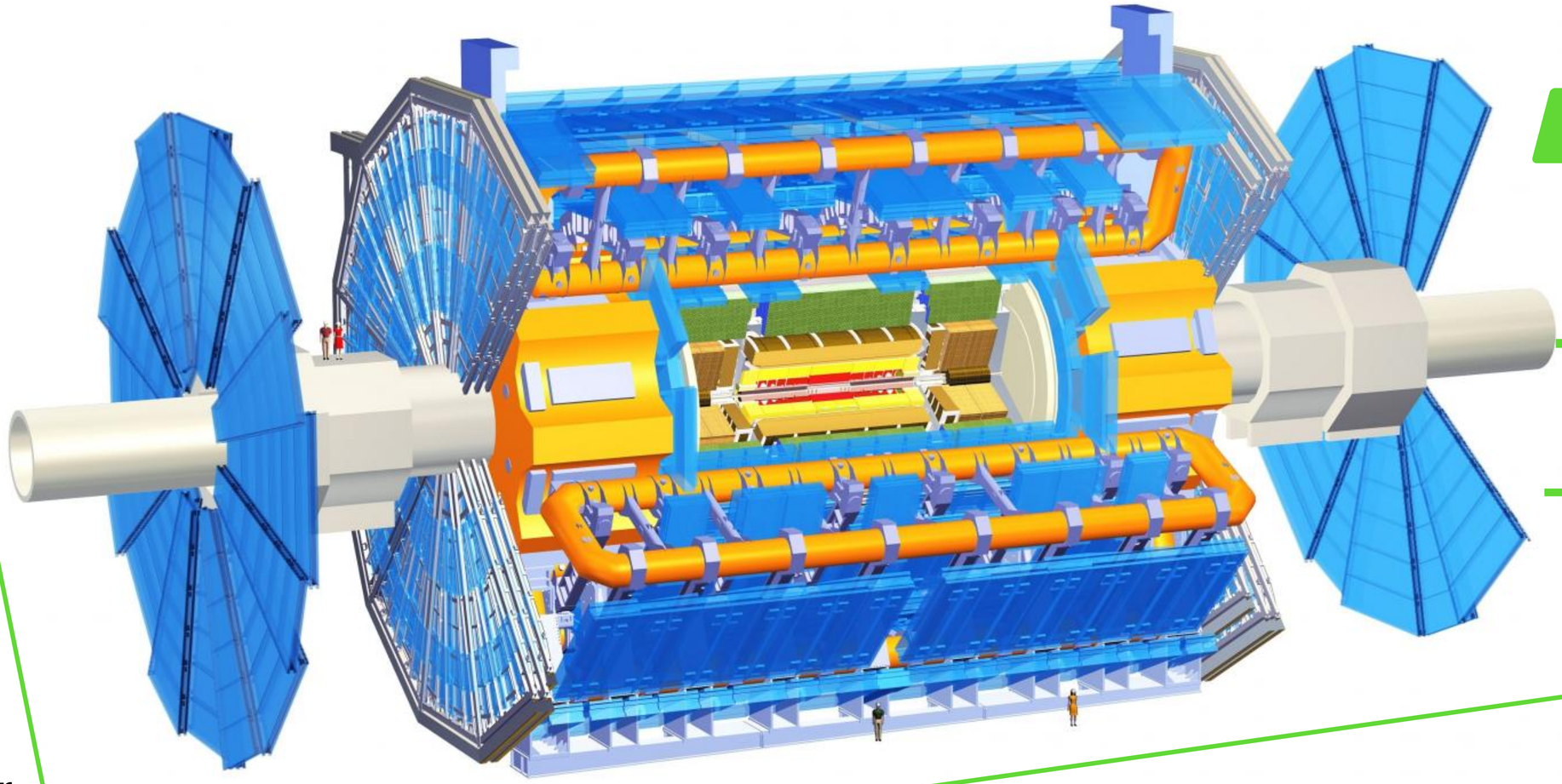
The observer: **A** **T**oroidal **L**HC **A**pparatu**S**



Question:

What's the object?

The **A** **T**oroidal **L**HC **A**pparatu**S**



7000 tons weight

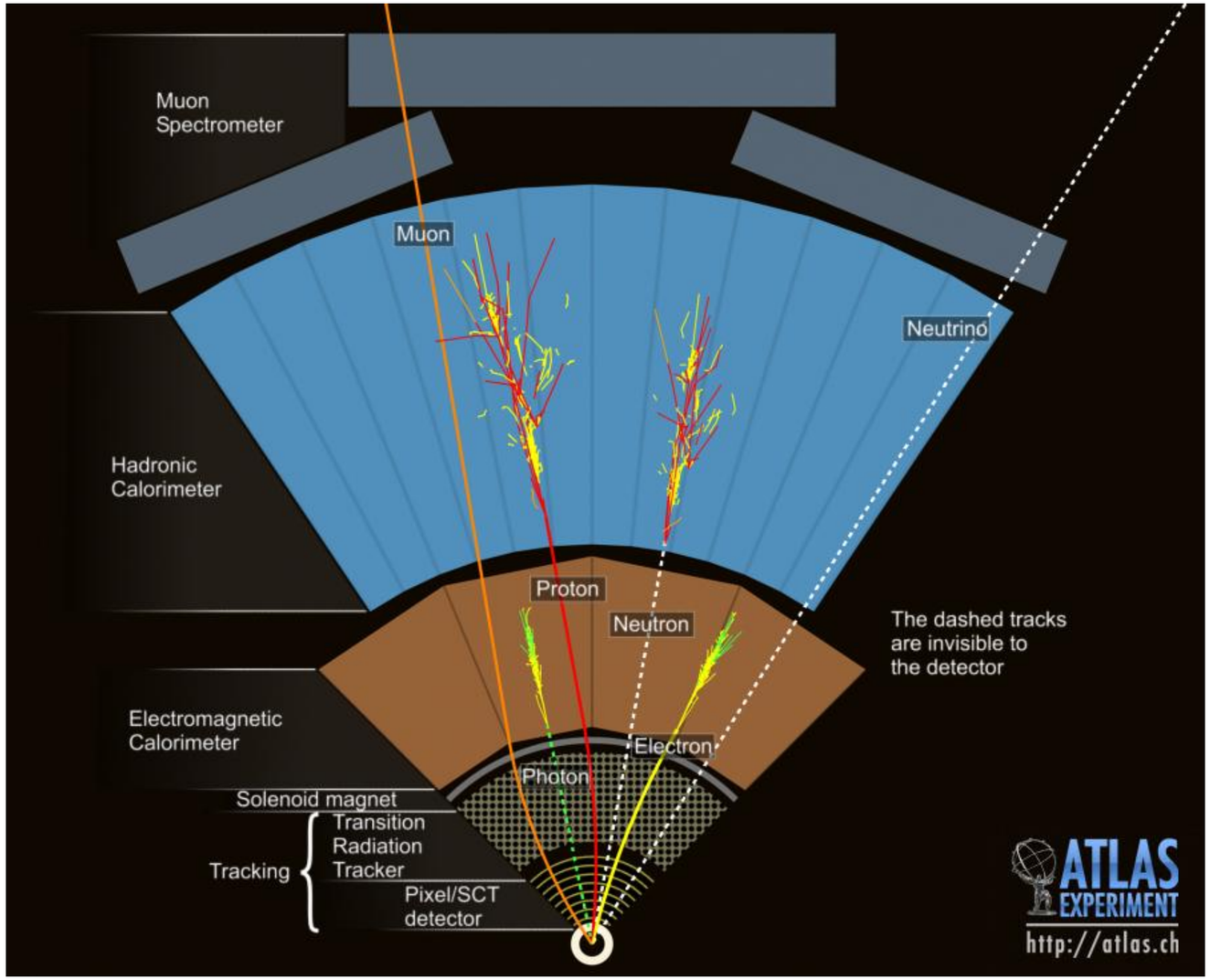
3000 km cables

100 million readout channels

25 m diameter

40 m long

Principles of a **Particle Detector**



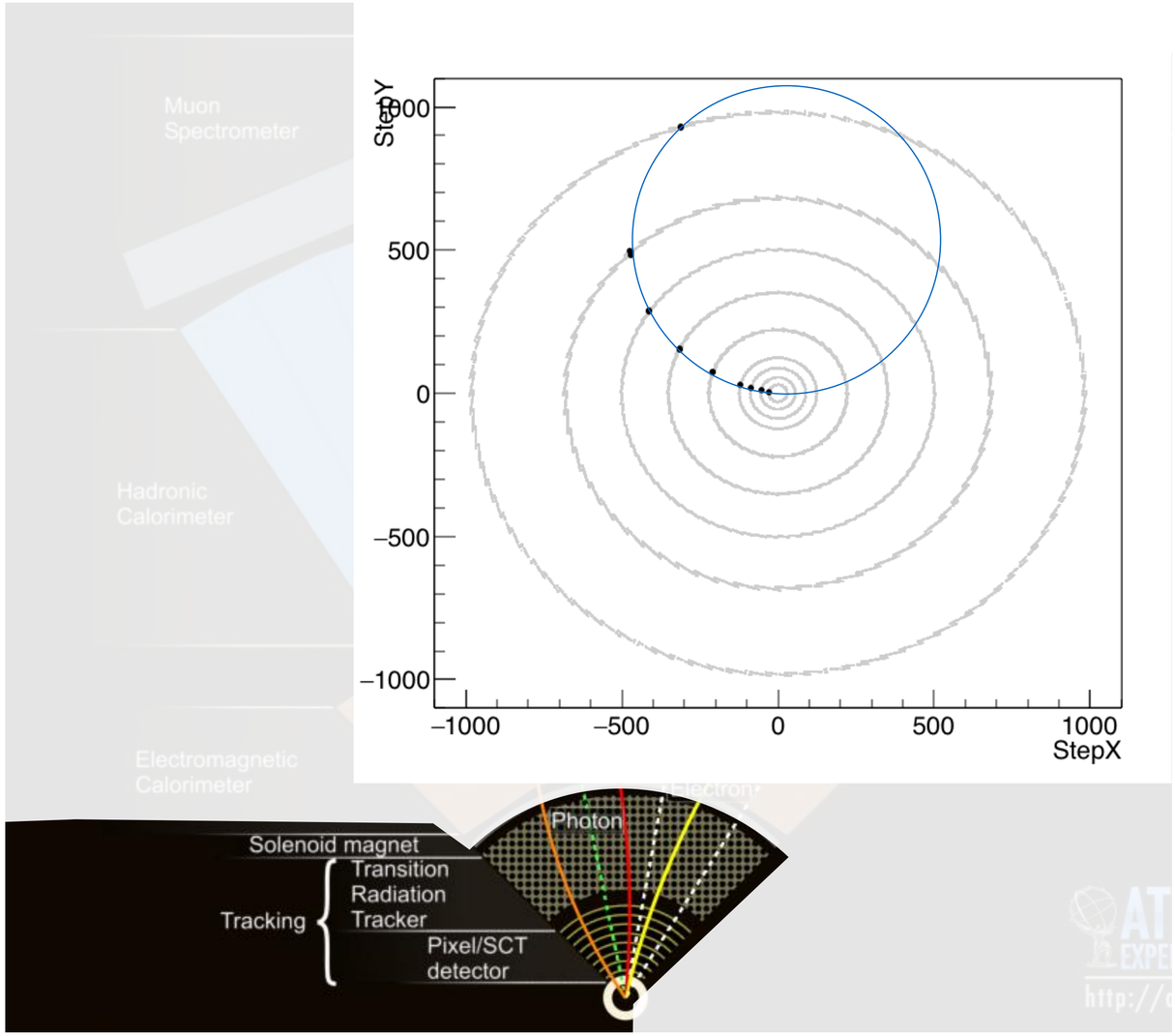
We want to

Identify Particles

Estimate their kinematics

Principles of a **Particle Detector**

Inner Tracker

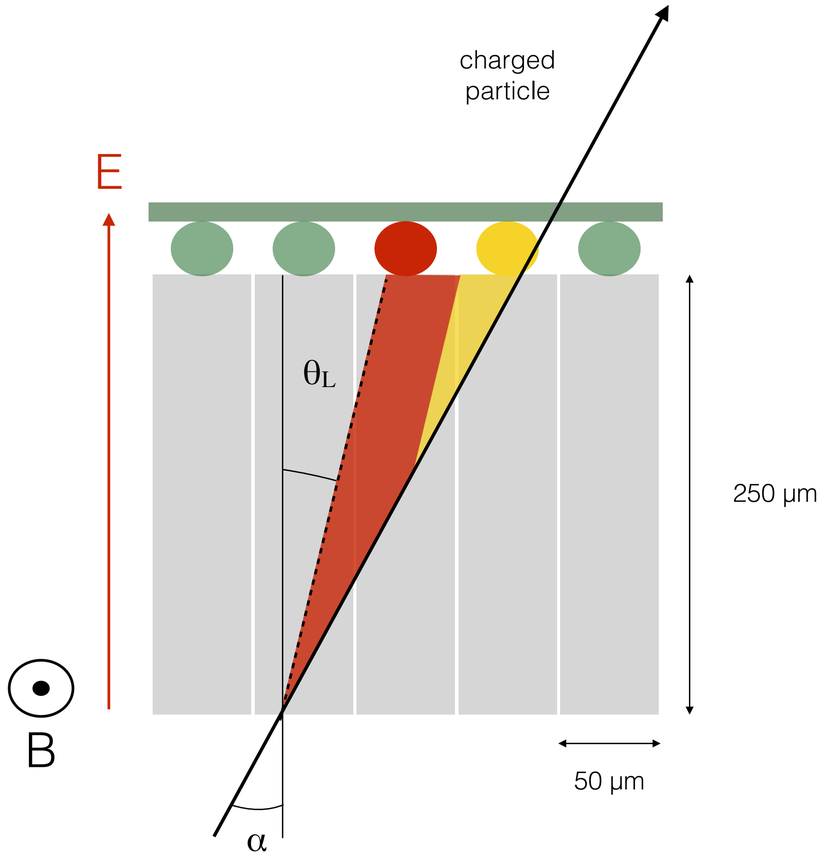


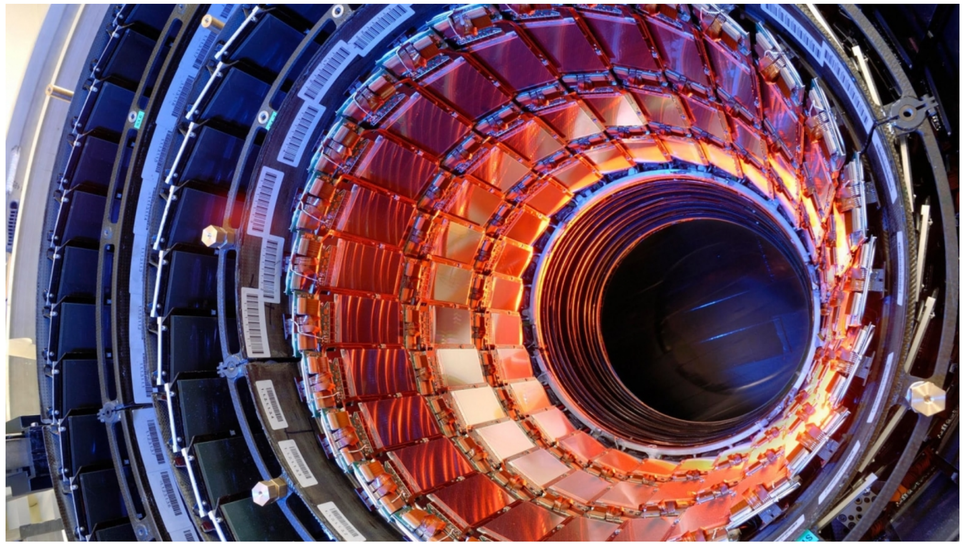
We need

Complicated pattern recognition algorithms to resolve this

Principles of a **Particle Detector**

Inner Tracker

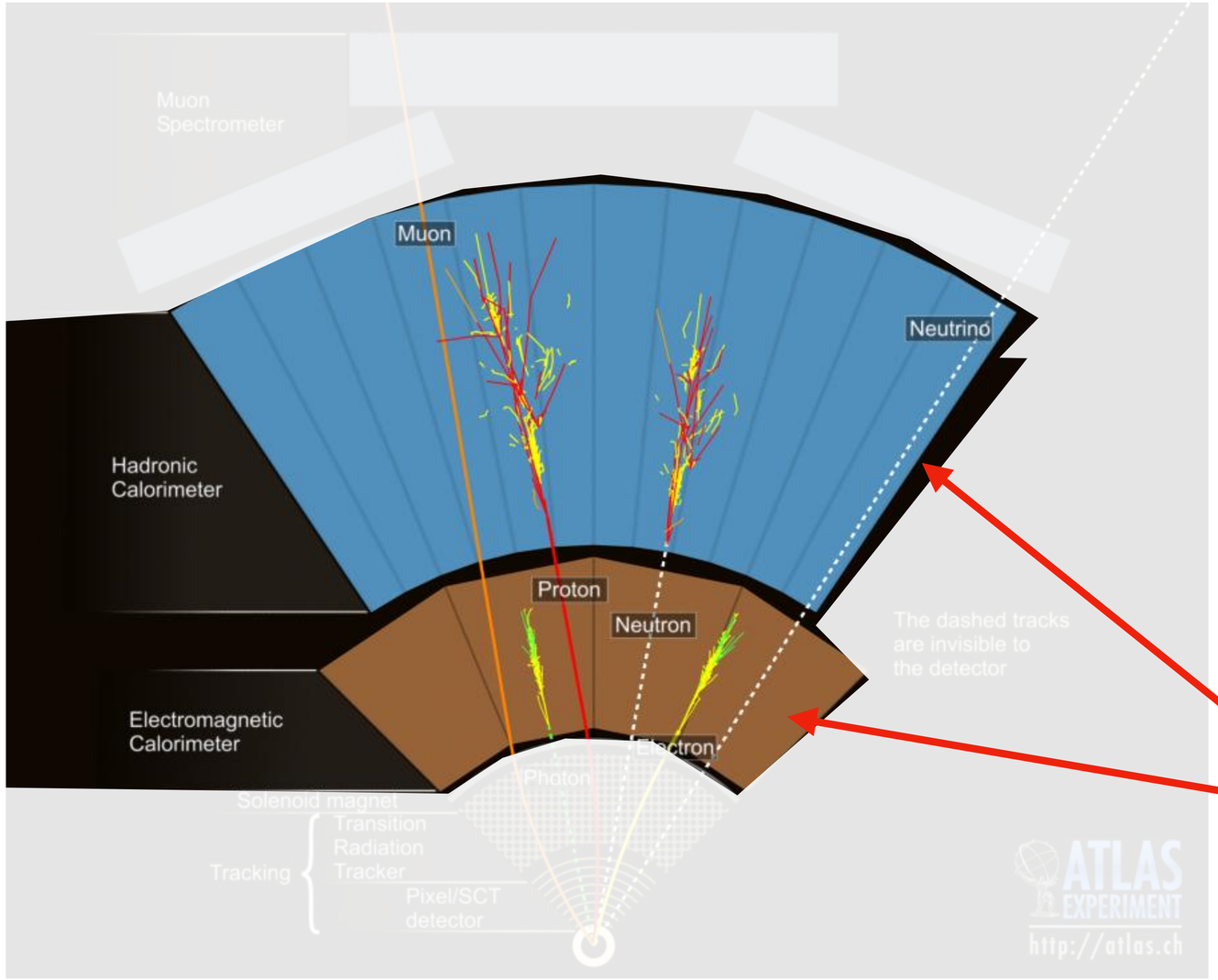




Most commonly semiconductor based detectors

Principles of a **Particle Detector**

Calorimeter



We want to

stop **all** particles
& measure their energy
& identify them

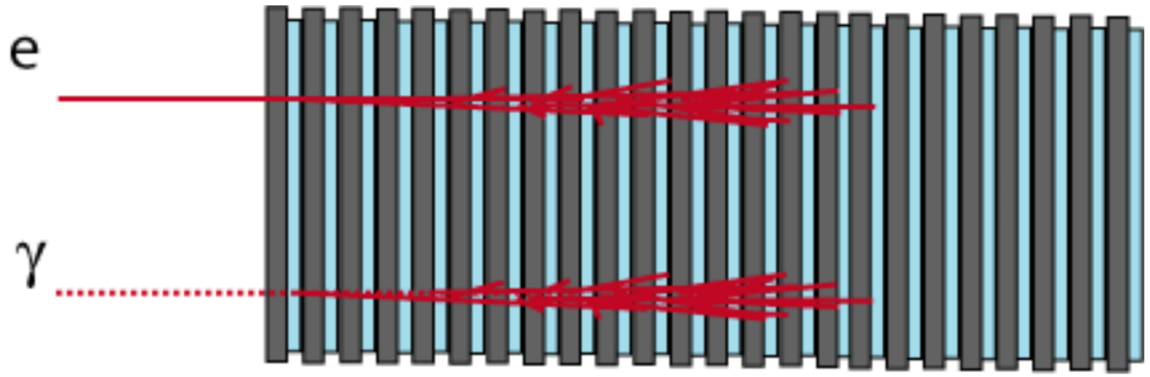
Electromagnetic calorimeter

Hadronic calorimeter

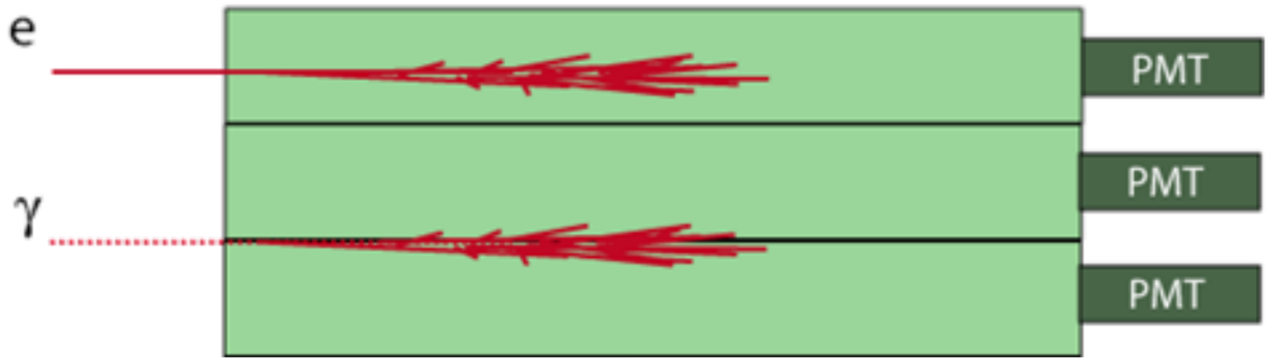
Principles of a **Particle Detector**

Calorimeter

Technology A

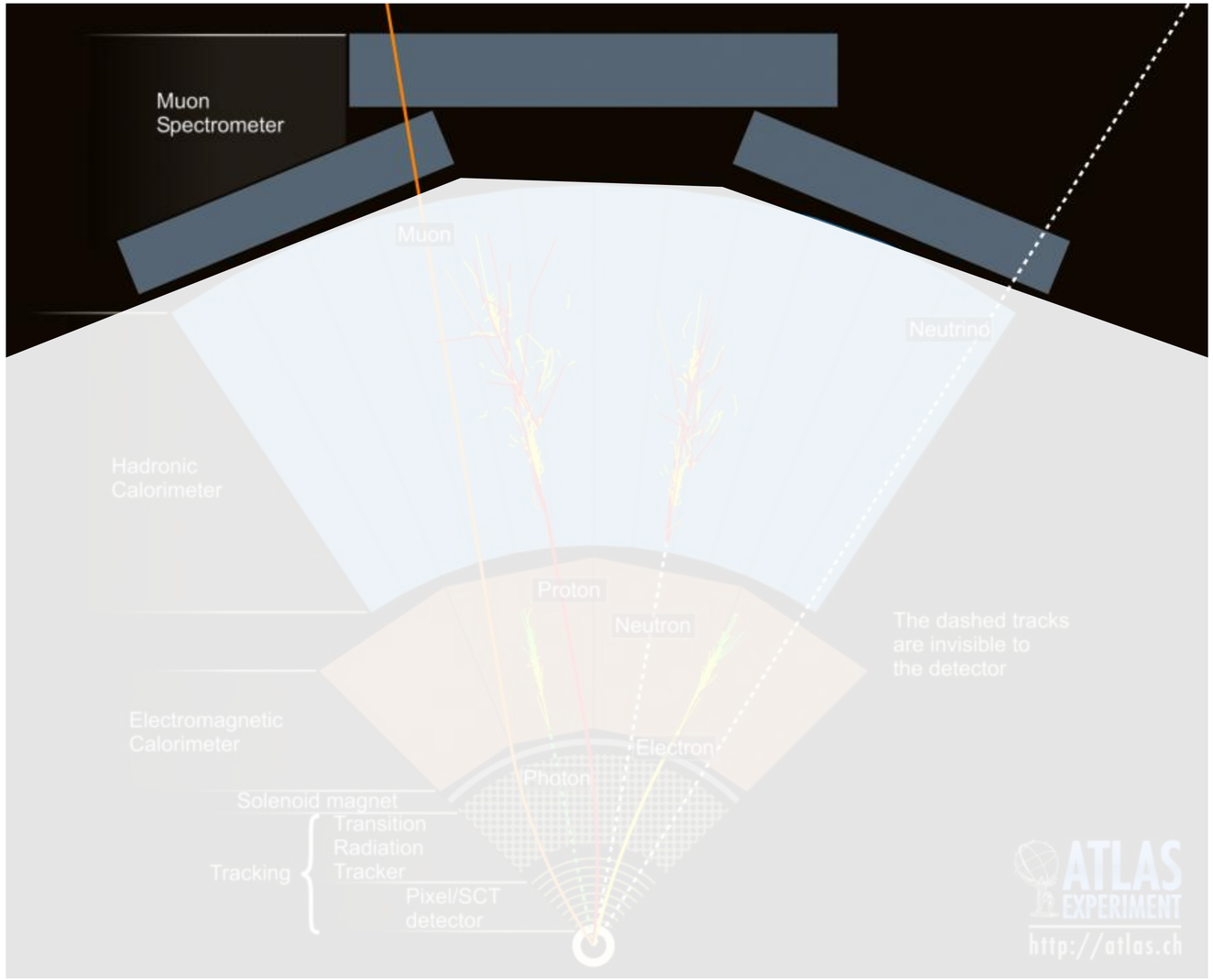


Technology B



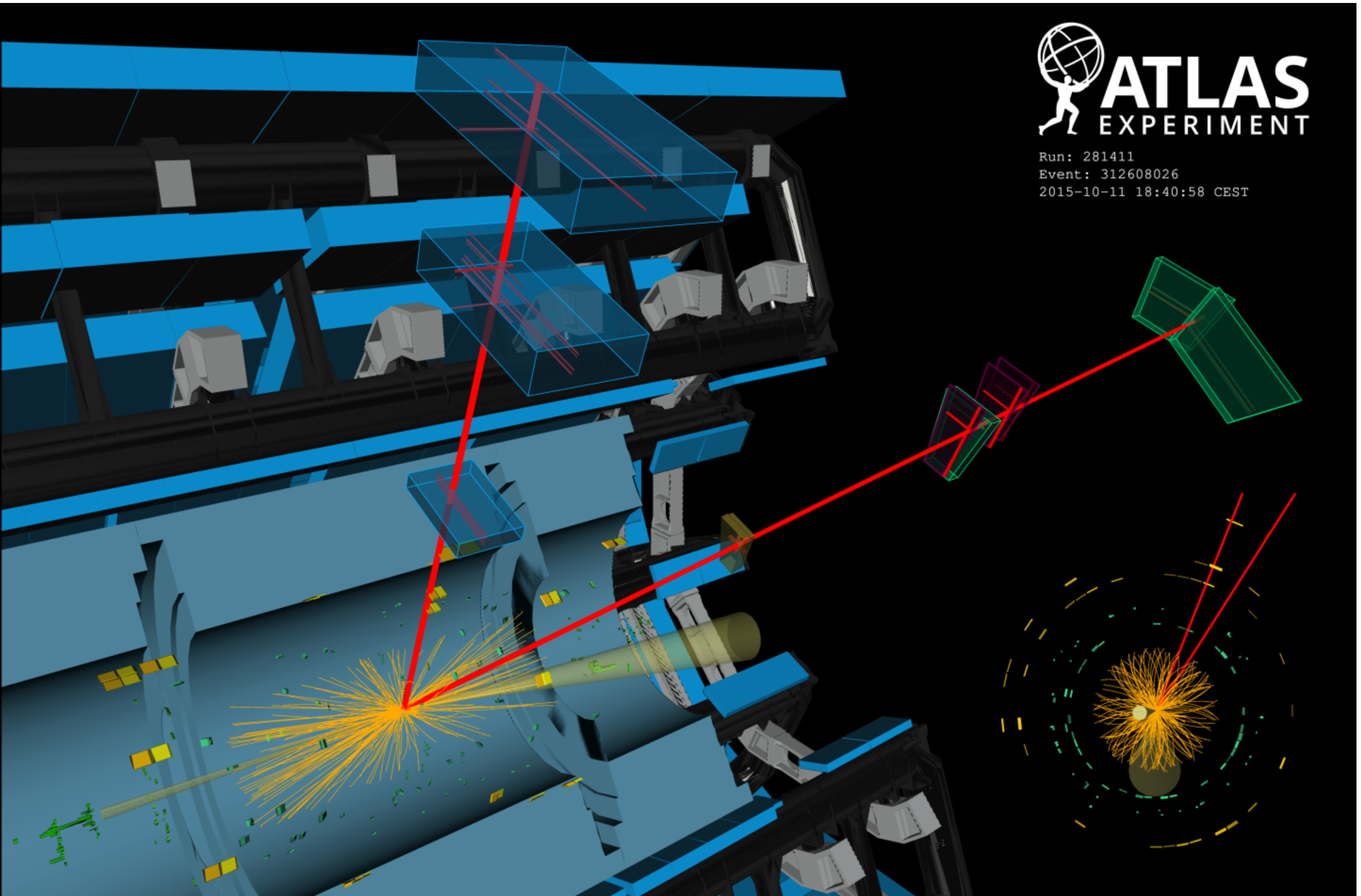
Principles of a **Particle Detector**

Muon System



We want to trace muons:
measure their kinematics
& identify them

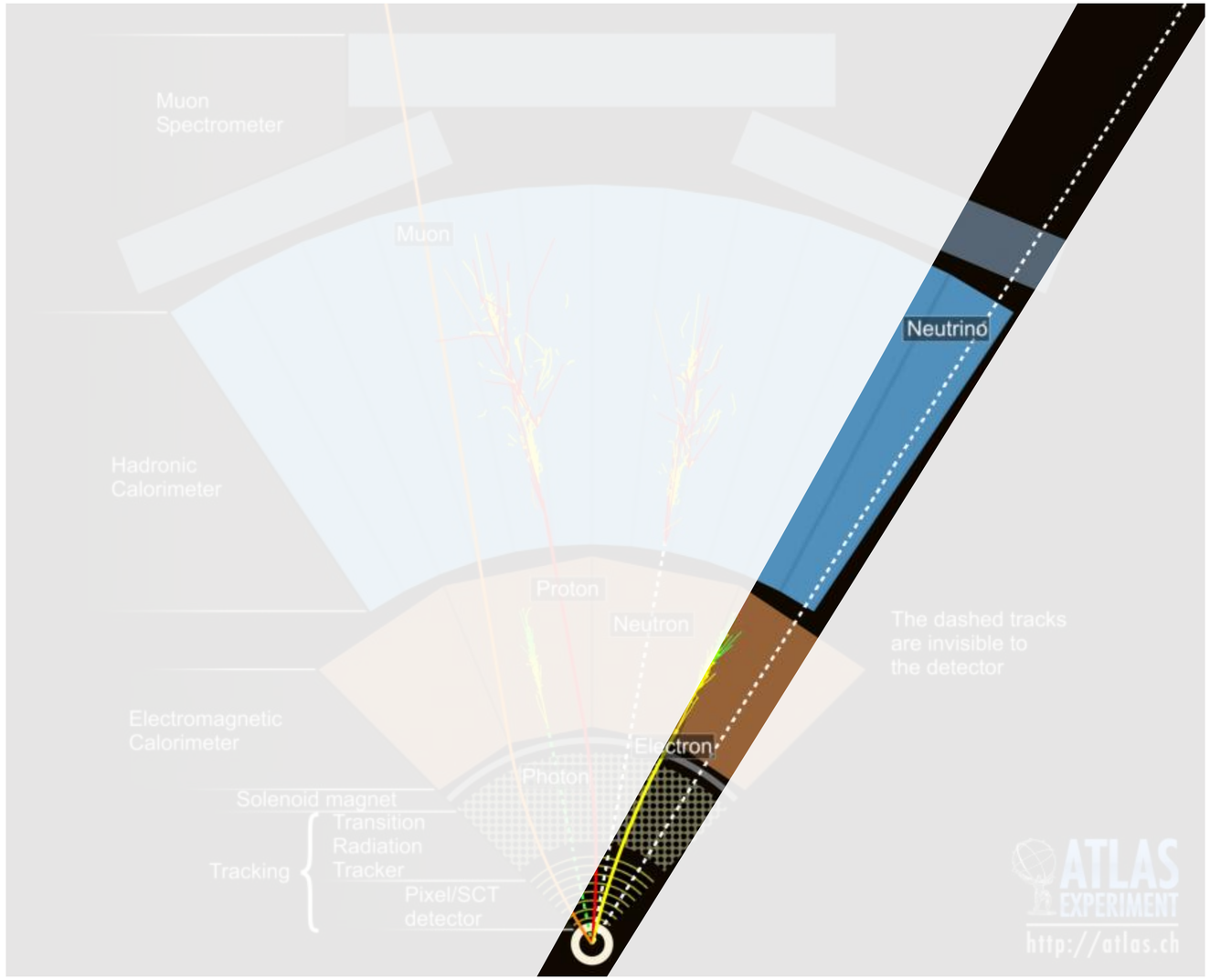
Principles of a **Particle Detector**



Muon System

In ATLAS:
Another tracking detector

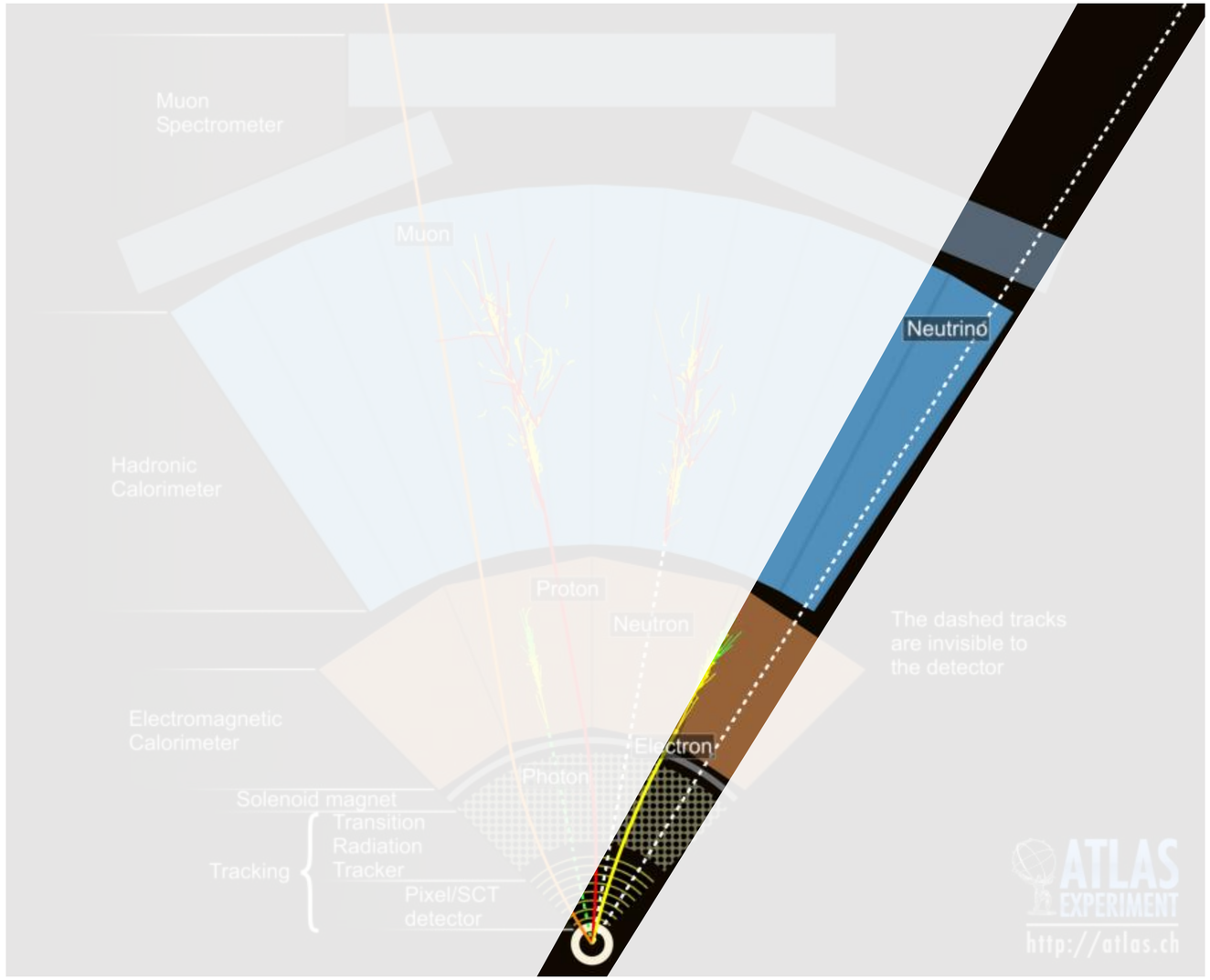
Principles of a **Particle Detector**



What about these guys?

Neutrinos do not cary at all for a small detector like ATLAS.

Principles of a **Particle Detector**



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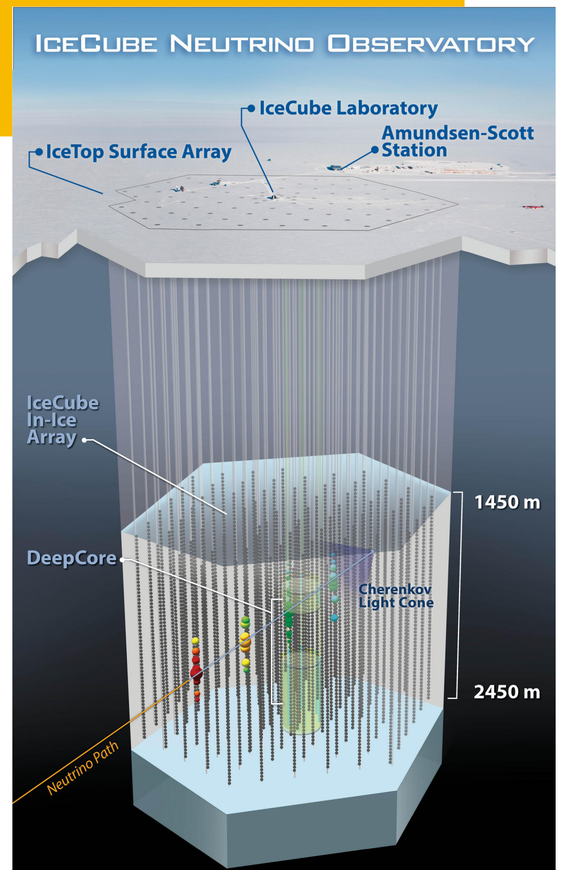
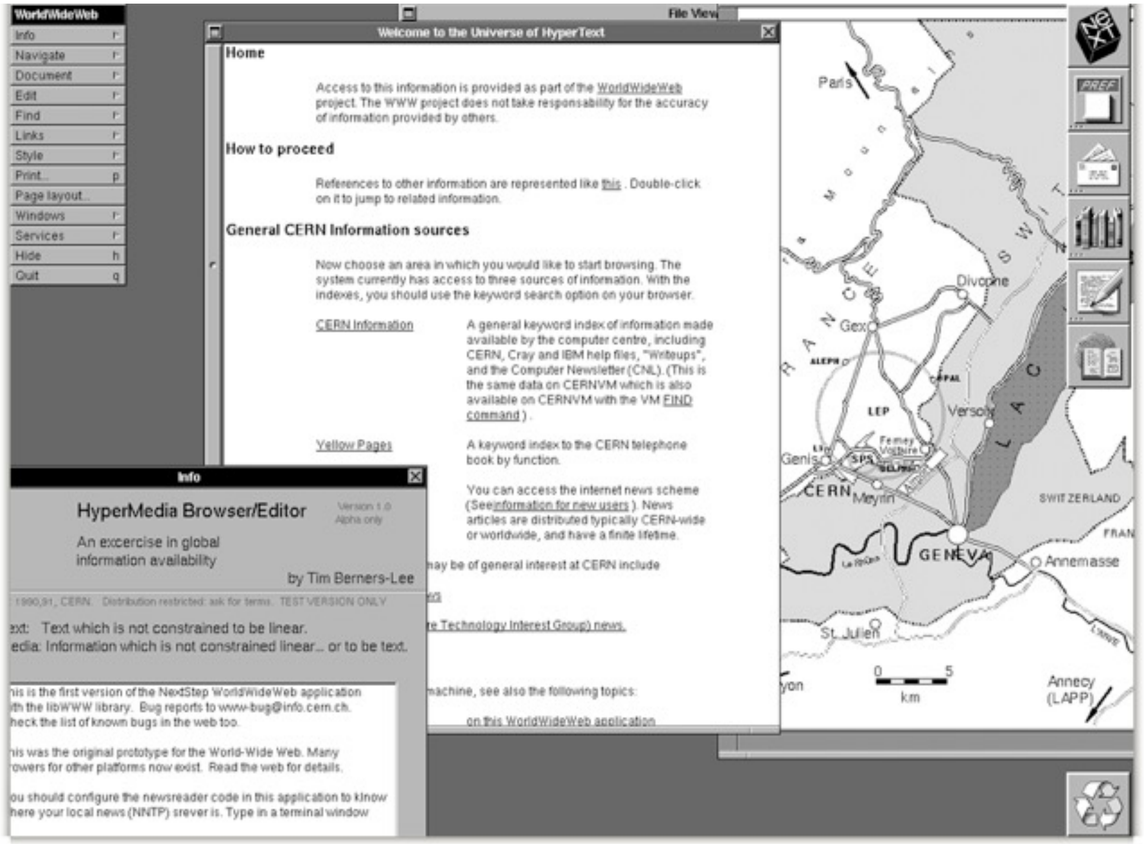


You need a bigger tool for that.

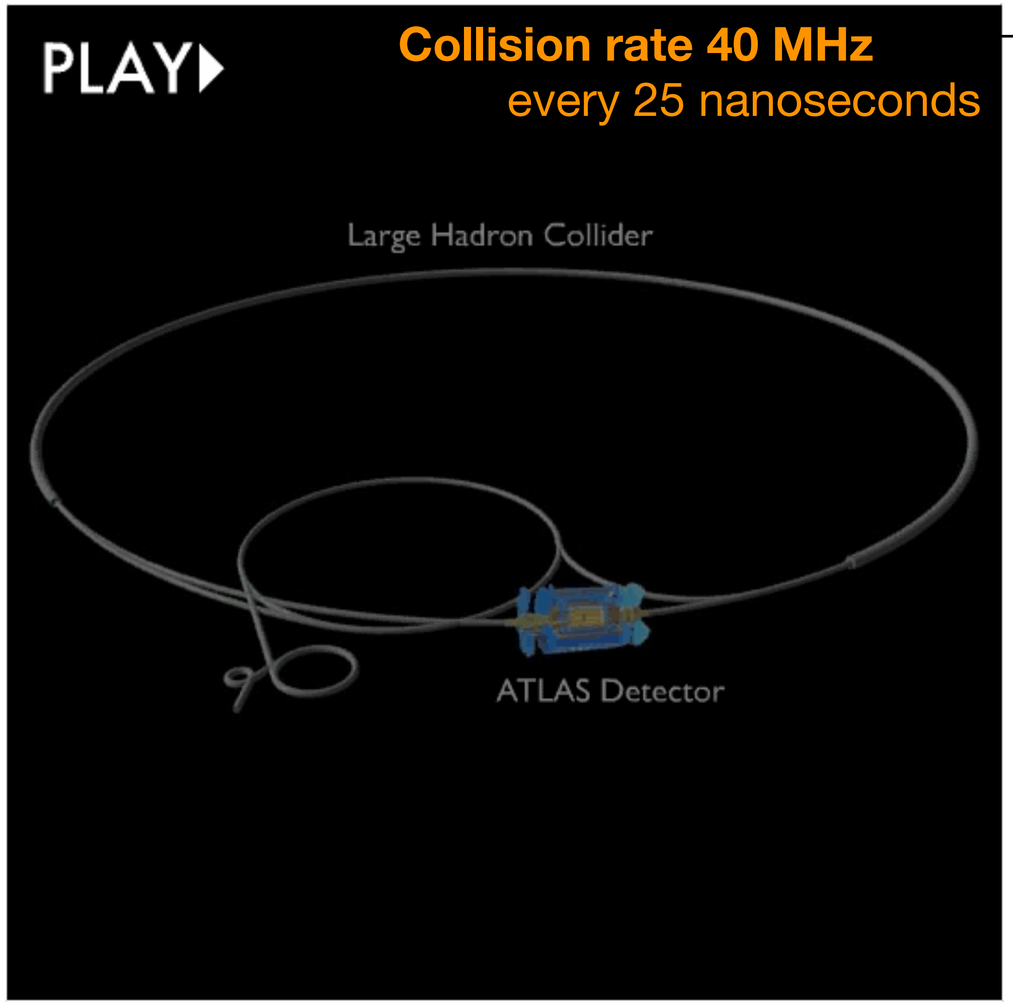
wwwhere the web was born

100 million readout channels



Tim Berners-Lee

LHC in **action** - data acquisition



Level 1 Trigger to 100 kHz
on detector electronics

High level trigger ~1kHz
close-by computer farm

Full processing of events
~1000 events/second
raw event size of 1.5 Mbyte/event

Data Analysis & publication

Nobel prize

LHC big data - how big is big?

300.000 PByte processed per day

Full processing of events

~1000 events/second

raw event size of 1.5 Mbyte/event

x multiple experiments, simulation

> 300 PByte stored at CERN

~ 1 PByte processed per day

[Data Source World] [Data Source CERN]

Why the hassle?

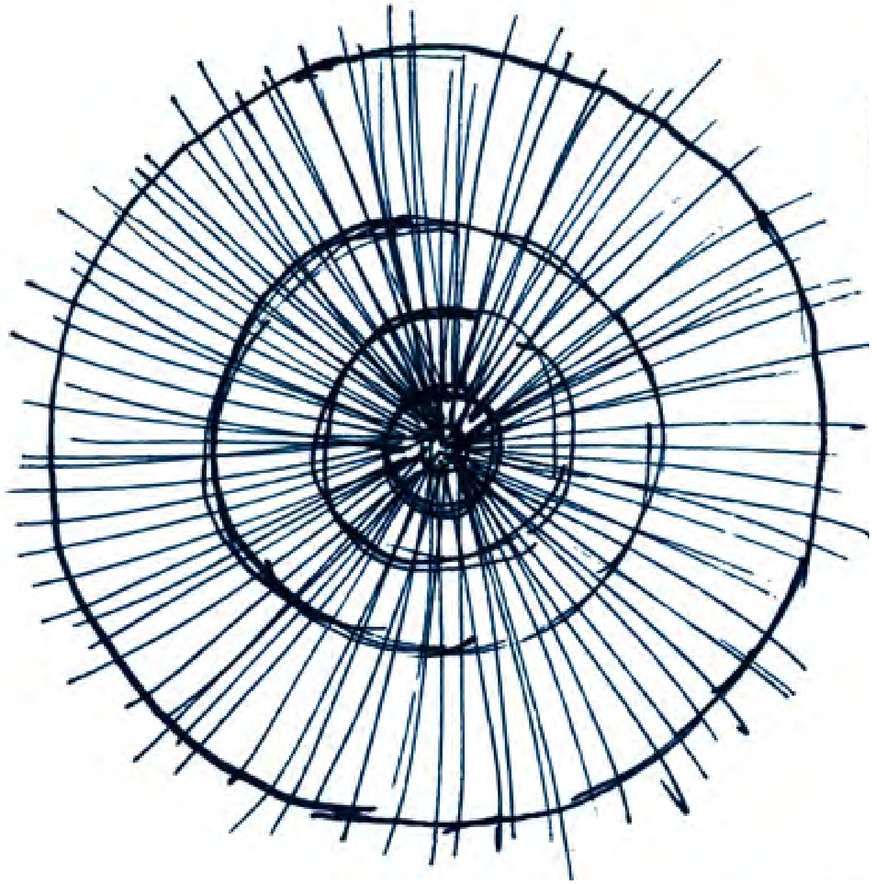


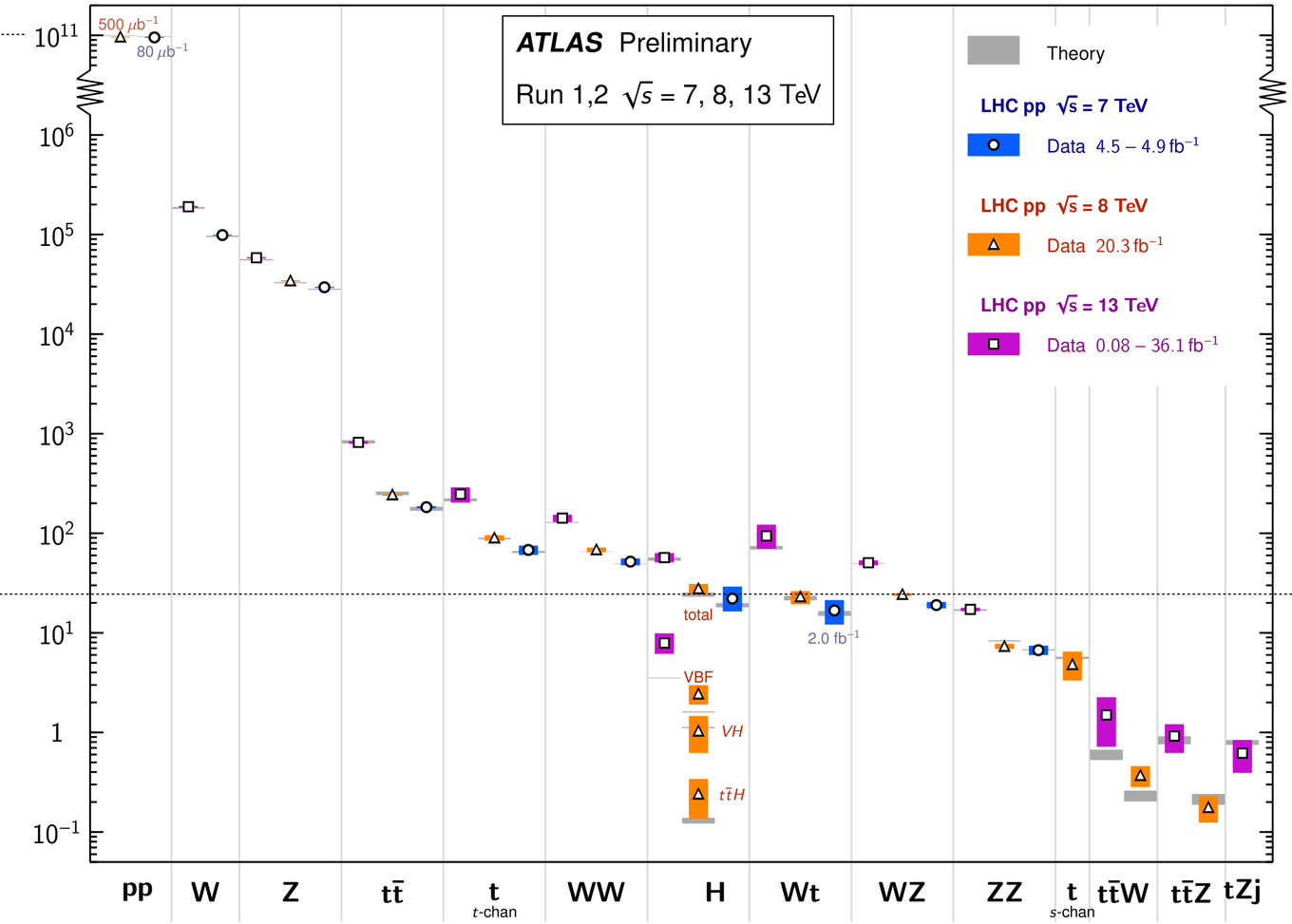
Illustration:
B. KUSSIN

Physics - or why boring things are boring

The boring regime:
"probability" of
any interaction

10^{10}

The exciting regime:
"probability" of
a Higgs boson
production



??

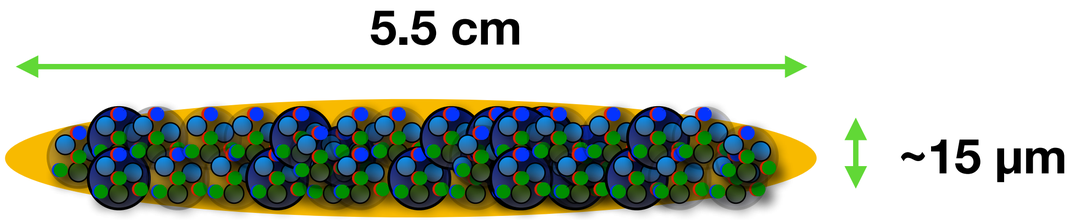
The crazy regime:
super symmetry?
extra dimensions?
magnetic monopoles?

Figure:
Standard Model cross sections measured with the ATLAS experiment and compared to theoretical predictions, July 2017

Ah … yeah, and the Higgs boson.

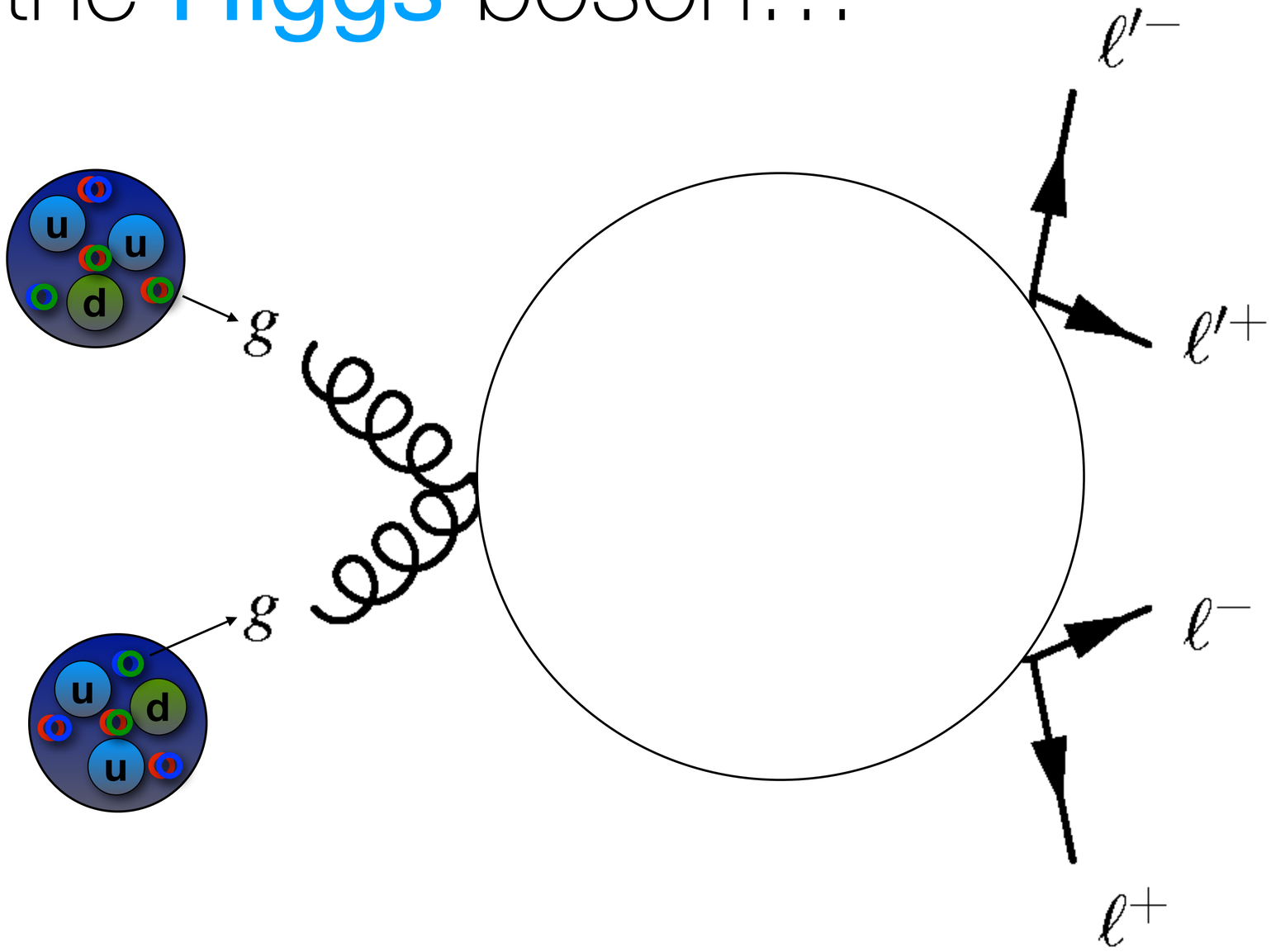
Illustration:
B. KUSSIN

Creating the Higgs boson…

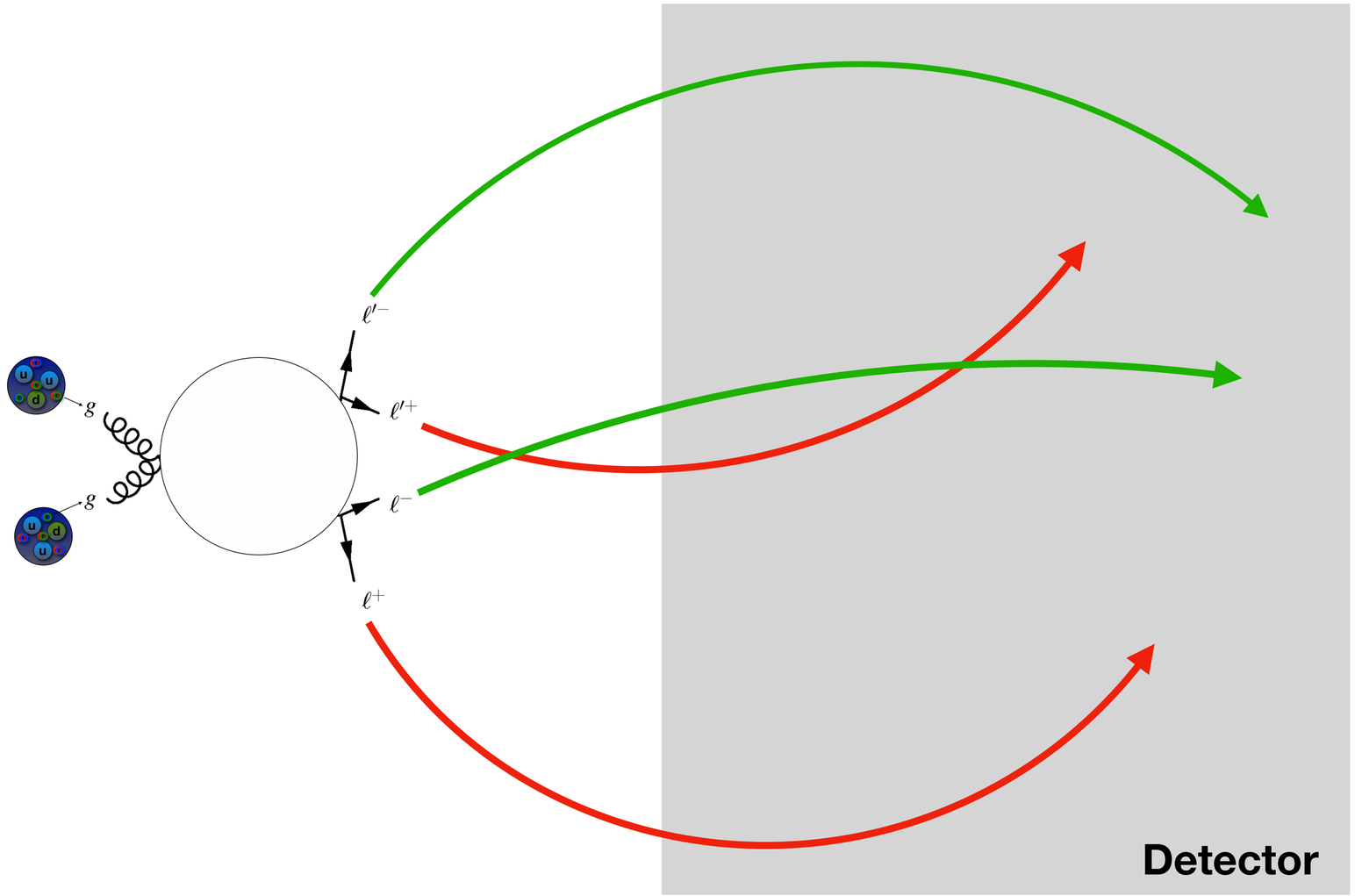


~ 40 individual proton-proton interactions

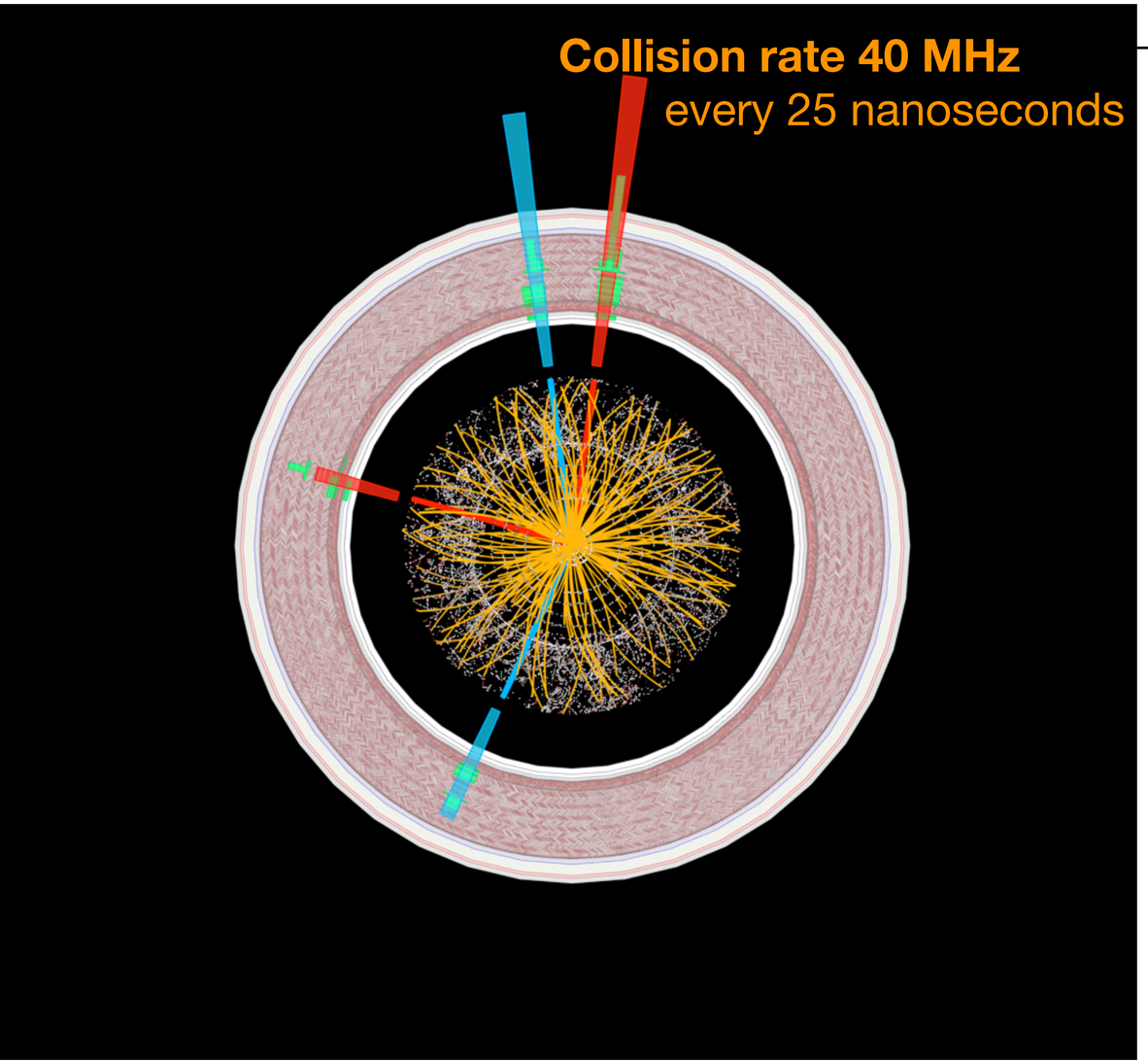
Creating the Higgs boson…



Finding the Higgs boson…



Finding the Higgs boson…



Level 1 Trigger to 100 kHz
on detector electronics

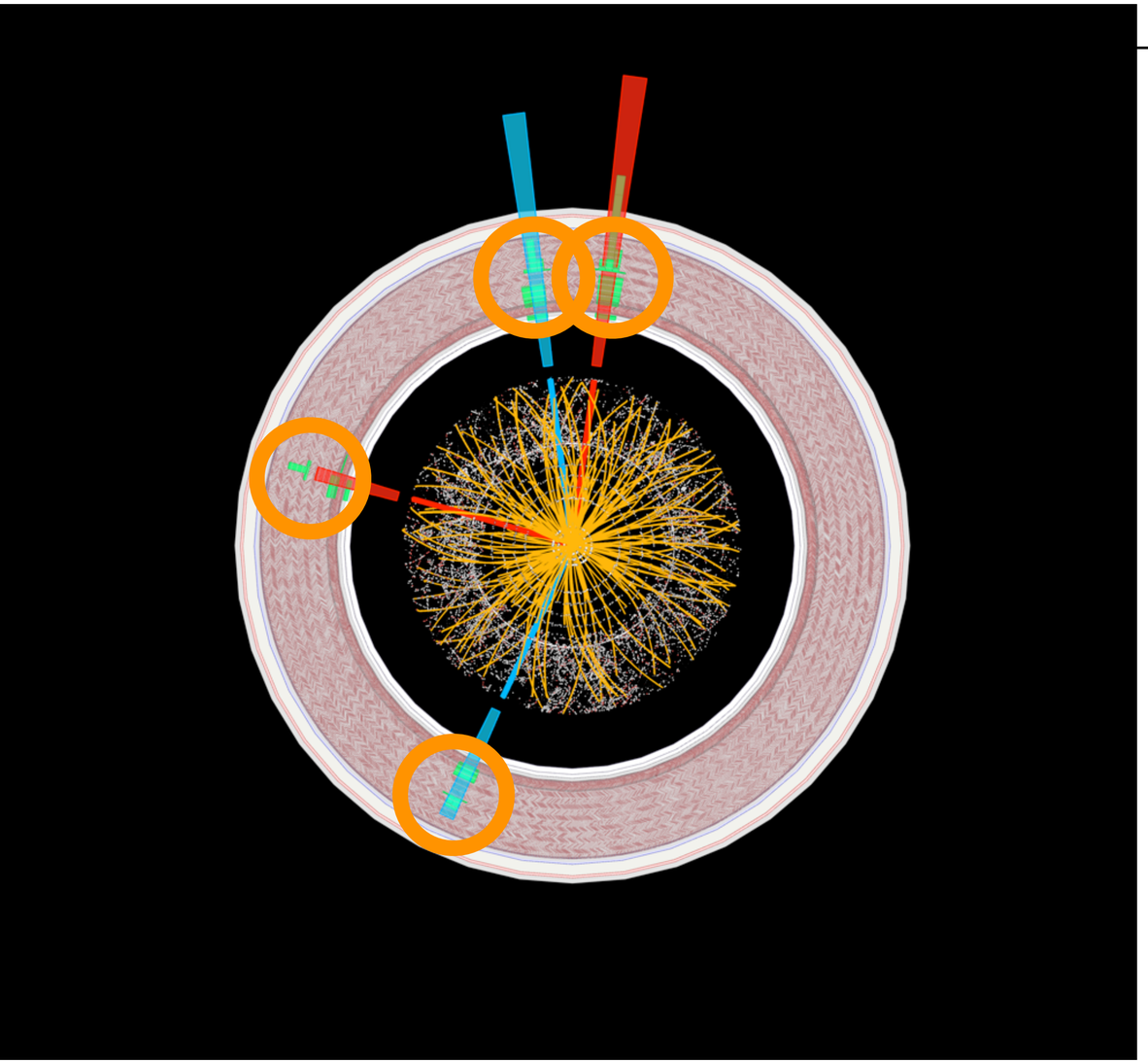
High level trigger ~1kHz
close-by computer farm

Full processing of events
1000 events/second

Data Analysis & publication

Nobel prize

Finding the Higgs boson…



Level 1 Trigger to 100 kHz
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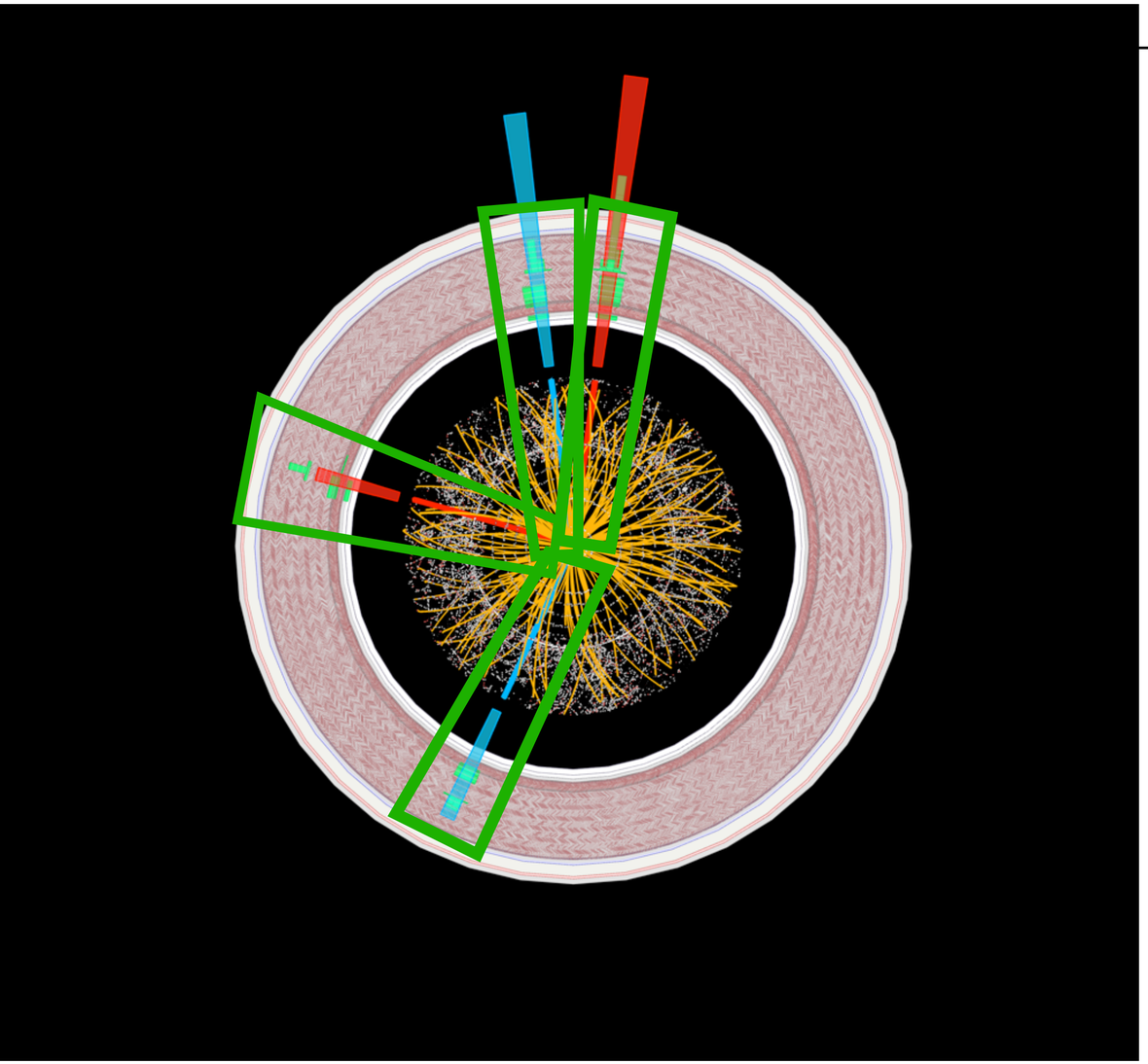
Full processing of events
1000 events/second

Data Analysis & publication

4 lepton signals

Nobel prize

Finding the Higgs boson…



Level 1 Trigger to 100 kHz
on detector electronics

4 lepton signals

High level trigger ~1kHz
close-by computer farm

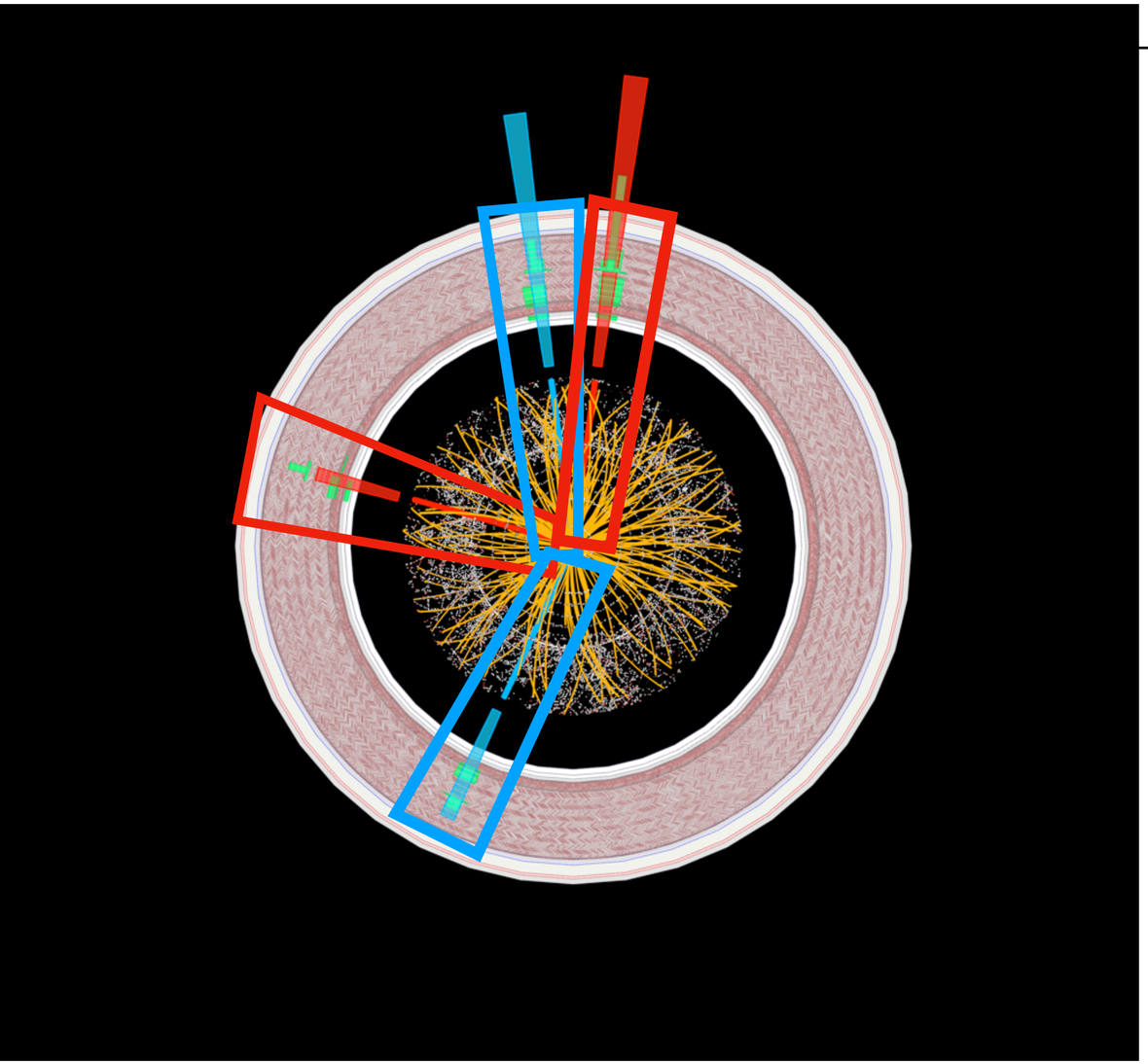
4 lepton signals confirmed

Full processing of events
1000 events/second

Data Analysis & publication

Nobel prize

Finding the Higgs boson…



Level 1 Trigger to 100 kHz
on detector electronics

4 lepton signals

High level trigger ~1kHz
close-by computer farm

4 lepton signals confirmed

Full processing of events
1000 events/second

2 positive leptons
2 negative leptons
and measured

Data Analysis & publication

Nobel prize

Finding the Higgs boson…

Lesson 1 – Minkowski arithmetic

$p_\mu = (E, p_x, p_y, p_z)$

energy momentum

Invariant mass:

$M^2 = E^2 - p_x^2 - p_y^2 - p_z^2$

Level 1 Trigger to 100 kHz
on detector electronics

4 lepton signals

High level trigger ~1kHz
close-by computer farm

4 lepton signals confirmed

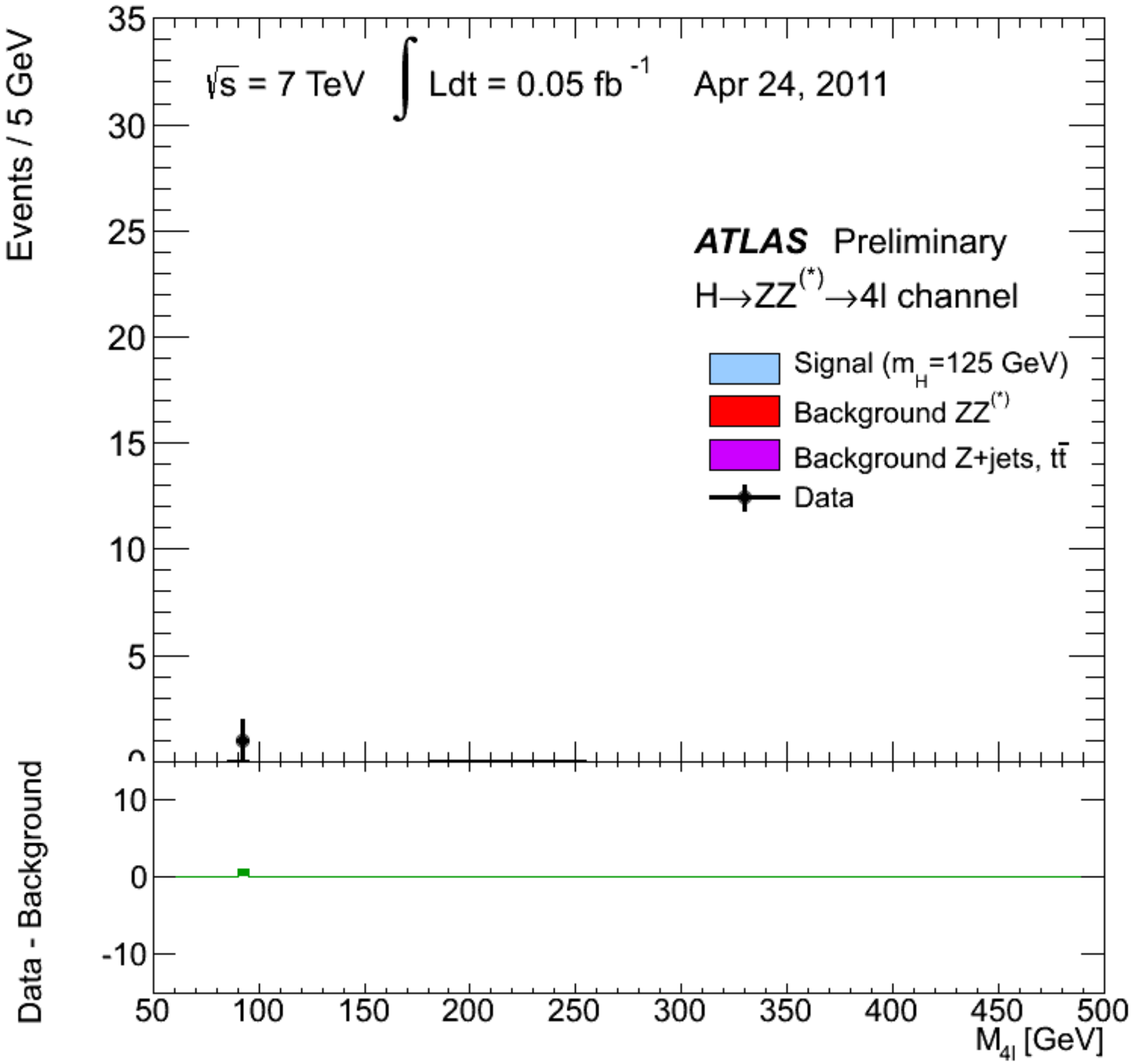
Full processing of events
1000 events/second

2 positive leptons
2 negative leptons
and measured

Data Analysis & publication

Nobel prize

Finding the Higgs boson… now really



Level 1 Trigger to 100 kHz
on detector electronics

High level trigger ~1kHz
close-by computer farm

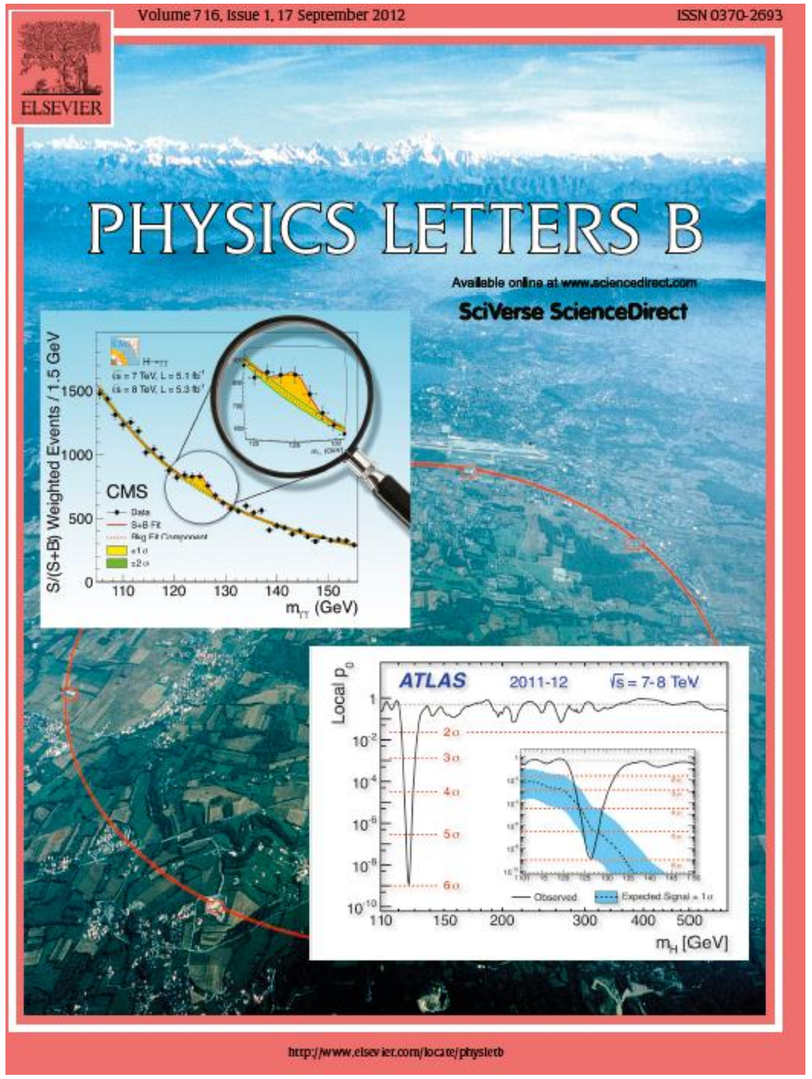
Full processing of events
1000 events/second

Data Analysis & publication

Nobel prize

[Animation source]

Finding the Higgs boson… now really



Level 1 Trigger to 100 kHz
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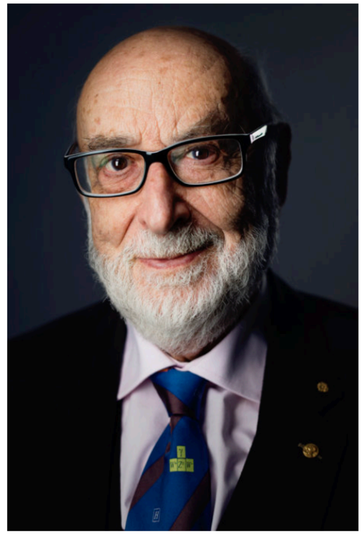
Data Analysis & publication

Nobel prize

[Animation source]

Finding the Higgs boson… now really

The Nobel Prize in Physics 2013



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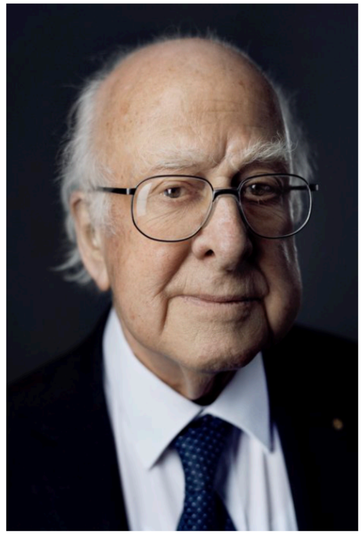
François Englert

Prize share: 1/2



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Peter W. Higgs

Prize share: 1/2

Level 1 Trigger to 100 kHz
on detector electronics

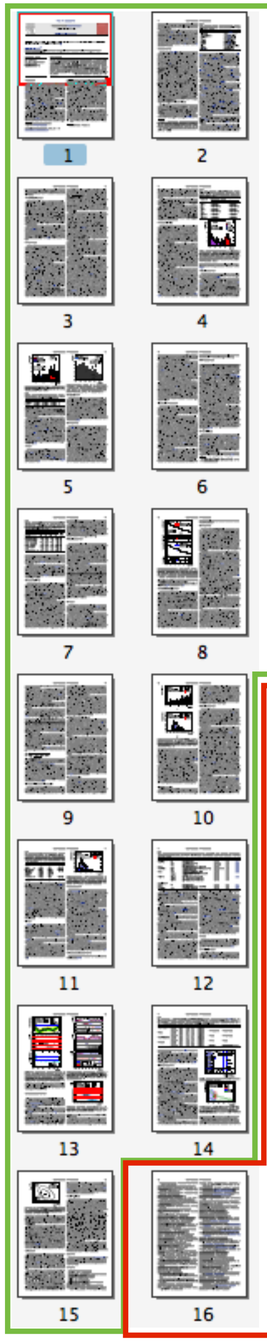
High level trigger ~1kHz
close-by computer farm

Full processing of events
1000 events/second

Data Analysis & publication

Nobel prize

[Animation source]



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www.elsevier.com/locate/physletb

Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC ☆

ATLAS Collaboration *

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

ARTICLE INFO

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ABSTRACT

A search for the Standard Model Higgs boson in proton–proton collisions with the ATLAS detector at the LHC is presented. The datasets used correspond to integrated luminosities of approximately 4.8 fb^{-1} collected at $\sqrt{s} = 7$ TeV in 2011 and 5.8 fb^{-1} at $\sqrt{s} = 8$ TeV in 2012. Individual searches in the channels $H \to ZZ^{(*)} \to 4\ell$, $H \to \gamma\gamma$ and $H \to WW^{(*)} \to e\nu\mu\nu$ in the 8 TeV data are combined with previously published results of searches for $H \to ZZ^{(*)}$, $WW^{(*)}$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from improved analyses of the $H \to ZZ^{(*)} \to 4\ell$ and $H \to \gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of 126.0 ± 0.4 (stat) ± 0.4 (sys) GeV is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9}, is compatible with the production and decay of the Standard Model Higgs boson.

author list information

L. Rumyantsev [64], Z. Rurikova [48], N.A. Rusakovich [64], J.P. Rutherfoord [7], P. Ruzicka [125], Y.F. Ryabov [121], M. Rybar [126], G. Rybkin [115], N.C. Ryder [118], A.F. Saavedra [150], I. Sadeh [153], H.F.-W. Sadrozinski [137], R. Sadykov [64], F. Safai Tehrani [132a], H. Sakamoto [155], G. Salamanna [75], A. Salamon [133a], M. Saleem [111], D. Salek [30], D. Salihagic [99], A. Salnikov [143], J. Salt [167], B.M. Salvachua Ferrando [6], D. Salvatore [37a,37b], F. Salvatore [149], A. Salvucci [104], A. Salzburger [30], D. Sampsonidis [154], B.H. Samset [117], A. Sanchez [102a,102b], V. Sanchez Martinez [167], H. Sandaker [14], H.G. Sander [81], M.P. Sanders [98], M. Sandhoff [175], T. Sandoval [28], C. Sandoval [162], R. Sandstroem [99], D.P.C. Sankey [129], A. Sansoni [47], C. Santamarina Rios [85], C. Santoni [34], R. Santonico [133a,133b], H. Santos [124a], J.G. Saraiva [124a], T. Sarangi [173], E. Sarkisyan-Grinbaum [8], F. Sarri [122a,122b], G. Sartisohn [175], O. Sasaki [65], Y. Sasaki [155], N. Sasao [67], I. Satsounkevitch [90], G. Sauvage [5,*], E. Sauvan [5], J.B. Sauvan [115], P. Savard [158,d], V. Savinov [123], D.O. Savu [30], L. Sawyer [25,m], D.H. Saxon [53], J. Saxon [120], C. Sbarra [20a], A. Sbrizzi [20a,20b], D.A. Scannicchio [163], M. Scarcella [150], J. Schaarschmidt [115], P. Schacht [99], D. Schaefer [120], U. Schäfer [81], A. Schaelicke [46], S. Schaepe [21], S. Schaetzel [58b], A.C. Schaffer [115], D. Schaile [98], R.D. Schamberger [148], A.G. Schamov [107], V. Scharf [58a], V.A. Schegelsky [121], D. Scheirich [87], M. Schernau [163], M.I. Scherzer [35], C. Schiavi [50a,50b], J. Schieck [98], M. Schioppa [37a,37b], S. Schlenker [30], P. Schmid [30], E. Schmidt [48], K. Schmieden [21], C. Schmitt [81], S. Schmitt [58b], M. Schmitz [21], B. Schneider [17], U. Schnoor [44], L. Schoeffel [136], A. Schoening [58b], A.L.S. Schorlemmer [54], M. Schott [30], D. Schouten [159a], J. Schovancova [125], M. Schram [85], C. Schroeder [81], N. Schroer [58c], M.J. Schultens [21], J. Schultes [175], H.-C. Schultz-Coulon [58a], H. Schulz [16], M. Schumacher [48], B.A. Schumm [137], Ph. Schune [136], C. Schwanenberger [82], A. Schwartzman [143], Ph. Schwegler [99],

15 pages scientific context

~ 3000 authors

The **ATLAS** collaboration

https://atlas.cern/discover/collaboration

Large **H**adron **C**ollider

H
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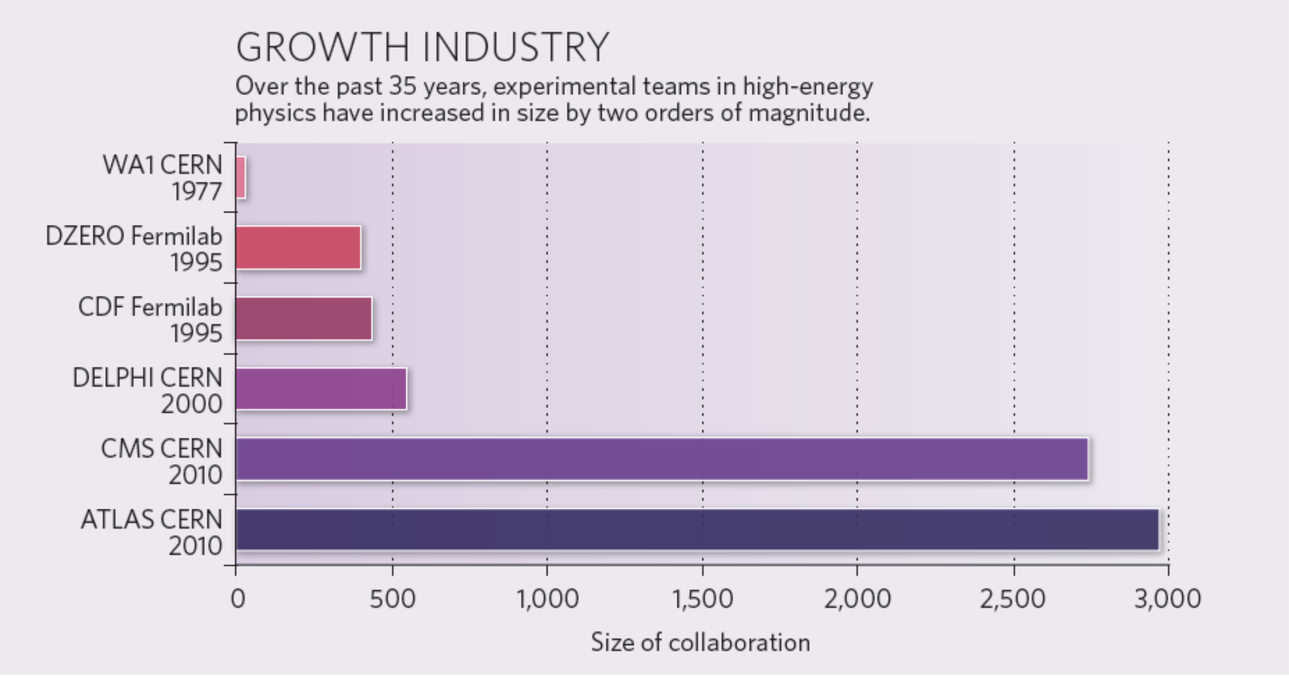


THE LARGE HUMAN COLLIDER

Social scientists have embedded themselves at CERN to study the world's biggest research collaboration. **Zeeya Merali** reports on a 10,000-person physics project.

"I am here to watch you." So began anthropologist Arpita Roy when introducing herself in 2007 to a roomful of particle physicists. At the time, those scientists were racing to finish work on the world's biggest machine, the Large Hadron Collider (LHC) at CERN, Europe's high-energy physics laboratory near Geneva, Switzerland.

The LHC carries the hopes of generations of physicists, who have designed it to reach energies never before achieved in a collider and — possibly — to produce a zoo of particles new to science. But the LHC is also a huge human experiment, bringing together an unprecedented number of scientists. So in recent years, sociologists, anthropologists, historians and philosophers have been visiting CERN to see just how these densely packed physicists collide, ricochet and sometimes explode.

"The LHC allows a unique sociological study of how an experiment develops in real time: how scientists form opinions, make technical decisions and circulate knowledge in such a big project," says Arianna Borrelli, a particle physicist and philosopher of physics at the University of Wuppertal in Germany.

Sergio Bertolucci, CERN's research director, is acutely aware of the importance of cohesive collaboration. "This is an incredible social experiment," he says, noting that roughly 10,000 physicists around the world are taking part in the LHC experiments and 2,250 of them are employed at CERN. Just reflecting on the size of the collaboration he co-manages makes Bertolucci's head ache. "Imagine the organization needed when 3,000 people all want to know in advance if they can go home for Christmas," he says.

Managers at CERN have endured a series of headaches since the LHC powered up in September 2008. A little more than a week after the collider came online, a faulty electrical coupling caused an explosion that brought the project to a halt for 14 months. That setback demoralized the scientists at CERN, particularly the graduate students, who worried about the fate of their degrees, says Roy. A graduate student herself, from the University of California, Berkeley, Roy has been camped out at CERN on and off for three years to observe the "language, taboos and rituals of this exotic community".

> "It's a cognitive bubble that you can't escape — that you don't want to escape."

The collider restarted in November 2009 and should gather two years of data before it shuts down for a year of scheduled upgrades in 2012. Next month, the LHC is expected to achieve record energies of 7 teraelectronvolts. The collider will reach such an extreme by accelerating two beams of protons to nearly the speed of light and then sending them in opposite directions around a 27-kilometre underground track. The beams cross each other at four spots along the ring, and it is here that the real science happens, within giant detectors surrounding each collision zone. The two biggest particle detectors, A Toroidal LHC Apparatus (ATLAS) and the Compact Muon Solenoid (CMS) experiment, are the size of apartment buildings and each boasts a team of nearly 3,000 people.

M. SCHMELING/CERN

Population explosion

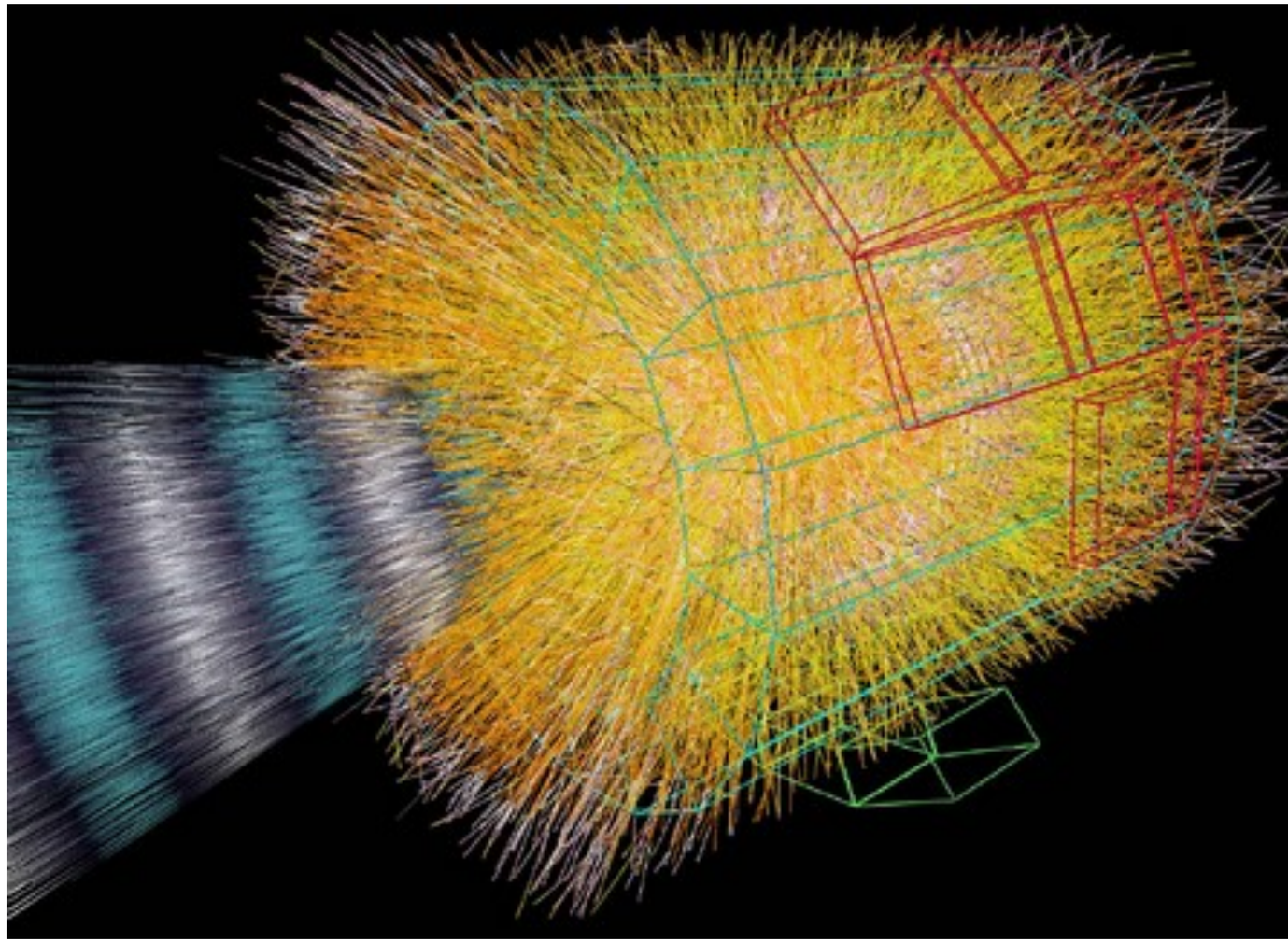
Each generation of collider has brought a jump in the size of the experimental collaborations (see graph, opposite), a trend that provides ample opportunities for researchers interested in human interactions. Karin Knorr Cetina, a sociologist at the University of Constance in Germany, is one of the few social scientists to have witnessed this growth directly over multiple generations. She has been studying CERN's collaborations for almost 30 years.

When Knorr Cetina first arrived, physicists there were working on a smaller collider and their detector teams were less than one-tenth the size of today's. "In those days 100 people in a team was considered huge," she says. Knorr Cetina says she was met with friendly bemusement by particle physicists, who were helpful, but thought of a sociologist "as a poor cousin of real scientists".

HEP and Artificial Intelligence

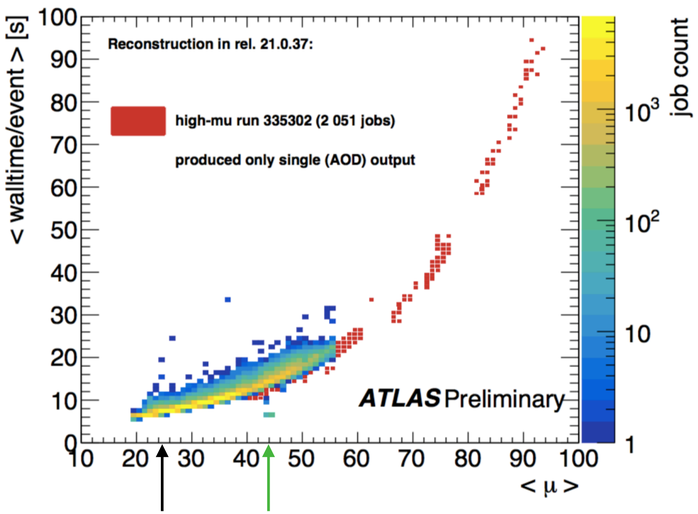
Event reconstruction becomes increasingly difficult

- Artificial Intelligence / Machine Learning has seen a boost in the tech industry
- Can we profit from that?

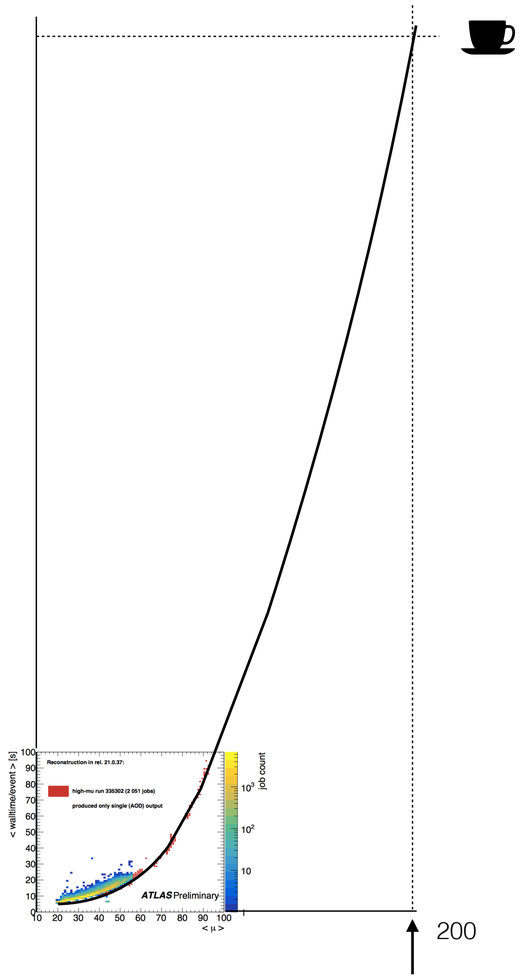


HEP and Artificial Intelligence

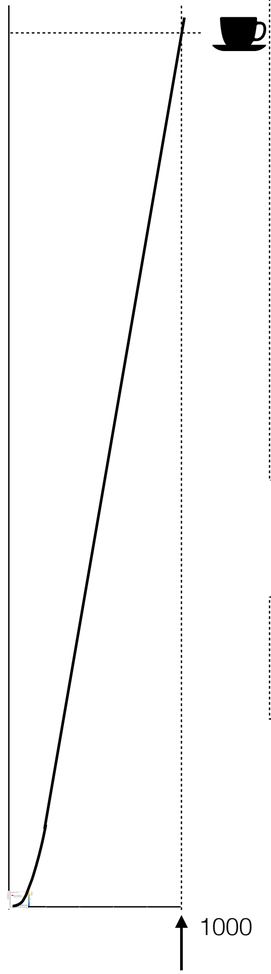
- Combinatorial problem
- And it <u>clearly scales</u> like such



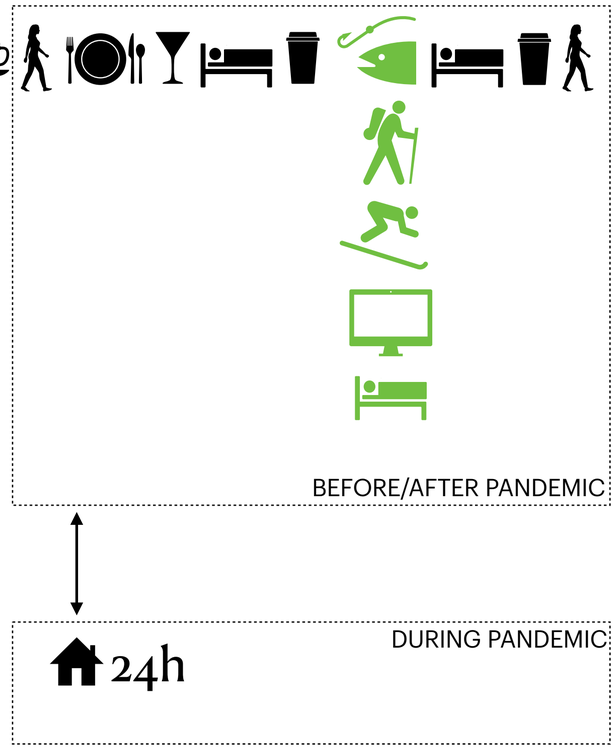
DESIGN/ACTUAL LUMINOSITY OF LHC
(+ DETECTORs, + ALGORITHMs)



HIGH LUMINOSITY LHC (HL-LHC)
(EXP 2027)



FCC-HH 25NS SCENARIO
(EXP ?)

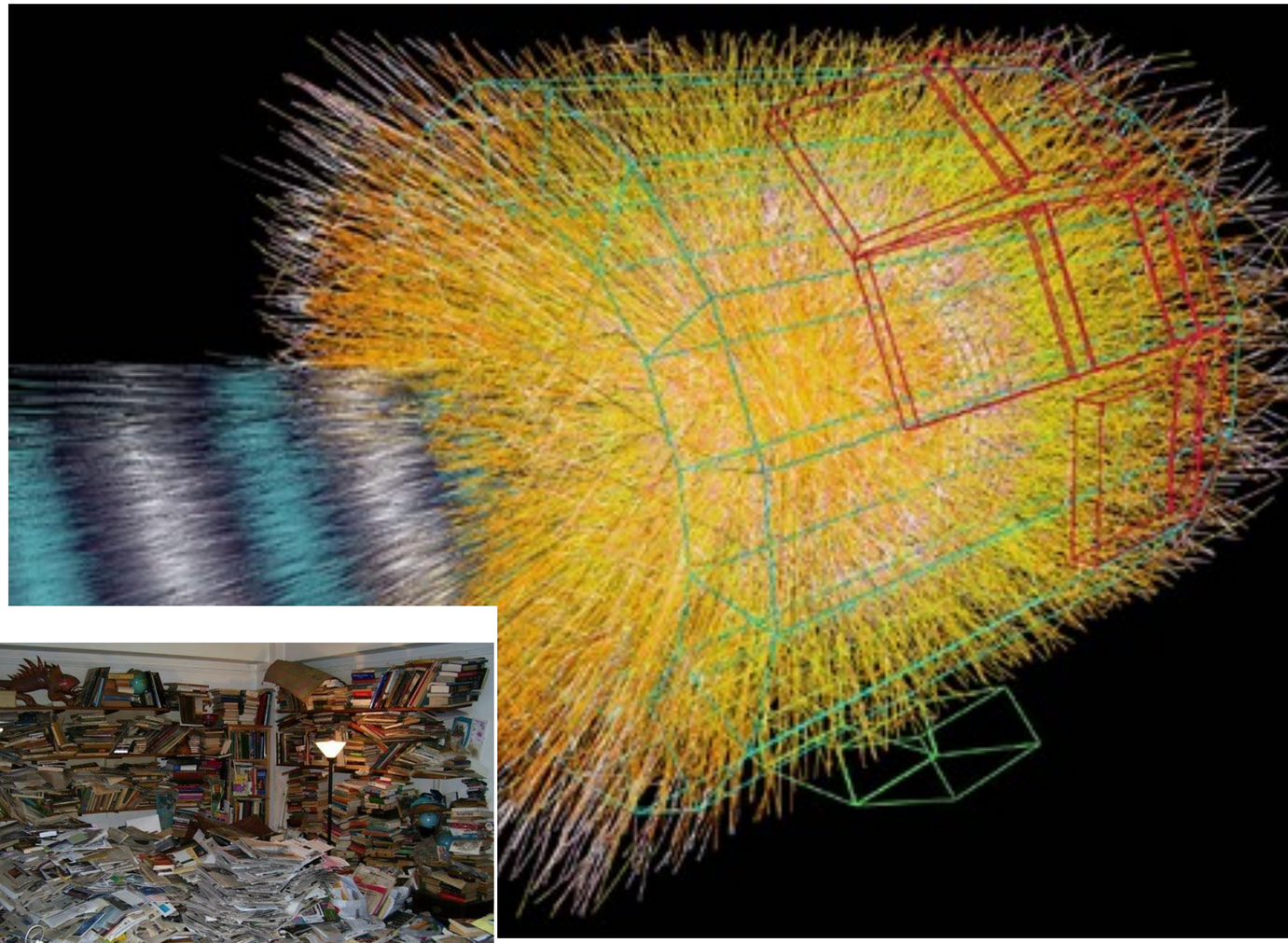


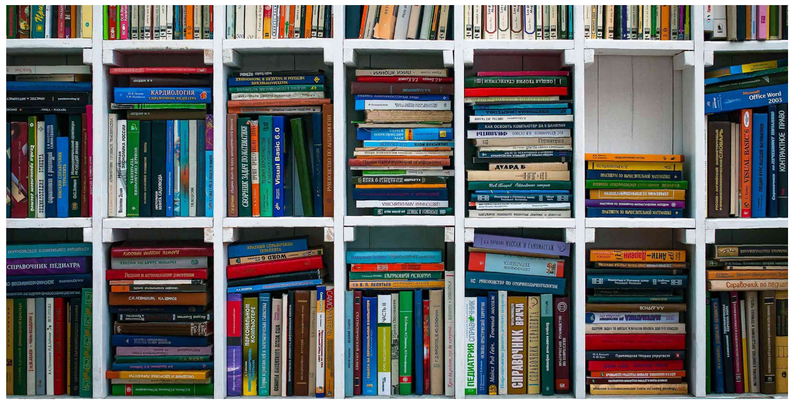
VERY NAIVE SCALING: HL-LHC DETECTORS & ALGORITHMS PERFORM WAY BETTER!

HEP and Artificial Intelligence

Event reconstruction becomes increasingly difficult

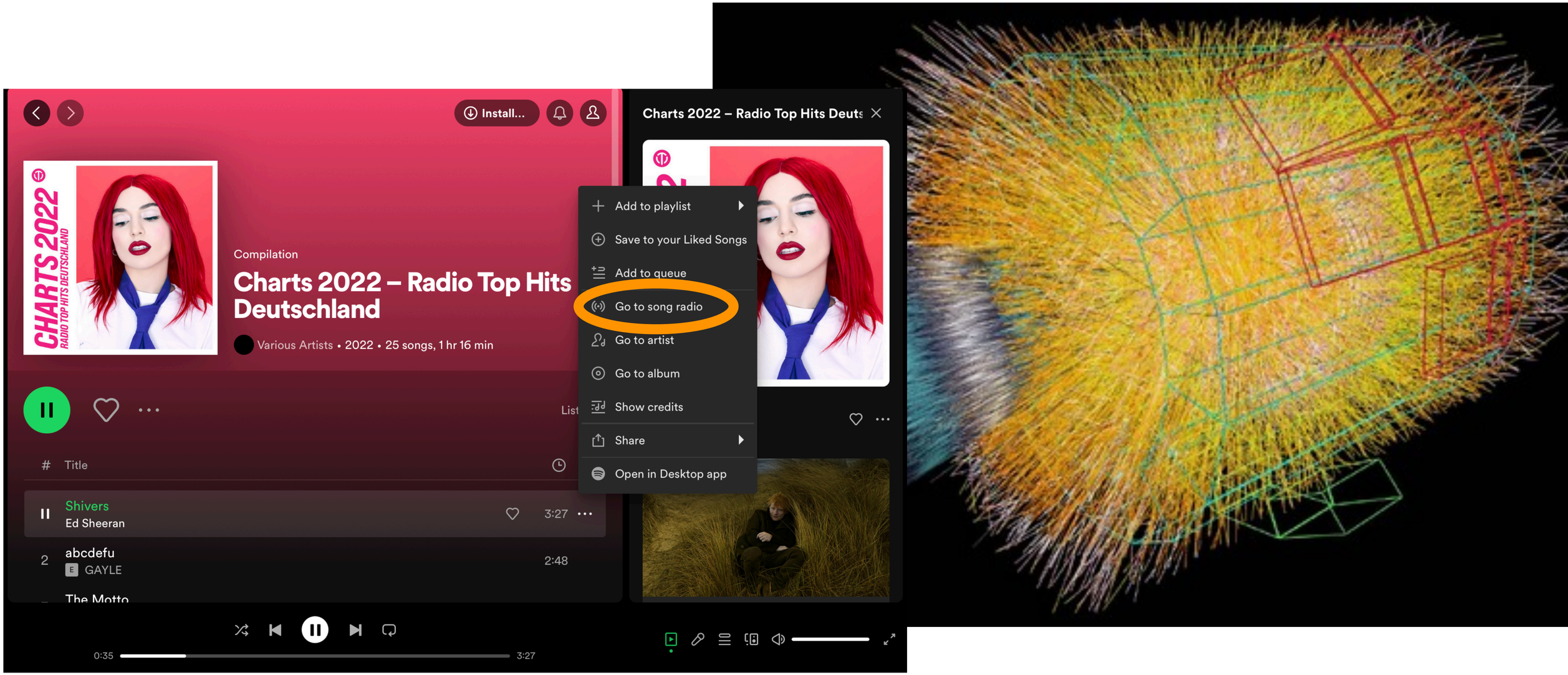
- Artificial Intelligence / Machine Learning has seen a boost in the tech industry
- Can we profit from that?



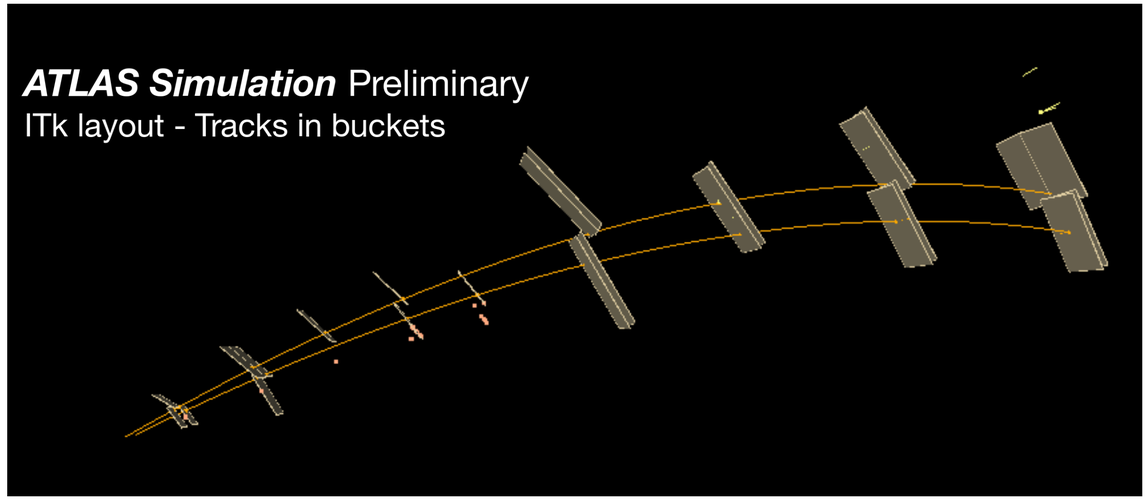


vs

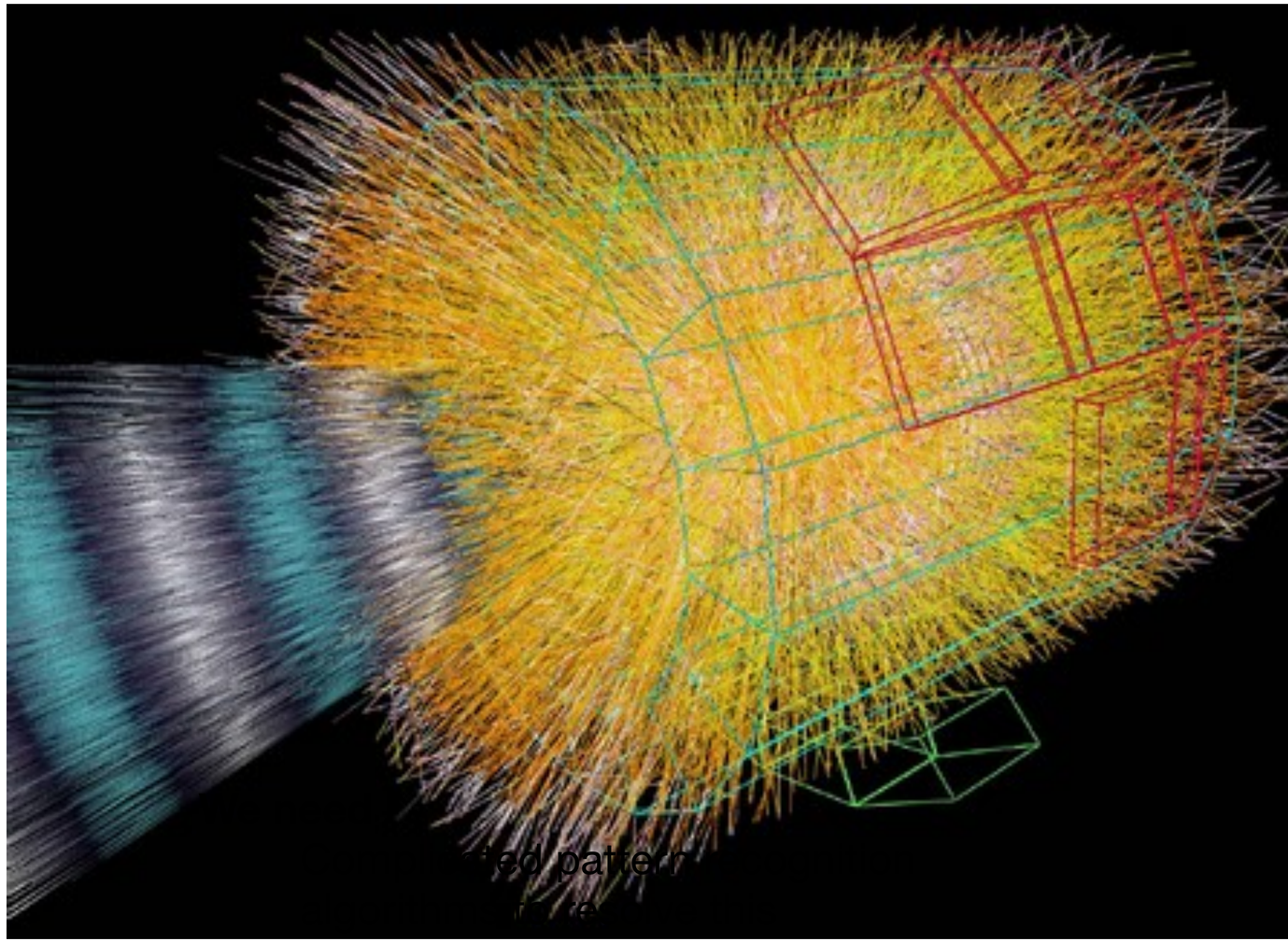
HEP and Artificial Intelligence



HEP and Artificial Intelligence



These tracks are brought to you by

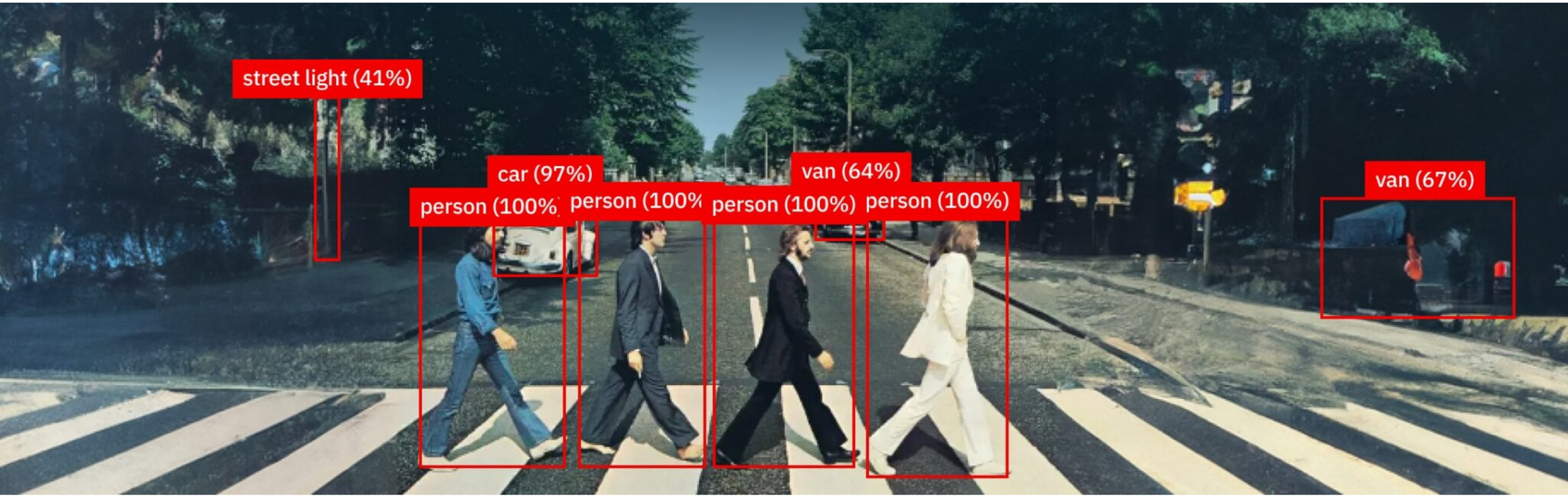


[S. Amrouche, T. Golling, M. Kiehn, AS: Music, Neighbours & Tracking]
[S. Amrouche, N. Calace, T. Golling, M. Kiehm. AS : Hashing & similarity learning]

HEP and Artificial Intelligence

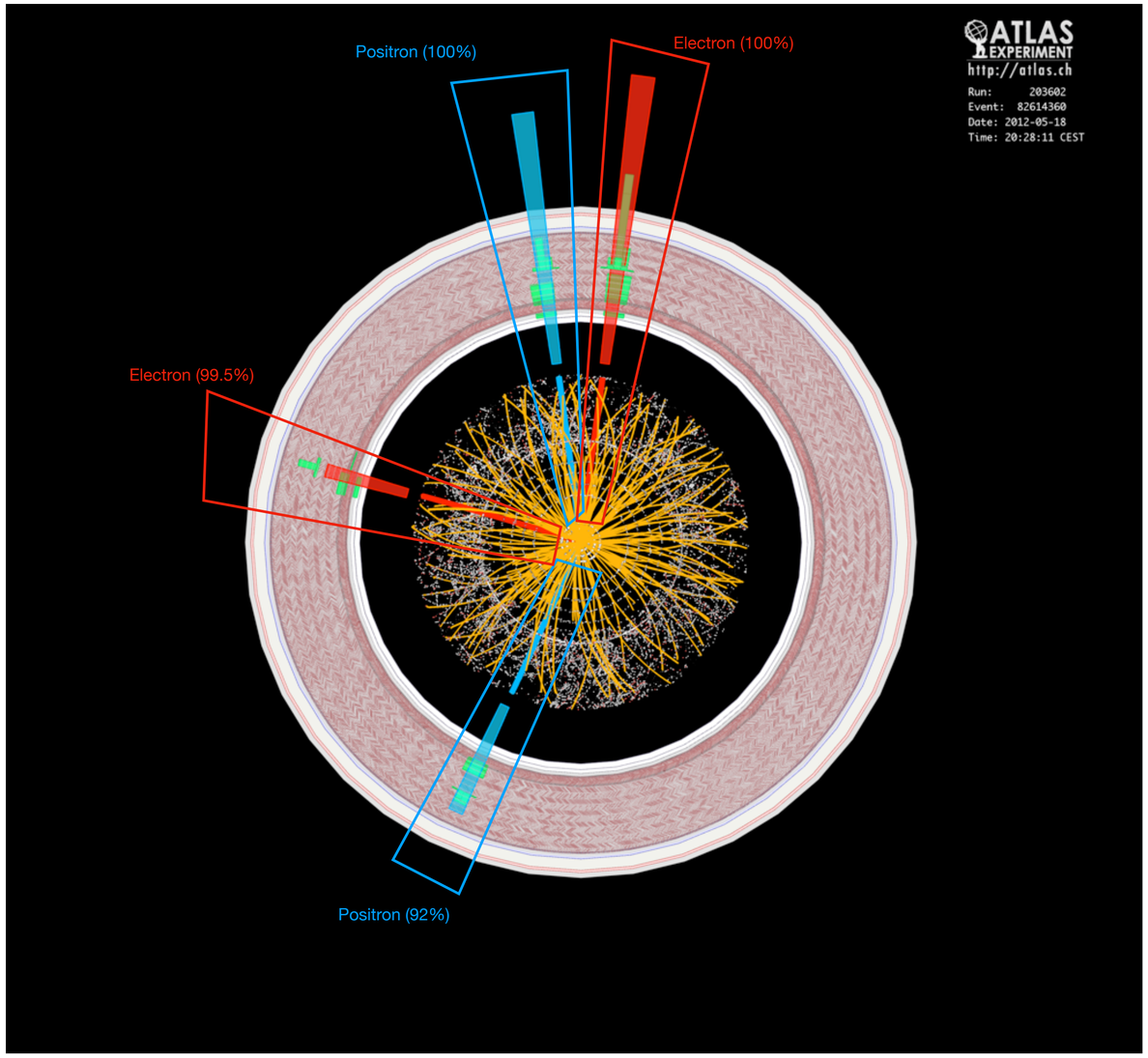
Object detection and recognition is a AI standard problem

- big advances achieved in the last years
- Both in object detection & object calssification
- Can we use this for HEP?



HEP and Artificial Intelligence

HEP and Artificial Intelligence

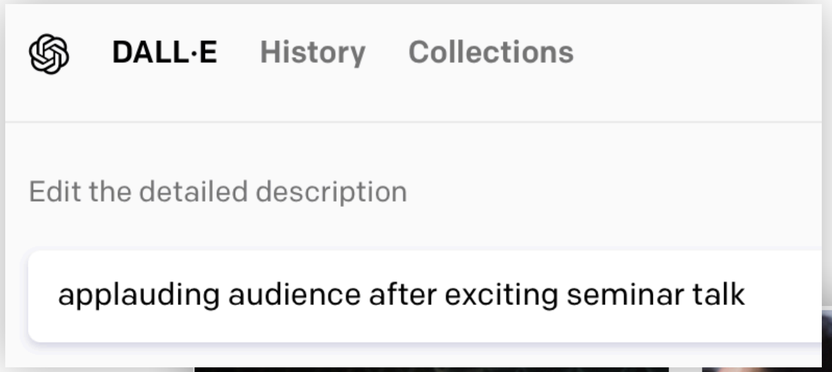


HEP and Artificial Intelligence

[www.thispersondoesnotexit.com]

Generative Models have experienced a tremendous boost in the last years

https://labs.openai.com/



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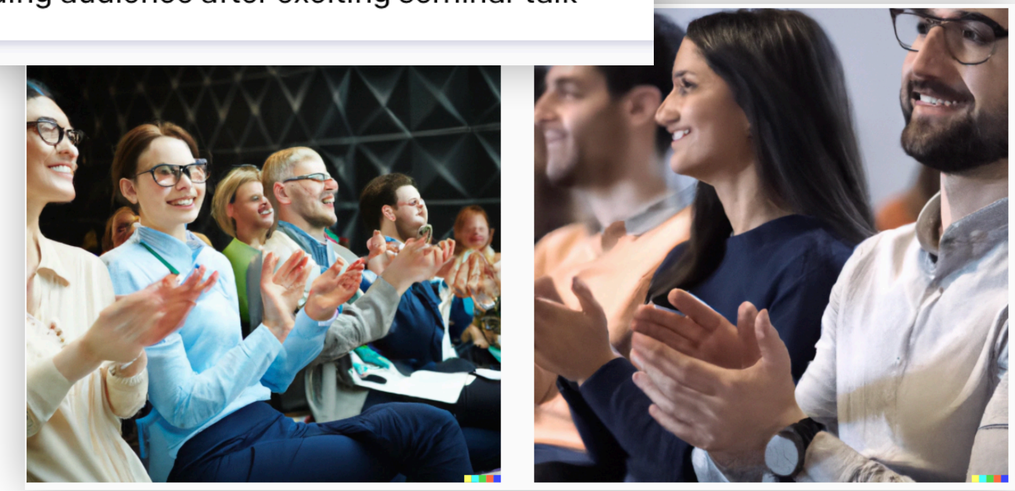
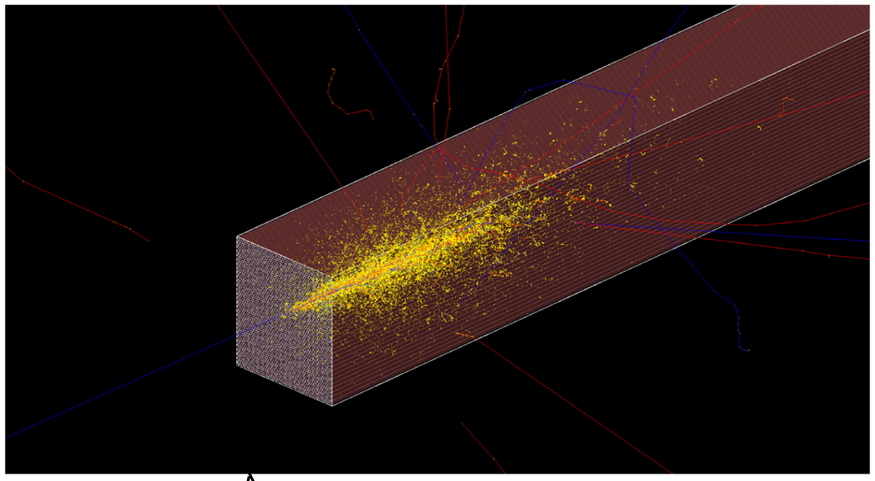
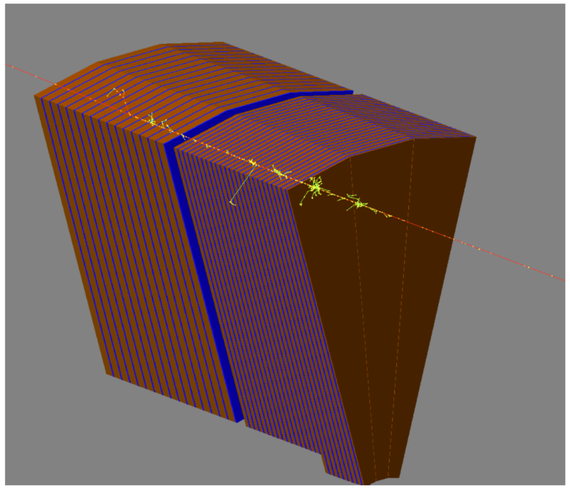
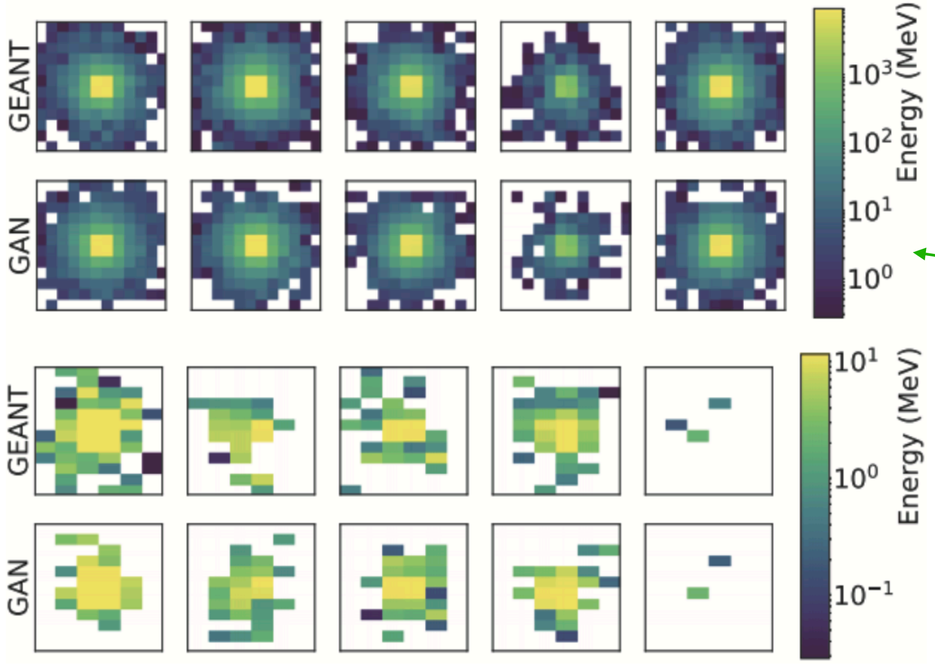
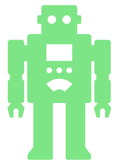


HEP and Artificial Intelligence









What’s next?

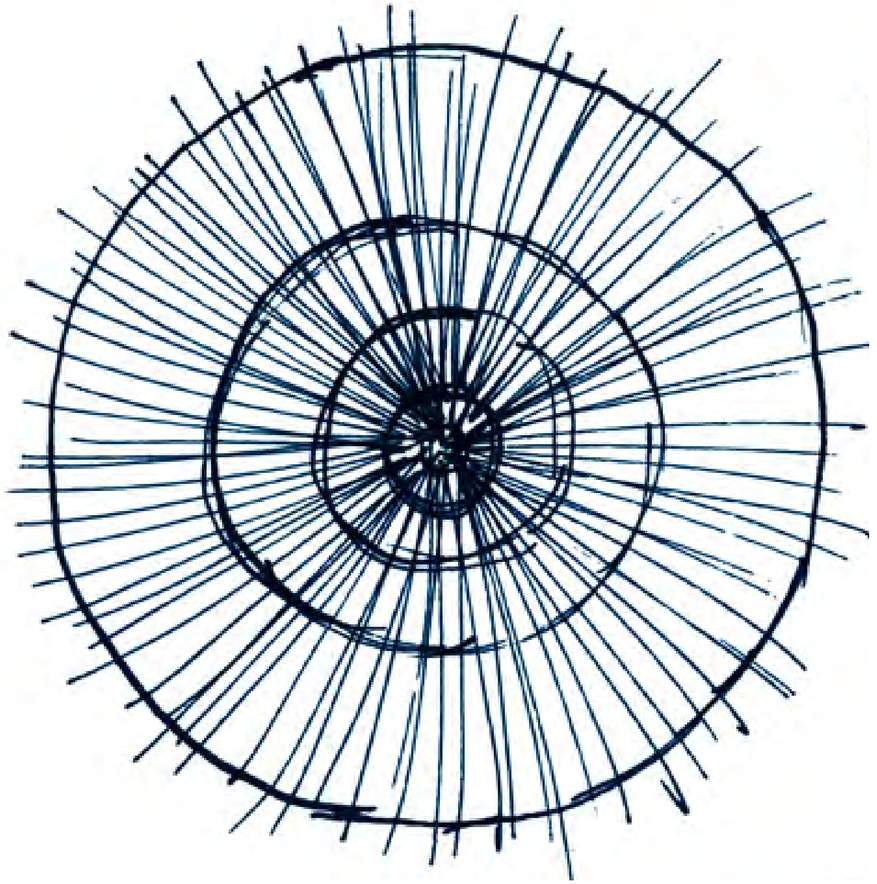
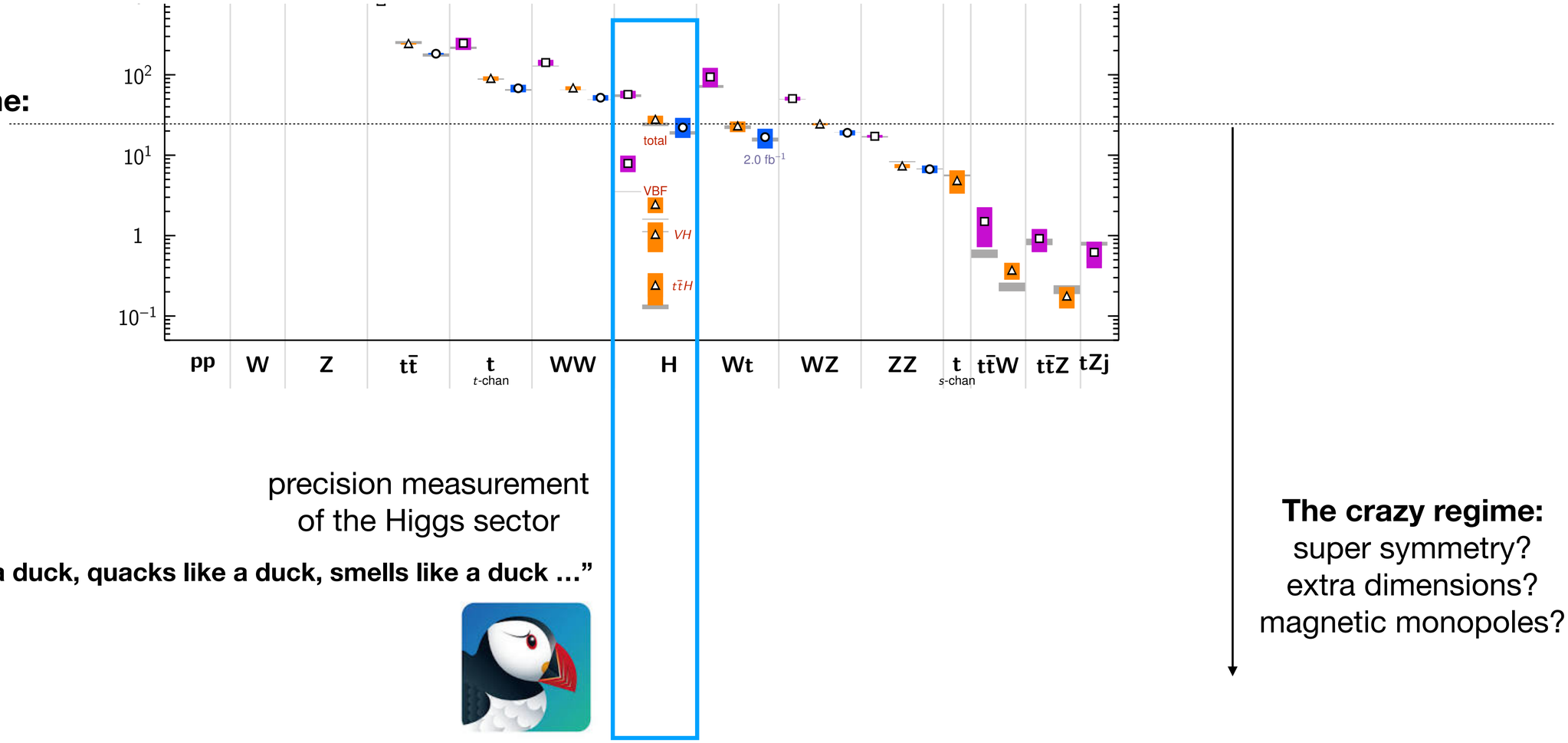


Illustration:
B. KUSSIN

The duck question

The exciting regime:
"probability" of
a Higgs boson
production

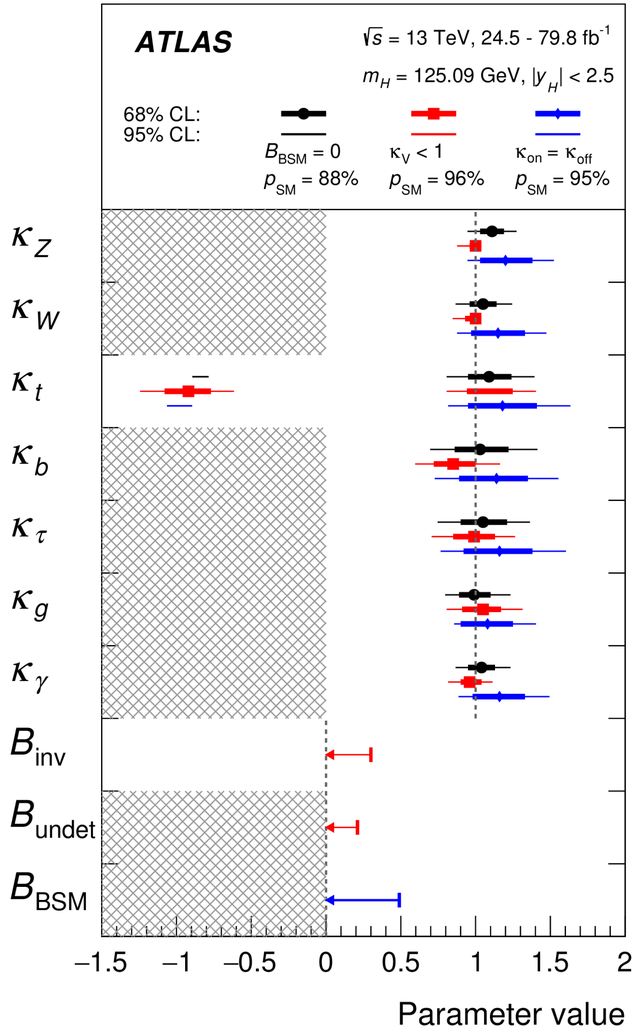


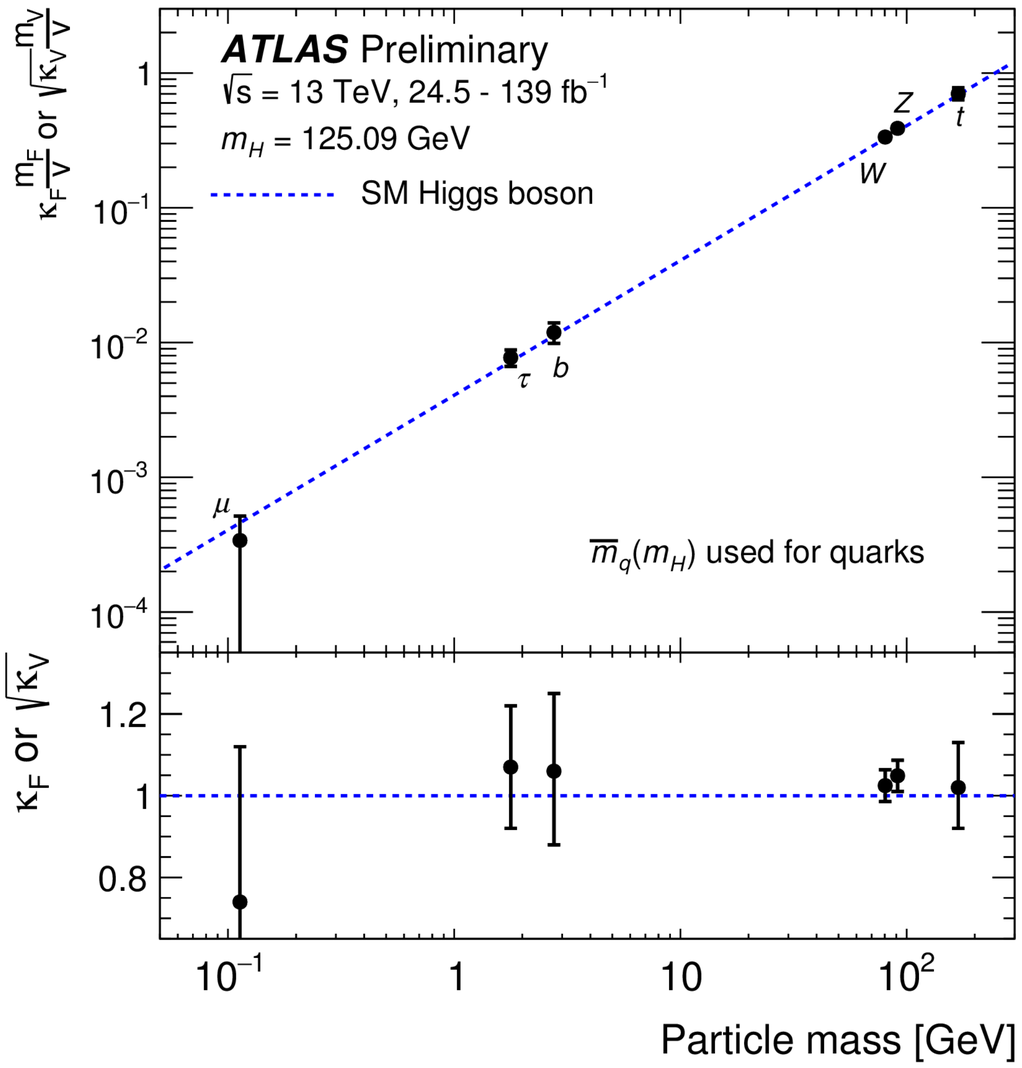
precision measurement
of the Higgs sector

"If it looks like a duck, quacks like a duck, smells like a duck …"

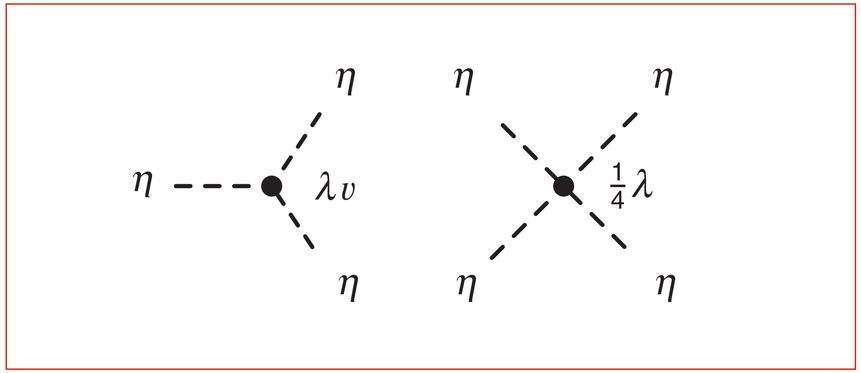
The crazy regime:
super symmetry?
extra dimensions?
magnetic monopoles?

Is it a duck?


ATLAS
√s = 13 TeV, 24.5 - 79.8 fb-1
mH = 125.09 GeV, |yH| < 2.5
68% CL:
95% CL:
BBSM = 0
pSM = 88%
κV < 1
pSM = 96%
κon = κoff
pSM = 95%
κZ
κW
κt
κb
κτ
κg
κγ
Binv
Bundet
BBSM
−1.5
−1
−0.5
0
0.5
1
1.5
2
Parameter value


ATLAS Preliminary
√s = 13 TeV, 24.5 - 139 fb-1
mH = 125.09 GeV
SM Higgs boson
mF/κFv or √κV mV/v
μ
τ
b
W
Z
t
m̄q(mH) used for quarks
κF or √κV
1.2
1
0.8
10−1
1
10
10²
Particle mass [GeV]

What's our* fate?

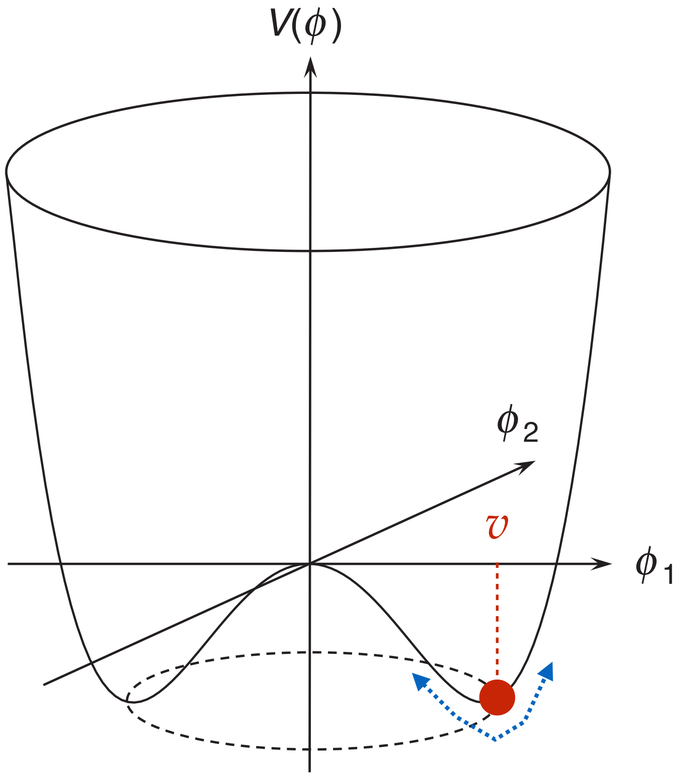


LHC:

-we have discovered the mechanism

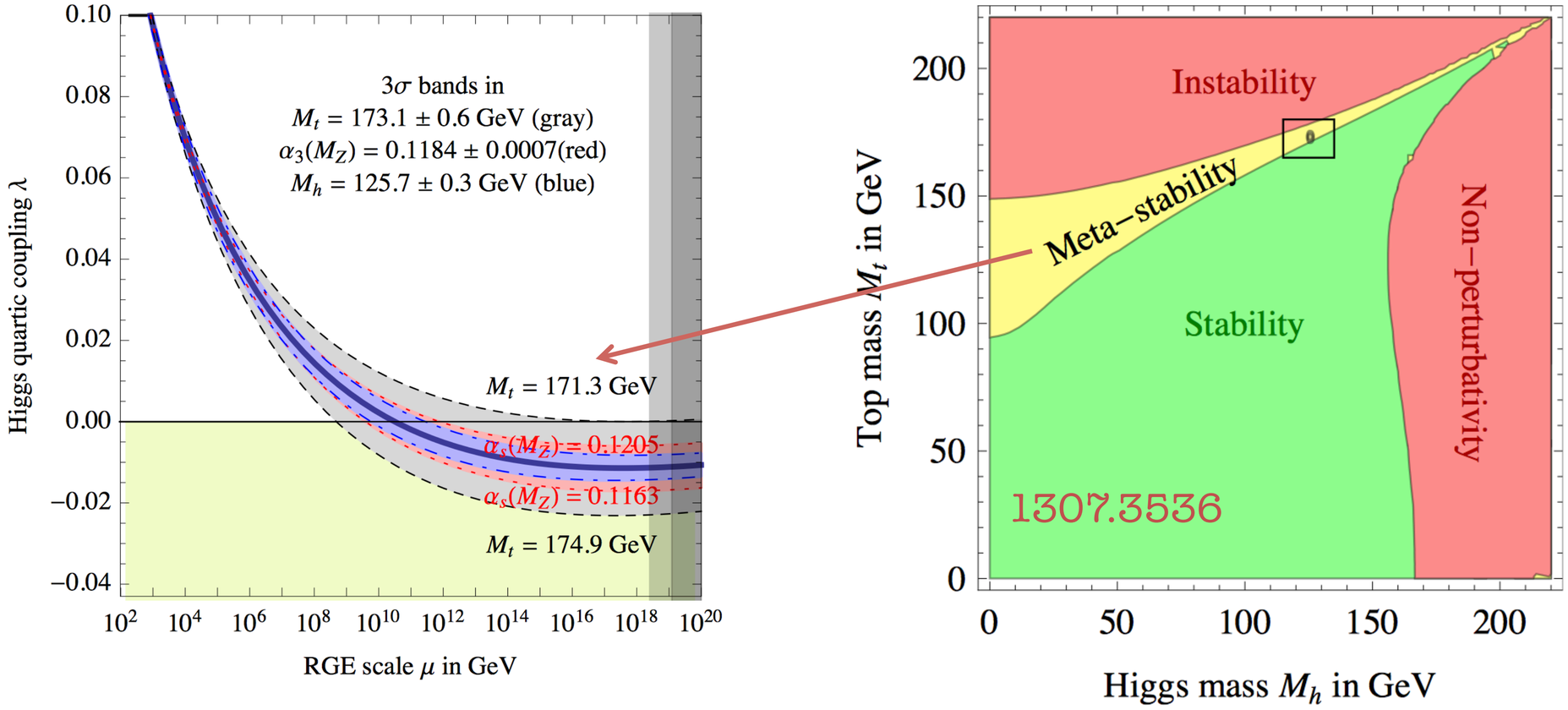
Future Collider:

-let's check the dynamics



*the universe's

What's our* fate?

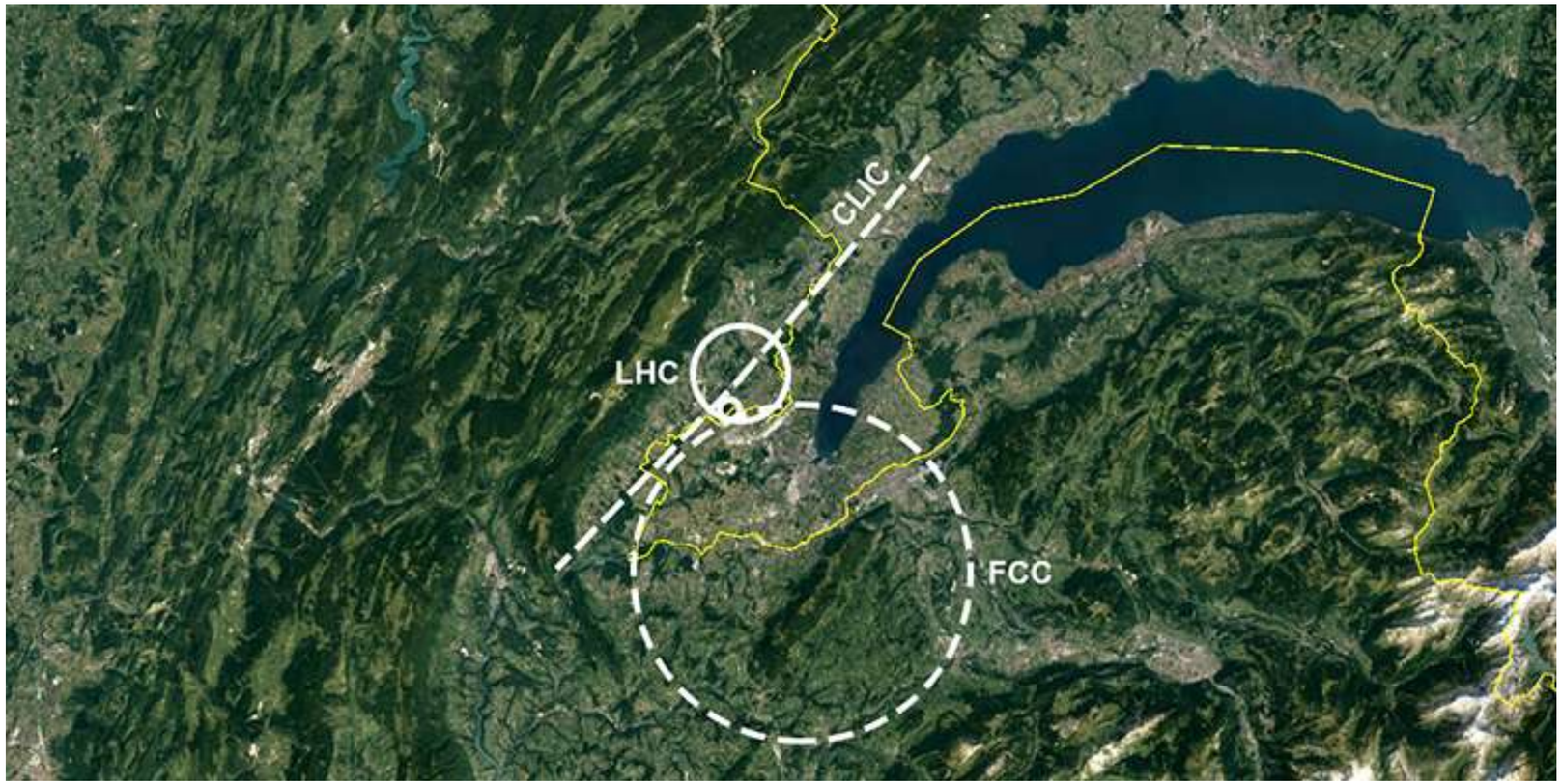


What's next?

The future, obviously.

New accelerator projects under study:

- linear collider as "Higgs factory"
- "Future circular collider (FCC)"



What to take away …

To understand the big things,
you sometimes have to look
for the small things.

Be persistent, even if it takes long.
(Higgs published 1964)

When uncertain, try to simulate it.

Even crazy things.

Thanks.