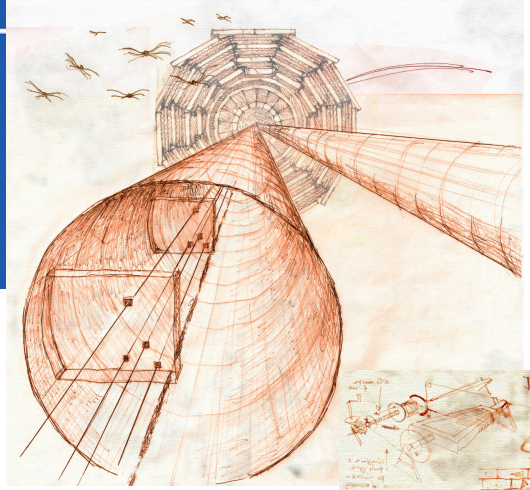
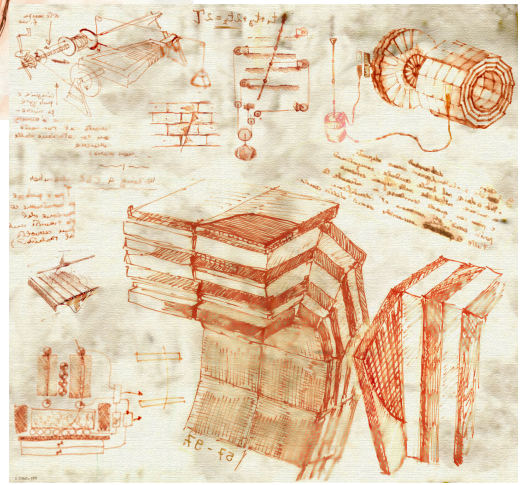
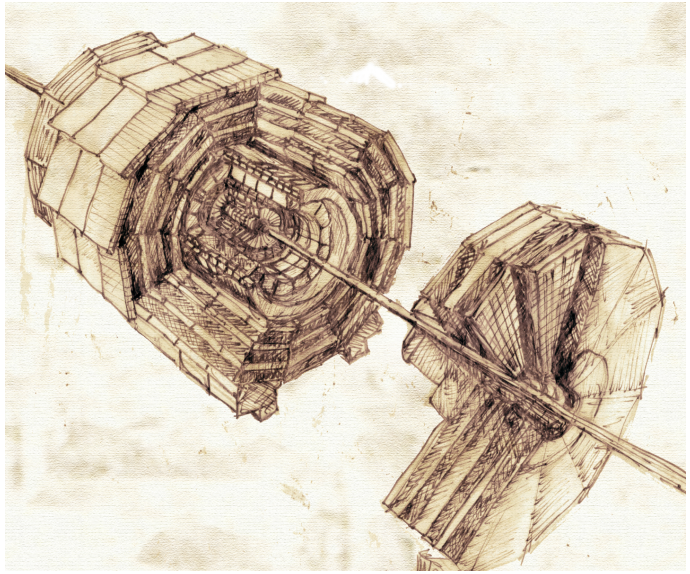
A quest from the infinitely small to the infinitely big







Alexis Kalogeropoulos

Senior Associated Researcher

Princeton University

- Conference will start shortly
- Switch off camera and microphone
- Open the *chat* tool (down-right)

Your virtual conference

Format

- Presentation (40-45 minutes in total)
- Questions and answers (20 minutes in total)

During presentation

- Ask questions using the chat
- Use microphone or camera only if needed

After presentation

- Please fill out survey on Indico page

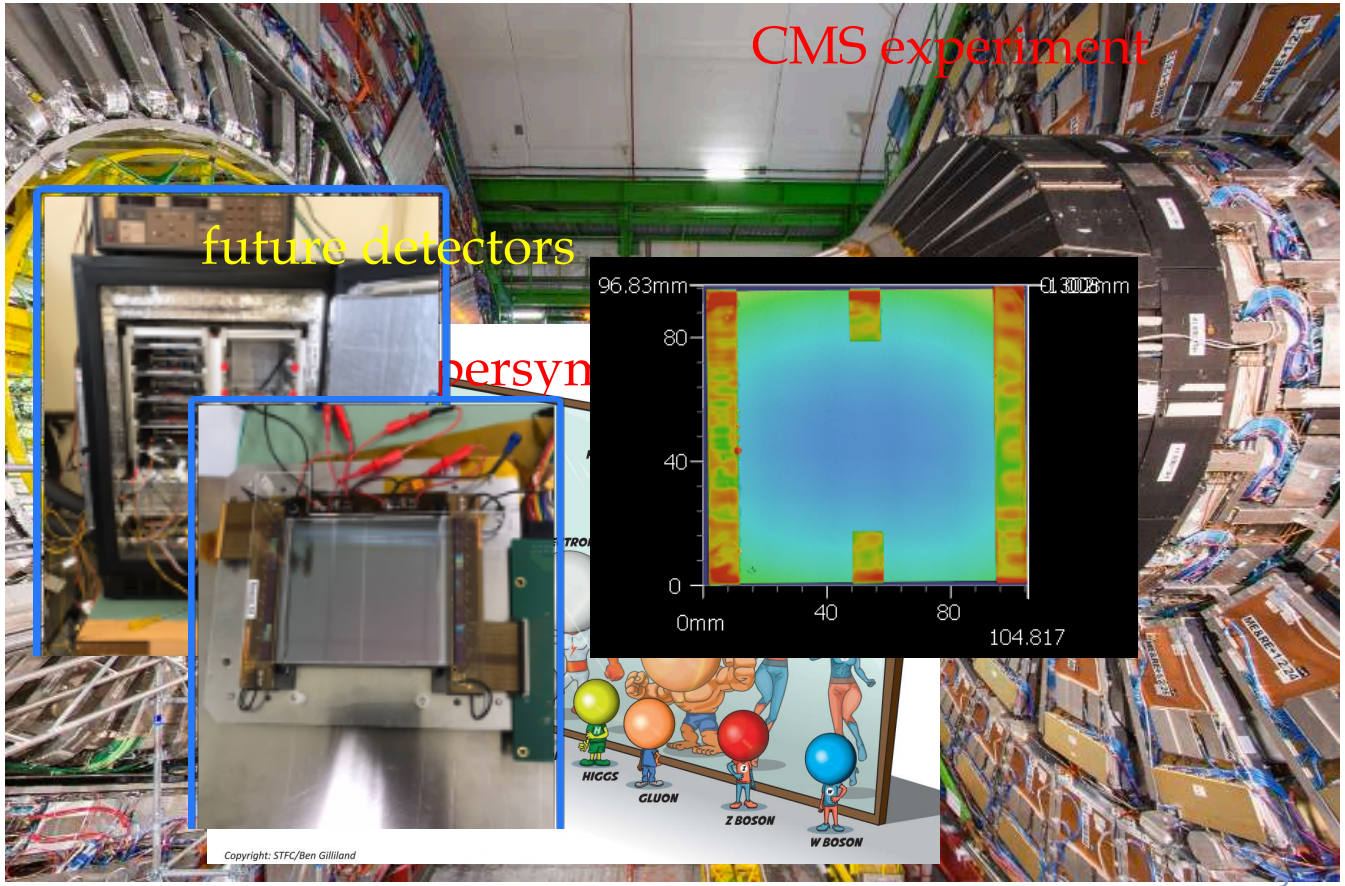
What someone like me do at CERN ?

BSc, MSc : Univ. of Athens

PhD : IIHE-VUB/Belgium

Post-doc: DESY and now

Senior Researcher @ Princeton



CERN

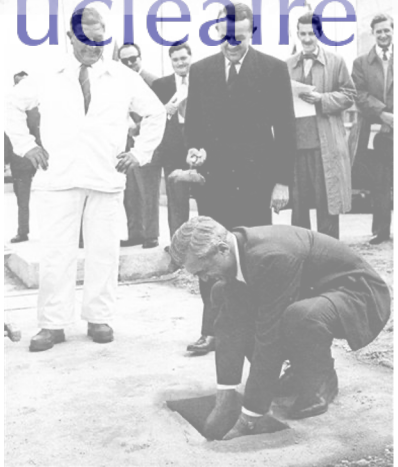
What is it?

What do you do and how?

Why do we need it?

What does *CERN* stand for ?

Conseil Européen pour la Recherche Nucléaire

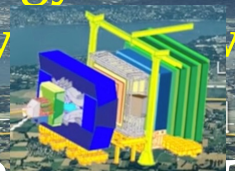


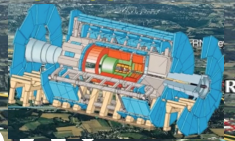
European Council for Nuclear Research

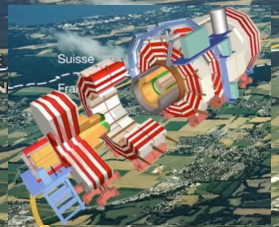
1953

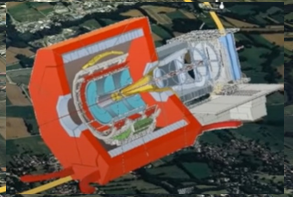
What CERN is all about?

Organization has hosted ~140 experiments of
High Energy and Nuclear Physics
Currently ...e experiments









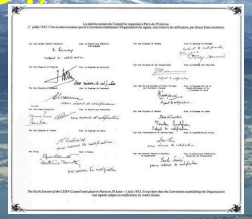
CERN Mission:

→build accelerators & detectors
→record/analyze collision data
→promote science
→transfer knowledge

Understanding nature and the laws of the universe

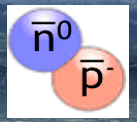
CERN History

1954, CERN is born



1957, 1st accelerator

Synchro-Cyclotron (SC)



1965,
1st observations
of antinuclei
(antideuteron)

1973, Bubble chambers

1976-83, SPS 7km

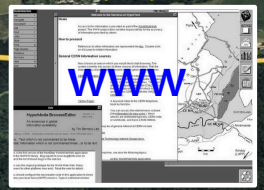
proton-antiproton
& Ion collisions

1983, Z^0, $W^{\pm}$ discovery

1989-2000,
LEP 27km,

e^-e^+ collisions

1989



1st website/server

1998-2008,
LHC + 4 experiments

….2040
long research program!

Video: CERN's history

A worldwide collaboration

23 member states

8 associated

6 observers

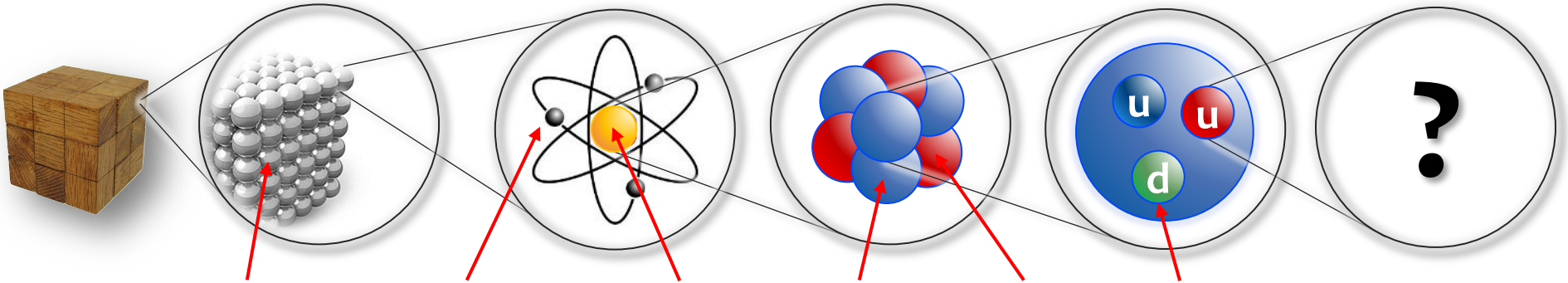
Budget (2020)
1,168 billion CHF
0,970 billion GBP
1,210 billion USD
1,1 billion EUR

1 coffee/per person/year!

61 with agreements

Fundamental research

What is the matter made of?



atom — 4^{th} - 5^{th} BCE

electron — nucleus — End of 19^{th} century

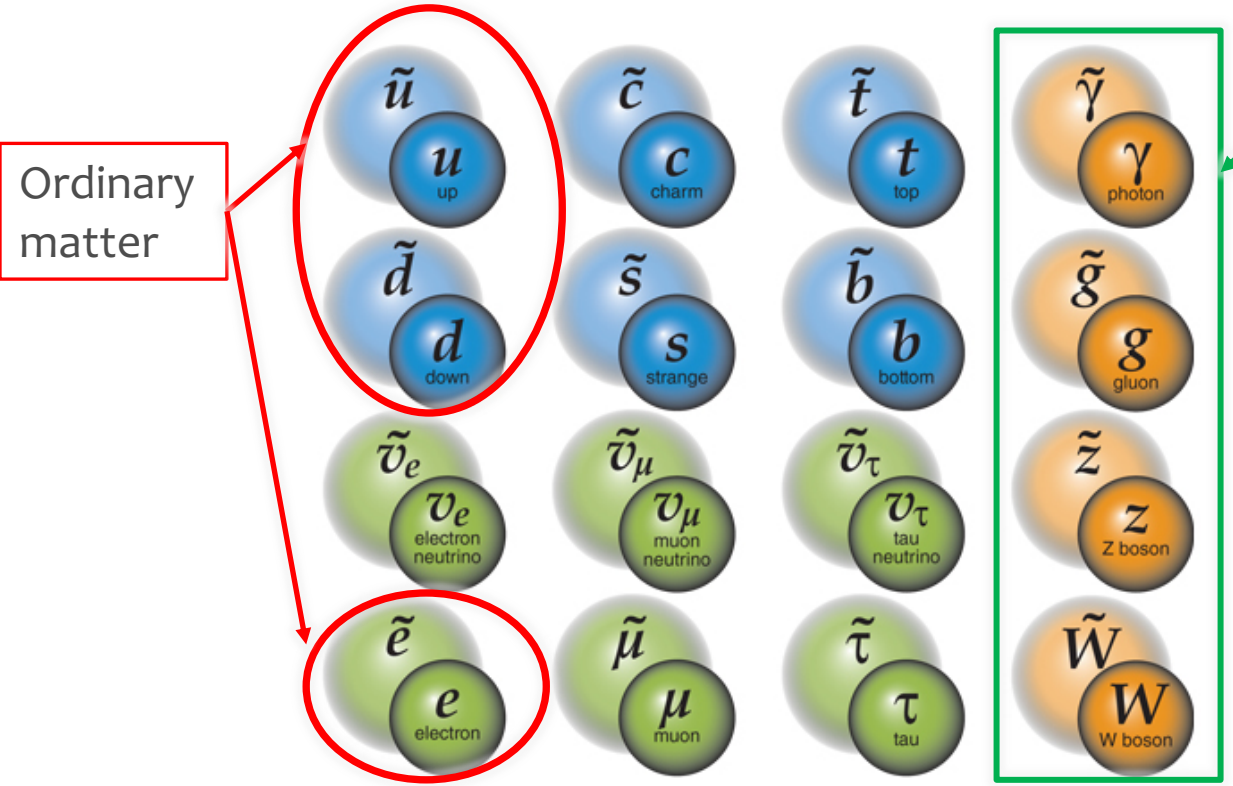
proton — neutron — Begining of 20^{th} century

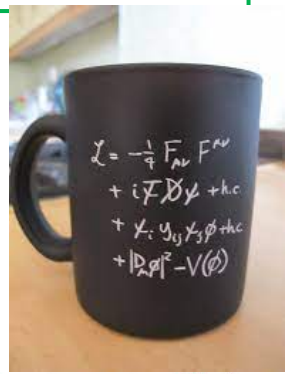
quark — 1960s

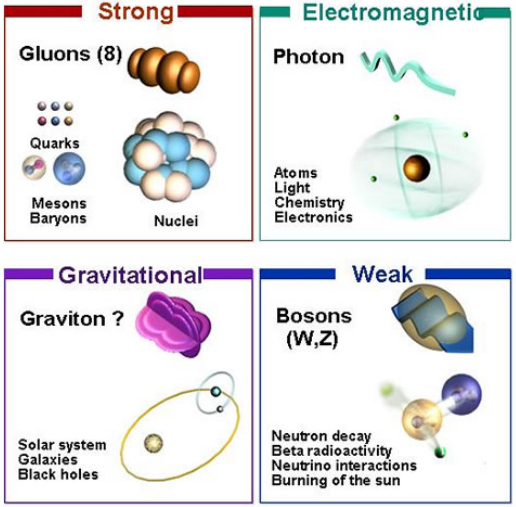
The standard model of particle physics

Ordinary matter

Force carriers





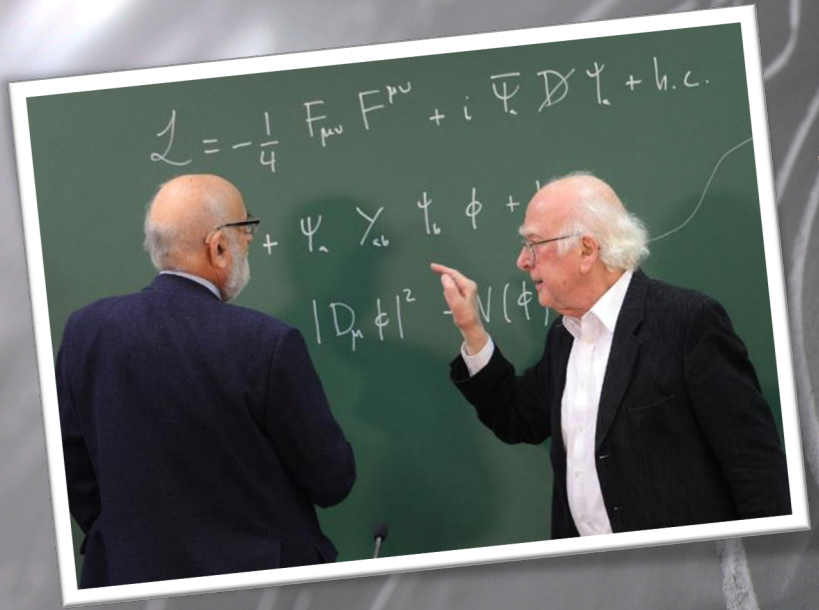


Gravity is not part of this picture. Do you know why?

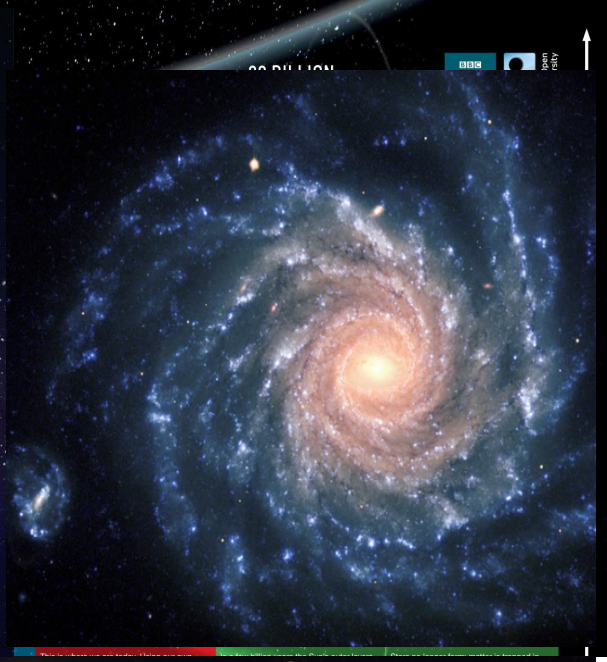
More on the Standard Model

Voyage to the world of atoms

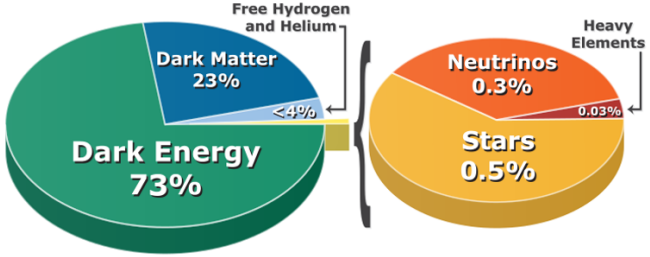
Answering questions…

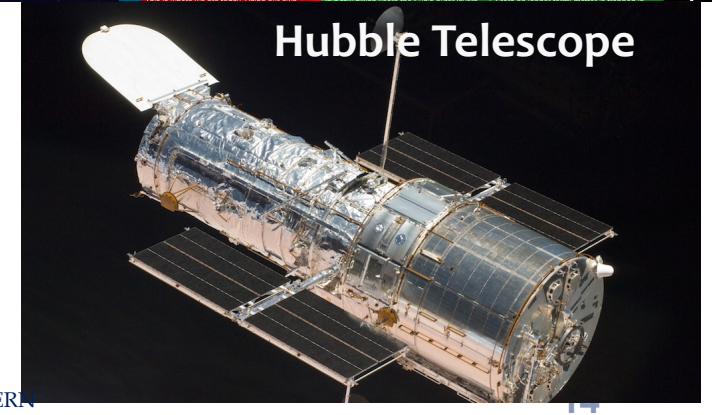


Higgs?



- Structure and evolution of the universe ?
- Dark Matter ?
- Dark Energy ?

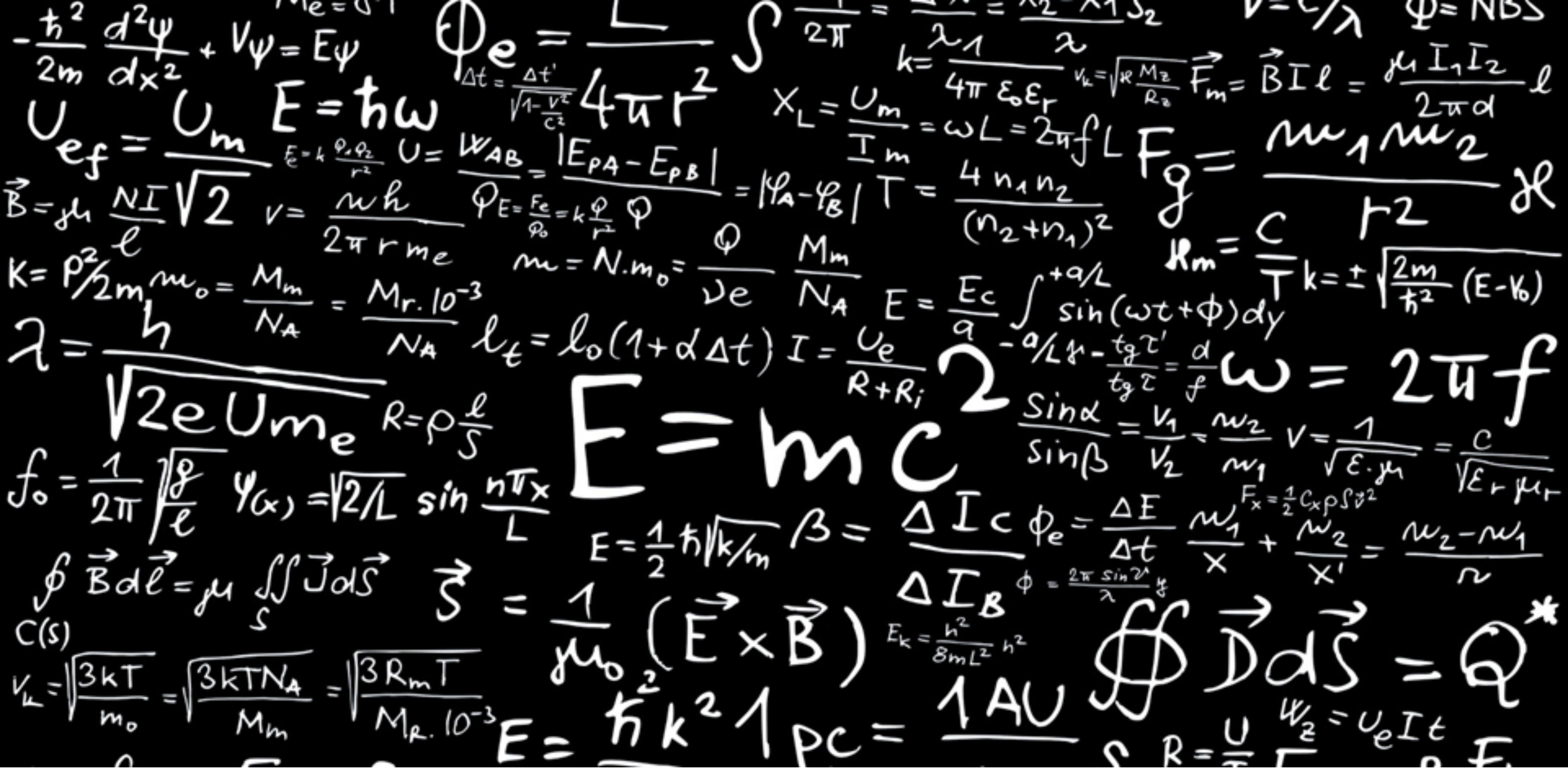


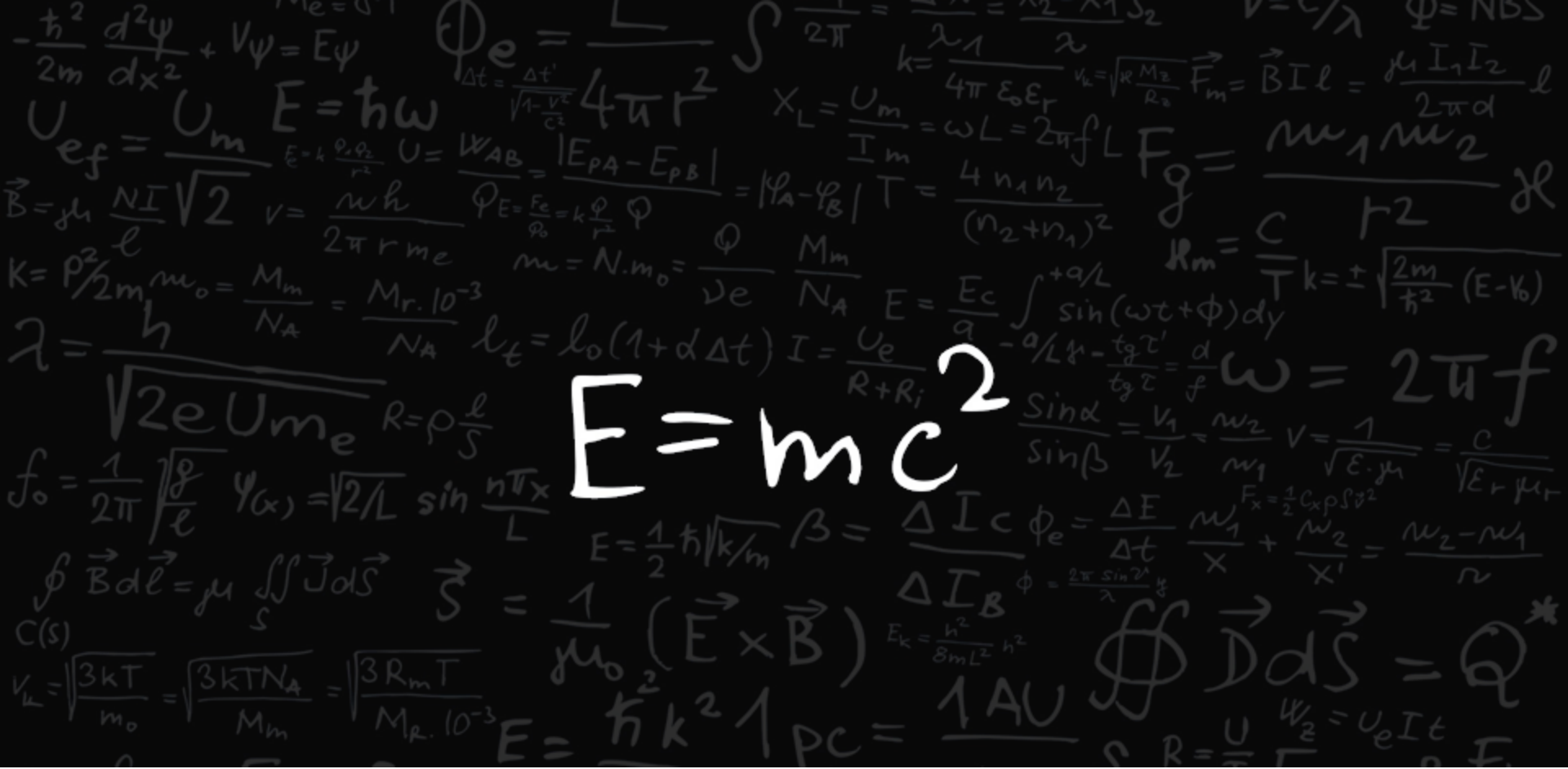


Matter & Antimatter

https://ams02.space/

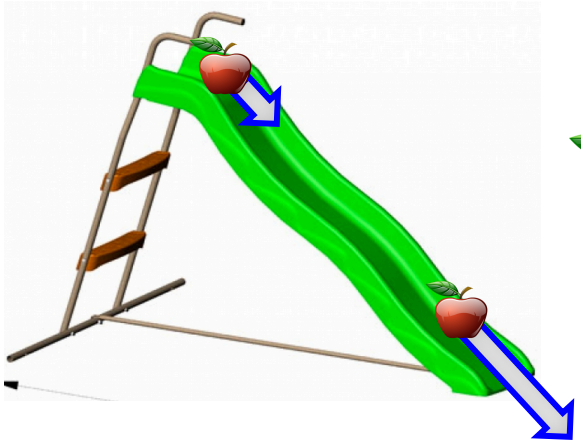
CERN
How does it work?


E = mc2
E = ħω
ω = 2πf

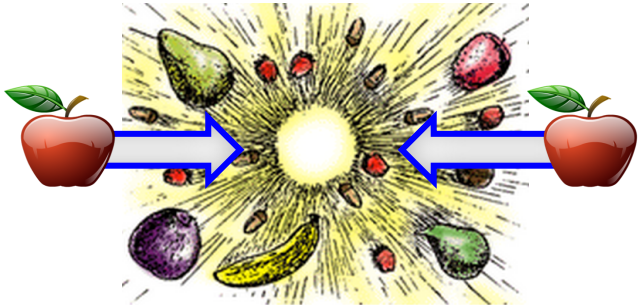

E=mc²

How do we study things?

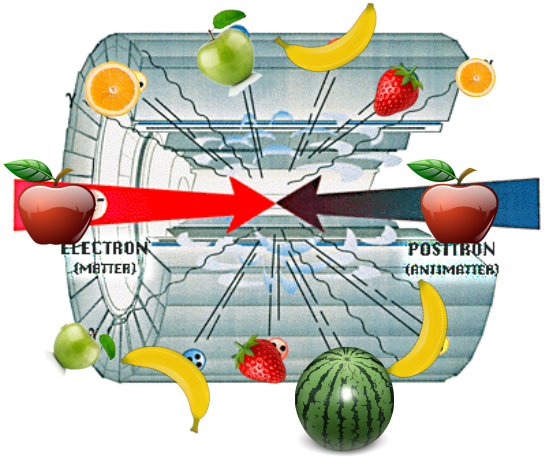
1.Acceleration !



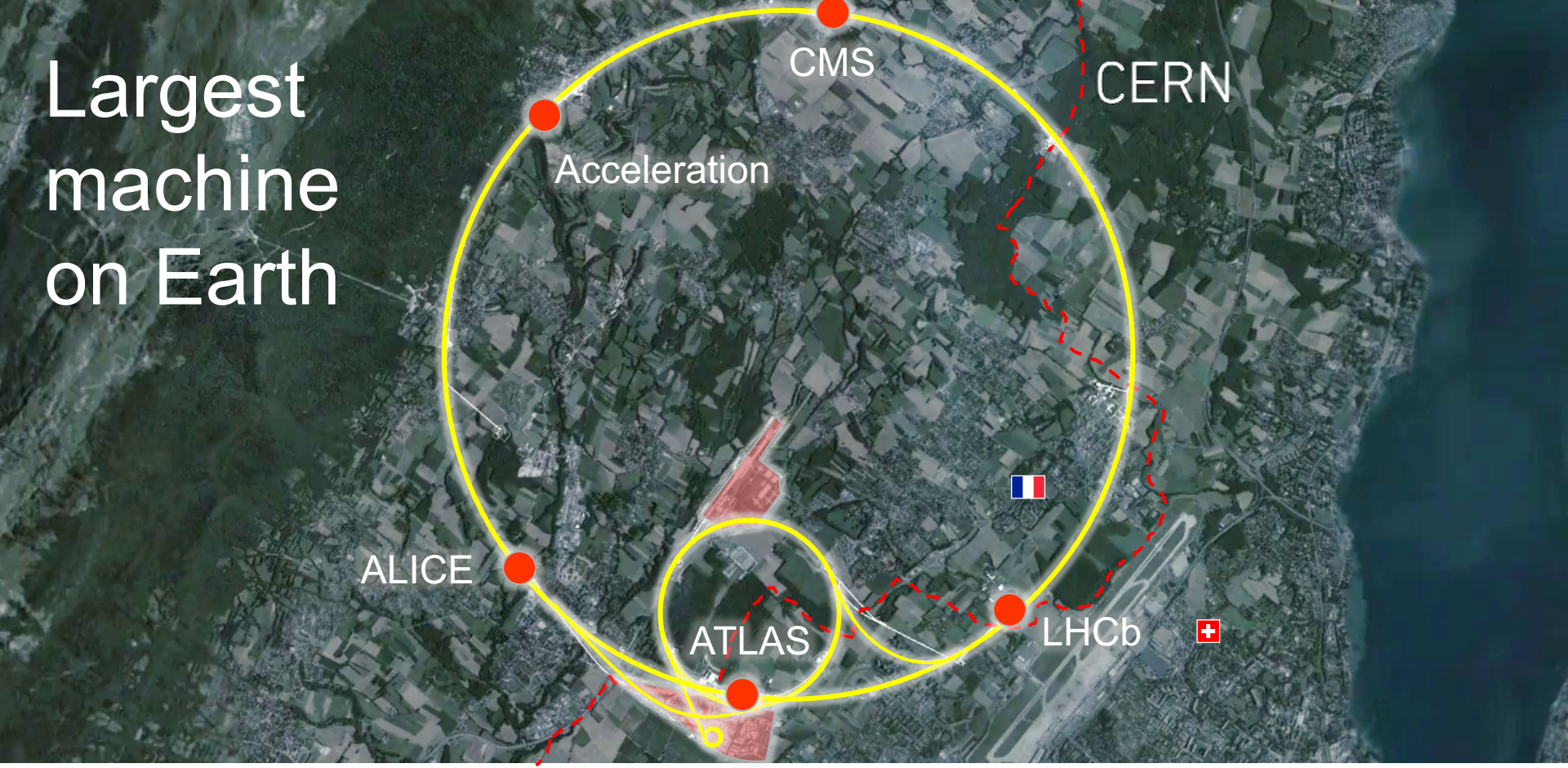
2.Collision !



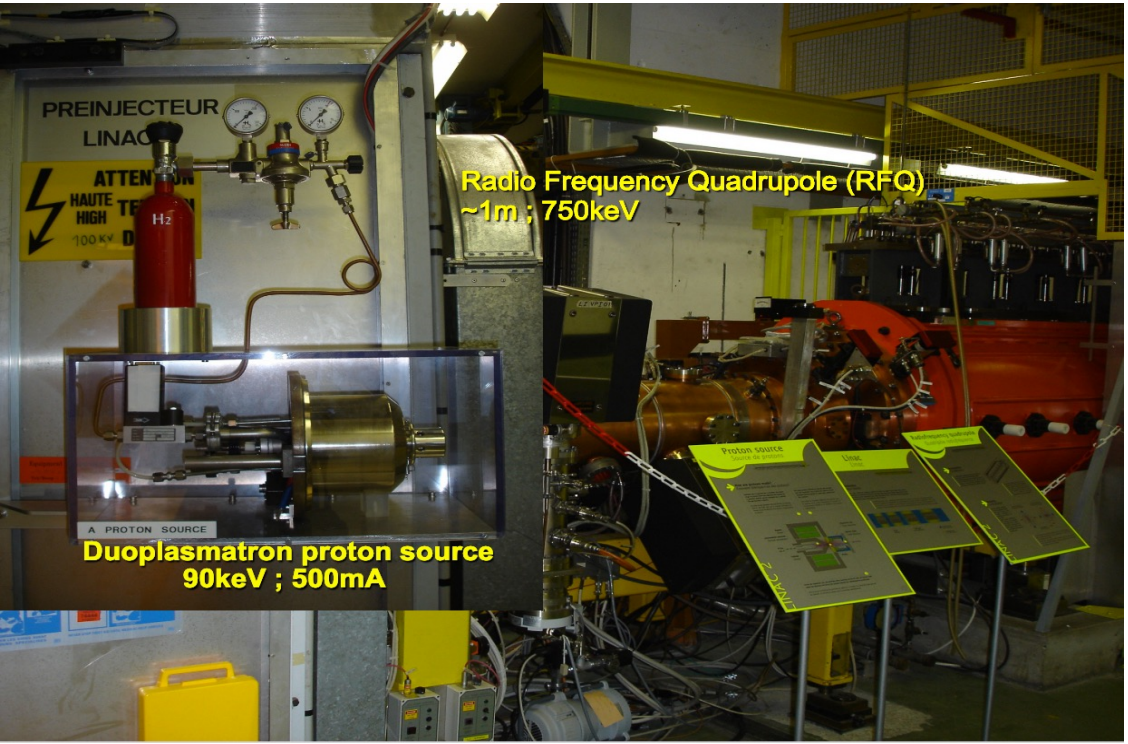
3.Detection !



Largest machine on Earth



How to make a proton beam?



1.Everything starts from a plain bottle of H_2

2.Hydrogen atoms are stripped from their electrons

to get protons

$$H_2 + e^- \rightarrow H_2^+ + 2e^-$$
$$H_2^+ + e^- \rightarrow H^+ + H + e^-$$
$$H + e^- \rightarrow H^+ + 2e^-$$
$$H_2 \rightarrow 2\,H^+ + 2e^-$$

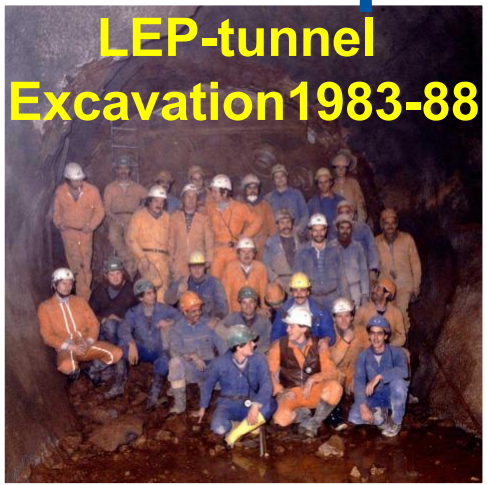
For the LHC beam, we need:
2808 bunches x $1.15 \cdot 10^{11} = 3 \cdot 10^{14}$ protons per beam
or, $6 \cdot 10^{14}$ protons for the two beams (1)

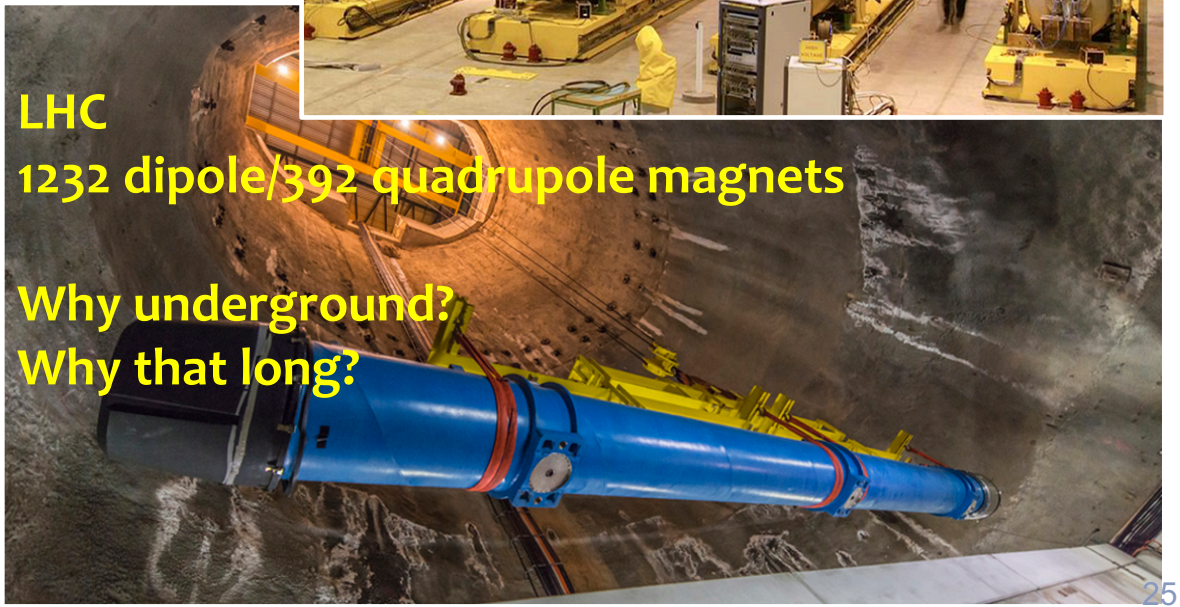
A single cubic centimetre of hydrogen gas at room temperature contains ~ **$N = 2.4 \cdot 10^{19}$ molecules**

Since the LHC is filled every ten hours, this cylinder could be used for:

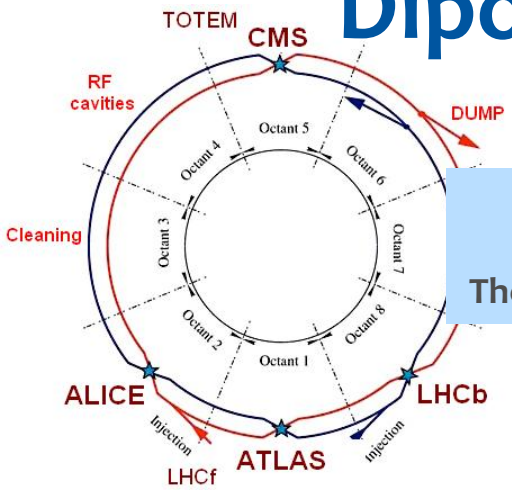
$10 \times 3.5 \cdot 10^{12} = 3.5 \cdot 10^{13}$ hours
~ $4 \cdot 10^9$ years !!!

Preparing the LHC ~1998-2010

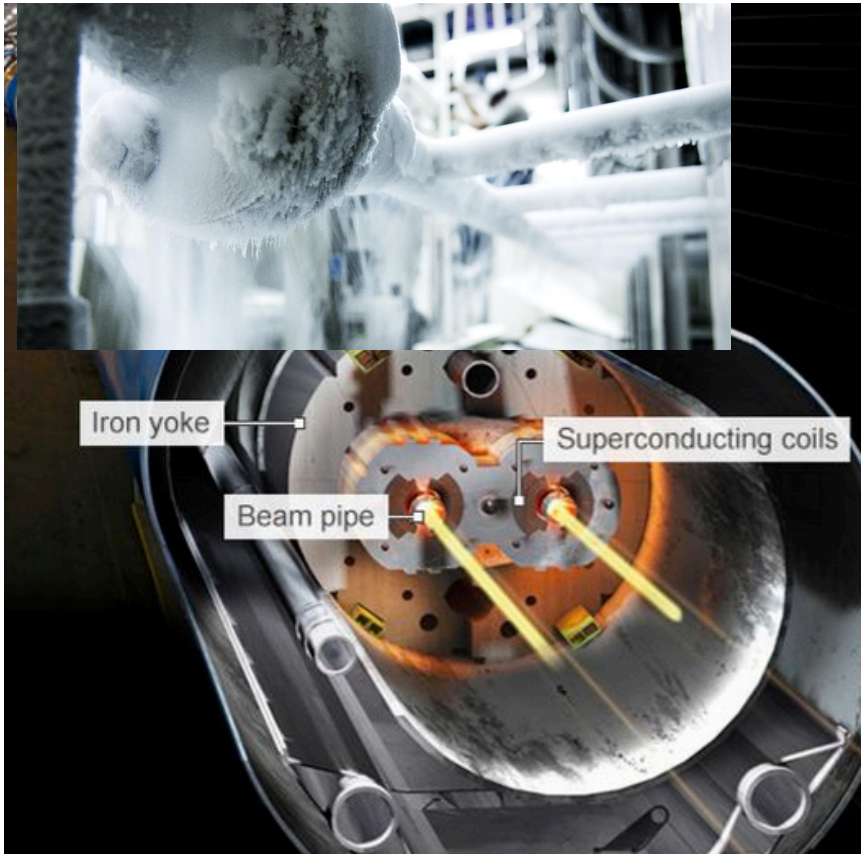




Dipole Magnet's Anatomy

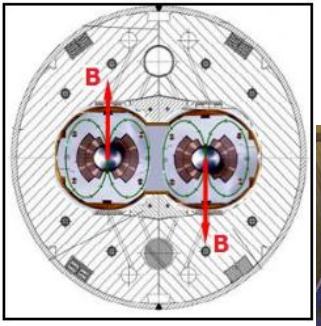


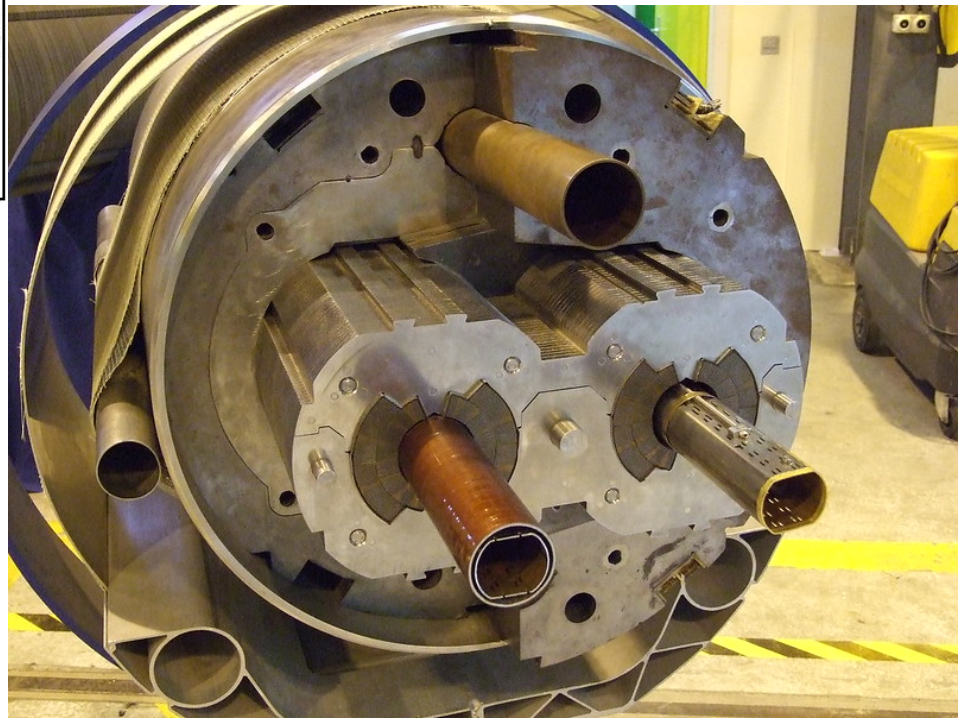
Liquid helium cooling
1.9 K = -271.3 C
The "coolest" place on earth

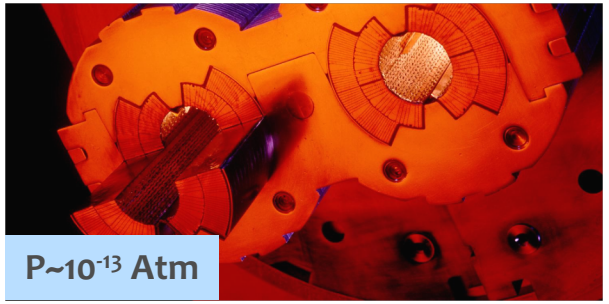


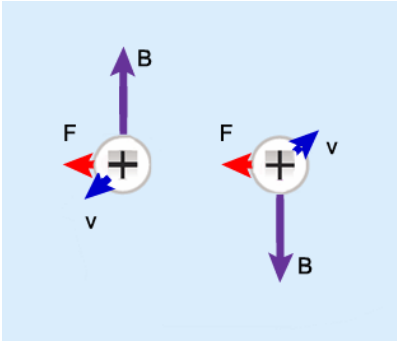
- ✓2 parallel p-p beams (7+7=14 TeV)
  - ✓How many turns the beams complete/sec?
- ✓Magnets to bend the beams (8.33 T)
- ✓Superconductors (12000 Ampere)
  - ✓How that compares to your household?

Magnetic Dipoles





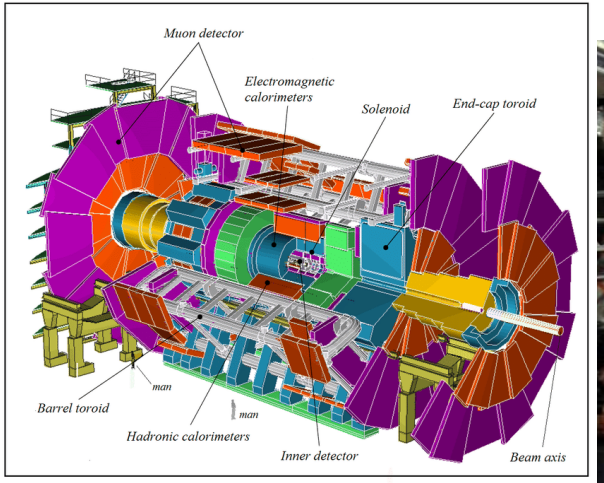




$$quB = \frac{mu^2}{r} \rightarrow p = qBr$$

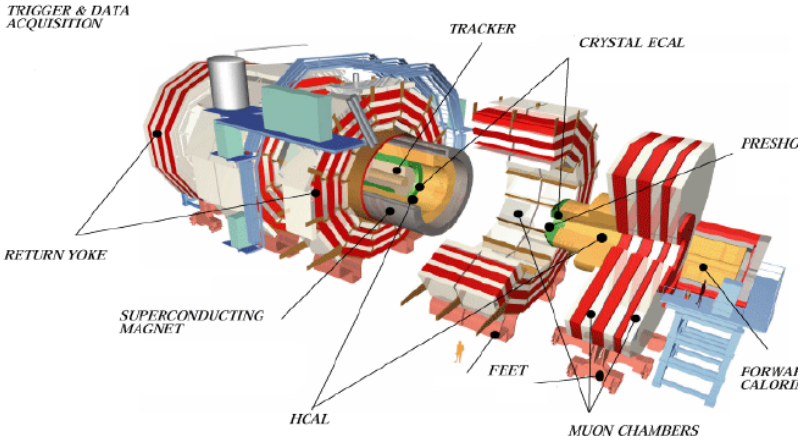
Curving the beams: Lorentz Forced achieved by the 8.33 T

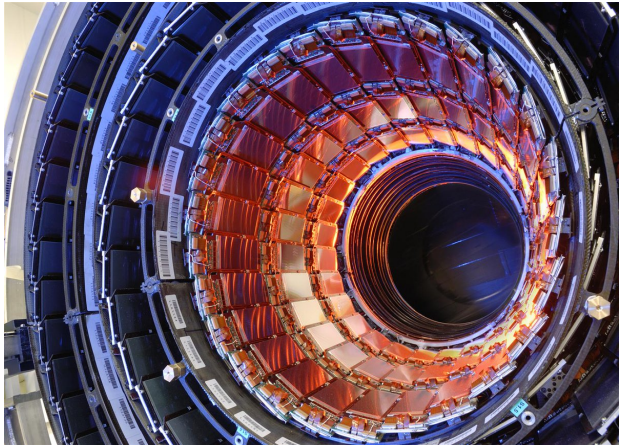
Q: Do you see the connection between strong magnets and big rings (ie why the LHC needs to be that long) ?

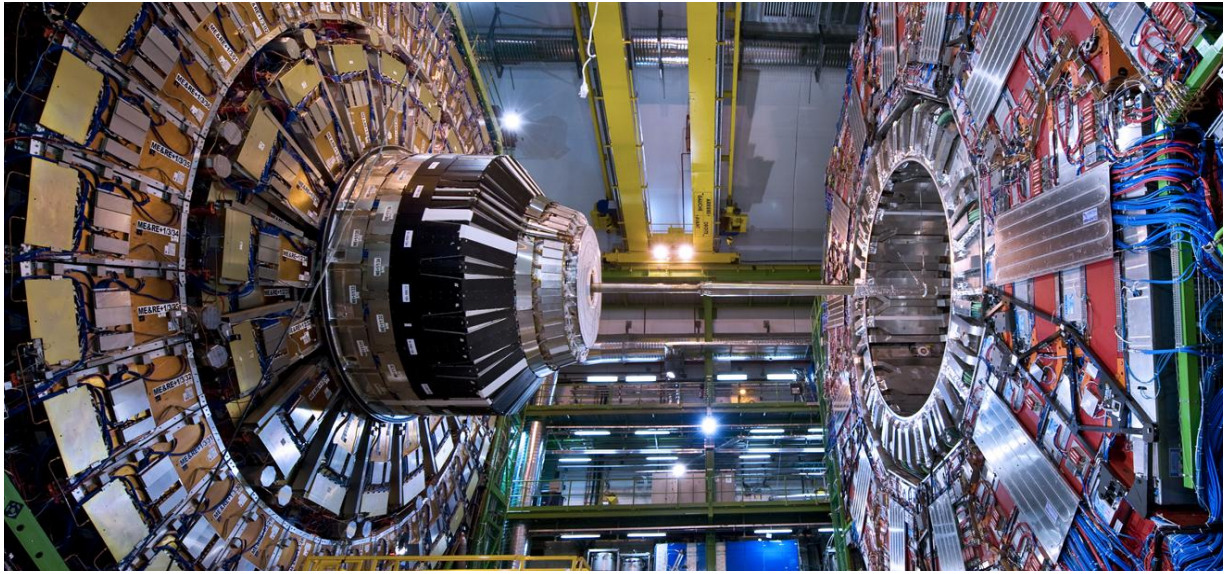

Muon detector
Electromagnetic calorimeters
Solenoid
End-cap toroid
Barrel toroid
man
man
Hadronic calorimeters
Inner detector
Beam axis

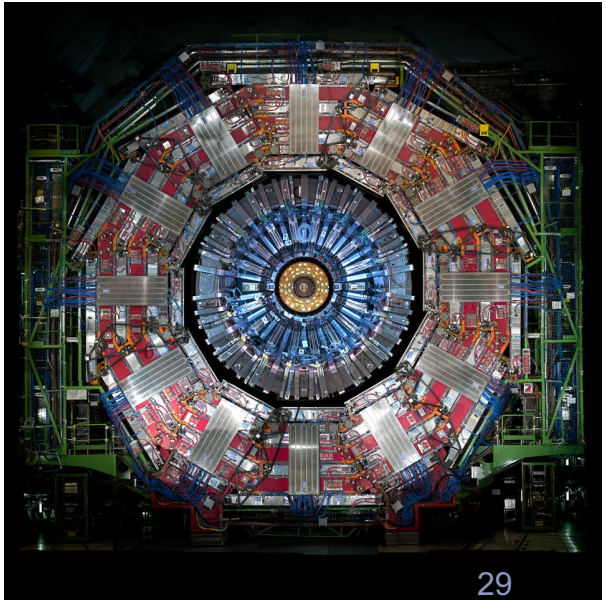
ATLAS

CMS

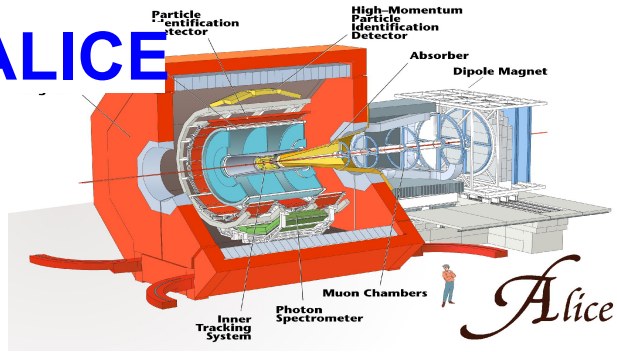

TRIGGER & DATA ACQUISITION
TRACKER
CRYSTAL ECAL
PRESHO
RETURN YOKE
SUPERCONDUCTING MAGNET
FEET
FORWAI CALORI
HCAL
MUON CHAMBERS





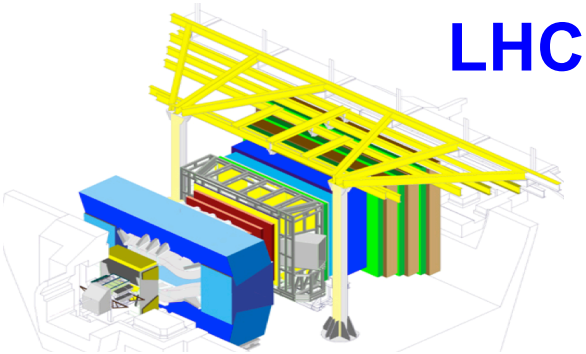


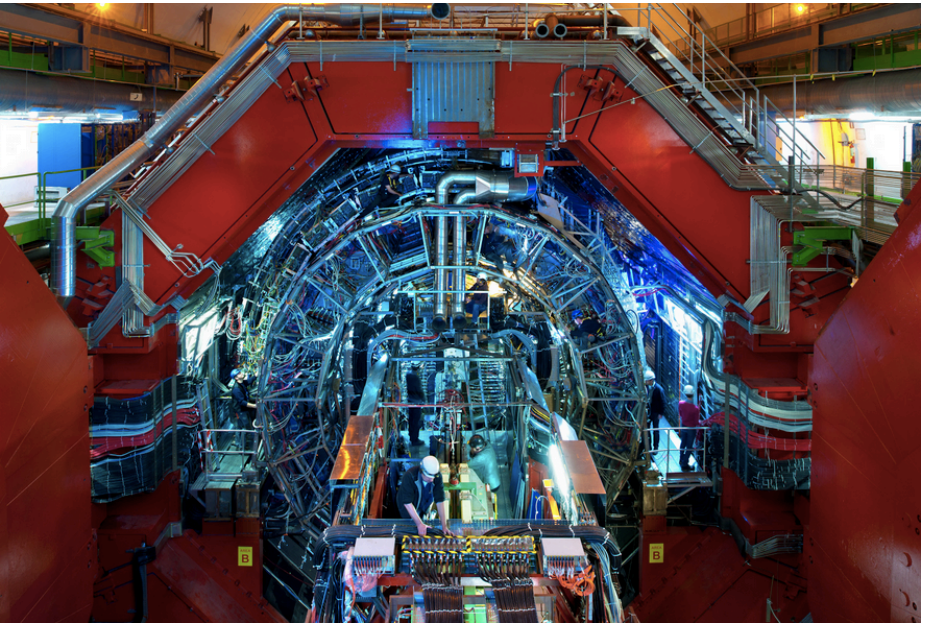
ALICE

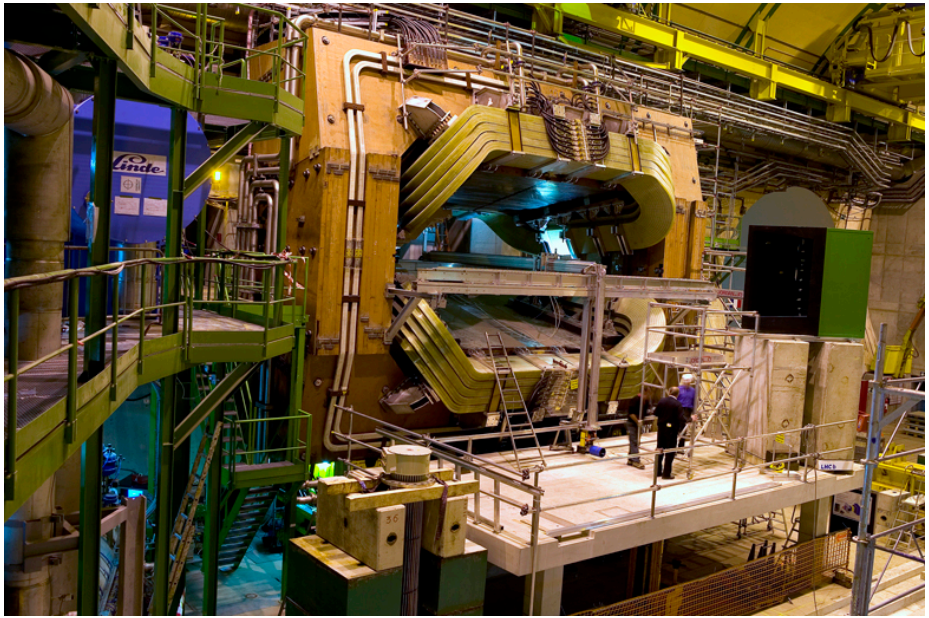


Non-General purpose experiments

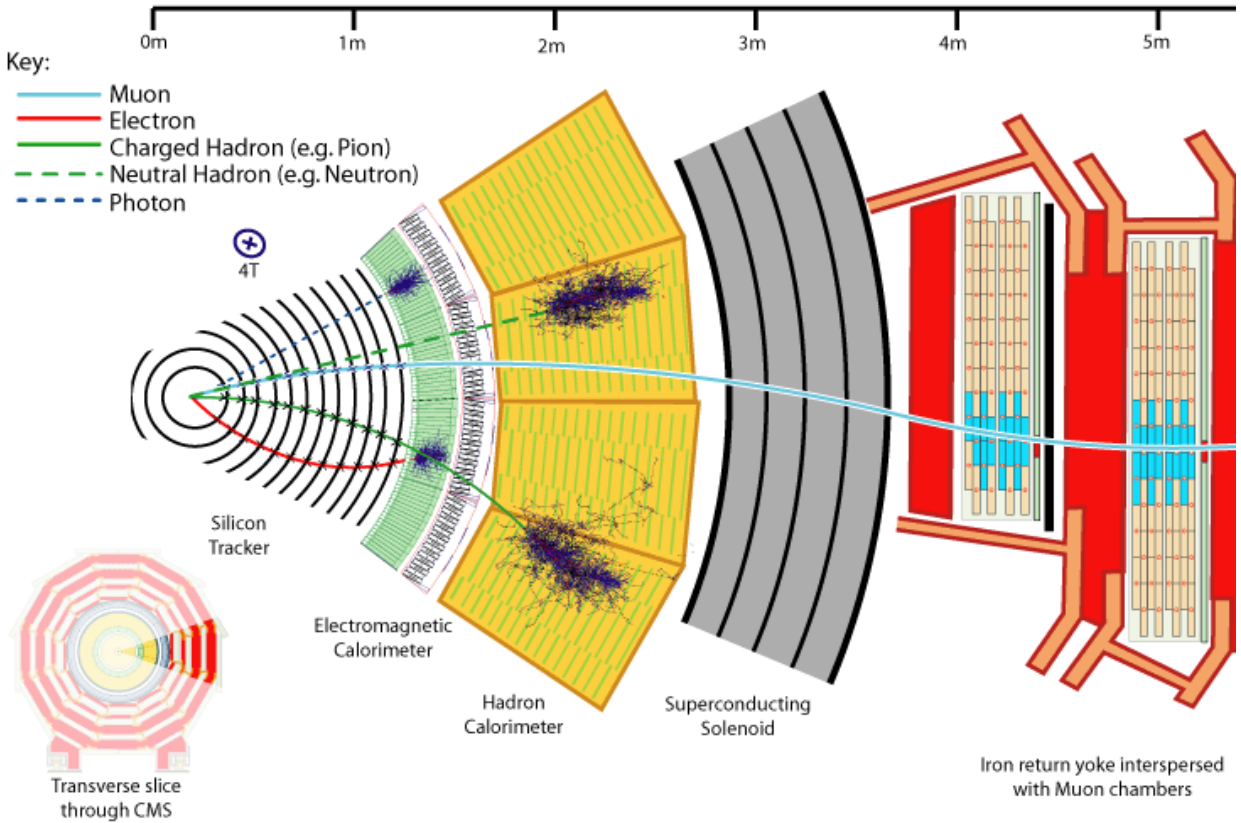
LHCb

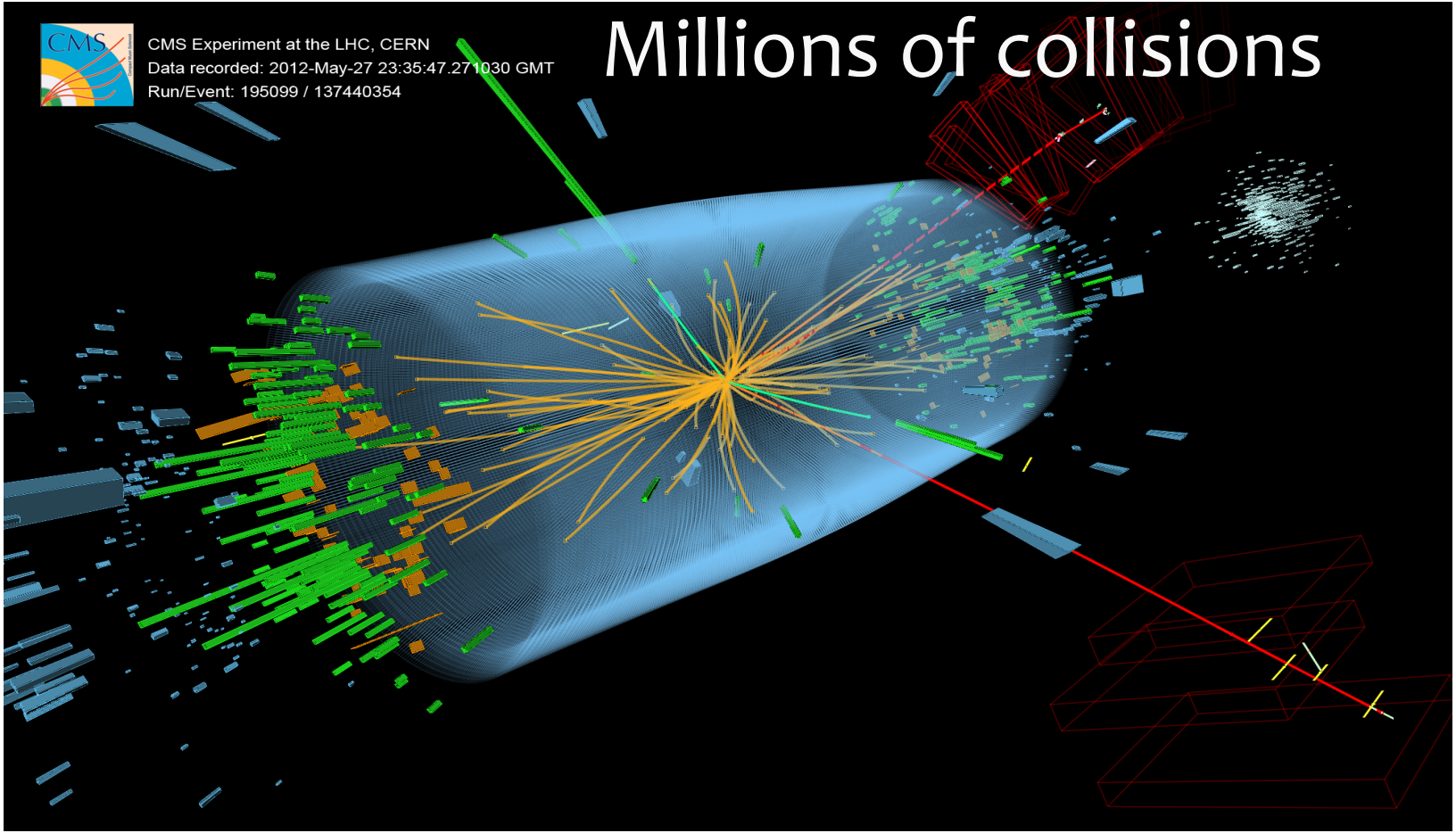




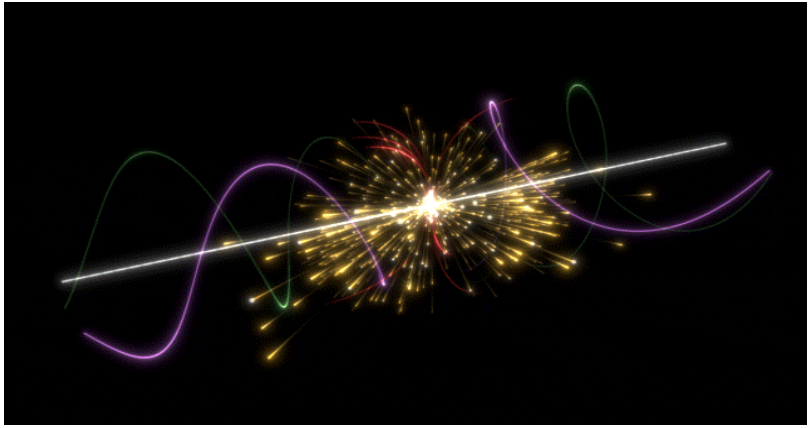


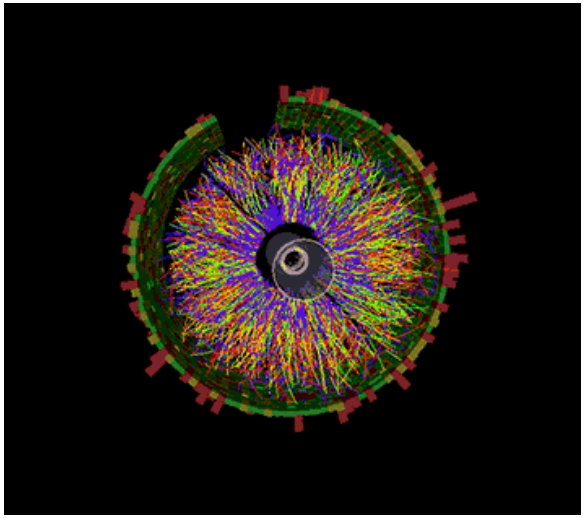
Anatomy of a detector

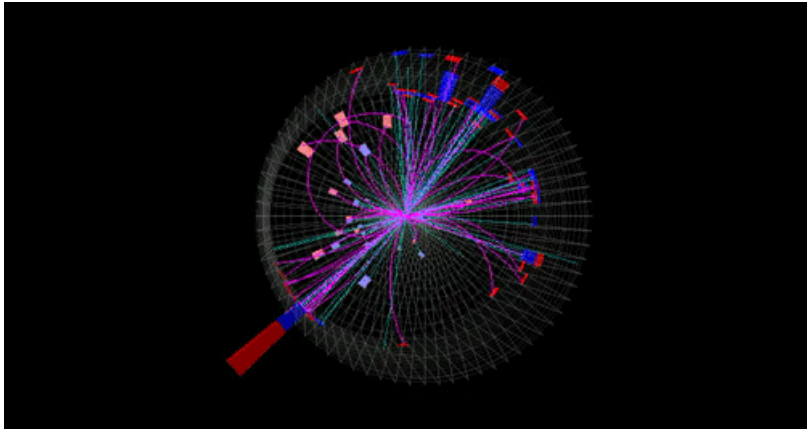


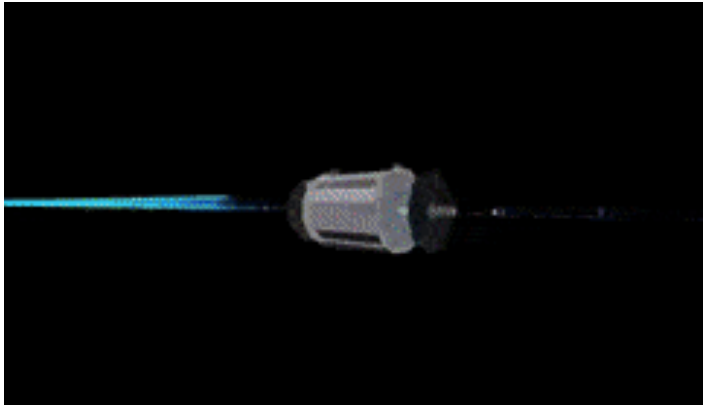

CMS Experiment at the LHC, CERN
Data recorded: 2012-May-27 23:35:47.271030 GMT
Run/Event: 195099 / 137440354
Millions of collisions

Millions of collisions!!!

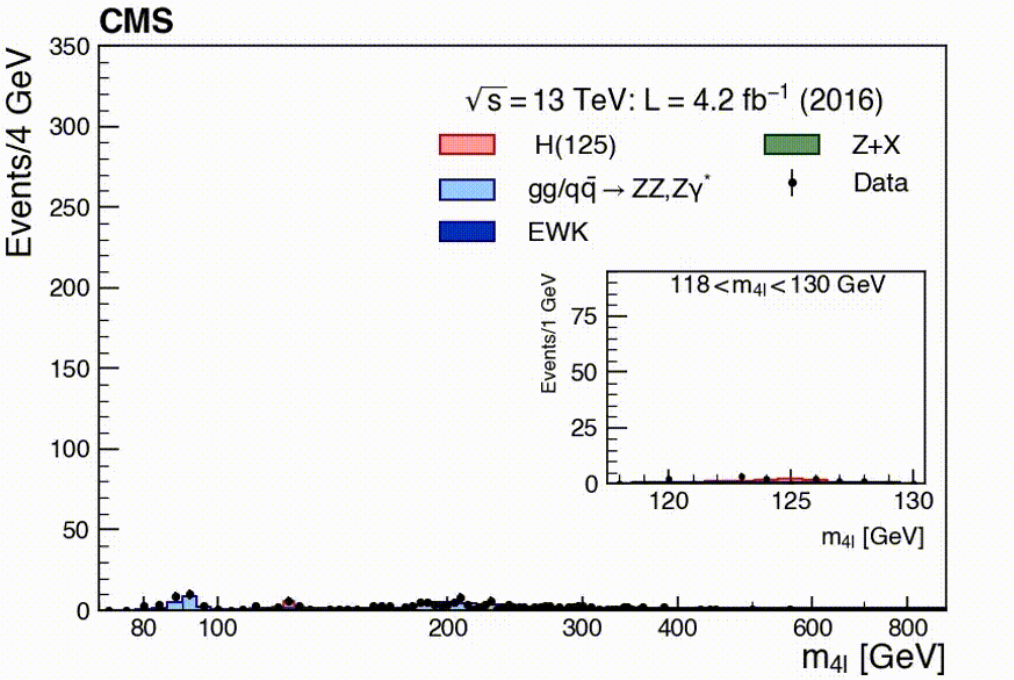


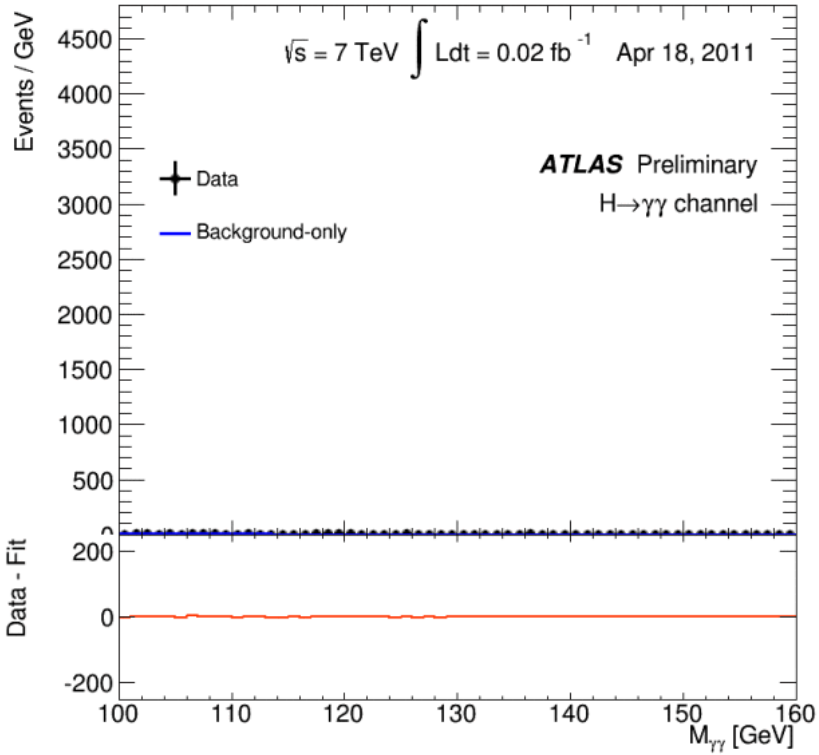




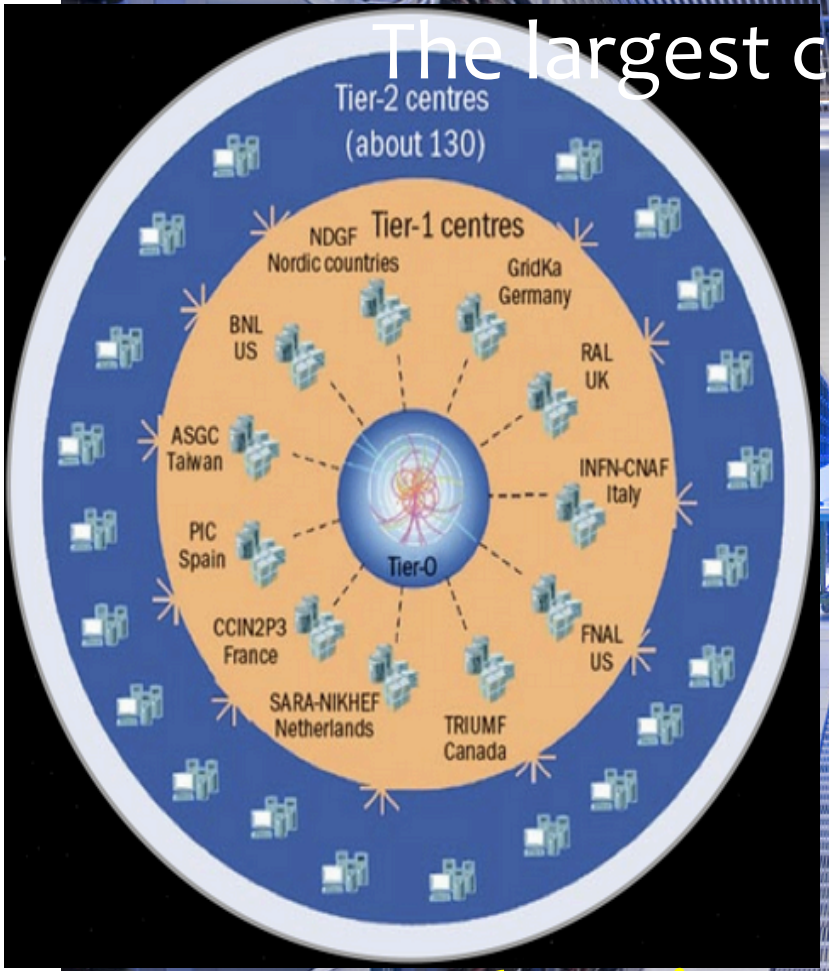


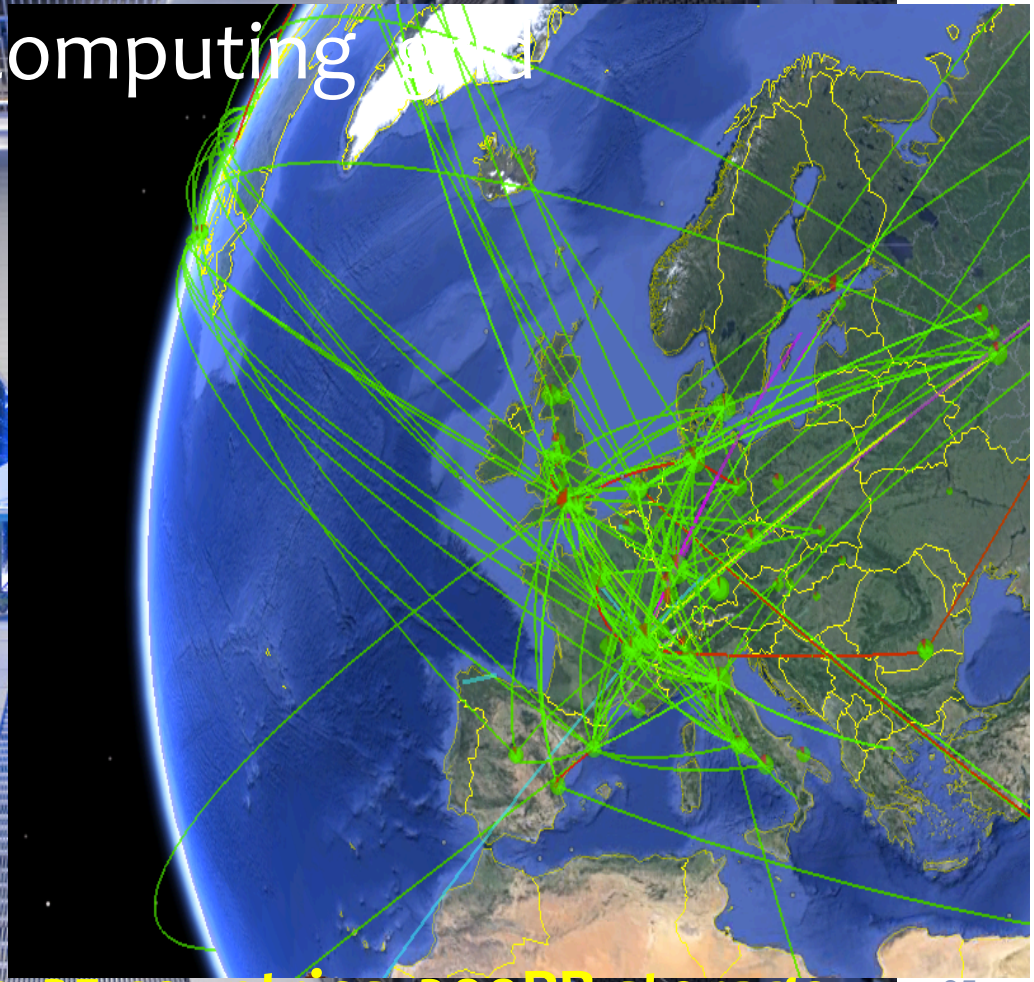
Physics @ LHC - Data analysis





The largest computing grid





250M cores,160 Institutes, 35 countries, 200PB storage

CERN
So what?

CERN is NOT just about physics…

- **Technology**
  Touch screen, WWW, GRID

- **Medicine applications,**
  Medical imaging (PET scan)
  Hadron therapy
  (Cancer treatment)

- **Education**
  [schools & seminars] (S'Cool lab etc)
  (b|d)rinks people together from all over the world

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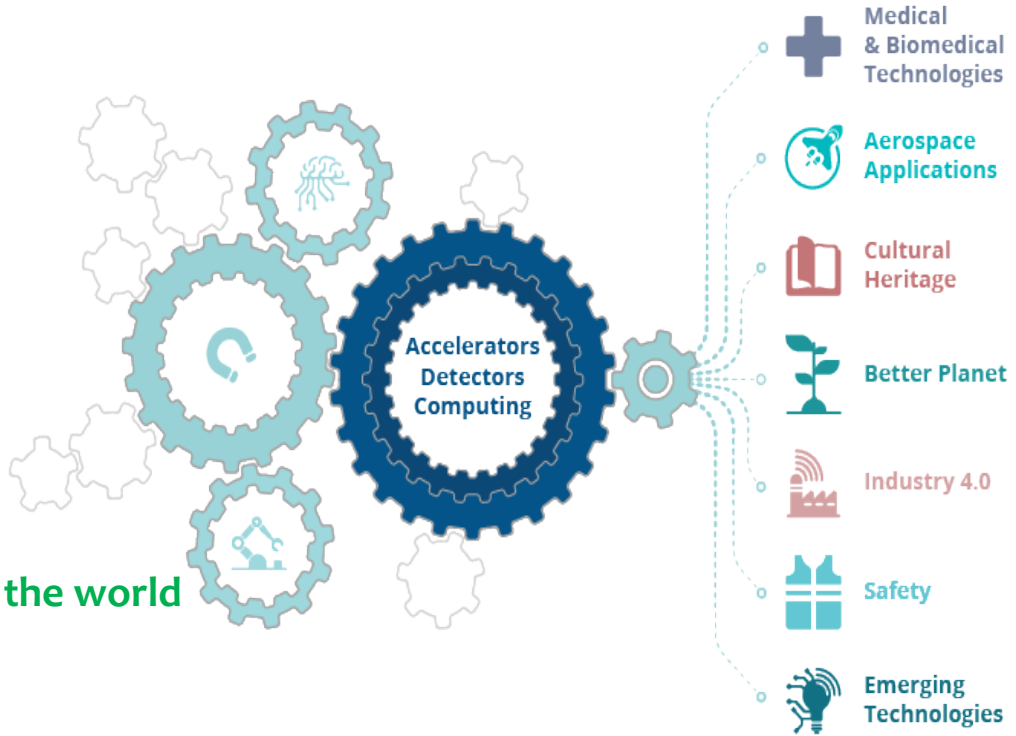
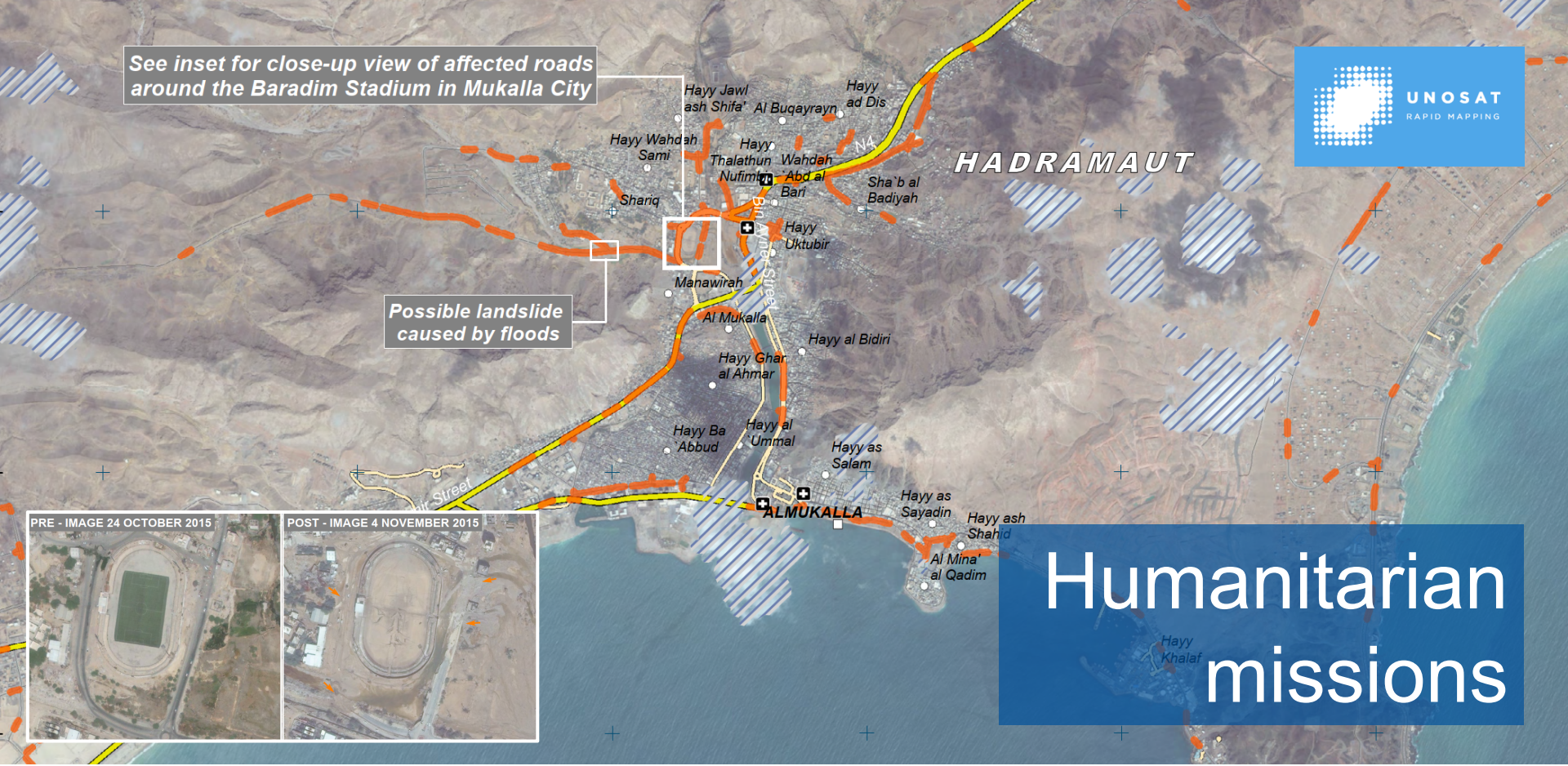
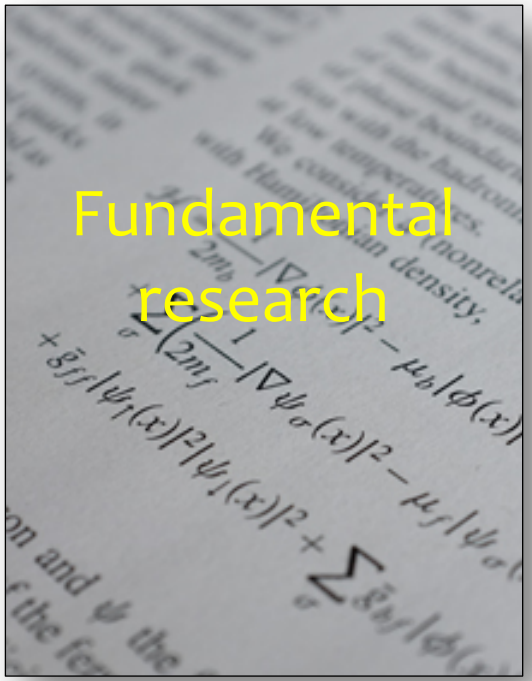
✓ **Knowledge transfer**

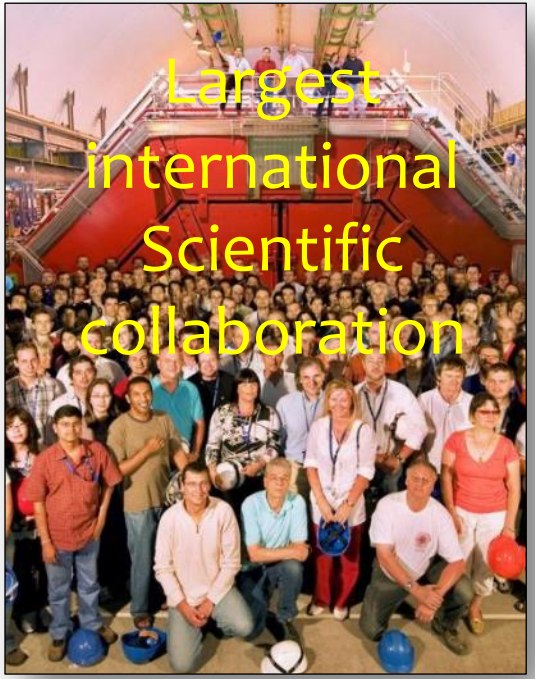
Learn more https://kt.cern/about-us




See inset for close-up view of affected roads around the Baradim Stadium in Mukalla City
Possible landslide caused by floods
UNOSAT
RAPID MAPPING
HADRAMAUT
Hayy Jawl ash Shifa'
Al Buqayrayn
Hayy ad Dis
Hayy Wahdah Sami
Hayy Thalathun Nufimbir
Wahdah
'Abd al Bari
N4
Sha`b al Badiyah
Shariq
Hayy Uktubir
Bir Ayne Street
Manawirah
Al Mukalla
Hayy al Bidiri
Hayy Ghar al Ahmar
Hayy Ba `Abbud
Hayy al `Ummal
Hayy as Salam
Hayy as Sayadin
Hayy ash Shahid
Al Mina' al Qadim
ALMUKALLA
Hayy Khalaf
PRE - IMAGE 24 OCTOBER 2015
POST - IMAGE 4 NOVEMBER 2015
Humanitarian missions

In a nutshell…





Thanks for your attention!

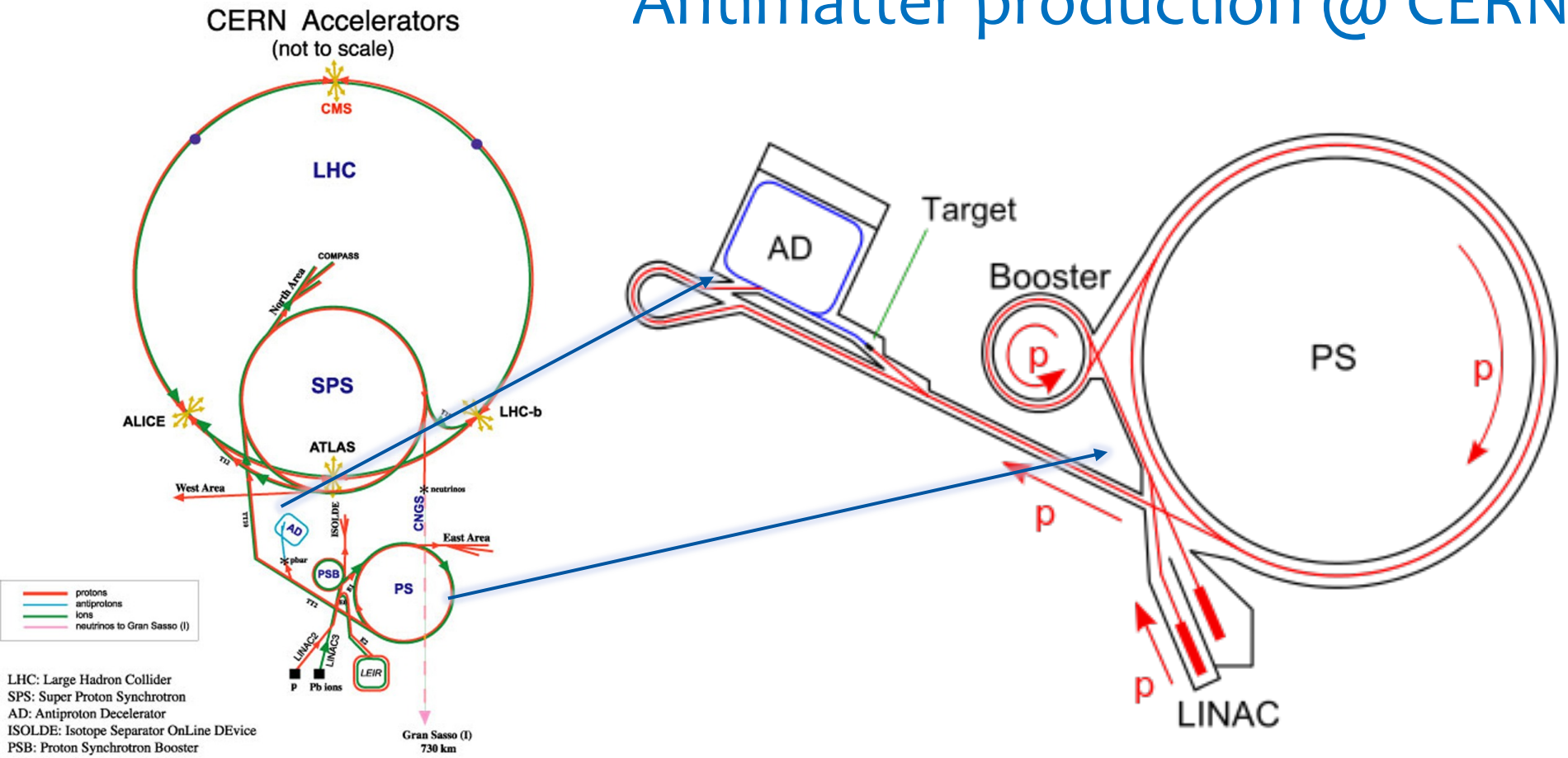
To learn further…

- home.cern
- visit.cern
- careers.cern

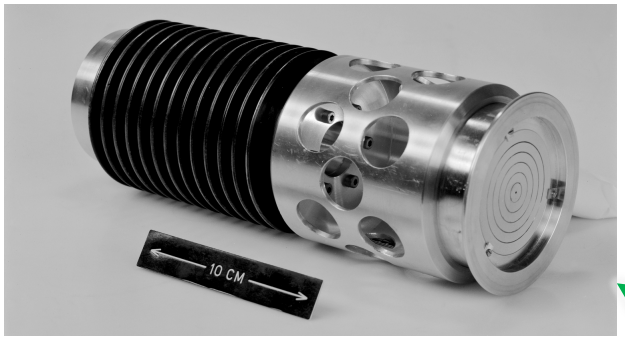
Thanks for filling up survey!

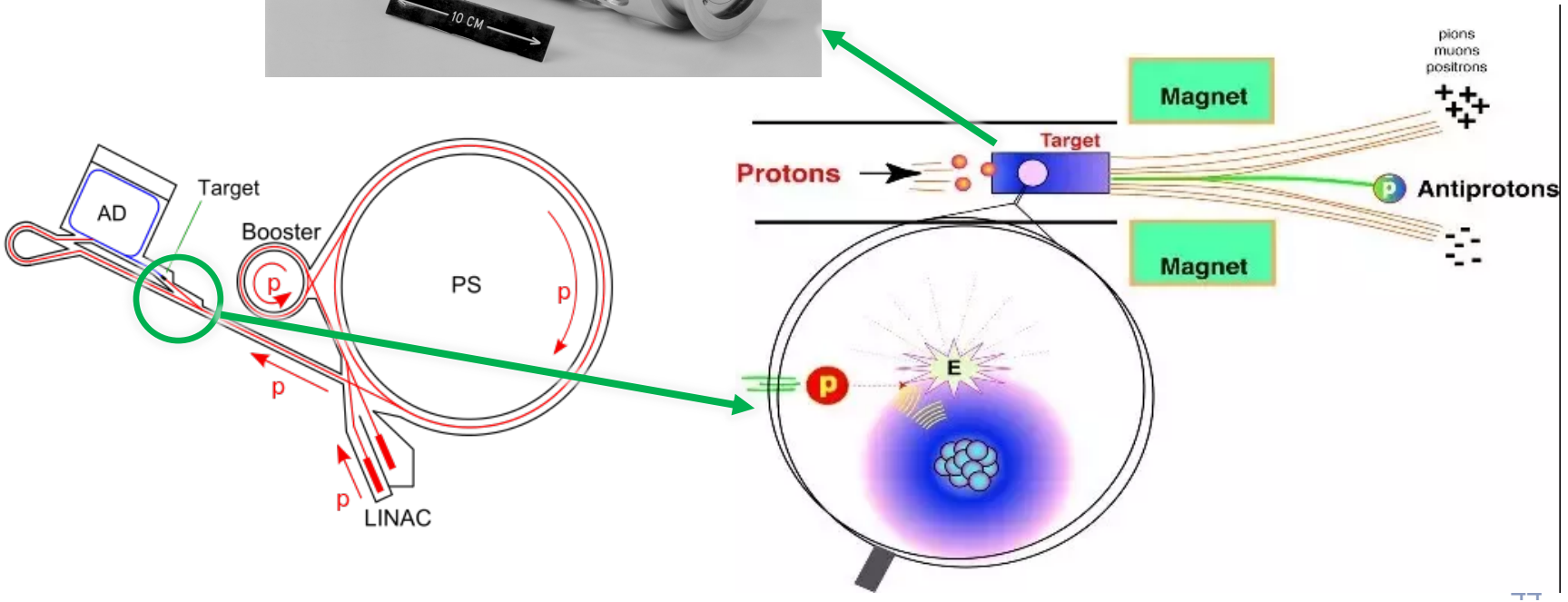
Backup

Antimatter production @ CERN



Antimatter production @ CERN





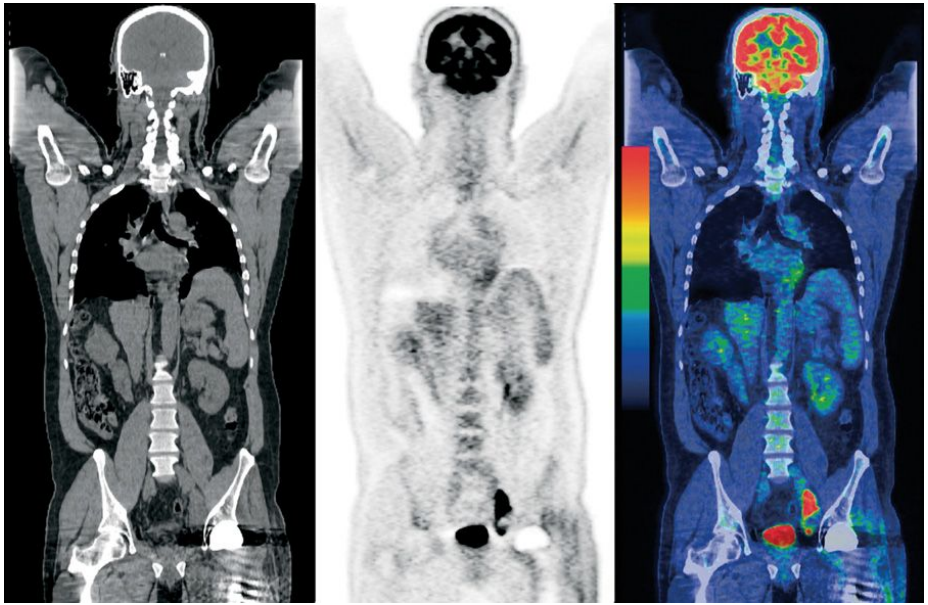
Experiments @ AD

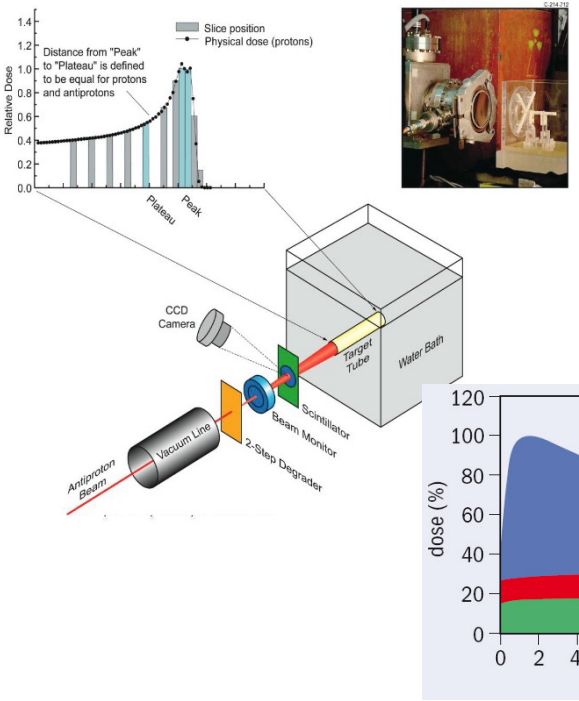
	ALPHA	ATRAP	ASACUSA	BASE	AEGIS	GBAR
Approved	2005	1997	1997	2013	2008	2012
Data Taking	2006	2002	2002	2014	*Soon*	*Soon*
Countries	8	4	8	3	11	9
Institutes	16	6	19	7	23	16
Researchers	57	31	51	41	113	87
Main goals	Compare hydrogen and antohydrogen (*spectroscopy)*	Compare hydrogen and antohydrogen (*spectroscopy)*	Compare the *hyperfine structure* of hydrogen and antihydrogen	Compare the *magnetic moments* of matter and antimatter.	Study effects of Earth's gravity on antimatter	Study effects of Earth's gravity on antimatter
Highlight	Jun 2011: trapped antiprotons for 16 minutes	Mar 2013: magnetic moment measurement	Nov 2016: measure the mass of antiproton	Jun 2014: first observations		

Credits : C.Alpigiani

Practical applications

Positron **E**mission **T**omography



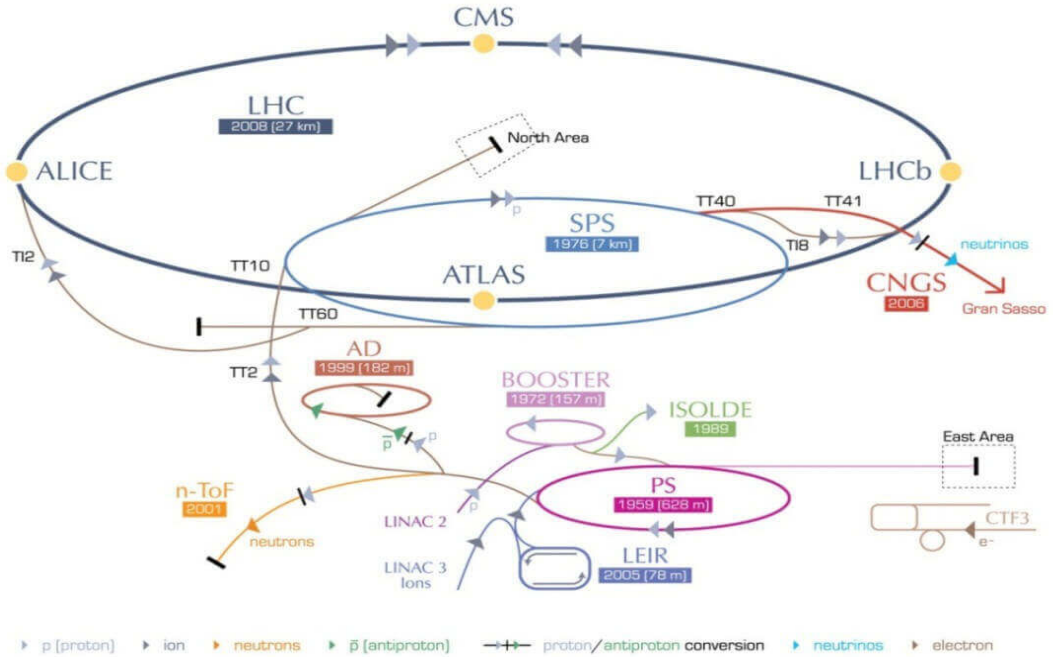


Cancer therapy with anti-protons

Reduction by X4 vs proton inficts the same cell damage

In practice, that means less damage to healthy cells

CERN's accelerator complex

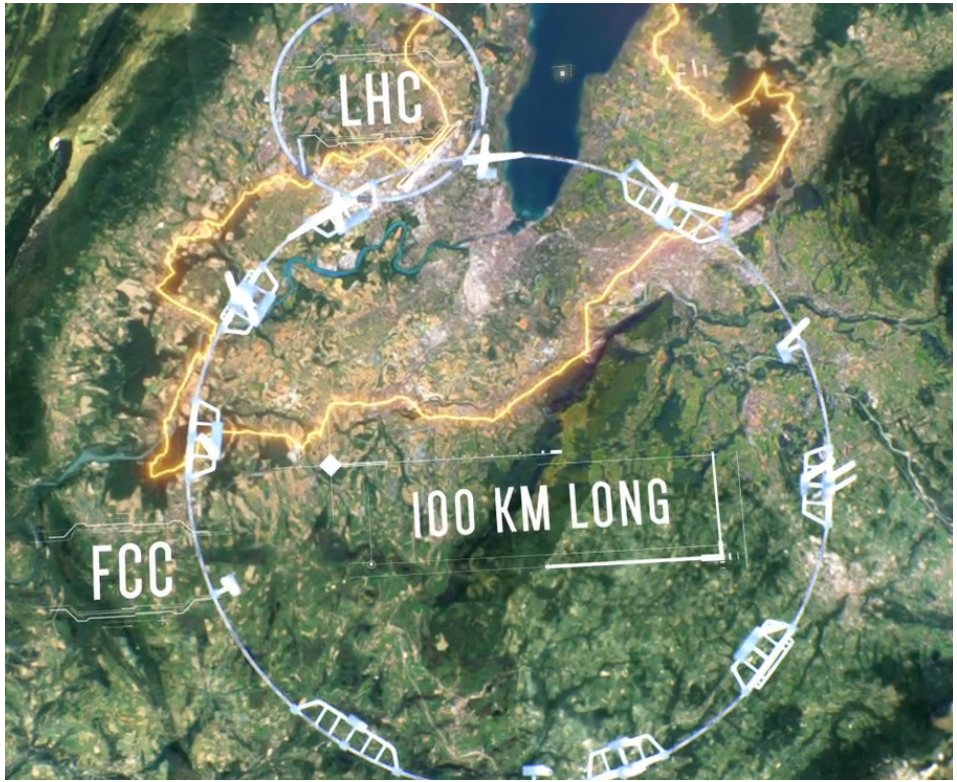


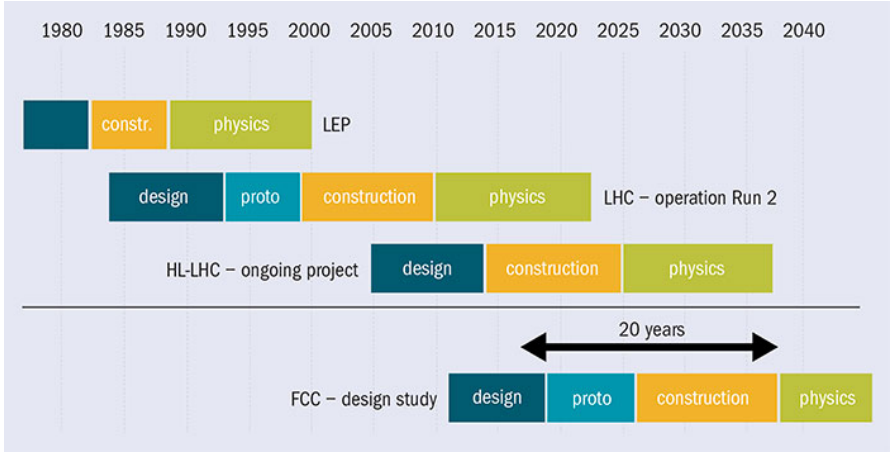
LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

AD Antiproton Decelerator CTF3 Clic Test Facility CNGS Cern Neutrinos to Gran Sasso ISOLDE Isotope Separator OnLine DEvice
LEIR Low Energy Ion Ring LINAC LINear ACcelerator n-ToF Neutrons Time Of Flight

European Organization for Nuclear Research | Organisation européenne pour la recherche nucléaire

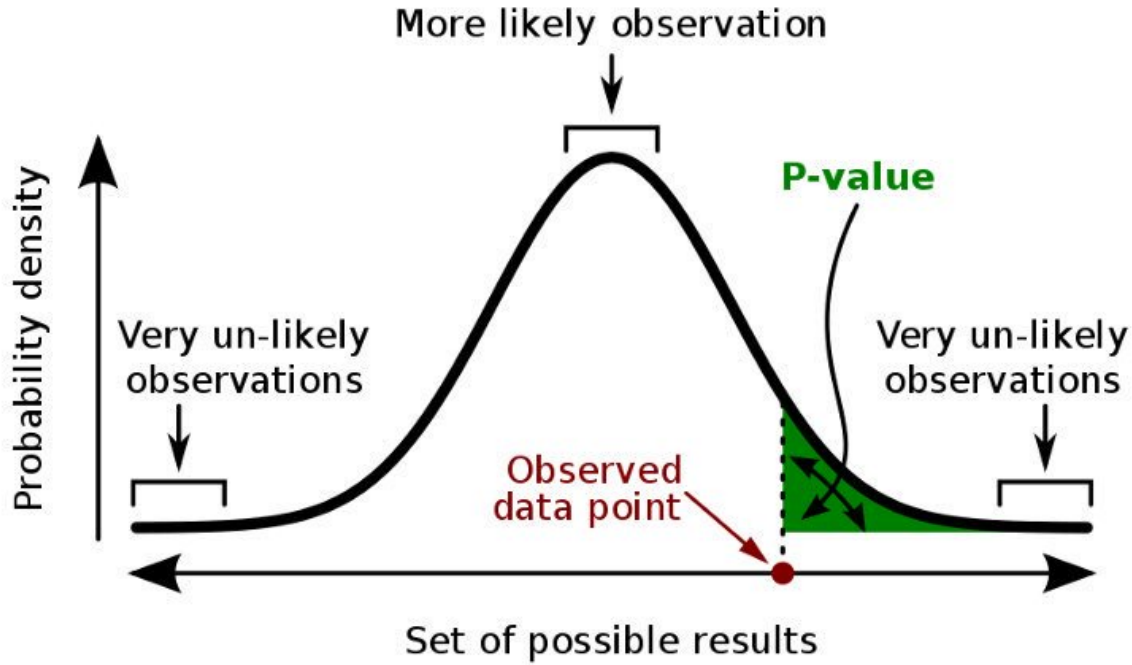
… the future





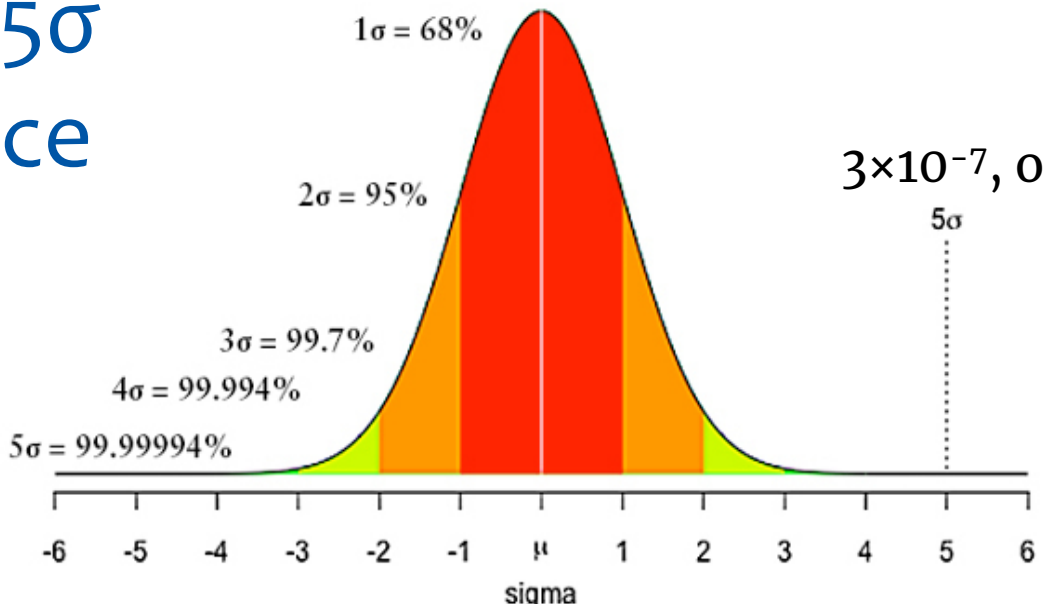
More on the FCC

What is a 5σ significance



A **p-value** (shaded green area) is the probability of an observed (or more extreme) result assuming that the null hypothesis is true.

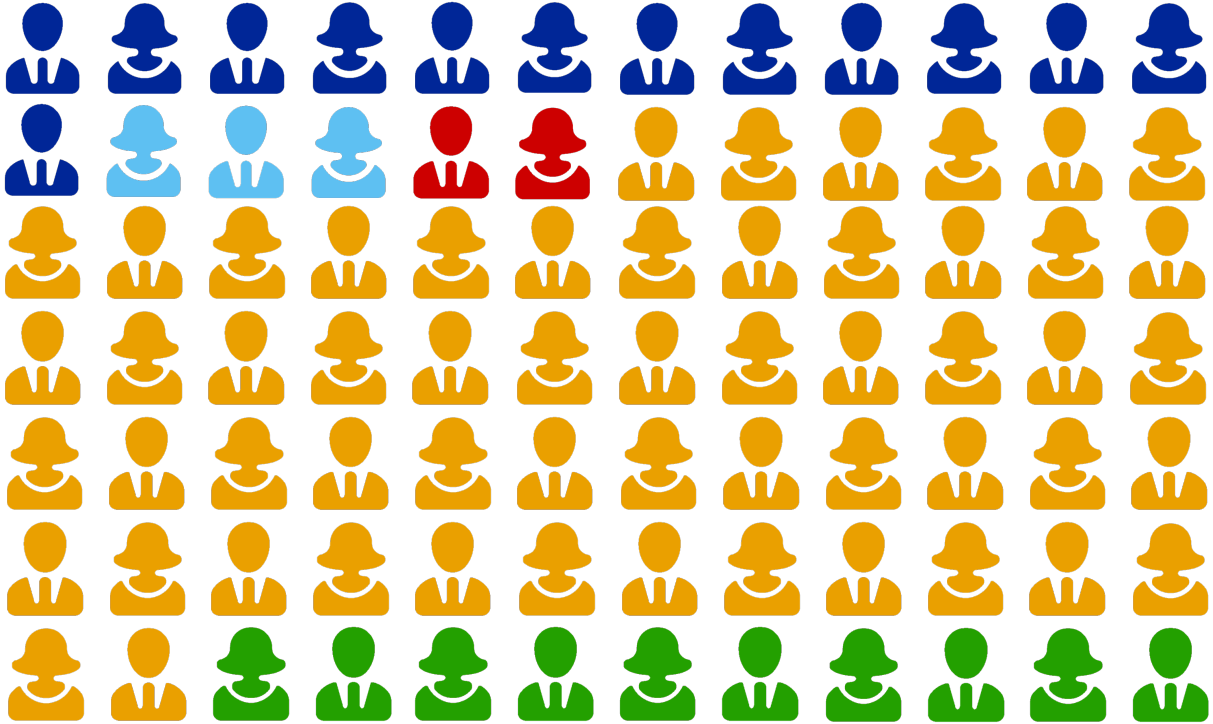
What is a 5σ significance



3×10^{-7}, or about 1 in 3.5 milli

between + / - 1σ	68.27 %	result: 317300 ppm outside (deviation)
between + / - 2σ	95.45 %	45500 ppm
between + / - 3σ	99.73 %	2700 ppm
between + / - 4σ	99.9937 %	63 ppm
between + / - 5σ	99.999943 %	0.57 ppm
between + / - 6σ	99.9999998 %	0.002 ppm

How many persons?



20 000!

2 600 staff

800 fellows
apprentices

550 students

15 000 users

2 000 external
companies