Accelerating Science through ART

Science & Art
Research & Creation

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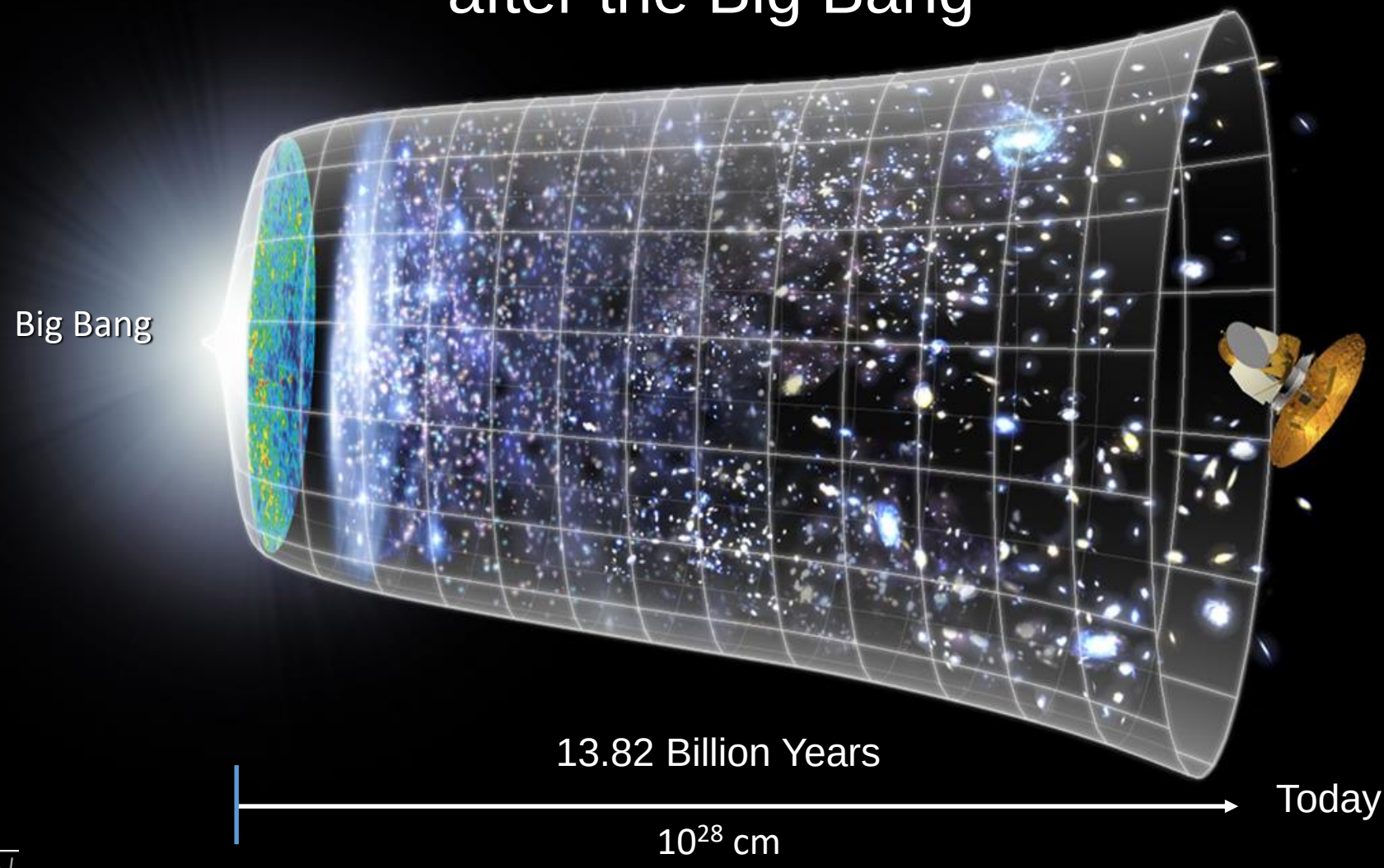
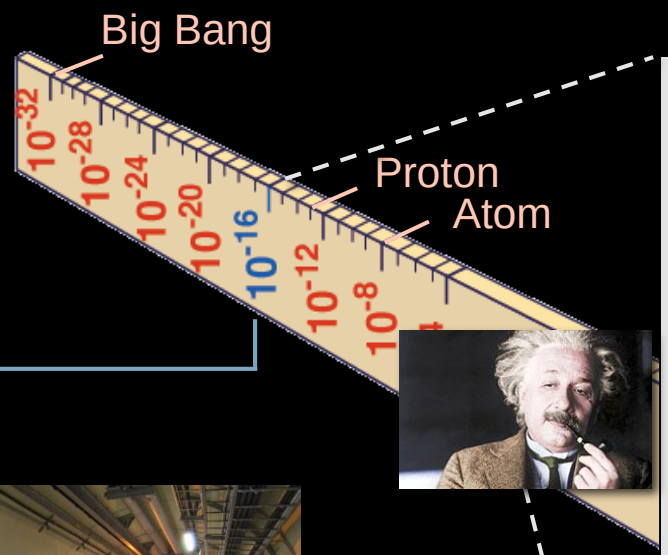
CERN / art@CMS

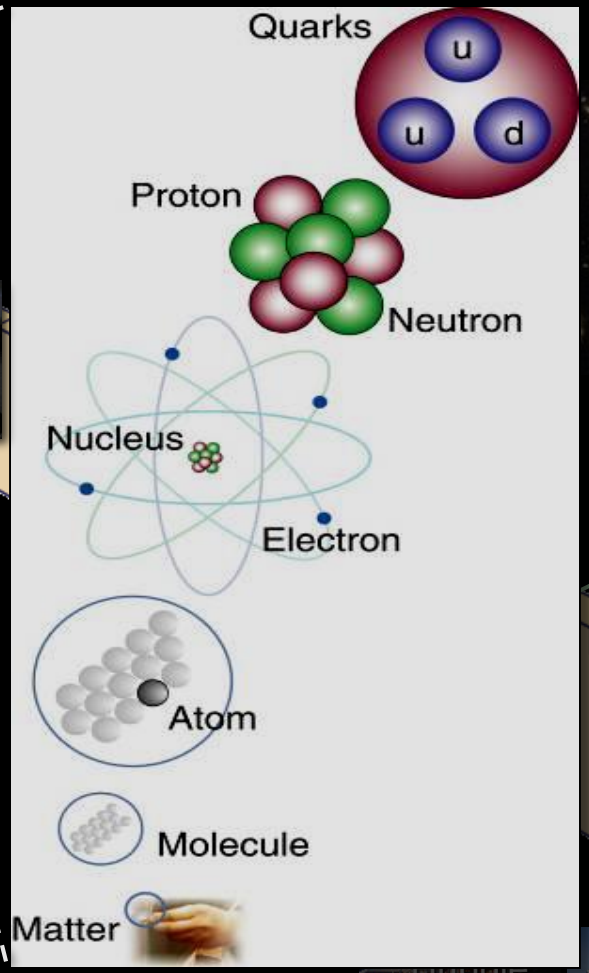
University of Montenegro 12/12/2017

Next Scientific Challenge:

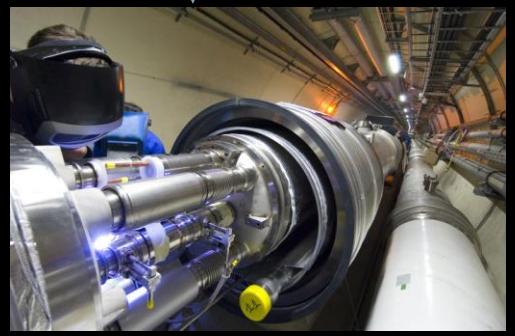
to understand the very first moments of our Universe after the Big Bang





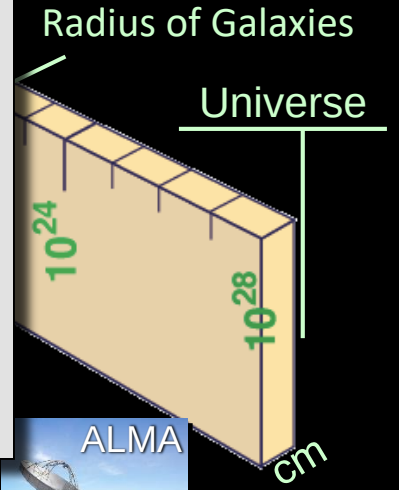


CERN

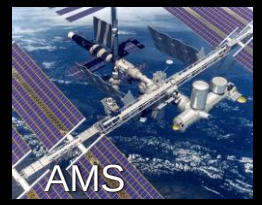


LHC

Super-Microscope



By studying physics laws of fundamental particles – the smallest construction elements of Nature - we can understand the rules of Astrophysics and Cosmology



Forces & Interactions

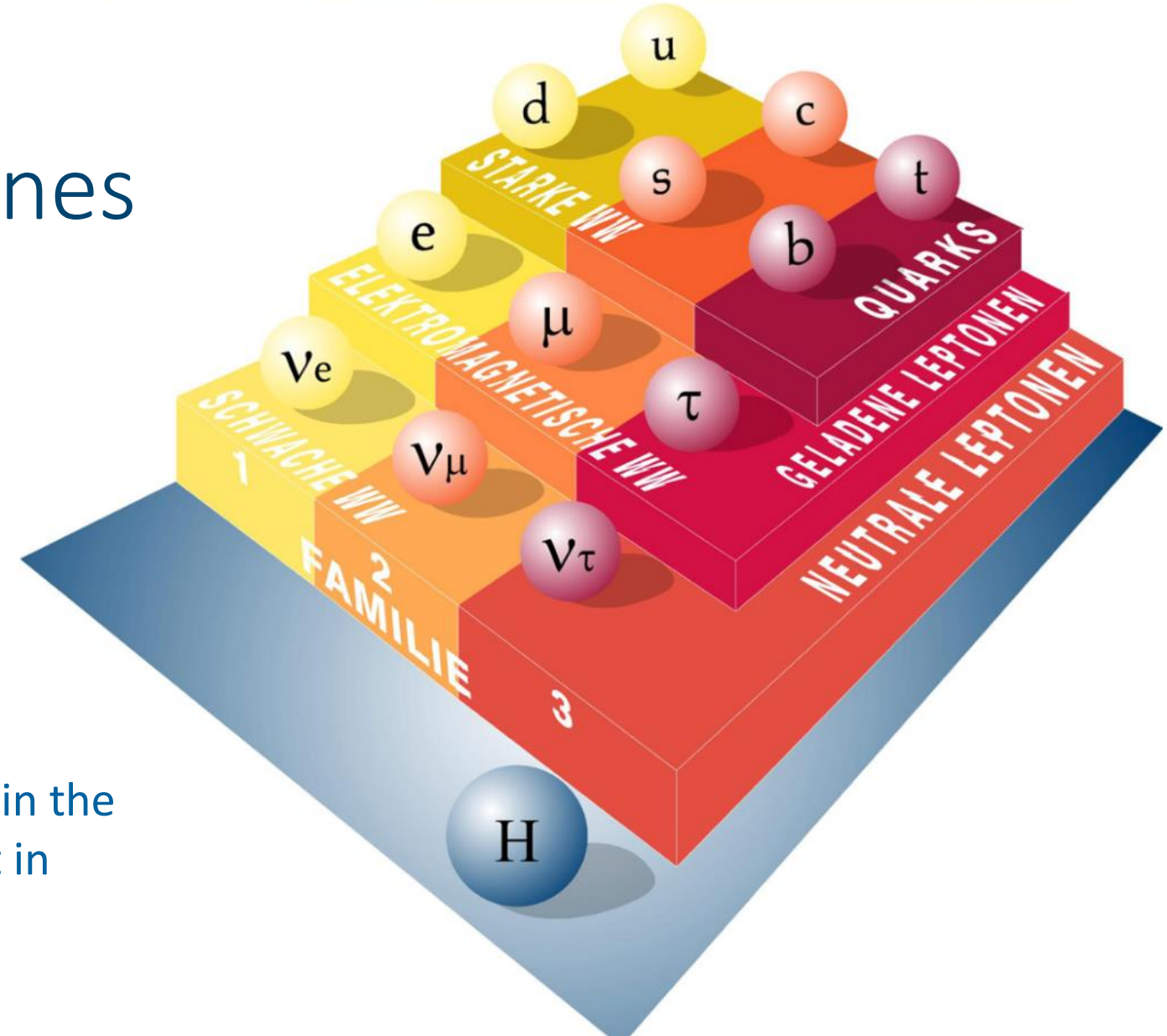
Electromagnetic force - photos
- electric and magnetic phenomes

Weak nuclear force - W & Z Bosons
- beta decay

Strong nuclear force – Gluon
burning in the Sun, nuclei

Gravitation – Graviton ?

Standard Model
Matter particles :
Quarks & Leptones



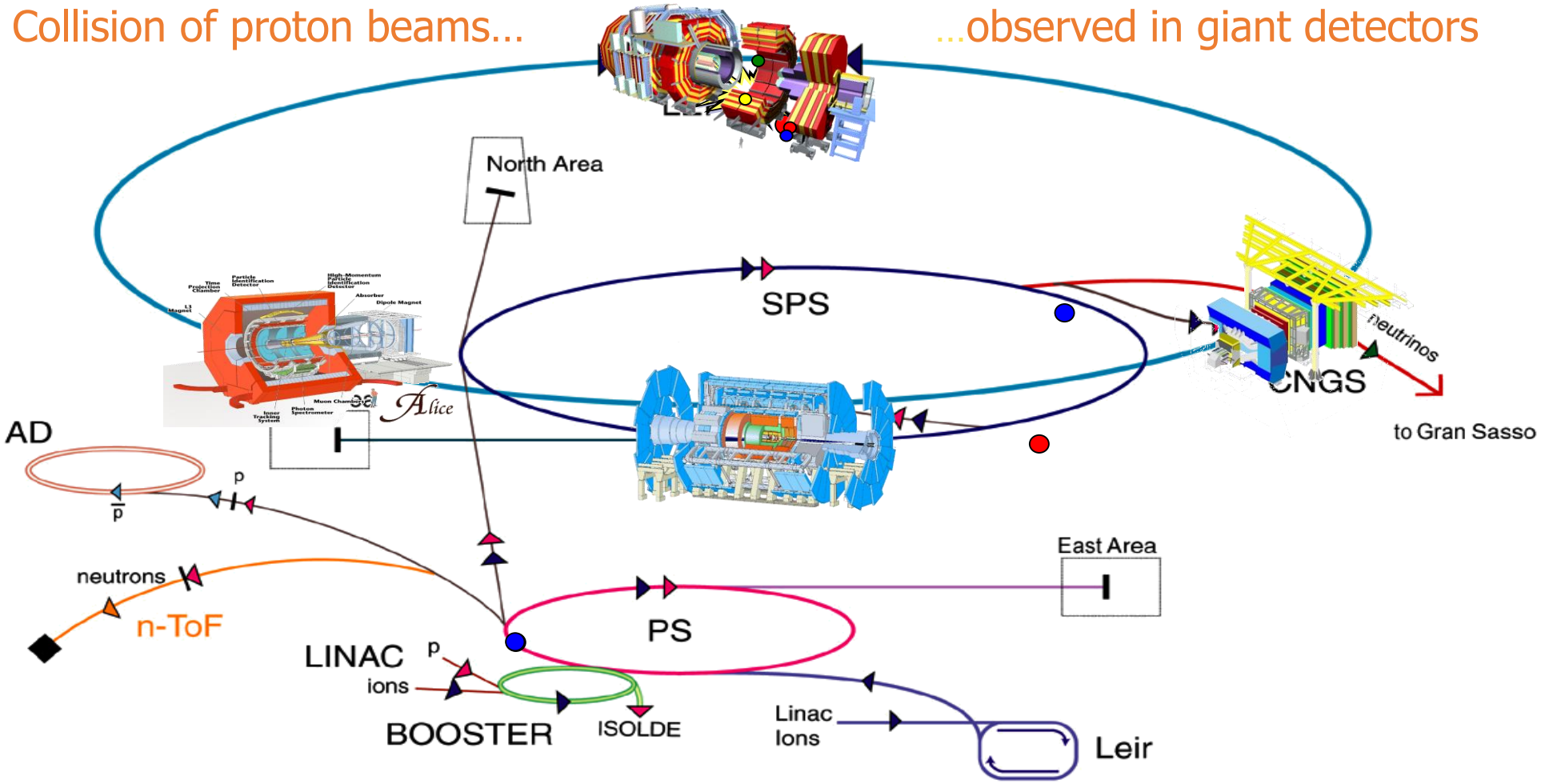
6 Quarks and 6 Leptons .

- 3 Families, with increasing mass
- Heavy particles decay to lighter ones
- Particles in Family 2 & 3 were existing in the eary Universe. Today they existing just in Cosmic Ray and particle accelerator.

The Large Hadron Collider LHC and experiments @CERN
- worlds most powerful microscope -

Collision of proton beams…

…observed in giant detectors

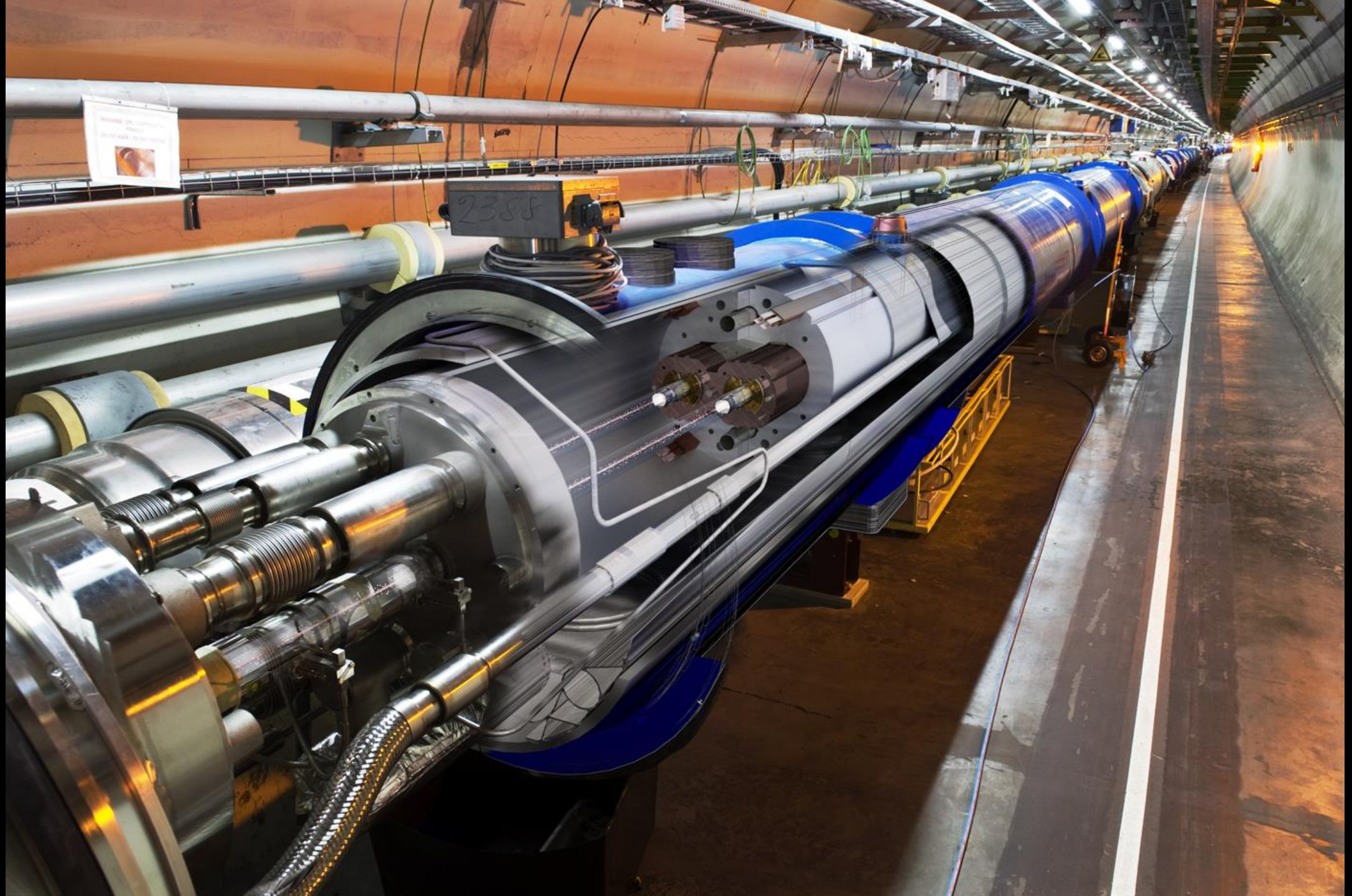


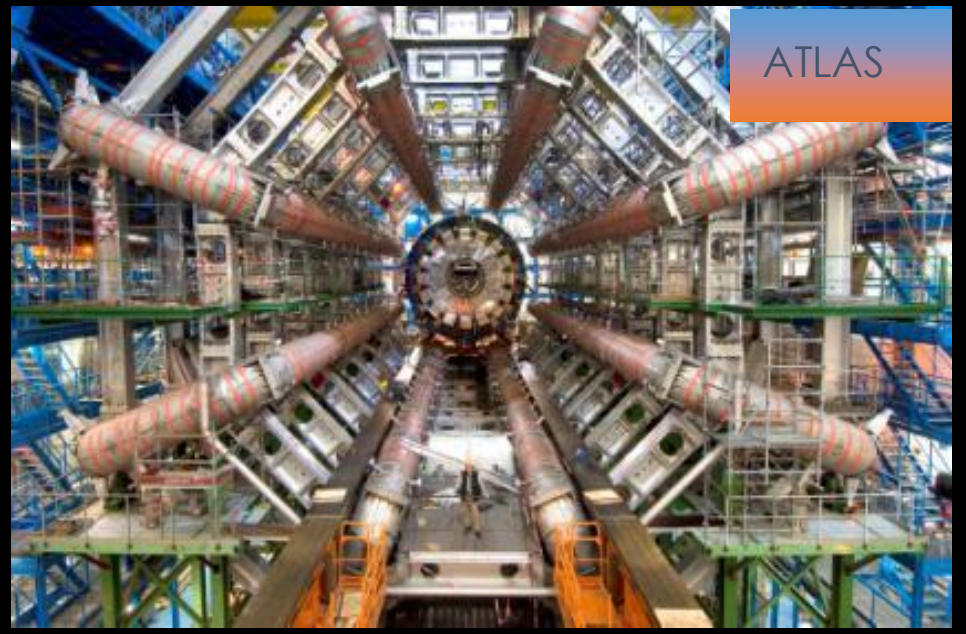
p (proton)
ion
neutron

p̄ (antiproton)
proton/antiproton conversion
neutrino

AD Antiproton Decelerator
PS Proton Synchrotron
SPS Super Proton Synchrotron

LHC Large Hadron Collider
n-ToF Neutron Time of Flight
CNGS Cern Neutrinos Gran Sasso





The
4
Large
Scale

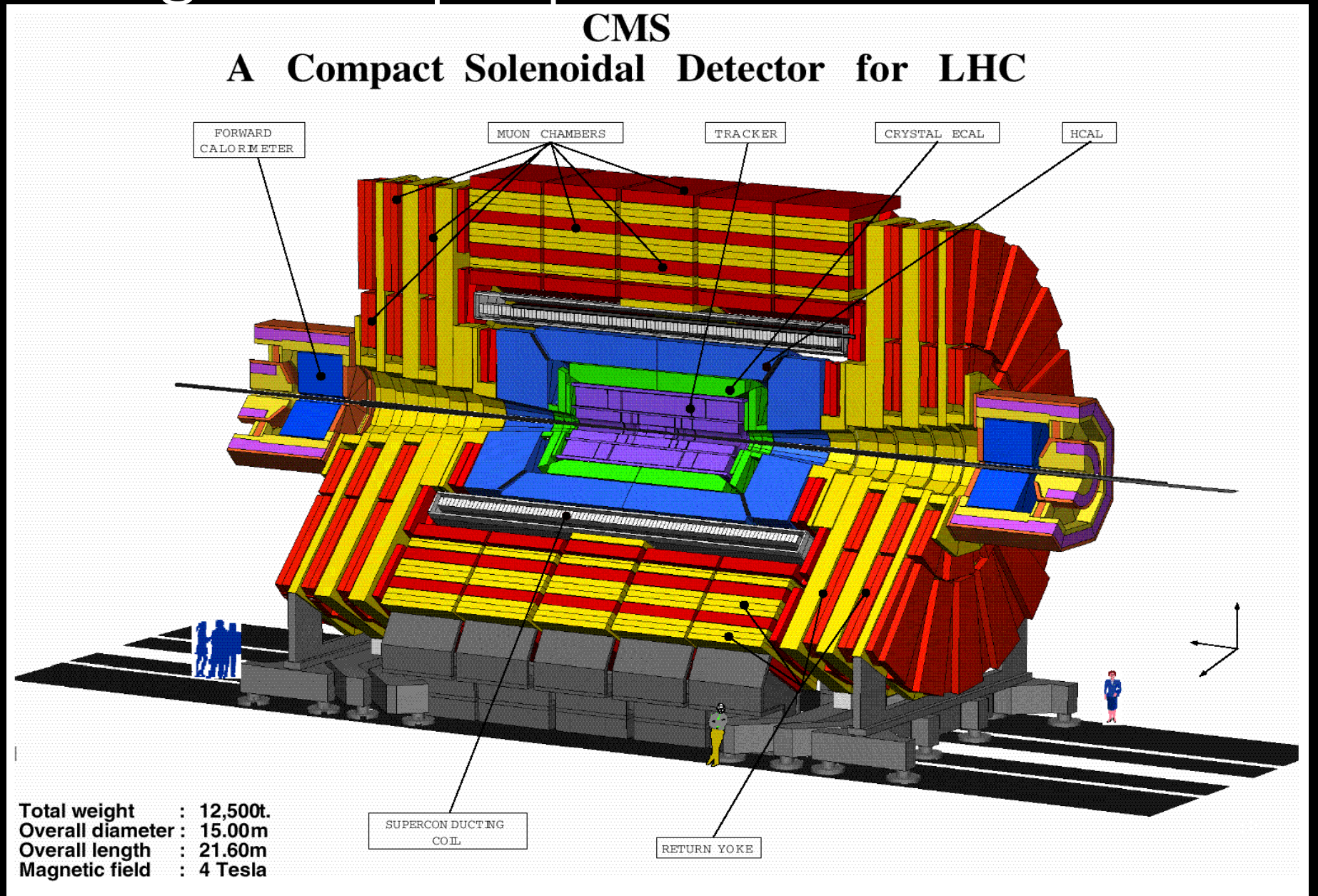
LHC

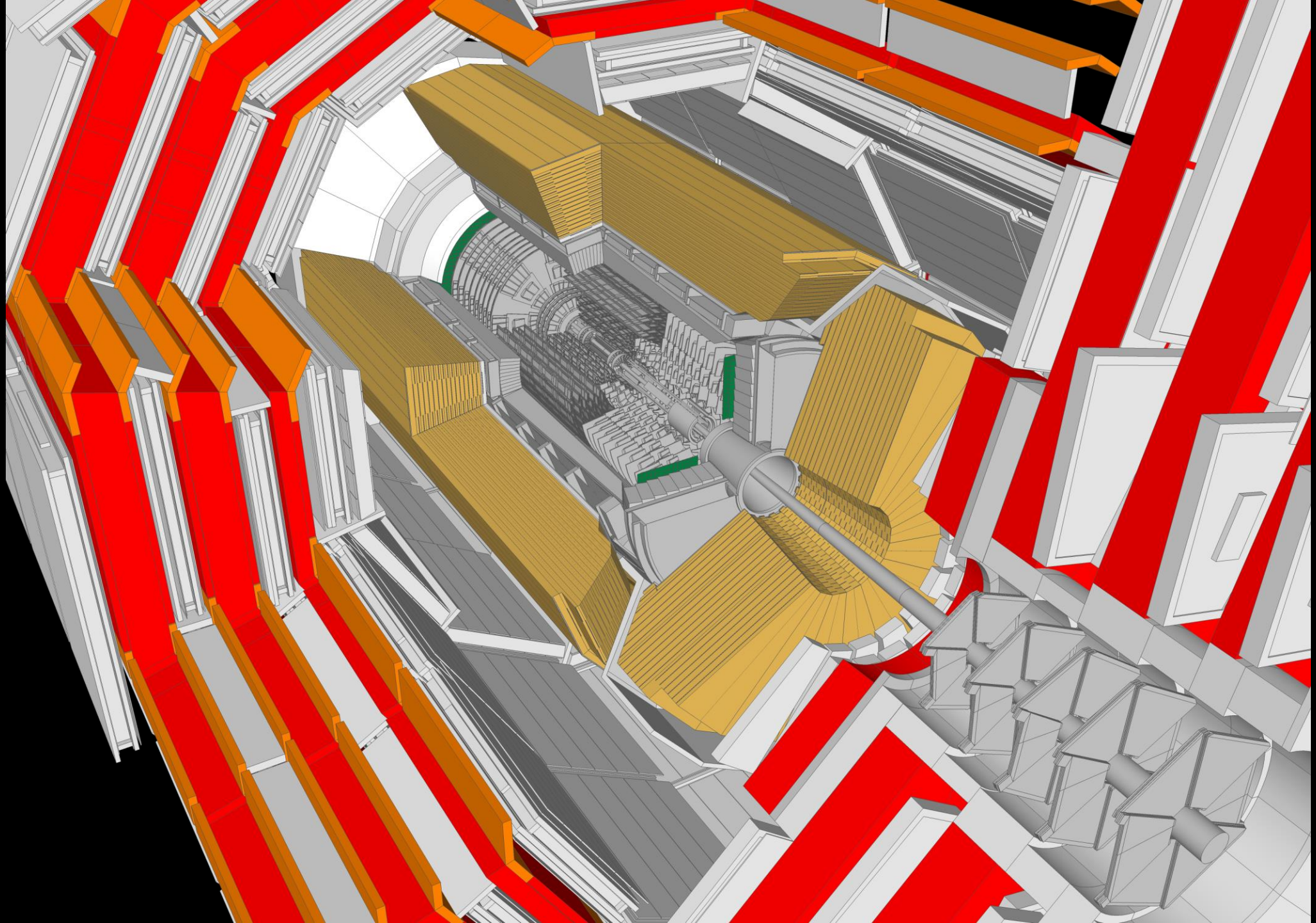
Experiments

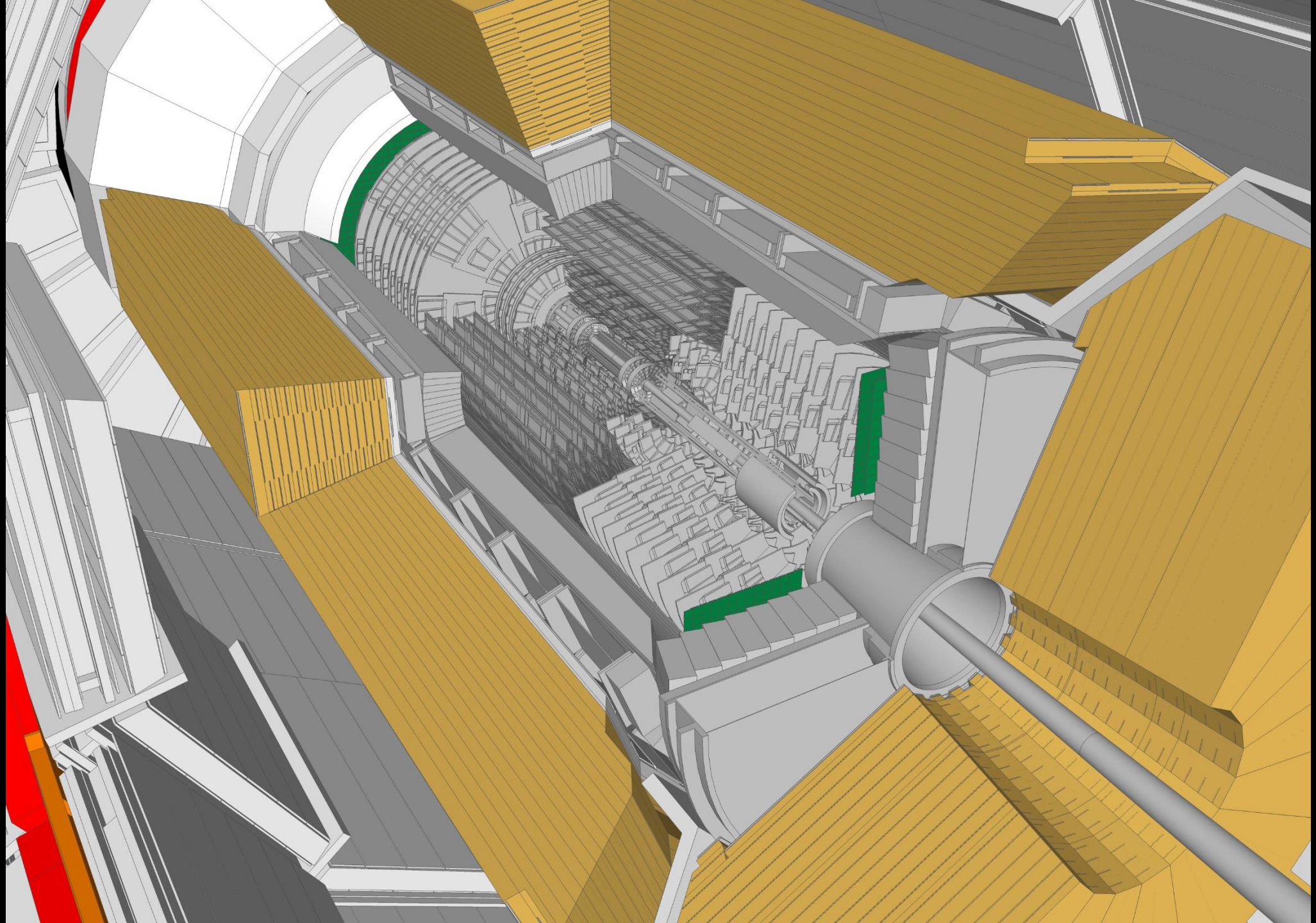
@

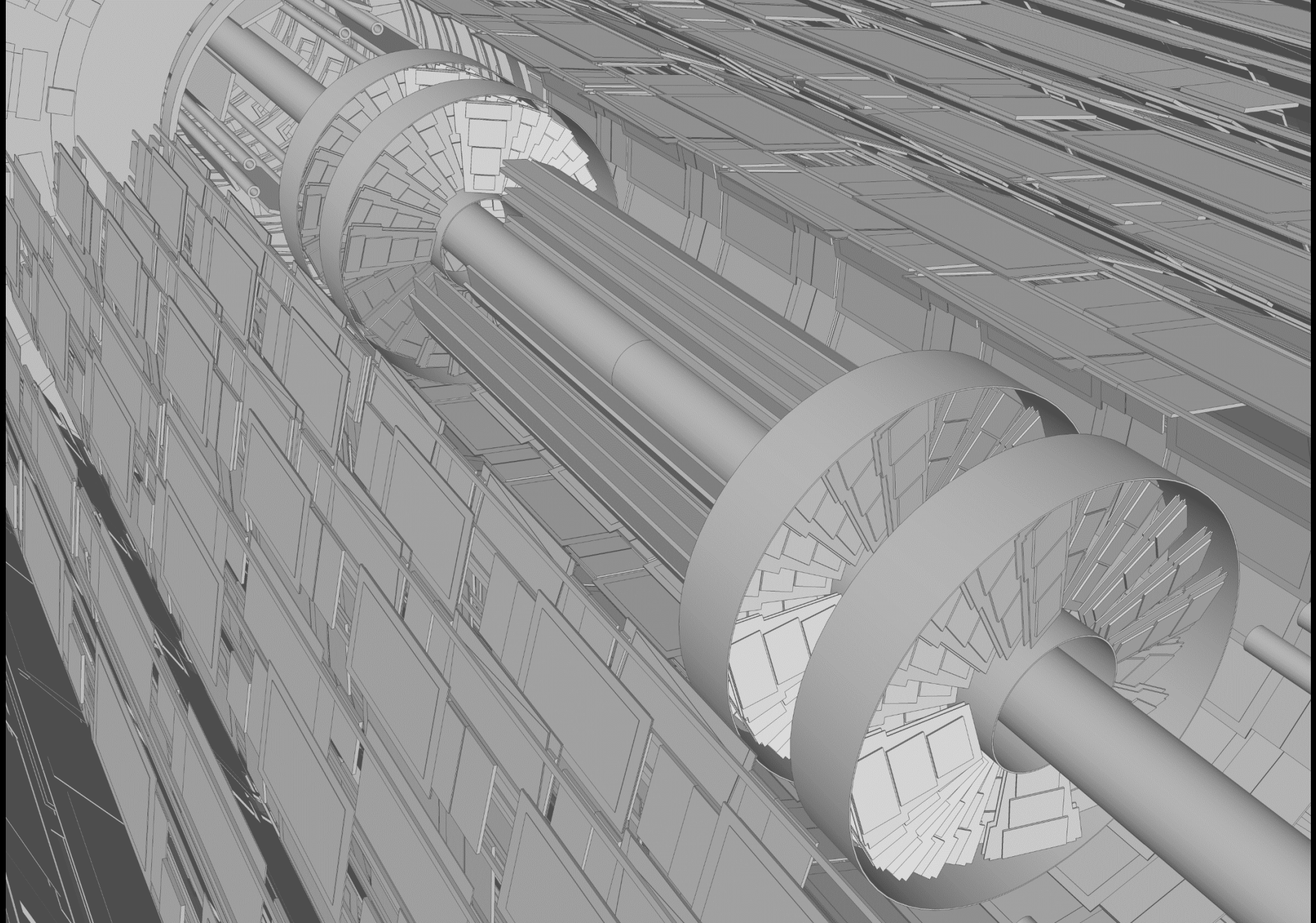
CERN

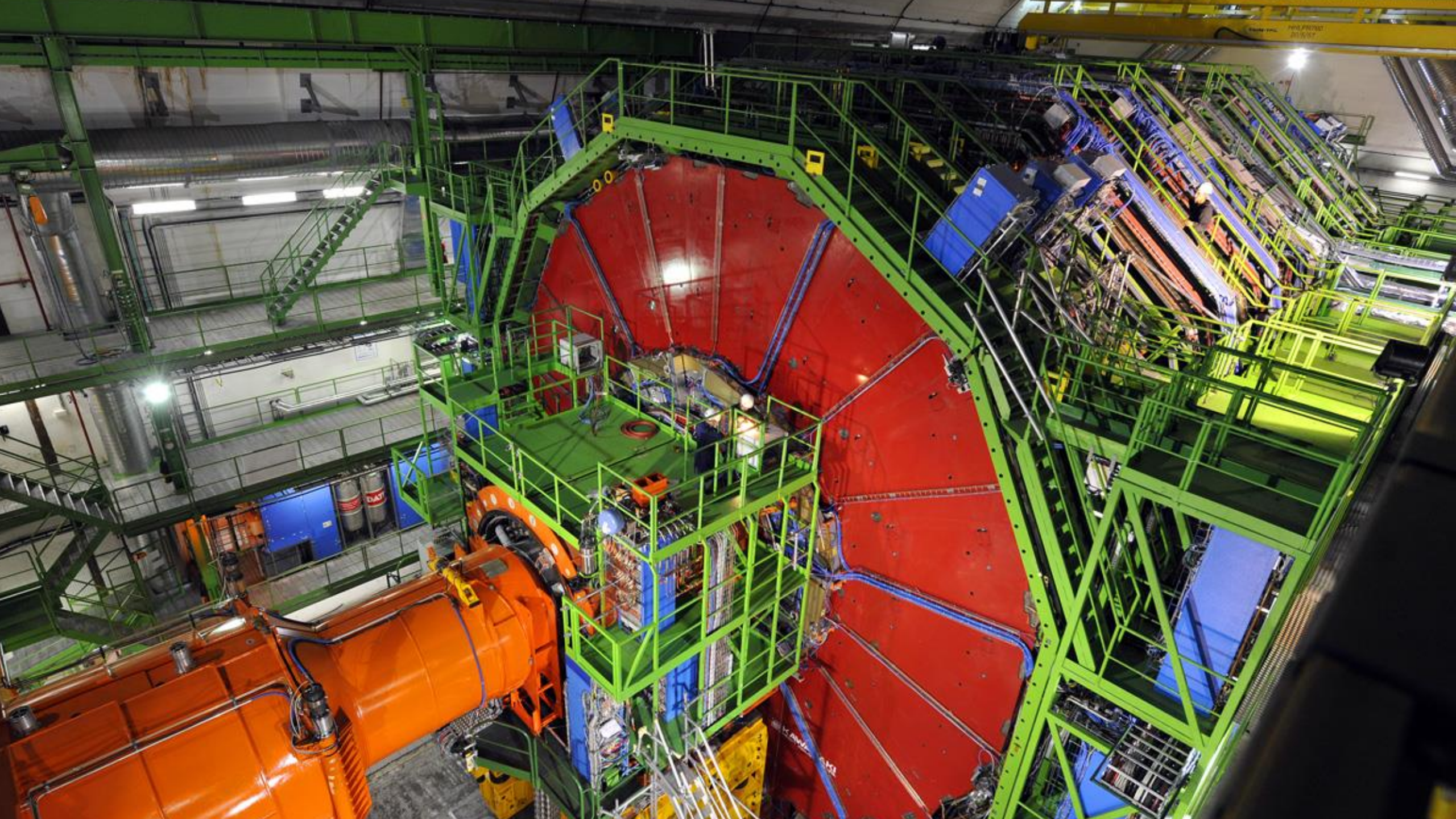
CMS - a general purpose LHC detector

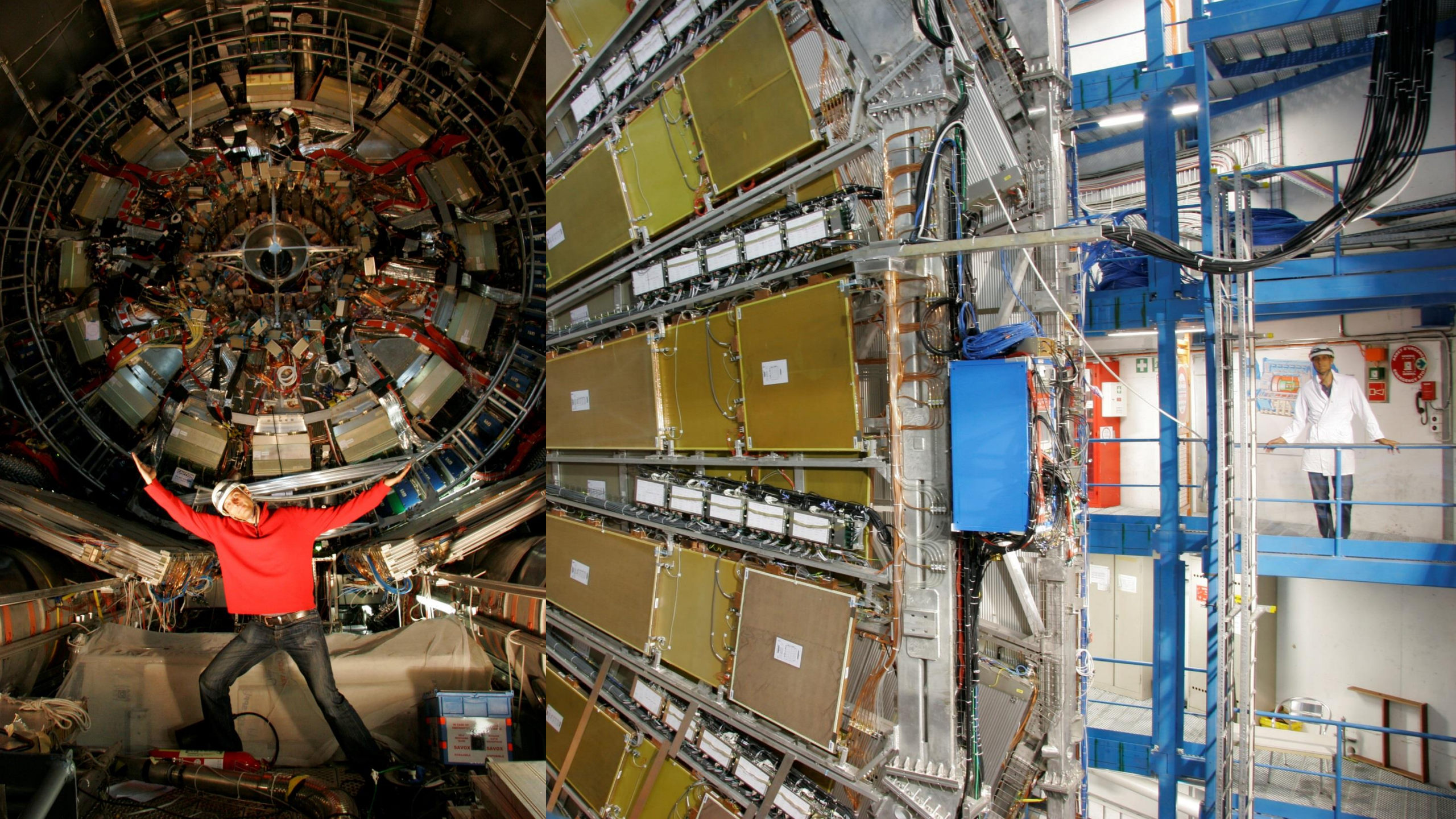




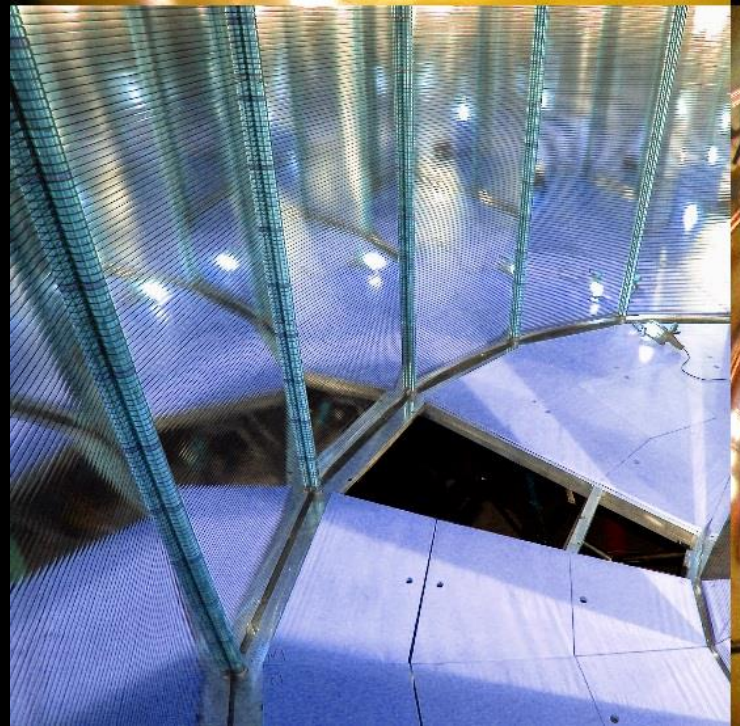


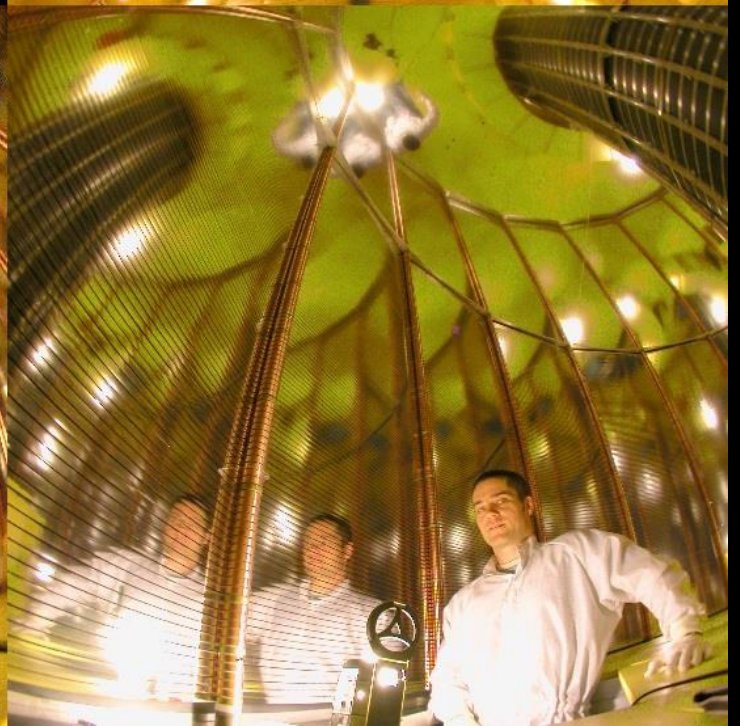


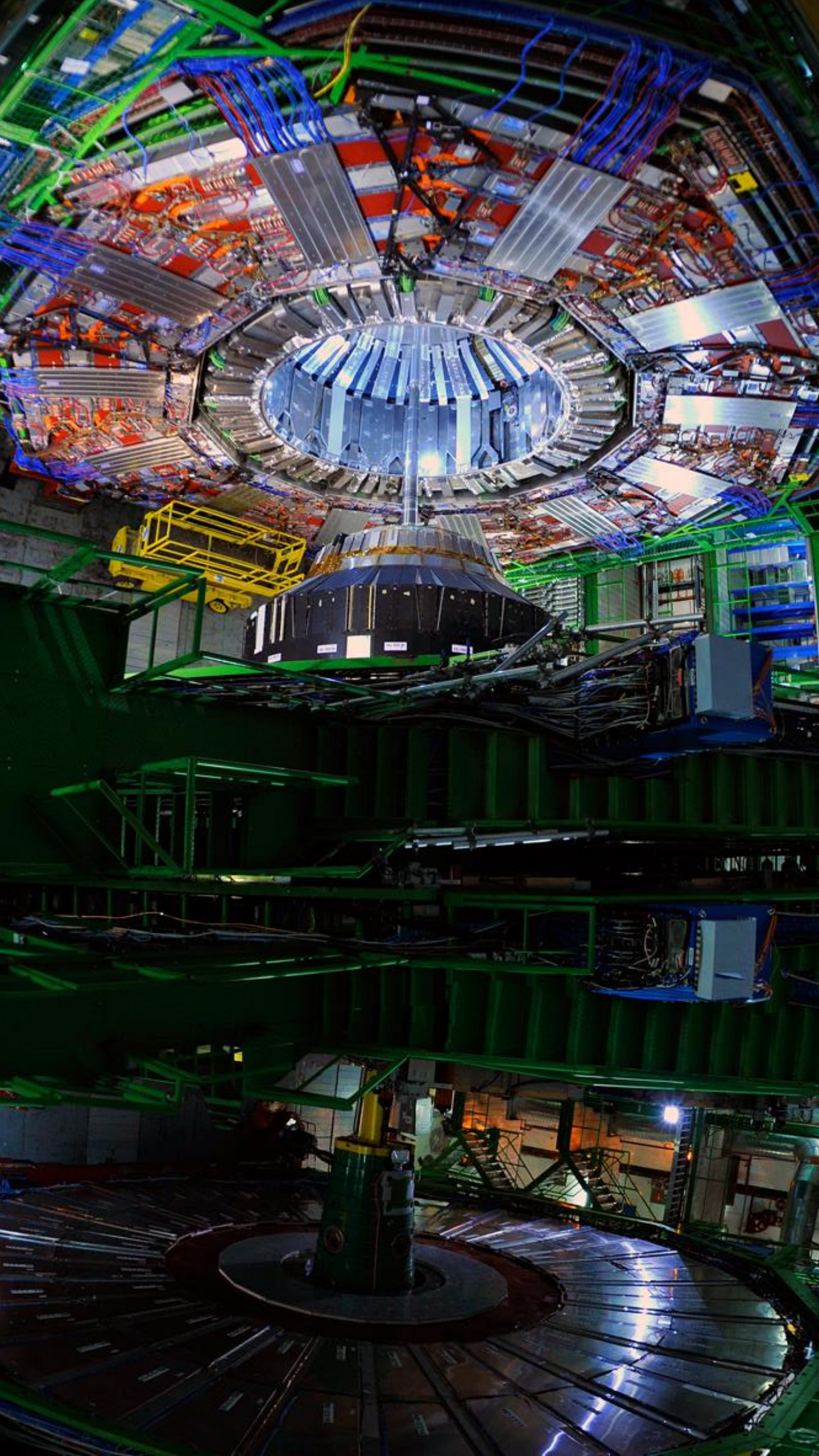


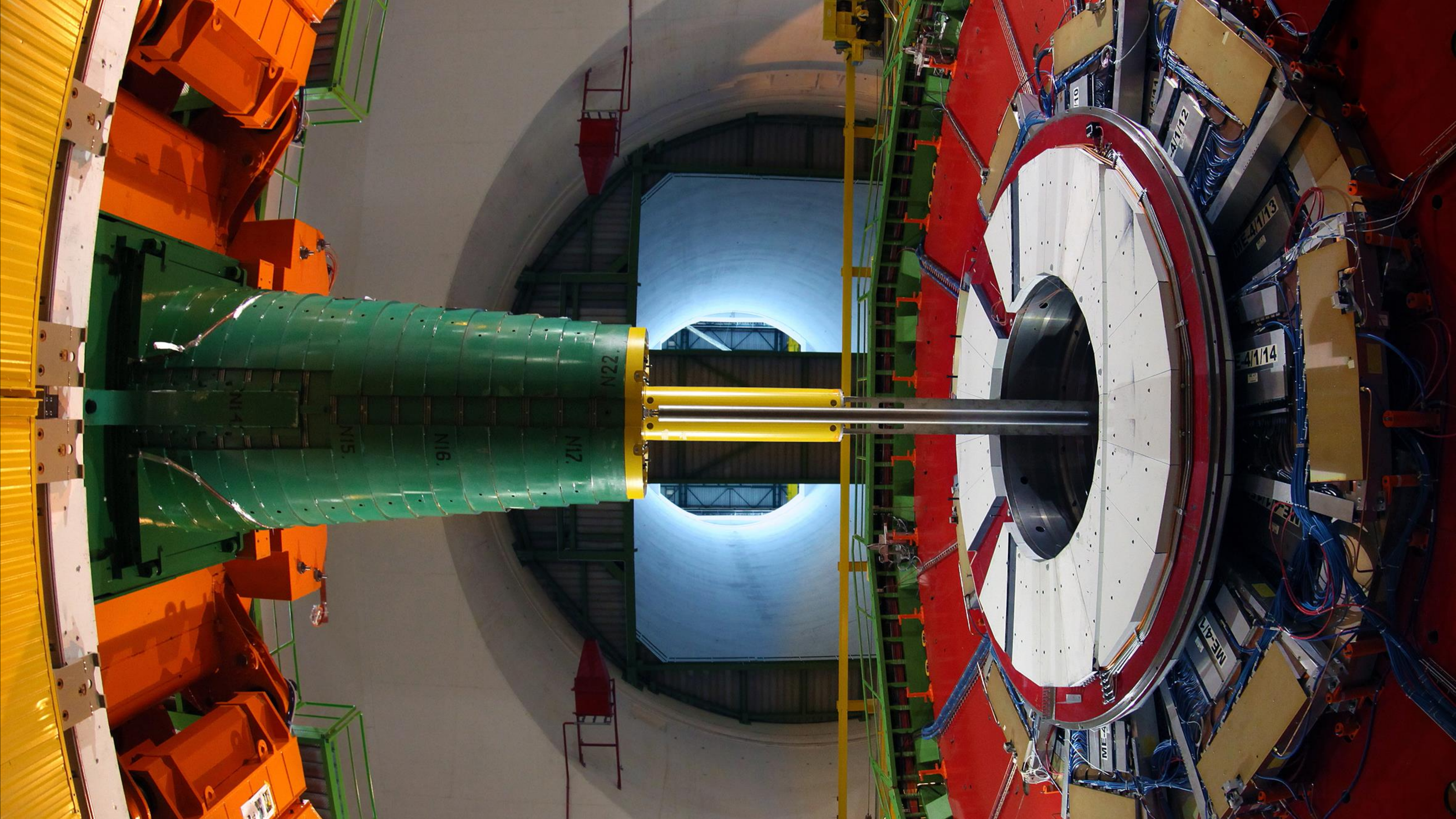


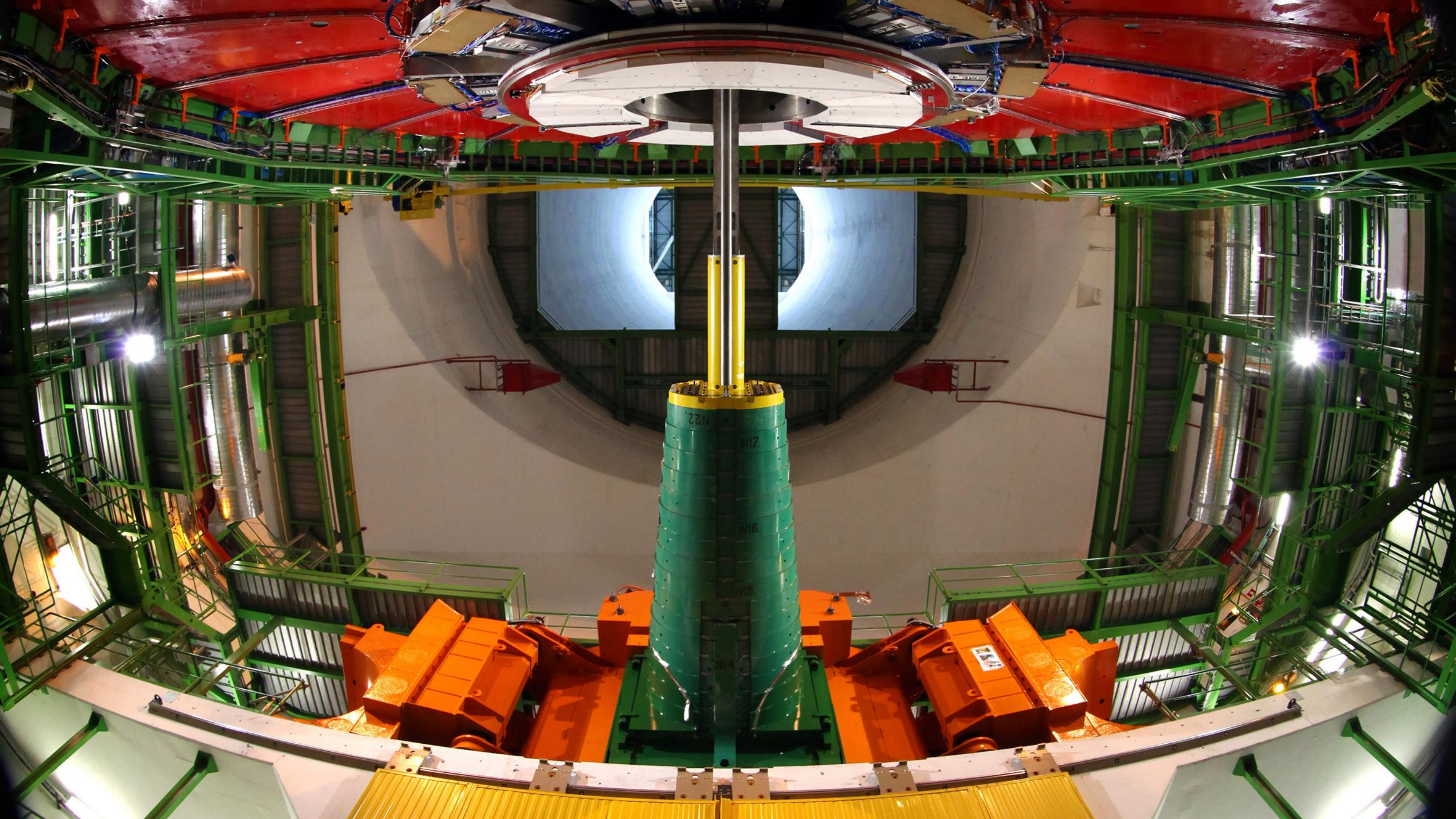


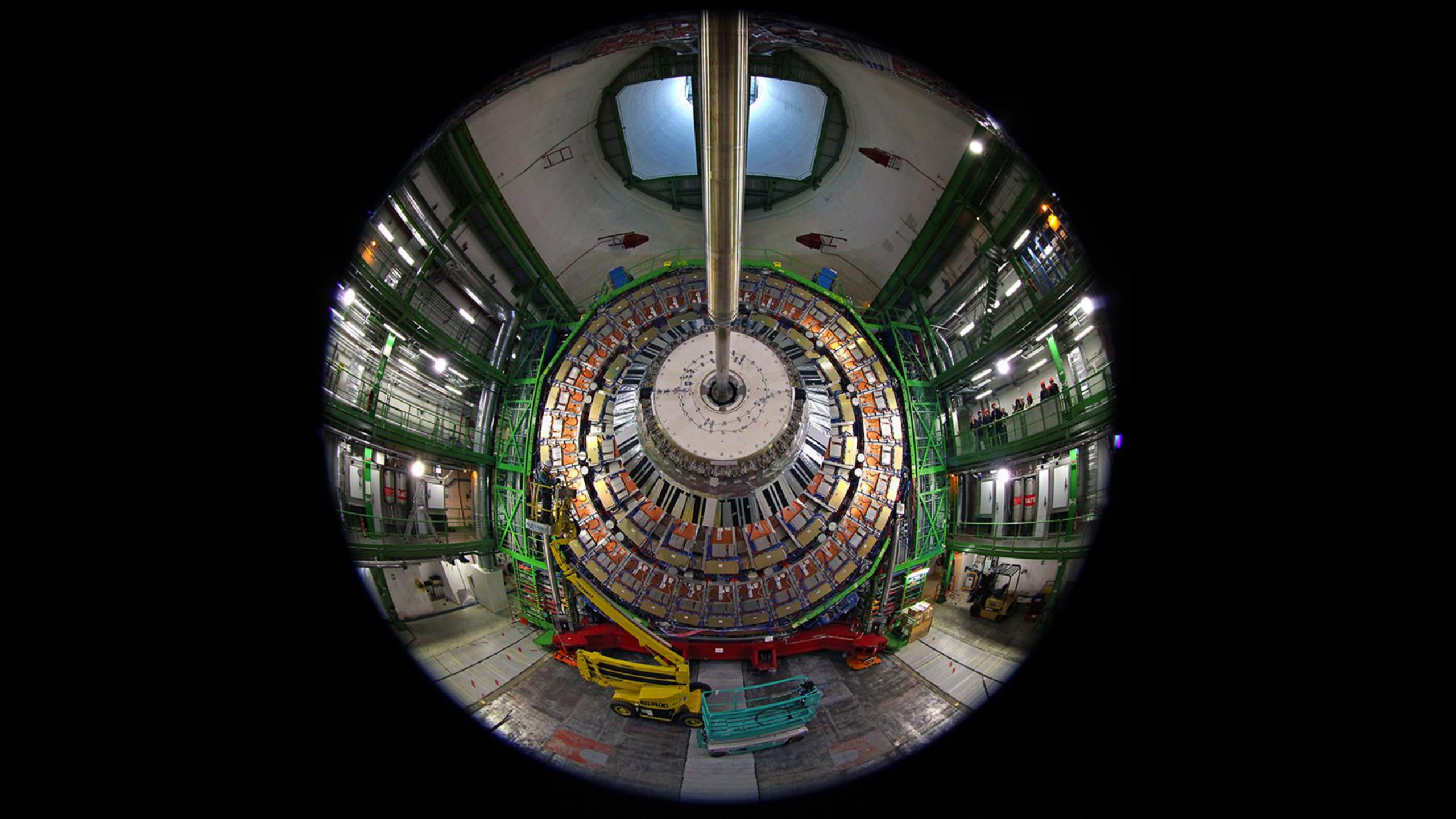



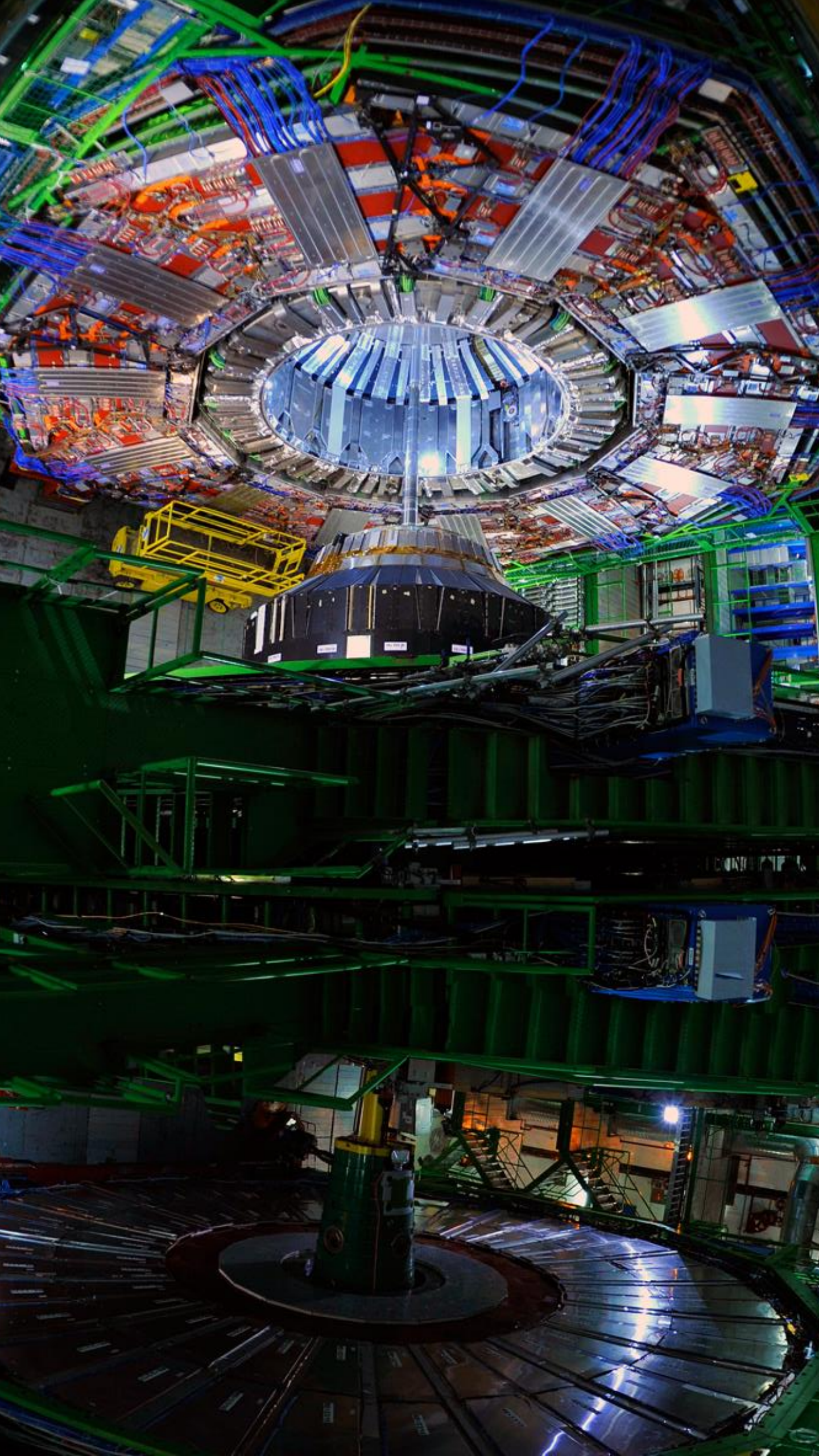




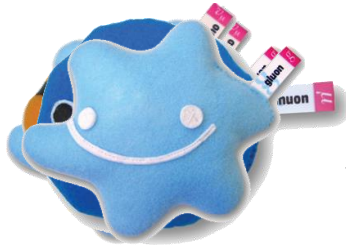

ME-4/1/13

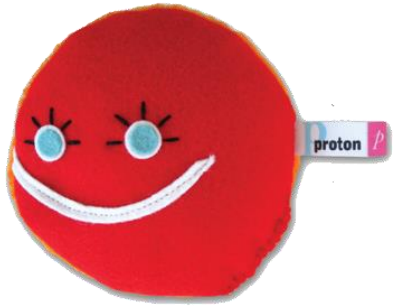

N17
N16
N15

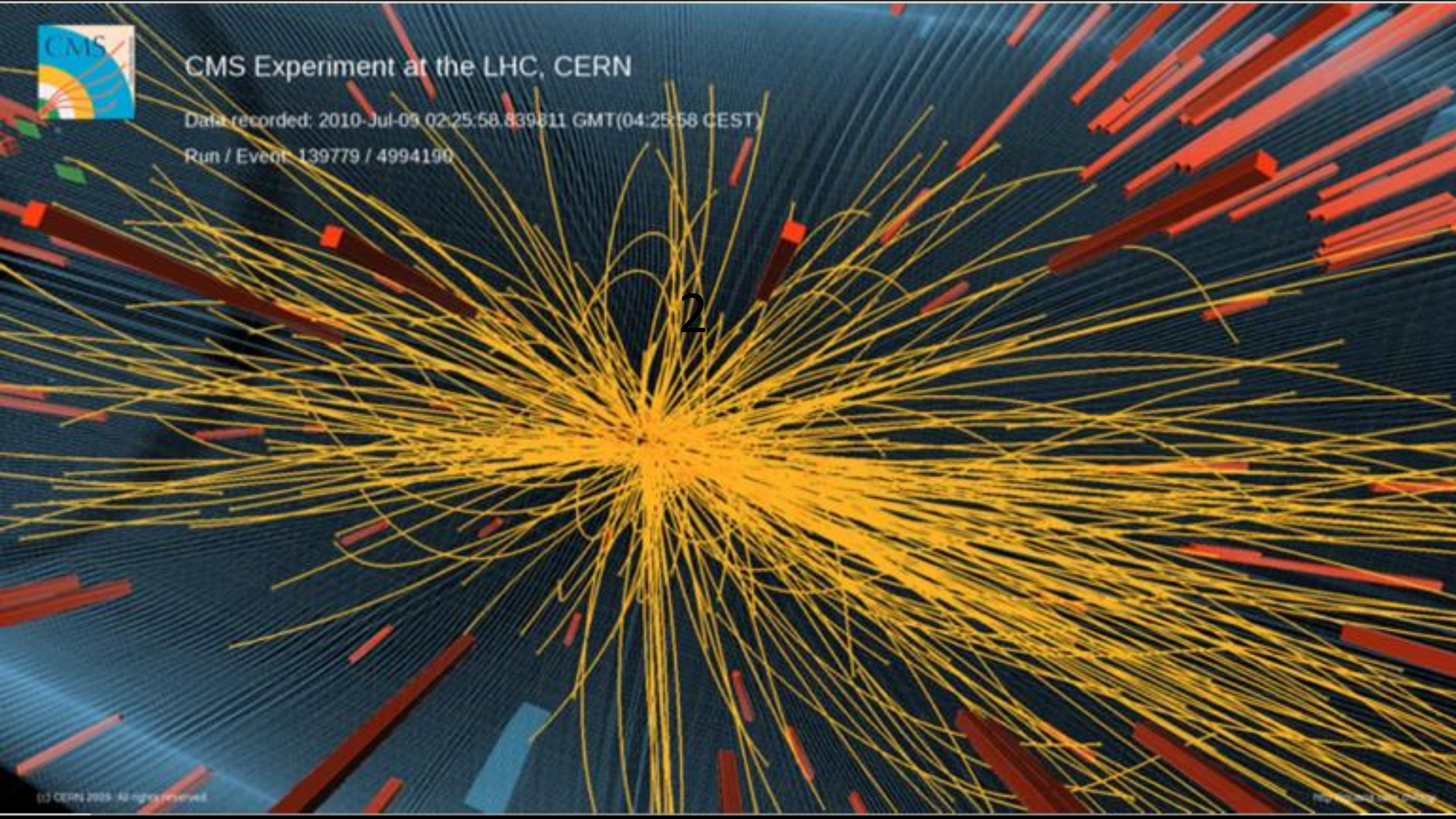


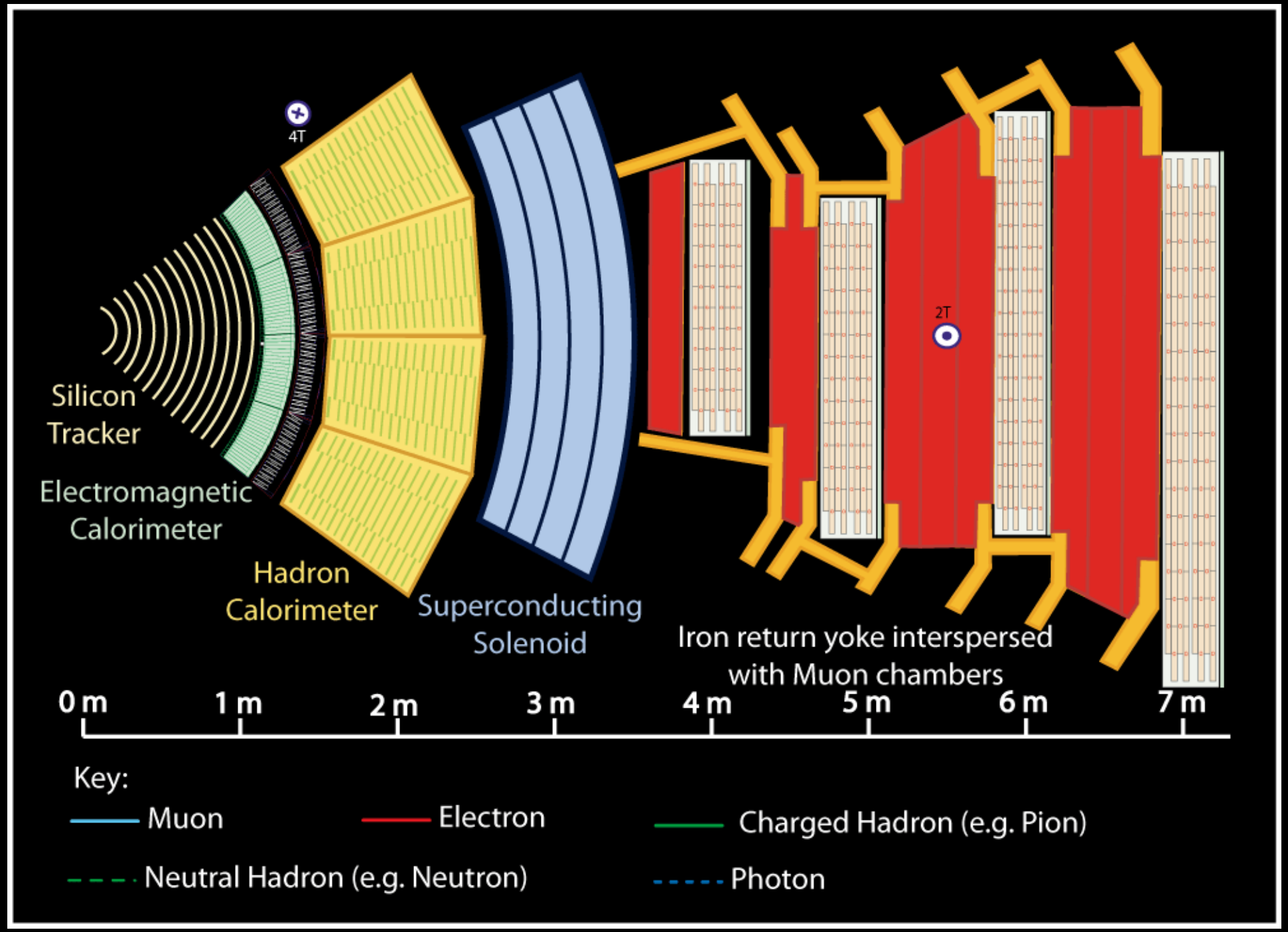


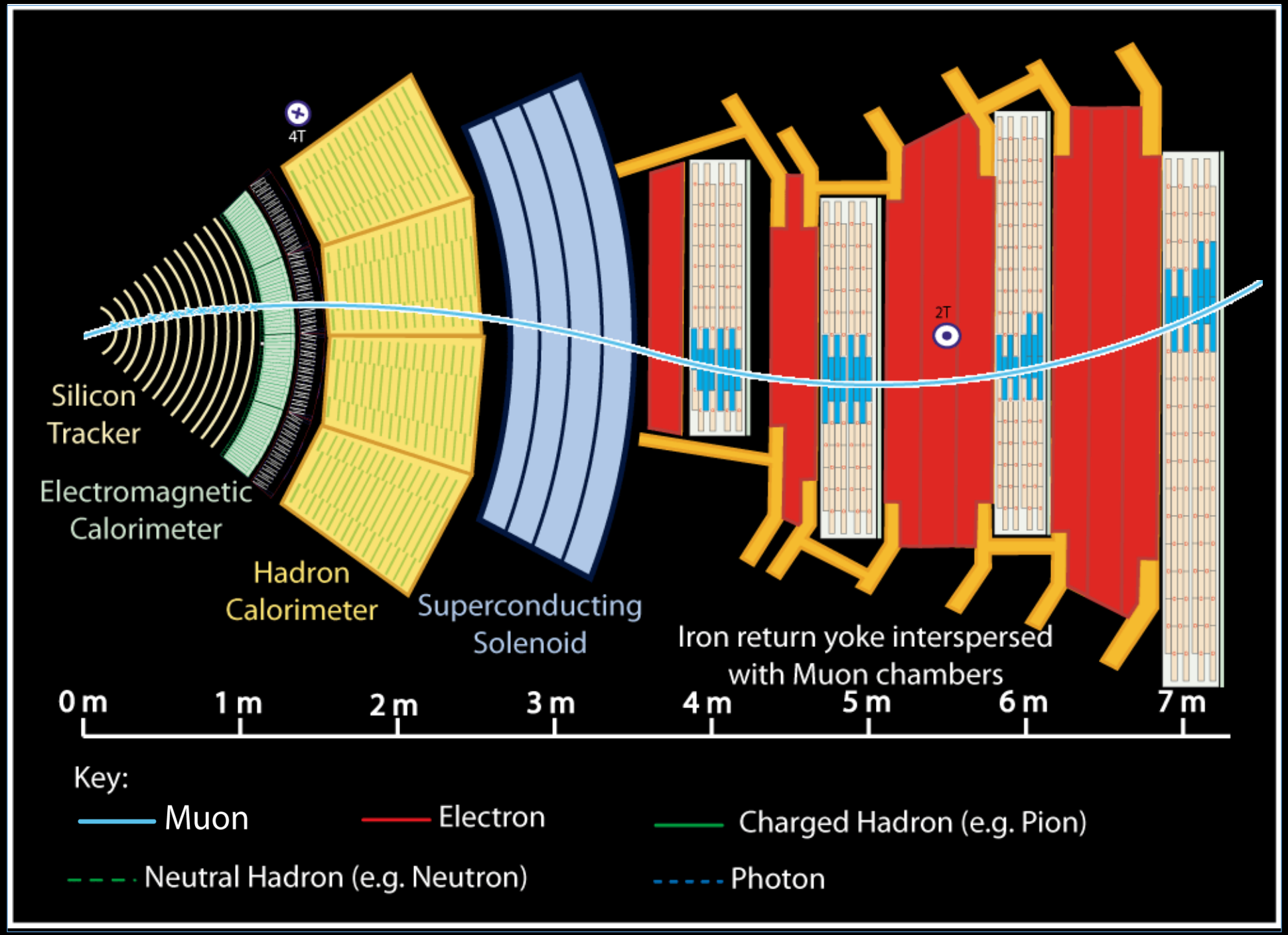
What happens during collisions of elementary particles ?






CMS Experiment at the LHC, CERN
Data recorded: 2010-Jul-09 02:25:58.839811 GMT(04:25:58 CEST)
Run / Event: 139779 / 4994190
2


4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
0 m
1 m
2 m
3 m
4 m
5 m
6 m
7 m
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon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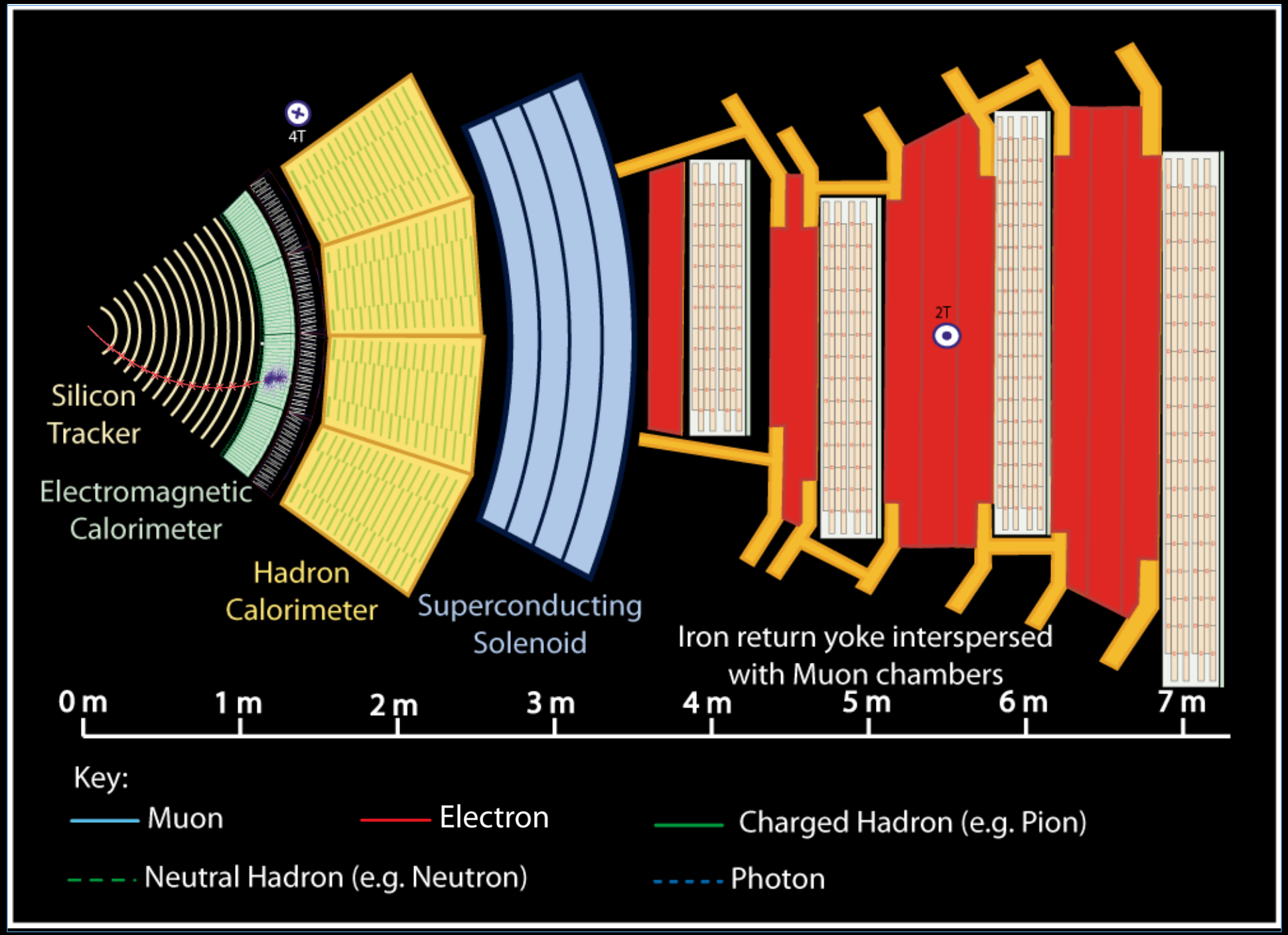
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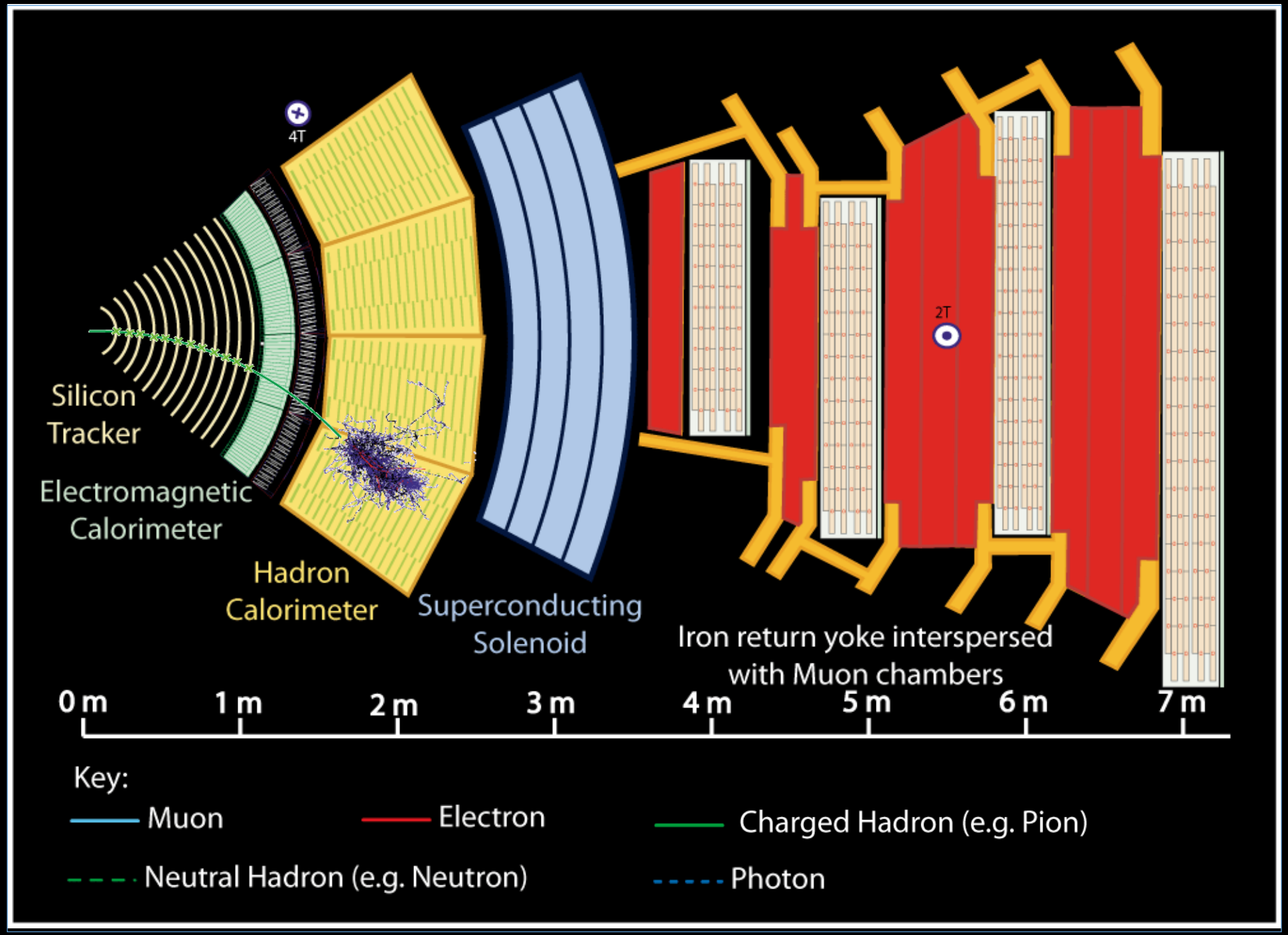
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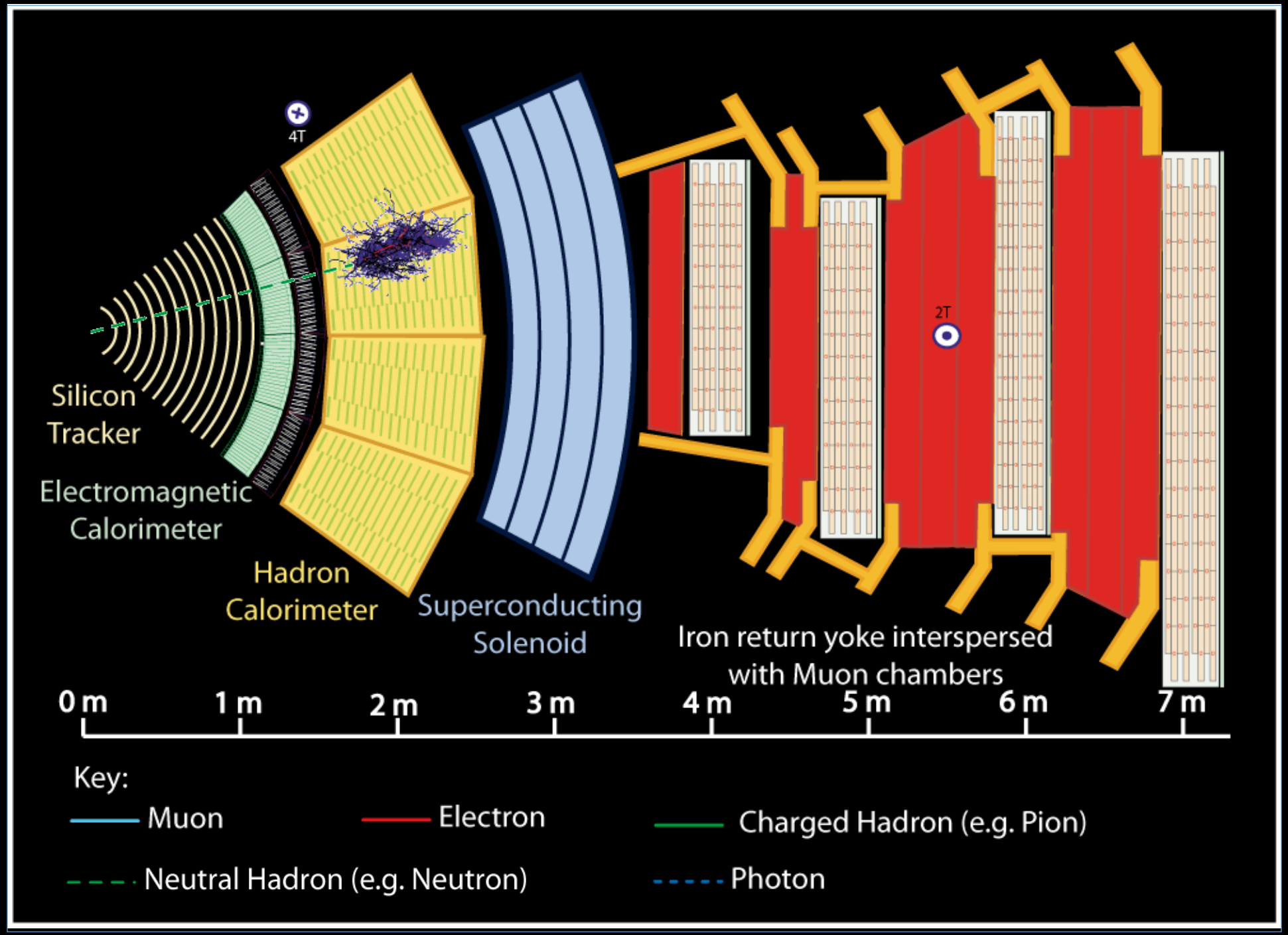
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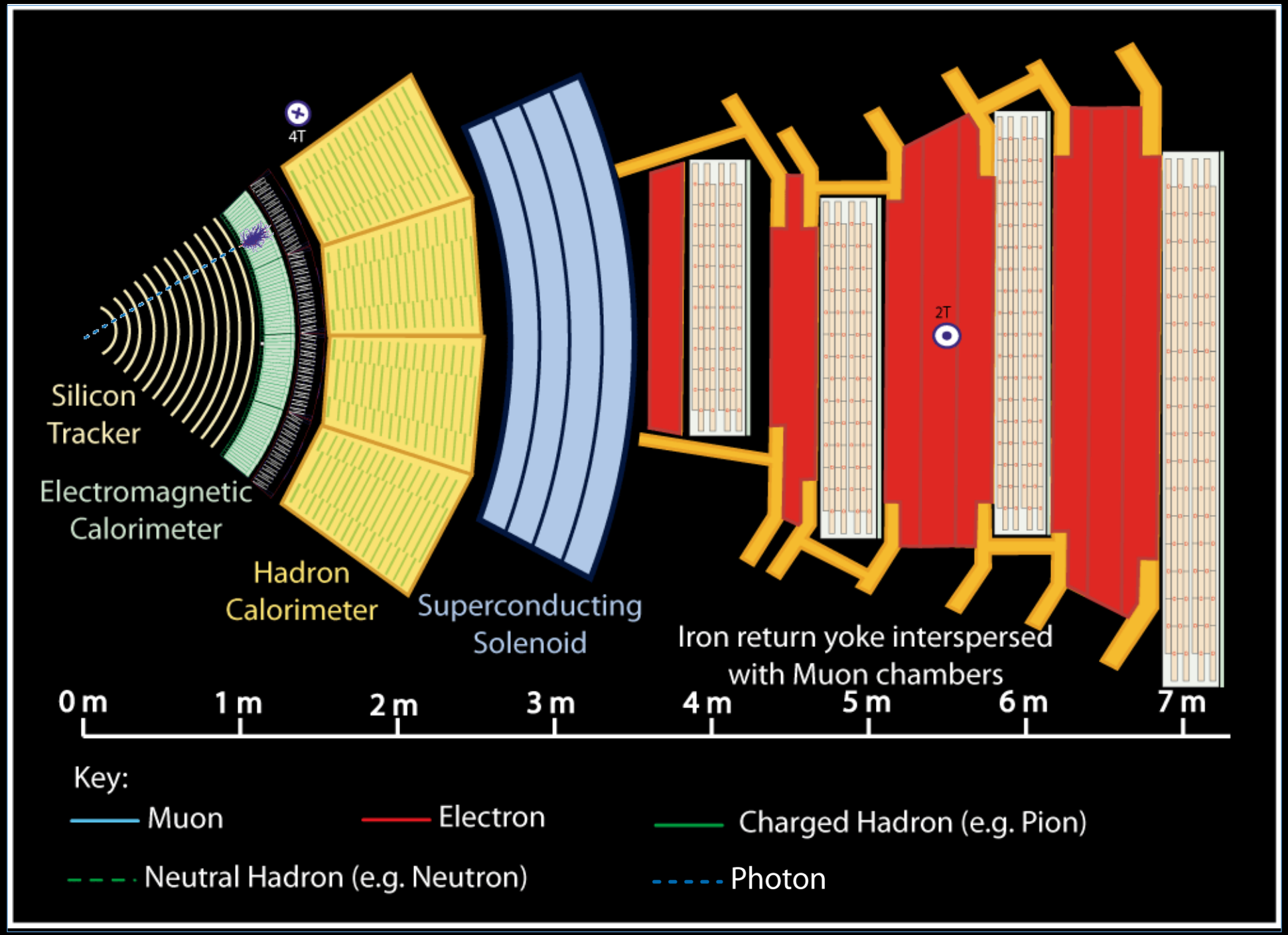
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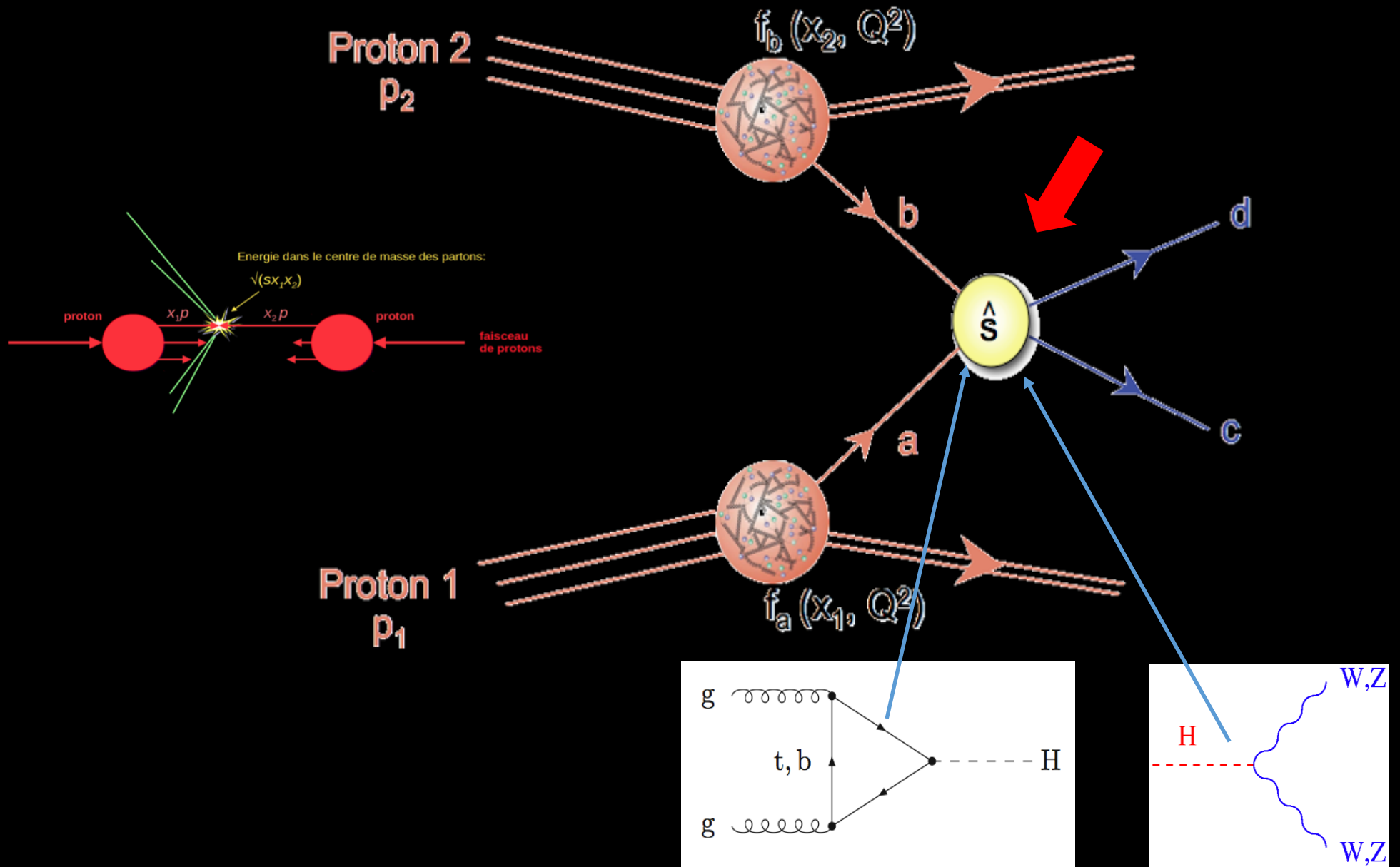
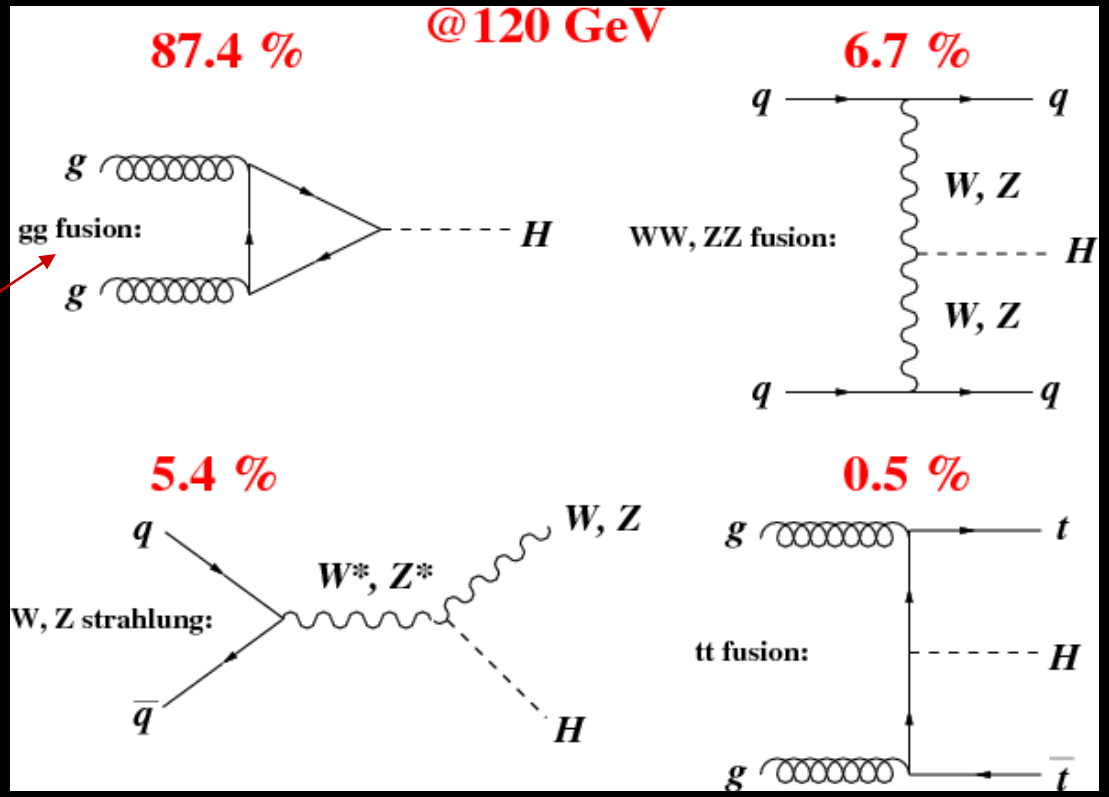
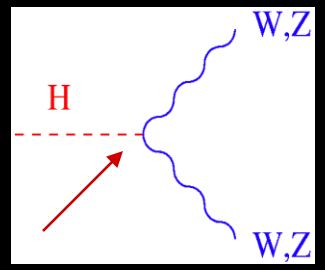

Proton 2
p_2
$f_b(x_2, Q^2)$
b
d
$\hat{s}$
c
a
Proton 1
p_1
$f_a(x_1, Q^2)$
Energie dans le centre de masse des partons:
$\sqrt{(sx_1x_2)}$
proton
x_1p
x_2p
proton
faisceau
de protons
g
t, b
g
H
H
W,Z
W,Z

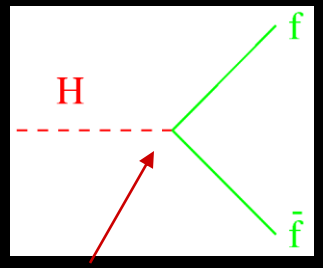
The various Higgs production mechanisms and decay modes



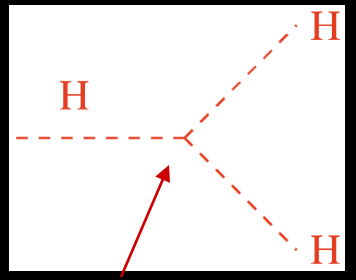
indirect coupling to gg, top in the loop



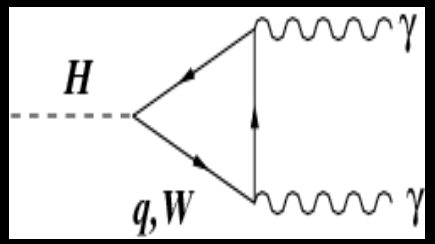
$g_{HVV} = 2m_V^2/v$
$g_{HWW} = g\, m_W$



$g_{Hff} = m_f/v$

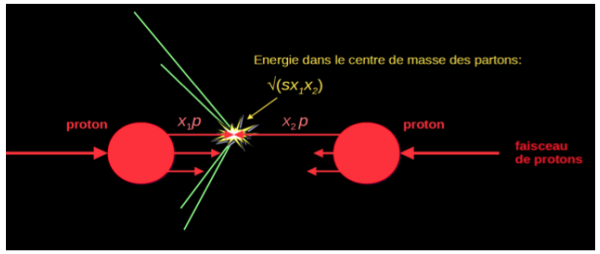


$g_{HHH} = 3m_H^2/v$

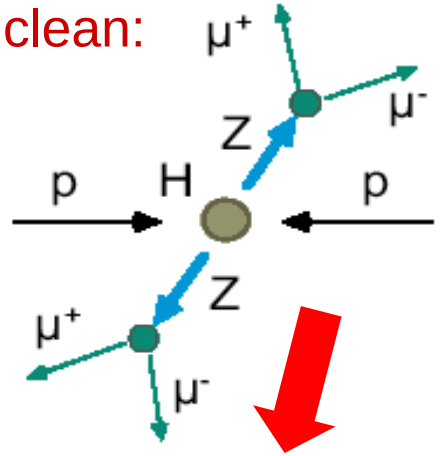


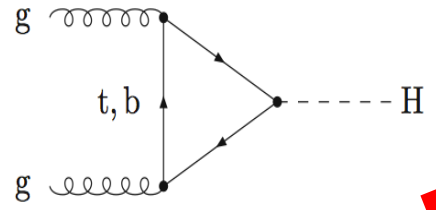
indirect coupling to $\gamma\gamma$

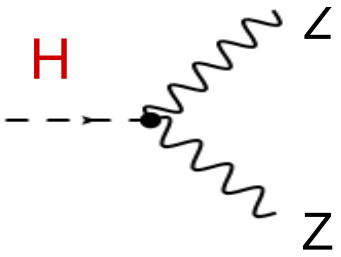
Production and detection of the Higgs in CMS

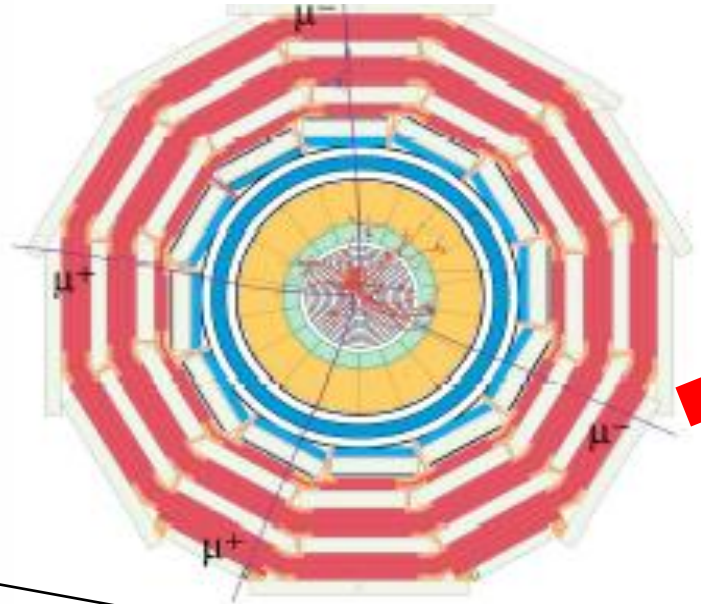


very rare collision 1 in 10^{15}, but clean:

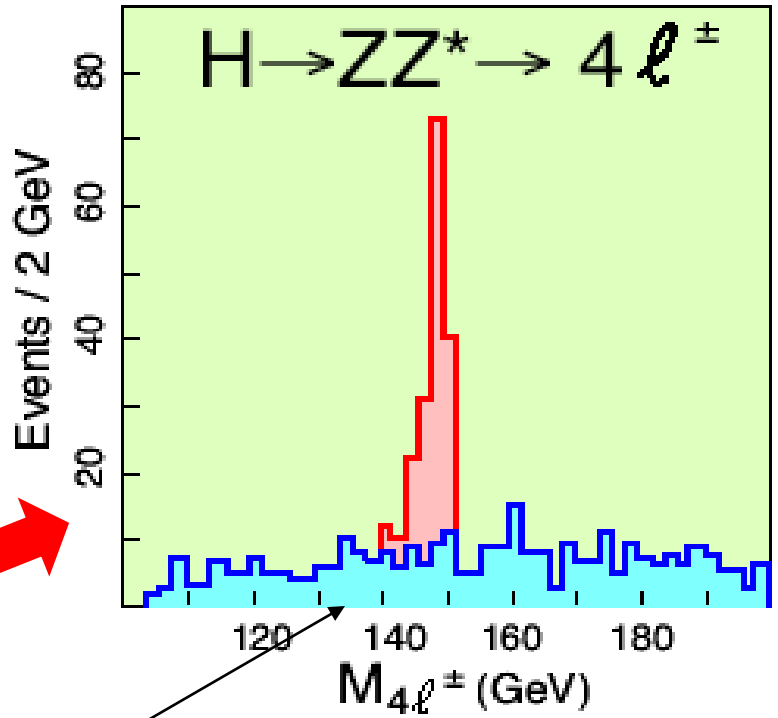


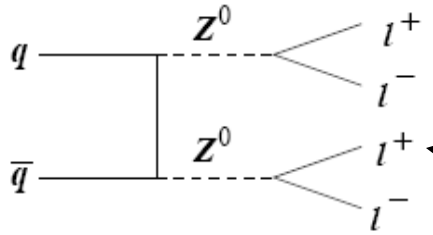






Expectations for signal and background if the Higgs has a mass ~ 150 GeV





Electroweak ZZ background

World Lagrangian -

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$
$$+ i\bar{\psi} \not{D} \psi + h.c$$
$$+ \chi_i y_{ij} \chi_j \phi + h.c.$$
$$+ |D_\mu \phi|^2 - V(\phi)$$

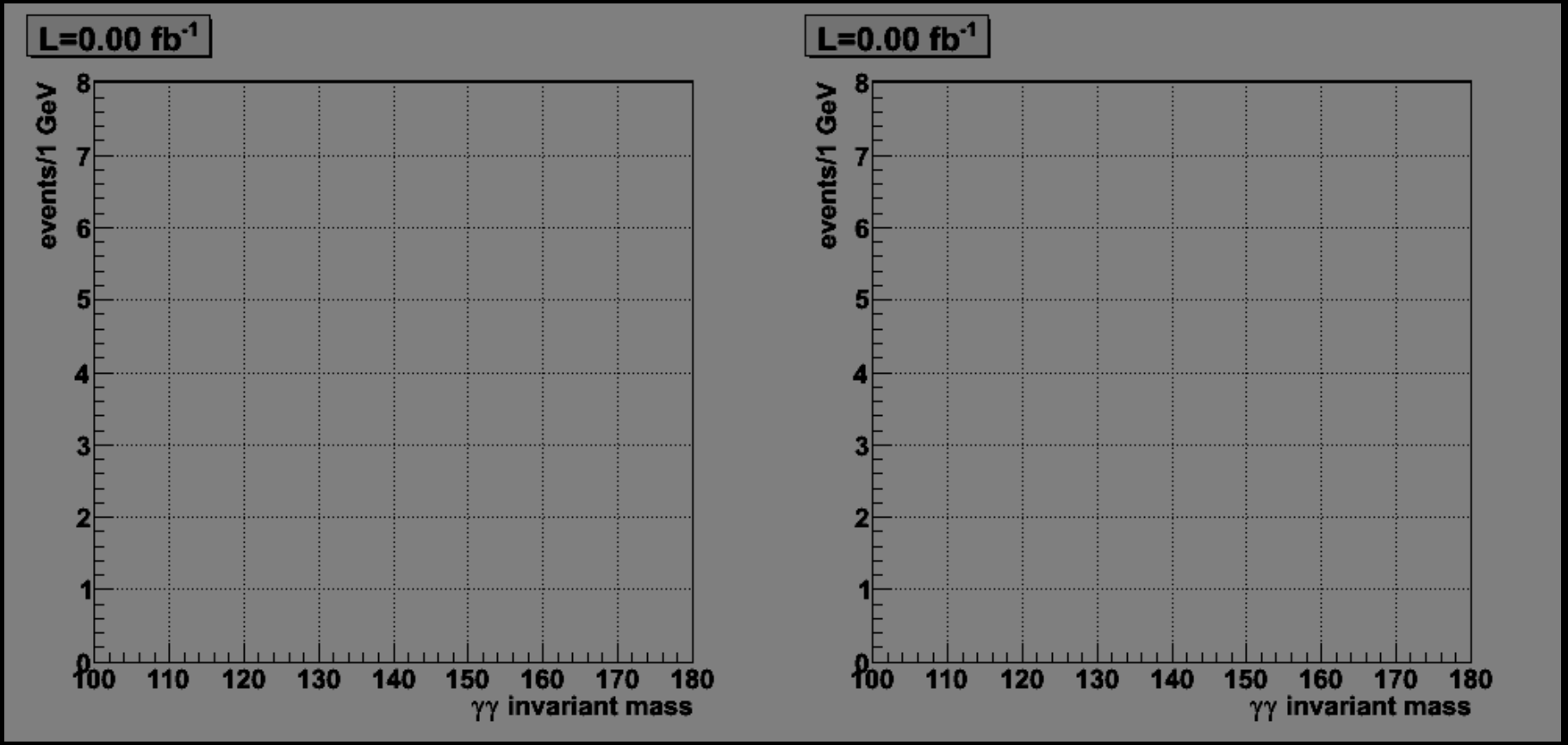
1. describes the forces: electricity, magnetism and the strong and weak nuclear forces
2. how these forces act on the fundamental particles of matter, namely quarks & leptons
3. how these particles obtain their masses from the Higgs boson
4. enables the Higgs boson to do the job

World Lagrangian - all the couplings are here!

$$
\begin{aligned}
&\mathcal{L}_{SM} = \\
&-\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4}g_s^2 f^{abc} f^{adc} g^b_\mu g^c_\nu g^d_\mu g^e_\nu + \frac{1}{2}ig_s^2(\bar{q}^\sigma_i \gamma^\mu q^\sigma_j) g^a_\mu + \bar{G}^a \partial^2 G^a + g_s f^{abc}\partial_\mu \bar{G}^a G^b g^c_\mu \\
&-\partial_\nu W^+_\mu \partial_\nu W^-_\mu - M^2 W^+_\mu W^-_\mu - \frac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \frac{1}{2c_w^2} M^2 Z^0_\mu Z^0_\mu - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \frac{1}{2}\partial_\mu H \partial_\mu H - \frac{1}{2}m_h^2 H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- \\
&-M^2 \phi^+ \phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \frac{1}{2c_w^2} M \phi^0 \phi^0 - \beta_h \left[\frac{2M^2}{g^2} + \frac{2M}{g} H + \frac{1}{2}(H^2 + \phi^0 \phi^0 + 2\phi^+ \phi^-) \right] + \frac{2M^4}{g^2}\alpha_h \\
&-igc_w \left[\partial_\nu Z^0_\mu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - Z^0_\nu (W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + Z^0_\mu (W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu) \right] \\
&-igs_w \left[\partial_\nu A_\mu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu (W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + A_\mu (W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu) \right] \\
&-\frac{1}{2}g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \frac{1}{2}g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2 c_w^2 \left(Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu \right) + g^2 s_w^2 \left(A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu \right) \\
&+g^2 s_w c_w \left[A_\mu Z^0_\nu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu \right] - g\alpha \left[H^3 + H\phi^0 \phi^0 + 2H\phi^+ \phi^- \right] \\
&-\frac{1}{8}g^2 \alpha_h \left[H^4 + (\phi^0)^4 + 4(\phi^+ \phi^-)^2 + 4(\phi^0)^2 \phi^+ \phi^- + 4H^2 \phi^+ \phi^- + 2(\phi^0)^2 H^2 \right] - gMW^+_\mu W^-_\mu H - \frac{1}{2}g\frac{M}{c_w^2} Z^0_\mu Z^0_\mu H \\
&-\frac{1}{2}ig \left[W^+_\mu (\phi^0 \partial_\mu \phi^- - \phi^- \partial_\mu \phi^0) - W^-_\mu (\phi^0 \partial_\mu \phi^+ - \phi^+ \partial_\mu \phi^0) \right] + \frac{1}{2}g \left[W^+_\mu (H\partial_\mu \phi^- - \phi^- \partial_\mu H) - W^-_\mu (H\partial_\mu \phi^+ - \phi^+ \partial_\mu H) \right] \\
&+\frac{1}{2}g\frac{1}{c_w} Z^0_\mu (H\partial_\mu \phi^0 - \phi^0 \partial_\mu H) - ig\frac{s_w^2}{c_w} M Z^0_\mu (W^+_\mu \phi^- - W^-_\mu \phi^+) + igs_w M A_\mu (W^+_\mu \phi^- - W^-_\mu \phi^+) - ig\frac{1-2c_w^2}{2c_w} Z^0_\mu (\phi^+ \partial_\mu \phi^- \\
&-\phi^- \partial_\mu \phi^+) + igs_w A_\mu (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) - \frac{1}{4}g^2 W^+_\mu W^-_\mu \left[H^2 + (\phi^0)^2 + 2\phi^+ \phi^- \right] - \frac{1}{4}g^2 \frac{1}{c_w^2} Z^0_\mu Z^0_\mu [H^2 + (\phi^0)^2 \\
&+2(2s_w^2 - 1)^2 \phi^+ \phi^-] - \frac{1}{2}g^2 \frac{s_w^2}{c_w} Z^0_\mu \phi^0 (W^+_\mu \phi^- + W^-_\mu \phi^+) - \frac{1}{2}ig^2 \frac{s_w^2}{c_w} Z^0_\mu H (W^+_\mu \phi^- - W^-_\mu \phi^+) + \frac{1}{2}g^2 s_w A_\mu \phi^0 (W^+_\mu \phi^- + W^-_\mu \phi^+) \\
&+\frac{1}{2}ig^2 s_w A_\mu H (W^+_\mu \phi^- - W^-_\mu \phi^+) - g^2 \frac{s_w}{c_w} (2c_w^2 - 1) Z^0_\mu A_\mu \phi^+ \phi^- - g^1 s_w^2 A_\mu A_\mu \phi^+ \phi^- - e^\lambda (\gamma\partial + m^\lambda_e) e^\lambda - \nu^\lambda \gamma \partial \nu^\lambda \\
&-\bar{u}^\lambda_j (\gamma\partial + m^\lambda_u) u^\lambda_j - \bar{d}^\lambda_j (\gamma\partial + m^\lambda_d) d^\lambda_j + igs_w A_\mu [-(\bar{e}^\lambda \gamma^\mu e^\lambda) + \frac{2}{3}(\bar{u}^\lambda_j \gamma^\mu u^\lambda_j) - \frac{1}{3}(\bar{d}^\lambda_j \gamma^\mu d^\lambda_j)] \\
&+\frac{ig}{4c_w} Z^0_\mu \left[(\nu^\lambda \gamma^\mu (1+\gamma^5) \nu^\lambda) + (e^\lambda \gamma^\mu (4s_w^2 - 1 - \gamma^5) e^\lambda) + (\bar{u}^\lambda_j \gamma^\mu (\frac{4}{3}s_w^2 - 1 - \gamma^5) u^\lambda_j) + (\bar{d}^\lambda_j \gamma^\mu (1 - \frac{8}{3}s_w^2 - \gamma^5) d^\lambda_j) \right] \\
&+\frac{ig}{2\sqrt{2}} W^+_\mu \left[(\nu^\lambda \gamma^\mu (1+\gamma^5) e^\lambda) + (\bar{u}^\lambda_j \gamma^\mu (1+\gamma^5) C_{\lambda\kappa} d^\kappa_j) \right] + \frac{ig}{2\sqrt{2}} W^-_\mu \left[(e^\lambda \gamma^\mu (1+\gamma^5) \nu^\lambda) + (\bar{d}^\kappa_j C^\dagger_{\lambda\kappa} \gamma^\mu (1+\gamma^5) u^\lambda_j) \right] \\
&+\frac{ig}{2\sqrt{2}} \frac{m^\lambda_e}{M} \left[-\phi^+ (\nu^\lambda (1-\gamma^5) e^\lambda) + \phi^- (e^\lambda (1+\gamma^5) \nu^\lambda) \right] - \frac{g}{2}\frac{m^\lambda_e}{M} \left[H(e^\lambda e^\lambda) + i\phi^0 (e^\lambda \gamma^5 e^\lambda) \right] \\
&+\frac{ig}{2M\sqrt{2}} \phi^+ \left[-m^\kappa_d (\bar{u}^\lambda_j C_{\lambda\kappa} (1-\gamma^5) d^\kappa_j) + m^\lambda_u (\bar{u}^\lambda_j C_{\lambda\kappa} (1+\gamma^5) d^\kappa_j) \right] + \frac{ig}{2M\sqrt{2}} \phi^- \left[m^\lambda_d (\bar{d}^\lambda_j C^\dagger_{\lambda\kappa} (1+\gamma^5) u^\kappa_j) - m^\kappa_u (\bar{d}^\lambda_j C^\dagger_{\lambda\kappa} (1-\gamma^5) u^\kappa_j) \right] \\
&-\frac{g}{2}\frac{m^\lambda_u}{M} H(\bar{u}^\lambda_j u^\lambda_j) - \frac{g}{2}\frac{m^\lambda_d}{M} H(\bar{d}^\lambda_j d^\lambda_j) + \frac{ig}{2}\frac{m^\lambda_u}{M} \phi^0 (\bar{u}^\lambda_j \gamma^5 u^\lambda_j) - \frac{ig}{2}\frac{m^\lambda_d}{M} \phi^0 (\bar{d}^\lambda_j \gamma^5 d^\lambda_j) + \bar{X}^+ (\partial^2 - M^2) X^+ + \bar{X}^- (\partial^2 - M^2) X^-
\end{aligned}
$$

It an statistical process

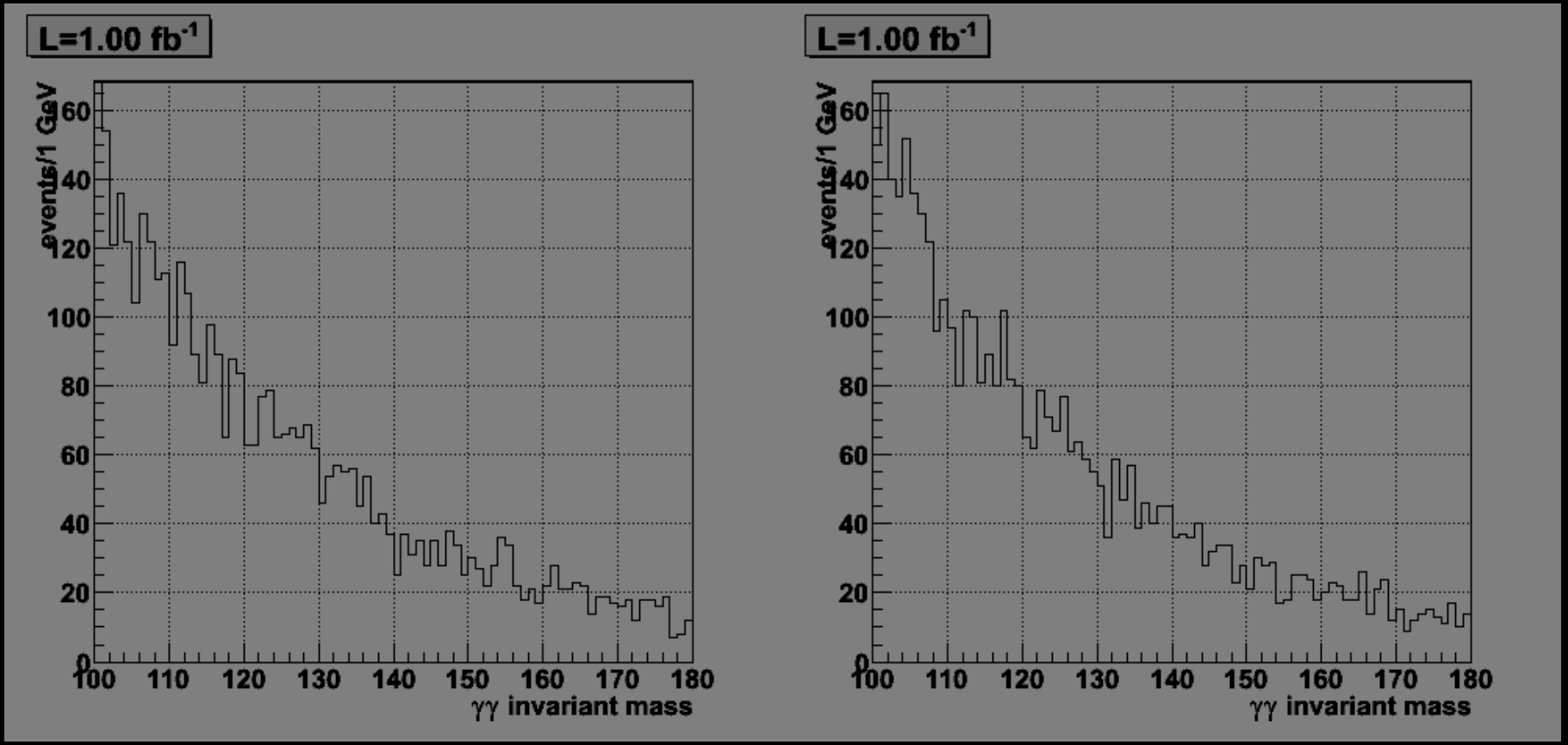
…… like play dice



One of these plots contains the (simulated) Higgs boson signal.

Can you spot it?

by Piotr Traczyk



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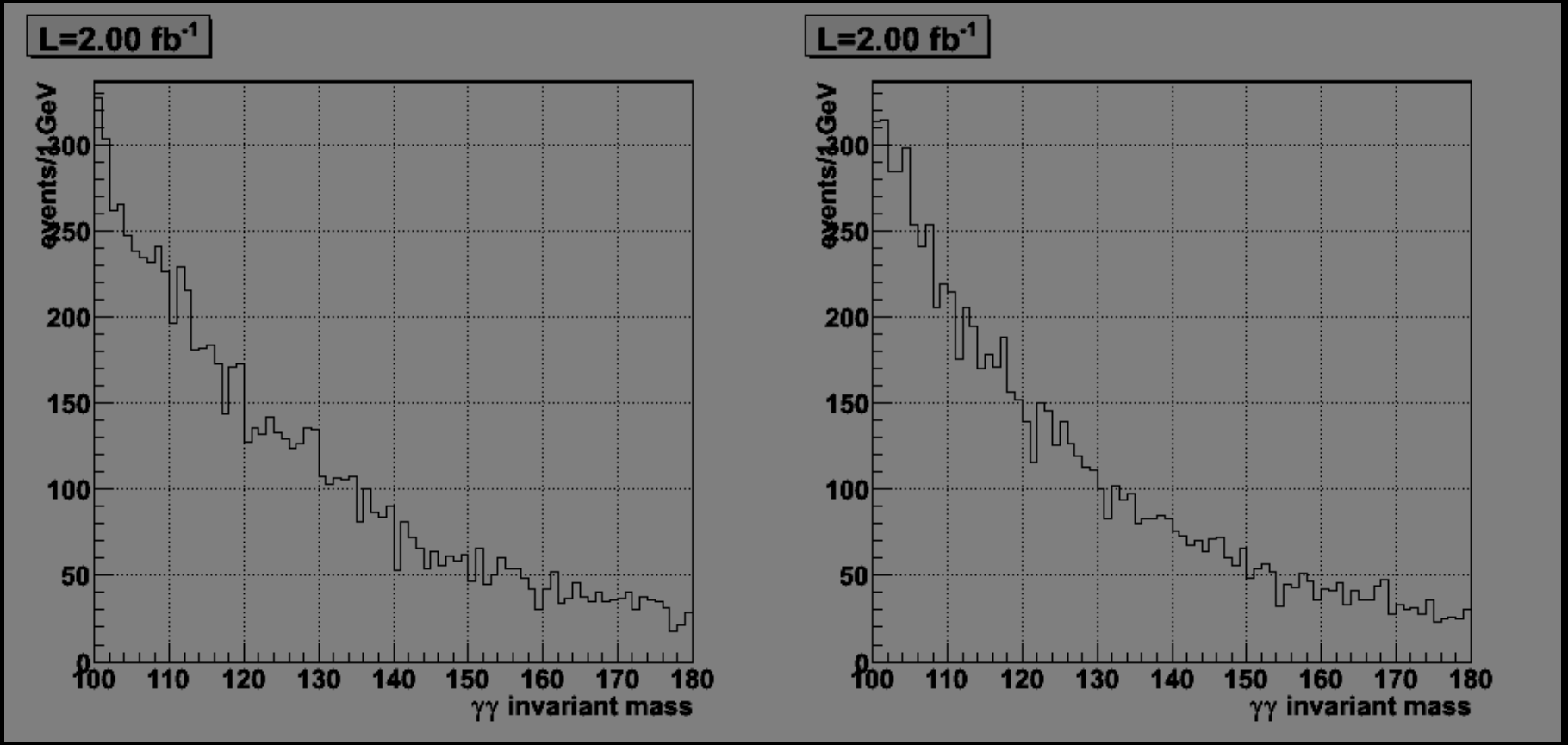

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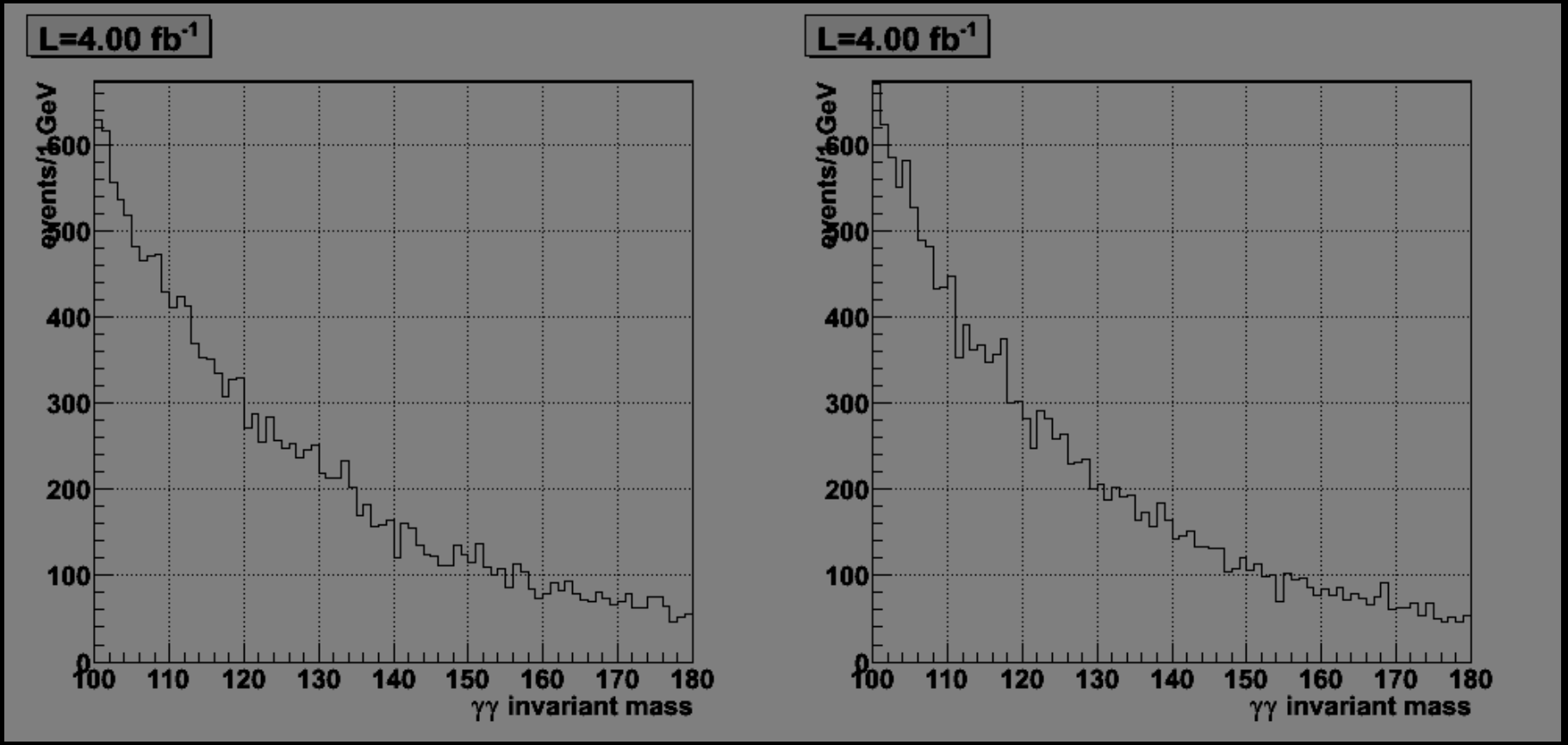

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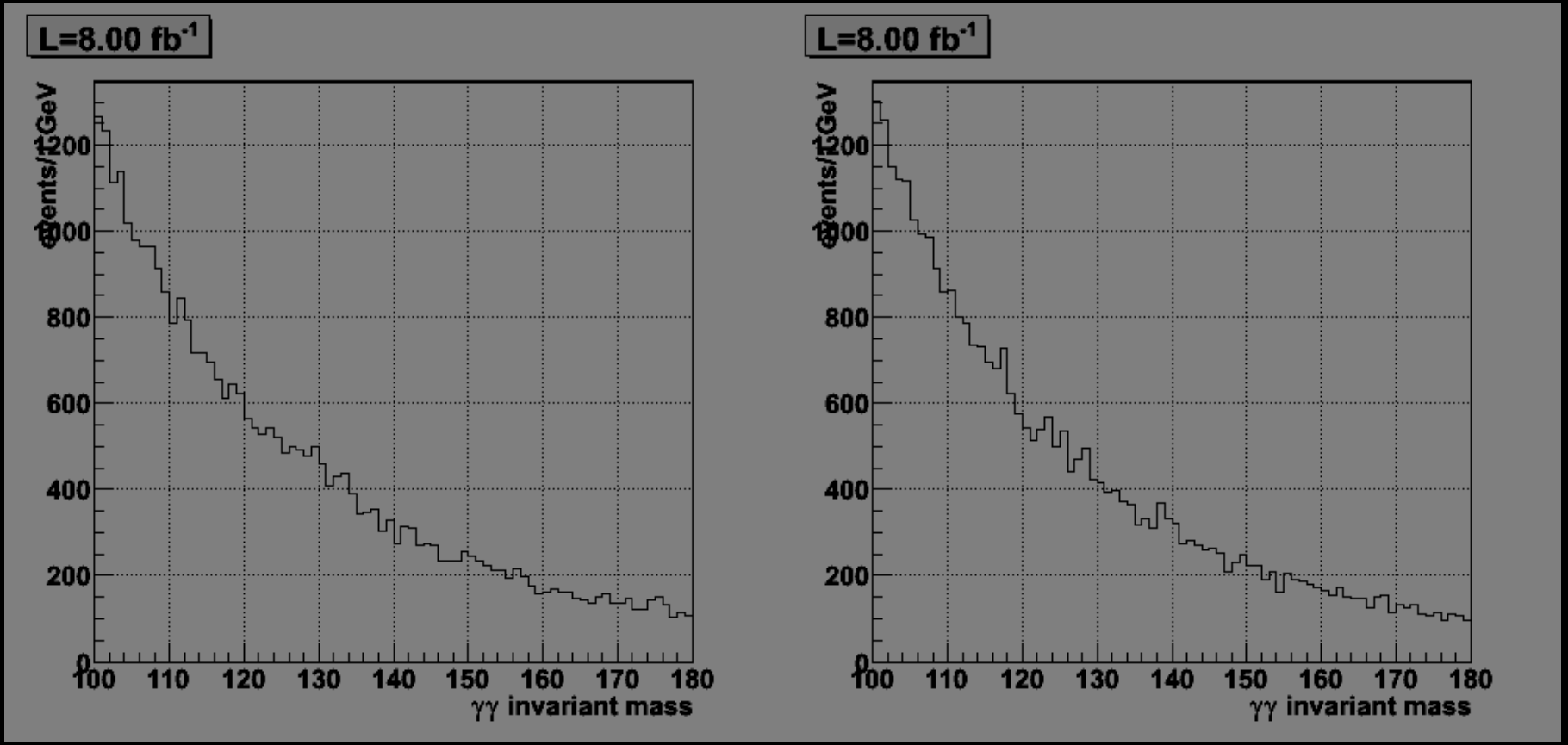
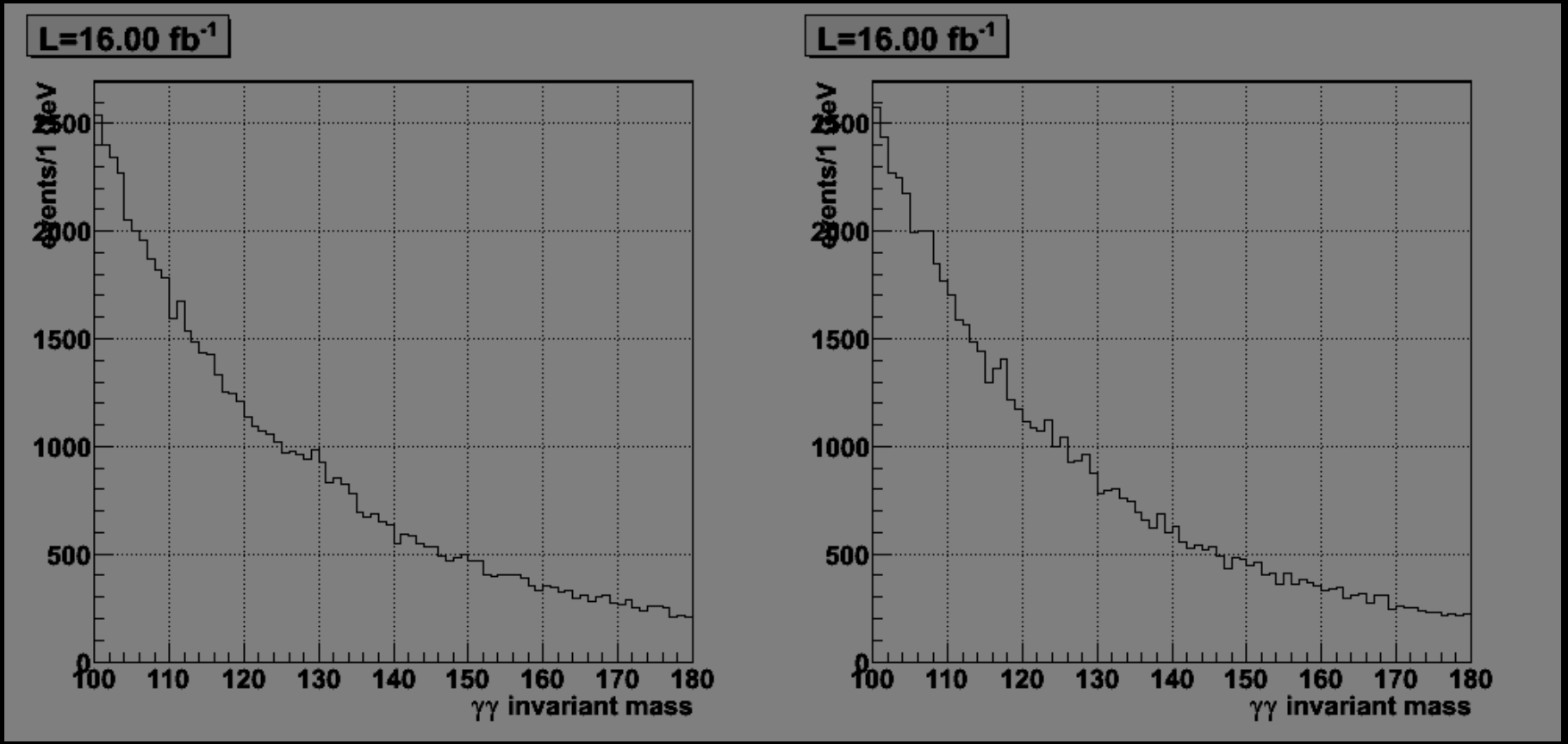


One of these plots contains the (simulated) Higgs boson signal.

Can you spot it?

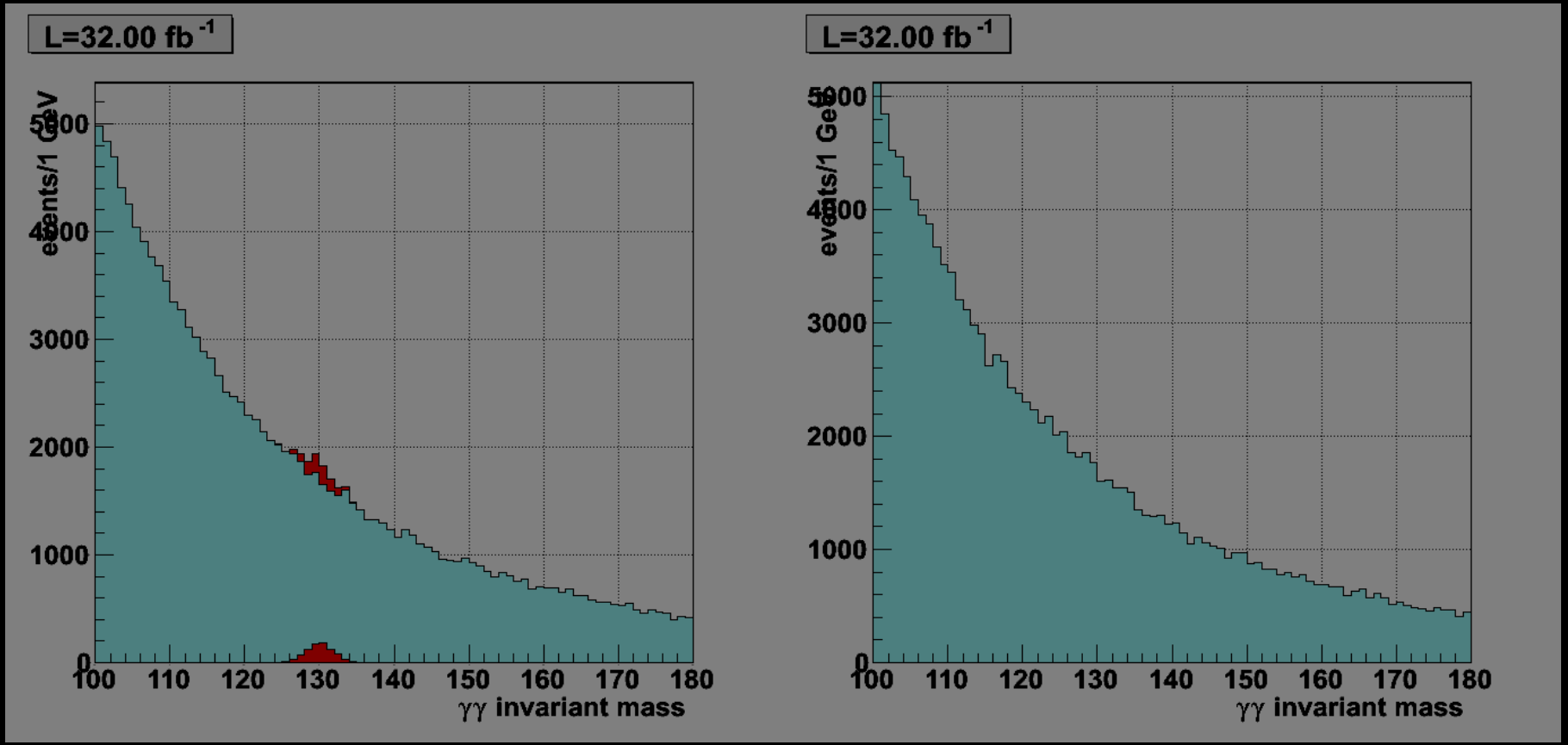
by Piotr Traczyk



One of these plots contains the (simulated) Higgs boson signal.

Can you spot it?

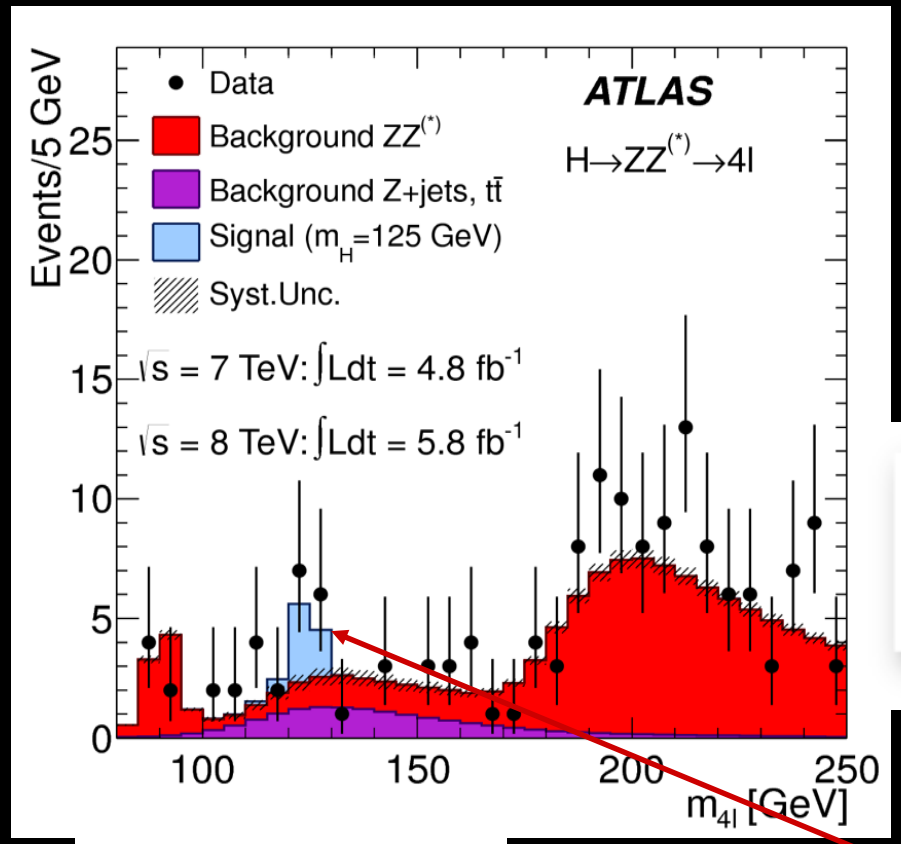
by Piotr Traczyk

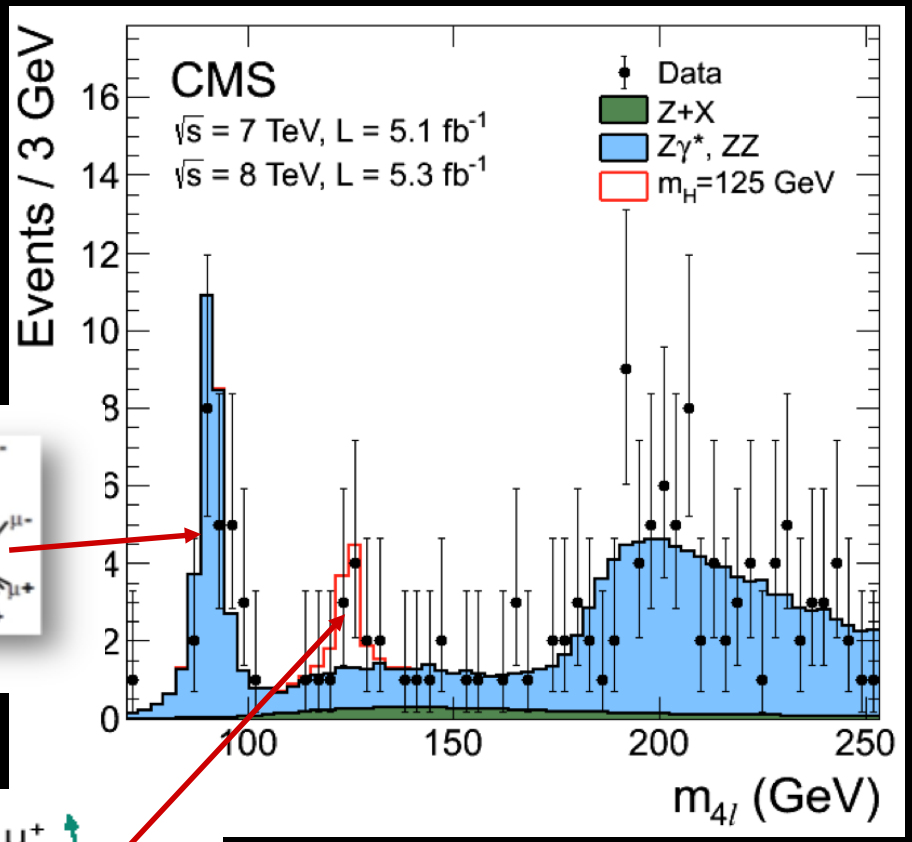


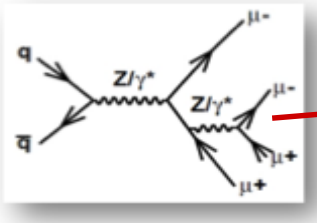
One of these plots contains the (simulated) Higgs boson signal.

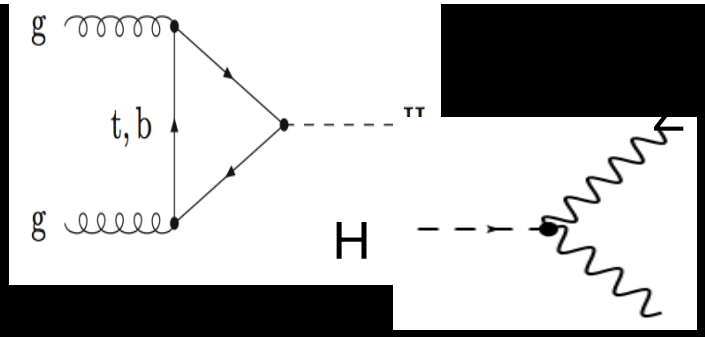
Can you spot it?

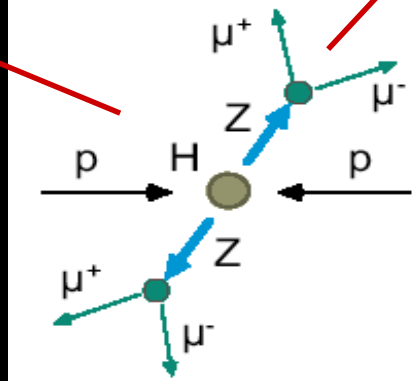
by Piotr Traczyk


ATLAS
Data
Background ZZ(*)
Background Z+jets, tt̄
Signal (mH=125 GeV)
Syst.Unc.
√s = 7 TeV: ∫Ldt = 4.8 fb-1
√s = 8 TeV: ∫Ldt = 5.8 fb-1
H→ZZ(*)→4l
Events/5 GeV
m4l [GeV]

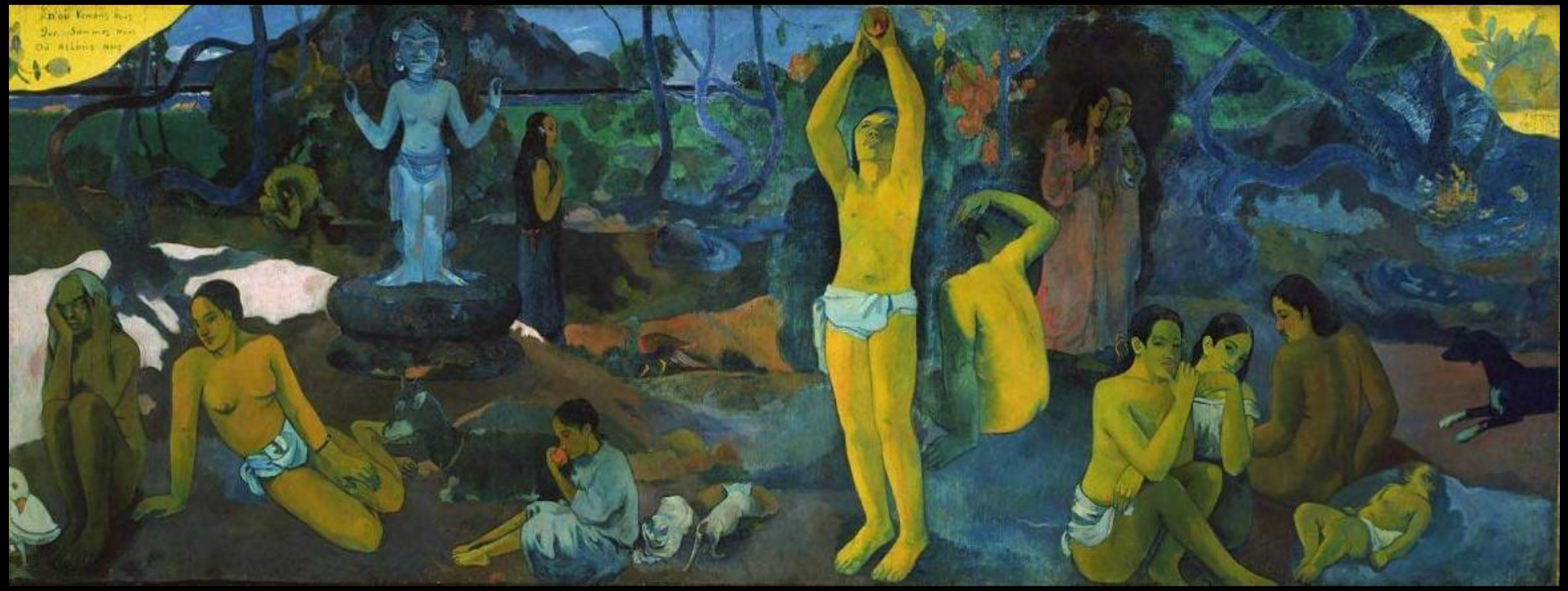

CMS
√s = 7 TeV, L = 5.1 fb-1
√s = 8 TeV, L = 5.3 fb-1
Data
Z+X
Zγ*, ZZ
mH=125 GeV
Events / 3 GeV
m4l (GeV)


q
q̄
Z/γ*
Z/γ*
μ-
μ-
μ+
μ+

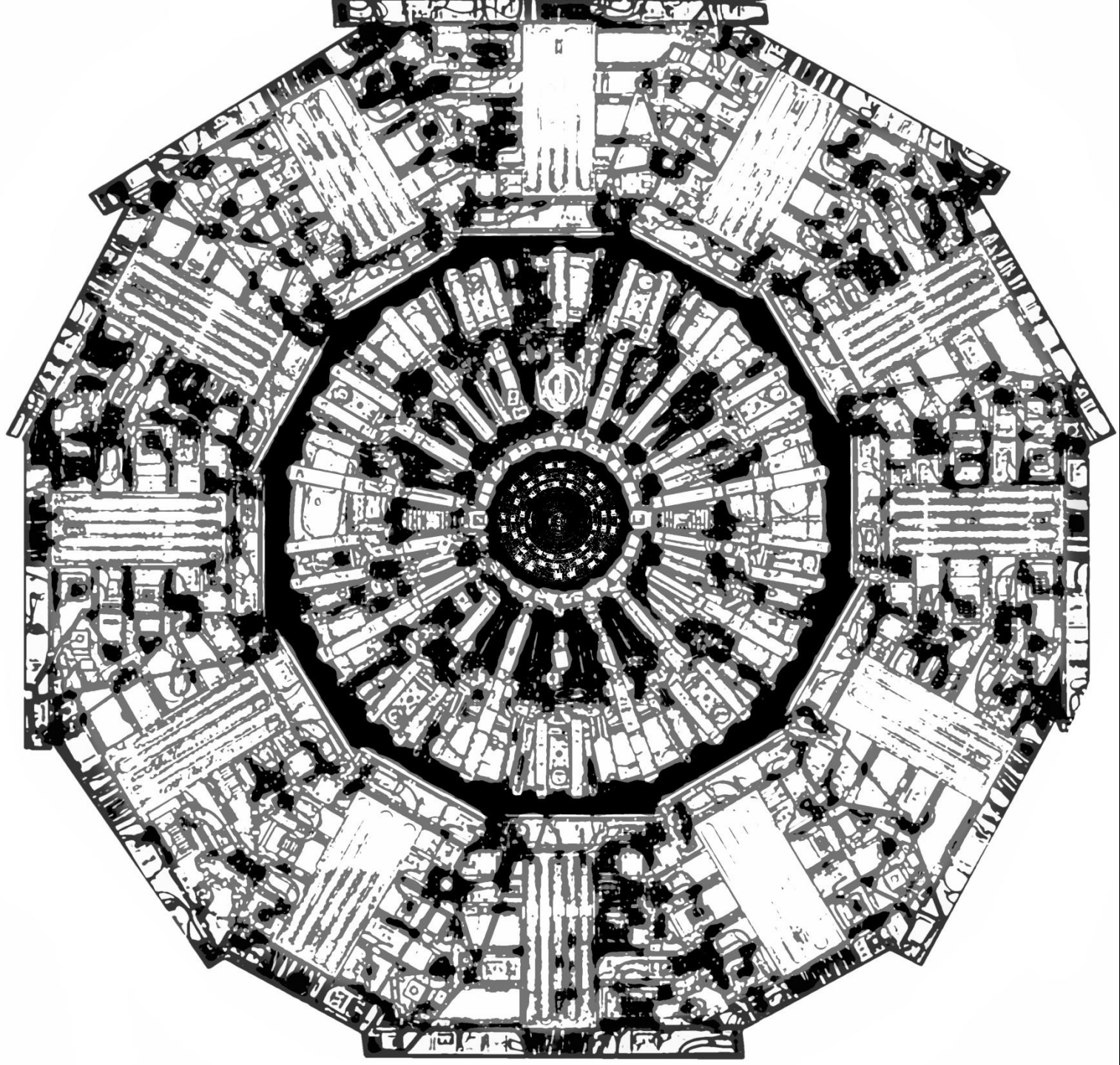

g
g
t, b
H

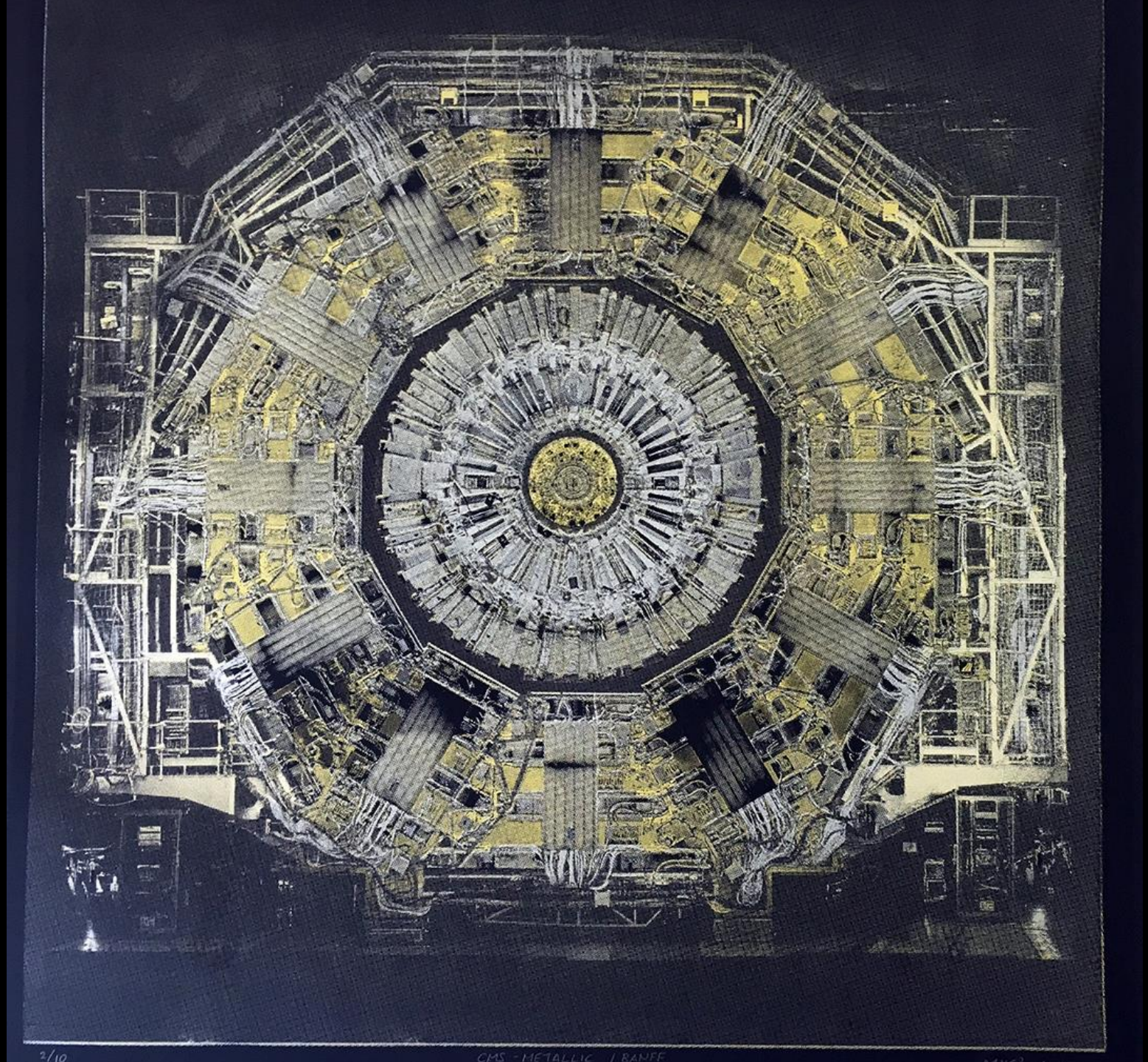

μ+
μ-
Z
p
H
p
Z
μ+
μ-

“Where do we come from? What are we? Where are we going?”

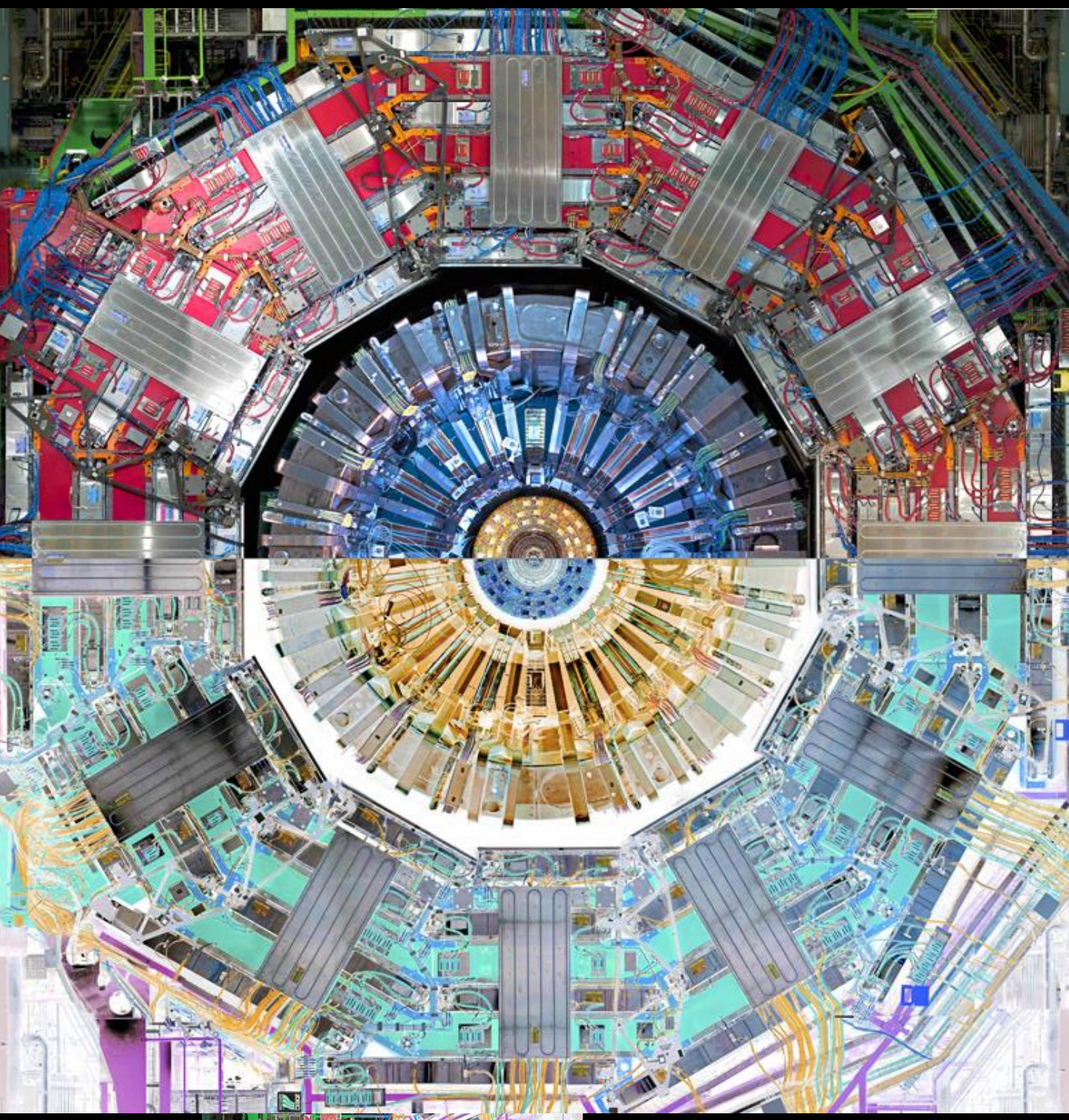


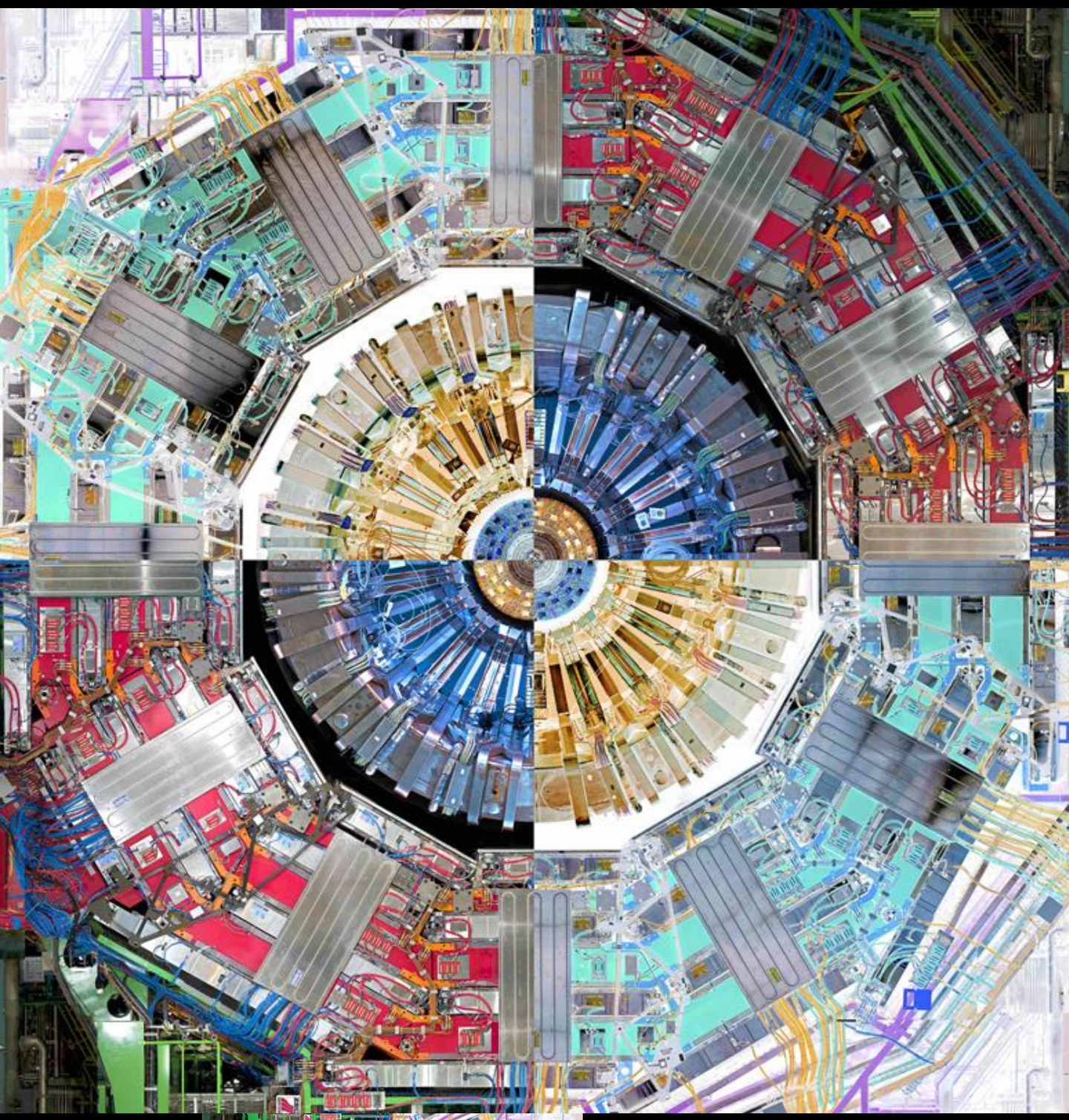
The aim of particle physics, CERN & the LHC:
What is the Universe made of ?

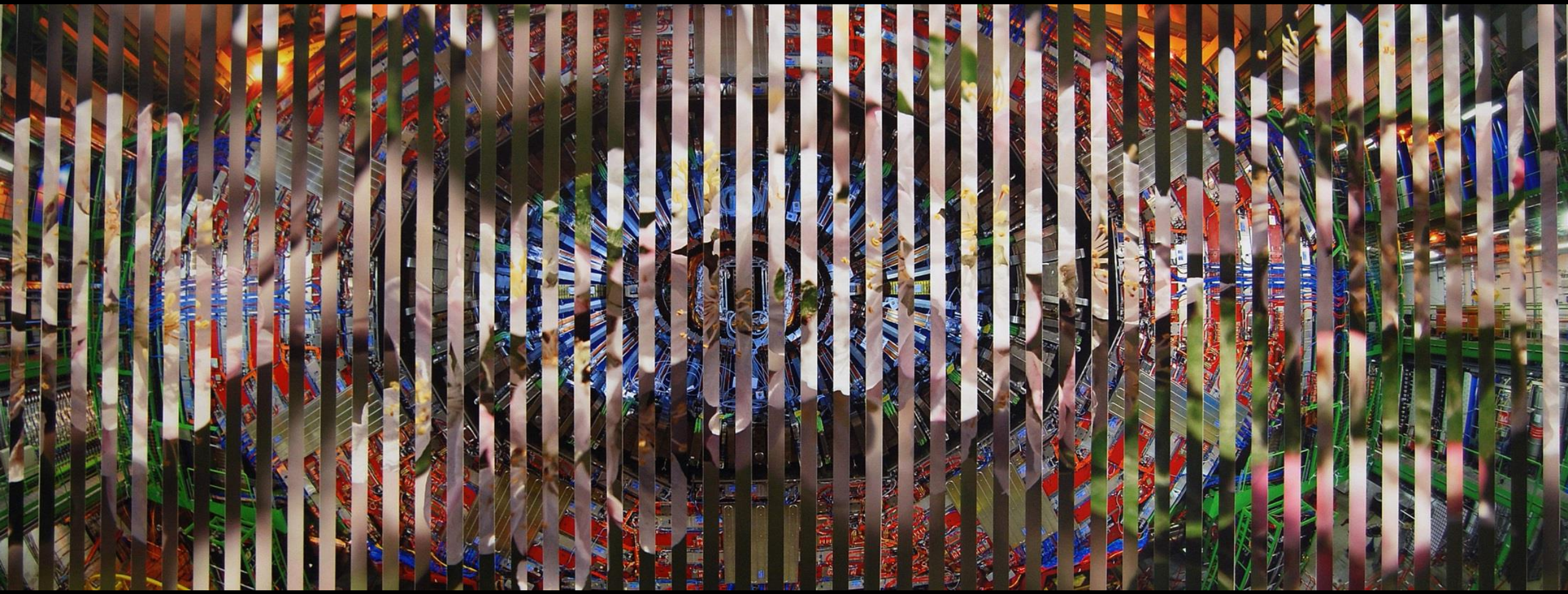


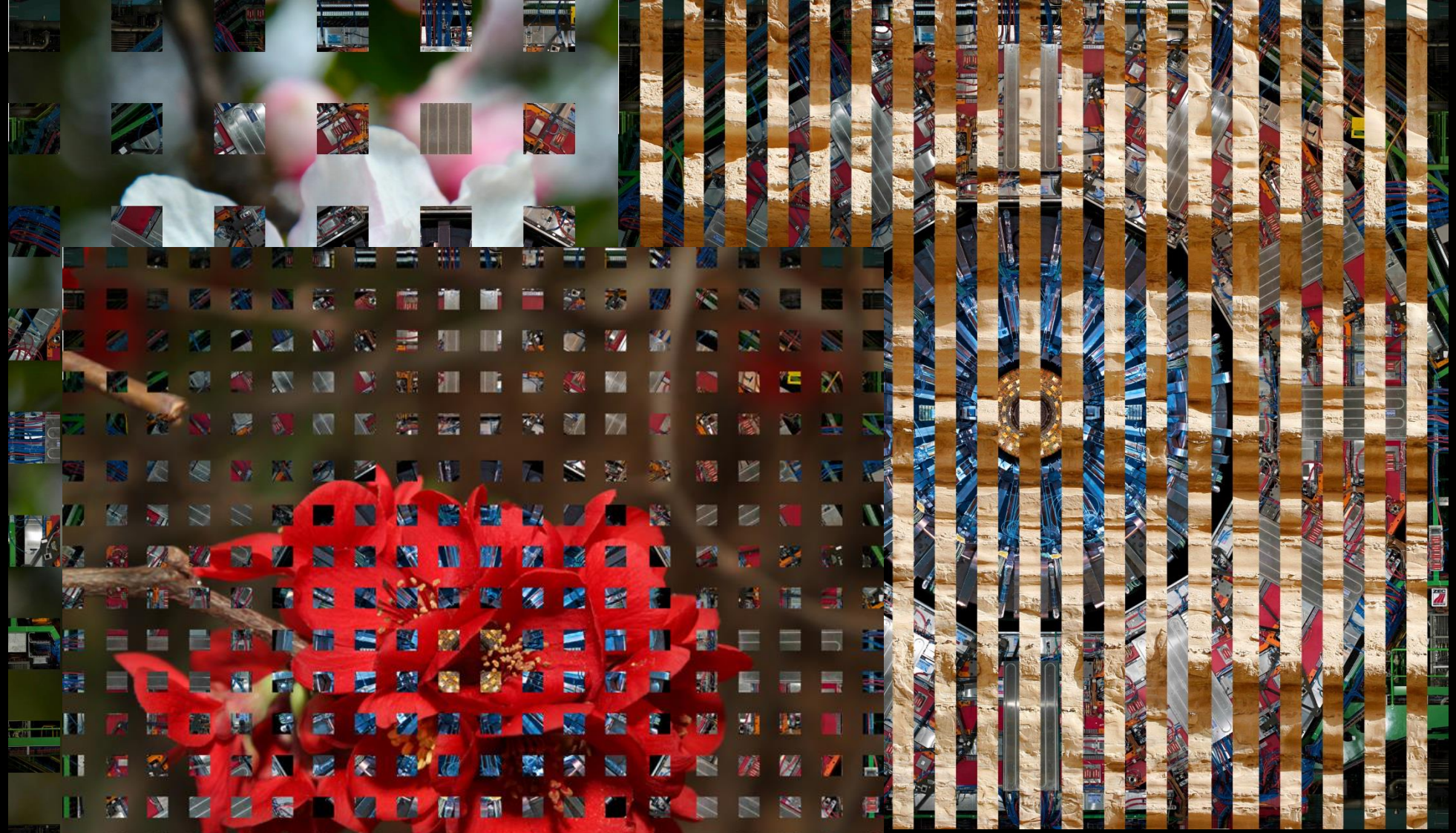


3/10 CMS - METALLIC / BANFF

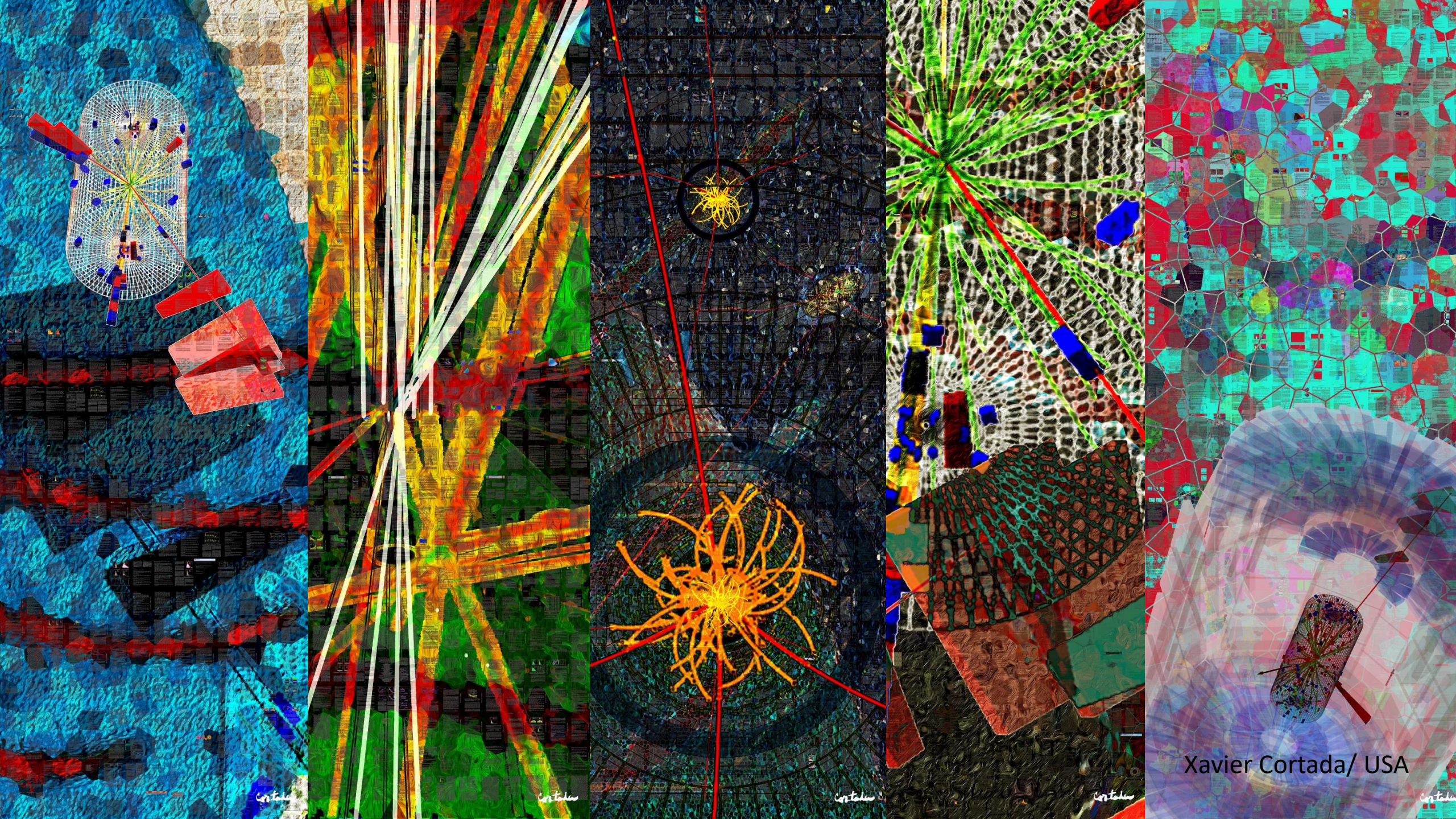


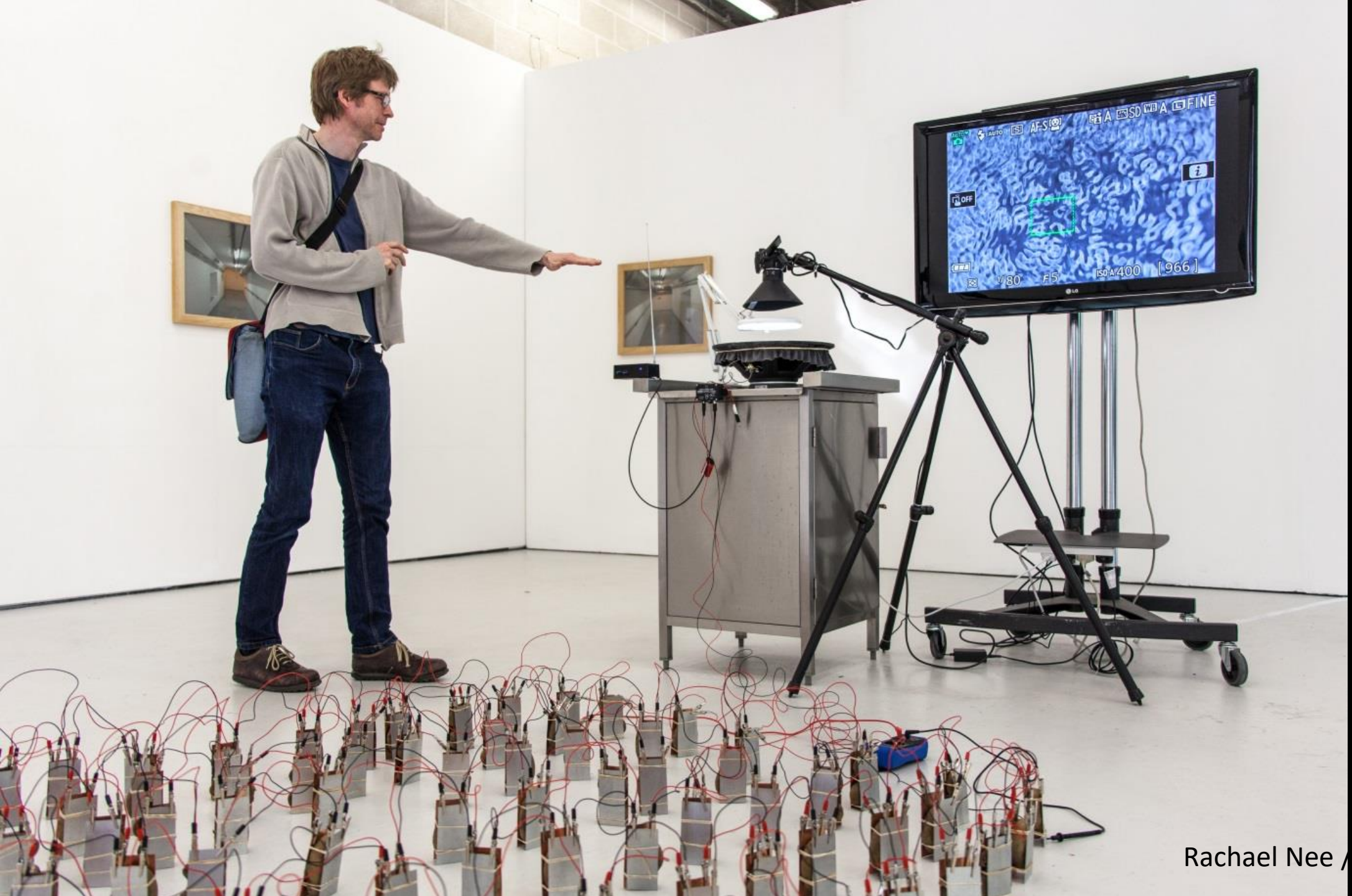




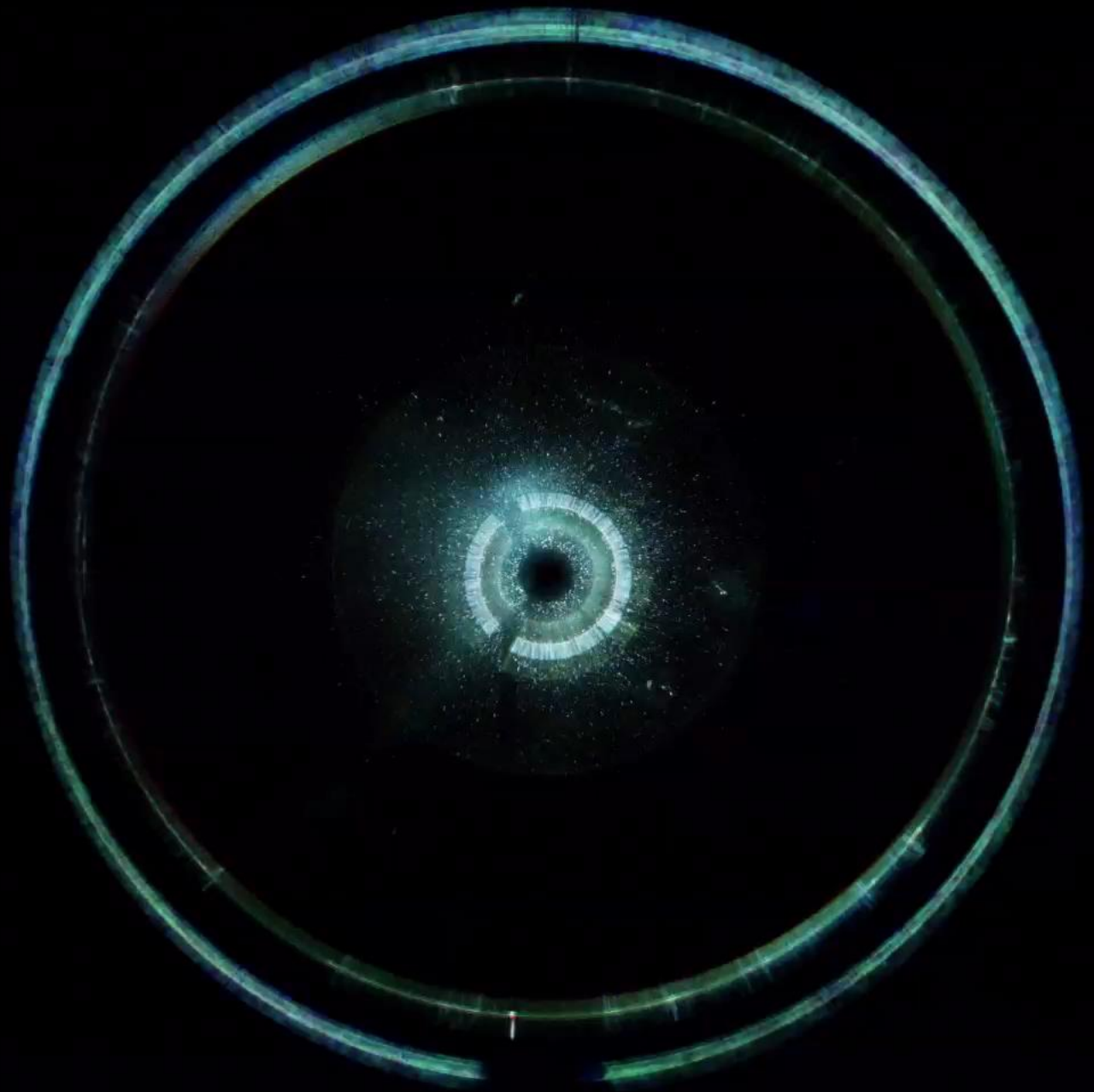


Michael Hoch / AUT


Xavier Cortada/ USA



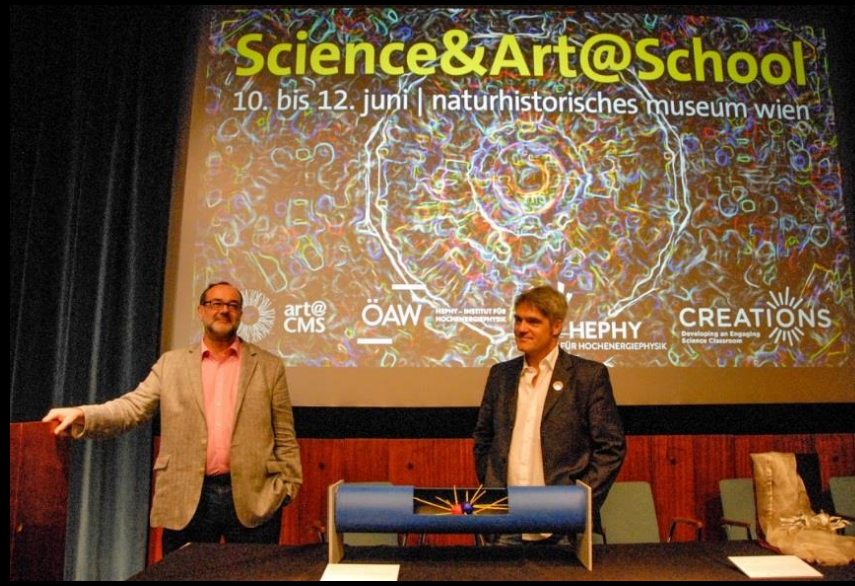
Rachael Nee /



Chris Henschke /AUS

Science&Art@School – Cultural Collisions

Photos : CERN Bldg 40 became a stage for students



art@CMS INFN Italian Tour has similar activities and creates synergies between various action to inspire students

Science&Art@School – Cultural Collisions

science&art@school event 2017 in Vienna (June) and the Cultural Collisions event at CERN (February) :

This is a Horizon 2020 EU project CREATIONS http://portal.opendiscoveryspace.eu/creations

Photos of the event in the Natural History Museum Vienna June 2017: https://goo.gl/photos/esmfuMAx8Xr5K3V66

Videos of the science&art@school event in the NHM :

Rhythm of Science : https://youtu.be/DjkH7f1PNpI

Cultural Collisions – dance : https://youtu.be/BIy_iERk5Ps

Science Rap "Particle Love": https://youtu.be/sdB2PydXUW8

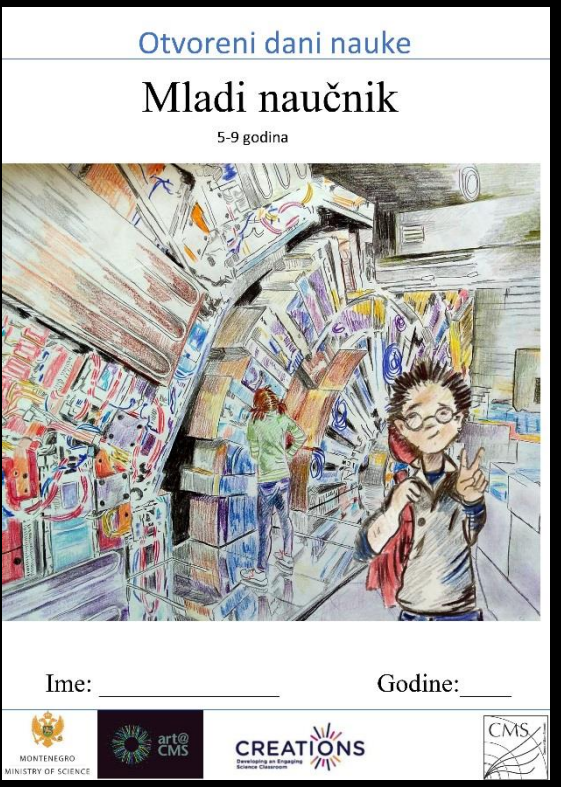
Cultural Collisons @ CERN February 2017

Photos: https://goo.gl/photos/2tpnAg7TnsWEjq9q6 https://1drv.ms/f/s!Al-rN-l0kS2sg_gLpGmn7xOEnwjIfQ

Video of a student of the workshop @ CERN: https://www.youtube.com/watch?v=TEsgtwUv6xk

CCC Cultural Collisions CERN – a dance performance by students @ CERN: https://youtu.be/ETjKwUS0yfg

sciARTmasterclass – Science Festival



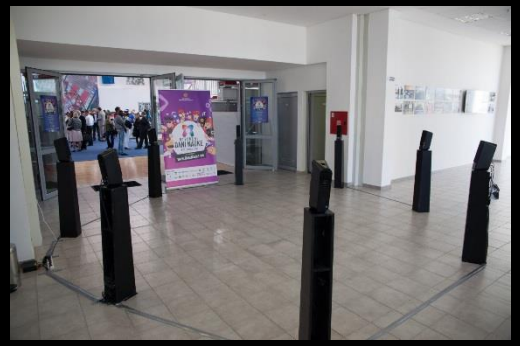
Students participating in the

CMS Junior Scientist Program

art@CMS interdisciplinary Exhibition with: real detector & accelerator equipment, art works, creative corners , lectures and detector workshops as well as sciART workshops.

Montenegro 2017: https://www.youtube.com/watch?v=9vfIW-Pf7vg

Athens 2015: https://www.youtube.com/watch?v=tT8MHsCaYks



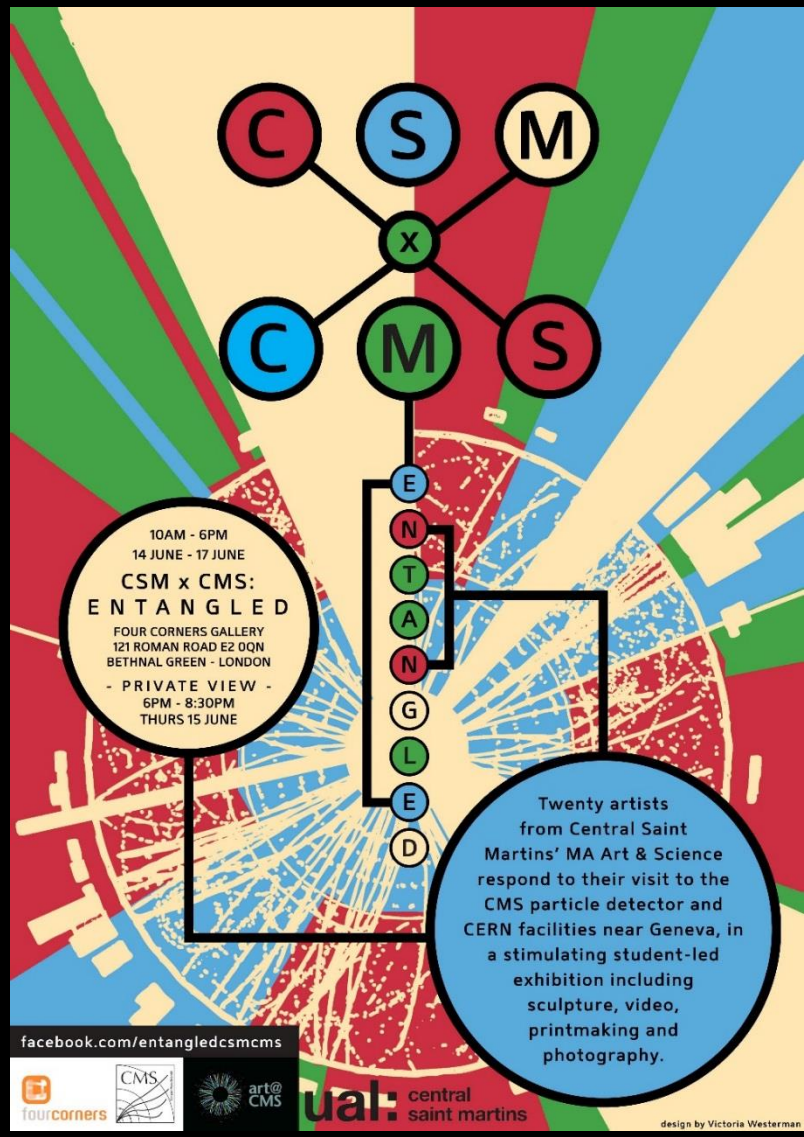
University of the Arts London -Saint Martins College of Art

local scientific partner: Imperial College

2 semester sciART course October 2016 – June 2017

- 22 students supervised by Prof. Nathan Cohen, Dr. Andrew Charalambous
- Weekly lectures at the UAL/CSM
  - Lectures from colleagues of **Imperial College**
  - Visit at CERN 5 days December 5 days May
  - Offered workshops at CERN during May visit
  - Final show in London June and November

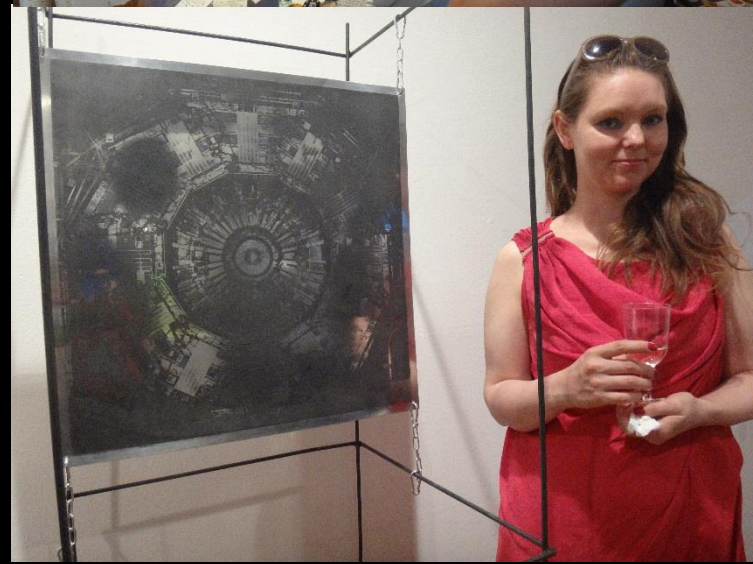
Photos: https://goo.gl/photos/VfSSqkg7cN7Ejzs97



University of the Arts London -Saint Martins College of Art

local scientific partner: Imperial College

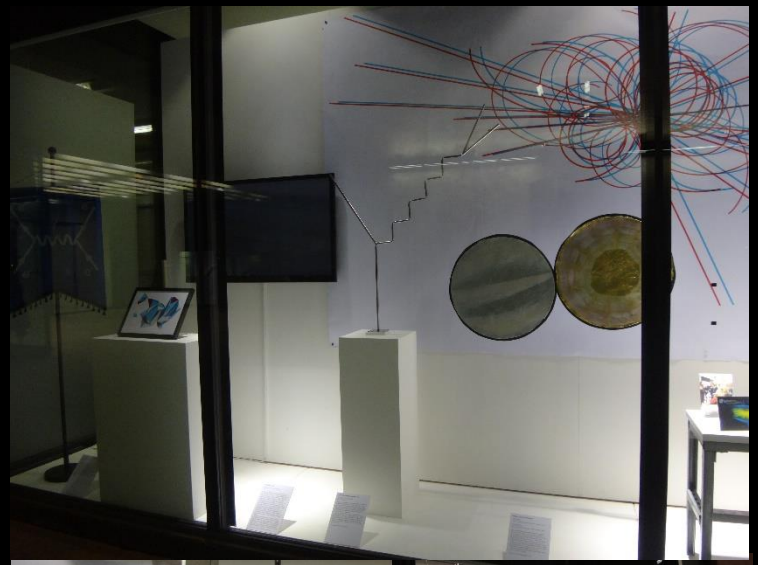
Vernissage / Exhibitions: June (Labyrinth) November (CSM) 2017

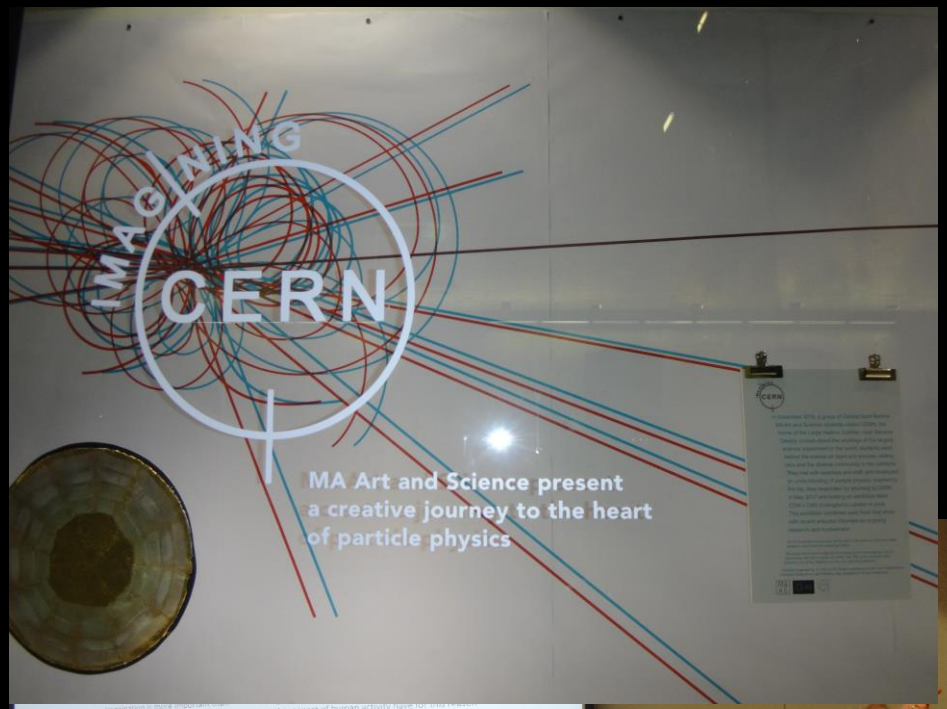


University of the Arts London -Saint Martins College of Art

local scientific partner: Imperial College

Windows Gallery Exhibition CSM –Nov 2017 Jan 2018 – Symposium No





Applied Arts University Vienna

local scientific partner: HEPHY

2 semester sciART course October 2016 – June 2017

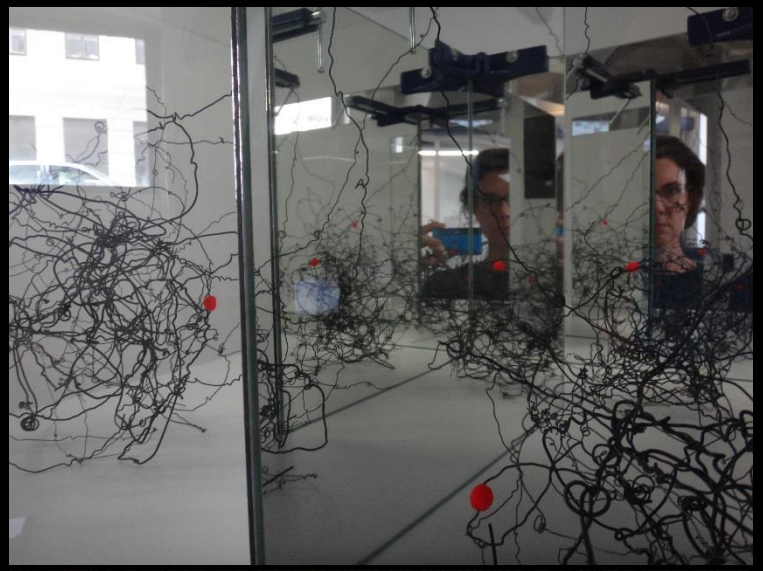
- 2 x 11 students / 11 staff
- Weekly lectures at the Applied Arts Universisty
  - Visit & Lectures from colleagues of **HEPHY & TU**
  - Visit at CERN 5 days December
  - Artwork rehearsal March
  - Particle detector construction workshop March
  - Final show in Vienna June

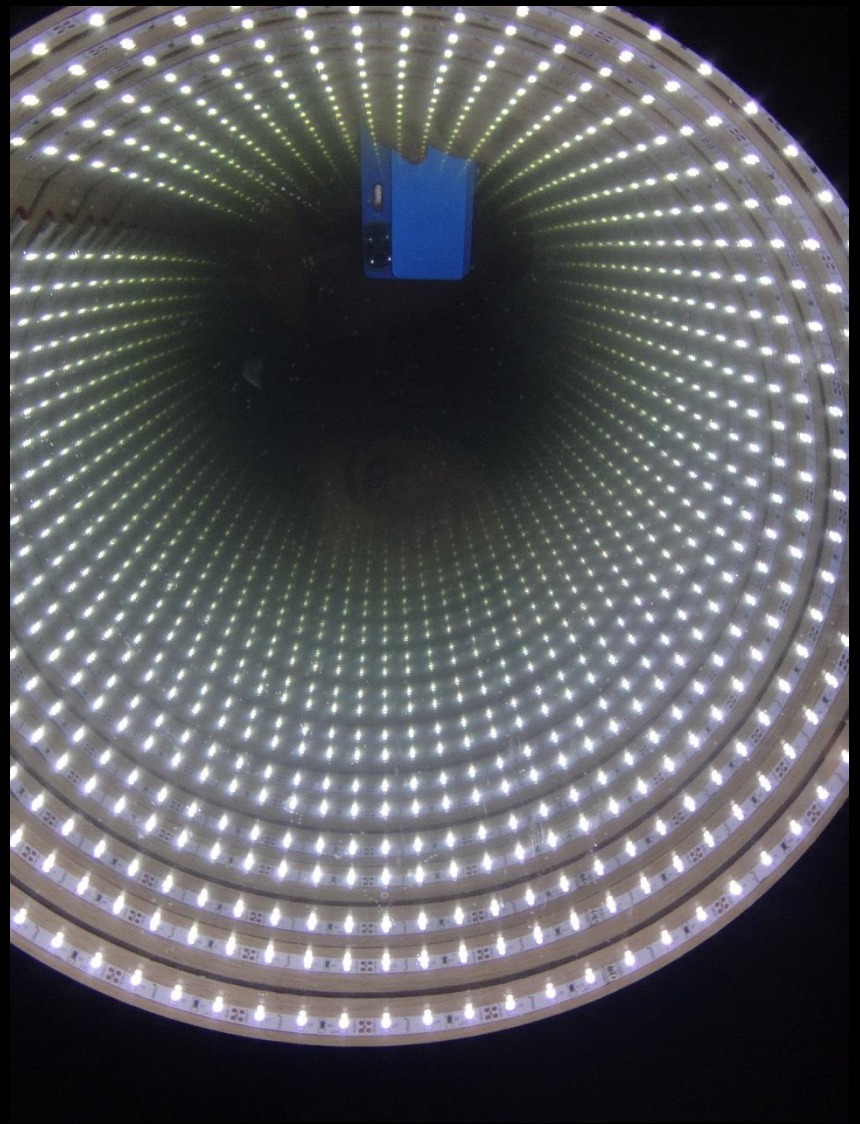
Photos : https://goo.gl/photos/i6MqYfwCRgnNVs4N9

Applied Arts University Vienna

local scientific partner: HEPHY

Vernissage / Exhibition June 2017





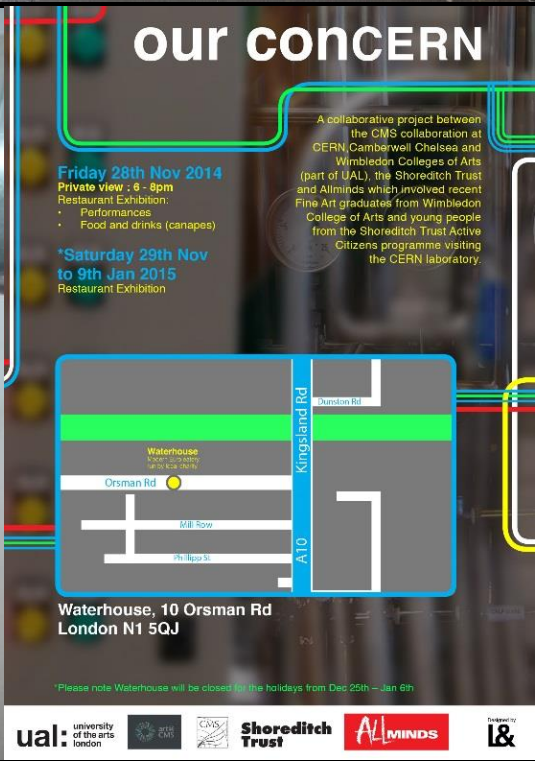
Chelsea College of Arts London

1 semester sciART course October 2014-2015-2016

- supervision Prof. Dave Webster
- Weekly lectures and discussions at UAL

  2014/ 2015 Visit at CERN with 4 students + 4 trainees Shoreditch Trust

  2015/2016 - Visit at CERN 5 days, Final show TriangleSpace London June



Feynman inspired art

a construction manual

Andy Charalambous in collaboration with CERN HST Programme 2017

Fig.1: Coreen, 2012

1. Introduction

When I left school I went to work as a technician for the Physics and Astronomy department at a university in London. I trained as an engineer and spent many years designing and building equipment for the research groups there. My interest in science grew as I worked with these groups and got a better understanding of the science they were researching. I loved my job because it gave me so much insight into the science involved.

When I left that job and started as an artist I found that the excitement of science was something I didn't want to move away from. So, I decided to use science as the inspiration for my art. Most of the art I make comes from some bit of science that has seeded an idea. Science is a tool for letting us see our world more clearly, and for me it also inspires my work. By the way, I have not moved very far from the university I worked at. I am Artist in Residence for the Astronomy group and the High Energy Physics groups there, as well as being part of the art@CMS project run by Michael Hoch at CERN.

sciARTbooklet

a manual for an art and a science teacher to re- create and create topical artworks art@CMS 2017

UK collaborative artists :
Rachael Nee , Andy Charalambous

in preparation:
"data sonification" by Federico IT,
"particle detection" by Ch. Henschke AU

Orders of Magnitude – Potato Powered Cosmos

a construction manual

Rachael Nee in collaboration with HST Programme 2017

1. Introduction

This booklet is written for science and art teachers with the aim of interdisciplinary learning. It assumes no knowledge of the other disciplines subject. In it you will read about the art installation from both the science and art viewpoints and how to reconstruct it. This becomes a jumping off point for the development of new artworks by High School students, with questions along the way.

Science and contemporary art have different end goals; however, they also have a lot in common. Both contemporary art and science have similar methodologies involving; investigation, research, testing out of ideas and theories through experiment. They share imagination, curiosity, quest for knowledge and are forms of inquiry. When successful both allow the world to be seen in new ways.

art@CMS
&
Architects of Air

is a synthesis of 2 unique partners whose core activity address the wonder of light and the wonder of the universe.

Combining the imageries of the machinery of CERN with the curvilinear environment of the Architects of Air dome creates an incredibly intriguing layer of visual experience.

art@CMS: collaborative artist CONSENSUS

CONSENSUS participates as well in science & artworkshops

*UK Rapper launches album CON**CERN**ED*

after 2 years of collaboration his science rap album ConCERNed. His scientific partner is Sudan Paramesvaran / CMS Bristol UK

CERN Article (all info)**:**
http://cms.cern/news/concerned-using-hip-hop-engage-new-audiences-particle-physics

More Infor & Links:

- The BBC interview of ConSensus and Sudan [the sequence starts at 1:11.18 until 1h26.26]

  http://www.bbc.co.uk/programmes/p04zv0g0#play

  https://www.youtube.com/watch?v=MJXaBq5VTNc
- Press article in the journal “The Voice” here's the online version:

  http://www.voice-online.co.uk/article/south-london-geneva-hip-hop-science-lessons
- Two music videos of the 9 tracks from the album is available on youtube

  https://www.youtube.com/watch?v=tJl8-ArzkBg&feature=youtu.be
- https://www.youtube.com/watch?v=1ju3fo37yLE&feature=youtu.be
- Science Rap StudentsWorkshop “Particle Love”: https://youtu.be/sdB2PydXUW8

Thank you for you attention

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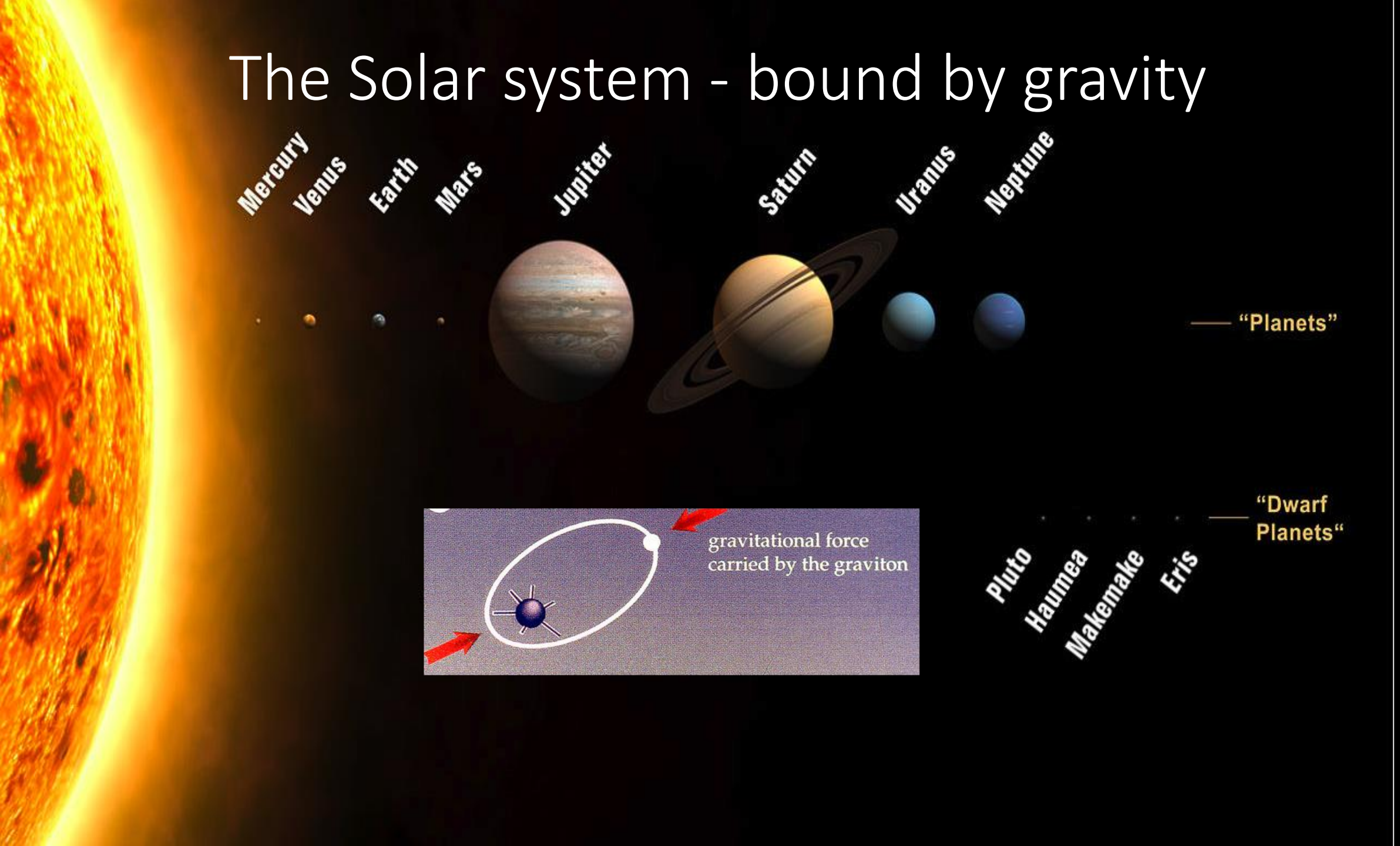
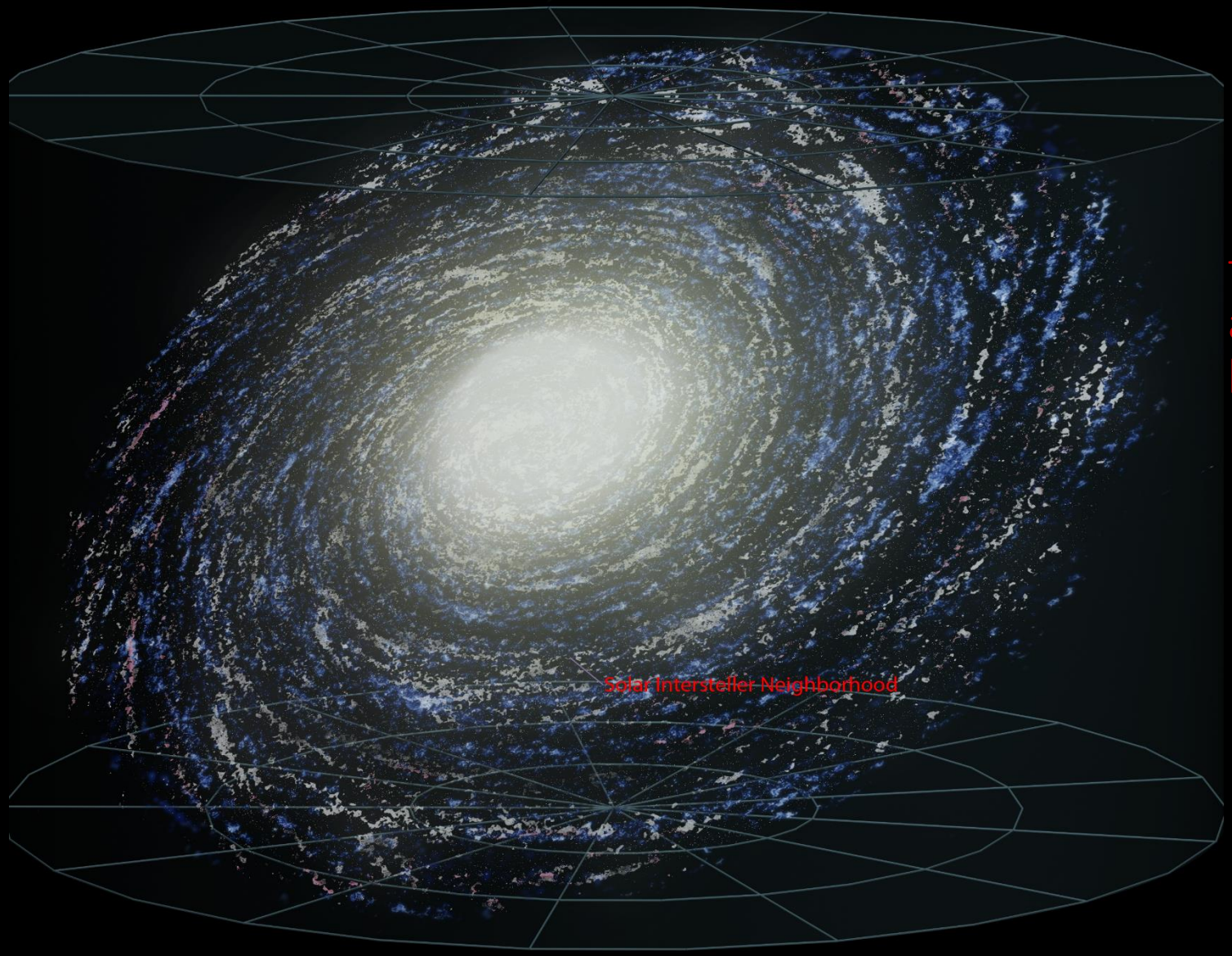
The Solar system - bound by gravity



Milky Way Galaxy



the Milky Way,
another system
bound by gravity

Nuclear Periodic Table

Chemical elements - elementary particles of 19-th century

Fusion Products
Heavy Activation Products
Light Activation Products
Fission Products
Cosmogenic Products
Natural Products

H Hydrogen																	He Helium
Li Lithium	Be Beryllium											B Boron	C Carbon	N Nitrogen	O Oxygen	F Fluorine	Ne Neon
Na Sodium	Mg Magnesium											Al Aluminum	Si Silicon	P Phosphorus	S Sulfur	Cl Chlorine	Ar Argon
K Potassium	Ca Calcium	Sc Scandium	Ti Titanium	V Vanadium	Cr Chromium	Mn Manganese	Fe Iron	Co Cobalt	Ni Nickel	Cu Copper	Zn Zinc	Ga Gallium	Ge Germanium	As Arsenic	Se Selenium	Br Bromine	Kr Krypton
Rb Rubidium	Sr Strontium	Y Yttrium	Zr Zirconium	Nb Nicobium	Mo Molybdenum	Tc Technetium	Ru Ruthenium	Rh Rhodium	Pd Palladium	Ag Silver	Cd Cadmium	In Indium	Sn Tin	Sb Antimony	Te Tellurium	I Iodine	Xe Xenon
Cs Cesium	Ba Barium	La Lanthanum	Hf Hafnium	Ta Tantalum	W Tungsten	Re Rhenium	Os Osmium	Ir Iridium	Pt Platinum	Au Gold	Hg Mercury	Tl Thallium	Pb Lead	Bi Bismuth	Po Polonium	At Astatine	Rn Radon
Fr Francium	Ra Radium	Ac Actinium	Rf Rutherfordium	Db Dubnium	Sg Seaborgium	Bh Bohrium	Hs Hassium	Mt Meitnerium	Ds Darmstadtium	Rg Roetgenium	Uub Ununbium	Uut Ununtrium	Uuq Ununquadium	Uup Ununpentium	Uuh Ununhexium	Uus Ununseptium	Uuo Ununoctium

Ce Cerium	Pr Praseodymium	Nd Neodymium	Pm Promethium	Sm Samarium	Eu Europium	Gd Gadolinium	Tb Terbium	Dy Dysprosium	Ho Holmium	Er Erbium	Tm Thullum	Yb Ytterbium	Lu Lutetium
Th Thorium	Pa Protactinium	U Uranium	Np Neptunium	Pu Plutonium	Am Americium	Cm Curium	Bk Berkelium	Cf Californium	Es Einsteinium	Fm Fermium	Md Mendelevium	No Nobelium	Lr Lawrencium