Introduction to CMS

CMS 실험을 소개합니다

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2024.07.03
Korea-CERN Summer School

Welcome to CERN

CERN Meyrin site

트램 정류장

Science Gateway 입구
(기념품, public event)

CERN training, education and outreach

300 Undergraduate students in Summer School Programmes

>10,000 teachers since 1998

>150,000 visitors on guided tours (free of charge)

Arts @ CERN program


장철원 작가


김윤철 작가

Outreach programs (KCMS, KoAlice, Theory team)

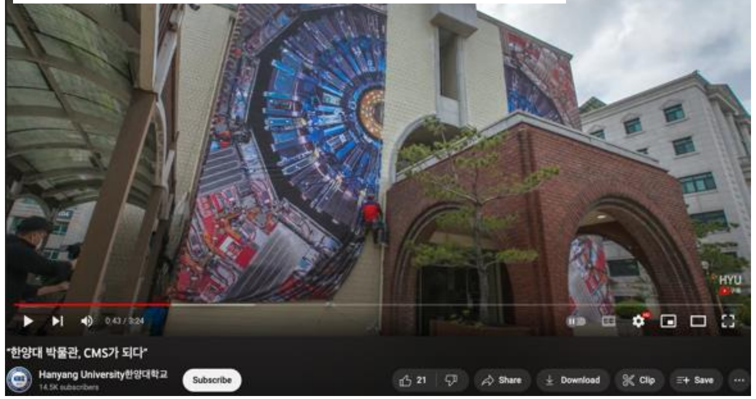
경희대학교

2019 IBS <신을 쫓는 기계> 展

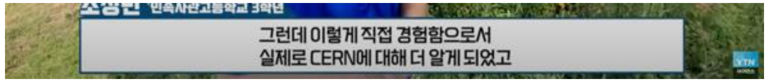
2023.07 Youtube 안될과학 생방송 랩미팅

2023.08 창의재단 청소년글로벌과학대장정

2021 한양대 박물관
<우주+人, 과학으로 풀고 예술로 빚다>



2023 Youtube 안될과학 떠날과학

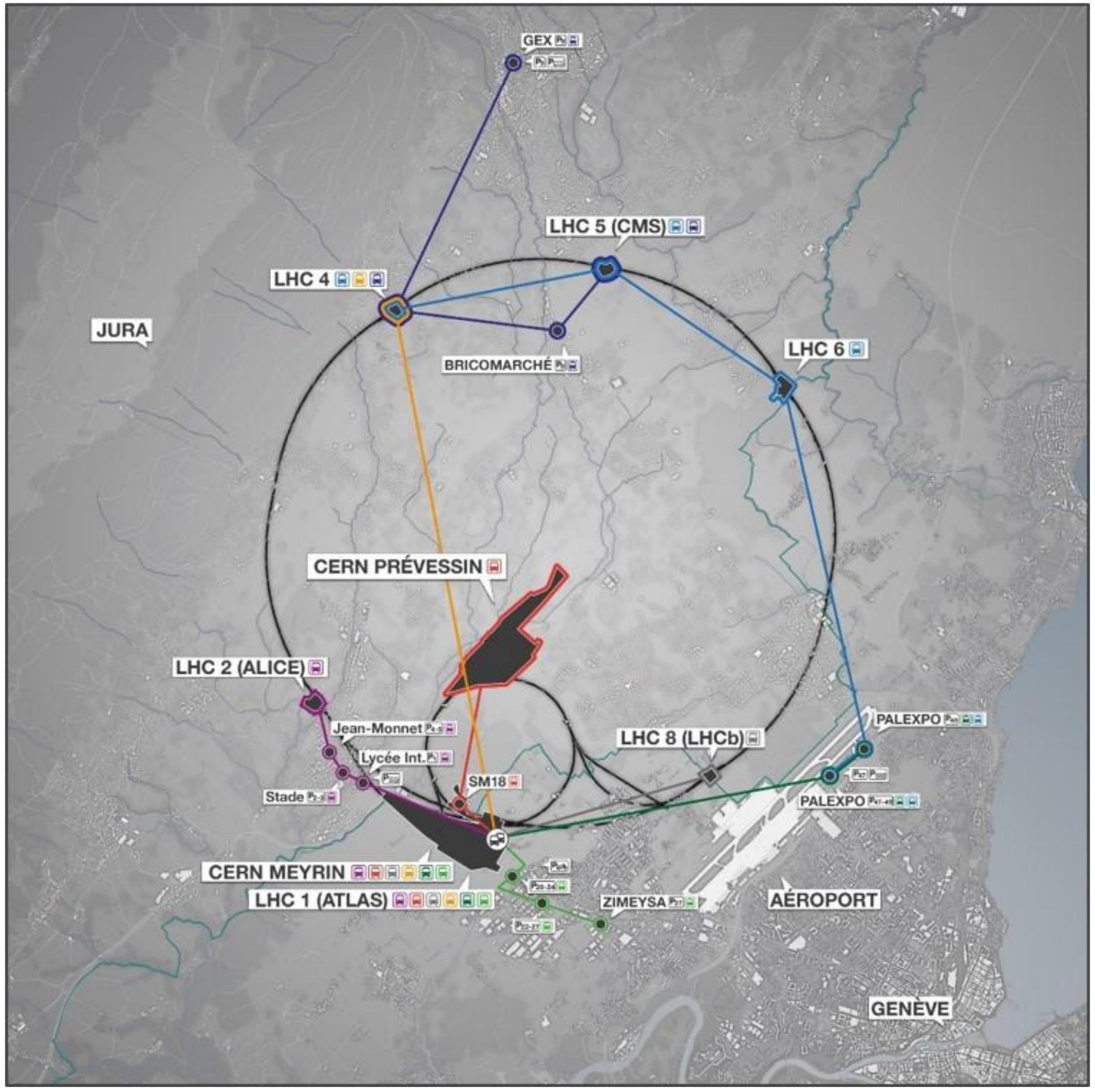


+ interviews, documentaries,
VIP visits, guided tours

CERN: World’s biggest laboratory
for particle physics
(Conseil Européen pour la Recherche Nucléaire)

Main goal: understand the most fundamental particles and laws of the universe…
developing the most advance technologies

CERN & LHC location




Accélérateur de science
CERN
www.cern.ch

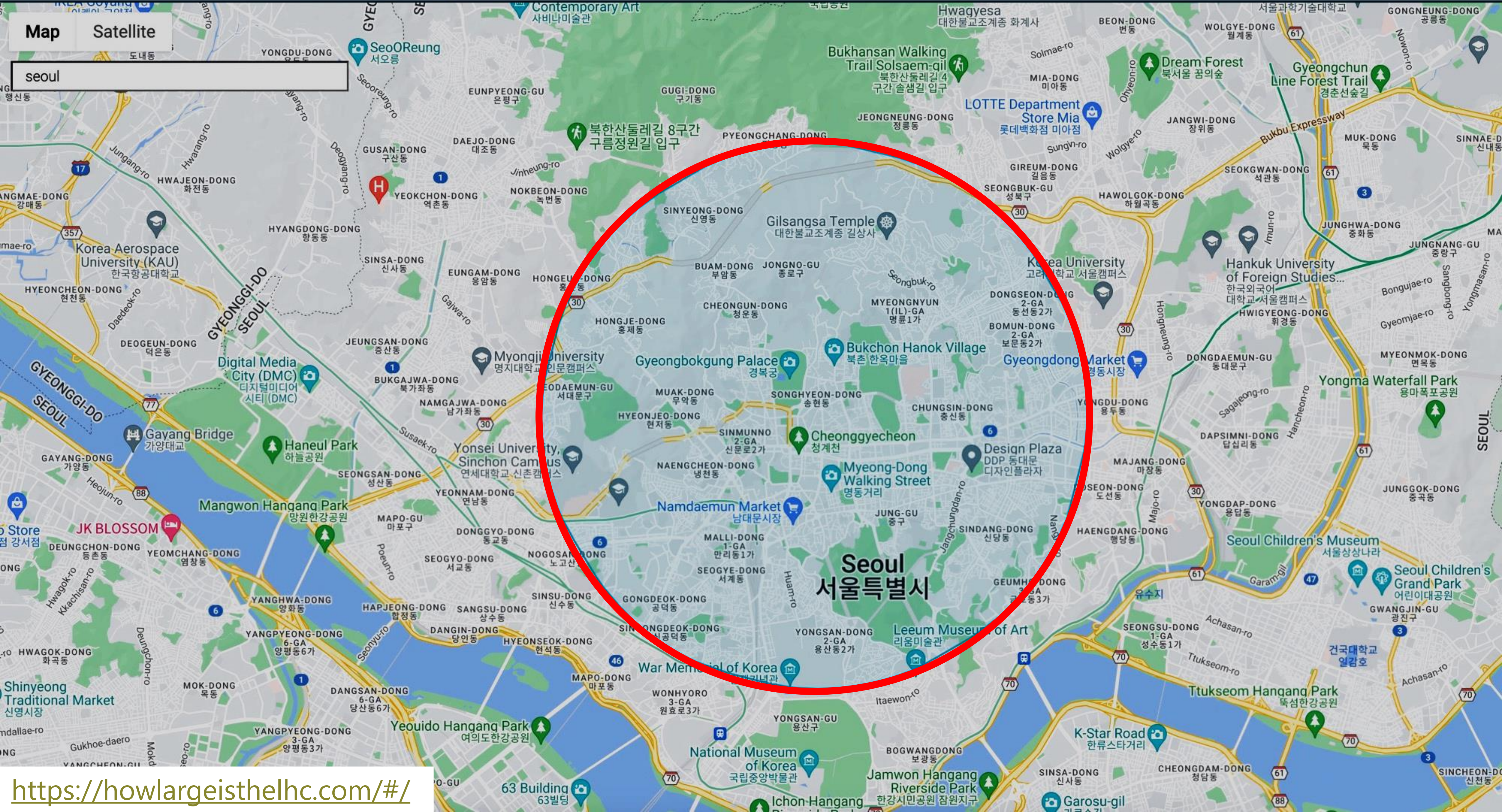

e
CERN
www.cern.ch


C
B
D


HowLargeIsTheLHC | About | Colliders | Floating | Share | Legal

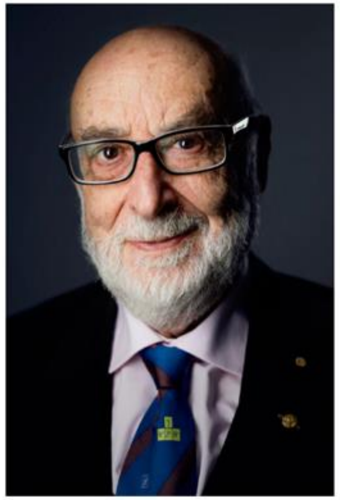
Map | Satellite

seoul



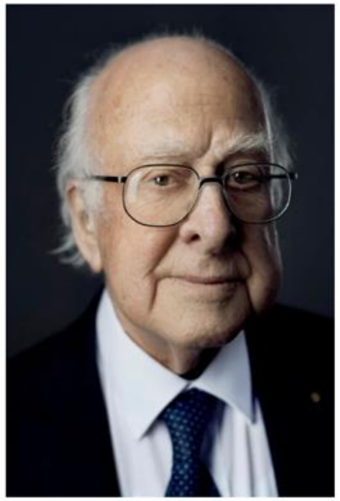
https://howlargeisthelhc.com/#/

The Nobel Prize in Physics 2013



François Englert

Prize share: 1/2



Peter W. Higgs

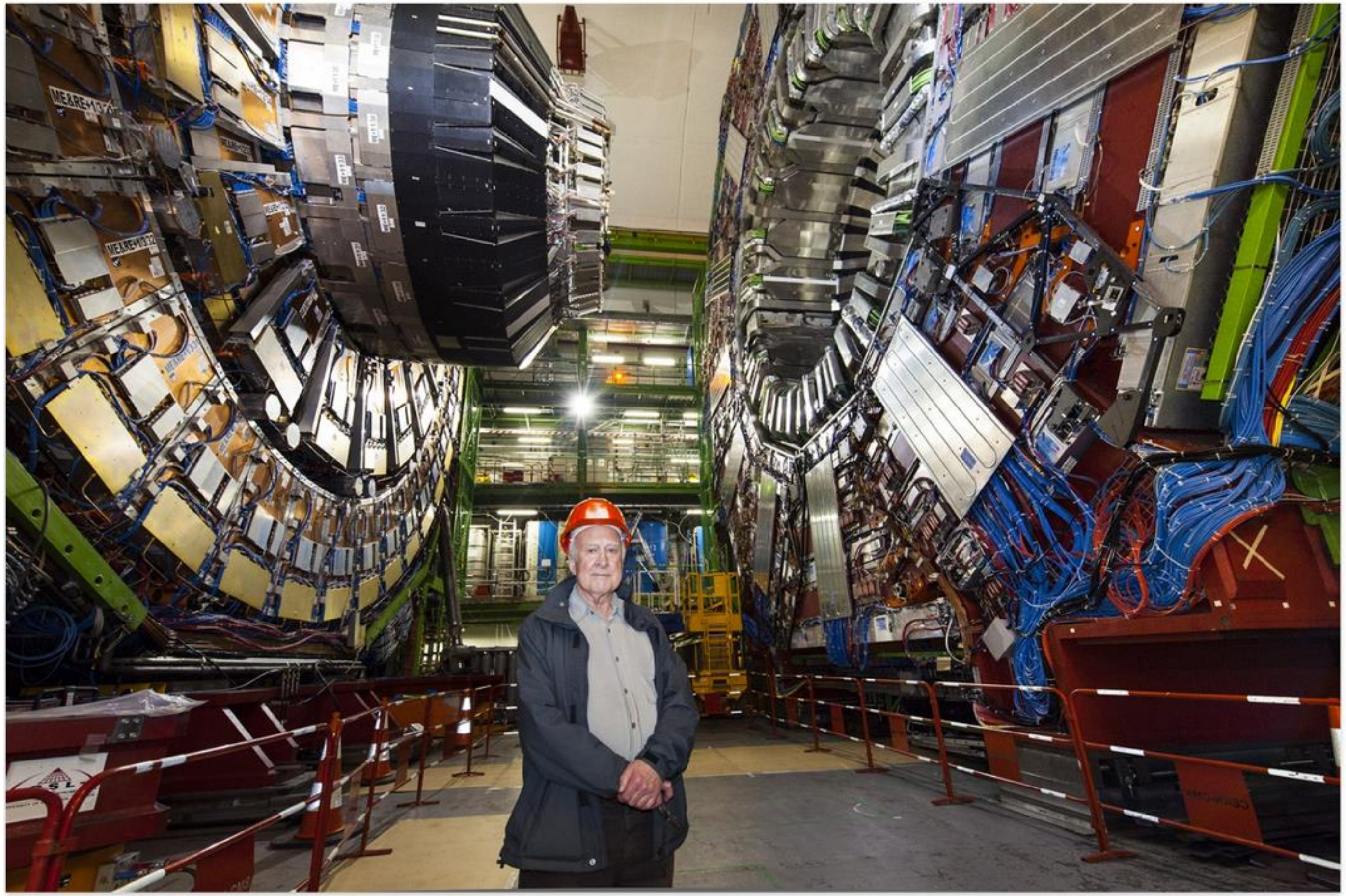
Prize share: 1/2

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"

CERN pays tribute to Peter Higgs

Peter Higgs passed away on 8 April at the age of 94

10 APRIL, 2024

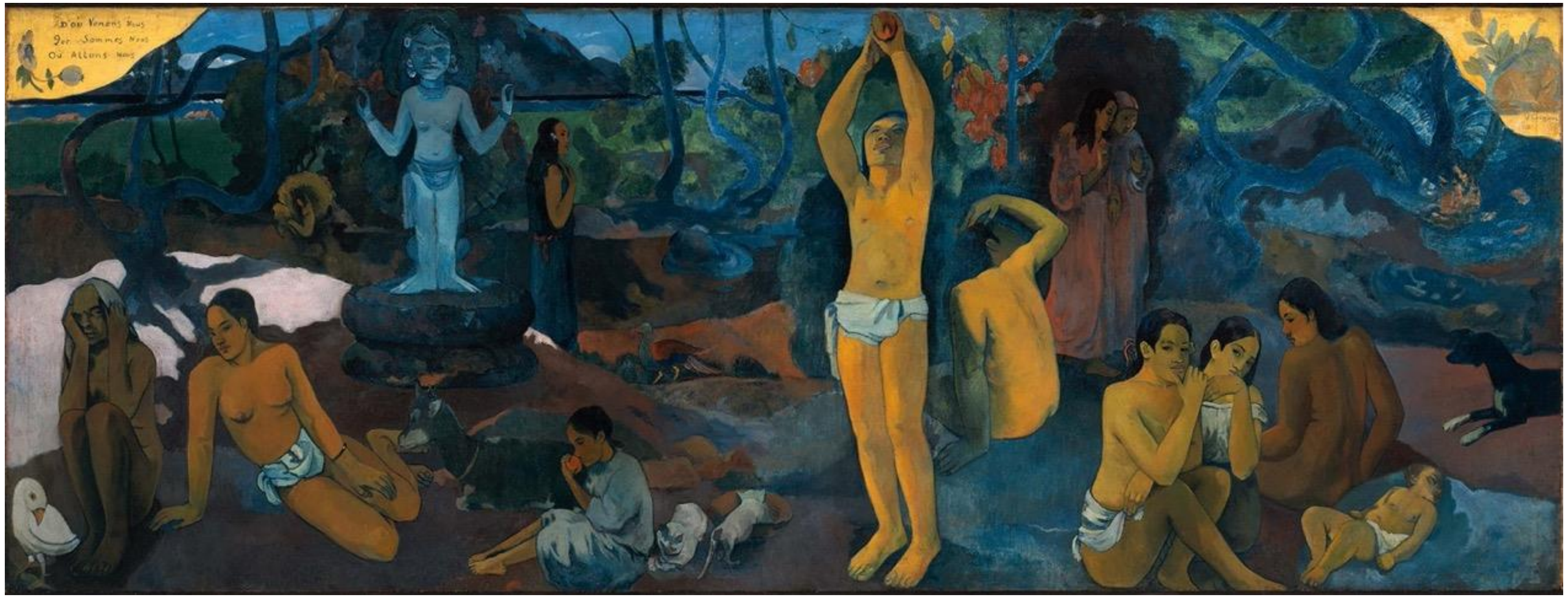


Peter Higgs, in front of the CMS detector, in 2008. (Image: Maximilien Brice/CERN).

Peter Higgs has passed away at the age of 94. An iconic figure in modern science, Higgs in 1964 postulated the existence of the eponymous Higgs boson. Its discovery at CERN in 2012 was the crowning achievement of the Standard Model (SM) of particle physics – a remarkable theory which explains the visible universe at the most fundamental level.

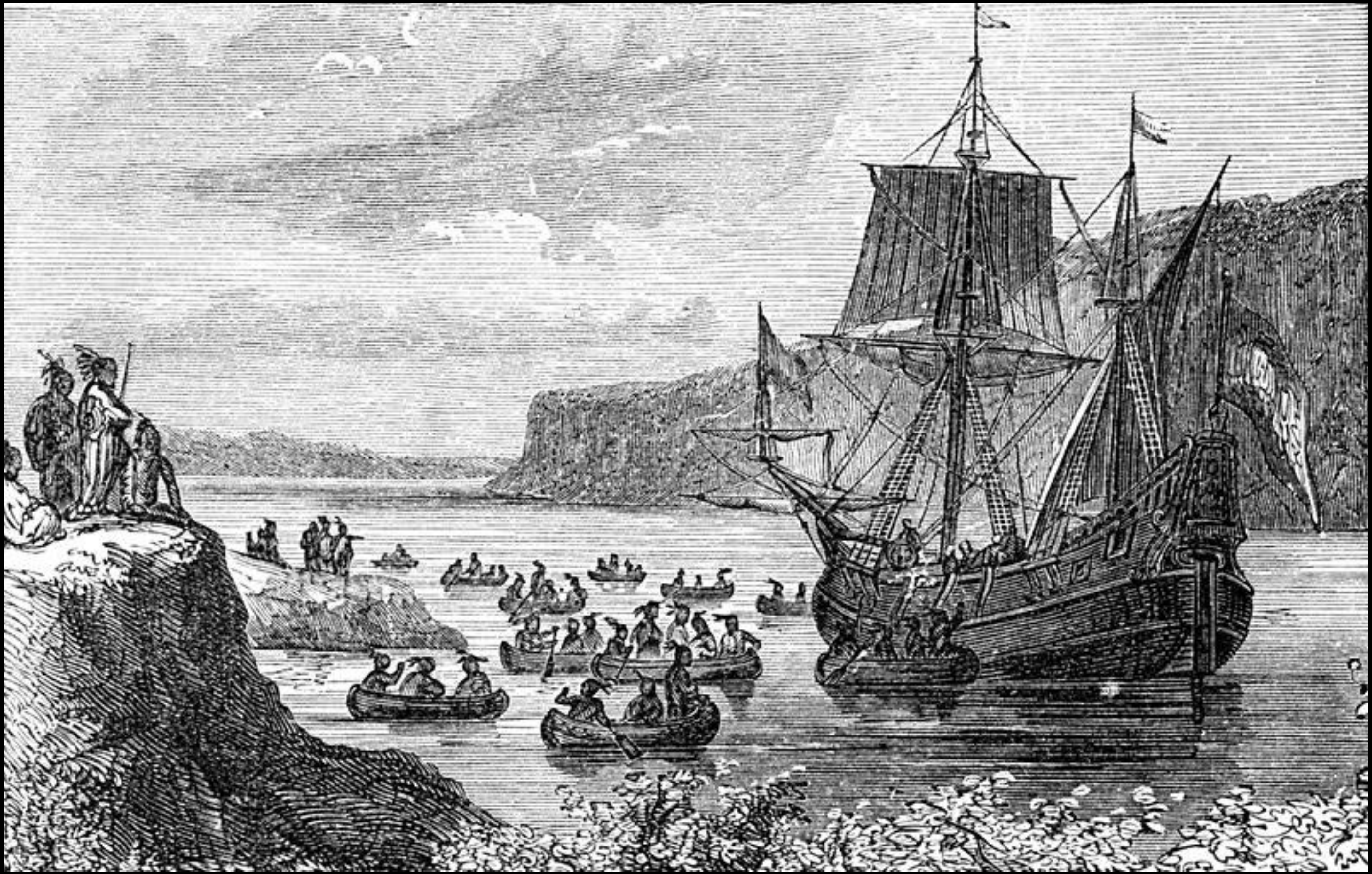
Fundamental question of natural sciences

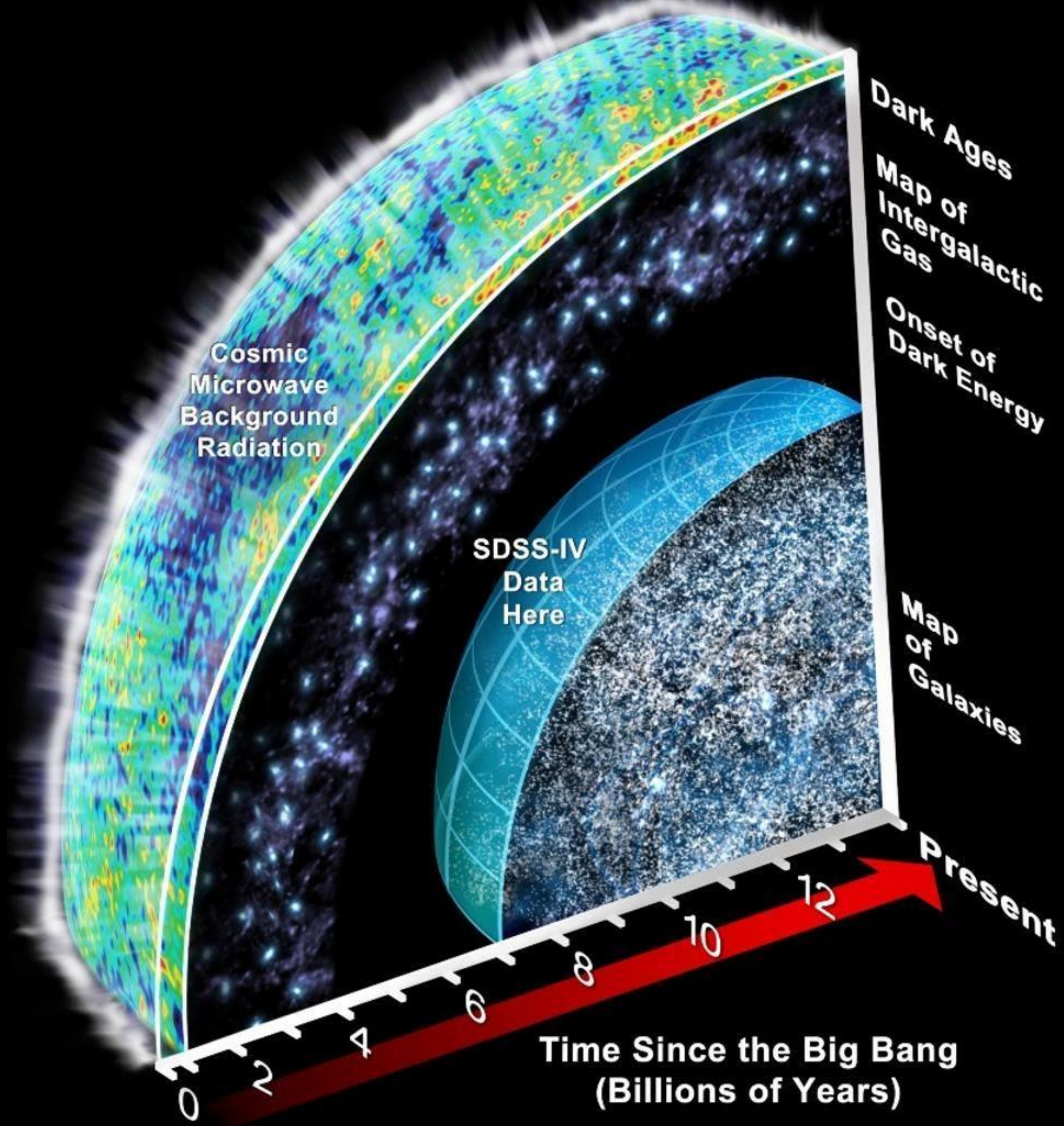
D' où Venons Nous 우리는 어디에서 왔는가
Que Sommes Nous 우리는 무엇인가
Où Allons Nous 우리는 어디로 가고 있는가



What is the universe made of?

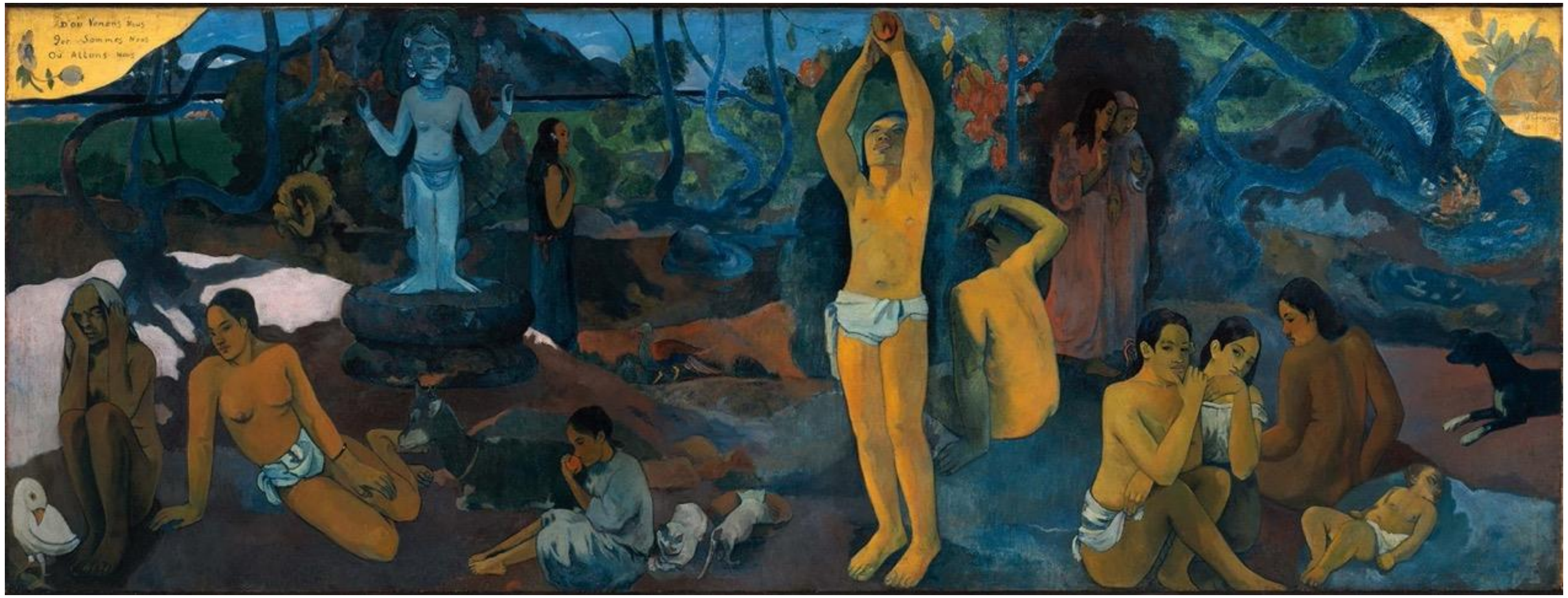
How did the universe begin?




Dark Ages
Map of Intergalactic Gas
Onset of Dark Energy
Map of Galaxies
Cosmic Microwave Background Radiation
SDSS-IV Data Here
0
2
4
6
8
10
12
Present
Time Since the Big Bang (Billions of Years)

Fundamental question of natural sciences

D’ où Venons Nous　　우리는 어디에서 왔는가
Que Sommes Nous　　우리는 무엇인가
Où Allons Nous　　우리는 어디로 가고 있는가



What is the universe made of?

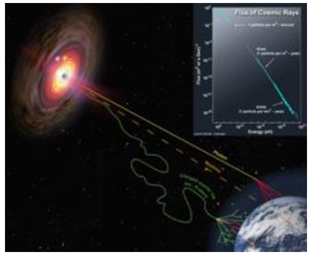
How did the universe begin?

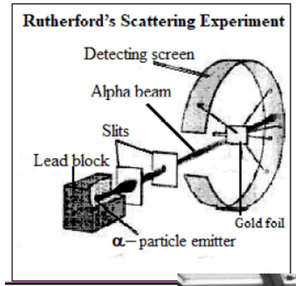
Looking into the small world, in one slide

Visible light x-ray,
then electron

$$\lambda = \frac{h}{p}.$$

or, particles
from the universe



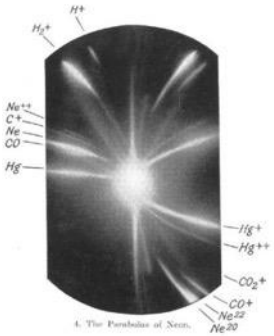


Smaller than nucleus,
protons/neutrons
or even smaller,
+ new particles
($E=mc^2$)

Inside of the "atom":
more energy

Bleeding edge of
the highest energy

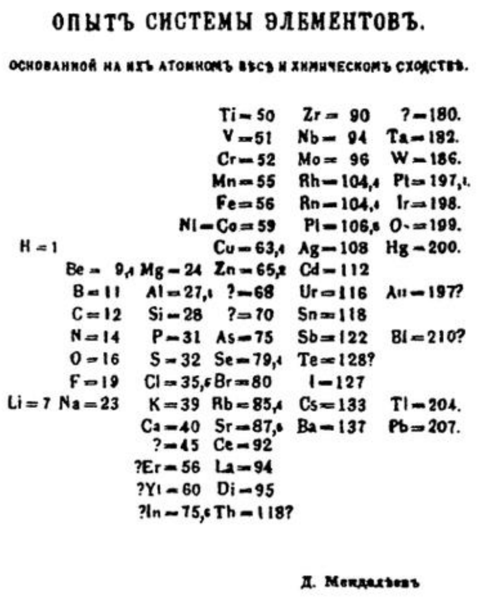
No bare eye, nor films,
Build particle detectors



Radiations from
radioactive materials,
then produce ourselves
with accelerator technique
(cyclotron, synchrotron)

Building block of the universe

Mendeleev

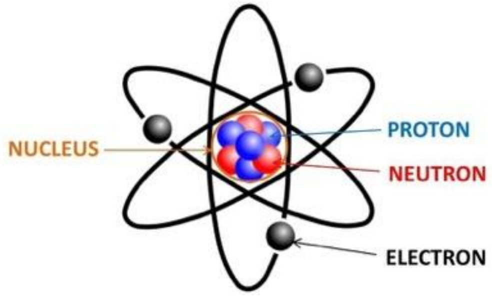


Periodic table

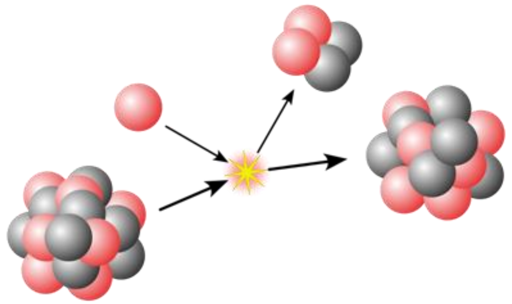
Group → / Period ↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	* 71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	** 103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

*	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
**	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

Atomic structure



Nuclear structure



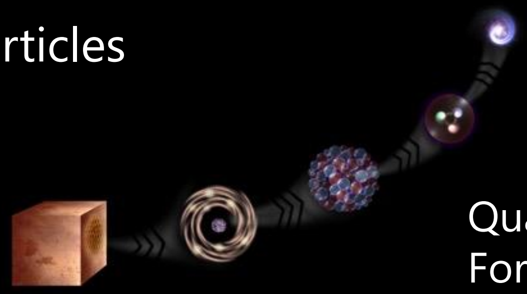
"If we consider protons and neutrons as elementary particles, we would have three kinds of elementary particles [p,n,e]…. This number may seem large but, from that point of view, two is already a large number"
Paul Dirac 1933 Solvay Conference

Frontier of fundamental physics and technology

What is the universe made of?

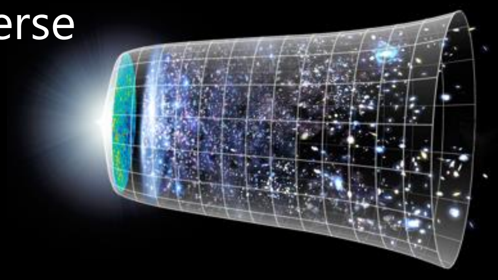
How did the universe begin?

Particles



Quarks, Leptons,
Force carriers, Higgs

Universe



Physics laws and matters at the beginning

Dark matter and energy

Technologies to answer the question:

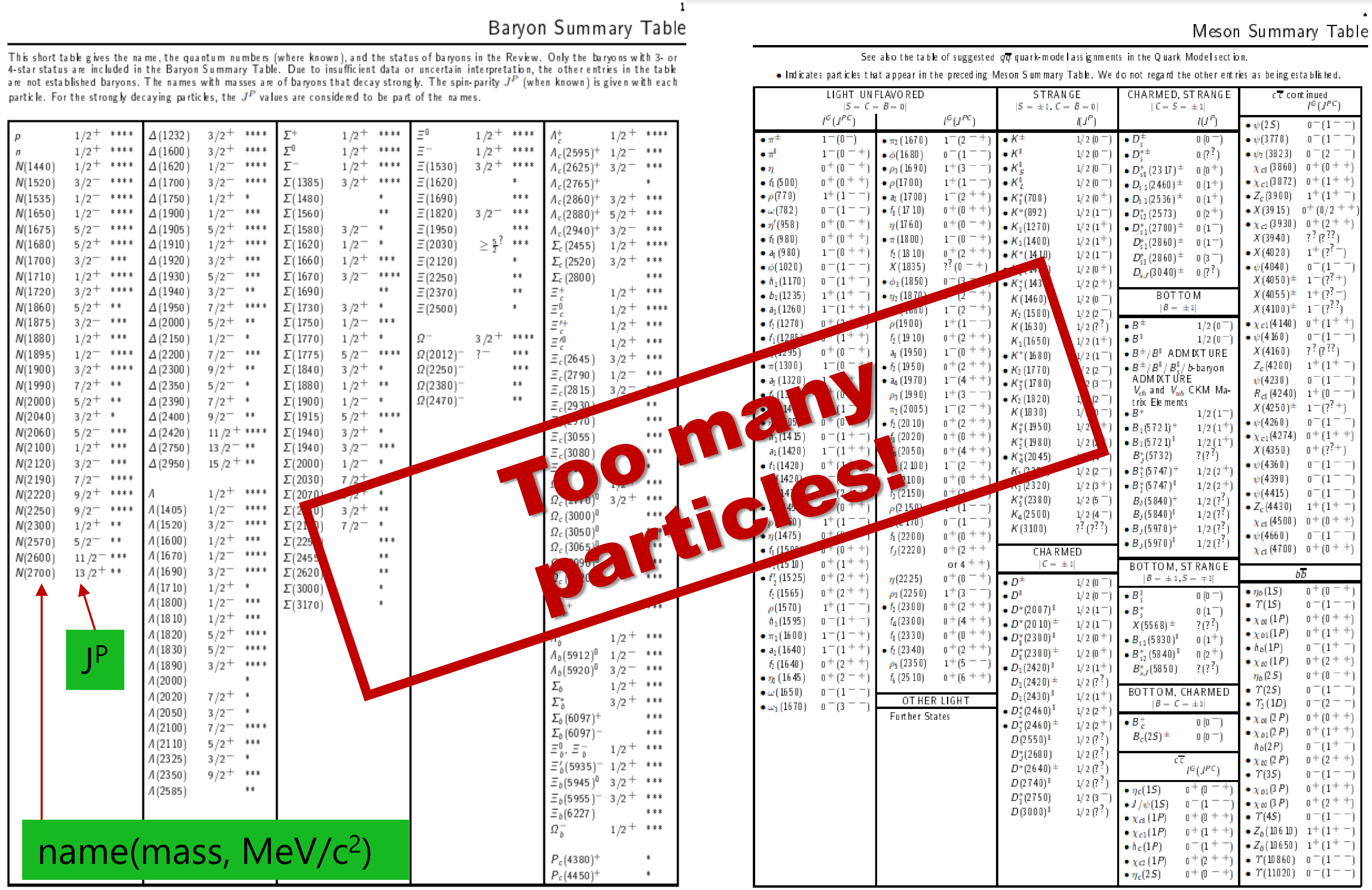
Accelerators

Detectors

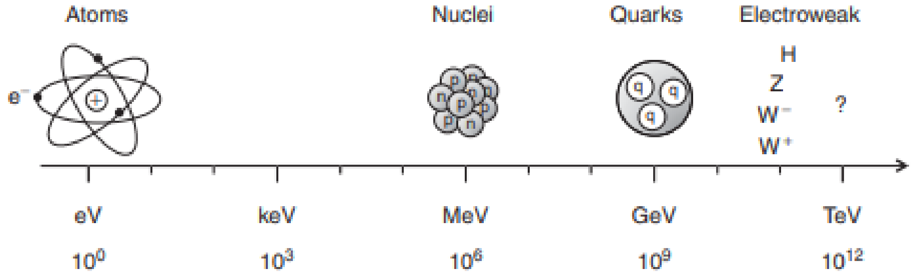
Computing

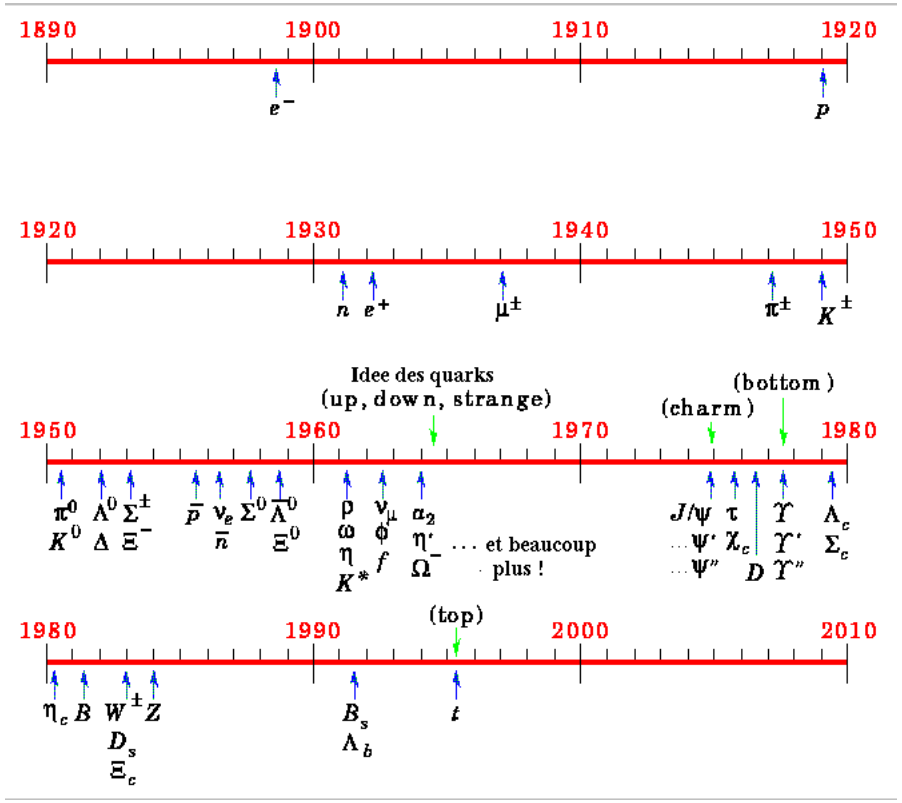
And?

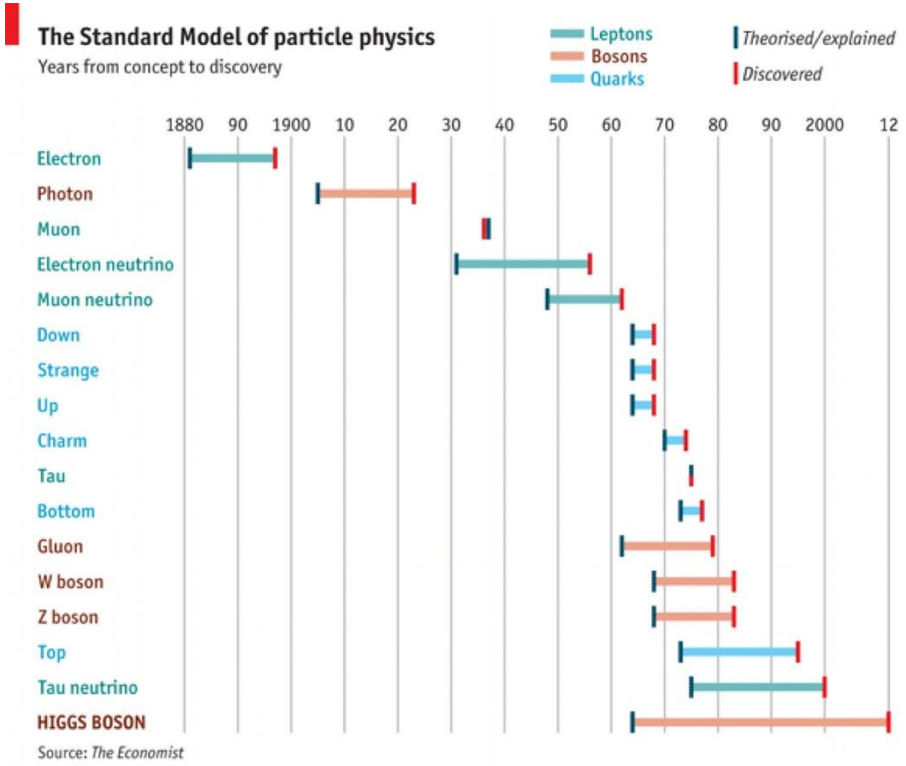
Particle Zoo



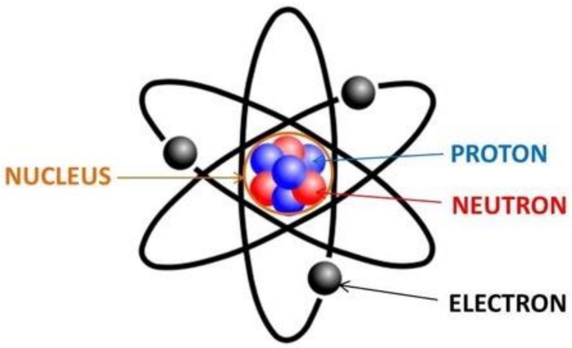
History of discoveries

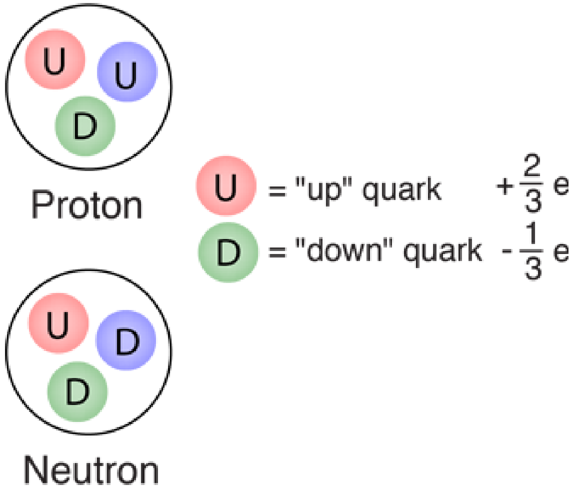


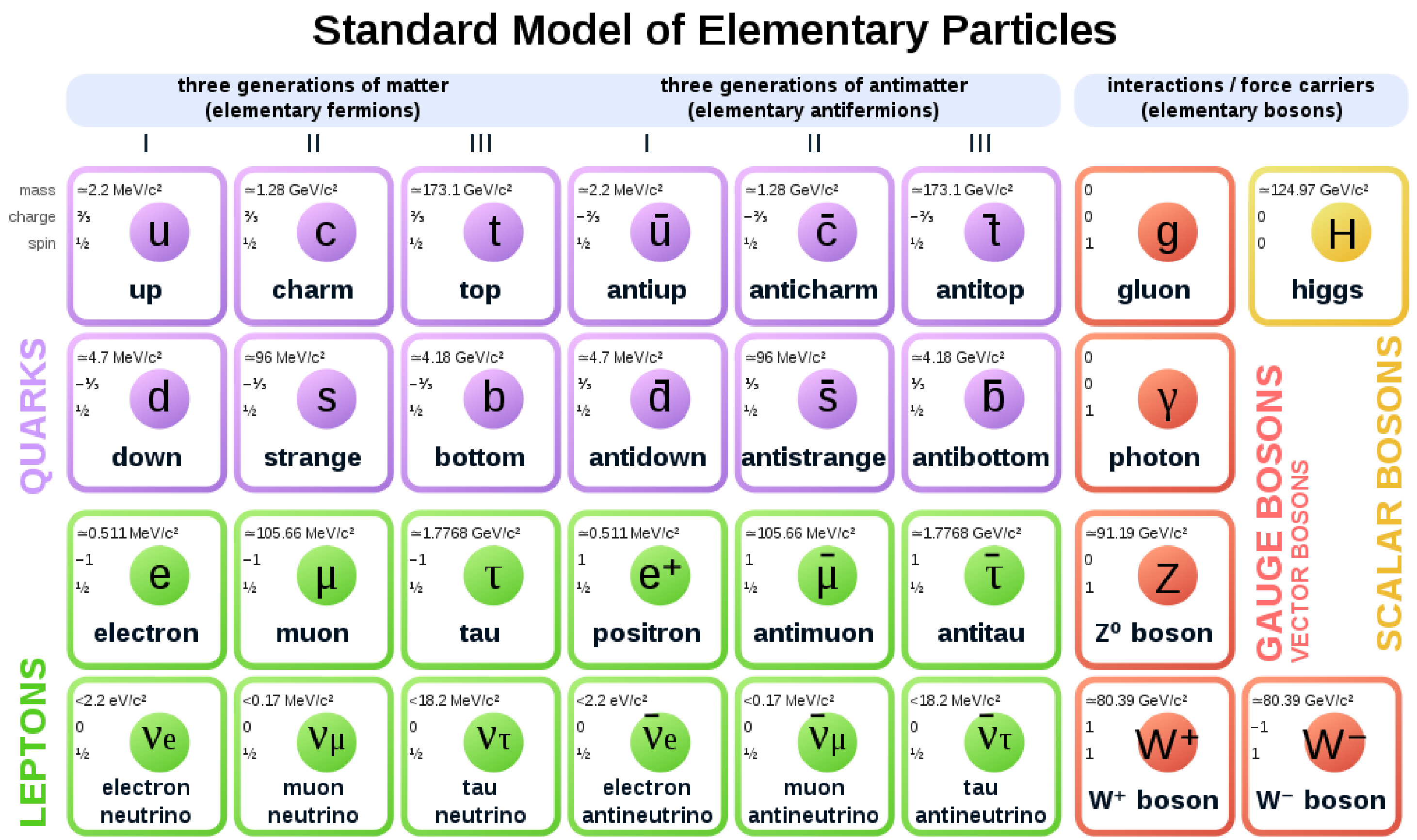




The Standard Model

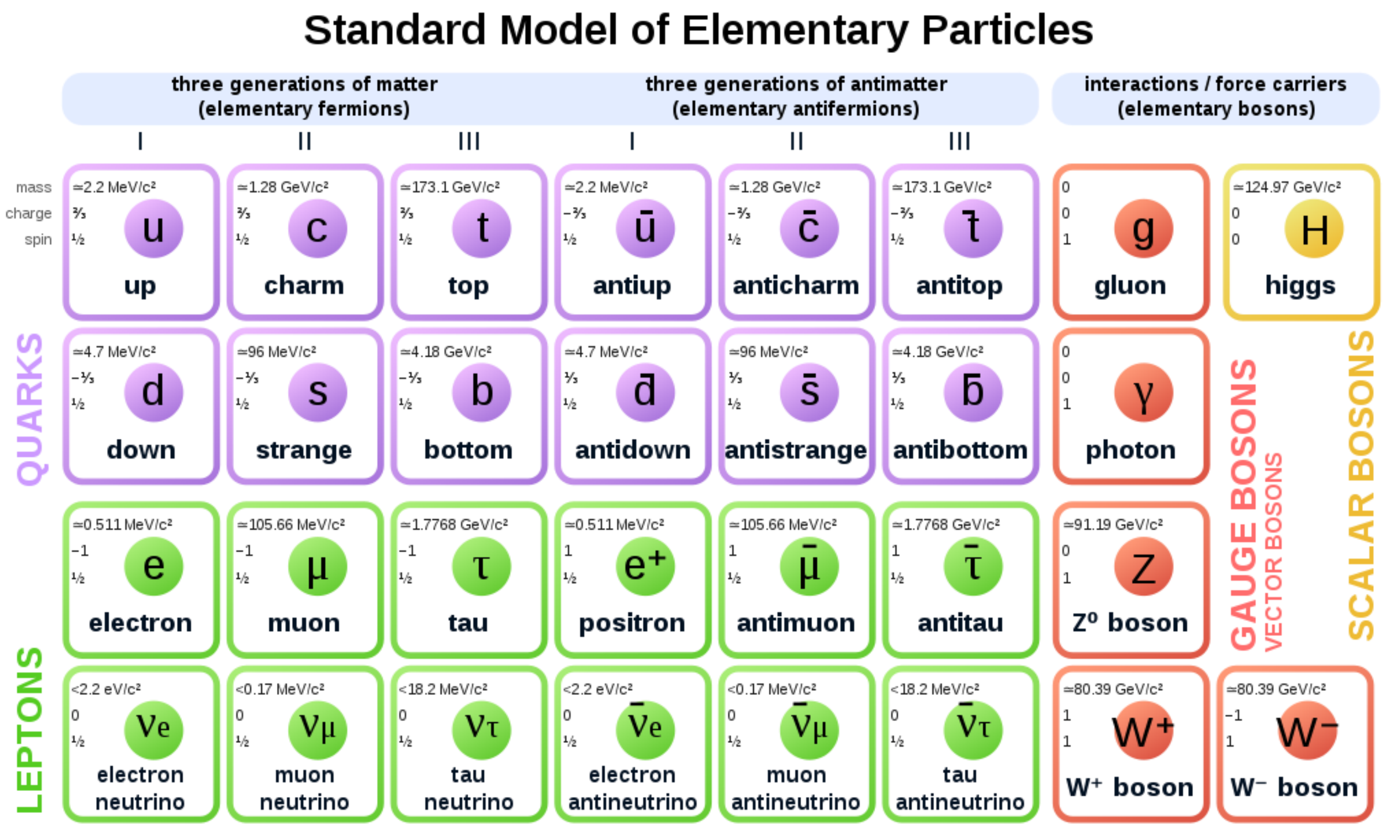


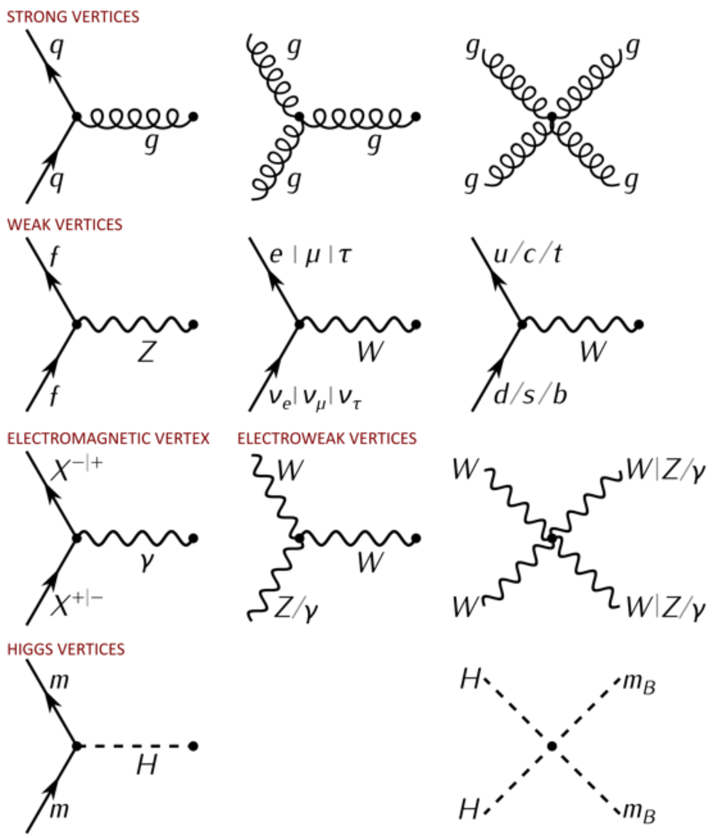




Note: no gravitation, dark matter, dark energy

Standard Model, still oversimplified

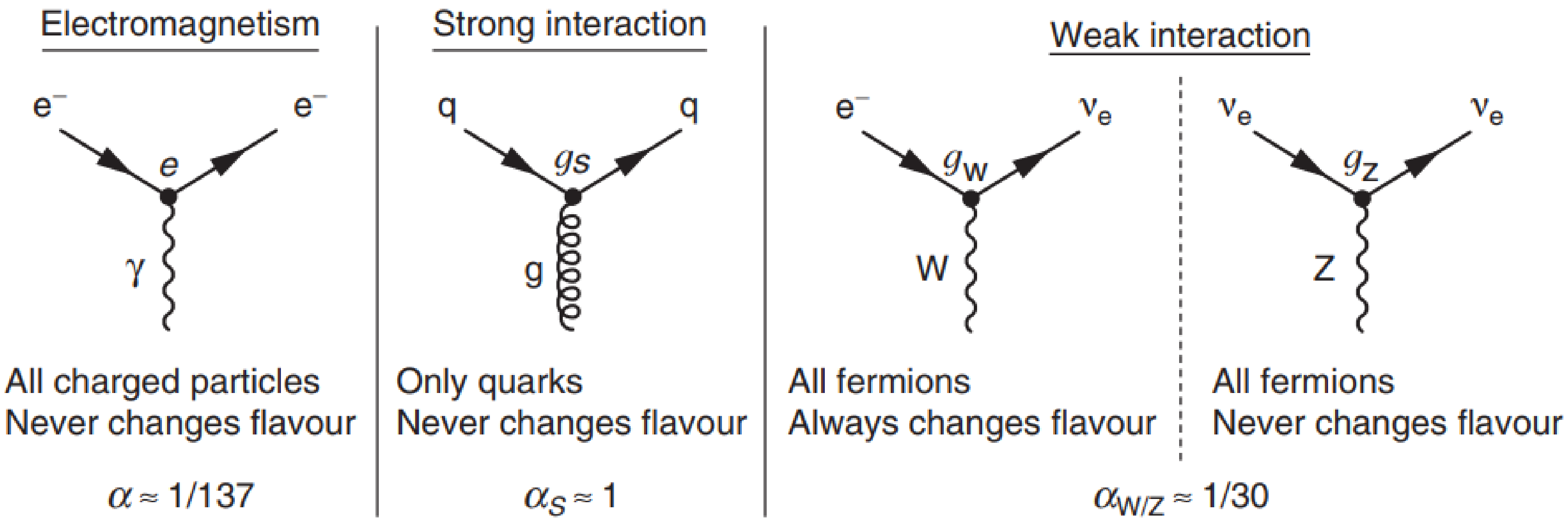




Incomplete theory: no gravitation, dark matter, dark energy

\+ Many *free* parameters

Basic building blocks

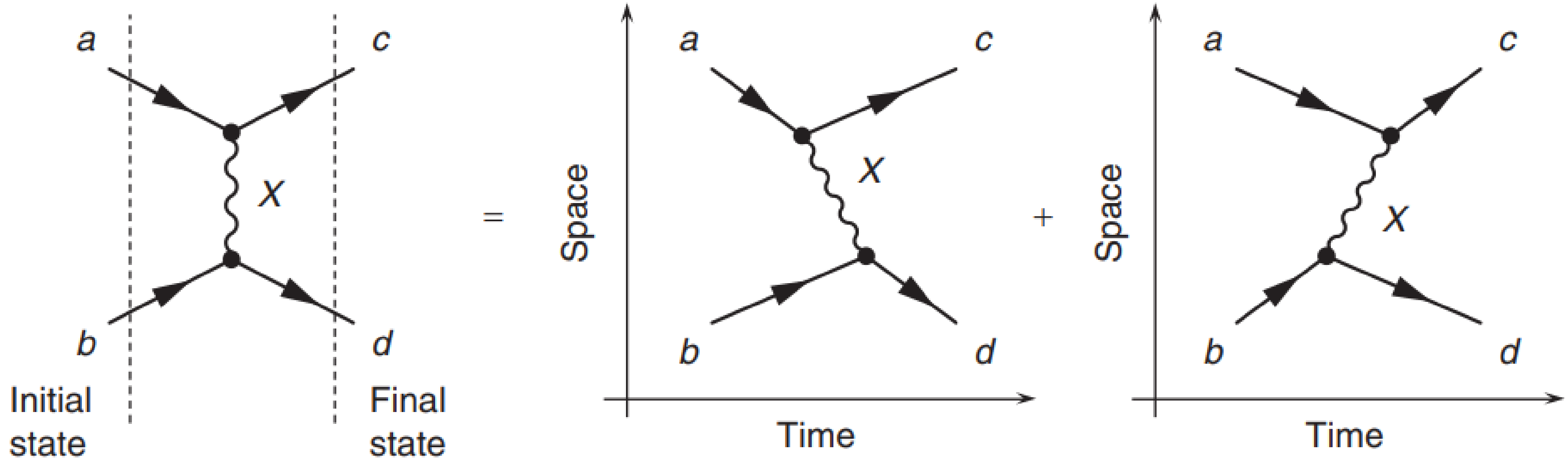


quarks,
W bosons

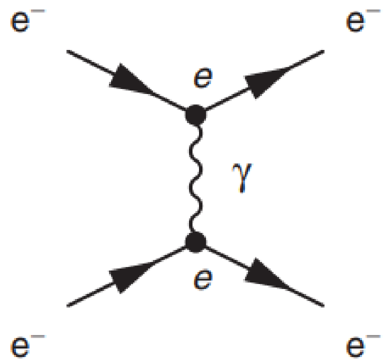
Has ggg, gggg

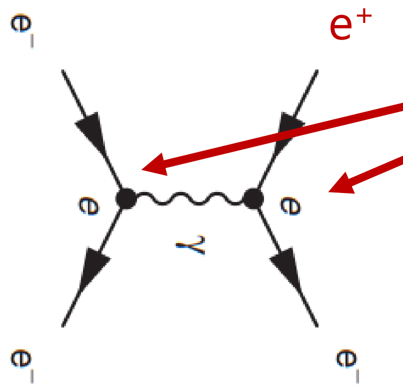
WWW,
WZZ, etc

Feynman diagram



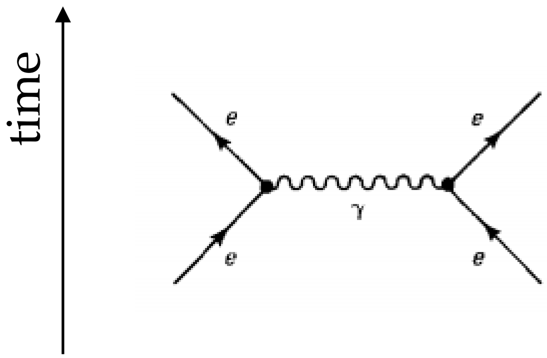
The diagram is still valid after stretching, rotating it



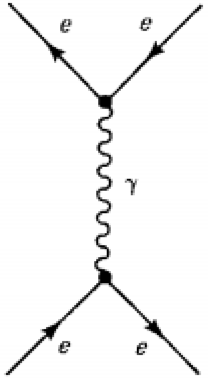


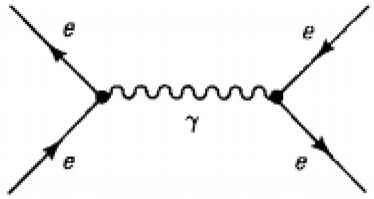
Multiplied to the Amplitude:
∴ Prob. ∝ e^4

Electrodynamics

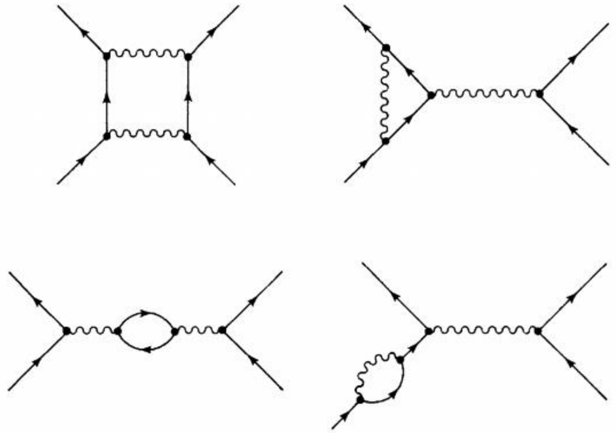


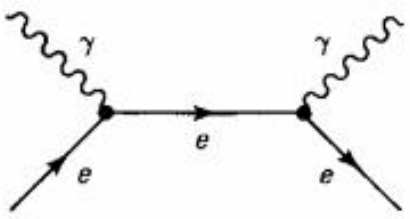
Moeller scattering





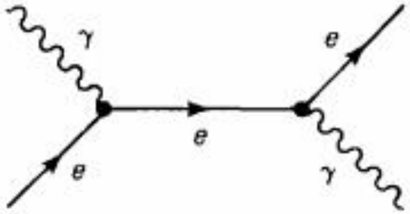
Bhabha scattering



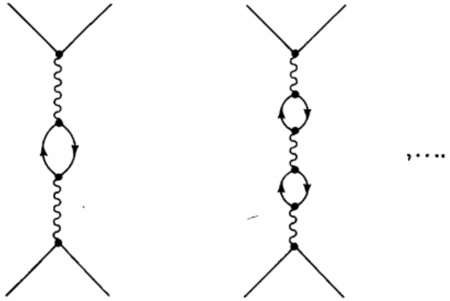


Pair annihilation

Pair production



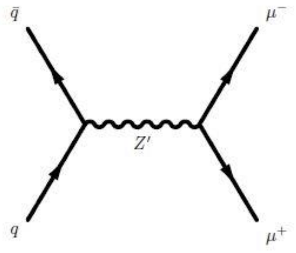
Compton scattering

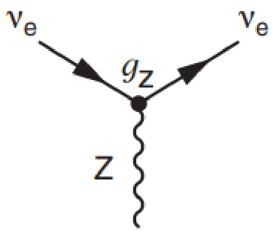


Weak interactions

Neutral current (Z):

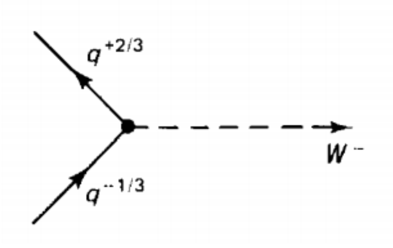
$Z \rightarrow q\bar{q}, Z \rightarrow l^{+}l^{-}, Z \rightarrow \upsilon_{l}\bar{\upsilon}_{l}$

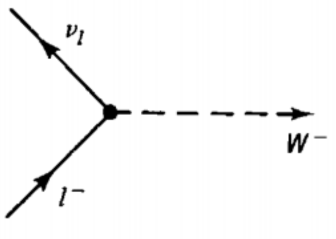




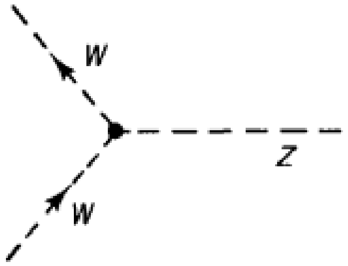
Charged current (W):

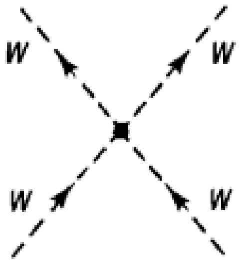
$W^{+} \rightarrow u\bar{d}, W^{+} \rightarrow c\bar{s}, W^{+} \rightarrow t\bar{b}, \ldots$
$W^{+} \rightarrow l^{+}\bar{\upsilon}_{l}$

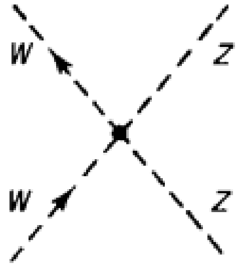


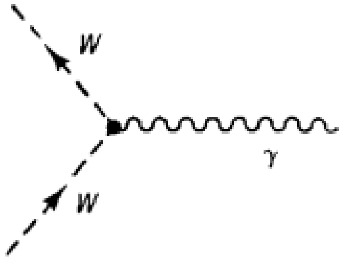


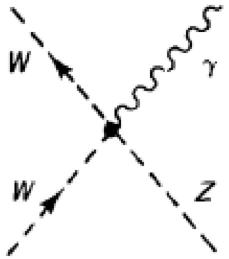
or, Between W/Z or γ

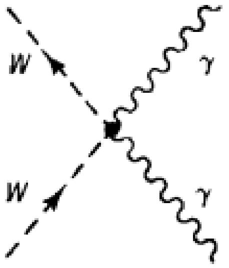




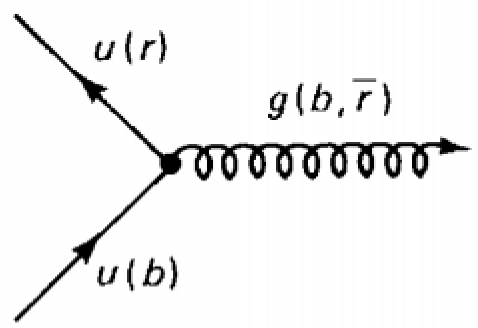


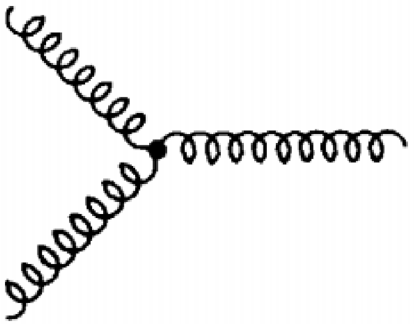


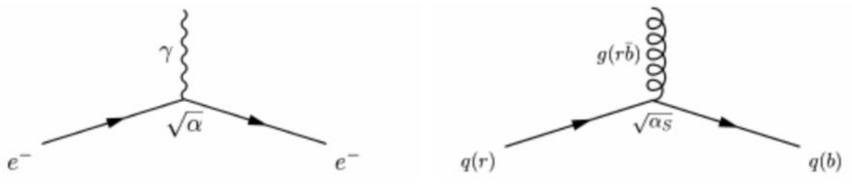




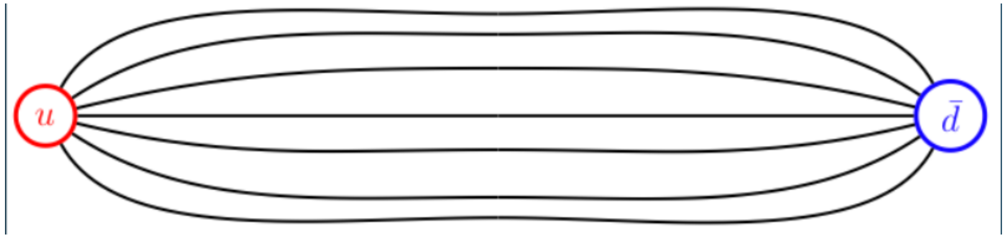
QCD diagrams

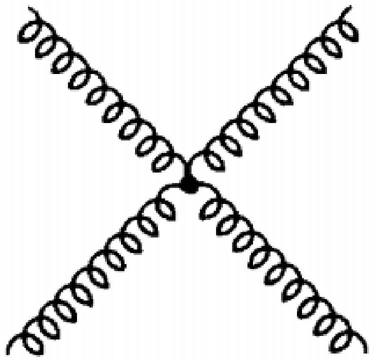


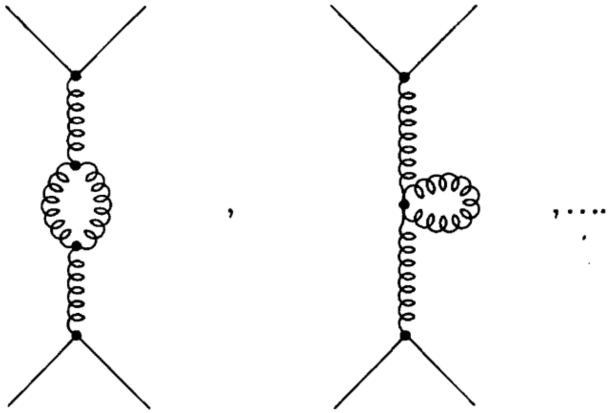


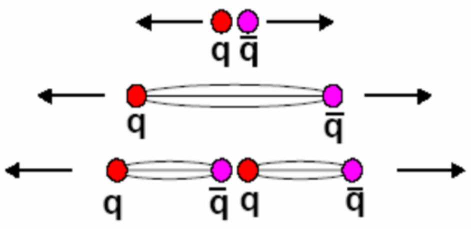


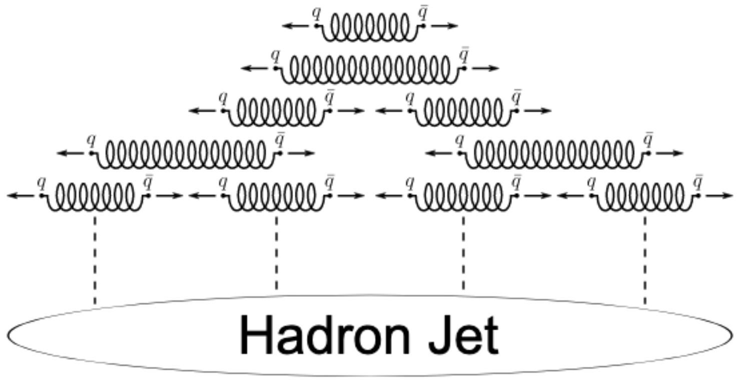
$\alpha = e^2/4\pi \approx 1/137$ $\alpha_S = g_S{}^2/4\pi \sim 1$

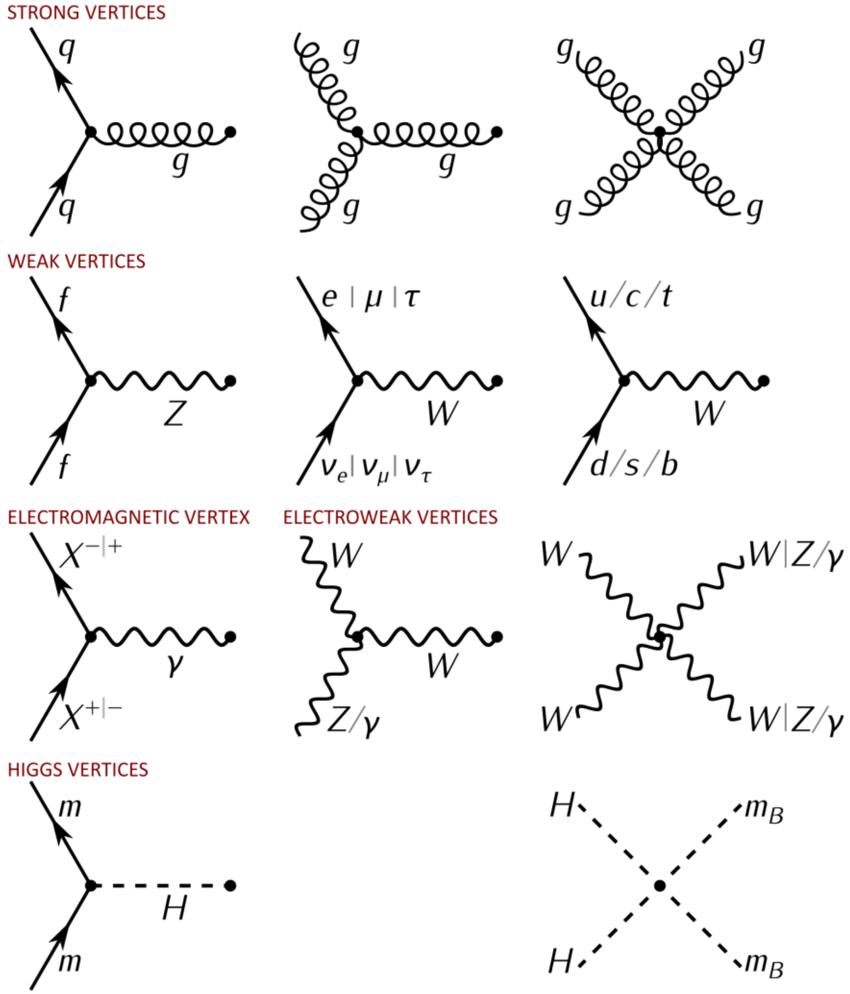












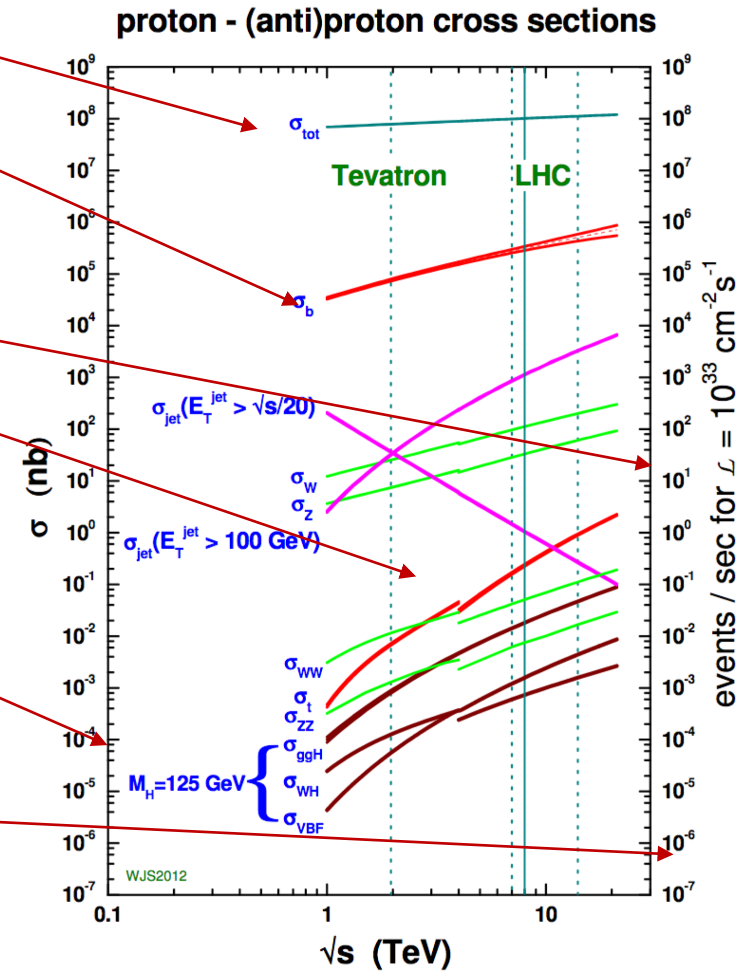
https://en.wikipedia.org/wiki/Standard_Model

QCD

Interesting SM in the textbook
(+ something "new")

Higgs

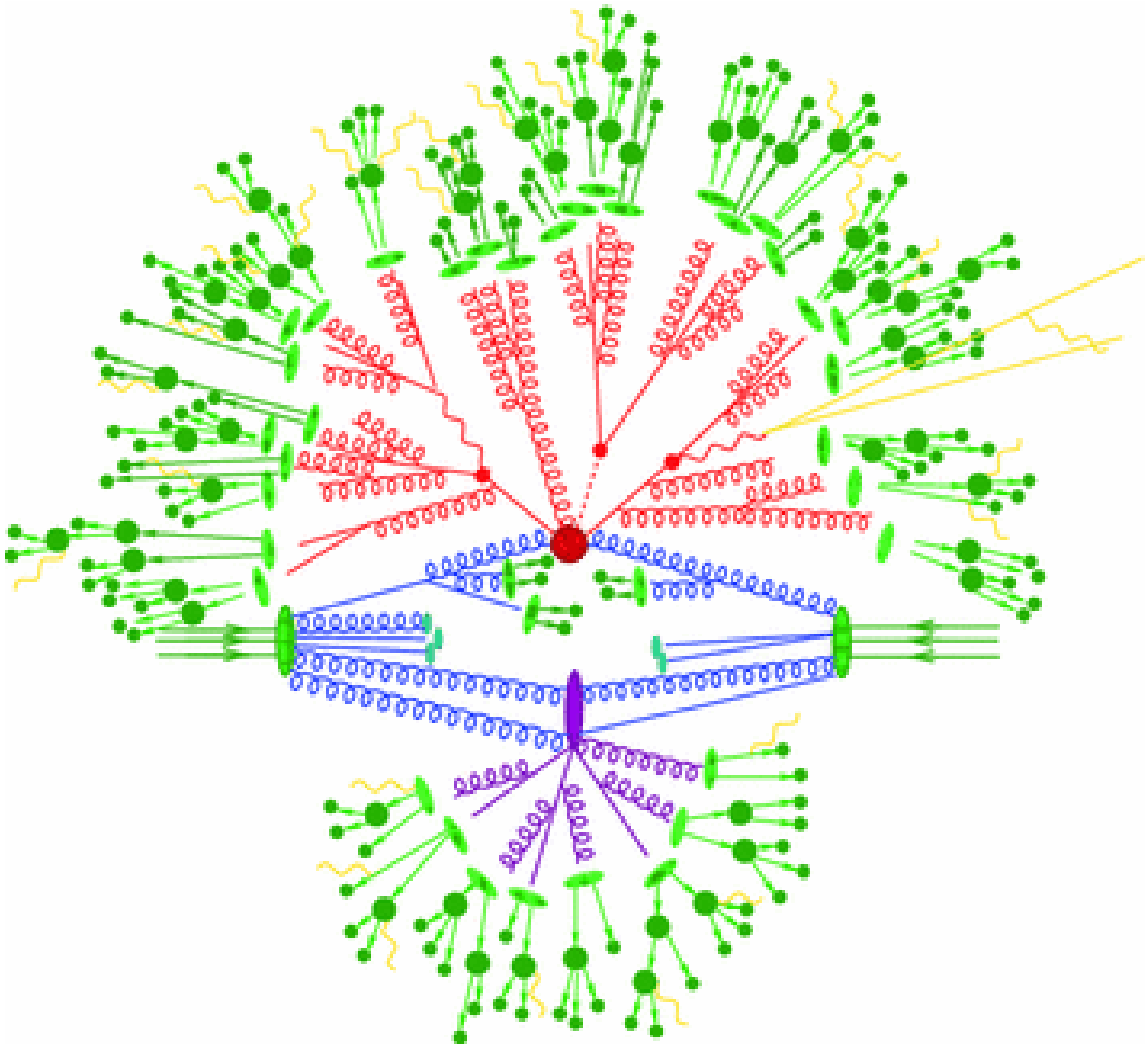
Something really new?

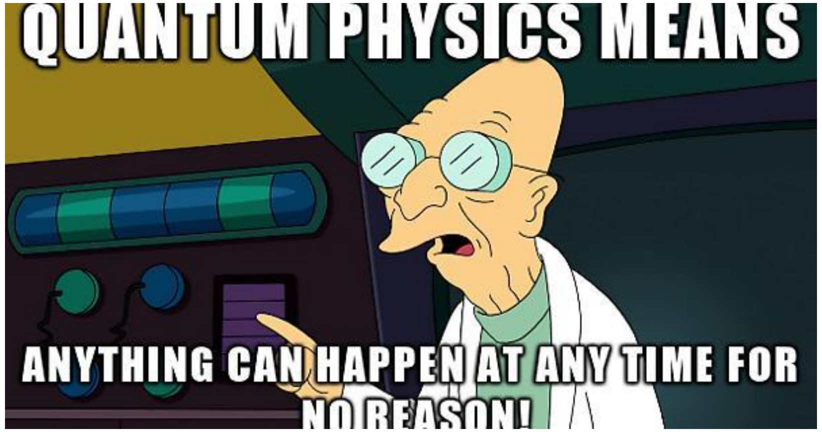


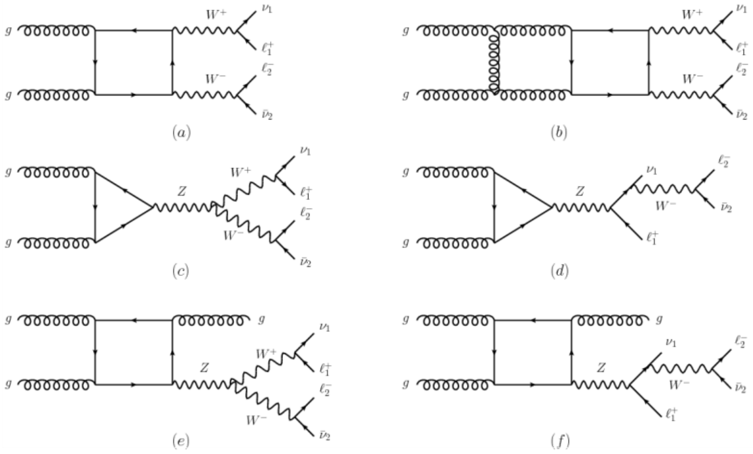
https://www.hep.ph.ic.ac.uk/~wstirlin

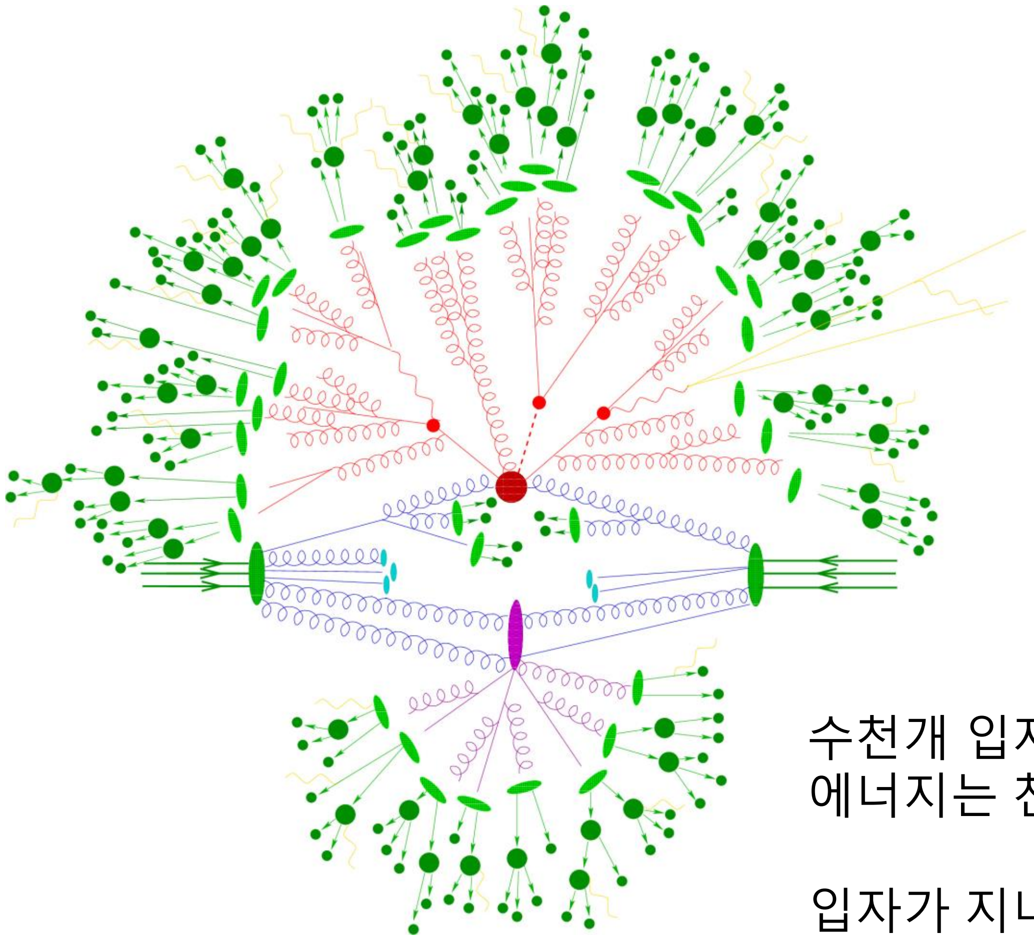
There's probability to have 1 Higgs candidate among $>10^{10}$ "junks"

Typical proton-proton collision









수천개 입자가 쏟아짐
에너지는 천차만별

입자가 지나간 궤적을 찾고,
운동량과 에너지 측정

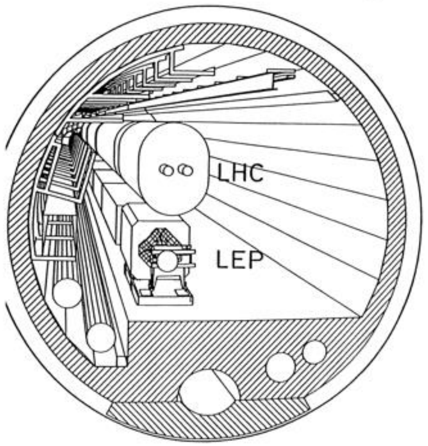

The Large Hadron Collider
LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
CMS
ALICE
LHC 27 km

LHC/CMS & ATLAS in the B.C. era

경희대학교

1984

ECFA 84/85
CERN 84-10
5 September 1984



LARGE HADRON COLLIDER
IN THE LEP TUNNEL

Vol. I

PROCEEDINGS OF THE ECFA-CERN WORKSHOP

held at Lausanne and Geneva,
21-27 March 1984

CERN and the European Committee for Future Accelerators (ECFA) hold a workshop in Lausanne, Switzerland and at CERN from the 21-27 March 1984. The event, Large Hadron Collider in the LEP Tunnel, marks the first official recognition of the concept of the LHC. Attendees consider topics such as what types of particles to collide and the challenges inherent to high-energy collisions. The image above shows one proposal from the workshop – adding the LHC in with the existing LEP machine – that was later scrapped.

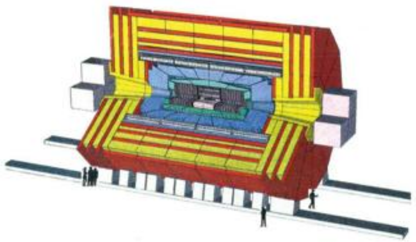
http://cdsweb.cern.ch/record/154938/files/CERN-84-10-V-1.pdf

1992

CERN/LHCC 92-3
LHCC/I 1
1 October 1992

LABORATOIRE EUROPÉEN POUR LA PHYSIQUE DES PARTICULES
CERN EUROPEAN LABORATORY FOR PARTICLE PHYSICS

CMS
The Compact Muon Solenoid



Letter of Intent

Abstract

We propose to build a general purpose detector designed to run at the highest luminosity at the LHC. The CMS (Compact Muon Solenoid) detector has been optimized for the search of the SM Higgs boson over a mass range from 90 GeV to 1 TeV, but it also allows detection of a wide range of possible signatures from alternative electro-weak symmetry breaking mechanisms. CMS is also well adapted for the study of top, beauty and tau physics at lower luminosities and will cover several important aspects of the heavy ion physics programme. We have chosen to identify and measure muons, photons and electrons with high precision. The energy resolution for the above particles will be better than 1% at 100 GeV. At the core of the CMS detector sits a large superconducting solenoid generating a uniform magnetic field of 4 T. The choice of a strong magnetic field leads to a compact design for the muon spectrometer without compromising the momentum resolution up to rapidities of 2.5. The inner tracking system will measure all high p_t charged tracks with a momentum precision of $\Delta p/p \approx 0.1\, p_t$ (p_t in TeV) in the range $|\eta| < 2.5$. A high resolution crystal electromagnetic calorimeter, designed to detect the two photon decay of an intermediate mass Higgs, is located inside the coil. Hermetic hadronic calorimeters surround the intersection region up to $|\eta| = 4.7$ allowing tagging of forward jets and measurement of missing transverse energy.

https://cdsweb.cern.ch/record/290808

16 DECEMBER 1994

LHC construction approved

The CERN council approves the construction of the Large Hadron Collider. To achieve the project without enlarging CERN's budget, they decide to build the accelerator in two stages.

31 JANUARY 1997

CMS and ATLAS experiments approved

Four years after the first technical proposals, the experiments CMS and ATLAS are officially approved. Both are general-purpose experiments designed to explore the fundamental nature of matter and the basic forces that shape our universe, including the Higgs boson.

14 FEBRUARY 1997

ALICE experiment approved

The CERN research board officially approves the ALICE experiment. Re-using the L3 magnet experiment from the LEP, ALICE is designed to study quark-gluon plasma, a state of matter that would have existed in the first moments of the universe.

10 SEPTEMBER 2008

The LHC starts up

19 SEPTEMBER 2008

Incident at the LHC

30 MARCH 2010

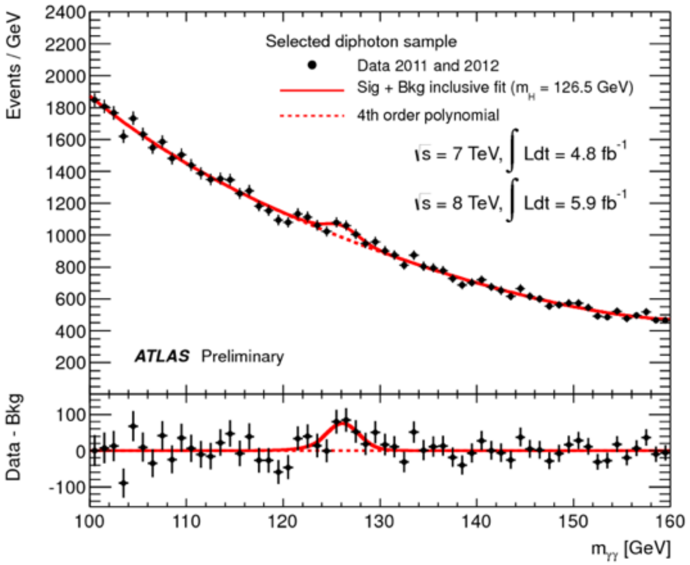
First LHC collisions at 7 TeV

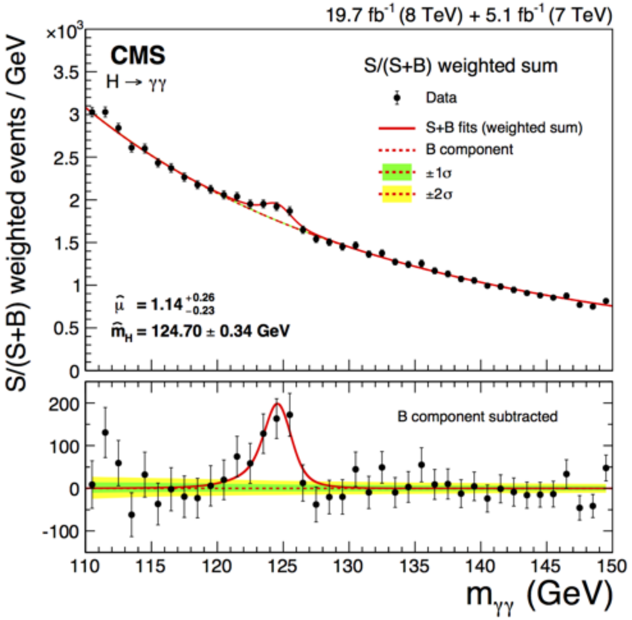
"A" major achievement of LHC: Higgs Discovery in 2012

04 JULY 2012

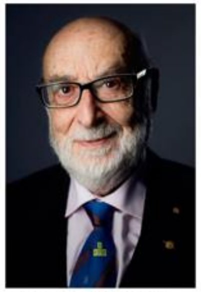
ATLAS and CMS observe a particle consistent with the Higgs boson

ATLAS spokesperson, Fabiola Gianotti, presents the collaboration's results. (IMAGE: CERN)





The Nobel Prize in Physics 2013



© Nobel Media AB. Photo: A. Mahmoud

François Englert

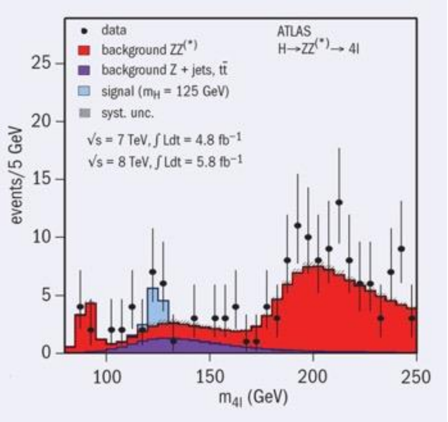
Prize share: 1/2

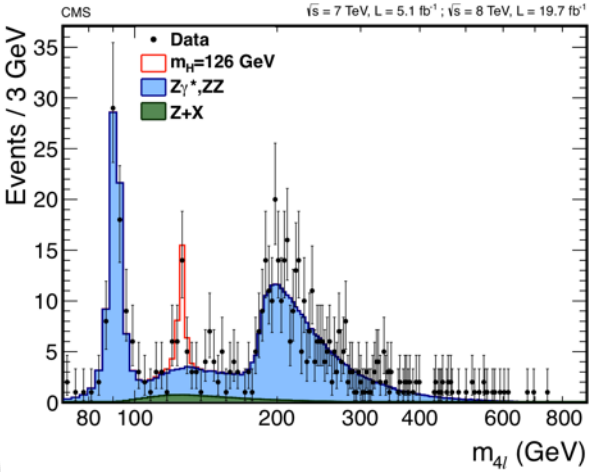
© Nobel Media AB. Photo: A. Mahmoud

Peter W. Higgs

Prize share: 1/2

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"

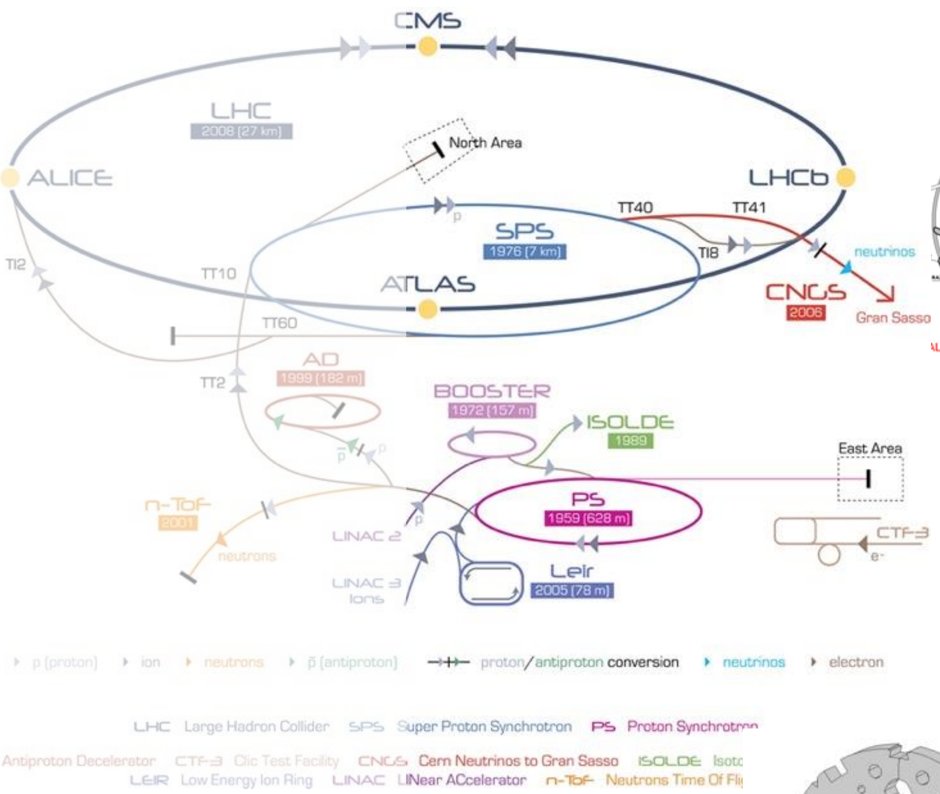


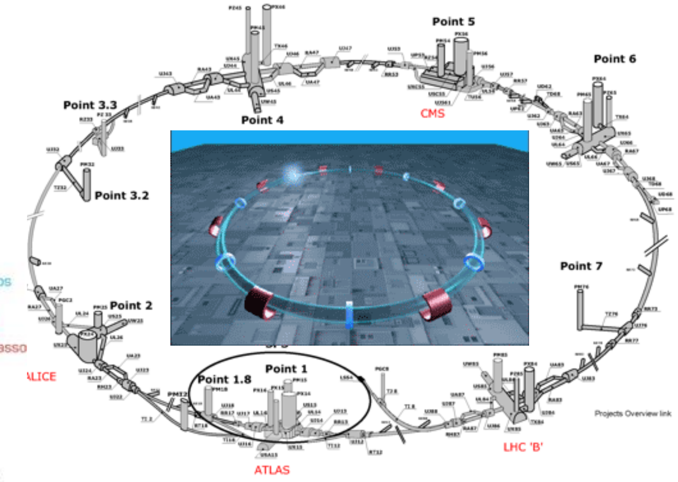


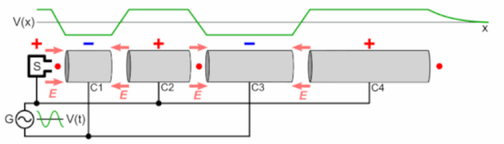
The stage: The LHC complex

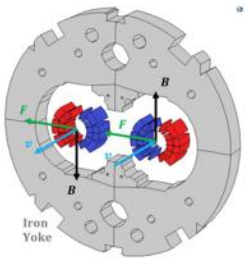
27km in circumference
~100m underground
Superconducting magnets
Particles ~ speed of light

Temperature 1.9K
He inventory 800,000L
Power consumption 120MW
Number of bunches 2808
Stored energy in magnet: 11GJ
N. of turns per sec. 11256
Beam life 0-30hrs

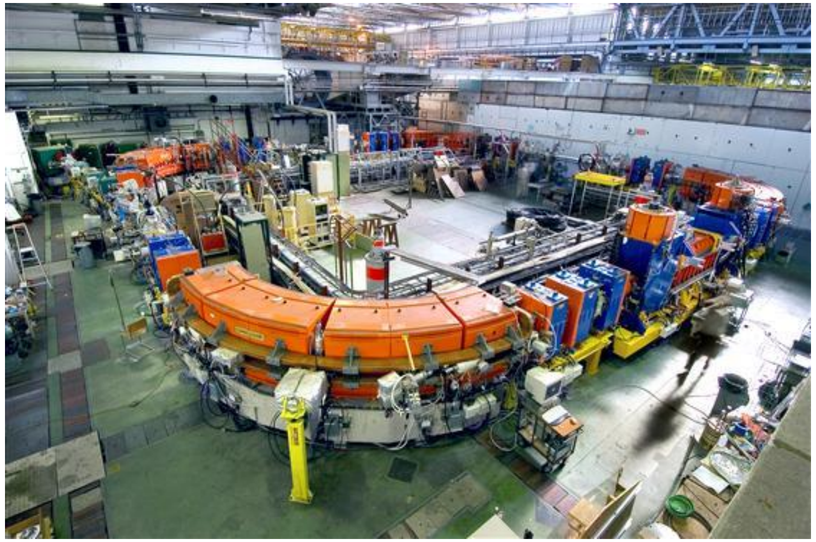
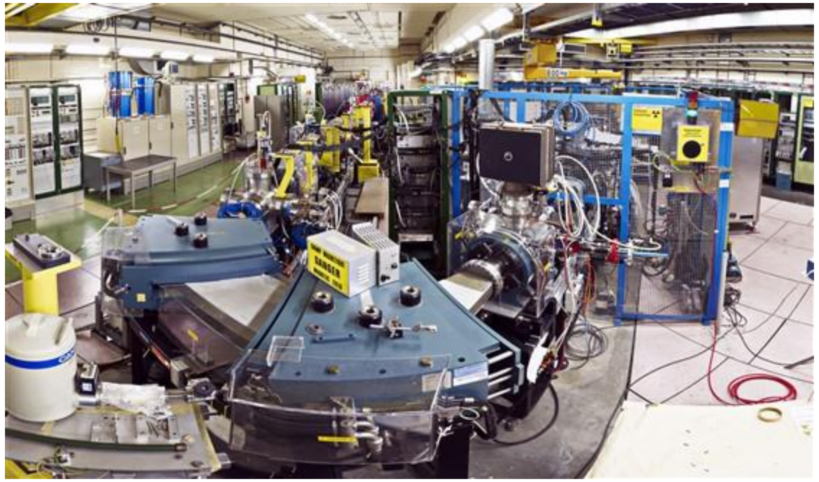


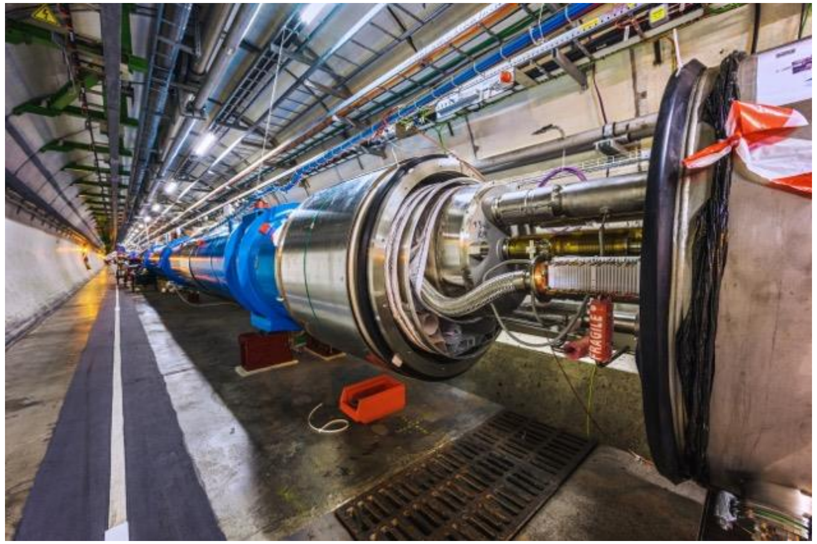




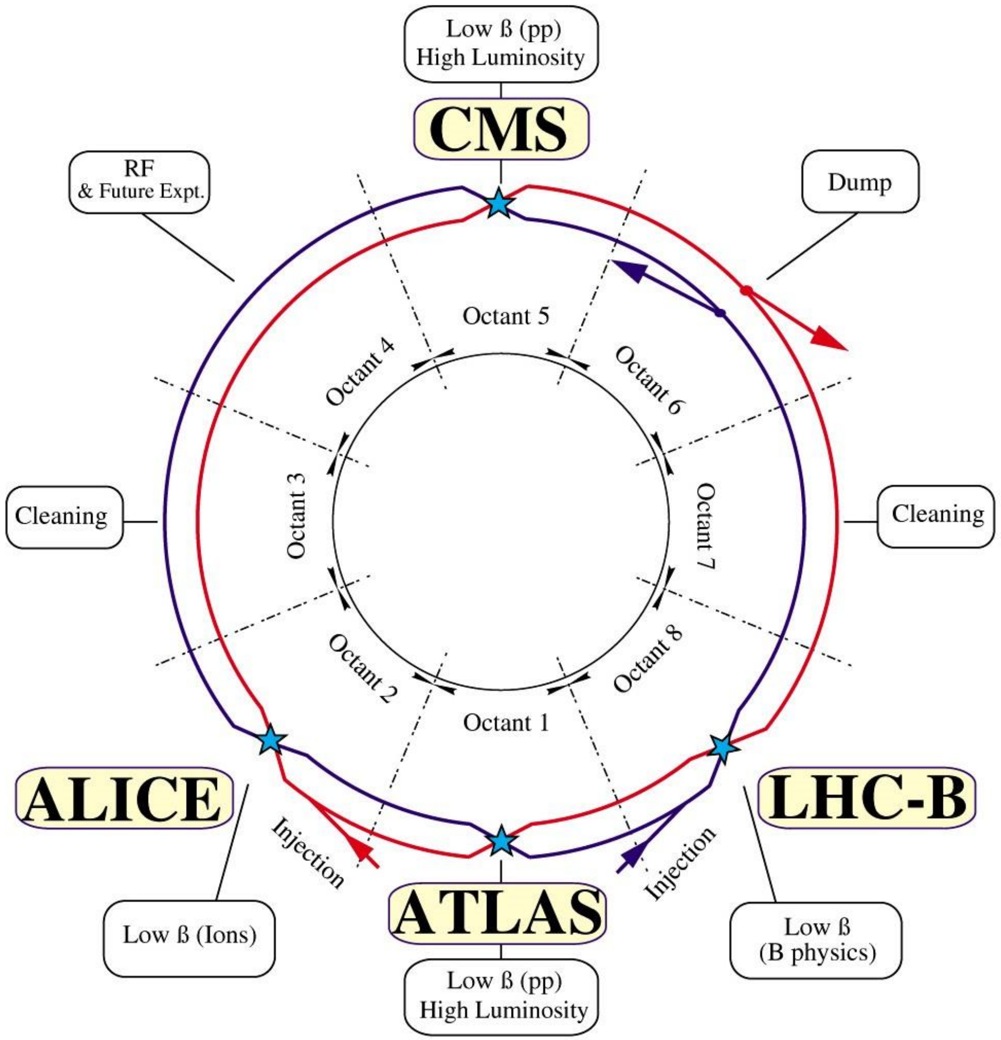


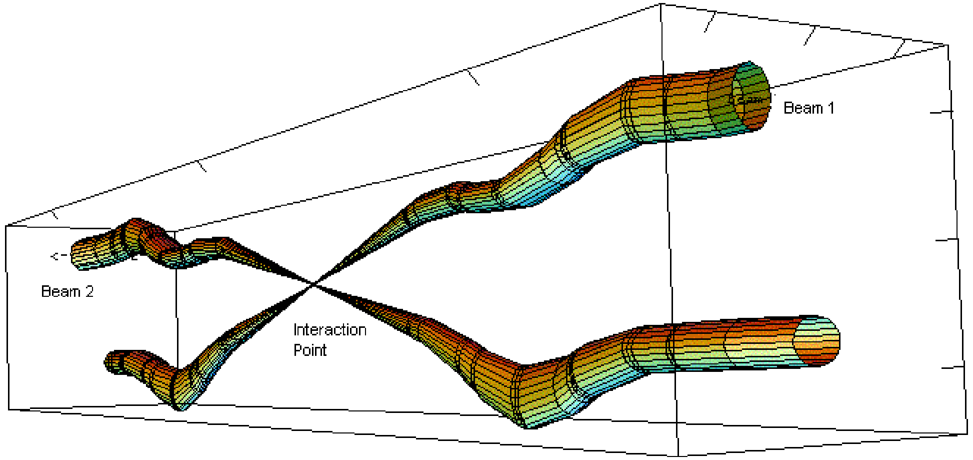
Accelerator complex

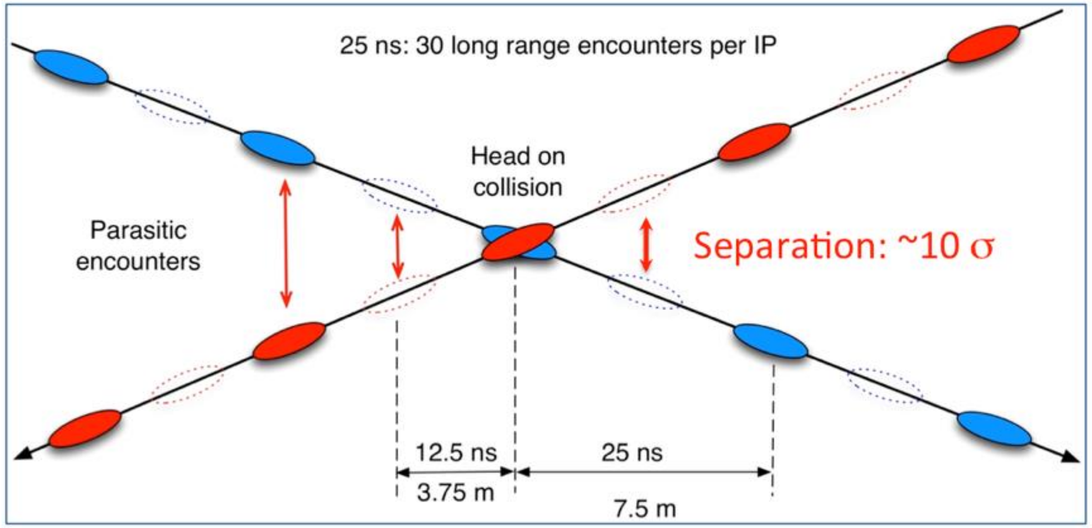



Particle collision at LHC



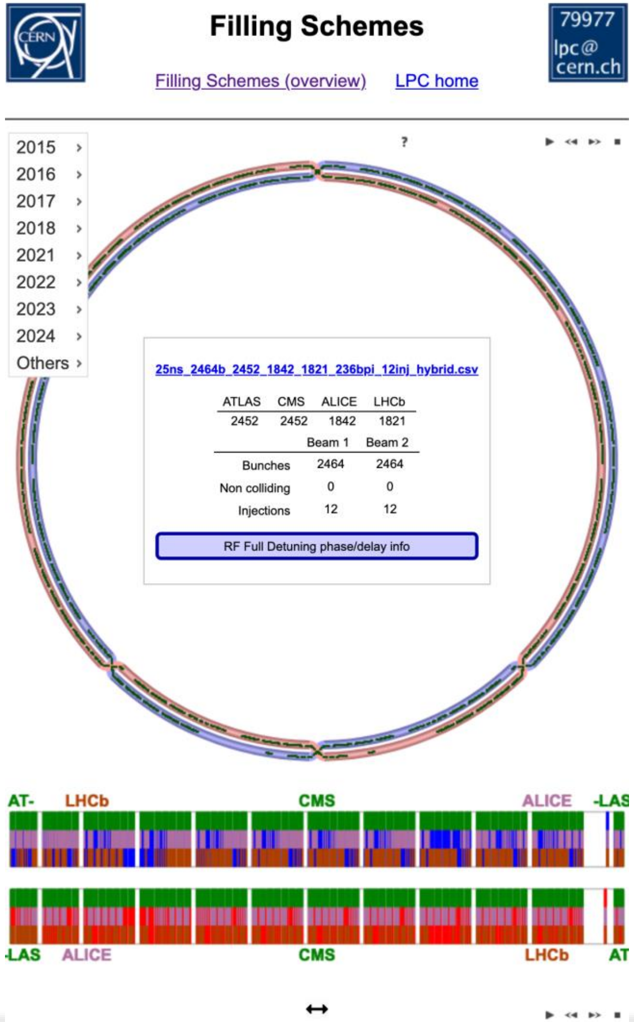


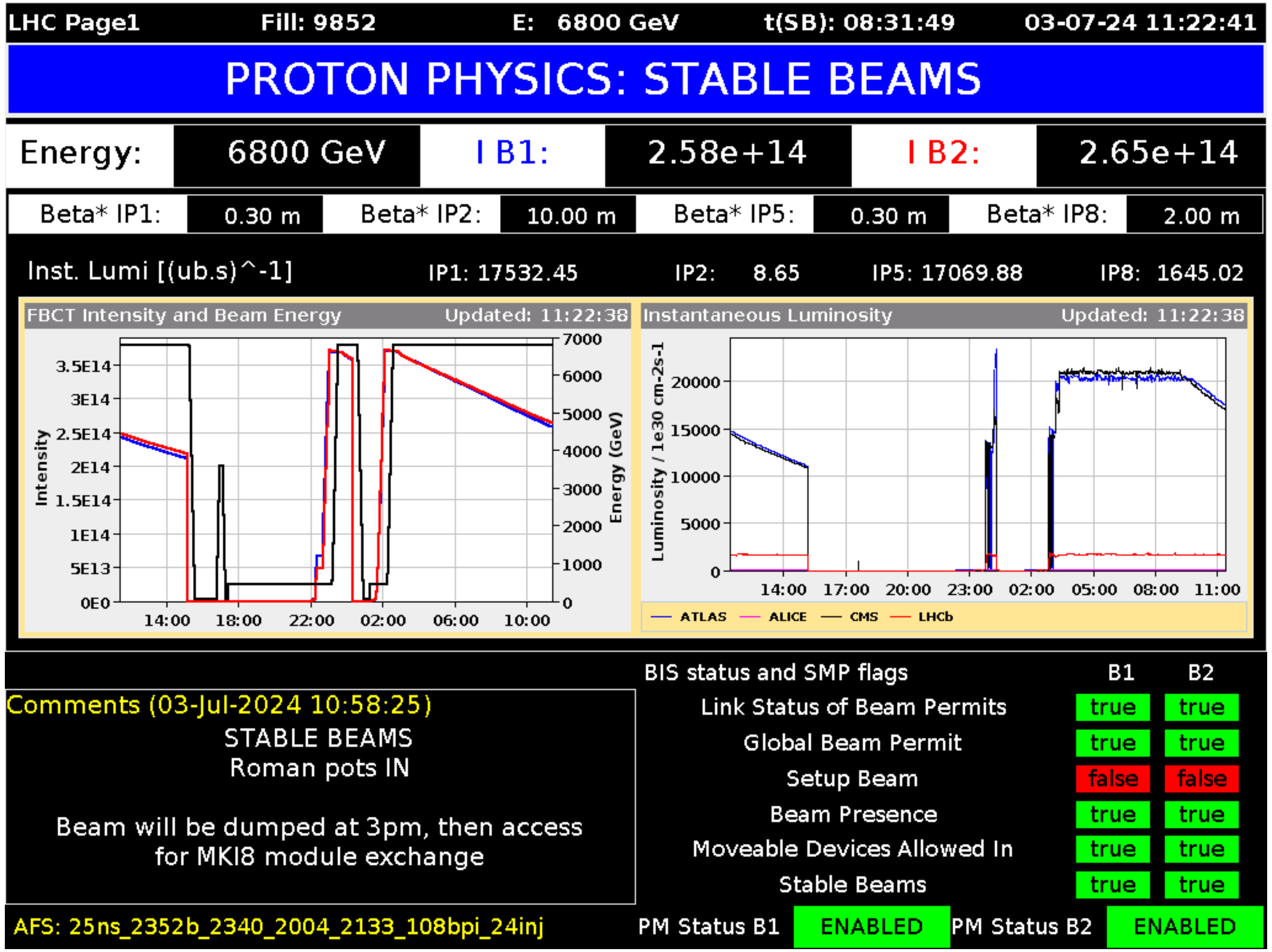
Relative beam sizes around IP1 (Atlas) in collision



LHC filling scheme

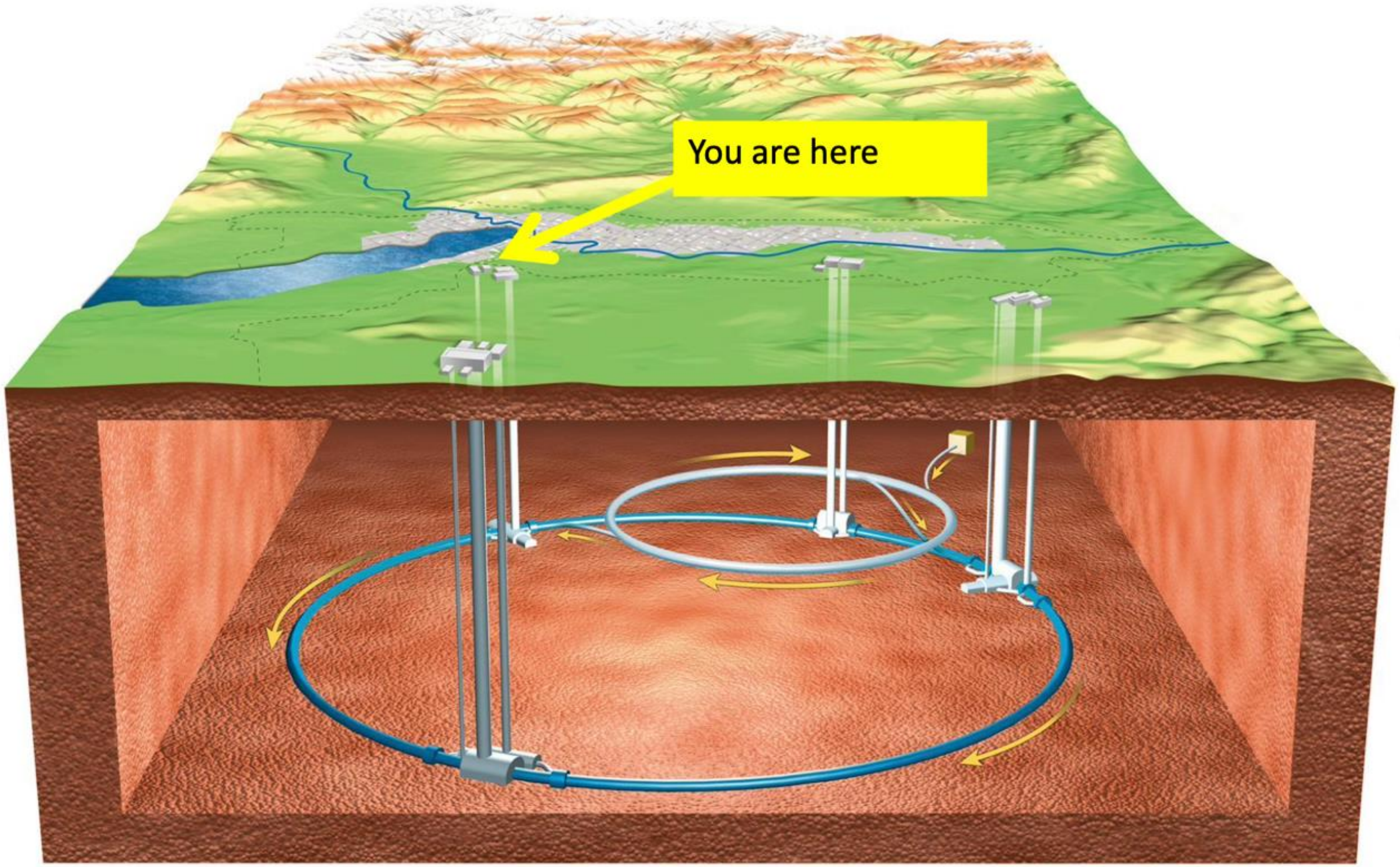
https://lpc.web.cern.ch/cgi-bin/filling_schemes.py

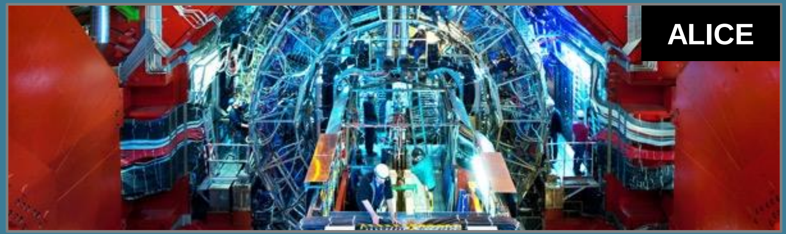




LHC page 1: https://op-webtools.web.cern.ch/vistar/

Camera: Giant detectors

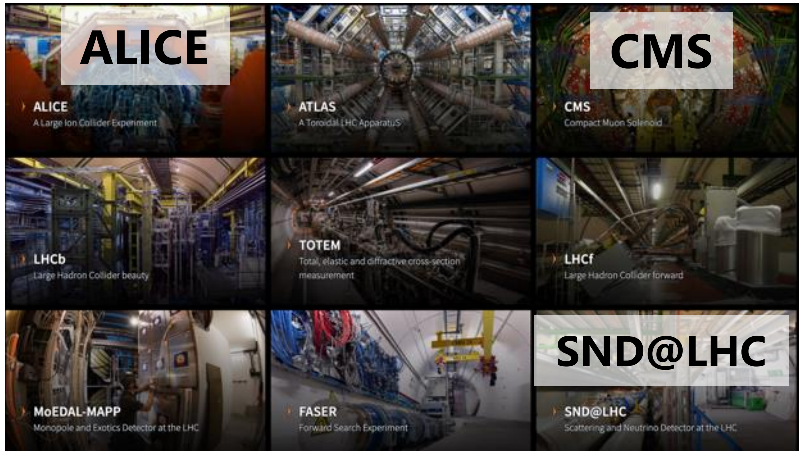




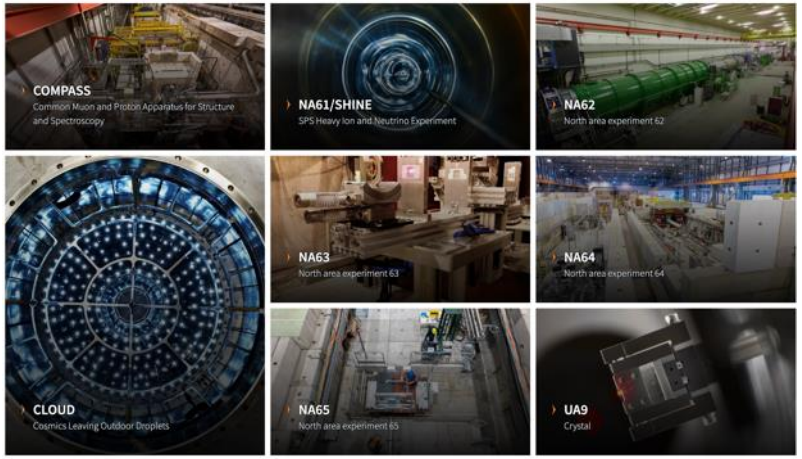
Camera: Giant detectors

Note: Experiments at CERN

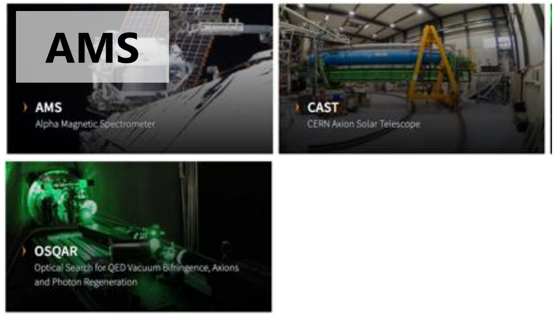
LHC experiments



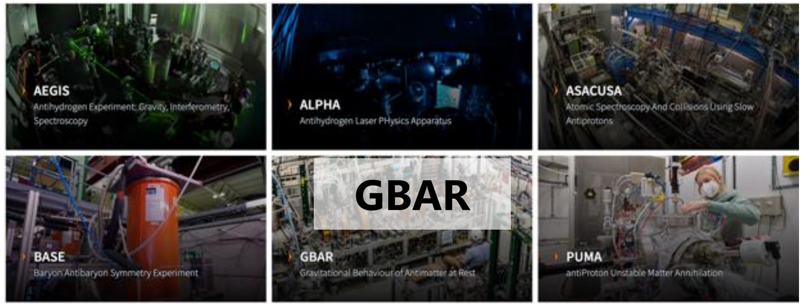
Fixed-target experiments



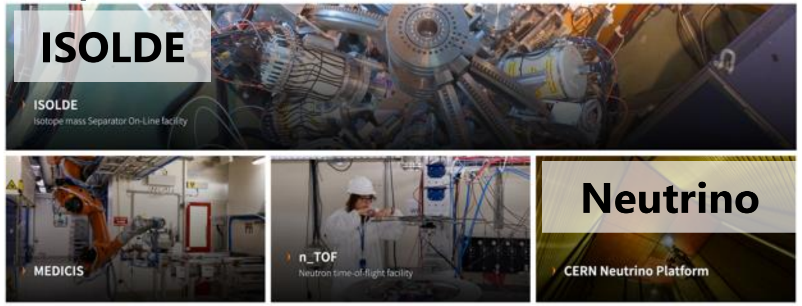
Non-accelerator



Antimatter experiments

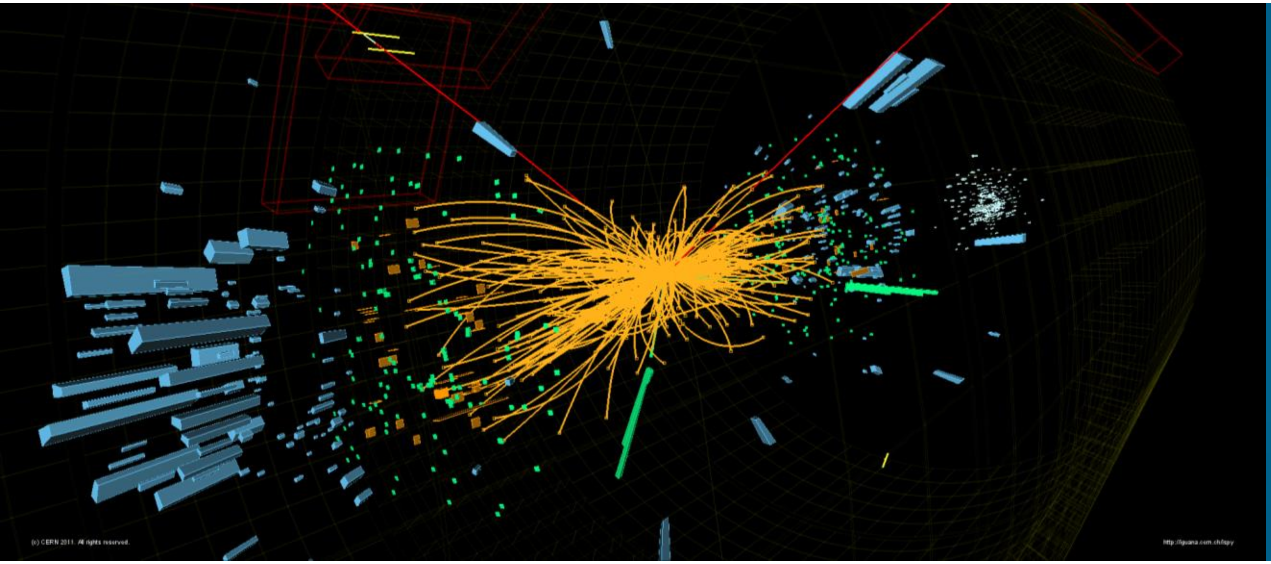


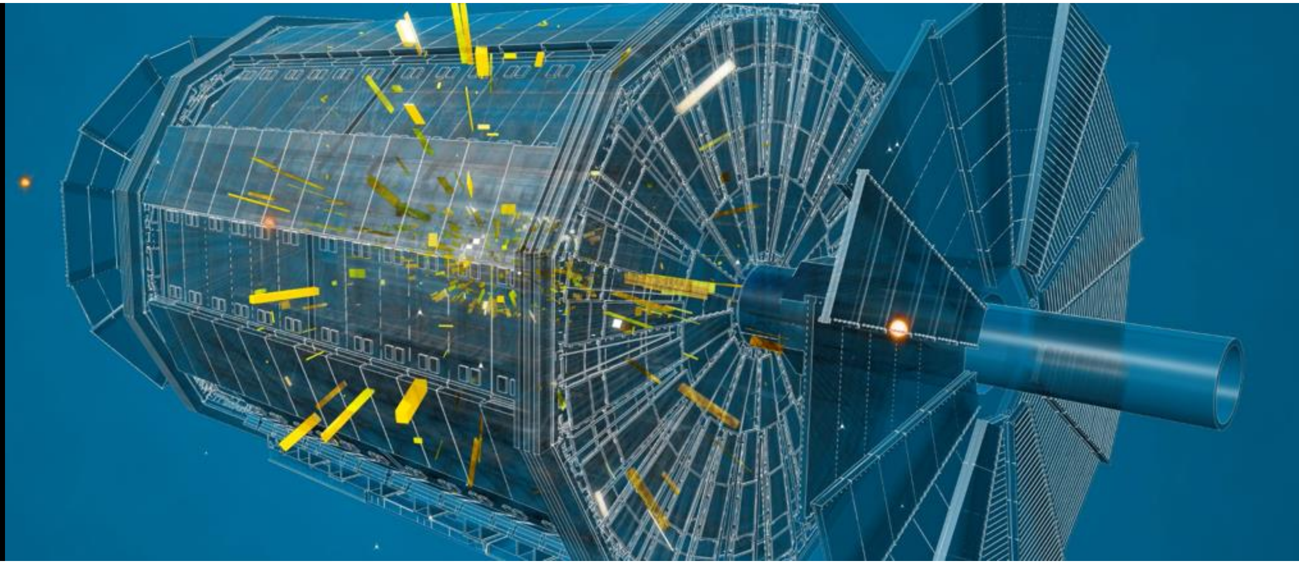
Experimental facilities

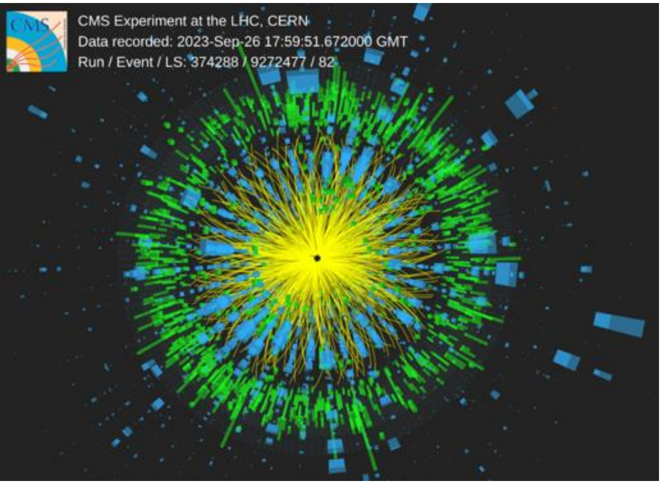


…And future experiments

Repeating experiments in every 25ns



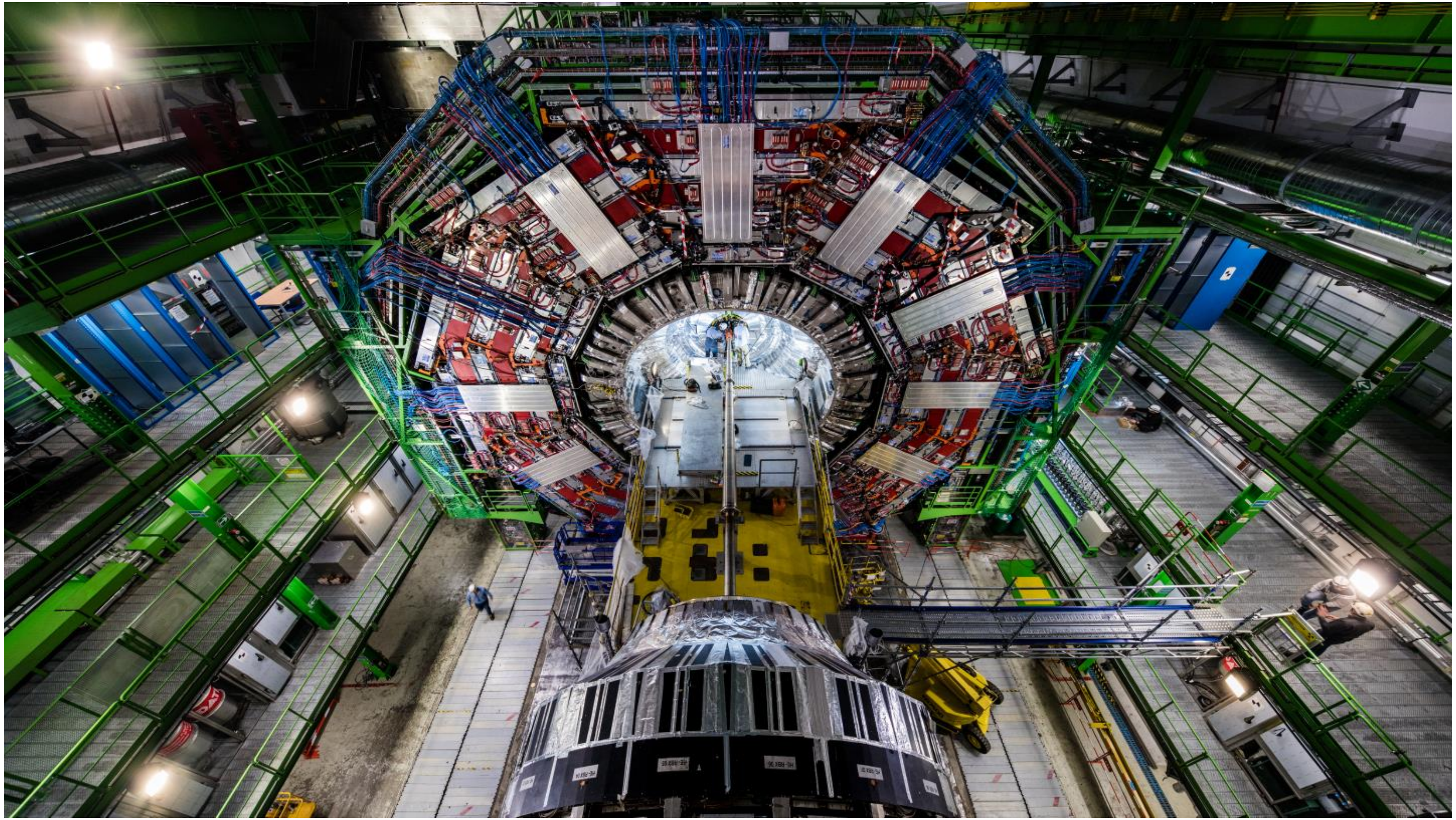




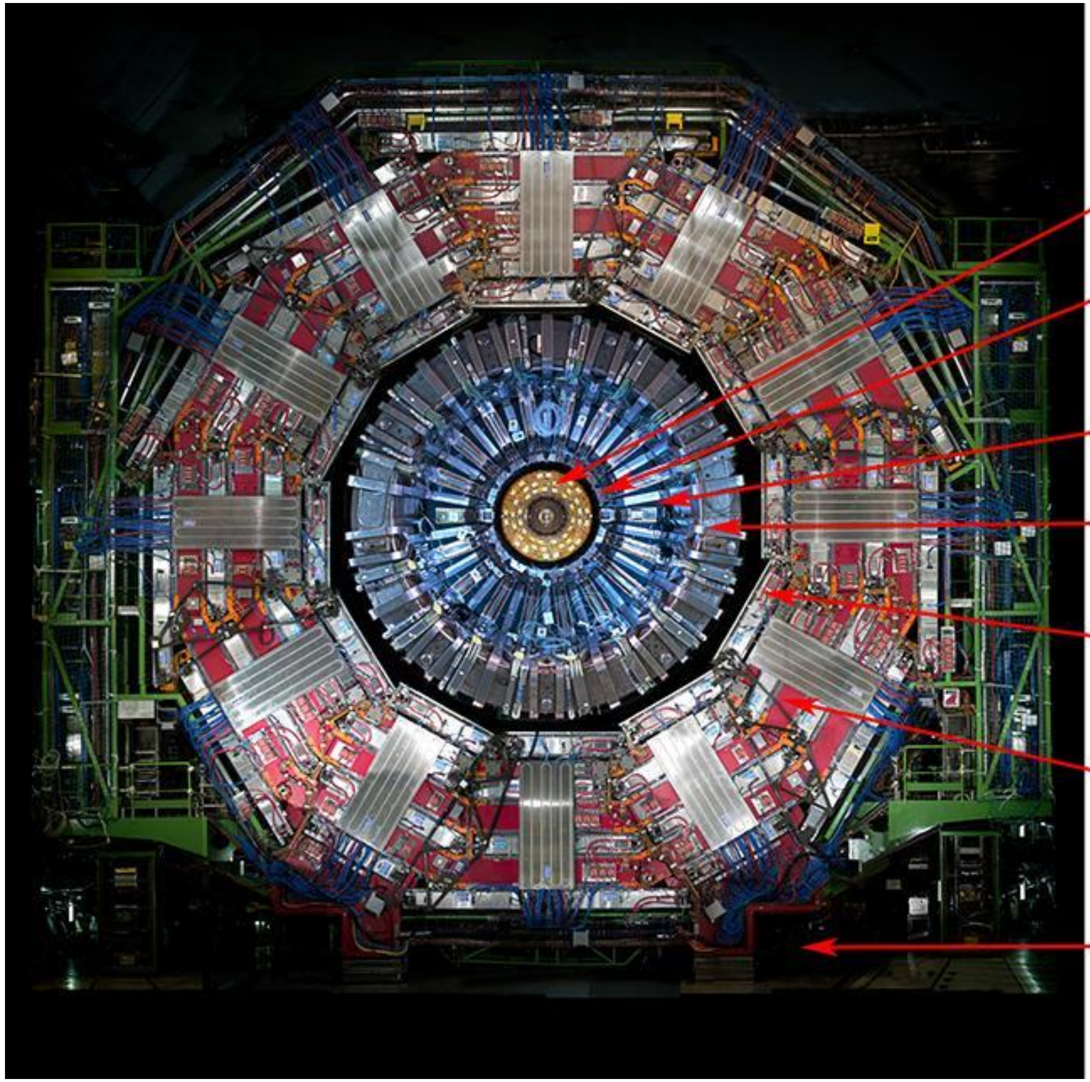
Particle collisions in every 25ns at 13.6TeV, average ~40 multiple collisions

- Data processing at 40MHz with >100M channels
- Extreme conditions: radiation with high energy particles (~GeV), superconducting magnet (1-4 Tesla) to cover large volume
- Random events according to the quantum physics – select rare cases only
- Operating +15 years and more

CMS Detector



CMS Detector



Tracking system
Germany, Italy, France, Belgium, USA, Austria, Finland, Switzerland, CERN...

Electromagnetic Calorimeter
Russia, China, France, Italy, Japan, UK, Switzerland, Greece, Taiwan

Hadron Calorimeter
USA, Russia, Ukraine, Turkey, Iran, India, Hungary...

Solenoid
France, Italy, Switzerland, Finland, CERN, UK, Japan, Croatia

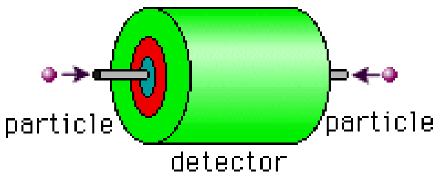
Muon system
Italy, Germany, Spain, USA, Russia, Belgium, Bulgaria, South Korea, Pakistan, CERN

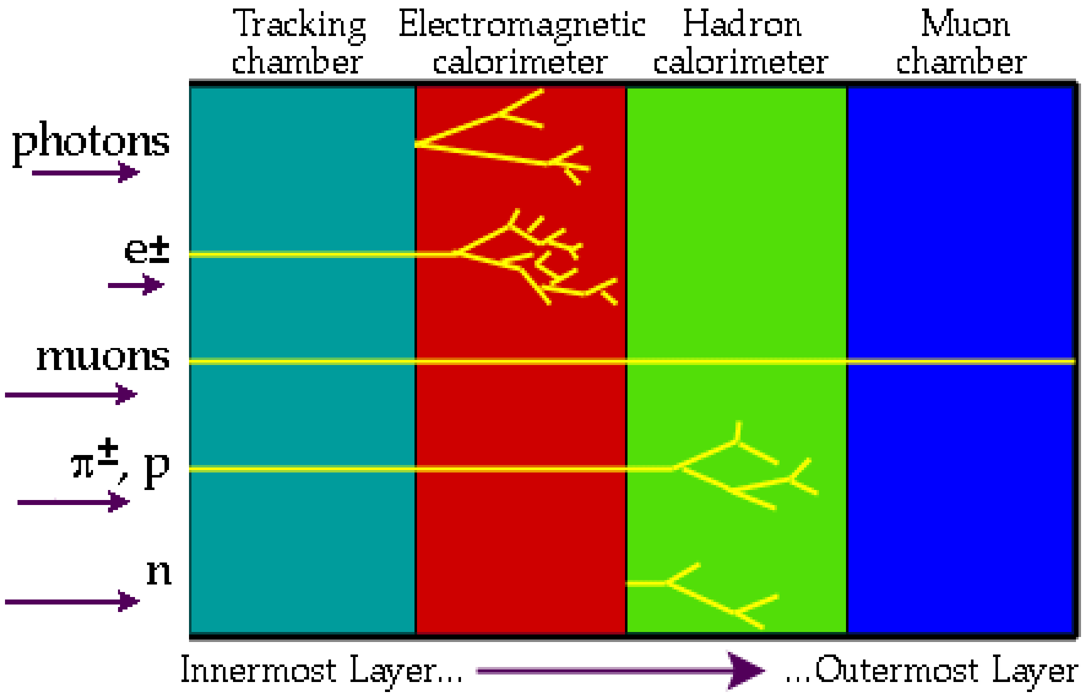
Flux-return yoke
Germany, Russia, Czechia, Japan, CERN

Support system
China, Pakistan, USA

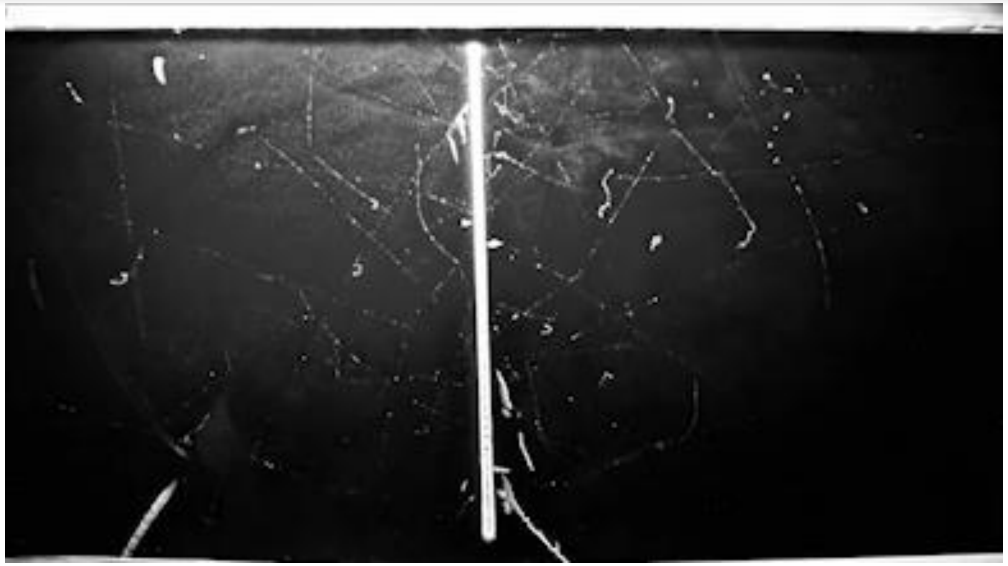
… is a generic particle detector

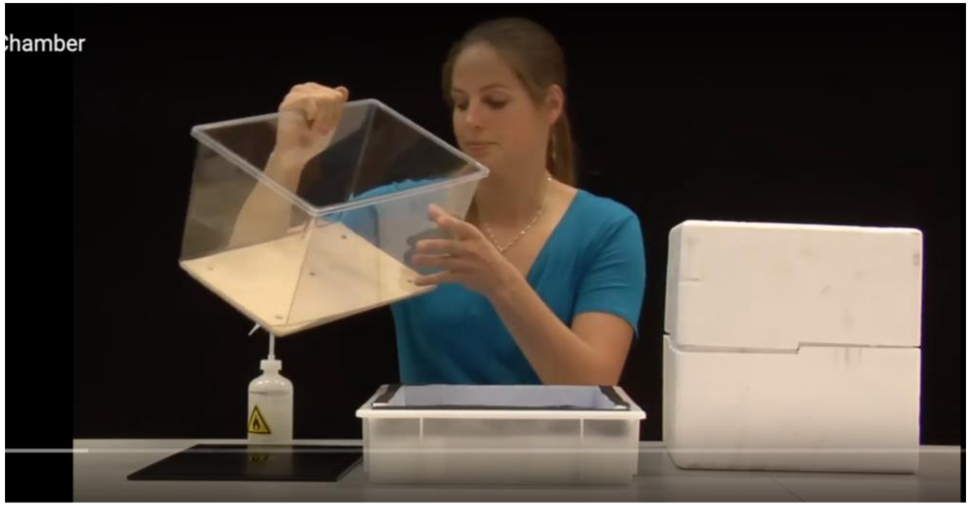
- Only 7+ particles:
  - p, n, $e^{\pm}$, $\mu^{\pm}$, γ, $\pi^{\pm}$, $K^{\pm}$, (K^0, ν)
- (Somehow) Distinguishable by their charge, interaction, energy loss
  - EM interaction?
    - Bends under B fields?
  - Nuclear interaction?
  - Minimum (but nonzero) interaction?
  - Or invisible?
  - Decays?





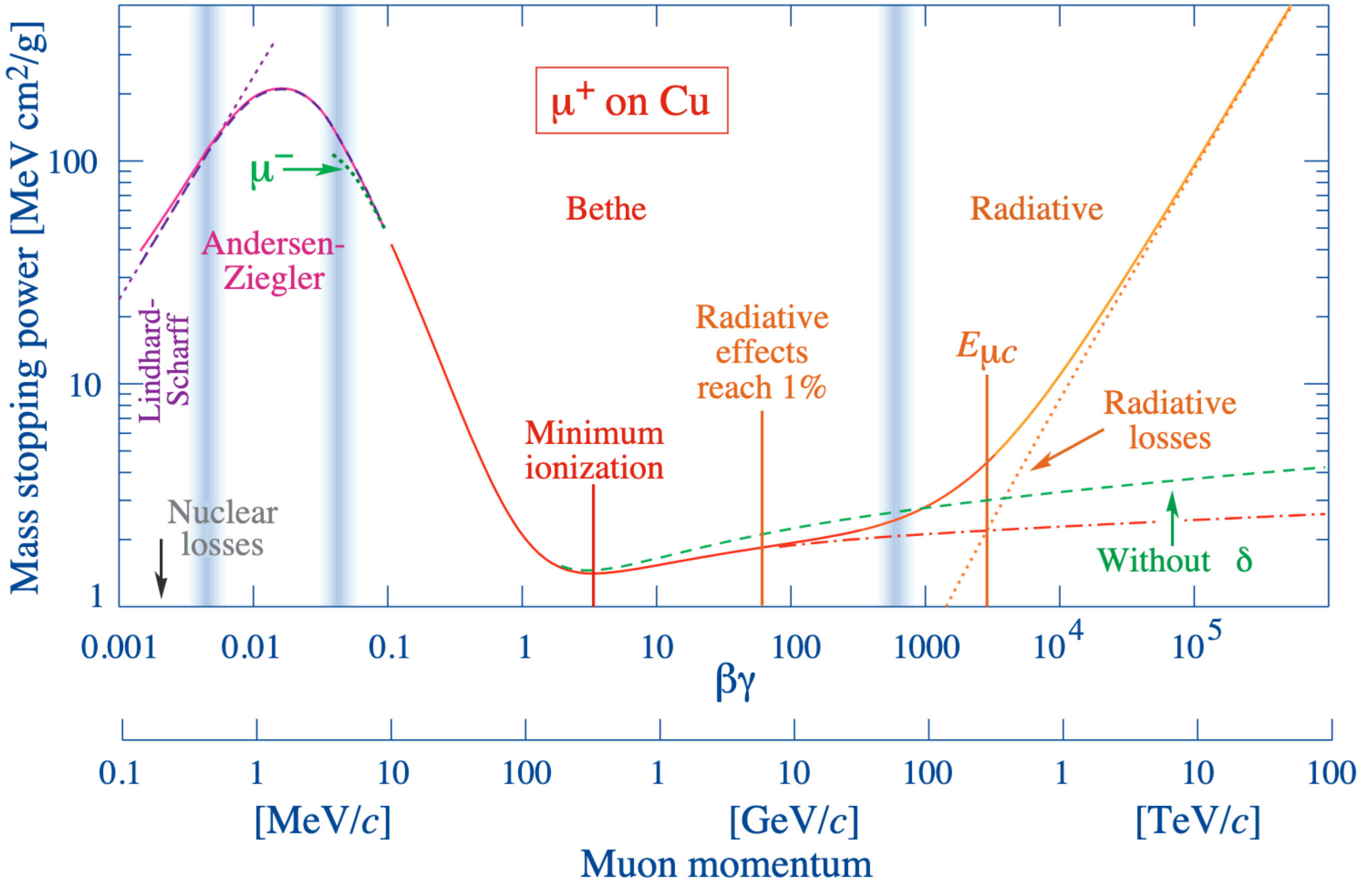
Example: Cloud Chamber

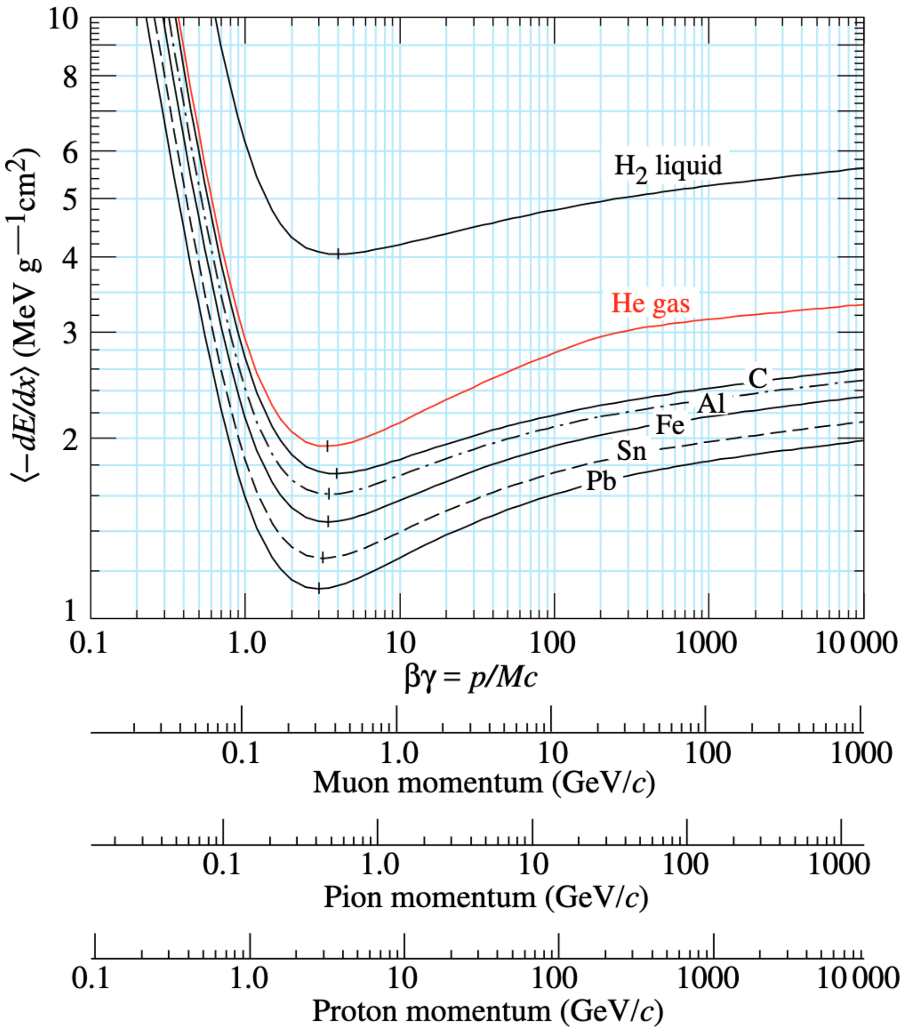




Build own one: https://cds.cern.ch/record/1999082

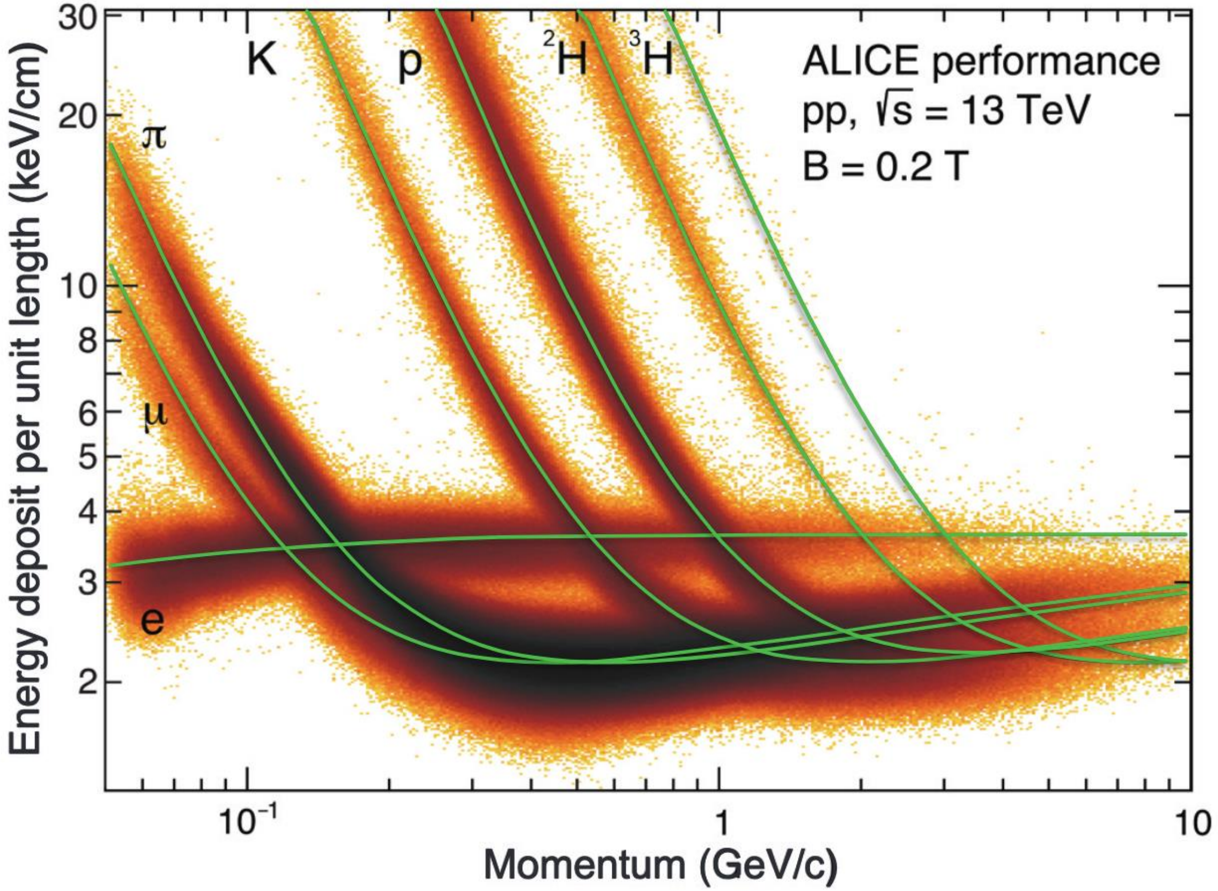
Particle passage in media



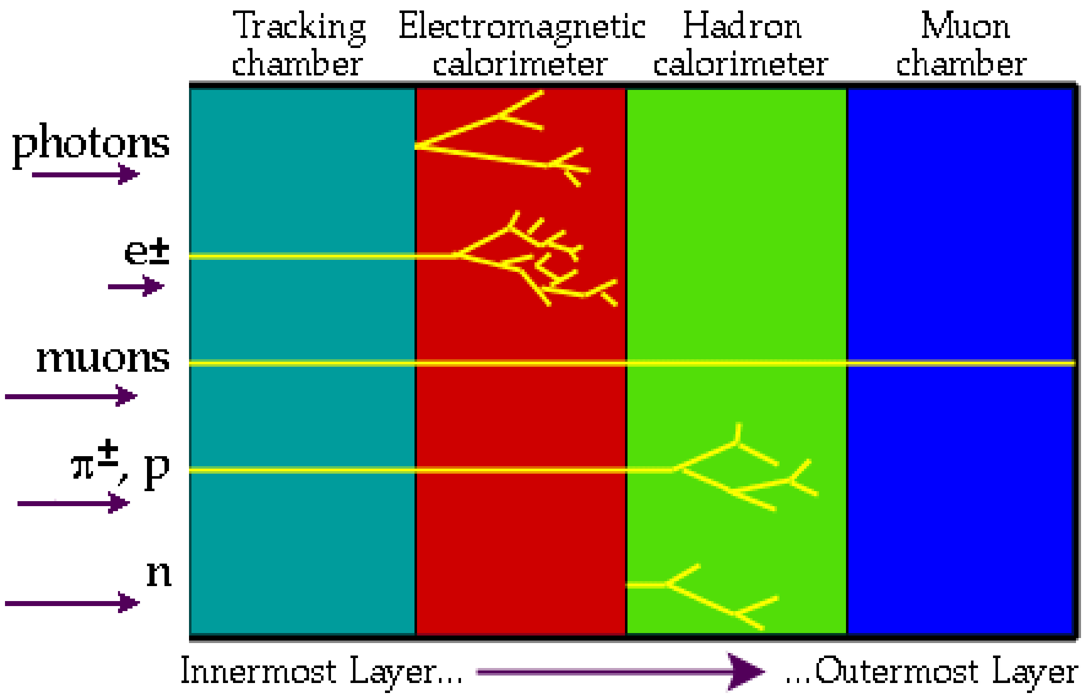


$$\left\langle -\frac{dE}{dx} \right\rangle = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 W_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

Energy loss

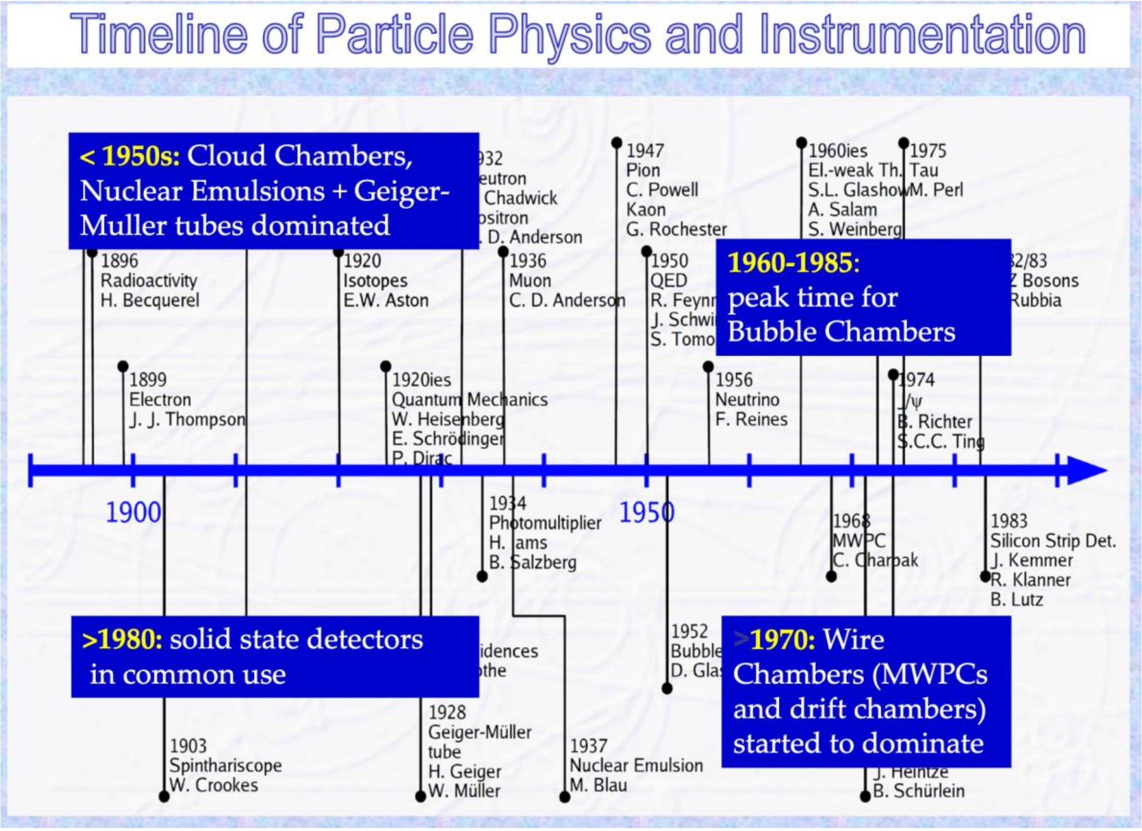


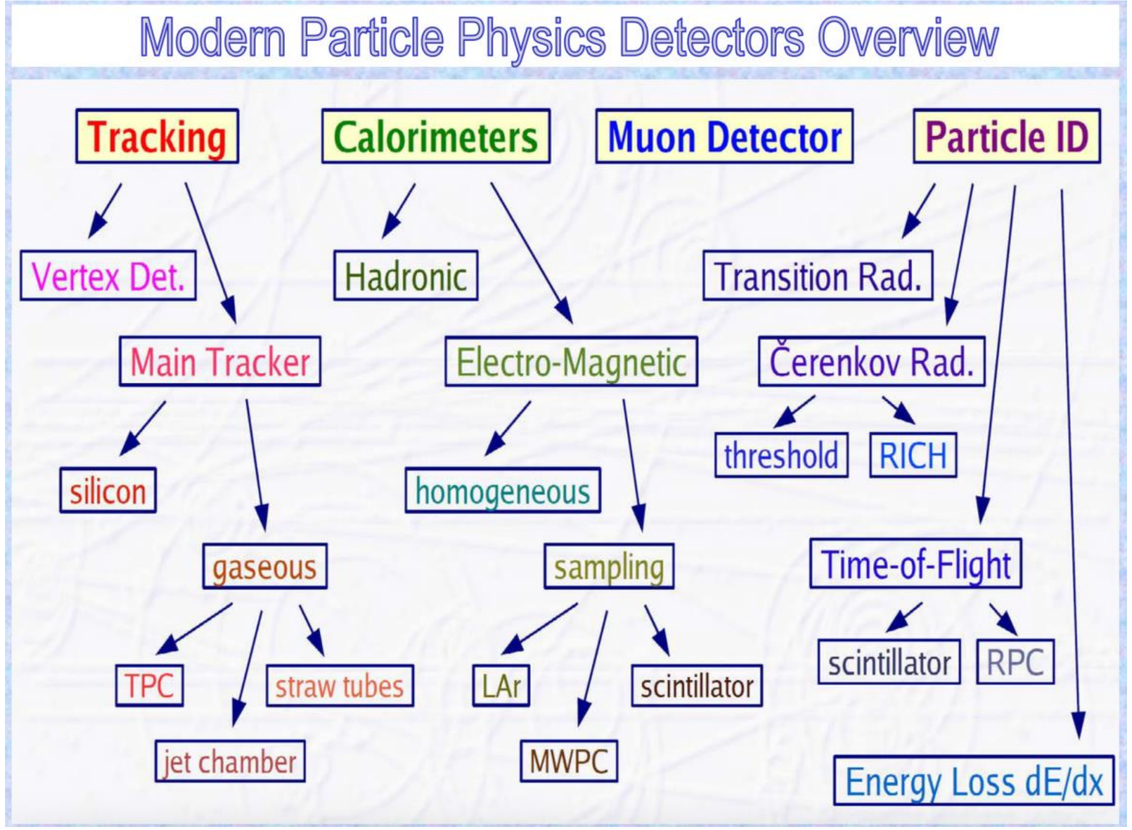
ALICE performance
pp, √s = 13 TeV
B = 0.2 T
K
p
^{2}H
^{3}H
π
μ
e
Energy deposit per unit length (keV/cm)
Momentum (GeV/c)
30
20
10
8
6
5
4
3
2
10^{-1}
1
10



Tracking chamber
Electromagnetic calorimeter
Hadron calorimeter
Muon chamber
photons
e±
muons
π±, p
n
Innermost Layer...
...Outermost Layer

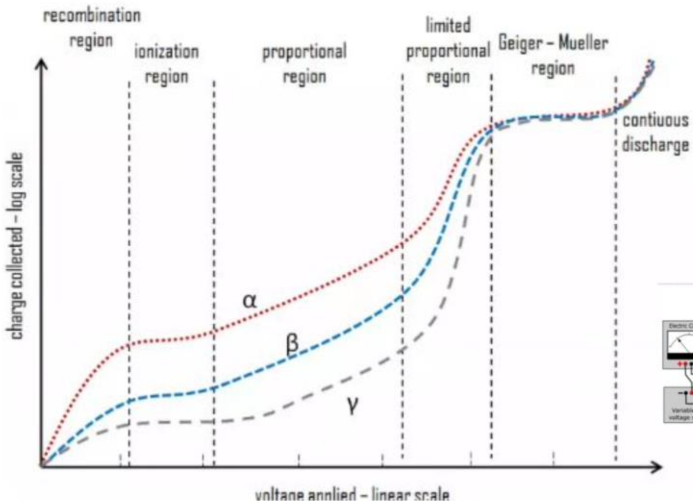
Particle detectors

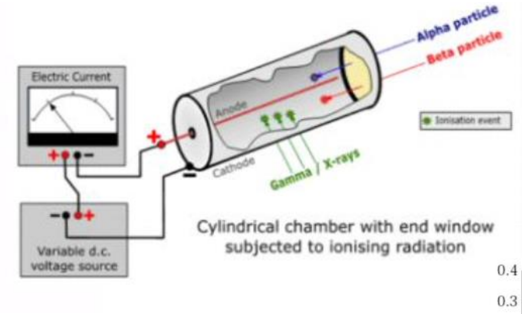


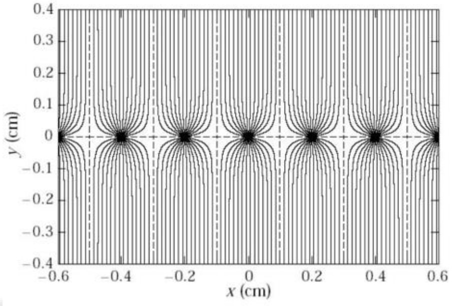


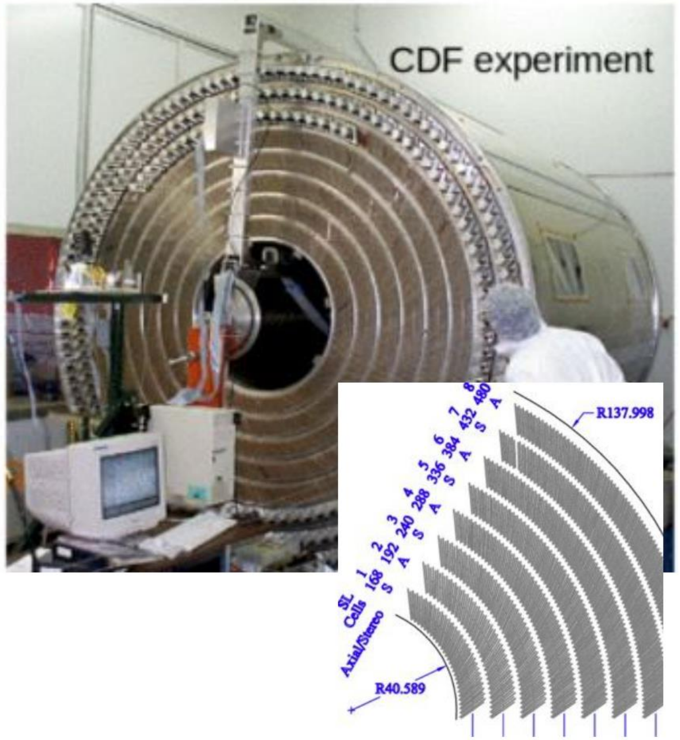
https://www.desy.de/~titov/1_2017_07_Cerklje-Slovenia_TESHEP_HistoryInstrumentation_ModernTrackingDetectors_14072017_FINAL.pdf

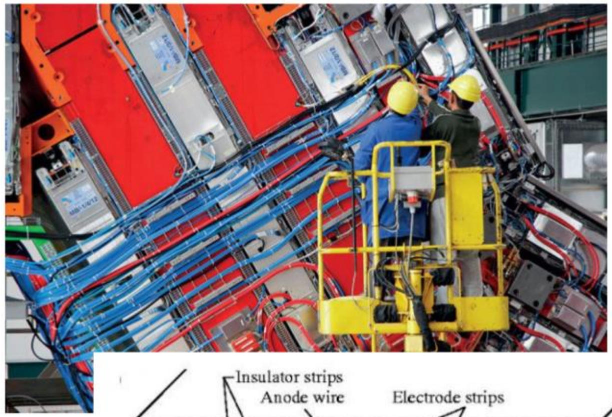
Particle detection: Gas

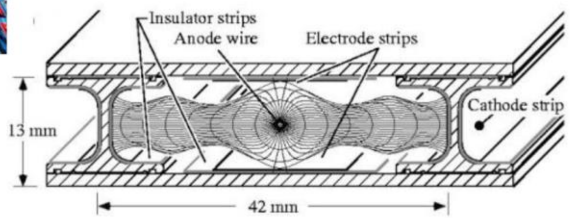


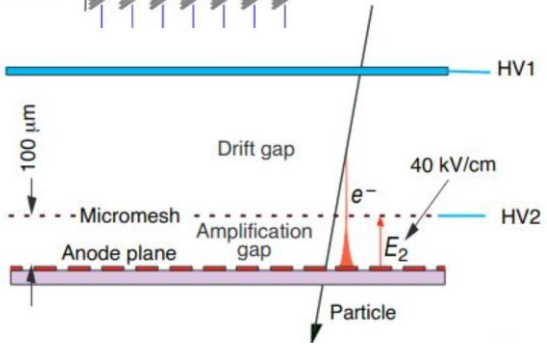


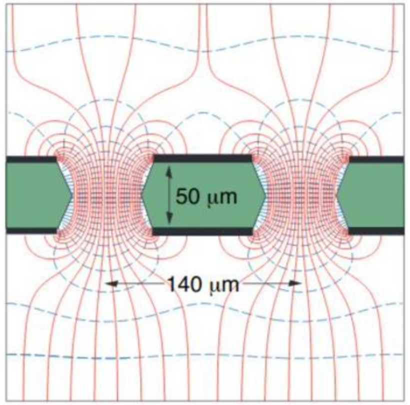






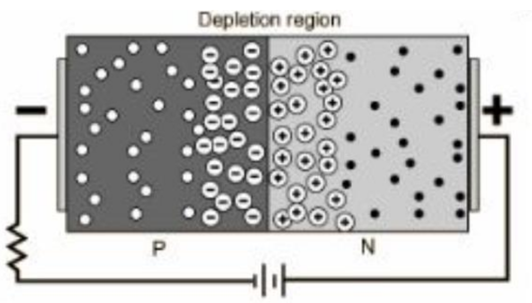


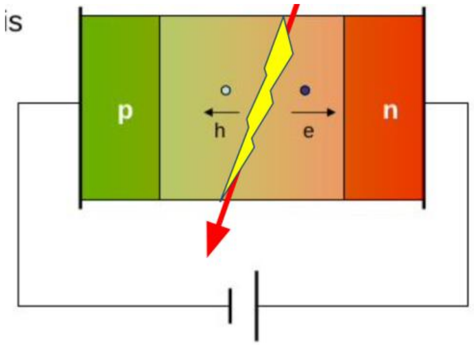


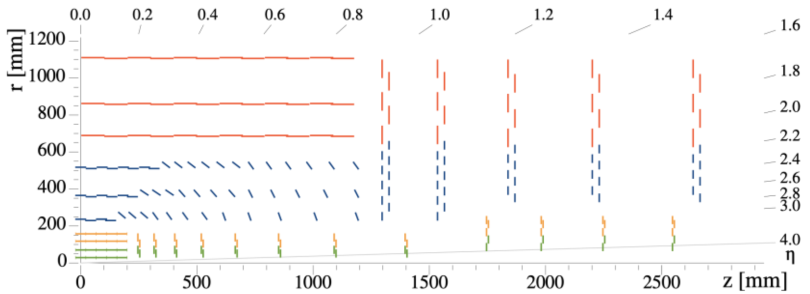


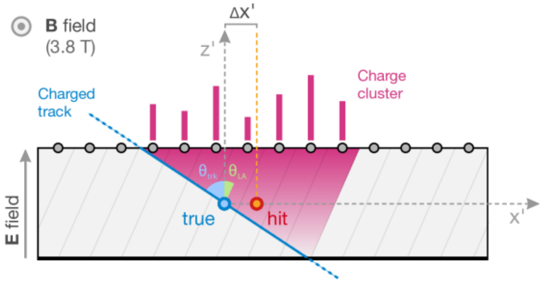
Particle detection: Silicon

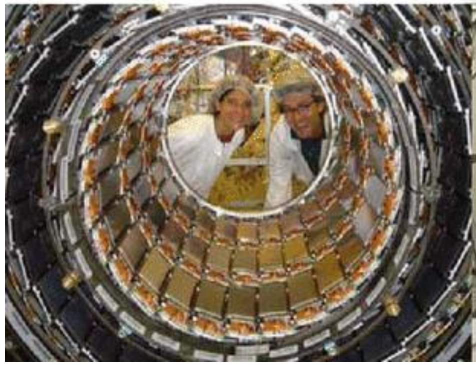
$$R = \frac{p}{0.3B}$$

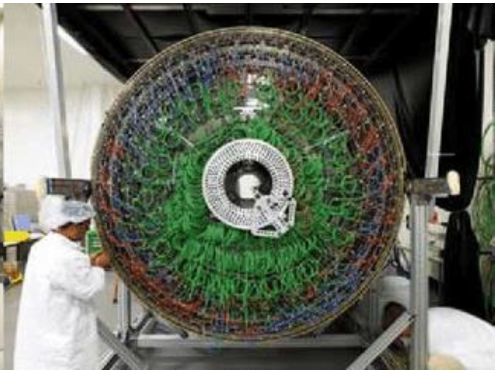


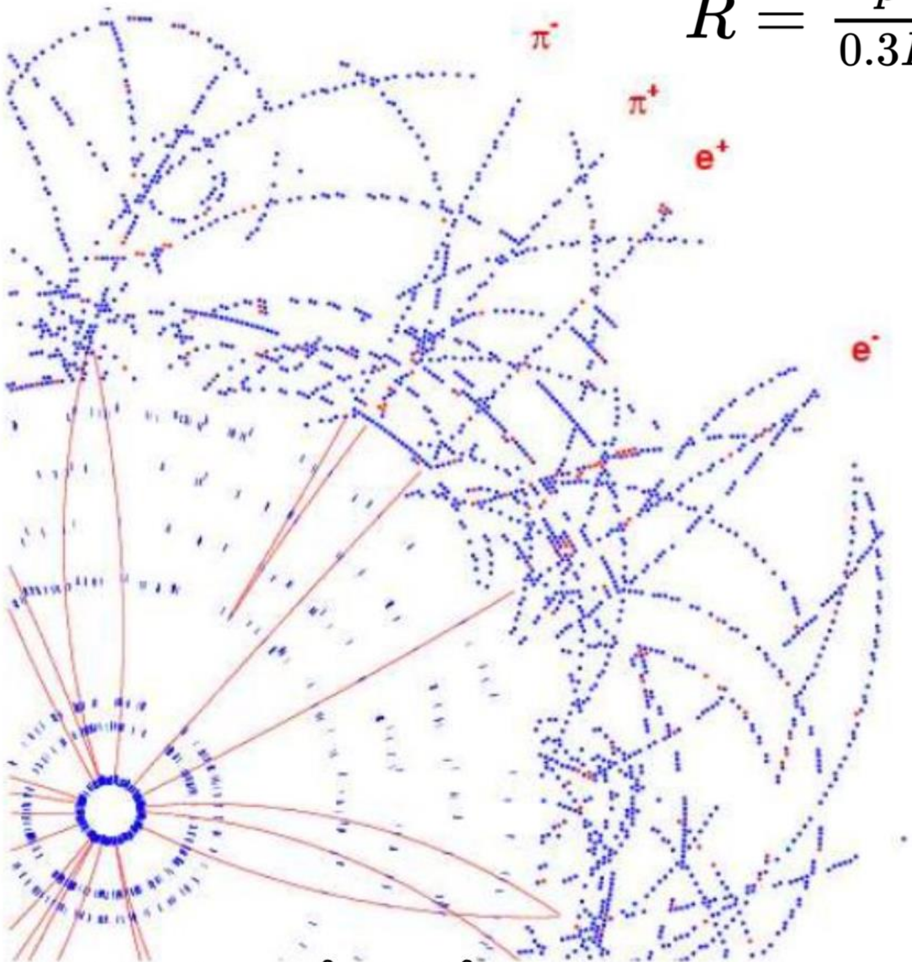






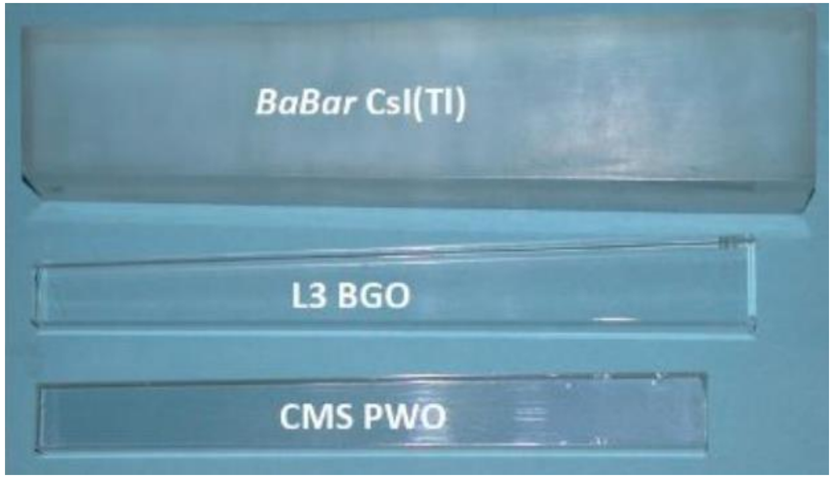


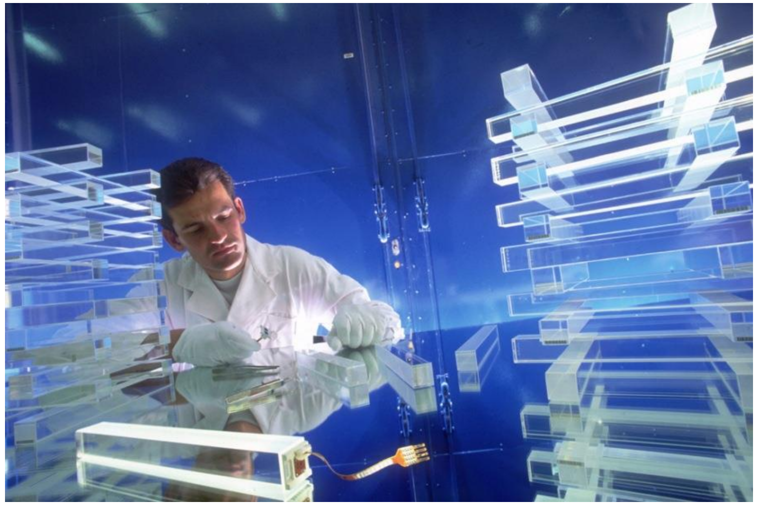


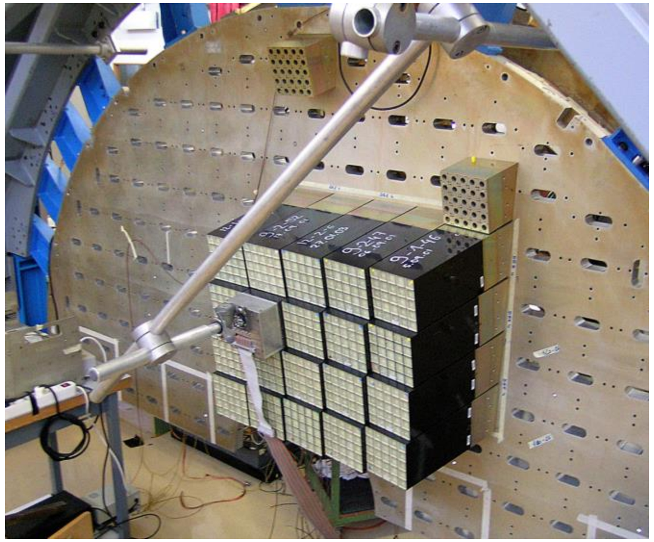


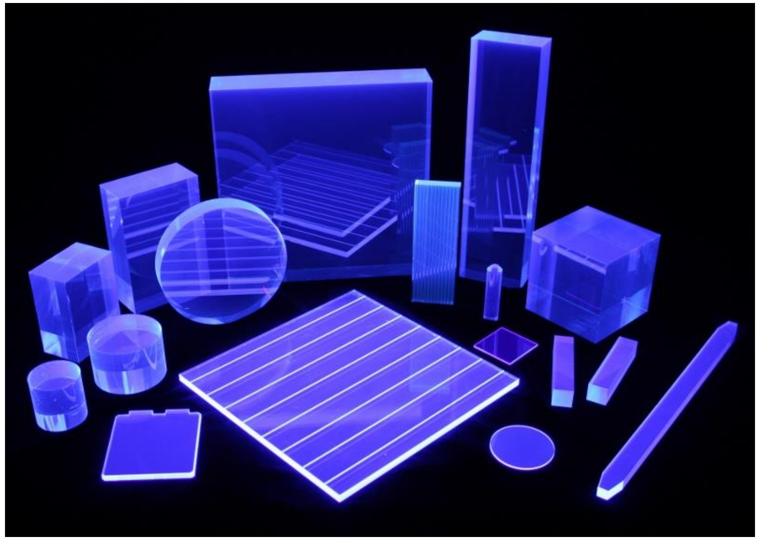
ATLAS traker ($B_d^0 \rightarrow J/\psi K_s^0$ simulated event)

Particle detection: Scintillator, etc

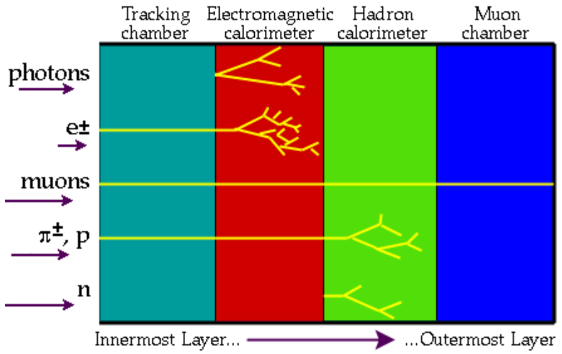


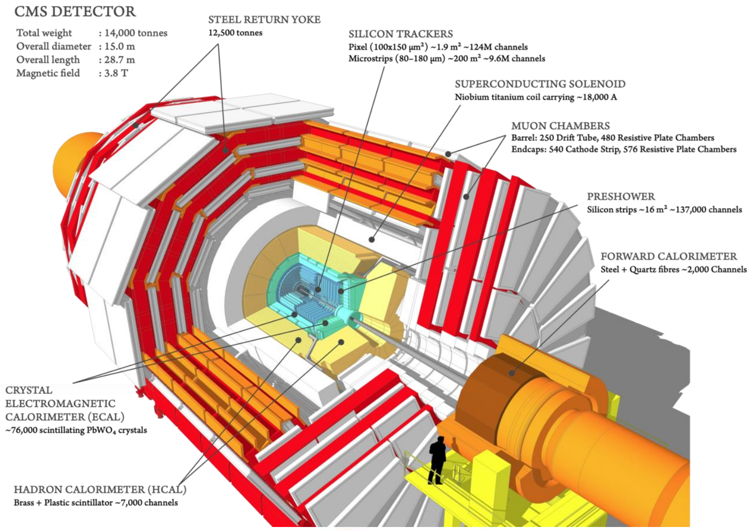


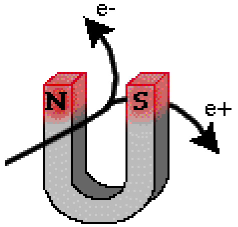




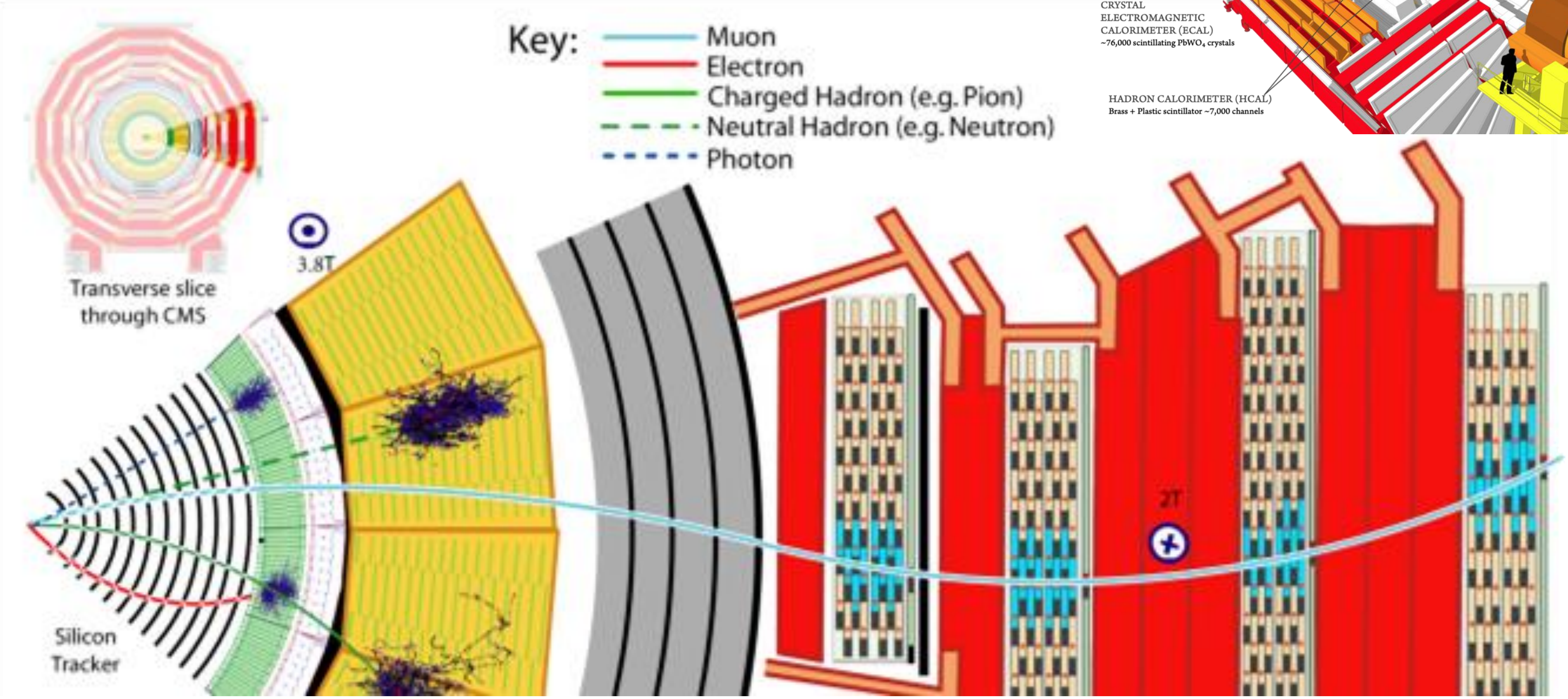
Particle trajectory in CMS detector



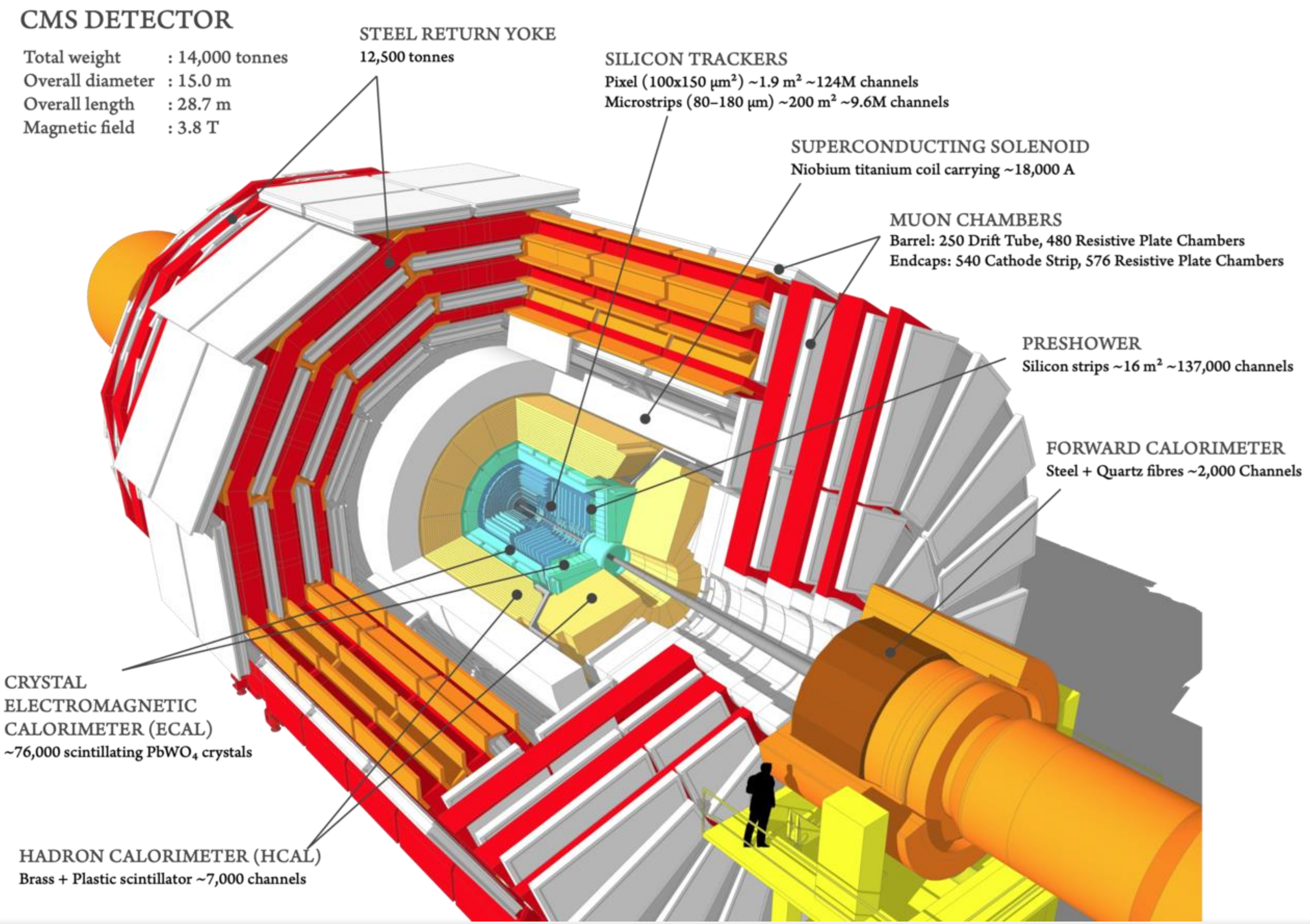




$$R = \frac{p}{0.3B}$$



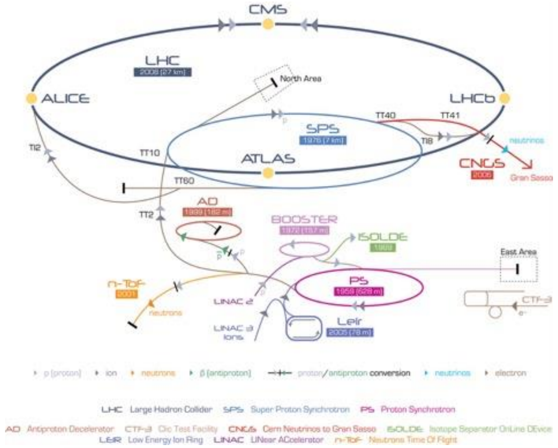
CMS Detector

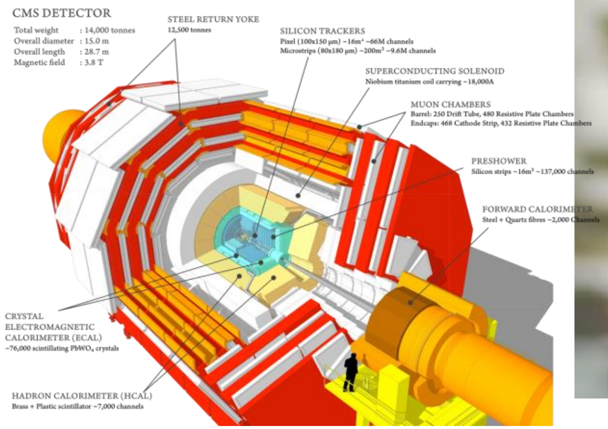


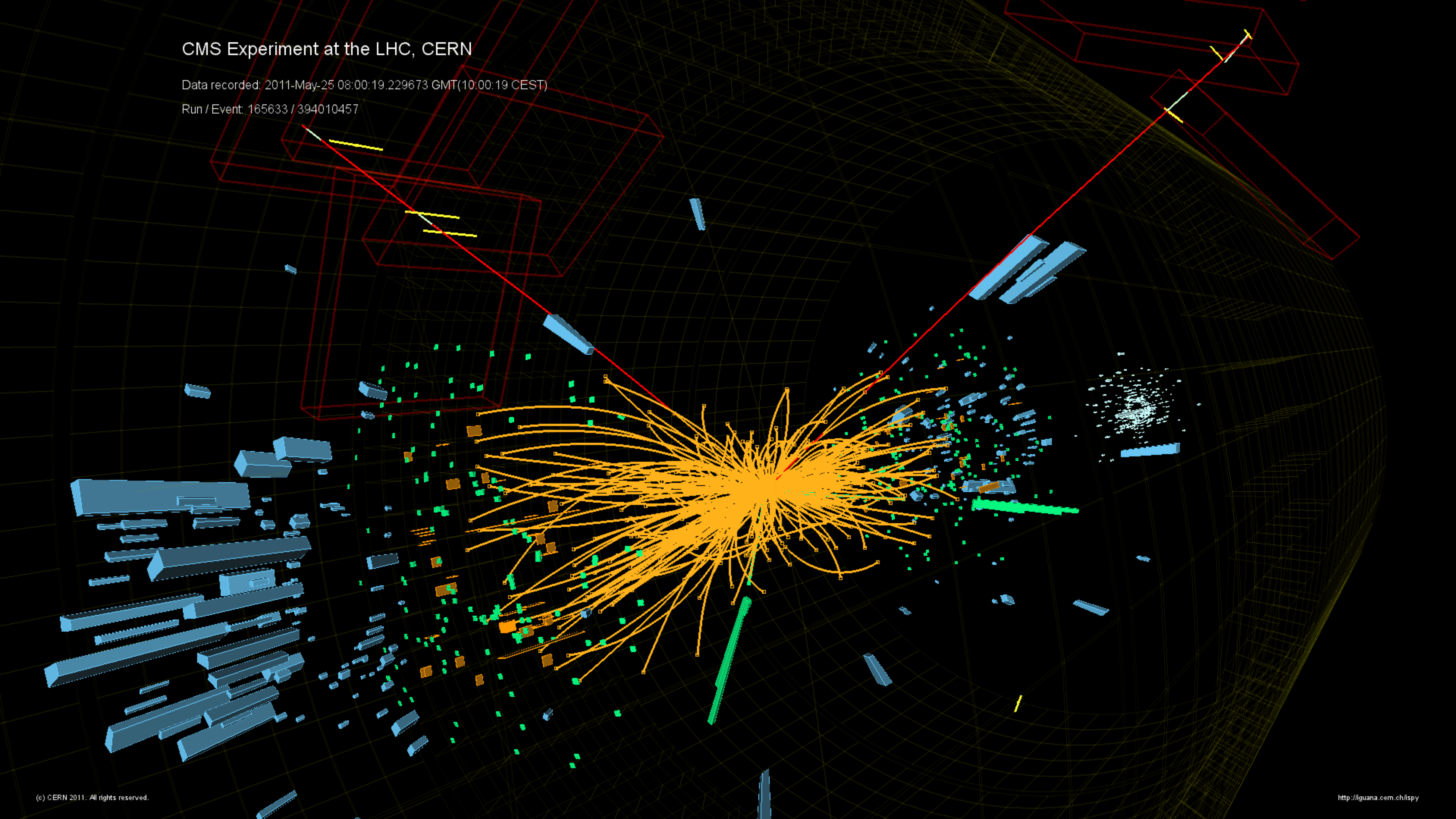
is a 4-D camera

LHC numbers

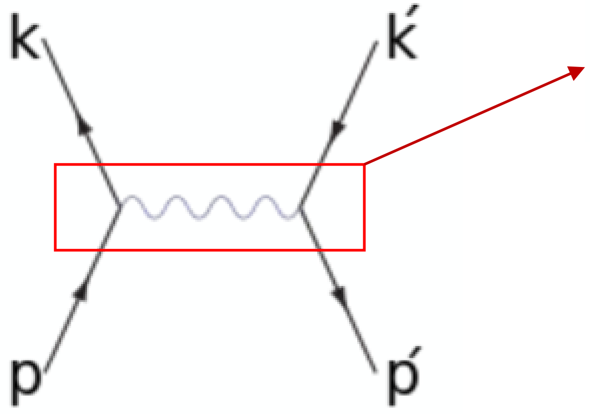
- 11’245 times per second for a proton
- √s = 13TeV
- Collisions can happen every 25ns = 40MHz
- ~40 pp interactions / collision
- Delivered more than 100fb^{-1} at 13TeV





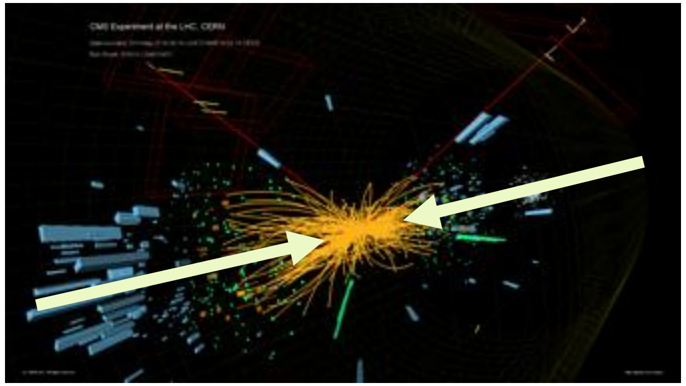

CMS Experiment at the LHC, CERN
Data recorded: 2011-May-25 08:00:19.229673 GMT(10:00:19 CEST)
Run / Event: 165633 / 394010457
(c) CERN 2011. All rights reserved.
http://iguana.cern.ch/ispy

How to find Higgs - oversimplified

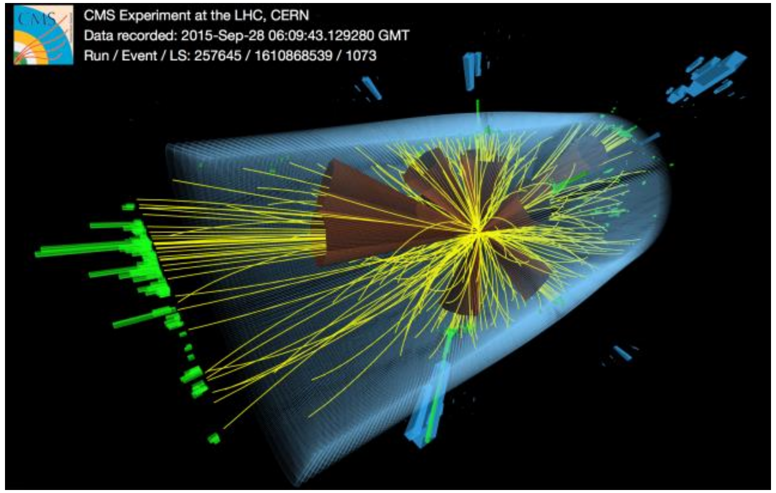


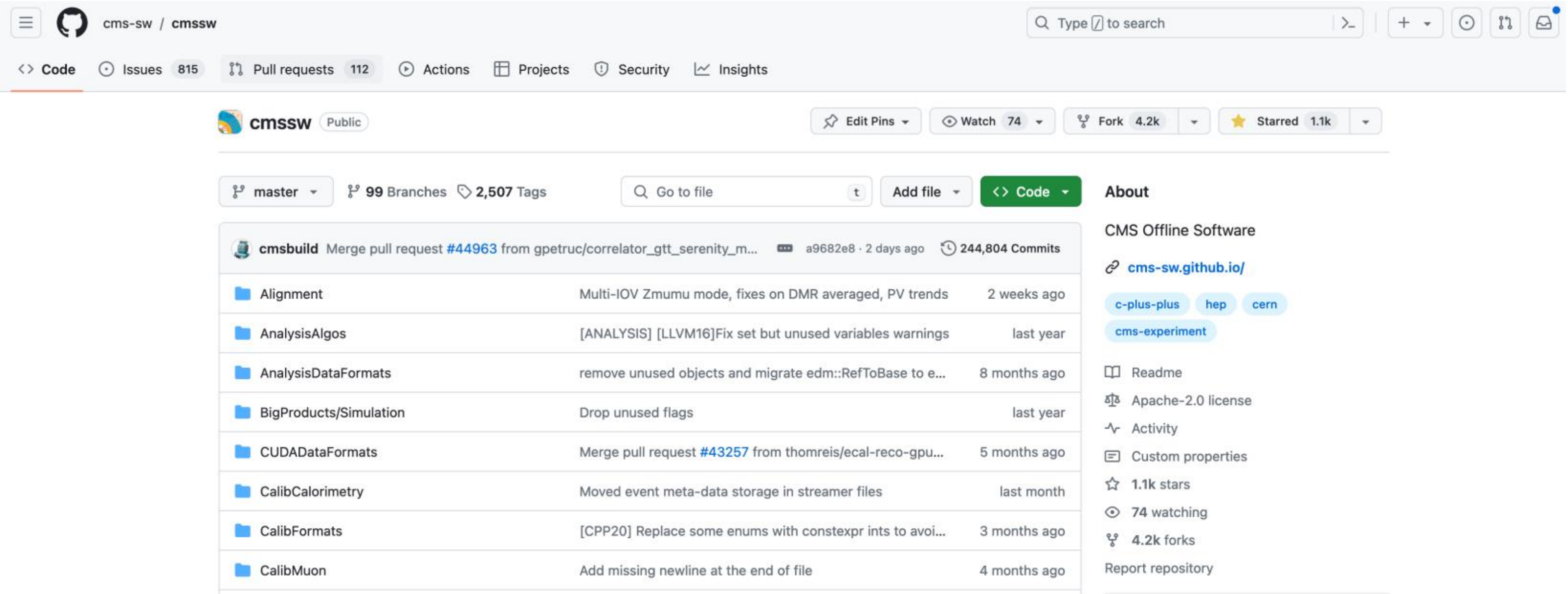
$$m^2c^4 = (E_k + E_p)^2 - (\vec{p}_k + \vec{p}_p)^2$$

1. Collide proton beams at high energy
2. Quarks or gluons inside of the protons collide
3. Heavy particles are produced, m = E/c^2
4. Unstable heavy particles decay immediately
   to other light particles, nice if the particle in the final state is easy to detect
5. Measure final state particle's kinematics, identification,
   guess what happened in this event
6. Collect as many as possible,
   Compare with expectations of theoretical models



Software





Contributors 1,149

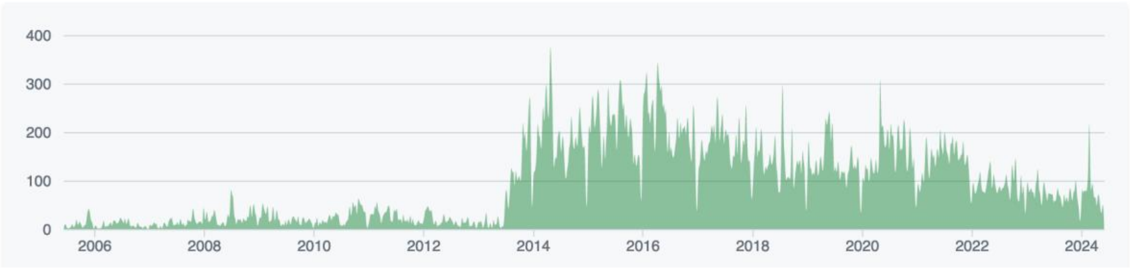
+ 1,135 contributors

Languages

- C++ 60.6%
- Python 28.6%
- Fortran 3.8%
- C 3.3%
- HTML 1.6%
- Shell 0.9%
- Other 1.2%

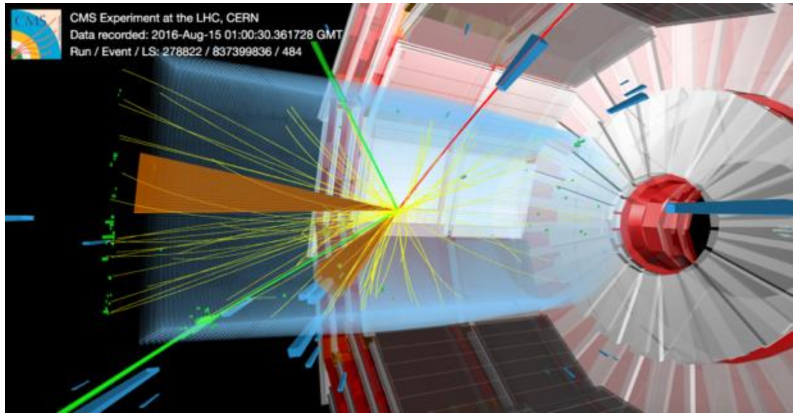
Jun 12, 2005 – Jun 5, 2024

Contributions to master, line counts have been omitted because commit count exceeds 10,000.

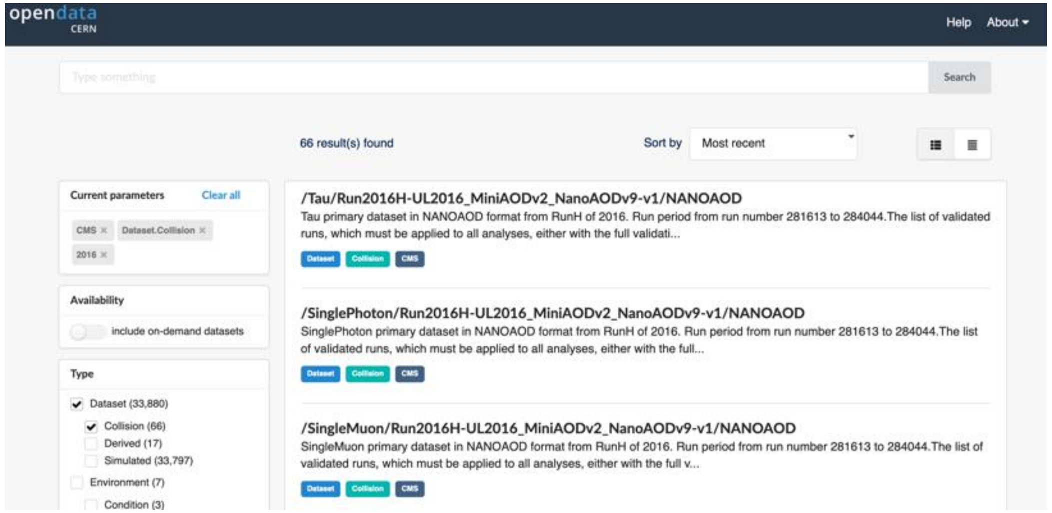


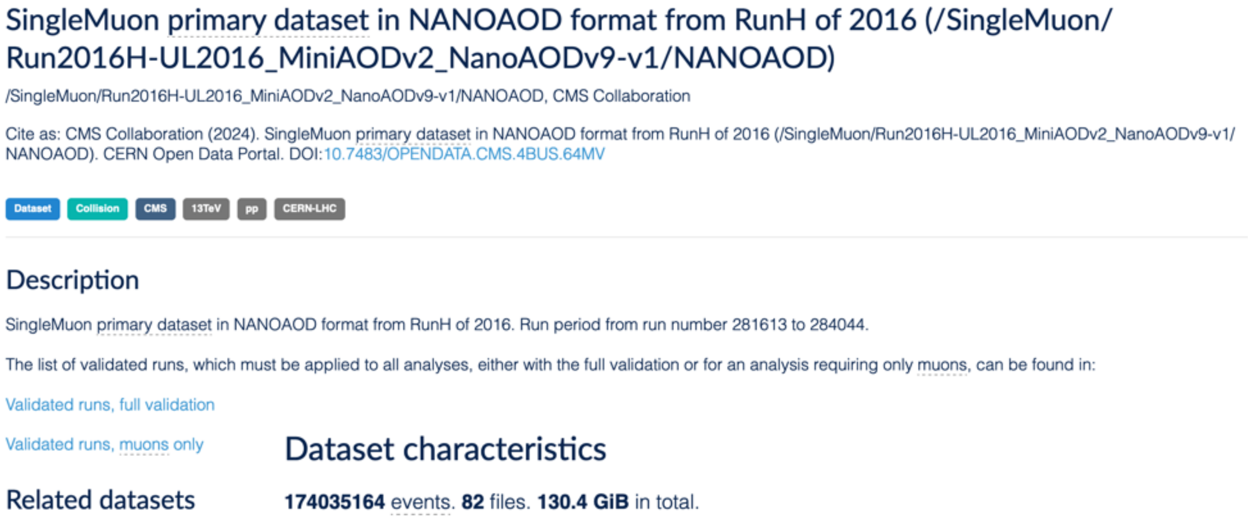
CMS Open data

https://cms.cern/news/cms-releases-13-tev-proton-collision-data-2016



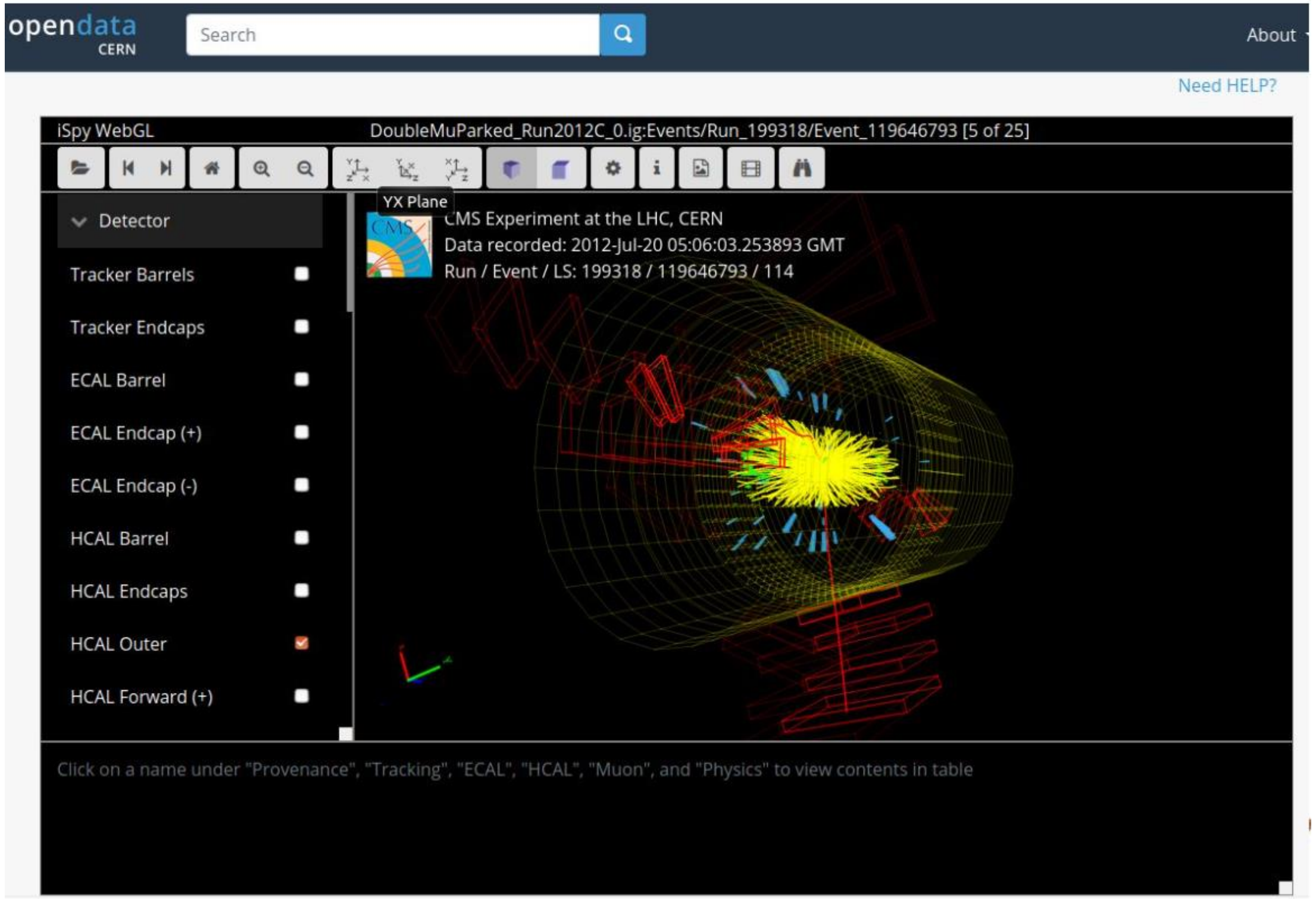
The CMS experiment at CERN is proud to announce the first release of 13 TeV proton-proton collision data collected in 2016. Over 70 TB of 13 TeV collision data and 830 TB of corresponding simulations are now accessible to the global scientific community and enthusiasts alike through the CERN Open Data Portal.





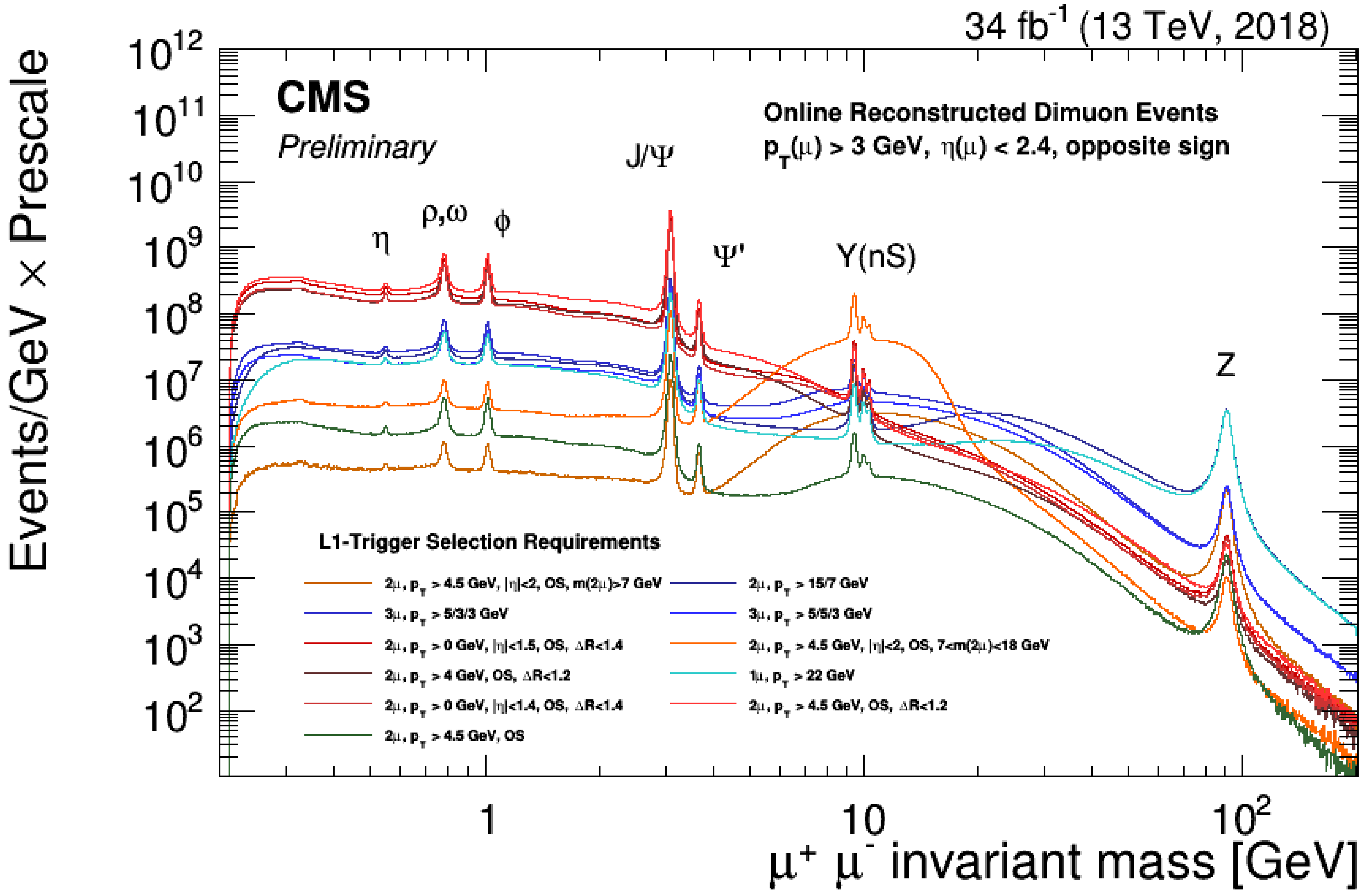
Exercise?

http://opendata.cern.ch/visualise/events/CMS



What you see in the real data

경희대학교

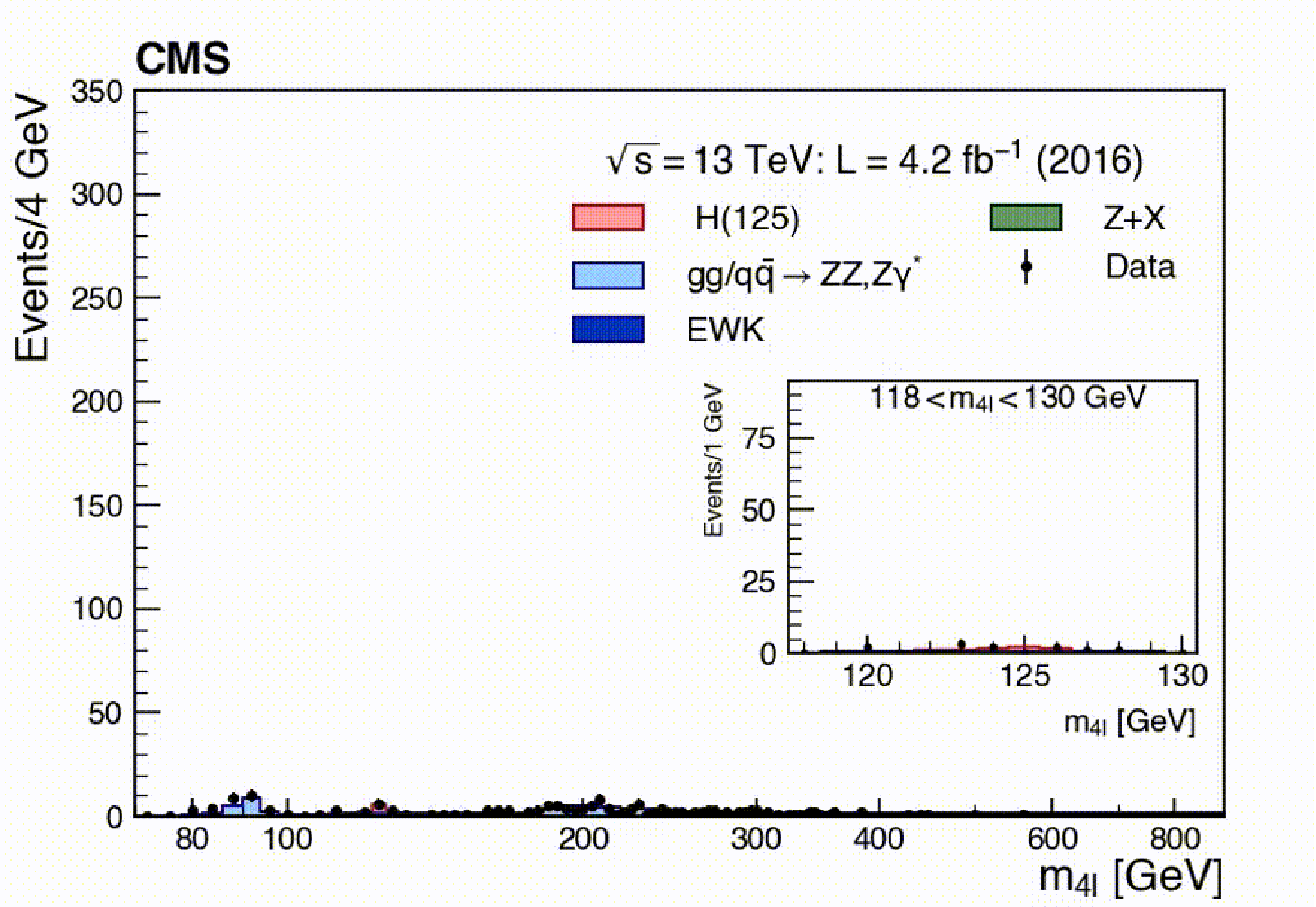


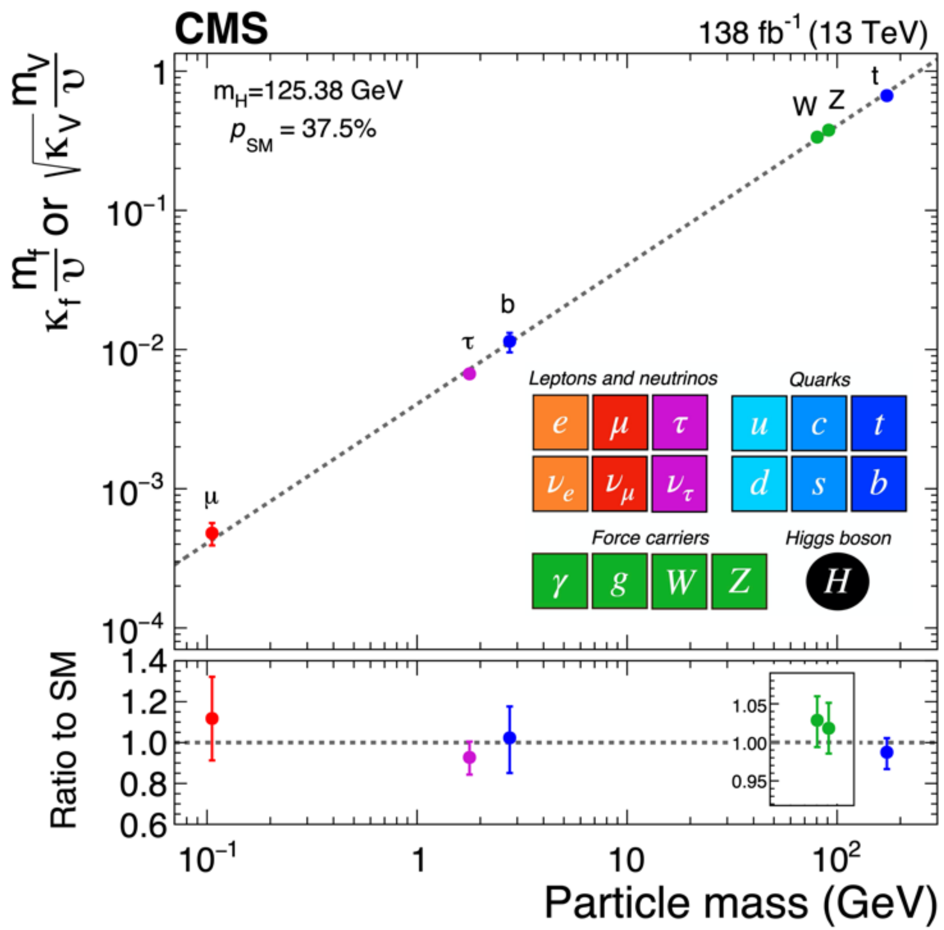
Physics of this figure:
E=mc^2

$$m^2c^4 = q_\mu q^\mu$$

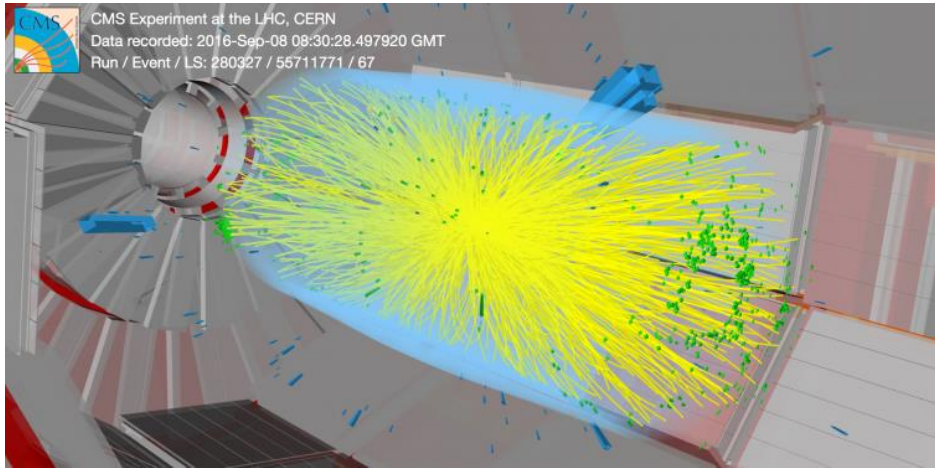
$$= (E_k + E_p)^2 - (\vec{p}_k + \vec{p}_p)^2$$

The Higgs at LHC, at 13TeV





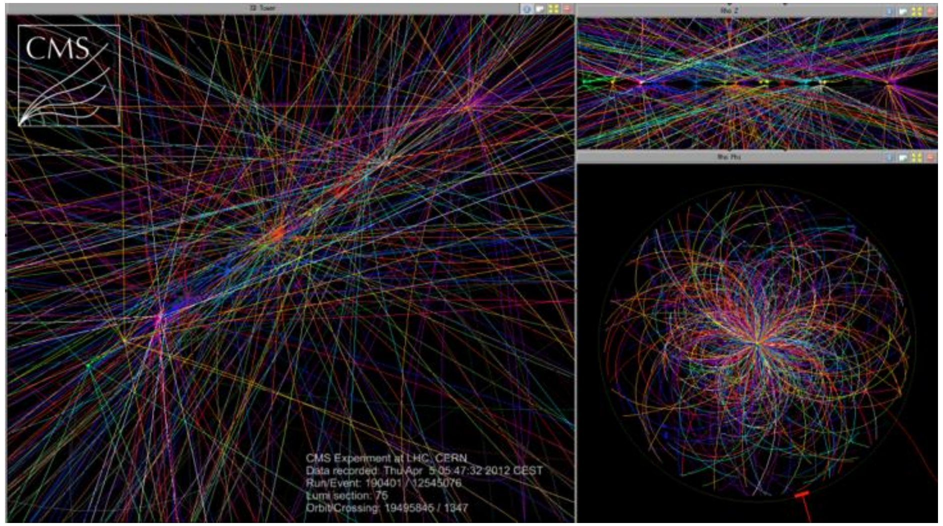
Quite complicated, actually

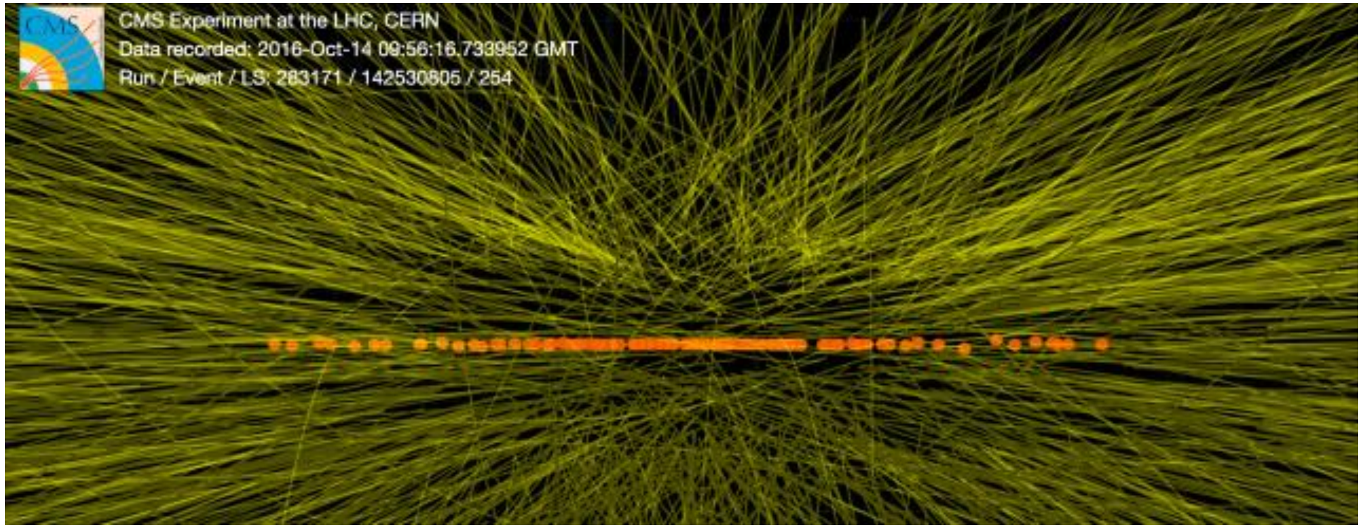


Proton-proton beam crossing in every 25 ns (40MHz)

But we are eager to increase the rate
– allow multiple pp collisions
Most of them are well-known, inelastic scattering

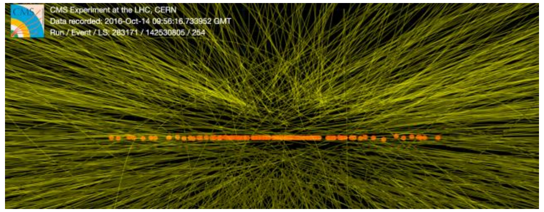
Only possible with high-granularity, radiation hard detectors with high-performing software algorithm

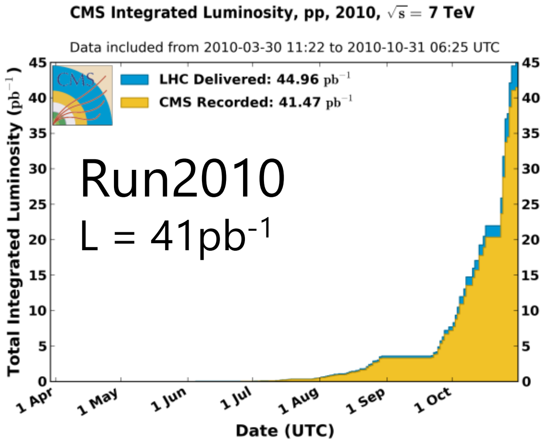


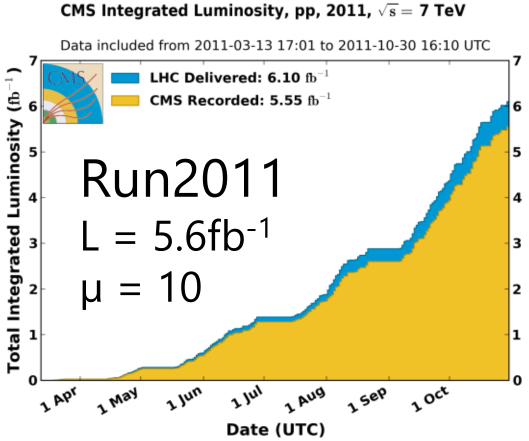


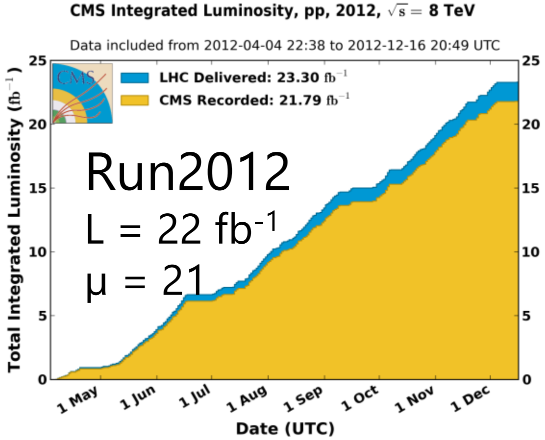
Data taking during Run1&2

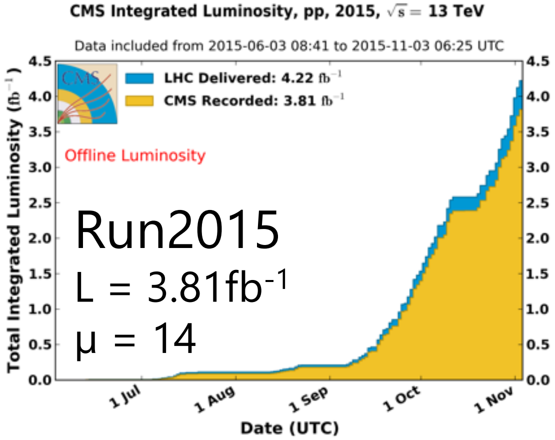
Very high data taking efficiency for > 10 years in extreme environment

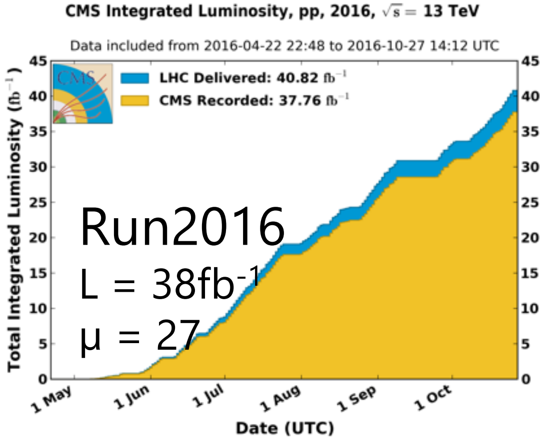


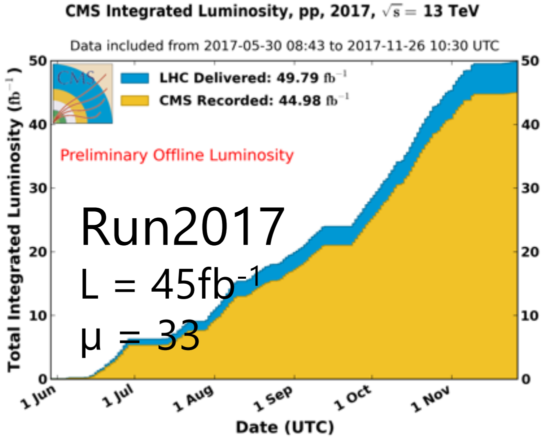


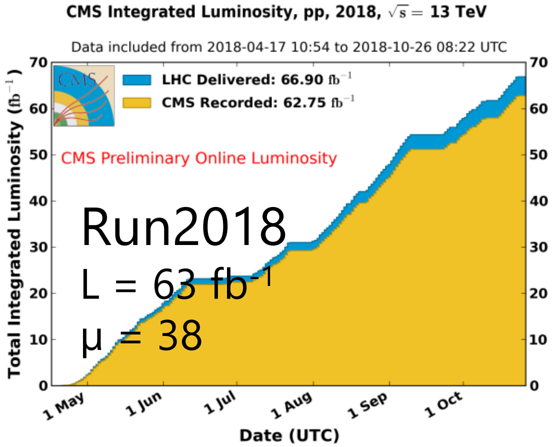




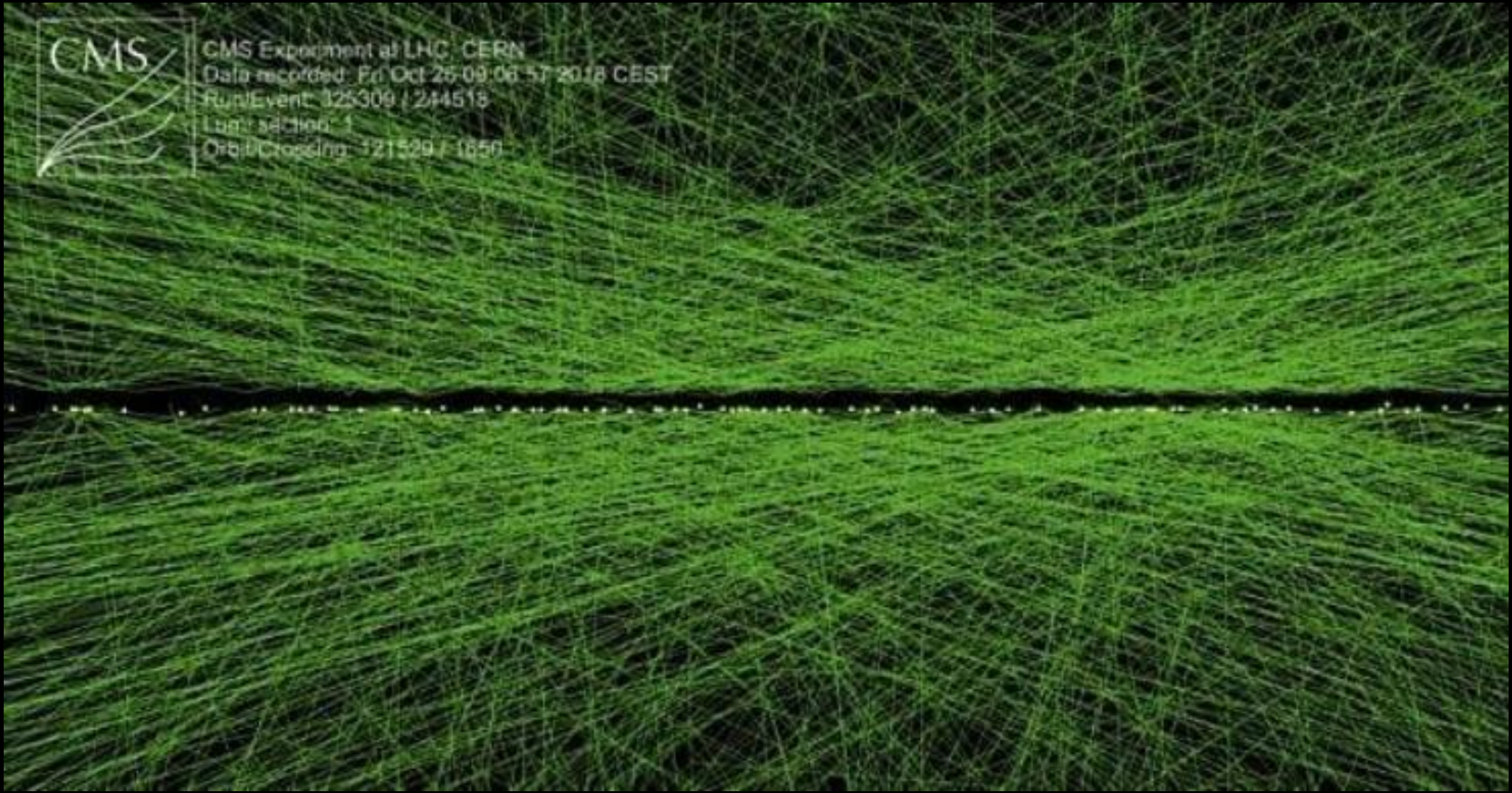






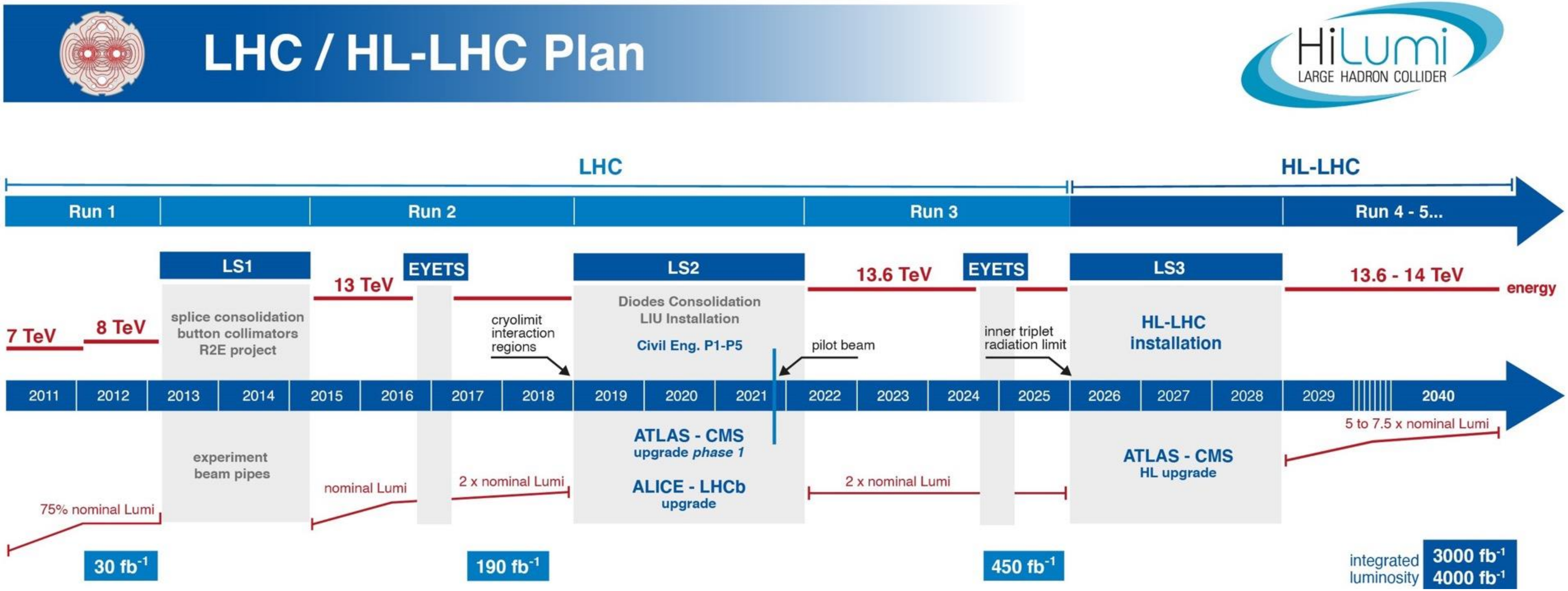


High-Pileup test in 2018



An overlay of 136 collisions

LHC schedule



More data to come: LHC Long term schedule

Last update: April 2023

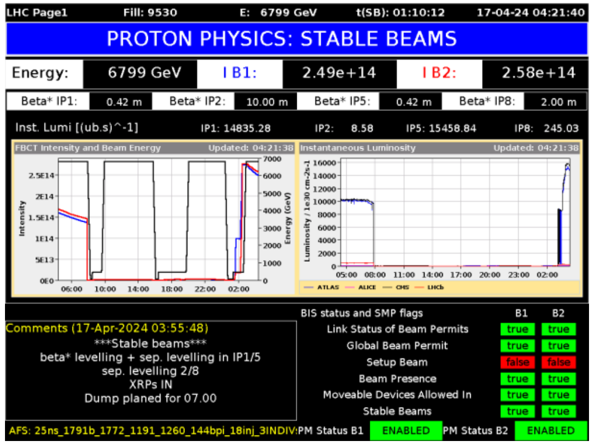
https://lhc-commissioning.web.cern.ch/schedule/LHC-long-term.htm

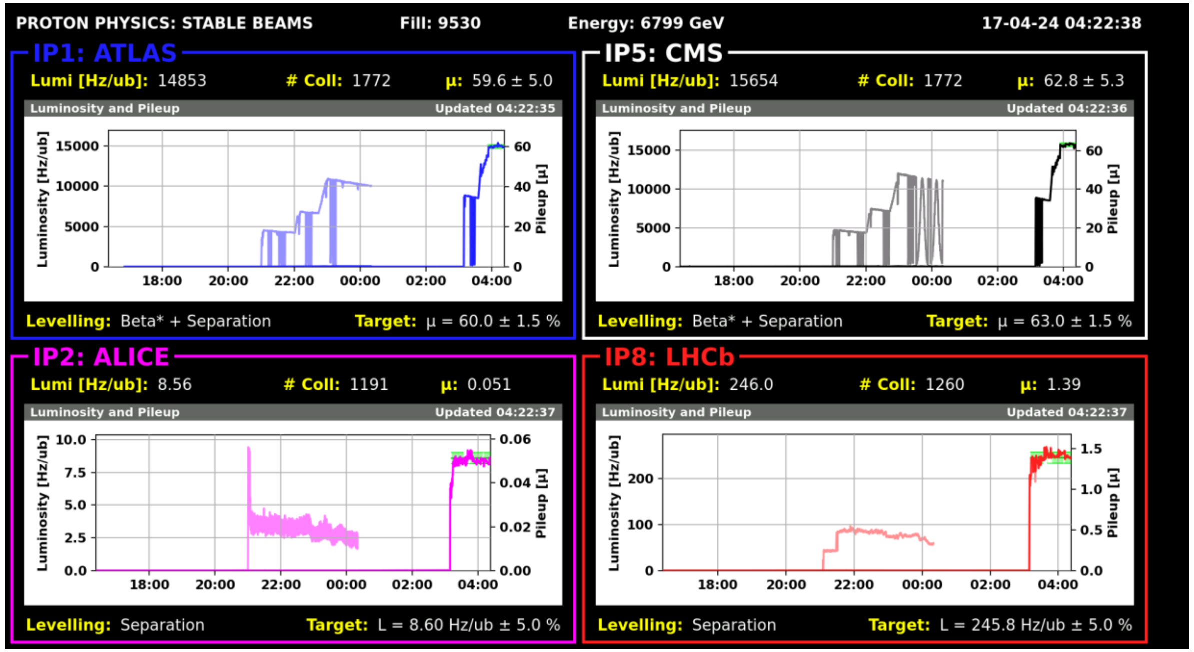


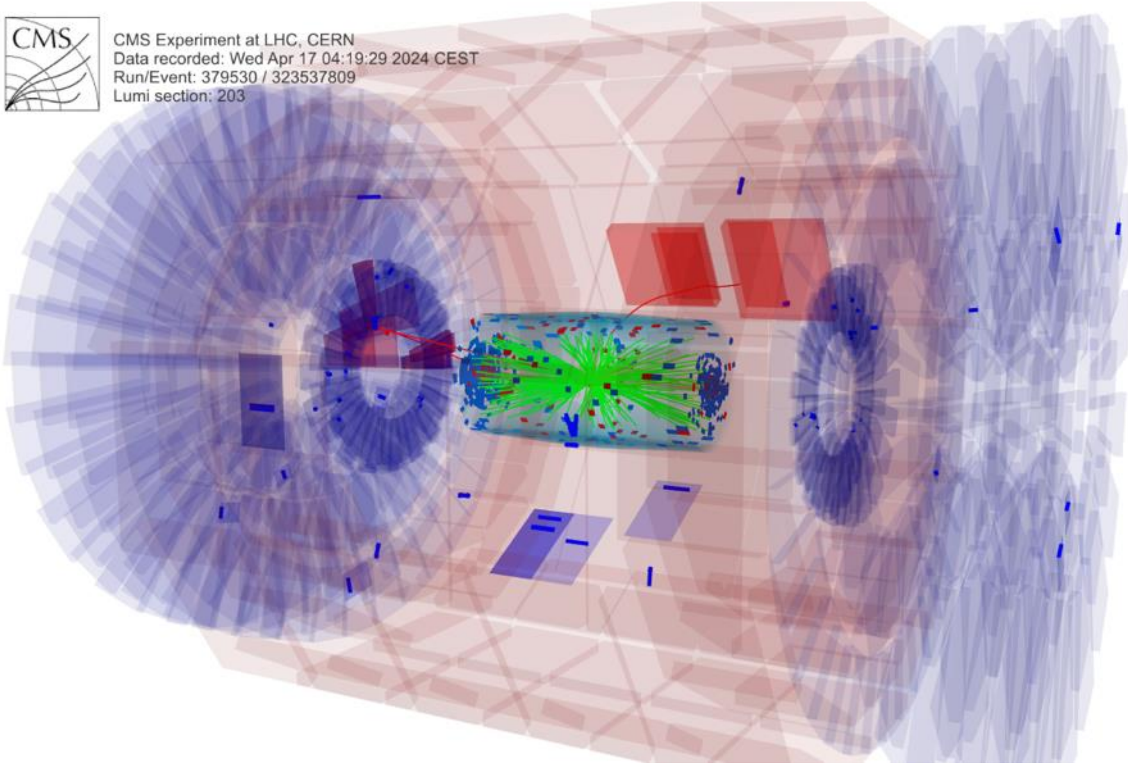

ME&RE+1/2/05


RE+4/2/08

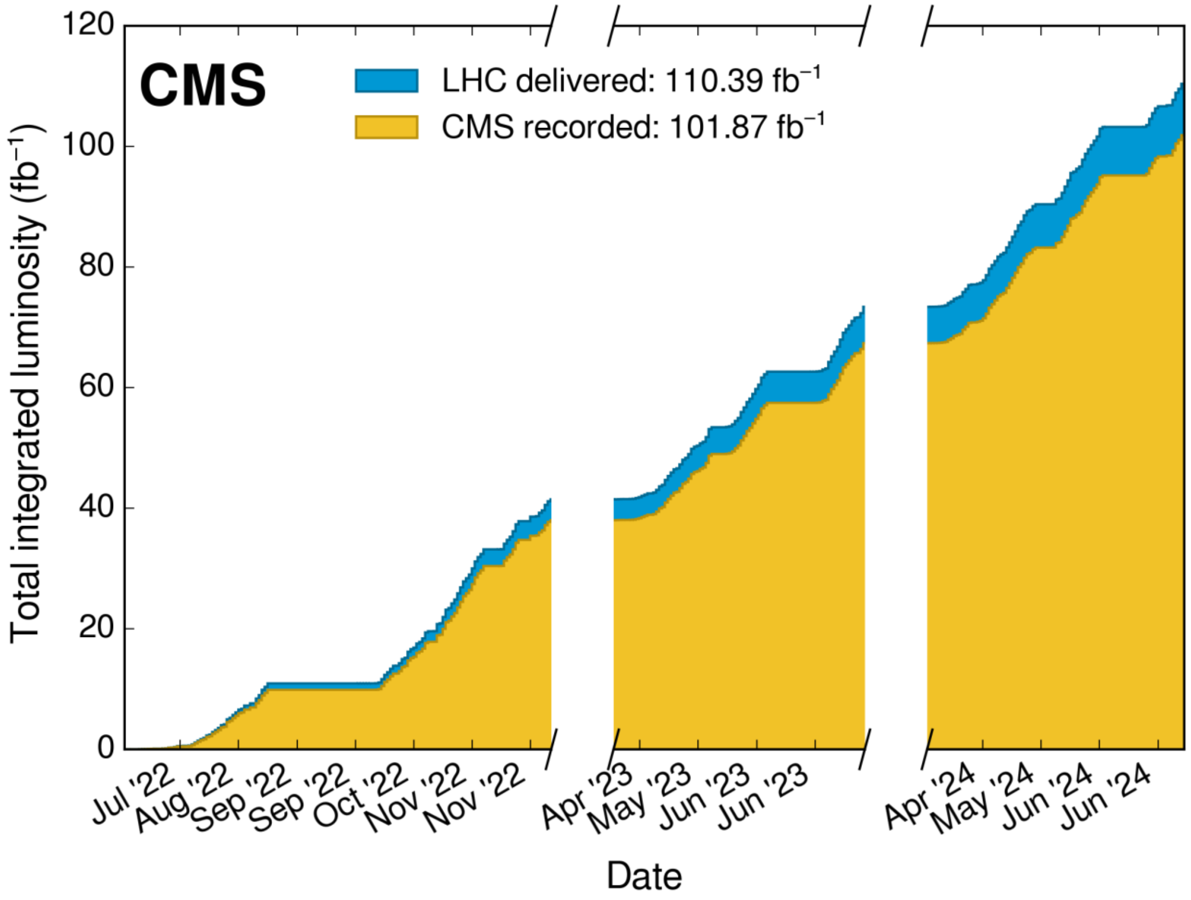
Collisions for Physics

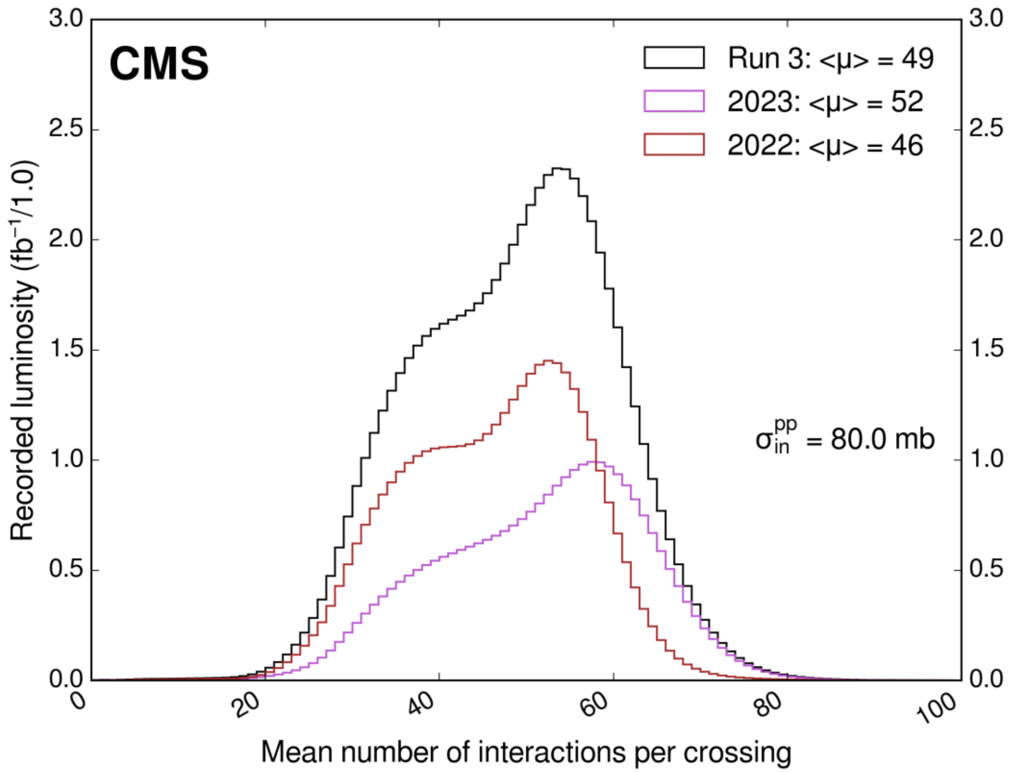




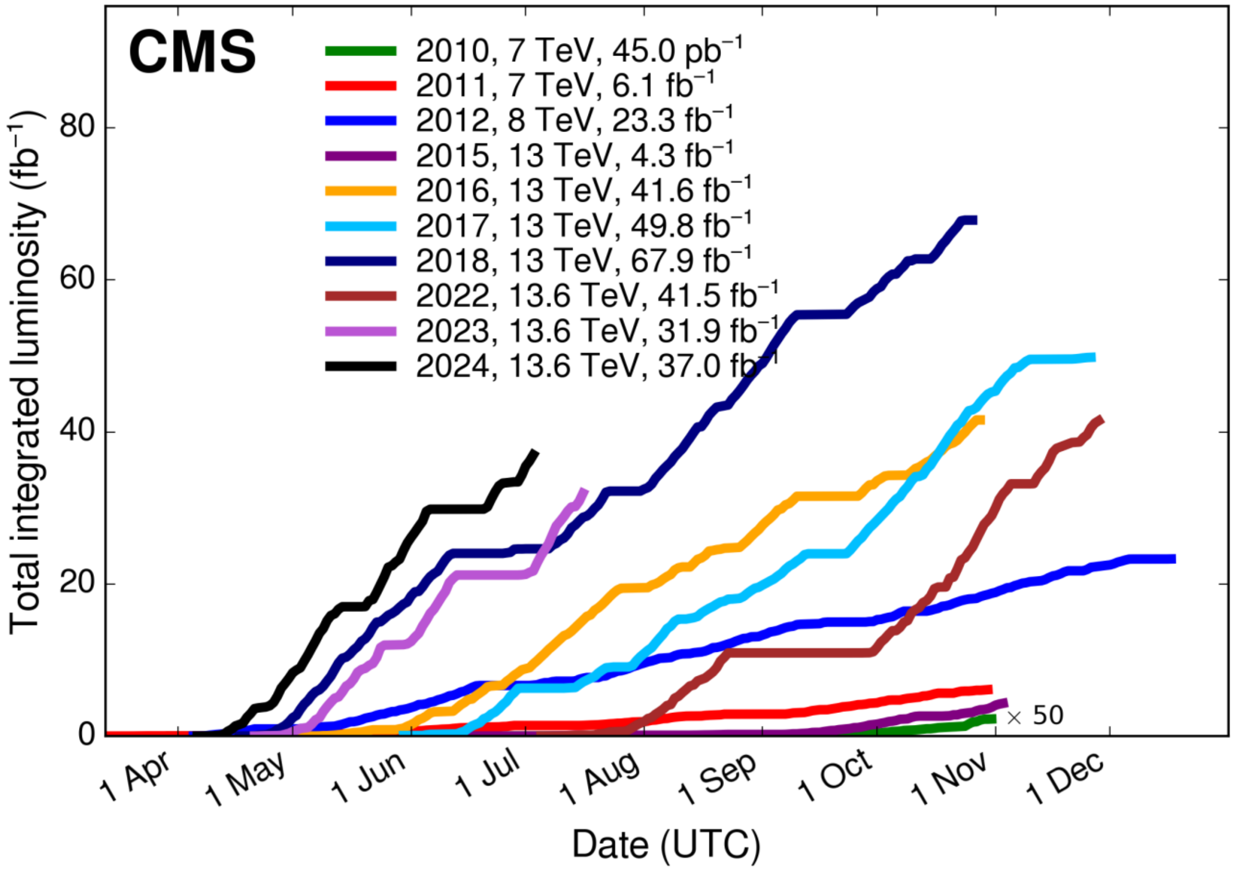


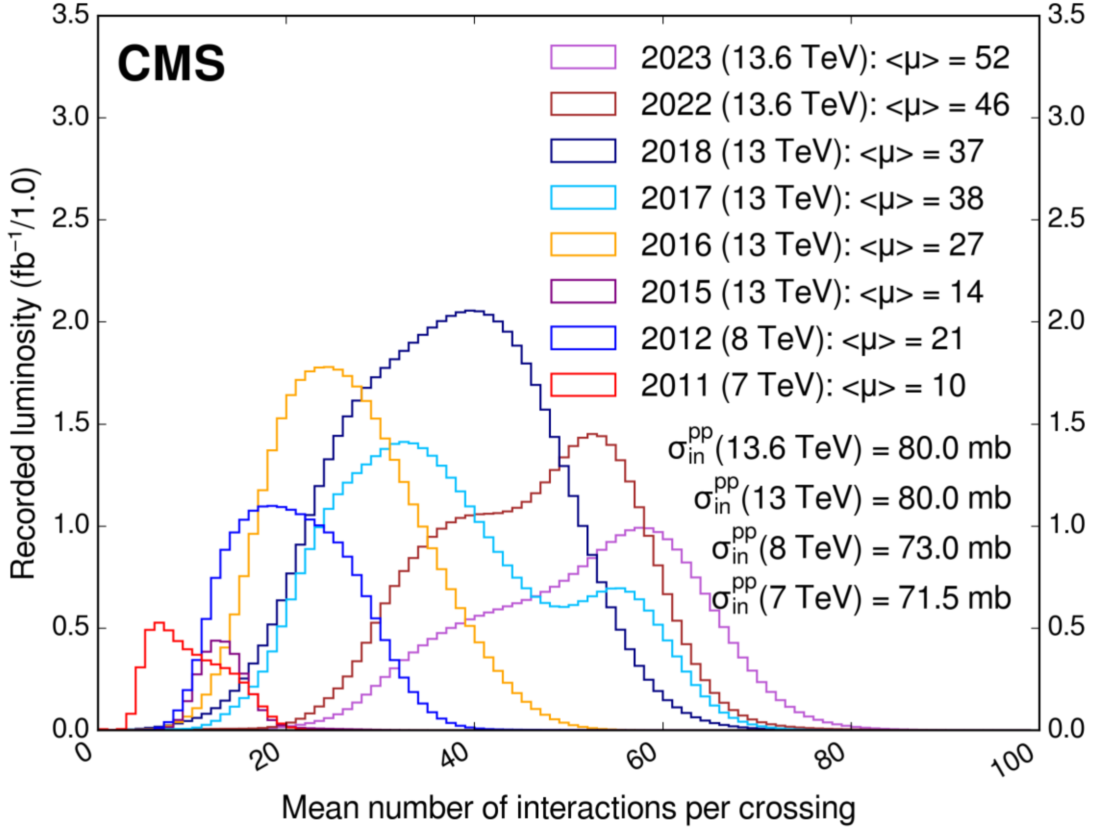
Run3 data taking



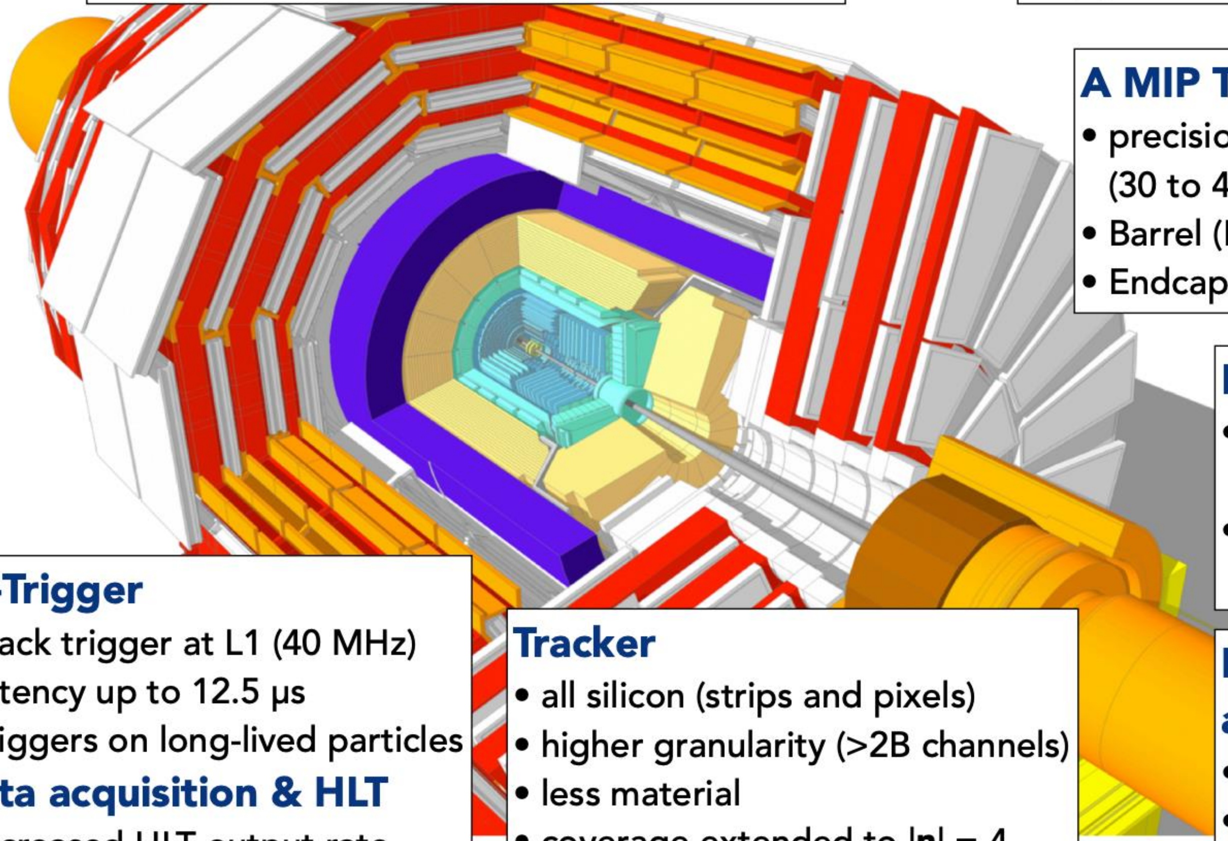


~15 years of data taking





Upgrade!



Muon Detectors
- DTs & CSCs: new FE/BE readout electronics
- RPCs: new electronics
- new GEM/iRPC chambers
- extended muon coverage to $|\eta| = 3$

Barrel Calorimeters
- crystal granularity readout at 40 MHz
- precise timing for $e/\gamma > 30$ GeV
- ECAL operation at low temperature (10°)
- upgraded laser monitoring system

A MIP Timing Detector (MTD)
- precision timing on single charged tracks (30 to 40 ps resolution)
- Barrel (BTL): LYSO crystals + SiPMs
- Endcaps (ETL): Low Gain Avalanche Diodes

Endcap Calorimeter (HGCAL)
- silicon pixels (EM) and scintillators + SiPMs (HAD)
- 3D shower reconstruction with precise timing

L1-Trigger
- track trigger at L1 (40 MHz)
- latency up to 12.5 μs
- triggers on long-lived particles

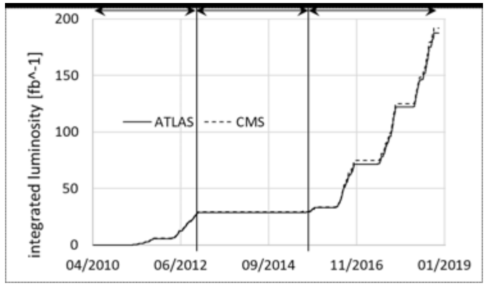
Data acquisition & HLT
- increased HLT output rate

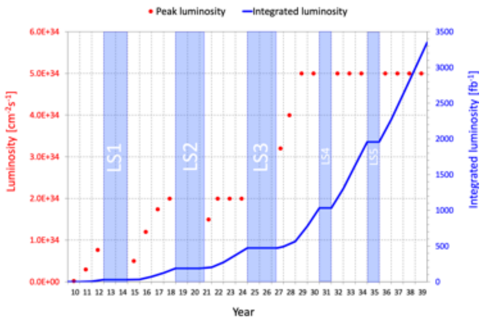
Tracker
- all silicon (strips and pixels)
- higher granularity (>2B channels)
- less material
- coverage extended to $|\eta| = 4$

Beam Radiation Instrumentation and Luminosity (BRIL)
- BCM/PLT refit
- new T2 tracker

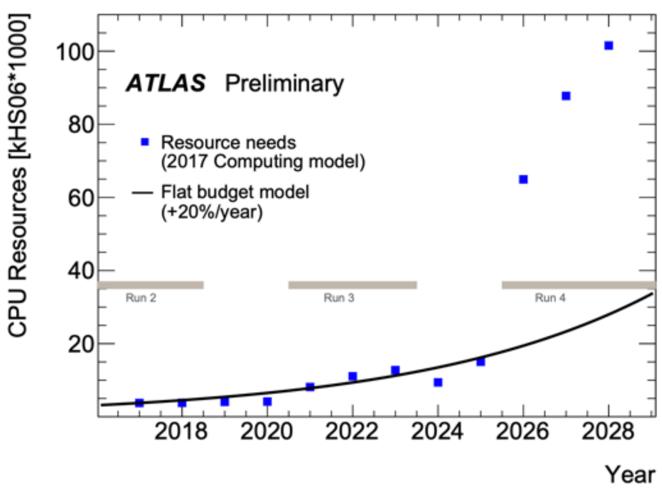
Big data is arriving

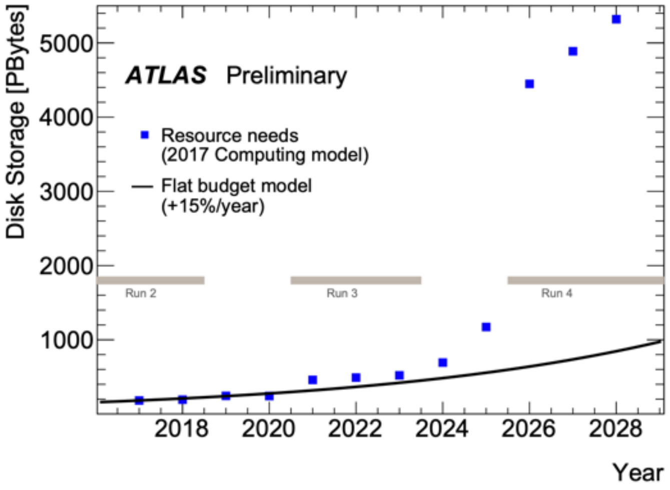
LHC doubles luminosity: data rate doubles
 ~ exponential growth in the early stage



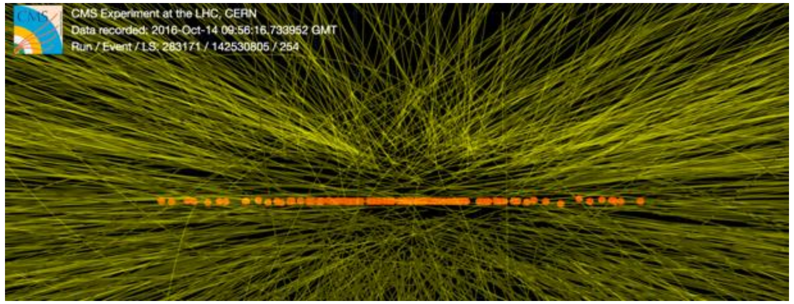


Computing resource needs will explode in the HL-LHC era

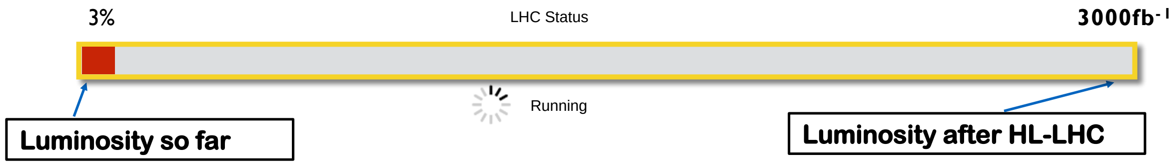




Even worse: data complexity
 - more particles in an event, combinatorial



… assuming the same technology trends in CPU & storage

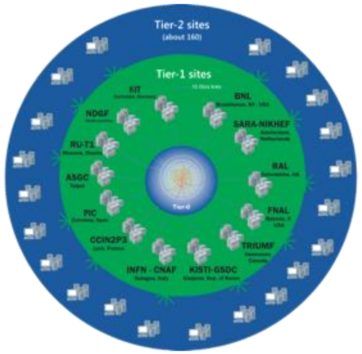


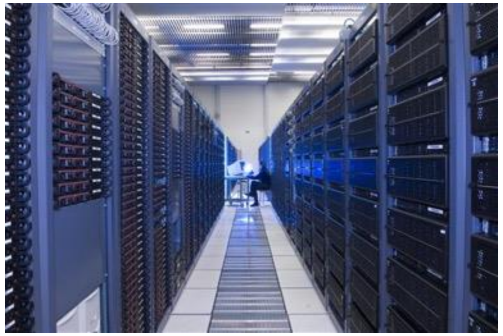
But in computing-wise, typical HEP analysis
are easy to speed up by increasing num. CPUs

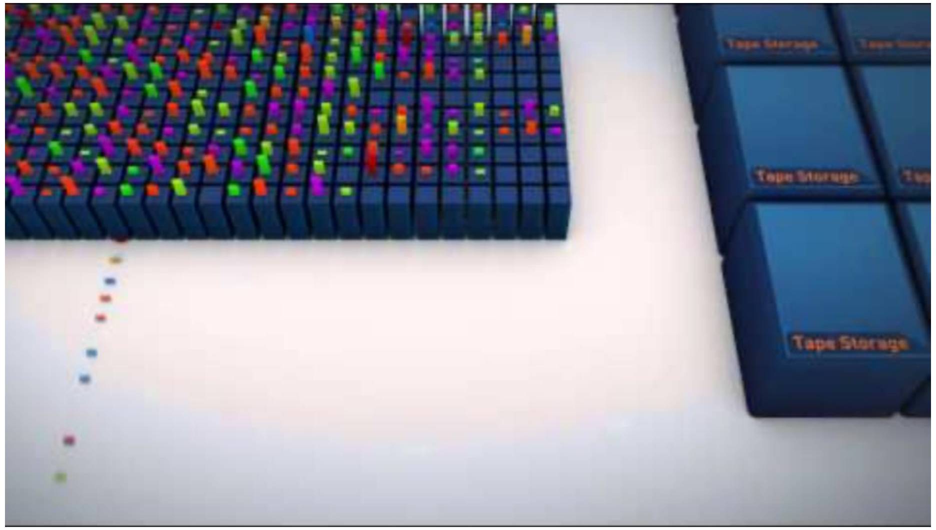
Learn from the recent
developments in the industry

Computing operations, R&D studies

The Worldwide LHC Computing Grid (WLCG)

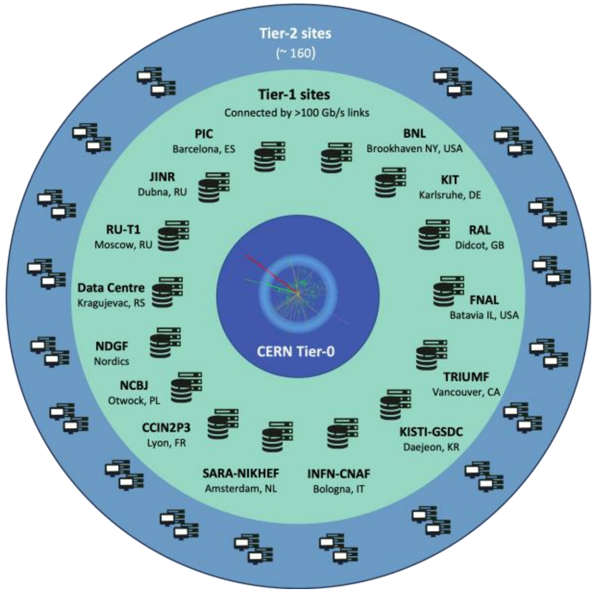


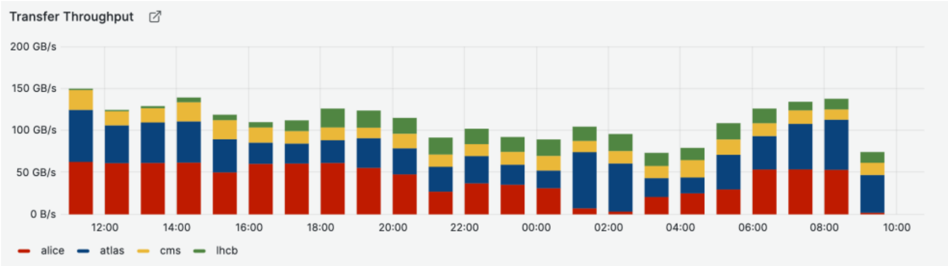


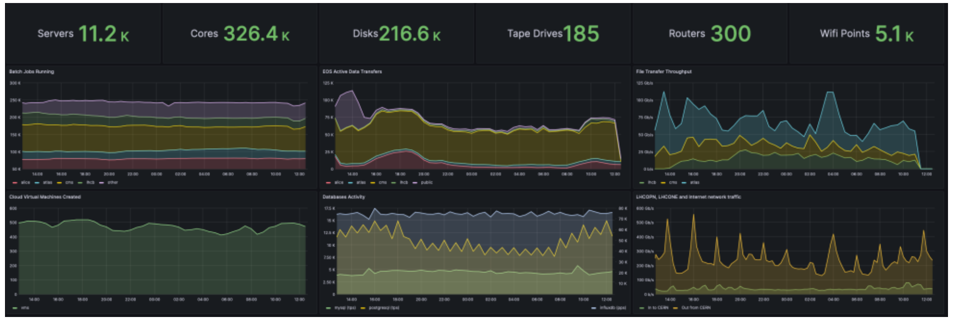


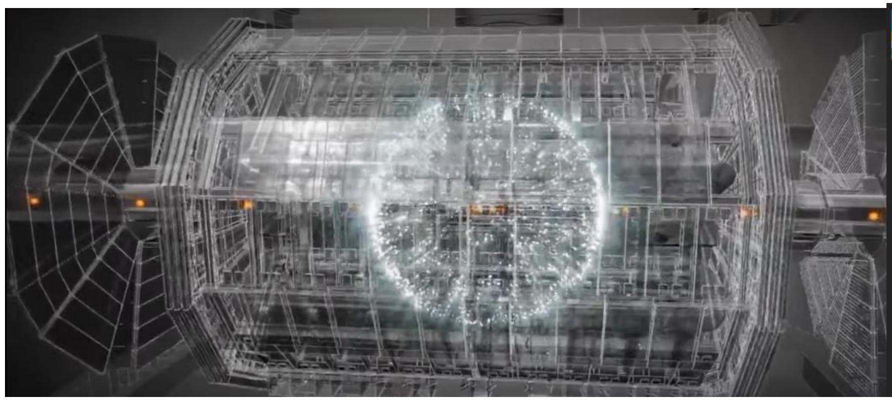
1M processing cores, 170 data centers in 42 countries
More than 1000 PB of CERN data stored world-wide

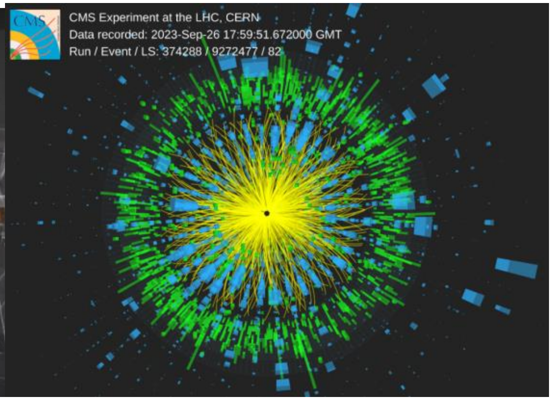
Computing, AI for data analysis



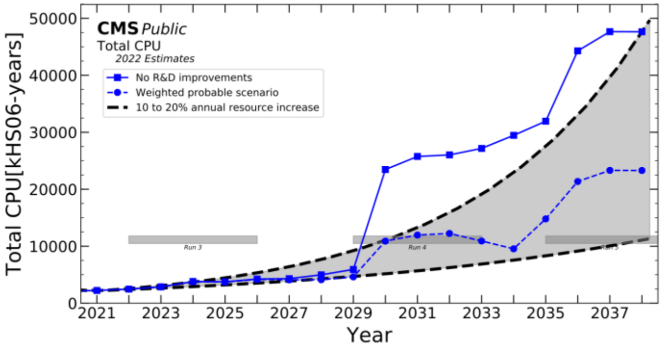


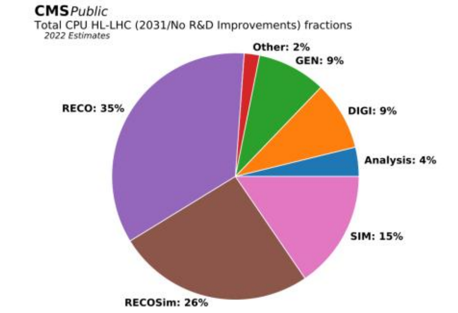


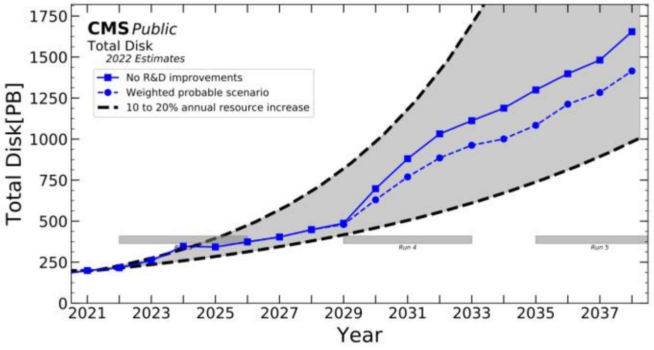


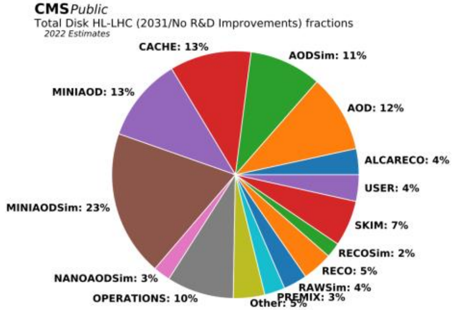


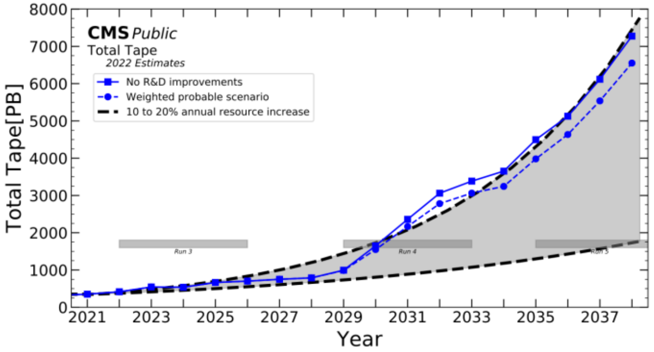
Computing R&D studies

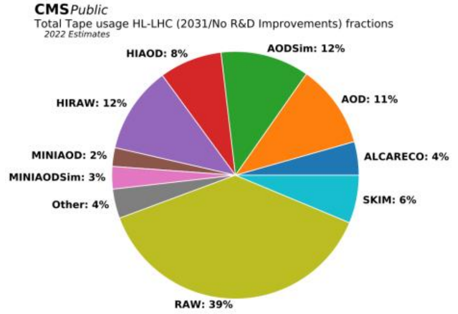






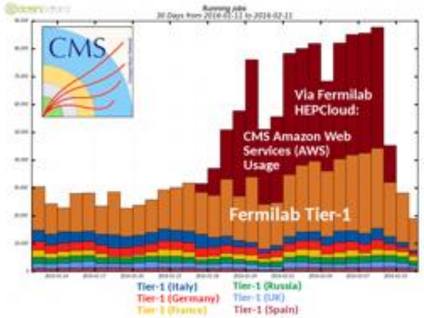


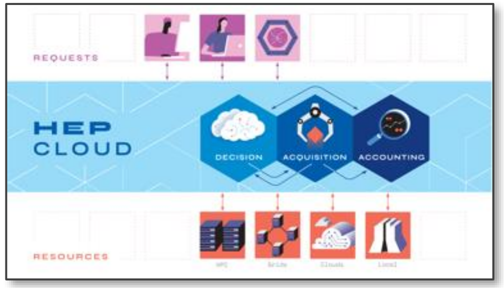




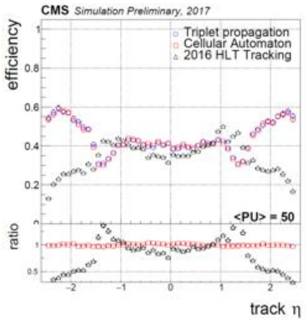
Data processing on cloud, exa-scale computing

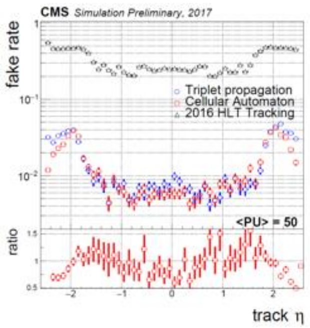
Title	DOE Office of Science Program	NERSC Computational Hours Awarded	Global File System Space
Enabling HEP Intensity Frontier Science through HEPCloud	HEP - High Energy Physics	70,400,000	20





CMS Patatrack – tracking with GPU, challenges with ML





The CMS Collaboration

CMS Collaboration

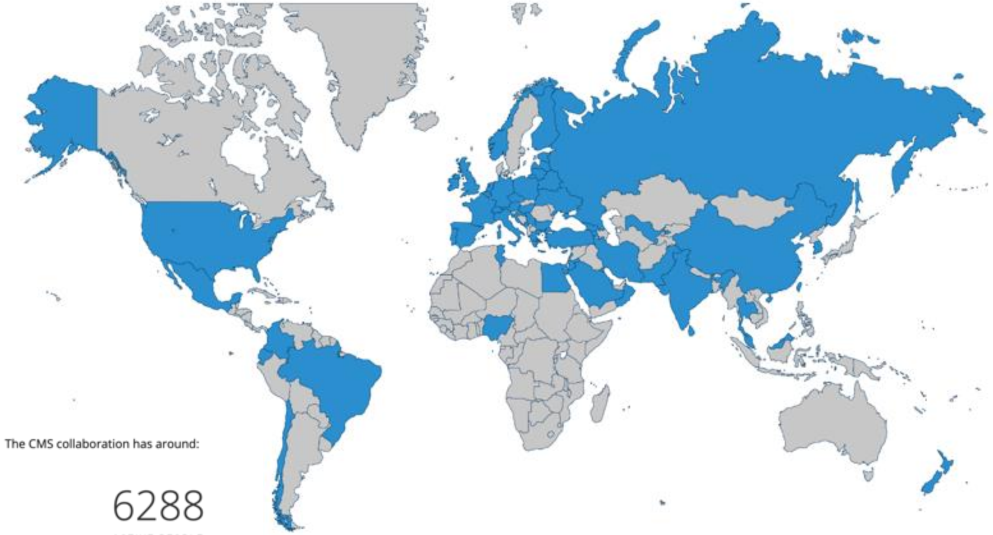
3394 PHYSICISTS (1228 STUDENTS)

1102 ENGINEERS

282 TECHNICIANS

247 INSTITUTES

57 COUNTRIES & REGIONS



The CMS collaboration has around:

6288 ACTIVE PEOPLE (PHYSICISTS, ENGINEERS, TECHNICAL, ADMINISTRATIVE, STUDENTS, ETC.)

Of these members there are about:

2166 PHD PHYSICISTS (1769 MEN, 397 WOMEN)

1228 PHYSICS DOCTORAL STUDENTS (919 MEN, 309 WOMEN)

1102 ENGINEERS (951 MEN, 151 WOMEN)

1388 UNDERGRADUATES (995 MEN, 393 WOMEN)

A typical CMS physics paper will be signed by the PhD physicists and a significant fraction of the doctoral students meaning it will typically have about 2100 signatures.

CERN-Korea collaboration

KCMS: 11개 대학 및 기관, 120여명

강릉원주대, 경북대, 경희대, 고려대,
서울대, 서울시립대, 성균관대, 세종대,
전남대, 연세대, <u>한양대</u>

KISTI: Associate member

https://cms-kr.org

Physics

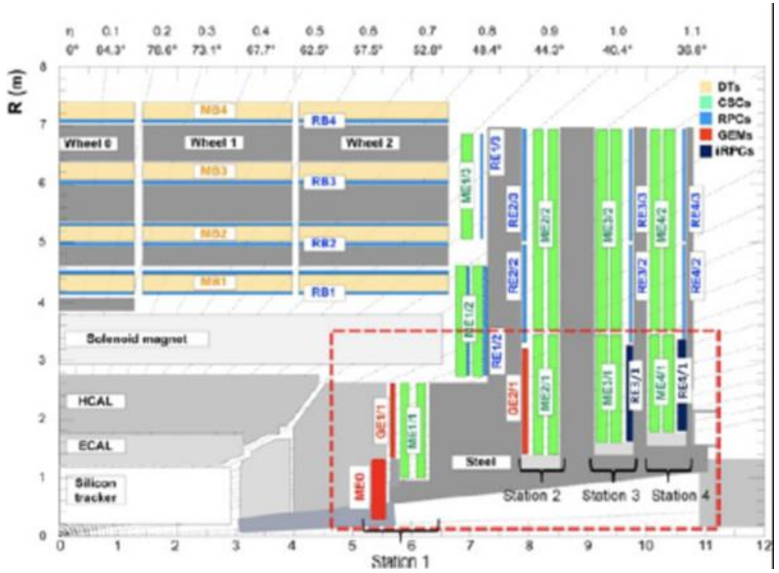
- Top-Higgs: J. Goh, H. Kim
- SM & POG: H. Yoo
- BSM: J. Yoo, C. Moon
- Heavy Ion: D. Moon, Y. Kim
- Machine Learning: J. Goh, J. Lee

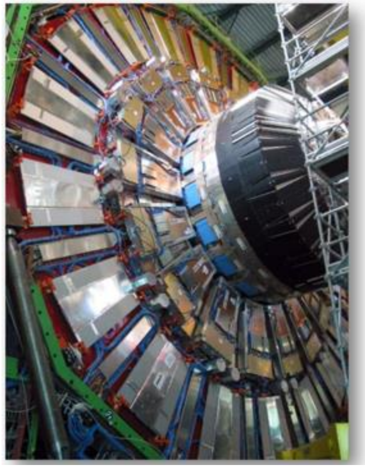
Detector

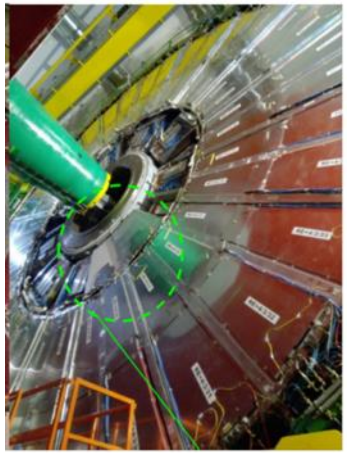
- RPC: T. J. Kim, S. Choi
- GEM: T. J. Kim, I. Park, U. Yang
- MTD: C. Moon, D. Moon, J. Yoo

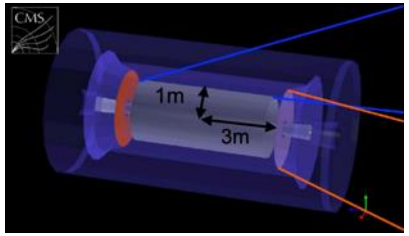
- 1997: Korea University joined CMS collaboration
- 1998: U. of Gangneung and Pohang joined ALICE collaboration
- 2002: Kyungpook National University joined CMS for computing
- 2006: Korean government signing the International Cooperation Agreement
- 2007: MOU for LHC ALICE, CMS, Computing
- 2008: Theoretical physics exchange program
- 2013: KISTI joined World-wide LHC Computing Grid as Tier-1 center
- 2017: 10th anniversary of signing of the ICA & 20th anniversary of Korea-CMS cooperation

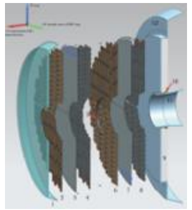
Korean contributions to CMS detector

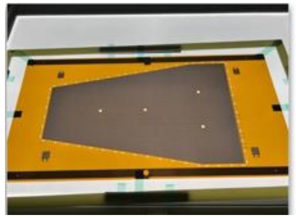


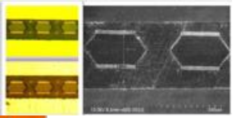


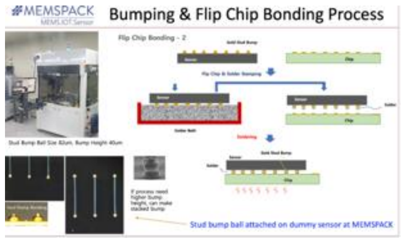


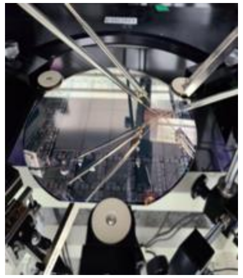












Korean CMS Awards

CMS Awards 2017
Minho Kang

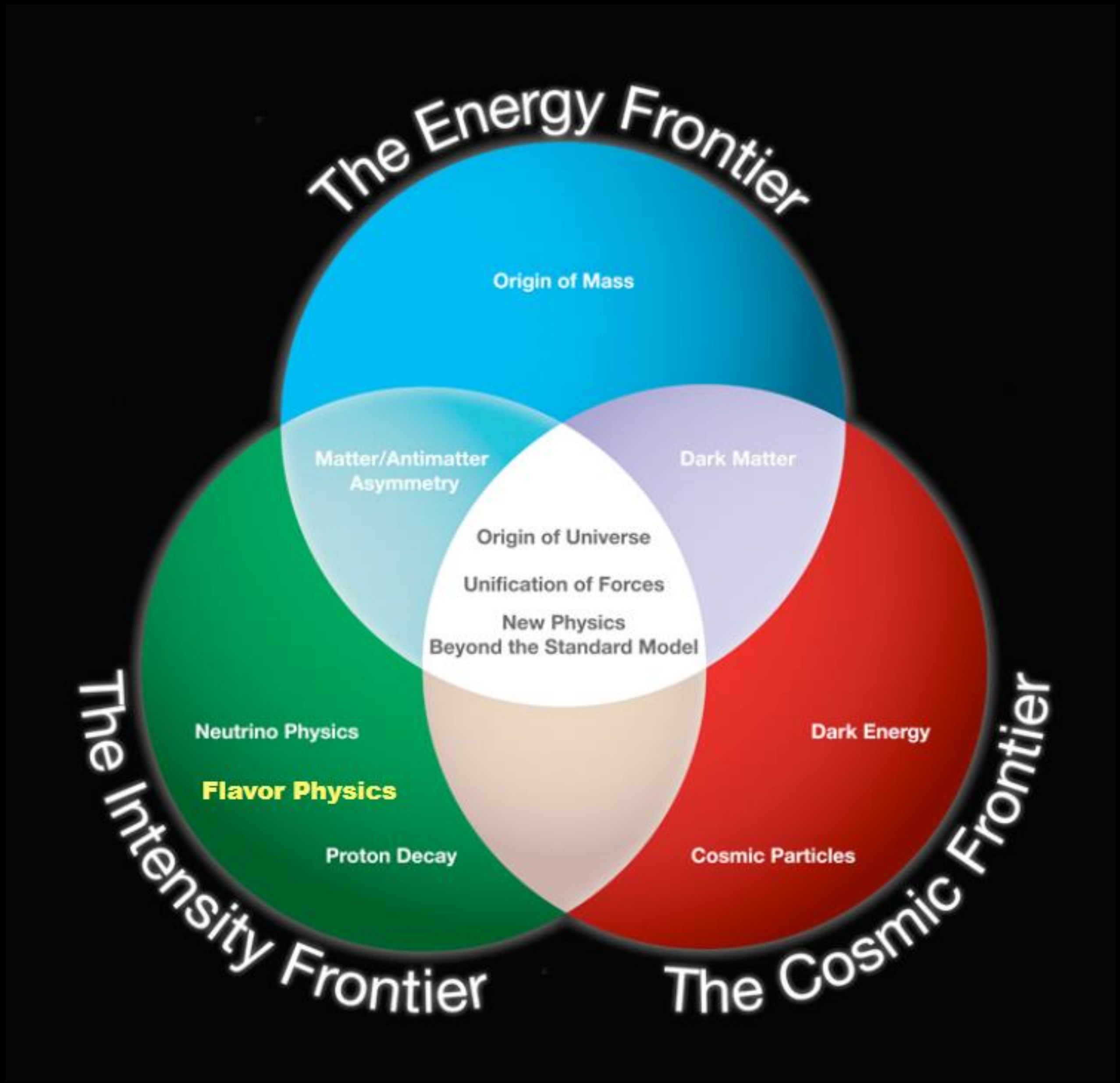
CMS Awards 2018
Kyeongpil Lee

CMS Awards 2020
Minseok Oh, Inseok Yoon

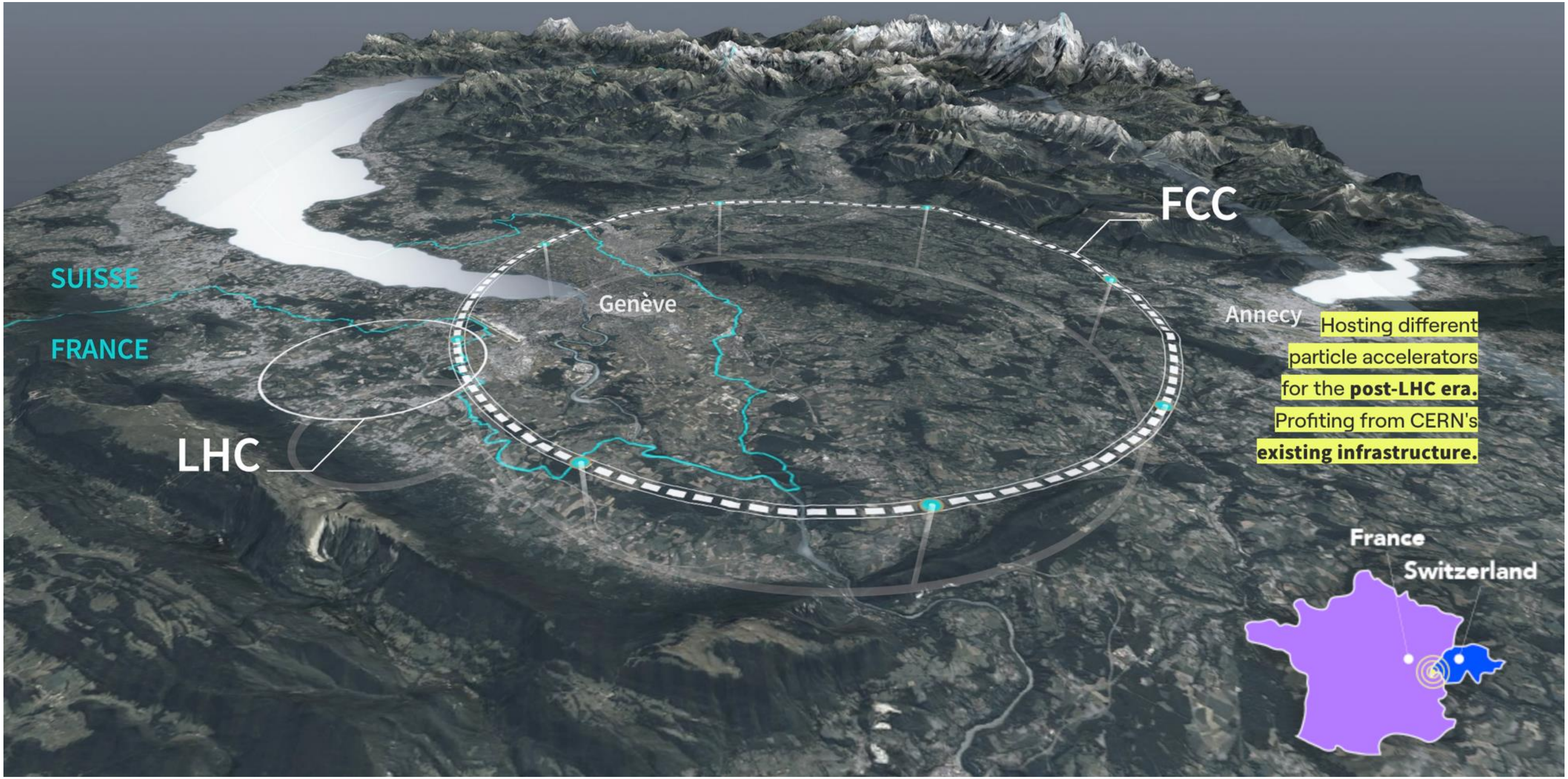
CMS Awards 2021
Benjamin Radbun-Smith

CMS Awards 2022
Ece Asilar, Sihyun Jeon

CMS Awards 2023
Won Jun


The Energy Frontier
Origin of Mass
Matter/Antimatter
Asymmetry
Dark Matter
Origin of Universe
Unification of Forces
New Physics
Beyond the Standard Model
Neutrino Physics
Flavor Physics
Proton Decay
Dark Energy
Cosmic Particles
The Intensity Frontier
The Cosmic Frontier

Your possible future



Size of LHC and FCC