

# Welcome to the



# Swiss High-School Students Internship Programme 2021

Hans Peter Beck – University of Bern

18/10/2021

## CERN





**C  
E  
R  
N**

Conseil  
Européen pour  
la  
Recherche  
Nucléaire

European  
**Organization** for  
Nuclear  
Research



- ◆ **1951** agreement among 11 countries
- ◆ **1952** Geneva was selected
- ◆ **1954** The Organization is officially born.  
Beginning of construction works
- ◆ First physics laboratory built across two countries CH and FR

<https://timeline.web.cern.ch>



C  
E  
R  
N

Conseil  
Européen pour  
la  
Recherche  
Nucléaire

European  
**Organization** for  
Nuclear  
Research



## CERN now

23 MEMBER STATES  
7 ASSOCIATE MEMBER STATES  
3 ASSOCIATE MEMBERS IN  
THE PRE-STAGE TO MEMBERSHIP  
3 OBSERVERS  
OTHER STATES

Budget in 2020: 1.19 billions of Euros  
3430 members of personnel  
550 students  
2000 contractors  
15000 users (482 CH)



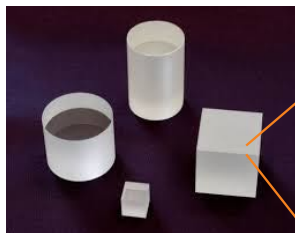
# CERN mission

- Provide the facilities for frontend fundamental physics research : accelerators.
- Research in fundamental physics.
- Bring people together and push the frontiers of science and technology for the benefit of all.
- Education of future generations of scientists.

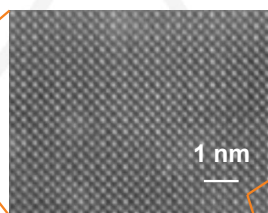


## Research at CERN

Macroscopic matter



Atomic structure



IV-V century BC

Fundamental constituents of matter and their interactions.

Scale  $10^{-10}$ – $10^{-15}$  m

electrons

protons and neutrons

quarks

Nucleus

End of IXX century

Beginning of XX century

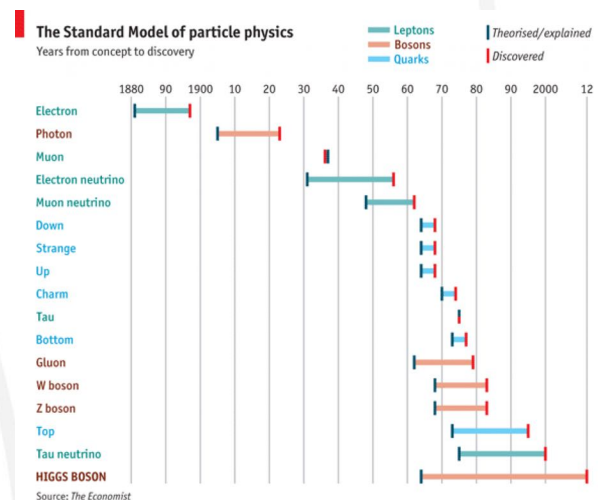
1960s

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18																		
Atomic Symbol		Periodic Table																Practicing Chalcogens Halogens																	
Name Weight																																			
1	<b>H</b> Hydrogen 1.008																	2	<b>He</b> Helium 4.0026																
3	<b>Li</b> Lithium 6.94	4	<b>Be</b> Beryllium 9.0122																	10	<b>Ne</b> Neon 20.180														
5	<b>Na</b> Sodium 22.990	11	<b>Mg</b> Magnesium 24.305																	19	<b>K</b> Potassium 39.098														
7	<b>Ca</b> Calcium 40.078	13	<b>Sc</b> Scandium 44.956	14	<b>Ti</b> Titanium 50.942	15	<b>V</b> Vanadium 50.942	16	<b>Cr</b> Chromium 51.996	17	<b>Mn</b> Manganese 54.938	18	<b>Fe</b> Iron 55.845	19	<b>Co</b> Cobalt 58.933	20	<b>Ni</b> Nickel 58.693	21	<b>Cu</b> Copper 63.546	22	<b>Zn</b> Zinc 65.38	23	<b>Ga</b> Gallium 69.723	24	<b>Ge</b> Germanium 72.630	25	<b>As</b> Arsenic 74.922	26	<b>Se</b> Selenium 78.971	27	<b>Br</b> Bromine 79.904	28	<b>Kr</b> Krypton 83.798		
9	<b>Rb</b> Rubidium 85.468	37	<b>Sr</b> Strontium 87.62	38	<b>Y</b> Yttrium 88.906	39	<b>Zr</b> Zirconium 91.224	40	<b>Nb</b> Niobium 92.906	41	<b>Mo</b> Molybdenum 95.95	42	<b>Tc</b> Technetium (98)	43	<b>Ru</b> Ruthenium 101.07	44	<b>Rh</b> Rhodium 102.91	45	<b>Pd</b> Palladium 106.42	46	<b>Ag</b> Silver 107.87	47	<b>Cd</b> Cadmium 112.41	48	<b>In</b> Indium 114.82	49	<b>Sn</b> Tin 118.71	50	<b>Sb</b> Antimony 121.76	51	<b>Te</b> Tellurium 127.60	52	<b>I</b> Iodine 126.90	53	<b>Xe</b> Xenon 131.29
11	<b>Cs</b> Cesium 132.91	55	<b>Ba</b> Barium 137.33	56-71	<b>Hf</b> Hafnium 178.49	72	<b>Ta</b> Tantalum 180.95	73	<b>W</b> Tungsten 183.84	74	<b>Re</b> Rhenium 186.21	75	<b>Os</b> Osmium 190.23	76	<b>Ir</b> Iridium 192.22	77	<b>Pt</b> Platinum 195.08	78	<b>Au</b> Gold 196.97	79	<b>Hg</b> Mercury 200.59	80	<b>Tl</b> Thallium 204.38	81	<b>Pb</b> Lead 207.2	82	<b>Bi</b> Bismuth 208.98	83	<b>Po</b> Polonium (209)	84	<b>At</b> Astatine (210)	85	<b>Rn</b> Radon (222)		
13	<b>Fr</b> Francium (223)	87	<b>Ra</b> Radium (226)	88-103	<b>Rf</b> Rutherfordium (267)	104	<b>Db</b> Dubnium (268)	105	<b>Sg</b> Seaborgium (269)	106	<b>Bh</b> Bohrium (270)	107	<b>Hs</b> Hassium (271)	108	<b>Mt</b> Meitnerium (272)	109	<b>Ds</b> Darmstadtium (281)	110	<b>Rg</b> Roentgenium (282)	111	<b>Cn</b> Copernicium (285)	112	<b>Nh</b> Nihonium (286)	113	<b>Fl</b> Flerovium (289)	114	<b>Mc</b> Moscovium (290)	115	<b>Lv</b> Livermorium (293)	116	<b>Ts</b> Tennessine (294)	117	<b> Og</b> Oganesson (294)		
For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.																																			
15	<b>La</b> Lanthanum 138.91	57	<b>Ce</b> Cerium 140.12	58	<b>Pr</b> Praseodymium 140.91	59	<b>Nd</b> Neodymium 144.24	60	<b>Pm</b> Promethium (145)	61	<b>Sm</b> Samarium 150.36	62	<b>Eu</b> Europium 151.96	63	<b>Gd</b> Gadolinium 157.25	64	<b>Tb</b> Terbium 158.93	65	<b>Dy</b> Dysprosium 162.50	66	<b>Ho</b> Holmium 164.93	67	<b>Er</b> Erbium 167.26	68	<b>Tm</b> Thulium 168.93	69	<b>Yb</b> Ytterbium 173.05	70	<b>Lu</b> Lutetium 174.97						
17	<b>Ac</b> Actinium (227)	89	<b>Th</b> Thorium 232.04	90	<b>Pa</b> Protactinium 231.04	91	<b>U</b> Uranium 238.03	92	<b>Np</b> Neptunium (237)	93	<b>Pu</b> Plutonium (244)	94	<b>Am</b> Americium (243)	95	<b>Cm</b> Curium (247)	96	<b>Bk</b> Berkelium (247)	97	<b>Cf</b> Californium (251)	98	<b>Es</b> Einsteinium (252)	99	<b>Fm</b> Fermium (257)	100	<b>Md</b> Mendelevium (258)	101	<b>No</b> Nobelium (259)	102	<b>Lr</b> Lawrencium (266)						

18 Oct 2021

### Drei Generationen der Materie (Fermionen)

	I	II	III	
Masse	2,3 MeV	1,275 GeV	173,07 GeV	125,9 GeV
Ladung	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0
Spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0
Name	u up	c charm	t top	q e/p Higgs Boson
	4,8 MeV	95 MeV	4,18 GeV	0
	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
	d down	s strange	b bottom	g Gluon
	<2 eV	<0,19 MeV	<18,2 MeV	91,2 GeV
	0	$\frac{1}{2}$	0	0
	$\nu_e$ Elektron-Neutrino	$\nu_\mu$ Myon-Neutrino	$\nu_\tau$ Tau-Neutrino	$Z^0$ Z Boson
	0,511 MeV	105,7 MeV	1,777 GeV	80,4 GeV
	-1	-1	-1	$\pm 1$
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
	e Elektron	$\mu$ Myon	$\tau$ Tau	$W^\pm$ W Boson





# To the standard model of particles

Drei Generationen der Materie (Fermionen)

	I	II	III	
Masse	2,3 MeV	1,275 GeV	173,07 GeV	125,9 GeV
Ladung	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0
Spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0
Name	u up	c charm	t top	q e/p-Quant
				H Higgs Boson
	4,8 MeV $-\frac{1}{3}$ $\frac{1}{2}$ d down	95 MeV $-\frac{1}{3}$ $\frac{1}{2}$ s strange	4,18 GeV $-\frac{1}{3}$ $\frac{1}{2}$ b bottom	0 0 1 g Gluon
Quarks				
	<2 eV 0 $\frac{1}{2}$ $\nu_e$ Elektron-Neutrino	<0,19 MeV 0 $\frac{1}{2}$ $\nu_\mu$ Myon-Neutrino	<18,2 MeV 0 $\frac{1}{2}$ $\nu_\tau$ Tau-Neutrino	91,2 GeV 0 1 Z <sup>0</sup> Z Boson
	0,511 MeV -1 $\frac{1}{2}$ e Elektron	105,7 MeV -1 $\frac{1}{2}$ $\mu$ Myon	1,777 GeV -1 $\frac{1}{2}$ $\tau$ Tau	80,4 GeV $\pm 1$ 1 W <sup>±</sup> W Boson
Leptonen				Eichbosonen

- The SM is now a theory, confirmed by many experiments.
- Is it all, or there is more ?
- How gravity can be integrated ?
- Why there is no more antimatter ?
- What is the dark matter and the dark energy ?

For each of these particles there is an antiparticle !

# To the standard model of particles

Drei Generationen der Materie (Fermionen)

	I	II	III	
Masse	2,3 MeV	1,275 GeV	173,07 GeV	125,9 GeV
Ladung	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0
Spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0
Name	u up	c charm	t top	q e/p-Quant
				H Higgs Boson
	4,8 MeV $-\frac{1}{3}$ $\frac{1}{2}$ d down	95 MeV $-\frac{1}{3}$ $\frac{1}{2}$ s strange	4,18 GeV $-\frac{1}{3}$ $\frac{1}{2}$ b bottom	0 0 1 g Gluon
Quarks				
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	0,511 MeV -1 $\frac{1}{2}$ e Elektron	105,7 MeV -1 $\frac{1}{2}$ $\mu$ Myon	1,777 GeV -1 $\frac{1}{2}$ $\tau$ Tau	80,4 GeV $\pm 1$ 1 W <sup>±</sup> W Boson
Leptonen				Eichbosonen

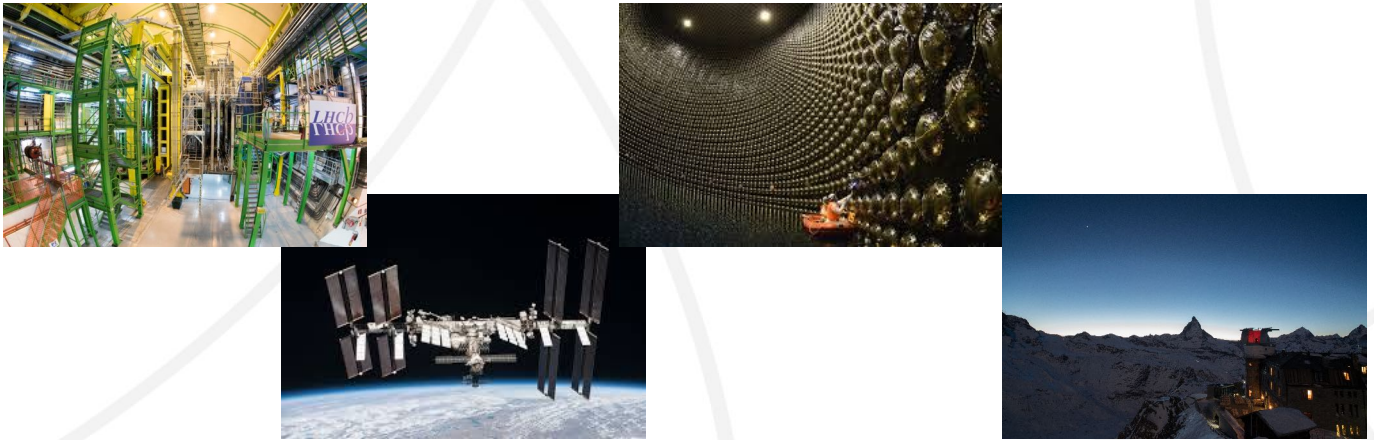
Only 5 % of the matter in the Universe

Gravity ?

- The SM is now a theory, confirmed by many experiments.
- Is it all, or there is more ?
- How gravity can be integrated ?
- Why there is no more antimatter ?
- What is the dark matter and the dark energy ?

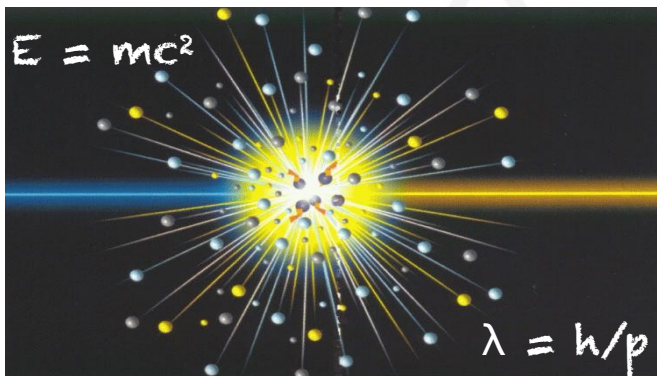
For each of these particles there is an antiparticle !

## Different purposes – different laboratories



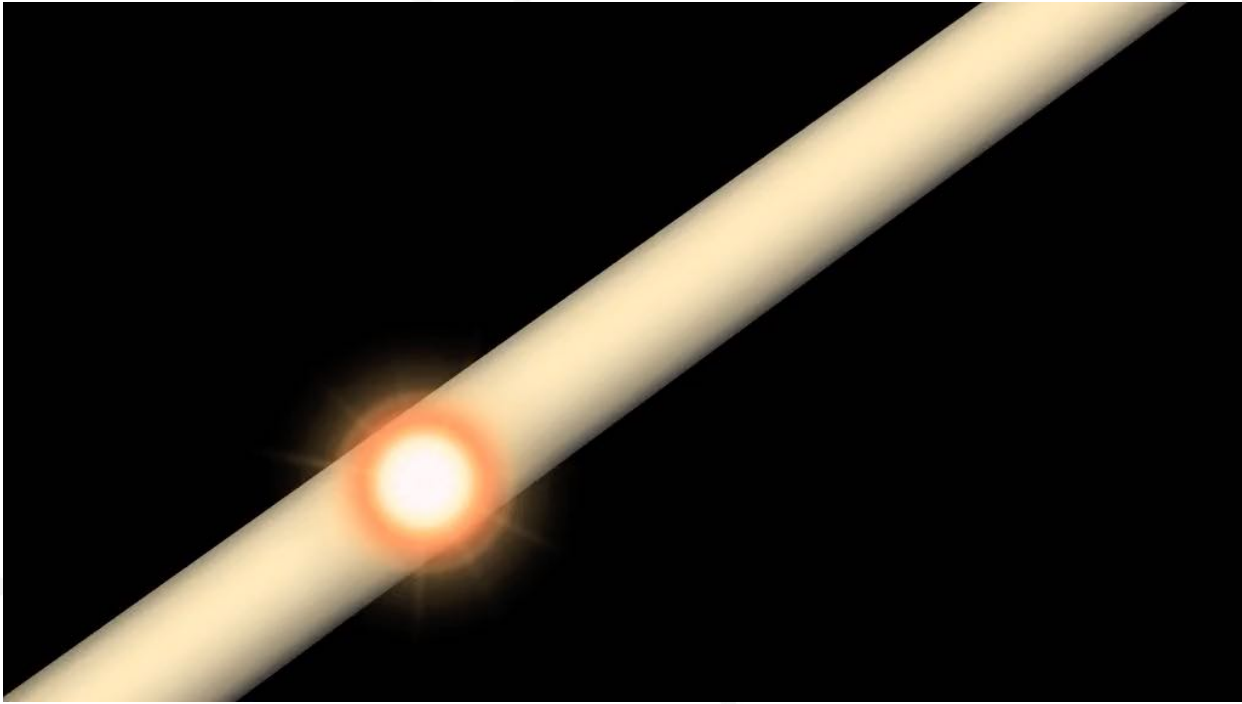
Particle accelerators have a prominent role in this picture

## Why particle accelerators?

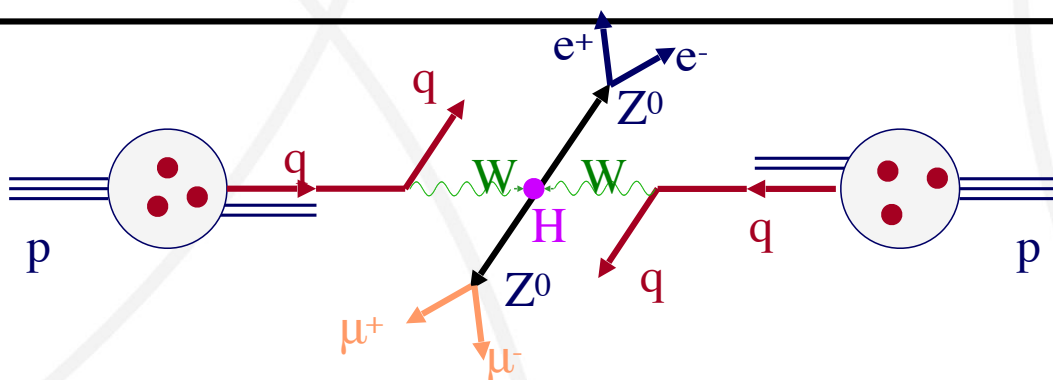


Energy ↔ Mass  
Momentum ↔ Resolution

- Particles are accelerated at almost the speed of light.
- The particles are made to collide.
- The products of these collisions are different from the initial particles.
- Particle detectors are our eyes to see the collision products.



## Higgs production in $p$ - $p$ collisions





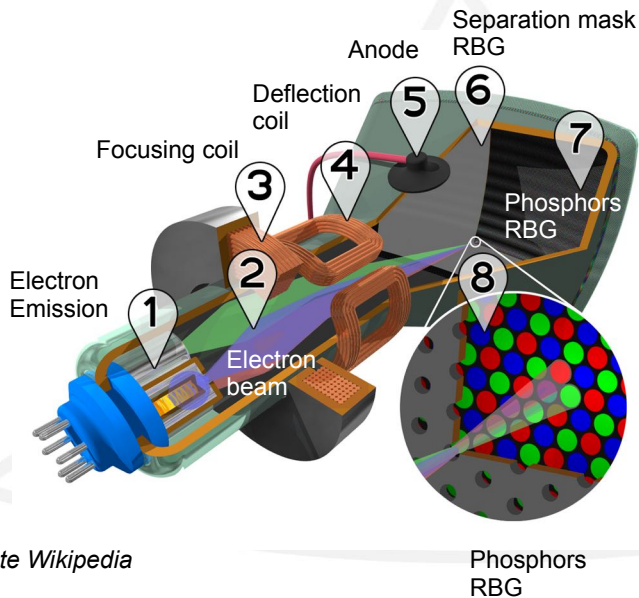


## Discovery 2012, Nobel Prize in Physics 2013



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"*.

# A (old-fashioned) TV set is a particle accelerator



Fonte Wikipedia

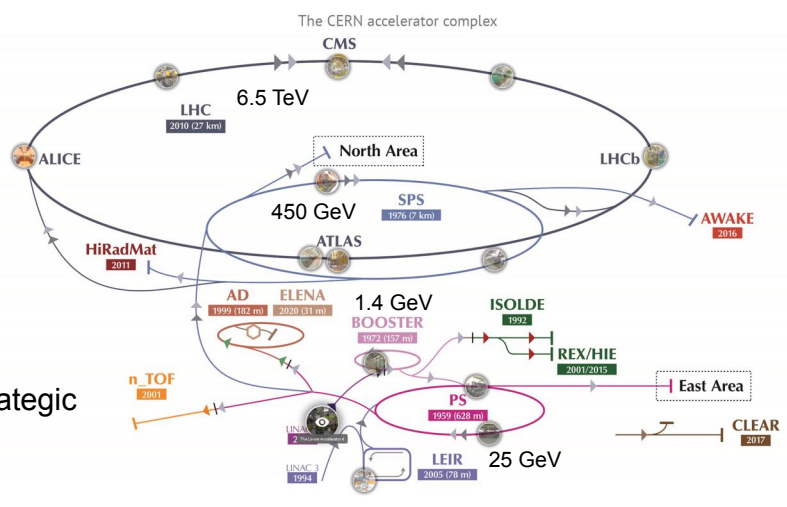
- Electrically charged particle source.
- Electric fields to accelerate.
- Magnetic fields to bend.

## CERN Accelerators

CERN has a complex of accelerators produce beams of :

- Protons and anti-protons
- Ions
- Neutrons
- Isotopes

Several experiments are placed in strategic points of the accelerators.





## Step 1 : an H2 bottle and a linear accelerator

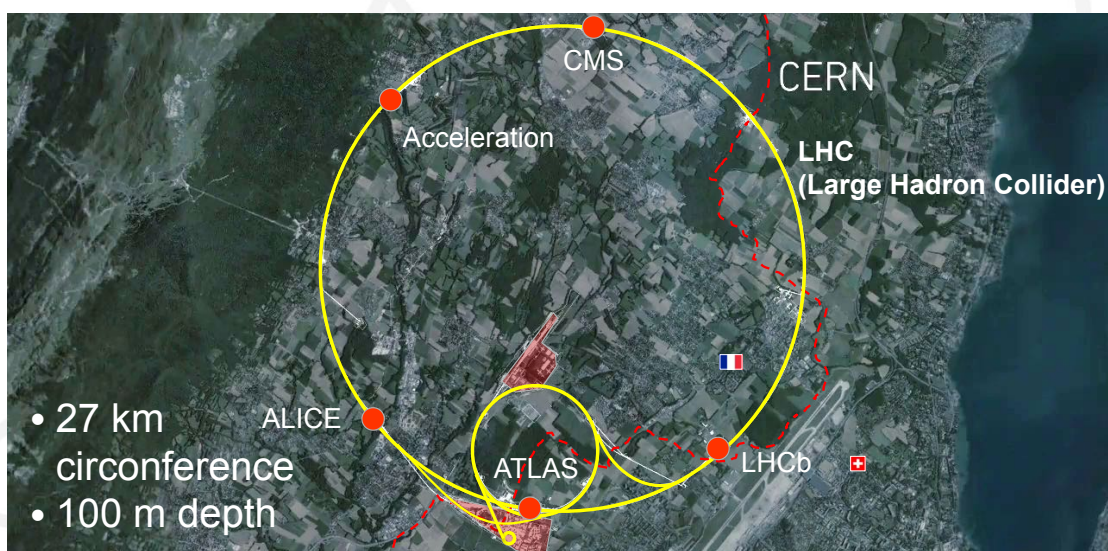


Gas bottle



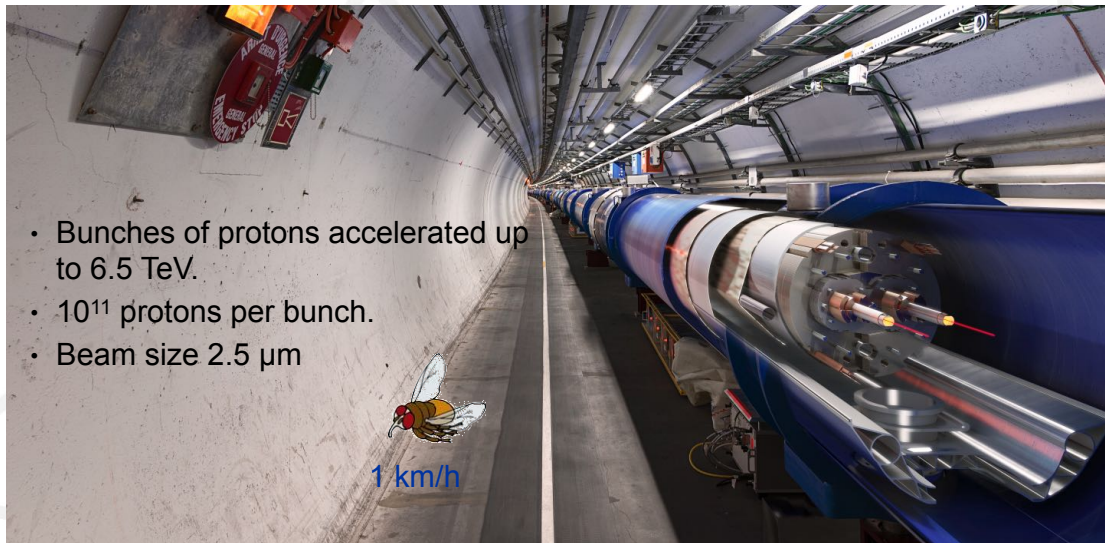
LINAC4 ca. 76 m, up to 160 MeV

## Final step : The Large Hadron Collider





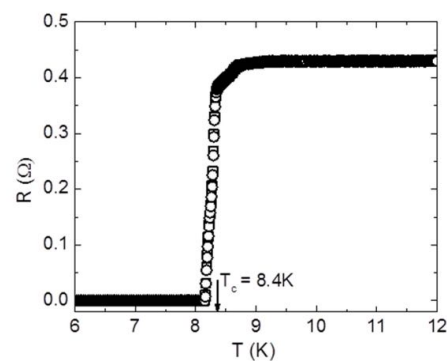
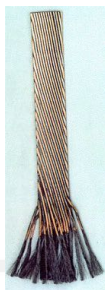
# Final step : The Large Hadron Collider



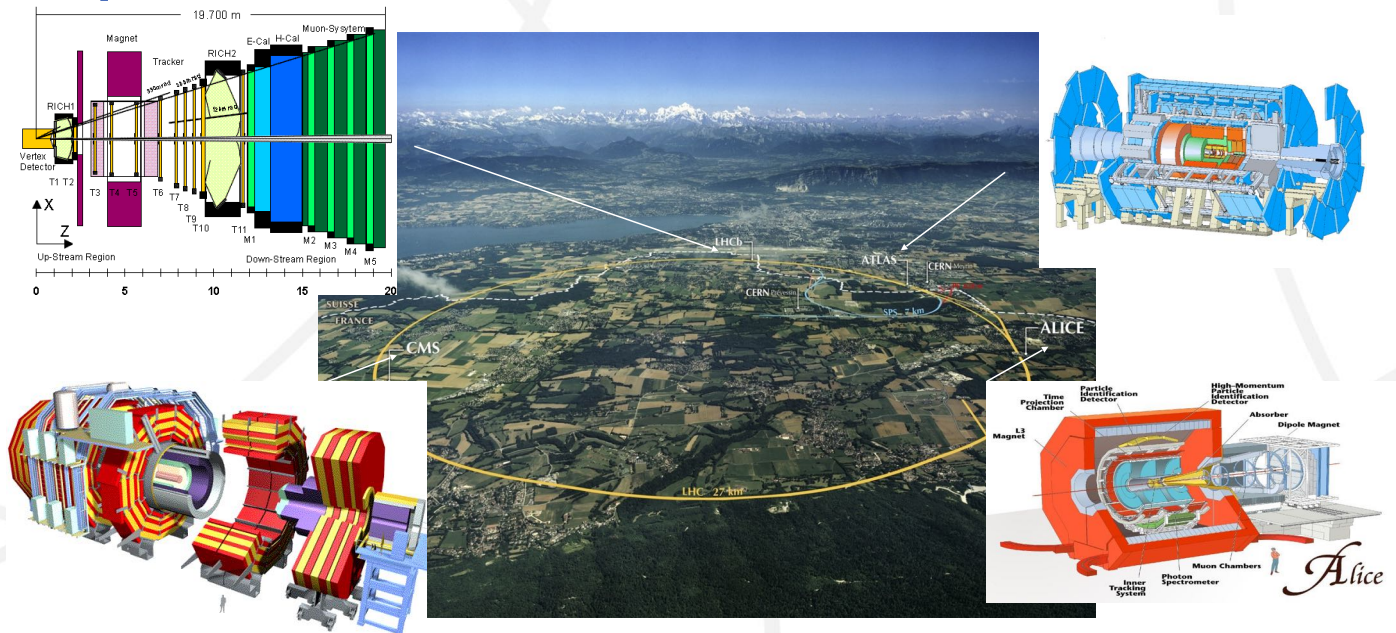
## The technology required

One of the main challenge of the LHC is the production and maintainance of the superconducting magnets.

- 1232 magnets to bend the particles.
- 220 000 km of **superconducting wires**.
- Working temperature : 1.9 K (-271.3 C), superfluid Helium.



# Experiments at the LHC



# Experiments at the LHC



The experiments are international collaborations.

Many research institutions are involved in :

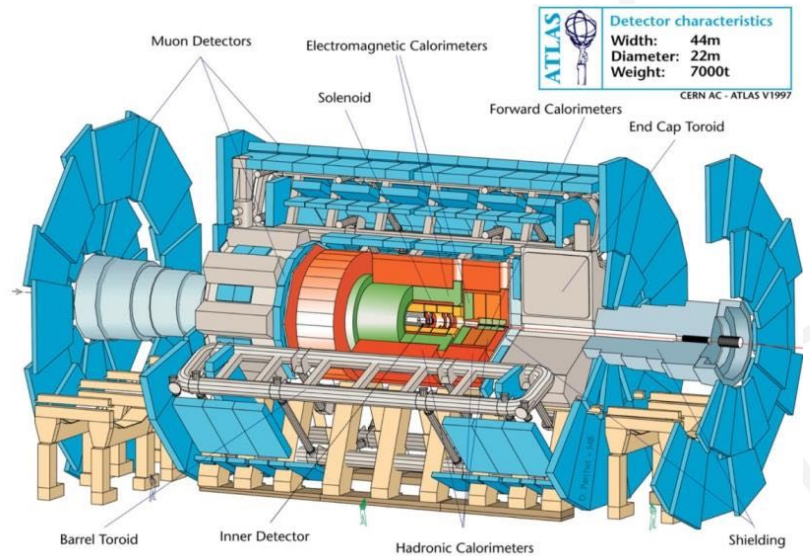
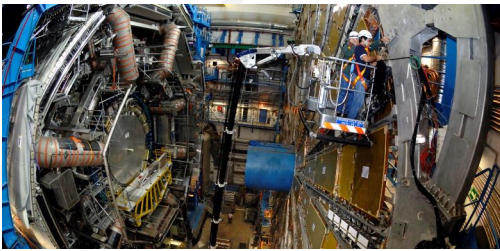
- Design
- Production
- Management
- Resources
- Data analysis etc..

Each experiment has a specific purpose.

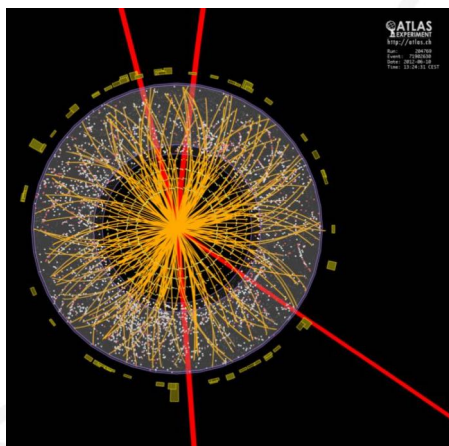


# A few words about ATLAS

- Multipurpose detector.
- 46 m long, 25 m in diameter.
- 7000 tons (Eiffel's tower 7300)
- 100 sensors
- 3500 members from 35 countries



## Detection of very rare events



- Inside ATLAS or CMS there are 800 million pairs of protons colliding.
- Higgs events are expected only once for  $10^{12}$  collisions.

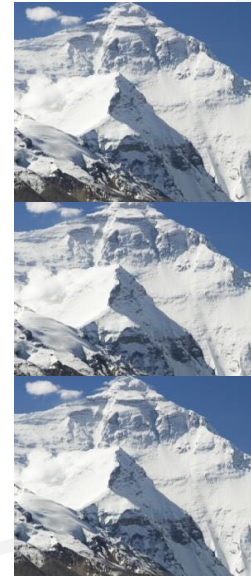


41 coins



# Data filtering

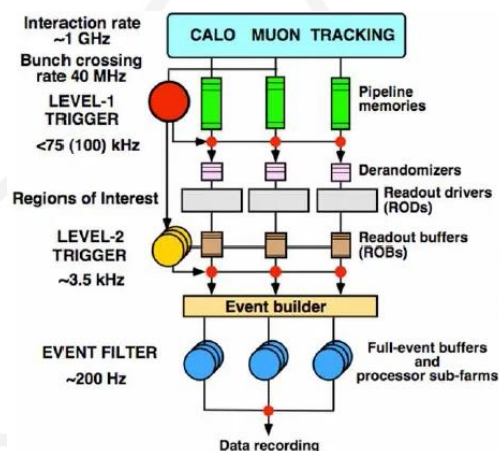
The raw data of ATLAS comes with a rate of 80 TB/s



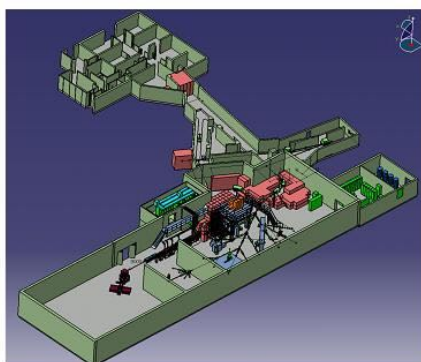
26 km

# Data filtering

A system implemented in hardware and software reduces the data of 3 order of magnitudes.

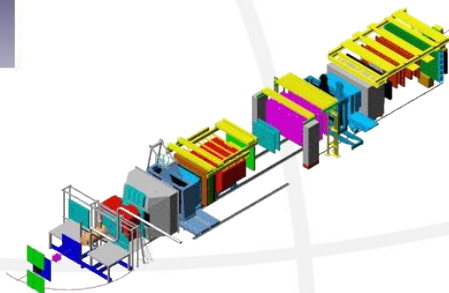


## Other CERN experiments



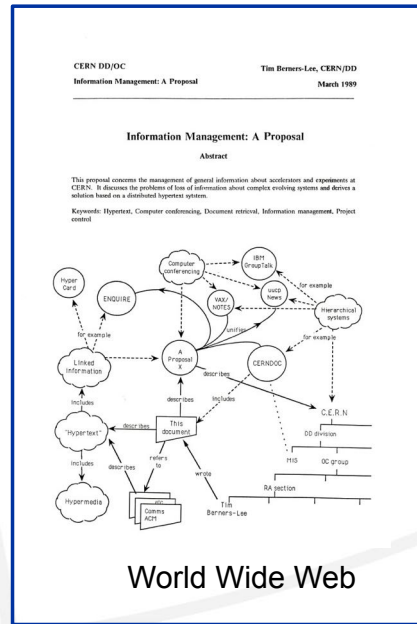
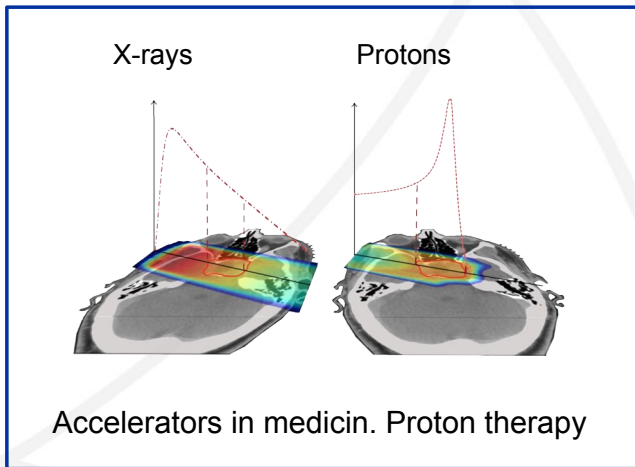
Isolde : Production and research with Isotopes

Fixed target experiments :  
R&D for detectors,  
COMPASS (Exploration of  
hadron structure)




Antimatter Factory


# Technological applications




And many others




## Switzerland and CERN




**Strong involvement in the LHC experimental programme**  
**ATLAS, CMS and LHCb**  
 presently: ~ 90 scientists and > 60 PhD students




**ATLAS:**  
University of Bern  
University of Geneva



**LHCb:**  
EPFL  
University of Zurich



**CMS:**  
ETH Zurich  
PSI  
University of Zurich



**Innovative technologies developed**  
**Swiss industry has played an important role**

High performance computing farm (Tier-2) at the Swiss National Supercomputing Center (CSCS), in Lugano (TI), complemented with a farm at Uni Bern, as part of the world-wide computing Grid.

F. Pauss

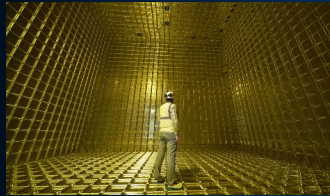




## Switzerland and CERN



Important and diverse involvement in many non-LHC experiments  
NA61/SHINE, ProtoDUNE, AMS, FASER, ArDM, CLOUD,  
SHIP, NA64, ISOLDE, ....



AMS flying on the ISS  
(AMS control room at CERN)

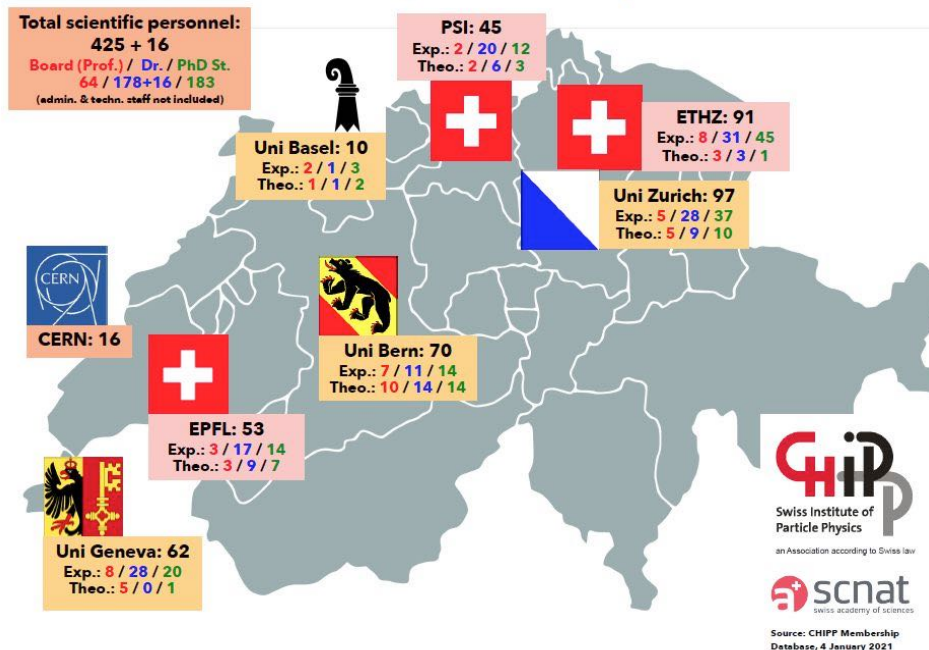
CLOUD

Innovative technologies developed  
Swiss industry has played an important role



HP Beck

## Swiss Particle Physics Landscape 2021



# Particle Physicists from all Swiss Universities Universities



37 Swiss High-School Students Internship Programme 2021, CERN, 17 — 30 October, 2021

18 Oct 2021



**Thank you very much !  
Questions ?**