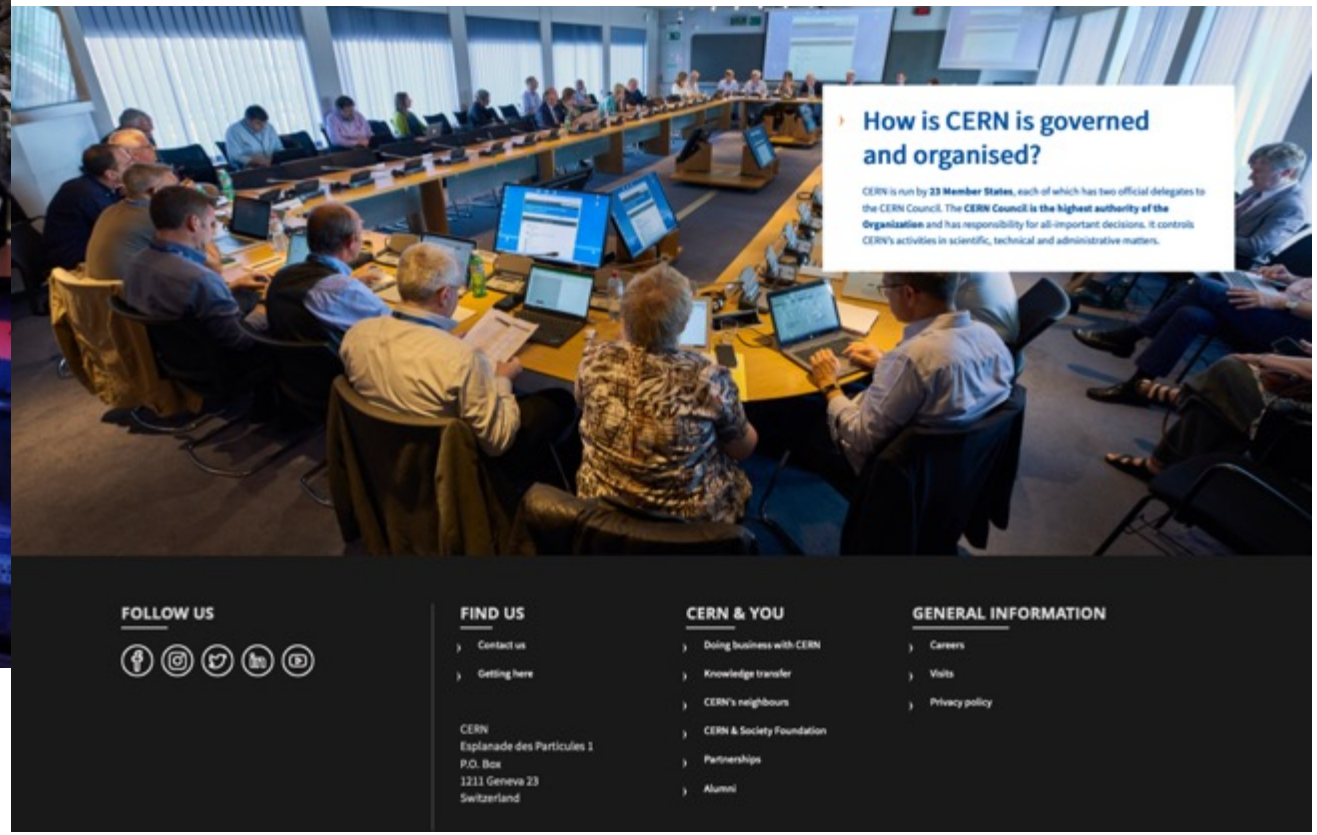
Romania @ CERN

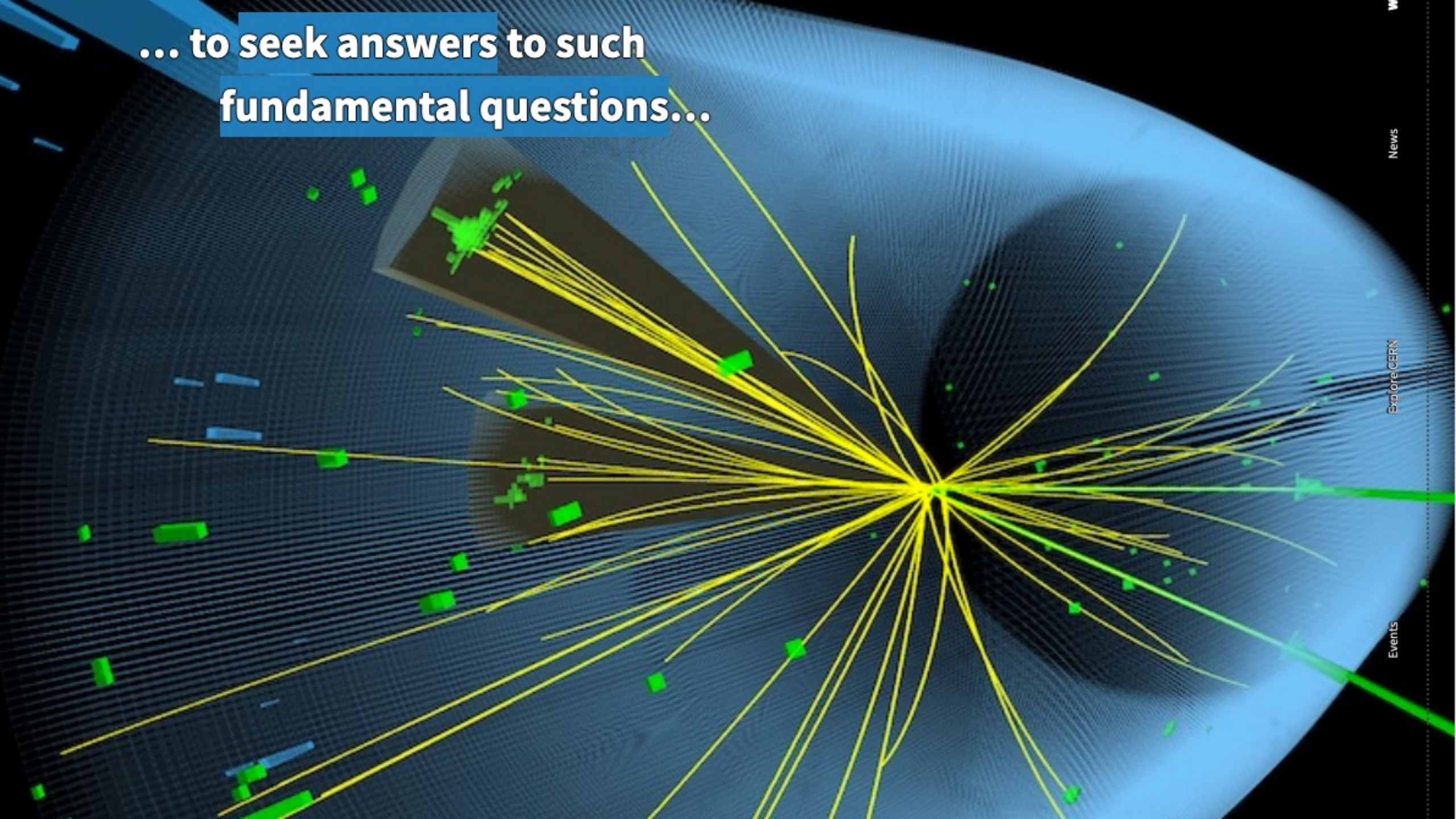
Călin Alexa,
Dept. Fizica Particulelor Elementare, IFIN-HH
Școala Doctorală de Fizică, Universitatea București

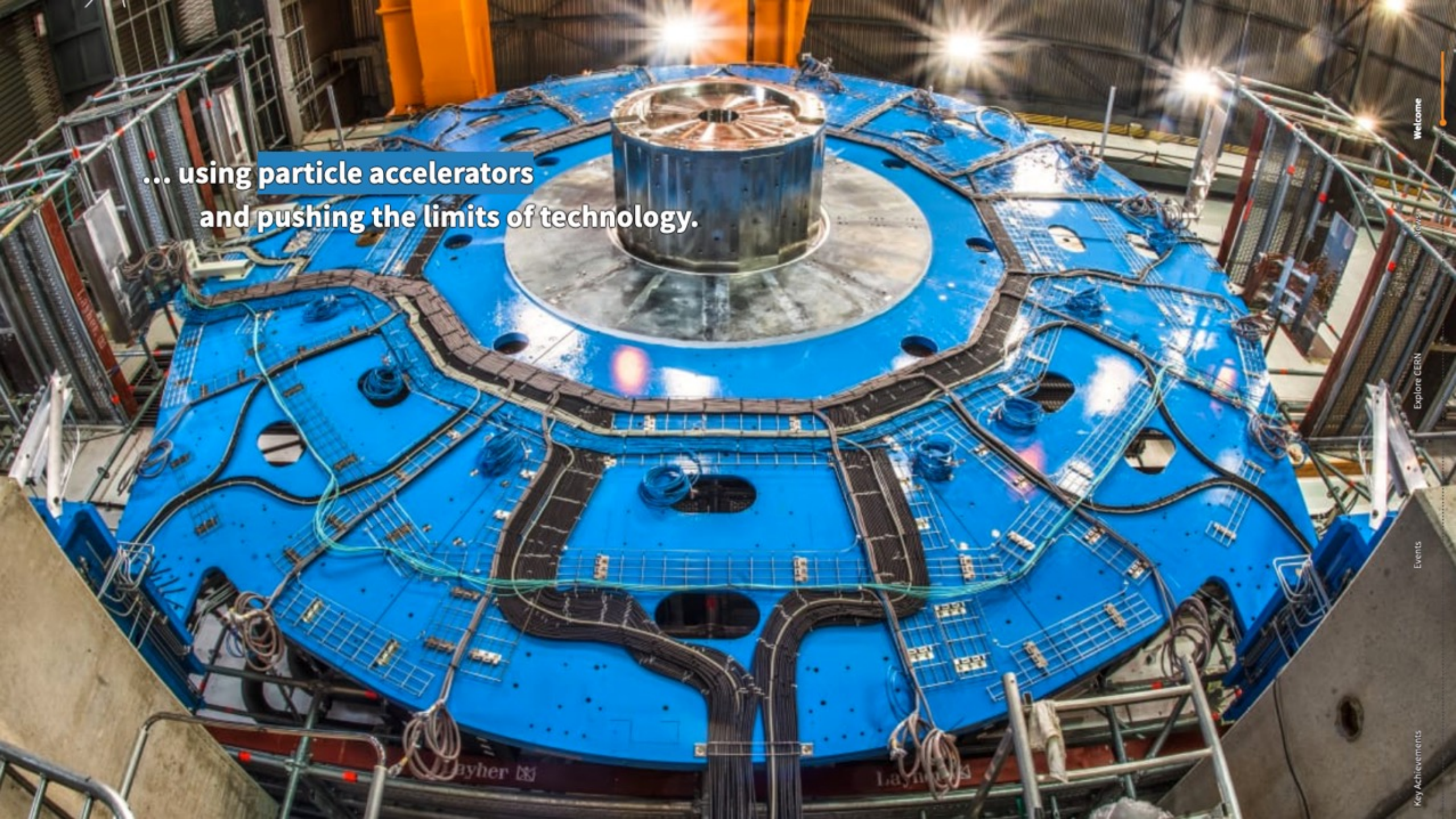
CERN (*Conseil Européen pour la Recherche Nucléaire 1954*)
este Laboratorul European pentru Fizica Particulelor.



https://home.cern/


CERN
Accelerating Science and Innovation


… to seek answers to such
fundamental questions…
News
Explore CERN
Events

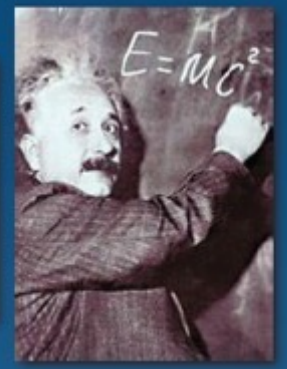


... using particle accelerators
and pushing the limits of technology.

The Mission of CERN

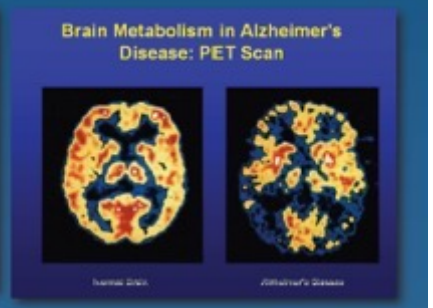
- **Push back** the frontiers of knowledge

  E.g. the secrets of the Big Bang …what was the matter like within the first moments of the Universe's existence?



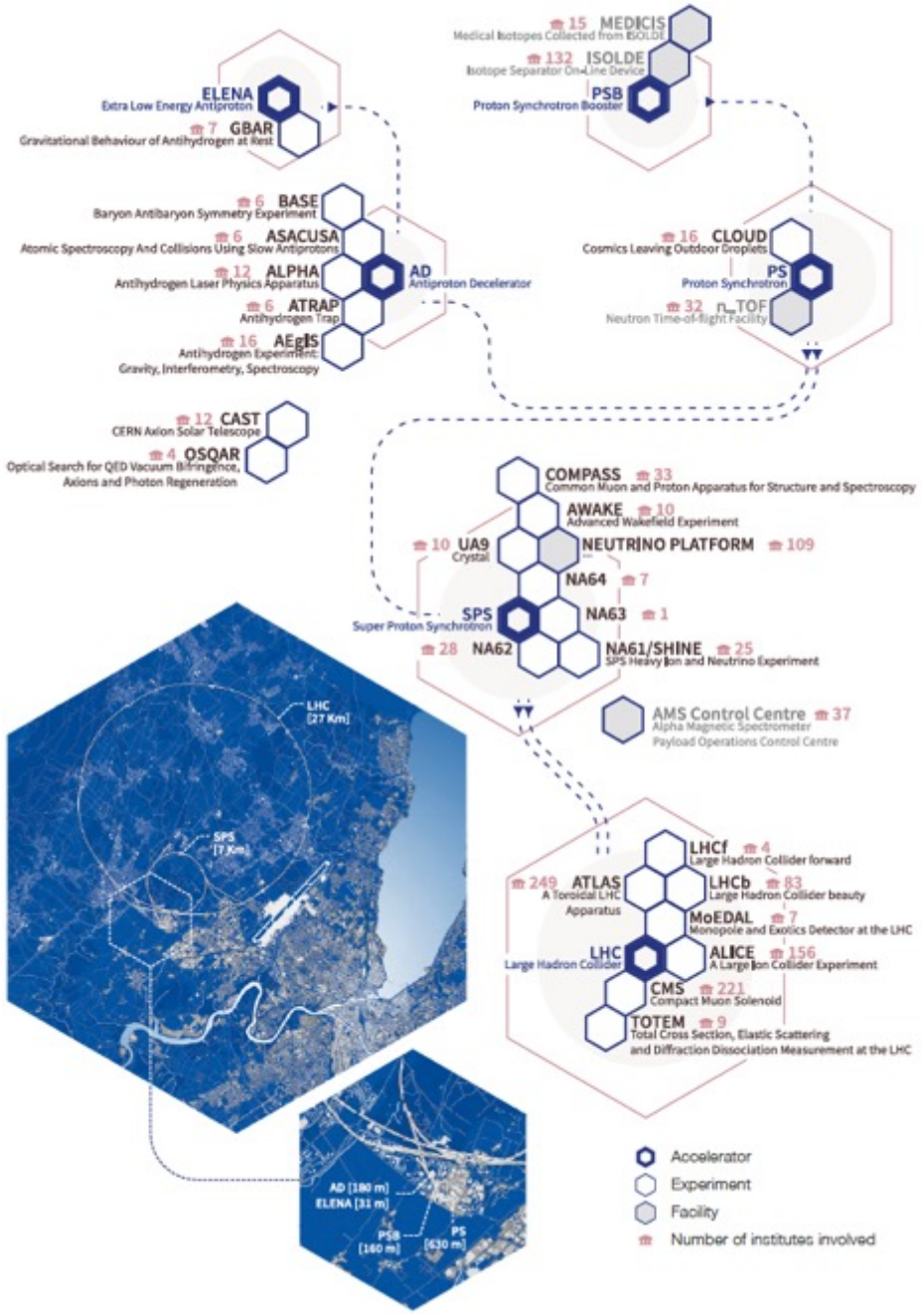
- **Develop** new technologies for accelerators and detectors

  Information technology - the Web and the GRID
  Medicine - diagnosis and therapy



- **Train** scientists and engineers of tomorrow

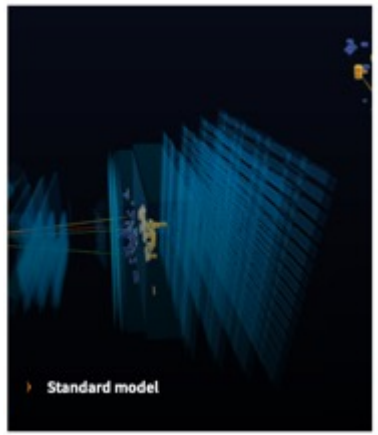
- **Unite** people from different countries and cultures

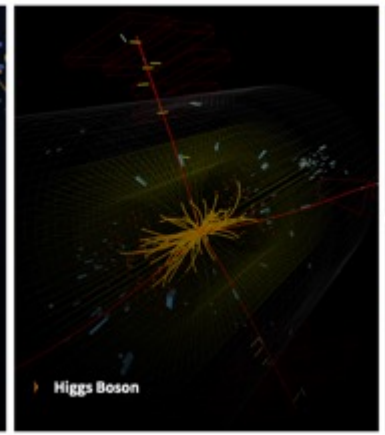


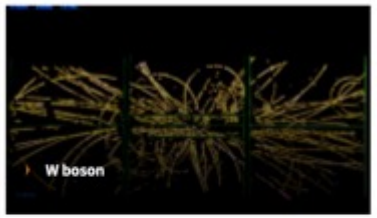
http://cds.cern.ch/record/2723123/files/AnnualReport2019EN.pdf

Particles and forces

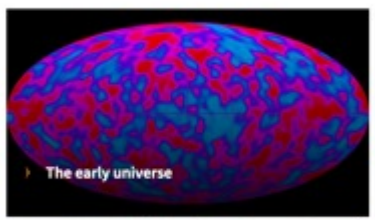
https://home.cern/science/physics

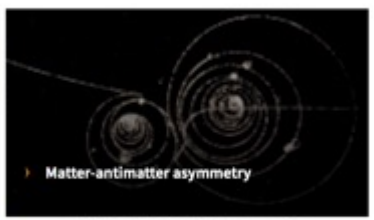


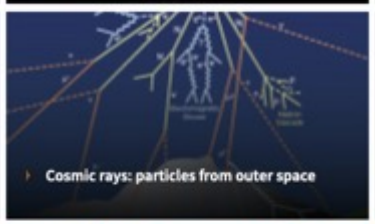


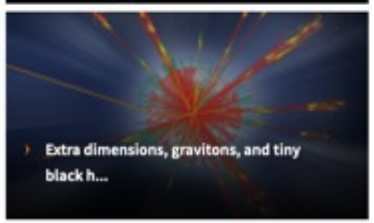


Understanding our universe

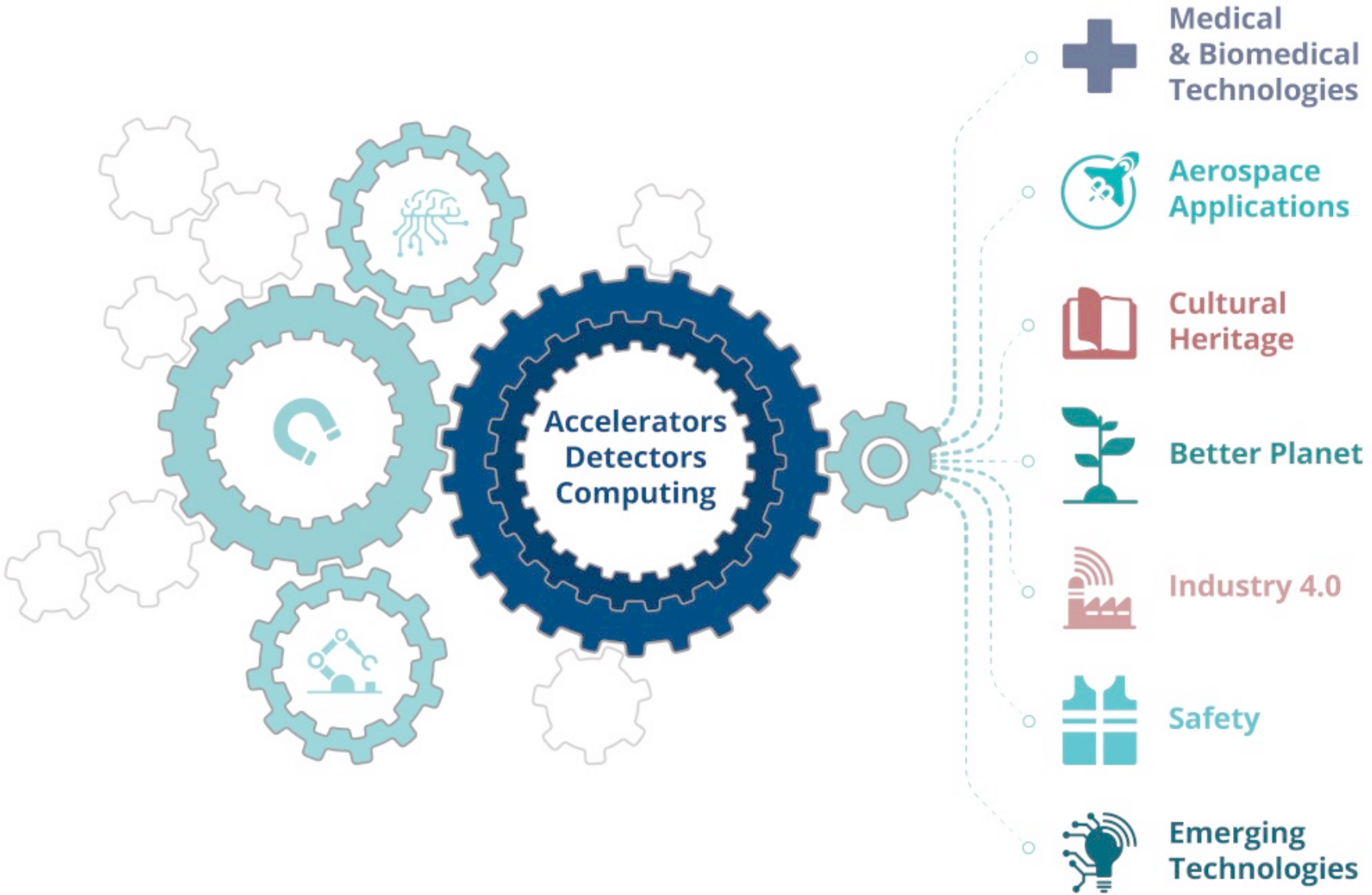


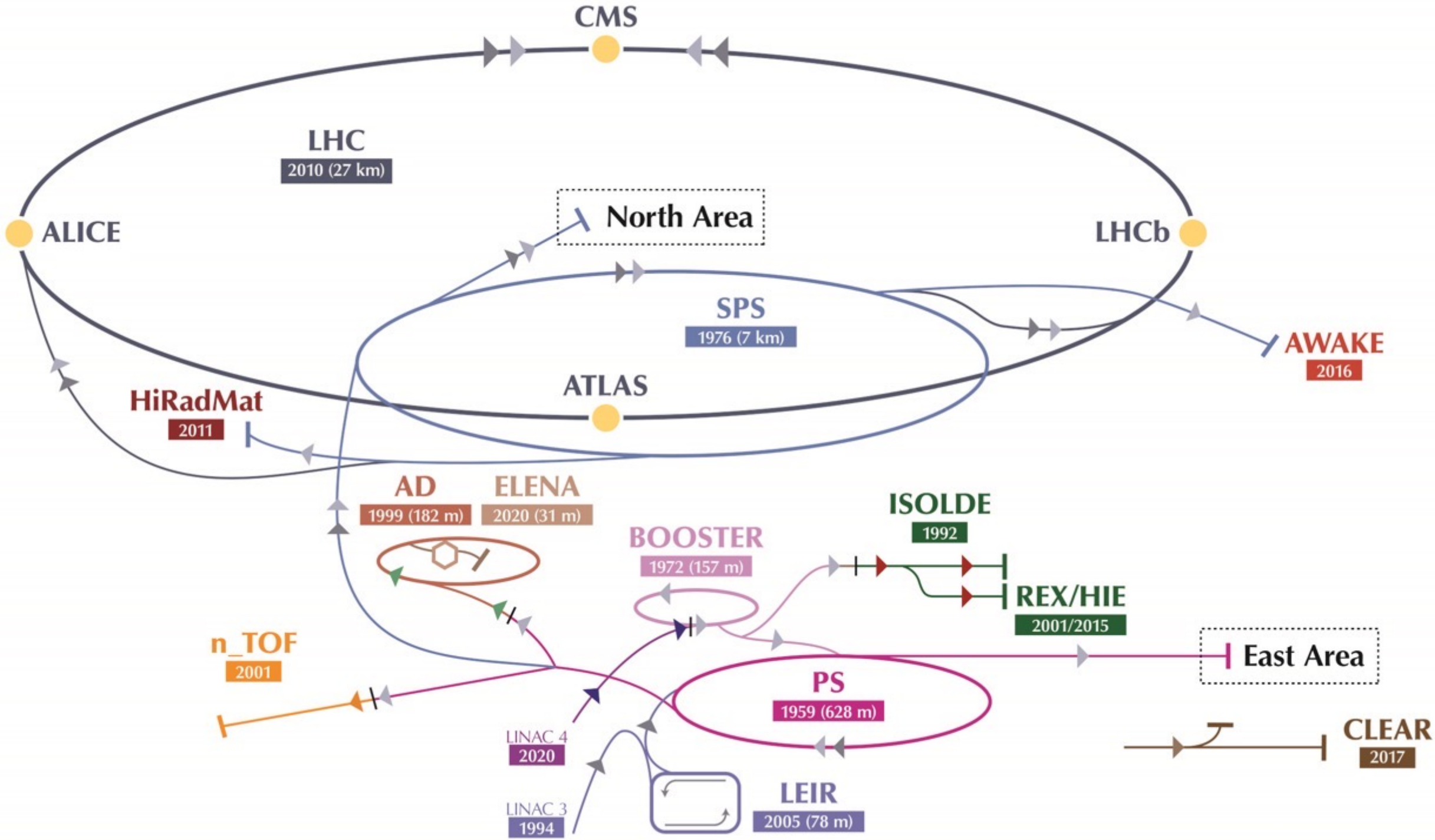


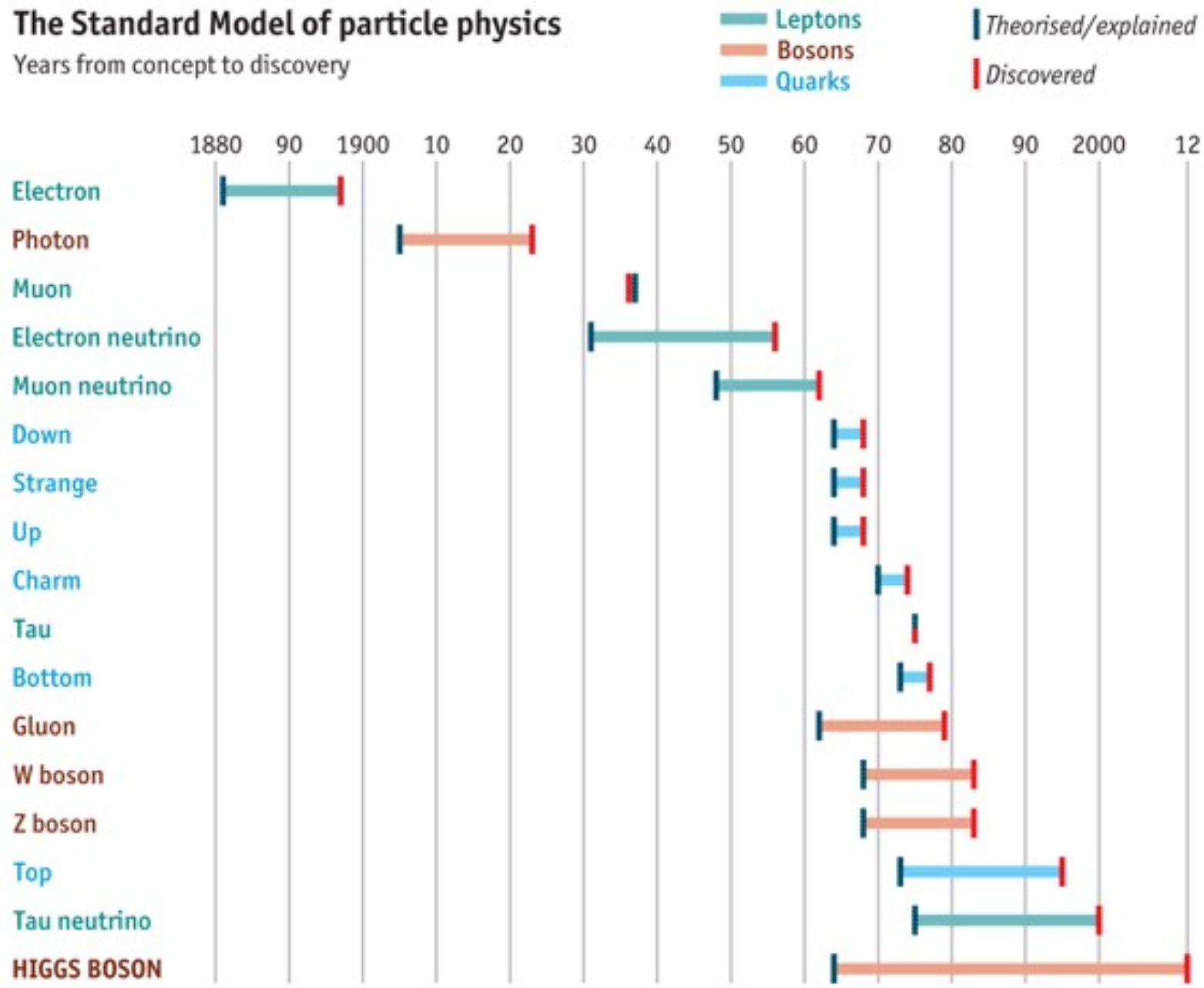




contribution to society: knowledge-transfer
https://home.cern/about/what-we-do/our-impact



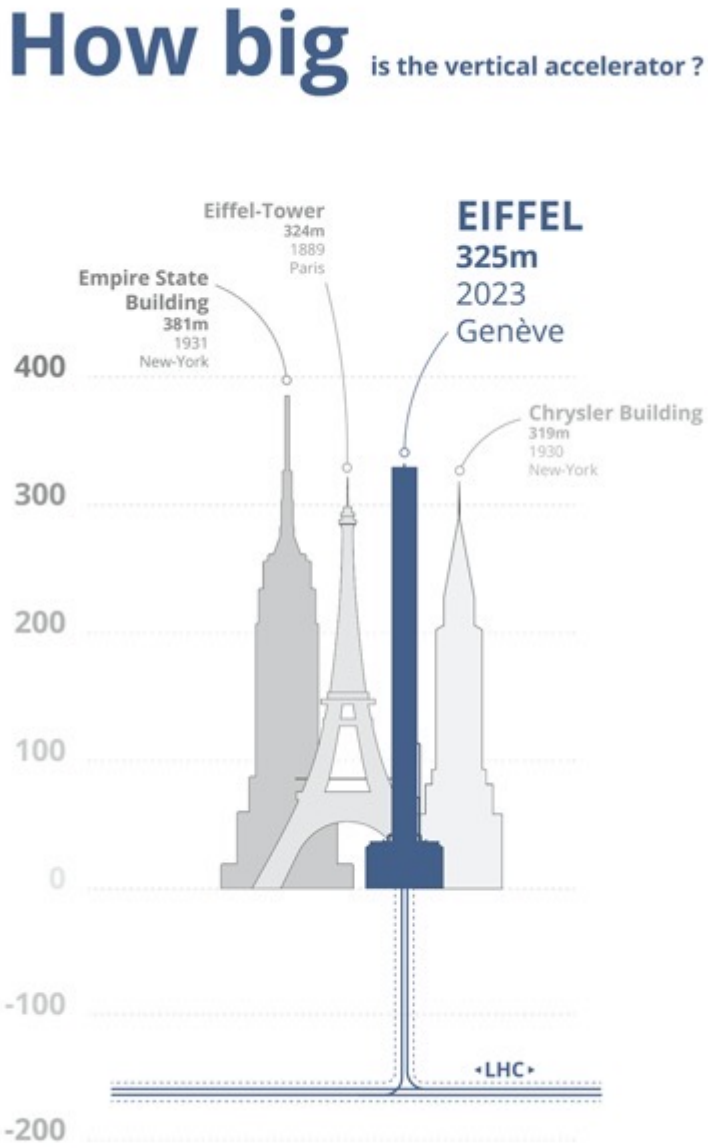

CMS
LHC
2010 (27 km)
ALICE
North Area
LHCb
SPS
1976 (7 km)
AWAKE
2016
ATLAS
HiRadMat
2011
AD
1999 (182 m)
ELENA
2020 (31 m)
ISOLDE
1992
BOOSTER
1972 (157 m)
REX/HIE
2001/2015
n_TOF
2001
East Area
PS
1959 (628 m)
LINAC 4
2020
CLEAR
2017
LINAC 3
1994
LEIR
2005 (78 m)


The Standard Model of particle physics
Years from concept to discovery
Leptons
Bosons
Quarks
Theorised/explained
Discovered
1880
90
1900
10
20
30
40
50
60
70
80
90
2000
12
Electron
Photon
Muon
Electron neutrino
Muon neutrino
Down
Strange
Up
Charm
Tau
Bottom
Gluon
W boson
Z boson
Top
Tau neutrino
HIGGS BOSON

CERN proposes “space elevator” accelerator

1 APRIL, 2021 | By Craig Edwards & Mark Rayner

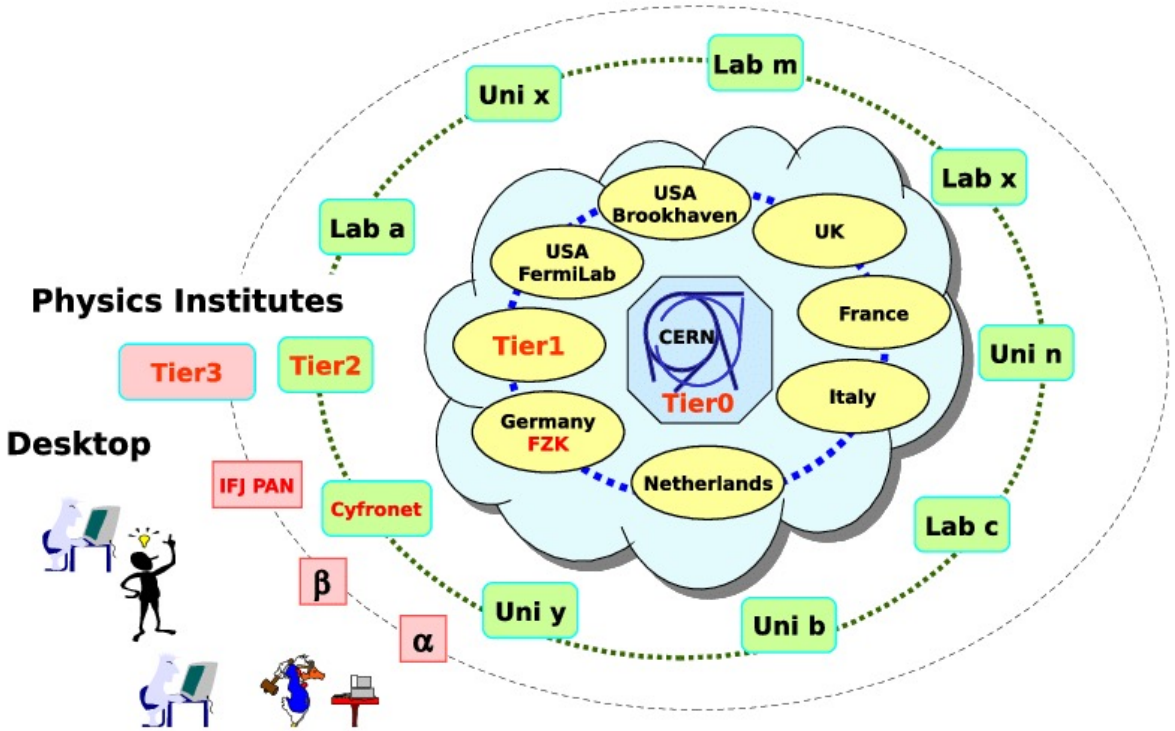
https://home.cern/news/news/cern/cern-proposes-space-elevator-accelerator



The Worldwide LHC Computing Grid (WLCG)

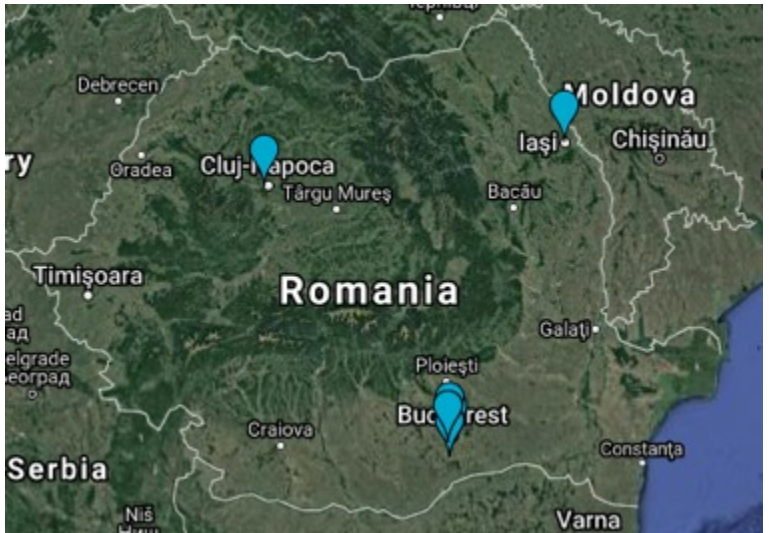
Dealing with the LHC data deluge

https://home.cern/science/computing/grid



900 000 computer cores
170 sites
42 countries
12 000 users

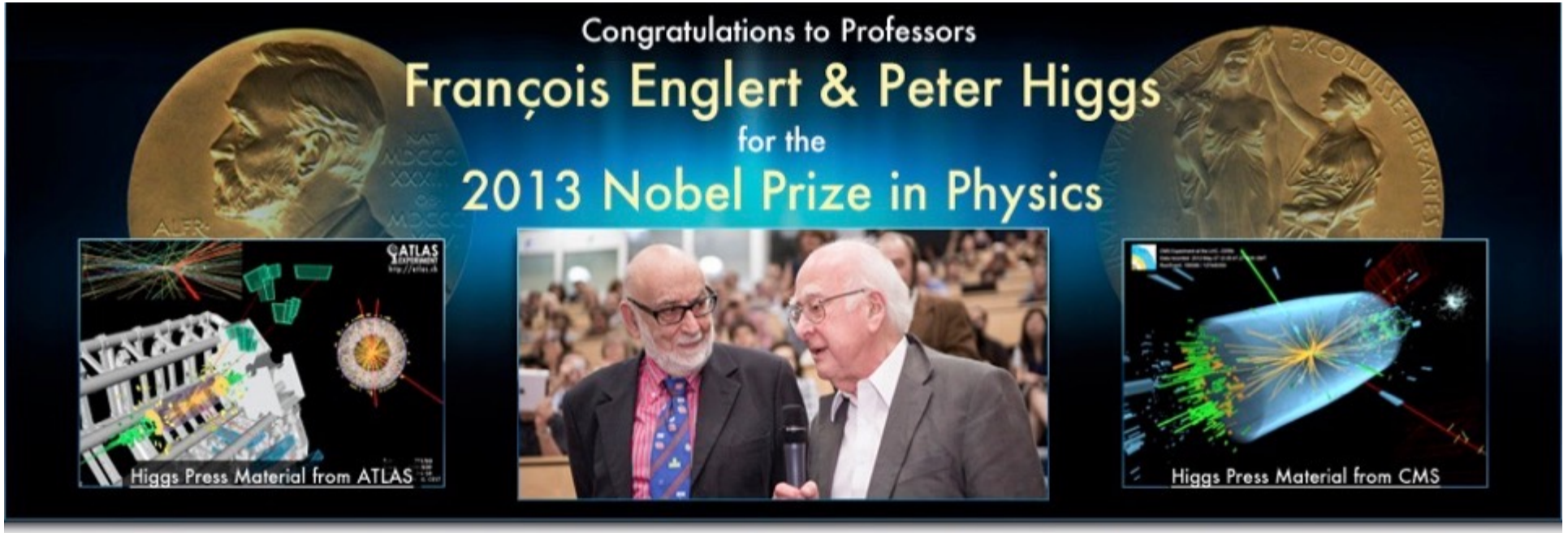
2 million tasks per day
60 GB/s



filte	Romania	filter by Fede	filter by Federation Accounting Name	filter by Site	filter by Alt name	ACTIVE x
Tier	**Country**	**Federations**	**Federation Accounting Name**	**Site Name**	**Alt name**	**State**
2	Romania	RO-LCG	Romanian Tier-2 Federation	RO-13-ISS	Institute of Space Science	ACTIVE
2	Romania	RO-LCG	Romanian Tier-2 Federation	RO-03-UPB	RO-03-UPB	ACTIVE
2	Romania	RO-LCG	Romanian Tier-2 Federation	RO-14-ITIM	National Institute for Research and Development of Isotopic and Molecular Technologies, Cluj-Napoca, Romania	ACTIVE
2	Romania	RO-LCG	Romanian Tier-2 Federation	RO-07-NIPNE	National Institut of Pyshics and Nuclear Engineering, IT Department	ACTIVE
2	Romania	RO-LCG	Romanian Tier-2 Federation	RO-16-UAIC	Alexandru Ioan Cuza University of Iasi	ACTIVE
2	Romania	RO-LCG	Romanian Tier-2 Federation	NIHAM	NIHAM	ACTIVE
2	Romania	RO-LCG	Romanian Tier-2 Federation	RO-11-NIPNE	LHCb Group of the Horia Hulubei National Institute for Physics and Nuclear Engineering (IFIN-HH)	ACTIVE
2	Romania	RO-LCG	Romanian Tier-2 Federation	RO-02-NIPNE	National Institute for Physics and Nuclear Engineering, Bucharest, Romania	ACTIVE

Tim Berners-Lee, World Wide Web inventor

Tim Berners-Lee invented the World Wide Web as an essential tool for high energy physics at CERN from 1989 to 1994.



The ATLAS and CMS experiments at CERN congratulate Professors François Englert and Peter Higgs for their pioneering work in identifying the electro-weak-symmetry-breaking mechanism. CMS and ATLAS independently announced the discovery of a new particle on 4 July 2012, later identified as a Higgs boson, confirming the predictions of Professors Higgs, Englert and others in seminal papers published in 1964. We join in this celebration of the triumph of human curiosity and ingenuity.

Higgs boson discovery was the culmination of the decades of dedicated and intense work by so many collaborators in designing, building and operating ATLAS, and in understanding and analysing the data. None of it would have been possible without the huge dedication also of the LHC accelerator team, the worldwide distributed computing teams, and the continuing support of the governments and funding agencies of the 38 countries home to our 177 member institutes.

We can all feel proud that our experimental observations demonstrated that the insights rewarded by the Nobel prize are realised in nature.

Nobel prizes

One dream of CERN's founders, to achieve European eminence in 'big' science, was realised in 1984, when Carlo Rubbia and Simon Van der Meer received the Nobel Prize in physics for *"their decisive contributions to the large project which led to the discovery of the field particles W and Z, communicators of the weak interaction."* The project was a magnificently executed scheme to collide protons and antiprotons in the existing Super Proton Synchrotron. The experimental results confirmed the unification of weak and electromagnetic forces, the electroweak theory of the Standard Model.

Less than a decade later, Georges Charpak, a CERN physicist since 1959, received the 1992 physics Nobel for *"his invention and development of particle detectors, in particular the multiwire proportional chamber, a breakthrough in the technique for exploring the innermost parts of matter."* Charpak's multiwire proportional chamber, invented in 1968, and his subsequent developments launched the era of fully electronic particle detection. Charpak's detectors are also used for biological research and could eventually replace photographic recording in applied radio-biology. The increased recording speeds translate into faster scanning and lower body doses in medical diagnostic tools based on radiation or particle beams.

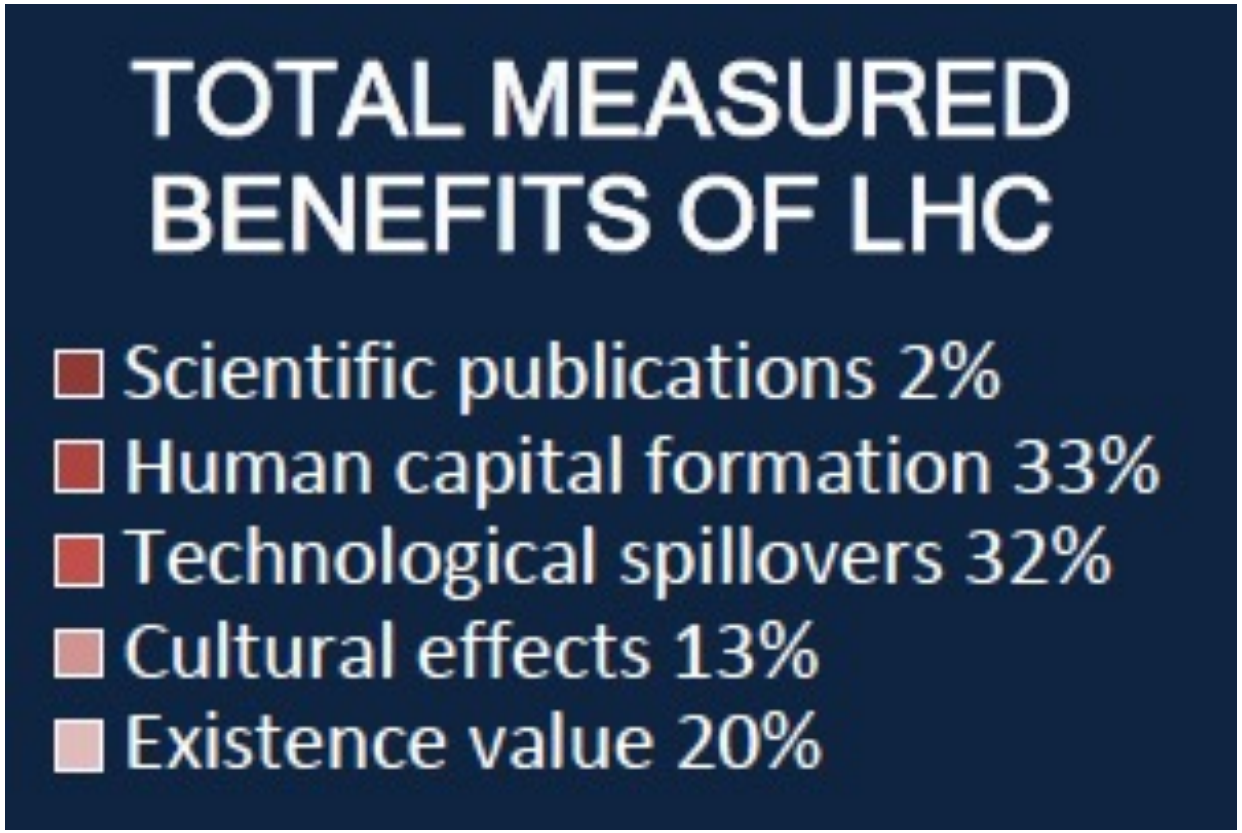
The Laboratory not only attracts Nobel Prizes but also Nobel Laureates. Indeed the first Director-General, Felix Bloch, was awarded the 1952 Nobel prize with Edward Mills Purcell, *"for their development of new methods for nuclear magnetic precision measurements and discoveries in connection therewith."*

The 1976 physics Prize was awarded to the Large Electron–Positron Collider (LEP) experiment L3 spokesman Sam Ting, with Burt Richter, *"for their pioneering work in the discovery of a heavy elementary particle of a new kind."* Discovered in 1974, the particle called J/ψ is a charm quark-antiquark composite.

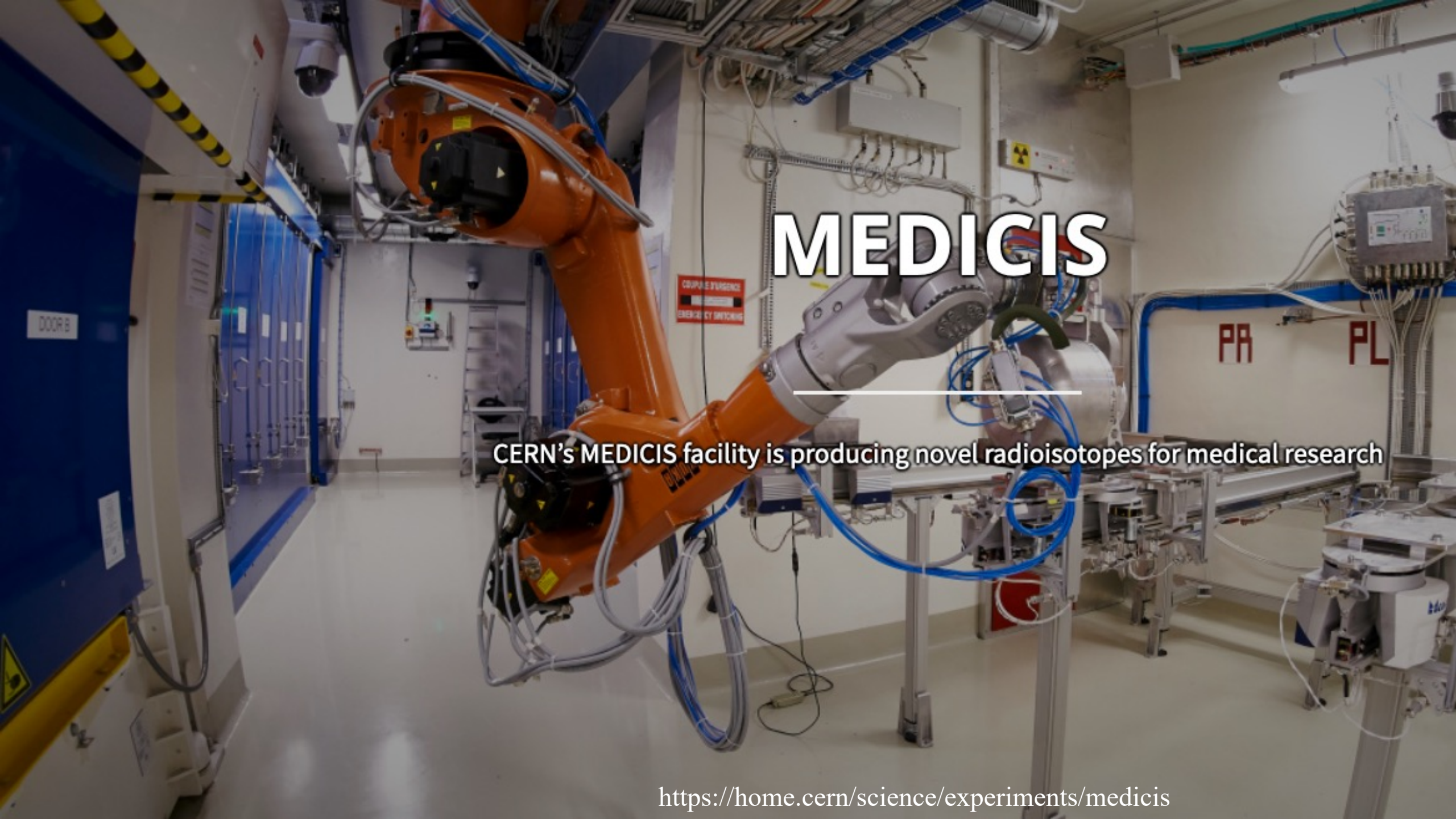
In 1988, Jack Steinberger, a CERN physicist since the late 1960s and head of the LEP ALEPH experiment at the time, was awarded the physics Prize with Leon Lederman and Mel Schwartz, *"for the neutrino beam method and the demonstration of the doublet structure of the leptons through the discovery of the muon neutrino."* The discovery, made in 1962 at the US Brookhaven National Laboratory, showed that there was more than one type of neutrino.

Related links

The Nobel Prize in Physics 1952; The Nobel Prize in Physics 1976; The Nobel Prize in Physics 1984; The Nobel Prize in Physics 1988; The Nobel Prize in Physics 1992



https://cds.cern.ch/record/2025538?ln=en

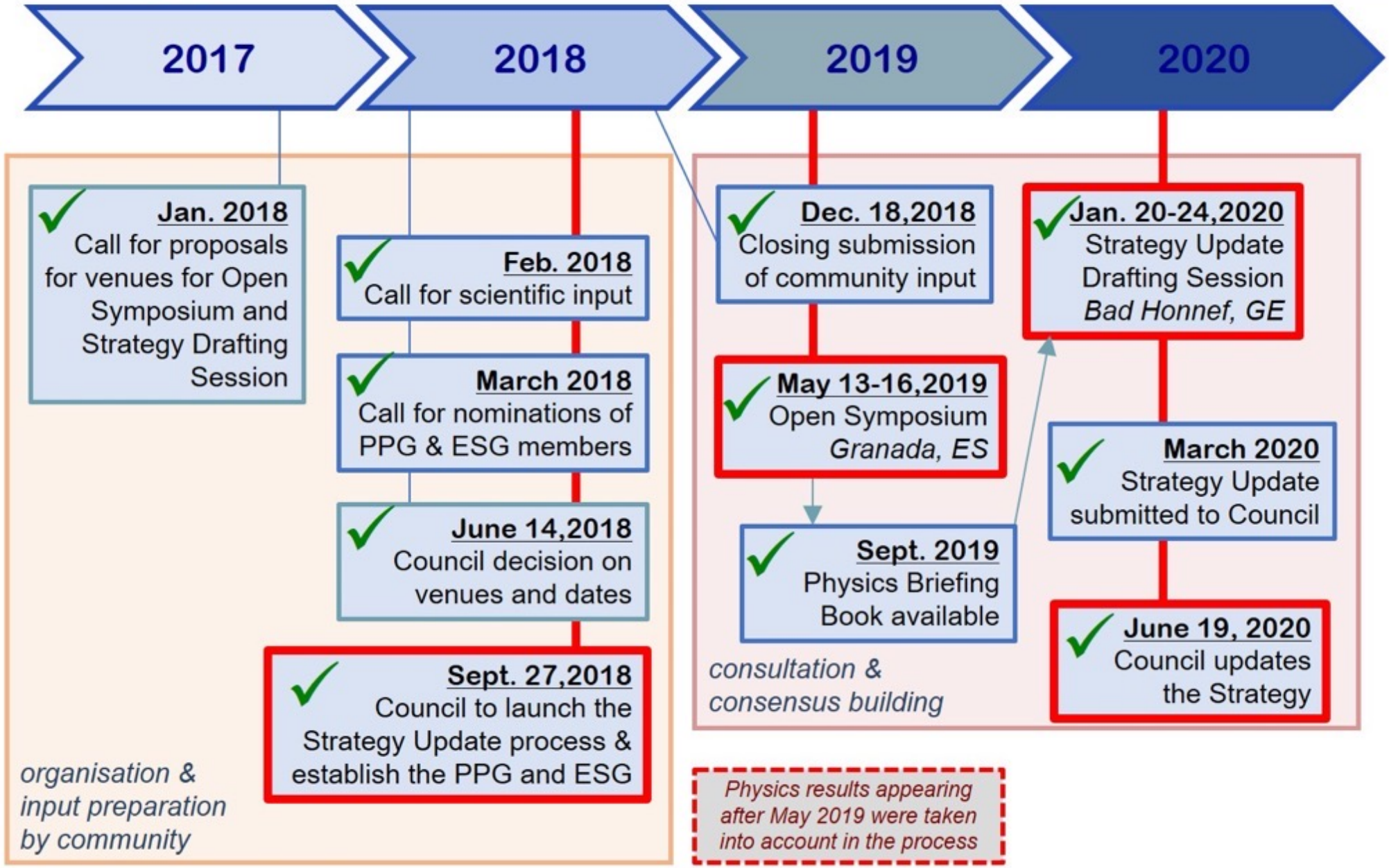


MEDICIS

CERN's MEDICIS facility is producing novel radioisotopes for medical research

https://home.cern/science/experiments/medicis

European Paricle Physics Strategy *Update*



European Strategy for Particle Physics Update 2018 - 2020

https://europeanstrategy.cern/european-strategy-for-particle-physics

_Contents

d) Exploring the fundamental properties of nature inspires and excites. It is part of the duty of researchers to share the excitement of scientific achievements with all stakeholders and the public. The concepts of the Standard Model, a well-established theory for elementary particles, are an integral part of culture. *Public engagement, education and communication in particle physics should continue to be recognised as important components of the scientific activity and receive adequate support. Particle physicists should work with the broad community of scientists to intensify engagement between scientific disciplines. The particle physics community should work with educators and relevant authorities to explore the adoption of basic knowledge of elementary particles and their interactions in the regular school curriculum.*

The International Particle Physics Outreach Group (IPPOG) has been established as a structural collaboration between countries to streamline particle physics education at the high-school level and its role could be further augmented to that of providing public engagement material. The European Particle Physics Communication Network (EPPCN) has proven to be an effective network for the professional communication of particle physics. Its effectiveness would be further improved if the vacancies for EPPCN representatives for all Member and Associate Member States were filled. IPPOG and the EPPCN have excellent opportunities for synergy with APPEC.

CERN has thriving teachers and students programmes, which are also capable of generating valuable data that should be made available to the education research community. Education and training of the next generation of particle physicists and engineers are crucial to sustaining the field in the long term. Good particle physics university education is guaranteed by the many CERN users in academic positions. Vocational education in the fields relevant for CERN should also be encouraged. It is important to be inclusive for all students, and initiatives to address under-represented groups should be supported.

The Science Gateway, under construction at CERN, will offer a golden opportunity to reinforce particle physics public engagement and education, which should be made to radiate across the whole of Europe.

CERN welcomes Romania as its twenty-second Member State

On 17 July 2016, Romania became the twenty-second Member State of CERN

17 JULY, 2016

President of Romania K.W. Iohannis on the occasion of the flag-raising ceremony to mark the accession of Romania as a Member State of CERN with President of CERN Council 2016-2018 S. De Jong and CERN Director-General 2016-2025 F. Gianotti.

https://home.cern/news/news/cern/cern-welcomes-romania-its-twenty-second-member-state

Romania

Romania entered into direct collaboration with CERN in the early 1990s. Even before becoming a CERN member, Romania made significant contributions to the ALICE, ATLAS and LHCb experiments.

Romania became CERN's 22nd Member State on 17 July 2016. The Institute of Atomic Physics is the funding agency covering the Romanian participation in the CERN experiments. In the current national plan, which started in 2016, the Romanian institutions contribute to the following experiments: ALICE, ATLAS, LHCb, WLCG, ISOLDE, NA62, n_TOF, MoEDAL and WA105. The participations are evaluated yearly by an International Scientific Advisory Board. There are four national R&D institutes and six universities from six cities involved in the CERN collaborations, with IFIN-HH being the largest stakeholder. The number of scientists and engineers involved is over 100 and it has been increasing steadily in the last decade.

This page was last updated on 12 May, 2020

CERN contact(s): P. Wells, O. Capatina

116 CERN users - Overview of participation

Industrial Liaison | Knowledge Transfer | Scientific Computing

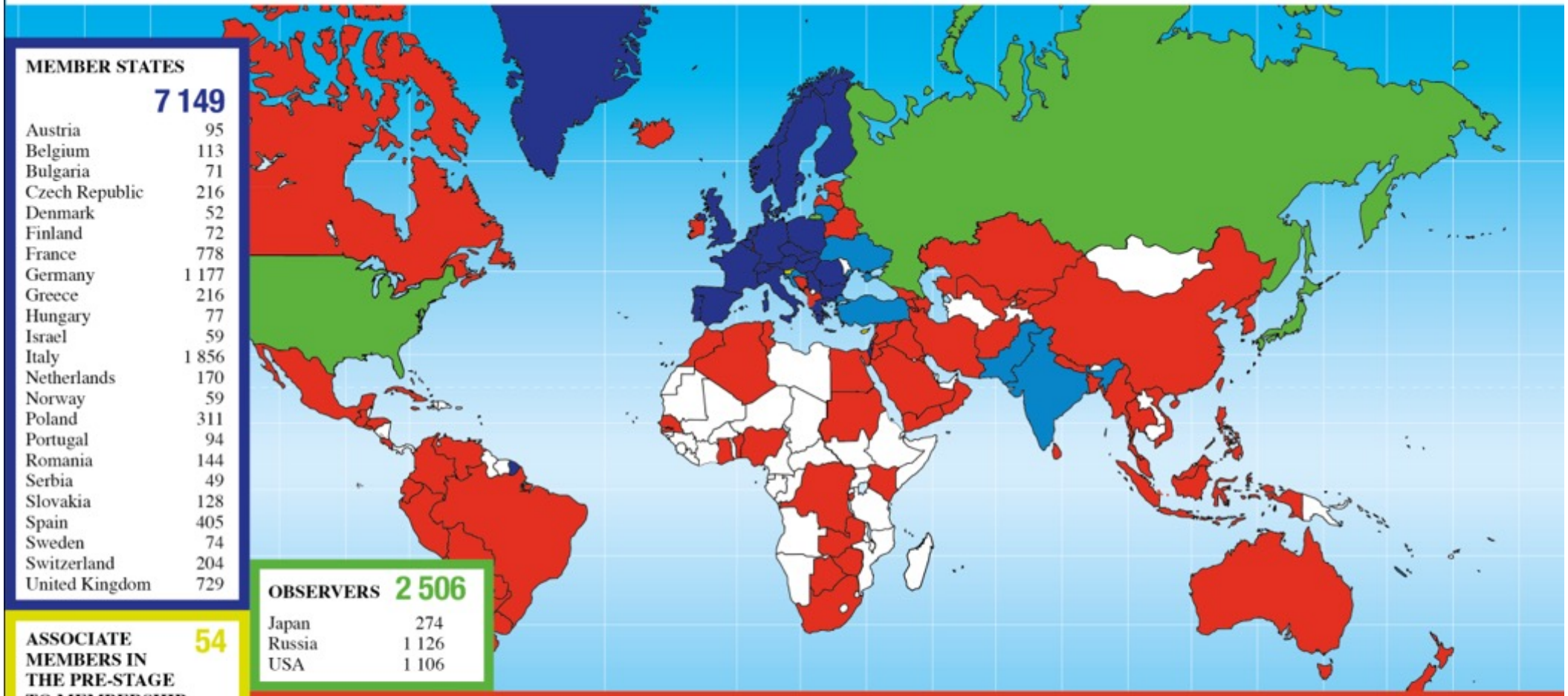
Teacher Student Forum | Communication | Outreach

Experiments	WLCG participation
ALICE , ATLAS , LHCb , DIRAC , ISOLDE , NA62 , CLICdp	Tier 2

Member States

- Austria
- Belgium
- Bulgaria
- Czech Republic
- Denmark
- Finland
- France
- Germany
- Greece
- Hungary
- Israel
- Italy
- Netherlands
- Norway
- Poland
- Portugal
- Romania
- Serbia
- Slovak Republic
- Spain
- Sweden
- Switzerland
- United Kingdom

Distribution of All CERN Users by Nationality on 27 January 2020



MEMBER STATES **7 149**

Austria	95
Belgium	113
Bulgaria	71
Czech Republic	216
Denmark	52
Finland	72
France	778
Germany	1 177
Greece	216
Hungary	77
Israel	59
Italy	1 856
Netherlands	170
Norway	59
Poland	311
Portugal	94
Romania	144
Serbia	49
Slovakia	128
Spain	405
Sweden	74
Switzerland	204
United Kingdom	729

OBSERVERS **2 506**

Japan	274
Russia	1 126
USA	1 106

ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP **54**

Cyprus	21
Slovenia	33

ASSOCIATE MEMBERS **770**

Croatia	47
India	367
Lithuania	31
Pakistan	63
Turkey	162
Ukraine	100

OTHERS

Albania	4	Bolivia	2	Egypt	26	Ireland	14	Montenegro	8	Saint Kitts and Nevis	1	Uzbekistan	3
Algeria	8	Bosnia & Herzegovina	2	El Salvador	1	Jamaica	1	Morocco	26	Saudi Arabia	2	Venezuela	10
Argentina	22	Bostwana	1	Estonia	16	Jordan	2	Myanmar	1	Senegal	1	Viet Nam	10
Armenia	18	Brazil	121	Georgia	54	Kazakhstan	12	Nepal	8	Singapore	4	Yemen	1
Australia	28	Burundi	1	Ghana	1	Kenya	1	New Zealand	6	South Africa	54	Zambia	1
Azerbaijan	7	Canada	155	Gibraltar	1	Korea	161	Nigeria	2	Sri Lanka	6	Zimbabwe	1
Bahrain	3	Chile	21	Guatemala	1	Kyrgyzstan	1	North Korea	3	Sudan	2		
Bangladesh	5	China	569	Hong Kong	1	Latvia	4	North Macedonia	2	Syria	2		
Belarus	49	Colombia	35	Honduras	1	Lebanon	23	Oman	1	Taiwan	47		
Benin	1	Congo	1	Iceland	5	Luxembourg	3	Palestine	7	Thailand	24		
		Costa Rica	1	Indonesia	11	Malaysia	19	Paraguay	1	Tunisia	5		
		Cuba	16	Iran	46	Malta	5	Peru	6	Uruguay	1		
		Ecuador	11	Iraq	1	Mexico	80	Philippines	4				

1 822

HEP landscape (2015)

	staff	Exp.	Theory	GRID
IFIN-HH Bucharest:		103	13	20
Univ. Politehnica Bucharest		4		5
ISS Bucharest:		6	5	5
Univ. Transylvania Brasov:		7		
ITIM Cluj Napoca:		7		4
Univ. Constanta:			1	
Univ. Craiova:			5	
Univ. Al. Ioan Cuza Iasi:		2	5	5
Univ. Stefan cel Mare Suceava:		4		
West Univ. Timisoara:		1	4	
TOTAL (staff): 206		134 (65%)	33 (16%)	39 (19%)

MINISTERUL CERCETĂRII ŞI INOVĂRII

HOME

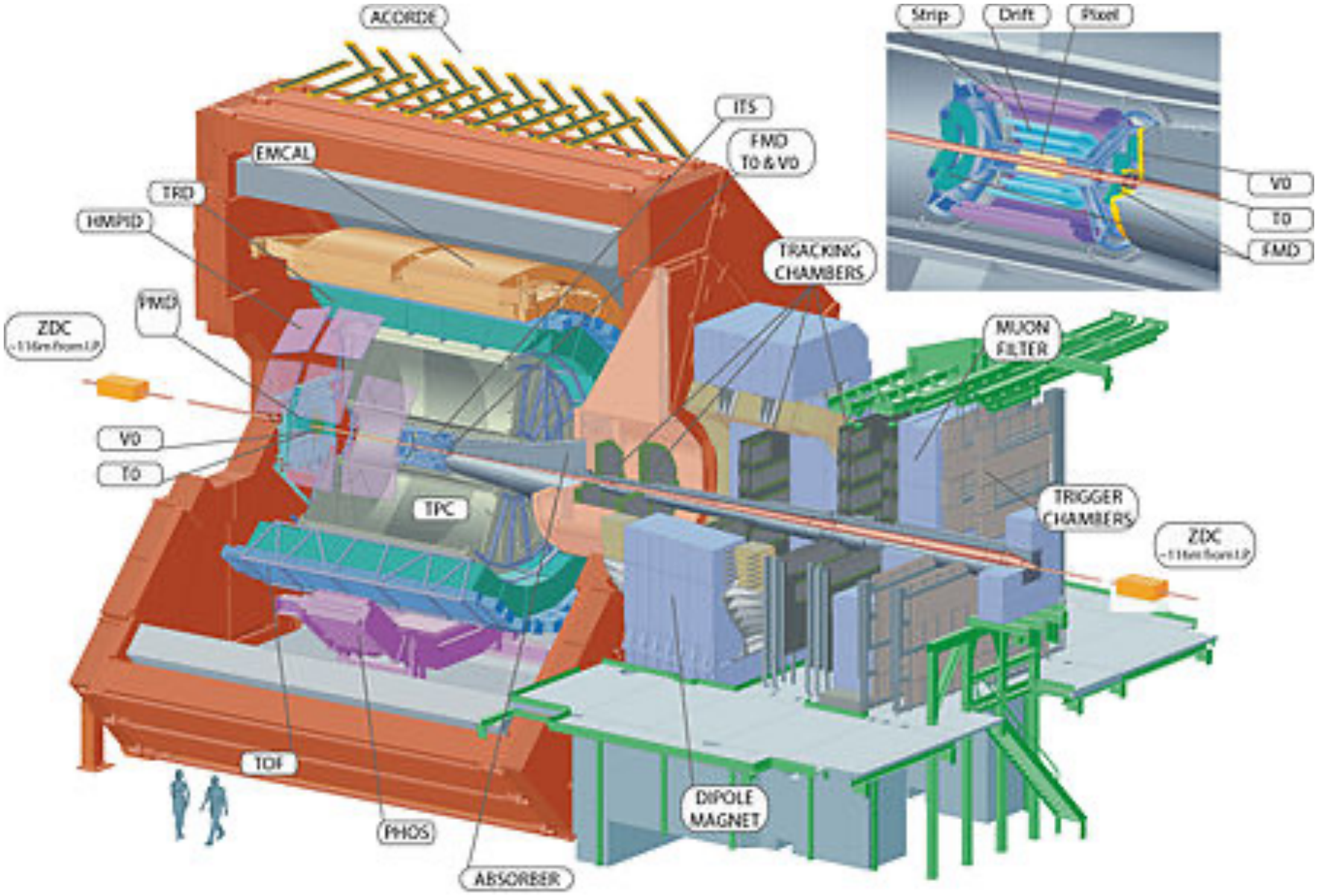
Programul CERN-RO

https://www.ifa-mg.ro/cern/programul-cern-ro.php

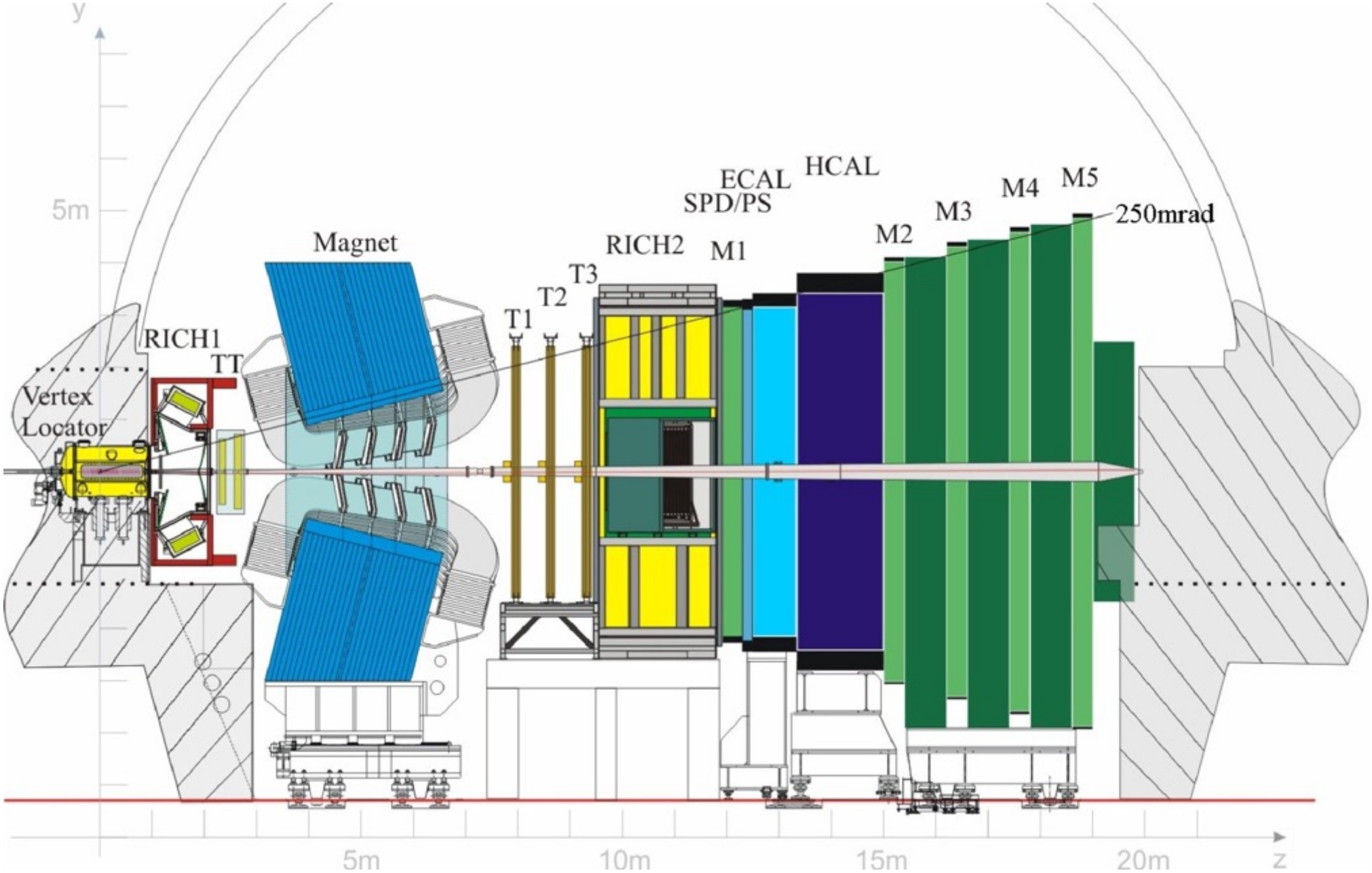
Experiment	Conducator proiect(CO)/ Parteneri	Director proiect	Titlul si rezumatul proiectului
ALICE	CO: IFIN-HH	Mihai PETROVICI mpetro@ifin.nipne.ro	Contributia IFIN-HH la experimentul ALICE de la CERN
	CO: ISS	Catalin RISTEA catalin.ristea@spacescience.ro	Descrierea QGP folosind metode de curgere si jeturi
ATLAS EXPERIMENT	CO: IFIN-HH	Calin ALEXA calin.alexa@cern.ch	Experimentul ATLAS de la LHC
	P1: ITIM-CJ		
	P2: UPB		
	P3: UAIC		
	P4: UVT		
	P5: UTB		
LHCb	CO: IFIN-HH	Florin MACIUC florin.maciuc@nipne.ro	LHCb – studiul productiei de hadroni, fizica aromelor pentru particule masive si programul de upgrade
	P1: USV		
WLCG	CO: IFIN-HH	Mihnea DULEA mid@ifin.nipne.ro	Contributia nationala la dezvoltarea gridului de calcul LCG pentru fizica particulelor elementare
	P1: ISS		
	P2: ITIM-CJ		
	P3: UAIC		
	P4: UPB		
ISOLDE	CO: IFIN-HH	Nicolae Marius MARGINEAN nicu@tandem.nipne.ro	Studii experimentale si teoretice asupra nucleelor exotice la ISOLDE
n_TOF	CO: IFIN-HH	Tudor GLODARIU glodariu@ifin.nipne.ro	Colaborarea n_TOF CERN
NA62	CO: IFIN-HH	Alexandru-Mario BRAGADIREANU mario.bragadireanu@nipne.ro	Studiul dezintegrarilor rare ale kaonilor la CERN SPS
RD50	CO: INCDFM	Ioana PINTILIE ioana@infim.ro	Inginerie de defecte in detectorii de siliciu de tip p pentru viitoarele experimente LHC
MoEDAL	CO: ISS	Vlad POPA vpopa@spacescience.ro	Contributia romaneasca la MoEDAL
WA105	CO:UB-FF	Ionel LAZANU ionel.lazanu@g.unibuc.ro	Contributii la fizica neutrinilor folosind prototipuri de dimensiuni mari de detectori cu Ar lichid


CMS Experiment
ATLAS Experiment
ALICE Experiment
LHCb Experiment

ALICE Experiment

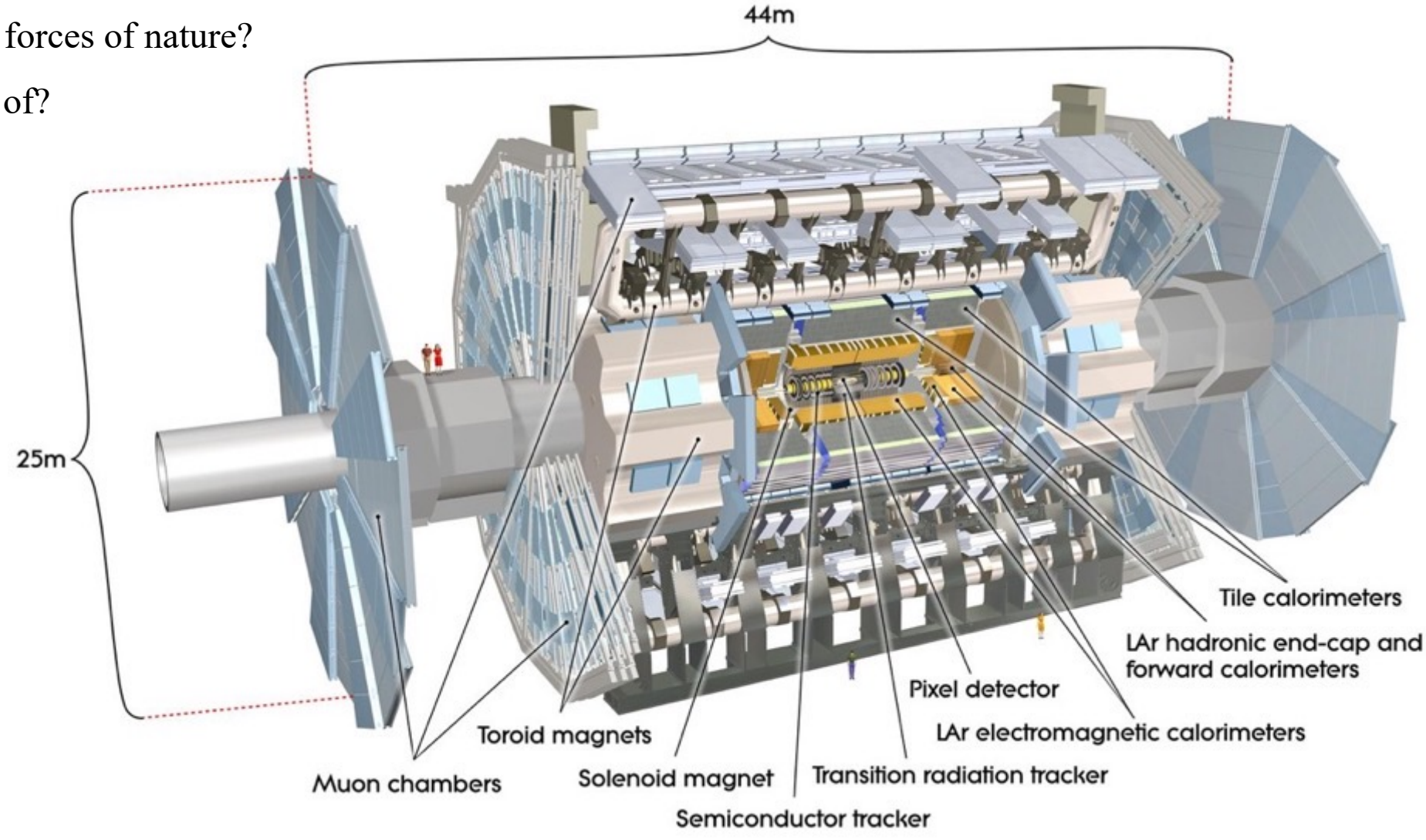


LHCb Experiment



ATLAS Experiment

- to exploit the full discovery potential of the LHC, pushing the frontiers of scientific knowledge
- precision measurement to push the frontiers of knowledge by seeking answers to fundamental questions such as
  - What are the basic building blocks of matter?
  - What are the fundamental forces of nature?
  - What is dark matter made of?



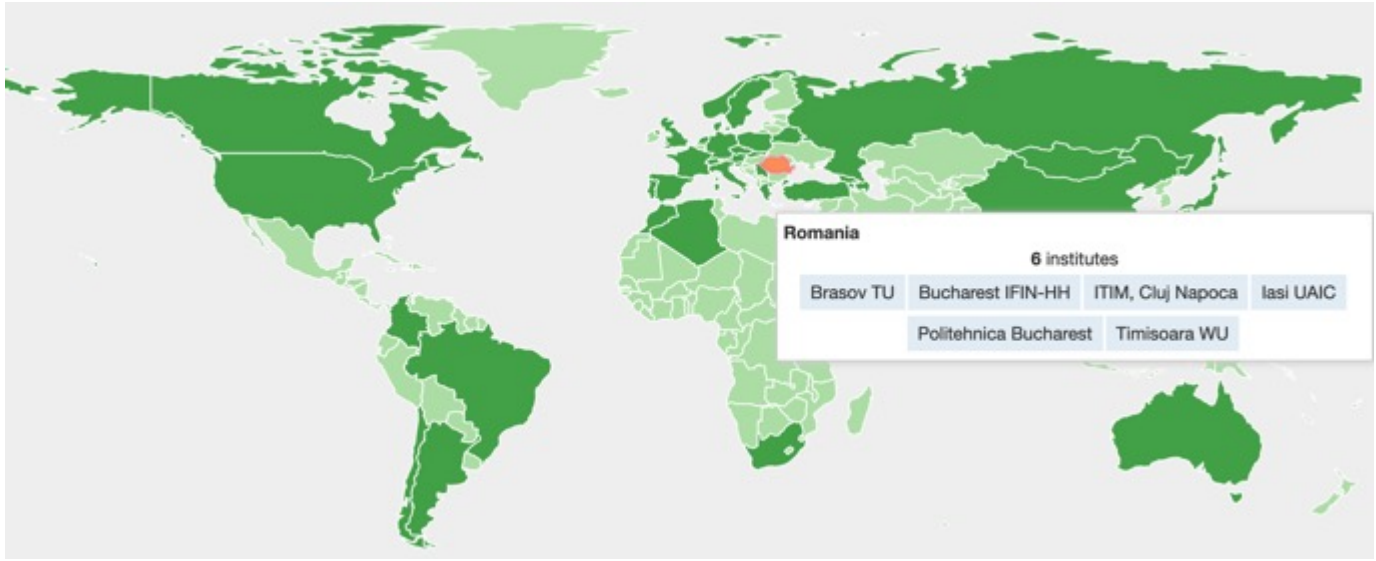
ATLAS Collaboration (Oct. 2020)

180 Institutions	162 Institutes (single)
from 38 countries	18 Clusters (61 Institutes in Clusters)
	12 Associate Institutes
	235 Institutes
	9 Technical Associate Institutes

- Active ATLAS Members	~	5800
(Physicists, Engineers, Technicians, Students, Administrators)		
- Scientific Authors		2830
- With PhD, contributing to M&O share		1912
- PhD Students	~	1200
- Master / Diploma Students	~	500

ATLAS Experiment - Exploring the secrets of the Universe https://atlas.cern/

Romanian ATLAS cluster



short name	name	active members	physicist	PhD std	master	ugraduate	eng PhD	eng	eng std	tech	admin
Brasov TU	Transilvania University of Brasov	3	0	0	0	0	2	1	0	0	0
Bucharest IFIN-HH	Horia Hulubei National Institute of Physics and Nuclear Engineering	22	14	4	0	0	3	1	0	0	0
ITIM, Cluj Napoca	National Institute for Research and Development of Isotopic and Molecular Technologies	16	1	0	0	0	4	6	0	5	0
Iasi UAIC	Alexandru Ioan Cuza University of Iasi	8	6	0	0	0	0	2	0	0	0
Politehnica Bucharest	University Politehnica Bucharest	14	0	0	0	0	4	6	4	0	0
Timisoara WU	West University in Timisoara	1	1	0	0	0	0	0	0	0	0
	total:	64	22	4	0	0	13	16	4	5	0

ATLAS CERN-RO project: human resources

- 75 members of the project: 18 physicists, 37 engineers, 5 PhD students, 2 technicians, 11 workers.

OTP - Operation Task Planner

Activity	Task
Detector Operation	ATLAS Calo/Fwd Shadow Shifts (ACR)
Detector Operation	ATLAS Calo/Fwd Shifts (ACR)
Detector Operation	Calo shifter (obsolete)
Detector Operation	ATLAS Run Control Shifter (ACR)
Detector Operation	DAQ/HLT shifts
Detector Operation	Tile ACR shifter
Detector Operation	Control & Config. on-call
Detector Operation	DAQ/HLT on-call
Detector Operation	Network on-call
Detector Operation	System Administrator on shift
Detector Operation	System administrator on-call
Computing/Software	Distributed Analysis Trainee Shifts
Computing/Software	Distributed Analysis Shifts 1st level
Data Preparation	Offline (general) DQ shifts (REMOTE)
Data Preparation	Offline DQ Shifter -- Calo Combined
Data Preparation	Offline DQ shifts (DQ-SCR or REMOTE) (Archive)
Data Preparation	LAr Data Inspection and Signoff
Detector Operation	L1 RPC Barrel Muon Trigger on-call (16 1853)
Detector Operation	Main LVL1 On-Call
Detector Operation	Muon Data Quality Expert Shifter
Detector Operation	Muon Data Quality Shifter
Detector Operation	RPC: Primary on-call: DAQ/LV1 OBSOLETE
Data Preparation	DQM Team Leader
Detector Operation	Tile DCS expert on call
Detector Operation	Tile DQ validator
Detector Operation	Tile SCR/Remote shifter Online DQ (finished by Dec-2010)
Detector Operation	Control & Configuration
Detector Operation	Networking
Detector Operation	ReadOut
Detector Operation	Sys. Admins.
Analysis Support	Generator Software
Analysis Support	Internal Software
Analysis Support	Performance Studies - Egamma
Analysis Support	Performance Studies - JetETmiss
Analysis Support	Performance Studies - Muon CP
Analysis Support	Performance Studies - Tracking CP
Computing/Software	ASCIG
Computing/Software	Analysis Model Group
Computing/Software	Cloud Operation & Management
Computing/Software	Core services: framework, geometry, EDM etc.
Computing/Software	Group activities
Computing/Software	SUSY Performance -Obsolete after 31 Dec 2012
Computing/Software	Simulation
Data Preparation	DCC Maintanence and Development
Data Preparation	Non-collision background task force
Data Preparation	Offline DQ Infrastructure Software
Detector Operation	Convener e/gamma CP
Trigger	Tau Efficiency and Optimisation
Trigger	e/g Efficiency and Optimisation
Trigger	e/g Software maintenance
Computing/Software	Cabling maps
Detector Operation	Muon DCS Maintenance
Detector Operation	RPC operation and maintenance
Trigger	Muon Detector related Trigger
Data Preparation	DCS Data OFL Monitoring
Data Preparation	HV/Gain Calibration
Data Preparation	Monitoring and DQ Tools Development
Data Preparation	Simulation Performance monitor (obsolete)
Detector Operation	Demonstrator Phase-II
Detector Operation	Tile Drawer Tools and Diagnostics Maintenance
Detector Operation	Tile fLVPS Power Supply Repair and Modification
Detector Operation	Tile on detector readout and control electronics maintenance during shutdown
Computing/Software	RO Romanian Tier-2 Federation
Computing/Software	US Tier-1
Detector Operation	Phase-I TDAQ Upgrade Construction
Detector Operation	Phase-II TDAQ Upgrade Construction
Detector Operation	Phase-I NSW Upgrade Construction
Detector Operation	Phase-I Tiles Upgrade Construction
Detector Operation	Phase-II Tiles Upgrade Construction


PROTON PHYSICS: RAMP DOWN
2783 GeV
ATLAS
EXPERIMENT
ATLAS Control Room

ATLAS SUSY Searches* - 95% CL Lower Limits

July 2020

ATLAS Preliminary

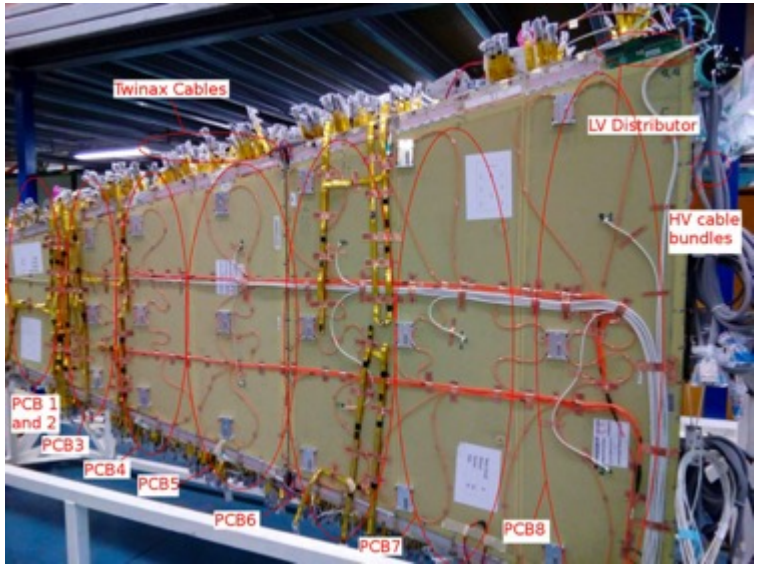
$\sqrt{s}$ = 13 TeV

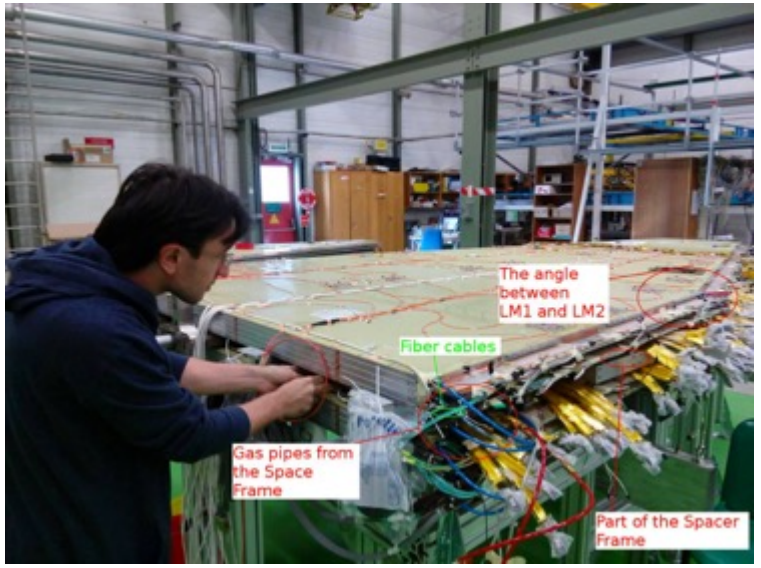
	Model	Signature			$\int \mathcal{L}\, dt$ [fb^{-1}]	Mass limit	Reference
Inclusive Searches	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	0 e,μ	2-6 jets	E_T^{miss}	139	$\tilde{q}$ [10x Degen.] 1.9 — m($\tilde{\chi}_1^0$)<400 GeV	ATLAS-CONF-2019-040
		mono-jet	1-3 jets	E_T^{miss}	36.1	$\tilde{q}$ [1x, 8x Degen.] 0.43 0.71 — m($\tilde{q}$)-m($\tilde{\chi}_1^0$)=5 GeV	1711.03301
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0 e,μ	2-6 jets	E_T^{miss}	139	$\tilde{g}$ 2.35 — m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2019-040
						$\tilde{g}$ Forbidden 1.15-1.95 — m($\tilde{\chi}_1^0$)=1000 GeV	ATLAS-CONF-2019-040
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}W\tilde{\chi}_1^0$	1 e,μ	2-6 jets		139	$\tilde{g}$ 2.2 — m($\tilde{\chi}_1^0$)<600 GeV	ATLAS-CONF-2020-047
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}(\ell\ell)\tilde{\chi}_1^0$	$ee,\mu\mu$	2 jets	E_T^{miss}	36.1	$\tilde{g}$ 1.2 — m($\tilde{g}$)-m($\tilde{\chi}_1^0$)=50 GeV	1805.11381
	$\tilde{g}\tilde{g}, \tilde{g}\to qqWZ\tilde{\chi}_1^0$	0 e,μ	7-11 jets	E_T^{miss}	139	$\tilde{g}$ 1.97 — m($\tilde{\chi}_1^0$) <600 GeV	ATLAS-CONF-2020-002
		SS e,μ	6 jets		139	$\tilde{g}$ 1.15 — m($\tilde{g}$)-m($\tilde{\chi}_1^0$)=200 GeV	1909.08457
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	E_T^{miss}	79.8	$\tilde{g}$ 2.25 — m($\tilde{\chi}_1^0$)<200 GeV	ATLAS-CONF-2018-041
		SS e,μ	6 jets		139	$\tilde{g}$ 1.25 — m($\tilde{g}$)-m($\tilde{\chi}_1^0$)=300 GeV	1909.08457
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0/t\tilde{\chi}_1^*$		Multiple		36.1	$\tilde{b}_1$ Forbidden 0.9 — m($\tilde{\chi}_1^0$)=300 GeV, BR($b\tilde{\chi}_1^0$)=1	1708.09266, 1711.03301
			Multiple		139	$\tilde{b}_1$ Forbidden 0.74 — m($\tilde{\chi}_1^0$)=200 GeV, m($\tilde{\chi}_1^*$)=300 GeV, BR($t\tilde{\chi}_1^*$)=1	1909.08457
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_2^0\to bh\tilde{\chi}_1^0$	0 e,μ	6 b	E_T^{miss}	139	$\tilde{b}_1$ Forbidden 0.23-1.35 — Δm($\tilde{\chi}_2^0$,$\tilde{\chi}_1^0$)=130 GeV, m($\tilde{\chi}_1^0$)=100 GeV	1908.03122
		2 τ	2 b	E_T^{miss}	139	$\tilde{b}_1$ 0.13-0.85 — Δm($\tilde{\chi}_2^0$,$\tilde{\chi}_1^0$)=130 GeV, m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2020-031
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to t\tilde{\chi}_1^0$	0-1 e,μ	$\geq$ 1 jet	E_T^{miss}	139	$\tilde{t}_1$ 1.25 — m($\tilde{\chi}_1^0$)=1 GeV	ATLAS-CONF-2020-003, 2004.14060
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}_1^0$	1 e,μ	3 jets/1 b	E_T^{miss}	139	$\tilde{t}_1$ 0.44-0.59 — m($\tilde{\chi}_1^0$)=400 GeV	ATLAS-CONF-2019-017
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to \tilde{\tau}_1 b\nu, \tilde{\tau}_1\to\tau\tilde{G}$	1 τ + 1 e,μ,τ	2 jets/1 b	E_T^{miss}	36.1	$\tilde{t}_1$ 1.16 — m($\tilde{\tau}_1$)=800 GeV	1803.10178
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$ / $\tilde{c}\tilde{c}, \tilde{c}\to c\tilde{\chi}_1^0$	0 e,μ	2 c	E_T^{miss}	36.1	$\tilde{c}$ 0.85 — m($\tilde{\chi}_1^0$)=0 GeV	1805.01649
						$\tilde{t}_1$ 0.46 — m($\tilde{t}_1$,$\tilde{c}$)-m($\tilde{\chi}_1^0$)=50 GeV	1805.01649
		0 e,μ	mono-jet	E_T^{miss}	36.1	$\tilde{t}_1$ 0.43 — m($\tilde{t}_1$,$\tilde{c}$)-m($\tilde{\chi}_1^0$)=5 GeV	1711.03301
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to t\tilde{\chi}_2^0, \tilde{\chi}_2^0\to Z/h\tilde{\chi}_1^0$	1-2 e,μ	1-4 b	E_T^{miss}	139	$\tilde{t}_1$ 0.067-1.18 — m($\tilde{\chi}_2^0$)=500 GeV	SUSY-2018-09
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1 + Z$	3 e,μ	1 b	E_T^{miss}	139	$\tilde{t}_2$ Forbidden 0.86 — m($\tilde{\chi}_1^0$)=360 GeV, m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)= 40 GeV	SUSY-2018-09
EW direct	$\tilde{\chi}_1^*\tilde{\chi}_2^0$ via WZ	3 e,μ		E_T^{miss}	139	$\tilde{\chi}_1^*/\tilde{\chi}_2^0$ 0.64 — m($\tilde{\chi}_1^0$)=0	ATLAS-CONF-2020-015
		$ee,\mu\mu$	$\geq$ 1 jet	E_T^{miss}	139	$\tilde{\chi}_1^*/\tilde{\chi}_2^0$ 0.205 — m($\tilde{\chi}_1^*$)-m($\tilde{\chi}_1^0$)=5 GeV	1911.12606
	$\tilde{\chi}_1^*\tilde{\chi}_1^*$ via WW	2 e,μ		E_T^{miss}	139	$\tilde{\chi}_1^*$ 0.42 — m($\tilde{\chi}_1^0$)=0	1908.08215
	$\tilde{\chi}_1^*\tilde{\chi}_2^0$ via Wh	0-1 e,μ	2 b/2 γ	E_T^{miss}	139	$\tilde{\chi}_1^*/\tilde{\chi}_2^0$ Forbidden 0.74 — m($\tilde{\chi}_1^0$)=70 GeV	2004.10894, 1909.09226
	$\tilde{\chi}_1^*\tilde{\chi}_1^*$ via $\tilde{l}_L/\tilde{\nu}$	2 e,μ		E_T^{miss}	139	$\tilde{\chi}_1^*$ 1.0 — m($\tilde{l}$,$\tilde{\nu}$)=0.5(m($\tilde{\chi}_1^*$)+m($\tilde{\chi}_1^0$))	1908.08215
	$\tilde{\tau}\tilde{\tau}, \tilde{\tau}\to\tau\tilde{\chi}_1^0$	2 τ		E_T^{miss}	139	$\tilde{\tau}$ [$\tilde{\tau}_L$, $\tilde{\tau}_{R,L}$] 0.16-0.3 0.12-0.39 — m($\tilde{\chi}_1^0$)=0	1911.06660
	$\tilde{l}_{L,R}\tilde{l}_{L,R}, \tilde{l}\to l\tilde{\chi}_1^0$	2 e,μ	0 jets	E_T^{miss}	139	$\tilde{l}$ 0.7 — m($\tilde{\chi}_1^0$)=0	1908.08215
		$ee,\mu\mu$	$\geq$ 1 jet	E_T^{miss}	139	$\tilde{l}$ 0.256 — m($\tilde{l}$)-m($\tilde{\chi}_1^0$)=10 GeV	1911.12606
	$\tilde{H}\tilde{H}, \tilde{H}\to h\tilde{G}/Z\tilde{G}$	0 e,μ	$\geq$ 3 b	E_T^{miss}	36.1	$\tilde{H}$ 0.13-0.23 0.29-0.88 — BR($\tilde{\chi}_1^0\to h\tilde{G}$)=1	1806.04030
		4 e,μ	0 jets	E_T^{miss}	139	$\tilde{H}$ 0.55 — BR($\tilde{\chi}_1^0\to Z\tilde{G}$)=1	ATLAS-CONF-2020-040
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^*$	Disapp. trk	1 jet	E_T^{miss}	36.1	$\tilde{\chi}_1^*$ 0.46 — Pure Wino	1712.02118
						$\tilde{\chi}_1^*$ 0.15 — Pure higgsino	ATL-PHYS-PUB-2017-019
	Stable $\tilde{g}$ R-hadron		Multiple		36.1	$\tilde{g}$ 2.0	1902.01636,1808.04095
	Metastable $\tilde{g}$ R-hadron, $\tilde{g}\to qq\tilde{\chi}_1^0$		Multiple		36.1	$\tilde{g}$ [$\tau(\tilde{g})$ =10 ns, 0.2 ns] 2.05 2.4 — m($\tilde{\chi}_1^0$)=100 GeV	1710.04901,1808.04095
RPV	$\tilde{\chi}_1^*\tilde{\chi}_1^0/\tilde{\chi}_1^0, \tilde{\chi}_1^*\to Z\ell\to\ell\ell\ell$	3 e,μ			139	$\tilde{\chi}_1^*/\tilde{\chi}_1^0$ [BR($Z\tau$)=1, BR(Ze)=1] 0.625 1.05 — Pure Wino	ATLAS-CONF-2020-009
	LFV $pp\to\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu,e\tau,\mu\tau$			3.2	$\tilde{\nu}_\tau$ 1.9 — λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
	$\tilde{\chi}_1^*\tilde{\chi}_1^0/\tilde{\chi}_2^0\to WW/Z\ell\ell\ell\ell\nu\nu$	4 e,μ	0 jets	E_T^{miss}	36.1	$\tilde{\chi}_1^*/\tilde{\chi}_2^0$ [$\lambda_{133}\neq 0, \lambda_{124}\neq 0$] 0.82 1.33 — m($\tilde{\chi}_1^0$)=100 GeV	1804.03602
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^0, \tilde{\chi}_1^0\to qqq$		4-5 large-R jets		36.1	$\tilde{g}$ [m($\tilde{\chi}_1^0$)=200 GeV, 1100 GeV] 1.3 1.9 — Large λ''_{112}	1804.03568
			Multiple		36.1	$\tilde{g}$ [λ''_{112}=2e-4, 2e-5] 1.05 2.0 — m($\tilde{\chi}_1^0$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}\tilde{t}, \tilde{t}\to t\tilde{\chi}_1^0, \tilde{\chi}_1^0\to tbs$		Multiple		36.1	$\tilde{t}$ [λ''_{323}=2e-4, 1e-2] 0.55 1.05 — m($\tilde{\chi}_1^0$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}\tilde{t}, \tilde{t}\to b\tilde{\chi}_1^*, \tilde{\chi}_1^*\to bbs$		$\geq$ 4b		139	$\tilde{t}$ Forbidden 0.95 — m($\tilde{\chi}_1^*$)=500 GeV	ATLAS-CONF-2020-016
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to bs$		2 jets + 2 b		36.7	$\tilde{t}_1$ [qq, bs] 0.42 0.61	1710.07171
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to q\ell$	2 e,μ	2 b		36.1	$\tilde{t}_1$ 0.4-1.45 — BR($\tilde{t}_1\to be/b\mu$)>20%	1710.05544
		1 μ	DV		136	$\tilde{t}_1$ [1e-10< λ'_{23k} <1e-8, 3e-10< λ'_{23k} <3e-9] 1.0 1.6 — BR($\tilde{t}_1\to q\mu$)=100%, cosθ=1	2003.11956

10^{-1} 1 **Mass scale [TeV]**

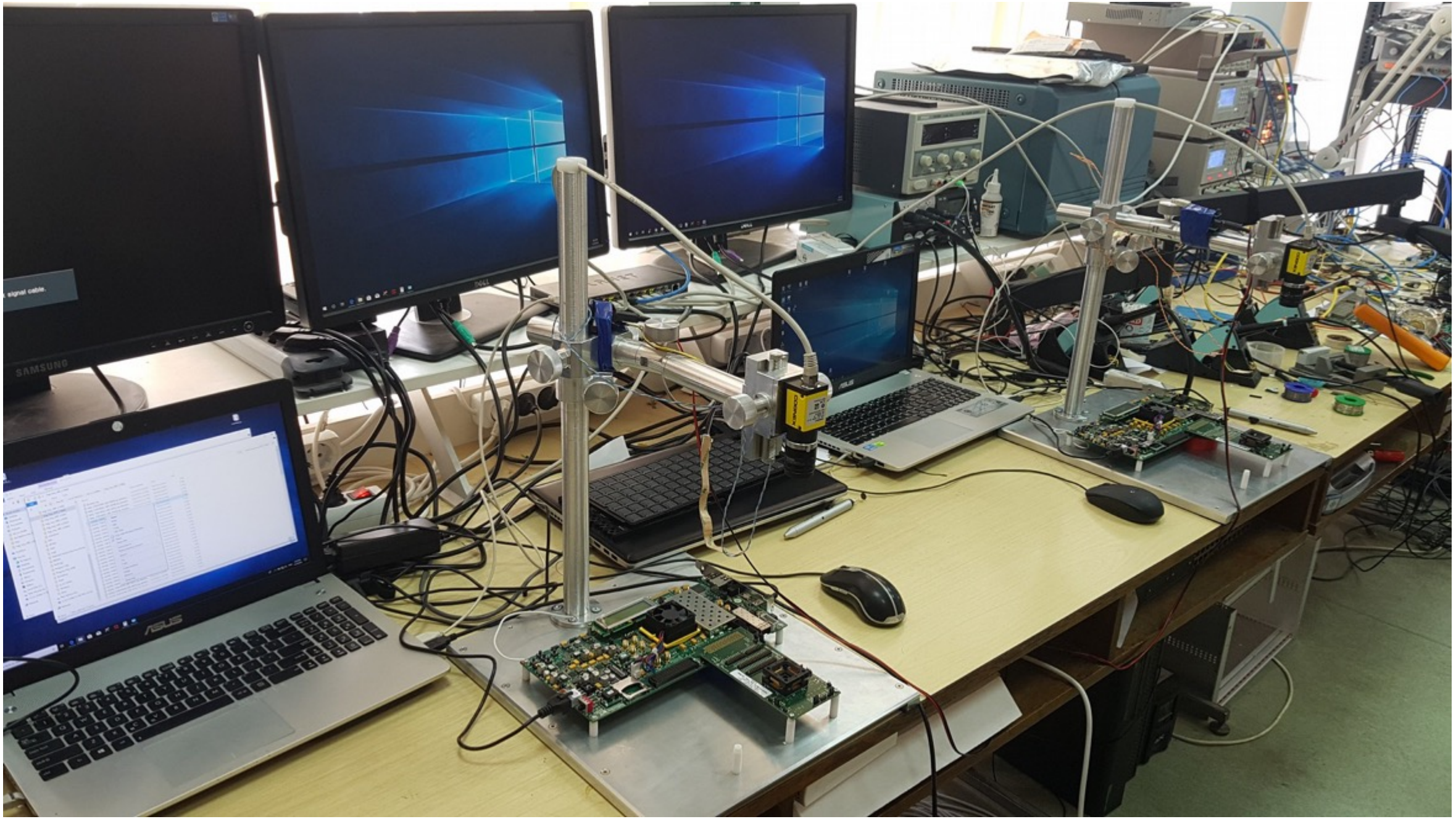
**Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.*

Integration & Commissioning





ASIC design, prototyping, production and testing

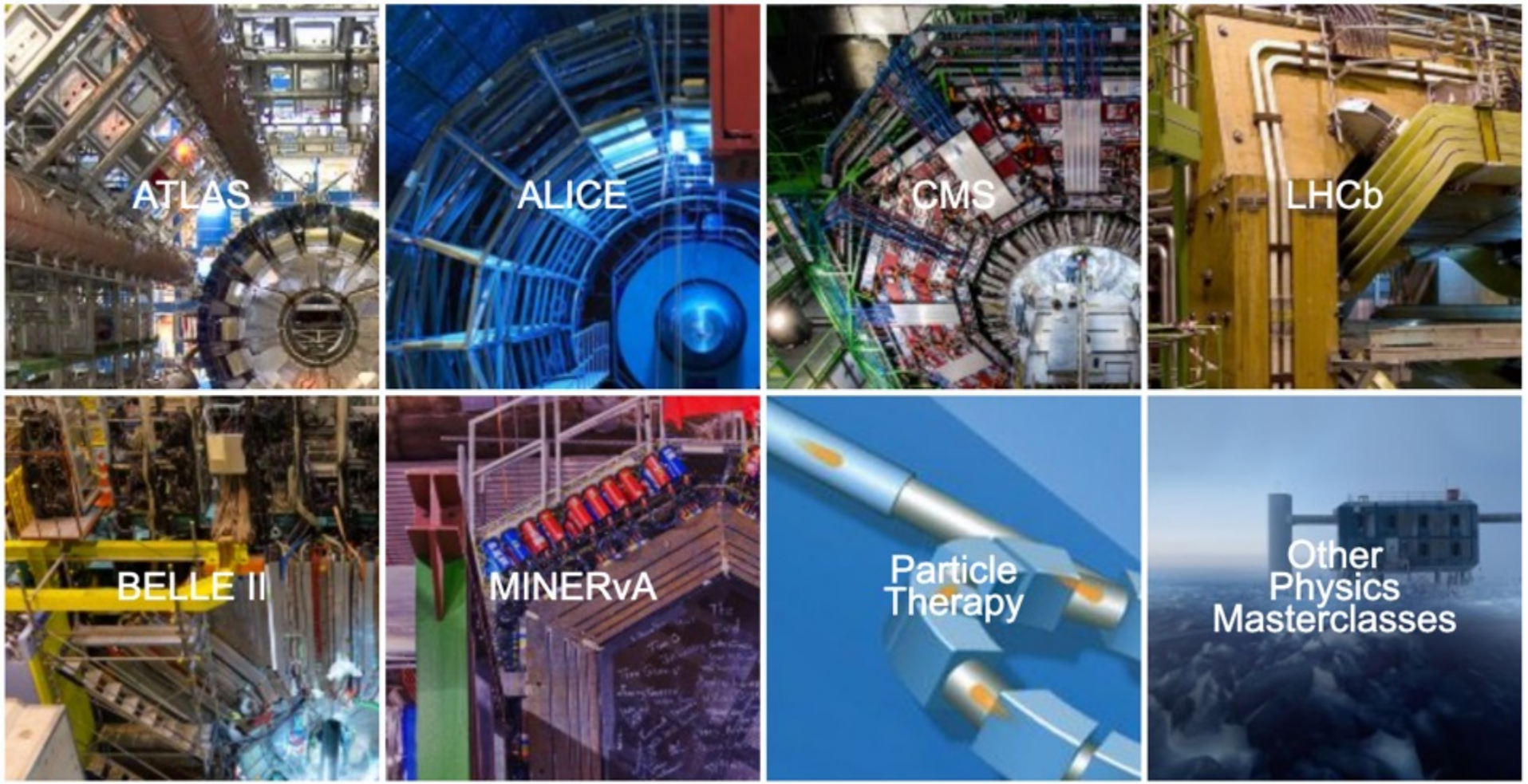


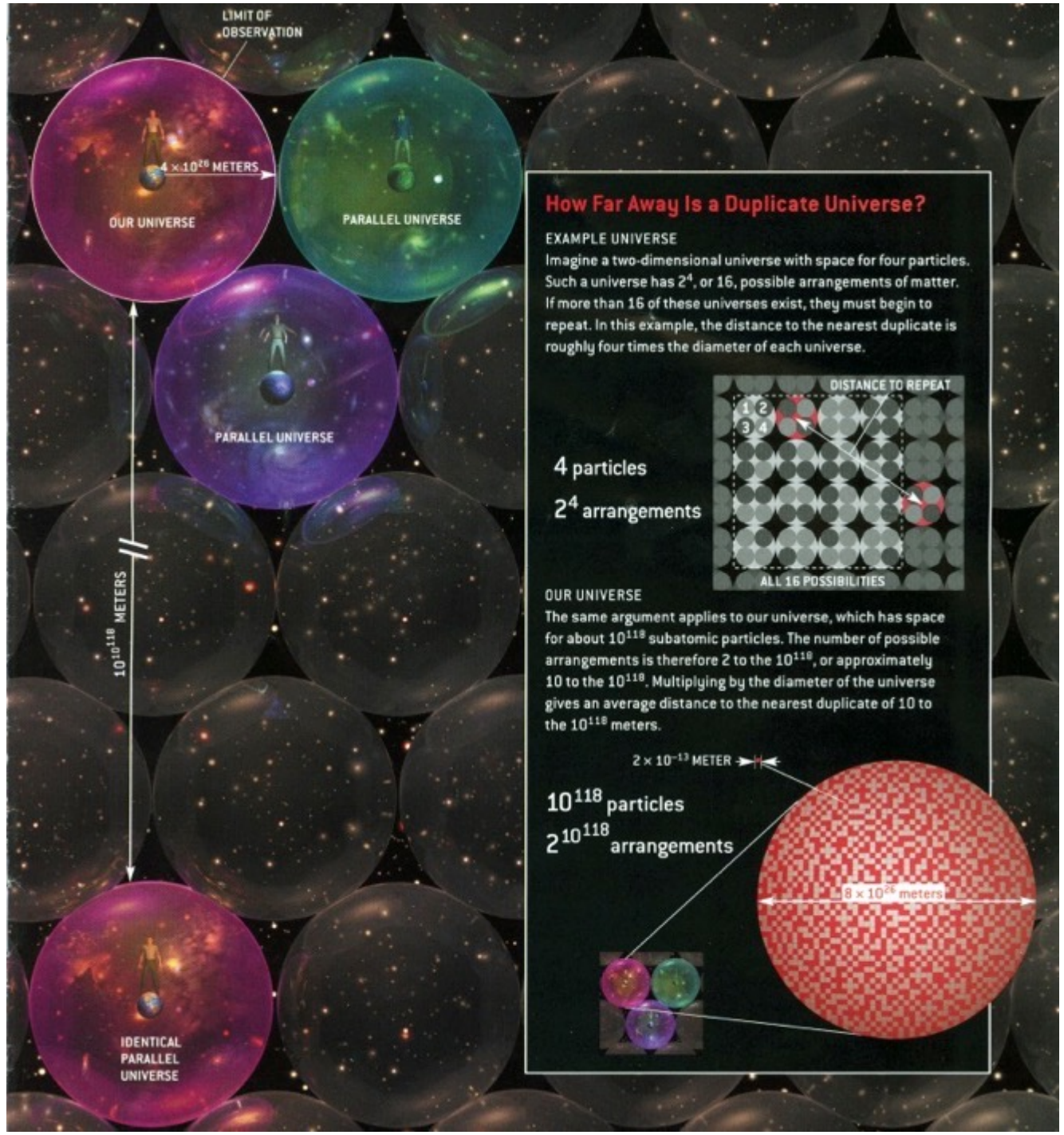
Outreach

International Particle Physics Outreach Group

INTERNATIONAL MASTERCLASSES

hands on particle physics




LIMIT OF OBSERVATION
4×10^{26} METERS
OUR UNIVERSE
PARALLEL UNIVERSE
PARALLEL UNIVERSE
$10^{10^{118}}$ METERS
IDENTICAL PARALLEL UNIVERSE
How Far Away Is a Duplicate Universe?
EXAMPLE UNIVERSE
Imagine a two-dimensional universe with space for four particles. Such a universe has 2^4, or 16, possible arrangements of matter. If more than 16 of these universes exist, they must begin to repeat. In this example, the distance to the nearest duplicate is roughly four times the diameter of each universe.
4 particles
2^4 arrangements
DISTANCE TO REPEAT
1
2
3
4
ALL 16 POSSIBILITIES
OUR UNIVERSE
The same argument applies to our universe, which has space for about 10^{118} subatomic particles. The number of possible arrangements is therefore 2 to the 10^{118}, or approximately 10 to the 10^{118}. Multiplying by the diameter of the universe gives an average distance to the nearest duplicate of 10 to the 10^{118} meters.
2×10^{-13} METER
10^{118} particles
$2^{10^{118}}$ arrangements
8×10^{61} meters