Electroweak*, Strong, and BeyondSM interactions

(* incl. Higgs & Flavour)

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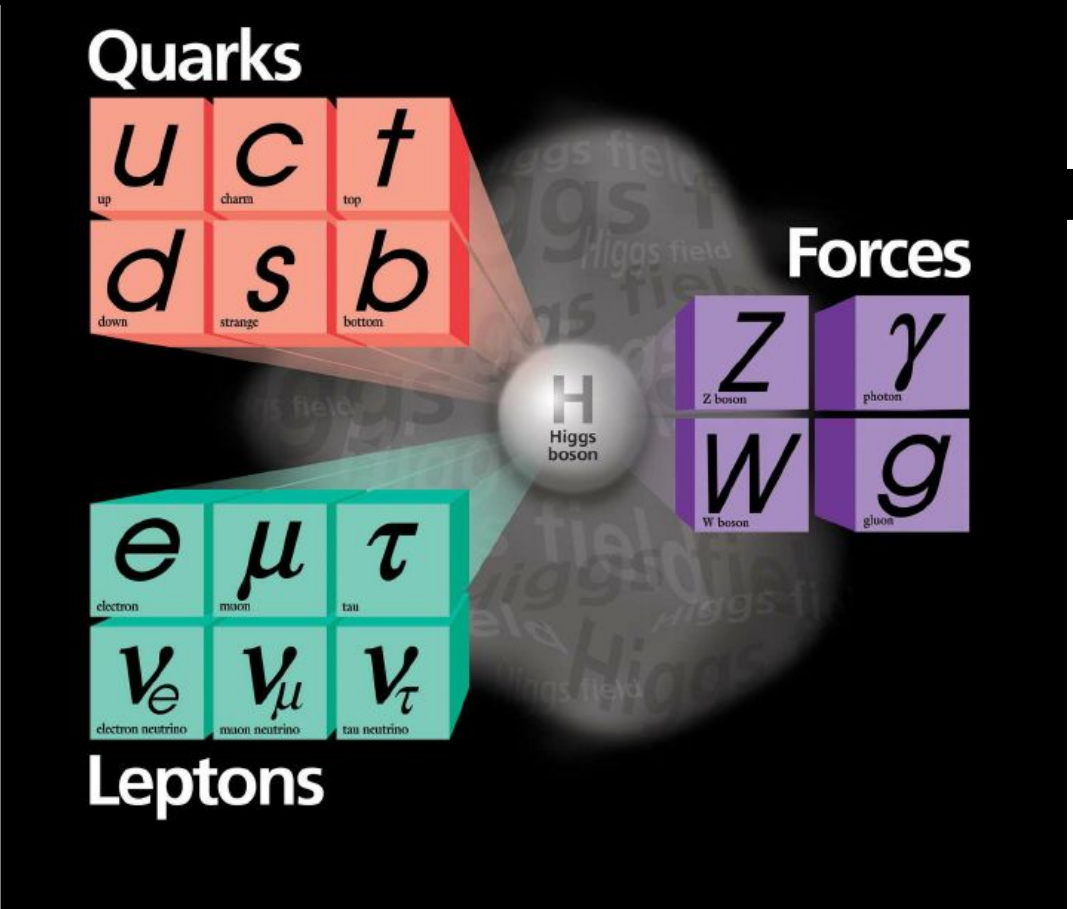
II LASF4RI: An Open Symposium for HECAP
July 6-10, 2020

EWK / Higgs / flavour / QCD + BeyondSM



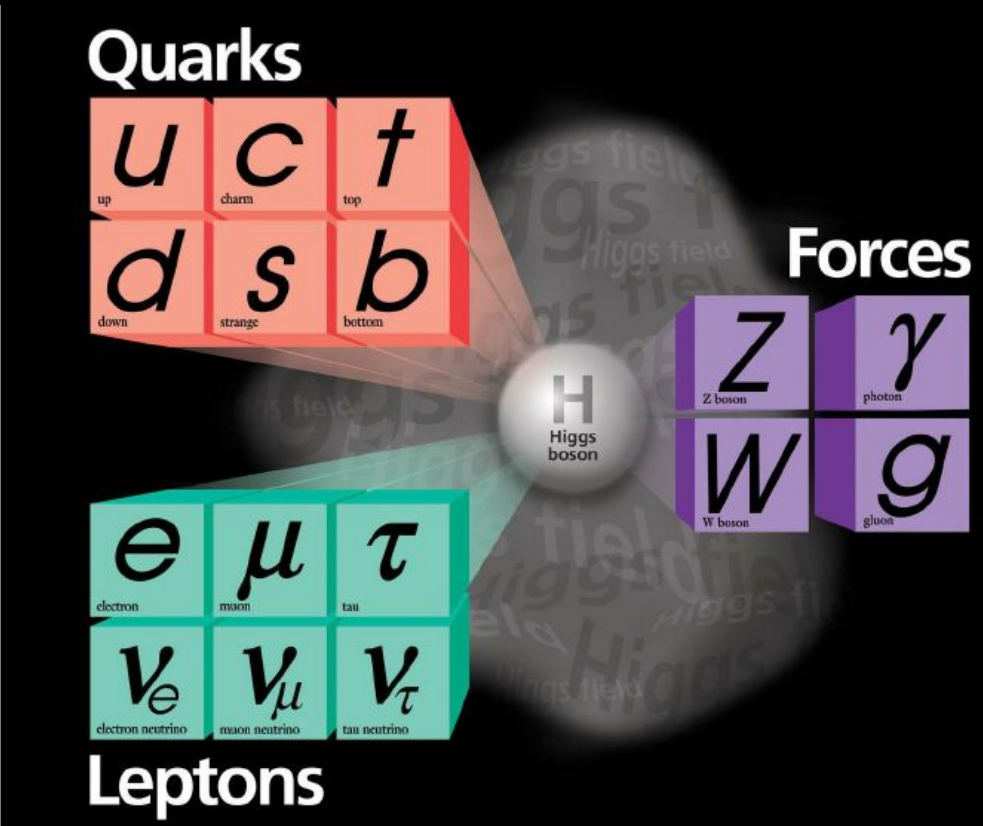
Standard Model
of particle physics

Theory that successfully describes all known fundamental particles and their interactions (except gravitation)

Culmination of >50(00) years of theoretical and experimental exploration

Deep understanding of Universe at the smallest scales connects to structures at largest possible scale (**Cosmology**)

EWK / Higgs / flavour / QCD



+ BeyondSM

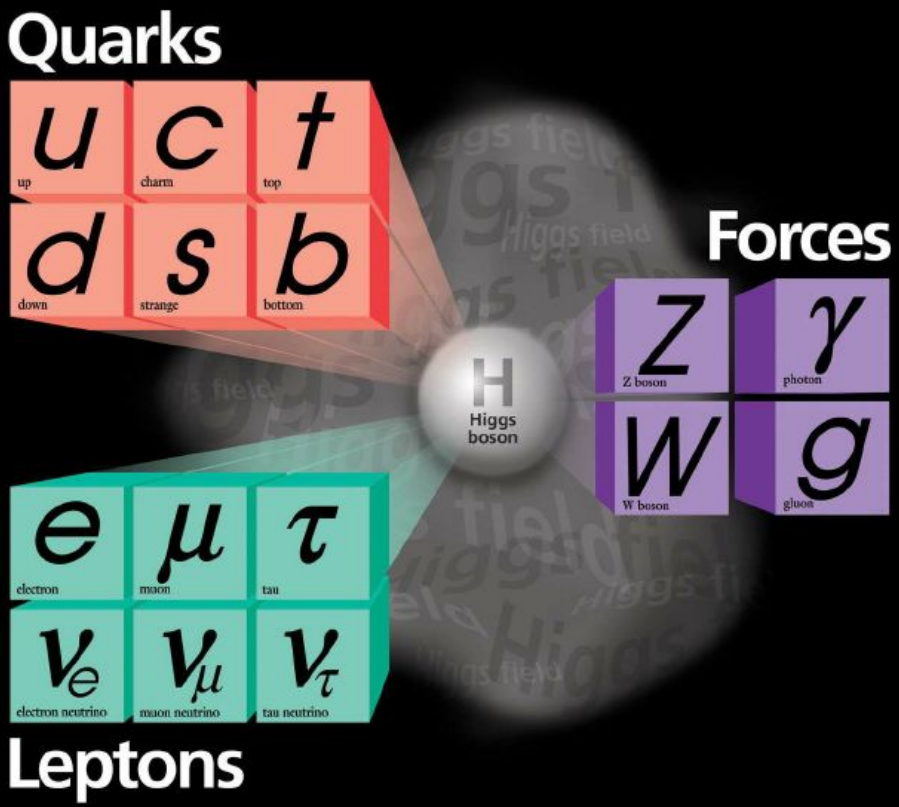
Still many Open Questions:

- Hierarchy of particle masses
- Unbearable lightness of the Higgs
- Matter vs anti-matter in the Universe
- High-energy behaviour of the SM (and the Higgs potential)
- ...

- **Neutrinos ?** (masses & mixing) → **Tuesday session**

- **Dark Matter ?** (and Energy) → **Wednesday session**

EWK / Higgs / flavour / QCD



+ BeyondSM ? ? ?

EXPERIMENT <--> THEORY

searches & measurements — models & predictions

- **Search** for new fundamental particles, symmetries, forces
- **Study** new phenomena with known particles and forces
- **Energy:** access highest possible energy scales
- **Precision:** study, analyze, measure in detail the SM
- **Rare processes:** observe rare production and decay

What are the main scientific drivers ? (1/2)

- **Electroweak Physics**
  - Explore properties of the Higgs Boson (mass, width, couplings, potential, self-coupling)
  - Electroweak precision variables (boson masses, couplings, symmetries)
  - Rare processes: observe, constrain couplings
  - Constrain possible deviations in Effective Field Theory framework
    → look for signs of higher-Energy-scale BSM physics

- **Flavour and CP violation**
  - Understand masses and mixing of quarks and leptons → constrain CKM matrix
  - Test underlying fundamental symmetries of nature
  - Spectroscopy of “exotic” hadron states
  - Look for signs of higher-E-scale BSM physics

What are the main scientific drivers ? (2/2)

- **The strong interaction**
  - Confront experimental precision measurements with ever-improving theory calculations
  - Determine strong coupling constant, probe proton structure (... and nuclear modifications)
  - Dynamics of strong interaction and non-perturbative effects:
    - Understand the phase diagram of strongly interacting matter (heavy ion)
    - Study collective effects and strong dynamics, also in smaller systems (pp, pPb)
    - Model “soft” QCD effects and hadronic showers → links with Cosmic Ray physics
    - Study properties of exotic bound states and nuclei → links with Flavor and Nuclear physics

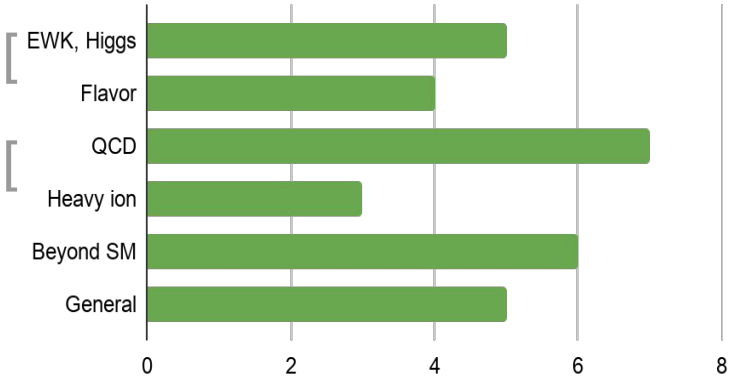
- **Beyond the Standard Model**
  - Discover new fundamental particles, symmetries, interactions …
  - As many models are being excluded, focus on weakly coupling scenarios (long lived particles?)
  - Some key questions:
    - What is Dark matter
    - What stabilizes the Higgs mass and potential
    - SM can not explain matter / anti-matter asymmetry in the Universe

Latin American ‘drivers’ from LASF4RI white papers

- Tables in the following slides list the “topics of interest” / drivers collected from the LASF4RI white papers received

- Organized in the 3 main topic areas :
  - Electroweak / Higgs & Flavor
  - Strong interactions
  - Beyond the Standard Model

14 white papers related to these topics, specifically or generally, with some overlaps:



This picture is certainly not complete and meant only as a starting point for further discussion !

Topics of interest / drivers summary in Latin America

ELECTROWEAK, HIGGS and FLAVOR PHYSICS		
Identified driver in LA	Current infrastructure involvement (countries)	Future infrastructure interest (countries)
Study of properties of Higgs boson	LHC-CMS (Brazil, Colombia, Ecuador), LHC-ATLAS (Argentina)	HL-LHC-CMS (Brazil, Colombia, Ecuador), HL-LHC-ATLAS (Argentina), CEPC (Brazil), ILC and CLIC (Brazil, Ecuador), FCC (Argentina, Brazil, Ecuador)
Study of top quark properties	LHC-CMS (Ecuador)	HL-LHC-CMS (Ecuador), FCC (Ecuador)
Study of Higgs boson pair production	LHC (Brazil)	HL-LHC (Brazil), CEPC (Brazil), ILC (Brazil), CLIC (Brazil), FCC (Brazil)
Flavor physics: Study charged lepton flavor violation, lepton flavor universality violation, heavy-flavored neutral meson oscillation (Brazil)		CEPC (Brazil), ILC and CLIC (Brazil), FCC (Brazil)
VBF, VBS Higgs production and topologies	LHC-CMS (Brazil, Colombia)	
Measurements of photon-photon production of vector bosons	LHC-PPS (Brazil)	
Studies of central exclusive production	LHC-PPS (Brazil)	HL-LHC PPS (Brazil)
Physics of charm quark, quarkonia and exotic states	LHC-LHCb (Colombia)	HL-LHC-LHCb (Colombia)
Measurements of spectroscopy and Heavy flavor production	LHC-CMS (Colombia, Mexico)	HL-LHC-CMS (Colombia, Mexico)
Production of J/Psi	LHC-ATLAS (Argentina)	HL-LHC-ATLAS (Argentina), FCC (Argentina)

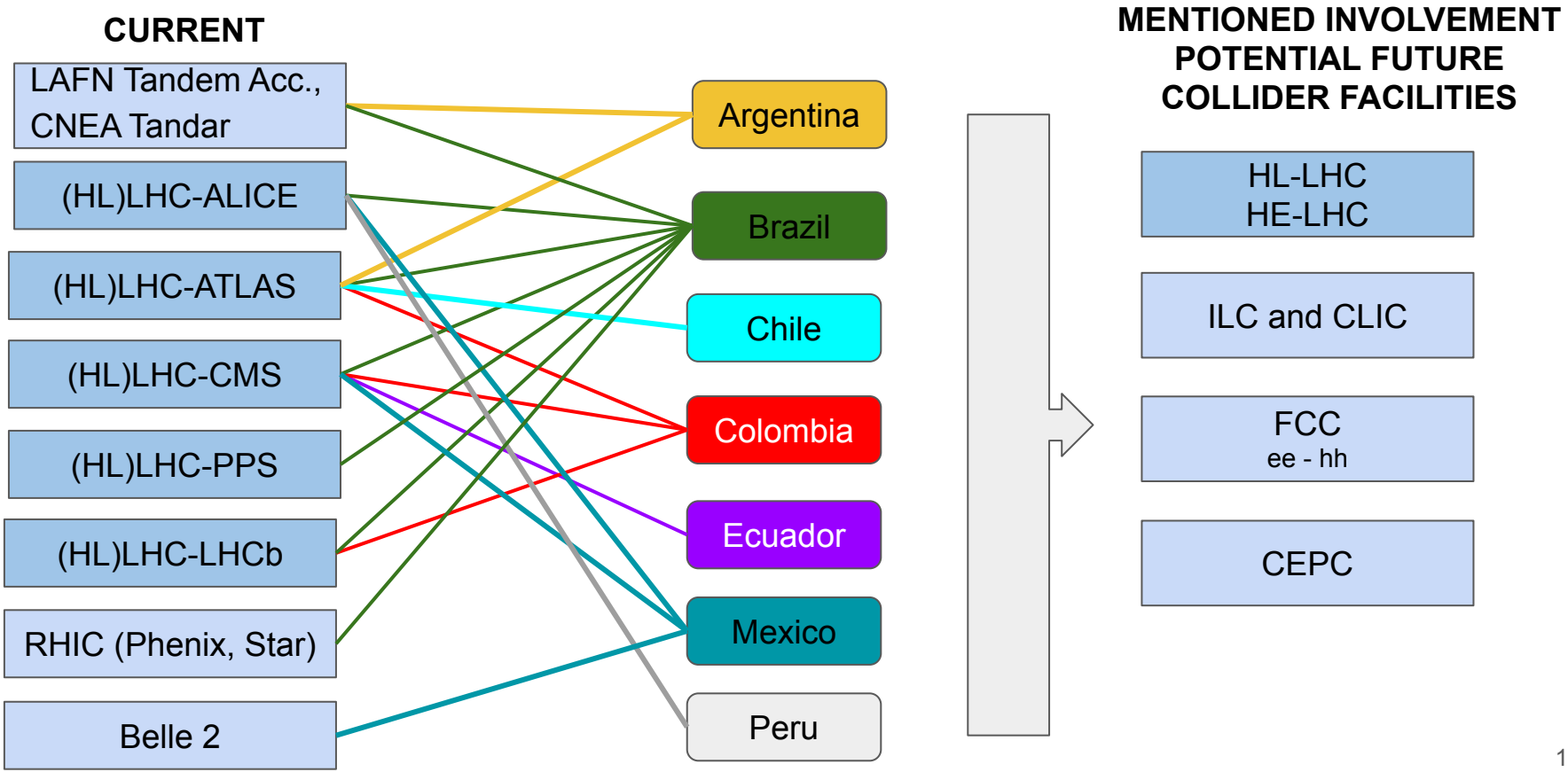
Topics of interest / drivers summary in Latin America

STRONG INTERACTIONS		
Identified driver in LA	Current infrastructure involvement (countries)	Future infrastructure interest (countries)
QCD thermodynamics and equilibration processes, hard probe production, exploration of saturated parton densities, strangeness production	LHC-ALICE (Brazil)	HL-LHC-ALICE (Brazil), HE-LHC (Brazil), FCC (Brazil)
Two-photon production of Higgs boson in ultraperipheral proton and nuclear collisions		HL-LHC (Brazil), HE-LHC (Brazil), FCC (Brazil)
Heavy ions studies	PHENIX at RHIC (Brazil)	
Heavy ions studies	STAR at RHIC (Brazil)	
Low-x QCD, nuclear structure	LAFN Tandem Accelerator (Brazil), Tandar (CNEA, Argentina)	
Prompt photon production	LHC-ATLAS (Argentina)	HL-LHC-ATLAS (Argentina), FCC (Argentina)
Flavored Bound States, Flavor Changing Neutral Currents (FCNC), Lepton universality violation in the B meson decays	Theory (Colombia)	
Jet production differential cross-section measurements	LHC-ATLAS (Argentina)	HL-LHC-ATLAS (Argentina), FCC (Argentina)
Search for resonances decays	LHC-ATLAS (Argentina)	HL-LHC-ATLAS (Argentina), FCC (Argentina)

Topics of interest / drivers summary in Latin America

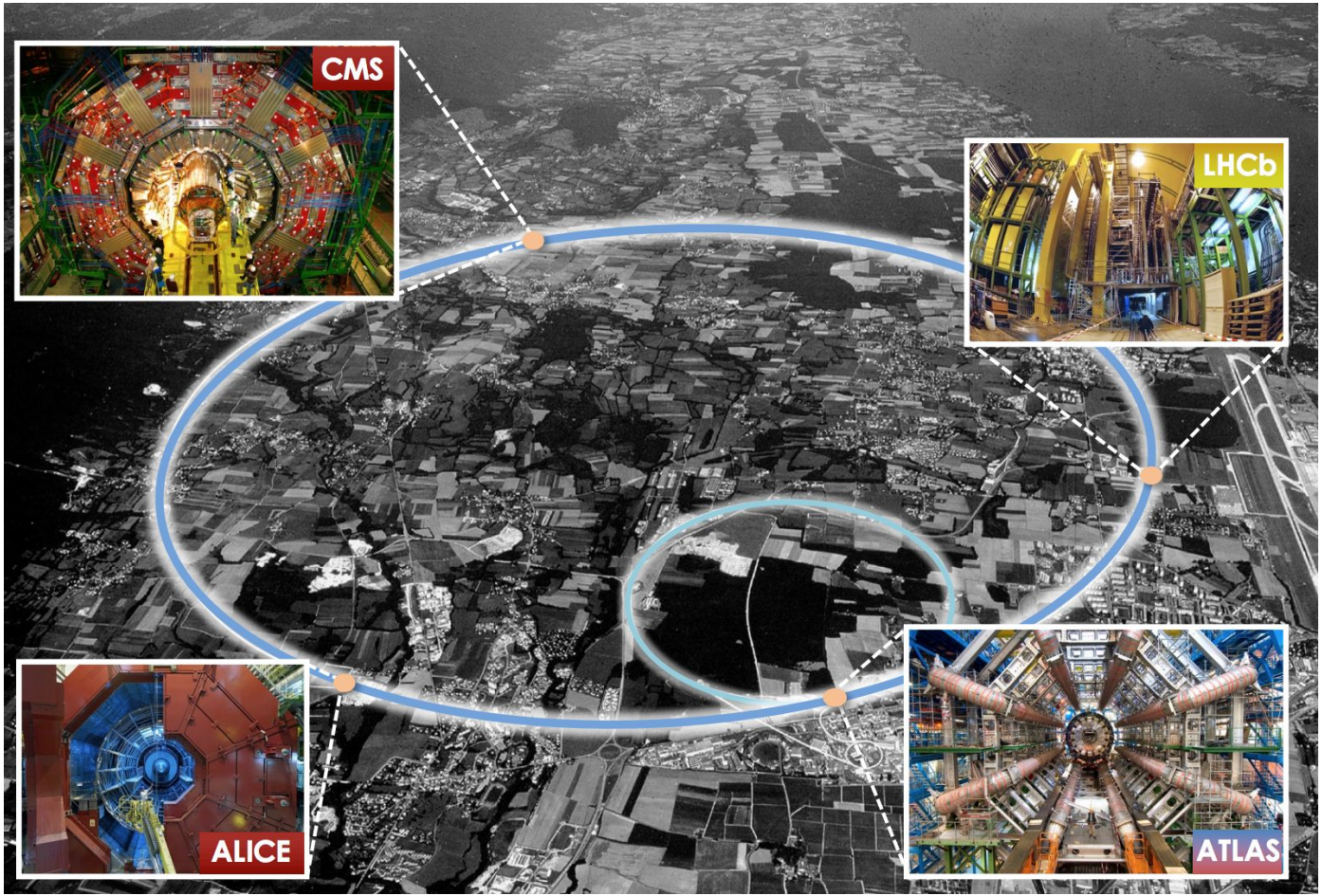
BEYOND THE SM INTERACTIONS		
Identified driver in LA	Current infrastructure involvement (countries)	Future infrastructure interest (countries)
General searches for new particles	LHC-CMS (Brazil, Colombia, Ecuador), LHC-ATLAS (Argentina, Colombia)	HL-LHC-CMS (Brazil, Colombia, Ecuador), HL-LHC-ATLAS (Argentina, Colombia), CEPC (Brazil), ILC and CLIC (Brazil, Ecuador), FCC (Argentina, Brazil, Ecuador)
Beyond the SM Higgs bosons	LHC-ATLAS (Colombia)	HL-LHC-ATLAS (Colombia)
General SUSY searches	LHC-ATLAS (Argentina, Colombia)	HL-LHC-ATLAS (Argentina, Colombia), CEPC (Brazil), ILC and CLIC (Brazil), FCC (Argentina, Brazil)
SUSY searches in compressed scenarios	LHC-CMS (Brazil, Colombia)	HL-LHC-CMS (Brazil, Colombia)
Electroweak extensions of the SM, discrete and global symmetries	Theory (Colombia)	
Searches for extra spatial dimensions	LHC-ATLAS (Argentina)	HL-LHC-ATLAS (Argentina), FCC (Argentina)
Axions and ALPs as DM candidates	Theory (Colombia)	
Mass scales problem	Theory (Colombia)	
Dark Matter	LHC-CMS (Colombia), DUNE (Colombia)	LHC-CMS (Colombia), DUNE (Colombia)

Summary of LA involvement (based on white papers)



Latin American involvement in LHC experiments

Brazil
Colombia
Ecuador
Mexico



Brazil
Colombia

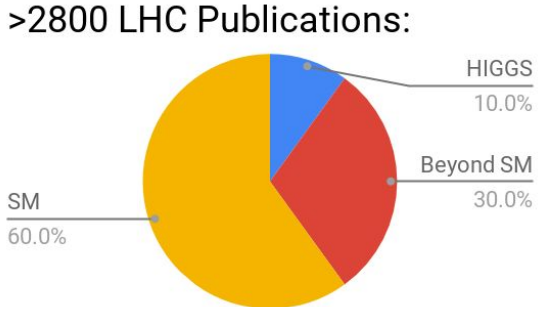
Brazil
Cuba
Mexico
Peru

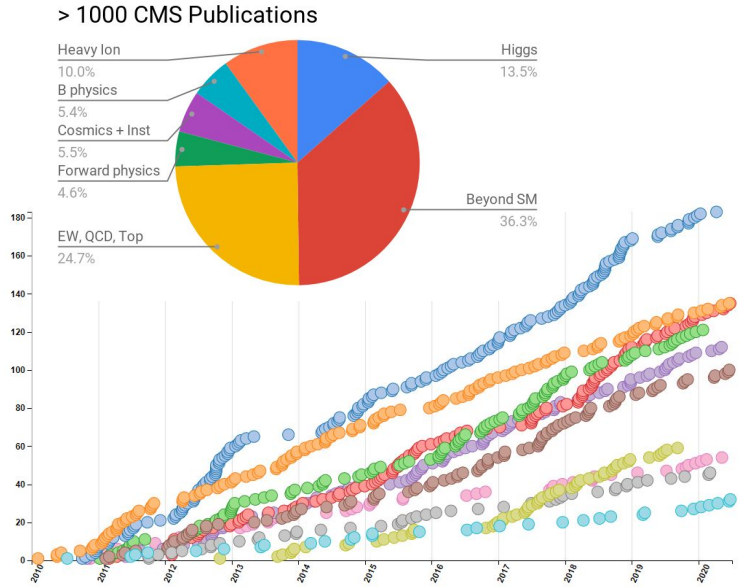
Argentina
Brazil
Chile
Colombia

10 years at the Energy Frontier

2009 - 2019: Run1 and Run2

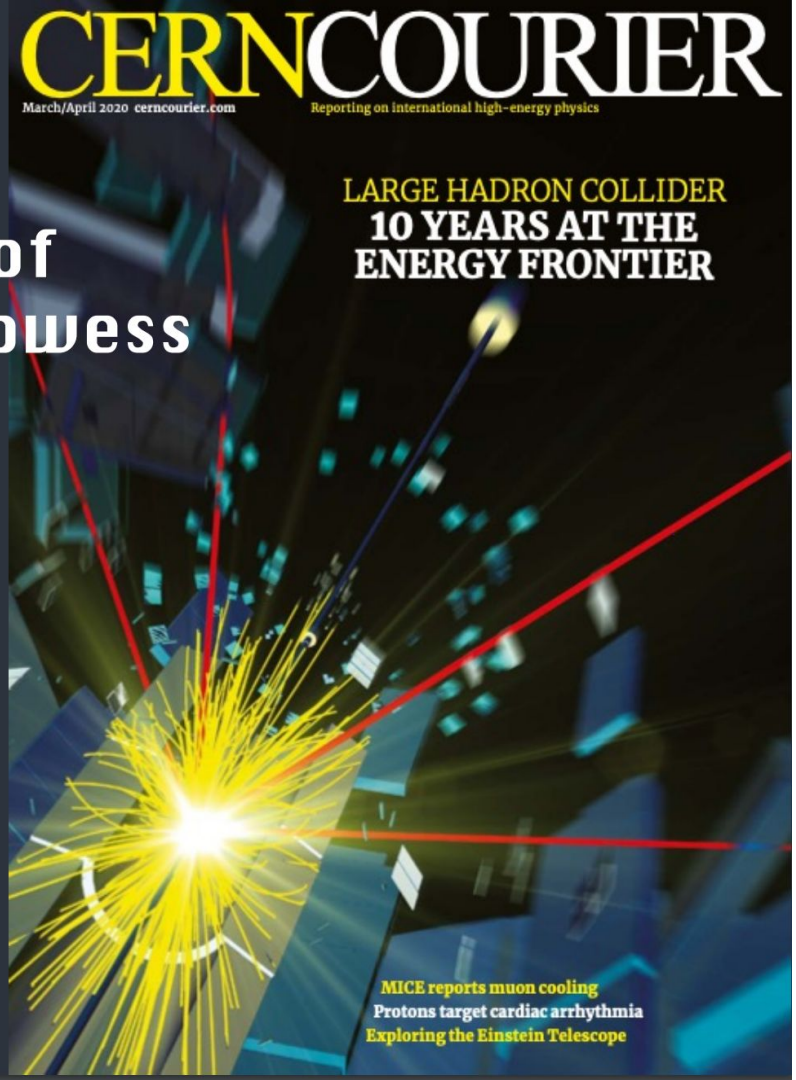
- Phenomenal performance LHC & experiments
- ALICE + ATLAS + CMS + LHCb published **>2800** journal articles
- A very rich and diverse physics programme
- Treasure trove of physics results has changed the way we look at possible BeyondSM scenarios, and properties of the SM itself
- During the Covid-19 lockdown, CMS submitted its 1000th paper for publication





We are celebrating 10 years of physics and technological prowess

- The Higgs boson exists
- There is — so far — no proof of physics beyond the SM up to the TeV scale
- Numerous discoveries within the SM were made involving rare processes, flavour, spectroscopy, high-density strong matter
- Accelerators, detectors, computing & analysis performed beyond expectations
- The LHC has prompted prodigious progress in particle theory



Michelangelo Mangano, CERN Courier March/April 2020

https://cerncourier.com/a/lhc-at-10-the-physics-legacy/

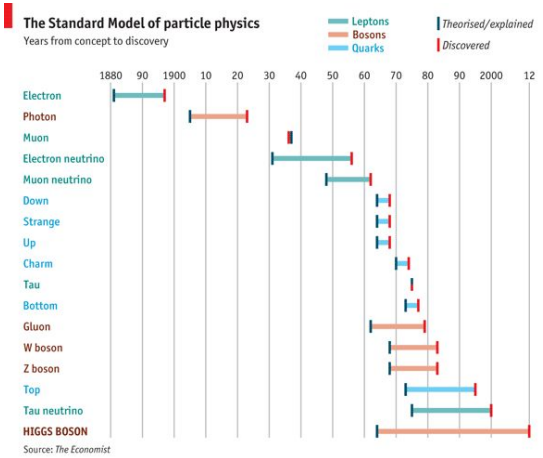
Theory vs data ‘drivers’

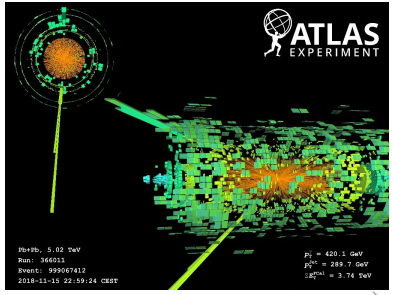
- The Higgs boson → predicted 50 years before discovery … a most successful theory driver!

However:

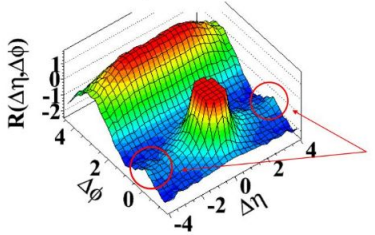
- Some of the most intriguing LHC results so far have been ‘data-driven’ surprises; often in heavy-ion and flavour physics; and not just in LHCb or ALICE
- Precision measurements and surprise observations in turn inspire and motivate HEP theory progress

→ Keep in mind for future research strategy





CMS Collaboration, arXiv:1009.4122

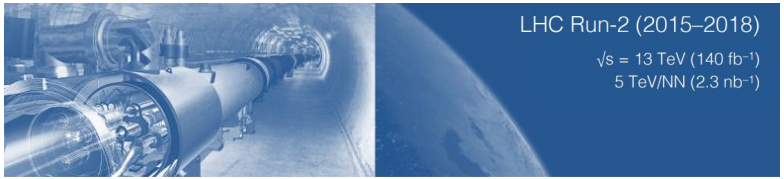


near-side, long-range rapidity correlation

First unexpected result from the LHC !
Possible collective effects in pp?

So far collected 5% of the total expected LHC data

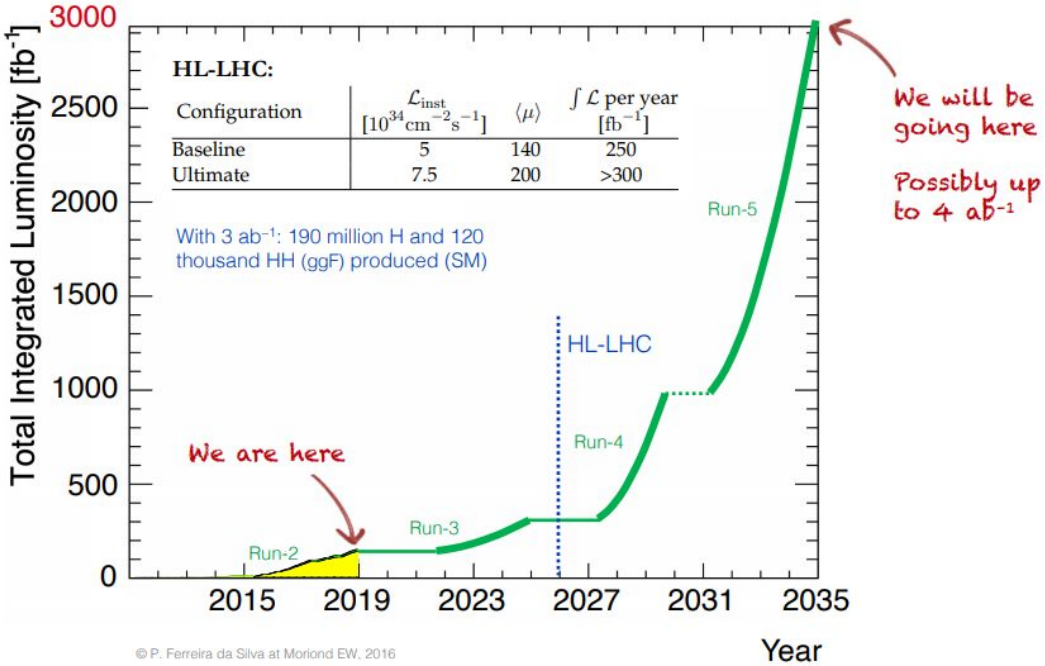
The LHC is an **everything** factory



Now — after an outstanding Run 2 — the LHC experiments have in their hands the richest hadron collision data sample ever recorded

Particle	Produced in 140 fb^{-1} pp at √s = 13 TeV	
Higgs boson	7.8 million	
Top quark	275 million	(115 million $t\bar{t}$)
Z boson	8 billion	($\rightarrow \ell\ell$, 270 million per flavour)
W boson	26 billion	($\rightarrow \ell\nu$, 2.8 billion per flavour)
Bottom quark	~160 trillion	(significantly reduced by acceptance)

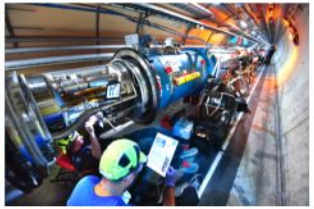
(A.Hoecker at LHCP 2020)



LS2: game changer ALICE (50x data) and LHCb (5x lumi)

Accelerators

New Linac 4



Inspecting & cleaning a diode enclosure

LHC Injector Upgrade (LIU): Linac 4, PSB, SPS
For improved beam brightness and reliability

LHC: consolidation of interconnections & diode boxes

Two 11 T dipoles at P7 to make room for collimator
Unclear whether will be installed

Civil engineering for HL-LHC

ALICE

Main theme: trigger-less readout
50-100 times min bias, 50 kHz readout (was 1 kHz)

New Pixel Inner (ITS2) and Fwd muon tracker (MFT) — 13B pixels
Pioneers monolithic MAPS (CMOS) technology

GEM-based TPC readout + Fast Interaction Trigger, new Online-Offline computing system, …

ATLAS

Main theme: refine trigger selection
In view of Run-3 and the HL-LHC

LAr upgrade for better L1Calo granularity
Exploited by more powerful L1 trigger boards

Muon New Small Wheel (NSW), …
Improved fake muon rejection at trigger level

CMS

Many upgrades already during Run-2
New Pixel, DCDC, L1 trigger, PPS, HCAL elec.

Finalise this work during LS2
Plus for HL-LHC: new beampipe, civil eng., muon electronics & GEMs, beam & Fwd systems

Additional consolidation tasks

LHCb

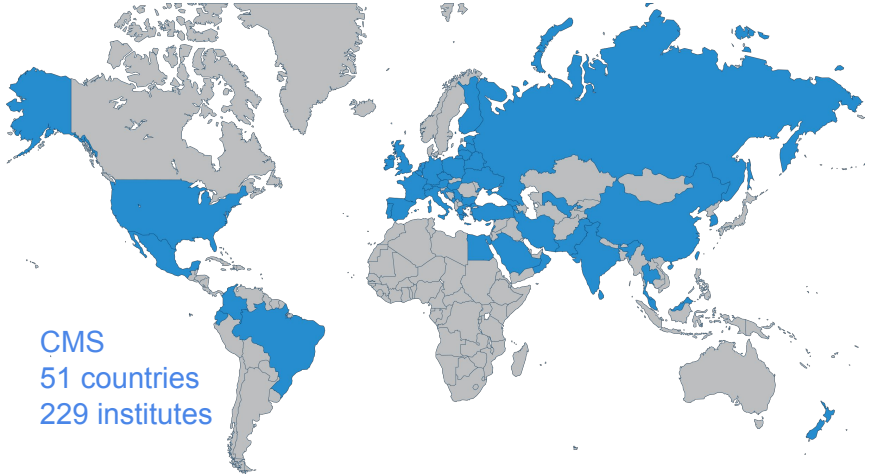
Main theme: 5 times luminosity and pileup
Maintain performance of detector — update ~all systems
- New tracking detectors: pixel, strips, outer (SciFi)
- New RICH optical system and photo detectors

40 MHz all-software trigger (current HW: 1.1 MHz)
New RICH, calorimeter, muon readout (L0 trigger removal)
HLT1 (first level) reconstruction on GPUs
Surface data centre for event filter and building

HL-LHC :
the next 15-20 years
(ALICE, ATLAS, CMS, LHCb)

- **High-Luminosity LHC** → 3-4x higher instantaneous luminosity in ATLAS and CMS, much more challenging radiation and pile-up conditions (~ 200 PU !)
- Incredible challenges for detectors, trigger, DAQ, software, computing
- New ideas and paradigms (eg Deep Learning AI in FPGAs, parallel GPU computing, L1 trigger to include particle tracking + timing + 40 MHz 'scouting' ?)
- Will further push large-scale high-performance computing, novel technologies, electronics and detector R&D, testing, building… → see **Monday Session**
- Very exciting detector upgrades planned (hermeticity, granularity, timing layers)

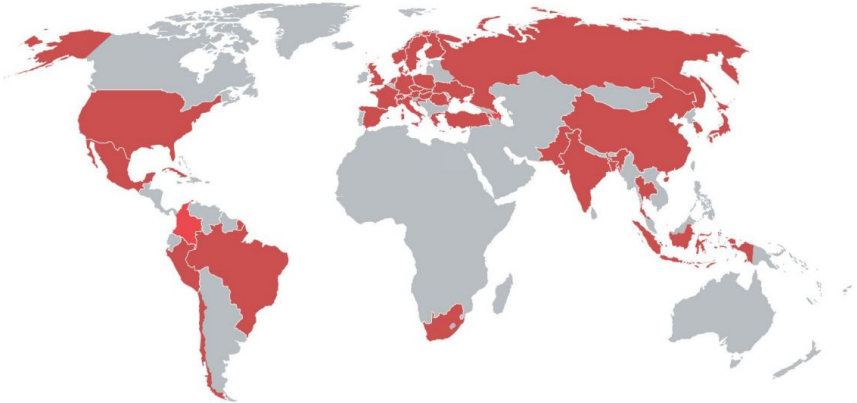
Global Collaborations



THE ALICE Collaboration

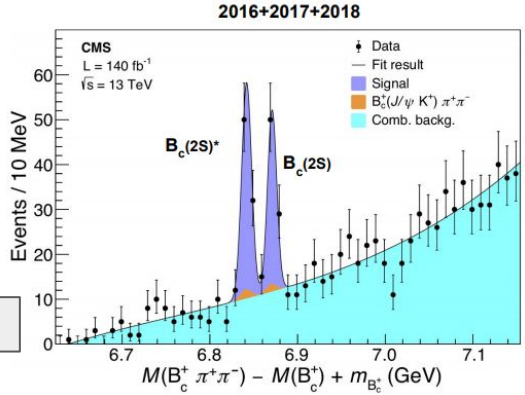
ALICE

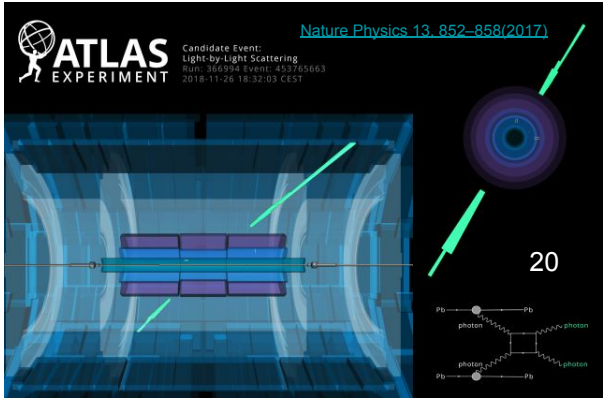
42 COUNTRIES – 174 INSTITUTES – 162'518 KCHF CAPITAL COST



Even in these huge collaborations, plenty of opportunity to have big impact in specific areas *(just a few examples -- help us find more !)*

- UERJ CMS group in Brazil plays leading role in CT-PPS detector and physics (all aspects)
- With ACORDE, Mexico brought cosmic ray physics, a LA speciality, to the ALICE detector
- Colombian and Mexican physicists lead on B*c spectroscopy with full Run2 data set in CMS
- Argentina: key roles in ATLAS trigger group
- Brazil: ATLAS light-by-light scattering (?)
- Theory ⇒ many world-leading theoretical contributions from Latin America

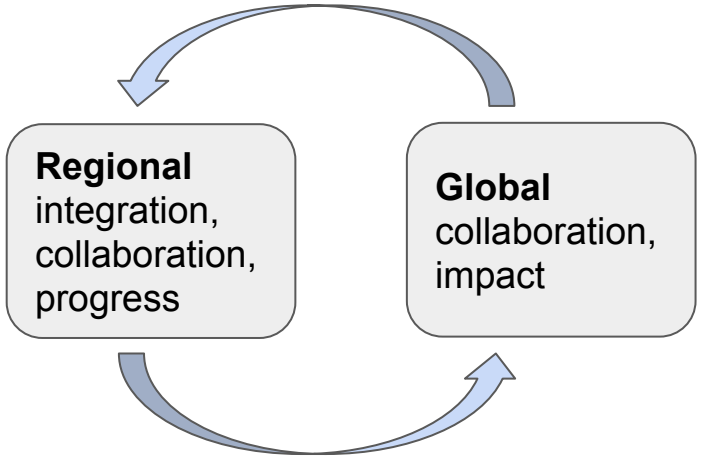




Enhance impact with more regional collaboration?

Could liaise based on :

1. Detector / electronics technologies
2. Physics drivers
3. Future facility interests
4. Educational programs



Examples:

- Muon chamber construction (RPC, GEM) → Chile, Mexico, Colombia, Brasil
- Electronics design
- Heavy flavour spectroscopy → Antioquia and Cinvestav
- Interest in **FCC, ILC, ..** → Argentina, Brazil, Colombia, Ecuador
- **LA CoNGA** international education program + capacity building

Technology, training, economic benefits

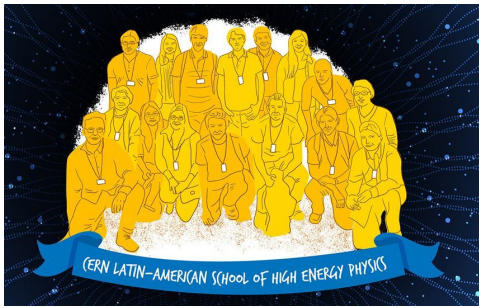
Particle physics → unprecedented technical challenges

- High-tech detector and electronics design, R&D and production
- International collaboration = connection with world leading experts
- Training for engineers, computer scientists
- Driver for high-performance computing, computer networks
- Involvement in cutting-edge particle physics will bring new skills and know-how, building detector parts with local industry will enlarge country's capacity to produce high-tech components, a driver for economic growth in the long run

Particle physics and education

On-the-job training for engineers, students, scientists in running experiments, ***and:***

- Inspiration, scientific content, access to tools and methods, for Science education programs in Latin America, Outreach and Media
- Resources for PhD prog + Masterclasses like **LA CoNGA, ICP-PWF, CEVALE2VE, PPGCosmo**
- Global network of world leading scientists, teachers, experts
- Access to Outreach programs of collaborations (virtual visits..)
- CERN education resources such as:
    - High-school teachers programme
    - Summer Student programmes
    - CERN Latin-American Schools of HEP



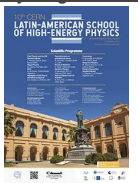
www.symmetrymagazine.org









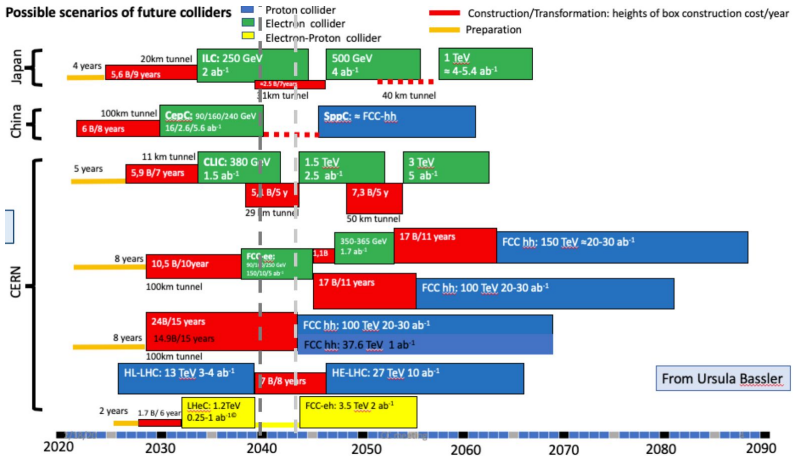
Some trends in particle physics collaborations…

(which could all be beneficial for LA involvement)

- Open Science: Open access publishing in Particle Physics (SCOAP[3])
- Increasing access to Open Data from the experiments: http://opendata.cern.ch/
- Improve recognition of contributions of young scientists in large collaborations
- Driving further improvements in remote access and collaboration tools (www, WLCG, indico, tele-working, video conferencing tools)
  ⇒ Covid-19 has accelerated this trend, to a new normal
  ⇒ may *reduce* (though not eliminate) the need for travel, perhaps mitigating to some extent the loss of successful EU mobility programs like HELEN and EPLANET
  ⇒ could be a (relative) advantage for collaboration from 'remote' regions

Future flagship collider facilities
(some interest in white papers but need further look)

- Electron-Ion Collider (Brookhaven)
- NICA ion collider (JINR, Dubna)
- e+ e- “Higgs factory”
  (FCC-ee, ILC, CLIC, CEPC)
- 100 TeV hadron collider (FCC-hh)
- Muon collider



Consider outcome of 2020 European Strategy update:
https://europeanstrategyupdate.web.cern.ch/

- → see presentation by Salvatore Mele in Tuesday session
- A preferred scenario: HL-LHC, e+e- Higgs factory, 100 TeV hadron collider… is this feasible?
- How to make it feasible? Exciting time for innovation, R&D, big ideas and strategy discussions!
- As a major and upcoming international partner, how does LA fit best in the Global puzzle?

Summary:

- Several countries in Latin America have established a vibrant participation in the (HL)LHC experiments, exploring the EW+Flavor, QCD and BSM domains
- There is also an involvement in Belle 2, experiments at RHIC, and nuclear science experiments at accelerator facilities in the LA region
- We believe our inputs reflect only a fraction of the activities from different countries, and would like to find ways to get a more complete picture

- Found several examples of areas where LA groups are leading
- Opportunities for regional growth and collaboration, based on physics topics, R&D for hardware and new tools, and education programmes
- Take into consideration future trends and opportunities
- Strong interest in Future Collider Facilities, which will require even MORE global contributions and involvement than the current experimental programs

Some questions to start our discussion

- We know we are missing many details about the ongoing efforts and plans in the region, how do we best go about identifying them and extracting this information?
- Most of the involvement in LA is through LHC experiments, but there are other important experiments that complement or enhance LHC's studies. Should we aim to be more involved in these (e.g. Belle 2)? Do we have the capabilities, person-power, can LA countries afford it, etc.?
- Most groups have clear interest in future flagship infrastructure, what specific synergies we should pursue to increase or speed up development so we could maximize our involvement and contributions to these?
- How about smaller scale experiments?
- The future will be even more global, how do we best prepare for this?
- What are the main issues and needs of each of the projects in the most immediate future (next 5 years) and which areas could be strengthened per country?
- What are/should be the scientific priorities of the region for the next decade?
- Which are our connections with neighbouring fields?
- How does our science contribute to knowledge and technology transfer? How can we impact and benefit society?

Some thoughts and follow-up on yesterday's discussion (1 / 2)

- We agree that it would probably be useful to collect more input on expected benefits in terms of technology and capacity building, from participation in experiments, so that we can properly reflect this in the Briefing Book
- Should the "LA Opportunities Briefing Book" focus less on science as a driver, and more on opportunities in terms of technology and R&D from HEPAP Science projects?
- But is 2 weeks enough to collect this information? Or recommend as outcome of this strategy exercise to collect and share this information in an organized way in future...

  Eg by setting up a platform, taskforce or organizing an Open Symposium focusing (mostly) on the technical challenges and opportunities in this field?

Some thoughts and follow-up on yesterday's discussion (2 / 2)

- How to balance the benefits of strengthening / joining successful efforts vs creating more diversity with new projects
- Question on how much to invest to have impact/recognition in large experiment?
  ⇒ answer depends on what impact/recognition means
  - Individual recognition / visibility inside large experiment for good work by talented and committed young scientist is "easy" → many examples of PhD students and young postdocs giving plenary talks and/or leading sizeable research teams inside the experiment with responsible leadership positions
  - To "prove" / explain this recognition to outside world is more challenging…
  - To be generally recognized as group / institute for a big role in a detector, technology, or physics analysis topic would of course require bigger investments

Thursday July 9 Chair: H. Wahlberg

10:30-11:00	**Plenary IV:** Electroweak, Flavour, Beyond SM and Strong Interactions **(M. Mulders)**
11::00-11:10	The Study of the Quark-Gluon Plasma with the ALICE-LHC Experiment. M. Munhoz.
11:10-11:20	Colombian Network on High Energy Physics Input on Theoretical HEP, N. Bernal.
11:20-11:30	Physics exploration with the LHCb experiment [EW/BSM], M. Rangel.
11:30-11:40	Argentina Experimental HEP Input, F. Monticelli.
11:40-11:50	Brazilian Participation in the Next-Generation Collider Experiments, T. Tomei.
11:50-12:00	White paper on Nuclear Science in Brazil, A.L-Szily.
12:00-12:10	Tau physics at Belle II, E. de la Cruz Burelo
12:10-12:55	Discussion