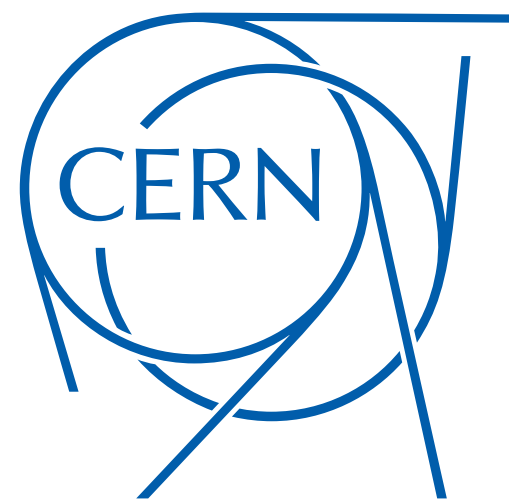


# Trends in Particle Physics

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Eckhard Elsen

Director Research and Computing



# 10 years of Experimental Physics at the LHC



from P McBride

# Initial Goals at the LHC

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- Discovery of SUSY
  - access to TeV scale was expected to quickly reveal the SUSY sector  
*(for large couplings)*
- Discovery of the Higgs Particle
  - In the Standard Model its couplings are well understood
- Precision Tests of the Standard Model
  - QCD and more

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 $\sim 300 \text{ fb}^{-1}$

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# Discovery of the Higgs Particle in 2012

---

- Higgs Particle at 125 GeV
  - light Higgs
    - state to stabilise a metastable vacuum
- Branching ratios such that many measurements became experimentally feasible
  - unique couplings allow a variety of searches
  - quickly turned into a tool to support search for **New Physics**

*Requires a programme  
with much larger  
statistics:  $\sim 3000 \text{ fb}^{-1}$*

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→ HL-LHC

# Experimental Requirements

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- Must maintain **low scale** capability even at the highest luminosity
  - Concept of simply raising trigger thresholds not viable
  - Need to separate all vertices of a collision (4d-reconstruction)
- Spectroscopy feasible at the LHC
  - **MeV-scale** precision physics viable at a **multi-TeV** collider
- Heavy Ion physics richer and more quantitative
  - variety of ion species and configurations

*Progress in experimental techniques supports such a programme*

# Experimental programme at the LHC

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- European Strategy update 2013 already identified the full exploitation of the LHC as the primary goal
  - HL-LHC was approved in 2016
  - Phase II upgrades of ATLAS and CMS were proposed and a cost envelope was acknowledged by Funding Agencies
    - Most Technical Design Reports have been presented; MoUs are being signed
    - upgrades well under way
  - ALICE and LHCb are both proposing upgrades on an LS3 and LS4 time scale



# LHC is the Flagship on the European Strategy Update 2020

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- Operation will extend far into the 2030ies
- ATLAS and CMS Phase II upgrades to be completed in LS3
- ALICE ITS3 and more scheduled for LS3 (still needs approval)
- Major upgrades of ALICE and LHCb planned for LS4

*LHC will continue to be the work horse for precision physics at the energy frontier for many years to come*

Near term schedule

# Reminder of Run 3 schedule as of November 2019

- Key conclusions at the time
- extend LS2 by 2(3.5) months
- delay LS3 by one year (to then start in 2025)

2021

	Jan				Feb				Mar				Apr
Wk	1	2	3	4	5	6	7	8	9	10	11	12	13
Mo	4	11	18	25	1	8	15	22	1	8	15	22	29

	May				June				July				
Wk	14	15	16	17	18	19	20	21	22	23	24	25	26
Mo	5	12	19	26	3	10	17	24	31	7	14	21	28

	Aug				Sep				Oct				
Wk	27	28	29	30	31	32	33	34	35	36	37	38	39
Mo	5	12	19	26	2	9	16	23	30	6	13	20	27

	Nov				Dec				Jan >>				
Wk	40	41	42	43	44	45	46	47	48	49	50	51	52
Mo	4	11	18	25	1	8	15	22	29	6	13	20	27

2023

	Jan				Feb				Mar				Apr
Wk	1	2	3	4	5	6	7	8	9	10	11	12	13
Mo	2	9	16	23	30	6	13	20	27	6	13	20	27

	May				June				July				
Wk	14	15	16	17	18	19	20	21	22	23	24	25	26
Mo	3	10	17	24	1	8	15	22	29	5	12	19	26

	Aug				Sep				Oct				
Wk	27	28	29	30	31	32	33	34	35	36	37	38	39
Mo	3	10	17	24	31	7	14	21	28	4	11	18	25

	Nov				Dec								
Wk	40	41	42	43	44	45	46	47	48	49	50	51	52
Mo	2	9	16	23	30	6	13	20	27	4	11	18	25

2022

	Jan				Feb				Mar				Apr
Wk	1	2	3	4	5	6	7	8	9	10	11	12	13
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2024

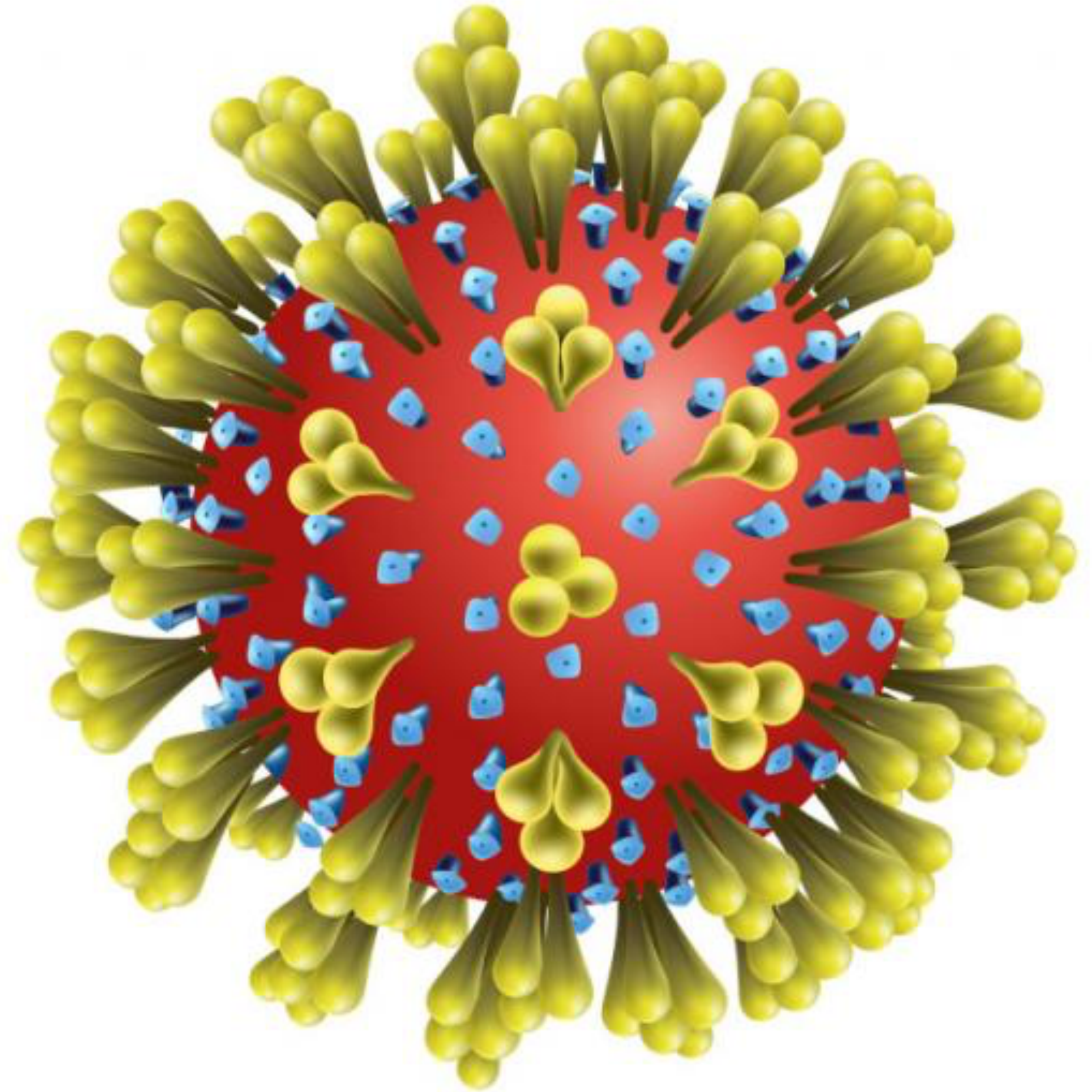
	Jan				Feb				Mar				
Wk	1	2	3	4	5	6	7	8	9	10	11	12	13
Mo	1	8	15	22	29	5	12	19	26	4	11	18	25

	Apr				May				June				
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Mo	1	8	15	22	29	6	13	20	27	3	10	17	24

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Wk	40	41	42	43	44	45	46	47	48	49	50	51	52
Mo	30	7	14	21	28	4	11	18	25	2	9	16	23

...and then



# Progress during lock-down

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- Limited progress with sub-detectors wherever possible including in remote institutes
- Teleworking has been used everywhere
  - Analysis unhindered thanks to availability of IT infrastructure
  - Design – access to CAD software (incl. remote licence usage)
  - ASIC development
    - design requires access to licensed software

*ASICs have been a major concern of upgrades*

# Logistics is a challenge

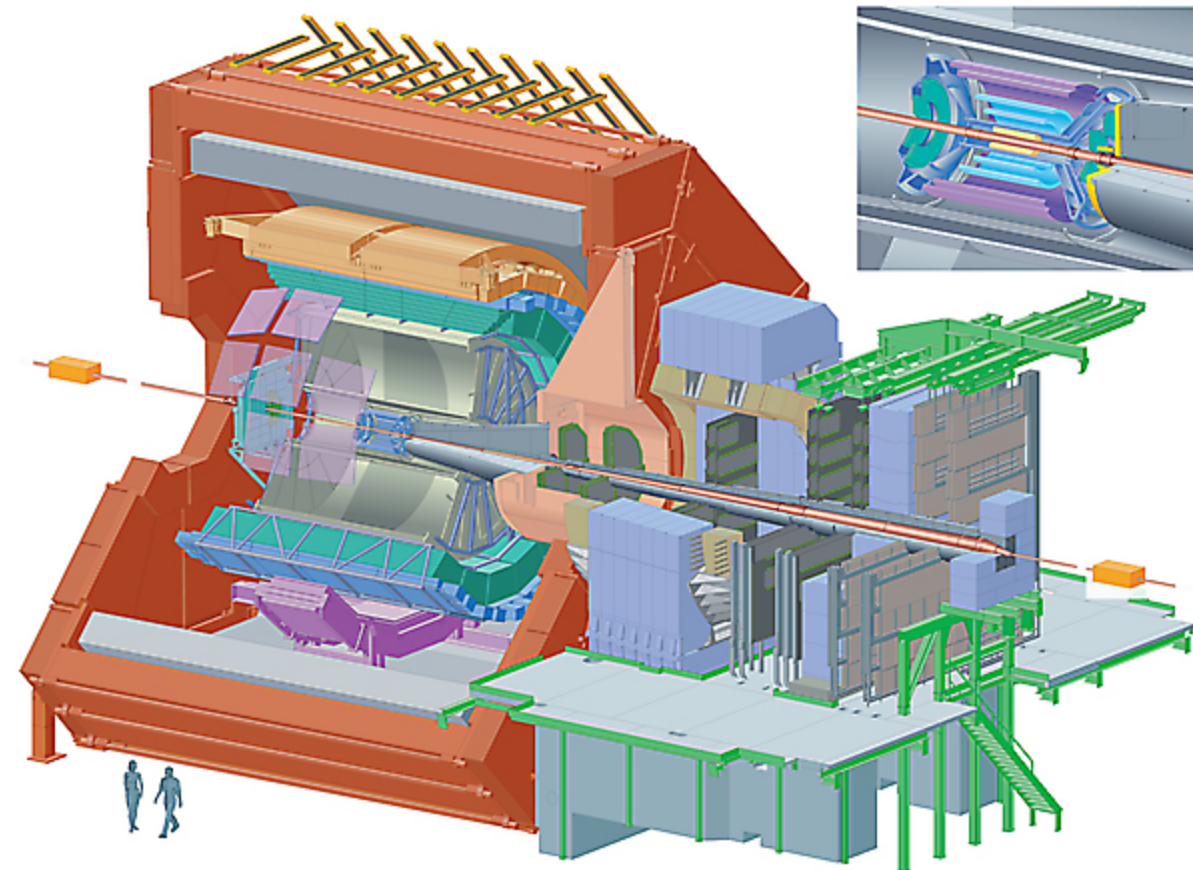
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- Delivery of components from other institutes (or companies)
  - Production halted
  - Delivery chain broken
- Availability of foreign experts is a major uncertainty
  - Varying travel restrictions
    - entry to France and Switzerland
    - departure from home country and uncertainty of returning home (quarantine)
    - permission from some countries for work at CERN still needs to be granted

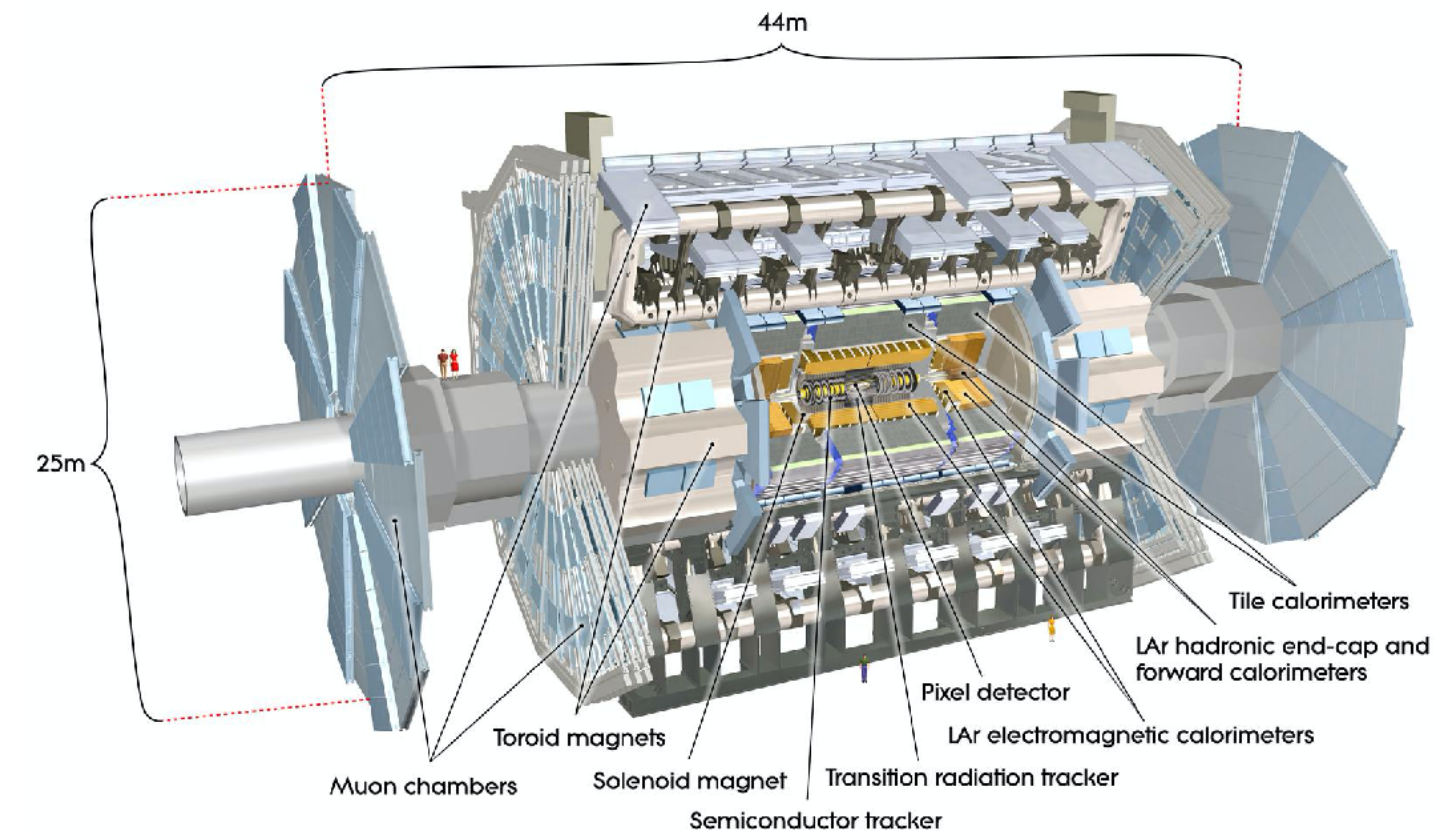
*Progress is very  
difficult to predict*

# Priority: completion of Phase 1 and preparation of Phase 2 upgrades

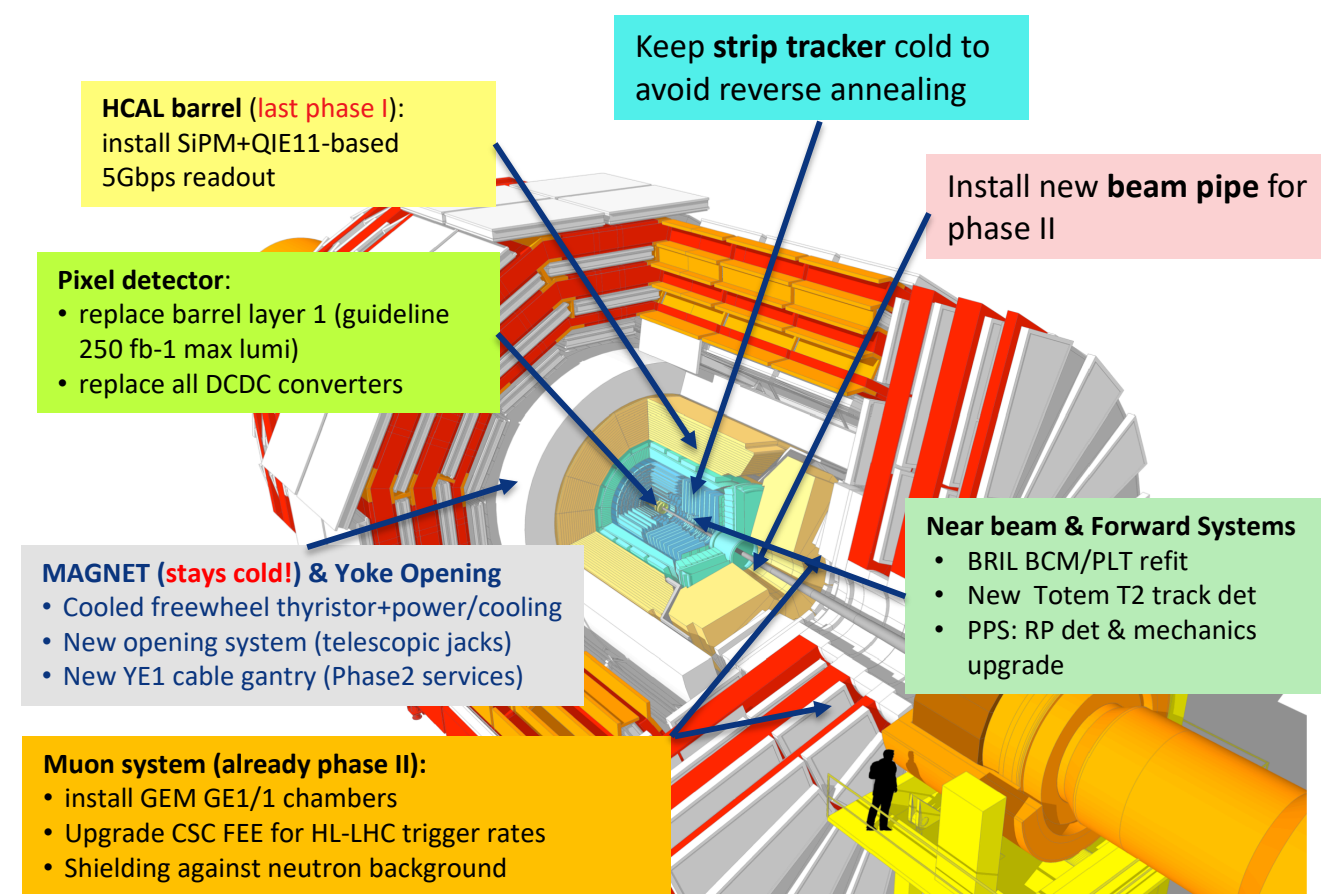
ALICE



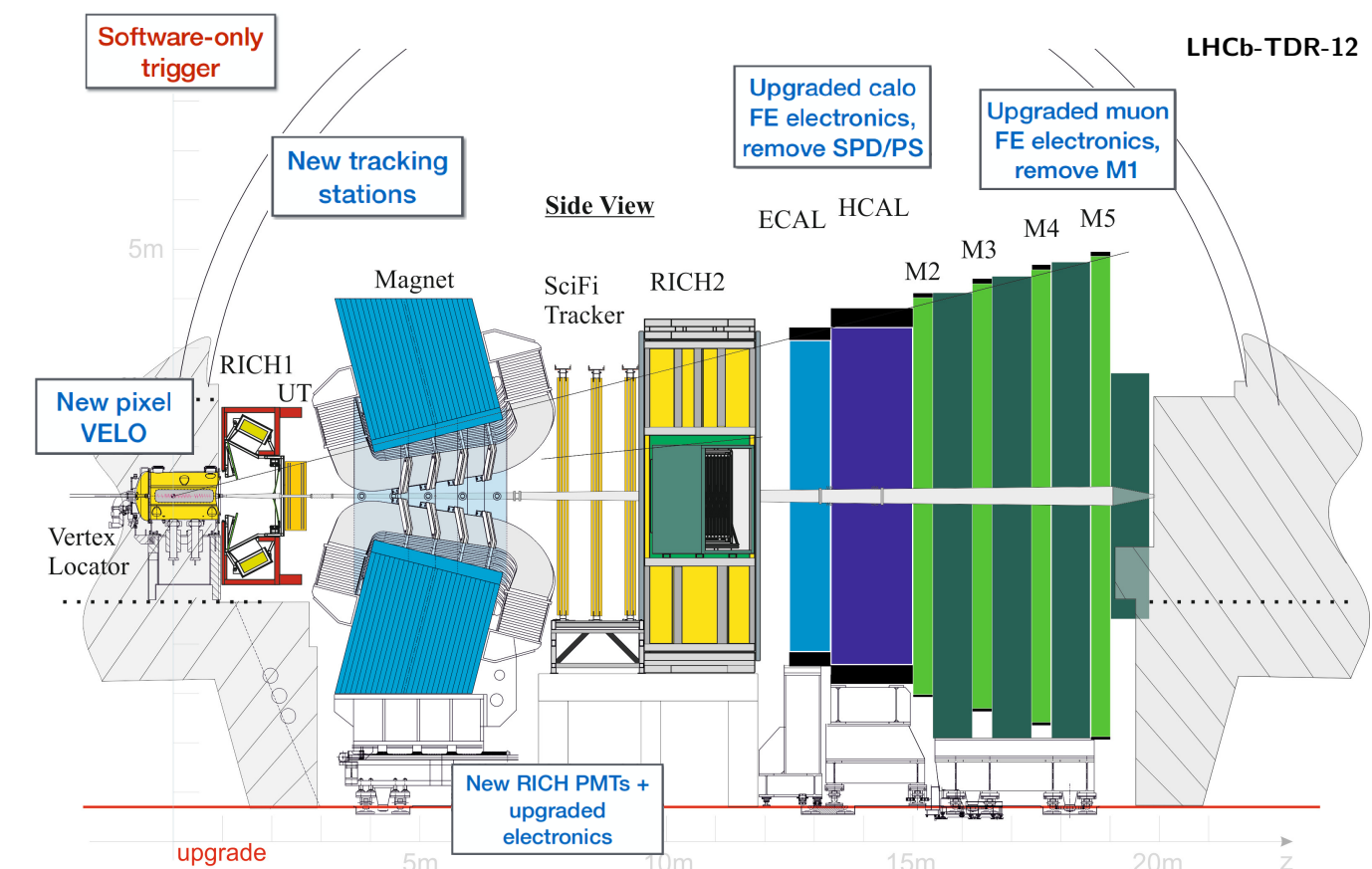
ATLAS



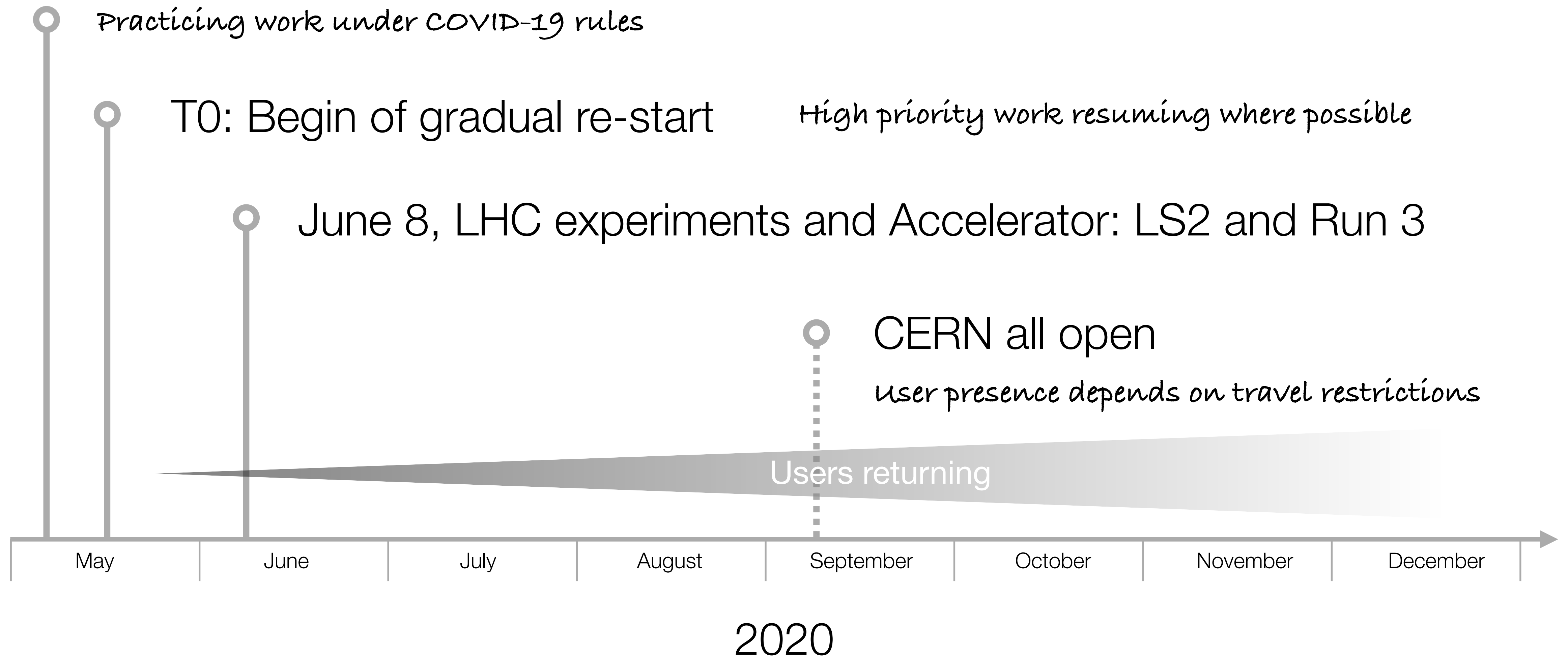
CMS



LHCb



# Re-start of Experiments depends on Availability of Users (experts)





# Impact on Schedule (preliminary)

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- LHC faces a linear delay of 3-4 months (see presentation of M Jiminez on Monday)
  - extended training of dipole magnets for operation at the highest energy (14 TeV?) conceivable
- Delays for experiments less well predictable e.g. because of travel restrictions for experts
  - Opportunities to advance some activities to allow for more efficient Run 3?
    - CMS neutron shielding
    - ATLAS NSW-C
    - ...

*Discussion has started;  
meeting June 8 to decide on a  
plan*

# Preliminary Observations for Run 3

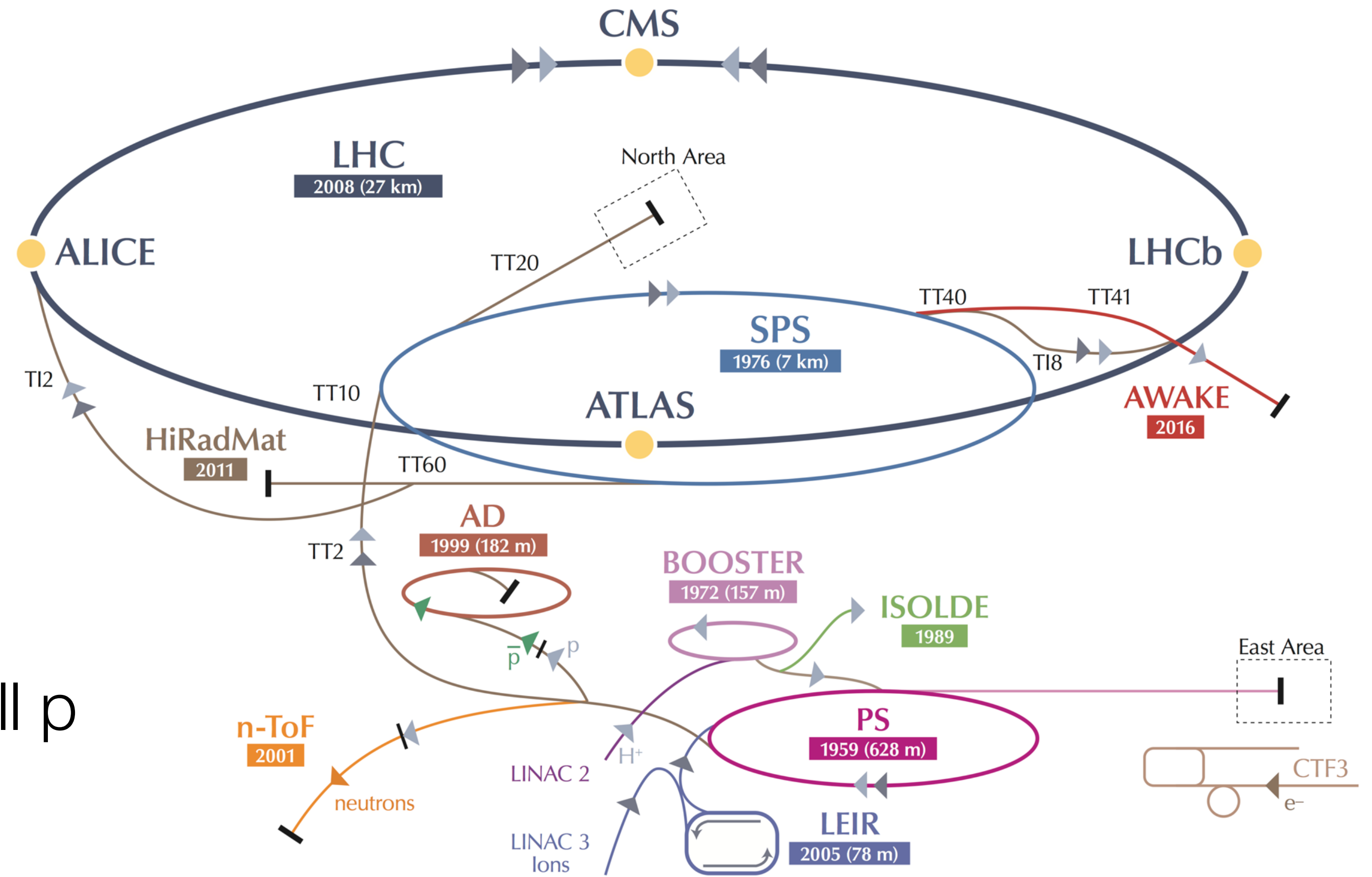
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- LS2 will have to be extended
- Machine expected to be commissioned at the highest energy
- Aim for shorter interruptions than originally planned during Run 3
  - Position of LS3 will not be affected
  - Integrated luminosity for Run 3 essentially maintained (double Run 1 and 2 statistics)
- Luminosity in 2021 will be small or zero; time profile of Run 3 will change

Other elements of the Update of European Strategy for  
Particle Physics 2020

# LHC and its injector chain

- LHC
  - operation at 13++ TeV
- Injectors supporting
  - Fixed target programme
  - ISOLDE (isotopes) } 75% of all p
  - n-ToF
  - AD-programme



# Initial Fixed Target Programme (and more)

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- PS and SPS beams will be available on 2021
- The initial Programme of 2021 has been approved by the Research Board
  - NA61, NA62, COMPASS, NA64
  - Feasibility Studies for MUonE with a test beam
- ISOLDE
- AD (Antimaterie)

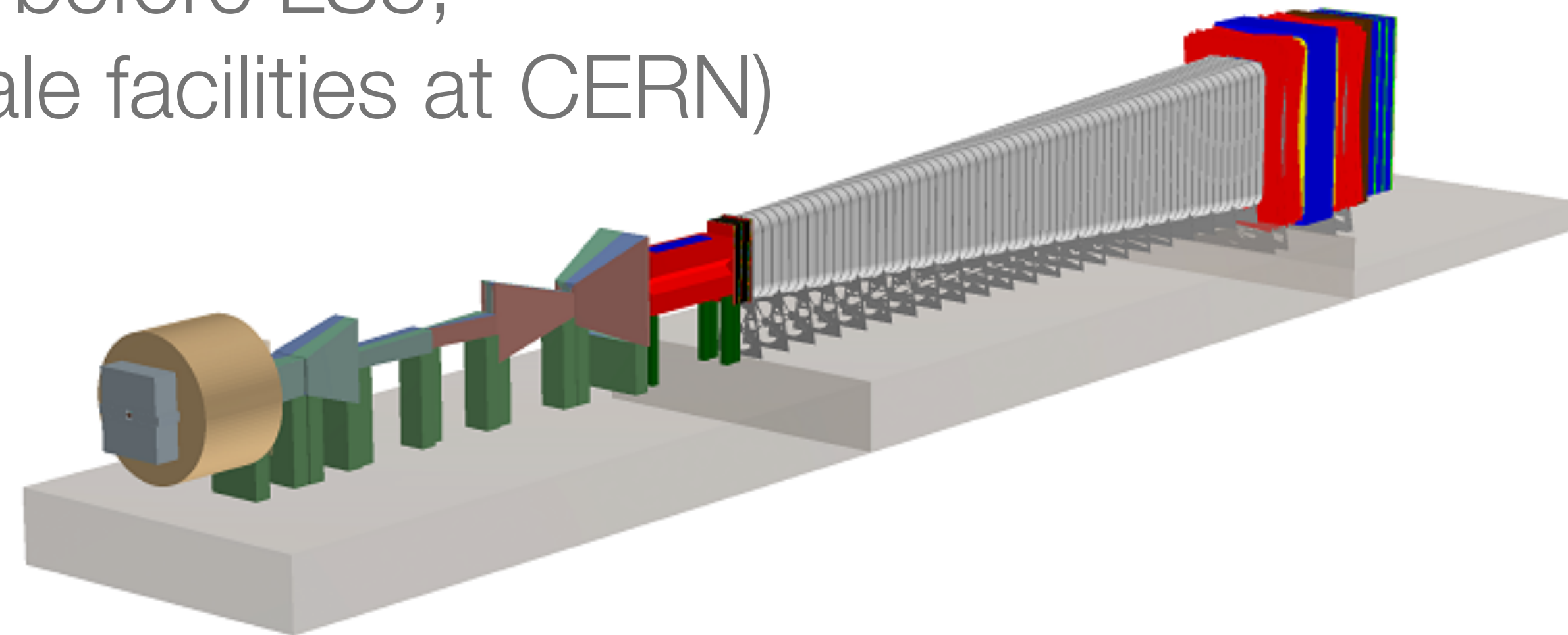
*available in 2021*

# Recommendations of the Physics Beyond Collider Study

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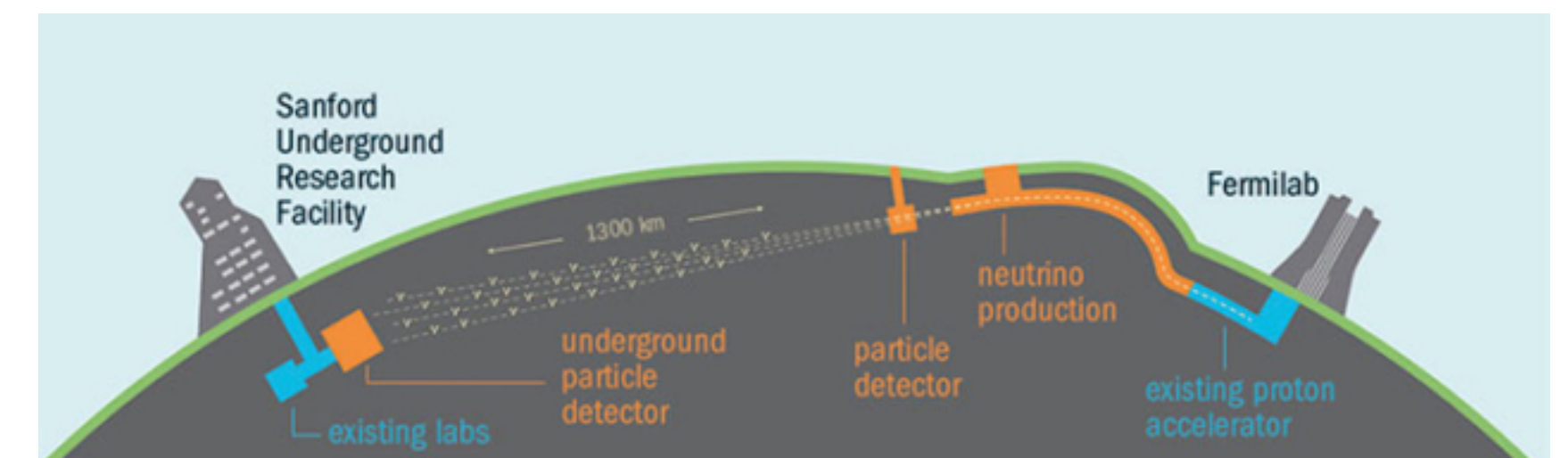
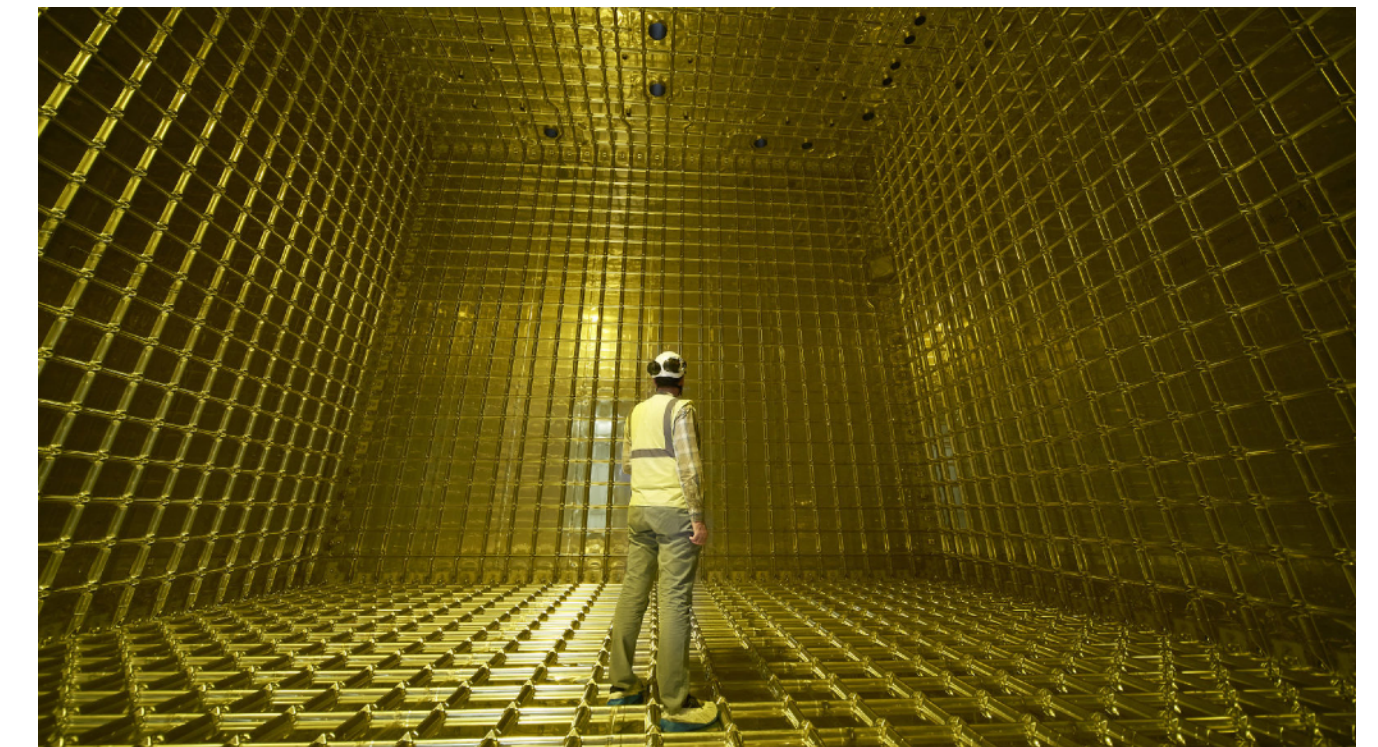
- COMPASS++/AMBER
- MUonE, if feasible
- ShiP requires a Beam Dump Facility (not before LS3;  
Decision depends on the future large scale facilities at CERN)
- eSPS
- pEDM
- BabyIAXO, etc.

} external



# Neutrino platform

- has been established following ESPPU 2013
- tremendous success for LArTPC technology
  - Single Phase protoDUNE, comfortable e-lifetime; would support large drifts (simplified construction)
  - Double Phase protoDUNE - first attempts; needs to be optimised
- CERN contributes one of the DUNE/LBNF cryostats





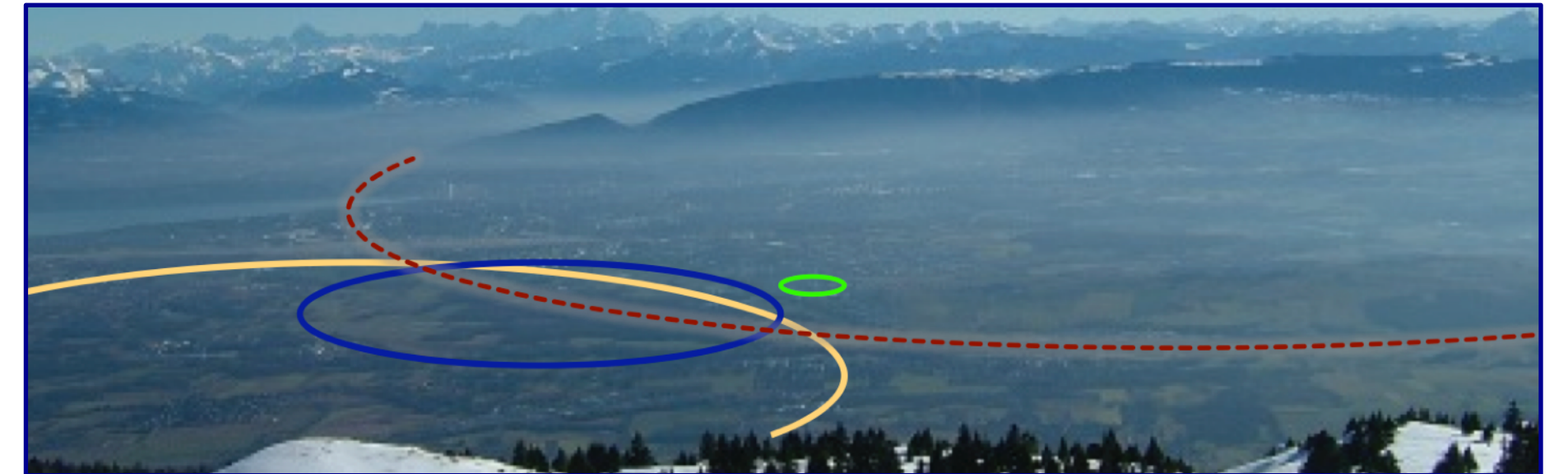
Update of European Strategy for Particle Physics 2020 scheduled to be released during June 2020 Council Session



# Community Input (Granada)

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- Precision Higgs Physics in  $e^+e^-$
- Need for Accelerator Technology Development
  - High Field Magnets
- Need for a future Energy Frontier machine
- Broad theoretical and experimental interest in axion-like particle searches.



*Dark matter remains an enigma*

# Summary

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- Experimental Programme of LHC extremely rich; long range experimental programme guarantees a broad physics return
  - by exploring the highest energies and the Higgs properties
  - by searching for violations of the SM in (highly sensitive) rare decays
- European Strategy for Particle Physics about to be released
  - LHC and HL-LHC ✓
  - Vibrant physics programme beyond colliders ✓
  - Future Facilities at the energy frontier...