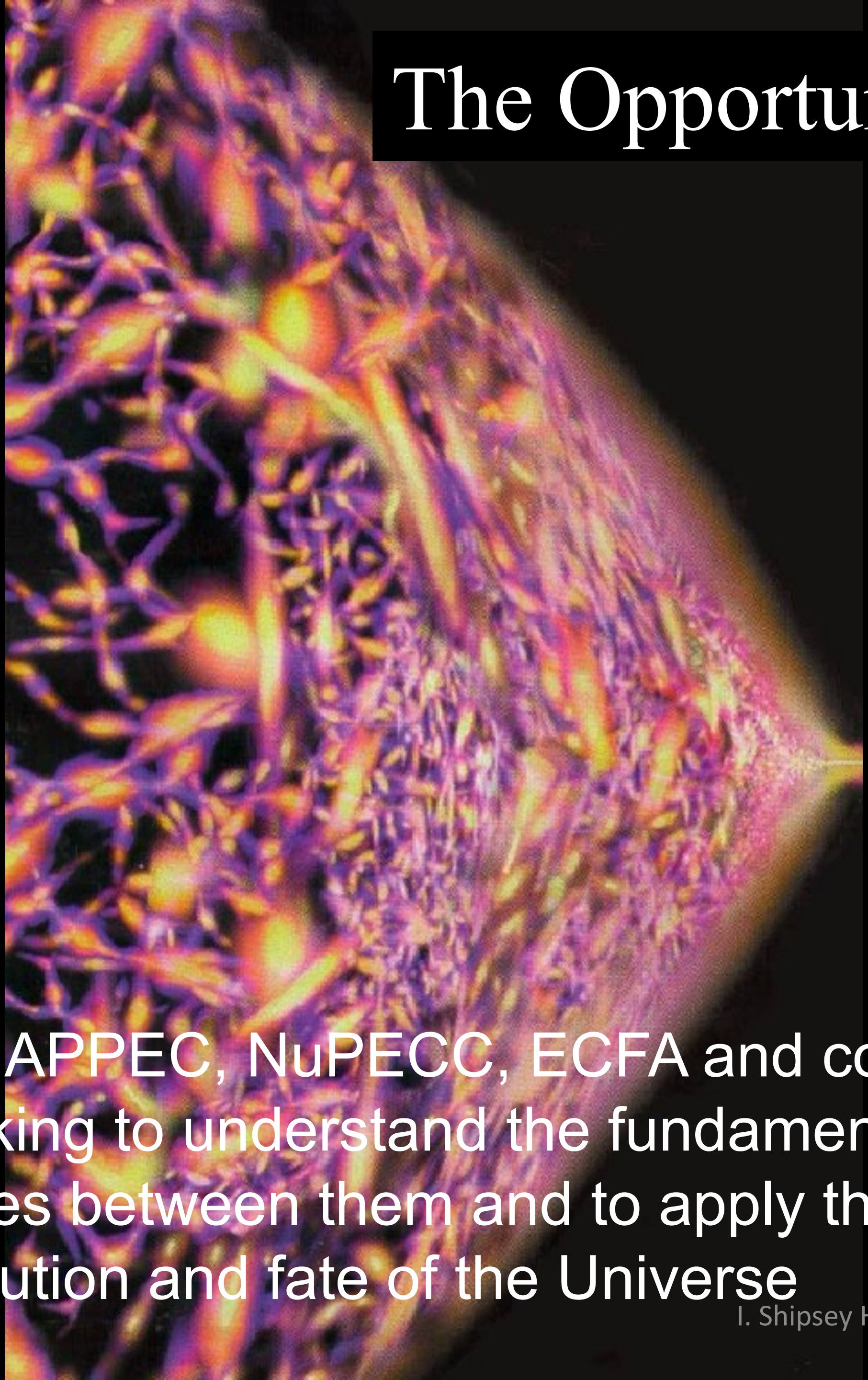
HarnewFest!

Ian Shipsey, Head Oxford Physics

The Opportunities for Discovery



The APPEC, NuPECC, ECFA and cosmology communities are united in seeking to understand the fundamental constituents of the Universe and the forces between them and to apply that knowledge to understand the birth, evolution and fate of the Universe

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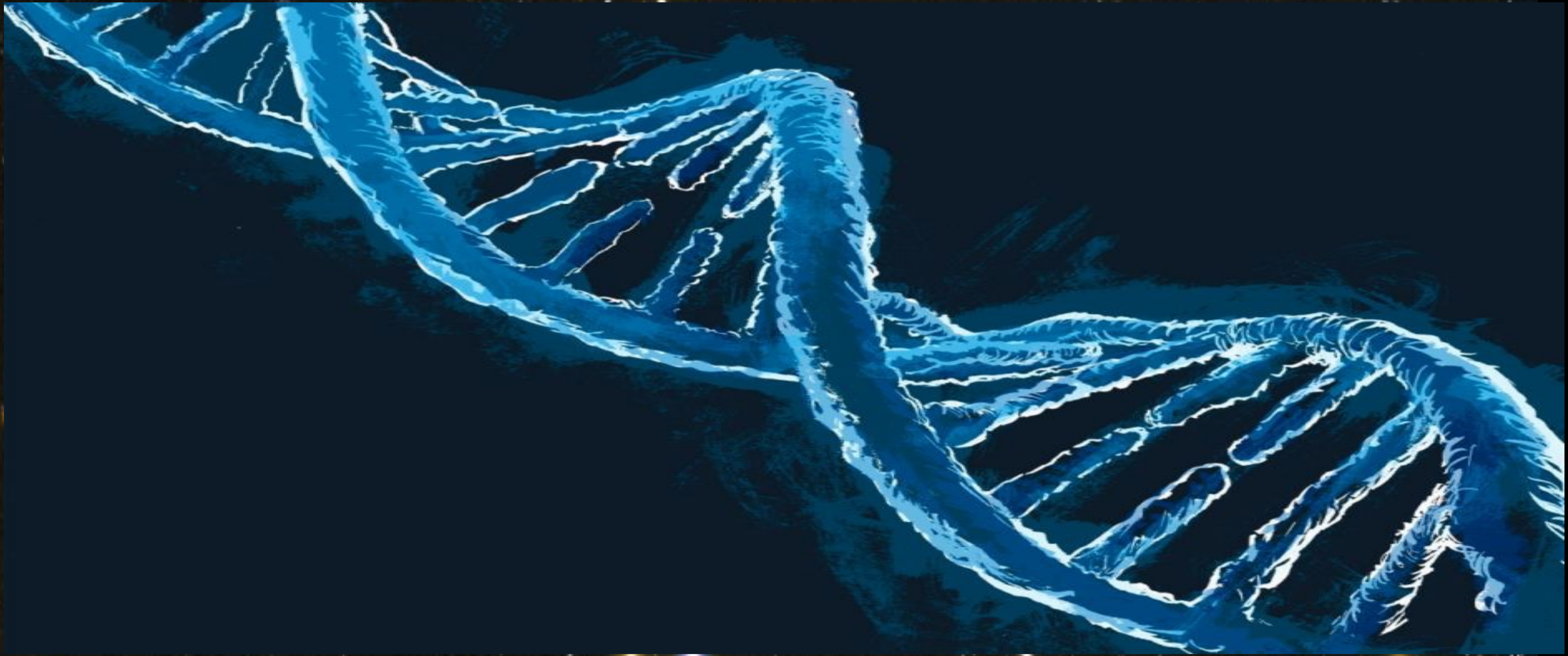
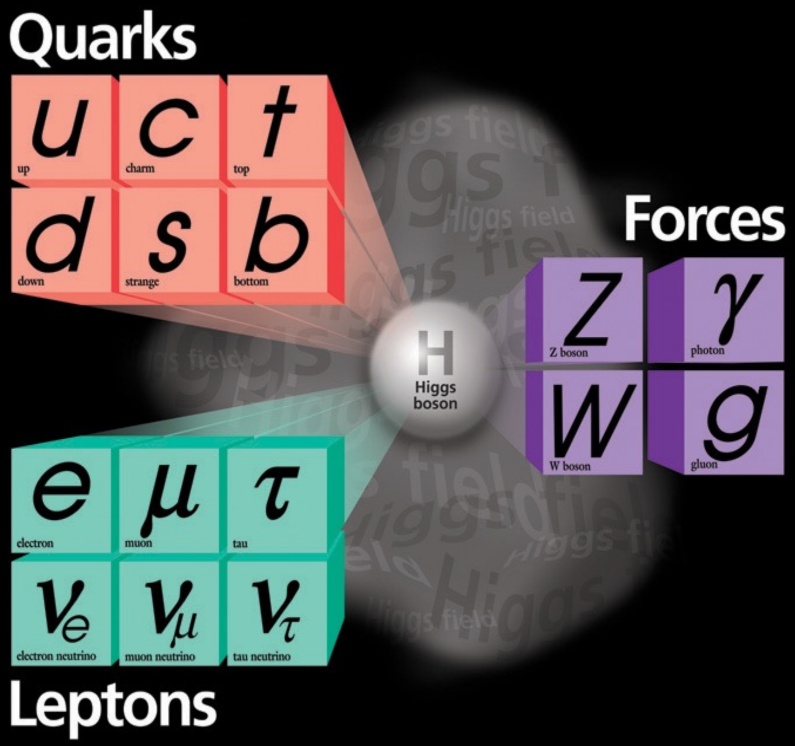
BUILDING AN UNDERSTANDING OF THE UNIVERSE: A WORK A CENTURY IN THE MAKING

Our communities have revolutionized human understanding of the Universe – its underlying code, structure and evolution

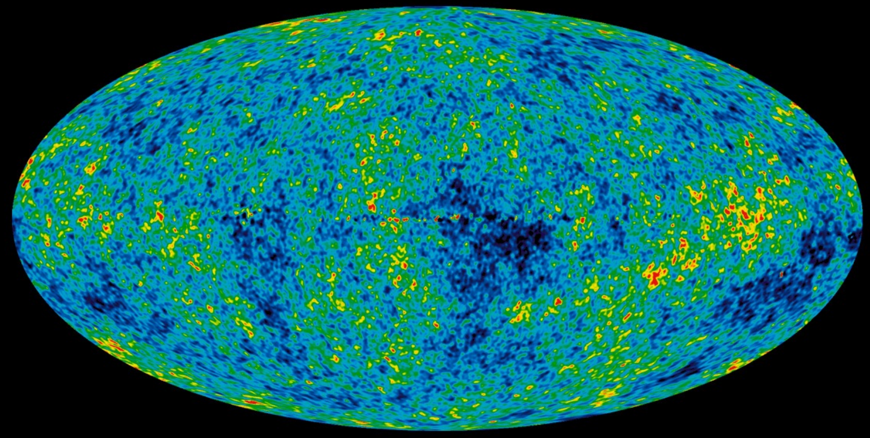


BUILDING AN UNDERSTANDING OF THE UNIVERSE: A WORK A CENTURY IN THE MAKING

Particle Standard Model



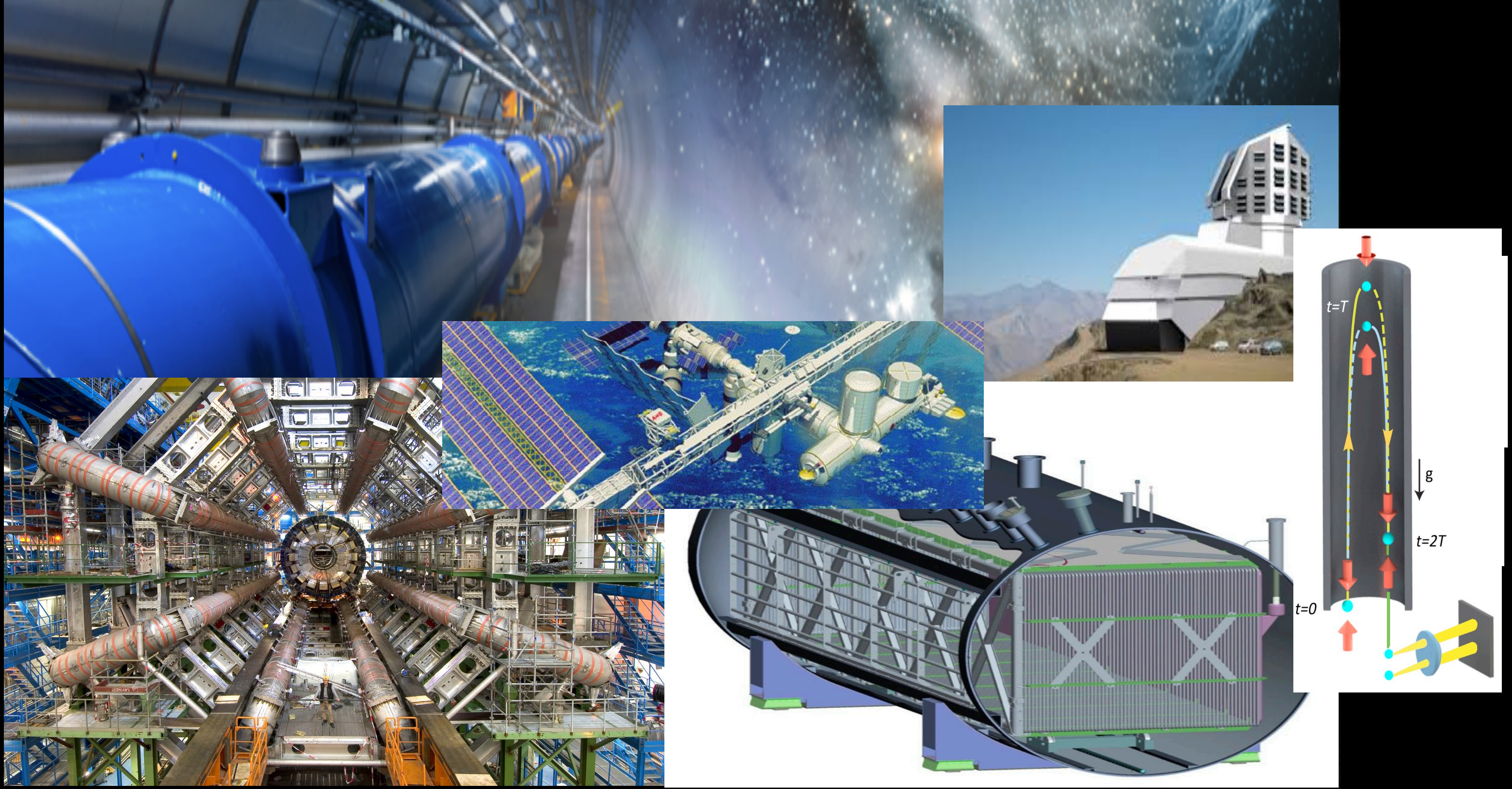
Cosmology Standard Model



Λ_{CDM}

……enabled by instrumentation

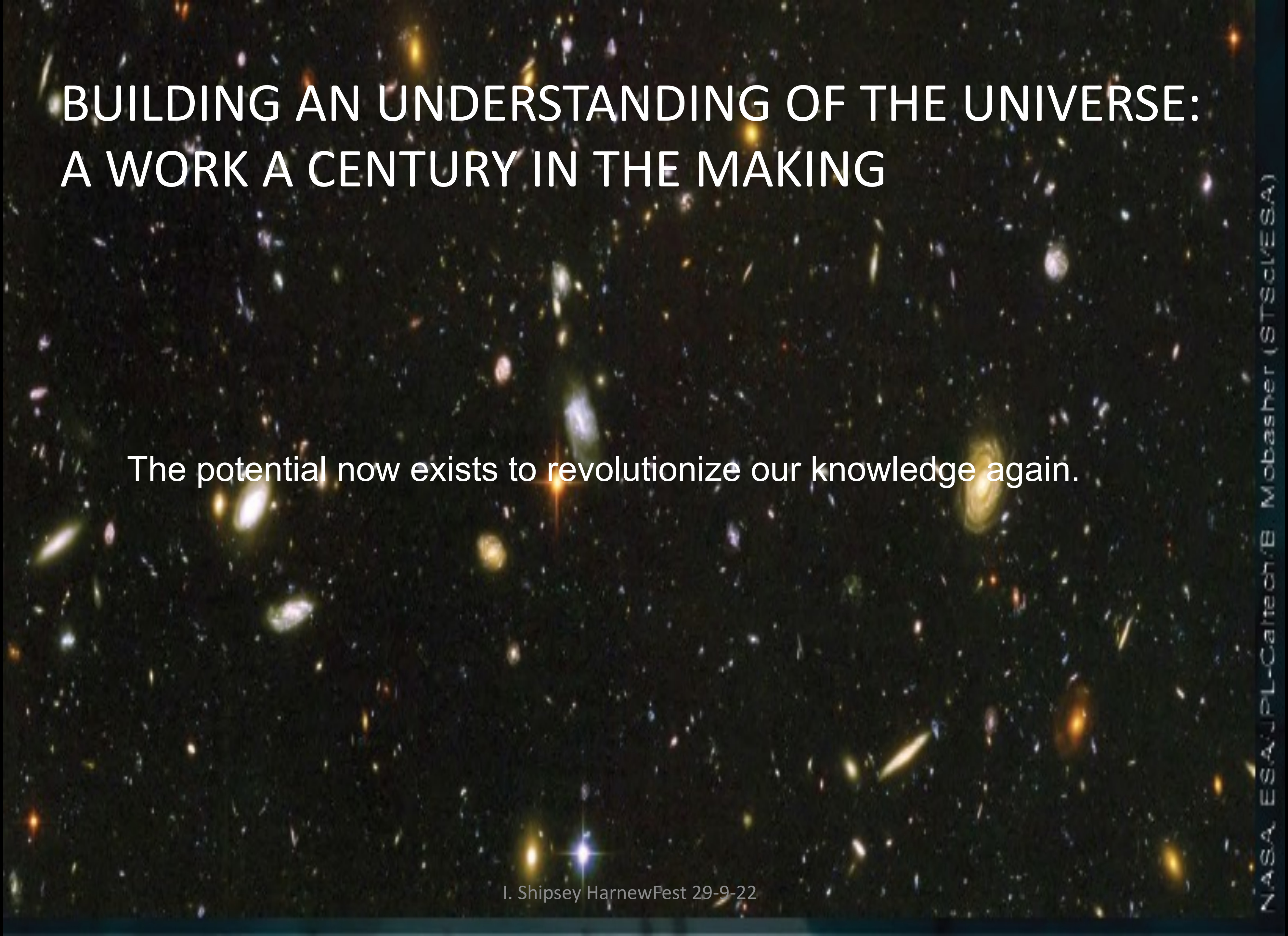
APPEC
ECFA
NuPECC



Our APPEC/ECFA/NuPECC scope is broad and we deploy many tools; accelerator, non-accelerator, astrophysical & cosmological observations all have a critical role to play

BUILDING AN UNDERSTANDING OF THE UNIVERSE: A WORK A CENTURY IN THE MAKING

The potential now exists to revolutionize our knowledge again.



Outstanding Questions in Particle Physics *circa* 2011

EWSB
- ❑ Does the Higgs boson exist?

Quarks and leptons:
- ❑ why 3 families ?
- ❑ masses and mixing
- ❑ *CP* violation in the lepton sector
- ❑ matter and antimatter asymmetry
- ❑ baryon and charged lepton number violation

Physics at the highest E-scales:
- ❑ how is gravity connected with the other forces ?
- ❑ do forces unify at high energy ?

Dark matter:
- ❑ composition: WIMP, sterile neutrinos, axions, other hidden sector particles, ..
- ❑ one type or more ?
- ❑ only gravitational or other interactions ?

Neutrinos:
- ❑ ν masses and and their origin
- ❑ what is the role of *H*(125) ?
- ❑ Majorana or Dirac ?
- ❑ *CP* violation
- ❑ additional species → sterile ν ?

The two epochs of Universe's accelerated expansion:
- ❑ primordial: is inflation correct ? which (scalar) fields? role of quantum gravity?
- ❑ today: dark energy (why is Λ so small?) or gravity modification ?

Outstanding Questions in Particle Physics *circa* 2022

… there has never been a better time to be a particle physicist!

Higgs boson and EWSB
- ❑ m_H natural or fine-tuned ?
- → if natural: what new physics/symmetry?
- ❑ does it regularize the divergent $V_L V_L$ cross-section at high $M(V_L V_L)$? Or is there a new dynamics ?
- ❑ elementary or composite Higgs ?
- ❑ is it alone or are there other Higgs bosons ?
- ❑ origin of couplings to fermions
- ❑ coupling to dark matter ?
- ❑ does it violate CP ?
- ❑ cosmological EW phase transition

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Opportunities for Discovery

Many mysteries to date go unanswered including:

The mystery of the Higgs boson

The mystery of Neutrinos

The mystery of Dark Matter

They mystery of Dark Energy

The mystery of quarks and charged leptons

The mystery of Matter – anti-Matter asymmetry

The mystery of the Hierarchy Problem

The mystery of the Families of Particles

The mystery of Inflation

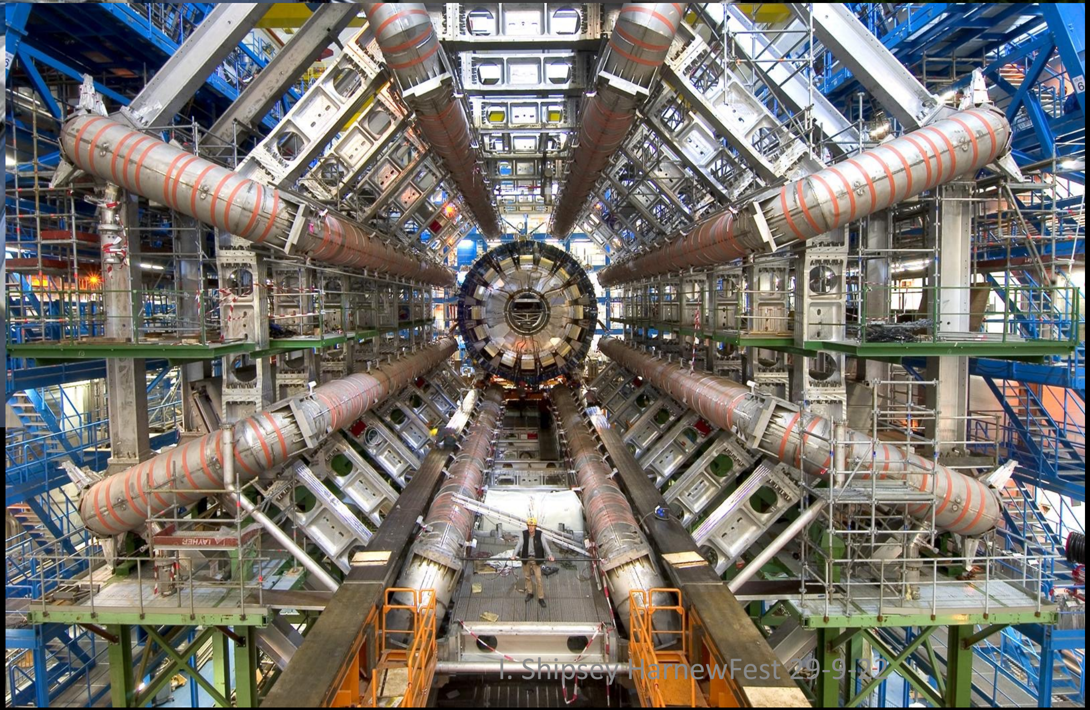
The mystery of Gravity

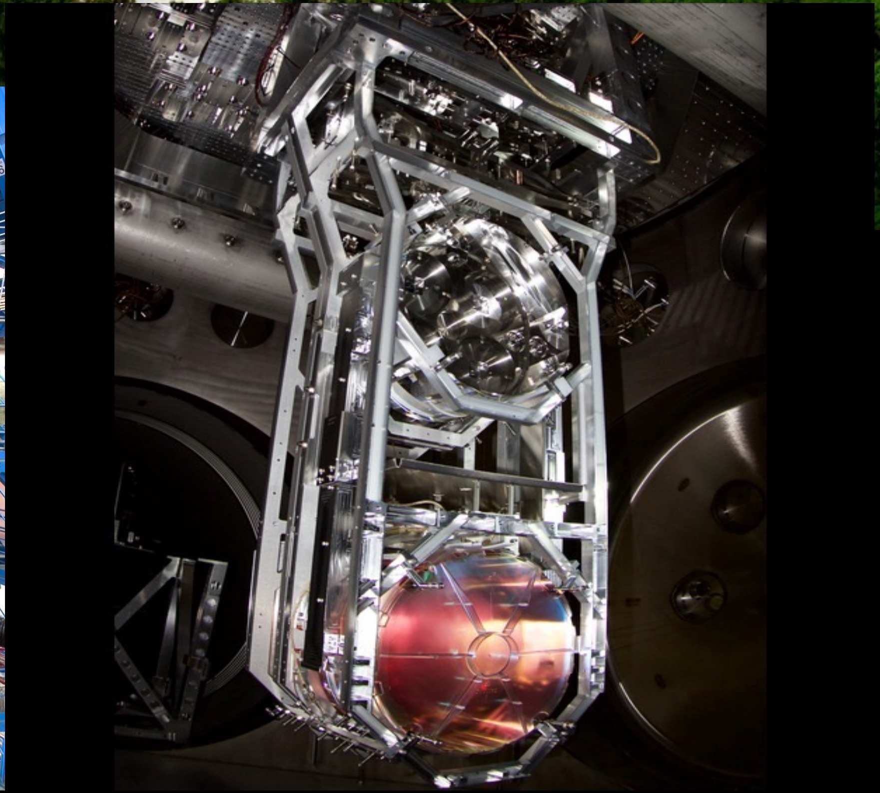
How do quarks and gluons give rise to the properties of nuclei
The mystery of the origin and engine of high energy cosmic particles

Multiple theoretical solutions – experiment must guide the way

We are very much in a data driven era for which we need new tools!

The gestation time to realize the tools and the experiments e.g. LHC & LIGO are decades long! For the most ambitious future experiments e.g FCCee/hh & Einstein Telescope to take the data and seize the opportunities for discovery, we must develop the tools (instrumentation and facilities) we need NOW.





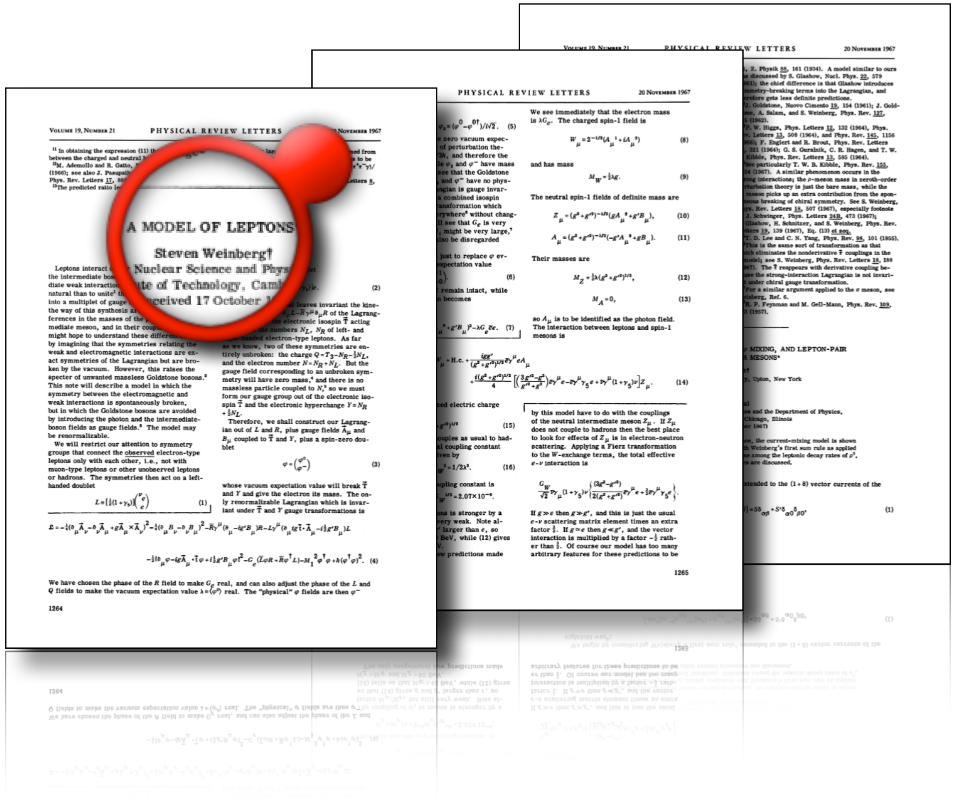
"New directions in science are launched by new tools much more often than by new concepts. The effect of a concept-driven revolution is to explain old things in new ways. The effect of a tool-driven revolution is to discover new things that have to be explained" (*Freeman Dyson)*

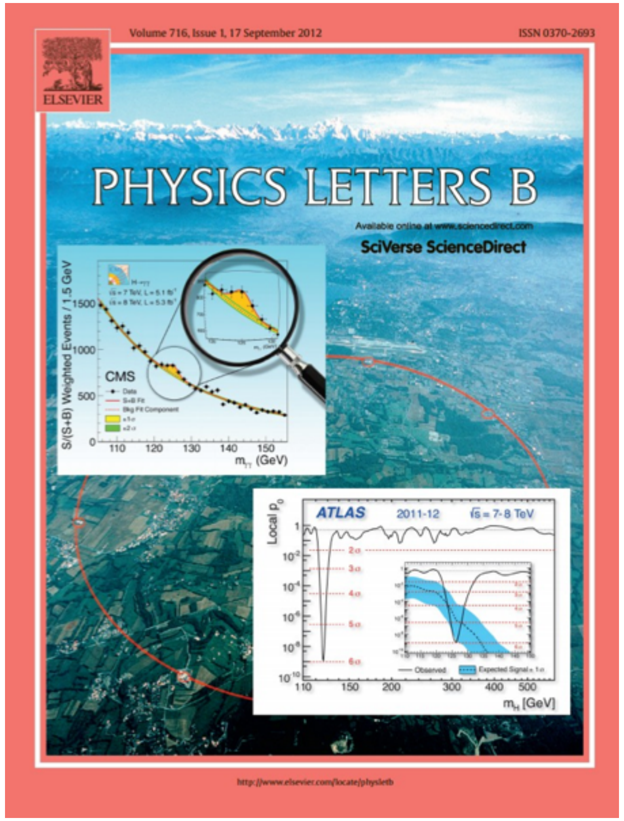
Photo credit: CERN

“Measure what is measurable, and make measurable what is not so” (*Galileo Galilei)*

Photo credit: CERN

between **1967 - 2012**





Slide credit Chip Brock

The Standard Model Guided Research

Slide credit
Chip Brock

No-lose completion of the Standard Model

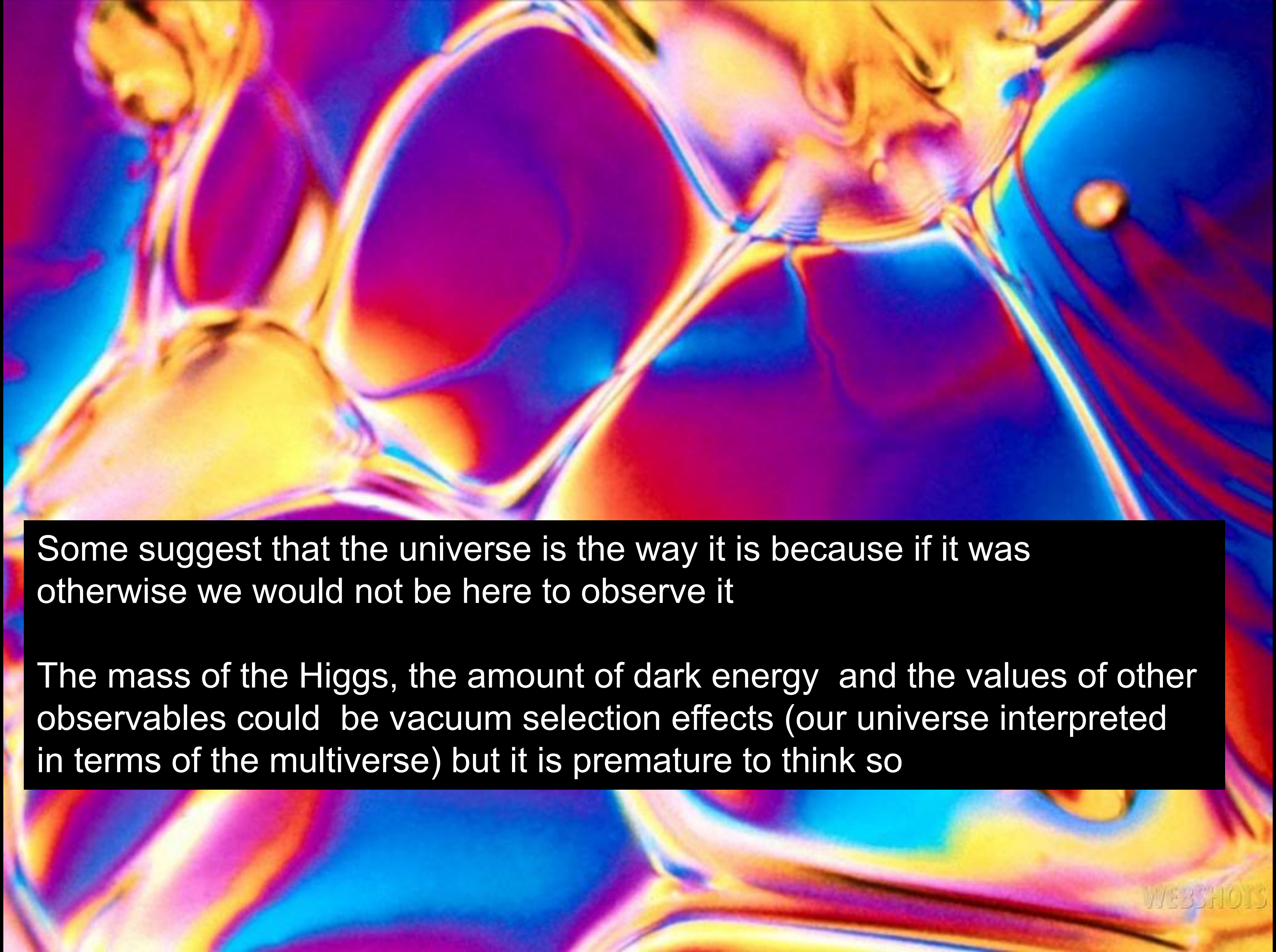
Guaranteed discoveries

W & Z	CERN SppS
Top quark	Tevatron
Higgs	LHC

No-lose completion of the Standard Model

Now that the Standard Model is complete, there are no further no-lose theorems
In principle, the Standard Model could be valid to the Planck scale. (If so much would be left unexplained.)

No guaranteed discoveries

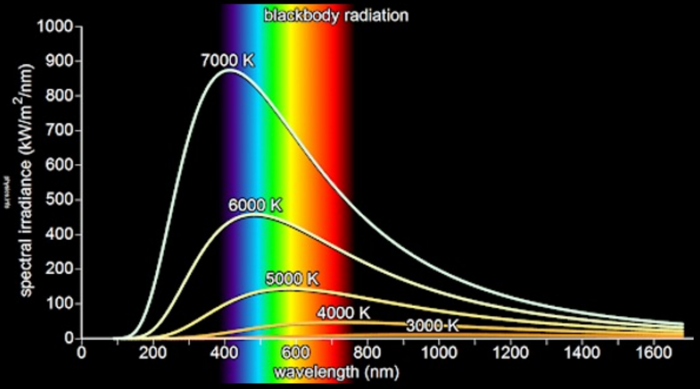


Some suggest that the universe is the way it is because if it was otherwise we would not be here to observe it

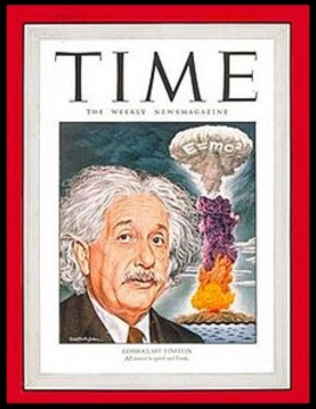
The mass of the Higgs, the amount of dark energy and the values of other observables could be vacuum selection effects (our universe interpreted in terms of the multiverse) but it is premature to think so

Science progresses by experimentation, observation, and theory

- Nobody would have predicted that slight irregularities in black body radiation would have led to the entirely new concept of the quantum world.



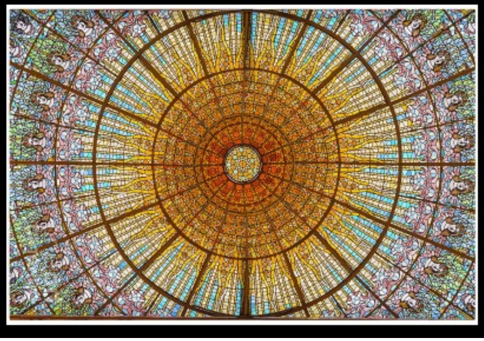
- That pondering the constancy of the speed of light would have led to $E= mc^2$



- That special relativity and quantum mechanics would have led to anti-matter

$$(i\gamma^{\mu}\partial_{\mu} - m)\psi = 0$$

- That Noether's theorem would lead to the importance of symmetries and the corresponding conservation laws



Experiments that explore uncharted territory, or study phenomena we do not understand with greater precision, lead to a deeper understanding of nature, the global program in particle physics, particle-astrophysics and nuclear physics does that

The program will continue to reveal a cosmos more wonderful than we can possibly imagine.

To play a major role in this journey of discovery is the aspiration of our fields

Discoveries in particle physics

Based on an original slide by S.C.C. Ting

Facility	Original purpose, Expert Opinion	Discovery with Precision Instrument
P.S. CERN (1960)	π N interactions	
AGS BNL (1960)	π N interactions	
FNAL Batavia (1970)	Neutrino Physics	
SLAC Spear (1970)	ep, QED	
ISR CERN (1980)	pp	
PETRA DESY (1980)	top quark	
Super Kamiokande (2000)	Proton Decay	
Telescopes (2000)	SN Cosmology	

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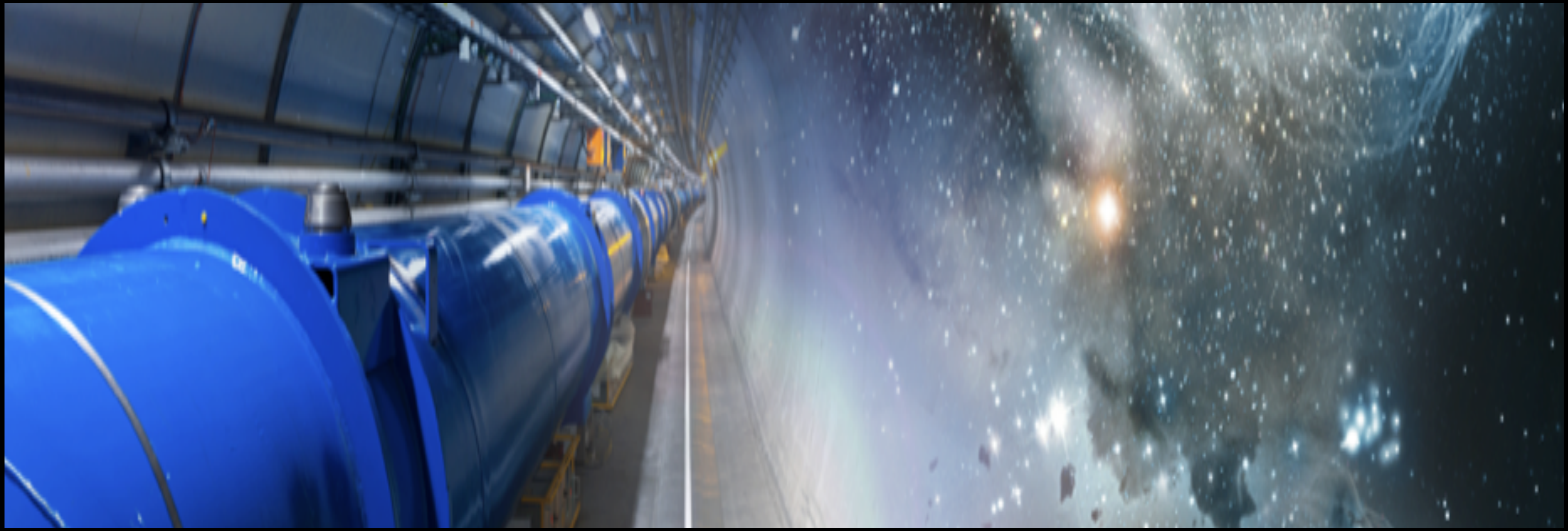
precision instruments are key to discovery when exploring new territory

L H C



precision instruments are key to discovery when exploring new territory

20 Years

- The technologies developed for the LHC took >20 years to research, develop and build
- These grew out of technologies developed for earlier rounds of experiments at earlier accelerators PS, SPS, SppbarS, & LEP @ CERN, the Tevatron @ Fermilab and other facilities worldwide in the 1960-1990s.
- The technologies for the HL- LHC began to be developed around 2008, the R&D, build, install and commission will be completed in 2029
- The technology R&D for experiments that commence operation in the 2030s, 2040s & 2050s and beyond e.g. FCC-ee/FCC-hh is either underway already or must begin now

Most recent European Strategies

the large …

weblink

2017-2026 European Astroparticle Physics Strategy

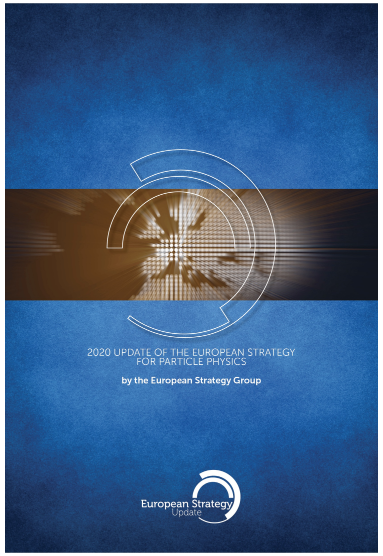
… the connection …

weblink

Long Range Plan 2017 Perspectives in Nuclear Physics

… the small

weblink



2020 Update of the European Particle Physics Strategy

Are community driven strategies outlining our ambition to address compelling open questions

Guidance for funding authorities to develop resource-loaded research programmes

Update of the European Strategy for Particle Physics

the update of the European Strategy for Particle Physics, recognizing the primacy of instrumentation, called on the community via ECFA to define a global detector R&D roadmap

*C. The **success of particle physics experiments relies on innovative instrumentation and state-of-the-art infrastructures.** To prepare and realise future experimental research programmes, the community must **maintain a strong focus on instrumentation. Detector R&D programmes and associated infrastructures should be supported at CERN, national institutes, laboratories and universities**. Synergies between the needs of different scientific fields and industry should be identified and exploited to boost efficiency in the development process and increase opportunities for more technology transfer benefiting society at large. Collaborative platforms and consortia must be adequately supported to provide coherence in these R&D activities. The community should define a **global detector R&D roadmap** that **should be used to support proposals at the European and national levels.***

Organised by ECFA, a roadmap should be developed by the community to balance the detector R&D efforts in Europe, taking into account progress with emerging technologies in adjacent fields. The roadmap should identify and describe a diversified detector R&D portfolio that has the largest potential to enhance the performance of the particle physics programme in the near and long term. …

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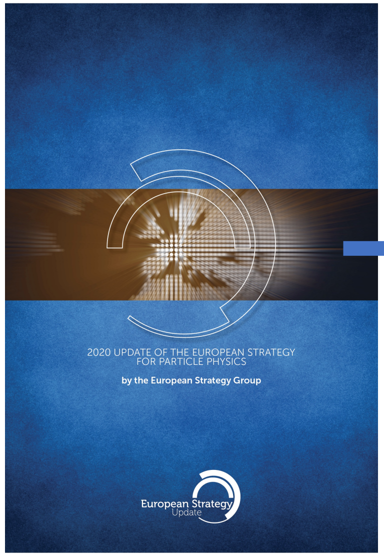
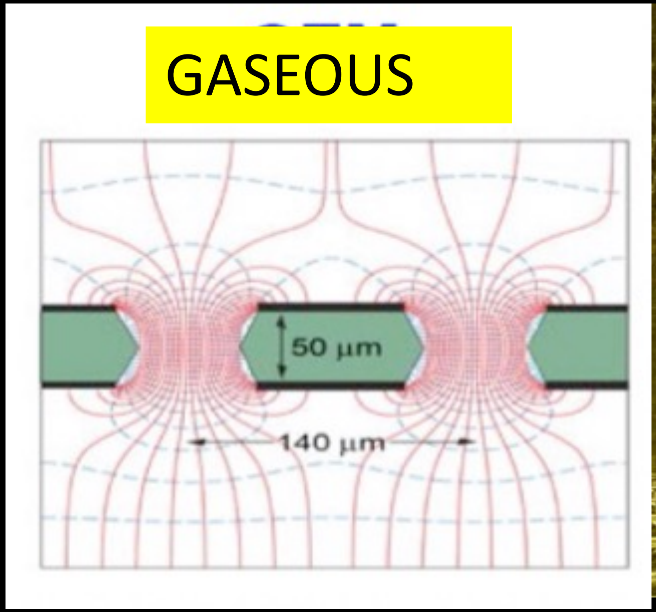
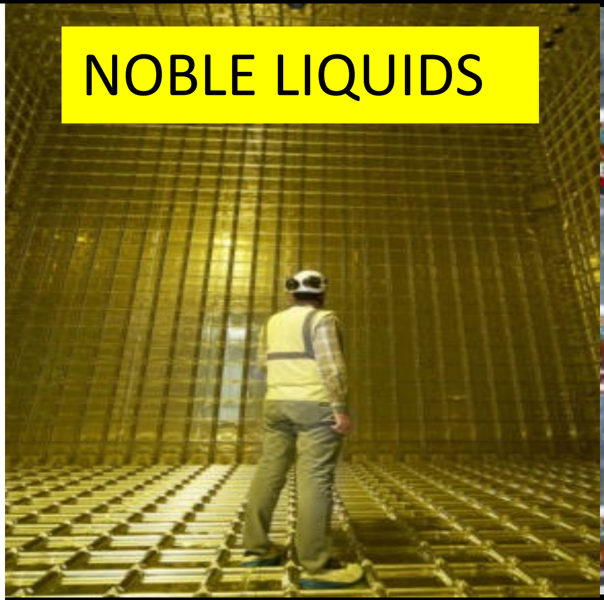


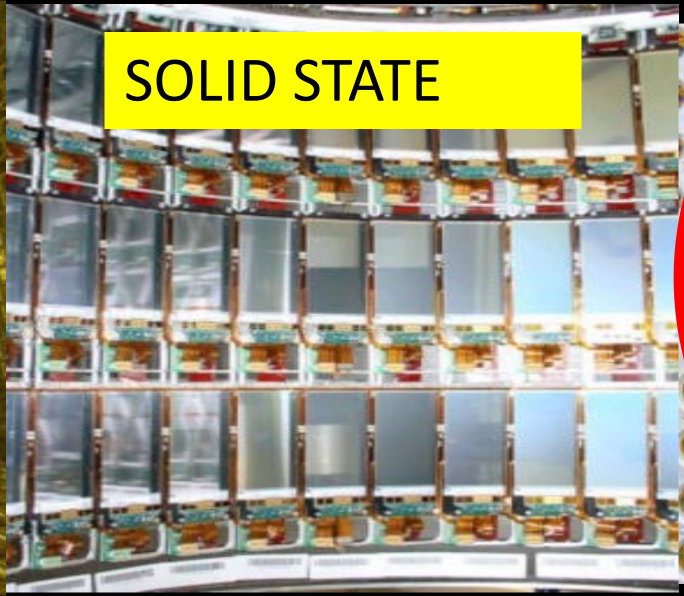
2020 Update of the European Particle Physics Strategy

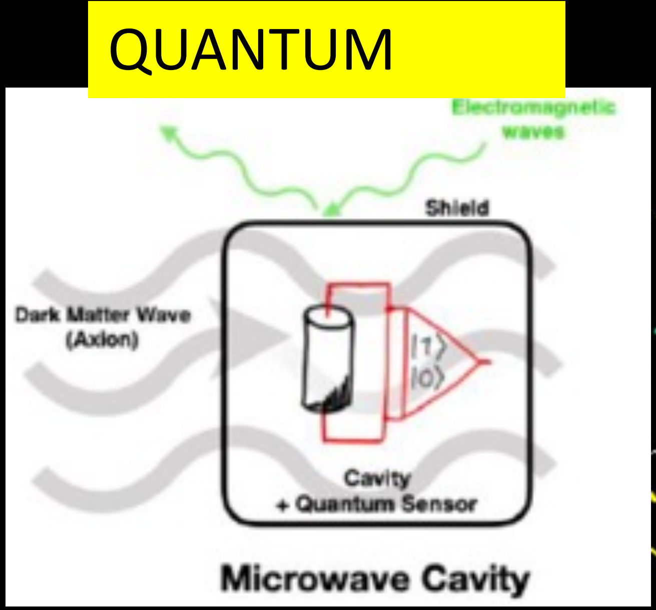
ECFA Detector R&D Roadmap

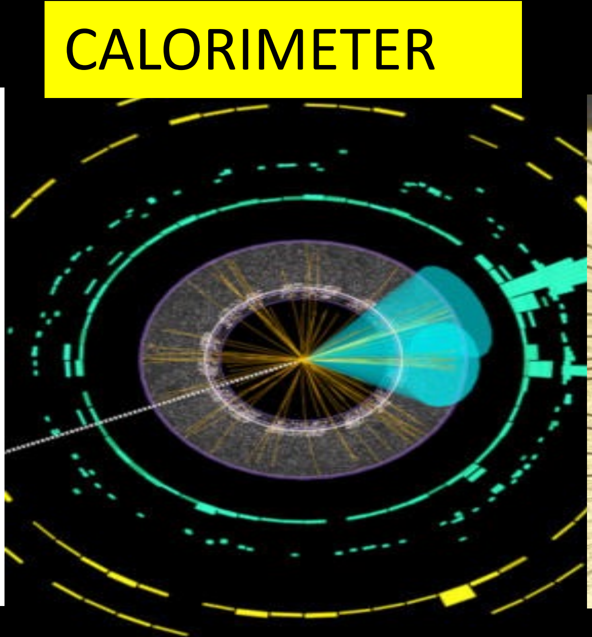
Technology Classification for the ECFA R&D Roadmap

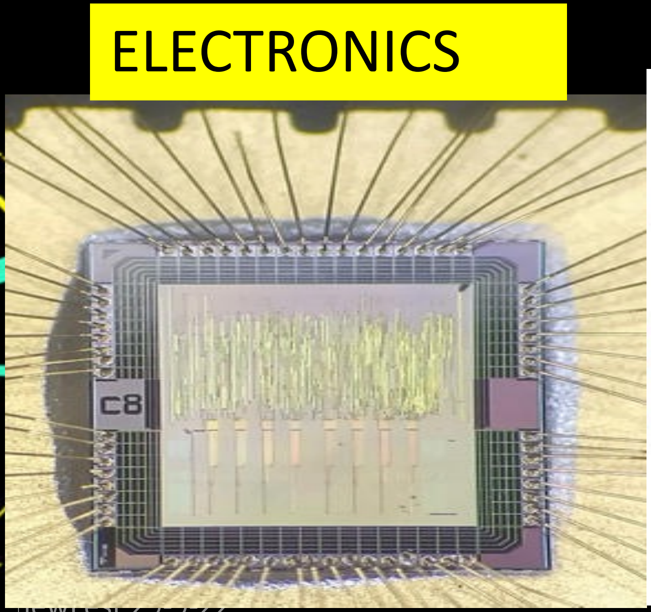


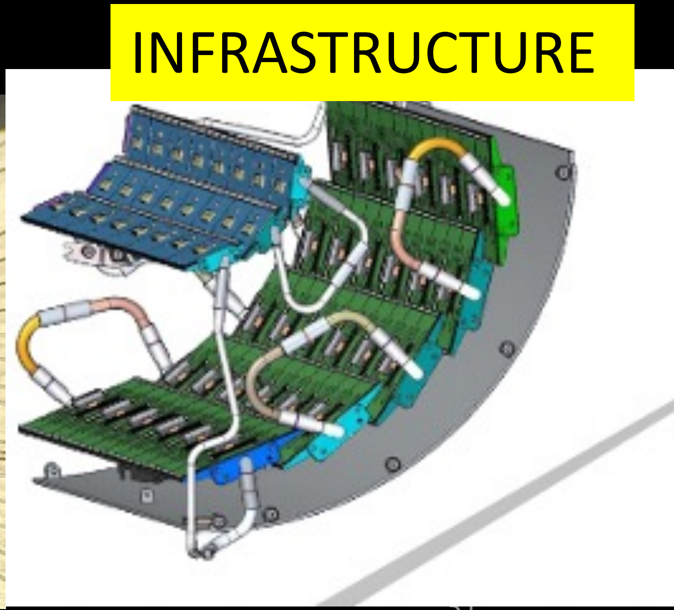












Roadmap Implementation Plan

- Next step: ECFA was mandated by Council in December 2021 to work out an implementation plan (*in close collaboration with the SPC, funding agencies & relevant research organisations in Europe and beyond)*

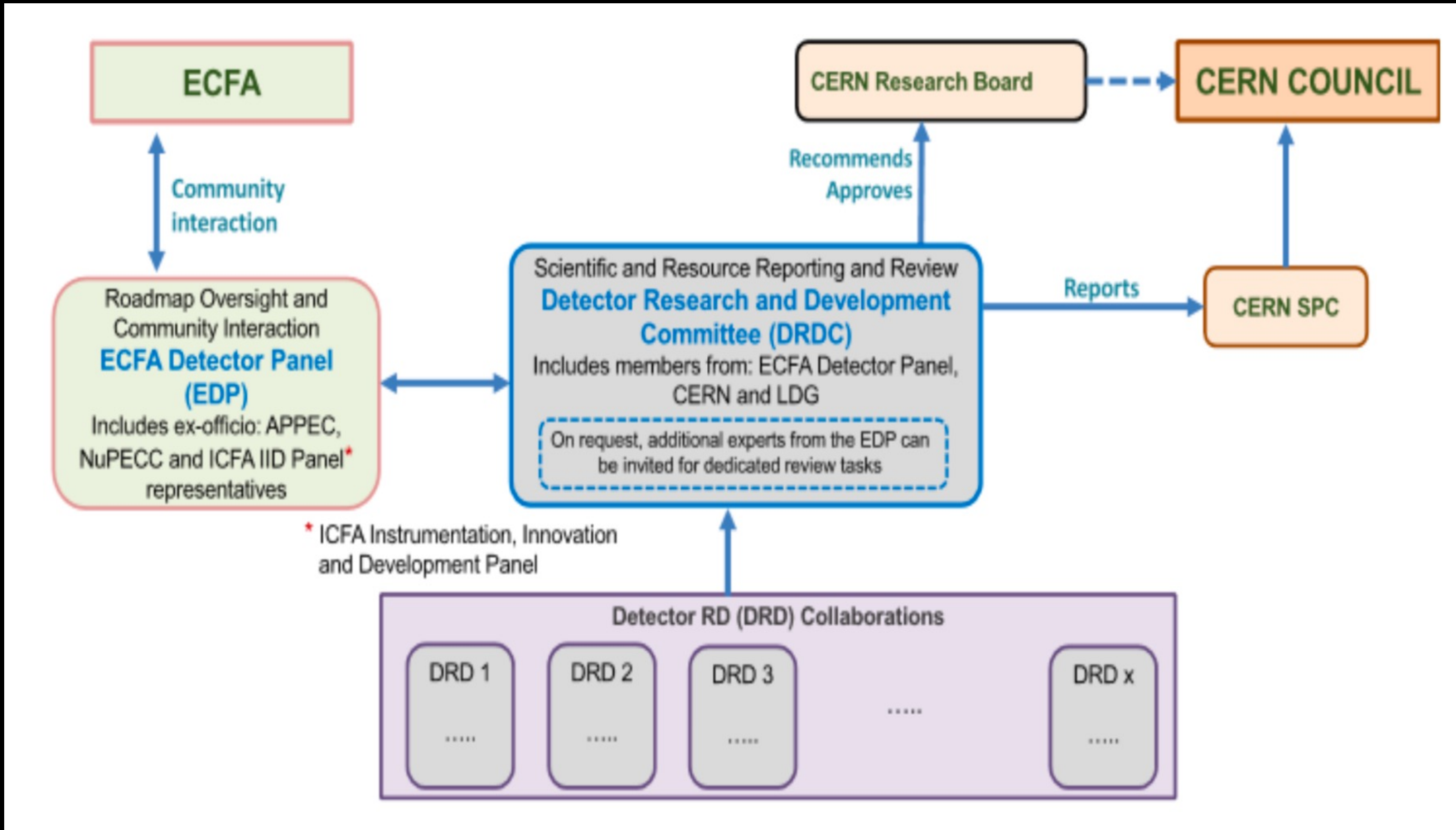
- Work ongoing

  - First implementation plan proposed

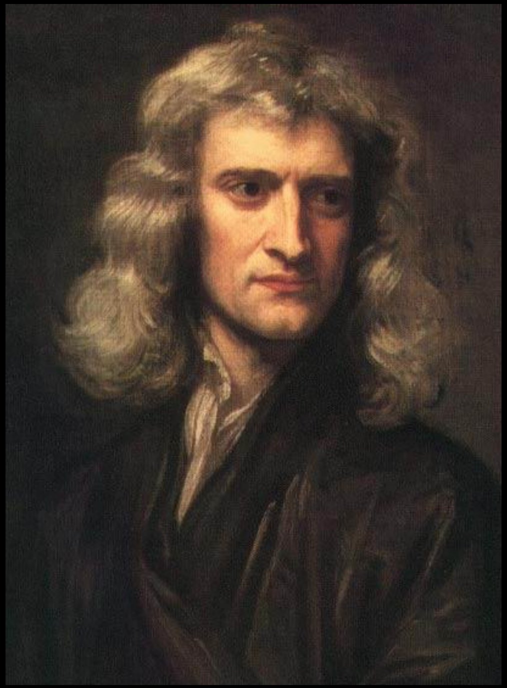
  - Discussions with CERN Council and Funding Agencies since 4/22

  - Request endorsement at SPC this week

  - Final approval CERN Council 12/22



Proposed structure:
- Establish new Detector R&D (DRD) Collaborations at CERN (one for each detector technology)
- Oversight and reviews by ECFA and CERN Committees



"What we know is a droplet, what we don't know is an Ocean"

Sir Isaac Newton (1643-1727)

The ocean is for all of us and future generations to explore.

LHCb is one of the world's premier tools for this exploration

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Neville has played a key leadership role in LHCb and in earlier experiments

And this will continue well into his retirement