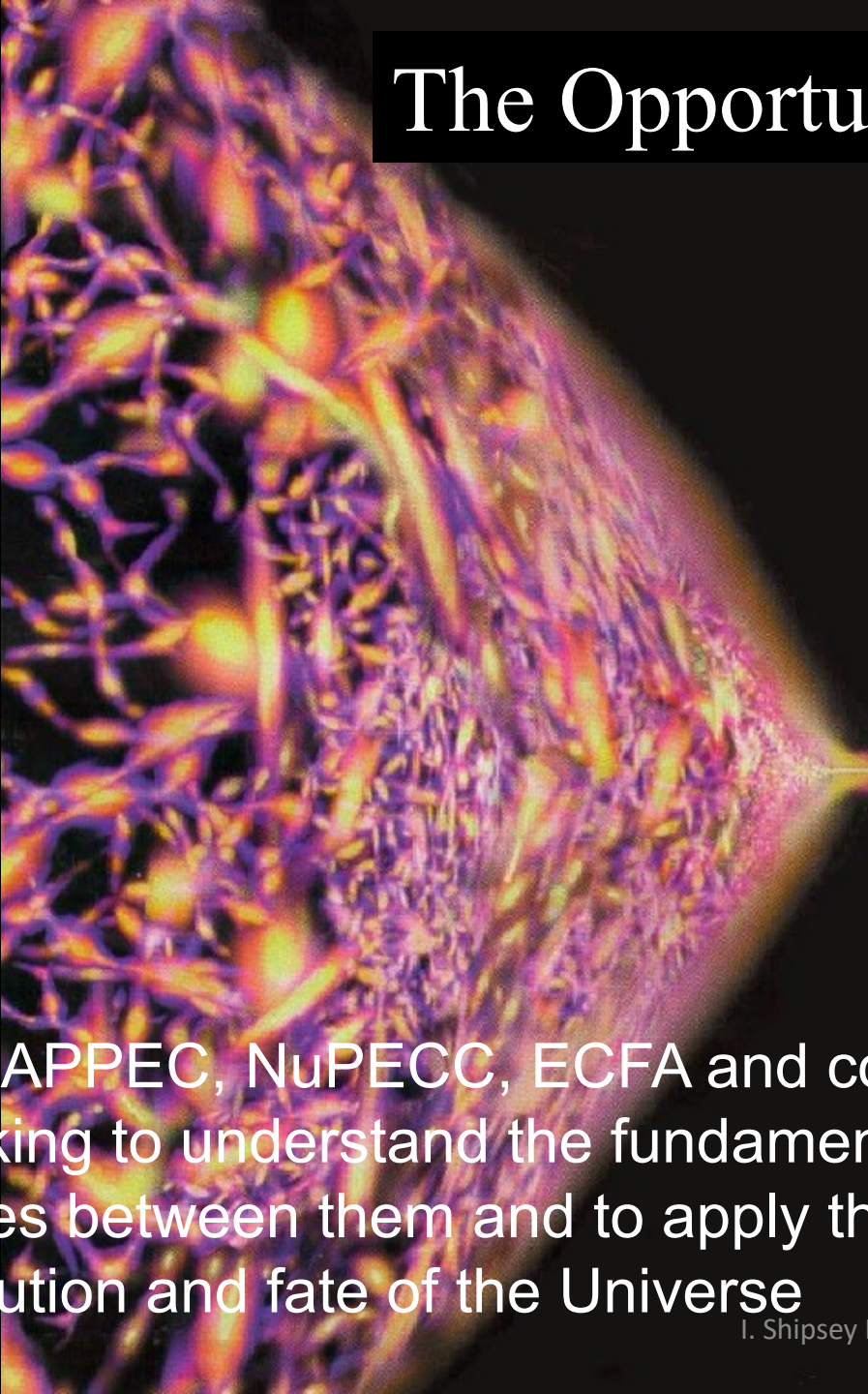


# HarnewFest!



# 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

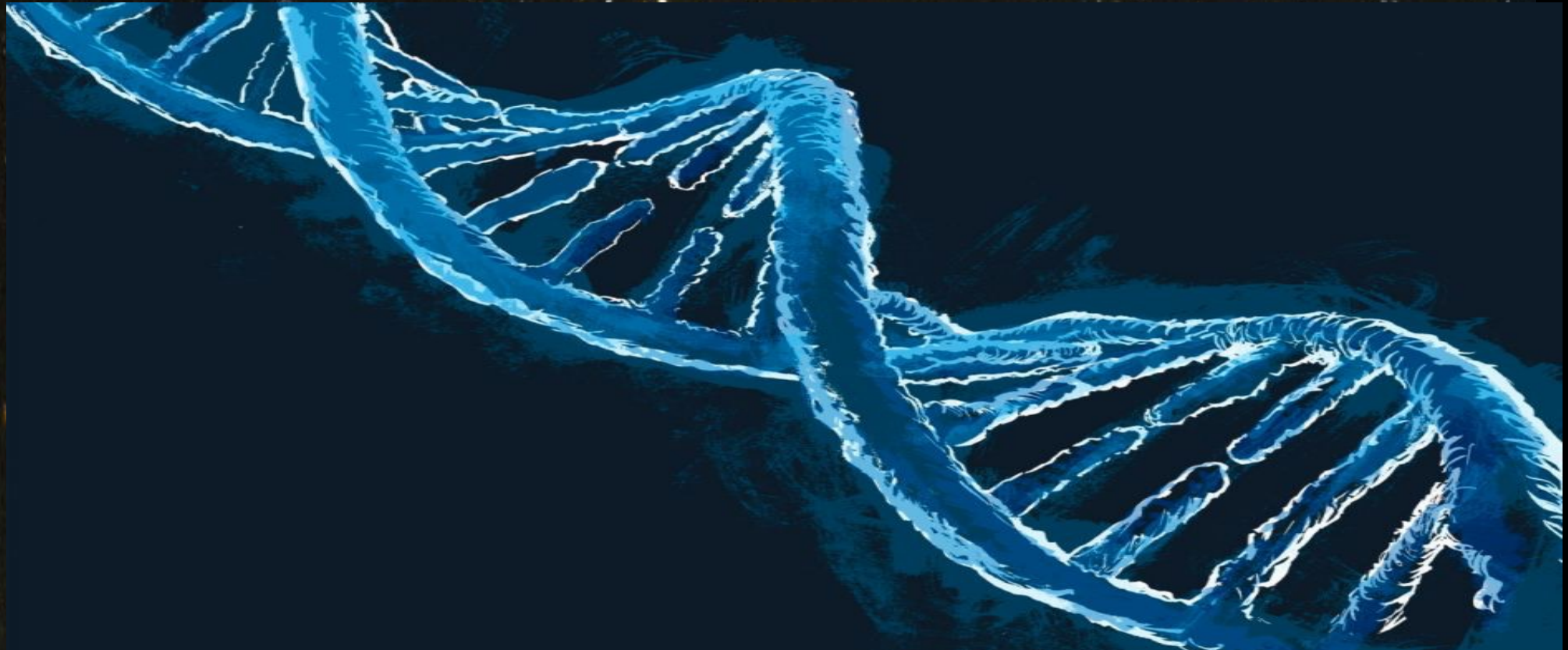
# The Opportunities for Discovery

The background of the slide is a composite image. On the left, there is a dense network of purple and orange filaments, resembling a cosmic web or a neural network. In the center, there is a lens-shaped region with a rainbow gradient, possibly representing a gravitational well or a lensing effect. On the right, there is a field of colorful galaxies, including spiral and elliptical galaxies, in various colors like blue, purple, and orange.

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

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

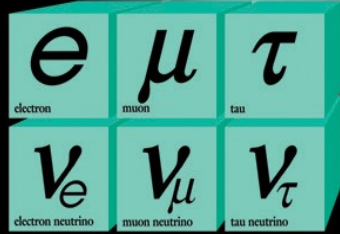
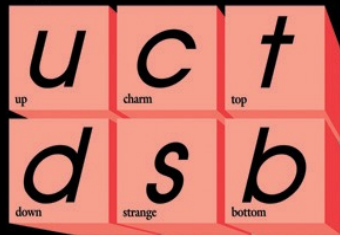
Our communities have revolutionized human understanding of the Universe  
– its underlying code, structure and evolution



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

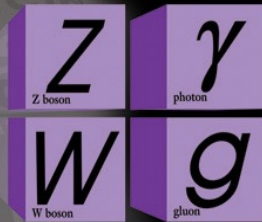
## Particle Standard Model

### Quarks

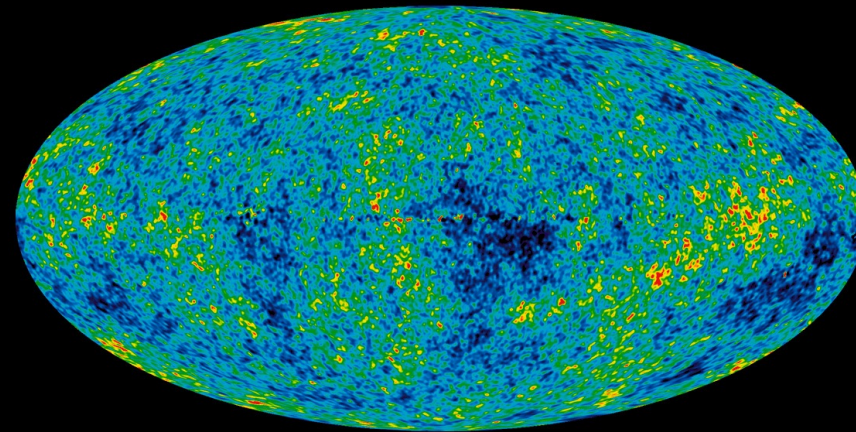


### Leptons

### Forces



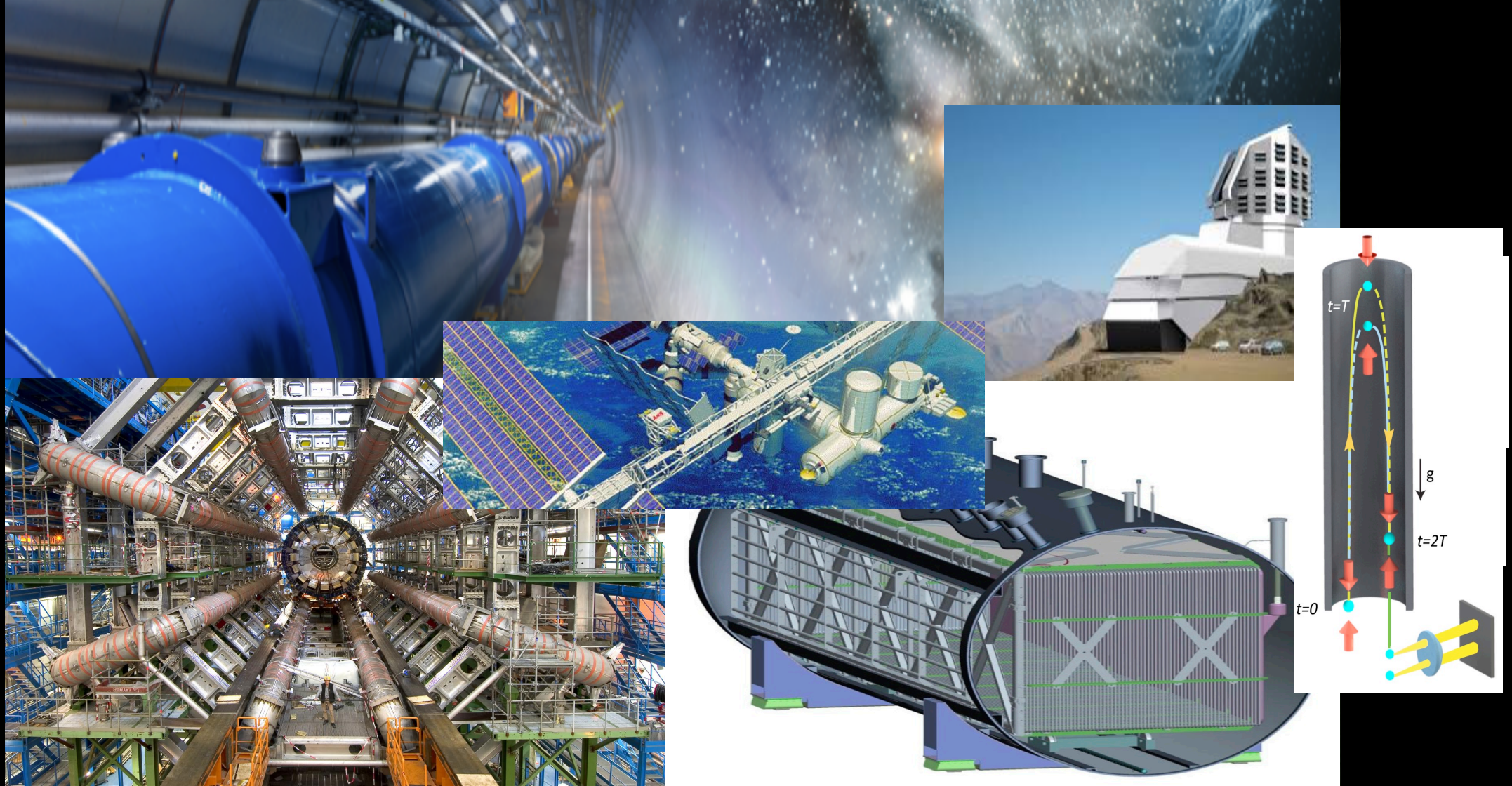
## Cosmology Standard Model



$\Lambda_{\text{CDM}}$

.....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:

- $\nu$  masses and their origin
- what is the role of  $H(125)$  ?
- Majorana or Dirac ?
- CP* violation
- additional species  $\rightarrow$  sterile  $\nu$  ?

## The two epochs of Universe's accelerated expansion:

- primordial: is inflation correct ?  
which (scalar) fields? role of quantum gravity?
- today: dark energy (why is  $\Lambda$  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

## Dark matter:

- composition: WIMP, sterile neutrinos, axions, other hidden sector particles, ..
- one type or more ?
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- CP violation
- additional species → sterile  $\nu$  ?

# 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

The 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

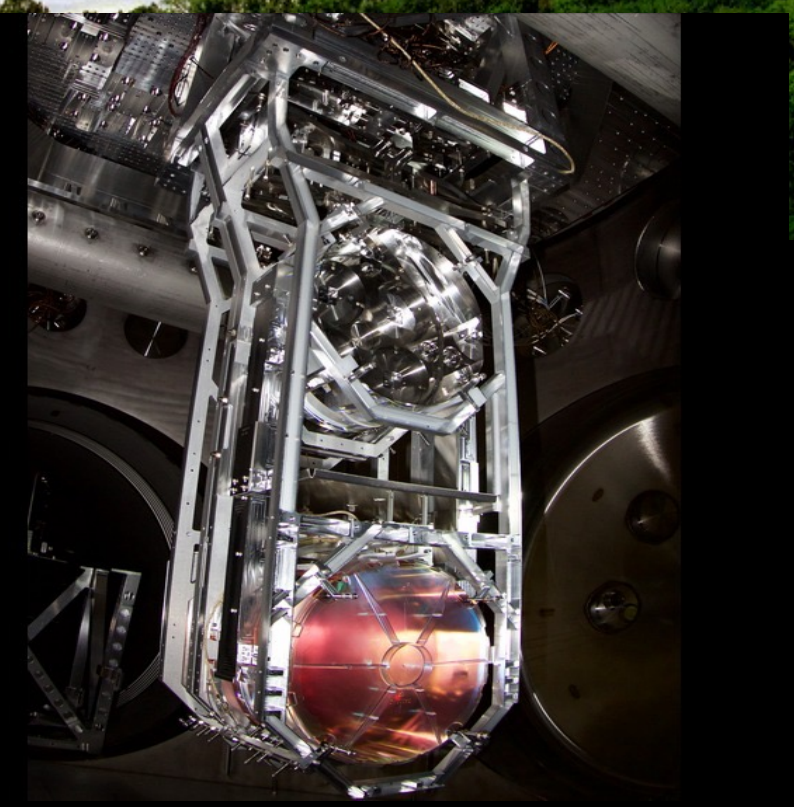
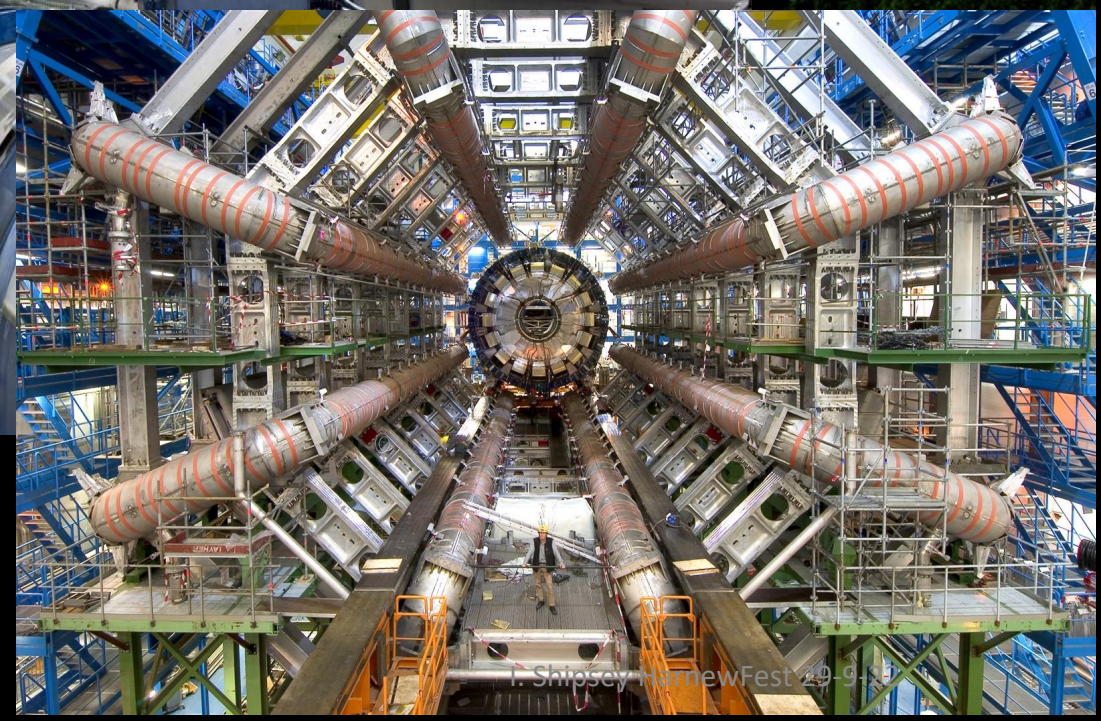
How do quarks and gluons give rise to the properties of nuclei

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.**



A group of children are gathered around a large, vertical digital display in a museum or science center. The display shows a user interface with various fields and buttons. The children are looking at the screen with interest, and one child is pointing at it. The background is dark with purple and blue lighting, and there are other displays and screens visible.

**“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)**



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

# between 1967 - 2012

**PHYSICAL REVIEW LETTERS** 20 November 1967

**A MODEL OF LEPTONS**

Steven Weinberg<sup>1</sup>  
 Nuclear Science and Technology, Cambridge University, Cambridge, England

Received 17 October 1967

Lepton interactions are assumed to be mediated by an intermediate boson, and the weak interaction is assumed to be mediated by an intermediate boson. The mass of the intermediate boson is assumed to be finite, and the mass of the lepton is assumed to be finite. The model is shown to be consistent with the experimental facts of the weak interaction, and it is shown that the model predicts the existence of a new particle, the  $W^0$  boson.

**PHYSICAL REVIEW LETTERS** 20 November 1967

We are immediately that the electron mass is  $m_e$ . The charged spin-1 field is

$$W_\mu = \frac{1}{\sqrt{2}}(W_\mu^+ - W_\mu^-) \quad (1)$$

and has mass

$$M_W = \frac{1}{2}g v \quad (2)$$

The neutral spin-1 fields of definite mass are

$$Z_\mu = \frac{1}{\sqrt{2}}(W_\mu^+ + W_\mu^-) \quad (3)$$

$$A_\mu = \frac{1}{\sqrt{2}}(W_\mu^+ - W_\mu^-) \quad (4)$$

Their masses are

$$M_Z = \frac{1}{2}g v \quad (5)$$

$$M_A = 0 \quad (6)$$

so  $A_\mu$  is to be identified as the photon field. The interaction between leptons and spin-1 mesons is

$$\mathcal{L}_{int} = -\bar{\psi} \gamma_\mu (g_V + g_A \gamma_5) \psi W_\mu \quad (7)$$

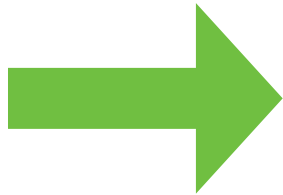
and electric charge

$$Q = \frac{1}{2}(1 + \tau_3) \quad (8)$$

by this model have to do with the couplings of the neutral intermediate meson  $Z_\mu$ .  $Z_\mu$  does not couple to hadrons the best place to look for effects of  $Z_\mu$  is in electron-neutrino scattering. Applying a Fierz transformation to the  $V$ -exchange terms, the total effective  $e$ - $\nu$  interaction is

$$\mathcal{L}_{eff} = \frac{G_F}{\sqrt{2}} \bar{\nu} \gamma_\mu (1 + \gamma_5) \nu \bar{e} \gamma_\mu (1 + \gamma_5) e \quad (9)$$

If  $g \neq e$  then  $e \neq \nu$ , and this is just the usual  $e$ - $\nu$  scattering matrix element times an extra factor  $1/2$ . If  $g = e$  then  $e = \nu$ , and the vector interaction is multiplied by a factor  $1/2$  rather than  $1$ . Of course our model has too many arbitrary features for these predictions to be



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**PHYSICS LETTERS B**

Available online at [www.sciencedirect.com](http://www.sciencedirect.com)

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# The Standard Model Guided Research



Slide credit  
Chip Brock

L. Shipsey HarnewFest 29-9-22

# No-lose completion of the Standard Model

Guaranteed  
discoveries

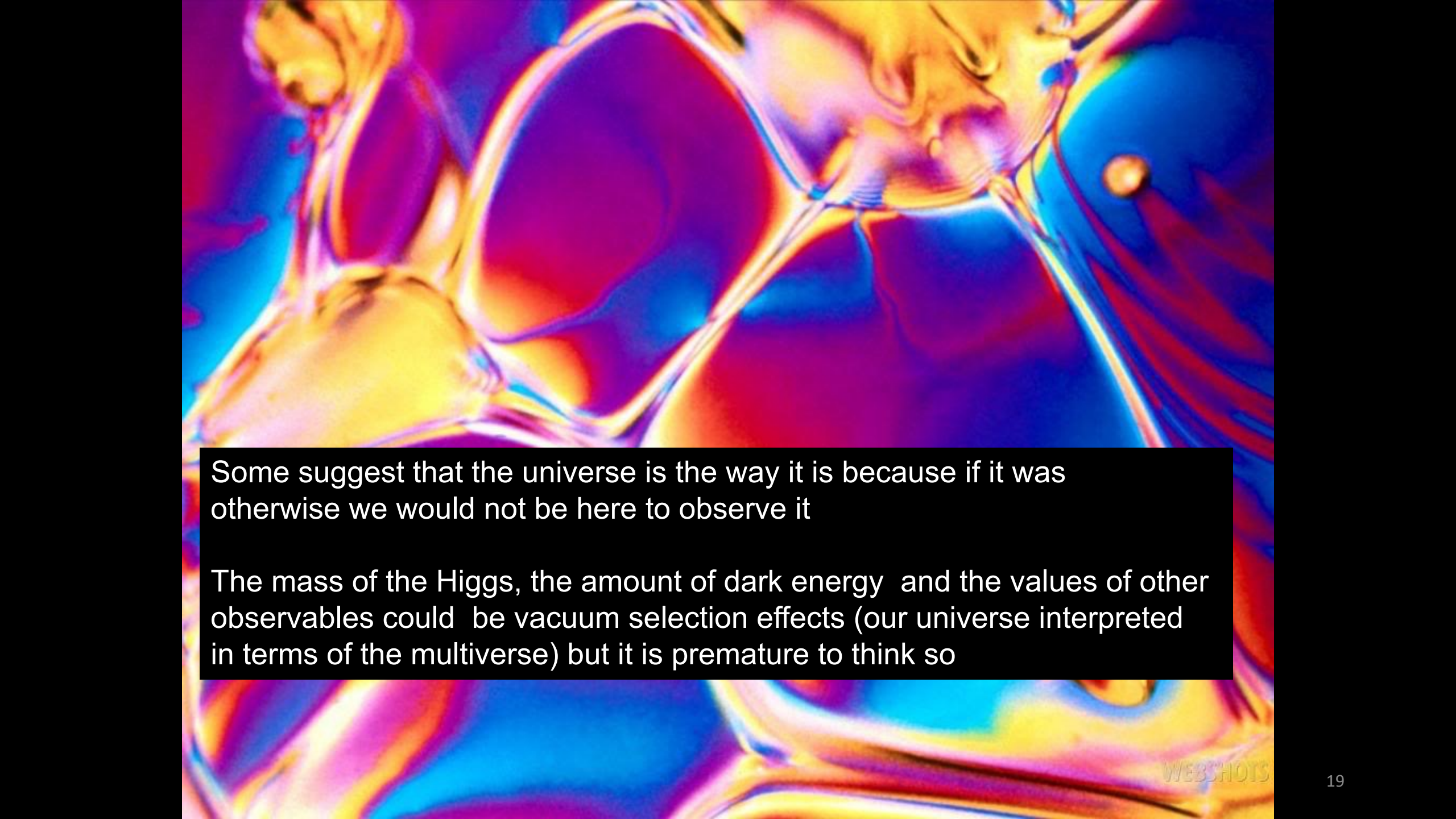
W & Z	CERN SppS
Top quark	Tevatron
Higgs	LHC



# 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

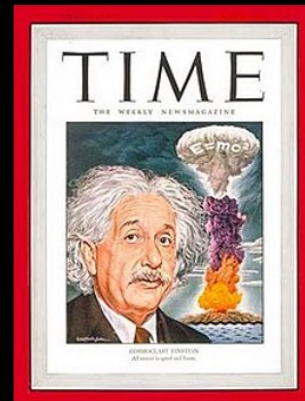
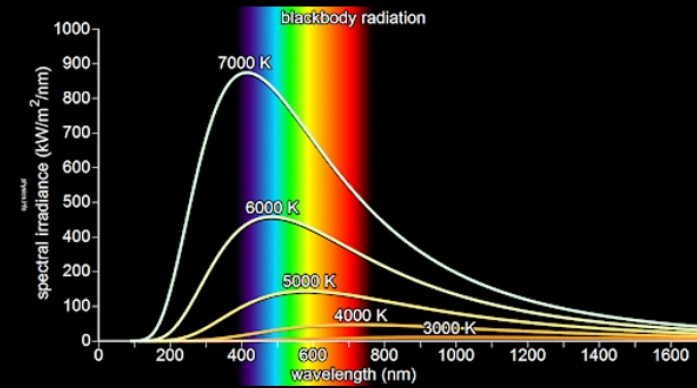


Some suggest that the universe is the way it is because if it was otherwise we would not be here to observe it

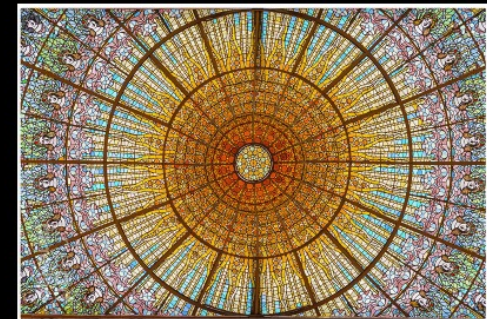
The mass of the Higgs, the amount of dark energy and the values of other observables could be vacuum selection effects (our universe interpreted in terms of the multiverse) but it is premature to think so

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



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



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)	$\pi$ N interactions	
AGS BNL (1960)	$\pi$ 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**

# LHC



**precision instruments are key to discovery  
when exploring new territory**

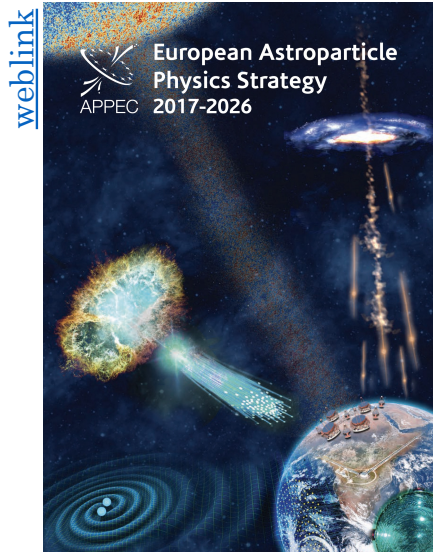


# 20 Years

- 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, SpbarS, & 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 ...



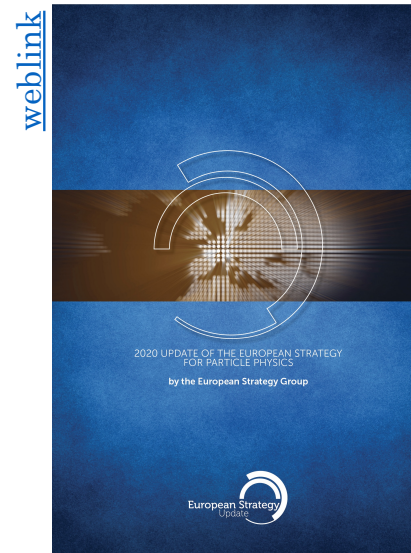
2017-2026 European  
Astroparticle Physics Strategy

... the connection ...



Long Range Plan 2017  
Perspectives in Nuclear Physics

... the small



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

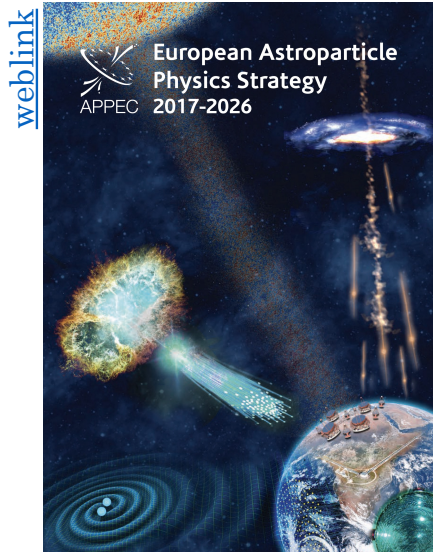


*C. The **success of particle physics experiments relies on innovative instrumentation and state-of-the-art infrastructures.** To prepare and realise future experimental research programmes, the community must **maintain a strong focus on instrumentation. Detector R&D programmes and associated infrastructures 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. ...*

# Most recent European Strategies

the large ...



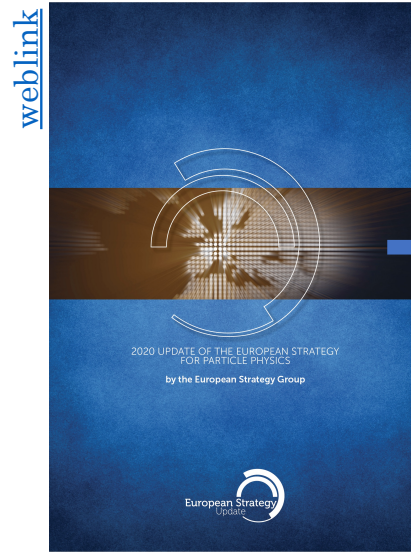
2017-2026 European Astroparticle Physics Strategy

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Long Range Plan 2017 Perspectives in Nuclear Physics

... the small



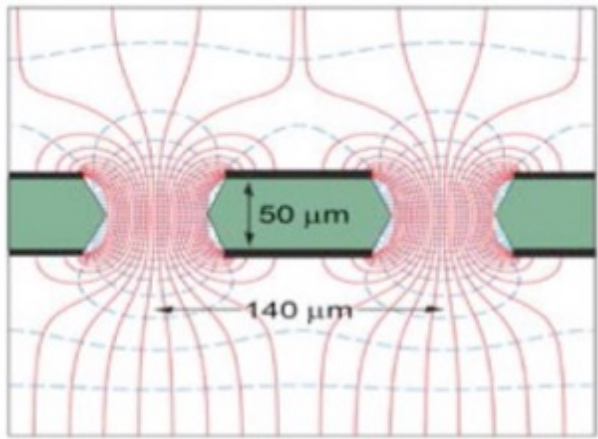
2020 Update of the European Particle Physics Strategy



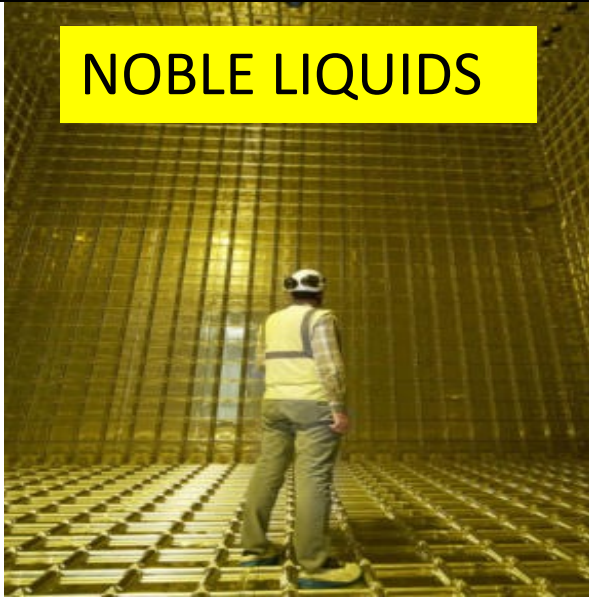
ECFA Detector R&D Roadmap

# Technology Classification for the ECFA R&D Roadmap

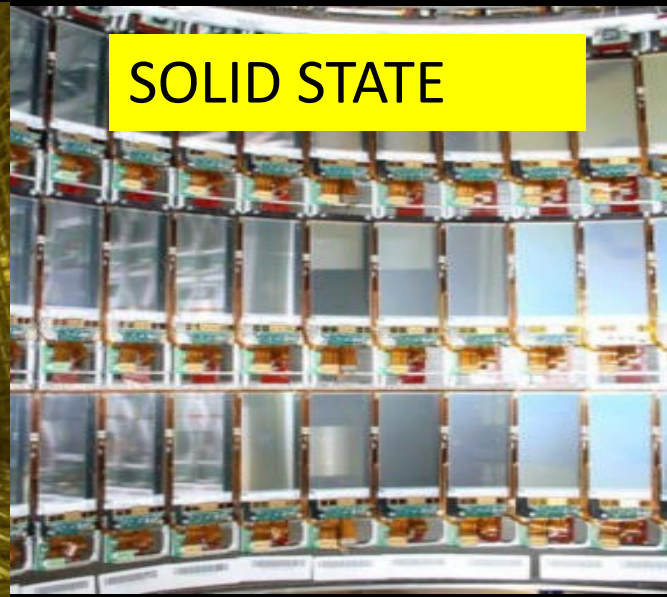
GASEOUS



NOBLE LIQUIDS



SOLID STATE

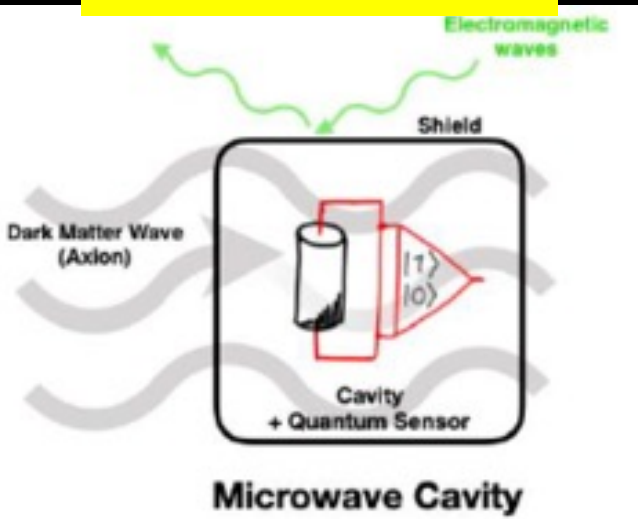


PARTICLE IDENTIFICATION & PHOTODETECTORS

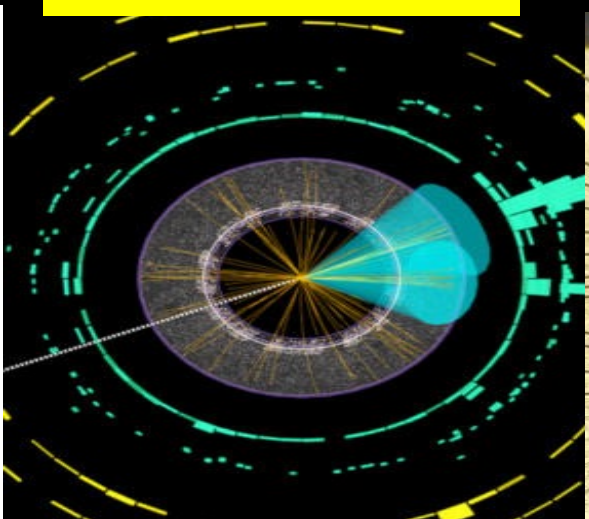


Led by Neville & Peter Krizan

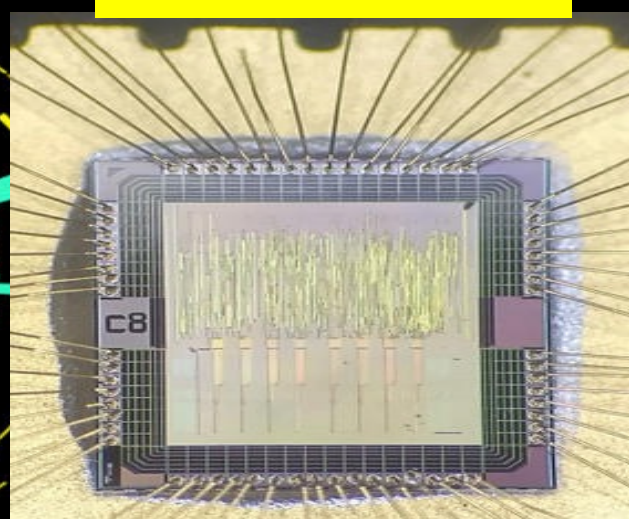
QUANTUM



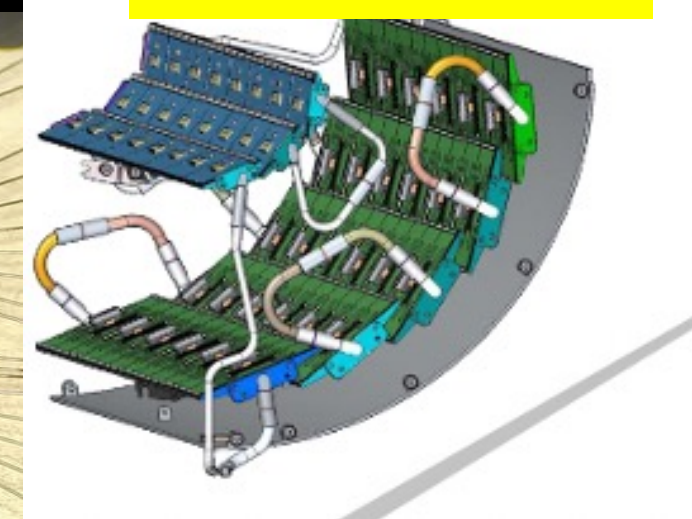
CALORIMETER



ELECTRONICS

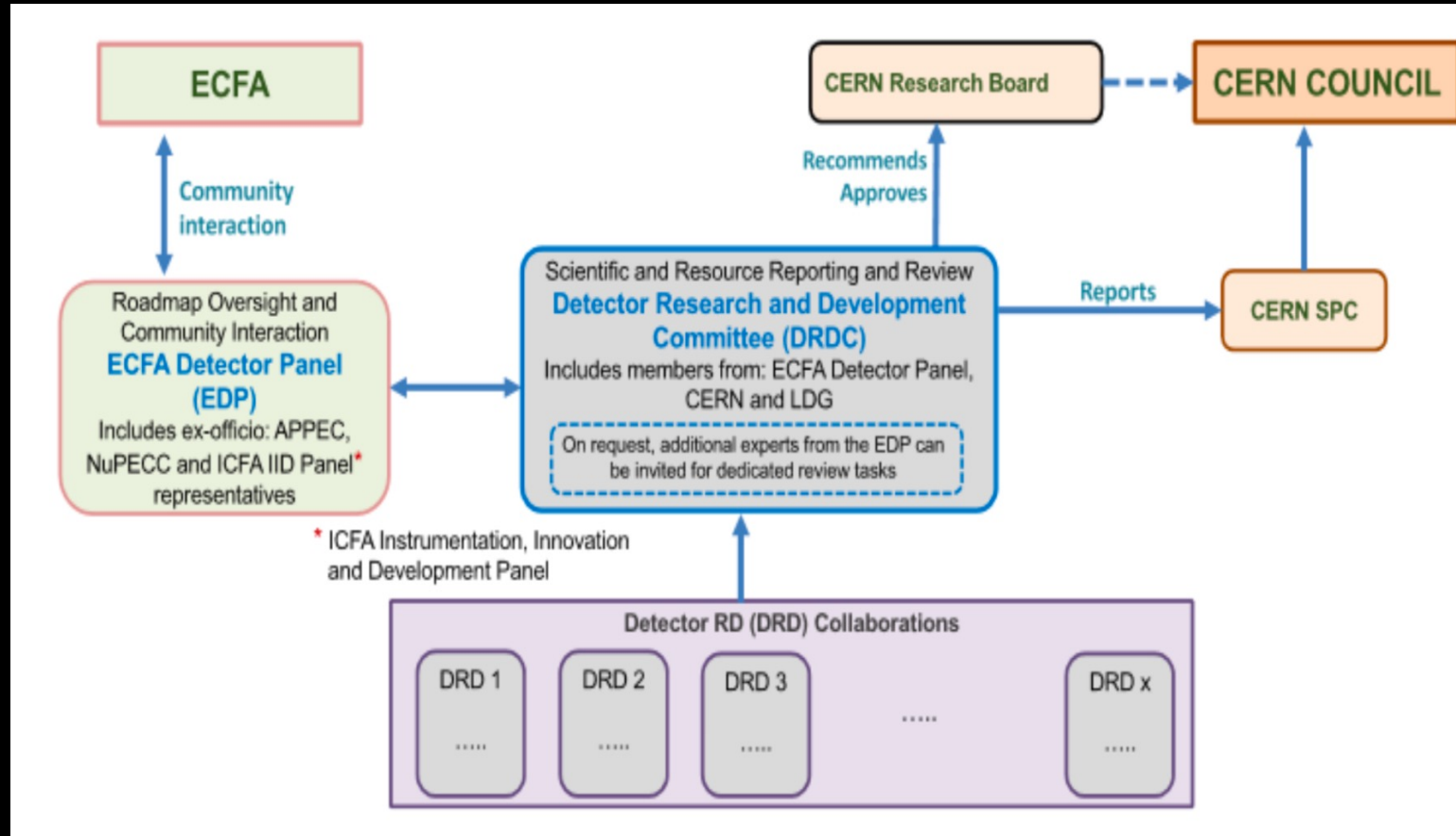


INFRASTRUCTURE



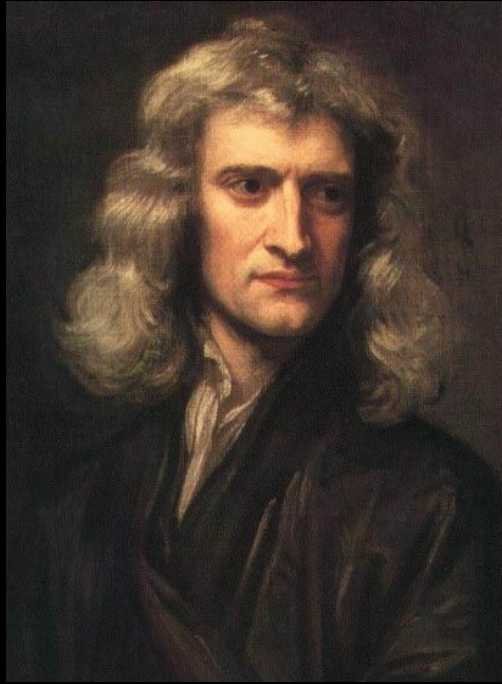
## Roadmap Implementation Plan

- 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”

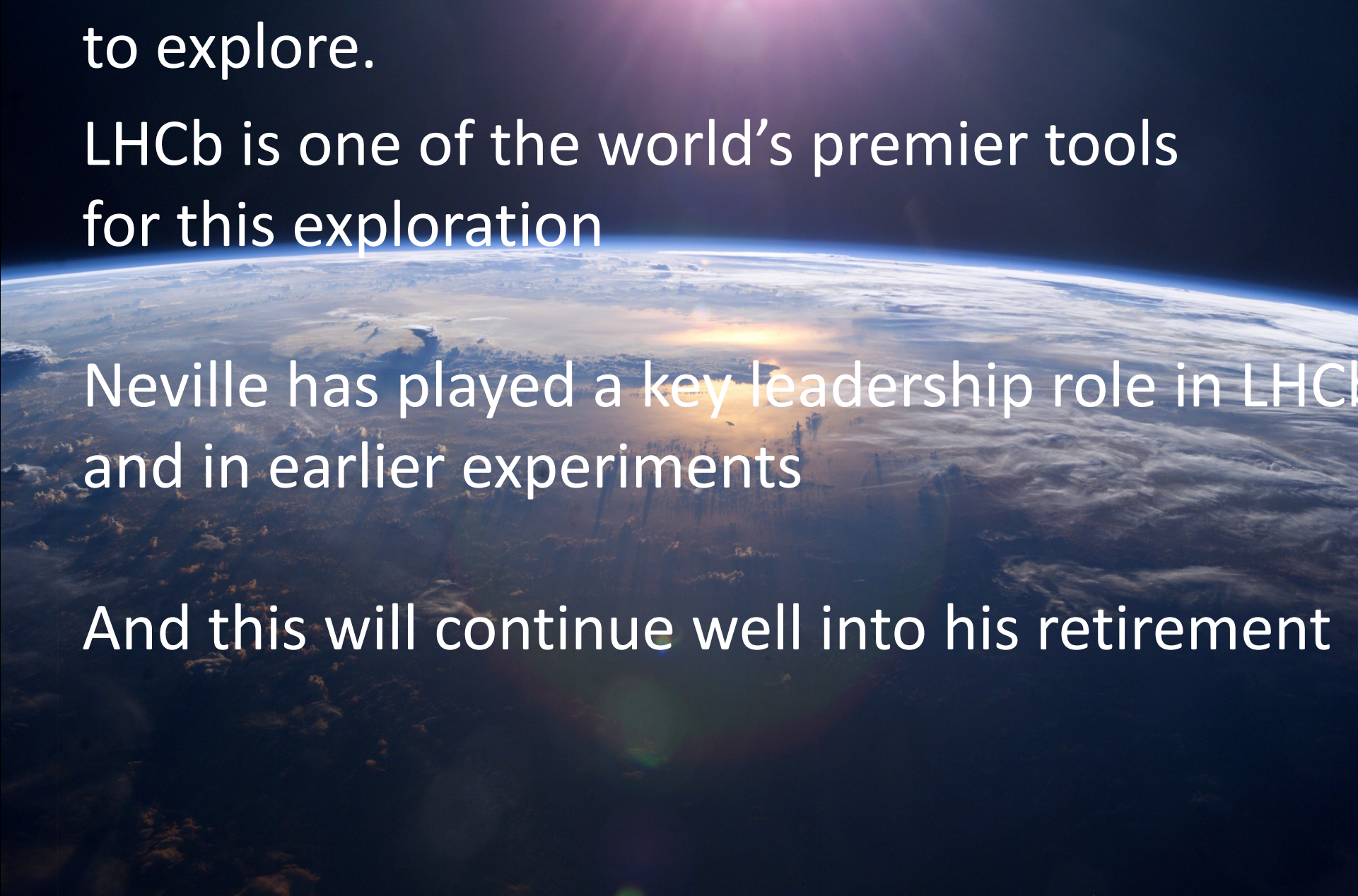
*Sir Isaac Newton (1643-1727)*

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

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







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

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

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

And this will continue well into his retirement