

Perspectives and Questions

Toward an Expansive Agenda for Particle Physics

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[arXiv:2510.06348]

(2005)

In a decade or two, we can hope to ...

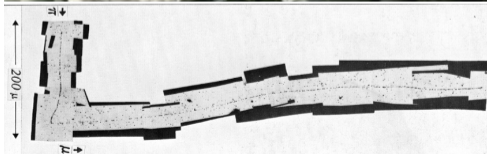
- Understand electroweak symmetry breaking
- Observe the Higgs boson
- Measure neutrino masses and mixings
- Establish neutrinos = antineutrinos
- Thoroughly explore CP violation in B decays
- Exploit rare decays (K, D, ...)
- Observe neutron's EDM, pursue electron's
- Use top quark as a tool
- Observe new phases of matter
- Understand hadron structure quantitatively
- Uncover the full implications of QCD
- Observe proton decay
- Understand the baryon excess
- Catalogue matter and energy of the universe
- Measure dark energy equation of state
- Search for new macroscopic forces
- Determine the unifying symmetry
- Detect neutrinos from the universe
- Learn how to quantize gravity
- Learn why empty space is nearly massless
- Test the inflation hypothesis
- Understand discrete symmetry violation
- Resolve the hierarchy problem
- Discover new gauge forces
- Directly detect dark-matter particles
- Explore extra spatial dimensions
- Understand the origin of large-scale structure
- Observe gravitational radiation
- Solve the strong CP problem
- Learn whether supersymmetry is TeV-scale
- Seek TeV-scale dynamical symmetry breaking
- Search for new strong dynamics
- Explain the highest-energy cosmic rays
- Formulate the problem of identity

... learn the right questions to ask ...

... and rewrite the textbooks!



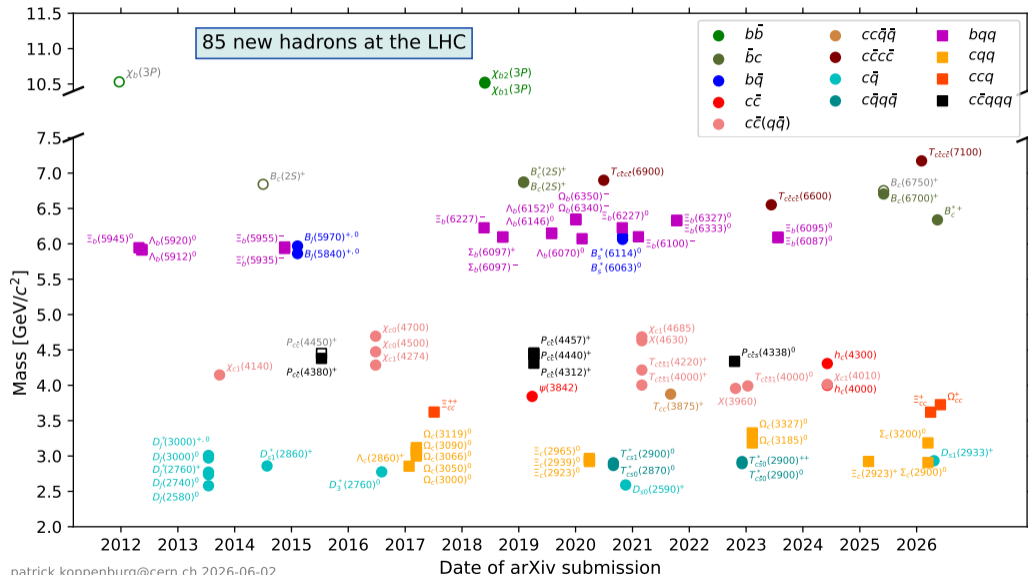
Powell (1950) on Occhialini's emulsions from Pic du Midi



*“It was immediately apparent that a whole new world had been revealed . . .
. . . It was as if, suddenly, we had broken into a walled orchard, where protected trees had flourished and all kinds of exotic fruits had ripened in great profusion.”*

Exotic fruits in great profusion

(+QWG Exotics Hub)



How to progress?

Explore the regions of the unknown,
the unanswered questions

Try to divine where the secrets are hidden

Seek out soft spots in our current understanding,
especially where the stories we tell are
unprincipled \equiv not founded on sound principles

Supersymmetry: + R -parity + μ problem + tame FCNC + ...

Big-Bang Cosmology: + inflation + dark matter + dark energy + ...

Particle content, even gauge groups, of the Standard Model

Guiding Principles

Symmetry (via Noether's Theorems) & Hidden Symmetry

Poincaré Invariance

Relativistic Quantum Field Theory

Unitarity, Causality

?? Renormalizability ?? ⟨Effective Field Theory⟩

Working hypotheses:

Gauge Symmetry

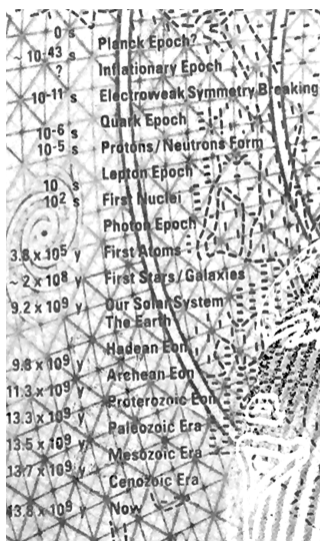
Pointlike constituents

Minkowski spacetime (for most purposes)

...

Questions about fundamentals

- 1 Is Lorentz invariance exact?
- 2 Are nature's laws the same at all times and places (accessible to us)?
- 3 What is the domain of validity of local field theory?
- 4 Can causality be violated?
- 5 Is CPT a good symmetry?
- 6 Do quarks and leptons show signs of compositeness?
Are they made of more elementary constituents?
- 7 Are there supplemental spacetime dimensions?
- 8 Are there novel sources of C, P, T, CP violation?



$$t_{\text{Pl}} \equiv \sqrt{\hbar G/c^5}$$

Lifetimes

$$^{136}\text{Xe}_{\beta\beta\nu\nu} : 3.2 \times 10^{21} \text{ yr}$$

$$^{124}\text{Xe}_{\text{ECEC}\nu\nu} : 2.6 \times 10^{22} \text{ yr}$$

$$\tau_p : > 10^{(29-33)} \text{ yr}$$

Visible . . . Invisible . . .

[P]articularly at the end of the last century, certain scholars considered that since the appearances on our scale were finally the only important ones for us, there was no point in seeking what might exist in an inaccessible domain. I find it very difficult to understand this point of view since what is inaccessible today may become accessible tomorrow (as has happened by the invention of the microscope), and also because coherent assumptions on what is still invisible may increase our understanding of the visible.

— Jean Perrin, Nobel Lecture (1926)

Victor Hugo: Beyond the Visible, the Invisible. Beyond the Invisible, the Unknown.

CQ: Beyond the Unknown, the Imaginary!

Our past—the importance of the electroweak (1-TeV) scale

EW theory does not predict Higgs-boson mass

Thought experiment: conditional upper bound

W^+W^- , ZZ , HH , HZ satisfy s -wave unitarity,

provided $M_H \lesssim (8\pi\sqrt{2}/3G_F)^{1/2} \approx 1 \text{ TeV}$

If bound is respected, perturbation theory is “everywhere” reliable

If not, weak interactions among W^\pm , Z , H become strong on 1-TeV scale

New phenomena (H or something else) are to be found around 1 TeV

$\Lambda_{\text{QCD}} \sim$ scale of confinement, chiral symmetry breaking

What LHC has taught us about the Higgs Boson*

Evidence is developing as it would for a “standard-model” Higgs boson

Unstable neutral particle with $M_H = 125.13 \pm 0.11$ GeV [PDG26]

Decays to W^+W^- , ZZ implicate H as agent of EWSB

$H \rightarrow \gamma\gamma, Z\gamma$ as expected (loop-level) Indirect $\Gamma_H \approx 3$ MeV

Dominant spin-parity $J^P = 0^+$

$Ht\bar{t}$ coupling from gg fusion, $t\bar{t}H$ production link to fermion mass origin

$\tau^+\tau^-$ and $b\bar{b}$ at expected rates; $\mu^+\mu^-$ constrained

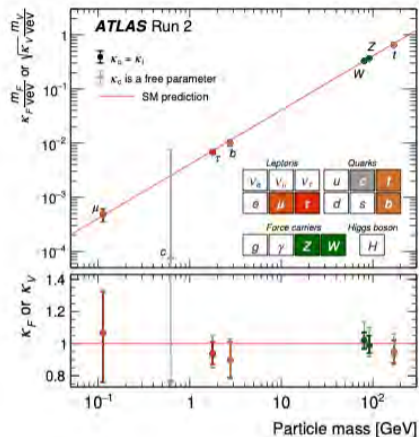
*ATLAS and CMS summaries in July 4, 2022, *Nature*

CQ (2009), “Unanswered Questions in the Electroweak Theory”

CQ (2015), “Electroweak Symmetry Breaking in Historical Perspective,”

CQ (2022), “Unanswered Questions . . . (Before & After) the Higgs-Boson Discovery”

Higgs Coupling Strengths



Consequences for the everyday world

$1/M_W^4$ controls β -decay rates, energy production in Sun, etc.

Role of Higgs boson established

No Higgs: QCD breaks EW symmetry to EM, $M_W \approx 28$ MeV

Bohr radius $\propto 1/m_e$ controls size of atoms; m_e sets scale of energy levels.

Role of Higgs boson not yet established

up/down quark mass difference determines proton/neutron stability

Role of Higgs boson not yet established

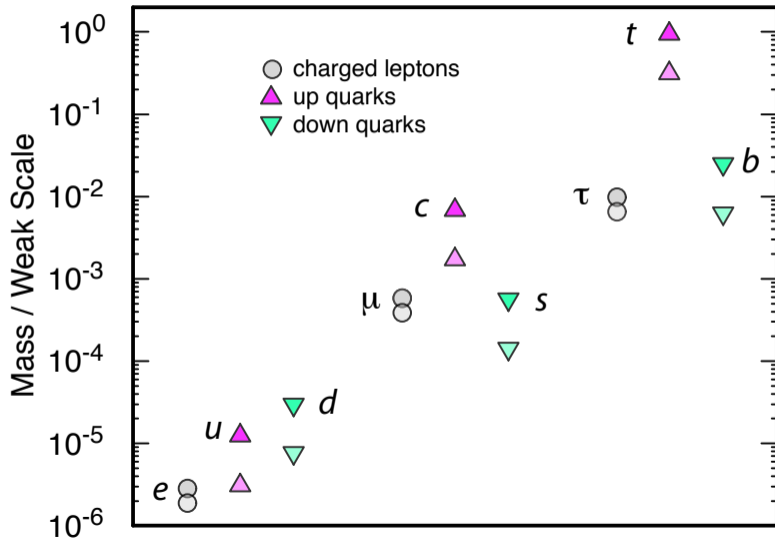
Quigg & Shrock, "Gedanken Worlds without Higgs . . .," Phys. Rev. D **79**, 096002 (2009)

Salam, Wang, & Zanderighi, "The Higgs boson turns ten," Nature 607, 41–47 (2022).

Questions about EWSB and the Higgs Sector

- 9 Is $H(125)$ the only member of its clan? Might there be others—charged or neutral—at higher or lower masses?
- 10 Does $H(125)$ fully account for electroweak symmetry breaking? Does it match standard-model branching fractions to gauge bosons? Are absolute couplings to W and Z as expected in the standard model?
- 11 Are all production rates as expected? Any surprise sources of $H(125)$?
- 12 What accounts for the immense range of fermion masses?
- 13 Is the Higgs field the only source of fermion masses?
Are fermion couplings proportional to fermion masses? $\mu^+\mu^-$ soon?
How can we detect $H \rightarrow c\bar{c}$ $e^+e^-??$ (basis of chemistry)
- 14 What role does the Higgs field play in generating neutrino masses?

Fermion mass: $m_f(U)$ (lower) and $m_f(m_f \text{ or } 1 \text{ GeV})$



More questions about EWSB and the Higgs Sector

- 15 Can we establish or exclude decays to new particles?
Does $H(125)$ act as a portal to hidden (dark/subliminal) sectors?
How convincingly can we measure Γ_H and compare with theory?
- 16 Do loop-induced decays ($gg, \gamma\gamma, \gamma Z$) occur at standard-model rates?
- 17 What can we learn from rare decays ($J/\psi \gamma, \Upsilon \gamma, \dots$)?
- 18 Does the EW vacuum seem stable, or suggest a new physics scale?
- 19 Can we find signs of new strong dynamics or (partial) compositeness?
- 20 Can we establish the HHH trilinear self-coupling?
- 21 How well can we test the notion that H regulates Higgs–Goldstone scattering, i.e., tames the high-energy behavior of WW scattering?
- 22 Is the electroweak phase transition first-order?

See Dawson, Englert, Plehn, arXiv:1808.01324 \rightsquigarrow *Phys. Rep.*

More new physics on the TeV scale and beyond?

Before LHC, much informed speculation—but no guarantees—about what might be found, beyond keys to EWSB.

Many eyes were on supersymmetry or Technicolor to enforce electroweak scale (M_W) \lll unification scale or Planck scale.

“WIMP miracle” pointed to the TeV scale for a dark matter candidate.

Some imagined that neutrino mass might be set on the TeV scale.

No direct sign of physics beyond the standard model has come to light.

Might first hints may come from precision measurements?

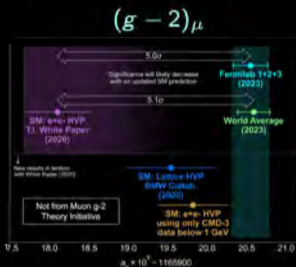
"sixth place of the decimal" and beyond ...



m_W [GeV]

ATLAS M_W (2024): 80.3665 ± 0.0159 MeV

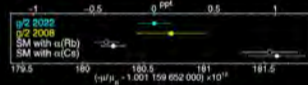
CMS (2024): $a_\tau = 0.0009^{+0.0032}_{-0.0031}$



$(g - 2)_\mu$

e magnetic dipole moment measured to 0.13 ppt

$$-\mu_e/\mu_B = 1.00115965218059(13)$$



Harvard-NU

(Anti)proton magnetic moments: CPT test

$$\mu_{\bar{p}} = -2.792\,847\,344\,1(42) \mu_N$$

VS.

$$\mu_p = +2.792\,847\,344\,62(82) \mu_N$$

BASE Collaboration @CERN Antiproton Decelerator

fine structure constant

Berkeley: $\alpha^{-1}(\text{Cs}) = 137.035\,999\,046(27)$

Paris: $\alpha^{-1}(\text{Rb}) = 137.035\,999\,206(11)$

(differ by 5.4 s.d.)

Have we misconstrued naturalness and the hierarchy problem?

- 23 Did existence of two once-and-done candidate solutions to the hierarchy problem (SUSY and technicolor) lead us to view the discipline of naturalness too simplistically?



Available online at www.sciencedirect.com



Nuclear Physics B (Proc. Suppl.) 140 (2005) 3–19

NUCLEAR PHYSICS B
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www.elsevierphysics.com

The Origins of Lattice Gauge Theory

K.G. Wilson

Smith Laboratory, Department of Physics, The Ohio State University, 174 W. 18th Ave., Columbus, OH 43210

Cf. M. Dine, “Naturalness under Stress”

G. F. Giudice, “The Dawn of the Post-Naturalness Era”

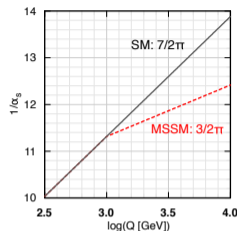
The final blunder was a claim that scalar elementary particles were unlikely to occur in elementary particle physics at currently measurable energies unless they were associated with some kind of broken symmetry [23]. The claim was that, otherwise, their masses were likely to be far higher than could be detected. The claim was that it would be unnatural for such particles to have masses small enough to be detectable soon. But this claim makes no sense when one becomes familiar with the history of physics. There have been a number of cases where numbers arose that were unexpectedly small or large. An early example was the very large distance to the nearest star as compared to the distance to the Sun, as needed by Copernicus, because otherwise the nearest stars would have exhibited measurable parallax as the Earth moved around the Sun. Within elementary particle physics, one has unexpectedly large ratios of masses, such as the large ratio of the muon mass to the electron mass. There is also the very small value of the weak coupling constant. In the time since my paper was written, another set of unexpectedly small masses was discovered: the neutrino masses. There is also the riddle of dark energy in cosmology, with its implication of possibly an extremely small value for the cosmological constant in Einstein’s theory of general relativity.

Questions about new physics on the TeV scale and beyond

- 24 Are there new forces of a novel kind?
- 25 Can we find evidence of a dark matter candidate?
- 26 Why is empty space so nearly massless? What is the resolution to the vacuum energy problem? $\langle H \rangle_0 \rightsquigarrow$ Jupiter mass, M_{J} , in one human
- 27 Will “missing energy” events signal the existence of spacetime dimensions beyond the familiar $3 + 1$?
- 28 Can we probe dark energy in laboratory experiments?
- 29 Can we find clues to the origin of electroweak symmetry breaking? Is there a dynamical origin to the “Higgs potential?”
- 30 What separates the electroweak scale from higher scales?
- 31 Are new phenomena to be found on extended time scales?

More questions about new physics on the TeV scale and beyond

- 32 Might we find indirect evidence for a new family of strongly interacting particles, such as those that are present in SUSY, by seeing a change in the evolution of $1/\alpha_s(Q^2)$?
- 33 How can we constrain—or provide evidence for—light dark-matter particles or other denizens of the dark in high-energy colliders or beam-dump experiments?
- 34 Does the gluon have heavy partners, indicating that QCD is part of a structure richer than $SU(3)_c$?



Flavor: the problem of identity

- 35 What makes an electron an electron, a top quark a top quark, ...?

We do not have a clear view of how to approach the diverse character of the constituents of matter

CKM paradigm: extraordinarily reliable framework in hadron sector

BUT—many parameters: no clue what determines them, nor at what energy scale they are set

Even if Higgs mechanism explains *how* masses and mixing angles arise, we do not know *why* they have the values we observe

Physics beyond the standard model!

Flavor: the problem of identity (continued)

Parameters of the Standard Model

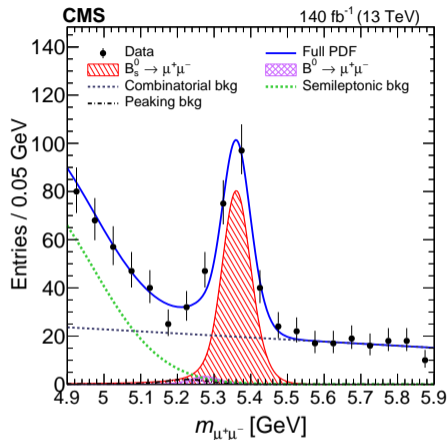
- 3 Coupling parameters, α_s , α_{em} , $\sin^2 \theta_W$
 - 2 Parameters of the Higgs potential
 - 1 Vacuum phase (QCD)
 - 6 Quark masses
 - 3 Quark mixing angles
 - 1 CP-violating phase
 - 3 Charged-lepton masses
 - 3 Neutrino masses
 - 3 Leptonic mixing angles
 - 1 Leptonic CP-violating phase (+ Majorana phases?)
-
- 26⁺ Arbitrary parameters
-

Will we see or diagnose a break in the standard model?

Questions concerning the problem of identity

- 36 Can we find evidence of right-handed charged-current interactions?
Is nature built on a fundamentally asymmetrical plan, or are the right-handed weak interactions simply too feeble for us to have observed until now, reflecting an underlying hidden symmetry?
- 37 What is the relationship of left-handed and right-handed fermions?
- 38 Are there additional electroweak gauge bosons, beyond W^\pm and Z ?
- 39 Are there additional kinds of matter?
- 40 Is charged-current universality exact?
- 41 What about lepton-flavor universality?
- 42 Can we find evidence for charged-lepton flavor violation?

$B_s \rightarrow l^+ l^-$ observation—search for BSM FCNC



$$\text{LHCb: } \mathcal{B}(B_s \rightarrow \mu^+\mu^-) = [3.09^{+0.46+0.15}_{-0.43-0.11}] \times 10^{-9}$$

$$\text{CMS: } \mathcal{B}(B_s \rightarrow \mu^+\mu^-) = [3.83^{+0.38}_{-0.36} \text{ (stat.) } +0.24 \text{ (syst.)}] \times 10^{-9}$$

$$\text{standard model: } \mathcal{B}(B_s \rightarrow \mu^+\mu^-) = [3.66 \pm 0.14] \times 10^{-9}$$

Searches for flavor-changing neutral currents

- 43 Where are flavor-changing neutral currents in quark transitions? In the standard model, these are absent at tree level and highly suppressed by the Glashow–Iliopoulos–Maiani mechanism. They arise generically in proposals for physics beyond the standard model, and need to be controlled. And yet we have made no sightings!

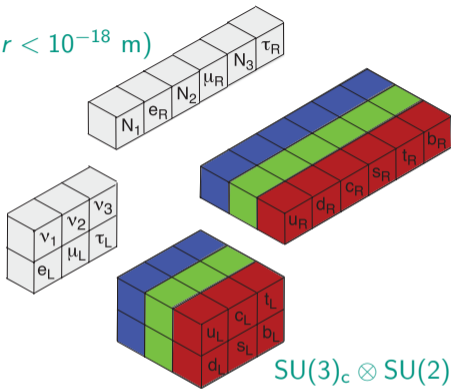
Why not?

$$B_{s,d} \rightarrow \mu^+ \mu^-, K^+ \rightarrow \pi^+ \nu \bar{\nu}, \dots$$

- 44 Can we detect flavor-violating decays $H(125) \rightarrow \tau^\pm \mu^\mp, \dots$?
- 45 How well can we test the standard-model correlation among $\mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu})$, $\mathcal{B}(B_s \rightarrow \mu^+ \mu^-)$, and the quark-mixing matrix parameter γ ?

Have we found the “periodic table” of elementary particles?

Pointlike spin-1/2 constituents ($r < 10^{-18}$ m)



- 46 What do generations mean? Is there a family symmetry?
- 47 Why are there three families of quarks and leptons? (Is it so?)
- 48 Are there new species of quarks and leptons? exotic charges?

More questions concerning the problem of identity

- 49 Is there any link to a dark sector?
- 50 What will resolve the disparate values of $|V_{ub}|$ and $|V_{cb}|$ measured in inclusive and exclusive decays?
- 51 Is the 3×3 (CKM) quark-mixing matrix unitary?
- 52 Will we establish and diagnose a break in the SM?
- 53 Do flavor parameters *mean* anything at all?
Contrast the landscape perspective.
- 54 If flavor parameters have meaning (beyond engineering information), what is the meta-question?

The top quark touches many topics in particle physics

- 55 How much can we tighten the m_t - M_W - M_H constraints?
- 56 Does top's large $Ht\bar{t}$ (Yukawa) coupling imply a special role in electroweak symmetry breaking? How does it influence $t\bar{t}$ dynamics? Does large m_t make top an outlier or the only normal fermion?
- 57 How well can we constrain V_{tb} in single-top production, ...?
- 58 How complete is our understanding of $t\bar{t}$ production in QCD: total & differential cross sections, charge asymmetry, spin correlations, etc.?
- 59 What can we learn from “dead-cone” studies using boosted tops?
- 60 How well can we constrain the top-quark lifetime? How free is t ?
- 61 Are there $t\bar{t}$ resonances? Might t hadronize a bit in AA environment?
- 62 Can we find evidence of flavor-changing top decays $t \rightarrow (Z, \gamma)(c, u)$?

Neutrinos . . .

Neutrinos oscillate among the three known species, ν_e, ν_μ, ν_τ
(discovered with neutrinos from natural sources)

Accelerator-based long-baseline experiments NO ν A and T2K
 \rightsquigarrow DUNE and Hyper-Kamiokande + new short-baseline experiments

Kinematics: ^3H β -decay experiment KATRIN; $^{163}\text{Ho} \rightarrow ^{163}\text{Dy}$
experiments that rely on reactors (JUNO)
or natural sources (IceCube and KM3Net)

Puzzling results: LSND–MiniBooNE, “Reactor anomaly”
 \rightsquigarrow MicroBooNE, . . .

Some outstanding questions about neutrino physics

- 63 What is the order of levels of the mass eigenstates ν_1, ν_2, ν_3 ? It is known that the ν_e -rich ν_1 is the lighter of the “solar pair,” with the more massive ν_2 . Does the ν_e -poor ν_3 lie above or below the other two (normal or inverted mass ordering)?
- 64 What is the absolute scale of neutrino masses? **KATRIN vs. Cosmo?**
- 65 What is the flavor composition of ν_3 ? Is it richer in ν_μ or ν_τ ?
- 66 Is CP violated in neutrino oscillations? To what degree?
- 67 Are neutrinos Majorana particles? While this issue is primarily addressed by searches for neutrinoless double- β decay, collider searches for same-sign lepton pairs also speak to it.
- 68 Do three light (left-handed) neutrinos suffice?
- 69 What is the nature of right-handed neutrinos?

More outstanding questions about neutrino physics

- 70 Are there light sterile neutrinos? If so, how could they arise?
- 71 Do neutrinos have nonstandard interactions, beyond those mediated by W^\pm and Z ?
- 72 How can we detect the cosmic neutrino background?
Each species, now: $\approx 56 \text{ cm}^{-3}$ $T_\nu \approx 2 \text{ K} \approx 1.7 \times 10^{-4} \text{ eV}$
- 73 Are all the neutrinos stable?
- 74 Do neutrinos contribute appreciably to the dark matter of the Universe?
- 75 How is neutrino mass a sign of physics beyond the standard model?
- 76 Will neutrinos give us insight into the matter excess in the Universe (through leptogenesis)?

Don't forget the strong interactions!

Heroic progress in perturbative and lattice methods
including resummation and electroweak quantum corrections

QCD could be complete, up to M_{Planck} (modulo strong CP problem)
... but that doesn't prove it must be

Prepare for surprises, such as

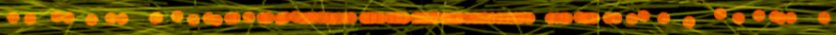
(Breakdown of factorization)

Free quarks / unconfined color

New kinds of colored matter

Quark compositeness

Larger color symmetry containing $SU(3)_c$



$$13.6 \text{ TeV} = 10^{12} \text{ Rydberg}$$

Questions pertaining to QCD

- 77 Why is isospin a good symmetry? What does it mean?
- 78 Are there new phenomena within QCD? **Role for machine learning?**
Multiple production beyond diffraction + short-range order?
Long-range correlations in y (or η)? Unusual event structures?
- 79 How will high density of wee partons affect pp collisions?
- 80 How will the 1-d ∞ -momentum-frame parton-model break down?
- 81 How will correlations among partons in a proton manifest themselves?
- 82 Can we distinguish spatial configurations of partons within protons?
- 83 What is the importance of intrinsic heavy flavors?
- 84 Hadron body plans beyond qqq and $q\bar{q}$? $XYZ, qqqQ\bar{Q}, QQ\bar{q}\bar{q}, \dots$
- 85 Can we *prove* that QCD confines color?
- 86 What resolves the strong CP problem? **PQ symmetry \rightsquigarrow axions?**

Where is the next important scale?

(Higher energies needed to measure HHH , verify that H regulates $W_L W_L$)

Planck scale $\sim 1.2 \times 10^{19}$ GeV (3 + 1-d spacetime); $\sim 1.6 \times 10^{-35}$ m

Unification scale $\sim 10^{15-16}$ GeV

- 87 At what scale are charged-fermion masses set (Yukawa couplings)?
- 88 At what scale are neutrino masses set?
- 89 Will new physics appear at $1\times, 10\times, 100\times, \dots$ EW scale?
- 90 Might new phenomena appear at macroscopic scales?

The Great Lesson of Twentieth-Century Science

The human scale of space and time is not privileged for understanding Nature, and may even be disadvantaged.

Renormalization group · Effective field theories

Resolution and extent in time and distance

Diversity and scale diversity in experimental undertakings

The discovery that *the human scale is not preferred* is as important as the discoveries that the human location is not privileged (Copernicus) and that there is no preferred inertial frame (Einstein), and will prove to be as influential.

Motivations for unified theories

Neutrality of atoms, balance of electron and proton charges

Quarks and leptons are spin- $\frac{1}{2}$ particles
that come in matched sets
as required by anomaly cancellation
for a renormalizable $SU(2)_L \otimes U(1)_Y$ theory

$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$ couplings tend to converge at high scales

Historical impulse for amalgamation / unification

Questions about unified theories

- 91 What is the relationship of quarks to leptons?
- 92 Should we regard lepton number as the “4th color?” Double Simplex
- 93 Which quark doublet is matched with which lepton doublet?
- 94 Are there new gauge interactions that link quarks with leptons?
Or other violations of lepton and baryon number?
- 95 What is the (grand) unifying symmetry?
- 96 What determines the low-energy gauge symmetries?
- 97 What are the steps to unification? One more, or multiple?
- 98 Is perturbation theory a reliable guide to coupling unification?
- 99 What sets the mass scale for the additional gauge bosons in a unified theory? ... for the additional Higgs bosons?

More questions about unified theories

- 100 Is the proton unstable? How does it decay?
- 101 Is neutron–antineutron oscillation observable?
- 102 Can we detect the magnetic monopoles of unified theories?
- 103 Are there millicharged particles?
Other signs of additional $U(1)$ gauge symmetries?
- 104 How can we incorporate gravity?
- 105 Why is gravity so weak?
- 106 To what scale does the inverse-square law of gravitation hold?
- 107 What is the nature of spacetime?
Is it emergent?
How many dimensions?

A word about the astro/cosmo connection

We do not know what the Universe at large is made of

We do not know the complete thermal history of the universe

$$\text{e.g., } H_0^{\text{local}} - H_0^{\text{Planck}} \approx (4-6)\sigma$$

We have not accounted for the predominance of matter over antimatter in the observed universe

We do not know what provoked inflation (if it happened)

We do not know why the expansion of the universe is accelerating i.e., the origin of dark energy or a cosmological constant

Imperatives: Learn to read new strata · Refine precision

Detection of gravitational radiation enriches multimessenger astronomy

Questions about the universe at large

- 108 To what degree does the **cosmological principle** hold?
- 109 How perfect a blackbody is the cosmic microwave background?
- 110 What is the “dark energy” equation of state? **Dynamics or Λ ?**
Dark energy **evolution in time** ($\propto a^{-3(1+w)}$)? **If Λ , what sets scale?**
- 111 Is there a dynamical interplay between cosmological evolution and scalar-field “relaxion” dynamics (including H)?
- 112 Are there any alternatives/complements to collisionless dark matter?
- 113 How can technologies developed for accelerators advance the search for axions? How can we observe axions, dark photons, ...?

G. Bertone & T. M. P. Tait, “A new era in the search for dark matter,” *Nature* **562**, 51–56 (2018)

Three final questions (for now)!

What deep questions have been with us for so long that they are less prominent in “top-ten” lists than they deserve to be?

What do we know that is not true?

How are we prisoners of conventional thinking?

How can we break out?

Questions for the National Accelerator Laboratory (1968)

Which, if any, of the particles that have so far been discovered, is, in fact, elementary, and is there any validity in the concept of "elementary" particles?

What new particles can be made at energies that have not yet been reached? Is there some set of building blocks that is still more fundamental than the neutron and the proton?

Is there a law that correctly predicts the existence and nature of all the particles, and if so, what is that law?

Will the characteristics of some of the very short-lived particles appear to be different when they are produced at such higher velocities that they no longer spend their entire lives within the strong influence of the particle from which they are produced?

Do new symmetries appear or old ones disappear for high momentum-transfer events?

What is the connection, if any, of electromagnetism and strong interactions?

Do the laws of electromagnetic radiation, which are now known to hold over an enormous range of lengths and frequencies, continue to hold in the wavelength domain characteristic of the subnuclear particles?

What is the connection between the weak interaction that is associated with the massless neutrino and the strong one that acts between neutron and proton?

Is there some new particle underlying the action of the "weak" forces, just as, in the case of the nuclear force, there are mesons, and, in the case of the electromagnetic force, there are photons? If there is not, why not?

In more technical terms: Is local field theory valid? A failure in locality may imply a failure in our concept of space. What are the fields relevant to a correct local field theory? What are the form factors of the particles? What exactly is the explanation of the electromagnetic mass difference? Do "weak" interactions become strong at sufficiently small distances? Is the Pomeranchuk theorem true? Do the total cross sections become constant at high energy? Will new symmetries appear, or old ones disappear, at higher energy?