

# **A Tale of Four Decades: thoughts on particle physics, theory, and experiment, 1968-2008**

**I comment on particle physics, especially the role of theory and experiment, in the years 1968, 1978, 1988, 1998, and 2008, and on implications for the LHC.**

## 1968: Confusion

- No basic understanding of strong or weak interactions; only incomplete phenomenological descriptions
- Little optimism for fundamental understanding “in our lifetime”
- Much effort: S-matrix theory (bootstrap) (but led to strings); axiomatic field theory (but TCP, spin-statistics, etc)
- “Practical” field theory out of fashion (QED off by itself)
- Important theoretical precursors: quark model (and statistics problem); chiral symmetry and current algebra;  $SU(2) \times U(1)$  model with Higgs speculation
- New accelerators coming online: SLAC, Fermilab.

## 1978: Coalescence

- A rush of developments in early 1970s
  - Theoretical precursors; proof of renormalizability; “practical FT”
  - Deep inelastic scattering (scaling, partons); weak neutral current; charm
  - Theory and experiment *came together*, not causal
- Theory: gauge theories taken seriously;  $SU(2) \times U(1)$  and alternatives vigorously explored; QCD developed (unique candidate); CKM (appreciated later)
- Experiment:  $ep$ ,  $e^+e^-$ , neutrino scattering, (later) weak-elm interference (early confusions)
- Implications: by 1978, gauge principle was generally accepted; SM was a consistent but not unique description of observations; confidence that we were on right track

- **Caveat: SM “problems”** (parameters, CP, fine-tunings) **starting to be recognized**
- **Fundamental theory: grand unification; technicolor** (alternative to Higgs); **supersymmetry**
- **Particle astrophysics begins, especially BBN-neutrino connection** (Particle physics played role of observations)

## 1988: Uniqueness

- Experiment: third generation WNC experiments (neutrino, APV,  $e^+e^-$ );  $W, Z$ ; DIS;  $e^+e^-$ ; gluon; flavor physics (and false alarms)
- Theory: needed unified treatment of theory, QCD effects, radiative corrections; global analyses; enlarged theoretical context (paradigm shift; presaged LEPEWWG)
- Implications: by 1988, SM was established as correct and unique to first approximation (except Higgs sector): gauge principle, groups, representations, renormalization;  $b$  and  $\tau$  couplings measured ( $\rightarrow t$  and  $\nu_\tau$  needed); upper limits on  $m_t$
- Cosmology: inflation
- Fundamental theory: supersymmetry; the first string revolution

## 1998: Precision

- SSC cancelled
- Experiment: LEP, SLC (precision); Tevatron ( $t$ ); LEP 2; HERA
- Theory:  $SU(2) \times U(1)$  tested at 0.1% level (rad. corrections much larger); QCD established, precise structure functions, running  $\alpha_s$
- Implications (theory essential): SM very accurate;  $m_t$  range; new TeV physics at TeV scale should decouple (supersymmetry appeared favored); precise gauge couplings consistent with MSSM unification
- Neutrino Mass: atmospheric (Solar) neutrinos (1998) (reactor and accelerator confirmation later); it “had to be there”; cosmological and astrophysical implications (SN 1987A)
- Fundamental theory: the second string revolution

## 2008: Search for New Physics

- Experiment: LEP 2; Tevatron;  $B$  factories;  $\nu$  physics; rare decays; EDMs
- Theory: Precise tests of unitarity triangle, CP breaking (paradigm shift); Higgs still not found, but EWPT strongly suggests low mass; supersymmetry and other new physics still not found; alternatives to SUSY: LED, DSB, Little Higgs (decoupling for  $T$ -parity, UED)
- Implications: SM works extraordinarily well; new physics surprisingly well hidden
- Cosmology: CMB, Type II SN, clusters; concordance of observations on dark matter and energy
- Fundamental theory: the string landscape (confusion)

# The Future: Great opportunities and challenges

(not counting political)

- Arguments for new physics at LHC are very strong; also cosmology,  $\nu$ , low energy
- SM backgrounds, QCD, complicated signals, plethora of possibilities
- Phenomenological theory, fundamental theory, and experiment essential (e.g., over optimism by string theorists, experimenters ignoring role of theory in “framing debate”)
- The new Fermi paradox: why haven't we seen more hints? (hierarchy; accidental symmetries of SM, such as  $L$ -flavor for  $m_\nu = 0$ ) **New physics should be apparent at LHC, FCNC, EDM** ( $m_\nu$  analog)

- **Be cautious of standard paradigm** (MSSM, seesaw, GUT; minimality, “motivation”; top-down vs bottom up); **beyond MSSM would allow/suggest EWBG, non-standard  $\nu$  mass**
- **The string connection: promising underlying framework** (contrast 1968, 1978, etc, and many types of TeV physics); **but interpretation of landscape** (environmental variables?); **possibility of unified theory of particle physics and cosmology to Planck scale**