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# High Energy Physics in 2015

## Outline

- 1.) Where are we now?
- 2.) Outstanding Problems & Theoretical Speculations
- 3.) Important Frontiers
- 4.) Expected & Possible Initiatives  $\leq 2015$
- 5.) Future Goals

1.) Where are we now?

Standard Model = Scientific Triumph of 20th Century

"Symmetry Dictates Dynamics"

<u>Poincaré Inv.</u>	+ <u><math>SU(3)_c \times SU(2)_L \times U(1)_Y</math></u>	+ <u><math>\lambda(\phi^2 - v^2/2)^2</math></u> <sup>Higgs Sector</sup>
spin, mass	gluons, $W^\pm, Z, \gamma$	$v \approx 250 \text{ GeV}$
↓	+ 3 fermion generations	scale of EW Sym. Br.
general cov. inv.	susy? Extra Dim?	
Gravity		

25 Years of Discovery + Confirmation!

$c, \tau, b, t, W^\pm, Z, \text{gluons}, \nu_\tau$

Precision EW Studies to  $\pm 0.1\%$ !! (Quantum loops tested)

FCNC, CP, ...  $\nu$ -osc!

No Big Surprises? ( $\tau_b, m_t, m_b \neq 0, \theta_1 \approx 45^\circ, \dots$ )

Where is the Higgs Scalar?

$m_H = \sqrt{2\lambda} v$     LEP II     $m_H \gtrsim 1136 \text{ GeV}$   $\rightarrow \lambda \gtrsim 0.1$



Great Desert Scenario: "No New Physics up to  $M_{Pl} \sim 10^{19} \text{ GeV}$ "

$$135 \text{ GeV} \lesssim m_H \lesssim 170 \text{ GeV} \quad (140 \text{ GeV})$$

$\underbrace{\hspace{100px}}$ 
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vac. stability
pert. th.
pert. unitarity

Quantum Loops:  $\alpha, G_H, m_2, m_t$  vs  $\sin^2 \theta_W^{\text{eff}}, m_W, \Gamma_Z \rightarrow m_H$

$\sim \frac{\alpha}{\pi} \ln \frac{m_H}{m_Z}$  small  $\mathcal{O}(0.1\%)$

Precision Global Fits  $\rightarrow m_H \approx 62^{+53}_{-30} \text{ GeV} < 170 \text{ GeV}$  (95% CL)

No Indication of "New Physics"

SUSY,  $Z'$ , Strong Dynamics, Extra Dimensions ....

SUSY MSSM:  $m_H \lesssim 130 \text{ GeV}$  (150 GeV) Problem?

No Experimental Anomalies:  $g_F, \text{edm}, \text{FCNC} \dots$  (Boring)

2.) Outstanding Problems & Theoretical Speculations

i) Origin of EW Sym. Br. & Mass Generation (Chivukula's talk)

Fundamental Higgs? SUSY  $\rightarrow h, H, A, H^\pm$  + sparticles (leading card.)

Strong Dynamics: Technicolor,  $t\bar{t}$  condensate

Extra Dimensions?

ii) Pattern of Fermion Masses, Mixing + CP Flavor Problem

Multi-Higgs Models, Extended Technicolor, ... GUTS

Not Really Addressed by SUSY

Why is top so heavy? Other fermions light?

iii) Origin of Parity Violation?  $SU(2)_L$  Chiral

$SU(2)_R$ ?,  $SO(10)$ , Extra Dim.?

iv) Why 3 Generations?

Why Gauge Symmetries?

⋮

Gravity?

} Very Fundamental Questions

Answers likely to require "New Physics" What scale?

1 TeV, ...  $10^{16}$  GeV,  $10^{19}$  GeV

Requires Exploration

3.) Important Frontiers (For Discovery)

\* i) High Energy Colliders (Forefront)

ii) Precision Measurements:  $\sin^2 \theta_W$ ,  $m_W$ ,  $APV$ ...

iii) FCNC, CP, edm ... proton decay

Push on all Fronts

4) Expected + Possible Initiatives  $\leq$  2015 (rough survey)

2) Rare or Forbidden Reactions: Rare B+K Studies, CP  
Explores 3-3000 TeV! CESR, B Factory, AGS, KAMI (Precision)  
 edm:  $d_n, d_e, d_\mu$  BTeV, LHCb  
 MECO  $\mu^+ A \rightarrow e^+ A \rightarrow 2 \times 10^{-17}$  (BNL)  
 $\rightarrow 10^{-18}$

Neutrino Osc.  $\Delta m_{32}^2, \Delta m_{31}^2, \Delta m_{21}^2, \theta_{23}, \theta_{12}, \theta_{13}, \delta \dots$  - 2 sterile  
 Atm, Solar, Cosmic, MINOS, MiniBooNE...  
 Super beams  $\rightarrow$  CP  
 Neutrino Factories (intense muon SR)  $\rightarrow$  CP,  $\theta_{13}$   
 ...

Proton Decay: Direct Exploration of GUT scale  $\rightarrow 10^{16}$  GeV!  
 $\tau(p \rightarrow e^+ \pi^0) \rightarrow 10^{34}$  yr,  $\tau(p \rightarrow k^+ \bar{\nu}) \rightarrow 10^{33}$  yr Super-K  
 UNO Proposal (500-1000 kTon)  $\rightarrow 10^{35}$  yr!

Major Discovery  $\rightarrow$  Revolutionize Physics

ii) Precision Measurements

TeV Run II:  $\Delta m_W \approx \pm 15$  MeV,  $\Delta \sin^2 \theta_W \approx \pm 0.0002$  (~SLD)  
 $\Delta m_t \approx \pm 2-3$  GeV

LHC: Further Improvement (How Much?)

Z Factory ( $e^+e^- \rightarrow Z$ )  $10^9 - 10^{10}$  Z decays (NLC low energy)

$\Delta \sin^2 \theta_W^{\text{eff}} \approx \pm 0.00002!$   $\Delta m_W \approx \pm 6$  MeV ...  $e^+e^- \rightarrow W^+W^-$   
 B,  $\tau$  physics

etc.

iii) Collider Studies (Most Imperative)

2001 TeV Run II ( $\sqrt{s} \approx 2\text{TeV}$ )  $\Delta m_t \approx \pm 26\text{GeV}$ ,  $\Delta m_W \approx \pm 15\text{MeV} \dots$

Higgs discovery: Needs High Luminosity (see fig.)

SUSY discovery: Some Potential (Hints)

2005-2006 LHC ( $\sqrt{s} = 14\text{TeV}$ ,  $\mathcal{L} \approx 10^{34}\text{cm}^{-2}\text{s}^{-1}$ ) Major Initiative

Higgs discovery + study: guaranteed!

SUSY discovery + study:  $m_{\text{SUSY}} \leq 1\text{TeV}$ ,  $m_H, m_{H^\pm} \dots$

$Z'$ , Heavy Fermions, Extra dim. ... Significant Reach

Possible LHC Upgrades Under Study (likely)

$\sqrt{s} \rightarrow 28\text{TeV}$  and/or  $\mathcal{L} \rightarrow 10^{35}$ ! (Higher Energy pref.)

Powerful for  $m_{\text{SUSY}} > 1\text{TeV}$ , extra dim., new dynamics...

Future Proposals Must Assume LHC II!

$e^+e^-$  Collider: TESLA, NLC, JLC...? Before 2015?

Two Interaction Option LE + HE (High luminosity)

$Z, H, t\bar{t}, W^+W^-, (\text{SUSY?})$

Higher Energy  $e^+e^-$   $\sqrt{s} \rightarrow 1\text{TeV}, 1.5\text{TeV} \rightarrow 3\text{TeV} \rightarrow 5\text{TeV}$

Very Hard before 2015 (Well Motivated)

Muon Colliders  $\mu^+\mu^-$   $\sqrt{s} = M_\mu$  (Resonance) FMC

$\sqrt{s} \approx 3\text{TeV}$  ( $e^+e^-$  Alternative)?

Neutrino Radiation?

Hard to do before 2015

More Likely  $\mu SR \rightarrow$  Neutrino Factory (10yr Project)

Well Motivated Physics Program ( $E_\mu \approx 20\text{GeV}$ )

$\theta_{13}, \Delta m^2, \delta, \nu_{\text{sterile}}$

Foot in the door for muon collider

VLHC (pp  $\sqrt{s} \approx 100\text{TeV}, \mathcal{L} \approx 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ ) After 2015

Wait for LHC results  $\rightarrow \sqrt{s}, \mathcal{L} > \text{LHCII}$

Will be well motivated (Perhaps  $\sqrt{s} \approx 150\text{-}200\text{TeV}$ )

Extra Dim., Strong Dynamics,  $Z'$ ... upgrade

Exciting  
Concept

### 5) Future Goals

Push: proton decay, edm.,  $\mu^- Al \rightarrow e^- Al, \dots$   $\nu$ -osc.  
 precision measurements:  $\sin^2 \theta_W$  (Z factory) ...  
 As far as possible

Must extend reach of  $pp, e^+e^-, (\mu^+\mu^-)$  colliders R&D

$pp^{(-)}$  Tevatron  $\rightarrow$  LHC  $\rightarrow$  LHC II  $\rightarrow$  VLHC  
 This Meeting

$e^+e^-$  <sup>When?</sup> LEP II  $\rightarrow$  NLC or TESLA (Higgs physics), Z, WW, ... SUSY

$\mu^+\mu^-$  Particularly good for  $\sqrt{s} > 3\text{TeV}$   
 ( $\mu SR$  - neutrino factory current focus)

Complementary Facilities  
 Should be pushed

Coordinated International Efforts (Affordable)

Good Luck



From J. Hobbs

$\mathcal{L} (fb^{-1})$

combined CDF/D0 thresholds

- 95% CL limit
- - - 3 $\sigma$  discovery
- ⋯ 5 $\sigma$  discovery

$10^2$   
 $10^1$   
 $10^0$

80 100 120 140 160 180 200

Higgs mass ( $GeV/c^2$ )

