Waiting for Godot?
The future of particle physics in the short term

XXI DAE-BRNS High Energy Physics Symposium
I.I.T. Guwahati
Evening Lecture

December 08, 2014

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A status report and future projection for SUPERSYMMETRY
Where are we headed?

- Accelerators, Facilities
- Experiments
- Theory

A combined effort: High Energy Physics

- What do we know today?
- What do we hope to learn in the future?
- What will be India’s role?

Summary
The known unknowns

- Higgs boson: $m_H \sim 125$ GeV Spin, Parity looks fine
- $B_s \to \mu^+\mu^-$ BR = $(2.9 \pm 0.7) \times 10^{-9}$
- Lepton mixing: $\theta_{13} \sim 9^0$
- UHE neutrinos seen at IceCube

- Higgs couplings
- Supersymmetry
- Other Beyond Standard Model Physics
- Neutrino mass ordering, Leptonic CP-violation
- Colour deconfinement: Quark Gluon Plasma
- Origin of Ultra-High-Energy neutrinos
The known unknowns

- Dark Matter, Dark Energy
- Baryon/Lepton Number violation
- Unification of forces
- Quantum Gravity
- Sterile neutrinos
- More generations of quarks/leptons

Future is rich!
Not to speak of unknown unknowns!
Accelerators, Facilities
Accelerators and facilities today

LHC

RHIC

BEPC

KEK-B
Accelerators and Facilities

CERN to Gran Sasso
Long-baseline $\nu$

BICEP2
Inflation/GUT

Planck
CMBR
LHC in the future

Data at $\sqrt{s} = 7 \& 8$ TeV, 75% of $L_{\text{nom}}$

\[ \text{LS1 } \downarrow \text{ 2014-15} \]

$\sqrt{s} = 13 \& 14$ TeV, 100% of $L_{\text{nom}}$ with $\int L \, dt = 100\text{fb}^{-1}$

\[ \text{LS2 } \downarrow \text{ 2018-19} \]

$\sqrt{s} = 14$ TeV, 200% of $L_{\text{nom}}$ with $\int L \, dt = 300\text{fb}^{-1}$

\[ \text{LS3 } \downarrow \text{ 2023-25} \]

HL: $\sqrt{s} = 14$ TeV, (5-7)00% of $L_{\text{nom}}$ with $\int L \, dt = 3000\text{fb}^{-1}$

HE-LHC33?
International Linear Collider

High energy $e^+e^-$ collider
Linear design to reduce synchrotron radiation loss

$\sqrt{s} = 250\text{--}500$ GeV (upgrade to 1 TeV)
500 fb$^{-1}$ in 4 years, Beam polarisation
Probe Higgs couplings with precision

CLIC at CERN
$\sqrt{s} = 3$ TeV $\sim 50$ km $\text{vis-à-vis}$ ILC 30km
R&D in progress
Future Circular Collider

\[ \sqrt{s} = 100 \text{ TeV} \quad \text{pp collider: CERN FCC} \]

Superconducting 16T \( \Rightarrow \) 100km

20T \( \Rightarrow \) 80km

Use same tunnel

e^+e^- : \( \sqrt{s} = 90-350 \text{ GeV} \) (80-100 km) TLEP

ep: \( \sqrt{s} = 3.6-5 \text{ TeV} \) (80-100 km) FCC

A richer alternative to the HE LHC33?

pp: Circular collider \( \sqrt{s} = 50-90 \text{ TeV} \) SppC China

Same tunnel

e^+e^-: Circular collider: \( \sqrt{s} = 240 \text{ GeV} \) (50-70 km) CEPC
Super KEK-B

Super KEK-B $e^+e^-: (4 \times 7)$ lumi $80 \times 10^{34}$ cm$^2$ s$^{-1}$ 3km

Spectacular increase of luminosity through narrower beams and improved magnet design.

KEK-B  (3.5x8) lumi $2.1 \times 10^{34}$ cm$^2$ s$^{-1}$  Browder

• Look for BSM physics through examination of CP-violation and B-physics in greater detail

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Neutrino facilities

• India-based Neutrino Observatory
• Inter-Institutional Centre for High-Energy Physics (IICHEP), Madurai

• Long baseline neutrino experiments:
  Neutrinos travel over hundreds of kms from production to detection: Interactions with matter important.
  LBNF: J. Strait

• Large-sized detectors: IceCube, PINGU
• Reactor antineutrino experiments
More details at this meeting

• Future accelerators
  Colliders: Godbole
  NICA: Meshkov
  ILC: Komamiya

• Intensity Frontier (Fermilab): High Intensity neutrino and muon beams for frontier experiments

• Neutrinos
  Long-baseline: Gandhi,
  Large-sized detectors INO, PINGU: N.Sinha
  Reactor antineutrino experiments: Naumov
India’s role

- India-CERN protocol for the LHC (1991)
- 60M SF in-kind contribution
- Superconducting sextupole, octupole, … magnets
- RRCAT in the lead role
- Tier-2 LHC Grids
- Observer status at CERN

- India-based Neutrino Observatory
- Planning, design, simulation, prototype, site selection
- IICHEP, Madurai
- Manpower training program well in place
In India in future

- Low energy accelerators at RRCAT
- IUAC at Delhi

- More indigenous accelerators at diverse energies

- Accelerators in wide use not just in HEP
  Especially medical applications

- Teaching program in Accelerator Science & Engineering needs development
- Investment promising good return.
Indian involvement

- CMS
- NISER, Panjab, Delhi,
- SINP, BARC, TIFR

**ALICE**
- Aligarh, IOP, NISER, Panjab, GauhatiU,
- IIT (Indore, Bombay), Jaipur, Jammu,
- BoseInst, SINP, VECC, BARC

**STAR@RHIC**
- VECC, Rajasthan, Panjab
- NISER, Jammu, IOP

**MINOZ**
Indian involvement

BELLE II
IIT (BBSR, Guwahati, Madras), TIFR, IMSc

MINOS, NISER

WASA@COSY
BARC, IIT Bombay, IIT Indore: \( \eta \) \& \( \eta' \) decays

IIT Guwahati
Indian involvement

FAIR facility (Darmstadt) CBM experiment

NOvA (off-axis) 2 GeV (BHU, Cochin, Delhi, IIT (Guwahati, Hyderabad),) Hyderabad, Jammu, Panjab
India’s role

- **LHC Experiments**: Involvement in detector fabrication, data taking, Tier-2 Grid support, science analysis for both CMS and ALICE.

- **Funding support**

- **Many students and post-docs trained.**

- **Long involvement also in Belle.**

- **Smaller connections with other experiments**
India’s role

• At CMS and ALICE at the LHC
  ~ 200 scientists, engineers, students

• India contributing to FAIR, NO\(\nu\)A

• India-based Neutrino Observatory
  IICHEP, Madurai
  ICAL magnetized neutrino detector
  Other proposals: DINO, 0\(\nu\)2\(\beta\)
  Training school
More details

- Higgs boson: K. Mazumdar
- Supersymmetry: Guchait

- Quark-Gluon plasma: S.Raniwalla
- Proton spin: Lorcé

- B physics results & Future: Browder

- Atmospheric nu: N. Sinha
- Reactor anti-nu: Naumov
- Long-baseline: Gandhi
India in future

• Funding is not scarce

• Expansion of IITs, IISERs, Central Universities provide job openings

• Not enough trained manpower available

• We must (and, I hope, will) do better in the years ahead
Theory
Future Theory

- What protects the light Higgs?
- Metastable Higgs potential?

- What lies beyond the Standard Model?
- Supersymmetry, Extra Dimensions, Little Higgs, Technicolor, ….
- More Higgs-like scalars?

- What could make the Higgs potential stable up to the Planck scale?
- Understanding confinement

B-physics signals BSM?
Future Theory

- Neutrino mass and mixing: what BSM features can we extract? And how? Sterile neutrinos?
- Origin of UHE neutrinos
- Dark Matter?
- Baryon/Lepton number non-conservation
- Unification of forces?
- Early universe, Inflation
- Quantum Gravity? Strings?
India’s role

• The increase in the number of formal theorists/phenomenologists very encouraging

• Some level of activity in most areas.

• Summer schools, focussed meetings, etc. many in number

• Travel funding easing: Increased international visibility
More details

- Higgs bosons: Morning discussion on 08/12
- Flavour & New Physics: Dighe
- Light flavours: Ananthanarayanan

- Lattice Gauge Theory: Soni
- Effective Field Theories: Wudka

- Inflation: Raghavan, A.Mazumdar
- Quantum Gravity:
  String Theory: Minwalla, A.Maharana, Ashoke Sen
India in future

• Take up more challenging problems!

• Activity in a very large number of institutions now. Yet not attracting enough high-quality students

• Intra-India collaborations should further increase

• Linkage with Astrophysics, Cosmology requires strengthening.

• Years ahead appear brighter
Peter Higgs and also Robert Brout and François Englert proposed the method by which particles get mass
Also Guralnik, Hagen, and Kibble (USA & UK)

They identified \textit{spontaneous breaking} of a symmetry as a solution to the conflict in writing down theories of interactions of short range and symmetries underlying them.

The signal for this solution is a massive particle: the Higgs boson.
Summary

• The discovery of the Higgs boson, emerging information about lepton mixing, etc. make this an exciting era.

• New facilities, increased energy, higher luminosity, & novel experiments are matched with creative developments in theory. Good days ahead!

• High Energy Physics research activity in India is on a steady rise

• Capacity building still remains a high priority for India
Thank You!!