Hunting for the Higgs at LHC

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The key to mass?
About the Higgs

The Standard Model (SM) (Glashow, Salam and Weinberg – 1979 Nobel prize)

Elementary Particles

Symmetry: SU3 × SU2 × U1

Quarks
- u (up)
- c (charm)
- t (top)
- d (down)
- s (strange)
- b (bottom)

Leptons
- νₑ (electron neutrino)
- νₘ (muon neutrino)
- νₜ (tau neutrino)
- e (electron)
- μ (muon)
- τ (tau)

Force Carriers
- g (gluon)
- γ (photon)
- W
- Z

Mₑ, g = 0
Mₑ, Z ~ 100 mₚ
M_top ~ M_gold

In the SM all particles have zero mass
The Higgs field is needed to renormalize the theory
⇒ “generates” mass - but not its own mass
Higgs mechanism

- Higgs: renormalizes the theory (removes infinities)
- One neutral Higgs boson
- "generates" the quark masses by coupling to quarks ~ mass.

Solves mass hierarchy problem ➔
The SM & RU

Evidence for quarks

CERN 1970s

BNL 1962 (my PhD thesis at Columbia)

Evidence for Z

BNL 1981 \( \nu_\mu p \rightarrow \nu_\mu p \)

Fermilab 1995

Glashow, Iliopoulos (RU), Miani

predict \textit{charm} in 1979

\[ M_\gamma, g = 0 \quad M_{W,Z} \sim 100 m_p \quad M_{\text{top}} \sim M_{\text{gold}} \]

What are we doing now in the search for the Higgs?
Particle accelerators

Rutherford Experiment

Source → $\alpha$-particles

Large angle scattering → atoms have nuclei

Fermilab Tevatron 1985
4 mile (6.4 km) tunnel → 2 TeV

CDF
D0

LHC 2010
27 km tunnel → 7 TeV
Large Hadron Collider
27 km circumference
Collisions at LHC

Proton-Proton (2835 x 2835 bunches)
Protons/bunch $10^{11}$
Beam energy 7 TeV ($7 \times 10^{12}$ eV)
Luminosity $10^{34}$ cm$^{-2}$ s$^{-1}$

Crossing rate 40 MHz

Collisions $\approx 10^7$ - $10^9$ Hz

search down to 1 part in $10^{13}$
Higgs searches at CMS - I

$H \rightarrow \gamma \gamma$

$H \rightarrow \tau^+ \tau^-$

$H \rightarrow b\bar{b}$ (displaced vertex)

$H \rightarrow W^+W^-$

$H \rightarrow Z^0Z^0$ ($Z^0 \rightarrow e^+e^- / \mu^+\mu^-$)
Higgs searches at CMS -II

**Light Higgs**
- $H \rightarrow bb$
- $H \rightarrow \tau\tau$
- $H \rightarrow \gamma\gamma$
- $H \rightarrow WW$
- $H \rightarrow ZZ \rightarrow 4l$

**Medium to Heavy Higgs**
- $H \rightarrow WW \rightarrow 2l2\nu$ (+jets)
- $H \rightarrow ZZ \rightarrow (2l2j, 2l2\nu, 4l, 2l2\tau)$
The SM is not stable at high energies because of loop corrections

SUSY → renormalizes the SM by introducing opposite sign contributions

The lightest SUSY particle (LSP) escapes detection

→ candidate for dark matter

...but what about dark energy???
Exclusive Higgs Production

\[ J_z = 0 \]
\[ 0^{++} \text{ state} \Rightarrow \text{identifies Higgs} \]
\[ \text{Rate}(q\bar{q}/gg) \sim \frac{m_q^2}{M^2} \sim 10^{-7} \]
\[ M \sim 2\delta p \]
\[ \text{TOF} \Rightarrow \delta M \sim 1 - 2 \text{ MeV} \]

\[ p + p \rightarrow p' + H + p' \]
With 5fb-1 & combination of CMS+ATLAS data the SM Higgs exclusion reach is in the range $140 < M_H < 600$ GeV

$\Rightarrow$ The non-discovery of the SM Higgs will be an even bigger discovery!
Backup
Neutrino mass hierarchy problem

Accelerator and CR experiments $\rightarrow M_{12}^2 \sim 7.9 \times 10^{-5} \text{ eV}^2$.

From cosmology:
CMB and large scale structure experiments $\rightarrow \Sigma = 0.03 < m_1 + m_2 + m_3 < 0.05 \text{ eV}$
\[ \delta t = (60.7 \pm 6.9 \text{ (stat.)} \pm 7.4 \text{ (sys.)}) \text{ ns} \]

\[ \frac{\nu - c}{c} = \frac{\delta t}{\text{TOF}_c - \delta t} = (2.48 \pm 0.28 \text{ (stat.)} \pm 0.30 \text{ (sys.)}) \times 10^{-5} \]

significance of 6.0 \sigma
Threading the MiniPlug fibers

About 1500 wavelength shifting fibers of 1 mm dia. are ‘strung’ through holes drilled in $36 \times \frac{1}{4}”$ lead plates sandwiched between reflective Al sheets and guided into bunches to be viewed individually by multi-channel photomultipliers.
Blow-hole at Grand Cayman
**p-p Interactions**

**Non-diffractive:**
Color-exchange

**Diffractive:**
Colorless exchange with vacuum quantum numbers

**Goal:** understand the QCD nature of the diffractive exchange
Dark Energy

Non-diffractive interactions
Rapidity gaps are formed by multiplicity fluctuations:

\[ P(\Delta y) = e^{-\rho \Delta y}, \quad \rho = \frac{dN_{\text{particles}}}{dy} \]

\( P(\Delta y) \) is exponentially suppressed

Diffractive interactions
Rapidity gaps at \( t=0 \) grow with \( \Delta y \):

\[ \Delta y \approx -\ln \xi = \ln s - \ln M^2 \]

\[ P(\Delta y) \bigg|_{t=0} \sim e^{2\varepsilon \Delta y} \]

\( 2\varepsilon \): negative particle density!

Gravitational repulsion?

http://physics.rockefeller.edu/dino/myhtml/talks/goulianos_konstantin_eds09_discussion.pdf

http://physics.rockefeller.edu/dino/myhtml/conference.html
Grant Unification