Lecture 23 Aspects of New Physics after LHC

ICPY473 Nuclear Physics, MUIC, 3-Trimester, 2021

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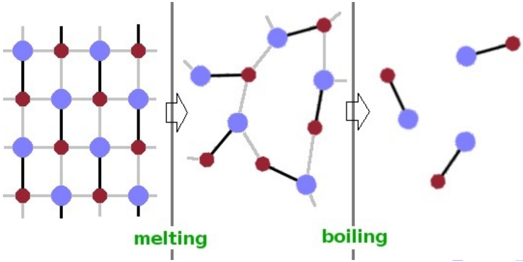
July 14, 2021

Today Topics

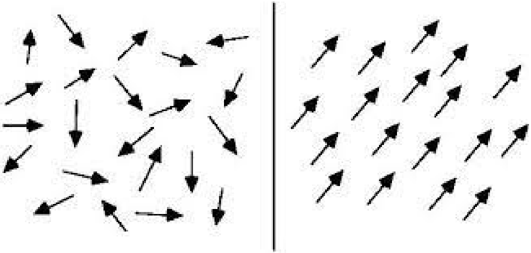
- Higgs physics
- Beyond the standard model physics

Higgs Physics

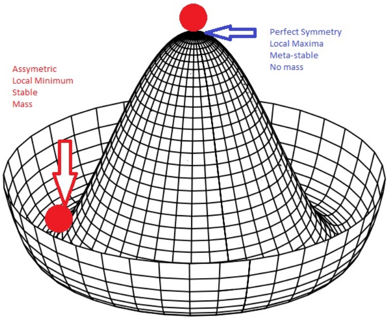
- Why do we need Higgs particle? According to the similarity of QED and Weak interaction, except the massless photon γ and the massive vector bosons $W^{\pm}, Z^0$.
- Energy range of QED in MeV, while weak interaction is GeV, so that something seem to be continuity from weak to QED by lowering the energy scale
- In classical physics, lowering in energy results to phase transition, i.e., gases condense into liquids and crystallize into solids, and all phase transitions are described by *symmetry breaking* mechanism



- Goldstone's theorem: *for breaking of any continuous symmetry there will correspond with massless boson, it is called Goldstone's boson*
- For magnetic materials, there are randomly orientation of magnetic moments (higher symmetry) after magnetization (directional oriented of magnetic moments) there appear with *magnon* as its elementary excitation
- For Helium gas, after Bose condensation there appear with *rotons* as its elementary excitation



- Higgs mechanism: *for breaking of any continuous symmetry there will correspond with massive boson, it is called Higgs's boson*



With $D_\mu = \partial_\mu - iqA_\mu$ and $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$, Higgs Lagrangian is

$$\mathcal{L} = [D_\mu \phi]^* [D^\mu \phi] - \mathcal{V}(\phi) - \frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

where $\mathcal{V} = -\mu^2 \phi^* \phi + \lambda (\phi^* \phi)^2$ is symmetry breaking potential

- Gauge boson get mass from Higgs as

$$-\frac{1}{4}F_{\mu\nu}F^{\mu\nu} \to -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}m^2 A_\mu A^\mu, \quad m^2 = g^2 v^2$$

where $v = \langle\phi\rangle$ is the vacuum expectation value of the Higgs field

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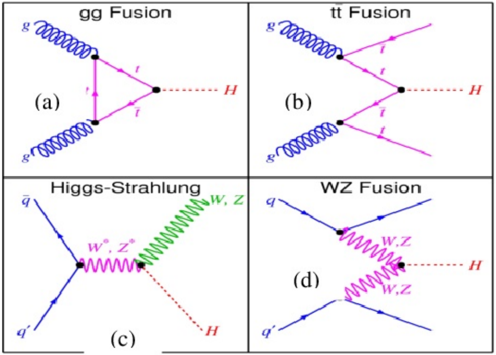
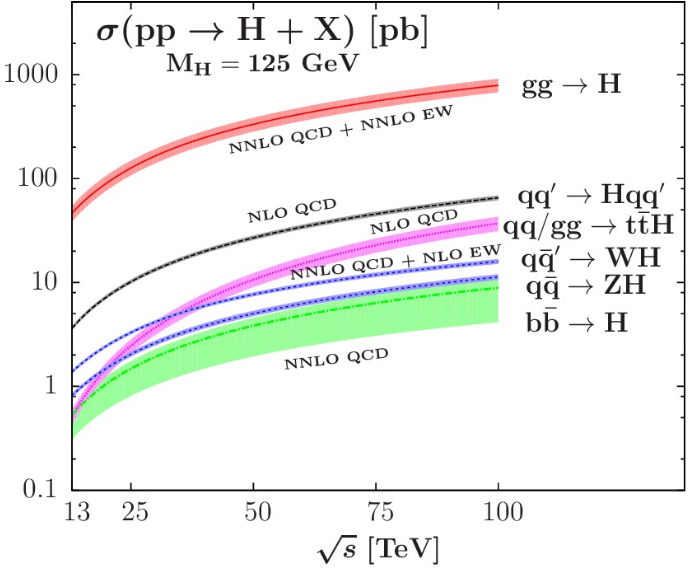
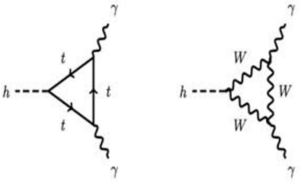
- Where is Higgs? Higgs production phenomenology



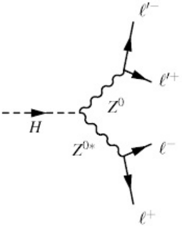
- The Higgs production cross section



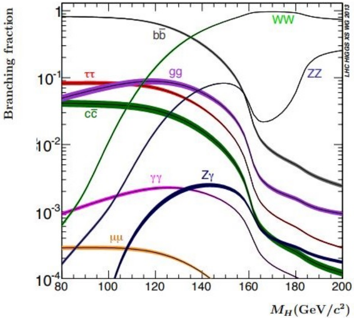
- The Higgs existence is observed through its decay remnants



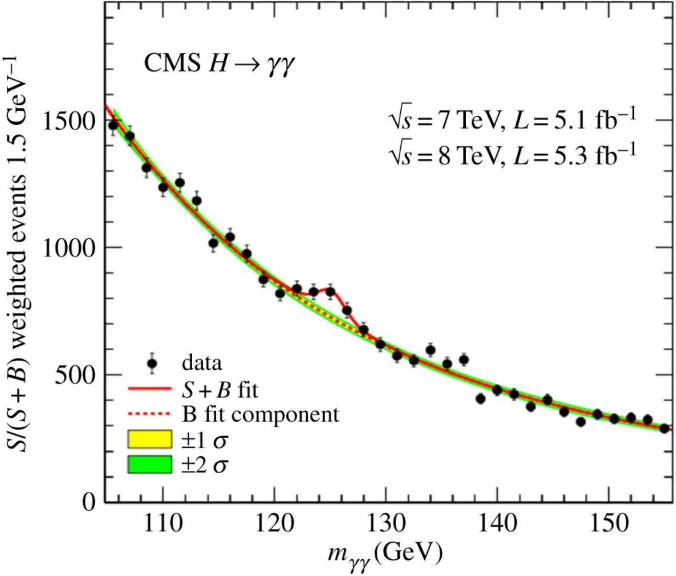
di-photon channel



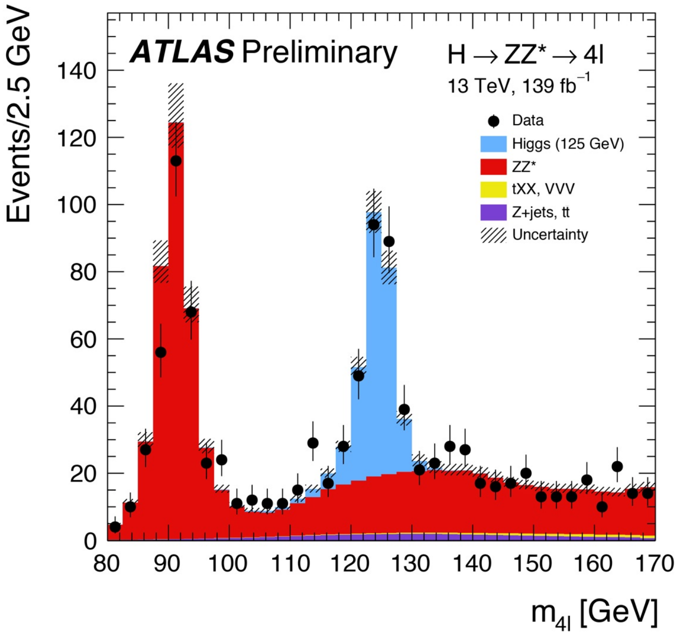
di-lepton channel



- Higgs detection at CMS-CERN



- Higgs detection at ATLAS-CERN



Celebration on October 2, 2015

Beyond the Standard Model Physics

- Problems with standard model
  - Too many parameters

me	Electron mass		511 keV
mμ	Muon mass		105.7 MeV
mτ	Tau mass		1.78 GeV
mu	Up quark mass	μMS = 2 GeV	1.9 MeV
md	Down quark mass	μMS = 2 GeV	4.4 MeV
ms	Strange quark mass	μMS = 2 GeV	87 MeV
mc	Charm quark mass	μMS = mc	1.32 GeV
mb	Bottom quark mass	μMS = mb	4.24 GeV
mt	Top quark mass	On-shell scheme	172.7 GeV
θ12	CKM 12-mixing angle		13.1°
θ23	CKM 23-mixing angle		2.4°
θ13	CKM 13-mixing angle		0.2°
δ	CKM CP-violating Phase		0.995
g1 or g'	U(1) gauge coupling	μMS = mZ	0.357
g2 or g	SU(2) gauge coupling	μMS = mZ	0.652
g3 or gs	SU(3) gauge coupling	μMS = mZ	1.221
θQCD	QCD vacuum angle		~0
v	Higgs vacuum expectation value		246 GeV
mH	Higgs mass		~ 125 GeV (tentative)

- $\alpha_1 = (5/3)g'^2/(4\pi) = 5\alpha/(3\cos^2\theta_W)$
- $\alpha_2 = g^2/(4\pi) = \alpha/\sin^2\theta_W$
- $\alpha_3 = g_s^2/(4\pi)$
  - $\alpha_1(M_Z) = 0.017$
  - $\alpha_2(M_Z) = 0.034$
  - $\alpha_3(M_Z) = 0.118 \pm 0.003.$

- Mass hierarchy problem of δm^2.

- Problems with standard model (cont.)
  - Asymmetry of particles and anti-particles

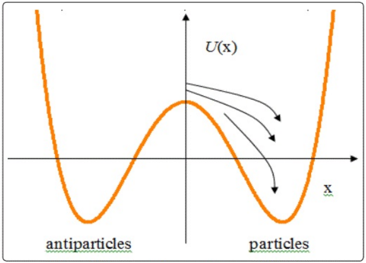


Figure 2. Asymmetric decay of a symmetric state.

- Problems with standard model (cont.)
  - Asymmetry of particles and anti-particles

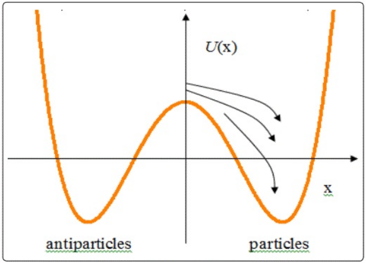
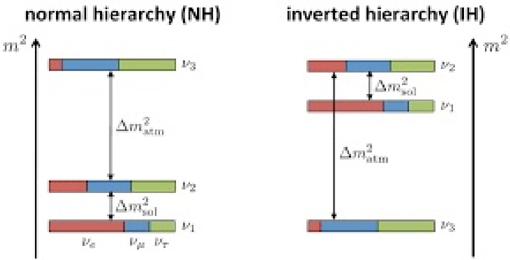


Figure 2. Asymmetric decay of a symmetric state.

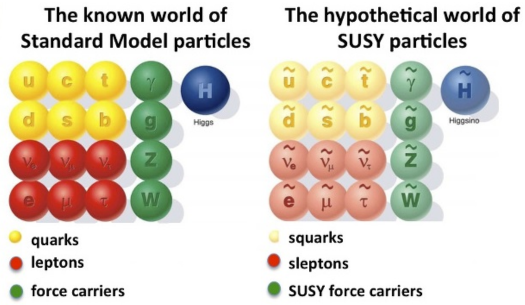
  - Non-zero masses of neutrinos



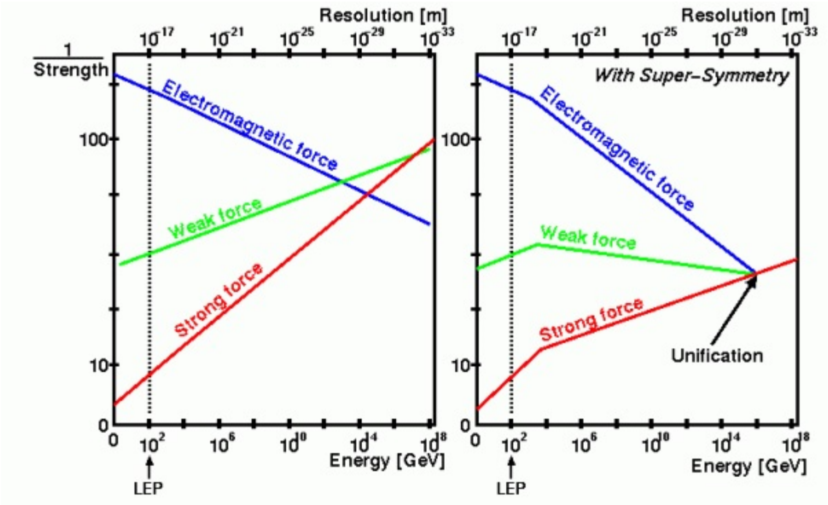
Beyond the standard model

- supersymmetry extension

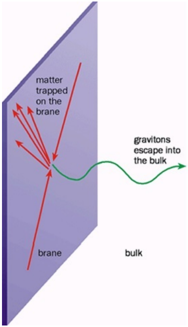
$$\underbrace{ISO(1,3)}_{spacetime} \times \underbrace{U(1) \times SU(2) \times SU(3)}_{gauge} \times \underbrace{SUSY}_{super-partner}$$

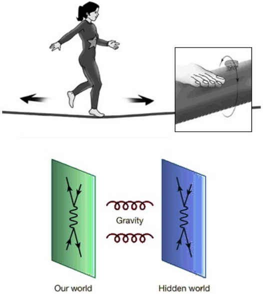


- supersymmetry unification



- Extra dimensions, braneworld extension





- Randall-Sundrum model