Doubly charged Higgs at LHC
or
testing neutrino physics at hadron colliders

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Outline

- Motivation
- Production process $pp \to \Phi^{++}\Phi^{--}$

  and LHC mass reach for Φ^{++}
- Relating decays $\Phi^{\pm\pm} \to \ell_i \ell_j$ to neutrino masses
- Conclusions

arXiv:0712.1453
arXiv:0712.3912
arXiv:0712.4019
arXiv:0801.2011
arXiv:0802.2510
arXiv:0802.3257

Motivations: EWSB

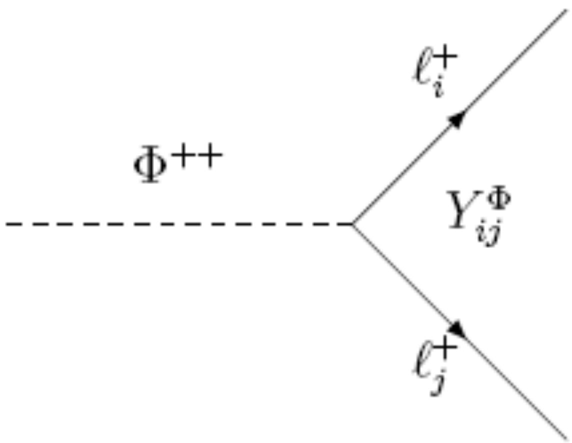
- The main purpose of LHC is to clarify the secrets of EWSB
- Precision data: $M_H < 180$ GeV at 95% CL
  $\Lambda_{NP} > 1$ TeV
- Little hierarchy problem
- Solution: Little Higgs models, $\Lambda_{NP} \geq 1$ TeV
- The SM Higgs is a pseudo-Goldstone boson protected by new symmetry

Littlest Higgs model

- Based on global symmetry SU(5)/SO(5)
- Predicts W', Z', 2 T' and a pseudo-Goldstone multiplet with $SU(2)_L \times U(1)_Y$ quantum n.

$\Phi \sim (3,2)$ with $M_\Phi < \Lambda_{NP}$

$(\Phi^{++}, \Phi^{+}, \Phi^{0})$



$$L = i\bar{\ell}^c_{Li}\tau_2 Y^{ij}_\Phi(\tau \cdot \Phi)\ell_{Lj} + h.c.,$$

$\mu \rightarrow eee \quad Y_{ee}Y_{e\mu} < 3 \cdot 10^{-5}(M/TeV)^2$

Tevatron: $M_\Phi > 136$ GeV

Motivations: neutrino masses

- Neutrinos are massive and mix
- Neutrinos are light compared to charged fermions $m_\nu < 0.2$ eV
- Oscillation experiments have measured
  - Two mass-squared differences
  - Two large mixing angles, bound on one small mixing
- Oscillation experiments are NOT sensitive to
  - Neutrino mass scale
  - Neutrino mass ordering (normal, inverse)
  - Majorana phases α_1, α_2

Seesaw I

N ~ (0,0)

$$L = \bar{N}_i Y_\nu^{ij} \ell_i H - \frac{1}{2} M_N N N + h.c.$$

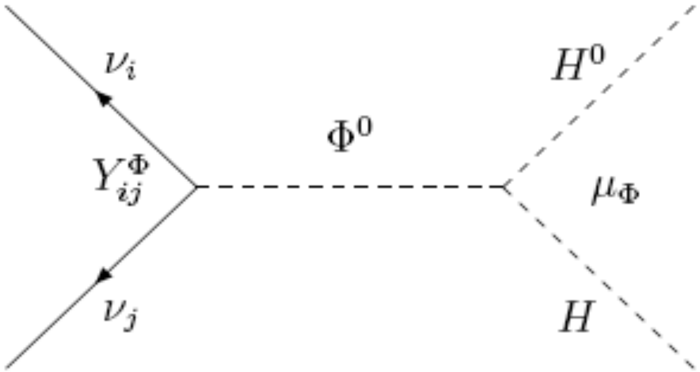
$$\boxed{m_\nu = Y_\nu^T M^{-1} Y_\nu v^2}$$

$M_N \sim 1$ TeV $\Rightarrow$ $Y_\nu \sim 10^{-7}$

- Very difficult to produce and detect at LHC

Seesaw II

$(\Phi^{++}, \Phi^{+}, \Phi^{0})$



$$(m_\nu)_{ij} = 2(Y_\Phi)_{ij} v_\Phi$$

$$v_\Phi = \mu_\Phi \frac{v^2}{M_\Phi^2}$$

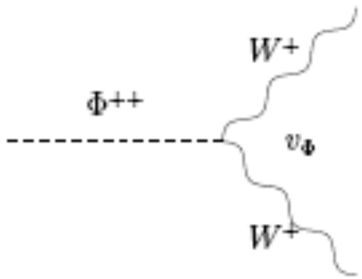
- m_ν small due to smallness of lepton number breaking parameter μ_Φ
- Decays $\Phi^{\pm\pm} \to \ell^\pm \ell^\pm \propto m_\nu$

Collider phenomenology

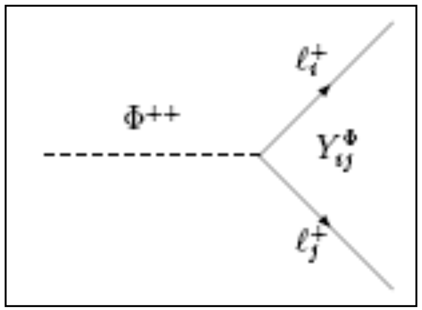
- s-channel γ, Z

$$pp \to \Phi^{++}\Phi^{--}$$

- The only unknown parameter is M_Φ



$\Phi^{++} \to W^+W^+ \propto v_\Phi$, negligible



$$\mathrm{BR}(\Phi^{\pm\pm} \to \ell_i^\pm \ell_j^\pm) = \frac{|(m_\nu)_{ij}|^2}{\sum_{i\geq j} |(m_\nu)_{ij}|^2 + 4kv_\Phi^4},$$

- Look for same-charged invariant mass peak

$$(m_I^{\pm\pm})^2 = (p_1^{\pm} + p_2^{\pm})^2$$

  in 4 charged lepton final states

- m_ν tell the e, μ, τ decomposition, e.g., NH

$$BR(\Phi^{++} \to \mu^+\mu^+) \approx BR(\Phi^{++} \to \tau^+\tau^+) \approx$$

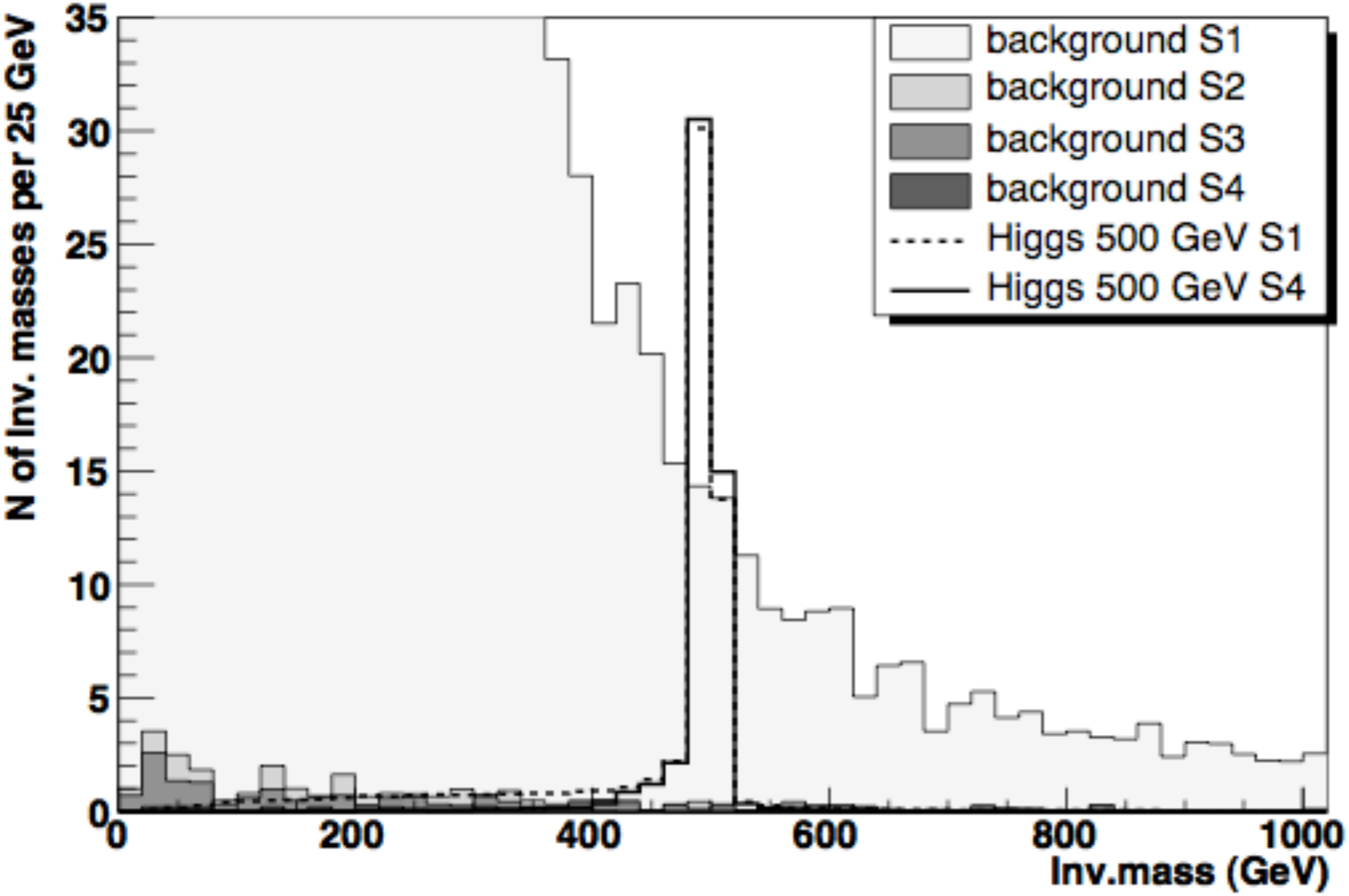
$$BR(\Phi^{++} \to \mu^+\tau^+) \approx 1/3$$

- SM background:
  - $pp \to t\bar{t}$,
  - $pp \to t\bar{t}Z$,
  - $pp \to ZZ$.

- MC study with PYTHIA and CompHEP + CMS detector configuration and lepton reconstruction efficiencies from TDR
- Background samples generated for 300 fb^{-1}

- Selection rules applied:
  - S1: at least 4 μ or τ-jets in $|\eta| < 2.4$ with $p_T > 5$ GeV
  - S2: $\sum p_T$ cut optimized for M_Φ
  - S3: Z-tagging
  - S4: $0.8 < m_I^{++}/m_I^{--} < 1.2$.

M_{Φ}=500 GeV, L=30 fb^{-1}



Background can be eliminated

Process	N of invariant masses				
	N of Φ	S1	S2	S3	S4
M_Φ=500 GeV	119.2	48.4	47.5	46.8	49.5
$t\bar{t} \to 4\ell$	-	178 (28)	2.1 (0.9)	1.65 (0.87)	0.10 (0.35)
$t\bar{t}Z$	-	6.6 (1.7)	2.3 (1.0)	1.0 (1.0)	0.00 (0.1)
ZZ	-	9.4 (2.9)	1.4 (0.2)	0.68 (0.19)	0.08 (0.09)

Brackets: 95% upper limit on background based on
Poisson statistics

S vs. B statistical analyses with very small numbers

LHC discovery potential at 95% CL

Optimization task

Mass of Φ (GeV)	200	300	400	500	600	700	800	900	1000
Optimal $\sum p_T$ for S2 (GeV)	300	400	600	700	860	860	860	860	860
Det Eff L_{min} (fb^{-1})	0.526	1.20	3.0	6.6	15	30	60	111	200
Det Eff L_{max} (fb^{-1})	0.546	2.19	6.5	16.6	39	86	190	420	900

- L_{min} corresponds to the generated background
- L_{max} corresponds to 95% upper limit on the background based on Poisson statistics

Neutrino physics at LHC

- Counting experiment of charged lepton flavours: e, μ, τ

- LHC is sensitive to neutrino parameters which oscillation experiments are insensitive to:
  - Mass ordering (normal, inverse)
  - Lightest neutrino mass m_1
  - Majorana phases

Mass ordering and m_1

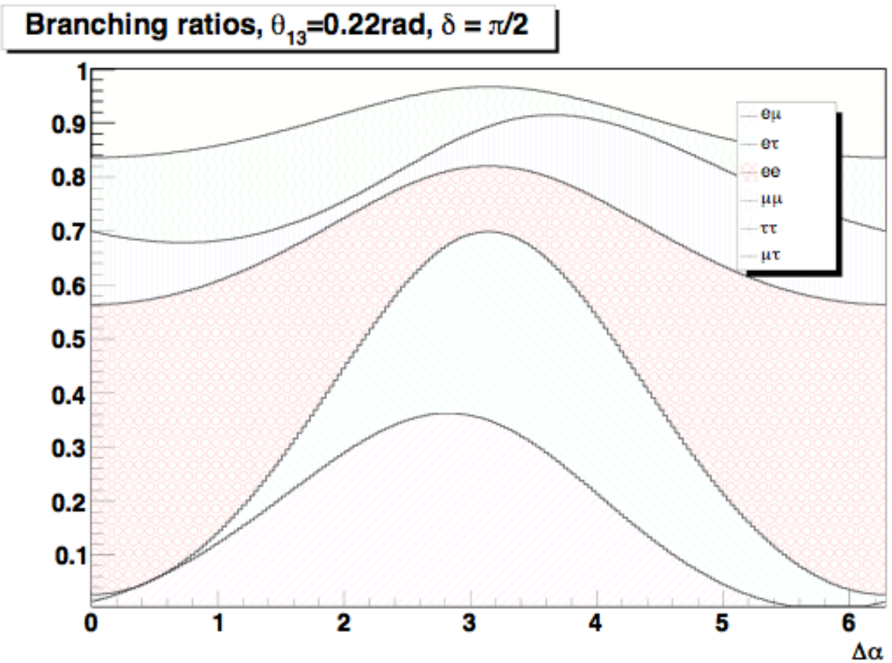
Define functions of lepton BR:

$$C_1 \equiv \frac{2\mathrm{BR}_{\mu\mu} + \mathrm{BR}_{\mu\tau} - \mathrm{BR}_{ee}}{\mathrm{BR}_{ee} + \mathrm{BR}_{e\mu}} = \frac{-m_1^2 + m_2^2 + 3m_3^2}{2m_1^2 + m_2^2}.$$

- $C_1 > 1$ – normal mass hierarchy,
- $C_1 < 1$ – inverted mass hierarchy,
- $C_1 \approx 1$ – degenerate masses.

$$m_1^2 = \frac{\Delta m_{sol}^2 (4 - C_1) + 3\Delta m_{atm}^2}{3(C_1 - 1)}.$$

Majorana phases



- BR depend on (α_1- α_2)
- Asymmetry due to CP-violation
- For m_1=0

$$C_4 \equiv \frac{\mathrm{BR}_{\mu\mu}}{\mathrm{BR}_{\mu\tau}}$$

$$\alpha_2 = \arccos\left(\frac{(2C_4-1)(13\Delta m^2_{sol}+9\Delta m^2_{atm})}{12(1+2C_4)\sqrt{\Delta m^2_{sol}}\sqrt{\Delta m^2_{sol}+\Delta m^2_{atm}}}\right)$$

Conclusions

- Light triplet Higgs is a well motivated by
  - Little Higgs models
  - Non-zero neutrino masses
- At L=30 fb^{-1} the LHC mass reach for Φ^{++} is

  $M_{\Phi} < 700$ GeV
- Neutrino physics at LHC is counting of lepton flavours. Sensitive to:
  - Mass ordering and lowest neutrino mass
  - Majorana phases

Thank you!