Probing neutral gauge boson (from the Higgs@ linear collider)

The 4th International Workshop on
"Higgs as a Probe of New Physics"
18 -22, February 2019, Osaka University, Japan

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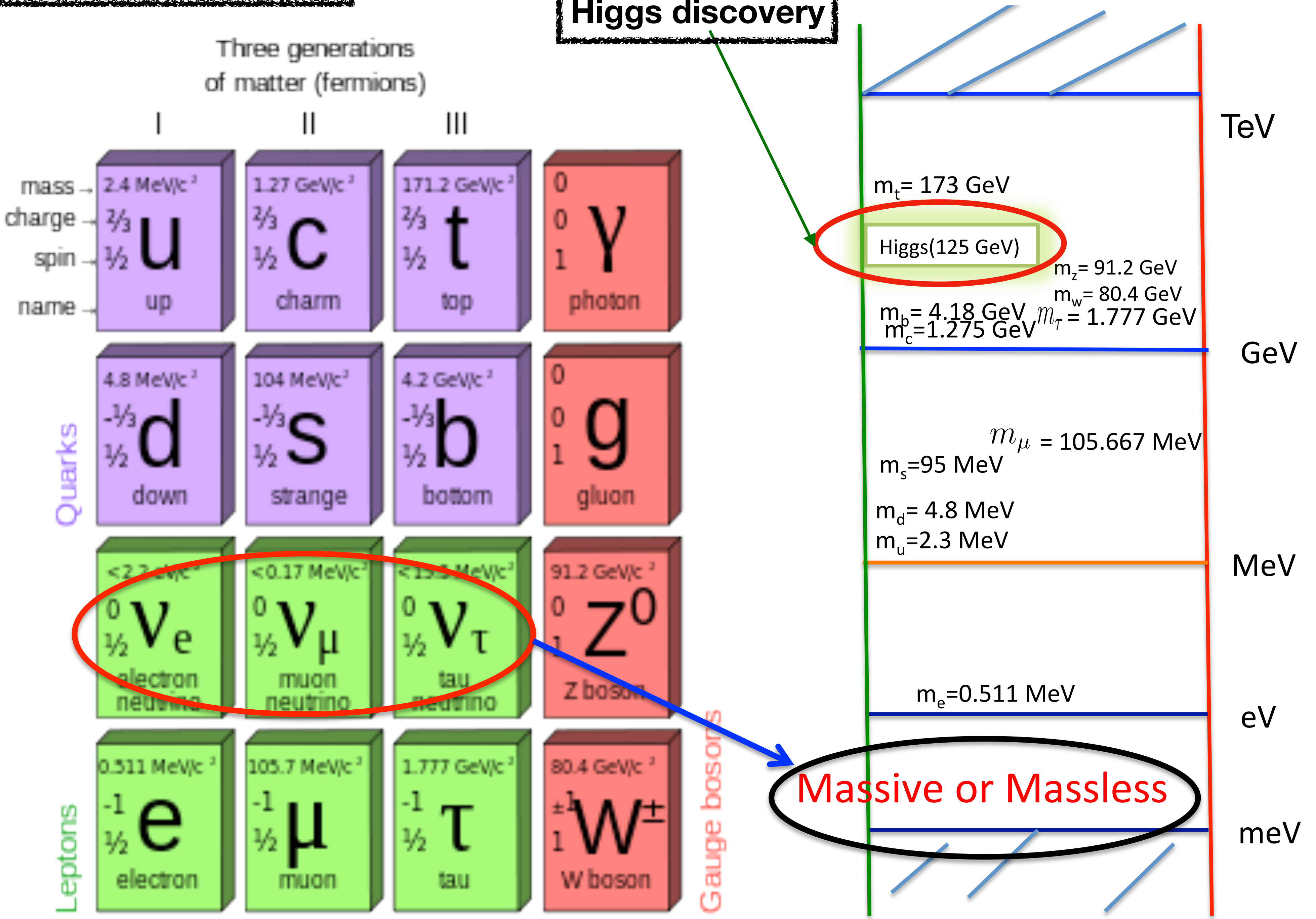
February 20, HPNP 2019

In progress with
(1) S. Goswami, Vishnudath K. N., and T. Nomura
(2) N. Okada
(3) E. J. Chun, P. Ghosh and S. Mondal

Introduction

Higgs discovery



m_t= 173 GeV

Higgs(125 GeV)

m_z= 91.2 GeV

m_w= 80.4 GeV

m_b= 4.18 GeV

m_c=1.275 GeV

m_τ = 1.777 GeV

m_μ = 105.667 MeV

m_s=95 MeV

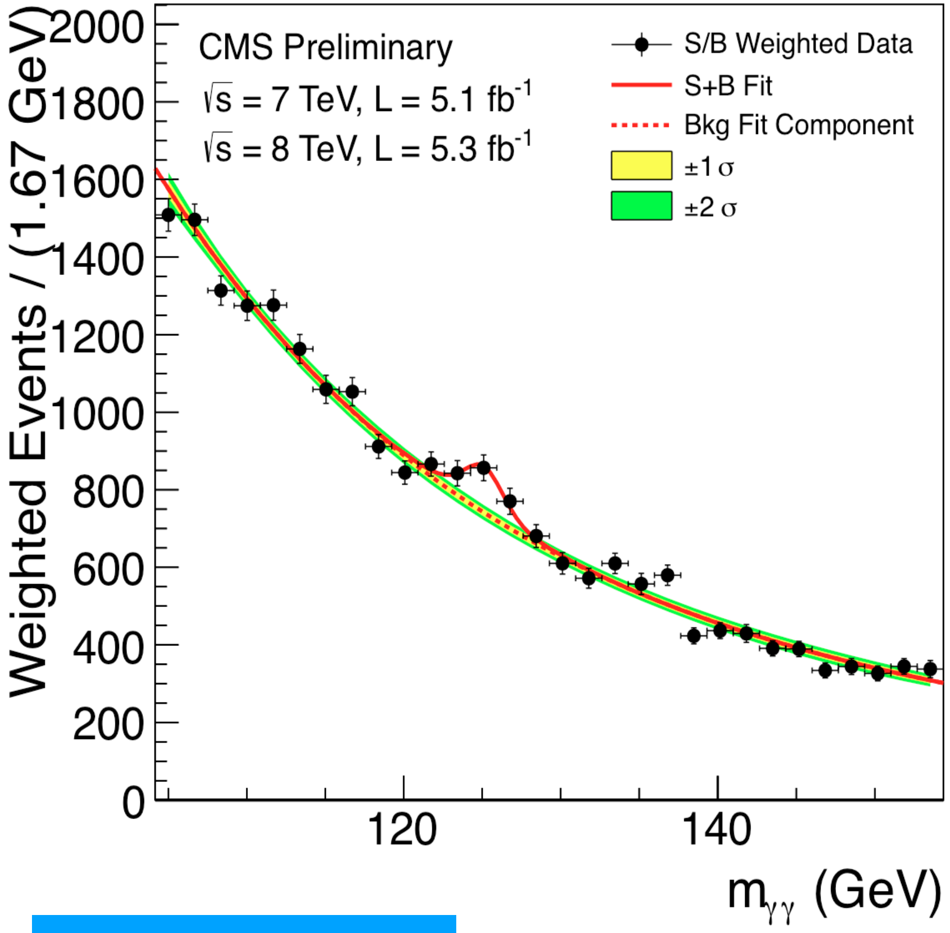
m_d= 4.8 MeV

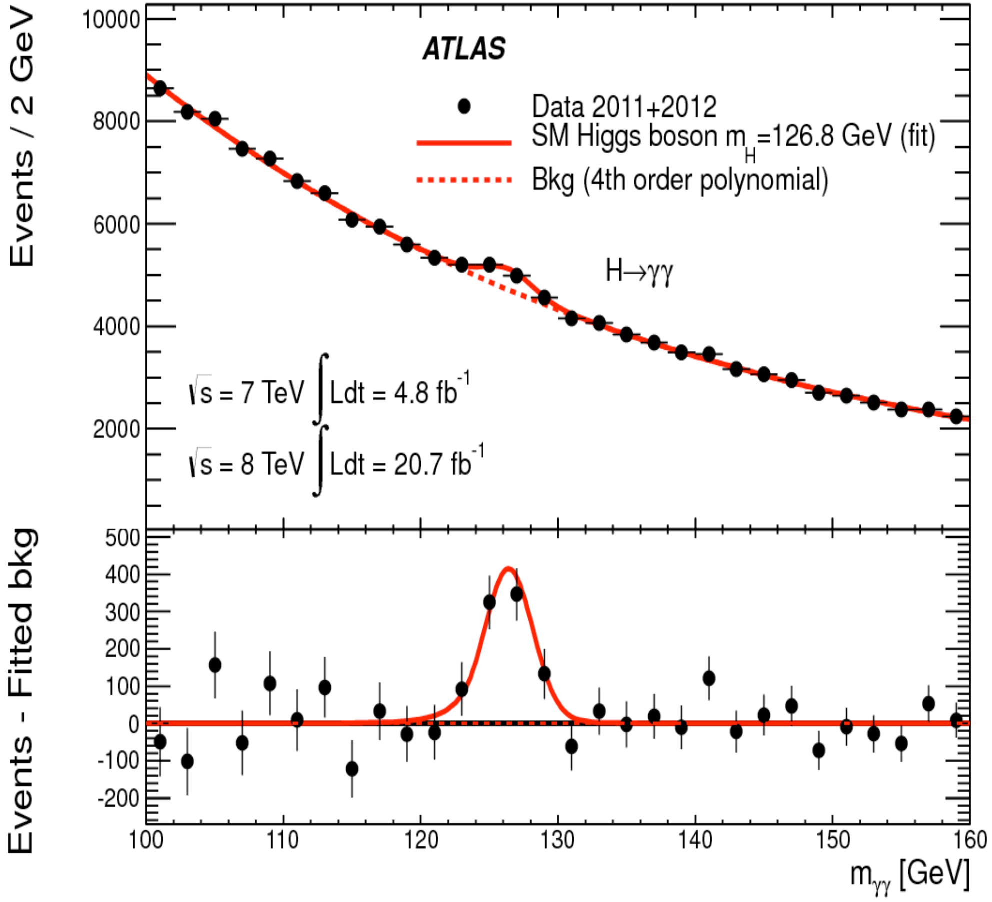
m_u=2.3 MeV

m_e=0.511 MeV

Massive or Massless

Discovery of Higgs boson



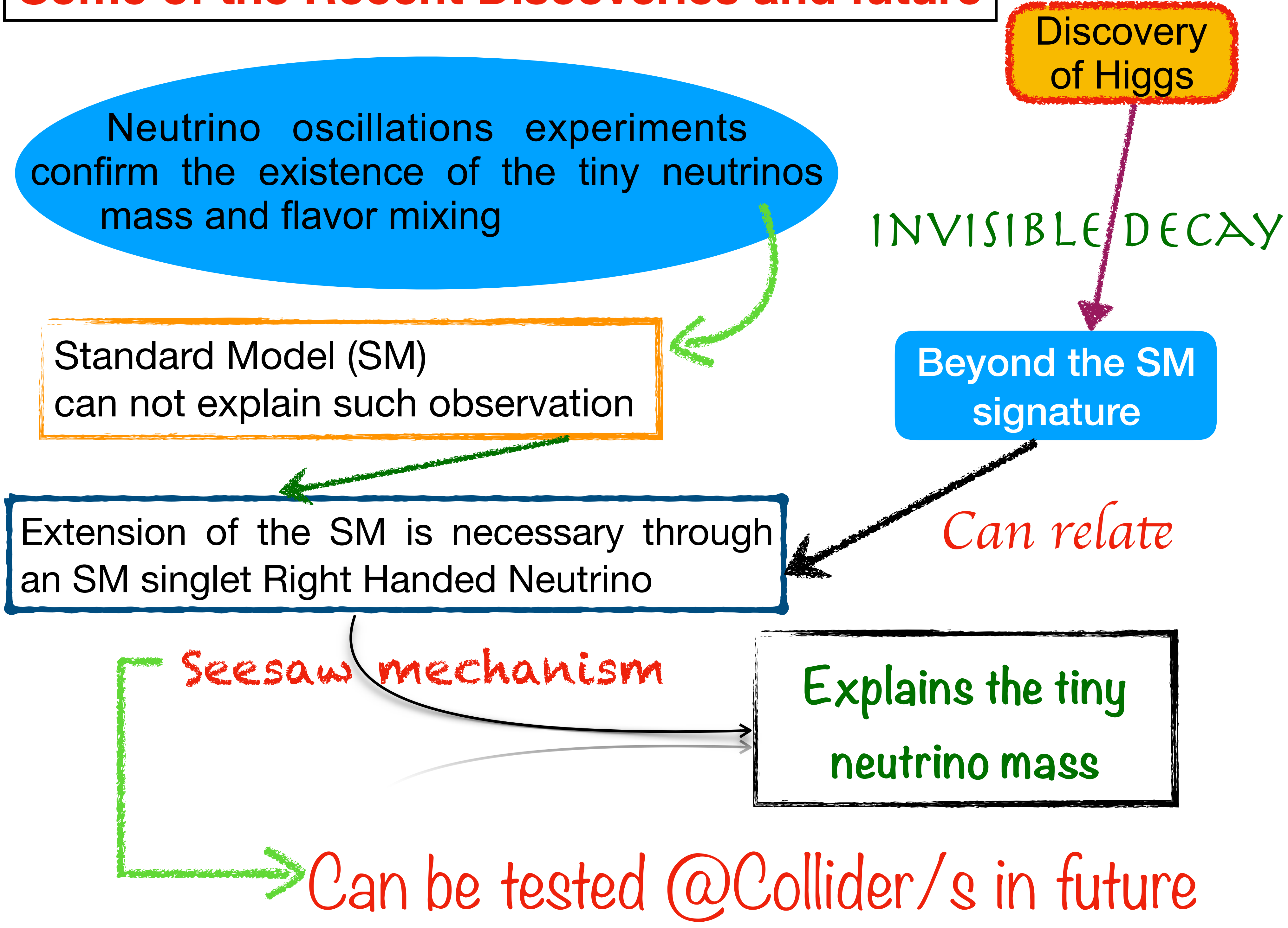


Nobel Prize in 2013

Role in future

Higgs boson mass around 125 GeV

Some of the Recent Discoveries and future



Discovery of Higgs

Neutrino oscillations experiments confirm the existence of the tiny neutrinos mass and flavor mixing

INVISIBLE DECAY

Standard Model (SM) can not explain such observation

Beyond the SM signature

Extension of the SM is necessary through an SM singlet Right Handed Neutrino

Can relate

Seesaw mechanism

Explains the tiny neutrino mass

Can be tested @Collider/s in future

A slice of BSM Scenarios

CP Asymmetry

Vacuum stability (Branchina)

(Multi-)Higgs scenarios (Haber, Cao, Ferreira, Santos, Muhlleitner,Ko, Ivanov, Goodsell, Benakli,Masubuchi,Heinemeyer, Munir, Chun, Kanemura), Future colliders (Su, Vos), Composite Higgs (De Curtis,Enberg, Flacke), Higgs couplings (Chiang), Exotic contributions (Logan), Light scalars (Wu), EFT (Tian), Precision (Yagyu)

Leptogenesis, Baryogenesis, Cosmological implications (Ramsey-Musolf, Fuyuto, Konstandin,Bruggisser, Senaha)

250 GeV ILC/collider/ associate production, QCD (Mawatari, Matsuzaki), New physics scale (Ge), ILC (Okada, Fuji)

Dark matter, Long-lived (Grzadkowski, Keus, Matsui, Nomura, Toma, Tseng, Redondo)

Models generated neutrino mass at one loop or more loops which include dark matter, Z’, extra scalar, Scotogenic models (Archie)

Tree level neutrinos mass, BSM gauge bosons (Z’) and Higgs (Das)

GHU (Hosotani, Lim)

Also long lived (Okada), Charged Higgs (Song), Higgs inflation (Park, Paßehr), Hierarchy problem (Iso), Topological aspects-2HDM (Nitta), Higgs Instability (Han), CLFV (Yamanaka)

$SU(3)\times SU(2)_L\times SU(2)_R\times U(1)_{B-L}$

scenario where a variety of searches have been performed including $W_R$and heavy neutrinos at the LHC, even people studied dark matter. ATLAS rules out (1809.11105) $M_{W_R} = 4.7$ TeV for Majorana and Dirac heavy neutrinos for

$M_{N_R} = 1.2$ TeV for eejj $M_{N_R} = 1$ TeV for $\mu\mu jj$

(SUSY-LR-type-II: Huitu)

Includes (plenty of) scalars, at different varieties

Discovery in future

Particle content of the model

	$\mathrm{SU}(3)_c$	$\mathrm{SU}(2)_L$	$\mathrm{U}(1)_Y$	$\mathrm{U}(1)_X$
q_L^i	$\mathbf{3}$	$\mathbf{2}$	$1/6$	$(1/6)x_H + (1/3)x_\Phi$
u_R^i	$\mathbf{3}$	$\mathbf{1}$	$2/3$	$(2/3)x_H + (1/3)x_\Phi$
d_R^i	$\mathbf{3}$	$\mathbf{1}$	$-1/3$	$-(1/3)x_H + (1/3)x_\Phi$
ℓ_L^i	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	$(-1/2)x_H - x_\Phi$
e_R^i	$\mathbf{1}$	$\mathbf{1}$	-1	$-x_H - x_\Phi$
H	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	$(-1/2)x_H$
N_R^j	$\mathbf{1}$	$\mathbf{1}$	0	$-x_\Phi$
Φ	$\mathbf{1}$	$\mathbf{1}$	0	$+2x_\Phi$

Linear combination of the SM $U(1)_Y$ and $U(1)_{\mathrm{B-L}}$

3 generations of SM singlet right handed neutrinos (anomaly free)

$$\mathcal{L}_Y \supset -\sum_{i,j=1}^{3} Y_D^{ij}\overline{\ell_L^i} H N_R^j - \frac{1}{2}\sum_{i=k}^{3} \boxed{Y_N^k \Phi \overline{N_R^{k\,c}} N_R^k} + \text{h.c.}$$

Involves a neutral BSM gauge boson Z'

$U(1)_X$ breaking

$$m_{Z'} = g_X\sqrt{4v_\Phi^2 + \frac{1}{4}x_H^2 v_h^2} \simeq 2g_X v_\Phi$$

LEP constraint $\quad {v_\Phi}^2 \gg {v_h}^2.$

Majorana after $U(1)_X$ breaking

EWSB

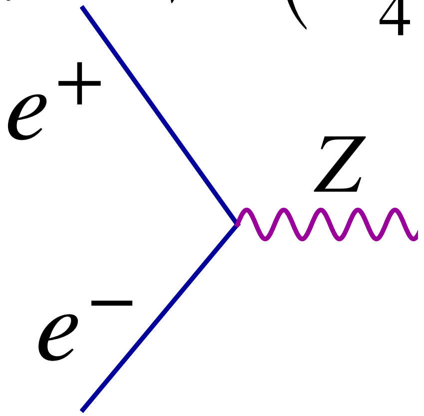
$$m_D^{ij} = \frac{Y_D^{ij}}{\sqrt{2}} v_h$$

$$m_{N^i} = \frac{Y_N^i}{\sqrt{2}} v_\Phi$$

Seesaw

Interaction between the SM leptons and Z

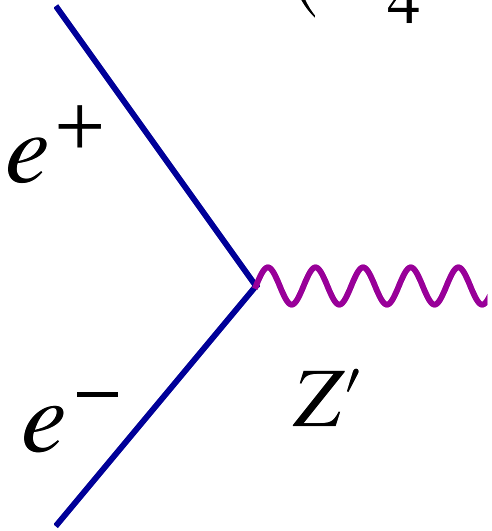
$$\mathscr{L}_{int} = g_z \bar{e} \gamma^\mu \left(C_V + C_A \gamma^5 \right) e Z_\mu \qquad C_V = \left(-\frac{1}{4} + \sin\theta_w^2 \right) \qquad C_A = \left(\frac{1}{4} \right)$$



Interaction between the SM leptons and Z'

$$x_\Phi = 1$$

$$\mathscr{L}_{int} = g_x \bar{e} \gamma^\mu \left(C'_V + C'_A \gamma^5 \right) e Z'_\mu \qquad C'_V = \left(-\frac{3}{4} x_H - 1 \right) \qquad C'_A = \left(-\frac{1}{4} x_H \right)$$



Interaction between the SM Higgs and Z

$x_\Phi = 1$

$$\mathcal{L}_{int} \supset \left| -i\frac{g_z}{2}Z_\mu \frac{1}{\sqrt{2}}(v+h)\right|^2 = \frac{g_z^2}{8}Z_\mu Z^\mu (v^2 + 2vh + h^2)$$

$$\supset \frac{m_z^2}{v} h Z_\mu Z^\mu$$

Interaction between the SM Higgs and $Z\,Z'$

$$\mathcal{L}_{int} \supset \left| \left\{ -i\frac{g_z}{2}Z_\mu - iZ'_\mu g_x\left(-\frac{1}{2}x_H\right)\right\}\frac{1}{\sqrt{2}}(v+h)\right|^2$$

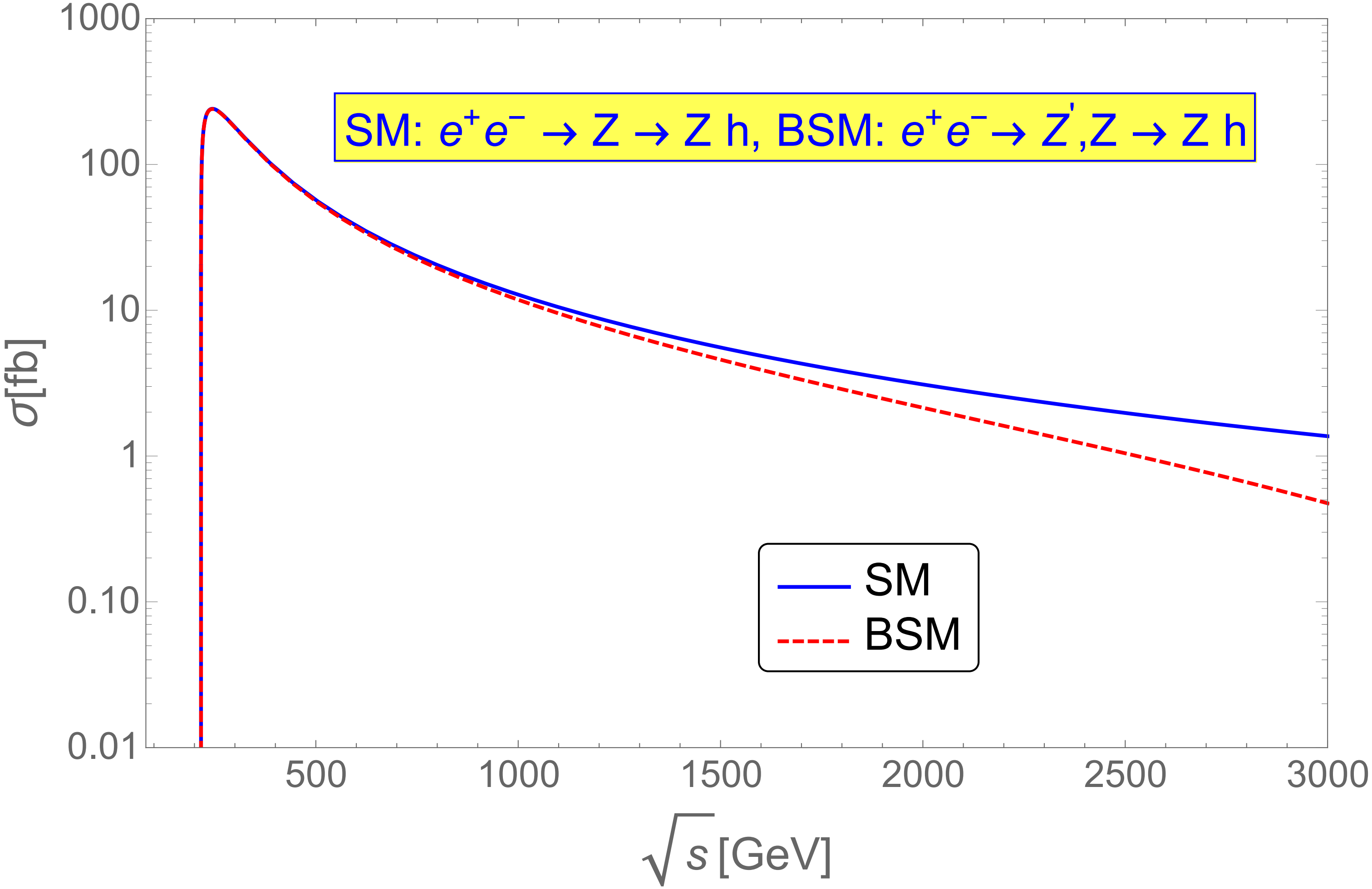
$$\supset -\frac{1}{2}g_z(g_x x_H) v h Z^\mu Z'_\mu = -M_Z (g_x x_H) h Z^\mu Z'_\mu$$

Comparing dimuon production with the ATLAS results at 36/fb [1707.02424] and future 3/ab [CERN-LHCC-2017-018 ; ATLAS-TDR-027] luminosities, we put bounds on the g_x vs M'_Z plane for different choices of x_H (1812.11931v1)

Higgs production at the linear collider

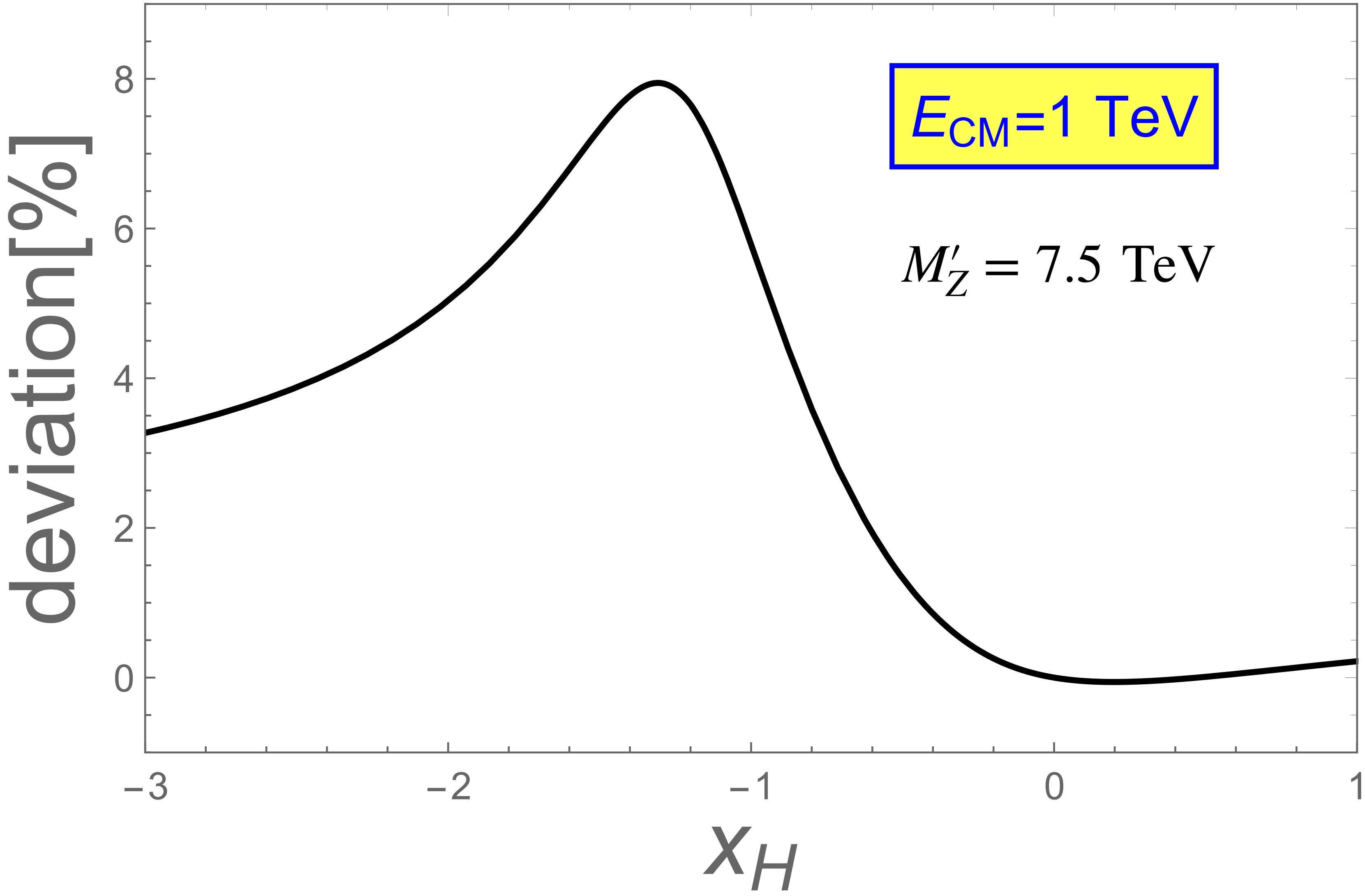
$M_{Z'} = 7.5$ TeV $\quad g' = 0.91$
$x_H = -1.2$
$x_\Phi = 1$

SM $\quad e^+e^- \to Z \to Zh$
BSM $\quad e^+e^- \to Z, Z' \to Zh$



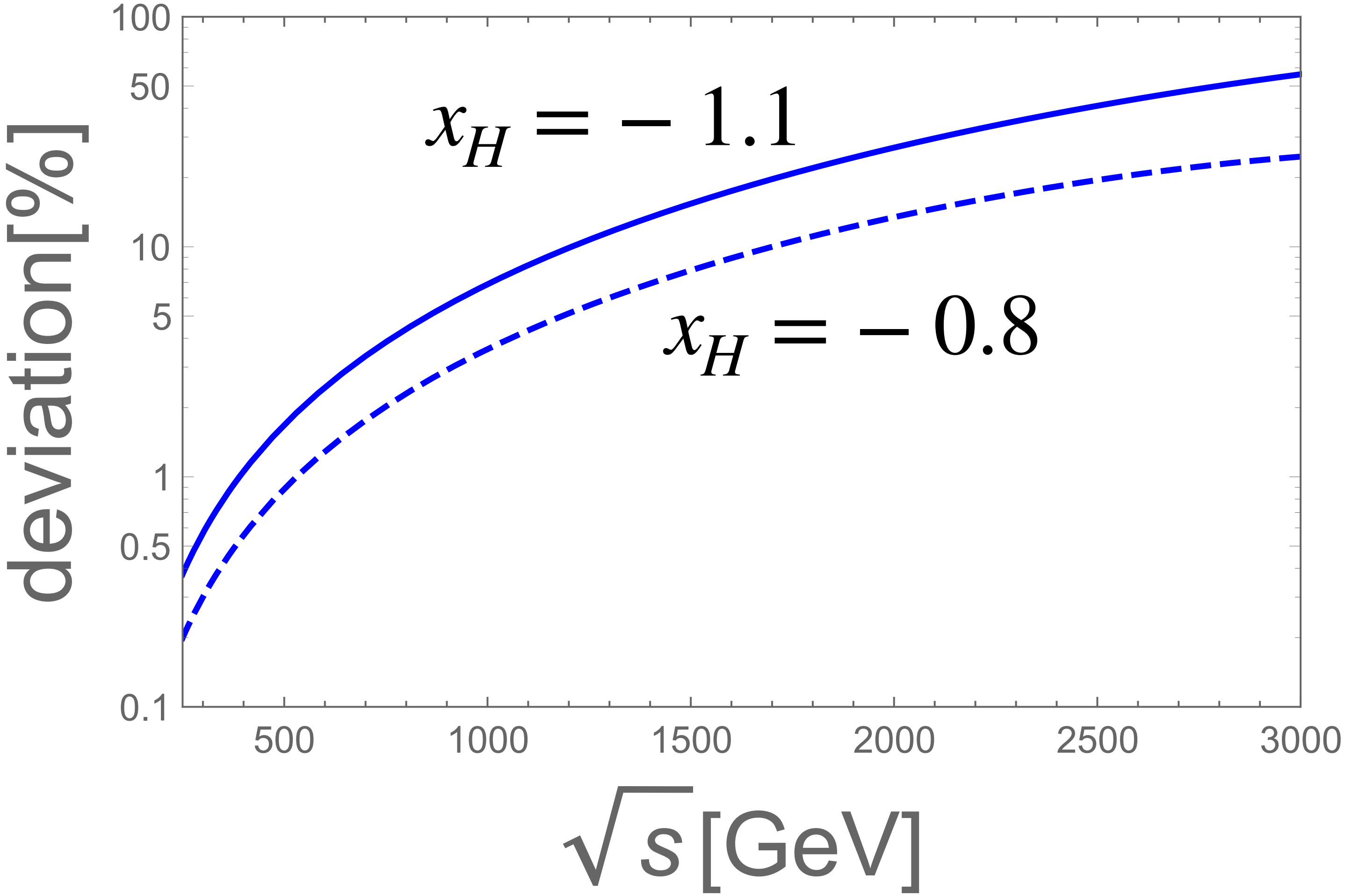
Deviation of cross sections

$$\text{Deviation} = \left[1 - \frac{\sigma_{\text{BSM}}[\text{E}_{\text{CM}}, \text{g}_{\text{x}}, \text{x}_{\text{H}}, \text{M}_{\text{Z}'}]}{\sigma_{\text{SM}}[\text{E}_{\text{CM}}]}\right] * 100\,\%$$



Deviation of cross sections

$$\text{Deviation} = \left[1 - \frac{\sigma_{\text{BSM}}[\text{E}_{\text{CM}}, \text{g}_\text{x}, \text{x}_\text{H}, \text{M}_{\text{Z}'}]}{\sigma_{\text{SM}}[\text{E}_{\text{CM}}]}\right] * 100\,\%$$



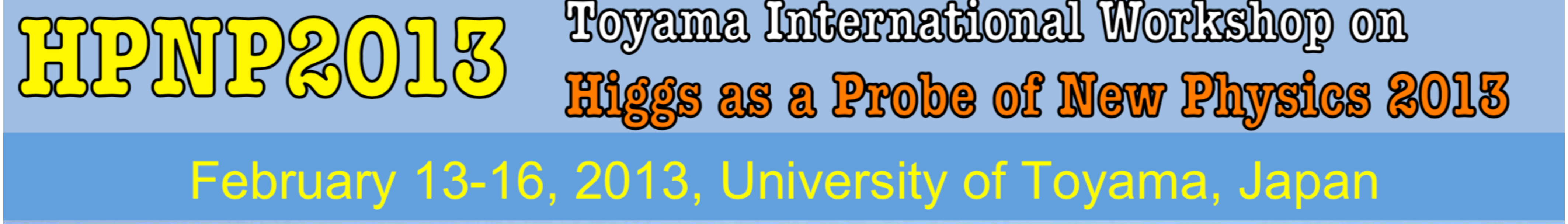
Conclusions

Several experimental results on the neutrino oscillation, DM have established the fact that the SM is not a complete one. In order to explain a simple scenario where a variety of such beyond the SM scenarios can be observed, we tried to figure out a general U(1) extension of the SM.

We have found that the in such models a neutral BSM gauge boson, commonly known as the Z' boson can be studied. As the U(1) charge sector is a free parameter even after the anomaly cancellations, the charge of the U(1) sector plays a crucial role in the observation of the BSM scenarios at the different colliders.

So far we have tested the Z' production at the linear collider followed by the decay into Higgs in association with SM Z boson. In this ongoing analysis we can further decay the Z and the Higgs depending upon the nature of the collider (SM backgrounds) and try to find the significance of the Z' discovery. We have found that even at the (250 GeV) linear collider we can probe 7.5 TeV Z'.

Slight variation of such model can study deeply the neutrino mass generations mechanisms, DM scenario and vacuum stability. The simplicity of such models are very attractive, however, having a plenty of phenomenological aspects which can be tested in the current and future experiments.

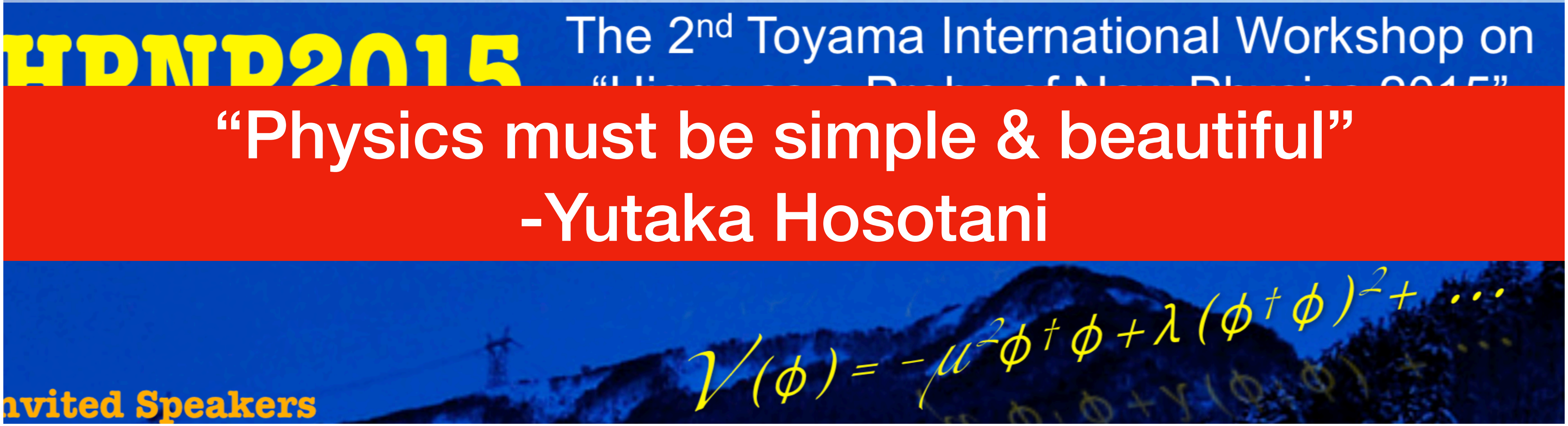


HPNP2013

Toyama International Workshop on

Higgs as a Probe of New Physics 2013

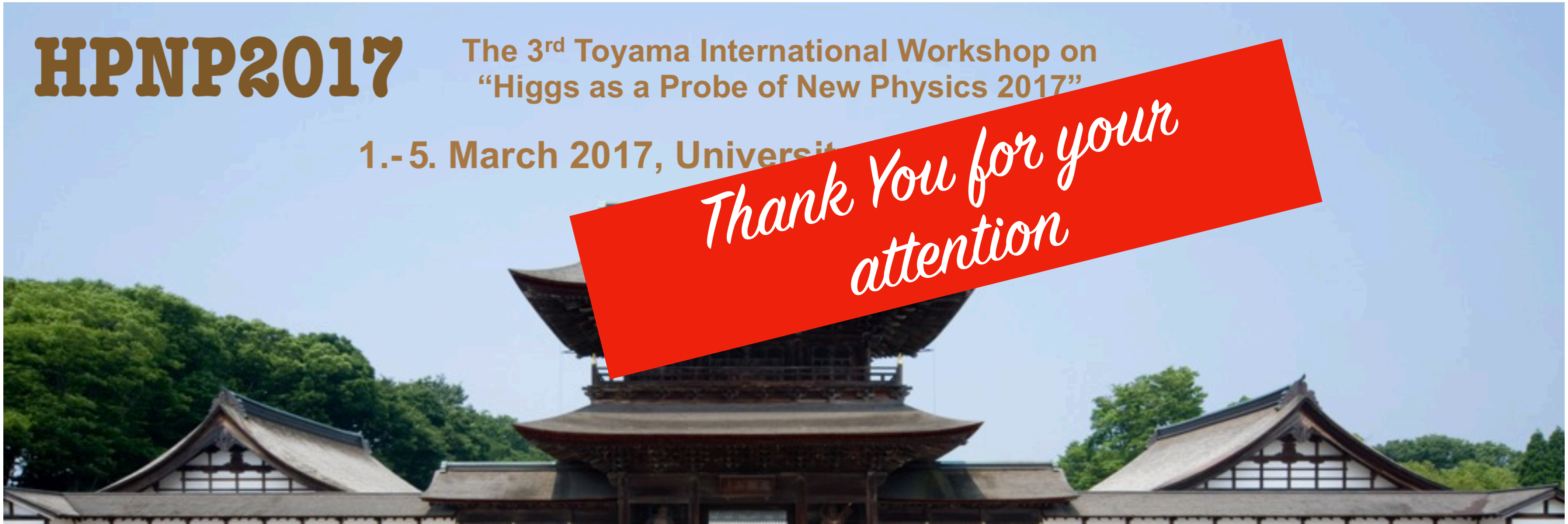
February 13-16, 2013, University of Toyama, Japan



HPNP2015

The 2nd Toyama International Workshop on

“Physics must be simple & beautiful”
-Yutaka Hosotani



HPNP2017

The 3rd Toyama International Workshop on
“Higgs as a Probe of New Physics 2017”

1.-5. March 2017, Universi

Thank You for your attention