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Higgs 2023 Nov 27-Dec 1, 2023



- Higgs and BSM physics
- BSM Higgs searches
 - Conventional Channels
 - Exotic channels
 - Not included in this talk: h₁₂₅ exotic decay, connection to dark matter,...
- Somplementarity
 - Indirect vs. direct searches
 - Conventional channels and exotic channels





- Daramators in V/(d) nood to come





Light, weakly coupled boson

- \Rightarrow spin 0, a new kind of fundamental particle
- \blacksquare Nothing protects its mass \Rightarrow New physics beyond the SM

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Then What? Still a lot of hard, but fun work to do!

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Then What? Theoretically ...

A Light Higgs is Putz 2 ht and $\varphi \neq \pi_{0}^{2} \varphi = \pi_{0}^{$



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A Light Higgs is Putz $2^{4} \overline{\phi} \overline{\phi} \phi + \frac{\lambda_0 \lambda_0}{6} \overline{\phi} \phi + \frac{\lambda_0 \lambda_0}{6} \overline{\phi} \phi \phi^2,$







Then What?













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friends of friends, squarks,gluinos

partners

Higgsinos



facebook



BSM Higgs Sector

Models with extended Higgs sector: arise in natural theories of EWSB

- Higgs sector of MSSM/NMSSM
- Generic 2HDM
- Little Higgs, twin Higgs ...
- Composite Higgs models ...
- GM model

- neutral Higgs
 - CP-even Higgses
 - CP-odd Higgs
 - mixed CP states
- Charged Higgses: H[±]
- Doubly charged Higgses: H^{±±,....}
- SM+singlet: parametrized by a simple mixing parameter
- 2HDM: covers board class of known models
- Allow for convenient parametrization
- Many features shared by many extended EWSB sectors

BSM Higgs Searches

- Search for extra Higgses
 - Precision Higgs study: couplings of the SM-like Higgs
 - Direct search of extra Higgses: direct evidence for BSM new physics
- Conventional search channel (even for non-SM Higgs):

γγ, ZZ, WW, ττ, bb, μμ, tt

- Charged Higgs is challenge!
- Exotic Higgs decay modes open for BSM Higgs
 - relax the current search bounds
 - ➡ offer new discovery channels
BSM Higgs Searches: Conventional Modes

-

γγ, ZZ, WW, ττ, bb, μμ, tt

Searching for Other Higgses



500 GeV parent particle

S. Su

Neutral Higgses

Search for non-SM neutral Higgs still in conventional channels: γγ, ZZ, WW, ττ, bb, μμ, tt

- suppressed production
 - gluon fusion/bb-associated production: large mass suppression
 - VBF, VH: suppressed coupling
- decay to γγ, ττ, bb, μμ
 - small Br or large BG
 - sub-leading when other decay modes open
- decay to tt
 - challenge to detect
- decay to WW/ZZ

absent or suppressed

$H/A \rightarrow \tau \tau$



ATLAS, PRL 125 (2020) 051801

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ATLAS, ATLAS-C.... _023-035

local 1.7 σ @ 95.4 GeV

arXiv:2311.00130 local (global) 3.1 (1.5) σ @ 19.4 GeV







 $H/A \rightarrow e \mu$

1.00130





3.8 (2.8) sigma local (global) @ 146 GeV

 $H/A \rightarrow e \mu$

1.00130

arXiv:2305.18106



3.8 (2.8) sigma local (global) @ 146 GeV

BSM Higgs Searches: Exotic Modes

New channels open up for non-SM Higgs decay

neutral Higgs	HH type	(bb/тт/WW/ZZ/ɣɣ)(bb/тт/WW/ ZZ/ɣɣ)	h _{SM} → AA, H → h _{SM} h _{SM} , H → AA,
	H⁺H⁻ type	(тv/tb)(тv/tb)	H → H+H-
	WH± type	(lv/qq') (тv/tb)	H/A→ WH±
	ZH type	(II/qq/vv)(tt/bb/ττ/WW/ZZ/γγ)	H → ZA, A→ ZH, Zh
charge Higgs	WH type	(lv/qq')(bb/тт)	tH [±] production, H [±] → WH H [±] → WA

New channels open up for non-SM Higgs decay

neutral Higgs	HH type	(bb/ττ/WW/ZZ/γγ)(bb/ττ/WW/ ZZ/γγ)	$ \begin{array}{l} h_{SM} \rightarrow AA, \\ H \rightarrow h_{SM} h_{SM}, \\ H \rightarrow AA, \end{array} $
	H⁺H⁻ type	(тv/tb)(тv/tb)	H → H+H-
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	ZH type	(II/qq/vv)(tt/bb/ττ/WW/ZZ/γγ)	H → ZA, A→ ZH, Zh
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	H⁺H⁻ type	(TV/tb)(TV/tb)		H → H+H-
	WH [±] type	(lv/qq') (τv/tb)		H/A→ WH±
	ZH type	(II/qq/vv)(tt/bb/ττ/WW/ZZ/γγ)	($H \rightarrow ZA, \\ A \rightarrow ZH, Zh$
charge Higgs	WH type	(lv/qq')(bb/тт)	(tH [±] production, H [±] → WH H [±] → WA

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ATLAS, EPJC 81 (2021) 396





m_H [GeV]

m_A [GeV]







²⁴

Charged Higgs: challenge!

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Charged Higgs is challenge for discovery

m_{H±} < m_t: ttbar production with t→ bH[±], H[±] → τν or cs



m_{H±} > m_t: tbH[±] production (small)
- H[±] → tb, large BG
- H[±] → Tv or cs, suppressed Br.







m_{H⁺} [GeV]

 $m_{Hpm} \sim m_H, m_A, m_h$ • direct searches

H±→cs, тv, tb

• flavor constraints

Charged Higgs Challenge



CMS, CMS-HIG-18-014, 1903,04560

Light $H^{\pm} \rightarrow cs$, Heavy $H^{\pm} \rightarrow tb$



Charged Higgs Challenge

• New decay mode for H^{\pm} : $H^{\pm} \rightarrow AW/HW$



200 GeV daughter particle

Η± Ligh









2.6 sigma local excess at 27 GeV.

ATLAS, 2304.14247

 $+ H^{\pm} \rightarrow$ Ligh



ATLAS, 2304.14247

g

SOGO

ğ

g

 H^{\pm}

q

Complementarity











Constraints

Neutral scalars

• theoretical constraints

vacuum stability/Unitarity/perturbativity/... $m_{12}^2 = m_{H^2} \sin\beta \cos\beta$

- Precision Higgs measurements (μ , Γ_h)
- Conventional channels: γγ, ZZ, WW, ττ, μμ, bb, tt
- Exotic decay into h: $A \rightarrow hZ$, $H \rightarrow hh$
- Exotic decay of hSM: $h \rightarrow AA$, $h \rightarrow HH$
- Exotic decay of BSM sector: $A \rightarrow HZ$, $H \rightarrow AZ$
- LEP searches: $e^+e^- \rightarrow Z \rightarrow HA$, $e^+e^- \rightarrow Z \rightarrow ZH$
- SM non-resonant processes: ttZ, tttt

Additional constraints arise for <u>charged scalars</u>










2HDM, LHC/FCC fit

















2HDM Neutral Scalars @ LHC



Conclusion

- BSM with extended Higgs sector: BSM Higgses
- Current search for BSM neutral Higgses: conventional channel
- Current search for charged Higgs: challenge
- Exotic Higgs decay modes open:

dominant, relax existing limits, new discovery channel

- \Rightarrow Higgs \rightarrow light Higgs + gauge boson
- ➡ Higgs → two light Higgses
- Exotic decay complementary to
 - ➡ Higgs precision: insensitive to alignment limit
 - conventional channels
 - \Rightarrow A \rightarrow Zh, H \rightarrow hh, H \rightarrow VV: vanish under the alignment limit