BSM Higgs in ATLAS and CMS

at LHC Day in Split, 2024

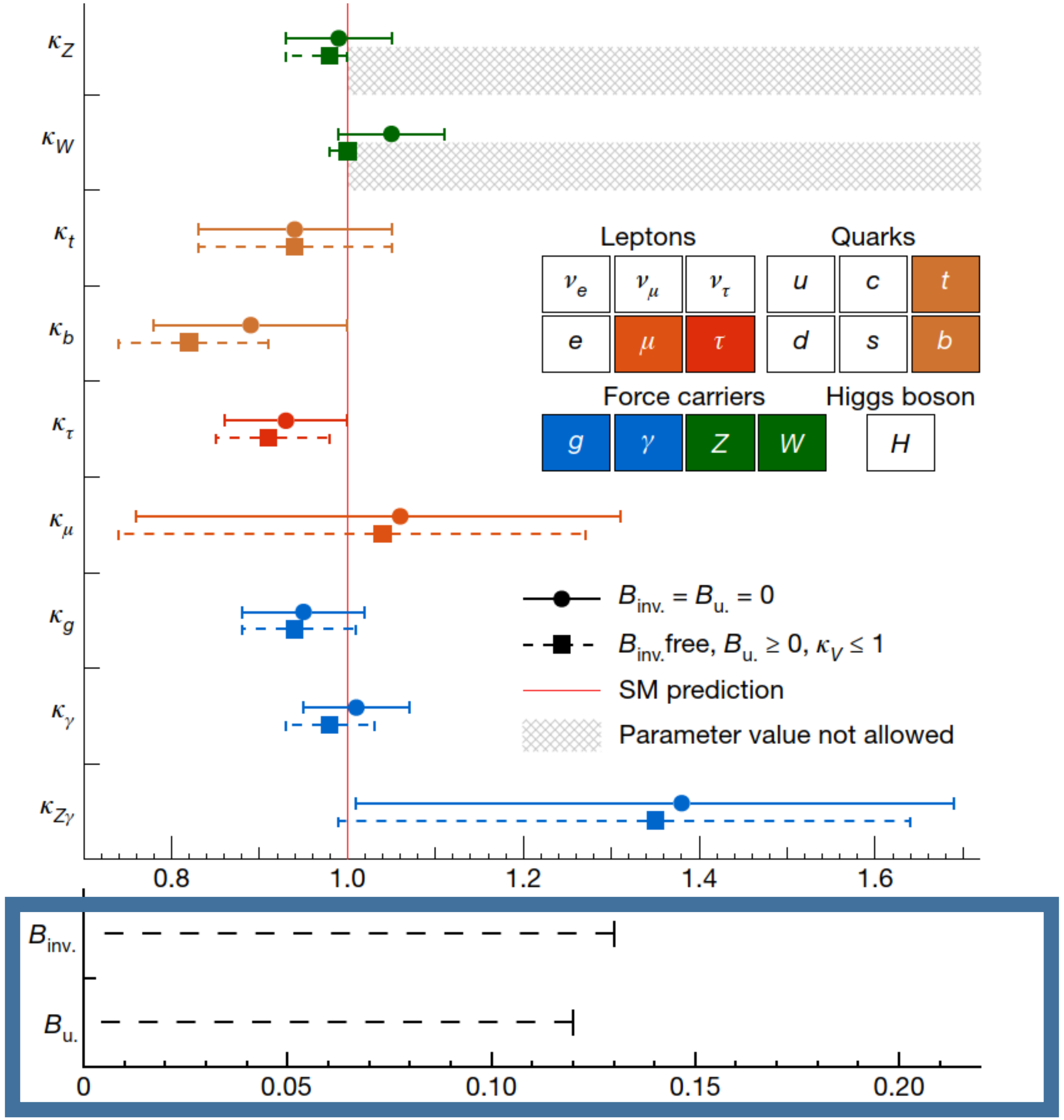
A. Nikitenko,

JINR Dubna, Russia; also Imperial College, London, UK

BSM physics with Higgs bosons

- find an additional Higgs bosons
- find non SM decays of h(125)
- precise measurement of h(125) using “SM channels”

Summary of coupling strength modifiers for h_{125}



B_i – probability to decay to invisible mode ($h_{125} \rightarrow$DM DM)
B_u – probability to decay to yet undetected BSM modes
$h_{125} \rightarrow \mu\tau$, hh,… + unknown/undetectable

$$\frac{\Gamma_H}{\Gamma_H^{SM}} = \frac{\kappa_H^2}{1-(BR_{undet.}+BR_{inv.})}$$

Room for New Physics with non SM decays of h_{125}:

$B_u < 0.12$ (expected 0.21)
$B_{inv} < 0.13$ (expected 0.08)
at 95 % CL

Nature 607, 52-59, (2022)

Additional Higgs bosons

in MSSM

$h, H, A, H^{\pm}$ ($m_h < m_H$)

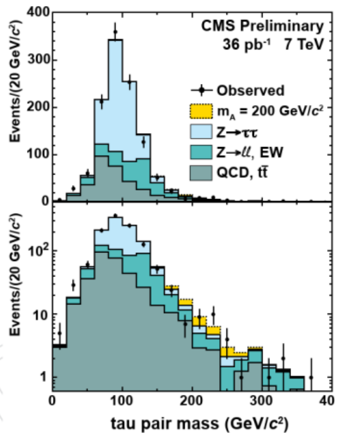
most probably h (not H) is discovered h_{125}

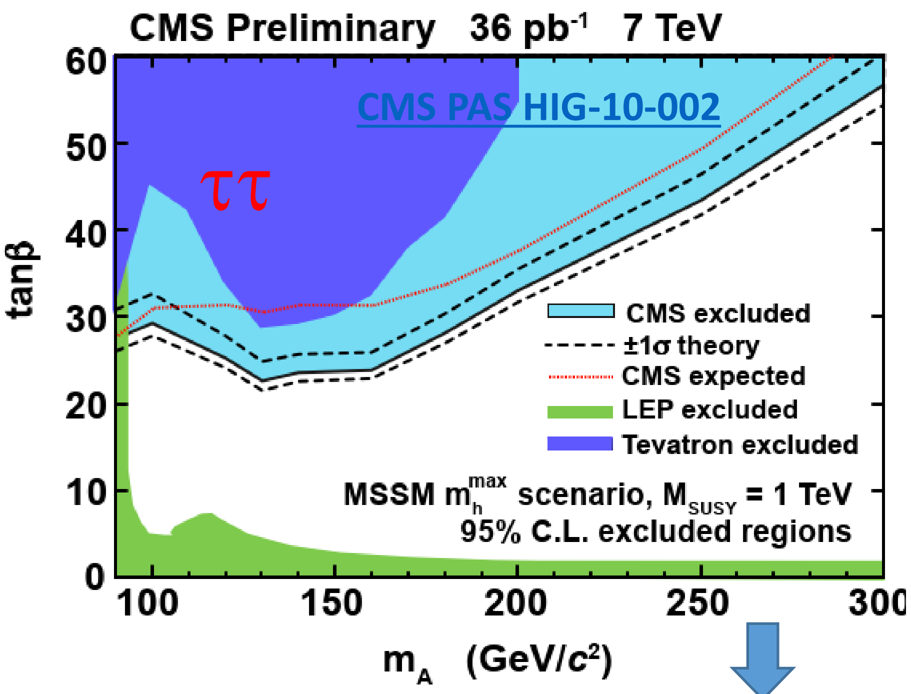
At tree level Higgs sector of MSSM is determined by only two parameters:

M_A and $\tan(\beta)$

$1 < \tan(\beta) = v_2/v_1 = (v \sin(\beta)) / (v \cos(\beta)) < 60$

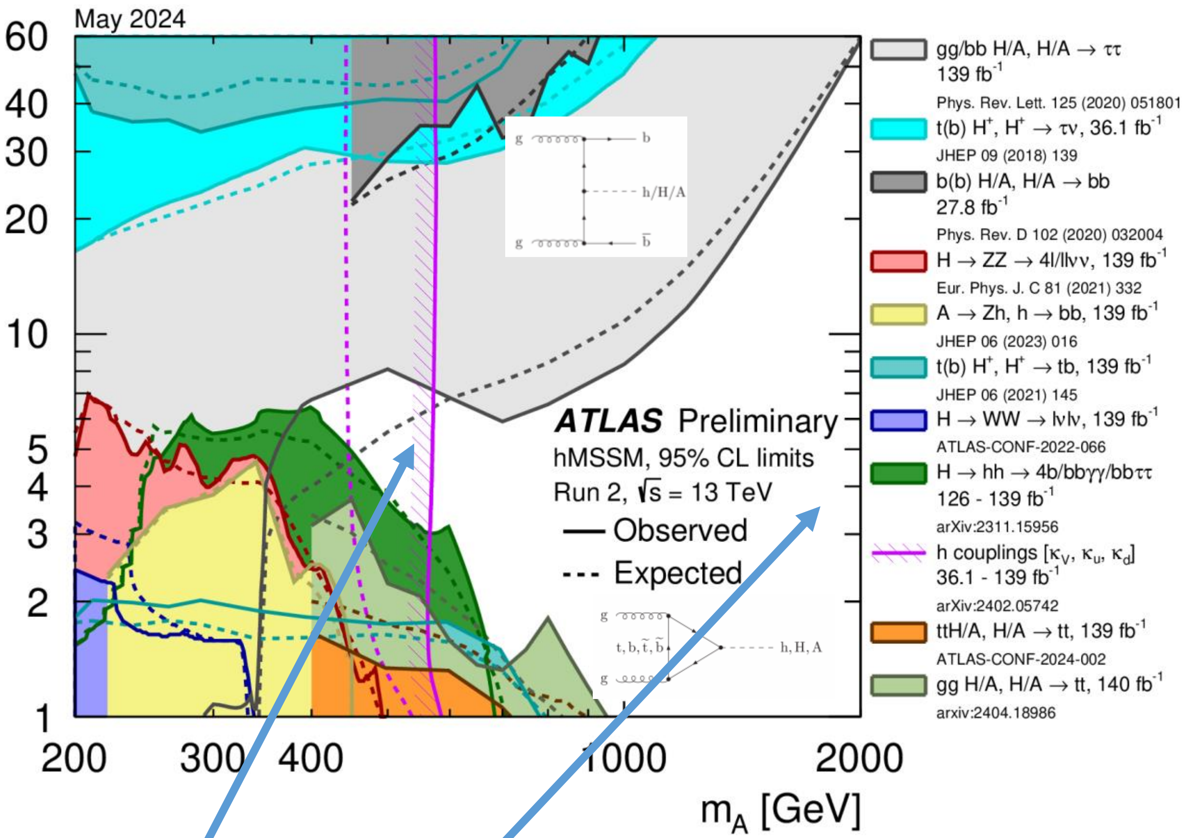
From 2010 to 2024 in MSSM Higgs searches

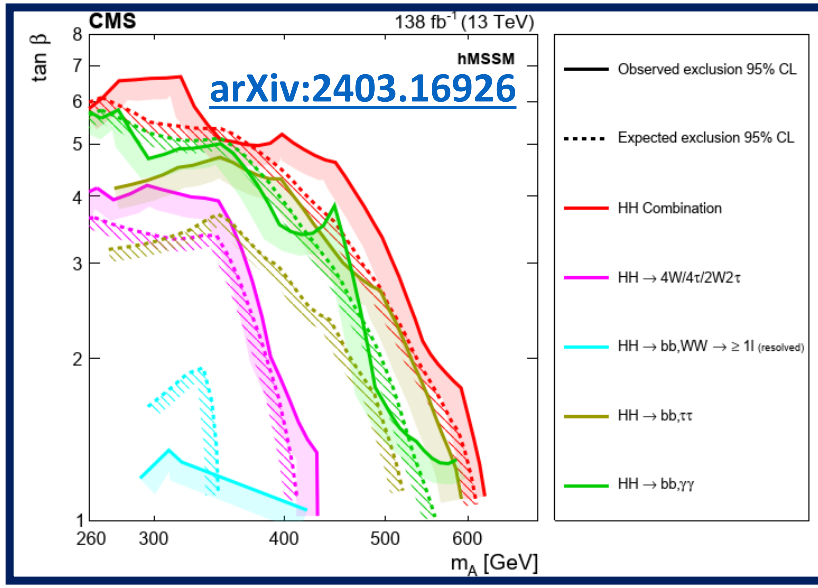




CMS PAS HIG-10-002

$\tau\tau$





arXiv:2403.16926

No interference with non resonant hh was taken into account in a signal model

H/A->χχ still to be done

(even in hMSSM:arXiv:2311.04033)

from h_{125} measurements and assuming $h==h_{125}$

Additional Higgs bosons

in 2HDM

$h,H,A,H^{\pm}$ ($m_h < m_H$), h or H is discovered

Free parameters of 2HDM:

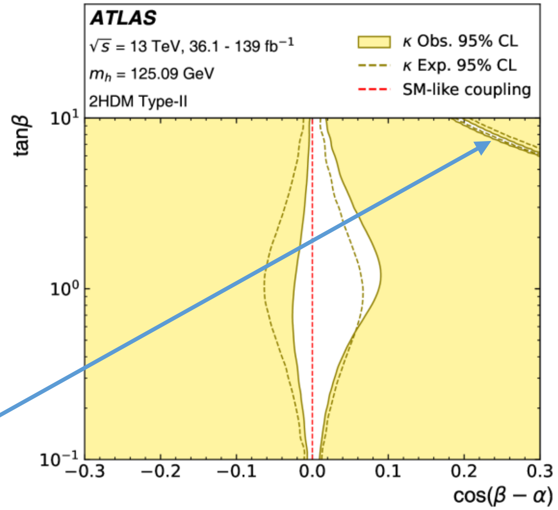
m_h, m_H, m_A, m_{H+}, α, $\tan\beta$, m_{12} (soft Z_2 symmetry (Φ_1->Φ_1, Φ_2->-Φ_2) breaking parameter)

m_{12} != 0 to have a new mass scale. This allows the model to have a decoupling limit. When m_{12} goes to infinity we recover the SM m_{12} is often taken as in MSSM: $m_A^2=m_{12}^2/(\sin\beta\cos\beta)-\lambda_5 v^2$ with $\lambda_5=0$ as in MSSM

arXiv:2402.05742

	Type I and Type II	Type I		Type II	
Higgs	C_V	C_U	C_D	C_U	C_D
h	$\sin(\beta-\alpha)$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$
H	$\cos(\beta-\alpha)$	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$
A	0	$\cot\beta$	$-\cot\beta$	$\cot\beta$	$\tan\beta$

$c_{\beta-\alpha}$	$s_{\beta-\alpha}$
HW^+W^-	hW^+W^-
HZZ	hZZ
ZAh	ZAH
$W^{\pm}H^{\mp}h$	$W^{\pm}H^{\mp}H$



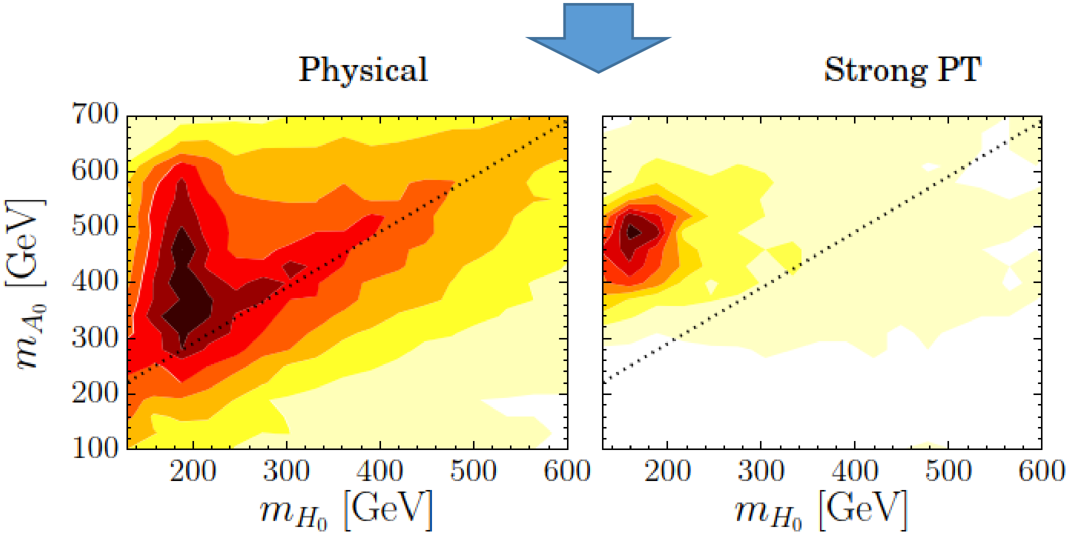
wrong sign Yukawa coupling (C_D≈-1, C_V=C_U ≈ 1) scenario, $\sin(\beta+\alpha)$≈1, can be excluded or confirmed with h→γγ at HL-LHC,3 ab^{-1}

Anaysis which does not make a sence in MSSM but does in 2HDM: **A(H)→ZH(A), h=h_{125}**

- **contrary to MSSM**
  - **A-boson can have a small mass**
  - **m_A !≈ m_H at large masses**
- **A→ZH decay ($m_A > m_H$) is the signature of a strongly first order electroweak phase transition (EWPT) in 2HDMs, as needed for Electroweak Baryogenesis** G. C. Dorsch, S. Huber, K. Mimasu and J. M. No, arXiv:1405.5537

See also:

Strong First Order Electroweak Phase Transition in the CP-Conserving 2HDM Revisited, M. Meuhlleitner at al, arXiv:1612.04086



2HDM Type I

Promising fast sim. result for llbb final state, m_A=400 GeV m_H=180 GeV. σ=5 at L=40fb^{-1} at 14 TeV LHC

Electroweak baryogenesis

Sakharov Conditions: A.D. Sakharov, ZhETF Pis'ma 5 (1967) 32 (JETP Letters 5 (1967) 24)

- B number violation (sphaleron processes).
- C- and CP-violation.
- Out-of-equilibrium

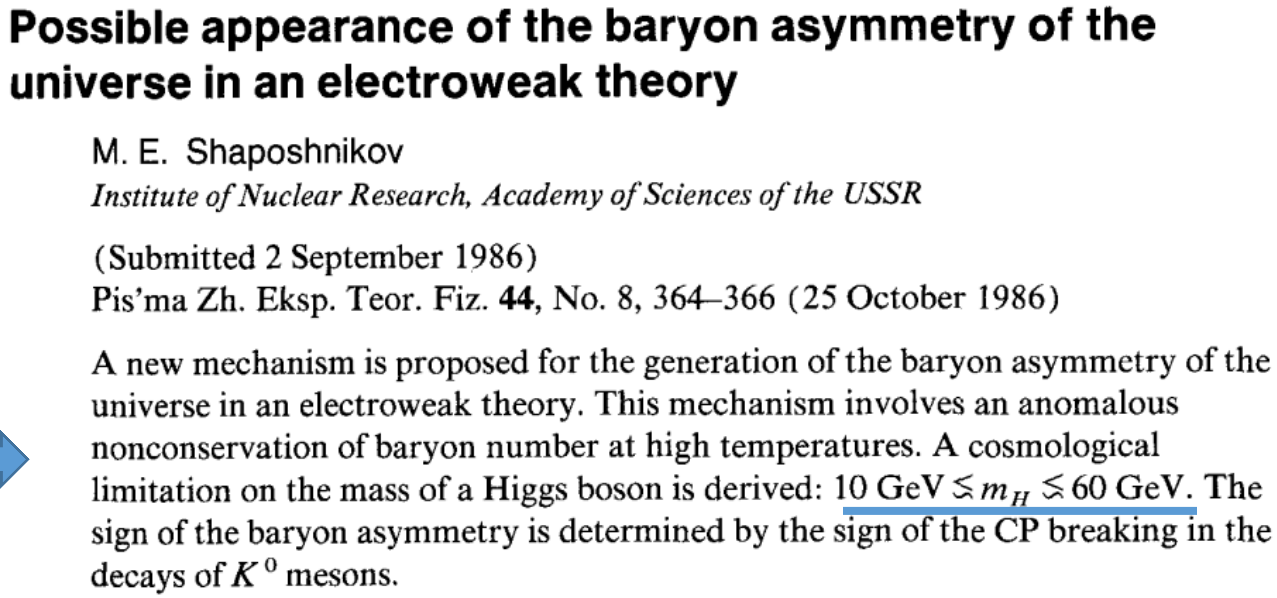
The EW phase transition must be a first order

create bubbles in early Universe with <Φ>‡0 and get system jumping from false to truth vev minimim

$$\xi_c \equiv \frac{\langle \Phi_c \rangle}{T_c} \geq 1$$

M. Quiros, Helv. Phys. Acta 67 (1994) 451.
G.D. Moore, Phys. Rev. D 59 (1999) 014503.

In SM m_H should be less than 125 GeV in order to get barion asymmetry in universe due to EWPT of the first order.

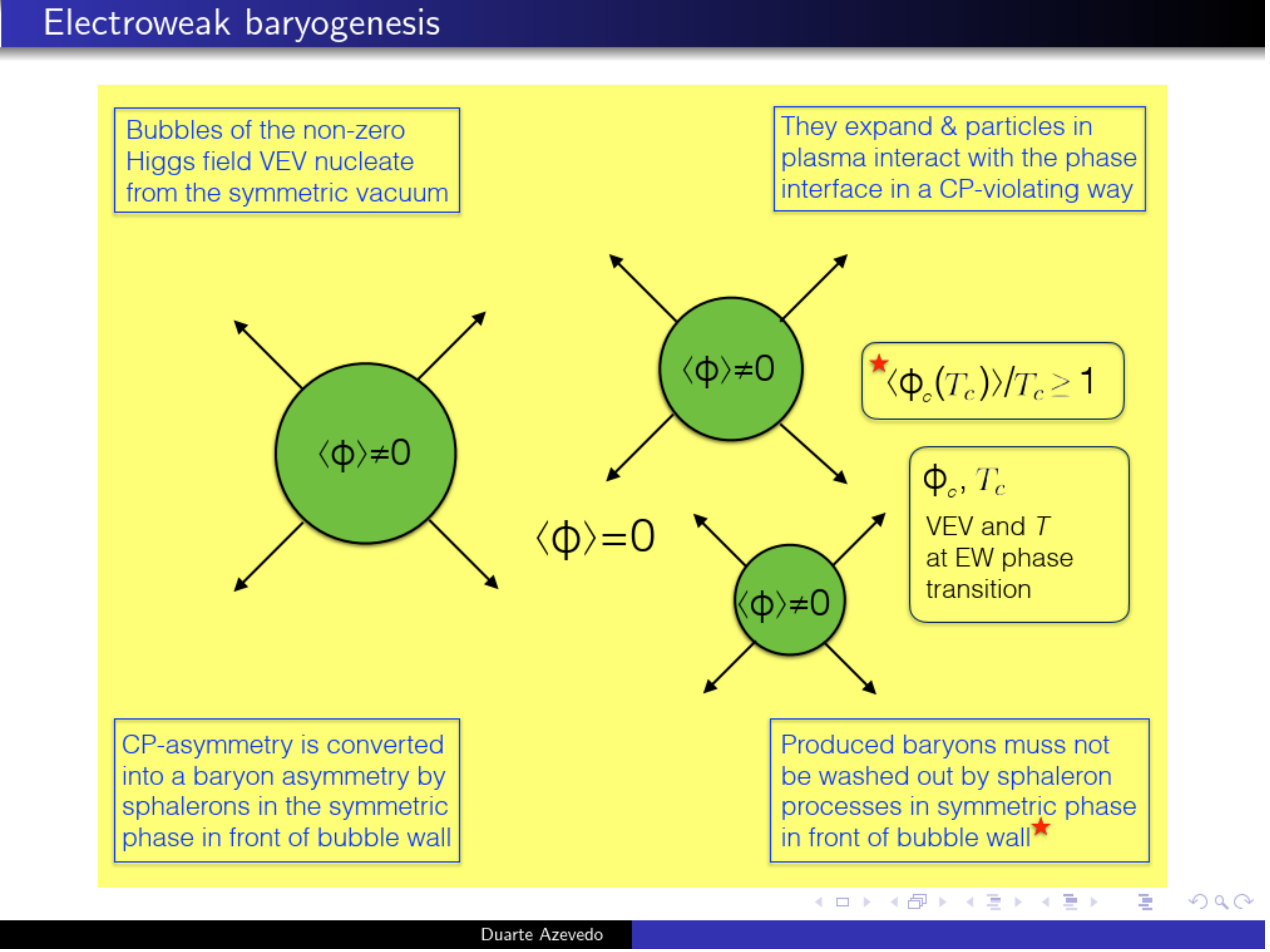


Possible appearance of the baryon asymmetry of the universe in an electroweak theory

M. E. Shaposhnikov
Institute of Nuclear Research, Academy of Sciences of the USSR

(Submitted 2 September 1986)
Pis'ma Zh. Eksp. Teor. Fiz. **44**, No. 8, 364–366 (25 October 1986)

A new mechanism is proposed for the generation of the baryon asymmetry of the universe in an electroweak theory. This mechanism involves an anomalous nonconservation of baryon number at high temperatures. A cosmological limitation on the mass of a Higgs boson is derived: $10\ \text{GeV} \lesssim m_H \lesssim 60\ \text{GeV}$. The sign of the baryon asymmetry is determined by the sign of the CP breaking in the decays of K^0 mesons.



Electroweak baryogenesis

Bubbles of the non-zero Higgs field VEV nucleate from the symmetric vacuum

They expand & particles in plasma interact with the phase interface in a CP-violating way

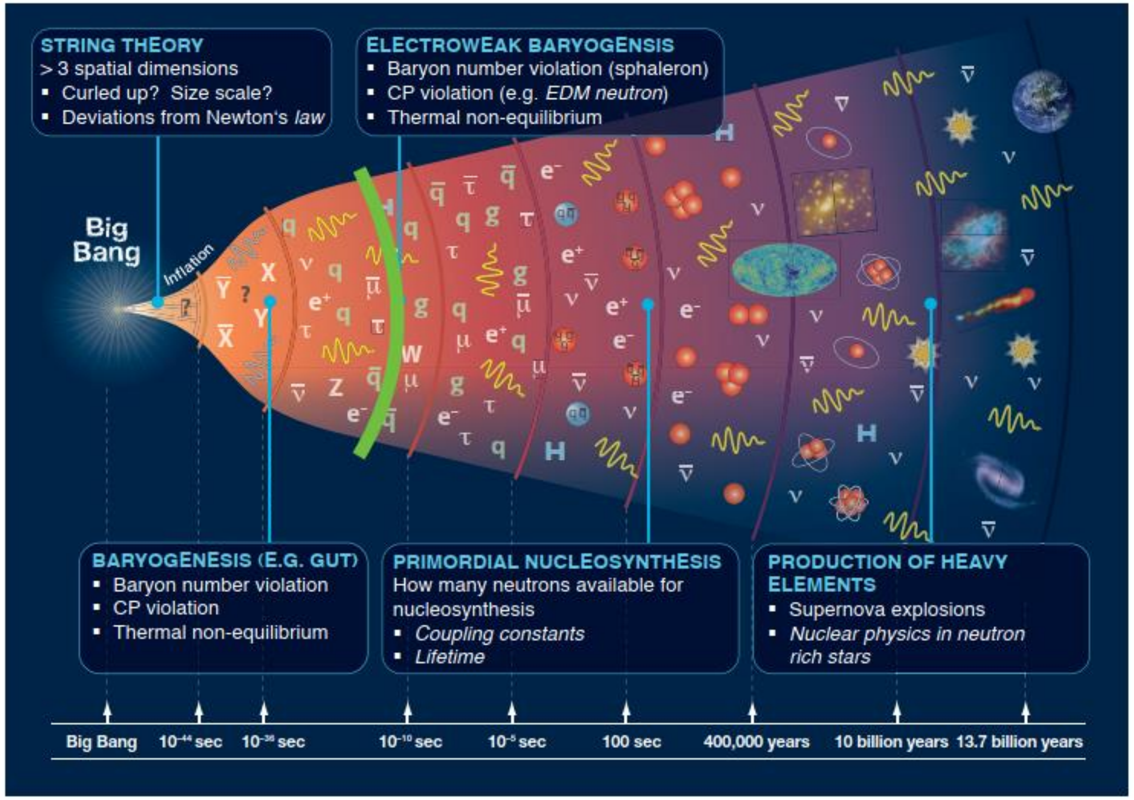
★ $\langle\phi_c(T_c)\rangle/T_c \geq 1$

ϕ_c, T_c
VEV and T
at EW phase transition

CP-asymmetry is converted into a baryon asymmetry by sphalerons in the symmetric phase in front of bubble wall

Produced baryons muss not be washed out by sphaleron processes in symmetric phase in front of bubble wall★

Duarte Azevedo



STRING THEORY
> 3 spatial dimensions
- Curled up? Size scale?
- Deviations from Newton's *law*

ELECTROWEAK BARYOGENSIS
- Baryon number violation (sphaleron)
- CP violation (e.g. *EDM neutron*)
- Thermal non-equilibrium

BARYOGENESIS (E.G. GUT)
- Baryon number violation
- CP violation
- Thermal non-equilibrium

PRIMORDIAL NUCLEOSYNTHESIS
How many neutrons available for nucleosynthesis
- *Coupling constants*
- *Lifetime*

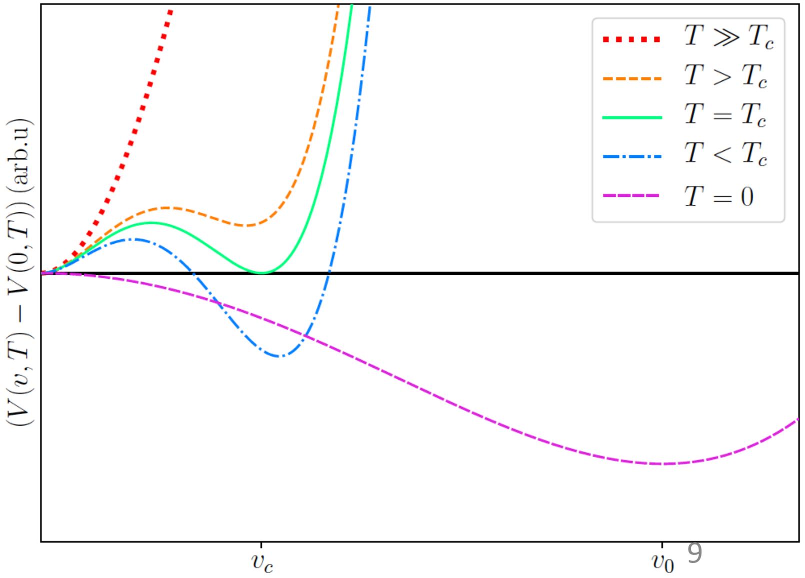
PRODUCTION OF HEAVY ELEMENTS
- Supernova explosions
- *Nuclear physics in neutron rich stars*

Condition for EWPT to be of strong first-order:

$$\xi_c \equiv \frac{v_c}{T_c} \gtrsim 1\,, \tag{14}$$

where $v_c \equiv \sqrt{\omega_1^2+\omega_2^2}|_{T_c}$ is the Higgs VEV at the critical temperature T_c, which is defined when the would-be true vacuum and false vacuum are degenerate.

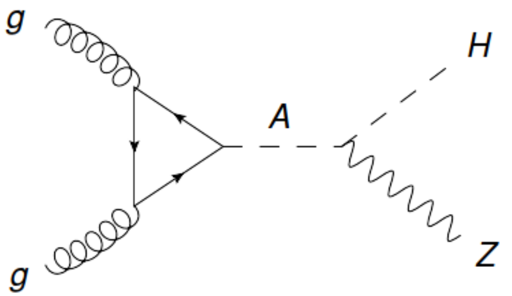
In the SM, we would need $m_H \approx 70$ GeV for $\xi_c \geq 1$ [Kajantie et. al; Jansen]

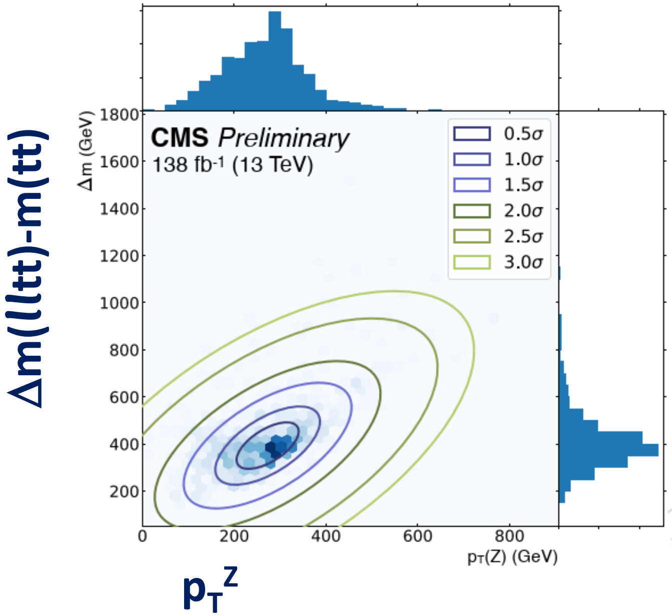


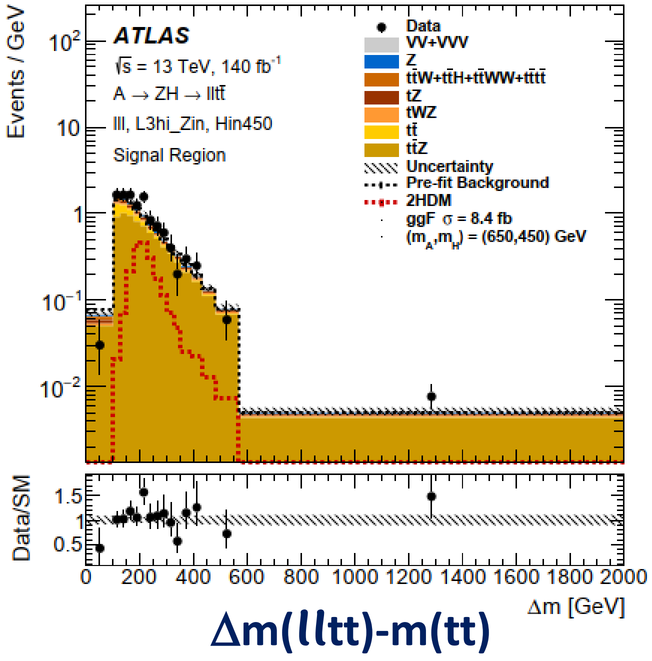
A→ZH→l⁺l⁻ tt analyses and interpretation

fully hadronic tt
CMS-PAS-B2G-23-006

semileptonic tt→lνbjjb
ATLAS:arXiv:2311.04033



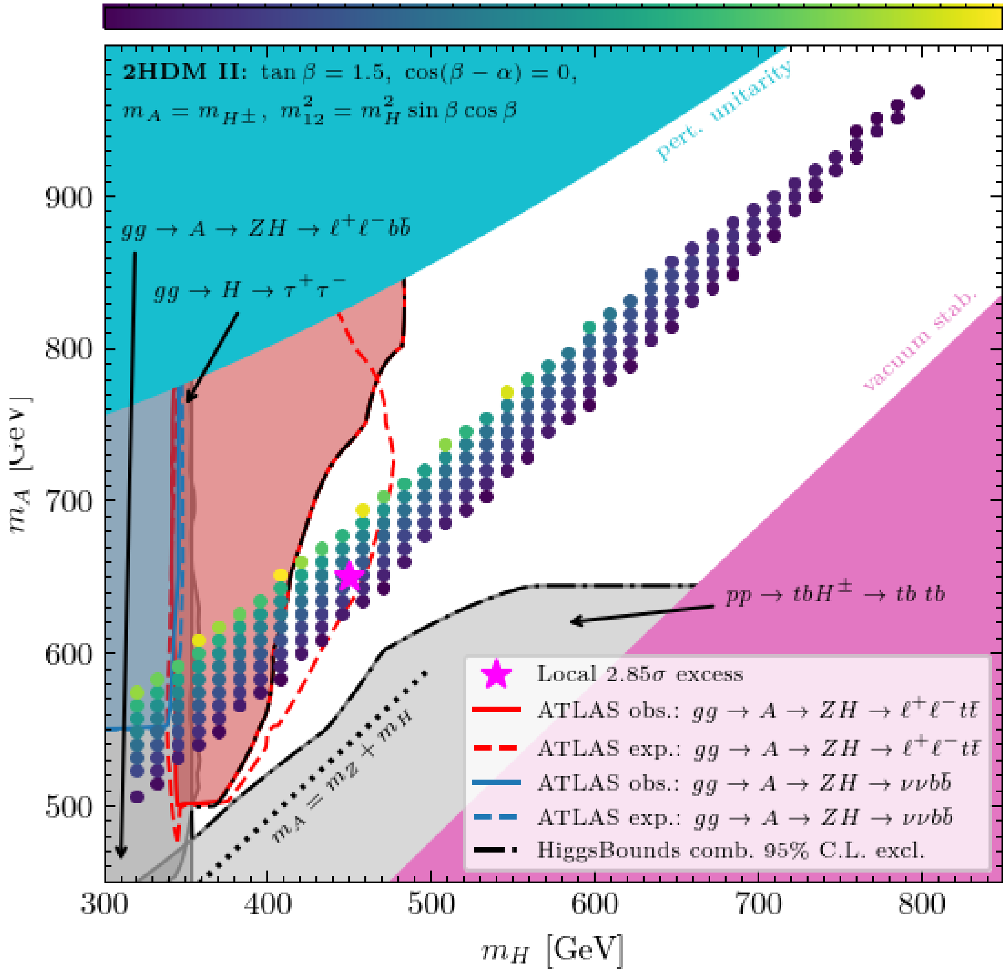




arXiv:2309.17431

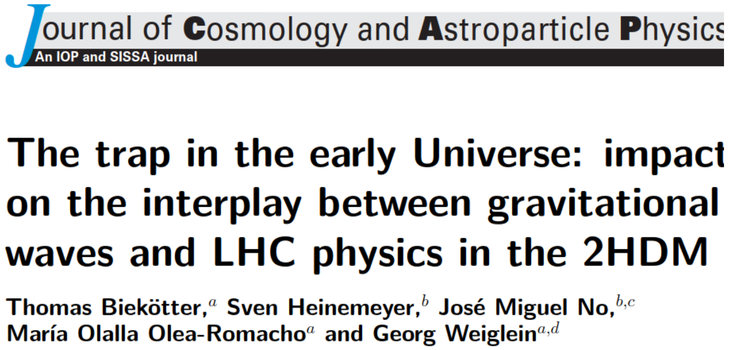
First shot of the smoking gun: probing the electroweak phase transition in the 2HDM with novel searches for $A \to ZH$ in $\ell^+\ell^- t\bar{t}$ and $\nu\nu b\bar{b}$ final states

Thomas Biekötter[1*], Sven Heinemeyer[2†], Jose Miguel No[2,3‡], Kateryna Radchenko[4§], María Olalla Olea Romacho[5¶] and Georg Weiglein[4,6‖]



The largest excess over the SM background prediction, amounting to a local significance of 2.85 σ, is observed in the $\ell^+\ell^- tt$ channel, for the signal hypothesis corresponding to (m_A, m_H) = (650, 450) GeV.

Prospects for A→ZH→l^+l^- tt at HL-LHC

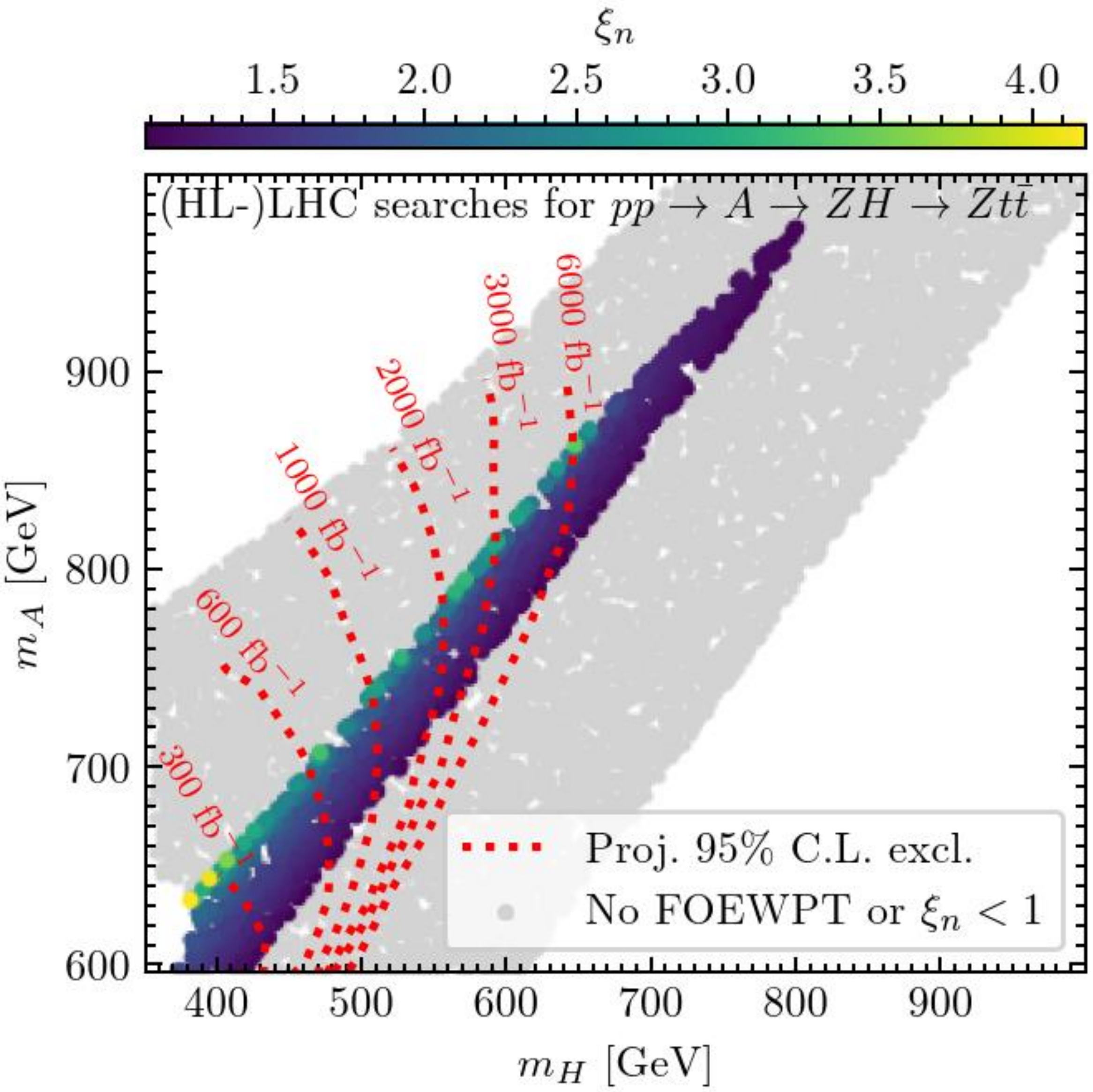


Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

The trap in the early Universe: impact on the interplay between gravitational waves and LHC physics in the 2HDM

Thomas Biekötter,[a] Sven Heinemeyer,[b] José Miguel No,[b,c]
María Olalla Olea-Romacho[a] and Georg Weiglein[a,d]

JCAP 03(2023) 031



qq→Z*→A+h/H→4τ (CMS-PAS-SUS-23-007)

- **motivated by the Type III 2HDM at large tanβ as an explanation of the muon g-2 anomaly (arXiv:2104.10175)**

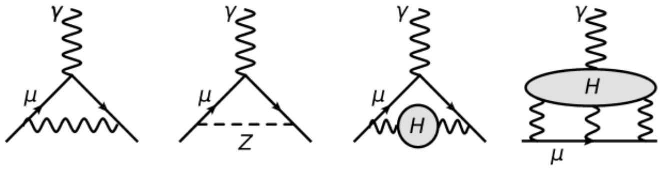
Four possible Z_2 charge assignments that forbid tree-level Higgs-mediated FCNC effects in the 2HDM

	Φ_1	Φ_2	t_R	b_R	τ_R	t_L, b_L, ν_L, e_L
Type I	+	−	−	−	−	+
Type II	+	−	−	+	+	+
Type X (lepton specific)	+	−	−	−	+	+
Type Y (flipped)	+	−	−	+	−	+

Couplings of Higgs particles to quarks and leptons

	u-type	d-type	leptons	ξ_A^u	ξ_A^d
type I	Φ_2	Φ_2	Φ_2	$\cot\beta$	$-\cot\beta$
type II	Φ_2	Φ_1	Φ_1	$\cot\beta$	$\tan\beta$
type III (lepton-specific)	Φ_2	Φ_2	Φ_1	$\cot\beta$	$-\cot\beta$
type IV (flipped)	Φ_2	Φ_1	Φ_2	$\cot\beta$	$\tan\beta$

SM contribution to magnetic momentum of muon



$$\Delta a_\mu^{\rm obs} = a_\mu^{\rm exp} - a_\mu^{\rm SM} = 251(59)\times 10^{-11}$$

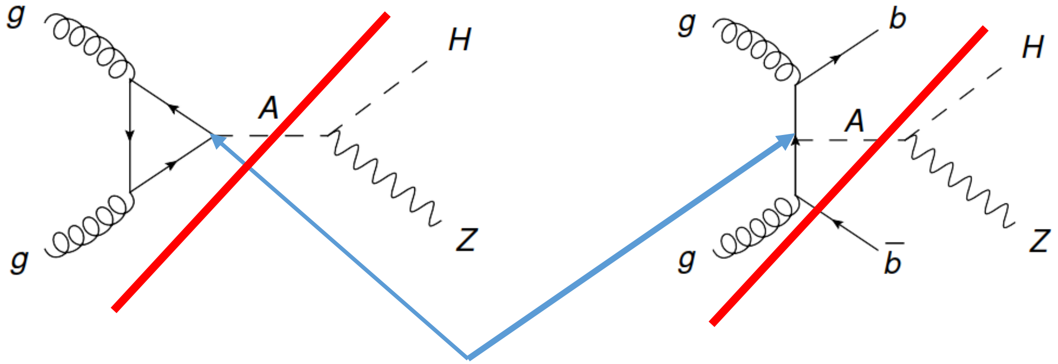
4.2 σ deviation from SM,

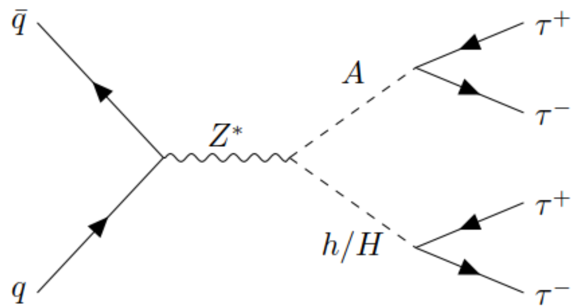
in 2HDM φ^0, A, $H^\pm$ contribute to loop

$$h_{\rm SM} = s_{\beta-\alpha}h + c_{\beta-\alpha}H.$$

normal scenario (NS)	inverted scenario (IS)
$h_{\rm SM}=h,\quad \varphi^0=H$	$h_{\rm SM}=H,\quad \varphi^0=h$
$y_f^{h_{\rm SM}}=1,\quad s_{\beta-\alpha}=1$	$y_f^{h_{\rm SM}}=1,\quad c_{\beta-\alpha}=1$
$y_t^A=-y_t^{\varphi^0}=\frac{1}{t_\beta},\quad y_\ell^A=y_\ell^{\varphi^0}=t_\beta$	$y_t^A=y_t^{\varphi^0}=\frac{1}{t_\beta},\quad y_\ell^A=-y_\ell^{\varphi^0}=t_\beta$

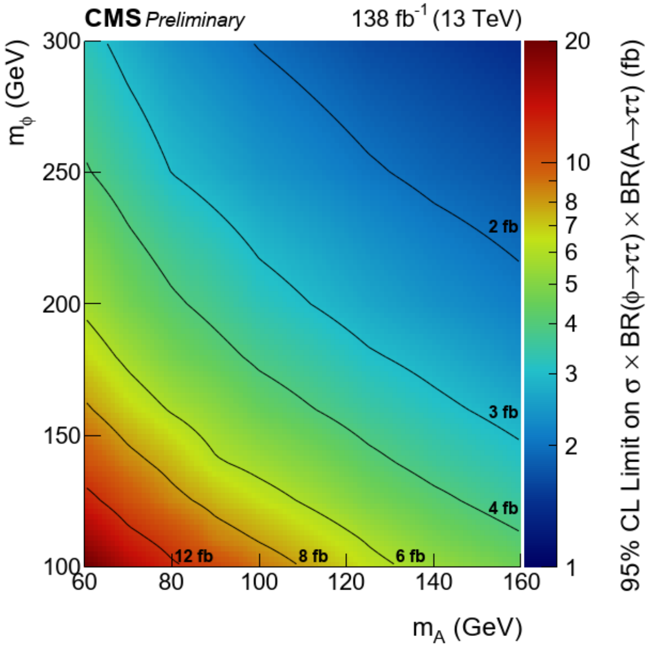
In Type III 2HDM couplings of A to up and down quarks are suppressed by 1/tanβ and couplings of A and φ^0 to leptons are enlarged by tanβ

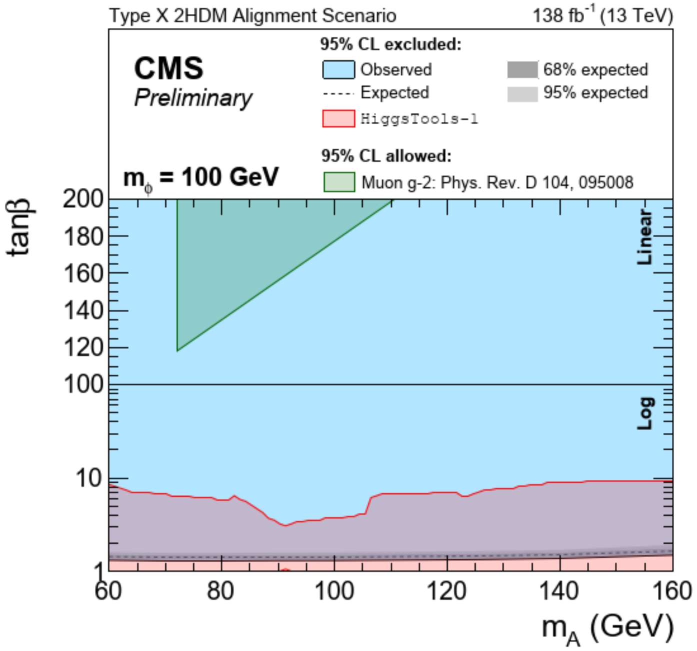


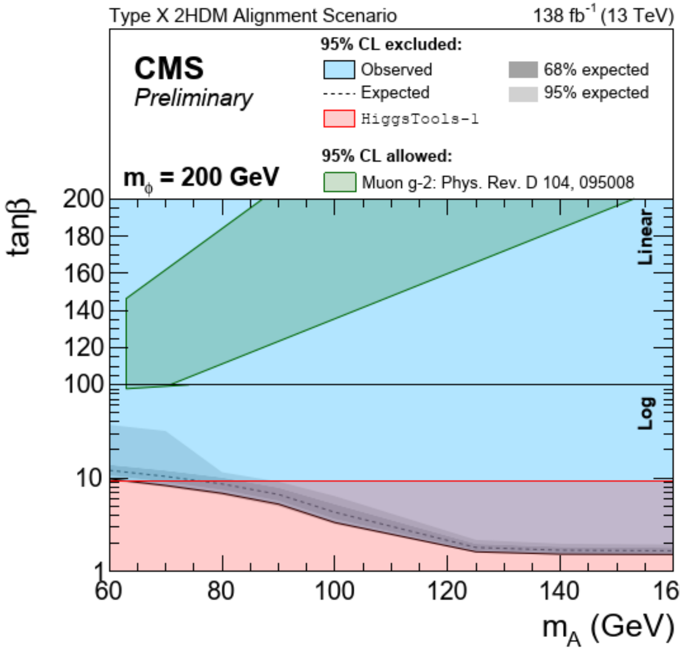


$\xi^{t}_{A} = -\xi^{b}_{A} = 1/\tan\beta$

$\xi_{AZ\varphi} \approx 1,\ \xi^{\tau}_{A} = \xi^{\tau}_{\varphi} = \tan\beta$







- **search excludes the allowed region for the g_{μ}-2 anomaly with a Type III 2HDM**
- **a complete exclusion of the type III 2HDM for many of the mass points scanned.**

Additional Higgs bosons

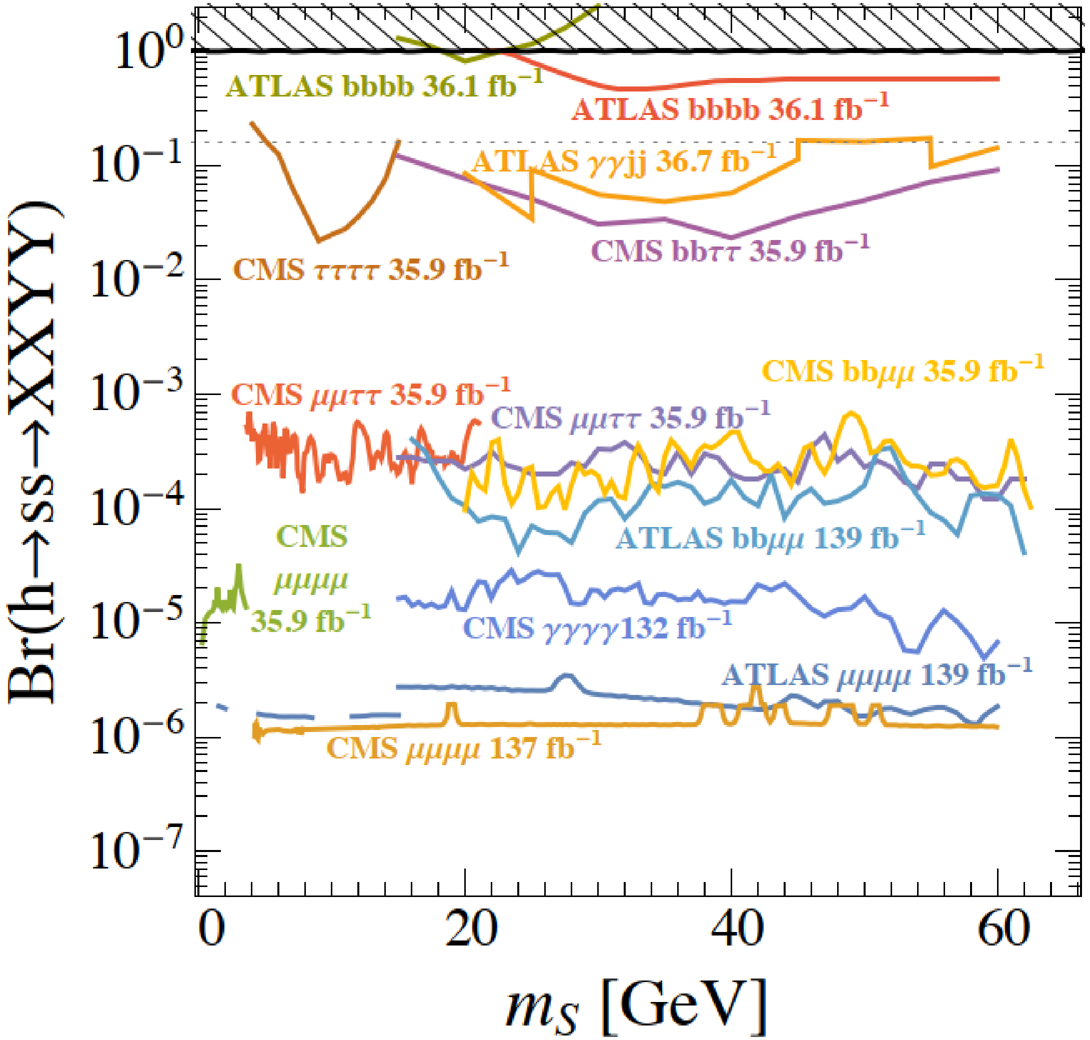
in NMSSM, 2HDM+S

h_1, h_2, h_3, a_1, a_2, $h^\pm$; $m_{h1}<m_{h2}<m_{h3}$, $m_{a1}<m_{a2}$

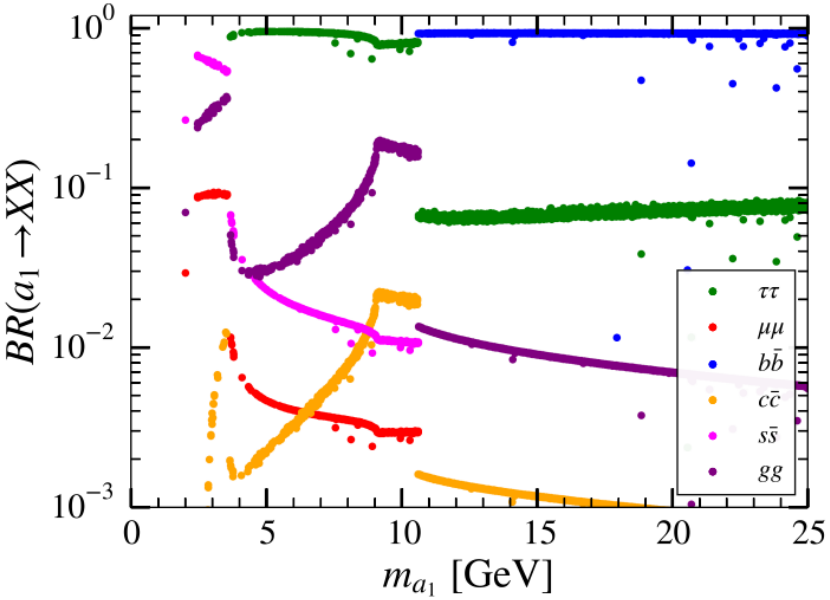
h_1 or h_2 is discovered h_{125}

Latest CMS and ATLAS searches for h_{125}→ss→xxyy on one plot

M. Carena et al arXIv:2203.08206
see also **M. Cepeda at el arXiv:2111.12751**

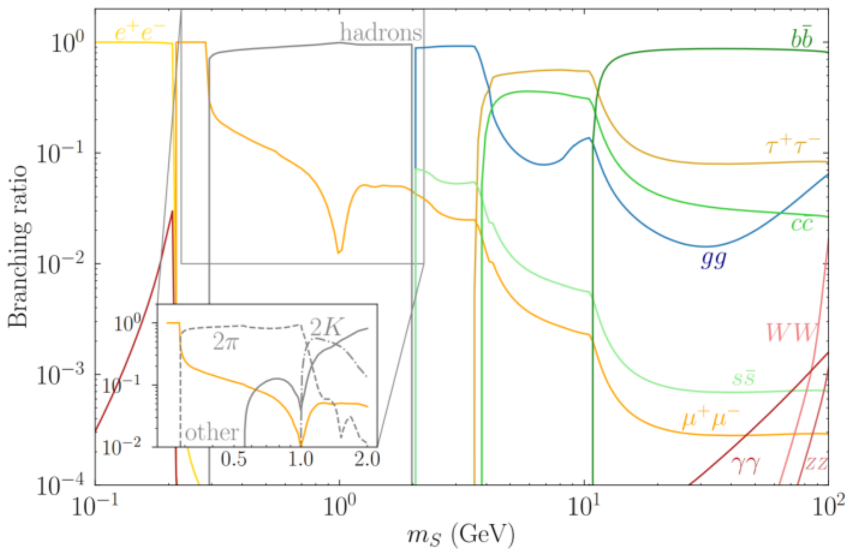


R. Aggleton at al, arXiv:1609.06089 Br's in NMSSM



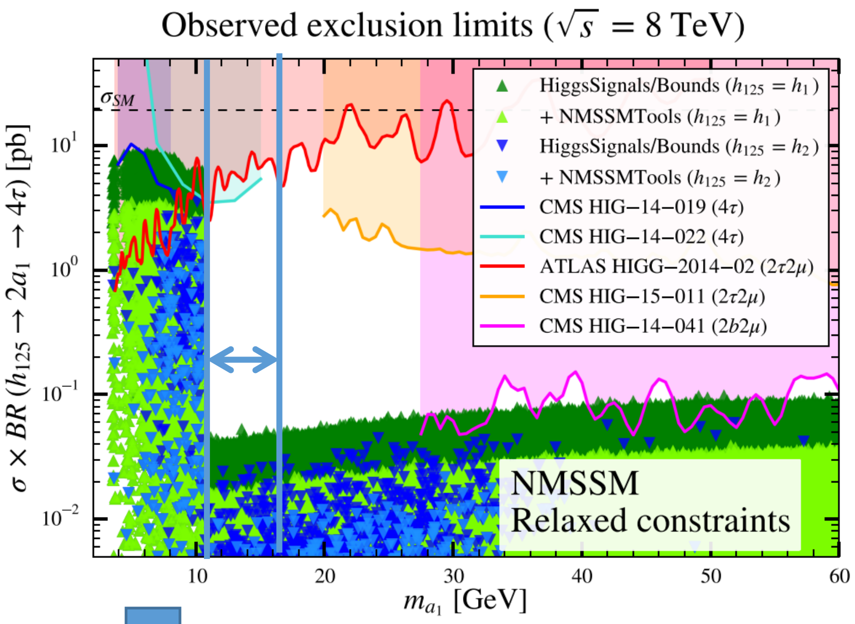
M. Carena et al arXIv:2203.08206

Br's in h125+singlet model



Searches for h_{125} decay to aa(hh) vs models

R. Aggleton at al, arXiv:1609.06089

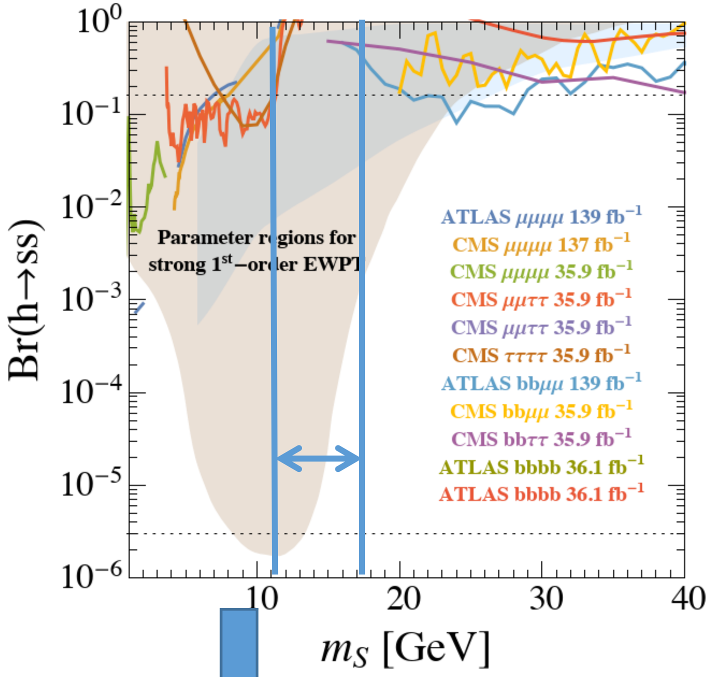


already sensitive to NMSSM

this plot need to be updated for 13 TeV (Run II) analyses. CMS:

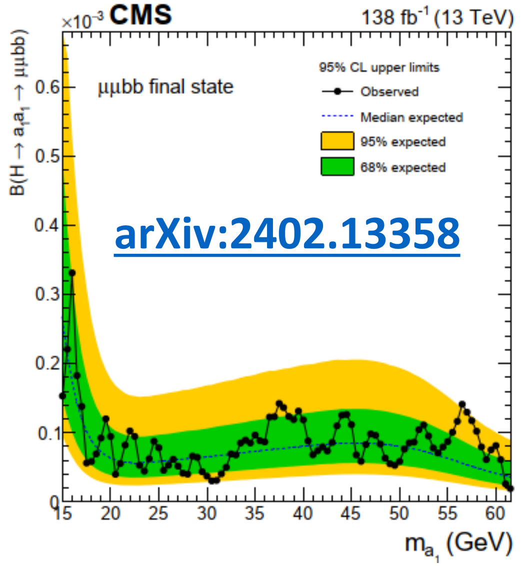
- **μμbb: arXiv:2402.13358 – m_a range is 20-60 GeV**
- **ττbb: arXIv:2402.13358 – m_a range is 15-60 GeV**
- **μμττ: arXiv:2005.08694 – m_a range is 3.6-21 GeV**
- **ττττ : arXiv:1907.07235 – m_a range is 4.0-15 GeV**
- **μμμμ: arXiv:1812.00380 – m_a range is 0.25-8.5 GeV**
- **bbbb: arXiv:2403.10341 – m_a range is 15-60 GeV**

M. Carena et al arXiv:2203.08206



h125+singlet model

Already sensitive to parameter regions for strong 1st order EWPT

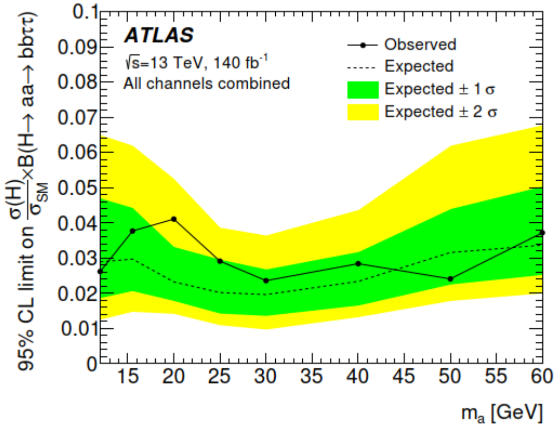


arXiv:2402.13358

mass range, m_a≈10-15 GeV was not accessible. μμ(ττ)bb could do it using a «fat jet», with two b-quarks inside.

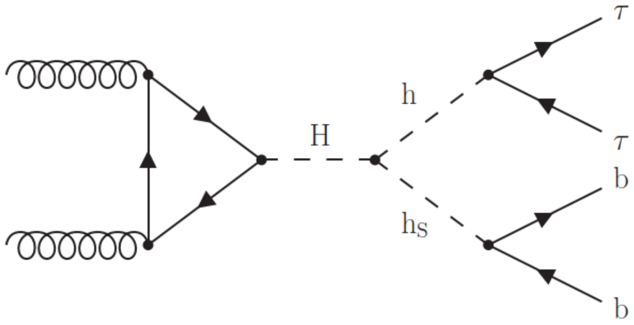
arXiv:2407.01335

ATLAS, DeXTer method



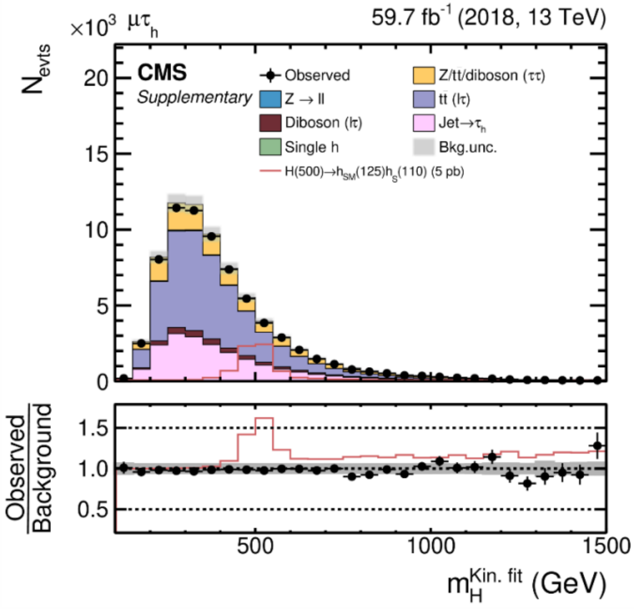
search for $H(A) \rightarrow h_{125} h(a)_S \rightarrow \tau\tau bb$ decay

- **$240 < m_{H(A)} < 3000$ GeV, $60 < m_{hS} < 2800$ GeV**



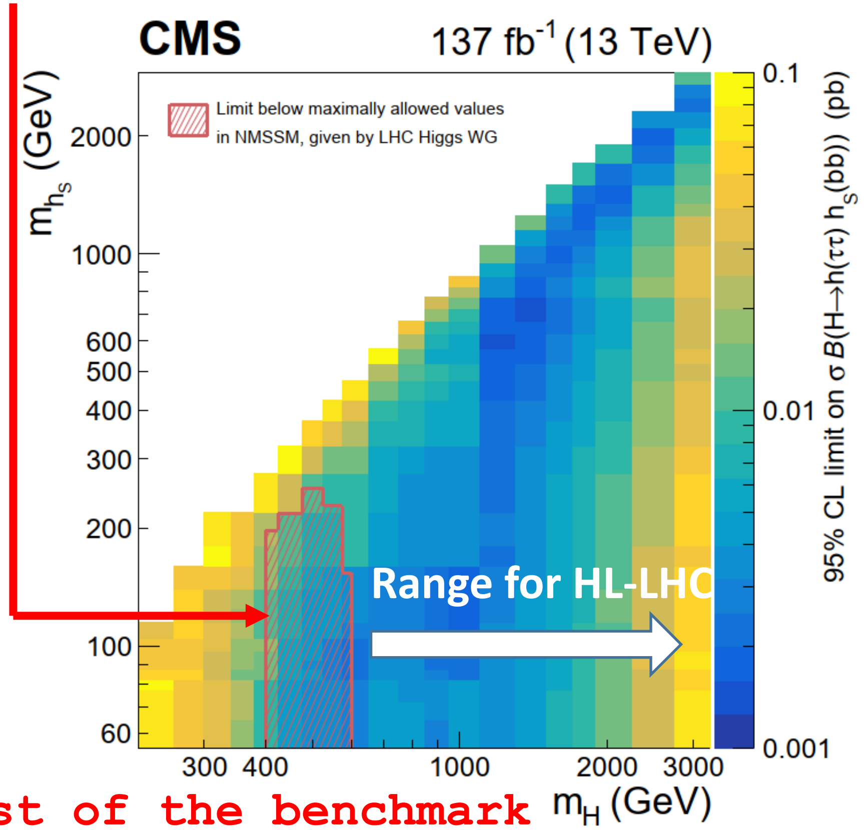
arXiv:2106.10361

already sensitive to NMSSM



$\tau_e\tau_h$, $\tau_\mu\tau_h$, $\tau_h\tau_h$ plus at least two jets (at least one b-tagged) final states are used

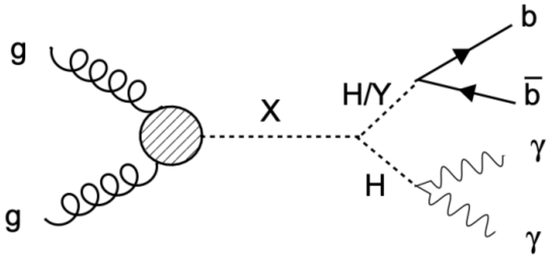
- Multi-class NN used, 4x background classes + 1 signal class
- Output is 5 scores, yi, that sum to 1
- Allocate events to categories based on largest y_i
- In each category fit maximum y_i as discriminating variable



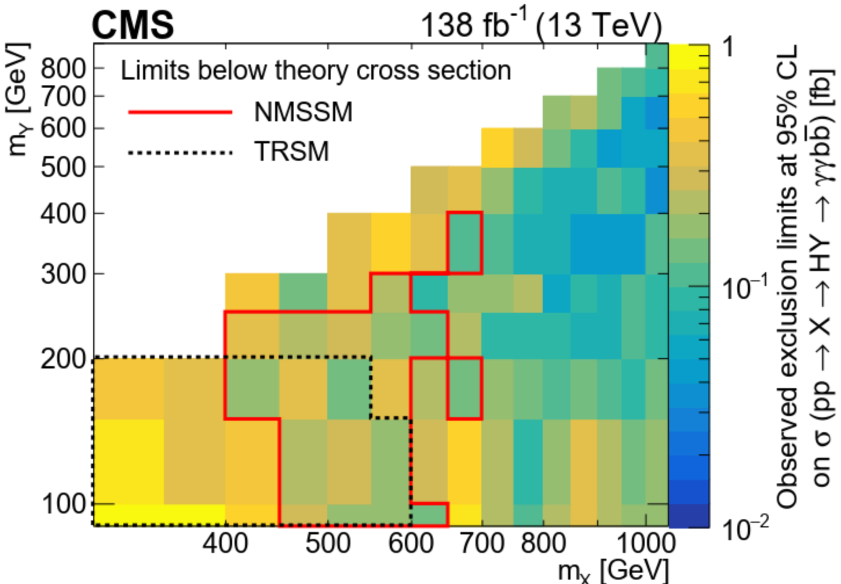
for m_H<400 GeV B physics kills most of the benchmark points (Ulrich Ellwanger, private communication)

search for $H(A) \rightarrow h_{125} h(a)_S \rightarrow \gamma\gamma bb$

arXiv:2310.01643

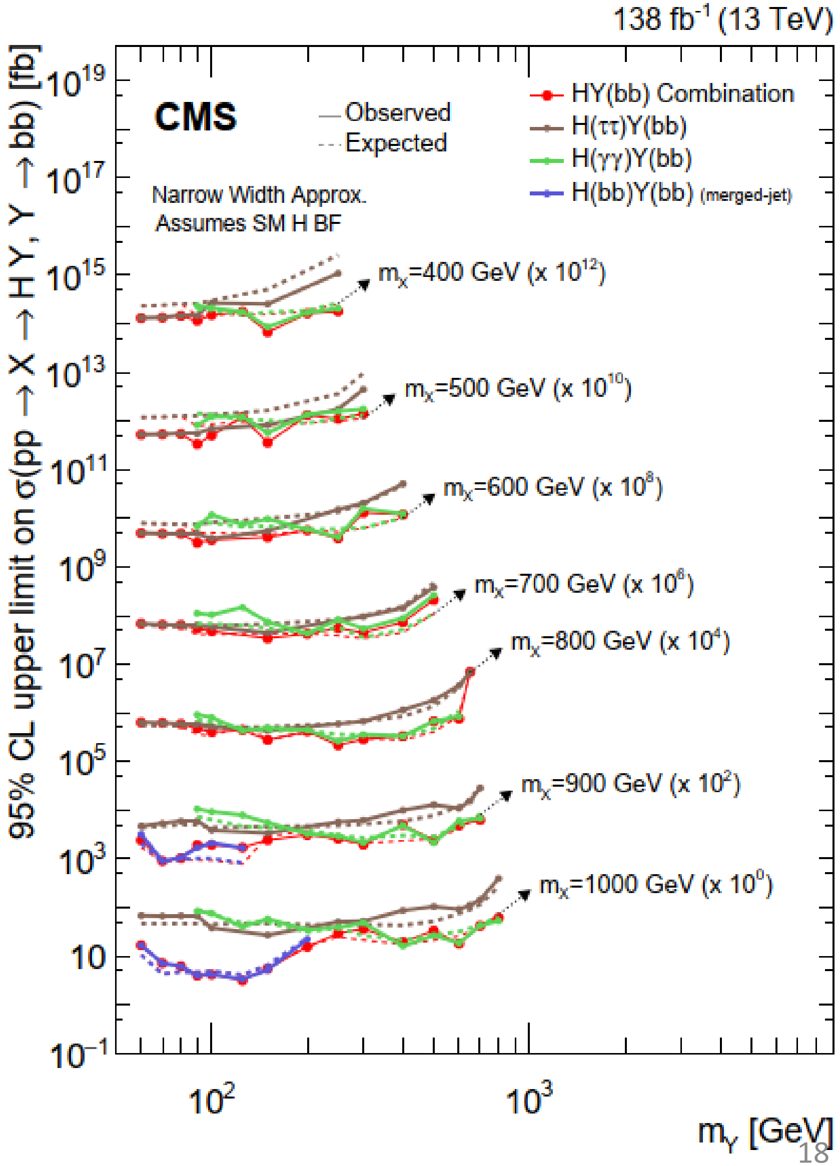


- Largest excess for m_Y=90 GeV, m_X = 650 GeV
    - Local (global) significance of 3.8 (2.8)σ @ m_Y=90 GeV



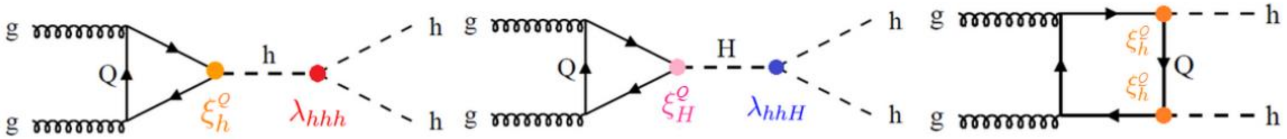
already sensitive to NMSSM

Combination assuming SM BR $h_{125} \rightarrow \gamma\gamma, \tau\tau, bb$ arXIv:2403.16926

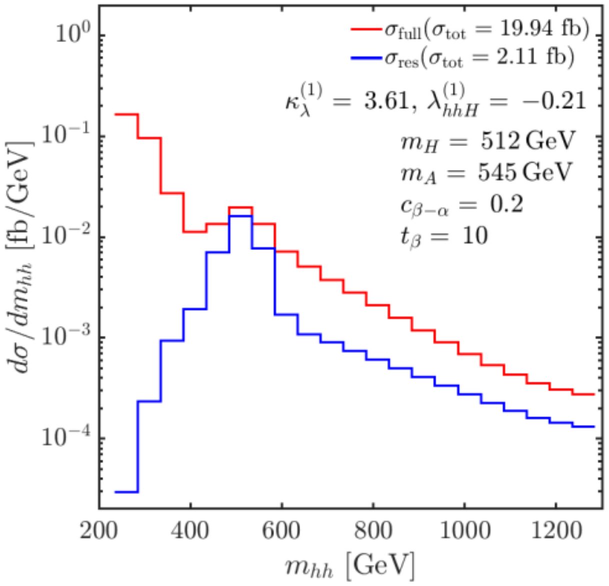


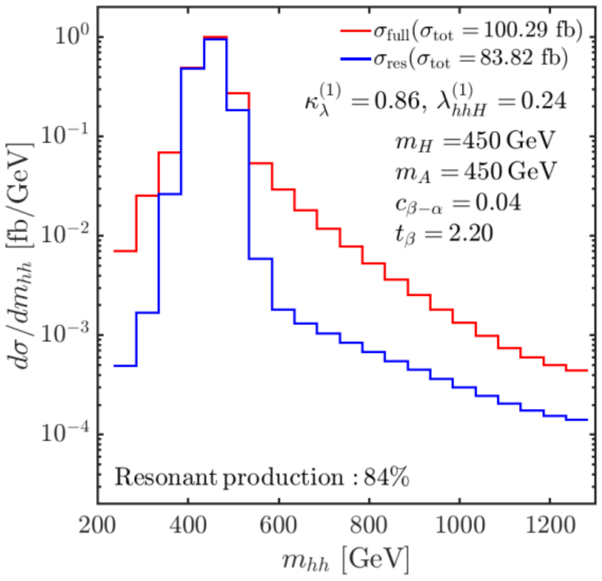
Do not show H→$h_{125}h_{125}$ CMS and ATLAS results since signal model taken in the analyses does not take into account interference with non resonant hh production

- **Importance of taking into account non-resonance production**
  - **S. Heinemeier at al. arXiv:2403.14776**
  - **T. Robens at al. arXiv:2409.06651**



Two BP in 2HDM Type I were claimed to be excluded using resonance model only and neglecting non-resonance contributions





Search for Dark Matter in non-SM h(125) decays: $h_{125} \rightarrow invisible$

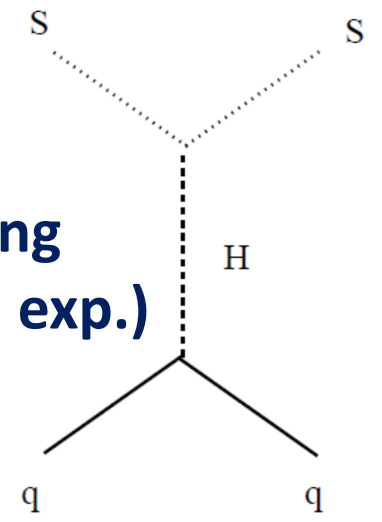
Connection between LHC H->inv. and direct DM searches”

$$\sigma^{SI}_{S-N} = \frac{\lambda^2_{hSS}}{16\pi m_h^4}\frac{m_N^4 f_N^2}{(M_S+m_N)^2} ,$$

$$\sigma^{SI}_{V-N} = \frac{\lambda^2_{hVV}}{16\pi m_h^4}\frac{m_N^4 f_N^2}{(M_V+m_N)^2} ,$$

$$\sigma^{SI}_{f-N} = \frac{\lambda^2_{hff}}{4\pi \Lambda^2 m_h^4}\frac{m_N^4 M_f^2 f_N^2}{(M_f+m_N)^2} ,$$

DM-nucleon scattering (by XENON, LUX,… exp.)



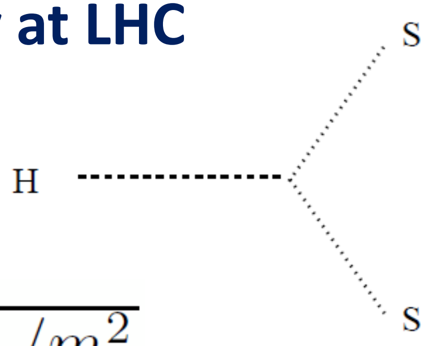
where f_N – Higgs-nucleon coupling

$$\Gamma^{\rm inv}_{h\to SS} = \frac{\lambda^2_{hSS} v^2 \beta_S}{64\pi m_h} ,$$

$$\Gamma^{\rm inv}_{h\to VV} = \frac{\lambda^2_{hVV} v^2 m_h^3 \beta_V}{256\pi M_V^4}\left(1-4\frac{M_V^2}{m_h^2}+12\frac{M_V^4}{m_h^4}\right)$$

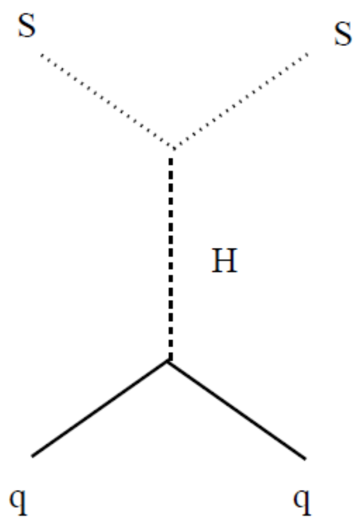
$$\Gamma^{\rm inv}_{h\to \chi\chi} = \frac{\lambda^2_{hff} v^2 m_h \beta_f^3}{32\pi \Lambda^2} , \quad \text{where } \beta_X = \sqrt{1-4M_X^2/m_h^2}$$

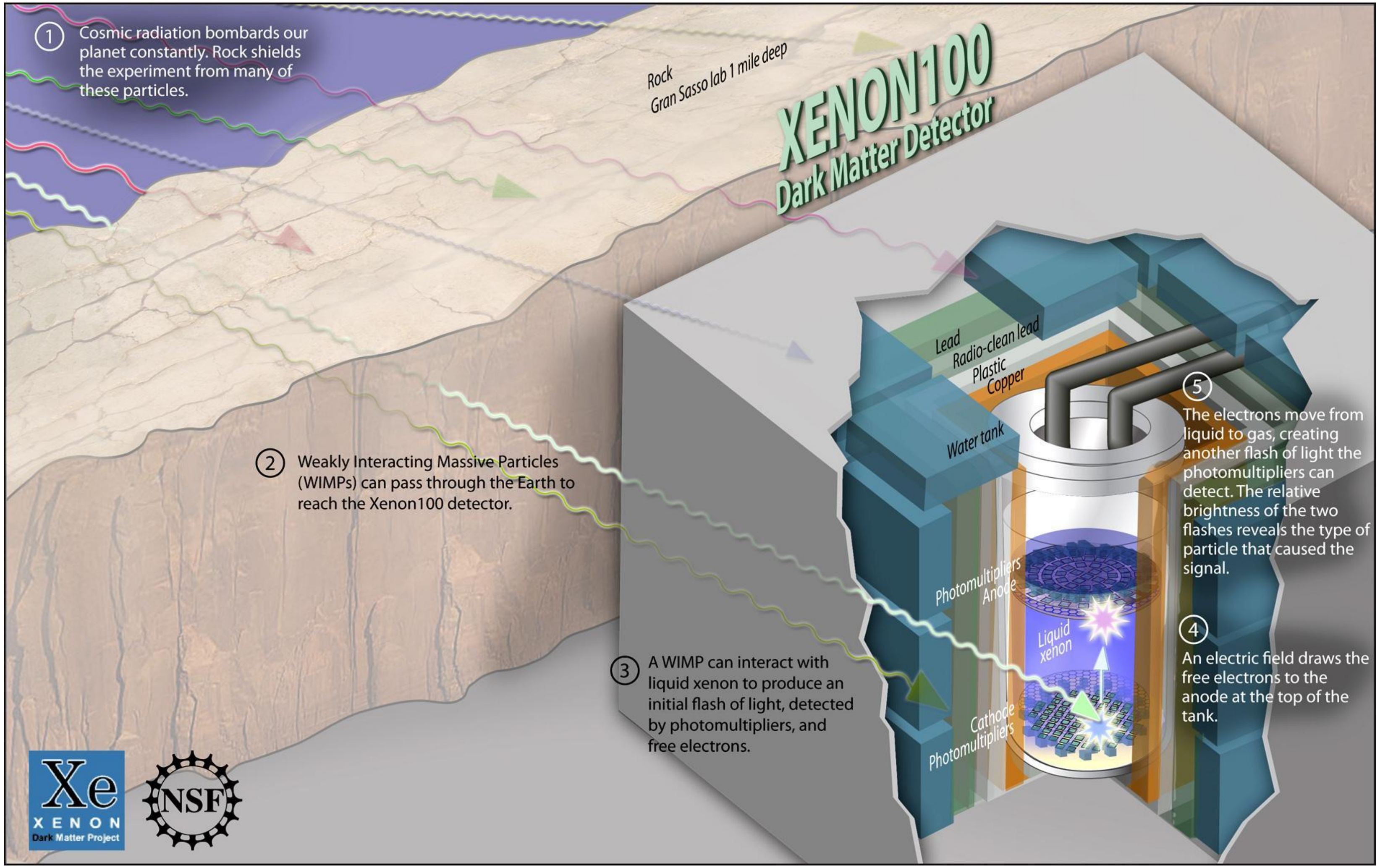
H->invisible decay at LHC



A. Djouadi et. al. arXiv:1112.3299

DM (WIMP) detection on Earth with XENON experiment





① Cosmic radiation bombards our planet constantly. Rock shields the experiment from many of these particles.

② Weakly Interacting Massive Particles (WIMPs) can pass through the Earth to reach the Xenon100 detector.

③ A WIMP can interact with liquid xenon to produce an initial flash of light, detected by photomultipliers, and free electrons.

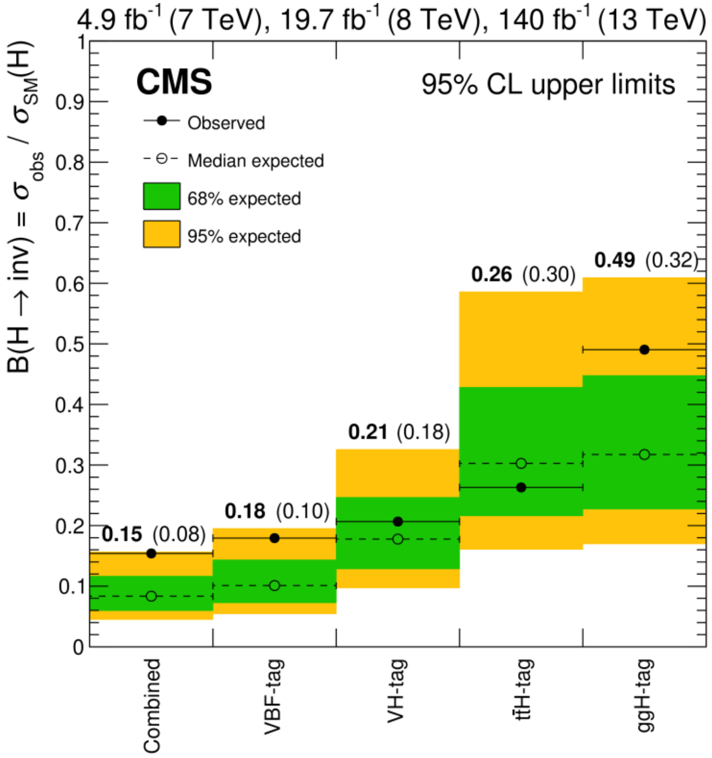
④ An electric field draws the free electrons to the anode at the top of the tank.

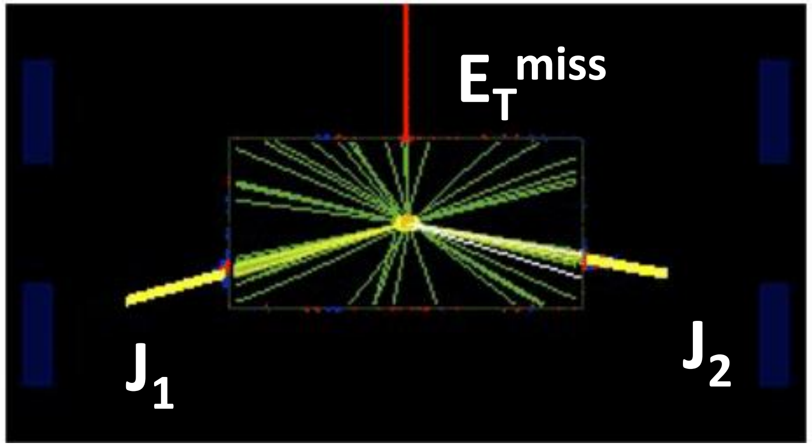
⑤ The electrons move from liquid to gas, creating another flash of light the photomultipliers can detect. The relative brightness of the two flashes reveals the type of particle that caused the signal.

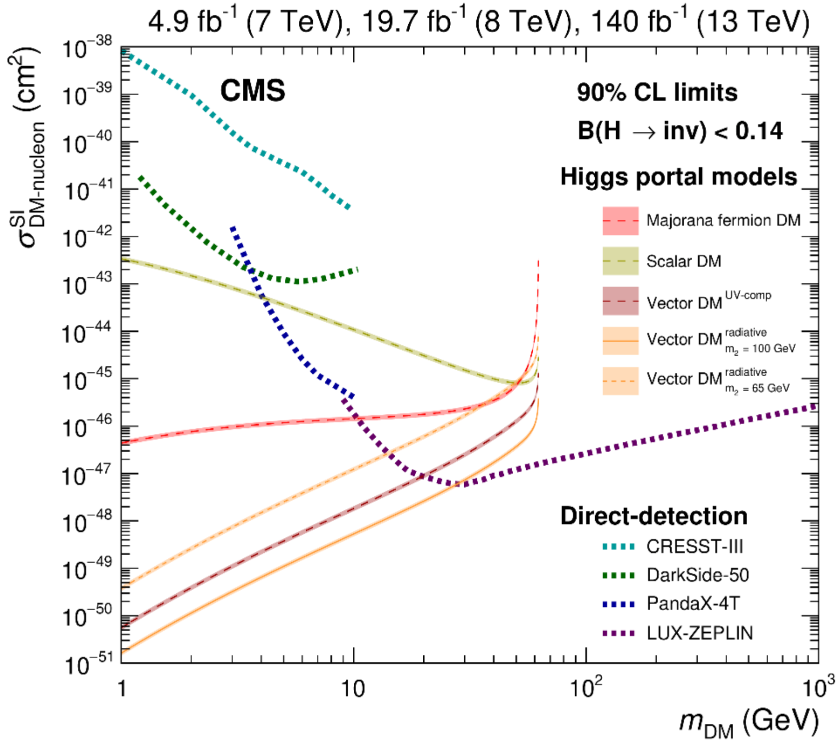
Start data taking in 2007 at Gran Sasso in Italy. Current XENON100 – 165 L xenon. Plan for 1000 L

most sensitive mode
qq'→qq'h (VBF h)

Eur. Phys. J. C 83 (2023) 933



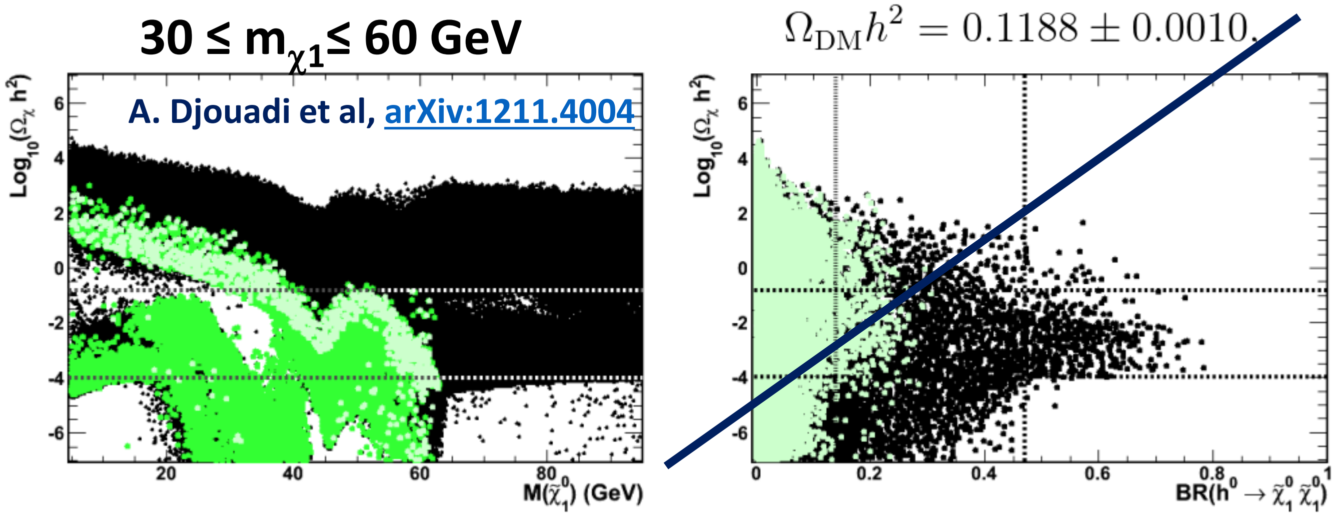




Expect to reach ≈ 4 % at HL-LHC with 3 ab^{-1} (FTR-19-001)

How it is compared with MSSM and NMSSM predictions

- **seems not interesting for pMSSM with new limits from LZ experiment**



30 ≤ $m_{\chi 1}$ ≤ 60 GeV

A. Djouadi et al, arXiv:1211.4004

$\Omega_{\rm DM} h^2 = 0.1188 \pm 0.0010,$

Figure 4: The neutralino relic density $\log_{10}(\Omega_\chi h^2)$ as a function of $M_{\chi_1^0}$ (left) and BR($h \to \chi_1^0\chi_1^0$) (right) for the accepted set of pMSSM points (black dots), those with BR($h \to \chi_1^0\chi_1^0$) $\geq 15\%$ (green dots) and those compatible at 90% C.L. with the Higgs data (light green dots). The horizontal lines show the constraint imposed on $\Omega_\chi h^2$ and the vertical lines on the panel on the right the 68% and 95% C.L. constraints on the Higgs invisible decay branching fraction obtained by [26].

latest update in R. Godbole at al. arXiv:2402.07991 , BR(h→χ_1 χ_1) < 0.1 %

- **interesting in NMSSM**

U. Ellwanger et al, arXiv:2403.16884

Scenarios with light neutralino 1

	BP1
M_{H3}	3966
M_{A1}	21
LSP	singl.
$M_{\rm LSP}$	9.0
NLSP	wino$^\pm$
$M_{\rm NLSP}$	115
Slepton	$\tilde{\nu}_\tau$
$M_{\rm Slepton}$	140

BR h→invisible can reach ≈10-15 % due to destructive interferences among processes mediated by the CP-even scalars.

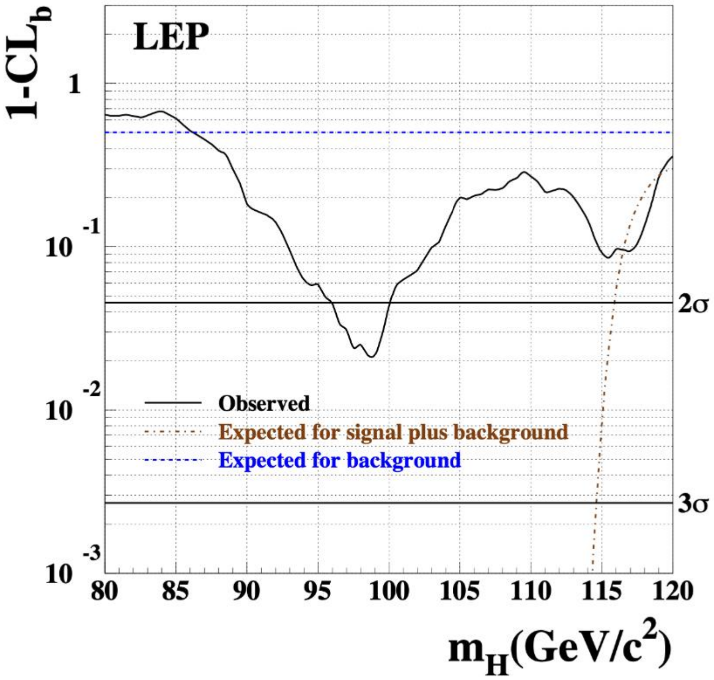
Cyril Hugonie, private communication

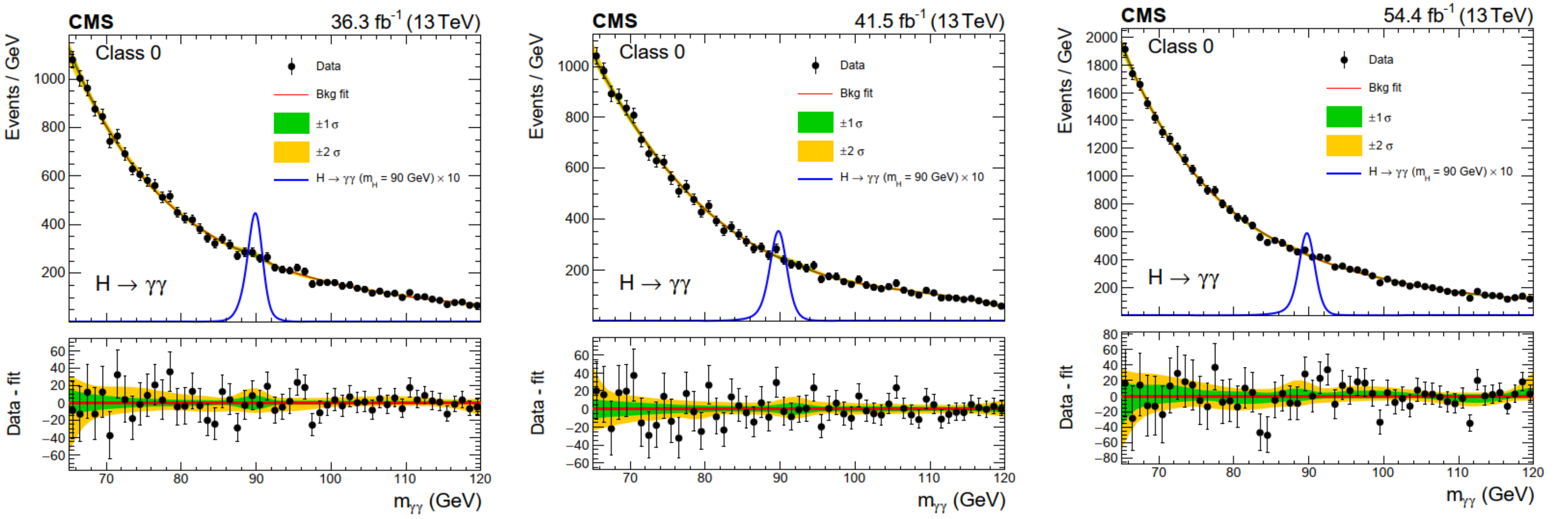
Excitement at the end:

some event excesses observed in CMS in searches for BSM Higgs bosons

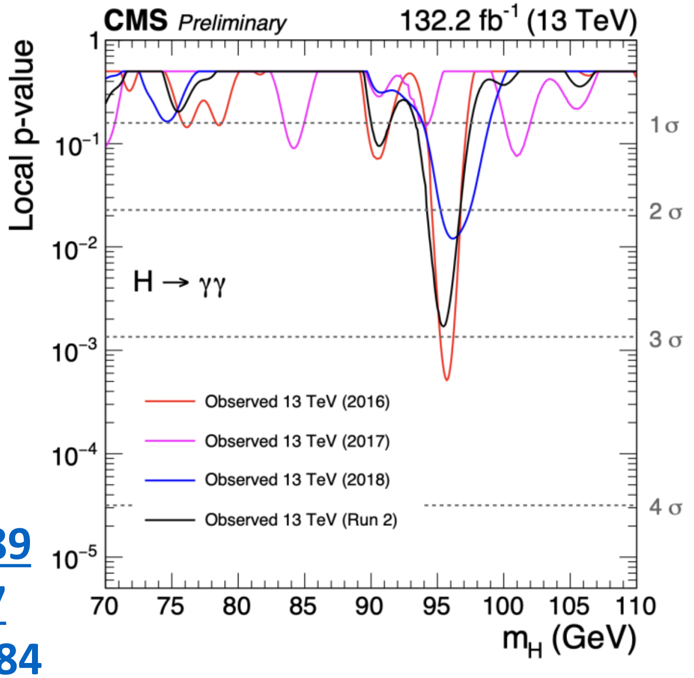
h95 GeV

Phys. Lett. B 565 (2003) 61–75

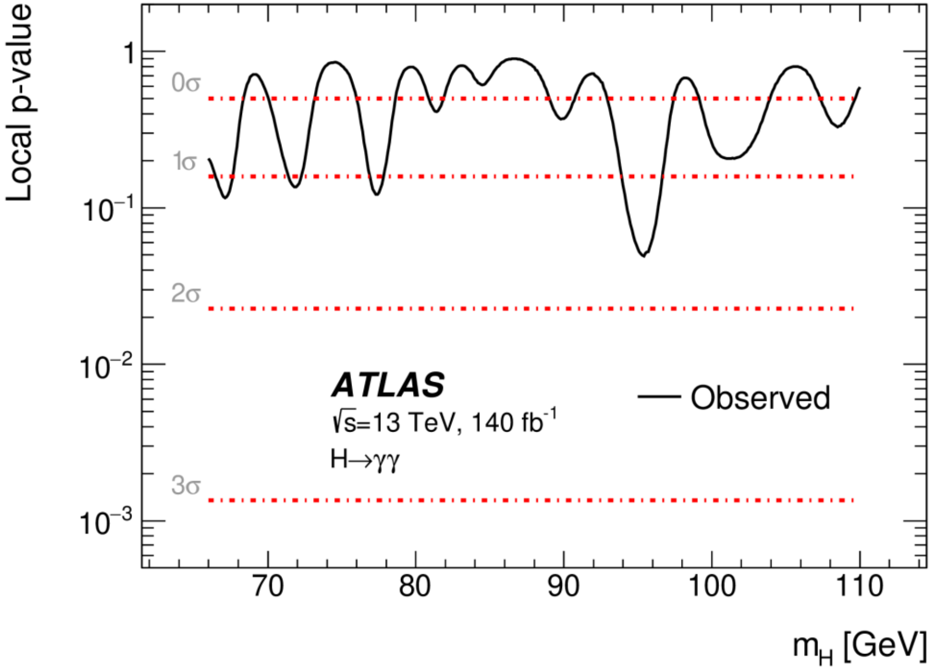




arXiv:2405.18149



arXiv:2407.07546



CMS: event classification according to di-photon BDT score (Class 0, 1, 2) + VBF in 2017, 2018

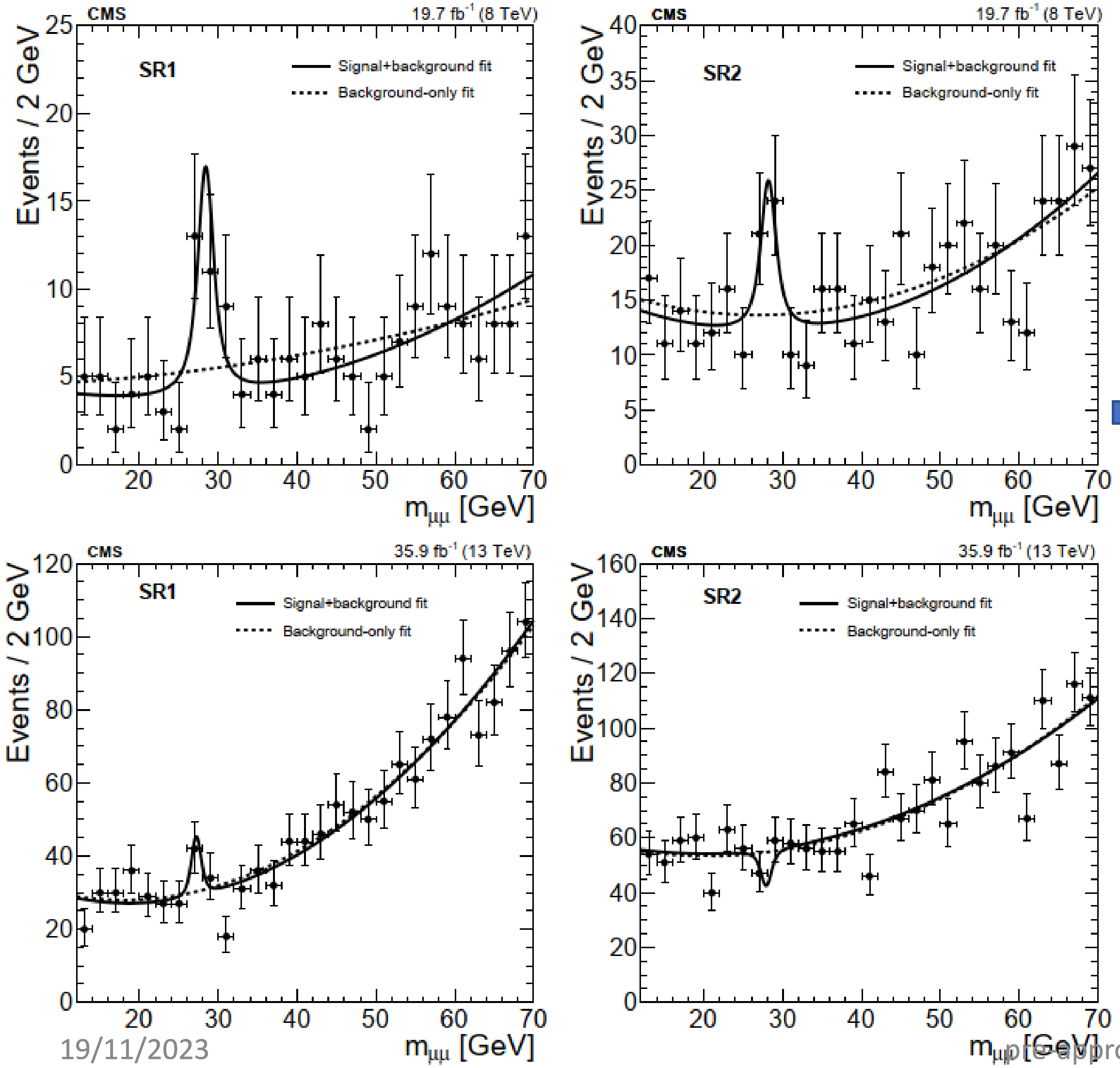
Class 0 has a largest sensitivity

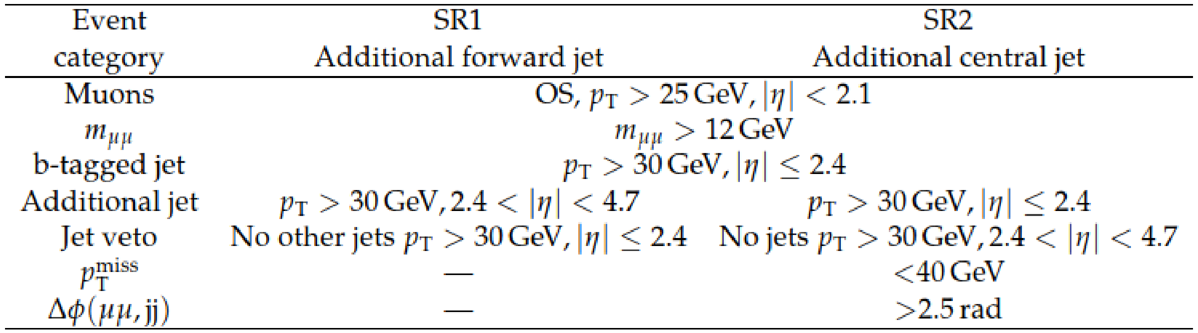
can be explained in S2HDM, arXiv:2306.03889

can be explained in 2HDM, JHEP11(2023)017

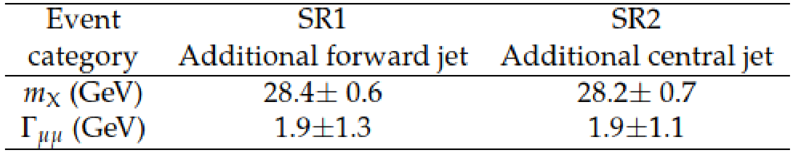
can be explained in NMSSM, arXiv:2403.16884

$\mu^+\mu^-$ + b-jet   JHEP 11 (2018) 161

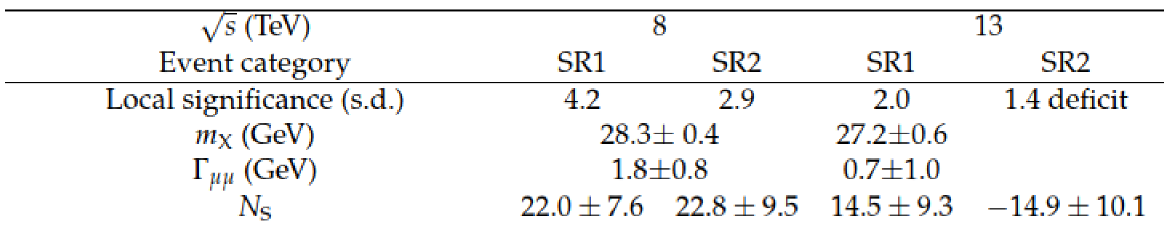




Event category	SR1 Additional forward jet	SR2 Additional central jet
Muons	OS, $p_T > 25\,\mathrm{GeV}, \lvert\eta\rvert < 2.1$	
$m_{\mu\mu}$	$m_{\mu\mu} > 12\,\mathrm{GeV}$	
b-tagged jet	$p_T > 30\,\mathrm{GeV}, \lvert\eta\rvert \leq 2.4$	
Additional jet	$p_T > 30\,\mathrm{GeV}, 2.4 < \lvert\eta\rvert < 4.7$	$p_T > 30\,\mathrm{GeV}, \lvert\eta\rvert \leq 2.4$
Jet veto	No other jets $p_T > 30\,\mathrm{GeV}, \lvert\eta\rvert \leq 2.4$	No jets $p_T > 30\,\mathrm{GeV}, 2.4 < \lvert\eta\rvert < 4.7$
p_T^{miss}	—	<40 GeV
$\Delta\phi(\mu\mu, \mathrm{jj})$	—	>2.5 rad



Event category	SR1 Additional forward jet	SR2 Additional central jet
m_X (GeV)	28.4± 0.6	28.2± 0.7
$\Gamma_{\mu\mu}$ (GeV)	1.9±1.3	1.9±1.1



$\sqrt{s}$ (TeV)	8		13	
Event category	SR1	SR2	SR1	SR2
Local significance (s.d.)	4.2	2.9	2.0	1.4 deficit
m_X (GeV)	28.3± 0.4		27.2±0.6	
$\Gamma_{\mu\mu}$ (GeV)	1.8±0.8		0.7±1.0	
N_S	22.0 ± 7.6	22.8 ± 9.5	14.5 ± 9.3	-14.9 ± 10.1

Conclusions

- very reach program for BSM Higgs physics at LHC and HL-LHC
- we hope for the new discovery in Higgs physics with Run II+III data and at HL-LHC

THE END

Two Higgs Doublet Model (I)

Consider two complex EW doublets

$$\Phi_1 = \begin{pmatrix} \phi_1^+ \\ \frac{1}{\sqrt{2}}(v_1 + \rho_1 + i\eta_1) \end{pmatrix}, \quad \Phi_2 = \begin{pmatrix} \phi_2^+ \\ \frac{1}{\sqrt{2}}(v_2 + \rho_2 + i\eta_2) \end{pmatrix} \qquad \langle\Phi_1\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v_1 \end{pmatrix}, \qquad \langle\Phi_2\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v_2 \end{pmatrix}$$

- For the correct gauge bosons mass $v_1^2 + v_2^2 = v^2 \approx (246)^2$ GeV^2

Higgs potential

$$\mathcal{V} = m_{11}^2\Phi_1^\dagger\Phi_1 + m_{22}^2\Phi_2^\dagger\Phi_2 - [m_{12}^2\Phi_1^\dagger\Phi_2 + \mathrm{h.c.}] + \tfrac{1}{2}\lambda_1(\Phi_1^\dagger\Phi_1)^2 + \tfrac{1}{2}\lambda_2(\Phi_2^\dagger\Phi_2)^2 + \lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2)$$
$$+\lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) + \left\{\tfrac{1}{2}\lambda_5(\Phi_1^\dagger\Phi_2)^2 + \left[\lambda_6(\Phi_1^\dagger\Phi_1) + \lambda_7(\Phi_2^\dagger\Phi_2)\right]\Phi_1^\dagger\Phi_2 + \mathrm{h.c.}\right\} . \quad (1)$$

parameters $\lambda_6,\lambda_7=0$ as result of Z_2 symmetry imposed to avoid FCNC (Φ_1->Φ_1, Φ_2->-Φ_2)

Soft Z_2 symmetry breaking: m_{12} != 0

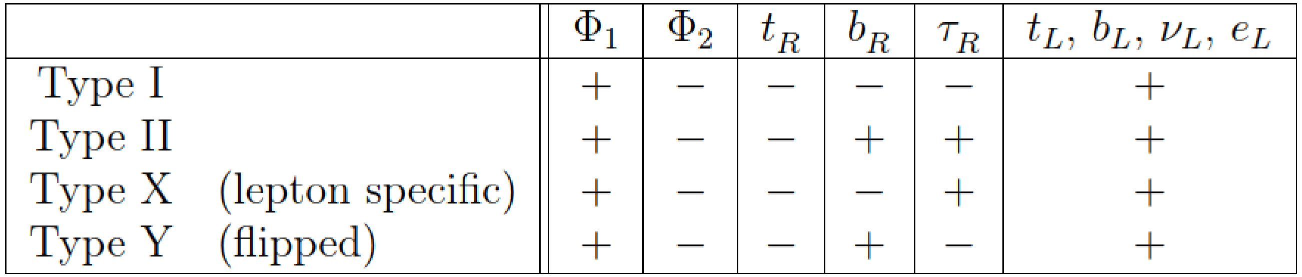
m_{12} != 0 to have a new mass scale. This allows the model to have a decoupling limit.
when m_{12} goes to infinity we recover the SM

Two Higgs Doublet Model (II)

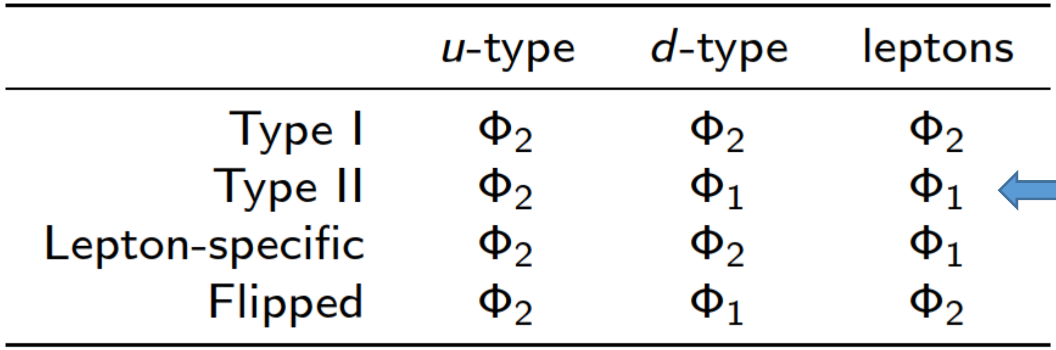
Yukawa interaction with fermions

$$-\mathscr{L}_{\text{Yuk}} = \mathcal{Y}_b^1 \bar{b}_R \Phi_1^{i*} Q_L^i + \mathcal{Y}_b^2 \bar{b}_R \Phi_2^{i*} Q_L^i + \mathcal{Y}_\tau^1 \bar{\tau}_R \Phi_1^{i*} L_L^i + \mathcal{Y}_\tau^2 \bar{\tau}_R \Phi_2^{i*} L_L^i + \epsilon_{ij} \left[\mathcal{Y}_t^1 \bar{t}_R Q_L^i \Phi_1^j + \mathcal{Y}_t^2 \bar{t}_R Q_L^i \Phi_2^j \right] + \text{h.c.}$$

Four possible Z_2 charge assignments that forbid tree-level Higgs-mediated FCNC effects in the 2HDM



	Φ_1	Φ_2	t_R	b_R	τ_R	$t_L,\, b_L,\, \nu_L,\, e_L$
Type I	$+$	$-$	$-$	$-$	$-$	$+$
Type II	$+$	$-$	$-$	$+$	$+$	$+$
Type X (lepton specific)	$+$	$-$	$-$	$-$	$+$	$+$
Type Y (flipped)	$+$	$-$	$-$	$+$	$-$	$+$



	u-type	*d*-type	leptons
Type I	Φ_2	Φ_2	Φ_2
Type II	Φ_2	Φ_1	Φ_1
Lepton-specific	Φ_2	Φ_2	Φ_1
Flipped	Φ_2	Φ_1	Φ_2

same as in MSSM