Extra Higgses at LHC:
The EW Road to Baryogenesis

Jose Miguel No (Sussex U.)

1310.6035 (PRD) *with M. Ramsey-Musolf.*
1305.6610 (JHEP), 1405.5537 (PRL), *with G. Dorsch, S. Huber, K. Mimasu.*
+ *Work in Progress*

University of Sussex
MARIE CURIE ACTIONS

Liverpool, March 2015

Motivation

What is the Origin of the Baryon Asymmetry?

$$\frac{n_B - n_{\bar{B}}}{n_\gamma} \sim 10^{-9} \text{ (from BBN)}$$

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B Violation

C/CP Violation

Departure from Thermal Equilibrium

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B Violation ✓ Sphalerons

V. A. Kuzmin, V. A. Rubakov, M. Shaposhnikov, Phys. Lett. B**155** (1985) 36

C/CP Violation ✗ not enough

Departure from Thermal Equilibrium ✗ not enough

SM

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BSM

New CP Sources → *EDMs*

First Order EW Phase Transition:
New Bosons at EW Scale → *LHC*

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C/CP Violation **?**

Departure from Thermal Equilibrium **?**

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LHC Signatures Revealing 1st Order EW Phase Transition

(LHC ROAD TO BARYOGENESIS)

EW Phase Transition & Baryogenesis

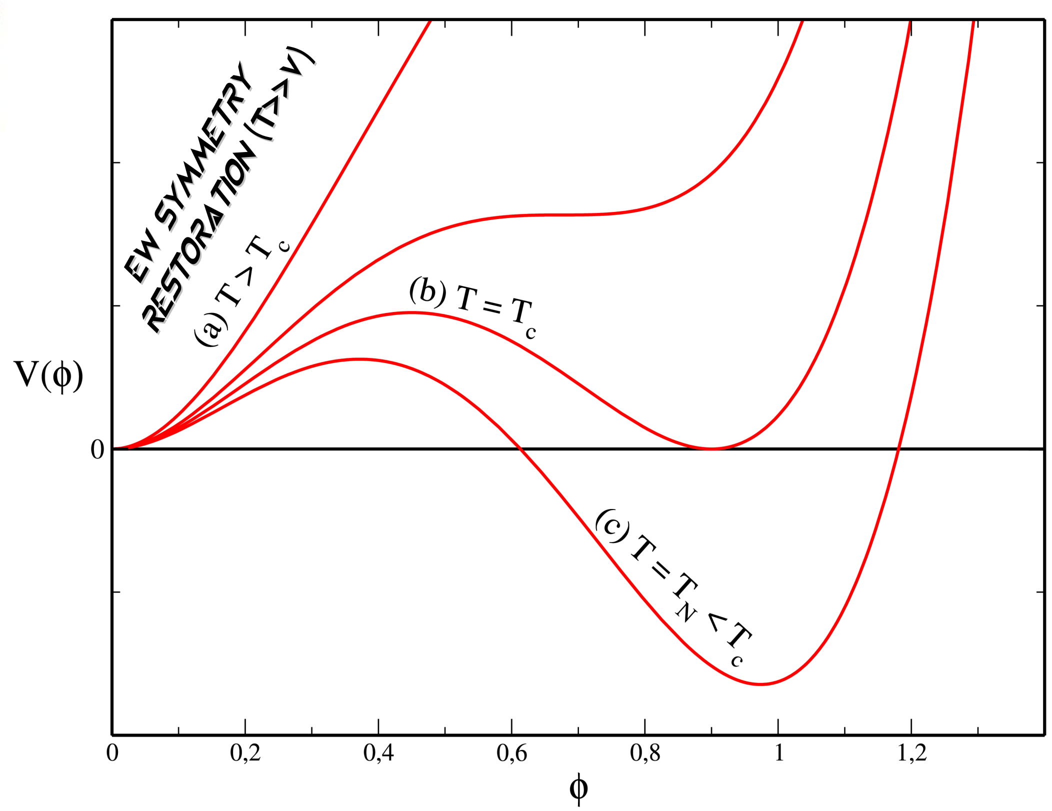
Universe Expands Adiabatically ⇨ *Equilibrium Thermal Field Theory*

Finite-T Effective Potential $V(\phi, T)$ for the Higgs

$$V(\phi,T) \approx (a\,T^2 - \mu^2)\,\phi^2 - b\,T\,\phi^3 + \lambda\,\phi^4$$

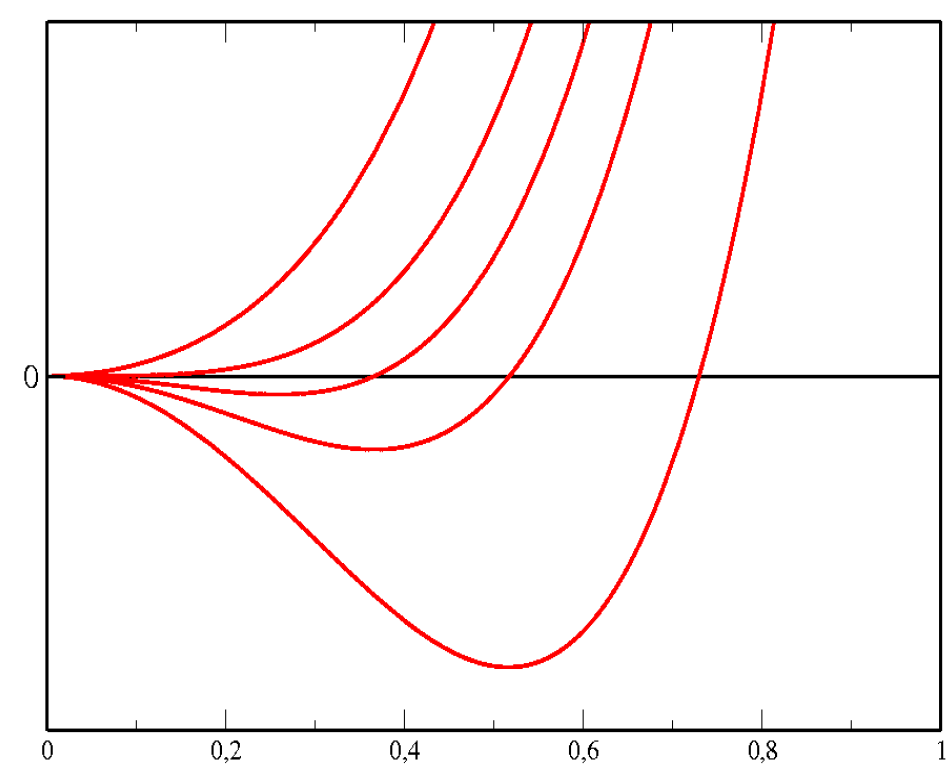
1st Order:

$\langle\phi\rangle = 0 \rightarrow \langle\phi\rangle = \phi(T)$ Discontinuous



2nd Order:

$\langle\phi\rangle = 0 \rightarrow \langle\phi\rangle = \phi(T)$ Continuous



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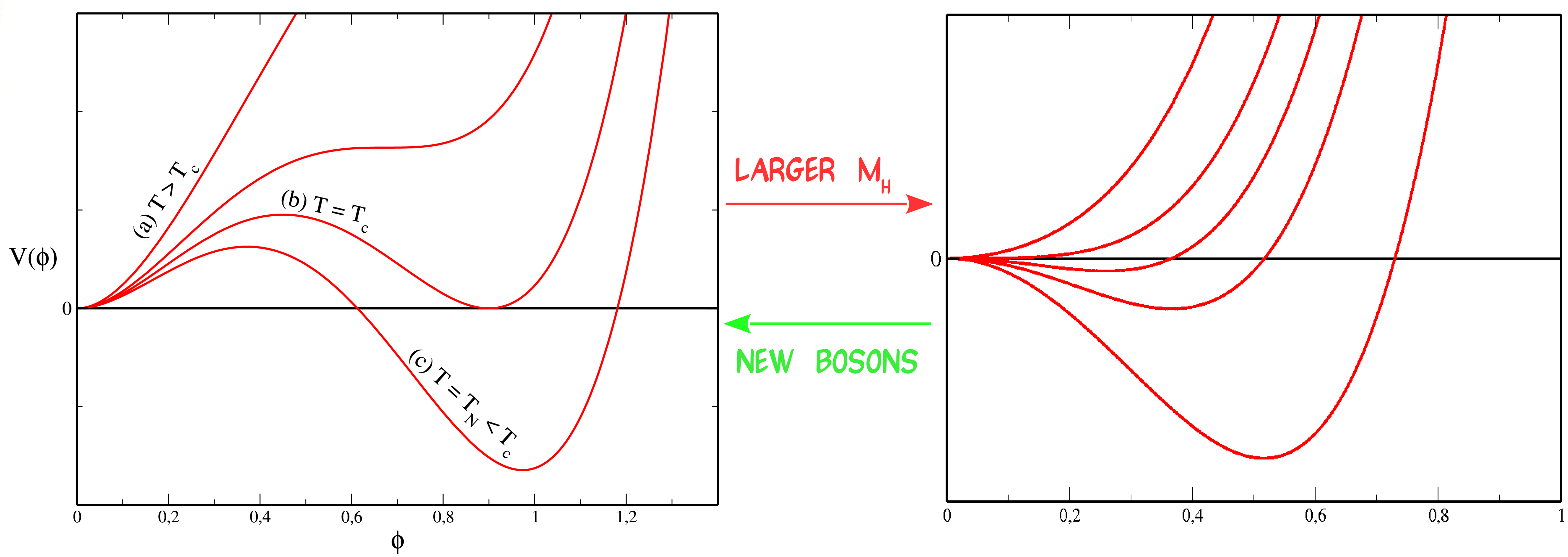

In the SM (m_h = 125 GeV) EW Phase Transition Smooth CrossOver

K. Kajantie, M. Laine, K. Rummukainen, M. Shaposhnikov, Phys. Rev. Lett. **77** (1996) 2887

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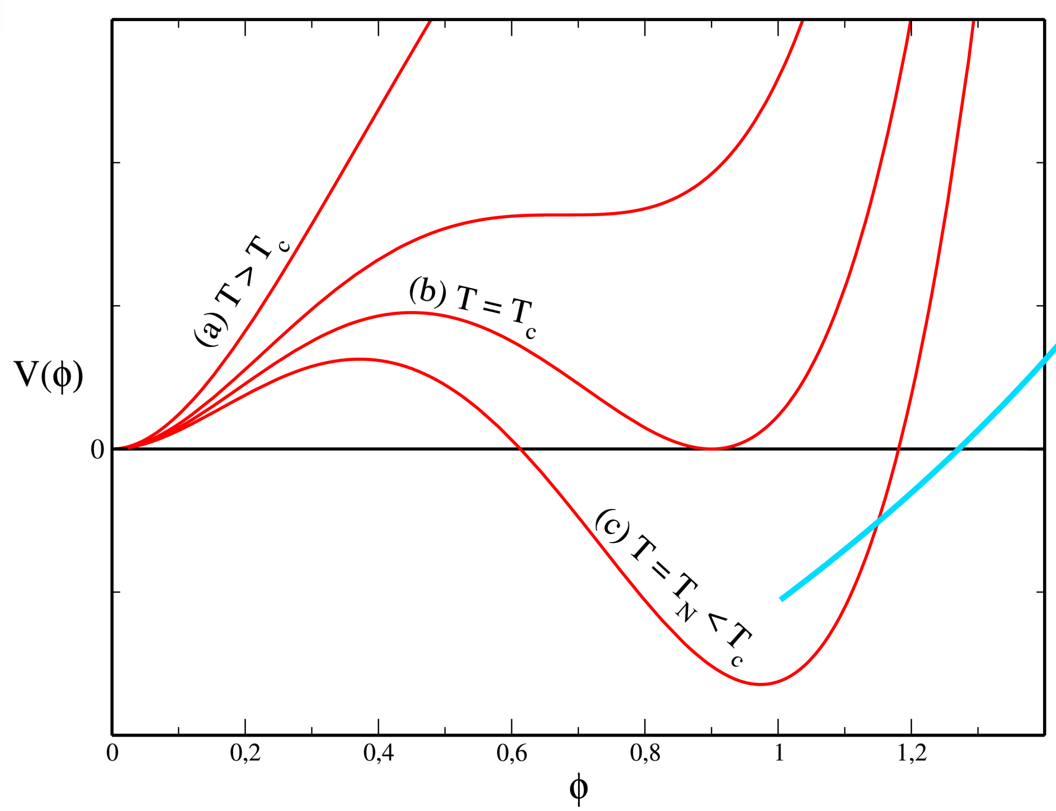
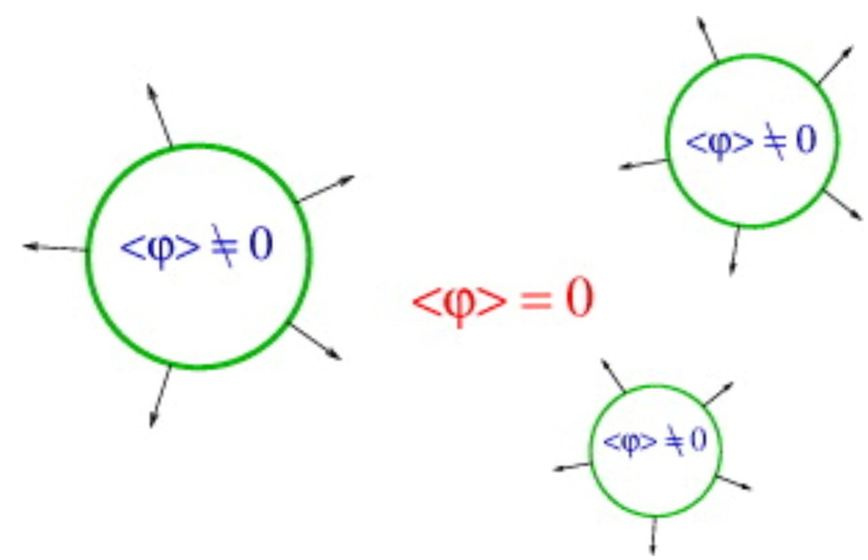


Nucleation of True Vacuum Bubbles
(in False Vacuum Sea)

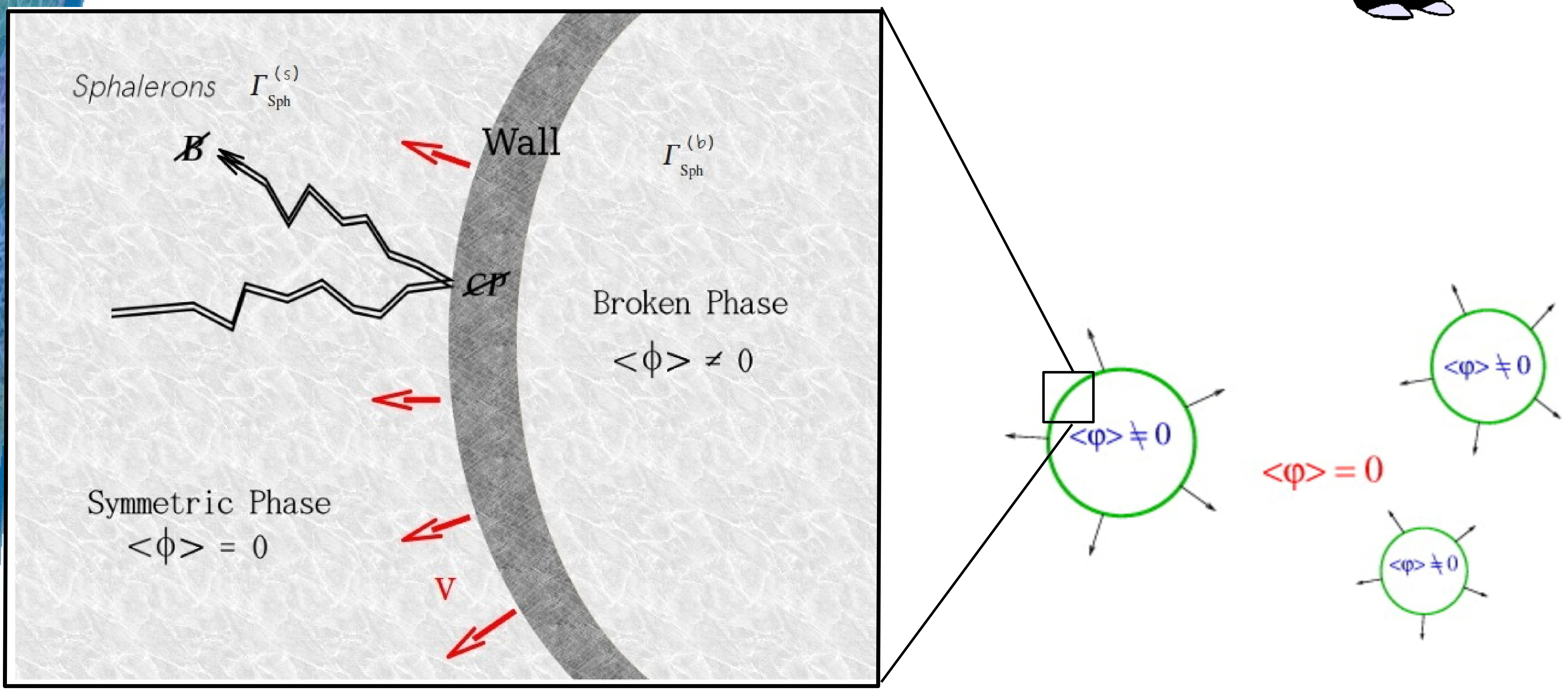
J. S. Langer, Ann. Phys. **54** (1969) 258
S. R. Coleman, Phys. Rev. D **15** (1977) 2929
A. D. Linde, Nucl. Phys. B **216** (1983) 421



SUDDEN CHANGE IN HIGGS VEV

EW Phase Transition & Baryogenesis

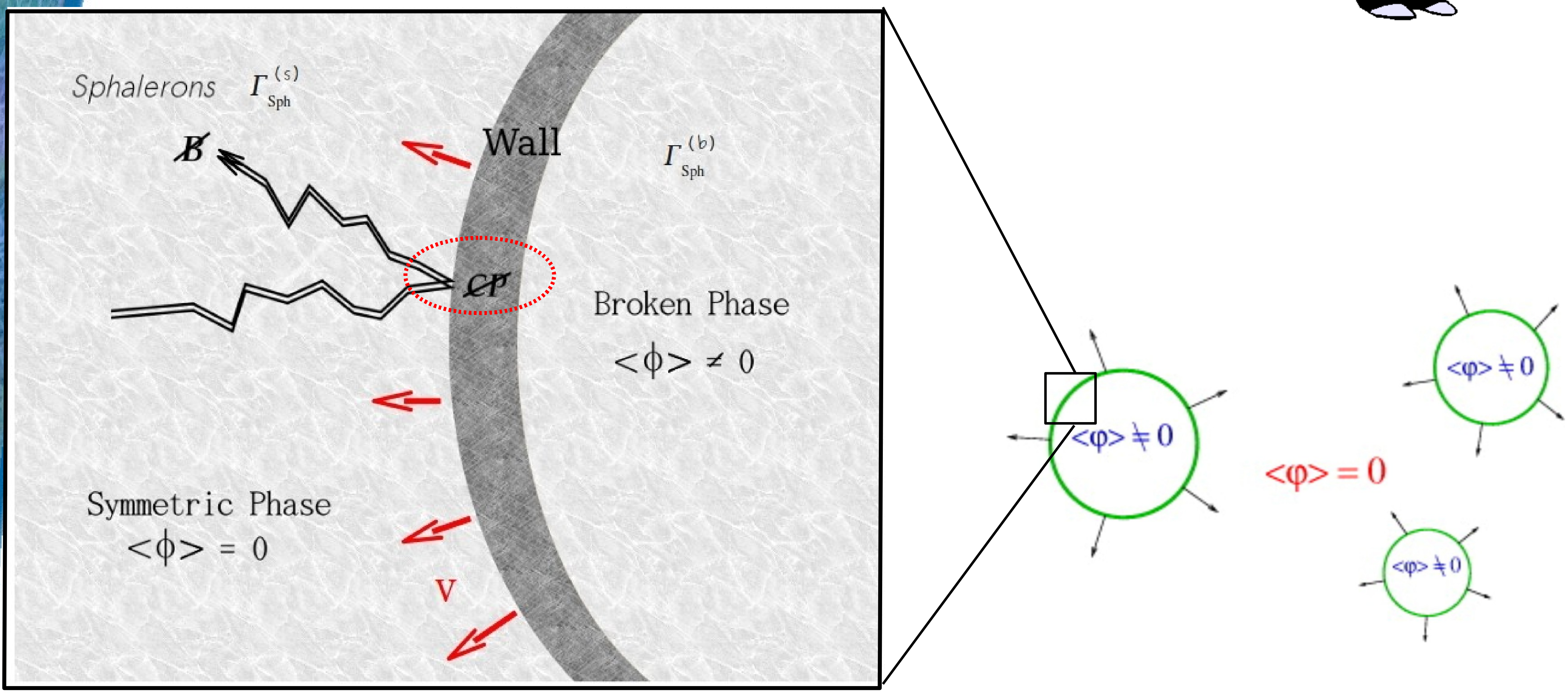
The EW Baryogenesis Recipe:



EW Phase Transition & Baryogenesis

The EW Baryogenesis Recipe:

❶ CP Violation + Transport (diffusion)



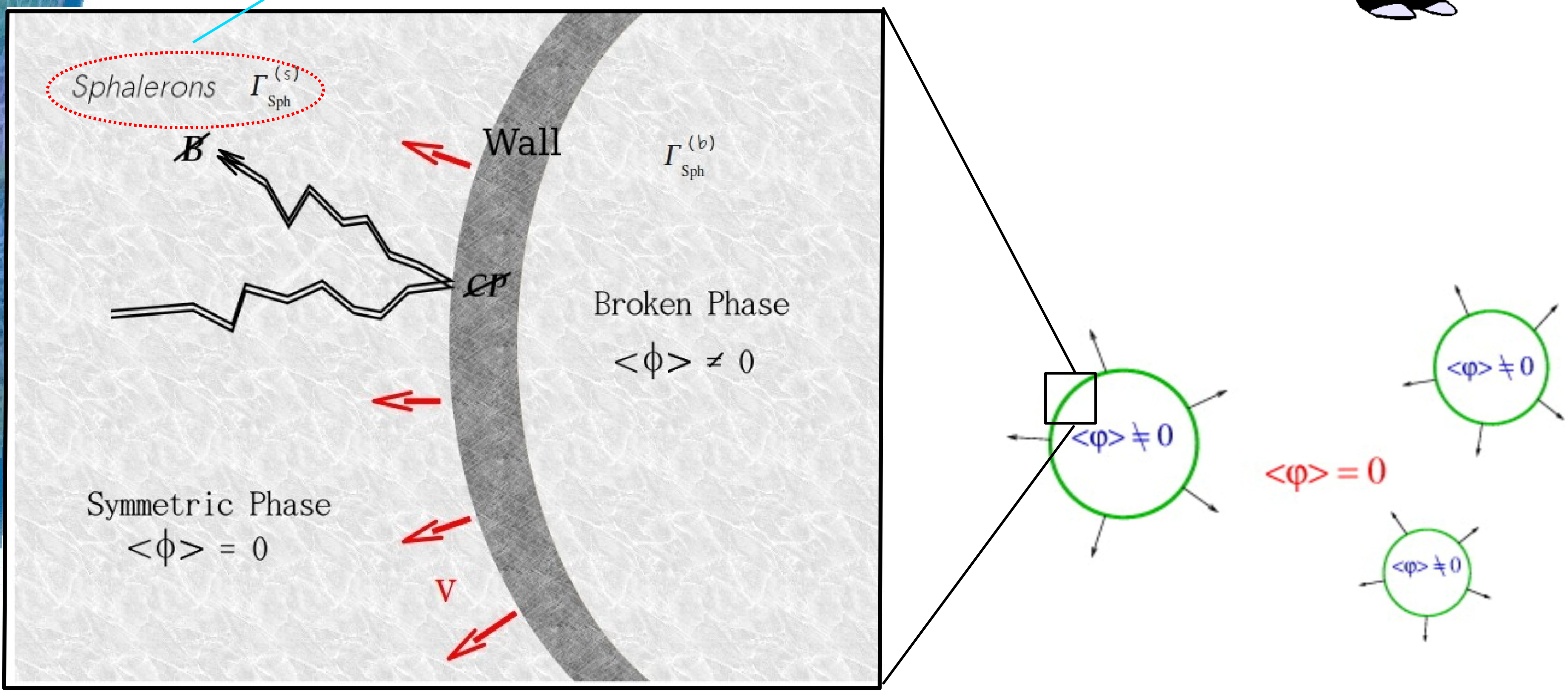
$$n_B = \underbrace{n_b^L - n_{\bar{b}}^L}_{\neq 0} + \underbrace{n_b^R - n_{\bar{b}}^R}_{\neq 0} = 0$$

EW Phase Transition & Baryogenesis

The EW Baryogenesis Recipe:

❷ Baryon Number Violation

$\Gamma^{S}_{Sph} \sim \alpha^{5}_{W} T^{4}_{N} \sim$ UNSUPPRESSED



$$n_B = \underbrace{n_b^L - n_{\bar{b}}^L}_{\textit{Changed}} + \underbrace{n_b^R - n_{\bar{b}}^R}_{\neq 0} \neq 0$$

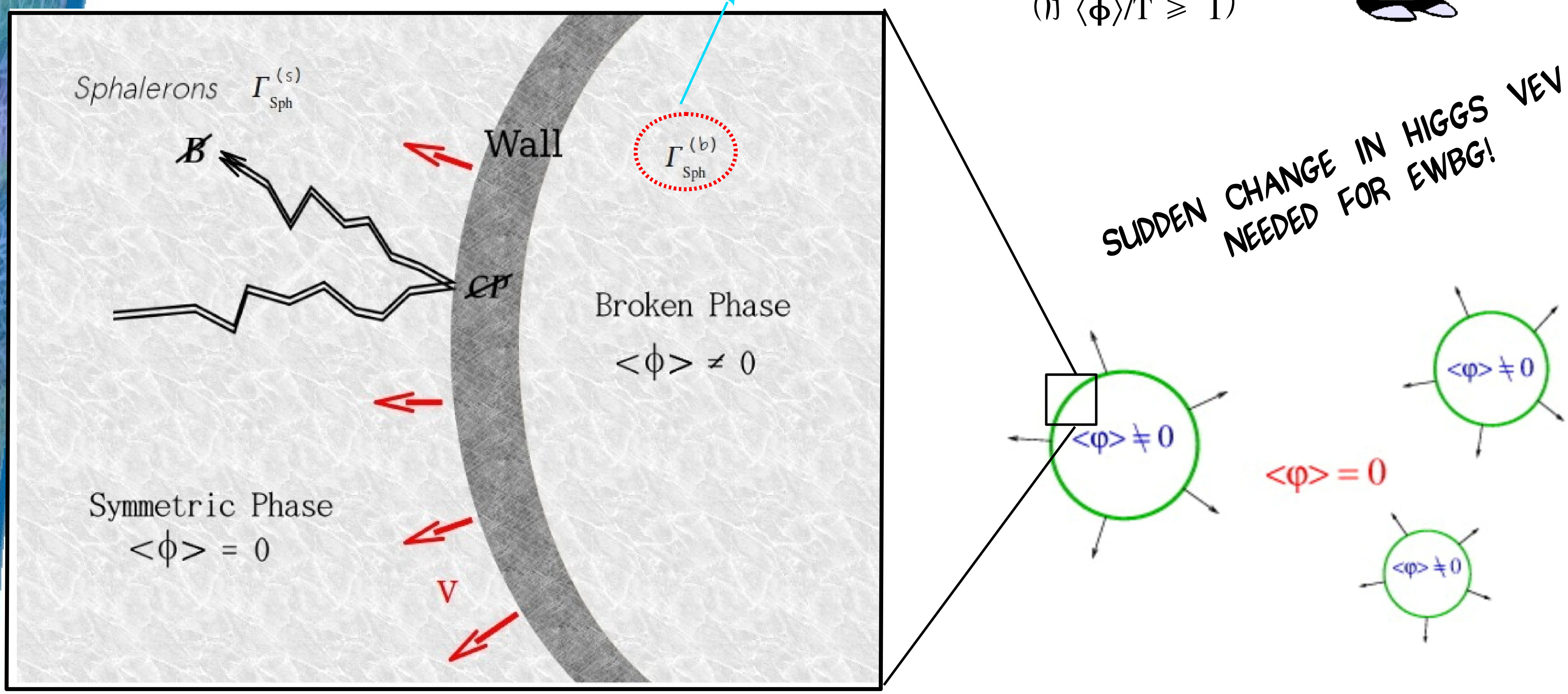
EW Phase Transition & Baryogenesis

The EW Baryogenesis Recipe:

❸ Out of Equilibrium

$\Gamma^{b}_{Sph} \sim \mathrm{Exp}(-E_{Sph}/T_N) \sim$ SUPPRESSED

(if $\langle\phi\rangle/T \gtrsim 1$)



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EW Scale Baryogenesis Needs:

- ➔ *New Bosons (EW Scale)*
- ➔ *Coupled to SM Higgs*

→ Strong 1^{st} Order EW Phase Transition

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Archetype Scenario: Extended Higgs Sectors

More Higgses!

- SIMPLE EXTENSIONS OF THE SM
- PROVIDE MISSING INGREDIENTS FOR EW BARYOGENESIS

I will discuss two well-motivated scenarios:

2HDM

(Singlet) Higgs Portal

Goal: ***LHC signals of EW Phase Transition***

2HDM

... Add a Second Scalar Doublet to the SM

$$V_s(\Phi_1,\Phi_2) = -\mu_1^2\Phi_1^\dagger\Phi_1 - \mu_2^2\Phi_2^\dagger\Phi_2 - \frac{\mu^2}{2}(\Phi_1^\dagger\Phi_2 + h.c.)$$
$$+\frac{\lambda_1}{2}(\Phi_1^\dagger\Phi_1)^2 + \frac{\lambda_2}{2}(\Phi_2^\dagger\Phi_2)^2 + \lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2)$$
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$\mathbb{Z}_2$ Symmetric
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$$h = \cos\alpha\ h_1 + \sin\alpha\ h_2 \qquad H^\pm = -\sin\beta\ \varphi_1^\pm + \cos\beta\ \varphi_2^\pm$$

$$H_0 = -\sin\alpha\ h_1 + \cos\alpha\ h_2 \qquad A_0 = -\sin\beta\ \eta_1 + \cos\beta\ \eta_2$$

Attention!

$\alpha = \beta \rightarrow$ light Higgs h is SM-like (Differs from Usual 2HDM Definition by $\frac{\pi}{2}$

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- *We Focus on Type I 2HDM* (all fermions coupled to same scalar doublet)

⇨ EW PHASE TRANSITION DOES NOT DEPEND ON THE TYPE

⇨ EXPERIMENTAL CONSTRAINTS DO DEPEND ON THE TYPE

Type	u_R	d_R	e_R
I	+	+	+
II	+	−	−
X	+	+	−
Y	+	−	+

EW Phase Transition in 2HDM

➔ We Scan m_{H_0} m_{A_0} $m_{H^\pm}$ μ α $\tan\beta$

- Stability of the Effective Potential at 1-loop
- Code interfaced to 2HDMC & HiggsBounds → Selects Points Satisfying: Unitarity, Perturbativity, EWPO, LEP/Tevatron/LHC Bounds

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  *P. Bechtle, O. Brein, S. Heinemeyer, G. Weiglein, K. Williams, Comput. Phys. Commun. **181** (2010) 138*

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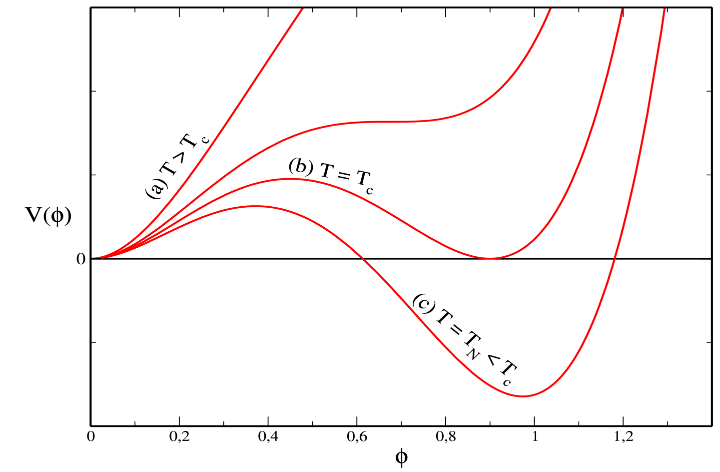
➔ *Strength of the EW Phase Transition:*

- ⇨ Use Daisy Resummed 1-loop Thermal Effective Potential $V_{\rm eff}(\phi, T)$
- ⇨ Critical Temperature T_C
- ⇨ $v_C / T_C > 1$ → Strongly First Order EW Phase Transition



EW Phase Transition in 2HDM

Strong EW Phase Transition vs "Physical"

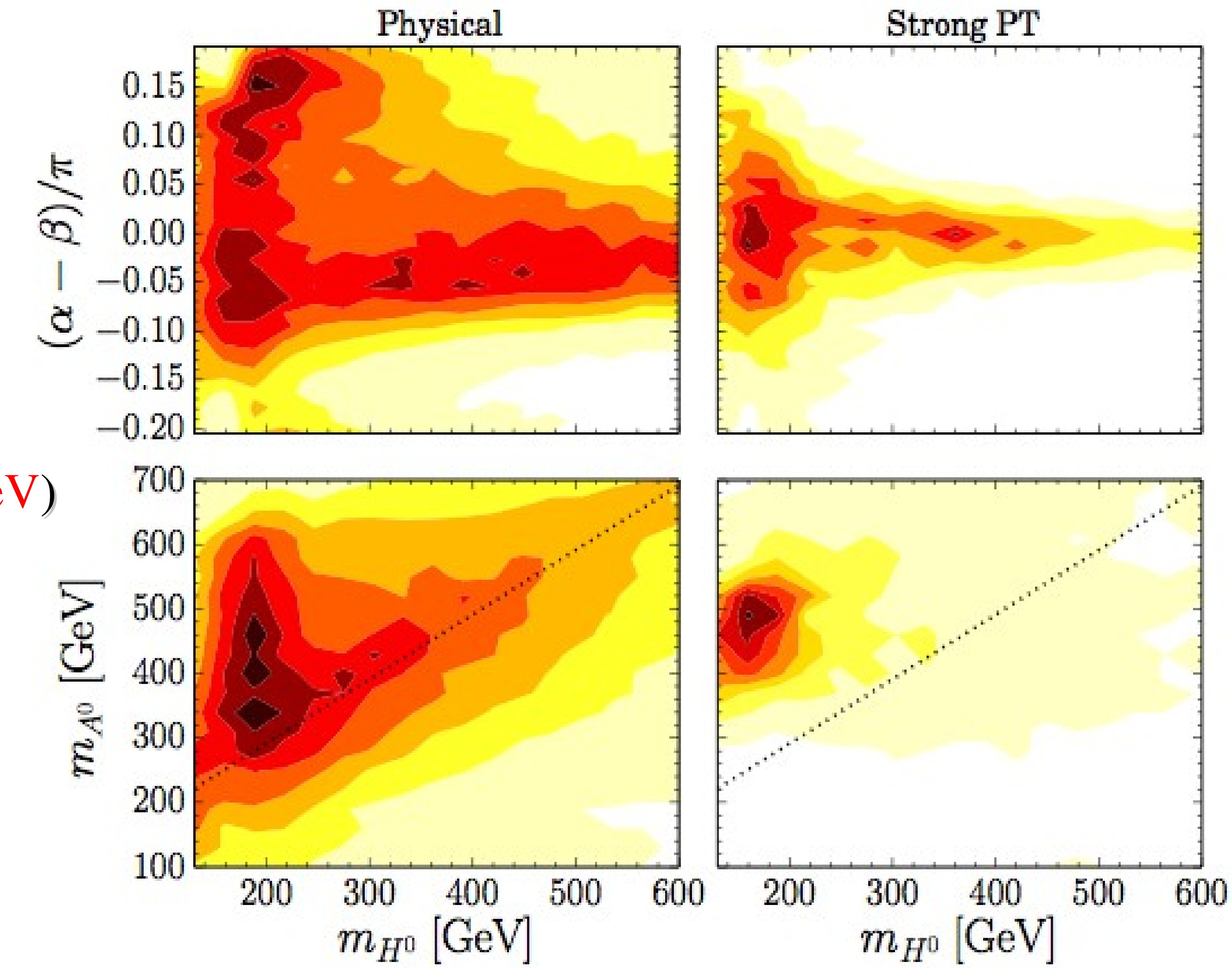
- SM-like light Higgs h

  (Small $\alpha - \beta$ and $\tan\beta \gtrsim 1$)

  *G. Dorsch, S. Huber, J.M. N, JHEP **1310** (2013) 029*

- $m_{H_0} < 250$ GeV

- $m_{A_0} - m_{H_0} \sim v$ (& $m_{A_0} > 300$ GeV)



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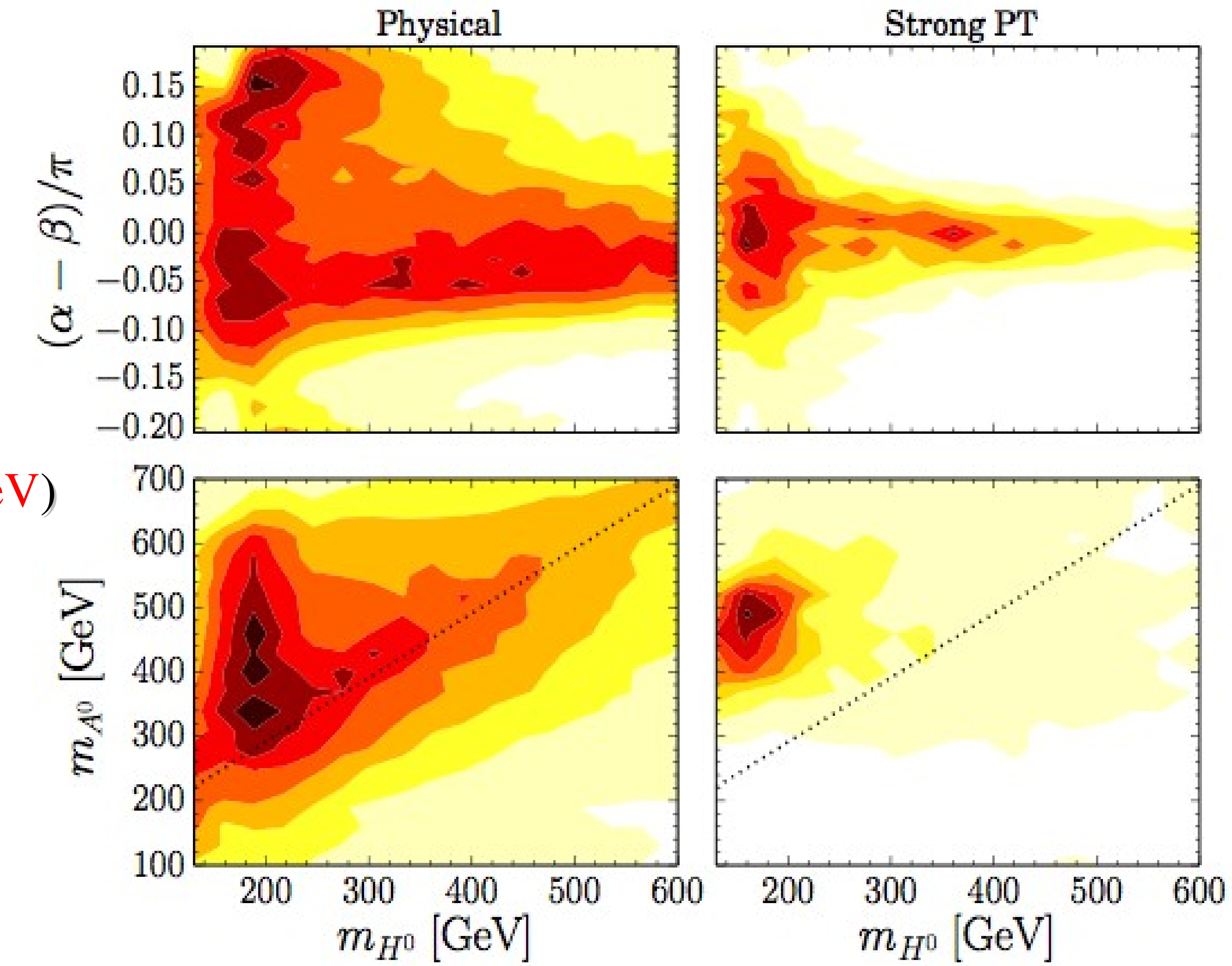

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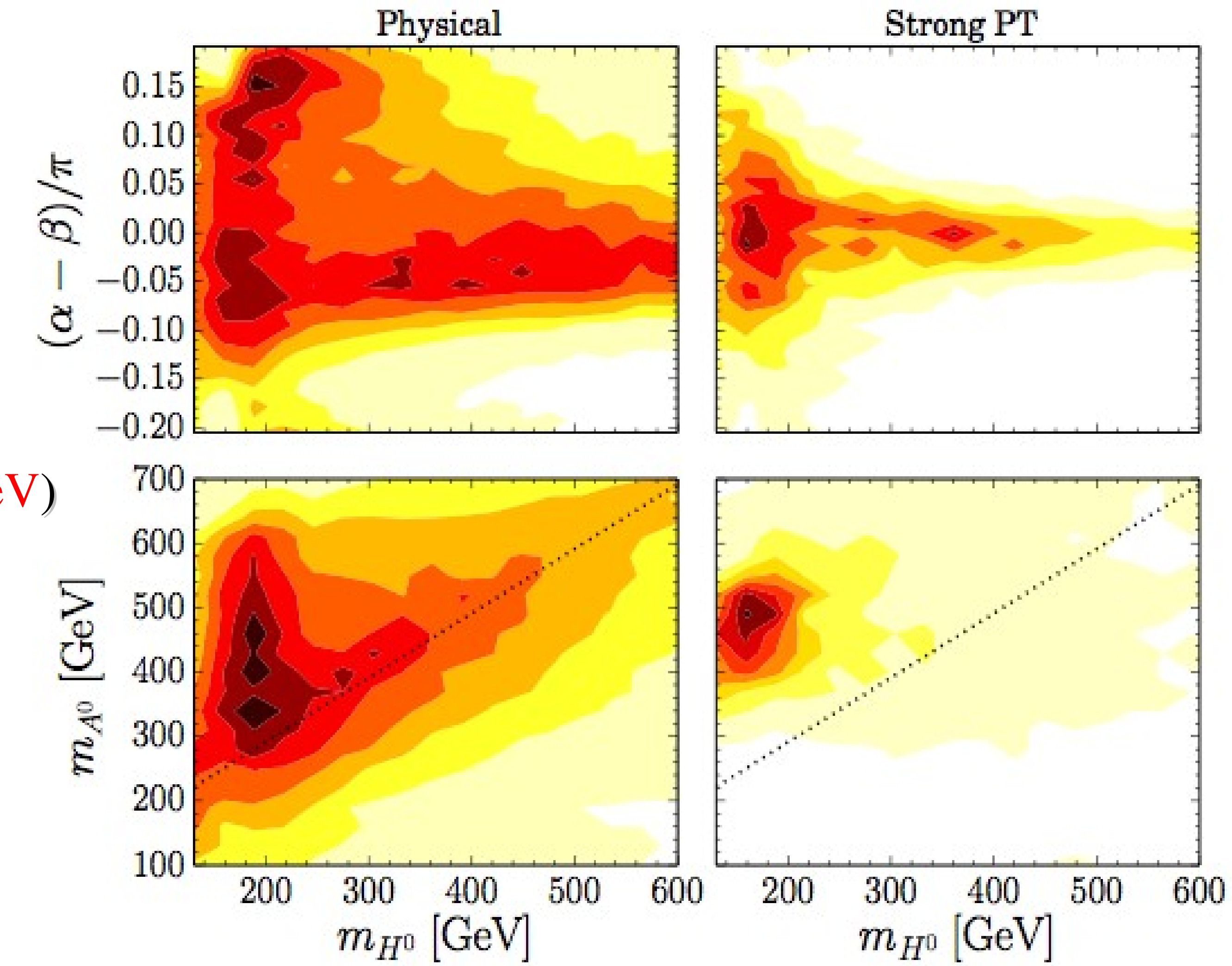

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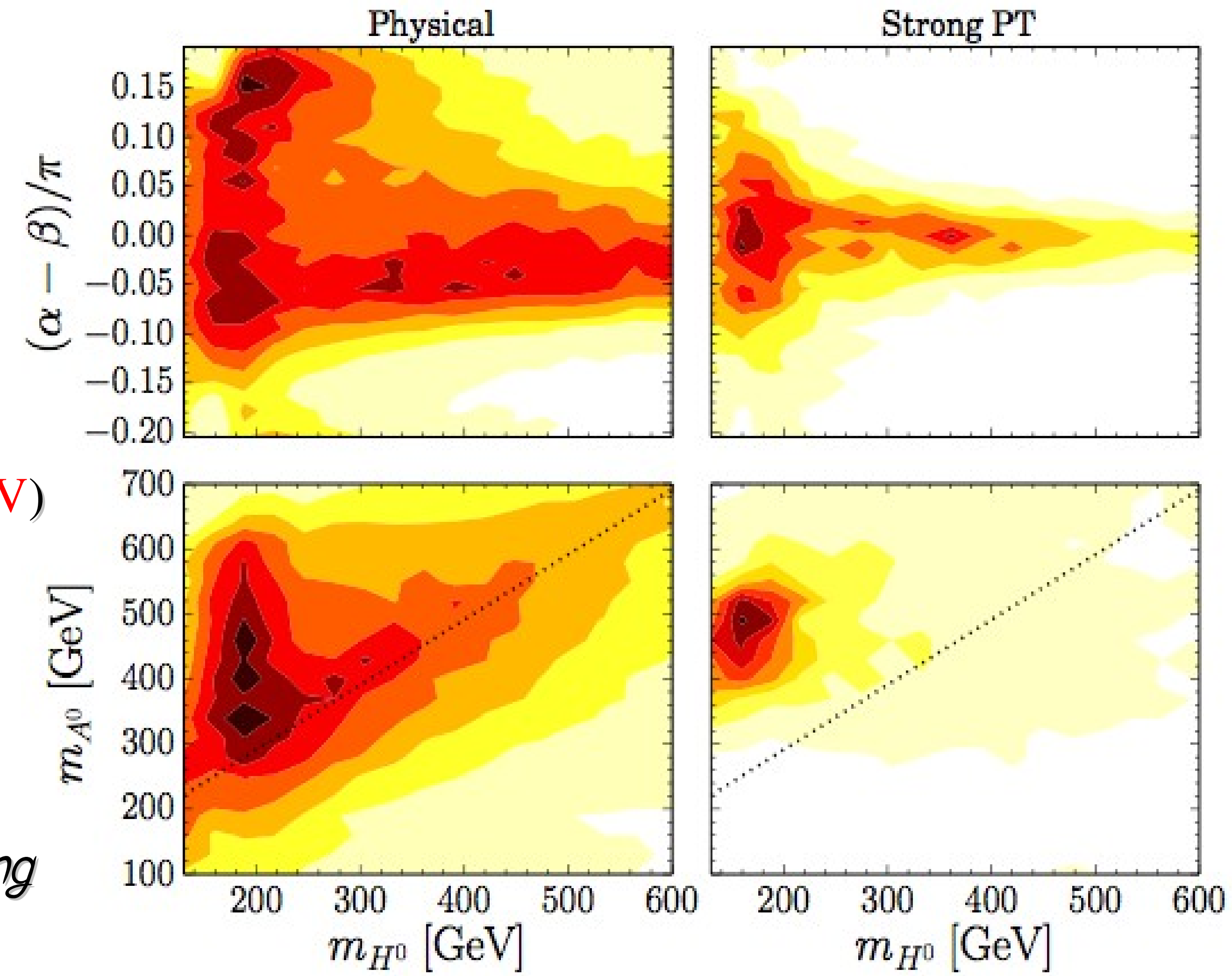

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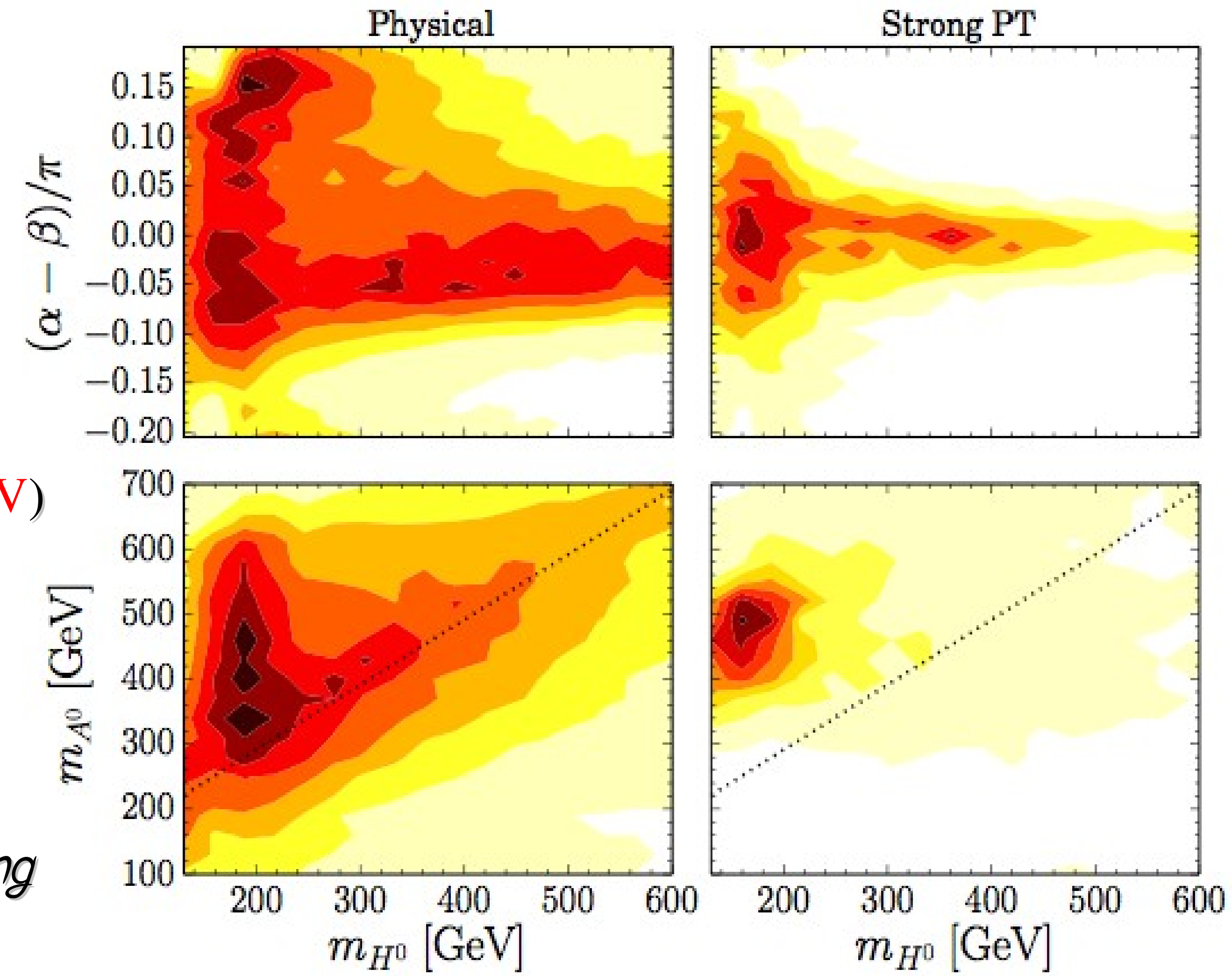
(not widely considered; Not Accessible in MSSM)



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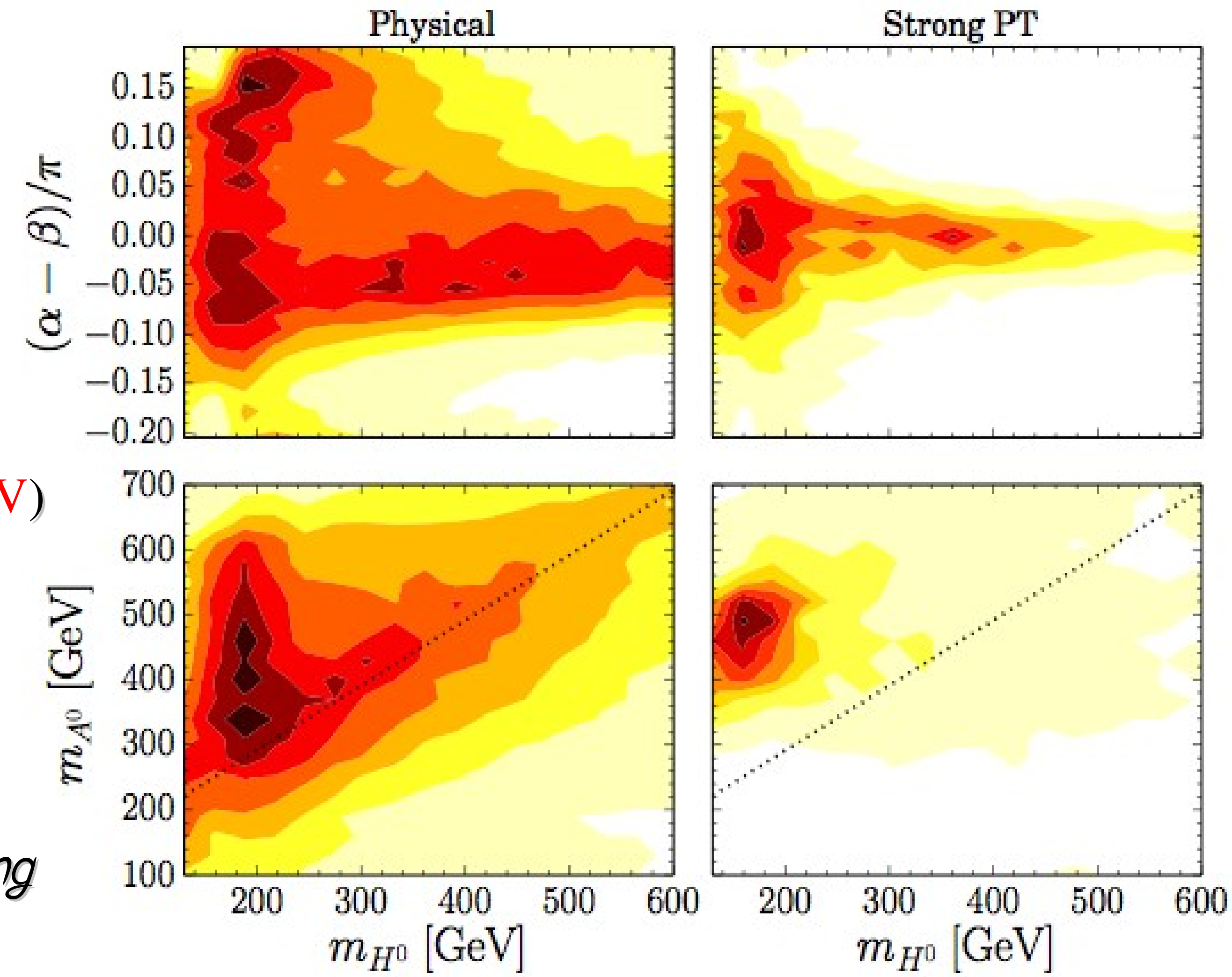

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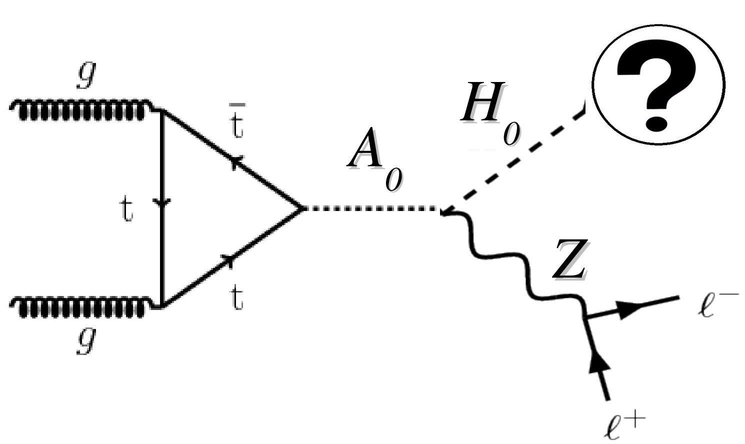
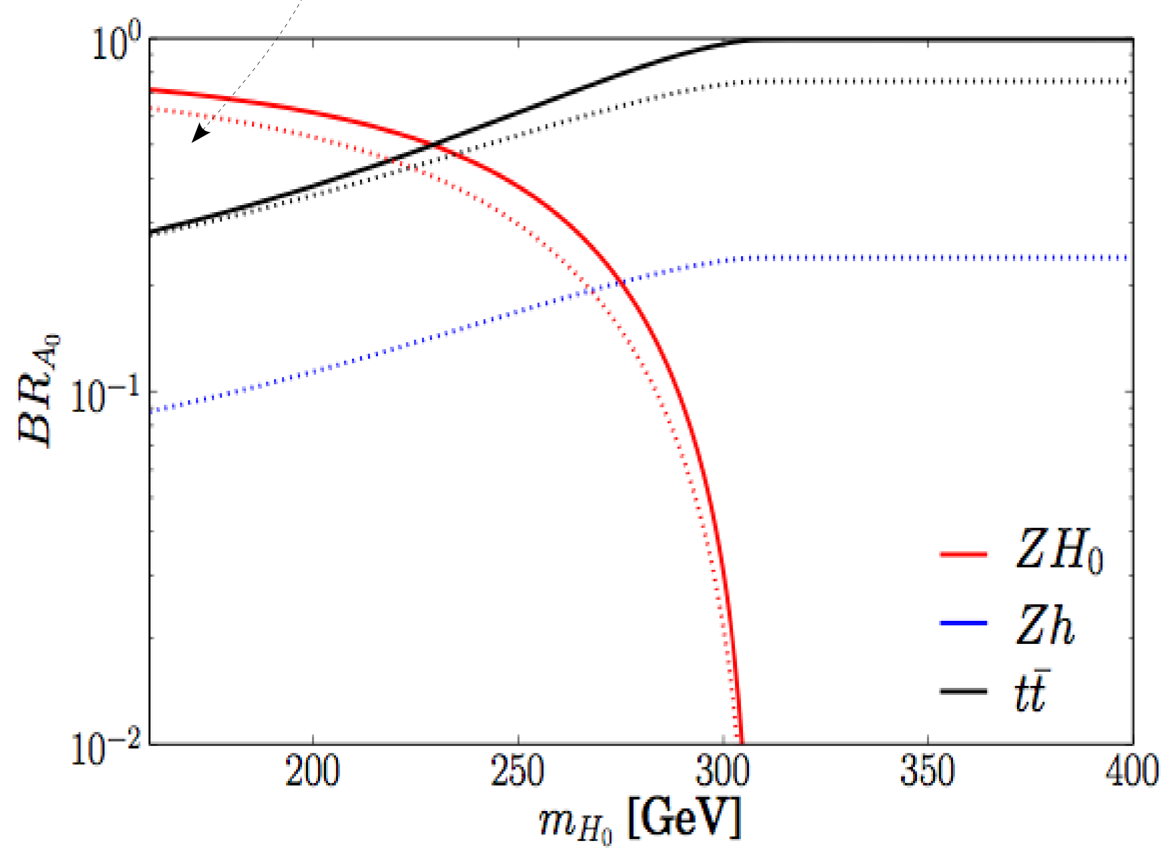


"SMOKING GUN" SIGNATURE

$$A_0 \to H_0\, Z$$

2HDM @LHC

- Decay $A_0 \to H_0 Z$ Dominant for $m_{A_0} - m_{H_0} \sim v$



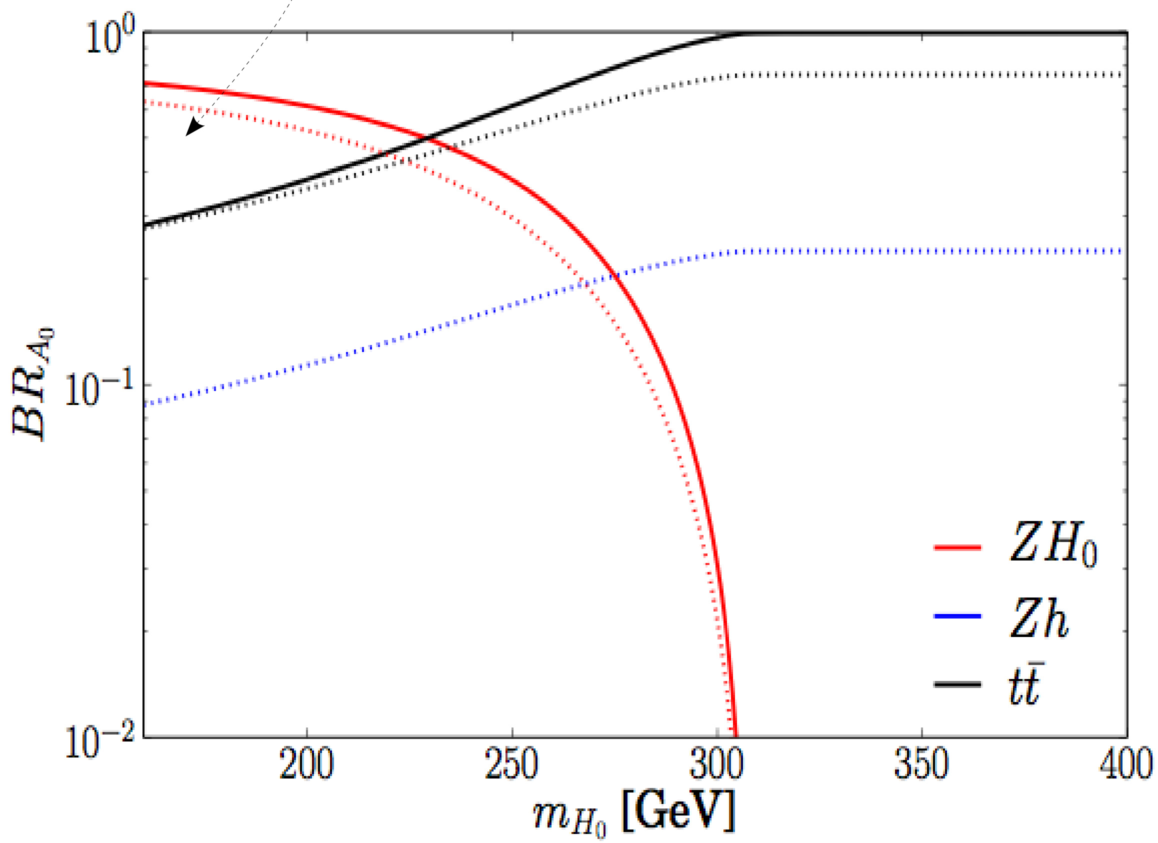
2HDM @LHC

- *Decay* $A_0 \to H_0\, Z$ *Dominant for* $m_{A_0} - m_{H_0} \sim v$

⇨ $A_0 \to h\, Z$ *supressed by* $\sin(\alpha - \beta)$

⇨ *Competing Channels*

$A_0 \to \bar{t}t \sim (\tan\beta)^{-2}$



2HDM @LHC

- *Decay* $A_0 \to H_0 Z$ *Dominant for* $m_{A_0} - m_{H_0} \sim v$

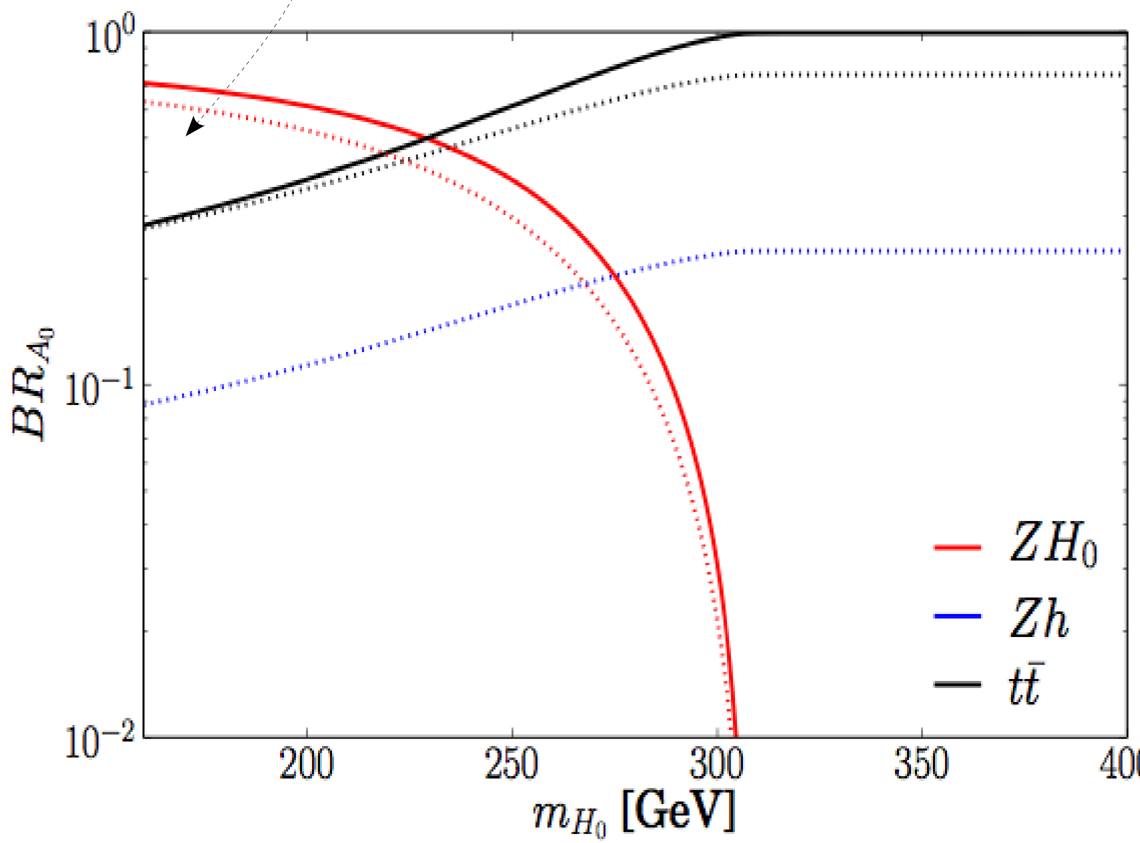
⇨ $A_0 \to h\, Z$ *supressed by* $\sin(\alpha - \beta)$

⇨ *Competing Channels*

$A_0 \to \bar{t}t \sim (\tan\beta)^{-2}$

$A_0 \to H^{\pm} W^{\mp}$

depends on $m_{H^{\pm}}$
(no preference
from strong PT)



G. Dorsch, S. Huber, K. Mimasu, J.M. N, In Preparation

B. Coleppa, F. Kling, S. Su, arXiv:1408.4119

2HDM @LHC

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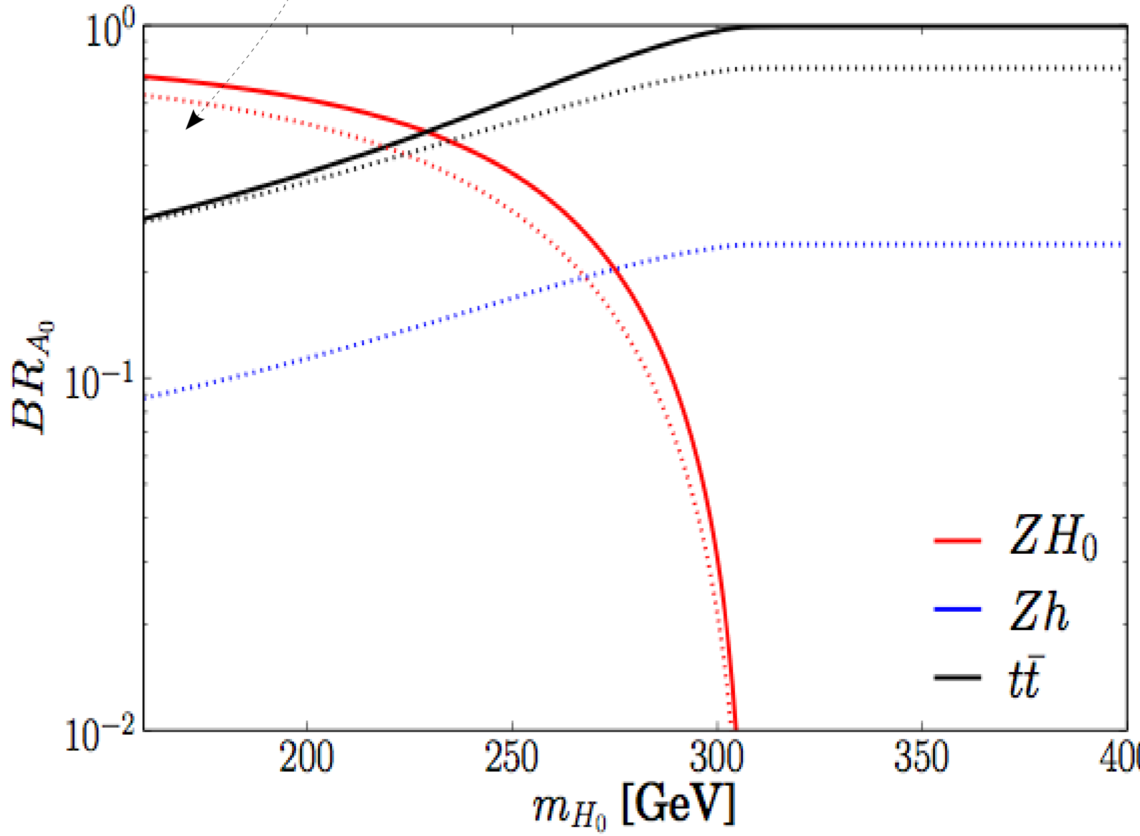
⇨ *Competing Channels*

$A_0 \to \bar{t}t \sim (\tan\beta)^{-2}$

$A_0 \to H^{\pm} W^{\mp}$

EWPO require $m_{H^\pm} \sim m_{A_0}$ or $m_{H^\pm} \sim m_{H_0}$

closed open



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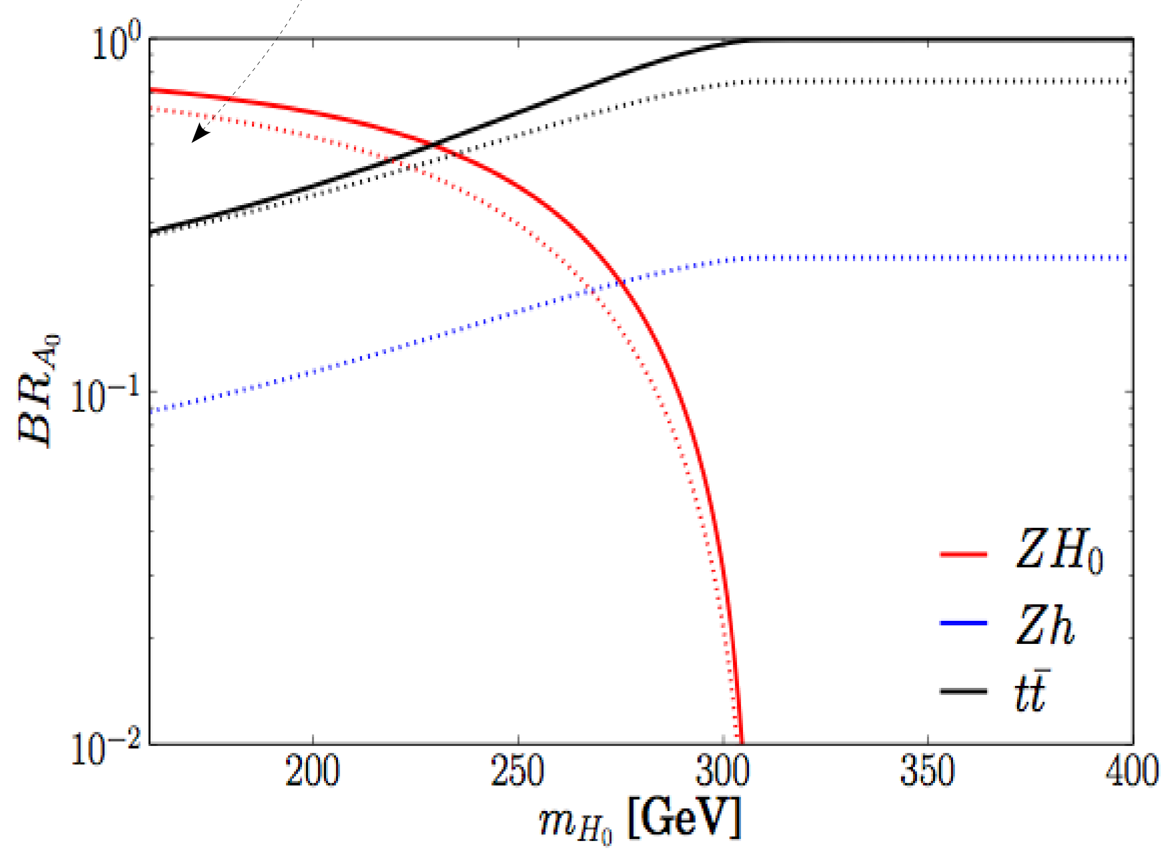
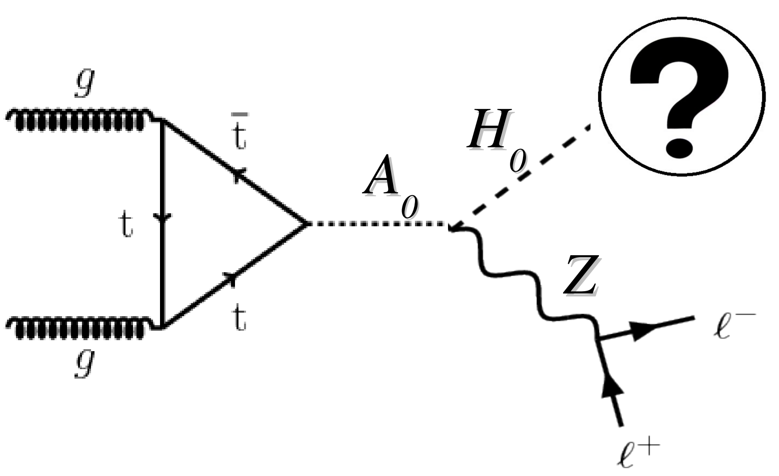


- *Simple Benchmarks for a Strong EW Phase Transition:*
  $m_{A_0} = m_{H^\pm} = 400,\ m_{H_0} = 180,\ \mu = 100$
  $\tan\beta = 2$ (controls $gg \to A_0$ production)



2HDM @LHC

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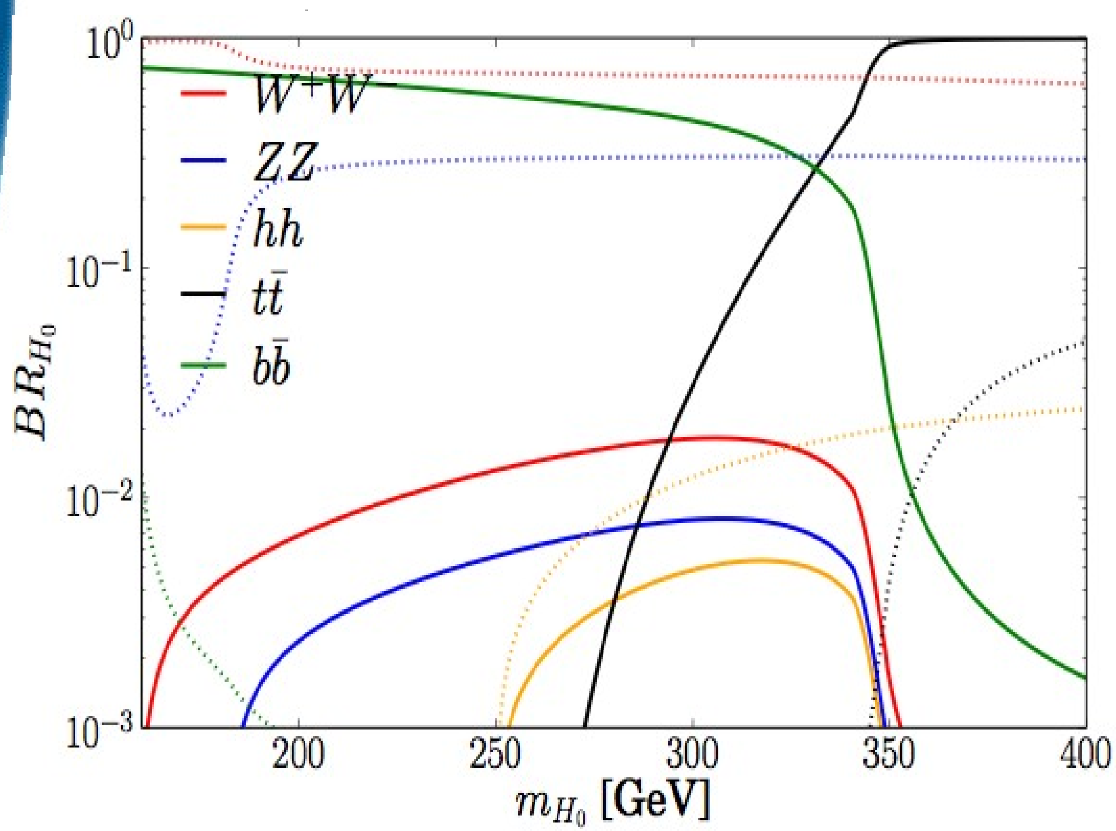

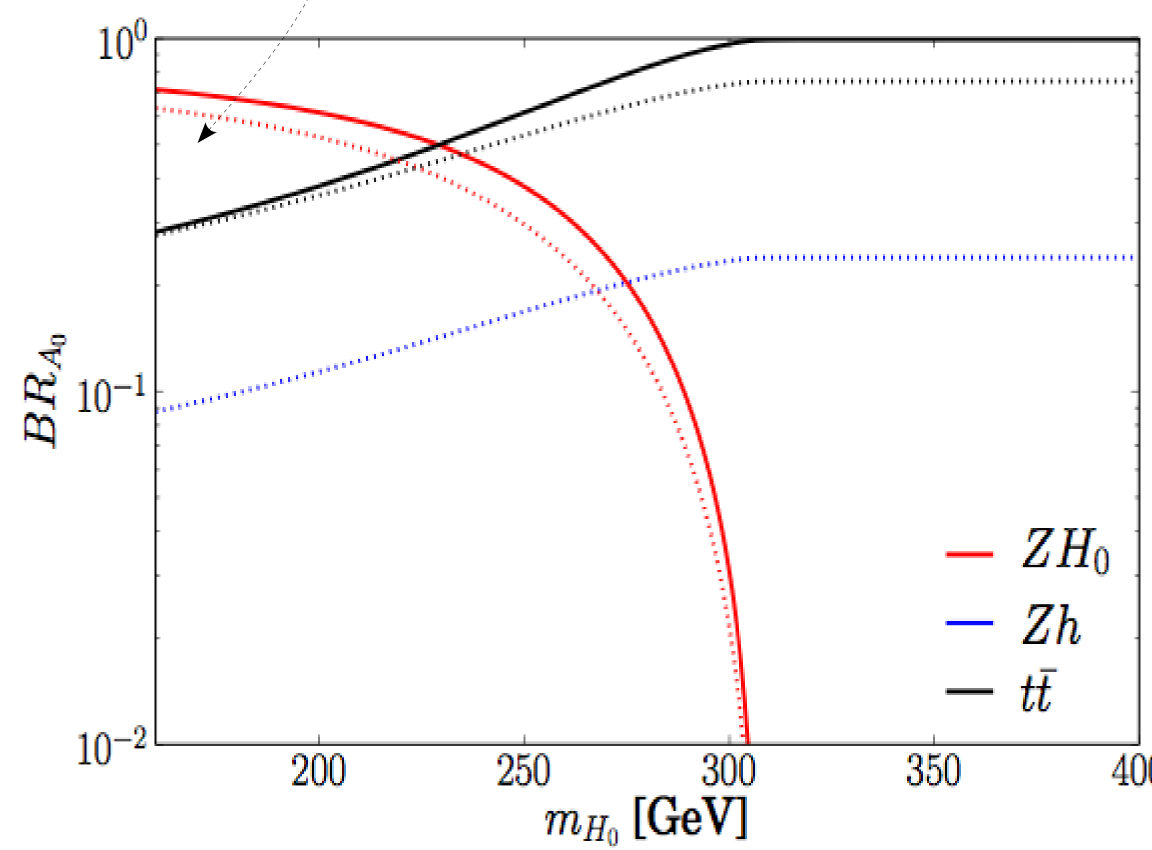

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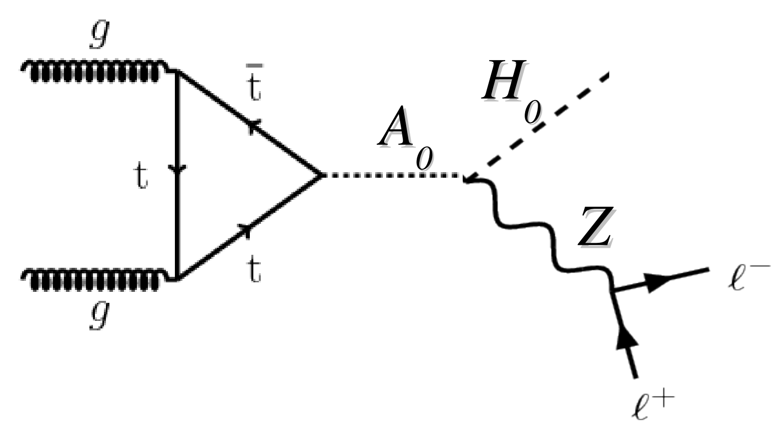
  $m_{A_0} = m_{H^\pm} = 400,\ m_{H_0} = 180,\ \mu = 100$

  $\tan\beta = 2$ (controls $gg \to A_0$ production)

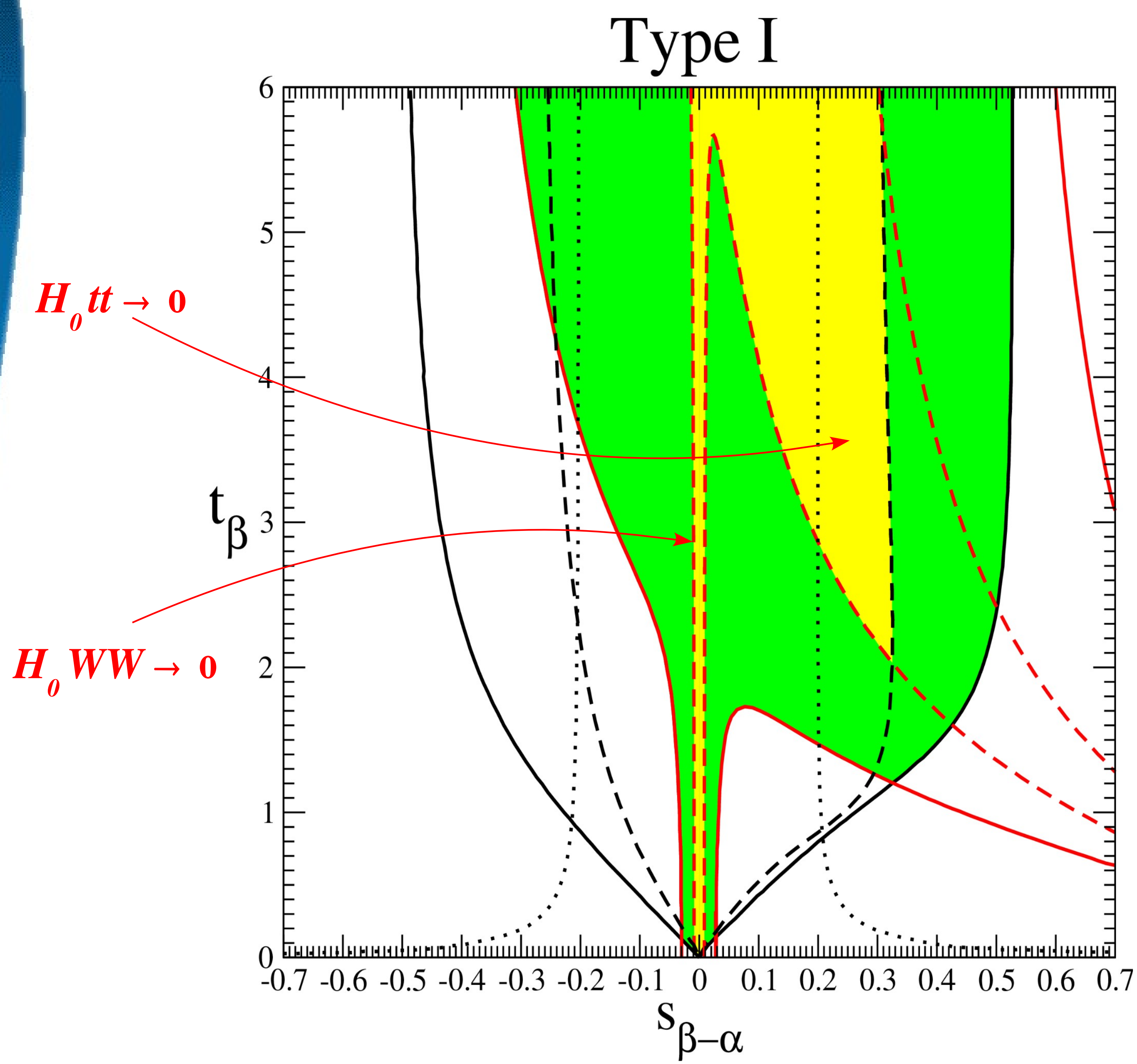
- *Search Strategy Dictated by Dominant Decay Mode of* H_0

  A: α-β = *0.001π* (aligned) $\bar{b}b$

  B: α-β = *0.1π* (non-aligned) WW, ZZ

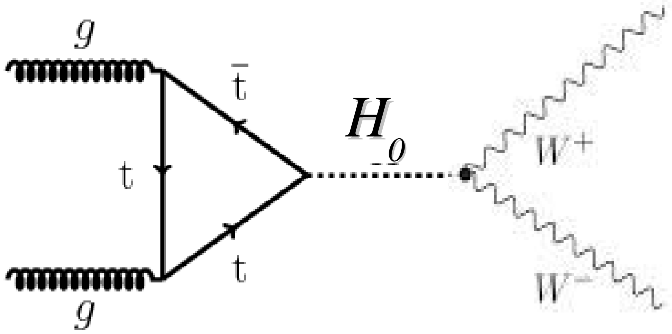


(A Word on H_0 searches at LHC)



G. Dorsch, S. Huber, K. Mimasu, J.M. N, In Preparation

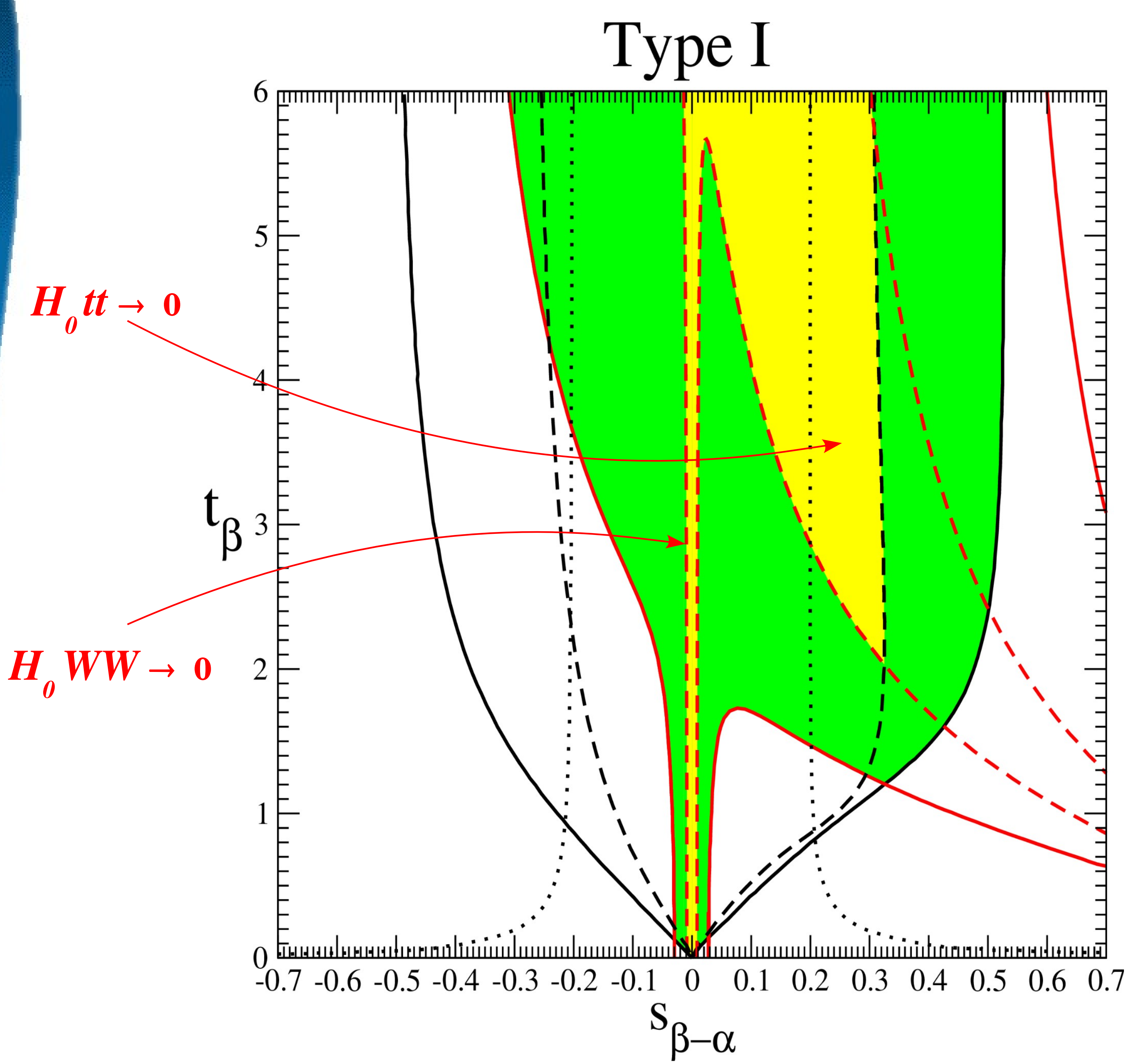
(m_{H_0} = 200 GeV)



+

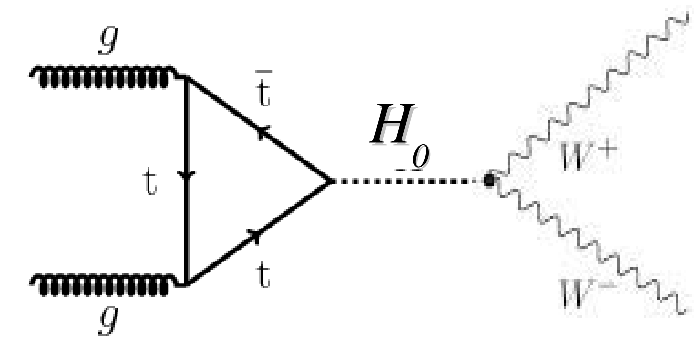
Measurements of light Higgs couplings

(A Word on H_0 searches at LHC)



G. Dorsch, S. Huber, K. Mimasu, J.M. N, In Preparation

$(m_{H_0} = 200 \text{ GeV})$



+

Measurements of light Higgs couplings

2HDM LHC Searches for a 1st Order EW Phase Transition Naturally fill the "Blind Spots"

2HDM @LHC

LHC DISCOVERY POTENTIAL OF BENCHMARK SCENARIOS

➊ *A few words on the Analysis...*

⇨ Type I 2HDM implemented in **FeynRules** (including gluon-fusion).

⇨ Signal & relevant backgrounds generated using **MadGraph5_aMC@NLO**. Generated events passed on to **Pythia** for Parton Showering and Hadronization and subsequently to **Delphes** for detector simulation.

→ Use of NLO flat K-factors for signal (**SusHi**) and dominant backgrounds.

⇨ "Cut & Count" analysis on a small set of kinematical variables, to extract signal over background.

⇨ Determined required Integrated Luminosity at 14 TeV to achieve 5 statistical significance via a CLs hypothesis test.

Only statistical uncertainties.
10% systematic uncertainty on background.

⇨ Also considered current 8 TeV LHC data for $\bar{b}b\,\ell\ell$

2HDM @LHC

LHC DISCOVERY POTENTIAL OF BENCHMARK SCENARIOS

❷ *Benchmark* A: $A_0 \to H_0\, Z \to \bar{b}b\, \ell\ell$ (α-β = 0.001π)

⇨ *Irreducible backgrounds are* $Z\bar{b}b,\ \bar{t}t,\ ZZ,\ hZ$

⇨ *Analysis at 14 TeV* (potential sensitivity already with 7-8 TeV LHC data): ***Event Selection***

ATLAS-CONF-2013-079

→ *Anti-kT Jets with distance parameter* $R = 0.6$

→ 2 *b-tagged Jets with* |η| < 2.5

→ 2 *Isolated (within a cone of 0.3), Same-flavour leptons.* |η| < 2.5 (2.7) for electrons (muons)

→ $P_T^{\ell_1} > 40$ GeV, $P_T^{\ell_2} > 20$ GeV.

K-factor:	1.6	1.5	1.4	-	-
	Signal	$t\bar{t}$	$Z\, b\bar{b}$	ZZ	$Z\,h$
Event selection	14.6	1578	424	7.3	2.7
$80 < m_{\ell\ell} < 100$ GeV	13.1	240	388	6.6	2.5
$H_T^{\rm bb} > 150$ GeV, $H_T^{\ell\ell \rm bb} > 280$ GeV	8.2	57	83	0.8	0.74
$\Delta R_{bb} < 2.5$, $\Delta R_{\ell\ell} < 1.6$	5.3	5.4	28.3	0.75	0.68
m_{bb}, $m_{\ell\ell bb}$ signal region	3.2	1.37	3.2	< 0.01	< 0.02

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Invariant mass windows:

$m_{\bar{b}b} \to (m_{H_0} - 20) \pm 30\,\text{GeV}$

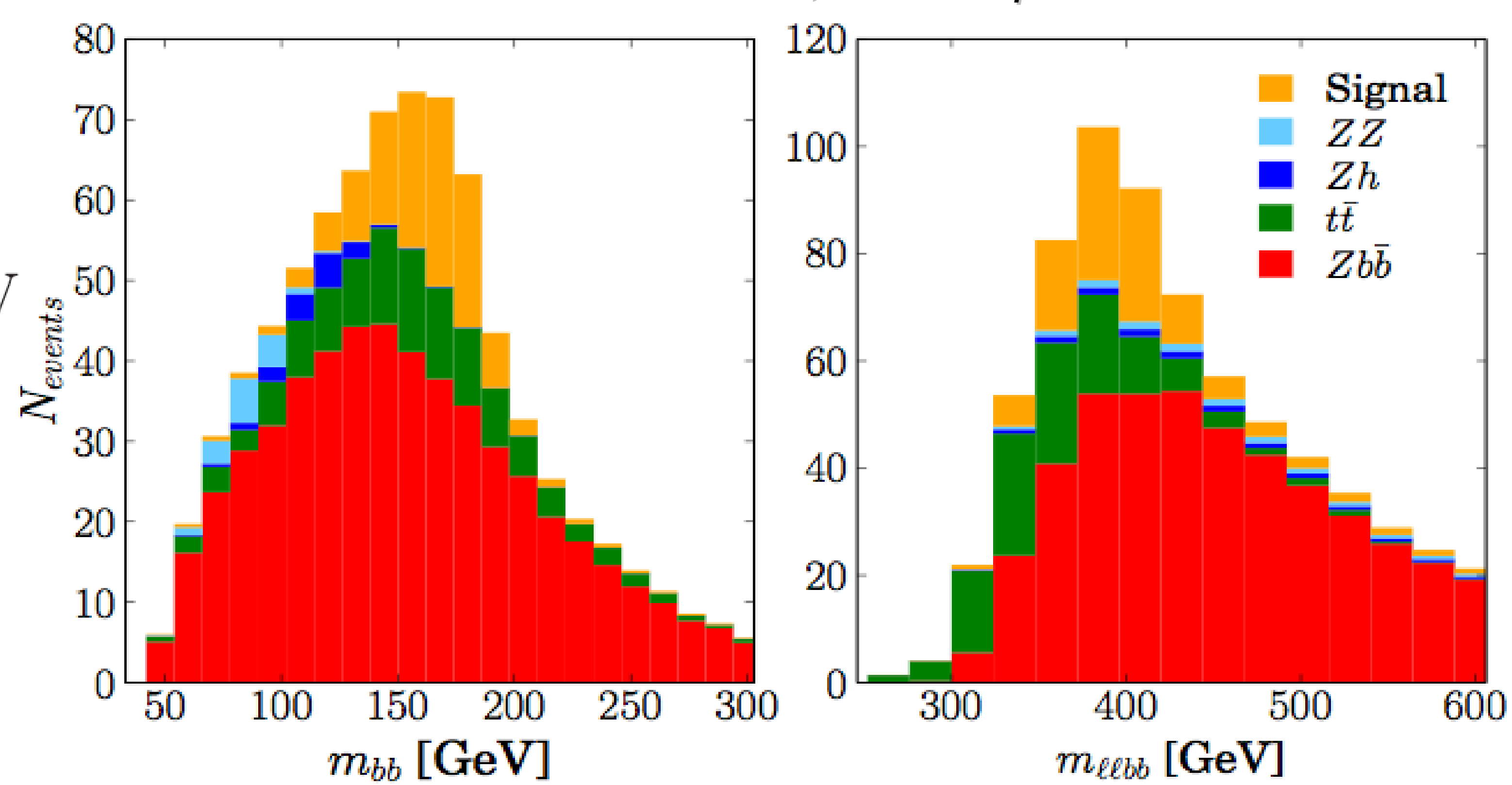
$m_{\ell\ell\bar{b}b} \to (m_{A_0} - 20) \pm 40\,\text{GeV}$

5σ signal significance for:

$\mathscr{L} \doteq 15\ fb^{-1}$ *(statistics only)*

$\mathscr{L} = 40\ fb^{-1}$ *(10% systematics)*

14 TeV LHC, $\mathscr{L} = 20\ fb^{-1}$



2HDM @LHC

LHC DISCOVERY POTENTIAL OF BENCHMARK SCENARIOS

❸ *Benchmark* B: $A_0 \to H_0\, Z \to W^+W^-\ell\ell \to 4\ell + 2\nu$ (α-β = 0.1π)

- ⇨ Most sensitive A_0 search channel away from alignment
- ⇨ $A_0 \to H_0\, Z \to ZZ\ell\ell \to 4\ell + 2j$ *also promising*

  *B. Coleppa, F. Kling, S. Su, JHEP **1409** (2014) 161*
- ⇨ *Main backgrounds are* ZZ, $Z\bar{t}t$ hZ, ZWW subdominant
- ⇨ *Analysis & Event Selection similar to previous case:*

  → 4 Isolated (cone of 0.3) leptons, same-flavour pairs. $|\eta| < 2.5\ (2.7)$ for electrons (muons)

  → $P_T^{\ell_1} > 40\ GeV$, $P_T^{\ell_{2,3,4}} > 20\ GeV$.

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  - → $P_T^{\ell_1} > 40$ GeV, $P_T^{\ell_{2,3,4}} > 20$ GeV.

→ *1 pair of SF leptons must reconstruct* m_Z

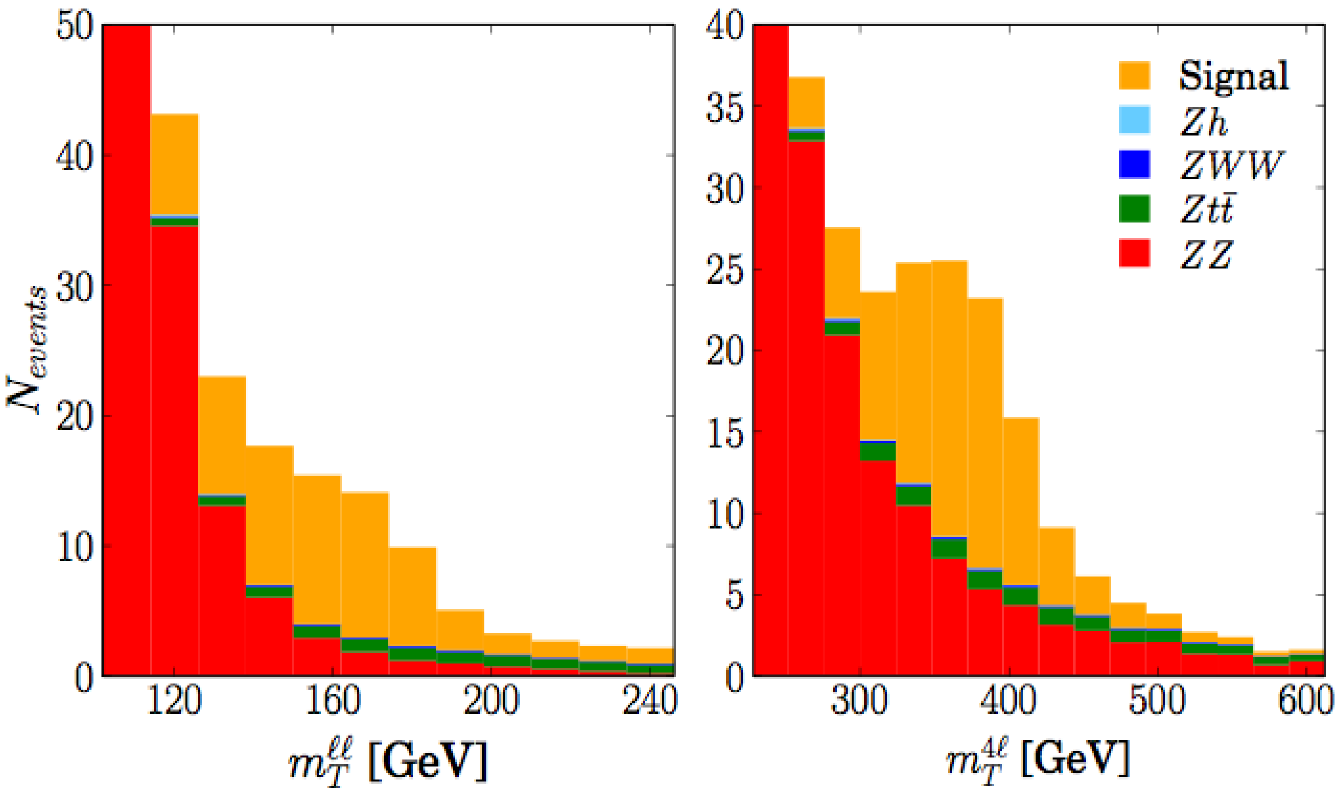
→ *Transverse mass variables*:

$$(m_T^{\ell\ell})^2 = \left(\sqrt{p^2_{T,\ell\ell} + m^2_{\ell\ell}} + \not{p}_T\right)^2 - (\vec{p}_{T,\ell\ell} + \vec{\not{p}}_T)^2$$

$$m_T^{4\ell} = \sqrt{p^2_{T,\ell'\ell'} + m^2_{\ell'\ell'}} + \sqrt{p^2_{T,\ell\ell} + (m_T^{\ell\ell})^2}$$

$m_T^{4\ell} > 260$ *GeV allows for Signal Extraction*

14 TeV LHC, $\mathscr{L}$ *= 60 fb*$^{-1}$



2HDM @LHC

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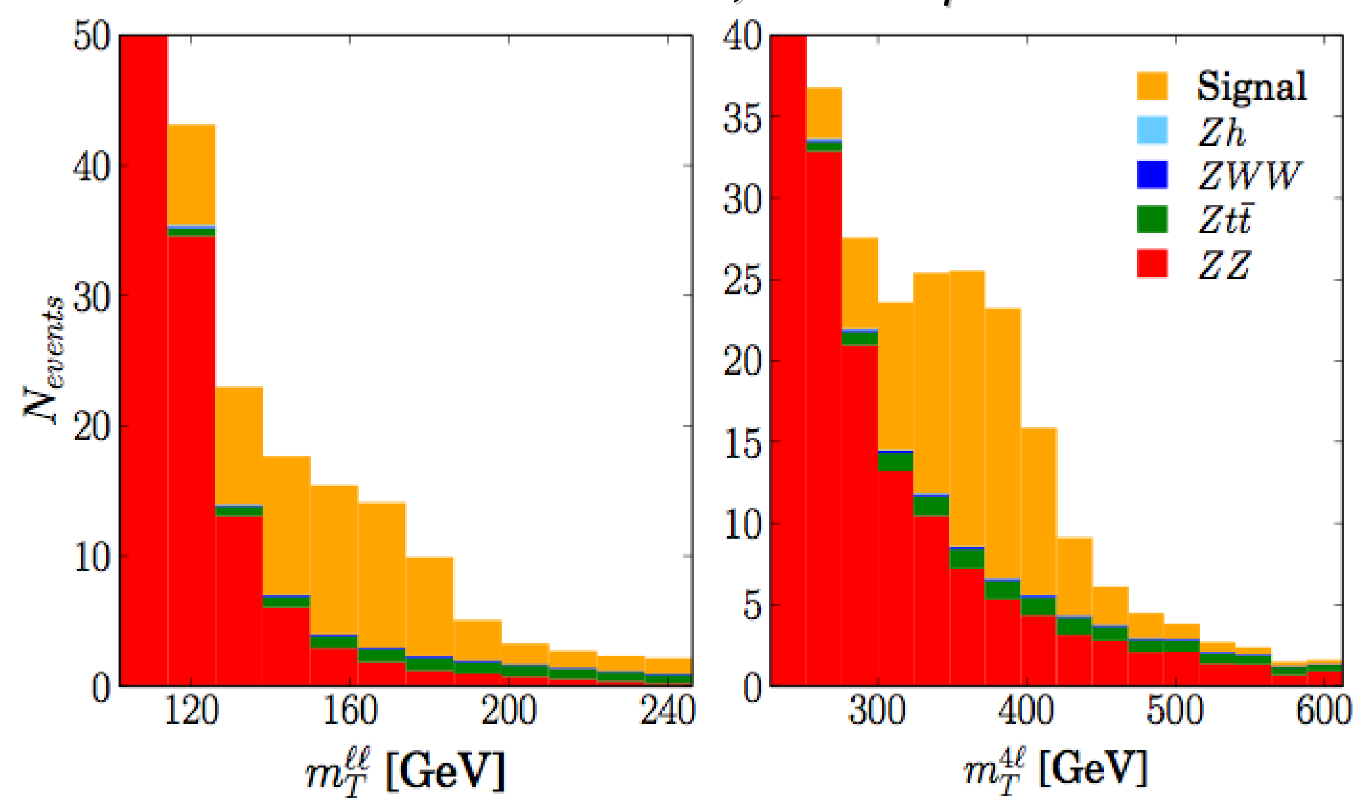


5σ signal significance for:

$\mathscr{L}$ = 60 fb^{-1} *(statistics only)*

$\mathscr{L}$ = 200 fb^{-1} *(10% systematics)*

(conservative...)

2HDM Summary

Very clear connection between
EW Phase Transition & LHC signatures

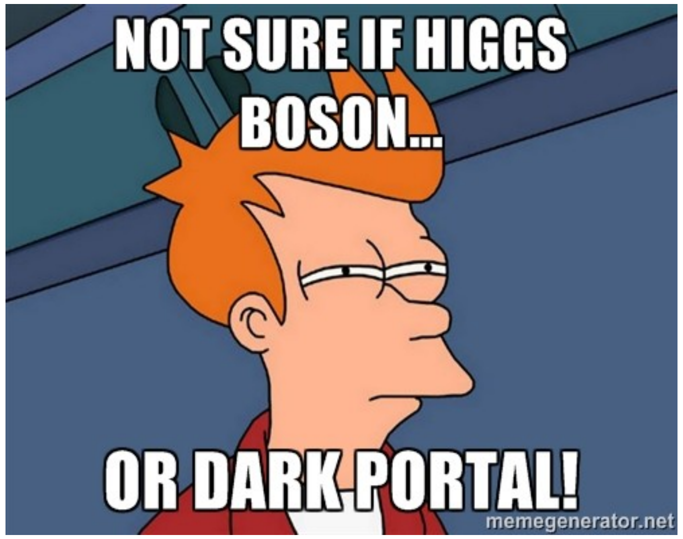
$$A_0 \to H_0\, Z \to \bar{b}b\, \ell\ell$$

$$A_0 \to H_0\, Z \to W^+W^-\ell\ell \to 4\ell + 2\nu$$

2HDM @LHC really promising!

Higgs Portal

R. Schabinger, J. Wells, Phys. Rev. **D72** (2005) 093007
B. Patt, F. Wilczek, hep-ph/0605188



$|\mathbf{H}|^2$ unique Lorentz & Gauge Invariant term w. d < 4

SM + (Real) Scalar Singlet S

$$V(H,S) = -\mu^2 |H|^2 + \lambda |H|^4 + \frac{b_2}{2} S^2 + \frac{b_4}{4} S^4 + \frac{a_1}{2} S|H|^2 + \frac{a_2}{2} S^2 |H|^2 + \frac{b_3}{3} S^3$$

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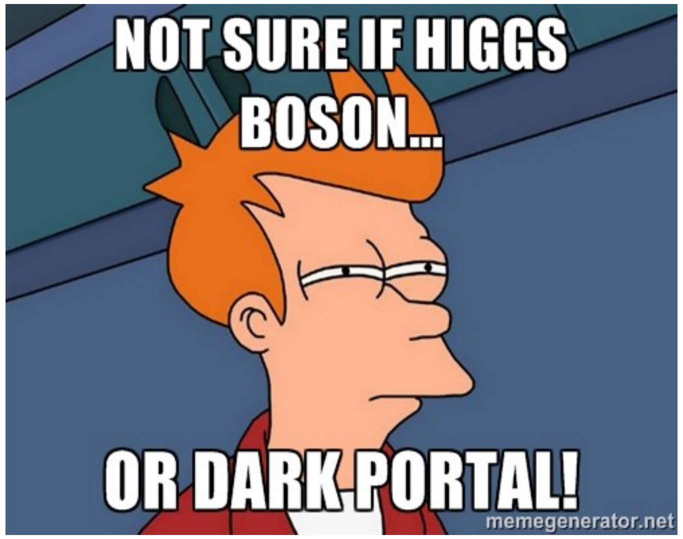

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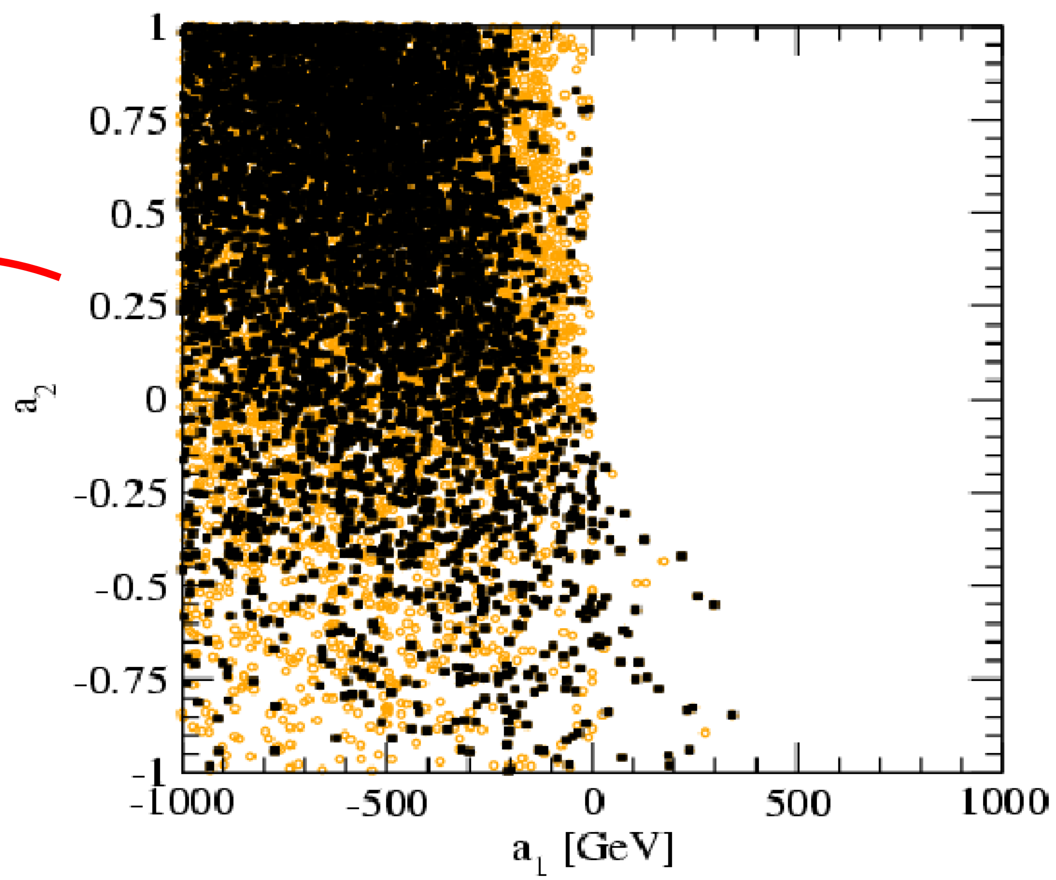
Singlet-Doublet Mixing

Scenarios w. Scalar Singlets can Lead to 1st Order EW Phase Transition

G. Anderson, L. Hall, Phys. Rev. **D45** (1992) 2685
J. R. Espinosa, M. Quiros, Phys. Lett. B **305** (1993) 98
S. Profumo, M. Ramsey-Musolf, G. Shaughnessy, JHEP **0708** (2007) 010
J. R. Espinosa, T. Konstandin, J. M. N, M. Quiros, Phys. Rev. **D78** (2008) 123528
J. R. Espinosa, T. Konstandin, F. Riva, Nucl. Phys. **B854** (2012) 592

A Strong EW Phase Transition
strongly prefers $a_1 < 0$ (Mixing)



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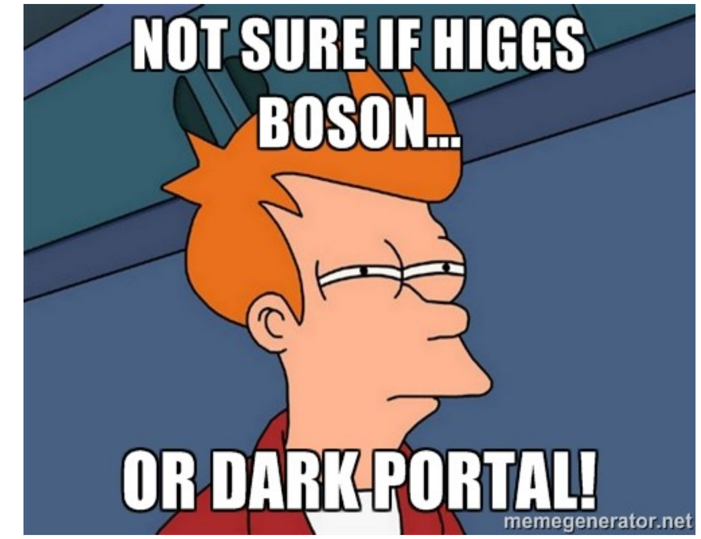

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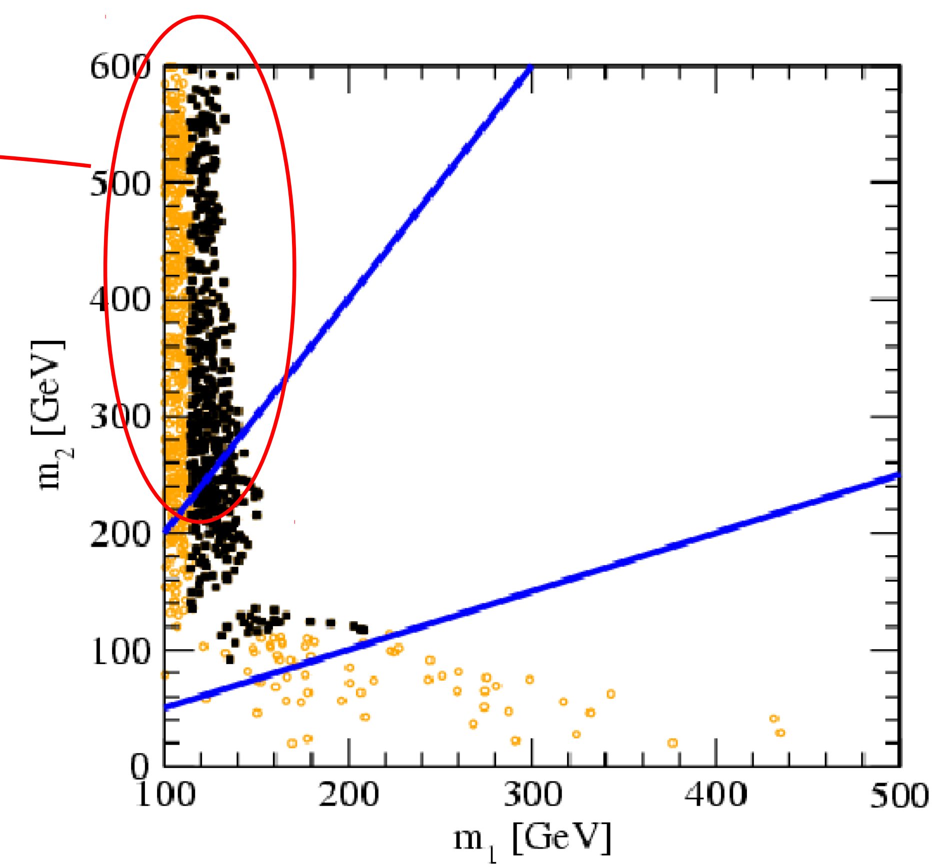
*J. R. Espinosa, T. Konstandin, F. Riva, Nucl. Phys. **B854** (2012) 592*

Decay Channel $h_2 \rightarrow h_1 h_1$

$$\lambda_{211} = b_3 s_\theta^2 c_\theta + a_2 v s_\theta (c_\theta^2 - s_\theta^2/2) + \frac{a_1}{4} c_\theta (c_\theta^2 - 2 s_\theta^2) - 3\lambda v c_\theta^2 s_\theta$$

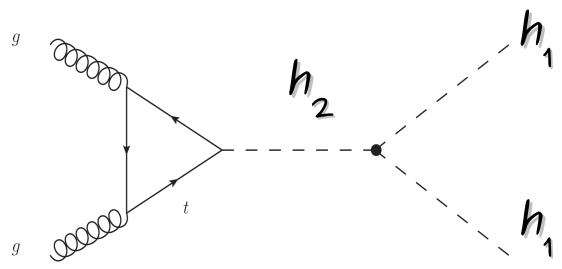
RESONANT HIGGS PAIR PRODUCTION @LHC

*J. M. N, M. Ramsey-Musolf, Phys. Rev. **D89** (2014) 095031*



*S. Profumo, M. Ramsey-Musolf, G. Shaughnessy, JHEP **0708** (2007) 010*

Higgs Portal @LHC



➔ Resonant Di-Higgs Production

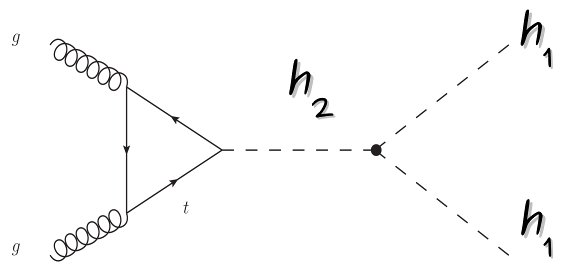
M. Dolan, C. Englert, M. Spannowsky, Phys. Rev. ***D87*** *(2013) 5, 055002*

J. Cao, Z. Heng, L. Shang, P. Wan, J. M. Yang, JHEP ***1304*** *(2013) 134*

J. M. N, M. Ramsey-Musolf, Phys. Rev. ***D89*** *(2014) 095031*

$bb\tau\tau$, $bb\gamma\gamma$ final states

Higgs Portal @LHC



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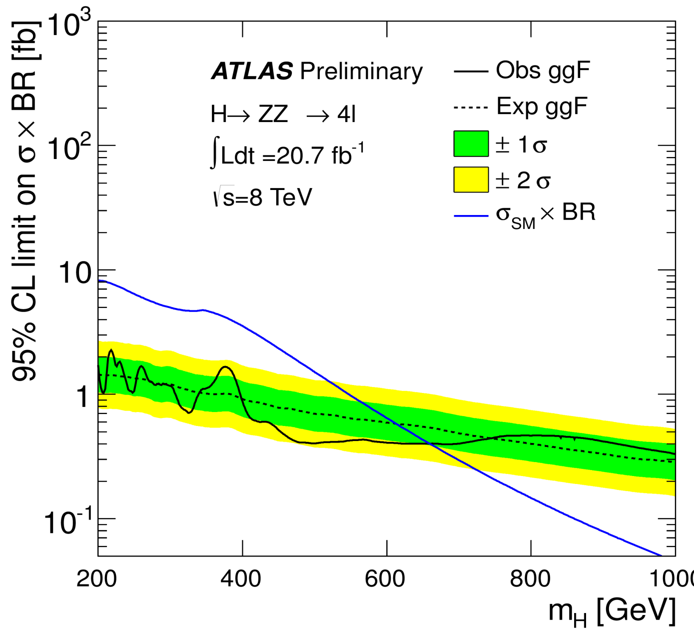
Potential Discovery Mode of h_2 (if $h_2 \rightarrow ZZ$ suppressed)



Probe of the EW Phase Transition

Higgs Portal @LHC

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*M. Dolan, C. Englert, M. Spannowsky, Phys. Rev. **D87** (2013) 5, 055002*

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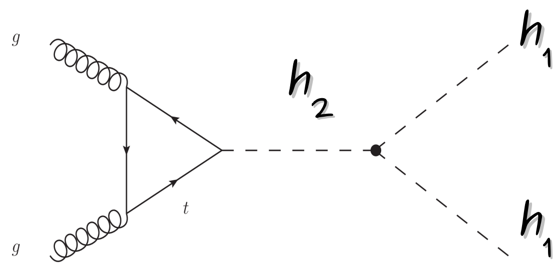

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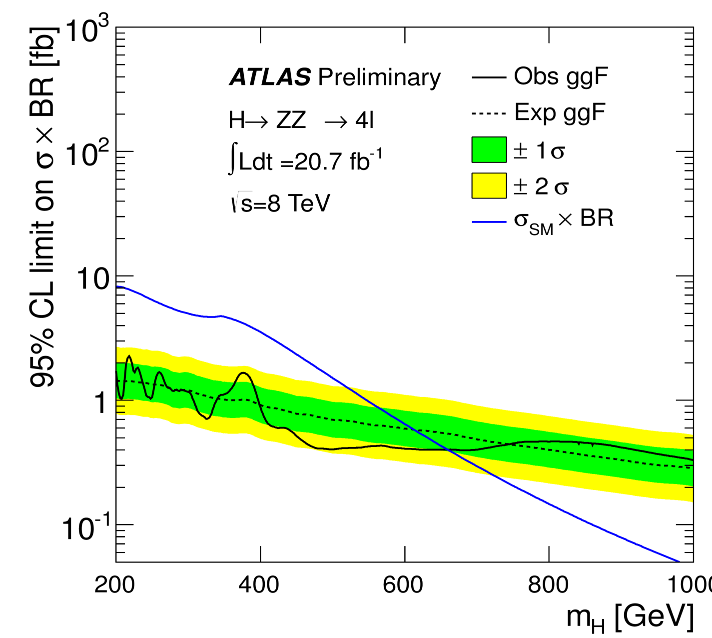


Probe of the EW Phase Transition

... Need to be combined with light Higgs data

S. Profumo, M. Ramsey-Musolf, C. Wainwright, P. Winslow, arXiv:1407.5342

A very interesting search!

M. Ramsey-Musolf, J.M.N, P. Winslow, et al, In Preparation

Higgs Portal @LHC

$p\,p \rightarrow h_2 \rightarrow h_1\, h_1 \rightarrow bb\, \tau\tau$

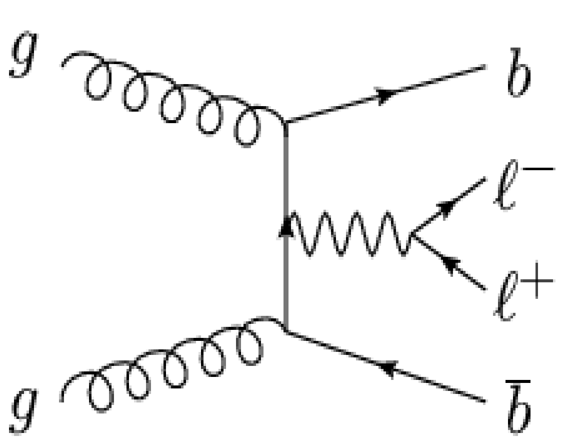
Classify according to Leptonic/Hadronic Nature of each τ-Decay

Benchmark Scenarios:

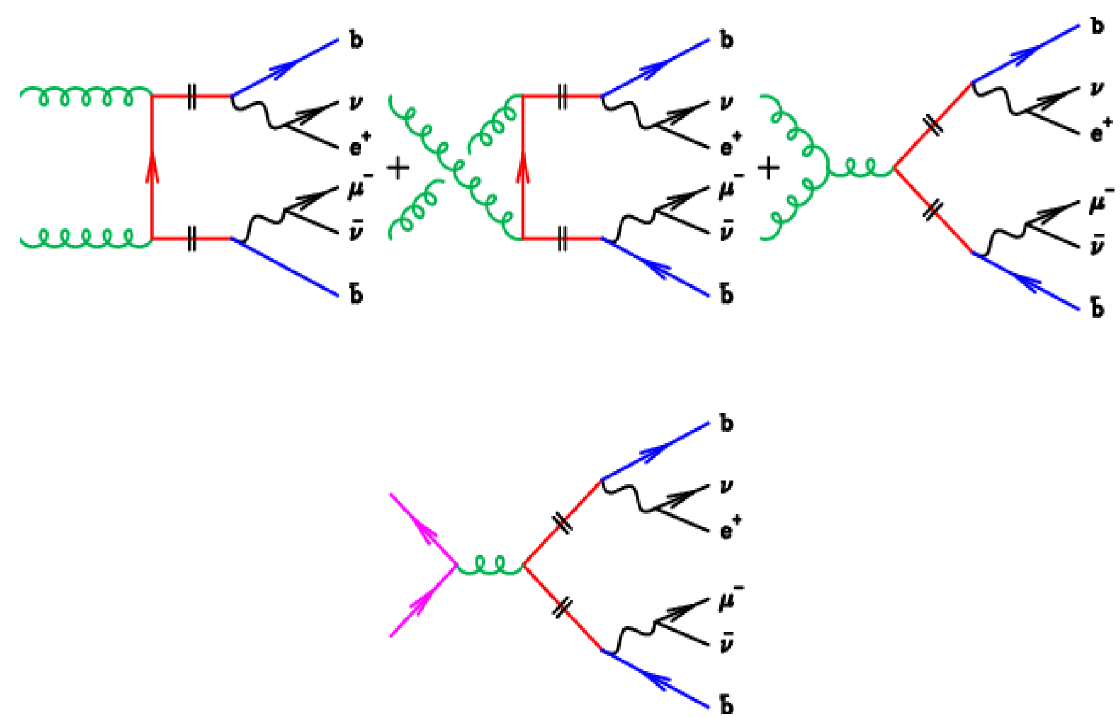
- Un-Boosted: $C_\theta^{\,2} \approx 0.66$, $m_2 \approx 270$ GeV , $\lambda_{211} \approx 325$ GeV
- Boosted: $C_\theta^{\,2} \approx 0.66$, $m_2 \approx 370$ GeV , $\lambda_{211} \approx 325$ GeV

Main SM Backgrounds

Z bb



tt



Higgs Portal @LHC

$p\,p \rightarrow h_2 \rightarrow h_1\; h_1 \rightarrow bb\; \tau\tau$

Classify according to Leptonic/Hadronic Nature of each τ-Decay

Need to Reconstruct both 125 GeV Higgses m_{bb}, $m_{\tau\tau}$ but *τ-Decay involves missing Energy*

⇨ COLLINEAR APPROXIMATION

R. Ellis, I. Hinchliffe, M. Soldate, J. J. van der Bij, Nucl. Phys. ***B297*** *(1988) 221.*

$$x_{1,2} = \frac{p^{\rm vis}_{1,2}}{p^{\rm vis}_{1,2} + p^{\rm mis}_{1,2}}$$

$$m^{\rm coll}_{\tau\tau} = \frac{m^{\rm vis}_{\tau\tau}}{\sqrt{x_1\, x_2}}$$

$$p^{\rm mis}_1 = \frac{\sin(\phi^{\rm vis}_2)E^{\rm miss}_{Tx} - \cos(\phi^{\rm vis}_2)E^{\rm miss}_{Ty}}{\sin(\theta^{\rm vis}_1)\sin(\phi^{\rm vis}_2 - \phi^{\rm vis}_1)}$$

$$p^{\rm mis}_2 = \frac{\cos(\phi^{\rm vis}_1)E^{\rm miss}_{Ty} - \sin(\phi^{\rm vis}_1)E^{\rm miss}_{Tx}}{\sin(\theta^{\rm vis}_2)\sin(\phi^{\rm vis}_2 - \phi^{\rm vis}_1)}$$

(needs boosted Higgs)

⇨ MISSING MASS CALCULATOR

A. Elagin, P. Murat, A. Pranko, A. Safonov, Nucl. Instrum. Meth. ***A654*** *(2011) 481*

Higgs Portal @LHC

$p\, p \rightarrow h_2 \rightarrow h_1\, h_1 \rightarrow bb\, \tau\tau$

SemiLeptonic Mode: $\tau_{lep}\tau_{had}$

UN-BOOSTED

	$h_2 \to h_1 h_1$	$t\bar{t}$		$Z\, b\bar{b}$	$Z\, jj$
	$bb\tau_{\rm lep}\tau_{\rm had}$	$bb\ell\tau_{\rm had}$	$bb\tau_{\rm lep}\tau_{\rm had}$	$bb\tau_{\rm lep}\tau_{\rm had}$	$jj\tau_{\rm lep}\tau_{\rm had}$
Event selection	19.17	5249	762	601	98
$\Delta R_{bb} > 2.1$, $P_{T,b_1} > 45$ GeV, $P_{T,b_2} > 30$ GeV	11.45	2639	384	188	10.8
h_1-mass: 90 GeV $< m_{bb} <$ 140 GeV	8.00	531	80	69	3.68
Collinear x_1, x_2 Cuts	4.81	209	36.4	41.6	2.41
$\Delta R_{\ell\tau} > 2$	4.10	129	23.1	26.5	2.03
$m_T^\ell < 30$ GeV	3.44	30.9	11.1	24.4	1.90
h_1-mass: 110 GeV $< m_{\tau\tau}^{\rm coll} <$ 150 GeV	1.56	4.97	2.05	4.92	0.38
$E_T^{\rm miss} < 50$ GeV	1.37	3.31	0.87	4.29	0.36
h_2-mass: 230 GeV $< m_{bb\tau\tau}^{\rm coll} <$ 300 GeV	1.29	0.39	0.17	1.21	0.13

$S/\sqrt{B} \sim 5 \rightarrow L \sim 50\ fb^{-1}$

BOOSTED

	$h_2 \to h_1 h_1$	$t\bar{t}$		$Z\, b\bar{b}$	$Z\, jj$
	$bb\tau_{\rm lep}\tau_{\rm had}$	$bb\ell\tau_{\rm had}$	$bb\tau_{\rm lep}\tau_{\rm had}$	$bb\tau_{\rm lep}\tau_{\rm had}$	$jj\tau_{\rm lep}\tau_{\rm had}$
Event selection	10.73	5249	762	601	98
$\Delta R_{bb} < 2.2$, $P_{T,b_1} > 50$ GeV, $P_{T,b_2} > 30$ GeV	6.02	1576	223	85	2.46
h_1-mass: 90 GeV $< m_{bb} <$ 140 GeV	4.77	672	94	31.5	0.84
$\lvert\vec{P}_T^{bb}\rvert > 110$ GeV	3.42	345	49	13.9	0.33
Collinear x_1, x_2 Cuts	2.31	136	22.3	8.38	0.22
$\Delta R_{\ell\tau} < 2.3$	1.71	68	11.1	4.31	0.055
$m_T^\ell < 30$ GeV	1.46	18.4	5.64	4.02	0.051
h_1-mass: 110 GeV $< m_{\tau\tau}^{\rm coll} <$ 150 GeV	1.05	4.2	1.26	0.30	0.003
25 GeV $< E_T^{\rm miss} <$ 90 GeV	0.76	2.93	0.75	0.23	0.002
h_2-mass: 330 GeV $< m_{bb\tau\tau}^{\rm coll} <$ 400 GeV	0.63	0.60	0.15	0.026	< 0.001

$S/\sqrt{B} \sim 5 \rightarrow L \sim 100\ fb^{-1}$

Conclusions

EW Baryogenesis as Motivation
for BSM Physics Near EW Scale

Extended Higgs Sectors: Archetype Scenarios for such a Connection between EW Cosmology and LHC Physics

2HDM:

EW Phase Transition "Smoking Gun"

$$A_0 \to H_0\, Z \to \bar{b}b\, \ell\ell$$

$$A_0 \to H_0\, Z \to W^+W^-\ell\ell \to 4\ell + 2\nu$$

HIGGS PORTAL: Resonant Di-Higgs Production

These Results Motivate Taking
These Searches Seriously @LHC14

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Let's Stay tuned @LHC14!

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Let's Stay tuned @LHC14!

Thanks!!

ATLAS $\bar{b}b\,\ell\ell$ at 7-8 TeV

[ATLAS-CONF-2013-079]

- *Defines signal regions according to number of leptons, additional jets.*
- *Splits them according to the p_T of the Z (no m_{bb} requirement).*
- *Global fit extracts the background normalisations and signal strength of a 125 GeV SM Higgs.*
- P_T^Z *in our signal set by* $m_{A_0} - m_{H_0}$. *Signal will populate boosted kinematical region.*