TeVPA 2019 at the University of Sydney

Testing the EWPT of 2HDM at future lepton Colliders

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1912.xxxxx (WS, M. White, A. Williams, M. Zhang)
1910.06269 (WS)
1909.09035 (WS, M. White, A. Williams, Y. Wu)

outline

- Precision measurements at lepton collider
- 2HDM: Brief Introduction
- Individual constraints: theory, EW, Higgs, flavour
- Results and Conclusion

SM-like Higgs

CMS-HIG-14-042
ATLAS-HIGG-2014-14

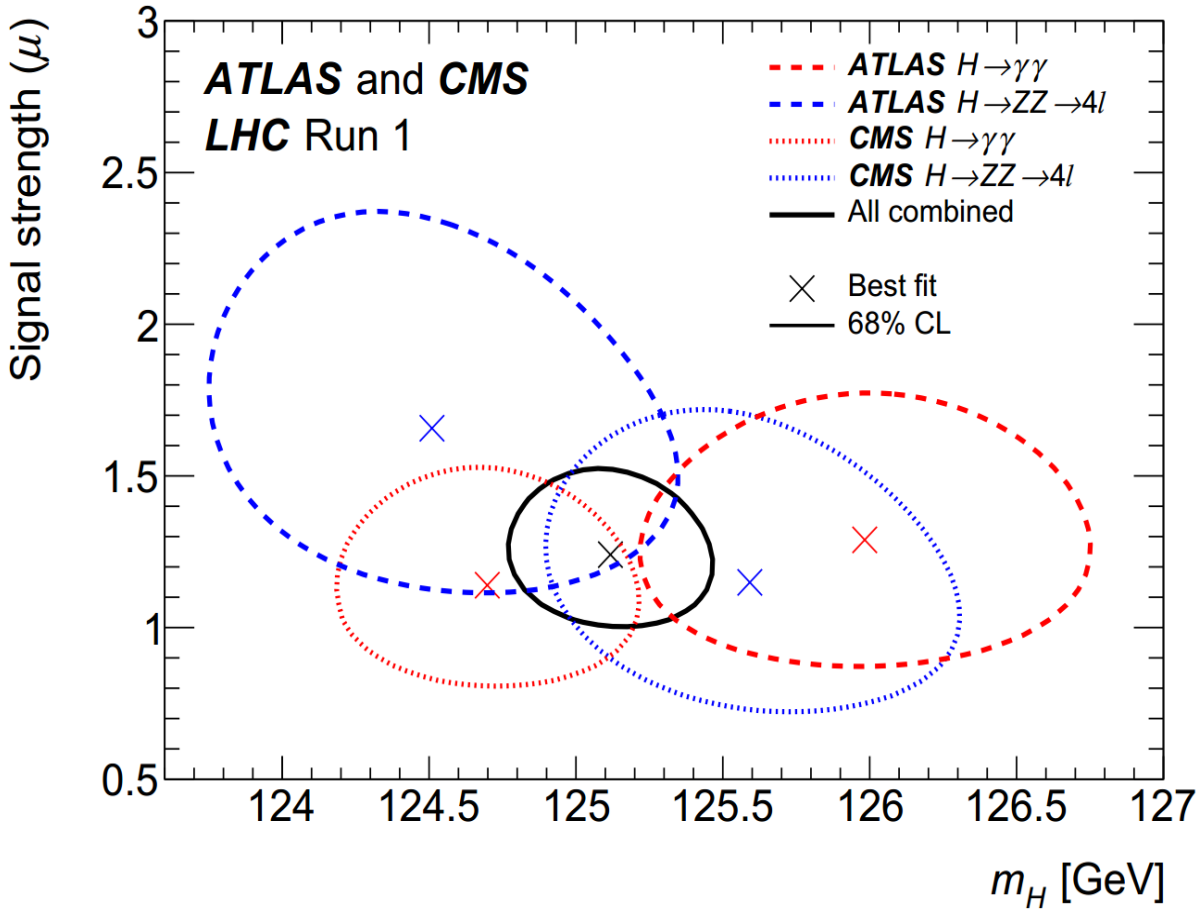
LHC Run-I:

$m_h = 125.09 \pm 0.24$ GeV

LHC Run-II

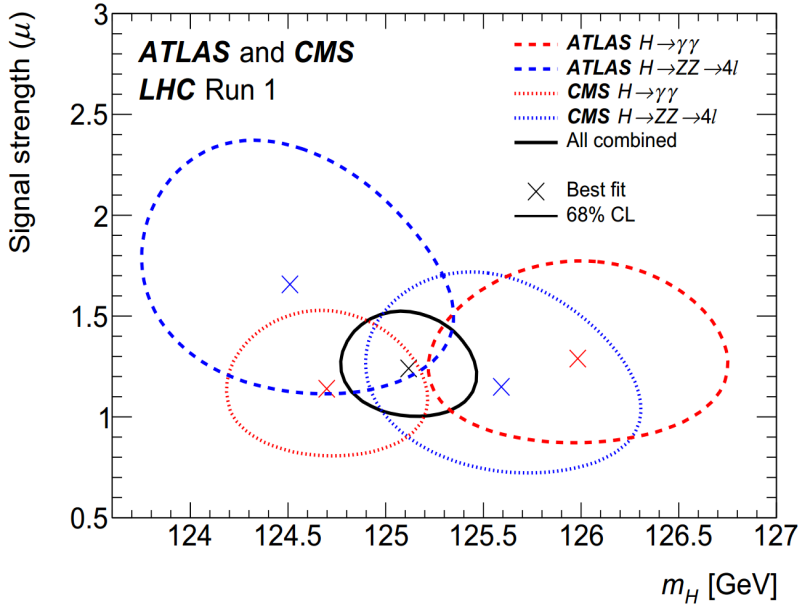
$\Delta = 160$ MeV

1. Higgs property
2. Higgs potential: EWPT

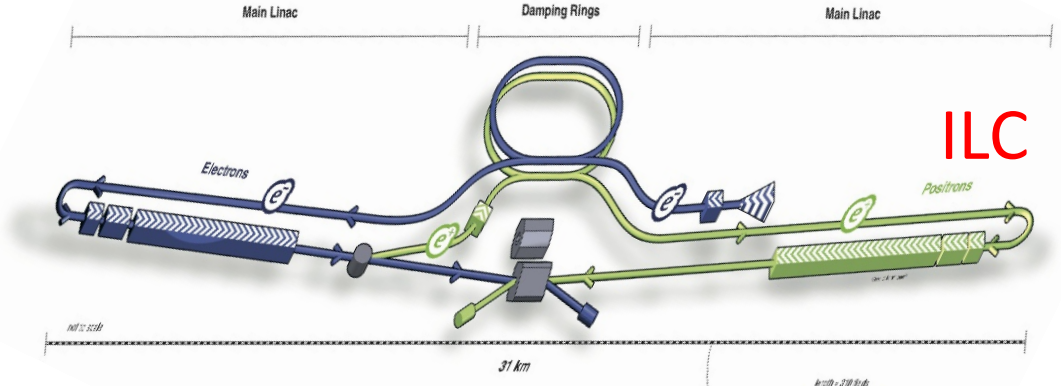


Precision Measurements

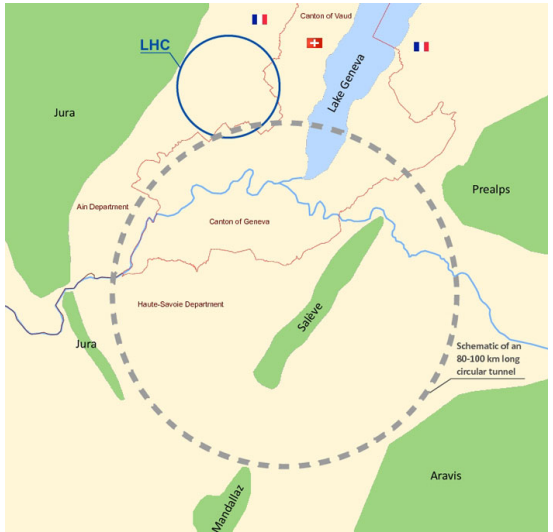
CMS-HIG-14-042
ATLAS-HIGG-2014-14



CEPC



ILC



LHC
HL-LHC
FCC

Precision: Higgs mass

CMS-HIG-14-042
ATLAS-HIGG-2014-14

LHC Run-I:

$m_h = 125.09 \pm 0.24$ GeV

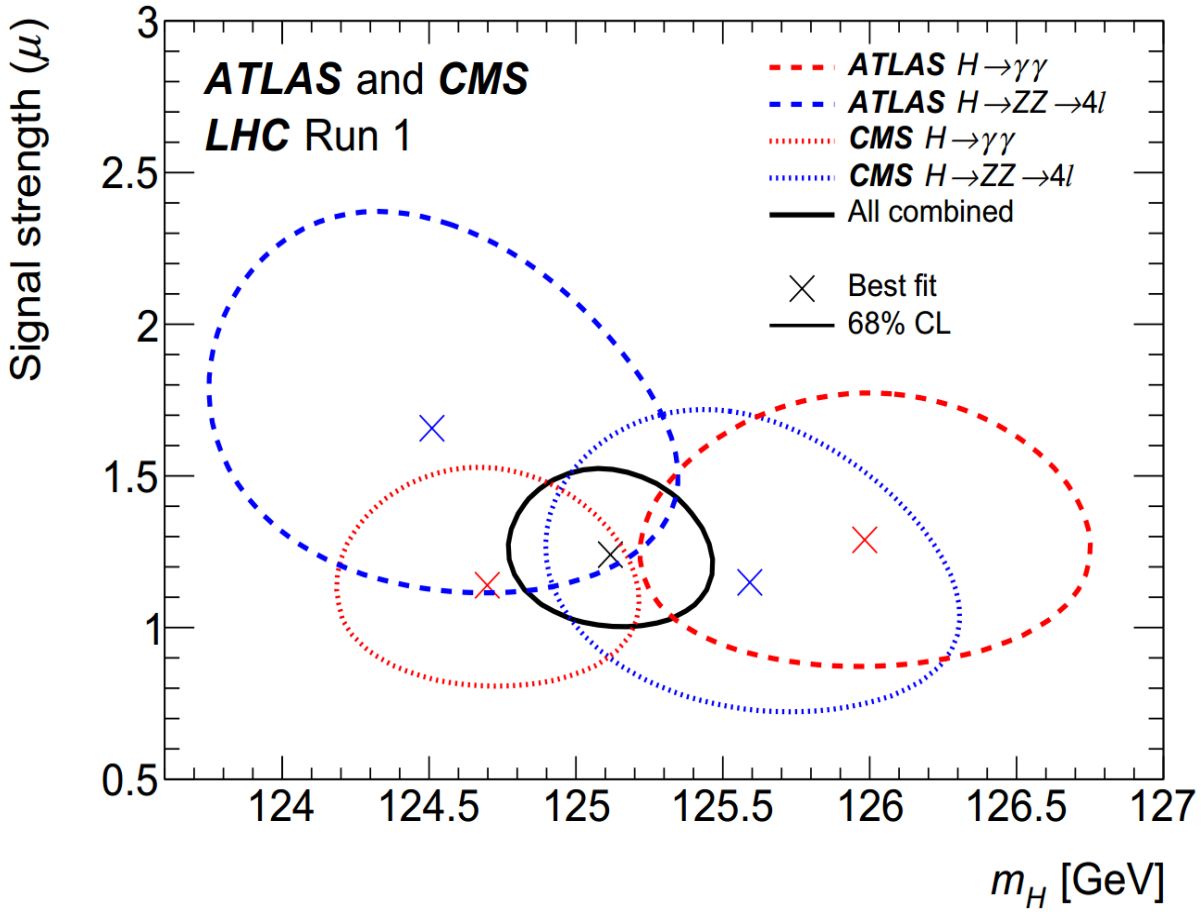
LHC Run-II

$\Delta = 160$ MeV

HL-LHC

$\Delta = 10 - 20$ MeV

CEPC: $\Delta m_h = 5.9$ MeV



Precision: Higgs couplings

CEPC-CDR , FCC-ee, ILC Operating Scenarios

collider	CEPC	FCC-ee			ILC				
$\sqrt{s}$	240 GeV	240 GeV	365 GeV		250 GeV	350 GeV		500 GeV	
$\int \mathcal{L}dt$	5.6 ab^{-1}	5 ab^{-1}	1.5 ab^{-1}		2 ab^{-1}	200 fb^{-1}		4 ab^{-1}	
production	Zh	Zh	Zh	$\nu\bar{\nu}h$	Zh	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$
$\Delta\sigma/\sigma$	0.5%	0.5%	0.9%	–	0.71%	2.0%	–	1.05	–
decay	$\Delta(\sigma \cdot BR)/(\sigma \cdot B$								
$h \to b\bar{b}$	0.27%	0.3%	0.5%	0.9%	0.46%				
$h \to c\bar{c}$	3.3%	2.2%	6.5%	10%	2.9%	12.3%	21.2%	4.5%	2.2%
$h \to gg$	1.3%	1.9%	3.5%	4.5%	2.5%	9.4%	8.6%	3.8%	1.5%
$h \to WW^*$	1.0%	1.2%	2.6%	3.0%	1.6%	6.3%	6.4%	1.9%	0.85%
$h \to \tau^+\tau^-$	0.8%	0.9%	1.8%	8.0%	1.1%	4.5%	17.9%	1.5%	2.5%
$h \to ZZ^*$	5.1%	4.4%	12%	10%	6.4%	28.0%	22.4%	8.8%	3.0%
$h \to \gamma\gamma$	6.8%	9.0%	18%	22%	12.0%	43.6%	50.3%	12.0%	6.8%
$h \to \mu^+\mu^-$	17%	19%	40%	–	25.5%	97.3%	178.9%	30.0%	25.0%
$(\nu\bar{\nu})h \to b\bar{b}$	2.8%	3.1%	–	–	3.7%	–	–	–	–

1608.06619 P. Huang, A. Long, LT. Wang

Precision: Higgs couplings

CEPC-CDR , FCC-ee, ILC Operating Scenarios

collider	CEPC	FCC-ee			ILC				
$\sqrt{s}$	240 GeV	240 GeV	365 GeV		250 G				
$\int \mathcal{L}dt$	5.6 ab^{-1}	5 ab^{-1}	1.5 ab^{-1}		2 ab				
production	Zh	Zh	Zh	$\nu\bar{\nu}h$					
$\Delta\sigma/\sigma$	0.5%	0.5%	0.9%	–	0.7				
decay					$\Delta(\sigma \cdot BR)/$				
$h \to b\bar{b}$	0.27%	0.3%	0.5%	0.9%	0.4				
$h \to c\bar{c}$	3.3%	2.2%	6.5%	10%	2.				
$h \to gg$	1.3%	1.9%	3.5%	4.5%	2.				
$h \to WW^*$	1.0%	1.2%	2.6%	3.0%	1.6%	6.3%	6.4%	1.9%	0.85%
$h \to \tau^+\tau^-$	0.8%	0.9%	1.8%	8.0%	1.1%	4.5%	17.9%	1.5%	2.5%
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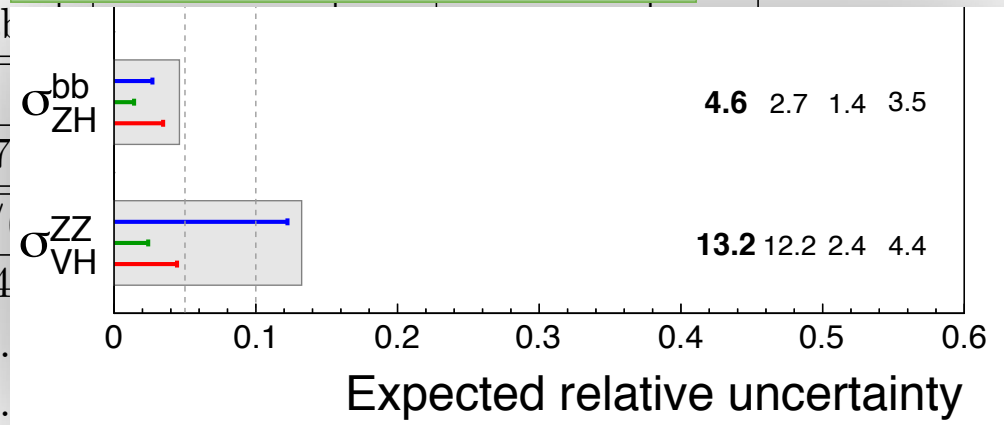
HL-LHC: 1902.00134



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production	Zh	Zh	Zh	$\nu\bar{\nu}h$					
$\Delta\sigma/\sigma$	0.5%	0.5%	0.9%	–	0.7				
decay					$\Delta(\sigma \cdot BR)/$				
$h \to b\bar{b}$	0.27%	0.3%	0.5%	0.9%	0.4				
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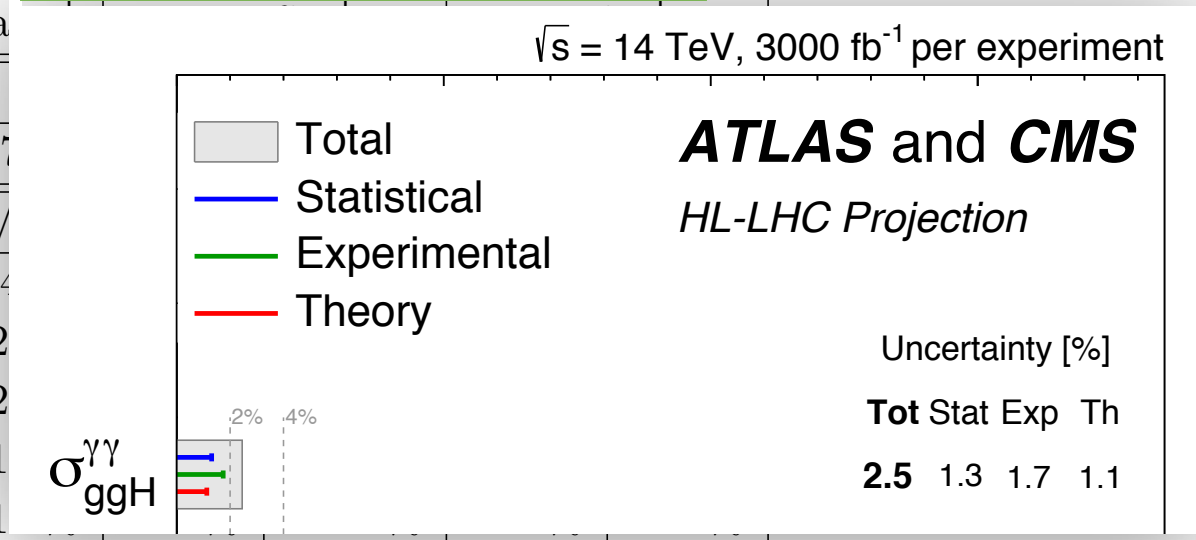
HL-LHC: 1902.00134



Precision: EW

	CEPC	ILC	FCC-ee
$\alpha_s(M_Z^2)$	$\pm 1.0 \times 10^{-4}$	$\pm 1.0 \times 10^{-4}$	$\pm 1.0 \times 10^{-4}$
$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$	$\pm 4.7 \times 10^{-5}$	$\pm 4.7 \times 10^{-5}$	$\pm 4.7 \times 10^{-5}$
m_Z [GeV]	± 0.0005	± 0.0021	$\pm 0.0001_{\rm exp}$
m_t [GeV] (pole)	$\pm 0.6_{\rm exp} \pm 0.25_{\rm th}$	$\pm 0.03_{\rm exp} \pm 0.1_{\rm th}$	$\pm 0.6_{\rm exp} \pm 0.25_{\rm th}$
m_h [GeV]	$< \pm 0.1$	$< \pm 0.1$	$< \pm 0.1$
m_W [GeV]	$(\pm 3_{\rm exp} \pm 1_{\rm th}) \times 10^{-3}$	$(\pm 5_{\rm exp} \pm 1_{\rm th}) \times 10^{-3}$	$(\pm 8_{\rm exp} \pm 1_{\rm th}) \times 10^{-3}$
$\sin^2\theta^{\ell}_{\rm eff}$	$(\pm 4.6_{\rm exp} \pm 1.5_{\rm th}) \times 10^{-5}$	$(\pm 1.3_{\rm exp} \pm 1.5_{\rm th}) \times 10^{-5}$	$(\pm 0.3_{\rm exp} \pm 1.5_{\rm th}) \times 10^{-5}$
Γ_Z [GeV]	$(\pm 5_{\rm exp} \pm 0.8_{\rm th}) \times 10^{-4}$	± 0.001	$(\pm 1_{\rm exp} \pm 0.8_{\rm th}) \times 10^{-4}$

CEPC-CDR , FCC-ee, ILC Operating Scenarios

Precision: EW

	CEPC	ILC	FCC-ee
$\alpha_s(M_Z^2)$	$\pm 1.0 \times 10^{-4}$	$\pm 1.0 \times 10^{-4}$	$\pm 1.0 \times 10^{-4}$
Γ_Z [GeV]	$(\pm 5_{\rm exp} \pm 0.8_{\rm th}) \times 10^{-4}$	± 0.001	$(\pm 1_{\rm exp} \pm 0.8_{\rm th}) \times 10^{-4}$

	Current (1.7×10^7 Z's)				CEPC ($10^{10} Z$'s)				FCC-ee ($7 \times 10^{11} Z$'s)				ILC ($10^9 Z$'s)			
	σ	correlation			σ (10^{-2})	correlation			σ (10^{-2})	correlation			σ (10^{-2})	correlation		
		S	T	U		S	T	U		S	T	U		S	T	U
S	0.04 ± 0.11	1	0.92	−0.68	2.46	1	0.862	−0.373	0.67	1	0.812	0.001	3.53	1	0.988	−0.879
T	0.09 ± 0.14	–	1	−0.87	2.55	–	1	−0.735	0.53	–	1	−0.097	4.89	–	1	−0.909
U	-0.02 ± 0.11	–	–	1	2.08	–	–	1	2.40	–	–	1	3.76	–	–	1

CEPC-CDR , FCC-ee, ILC Operating Scenarios

Precision: EW

	CEPC	ILC	FCC-ee
$\alpha_s(M_Z^2)$	$\pm 1.0 \times 10^{-4}$	$\pm 1.0 \times 10^{-4}$	$\pm 1.0 \times 10^{-4}$

	Current (1.7×10^7 Z's)				CEPC ($10^{10} Z$'s)				FCC-ee ($7 \times 10^{11} Z$'s)				ILC ($10^9 Z$'s)			
	σ	correlation			σ (10^{-2})	correlation			σ (10^{-2})	correlation			σ (10^{-2})	correlation		
		S	T	U		S	T	U		S	T	U		S	T	U
S	0.04 ± 0.11	1	0.92	−0.68	2.46	1	0.862	−0.373	0.67	1	0.812	0.001	3.53	1	0.988	−0.879
T	0.09 ± 0.14	–	1	−0.87	2.55	–	1	−0.735	0.53	–	1	−0.097	4.89	–	1	−0.909
U	-0.02 ± 0.11														–	1

$$\Delta S = \pm 0.0246\,, \quad \Delta T = \pm 0.0255\,, \quad \Delta U = \pm 0.0208$$

CEPC-CDR , FCC-ee, ILC Operating Scenarios

2HDM: Brief Introduction

- Two Higgs Doublet Model

$$\Phi_i = \begin{pmatrix} \phi_i^+ \\ (v_i + \phi_i^0 + iG_i)/\sqrt{2} \end{pmatrix}$$

$$v_u^2 + v_d^2 = v^2 = (246\text{GeV})^2$$
$$\tan\beta = v_u/v_d$$

$$\begin{pmatrix} H^0 \\ h^0 \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} \phi_1^0 \\ \phi_2^0 \end{pmatrix}, \quad \begin{aligned} A &= -G_1 \sin\beta + G_2 \cos\beta \\ H^\pm &= -\phi_1^\pm \sin\beta + \phi_2^\pm \cos\beta \end{aligned}$$

	Φ_1	Φ_2
Type I	u,d,l	
Type II	u	d,l
lepton-specific	u,d	l
flipped	u,l	d

- Parameters (CP-conserving, Z_2 Symmetry)

$m_{11}^2, m_{22}^2, \lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5$ → $v, \tan\beta, \alpha, m_h, m_H, m_A, m_{H^\pm}$

Soft Z_2 symmetry breaking: m_{12}^2

246 GeV

125. GeV

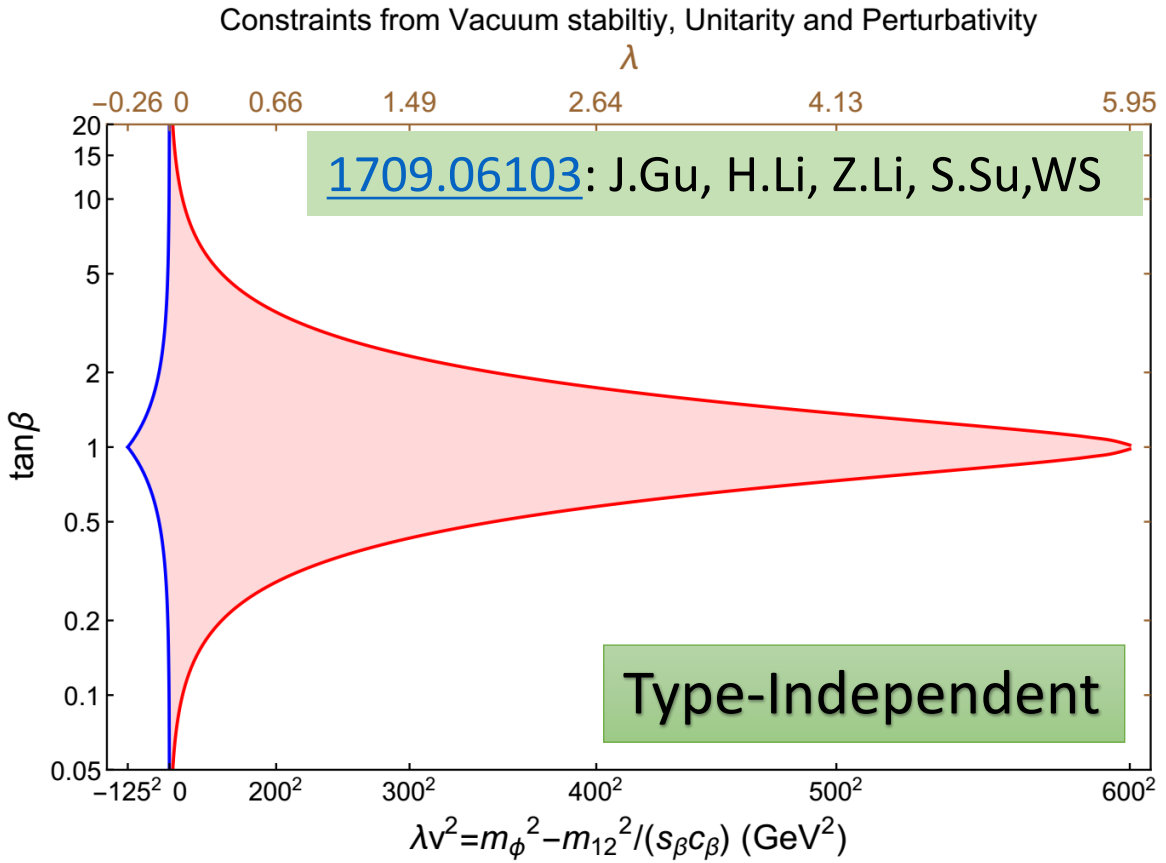
Constraints: theory

- Perturbativity
- Stability of the potential
- Unitarity of the scattering matrix

$$\cos(\beta-\alpha)=0,$$
$$m_\Phi \equiv m_H = m_A = m_{H^\pm}$$

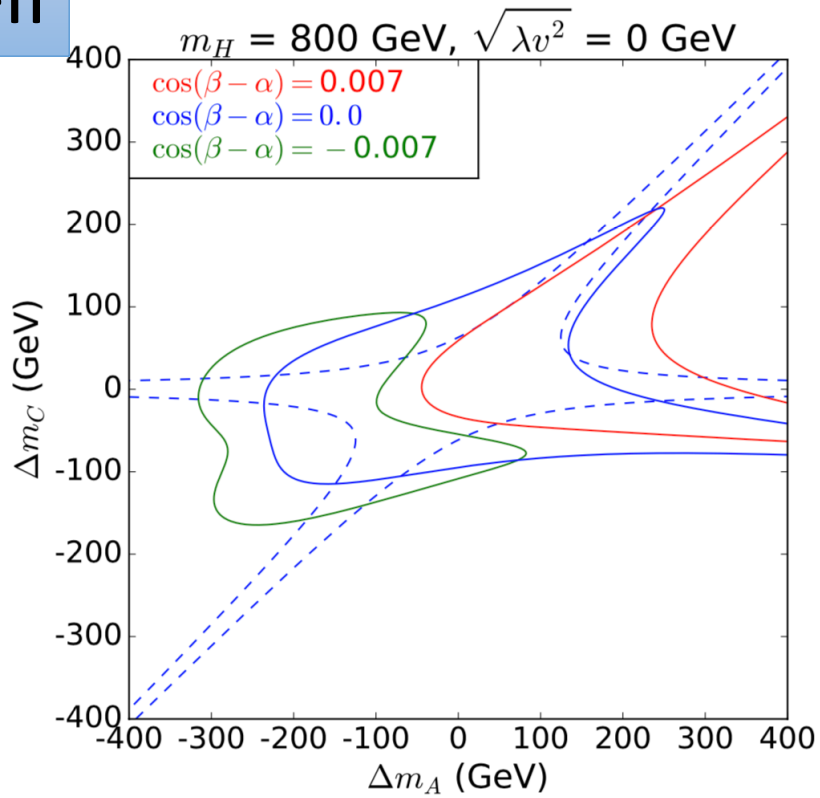
$$\lambda v^2 \equiv m_\Phi^2 - m_{12}^2/s_\beta c_\beta$$

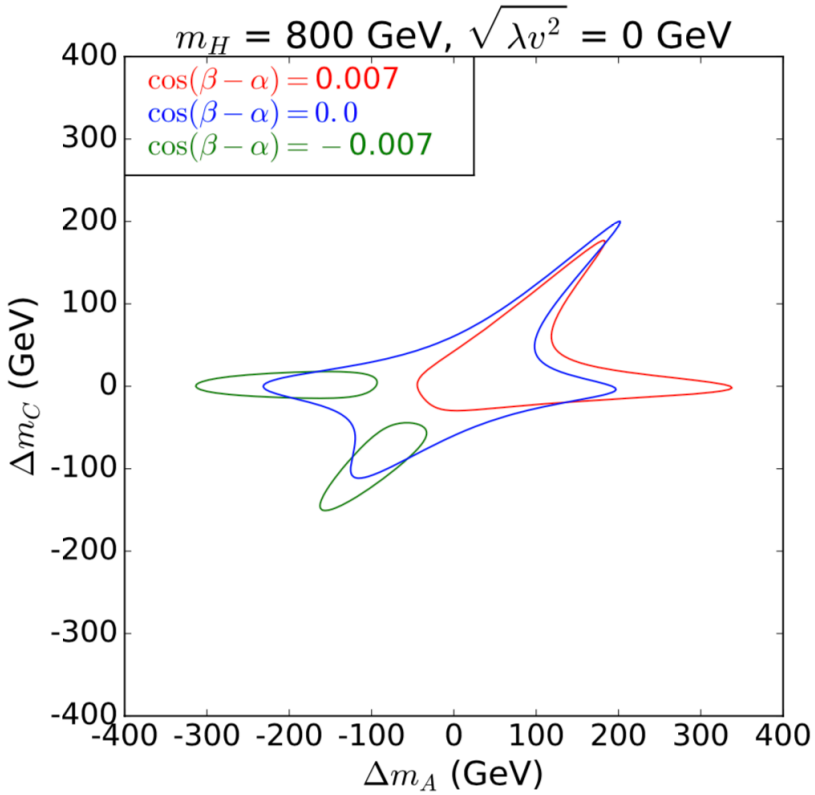
$$-125^2\,\mathrm{GeV}^2 < \lambda v^2 < 600^2\,\mathrm{GeV}^2$$



Constraints: EW+Higgs (indirect)

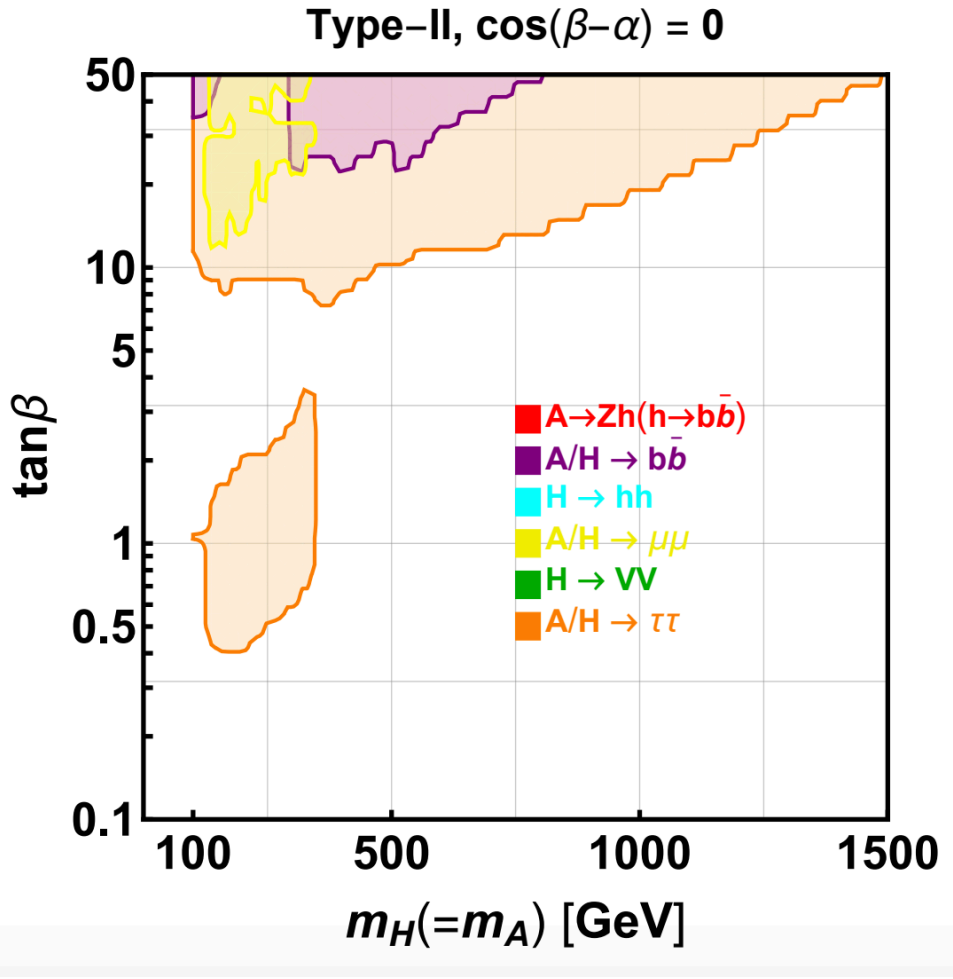
Type-II





Constraints: heavy Higgs (direct)

Type-II



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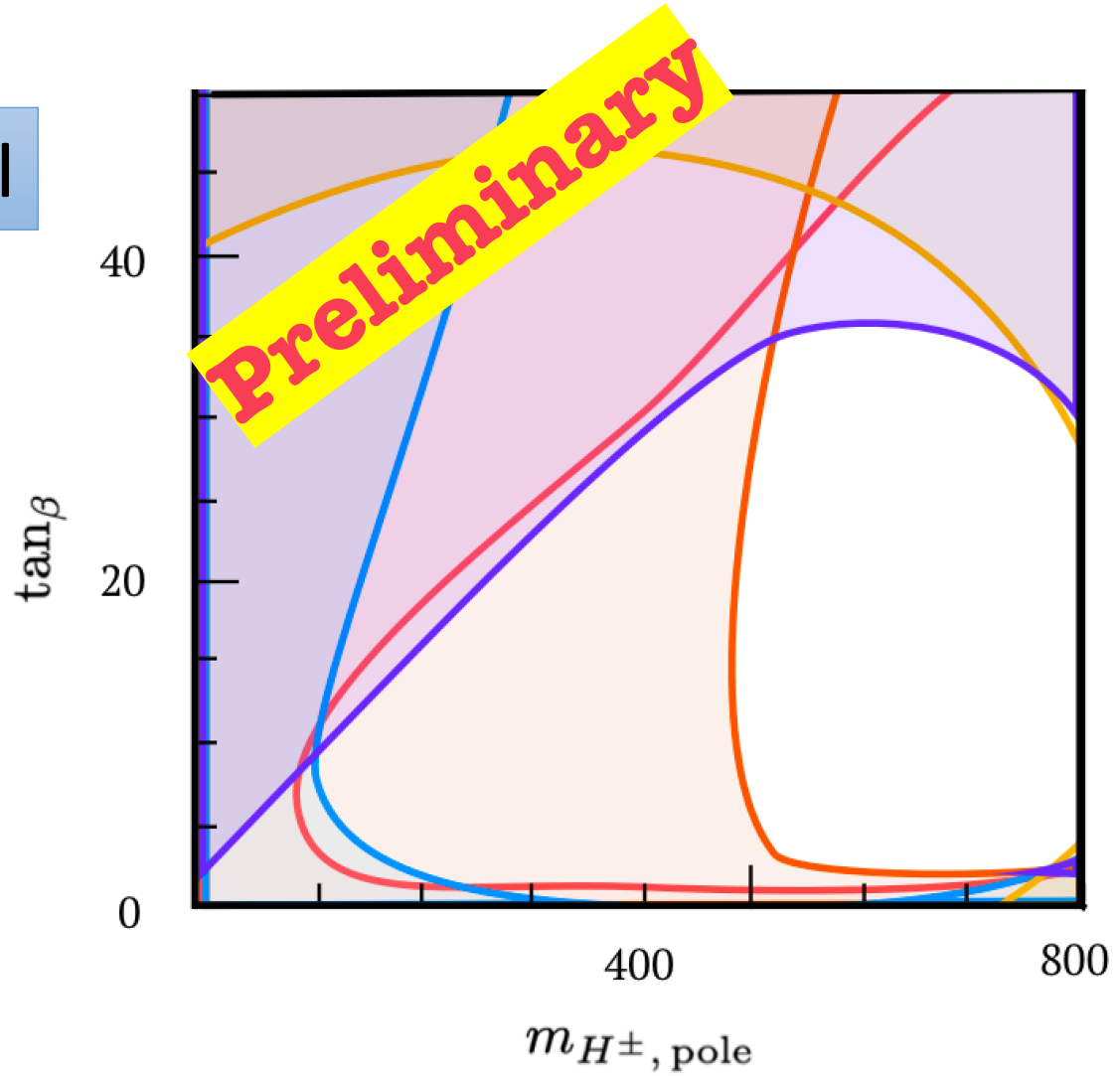
Constraints: flavor

Type-II



bsll

b2sgamma

MBs/MBd

LUV

SL

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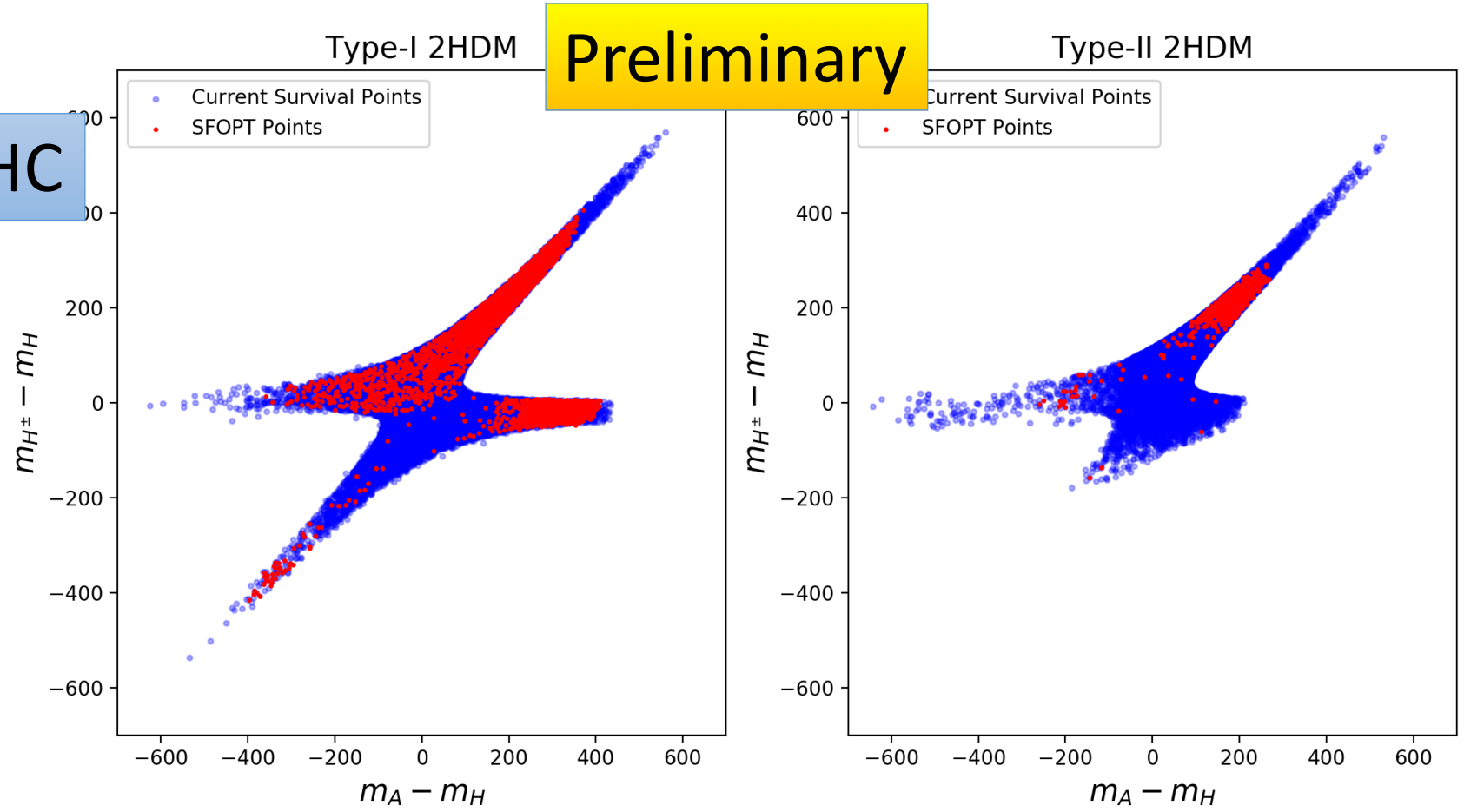
Results: Strong First Order Phase Transition

Allowed by LHC

SFOPT

Preliminary

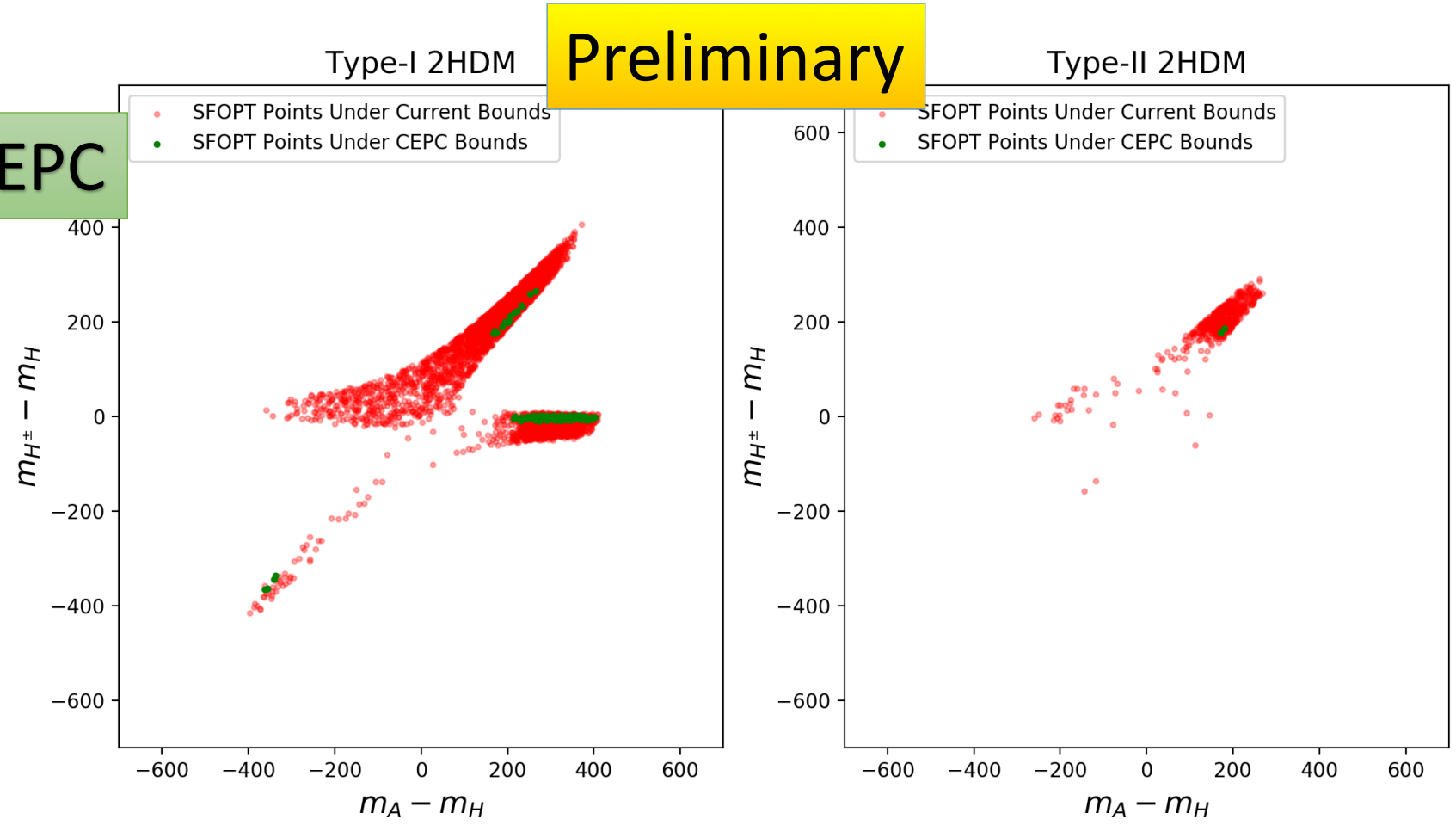


Results: Strong First Order Phase Transition

Allowed by CEPC

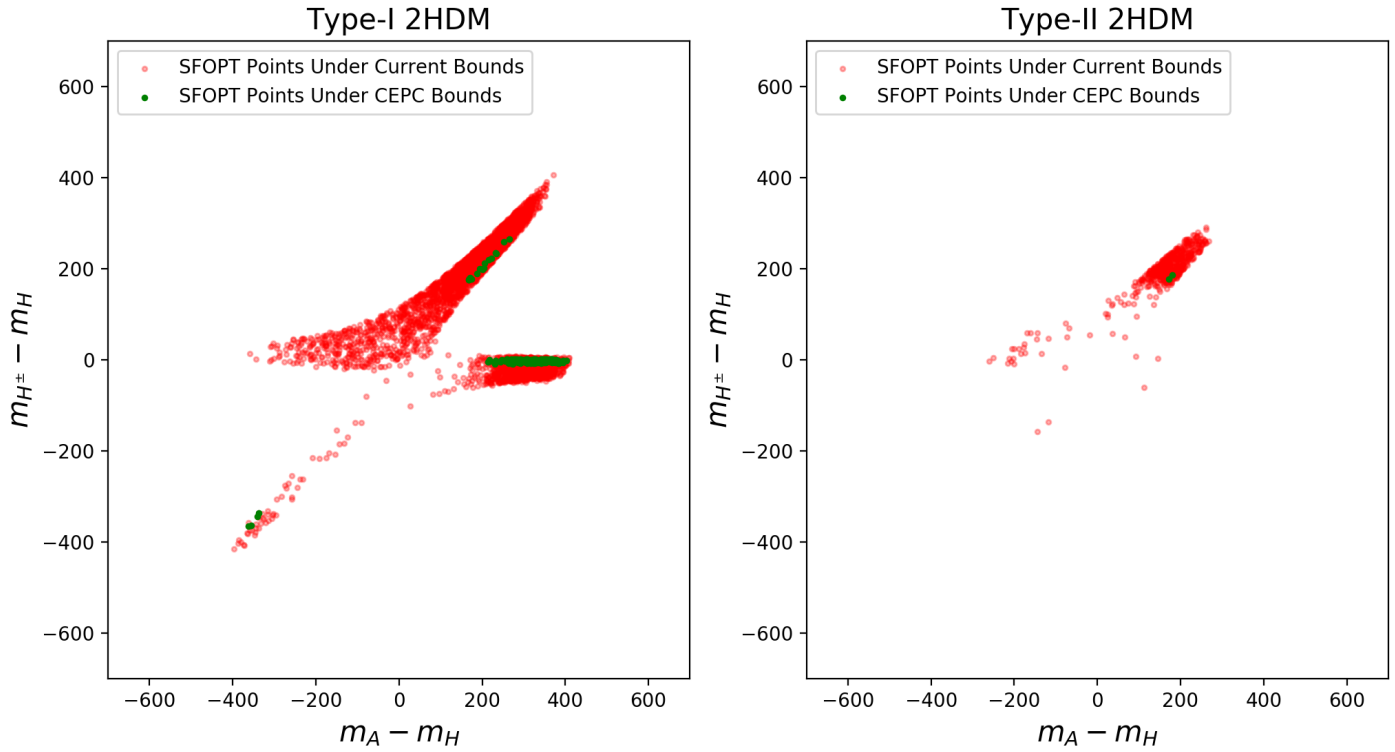
SFOPT

Preliminary



Conclusion

- Theory,
- EW,
- Higgs,
- flavour



Thanks!