Physics beyond the Standard Model in light of the CDF W boson mass anomaly

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2HDM in light of the CDF W mass and the muon anomalous magnetic moment

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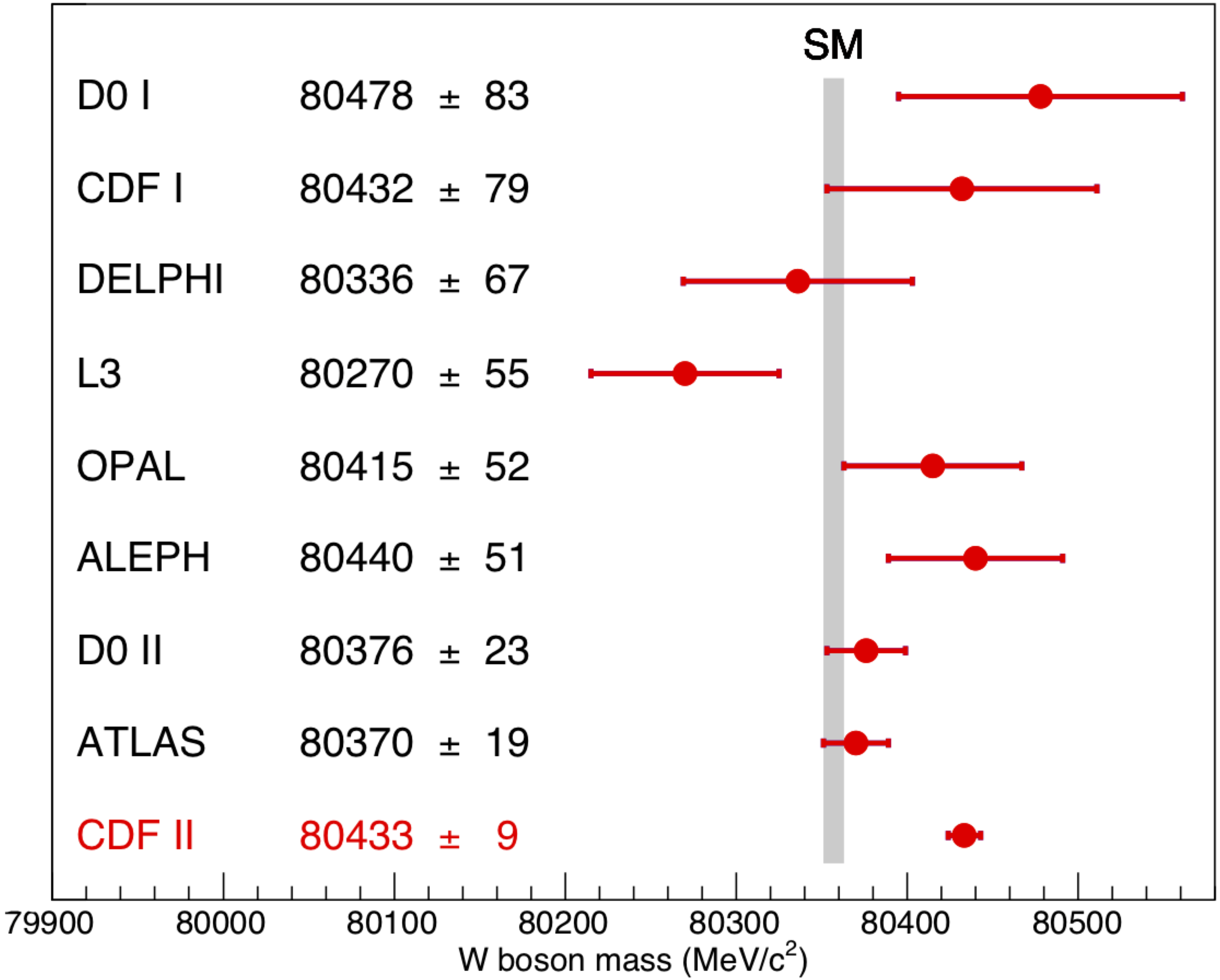
w/ J. Kim, S. Lee, K. Cheung, C. Lu, P. Sanyal,
2204.10338, 2205.01701

0. CDF W boson mass
1. Peskin-Takeuchi oblique parameters
2. 2HDM
3. Status of 2HDM in light of CDF W mass
4. Characteristics of the allowed parameters
5. Higgs-phobic type-X for Muon g-2
6. Conclusions

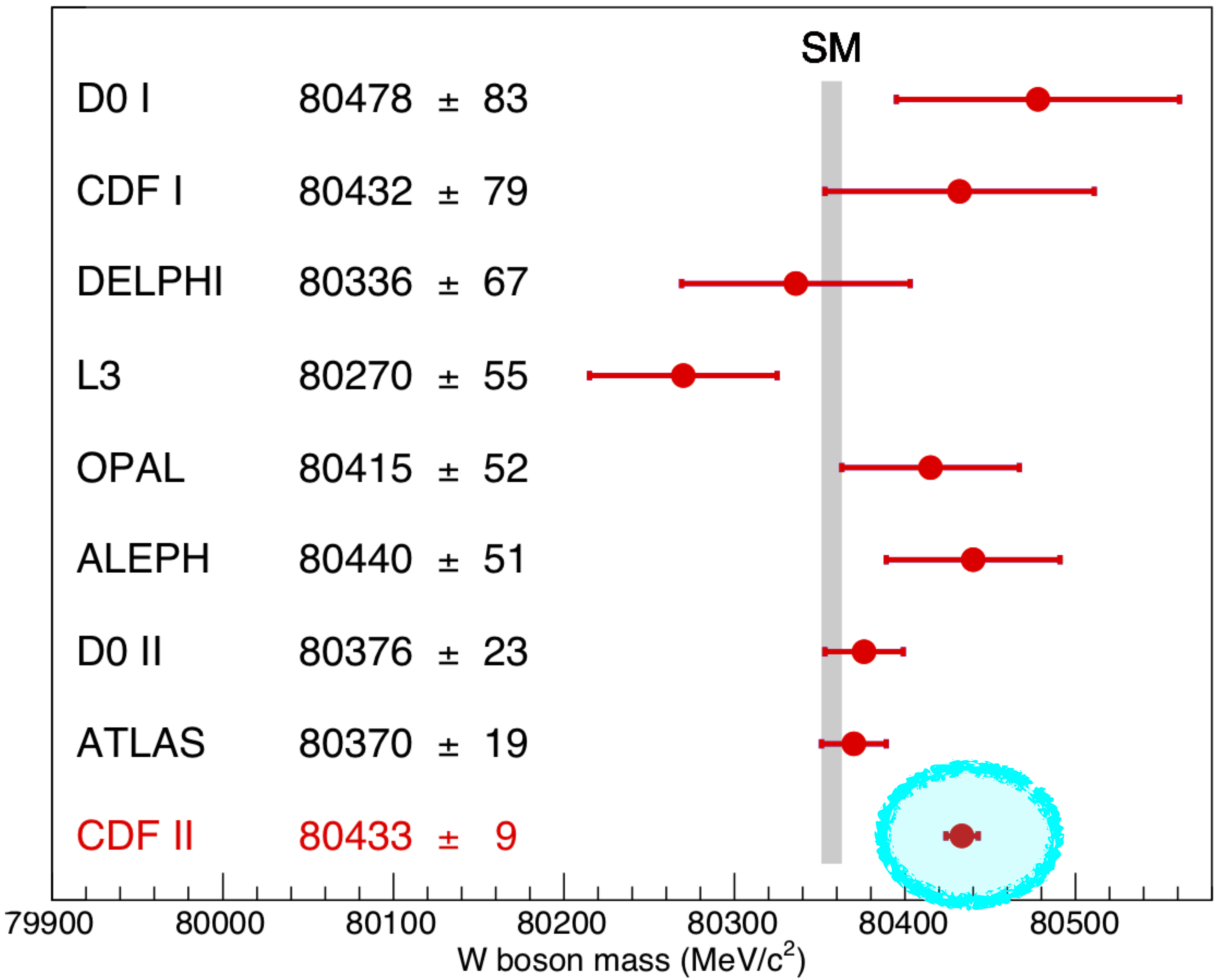
0. CDF W boson mass: How much can we trust?

0. mW



Science 376 (2022)

0. mW



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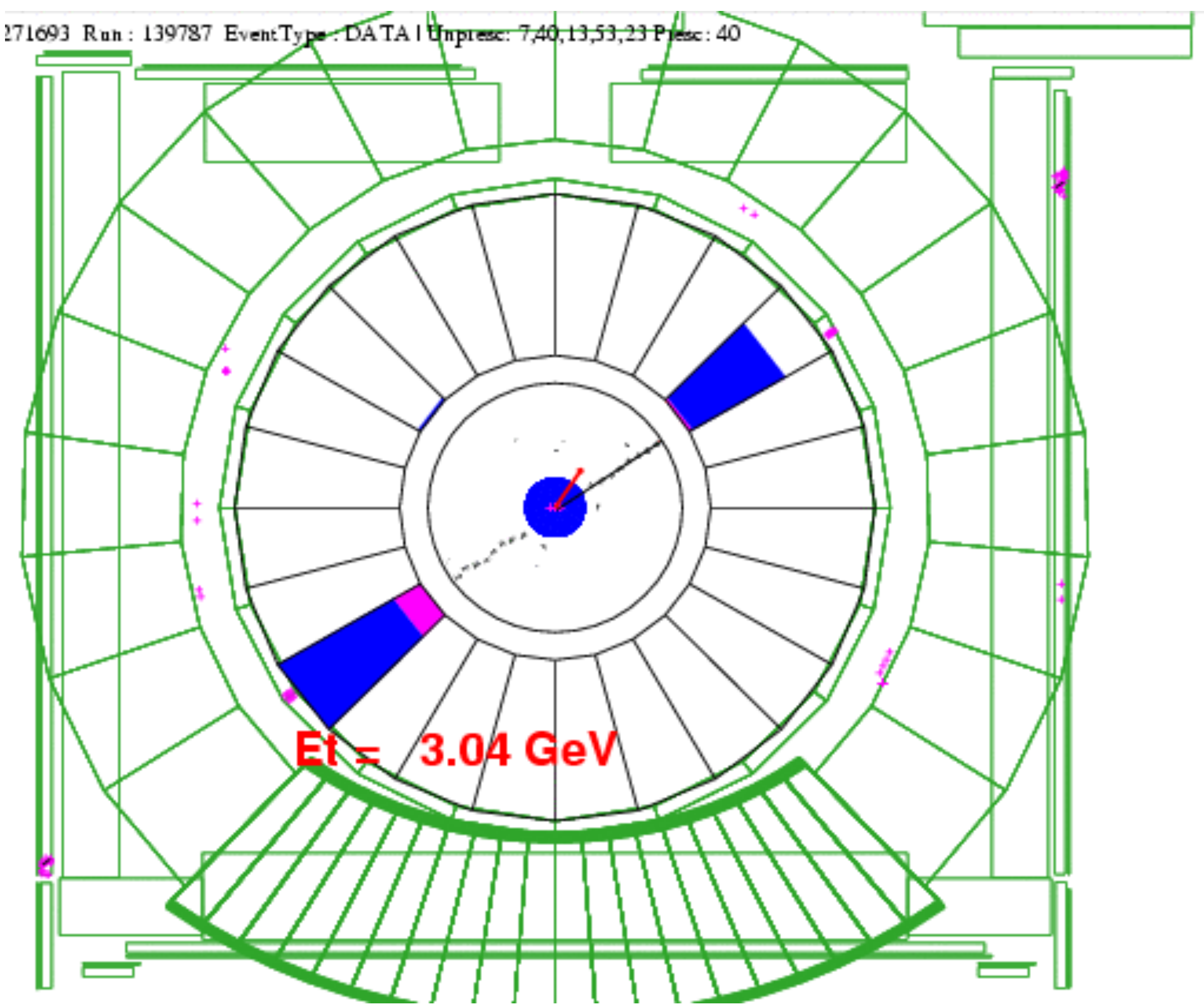
0. mW

- Some figures which impressed a theorist.

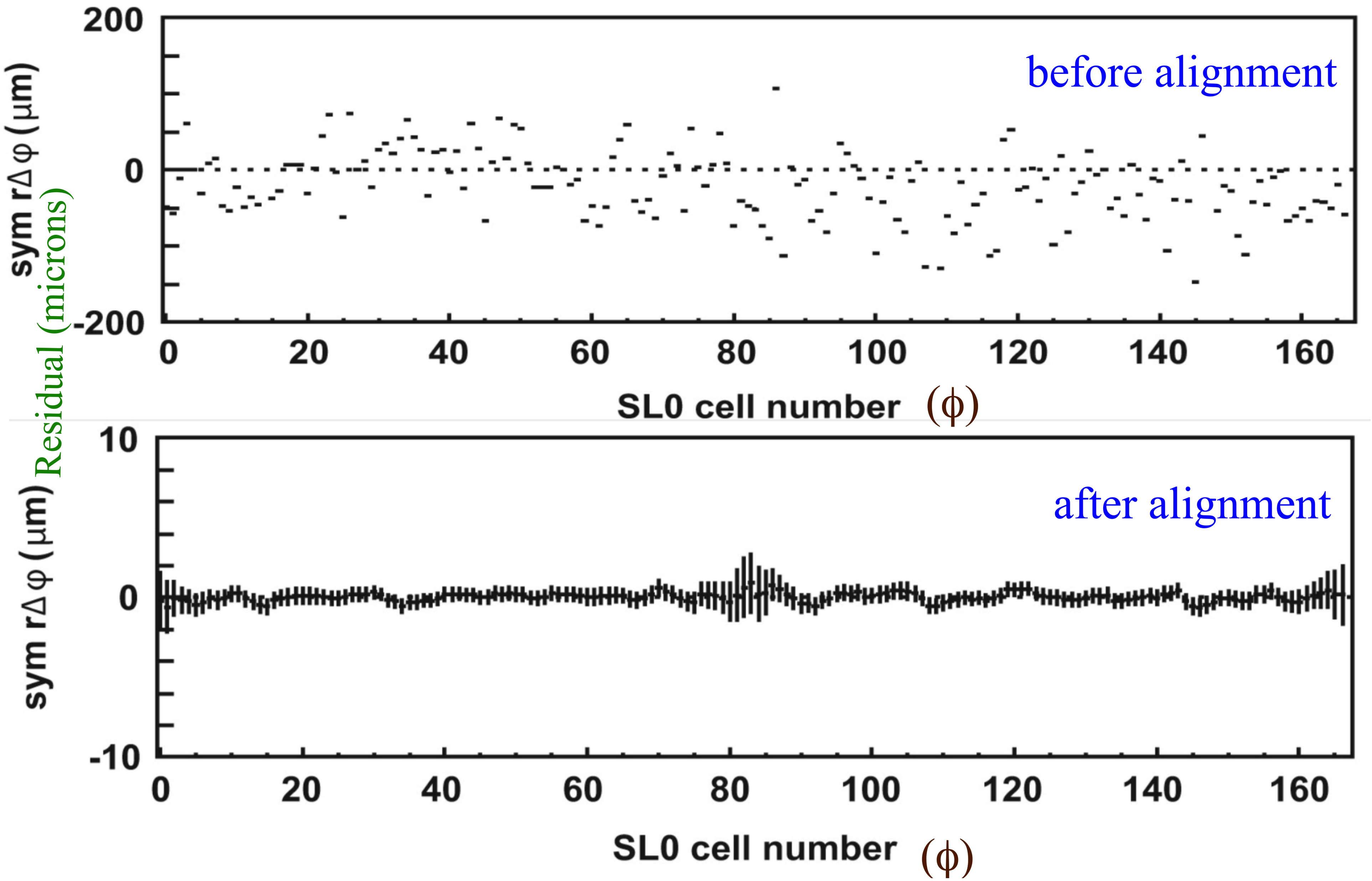
Drift Chamber (COT) Alignment



Use a clean sample of ~480k cosmic muon rays

0. mW

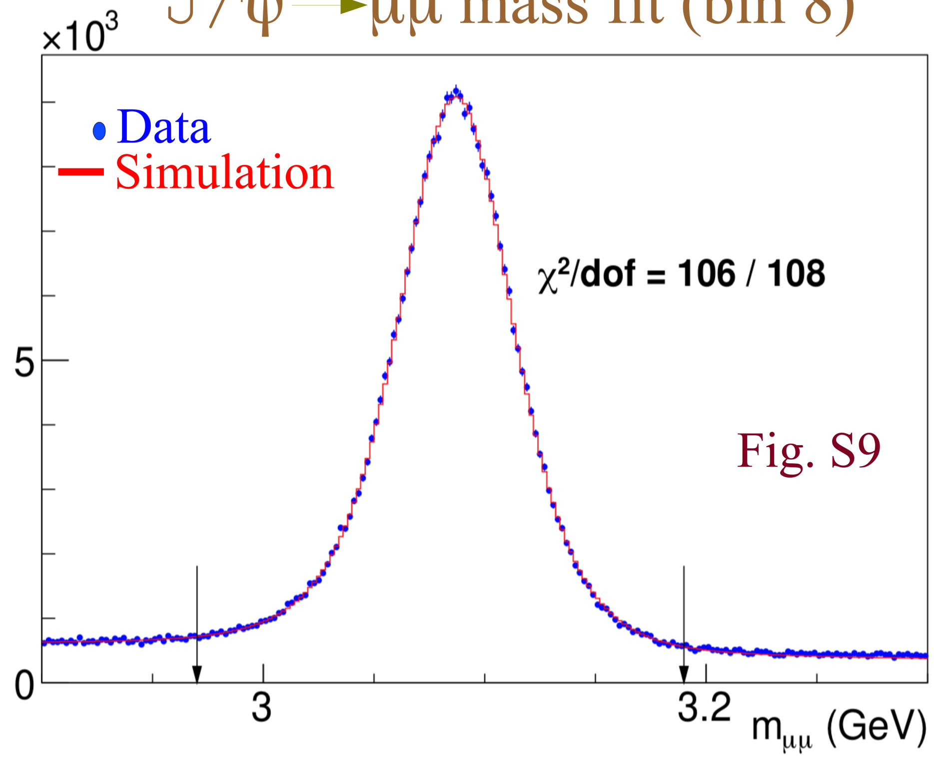
- Some figures which impressed a theorist.



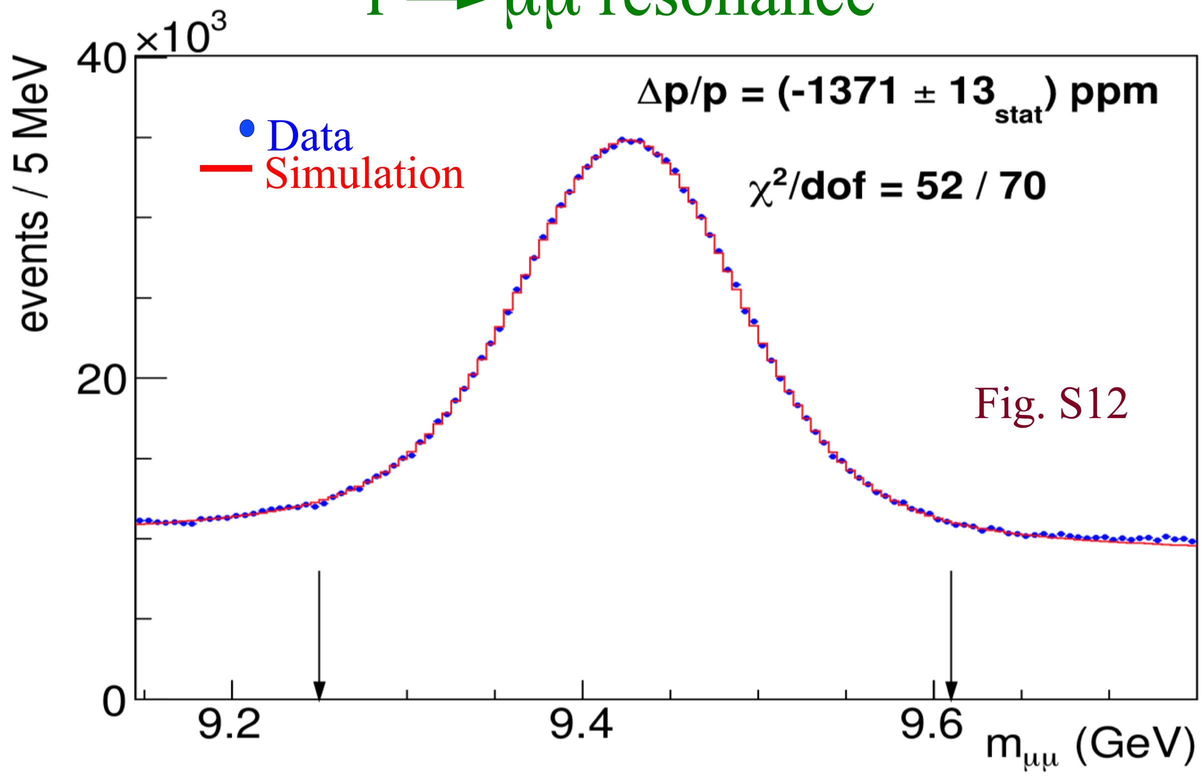
0. mW

- Some figures which impressed a theorist.
  - Tracker Calibration
    - alignment of the COT (~2400 cells, ~30k sense wires) using cosmic rays
    - COT momentum scale and tracker non-linearity constrained using $J/\psi \rightarrow \mu\mu$ and $\Upsilon \rightarrow \mu\mu$ mass fits
    - Confirmed using $Z \rightarrow \mu\mu$ mass fit

$J/\psi \rightarrow \mu\mu$ mass fit (bin 8)

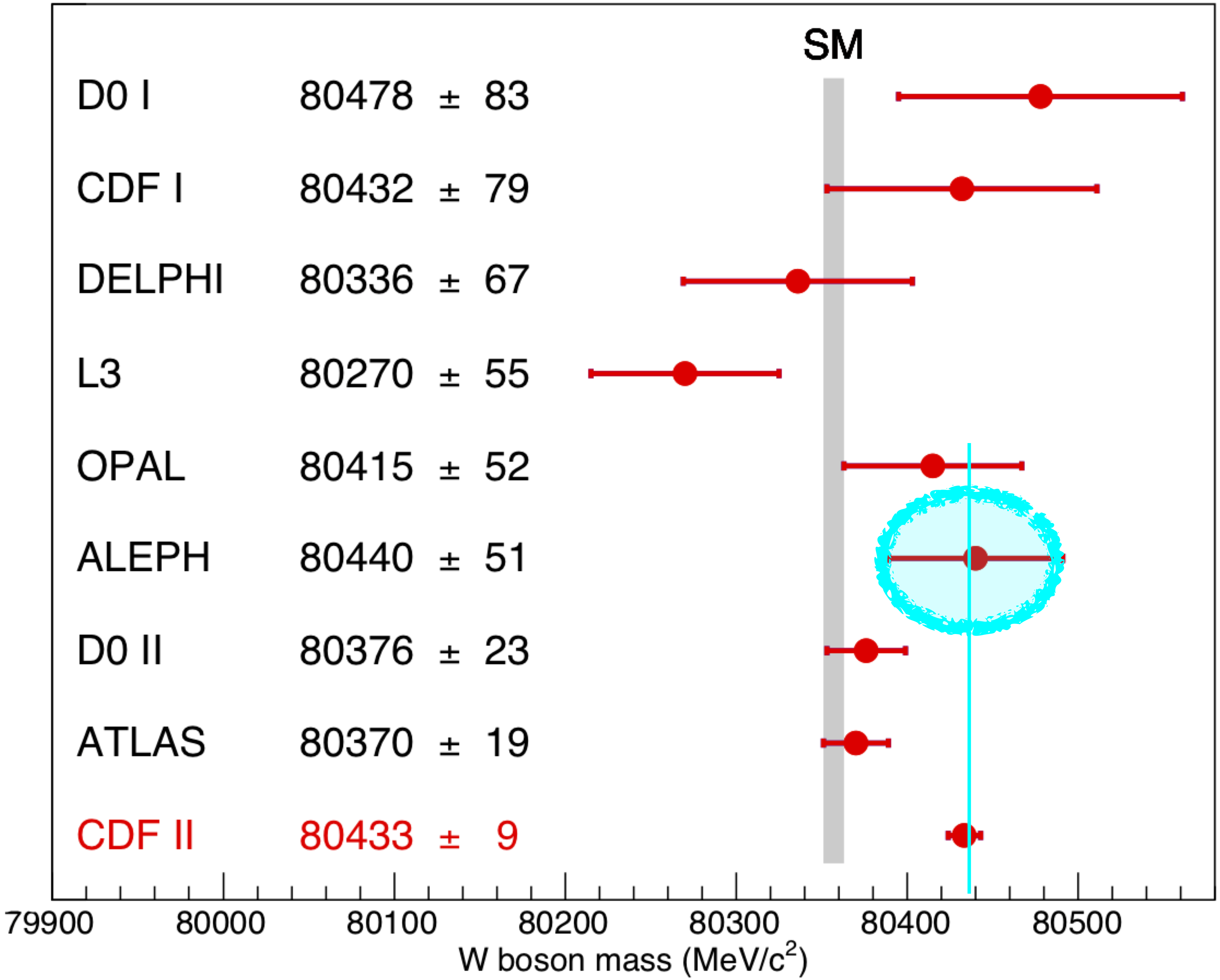


$\Upsilon \rightarrow \mu\mu$ resonance



Kotwal, KIAS, 31/5/22

0. mW



Science 376 (2022)

0. mW

Unique methods of the ALEPH

- All data collected at centre-of-mass energies between 161 and 209 GeV are fully analyzed homogeneously.
- The systematic uncertainties are determined taking into account correlations between all channels and CM energies.

ALEPH, hep-ex/0605011

0. mW

PDG from the global fit:

$$m_W^{\text{PDG}} = 80.357 \pm 0.006 \text{ GeV}$$

ATLAS[2017]:

$$m_W^{\text{ATLAS}} = 80.370 \pm 0.019 \text{ GeV}$$

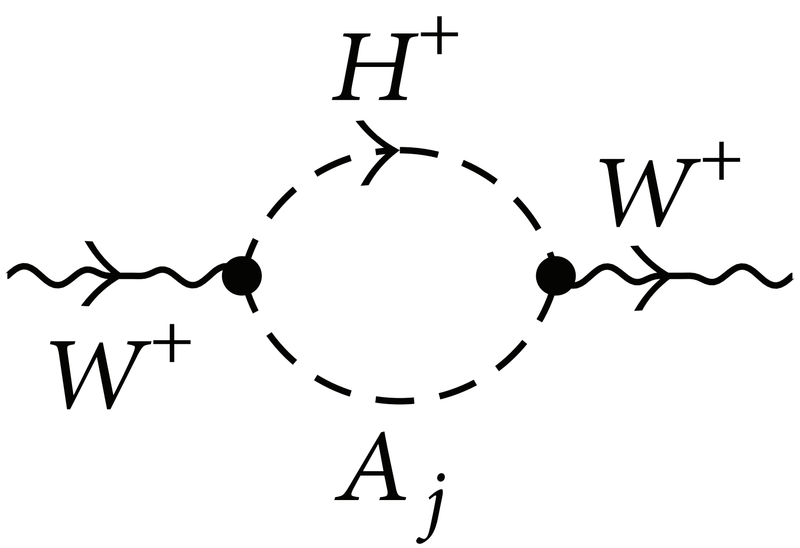
CDF[2022]:

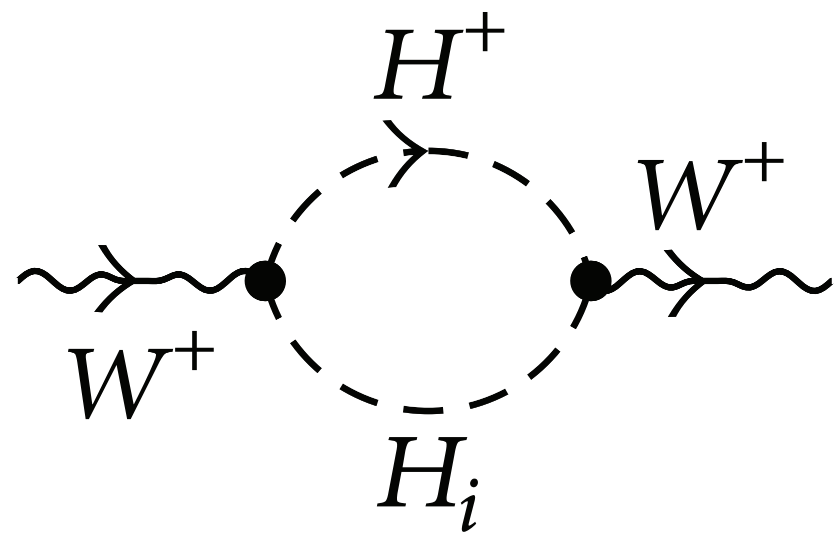
$$m_W^{\text{CDF}} = 80.4335 \pm 0.0094 \text{ GeV}$$

1. Peskin-Takeuchi oblique parameters

1. S/T/U

- Efficient parameterization of new contributions to the gauge boson self-energies.
- For example, new Higgs bosons change S/T/U through loop corrections.





- In the SM, S=T=U=0

1. S/T/U

- Global χ^2 fit of the SM to the electroweak input parameters

Parameter	Input Value
$\Delta\alpha_{\rm had}^{(5)\ 1}$	0.02761(11)
m_h [GeV]	125.25(17)
m_t [GeV]^2	172.76(58)
$\alpha_s(m_Z)$	0.1179(9)
Γ_W [GeV]	2.085(42)
Γ_Z [GeV]	2.4952(23)
m_Z [GeV]	91.1875(21)
$A_{\rm FB}^{0,b}$	0.0992(16)
$A_{\rm FB}^{0,c}$	0.0707(35)
$A_{\rm FB}^{0,\ell}$	0.0171(10)
A_b	0.923(20)

Parameter	Input Value
A_c	0.670(27)
A_ℓ(SLD)	0.1513(21)
A_ℓ(LEP)	0.1465(33)
R_b^0	0.21629(66)
R_c^0	0.1721(30)
R_ℓ^0	20.767(25)
σ_h^0 [nb]	41.540(37)
$\sin^2\theta_{\rm eff}^\ell(Q_{FB})$	0.2324(12)
$\sin^2\theta_{\rm eff}^\ell$(Teva)	0.23148(33)
$\overline{m}_c$ [GeV]	1.27(2)
$\overline{m}_b$ [GeV]	$4.18^{(3)}_{(2)}$

[2204.03796]

1. S/T/U

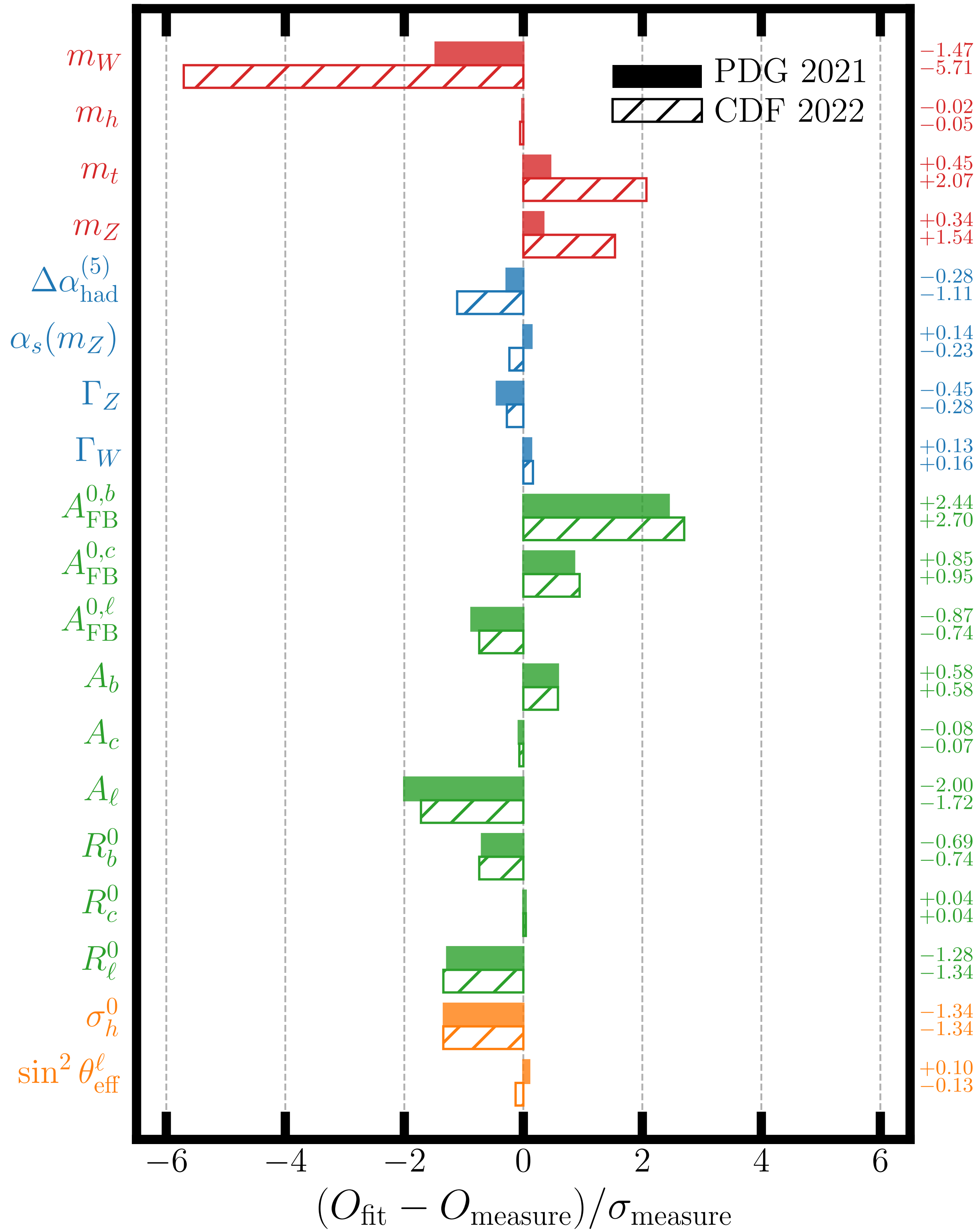
- 23 observable - 7 free parameters = 16 d.o.f in the SM

- 7 free parameters

$$M_h, \quad m_Z, \quad \bar{m}_c, \quad \bar{m}_b, \quad \bar{m}_t, \quad \Delta\alpha^{(5)}_{\text{had}}, \quad \alpha_s(m_Z^2)$$

[2204.03796]

1. S/T/U



PDG 2021

$$\chi^2_{\rm min}({\rm dof}) = 18.73(16)$$

p=0.28

CDF 2022

$$\chi^2_{\rm min}({\rm dof}) = 64.45(16)$$

p<0.00001

[2204.03796]

1. S/T/U

- We need BSM.
- U from dimension-8 operator
- Setting U=0, but S and T as free parameters
- 23 observable - 9 free parameters = 14 d.o.f

$U = 0$	PDG 2021			CDF 2022		
	Result	Correlation		Result	Correlation	
14 dof	$\chi^2_{\text{min}} = 15.48$	S	T	$\chi^2_{\text{min}} = 17.82$	S	T
S	0.05 ± 0.08	1.00	0.92	0.15 ± 0.08	1.00	0.93
T	0.09 ± 0.07		1.00	0.27 ± 0.06		1.00

p=0.22

[2204.03796]

2. 2HDM

2. 2HDM

- Basic theory setup

$$\Phi_i = \begin{pmatrix} w_i^+ \\ \dfrac{v_i + h_i + i\eta_i}{\sqrt{2}} \end{pmatrix}, \quad i = 1, 2,$$

where $v = \sqrt{v_1^2 + v_2^2} = 246$ GeV.

- Discrete Z_2 symmetry to avoid tree-level FCNC

$$\Phi_1 \to \Phi_1, \quad \Phi_2 \to -\Phi_1$$

- Scalar potential with CP-invariance

$$\begin{aligned} V_\Phi = \; & m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 - m_{12}^2 (\Phi_1^\dagger \Phi_2 + \text{H.c.}) \\ & + \frac{1}{2}\lambda_1 (\Phi_1^\dagger \Phi_1)^2 + \frac{1}{2}\lambda_2 (\Phi_2^\dagger \Phi_2)^2 + \lambda_3 (\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + \lambda_4 (\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1) \\ & + \frac{1}{2}\lambda_5 \left[(\Phi_1^\dagger \Phi_2)^2 + \text{H.c.} \right], \end{aligned}$$

2. 2HDM

- Four types

	Φ_1	Φ_2	u_R	d_R	ℓ_R	Q_L, L_L
Type I	+	−	−	−	−	+
Type II	+	−	−	+	+	+
Type X	+	−	−	−	+	+
Type Y	+	−	−	+	−	+

- 2 scenarios

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

$$\text{NS:} \quad m_h = m_{125};$$

$$\text{IS:} \quad M_H = m_{125},$$

2. 2HDM

- Four types & two scenarios = 8 cases

- 8 cases for PDG mW and CDF mW ➡16 cases

- No assumptions on the masses and couplings: 6 parameters

$$\left\{ m_h, \quad M_{H^\pm}, \quad M_H, \quad M_A, \quad m_{12}^2, \quad t_\beta, \quad s_{\beta-\alpha} \right\}.$$

2. 2HDM

- theoretical stability ➡ quartic couplings cannot be too large

In the Higgs alignment limit

$$\lambda_1 = \frac{1}{v^2}\left[m_{125}^2 + \boxed{t_\beta^2}\left(m_{\varphi^0}^2 - M^2\right)\right],$$

$$\lambda_2 = \frac{1}{v^2}\left[m_{125}^2 + \frac{1}{t_\beta^2}\left(m_{\varphi^0}^2 - M^2\right)\right],$$

$$\lambda_3 = \frac{1}{v^2}\left[m_{125}^2 - m_{\varphi^0}^2 - M^2 + 2M_{H^\pm}^2\right],$$

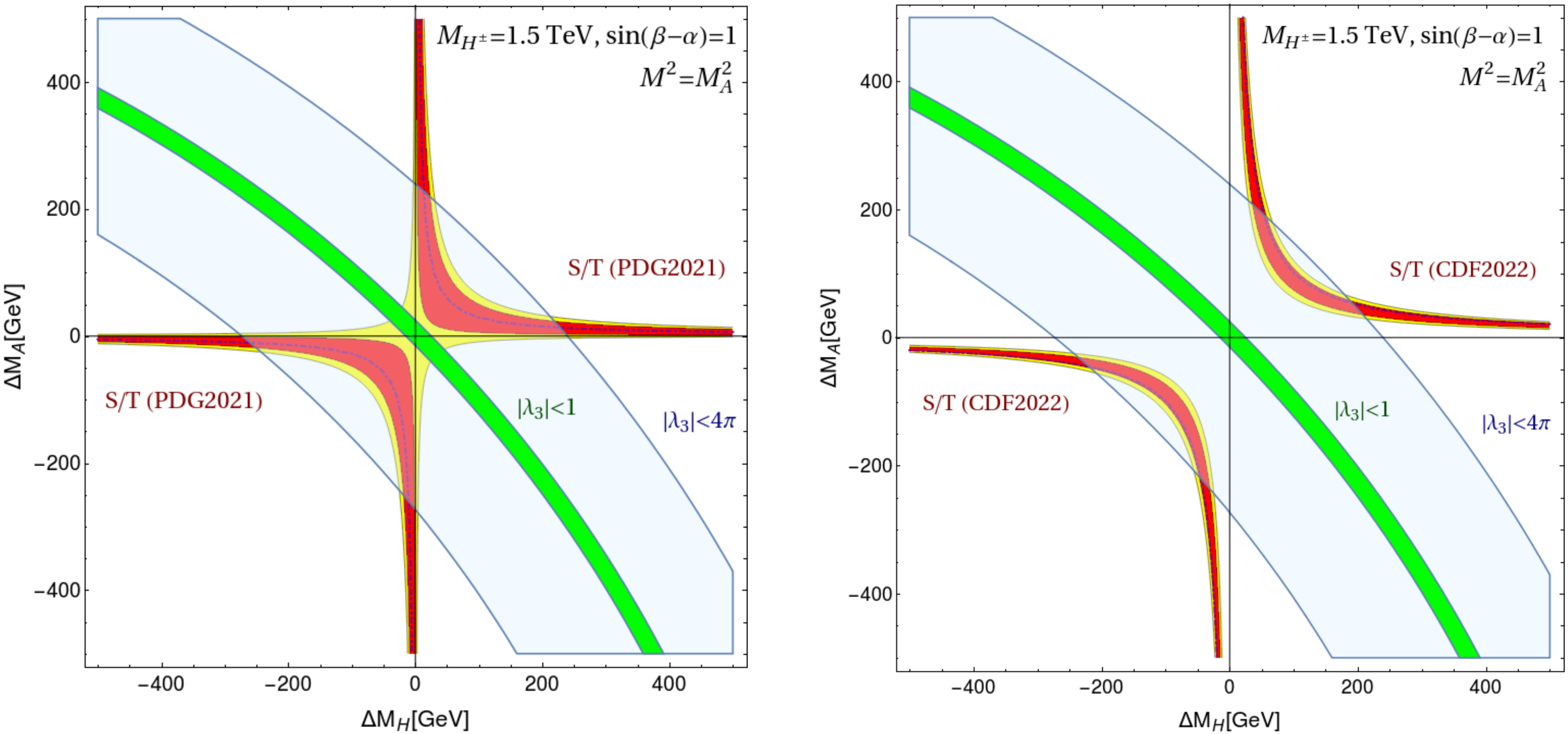
$$\lambda_4 = \frac{1}{v^2}\left[M^2 + M_A^2 - 2M_{H^\pm}^2\right],$$

$$\lambda_5 = \frac{1}{v^2}\left[M^2 - M_A^2\right],$$

Mass degeneracy!

$$\boxed{M^2 = m_{12}^2/(s_\beta c_\beta)}$$

- CDF mW + theoretical stability ➡ upper bounds on the masses



$$\Delta M_i = M_i - M_{H^\pm}$$

3. Status of 2HDM
In light of CDF W mass

3. Scan

- Scanning ranges

$$\text{NS: } M_H \in [130, 2000] \text{ GeV}, \; M_A \in [15, 2000] \text{ GeV},$$
$$s_{\beta-\alpha} \in [0.8, 1.0], \; m_{12}^2 \in \left[0, 1000^2\right] \text{ GeV}^2,$$

$$\text{IS: } m_h \in [15, 120] \text{ GeV}, \; M_A \in [15, 2000] \text{ GeV},$$
$$c_{\beta-\alpha} \in [0.8, 1.0], \; m_{12}^2 \in \left[0, 1000^2\right] \text{ GeV}^2.$$

$$\text{type-I \& type-X: } M_{H^\pm} \in [80, 2000] \text{ GeV}, \quad t_\beta \in [1, 50],$$
$$\text{type-II \& type-Y: } M_{H^\pm} \in [580, 2000] \text{ GeV}, \quad t_\beta \in [0.5, 50].$$

3. Scan

- Scanning steps

Step-(i) Theory+FCNC:

Step-(ii) EWPD:

Step-(iii) RGEs for $\Lambda_c > 1$ TeV**:**

Step-(iv) Collider:

3. Scan

Step-(i) Theory+FCNC:

1. Higgs potential being bounded from below;
2. Perturbative unitarity of the scattering amplitudes;
3. Perturbativity of the quartic couplings;
4. Vacuum stability;
5. FCNC observables.

3. Scan

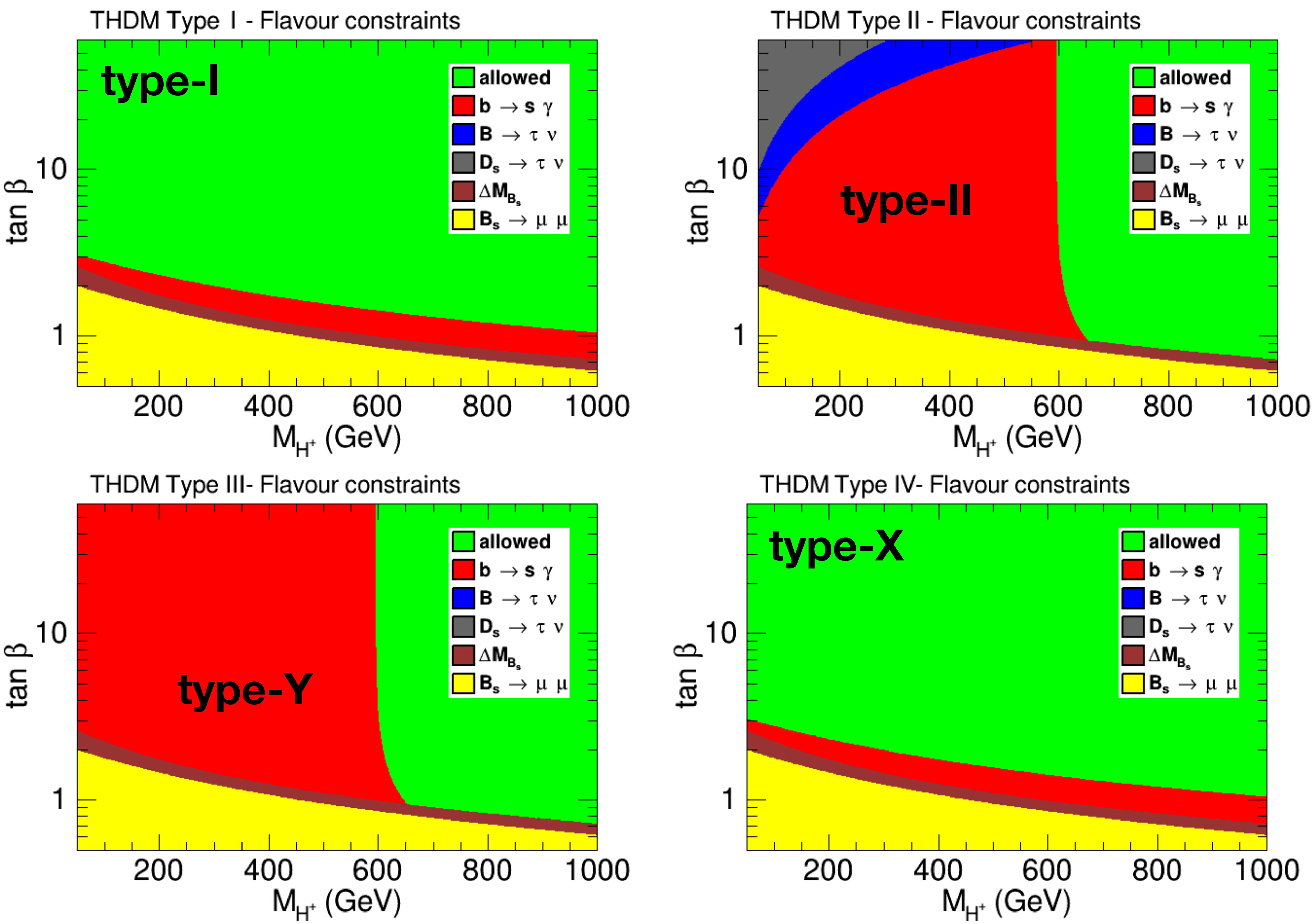
Step-(i) Theory+FCNC:

Not too large quartic couplings

4. Vacuum stability;
5. FCNC observables.

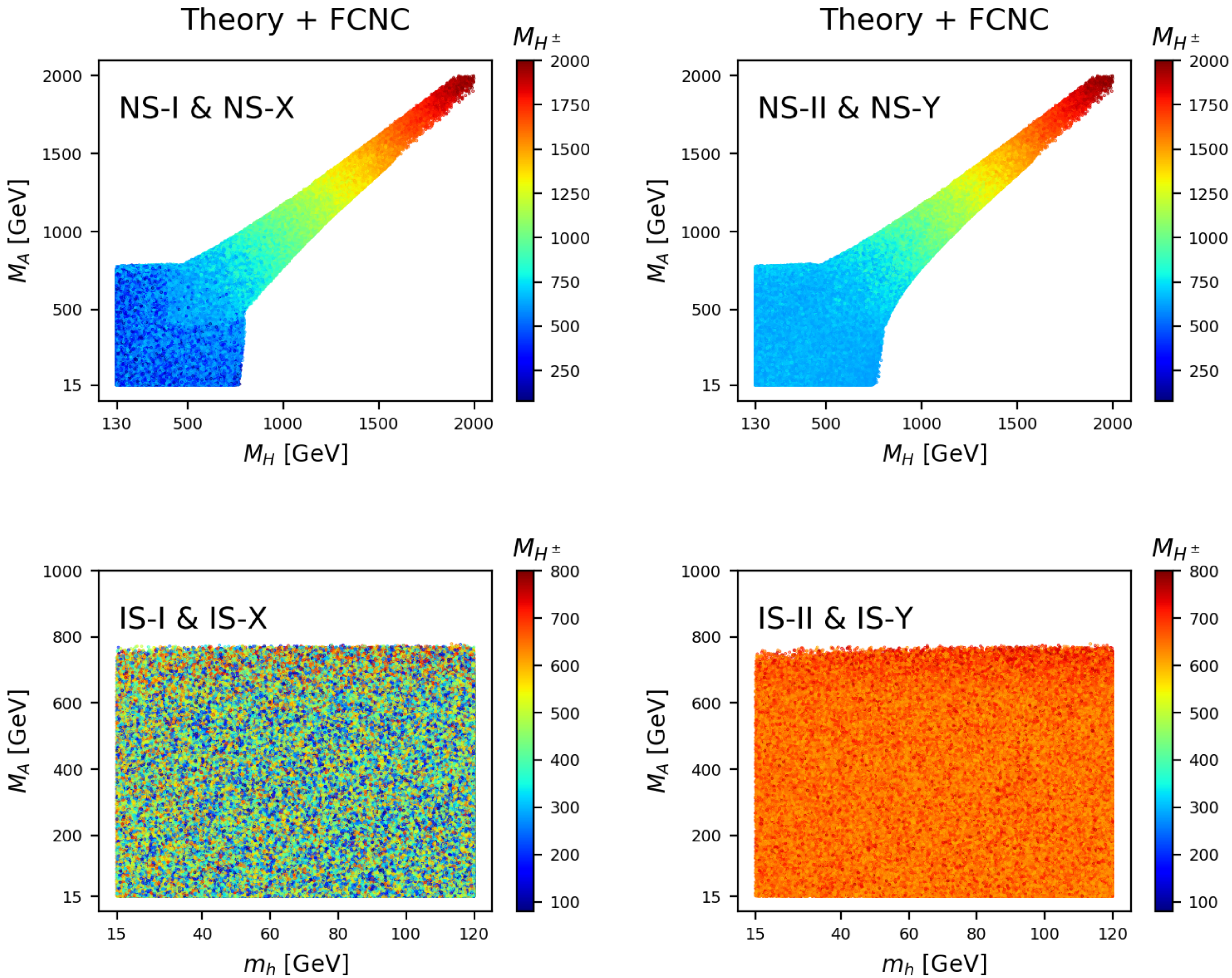
3. Scan

- Constraints from FCNC

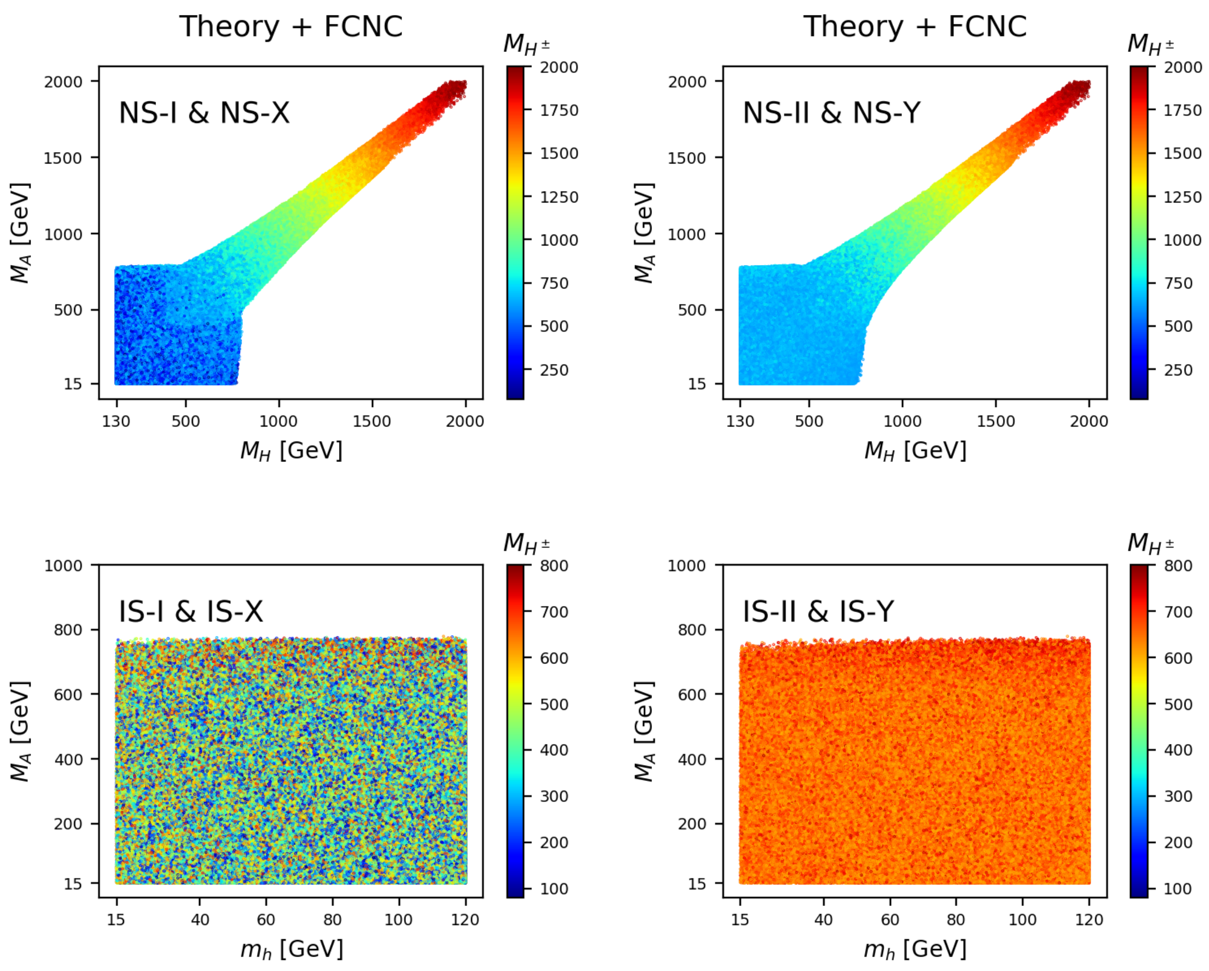


[1706.07414]

Allowed regions after Step-(i)



3. Scan



Similar masses

- NS: almost degenerate masses for heavy BSM scalars
- IS: light mh brings down the other new scalars

3. Scan

- Origin of the similar masses: theoretical stability

$$\lambda_1 = \frac{1}{v^2}\left[m_{125}^2 + t_\beta^2\left(m_{\varphi^0}^2 - M^2\right)\right],$$

$$\lambda_2 = \frac{1}{v^2}\left[m_{125}^2 + \frac{1}{t_\beta^2}\left(m_{\varphi^0}^2 - M^2\right)\right],$$

$$\lambda_3 = \frac{1}{v^2}\left[m_{125}^2 - m_{\varphi^0}^2 - M^2 + 2M_{H^\pm}^2\right],$$

$$\lambda_4 = \frac{1}{v^2}\left[M^2 + M_A^2 - 2M_{H^\pm}^2\right],$$

$$\lambda_5 = \frac{1}{v^2}\left[M^2 - M_A^2\right],$$

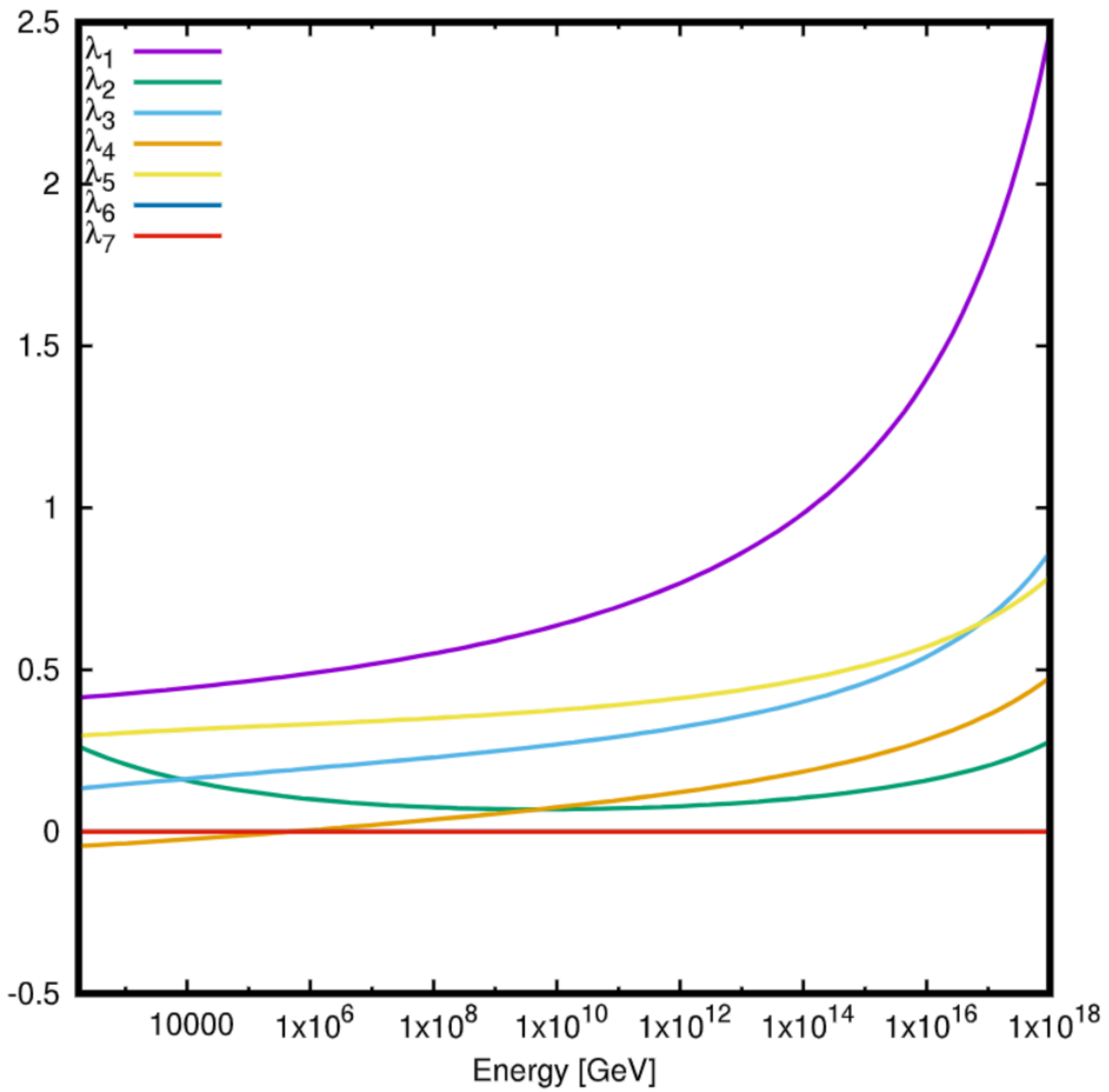
Step-(ii) EWPD:

$U = 0$	PDG 2021			CDF 2022		
	Result	Correlation		Result	Correlation	
14 dof	$\chi^2_{\text{min}} = 15.48$	S	T	$\chi^2_{\text{min}} = 17.82$	S	T
S	0.05 ± 0.08	1.00	0.92	0.15 ± 0.08	1.00	0.93
T	0.09 ± 0.07		1.00	0.27 ± 0.06		1.00

3. Scan

Step-(iii) RGEs for $\Lambda_c > 1$ TeV:

- Running of quartic couplings via RGE can be too fast to break unitarity, vacuum stability, or perturbativity.
- We require that the scalar potential be stable up to 1 TeV.



Step-(iv) Collider:

1. Higgs precision data via HiggsSignals;
2. direct searches at high energy collider via HiggsBounds.

3. Scan

- Survival probabilities about ten million points that pass Step-(i)

		EWPD	$\Lambda_c > 1$ TeV	Collider	EWPD	$\Lambda_c > 1$ TeV	Collider
		Normal scenario			Inverted scenario		
type-I	PDG	12.98%	5.13%	0.60%	7.20%	5.08%	0.85%
	CDF	4.42%	1.31%	0.14%	1.30%	0.72%	0.19%
type-II	PDG	10.76%	0.43%	0.20%	2.14%	0	0
	CDF	3.36%	0.03%	0.01%	0.69%	0	0
type-X	PDG	12.98%	5.13%	0.18%	7.20%	5.08%	0.03%
	CDF	4.42%	1.31%	0.03%	1.30%	0.72%	0.01%
type-Y	PDG	10.76%	0.43%	0.20%	2.14%	0	0
	CDF	3.36%	0.03%	0.01%	0.69%	0	0

3. Scan

- Survival probabilities about Step-(i)

		EWPD	$\Lambda_c > 1$ TeV	Collider	EWPD	$\Lambda_c > 1$ TeV	Collider
		Normal scenario			Inverted scenario		
type-I	PDG	12.98%	5.13%	0.60%	7.20%	5.08%	0.85%
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	CDF	4.42%	1.31%	0.03%	1.30%	0.72%	0.01%
type-Y	PDG	10.76%	0.43%	0.20%	2.14%	0	0
	CDF	3.36%	0.03%	0.01%	0.69%	0	0

- In terms of survival probabilities, PDG wins, especially in type-II and type-Y

3. Scan

- Survival probabilities about Step-(i)

		EWPD	$\Lambda_c > 1$ TeV	Collider	EWPD	$\Lambda_c > 1$ TeV	Collider
		Normal scenario			Inverted scenario		
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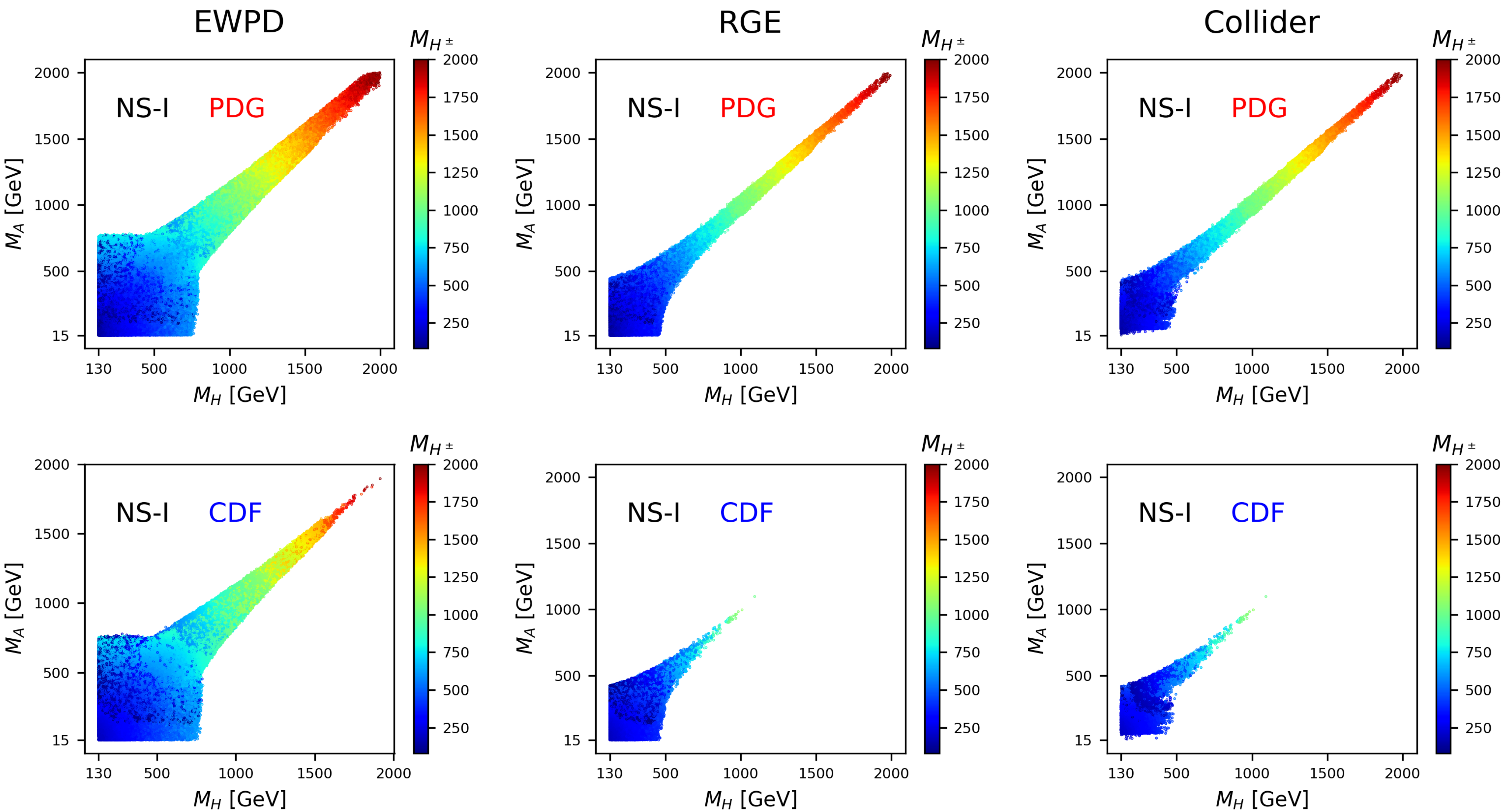
	CDF	4.42%	1.31%	0.14%	1.30%	0.72%	0.19%
type-II	PDG	10.76%	0.43%	0.20%	2.14%	0 EXCLUDED!	0
	CDF	3.36%	0.03%	0.01%	0.69%	0	0
type-X	PDG	12.98%	5.13%	0.18%	7.20%	5.08%	0.03%
	CDF	4.42%	1.31%	0.03%	1.30%	0.72%	0.01%
type-Y	PDG	10.76%	0.43%	0.20%	2.14%	0 EXCLUDED!	0
	CDF	3.36%	0.03%	0.01%	0.69%	0	0

- PDG wins, especially in type-II and type-Y

4. Characteristics: Which step removes which parameters?

4. Characteristics

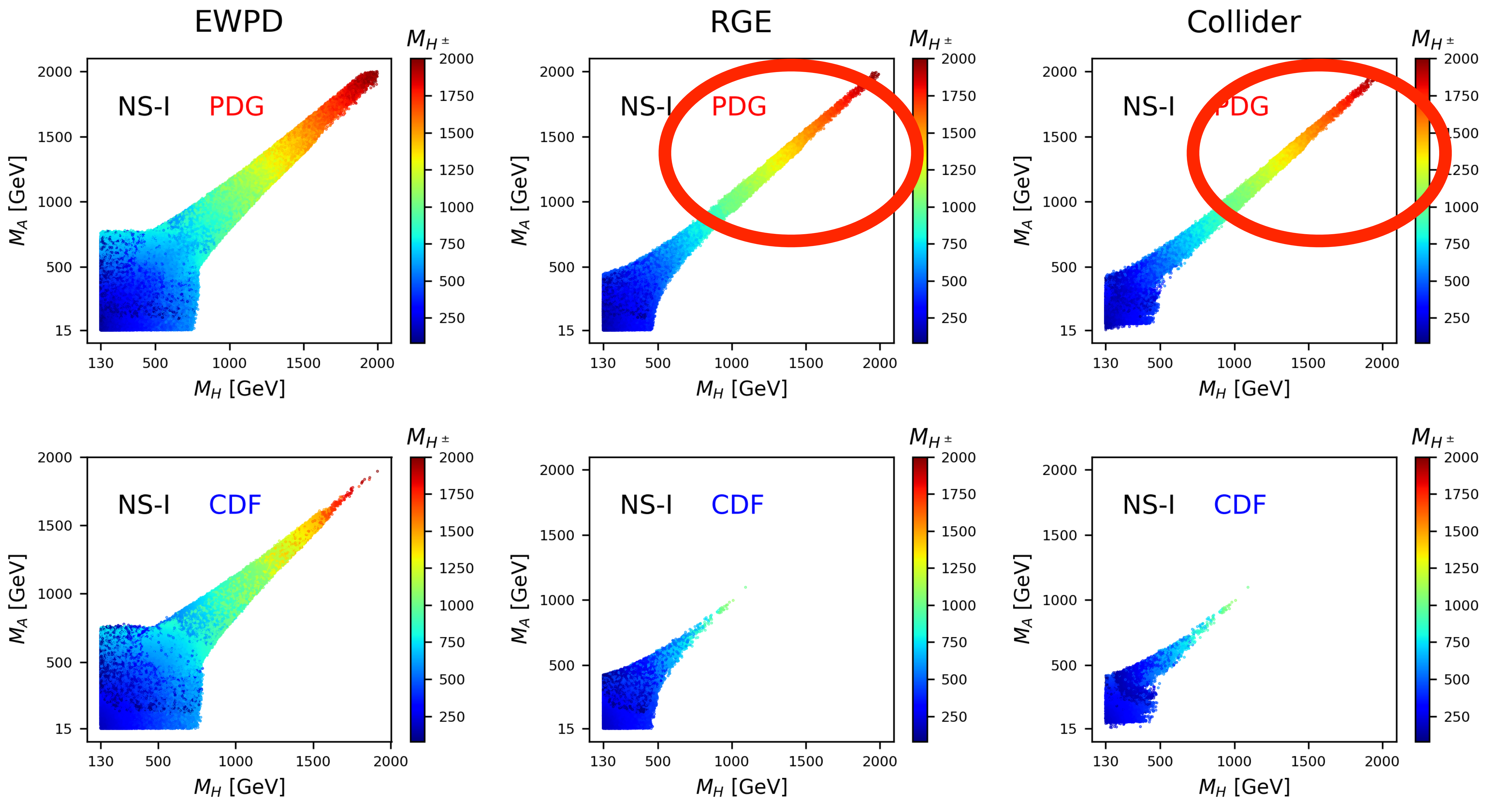
- type-I in NS



4. Characteristics

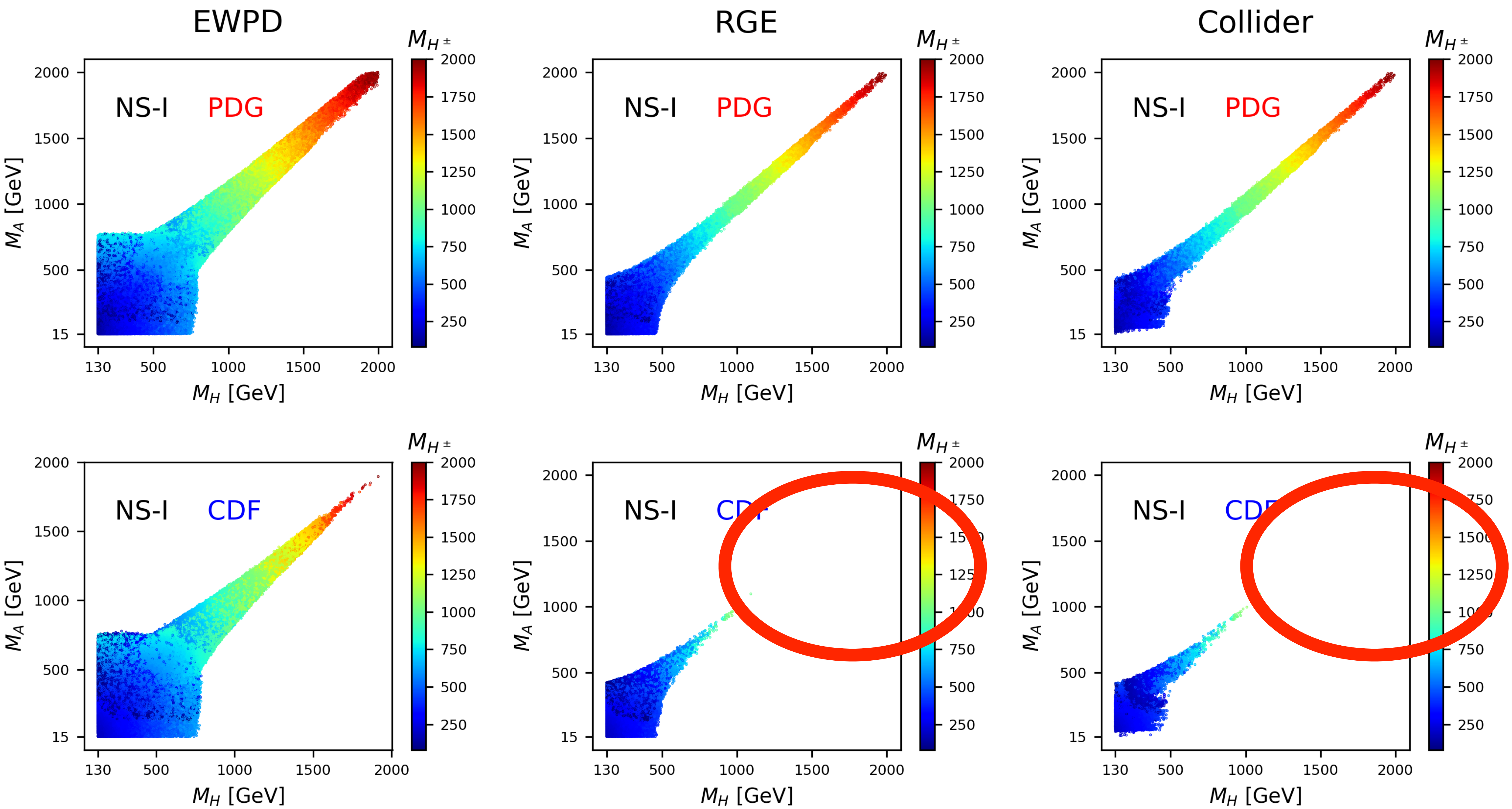
- type-I in NS

Torture by hope



- In the PDG, heavy BSM scalar with degenerate masses are still allowed.

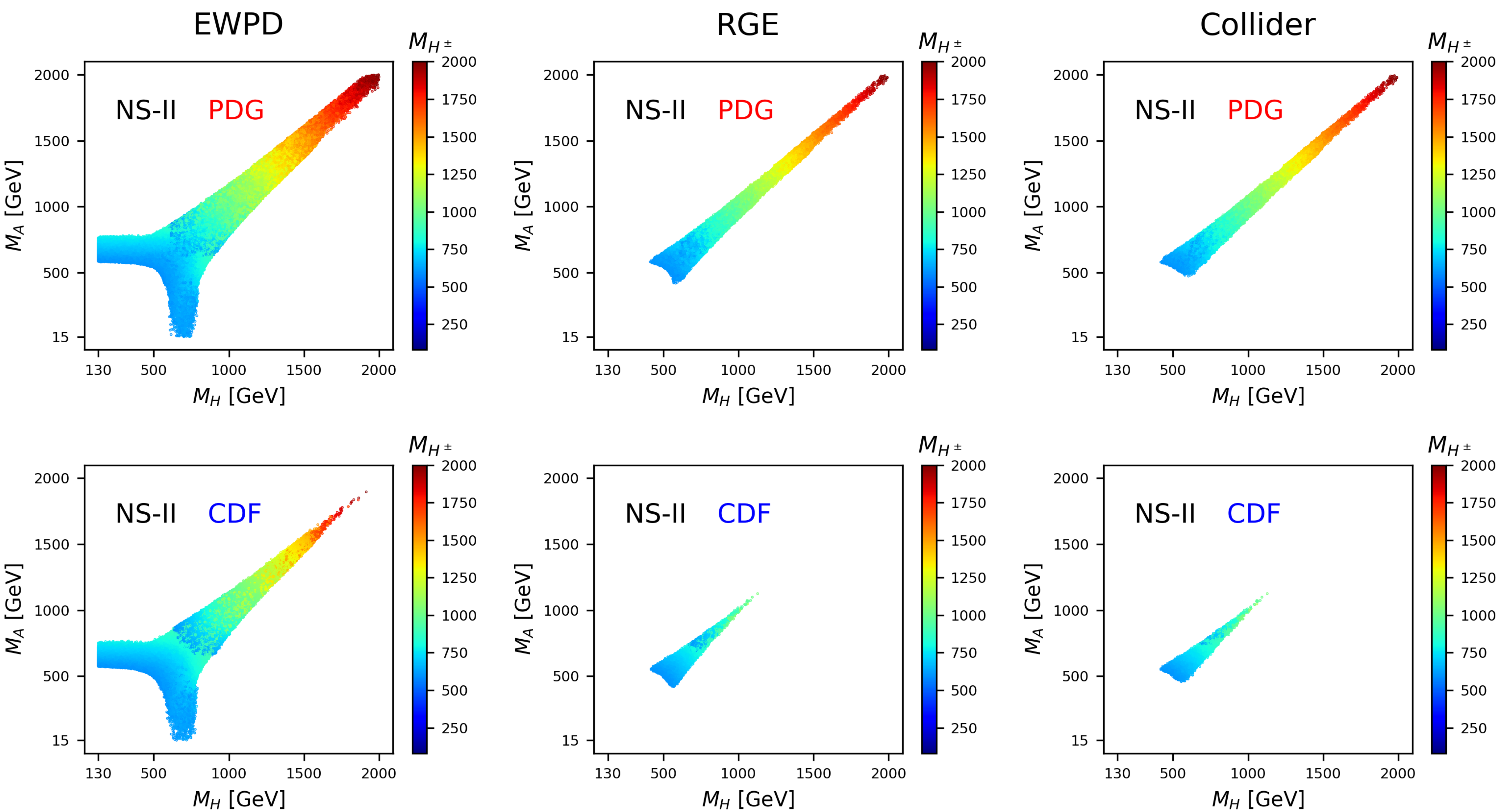
- type-I in NS



- In the CDF, RGE removes BSM Higgs masses above 1 TeV.

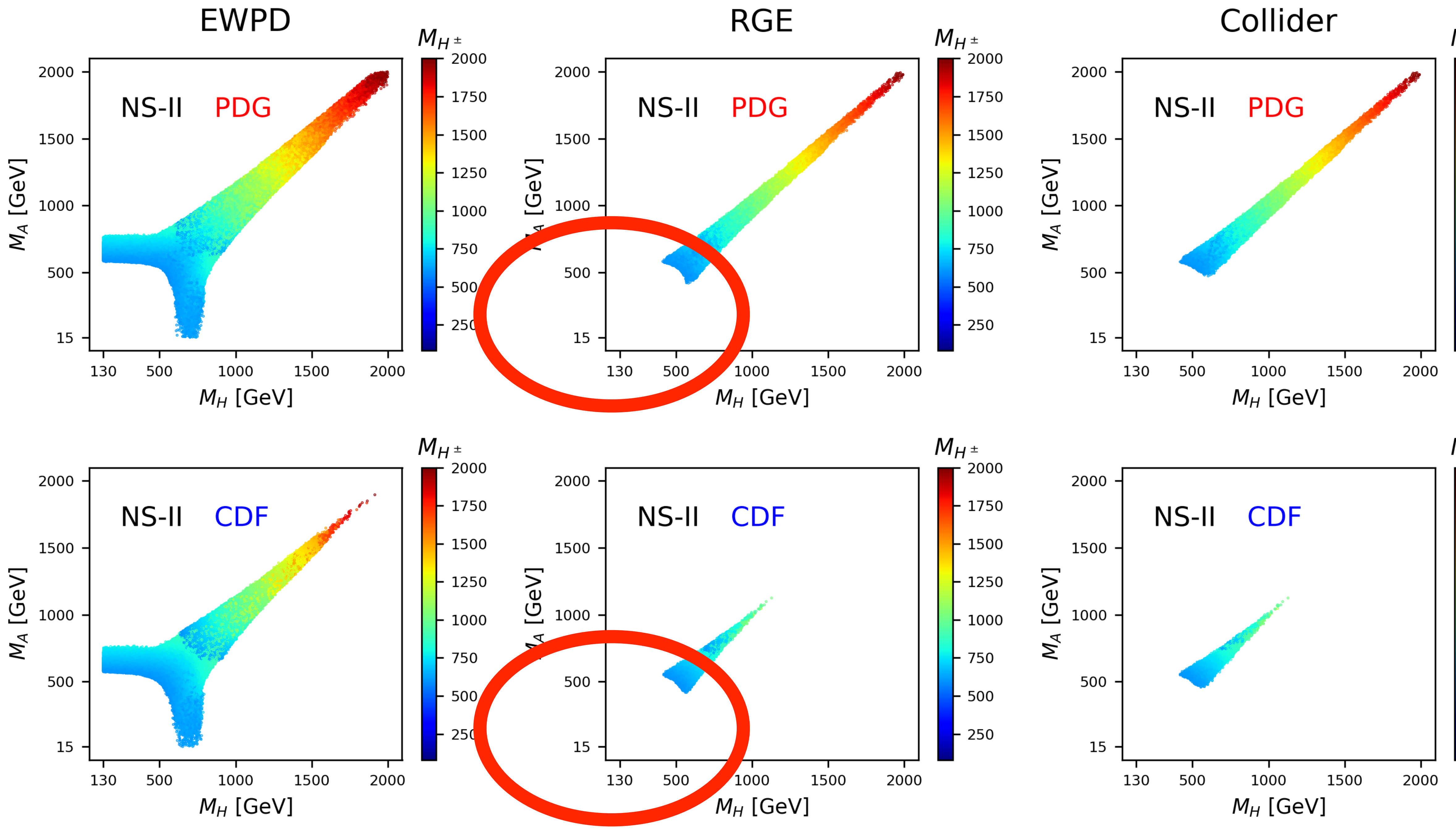
4. Characteristics

- type-II in NS



4. Characteristics

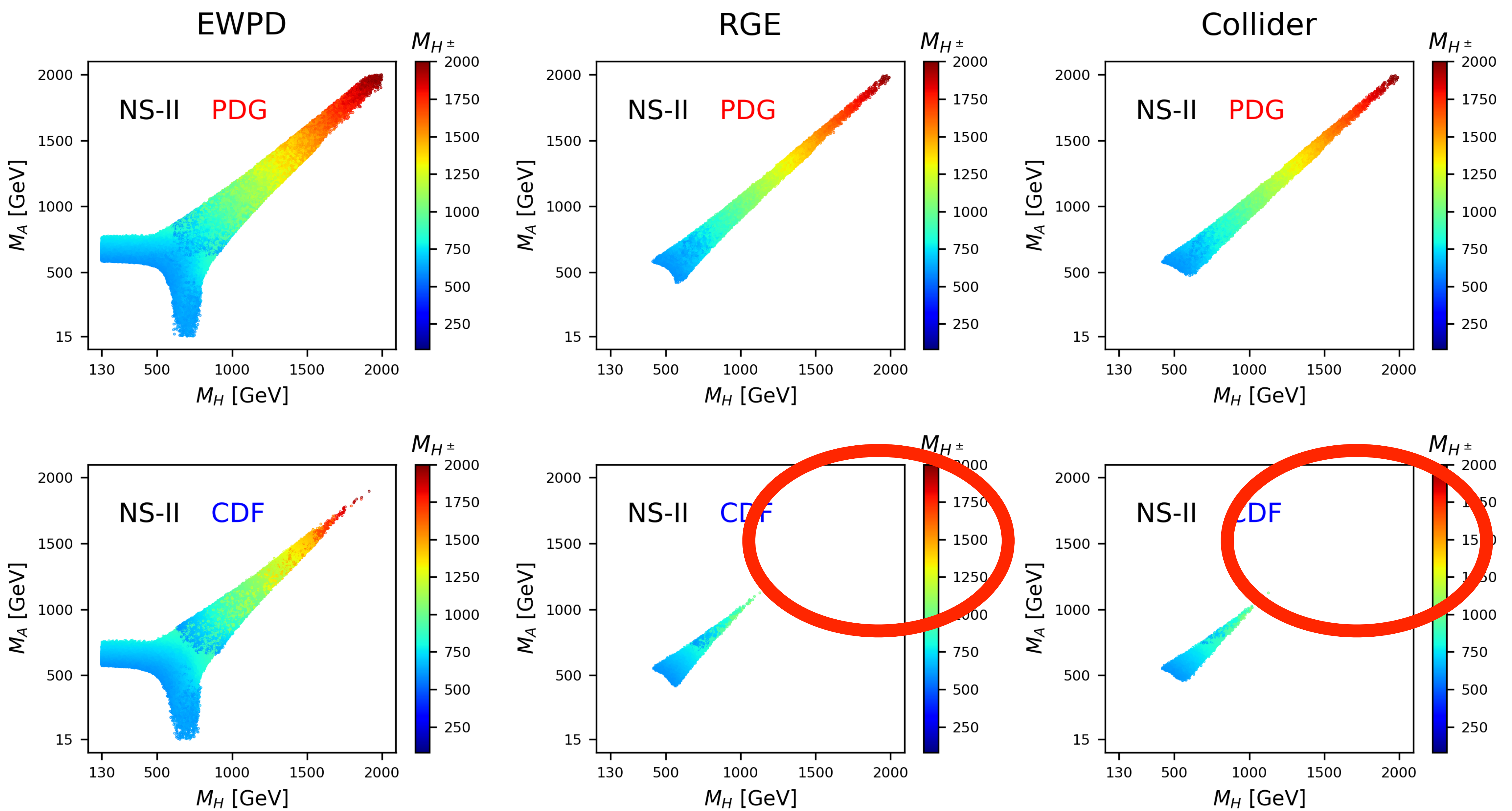
- type-II in NS



- RGE excludes sizable mass gaps among BSM Higgs masses below 500 GeV.

4. Characteristics

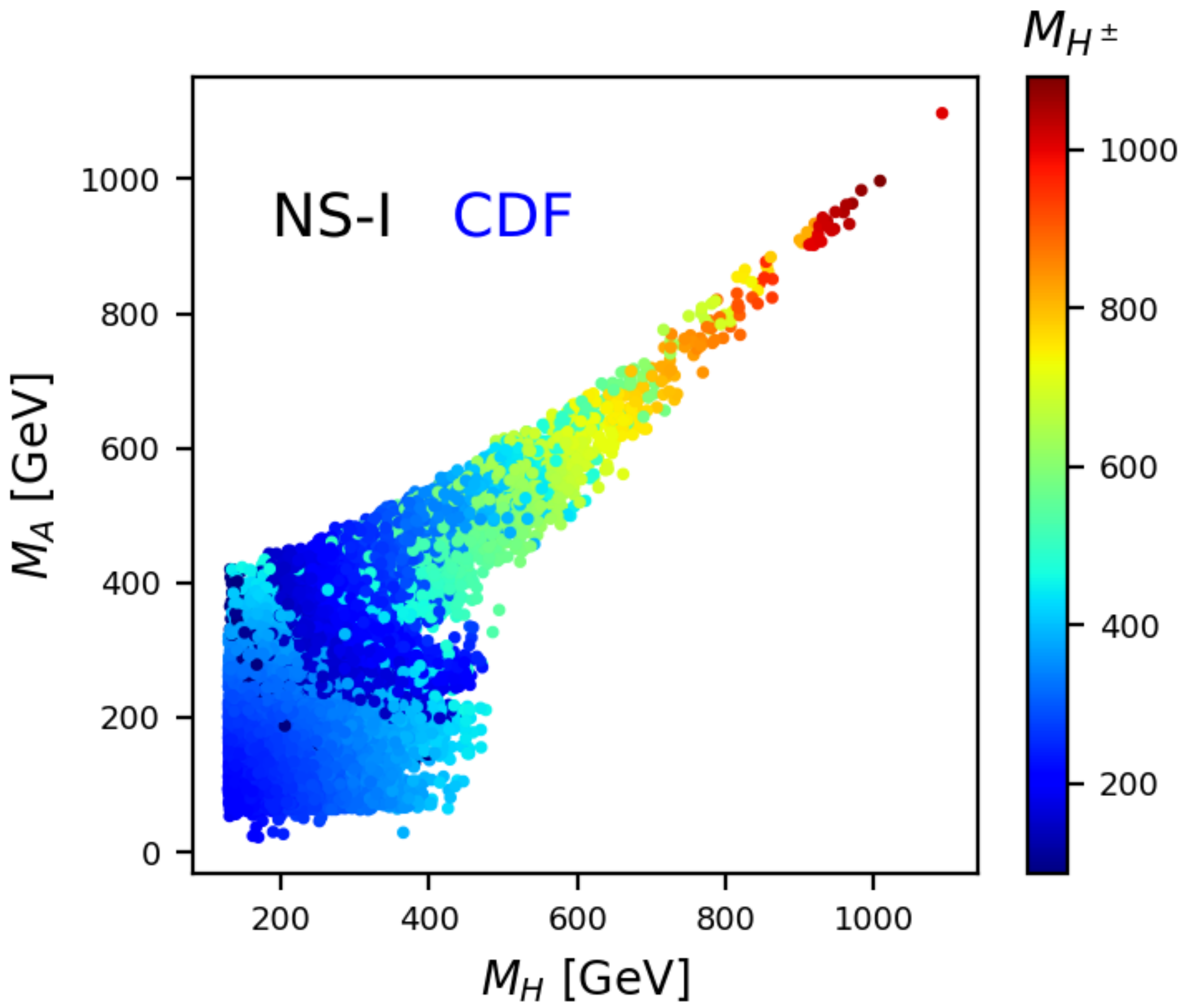
- type-II in NS

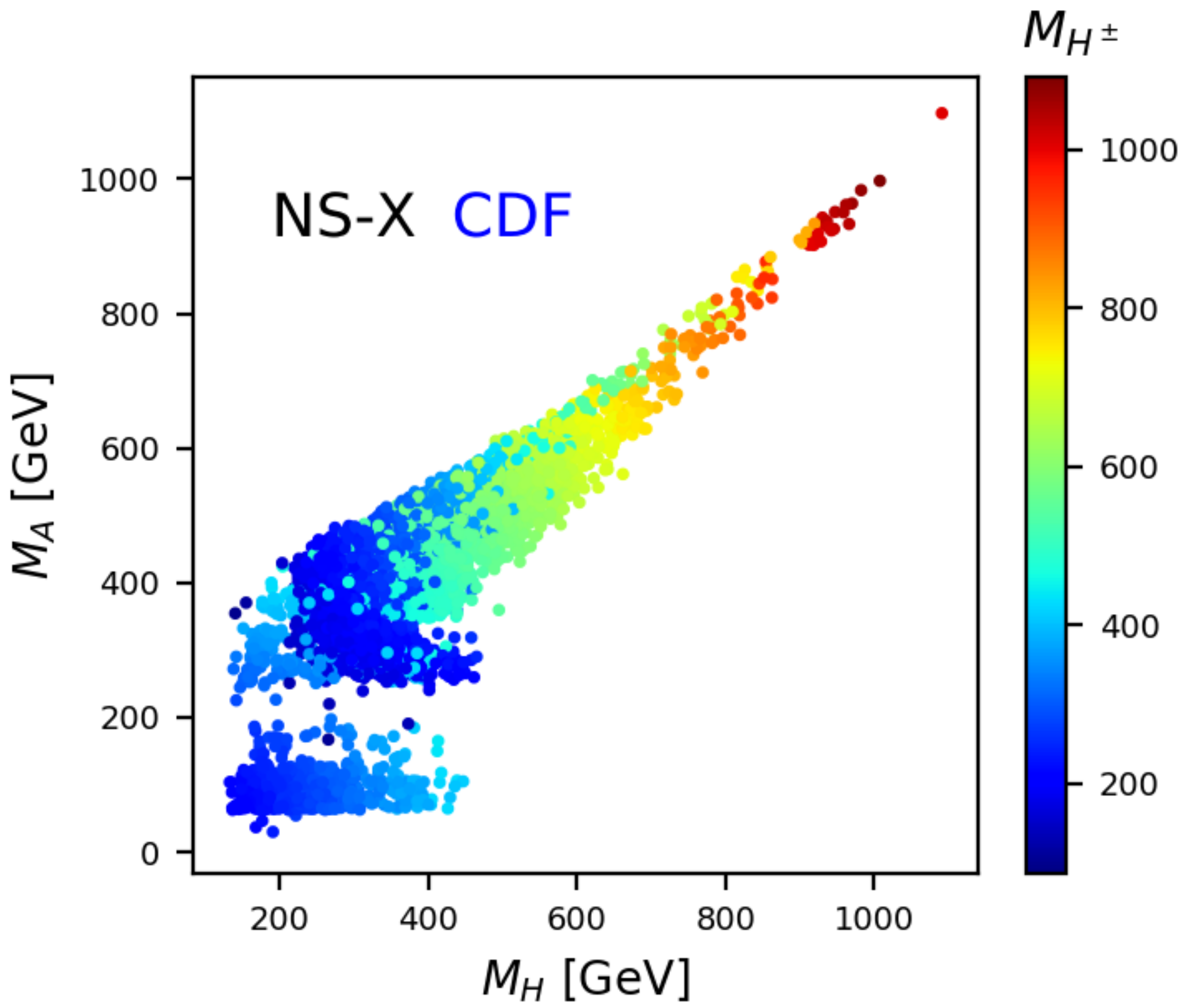


- In the CDF, there are upper bounds on BSM Higgs masses.

4. Characteristics

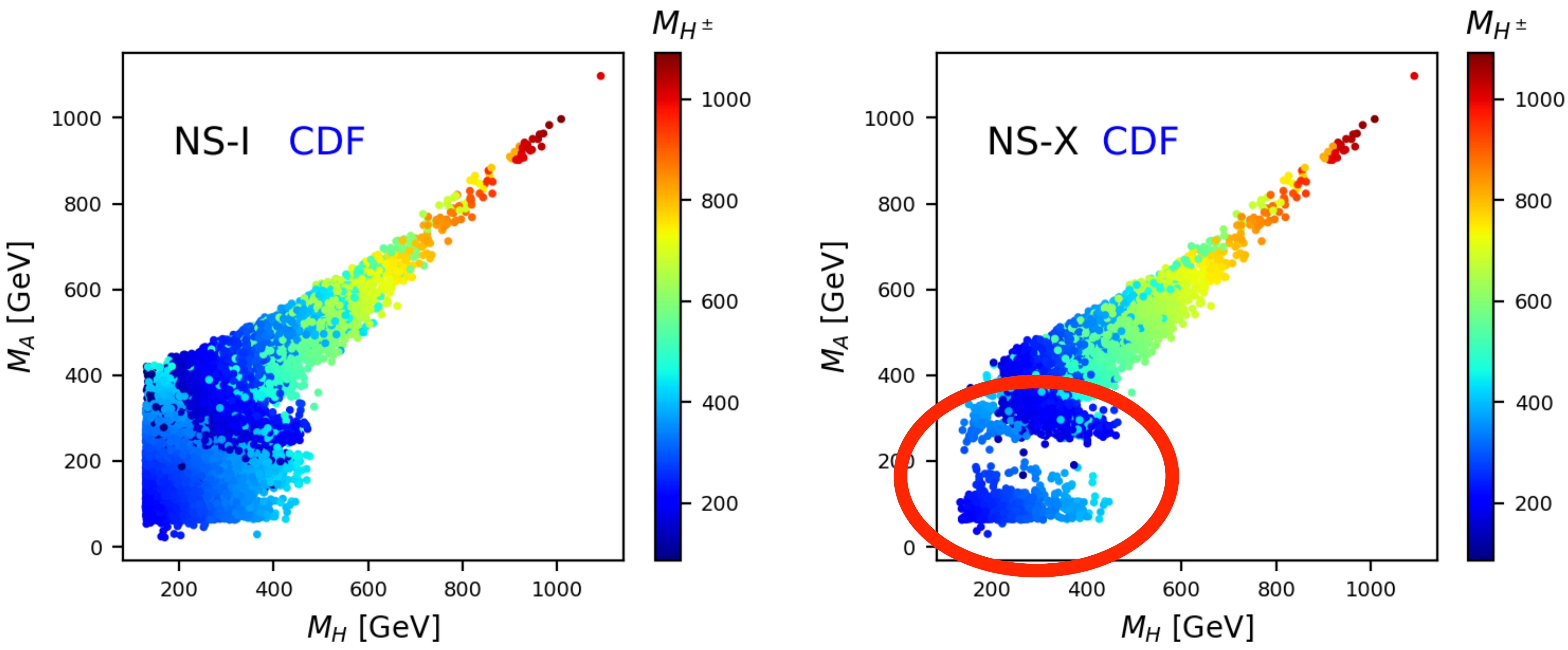
- type-I vs type-X in NS





4. Characteristics

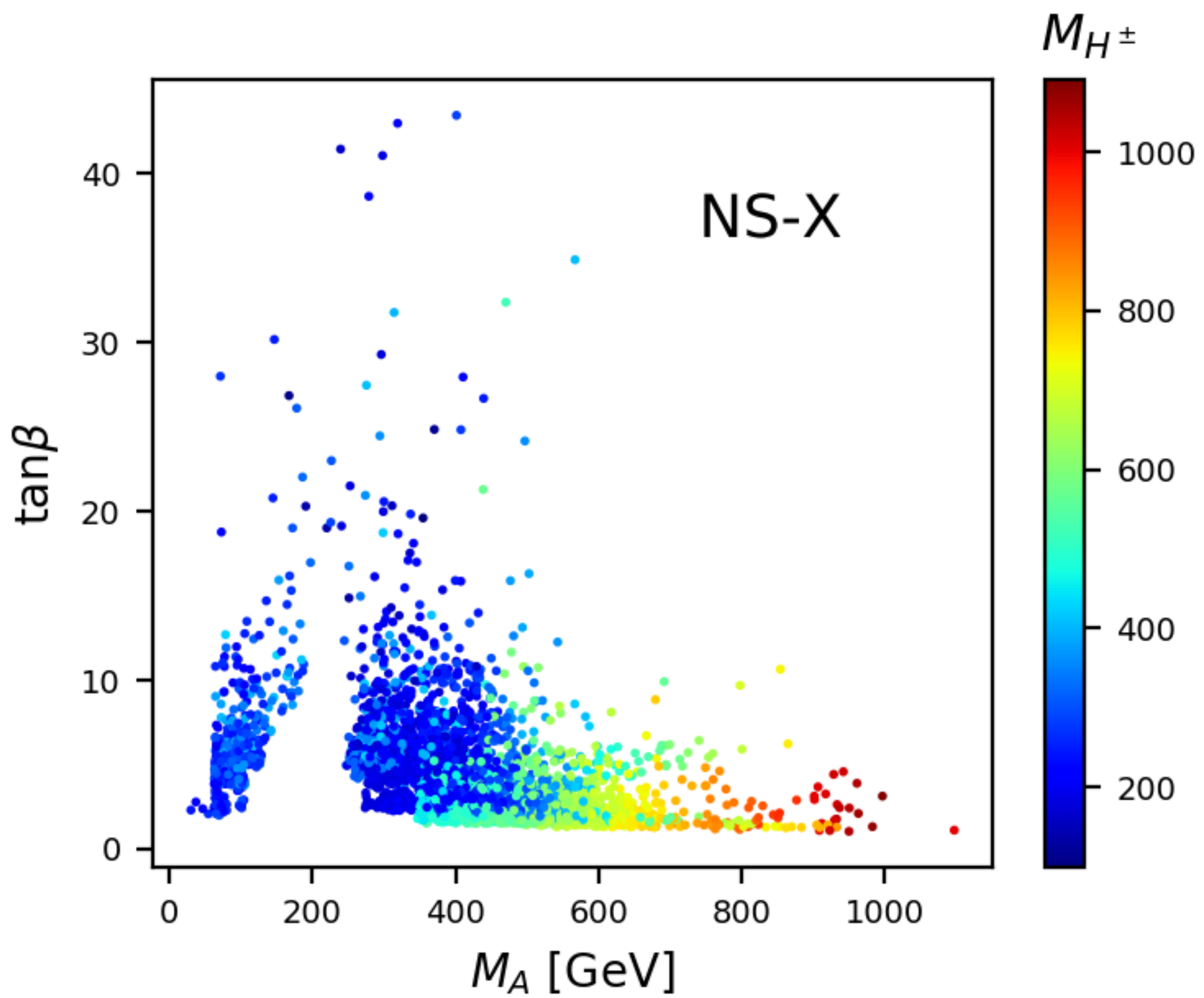
- type-I vs type-X in NS



- MA ~ 200 GeV is excluded in type-X.

4. Characteristics

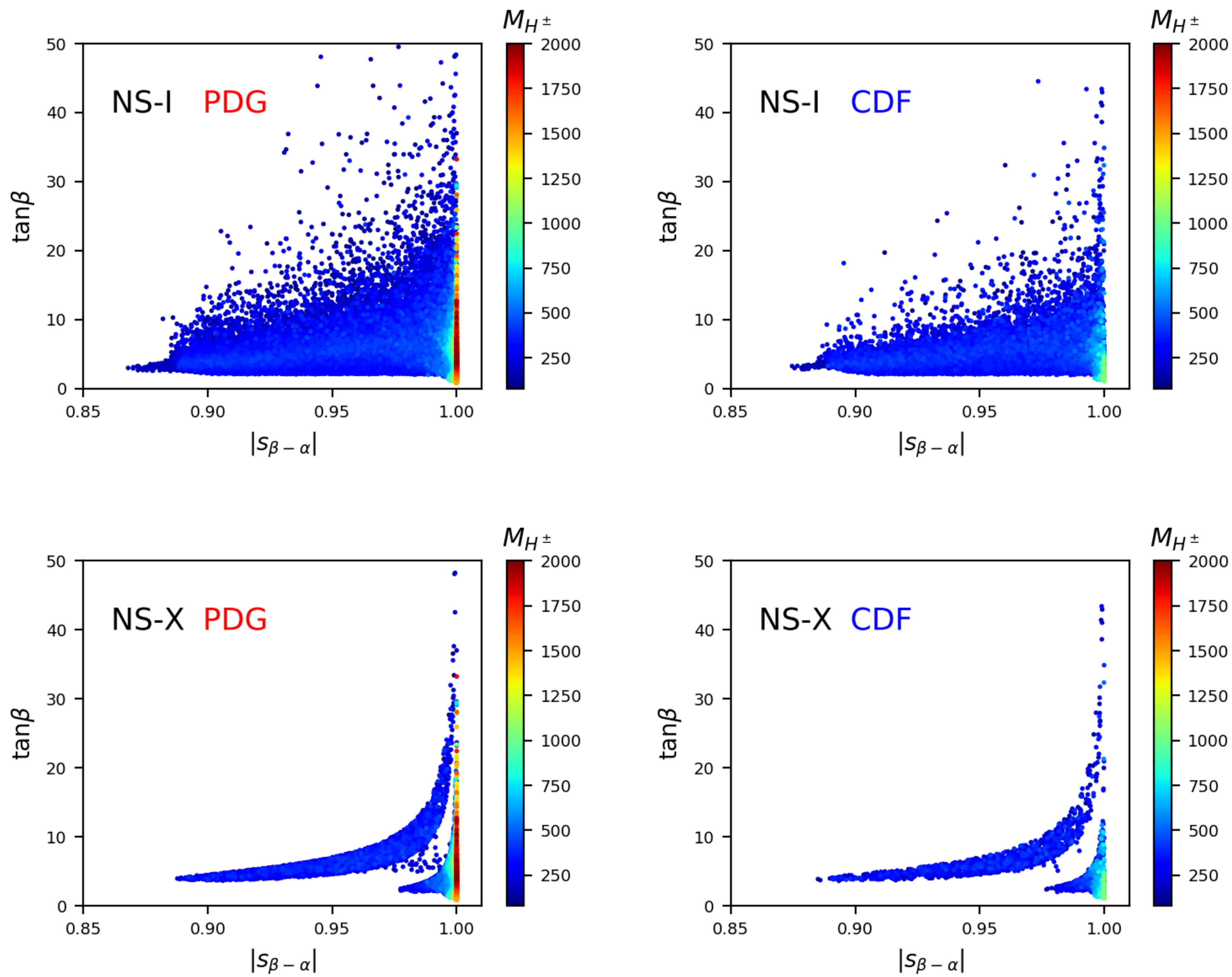
- Mysterious disappearance of MA=200 in type-X



1. $t \to H^\pm b \to \tau\nu b$ in ATLAS;
2. $pp \to H/A \to \tau^+\tau^-$ in ATLAS;
3. $gg \to A \to Zh \to \ell\ell b\bar{b}$ in CMS & ATLAS.

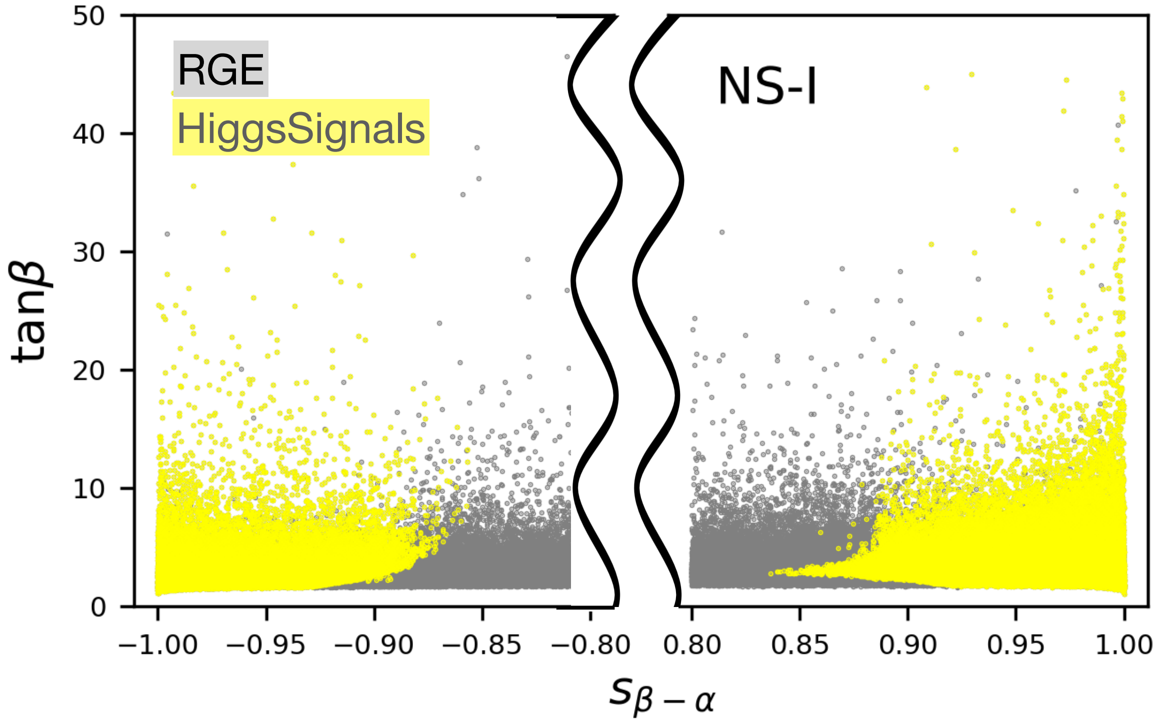
- Why MH+, MH affect the pseudoscalar phenomenology?
- Similar masses.

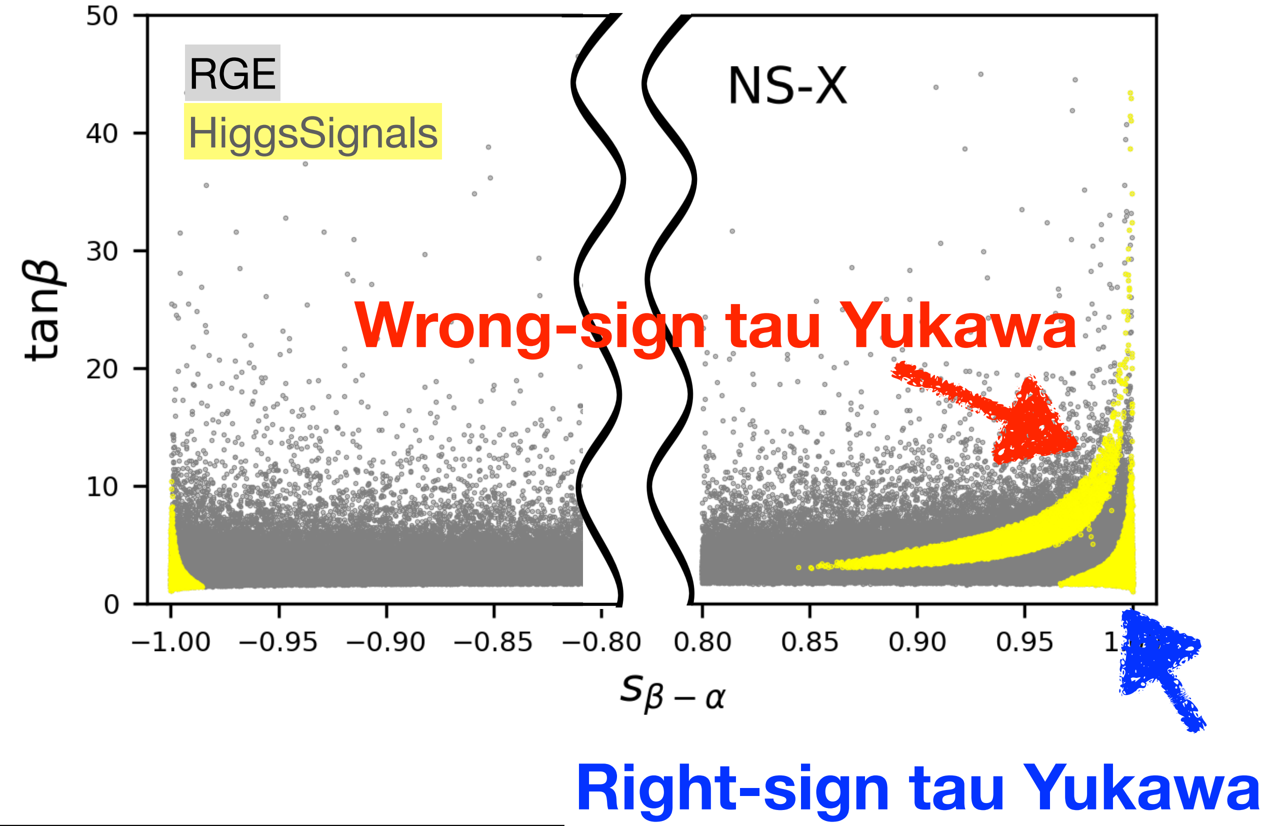
- type-I vs type-X



- More separated two regions in type-X with CDF W mass.

- Effects of Higgs precision data on type-I vs type-X in NS



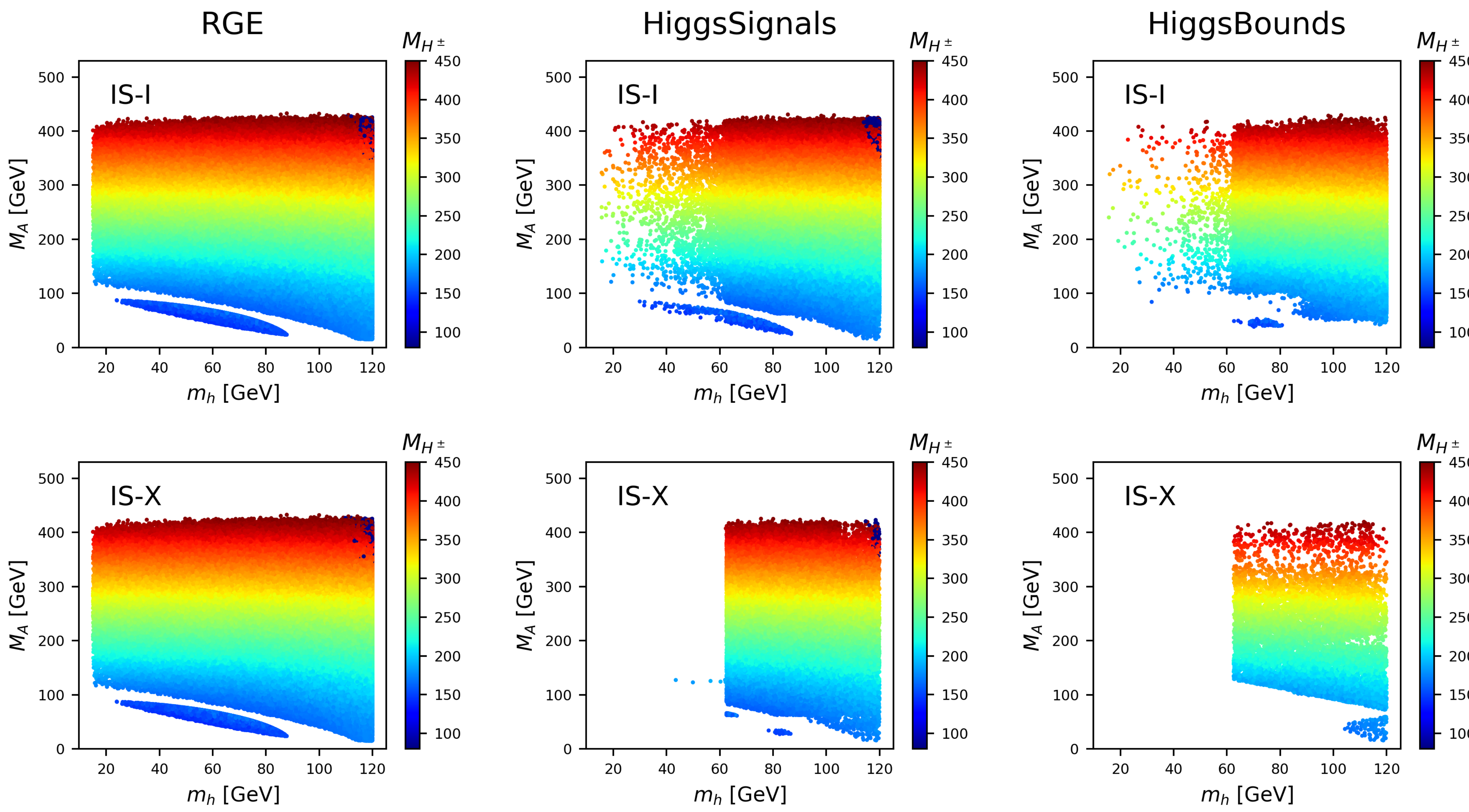


$$\text{type-I:}\quad \xi_\tau^h = \frac{c_\alpha}{s_\beta} = s_{\beta-\alpha} + \frac{c_{\beta-\alpha}}{t_\beta},$$

$$\text{type-X:}\quad \xi_\tau^h = -\frac{s_\alpha}{c_\beta} = s_{\beta-\alpha} - t_\beta c_{\beta-\alpha}.$$

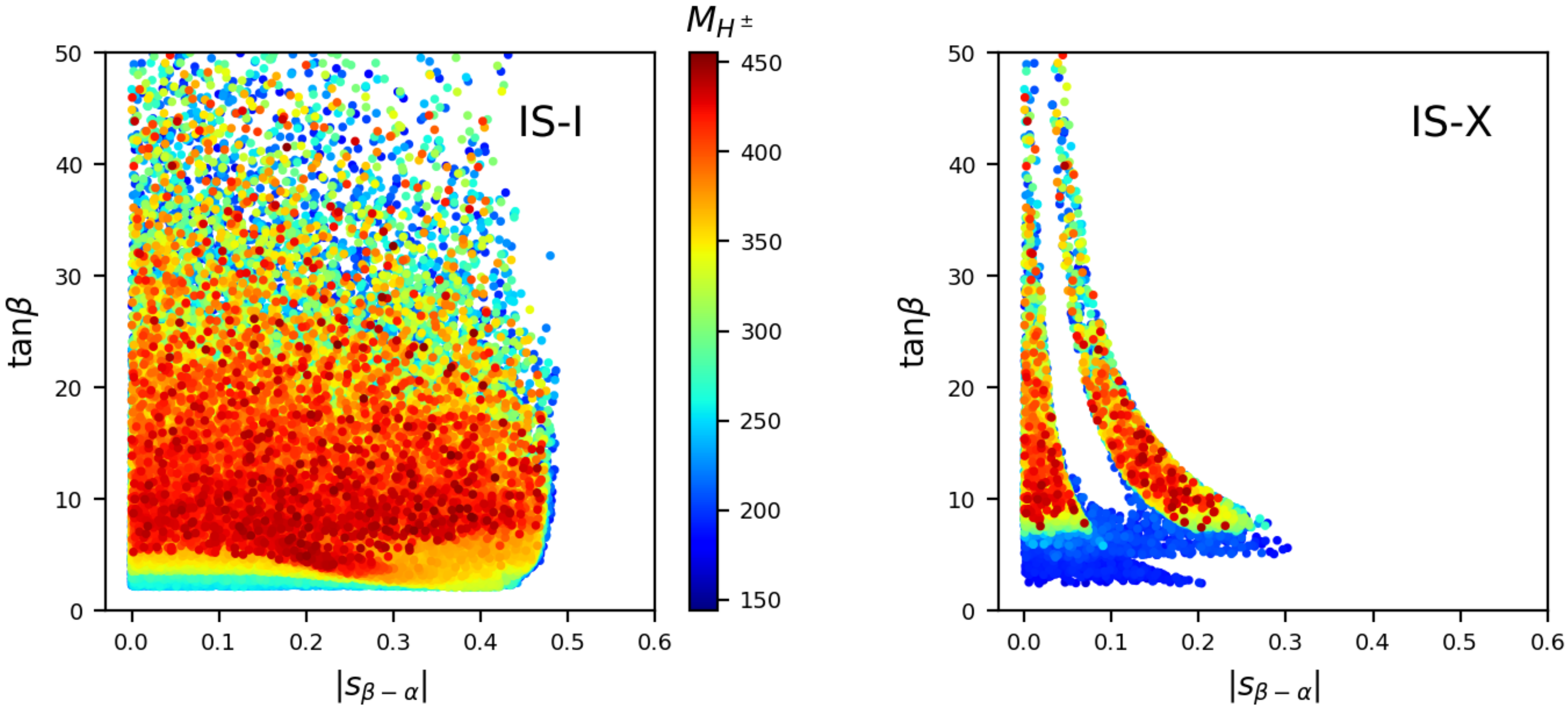
4. Characteristics

- Inverted Senario



4. Characteristics

- type-I vs type-X in IS



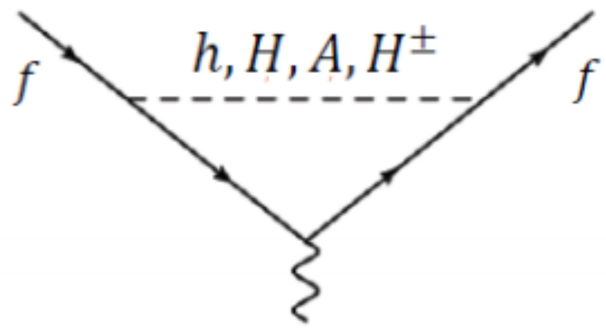
5. Higgs-phobic type-X for Muon g-2

5. Muon g-2

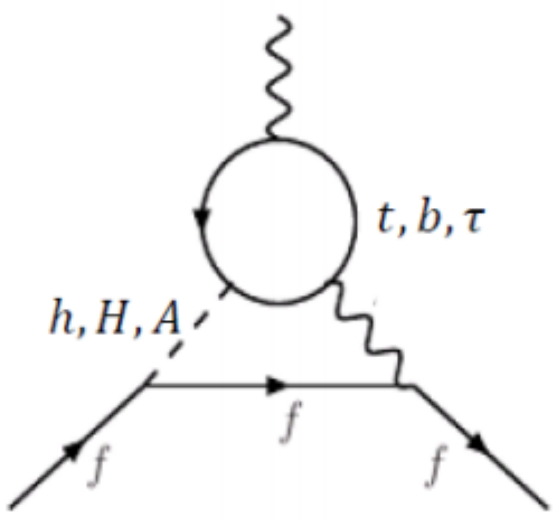
- Persistent anomaly with 4.2σ which has been around for some time

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

- 2HDM: two kinds of contributions



1-loop



Barr-Zee 2-loop

5. Muon g-2

- Higgs aligned type-X cannot explain Lepton Flavor Universality (LFU) data

1. For the τ decay,

$$\frac{g_\tau}{g_\mu}, \quad \frac{g_\tau}{g_e}, \quad \frac{g_\mu}{g_e}, \quad \left(\frac{g_\tau}{g_\mu}\right)_\pi, \quad \left(\frac{g_\tau}{g_\mu}\right)_K.$$

2. Michel parameters, based on the energy and angular distribution of ℓ^- in the decay of $\tau^- \to \ell^- \nu \nu_\tau$:

$$\rho_e, \quad (\xi\delta)_e, \quad \xi_e, \quad \eta_\mu, \quad \rho_\mu, \quad (\xi\delta)_\mu, \quad \xi_\mu, \quad \xi_\pi, \quad \xi_\rho, \quad \xi_{a_1}.$$

3. Leptonic Z decays:

$$\frac{\Gamma(Z \to \mu^+\mu^-)}{\Gamma(Z \to e^+e^-)}, \quad \frac{\Gamma(Z \to \tau^+\tau^-)}{\Gamma(Z \to e^+e^-)}.$$

2104.10175 [hep-ph]

5. Muon g-2

- Higgs aligned type-X cannot explain Lepton Flavor Universality (LFU) data

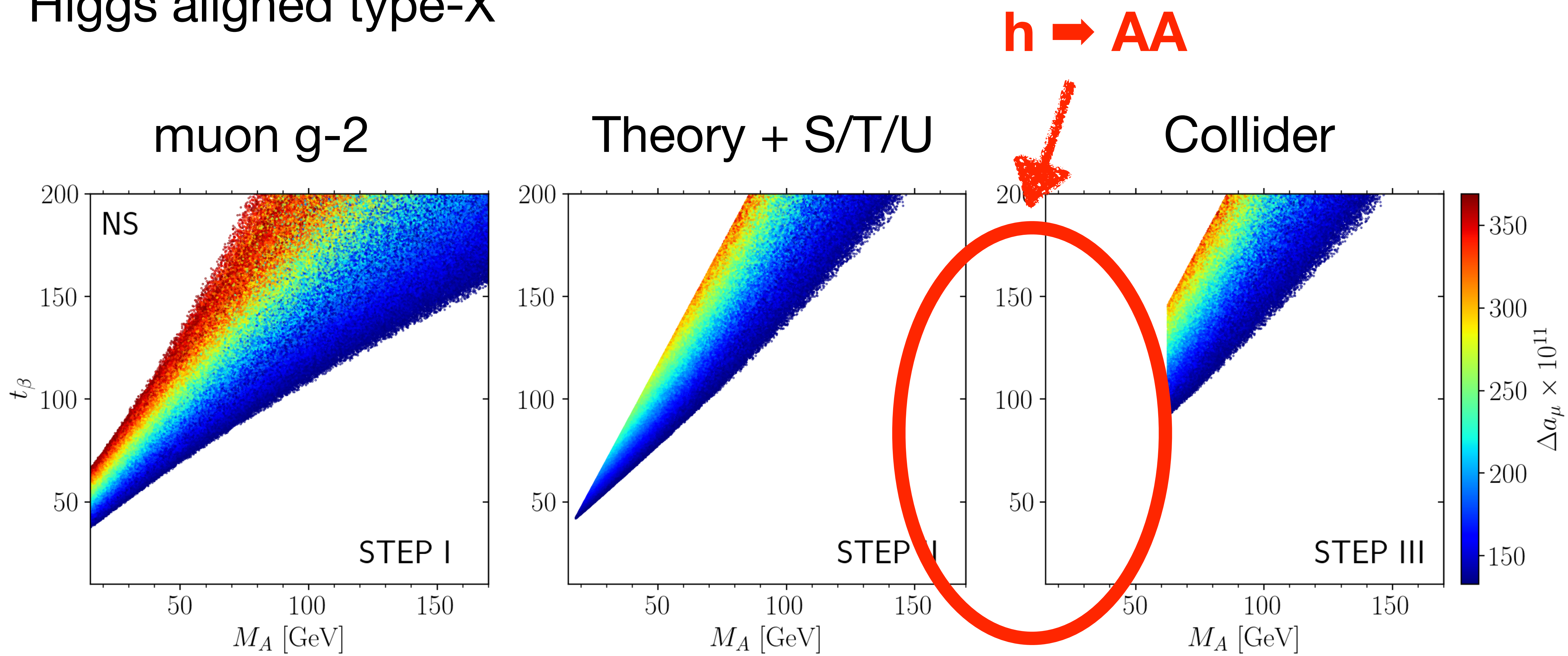
Global fit to Δa_μ and the LFU data
after all the theoretical/experimental constraints

$$p(\mathrm{SM}) = 0.003 \quad p(\mathrm{aligned\ type-X}) < 0.02$$

Why?

5. Muon g-2

- Higgs aligned type-X



Very large $\tan\beta$ ➡ $$\delta_{\rm tree} = \frac{m_\mu m_\tau t_\beta^2}{M_{H^\pm}^2}.$$

2104.10175 [hep-ph]

5. Muon g-2

- Higgs-phobic A in type-X

$$\hat{\lambda}_{hAA} = \left(2M^2 - 2M_A^2 - m_h^2\right) s_{\beta-\alpha} + \left(m_h^2 - M^2\right) \left(t_\beta - \frac{1}{t_\beta}\right) c_{\beta-\alpha}.$$

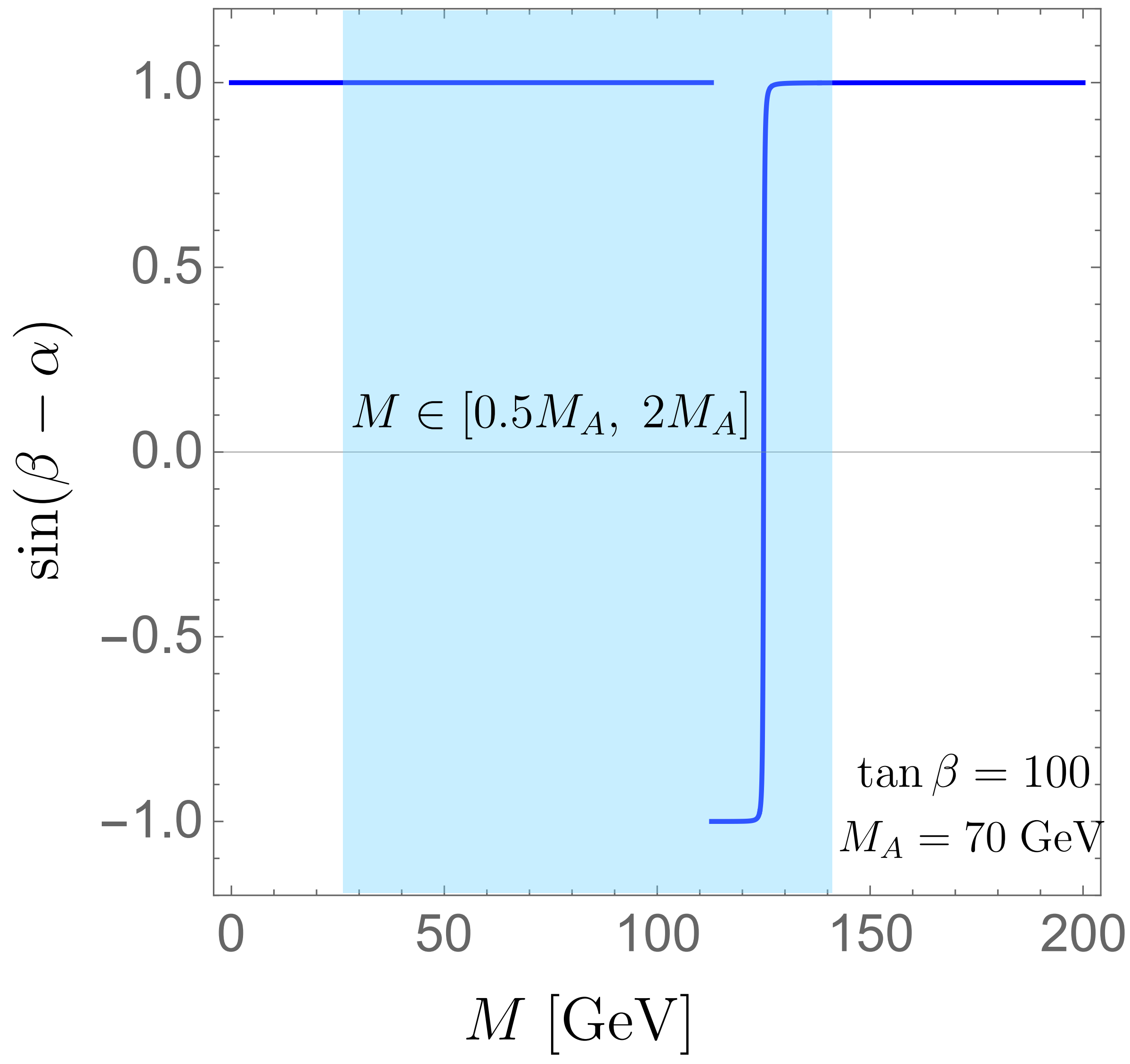
$$\text{Higgs-phobic } A: \quad \frac{s_{\beta-\alpha}}{c_{\beta-\alpha}} = -\left(t_\beta - \frac{1}{t_\beta}\right) \frac{m_h^2 - M^2}{2M^2 - 2M_A^2 - m_h^2}.$$

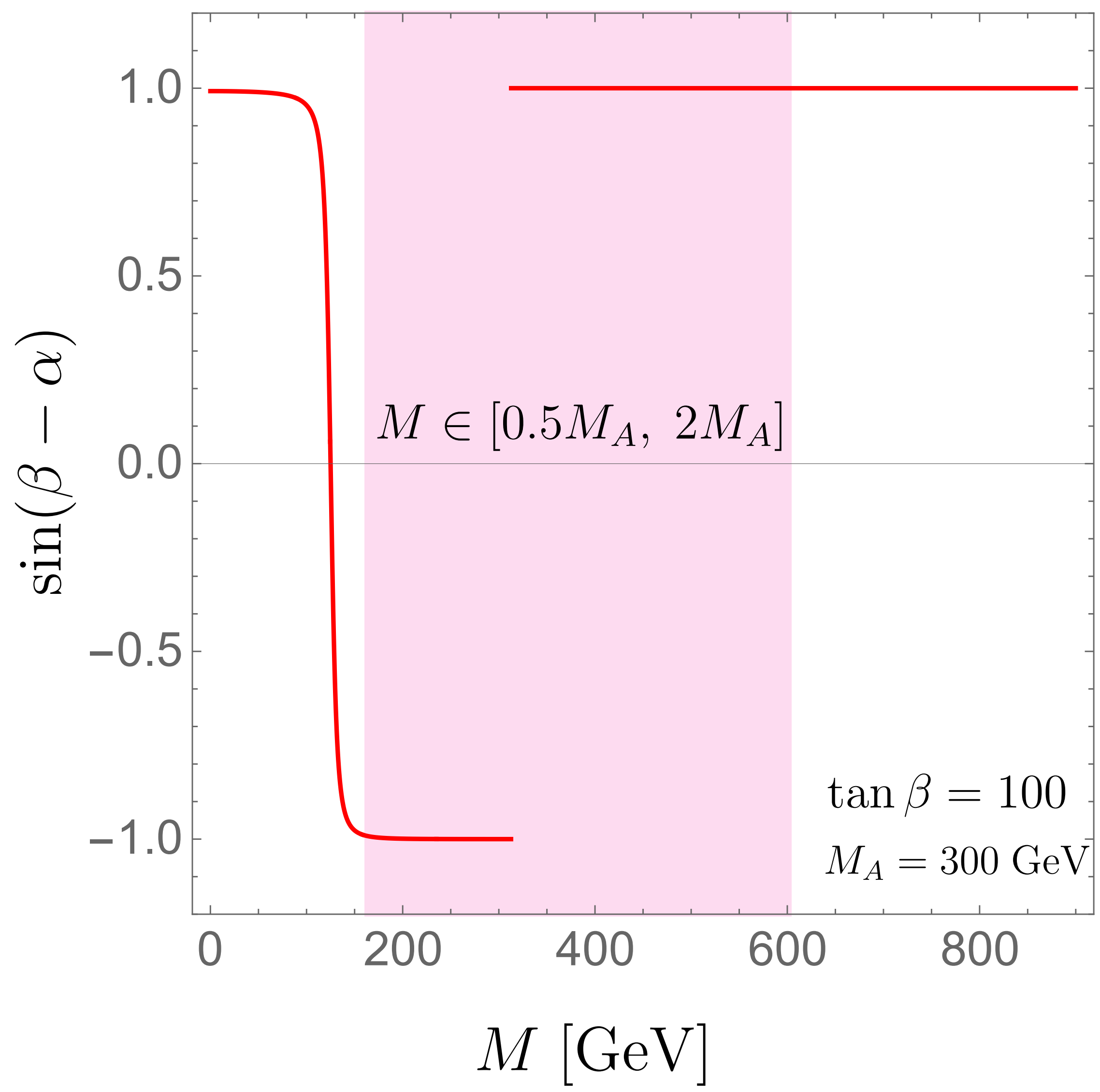
- Higgs-phobic A cannot coexist with 100% alignment. BUT

Chun et al 1507.08067

5. Muon g-2

- Higgs-phobic → almost Higgs alignment





5. Muon g-2

- Random scanning

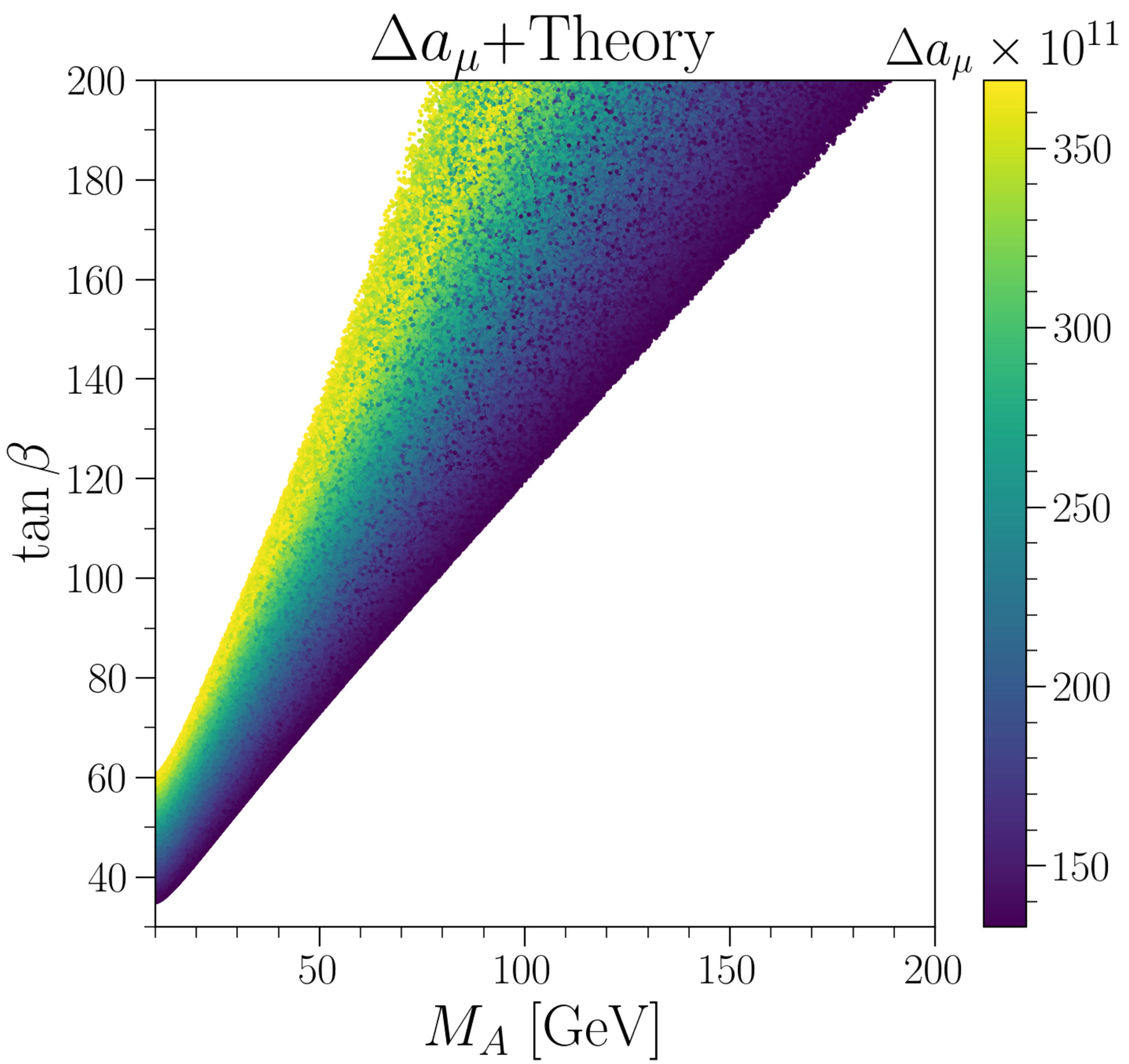
  - **step I:** Δa_μ**+Theory**
  - **step II:** S/T
  - **step III: Higgs precision and direct search bounds (Collider)**
  - **step IV: global fit to** Δa_μ**+LFU**

- Survival probabilities about step I

$$\text{PDG:} \quad P_{\text{Step-II}} = 5.47\%, \quad P_{\text{Step-III}} = 3.15\%, \quad P_{\text{Step-IV}} = 0.62\%,$$
$$\text{CDF:} \quad P_{\text{Step-II}} = 1.56\%, \quad P_{\text{Step-III}} = 1.00\%, \quad P_{\text{Step-IV}} = 0.21\%.$$

5. Muon g-2

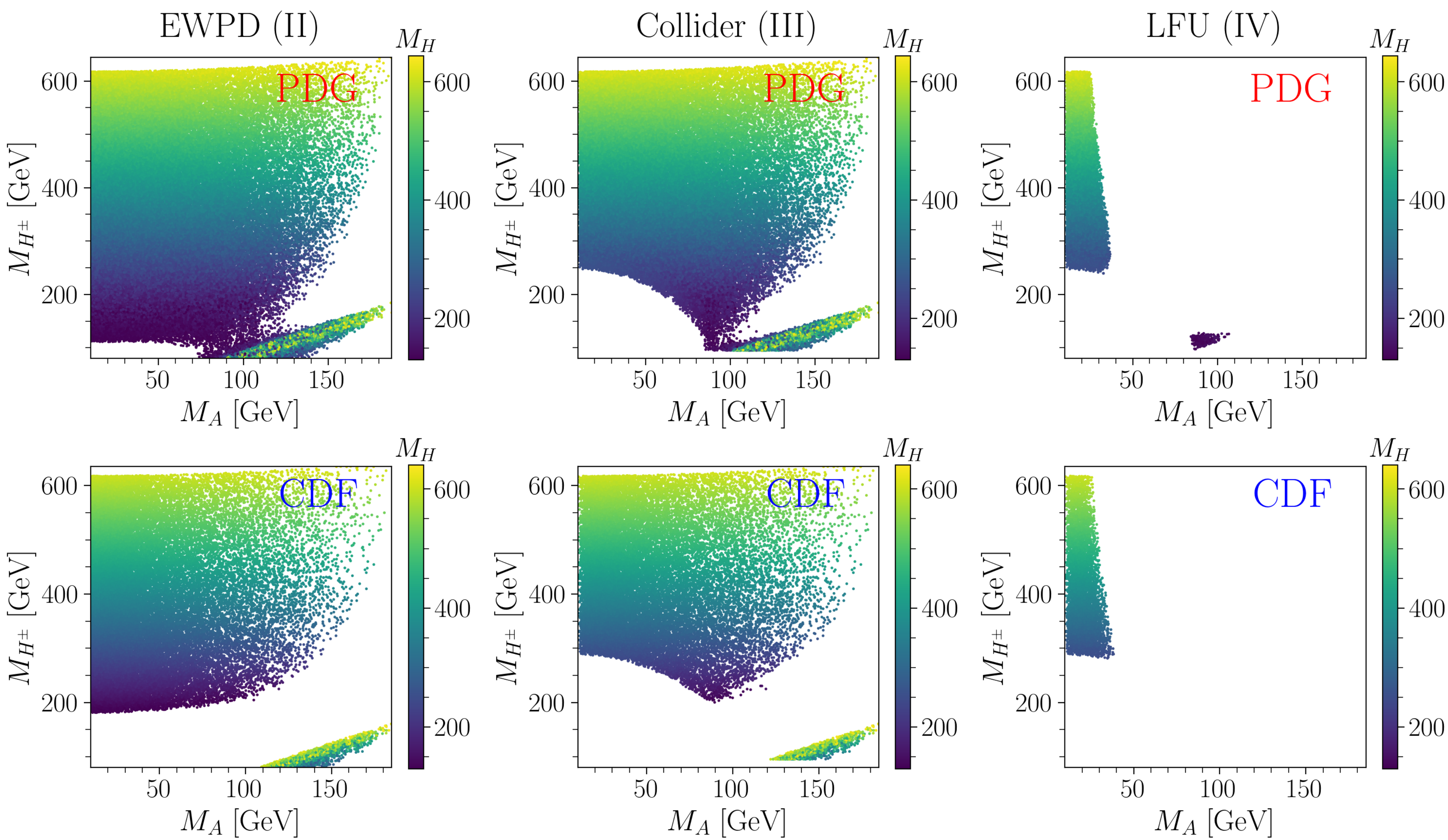
- **step I:** Δa_μ**+Theory**



- Light MA and large tan β

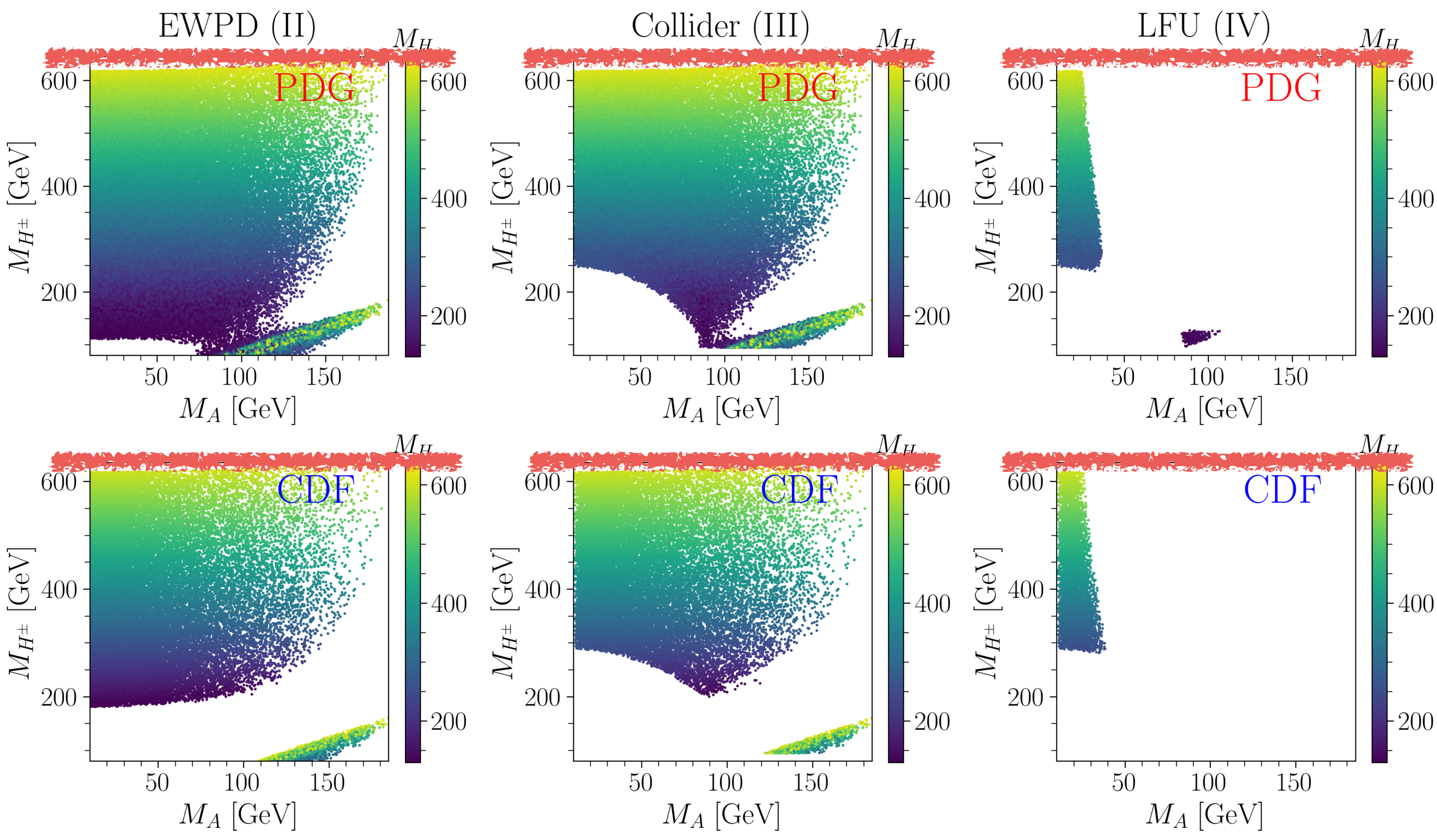
5. Muon g-2

- Random scanning



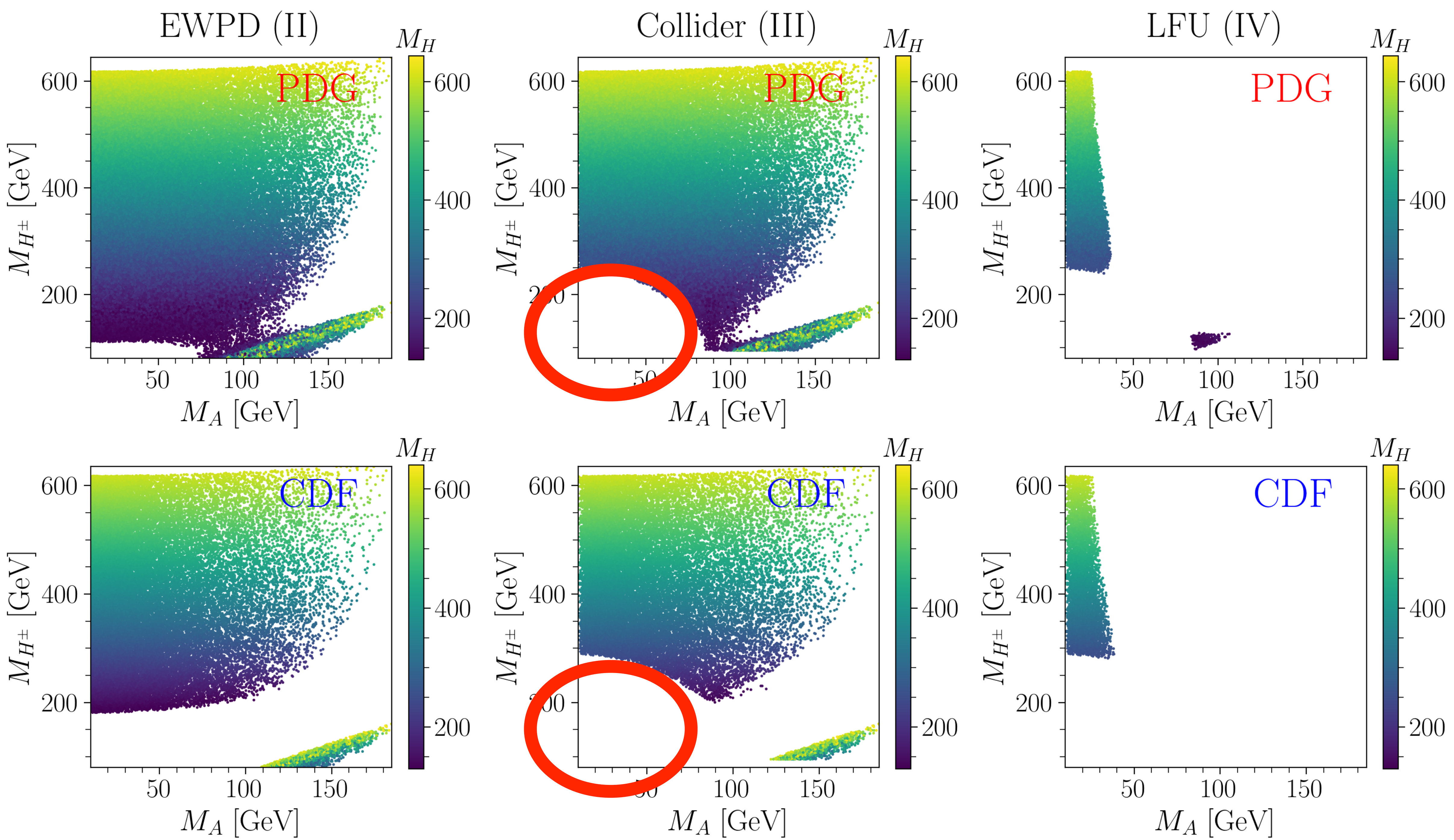
5. Muon g-2

- Common feature 1: upper bounds on MH and MH+



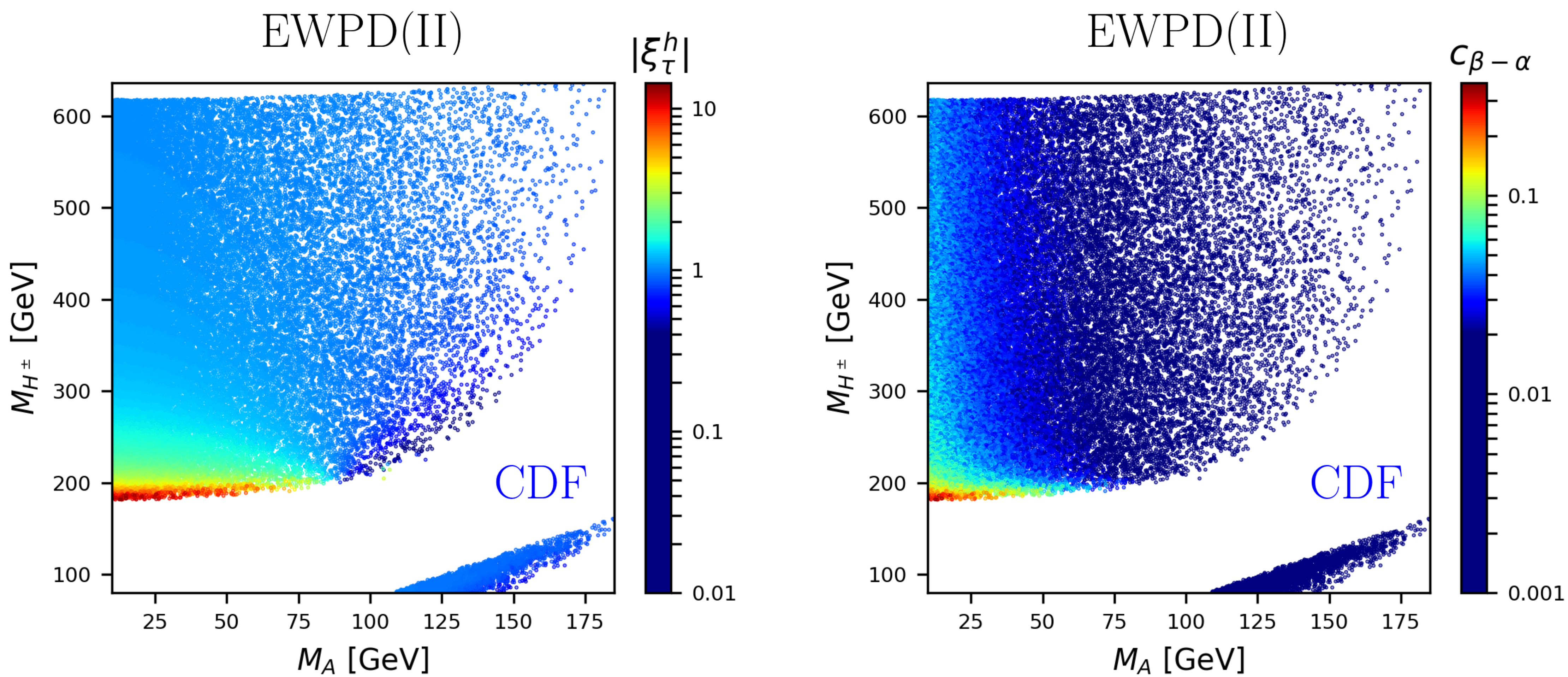
5. Muon g-2

- Common feature 2: lower bounds on MH+ for light MA



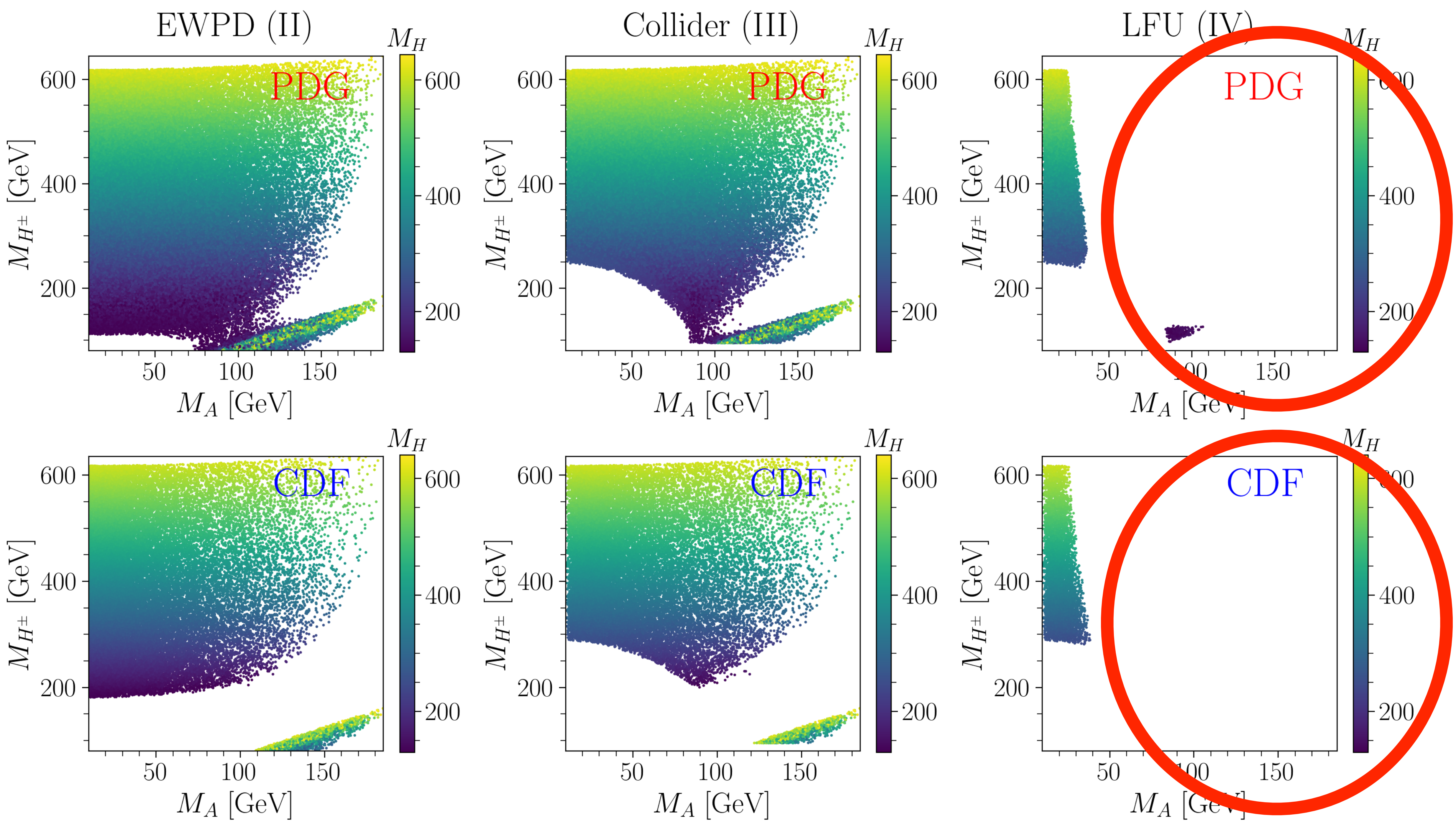
5. Muon g-2

- Common feature 2: lower bounds on MH+ for light MA from h → $\tau\ \tau$

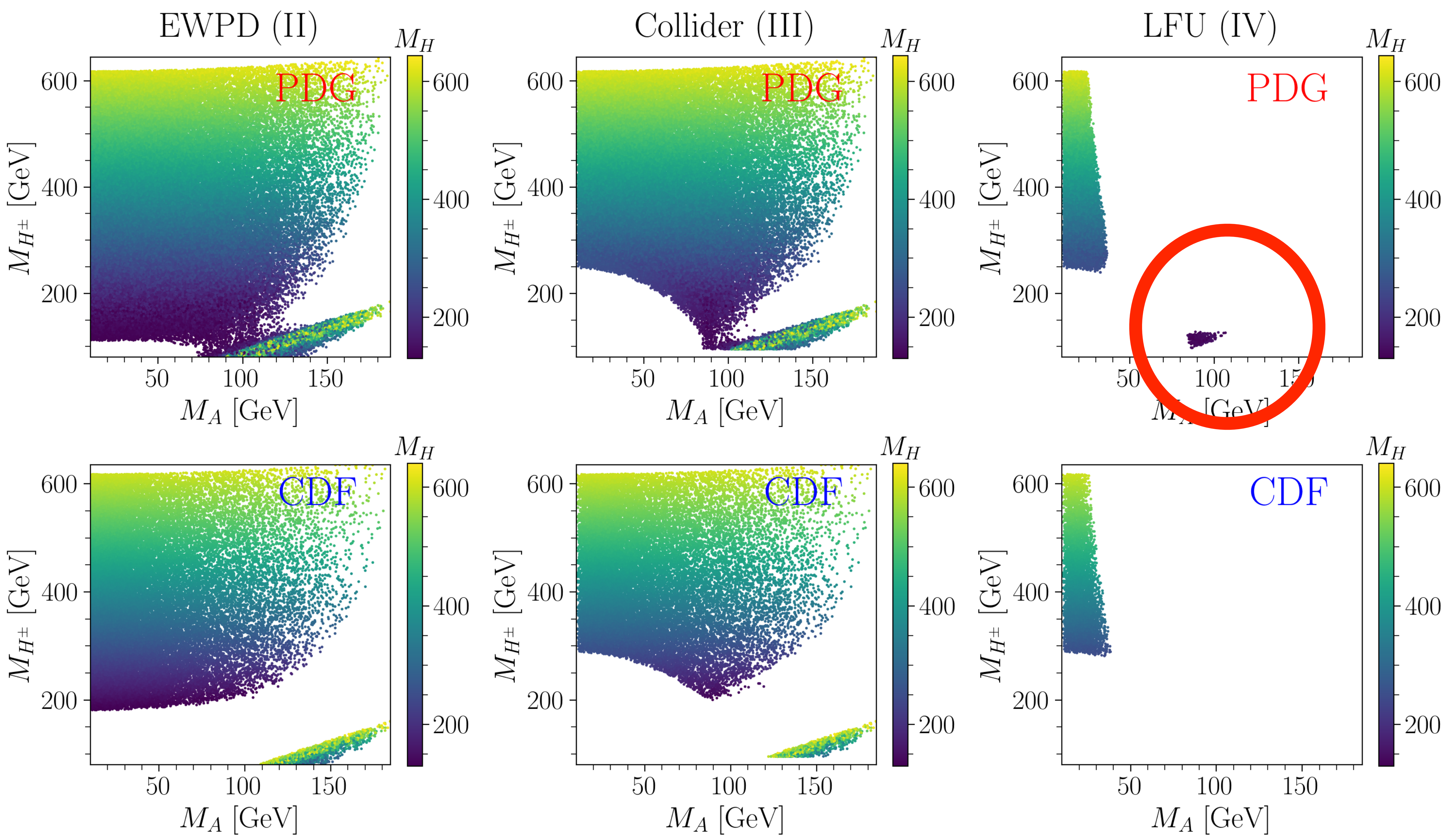


5. Muon g-2

- Common feature : LFU removes most of region with MA>38 GeV

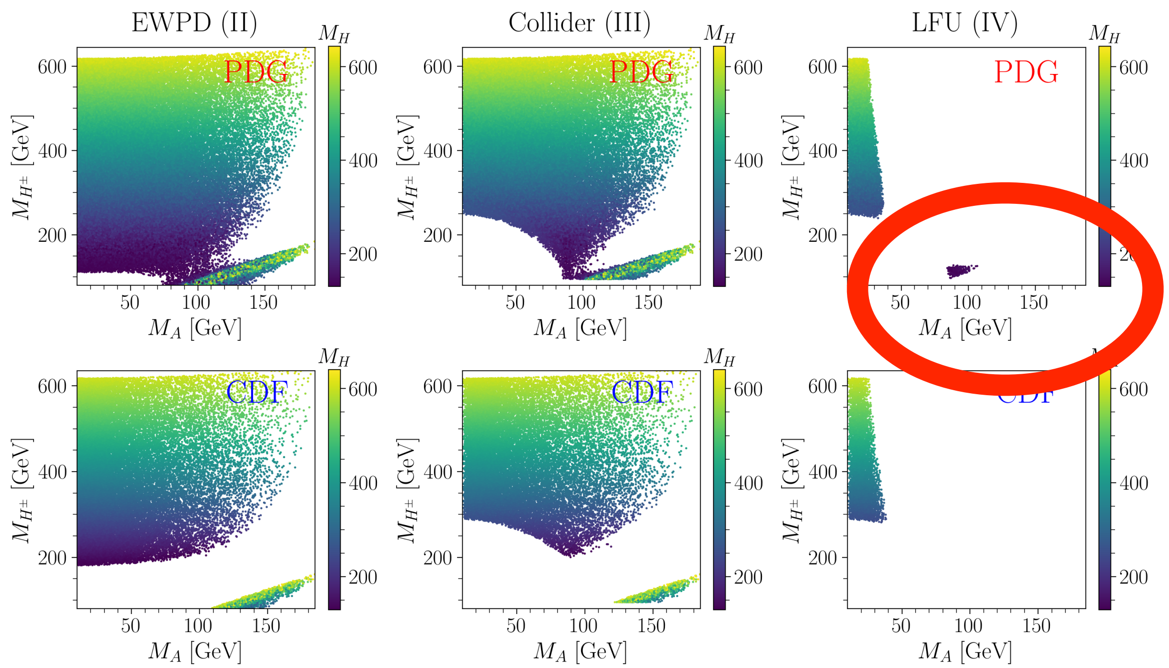


- Difference-1: PDG island



5. Muon g-2

- Difference-1: PDG island

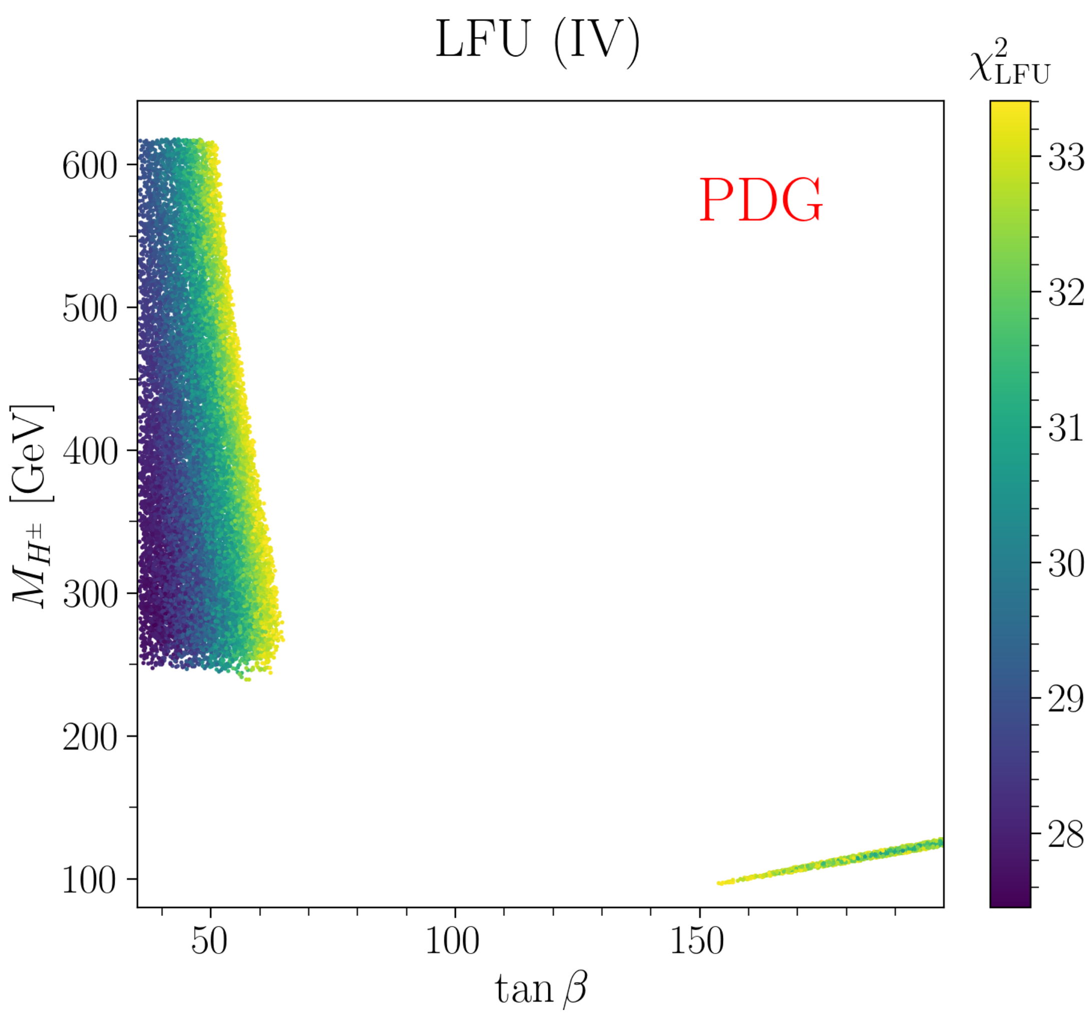


$$\text{PDG-island:}\ \ M_H \in [130.0, 165.3]\ \text{GeV}, \quad M_A \in [84.1, 111.9]\ \text{GeV},$$
$$M_{H^\pm} \in [96.5, 127.9]\ \text{GeV}, \quad t_\beta > 154.9.$$

5. Muon g-2

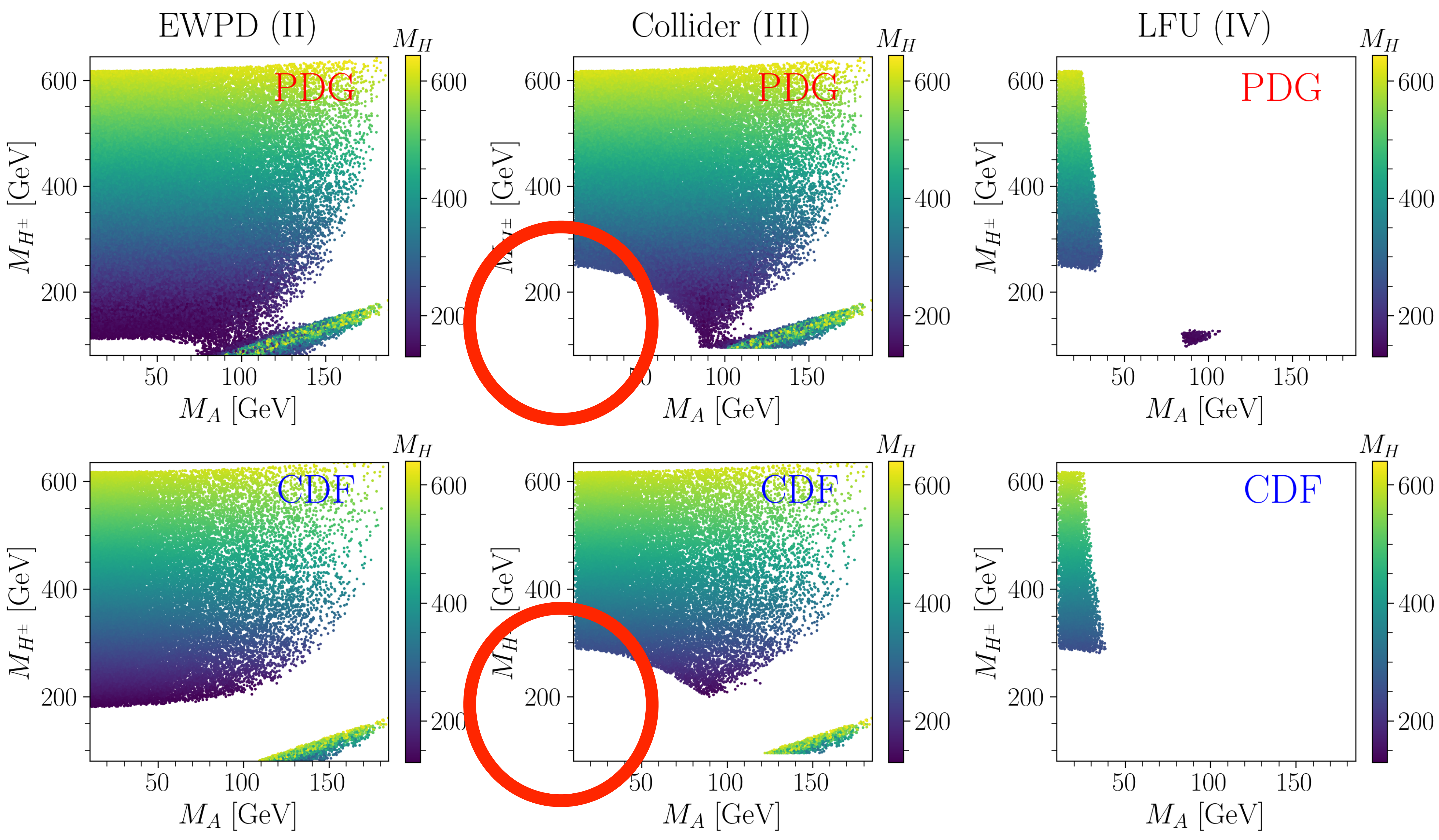
- Difference-1: How can the PDG-island evade the LFU?
- Cancellation!

$$\epsilon^{\tau}_{\rm tree} = \delta_{\rm tree}\left[\frac{\delta_{\rm tree}}{8} - \frac{m_\mu}{m_\tau}\frac{g\left(\rho^\mu_\tau\right)}{f\left(\rho^\mu_\tau\right)}\right]$$



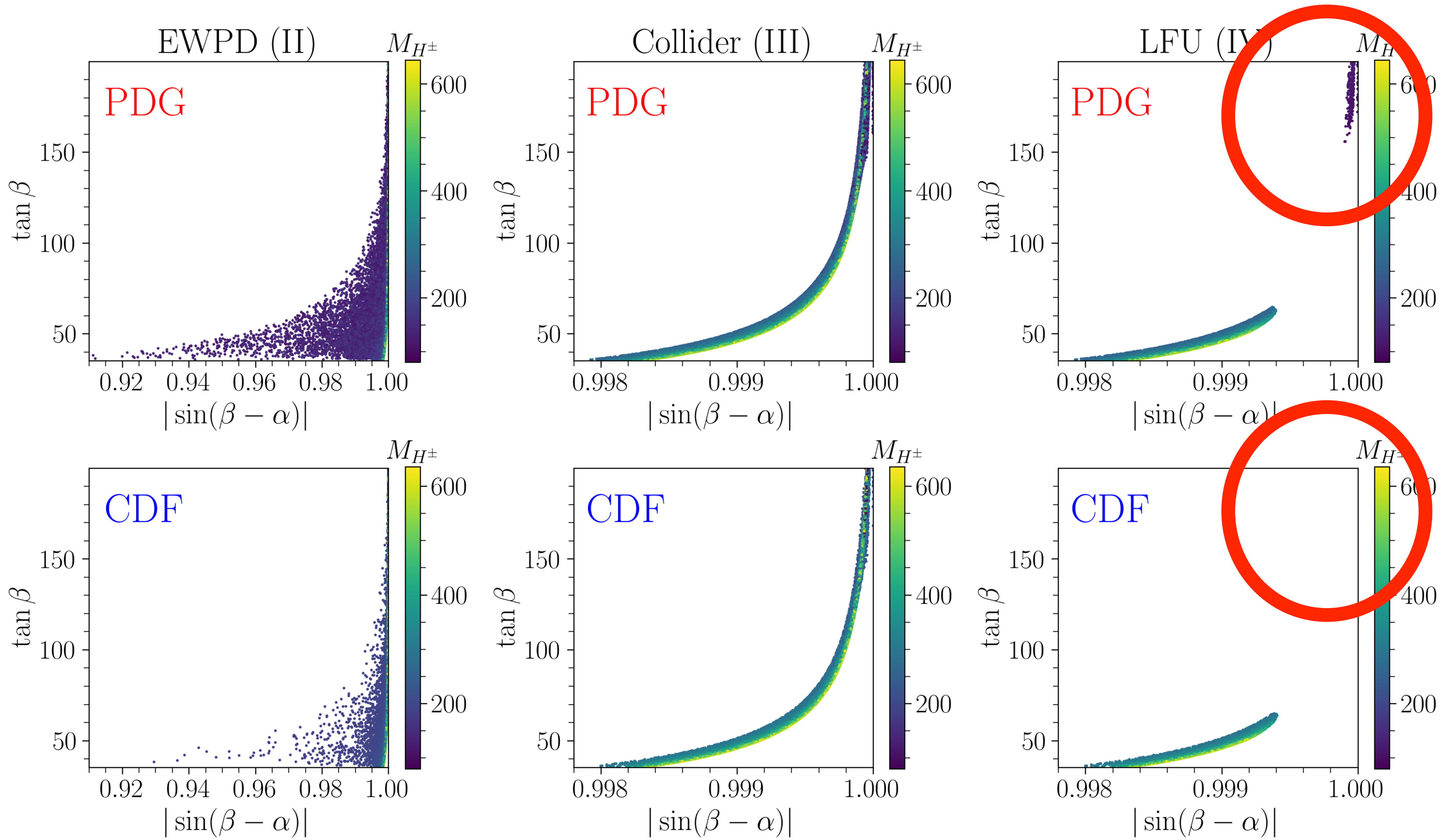
5. Muon g-2

- Difference-2: lower bound on MH+



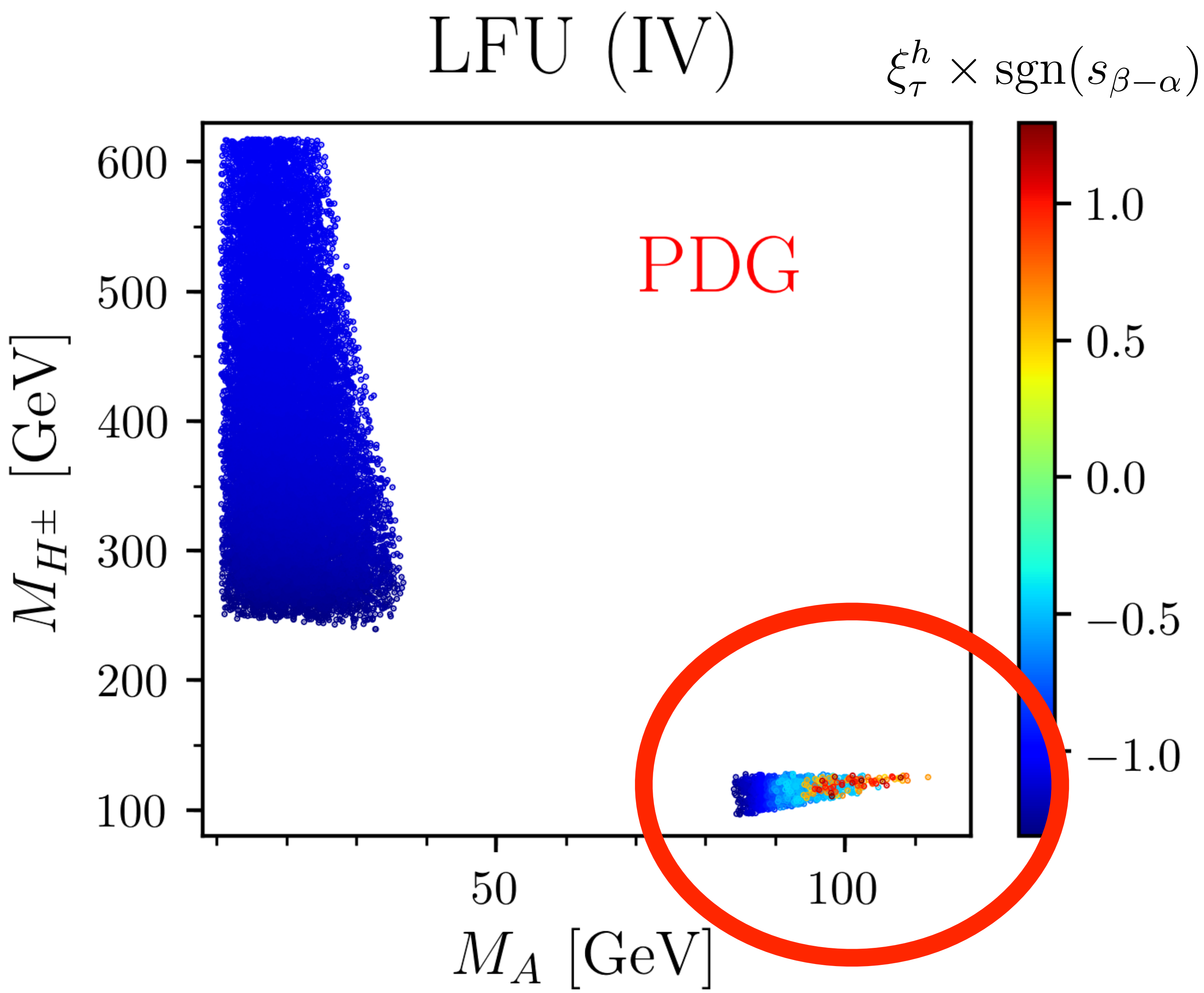
5. Muon g-2

- Difference-3: tan β



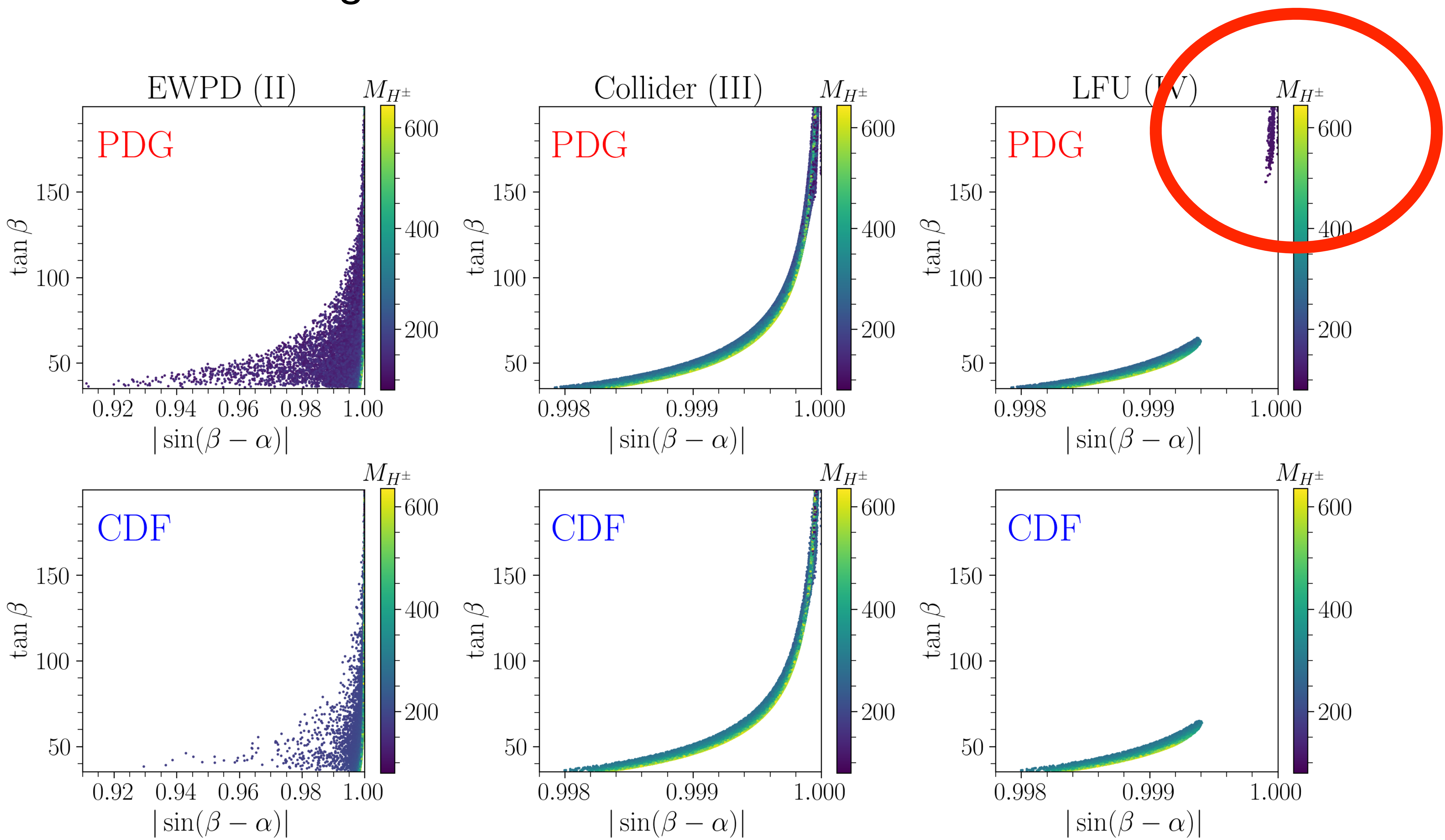
5. Muon g-2

- Difference-4: right-sign and wrong-sign tau Yukawa coupling



5. Muon g-2

- Random scanning



5. Muon g-2

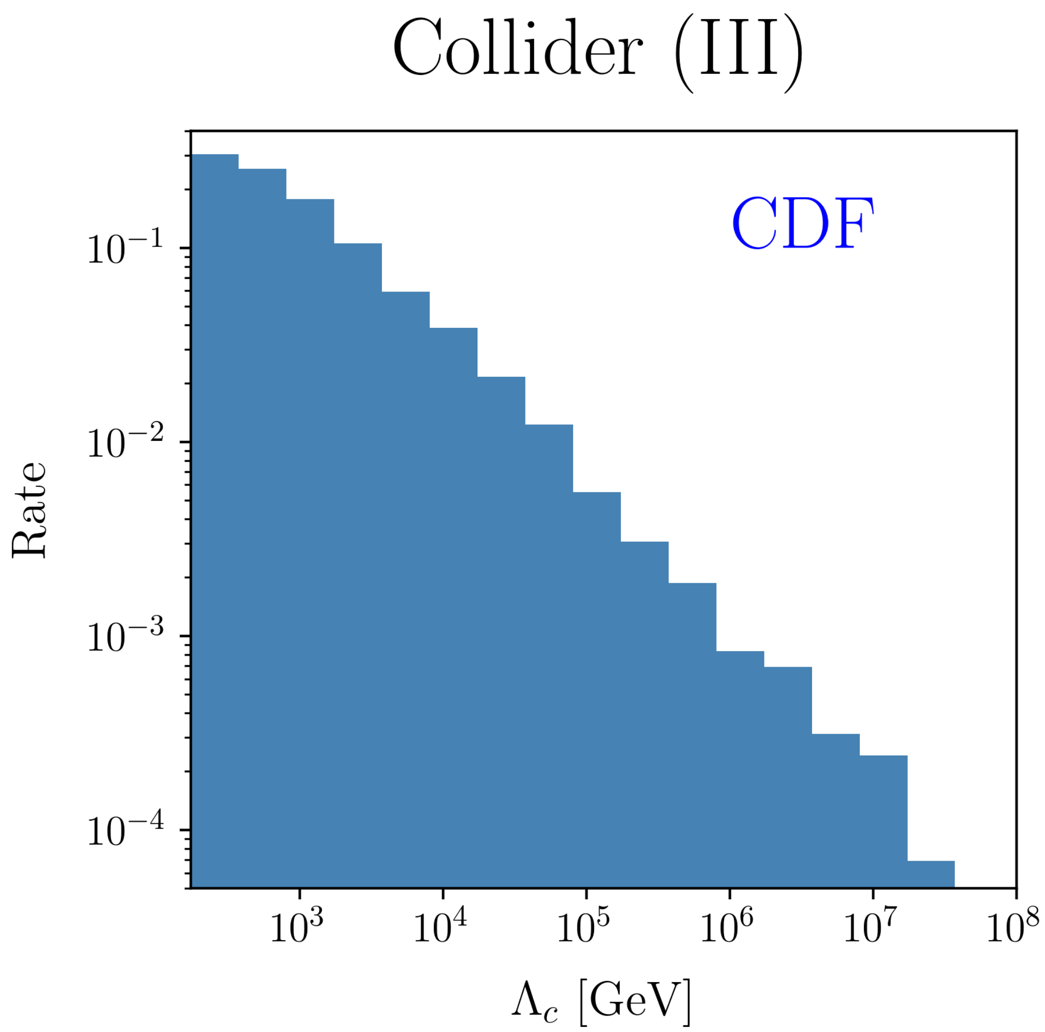
- RGE analysis

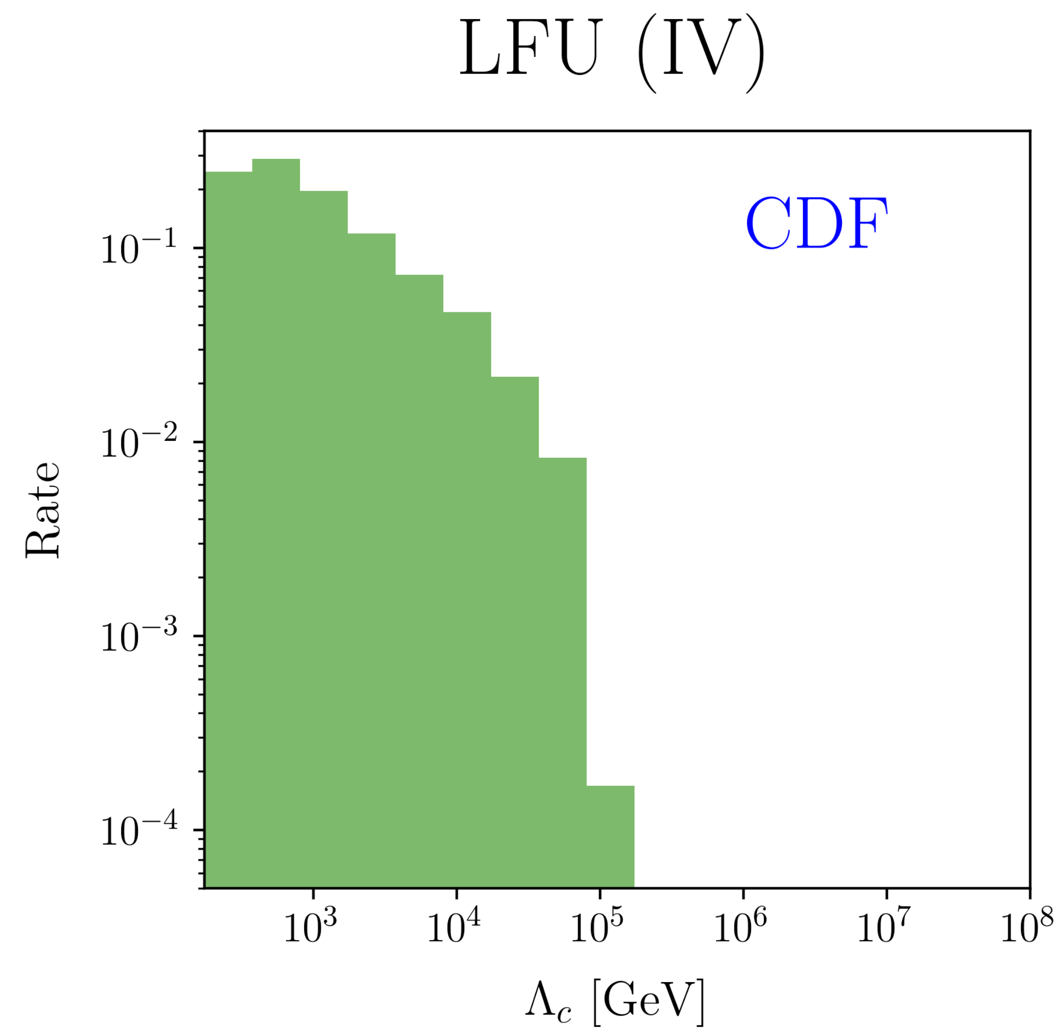
1. Run each parameter point via the RGEs.
2. Check three conditions—unitarity, perturbativity, and vacuum stability—as increasing the energy scale.
3. If any condition is broken at a particular energy scale, we stop the evolution and record the energy scale as the cutoff scale.

$$g_s, \quad g, \quad g', \quad \lambda_{1,\cdots,5}, \quad \xi_f^{h,H,A}, \quad m_{ij}^2, \quad v_i, \quad (i=1,2).$$

5. Muon g-2

- RGE: distribution of the cutoff scales

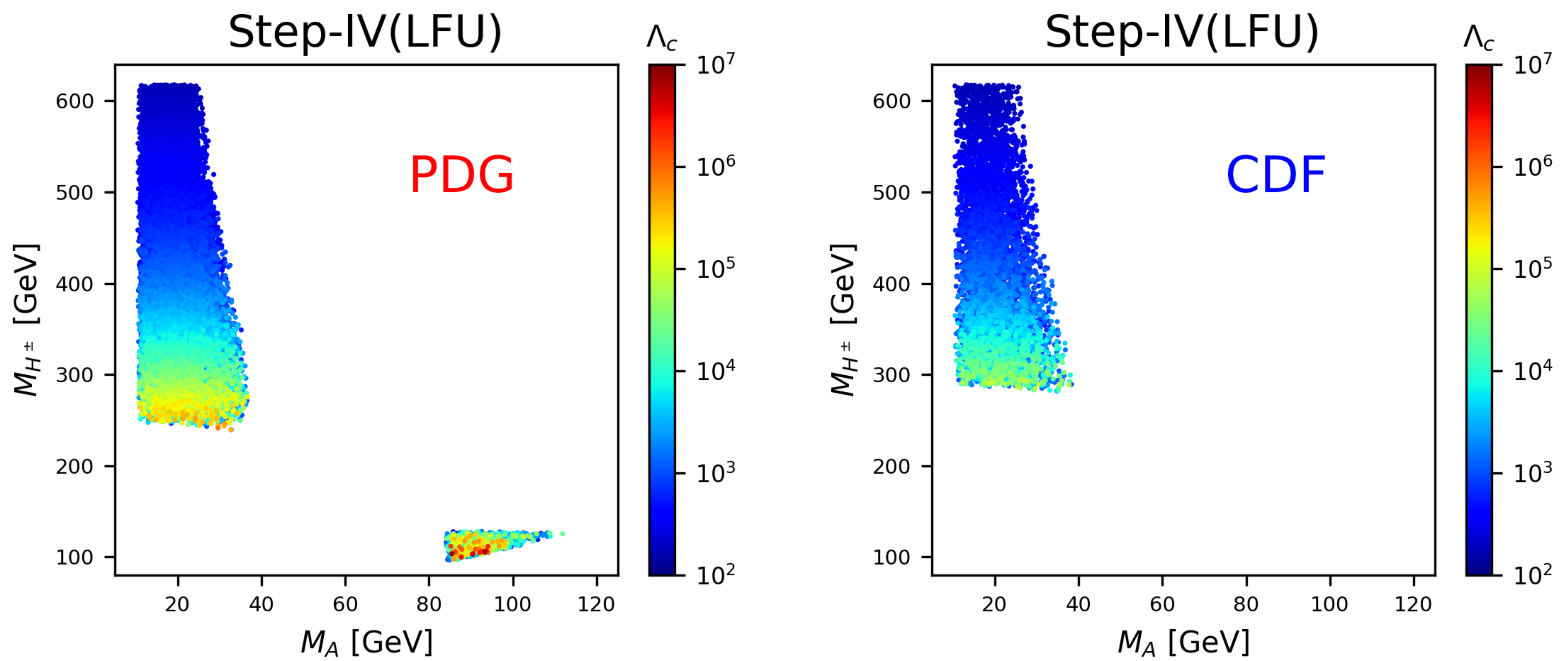




- In the CDF, the maximum cutoff scale is about 100 TeV, due to LFU.

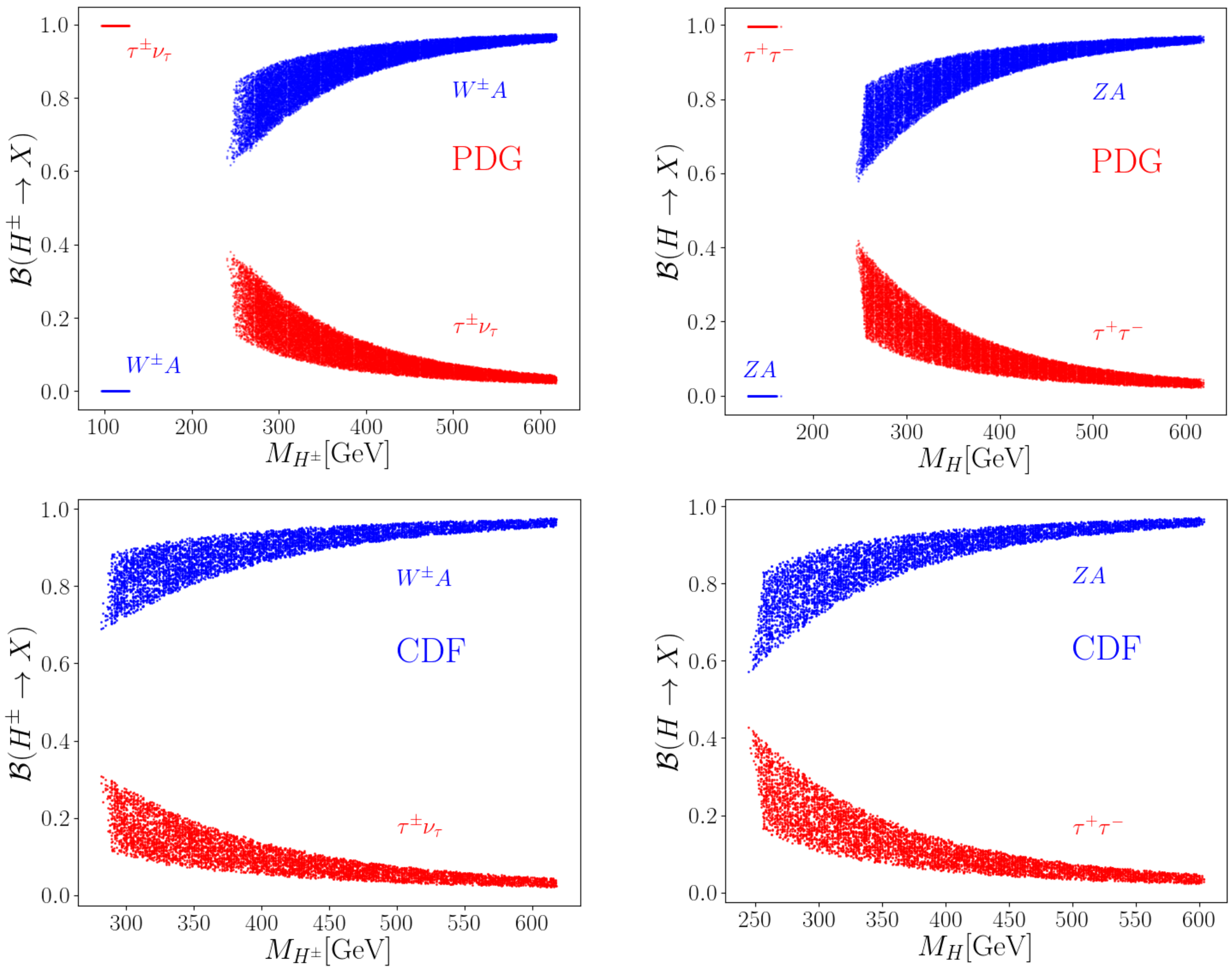
5. Muon g-2

- PDG vs CDF in the RGE analysis



- The maximum cutoff scale is in the PDG-island.

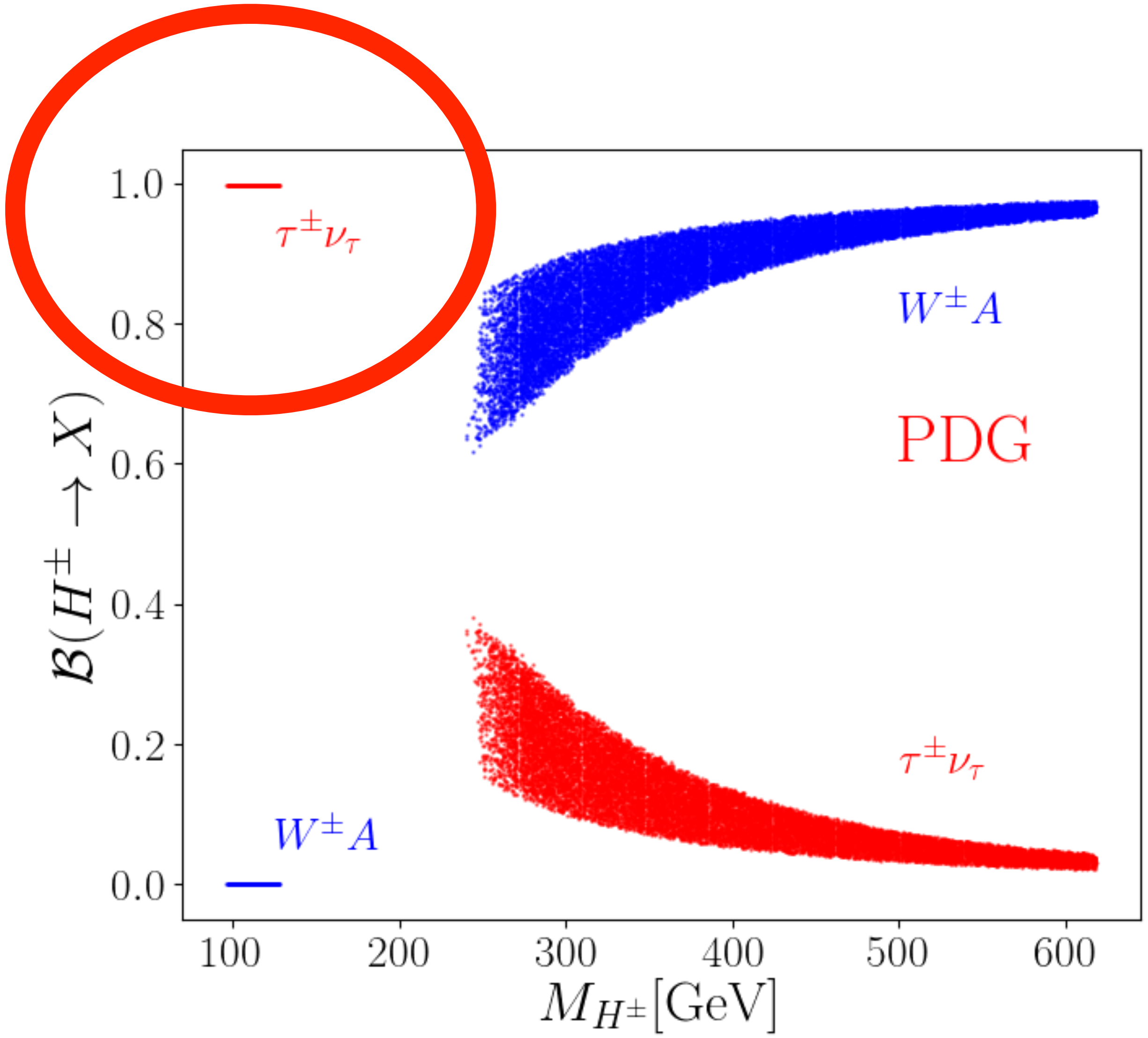
- Branching ratios of BSM Higgs bosons

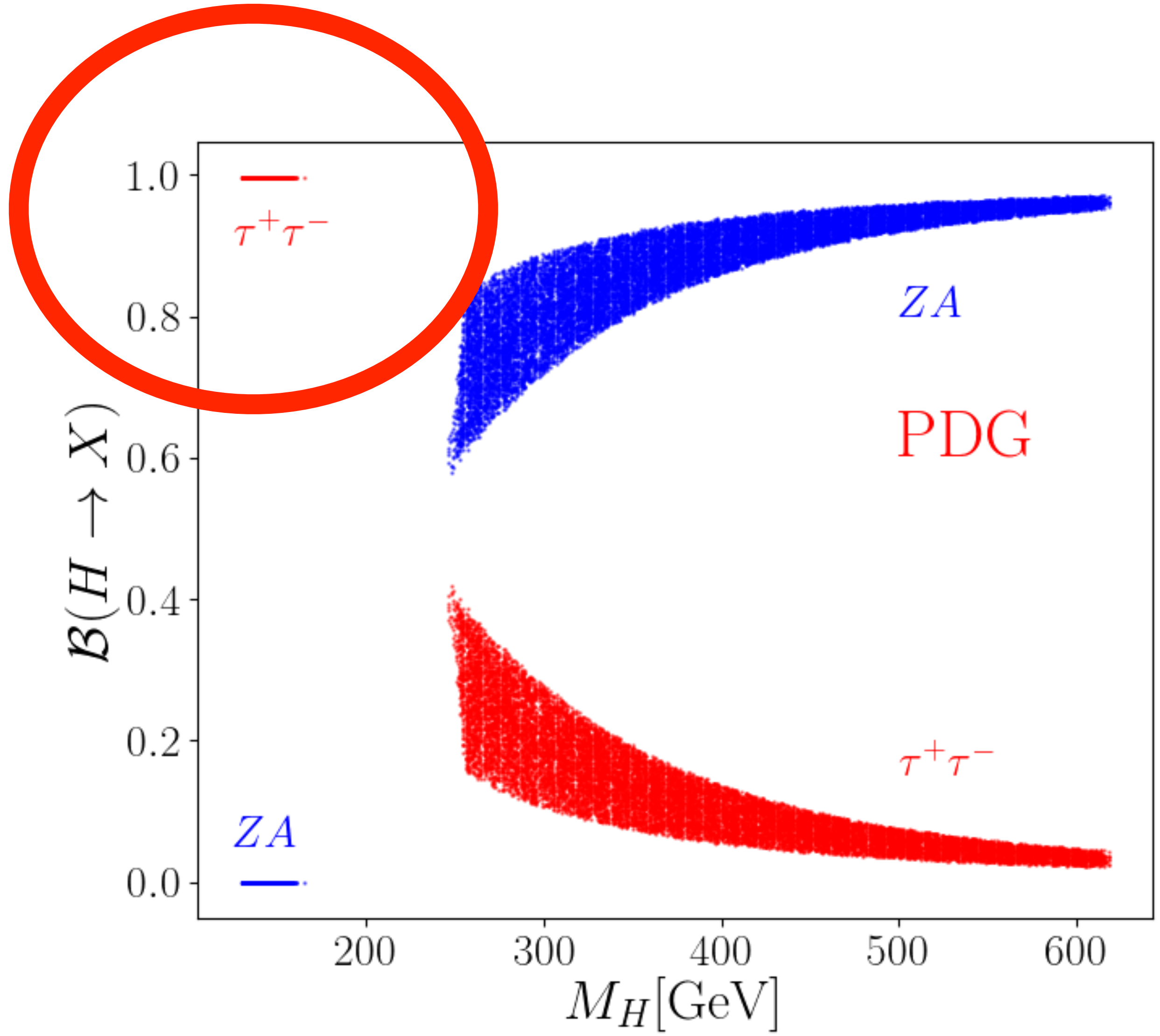


- In most of the parameter space, bosonic modes are dominant.

5. Muon g-2

- Branching ratios of BSM Higgs bosons





- In the PDG-island, the leptonic decays are dominant.

5. Muon g-2

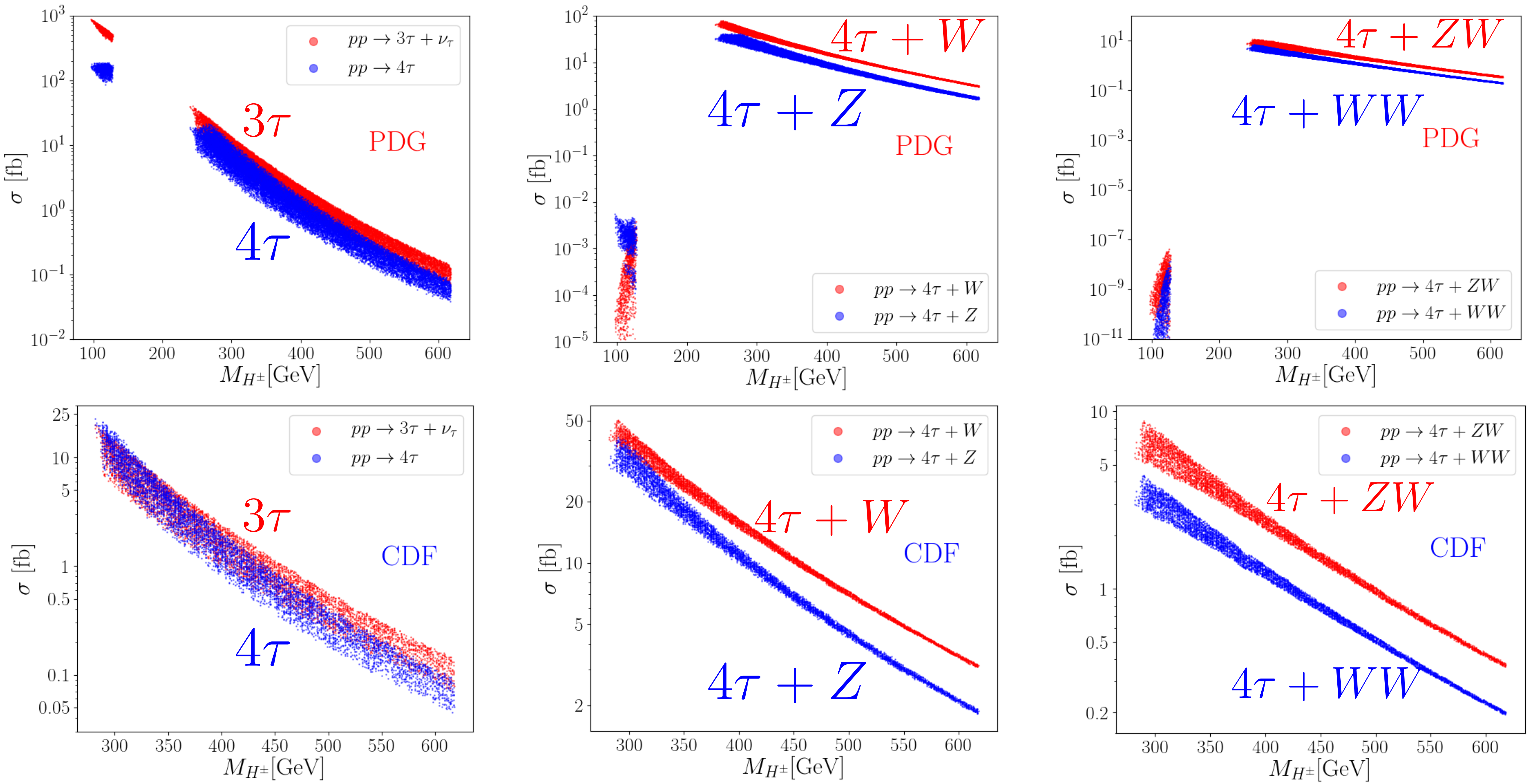
- 3τ and 4τ states associated with gauge bosons

$$3\tau: \quad pp \to H^\pm A \to [\tau^\pm \nu_\tau][\tau^+\tau^-],$$
$$pp \to H^\pm H \to [\tau^\pm \nu_\tau][\tau^+\tau^-].$$

$$4\tau: \quad pp \to HA \to [\tau^+\tau^-][\tau^+\tau^-],$$
$$4\tau + V: \quad pp \to H^\pm A \to [W^\pm A]A \to [W^\pm \tau^+\tau^-][\tau^+\tau^-],$$
$$pp \to HA \to [ZA]A \to [Z\tau^+\tau^-][\tau^+\tau^-],$$
$$4\tau + VV': \quad pp \to H^\pm H \to [W^\pm A][ZA] \to [W\tau^+\tau^-][Z\tau^+\tau^-],$$
$$pp \to H^+H^- \to [W^+A][W^-A] \to [W^+\tau^+\tau^-][W^-\tau^+\tau^-],$$

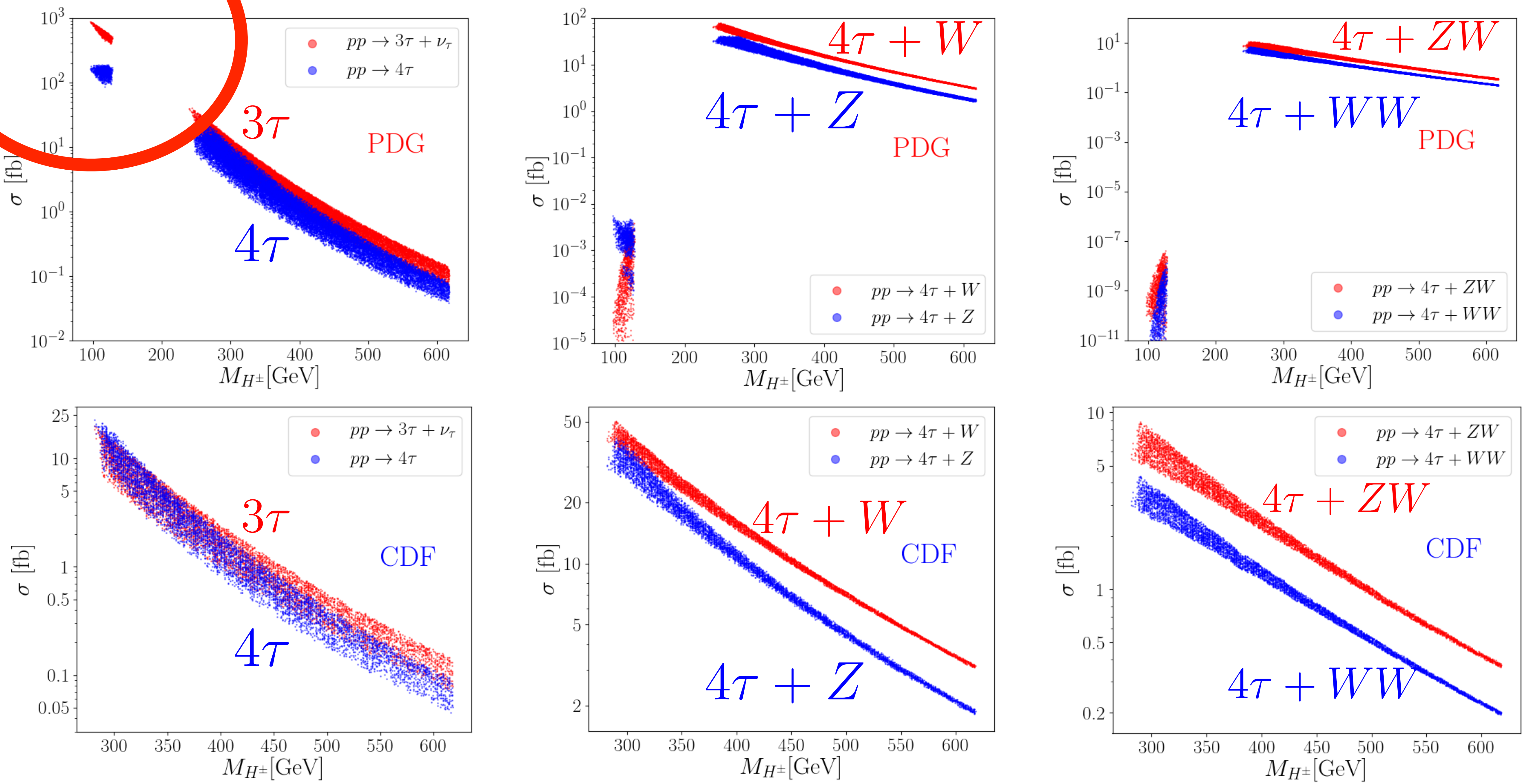
5. Muon g-2

- Cross sections of 3τ and 4τ states associated with gauge bosons



5. Muon g-2

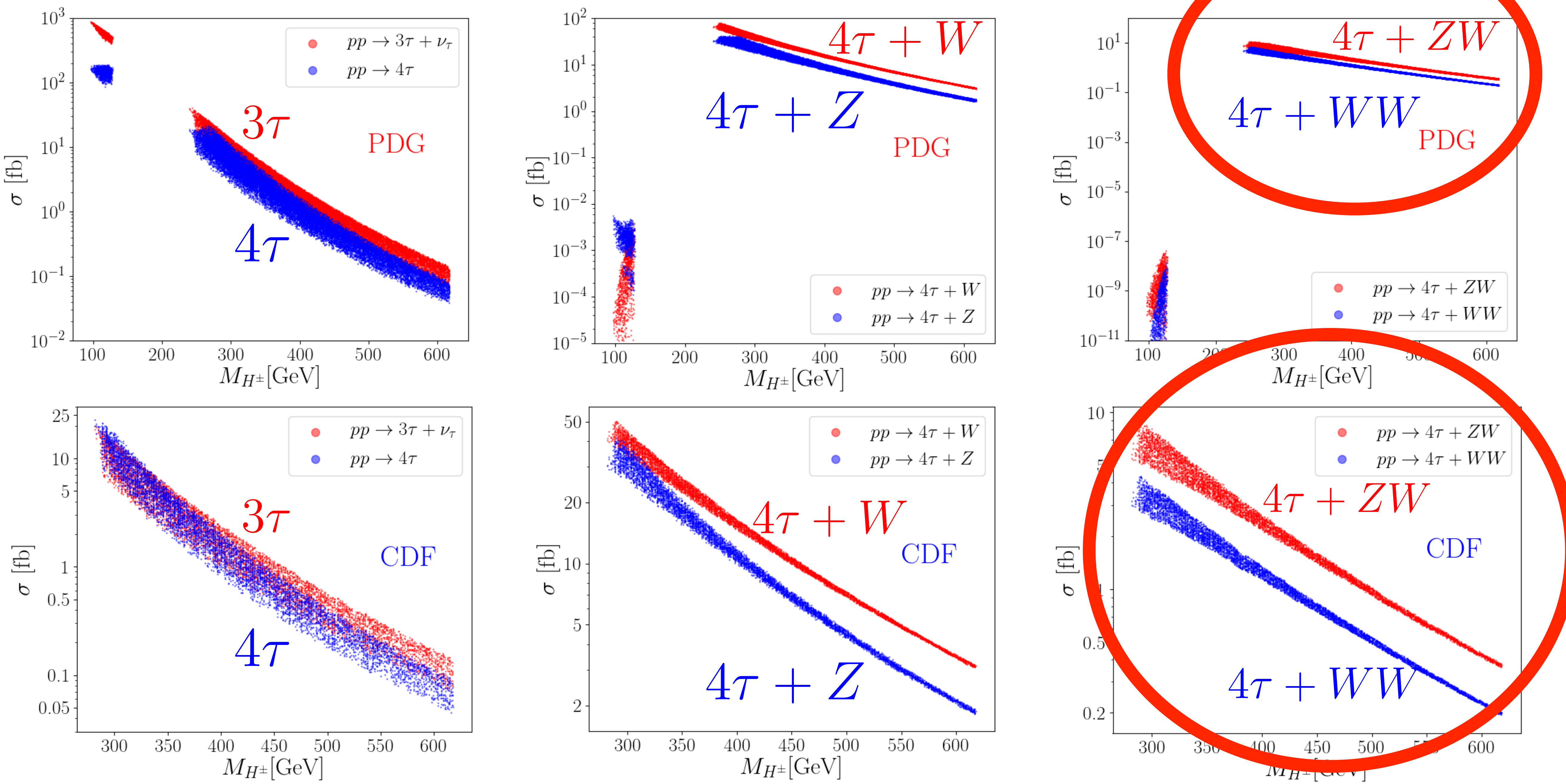
- Cross sections of 3τ and 4τ states associated with gauge bosons



- In the PDG-island, 3τ and 4τ states are the golden channels.

5. Muon g-2

- Cross sections of 3τ and 4τ states associated with gauge bosons



- In the mainland, 4τ+VV' states are the golden channels.

5. Muon g-2

- Almost the background-free environment
- Irreducible backgrounds

$$\sigma(pp \to 4\tau + ZW^{\pm}) \simeq 0.26\,\mathrm{ab},$$
$$\sigma(pp \to 4\tau + W^{+}W^{)} \simeq 0.54\,\mathrm{ab}.$$

- Reducible backgrounds: 4 QCD jets + VV' can be tamed

$$P_{j\to\tau_h} \simeq 0.01 \Longrightarrow P^4_{j\to\tau_h} \simeq 10^{-8}$$

6. Conclusions

- The new W boson mass measurement by the CDF constrains NP models.
- NP scale is below about 1 TeV.
- When combined with the muon g-2 anomaly, the NP scale is further reduced.
- High-energy and high-luminosity experiments are more important than ever.