Higgs Triplets: LHC and Inflation

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Bolshoi simulation, NASA

Outline

- Triplet phenomenology (TMSSM)

  (a) Model with Higgs Triplets in the MSSM

  (b) Higgs phenomenology in the TMSSM

  (c) Impact of DM constraints on the Higgs phenomenology

C.A., V.Martín-Lozano and G.Nardini, arXiv:1403.6434

- Higgs Inflation and its extensions and BICEP2

  (a) What is standard Higgs inflation

  (b) Extension of the Higgs sector with Higgs Triplets and predictions for inflation

  (c) How to save the inflationary picture in this model

  (d) General consequences from BICEP2 for Inflation

C.A., J.-O.Gong and N.Sahu, Nucl.Phys.B865 (2012) arXiv:1206.0009 [hep-ph]

TMSSM Phenomenology

The TMSSM

$$\Sigma = \begin{pmatrix} \xi^0/\sqrt{2} & -\xi_2^+ \\ \xi_1^- & -\xi^0/\sqrt{2} \end{pmatrix} \qquad Y = 0 \ SU(2)_L\text{-triplet superfield}$$

$$W_{\rm TMSSM} = W_{\rm MSSM} + \lambda H_1 \cdot \Sigma H_2 + \frac{1}{2}\mu_\Sigma \,{\rm Tr}\, \Sigma^2$$

$$\mathcal{L}_{\rm TMSSM_{SB}} = \mathcal{L}_{\rm MSSM_{SB}} + m_4^2\,{\rm Tr}(\Sigma^\dagger \Sigma) + \left[B_\Sigma\,{\rm Tr}(\Sigma^2) + \lambda A_\lambda H_1 \cdot \Sigma H_2 + {\rm h.c.}\right]$$

- Scalar triplet is constrained by electroweak parameters

$$\langle \xi^0 \rangle \lesssim 4\,{\rm GeV} \qquad |A_\lambda|,\ |\mu|\,,\ |\mu_\Sigma| \lesssim 10^{-2}\,\frac{m_\Sigma^2 + \lambda^2 v^2/2}{\lambda v}$$

A.Delgado, G.Nardini and M.Quiros ’12, ’13

Higgs sector

- If the Scalar Triplet is heavy it doesn't mix with the CP-even Higgs sector

$$m_\Sigma = \quad 5\,\mathrm{TeV}$$

- After electroweak symmetry breaking the CP-even Higgs mass matrix is

$$\mathcal{M}^2_{h,H} = \begin{pmatrix} m_A^2 \cos^2\beta + m_Z^2 \sin^2\beta & (\lambda^2 v^2 - m_A^2 - m_Z^2)\sin\beta\cos\beta \\ (\lambda^2 v^2 - m_A^2 - m_Z^2)\sin\beta\cos\beta & m_A^2 \sin^2\beta + m_Z^2 \cos^2\beta \end{pmatrix}$$

- Triplet alleviates the little hierarchy problem (similar to MSSM extension with singlets)
- In the decoupling limit, Higgs is SM-like except in loop-induced processes

$$m^2_{h,tree} = m_Z^2 \cos^2 2\beta + \frac{\lambda^2}{2} v^2 \sin^2 2\beta$$

Electroweak sector

• Triplet introduces additional degrees of freedom in the electroweakino sector, hence can provide larger diphoton rate with respect to singlets extensions

$$\mathcal{M}^{tree}_{\tilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & -\frac{1}{2}g_1 v_1 & \frac{1}{2}g_1 v_2 & 0 \\ 0 & M_2 & \frac{1}{2}g_2 v_1 & -\frac{1}{2}g_2 v_2 & 0 \\ -\frac{1}{2}g_1 v_1 & \frac{1}{2}g_2 v_1 & 0 & -\mu & -\frac{1}{2}v_2\lambda \\ \frac{1}{2}g_1 v_1 & -\frac{1}{2}g_2 v_2 & -\mu & 0 & -\frac{1}{2}v_1\lambda \\ 0 & 0 & -\frac{1}{2}v_2\lambda & -\frac{1}{2}v_1\lambda & \mu_T \end{pmatrix}$$

Neutralino sector relevant for Higgs invisible decay width and for DM

$$\mathcal{M}^{tree}_{\tilde{\chi}^\pm} = \begin{pmatrix} M_2 & g_2 v \sin\beta & 0 \\ g_2 v \cos\beta & \mu & -\lambda v \sin\beta \\ 0 & \lambda v \cos\beta & \mu_\Sigma \end{pmatrix}$$

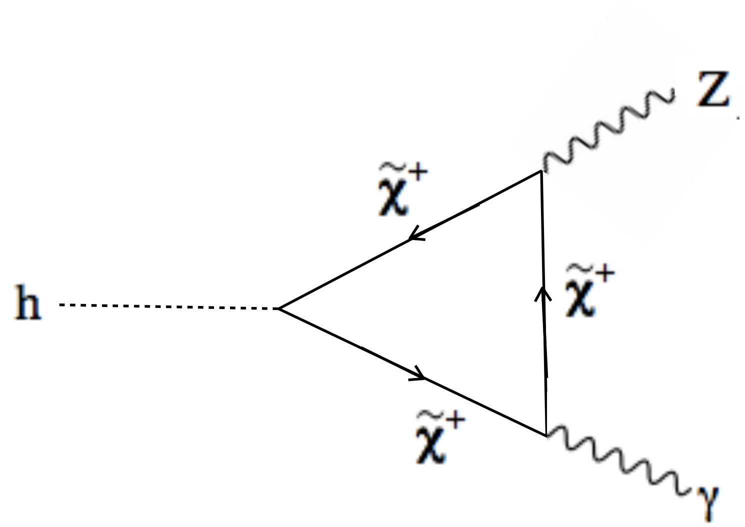
Chargino sector relevant for
$$\begin{cases} h \to \gamma\gamma \\ h \to Z\gamma \end{cases}$$

Higgs signatures

$$R_{\gamma\gamma} = \left| 1 + \frac{A^{\gamma\gamma}_{\widetilde{\chi}^\pm_{1,2,3}}}{A^{\gamma\gamma}_W + A^{\gamma\gamma}_t} \right|^2$$

$$A^{\gamma\gamma}_{\widetilde{\chi}^\pm_{1,2,3}} = \sum_{i=1}^{3} \frac{2M_W}{\sqrt{2}\, m_{\widetilde{\chi}^\pm_i}} (g^L_{h\widetilde{\chi}^+_i \widetilde{\chi}^-_i} + g^R_{h\widetilde{\chi}^+_i \widetilde{\chi}^-_i}) A_{1/2}(\tau_{\widetilde{\chi}^\pm_i})$$

$$R_{Z\gamma} = \left| 1 + \frac{A^{Z\gamma}_{\widetilde{\chi}^\pm_{1,2,3}}}{A^{Z\gamma}_W + A^{Z\gamma}_t} \right|^2$$



$$A^{Z\gamma}_{\widetilde{\chi}^\pm_{1,2,3}} = \sum_{j,k=1}^{3} \frac{g_2\, m_{\widetilde{\chi}^\pm_j}}{g_1\, m_Z} f\left(m_{\widetilde{\chi}^\pm_j}, m_{\widetilde{\chi}^\pm_k}, m_{\widetilde{\chi}^\pm_k}\right) (g^L_{h\widetilde{\chi}^+_j \widetilde{\chi}^-_i} + g^R_{h\widetilde{\chi}^+_j \widetilde{\chi}^-_i})(g^L_{Z\widetilde{\chi}^+_j \widetilde{\chi}^-_i} + g^R_{Z\widetilde{\chi}^+_j \widetilde{\chi}^-_i})$$

Any signal strength computed disregarding the Higgs invisible channel should be corrected:

$$R_{XY} \equiv \mathrm{BR}(h \to XY)/\mathrm{BR}_{\mathrm{SM}}(h \to XY) \quad \times \; (1 - \mathrm{BR}(\mathrm{h} \to \tilde{\chi}^0 \tilde{\chi}^0))$$

Set up of the analysis

SUSY Model = TMSSM

SARAH

Supersymmetric mass spectrum

SPheno

(masses computed at full 1-loop + higgs has 2 loop corrections)

micrOMEGAs

Relic Abundance $\Omega_{\rm DM}h^2$

+ dark matter direct detection predictions

SPheno, CPSuperH

Higgs Physics

Sampling method and free parameters

PARAMETER SPACE with 7 free parameters

$$\{\theta_i\} = \{M_1, M_2, M_3, \widetilde{m}, \tan\beta, \mu, \lambda, \mu_\Sigma\}$$

Sampling with the algorithm MultiNest

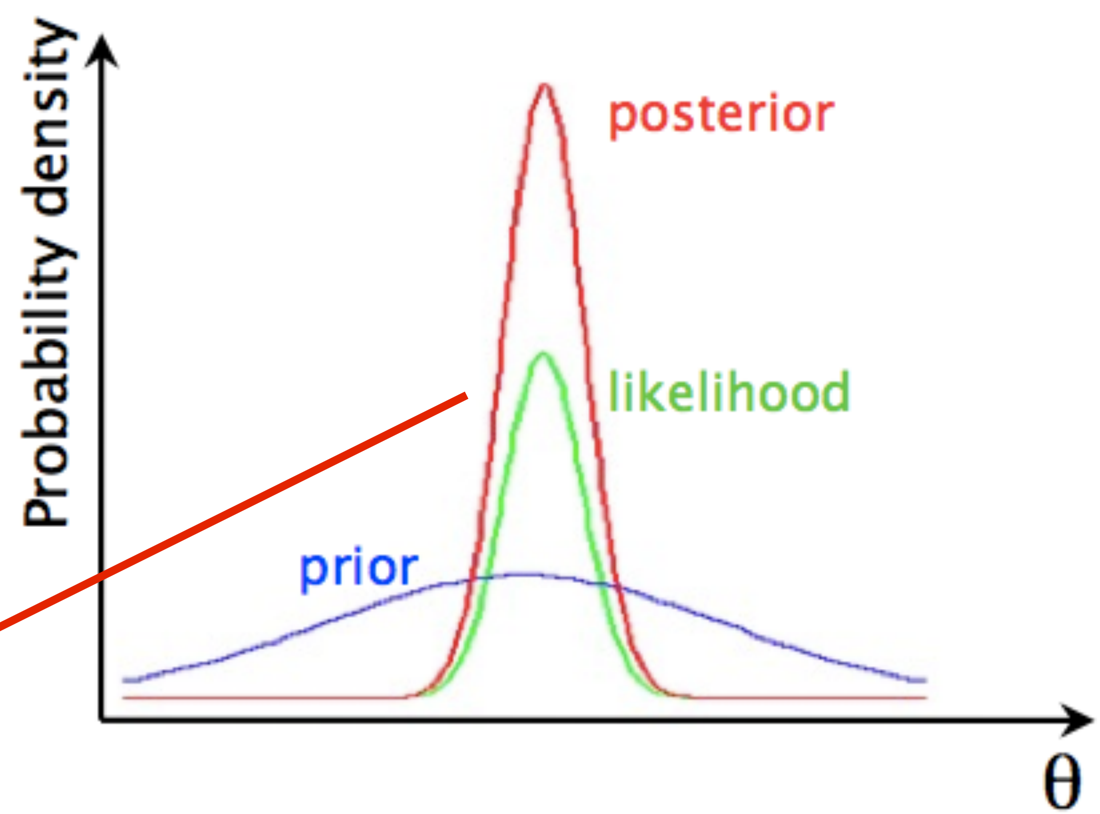
- Nested sampling
- Sampling scale as n instead of n^2 as for a random scan
- Based on Bayes theorem

Likelihood for the theoretical model given the data d

$$p(\theta_i|d) \propto \mathcal{L}(d|\theta_i)\pi(\theta_i)$$

Posterior probability function = result

Priors on the theoretical model



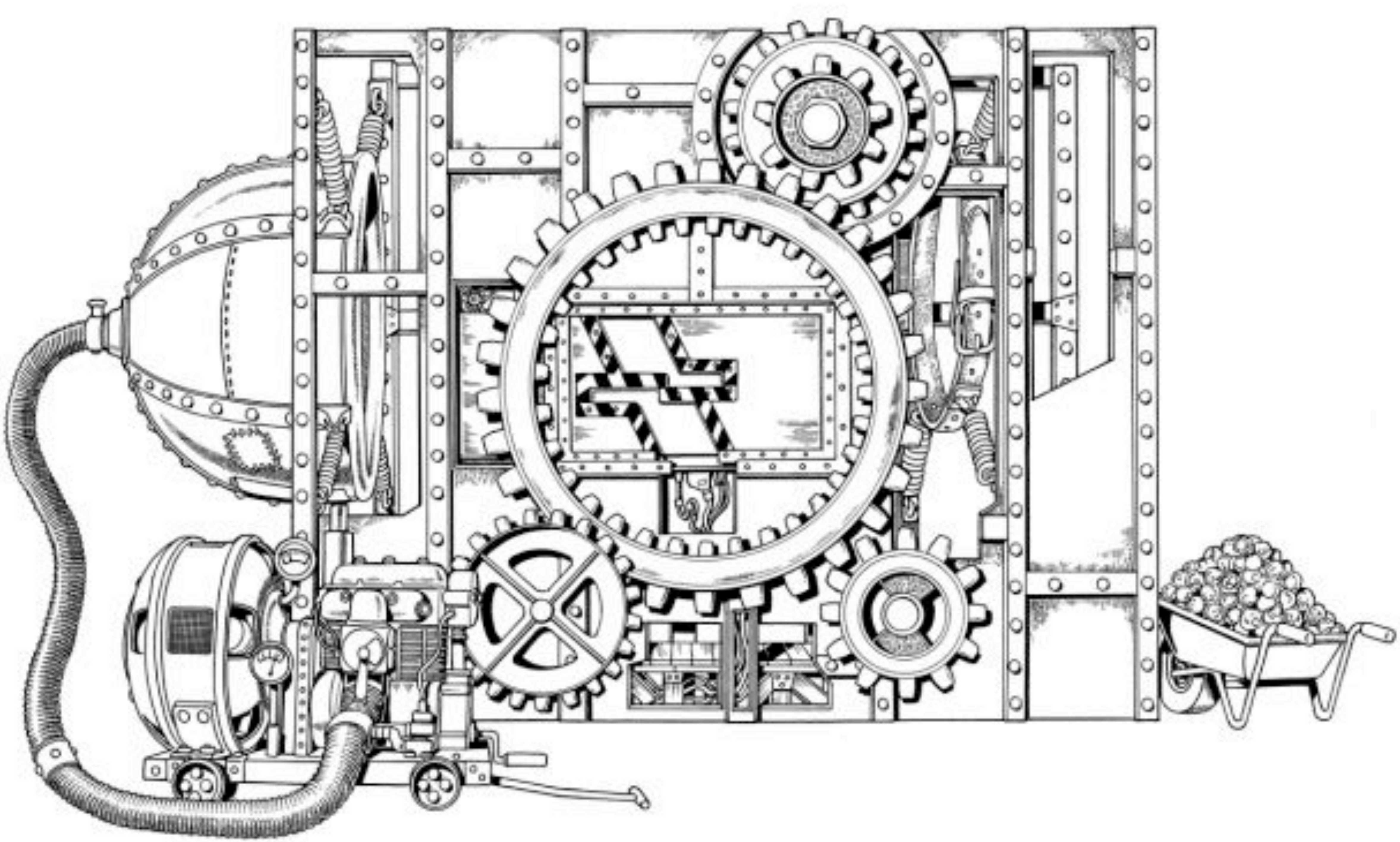
For the results used a sample extracted randomly from the pdf distribution, no statistical meaning

Likelihood and priors

Observable	Measurement/Limit	
m_h	125.85 ± 0.4 GeV (exp) ± 3 GeV (theo)	Gaussian likelihood
$\Omega_{\rm DM} h^2$	0.1186 ± 0.0031 (exp) $\pm 20\%$ (theo)	
$\Gamma(Z \to \widetilde{\chi}_1^0 \widetilde{\chi}_1^0)$	< 2 MeV	Step function
$m_{\tilde{t}_1}$	> 650 GeV (LHC 90% CL)	
$m_{\tilde{\chi}_1^+}$	> 101 GeV (LEP 95% CL)	
$\sigma^{SI}_{\rm Xe}$	LUX (90% CL)	

NS parameters	Prior range
$\log_{10}(M_1/\mathrm{GeV}), \log_{10}(\mu_\Sigma/\mathrm{GeV})$	$1 \to 3$
$\log_{10}(\mu/\mathrm{GeV}), \log_{10}(M_2/\mathrm{GeV})$	$2 \to 3$
$\widetilde{m}/\mathrm{TeV}$	$0.63 \to 2$
$\log_{10}(\tan\beta)$	$0 \to 1$
λ	$0.5 \to 1.2$

Running the machinery for Higgs physics alone ...



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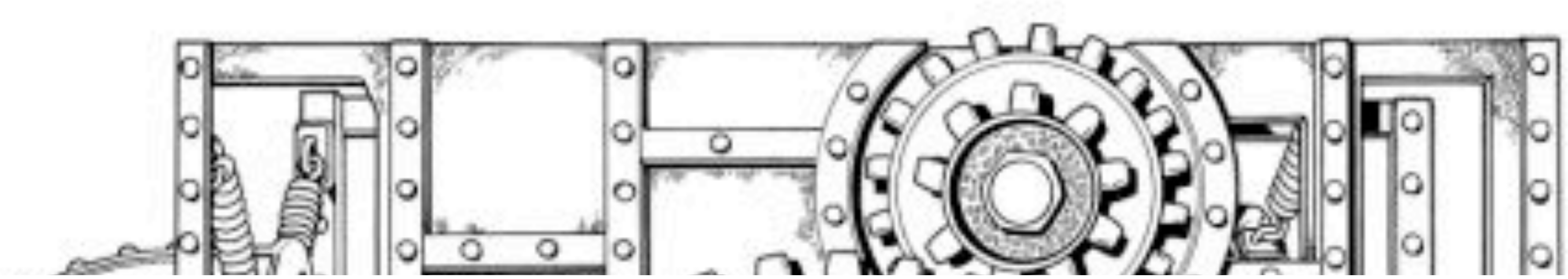

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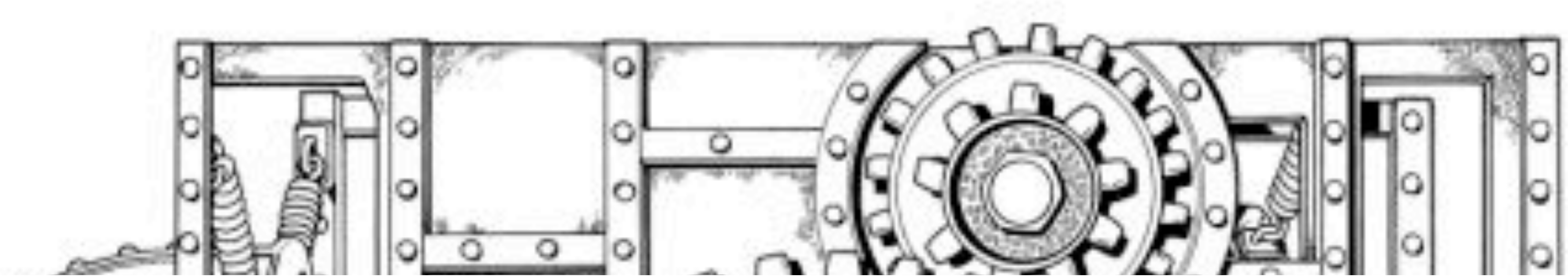

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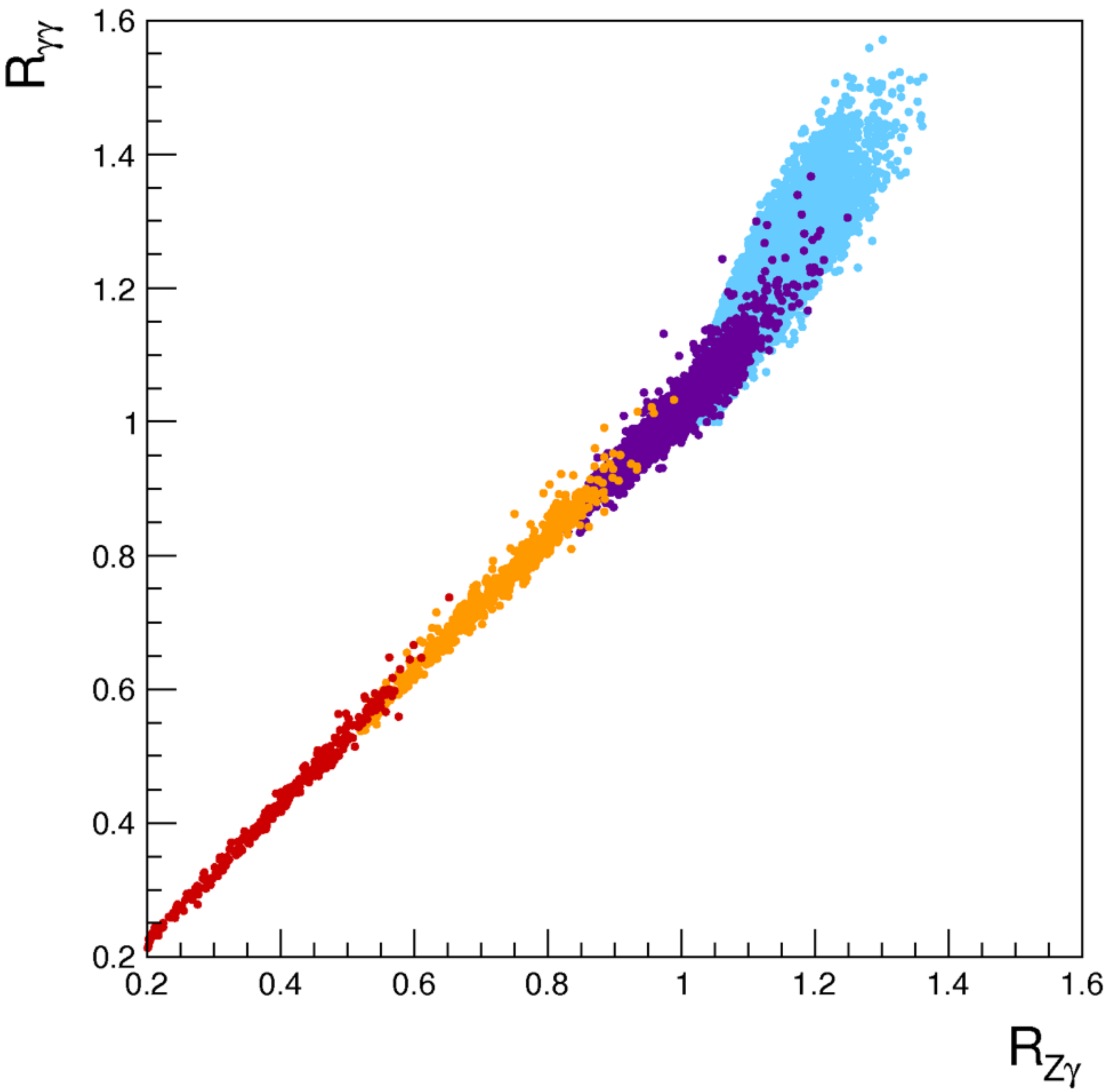
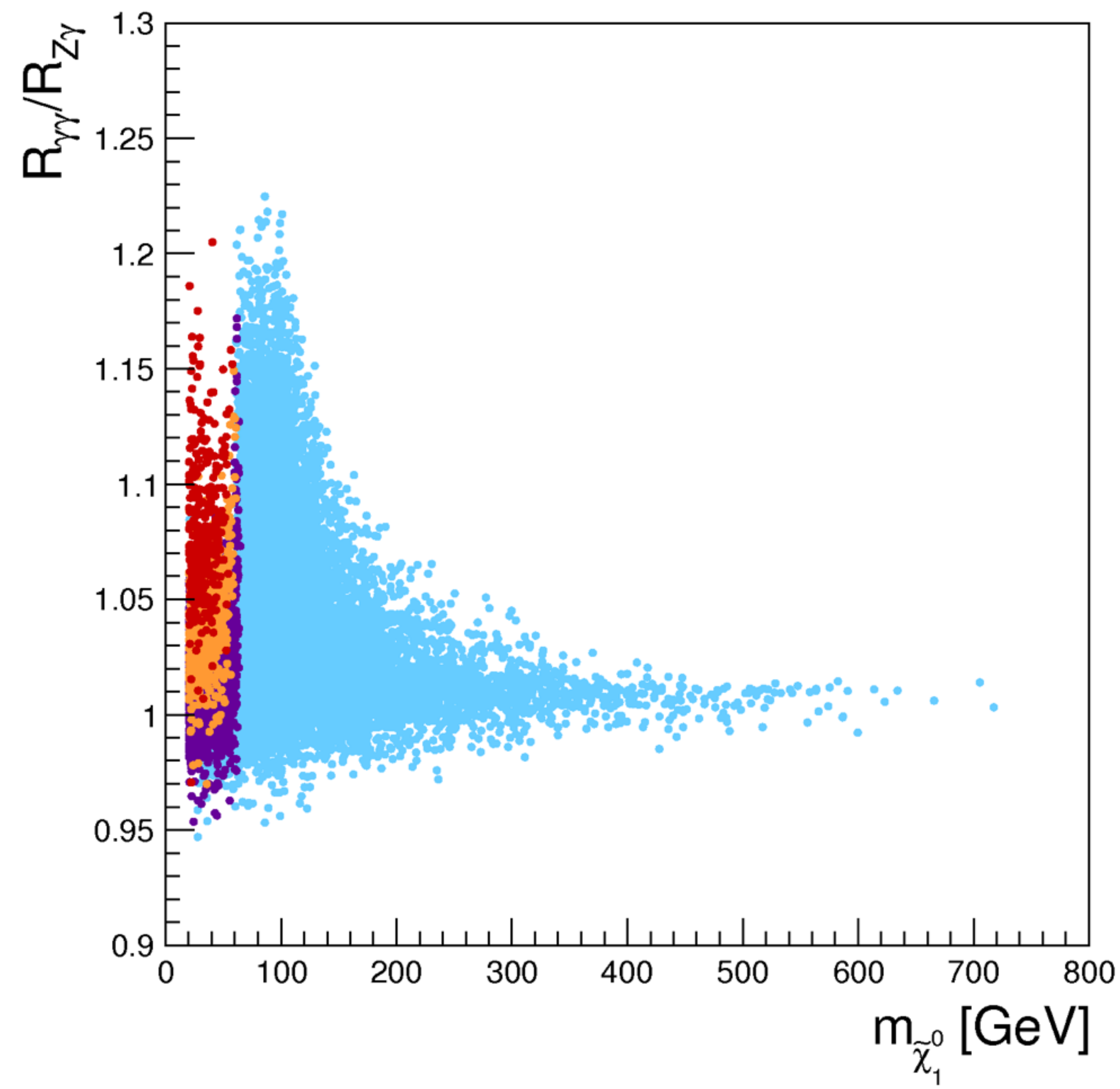
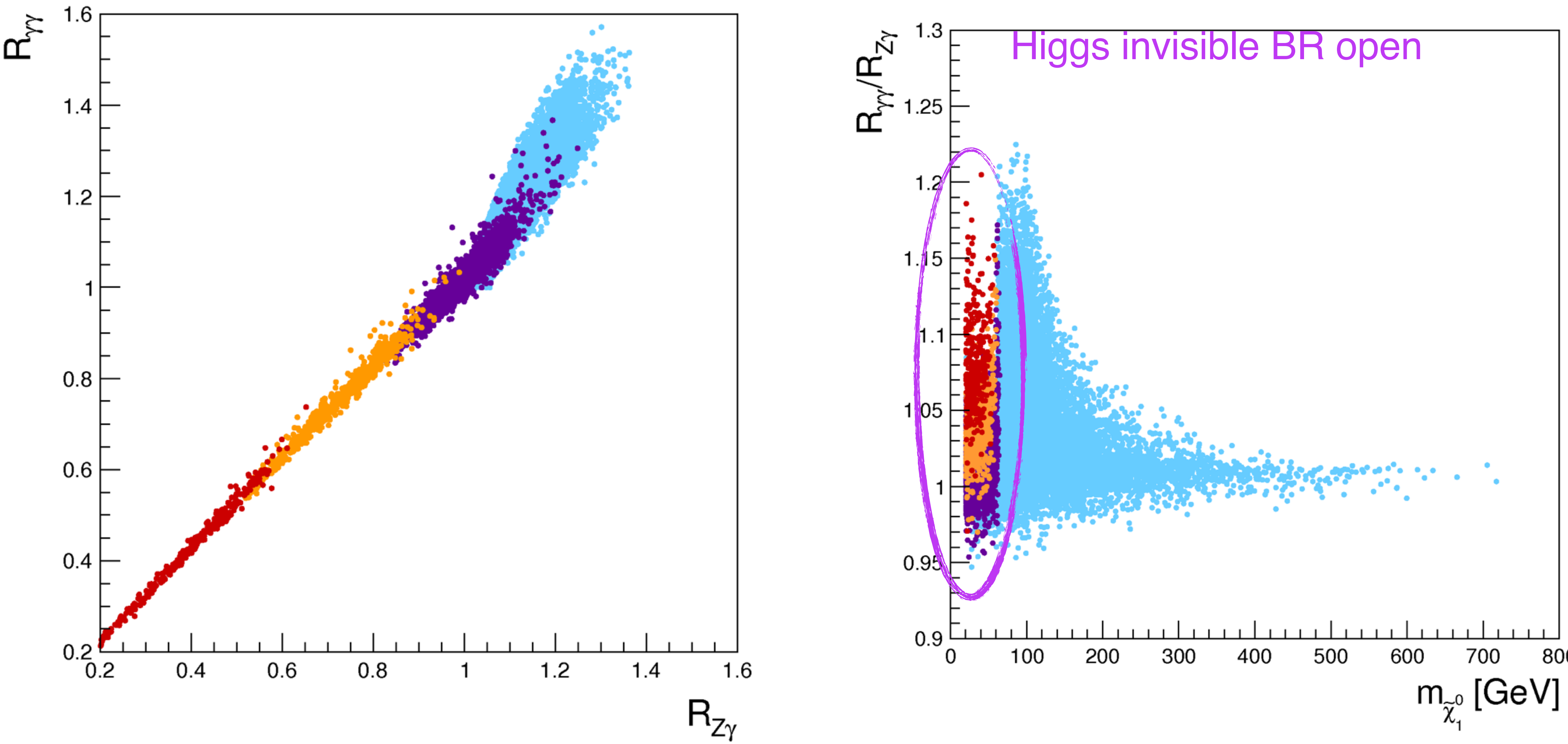
Higgs signal strengths





Enhancement up 60% compared to the MSSM case up to 20%

Higgs signal strengths



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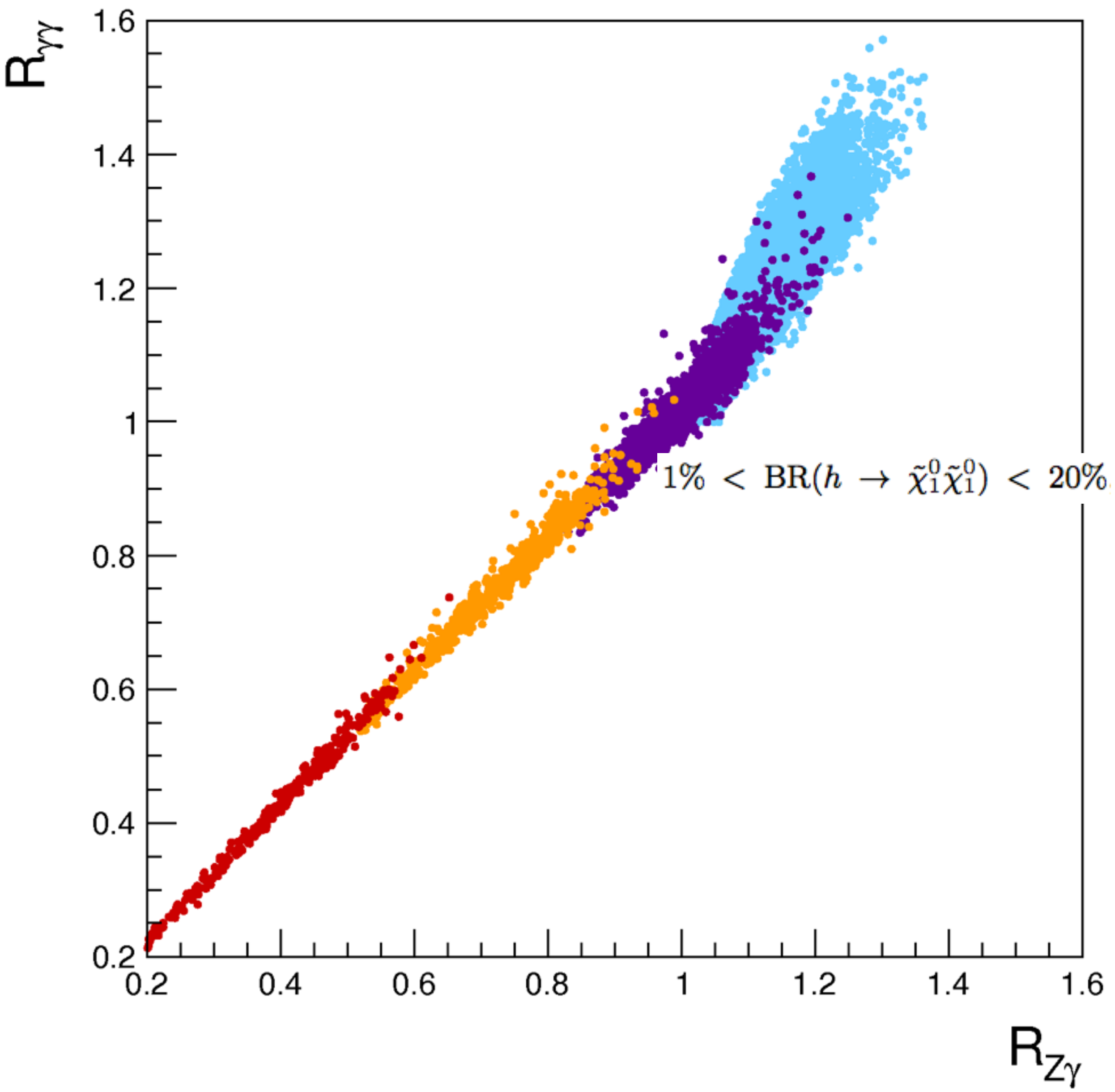

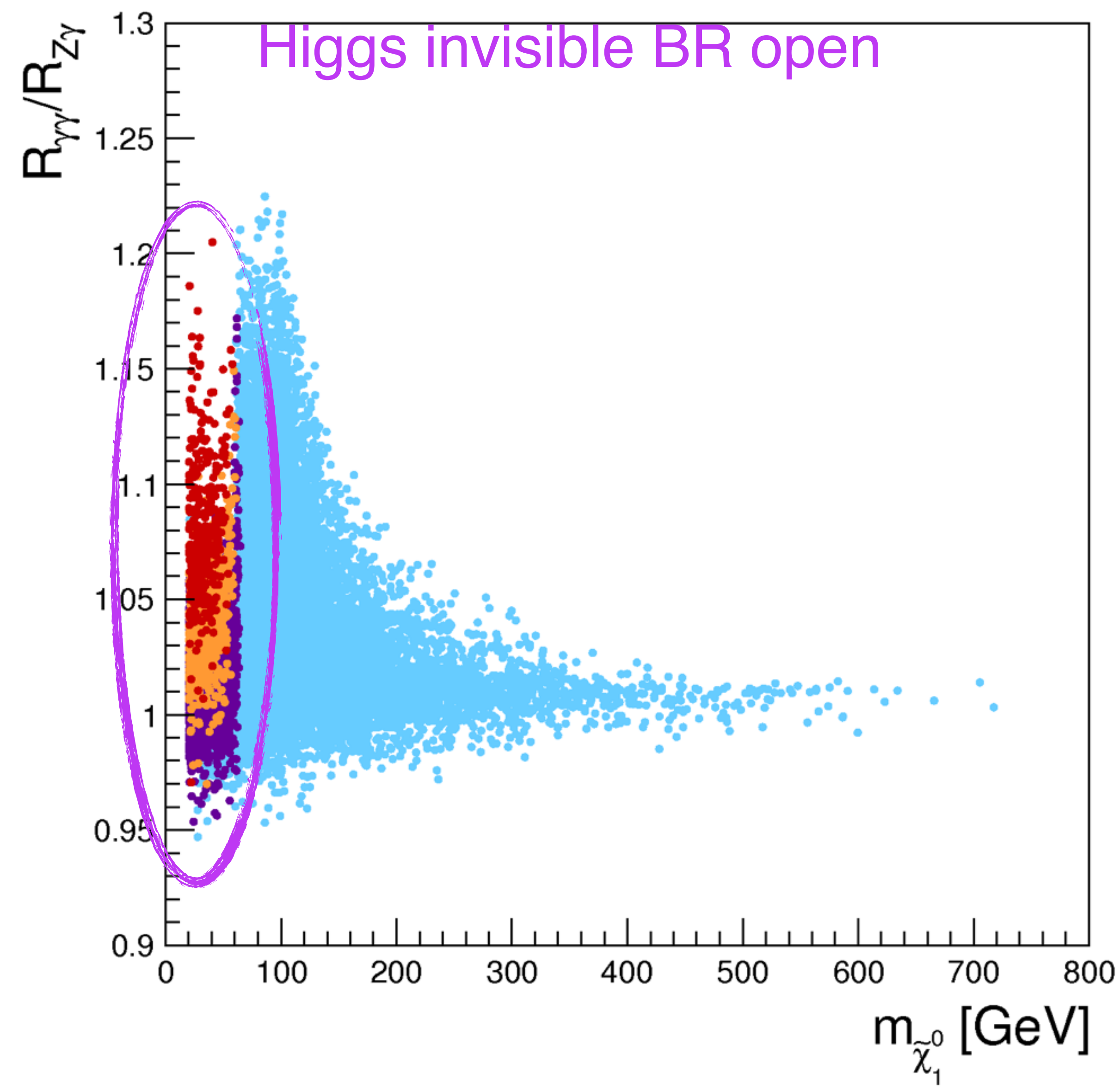

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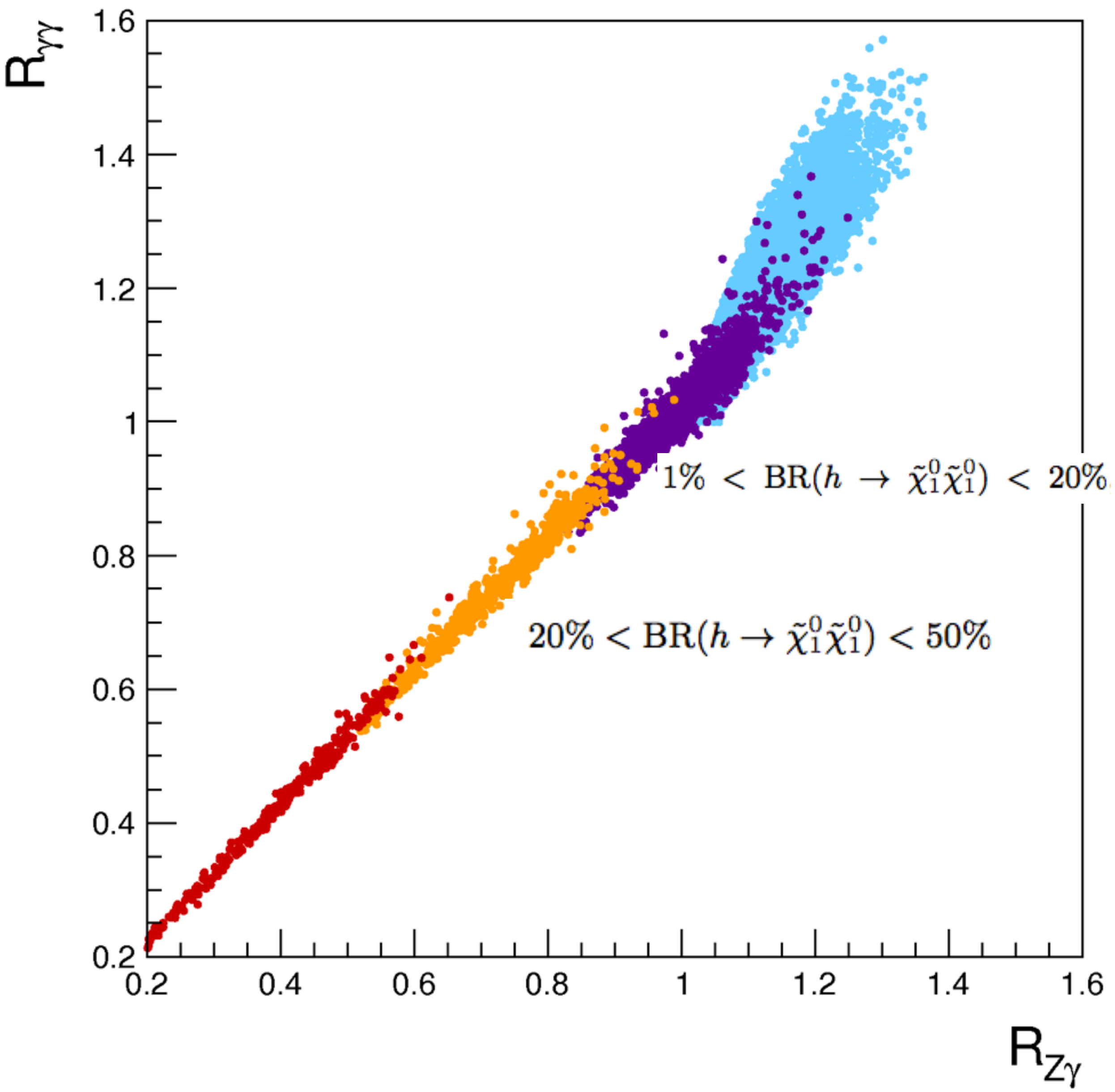

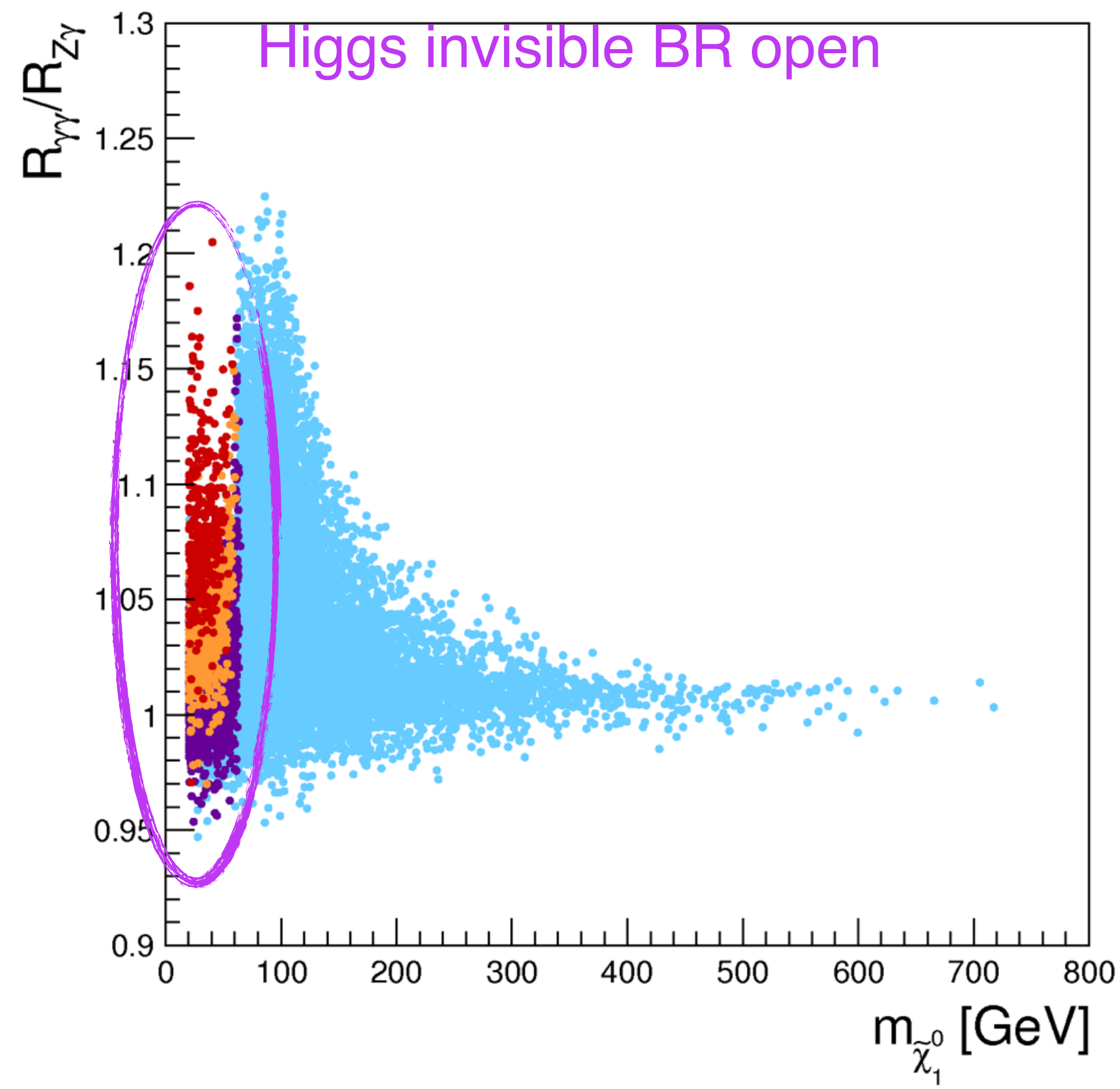

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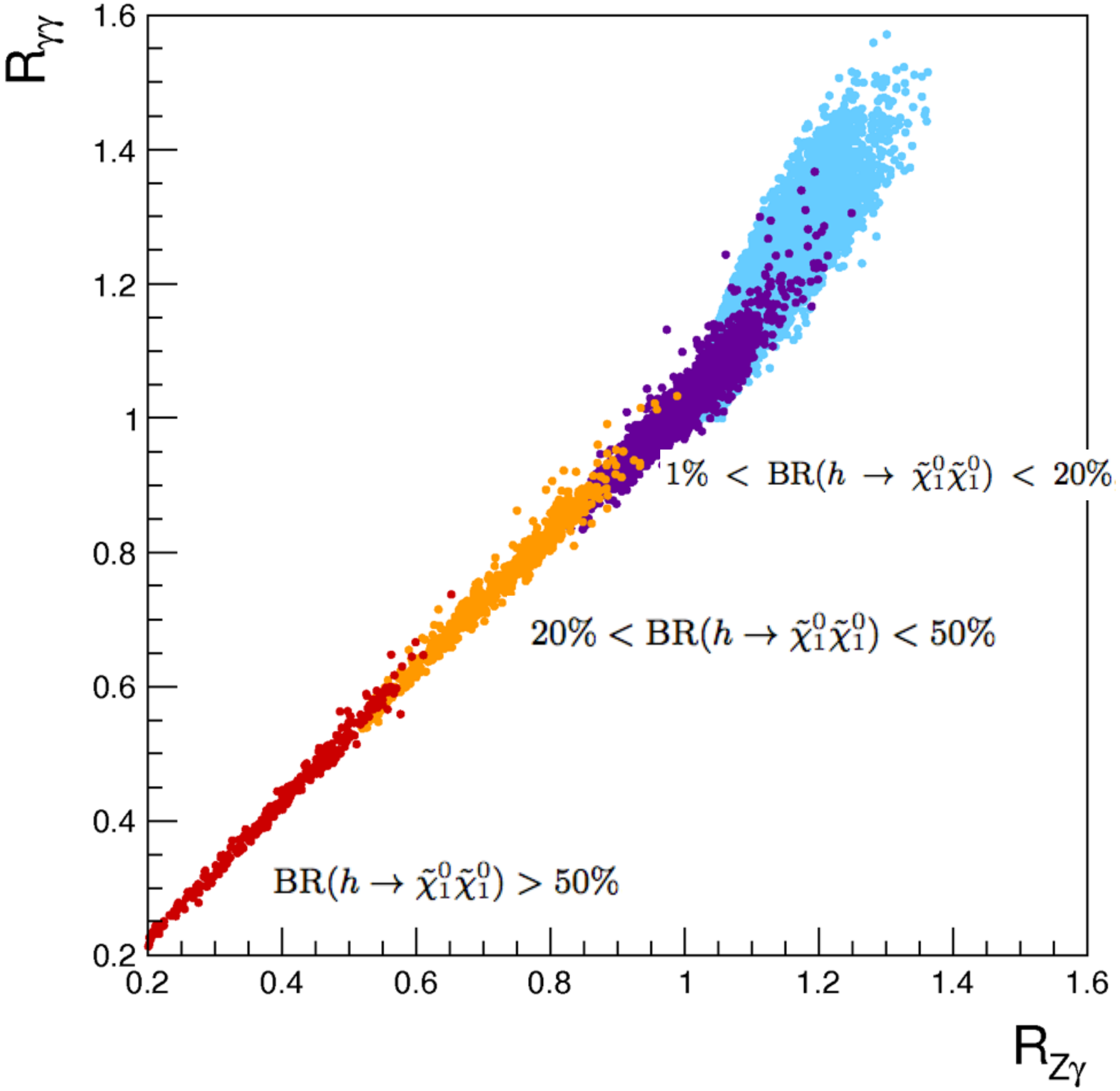

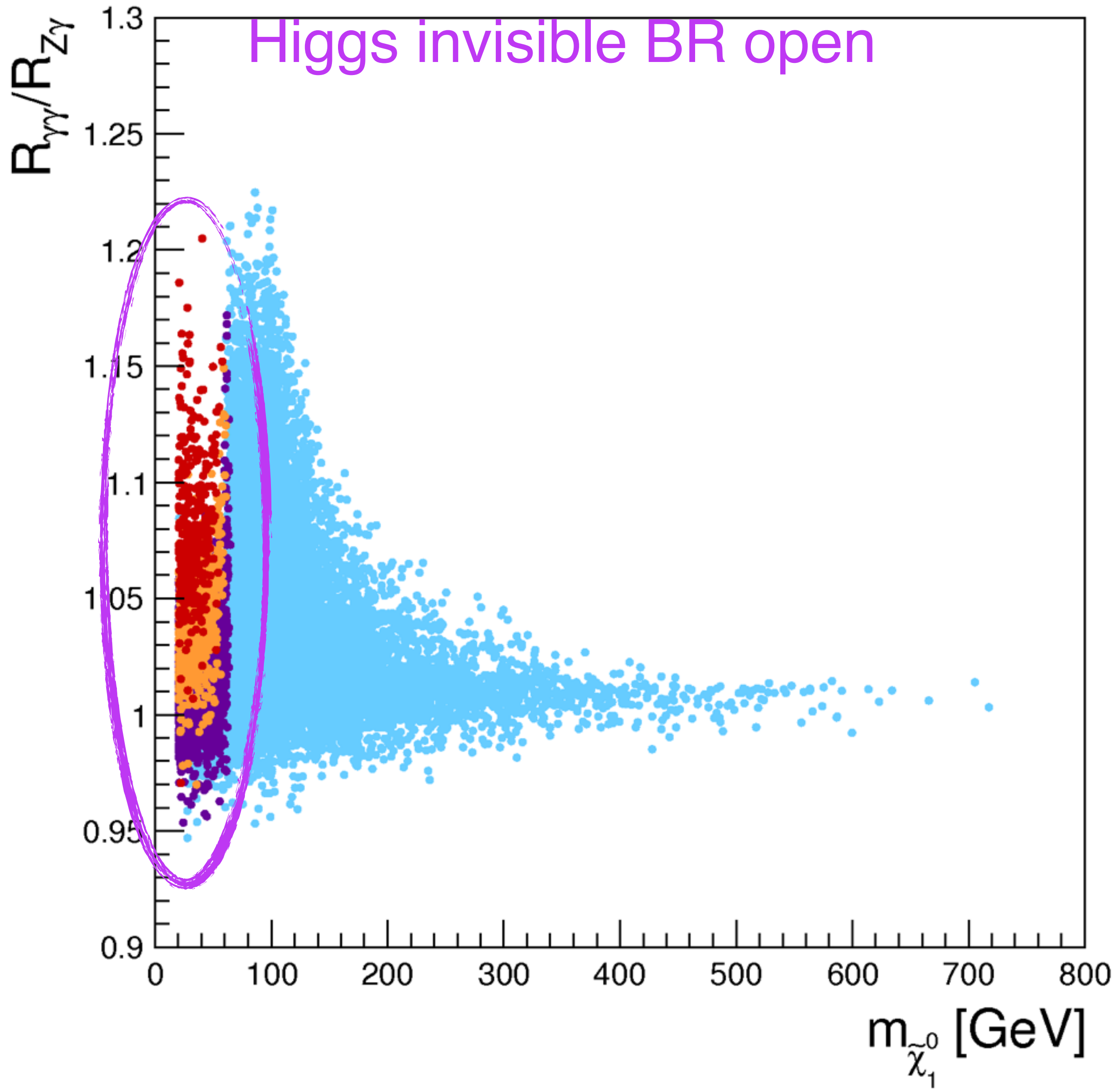

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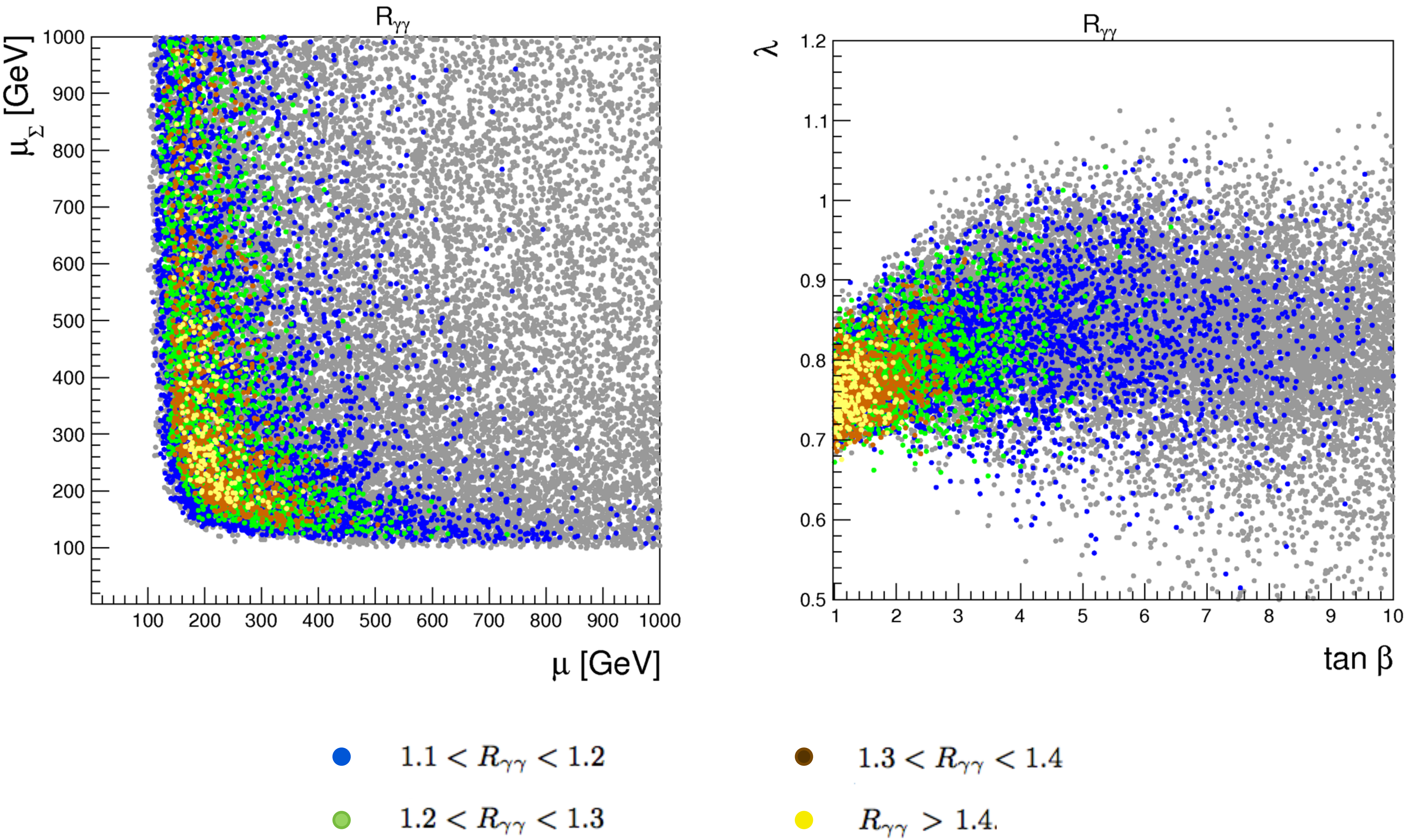
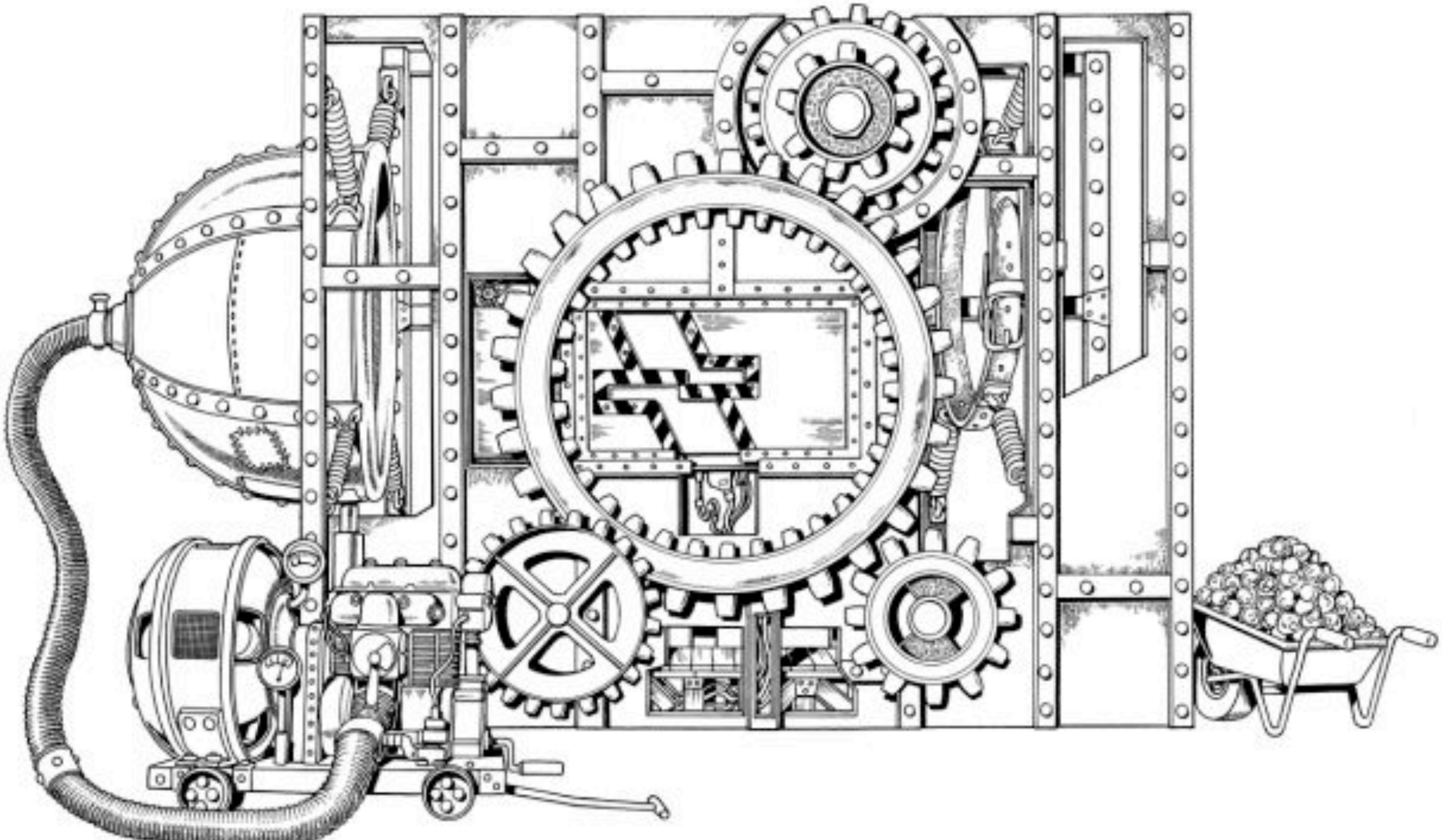
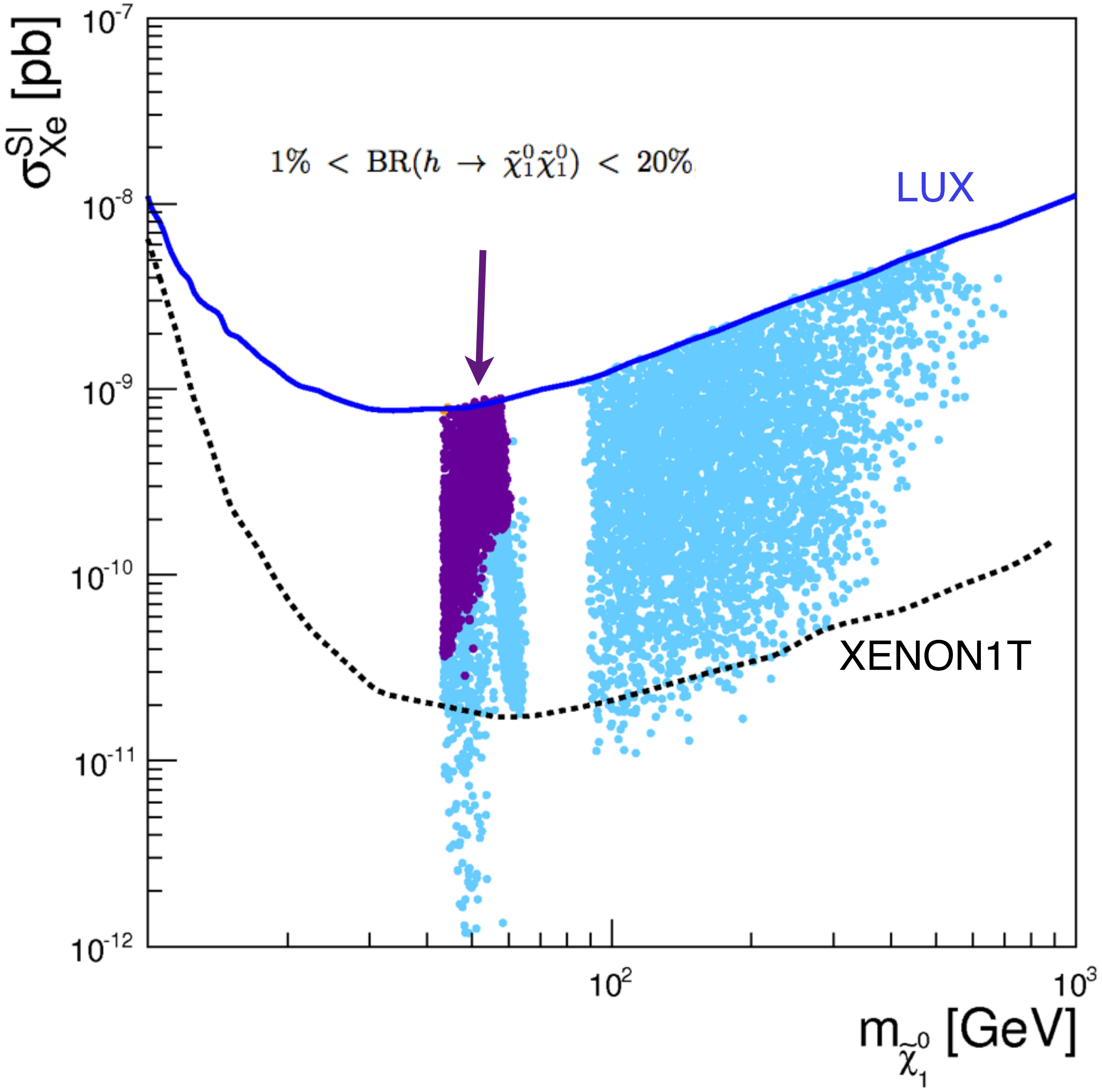


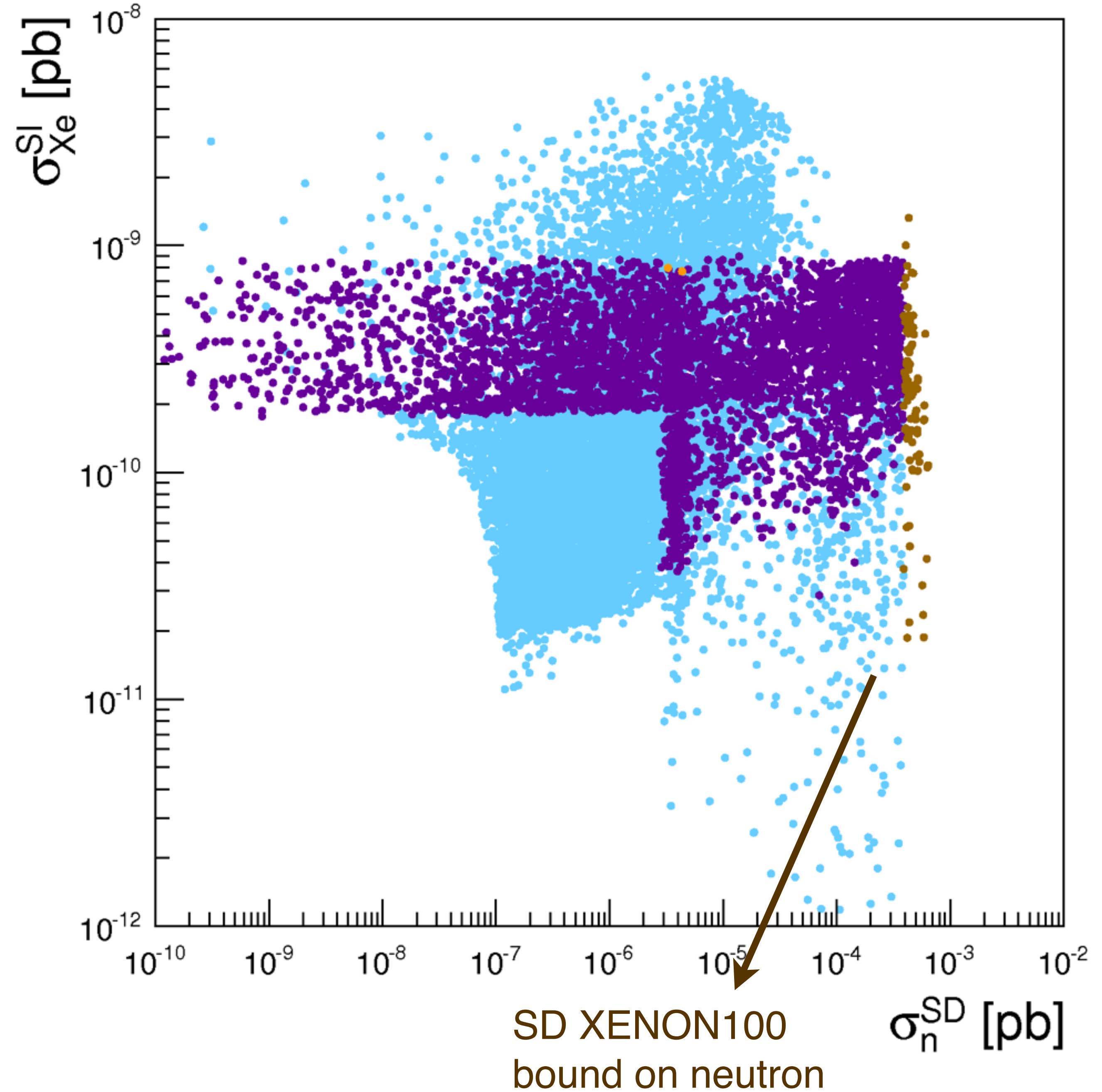
Running the machinery with DM constraints ...



Neutralino as DM

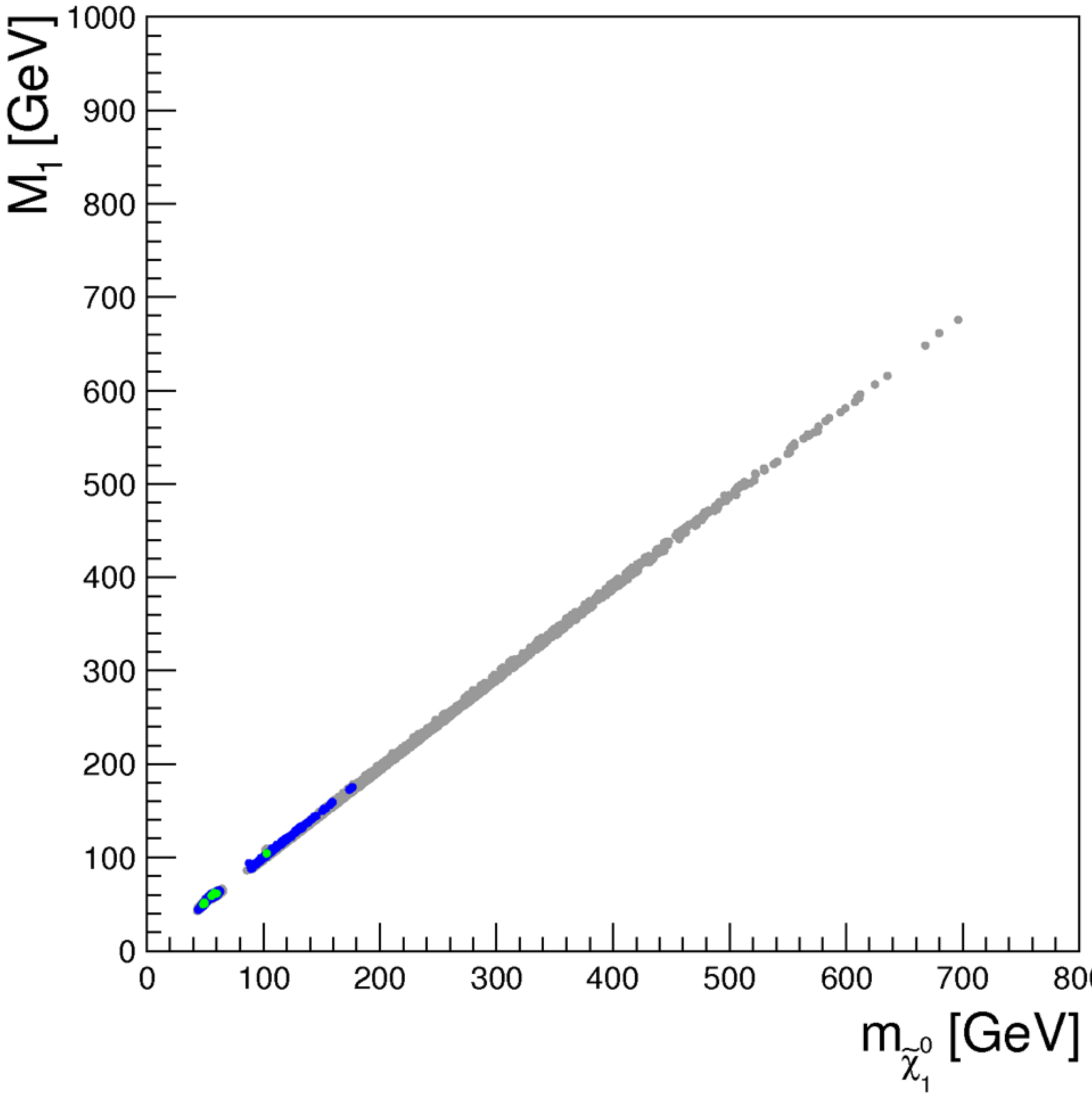
The LSP can be DM in the Higgs pole or in the well-tempered region

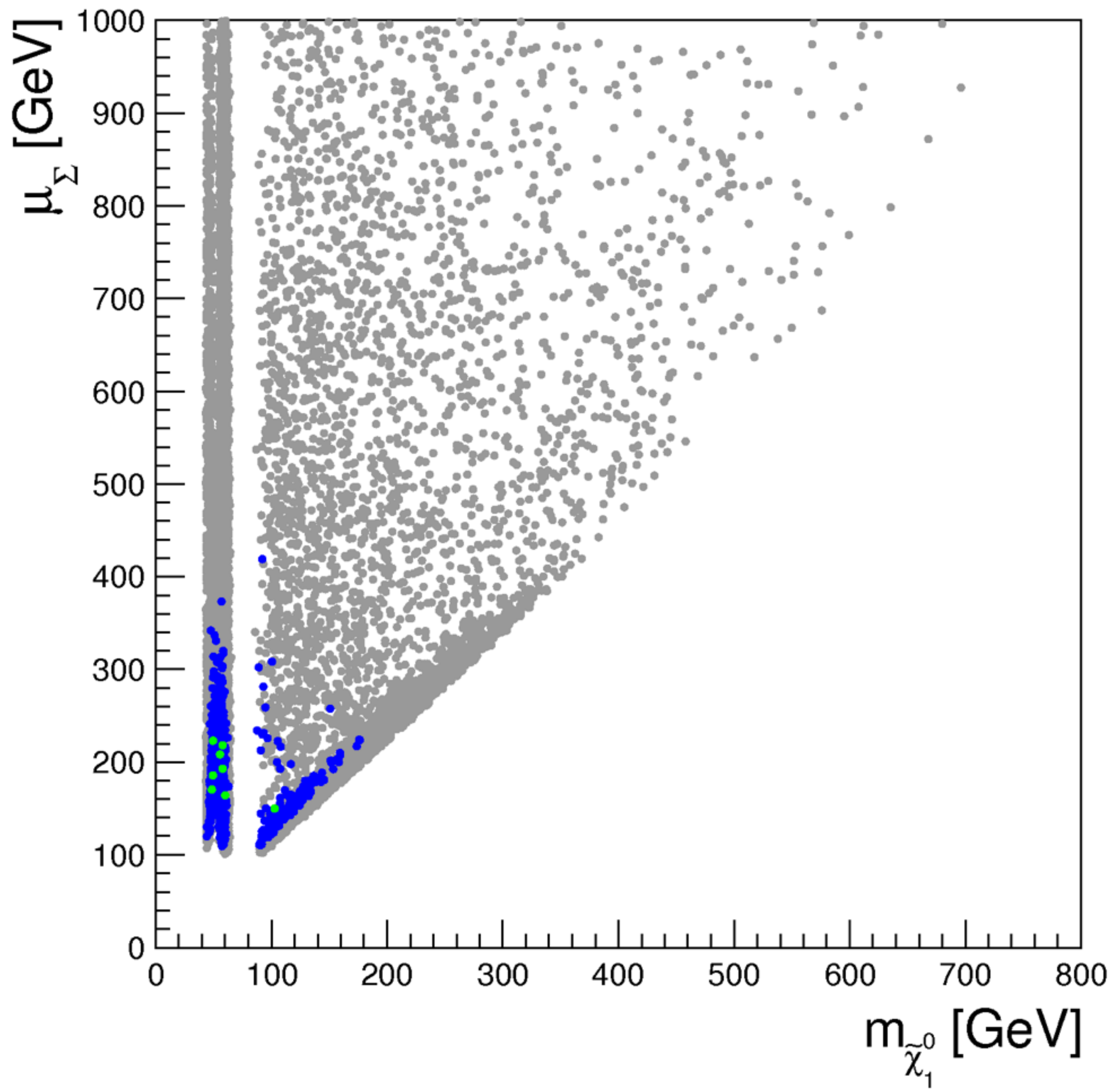




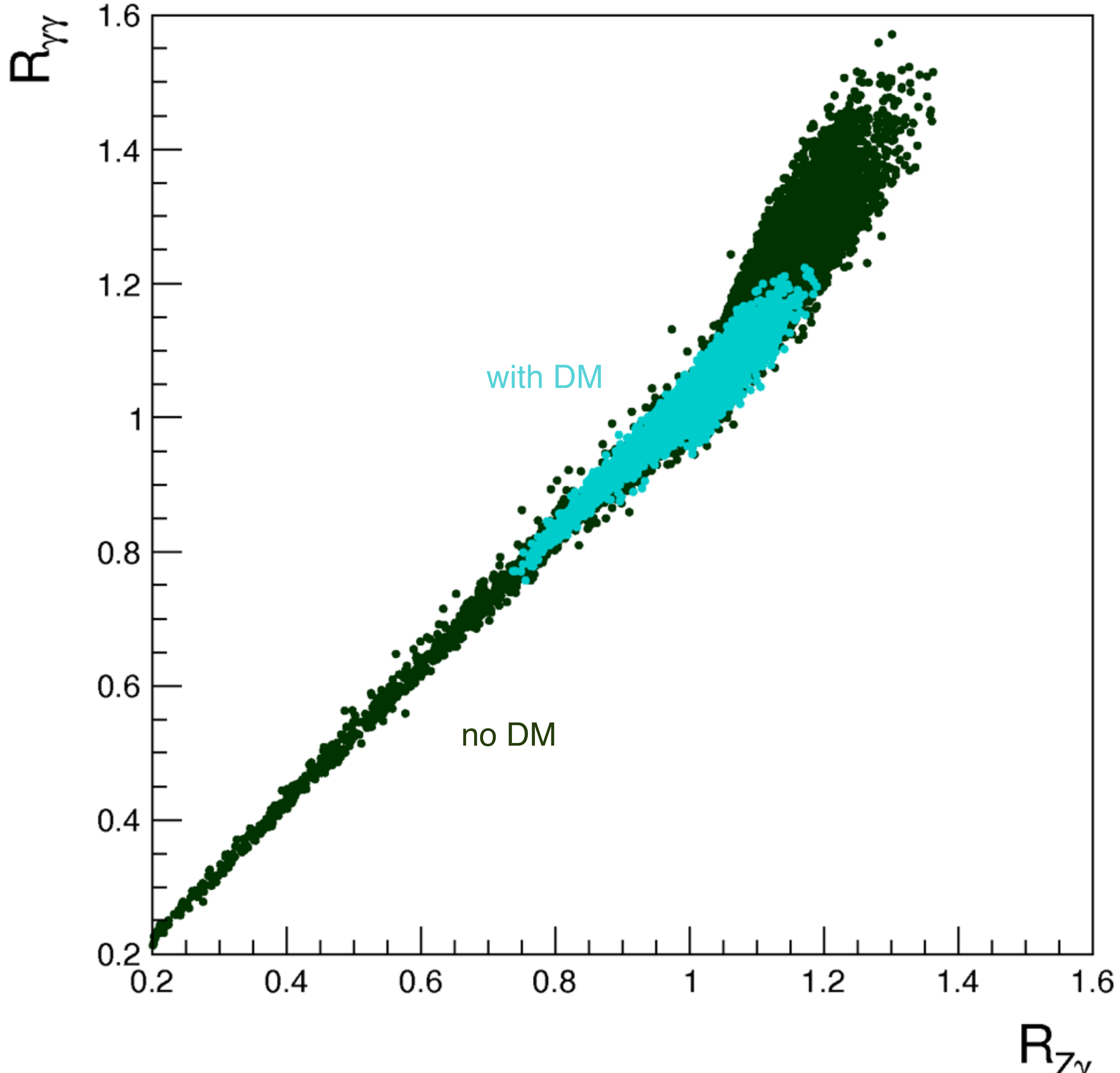
Complementarity between DM direct detection and colliders

Composition of the neutralino





DM and Higgs pheno



Conclusions TMSSM

- Triplet extension of the MSSM

  (a) Motivated to reduce fine-tuning in the Higgs mass as it provides additional contribution at tree level

  (b) Phenomenology of a Higgs which is SM-like

  (c) Deviation from SM only in loop-induced processes due to enlarged chargino sector

- Higgs physics uncorrelated from DM

  (a) Large enhancement in the signal strength into diphotons (60%)

  (b) Correlation with the decay process into photon+Z (40%)

- DM phenomenology

  (a) Neutralino viable DM in the well-tempered regime (Bino-Triplino) or in the Higgs pole

  (b) The LUX constraint on SI cross-section reduces the diphoton and Z gamma signal strenghts

Higgs inflation and its extensions

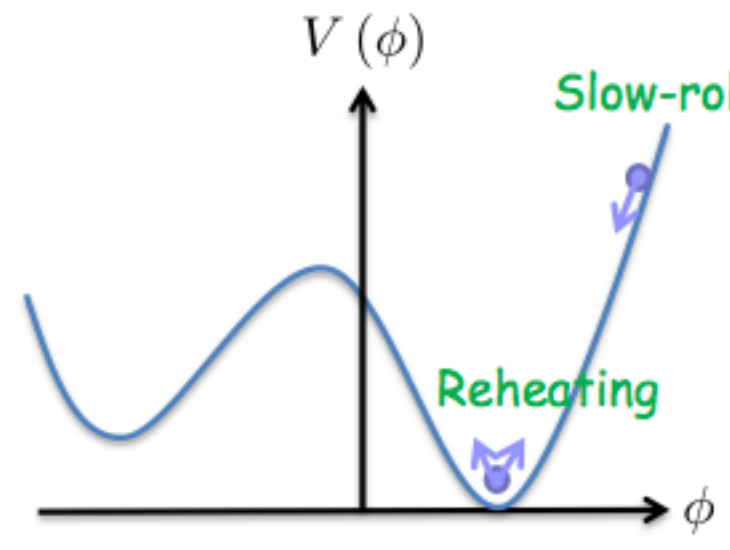
Once upon a time Higgs inflation ...

Inflation

Single field inflation characterized
by only the scalar potential

$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{1}{3M_{\rm Pl}^2}\left[\frac{\dot{\phi}^2}{2} + V(\phi)\right]$$

$$\ddot{\phi} + 3H\dot{\phi} + V_\phi = 0$$



Slow roll parameters

$$\epsilon_1 \simeq \frac{1}{2M_{\rm Pl}^2}\left(\frac{V_\phi}{V}\right)^2$$

$$\epsilon_2 \simeq \frac{2}{M_{\rm Pl}^2}\left[\left(\frac{V_\phi}{V}\right)^2 - \frac{V_{\phi\phi}}{V}\right]$$

Tensor to scalar ratio $r \equiv \frac{\mathcal{P}_\zeta}{\mathcal{P}_h} = 16\epsilon_1$

Spectral index

$$\begin{cases} n_{\rm s} - 1 \equiv \frac{\mathrm{d}\ln \mathcal{P}_\zeta}{\mathrm{d}\ln k} \\ n_{\rm s} - 1 = -2\epsilon_1 - \epsilon_2 \end{cases}$$

Higgs Inflation

F.Bezrukov and M.Shaposhnikov '07

- The nature of the inflaton field is unknown

- What about the Higgs?

- Chaotic Inflation for the Higgs doesn't work because its self-coupling is $\mathcal{O}(0.1)$ which produces large matter fluctuations

- Non-minimal coupling to gravity (Jordan frame)

$$S_J = \int d^4x \sqrt{-g} \left[\frac{R}{2} + \left(\xi_H H^\dagger H + c.c. \right) R - |\mathcal{D}_\mu H|^2 - \quad V(H) \right]$$

- Conformal transformation in the Einstein frame to retrieve the standard Einstein eqs.

$$\tilde{g}_{\mu\nu} = \Omega^2 g^J_{\mu\nu} \qquad \Omega^2 = 1 + 2\xi_H |H|^2$$

- The matter content now has non trivial kinetic terms: redefinition of the field

$$\frac{d\chi}{dh} = \frac{\sqrt{1+\xi(1+6\xi)h^2}}{\sqrt{2}(1+\xi h^2)} \qquad S = \int d^4x \sqrt{-g} \left[\frac{R}{4} - \frac{1}{2} g^{\mu\nu} \partial_\mu \chi \partial_\nu \chi - W(\chi) \right]$$

Higgs Inflation

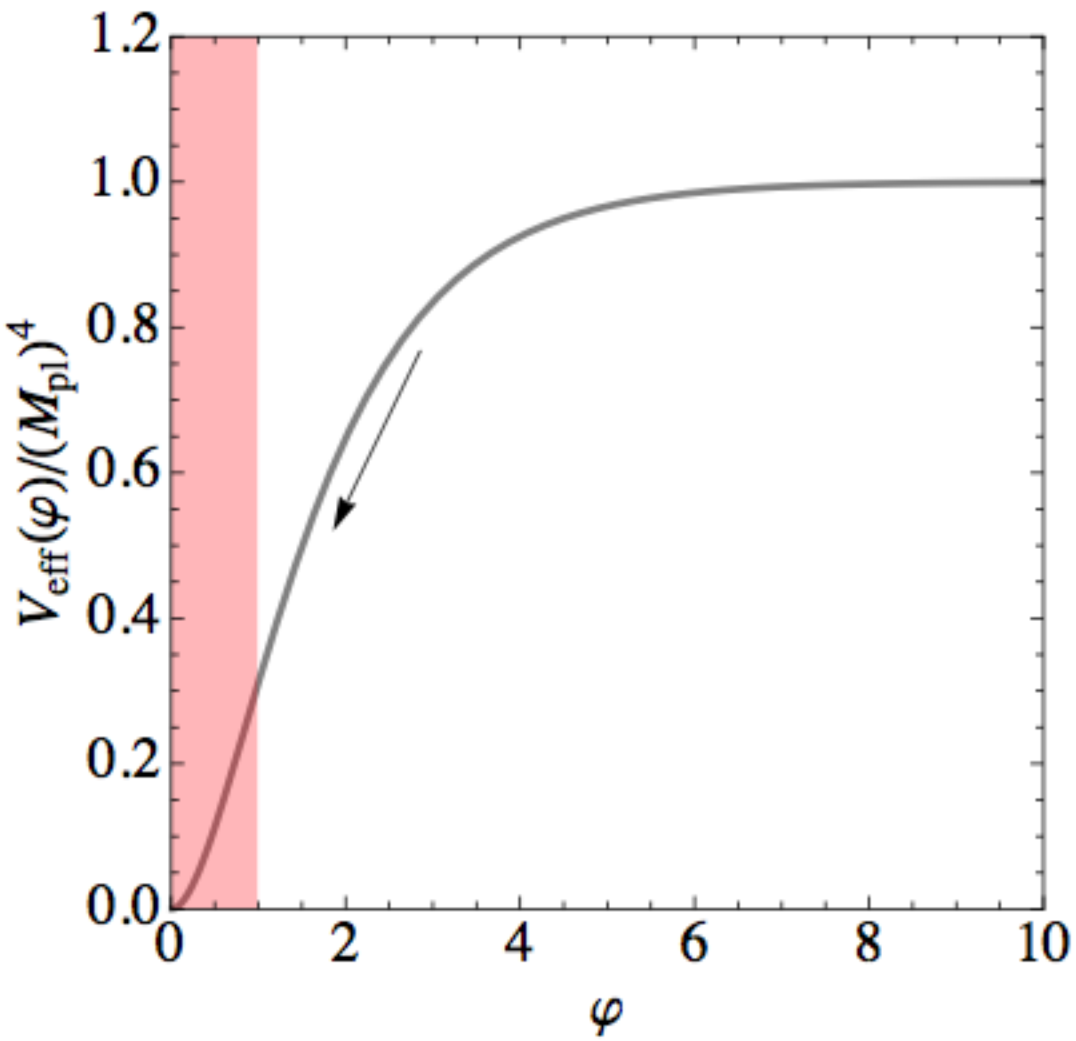
After taking care of all normalizations the scalar potential is of the form

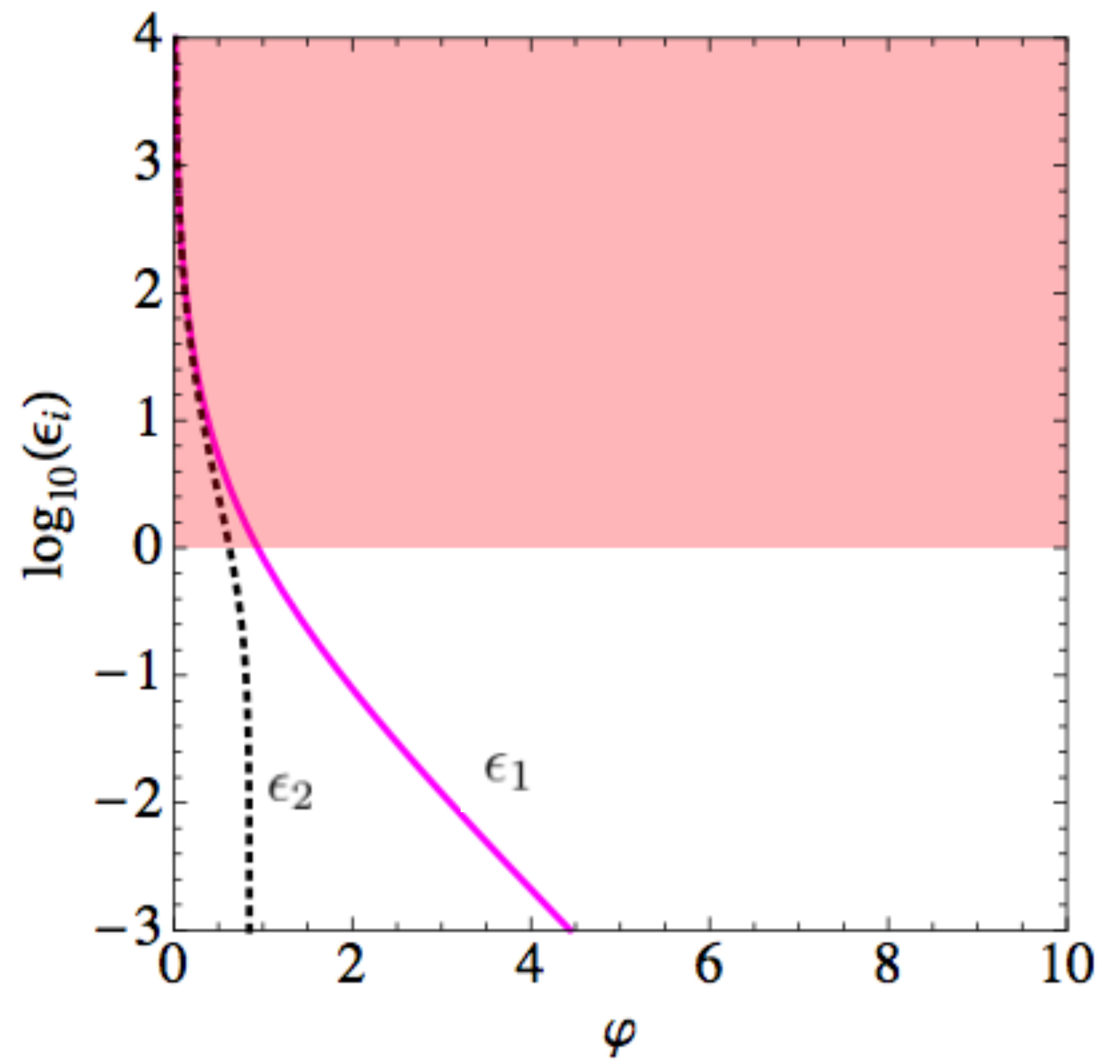
$$V(\varphi) = V_0 \left(1 - e^{-2\varphi/\sqrt{6}}\right)^2$$

$$V_0 = \frac{\lambda_H}{8\xi_H^2}$$

$$\epsilon_1 = \frac{4}{3}\left(1 - e^{\sqrt{2/3}\varphi}\right)^{-2}$$

$$\epsilon_2 = \frac{2}{3}\left[\sinh\left(\frac{\varphi}{\sqrt{6}}\right)\right]^{-2}$$





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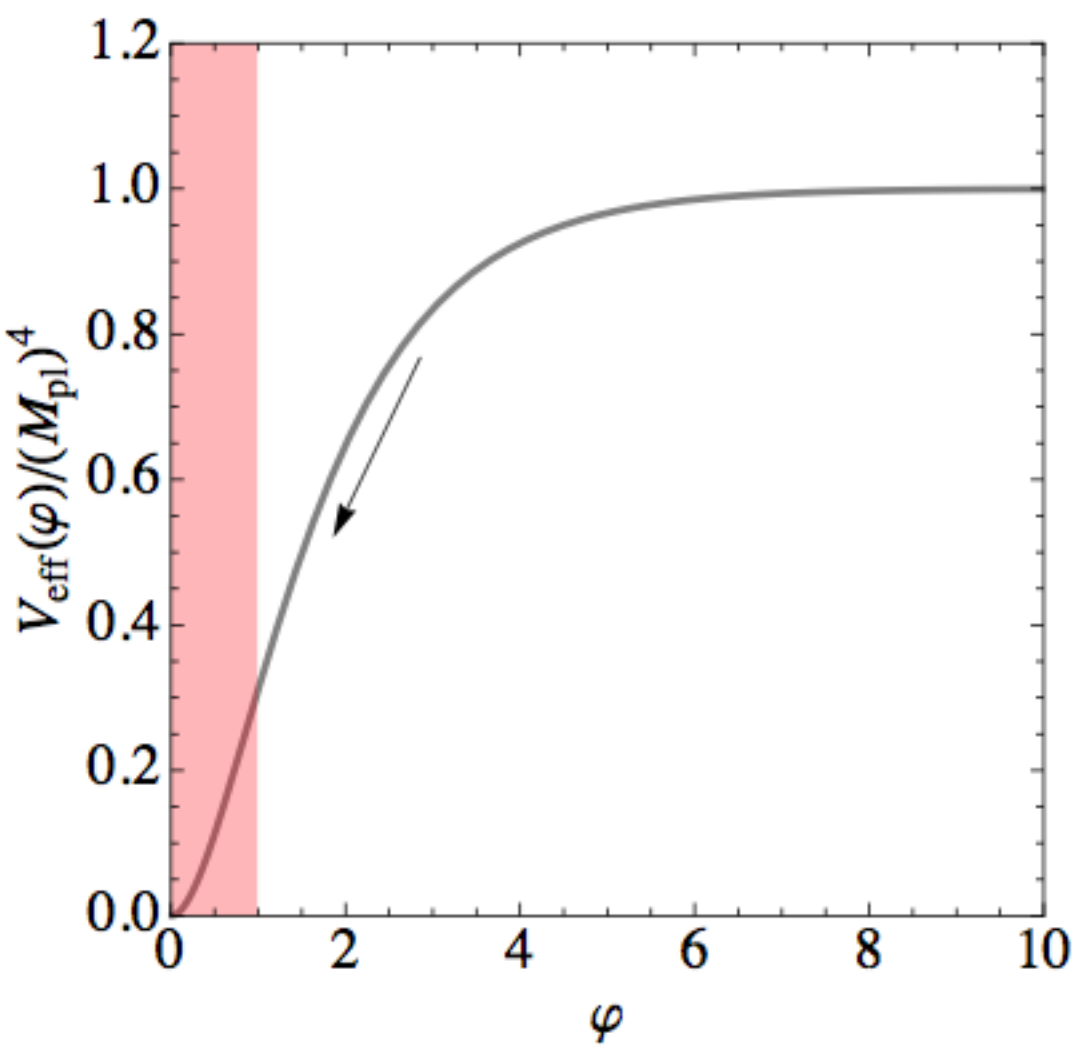
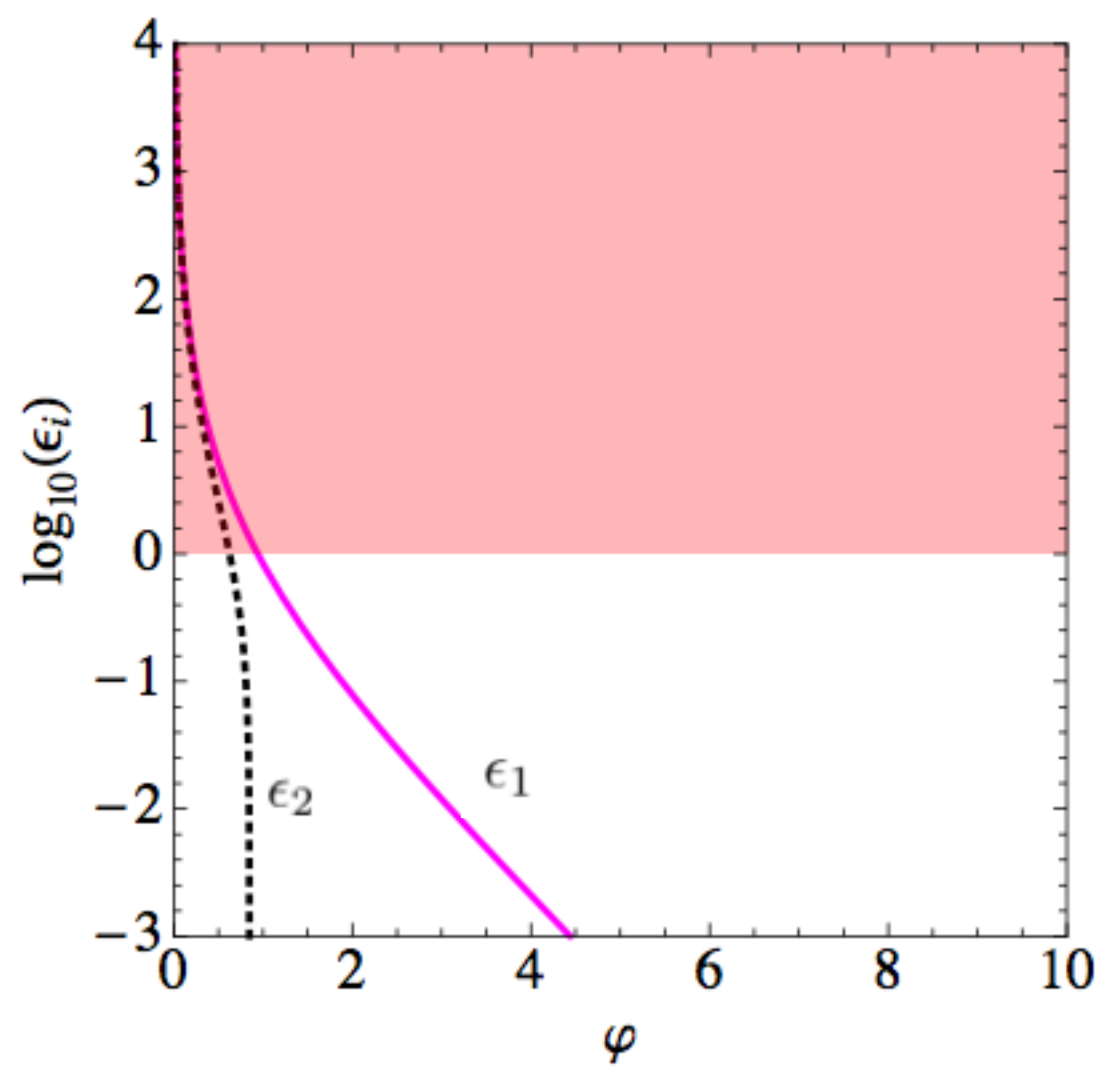
HIGHLY PREDICTIVE, no free parameters





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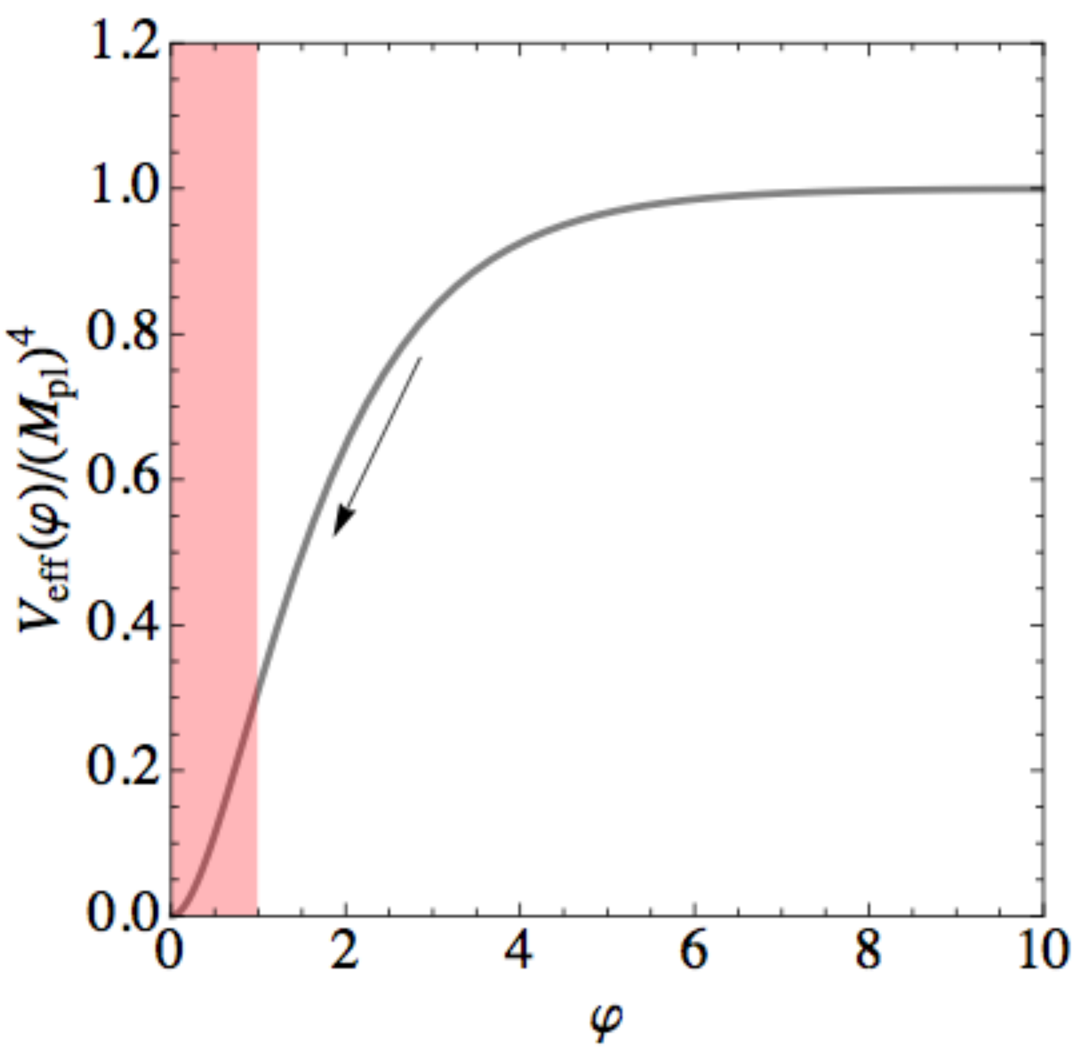
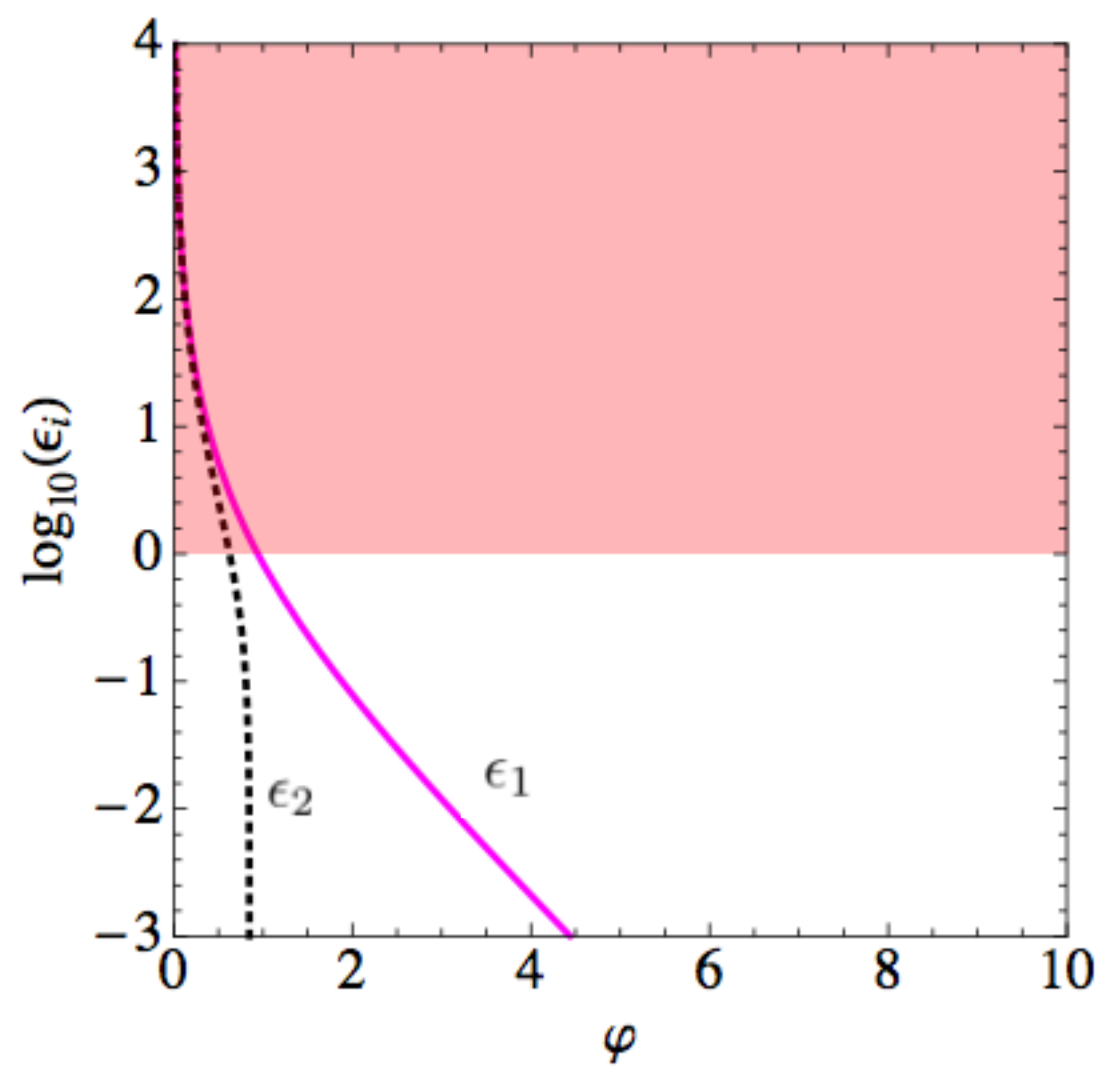
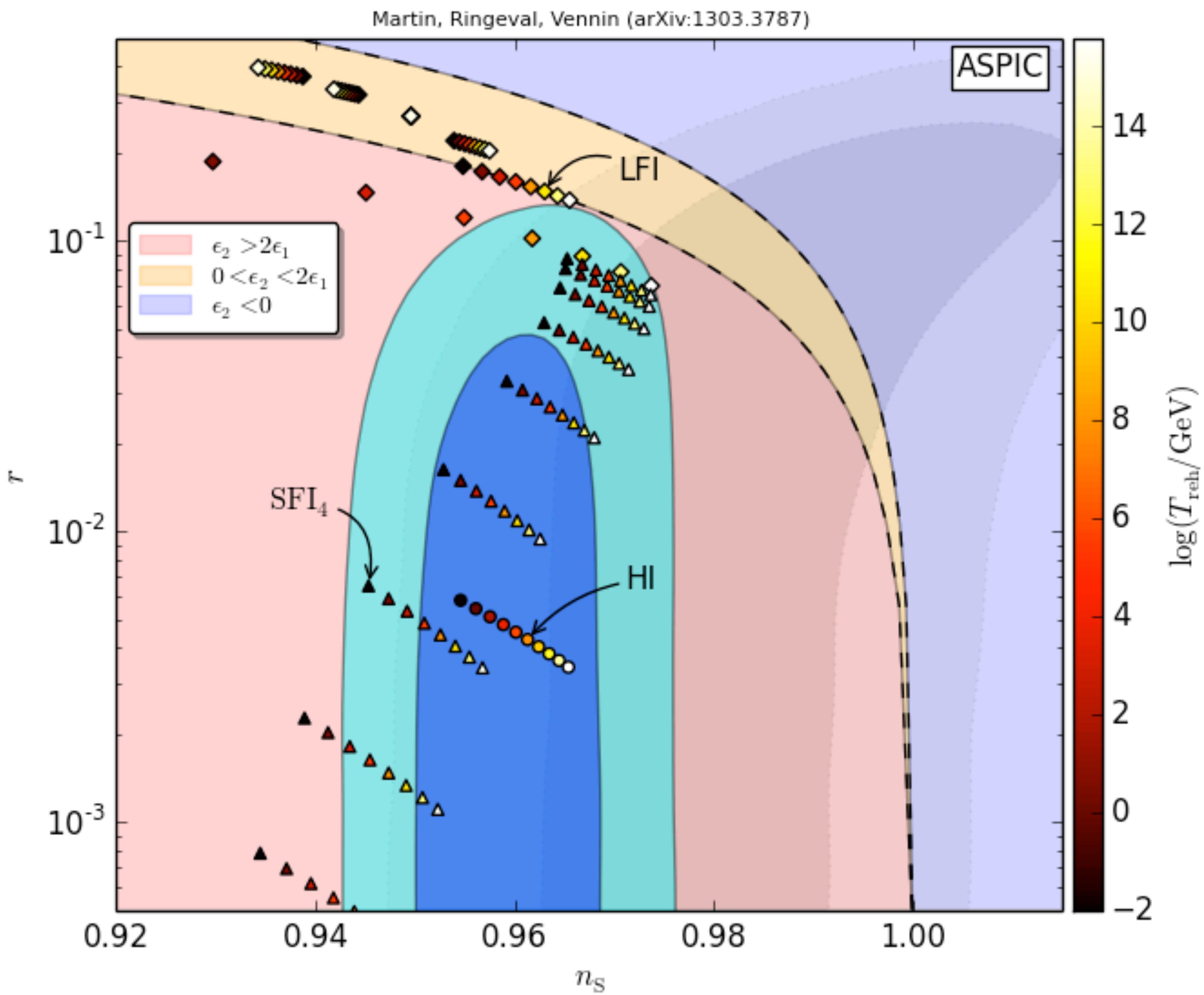


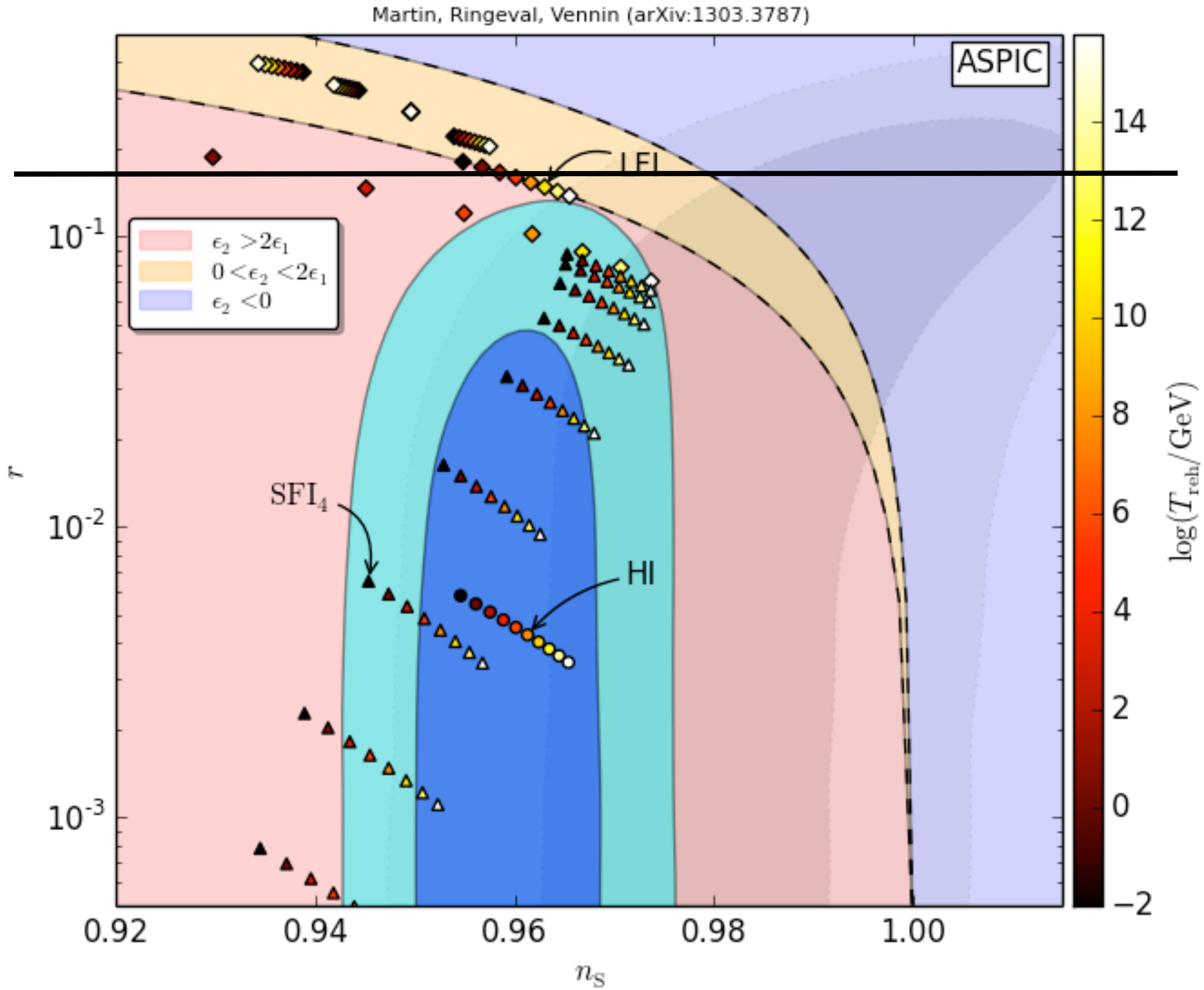


Higgs Inflation, Planck and BICEP2



Higgs Inflation, Planck and BICEP2

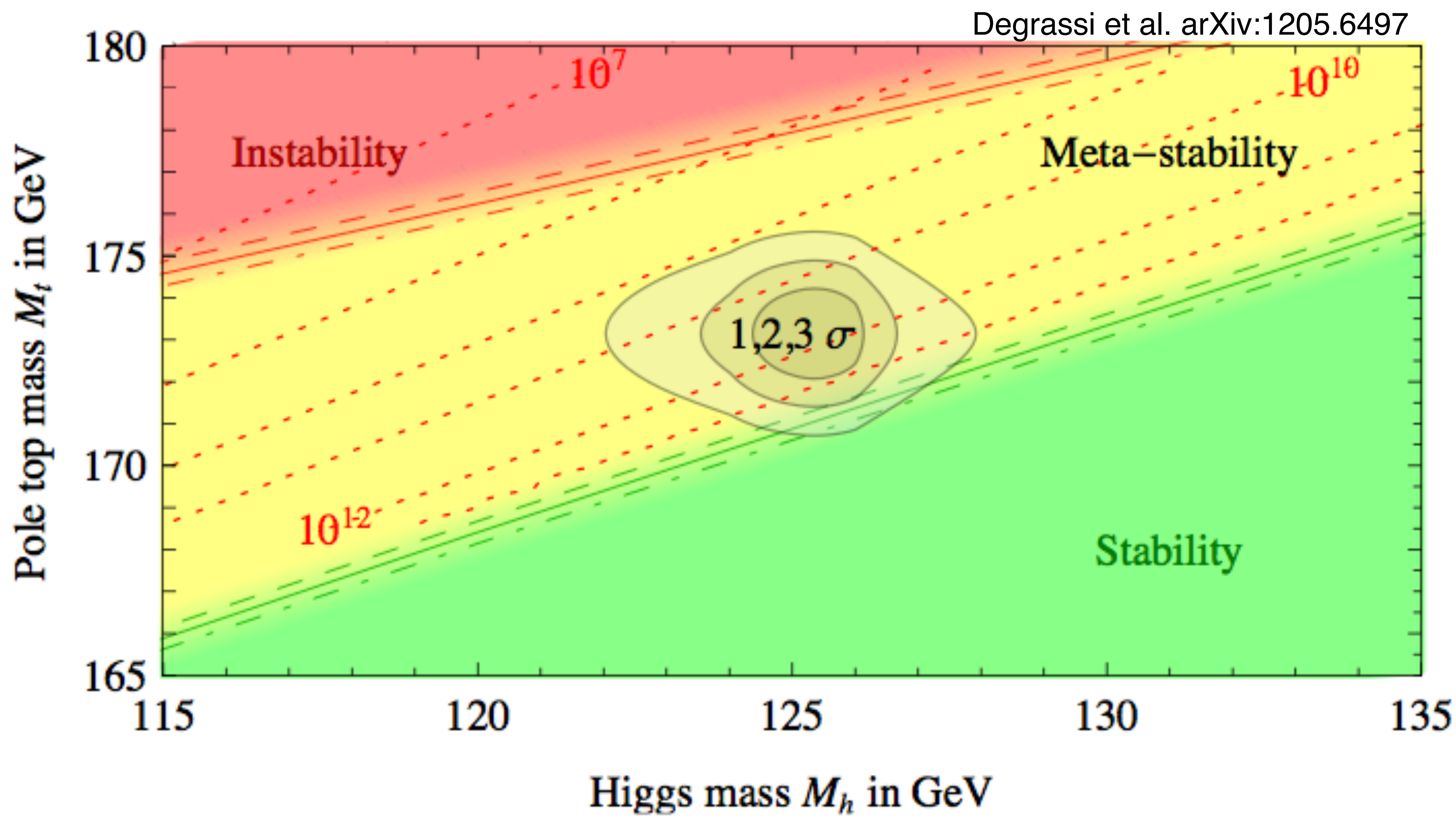
r = 0.16 +- 0.06



BICEP2

Higgs Scalar potential

- With a Higgs mass at 125-126 GeV the scalar potential is metastable



- Introduction of additional scalar fields might help in uplifting the running of the quartic coupling
- We consider scalar triplets with Y=2
- Why such fields?

Original idea based on:
Asymmetric Dark Matter

CA and N. Sahu, arXiv:1108.3967

$$n_b \equiv n_B - n_{\bar{B}}$$

$$\eta_b = \left(\frac{n_b}{n_\gamma}\right)\Big|_0 = (6.15 \pm 0.25) \times 10^{-10}$$

- The dark and visible matter have similar densities: $\frac{\Omega_{\rm DM}}{\Omega_b} \sim 5$
- Is it possible to generate a dark matter particle which is asymmetric as well (made only by particles or anti-particles)?

Higgs triplets for type-II Leptogenesis

The Sakharov conditions to generate baryon asymmetry

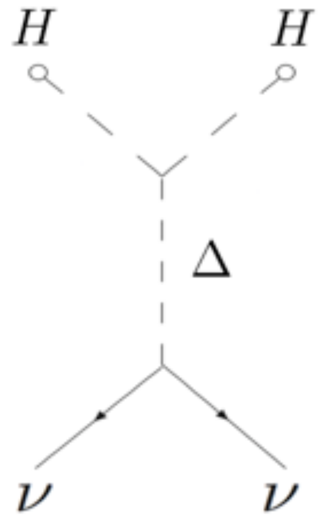
(i) Baryon number violation ($B \neq 0$);

(ii) C ($q_L \to \bar{q}_L$) and CP violation ($q_L \to \bar{q}_R$) so that $\Gamma(X \to qq) \neq \Gamma(\overline{X} \to \overline{qq})$

(iii) Departure from thermal equilibrium (because CPT is conserved).

Leptogenesis provides neutrino masses via seesaw mechanism as well

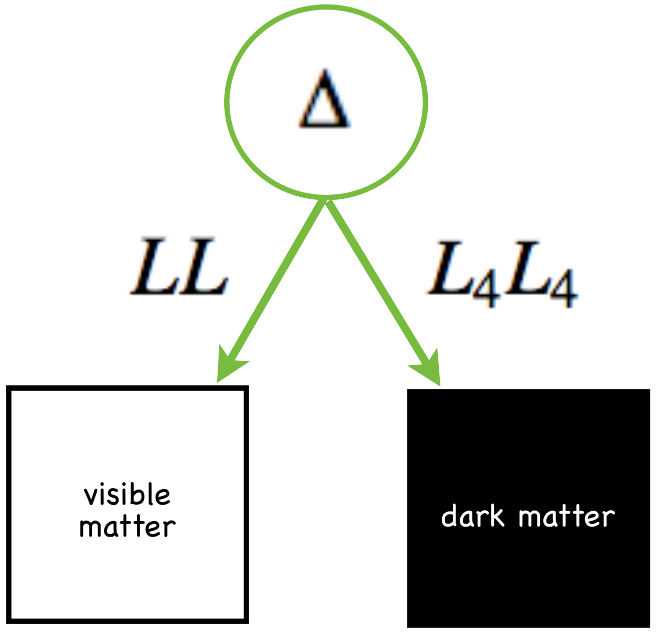
Type-II seesaw $\mathcal{L} \supset M_\Delta^2 \Delta^\dagger \Delta + \frac{1}{\sqrt{2}} \left[\mu_H \Delta^\dagger H H + f_{\alpha\beta} \Delta L_\alpha L_\beta + \text{h.c.} \right]$



$$\begin{array}{l} \Delta \to LL \\ \Delta \to HH \end{array} \longrightarrow \Delta L = 2$$

- The field Δ is heavy (10^8-10^{14} GeV)
- Its interaction violates L: violation of B given by sphalerons at EW phase transition

Asymmetric DM from type-II Leptogenesis



CA and N. Sahu, arXiv:1108.3967

DM generated by triplet decay, providing an asymmetry in the dark sector (violating of DM number)

$$f_4 \Delta L_4 L_4$$

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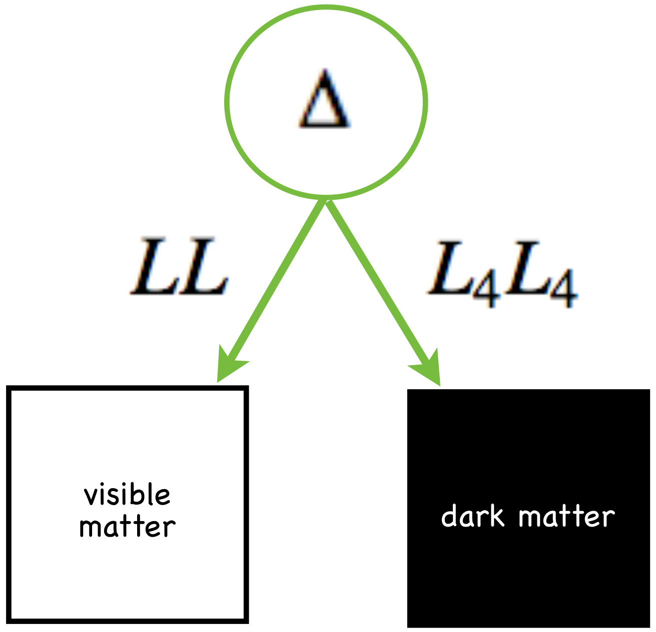

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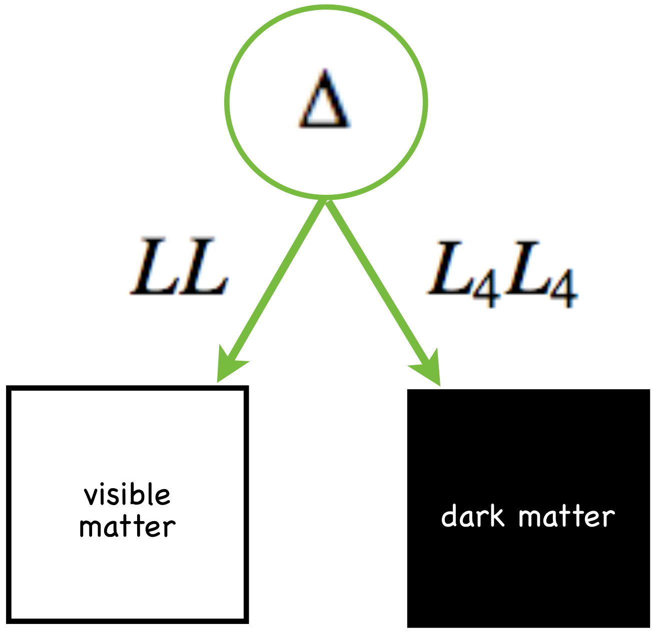

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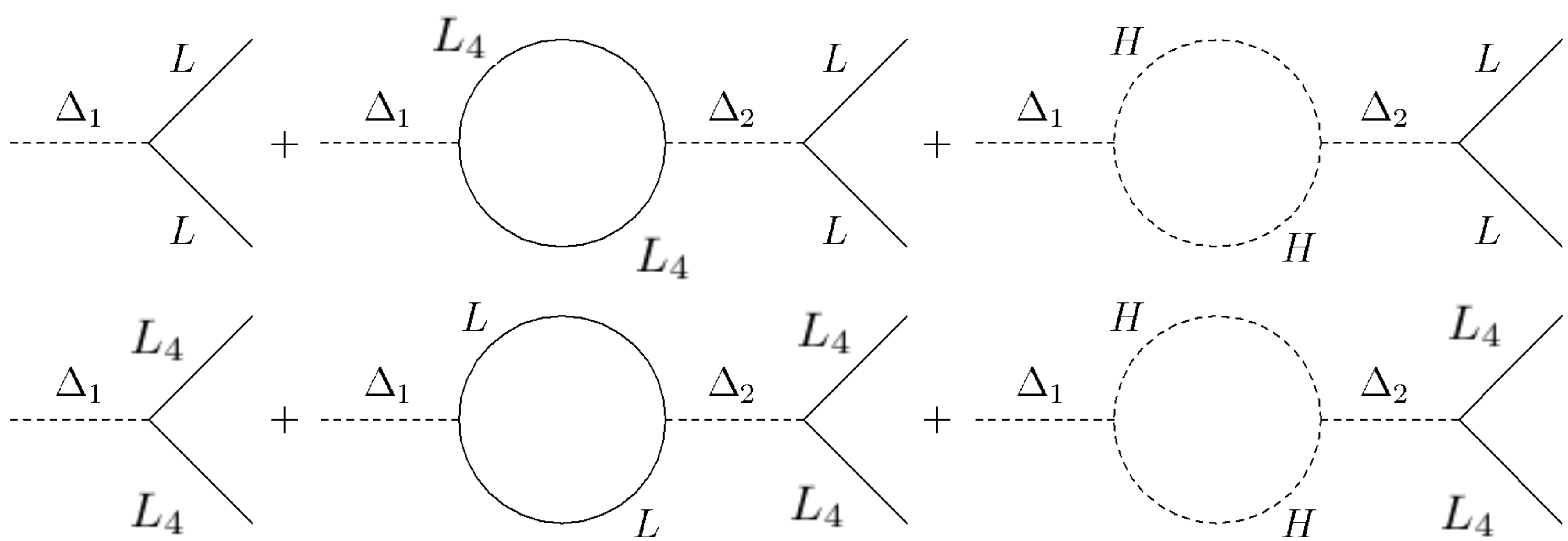

$$\epsilon_L = \frac{1}{8\pi^2}\frac{M_1 M_2}{M_2^2 - M_1^2}\left[\frac{M_1}{\Gamma_1}\right] \mathrm{Im}\left[\left(f_{1N_4} f^*_{2N_4} + f_{1H} f^*_{2H}\right)\sum_{\alpha\beta}(f_{1L})_{\alpha\beta}(f^*_{2L})_{\alpha\beta}\right]$$

$$\epsilon_{DM} = \frac{1}{8\pi^2}\frac{M_1 M_2}{M_2^2 - M_1^2}\left[\frac{M_1}{\Gamma_1}\right] \mathrm{Im}\left[f_{1N_4} f^*_{2N_4}\left(f_{1H} f^*_{2H} + \sum_{\alpha\beta}(f_{1L})_{\alpha\beta}(f^*_{2L})_{\alpha\beta}\right)\right]$$

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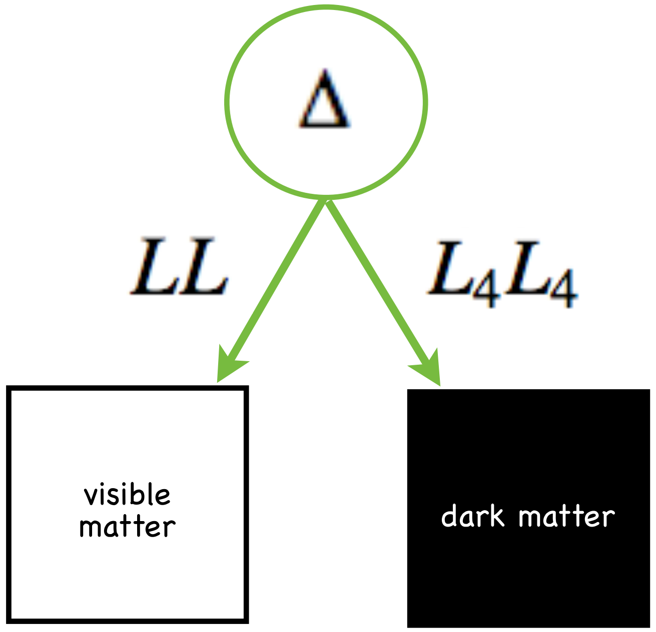

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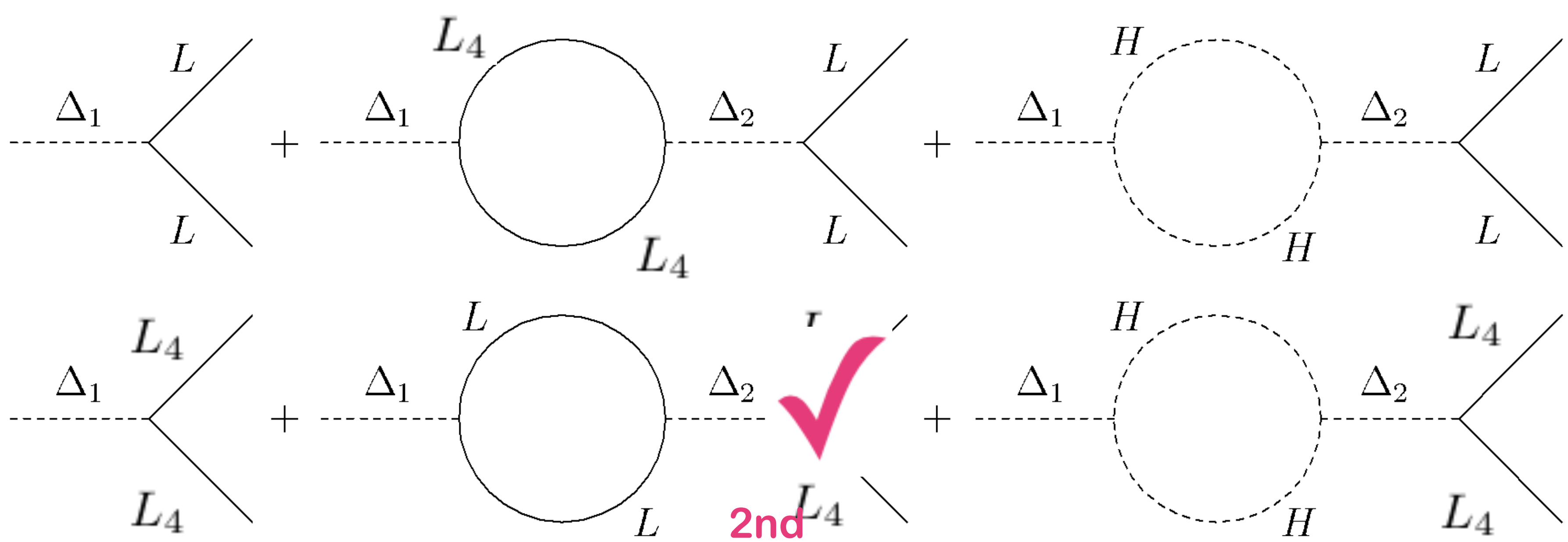

2nd Sakharov condition

$$\epsilon_L = \frac{1}{8\pi^2}\frac{M_1 M_2}{M_2^2 - M_1^2}\left[\frac{M_1}{\Gamma_1}\right] \mathrm{Im}\left[\left(f_{1N_4} f^*_{2N_4} + f_{1H} f^*_{2H}\right)\sum_{\alpha\beta}(f_{1L})_{\alpha\beta}(f^*_{2L})_{\alpha\beta}\right]$$

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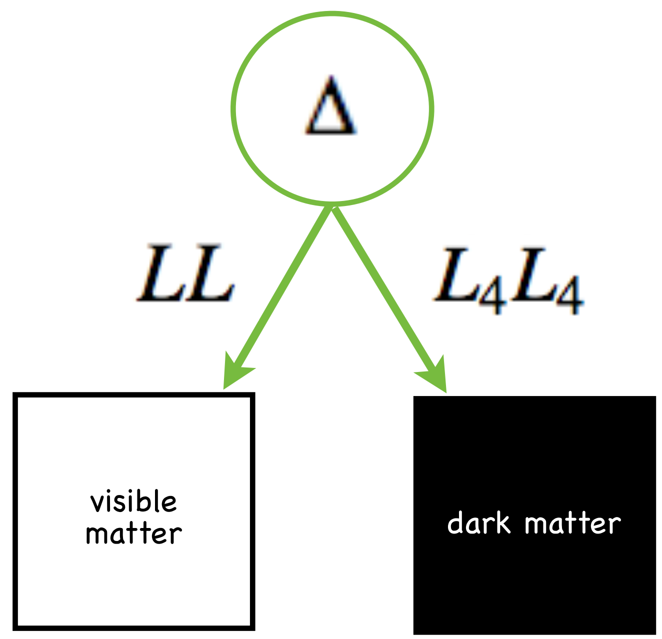

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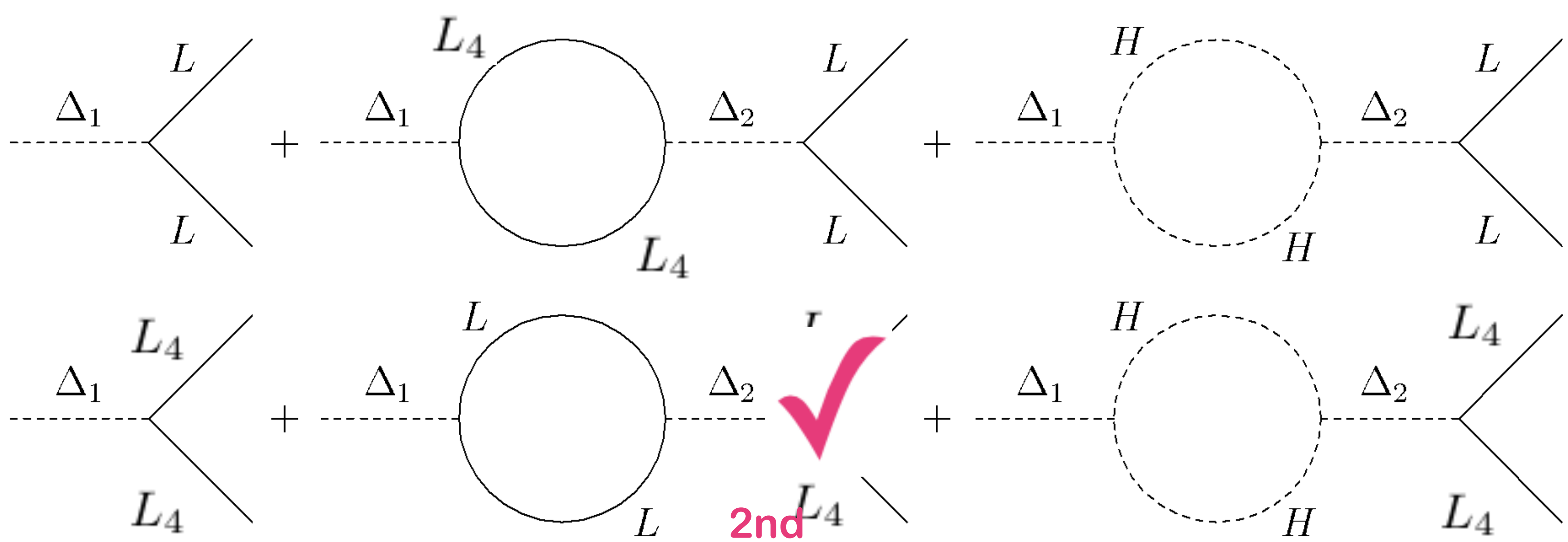

Above 10^8 GeV the condition of out of equilibrium decay is satisfied: viable model!

2nd Sakharov condition

3rd Sakharov condition

$$\epsilon_L = \frac{1}{8\pi^2}\frac{M_1 M_2}{M_2^2-M_1^2}\left[\frac{M_1}{\Gamma_1}\right]\mathrm{Im}\left[\left(f_{1N_4}f^*_{2N_4}+f_{1H}f^*_{2H}\right)\Sigma_{\alpha\beta}(f_{1L})_{\alpha\beta}(f^*_{2L})_{\alpha\beta}\right]$$

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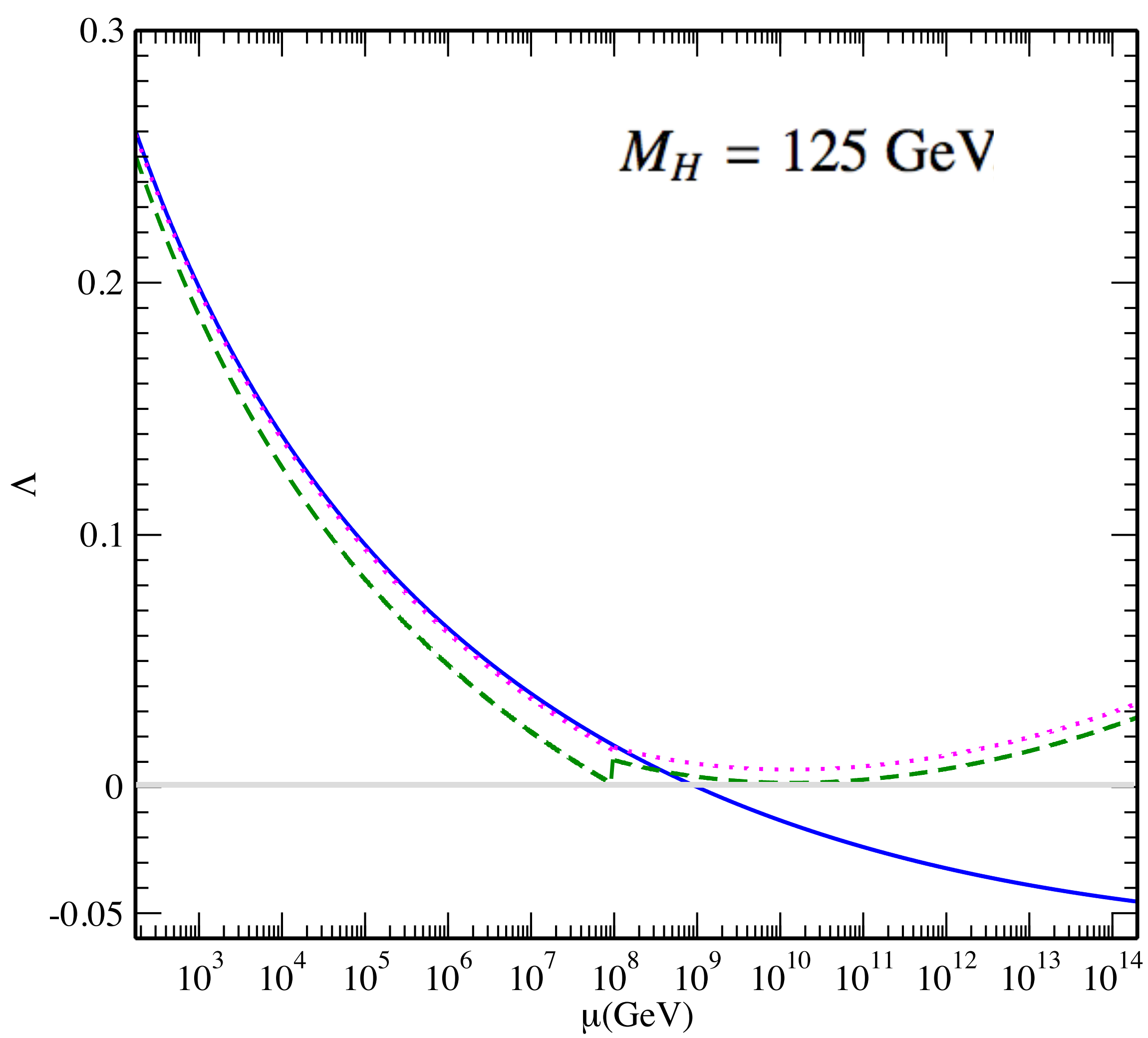
Triplet contribution to the scalar potential

CA, J.O. Gong and N.Sahu '12

$$V(\Delta, H) = M_\Delta^2 \Delta^\dagger \Delta + \frac{\lambda_\Delta}{2}(\Delta^\dagger \Delta)^2 - M_H^2 H^\dagger H + \frac{\lambda_H}{2}(H^\dagger H)^2 + \lambda_{\Delta H} H^\dagger H \Delta^\dagger \Delta + \frac{1}{\sqrt{2}}\left[\mu_H \Delta^\dagger HH + \text{h.c.}\right]$$

Above the mass scale of the triplet:

$$16\pi^2 \beta_{\lambda_H} = 12\lambda_H^2 + 6\lambda_{H\Delta}^2 - \left(\frac{9}{5}g_1^2 + 9g_2^2\right)\lambda_H + \frac{9}{4}\left(\frac{3}{25}g_1^4 + \frac{2}{5}g_1^2 g_2^2 + g_2^4\right) + \left(12\lambda_H Y_t^2 - 12Y_t^4\right)$$



Below the mass scale of the triplet, the triplet is integrated out, effective theory with

$$\Lambda = \lambda_H - \frac{1}{2}\left(\frac{\mu_H^\dagger \mu_H}{M_\Delta^2}\right)$$

Higgs physics constraint $\longrightarrow$ $M_\Delta = 10^8$ GeV

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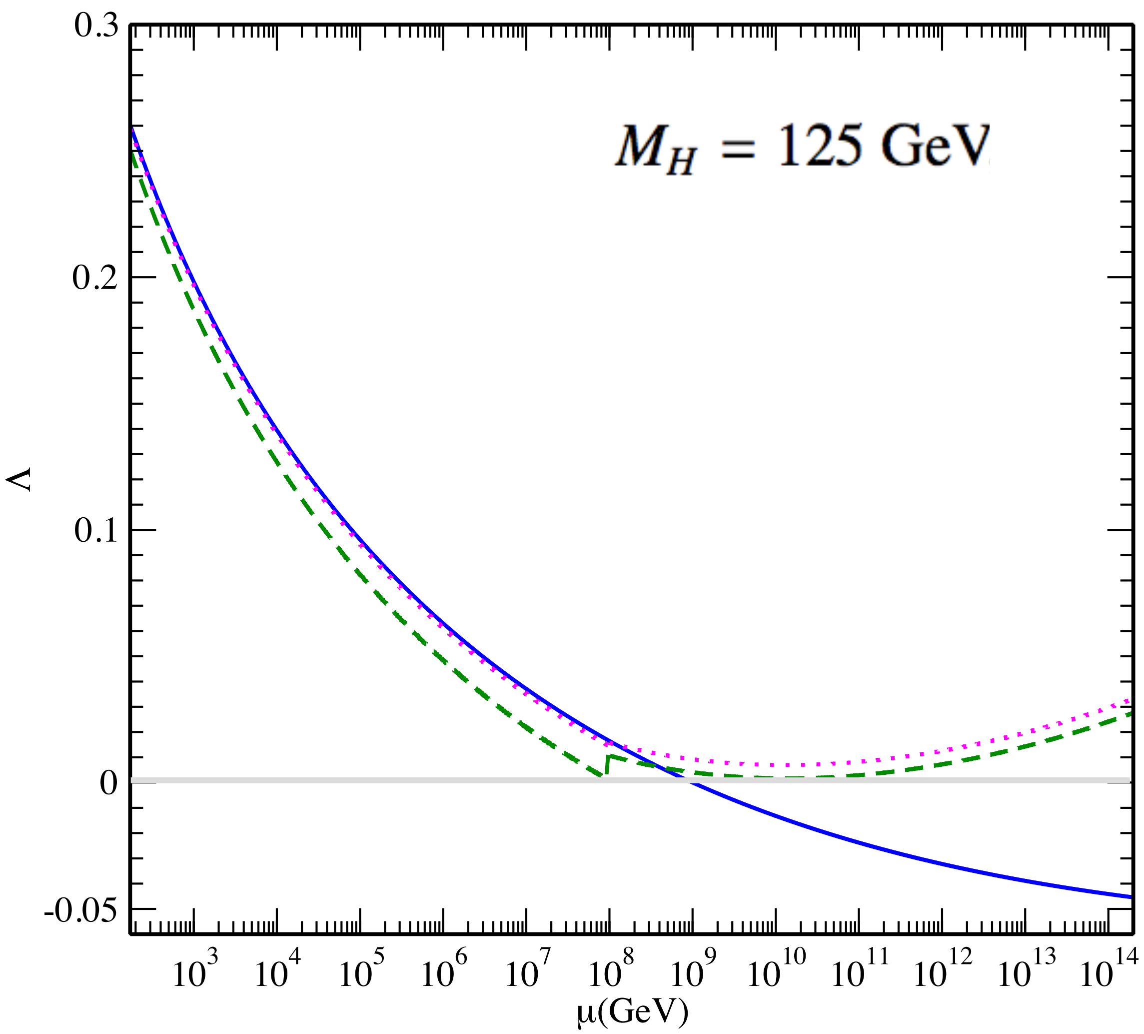

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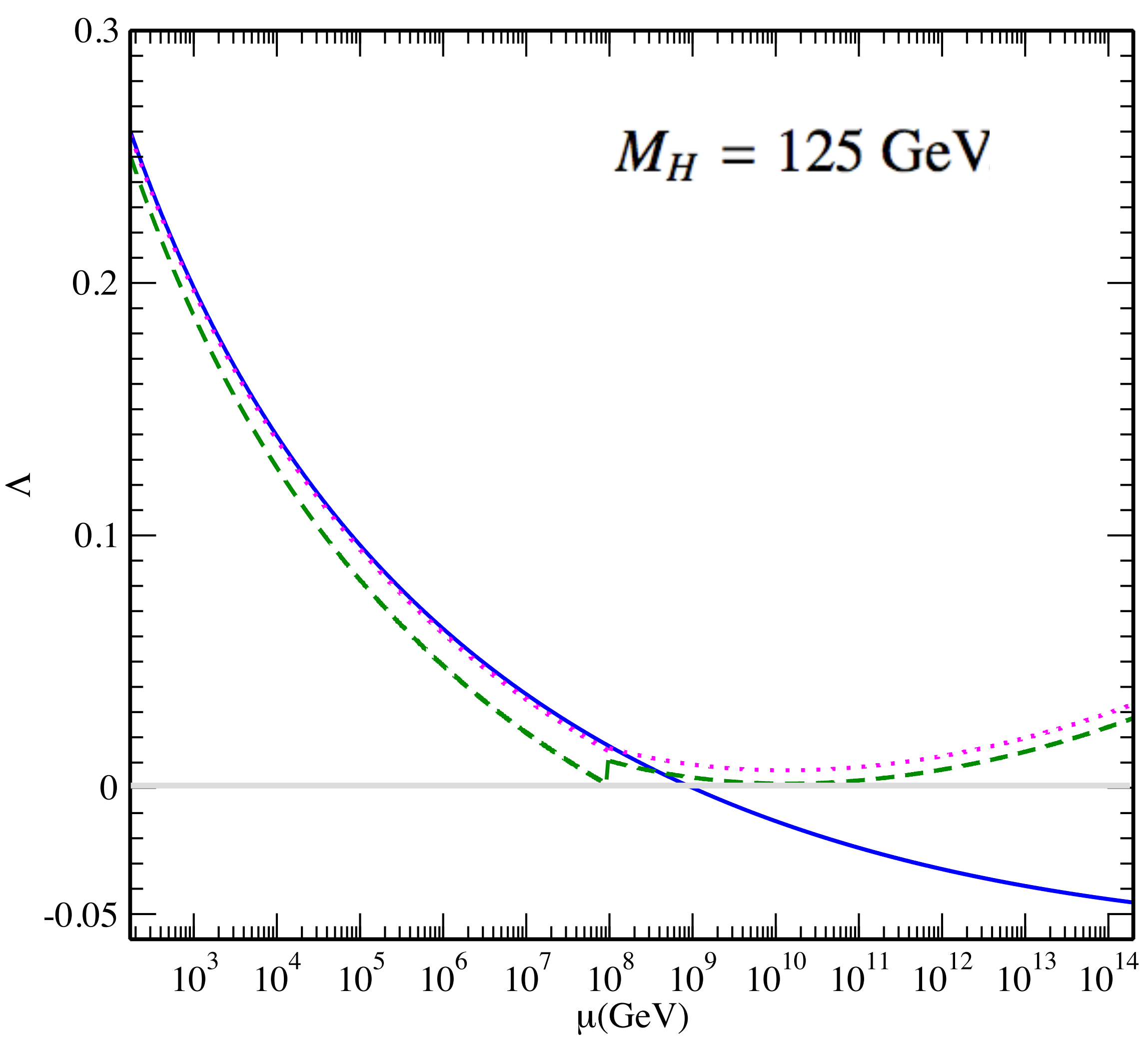

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Triplet contribution to Higgs inflation

$$V_J(\Delta, H) = M_\Delta^2 \Delta^\dagger \Delta + \frac{\lambda_\Delta}{2}(\Delta^\dagger \Delta)^2 - M_H^2 H^\dagger H + \frac{\lambda_H}{2}(H^\dagger H)^2 + \lambda_{\Delta H} H^\dagger H \Delta^\dagger \Delta + \frac{1}{\sqrt{2}}\left[\mu_H \Delta^\dagger H H + \text{h.c.}\right]$$

$$S_J = \int d^4x \sqrt{-g}\left[\frac{R}{2} + \left(\xi_H H^\dagger H + \xi_\Delta \Delta^\dagger \Delta + c.c.\right) R - |\mathcal{D}_\mu H|^2 - |\mathcal{D}_\mu \Delta|^2 - V_J(H, \Delta)\right]$$

Further steps

1. Fix in the unitary gauge and the charged component of the triplet = 0
2. Take large limit for the non-minimal couplings
3. The fields are redefined

$$H = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ h \end{pmatrix}, \quad \Delta = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 0 \\ \delta e^{i\theta} & 0 \end{pmatrix} \quad \longrightarrow \quad \varphi = \sqrt{\frac{3}{2}} \log\left(1 + \xi_\Delta \delta^2 + \xi_H h^2\right), \quad r = \frac{\delta}{h}$$

4. The Lagrangian becomes quite cumbersome and the kinetic terms are non minimal
5. The field r is much heavier then the Planck scale hence it rolls to a minimum and does not contribute
6. Reconducted to single field inflation (quartic term dominates the scalar potential + potential defined > 0)

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both fields are non minimally coupled to gravity: inflation possible

Further steps

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Inflationary predictions

- Effective final potential is equivalent to Higgs inflation: $V(\varphi) = V_0 \left(1 - e^{-2\varphi/\sqrt{6}}\right)^2$
- V_0 depends on the minimum in which rolls $r = \frac{\delta}{h}$

φ Mixed Inflaton	φ Higgs Inflaton	φ Triplet Inflaton
$r^2 = (\lambda_{H\Delta}\xi_H - \lambda_H\xi_\Delta)/(\lambda_{H\Delta}\xi_\Delta - \lambda_\Delta\xi_H)$	$r^2 \to 0$	$r^2 \to \infty$
$V_0^{(\text{mixed})} = \frac{\lambda_\Delta\lambda_H - \lambda_{H\Delta}^2}{8\left(\lambda_\Delta \xi_H^2 + \lambda_H \xi_\Delta^2 - 2\lambda_{H\Delta}\xi_\Delta\xi_H\right)}$	$V_0^{(H)} = \frac{\lambda_H}{8\xi_H^2}$	$V_0^{(\Delta)} = \frac{\lambda_\Delta}{8\xi_\Delta^2}$

- Exact same prediction as Higgs inflation
- Large non-minimal couplings to match the matter fluctuations, which fix the scale of inflation

$$\frac{\lambda_{\text{eff}}}{8\xi_{\text{eff}}^2} = 1920\pi^2 \left(1 - e^{\sqrt{\frac{2}{3}}\varphi_\star}\right)^{-4} e^{2\sqrt{\frac{2}{3}}\varphi_\star} \frac{Q_{\text{rms}-\text{PS}}^2}{T^2}$$

$$\xi_{\text{eff}} \simeq 49000\sqrt{\lambda_{\text{eff}}}$$

$$M_{\text{pl}}/\xi_{\text{eff}} \simeq 10^{14}\ \text{GeV}$$

Inflation after BICEP2

Credit J. Martin, IAP

$$\mathcal{P}_h \simeq \left(\frac{H}{m_{\rm Pl}}\right)^2 \simeq 0.2\left(\frac{\delta T}{T}\right)^2 \simeq 0.2\times 10^{-10} \rightarrow$$

Energy scale of inflation measured to be ~ the GUT scale

$$H \simeq 1.23\left(\frac{r}{0.2}\right)^{1/2} 10^{14}\mathrm{GeV}$$

$$\rho^{1/4} \simeq 2.26\left(\frac{r}{0.2}\right)^{1/4} 10^{16}\mathrm{GeV}$$

$$r = \frac{T}{S} = 16\epsilon_1 = \frac{8}{M_{\rm Pl}^2}\left(\frac{V_\phi}{V}\right)^2 = 0.2 \rightarrow$$

First derivative measured!

$$n_{\rm S} - 1 = -2\epsilon_1 - \epsilon_2 \simeq 0.96 \rightarrow$$

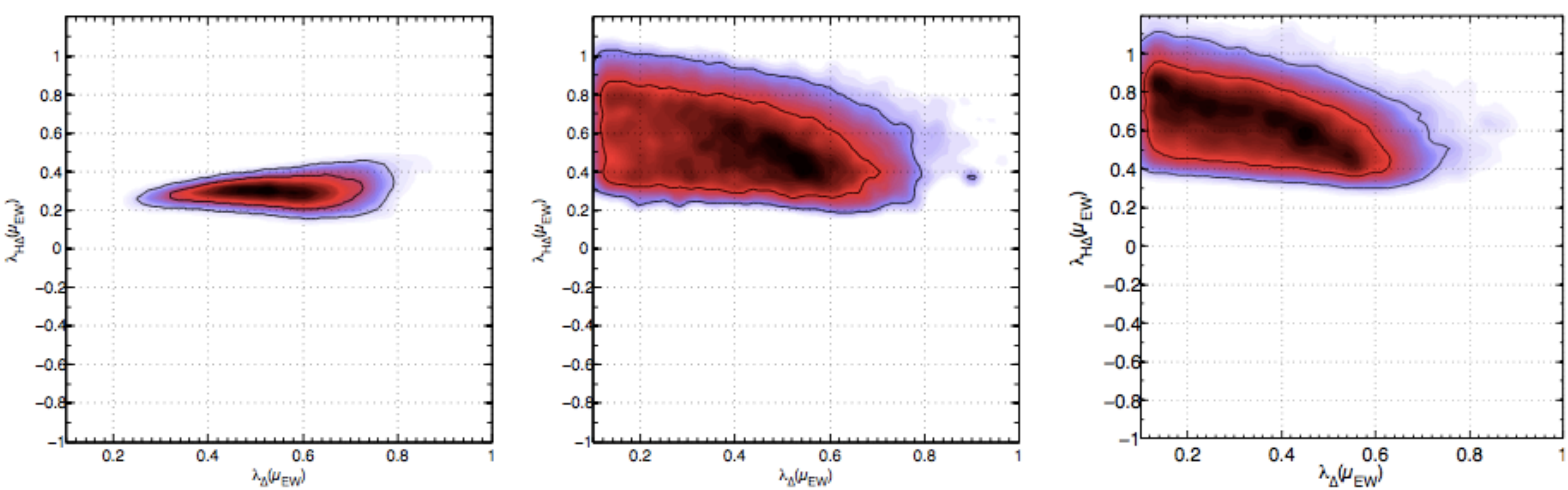
Second derivative measured but different value

Extended Higgs Inflation after BICEP2

- Is is possible to find the the correct combination lambda - non minimal coupling to match both power spectrum and scale of inflation measured by BICEP2?

- For pure Higgs Inflation: scale of inflation means smaller non-minimal coupling (~ 10^2 instead of 10^4)
- However it go to a much small self-coupling to match the amplitude power spectrum (~ 10^{-4} - 10^{-5} instead of 0.1)
- Can the triplet help?

$$\begin{cases} \lambda_{\text{eff}} = \frac{\lambda_H}{2} + \lambda_{H\Delta} r_0^2 + \frac{\lambda_\Delta}{2} r_0^4 \\ \xi_{\text{eff}} = \xi_H + \xi_\Delta r_0^2 \end{cases}$$



Conclusion Higgs Inflation

- Inflation with the Triplet: chaotic Inflation

$$V(\Delta) = M_\Delta^2 \Delta^\dagger \Delta + \frac{\lambda_\Delta}{2}(\Delta^\dagger \Delta)^2$$

$$M_\Delta^2 = 10^{14} \text{-} 10^{16}\ \text{GeV}$$

$$\lambda_\Delta = 10^{-13}$$

- Can Higgs Inflation survive?

→ Talk by Veronica Sanz