Maximal stop mixing and the 125-GeV Higgs in MSSM

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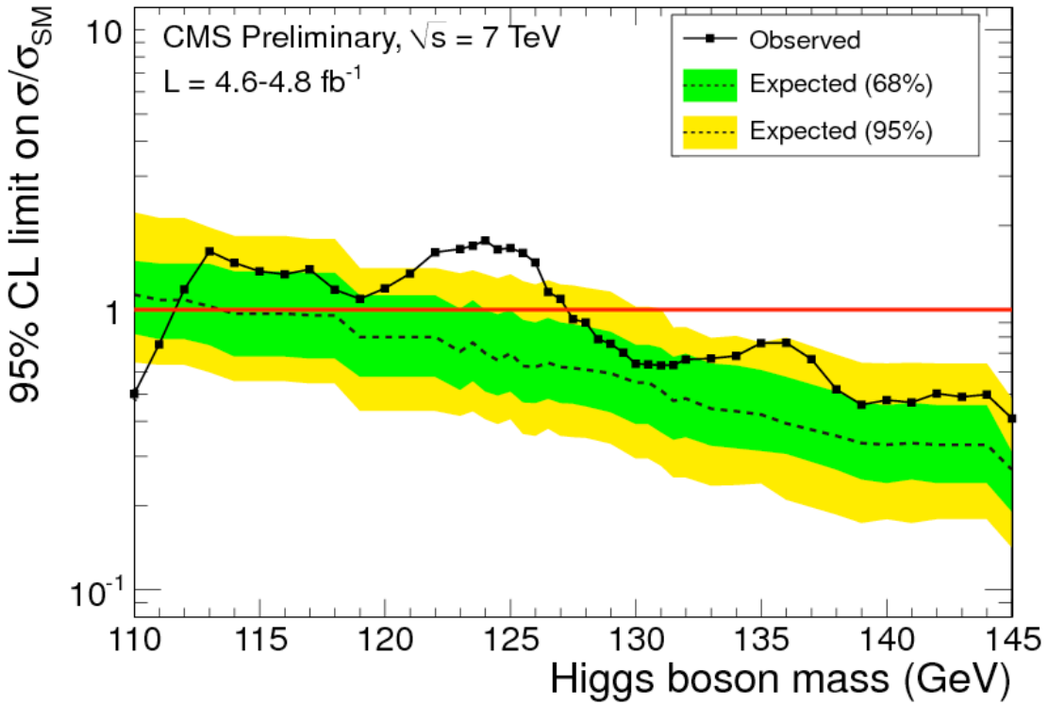
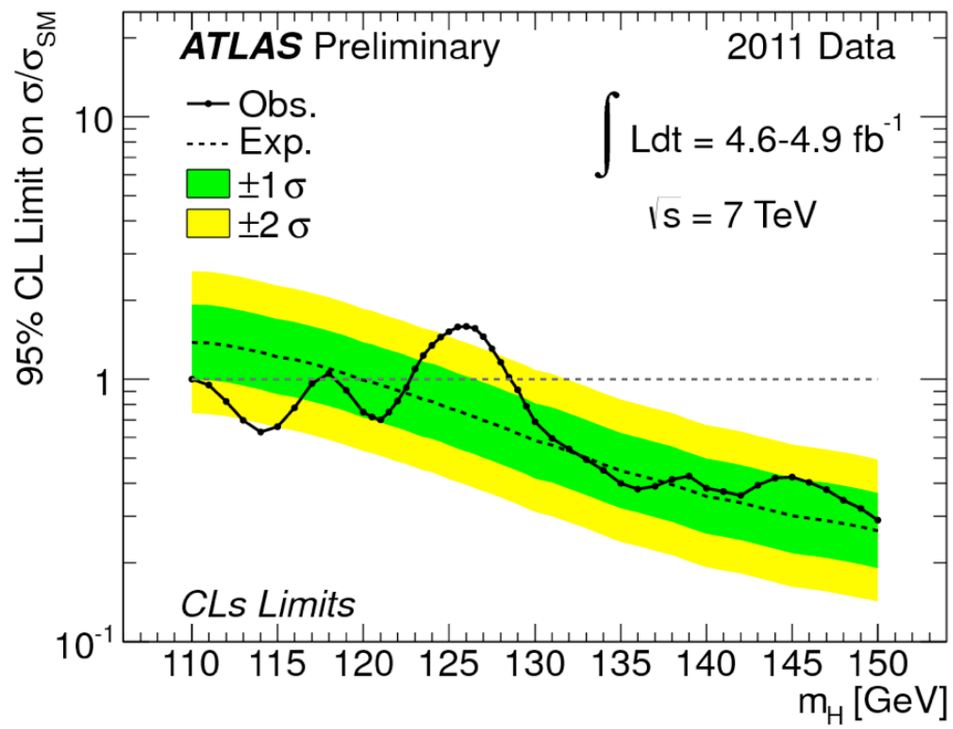
with Felix Brümmer (DESY) and Sabine Kraml (LPSC, Grenoble)
(to appear)

- Disclaimer: A huge amount of work is done/being done to explain the possible 125 GeV Higgs signal, I will not attempt to take any literature review.

Higgs où êtes-vous?





- LHC and Tevatron observe an excess in the lightest Higgs cross-section in various channels
- If confirmed this excess will correspond to Higgs mass around 125 GeV
- If we want to explain this in the context of SUSY ...

The Higgs - stop relationship

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m_h^2 &= m_h^{2,\text{tree}} + \Delta m_h^{2,\text{1-loop}} \\
&= m_Z^2 \cos^2 2\beta + \frac{3}{4\pi^2}\frac{m_t^4}{v^2}\left(\log\frac{M_S^2}{m_t^2} + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12\,M_S^2}\right)\right)
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$$X_t = A_t - \mu \cot\beta$$
$$M_S \approx \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

Can be increased arbitrarily
not desired due to naturalness

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$$X_t = A_t - \mu \cot\beta$$

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Maximized at $|X_t/M_S| \simeq \sqrt{6} = 2.45$

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$$X_t = A_t - \mu \cot\beta$$
$$M_S \approx \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

- Some studies claim $|X_t/M_S| \approx 2$
- Hence we define

$$1.5 < \left|\frac{X_t}{M_S}\right| < 2.5$$

as maximal mixing range

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- Aim: Obtain light stops (good for naturalness) and explain observed hints of higgs signal in SUSY-GUT scenarios
- Places non-trivial restrictions on GUT - scale parameters as trilinear couplings as soft mass terms contributing to stop mass and mixing get affected by gluino masses during RGE running
- Question: What are the implications of maximal mixing for the GUT scale parameters

Analytical results

$$m_h^2 = m_h^{2,\text{tree}} + \Delta m_h^{2,\text{1-loop}}$$
$$= m_Z^2 \cos^2 2\beta + \frac{3}{4\pi^2}\frac{m_t^4}{v^2}\left(\log\frac{M_S^2}{m_t^2} + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12\,M_S^2}\right)\right)$$

$$X_t = A_t - \mu\cot\beta$$
$$M_S \approx \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

- Semi-numerical solutions of two loop RGE

$$X_t^4 \approx 9.4\,M_{1/2}^4 - 7.5\,A_0\,M_{1/2}^3 + 2.2\,A_0^2\,M_{1/2}^2 - 0.3\,A_0^3\,M_{1/2}$$
$$+1.1\,M_{1/2}^3\,\widehat{\mu} - 0.7\,A_0\,M_{1/2}^2\,\widehat{\mu}$$

$$M_S^4 = m_{U_3}^2 m_{Q_3}^2\big|_{M_S} \approx 8.7\,M_{1/2}^4 + 2.5\,M_{1/2}^2\,\widehat{m}_{U_3}^2 + 1.7\,M_{1/2}^2\,\widehat{m}_{Q_3}^2 + 1.2\,A_0\,M_{1/2}^3$$
$$-0.4\,A_0^2\,M_{1/2}^2 - 0.9\,M_{1/2}^2\,\widehat{m}_{H_u}^2 + 0.8\,\widehat{m}_{U_3}^2\,\widehat{m}_{Q_3}^2$$

- Possible to read - off conditions for maximal mixing
  - for example: if $M_{1/2}$ is the largest GUT scale parameter

    $\left|\frac{X_t}{M_S}\right| \approx \frac{9.4}{8.7} \approx 1 \Rightarrow$ maximal mixing excluded

- Conditions for maximal mixing:
  - large -ve $A_0 \approx -(1-3)max\left(M_{1/2}, \widehat{m}_{Q_3}, \widehat{m}_{U_3}\right)$
  - small third generation soft masses
  - positive up-type Higgs soft masses

Models

- F-term SUSY breaking in some hidden sector mediated to visible sector via messengers

- Scenarios: Gauge-Higgs mediation, Radion mediation, Gauge mediation

- Maximal mixing not possible in pure Gaugino mediated SSB due to absence of mu term but possible with extended Gaugino - Higgs mediated SSB models

- Not possible in radion mediation SSB because ratio of A0 to Mhf is at most one.

- Not possible in gauge mediated SSB models as they predict vanishing A terms

Models under consideration for numerical analysis:

- Gaugino-Higgs Mediation: Non-zero Gaugino masses at GUT scalea and direct Higgs coupling to hidden sector to generate non-zero mu

- NUHM: A generic representative of GUT scale models, with non-Universal Higgs soft mass terms at GUT scale

Numerical results

We exchange GUT scale Higgs soft mass terms in favor of weak scale mu and MA

- Gaugino mediation

$$m_0 = 0$$
$$200 < M_{1/2} < 2000\,GeV$$
$$-4 < A_0/M_{1/2} < 3$$
$$0 < \tan\beta < 60$$
$$0 < M_A < 2000\,GeV$$
$$0 < \mu < 2000\,GeV$$

- NUHM - a general representative

$$0 < m_0 < 5000\,GeV$$
$$200 < M_{1/2} < 2000\,GeV$$
$$-6000 < A_0 < 6000\,GeV$$
$$0 < \tan\beta < 60$$
$$0 < M_A < 2000\,GeV$$
$$0 < \mu < 2000\,GeV$$

- Masslimits

$$m_{\tilde{\chi}_1^\pm} > 103\ GeV$$
$$m_{\tilde{\tau}_1} > 92\ GeV$$
$$m_{\tilde{e}_{L,R}} > 100\ GeV$$
$$m_{\tilde{t}_1,\tilde{b}_1} > 100\ GeV$$
$$m_{\tilde{g}} > 500\ GeV$$
$$m_h > 115\ GeV$$

- Flavor Physics

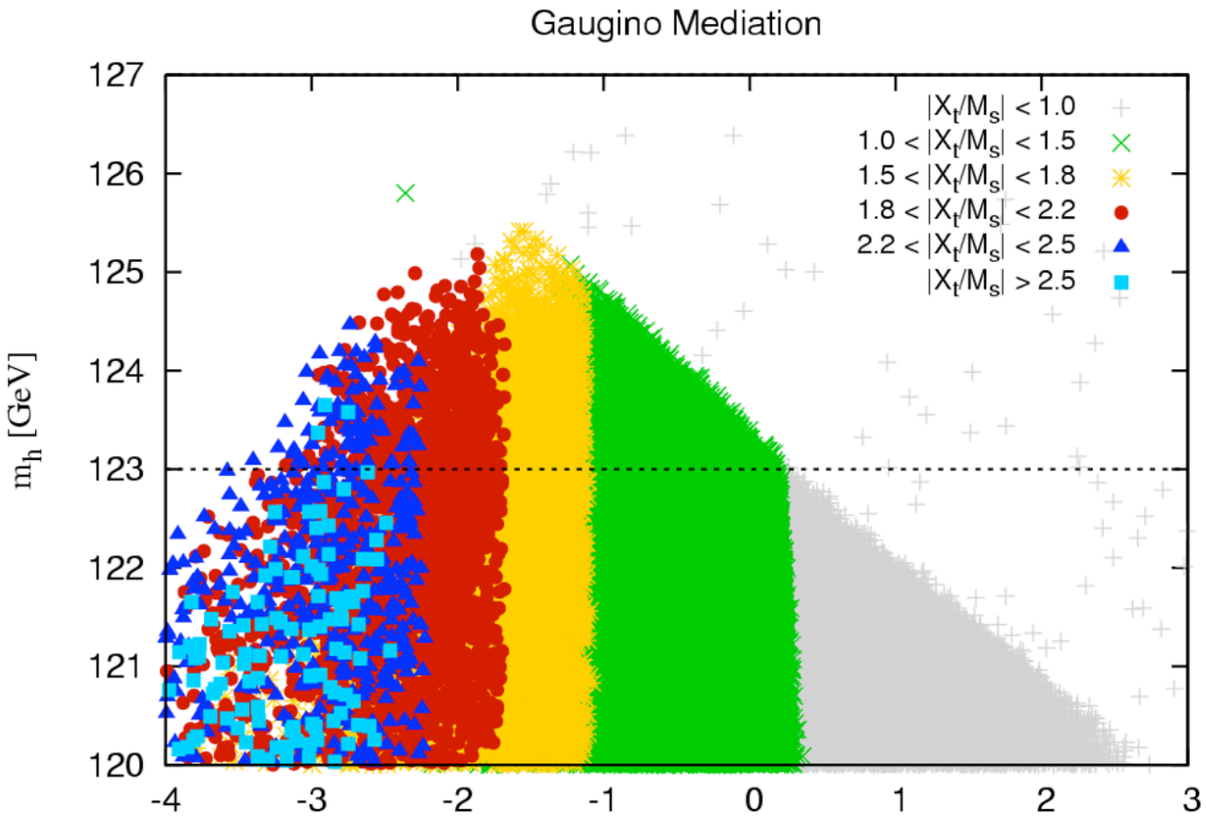
$$2.87 \times 10^{-4} < \mathrm{BR}(B \to X_s\gamma) < 4.23 \times 10^{-4}$$
$$\mathrm{BR}(B_s \to \mu^+\mu^-) < 5.4 \times 10^{-9}$$

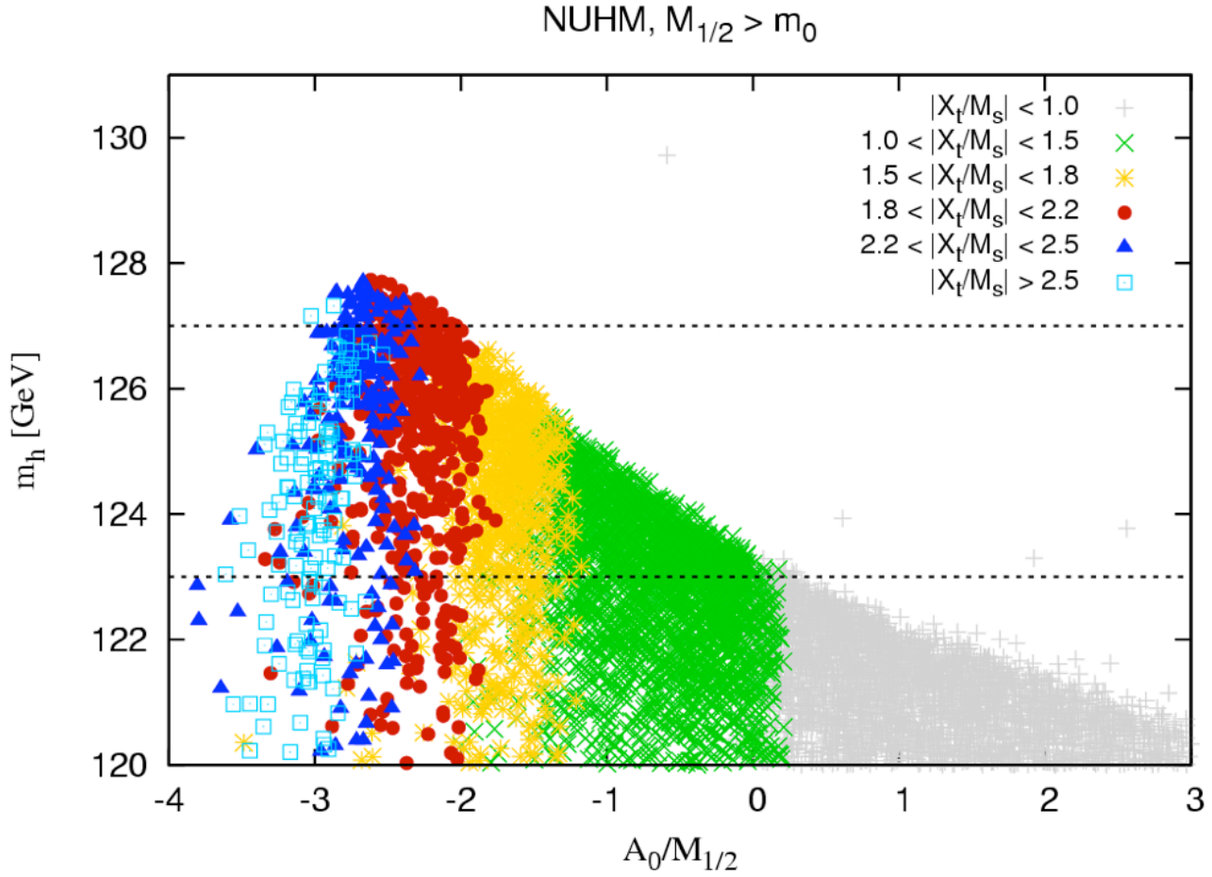
- Interesting Higgs mass

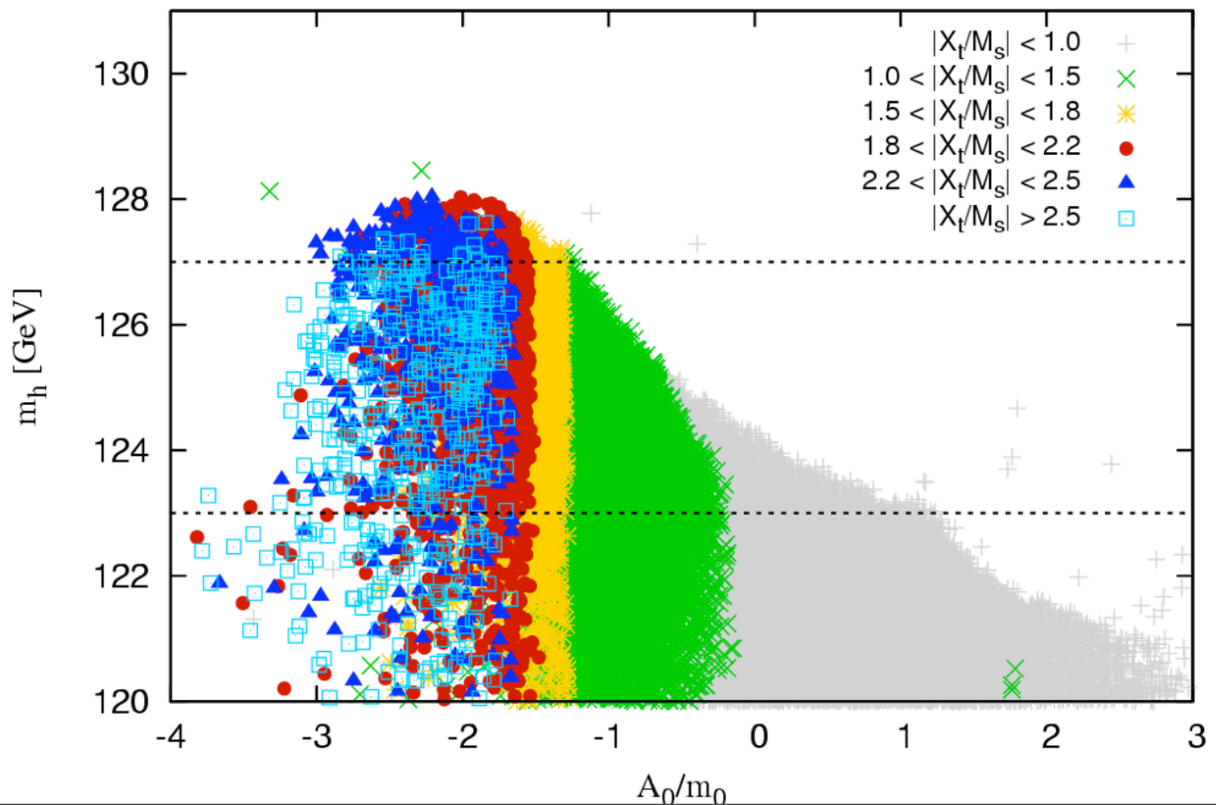
$$123\,GeV < m_h < 127\,GeV$$

We perform a flat random scan

Testing MaxMixing - I







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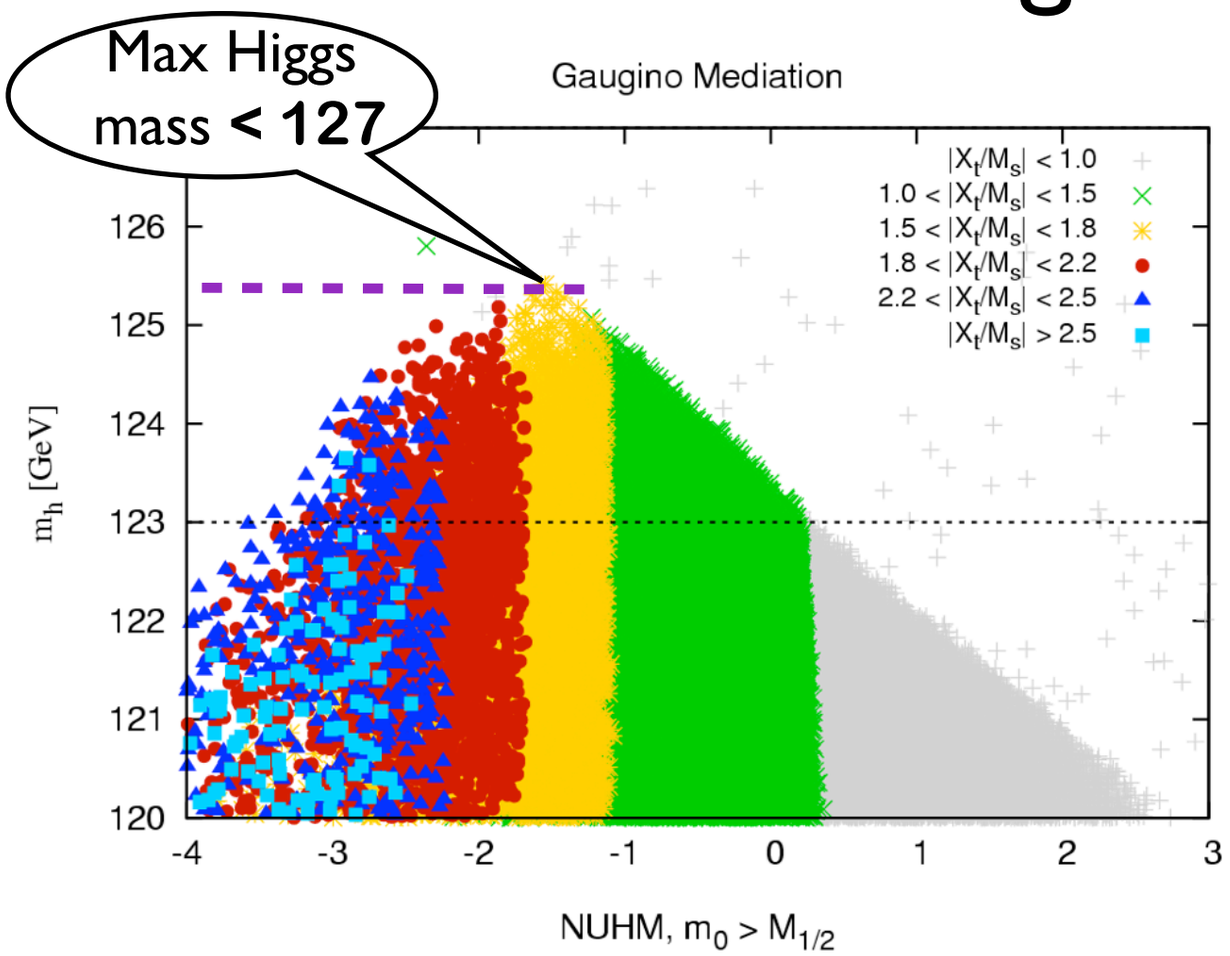

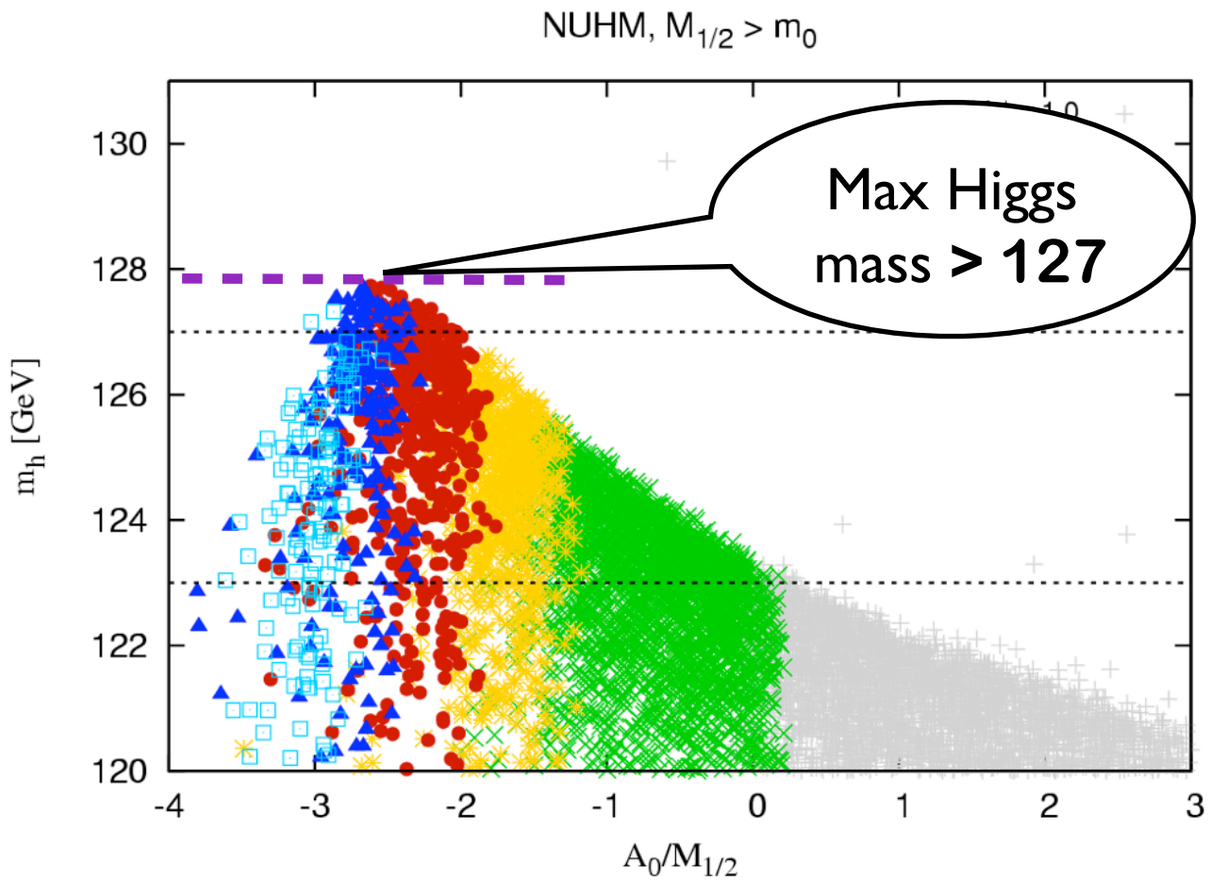

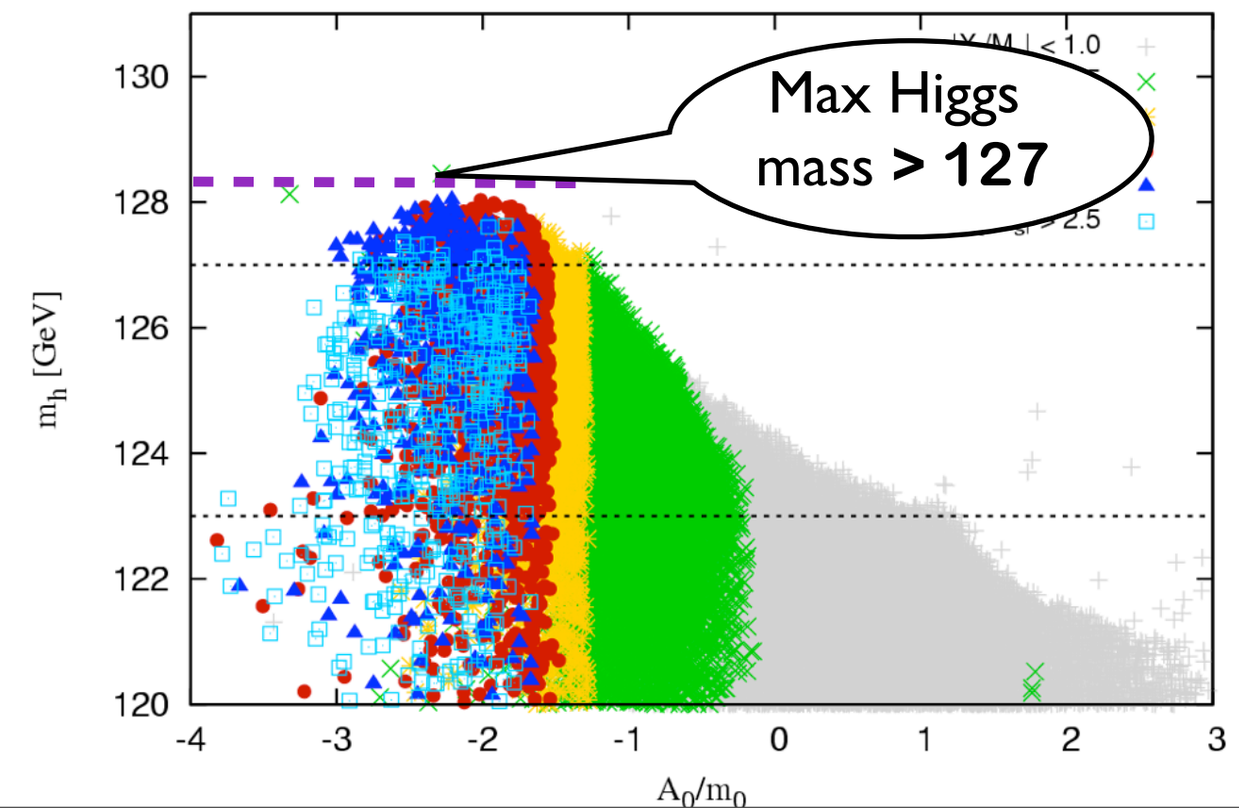

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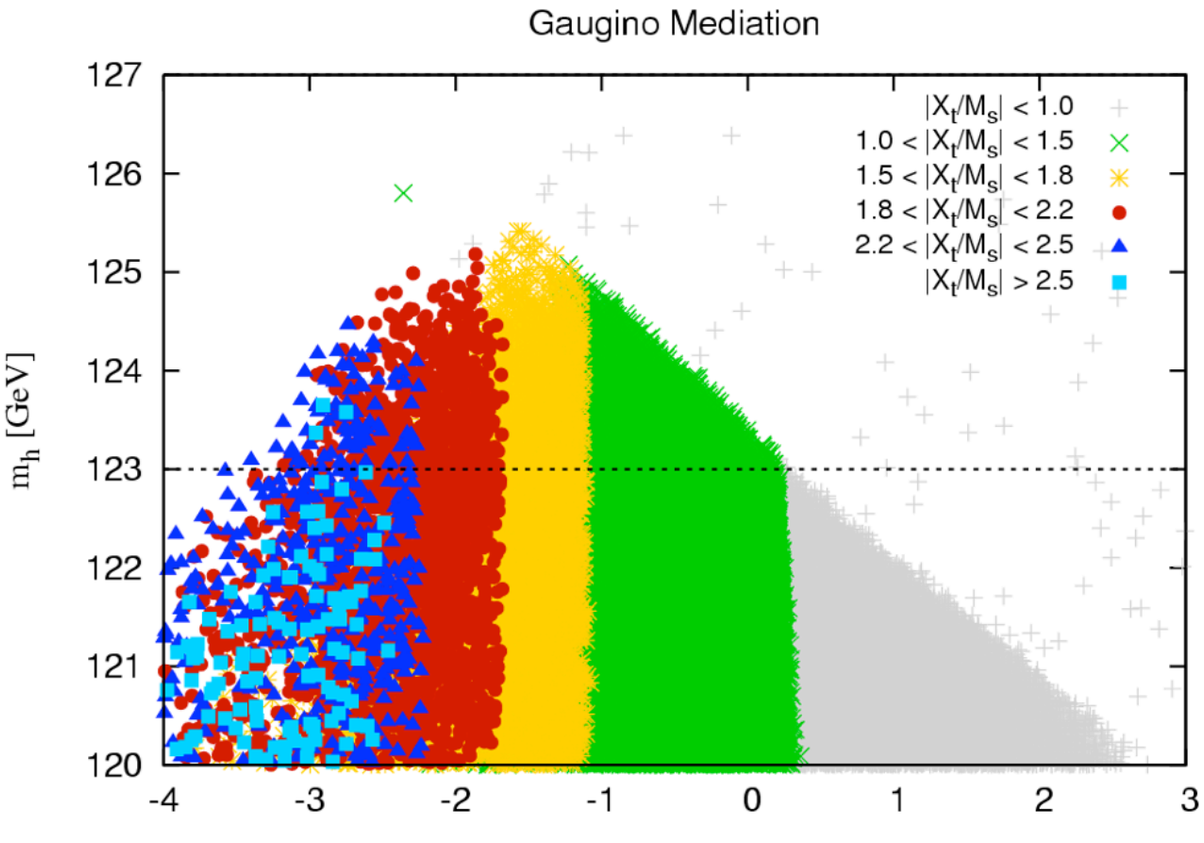

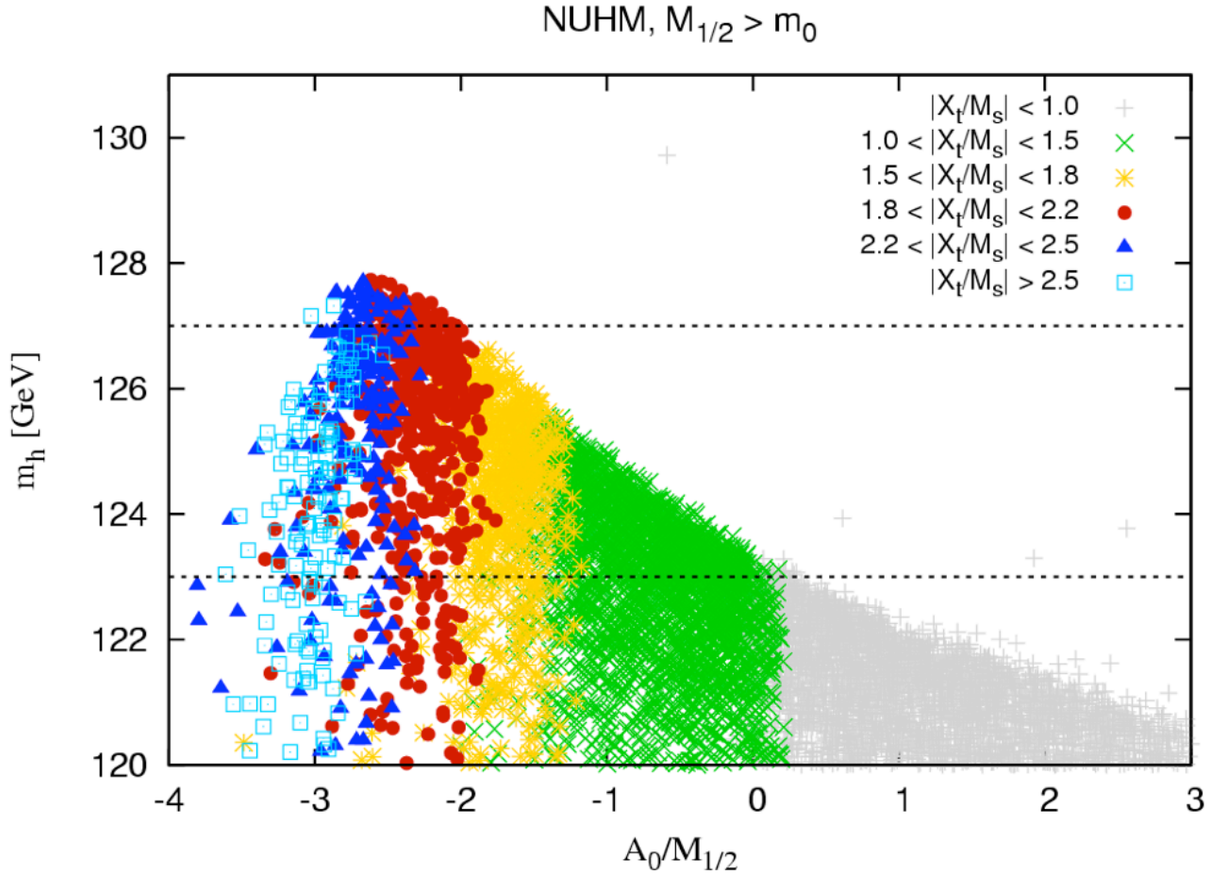

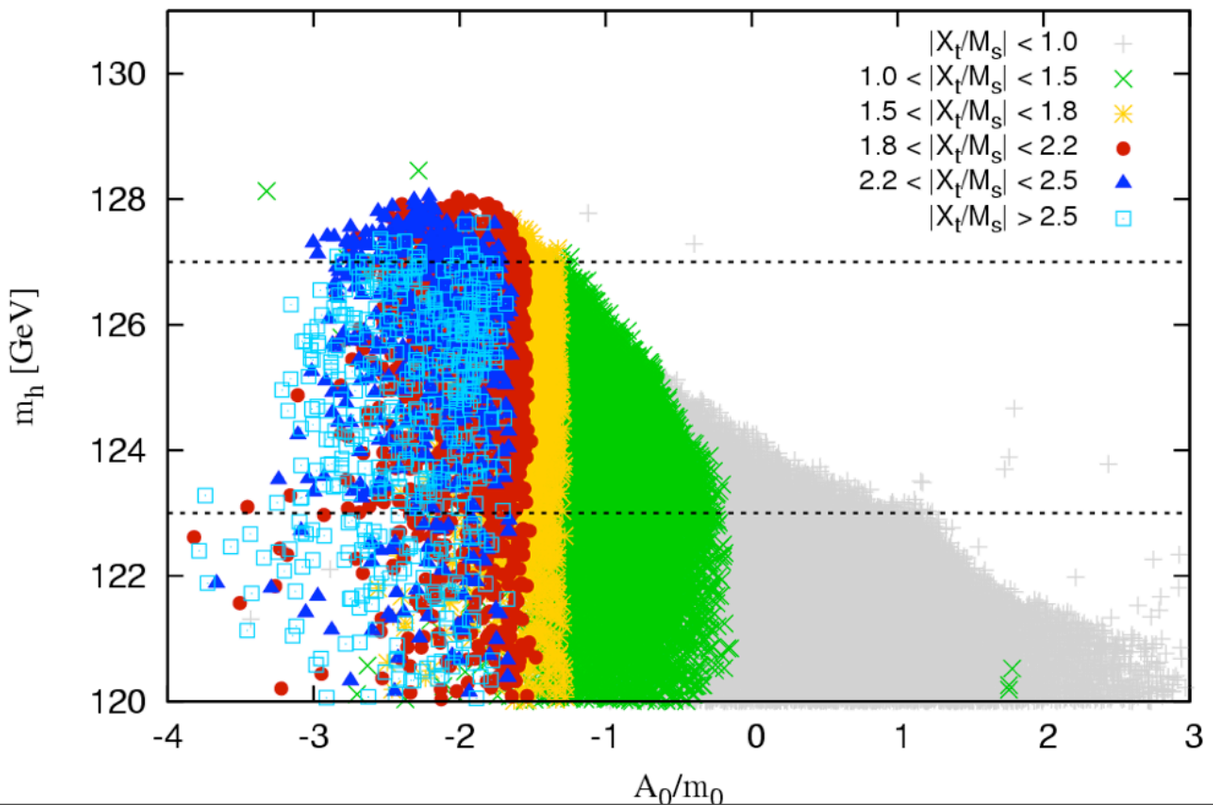

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- In NUHM, due to non-zero m0 Max Higgs mass > 127 GeV (compatible with limits at 95% C.L.)

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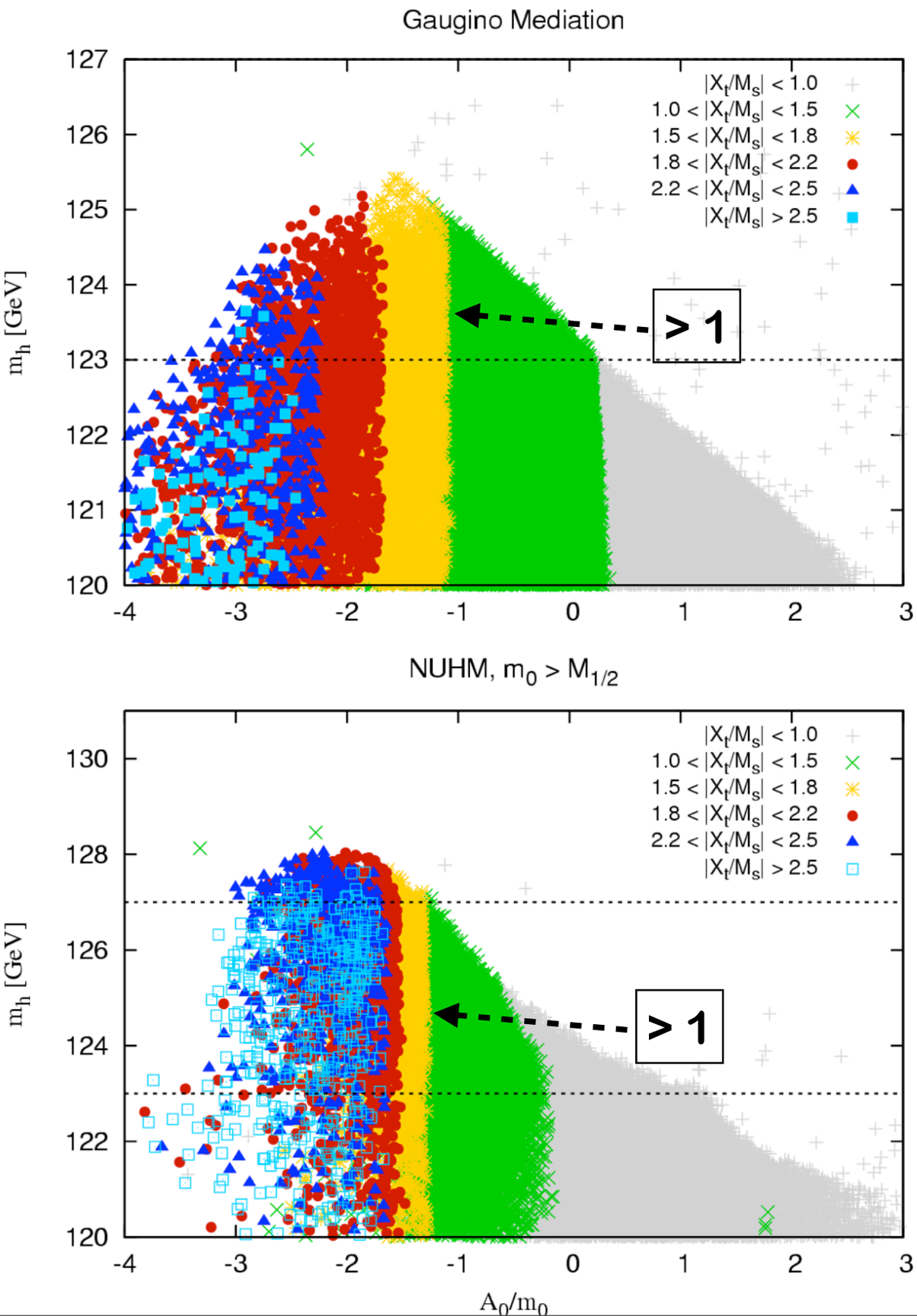

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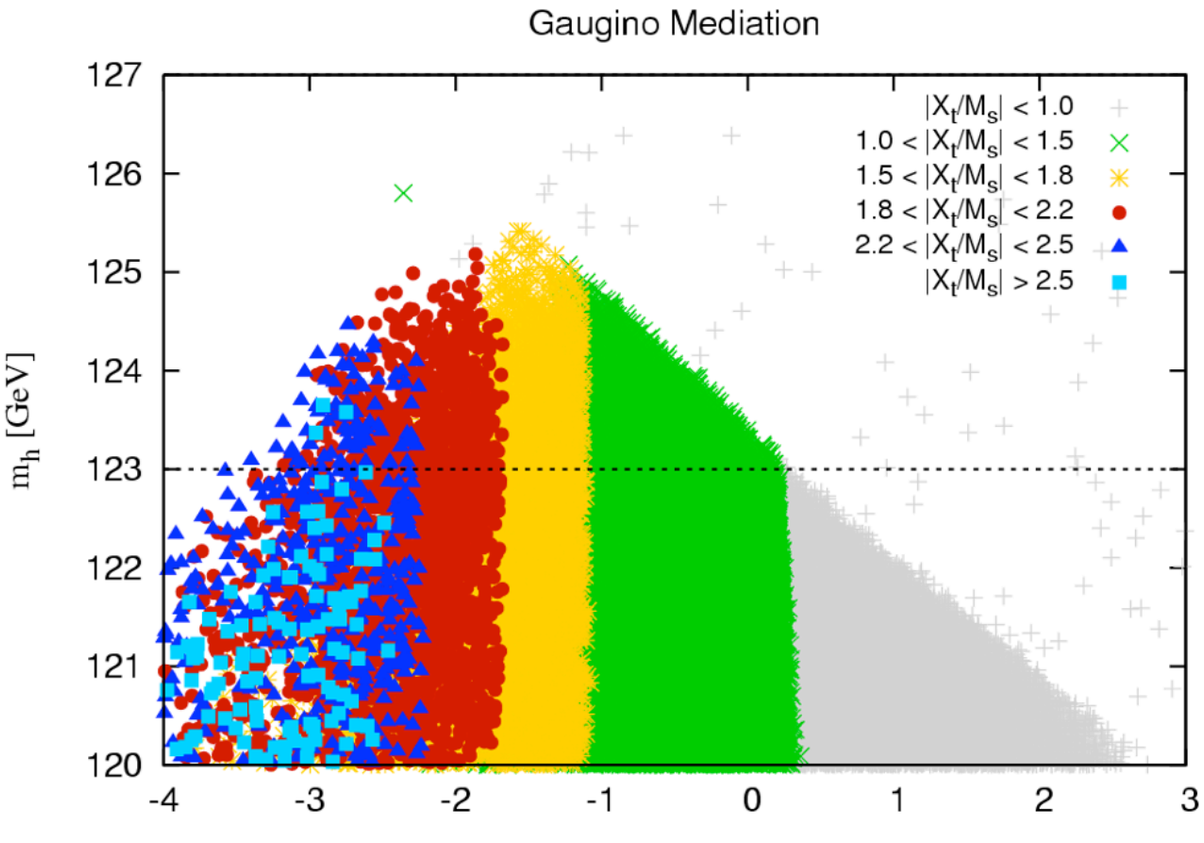

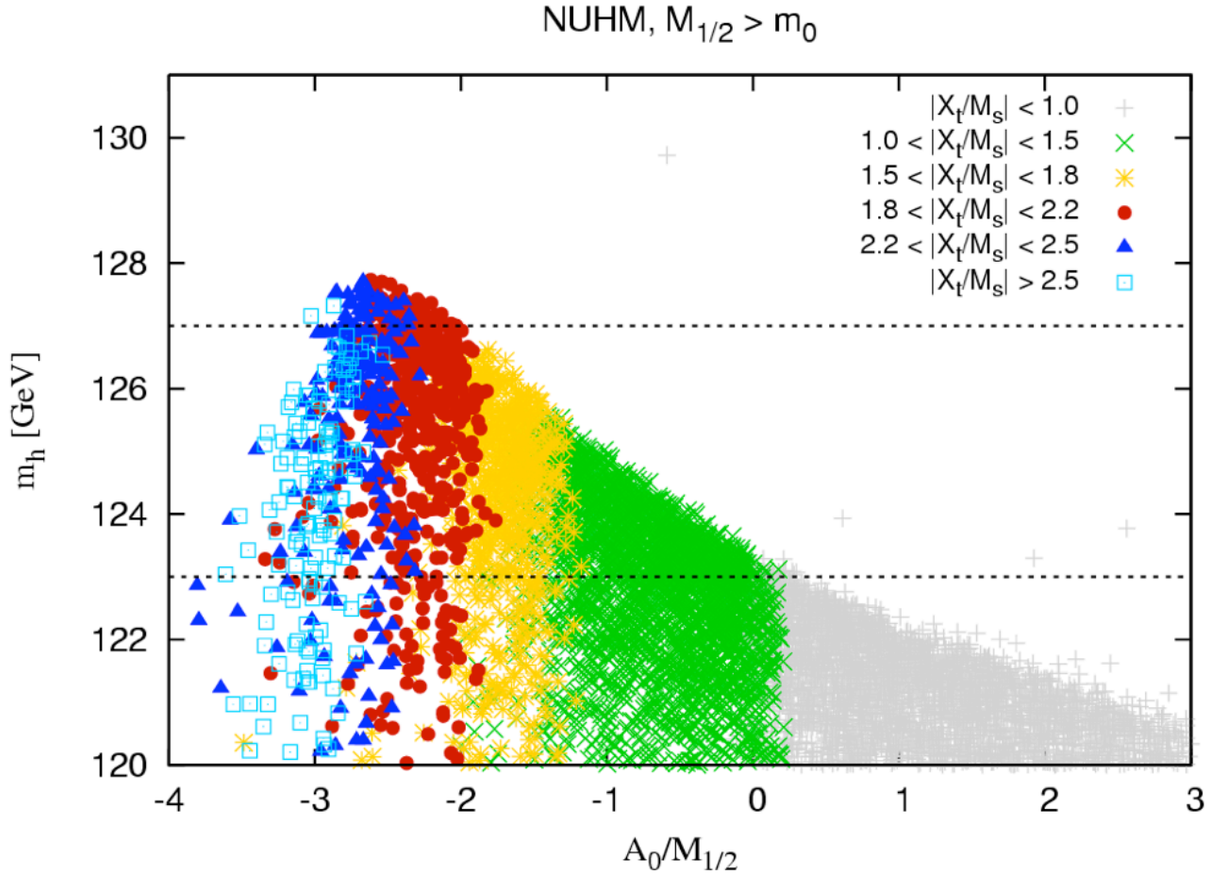

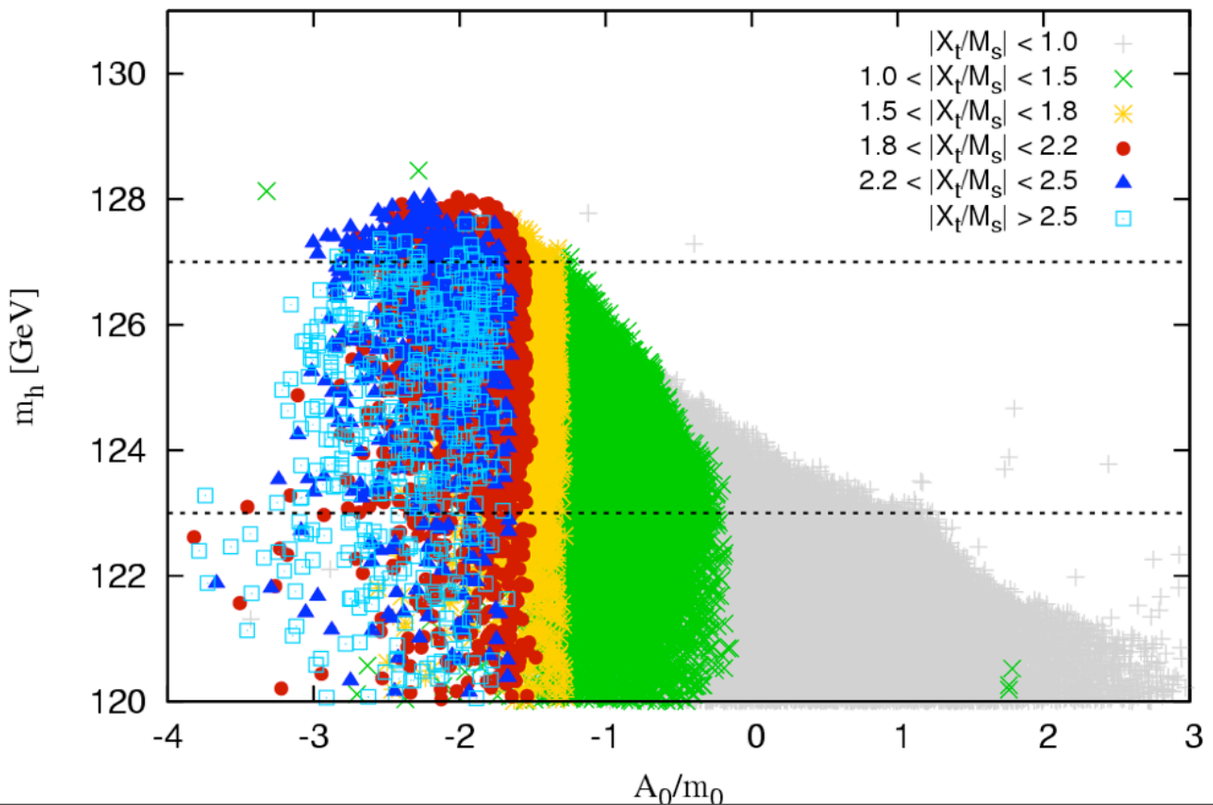

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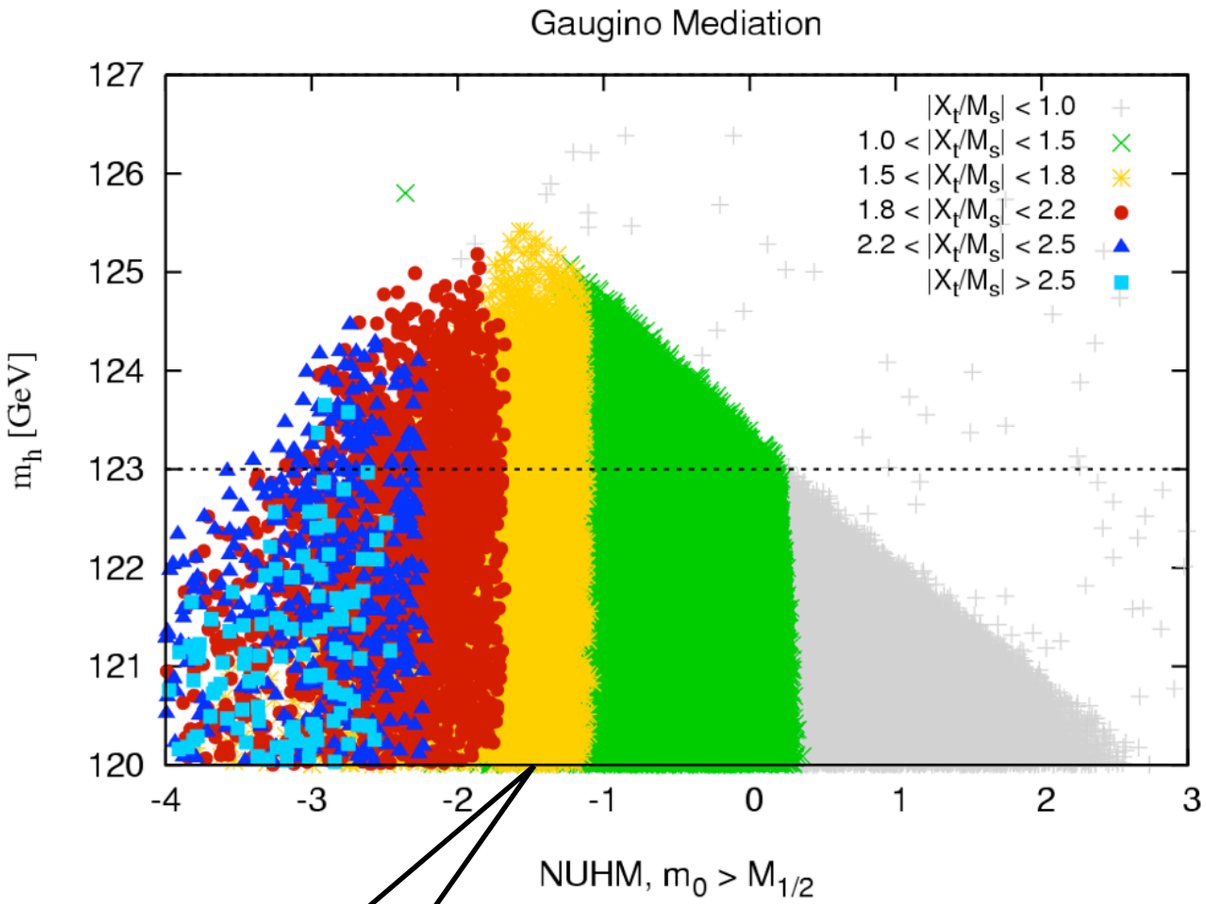

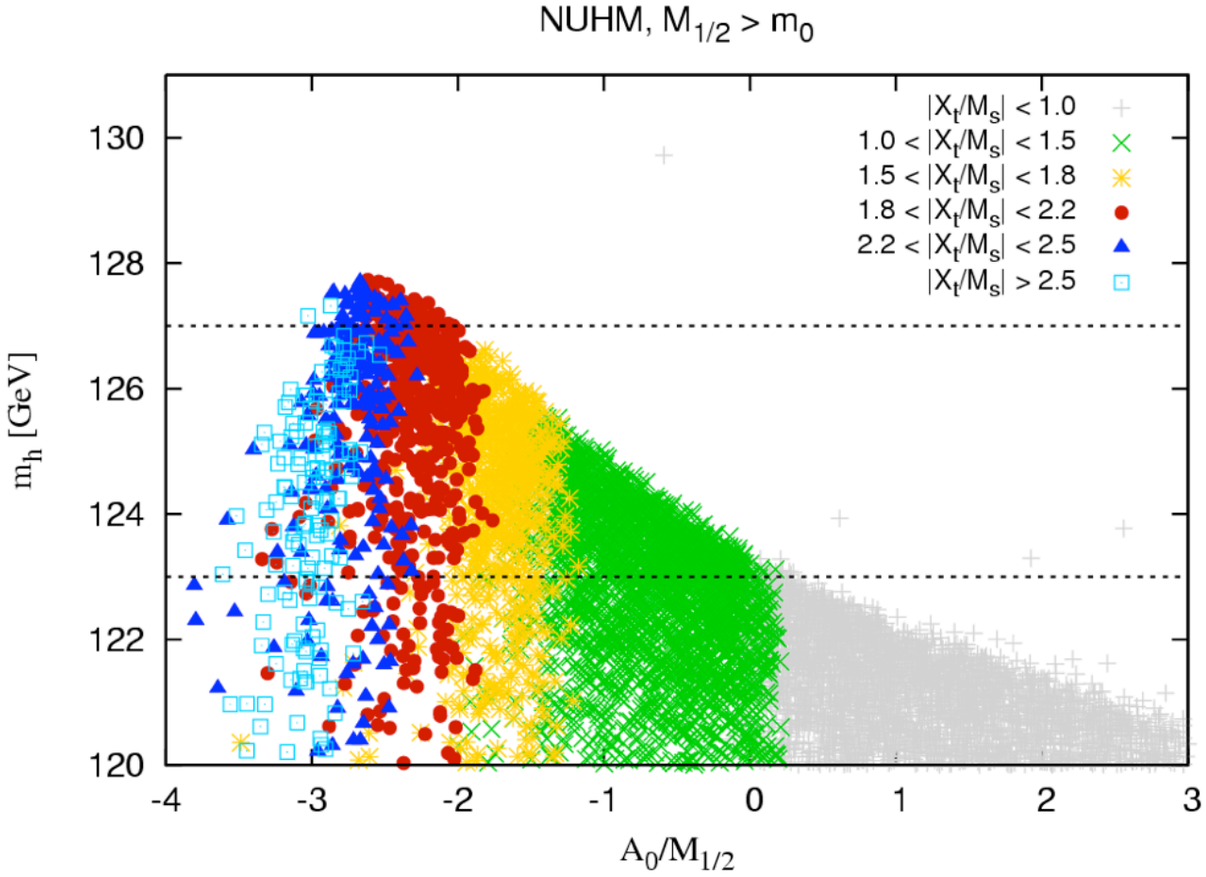

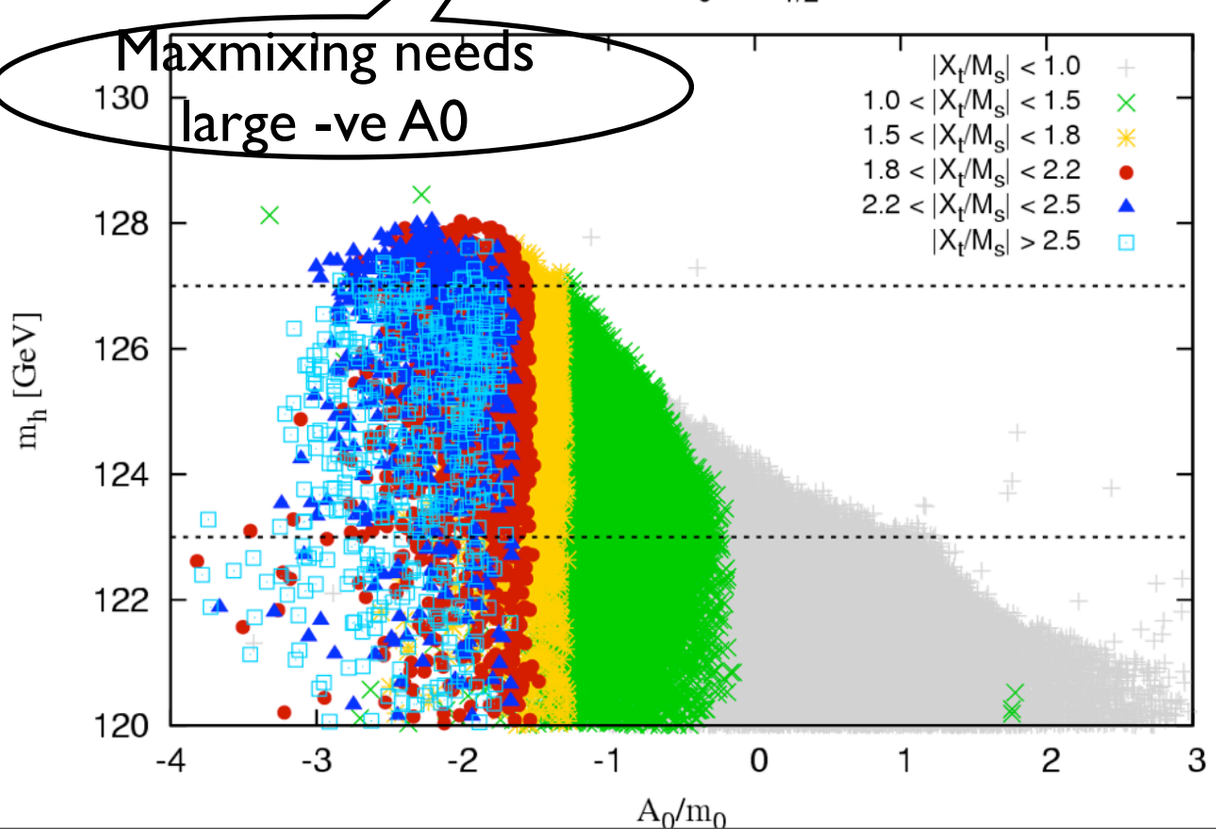

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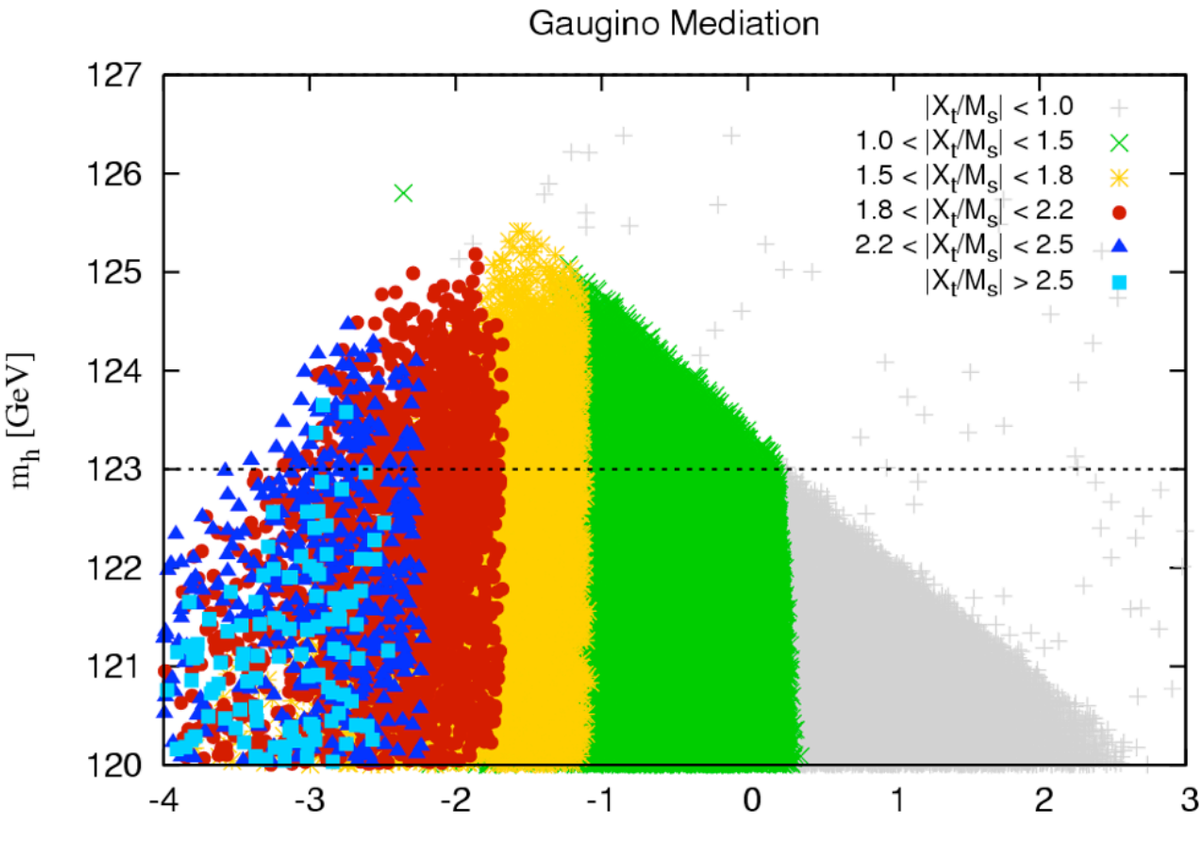
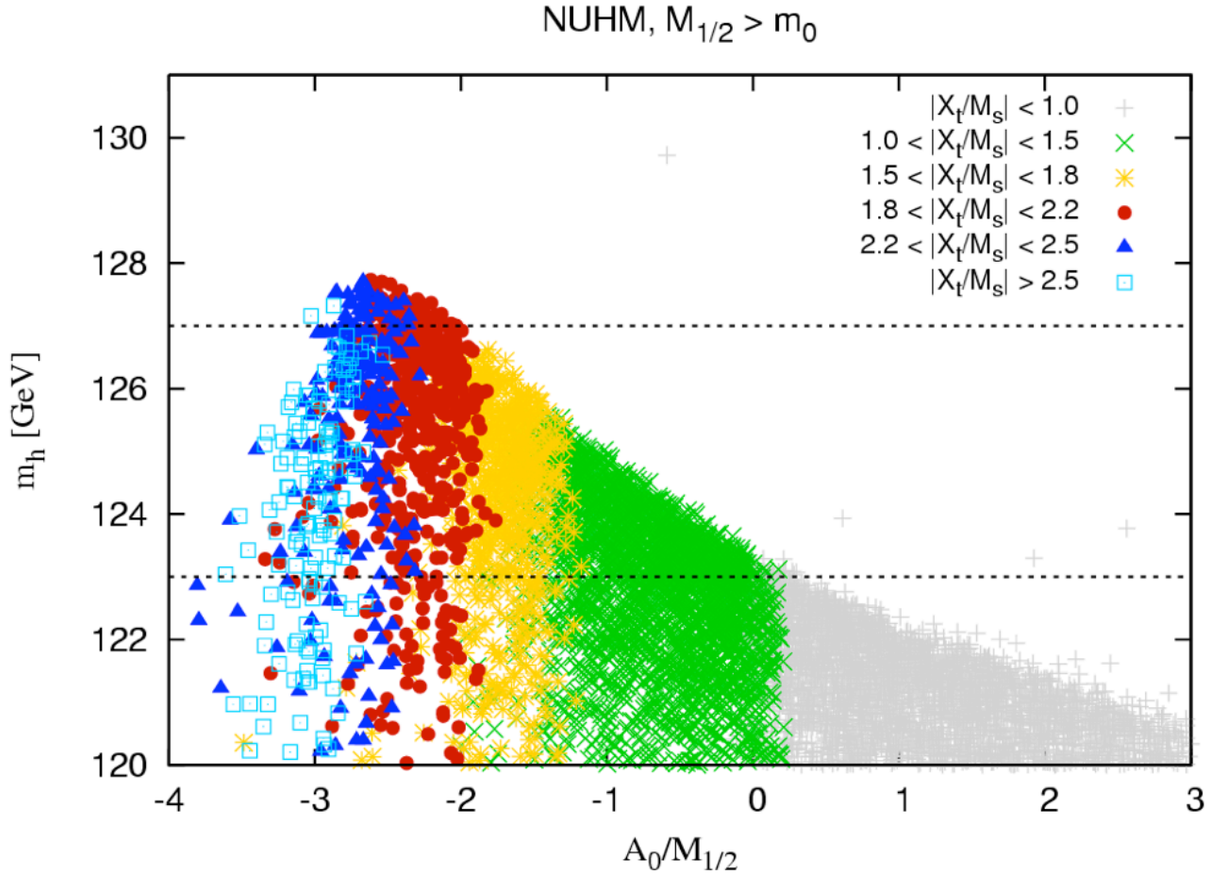
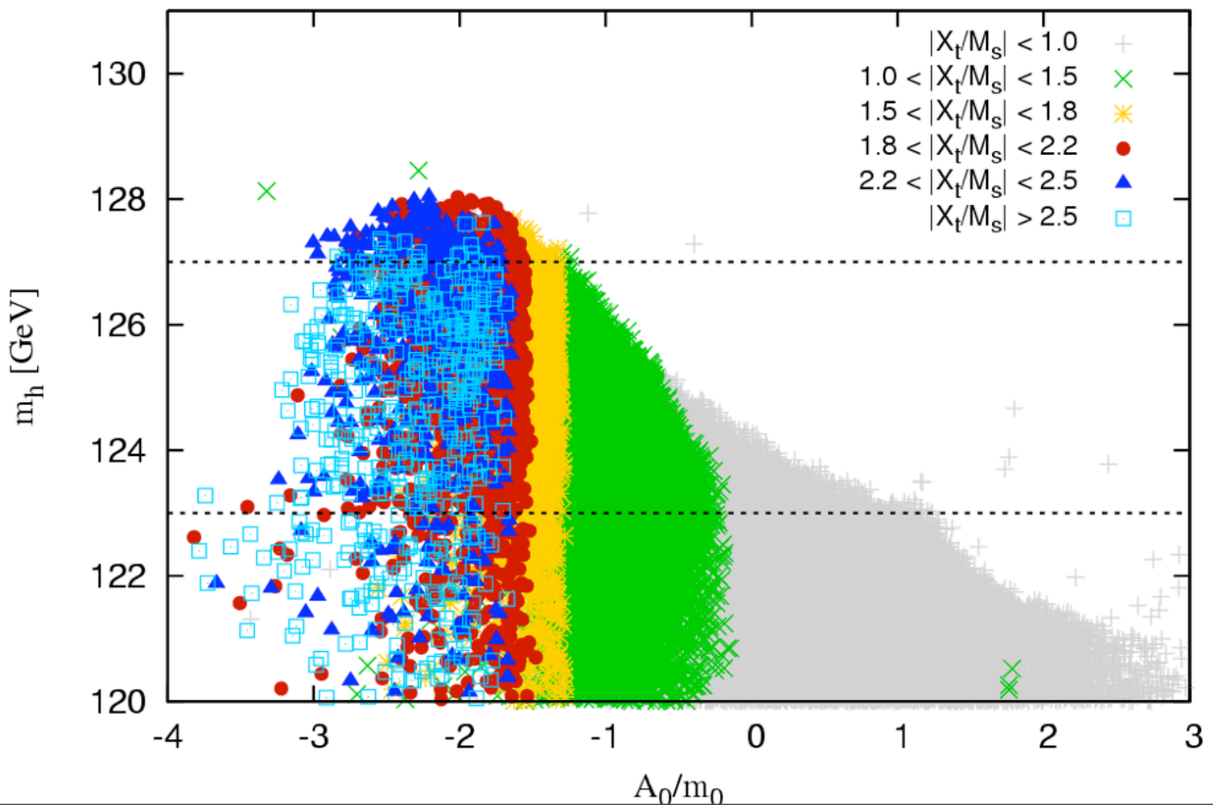


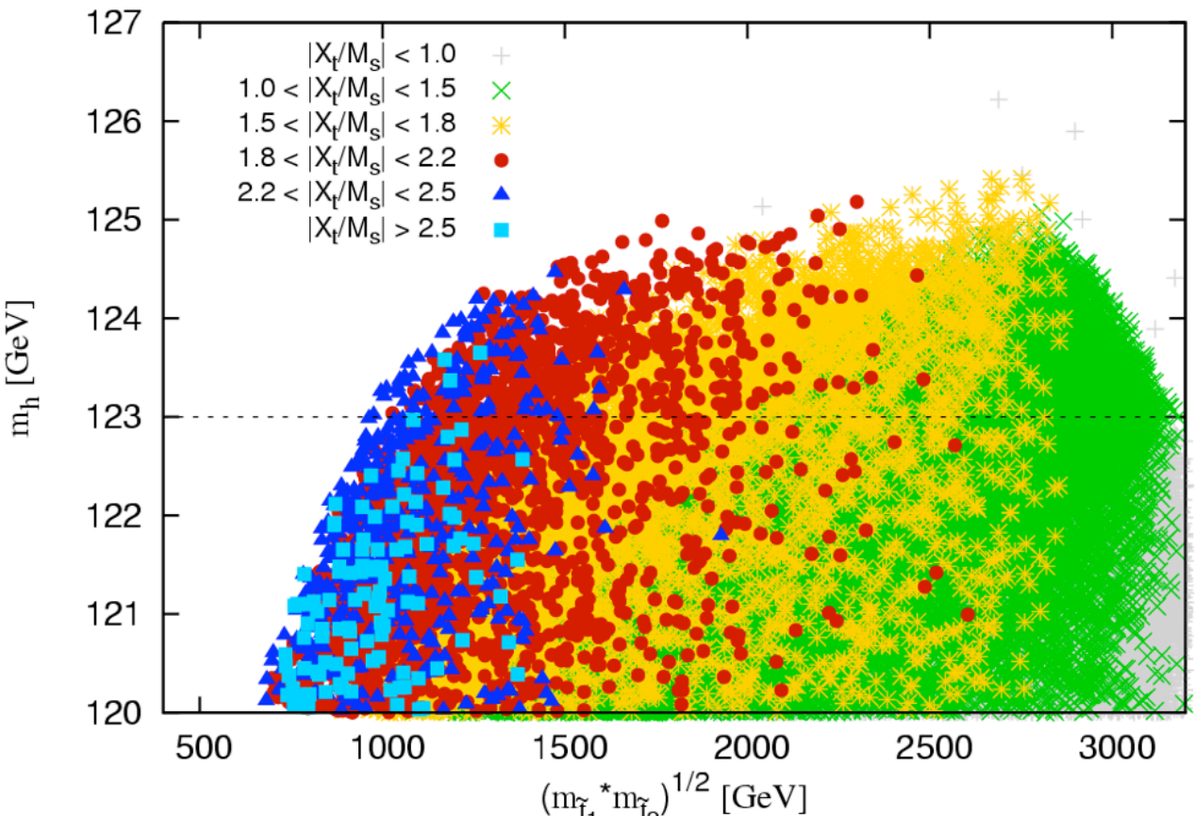




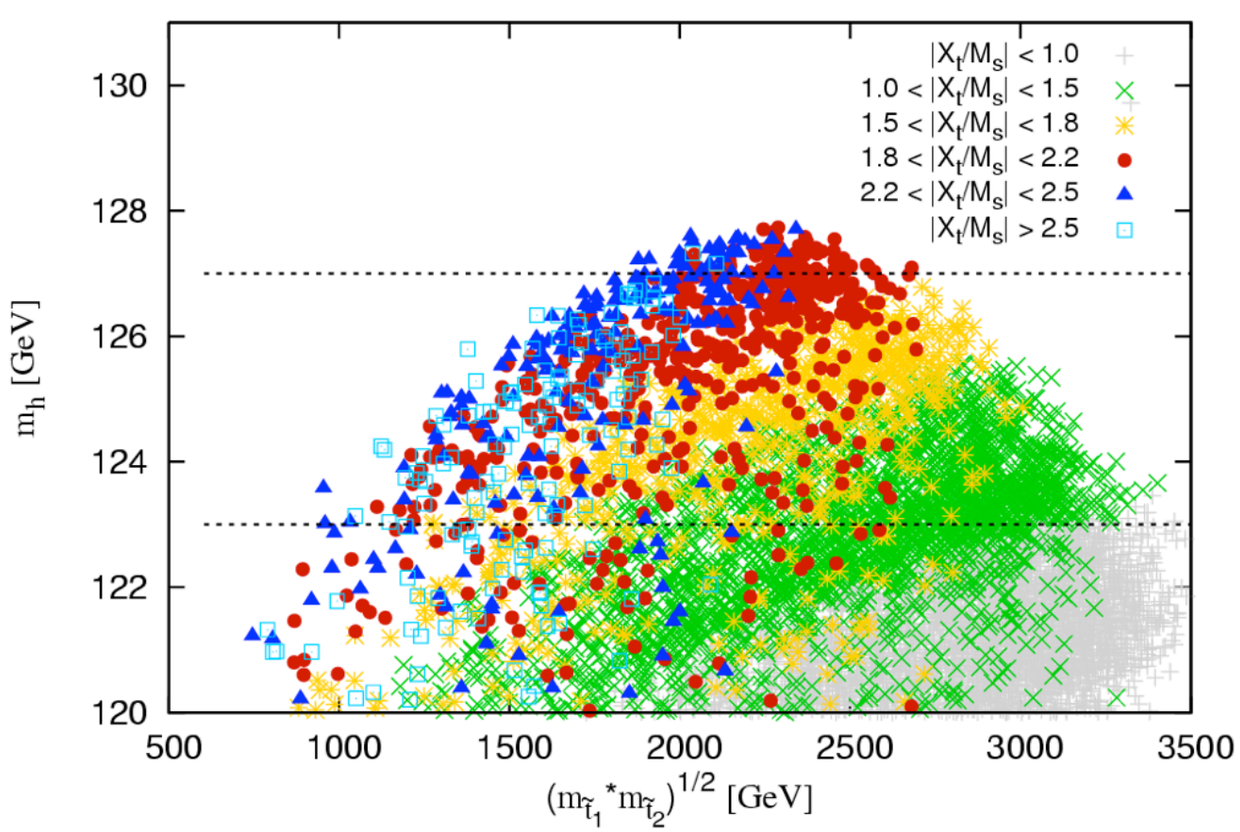
- In Gaugino Mediation - Max Higgs mass < 127 GeV
- In NUHM, due to non-zero m0 Max Higgs mass > 127 GeV (compatible with limits at 95% C.L.)
- Maximal mixing needs large -ve A0 and A0/Mhf OR A0/m0 > 1

Testing MaxMixing - 2

Gaugino Mediation



NUHM, $M_{1/2} > m_0$



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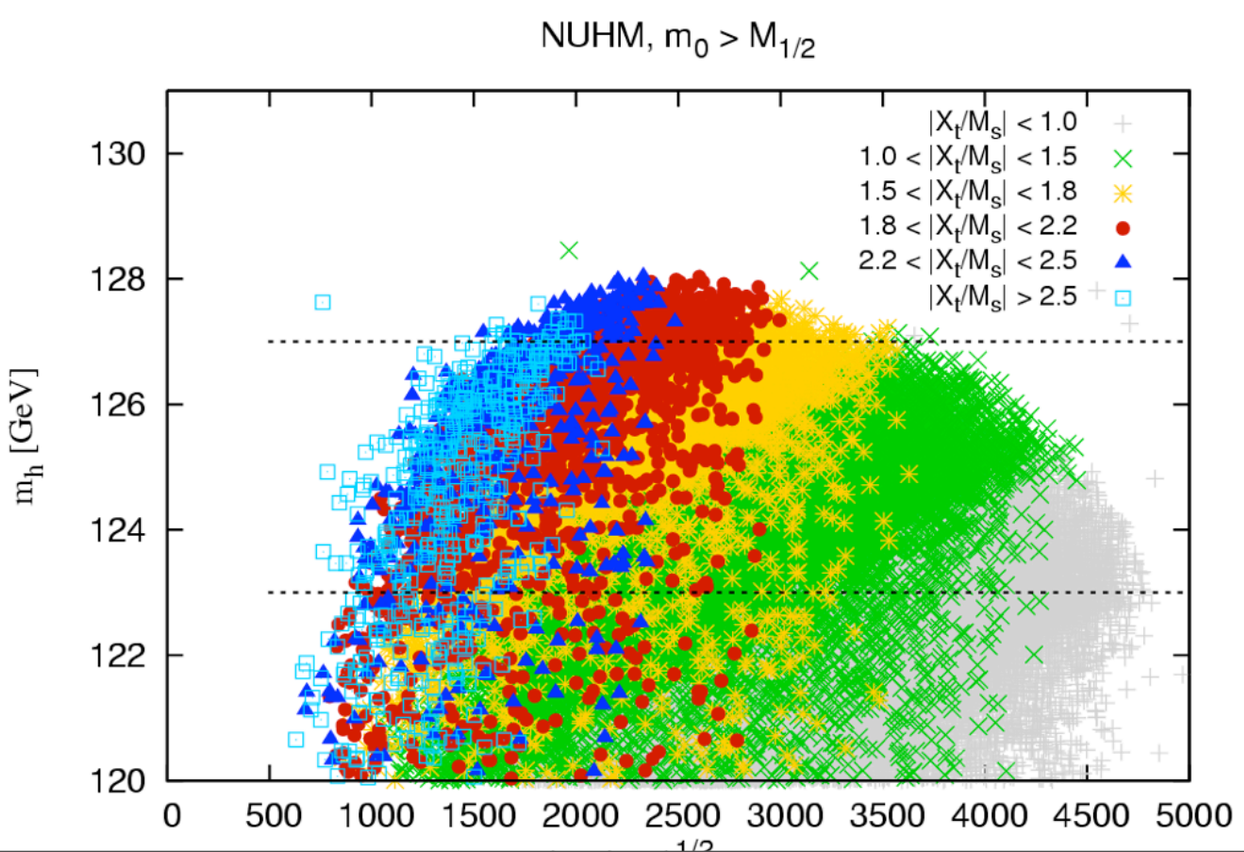

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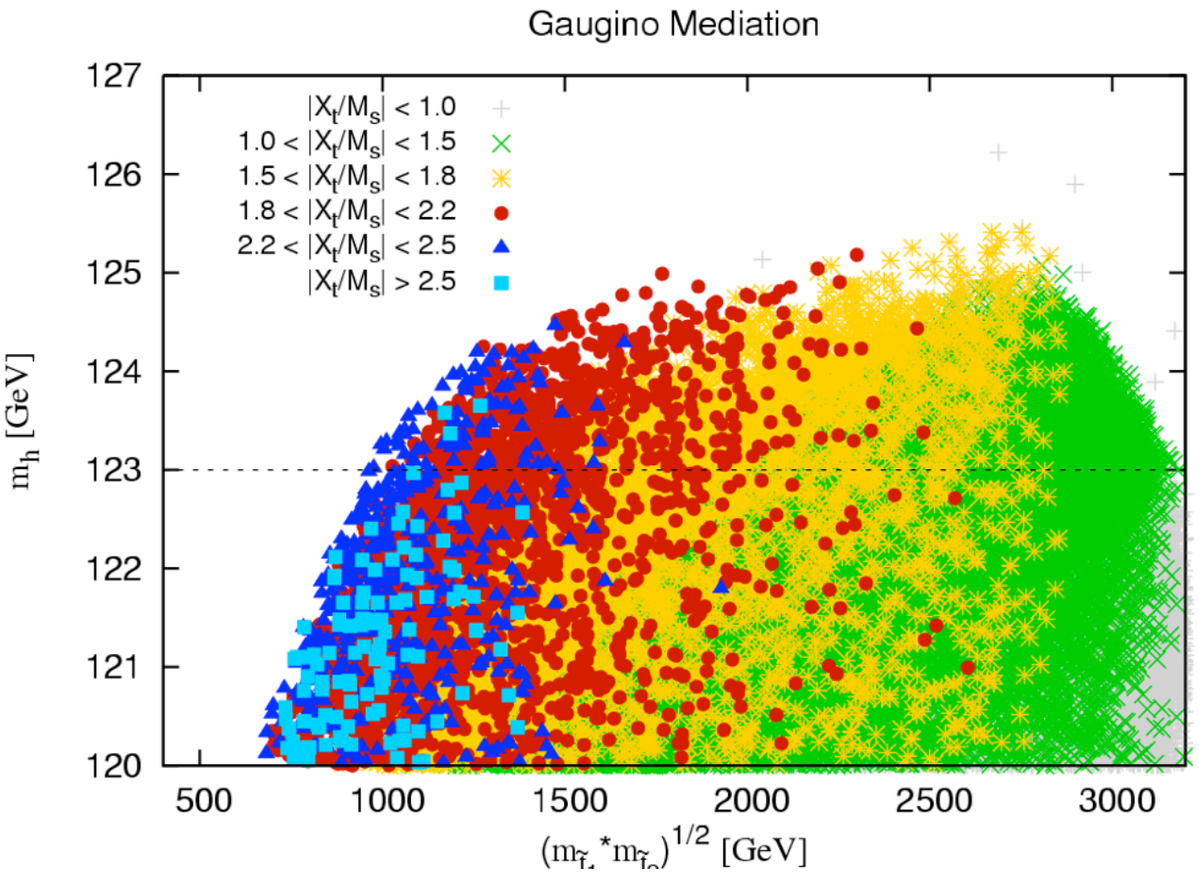
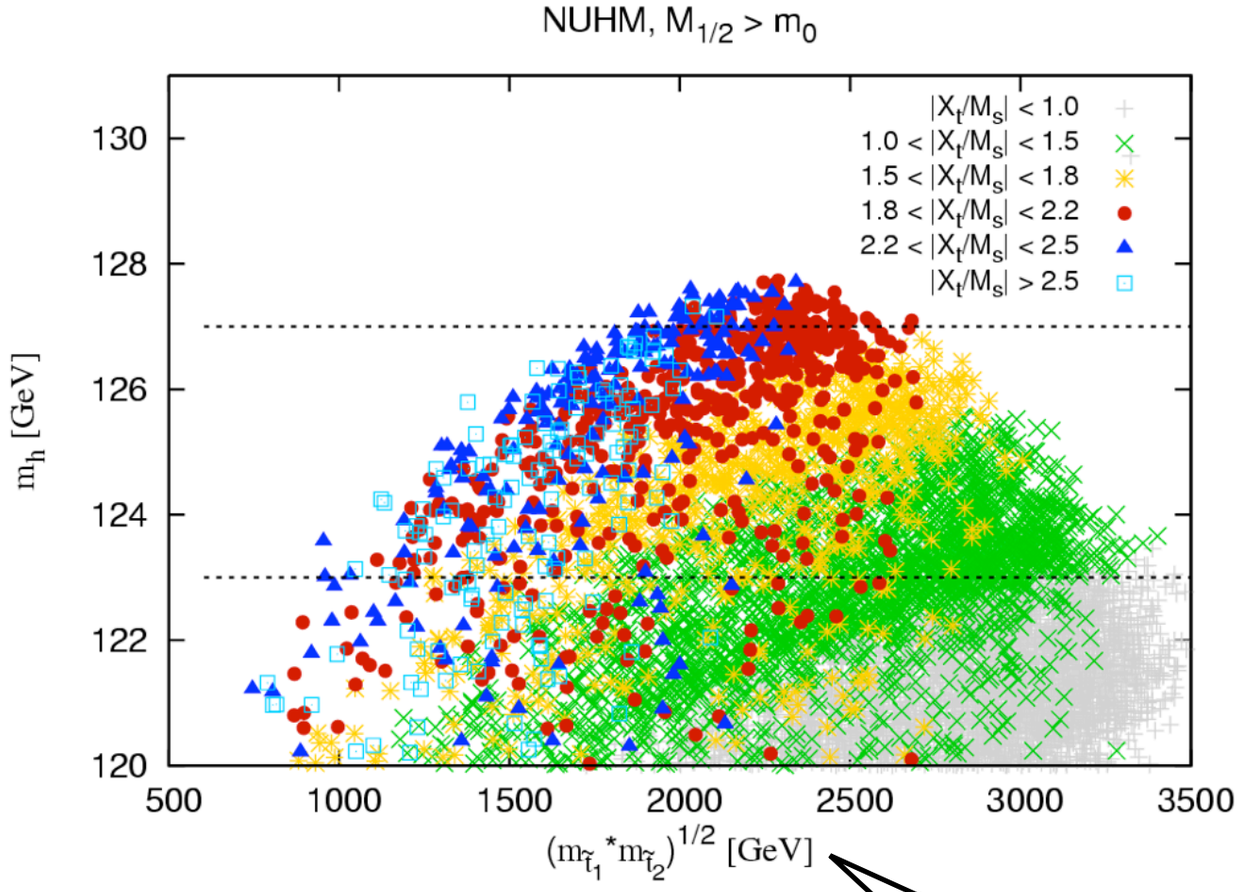
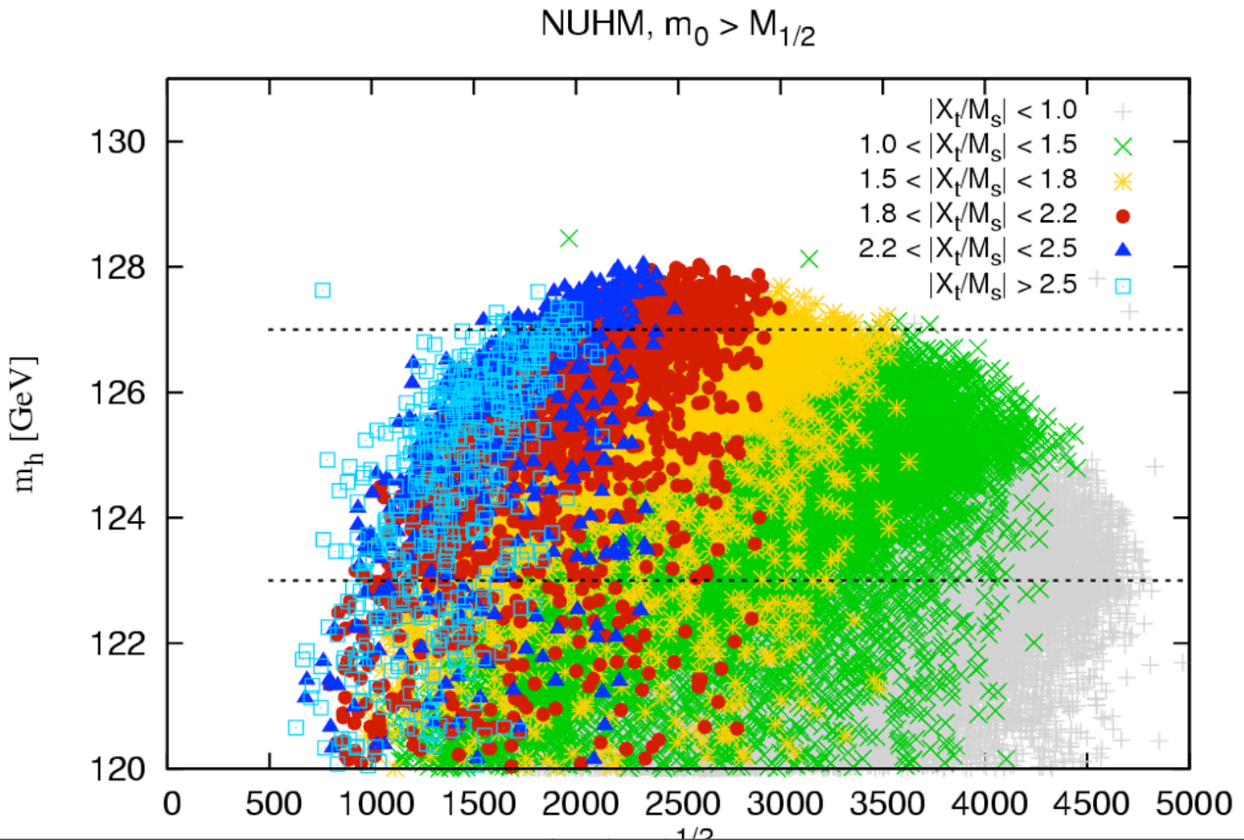




Msusy



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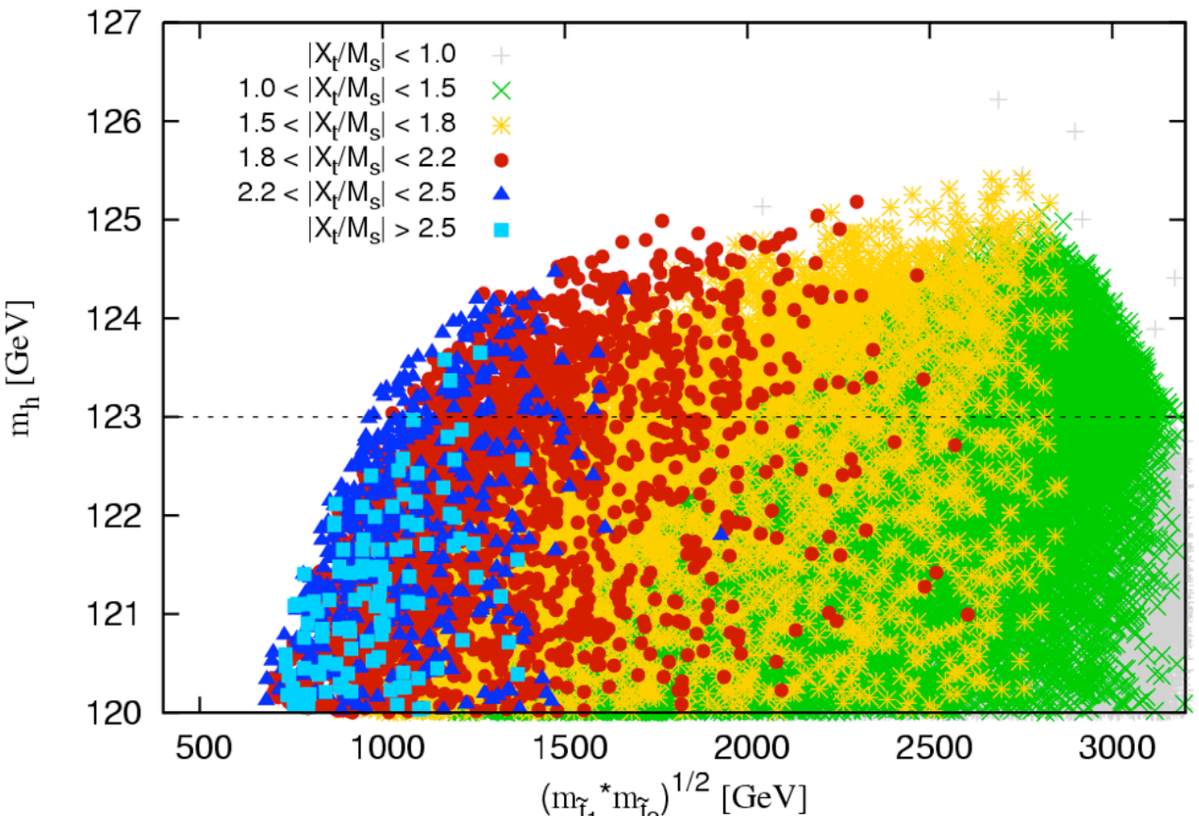

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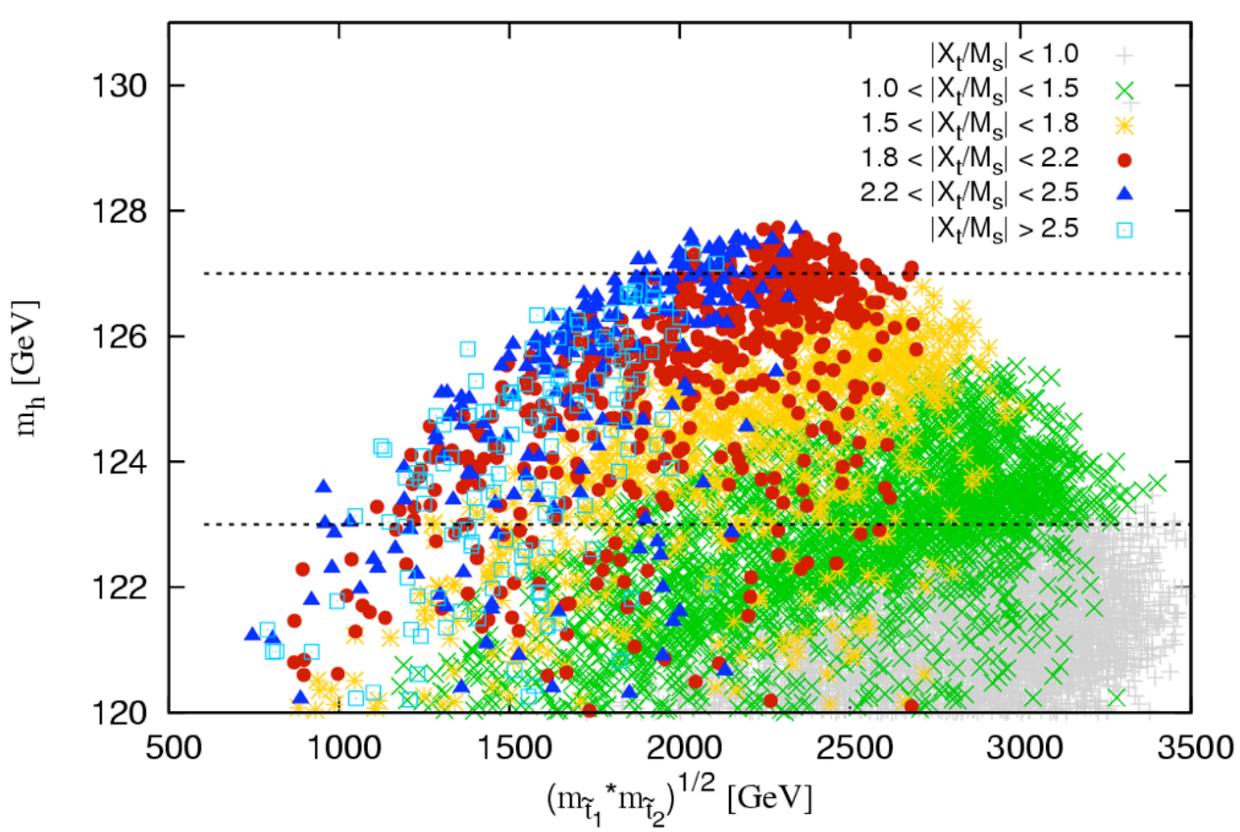

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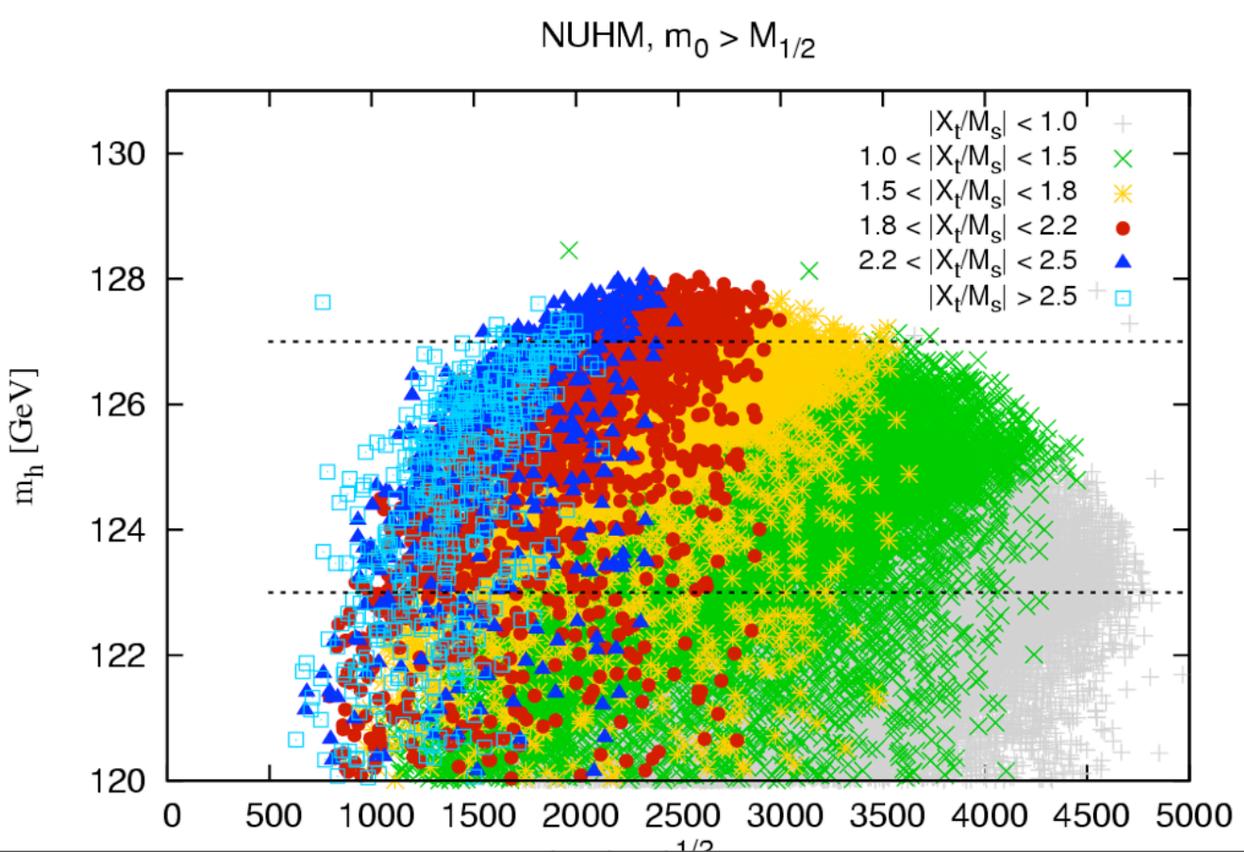

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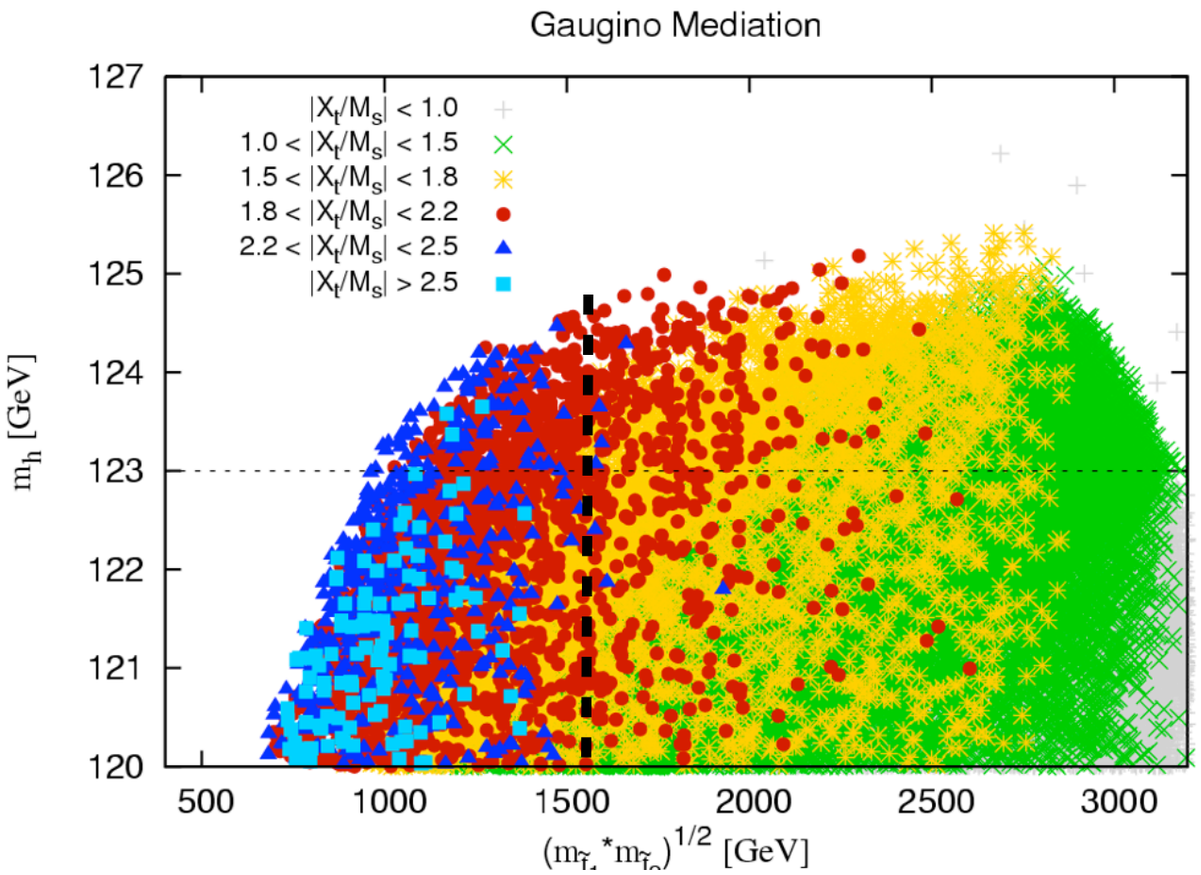

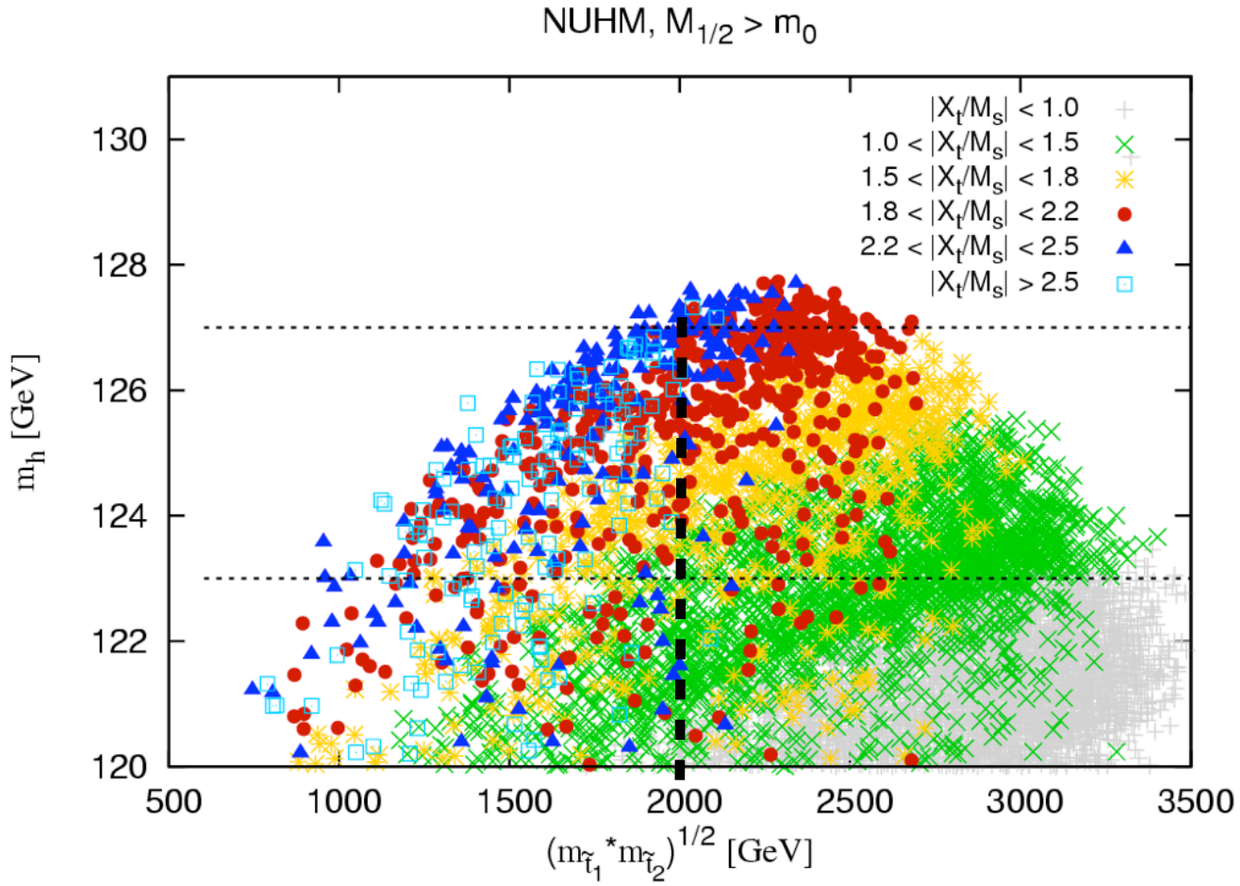

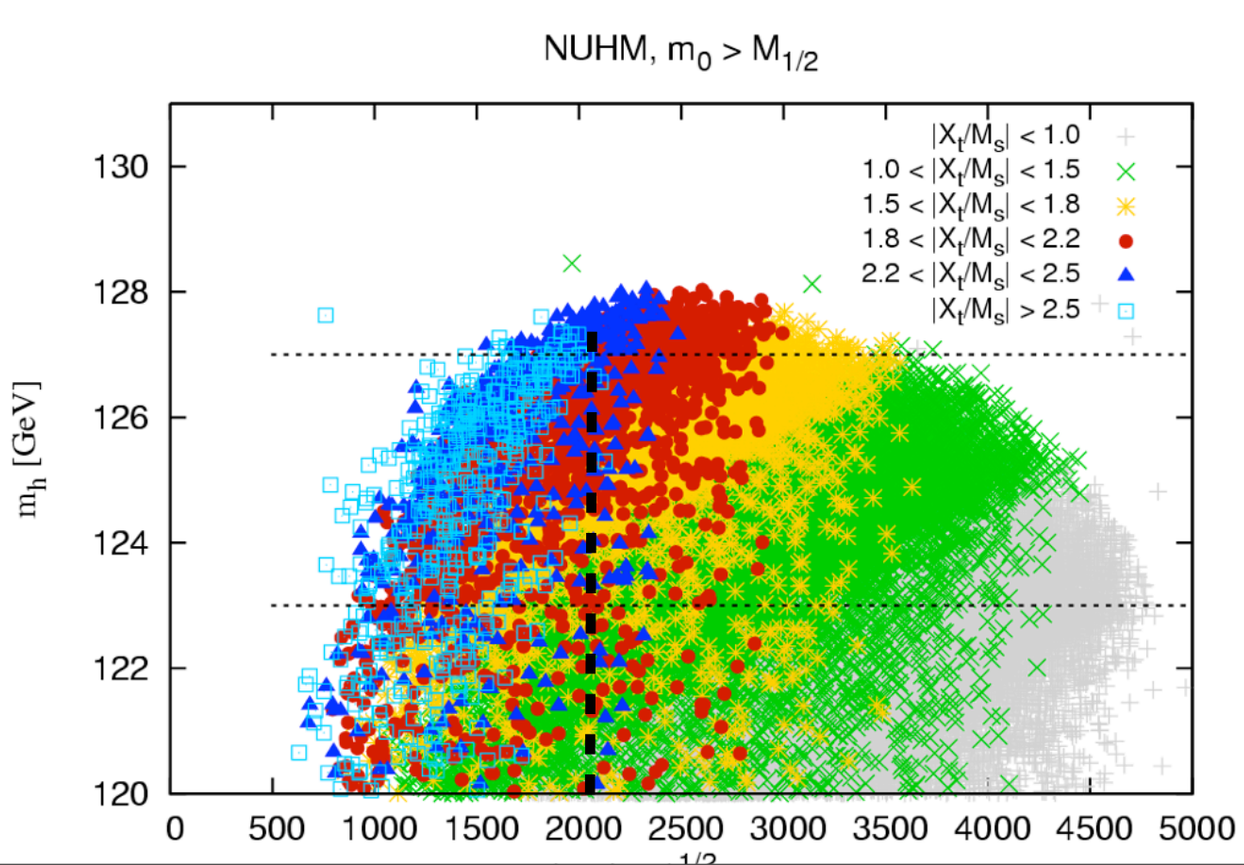

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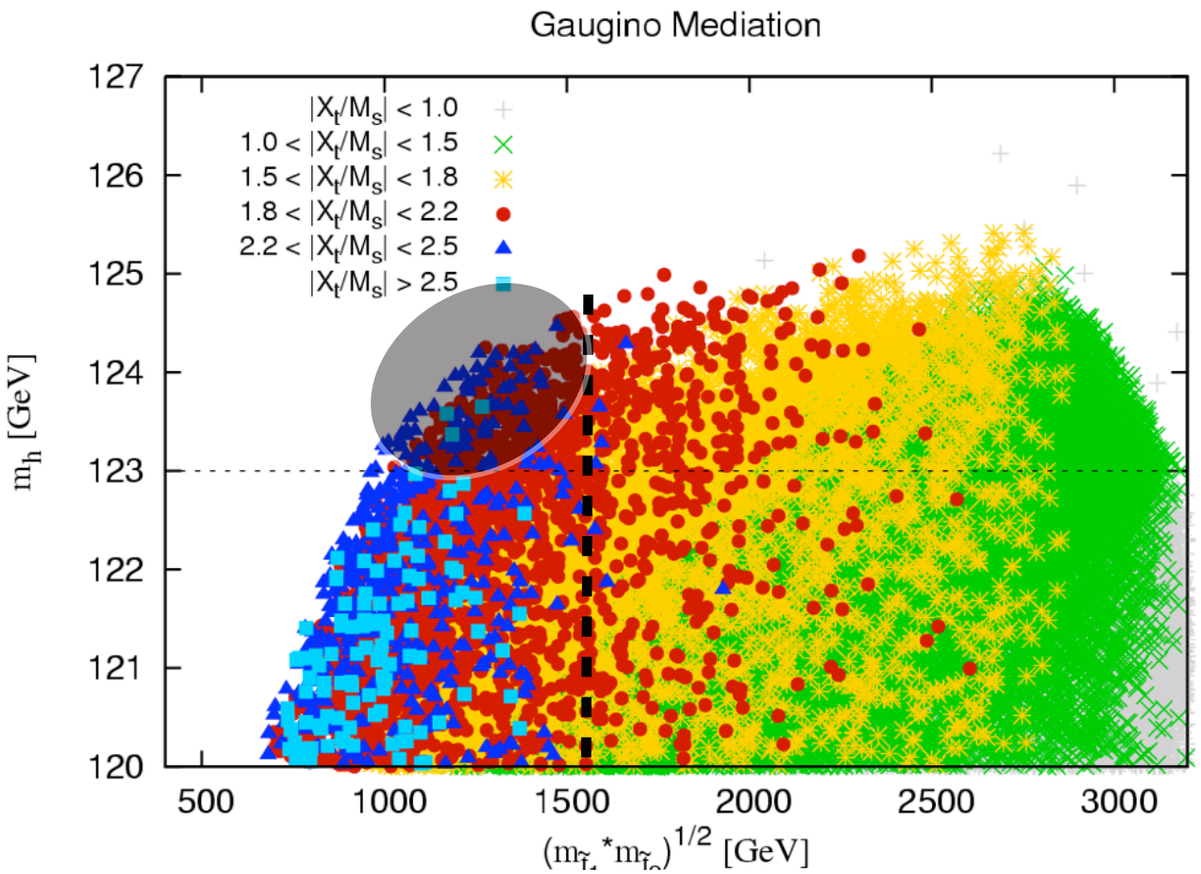
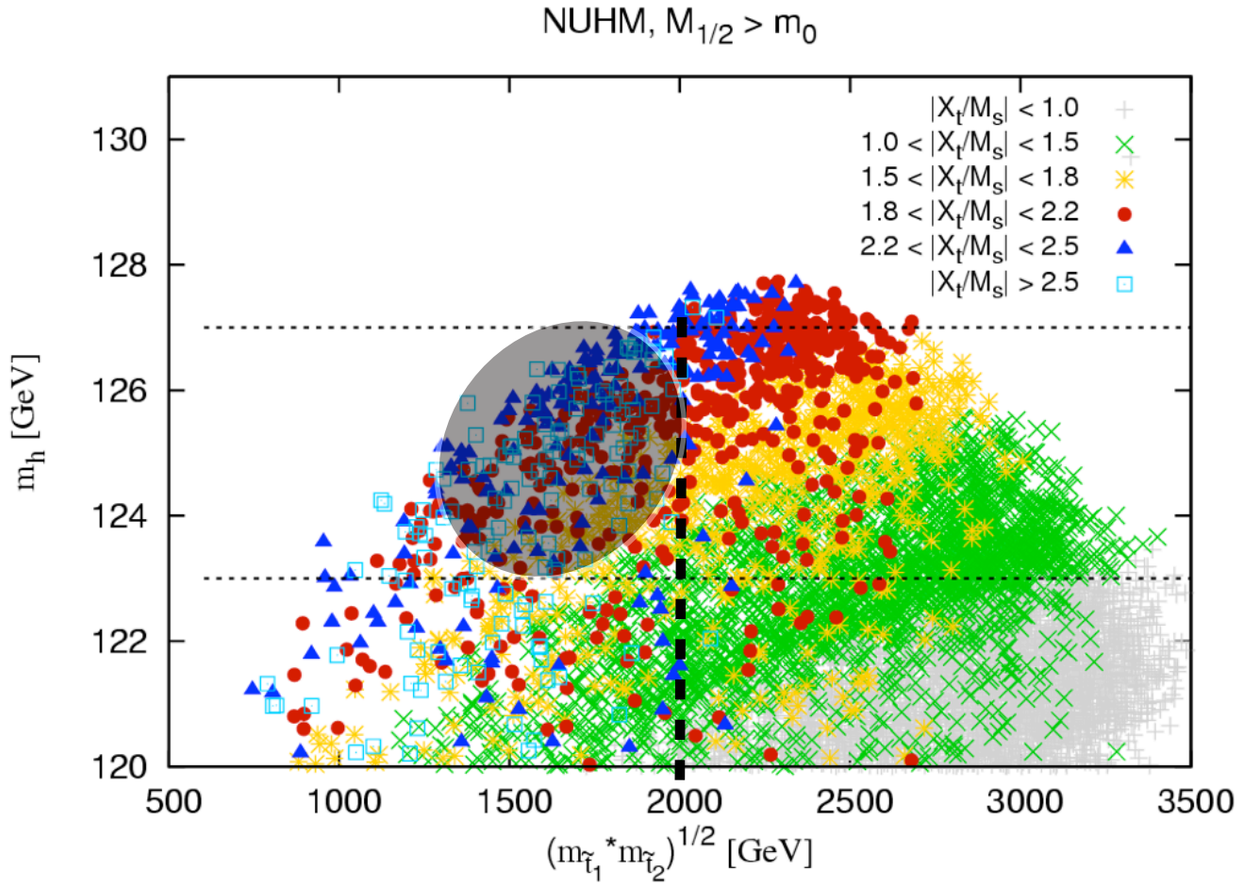
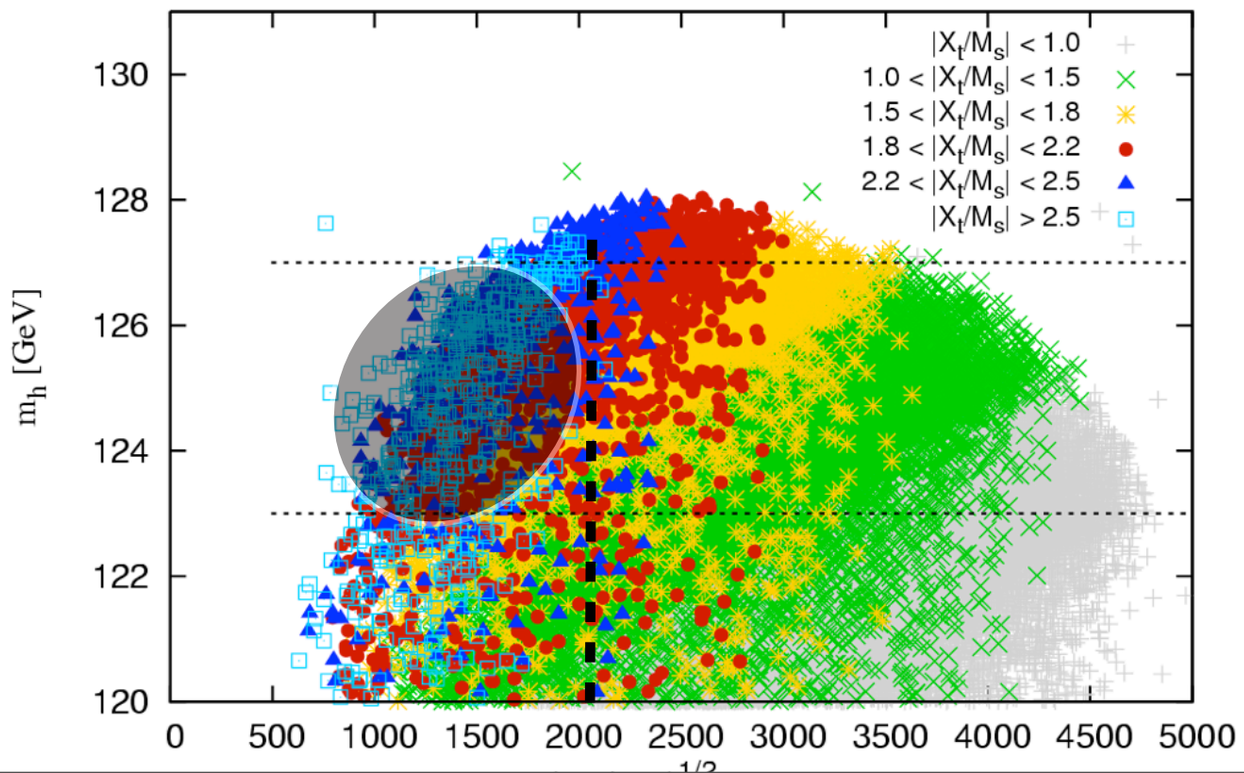
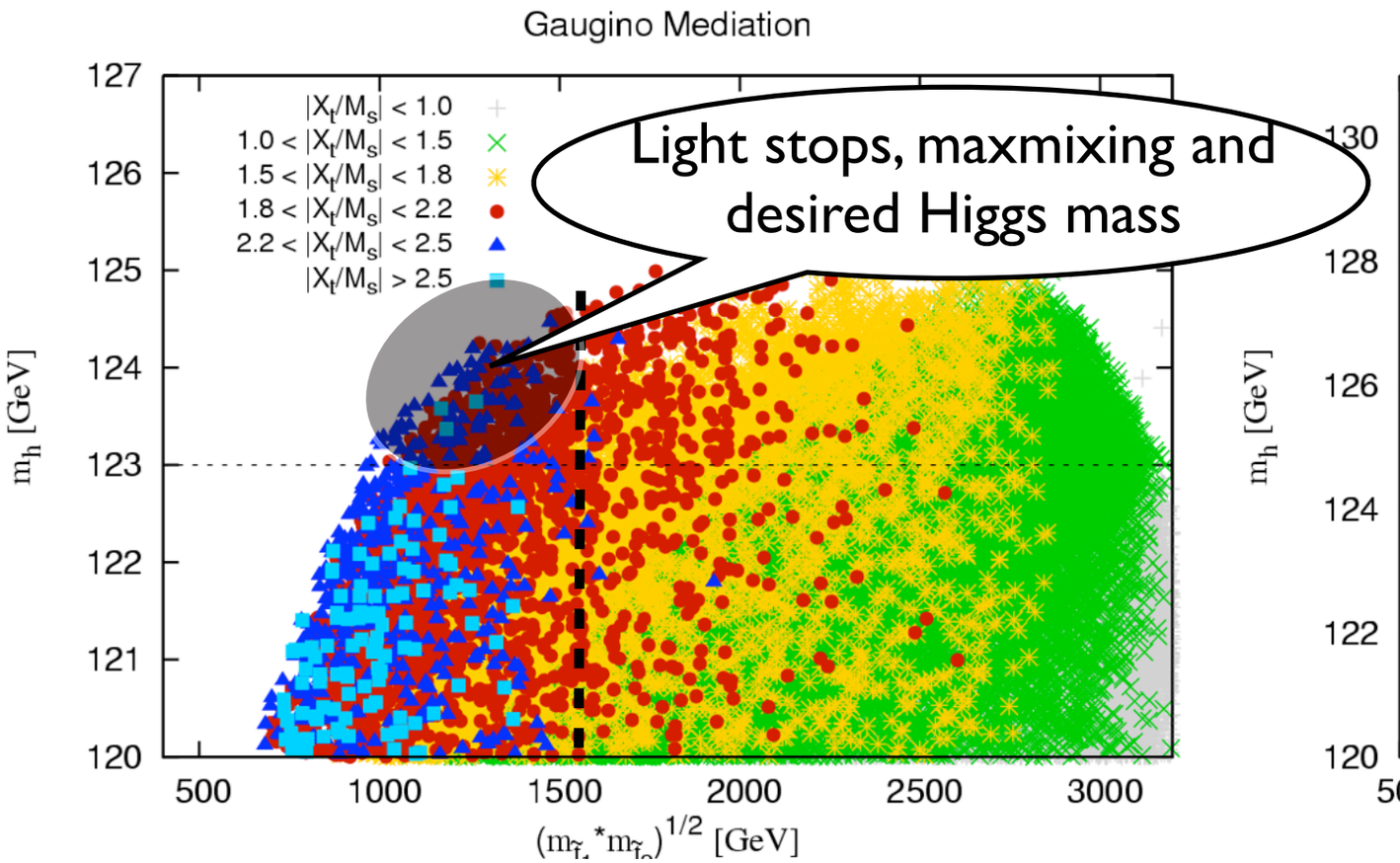
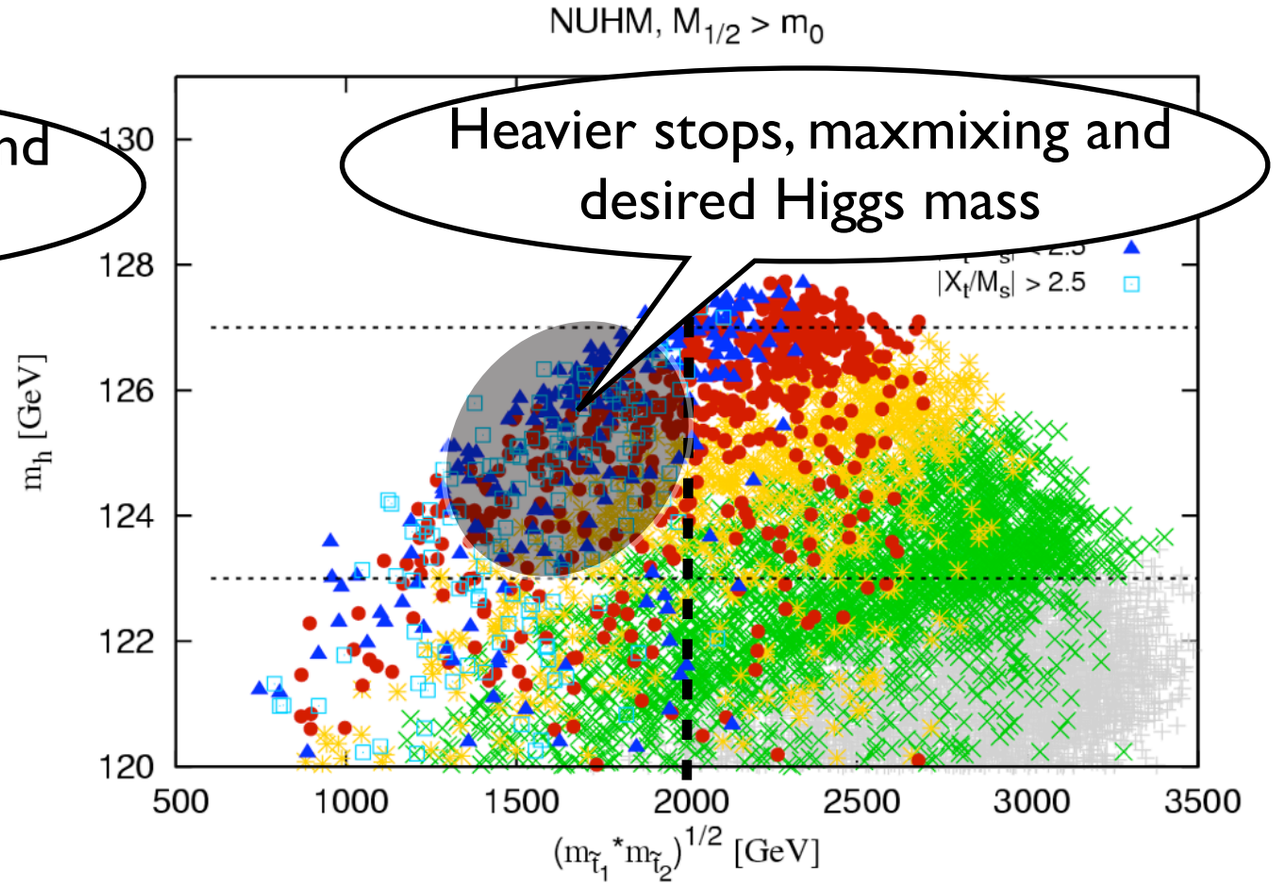


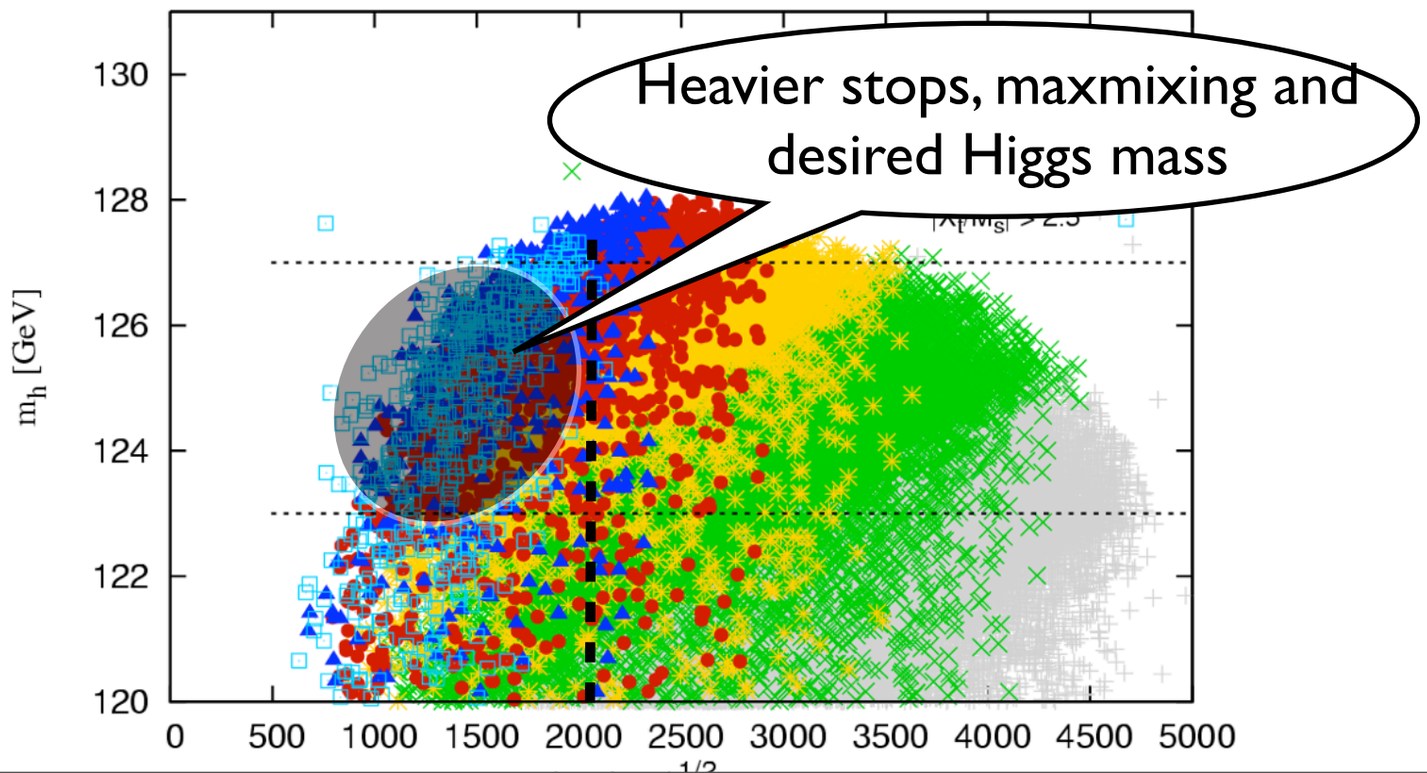




Testing MaxMixing - 2







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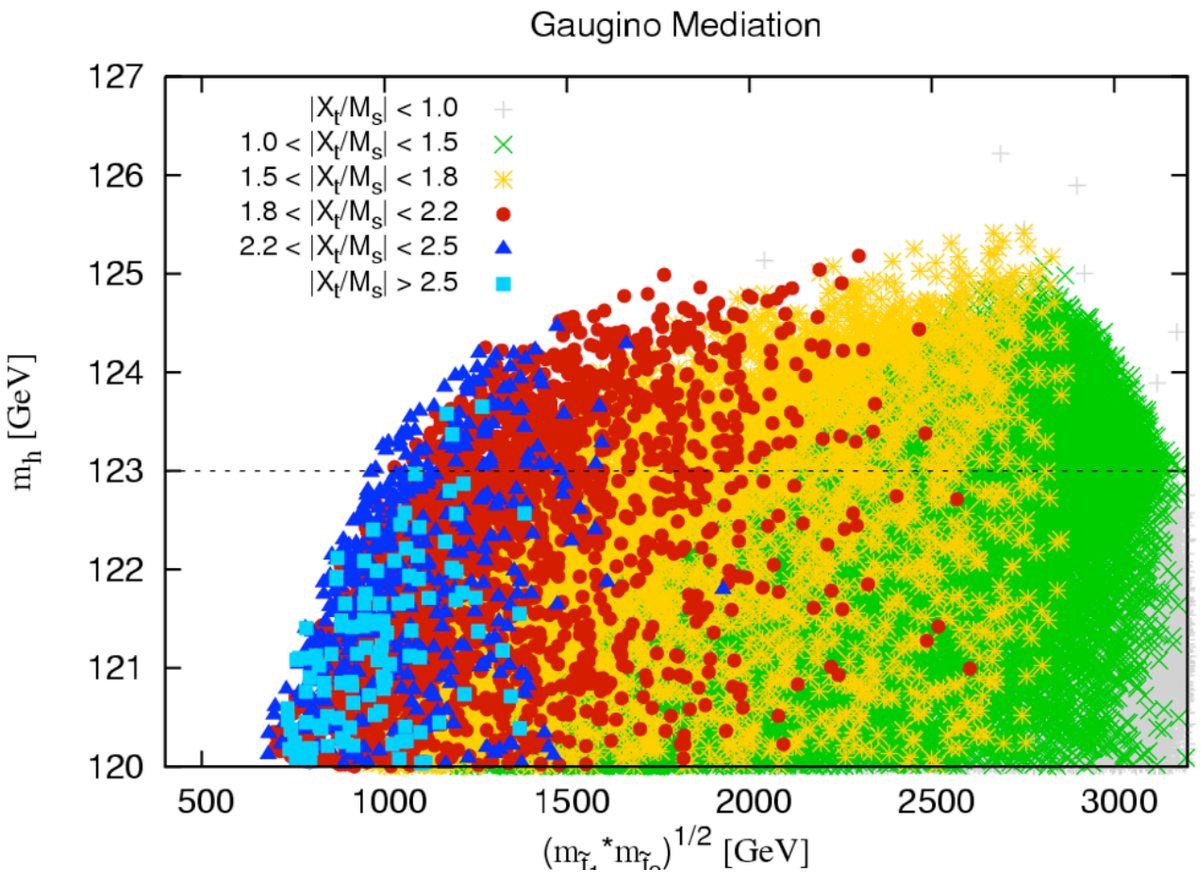
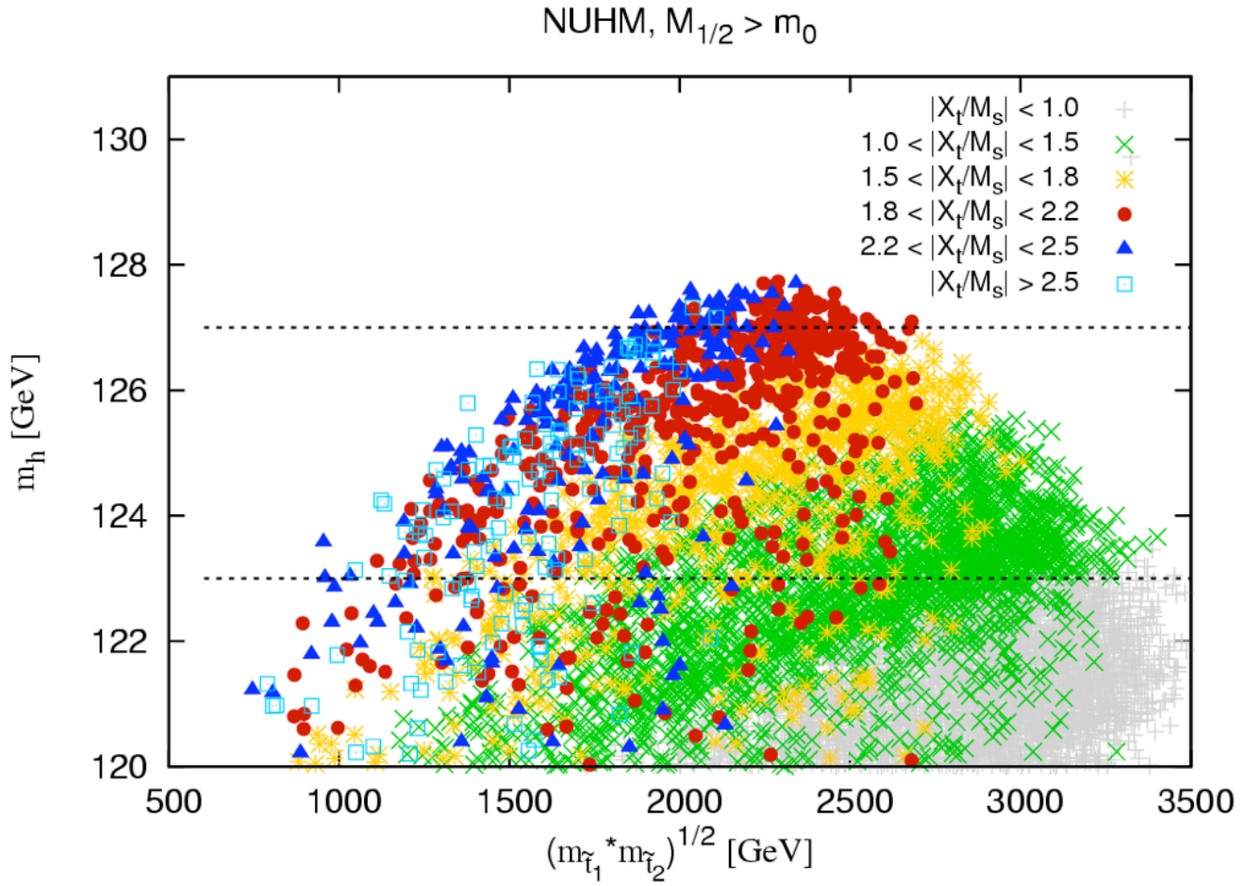
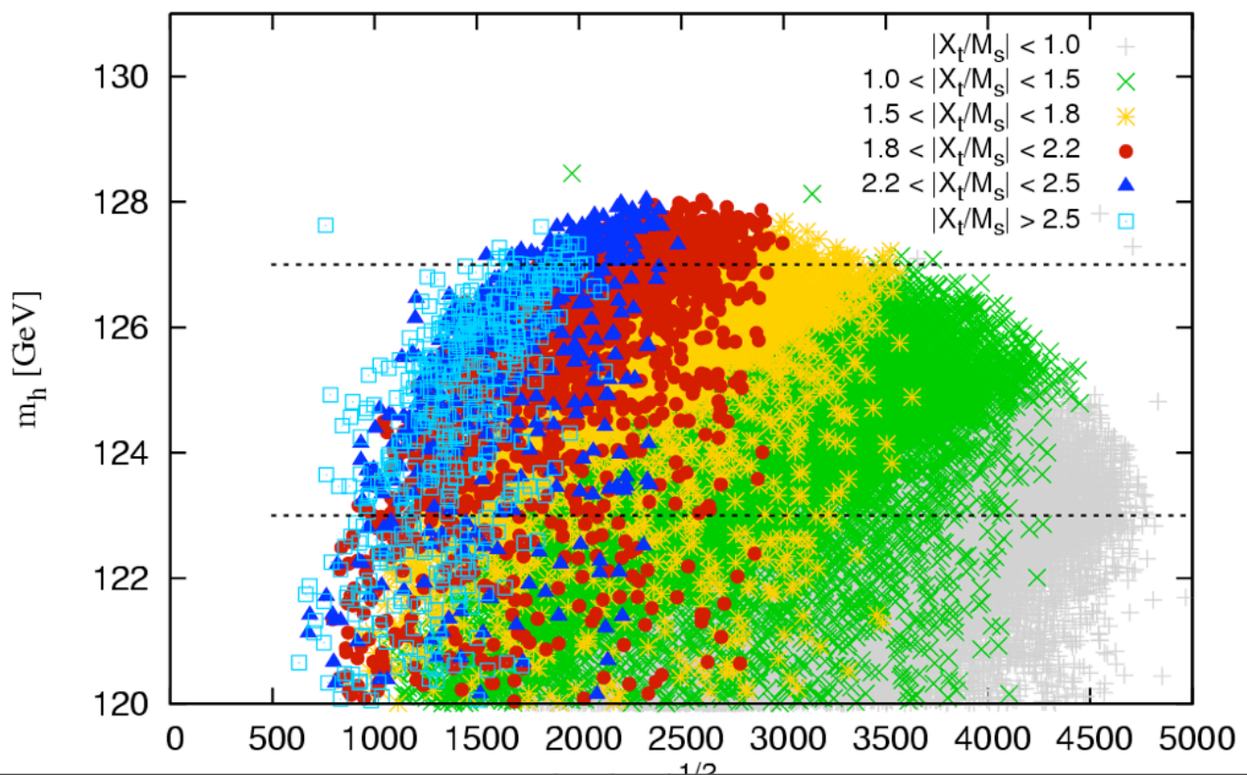
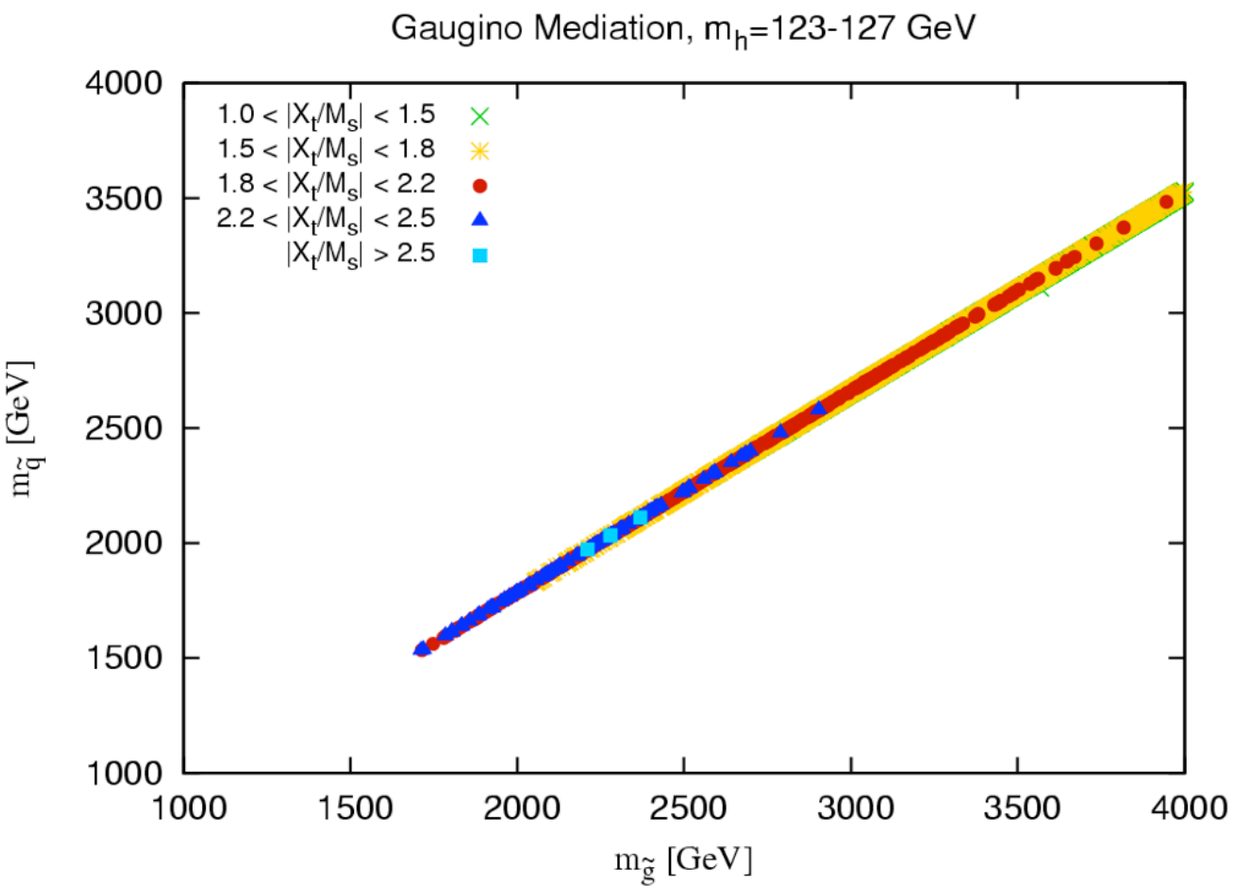


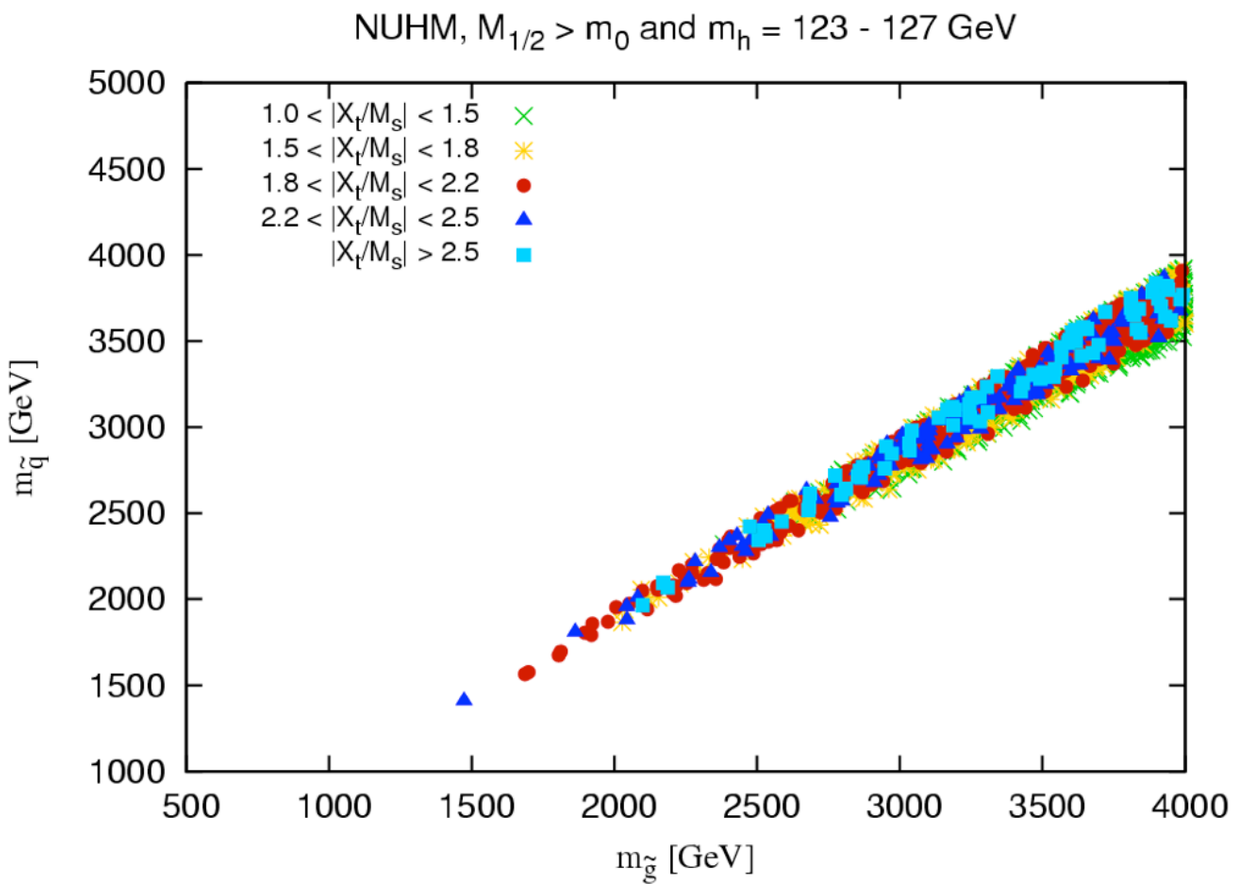


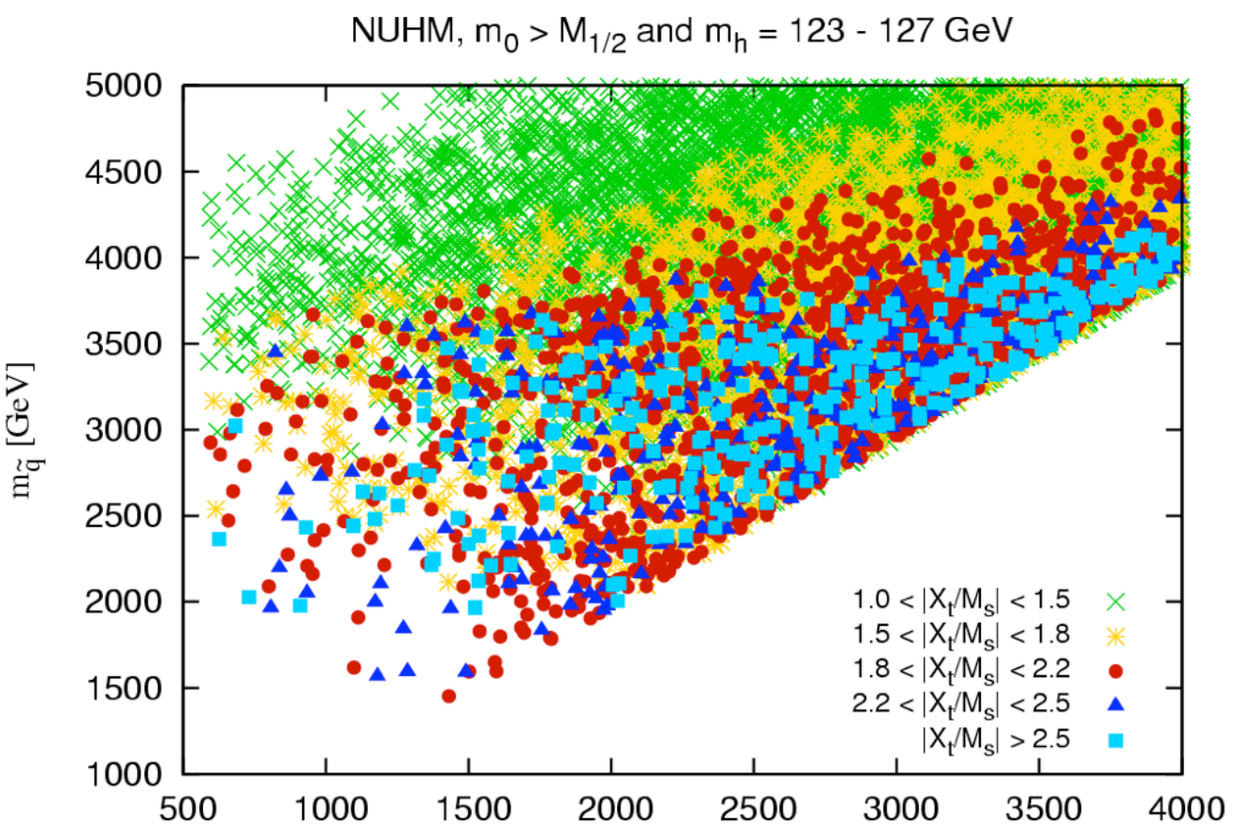


- Avg stop mass in NUHM is larger than in Gaugino Mediation this is because non-zero m0
- Possible to obtain maximal mixing and sub-TeV average stop masses

Impact on spectrum







- Gaugino mediation: the latest bounds on gluino squark masses for cMSSM like scenario (> 1.5TeV) automatically evaded
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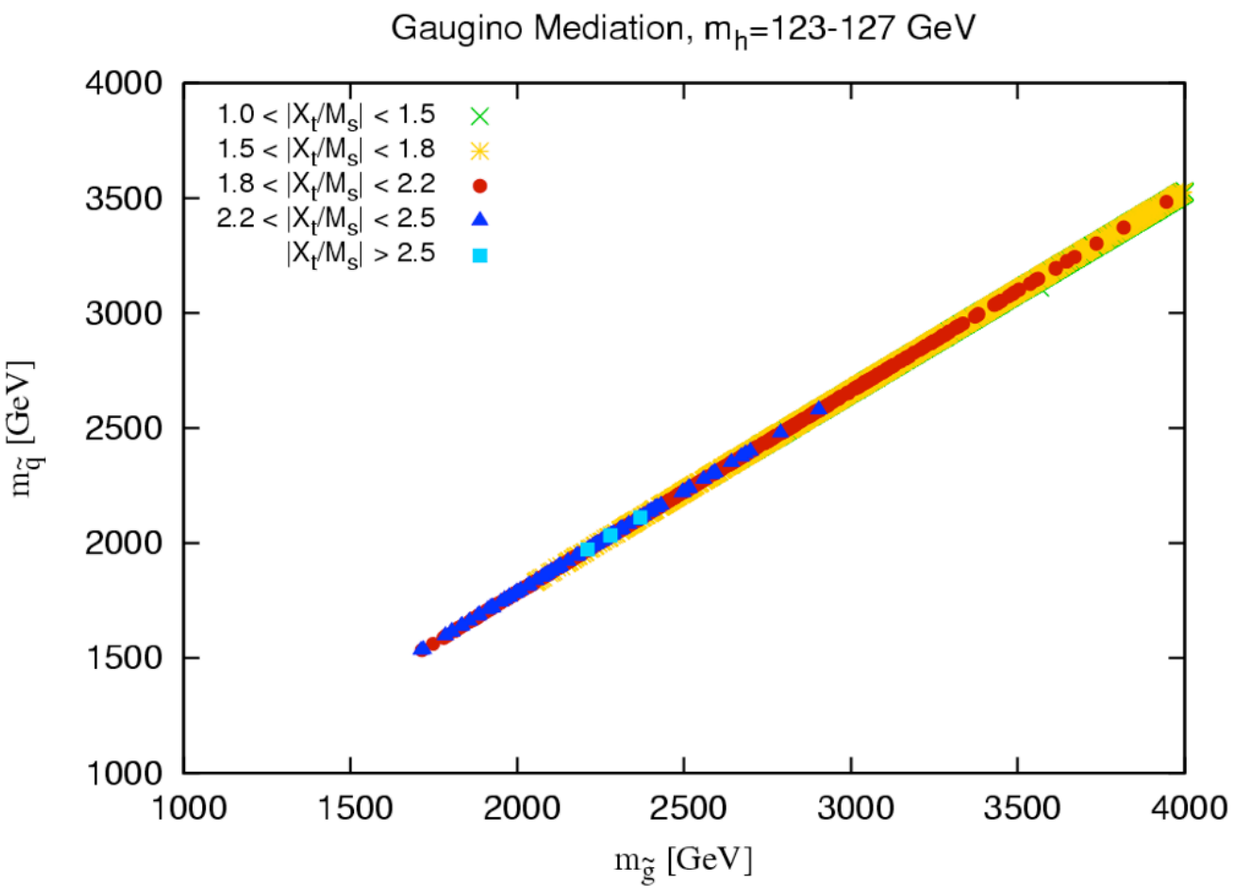

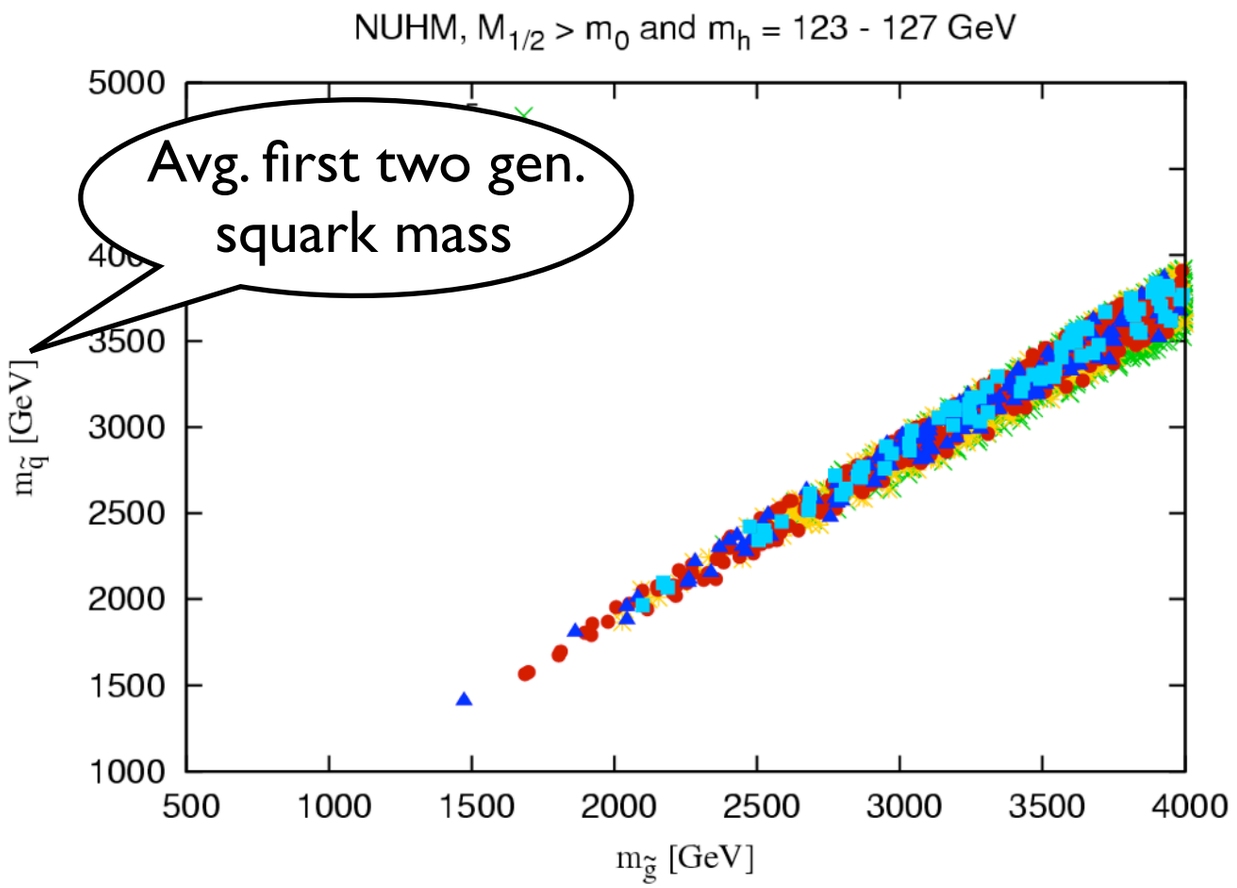

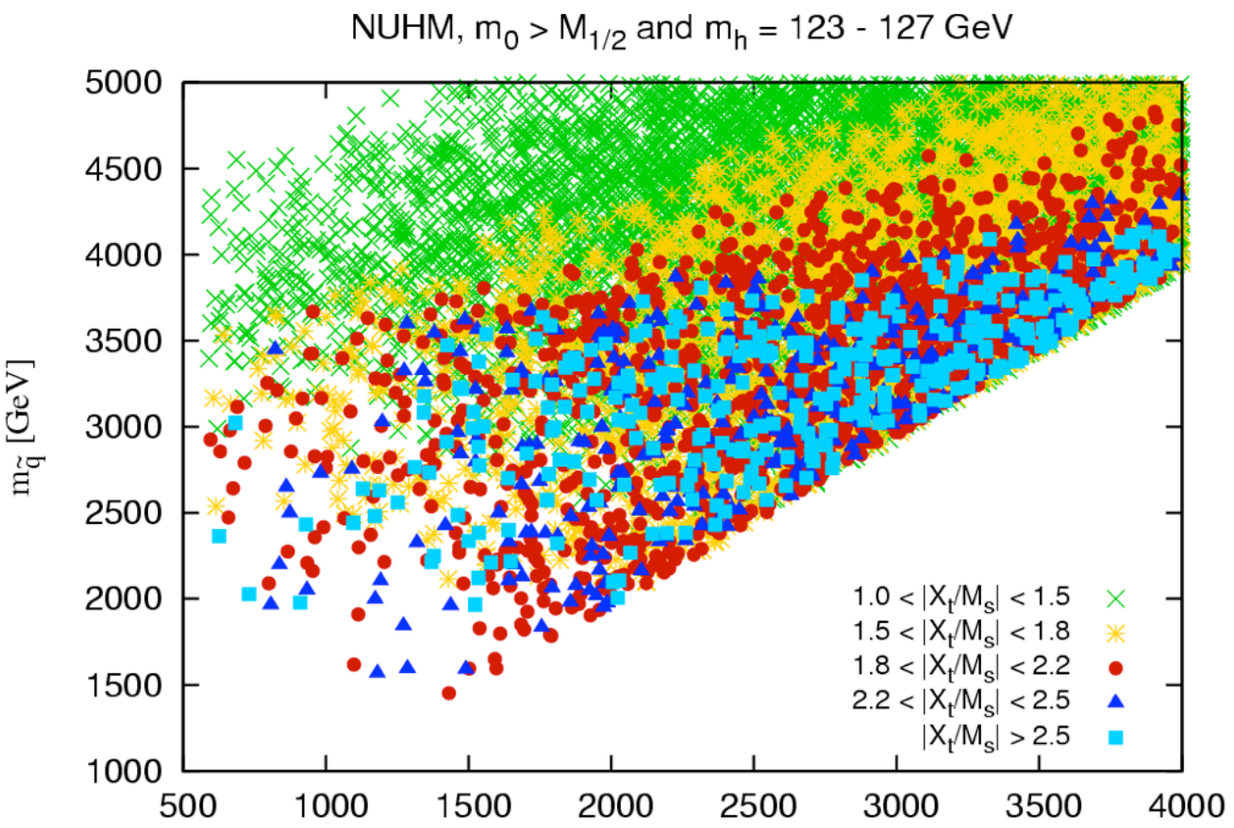

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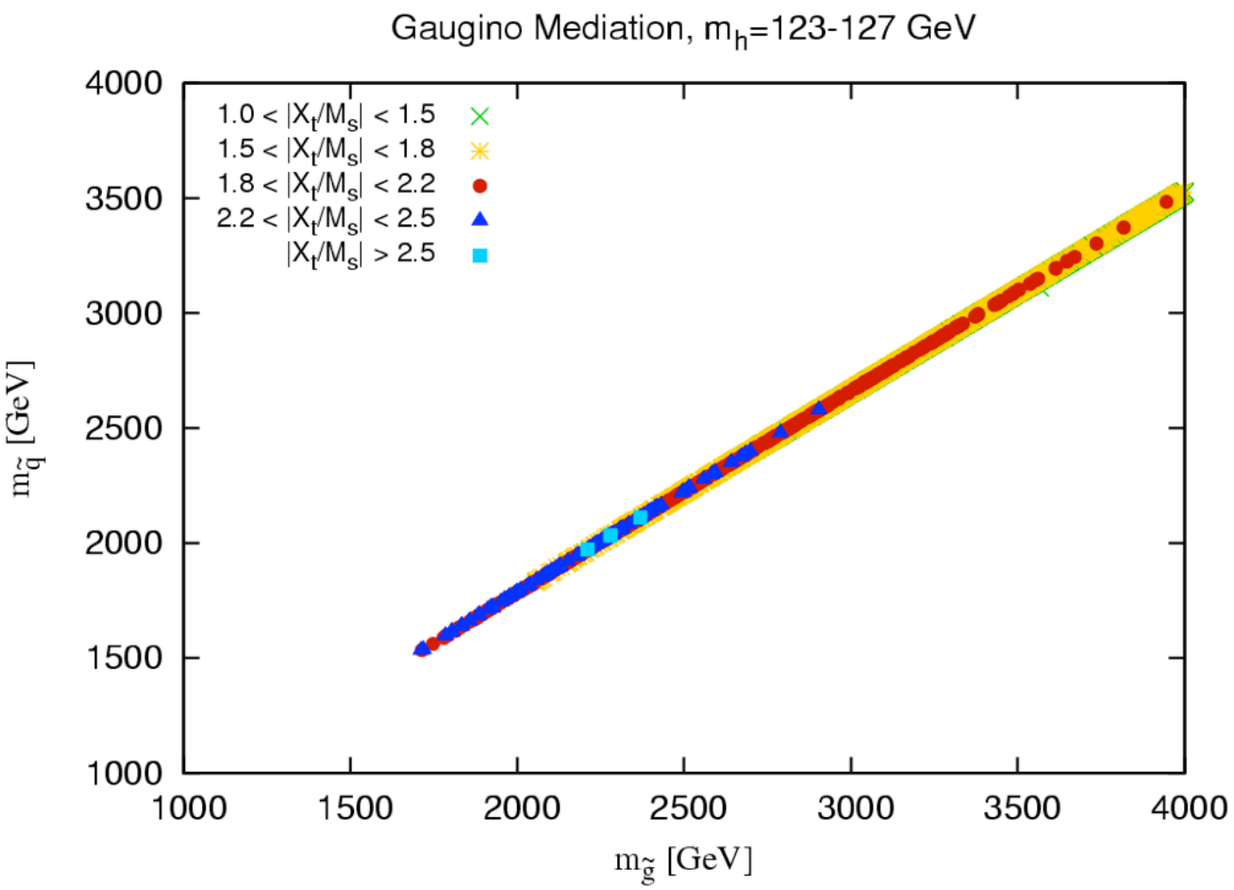

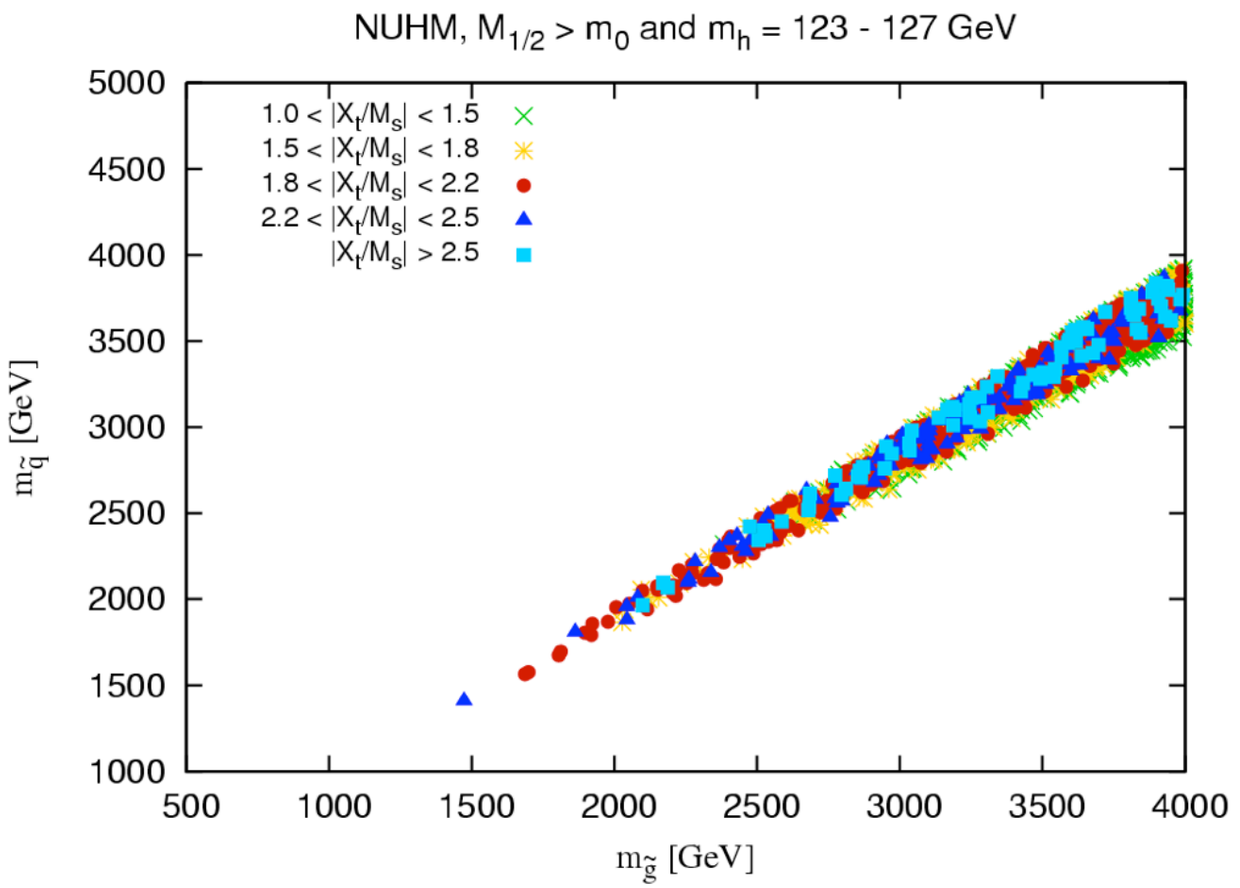

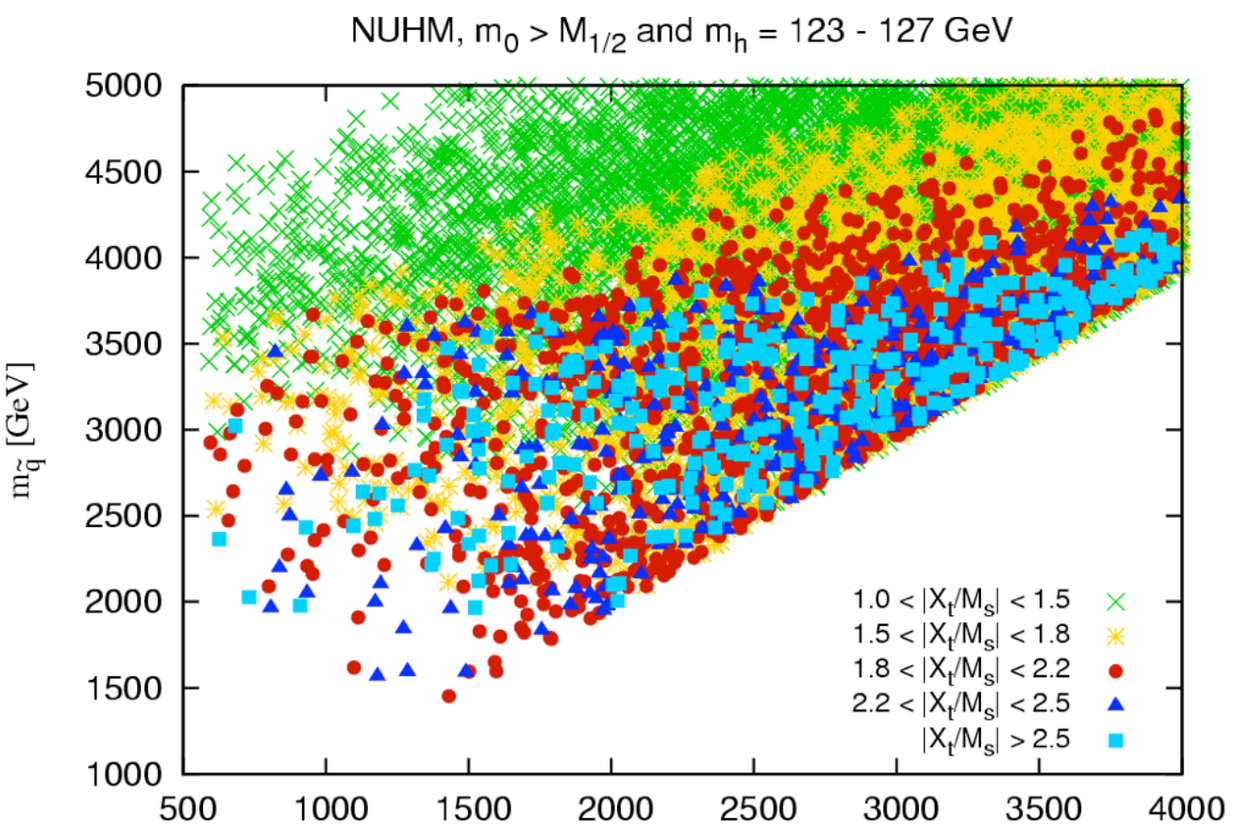

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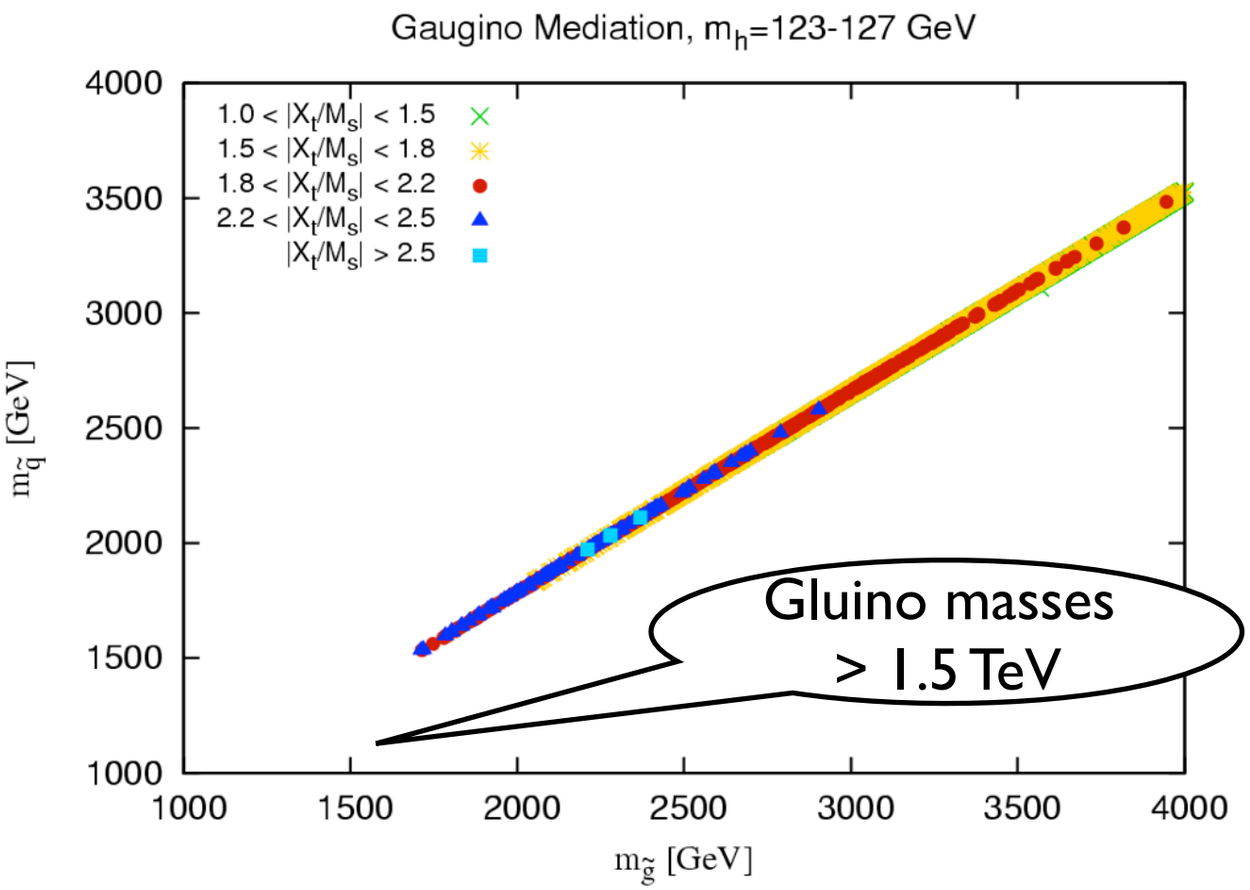

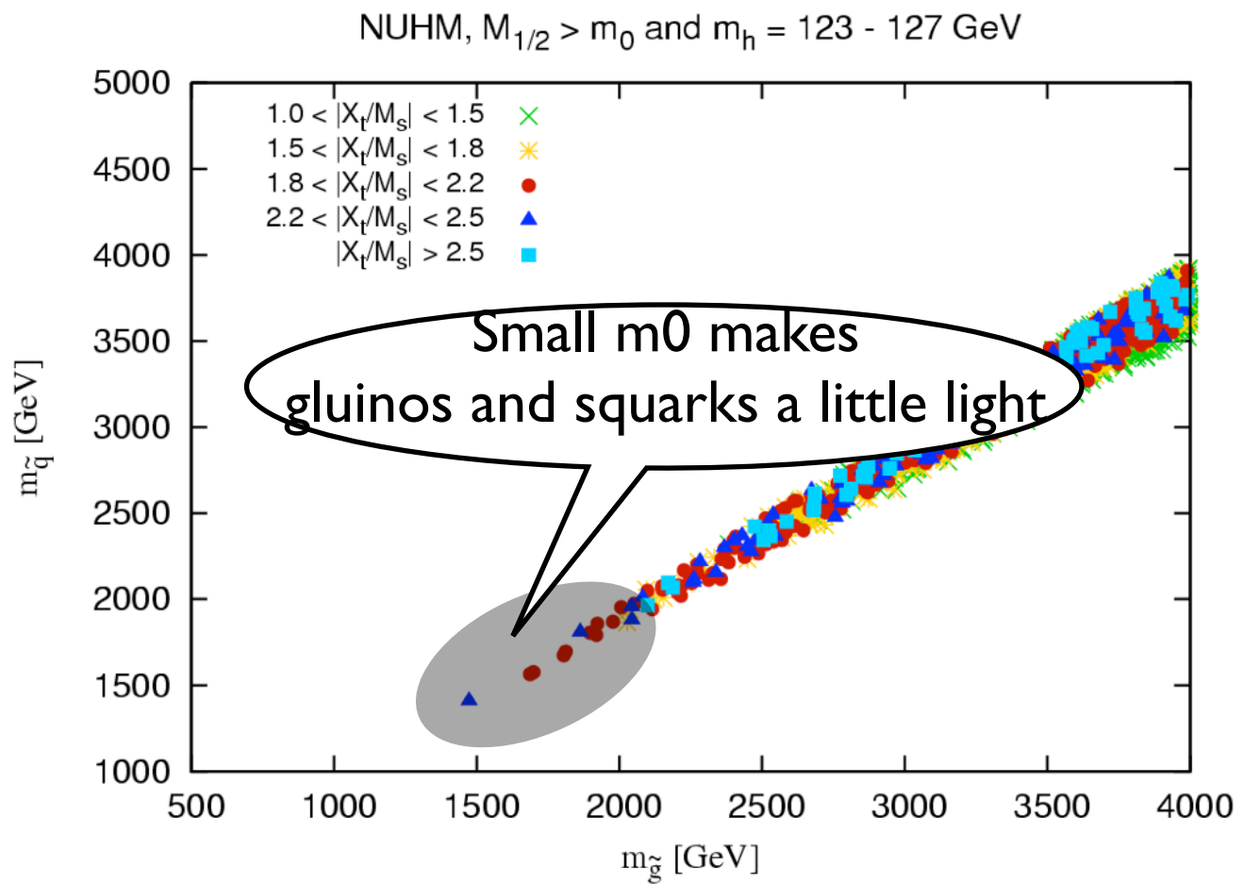

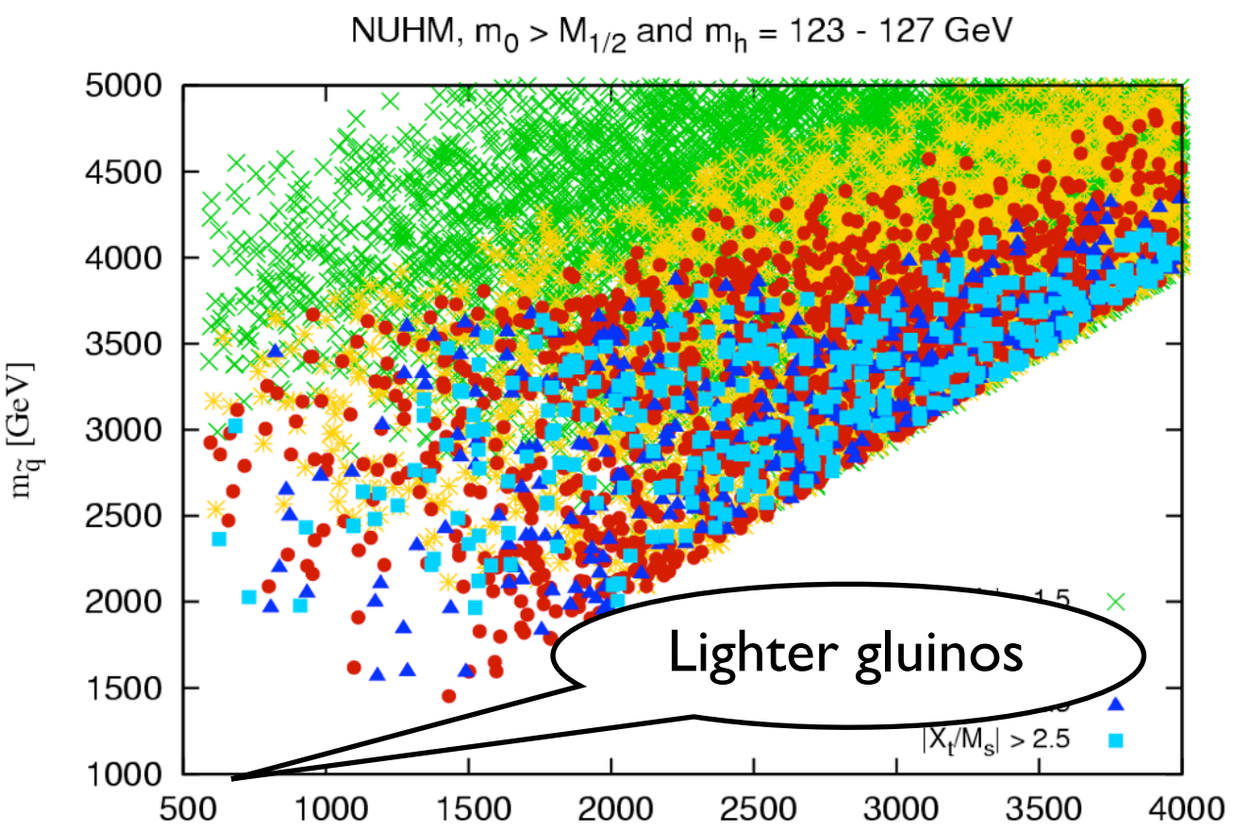

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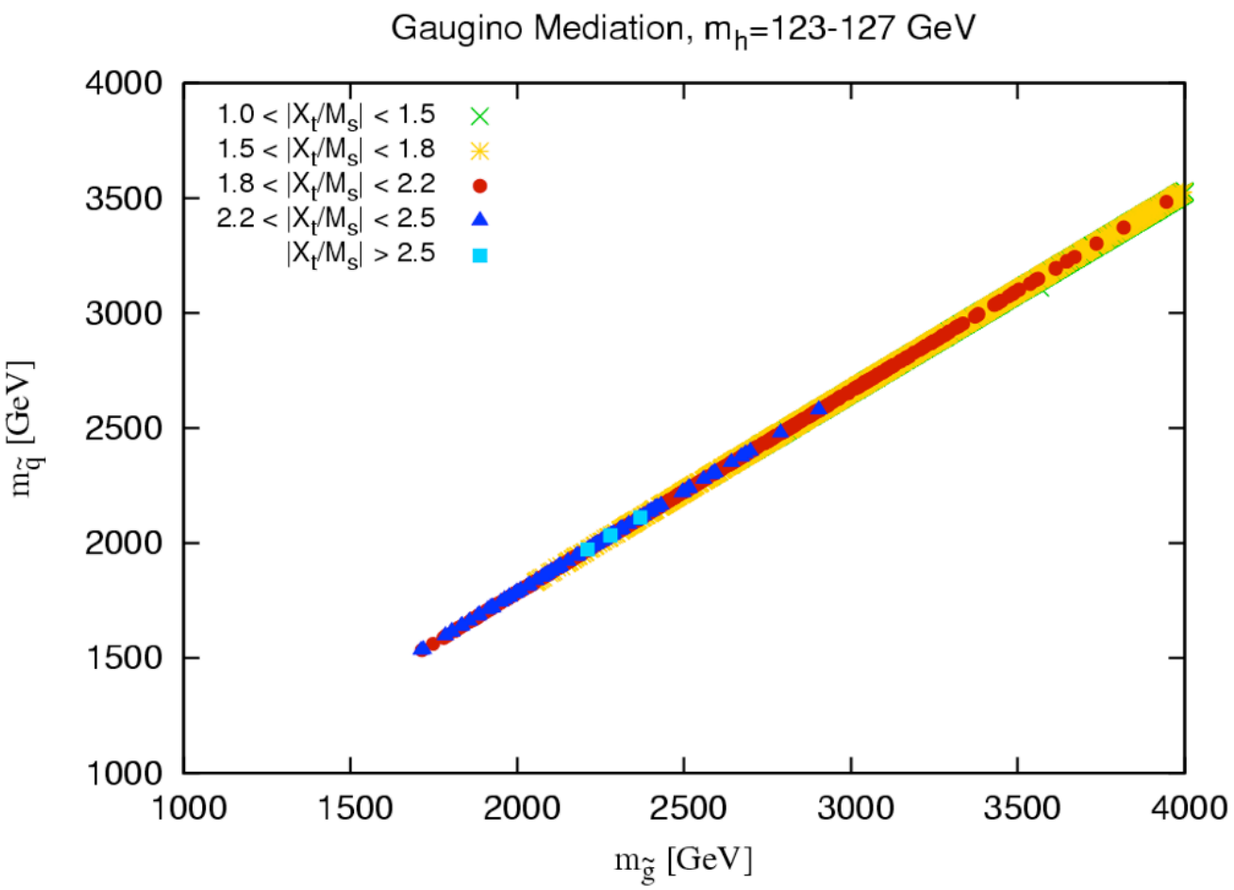

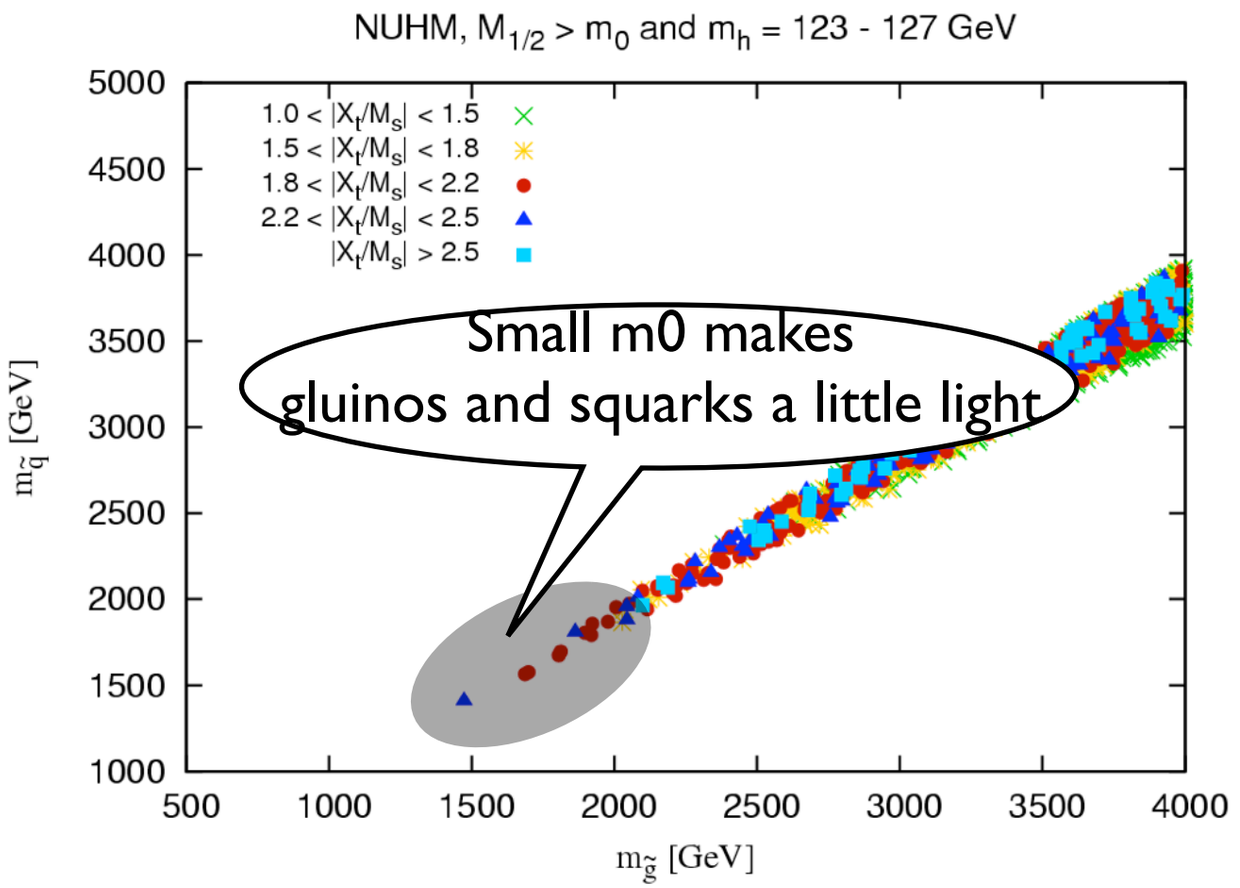

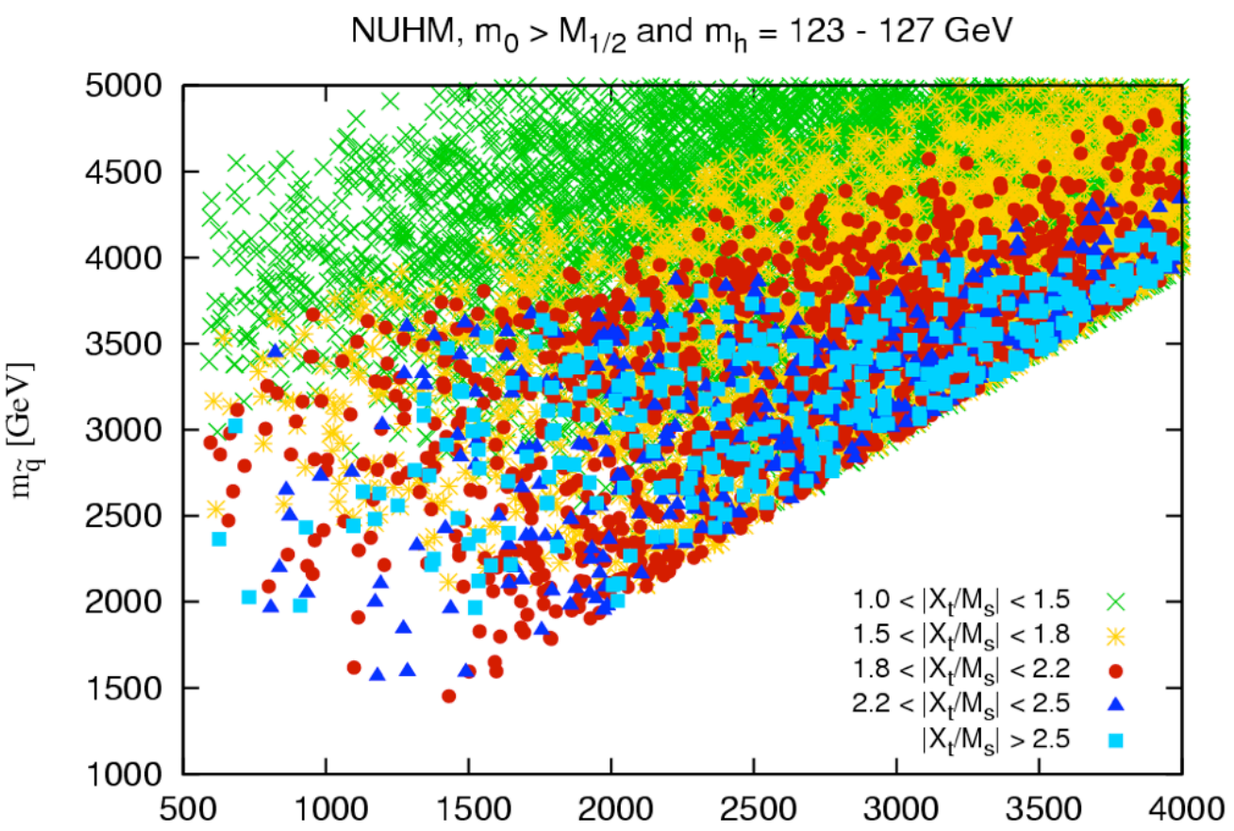

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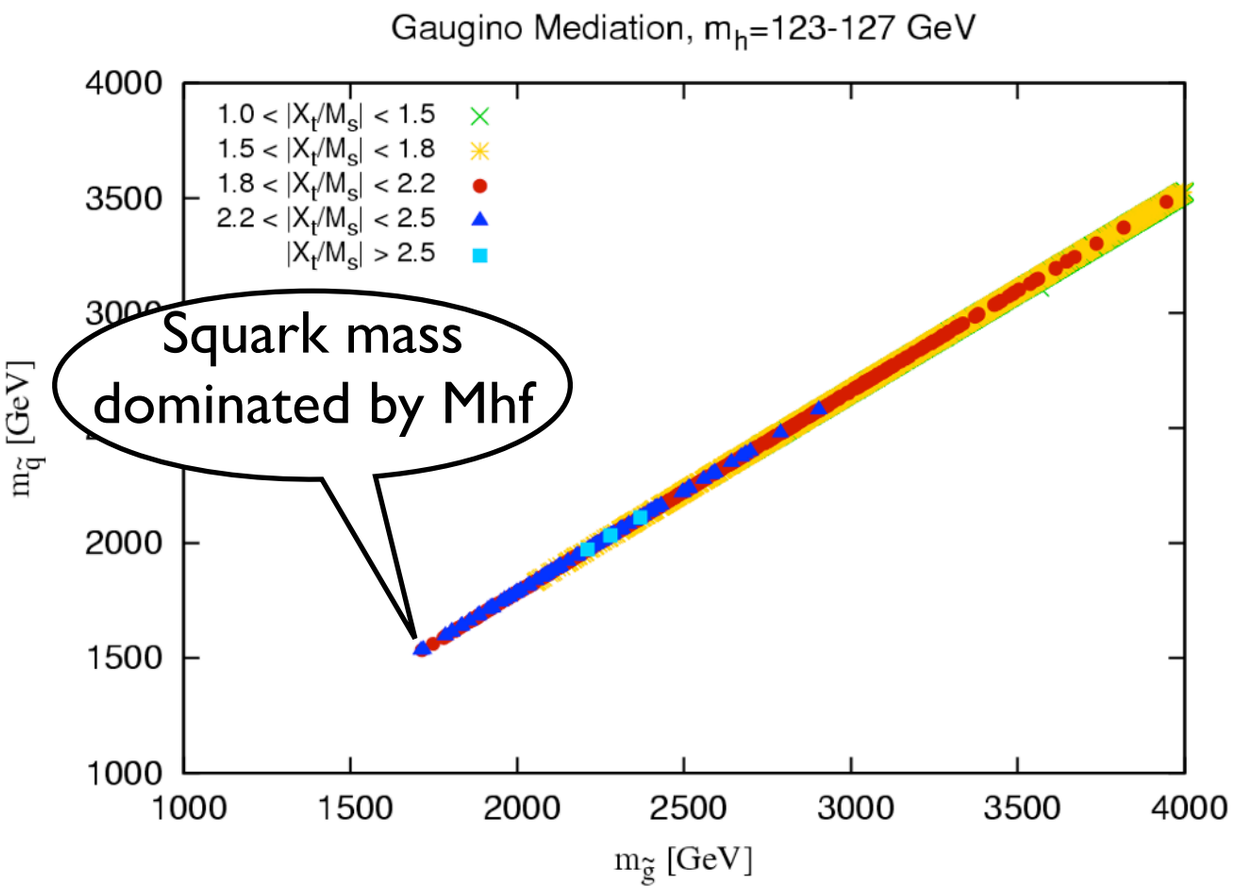

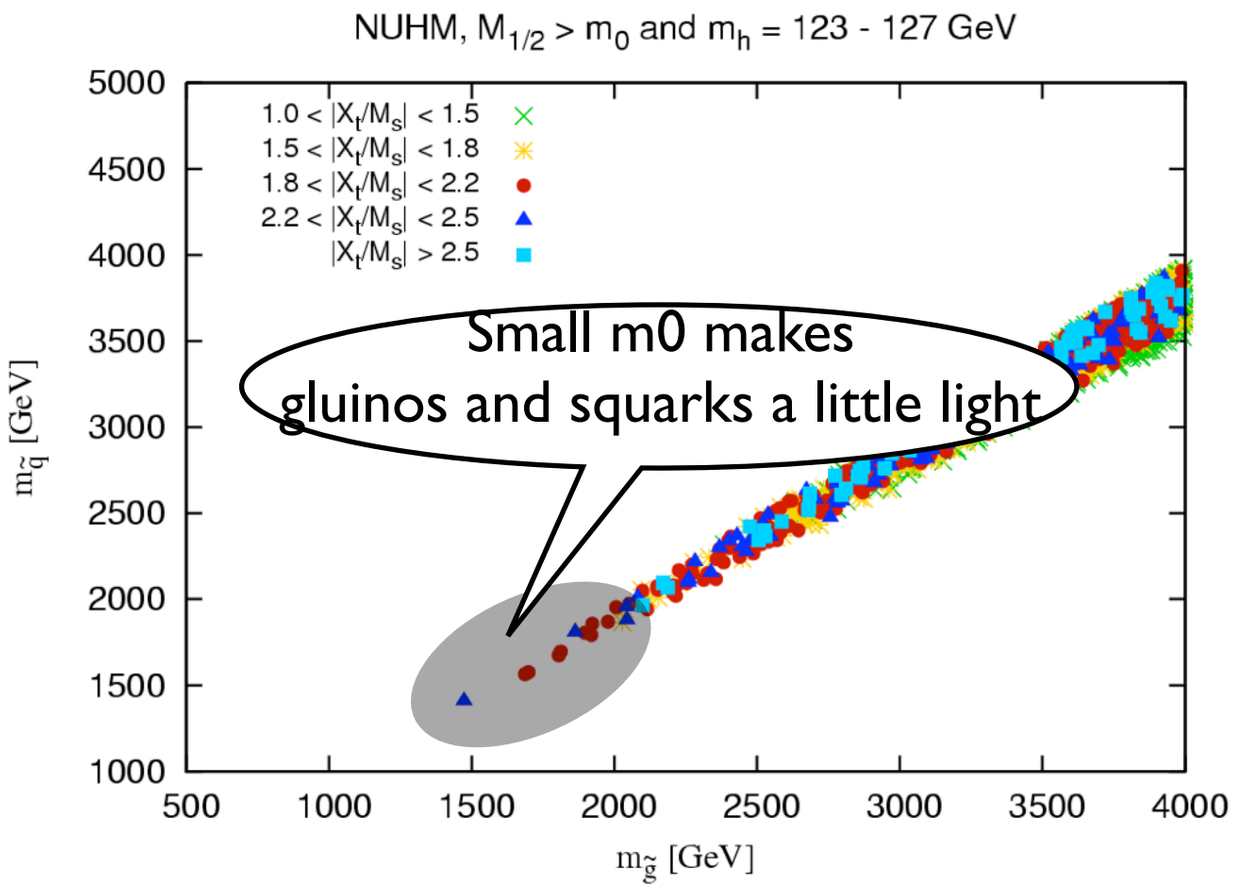

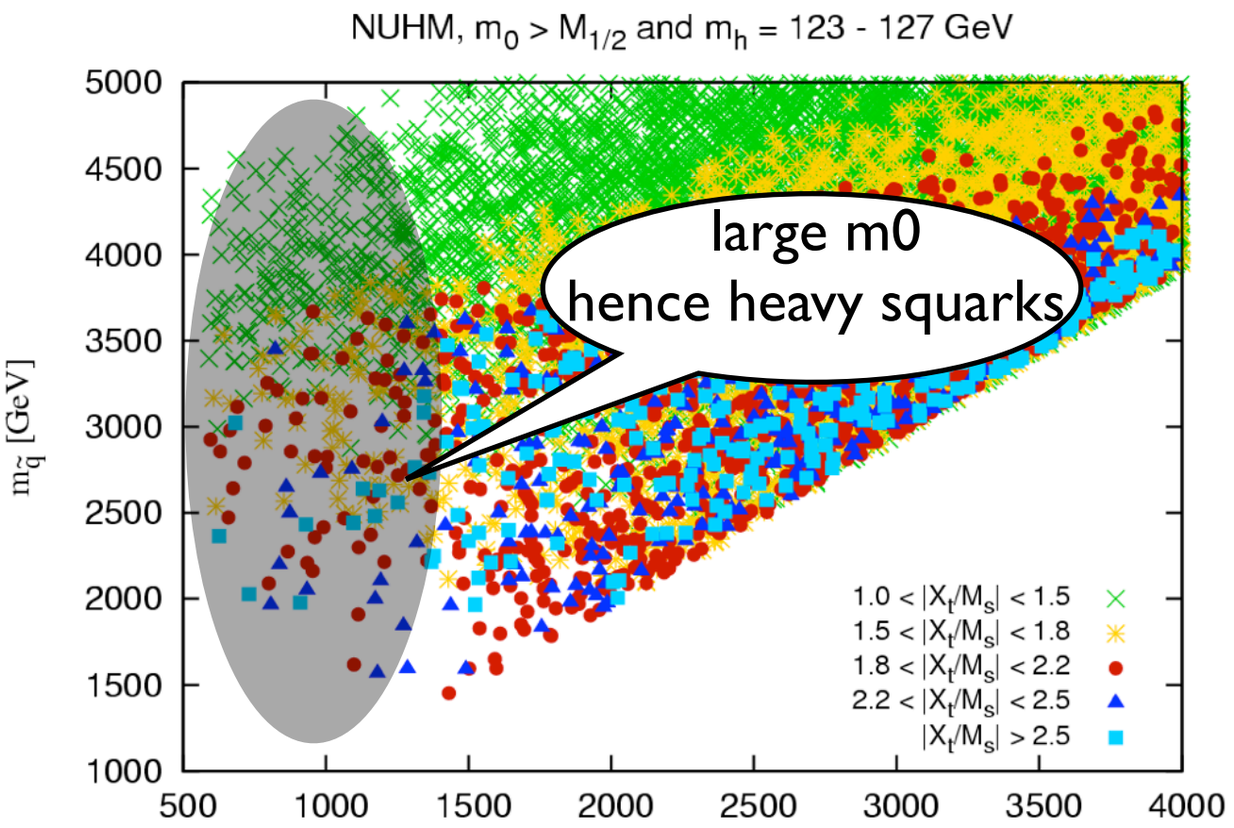

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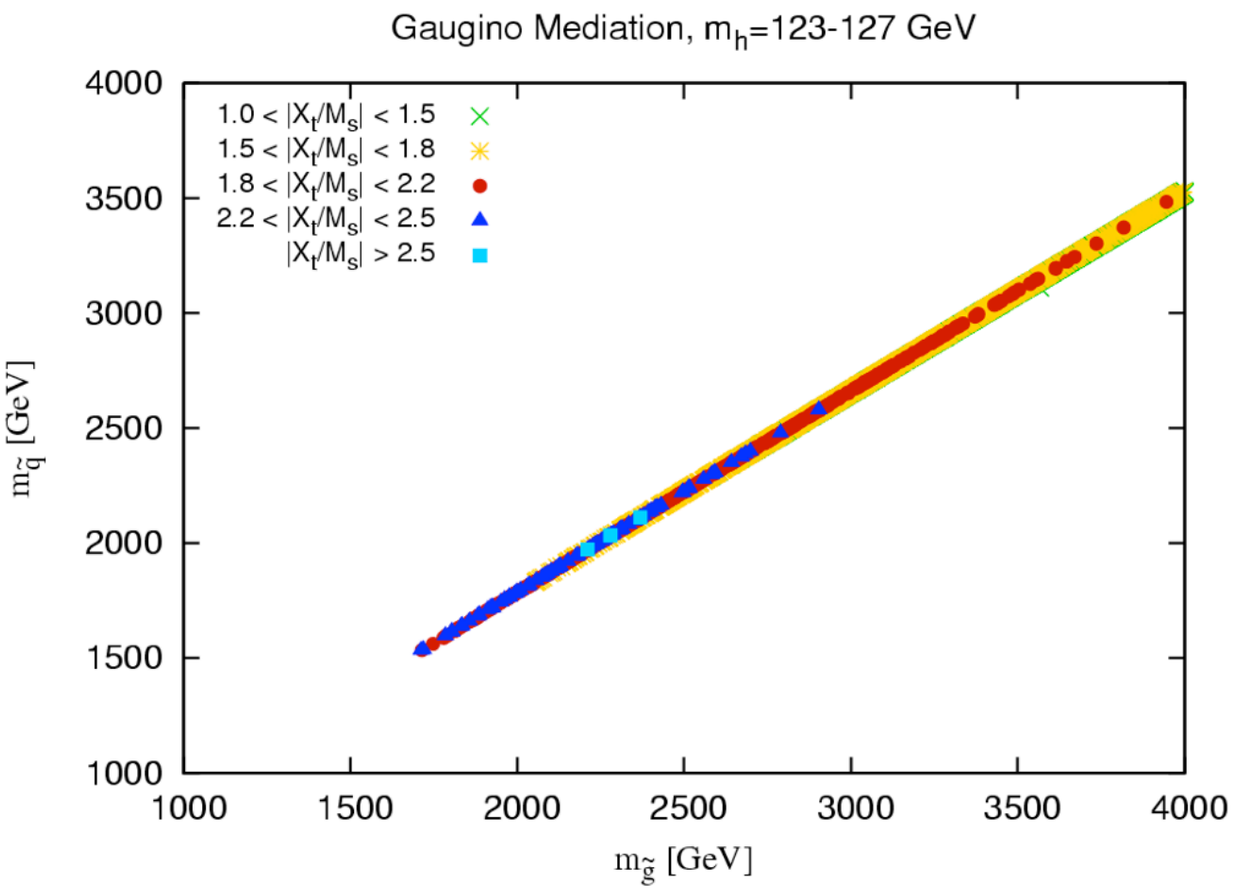

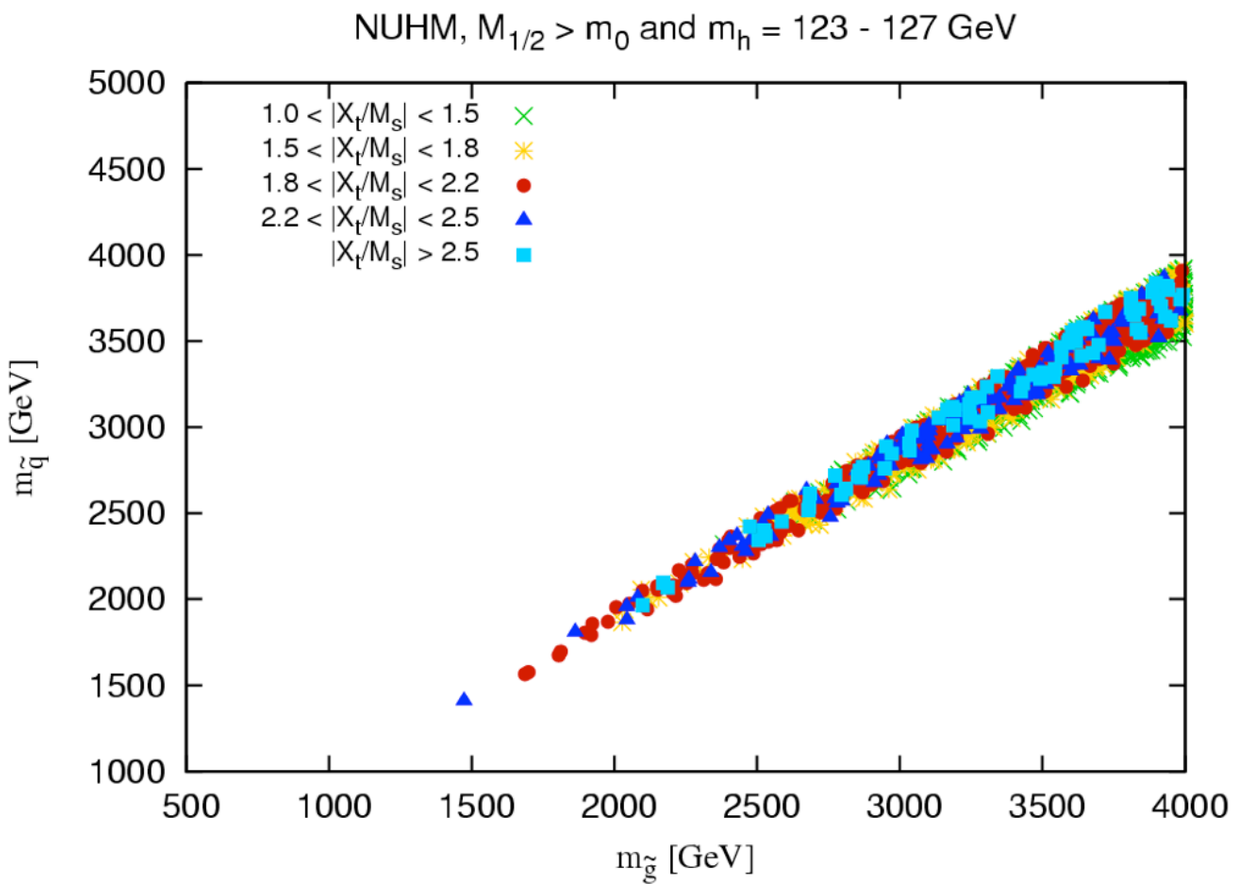

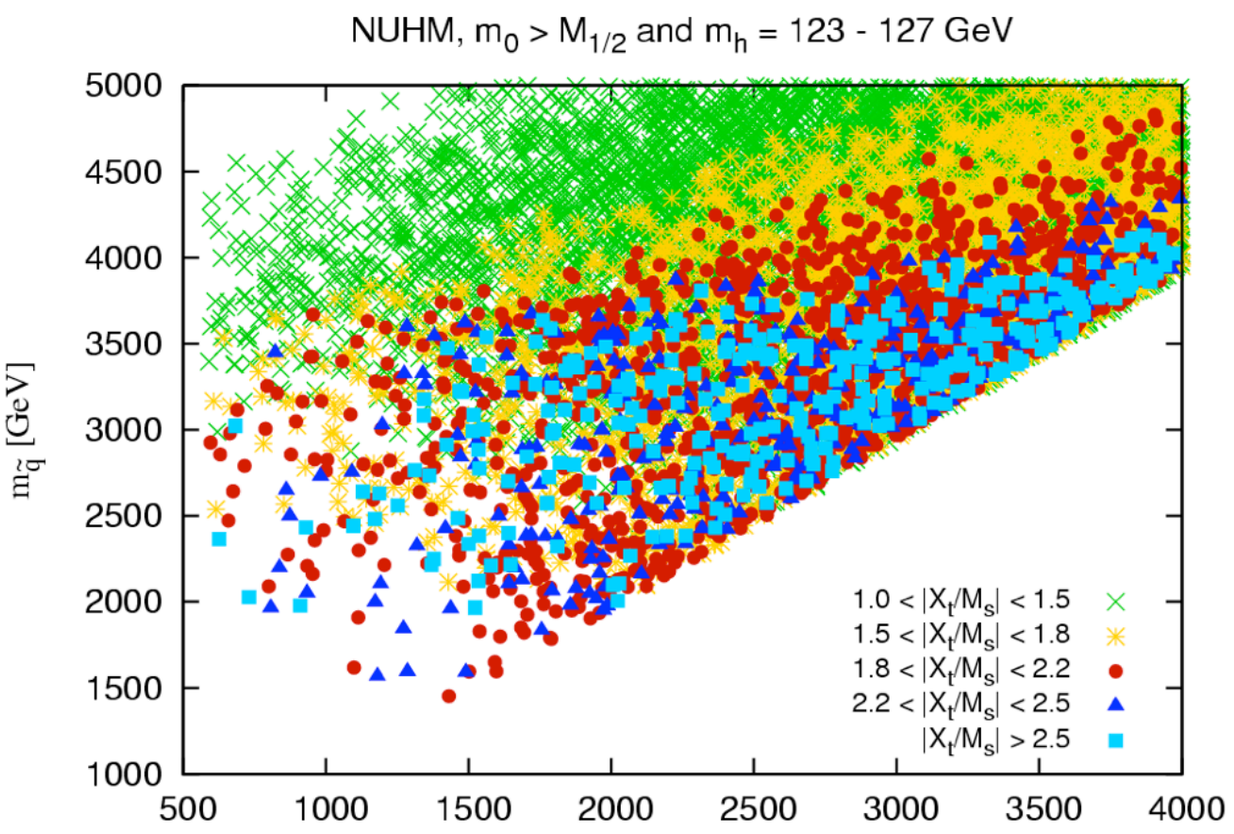

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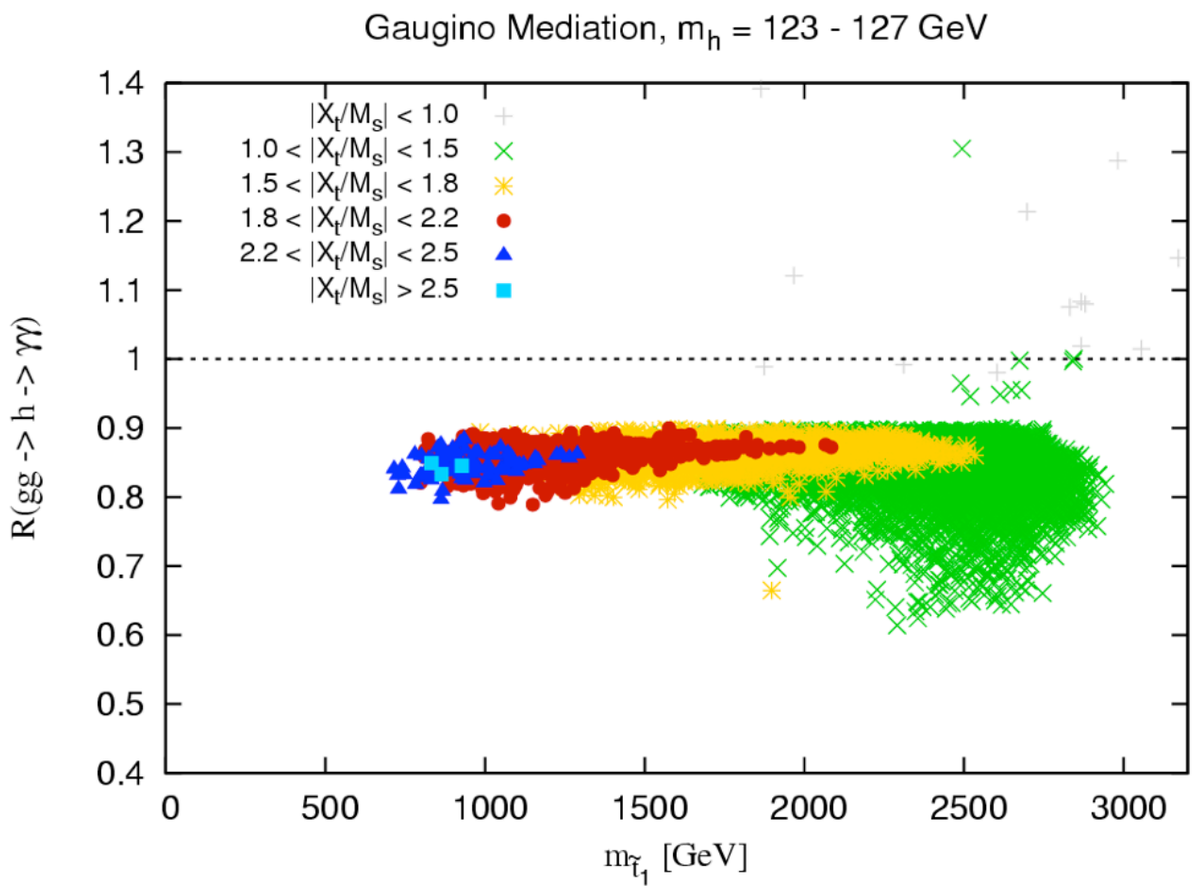
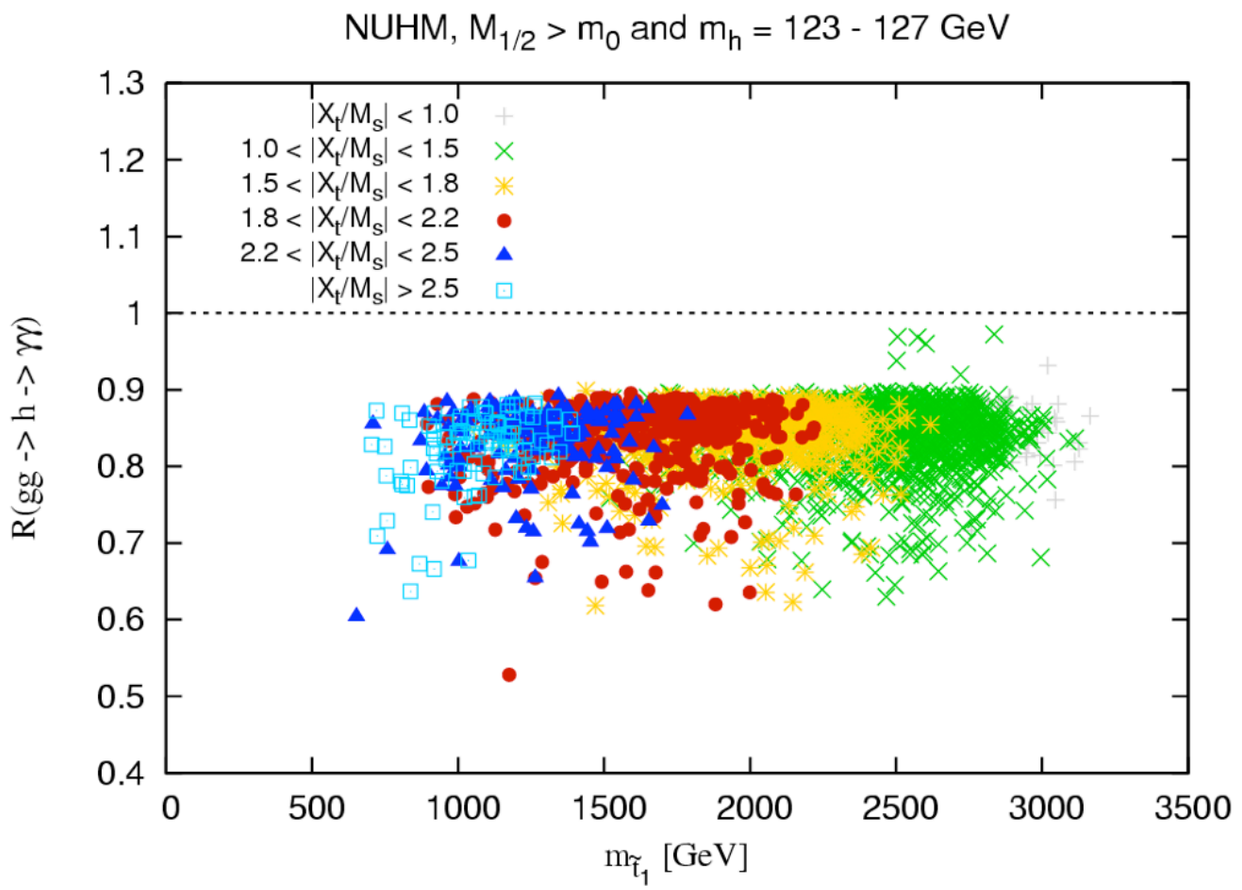
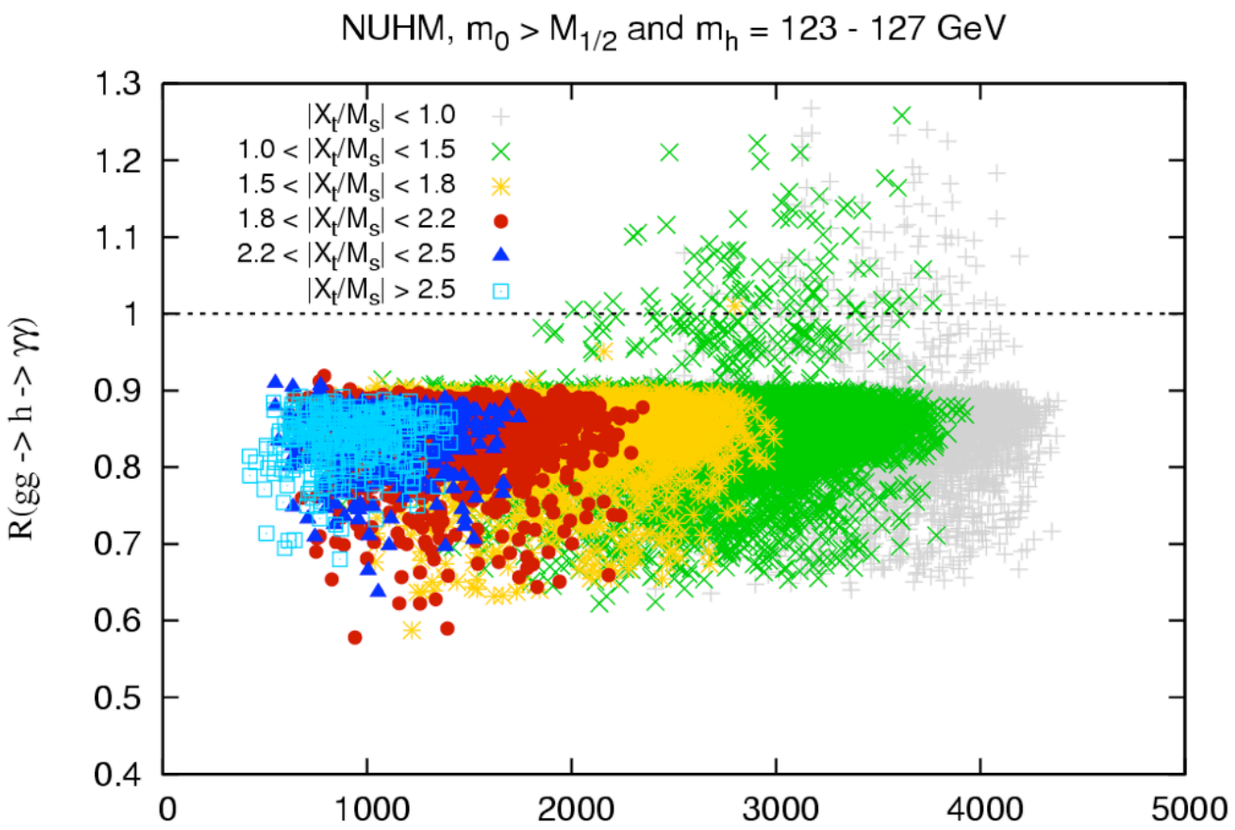
The famous $\gamma\gamma$ channel







$$R(X) \equiv \frac{[\sigma(gg \to h)\,\mathrm{BR}(h \to X)]_{\mathrm{MSSM}}}{[\sigma(gg \to h)\,\mathrm{BR}(h \to X)]_{\mathrm{SM}}}$$

$$\approx \frac{[\Gamma(h \to gg)\,\mathrm{BR}(h \to X)]_{\mathrm{MSSM}}}{[\Gamma(h \to gg)\,\mathrm{BR}(h \to X)]_{\mathrm{SM}}}$$

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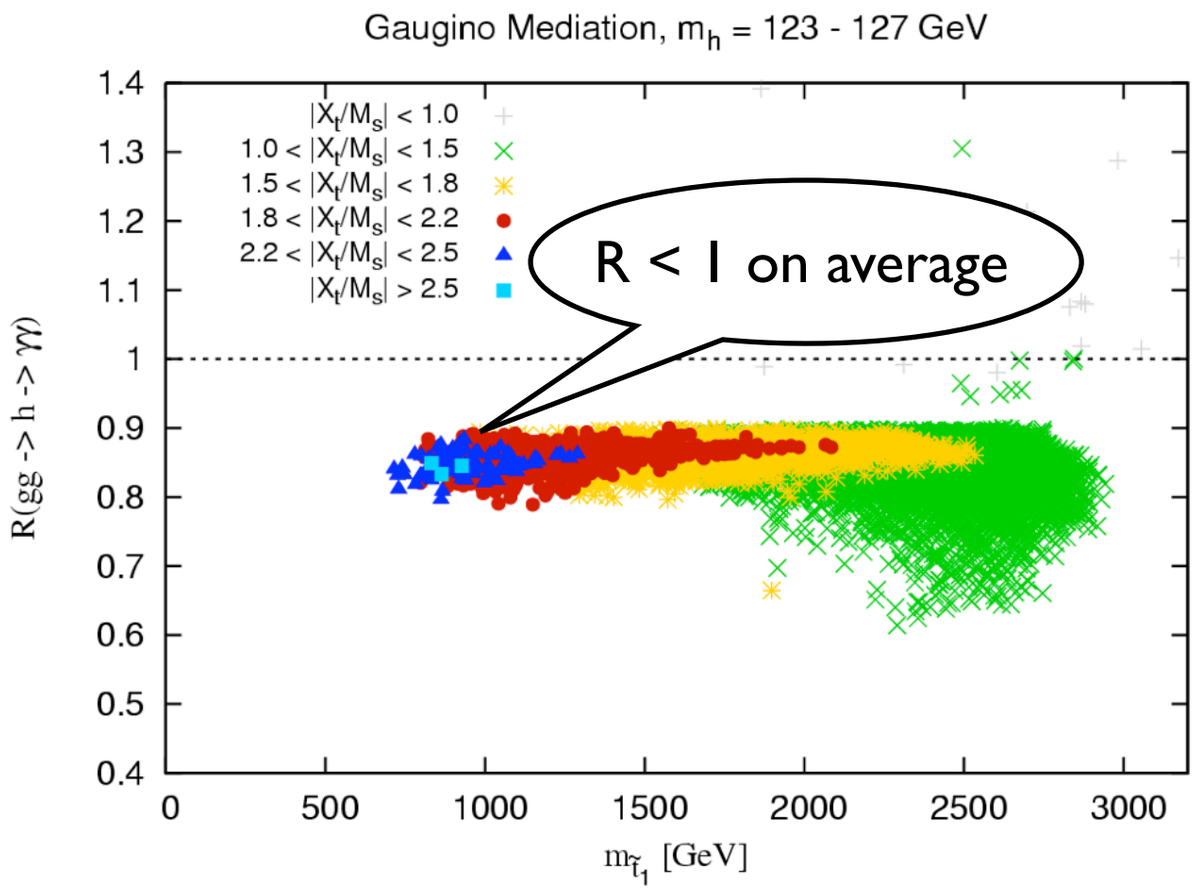

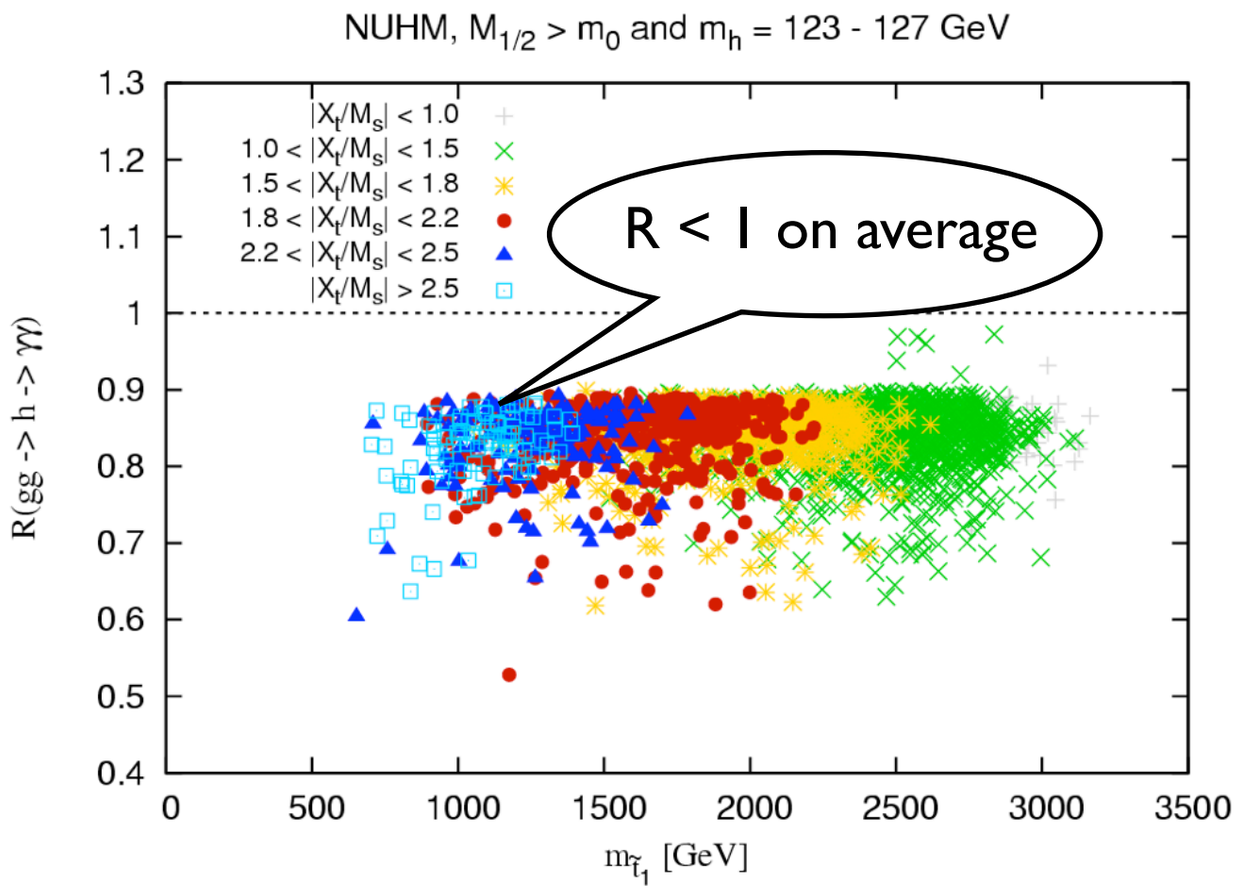

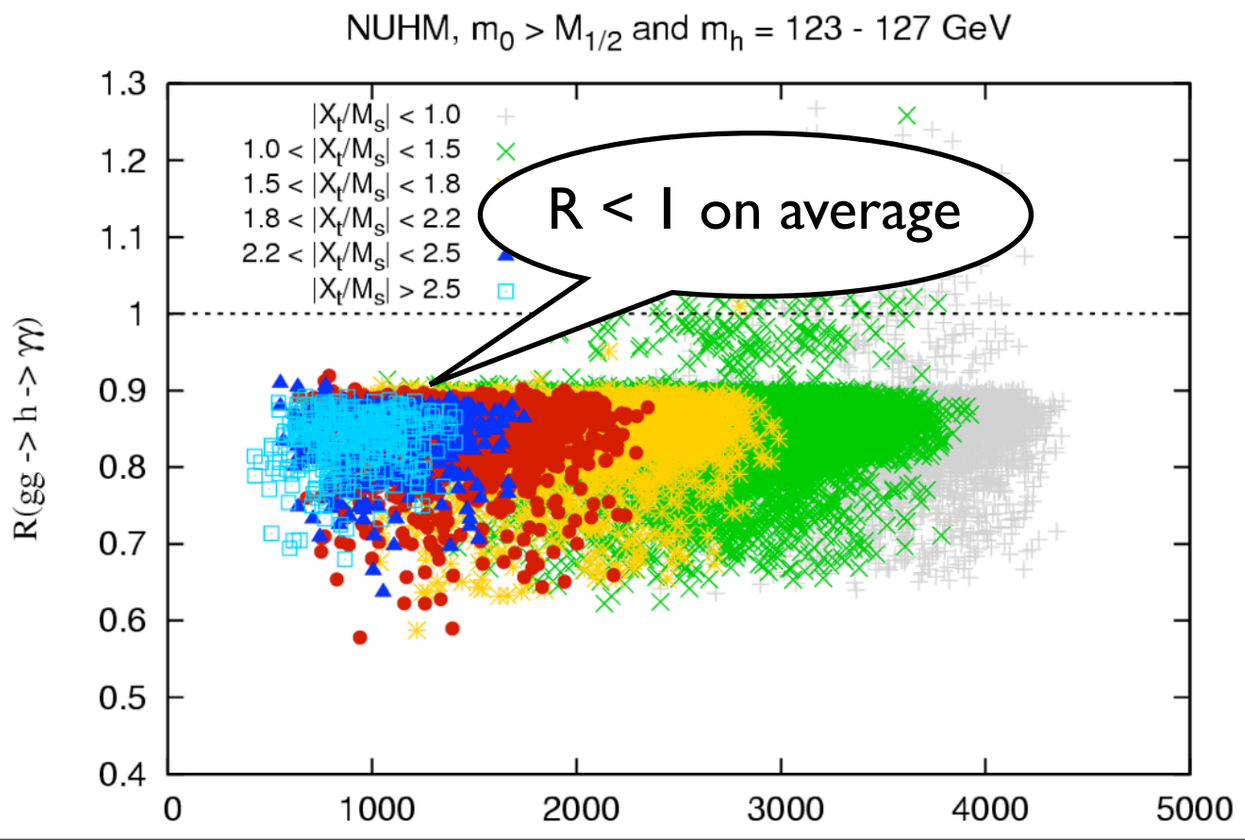

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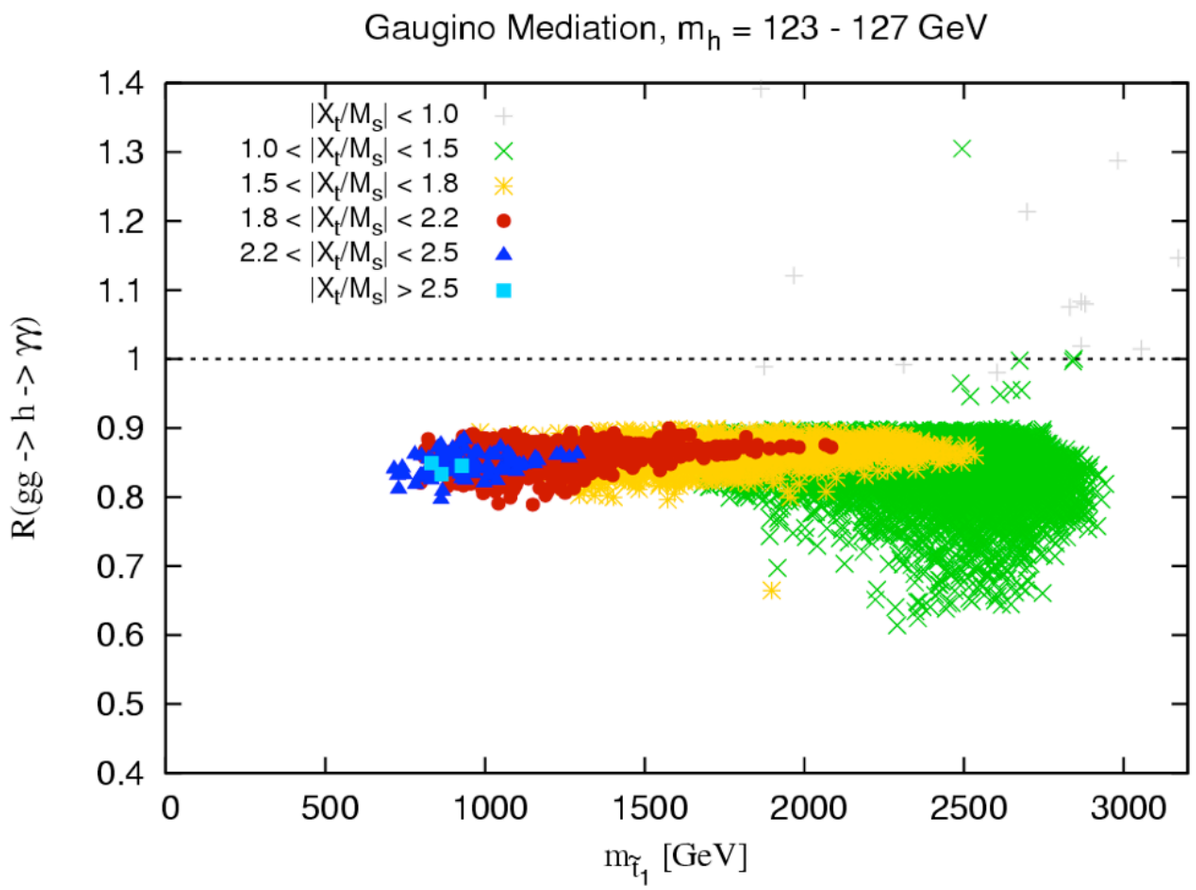

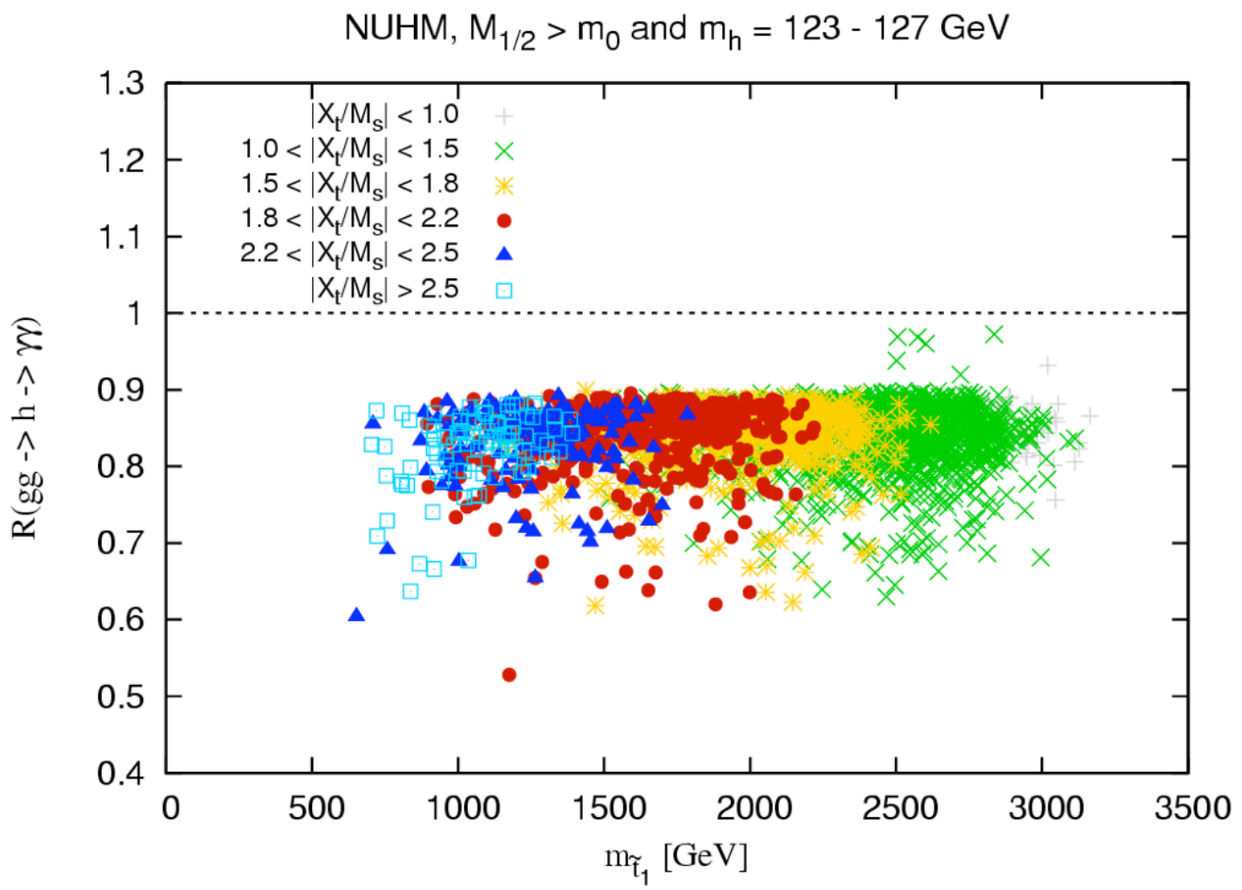

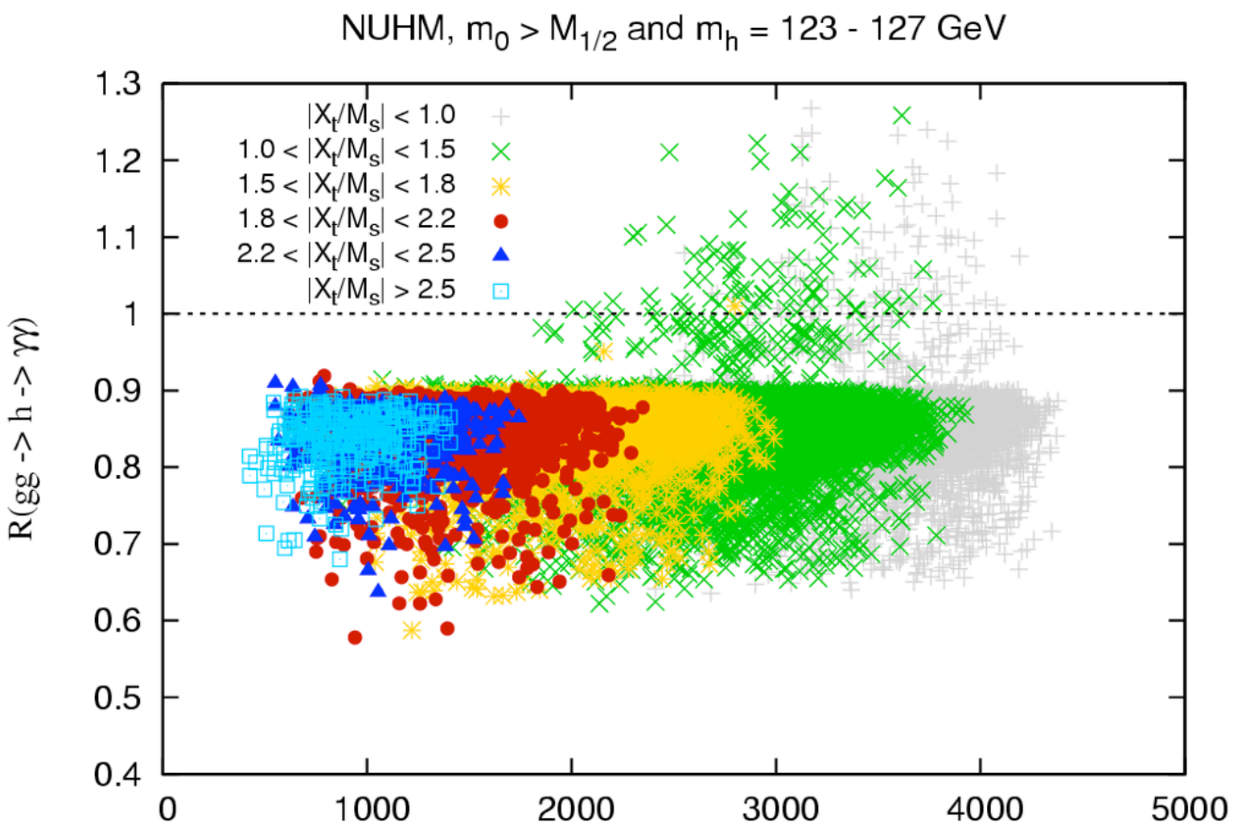

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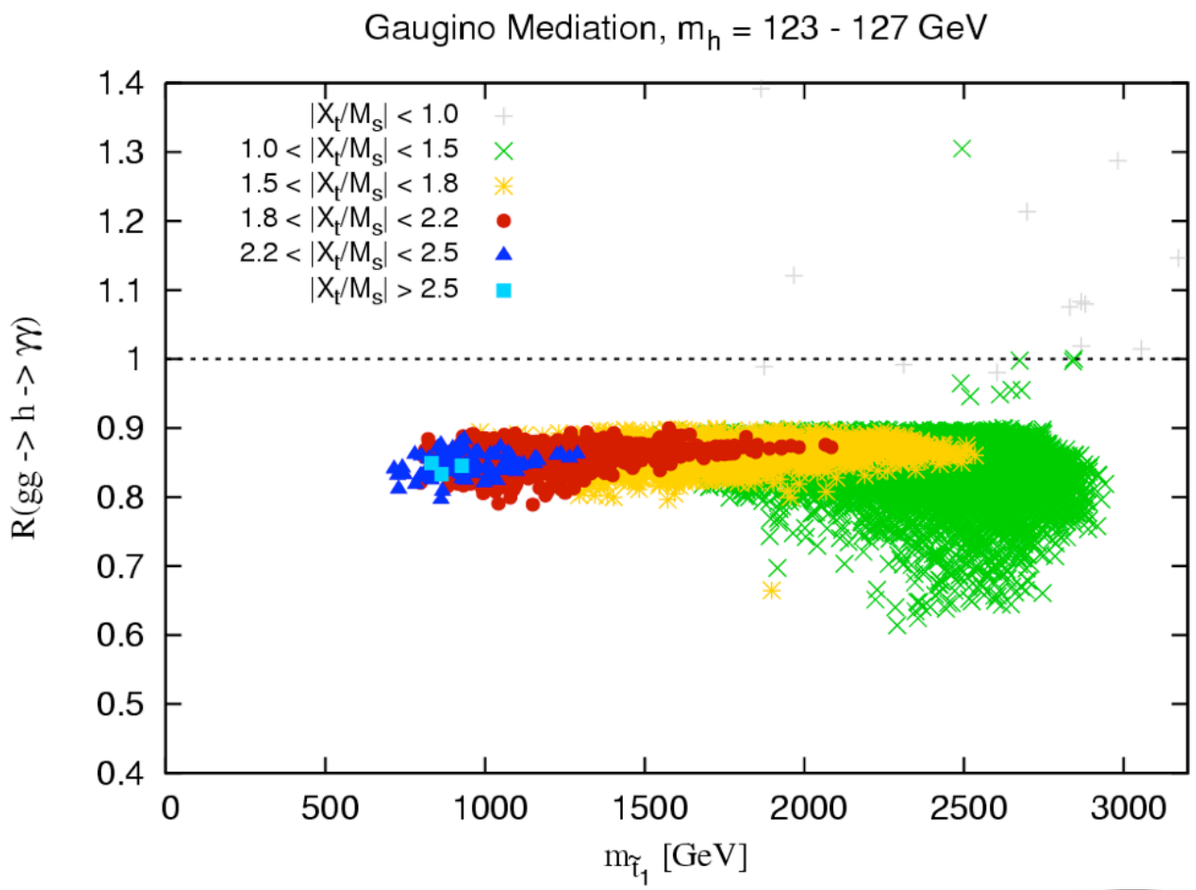

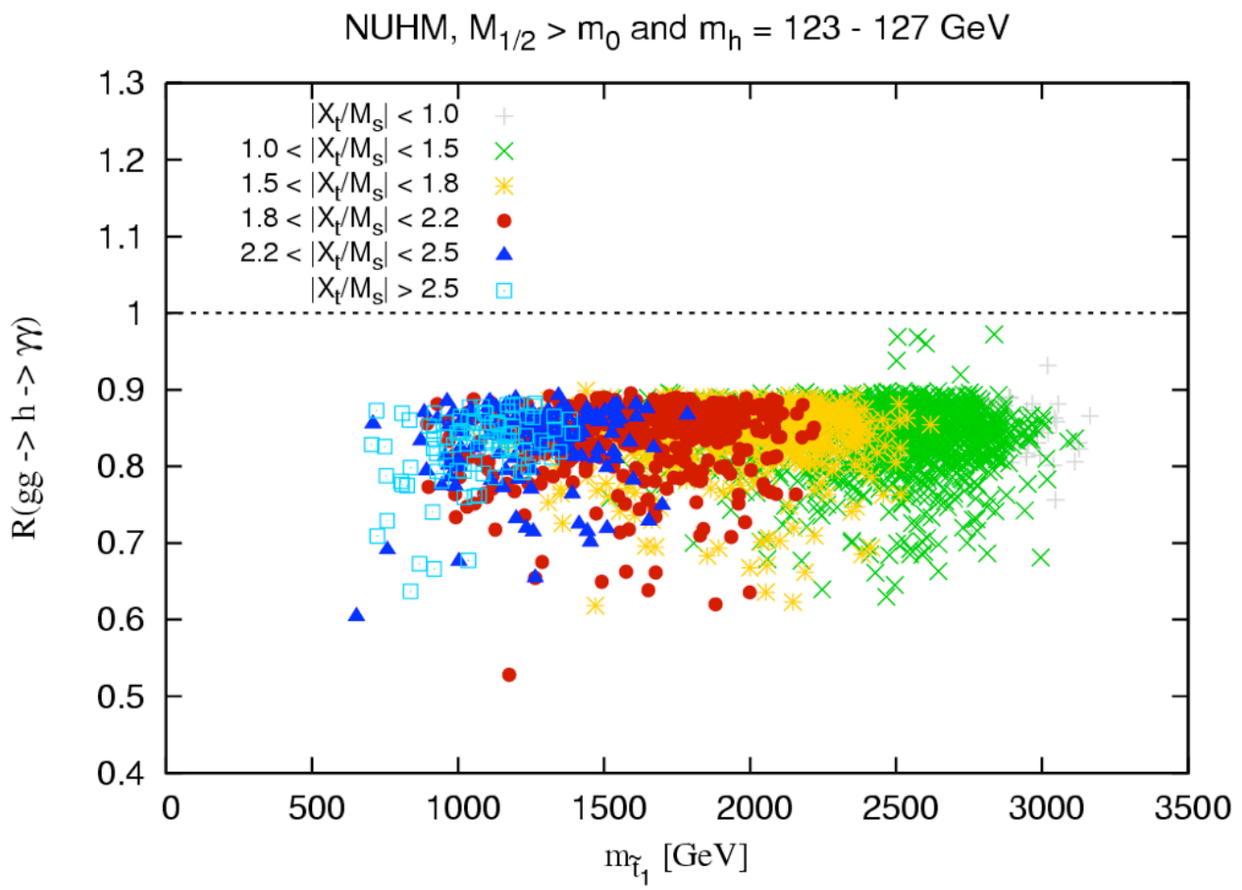

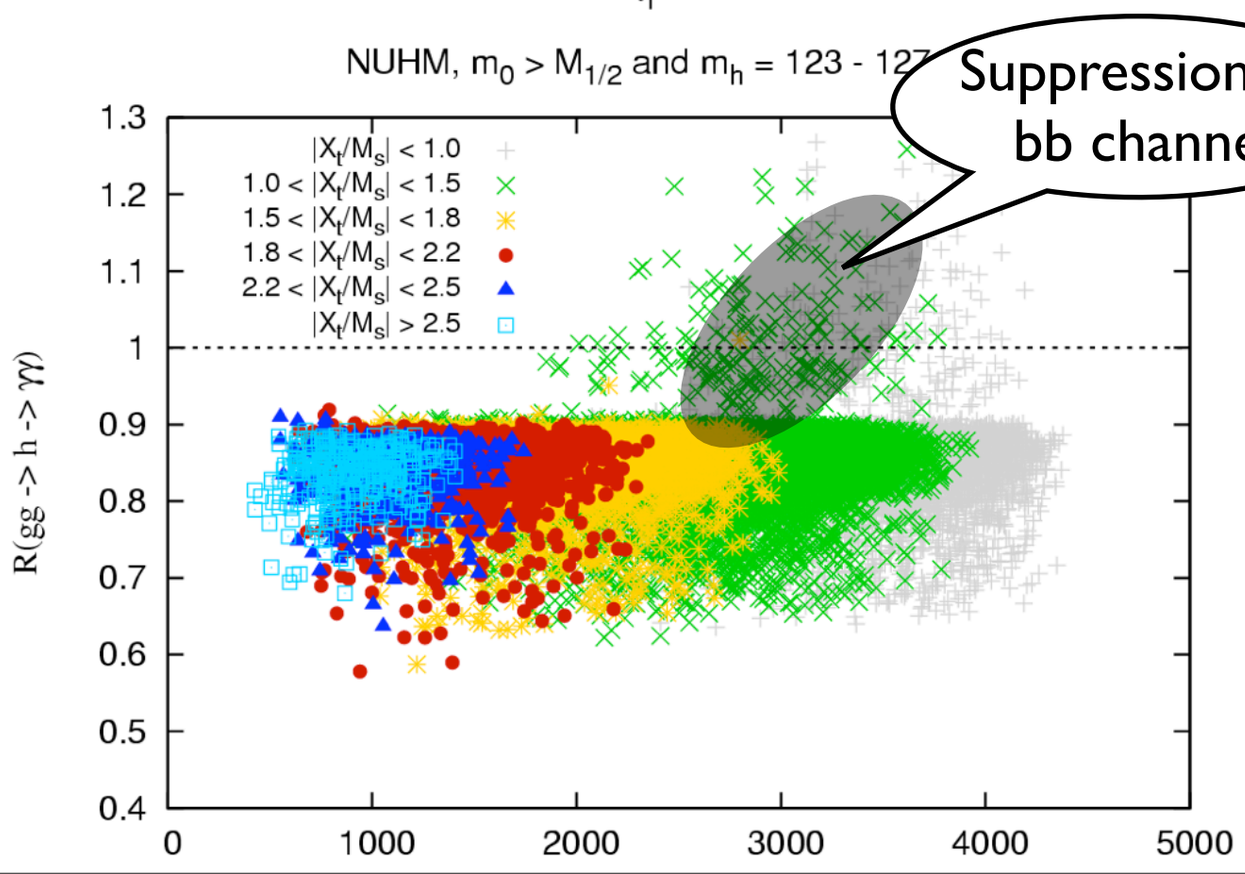

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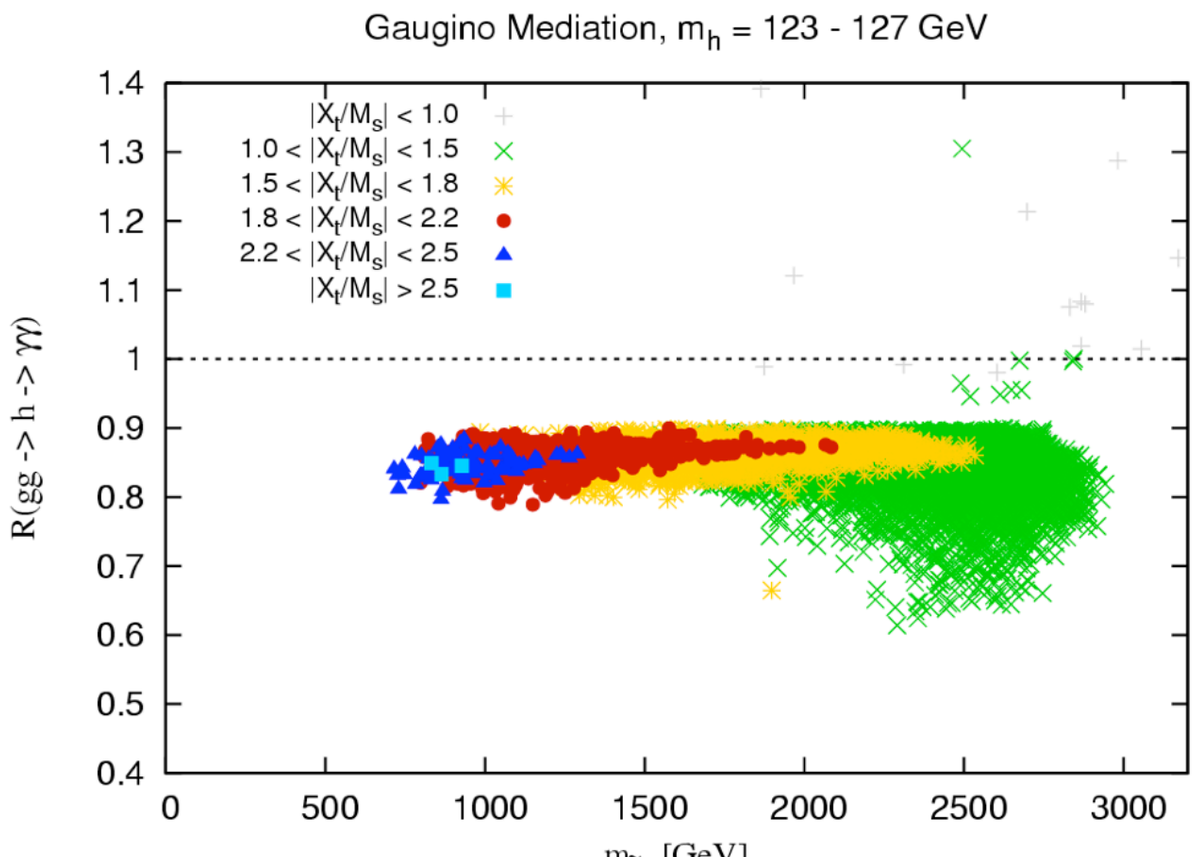

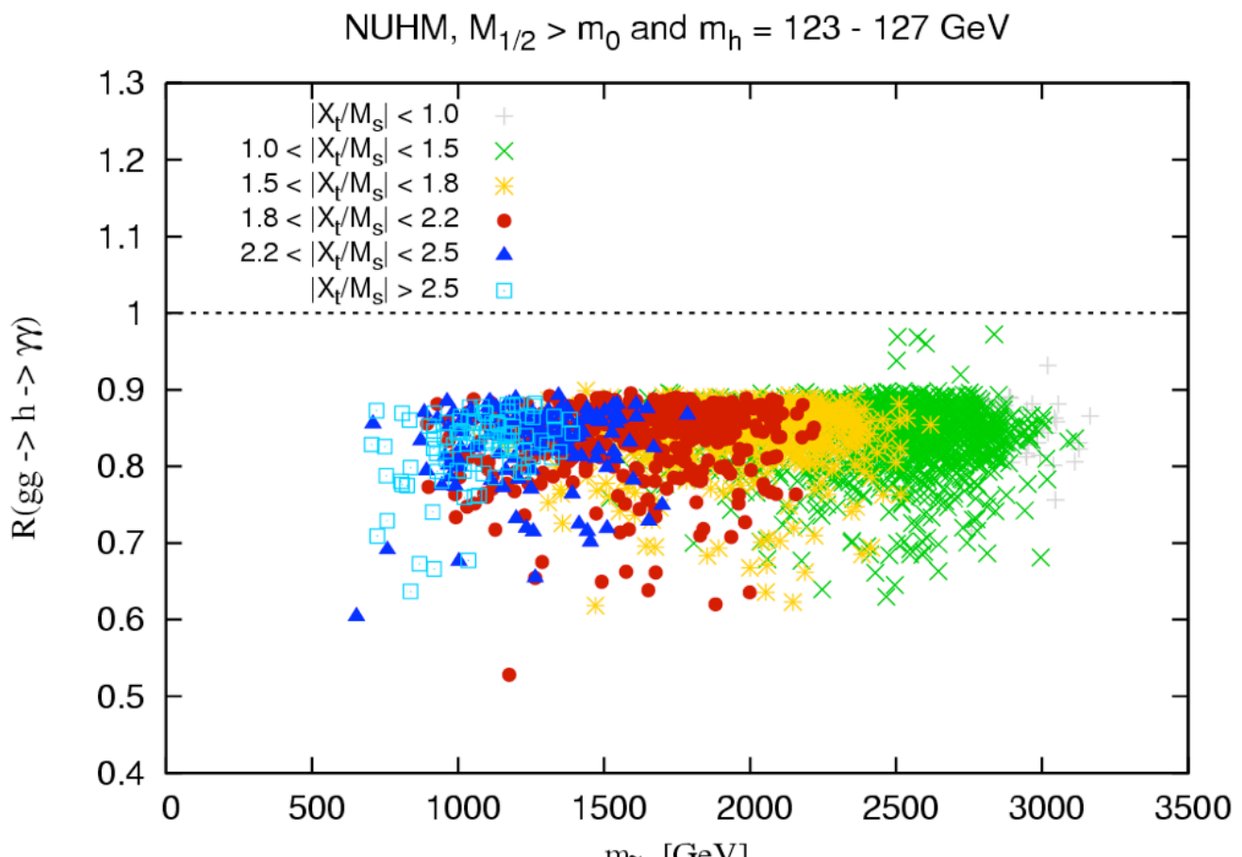

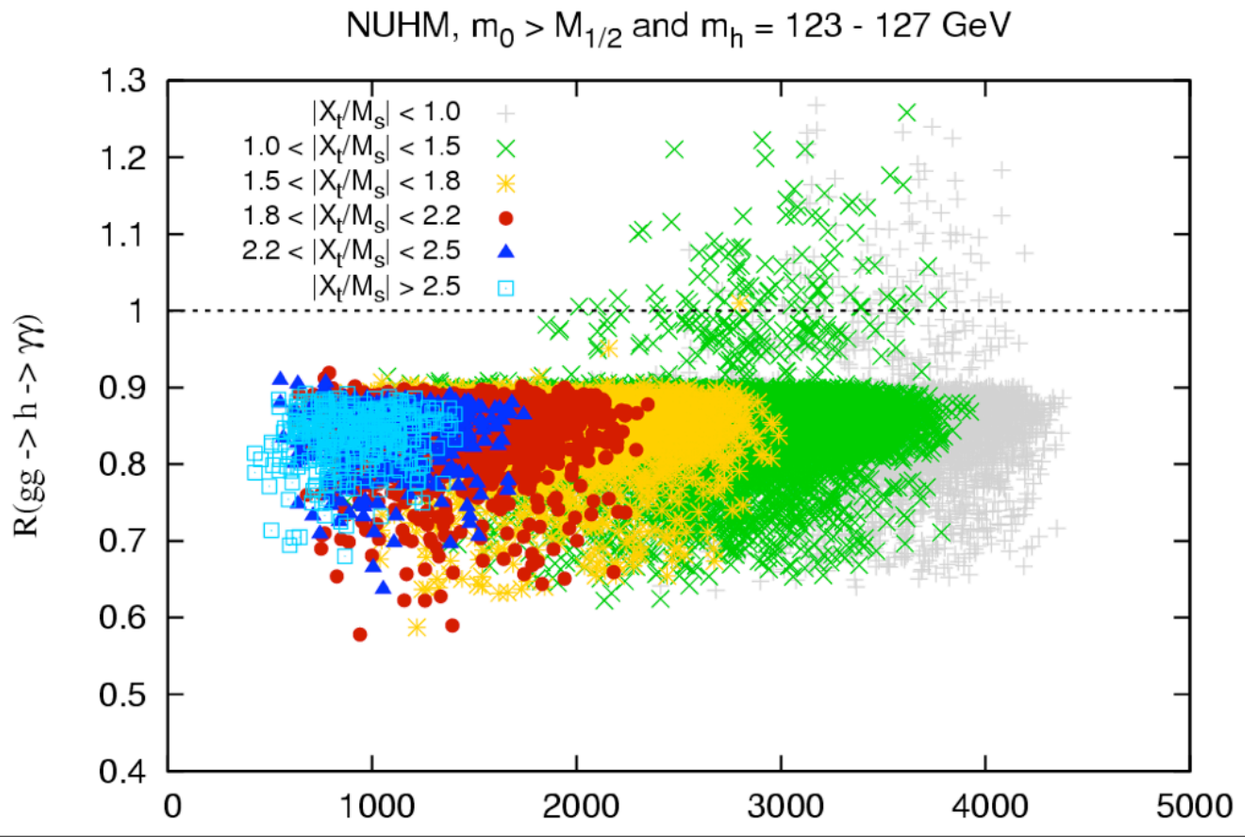

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- On average R < 1
- Enhancement results from suppression in bb channel

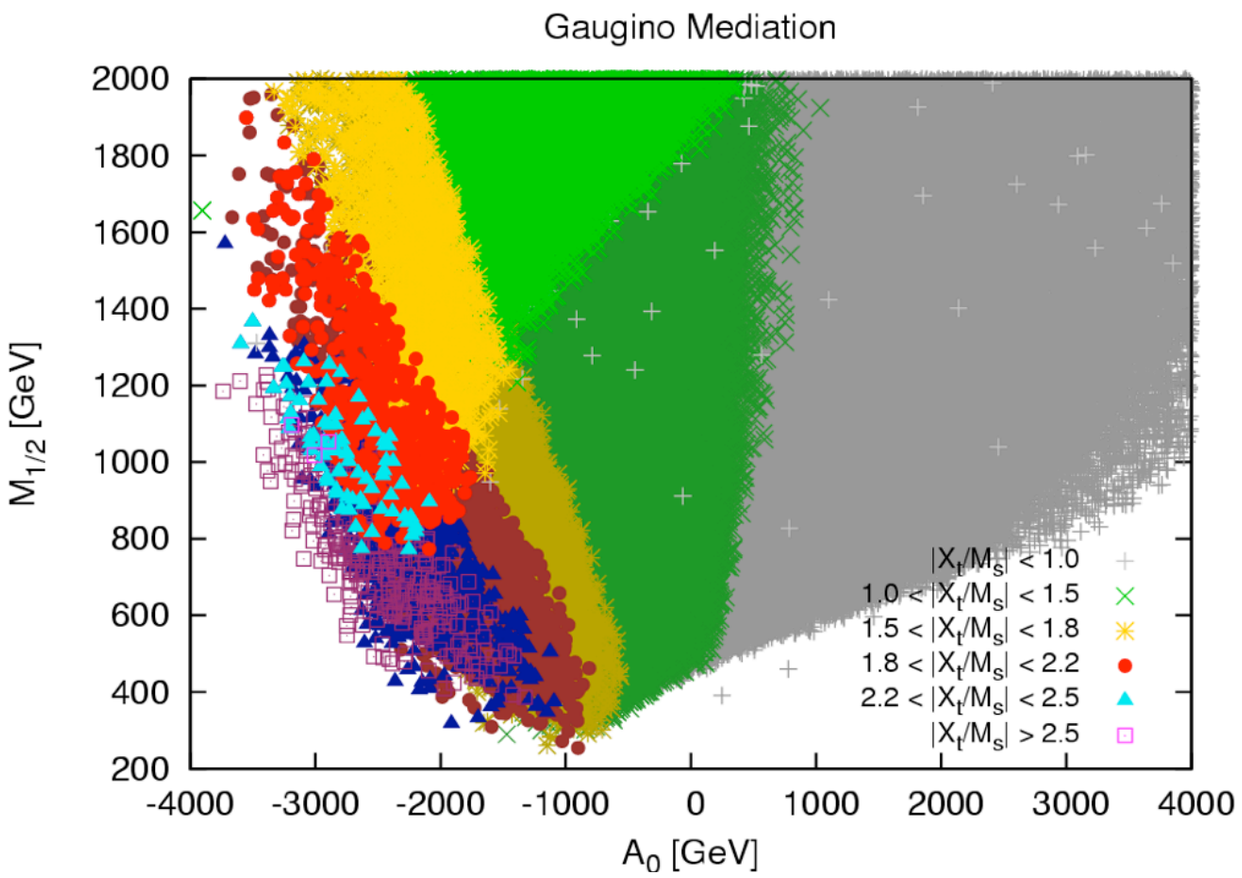
Conclusions

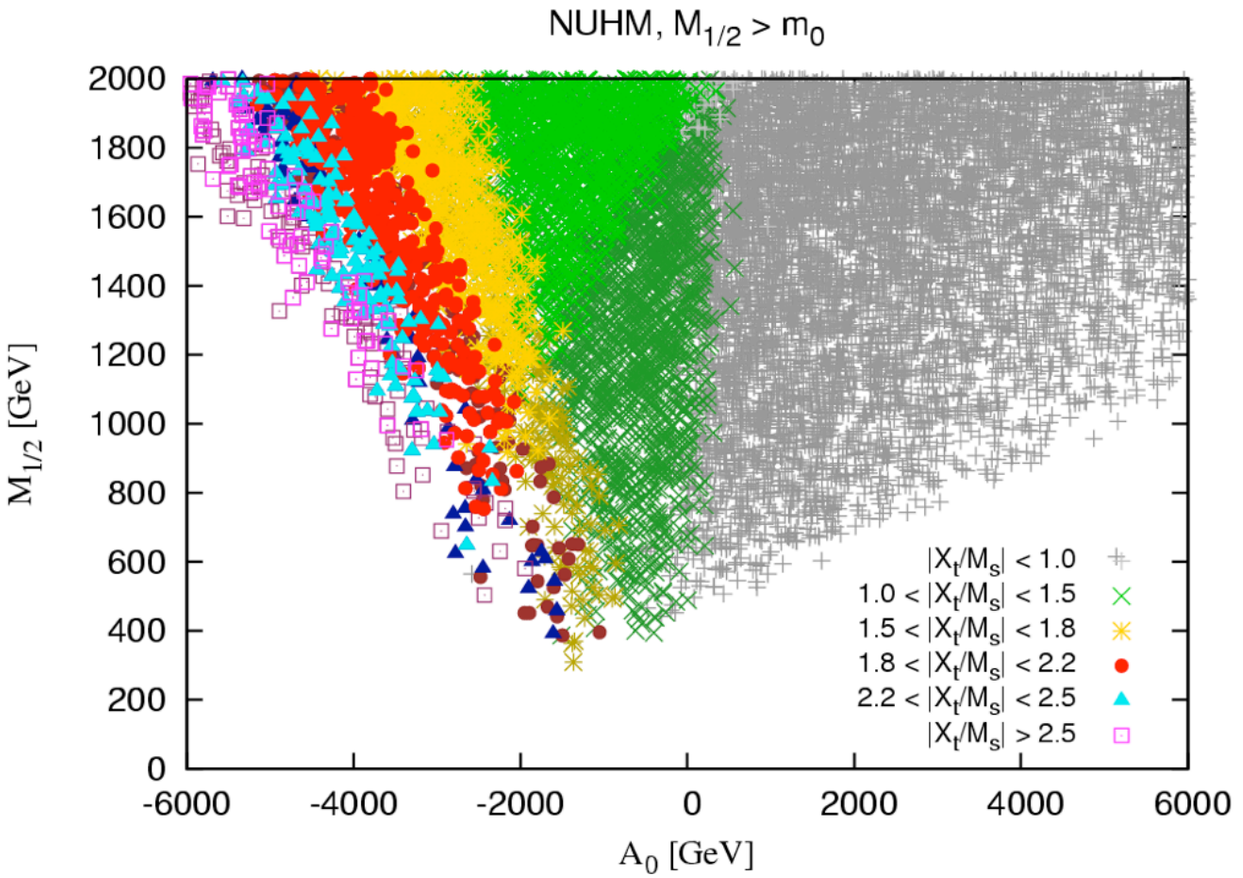
- If GUT models of SUSY are to explain the hints of Higgs signal with sub-TeV stops then maximal mixing is the only way
- This places non-trivial restrictions on GUT-scale parameters affecting the most, the Gaugino, the trilinear coupling and the third generation soft mass terms
- For models where all GUT-scale soft parameters are of the order gaugino mass or smaller, trilinear coupling must be large and negative at GUT-scale
- Maximal mixing does not single out a favorable scenario, but it does disfavor in their simplistic setup some class of models like gauge mediation and 5D radion mediation
- We studied two classes of models the Gaugino-Higgs mediation and the NUHM
- They can explain the desired Higgs mass with the help of maximal mixing and have interesting phenomenological consequences

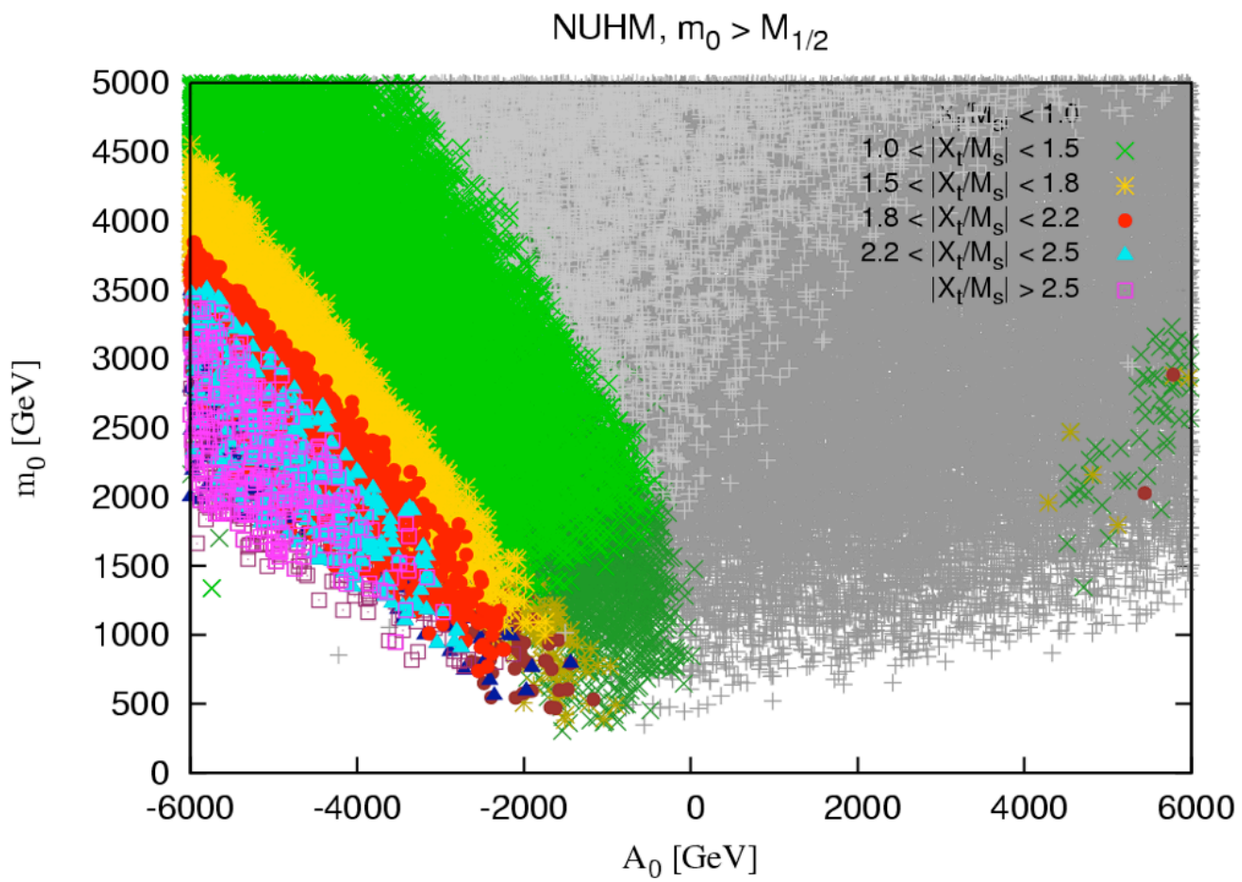
Thanks!

Back up

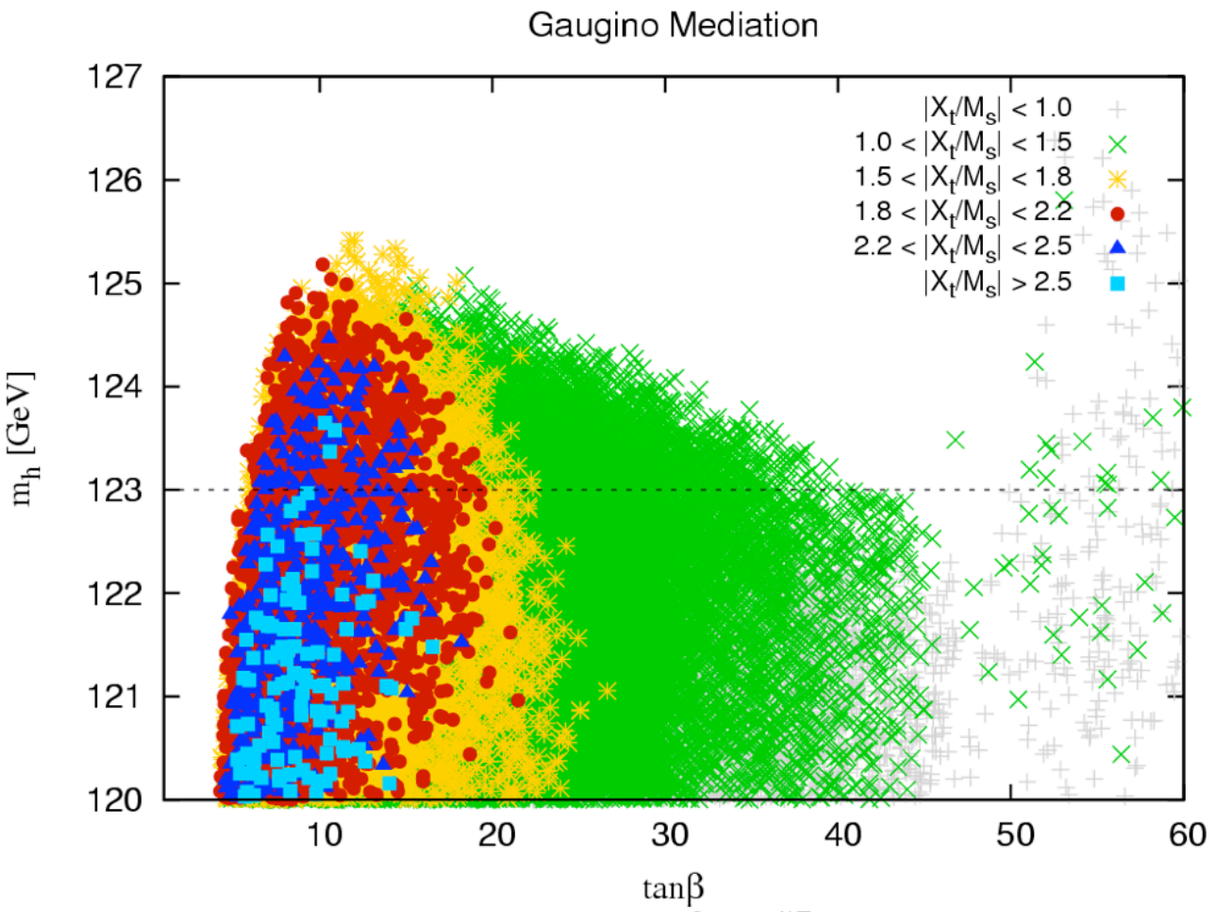
A0 - Mhf plots

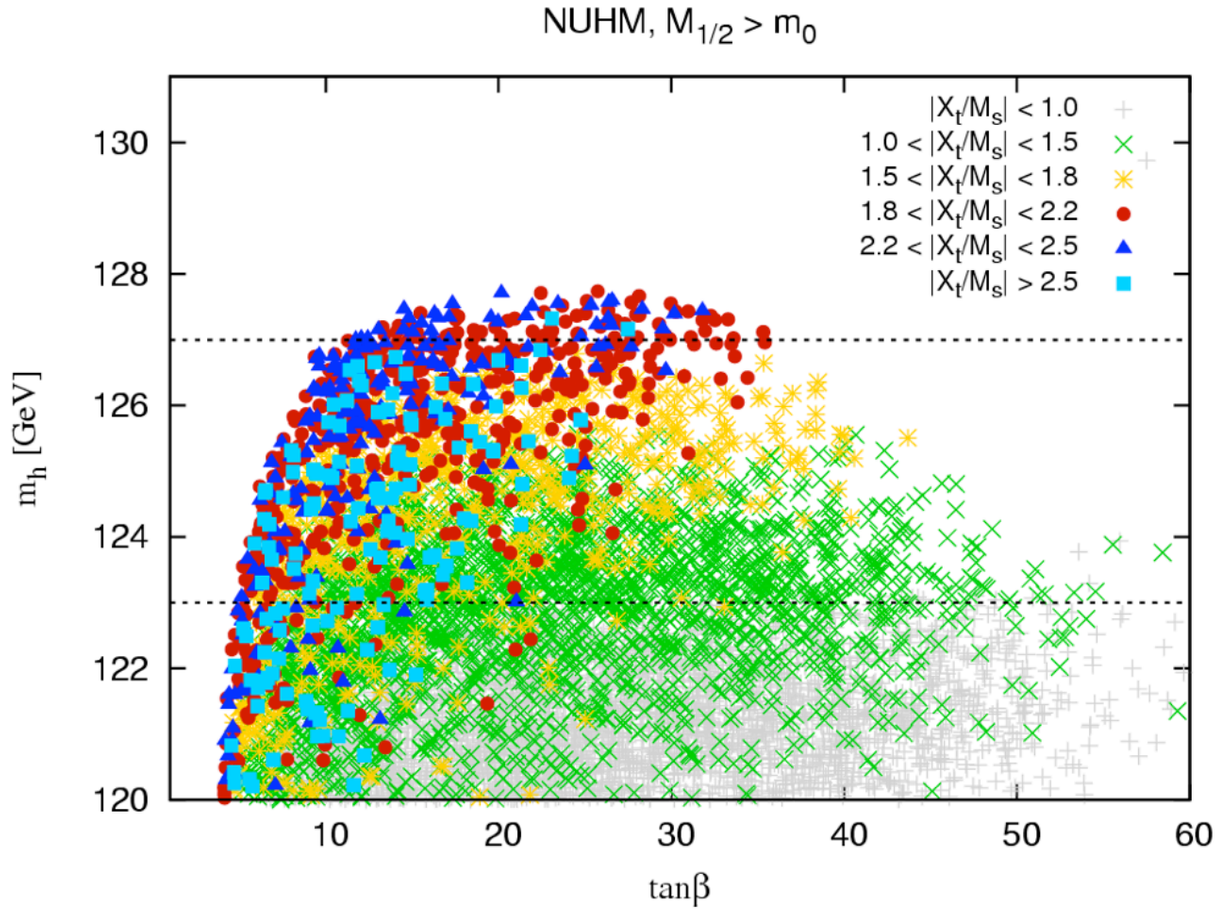

Gaugino Mediation
$M_{1/2}$ [GeV]
A_0 [GeV]
$|X_t/M_s| < 1.0$
$1.0 < |X_t/M_s| < 1.5$
$1.5 < |X_t/M_s| < 1.8$
$1.8 < |X_t/M_s| < 2.2$
$2.2 < |X_t/M_s| < 2.5$
$|X_t/M_s| > 2.5$

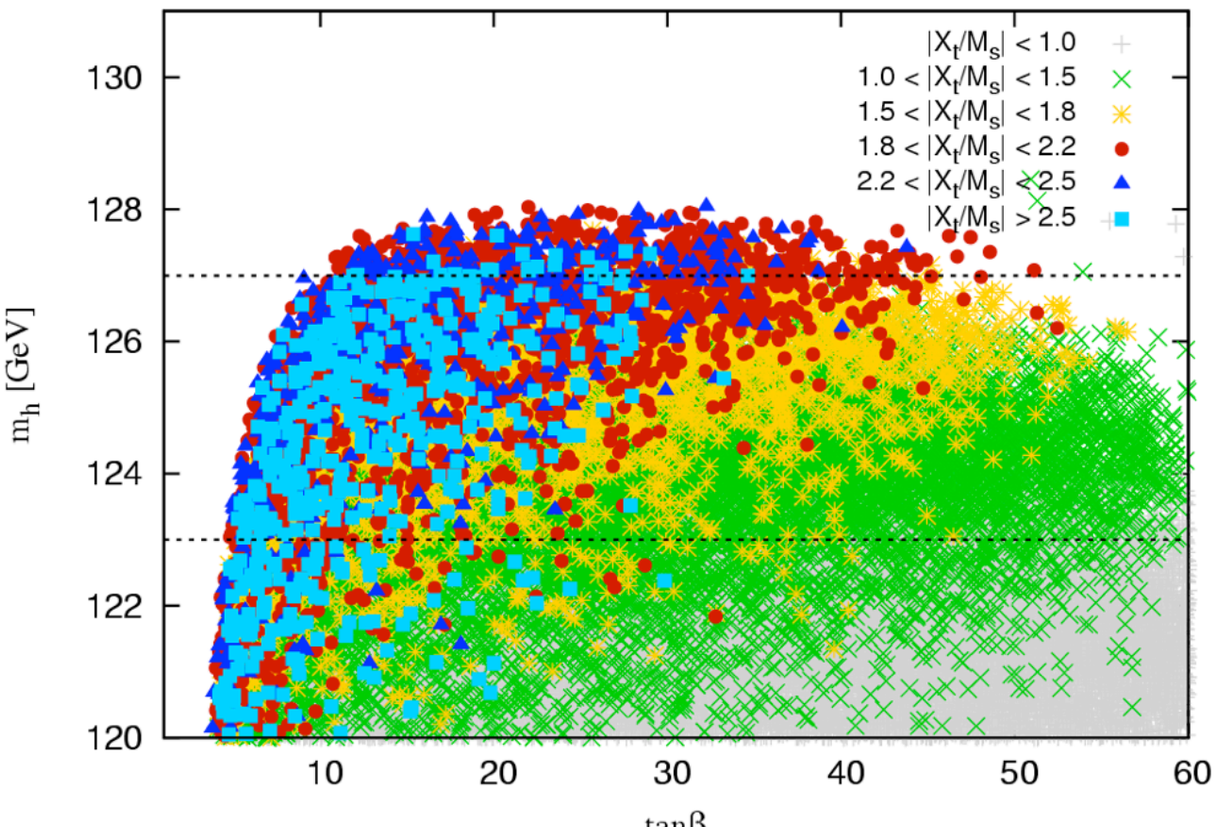

NUHM, $M_{1/2} > m_0$
$M_{1/2}$ [GeV]
A_0 [GeV]
$|X_t/M_s| < 1.0$
$1.0 < |X_t/M_s| < 1.5$
$1.5 < |X_t/M_s| < 1.8$
$1.8 < |X_t/M_s| < 2.2$
$2.2 < |X_t/M_s| < 2.5$
$|X_t/M_s| > 2.5$


NUHM, $m_0 > M_{1/2}$
m_0 [GeV]
A_0 [GeV]
$1.0 < |X_t/M_s| < 1.5$
$1.5 < |X_t/M_s| < 1.8$
$1.8 < |X_t/M_s| < 2.2$
$2.2 < |X_t/M_s| < 2.5$
$|X_t/M_s| > 2.5$

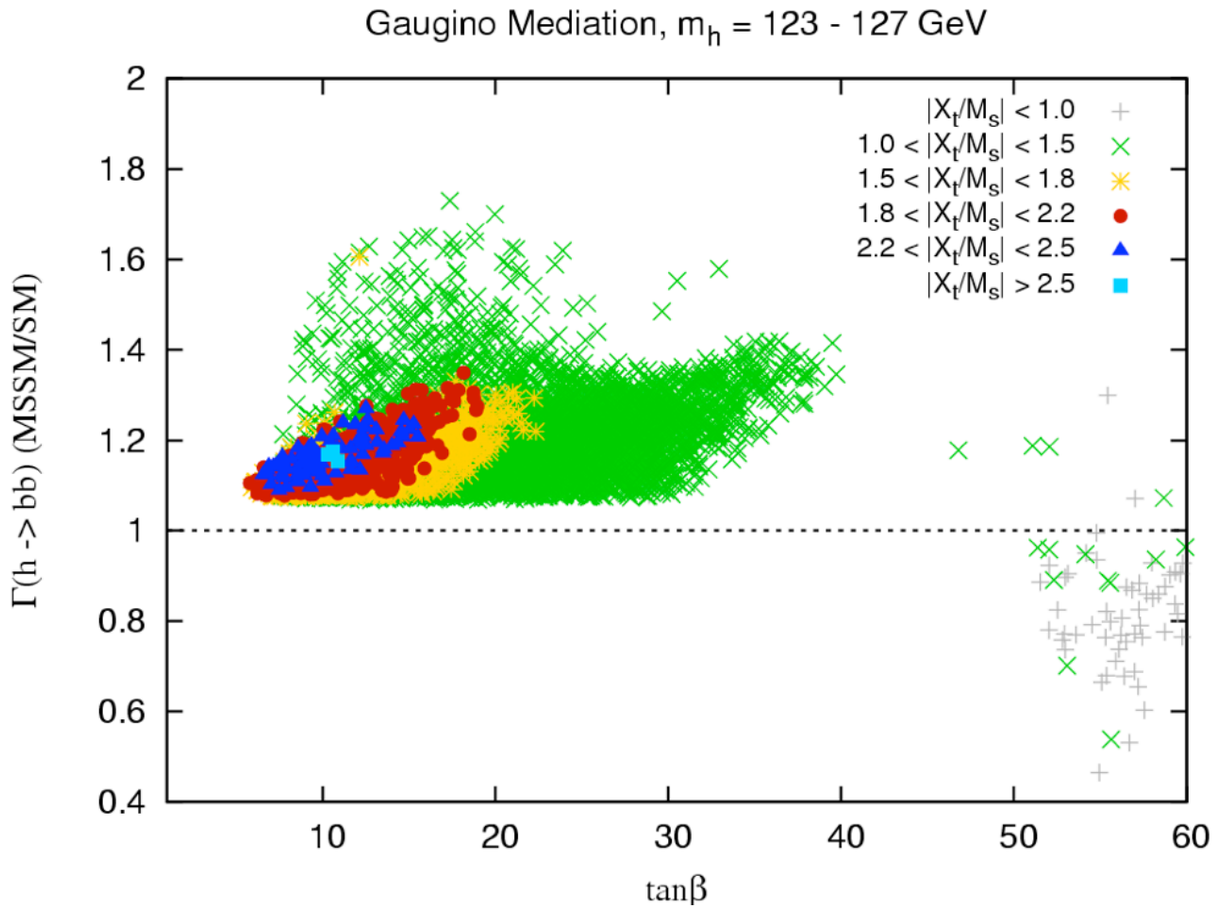
mh - tan beta plots

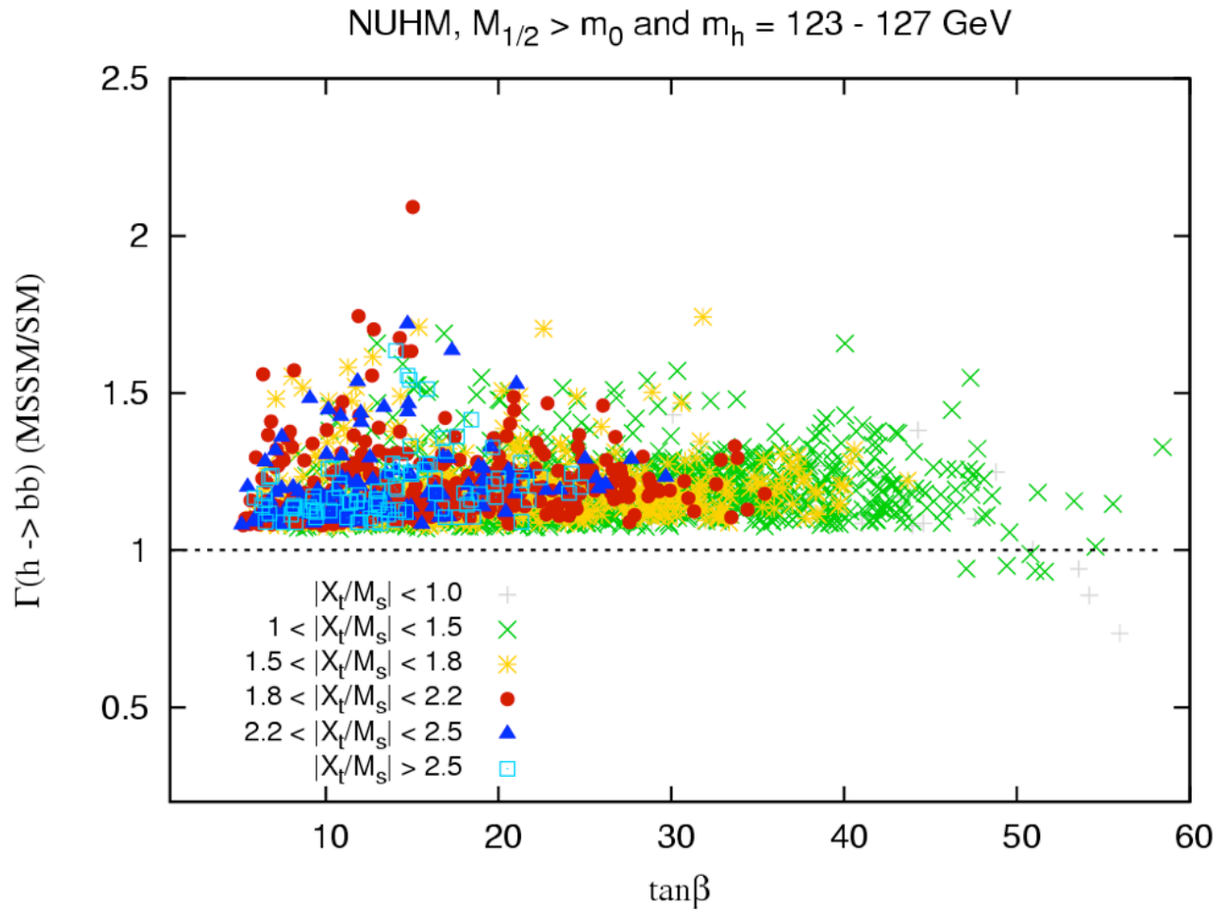


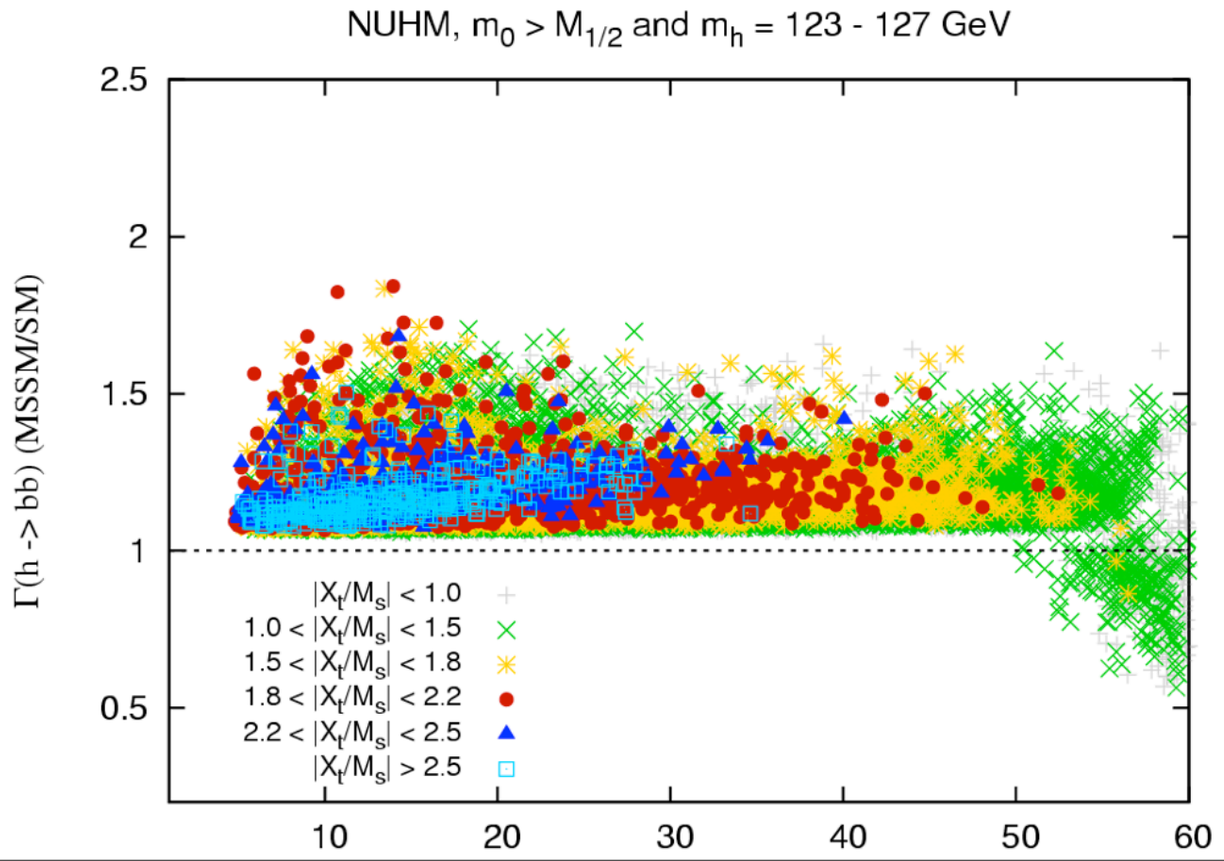




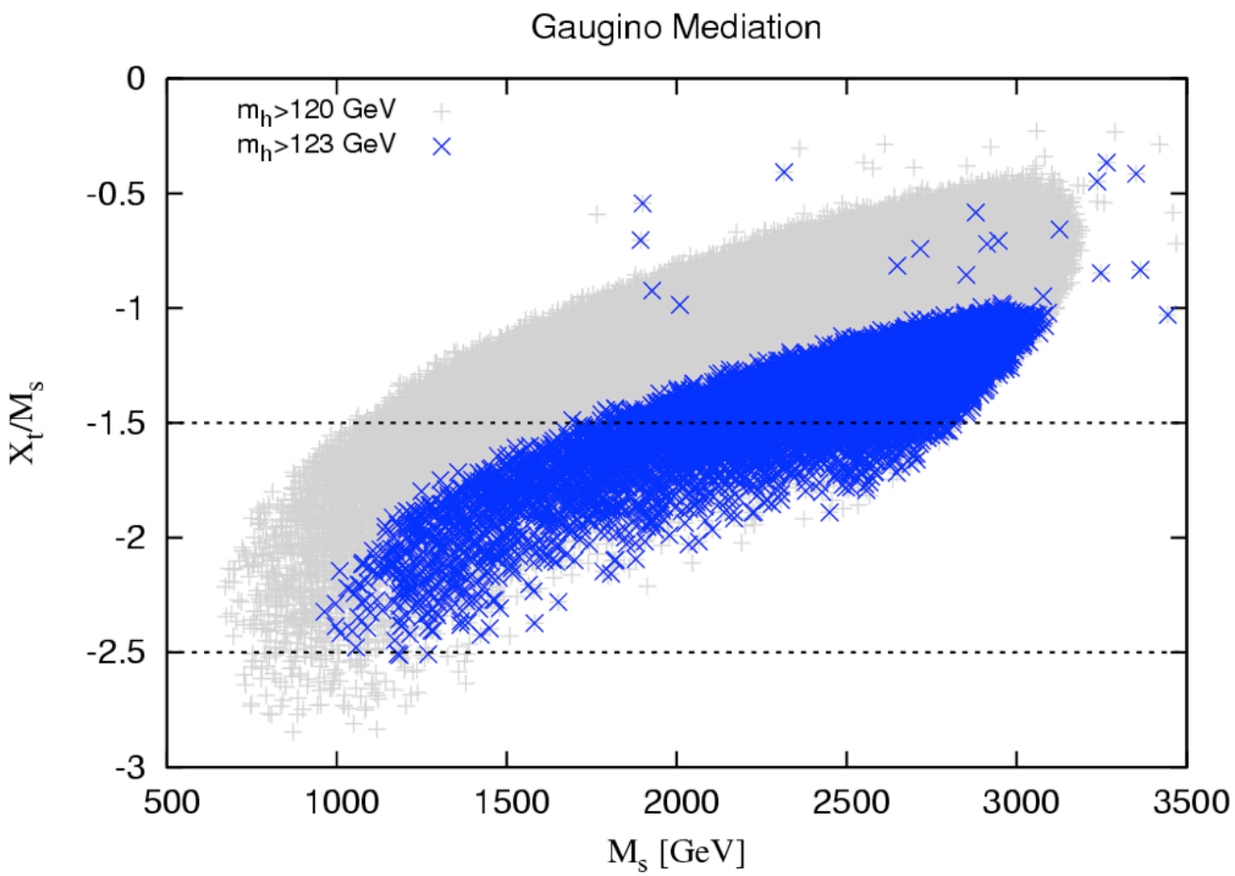
Gbb supression

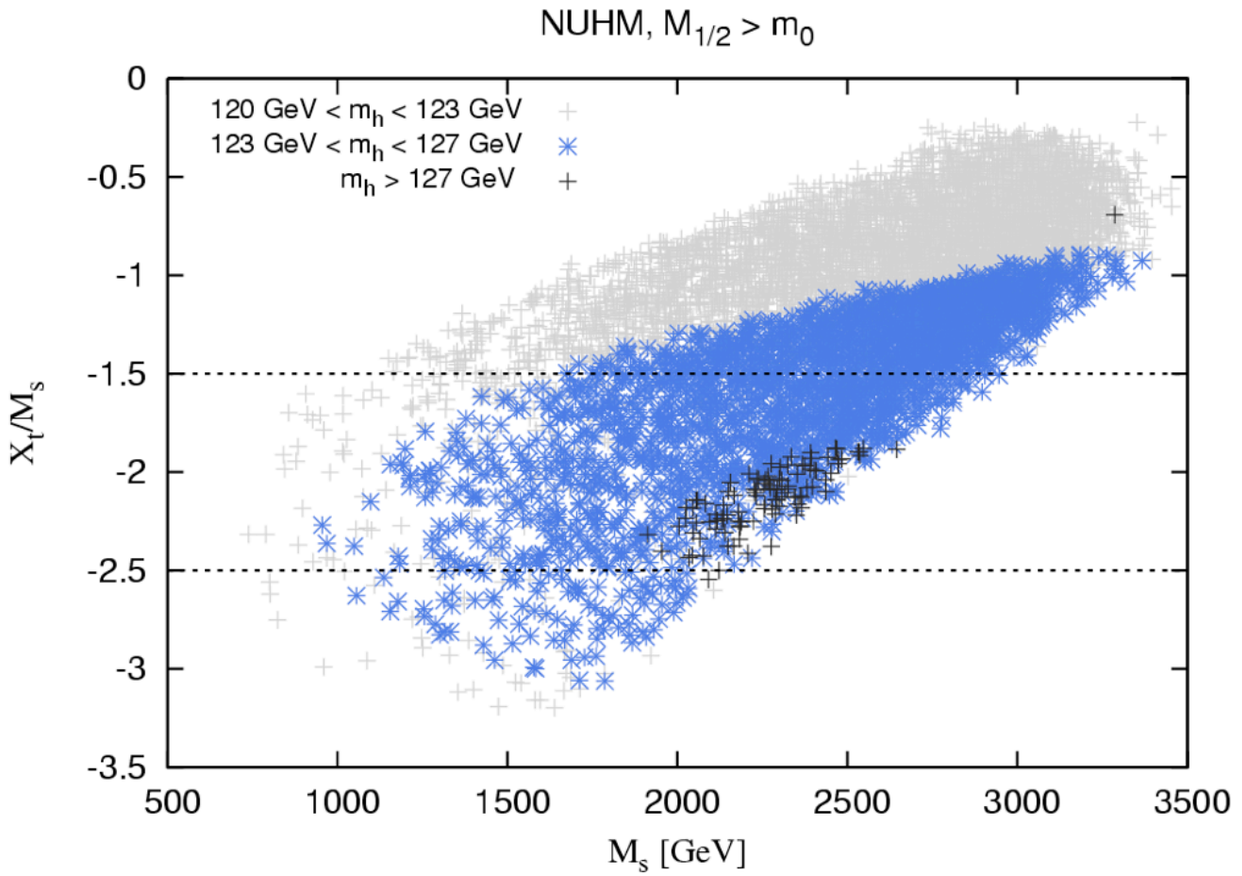


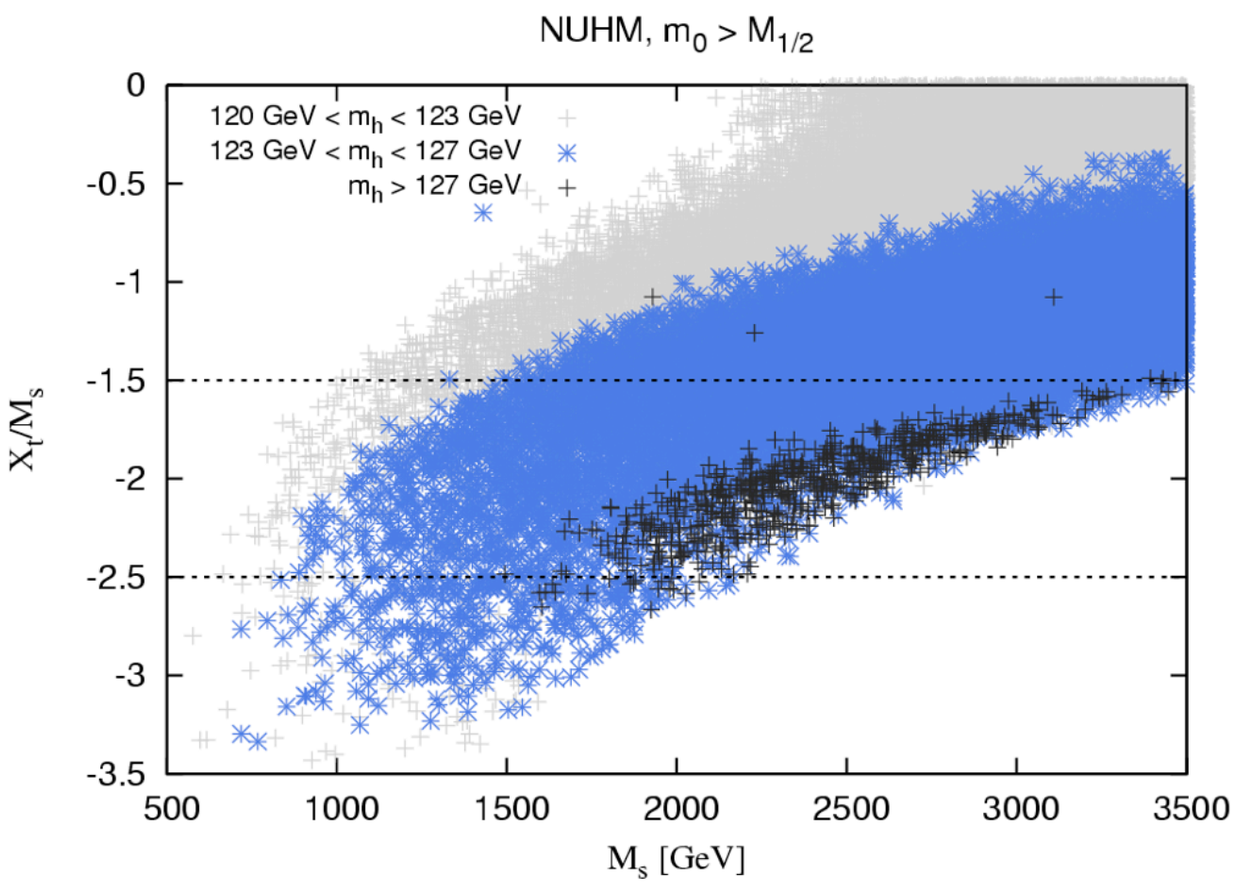




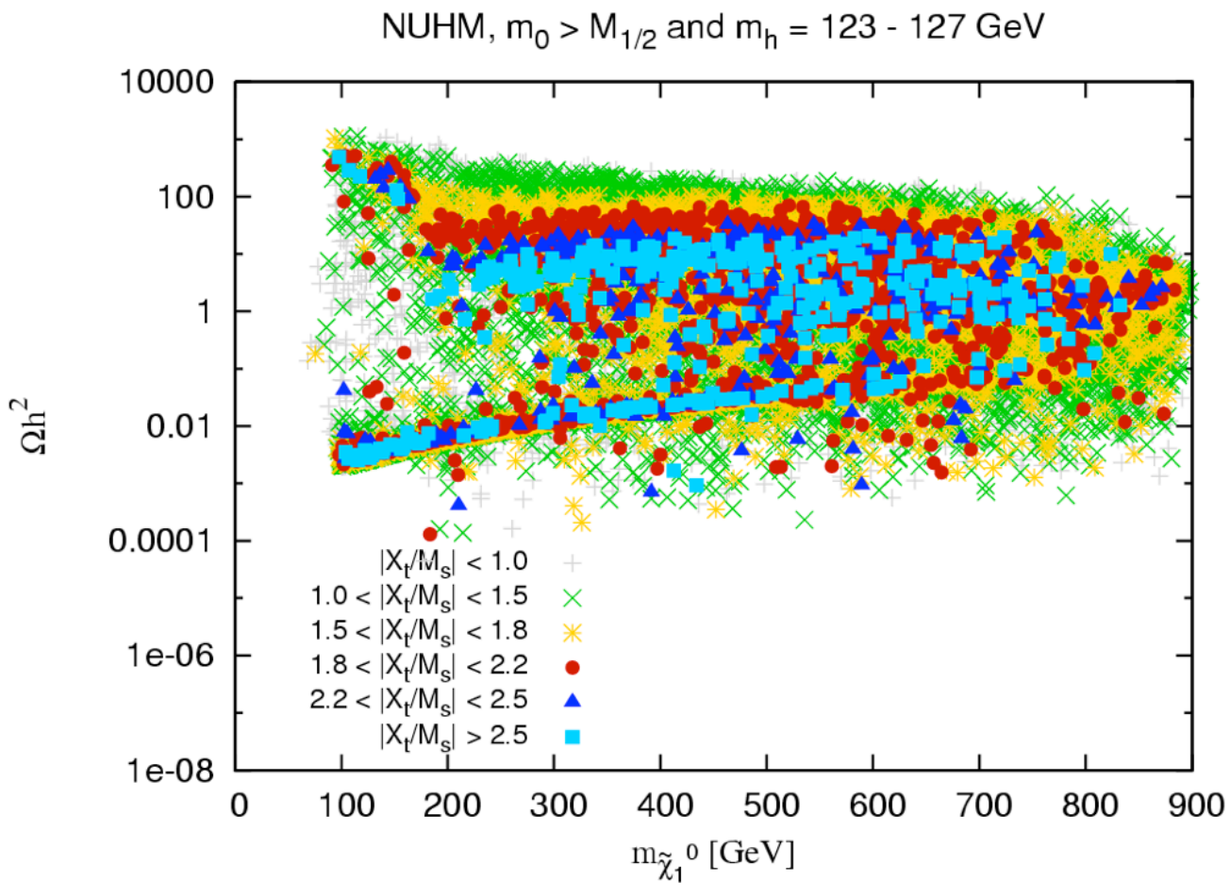
Msusy against mixing plots

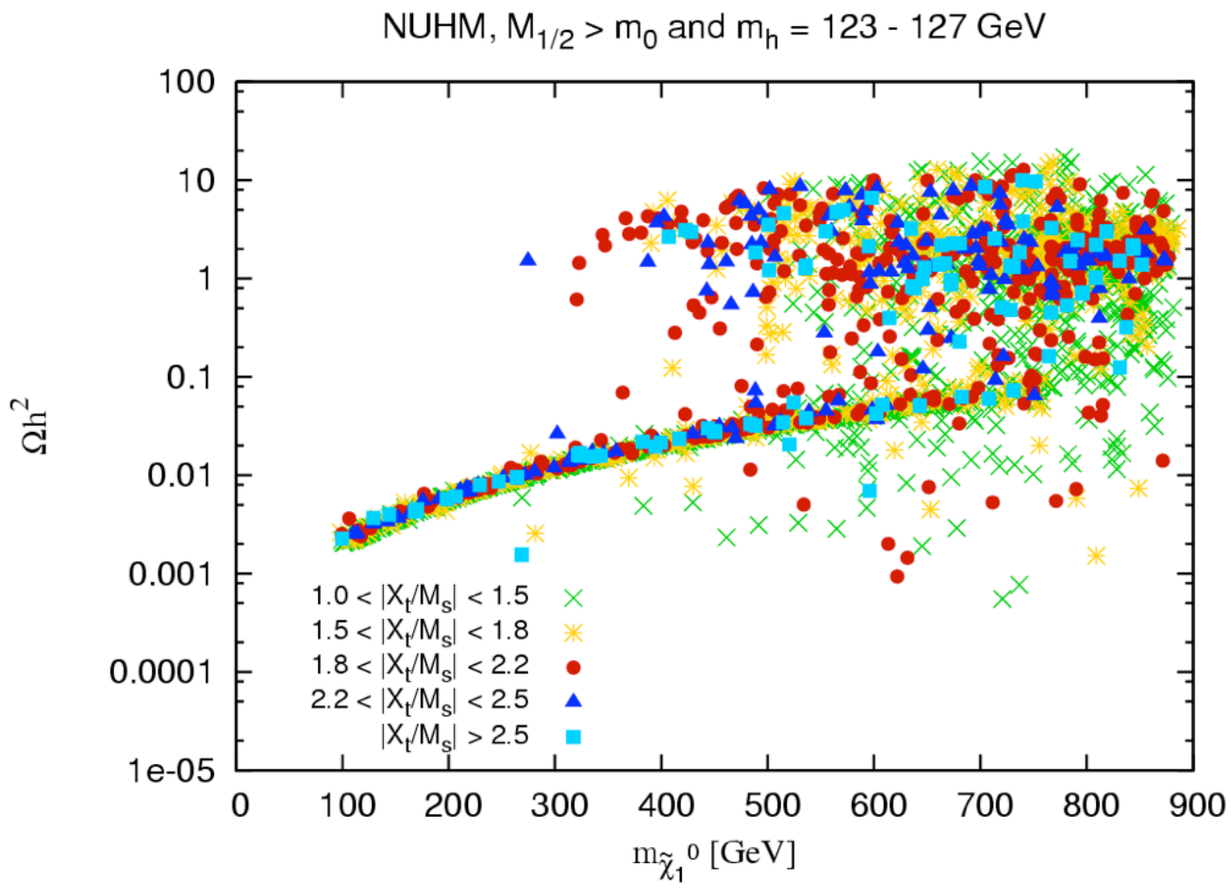




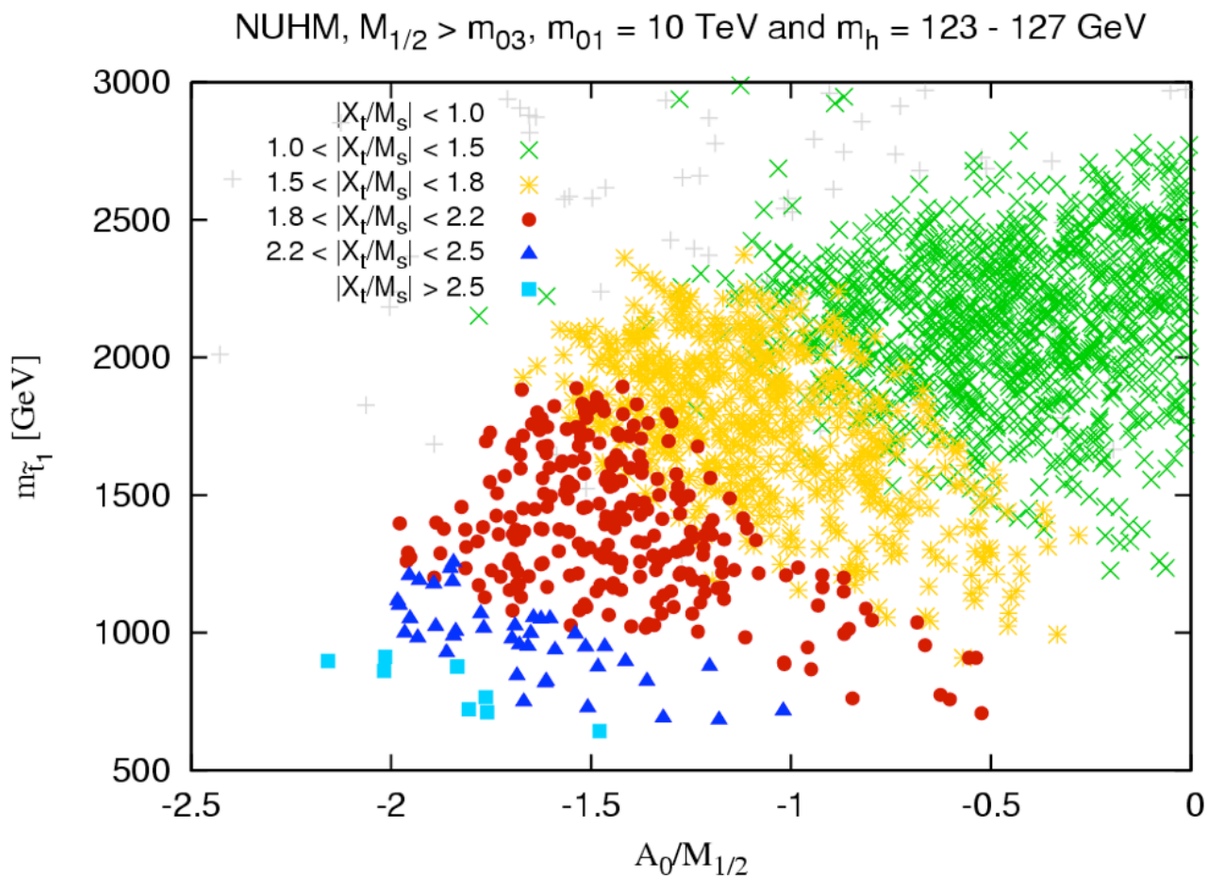


NUHM relic density analysis





Multi-TeV first two generation



- Two loop effects allow for much lower A0/Mhf ratio

Model analysis - 5D Radion mediation

- The F-term breaking operator is T M / (2R)
  - M - 5D Planck mass,
- Trilinear coupling receives contribution from origin of Higgs field and localization of matter fields
- Rough analysis:
  - Gauge-Higgs unified models:
    - Higgs originates from 5D Gauge multiplet and contributes

$$\Delta \widehat{A}_t = -\frac{F^T}{2R}$$

    - The third generation matter fields originate from 5D hypermultiplets and each contribute

$$\Delta \widehat{A}_t = \frac{F^T}{2R}$$

$$\Rightarrow \widehat{A}_t = +M_{1/2}$$

- When matter fields are completely brane localized, the Yukawa couplings vanish