95 GeV scalar and dark matter in the MRSSM

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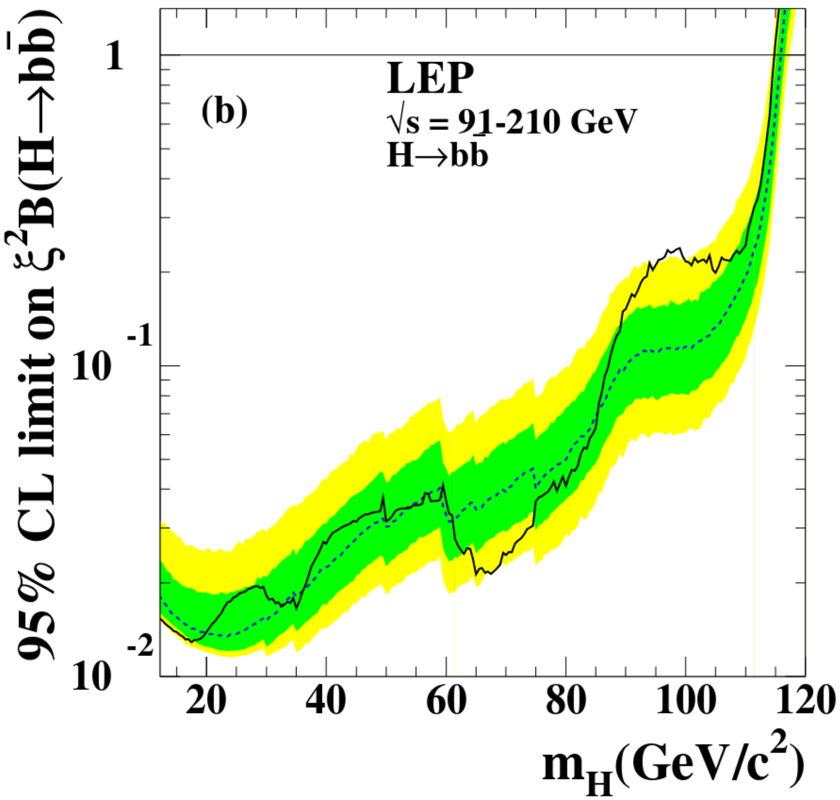
LEP hints of a 95 GeV scalar

- Higgsstrahlung excess in the $b\bar{b}$ channel [arXiv:0306033]
- Can be accommodate by a intermediate state ϕ [arXiv:1612.08522]

$$\mu_{b\bar{b}}^{\mathrm{LEP}} = \frac{\sigma^{exp}(e^+e^- \to Z\phi \to Zb\bar{b})}{\sigma^{\mathrm{SM}}(e^+e^- \to ZH \to Zb\bar{b})} = 0.117 \pm 0.057$$



LHC hints of a 95 GeV scalar

- Recent ATLAS result based on the full Run 2 data set

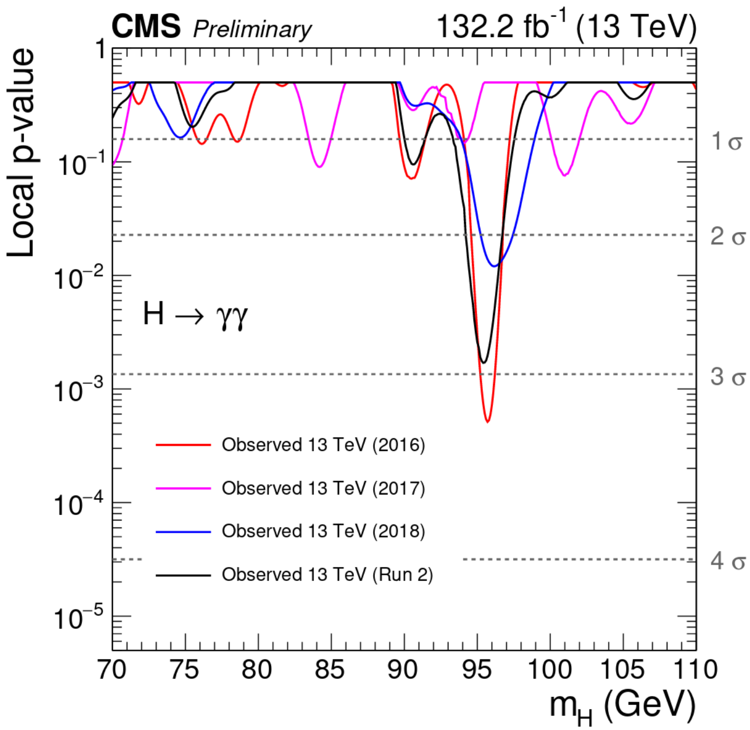
$$\mu_{\gamma\gamma}^{\text{ATLAS}} = \frac{\sigma^{\text{exp}}(pp \to \phi \to \gamma\gamma)}{\sigma^{\text{SM}}(pp \to H \to \gamma\gamma)} = 0.18^{+0.10}_{-0.10}$$

- Consistent with the already existing CMS excess

$$\mu_{\gamma\gamma}^{\text{CMS}} = \frac{\sigma^{\text{epx}}(pp \to \phi \to \gamma\gamma)}{\sigma^{\text{SM}}(pp \to H \to \gamma\gamma)} = 0.33^{+0.19}_{-0.12}$$

- Combined (Biekotter, Heinemeyer, Weiglein [arXiv:2306.03889])

$$\mu_{\gamma\gamma}^{\text{ATLAS + CMS}} = 0.24^{+0.09}_{-0.08}$$



Generic setup

- Mostly gauge singlet state

$$h_1 = \frac{1}{\sqrt{10}} h_{\rm SM} + \dots$$

with mass 95.4 GeV. Such composition solves this

$$\mu_{b\bar{b}}^{\rm LEP} = \frac{\sigma^{\rm BMS}(e^+e^- \to Zh_1 \to Zb\bar{b})}{\sigma^{\rm SM}(e^+e^- \to ZH \to Zb\bar{b})} \approx 0.1$$

- But it equally (by a factor 1/10) suppreses

$$\mu_{\gamma\gamma} = \frac{\sigma^{\rm BSM}(pp \to h_1 \to \gamma\gamma)}{\sigma^{\rm SM}(pp \to H \to \gamma\gamma)} \approx 0.1$$

- You need a way to enhance

$$\mathrm{BR}(\phi \to \gamma\gamma) \approx (2 - 2.5)\mathrm{BR}(H \to \gamma\gamma)$$

This can be achieved in models where the singlet mixes differently with 2 components making up a SM-like Higgs, like H_u and H_d in models with two Higgs doublets

Light singlet setup

- Two lightest Higgses are a mixture of H_u and S

$$\mathcal{M}^{\phi}_{u,S} = \begin{pmatrix} m_Z^2 + \Delta m_{rad}^2 & v_u\left(\sqrt{2}\lambda_u\mu_u^{\mathrm{eff},-} + g_1 M_B^D\right) \\ v_u\left(\sqrt{2}\lambda_u\mu_u^{\mathrm{eff},-} + g_1 M_B^D\right) & 4(M_B^D)^2 + m_S^2 + \frac{\lambda_u^2 v_u^2}{2} \end{pmatrix}$$

- Obvious constraints:
  - mixing has to be small
  - $4(M_B^D)^2 + m_S^2 \approx (95\mathrm{GeV})^2 \Rightarrow$ this setup enforces light DM candidate
  - $|\lambda|_u \ll 1$

How to accommodate LEP and LHC excesses?

- Required pattern of partial widths is generated exclusively via mixing
- Two categories of processes (assuming we are in the limit of large $\tan\beta$):
  - occuring mostly via the H_u admixture like $\Gamma(h_1 \to \gamma\gamma)/\Gamma(h^{\rm SM}_{95.4} \to \gamma\gamma)$ $\Gamma(h_1 \to gg)/\Gamma(h^{\rm SM}_{95.4} \to gg), \Gamma(h_1 \to ZZ)/\Gamma(h^{\rm SM}_{95.4} \to ZZ) \approx 0.13$
  - occuring via the H_d admixture like the $\Gamma(h_1 \to b\bar{b}) \approx 0.074 \cdot \Gamma(h^{\rm SM}_{95.4} \to b\bar{b})$
- Despite the suppresion of $\Gamma(h_1 \to b\bar{b})/\Gamma(h^{\rm SM}_{95.4} \to b\bar{b})$ we still have $\mathrm{BR}(h_1 \to b\bar{b}) \approx 0.9 \cdot \mathrm{BR}(h^{\rm SM}_{95.4} \to b\bar{b})$
- The value of LEP excess can be read of from the combination of $\mathrm{BR}(h_1 \to b\bar{b})/\mathrm{BR}(h^{\rm SM}_{95.4} \to b\bar{b})$ and $\Gamma(h_1 \to ZZ)/\Gamma(h^{\rm SM}_{95.4} \to ZZ)$ giving $\mu^{\rm LEP}_{b\bar{b}} = 0.13 \cdot 0.9 = 0.117$
- In the case where $\mathrm{BR}(h_1 \to \gamma\gamma) \approx \mathrm{BR}(h^{\rm SM}_{95.4} \to \gamma\gamma)$, $\mu_{\gamma\gamma} \approx 0.13$ and not the 0.24 we are targeting. However, $\mathrm{BR}(h_1 \to \gamma\gamma)/\mathrm{BR}(h^{\rm SM}_{95.4} \to \gamma\gamma)$ is enhanced to around 2 because total width of h_1 is suppresed by a factor 2 less than a partial width $\Gamma(h_1 \to \gamma\gamma)$ compared to their SM values.

2 classes of solutions

distinquished by how correct relic density is achieved, not by the Higgs sector

	BMP7	BMP8
m_{h_1}	95.4	95.4
m_{h_2}	125.25	124.72
$m_{W^\pm}$	80.375	80.371
$m_{\chi 1}$	44.98	42.65
$m_{\tilde{\tau}_R}$	1000	124.7
$\rho_1^\pm$	717	1310
m_a	24.85	54.20

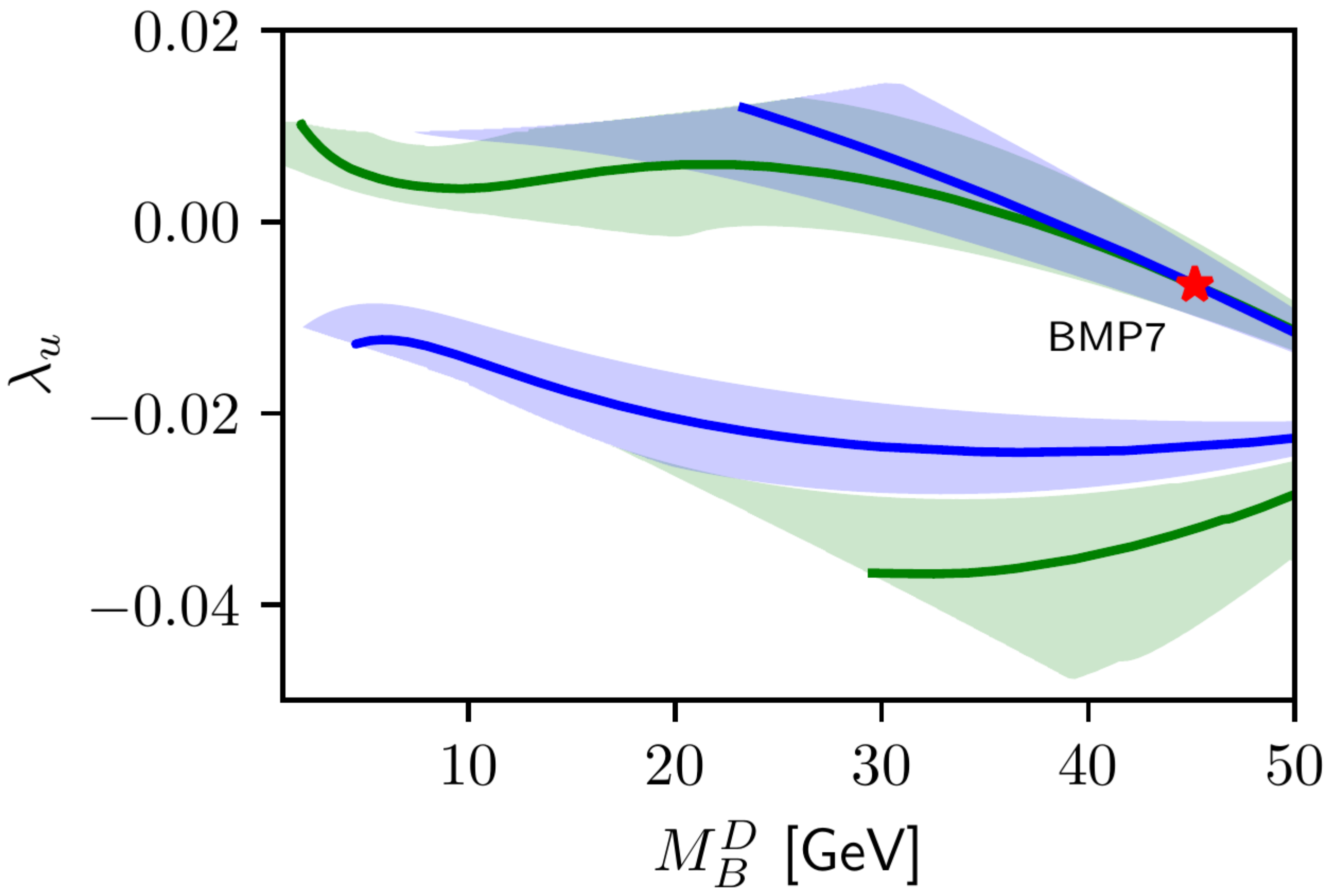
light Higgsino, fixed neutralino mass

heavy Higgsino, light right handed stau

LEP and LHC excesses

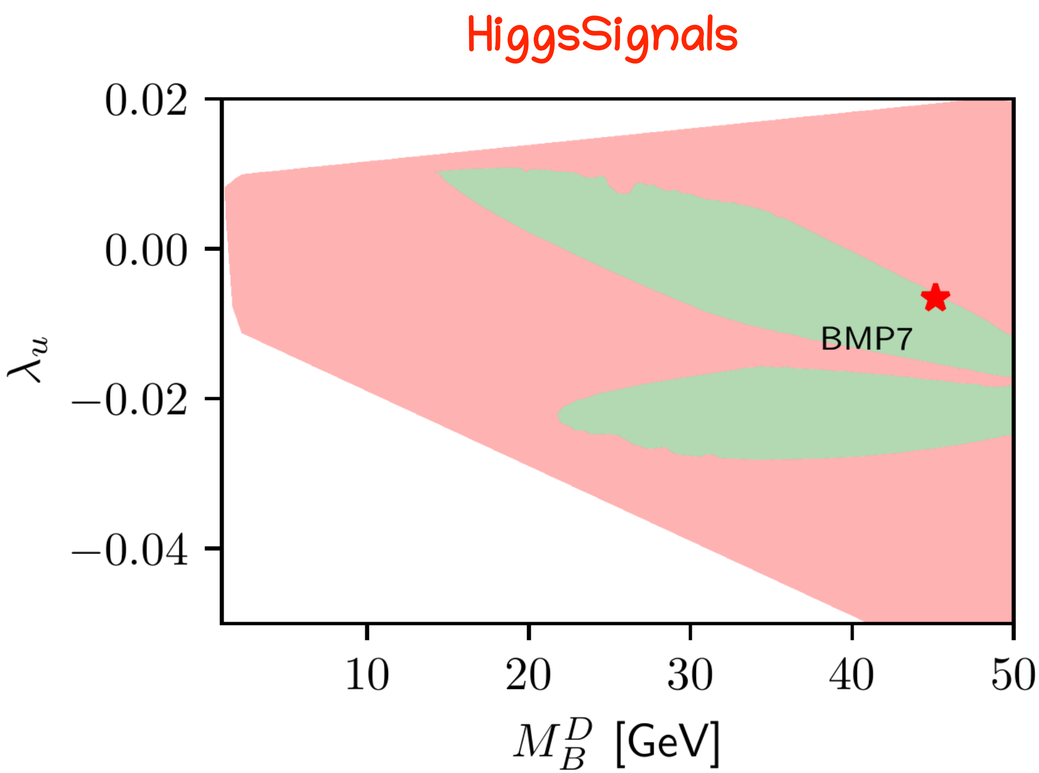
$$\mu_{Zb\bar{b}} = 0.117 \pm 0.057 \text{ (blue)}$$

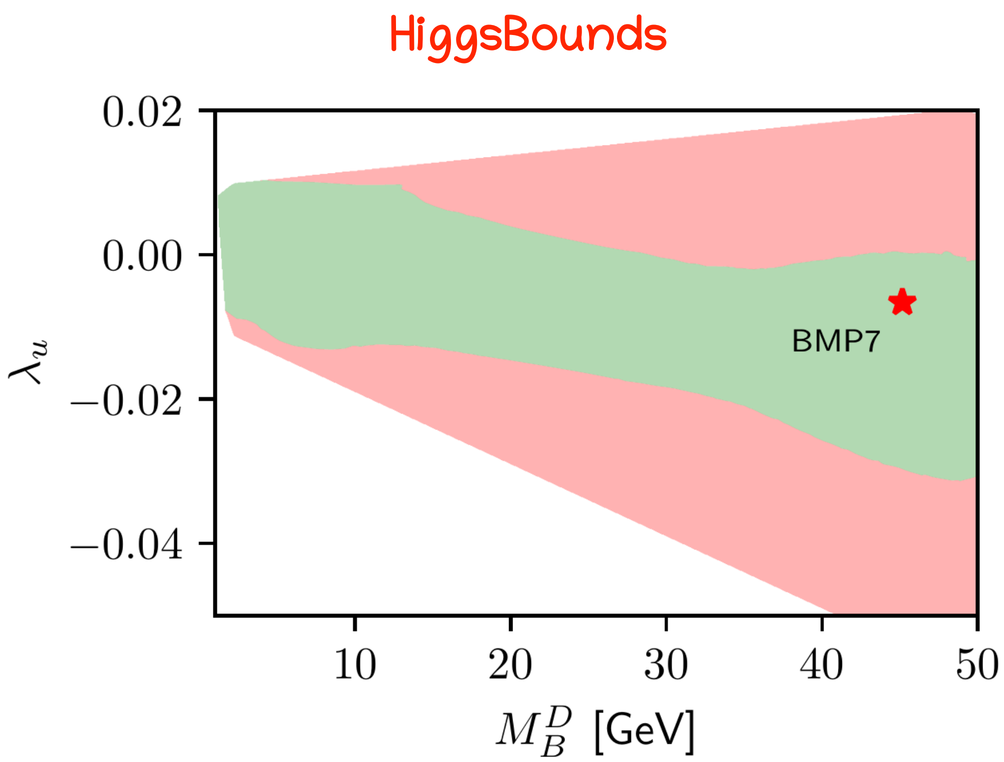
$$\mu_{\gamma\gamma} = 0.24^{+0.09}_{-0.08} \text{ (green)}$$



the scaling of partial widths required by the setup in some regions of parameter space, but no throughout all of it

Higgs constraints

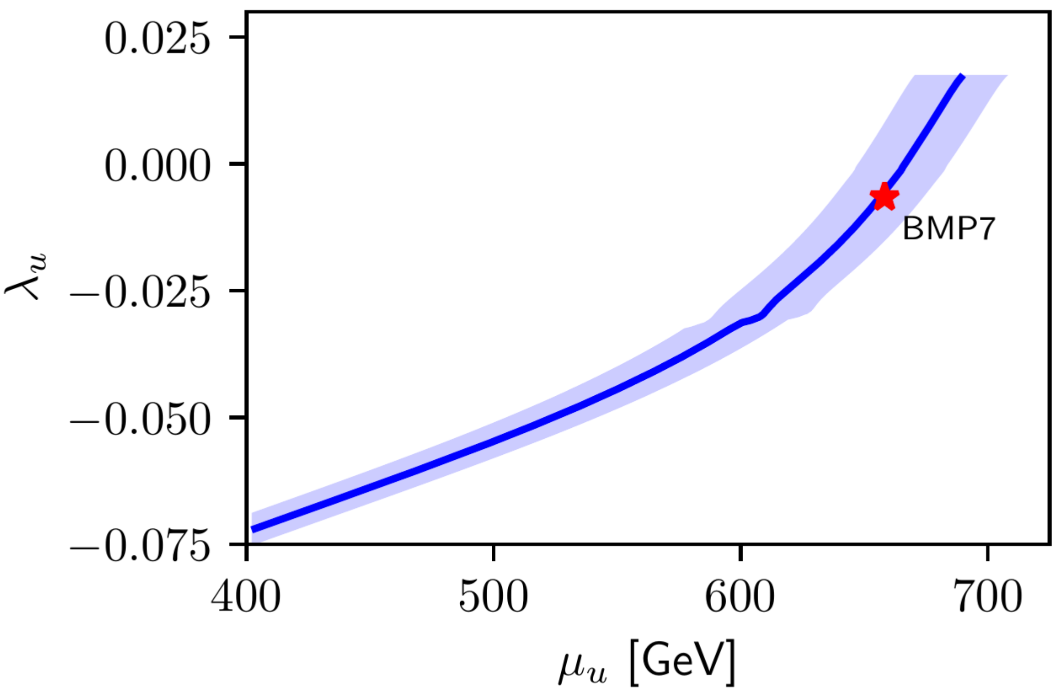


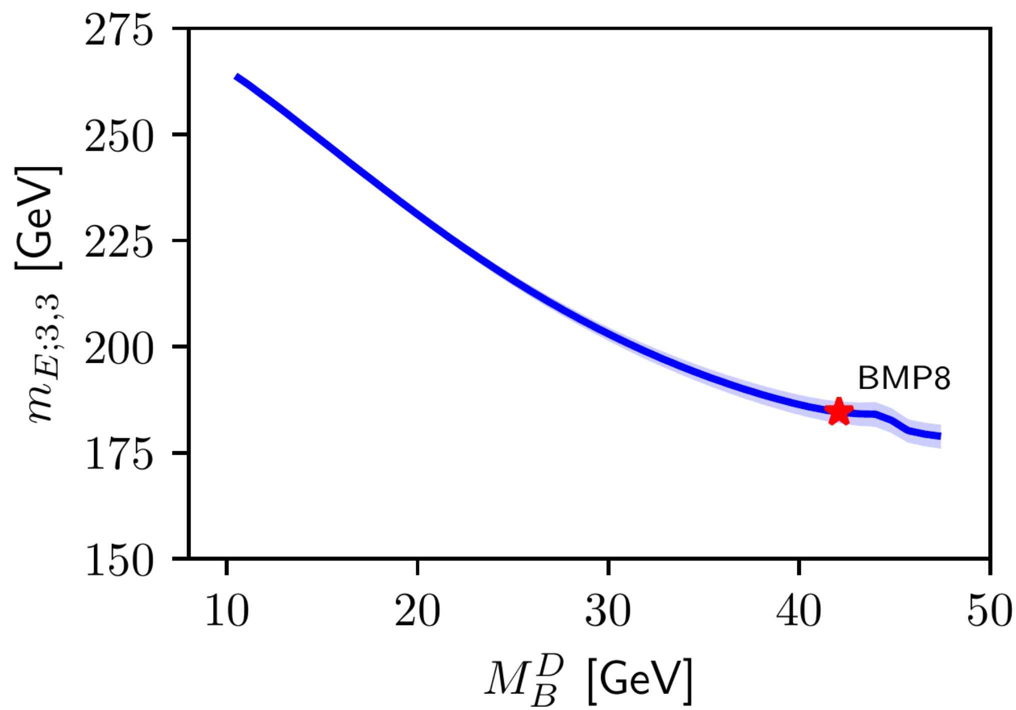


The mixing between the 95 GeV and SM-like Higgs is necessary to generate LEP and LHC excesses. But too much of the mixing destabilizes the SM-like Higgs properties and would make 95 GeV one discoverable already at LEP.

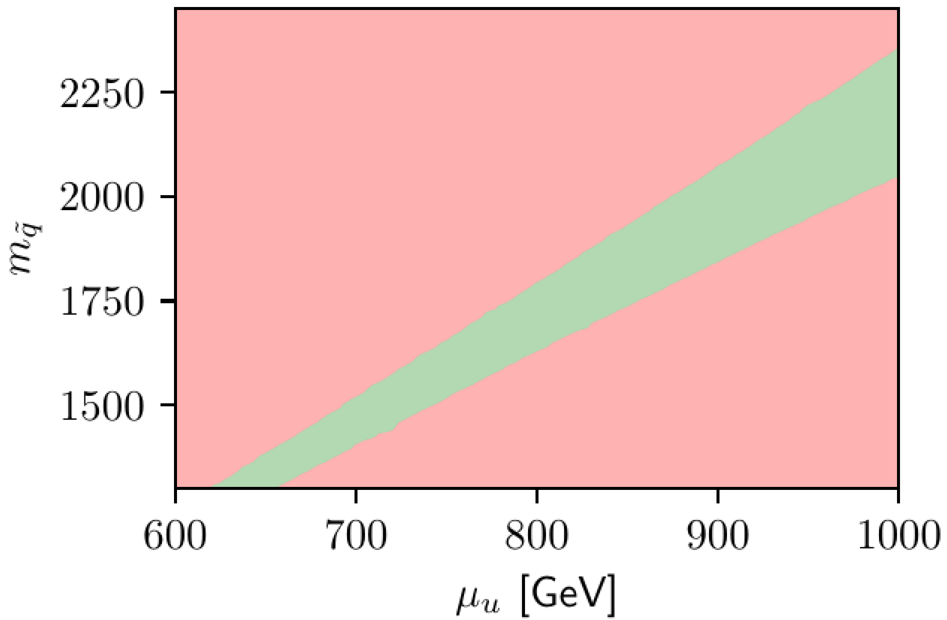
Dark matter relic density

two classes of solutions:
DM anihilation via s-channel Z-exchange or t-channel right handed stau exchange

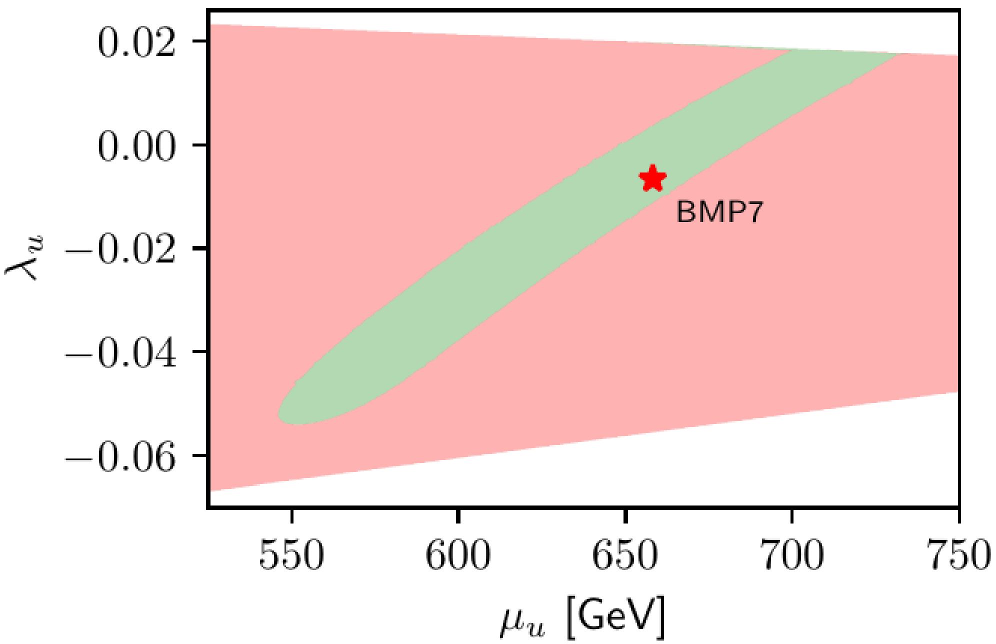




Dark matter direct detection



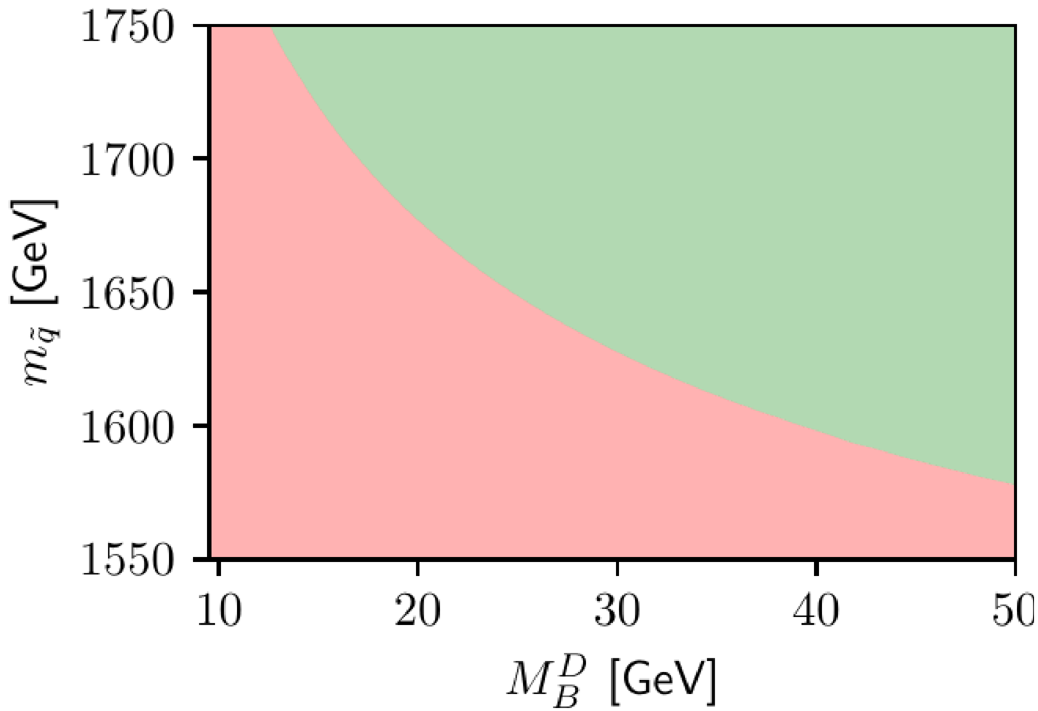
destructive interference between
Z and squark exchange

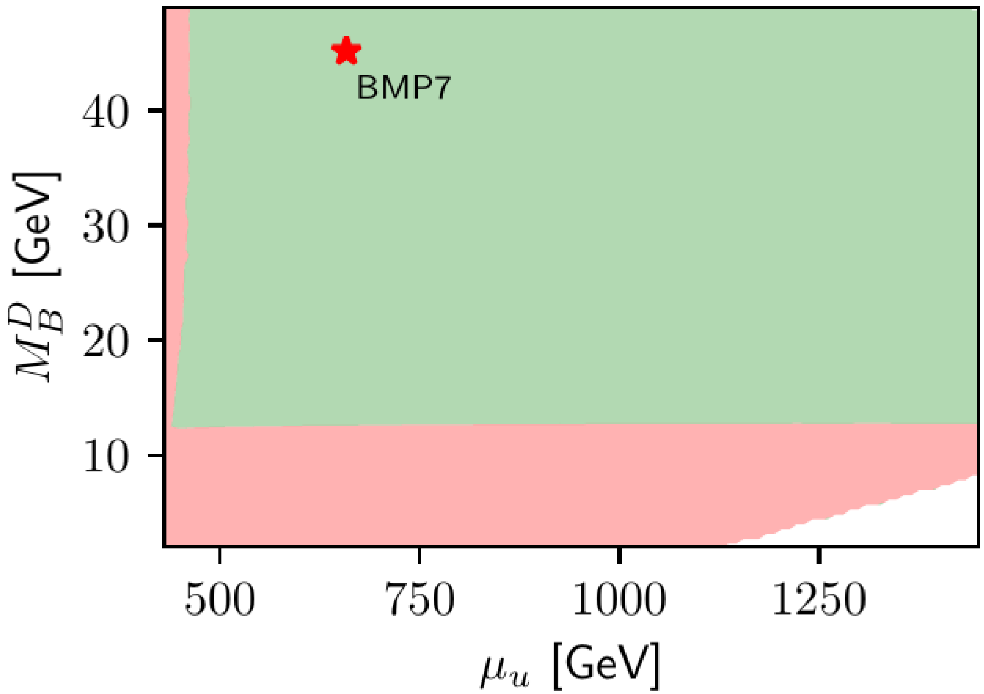


for fixed squark masses, Z-
exchange must be keep constant
to ensure destructuctive
inteference

Collidear constraints

in general we have 4 possibly light states: light scalar, light neutralino, ~1 TeV squarks and possibly a light Higgsino





Conclusions and outlook

- Scenario with a light singlet is very predictive:
  - it can explain LEP and LHC excesses
  - is consistent with experimental contraints
  - predicts existance of light dark matter candidate, which can have correct relic density while being allowed by current direct detection experiments
  - predicts some light states and could be seen at the LHC