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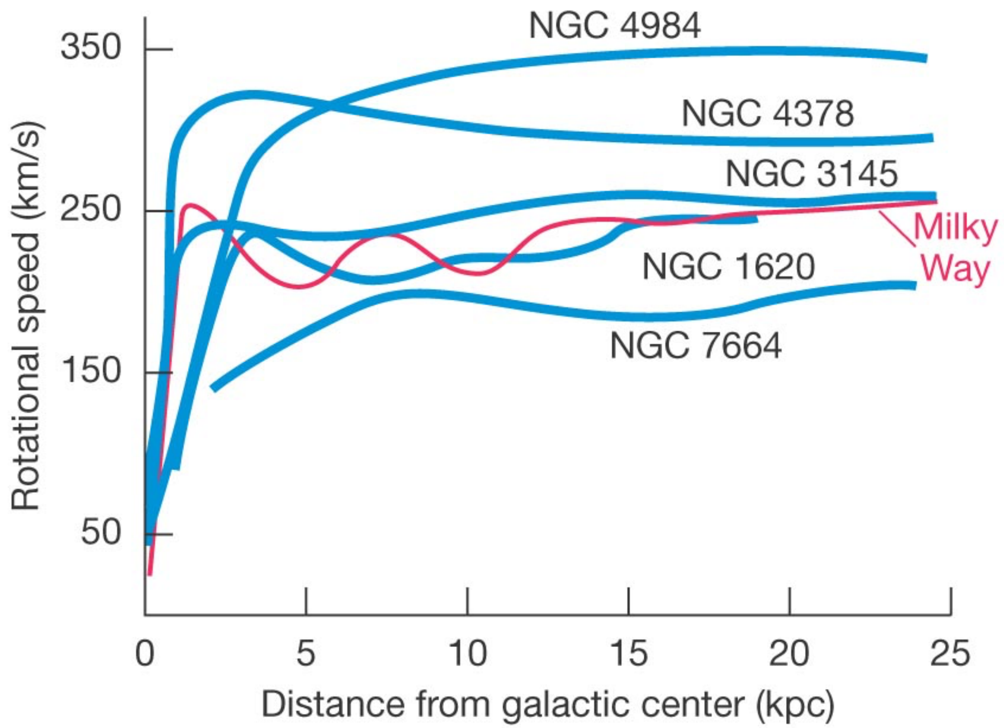
Based on work done with: J. Ellis, F. Luo and J. Marrouche;
J. Bramante, P. Fox, A. Martin, B. Ostdiek, T. Plehn;.

Phys. Rev. D90, 055031
Phys.Rev. D93 (2016) 063525

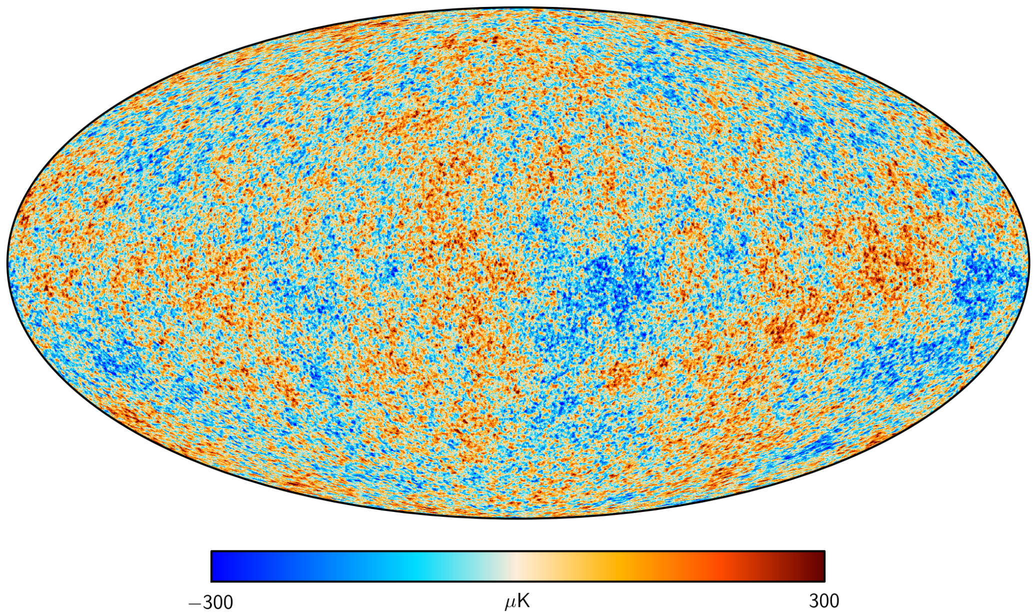
# SUSY DARK MATTER @ THE LHC AND BEYOND

15 Sep 2016
TIFR



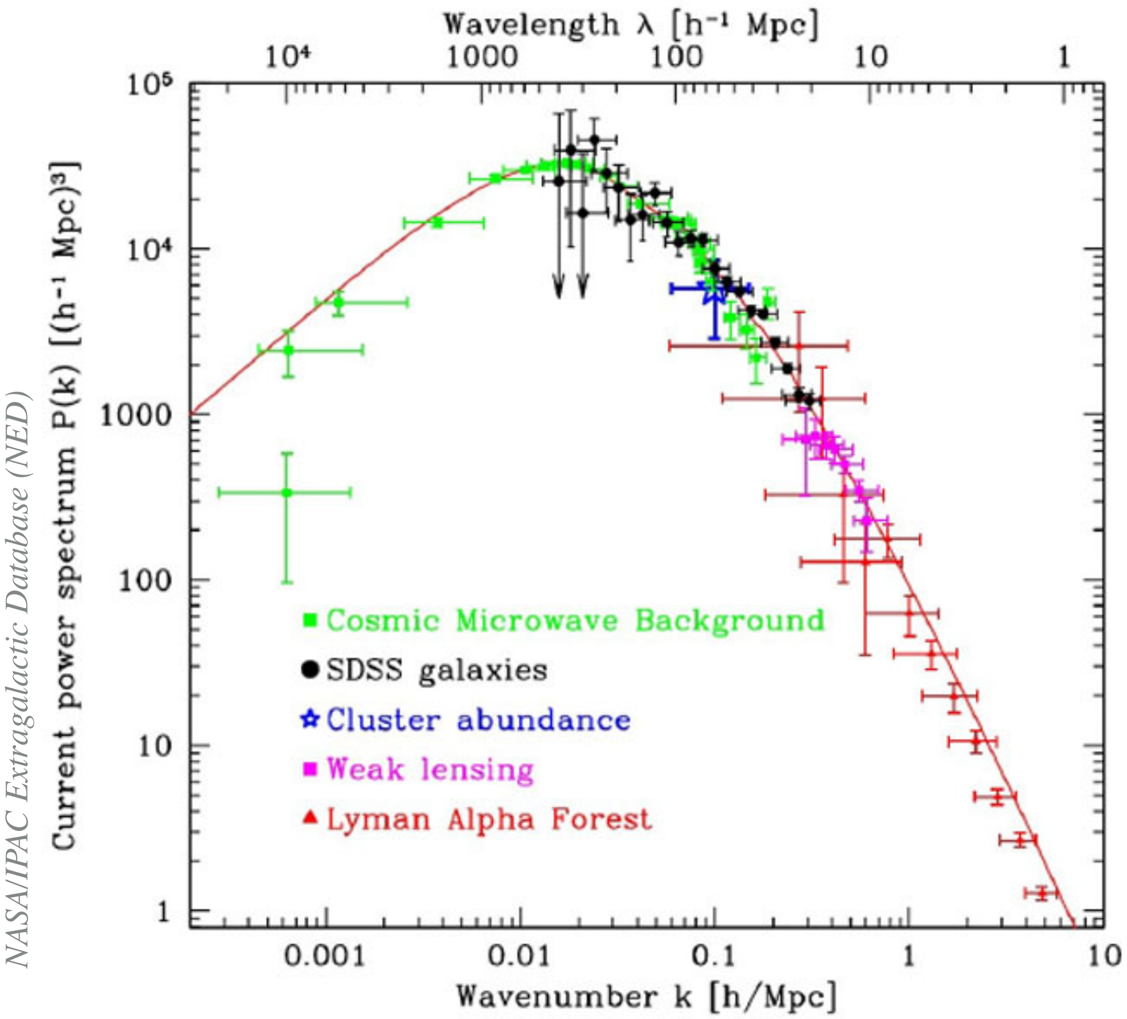

Eric Chaisson, Steve McMillan

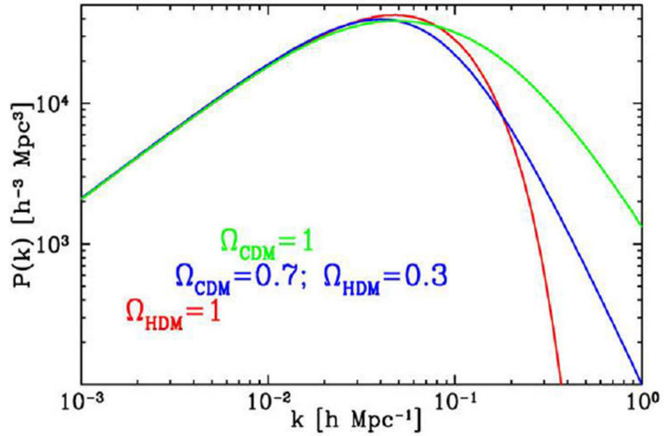





$$
\begin{aligned}
\Omega_m h^2 &= 0.1415 \pm 0.0019 \\
\Omega_b h^2 &= 0.02226 \pm 0.00023 \\
\Omega_c h^2 &= 0.1186 \pm 0.0020
\end{aligned}
$$

# (DARK) MATTER POWER SPECTRUM

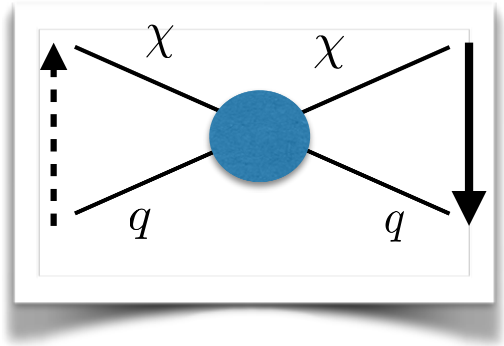


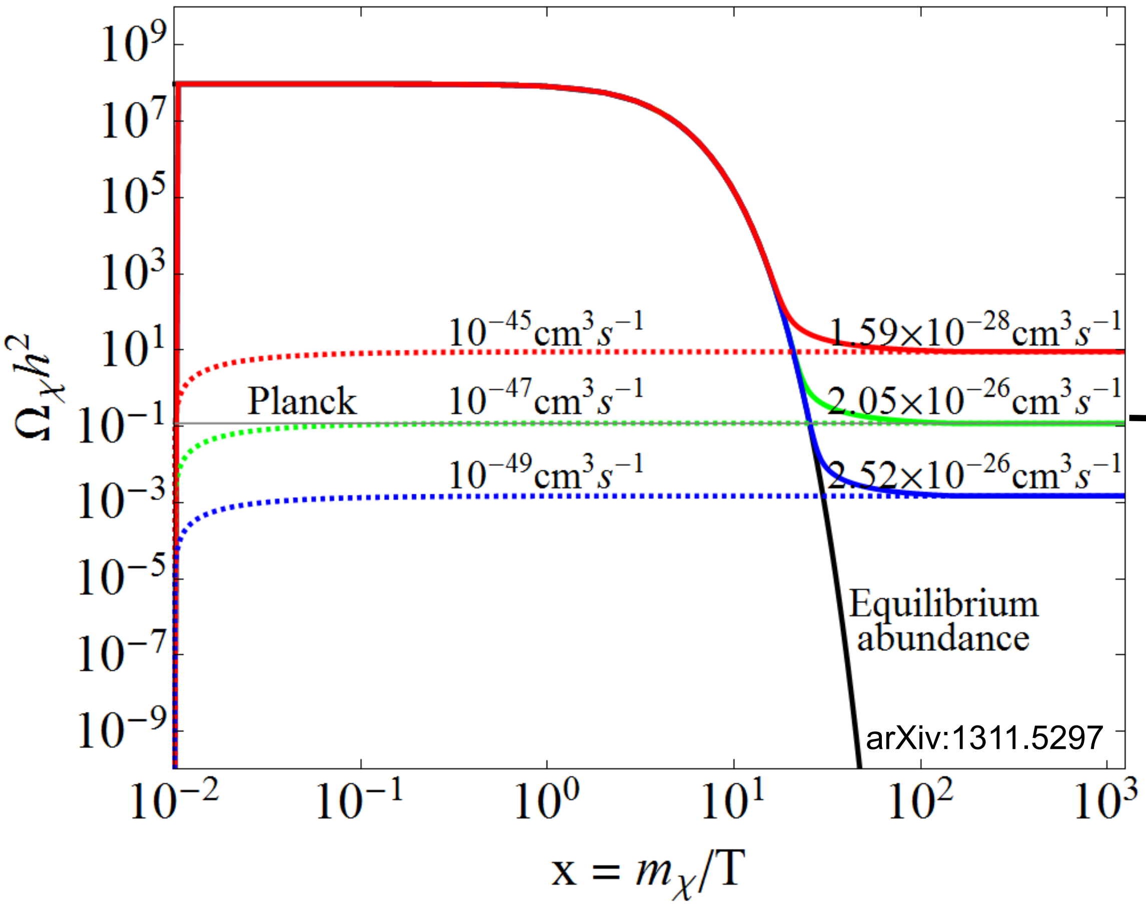




**THE ASSUMPTION OF CDM IS ESSENTIAL TO EXPLAIN OUR UNIVERSE**

# HOW TO CALCULATE THE RELIC DENSITY?

$$\frac{dn}{dt} + 3n\mathrm{H} = -\frac{1}{2}\langle\sigma \mathrm{v}\rangle \left(n^2 - (n^{eq})^2\right)$$

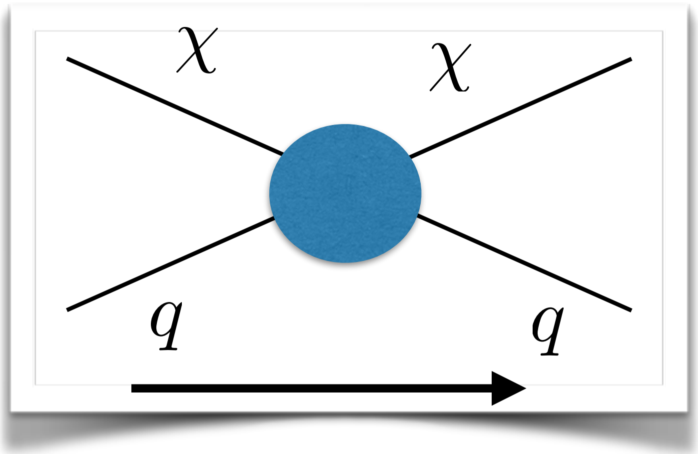


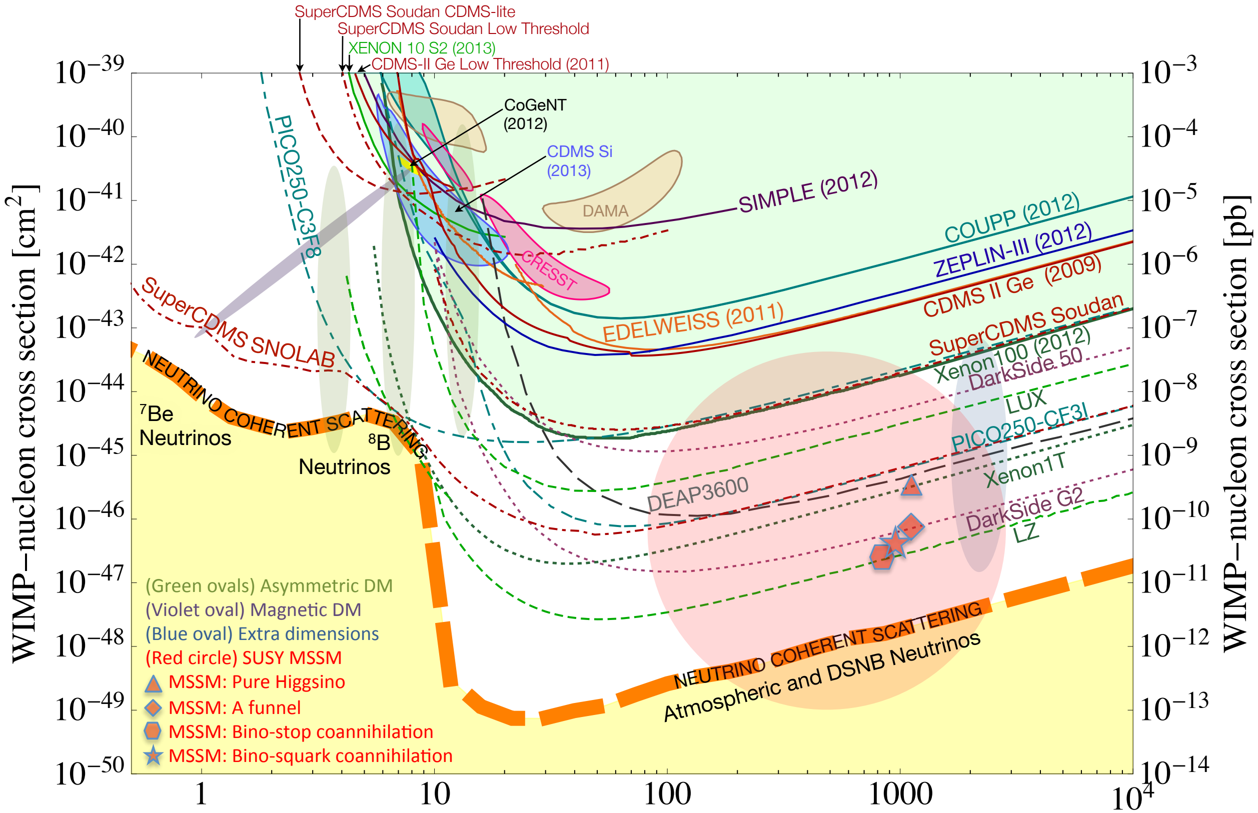



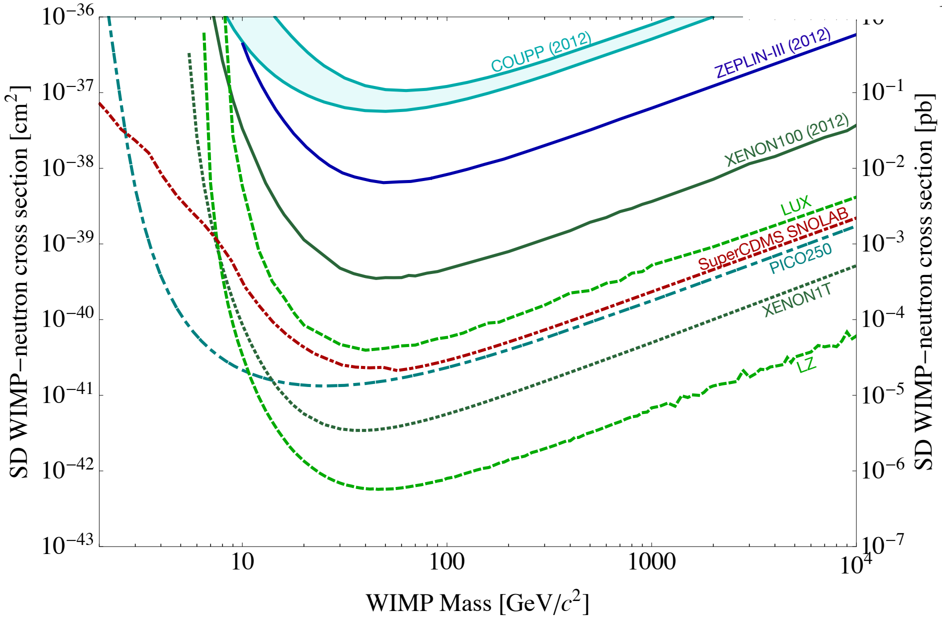

$$m_\chi \sim 100\ \mathrm{GeV}$$

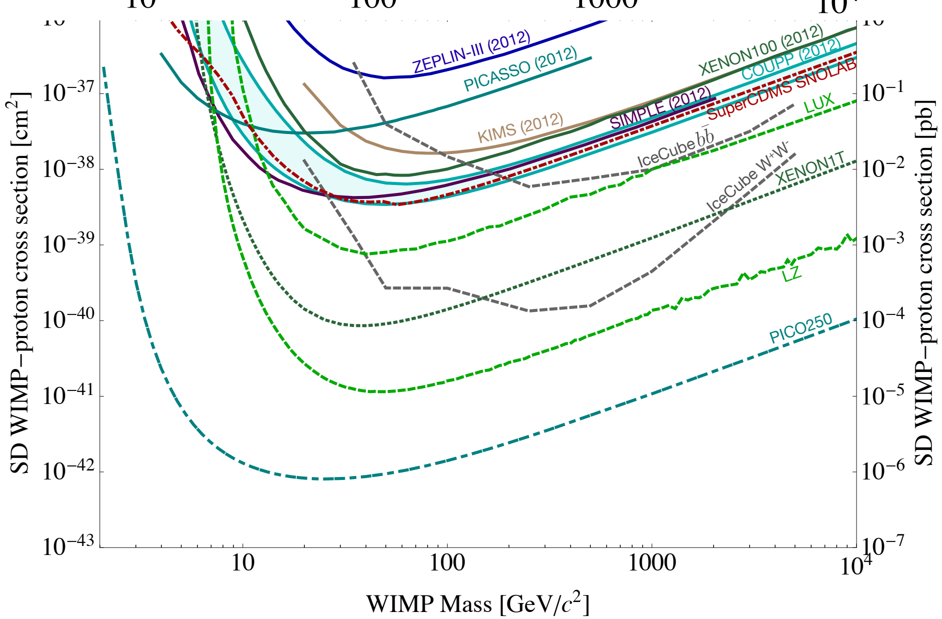
$$g \sim g_{EW}$$

# LOOKING FOR DM WINDS: DIRECT DETECTION



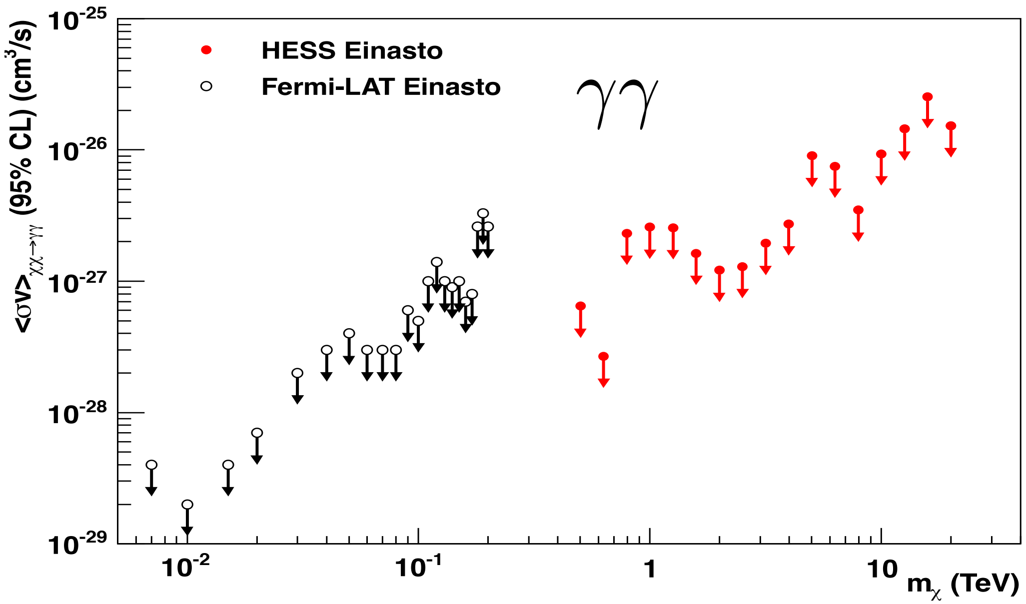



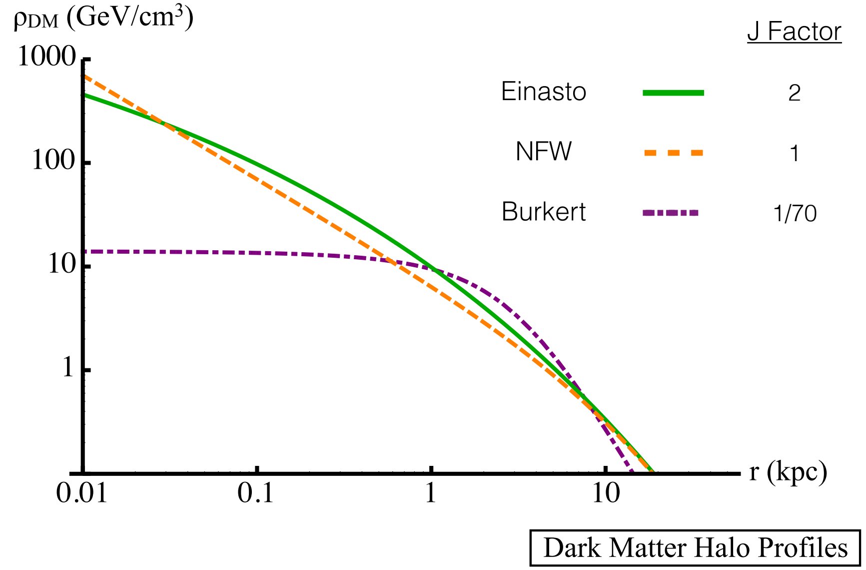



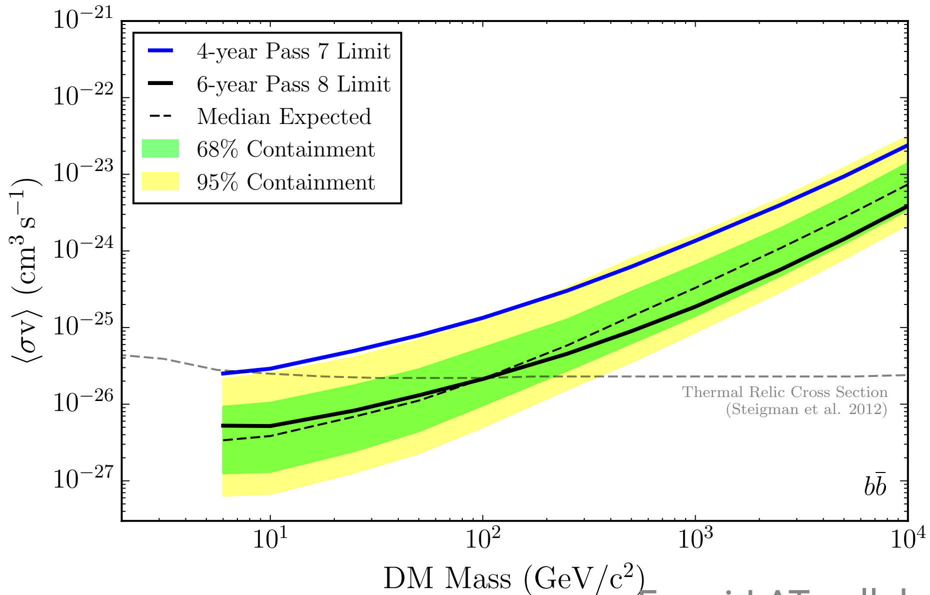

arXiv:1310.8327v2

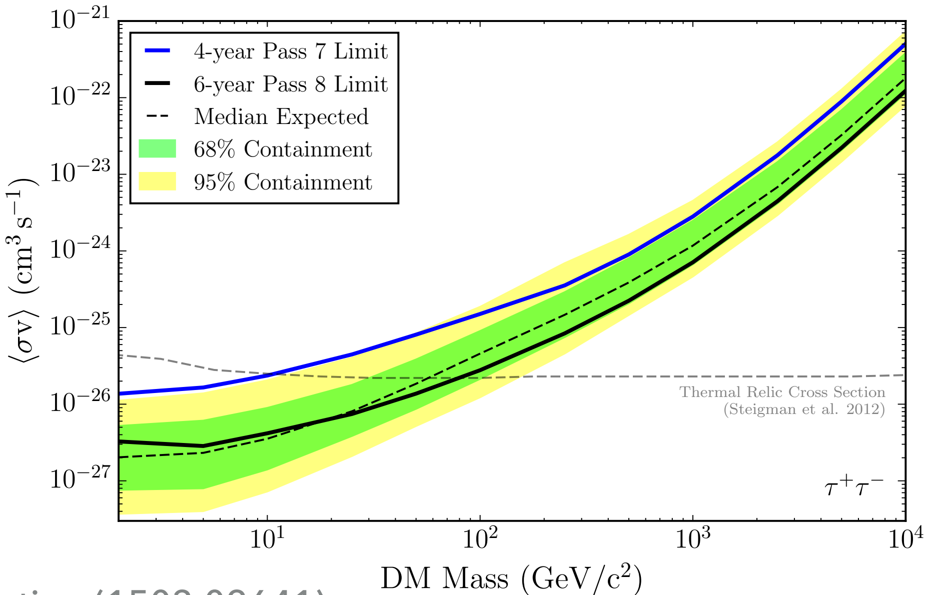
# LOOKING FOR LINES IN THE SKY: INDIRECT DETECTION




$$\rho_{\rm NFW}(r) = \frac{\rho_\odot}{(r/R)\,(1+r/R)^2}, \quad \rho_{\rm Ein}(r) = \rho_\odot \;\exp\left[-\frac{2}{\alpha}\left(\left(\frac{r}{R}\right)^\alpha - 1\right)\right]$$




Fermi-LAT collaboration (1503.02641)

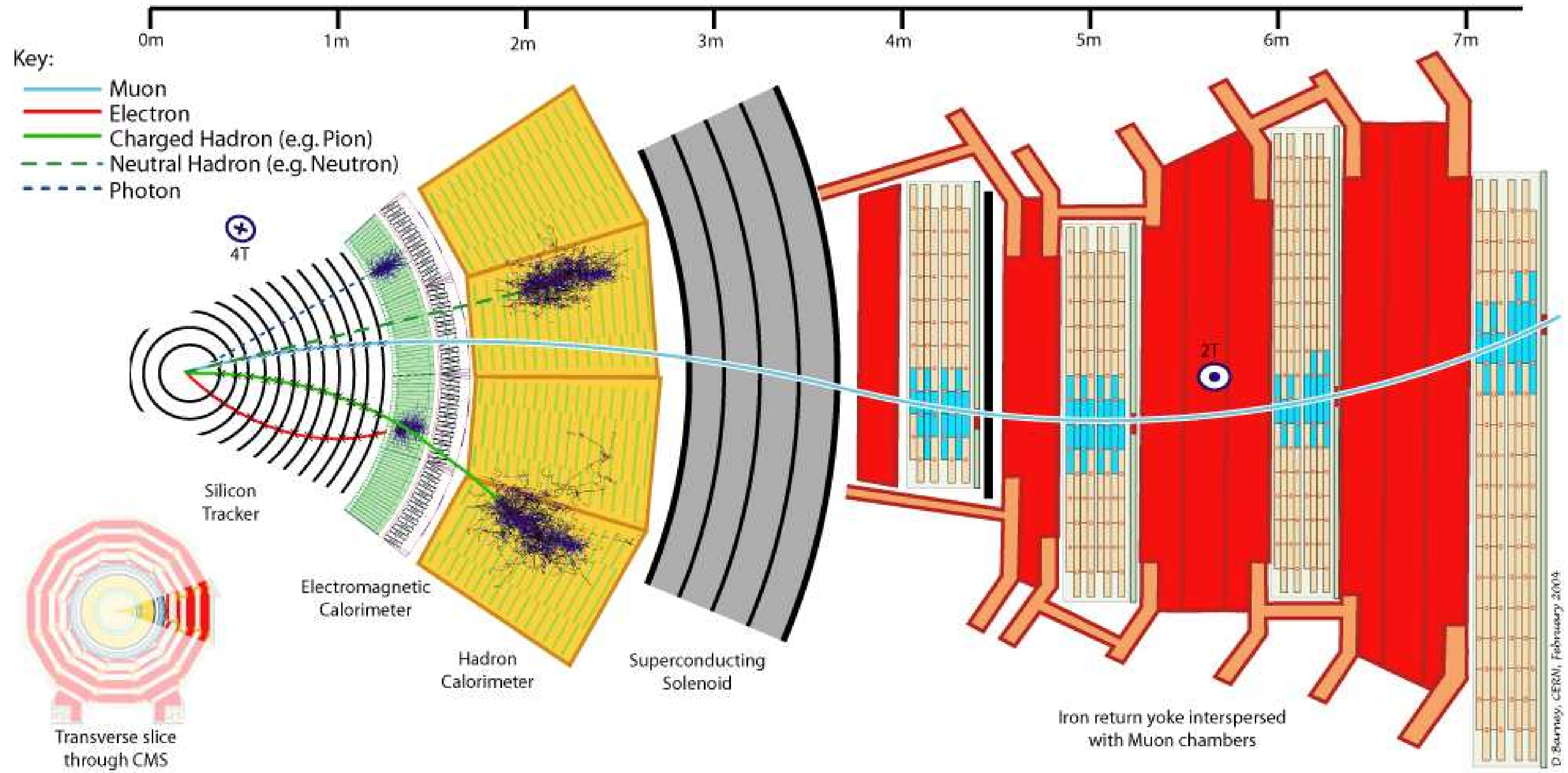
# WHY USE COLLIDERS?

WE HAVE ONE, MIGHT AS WELL USE IT!

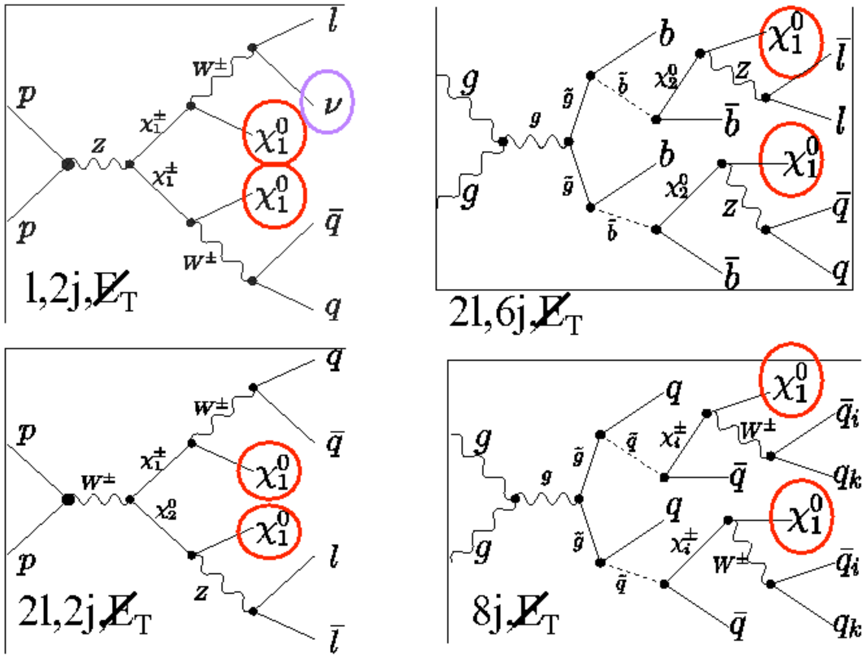
BUT ALSO…

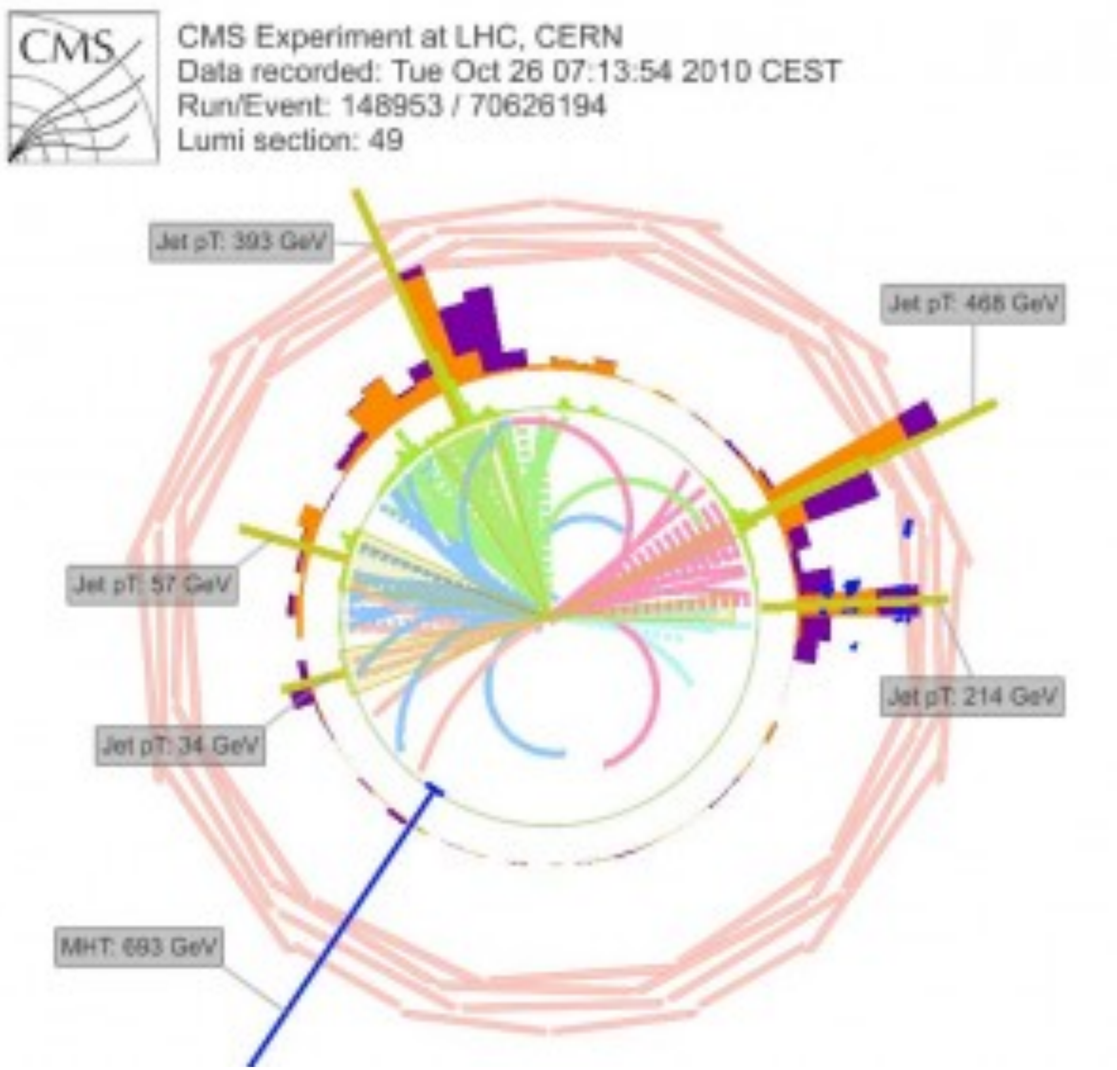
IT TURNS OUT, COLLIDERS CAN DO THINGS OTHER EXPERIMENTS CAN'T — BETTER SPIN DEPENDENT SENSITIVITY + CONSTRAIN LOW RECOIL REGION + LOOK FOR ACCOMPANYING PARTICLES

# HOW DOES ATLAS/CMS MAKE OBSERVATIONS? — OBJECTS, CUTS, STATISTICS

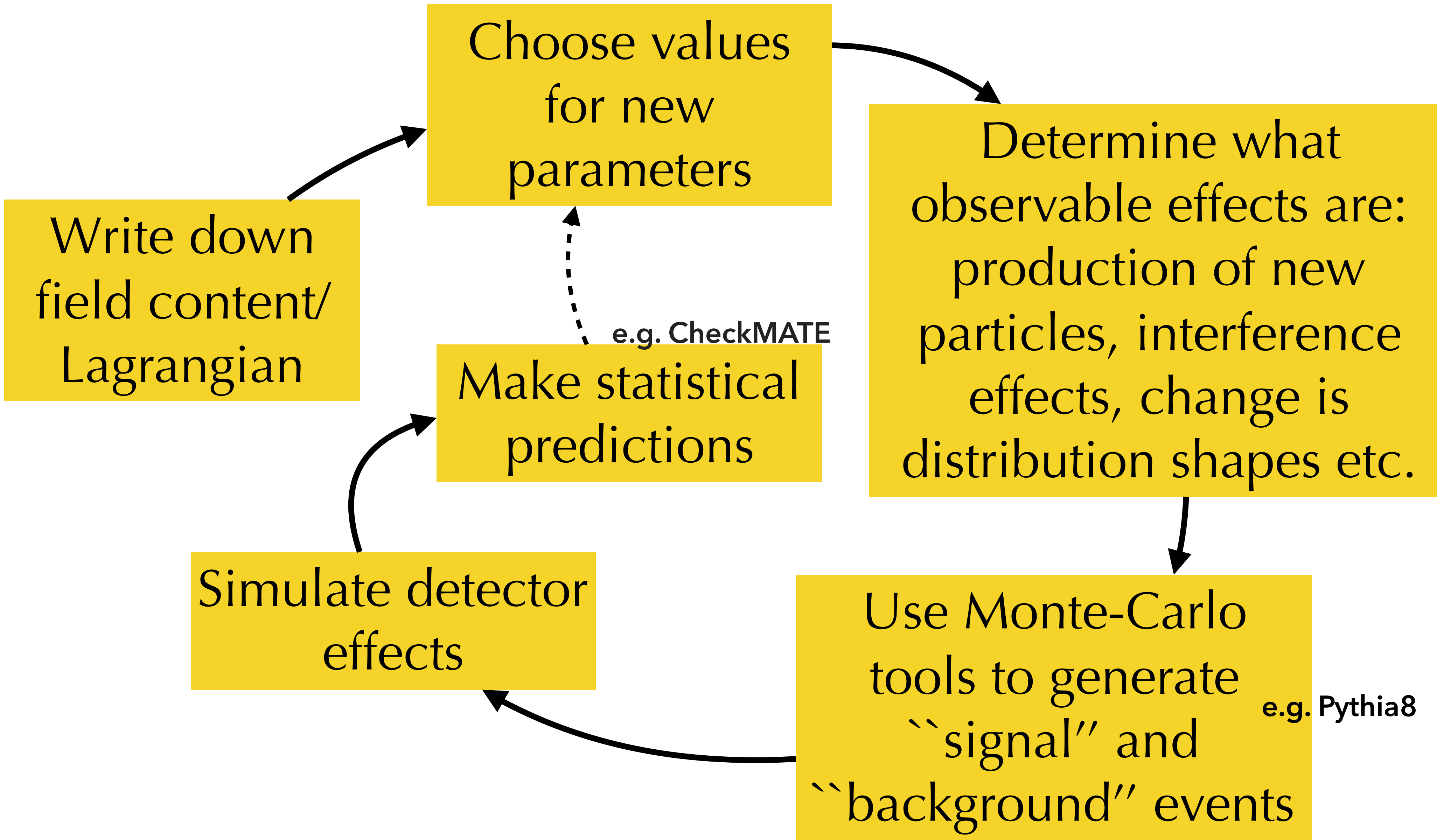


# OBSERVING LSP PRODUCTION AT THE LHC: JETS + MET



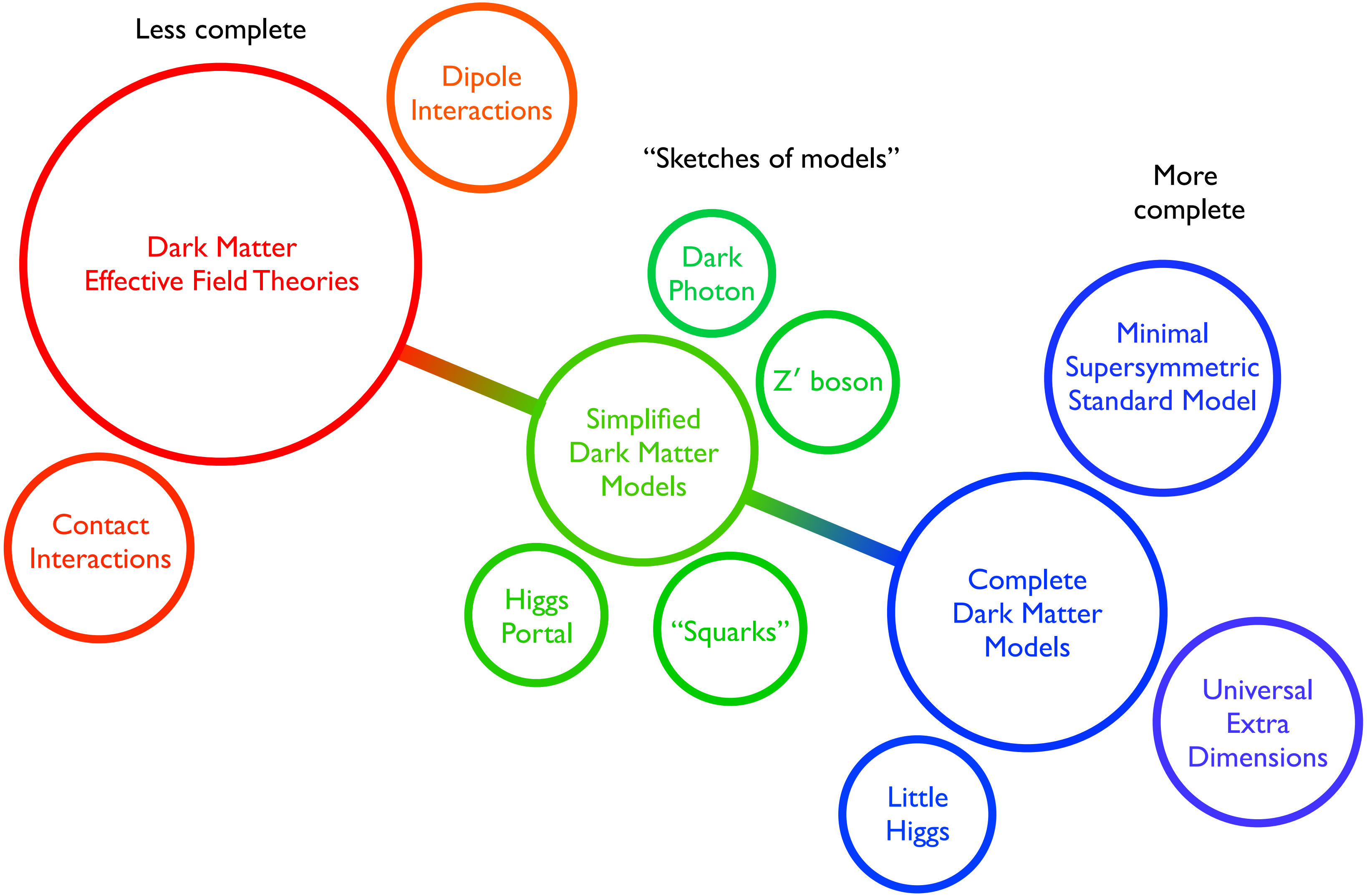
# HOW DO THEORISTS DETERMINE WHAT SIGNALS FOR THEIR THEORY WILL LOOK LIKE AT A COLLIDER EXPERIMENT?



# TO MODEL DM WE NEED TO KNOW:

Does it couple directly to some SM particle?

If there is a mediator, how does the mediator couple to SM? to DM?



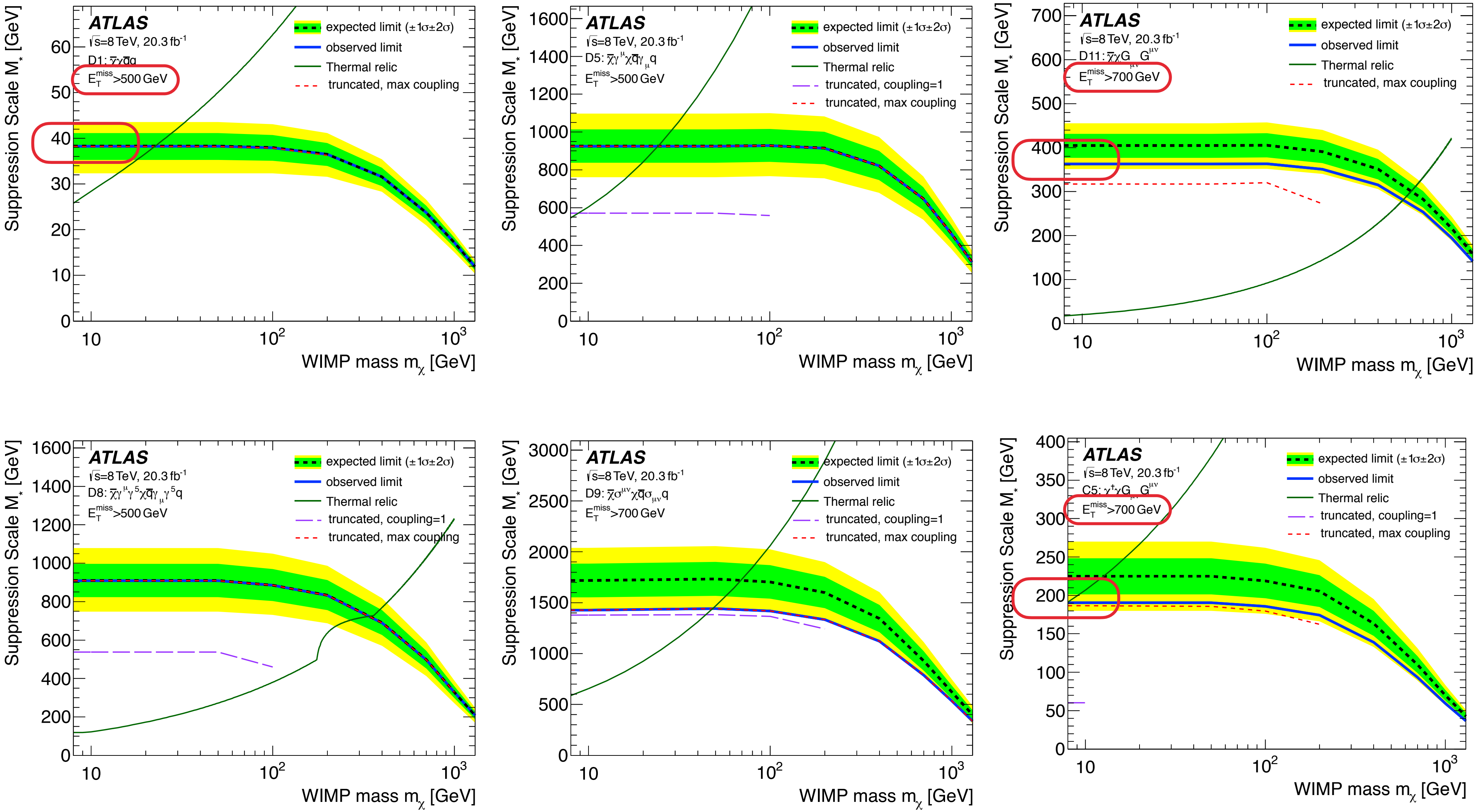
# COLLIDER SEARCHES: A COMPLEMENTARY VIEW

Goodman et al. (2010)

| Name | Operator | Coefficient |
|---|---|---|
| D1 | $\bar{\chi}\chi\bar{q}q$ | $m_q/M_*^3$ |
| D2 | $\bar{\chi}\gamma^5\chi\bar{q}q$ | $im_q/M_*^3$ |
| D3 | $\bar{\chi}\chi\bar{q}\gamma^5 q$ | $im_q/M_*^3$ |
| D4 | $\bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$ | $m_q/M_*^3$ |
| D5 | $\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$ | $1/M_*^2$ |
| D6 | $\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu q$ | $1/M_*^2$ |
| D7 | $\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu\gamma^5 q$ | $1/M_*^2$ |
| D8 | $\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$ | $1/M_*^2$ |
| D9 | $\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$ | $1/M_*^2$ |
| D10 | $\bar{\chi}\sigma_{\mu\nu}\gamma^5\chi\bar{q}\sigma_{\alpha\beta}q$ | $i/M_*^2$ |
| D11 | $\bar{\chi}\chi G_{\mu\nu}G^{\mu\nu}$ | $\alpha_s/4M_*^3$ |
| D12 | $\bar{\chi}\gamma^5\chi G_{\mu\nu}G^{\mu\nu}$ | $i\alpha_s/4M_*^3$ |
| D13 | $\bar{\chi}\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$ | $i\alpha_s/4M_*^3$ |
| D14 | $\bar{\chi}\gamma^5\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$ | $\alpha_s/4M_*^3$ |

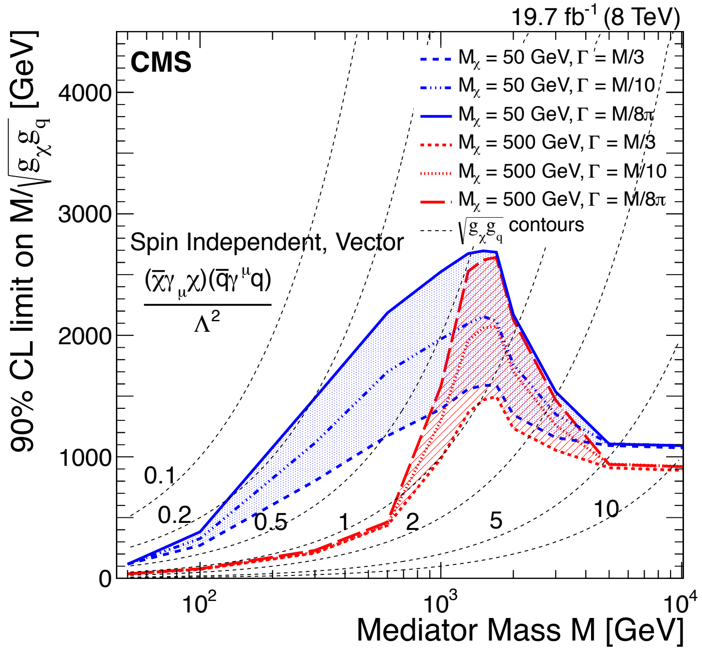
| Name | Operator | Coefficient |
|---|---|---|
| C1 | $\chi^\dagger\chi\bar{q}q$ | $m_q/M_*^2$ |
| C2 | $\chi^\dagger\chi\bar{q}\gamma^5 q$ | $im_q/M_*^2$ |
| C3 | $\chi^\dagger\partial_\mu\chi\bar{q}\gamma^\mu q$ | $1/M_*^2$ |
| C4 | $\chi^\dagger\partial_\mu\chi\bar{q}\gamma^\mu\gamma^5 q$ | $1/M_*^2$ |
| C5 | $\chi^\dagger\chi G_{\mu\nu}G^{\mu\nu}$ | $\alpha_s/4M_*^2$ |
| C6 | $\chi^\dagger\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$ | $i\alpha_s/4M_*^2$ |
| R1 | $\chi^2\bar{q}q$ | $m_q/2M_*^2$ |
| R2 | $\chi^2\bar{q}\gamma^5 q$ | $im_q/2M_*^2$ |
| R3 | $\chi^2 G_{\mu\nu}G^{\mu\nu}$ | $\alpha_s/8M_*^2$ |
| R4 | $\chi^2 G_{\mu\nu}\tilde{G}^{\mu\nu}$ | $i\alpha_s/8M_*^2$ |

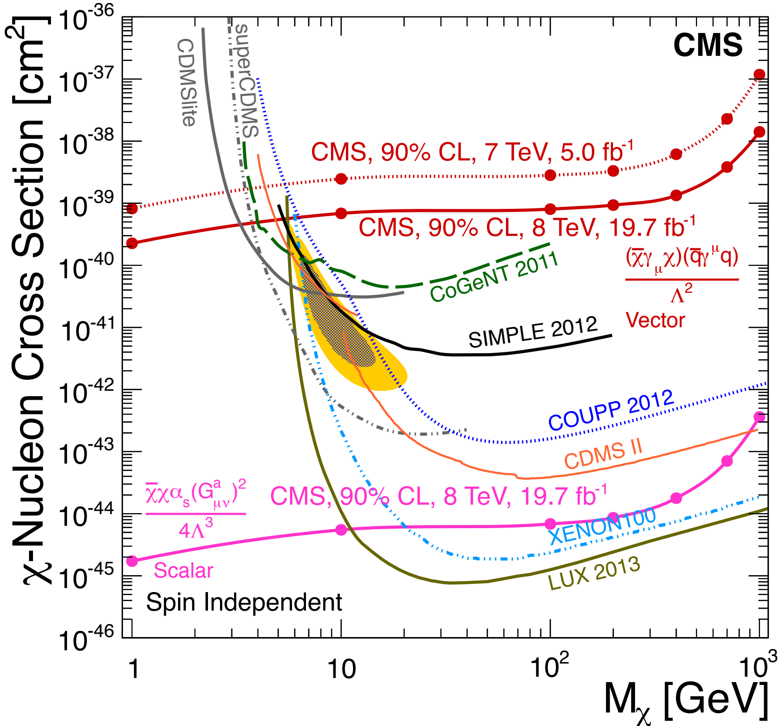
# ATLAS LIMITS ON EFT OPERATORS

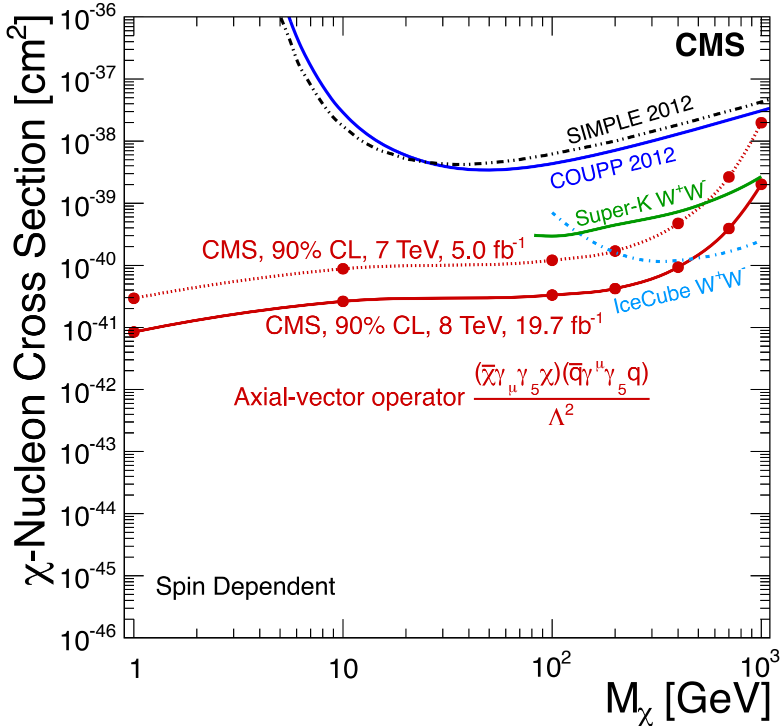



(c) (d)

# CMS LIMITS ON EFT OPERATORS



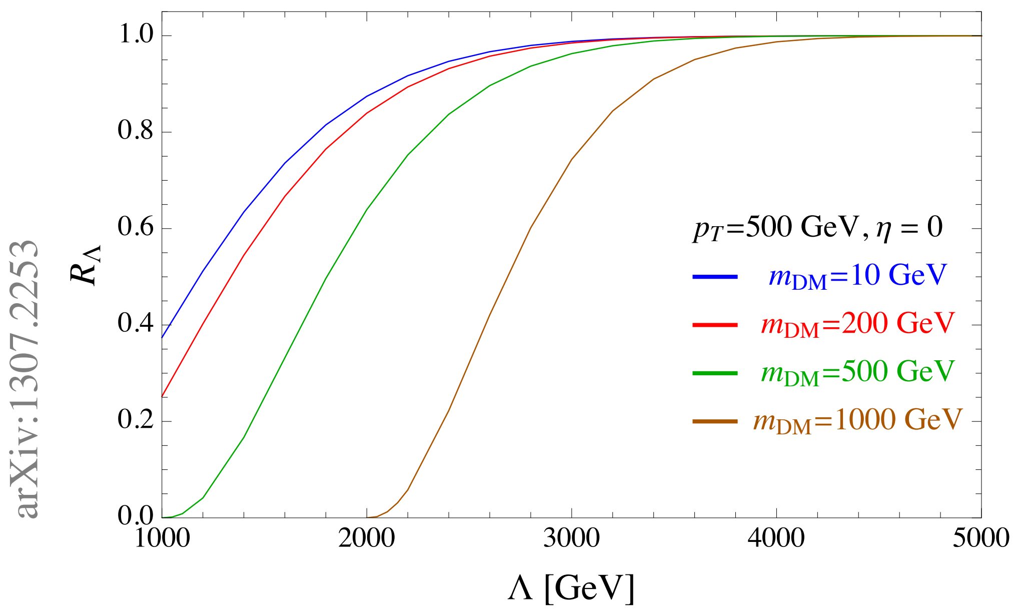



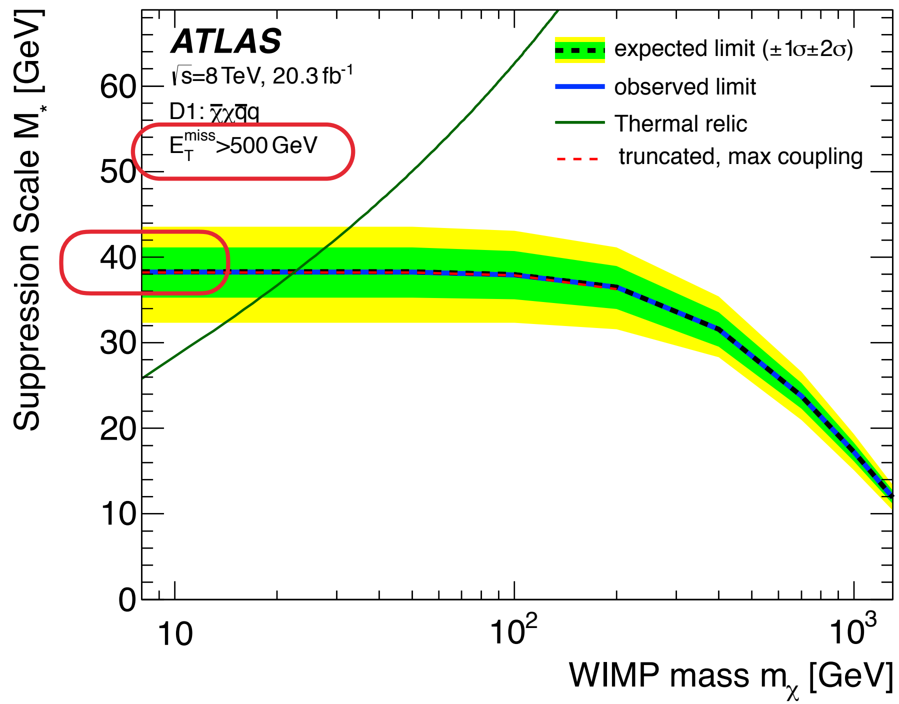



# Original idea of "EFT":

$$\bar{q}q\frac{g}{p^2 - M^2}\bar{\psi}\psi \quad \xrightarrow{M \gg p} \quad \frac{g}{M^2}\bar{q}q\bar{\psi}\psi$$

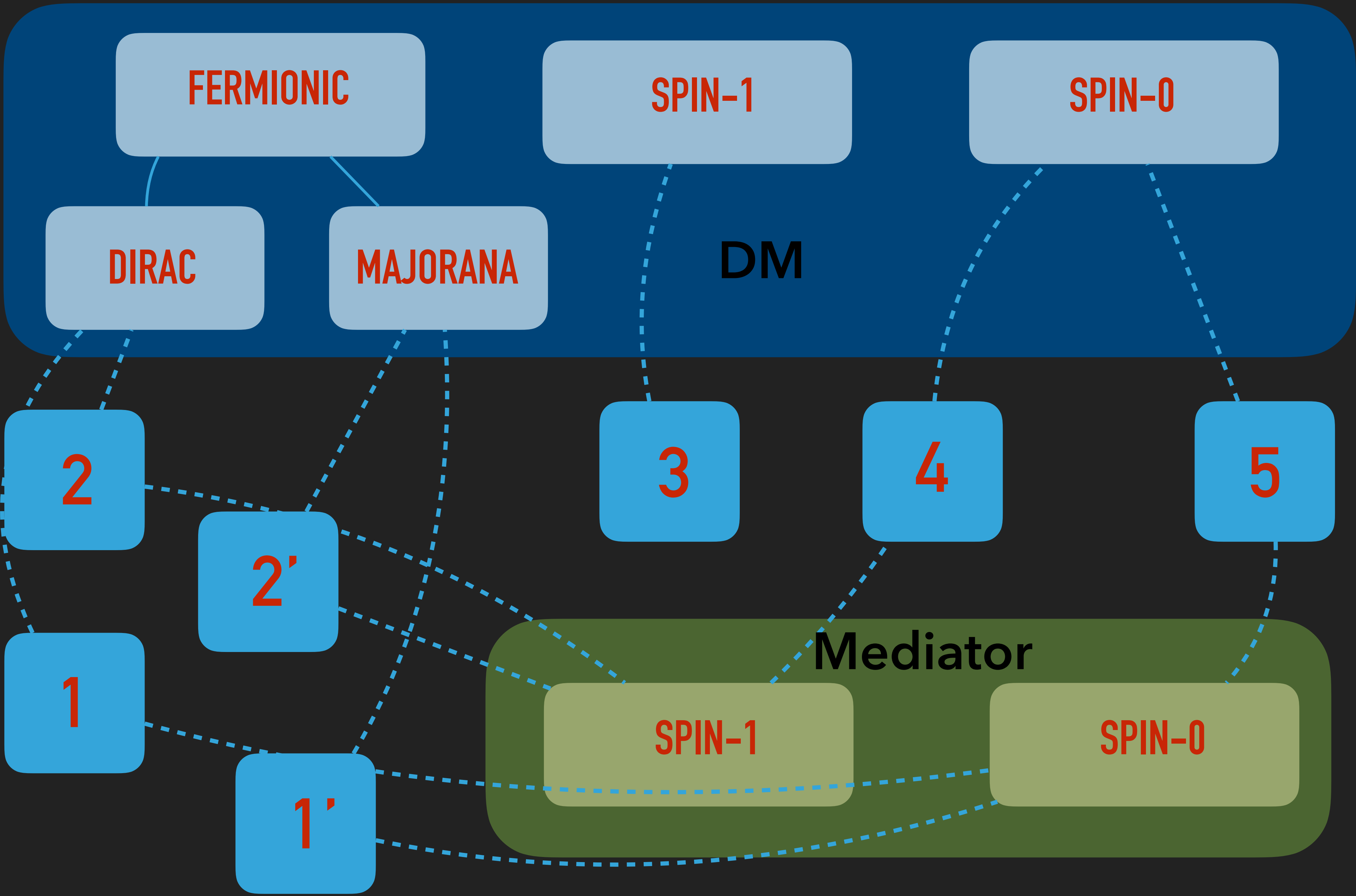
# So how does one live with:




Option 1: Use only the EFT events with $p < $ Lambda

Option 2: Treat the EFT as simply a basis of operators and not as a result of integrating out massive particles.




# HOW TO WRITE A SIMPLIFIED MODEL?

1

$$\mathcal{L}_S = \frac{1}{2}\partial_\mu S \partial^\mu S - m_S^2 S^2 + \sum g_{s\chi\bar{\chi}}\bar{\chi}\chi S + \sum g_{sq\bar{q}}\bar{q}qS + \bar{\chi}(i\partial_\mu\gamma^\mu - m_\chi)\chi$$

$$\mathcal{L}_P = \frac{1}{2}\partial_\mu P \partial^\mu P - m_P^2 P^2 + \sum g_{s\chi\bar{\chi}}\bar{\chi}\gamma^5\chi P + \sum g_{sq\bar{q}}\bar{q}\gamma^5 qP + \bar{\chi}(i\partial_\mu\gamma^\mu - m_\chi)\chi$$

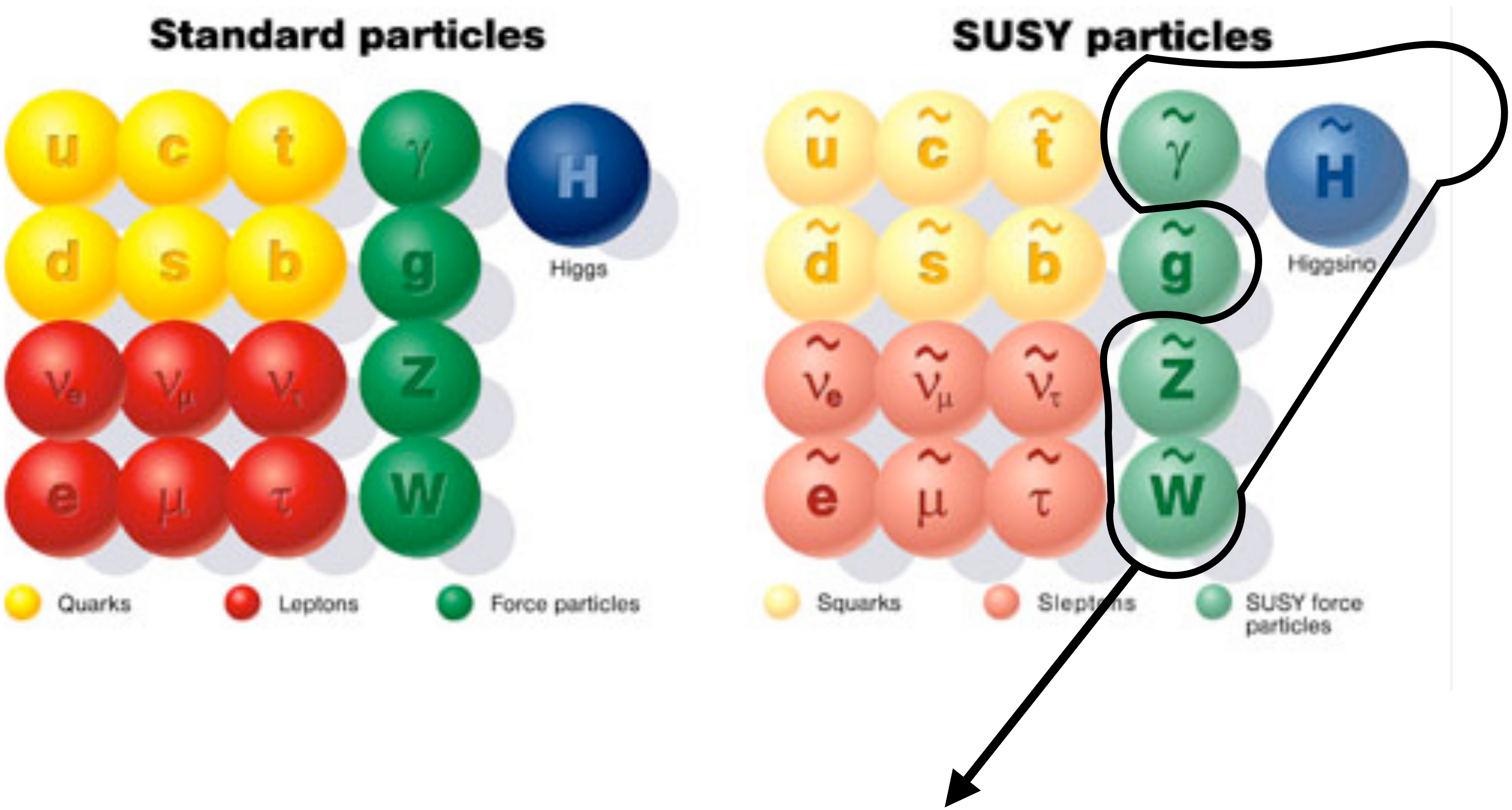
$$\begin{aligned}\mathcal{L}_T &= \frac{1}{2}D_\mu T D^\mu T - m_T^2 T^2 + \sum g_{T\chi\bar{\chi}}(\bar{\chi}qT^* + \text{c.c.}) \\ &\quad + \bar{\chi}(i\partial_\mu\gamma^\mu - m_\chi)\chi\end{aligned}$$

2

$$\begin{aligned}\mathcal{L}_{Z'} &= \sum g_{Z'\chi\bar{\chi}}\bar{\chi}\gamma^\mu\chi Z'^\mu + \sum g_{Z'q\bar{q}}\ \bar{q}\gamma^\mu q Z'^\mu \\ &\quad + \bar{\chi}(i\partial_\mu\gamma^\mu - m_\chi)\chi + \text{gaugeterms}\end{aligned}$$

$$\begin{aligned}\mathcal{L}_{A'} &= \sum g_{A'\chi\bar{\chi}}\bar{\chi}\gamma^\mu\gamma^5\chi A'^\mu + \sum g_{A'q\bar{q}}\ \bar{q}\gamma^\mu\gamma^5 q A'^\mu \\ &\quad + \bar{\chi}(i\partial_\mu\gamma^\mu - m_\chi)\chi + \text{gaugeterms}\end{aligned}$$

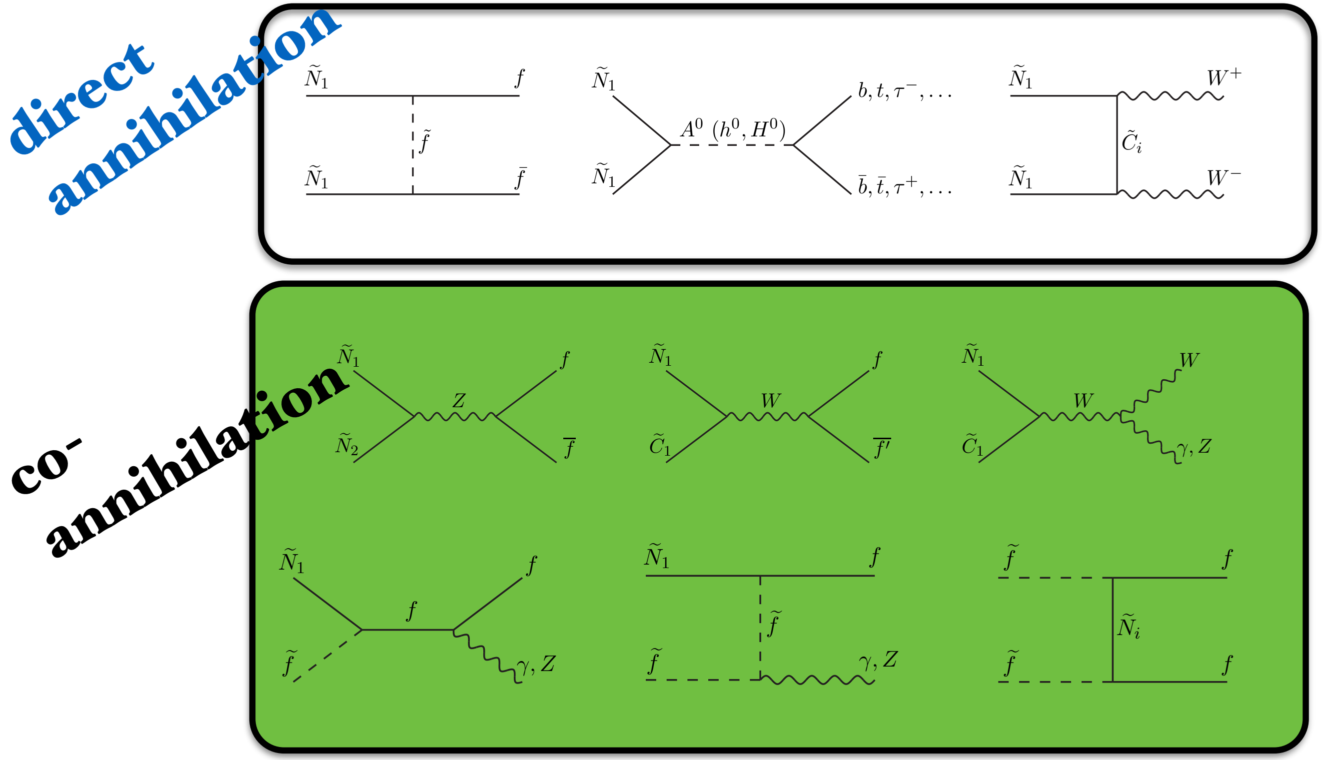
# DM IN SUSY




Mix to form “neutralinos" and “charginos”

$$\tilde{\chi}_i^0 = N_{ij}(\tilde{B}, \tilde{W}^0, \tilde{H}_u^0, \tilde{H}_d^0) \qquad \tilde{\chi}_i^\pm = V_{ij}(\tilde{W}^\pm, \tilde{H}^\pm)$$

1. Find parameter space that gives the right relic density




(Source: S.P. Martin; hep-ph/9709356)

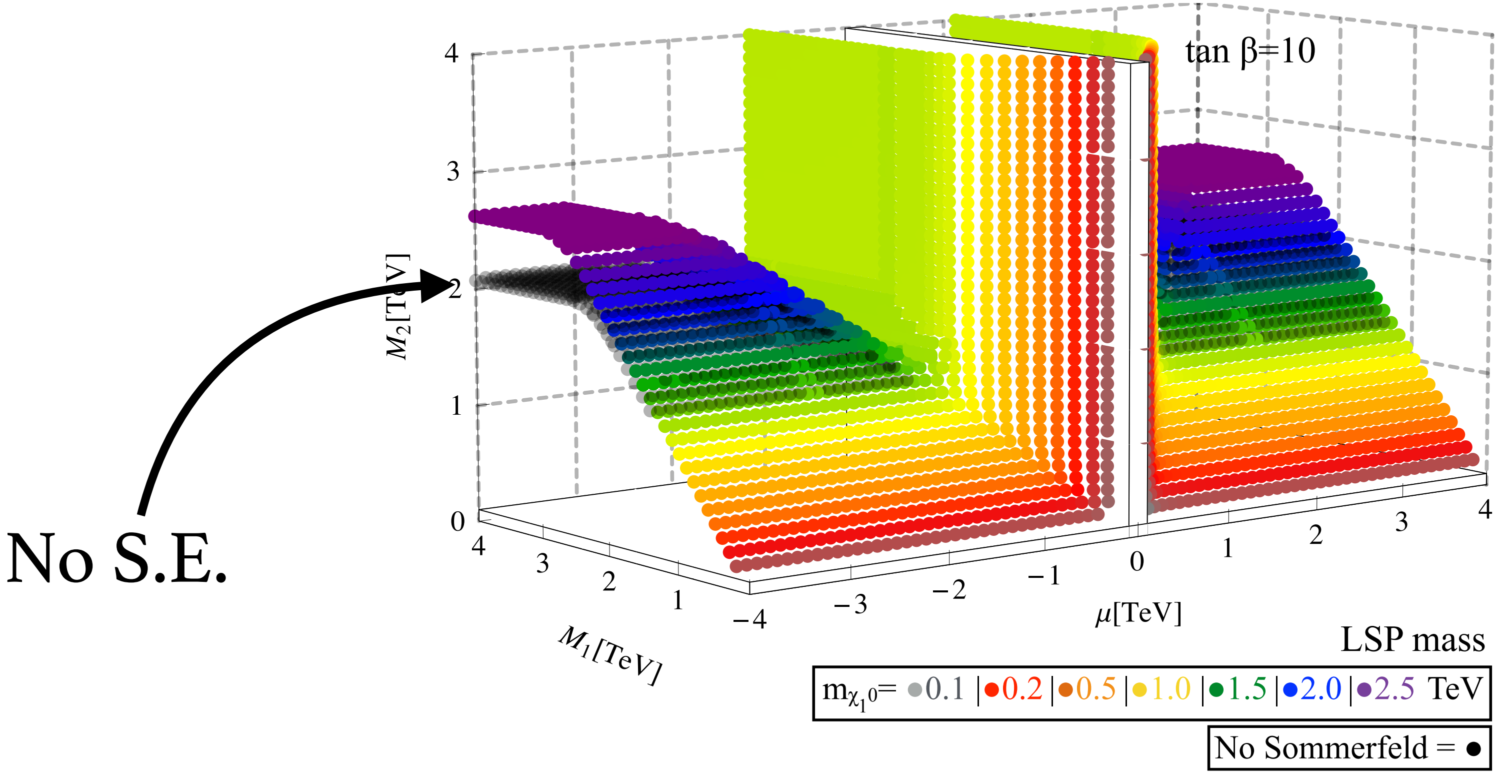
2. Look at Direct/Indirect/Collider constraints (both present and future expectations)

# PART I: DIRECT ANNIHILATION

# RELIC SURFACE WITH SE

$$M_1, \;\; M_2, \, \mu, \;\; \text{and} \;\; \tan\beta$$

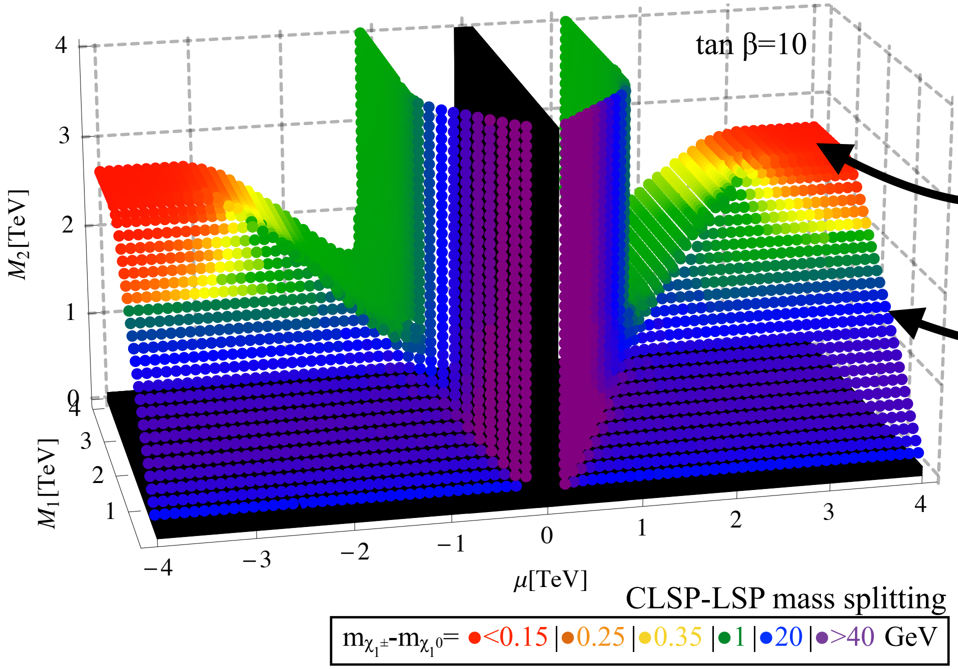
$$\Omega h^2 = 0.120 \pm 0.005$$




$$\Omega_{\tilde{W}} h^2 \simeq 0.12 \left(\frac{m_{\tilde{\chi}}}{2.1\ \text{TeV}}\right)^2 \xrightarrow{\text{SE}} 0.12 \left(\frac{m_{\tilde{\chi}}}{2.6\ \text{TeV}}\right)^2 \,.$$

$$\Omega_{\tilde{H}} h^2 \simeq 0.12 \left(\frac{m_{\tilde{\chi}}}{1.13\ \text{TeV}}\right)^2 \xrightarrow{\text{SE}} 0.12 \left(\frac{m_{\tilde{\chi}}}{1.14\ \text{TeV}}\right)^2 \,.$$

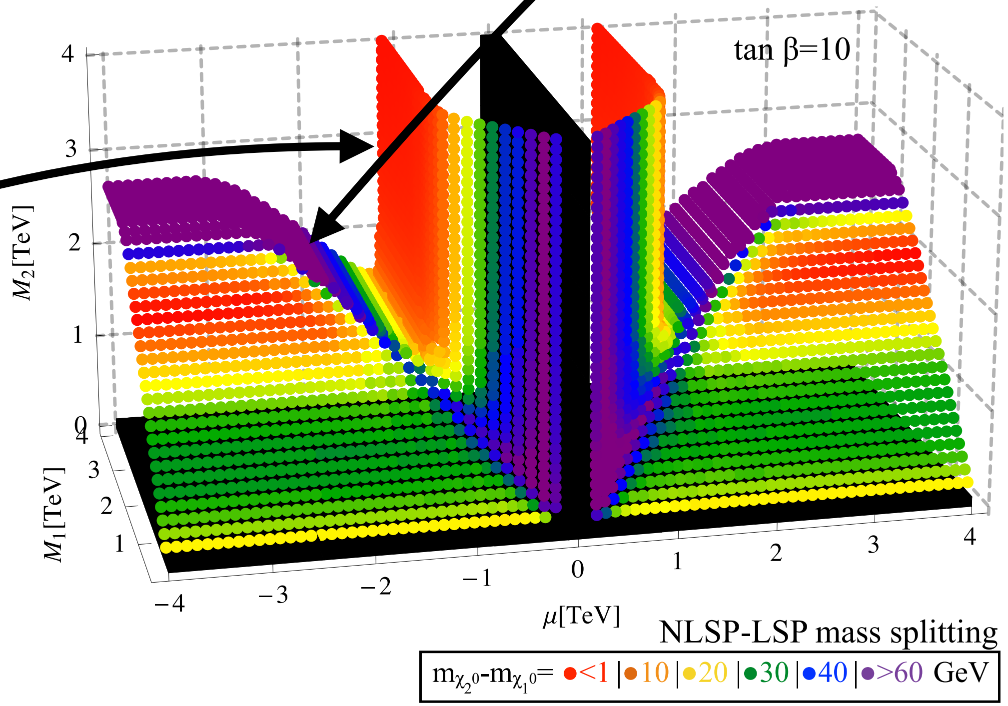
# MASS SPLITTING




pure Wino => co-annihilation with chargino

Wino-Higgsinos

Bino-Winos

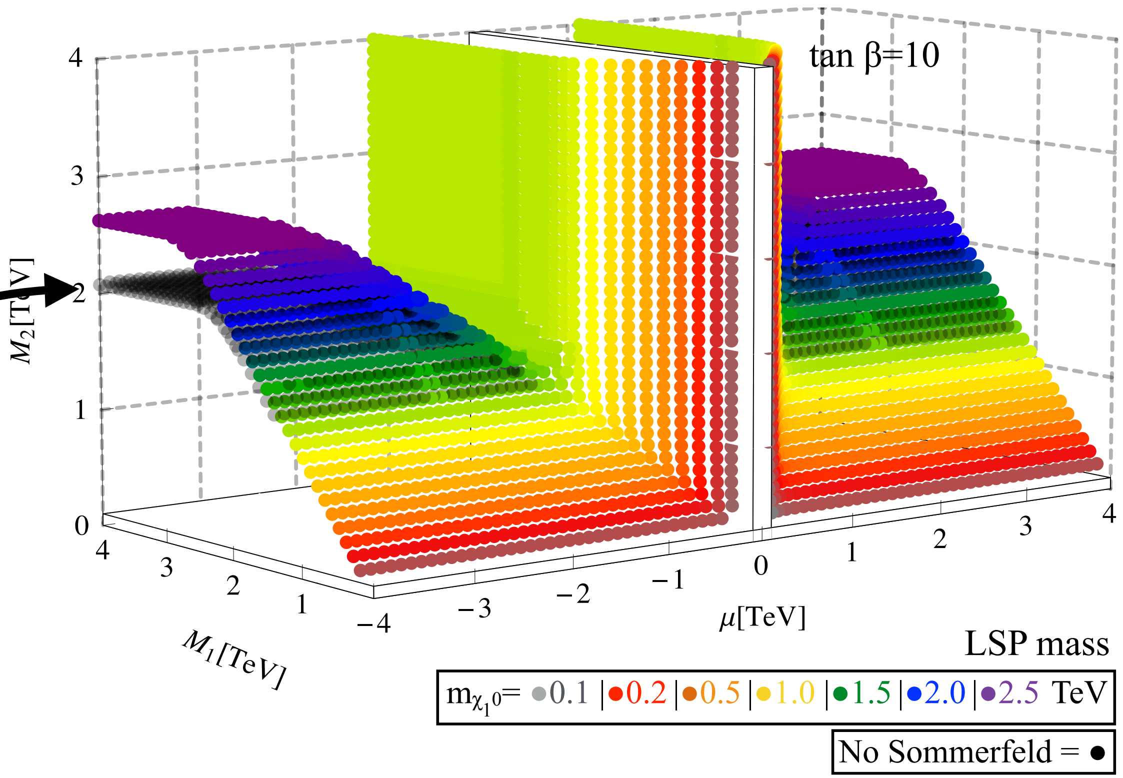



pure Higgsinos =>
co-annihilation with second neutralino + chargino

# RELIC SURFACE WITH SE

$$\Omega h^2 = 0.120 \pm 0.005$$

No S.E.




$$\Omega_{\tilde{W}} h^2 \simeq 0.12 \left(\frac{m_{\tilde{\chi}}}{2.1 \text{ TeV}}\right)^2 \xrightarrow{\text{SE}} 0.12 \left(\frac{m_{\tilde{\chi}}}{2.6 \text{ TeV}}\right)^2 .$$

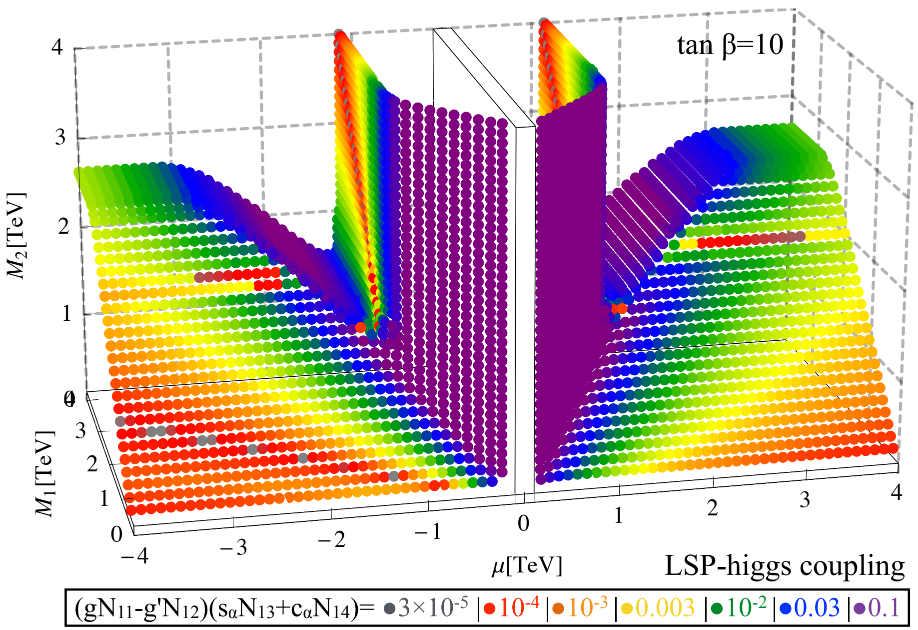
$$\Omega_{\tilde{H}} h^2 \simeq 0.12 \left(\frac{m_{\tilde{\chi}}}{1.13 \text{ TeV}}\right)^2 \xrightarrow{\text{SE}} 0.12 \left(\frac{m_{\tilde{\chi}}}{1.14 \text{ TeV}}\right)^2 .$$

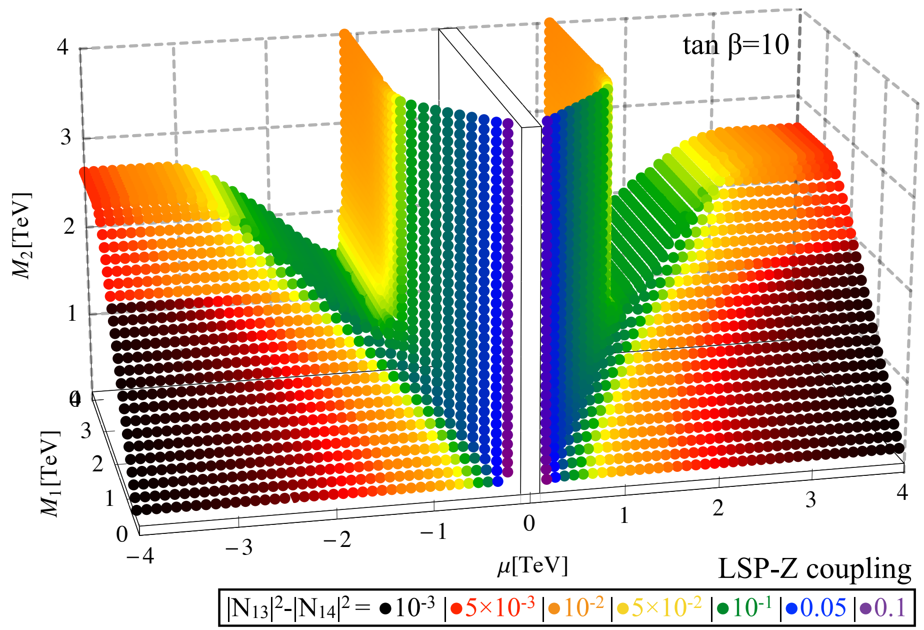
# COUPLINGS

$$g_{Z\tilde{\chi}_1^0\tilde{\chi}_1^0} = \frac{g}{2\cos\theta_w}\left(|N_{13}|^2 - |N_{14}|^2\right)$$

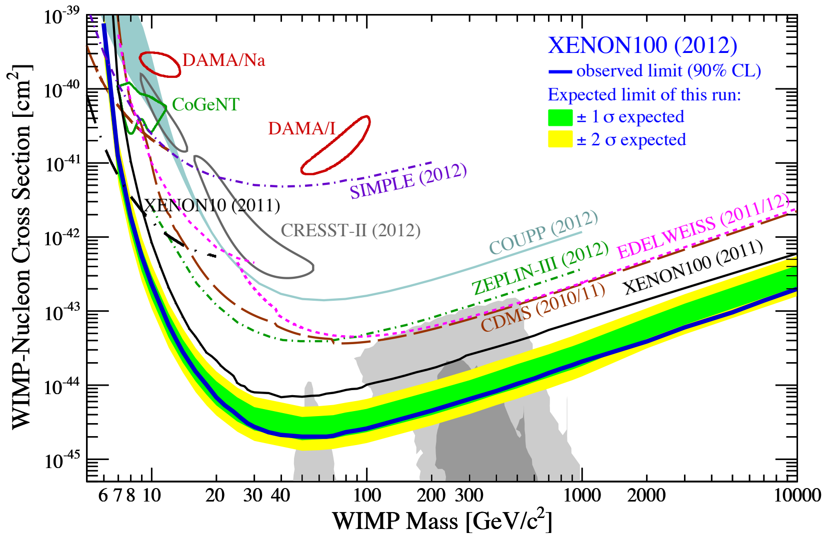
$$g_{h\tilde{\chi}_1^0\tilde{\chi}_1^0} = \left(gN_{11} - g'N_{12}\right)\left(\sin\alpha\ N_{13} + \cos\alpha\ N_{14}\right)$$

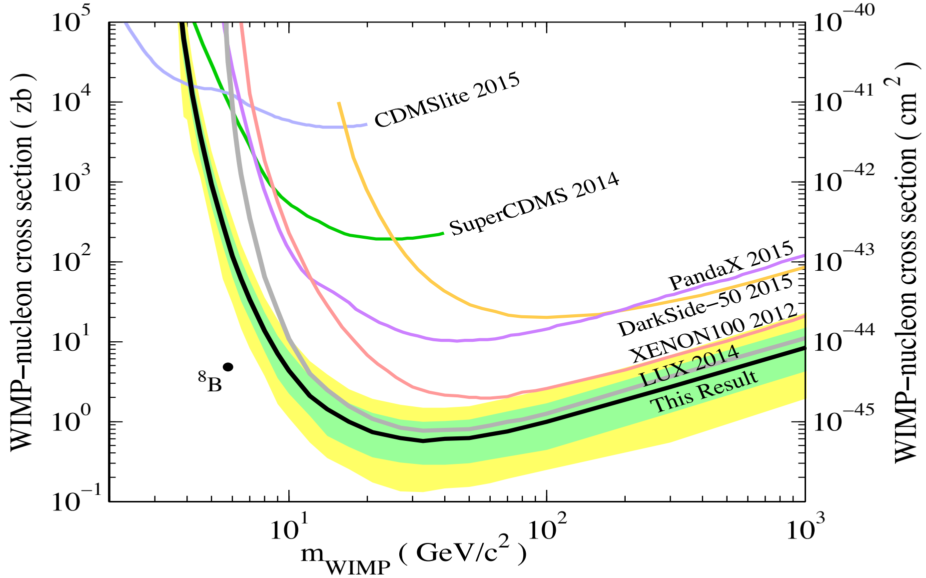
$$g_{W\tilde{\chi}_1^0\tilde{\chi}_1^+} = \frac{g\sin\theta_w}{\sqrt{2}\cos\theta_w}\left(N_{14}V_{12}^* - \sqrt{2}N_{12}V_{11}^*\right),$$

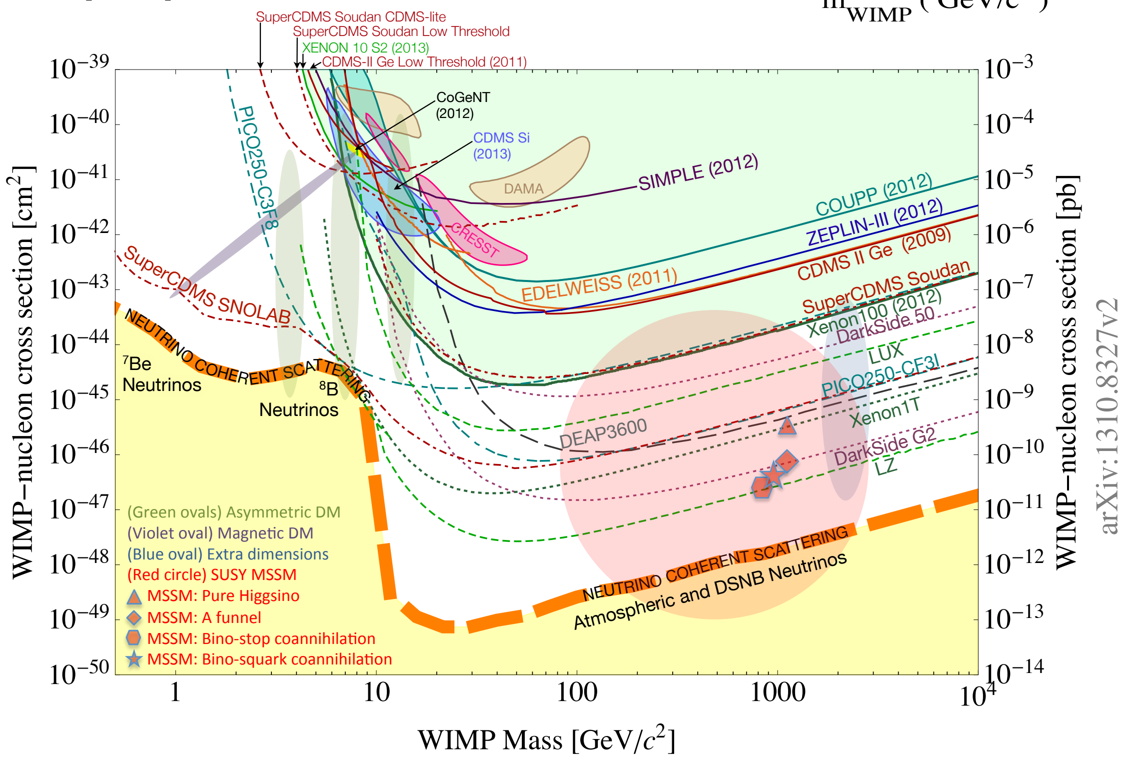


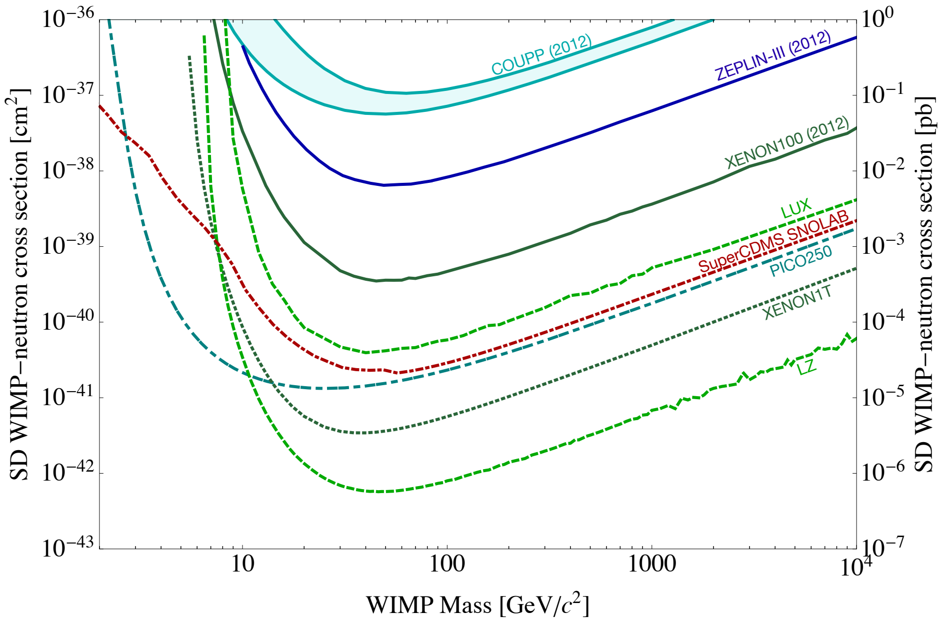
# SI DIRECT DETECTION LIMITS

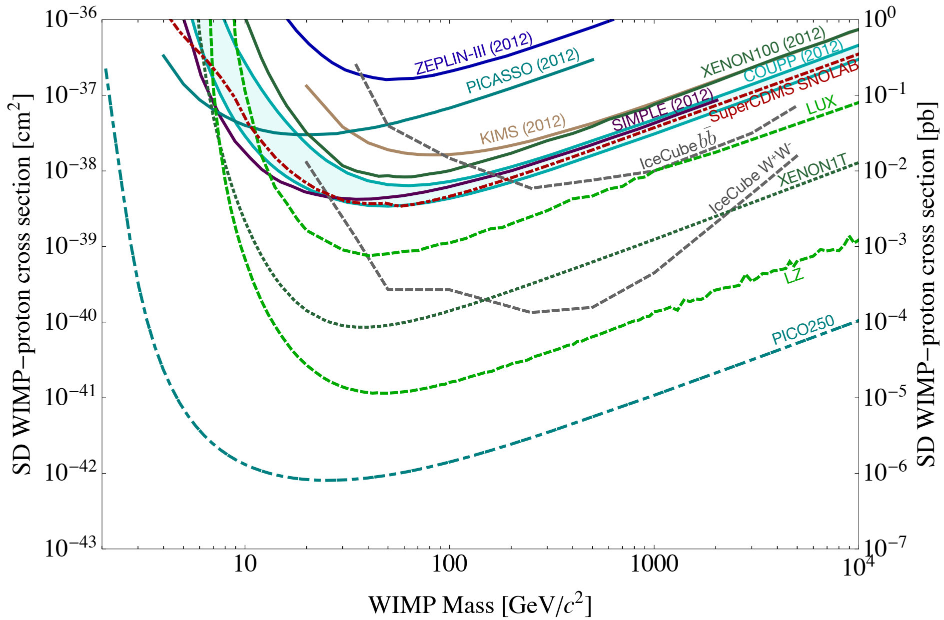


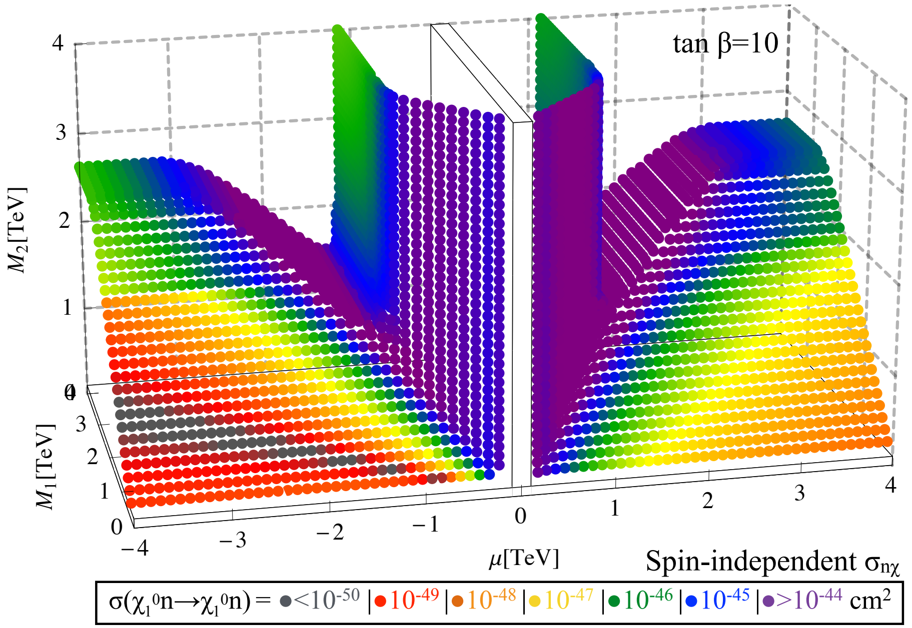
# SD DIRECT DETECTION LIMITS

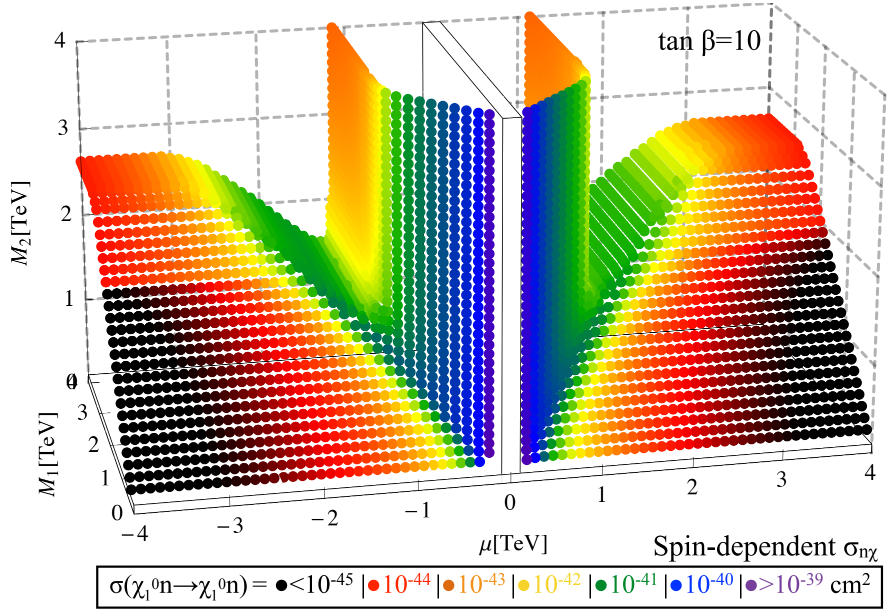


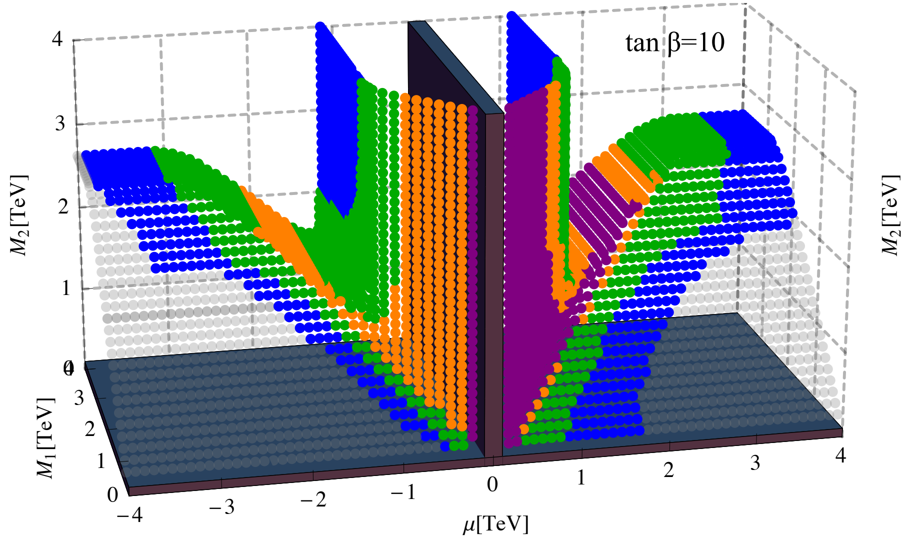




arXiv:1310.8327v2

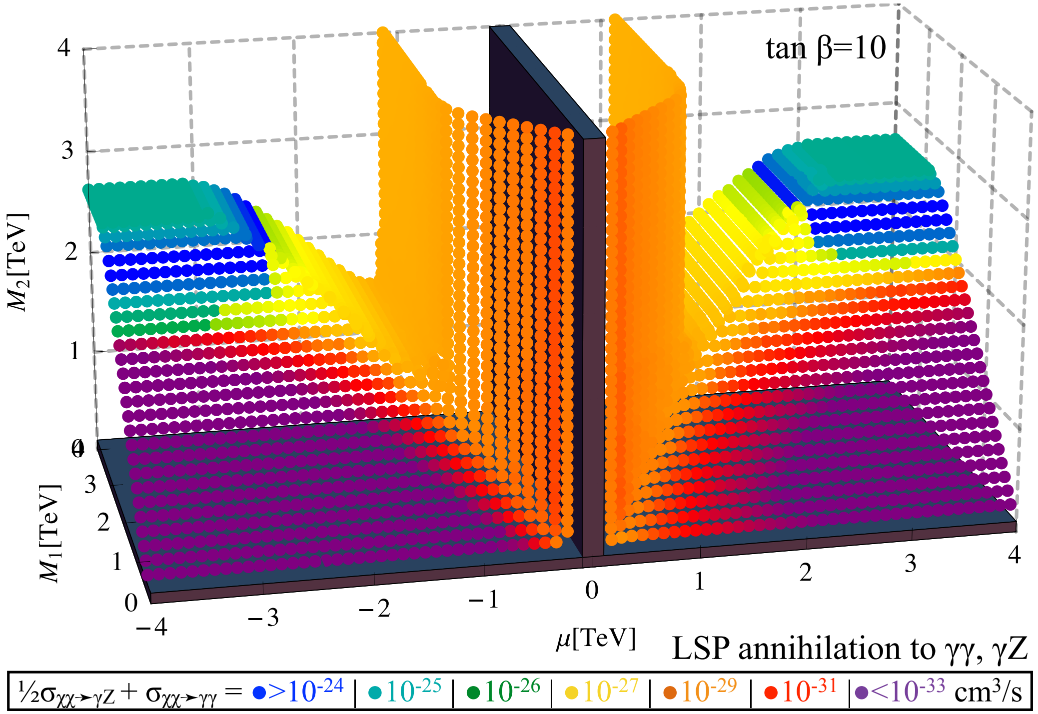
# DIRECT DETECTION

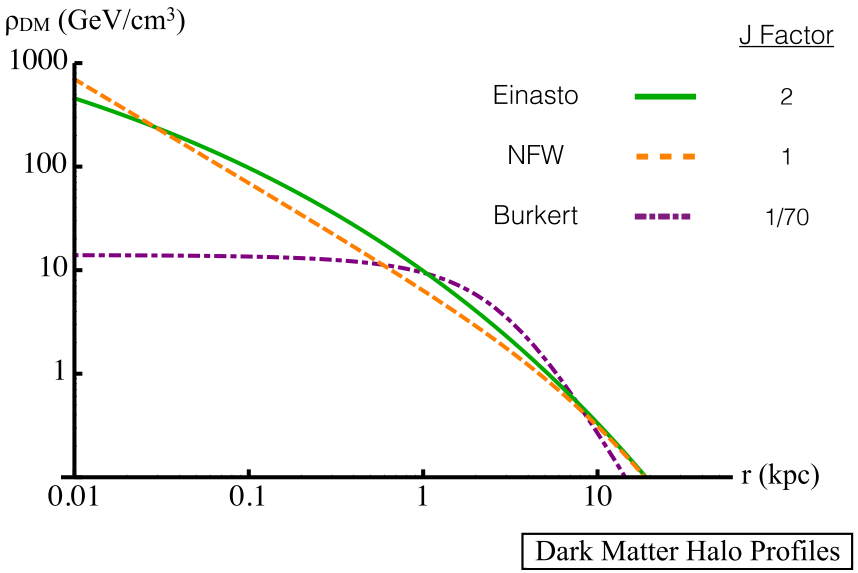


# INDIRECT DETECTION



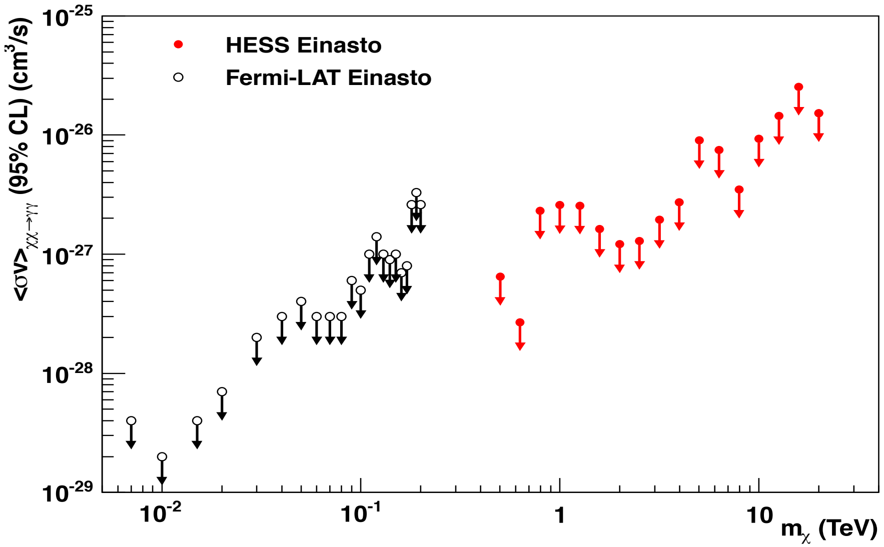



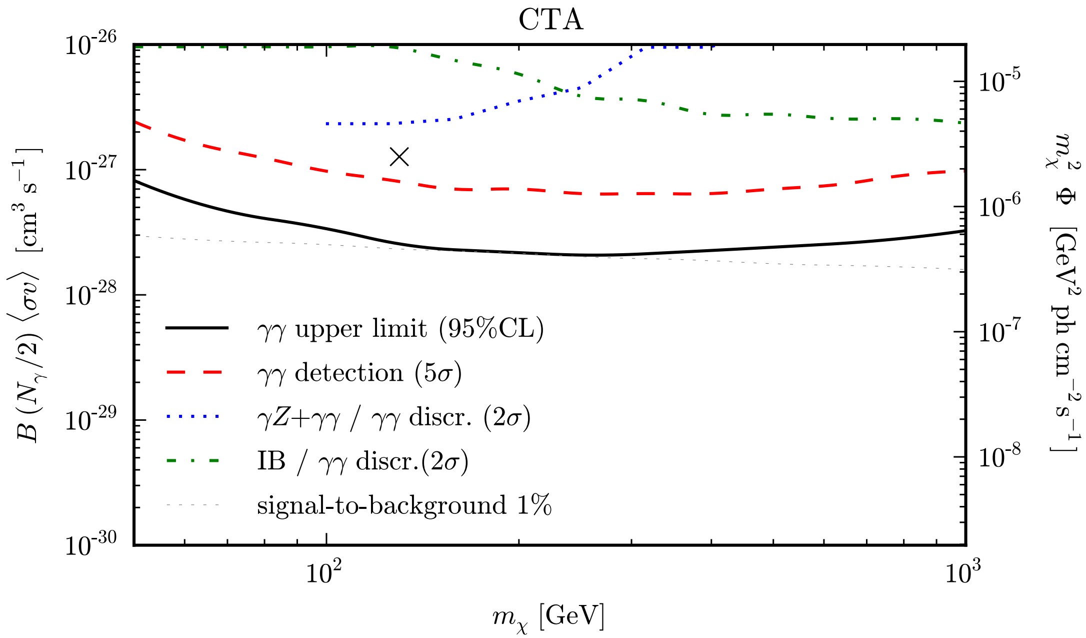

$$\rho_{\mathrm{NFW}}(r) = \frac{\rho_\odot}{(r/R)\,(1+r/R)^2},$$

$$\rho_{\mathrm{Ein}}(r) = \rho_\odot\ \exp\left[-\frac{2}{\alpha}\left(\left(\frac{r}{R}\right)^{\alpha} - 1\right)\right],$$

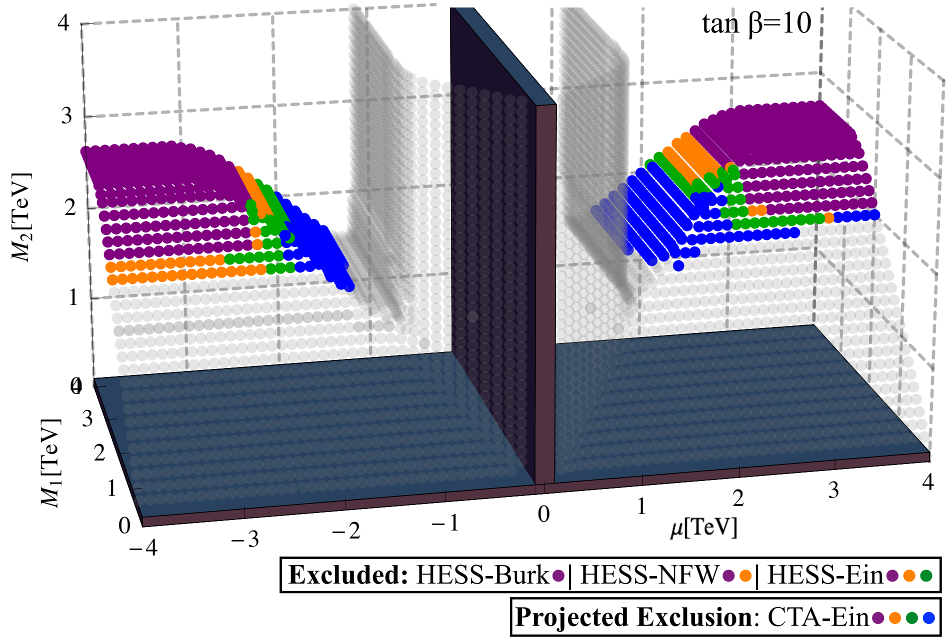
$$\rho_{\mathrm{Burk}}(r) = \frac{\rho_\odot}{(1+r/r_c)\,(1+(r/r_c)^2)},$$

# ANNIHILATION INTO PHOTONS



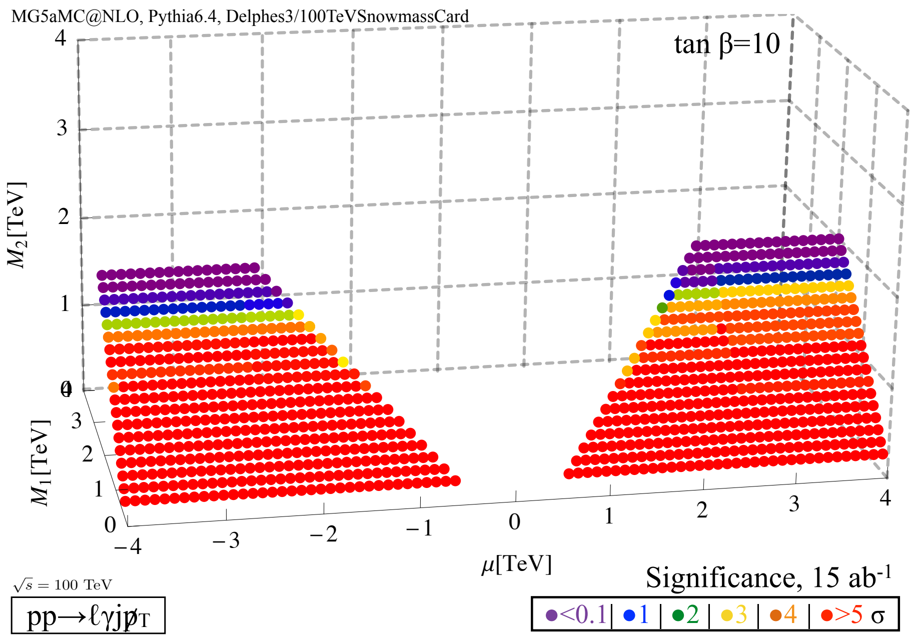



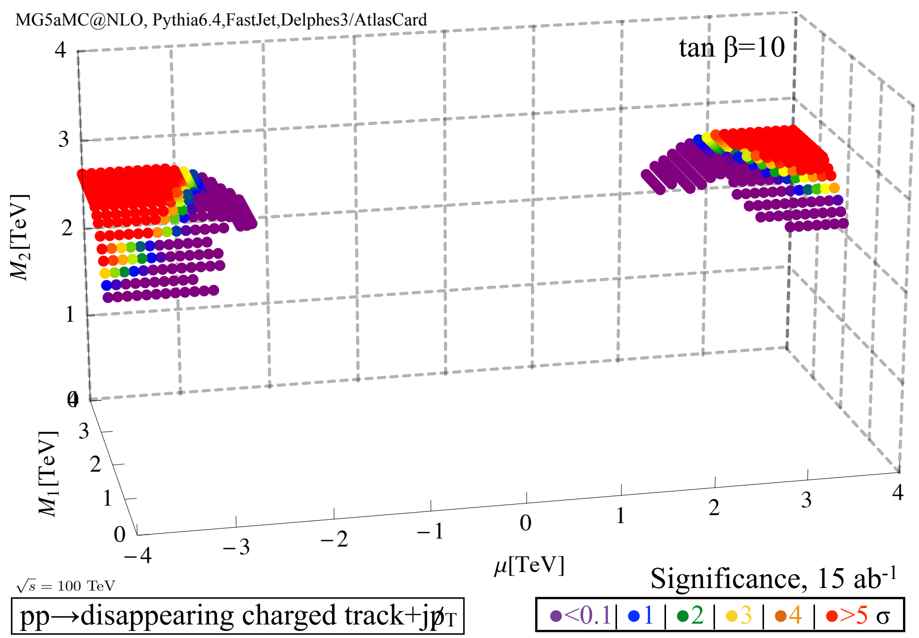

arXiv:1207.6773



# (POTENTIAL) COLLIDER SEARCHES

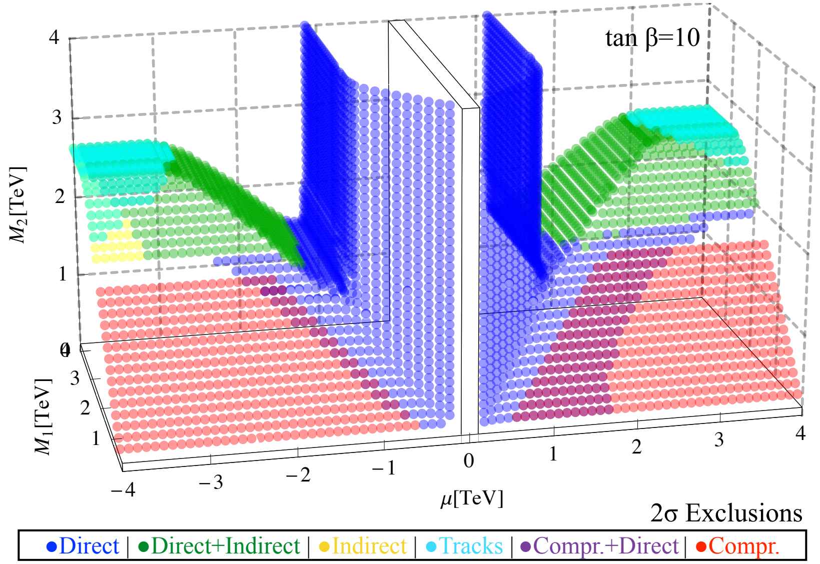
$$pp \to (\tilde{\chi}_2^0 \to \gamma \tilde{\chi}_1^0)\,(\tilde{\chi}_1^\pm \to \ell^\pm \nu_\ell \tilde{\chi}_1^0) j \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 \ell^\pm \nu_\ell \gamma j\ ,$$




$$pp \to \chi_1^+ \chi_1^-,\ \chi_1^0 \chi_1^+$$

# PUTTING IT ALL TOGETHER



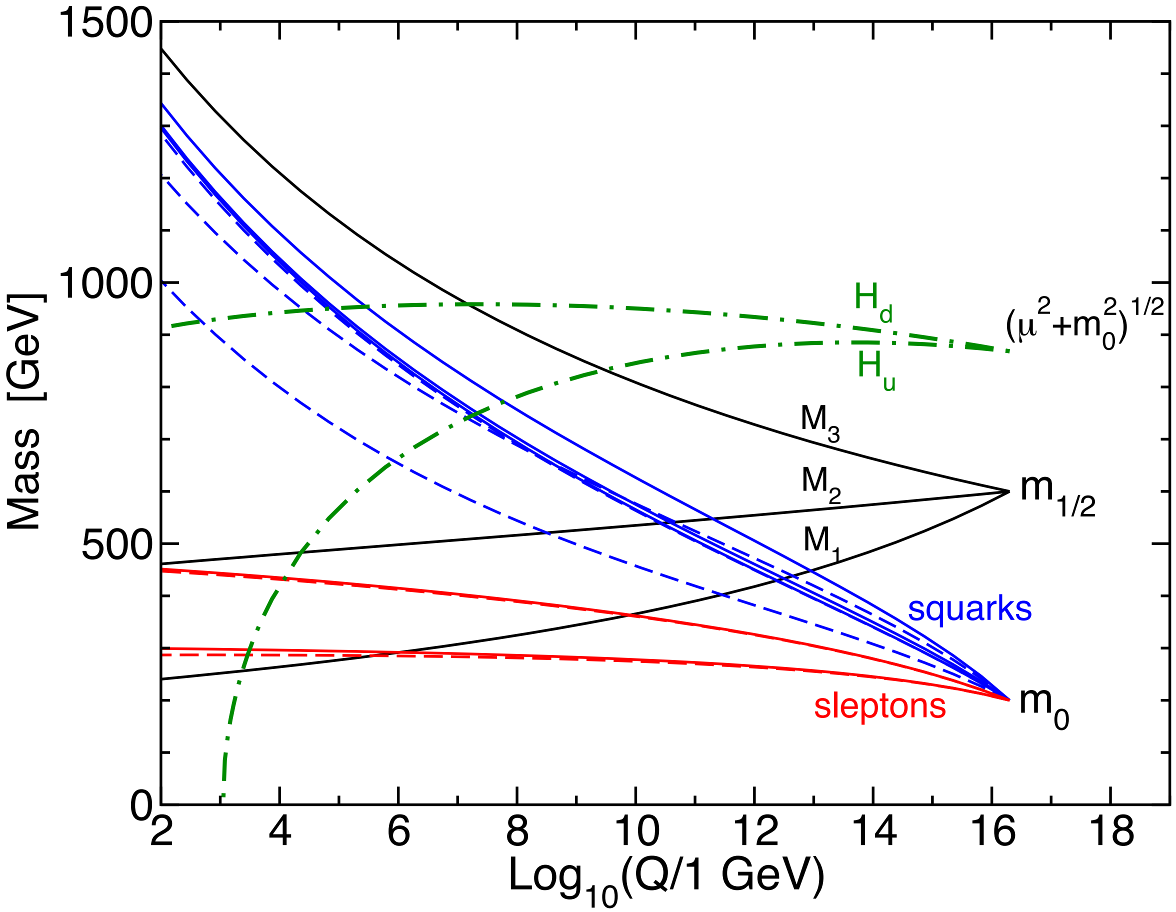

- Pure winos can best be detected with tracks + indirect detection
- Pure Higgsinos as well as Wino-Higgsinos can be detected with direct (and/or) indirect detection
- Bino-Winos can only be detected with collider searches

**Almost all of SUSY DM can be detected within next 10-20 years!**

# PART II: STAU CO-ANNIHILATION

# CMSSM PARAMETER SPACE

$$m_0, m_{1/2}, A_0, \tan\beta, sign(\mu)$$

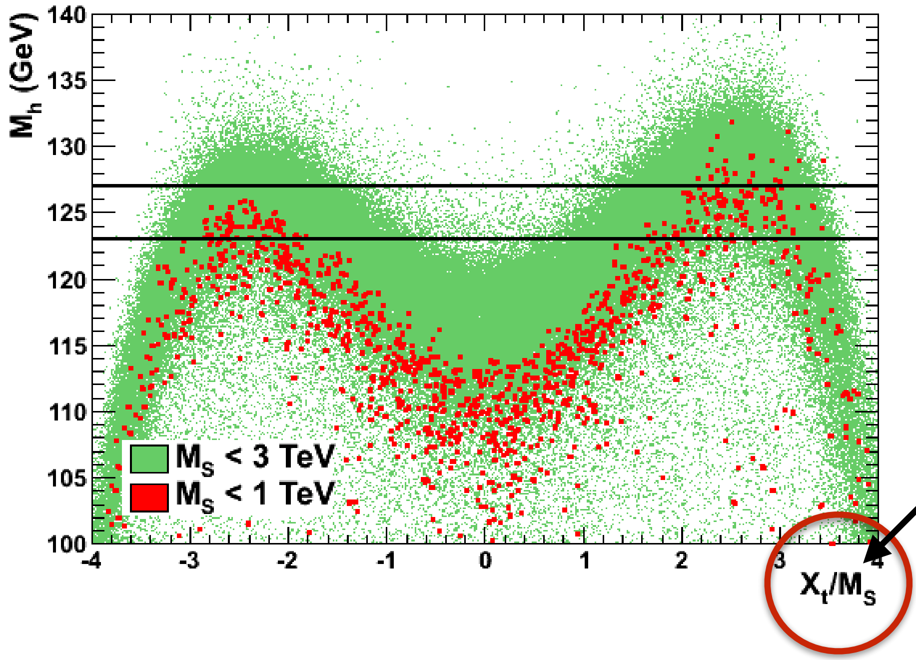



(Source: S.P. Martin; hep-ph/9709356)

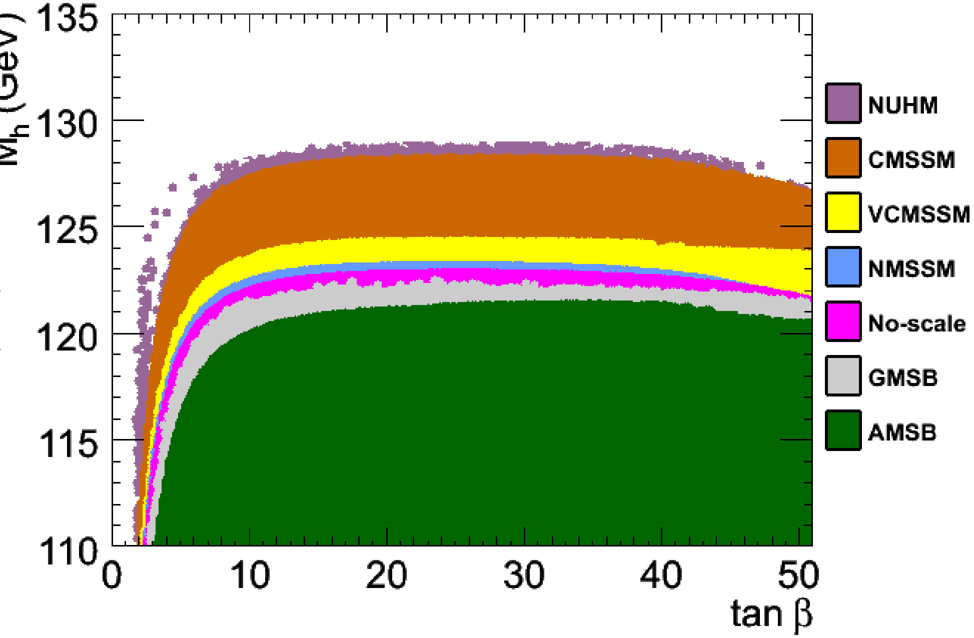
Advantage:
fewer parameters
⇒ easy to test

Disadvantage:
fewer parameters
⇒ not all variants are covered
⇒ "indirect" limits on sparticle masses

# HIGGS MASS IN THE (C)MSSM




Depends on $A_0$




Phys. Lett. B708 (2012) 162.

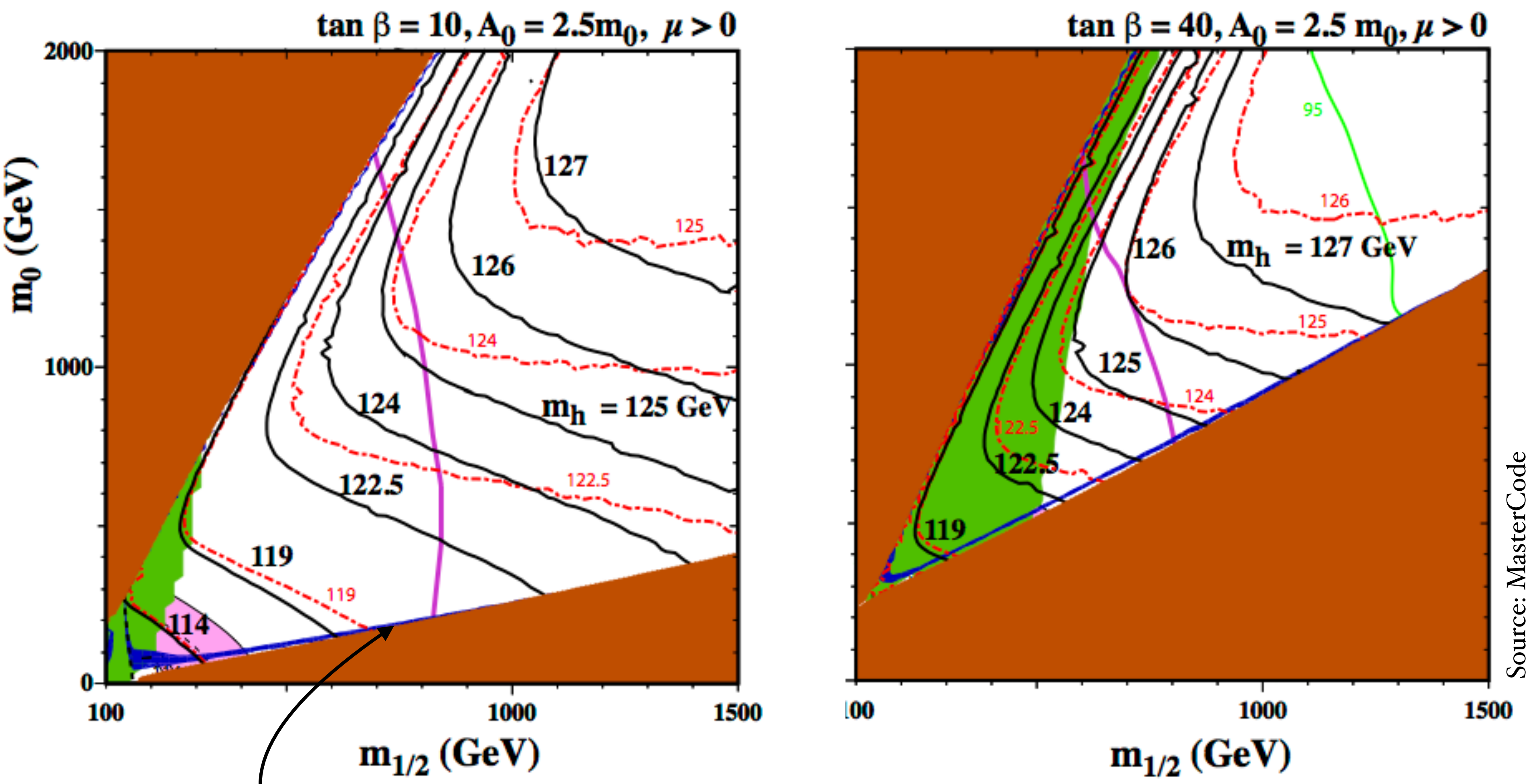
# QUESTIONS TO ASK:

1. Does it give the correct Higgs mass?
2. Does it give the right relic density?
3. Does it satisfy constraints from the LHC?

| Fittino | MasterCode | Sfitter |
|---|---|---|
| $M_{1/2} = 1016$ GeV | $M_{1/2} = 1040$ GeV | $M_{1/2} = 999$ GeV |
| $M_0 = 504$ GeV | $M_0 = 670$ GeV | $M_0 = 442$ GeV |
| $\tan\beta = 18$ | $\tan\beta = 21$ | $\tan\beta = 24.6$ |
| $A_0 = -2870$ GeV | $A_0 = -3440$ GeV | $A_0 = -1347$ GeV |

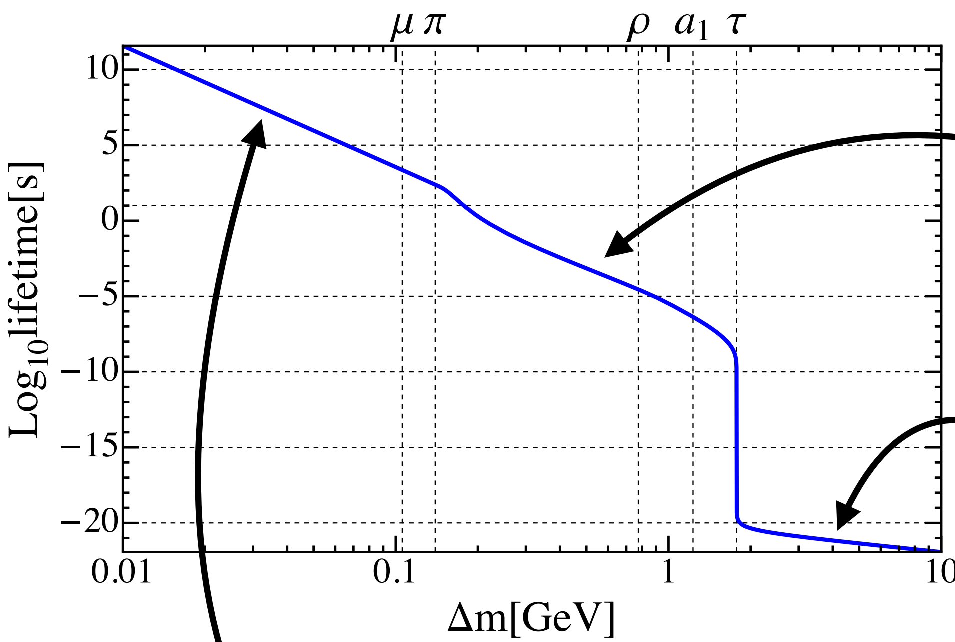
**All of them in the stau co-annihilation strip!**

# WHAT DOES THE STAU CO-ANNIHILATION STRIP LOOK LIKE TODAY?




$m_\tau > \Delta m (= m_\chi - m_{\tilde{\tau}})$ $\Rightarrow$ Long-lived or stable staus
(is jets+MET still sensitive?)

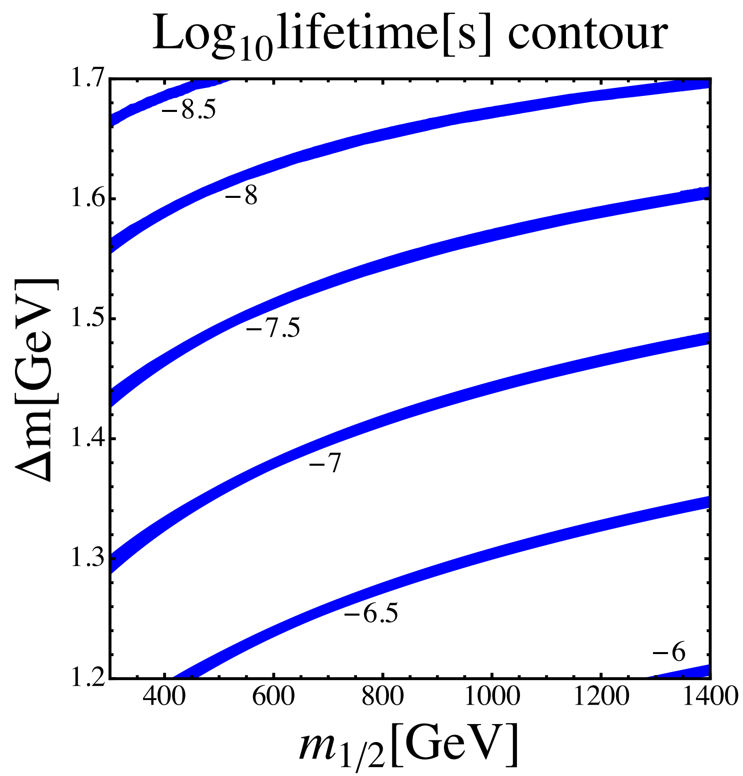
# LIFETIME OF THE STAU

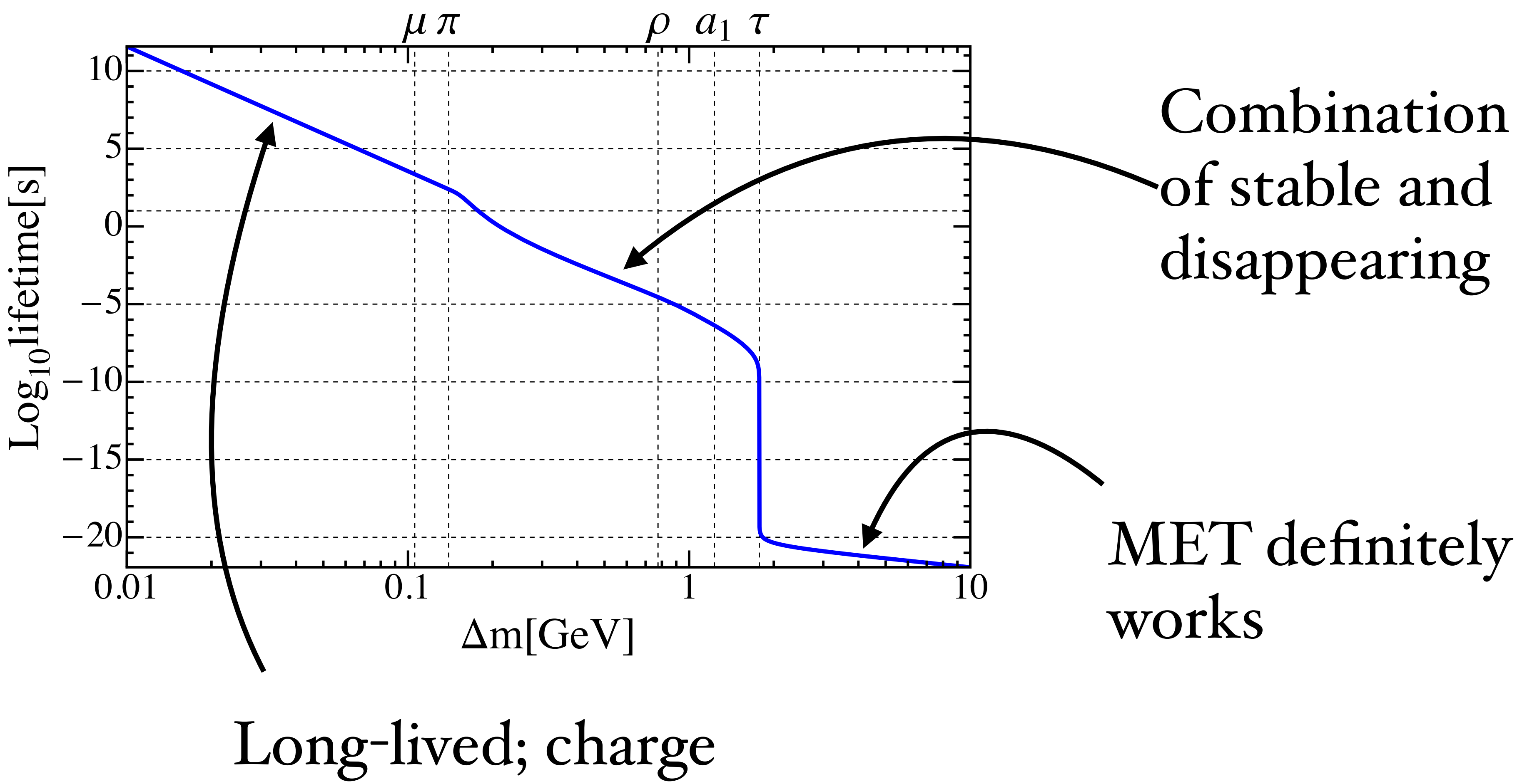



$$\tilde{\tau}_1^- \rightarrow a_1^- \nu_\tau \chi$$
$$\tilde{\tau}_1^- \rightarrow \rho^- \nu_\tau \chi$$
$$\tilde{\tau}_1^- \rightarrow \pi^- \nu_\tau \chi$$

$$\tilde{\tau}_1^- \rightarrow \tau^- \chi.$$

$$\tilde{\tau}_1^- \rightarrow e^- \bar{\nu}_e \nu_\tau \chi$$
$$\tilde{\tau}_1^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau \chi.$$

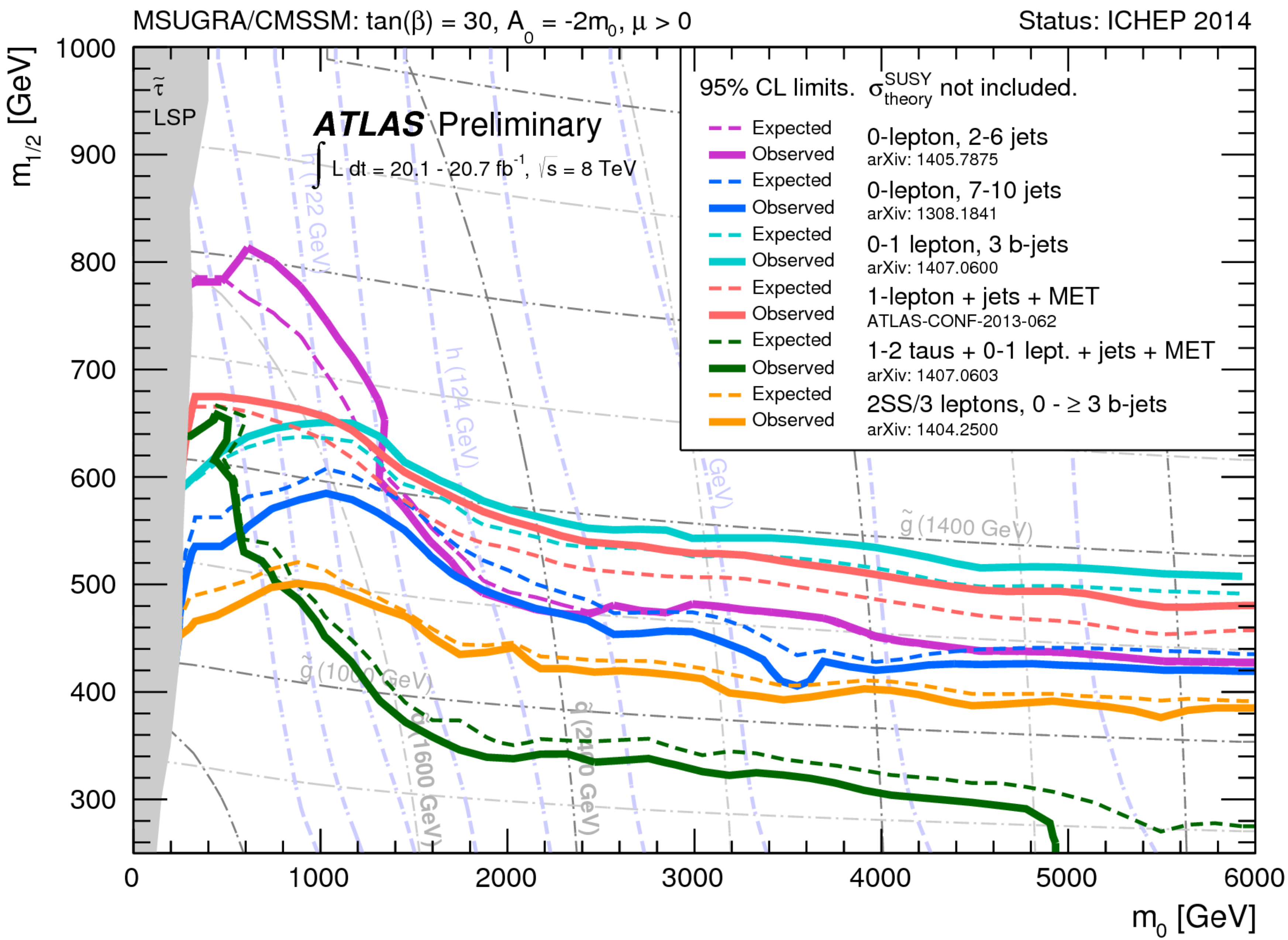





Useful parameters to probe the co-annihilation

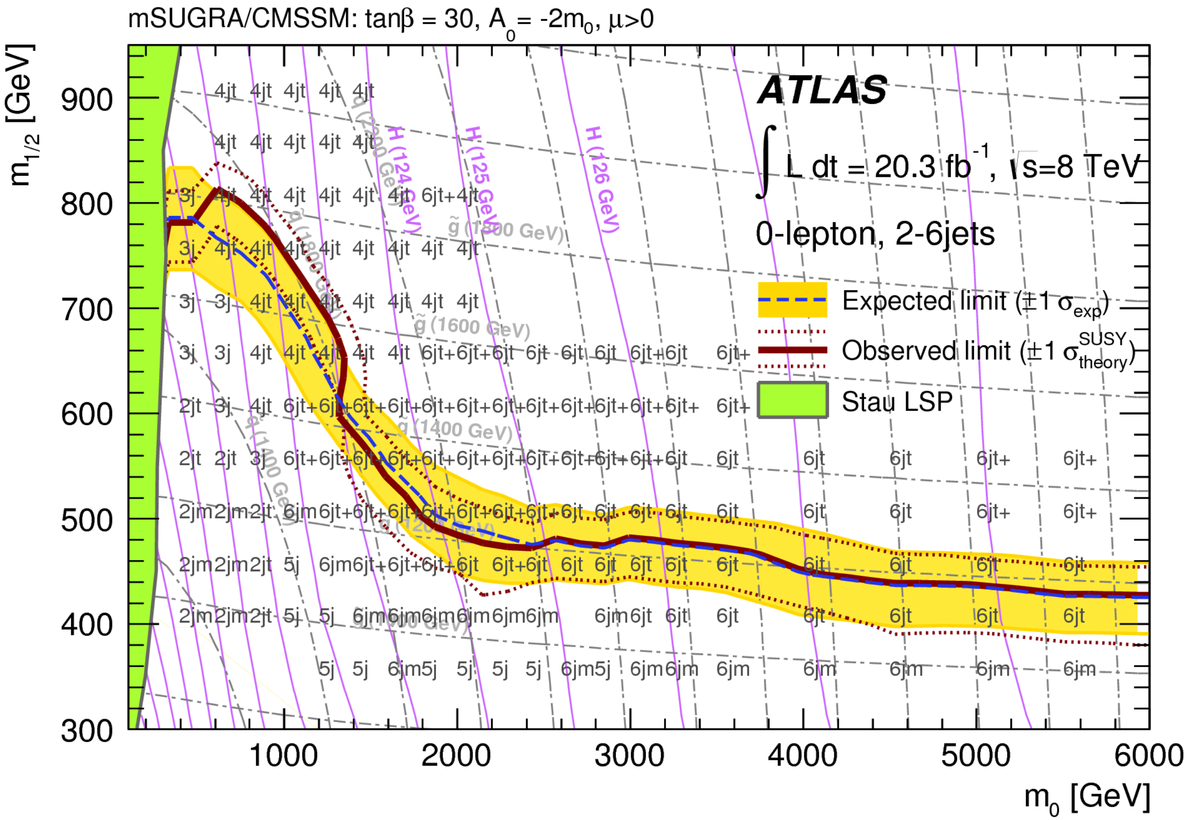
$$m_{\frac{1}{2}}, \Delta m, \tan\beta, A_0$$

# MET-BASED SEARCHES



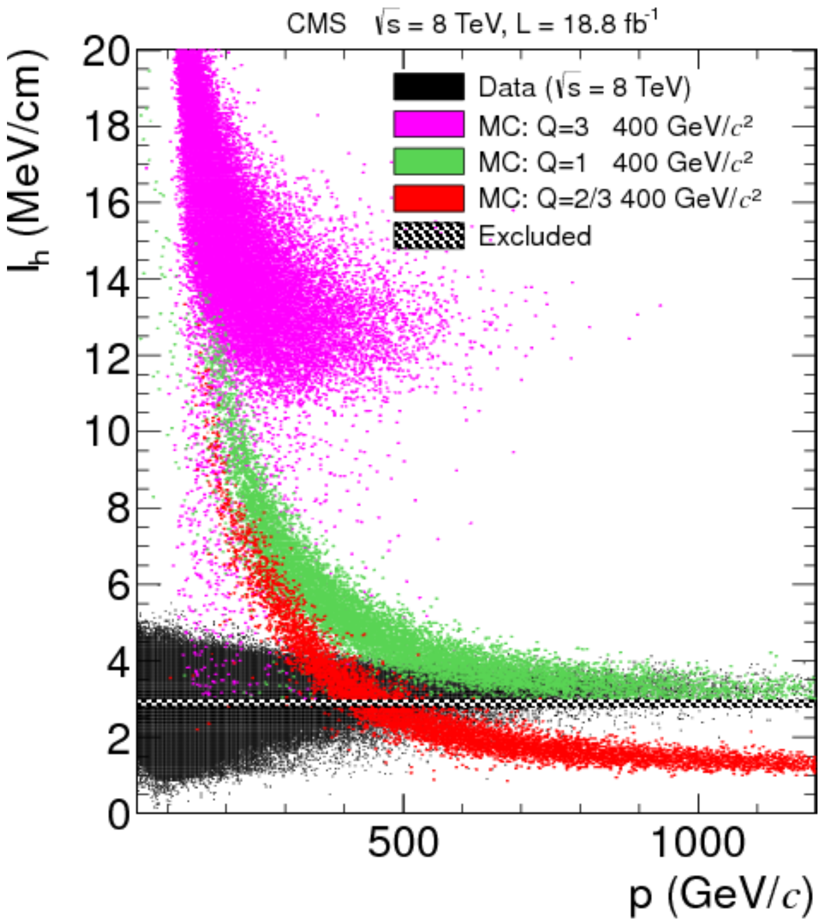
# 2–6 JETS + MET

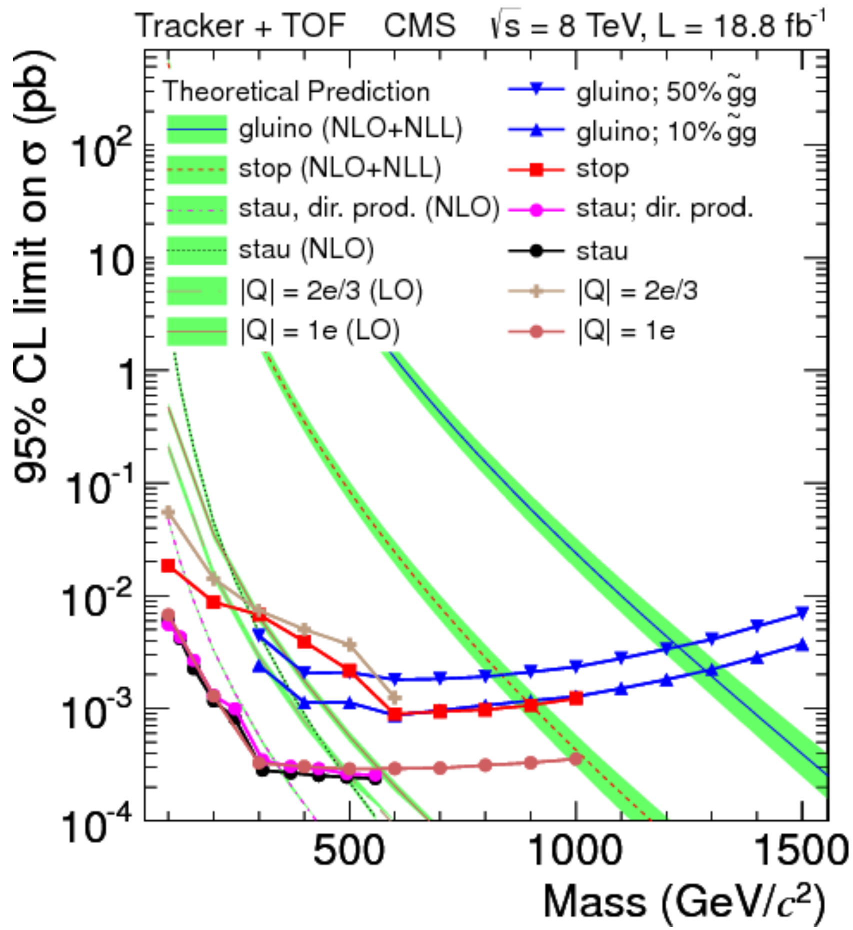
JHEP09(2014)176




| Requirement | Signal Region | |
|---|---|---|
| | **2jW** | **3j** |
| $E_{\mathrm{T}}^{\mathrm{miss}}$[GeV] $>$ | 160 | |
| $p_{\mathrm{T}}(j_1)$ [GeV] $>$ | 130 | |
| $p_{\mathrm{T}}(j_2)$ [GeV] $>$ | 60 | |
| $p_{\mathrm{T}}(j_3)$ [GeV] $>$ | | 60 |
| $p_{\mathrm{T}}(j_4)$ [GeV] $>$ | | |
| $\Delta\phi(\mathrm{jet}_{1,2,(3)}, \mathbf{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}} >$ | 0.4 | |
| $\Delta\phi(\mathrm{jet}_{i>3}, \mathbf{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}} >$ | | |
| $W$ candidates | $2(W \to j)$ | – |
| $E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$ [GeV$^{1/2}$] $>$ | | |
| $E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}(N_{\mathrm{j}}) >$ | 0.25 | 0.3 |
| $m_{\mathrm{eff}}$(incl.) [GeV] $>$ | 1800 | 2200 |

# CMS: EXOTIC CHARGED TRACKS

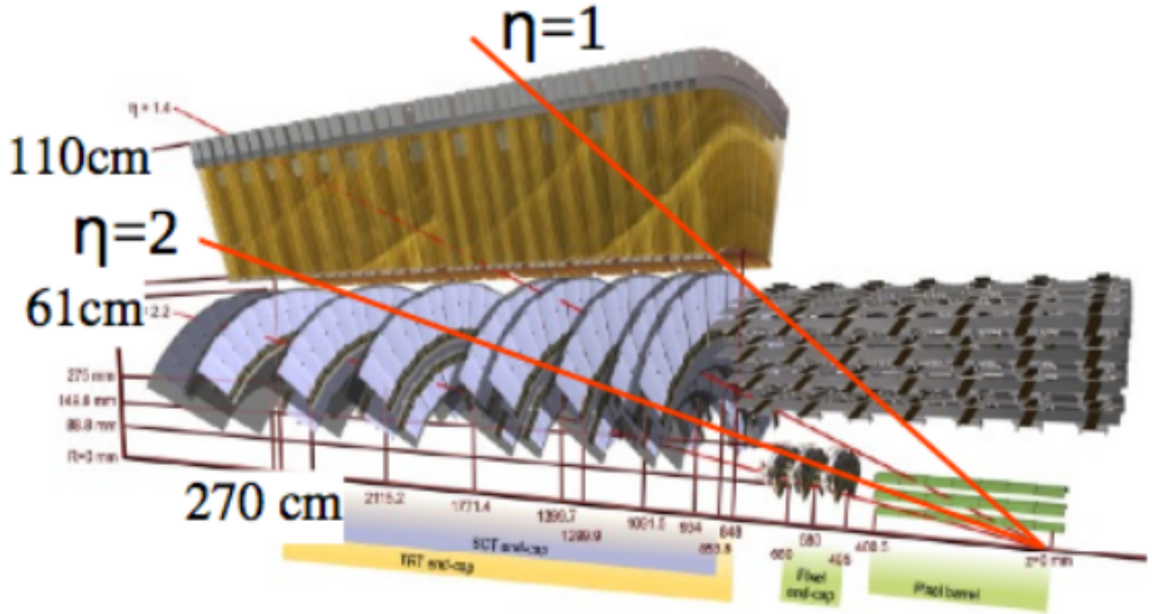


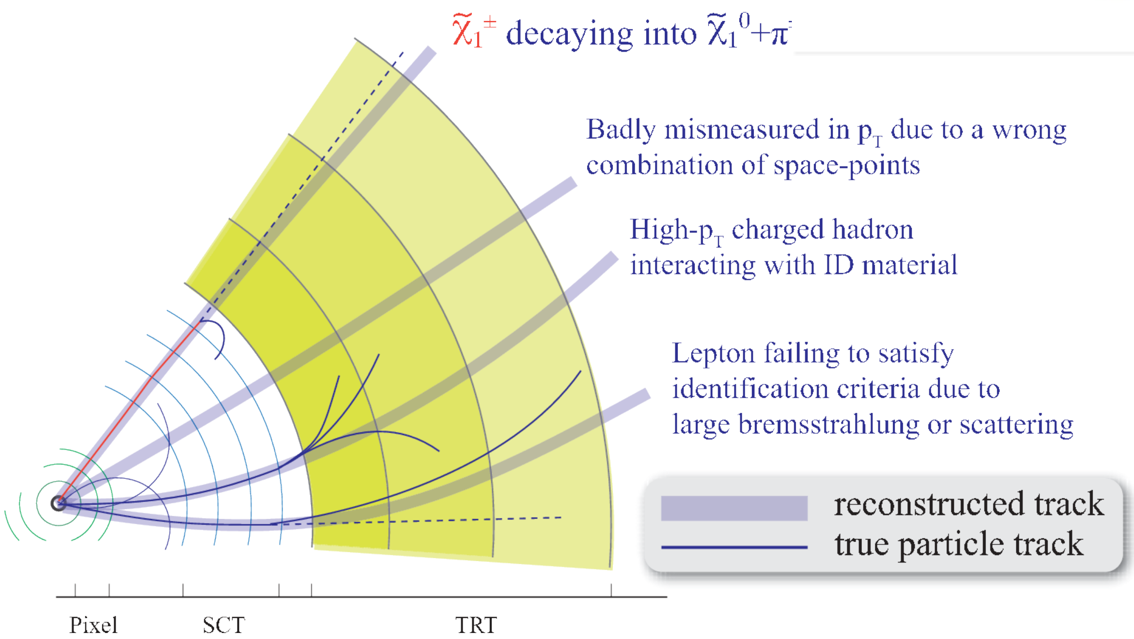




| Mass ($\mathrm{GeV}/c^2$) | $M$ req. ($\mathrm{GeV}/c^2$) | $\sigma$ (pb) ($\sqrt{s}=7$ TeV) Exp. | Obs. | Acc. | $\sigma$ (pb) ($\sqrt{s}=8$ TeV) Exp. | Obs. | Acc. | $\sigma/\sigma_{th}$ (7+8 TeV) Exp. | Obs. |
|---|---|---|---|---|---|---|---|---|---|
| Direct+indirect produced stau — tracker+TOF analysis | | | | | | | | | |
| 126 | >40 | 0.0046 | 0.0035 | 0.29 | 0.0042 | 0.0042 | 0.25 | 0.0074 | 0.0065 |
| 308 | >190 | 0.00094 | 0.0015 | 0.63 | 0.00029 | 0.00028 | 0.56 | 0.16 | 0.21 |
| 494 | >330 | 0.00079 | 0.00084 | 0.74 | 0.00023 | 0.00024 | 0.66 | 1.9 | 1.9 |
| Direct produced stau — tracker+TOF analysis | | | | | | | | | |
| 126 | >40 | 0.0056 | 0.0046 | 0.26 | 0.0044 | 0.0043 | 0.24 | 0.18 | 0.16 |
| 308 | >190 | 0.0011 | 0.0017 | 0.54 | 0.00035 | 0.00035 | 0.46 | 0.62 | 0.66 |
| 494 | >330 | 0.00084 | 0.00088 | 0.69 | 0.00025 | 0.00026 | 0.61 | 4.7 | 5.0 |

# ATLAS: DISAPPEARING TRACK SEARCH

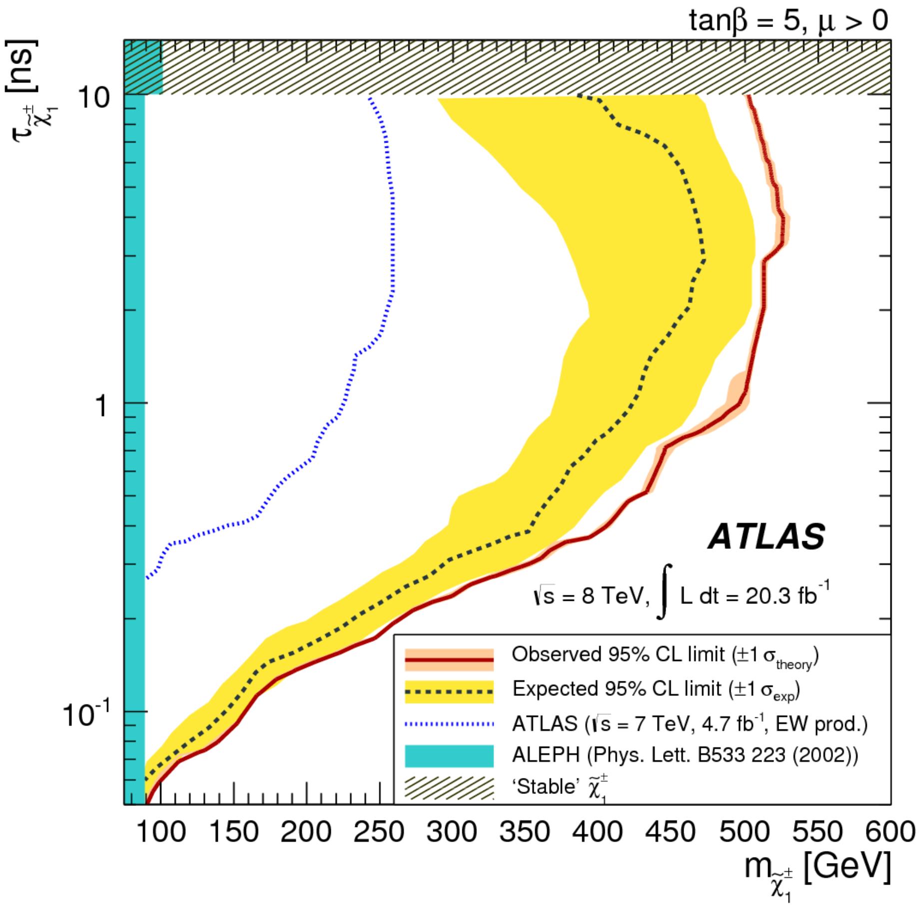
| Selection requirement |
| --- |
| Quality requirements and trigger |
| Jet cleaning |
| Lepton veto |
| Leading jet $p_{\mathrm{T}} > 90$ GeV |
| $E_{\mathrm{T}}^{\mathrm{miss}} > 90$ GeV |
| $\Delta\phi_{\mathrm{min}}^{\mathrm{jet}\text{-}E_{\mathrm{T}}^{\mathrm{miss}}} > 1.5$ |
| High-$p_{\mathrm{T}}$ isolated track selection |
| Disappearing-track selection |




Phys. Rev. D 88, 112006 (2013)

# ATLAS: DISAPPEARING TRACK SEARCH



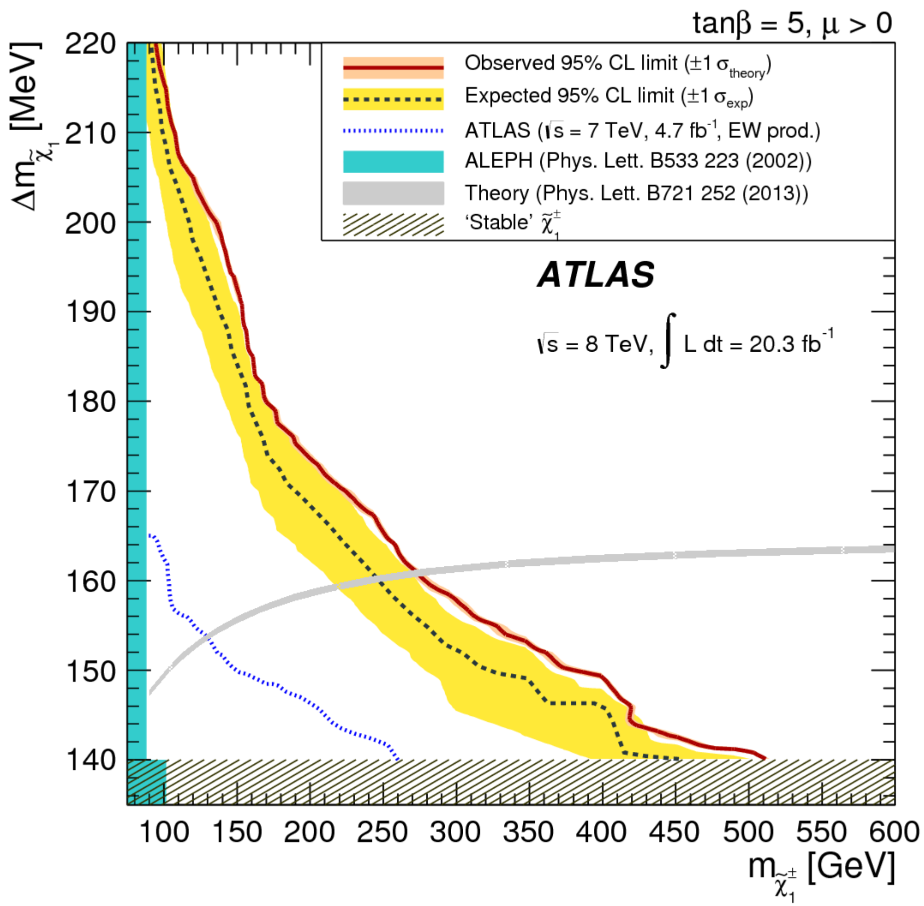




TABLE III. Numbers of observed and expected background events as well as the probability that a background-only experiment is more signal-like than observed ($p_0$) and the model-independent upper limit on the visible cross-section ($\sigma_{\rm vis}^{95\%}$) at 95% CL.

| | $p_T^{\rm track} > 75$ GeV | $p_T^{\rm track} > 100$ GeV | $p_T^{\rm track} > 150$ GeV | $p_T^{\rm track} > 200$ GeV |
|---|---|---|---|---|
| Observed events | 59 | 36 | 19 | 13 |
| Expected events | $48.5 \pm 12.3$ | $37.1 \pm 9.4$ | $24.6 \pm 6.3$ | $18.0 \pm 4.6$ |
| $p_0$ value | 0.17 | 0.41 | 0.46 | 0.44 |
| Observed $\sigma_{\rm vis}^{95\%}$ [fb] | 1.76 | 1.02 | 0.62 | 0.44 |
| Expected $\sigma_{\rm vis}^{95\%}$ [fb] | $1.42^{+0.50}_{-0.39}$ | $1.05^{+0.37}_{-0.28}$ | $0.67^{+0.27}_{-0.19}$ | $0.56^{+0.23}_{-0.16}$ |

# METHOD

- ➡ Simulate events using Pythia8

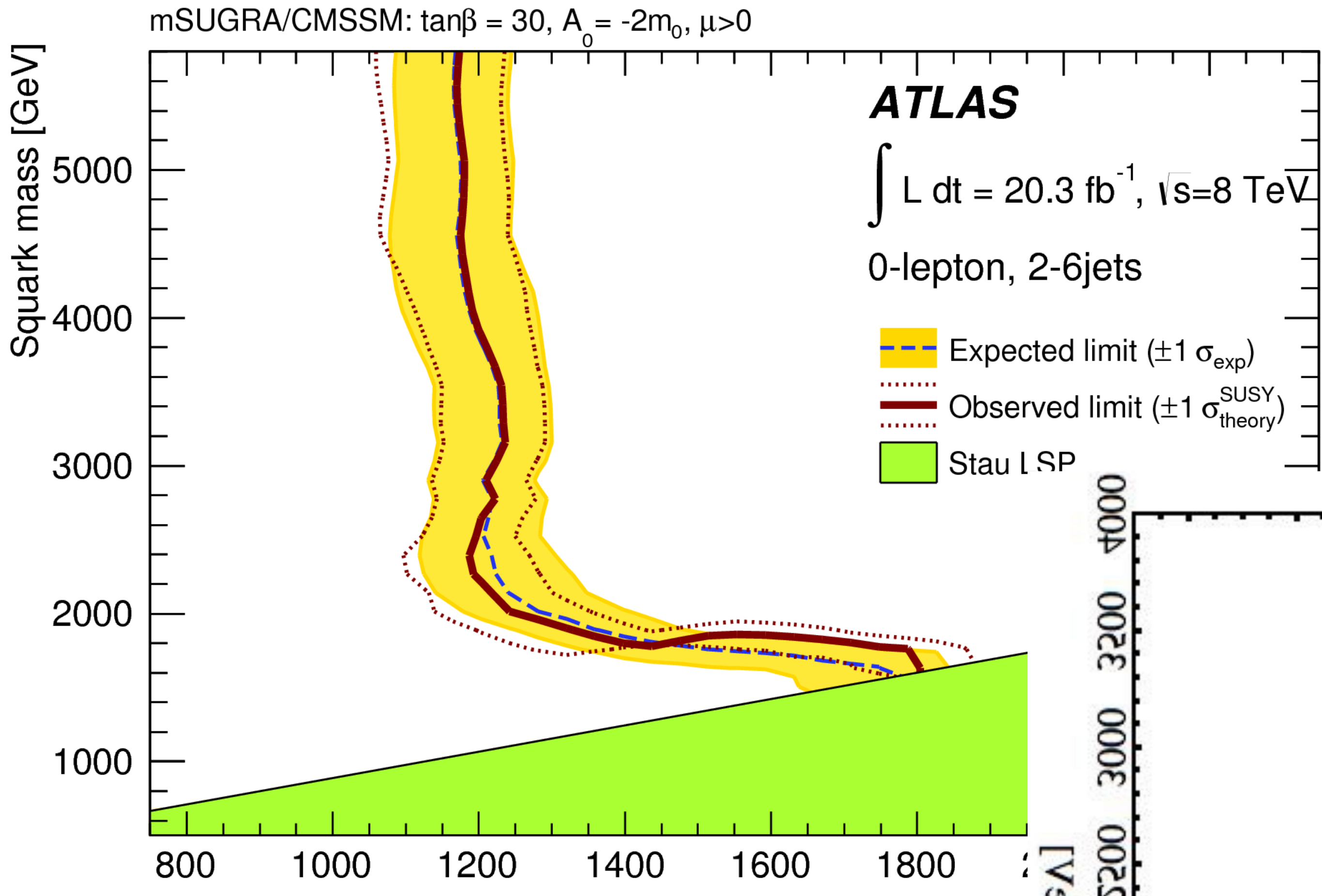
ND, P. Skands (2012);
T. Sjostrand, ND, et al. (2014)

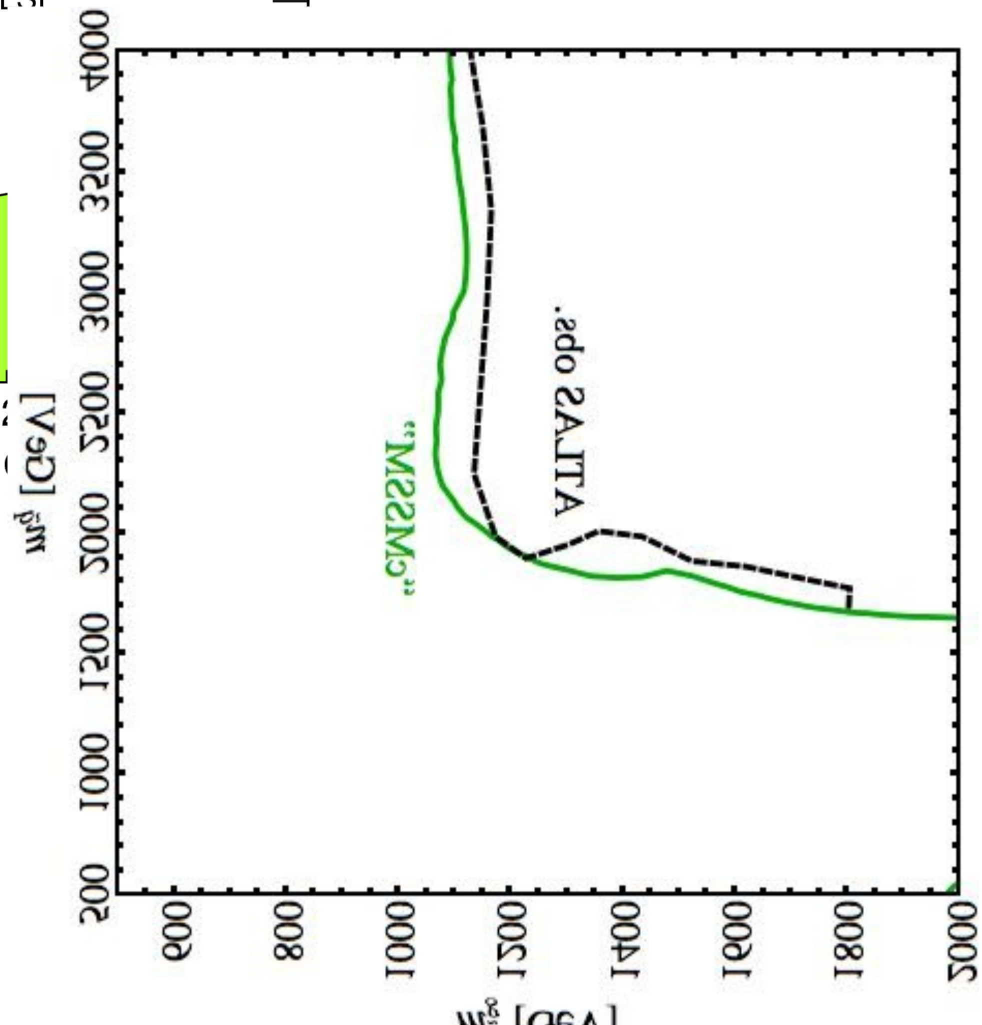
- ➡ Gaussian smearing for jets/leptons
- ➡ Validate against published cut flow or efficiencies for benchmarks
- ➡ Look at limits from each of the three searches.

Instead of focussing only on the best fit parameters, we examine the co-annihilation strip plotted in terms of $(m_{\frac{1}{2}}, \Delta m)$ in various slices

$$\tan\beta = 10, 40$$

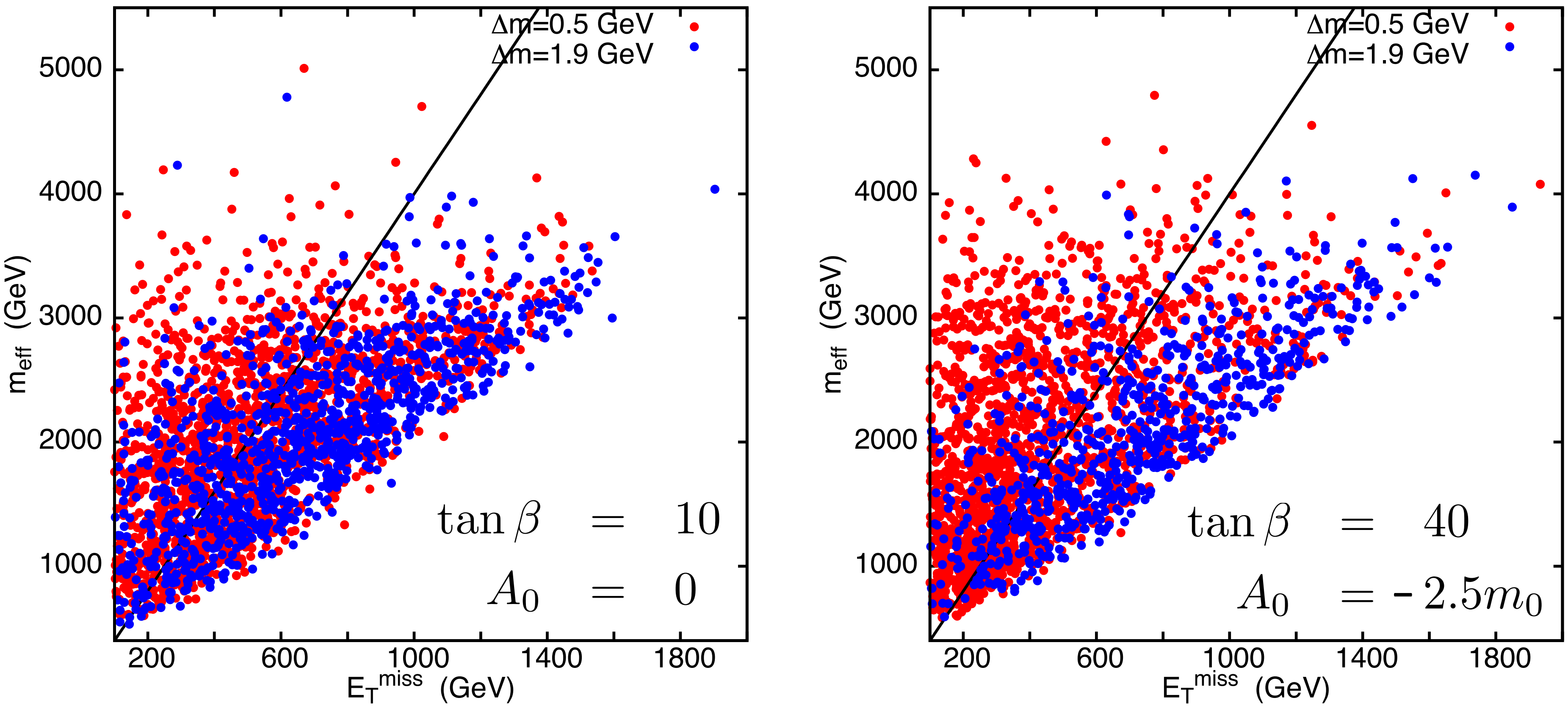
$$A_0 = 0, -2.5 m_0$$


mSUGRA/CMSSM: tanβ = 30, A0 = -2m0, μ>0
Squark mass [GeV]
ATLAS
∫ L dt = 20.3 fb-1, √s=8 TeV
0-lepton, 2-6jets
Expected limit (±1 σexp)
Observed limit (±1 σSUSYtheory)
Stau LSP
1000
2000
3000
4000
5000
800
1000
1200
1400
1600
1800



# 2-6 Jets + MET

# EFFECT OF MET AND MEFF CUTS



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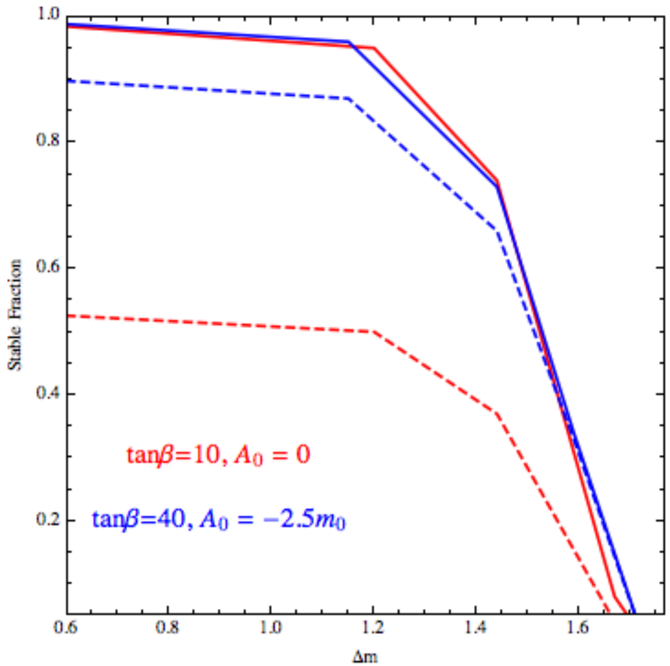


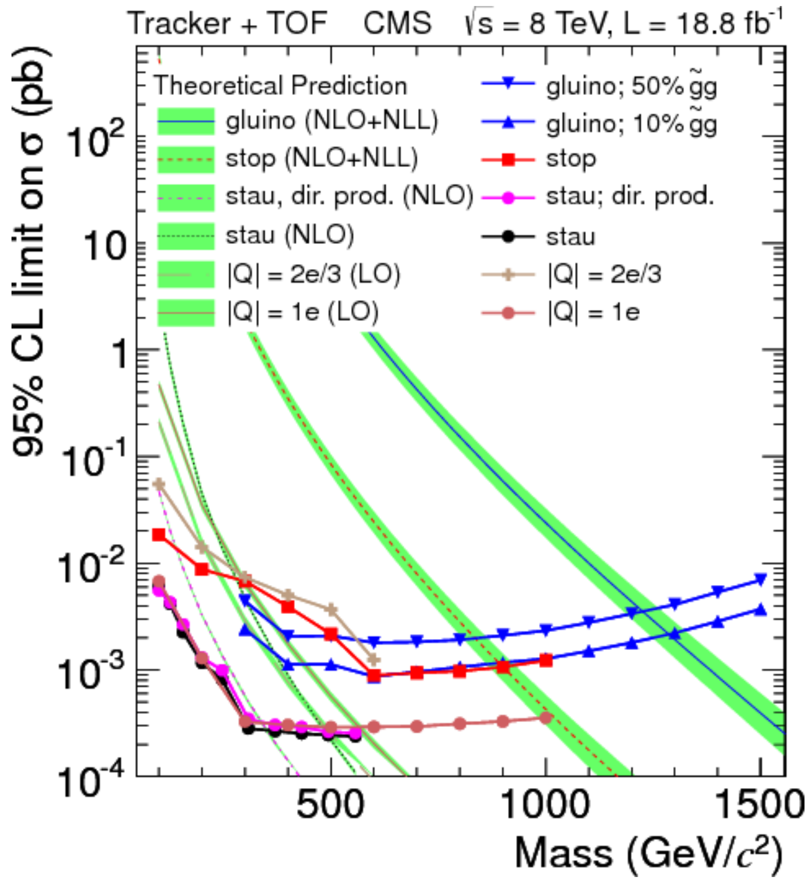


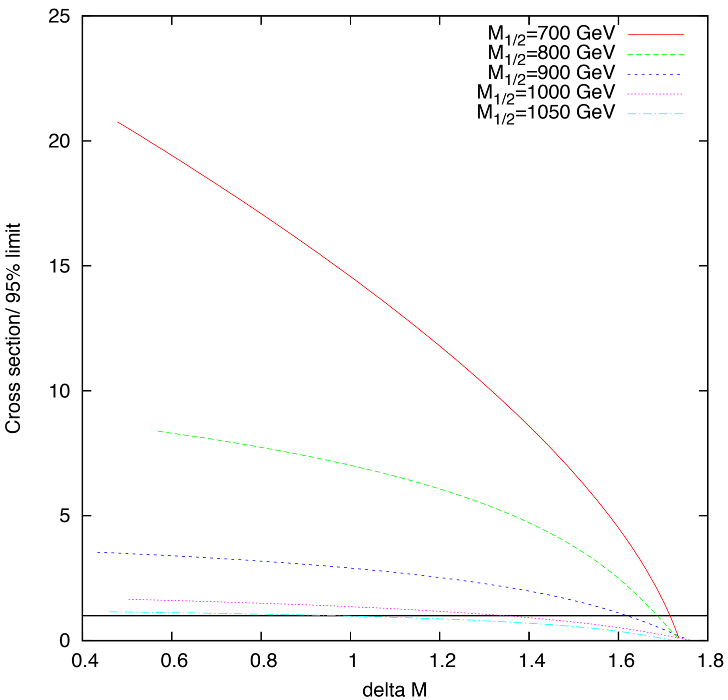


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| 308 | >190 | 0.00094 | 0.0015 | 0.63 | 0.00029 | 0.00028 | 0.56 |
| 494 | >330 | 0.00079 | 0.00084 | 0.74 | 0.00023 | 0.00024 | 0.66 |
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|---|
| ~~Quality requirements and trigger~~ |
| ~~Jet cleaning~~ |
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| $E_{\mathrm{T}}^{\mathrm{miss}} > 90$ GeV |
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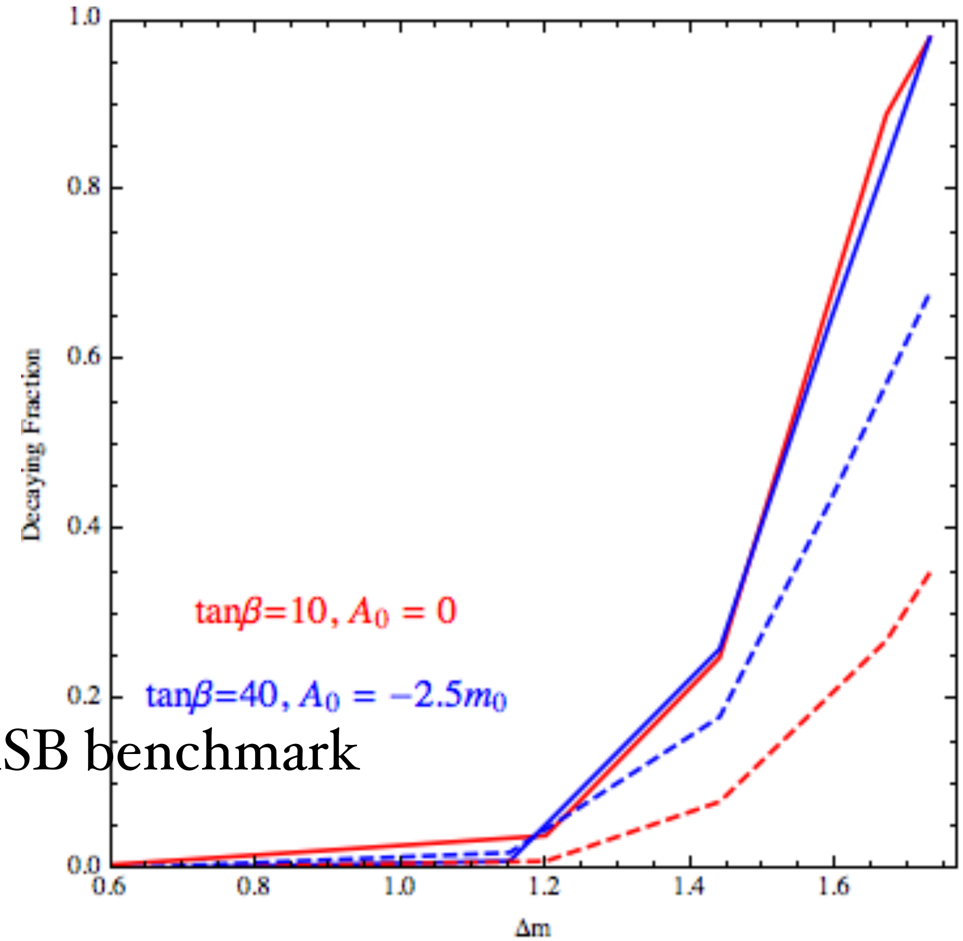
| High-$p_{\mathrm{T}}$ isolated track selection |
| Disappearing-track selection |




Validate efficiencies against their AMSB benchmark

TABLE III. Numbers of observed and expected background events as well as the probability that a background-only experiment is more signal-like than observed ($p_0$) and the model-independent upper limit on the visible cross-section ($\sigma_{\mathrm{vis}}^{95\%}$) at 95% CL.

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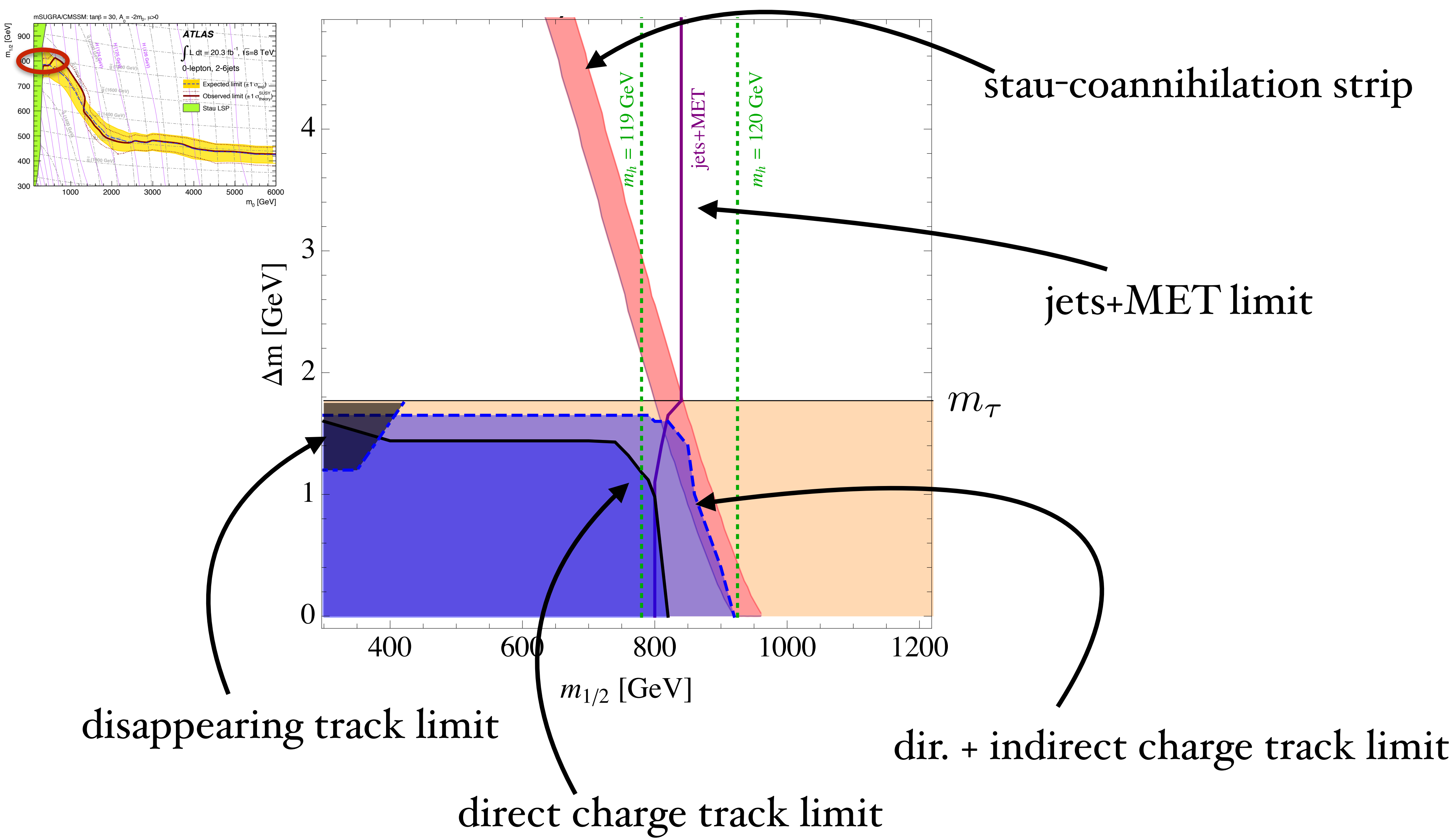
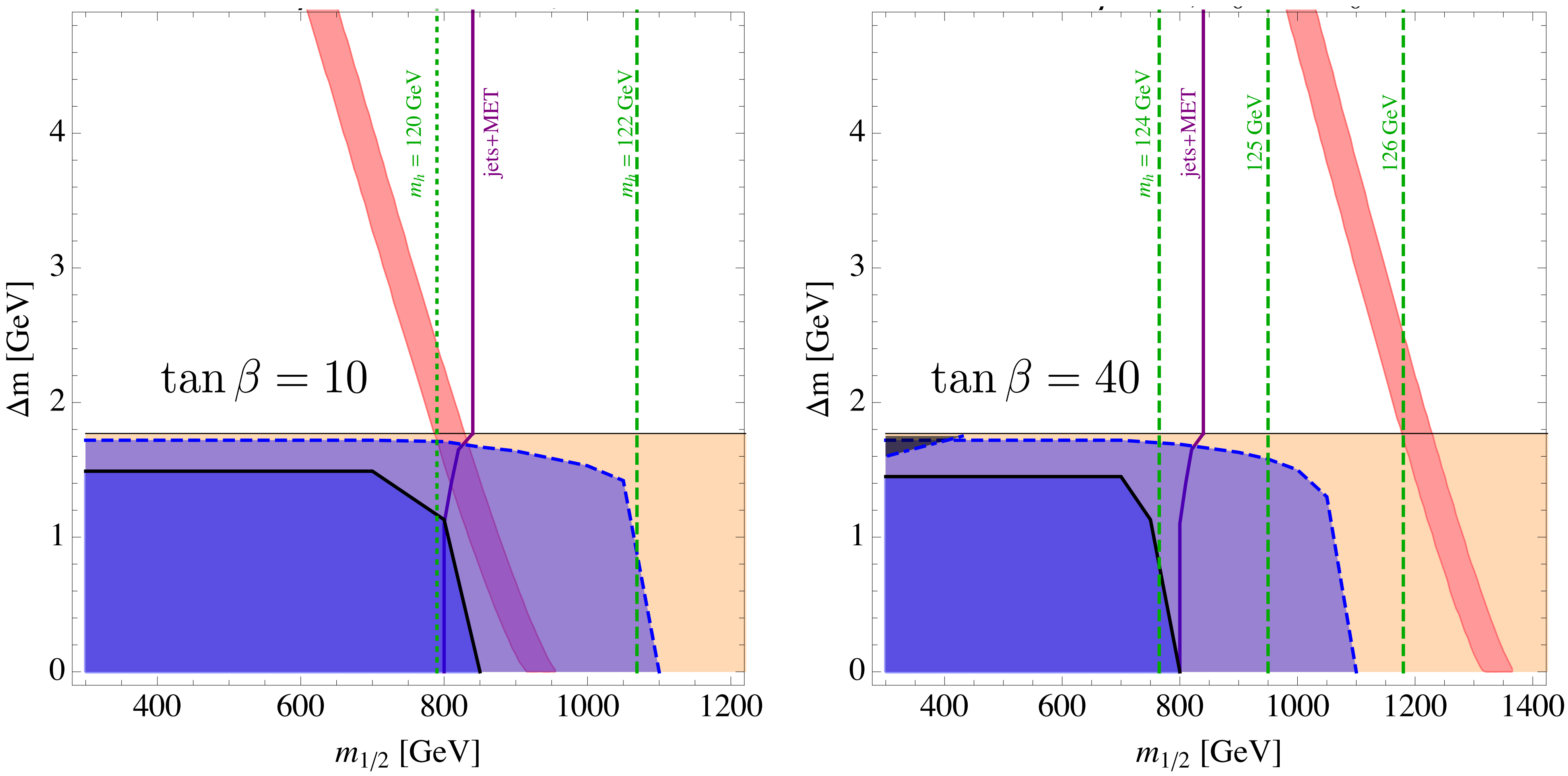
# COMBINATION OF ALL LIMITS

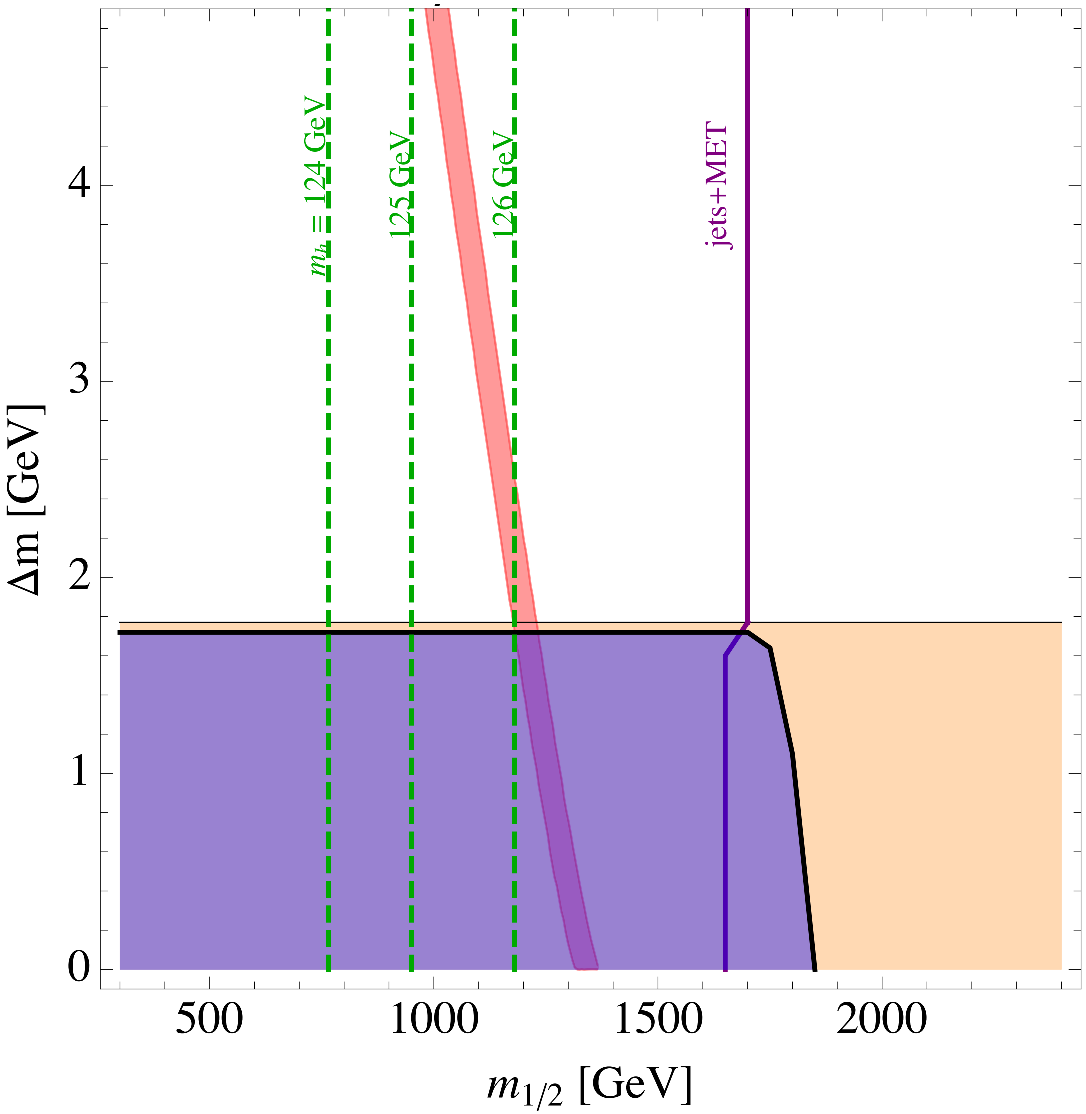


# RESULTS:

$$A_0 = -2.5m_0$$



# PROJECTION TO 13 TEV@LHC WITH 300 FB$^{-1}$



# CONCLUSIONS FOR STAU CO-ANNIHILATION

- LHC jets+MET search slightly weakened in region where staus are long-lived. The limit is close to probing the tip of the co-annihilation strip for $\tan\beta = 10$.
- The stable track search for direct stau production (model ind.) rules out stau masses up to 336 - 345 GeV for $m_{1/2}$ values of 800-850 GeV (**stronger than the MET search!**)
- This is improved to $m_{1/2}$ values of 930-1100 GeV when all stau production modes are taken into account.
- The model independent track search will be able to rule out the full strip for $\tan\beta = 40$ with 75 $\mathrm{fb}^{-1}$ at 13 TeV.