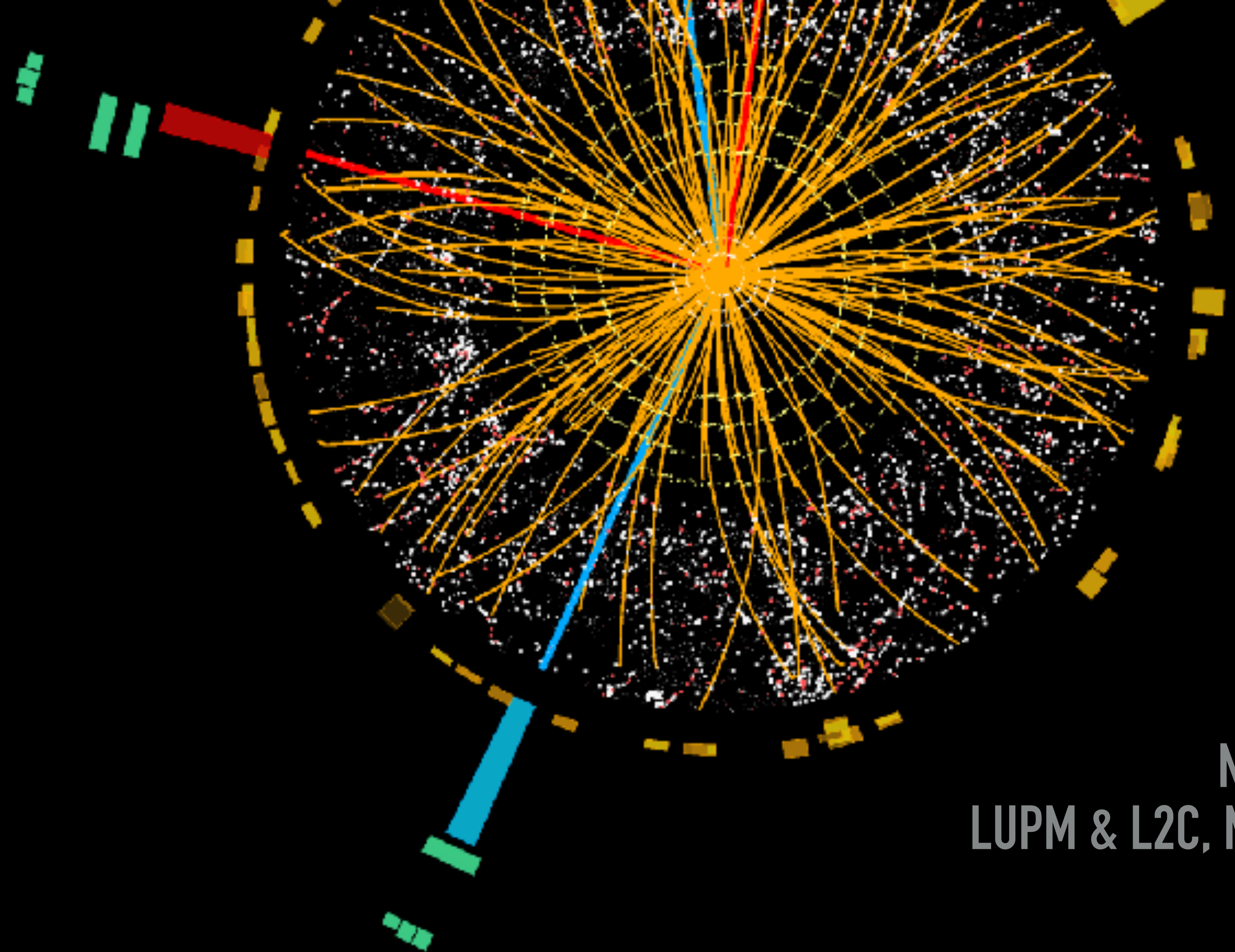


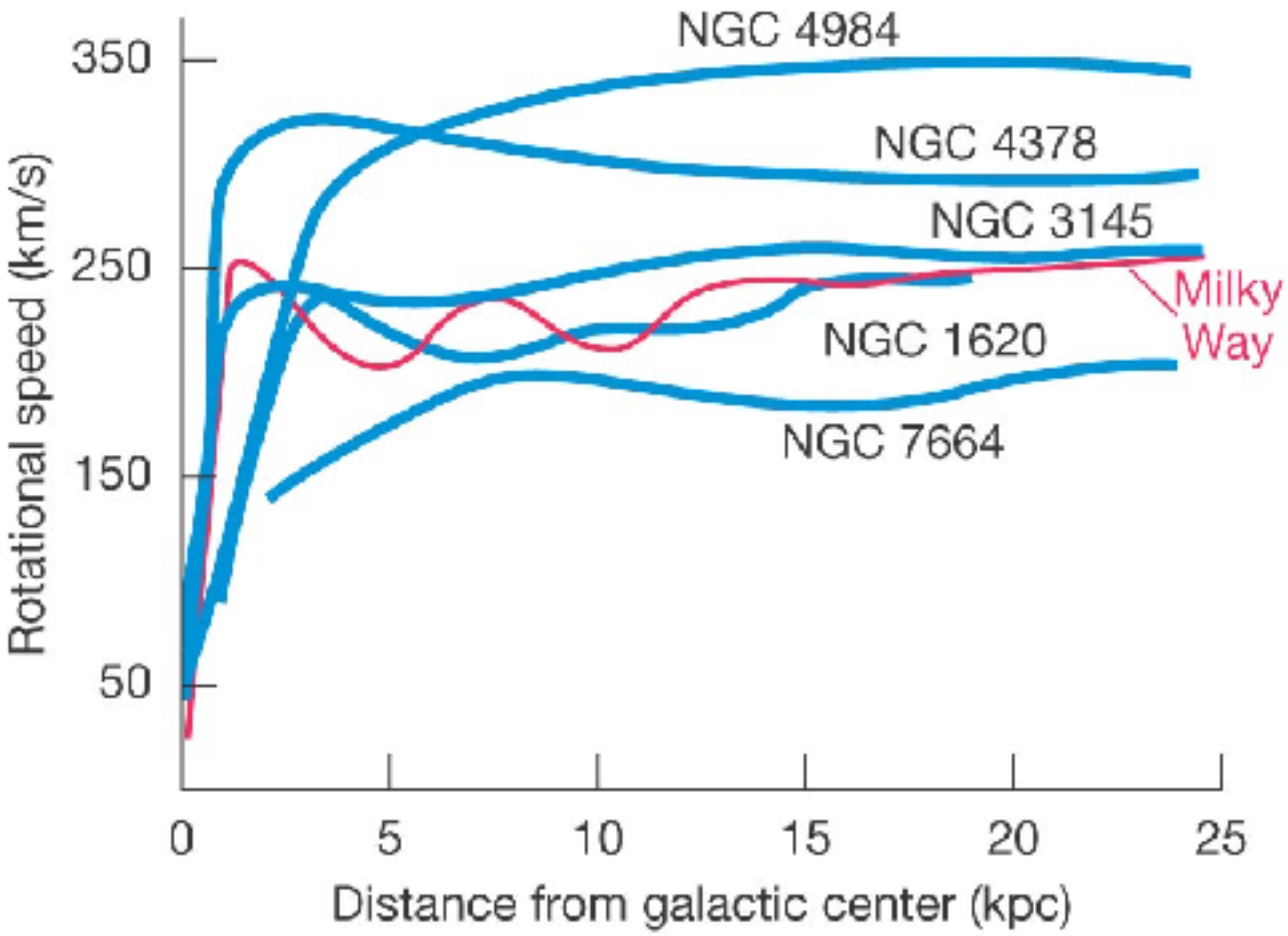
NISHITA DESAI
LUPM & L2C, MONTPELLIER

# SEARCHING FOR DARK MATTER AT THE LHC AND BEYOND

**Grenoble; 4 April 2017**

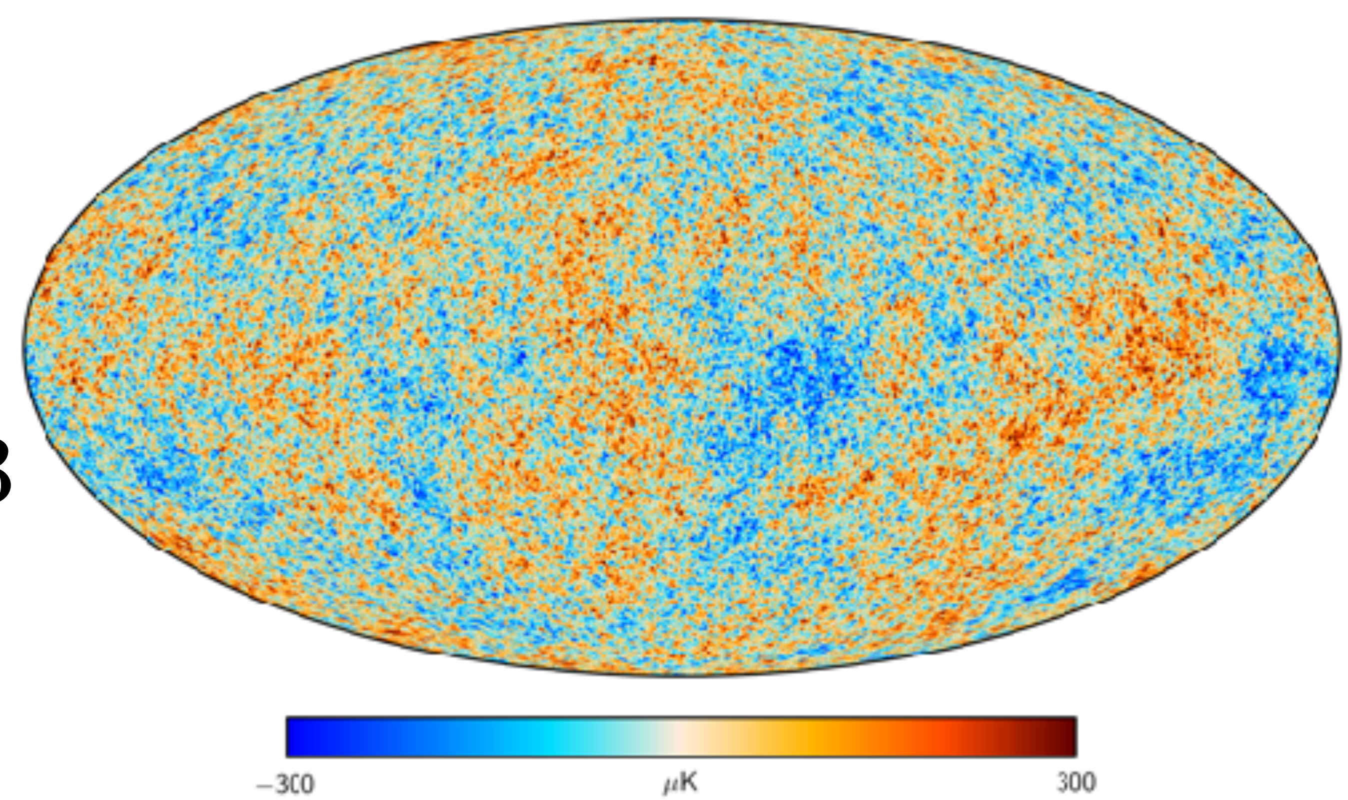
Based on work done with: M. Bauer, A. Butter, J. Gonzalez-Fraile, T. Plehn, J. Bramante, P. Fox, A. Martin, B. Ostdiek

# WHAT DO WE KNOW SO FAR?




(b) Eric Chaisson, Steve McMillan





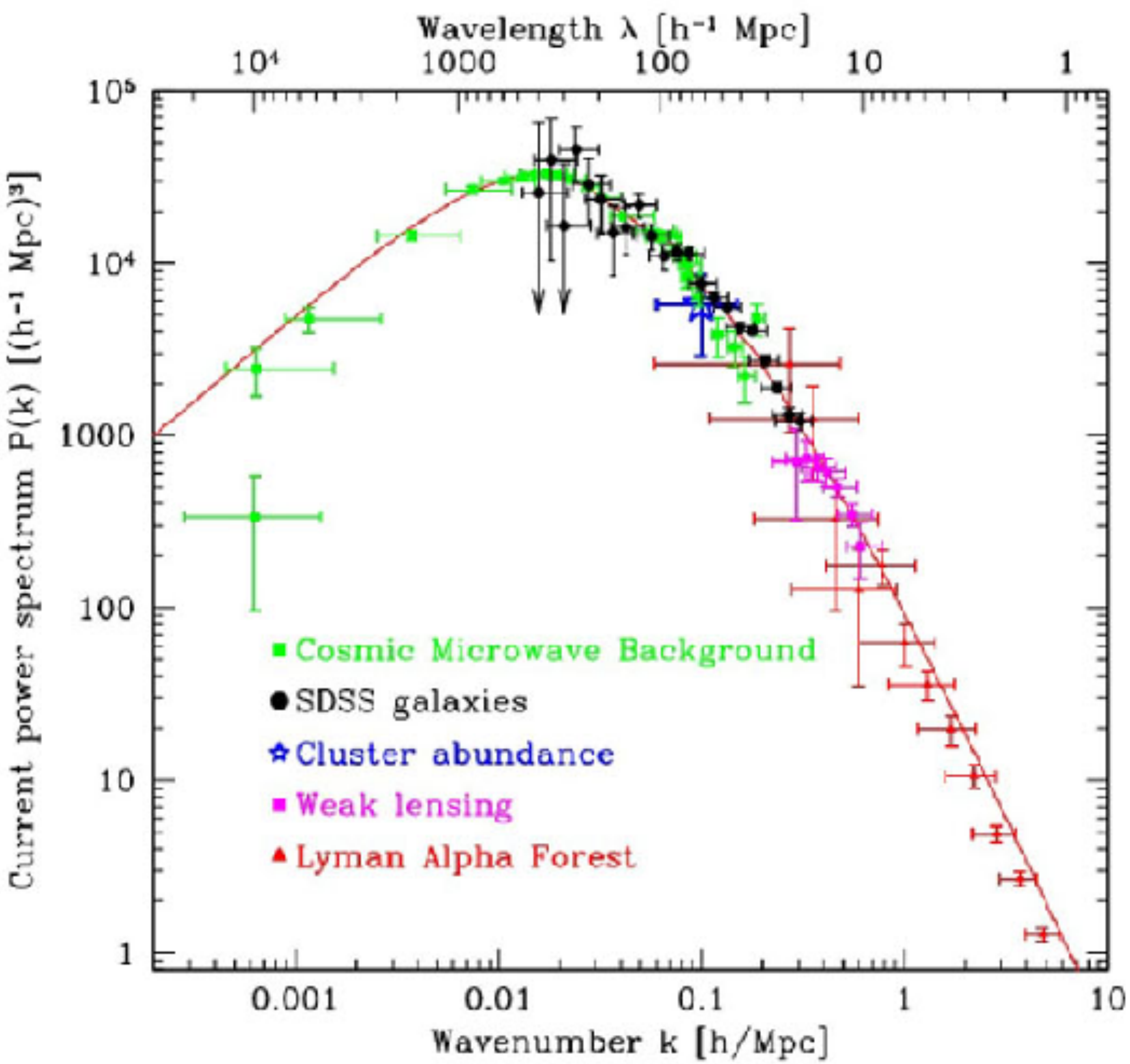

$$\Omega_m h^2 = 0.1415 \pm 0.0019$$

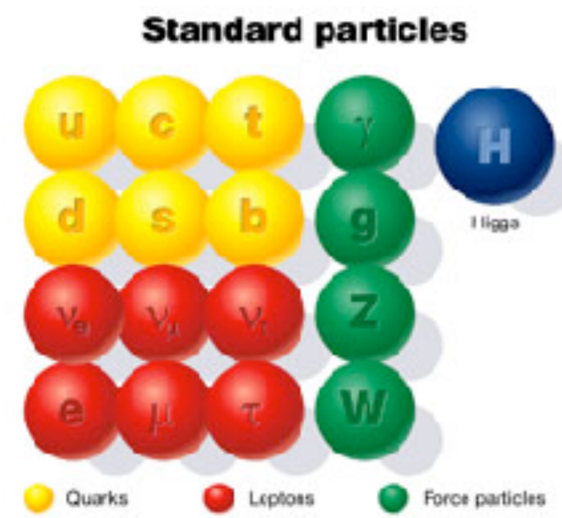
$$\Omega_b h^2 = 0.02226 \pm 0.00023$$

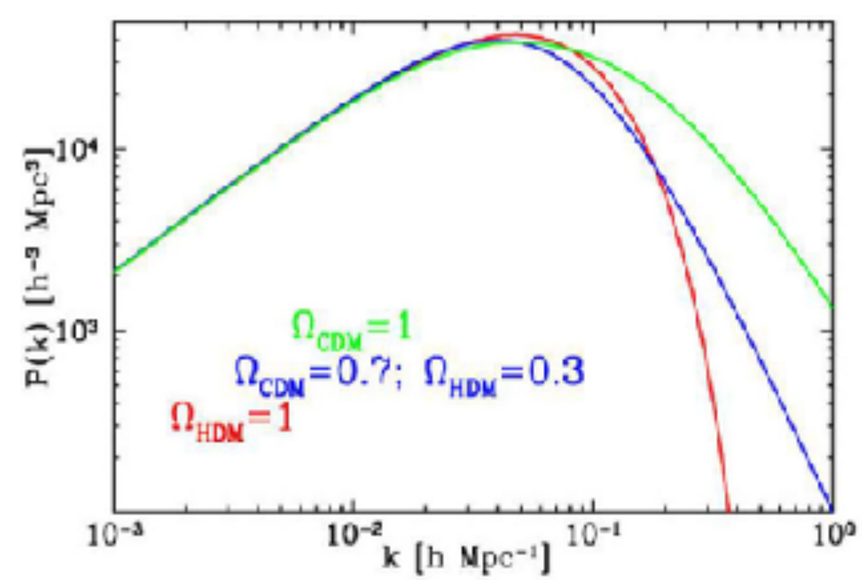
$$\Omega_c h^2 = 0.1186 \pm 0.0020$$

## PROPERTIES: SHOULD BE NEUTRAL, MASSIVE, NON-RELATIVISTIC IN CURRENT EPOCH

NASA/IPAC Extragalactic Database (NED)



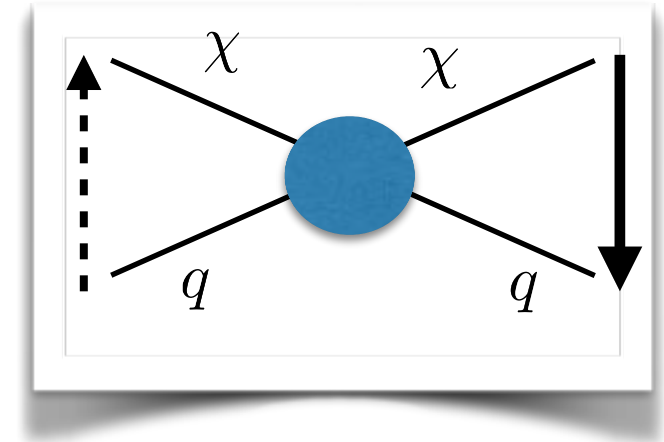



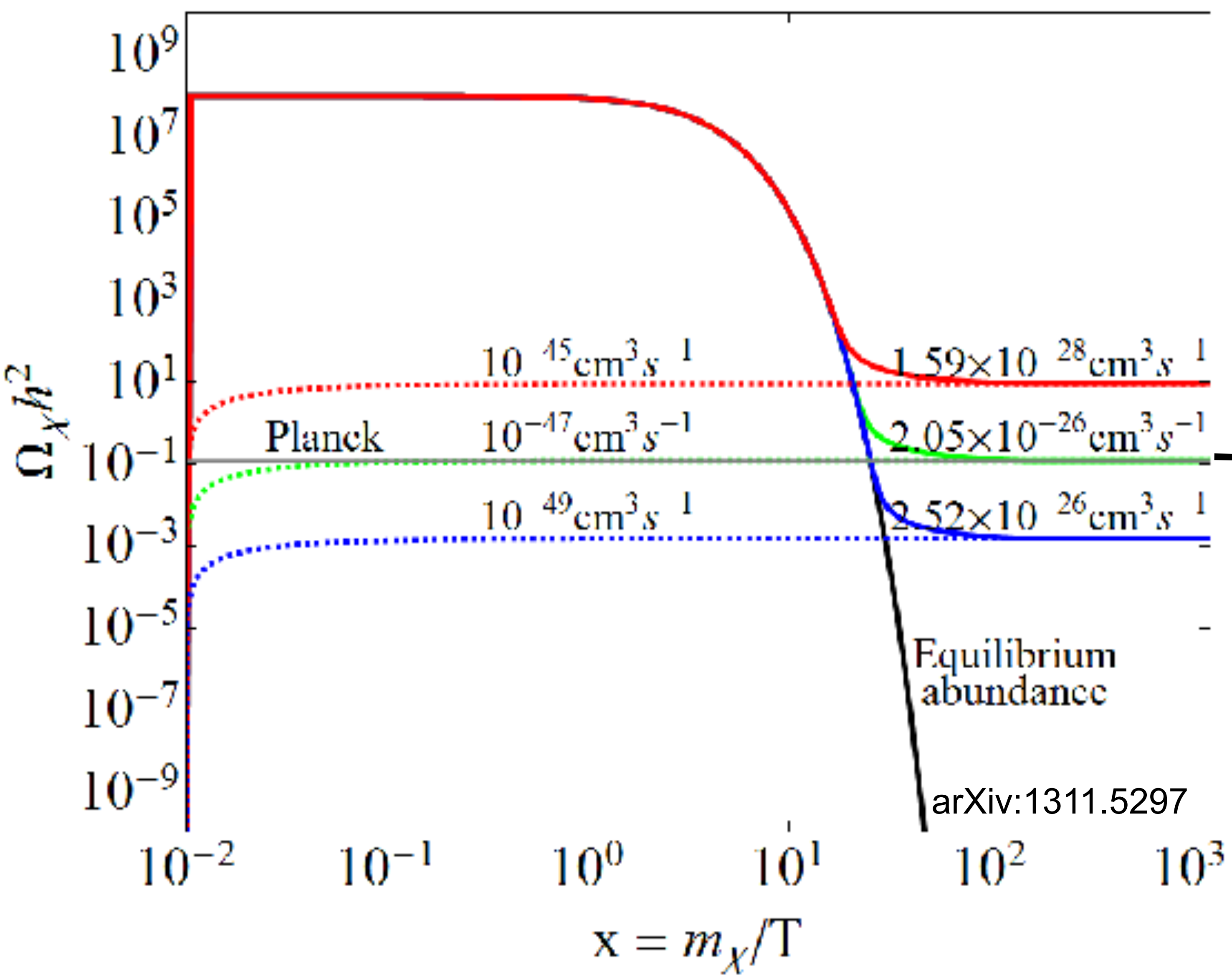




**THE ASSUMPTION OF CDM IS ESSENTIAL TO EXPLAIN OUR UNIVERSE**

# HOW TO CALCULATE THE RELIC DENSITY?

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

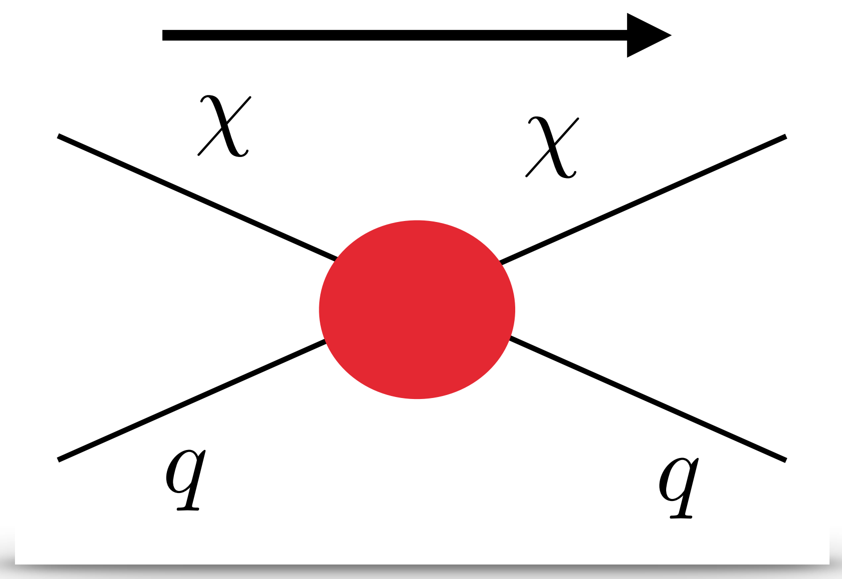


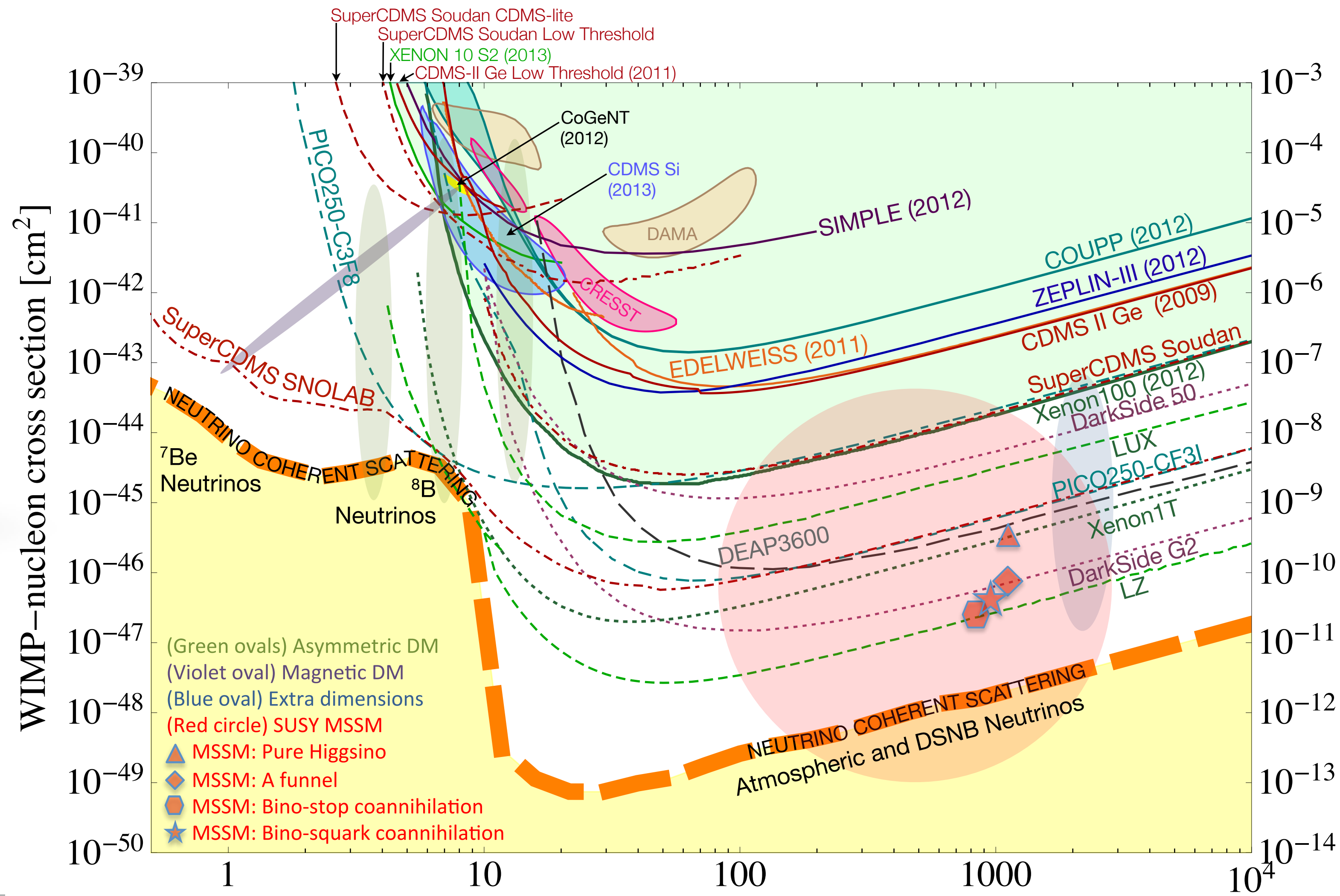



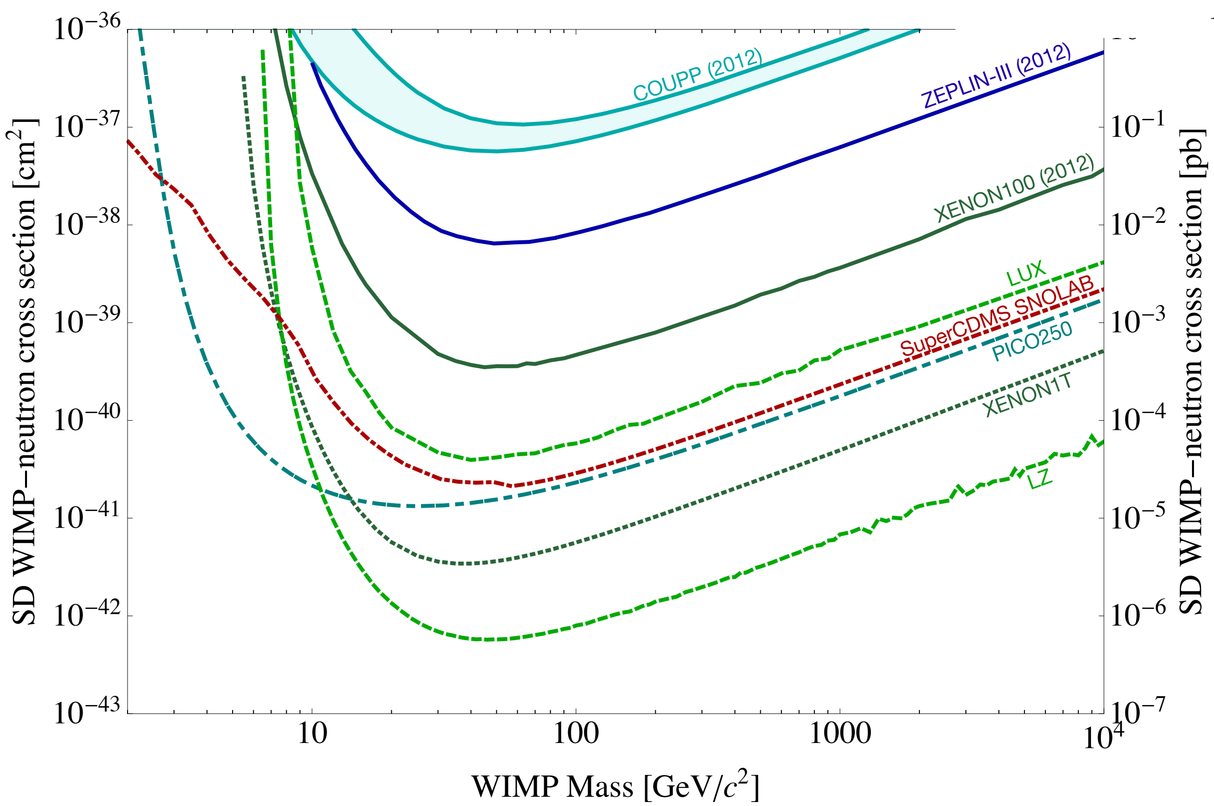

$$m_\chi \sim 100 \text{ GeV}$$

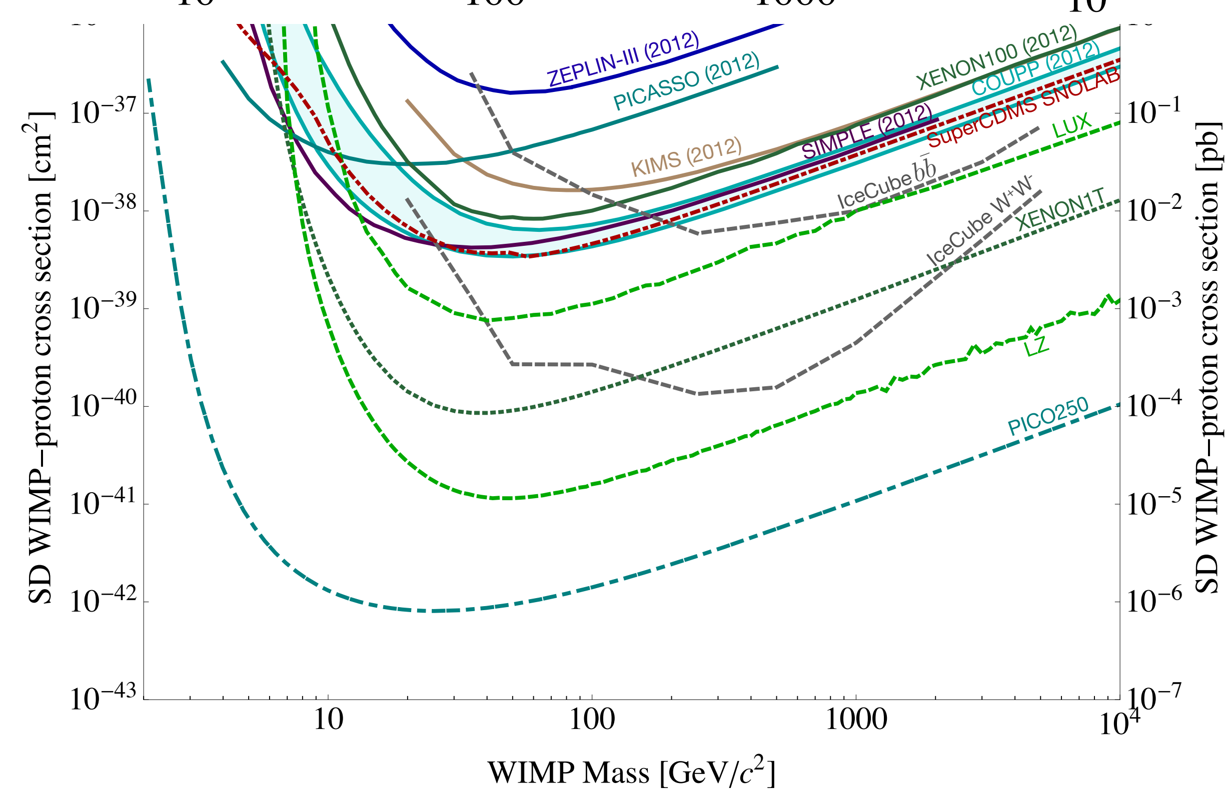
$$g \sim g_{EW}$$

# LOOKING FOR DM WINDS: DIRECT DETECTION



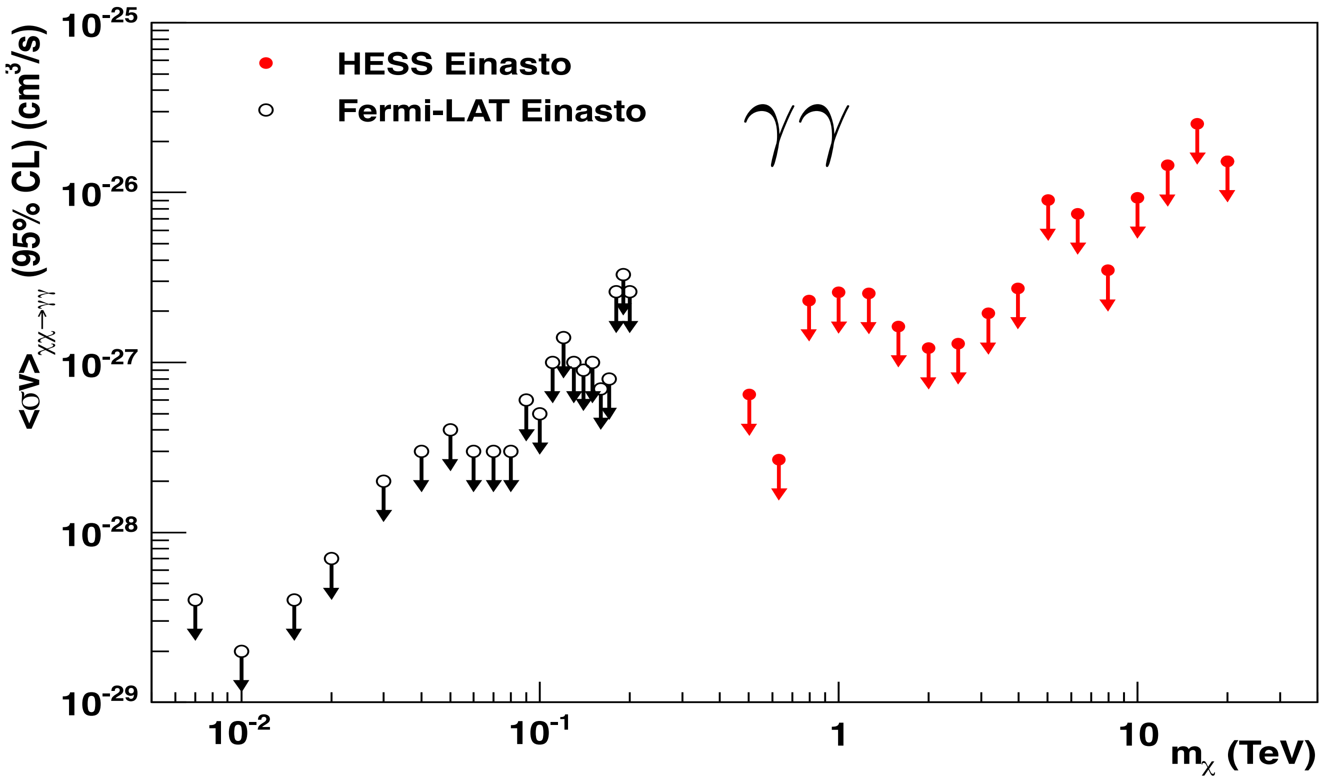



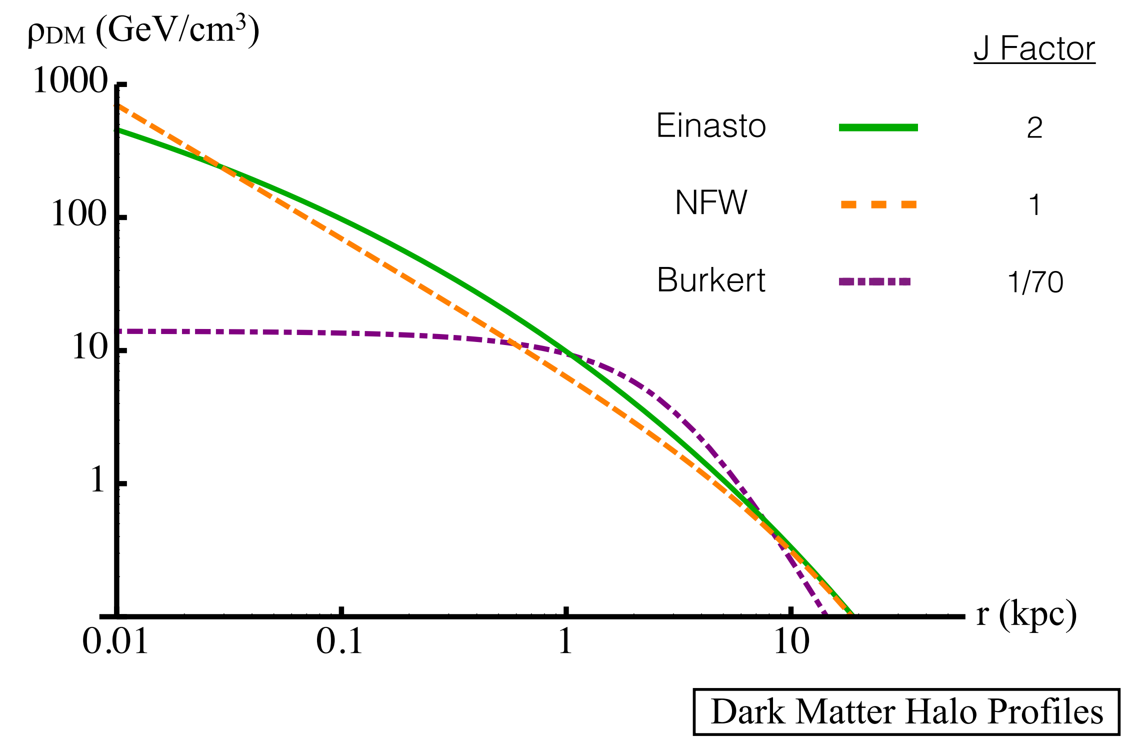



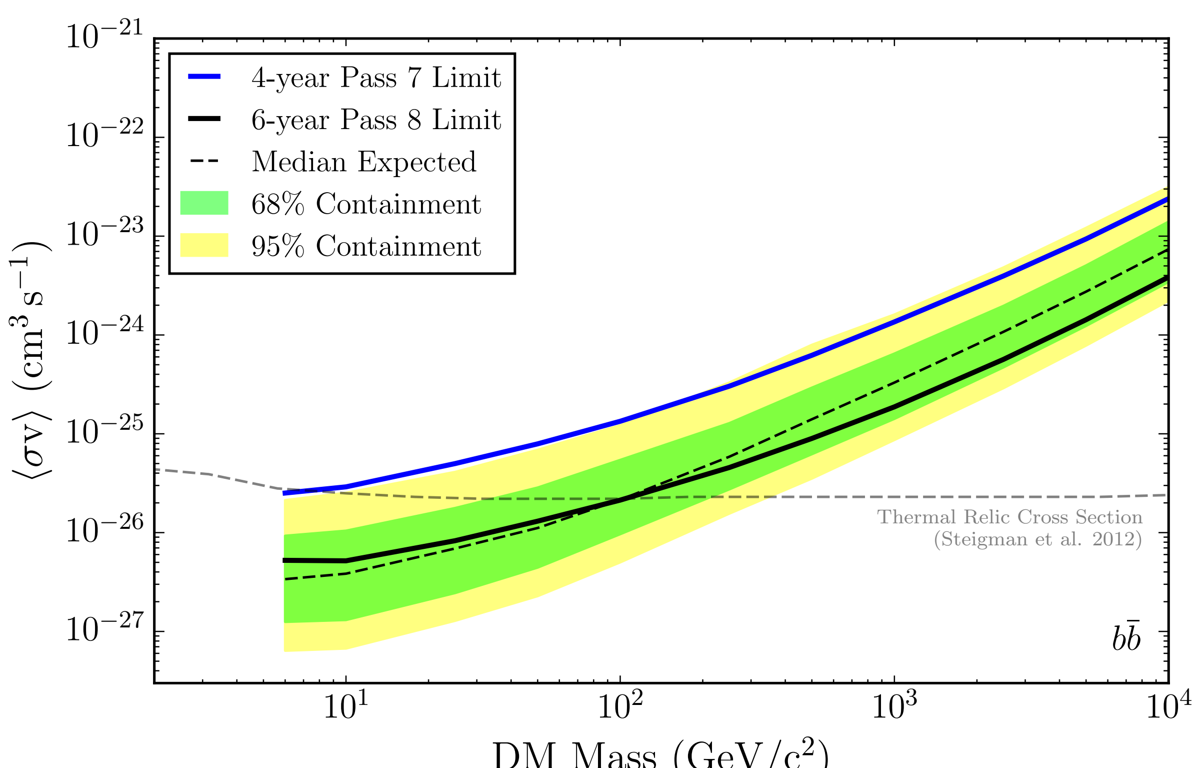

arXiv:1310.8327v2

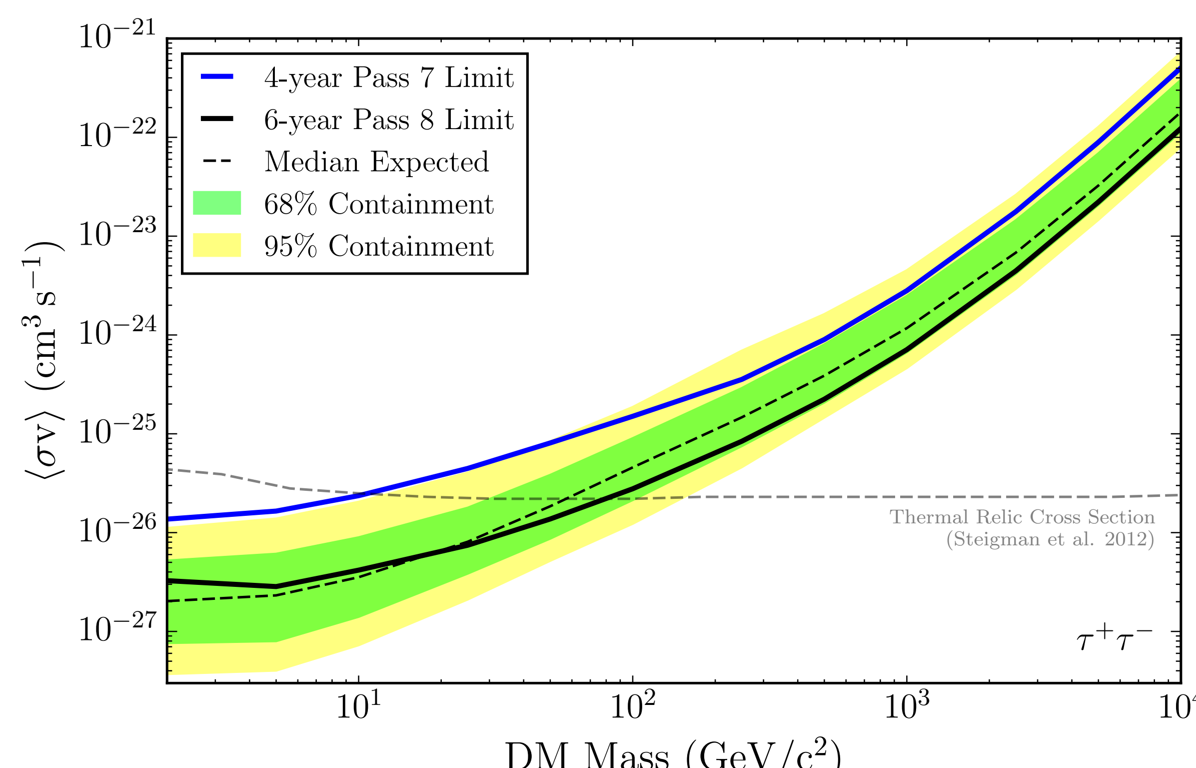
# LOOKING FOR PHOTONS: INDIRECT DETECTION

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



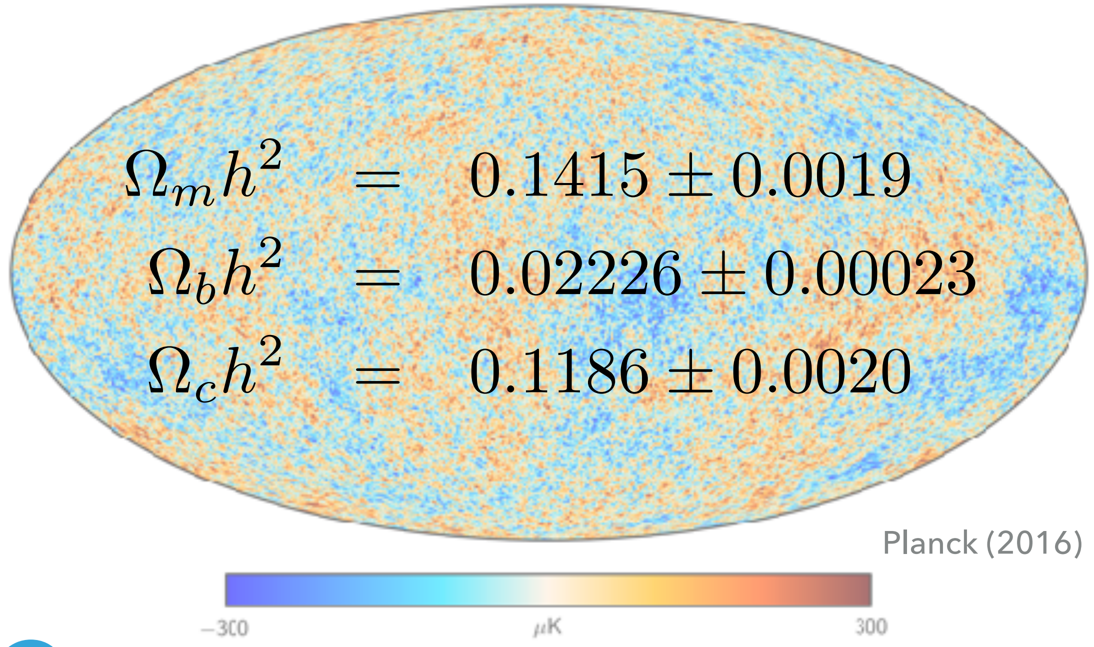




Fermi-LAT collaboration (1503.02641)

Goal of Dark Matter theories: To reproduce the observed relic density (satisfying all other constraints)




$$\Omega_m h^2 = 0.1415 \pm 0.0019$$
$$\Omega_b h^2 = 0.02226 \pm 0.00023$$
$$\Omega_c h^2 = 0.1186 \pm 0.0020$$

Planck (2016)

# WHY USE COLLIDERS?

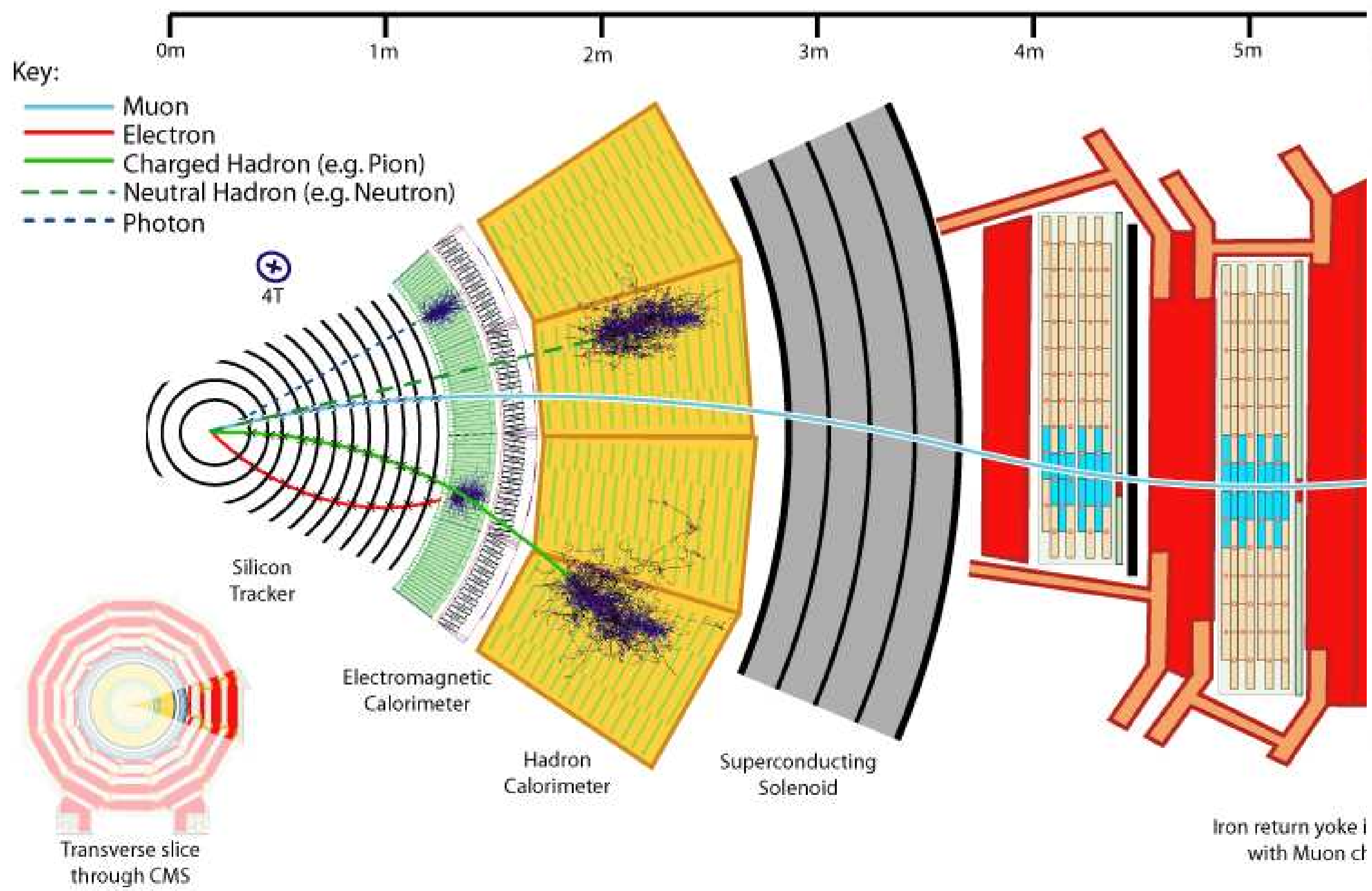
WE HAVE ONE RUNNING WITH HIGHEST ENERGY SO FAR

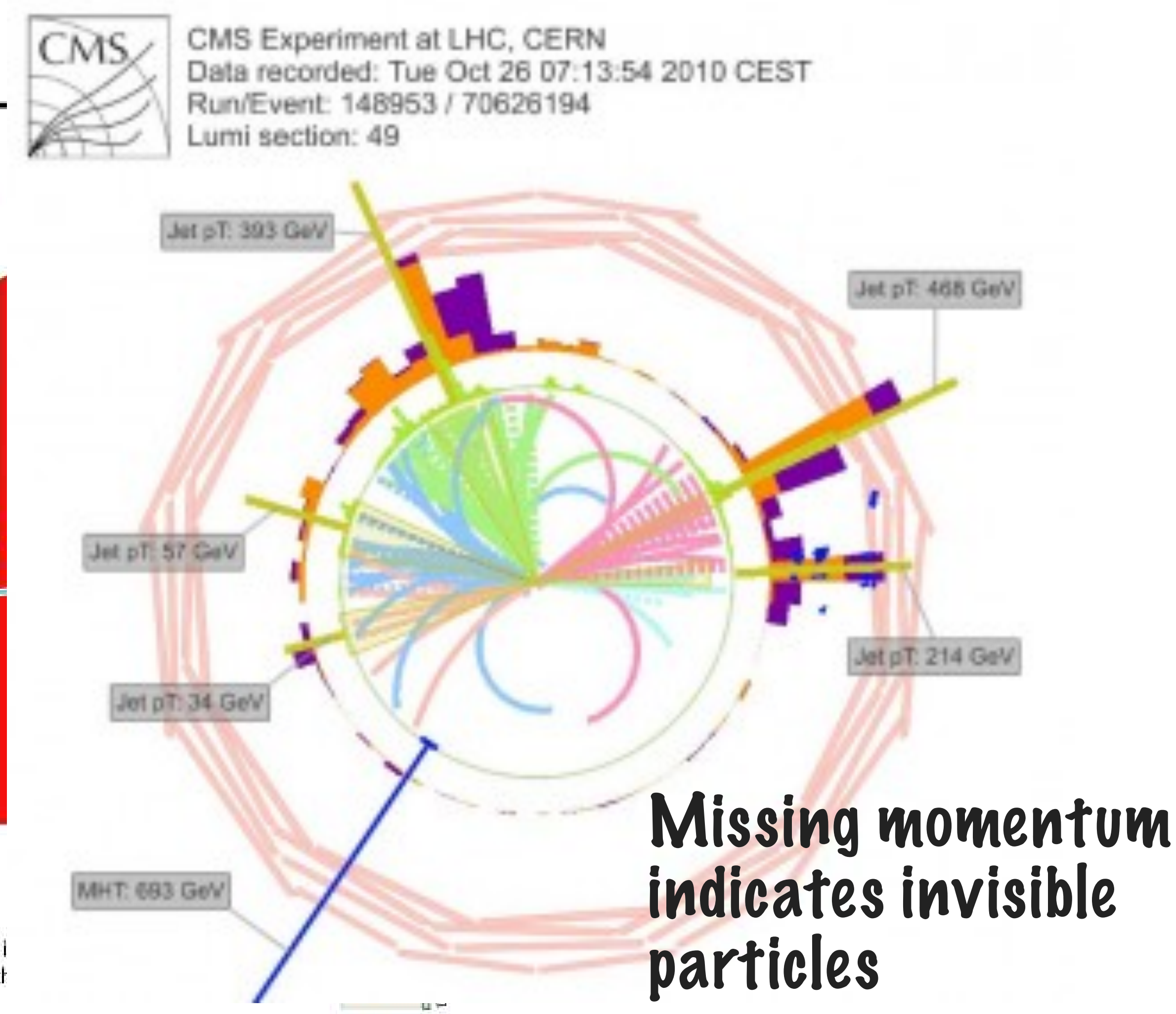
BUT ALSO…

IT TURNS OUT, COLLIDERS CAN DO THINGS OTHER EXPERIMENTS CAN'T —

- BETTER SPIN DEPENDENT SENSITIVITY
- CONSTRAIN LOW RECOIL REGION
- LOOK FOR ACCOMPANYING PARTICLES

# ATLAS/CMS OBSERVATIONS — OBJECTS, CUTS, STATISTICS




A. Experiments can provide “high-level” information, e.g. **number of events** with X jets, Y electrons/muons and a large missing momentum.

B. There can be certain kinematic requirements on these objects, which are placed based on expected “background”. Experiments provide **cut flows, efficiency maps**.

C. Complex statistical machinery – likelihoods, MVA, Neural Nets etc. to get best **upper limits/signal strengths/measurements**

# MODELLING DARK MATTER

## Is it a Scalar? Vector? Dirac or Majorana Fermion?

**Does it couple directly to some SM particle (Z, h) ?**

**If there is a mediator, how does the mediator couple to SM? to Dark Matter?**

**Effective Field Theory**

**Complete Models**
eg. SUSY, Universal Extra Dim,
Little Higgs,…

PRO: Simple, Easy to relate observables

CON: bad high-energy behaviour

**Simplified models**

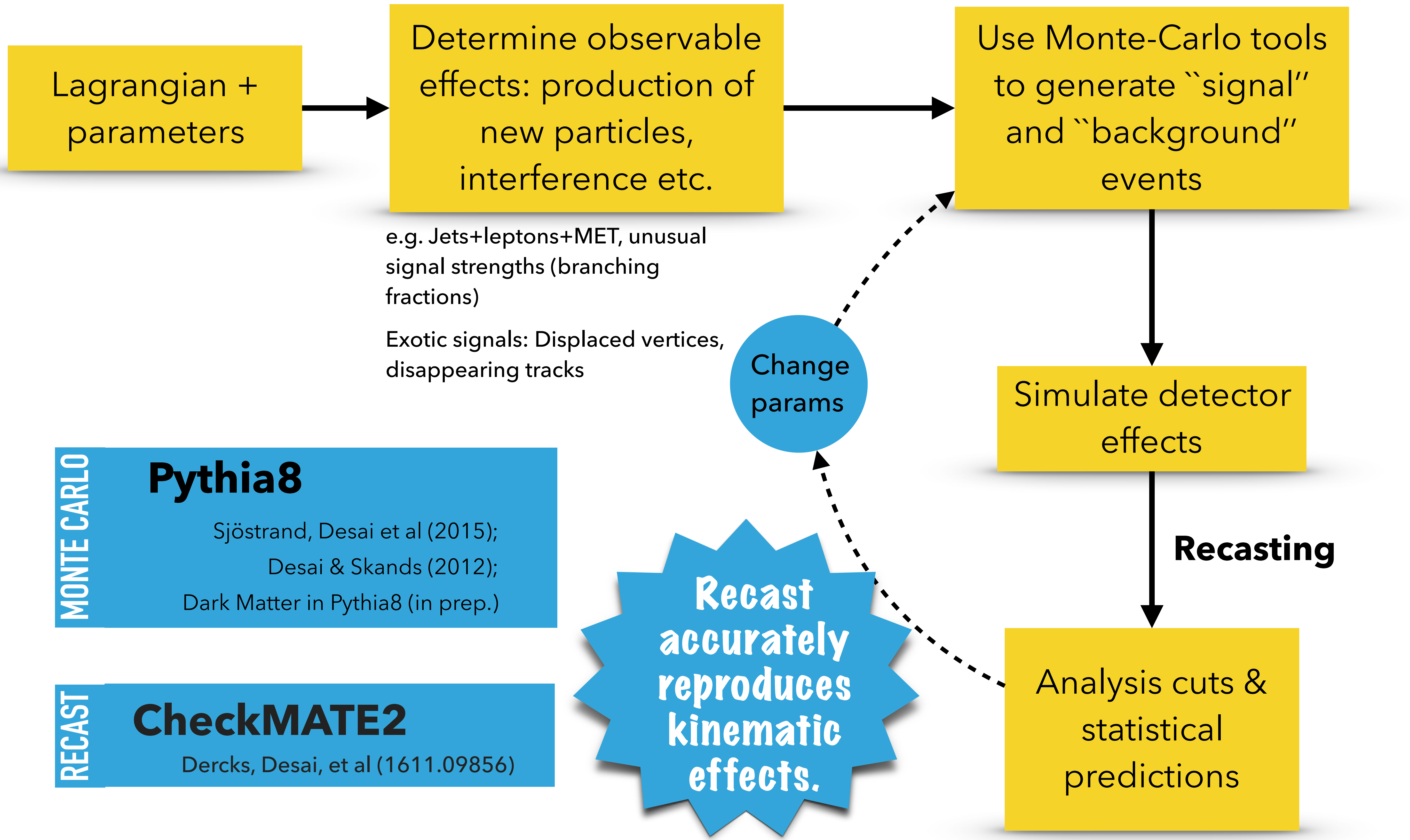
Trying to get the best of both worlds

IDEA: write down the simplest field content (often a DM field + one mediator)

PRO: Theoretically well motivated, fully calculable, extra particles

CON: Model Prejudices, complicated to understand

# TESTING NEW PHYSICS AT A COLLIDER




MONTE CARLO

**Pythia8**

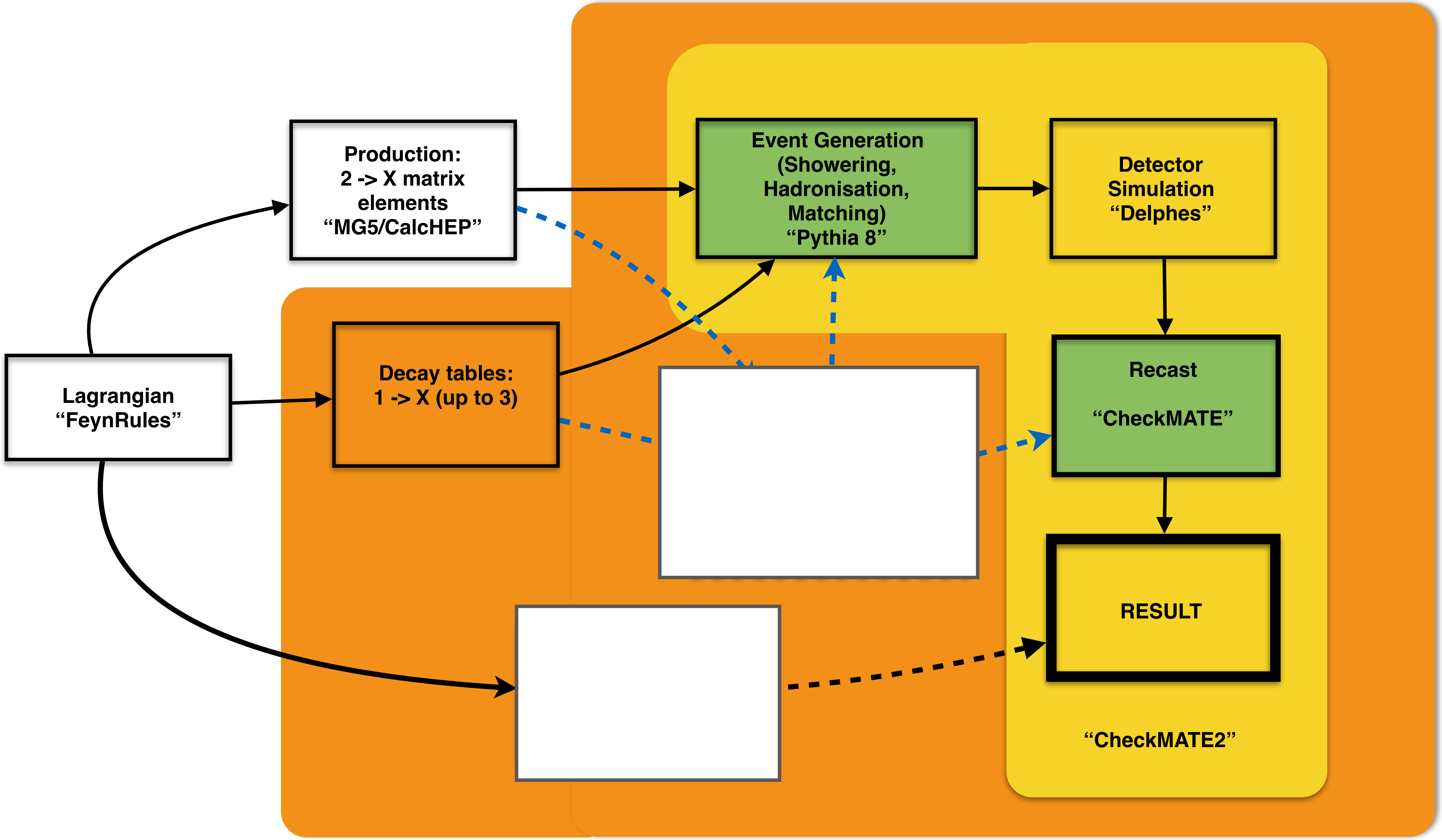
Sjöstrand, Desai et al (2015);
Desai & Skands (2012);
Dark Matter in Pythia8 (in prep.)

RECAST

**CheckMATE2**

Dercks, Desai, et al (1611.09856)

# TESTING ANY NEW PHYSICS MODEL




CURRENT: If you can write a Lagrangian (in UFO), we can test it!
FUTURE: Automatically decide what the best signal could be (based on simplified models, e.g. SmodelS developed in Grenoble)
FUTURE: Add Dark Matter observables (e.g. using microMEGAS developed in Annecy)

# PART I:

# EFT & SIMPLIFIED MODELS

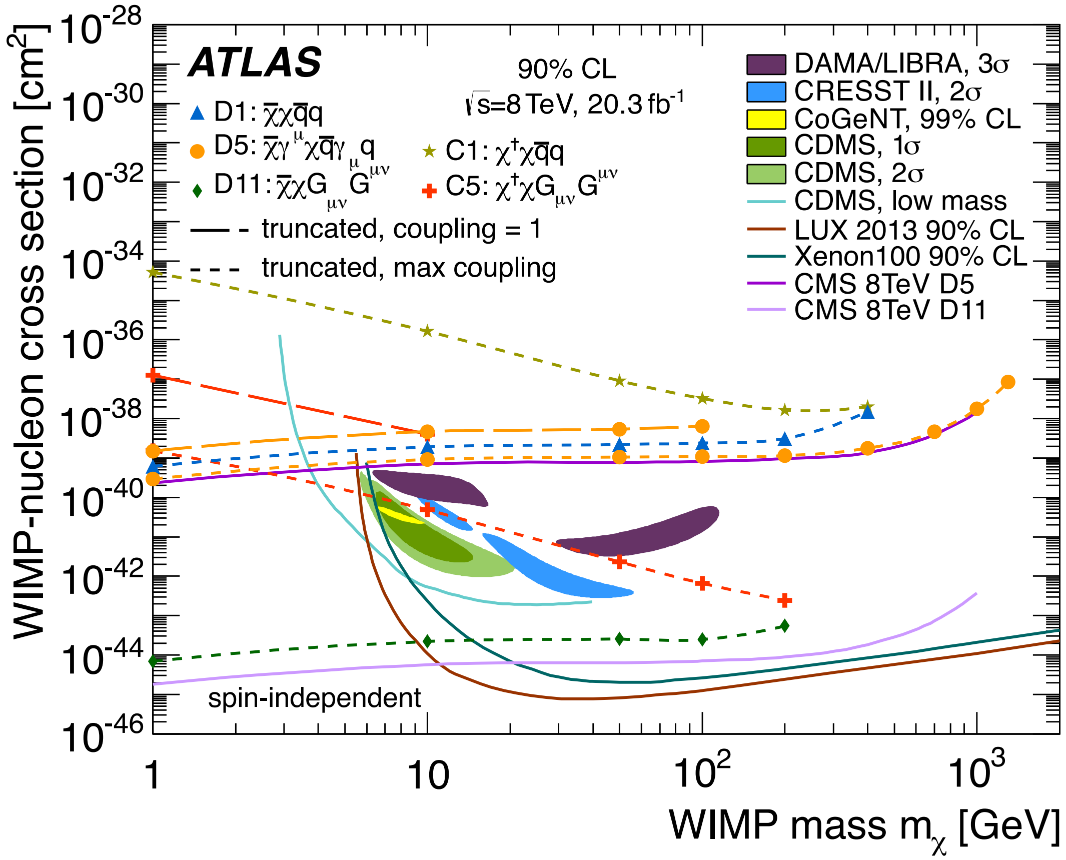
# COLLIDER SEARCHES: A COMPLEMENTARY VIEW

Goodman et al. (2010)

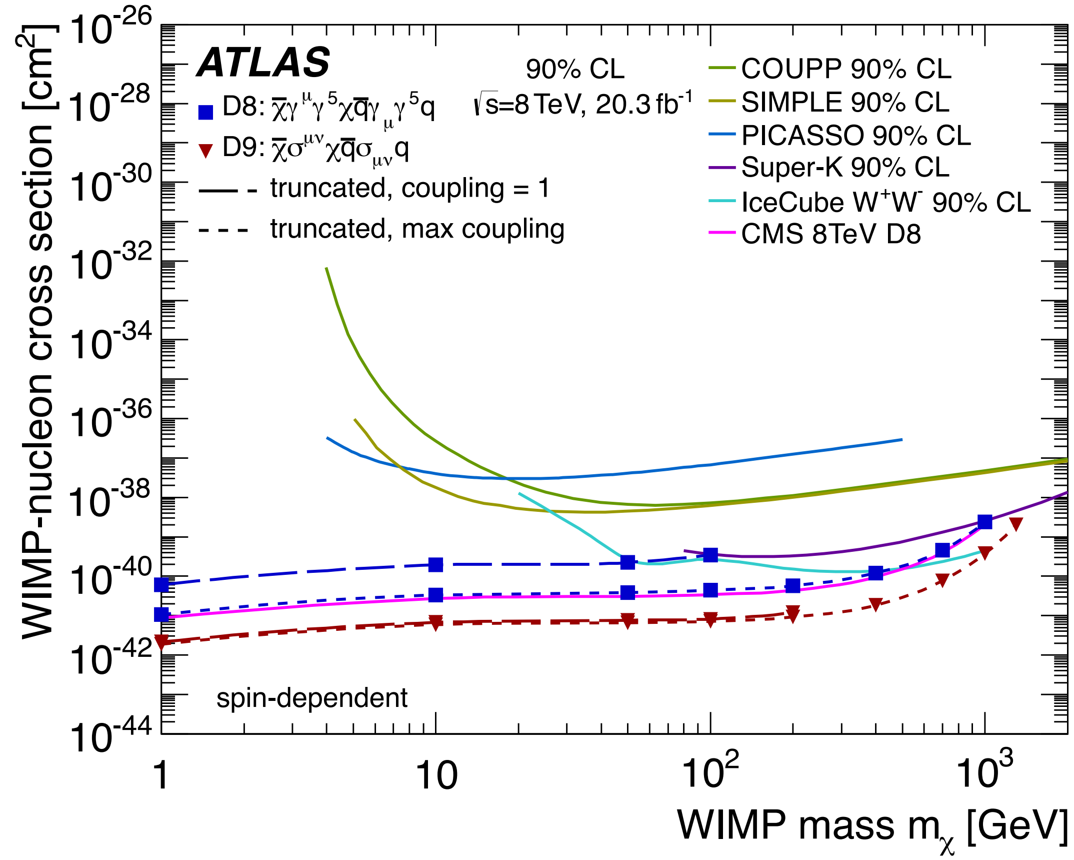
| Name | Operator | Coefficient |
|---|---|---|
| D1 | $\bar{\chi}\chi\bar{q}q$ | $m_q/M_*^3$ |
| D2 | $\bar{\chi}\gamma^5\chi\bar{q}q$ | $im_q/M_*^3$ |
| D3 | $\bar{\chi}\chi\bar{q}\gamma^5 q$ | $im_q/M_*^3$ |
| D4 | $\bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$ | $m_q/M_*^3$ |
| D5 | $\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$ | $1/M_*^2$ |
| 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 | $\chi^2 G_{\mu\nu}\tilde{G}^{\mu\nu}$ | $i\alpha_s/8M_*^2$ |

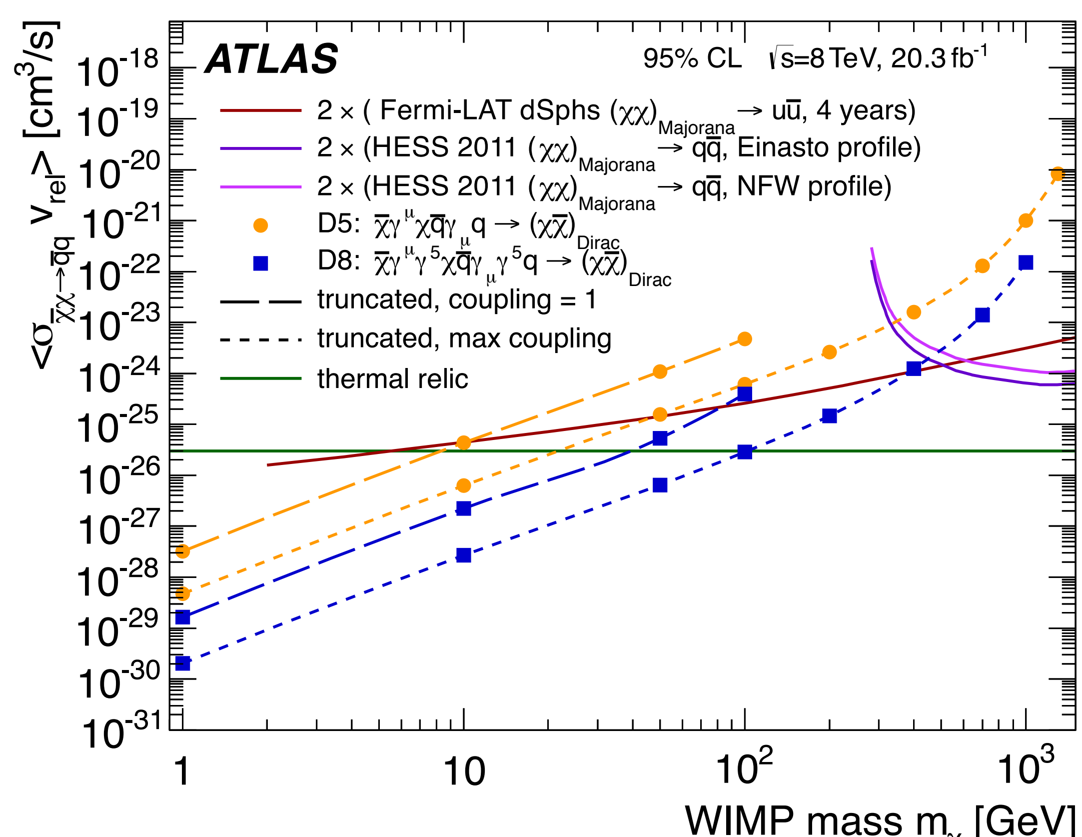
# ATLAS LIMITS



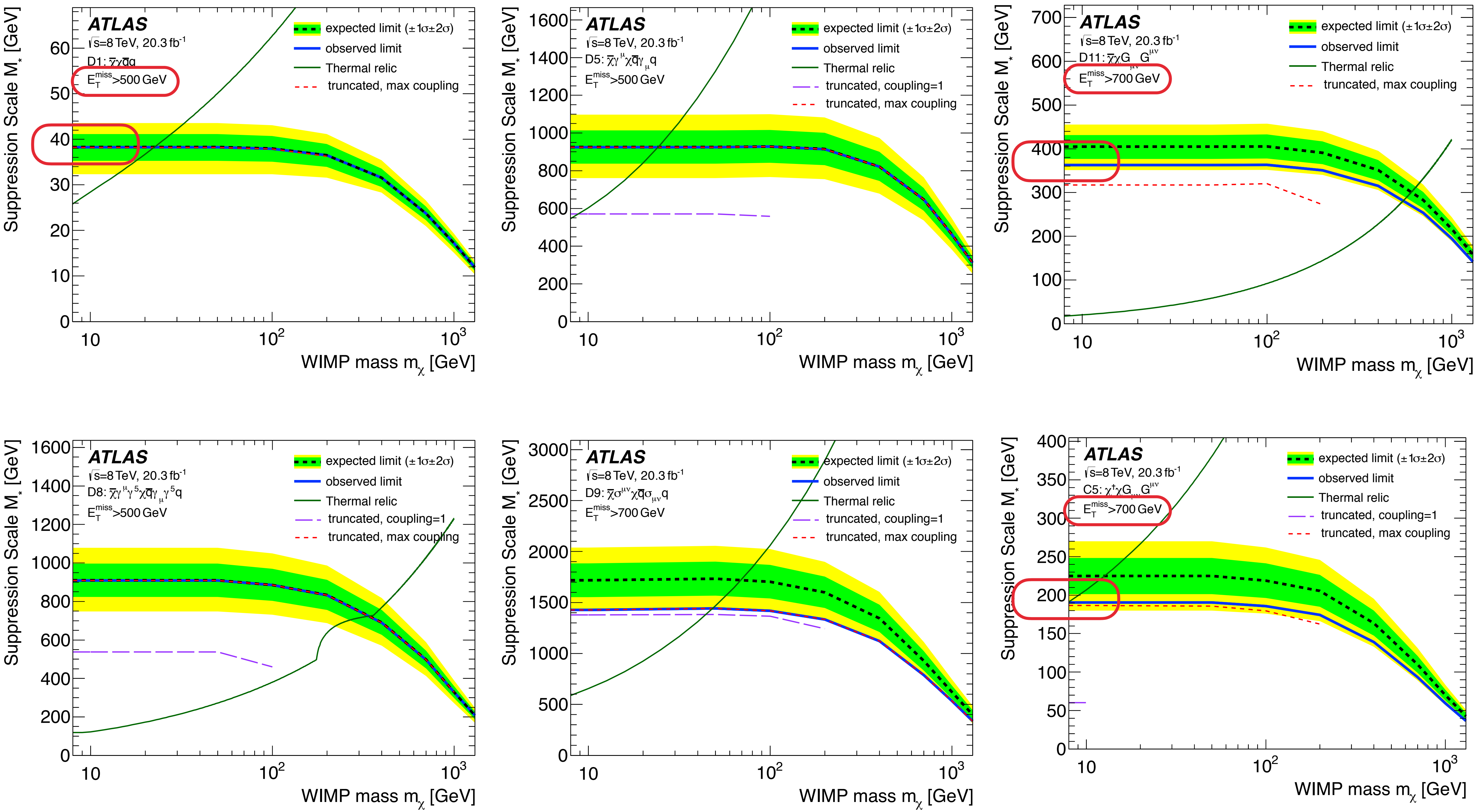

(a)




(b)



# ATLAS LIMITS ON EFT OPERATORS




(c)

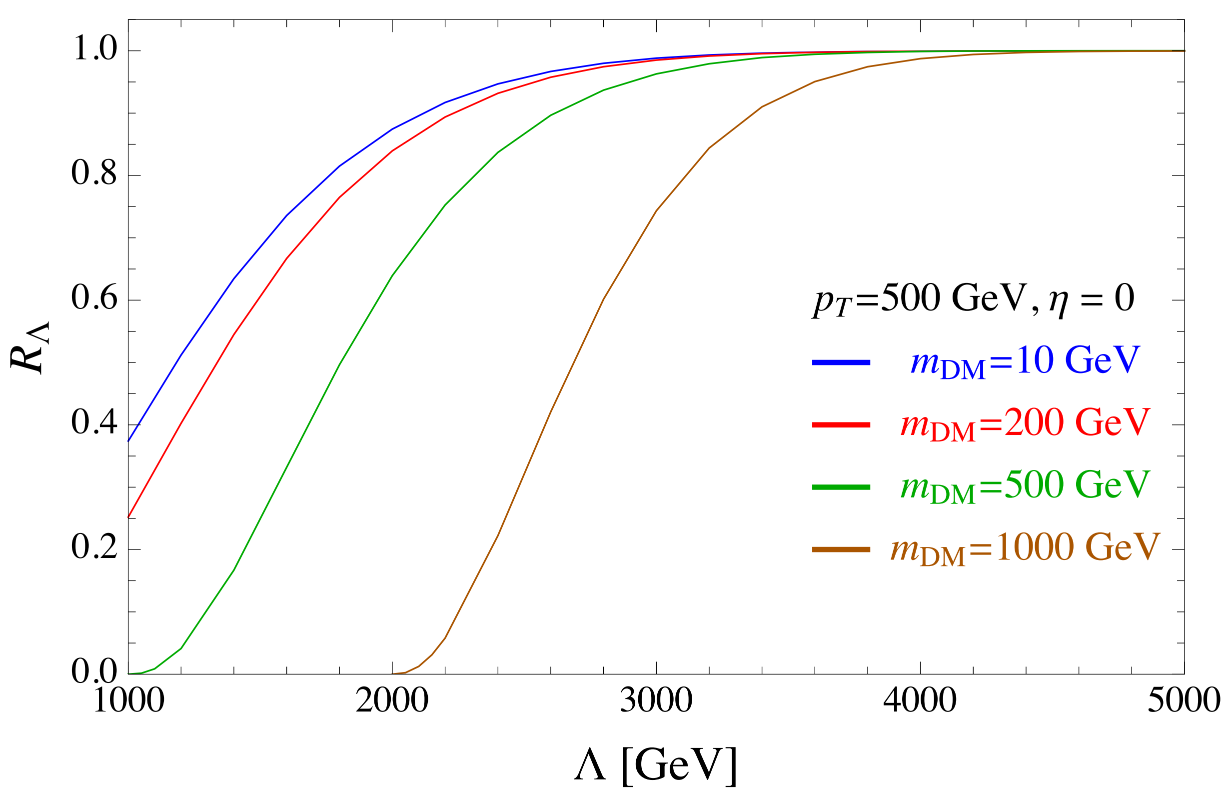
(d)

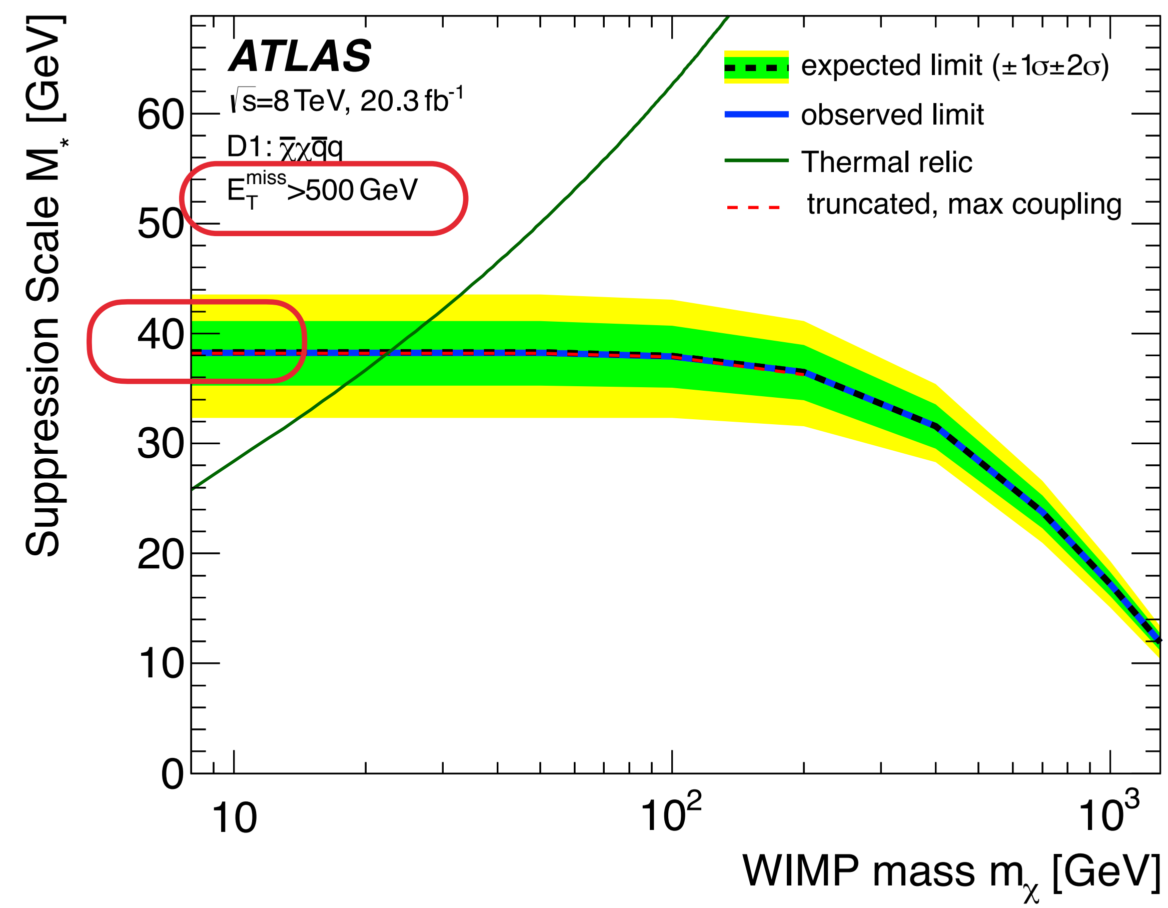
# Original idea of "EFT":

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

# So how does one live with:

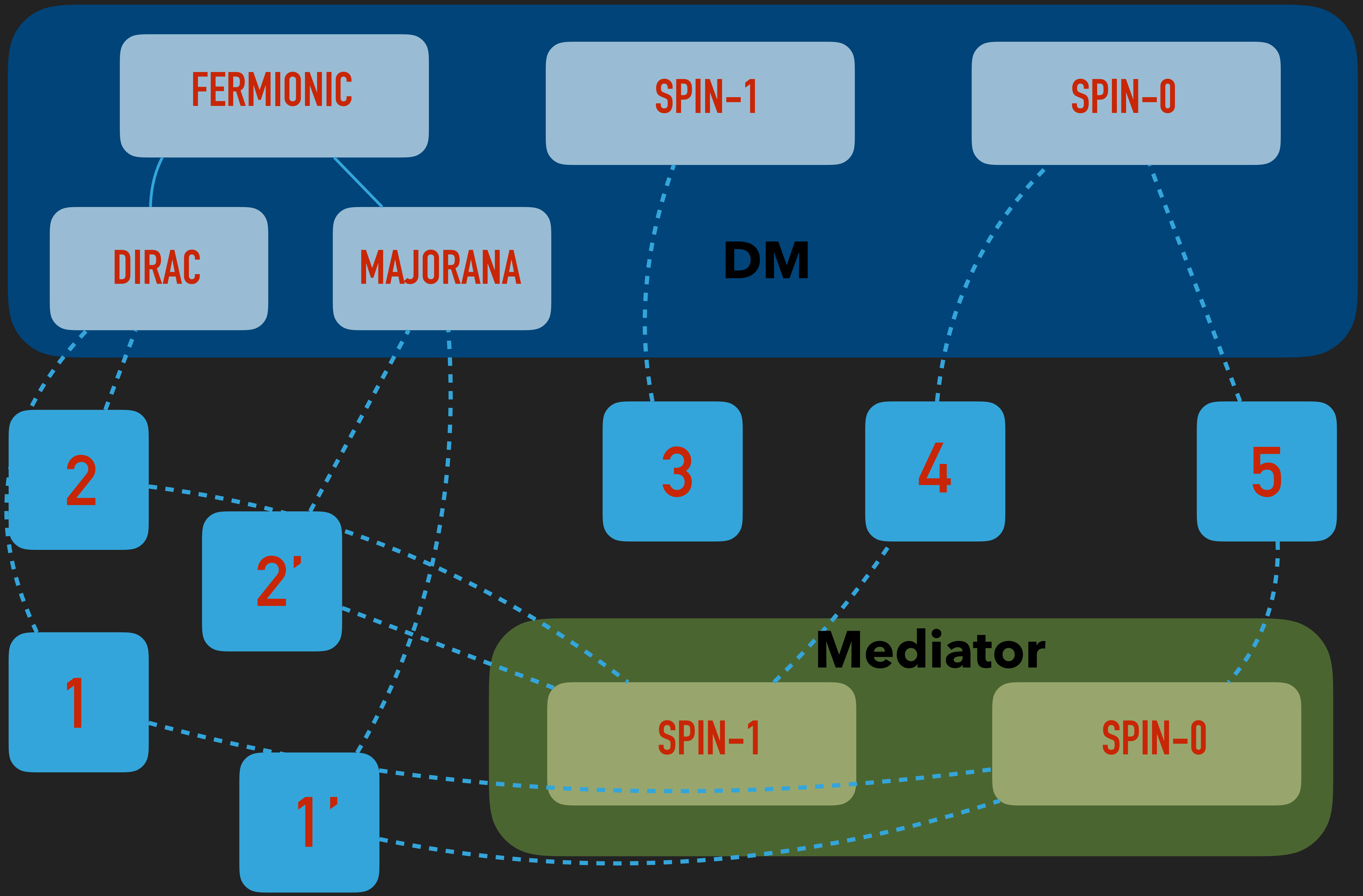
arXiv:1307.2253




Option 1: Treat the EFTs as simply basis of operators and not as a result of integrating out massive particles.

Option 2: Use only the events with $p <$ Lambda




# HOW TO WRITE A SIMPLIFIED MODEL?

1

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

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

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

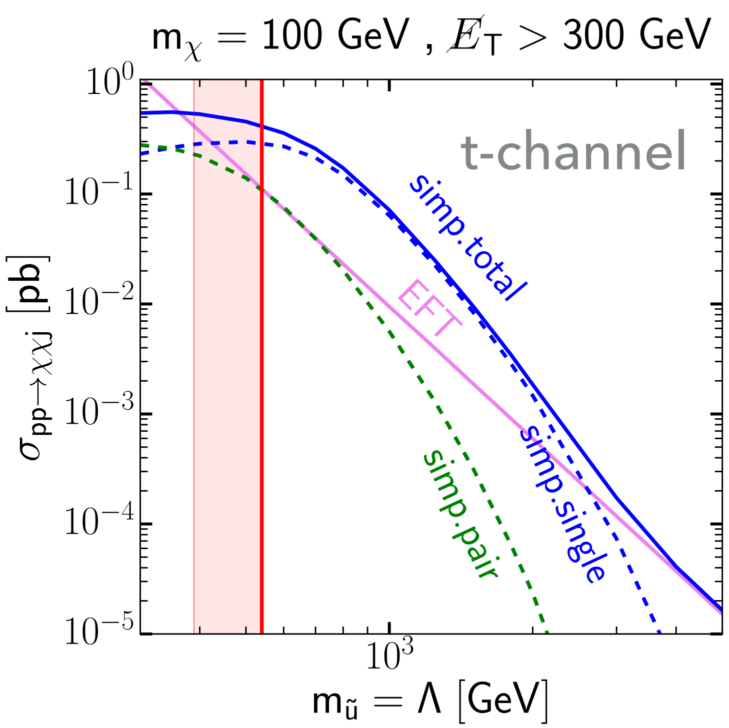
2

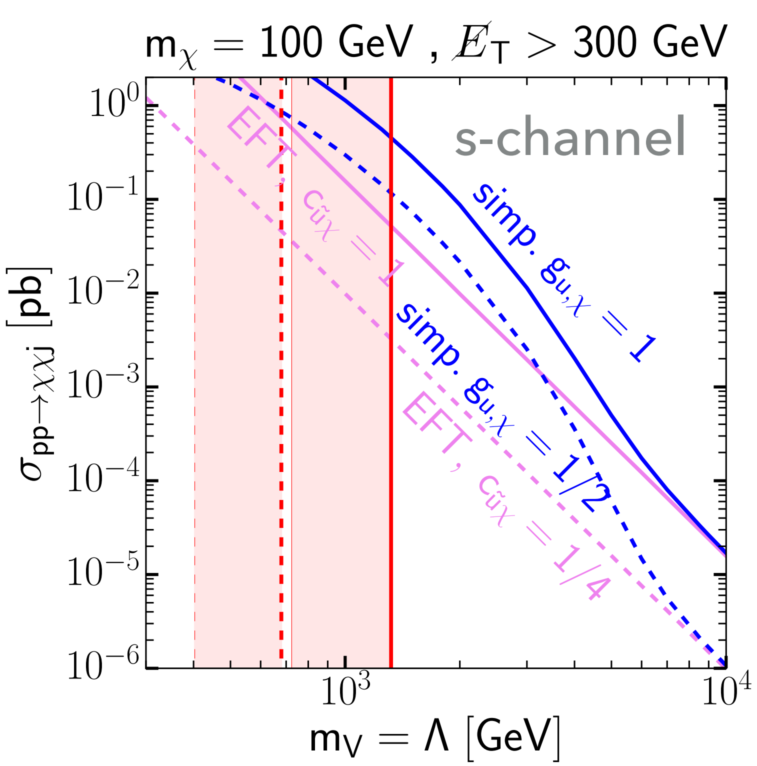
$$\mathcal{L}_{Z'} = \sum g_{Z'\chi\bar{\chi}} \bar{\chi}\gamma^\mu \chi Z'^\mu + \sum g_{Z'q\bar{q}} \; \bar{q}\gamma^\mu q Z'^\mu + \bar{\chi}(i\partial_\mu \gamma^\mu - m_\chi)\chi + \text{gaugeterms}$$

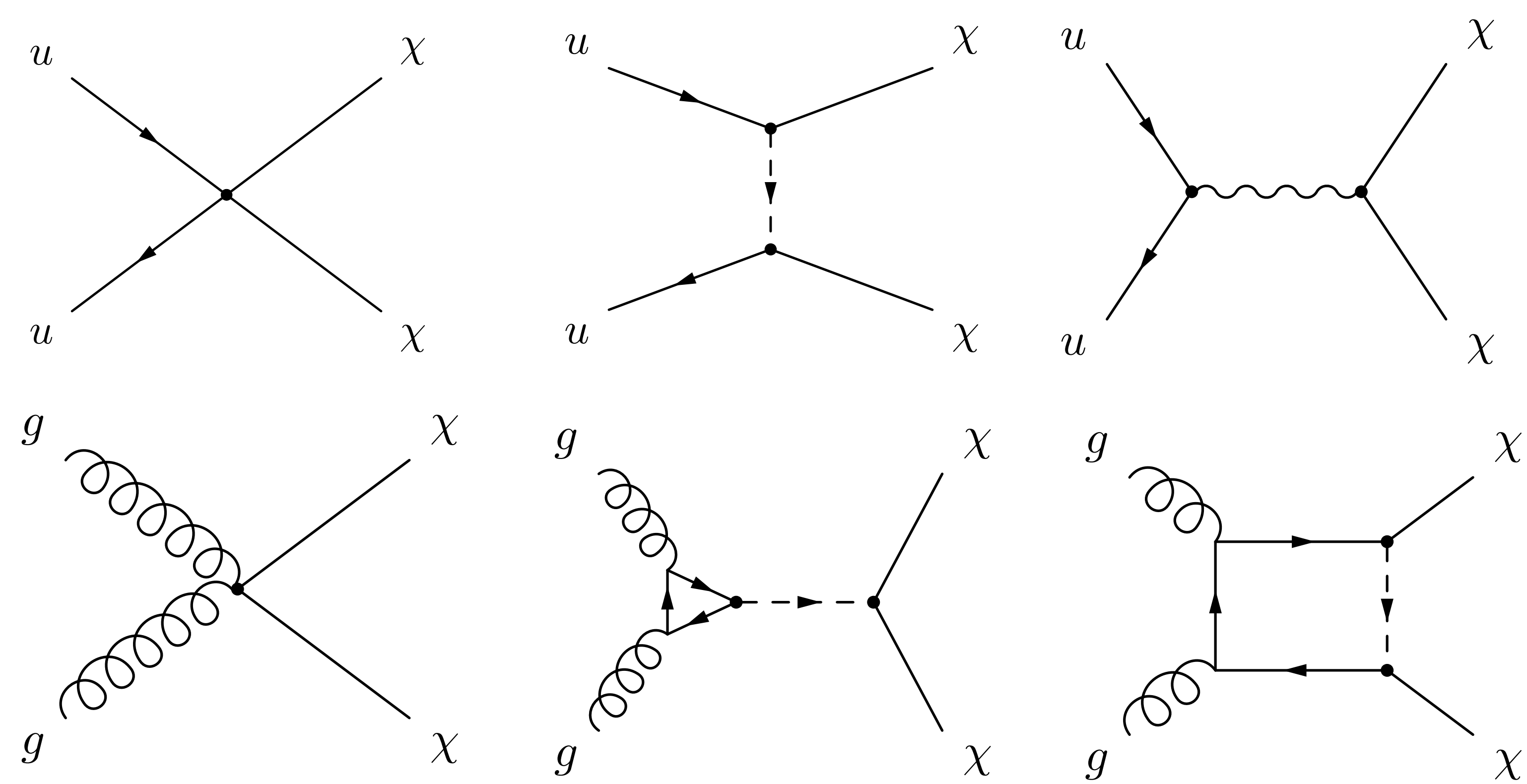
$$\mathcal{L}_{A'} = \sum g_{A'\chi\bar{\chi}} \bar{\chi}\gamma^\mu \gamma^5 \chi A'^\mu + \sum g_{A'q\bar{q}} \; \bar{q}\gamma^\mu \gamma^5 q A'^\mu + \bar{\chi}(i\partial_\mu \gamma^\mu - m_\chi)\chi + \text{gaugeterms}$$

# COMPARING EFT TO SIMPLIFIED MODELS

‣ Bauer, Desai et al. (2016)



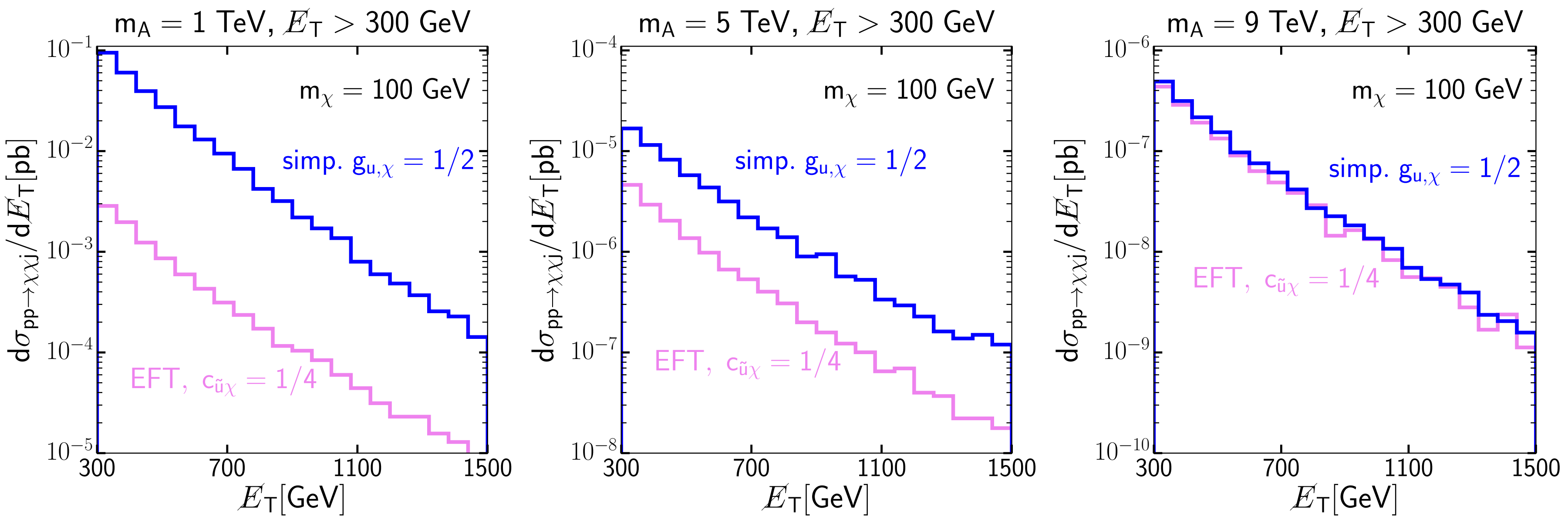



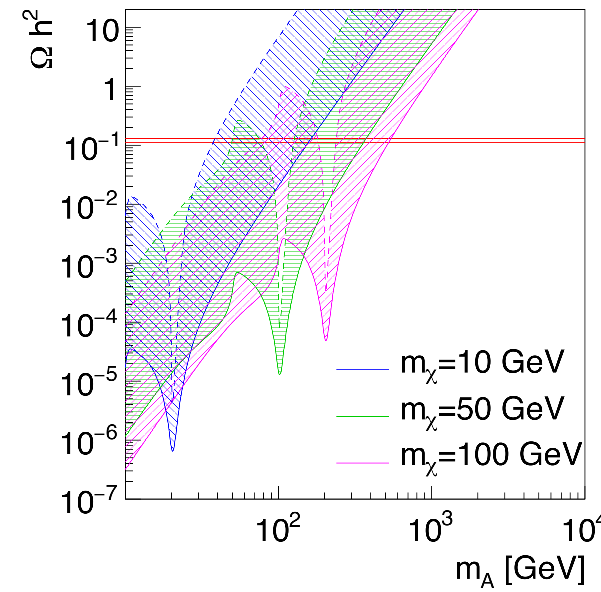

- Need large missing energy cuts to discriminate from SM backgrounds ⇒ large momentum transfer
- This brings into question the idea of "EFT" where the requirement is p≪M (some solutions proposed for this e.g. truncation).
- Cross section does not match even when $c/\Lambda^2 = g_{SM} g_{DM} / M^2$

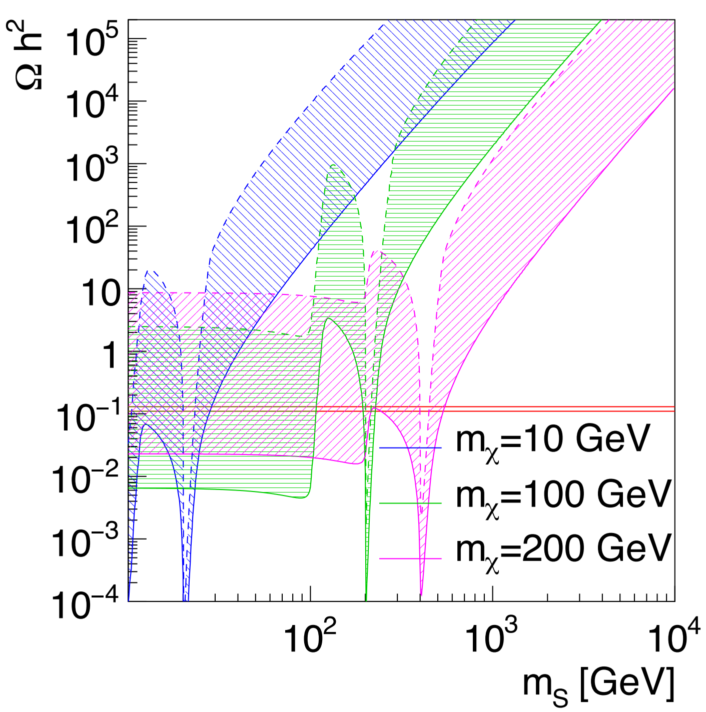
**Conclusion: better to use simplified models for LHC search limits.**

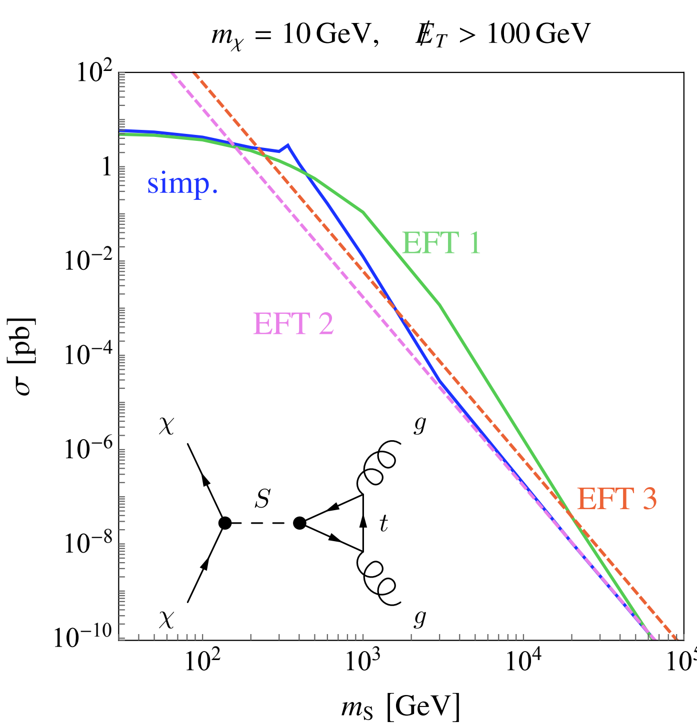
**FUTURE: PROVIDE MAPS OF LHC SEARCH LIMITS WITH DIRECT DETECTION AND RELIC DENSITY BASED ON SIMPLIFIED MODELS**

# WHY DOES THE EFT NOT WORK: CASE S-CHANNEL



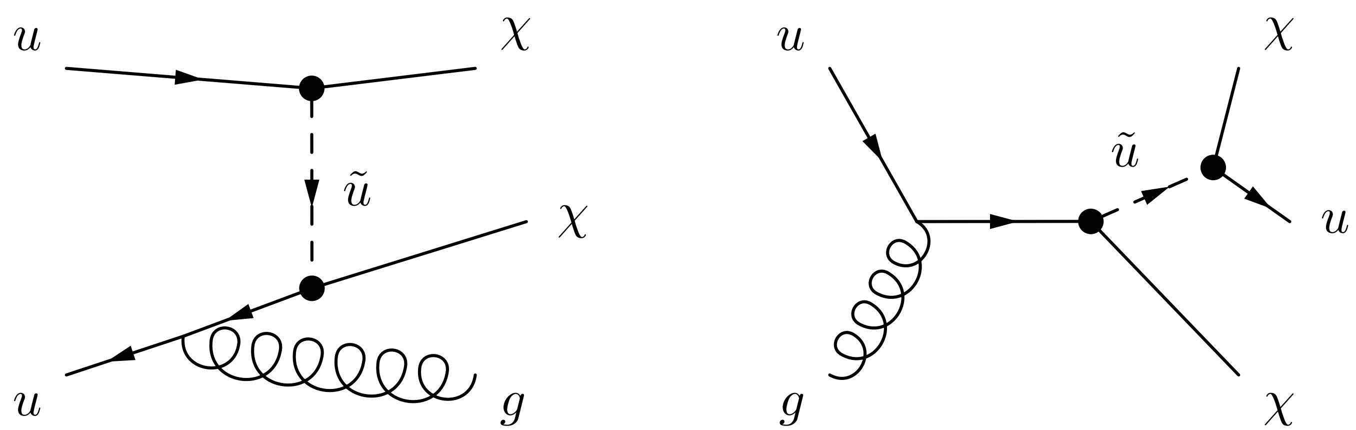



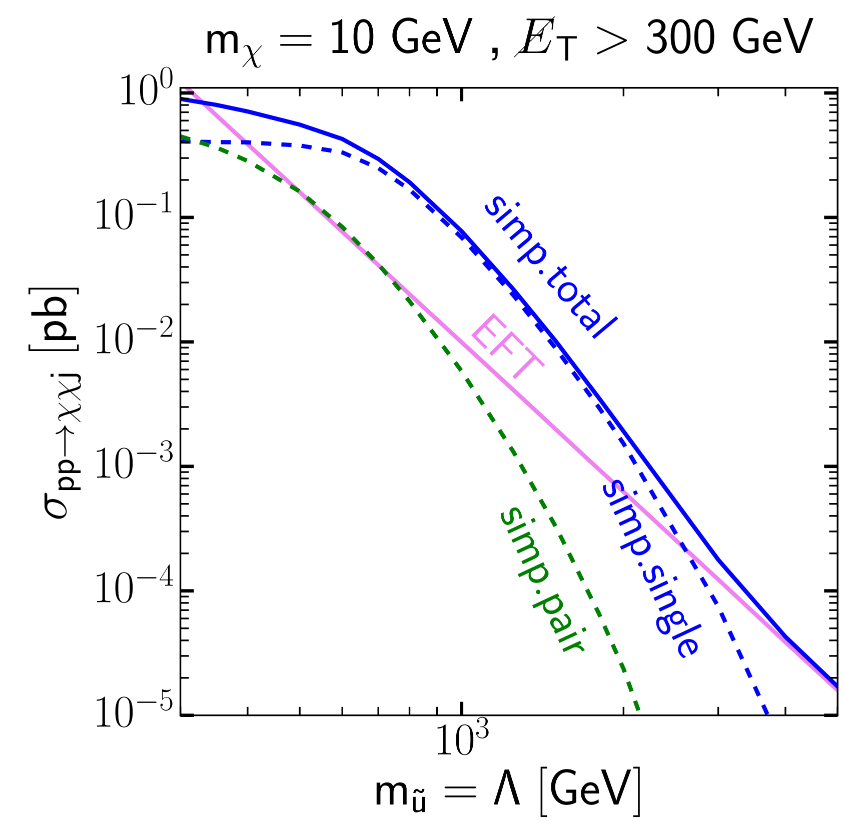

$$\mathcal{L}_{\text{eff},1} \supset \frac{c_S^g}{\Lambda} S\, G_{\mu\nu} G^{\mu\nu}$$

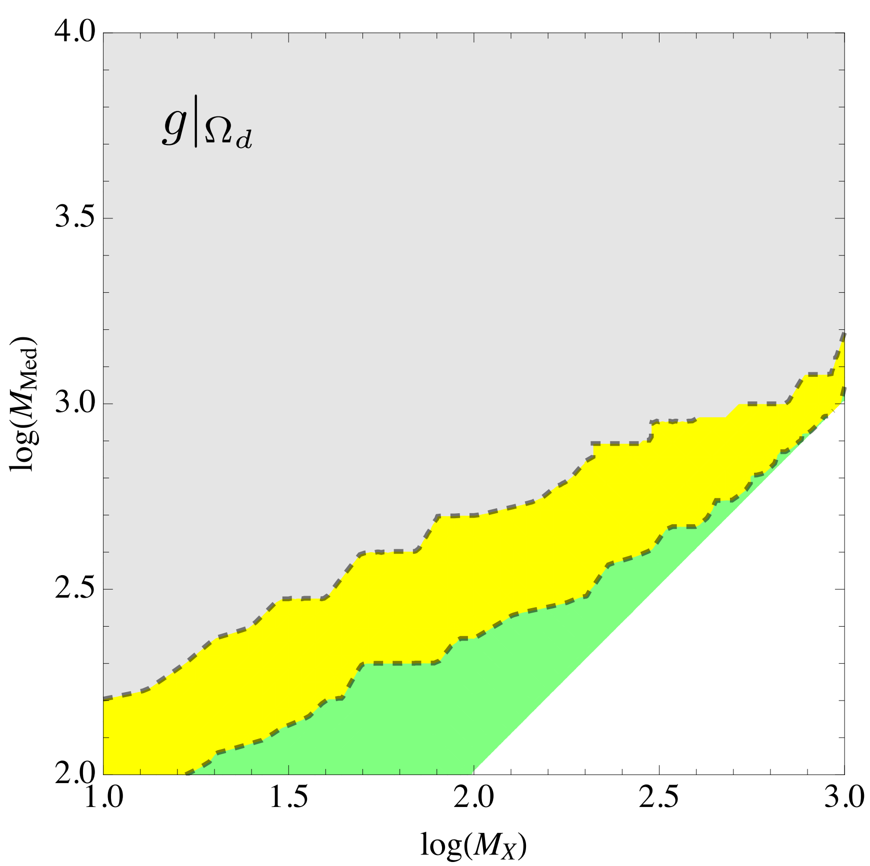
$$\mathcal{L}_{\text{eff},2} \supset \frac{c_S^t}{\Lambda^2} (\bar{t}t)\, (\bar{\chi}\chi)$$

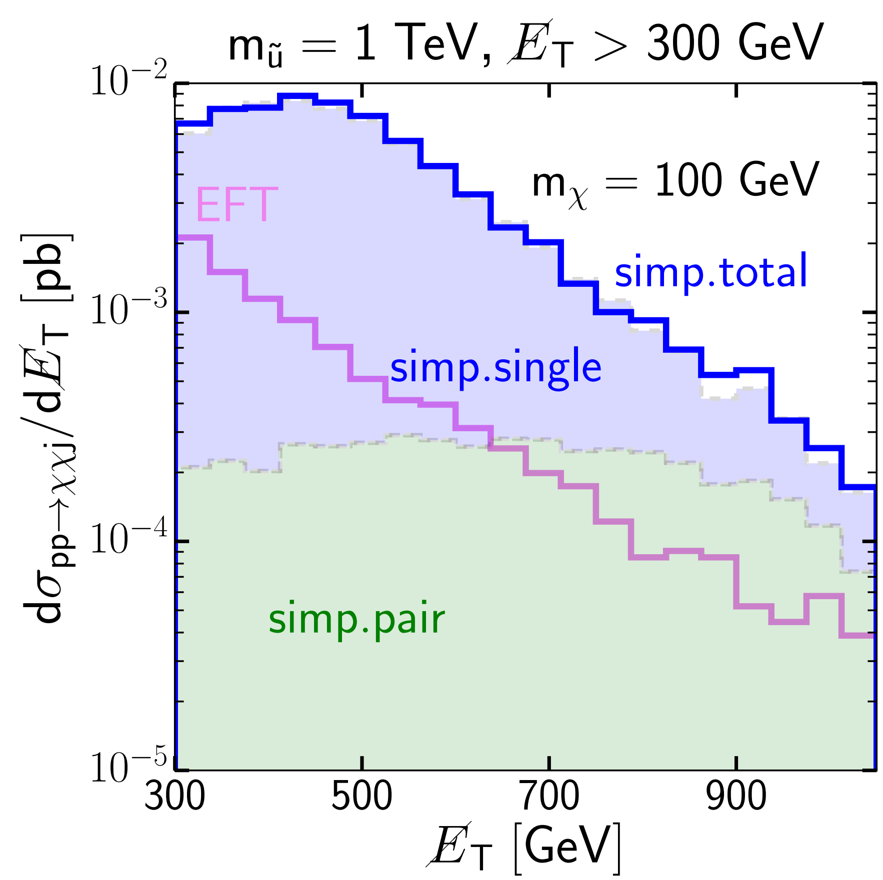
$$\mathcal{L}_{\text{eff},3} \supset \frac{c_\chi^g}{\Lambda^3} (\bar{\chi}\chi)\, G_{\mu\nu} G^{\mu\nu}$$

# WHY DOES THE EFT NOT WORK: CASE T-CHANNEL

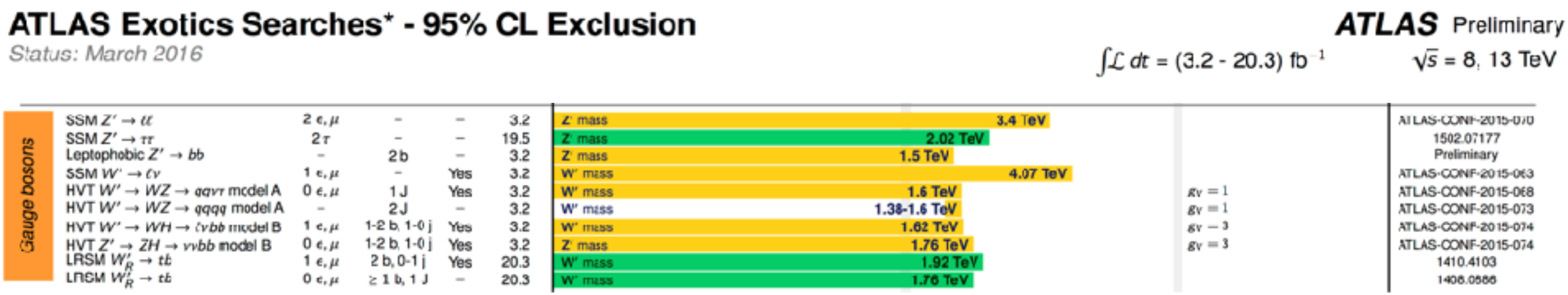


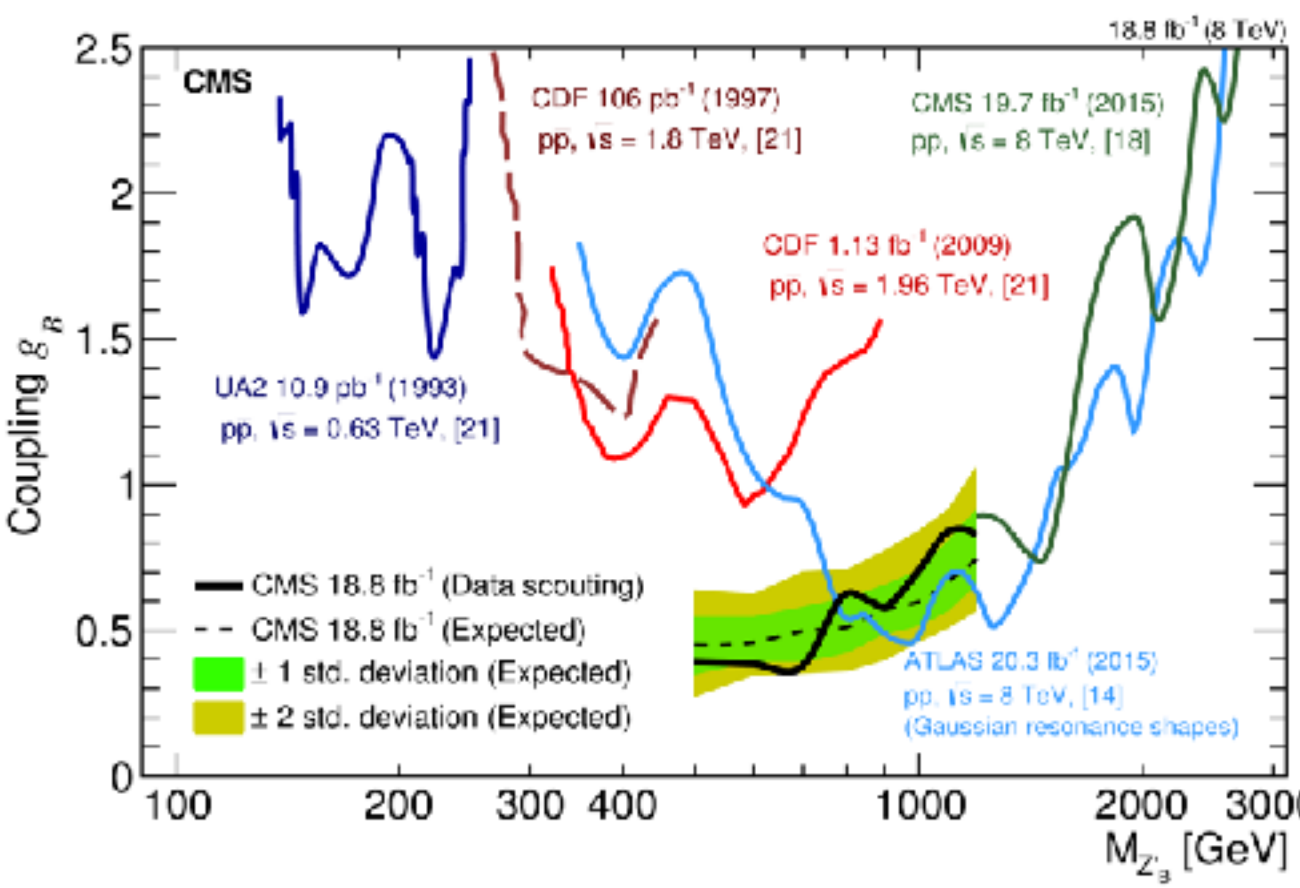



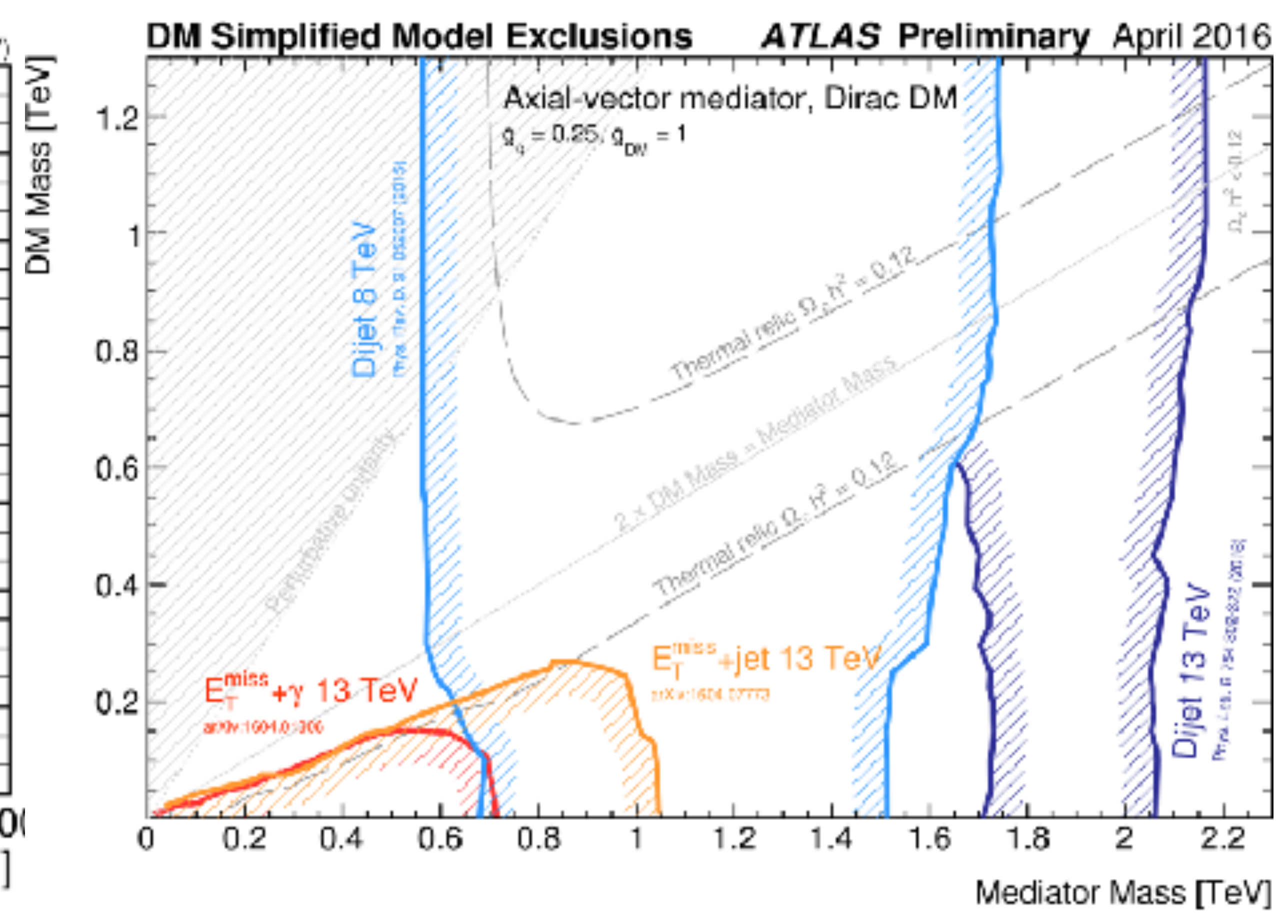



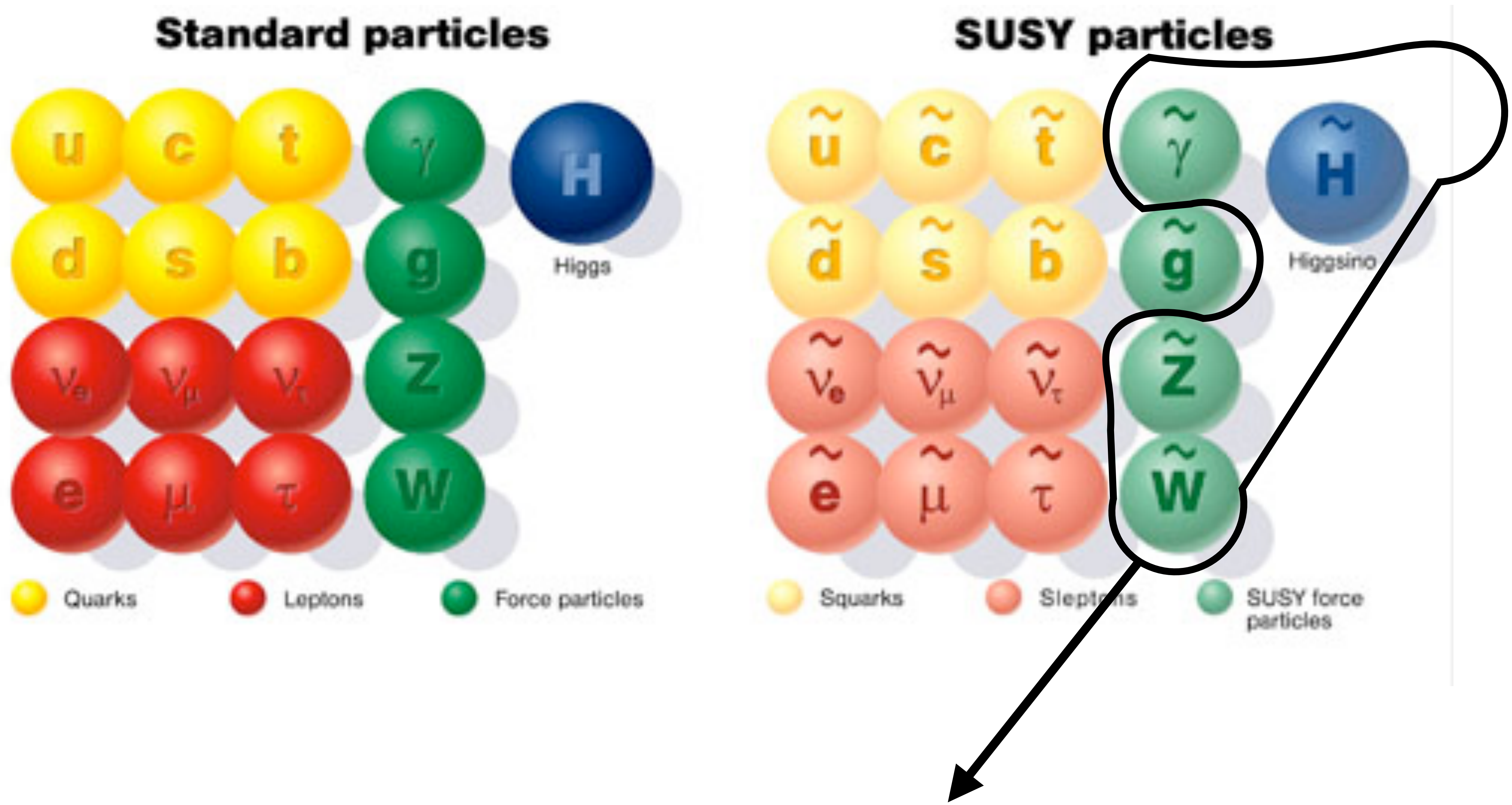
# LOOKING FOR THE MEDIATOR



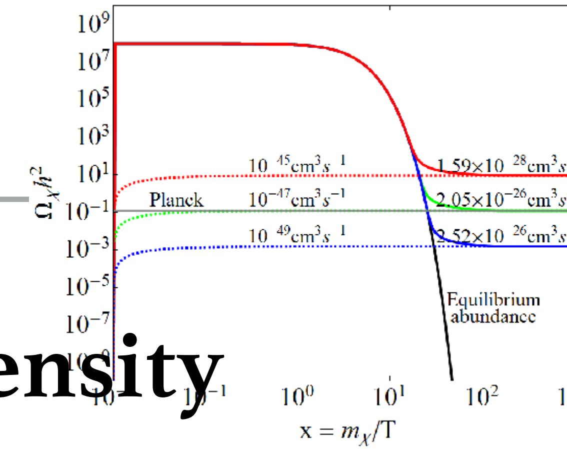
# A MORE COMPLICATED MODEL: DM IN SUPERSYMMETRY



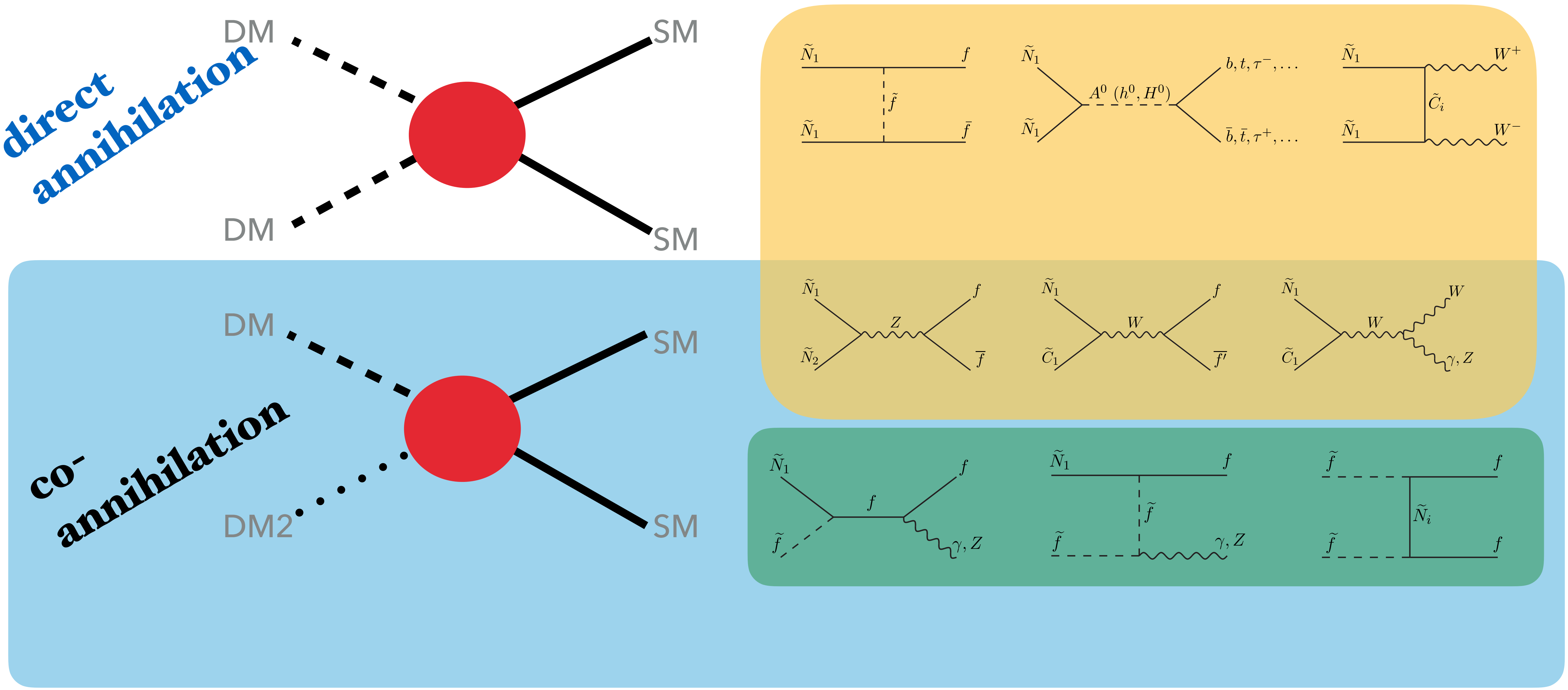

Mix to form “neutralinos" and “charginos”

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

# SUSY DARK MATTER




1.Find parameter space that gives the right relic density




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

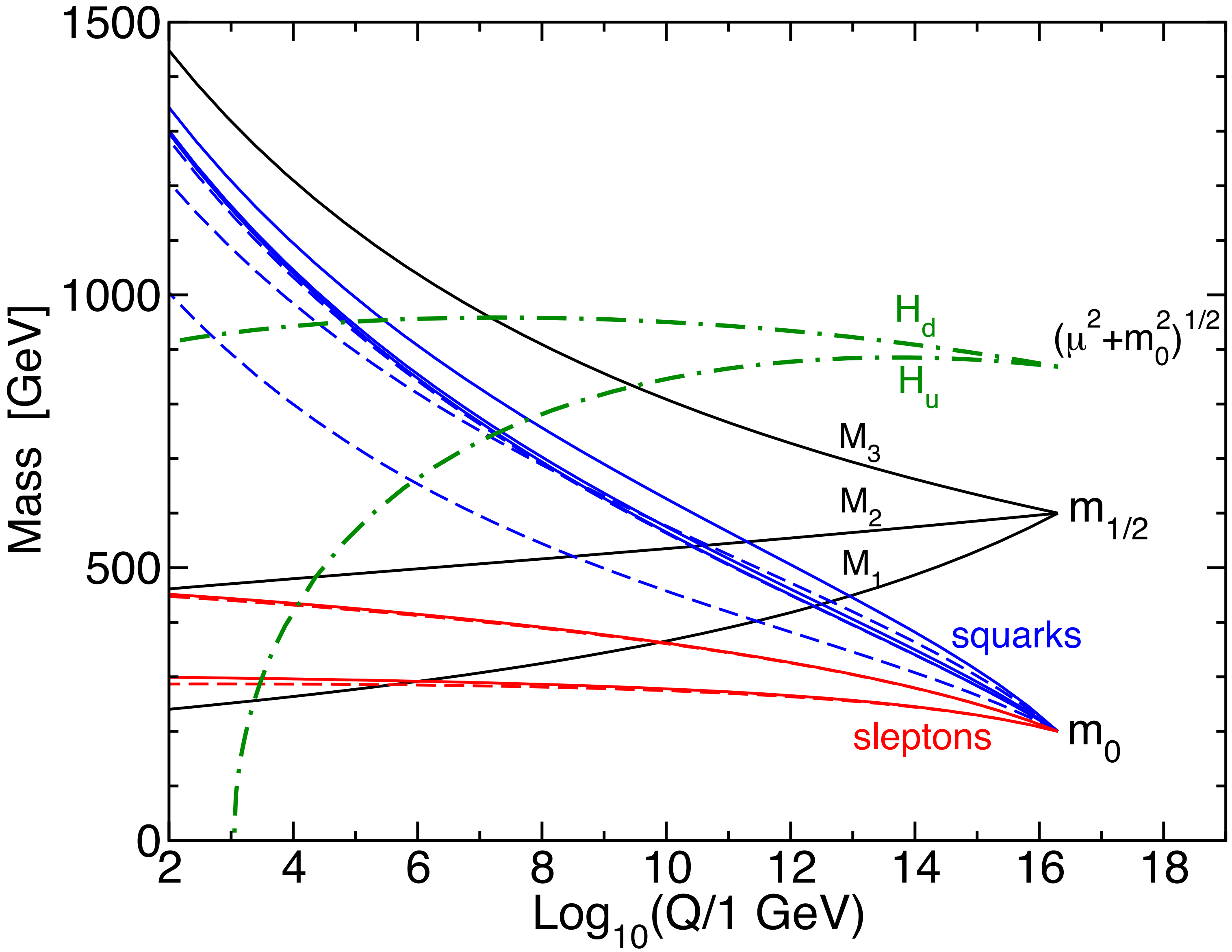
2.Look at Direct/Indirect/Collider constraints (both present and future expectations)

# PART II: STAU CO-ANNIHILATION

I.e. looking for accompanying particles

# 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

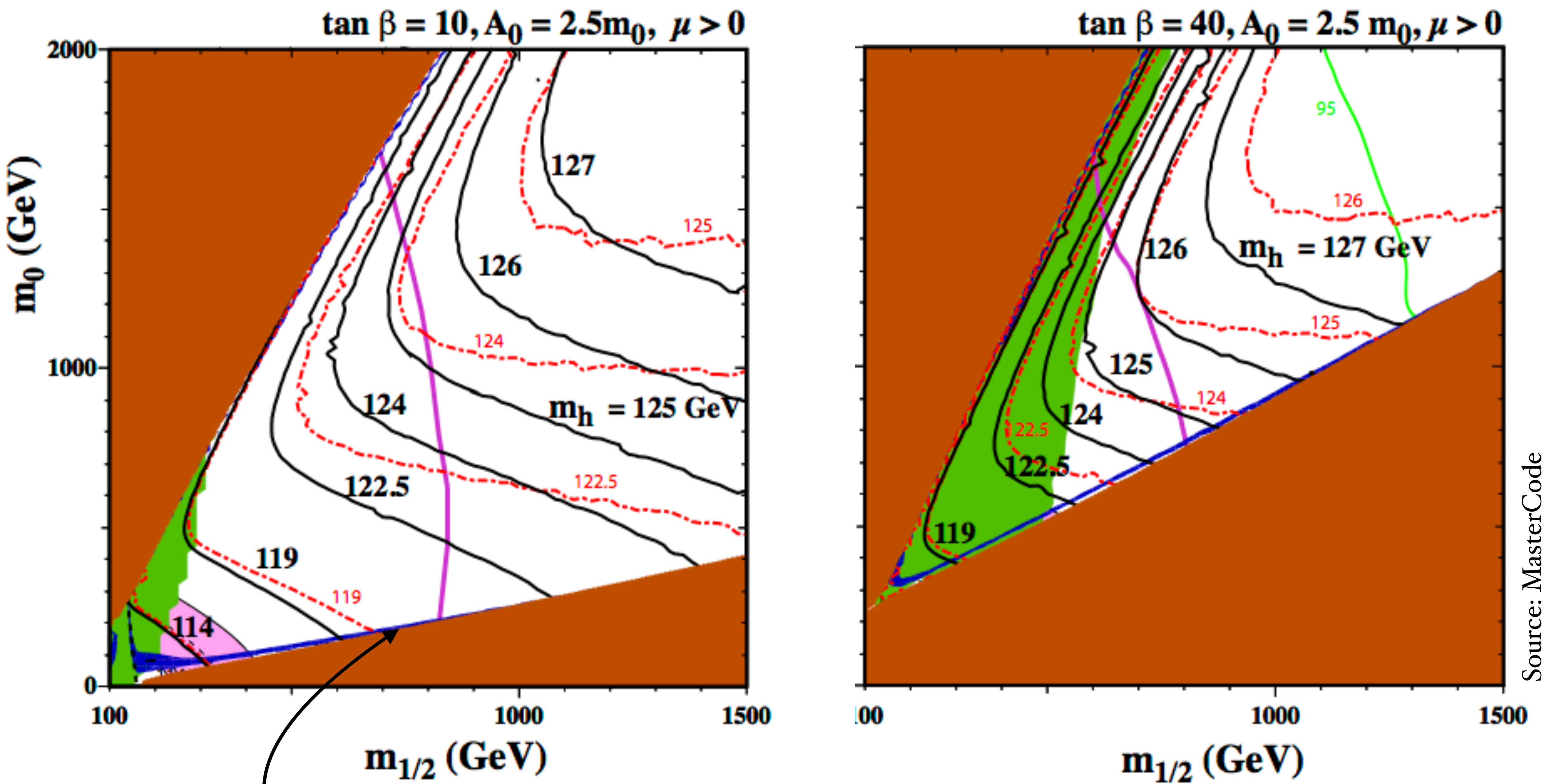
# QUESTIONS TO ASK:

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 |

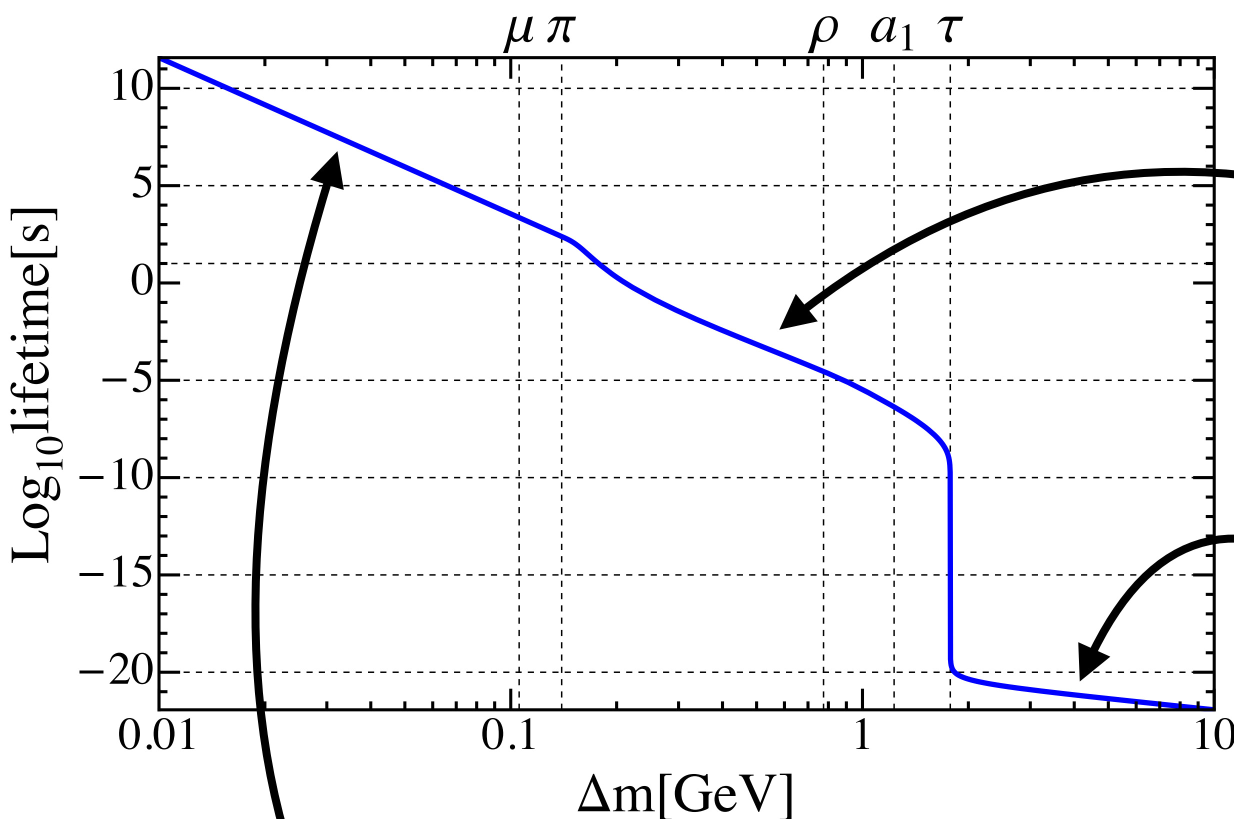
**All of them in the stau co-annihilation strip!**

# 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?)

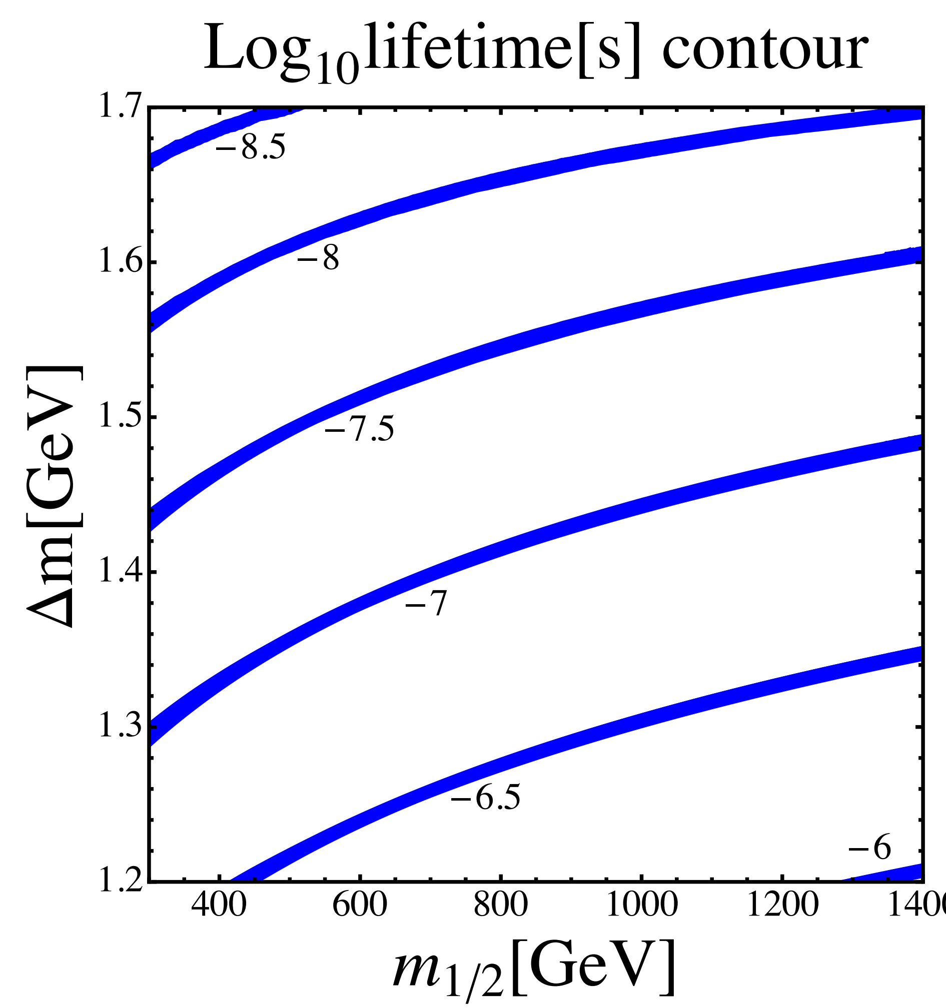
# LIFETIME OF THE STAU

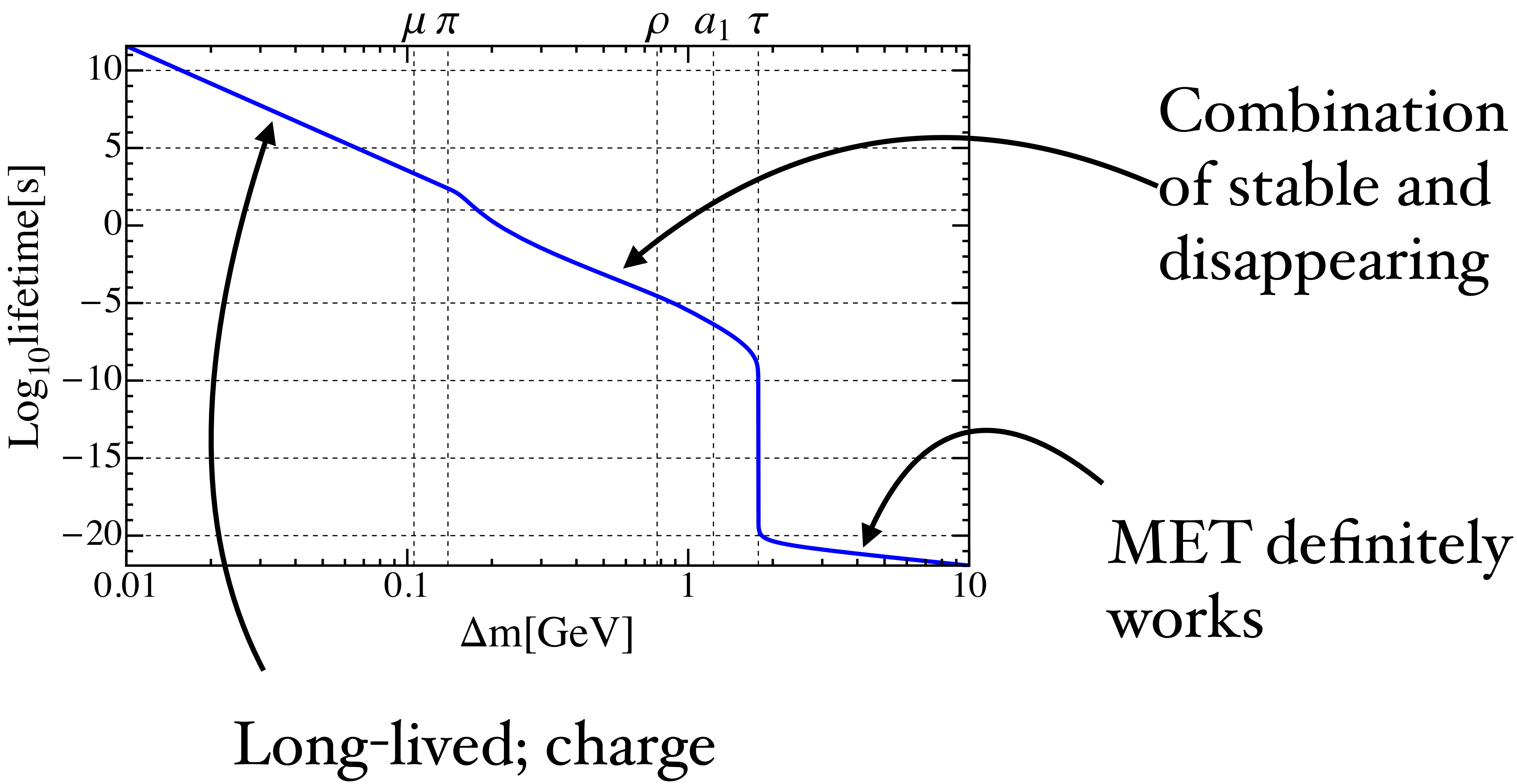



$$\tilde{\tau}_1^- \rightarrow a_1^- \nu_\tau \chi$$
$$\tilde{\tau}_1^- \rightarrow \rho^- \nu_\tau \chi$$
$$\tilde{\tau}_1^- \rightarrow \pi^- \nu_\tau \chi$$

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

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

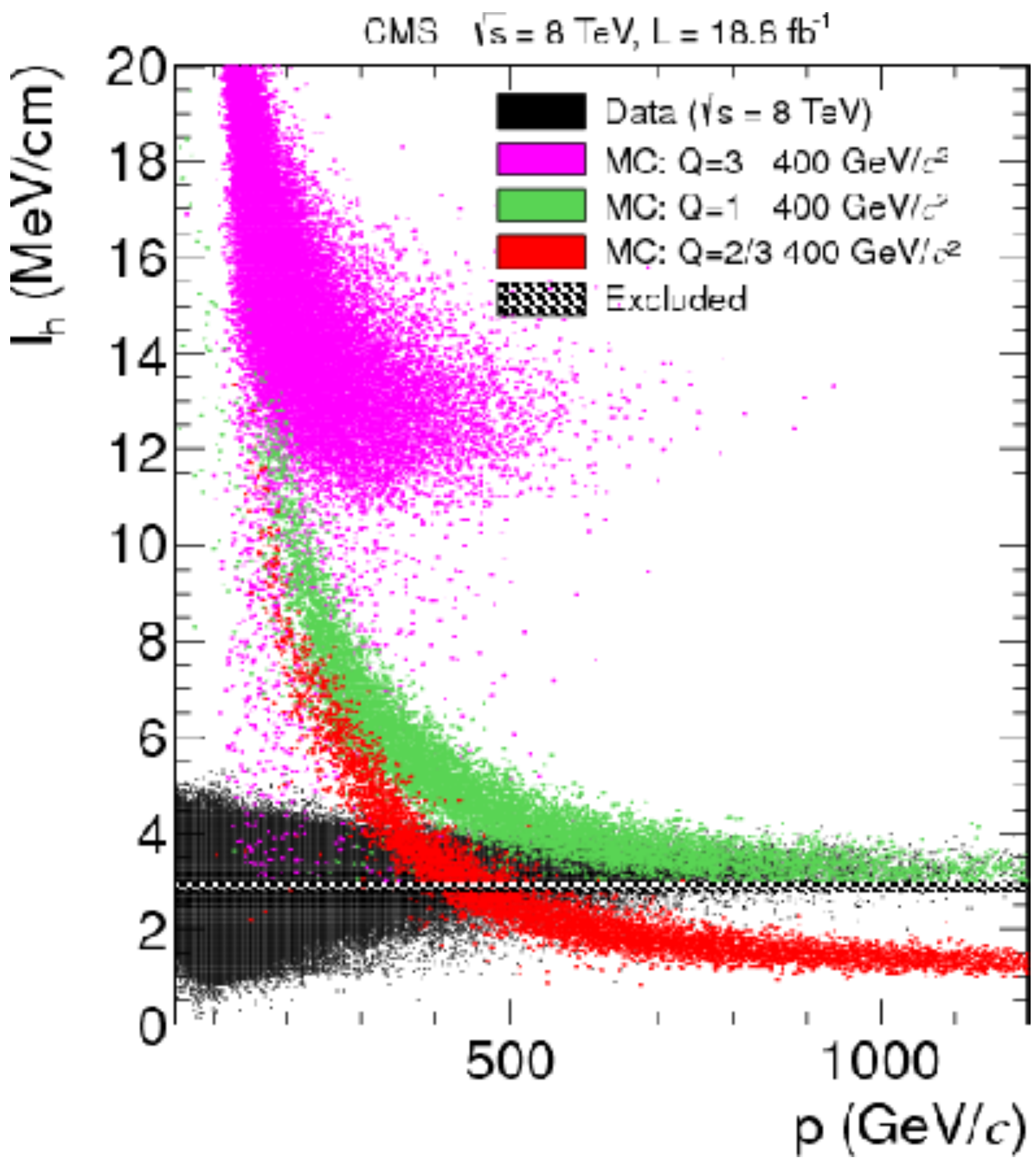


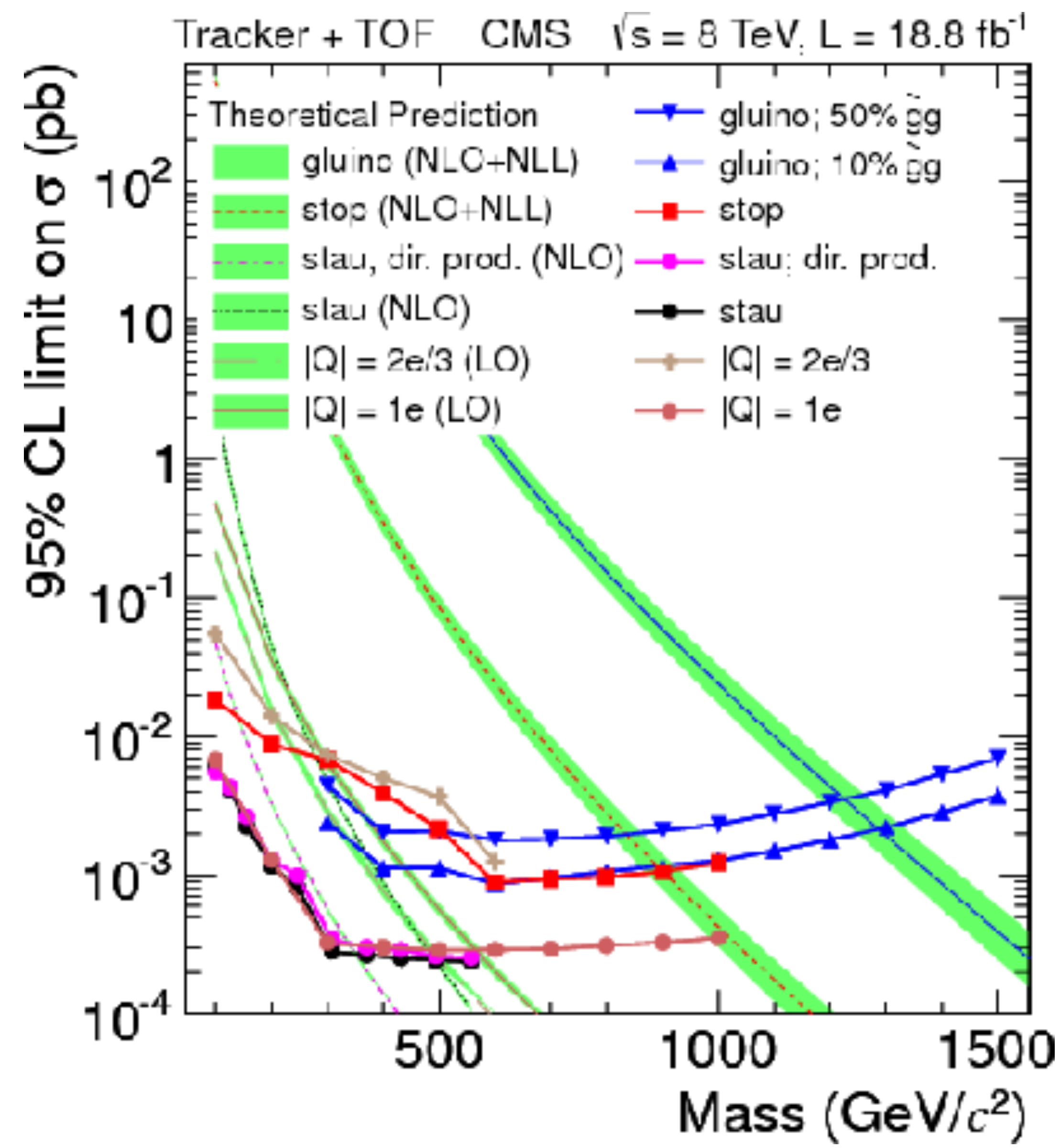



Useful parameters to probe the co-annihilation

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

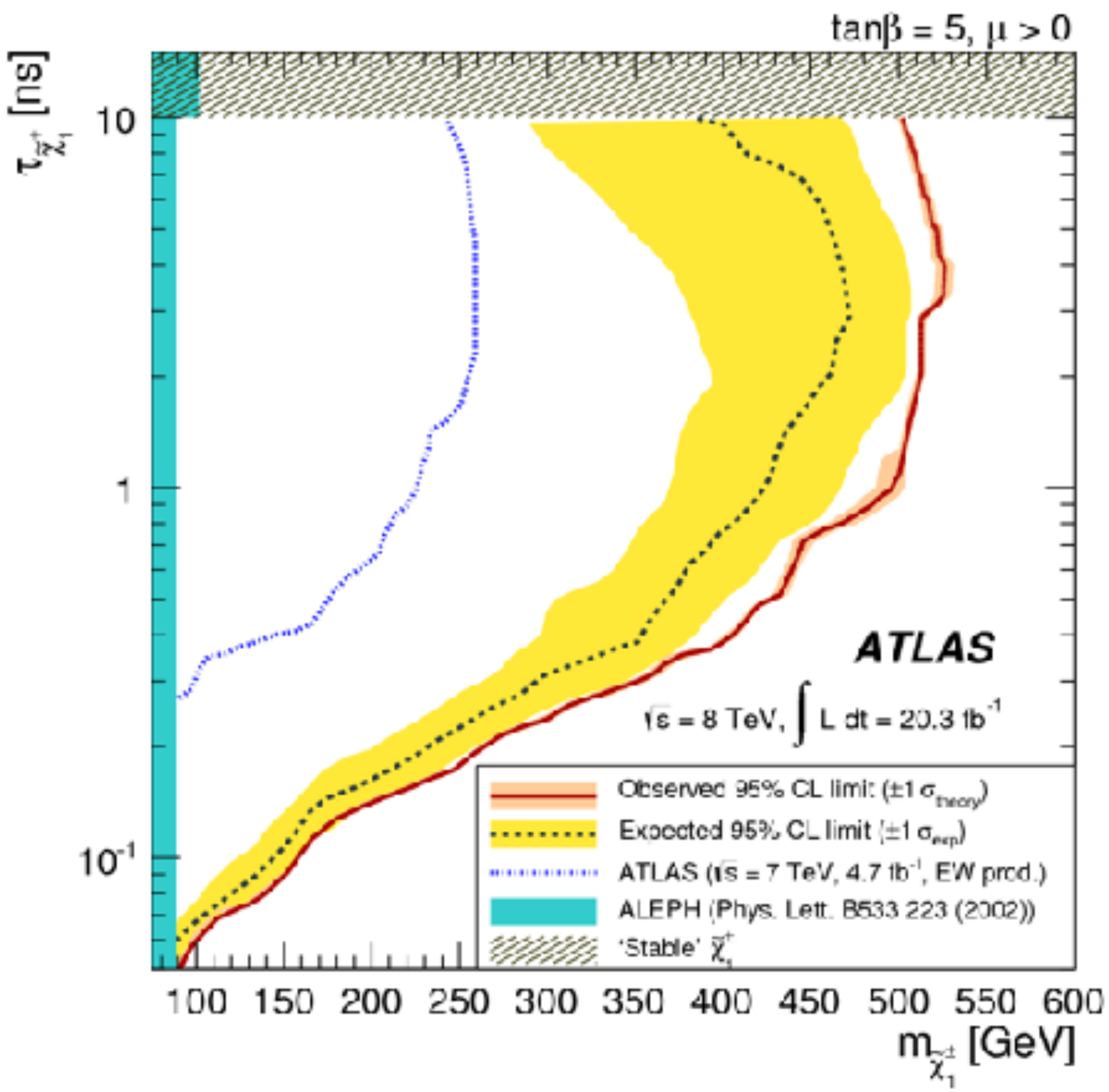
# CMS: EXOTIC CHARGED TRACKS




| Mass (GeV/$c^2$) | $M$ req. (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



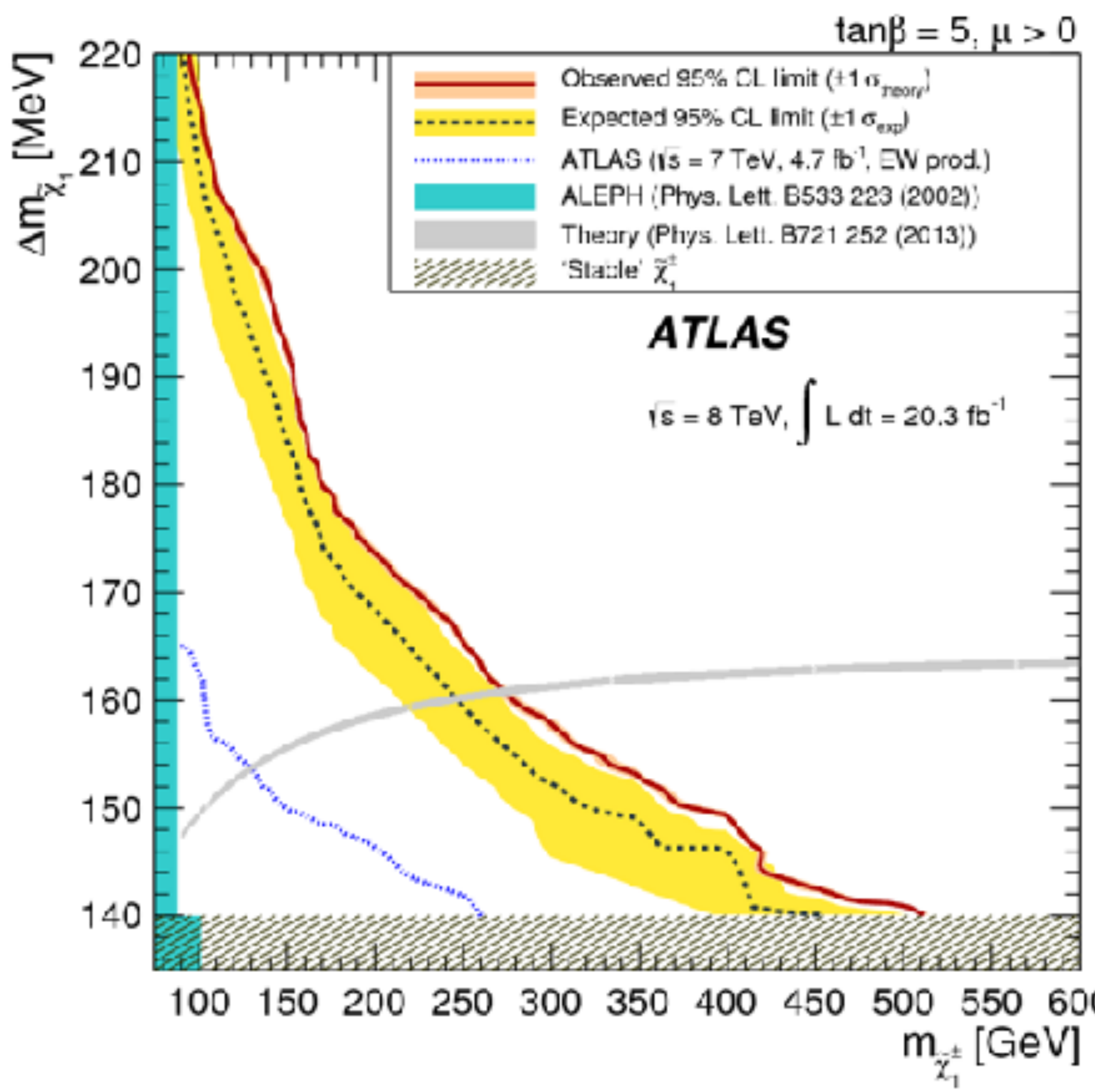
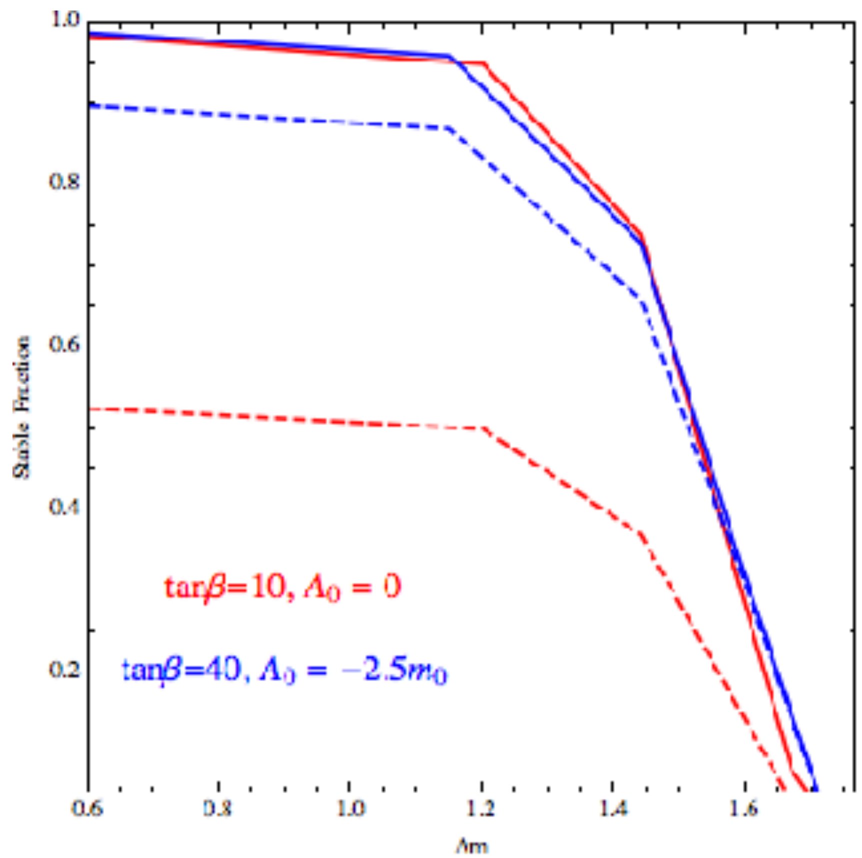
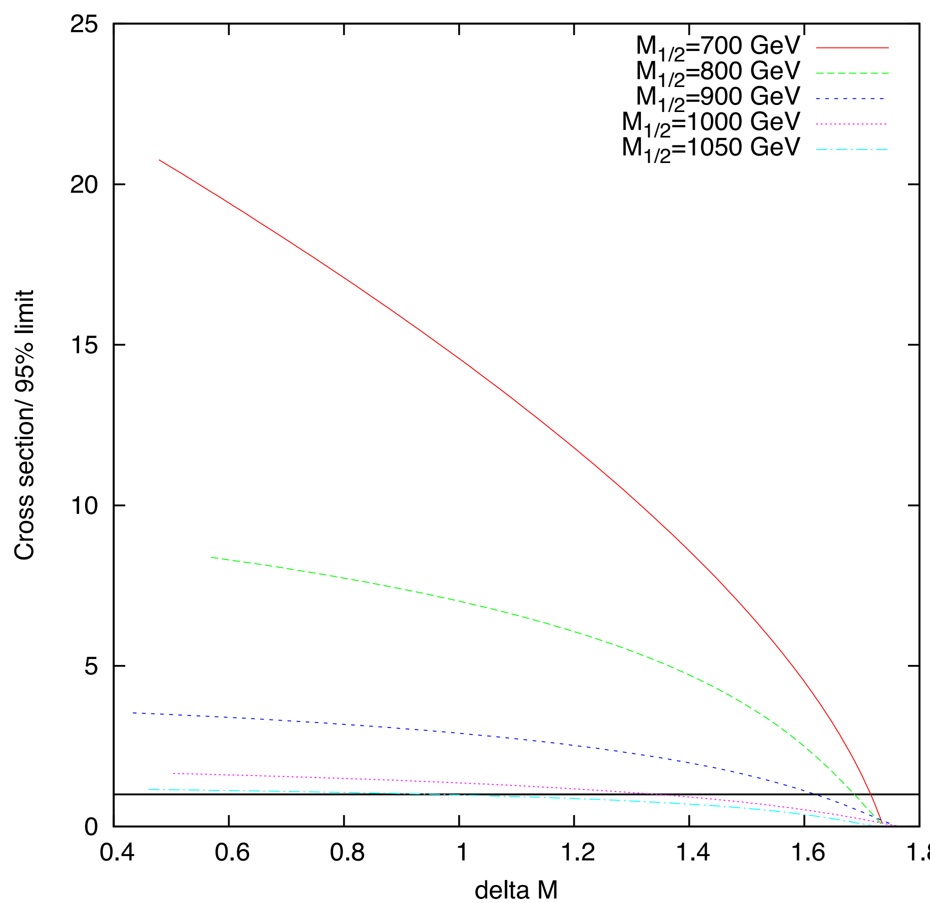



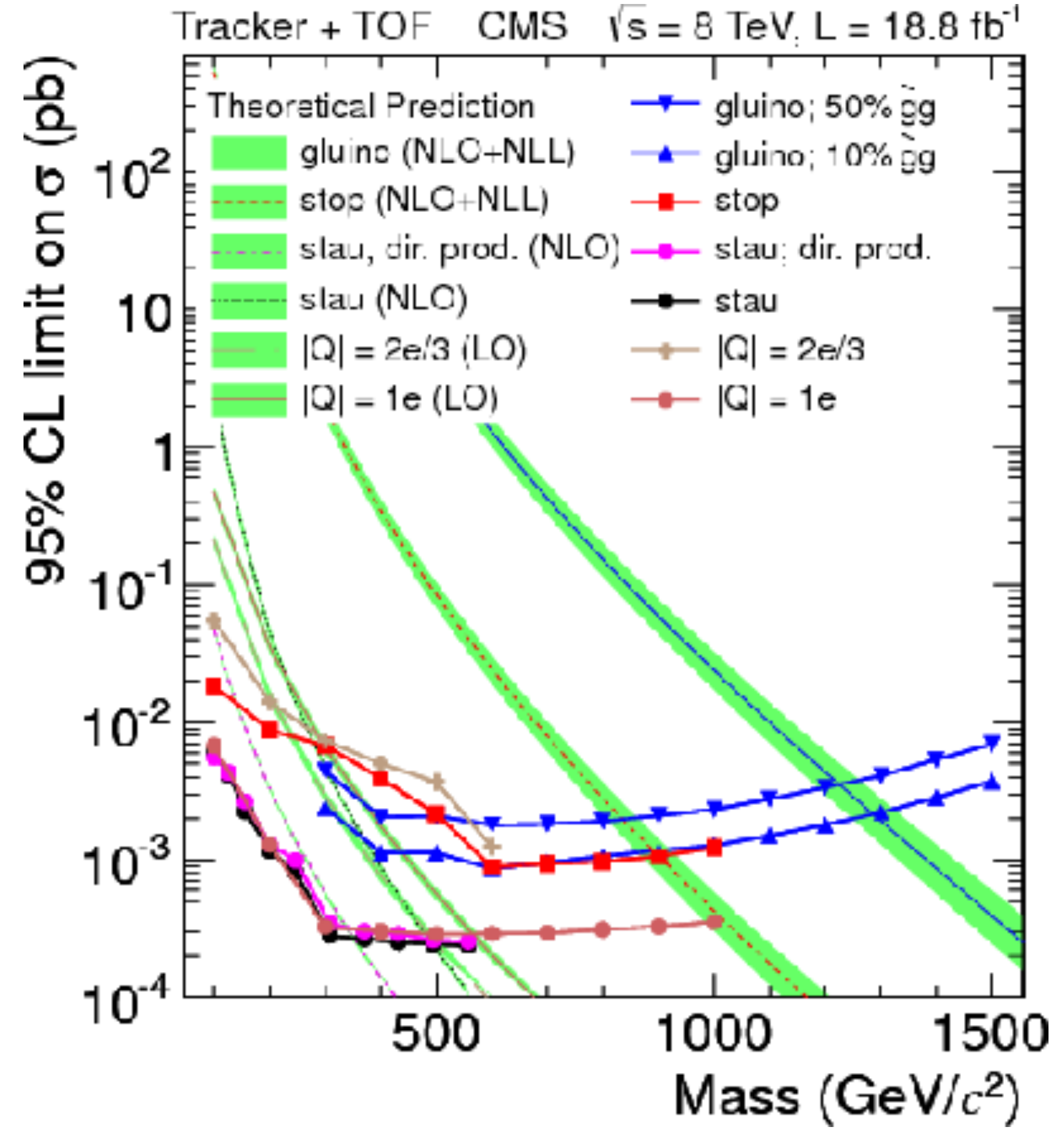

TABLE III. Numbers of observed and expected background events as well as the probability that a background-only experiment is more signal-like than observed ($p_0$) and the model-independent upper limit on the visible cross-section ($\sigma_{\rm vis}^{95\%}$) at 95% CL.

| | $p_{\rm T}^{\rm track} > 75$ GeV | $p_{\rm T}^{\rm track} > 100$ GeV | $p_{\rm T}^{\rm track} > 150$ GeV | $p_{\rm T}^{\rm track} > 200$ 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] | $1.42^{+0.50}_{-0.39}$ | $1.05^{+0.37}_{-0.28}$ | $0.67^{+0.27}_{-0.19}$ | $0.56^{+0.23}_{-0.16}$ |

# CMS: EXOTIC CHARGED TRACKS




| Mass (GeV/$c^2$) | $M$ req. (GeV/$c^2$) | $\sigma$ (pb) ($\sqrt{s}=7$ TeV) Exp. | Obs. | Acc. | $\sigma$ (pb) ($\sqrt{s}=8$ TeV) Exp. | Obs. | Acc. |
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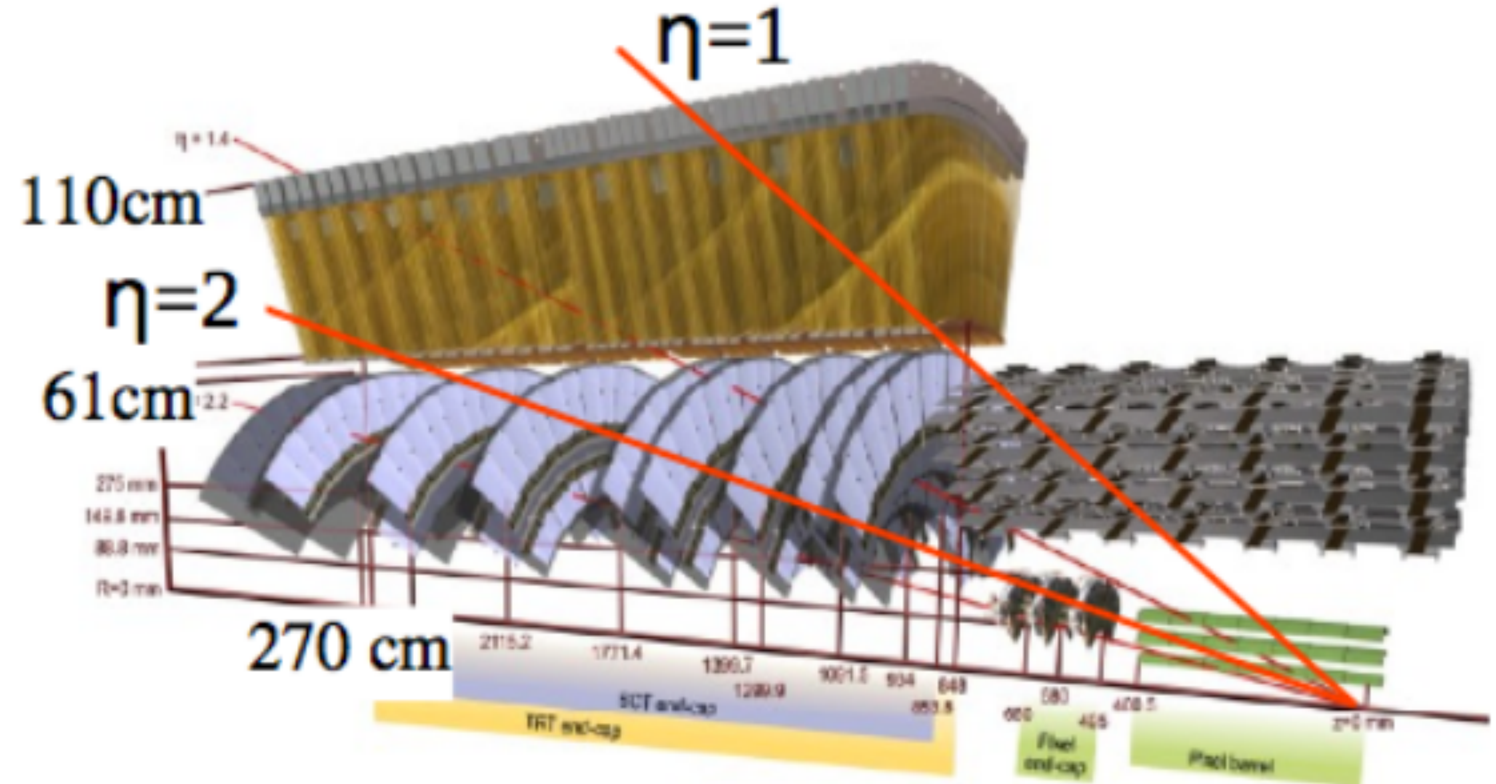
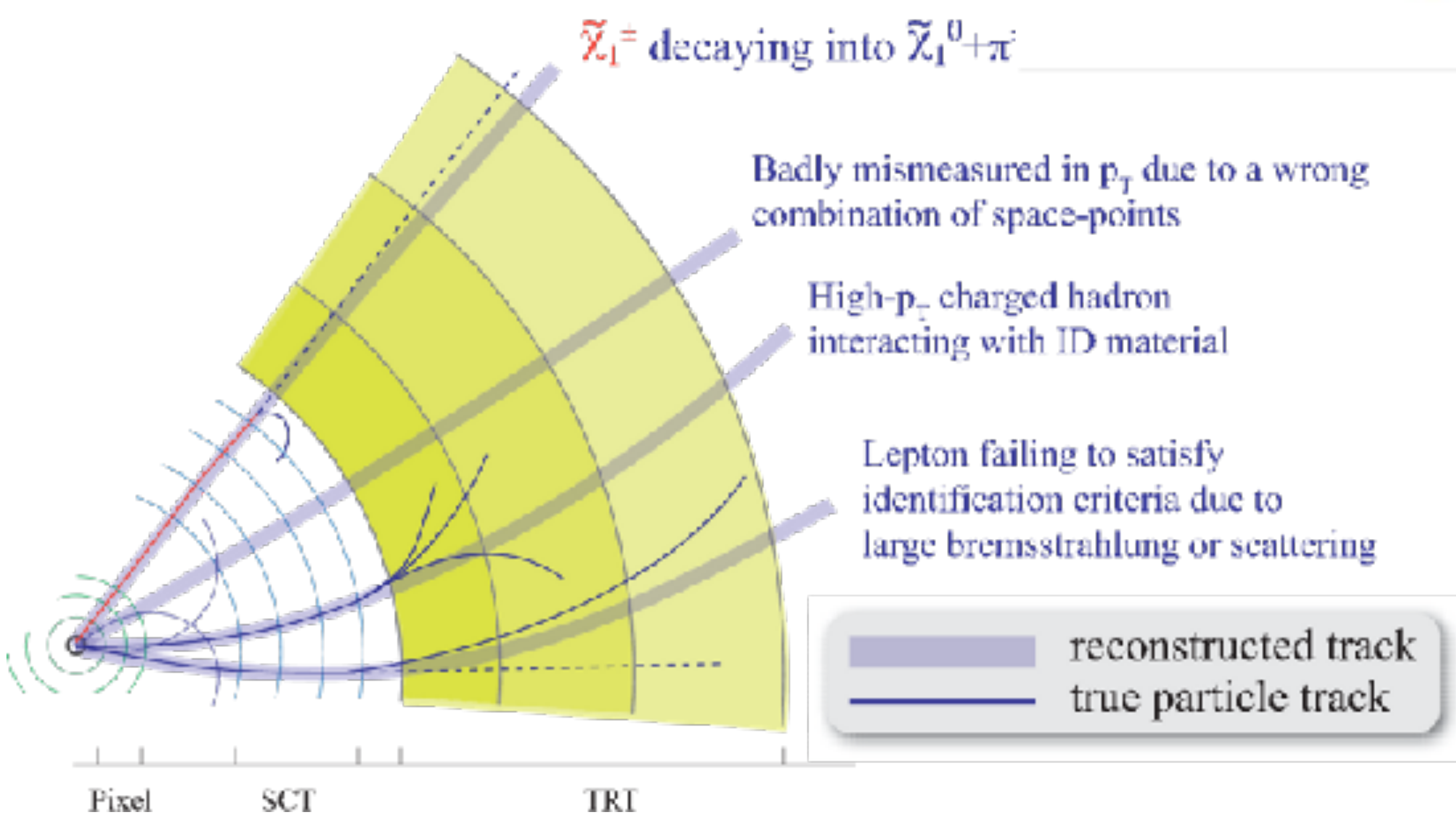
# ATLAS: DISAPPEARING TRACK SEARCH

| 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 |

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# ATLAS: DISAPPEARING TRACK SEARCH

| Selection requirement |
|---|
| ~~Quality requirements and trigger~~ |
| ~~Jet cleaning~~ |
| Lepton veto |
| Leading jet $p_T > 90$ GeV |
| $E_T^{miss} > 90$ GeV |
| $\Delta\phi_{min}^{jet\text{-}E_T^{miss}} > 1.5$ |
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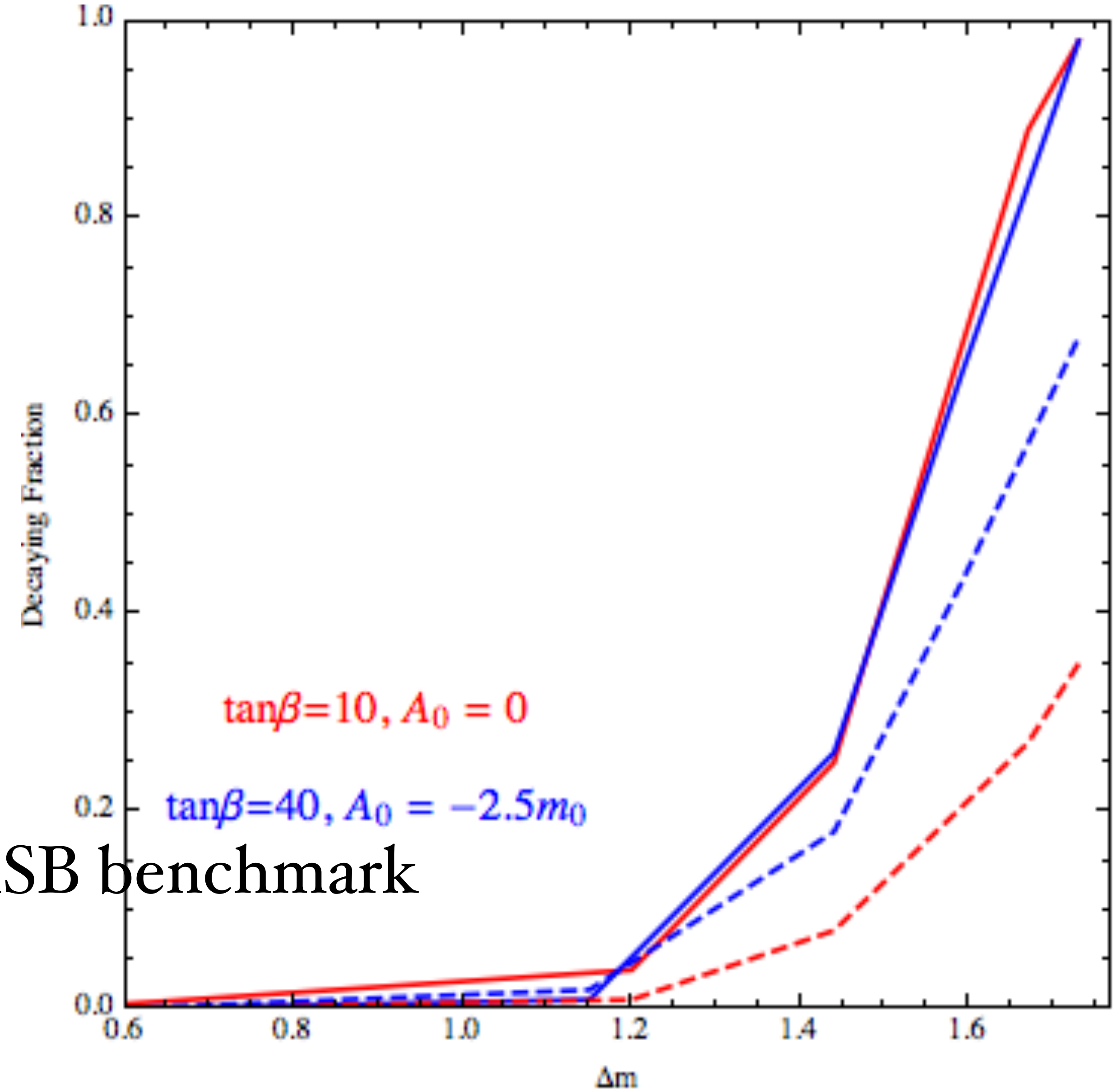
| Disappearing-track selection |




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 ($\sigma_{vis}^{95\%}$) at 95% CL.

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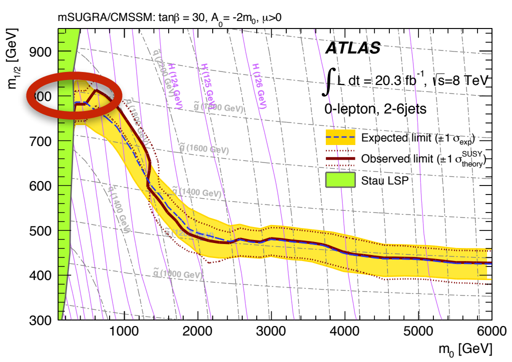
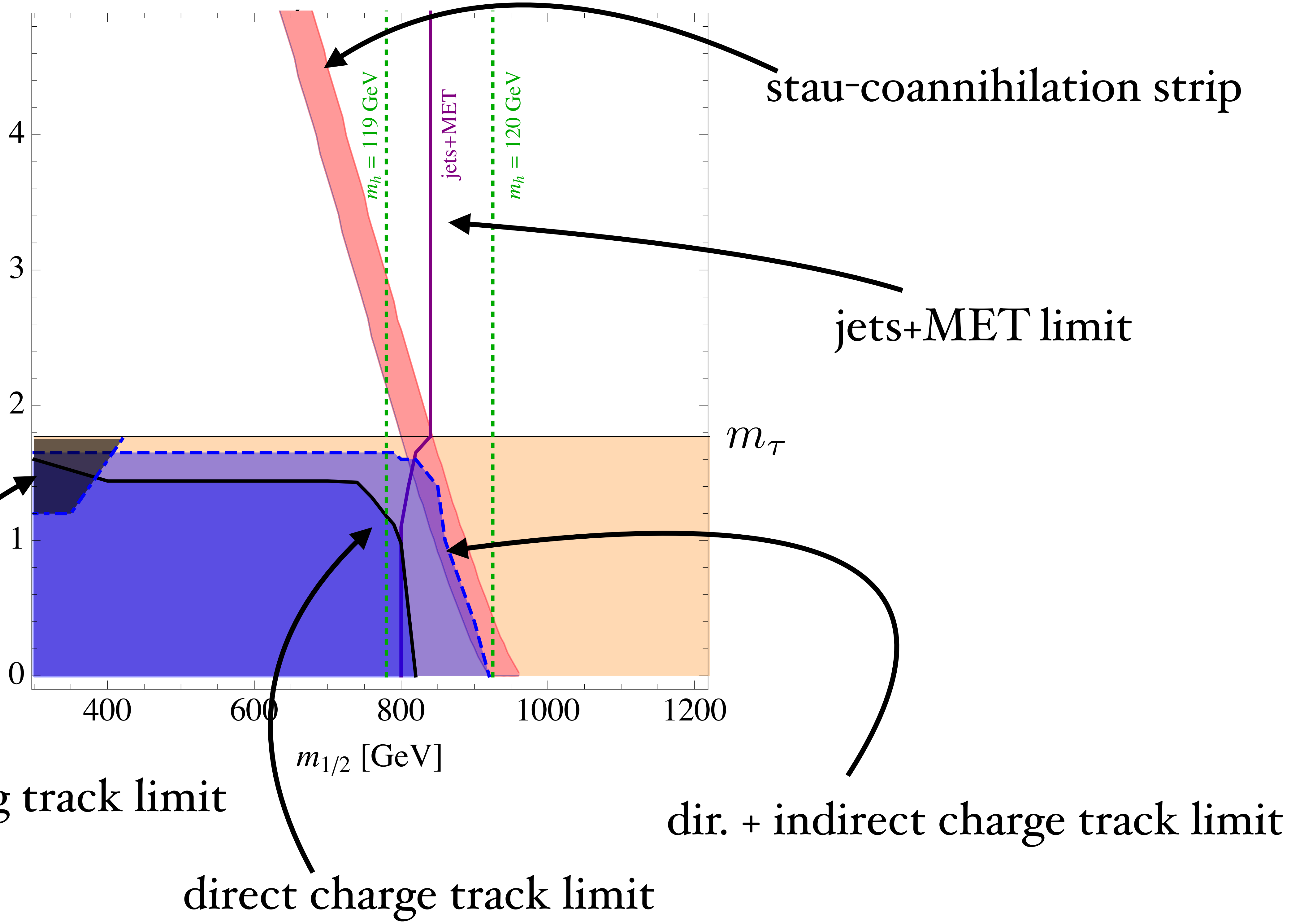
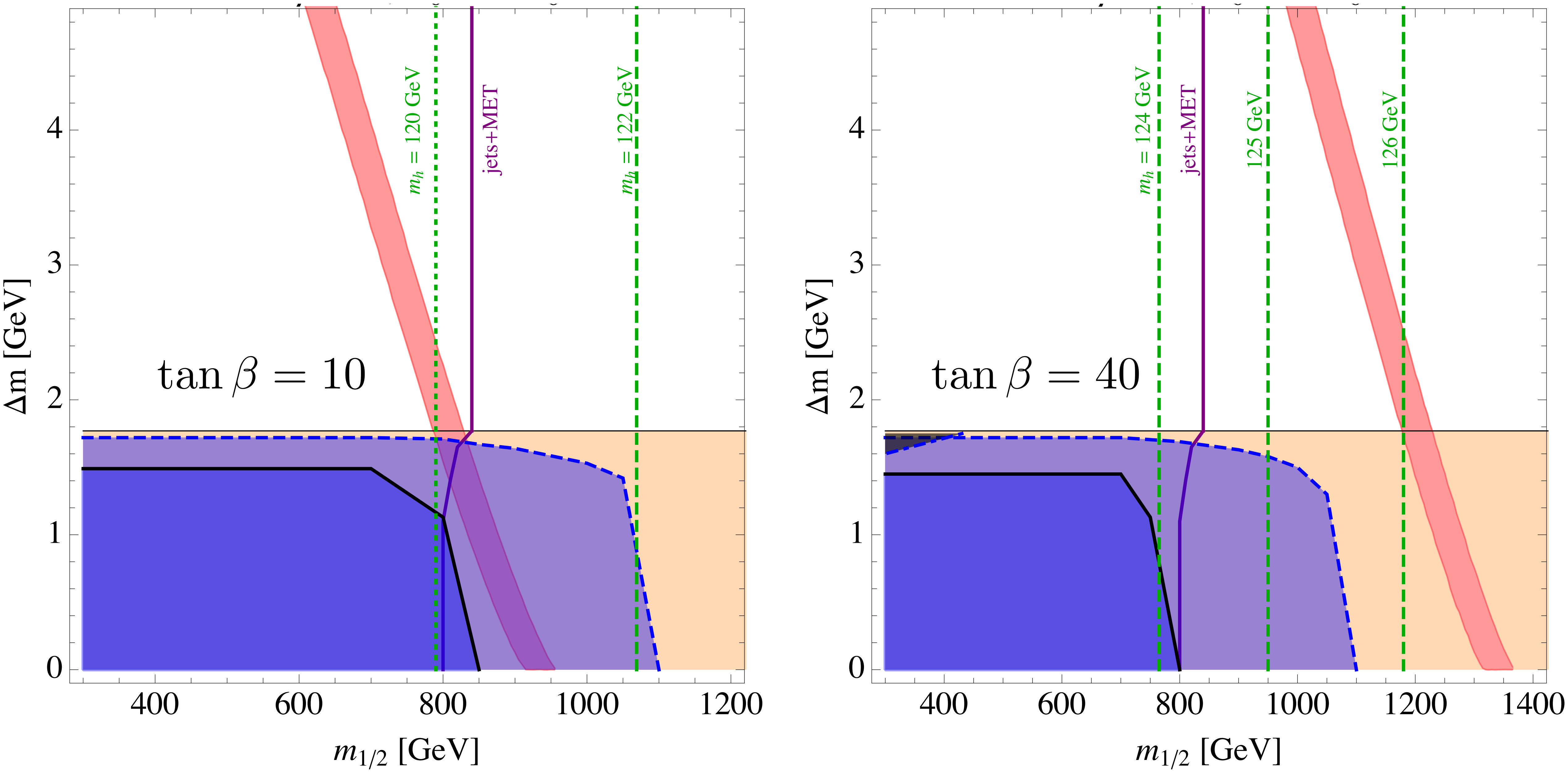
# COMBINATION OF ALL LIMITS



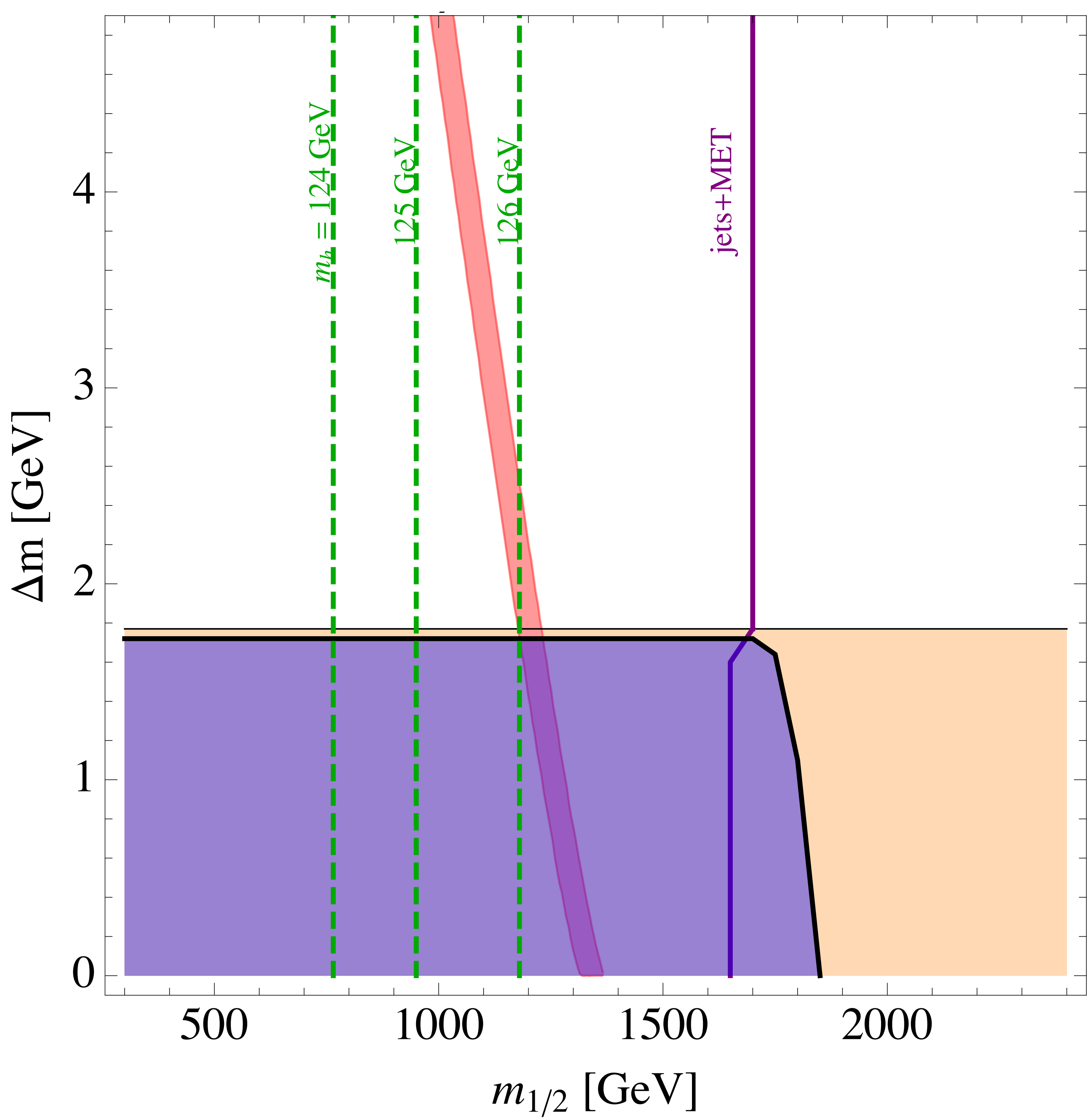



# RESULTS:

$$A_0 = -2.5m_0$$



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




**Conclusion:**

**Stau-coannihilation strip can be completely ruled out with 75/fb data.**

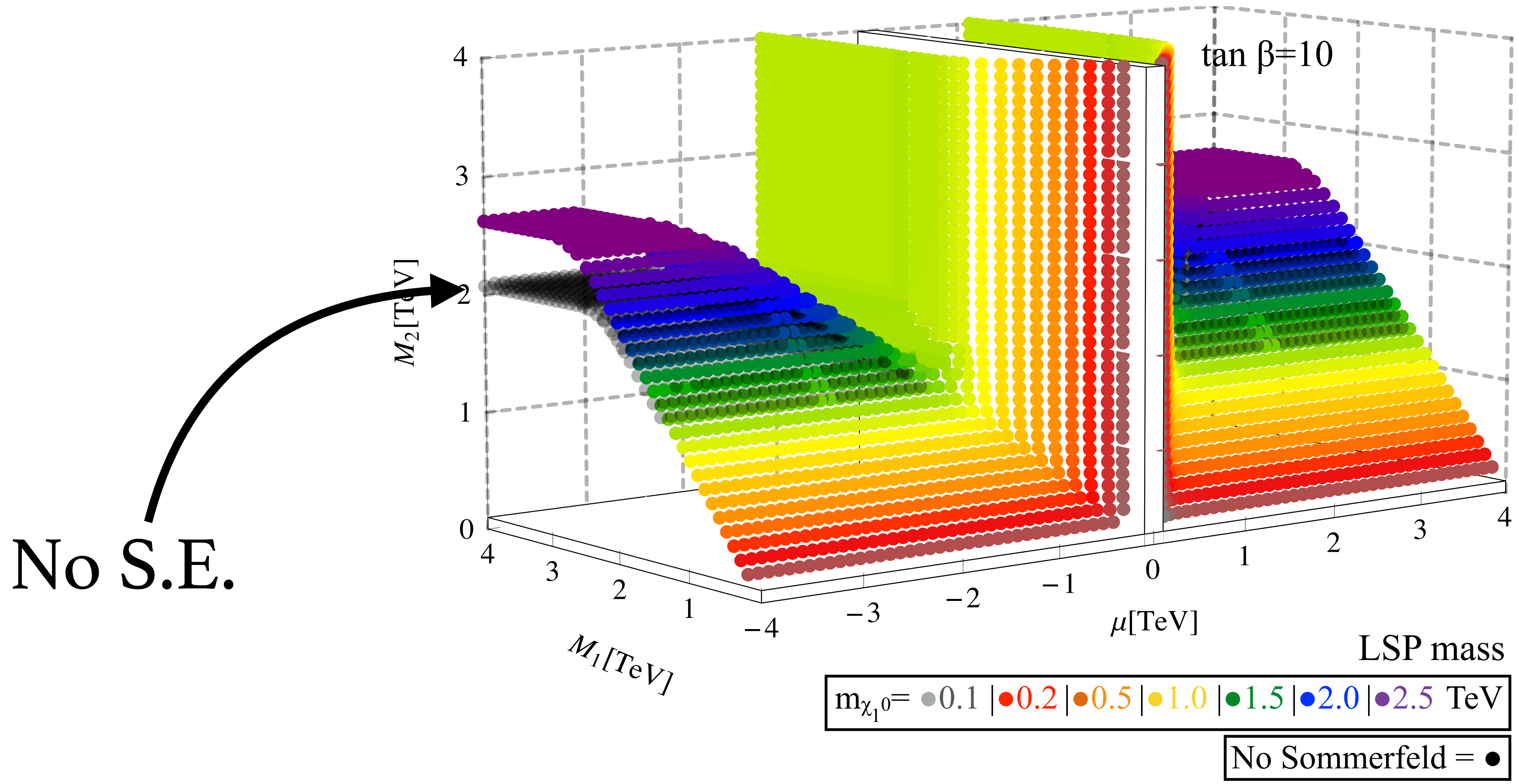
# PART III: FUTURE OF SUSY DM

# RELIC SURFACE WITH SE

$M_1$, $M_2$, $\mu$, and $\tan\beta$

Bino Wino Higgsino

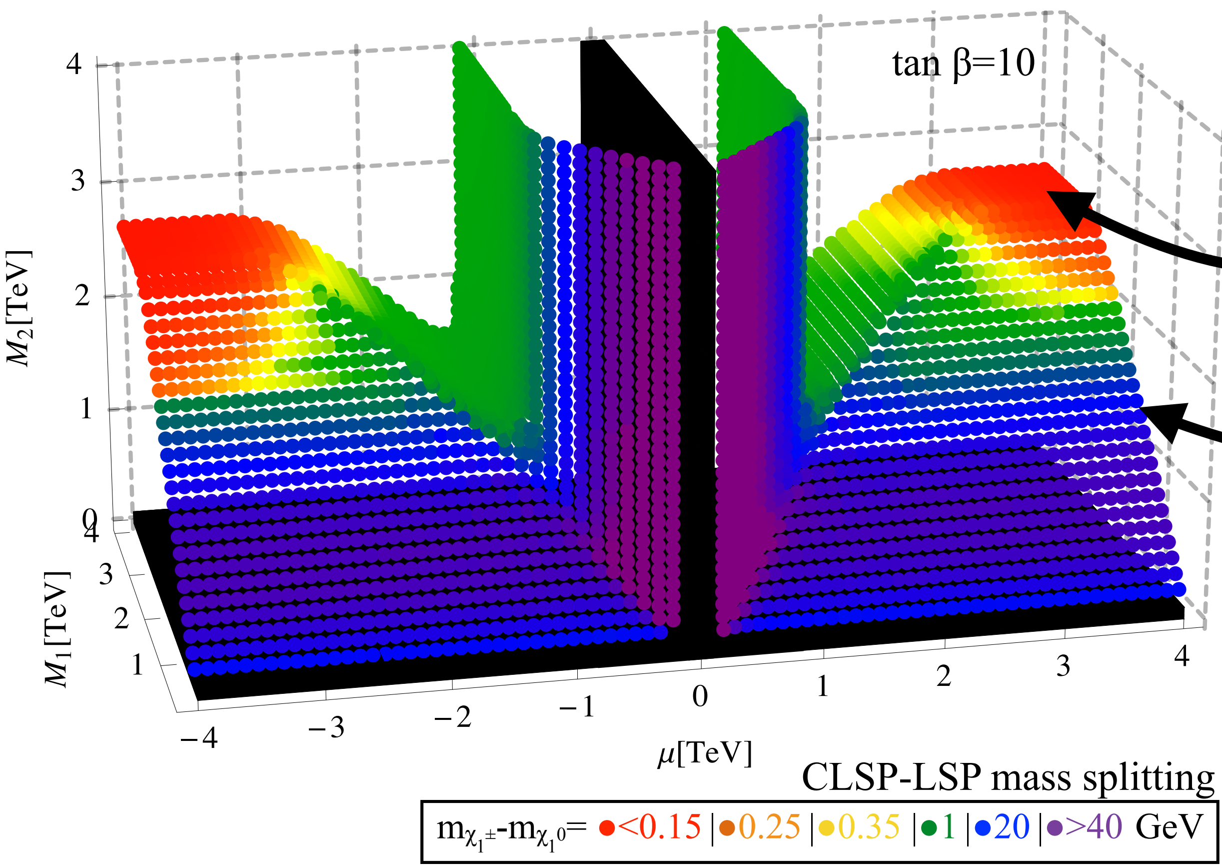
$$\Omega h^2 = 0.120 \pm 0.005$$




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

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

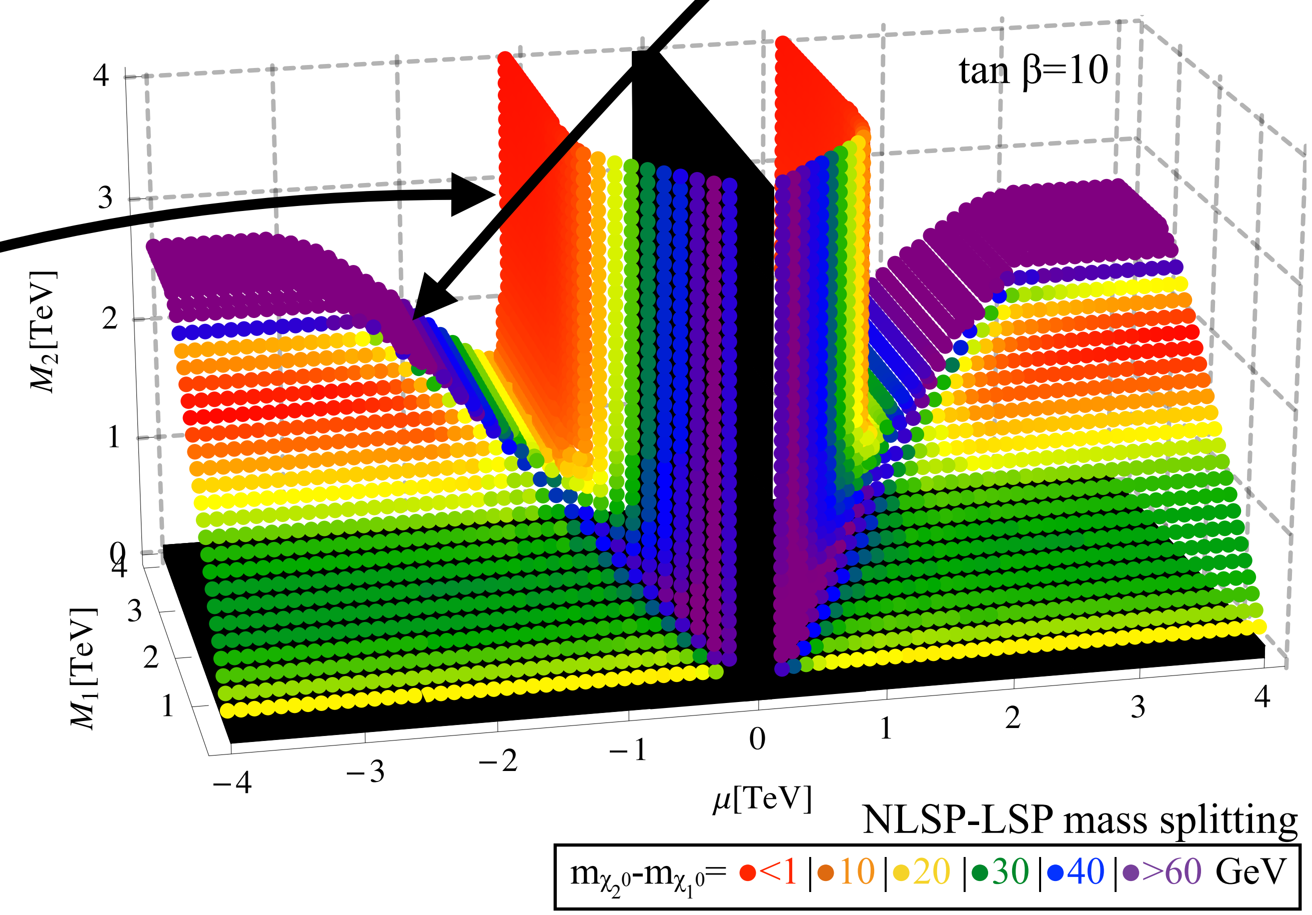
# MASS SPLITTING




pure Wino => co-annihilation with chargino

Bino-Winos

Wino-Higgsinos



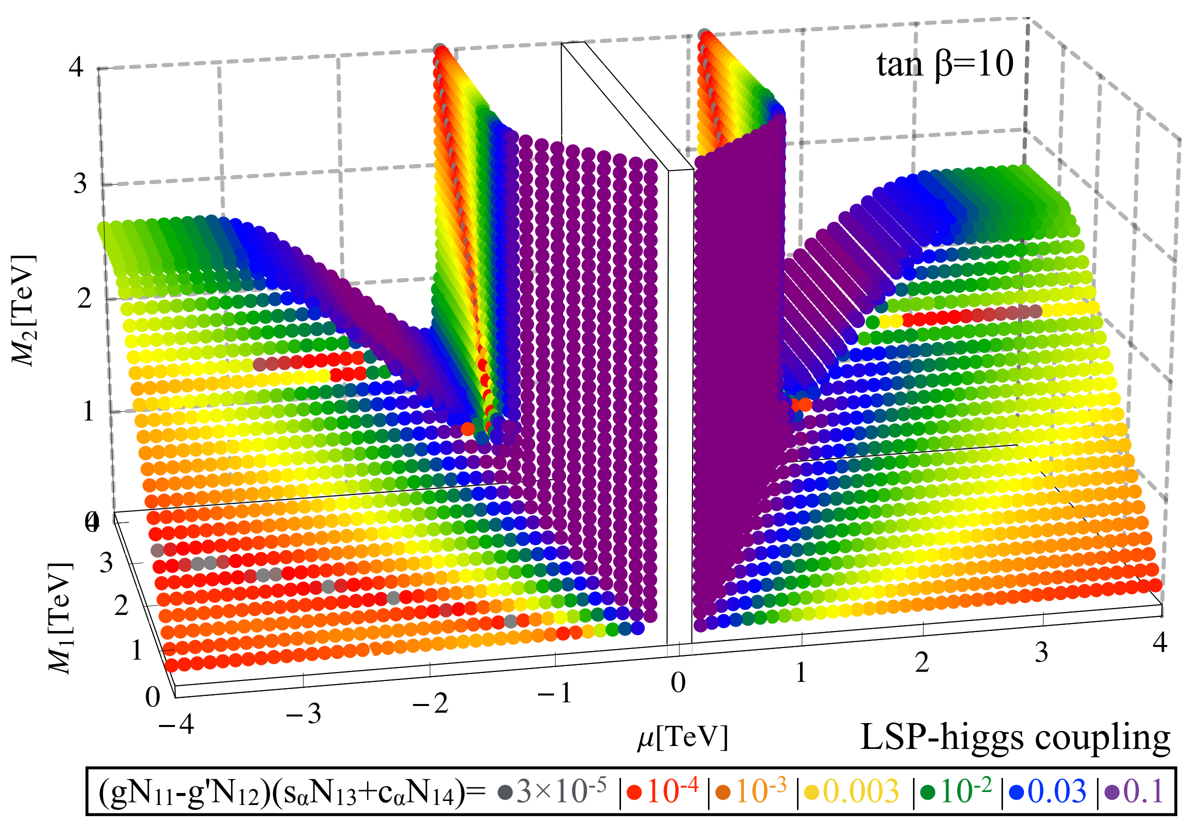

pure Higgsinos => co-annihilation with second neutralino + chargino

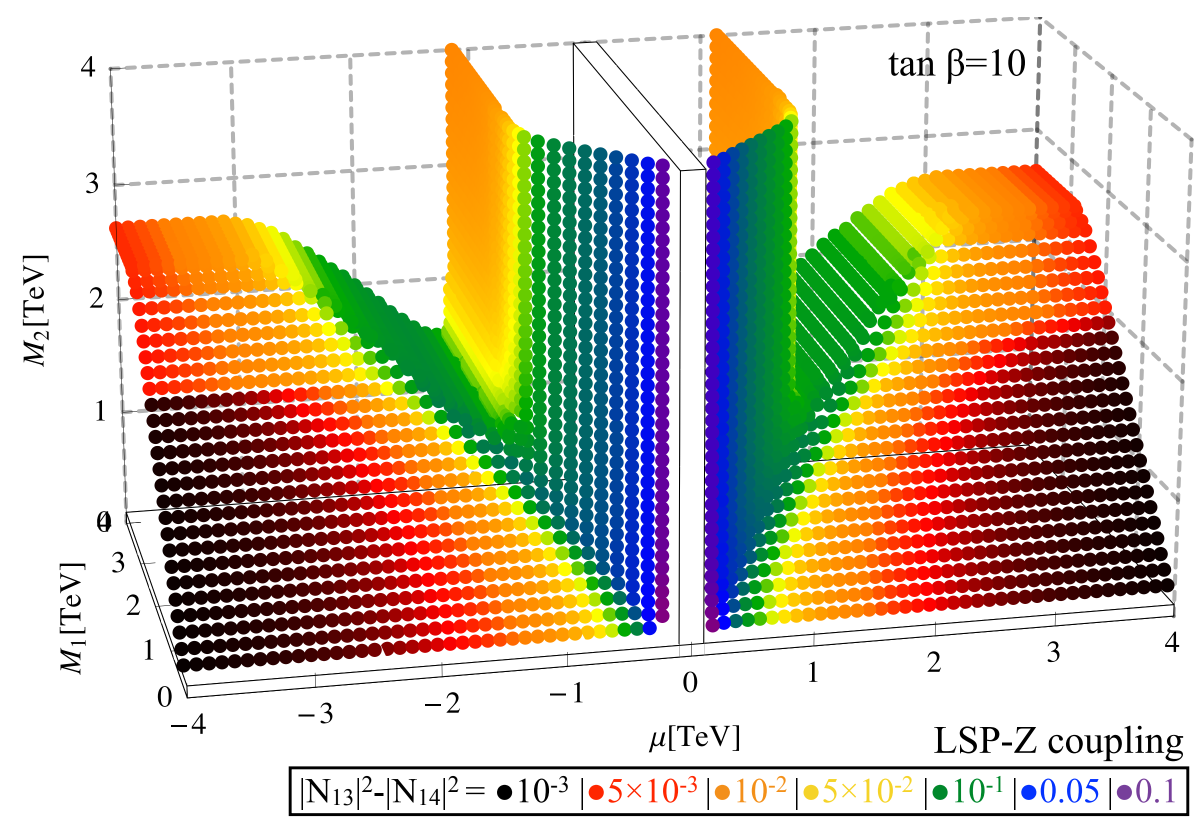
# COUPLINGS

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

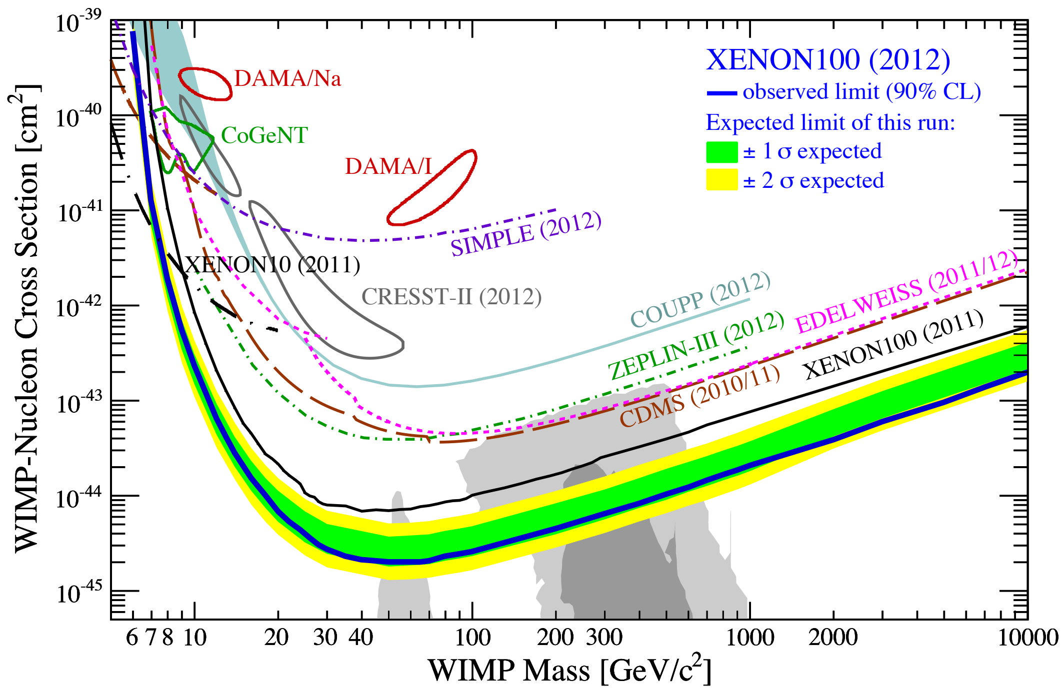
$$g_{h\tilde{\chi}_1^0\tilde{\chi}_1^0} = \left(gN_{11} - g'N_{12}\right) \left(\sin\alpha \; N_{13} + \cos\alpha \; N_{14}\right)$$

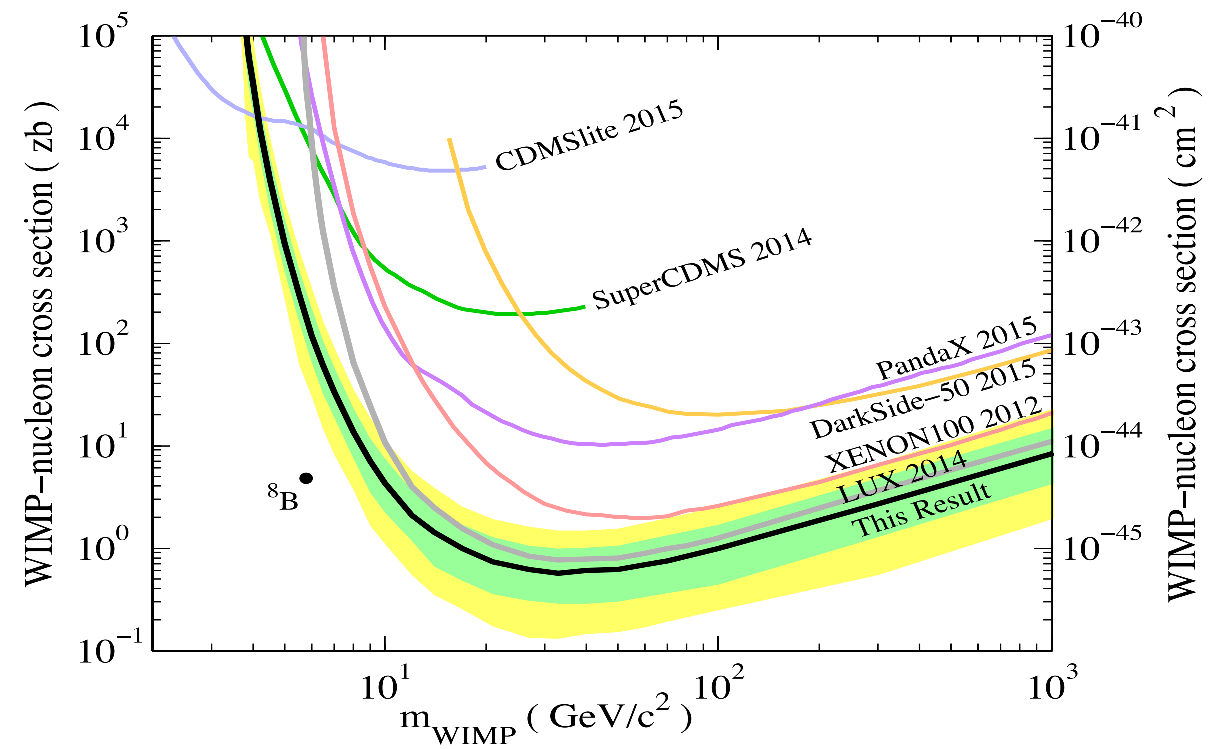
$$g_{W\tilde{\chi}_1^0\tilde{\chi}_1^+} = \frac{g\sin\theta_w}{\sqrt{2}\cos\theta_w} \left(N_{14}V_{12}^* - \sqrt{2}N_{12}V_{11}^*\right) \; ,$$

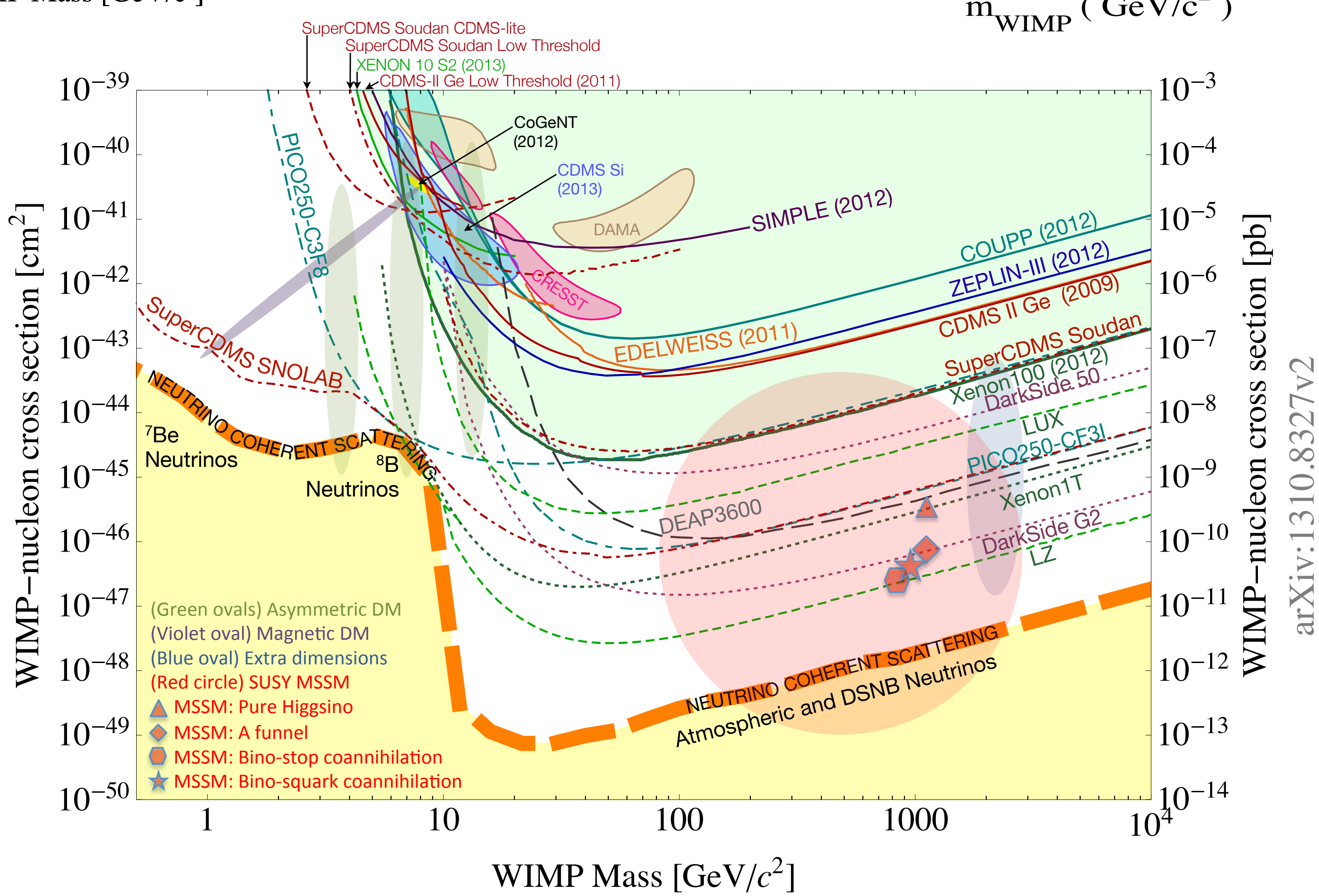


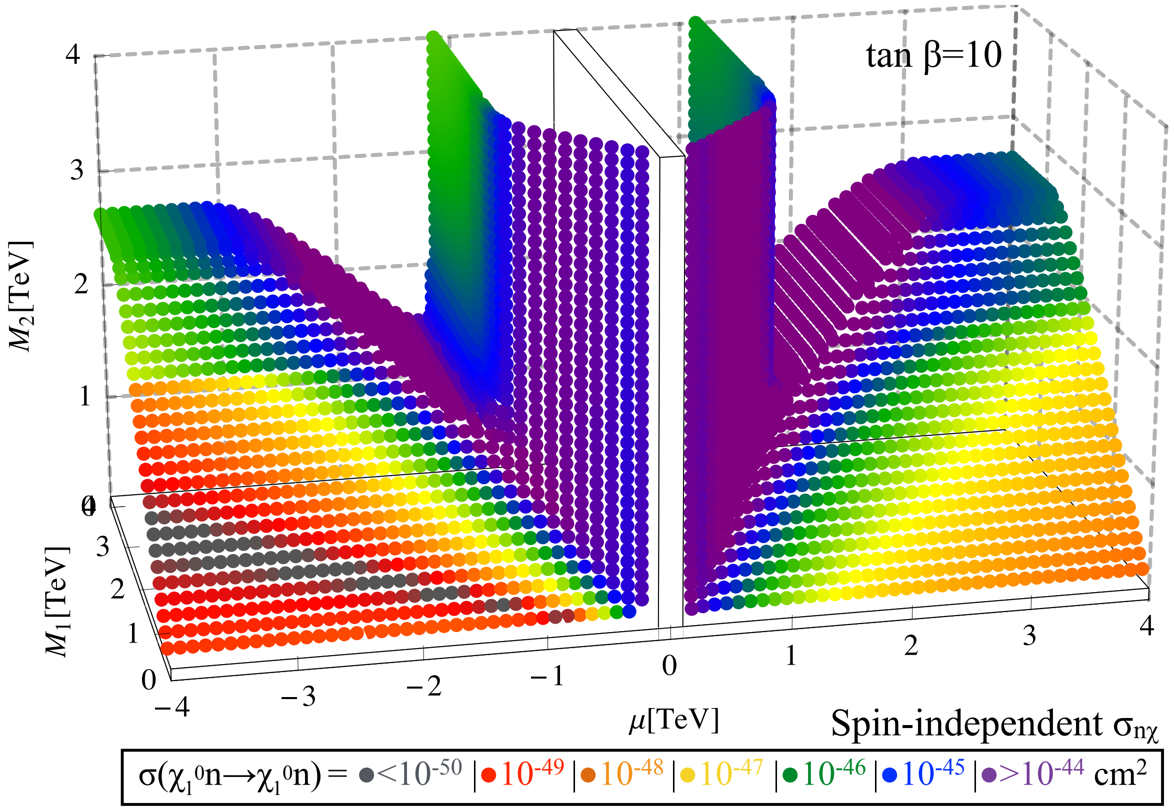
# SI DIRECT DETECTION LIMITS

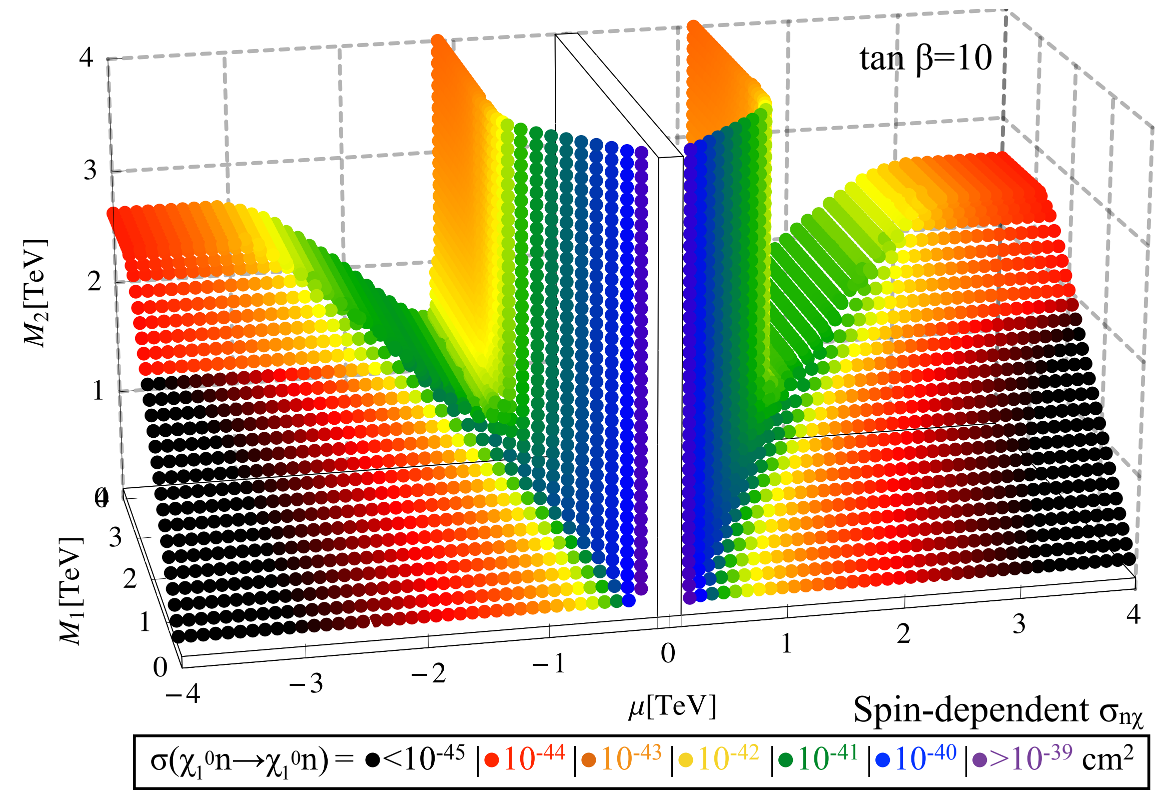


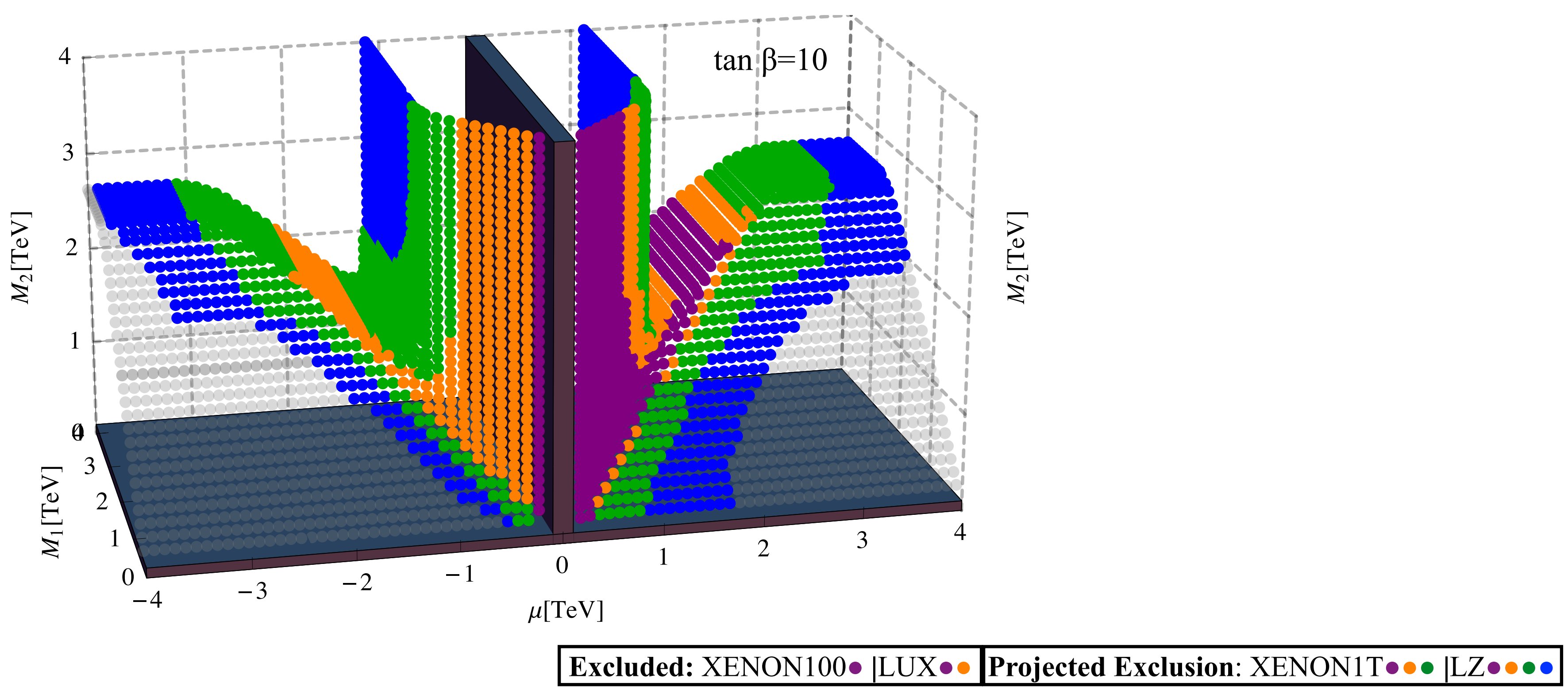



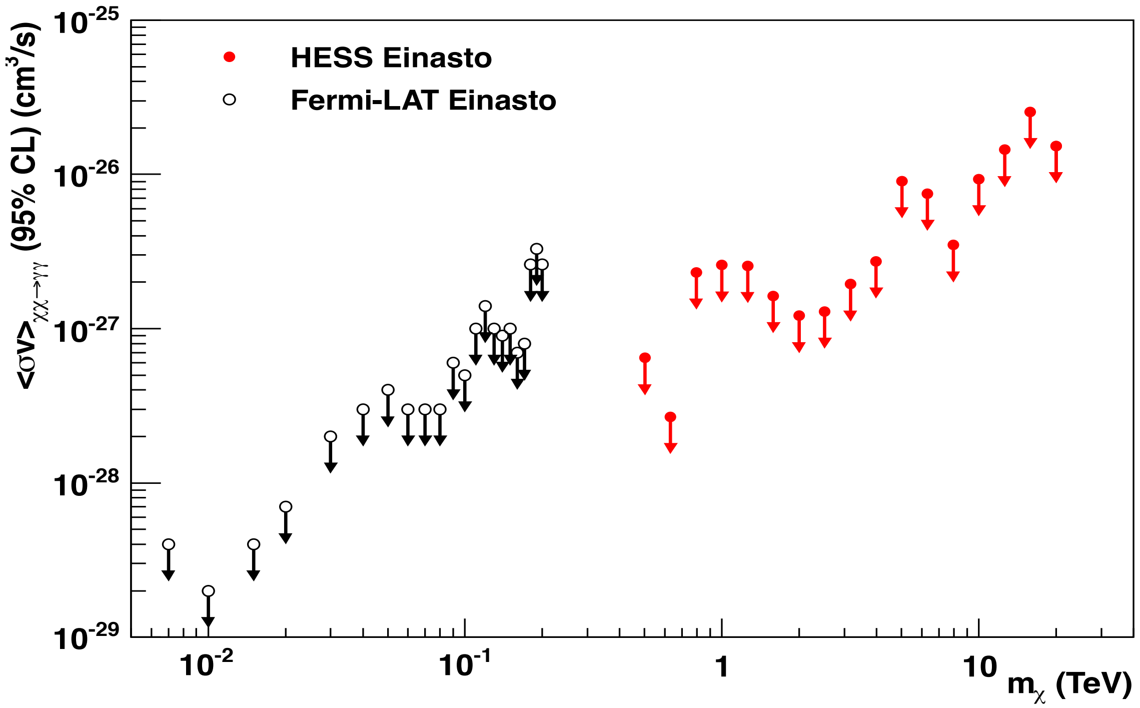
# DIRECT DETECTION

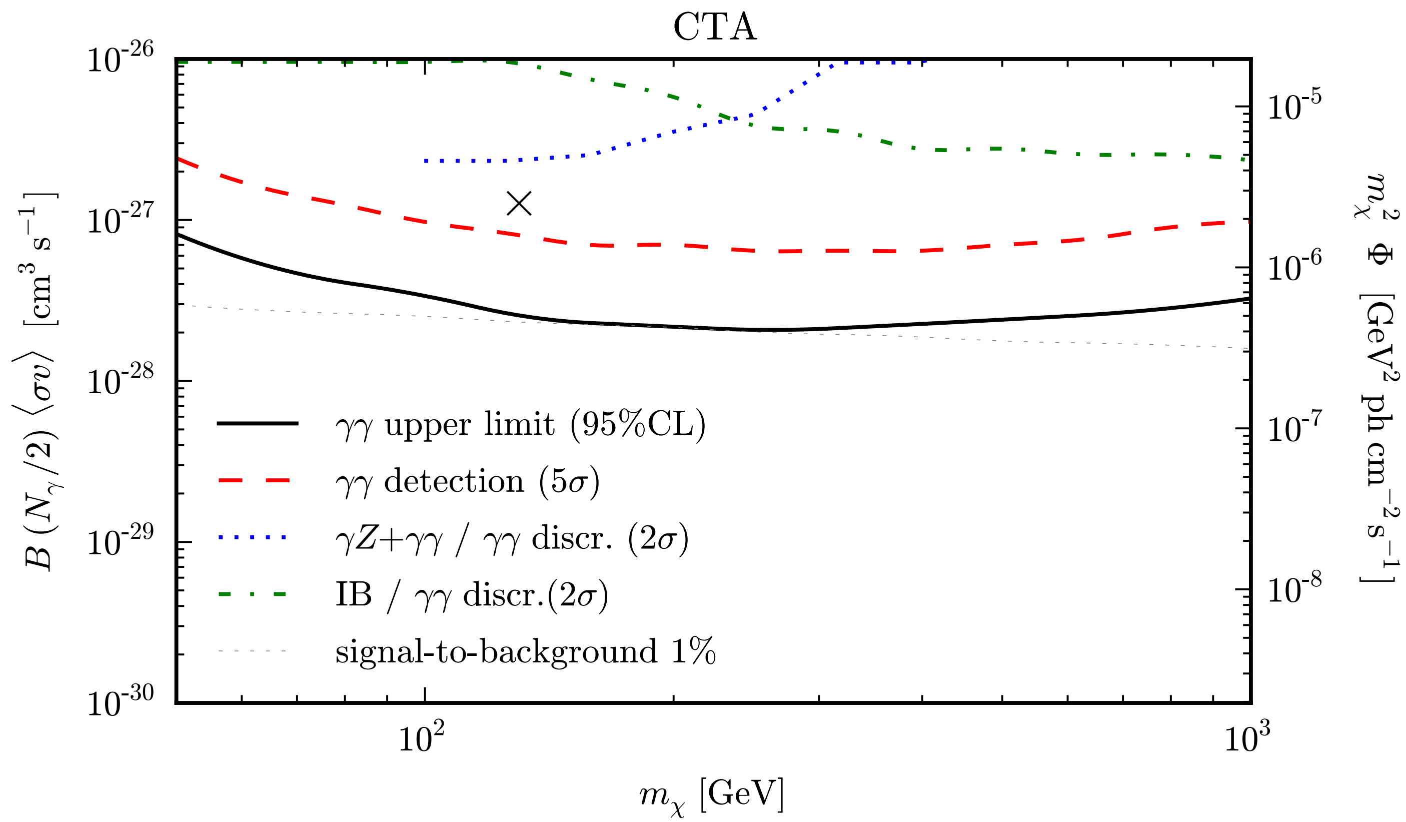


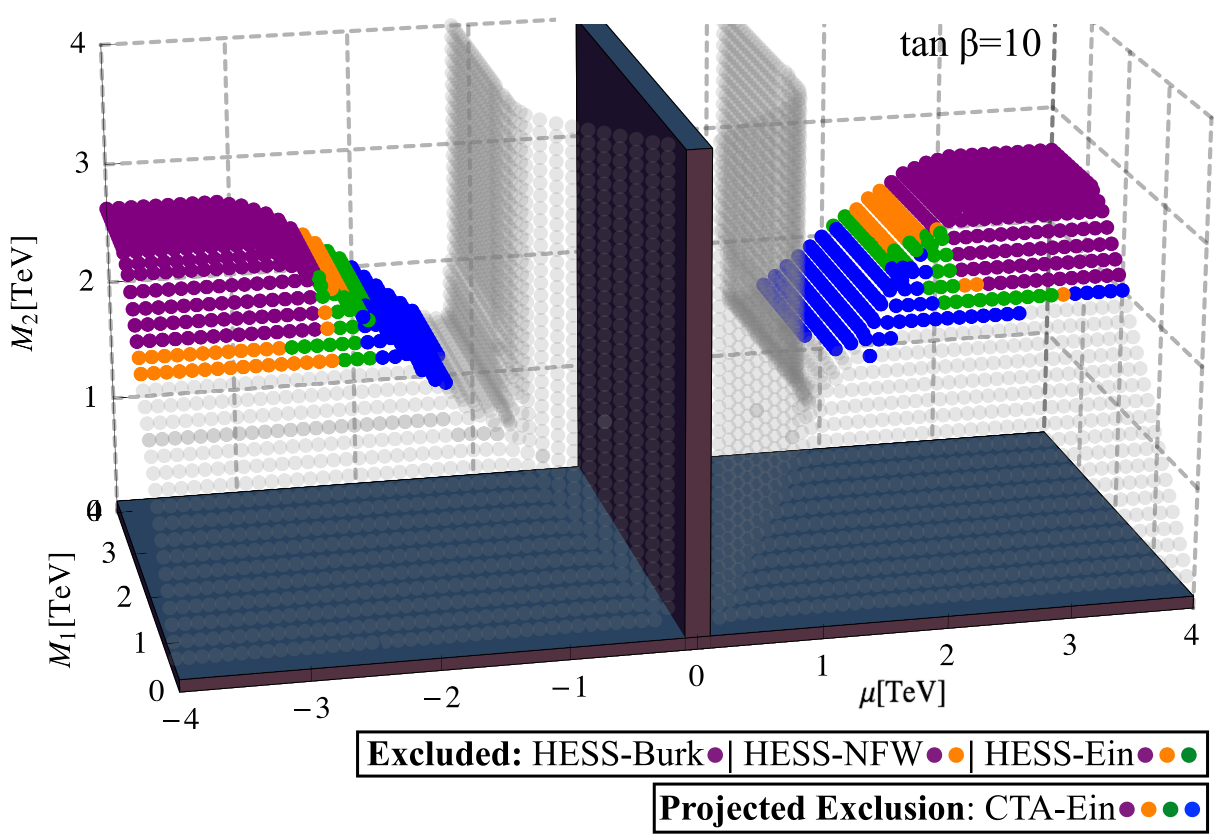



# ANNIHILATION INTO PHOTONS



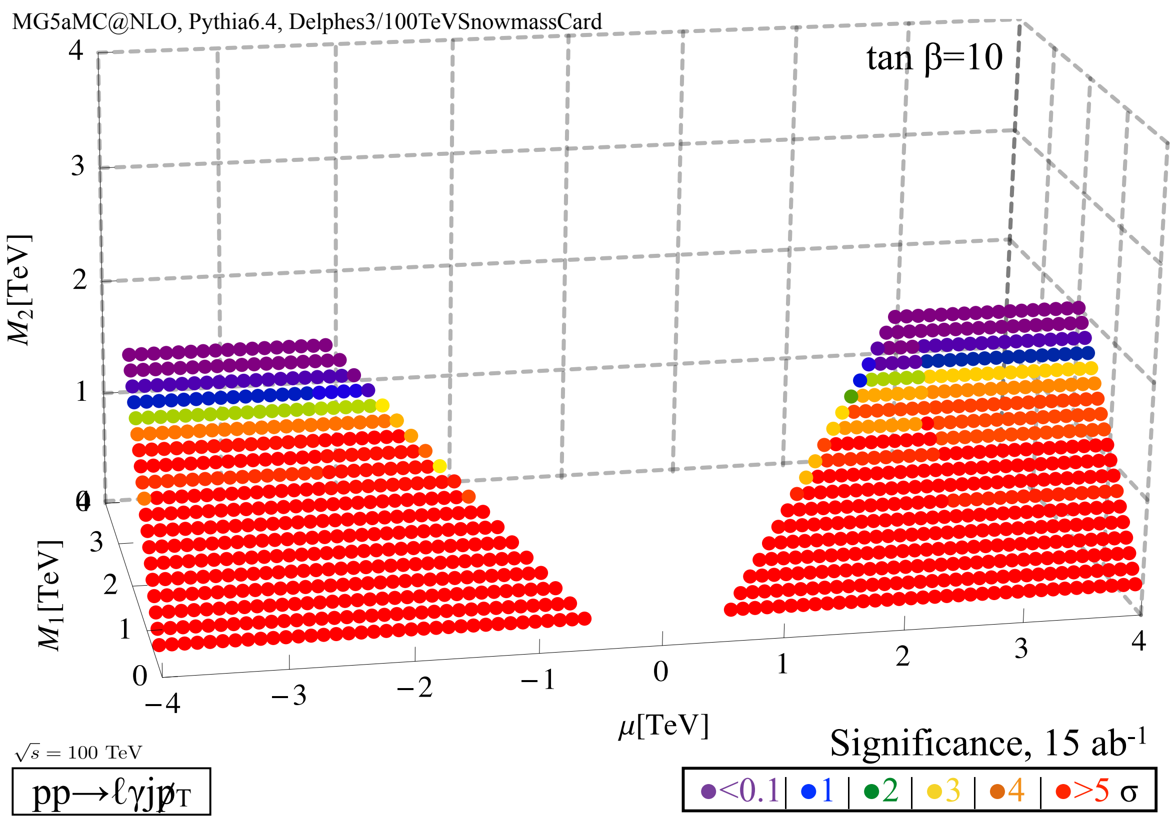



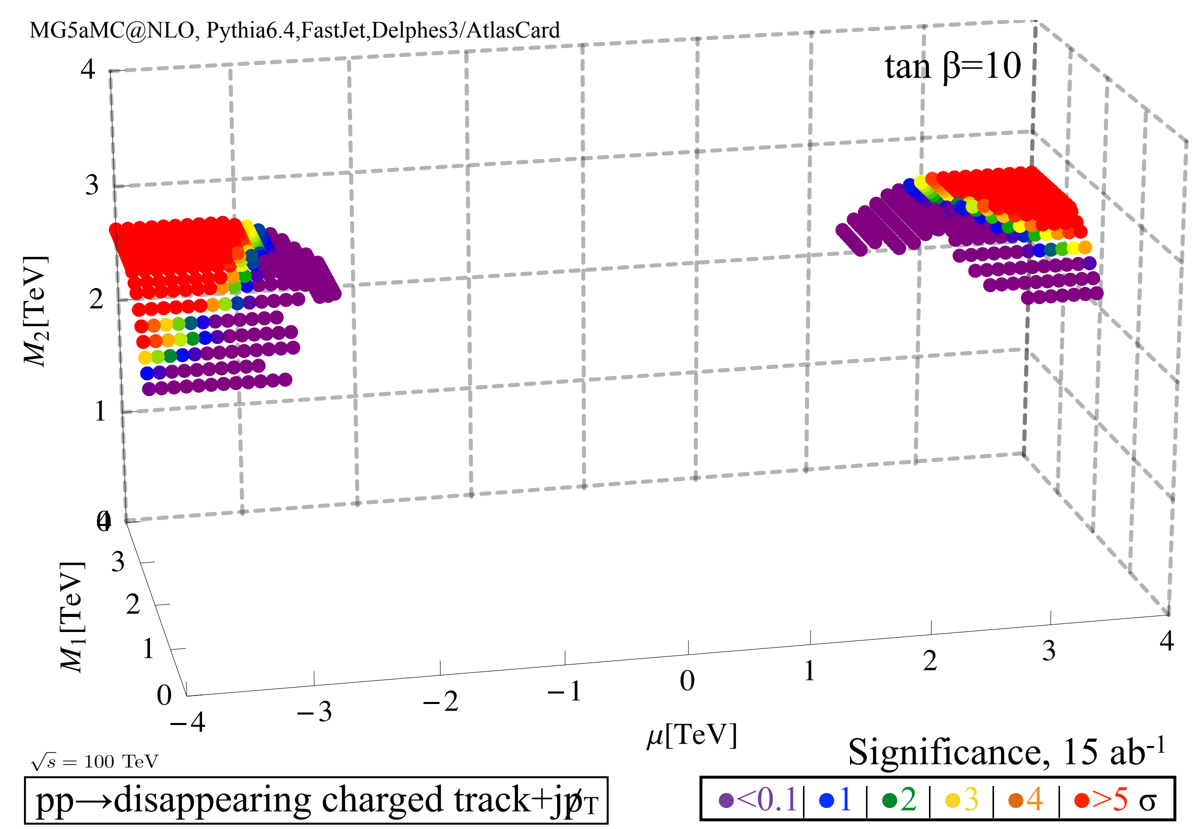

arXiv:1207.6773



# (POTENTIAL) COLLIDER SEARCHES

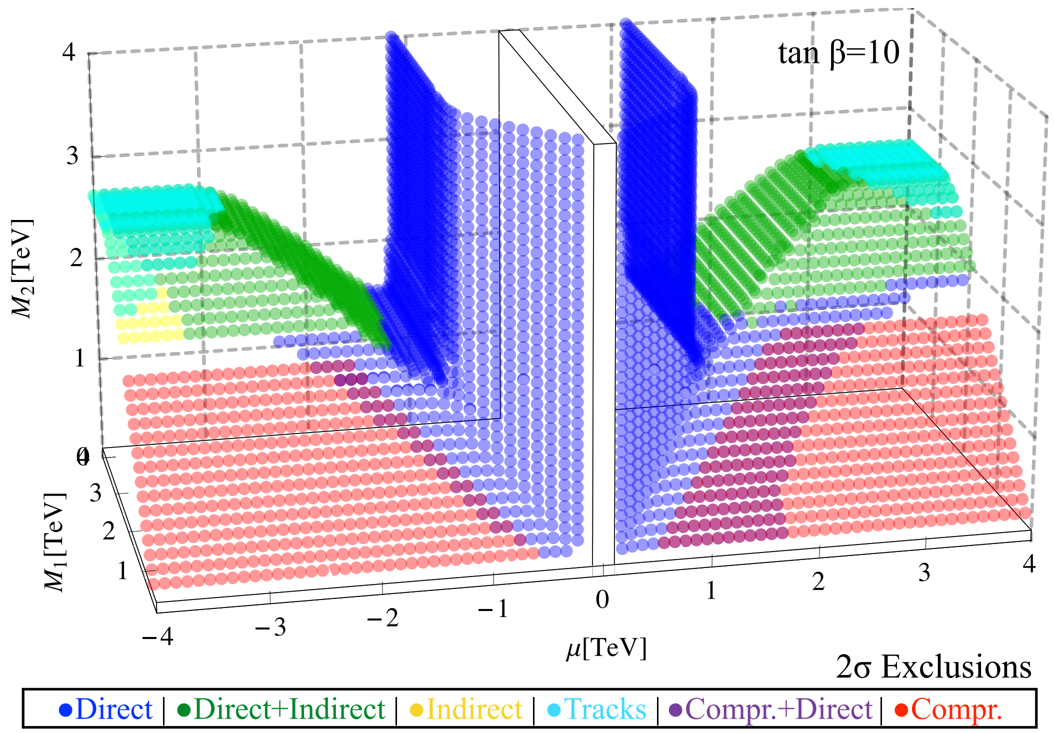
$$pp \to (\tilde{\chi}_2^0 \to \gamma \tilde{\chi}_1^0)\ (\tilde{\chi}_1^\pm \to \ell^\pm \nu_\ell \tilde{\chi}_1^0) j \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 \ell^\pm \nu_\ell \gamma j\ ,$$




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

# 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!**