FERMION PORTAL DARK MATTER

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UC Davis Theory Seminar

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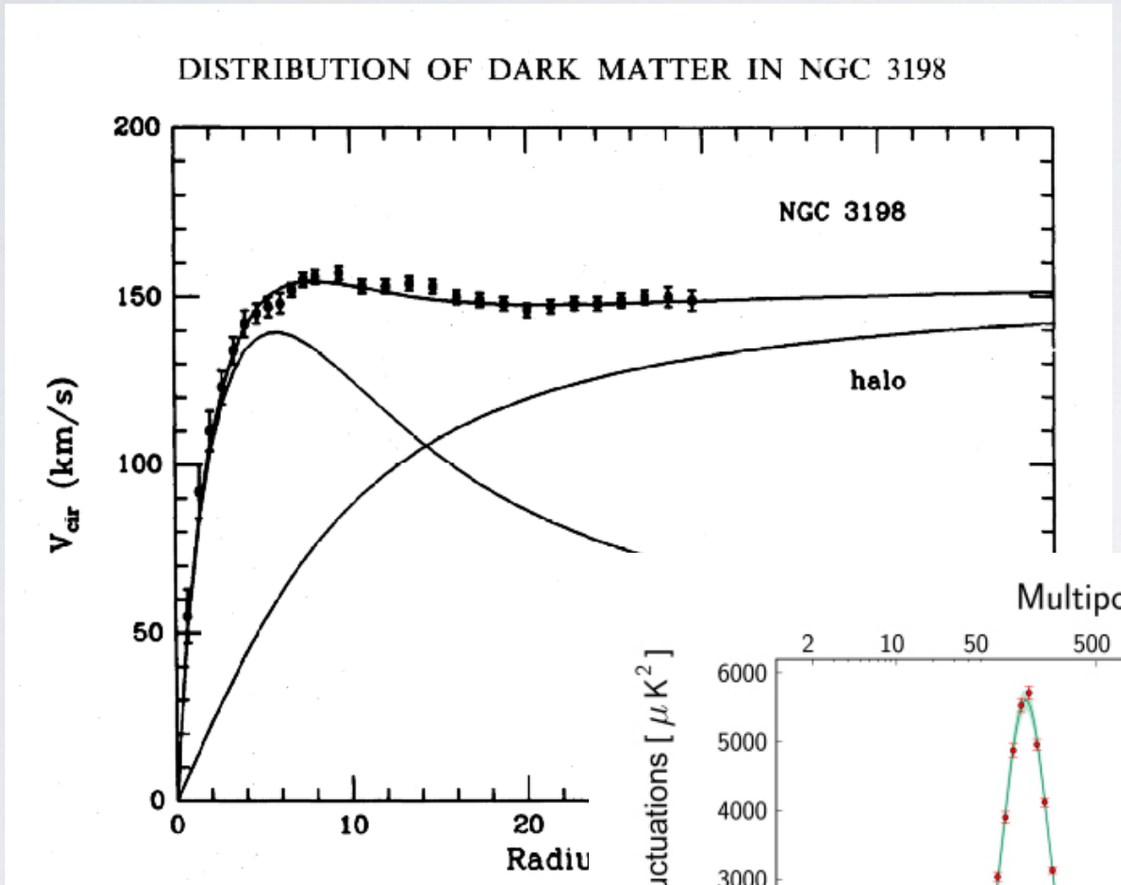
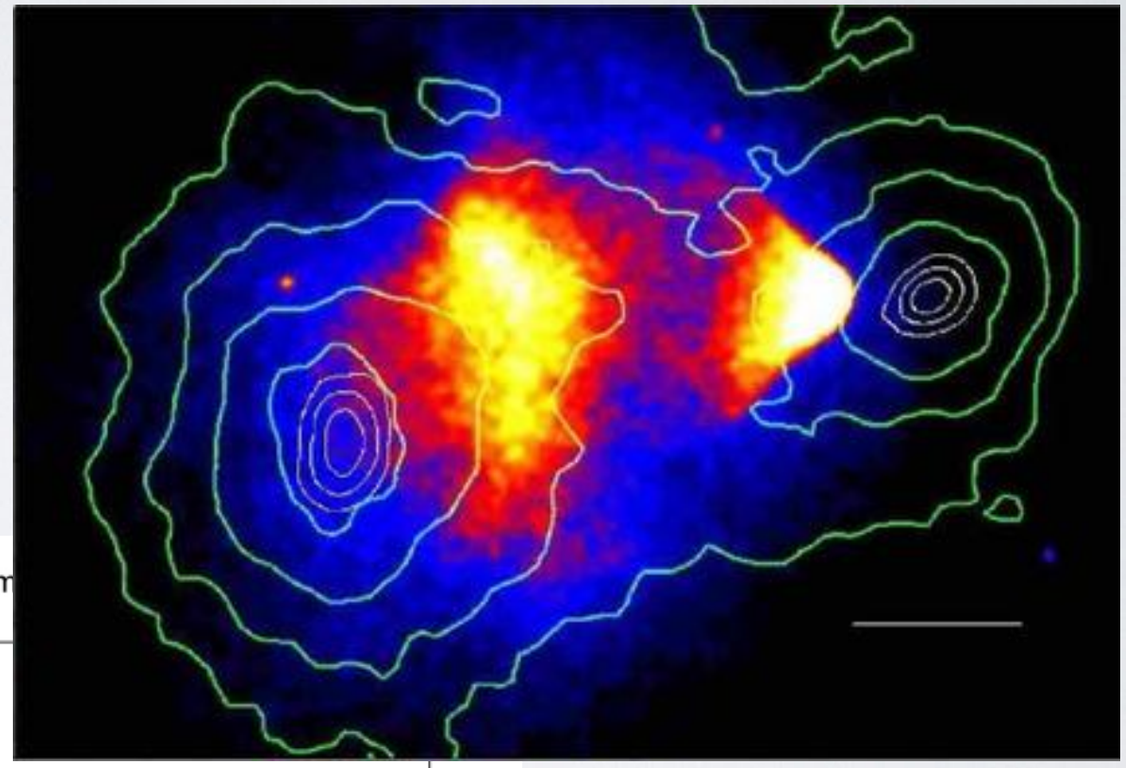
March 10, 2014

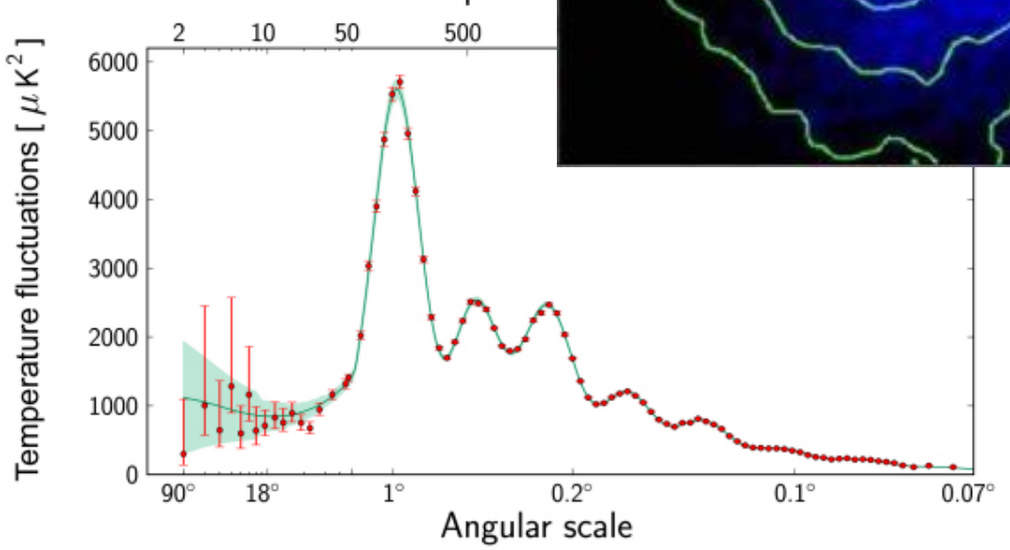
A HOLE IN THE SM



Van Albada et. al.



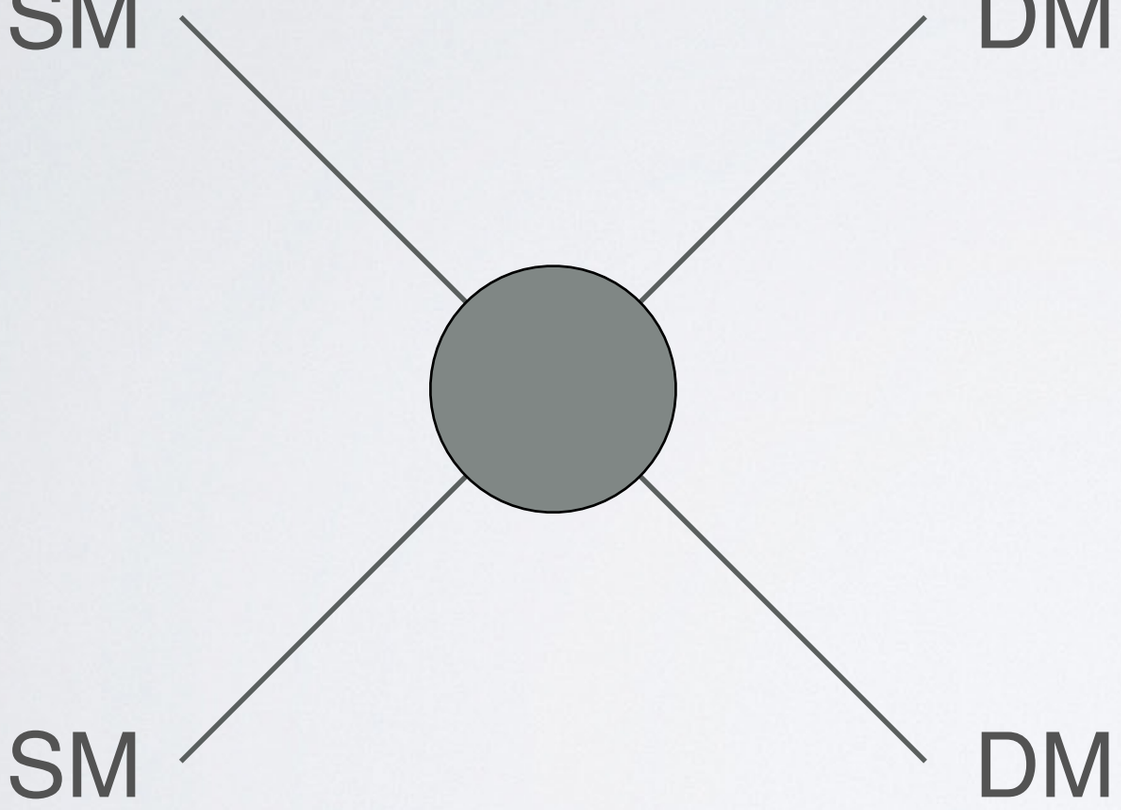
Chandra + Hubble

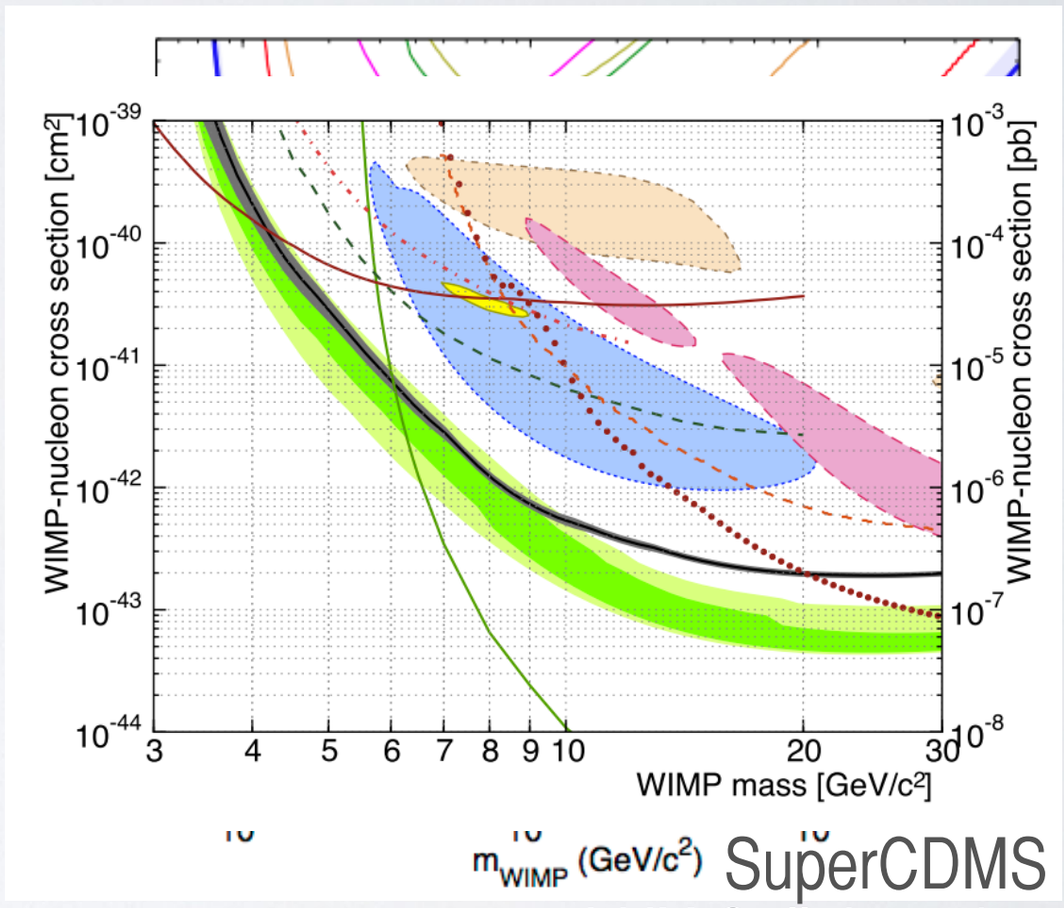


Planck Collaboration

- What else can we learn about Dark Matter?

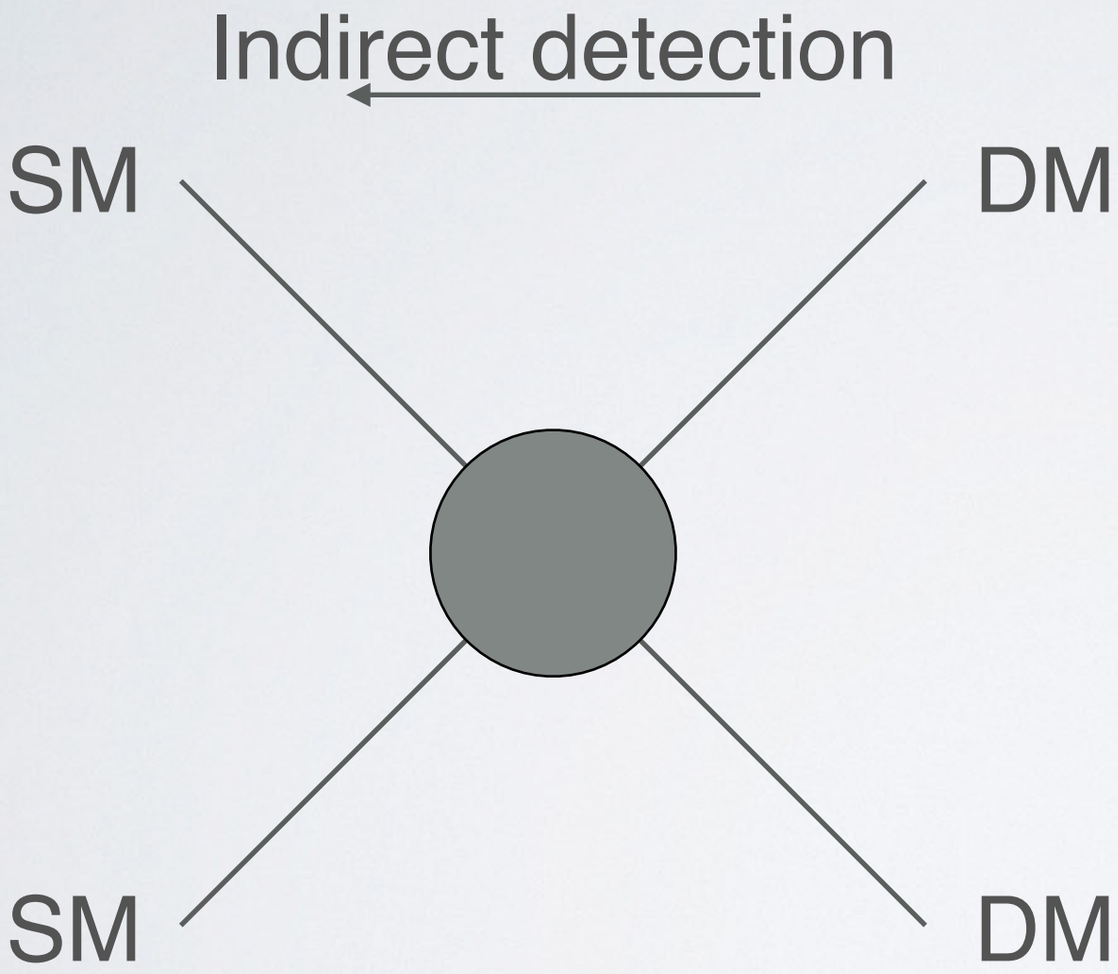
THE SEARCH IS ON

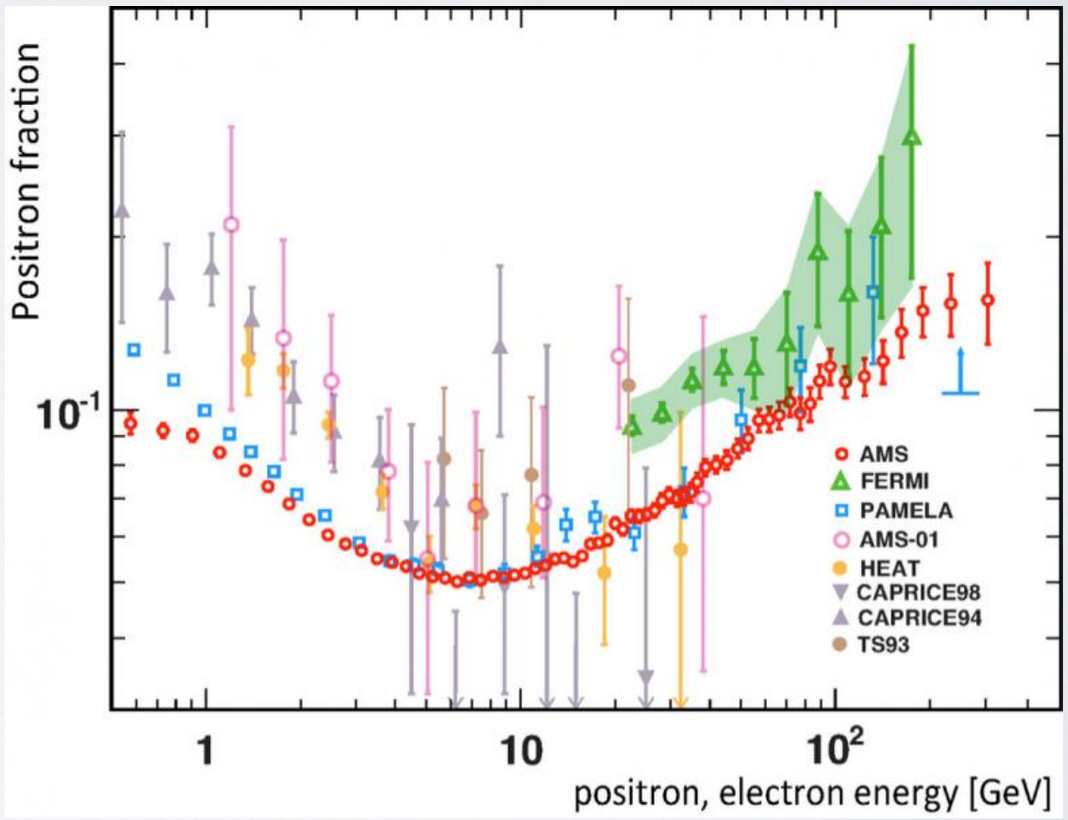




SuperCDMS
LUX Collaboration

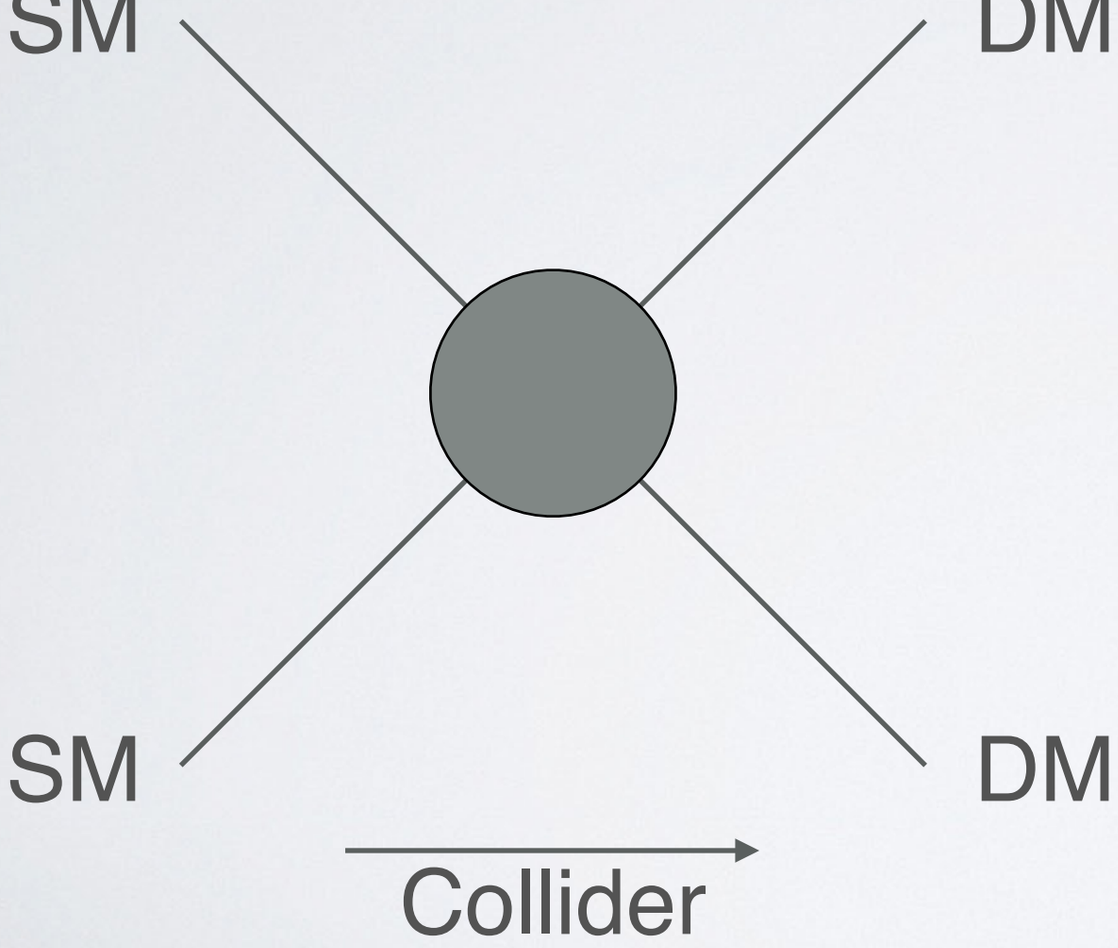
THE SEARCH IS ON

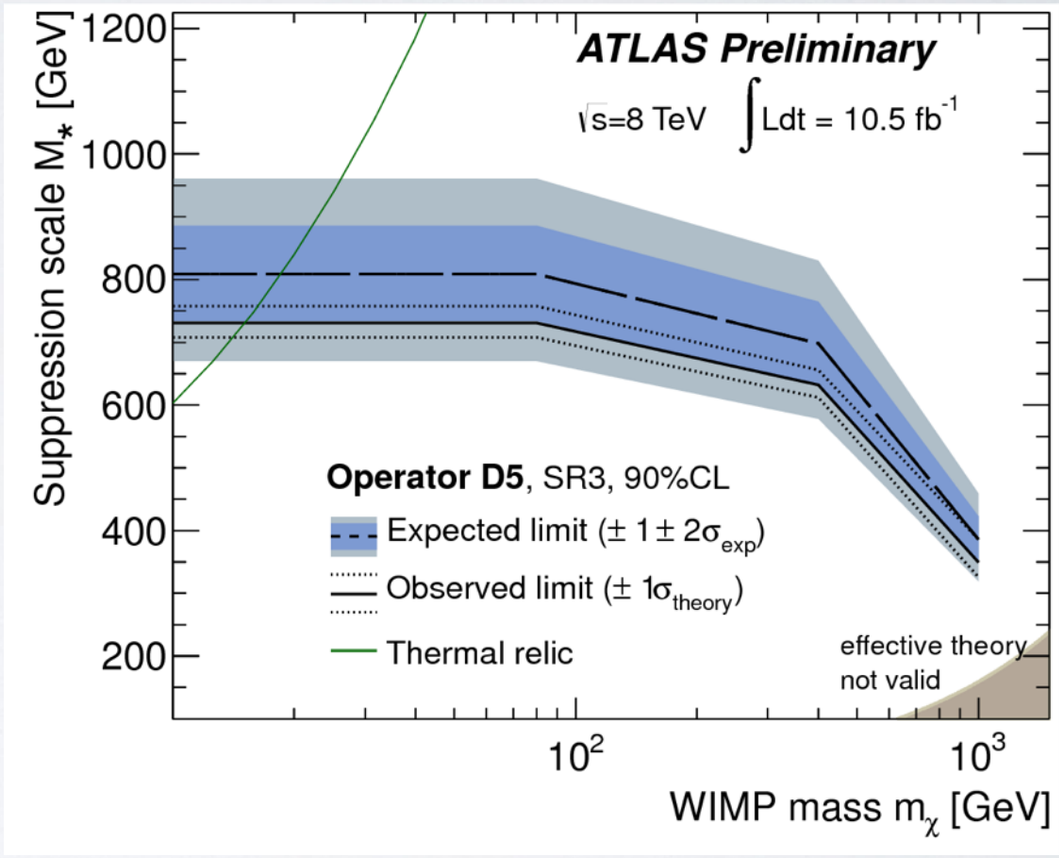




AMS-02 Collaboration

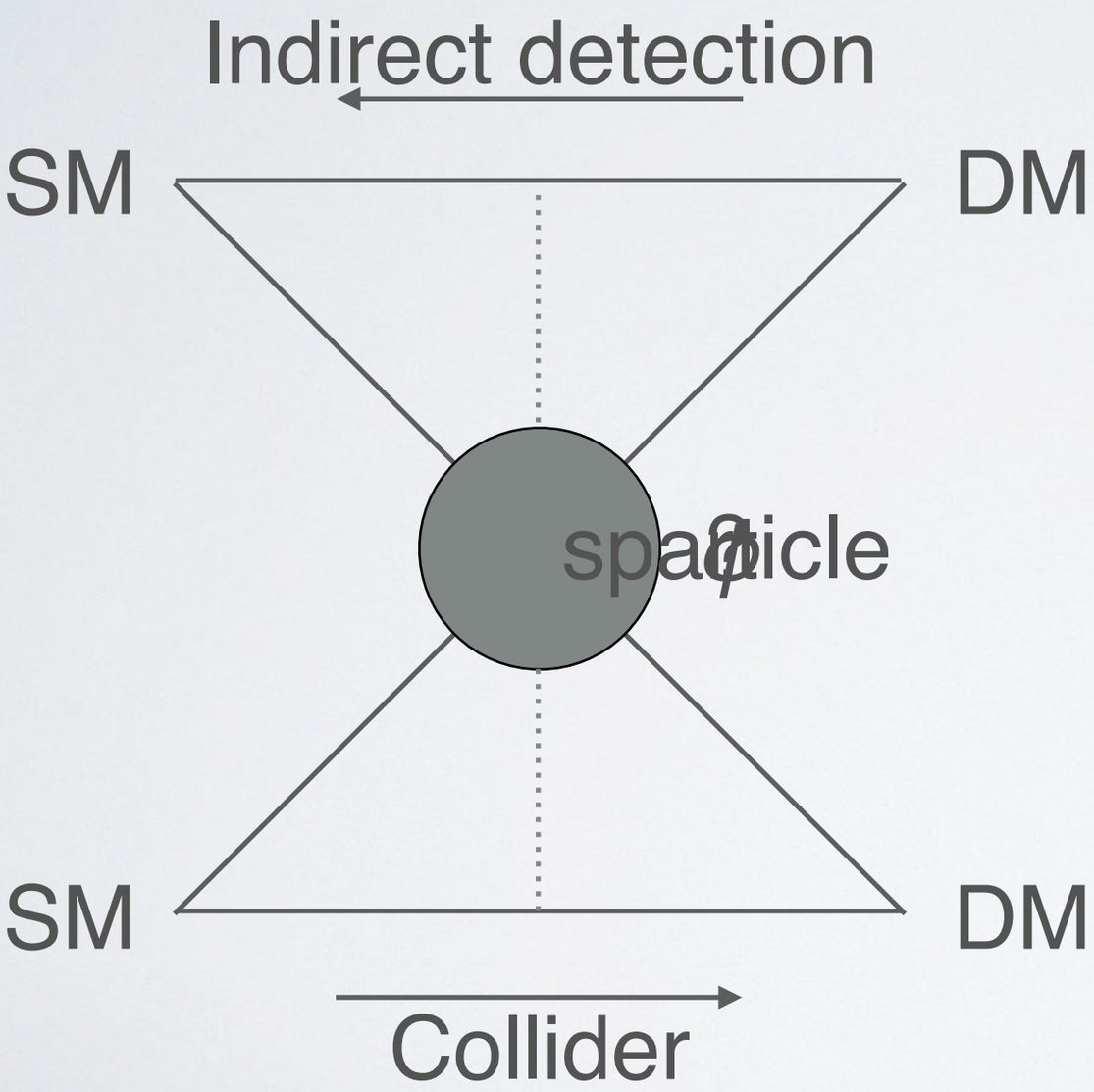
THE SEARCH IS ON





ATLAS Collaboration

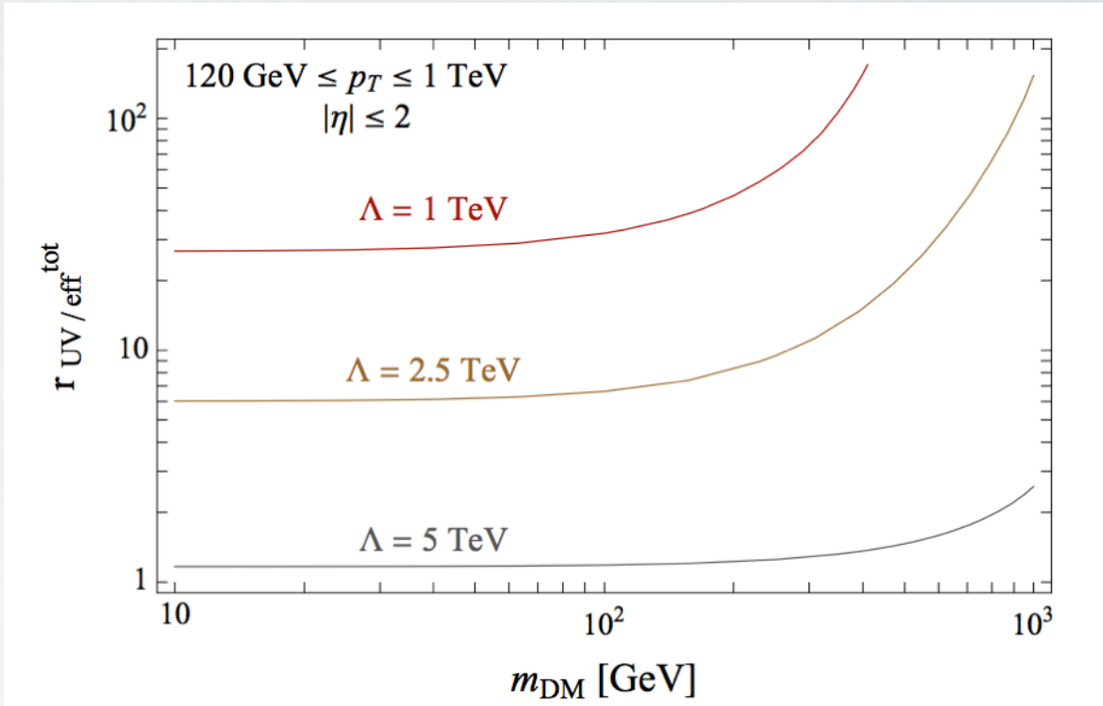
WHAT'S IN THE BLOB?



- Irrelevant operator?
- Mediators from UV?
- Somewhere in between!

WAIT, WHY NOT EFT?

$$\sigma_{\text{monojet}} \propto \begin{cases} \frac{1}{p_T^2}, & M \lesssim p_T \\ \frac{p_T^2}{M^4}, & M \gtrsim p_T \end{cases}$$



Busoni, De Simone, Morgante, Riotto

- Behavior changes for light mediator
- Collision energy ≫ Mediator mass

A SIMPLIFIED FRAMEWORK

- Aim for minimal UV bias
- Renormalizable interactions with SM, aka Portal
- Portals of old:
  - Higgs portal: $(H^\dagger H)(\phi^* \phi)$
  - Gauge portal: $F^{\mu\nu}\, F'_{\mu\nu}$
  - Neutrino portal: $\bar{L}_L\, H\, \chi_R$

THE FERMION PORTAL

- Two categories:
  - Part 1 - Quark portal: $\bar{q}\,\chi\,\phi$
  - Part 2 - Lepton portal: $\bar{l}\,\chi\,\phi$

See also:
Chang, Edezhath, Hutchinson, Luty, 1307.8120
An, Wang, Zhang, 1308.0592
DiFranzo, Nagao, Rajaraman, Tait, 1308.2679

QUARK PORTAL

FOUR CASES

- Depending on Lorentz representation of DM
  - Dirac fermion DM (Scalar mediator) **~ limit of MSSM**
  - Majorana fermion DM (Scalar mediator)
  - Complex scalar DM (Fermionic mediator)
  - Real scalar DM (Fermionic mediator)

THE INTERACTIONS

- Fermionic DM: $\mathscr{L} = \lambda_i \, \bar{q}_i \, \chi \, \phi_i$ + h.c.
  - χ: DM, ϕ_i: Scalar triplet mediator
- Scalar DM: $\mathscr{L} = \lambda_i \, \bar{q}_i \, \psi_i \, X$ + h.c.
  - X: DM, ψ_i: Fermionic triplet mediator
- One flavor at a time: DM exp't constraints only

CONSTRAINTS OVERVIEW

- Direct detection
  - Dirac & Complex: Spin independent
  - Majorana: Spin dependent
- Collider
  - Constraints from both Jets + MET and Monojets
- Abundance via “WIMP miracle”

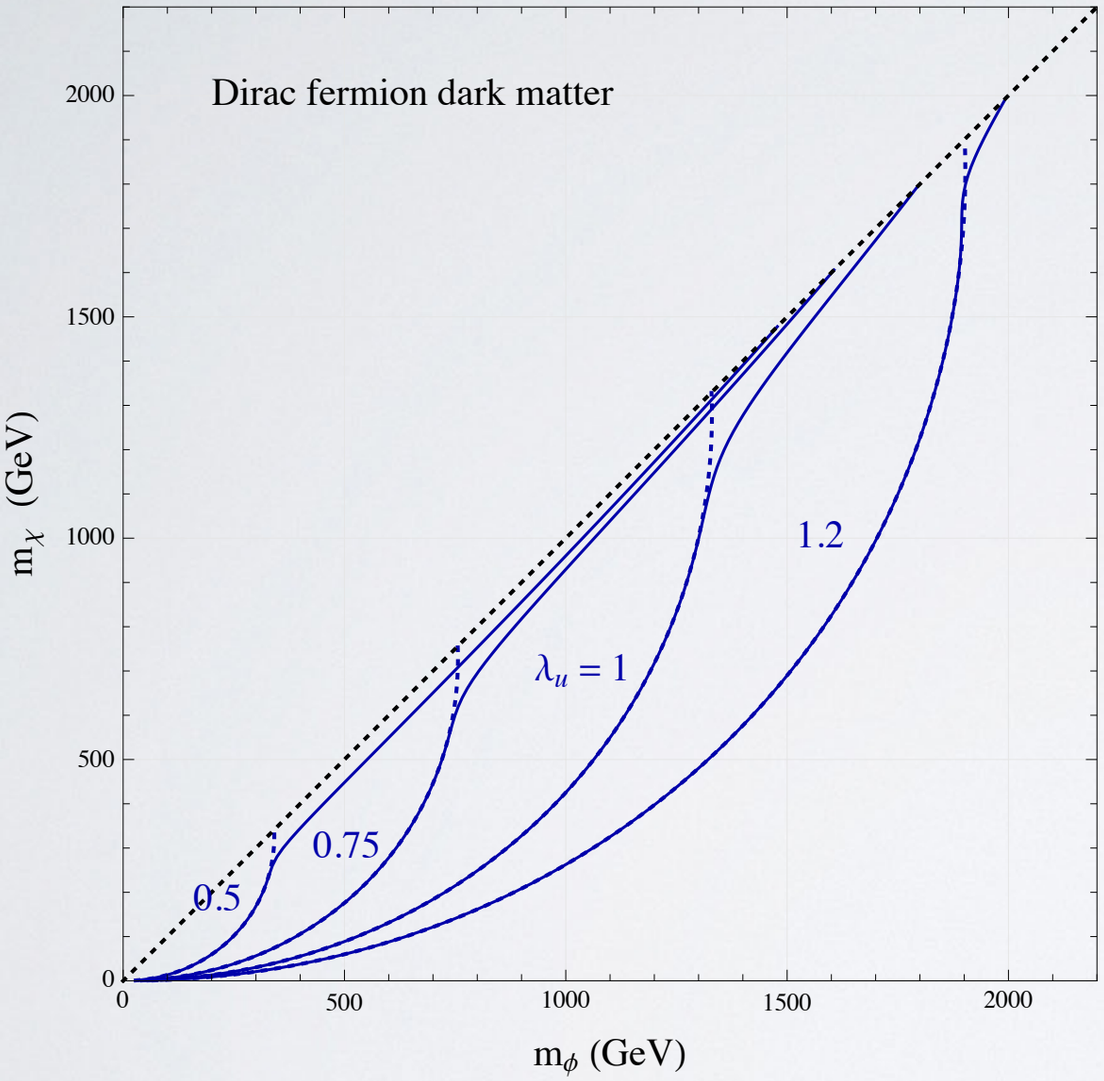
FERMION PORTAL AS WIMP

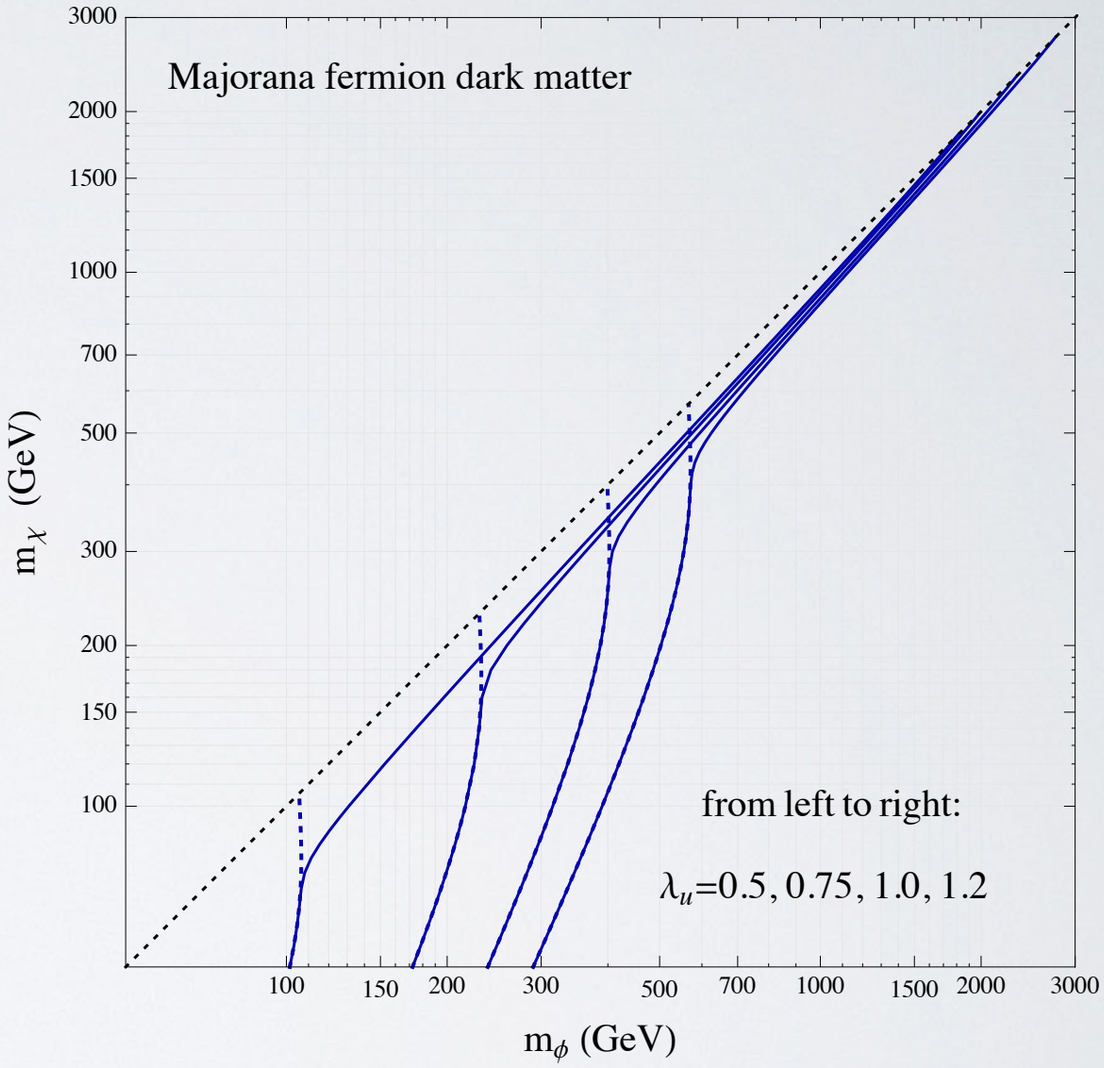
- For weak-scale mediator, DM can be thermal relic

$$\langle \sigma v \rangle = s + p\, v^2$$

- Dirac DM: s-wave annihilation allowed
- Majorana, Complex DM: p-wave suppression

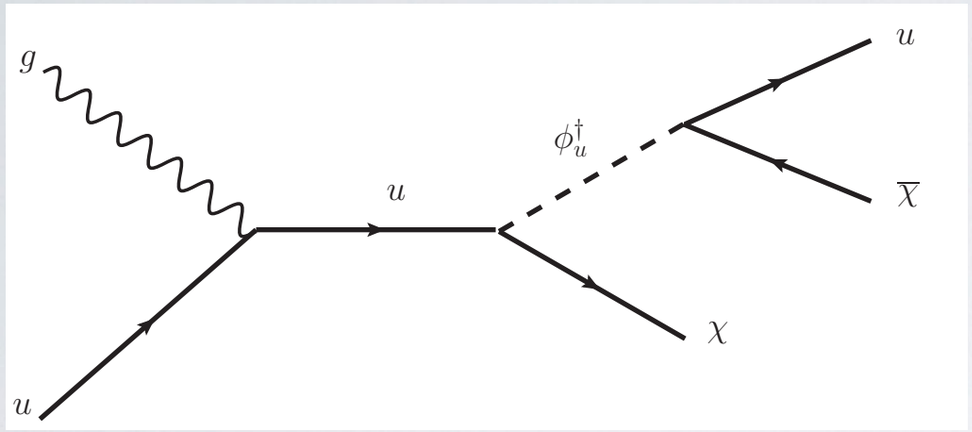
THERMAL ABUNDANCE

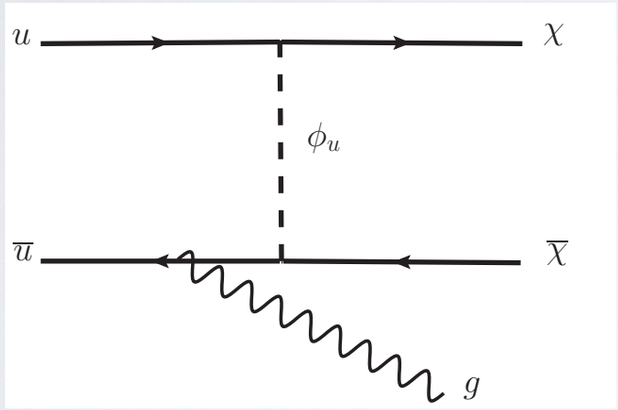


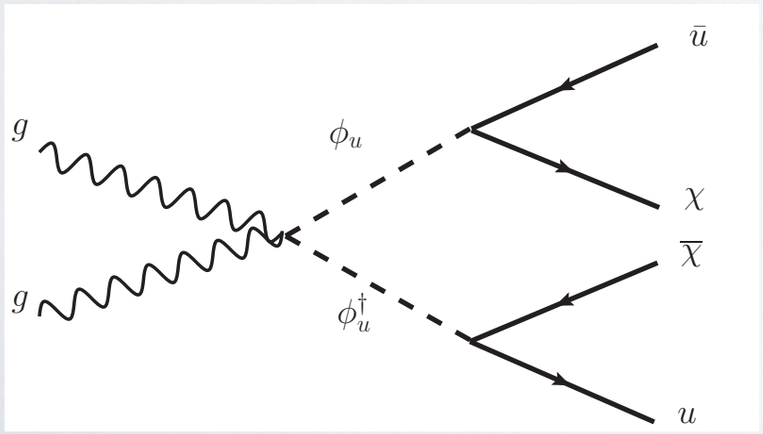


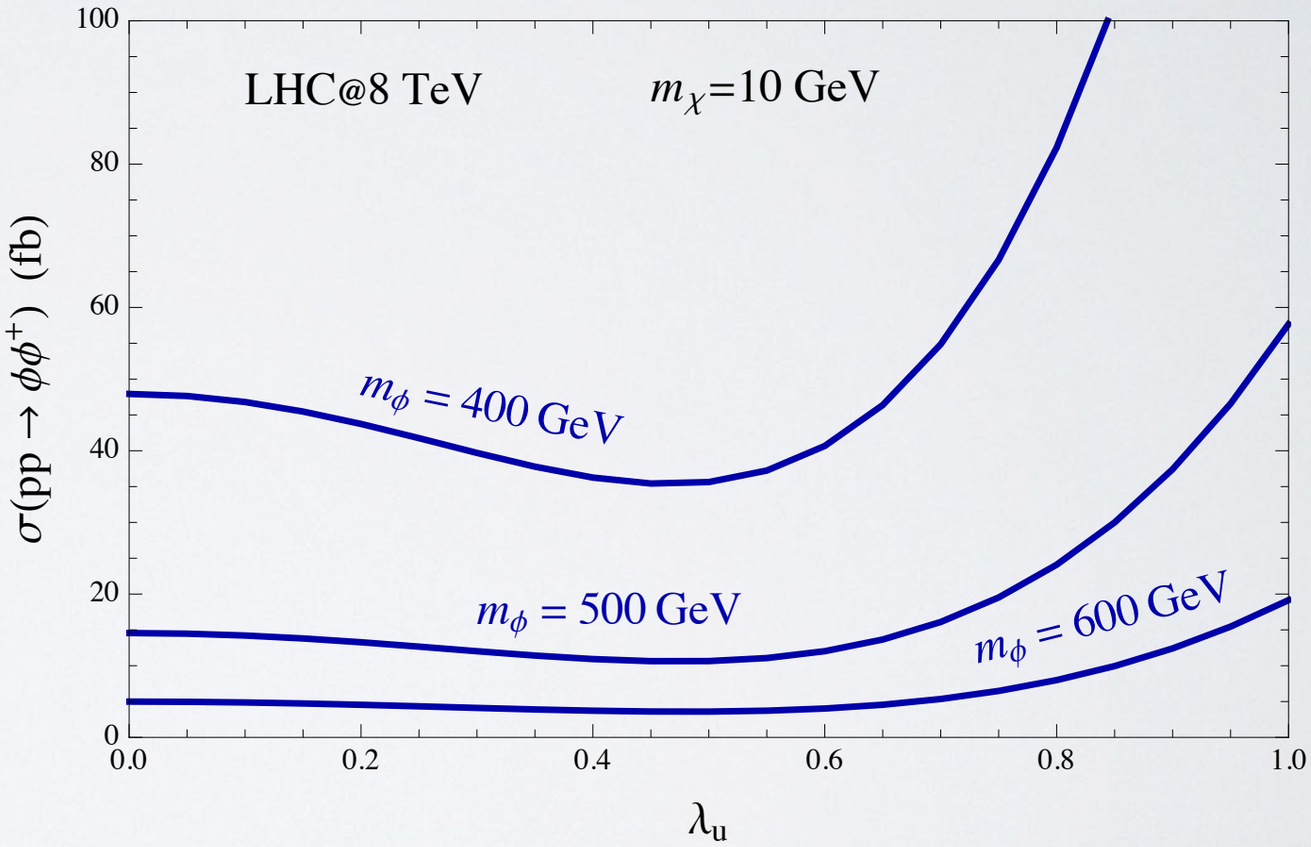
$$\Omega_\chi h^2 = 0.1199 \pm 0.0027$$

COLLIDER PRODUCTION

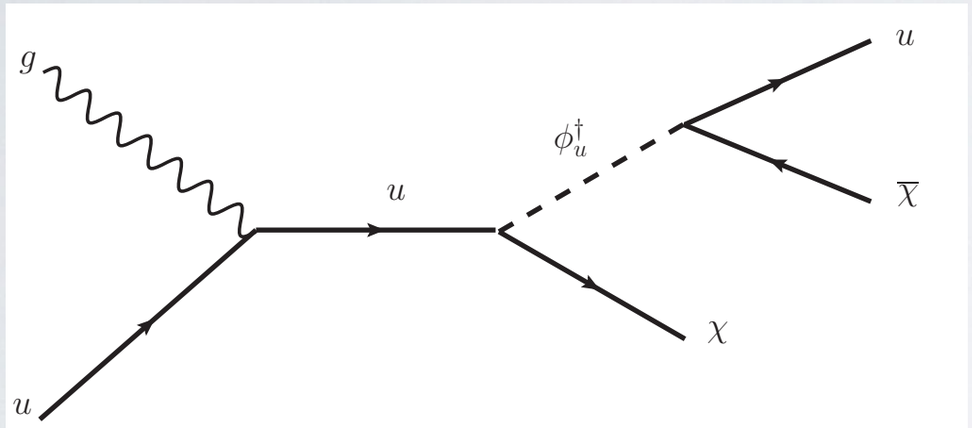


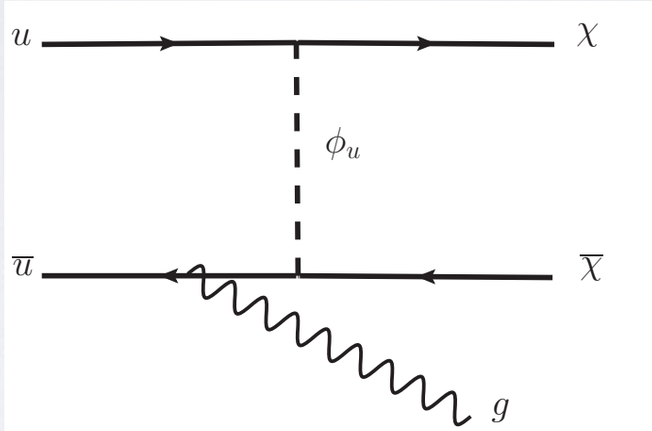


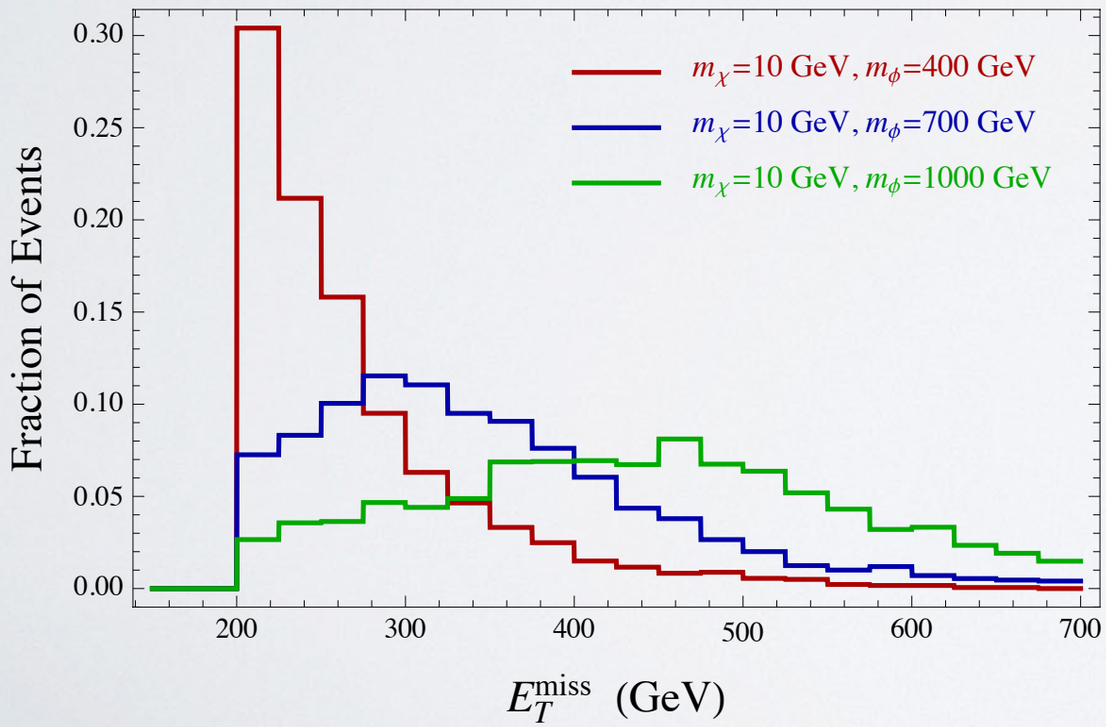


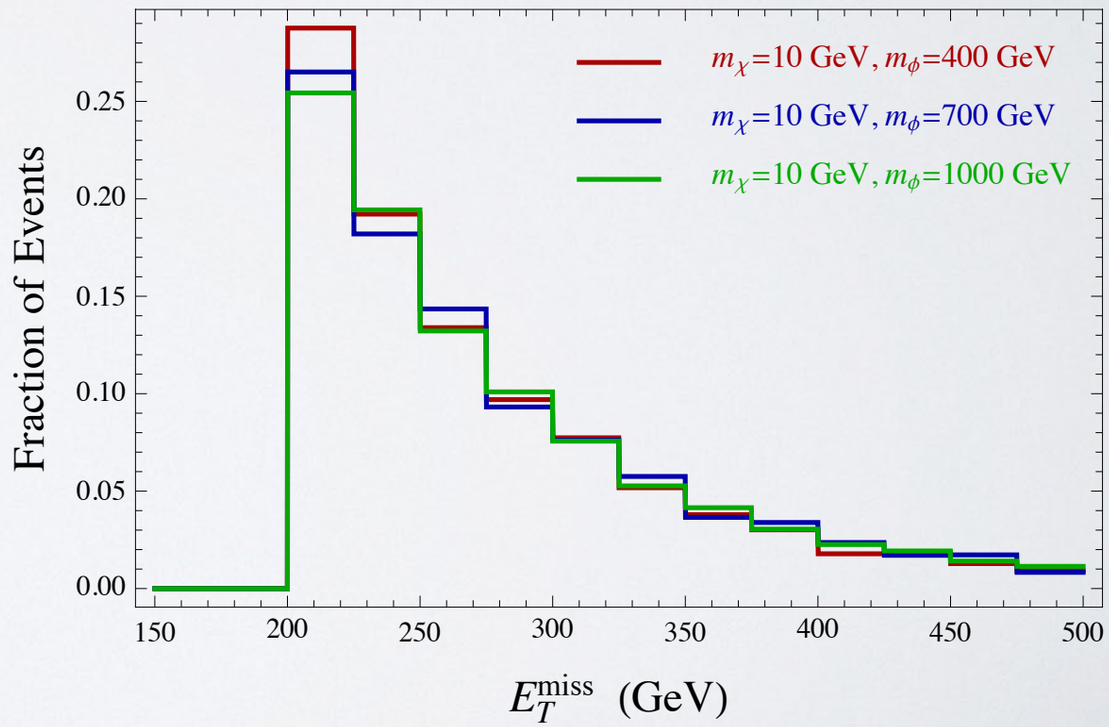


EVENT SHAPE


g
u
u
$\phi_u^\dagger$
u
$\overline{\chi}$
χ

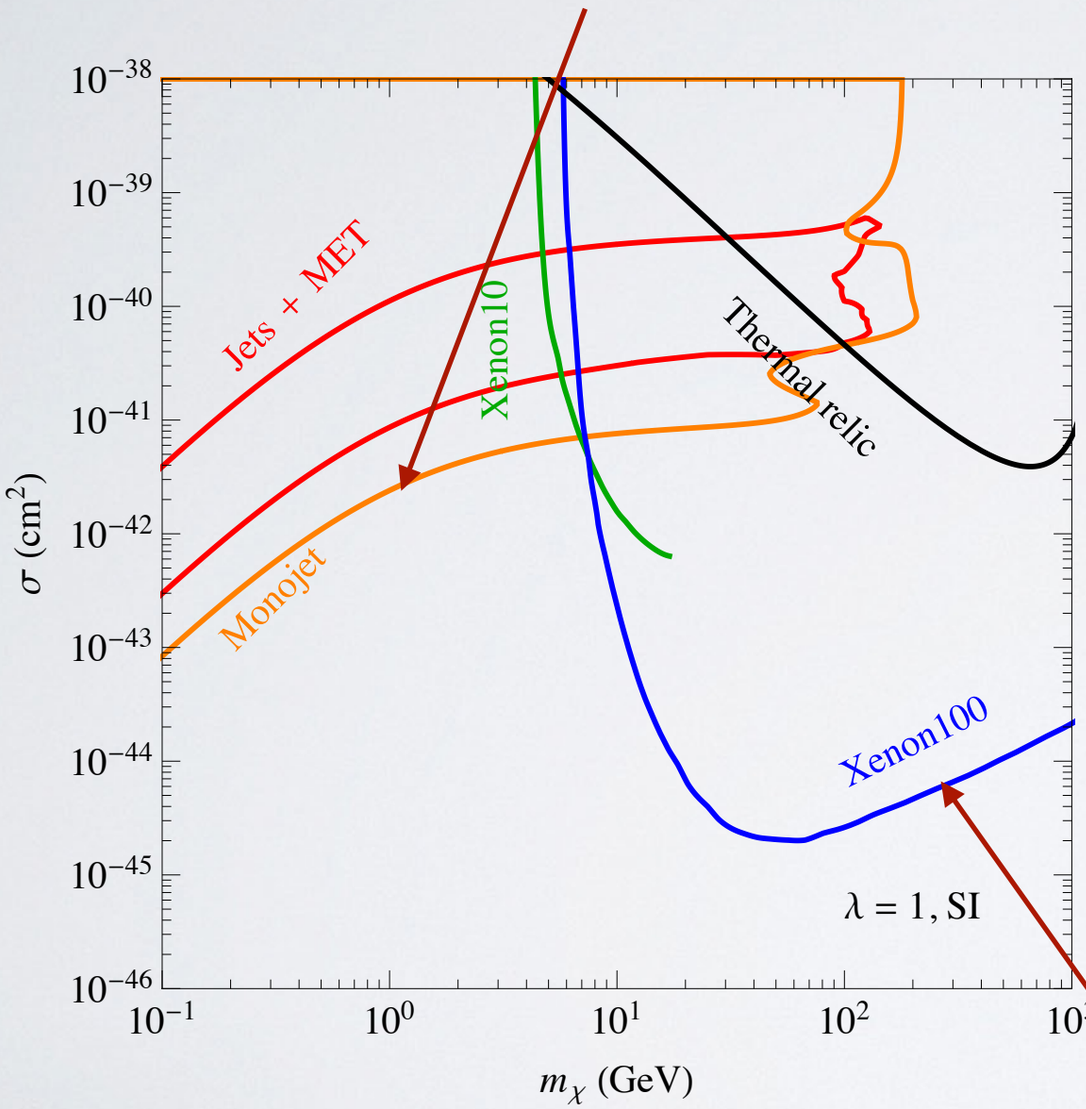

u
χ
ϕ_u
$\overline{u}$
$\overline{\chi}$
g


Fraction of Events
0.30
0.25
0.20
0.15
0.10
0.05
0.00
200
300
400
500
600
700
E_T^{miss} (GeV)
m_χ=10 GeV, m_ϕ=400 GeV
m_χ=10 GeV, m_ϕ=700 GeV
m_χ=10 GeV, m_ϕ=1000 GeV

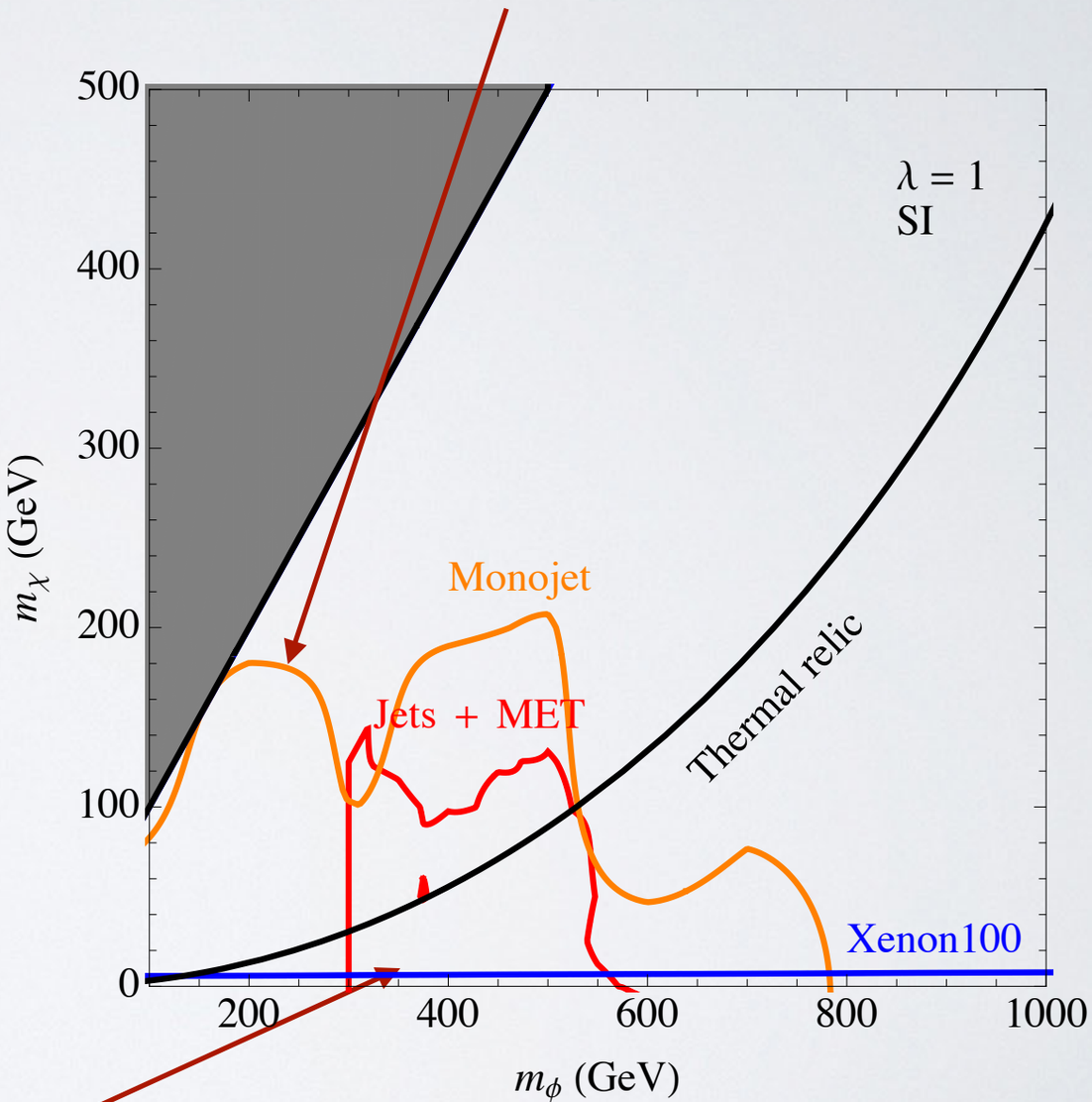

Fraction of Events
0.25
0.20
0.15
0.10
0.05
0.00
150
200
250
300
350
400
450
500
E_T^{miss} (GeV)
m_χ=10 GeV, m_ϕ=400 GeV
m_χ=10 GeV, m_ϕ=700 GeV
m_χ=10 GeV, m_ϕ=1000 GeV

DIRAC DM LIMITS

need colliders @ low mass



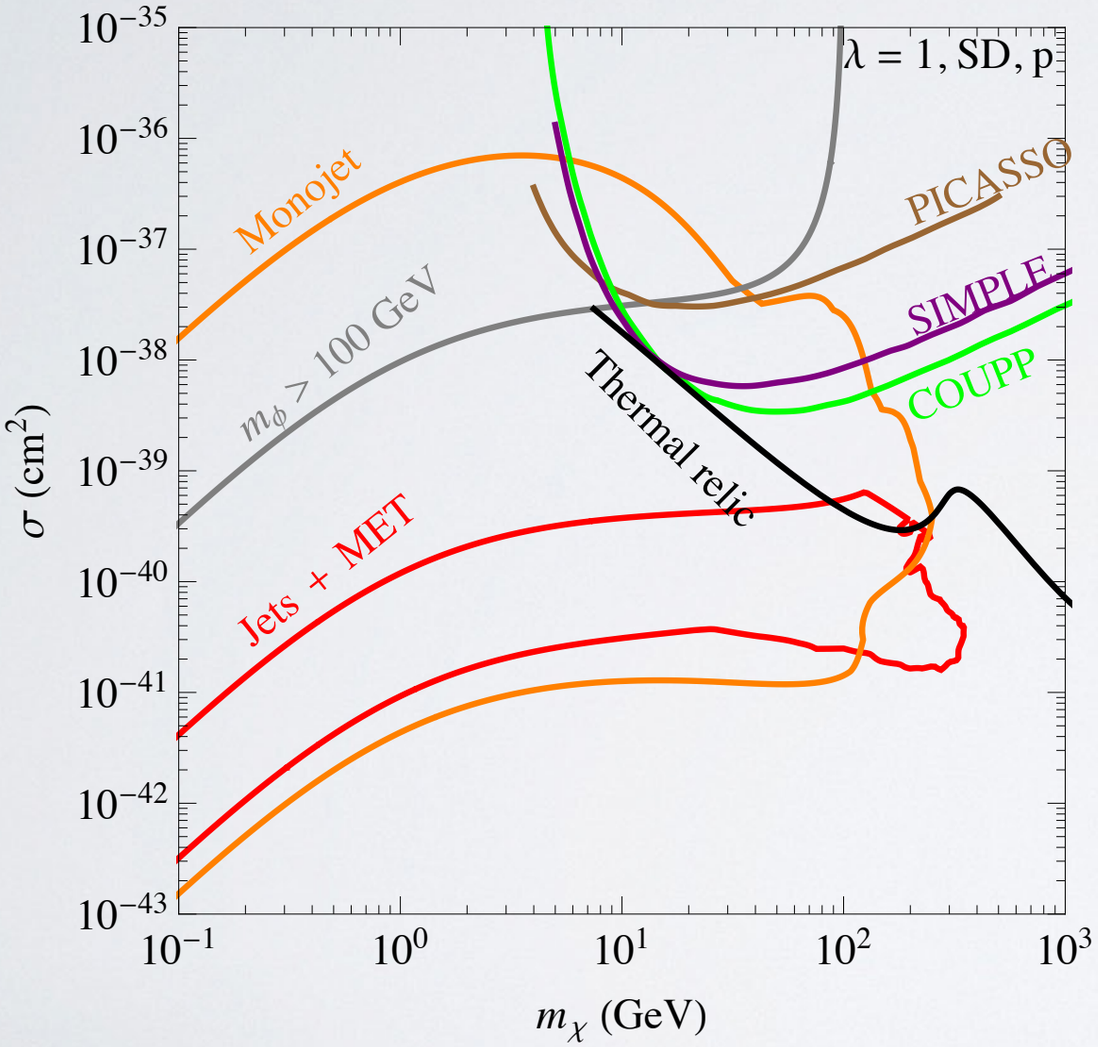
monojets win near degeneracy

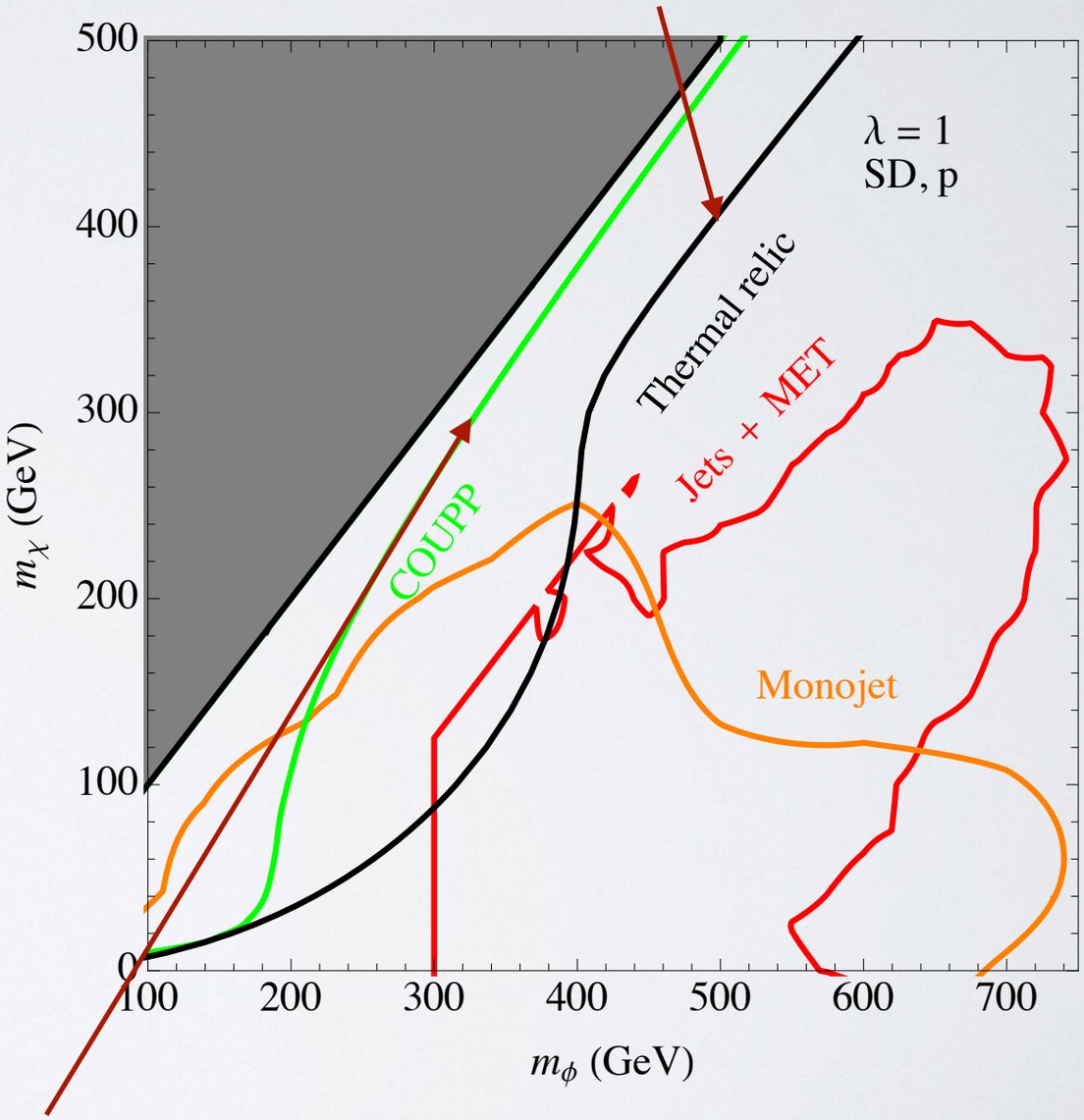


direct detection extremely powerful

MAJORANA DM LIMITS

Scattering off proton

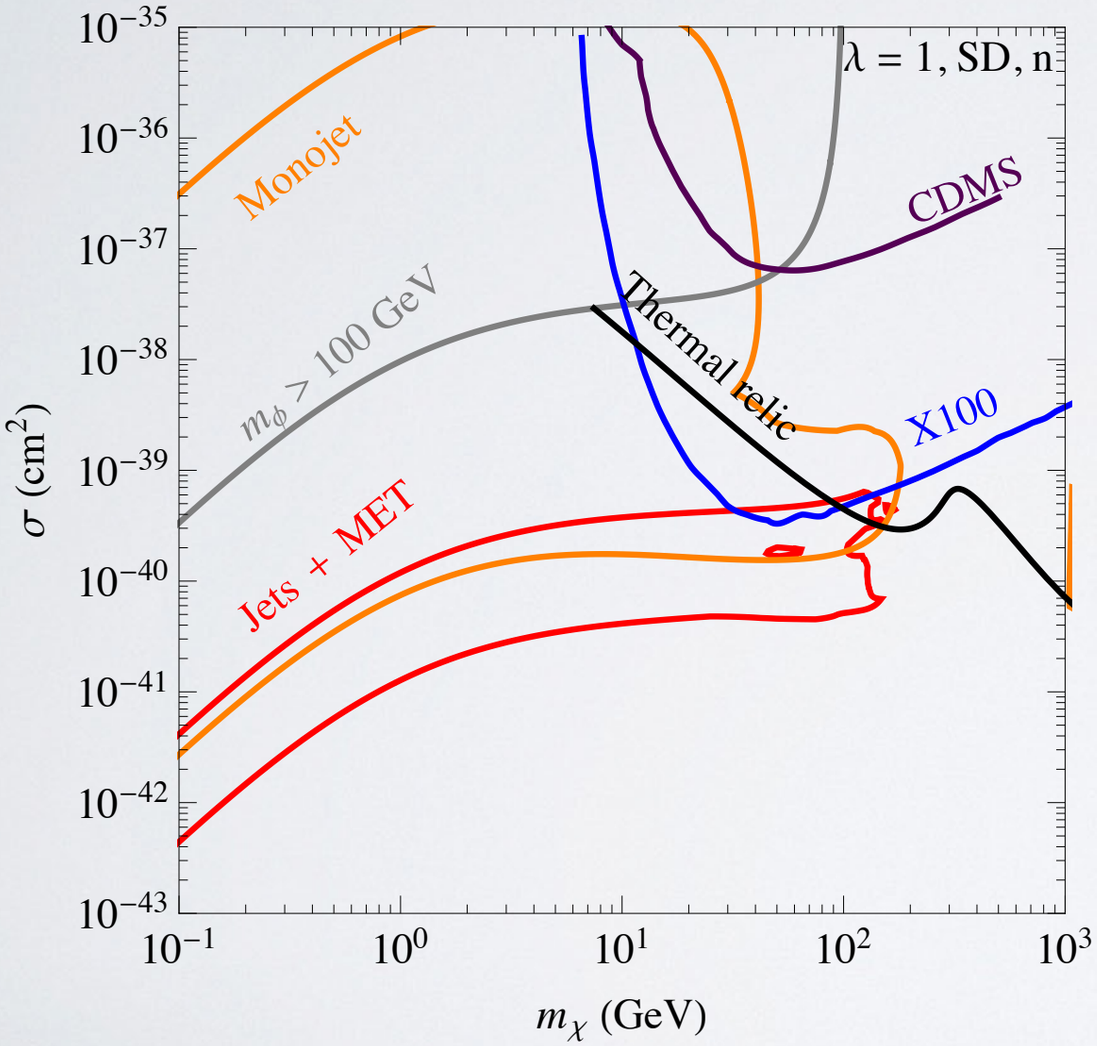


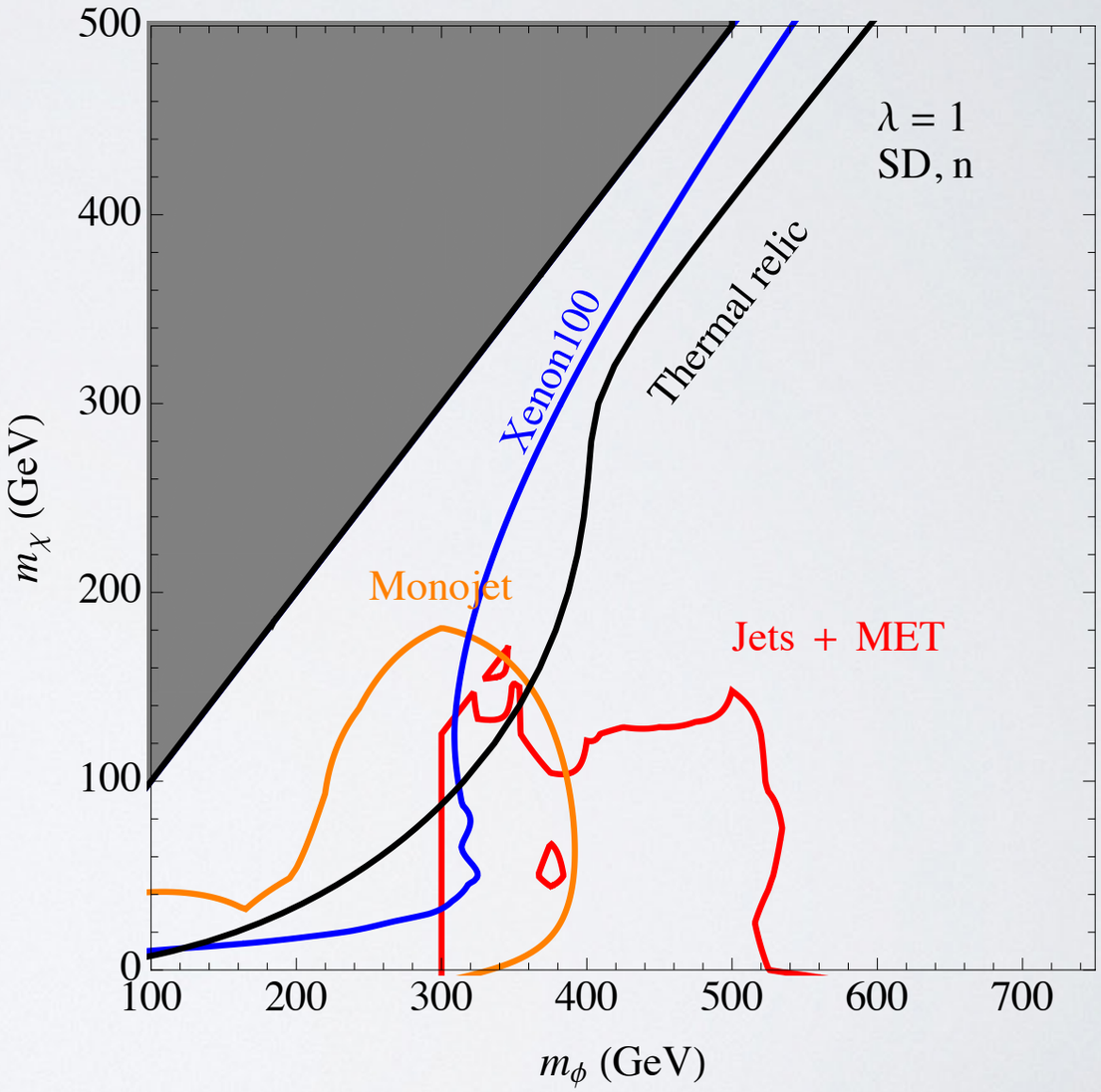


DD resonant enhancement near degeneracy

MAJORANA DM LIMITS

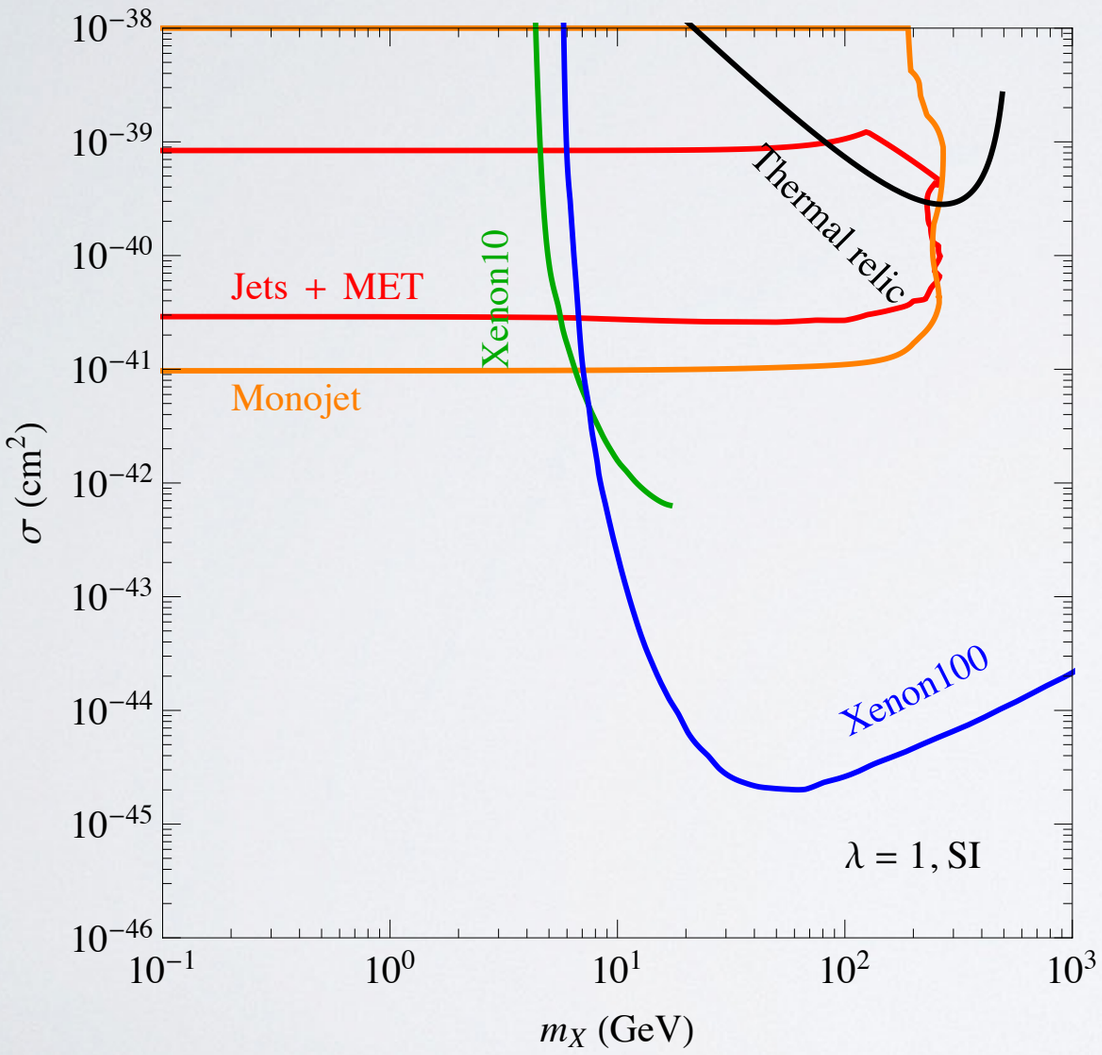
Scattering off neutron

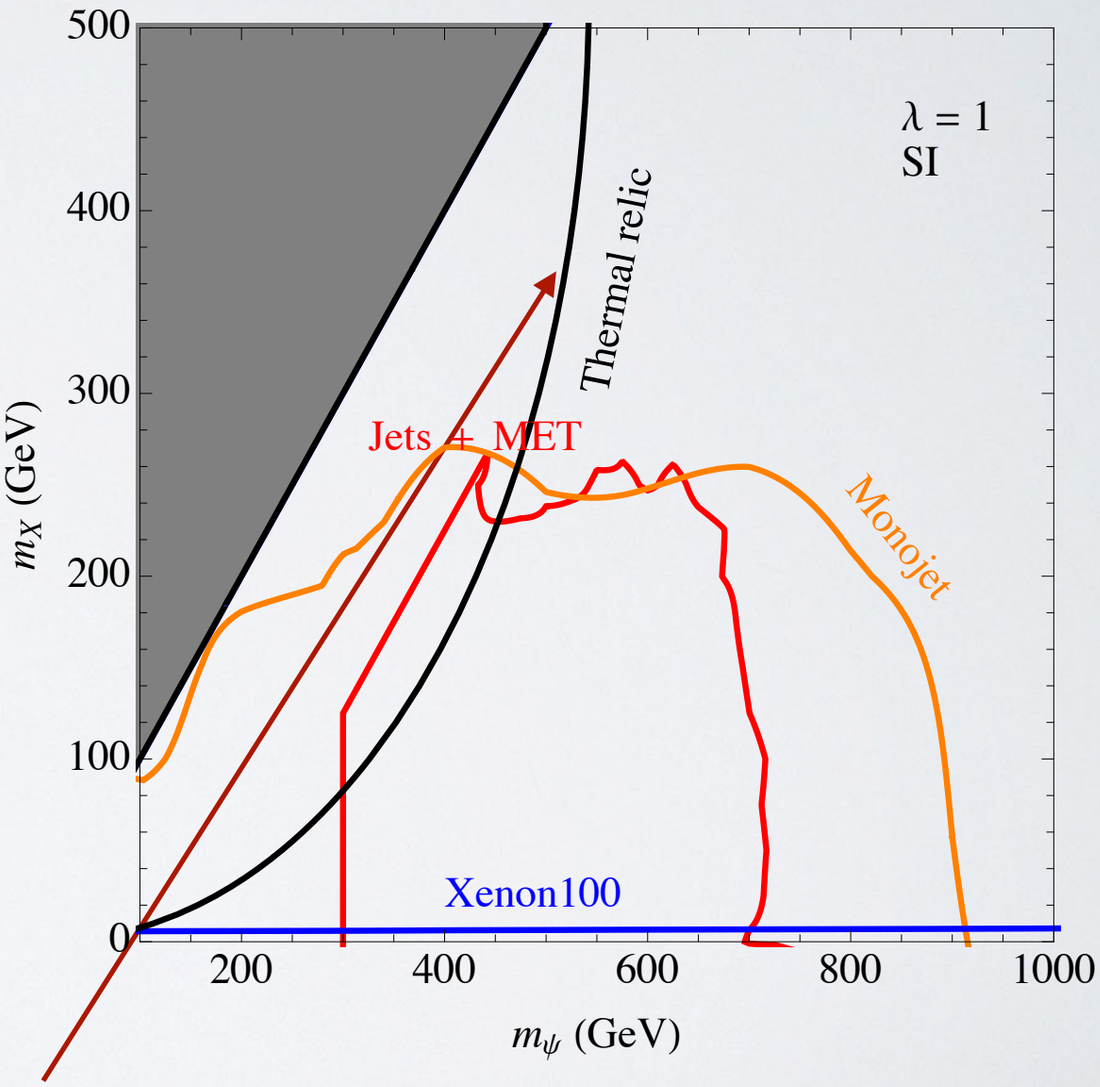




scattering off neutrons wins

COMPLEX DM LIMITS





thermal relic for smaller masses (p-wave suppression)

QUARK PORTAL WRAP UP

- Quark portal provides a simple framework for DM phenomenology studies

- Parameter space being complementarily probed by both collider searches & DD

- Specific kinematic features may help at colliders

LEPTON PORTAL

SOME NEW CASES

- Consider coupling to each generation in turn
- Now: strong, but different constraints on all
- Assume flavor diagonal couplings

SOME NEW CONSTRAINTS

- DD from loop-generated photon coupling
- Collider from dilepton + MET
- ID from high energy positrons
- $(g\text{-}2)_\mu$ contraint (or explanation?)

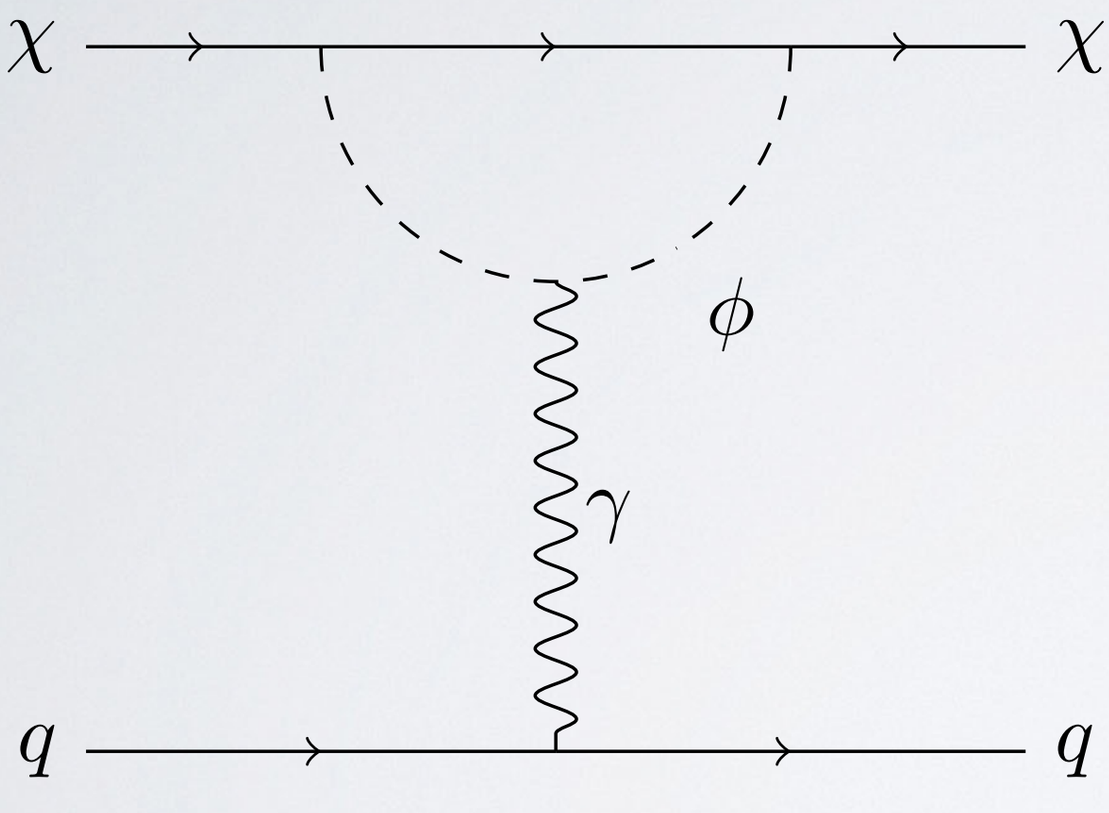
REMINDER: THERMAL RELIC PARAMETER SPACE

- Story is the same as for quark portal

- Dirac DM: s-wave annihilations

- Majorana, Complex DM: p-wave annihilations

DD @ 1 LOOP



- Dim 5:
  - Breaks chiral sym.
- Dim 6:
  - Several operators

THE OPERATORS

Dirac

$$\mathcal{O}_1 = [\overline{\chi}\gamma^\mu(1-\gamma^5)\partial^\nu\chi + \text{h.c.}]F_{\mu\nu}$$

$$\mathcal{O}_2 = [i\overline{\chi}\gamma^\mu(1-\gamma^5)\partial^\nu\chi + \text{h.c.}]F^{\alpha\beta}\epsilon_{\mu\nu\alpha\beta}$$

Agrawal, Blanchet, Chacko, Kilic

C,P even: charge radius, magnetic dipole; C,P odd: anapole

Majorana $\mathcal{O}_1 = [-\overline{\chi}\gamma^\mu\gamma^5\partial^\nu\chi + \text{h.c.}]F_{\mu\nu}$

Only anapole allowed

Complex $\mathcal{O} = \partial_\mu X^\dagger \partial_\nu X F^{\mu\nu}$

Only charge radius allowed

FERMION CASE

$$c_1 = \frac{\lambda^2 e}{64\pi^2 m_\phi^2}\left(\frac{1}{2} + \frac{2}{3}\log\frac{m_e^2}{m_\phi^2}\right), \quad c_2 = \frac{\lambda^2 e}{256\pi^2 m_\phi^2}$$

$$\sigma_{XN} = c_1^2 e^2 Z^2 \frac{\mu_{XN}^2}{A^2\pi}$$

- $c_1 \gg c_2$ from log enhancement
- Majorana case: only *v*-suppressed anapole-charge coupling

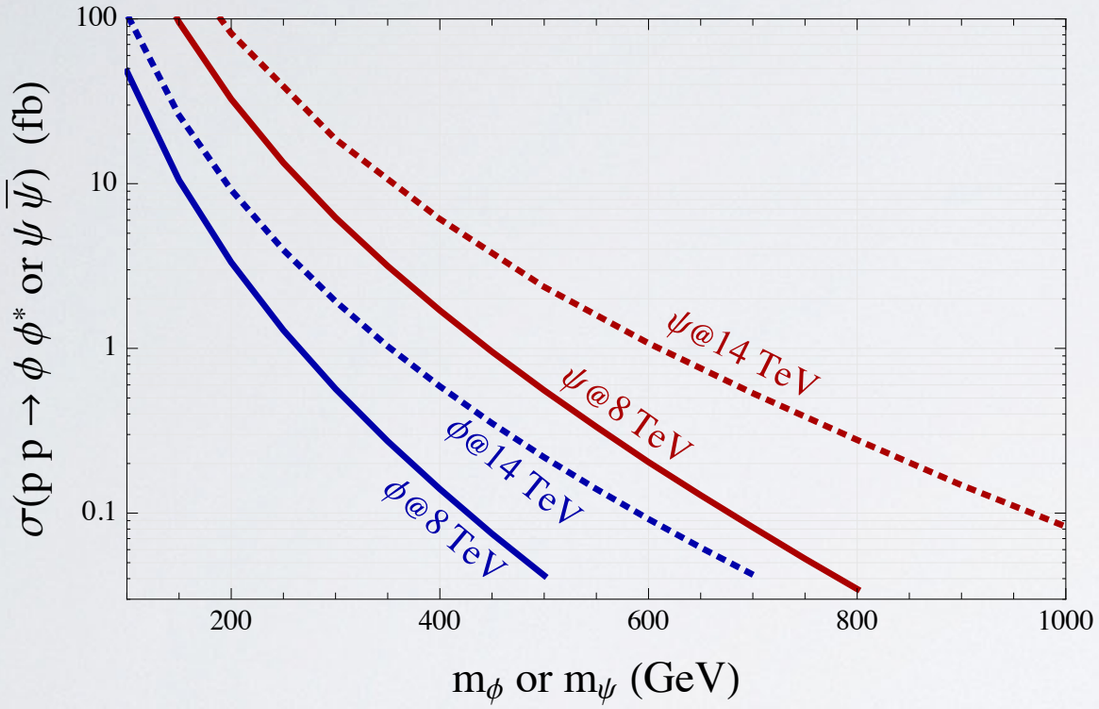
SCALAR CASE

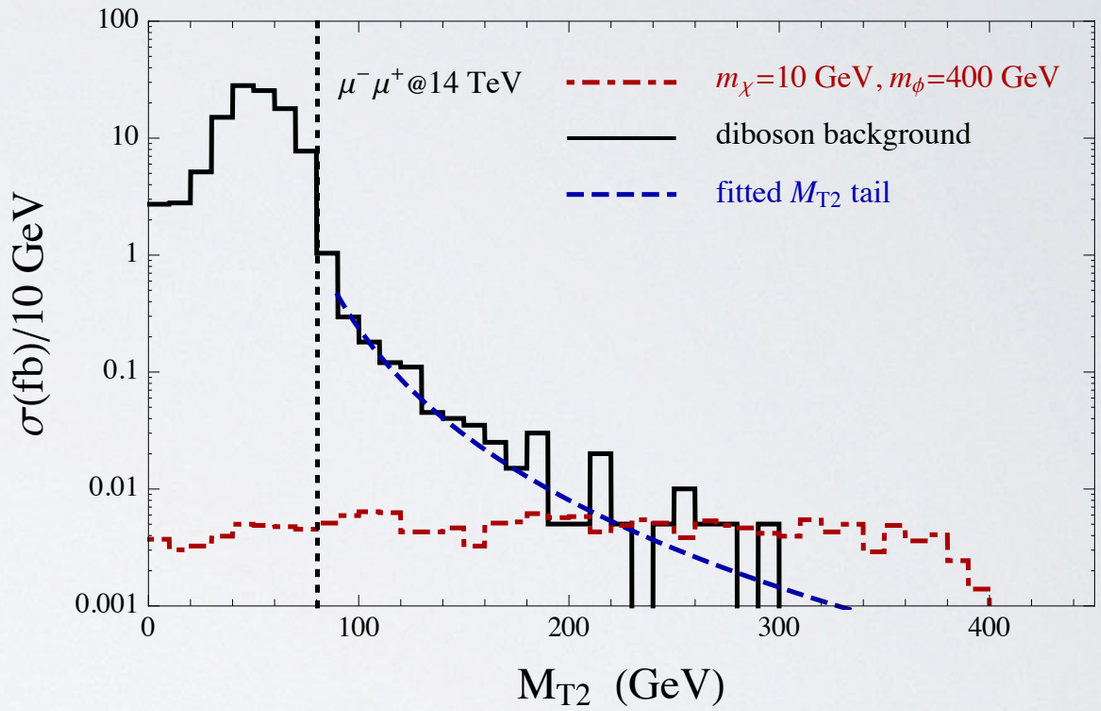
$$C = -\frac{\lambda^2 e}{64\pi^2 m_\psi^2}\left(1+\frac{2}{3}\log\frac{m_e^2}{m_\psi^2}\right)$$

$$\sigma_{XN} = C^2 e^2 Z^2 \frac{\mu_{XN}^2}{A^2\pi}$$

- Unsuppressed charge radius-charge coupling

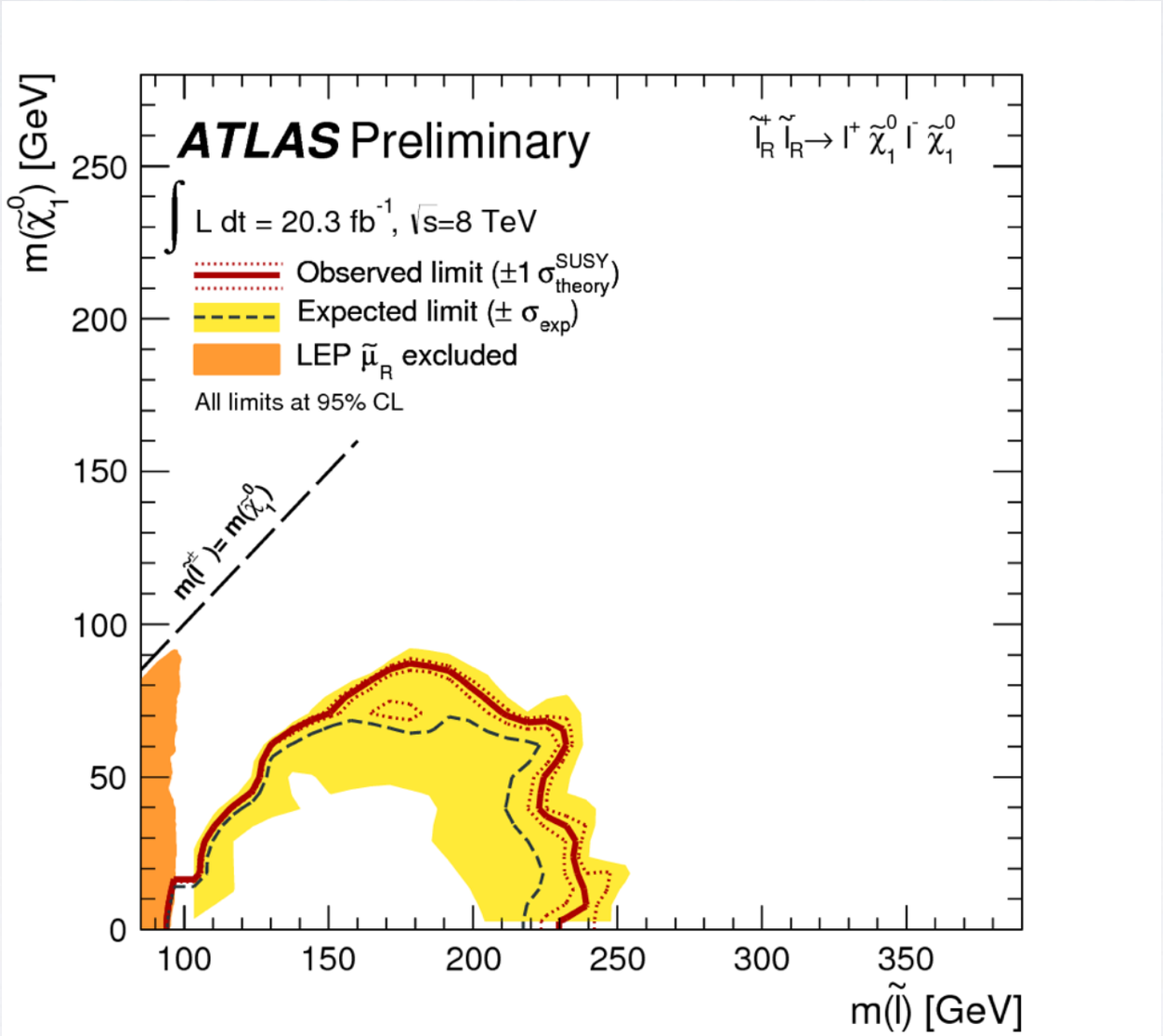
COLLIDER CONSTRAINTS





$$F(M_{T2}) = \frac{N_0}{[\eta M_{T2}^2 - M_W^2]^2 + \eta^2 M_{T2}^4 \Gamma_W^2 / M_W^2}$$

CURRENT LIMITS



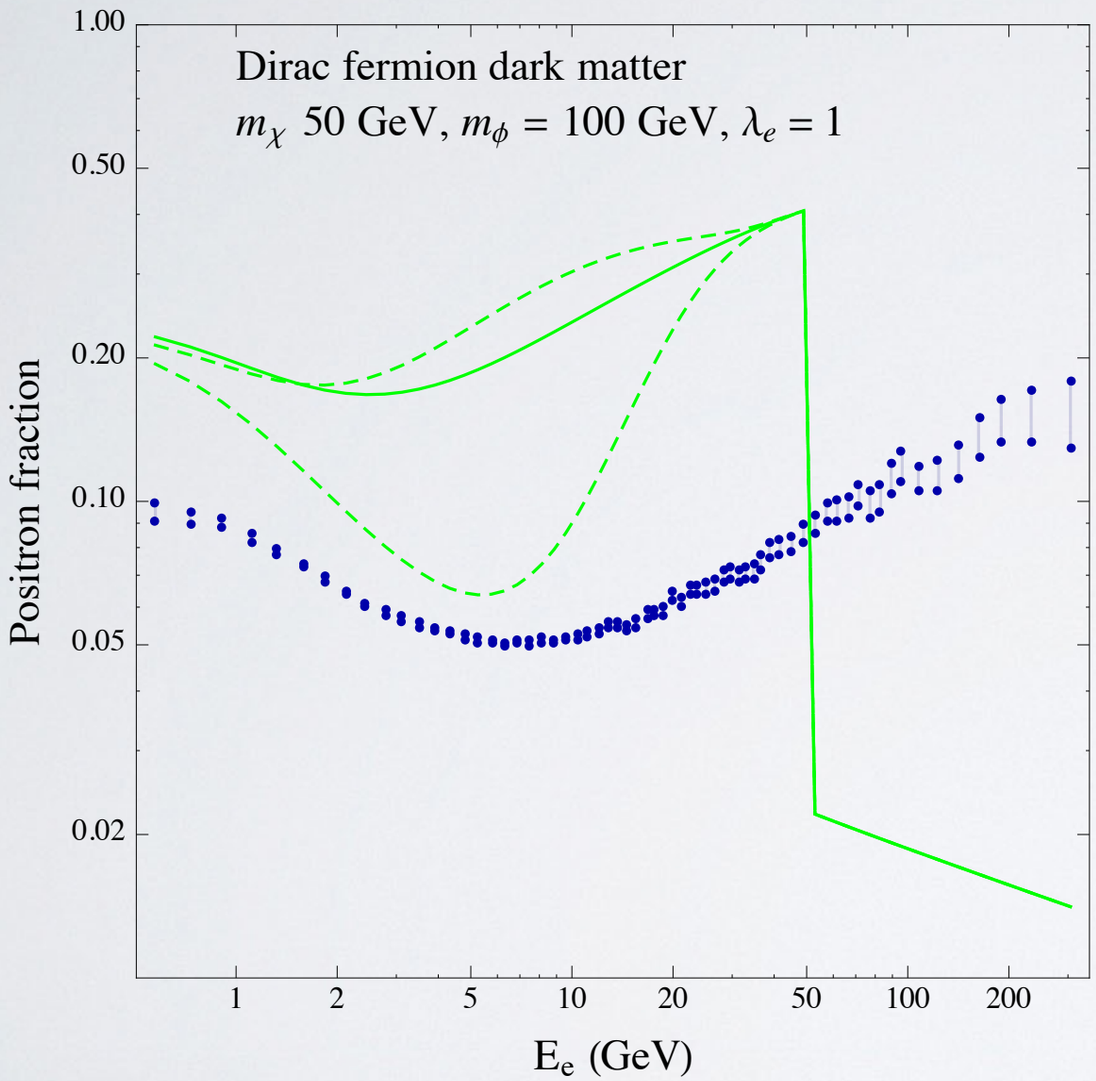
POSITRON FLUX @ AMS

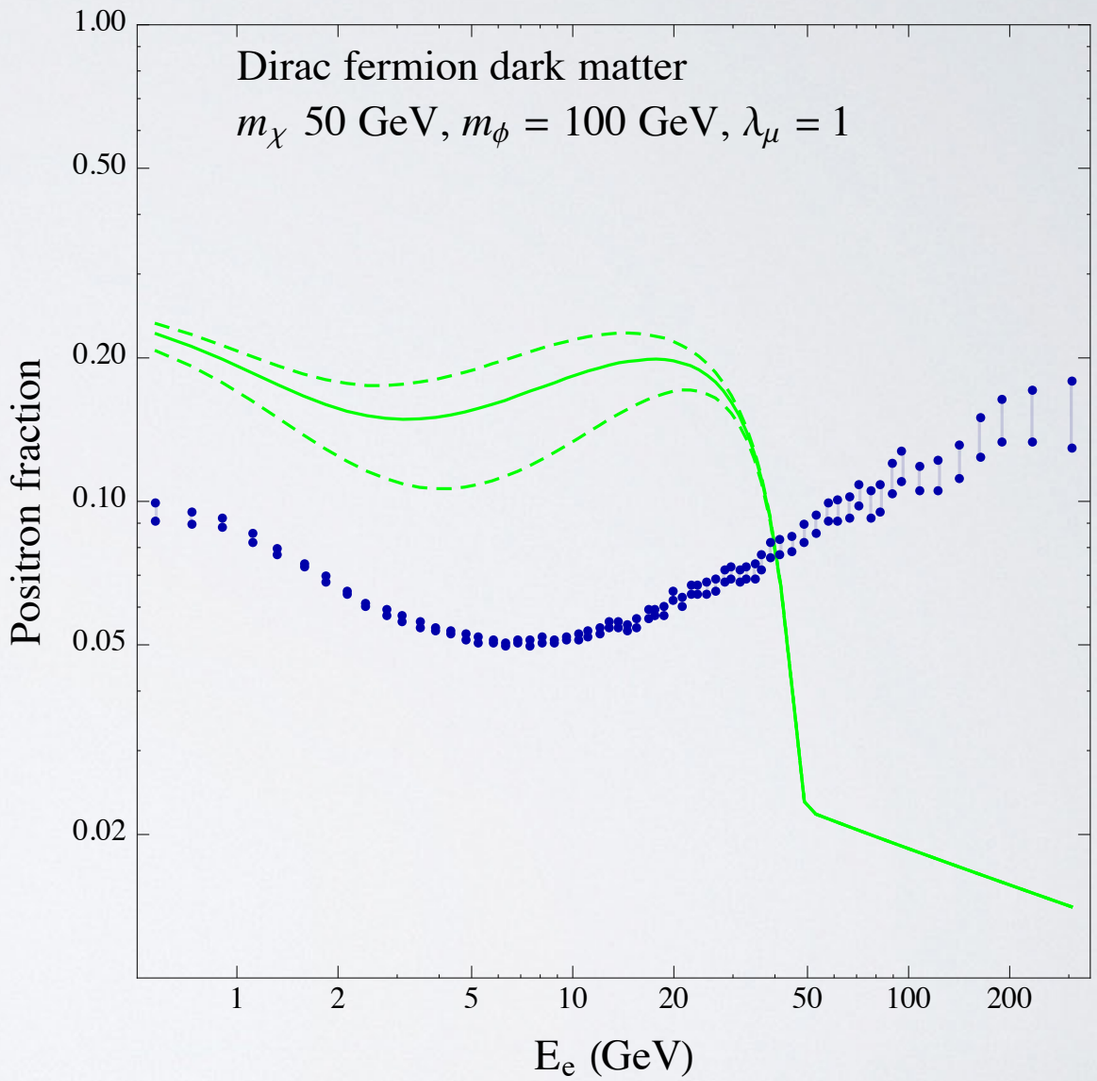
- Parametrize the transfer function to go from injection spectrum to flux

- Three different sets of “standard” astrophysical assumptions

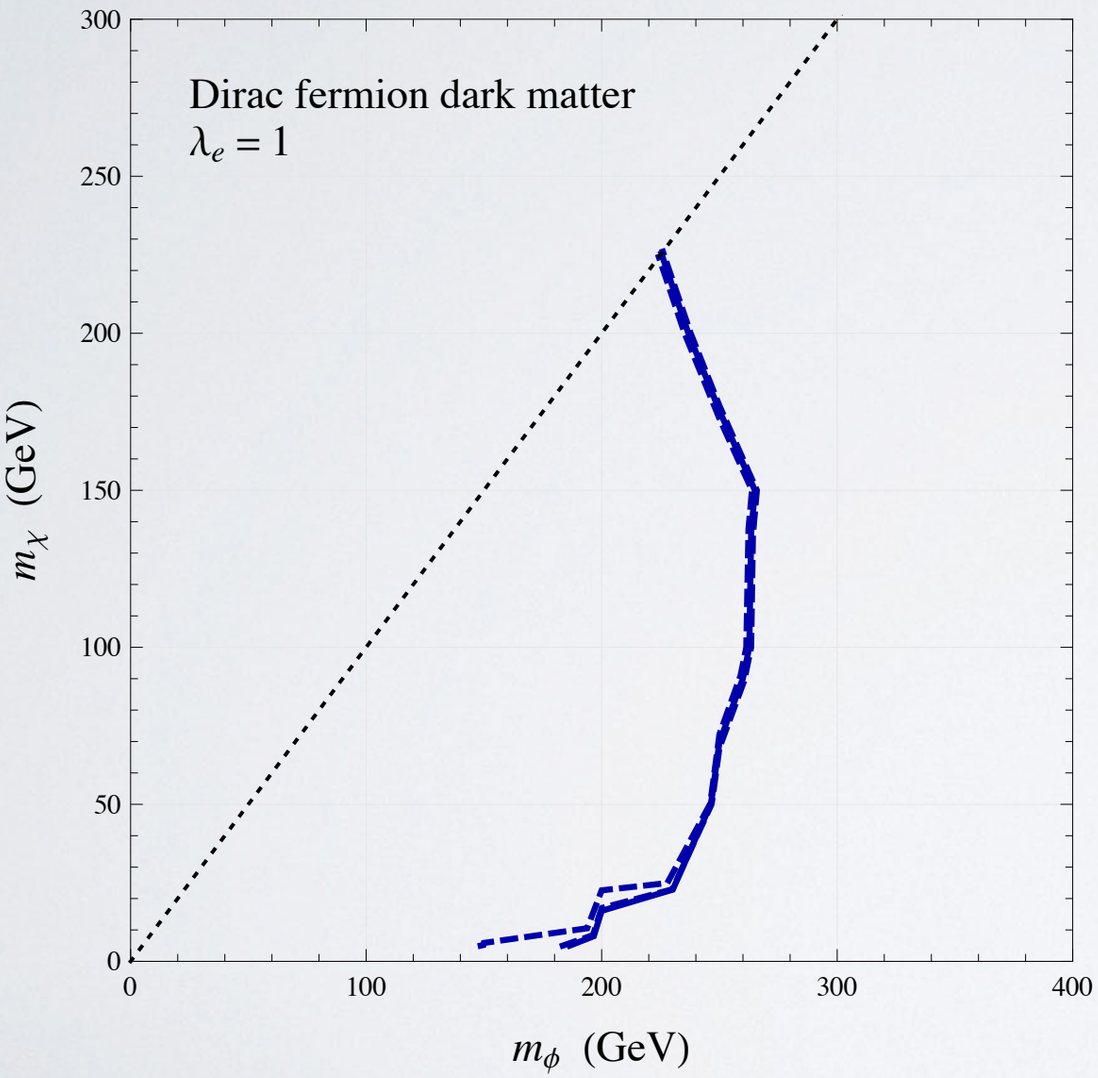
- Compare bin-by-bin to total positron flux and excluded if there is a 2σ excess in any bin

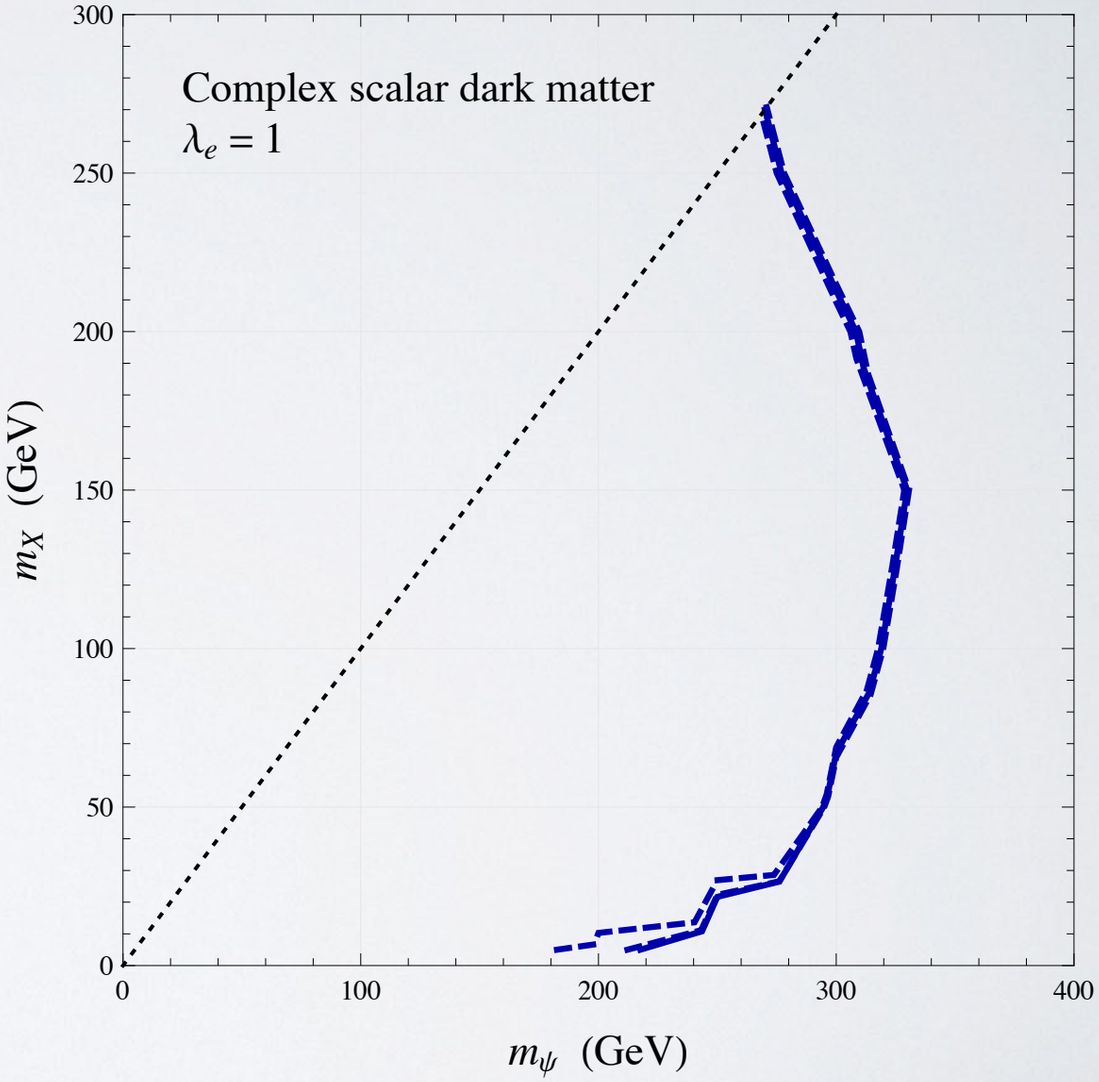
AMS-02 LIMITS



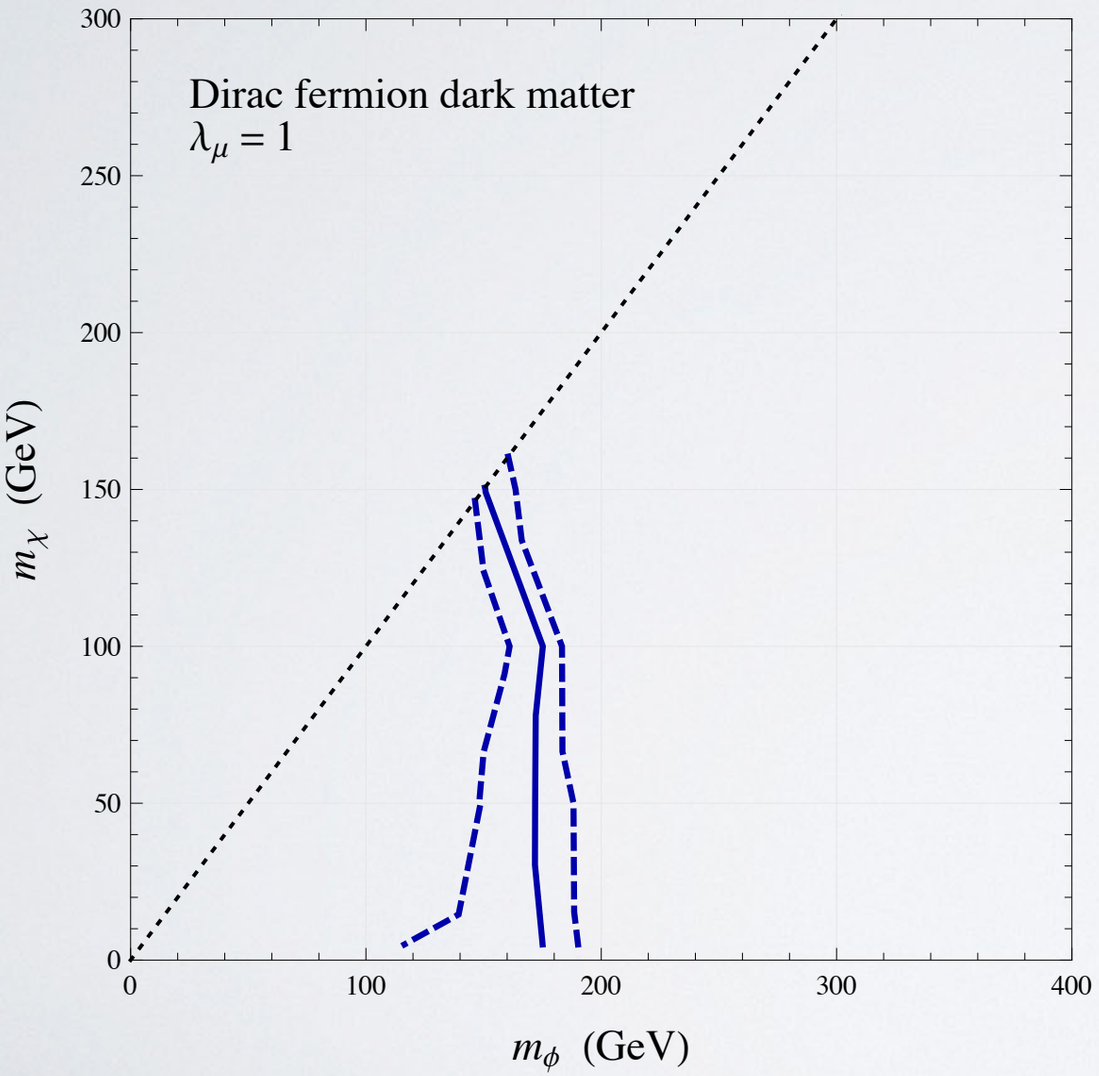


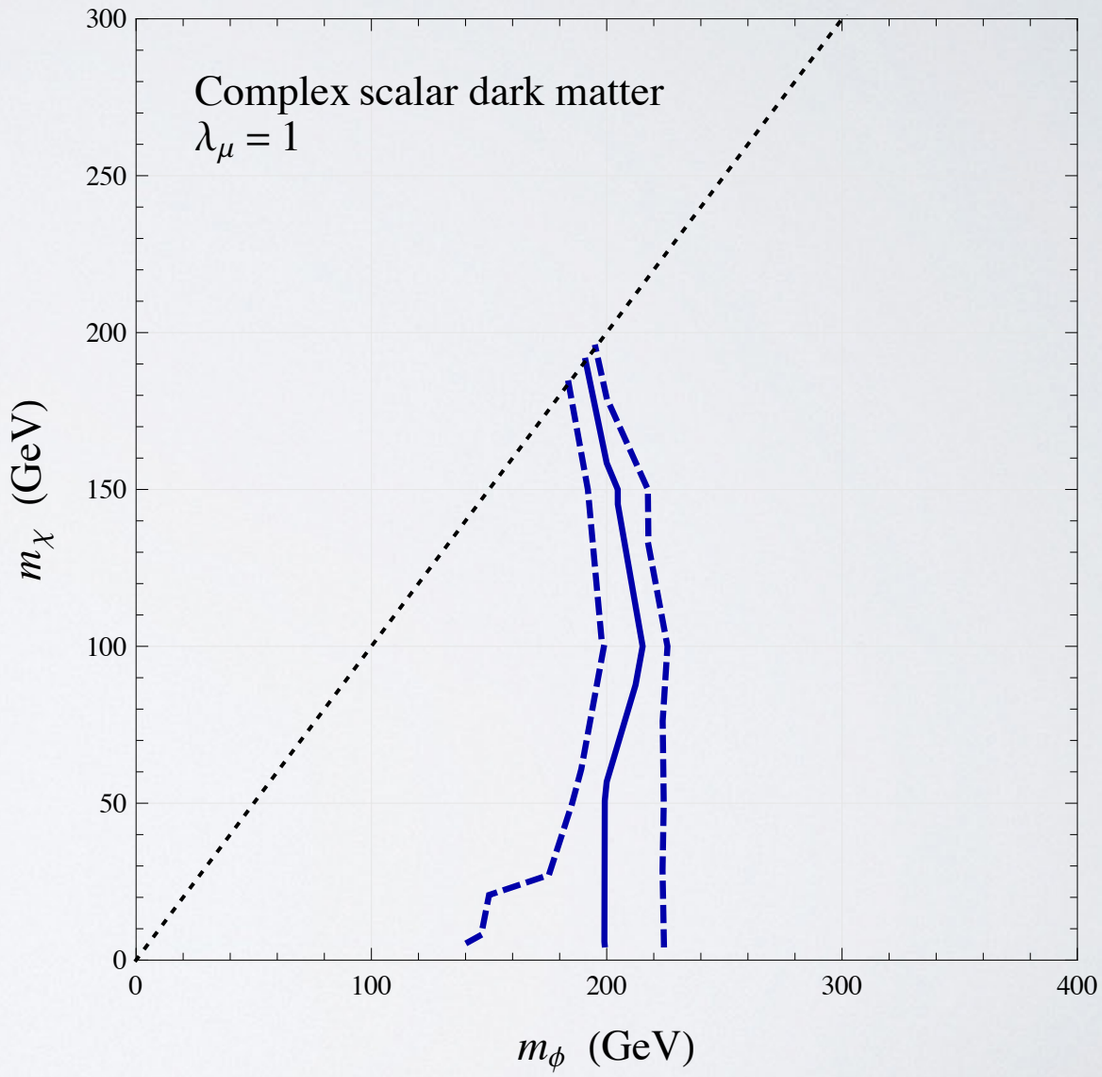
INDIRECT DETECTION ELECTRON PORTAL



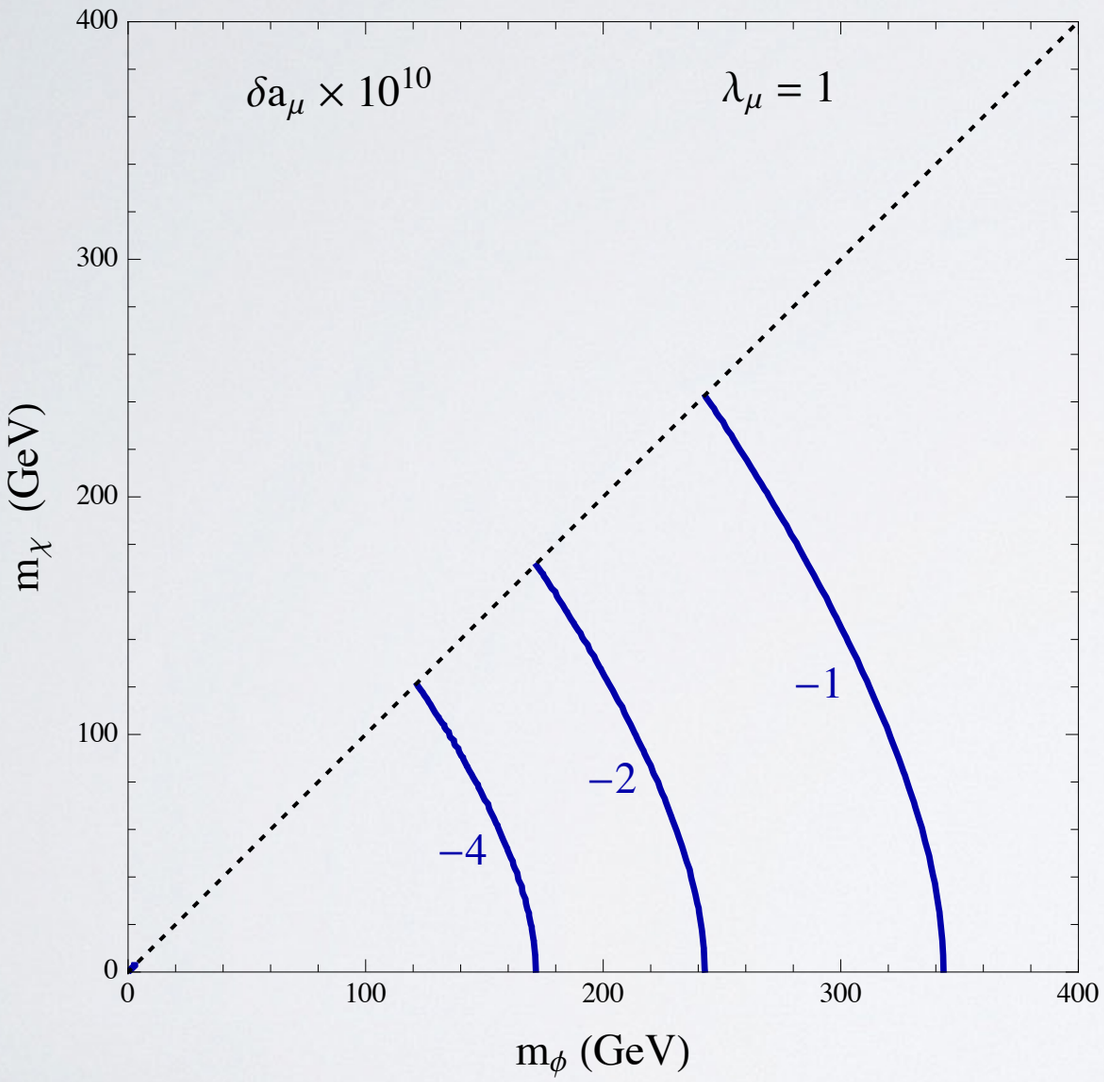


INDIRECT DETECTION
MUON PORTAL

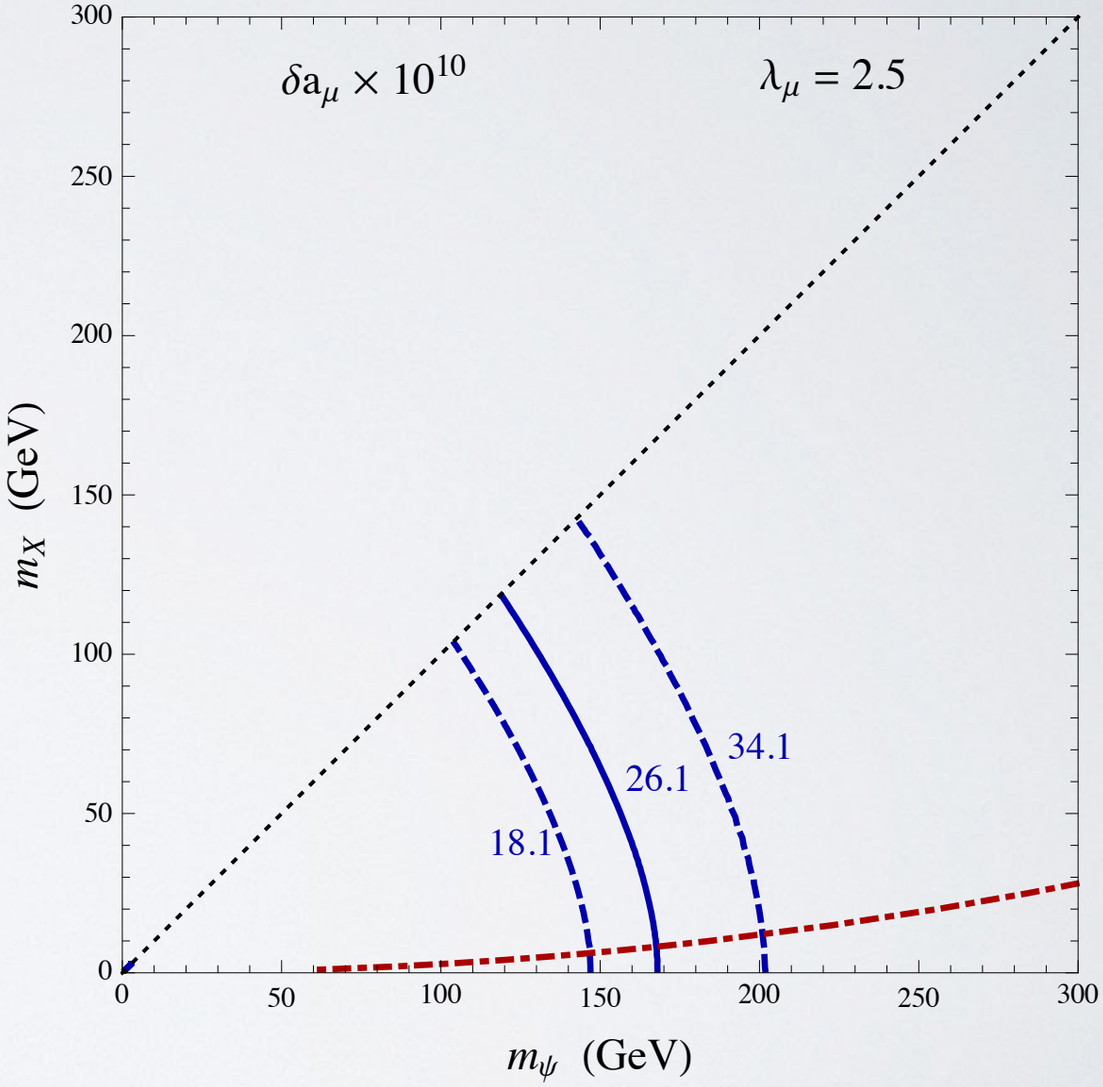




MUON g-2

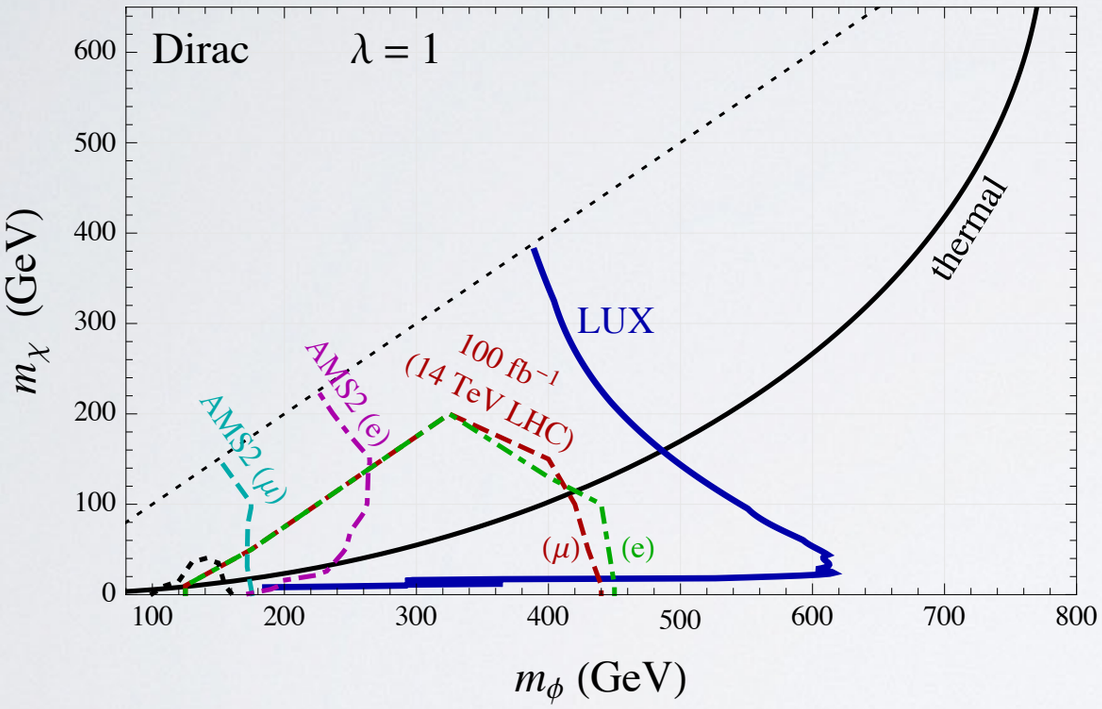


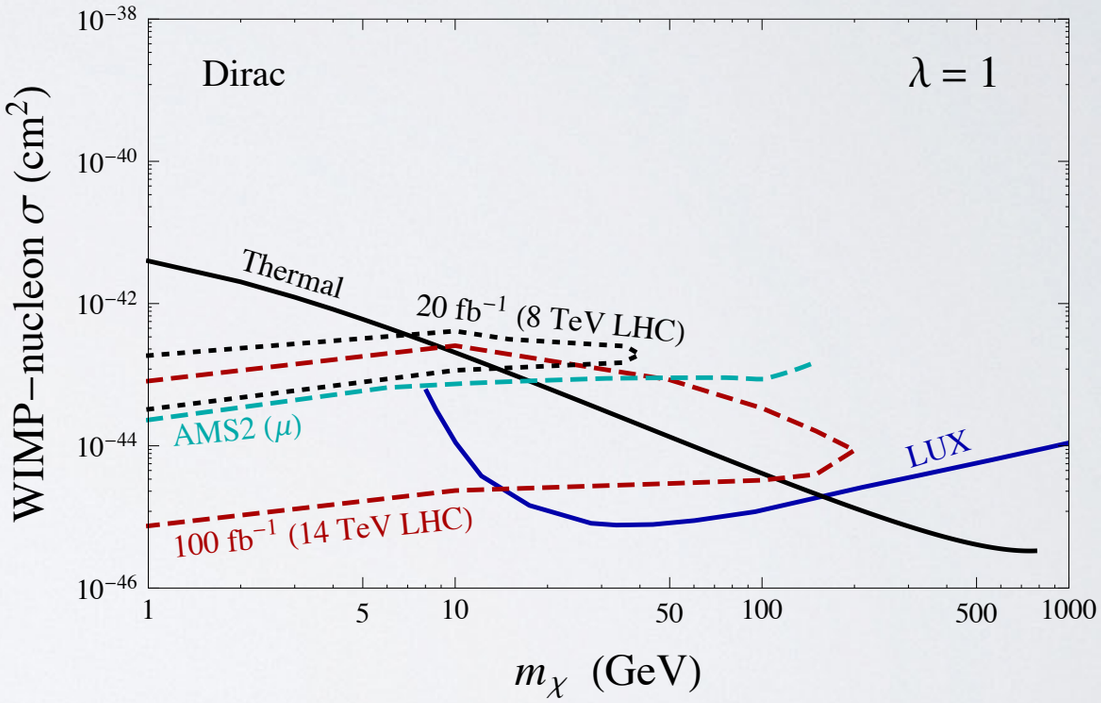
Dirac DM



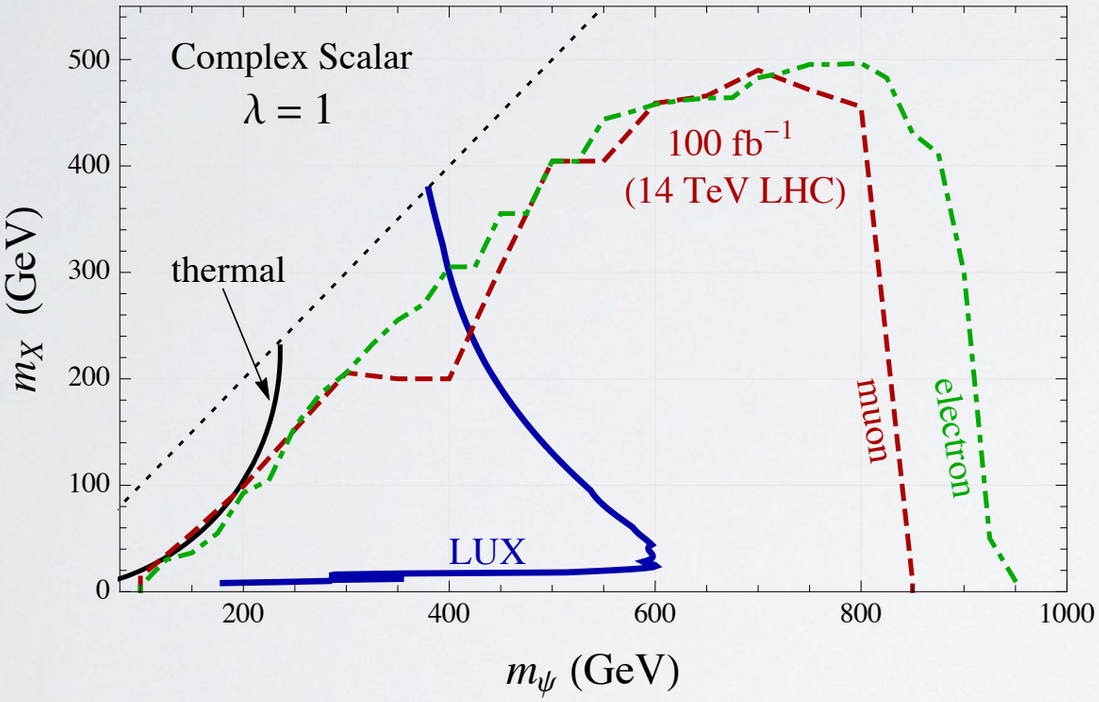
Complex Scalar DM

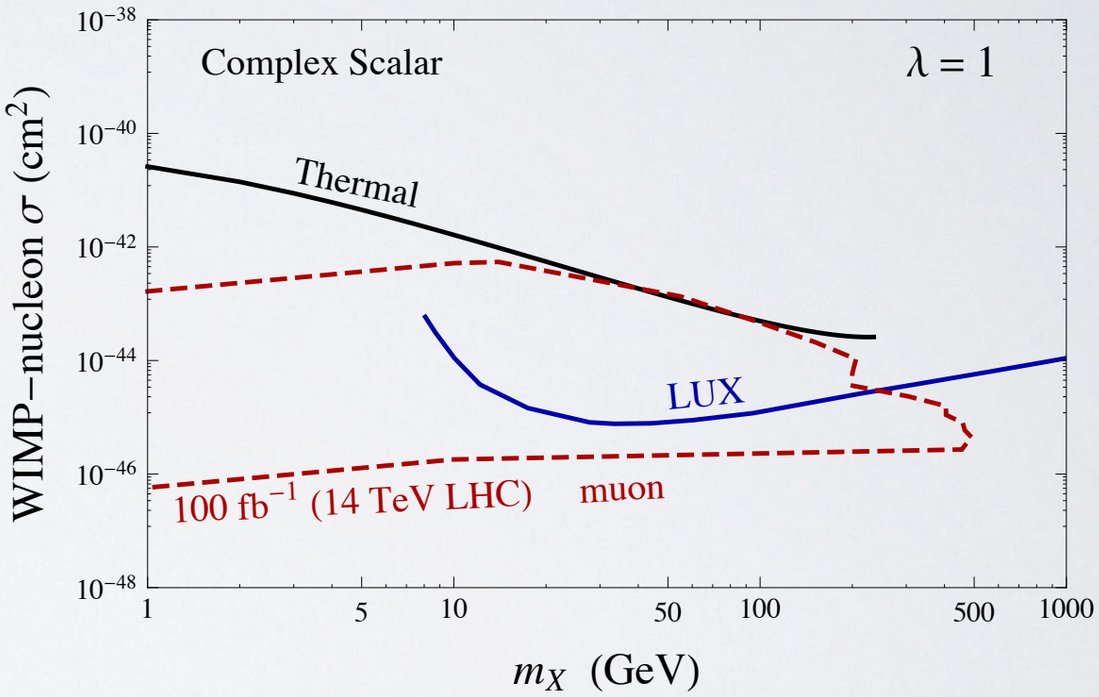
COMBINED FERMION RESULTS





COMBINED SCALAR RESULTS





LEPTON PORTAL WRAP UP

- Lepton portal models have a rich array of signatures, with parameter space waiting to be explored

- All three methods of DM search (+ g-2) provide important constraints

CONCLUSIONS

STATUS REPORT

- Effective theories may not be sufficient to make predictions for all DM searches

- The fermion portal framework is one possible simple alternative

- It exhibits complementarity between various searches for both quark and lepton couplings

FUTURE PROGRESS

- More complete study of collider constraints
- Distinctive features in interaction spectra
- From experiment: More data from LUX, AMS-02 = pulsars?, new g-2, LHC13+, ILC?