HIDDEN SECTORS: INDIRECT AND DIRECT SEARCHES

REBECCA LEANE
SLAC NATIONAL ACCELERATOR LABORATORY

CF-01 SNOWMASS MEETING
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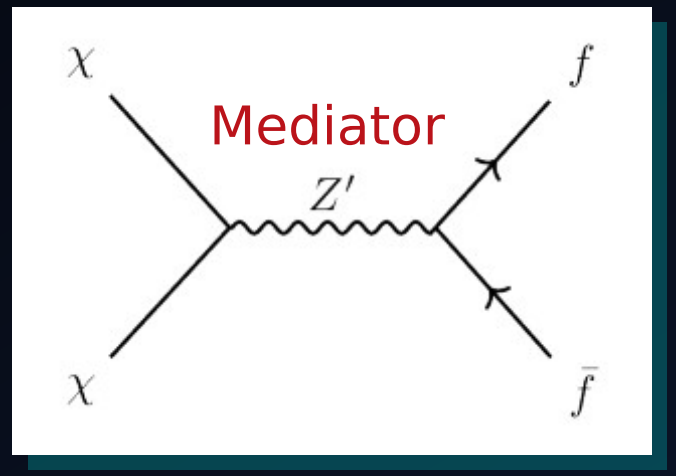
Dark Sectors

- Standard Model (SM) mediated WIMP processes, e.g. with Z bosons, extremely constrained
- Need new fields beyond the SM!
- These can mediate interactions between the dark sector, and the SM

DM



SM

Couplings can in principle be sizeable

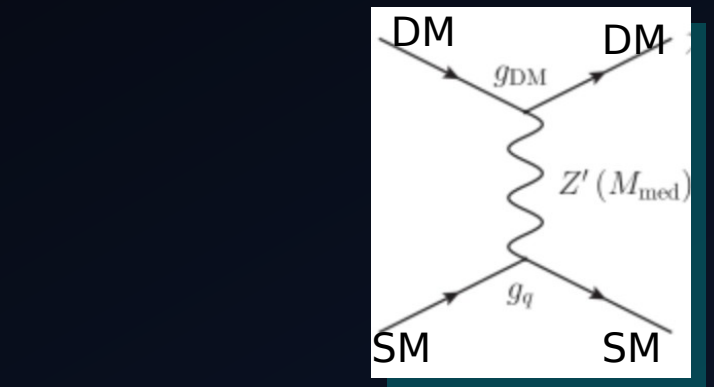
Hidden dark sectors:

- New fields that have small couplings to the SM
- Naturally occurs in many model scenarios; symmetry only softly broken, or Higgs may have mass coupling dependence, etc
- If zero coupling to the SM, can’t detect the DM!
- Need to interact at least very weakly with the SM to probe at particle experiments

Searching for hidden dark sectors

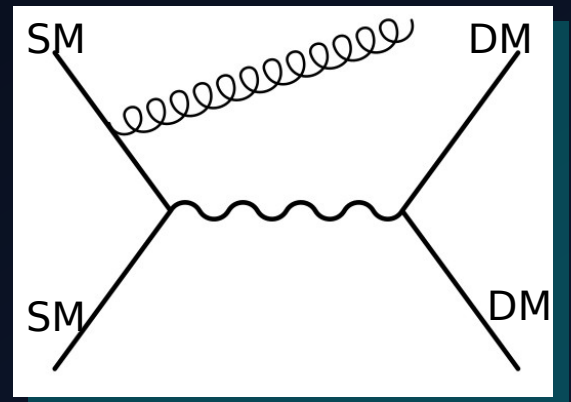
- Small coupling to SM minimize constraints from direct detection or colliders
  - Difficult but not impossible to probe!

Scattering



Suppressed :(

Production

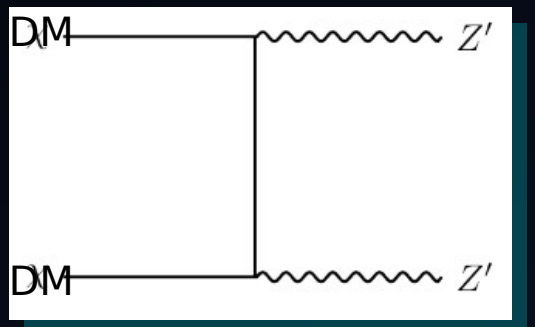


Suppressed :(

Searching for hidden dark sectors

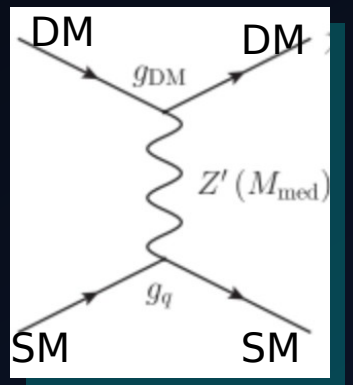
- Small coupling to SM minimize constraints from direct detection or colliders
  - Difficult but not impossible to probe!
- Large signals still possible for indirect detection!
  - Cross section independent of SM coupling if particles produced on shell
  - Only then multiplied by branching fraction

Annihilation



Not suppressed :)

Scattering



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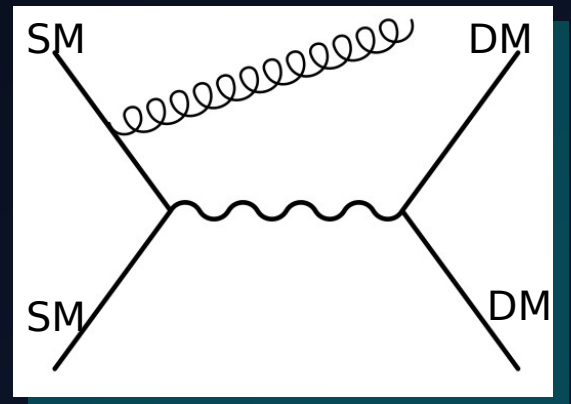
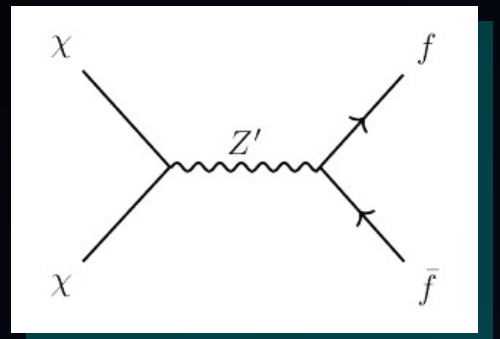


Suppressed :(

Targets for searches?

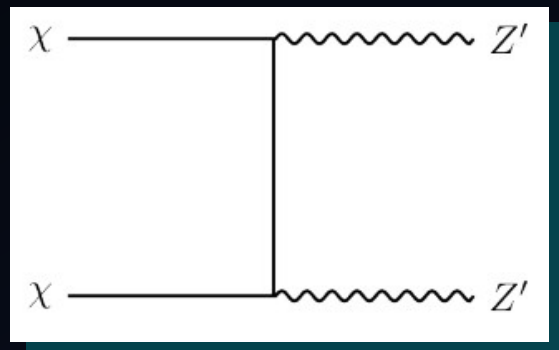
Relic abundance: important target

Non-hidden sector

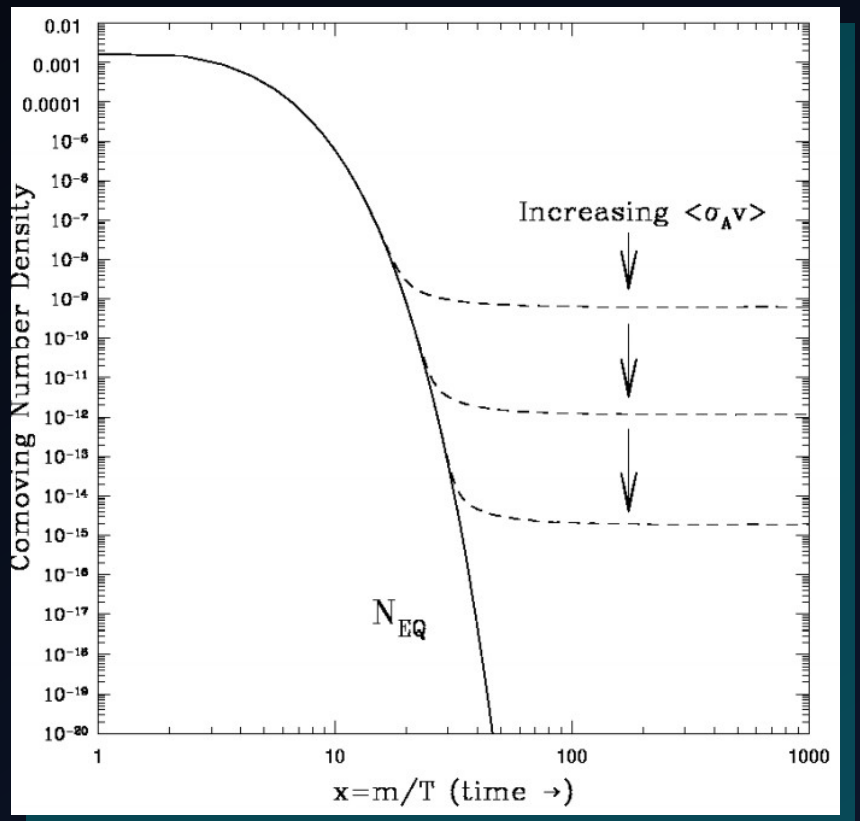


Two powers of coupling to SM

Hidden sector



$$\langle \sigma v \rangle \sim \frac{g_\chi^4}{m_\chi^2}$$



Abundance set by dark sector!

Hidden Sectors: Theory Space?

- Need new fields beyond the SM, consider extensions:
  - New scalar, pseudoscalar, fermion, or vector
- Symmetries of SM restrict how these fields interact with the SM

$-\lambda_{HS}(S^\dagger S)(H^\dagger H)$ Higgs Portal

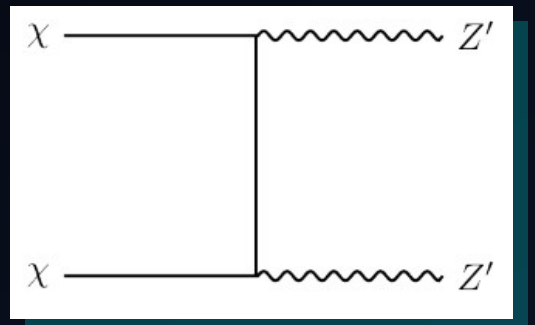
$\frac{a}{f_a}F_{\mu\nu}\tilde{F}^{\mu\nu}$ Axion Portal

$-\frac{\epsilon}{2}B_{\mu\nu}Z'^{\mu\nu}$ Hypercharge Portal

$y_n LHN$ Fermion Portal

Generally easiest to parameterize searches by generic masses and couplings

Indirect detection: probing annihilation



Indirect Detection: Hidden Sector Targets

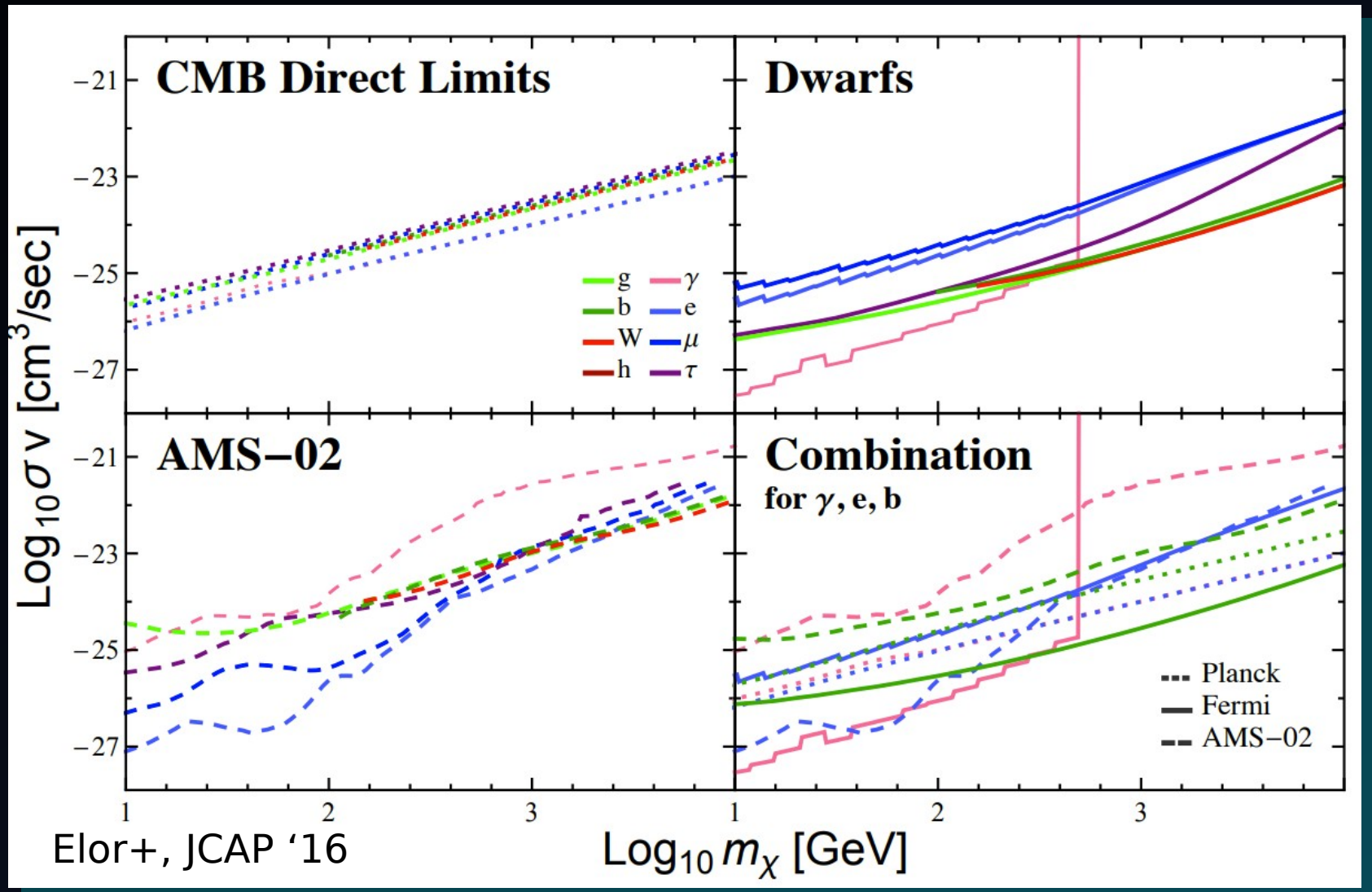
- Relic cross section:
  - Assuming models with s-wave annihilation, still comparable to rate for 2→2 cross section. Same (approximate) target for many models at once
  - Can of course vary for different models

- Explaining excesses:
  - Galactic center gamma-ray excess origin still unknown;
    - if DM, hidden sectors popular to explain potential particle nature
  - Overlaps with other excesses? Antiprotons?

Indirect Detection: Model Independent

Planck, CMB

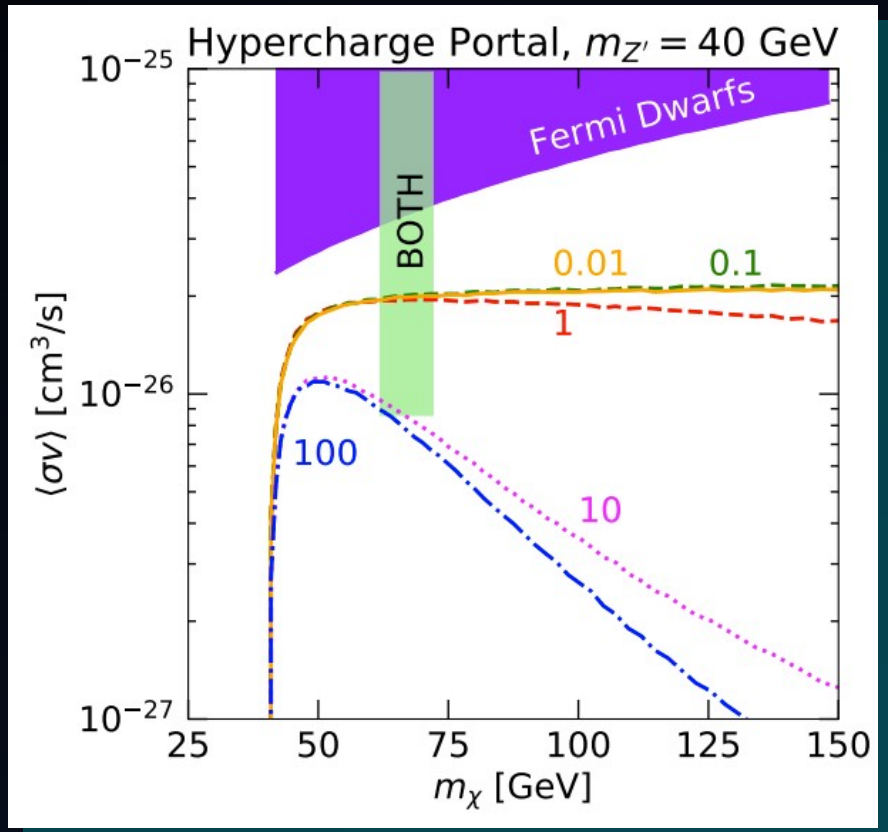
AMS, positron fraction



Elor+, JCAP ‘16

Fermi, Dwarf Spheroidal Galaxies

Indirect Detection: Hypercharge Portal

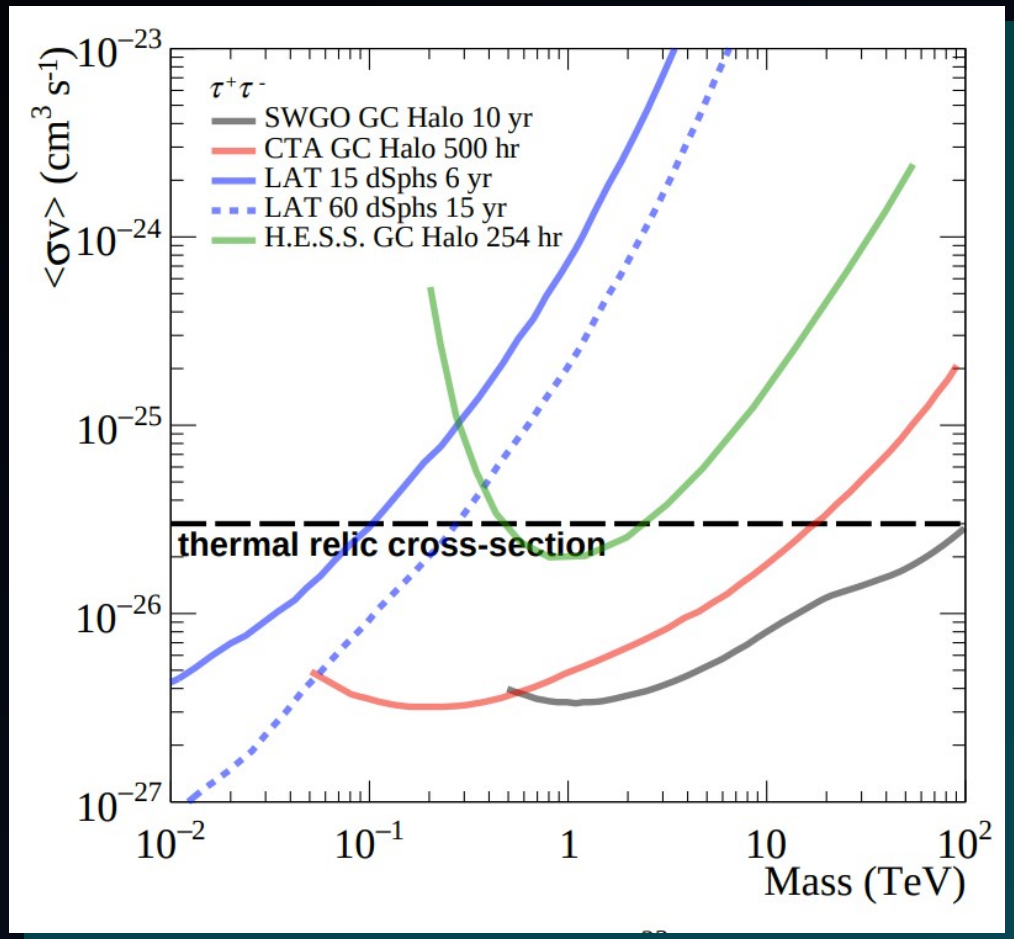


Hooper, **RL**, Tsai, Wegsman, Witte, JHEP '20

Labeled numbers are relic density, ratio of vector to axial-vector couplings

"Both" region overlaps with Galactic Center gamma-ray excess, and antiproton excess!

Indirect Detection: Future



Viana+, JCAP ‘19

Southern Wide Field of View Gamma Ray Observatory (SWGO) + Cherenkov Telescope Array (CTA) upcoming!

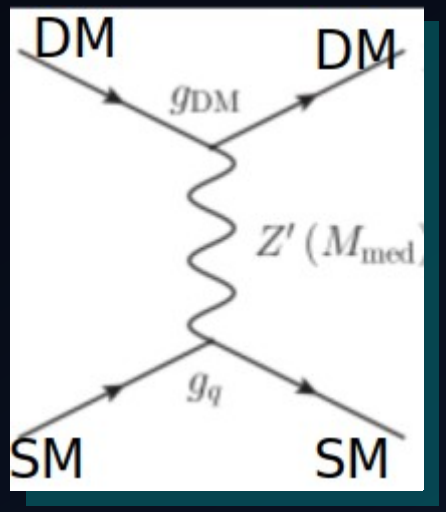
Fermi (LAT): more dwarfs!

For hidden sectors, results generally softened by factor ~few

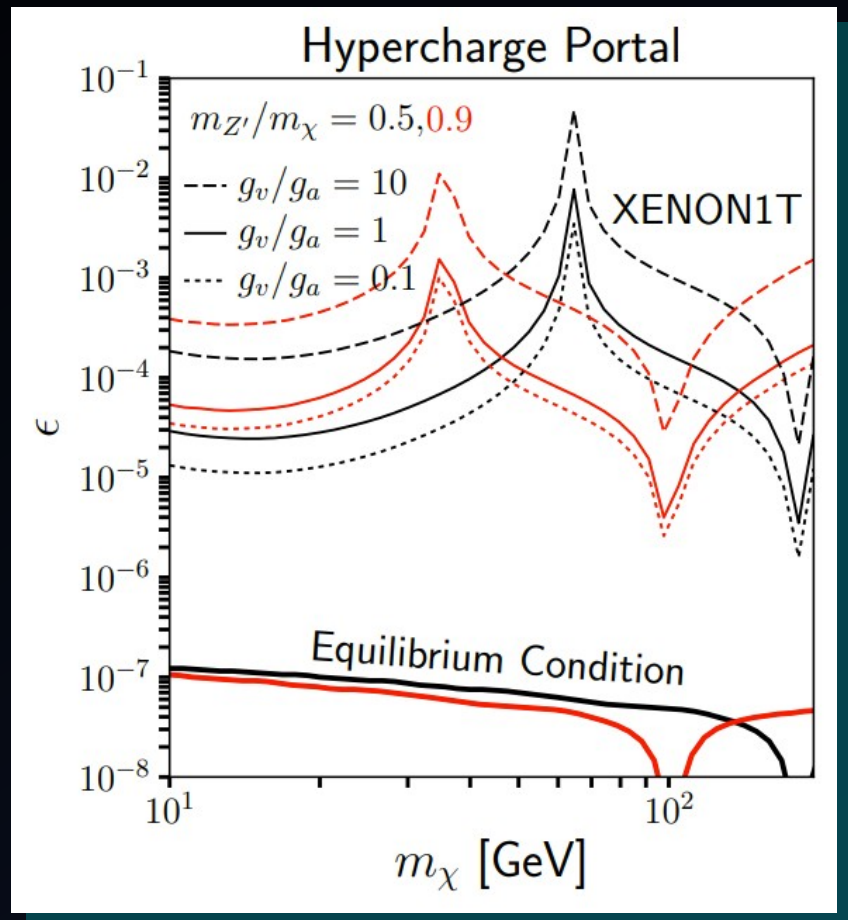
Potentially can cover Galactic Center Excess favored region

NB: improvements here are only gamma rays

Direct detection: probing scattering



Direct Detection: Hypercharge Portal



Hooper, **RL**, Tsai, Wegsman, Witte, JHEP '20

- Qualitatively similar story for other models
- Xenon1T strongest limits
  - Shown with relic density fixed (which doesn't depend on mixing)
- Can also be bound by assumption of equilibrium
- What more can we do?
  Neutrino floor limitation, expect about an order of magnitude lower in coupling bounds
- Keep in mind however some models may have further suppressed direct detection (i.e. spin-dependent only)

SUMMARY

- Hidden dark sectors: DM exists in own sector, mediating particle(s) have small couplings to SM

- Direct detection (and collider) bounds greatly weakened
  - Can still probe parameter space, but too feeble coupling may be out of reach

- Indirect detection not suppressed
  - Hidden sectors can explain astrophysical anomalies
  - Target thermal relic cross section can be probed
  - Progress in near future, joint-telescope approach

- Interplay interesting moving forward: increased DM parameter space can be probed with all experiments, though indirect detection likely most informative

EXTRA SLIDES

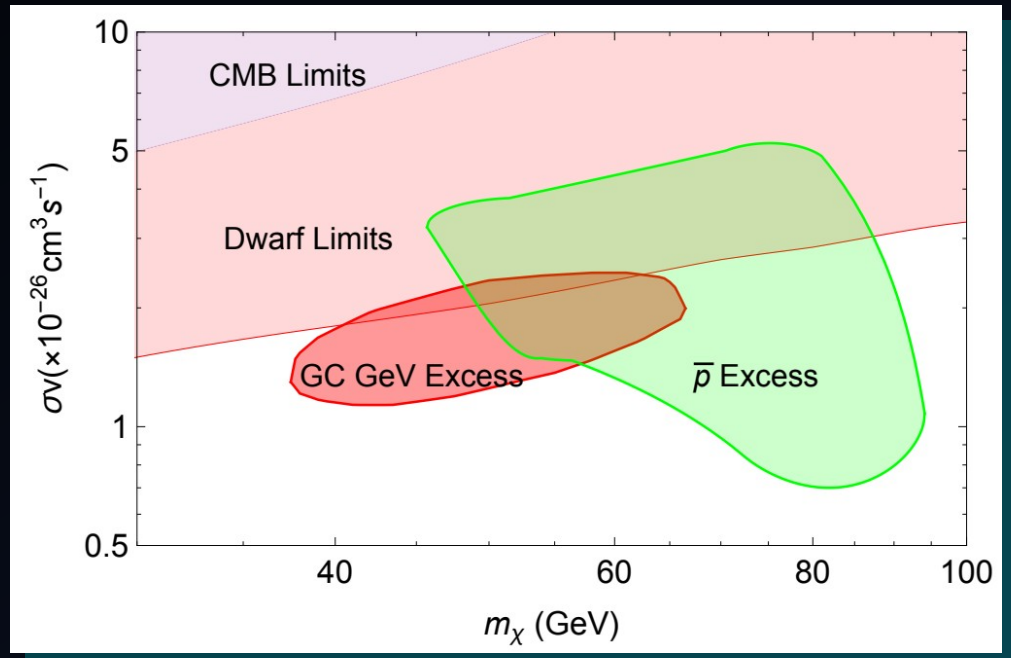
Rebecca Leane

To include specific models, or not...?

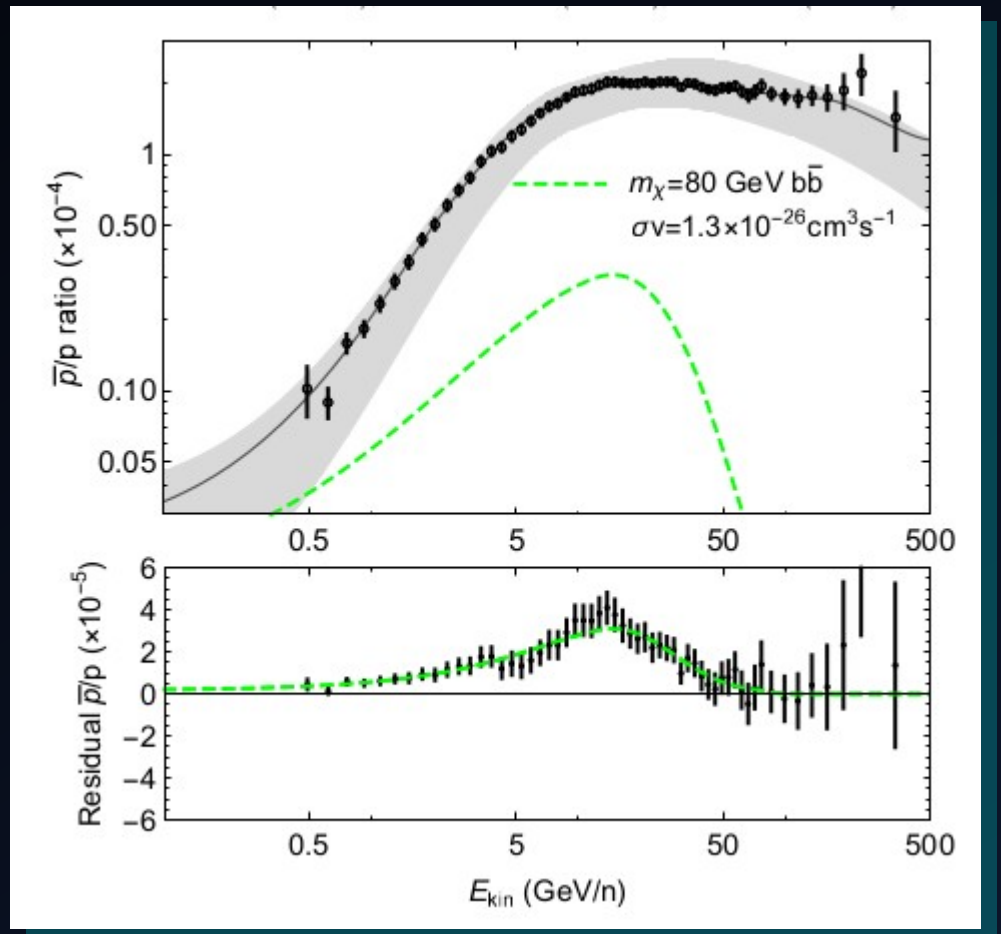
- Reasons for specifying model:
  - Accurately calculating thermal relic cross section
  - Fully capture all phenomenology
  - Can clearly interpret/fit to an excess
  - Can clearly compare with other experiments
- Reasons against specifying model:
  - Lots of models, unclear which is correct *(big reason)*
  - Can instead just parameterize in terms of minimal ingredients, e.g. mass, coupling (see simplified models)

ANTIPROTON EXCESS

- Excess in antiprotons
- AMS correlated uncertainties?
- Link to GCE?

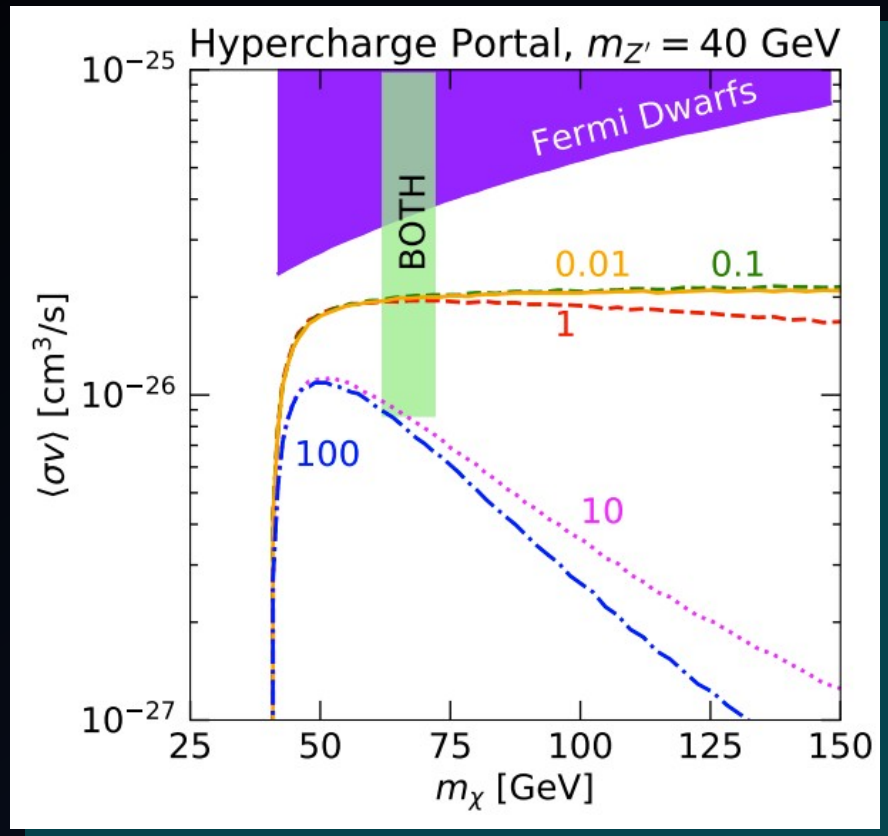


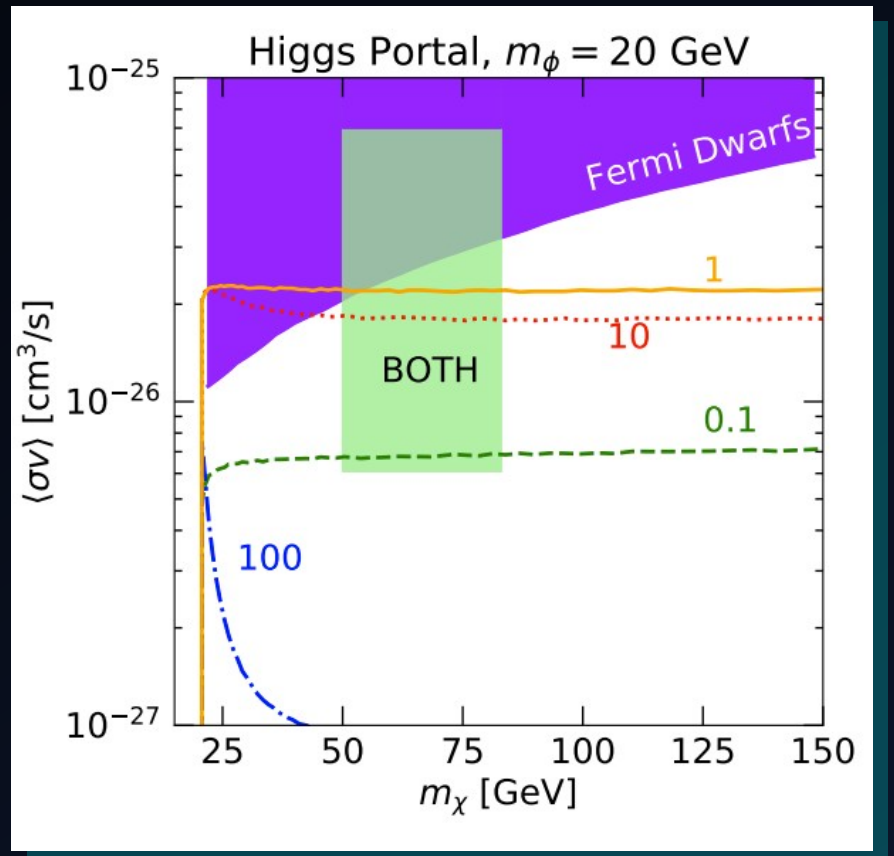
Cholis et al ‘19



Cuoco et al ‘16 and ‘19, Cui et al ‘16 and ‘19, Cholis et al ‘19

Indirect Detection: Model Dependent





Hooper, **RL**, Tsai, Wegsman, Witte, JHEP '20

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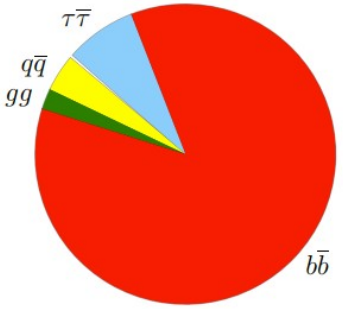
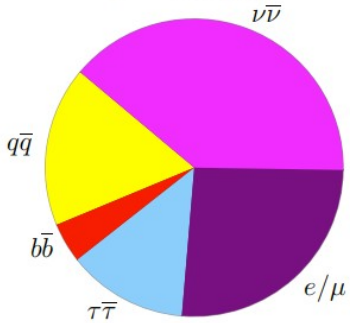
Hypercharge Portal

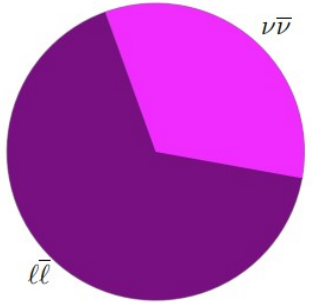
Higgs Portal



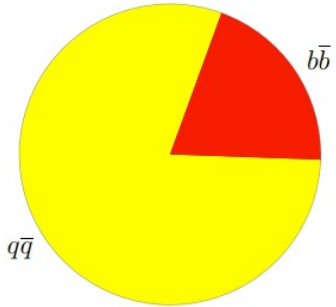
$B - L$ Portal



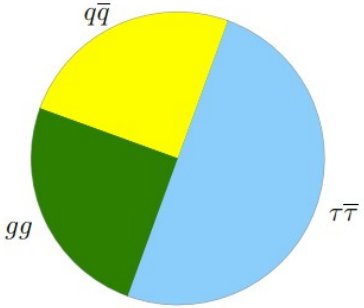
$L_i - L_j$ Portal



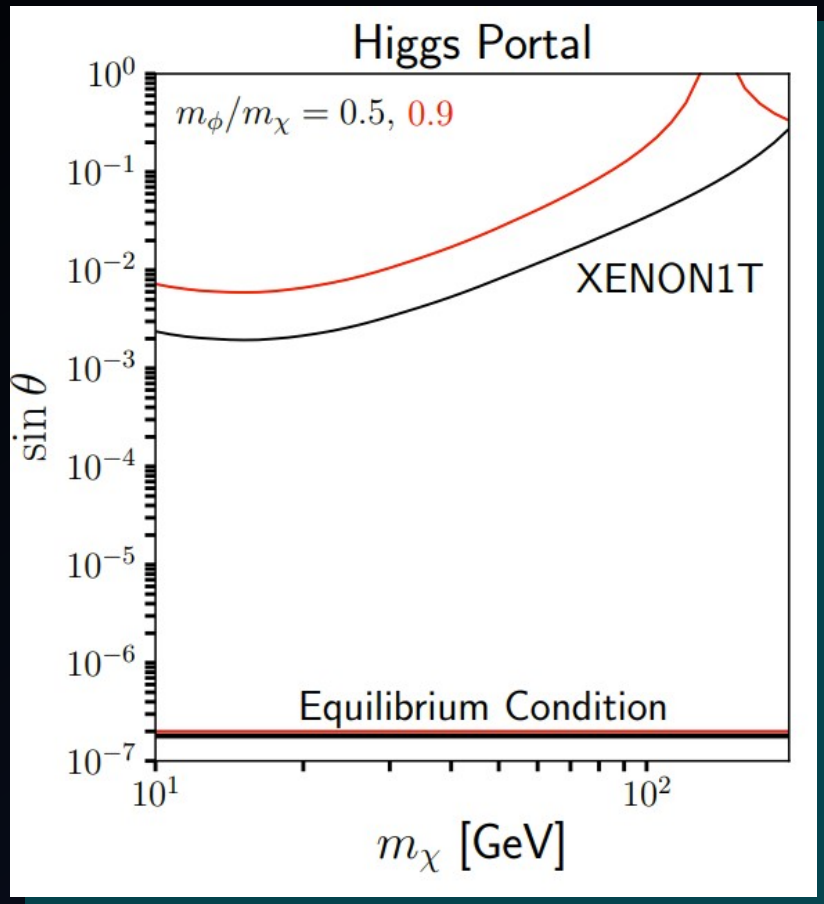
Baryon Portal



2HDM Portal



Direct Detection: Higgs Portal



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Hooper, **RL**, Tsai, Wegsman, Witte, JHEP '20

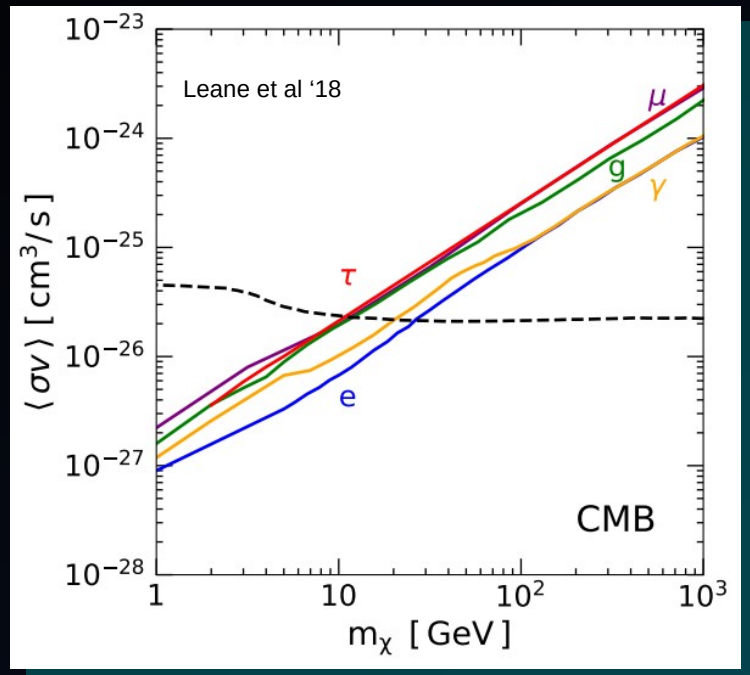
Hypercharge Portal

$$\Gamma_{Z'} = \sum_f \frac{m_{Z'} N_c}{12\pi} \sqrt{1 - \frac{4m_f^2}{m_{Z'}^2}} \left[g_{fV}^2 \left(1 + \frac{2m_f^2}{m_{Z'}^2} \right) + g_{fA}^2 \left(1 - \frac{4m_f^2}{m_{Z'}^2} \right) \right]$$

$$g_{f_R, f_L} = \epsilon \left(\frac{m_{Z'}^2 g_Y Y_{f_{R,L}} - m_Z^2 g \sin\theta_W Q_f}{m_Z^2 - m_{Z'}^2} \right)$$

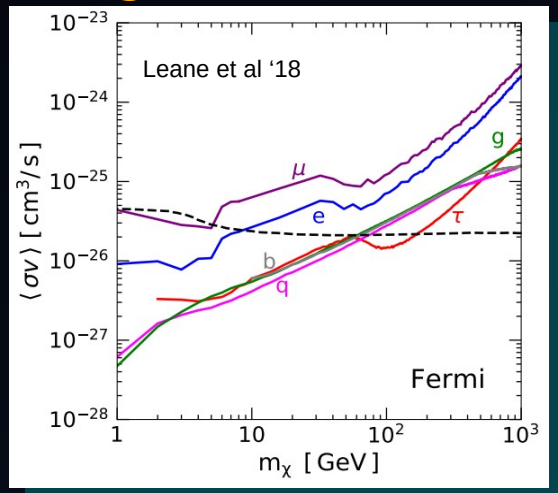
BOUNDS

Strongest low mass

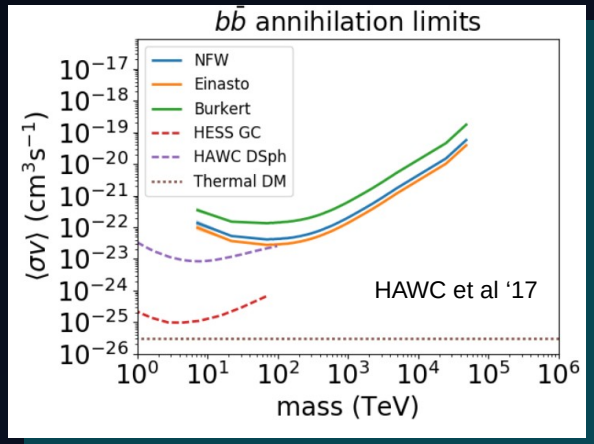


Also see Slatyer '15

Strongest for hadrons

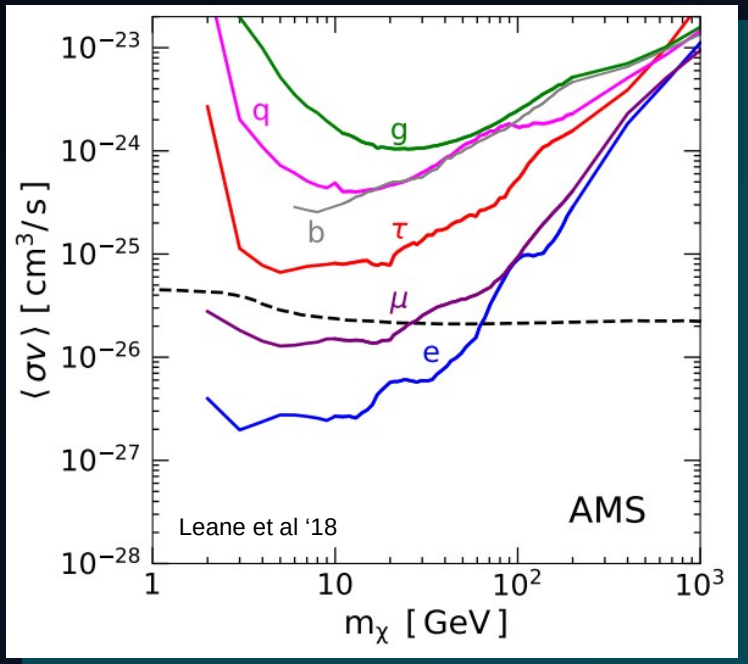


Also see Fermi Collab '16



Rebecca Leane

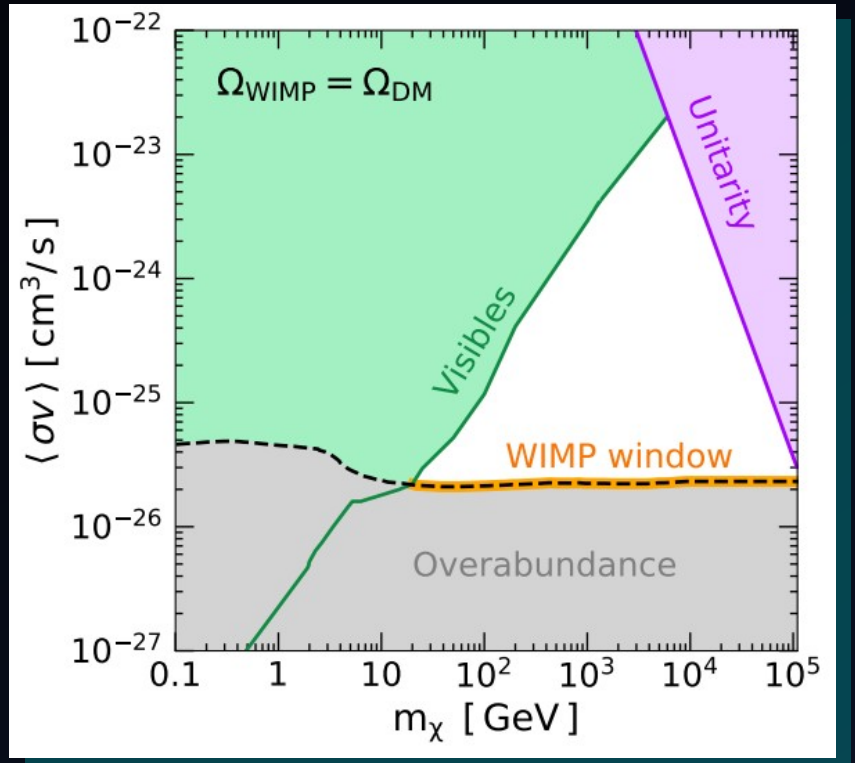
Strongest for leptons



Also see AMS collab '14

(strongest *and most robust* bounds)

COMBINING ALL CONSTRAINTS



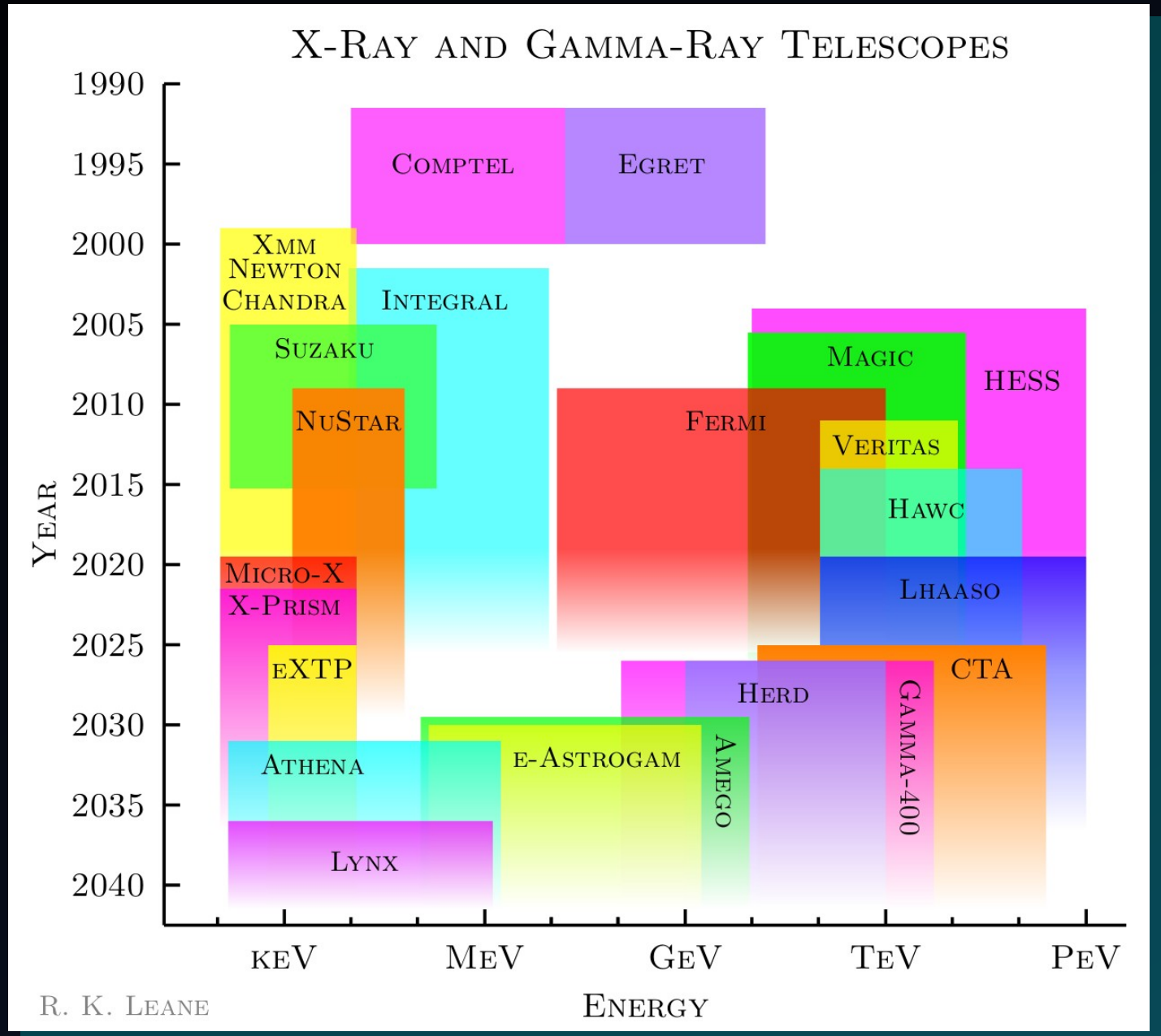
WIMP is not dead!

RL, Slatyer, Beacom, Ng ‘18

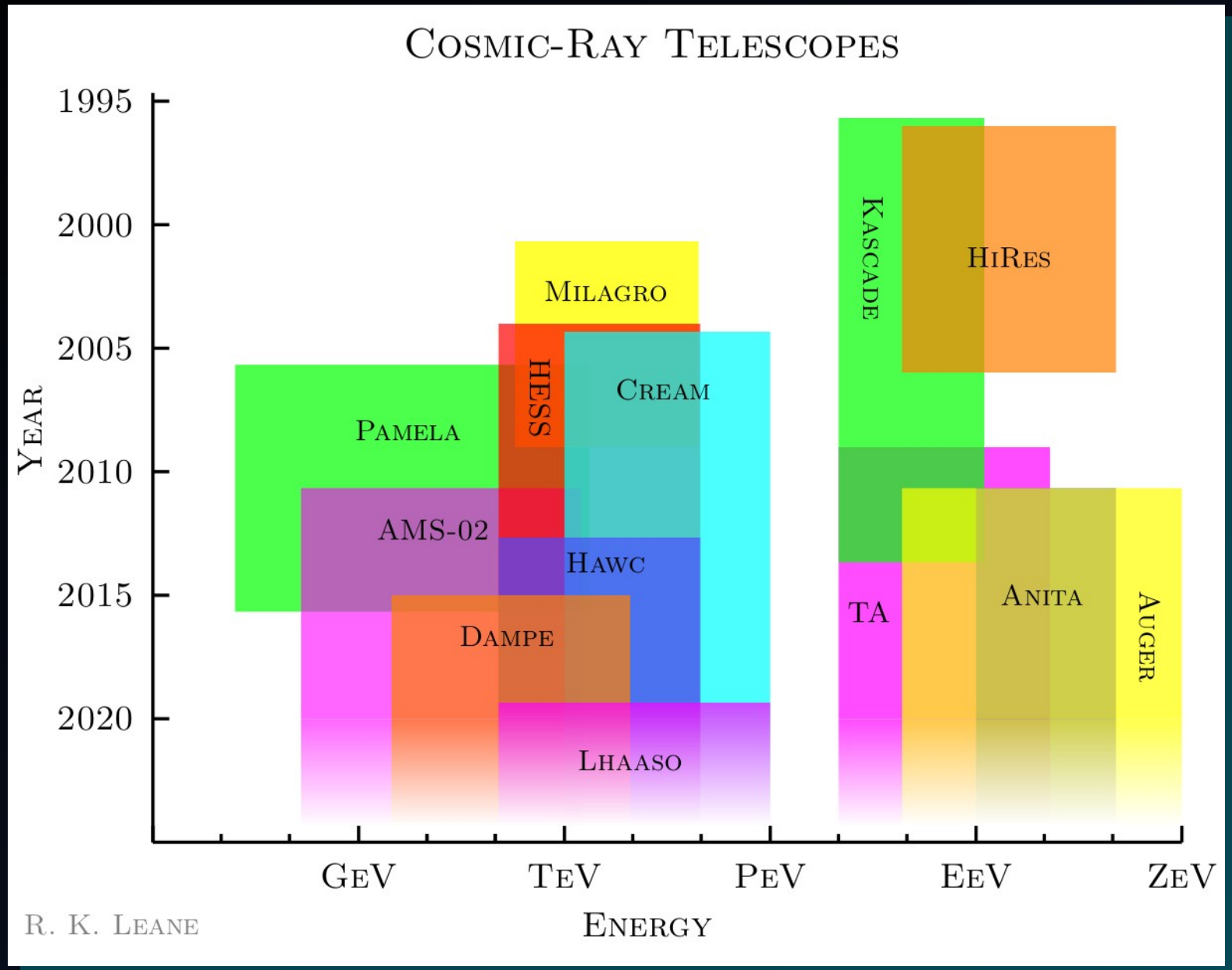
S-wave 2→2 thermal DM to visible states must have mass greater than 20 GeV

Indirect detection: now

- Gamma rays, best annihilation sensitivity is:
  - GeV DM: Fermi measurements of dwarf spheroidal galaxies
  - TeV DM: HESS measurements of Galactic Center
- Charged cosmic rays, best annihilation sensitivity:
  - GeV DM: AMS electron/positrons
  - TeV DM: DAMPE
- Planck measurements of CMB, competitive for about <10 GeV

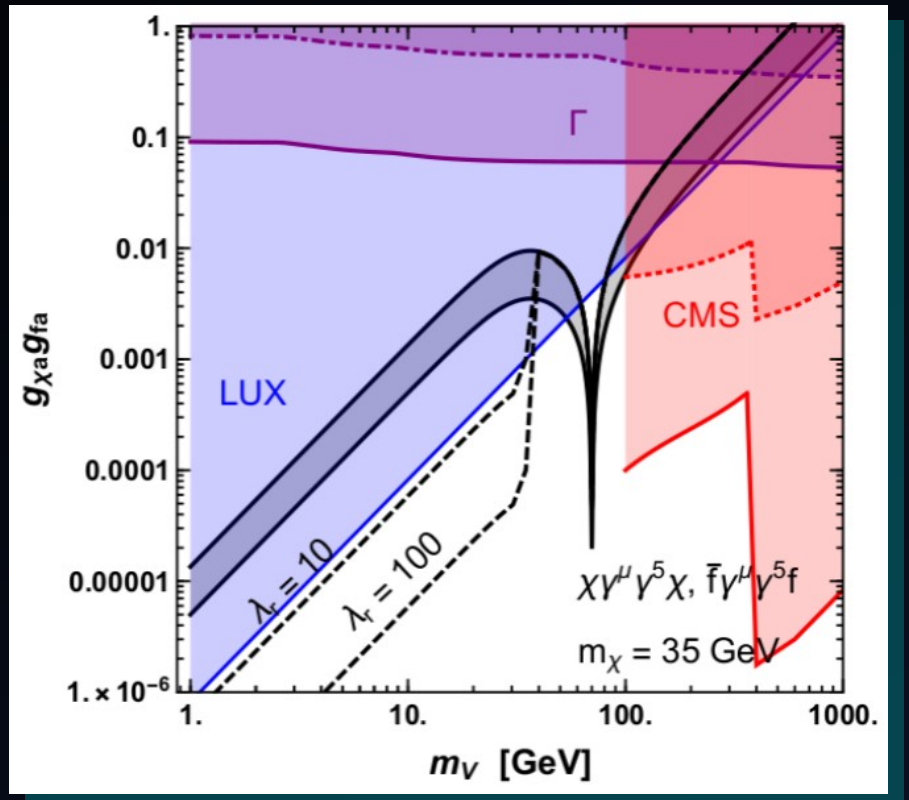


Leane, 2006.00513



Leane, 2006.00513

SPIN-1 MEDIATOR SIMPLIFIED MODEL

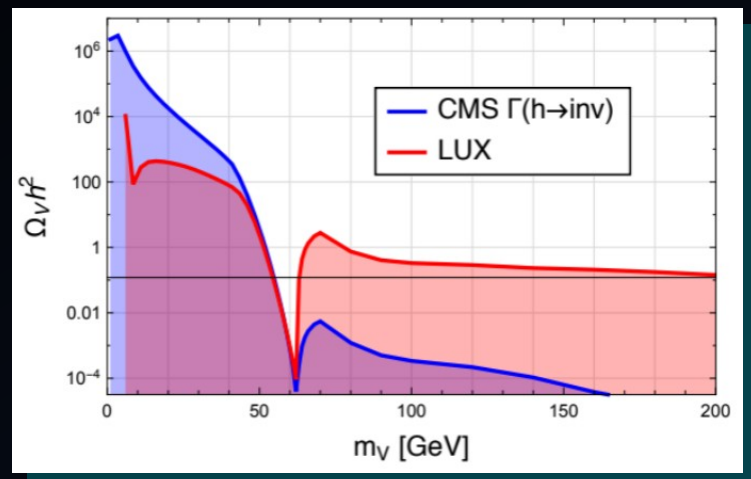


Escudero et al ‘16

- Vector mediator: don’t even go there
- Axial vector mediator: DD suppressed, better, but have to be right on resonance (note new DD bounds…)

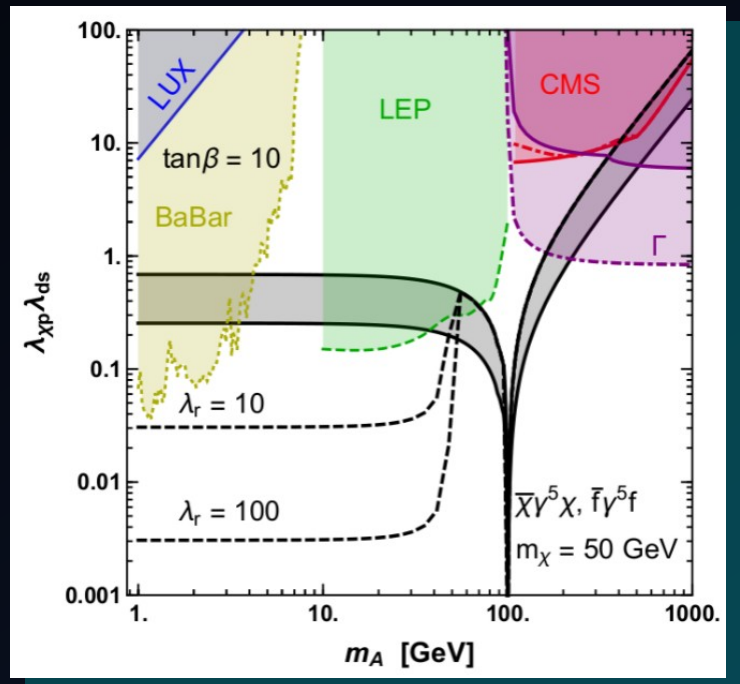
SPIN-0 MEDIATOR SIMPLIFIED MODELS

Higgs portal, spin-1 DM



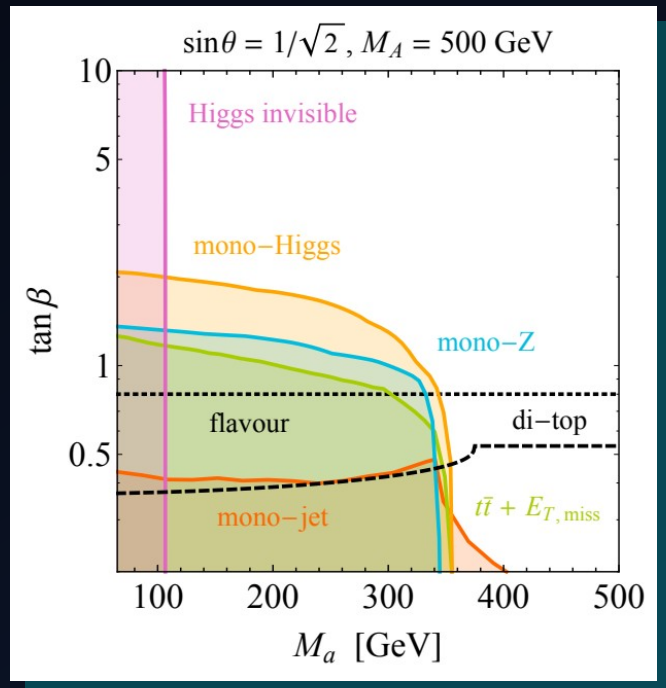
DiFranzo et al ‘15
(also see Djouadi et al ‘11)

2HDM



Escudero et al ‘16

2HDM+pseudoscalar

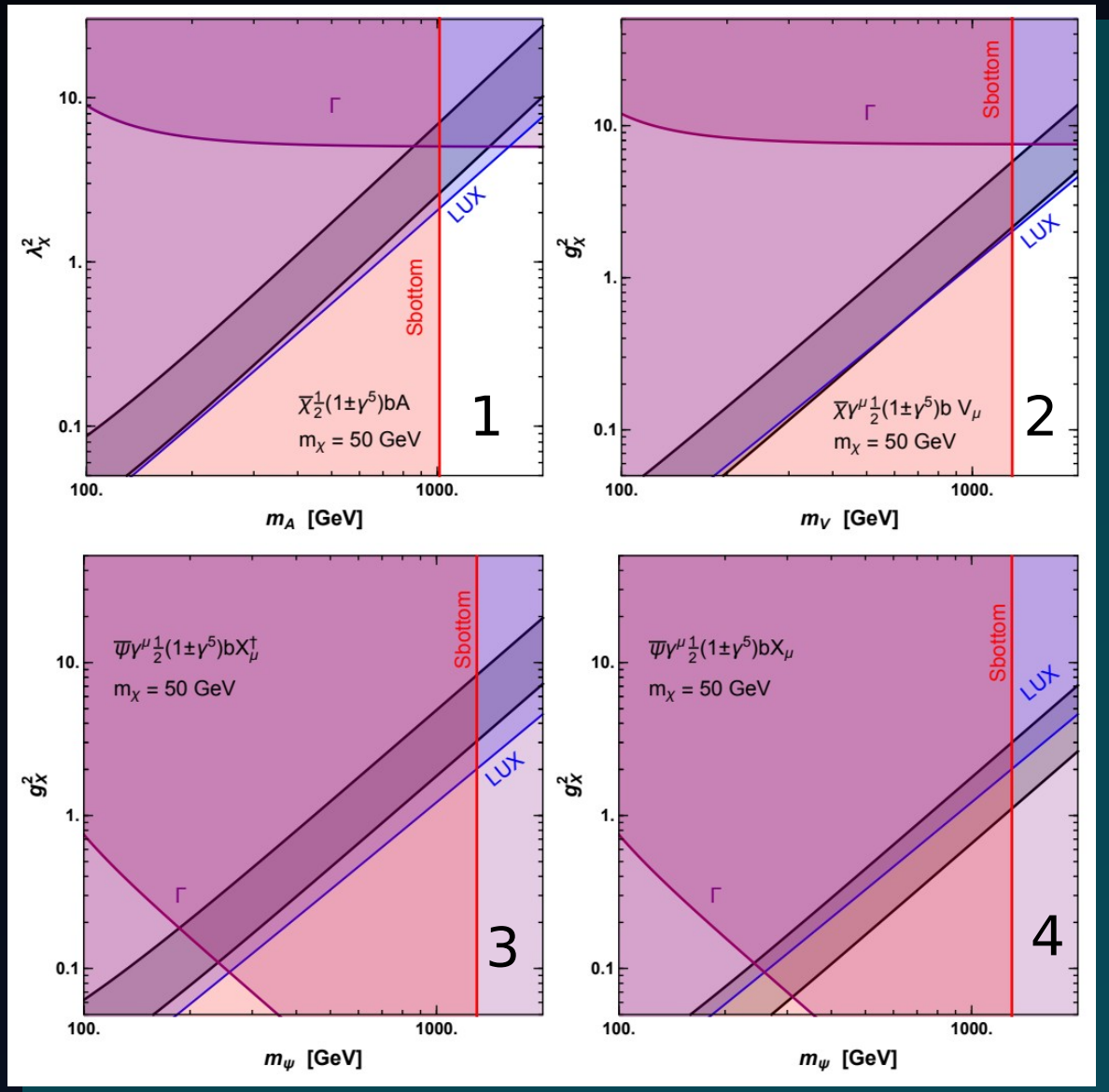


Bauer et al ‘17
(also see Ipek et al ‘14)

T-CHANNEL PROCESS

1. Dirac DM + scalar med
2. Dirac DM + vector med
3. Complex vec DM + fermonic med
4. Real vec DM + fermonic med

T-channel is out.
All excluded from CMS sbottom search and direct detection !



Escudero et al ‘16

Some specific models

- Hypercharge portal: only renormalizable theory (dark photon)
- Still can consider other vector portals, including:
  - Gauged B-L, gauged lepton, or baryon number
- Higgs portal
- Combined vector and scalar portals (can be required by gauge invariance)