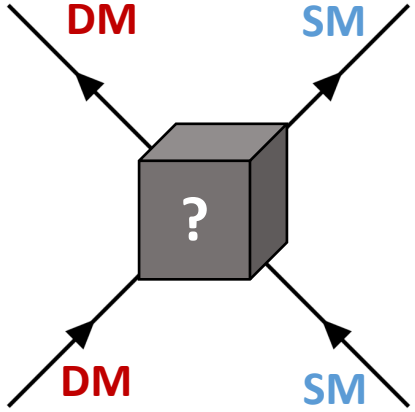
Simplified Models for Dark Matter Searches



Suzan Basegmez du Pree, *Nikhef, Amsterdam, Netherlands*
External Collaborators MadDM Team, UCLouvain, Belgium

Hidden Universe Kick-off Meeting, Nikhef, 30 October 2019

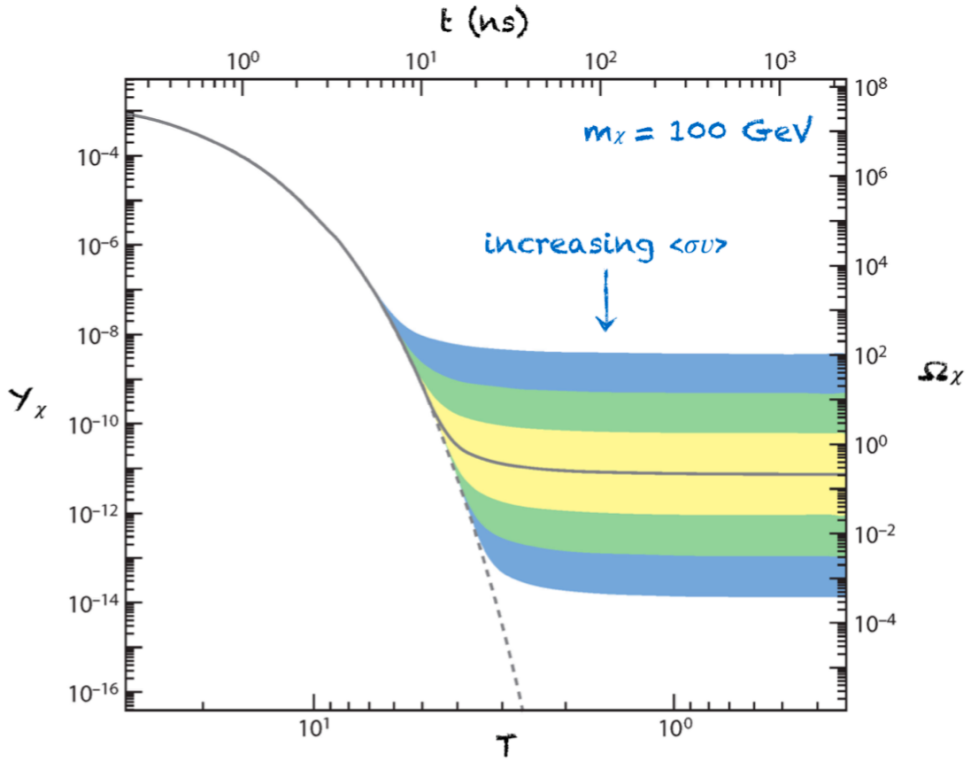
Dark Matter Searches

A New Era in the Quest for Dark Matter, G. Bertone and T. Tait, arXiv:1810.01668

Figure 1. Visualization of possible solutions to the dark matter problem.

Dark Matter Thermal Relic Density

- ✓ Although DM historically discovered in galactic (galaxy clusters) scales, cosmological observations suggest that DM is non-baryonic, stable, cold, gravitationally interacting!



- ✓ Thermal relic density (Planck Observation)

$$\Omega_{DM}\, h^2 = 0.1198 \pm 0.00015$$

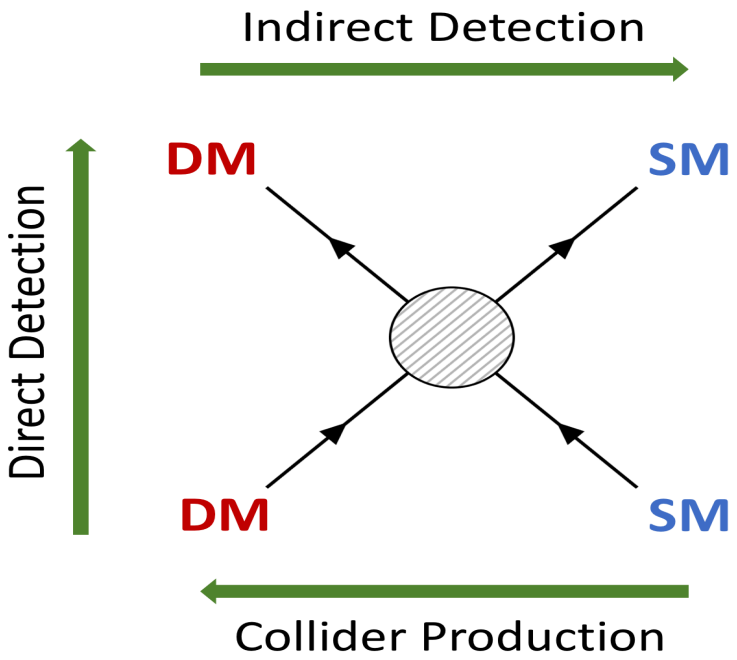
$$\langle \sigma v \rangle = 3 \times 10^{-26}\ \text{cm}^3\ \text{s}^{-1}$$

Particle Dark Matter Searches

HESS, HAWC, VERITAS, MAGIC, IceCube,…
PAMELA, FERMI, CALET, DAMPE, AMS, …

+ KM3NeT

XENON
CDEX
CDMS
CRESST
DARKSIDE
DEAP
LUX
PandaX
PICO
…



CMS and ATLAS

Particle Dark Matter Searches

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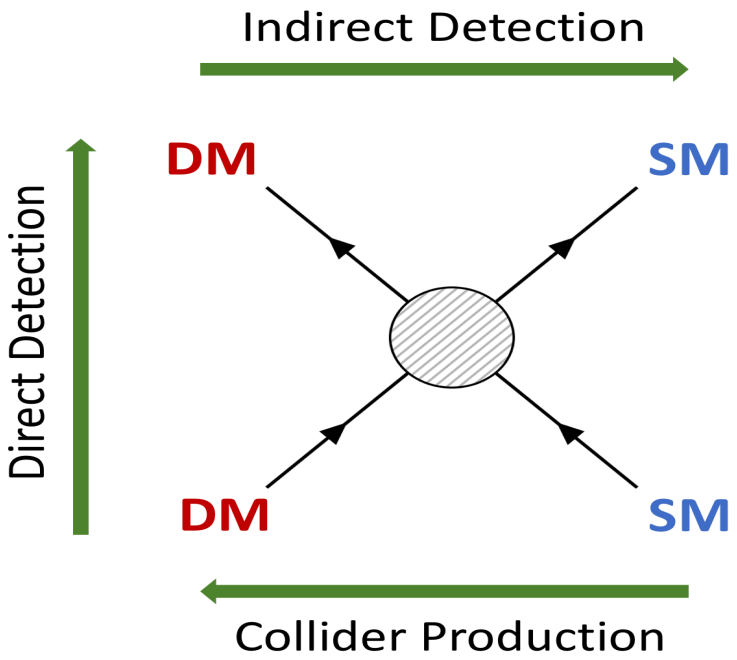
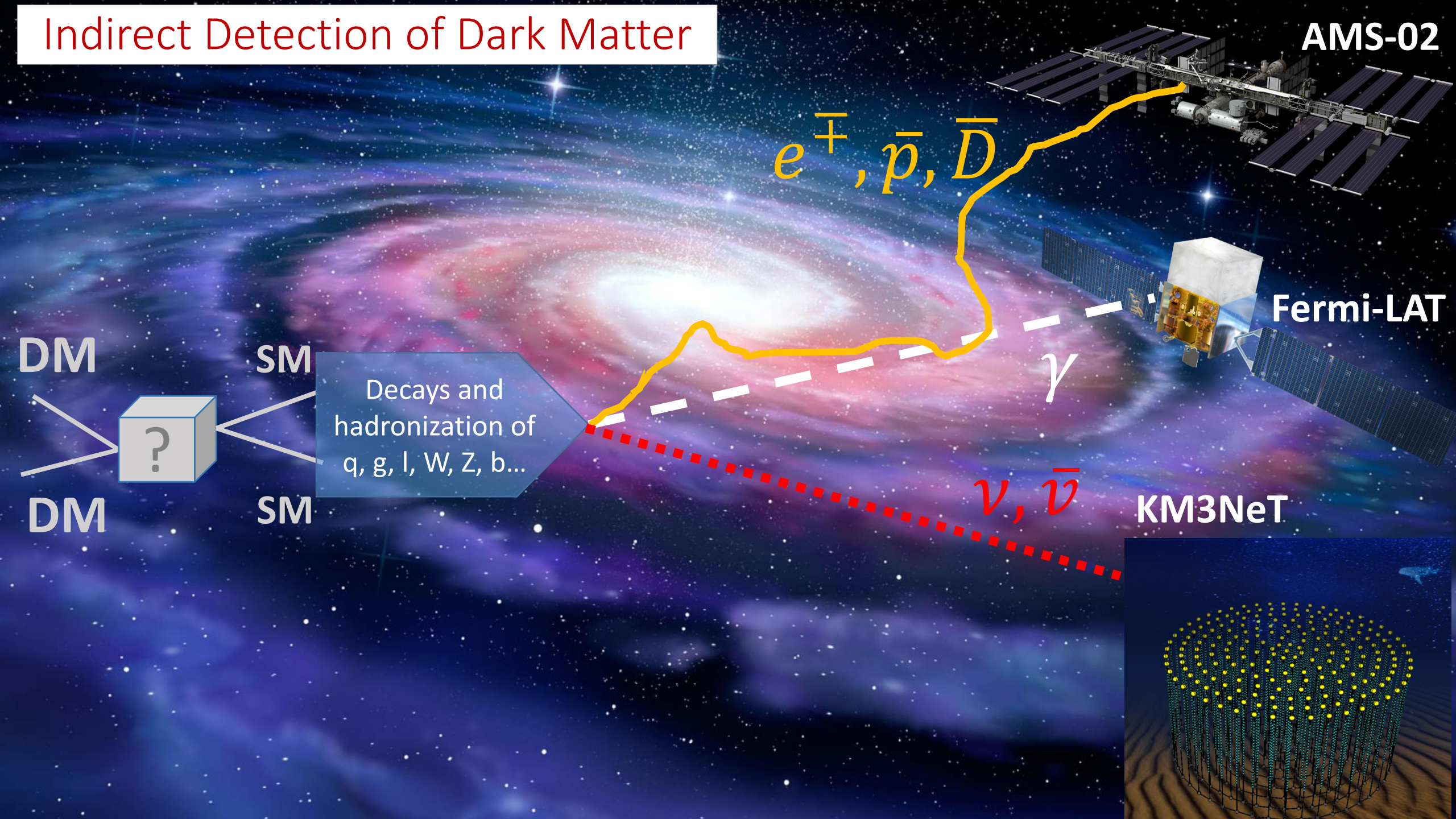


$(q, \bar{q}, g, W^{\mp}, Z, H, l^{\mp}, \ldots) \longrightarrow \gamma, e^{+}, e^{-}, p, \bar{p}, \upsilon, \bar{\upsilon}, \bar{D} \ldots$

$(q, \bar{q}, g, W^{\mp}, Z, H, l^{\mp}, \ldots) \longrightarrow \gamma, e^{+}, e^{-}, p, \bar{p}, \upsilon, \bar{\upsilon}, \bar{D} \ldots$

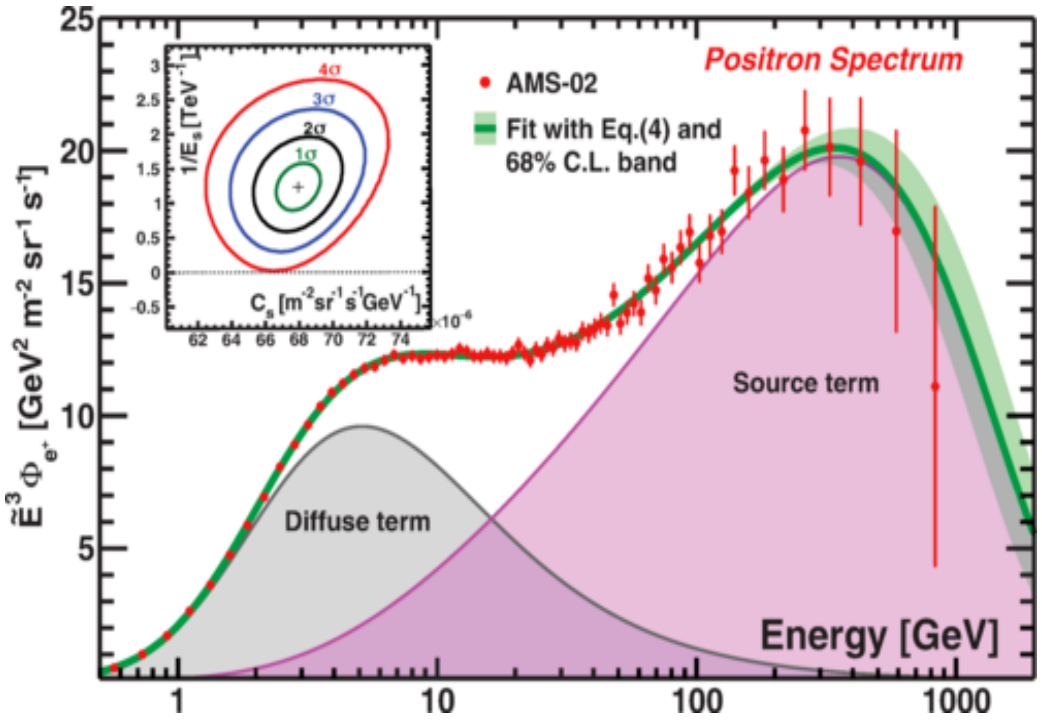
CMS and ATLAS

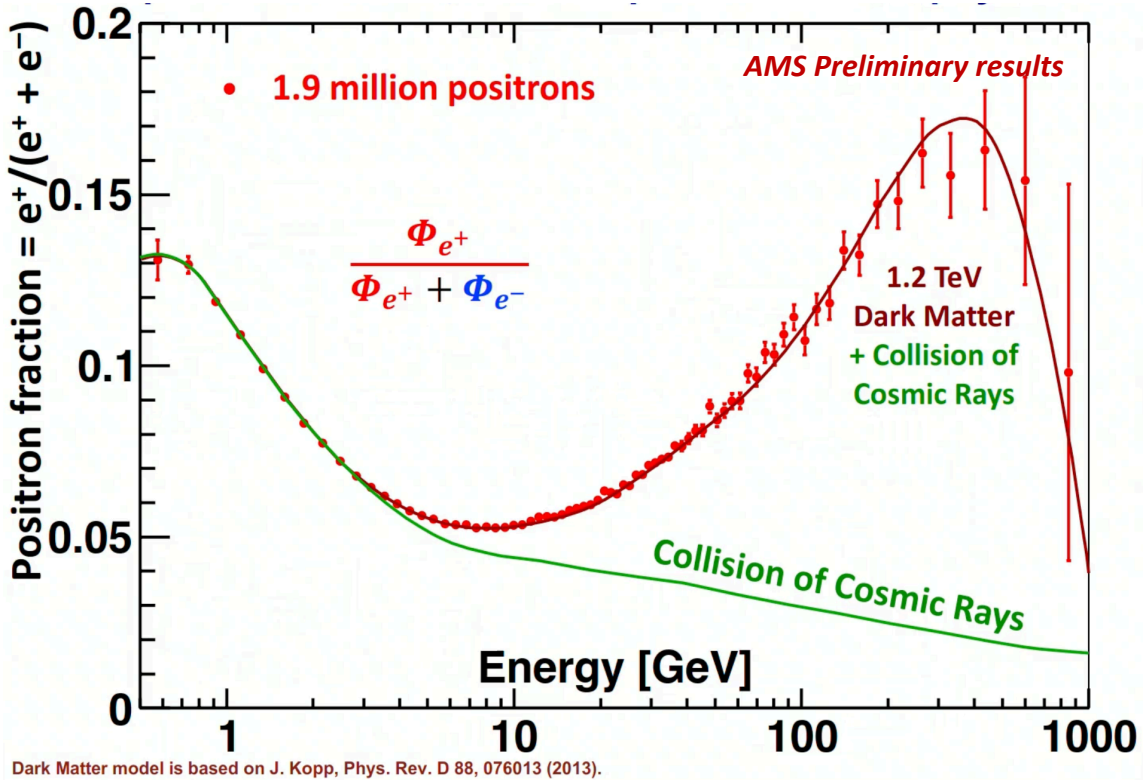
Indirect Detection of Dark Matter



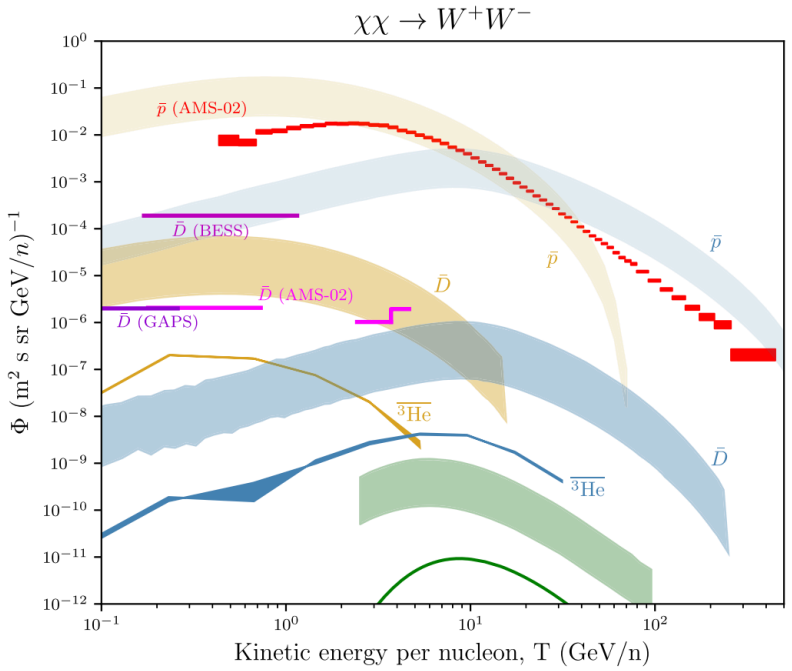
AMS-02 DM Interpretations

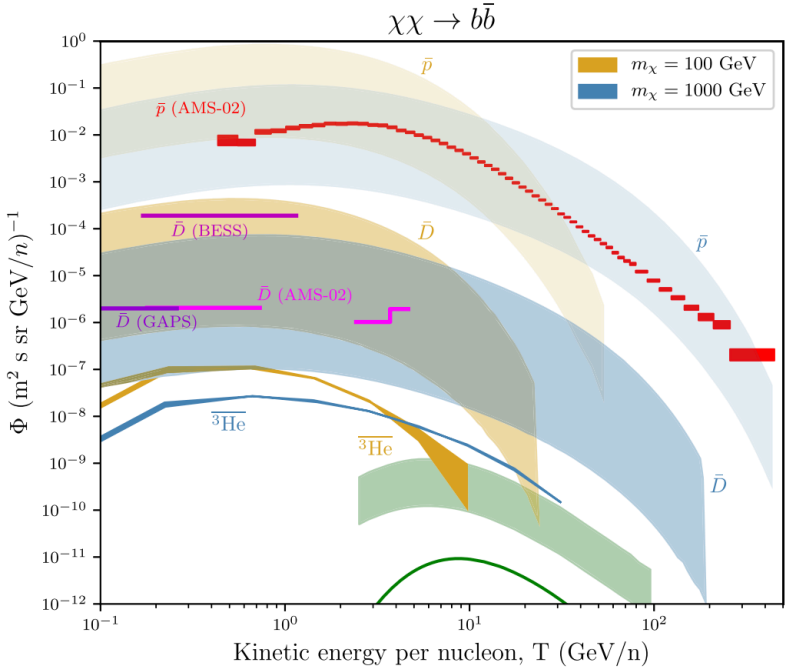
Towards Understanding the Origin of Cosmic-Ray Positrons, Phy. Rev. Let. 122, 041102 (2019)



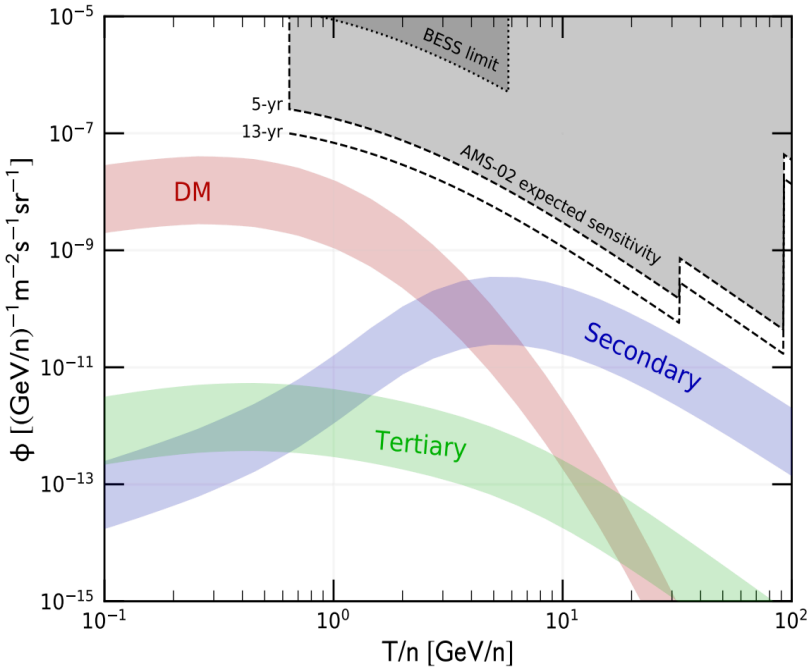


DM Searches and Interpretations





Coogan&Profumo, PRD 96 (2017)



Korsmeier et al., 1711.08465

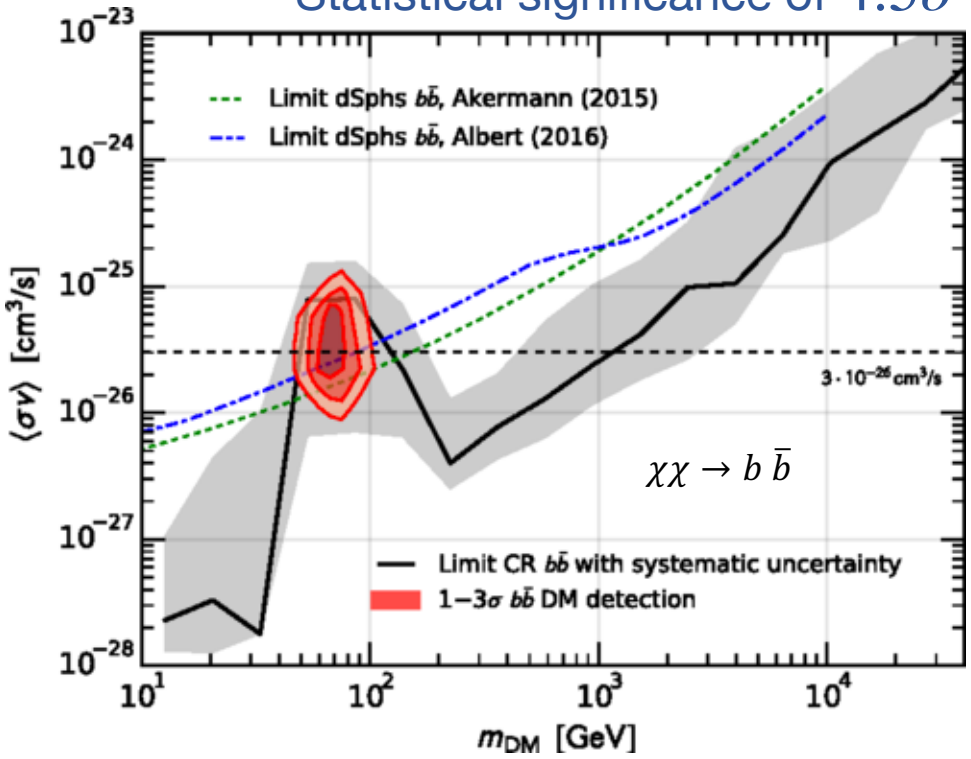
In AMS-02 6 anti-He^3 and 2 anti-He^4 event candidates. The event rate is ~ 1 anti-He for 10^8 He.

Limits on Annihilation Cross Section

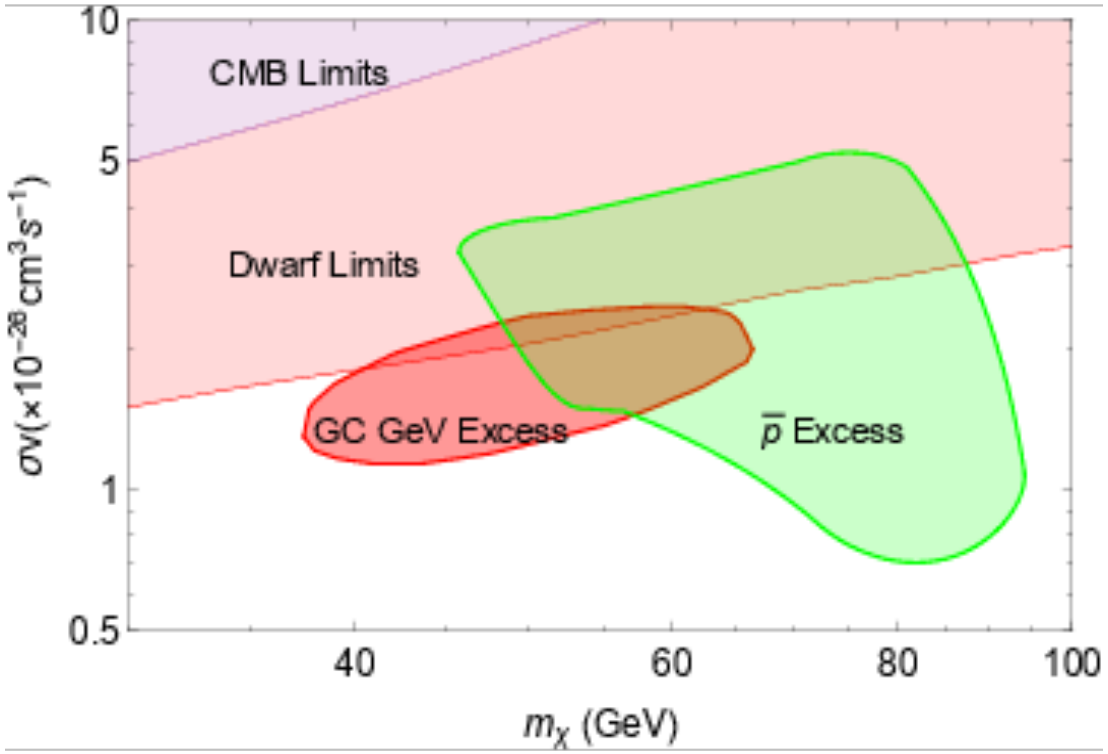
- Scrutinizing the evidence for dark matter in cosmic-ray antiprotons, A. Cuoco et al., 2019, arXiv: 1903.01472
- A Robust Excess in the Cosmic-Ray Antiproton Spectrum: Implications for Annihilating Dark Matter, D. Hooper et al., 2019, arXiv:1903.02549

A.Cuoco et al.,Phys. Rev. Lett. **118**, 191102 (2017)

Statistical significance of 4.5σ



3.3σ to 4.7σ : robust excess

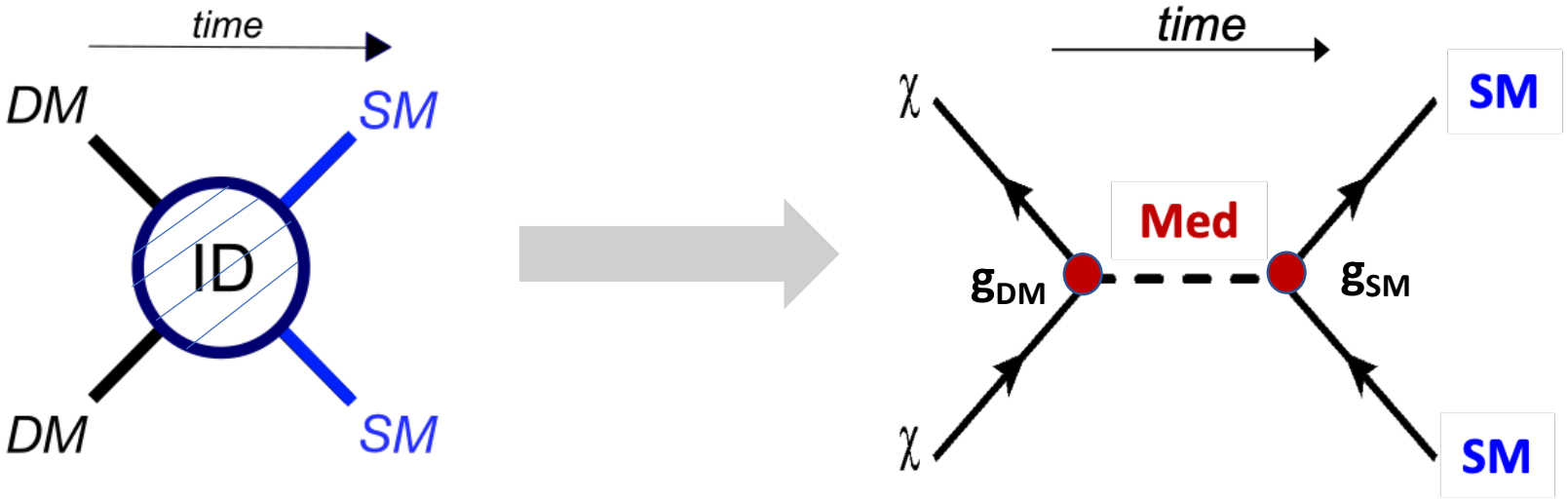


AMS $\bar{p}$ data interpretation (NFW halo profile)

Simplified Models for DM Searches

Dark Matter Benchmark Models for Early LHC Run-2 Searches: Report of the ATLAS/CMS Dark Matter Forum, arXiv:1507.00966

Simplified Models



- ✓ Interaction between the Dark Matter and SM is characterized by a mediator with minimal set of parameters e.g. Dark Matter mass (m_{DM}), Mediator mass (m_{med}), couplings.
- ✓ Simplified models are widely used in interpretations of the LHC Dark Matter searches.
- ✓ Allows for comparison of different search methods in one framework!
- ✓ Benchmark models used in this studies are **scalar** and **vector** mediators.

Indirect DM Detection: Annihilation

Particle Physics

Dark Matter Density, J-Factor

$$\frac{d\Phi}{dE}(E,\psi) = \frac{\langle\sigma\nu\rangle}{2m_\chi^2}\sum_i B_i\frac{dN^i}{dE}\frac{1}{4\pi}\int_\psi \frac{d\Omega}{\Delta\psi}\int_{los}\rho^2(\psi,l)dl$$

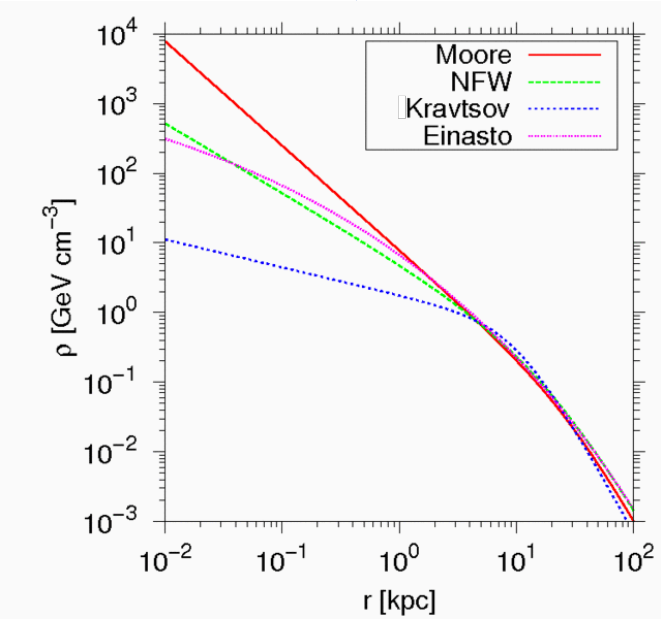
Model dependent : DM type (Dirac), DM mass, mediator mass, couplings, mediator width, etc.

MadGraph_5@NLO:MadDM:

F. Ambrogi, C. Arina, et al., arXiv:1804.00044

Pythia 8: Parton showering and hadronization

Dragon Cosmic Ray propagation in the galaxy, arXiv:1607.07886

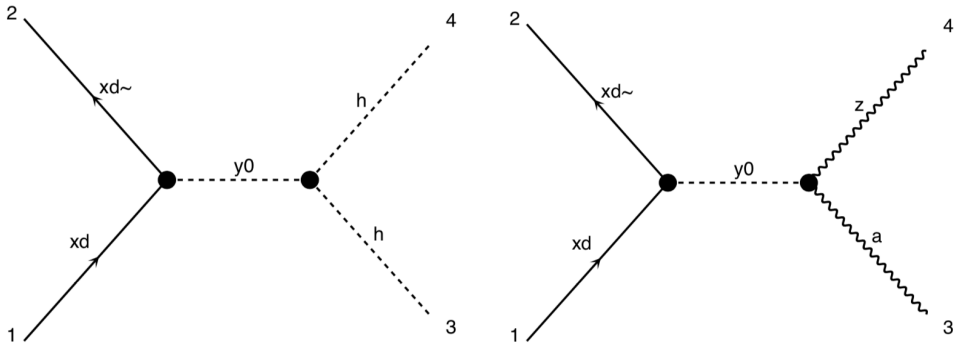


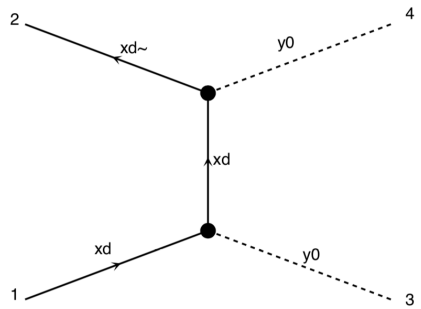
Region of Galactic Center and the Halo

Indirect DM Detection

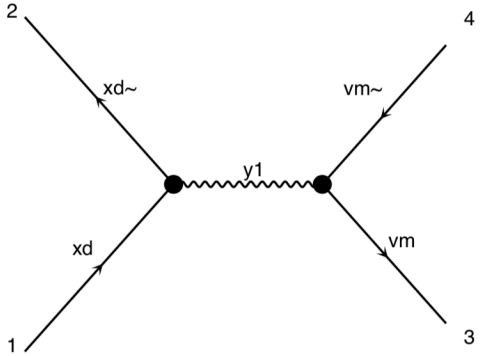
MadDM

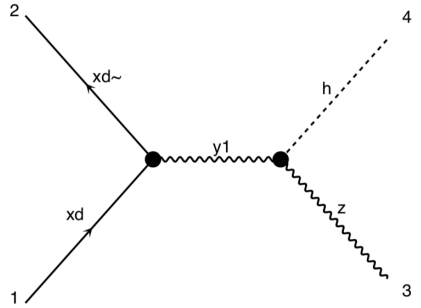
Scalar Mediator

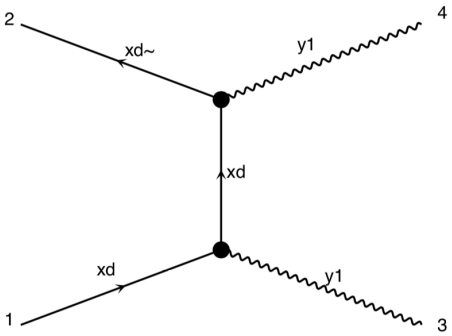




Vector Mediator





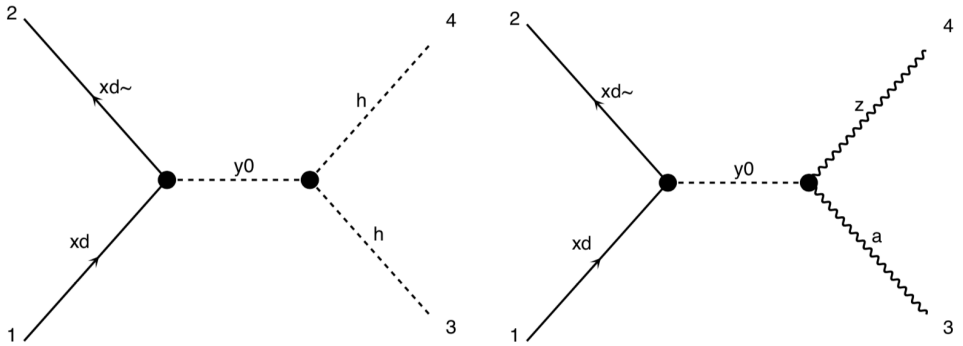


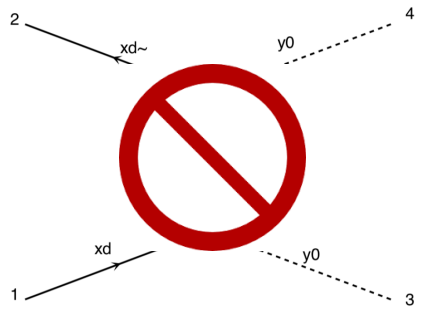
Kinematically all possible final states!

Generation Process

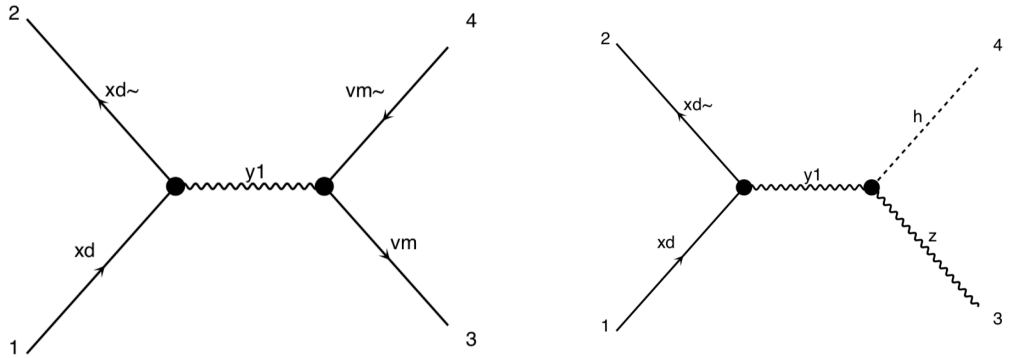
MadDM

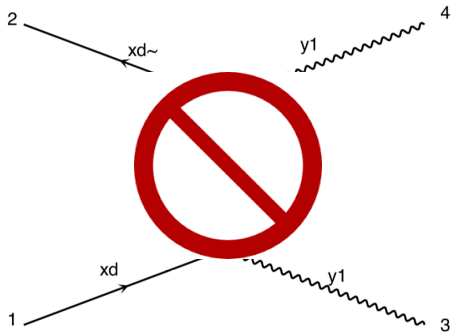
Scalar Mediator





Vector Mediator

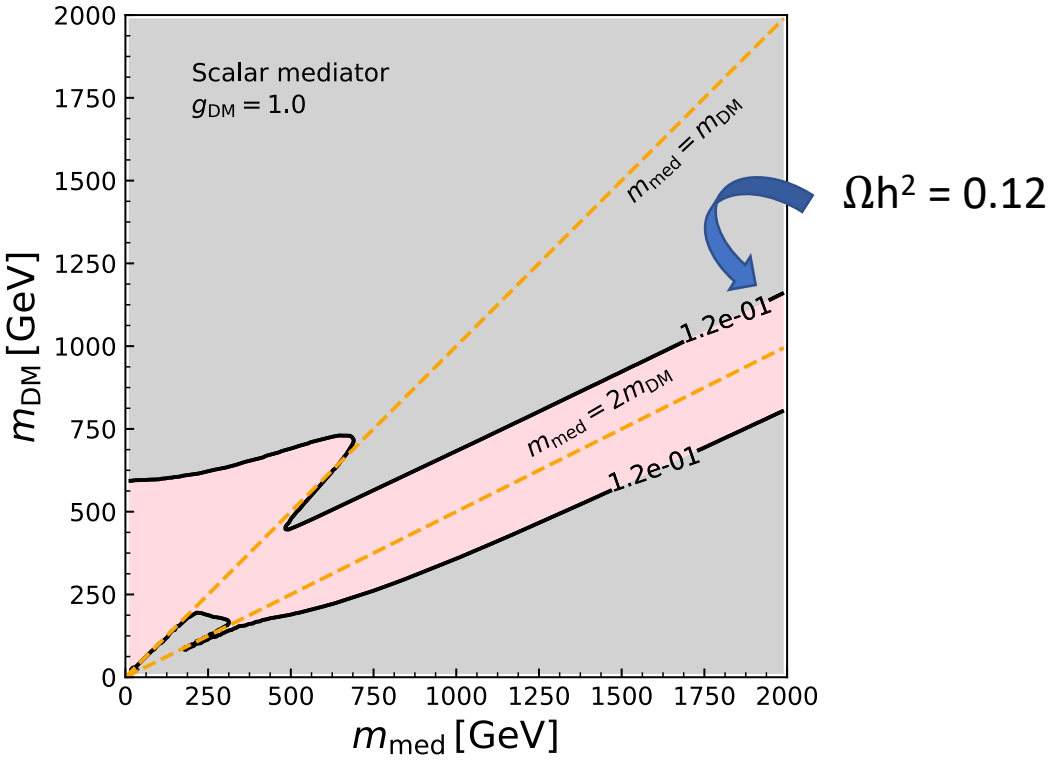




Thermal Relic Density

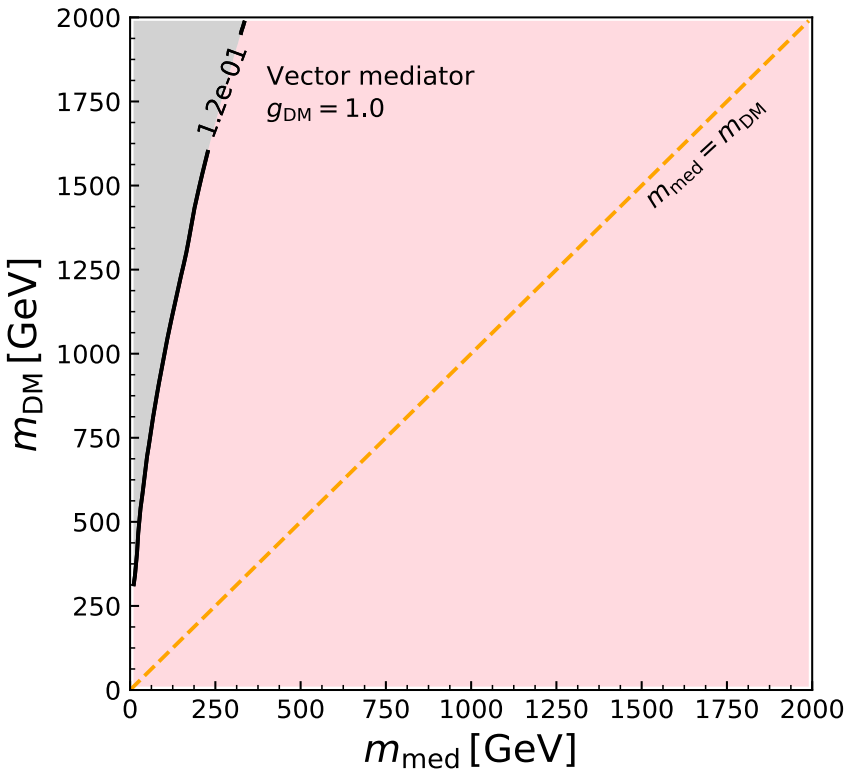
Preliminary

Scalar Mediator



$\Omega h^2 = 0.12$

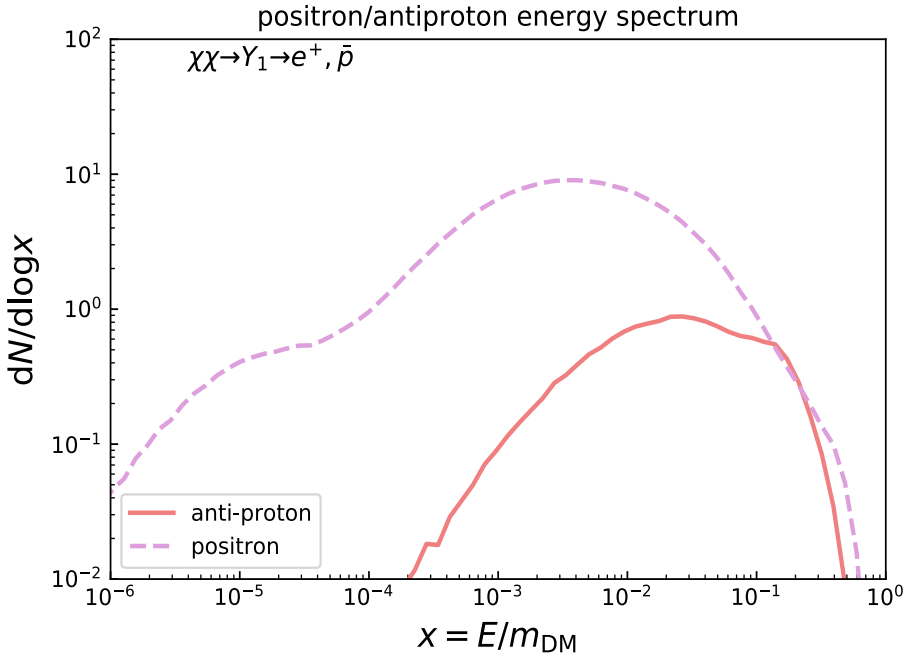
Vector Mediator

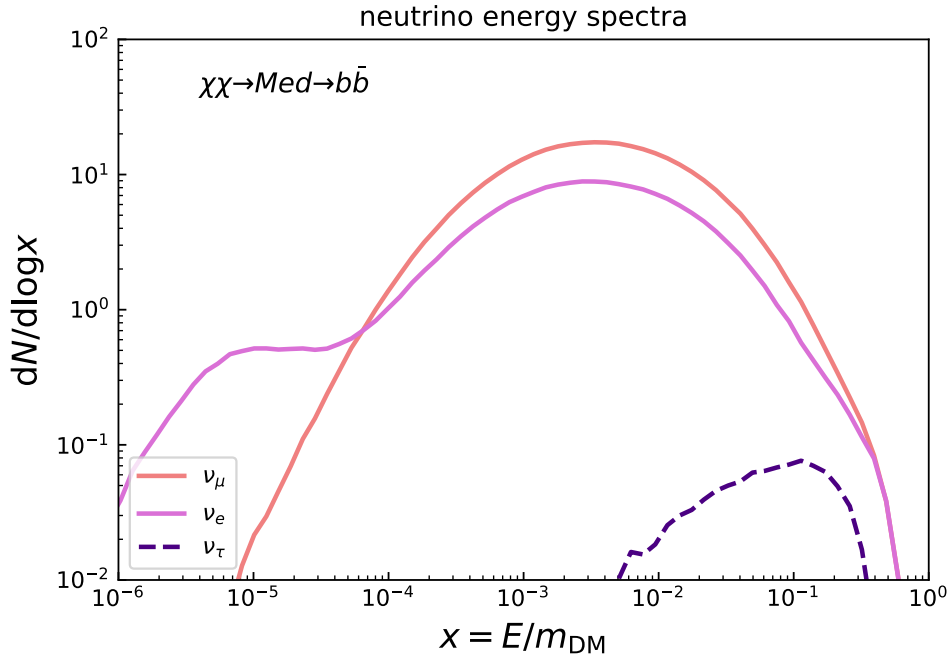


Annihilation Energy Spectra: $b\bar{b}$

Vector Mediator, M_{DM} = 100 GeV, M_{Med} = 100 GeV, g_{DM} =1

Preliminary

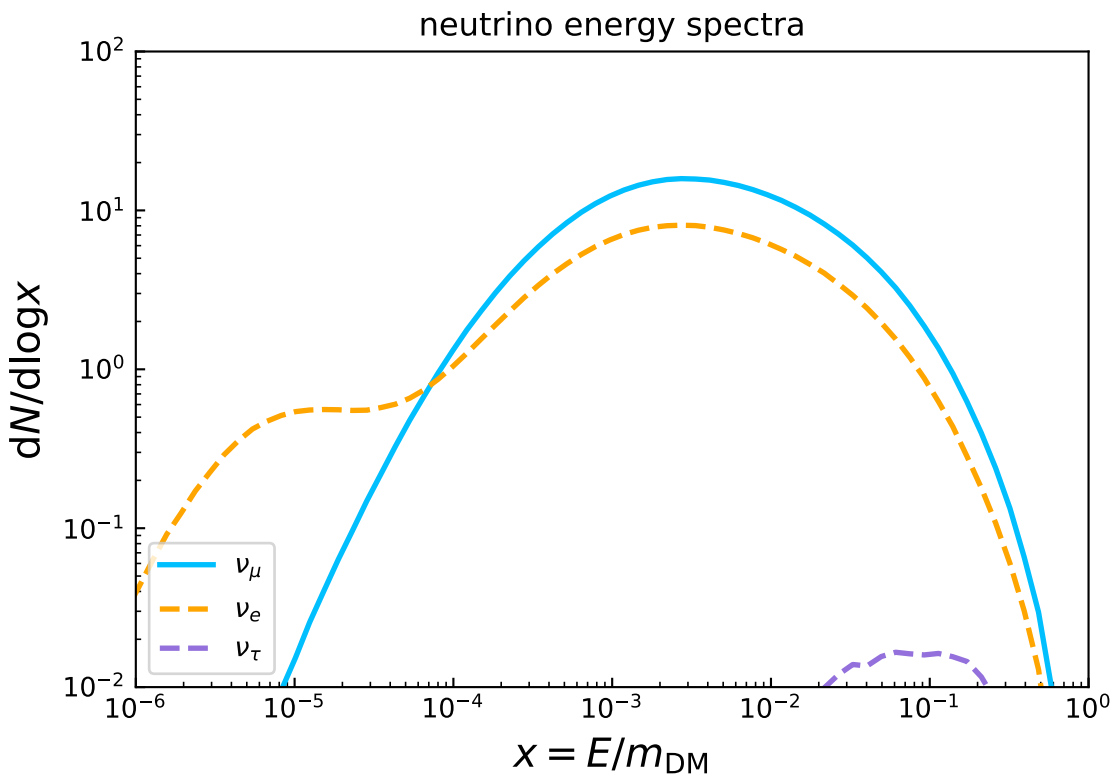




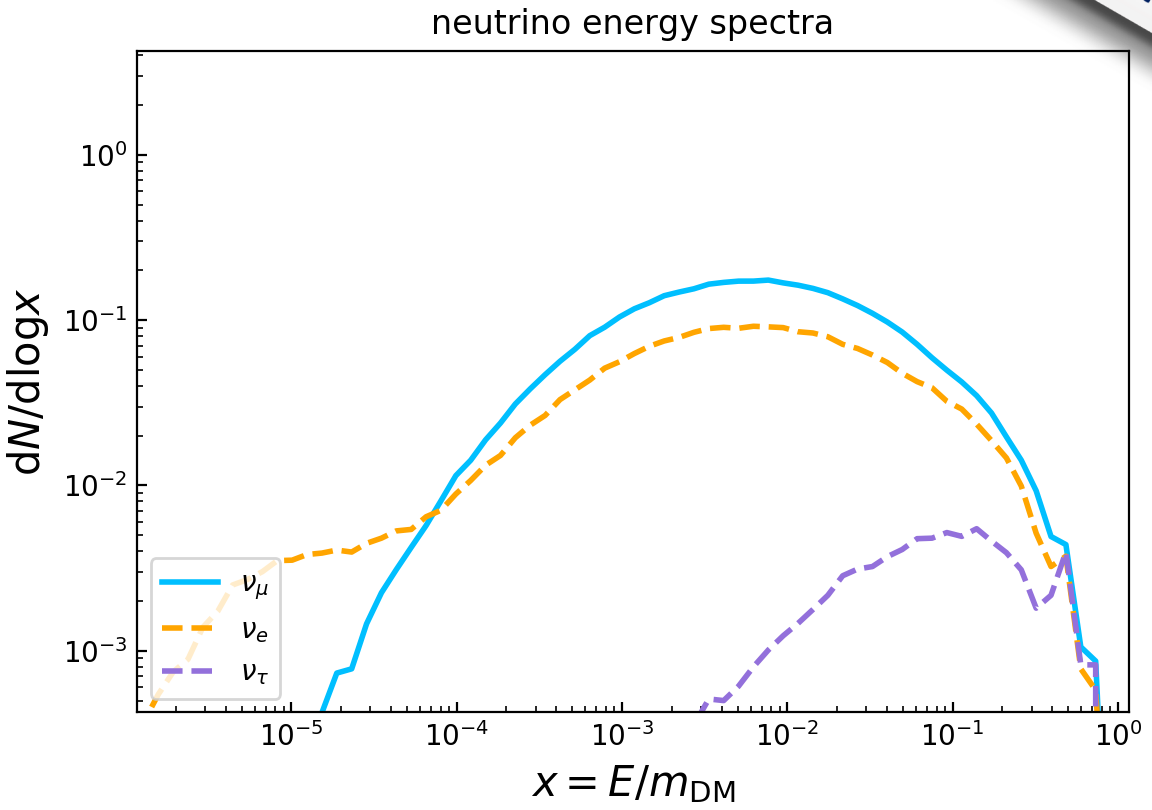
Annihilation Energy Spectra

Preliminary

Vector Mediator



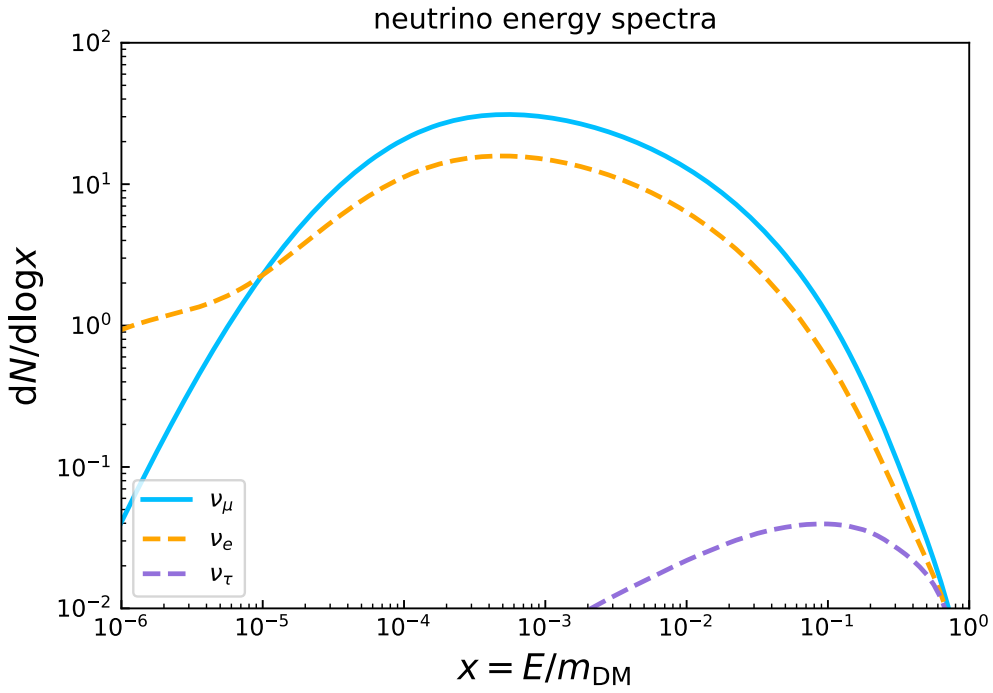
Scalar Mediator



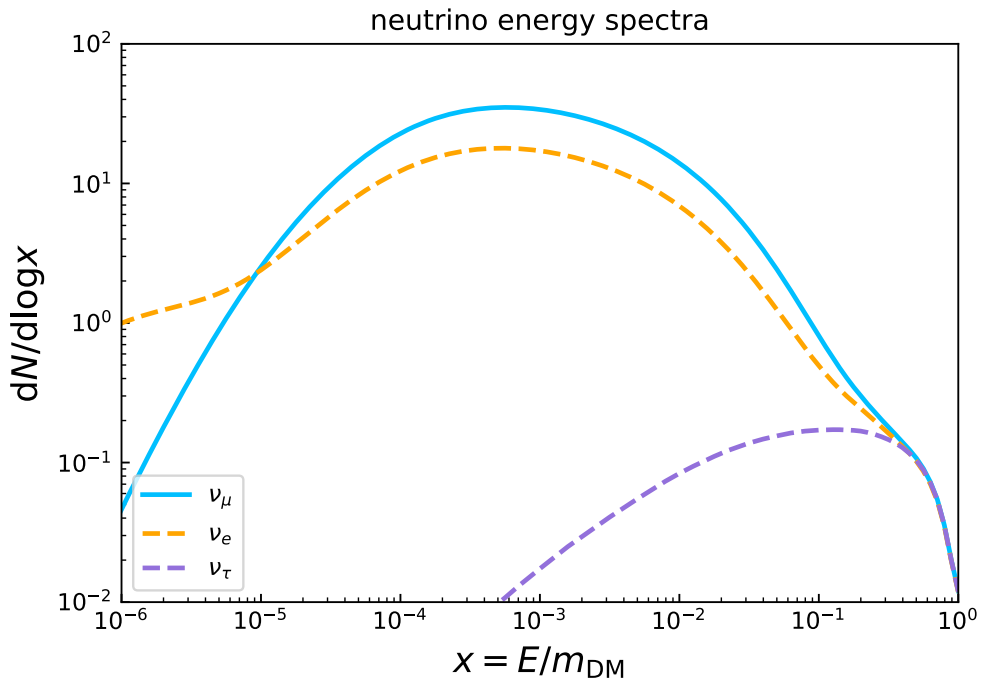
M_{DM} = 100 GeV, M_{Med} = 100 GeV, g_{DM} =1

Annihilation Energy Spectra

Vector Mediator



Scalar Mediator

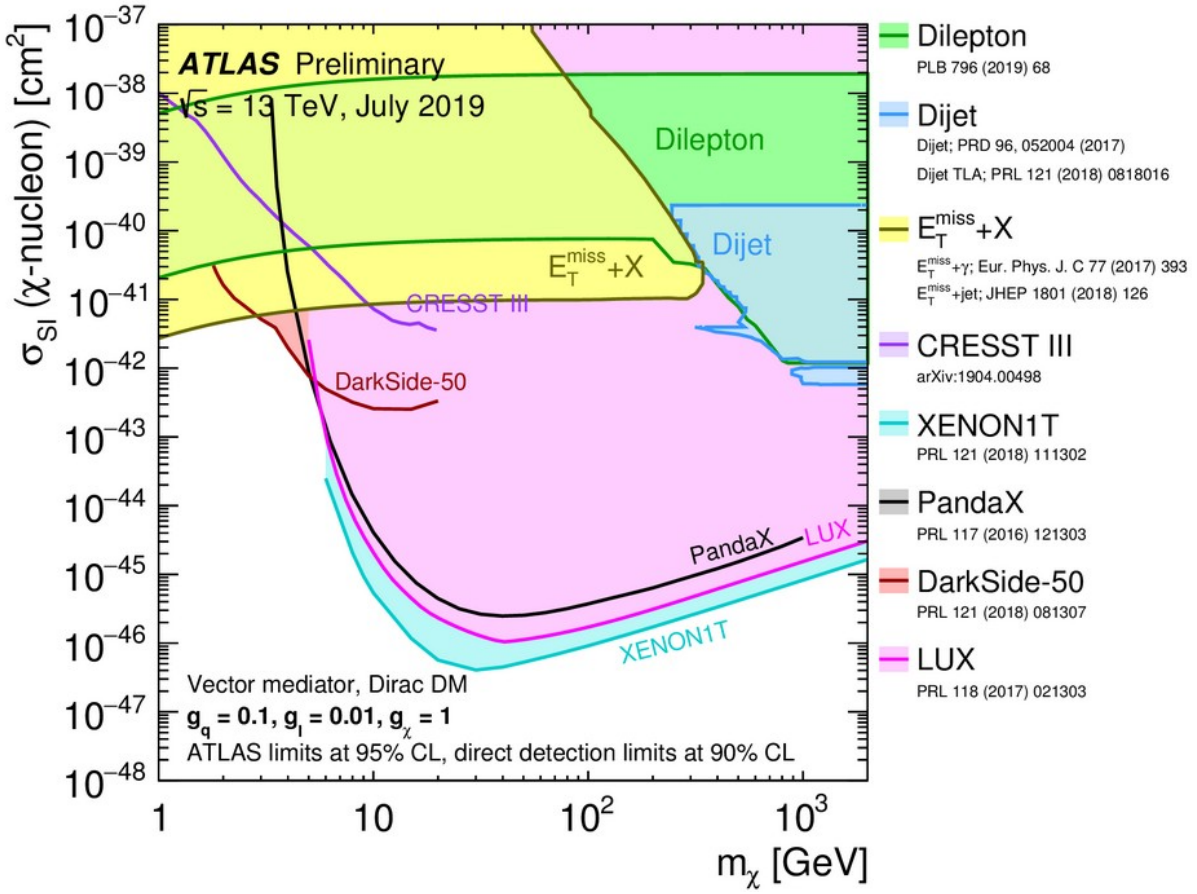


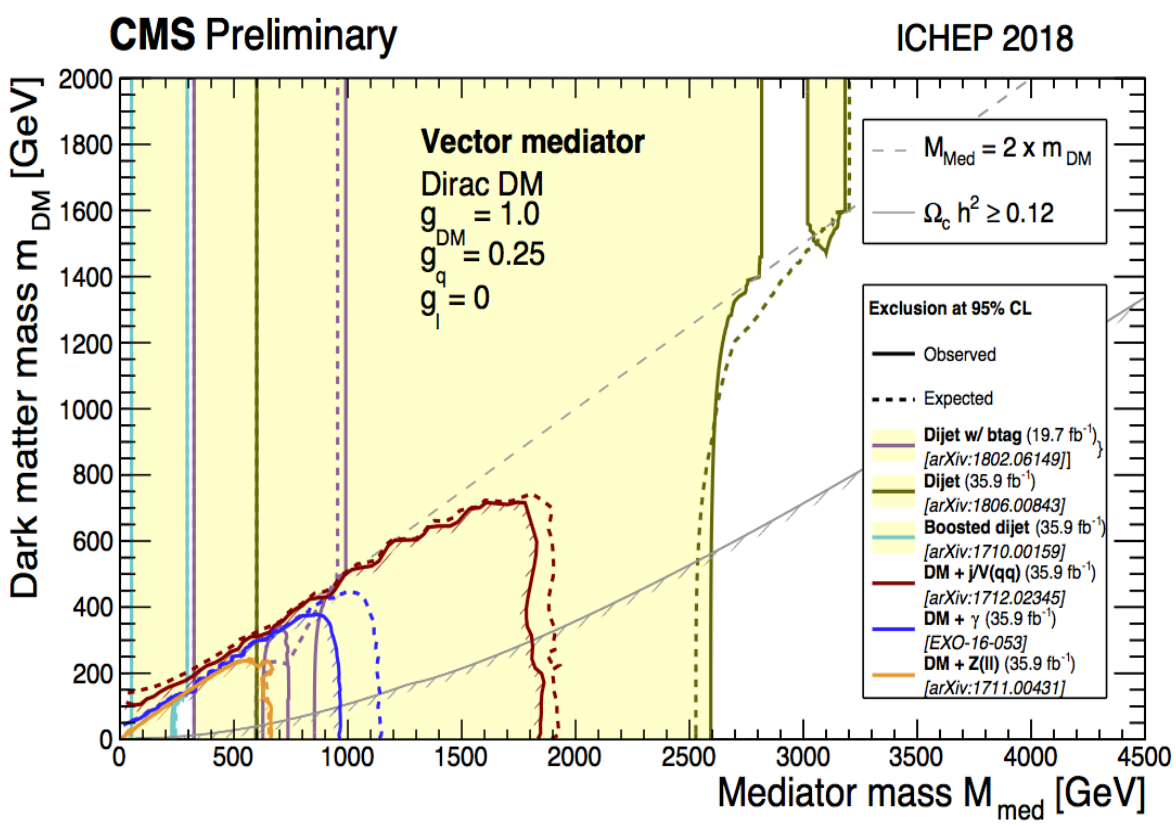
Preliminary

M_{DM} = 1 TeV, M_{Med} = 2 TeV, g_{DM} = 1

Complementarity of Searches

ATLAS and CMS Summary Plots





- ✓ LHC probes better low DM masses and if mediator is on-shell produced
- ✓ Direct Detection is more competitive for high DM masses
- ✓ What about Indirect Detection (and KM3NeT sensitivity)?

Summary and Outlook

- A new analysis framework with **Simplified Dark Matter Models** for Indirect DM searches specifically for low energies is being developed.
- Full parameter scan is necessary in order define the allowed **parameter space** (masses, couplings etc.). Constraints from LHC and the other experiments can be taken into account.
- **Complementarity and comparison** of different search techniques (Collider, Direct and Indirect Detection) can be verified for given benchmark models.

New approaches will be promising to be more sensitive in DM searches and to better understand the origin of observed astrophysical excesses!