Marco Taoso

INFN-Torino

22 July 2021

Rapporteur Talk: Dark Matter

Dark Matter @ ICRC 2021

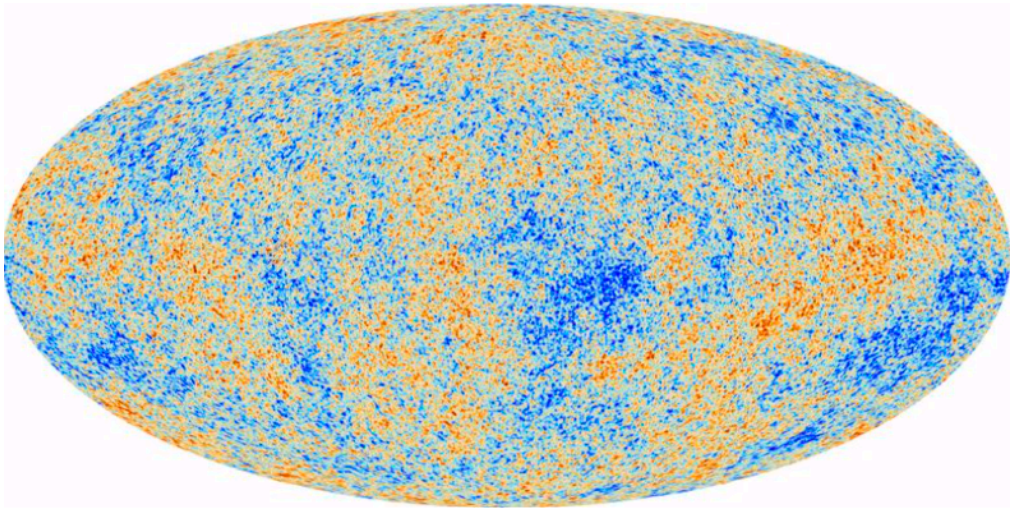
46 online talks

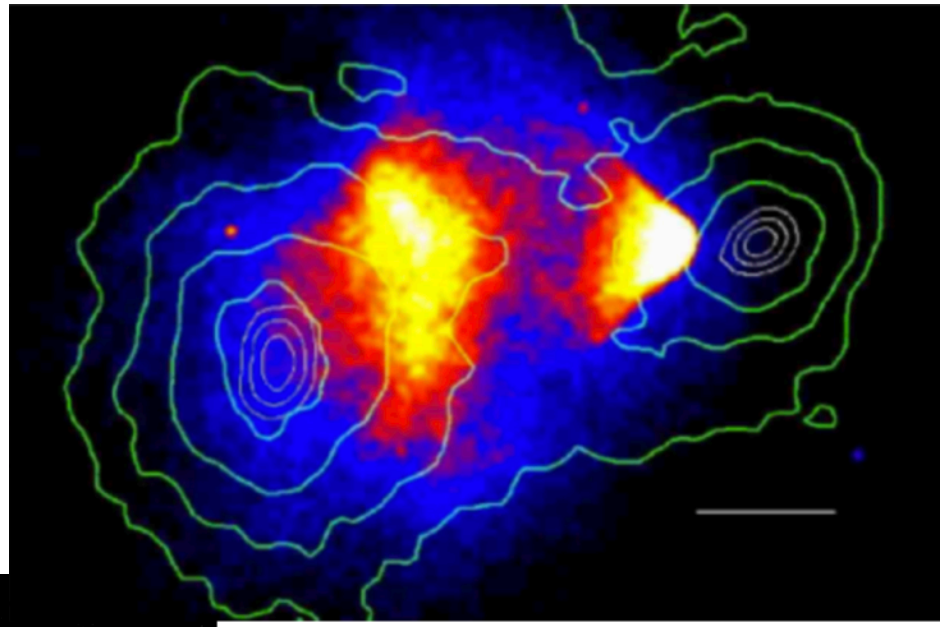
34 online posters

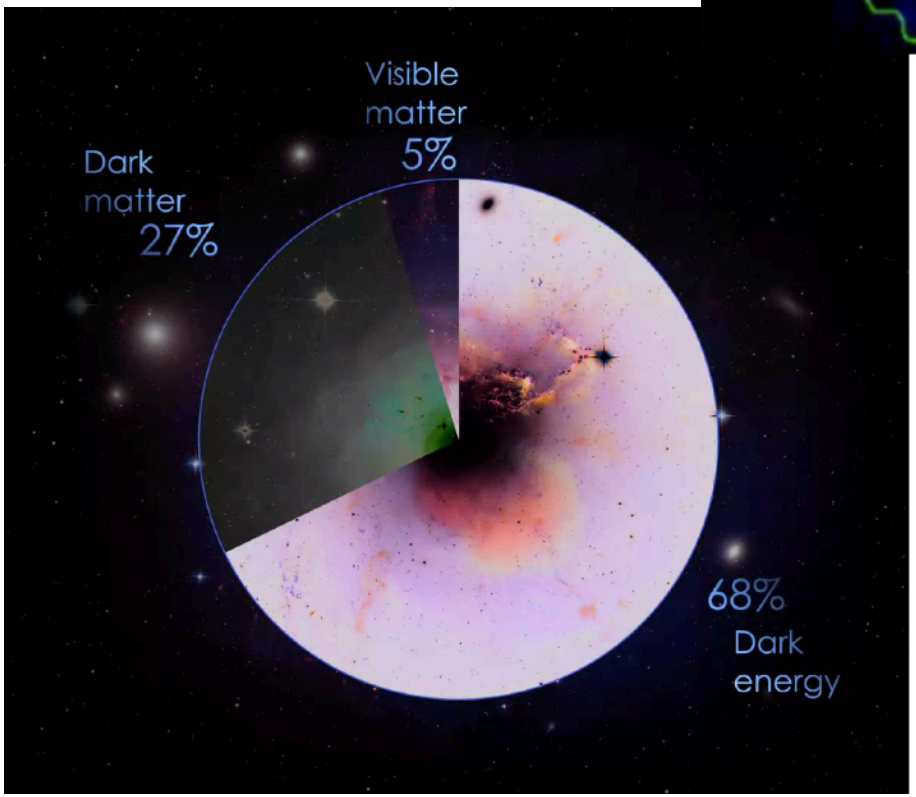
2 plenary highlights talks

+ discussion sessions + talks in other categories

Evidences for Dark Matter





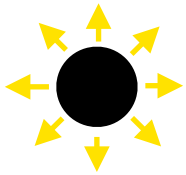


Dark Matter candidates

Mass [eV]

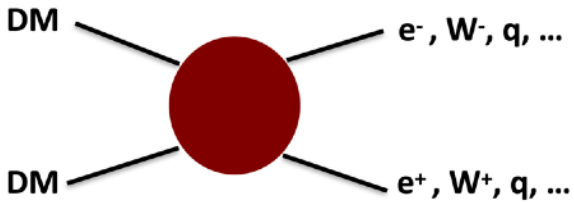
$M_\odot$

Primordial black holes



10^{30}

M_P

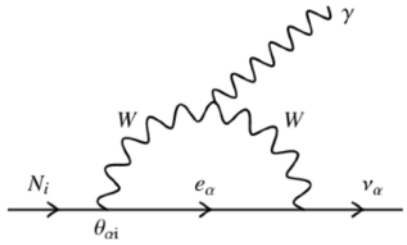


10^{20}

10^{10}

WIMPs

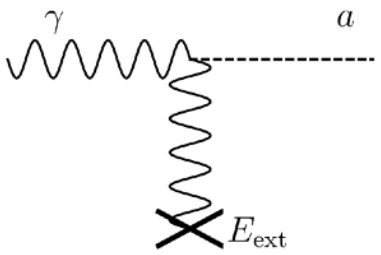
ν_s



1

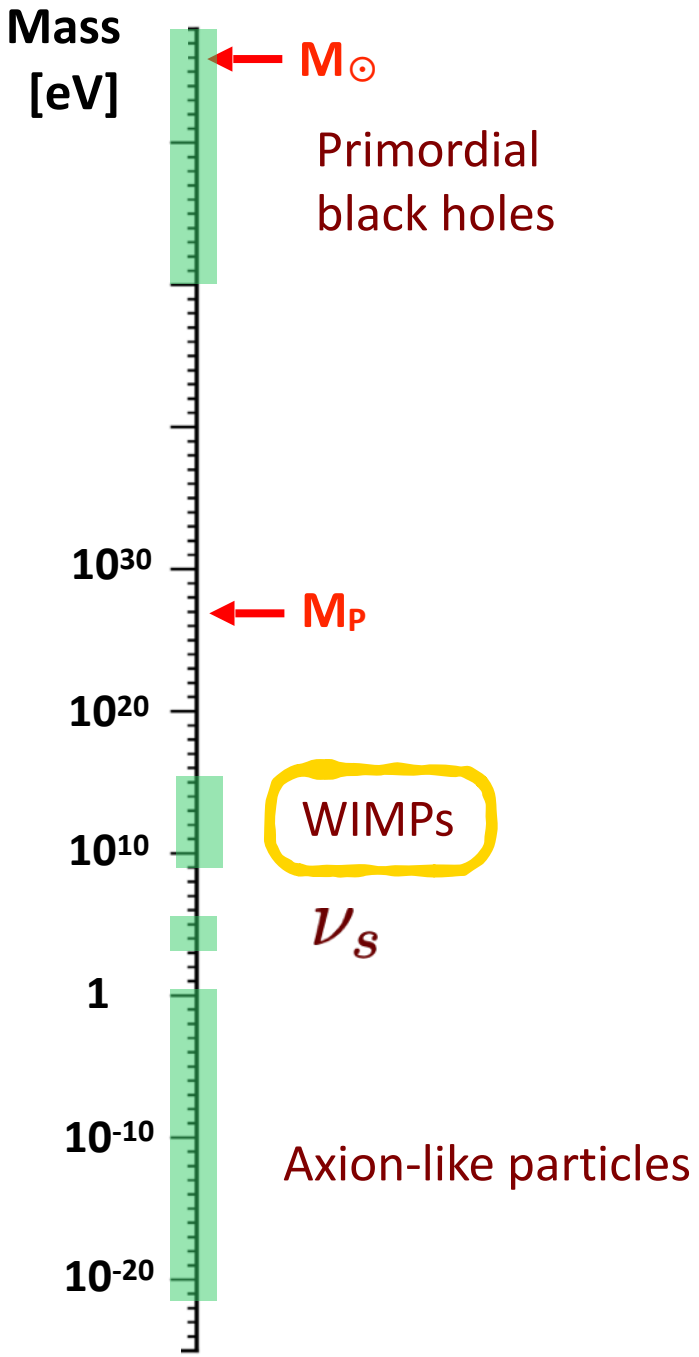
10^{-10}

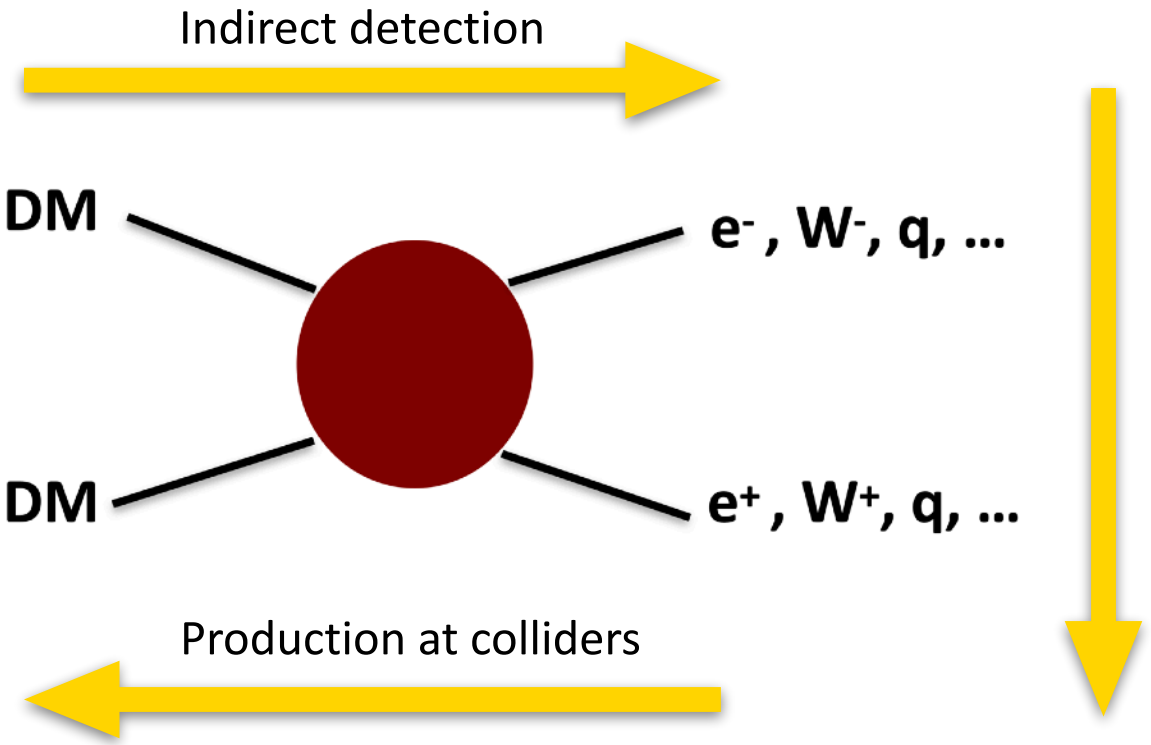
Axion-like particles



10^{-20}

Weakly Interacting Massive Particles





Direct detection of WIMPs

arXiv:2104.07634

Schumann #1461

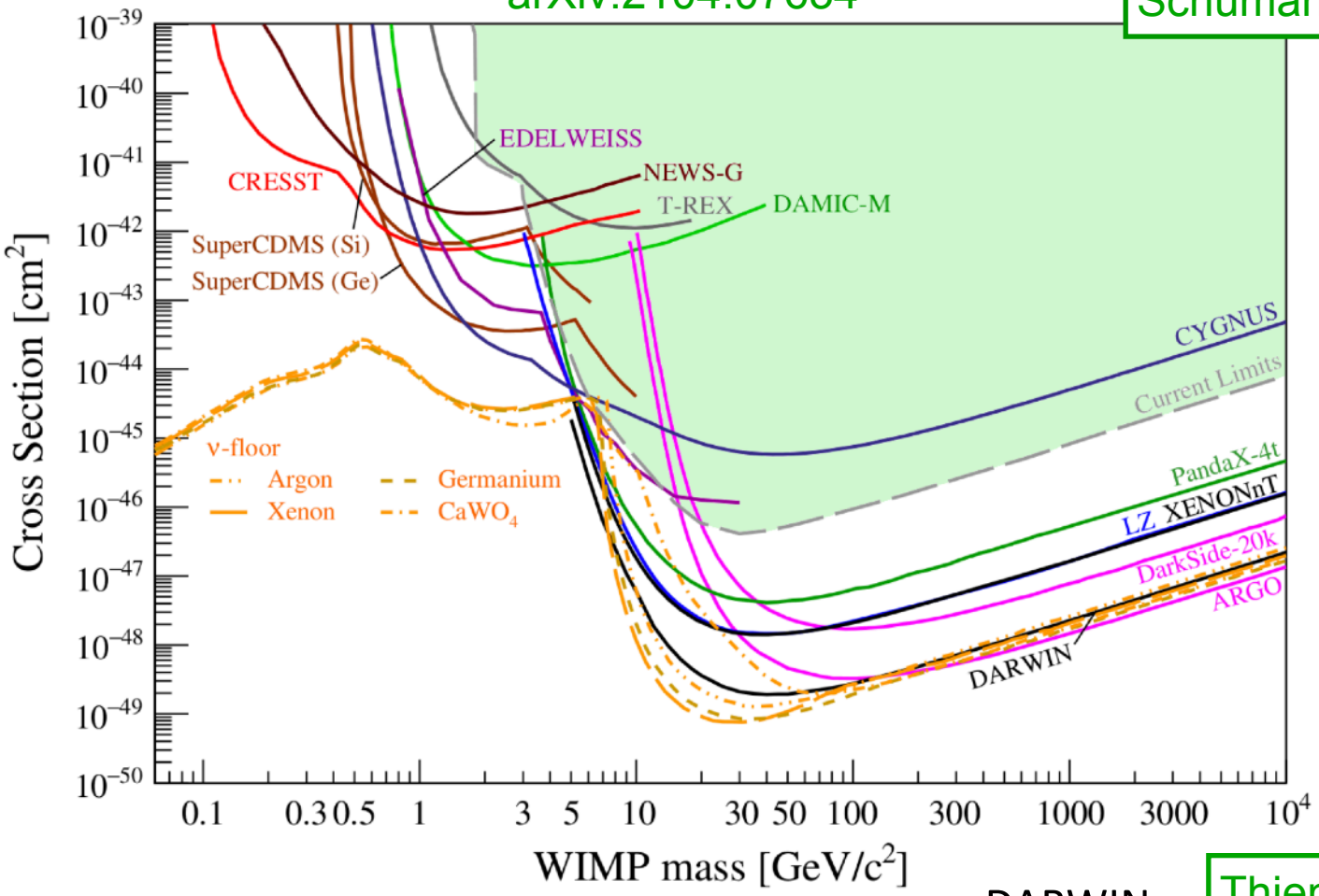
DAMIC@SNOLAB

Traina #1328

DAMIC-M

De Dominicis #1196

Botti #1312



NEW

ANAIS (NaI) PRD 103, 102005 (2021)
3 years data: 314 kg x y exposure

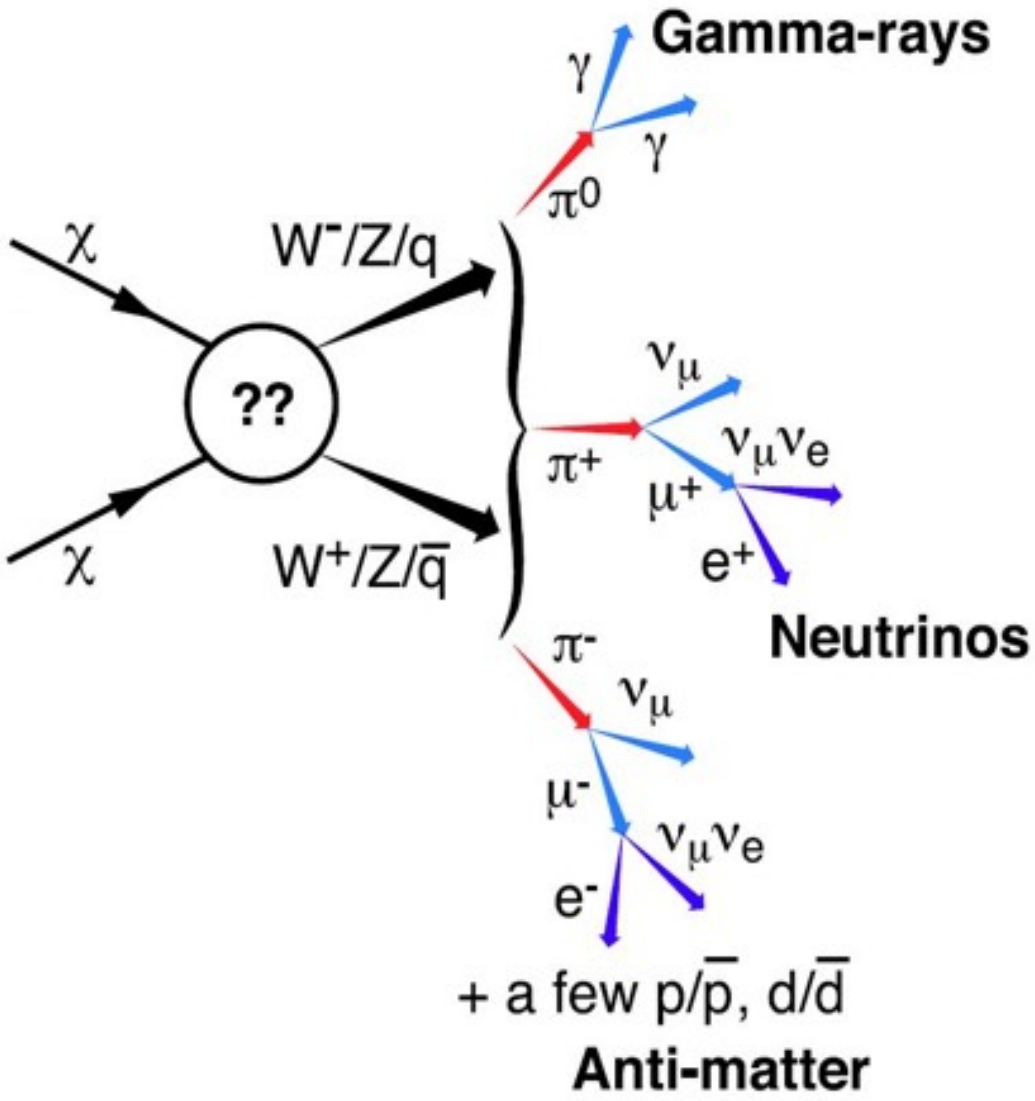
DARWIN Thieme #589

DEAP-3600 Stringer #655

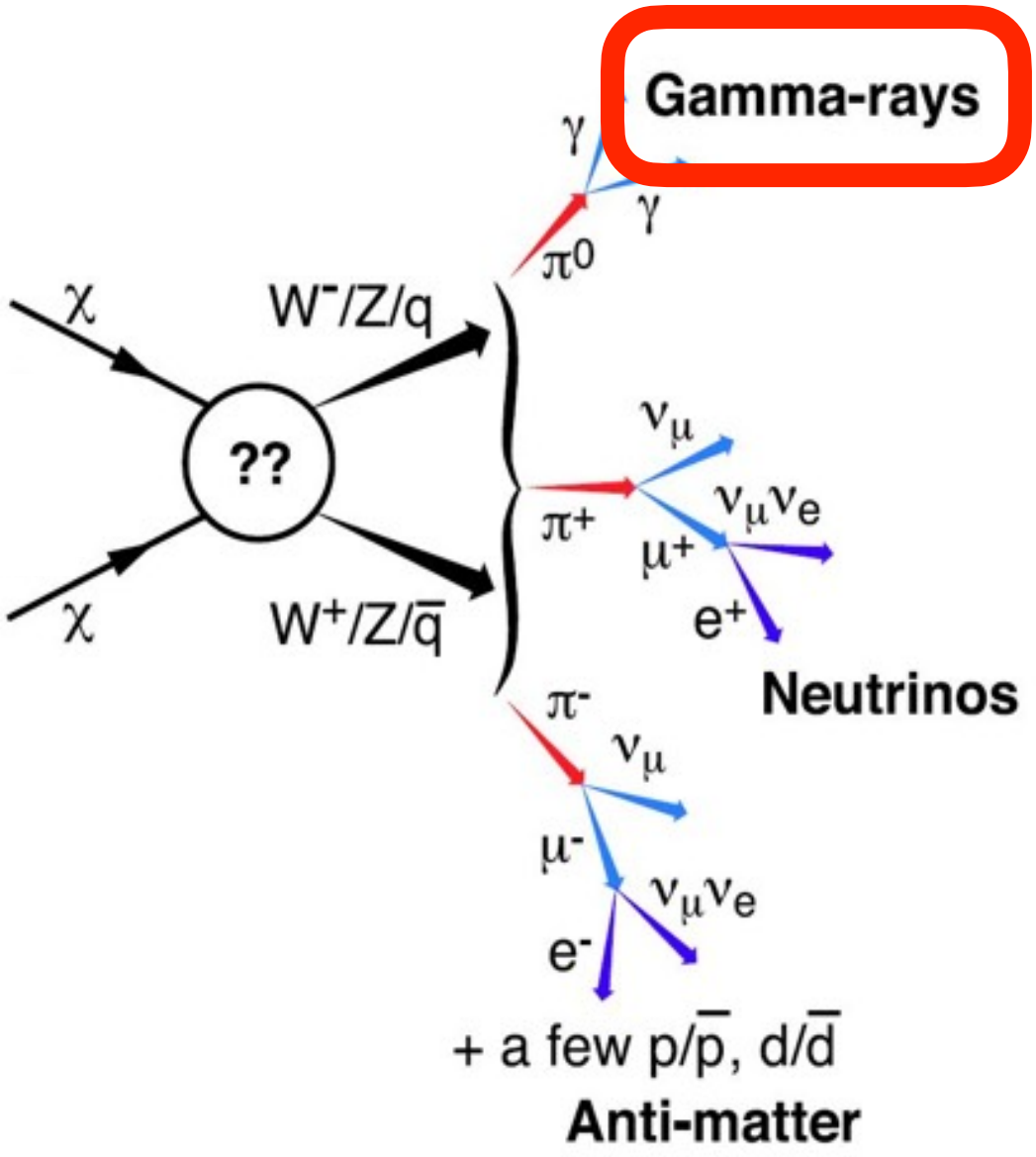
XENON Pierre #1349

Data consistent with no modulation: incompatible with DAMA at 3.3σ [1-6 keV]

Indirect detection



Indirect detection

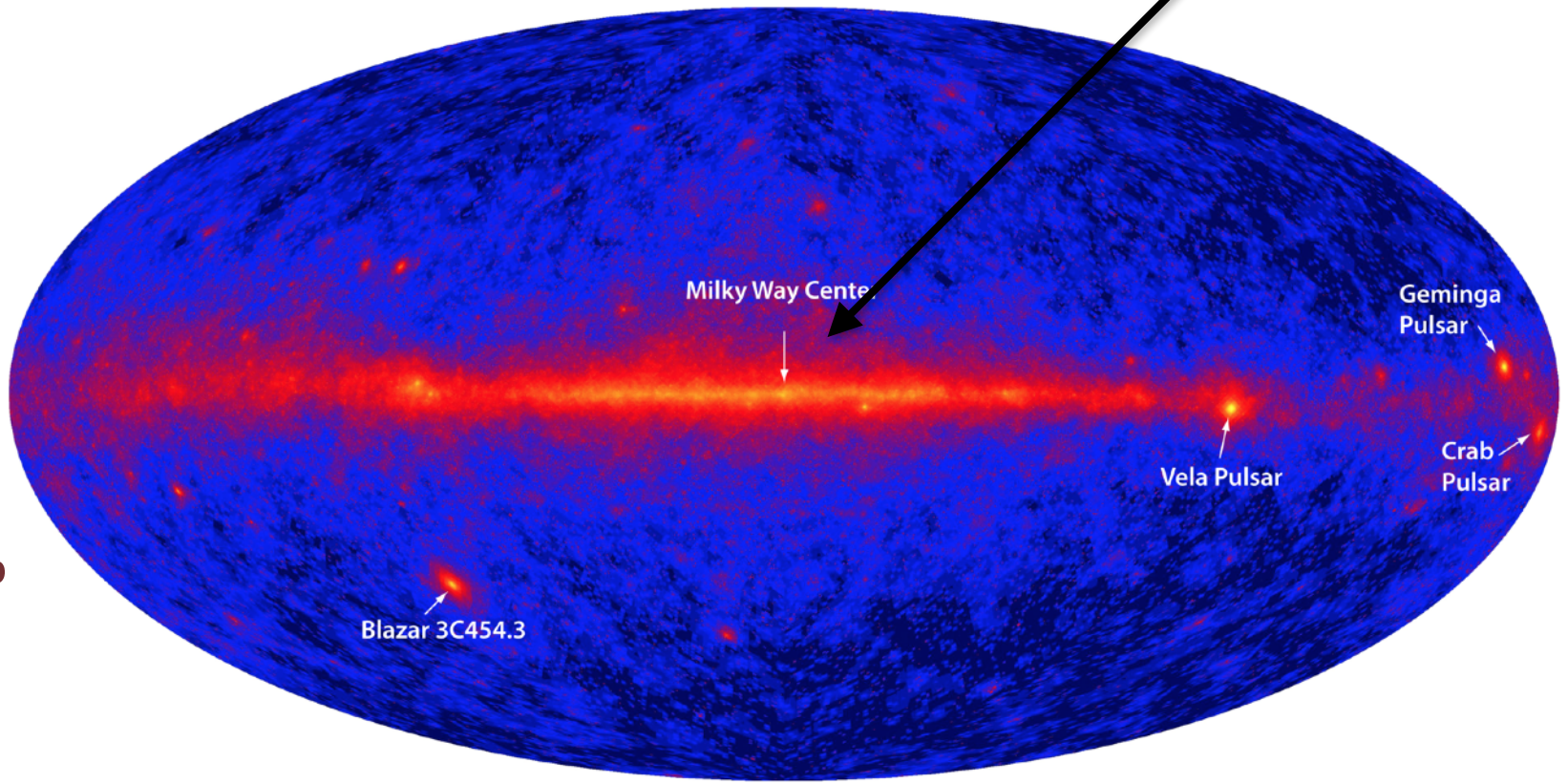


Targets

Dwarf Spheroidal galaxies

Extragalactic emission

Galactic center



DM halo

Clusters of galaxies

DM clumps

See discussion session on

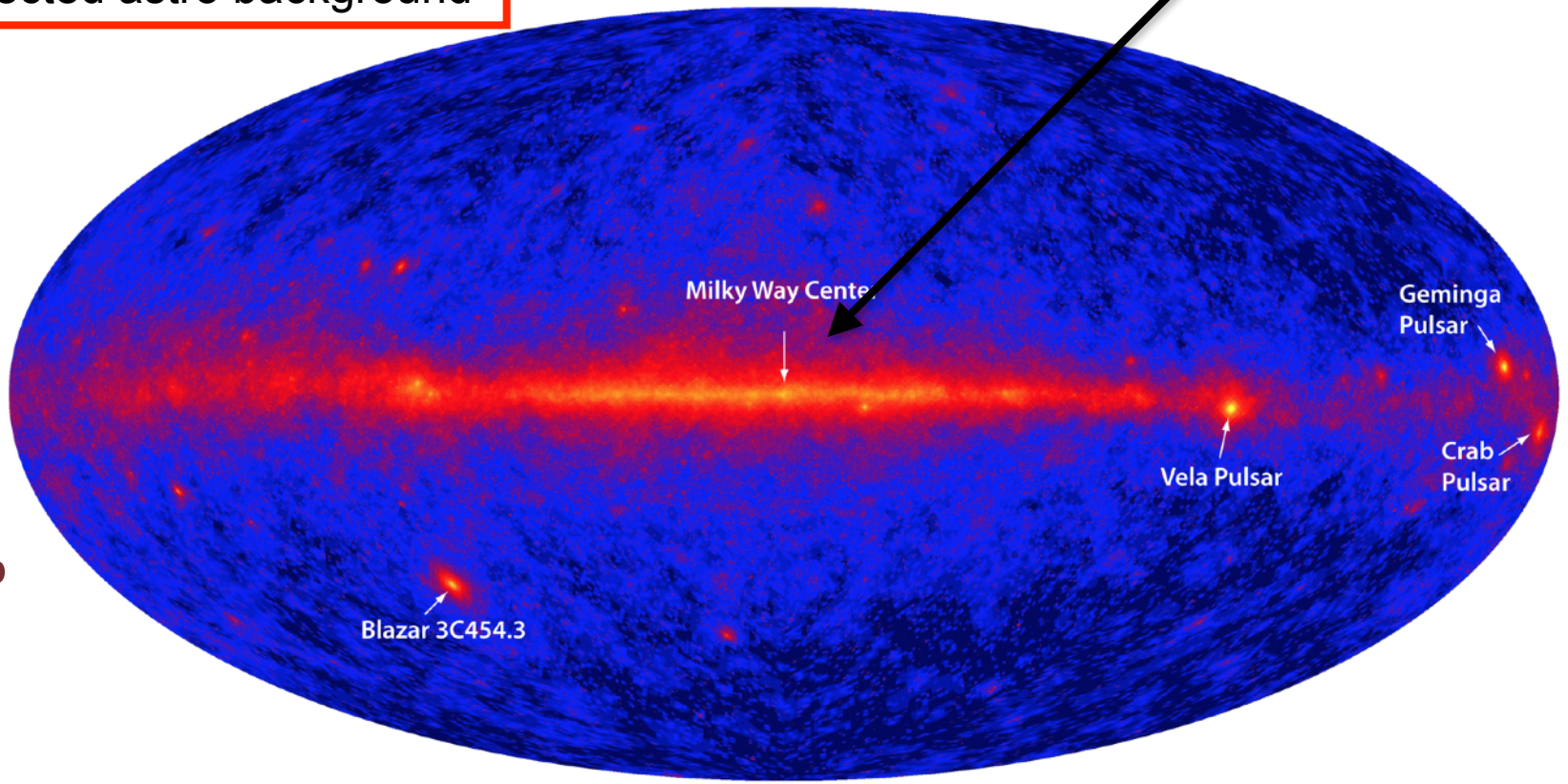
DM ID detection and cosmological substructures

Targets

Dwarf Spheroidal galaxies
DM dominated
Low expected astro background

Extragalactic emission

Galactic center



DM halo

Clusters of galaxies

DM clumps

See discussion session on
DM ID detection and cosmological substructures

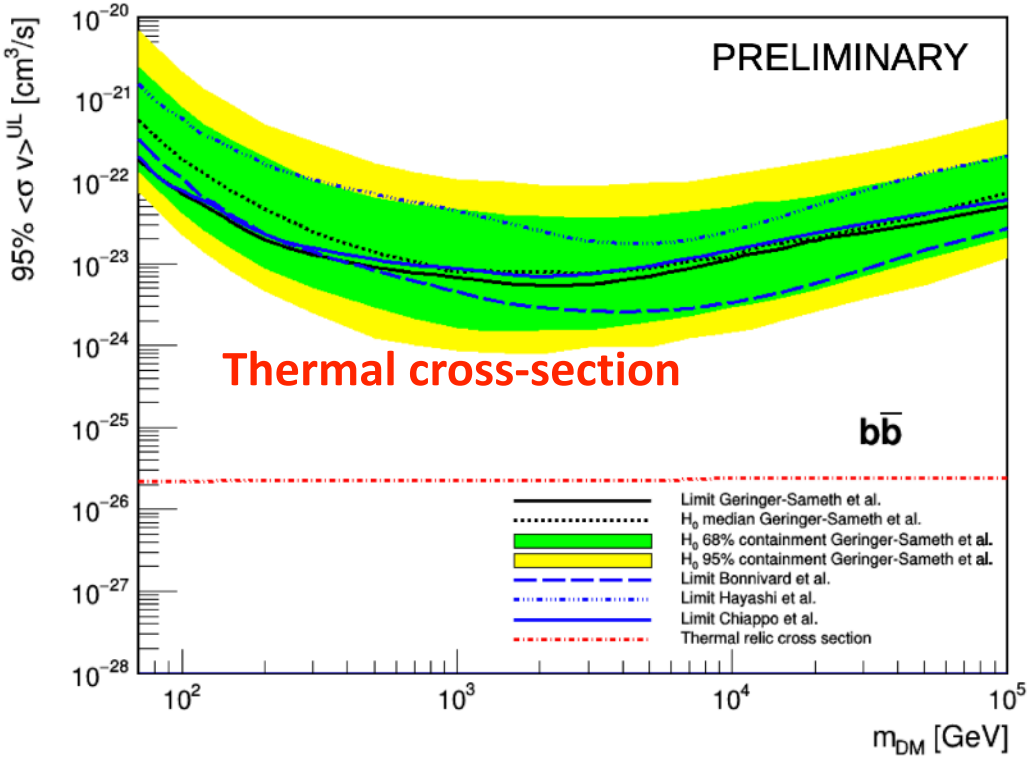
Dwarf Spheroidal galaxies

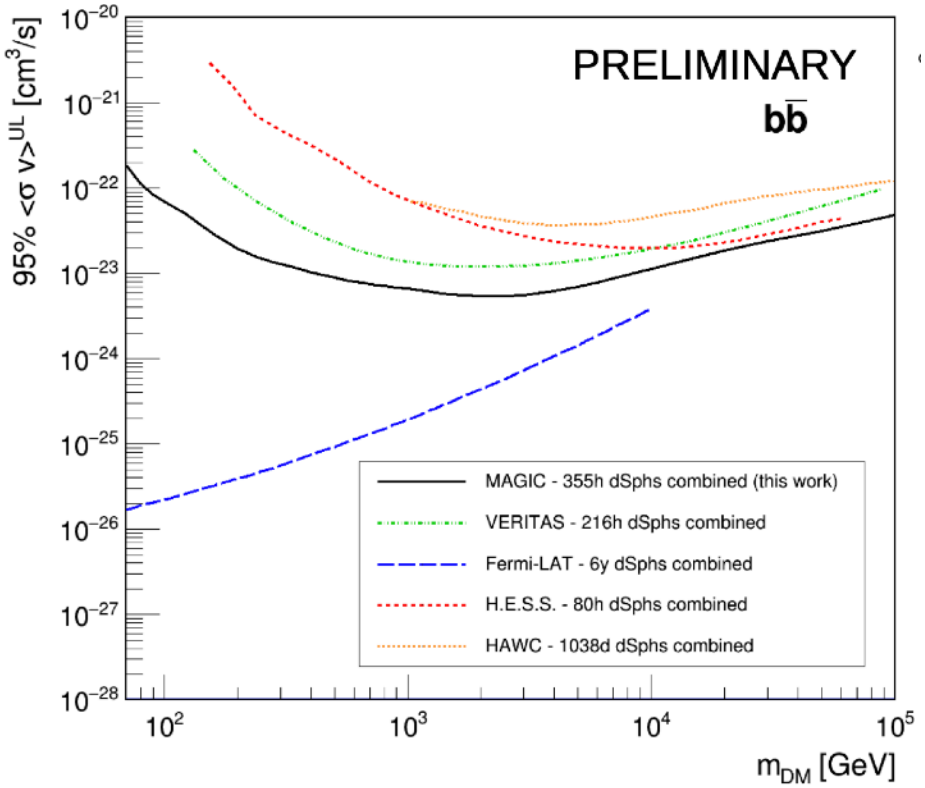
$$\phi_s(\Delta\Omega) = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{\rm DM}^2}\int_{E_{\rm min}}^{E_{\rm max}}\frac{{\rm d}N_\gamma}{{\rm d}E_\gamma}{\rm d}E_\gamma \cdot \int_{\Delta\Omega}\left\{\int_{\rm l.o.s.}\rho^2(\boldsymbol{r}){\rm d}l\right\}{\rm d}\Omega'$$

J-factor

Maggio #292

MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescope

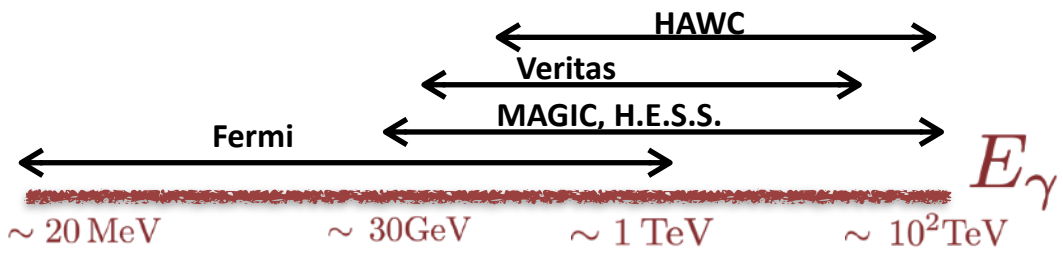




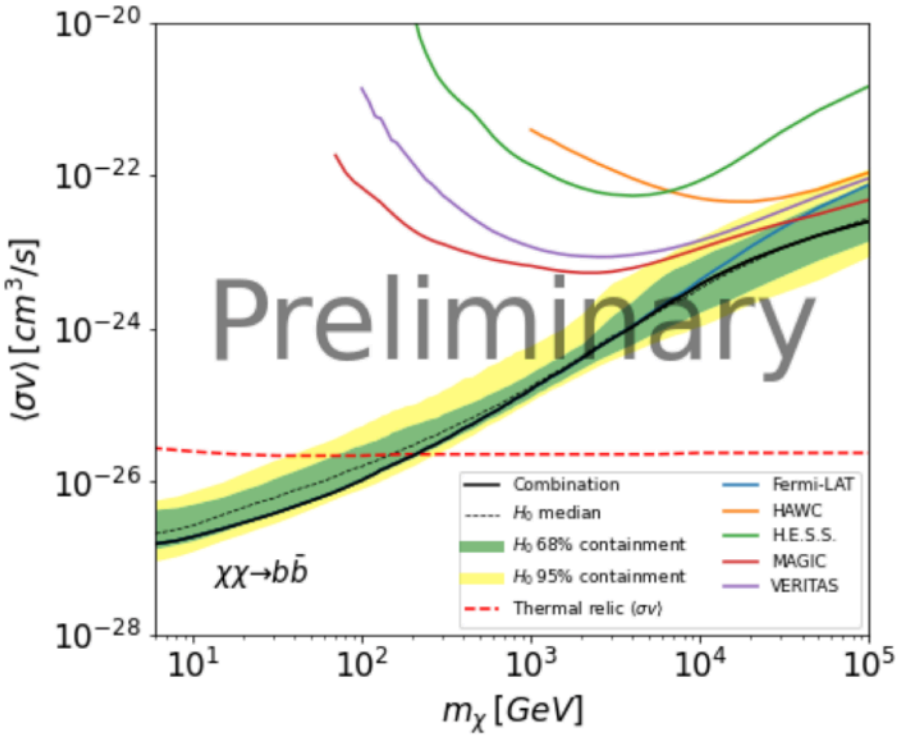
354h of data from observations of 4 targets: Segue 1, Ursa Major II, Draco, Coma Berenices
No excess observed. Different determinations of the J-factors tested.

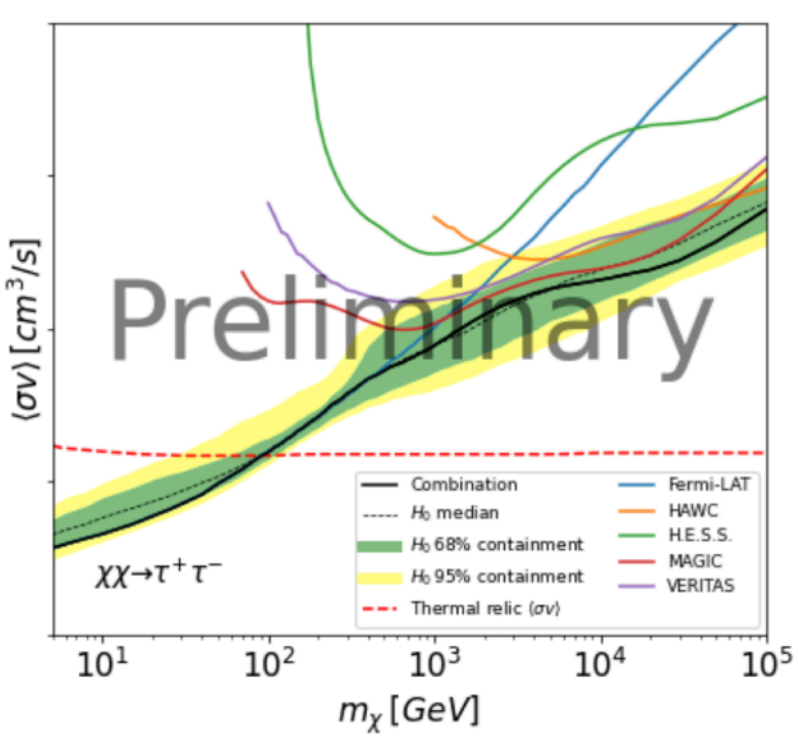
VERITAS DM search in dSph galaxies Giuri #399

Dwarf Spheroidal galaxies



Armand #675





Combination of 20 dSph observed by Fermi, HAWC, Hess, MAGIC, VERITAS.
Common treatment of several systematics and statistical approach.
Combined upper limits **2-3 times more stringent than individual analysis.**

Galactic Center GeV excess

Excess discovered in the Fermi-LAT data. Extends from the Galactic center up to mid latitudes and peaks at few GeV energies.

Vitale and Morsell 2009, Godenough, Hooper 2009; Hooper, Linden 2011; Abazajian Kaplinghat 2012; Hooper, Slatyer 2013; Gordon, Macias 2013; Huang,Urbano,Xue 2013; Abazajian et al. 2014; Daylan et al. 2014;Calore et al. 2014; Calore,Cholis,Weniger 2014; Zhou et al. 2015; Ackermann et al. 2017; +…

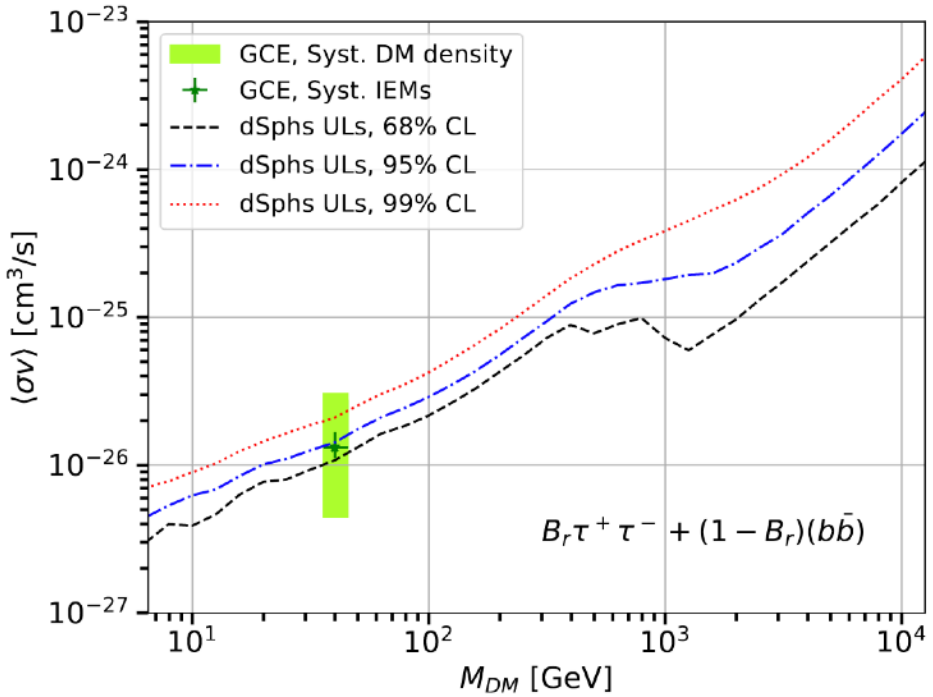
Recent analyses @ICRC: Manconi #562, Gordon #496

Among the most discussed interpretations:

- **DM annihilations**
- Population of unresolved **millisecond pulsars**

Di Mauro #36

Constraints from dwarf spheroidal galaxies **compatible** with the GCE.
Severe bounds from anti-protons on hadronic scenarios.
Need to invoke small diffusion zone in tension with CRs data.



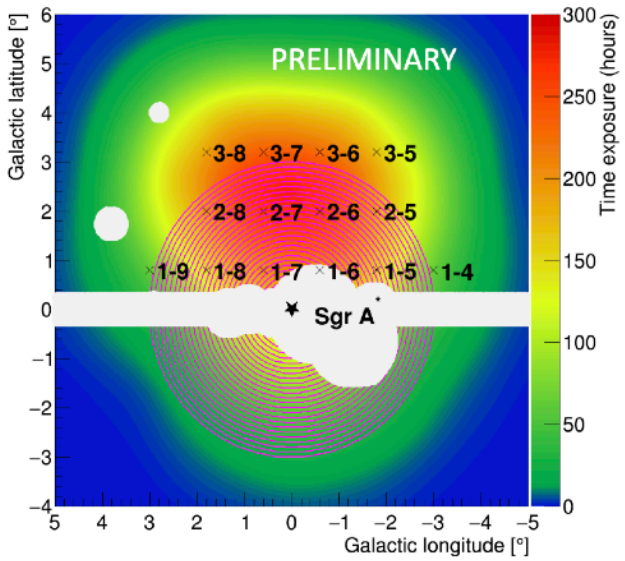
Test of Millisecond pulsars interpretation

Detection in X-ray Berteaud #794 or radio bands Calore et al. 2016

Macias #110

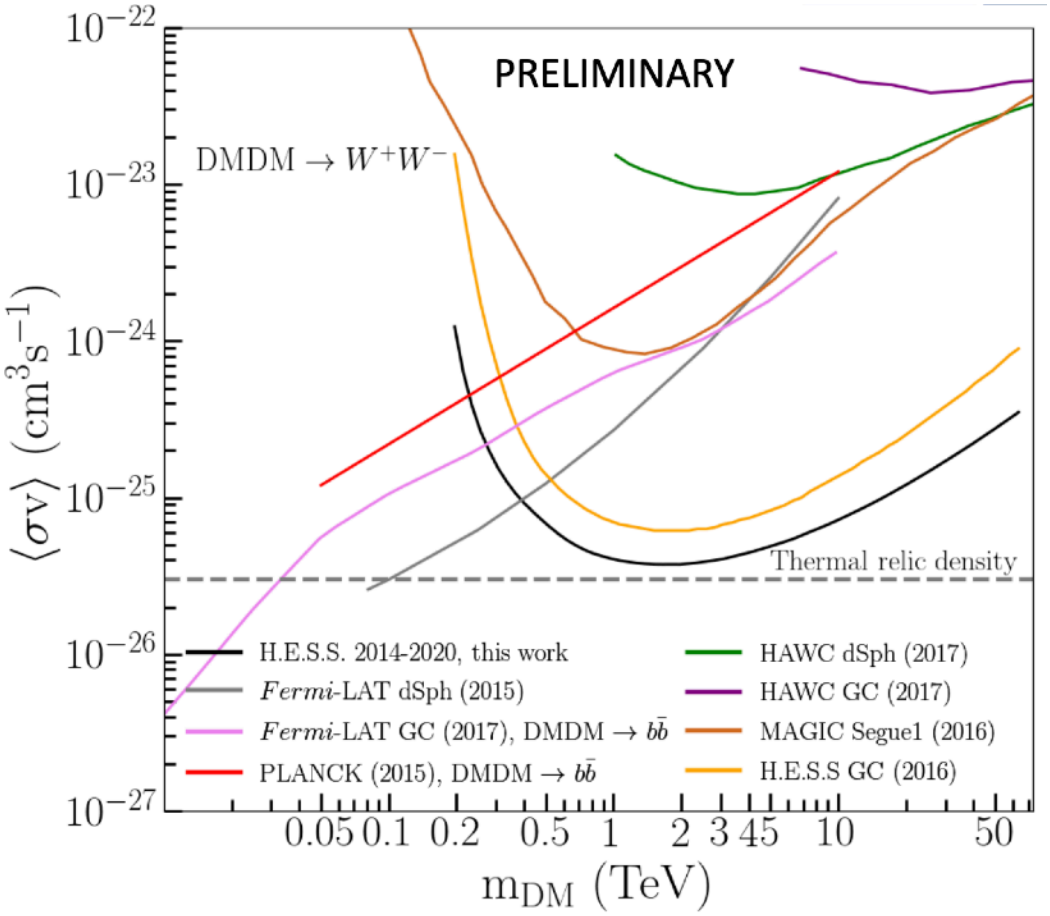
High-energy tail produced through Inverse Compton $e^{\pm}$ emission potentially detectable by **CTA**

H.E.S.S. inner Galaxy survey



Around 546h of observation of the GC region, 2014-2020.
Pointing positions up to 3.2 deg

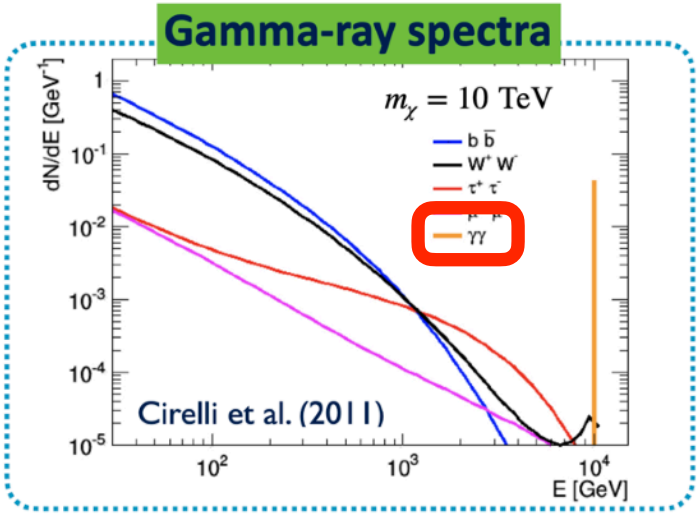
Montanari #279



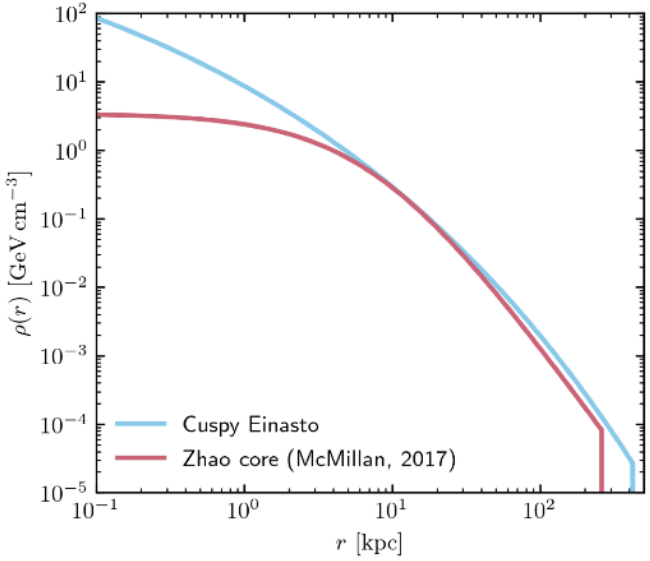
Search for DM annihilations/decays in the GC with HAWC:

Harding #695

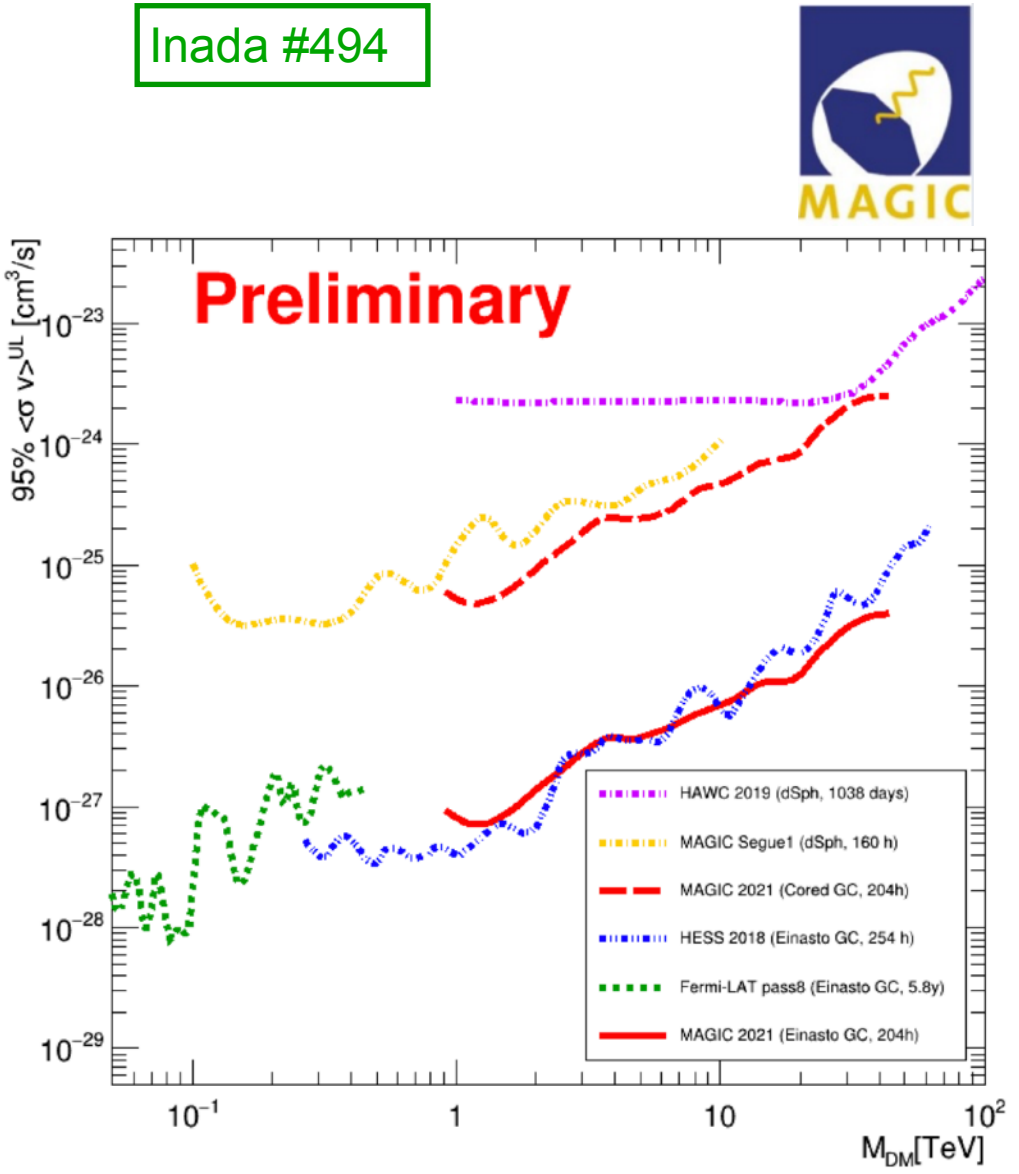
Search for gamma-ray lines



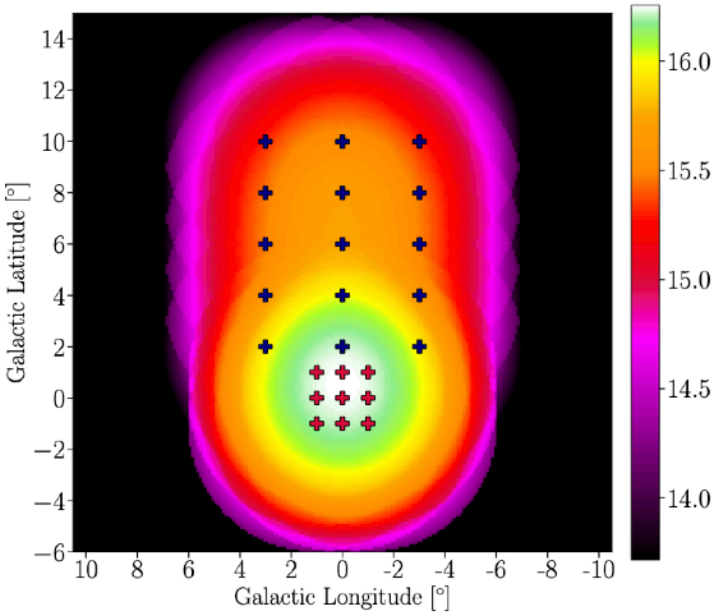
204h of observation of the GC region.
Search for spectral features using the sliding window technique.



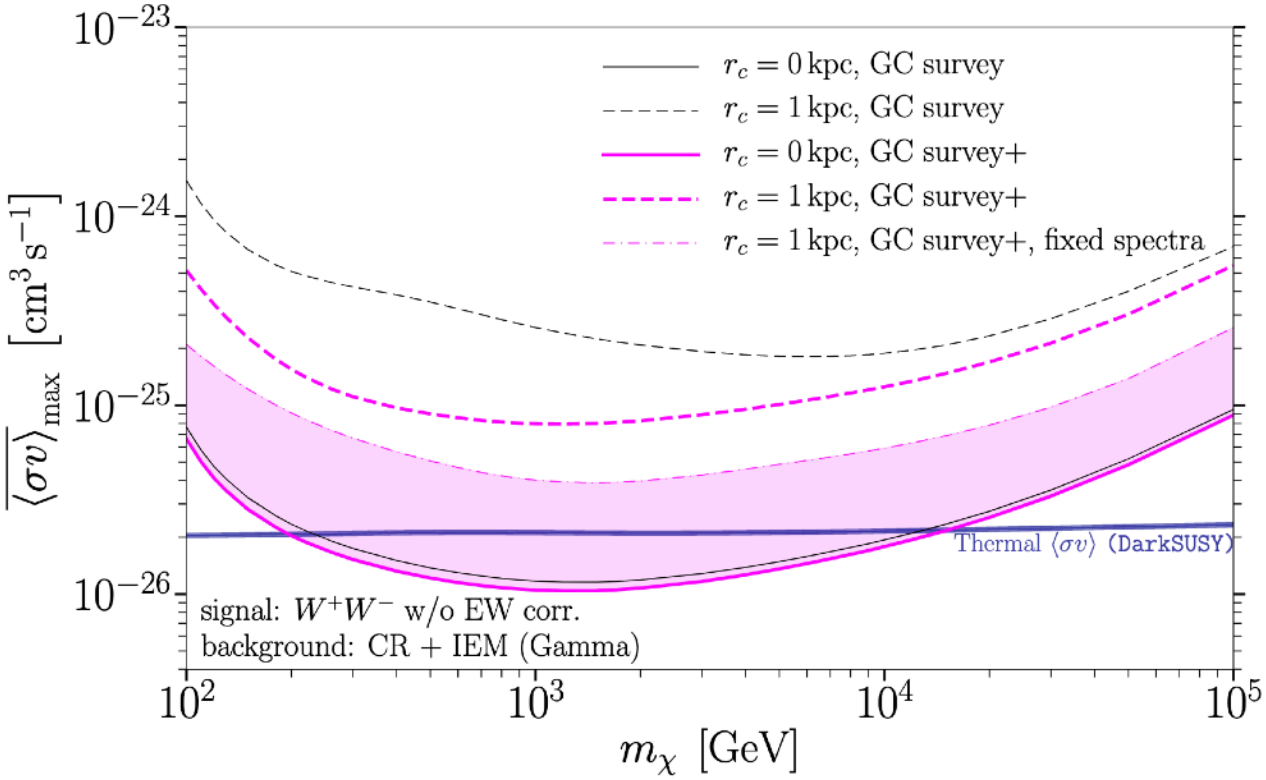
Inada #494



Prospects with CTA



Eckner #316

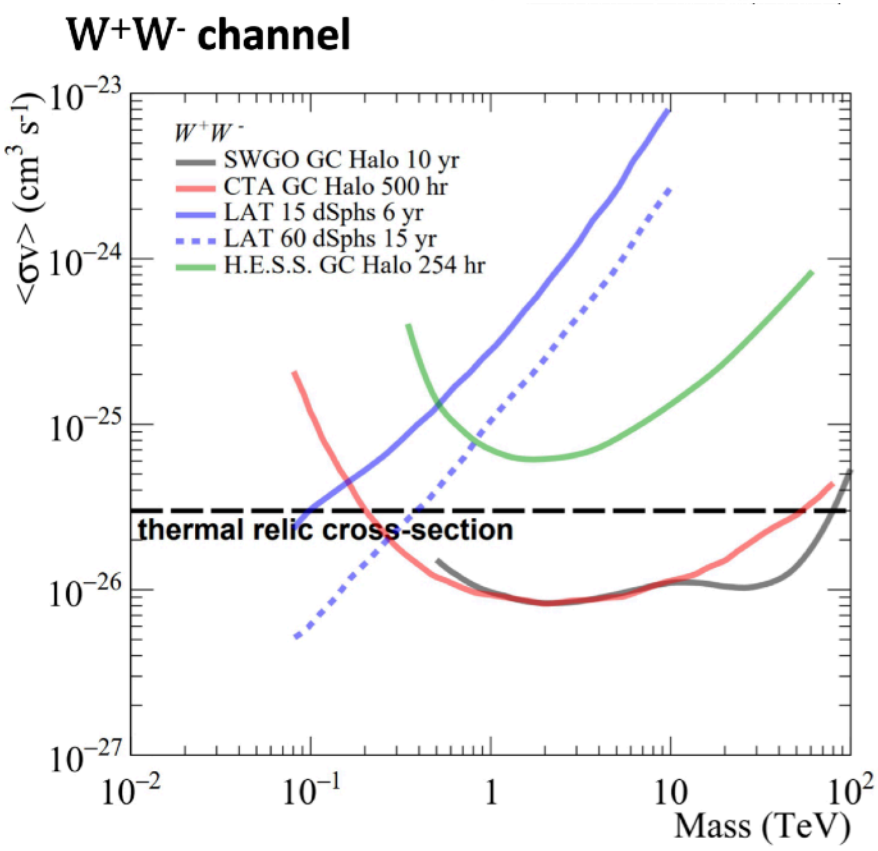


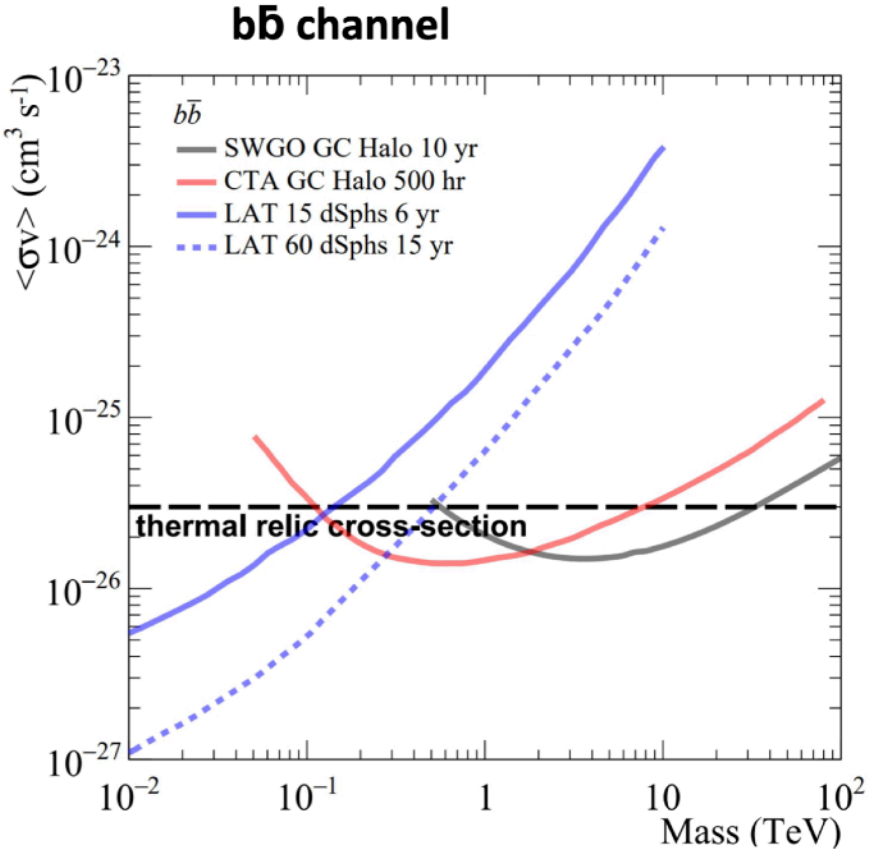
CTA's sensitivity to DM in the Galactic center region.
Template fitting analysis.
Sensitive to thermal TeV DM unless the DM profile has a sizeable core.

DM from the Perseus galaxy cluster with CTA: Romero #288

Prospects with SWGO

Viana #316





Search for DM from the GC inner 10 deg region.

Wide-angle air shower particle detector complementary to CTA South.

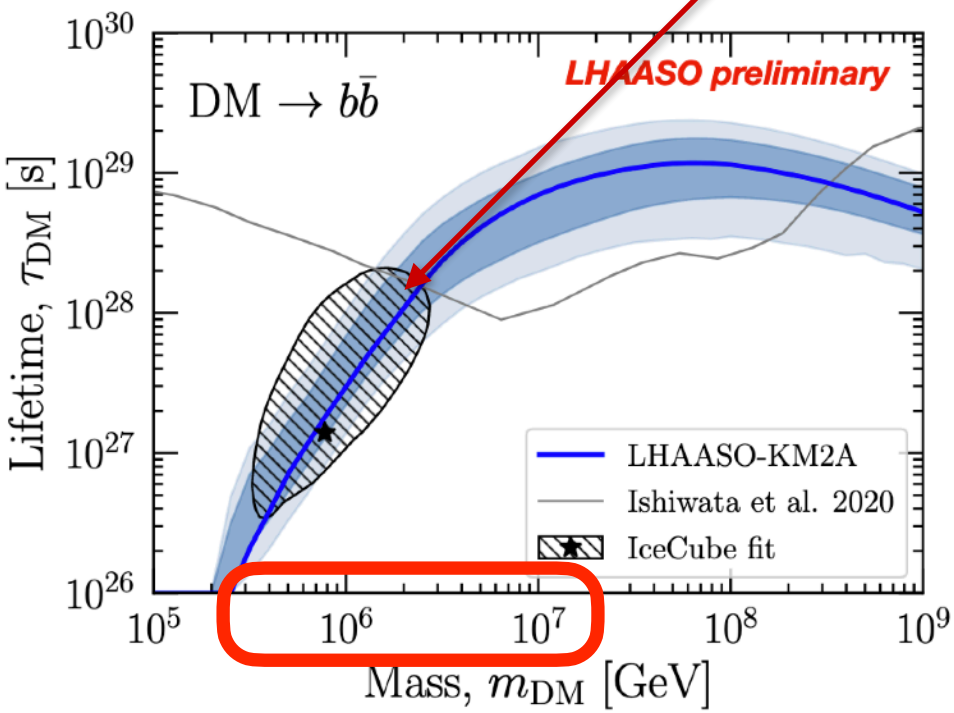
Energy range from 100 GeV to 100 TeV.

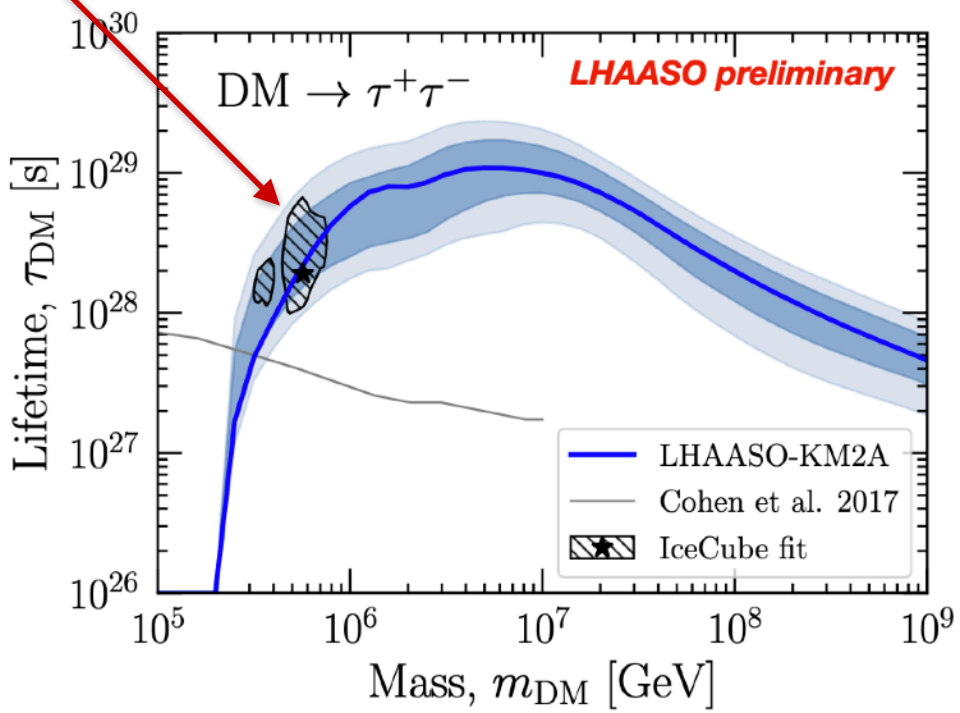
Significant sensitivity improvement over HAWC.

Decaying DM with LHAASO

Explain IceCube HE neutrinos

Chianese #894



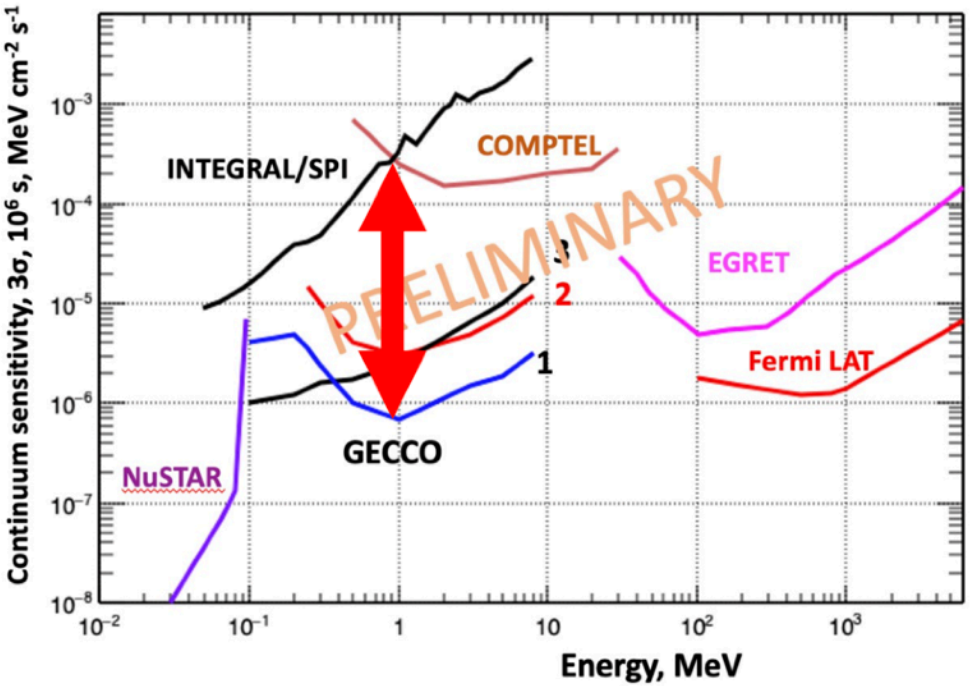


Search for DM signals from the galactic halo with **LHAASO-KM2A**.
340 days of 1/2-KM2A data. Use ON/OFF approach.
DM signal: prompt photons + secondaries from Inverse Compton.

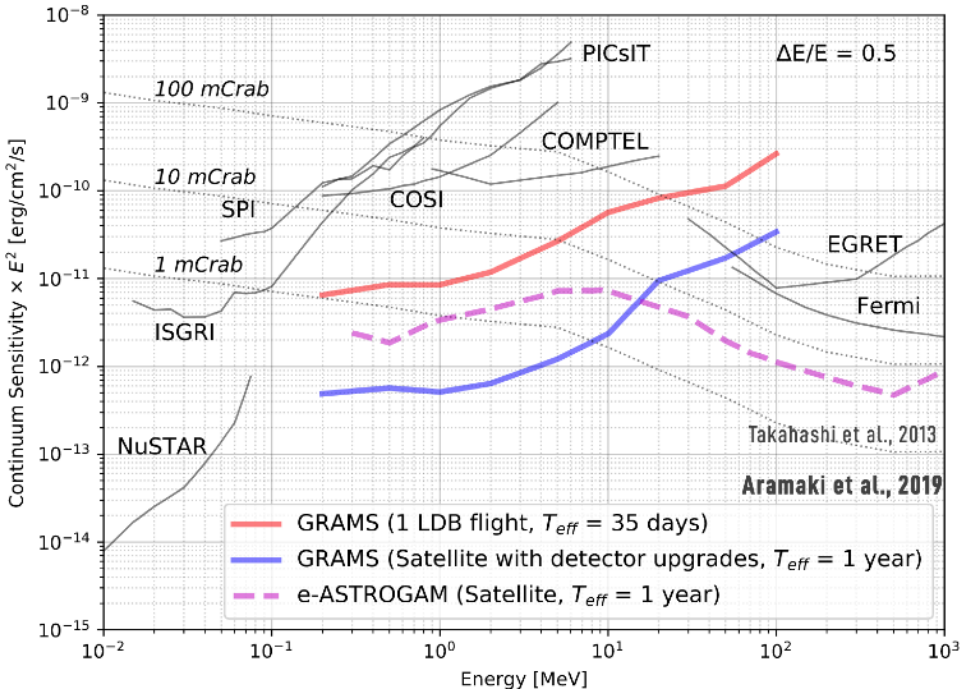
Heavy DM with LHAASO also in Addazi #123

The MeV gap

Profumo #70



Leyva #1054



GECCO

Galactic Explorer with a Coded Aperture Mask Compton Telescope

GRAMS

Plan first ballon flight in 5 years

First satellite mission in 10+ years

Constrain sub-GeV DM using Inverse Compton emission -> INTEGRAL data

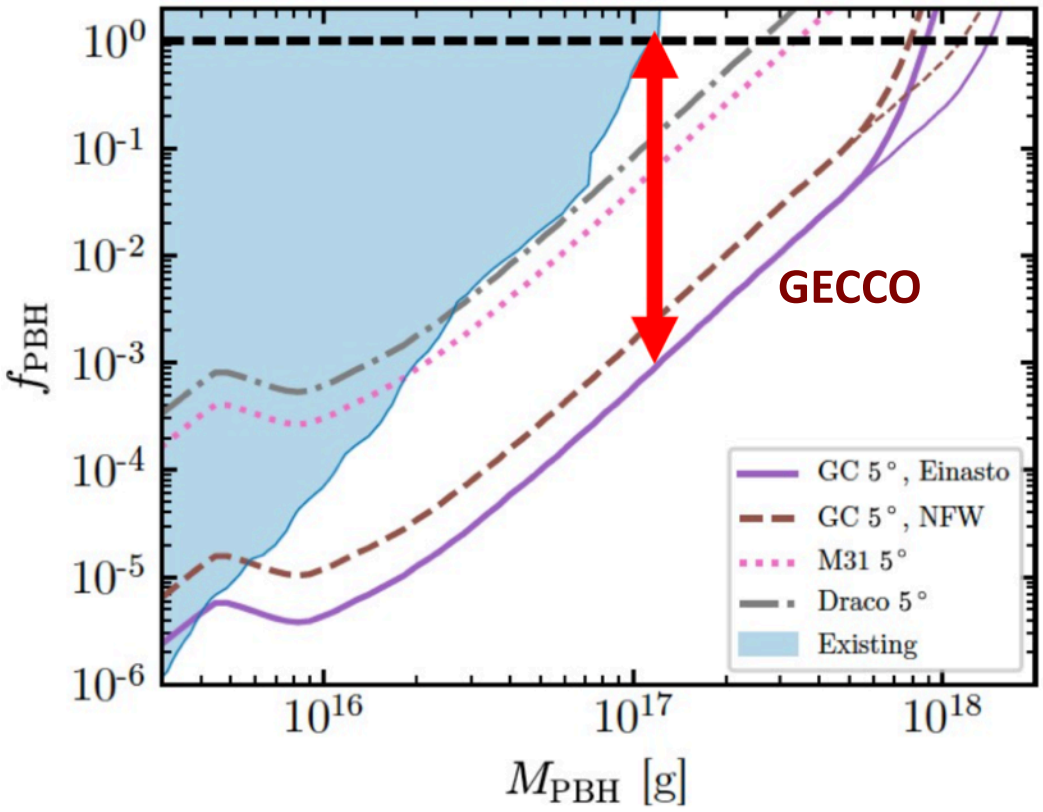
See talk by Pinetti #244

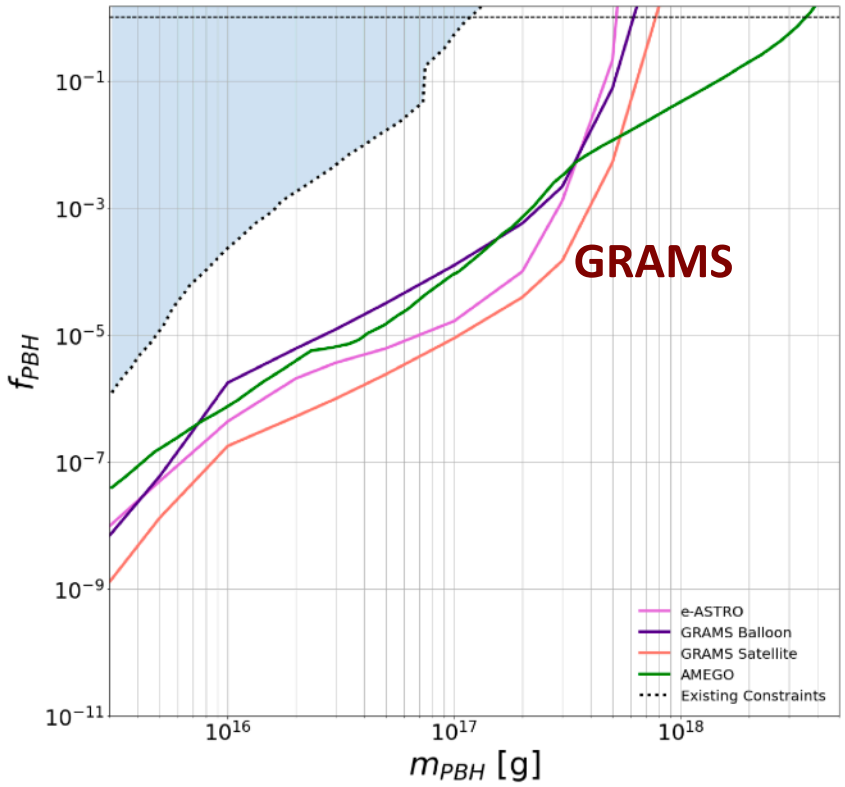
Primordial Black Holes

Profumo #70

Leyva #1054

Photon signals from PBHs evaporation

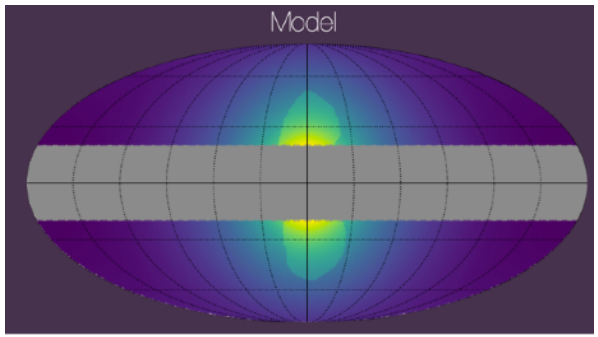




Searches of light PBHs evaporation signals with HESS Tavernier #477

O(1) $M_\odot$ PBHs can accrete gas in CMZ of our galaxy -> X-rays signals Scarcella #376

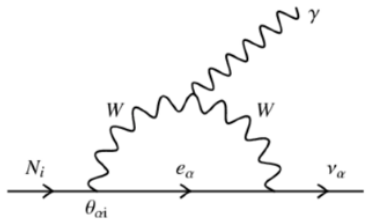
Sterile ν DM

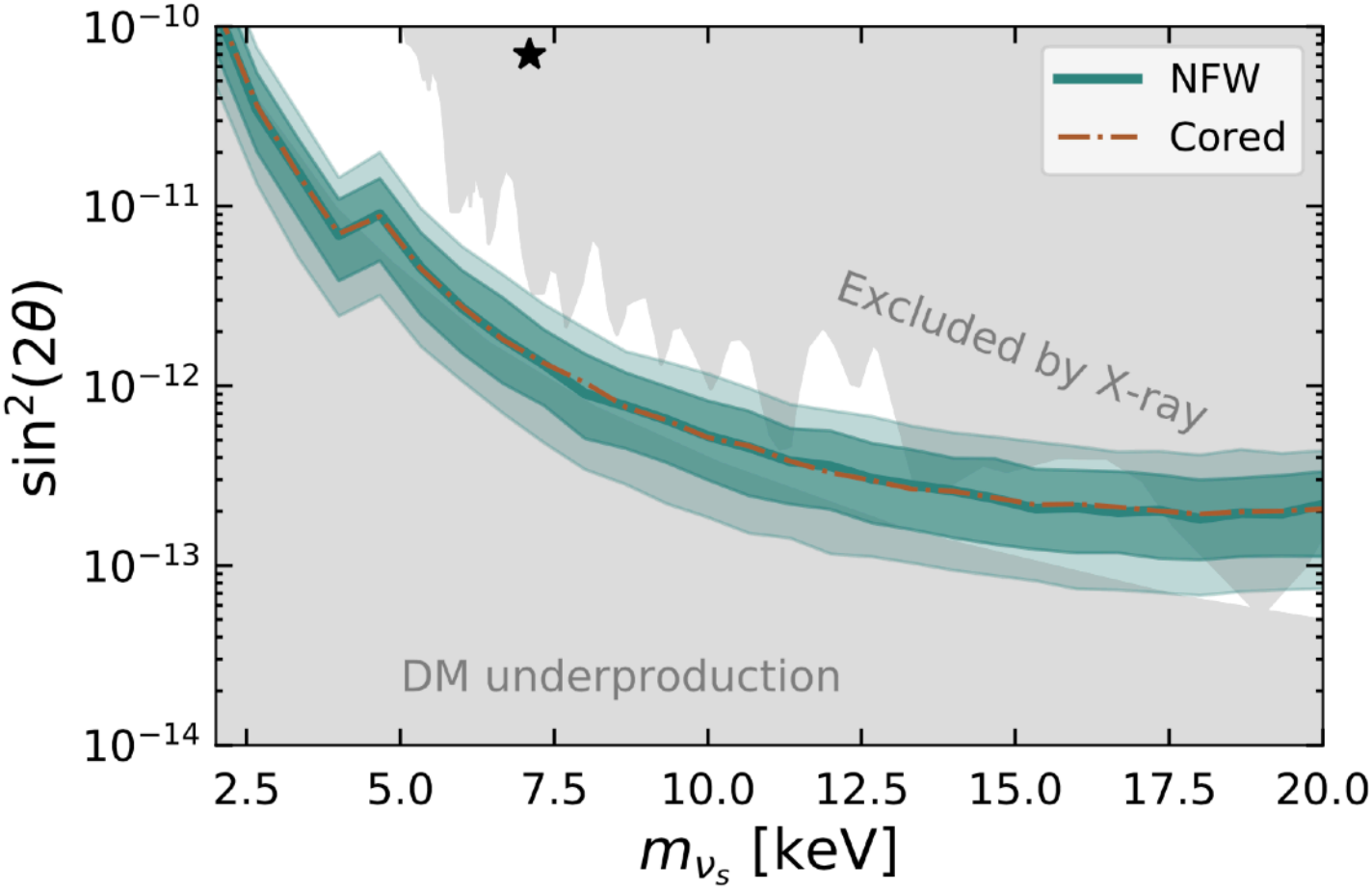


Dekker #1367

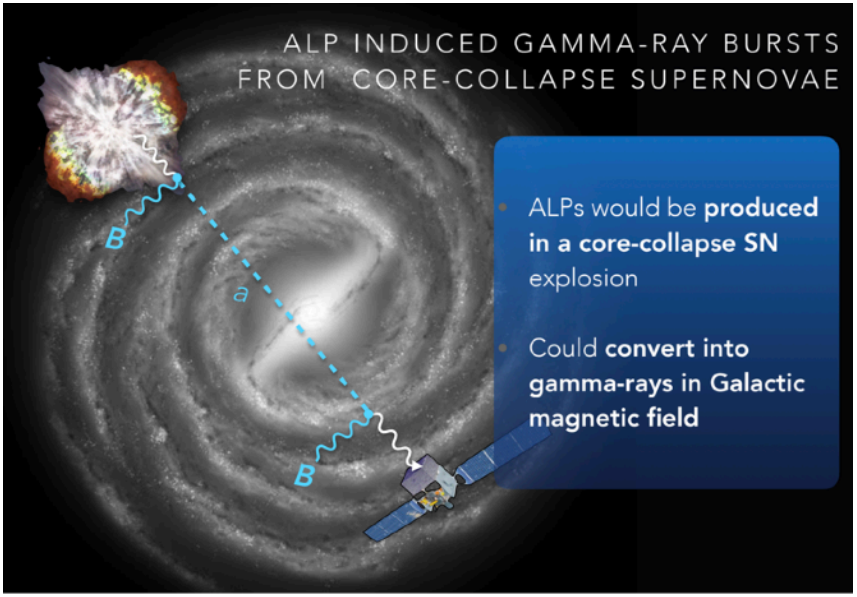
Sensitivities of **eROSITA** X-ray telescope to DM decays

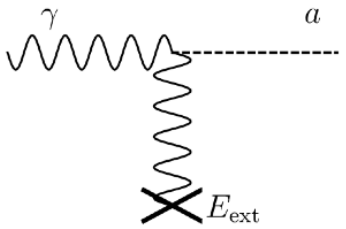
See also Zimmer #447



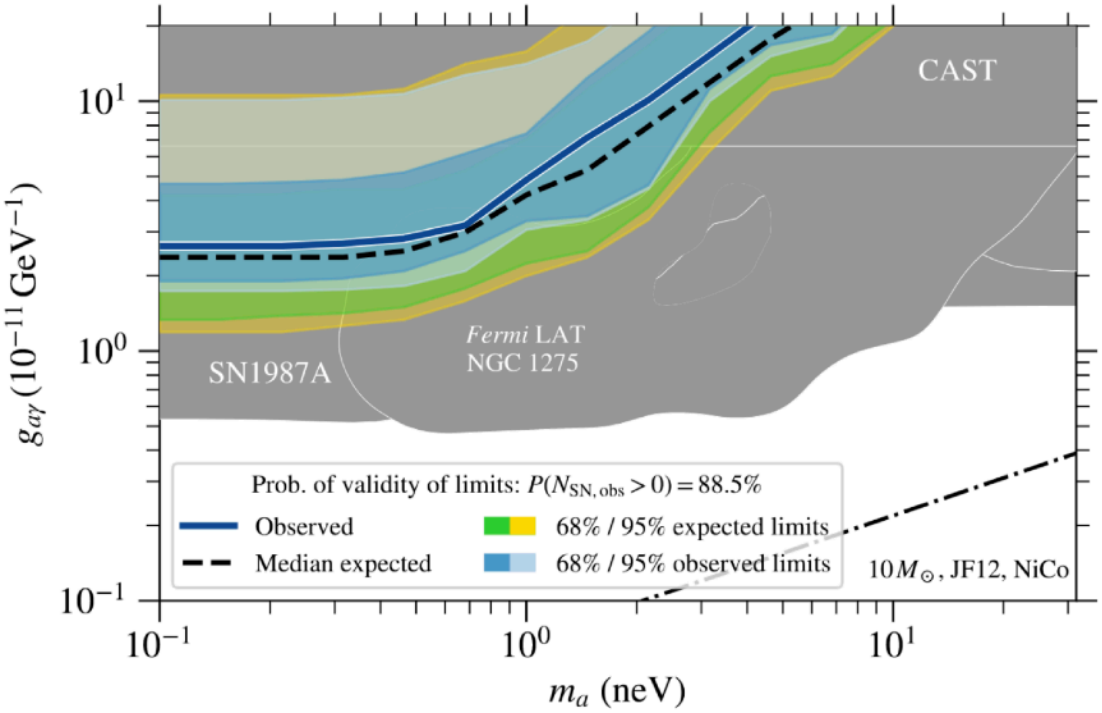


Axion-like particles





Meyer #172



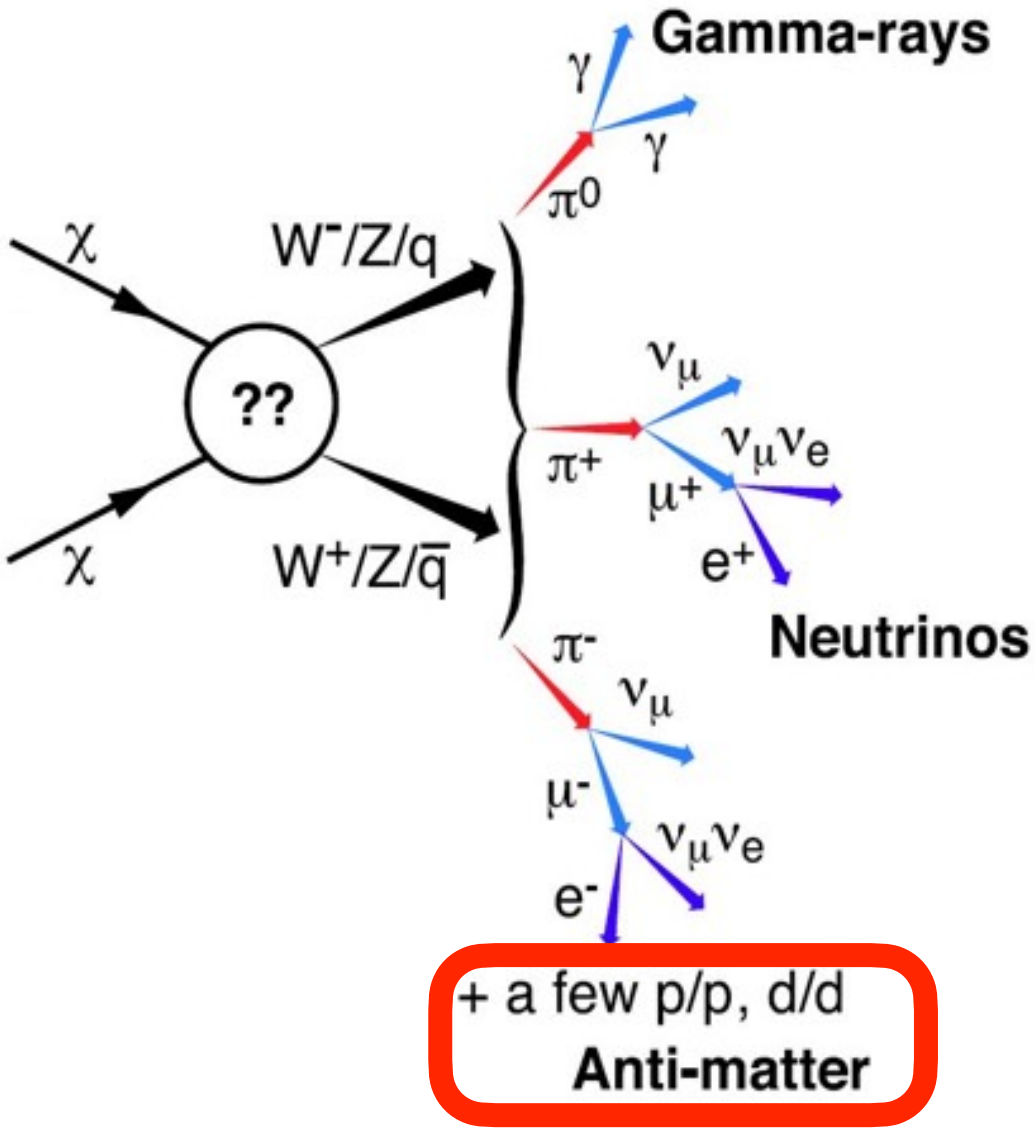
Search for bursts of gamma-ray signals with Fermi-LAT.
Use optical SN sample and estimate the explosion time from light curves.

Other classes of DM candidates @ ICRC-2021

Secluded DM Loparco #348, Siqueira #1267, Toennis #520

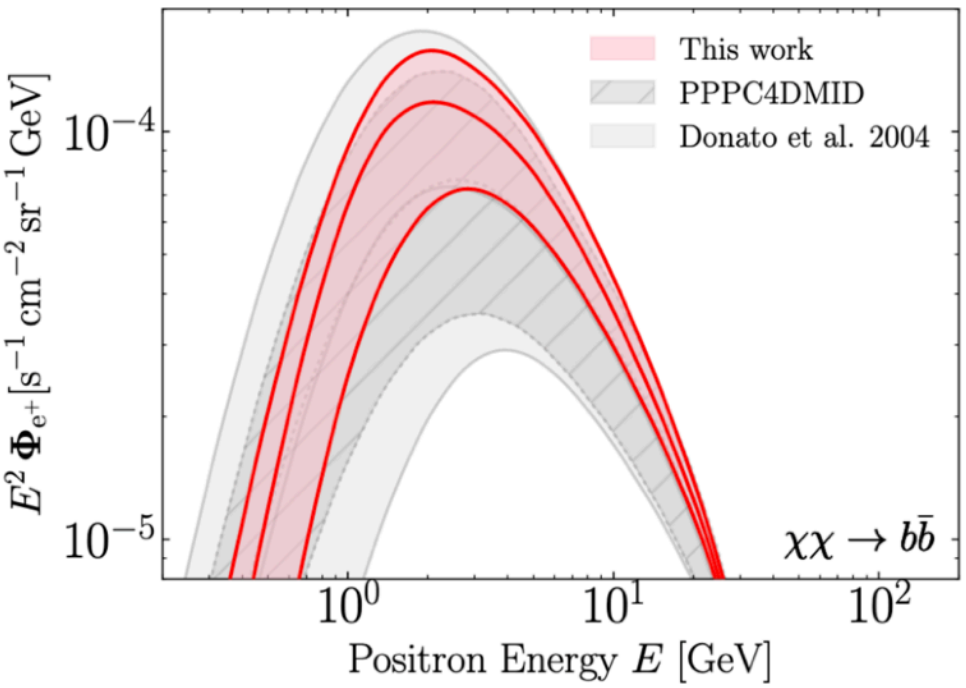
Nuclearites Kajino #1236, Paul #490, Piotrowski #1185

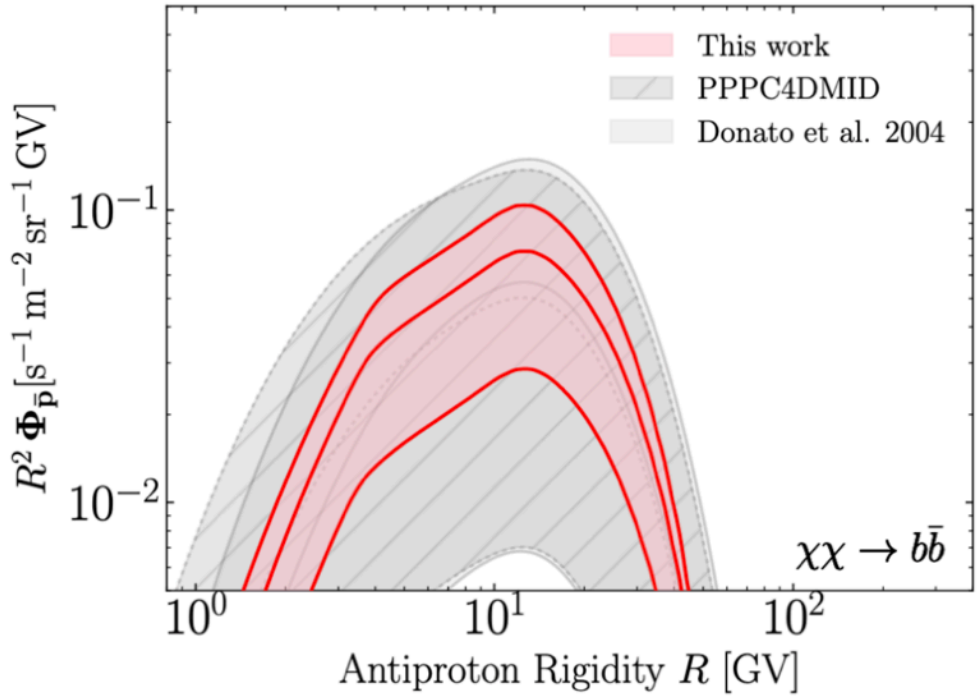
Charged cosmic-rays



CRs benchmark models

Salati #668





New MIN-MED-MAX benchmark CR propagation models to bracket uncertainties on DM signals.

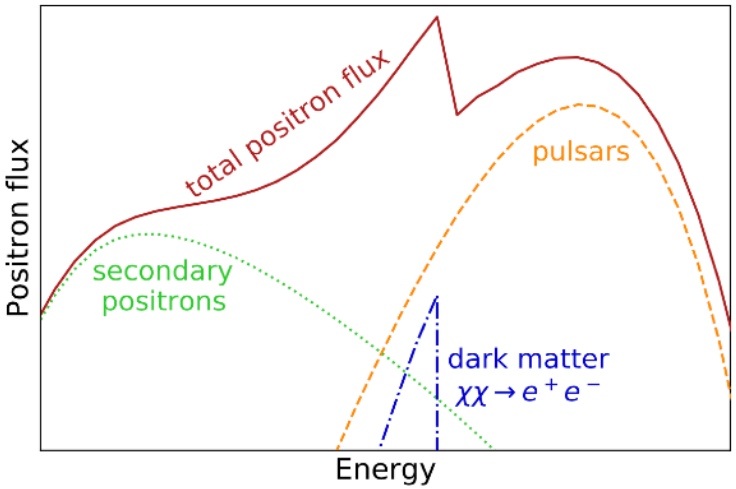
Revision based on latest measurements of CR nuclei.

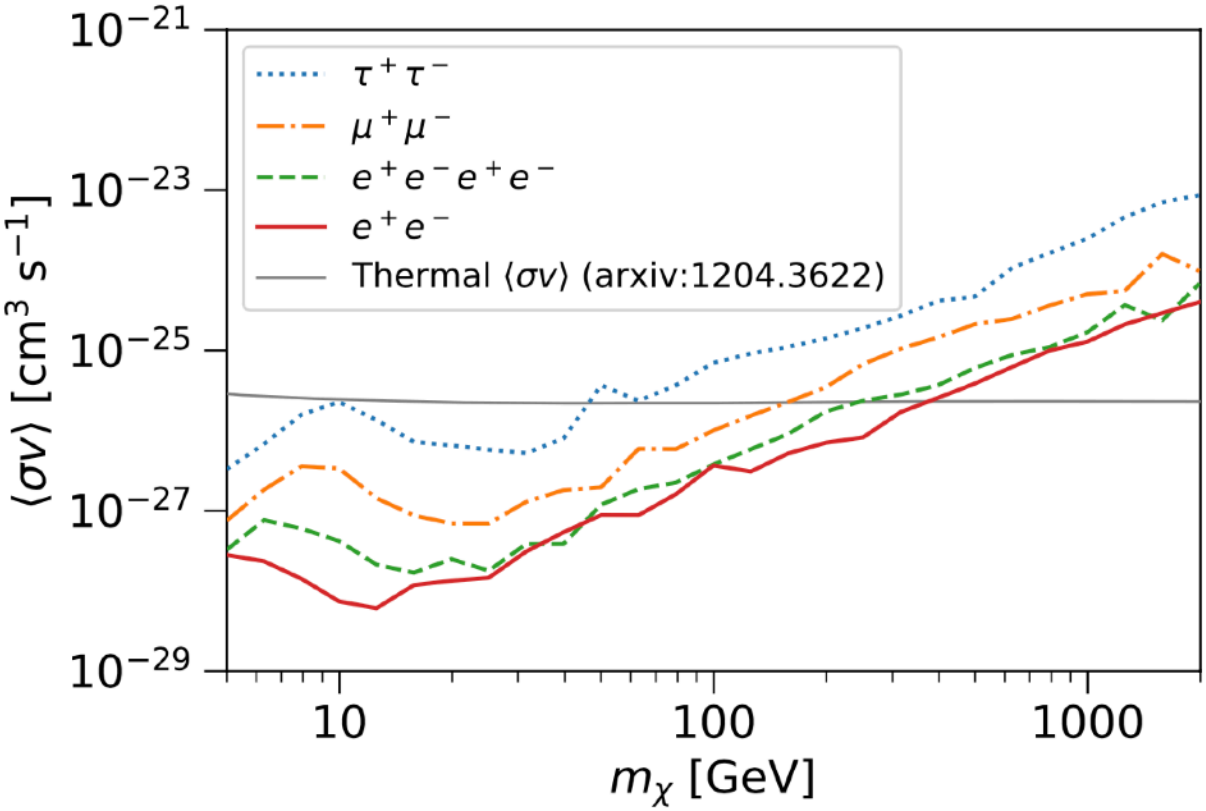
Uncertainties reduced by a factor 3-5.

SLIM	L [kpc]	δ	$\log_{10} K_0$ [kpc^2 Myr^{-1}]	R_l [GV]	δ_l
MAX	8.40	0.490	-1.18	4.74	-0.776
MED	4.67	0.499	-1.44	4.48	-1.11
MIN	2.56	0.509	-1.71	4.21	-1.45

Positrons

John #450





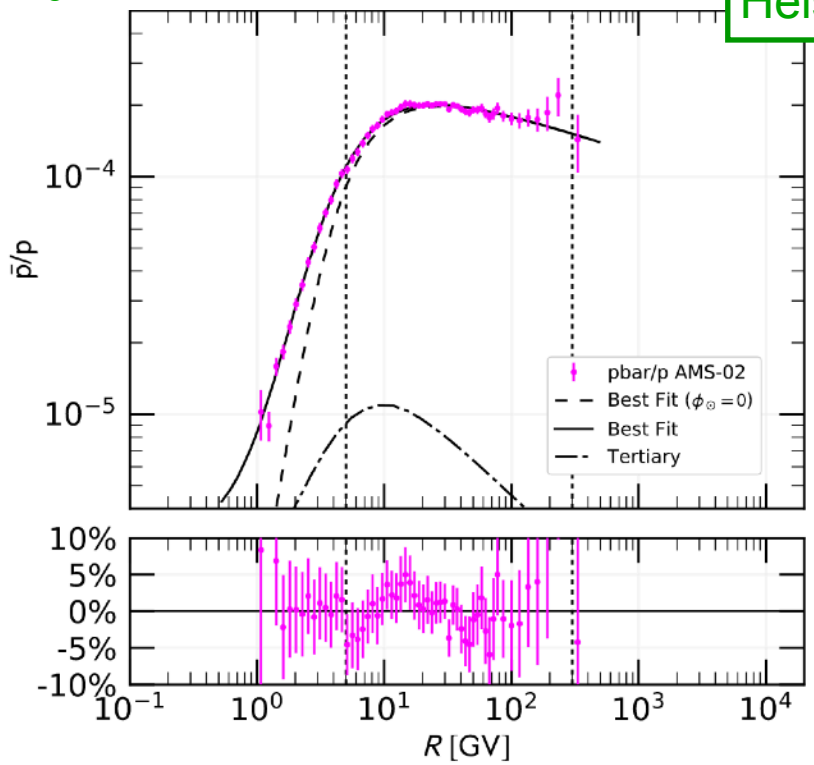
Constraints on leptophilic DM from the positron flux.

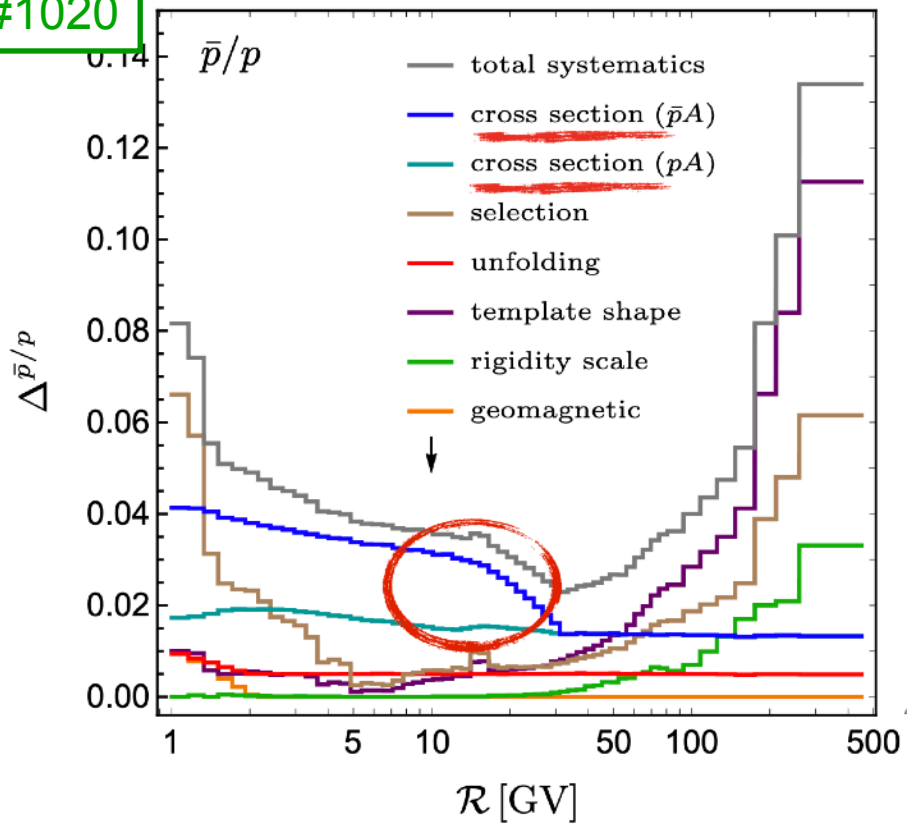
Cosmic-ray propagation parameters from fit of CRs data.

p̄ excess

Cuoco, Heisig, Klamt, Korsmeier and Kramer 2019

Heisig #1020





Hint for an excess in anti-p data compatible with DM.

Cuoco, Kramer, Korsmeier 2017 ; Cui, Yuan, Tsai, Fan 2017; + subsequent analisys

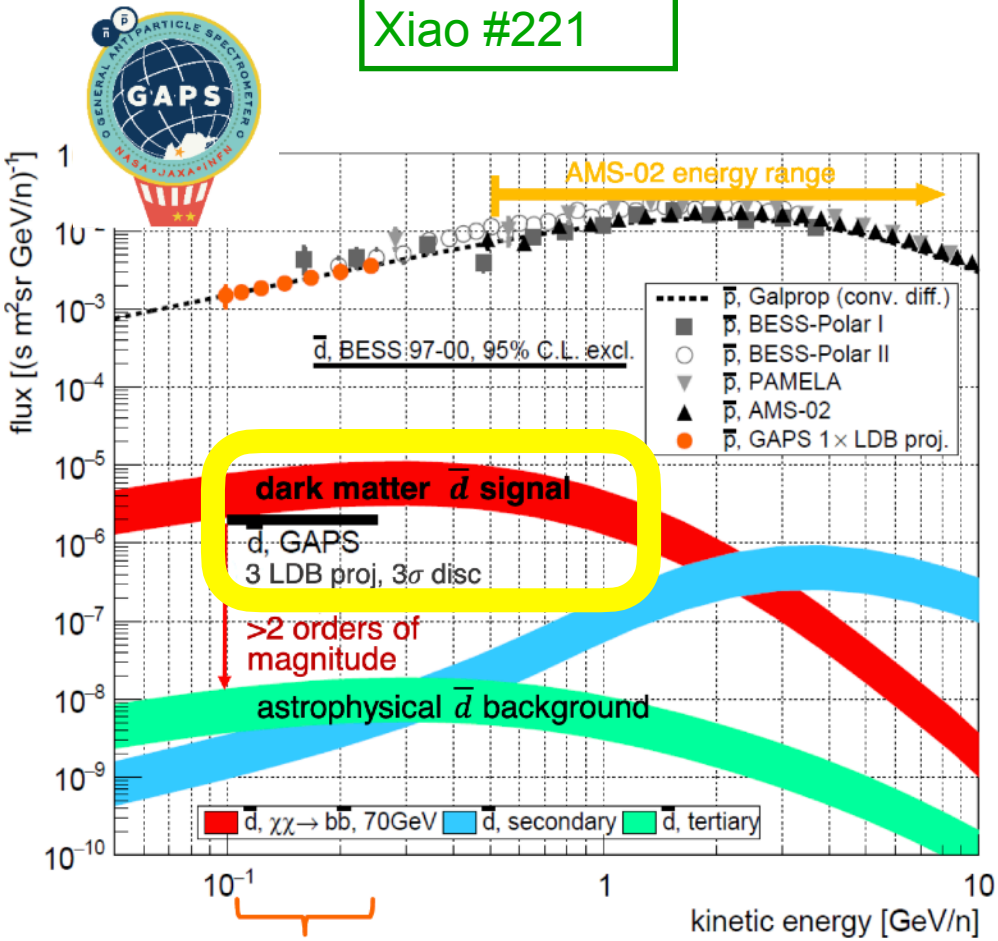
Systematic uncertainties at few % level are important.
Perform an estimate of the correlations in the AMS-02 systematic errors.
Correlated systematics errors in combination the other main uncertainties **reduce global significance < 1σ.**

See also De la Torre Luque #548

See also analysis of Boudaud, Genolini, Derome, Lavalle, Maurin, Salati, and Serpico 2020

Anti-nuclei

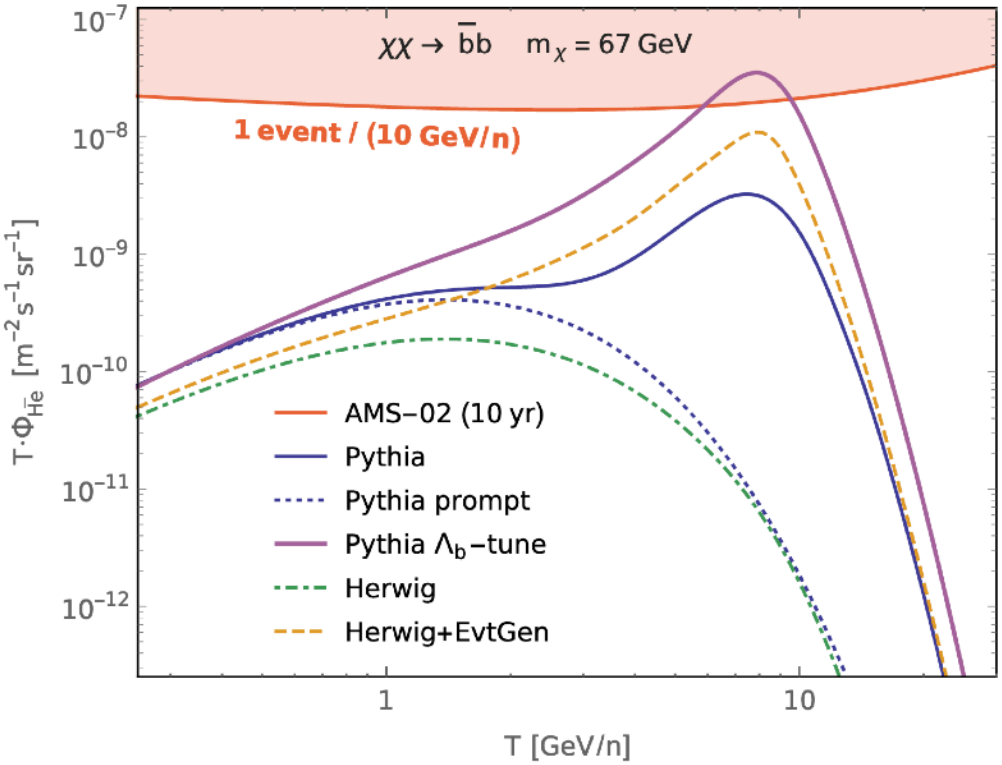
Xiao #221



GAPS optimized for low-energy (<0.25 GeV/n) anti-p, anti-deuterons, anti-He.

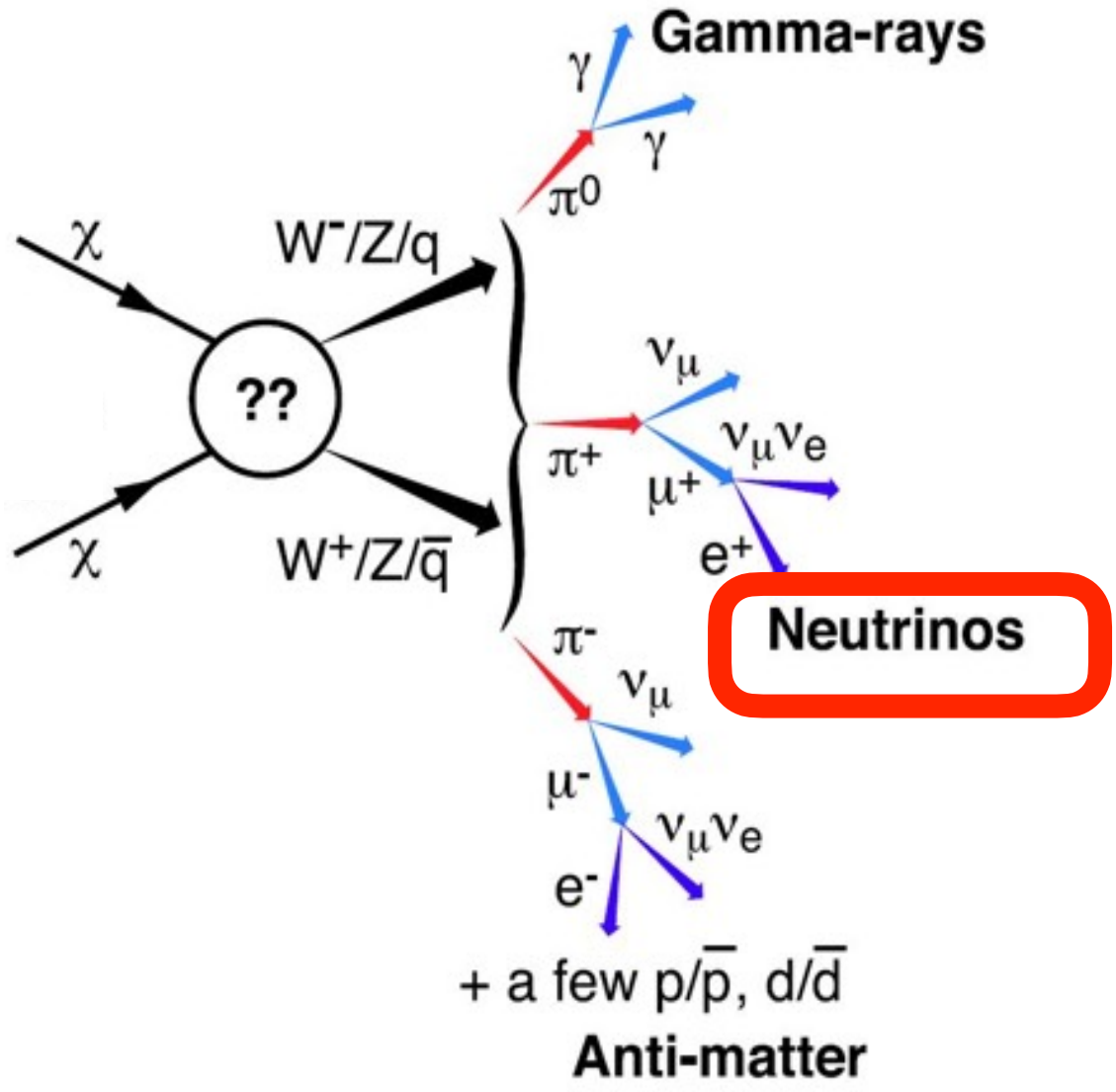
First science flight scheduled in late 2022.

Winkler #1353

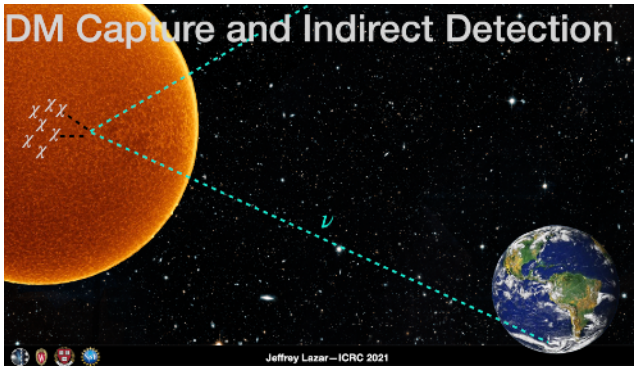


Boost of anti-He production from DM due to previously overlooked channel: displaced vertex decays of anti-Λ_b.

Neutrinos

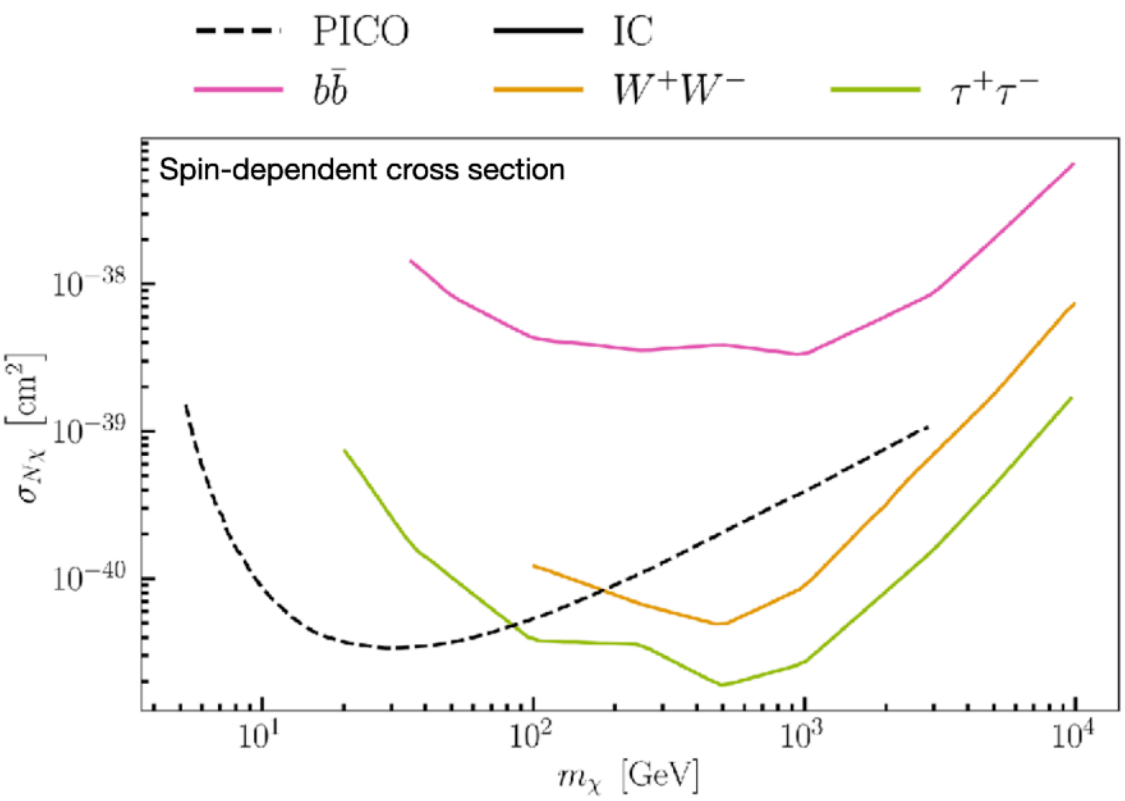

Gamma-rays
γ
γ
π0
χ
W-/Z/q
??
χ
W+/Z/q̄
νμ
π+
νμνe
μ+
e+
Neutrinos
π-
νμ
μ-
νμνe
e-
+ a few p/p̄, d/d̄
Anti-matter

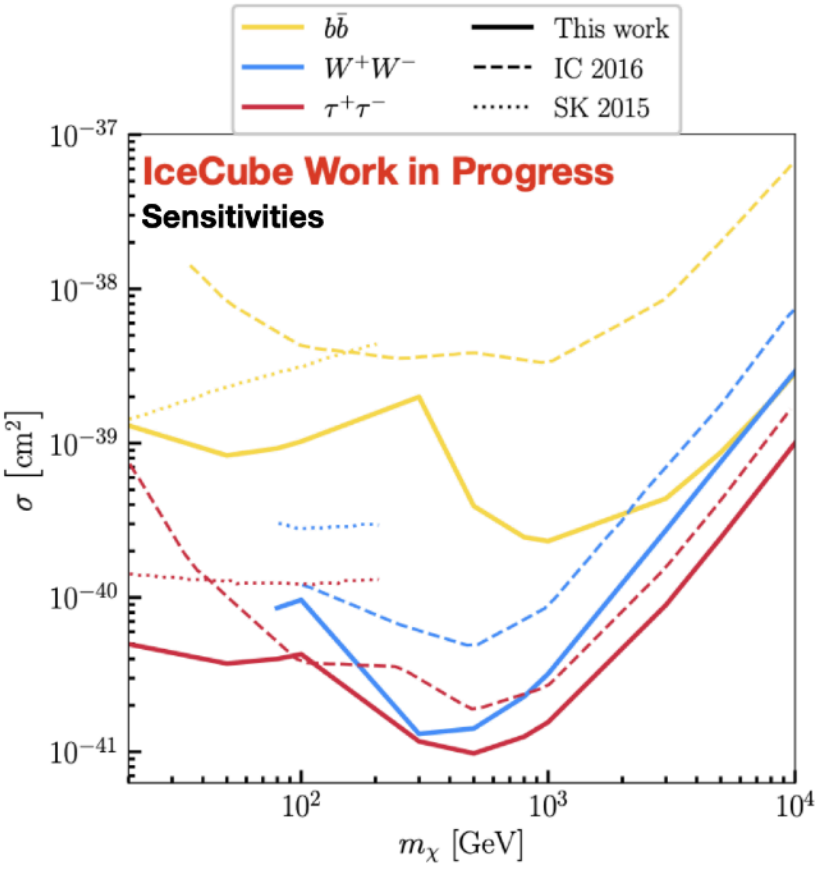
νs from the Sun



$$\frac{\Gamma_A}{2} = C_C \propto \sigma_{\chi N}$$

Lazar # 1379





νs from the Sun

Non-relativistic effective theory of dark matter-nucleon interactions .

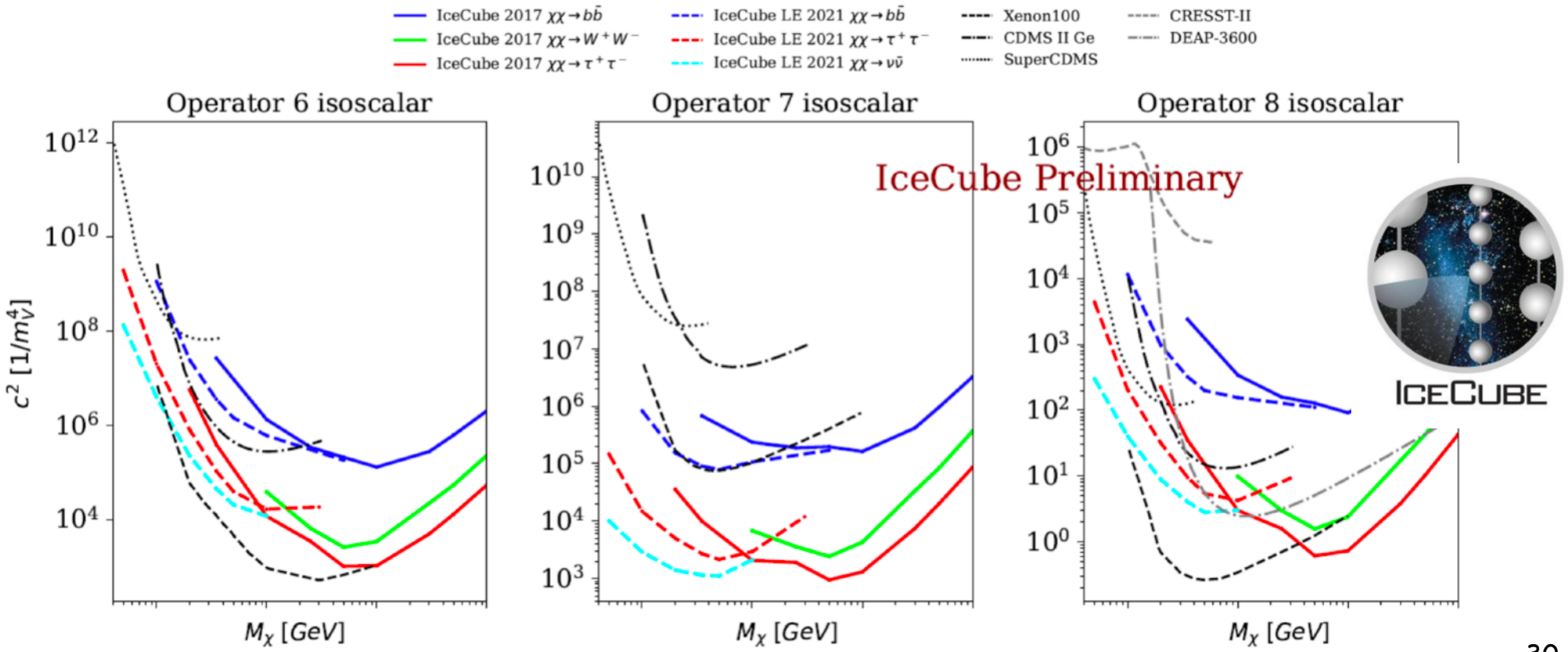
Peters # 522

SI →	$\mathcal{O}_1 = \mathbb{1}_X \mathbb{1}_N$	$\mathcal{O}_{11} = i\boldsymbol{S}_X \cdot \frac{q}{m_N} \mathbb{1}_N$
	$\mathcal{O}_3 = i\boldsymbol{S}_N \cdot \left(\frac{q}{m_N} \times v^\perp\right) \mathbb{1}_X$	$\mathcal{O}_{12} = \boldsymbol{S}_X \cdot (\boldsymbol{S}_N \times v^\perp)$
SD →	$\mathcal{O}_4 = \boldsymbol{S}_X \cdot \boldsymbol{S}_N$	$\mathcal{O}_{13} = i\left(\boldsymbol{S}_X \cdot v^\perp\right)\left(\boldsymbol{S}_N \cdot \frac{q}{m_N}\right)$
	$\mathcal{O}_5 = i\boldsymbol{S}_X \cdot \left(\frac{q}{m_N} \times v^\perp\right) \mathbb{1}_N$	$\mathcal{O}_{14} = i\left(\boldsymbol{S}_X \cdot \frac{q}{m_N}\right)\left(\boldsymbol{S}_N \cdot v^\perp\right)$
	$\mathcal{O}_6 = \left(\boldsymbol{S}_X \cdot \frac{q}{m_N}\right)\left(\boldsymbol{S}_N \cdot \frac{q}{m_N}\right)$	$\mathcal{O}_{15} = -\left(\boldsymbol{S}_X \cdot \frac{q}{m_N}\right)\left[\left(\boldsymbol{S}_N \times v^\perp\right) \cdot \frac{q}{m_N}\right]$
	$\mathcal{O}_7 = \boldsymbol{S}_N \cdot v^\perp \mathbb{1}_X$	$\mathcal{O}_{17} = i\frac{q}{m_N} \cdot \boldsymbol{\mathcal{S}} \cdot v^\perp \mathbb{1}_N$
	$\mathcal{O}_8 = \boldsymbol{S}_X \cdot v^\perp \mathbb{1}_N$	$\mathcal{O}_{18} = i\frac{q}{m_N} \cdot \boldsymbol{\mathcal{S}} \cdot \boldsymbol{S}_N$
	$\mathcal{O}_9 = i\boldsymbol{S}_X \cdot \left(\boldsymbol{S}_N \times \frac{q}{m_N}\right)$	$\mathcal{O}_{19} = \frac{q}{m_N} \cdot \boldsymbol{\mathcal{S}} \cdot \frac{q}{m_N}$
	$\mathcal{O}_{10} = i\boldsymbol{S}_N \cdot \frac{q}{m_N} \mathbb{1}_X$	$\mathcal{O}_{20} = \left(\boldsymbol{S}_N \times \frac{q}{m_N}\right) \cdot \boldsymbol{\mathcal{S}} \cdot \frac{q}{m_N}$

Beyond standard SI and SD interactions.

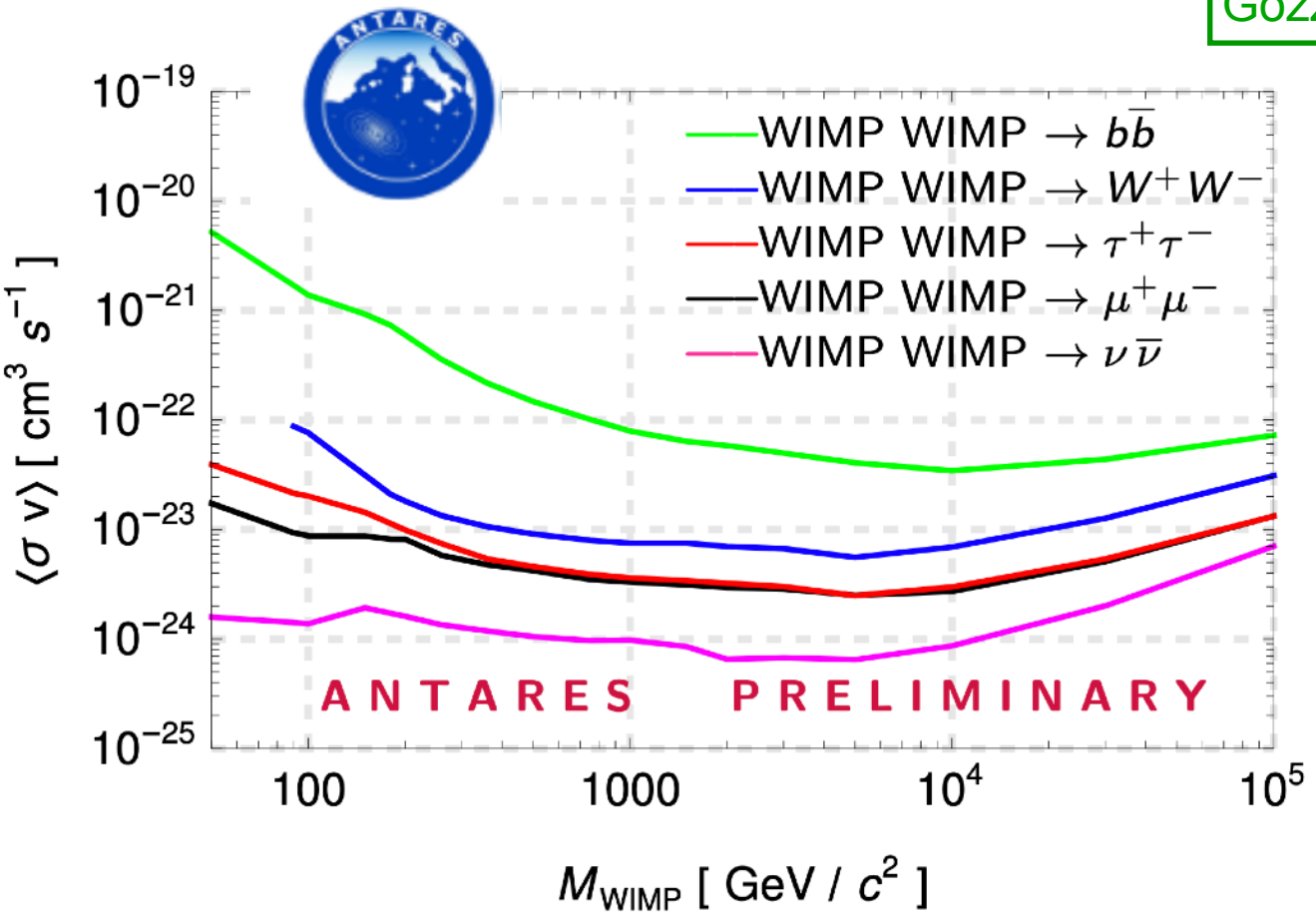
Based on IceCube searches of ν from the Sun.

Complementarity with direct detection.



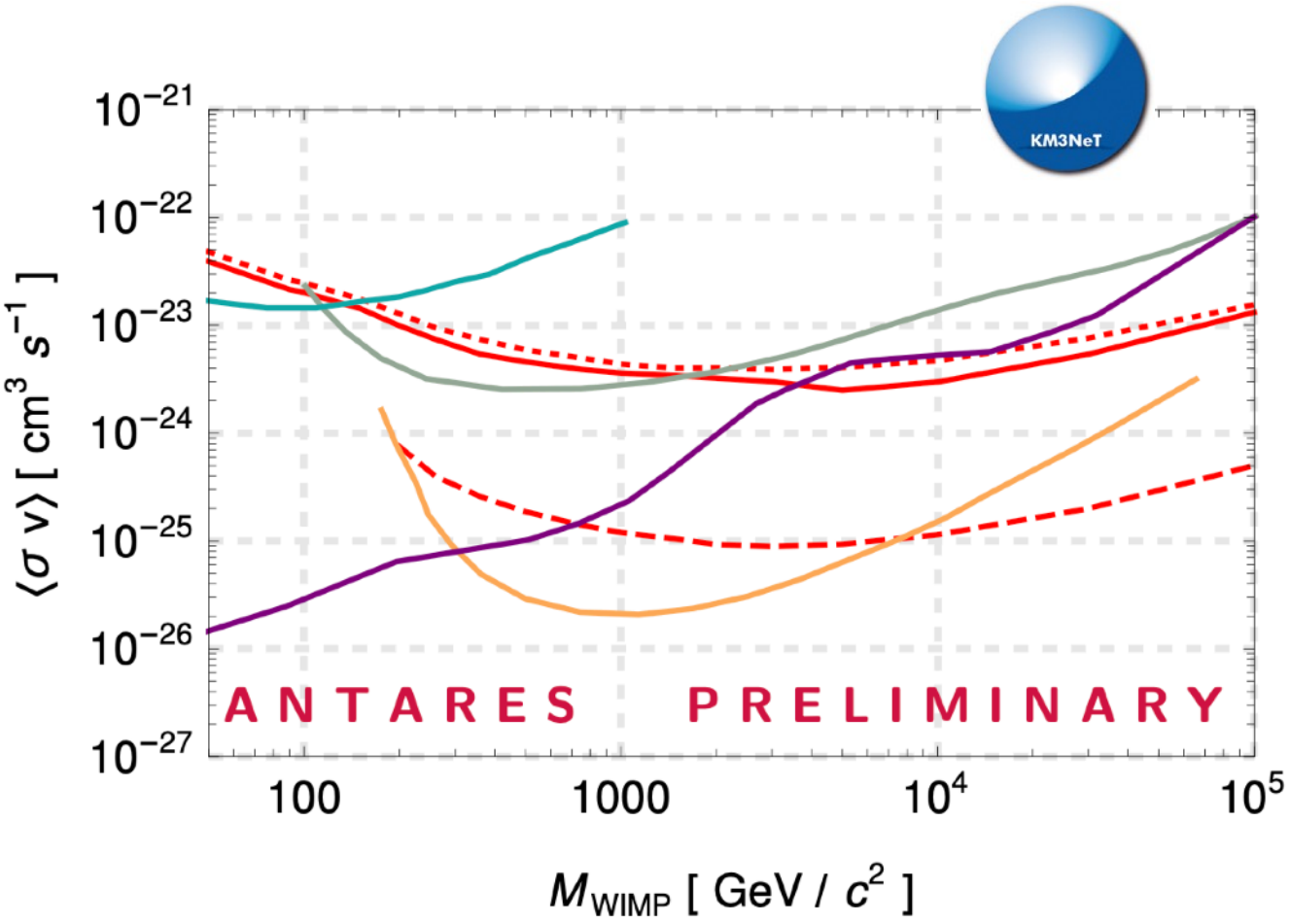
νs from the Galactic Center

Gozzini #1207



Search for neutrinos from DM annihilations in the Galactic Center with **ANTARES data**
Jan 2007 - Feb 2020

DM searches with KM3NeT



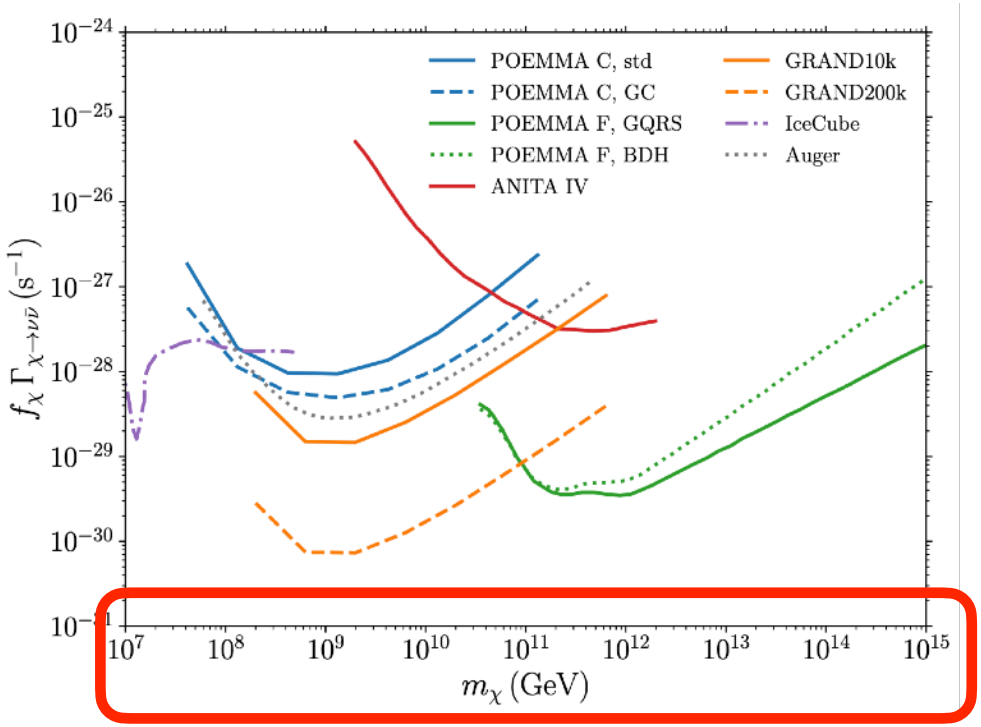
Gozzini #1207

WIMP WIMP $\rightarrow \tau^+\tau^-$

- ANTARES 14 years (NFW)
- ANTARES 11 years (NFW)
- KM3NeT 1 year (NFW)
- HESS 10 years (Einasto)
- Fermi-MAGIC (Dwarf Sph.)
- VERITAS (Dwarf Sph.)
- IceCube 3 years (NFW)

Sensitivities with 1yr of **KM3NeT**

Future HE ν detectors



Guepin #1033

Sensitivities of **POEMMA** and **GRAND** to **heavy DM**

POEMMA: Cherenkov and fluorescence detectors on satellites

GRAND: ground-based arrays of 10k -200k radio antennas

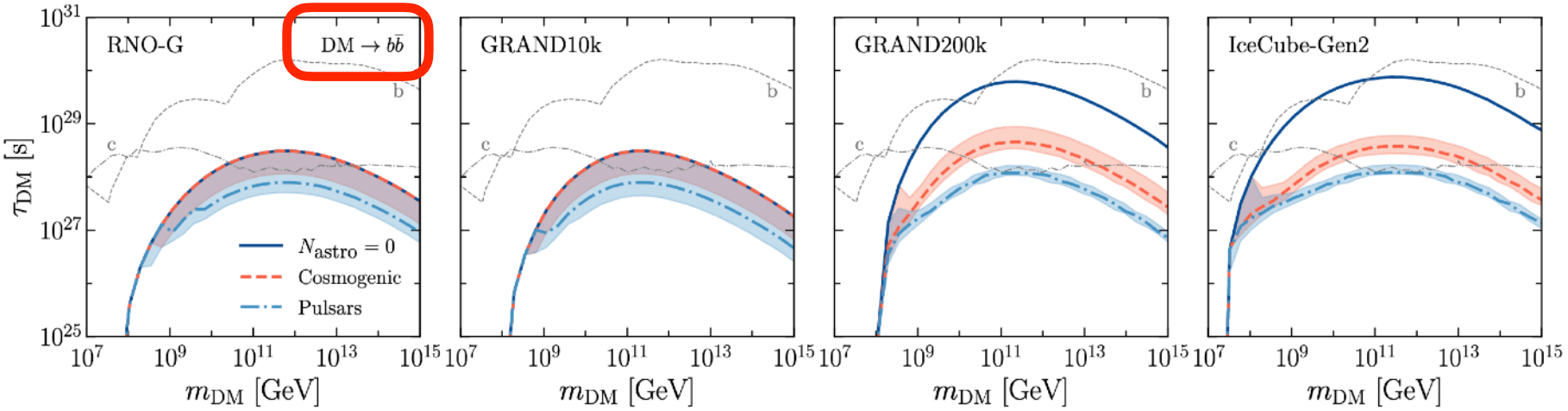
Sensitivities of **RNO-G**, **GRAND, IceCube-Gen2** to **heavy DM**

RNO-G: in-ice radio detectors

DM decays in $\nu\,\nu$: unprecedented sensitivities

DM decays in bb : complementary to gamma-rays

Hajjar #791



Conclusions

Broad programme of Dark Matter searches @ ICRC-2021

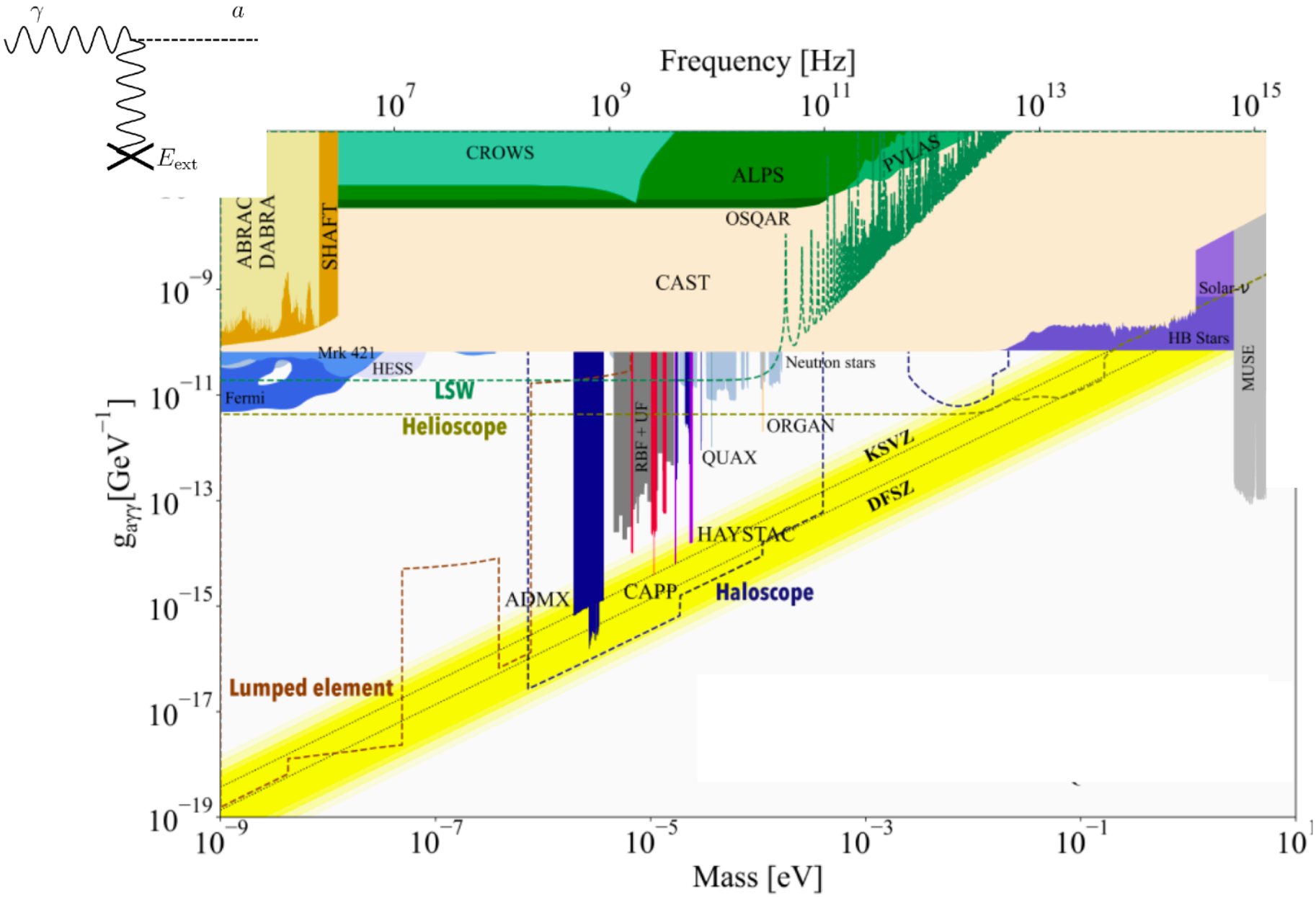
Several classes of Dark Matter candidates explored

Few anomalies possibly hinting to Dark Matter

Significant progress is expected thanks to upcoming new experiments

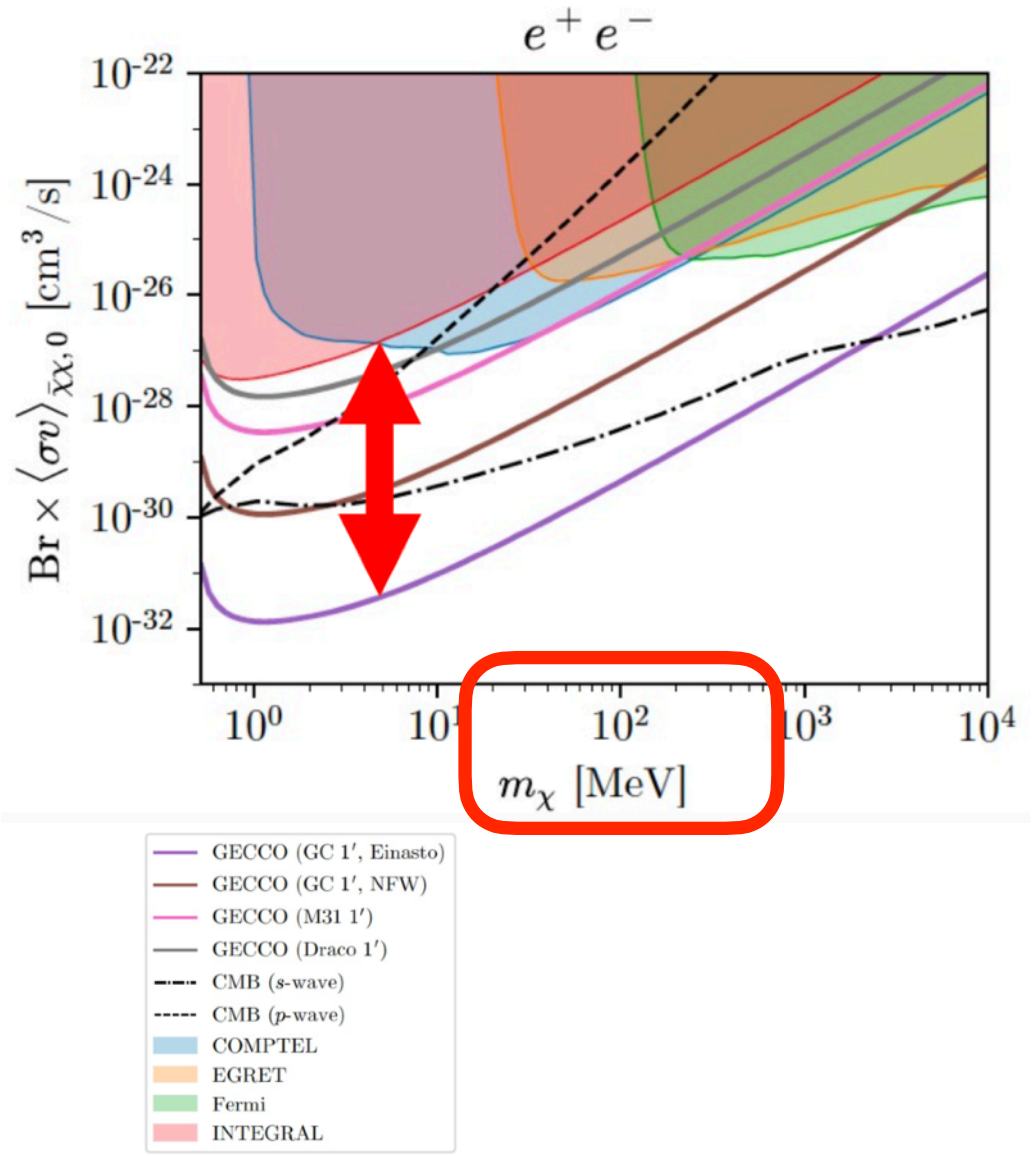
Backup slides

Axion-like particles

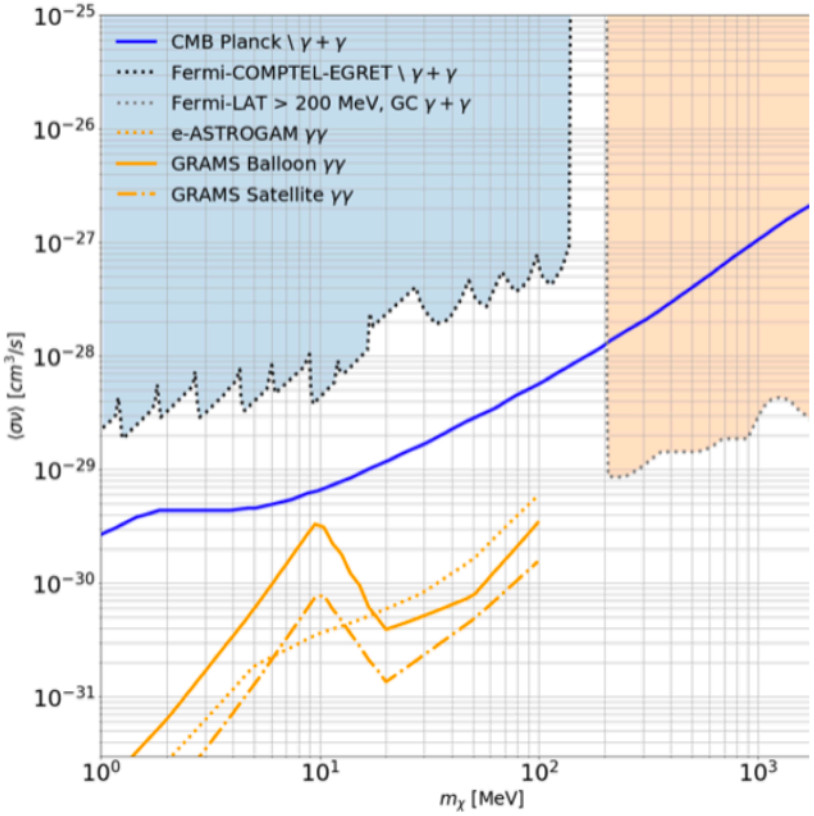


MeV DM

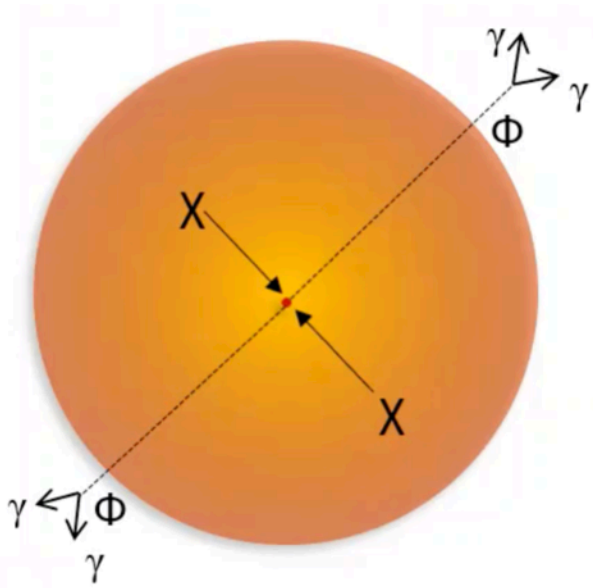
Profumo #70



Leyva #1054

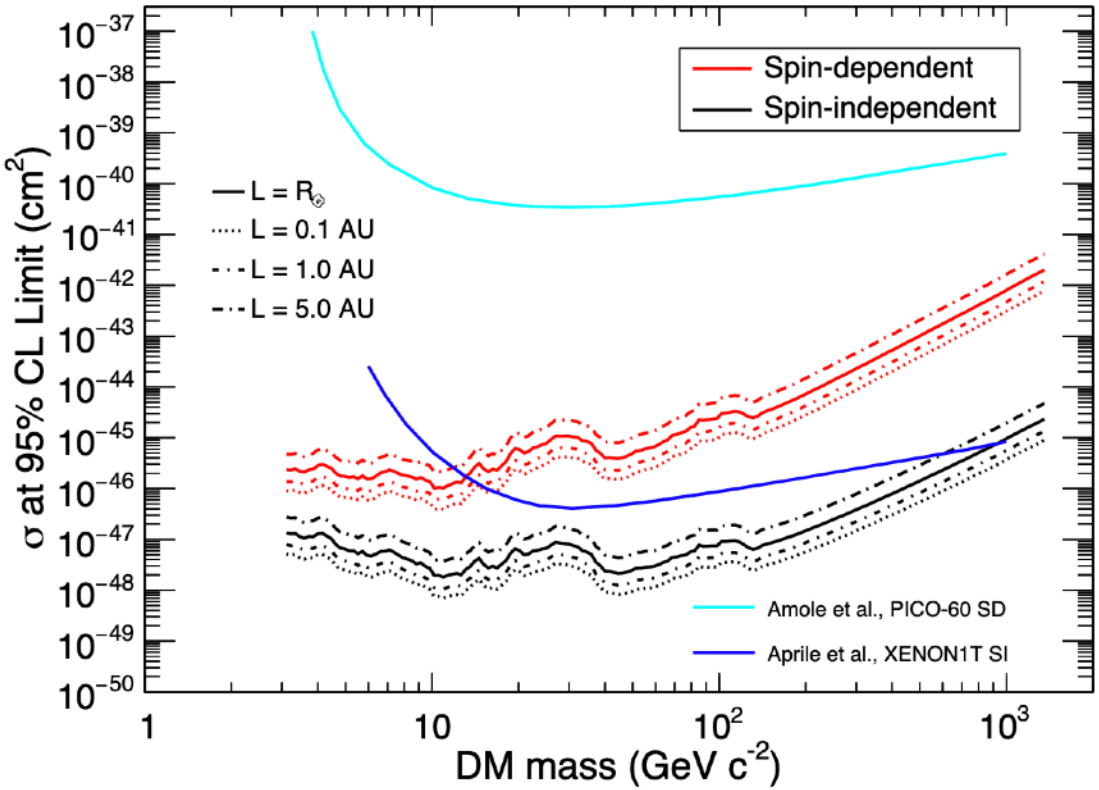


Secluded dark matter



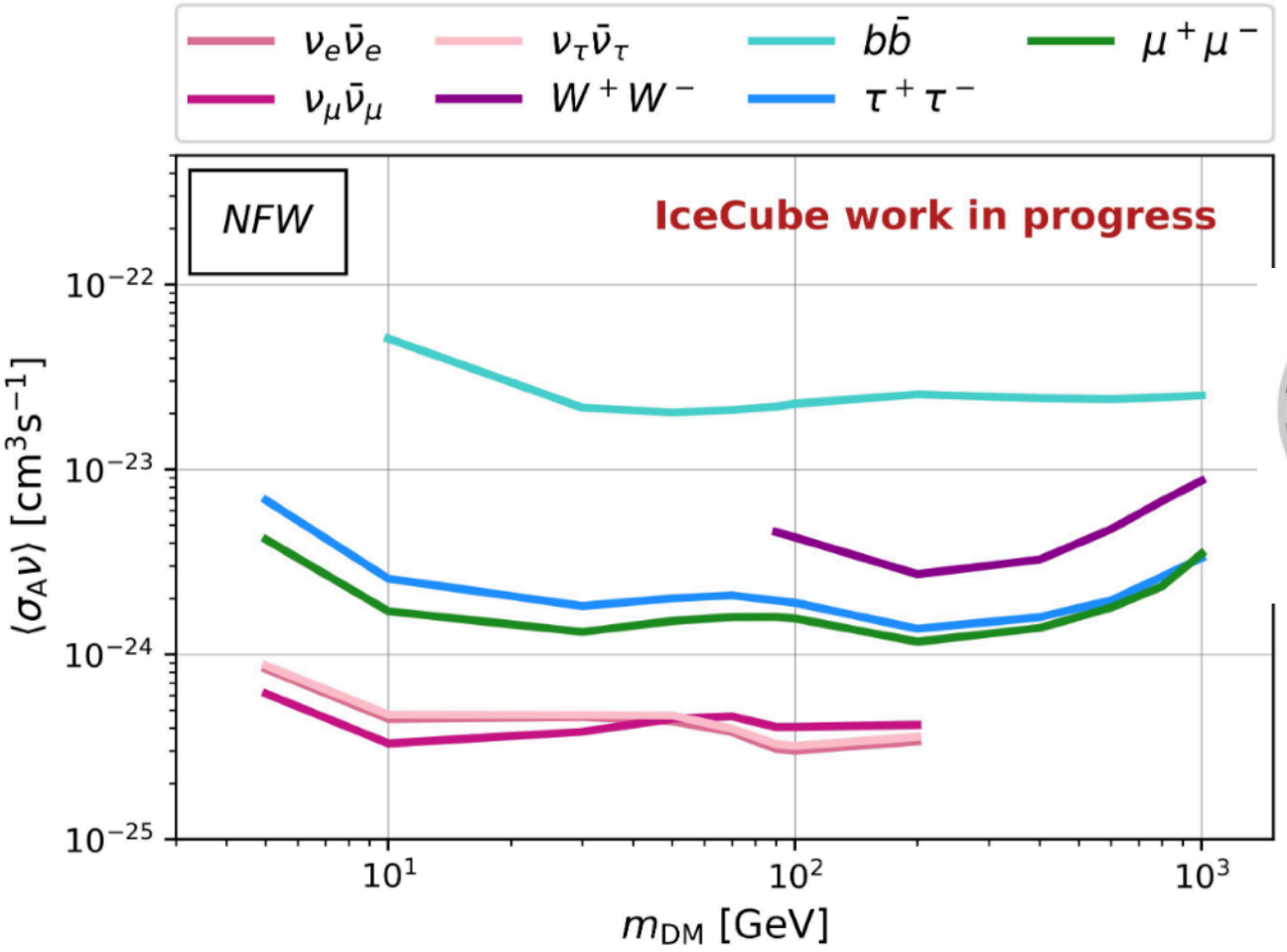
Search for **spectral features** in the gamma-ray energy spectrum from the Sun.

Loparco #348



Secluded DM also in Siqueira #1267, Toennis #520

νs from the Galactic Center

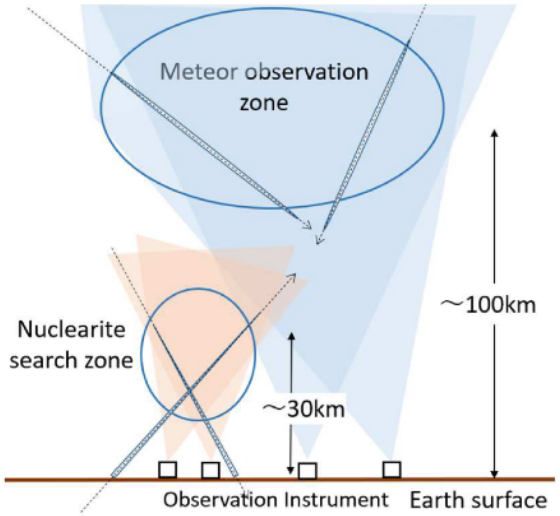


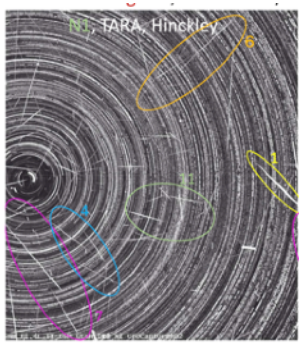
Iovine # 619

Analysis based on 8 years of Deep Core data 2012-2020.
Considerable improvement wrt previous IceCube analysis due to:

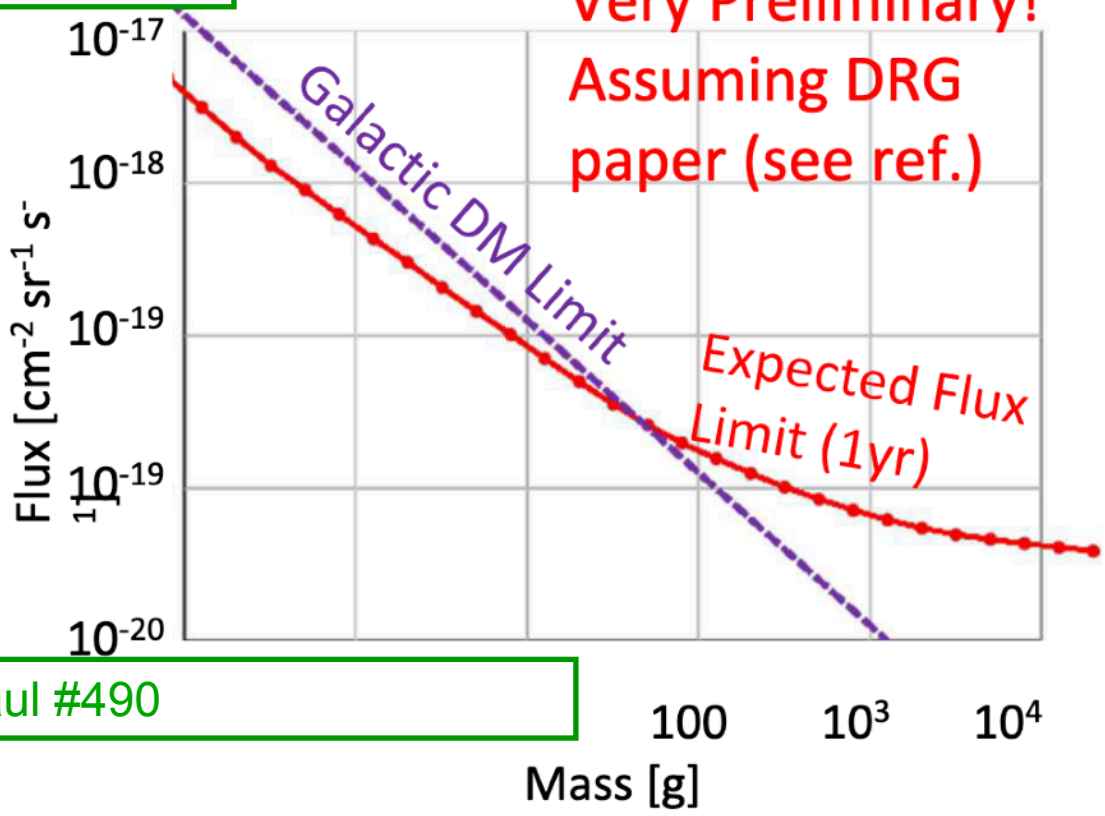
Improved dataset + additional info on PDF (ν flavour and energy).

Nuclearites





Kajino # 1236



Kajino #1236, Paul #490

Witten 1984 ; De-Rujula, Glashow 1984

Dark Matter made by macroscopic lumps of strange quark matter.
Produce light when they pass through the atmosphere and appear as unusual meteors.
Differences wrt meteors: larger velocities, mostly in lower atmosphere, brightness of the tracks.