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Plan de Recuperación, Transformación y Resiliencia

AGENCIA ESTATAL DE INVESTIGACIÓN

# Indirect Searches of Dark Matter with Cosmic Rays


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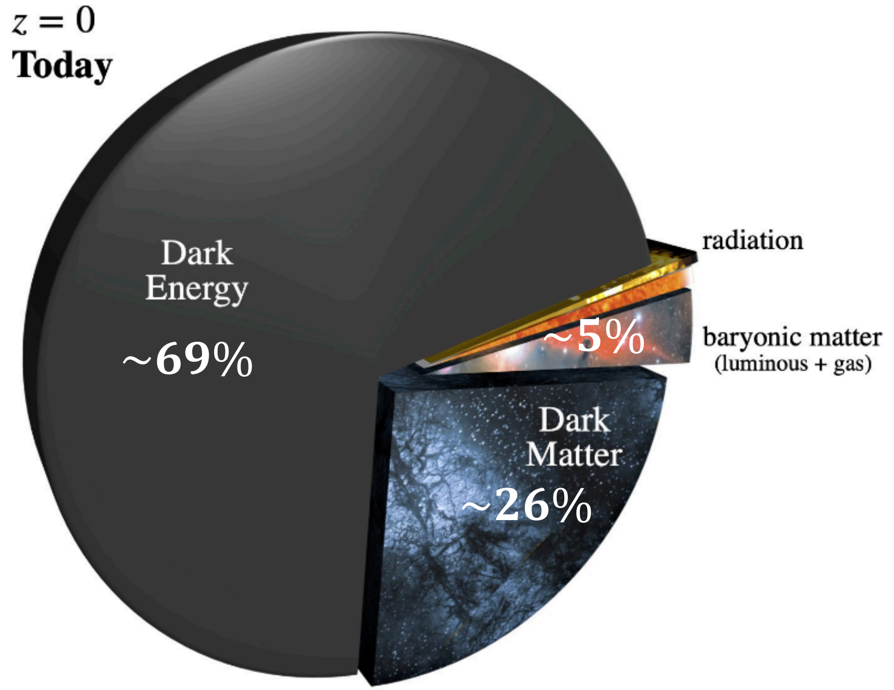
UNDARK

# Dark Matter in the Universe

M. Cirelli, 2406.01705

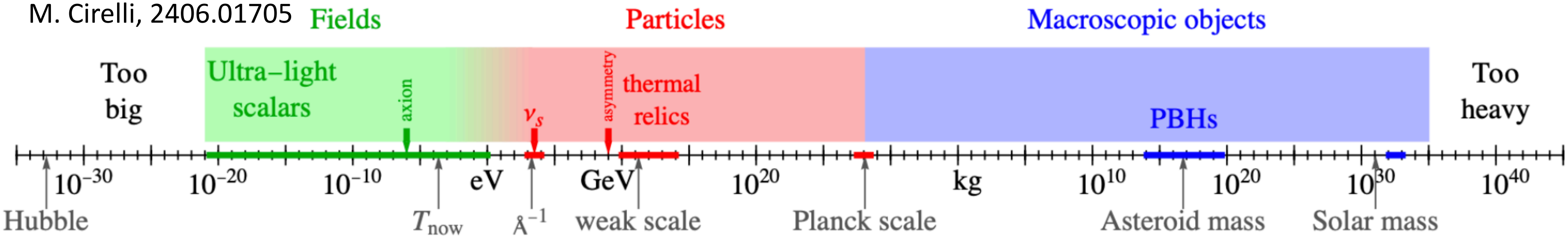



DM constitutes about 84% of the total matter content

# Dark Matter Candidates

Possible range for Dark Matter particles

M. Cirelli, 2406.01705

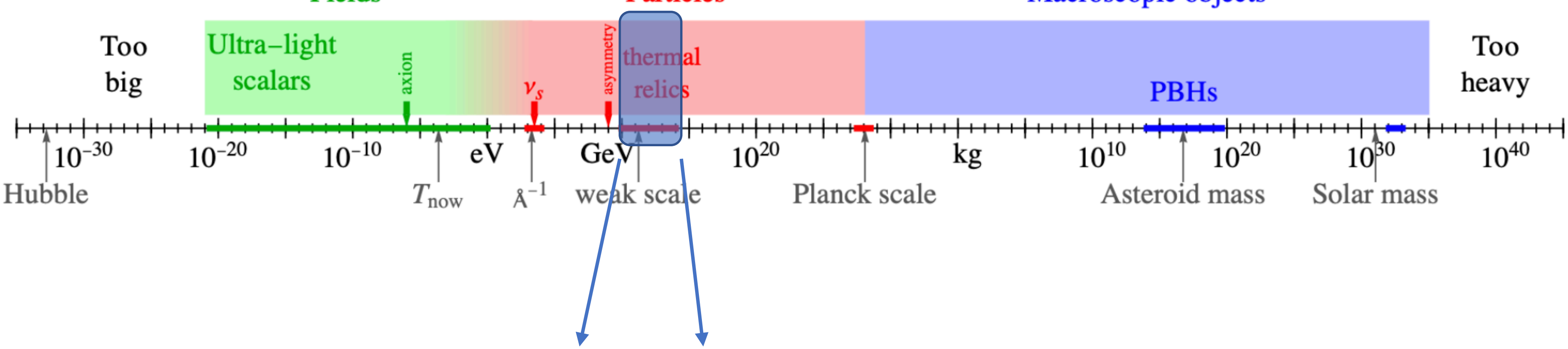



90 orders of magnitude

# Dark Matter Candidates

Possible range for Dark Matter particles

M. Cirelli, 2406.01705




We will consider only candidates with weak interactions with the Standard Model
$\Longrightarrow$ WIMPS

# Dark Matter Candidates

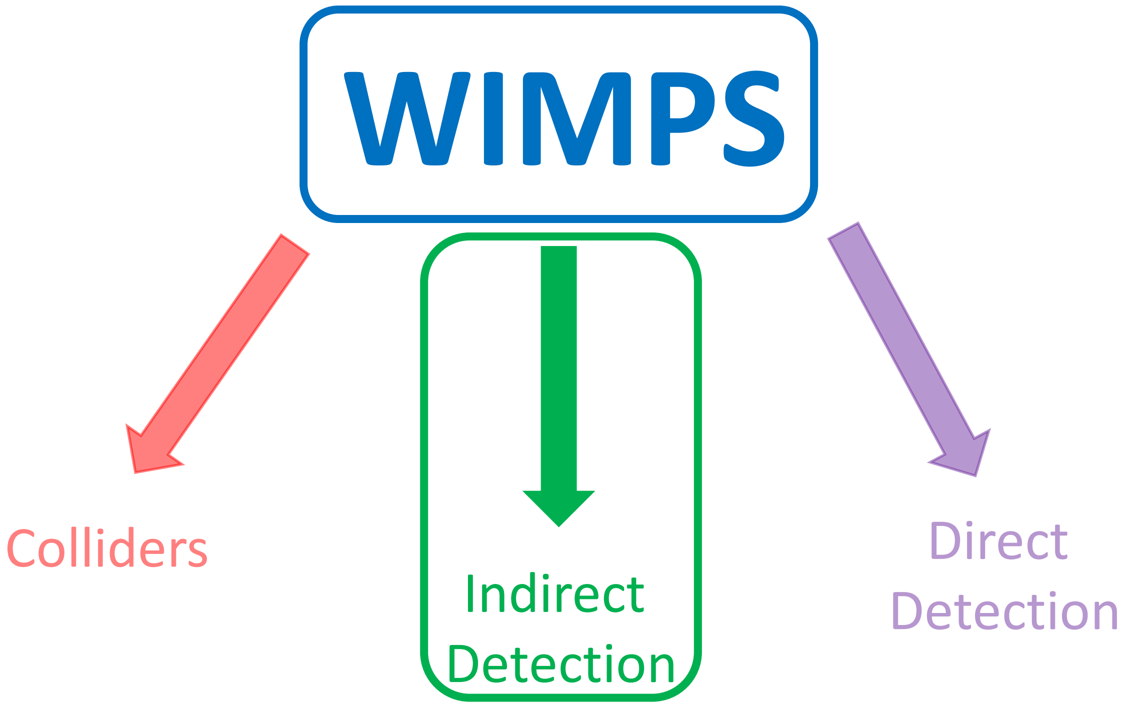
**WIMPS**

Colliders

Indirect Detection

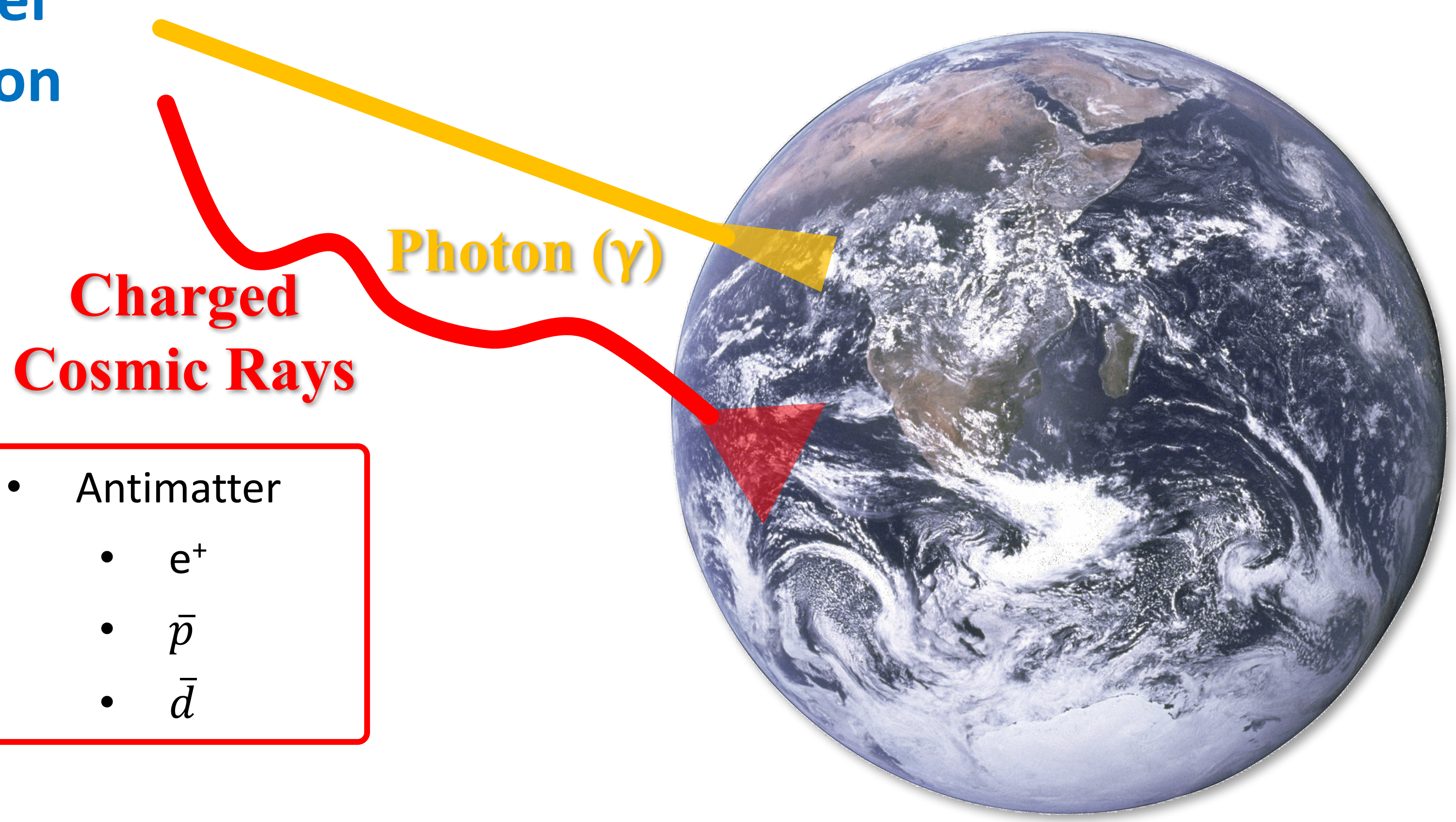
Direct Detection

# Dark Matter Candidates



# Dark Matter Indirect Detection

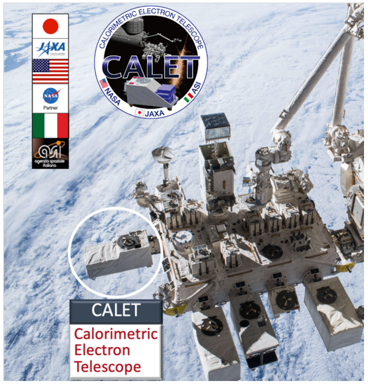
**Dark Matter Annihilation**

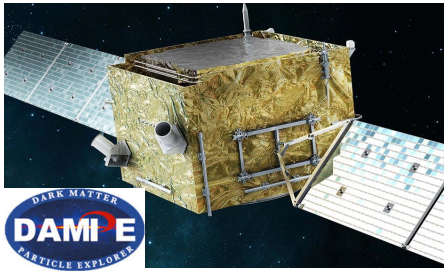



- Antimatter
  - $e^+$
  - $\bar{p}$
  - $\bar{d}$

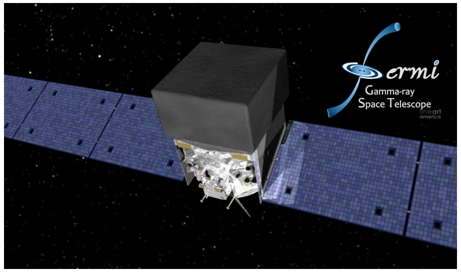
# Dark Matter Indirect Detection

## Space-based



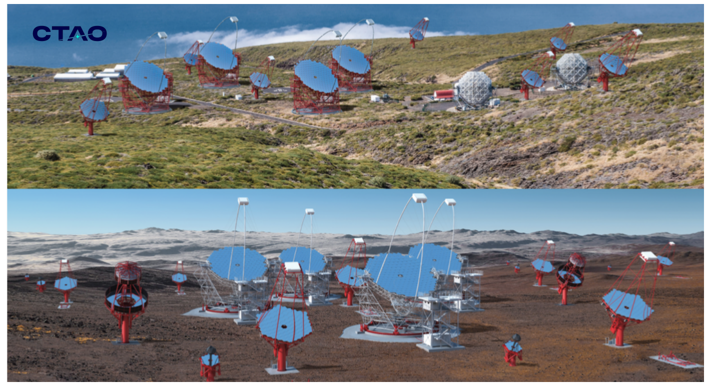




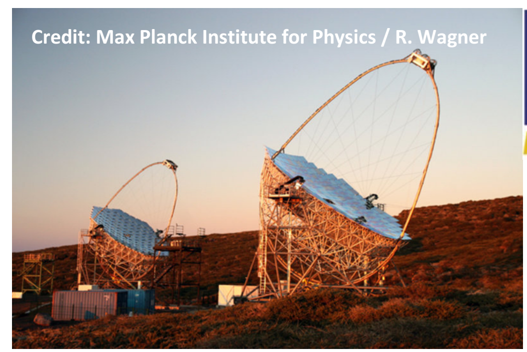


# Dark Matter Indirect Detection

## Ground-based

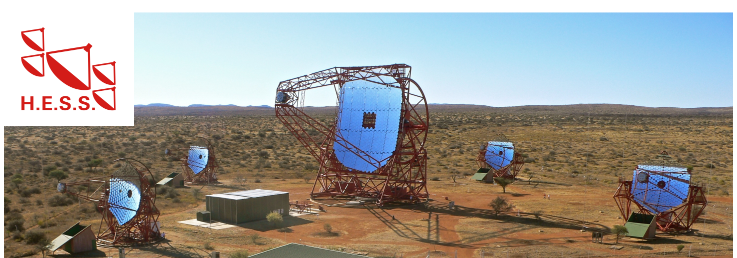



HAWC
High Altitude Water Cherenkov Gamma-Ray Observatory




MAGIC

H.E.S.S.



# Dark Matter Indirect Detection

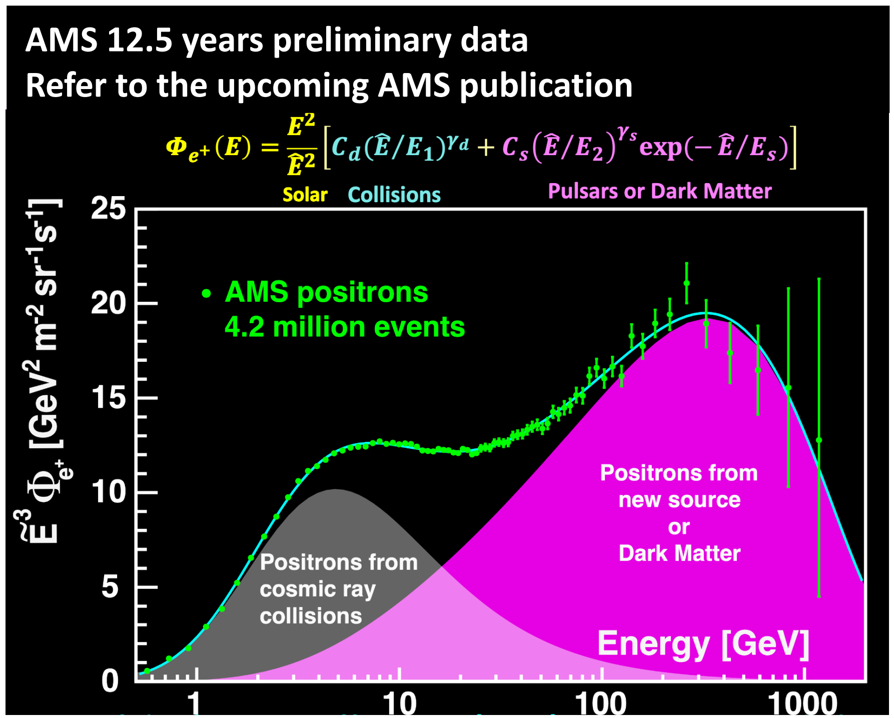
**Dark Matter Annihilation**

**Charged Cosmic Rays**

- Antimatter
  - $e^+$
  - $\bar{p}$
  - $\bar{d}$

# Indirect Detection: Charged CRs

The positron flux is the sum of a low-energy part from cosmic ray collisions plus a high-energy part from a primary source with a cutoff at ~ 800 GeV



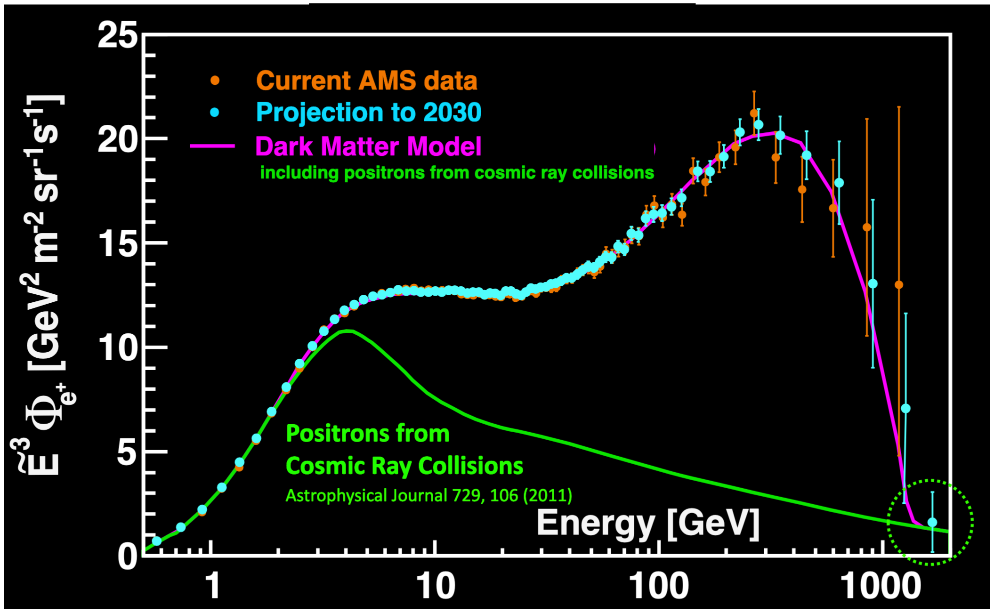

Interpretations include Dark Matter and pulsars as primary sources to explain the positron excess

# Indirect Detection: Charged CRs

The positron excess could be explained by a Dark Matter scenario

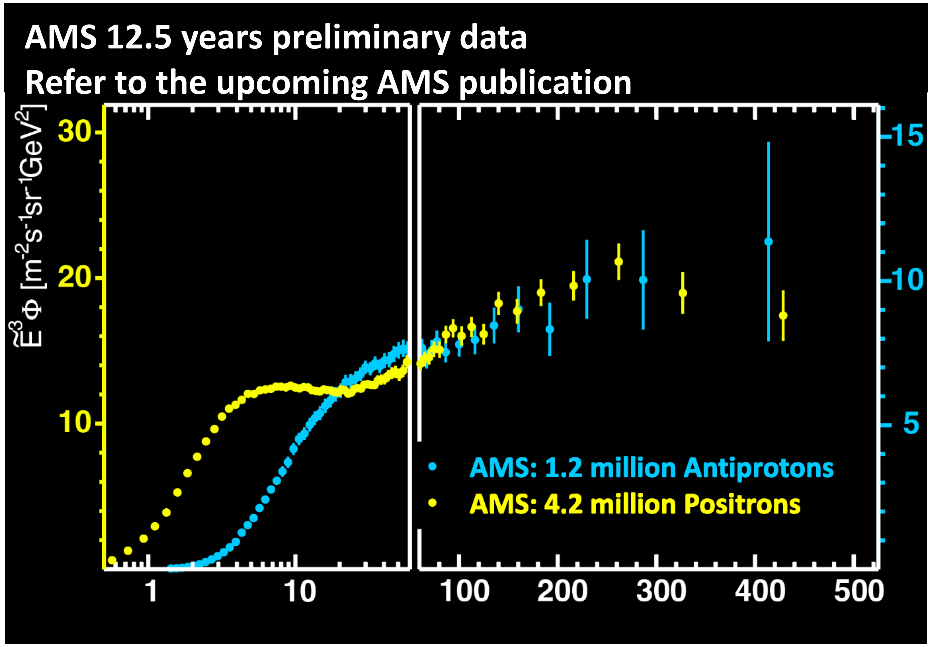
## Dark Matter Models

- I. Krommydas, I. Cholis, Phys. Rev. D 107 (2023) 2, 023003
- I. John, T. Linden, JCAP 12 (2021) 007
- H. Motz, H. Okada, Y. Asaoka, and K. Kohri, Phys.Rev. D102 (2020) 8, 083019
- Z.Q. Huang, R.Y. Liu, J.C. Joshi, X.Y. Wang, Astrophys.J. 895 (2020) 1, 53
- R. Diesing and D. Caprioli, Phys.Rev. D101 (2020) 10
- A. Das, B. Dasgupta, and A. Ray, Phys.Rev. D101 (2020) 6
- F. S. Queiroz and C. Siqueira, Phys.Rev. D101 (2020) 7, 075007
- Z.L. Han, R. Ding, S.J. Lin, and B. Zhu, Eur.Phys.J. C79 (2019) 12, 1007
- C.Q. Geng, D. Huang, and L. Yin, Nucl.Phys. B959 (2020) 115153
- S. Profumo, F. Queiroz, C. Siqueira, J.Phys.G 48 (2020) 1, 015006



# Indirect Detection: Charged CRs

The antiproton flux exhibits an unexpected energy dependence. This dependence is distinctly different from antiprotons from collision of cosmic rays



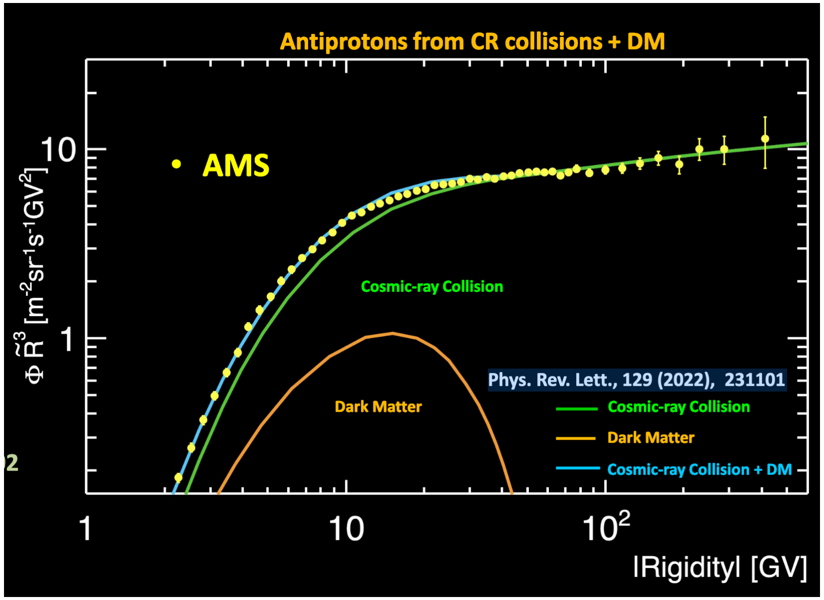

Positron and antiproton fluxes have nearly identical energy dependence

# Indirect Detection: Charged CRs

Antiprotons cannot be produced by pulsars

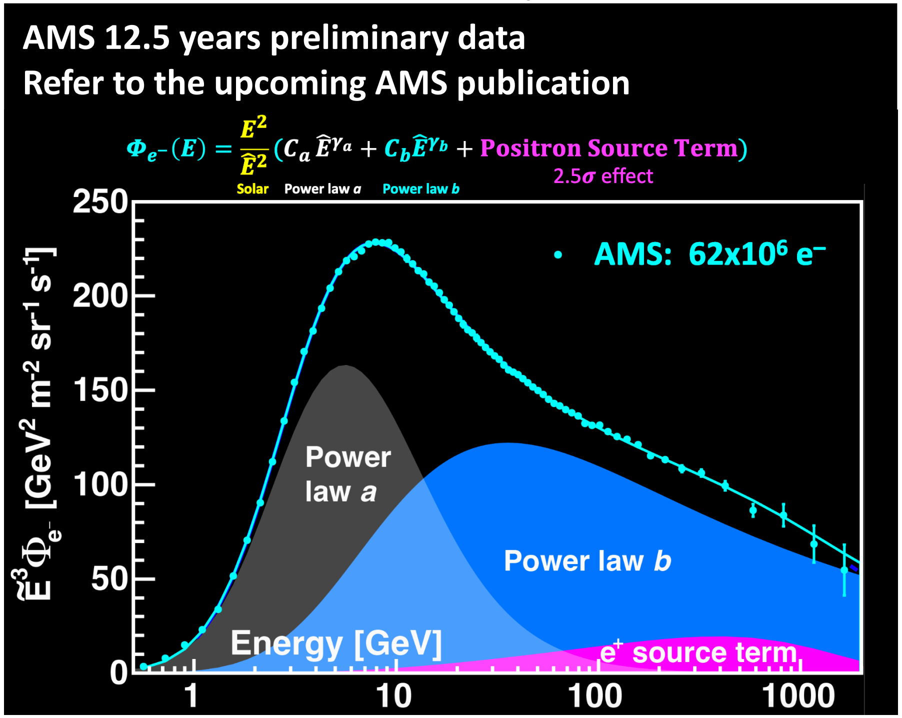
## Dark Matter Models

P. De la Torre Luque, et al., JCAP 05 (2024) 104
X. Qin et al., Phys. Rev. D., 107 (2023), 095026
C. Zhu et al., Phys. Rev. Lett., 129 (2022), 231101
J. Heisig, Modern Physics Letters A, (2021), 36, 05
Y. Genolini et al., Phys. Rev. D 104 (2021), 083005
I. Cholis et al., Phys. Rev. D, 99 (2019), 103026
A. Cuoco et al., Phys. Rev. D, 99 (2019), 103014
M. Carena et al., Phys. Rev. D, 100 (2019), 055002
A. Reinert et al., JCAP, 01 (2018), p. 055
A. Cuoco et al., Phys. Rev. Lett., 118 (2017), 191102
M. Cui et al., Phys. Rev. Lett., 118 (2017), 191101
Y. Chen et al., Phys. Rev. D, 93 (2016), p. 015015



# Indirect Detection: Charged CRs

The electron flux is well described with two power laws (a, b) and a source term like positrons

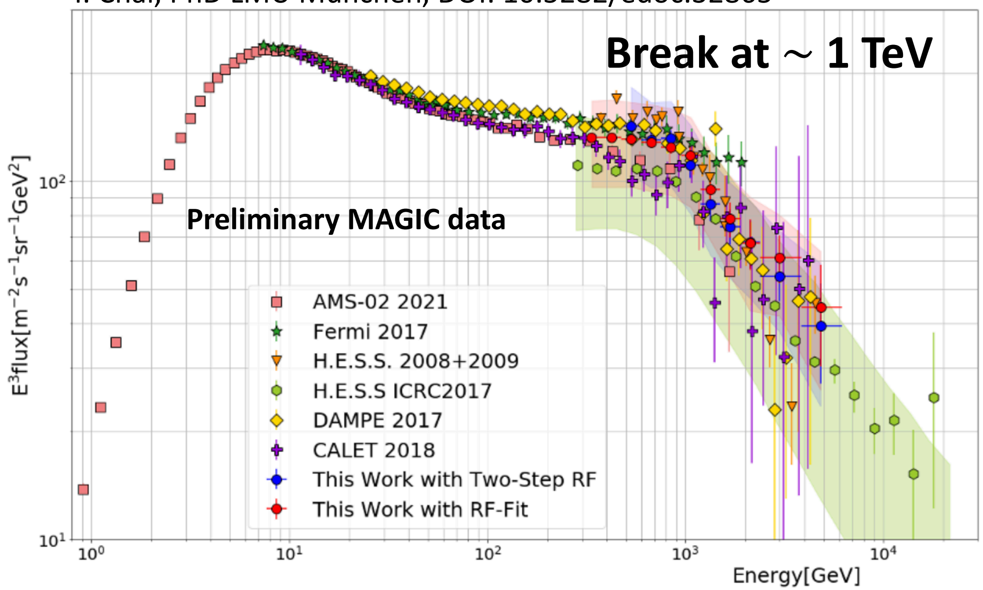



Dark Matter source produces equal amount of positrons and electrons

# Indirect Detection: Charged CRs

The electron+positron flux can be also measured by space-based calorimeters and ground-based detectors

Y. Chai, PhD LMU Munchen, DOI: 10.5282/edoc.32865



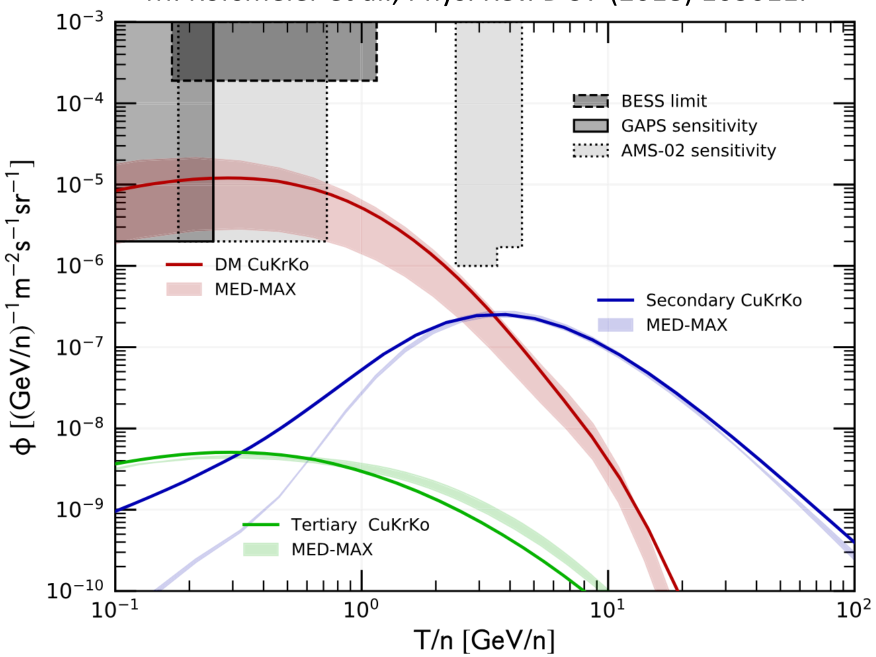

This channel provides additional information to understand and constrain models from the previous observations

**N.B:** MAGIC data on the $e^{+}+e^{-}$ flux will be published soon

# Indirect Detection: Charged CRs

Anti-deuterons are believed to be a clean channel for indirect dark matter searches

M. Korsmeier et al., Phys. Rev. D 97 (2018) 103011.

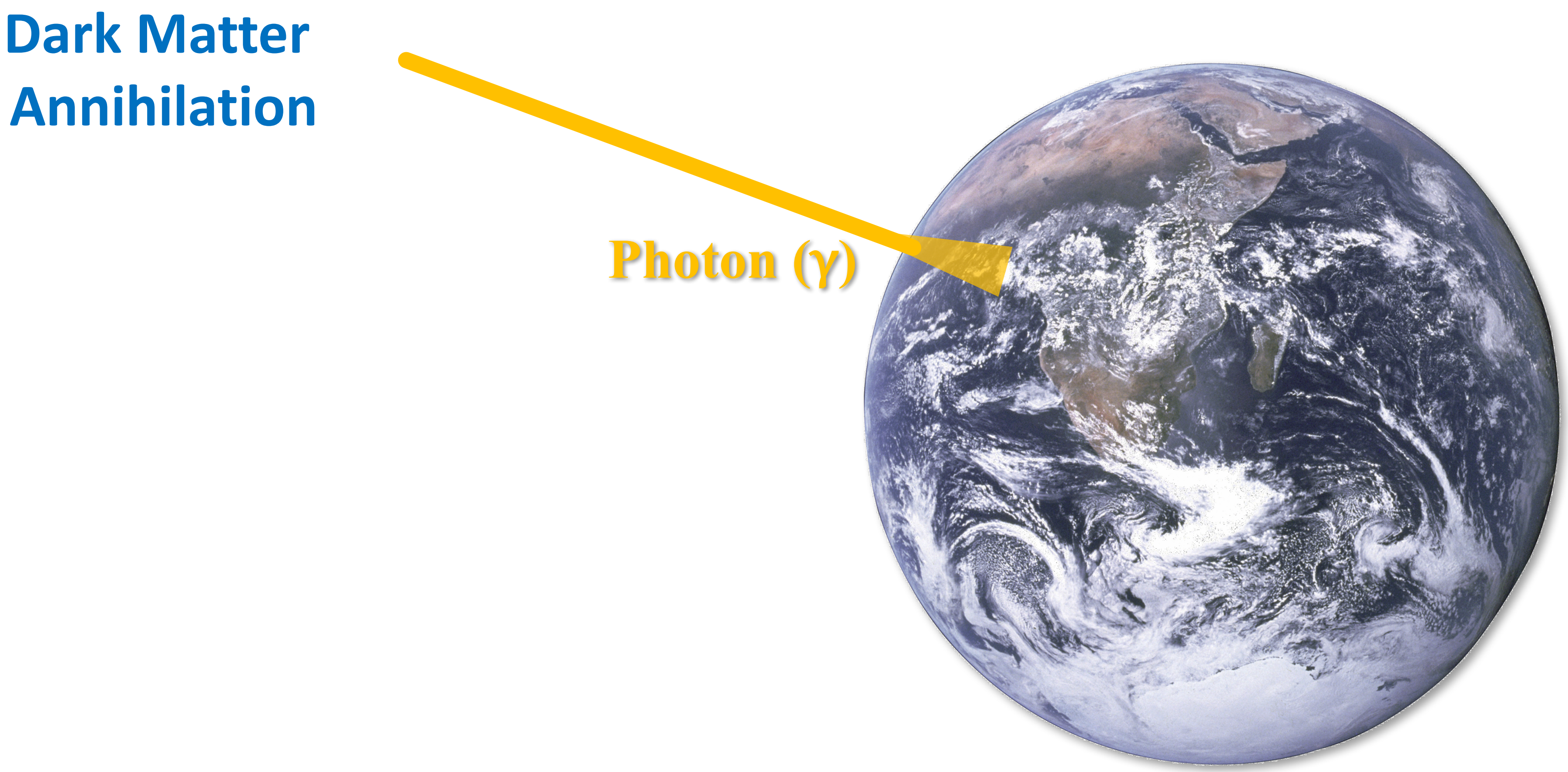




Anti-deuterons secondary production is very suppressed at low energies and can be efficiently produced by dark matter annihilation

[original idea published in F. Donato et al., Phys. Rev. D 62 (1999) 043003]

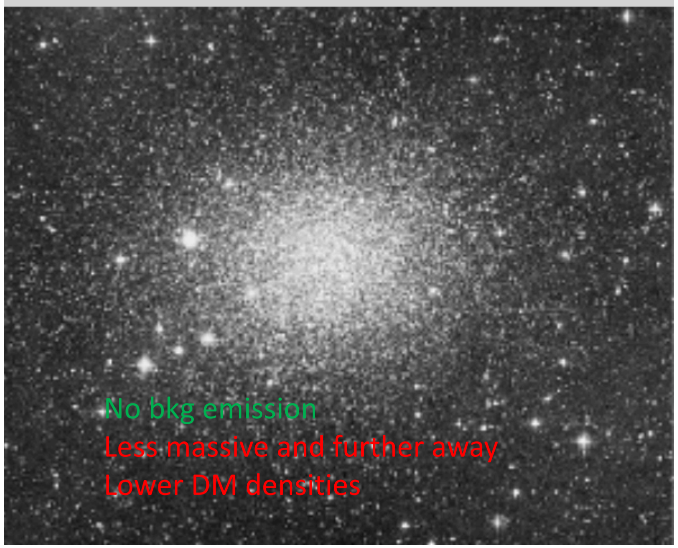
# Dark Matter Indirect Detection



# Indirect Detection: Gammas

## Galactic Center (GC) and Halo

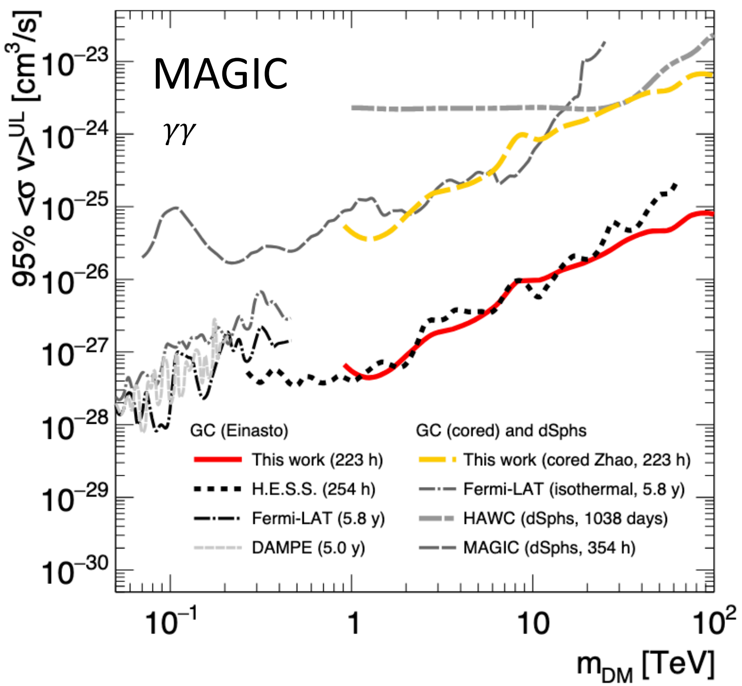

## Dwarf spheroidal galaxies (dSphs)



# Indirect Detection: Gammas

## Galactic Center

Phys. Rev. Lett. 130, 061002



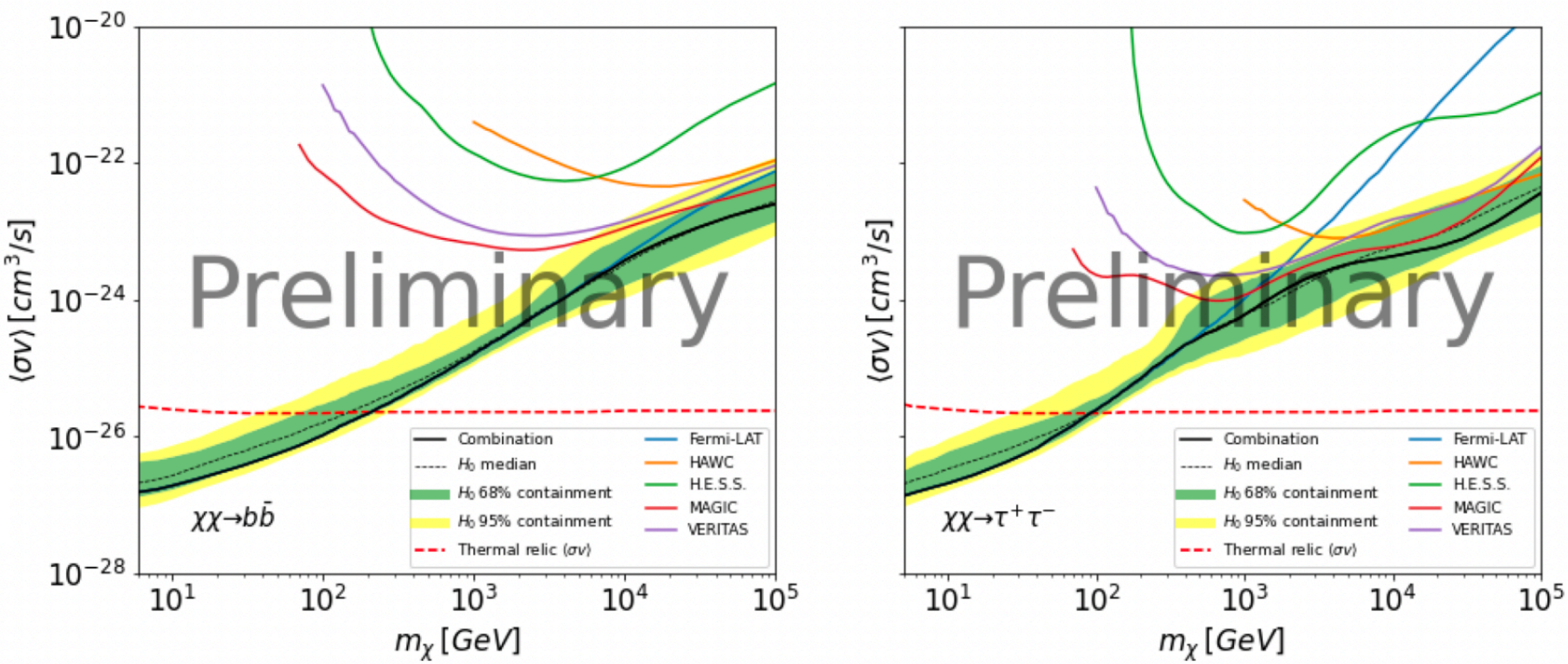

MAGIC results improve the sensitivity above 20 TeV
by a factor of 1.5 to 2

# Indirect Detection: Gammas

## Dwarf Spheroidal

Combined observations of dSphs by Fermi-LAT, H.E.S.S., MAGIC, VERITAS and HAWC

arxiv: 2108.13646



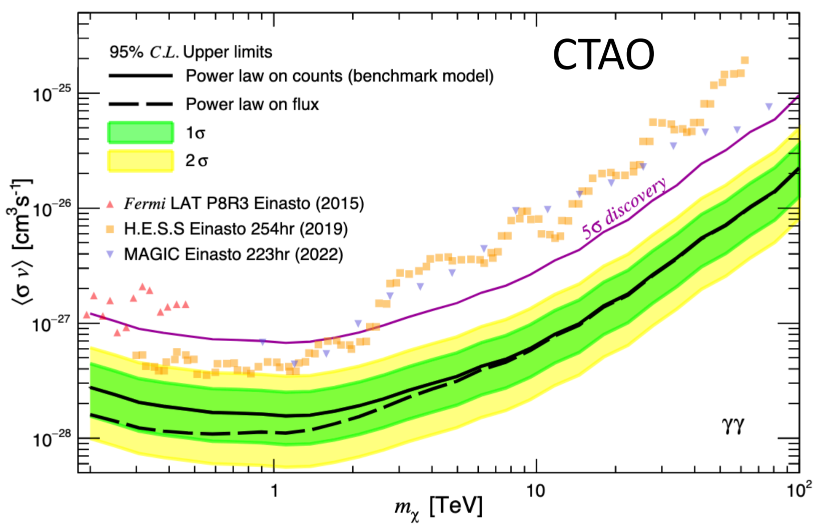

Combined results allows the derivation of up to 2-3 times more constraining upper limits on ⟨σv⟩ than the individual ones

**N.B:** Paper will be published soon

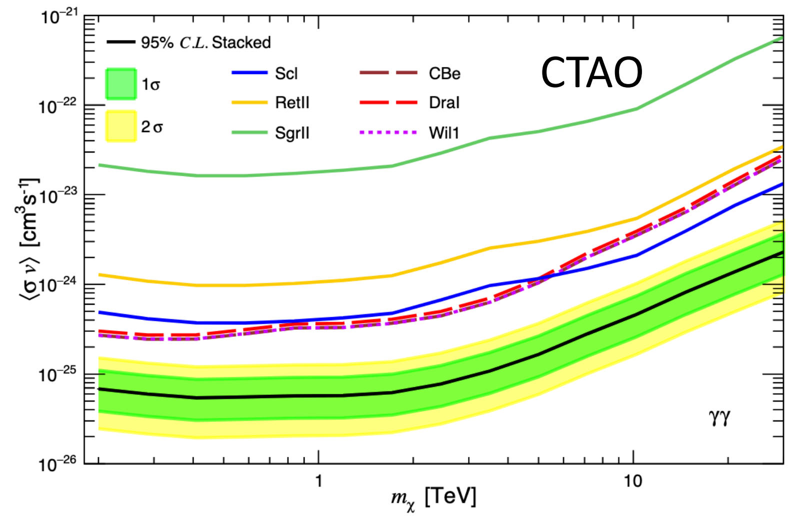
# Indirect Detection: Gammas

S. Abe et al JCAP07(2024)047

**Galactic Center**




**dSphs**




Cherenkov Telescope Array will be the most sensitive observatory for Dark Matter line searches with gamma rays

# Conclusions

Not seen yet

- Dark Matter constitutes around 84% of the total matter content and still remains unknown

- Cosmic rays represent an important tool for indirect searches of Dark Matter in the TeV range:
  - Charged cosmic rays: antimatter channels show unexpected features in the fluxes
  - Gamma rays: good sensitivities for different annihilation channels up to 100s TeV

- Prospects in Dark Matter searches with cosmic rays:
  - Charged cosmic rays: Deeper understanding of the spectral features will be improved with more precise measurements by upgraded or new detectors
  - Gamma rays: current limits and detection prospects for dark matter will be significantly improved in the CTA era