Search for gamma-ray spectral lines from Dark Matter annihilation in the Galactic Centre region with MAGIC

D. Kerszberg (IFAE-BIST), T. Inada, M. Hütten, M. Teshima, J. Rico, K. Kohri, and N. Hiroshima for the MAGIC collaboration

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MAGIC

IFAE Institut de Física d'Altes Energies

EXCELENCIA SEVERO OCHOA

BIST Barcelona Institute of Science and Technology

Indirect dark matter search with gamma-rays

- **Gamma-rays are not deflected by magnetic fields and trace back to original source**

  → Critical to identify the (physical) origin of the signal and study DM spatial distribution

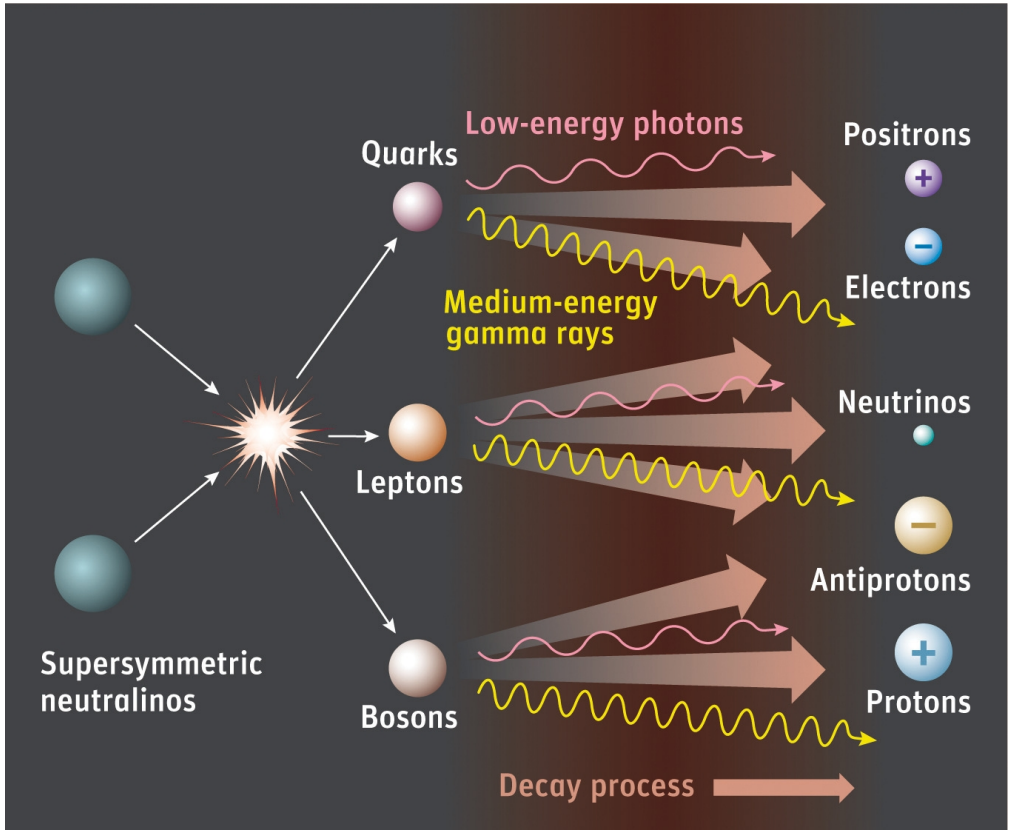
- **Classical targets for gamma-ray experiments include among others:**
  - The Galactic Center (high DM content with high uncertainties)
  - Dwarf spheroidal galaxies (lower DM content with smaller uncertainties)
  - Galaxy clusters

- **Looking for Dark Matter particles self-annihilating (or decaying) into Standard Model particles**

  → Weakly Interacting Massive Particles (WIMP) scenario

Expected Dark Matter flux

$$\frac{d\Phi(\Delta\Omega)}{dE} = \frac{1}{4\pi}\frac{\langle\sigma_{\rm ann}v\rangle}{2m^2_{\rm DM}}\frac{dN}{dE} \times \int_{\Delta\Omega} d\Omega' \int_{\rm l.o.s.} dl\,\rho^2(l,\Omega')$$



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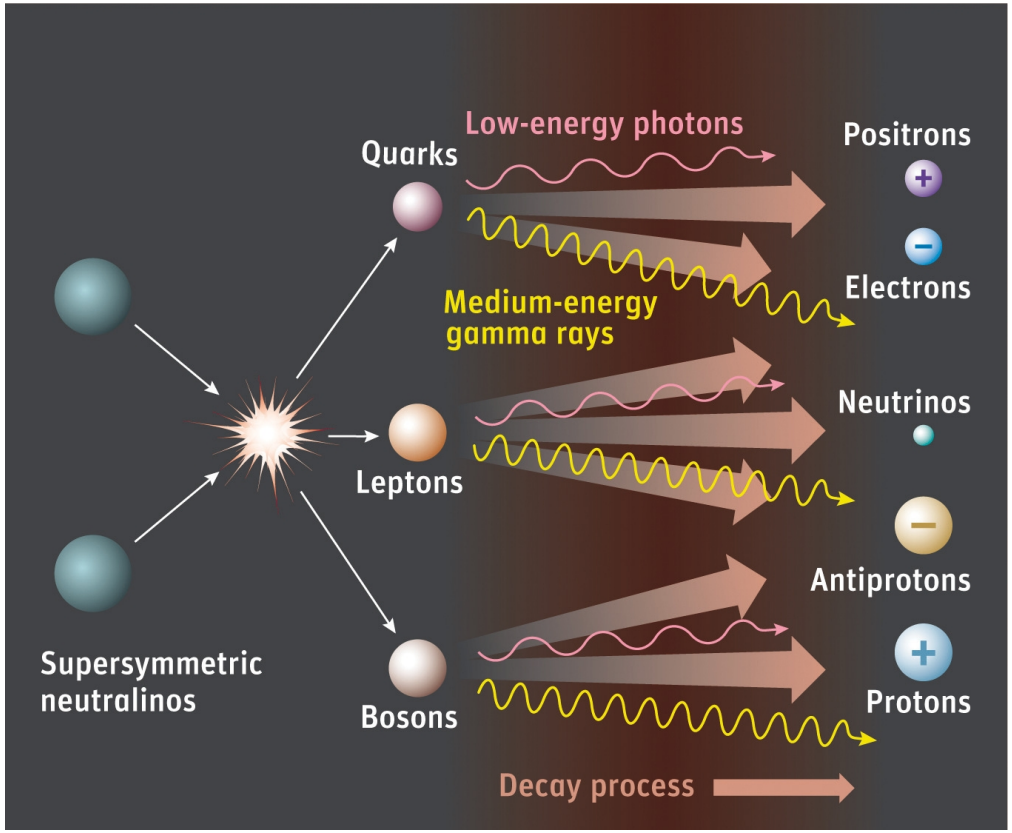

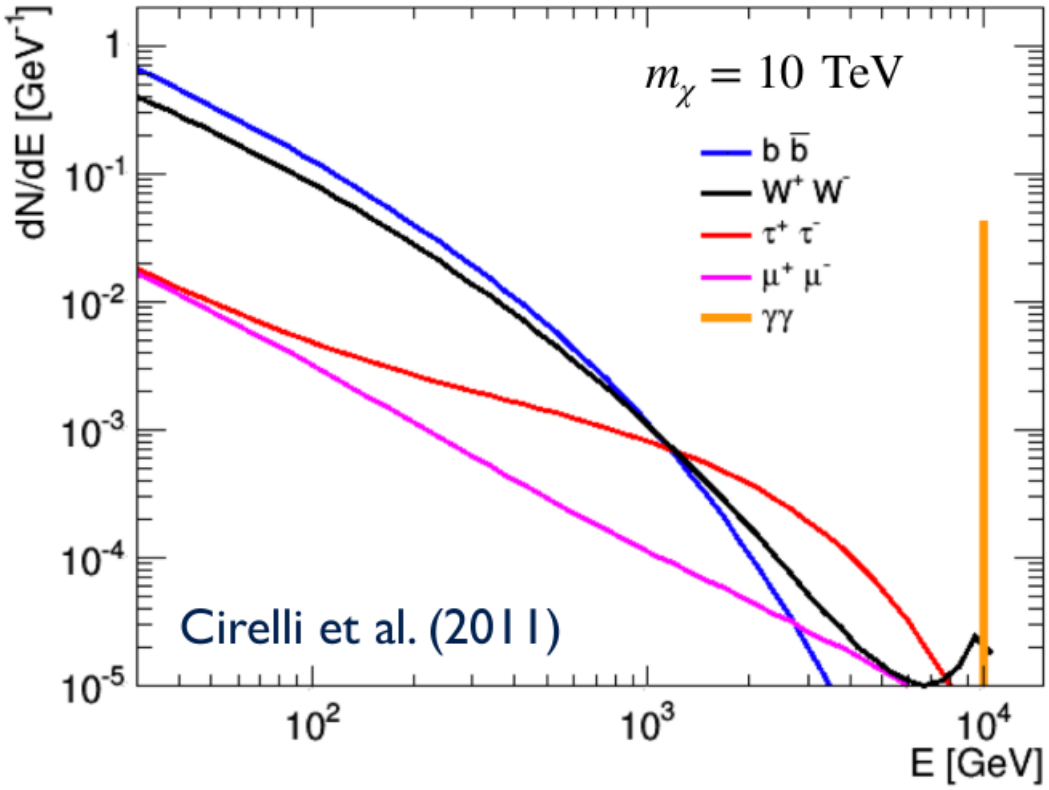

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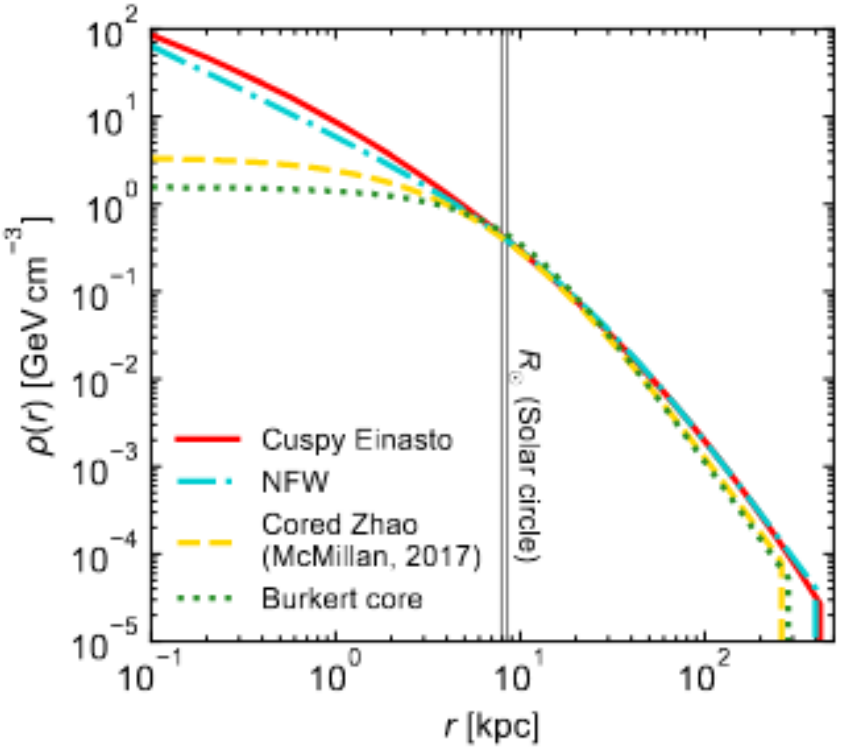
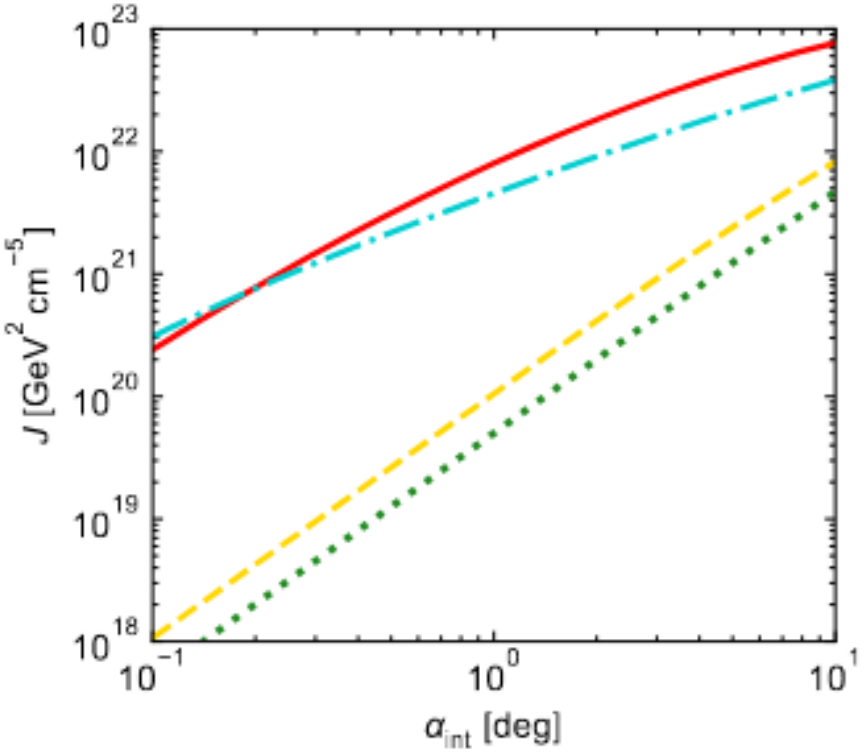




Examples of DM content profiles for the Galactic Centre

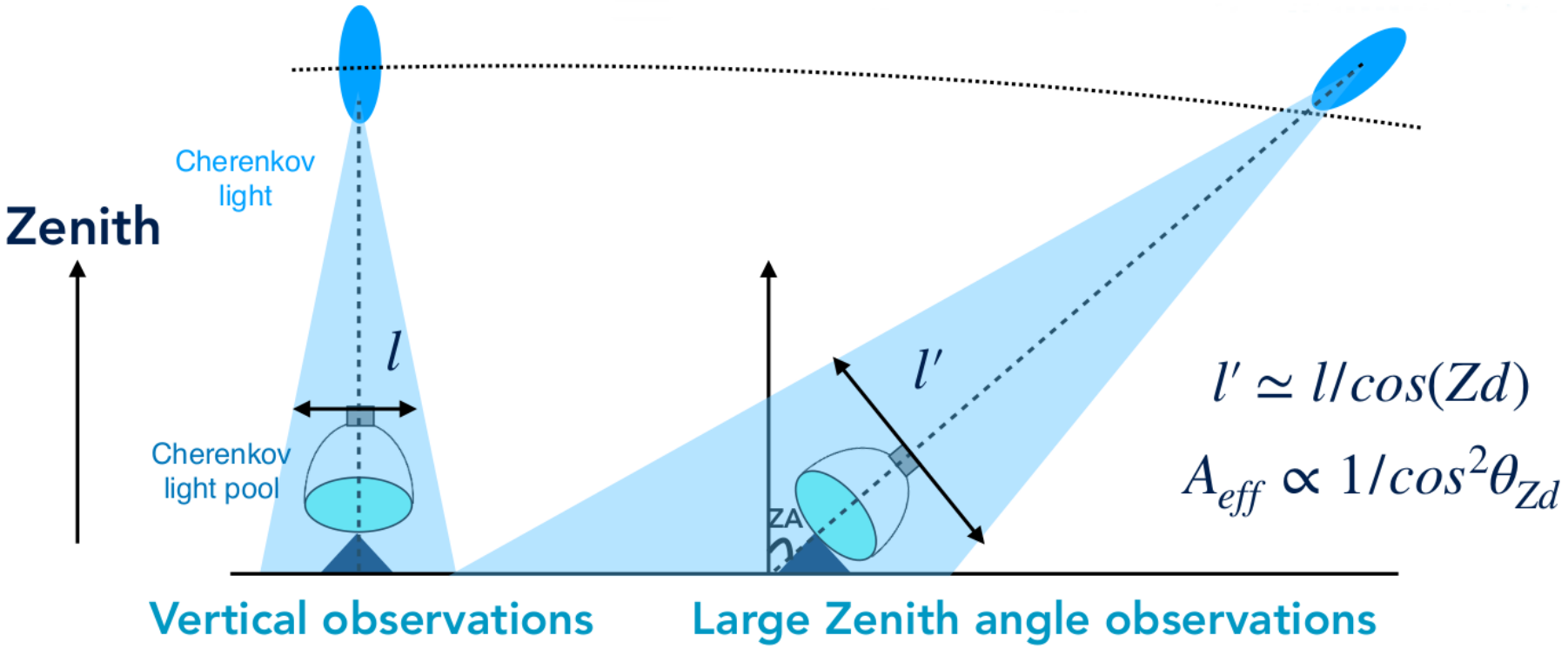
The MAGIC experiment

- **Two Imaging Atmospheric Cherenkov Telescopes located in the Observatory Roque del Muchachos at La Palma, Canary Islands (Northern hemisphere):**
  - Altitude: ~ 2200 m asl
  - Detects gamma rays between ~20 GeV and ~100 TeV
  - Field of view of ~3.5°
  - Angular resolution ~ 0.1° (energy dependent)

The Galactic Centre as seen by MAGIC

- Optimal observation conditions (ie low zenith) is from the Southern hemisphere
- But MAGIC is located in the Northen hemisphere, so Galactic Centre can only be seen from a zenith of ~50 degrees

  → larger effective area but higher energy threshold



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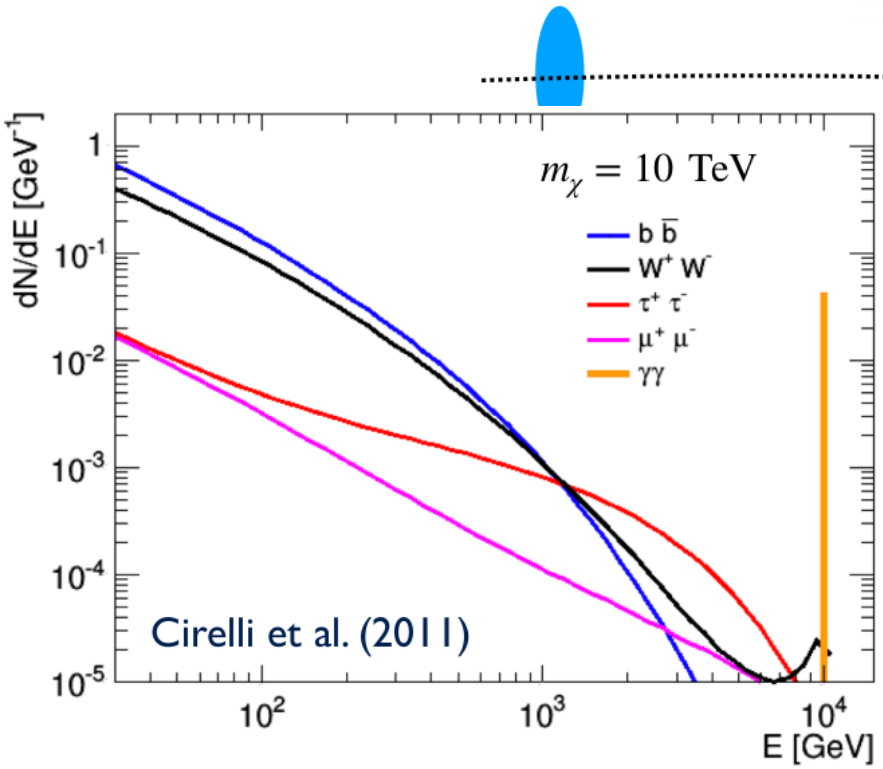

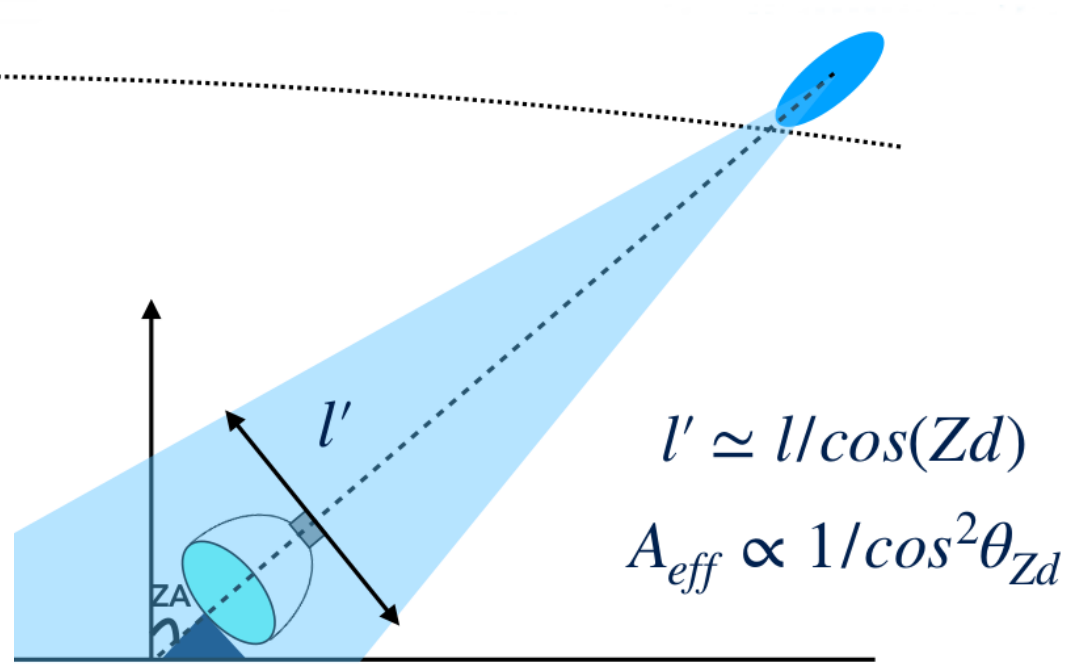

Large Zenith angle observations

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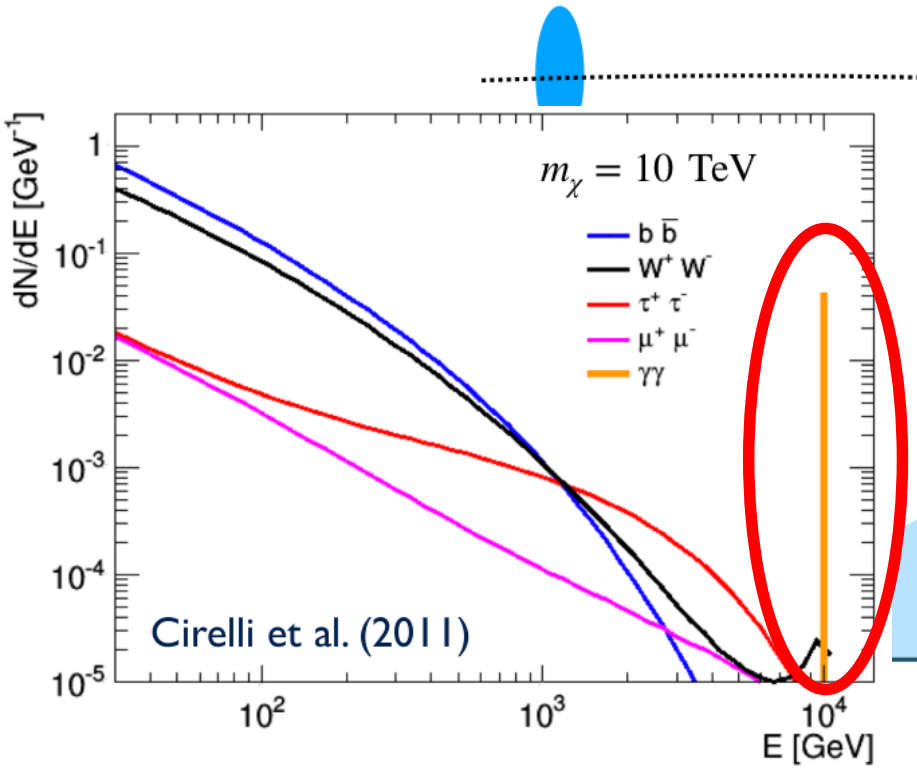
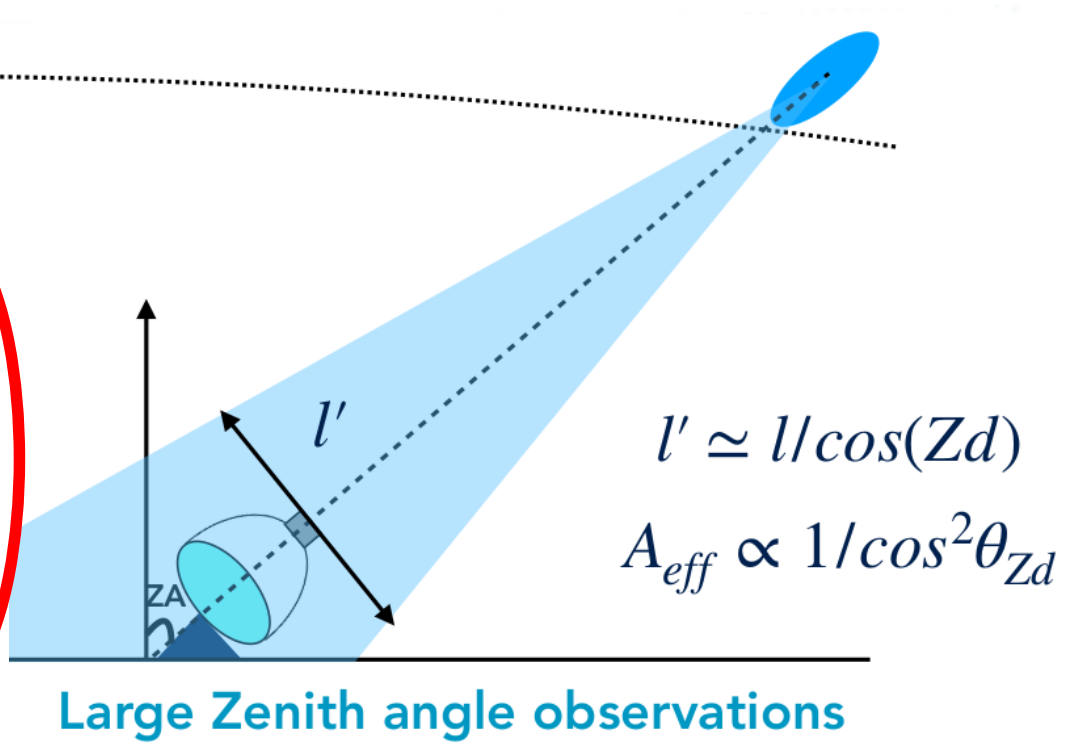




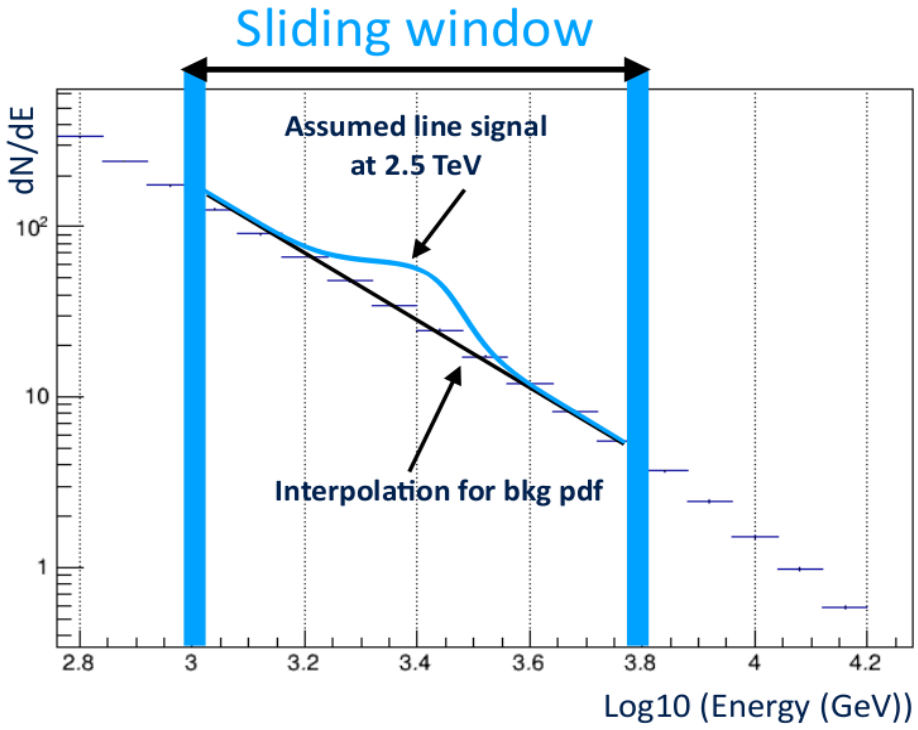
Unbinned likelihood analysis

$$\mathcal{L}_i(g_i; \nu_i \,|\mathcal{D}_i) = \mathcal{L}_i(g_i; b_i, \tau_i \,|\{E'_j\}_{j=1,\ldots,N_{\mathrm{ON},i}}, N_{\mathrm{ON},i})$$

$$= \frac{(g_i + \tau_i b_i)^{N_{\mathrm{ON},i}}}{N_{\mathrm{ON},i}!} e^{-(g_i+\tau_i b_i)} \times \frac{1}{g_i + \tau_i b_i} \prod_{j=1}^{N_{\mathrm{ON}}} (g_i f_g(E'_j) + \tau_i b_i f_b(E'_j))$$

$$\times \mathcal{T}(\tau_i | \tau_{\mathrm{obs},i}, \sigma_{\tau,i}).$$

- **Unbinned (in energy) likelihood**
  - N_ON: observed number of events
  - i: index running over different data samples
  - g: estimated number of signal events
  - b: estimated number of background events
  - f_g: line signal PDF
  - f_b: background PDF



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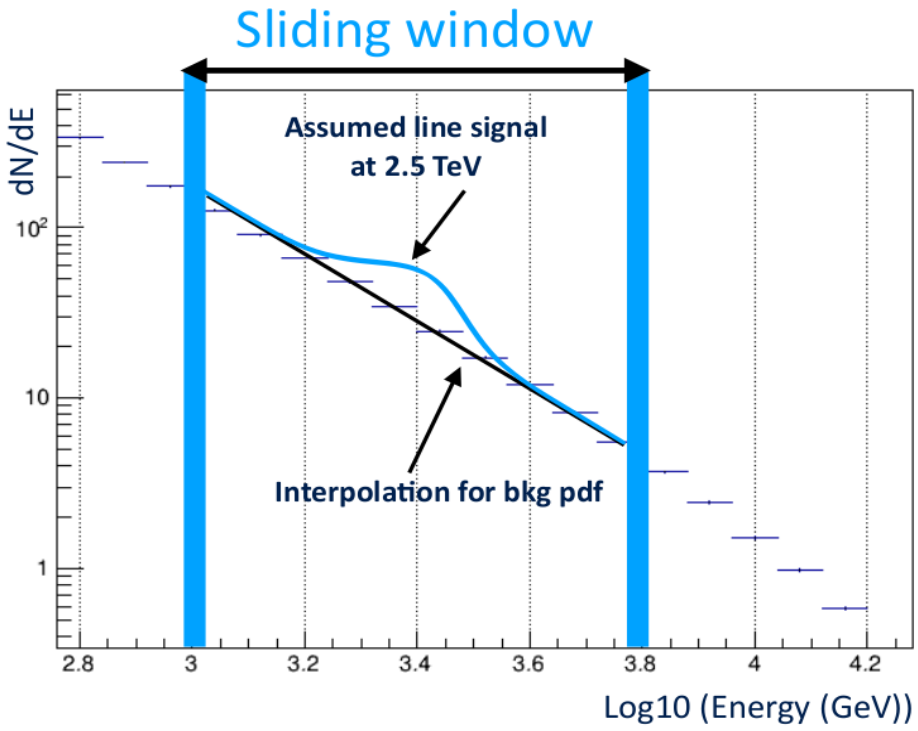
$$\times \mathcal{T}(\tau_i|\tau_{\mathrm{obs},i}, \sigma_{\tau,i}).$$

- **PDF for the normalization factor of the background model**

  → taken into account as nuisance parameter in the likelihood

  → allow proper treatment of instrumental systematic errors, important in the case of Cherenkov telescopes

  → no overestimation of the limits



The dataset on the Galactic Centre

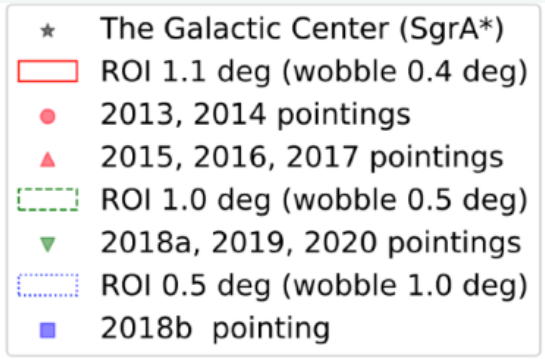
- Data accumulated over

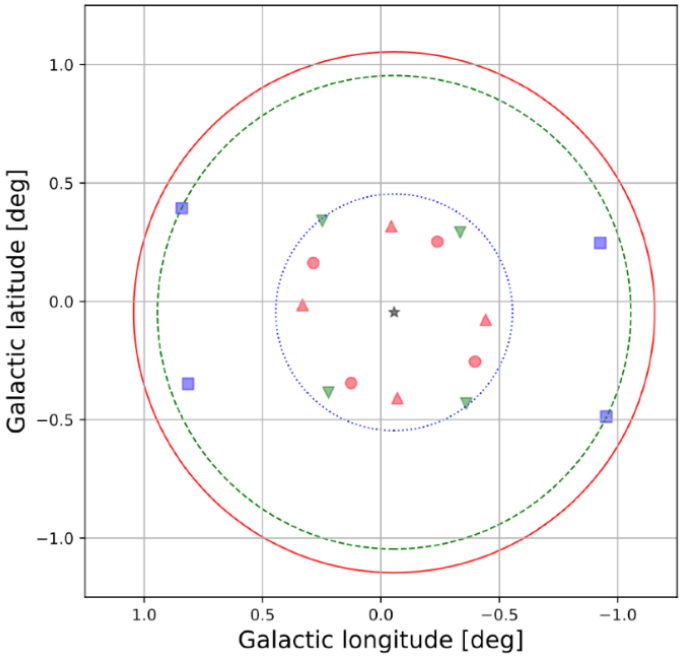
  ~7 years: March 2013 to August 2020

  - zenith range: 58° to 70°
  - ~223 hours of data (after quality cuts)

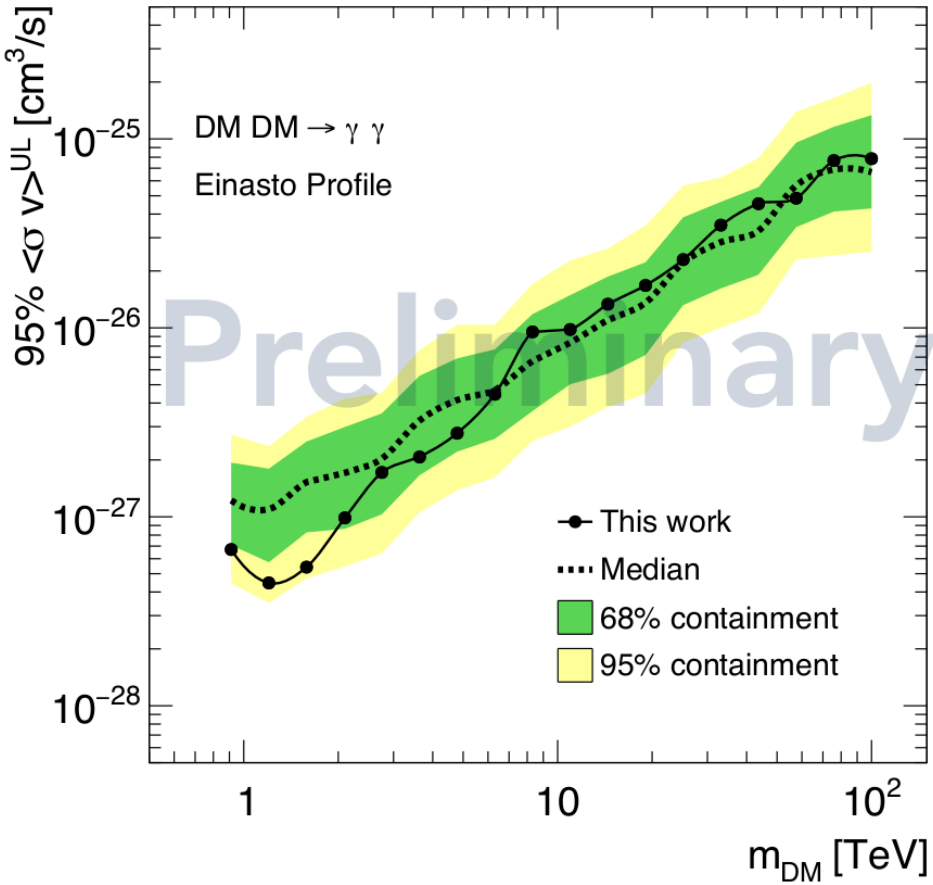
Dates	Label	Total observation time [h] (before quality cuts)	Effective live time [h] (after quality cuts)
2013/03/10 – 2013/07/18	2013	47.1	38.8
2014/03/01 – 2014/07/07	2014	37.3	30.1
2015/03/29 – 2016/04/13	2015	27.0	18.9
2016/05/02 – 2016/08/05	2016	24.8	17.3
2017/03/26 – 2017/06/24	2017	26.0	22.1
2018/02/19 – 2018/09/30	2018a	26.3	19.1
	2018b	7.0	5.8
2019/03/11 – 2019/08/04	2019	54.4	52.0
2020/06/19 – 2020/08/21	2020	22.9	19.1
Total		272.8	223.2

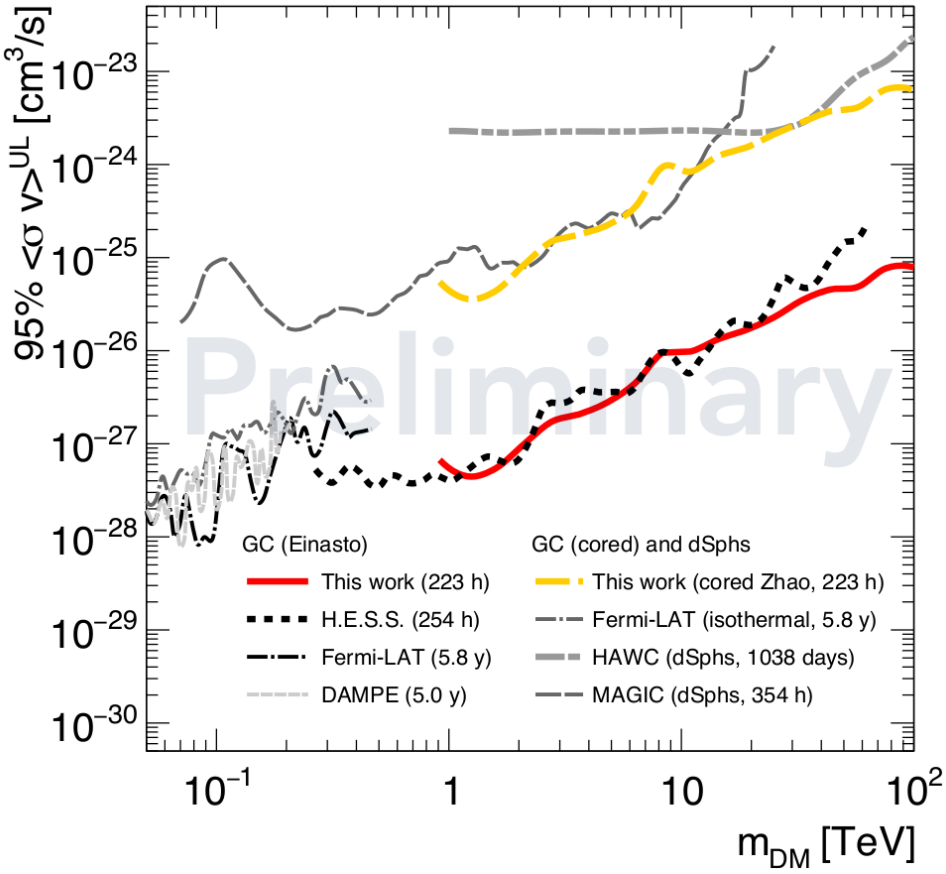
- Analysis performed in regions (ROI) within 1.5° away from the camera center: different pointings of the telescope → different region sizes





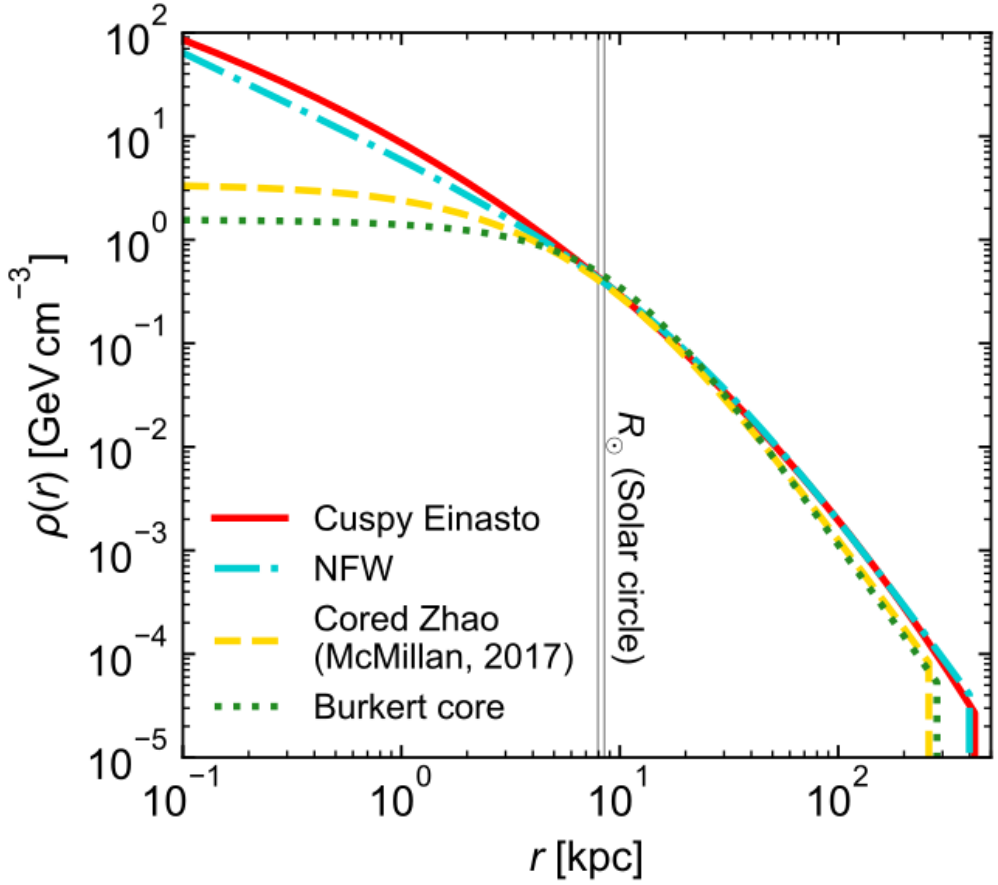
Results

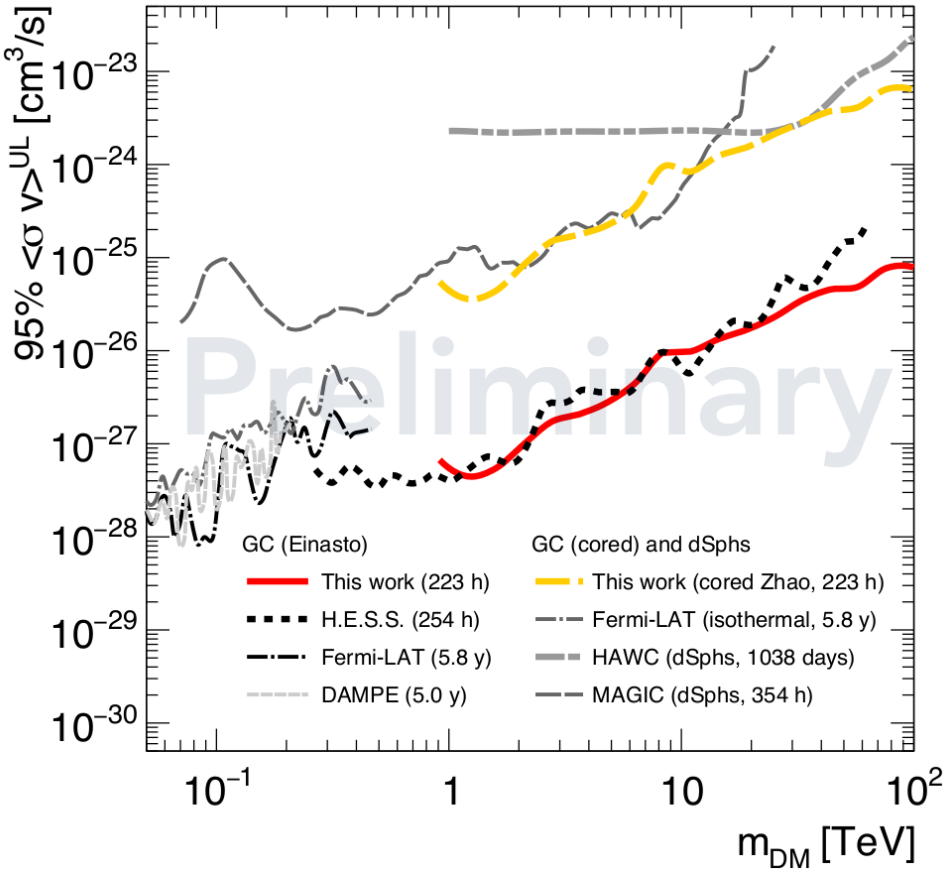




- **Results from ~223 hours of data from 0.9 TeV to 100 TeV**
- **No significant excess detected**

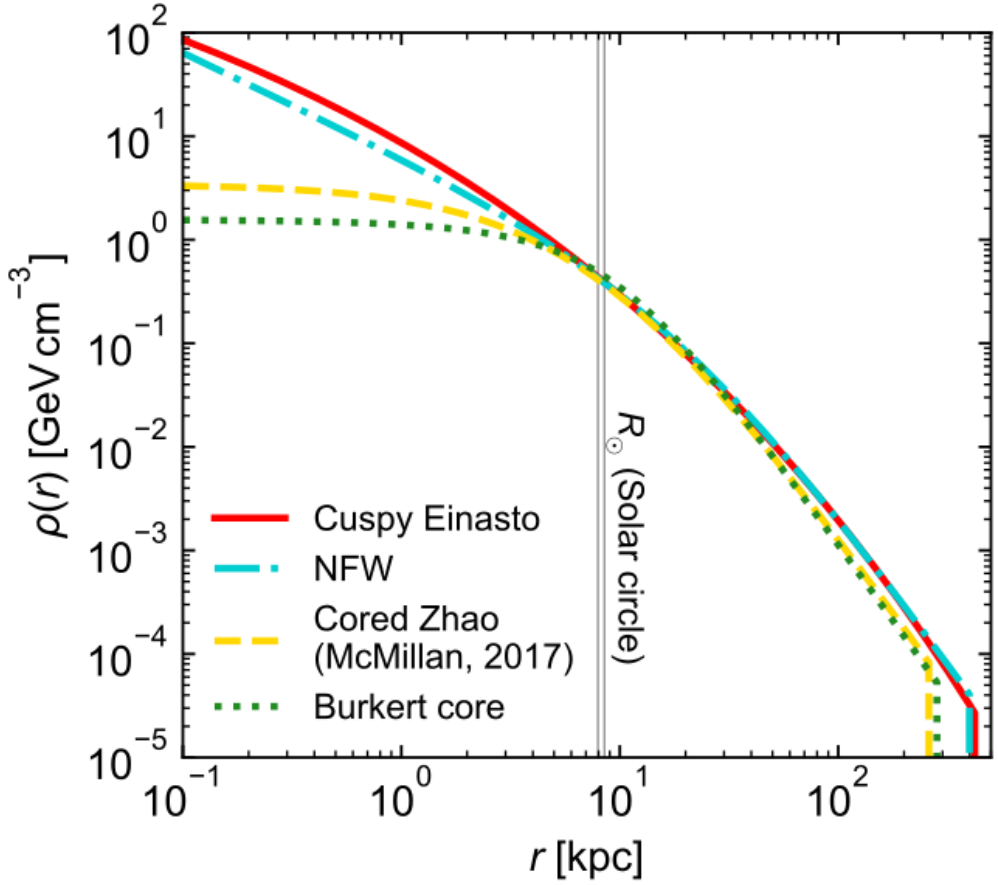
Results

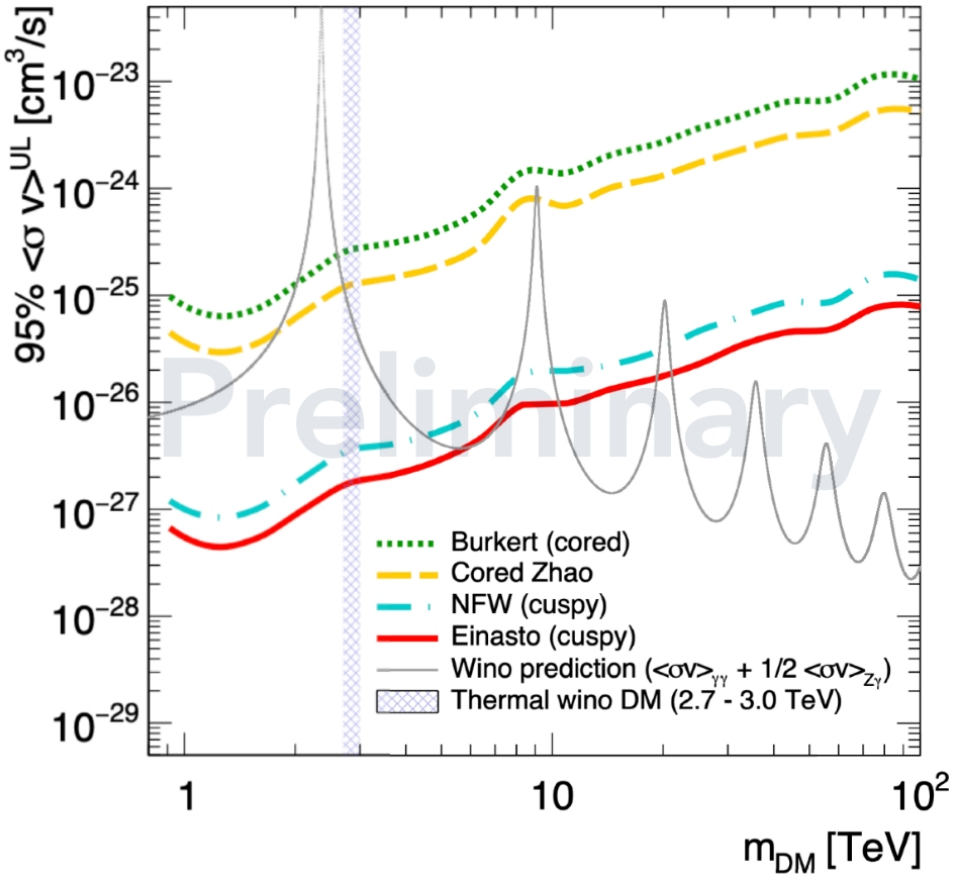




- **Results from ~223 hours of data from 0.9 TeV to 100 TeV**
- **Limits for cuspy profile comparable to H.E.S.S. and limits for core profile comparable to best limits from dSphs**

Results





- **Results from ~223 hours of data from 0.9 TeV to 100 TeV**
- **Strong constraints on SUSY-wino models**

Conclusion

- Search for line-like signals in VHE gamma rays can test promising TeV DM particle models

- Observations of the Galactic Centre from the MAGIC site are done at large zenith angle

  → larger effective area but higher energy threshold

  → search of TeV DM line-like signals is boosted!

  → analysis technique allow to constrain both cuspy and core profiles

- No significant excess was discovered
  - upper limits were set on the annihilation cross section
  - best limits > 20 TeV, competitive limits at low masses as well
  - strong constraint on well motivated SUSY-wino DM model