Search for gamma-ray line emission from Dark Matter annihilation in the Galactic Centre with the MAGIC telescopes

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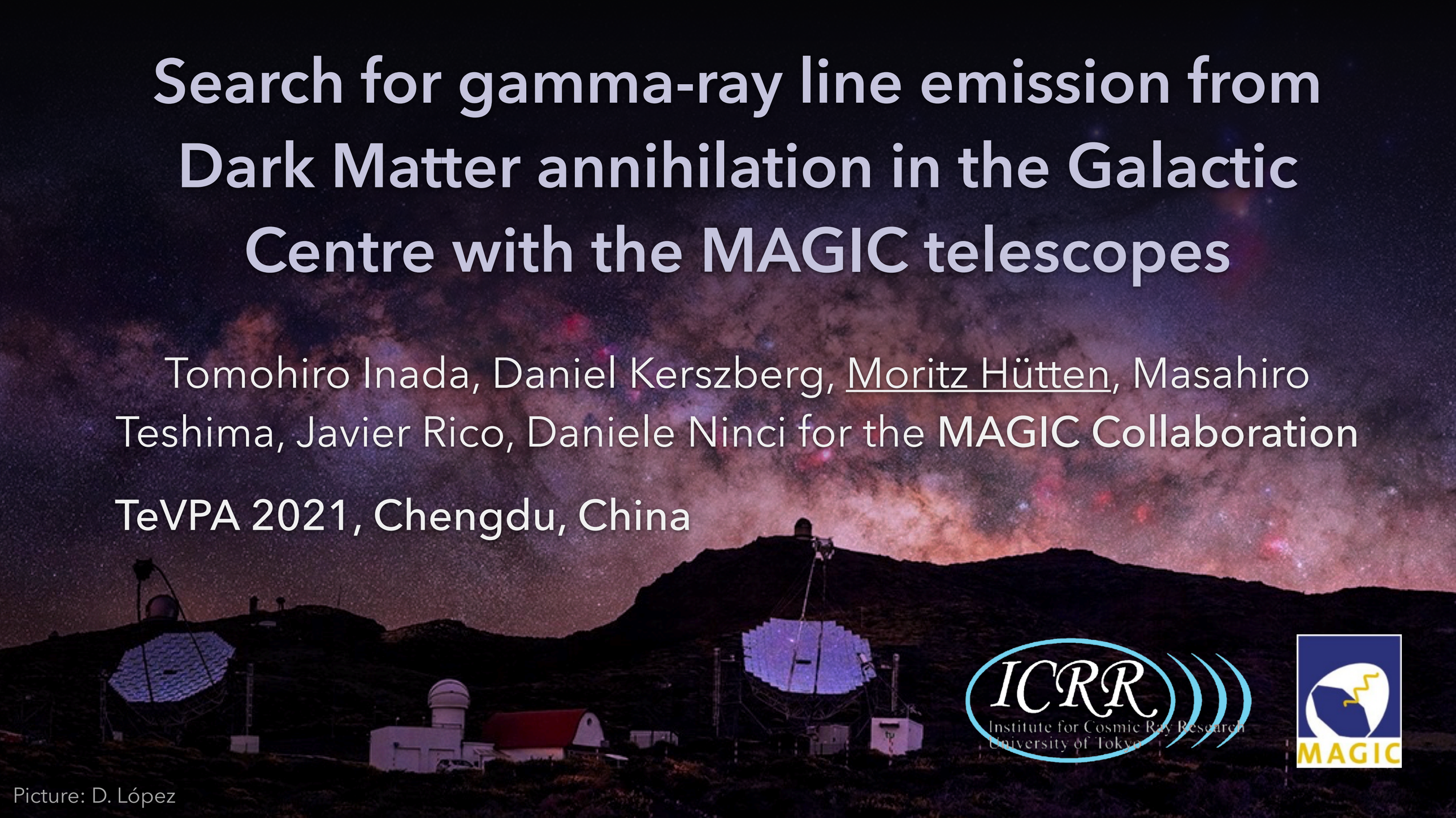

Picture: D. López

The MAGIC telescopes

Picture: L. Heckmann

The MAGIC telescopes

System of two **M**ajor **A**tmospheric **G**amma-ray **I**maging **C**herenkov telescopes

In operation for 18 years (12 years in stereo)

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LST-1 (CTA)

MAGIC-2

LIDAR system

MAGIC-1

Picture: L. Heckmann

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very-high energy (VHE, >GeV) γ-ray

Air shower

1º

Cherenkov light pool

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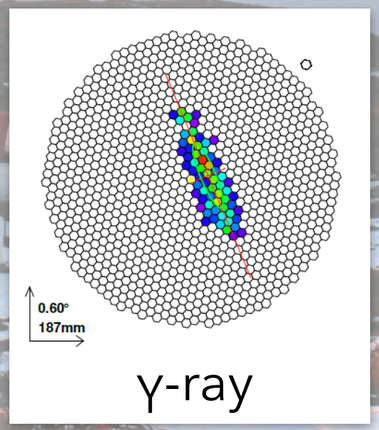
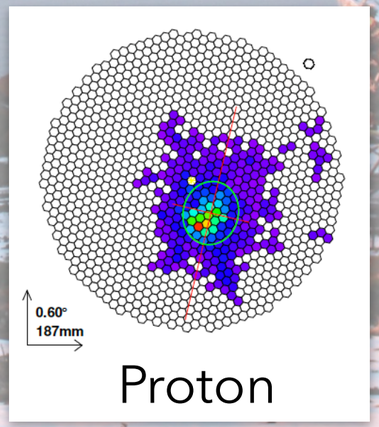




Picture: L. Heckmann

The MAGIC telescopes

very-high energy (VHE, >GeV) γ-ray

Air shower

1°

Cherenkov light pool

- Mirror diameter: 17 m
- Camera field of view: 3.5°
- Energy range: 50 GeV – 50 TeV (Low zenith ~20°)
- Energy resolution: 15% – 25%
- Angular resolution: 0.05° – 0.10°

Picture: L. Heckmann

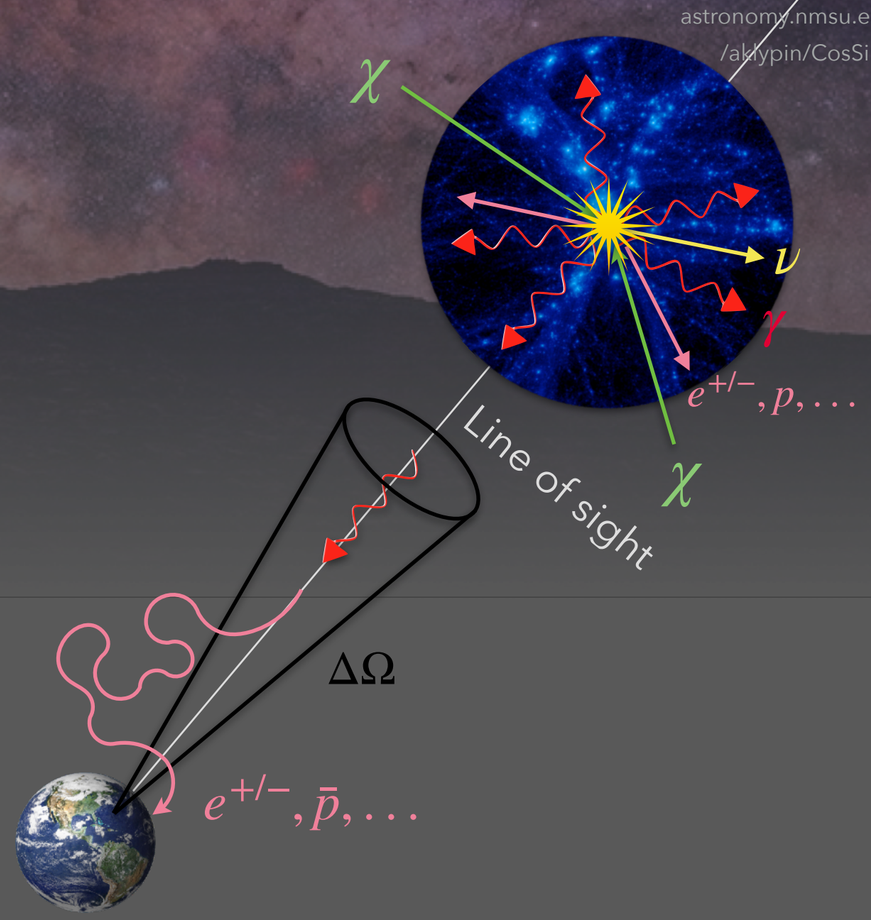
Why (to search for) Dark Matter γ-ray signals?

- Relic annihilations in high-density astrophysical DM budgets
- γ-ray flux from DM annihilation:

$$\frac{\mathrm{d}N_\gamma}{\mathrm{d}A\mathrm{d}t} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{\delta\, m_\chi^2} \times \int \frac{\mathrm{d}N_\gamma^{\text{per interact.}}}{\mathrm{d}E}\,\mathrm{d}E \times \int_{\Delta\Omega}\int_{l.o.s.} \rho_\chi^2\,\mathrm{d}l\mathrm{d}\Omega$$

Particle physics factor — Astrophysical *J*-factor

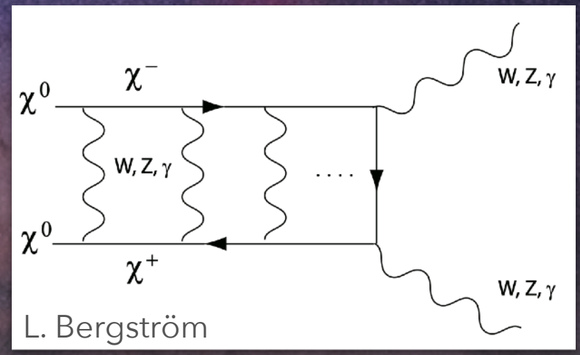
- Annihilation into two γ's, $\langle\sigma v\rangle_{\gamma\gamma}$: $\dfrac{dN_\gamma^{\text{per interact.}}}{dE} = 2\delta(E - m_\chi)$



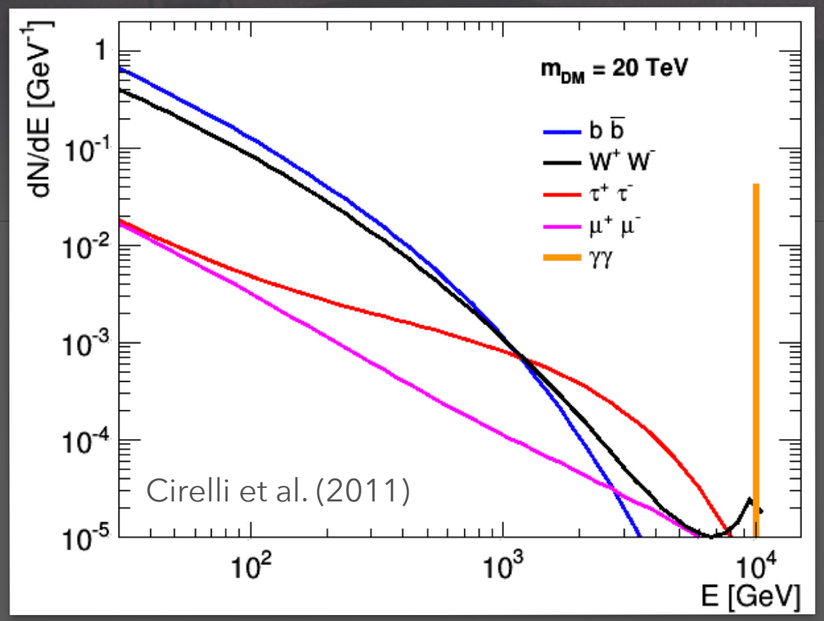
Sharp spectral feature at TeV scale smoking gun for DM + new physics: Identify the **DM particle character**, **mass**, and **cross section**

Where to expect DM lines?

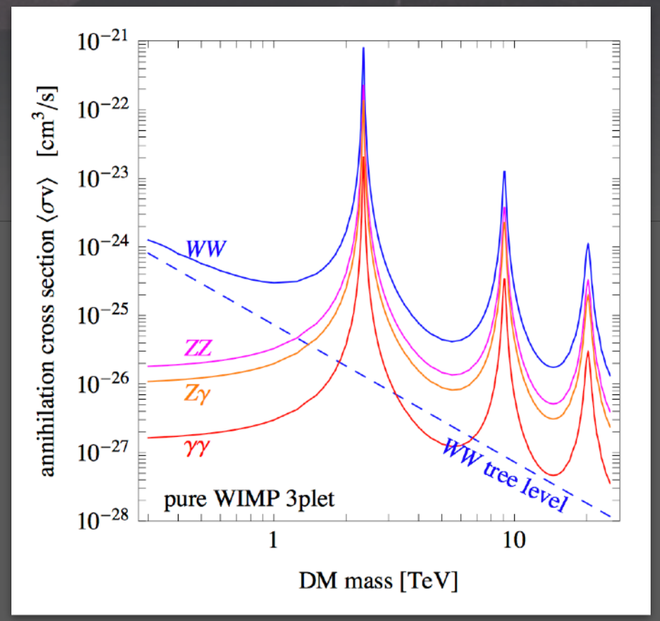
- Sharp peak at DM mass
- $\chi\chi \rightarrow \gamma\gamma$ channel loop-suppressed by α^2
- Some DM particle models at TeV scale expected with Sommerfeld enhanced σv
- Line-like features also by three-body annihilations (virtual internal bremsstrahlung)



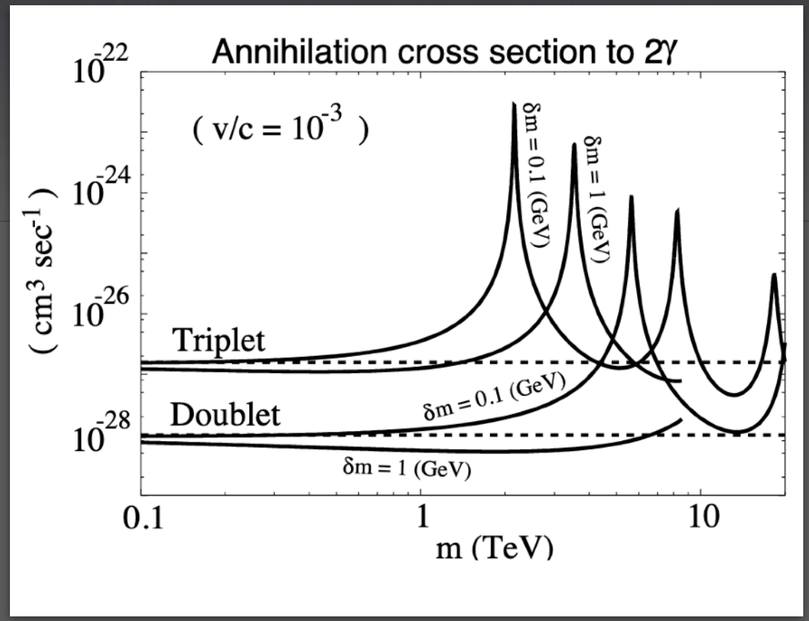
L. Bergström



Cirelli et al. (2011)



H.E.S.S. collaboration JCAP11(2018)

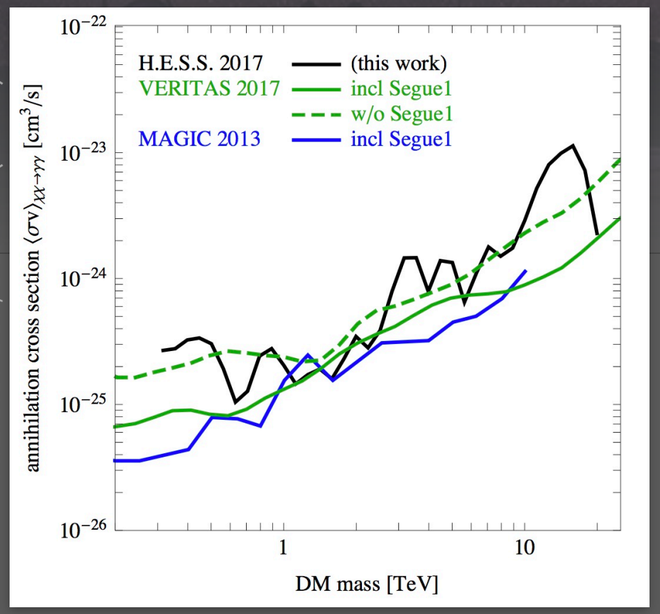


Hisano et at. (2005), Phys. Rev. D 71, 063528

Current status of TeV DM gamma ray line searches

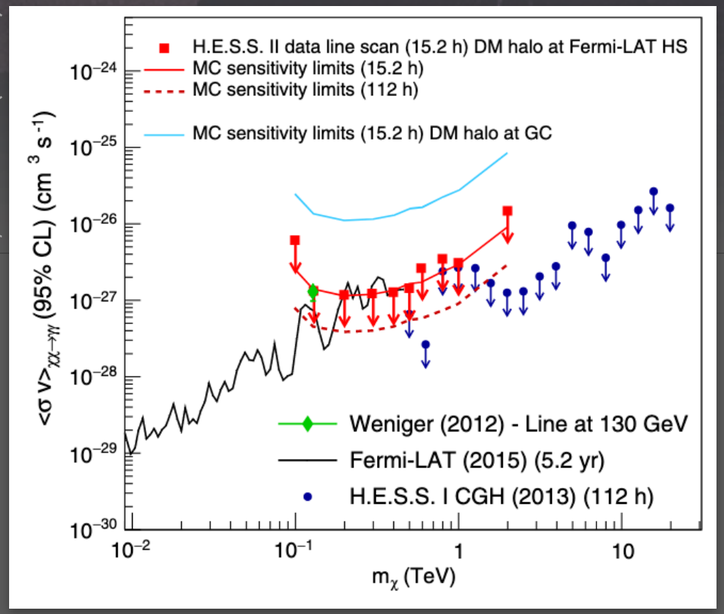
	+	-
Galactic Centre	By far strongest signal for all DM models	Uncertainty on cusp/core
		Continuum astrophysical backgrounds
Dwarf Galaxies	Relatively robust *J*-factor constraints	lower fluxes than from GC region
		J-factor uncertainties in ultrafaint dSphs

H.E.S.S. Coll, JCAP11(2018)037

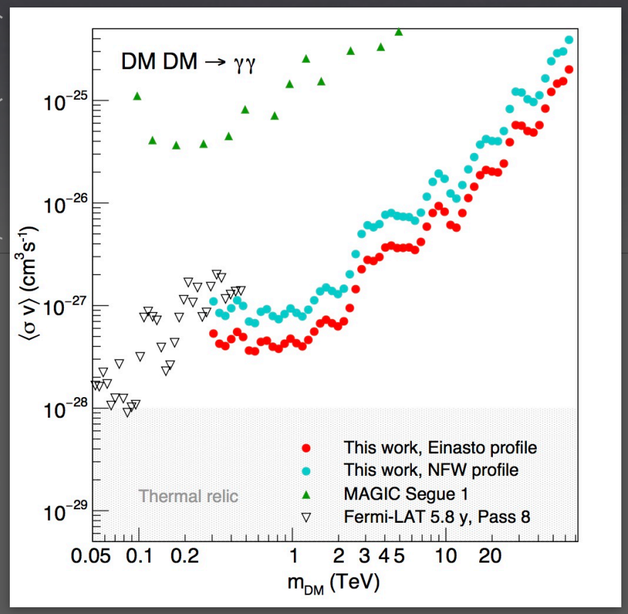


Dwarf Galaxies

H.E.S.S. Coll. PRL 117, 151302 (2016)



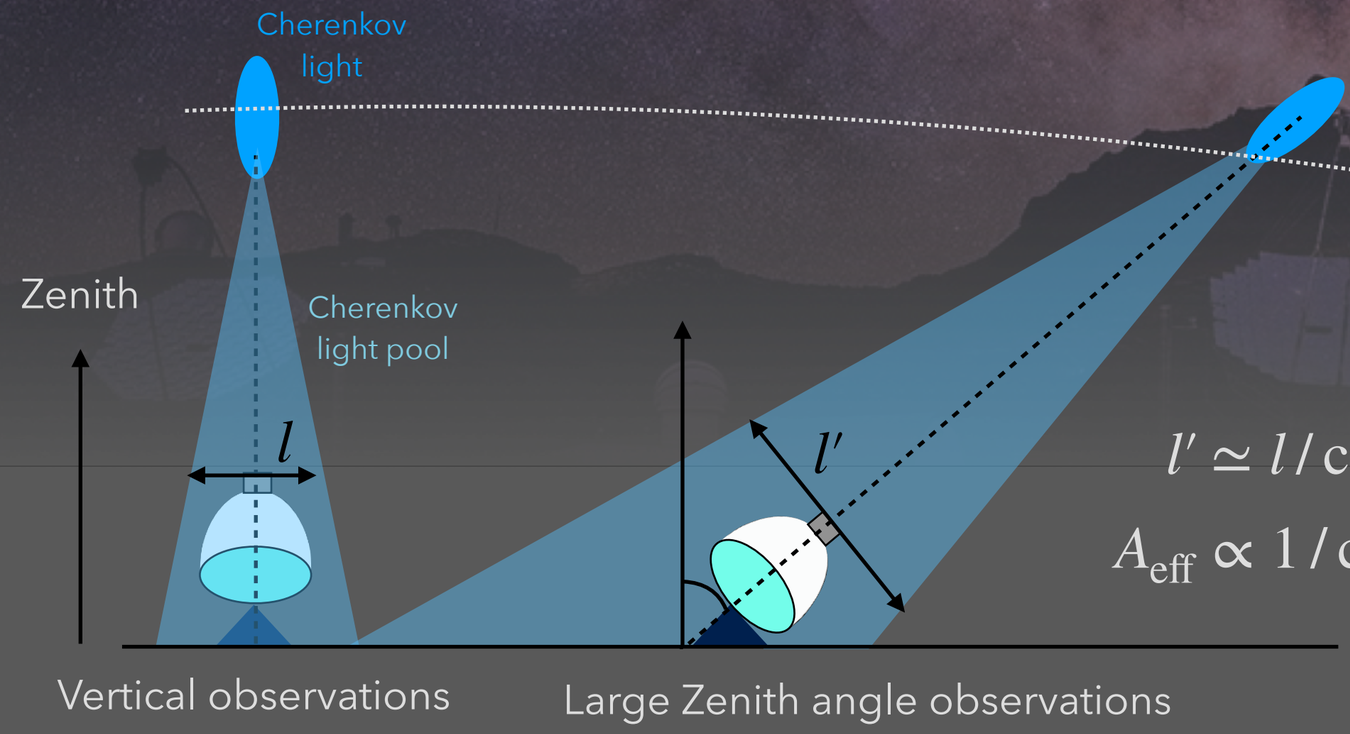
H.E.S.S. Coll. PRL 120, 201101 (2018)



Galactic Centre

MAGIC observations of the Galactic Centre

58° - 70° distance from zenith: large zenith angle observation (LZA)



$$l' \simeq l / \cos\theta_{\mathrm{zd}}$$

$$A_{\mathrm{eff}} \propto 1 / \cos^2\theta_{\mathrm{zd}}$$

+	Increased γ-ray detection area: larger statistics at TeV energies
-	Increased energy threshold

Large Zenith angle observations boost the sensitivity to line signals from TeV DM

Collected dataset

Data taken: March 2013 - August 2019

- Zenith range : $58° < \theta_{zd} < 70°$
- Total observation time: 204 hours after quality cuts

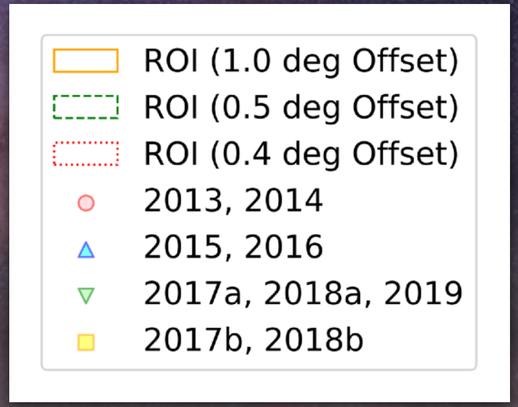
Analysis region (ROI)

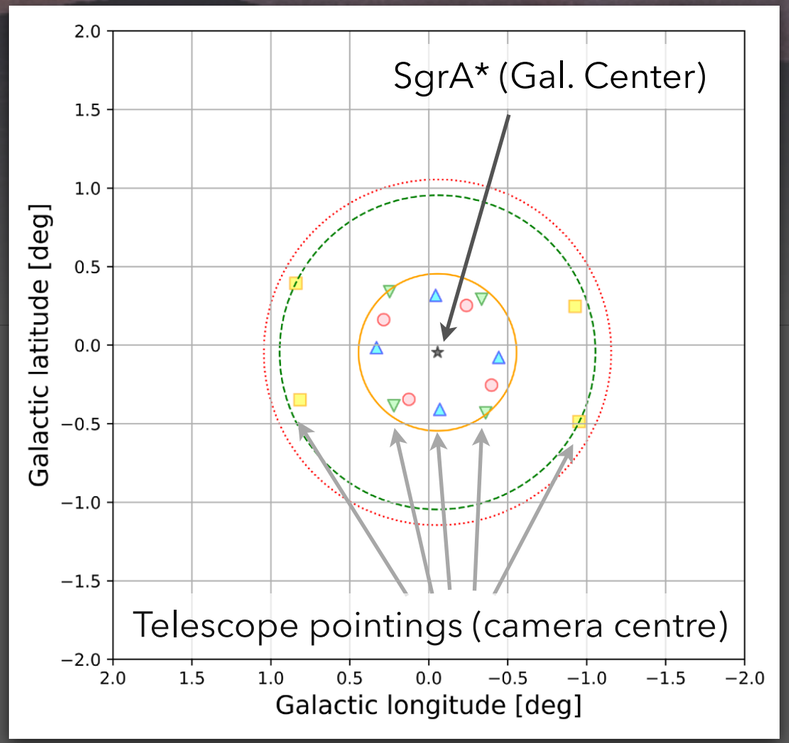
- Circular regions around SgrA* not exceeding 1.5° distance from the camera centre
- Different ROI sizes due to variation in pointing directions

Astrophysical *J*-factor

- Computed with each ROI for both a cuspy and core profile

Profile name	$J(0.5°)$	$J(1.0°)$	$J(1.1°)$
Cuspy Einasto	3.14×10^{21}	8.01×10^{21}	9.03×10^{21}
Zhao γ=0 core	2.66×10^{19}	1.06×10^{20}	1.28×10^{20}



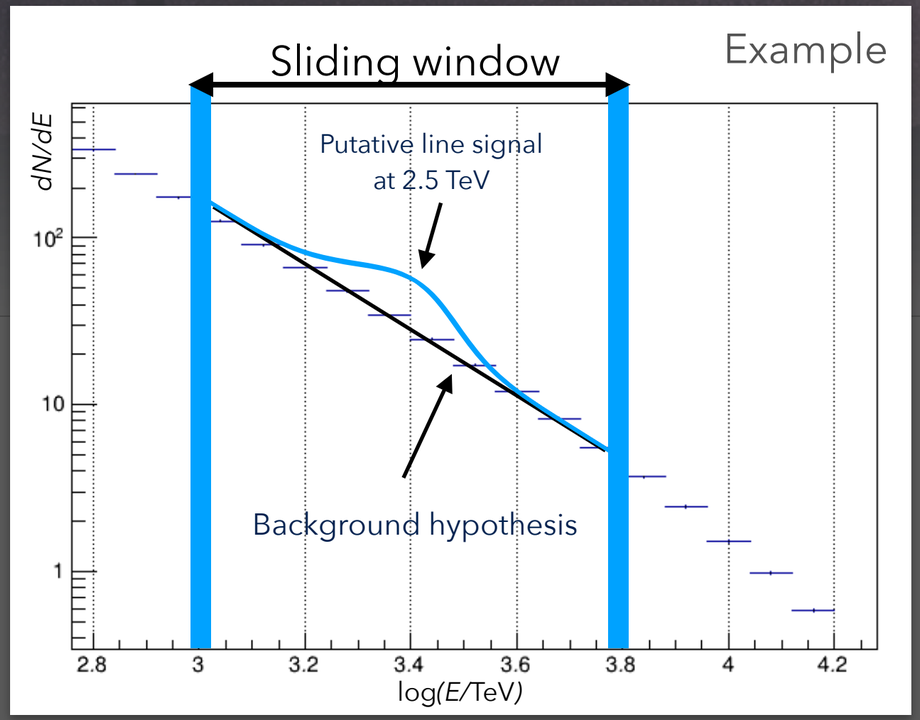


Unbinned likelihood analysis in a sliding window

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

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

$$\times \mathcal{T}(\tau_i | \tau_{\mathrm{obs},i}, \sigma_{\tau,i})$$ systematic uncertainty of background



Index i : Nine samples w/ different observation conditions

N_{on} : observed events in a ROI

g : **estimated signal events** — Parameter of interest

b : estimated background events — Nuisance parameters

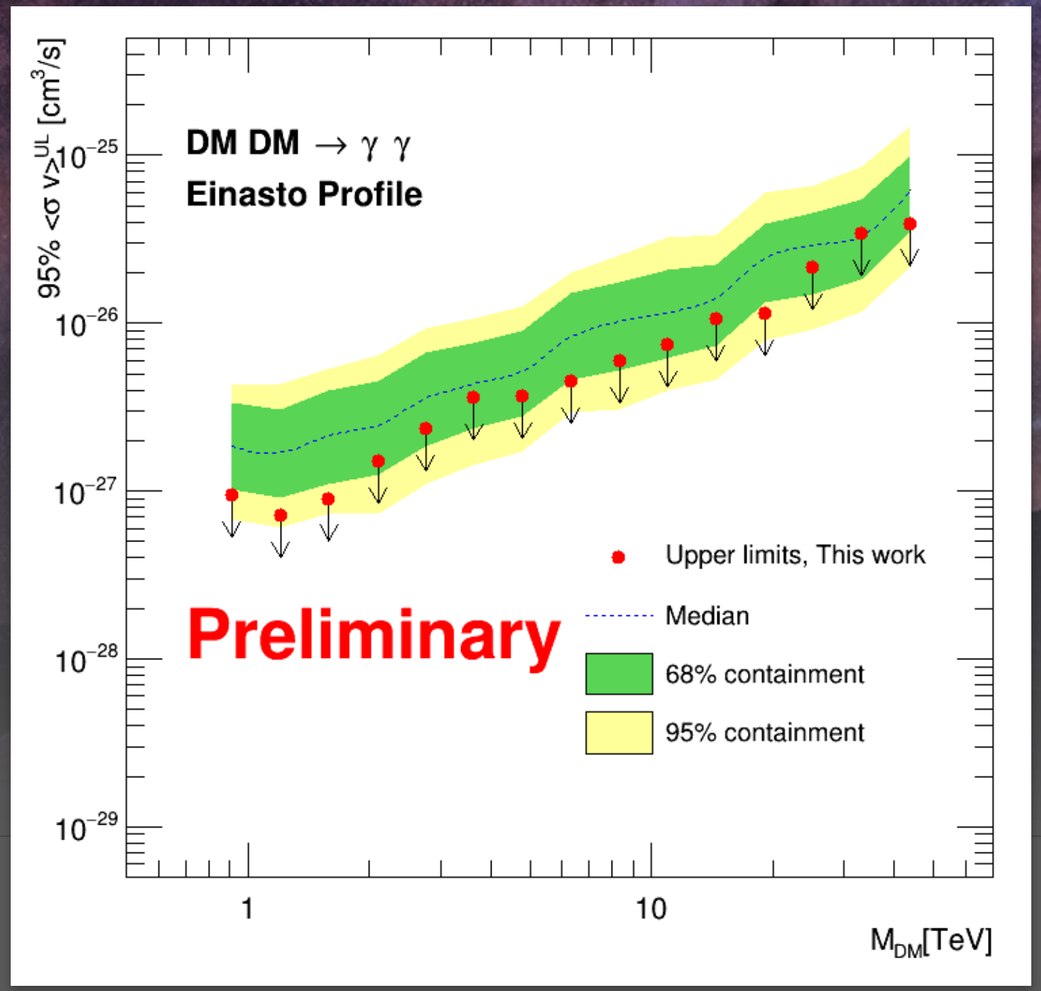
τ : normalization factor for bkg model

f_g : line signal pdf: δ-function convolved with the response function

f_b : background pdf: interpolated between window edges

Assumption: background behaves as power-law within the window

Results

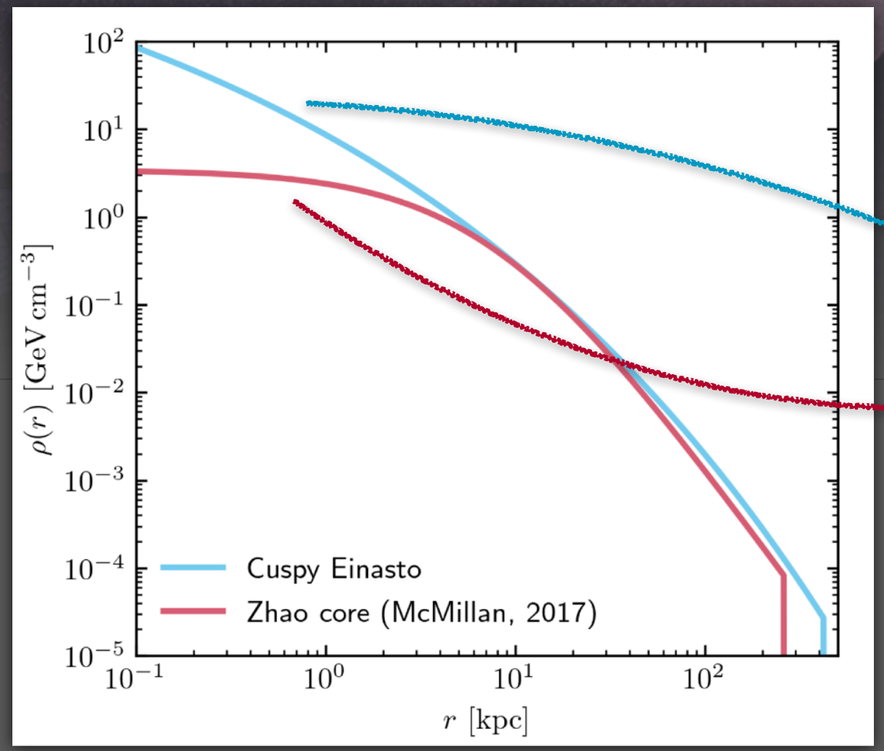


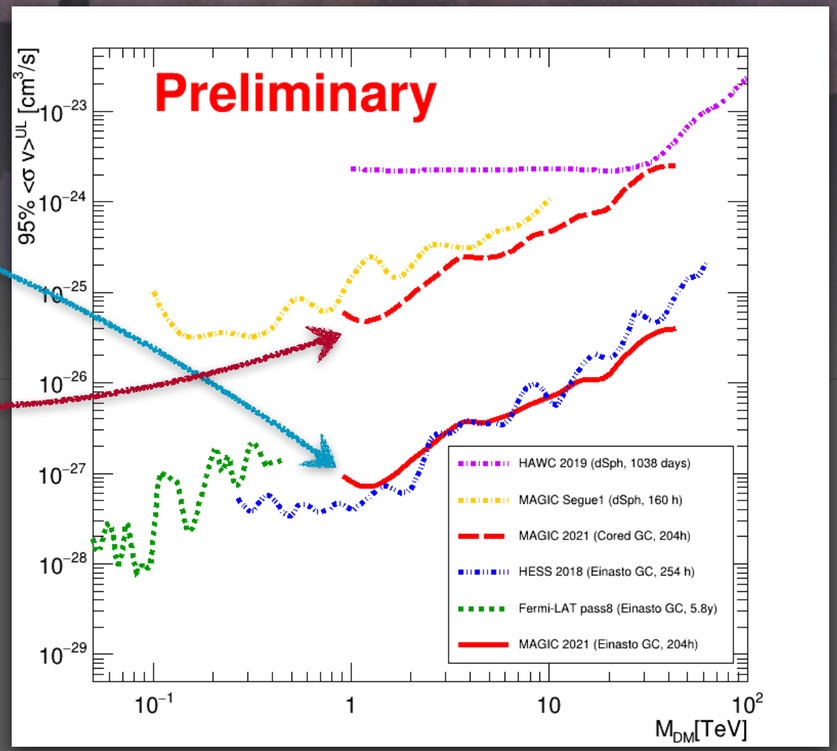
- No significant line-like excess found
- Set upper limits at 95% C.L. on 15 masses between 912 GeV - 43 TeV
- Sensitivity based on 300 simulations

Results

Limits obtained for Einasto (cuspy) and GC profile with ~500pc core (McMillan, 2017)

- For GC DM cusp: Competitive to most stringent limits to $\chi\chi \rightarrow \gamma\gamma$ at E > 10 TeV
- For GC DM core: Limit competitive to dSph results





Summary

- Search for line-like signals in VHE γ-rays smoking-gun test for TeV particle DM
- Reported search in 204h of observations with the MAGIC telescopes on La Palma, Spain
  Performed large-zenith-angle observations focusing on TeV DM
  First search for DM lines at the GC with MAGIC
- No significant excess was found
  Upper limits were set on the annihilation cross section
  Limits competitive for both cuspy and cored DM profiles
- For the future (CTA era):
  Large-zenith-angle observations of the GC well suited for heavy DM searches
  High potential of the northern CTA site to contribute to next-generation DM searches