Upper limits on the WIMP annihilation cross section from a joint analysis of dwarf spheroidal satellite galaxy observations with the MAGIC telescopes

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ONLINE ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
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37th International Cosmic Ray Conference
12–23 July 2021

Outline

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1. Indirect dark matter searches with Imaging Atmospheric Cherenkov Telescopes

2. The MAGIC telescopes

3. The MAGIC multi-year dSphs observation program for dark matter searches

4. Results for DM annihilation in dSphs

5. Conclusions and future steps

WIMP indirect DM searches

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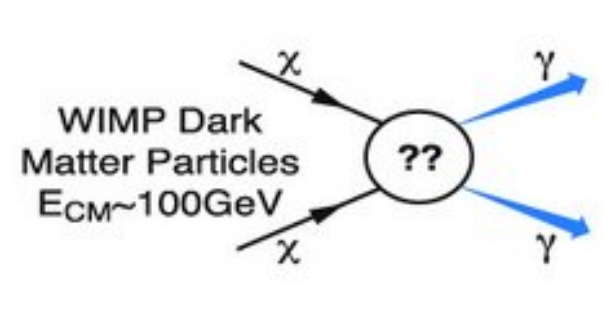
GAMMA-RAY FLUX (FROM WIMP ANNIHILATION)

$$\frac{d\Phi_\gamma}{dE} = \frac{d\Phi_\gamma^{PP}}{dE} \times J(\Omega)$$

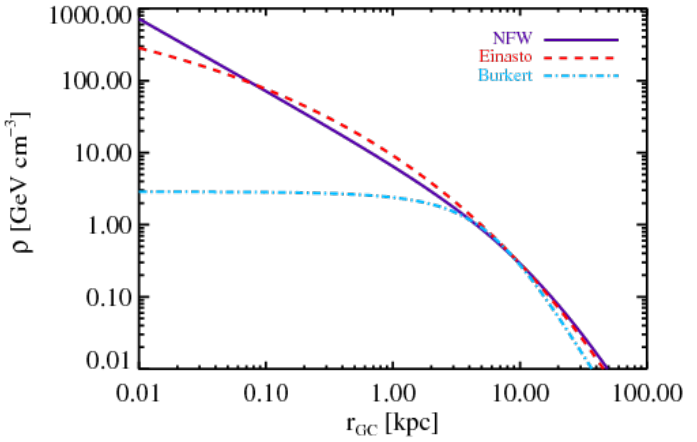


ASTROPHYSICAL (J-) FACTOR

$$J(\Omega) = \int_{\Delta\Omega} \int_{l.o.s.} \rho^2(l, \Omega')\, dl\, d\Omega'$$

$$\frac{d\Phi_\gamma^{PP}}{dE} = \frac{\langle \sigma v \rangle}{4\pi m_\chi^2} \frac{dN_\gamma}{dE}$$

PARTICLE PHYSICS FACTOR



The Major Atmospheric Gamma Imaging Cherenkov experiment

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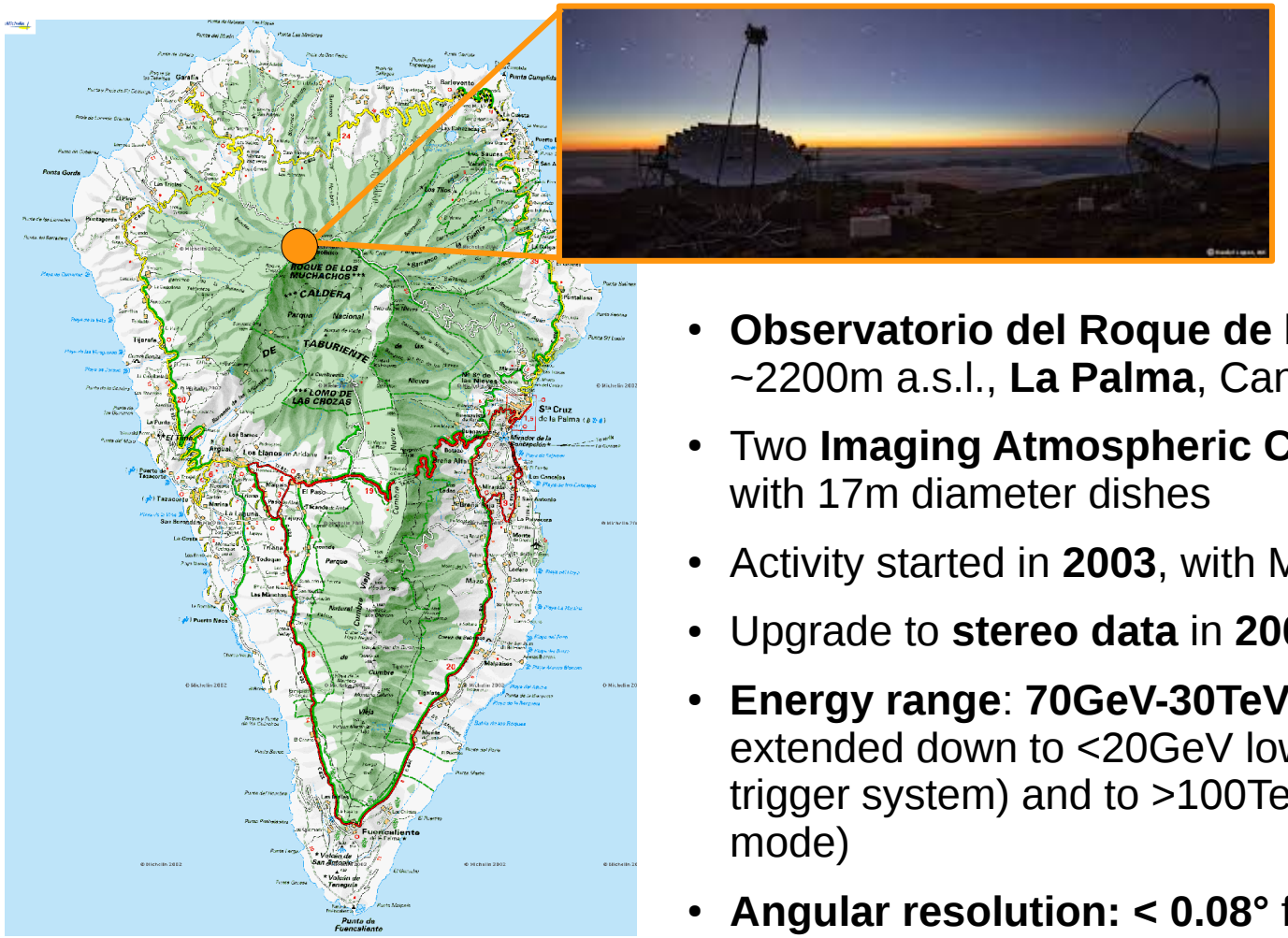

- ~ 290 members in total
- 12 countries

- **Observatorio del Roque de los Muchachos (ORM)** ~2200m a.s.l., **La Palma**, Canary Island, Spain
- Two **Imaging Atmospheric Cherenkov Telescopes (IACTs)** with 17m diameter dishes
- Activity started in **2003**, with M1 only (mono data)
- Upgrade to **stereo data** in **2009**, M2 construction
- **Energy range**: **70GeV-30TeV** (with standard trigger), extended down to <20GeV low limit (thanks to the sum-trigger system) and to >100TeV (in very large zenith angle mode)
- **Angular resolution: < 0.08°** for energies E≥200GeV

MAGIC multi-year dSphs observation program for dark matter searches

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- **Observational diversification strategy:**
  - enlarge the pool of dSphs observed by MAGIC
  - reduce J-factor systematics
  - enrich the data sample available with the goal of a joint analysis with Fermi-LAT, HAWC, H.E.S.S. and VERITAS
    → *Glory Duck project* [PoS (ICRC2019) 012]

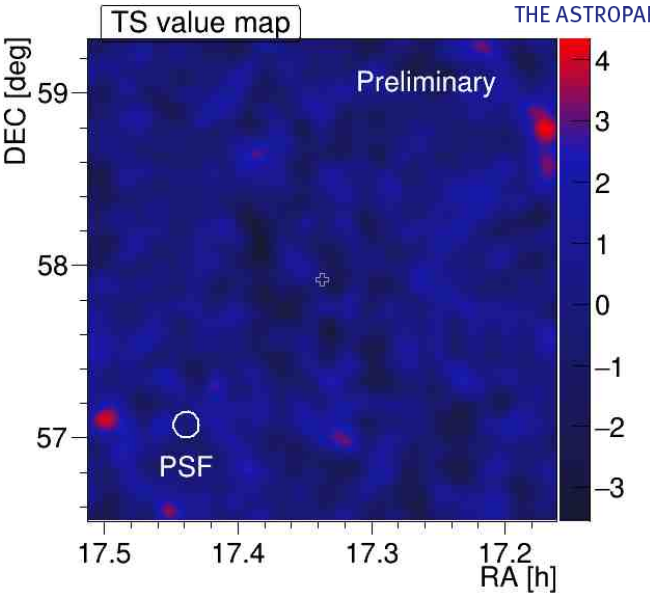
- **Optimal dSphs ranked** from A. Geringer-Sameth, S. M. Koushiappas, M. Walker paper [ApJ, 801, 74 (2015)] and observed by MAGIC:

TARGET	logJ ± DlogJ [GeV²/cm⁵]
Segue 1	19.36 ± 0.35
Ursa Major II	19.42 ± 0.42
NEW! Draco	19.05 ± 0.21
NEW! Coma Berenices	19.02 ± 0.41

Draco and Coma Berenices dSphs

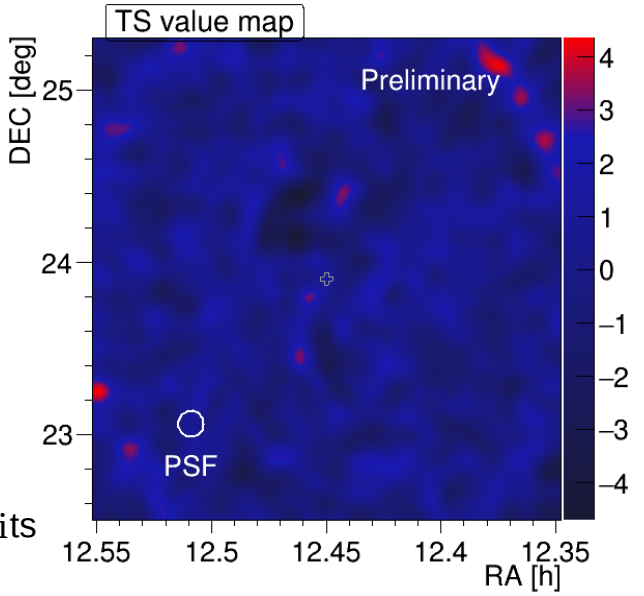
Draco [RA 17:20:12.4, Dec +57:54:55]

- Data taking: 2018/03/17-2018/09/02
- Tot. amount of good quality data: 52.1h
- Dark time
- Zenith distance: 29-46 deg



Coma Berenices [RA 12:26:59.0 Dec +23:54:15]

- Data taking: 2019/01/29-2019/06/03
- Tot. amount of good quality data: 49.5h
- Dark time
- Zenith distance: 5-36 deg



NO GAMMA-RAY EXCESS!

Low level analysis for extended sources: the Donut Monte Carlo method

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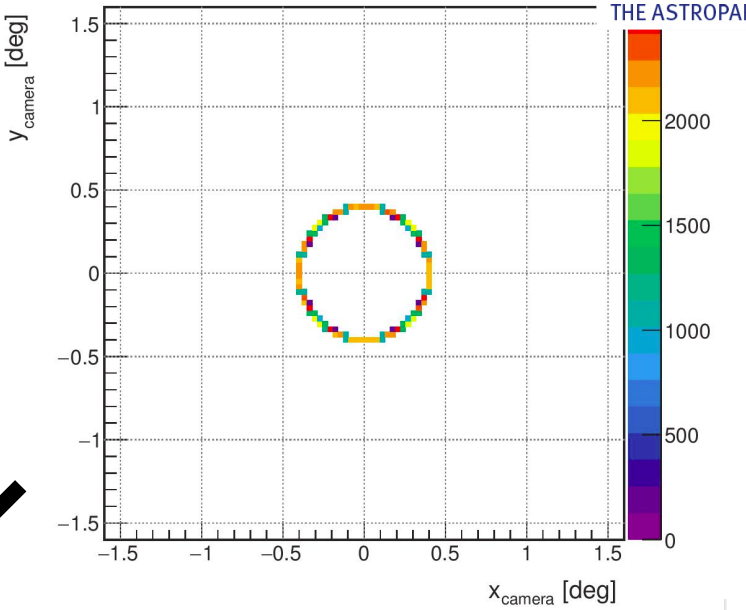
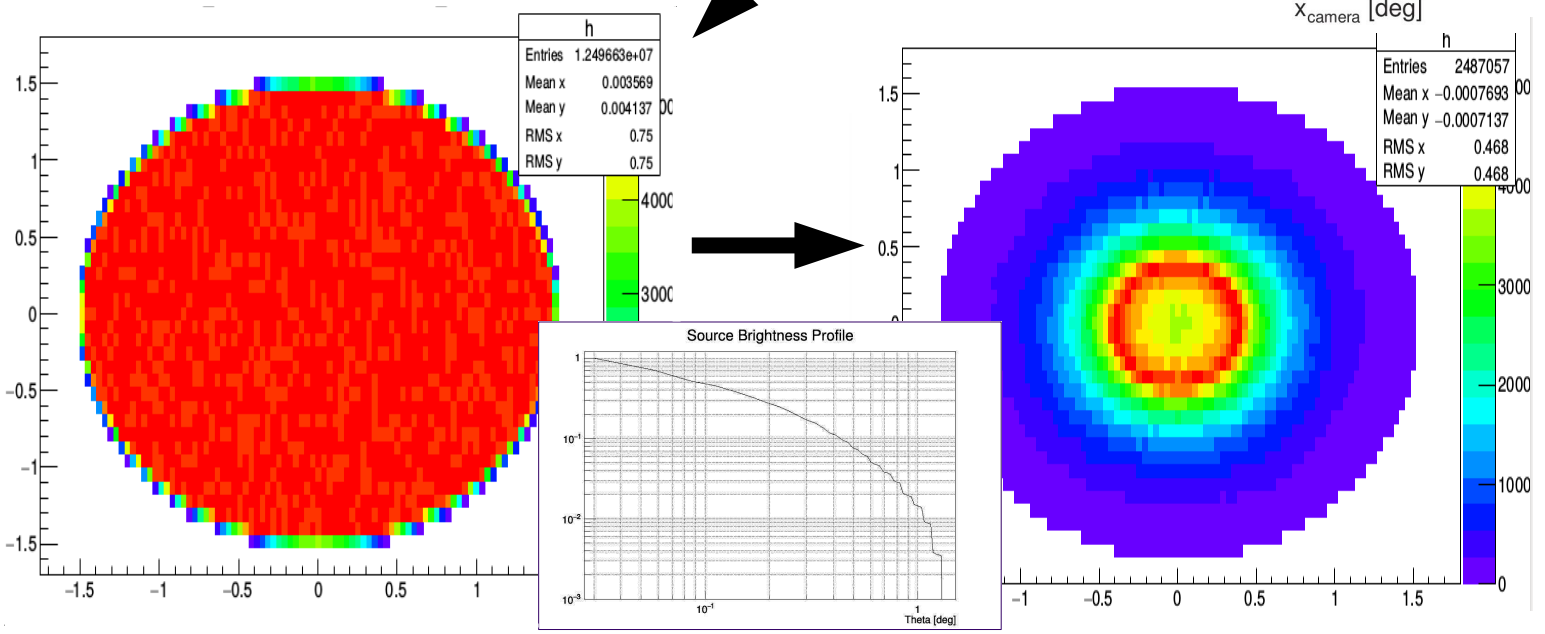
MAGIC PSF ≃ 0.1deg

TARGET	EXTENSION θ_{max} [deg]
Segue 1	0.35
Ursa Major II	0.53
Draco	1.30
Coma Berenices	0.31



MC SIMULATIONS FOR POINTLIKE TARGETS

MC SIMULATIONS FOR EXTENDED TARGETS



DONUT MONTE CARLO METHOD

JCAP 1803 (2018) 009

Individual dSphs and dSphs data combination analyses

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	Target	$\log_{10} J(\theta_{\max})$ [GeV^{2}cm^{-5}]	$\theta_{\max}$ [deg]	$\theta_{0.5}$ [deg]	$T_{\rm eff}$ [h]	Year
new	Coma Berenices	$19.02^{+0.37}_{-0.41}$	0.31	$0.16^{+0.02}_{-0.05}$	49.5	2019
new	Draco	$19.05^{+0.22}_{-0.21}$	1.30	$0.40^{+0.16}_{-0.15}$	52.1	2018
JCAP 03 (2018) 009	Ursa Major II	$19.42^{+0.44}_{-0.42}$	0.53	$0.24^{+0.06}_{-0.11}$	94.8	2016–2017
JCAP 02 (2014) 008 revised	Segue 1	$19.36^{+0.32}_{-0.35}$	0.35	$0.13^{+0.05}_{-0.07}$	157.9	2011–2013
					354.4 h	

Data combination

- Improve sensitivity and upper limits thanks to a larger data sample
- Distribute/reduce target-related systematic uncertainties

MAGIC DM high-level analysis

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Output of the first analysis steps:

- gamma-like events from source (ON) and background (OFF) region
- Instrument Response Function:
  - · energy migration matrix G(E,E')
  - · effective area A(E)
- ON/OFF normalization factor τ

Inputs for the final analysis:

- use only positive values for the tested flux (parameter of interest) g(<σv>,J)
- take into account a systematic uncertainty of 1.5% for the background evaluation (τ) [Gaussian distribution]
- take into account the uncertainty in J [Gaussian distribution]

→ **BINNED LIKELIHOOD ANALYSIS**

$$L\left(\langle\sigma v\rangle;\boldsymbol{\nu}\middle|\boldsymbol{D}\right)=L\left(g\left(\langle\sigma v\rangle,J\right);b,\tau\middle|\left(N_{ON},N_{OFF}\right)_{j=1,\ldots,N_{bins}}\right)\cdot J\left(J\middle|J_{obs},\sigma\right)$$

Where *g* is the expected number of gamma rays (detected with reconstructed energy E'):

$$g\left(\langle\sigma v\rangle,J\right)=T_{obs}\int_{E'_{min}}^{E'_{max}}dE'\int_{0}^{\infty}dE\,\frac{d\Phi}{dE}\left(\langle\sigma v\rangle,J\right)A\left(E\right)G\left(E,E'\right)$$

for more details have a look at the proceeding and at J. Aleksić, J. Rico, M. Martinez paper JCAP 1210 (2012) 032

Upper limits for DM annihilation from the combined datasample and for the individual dSphs

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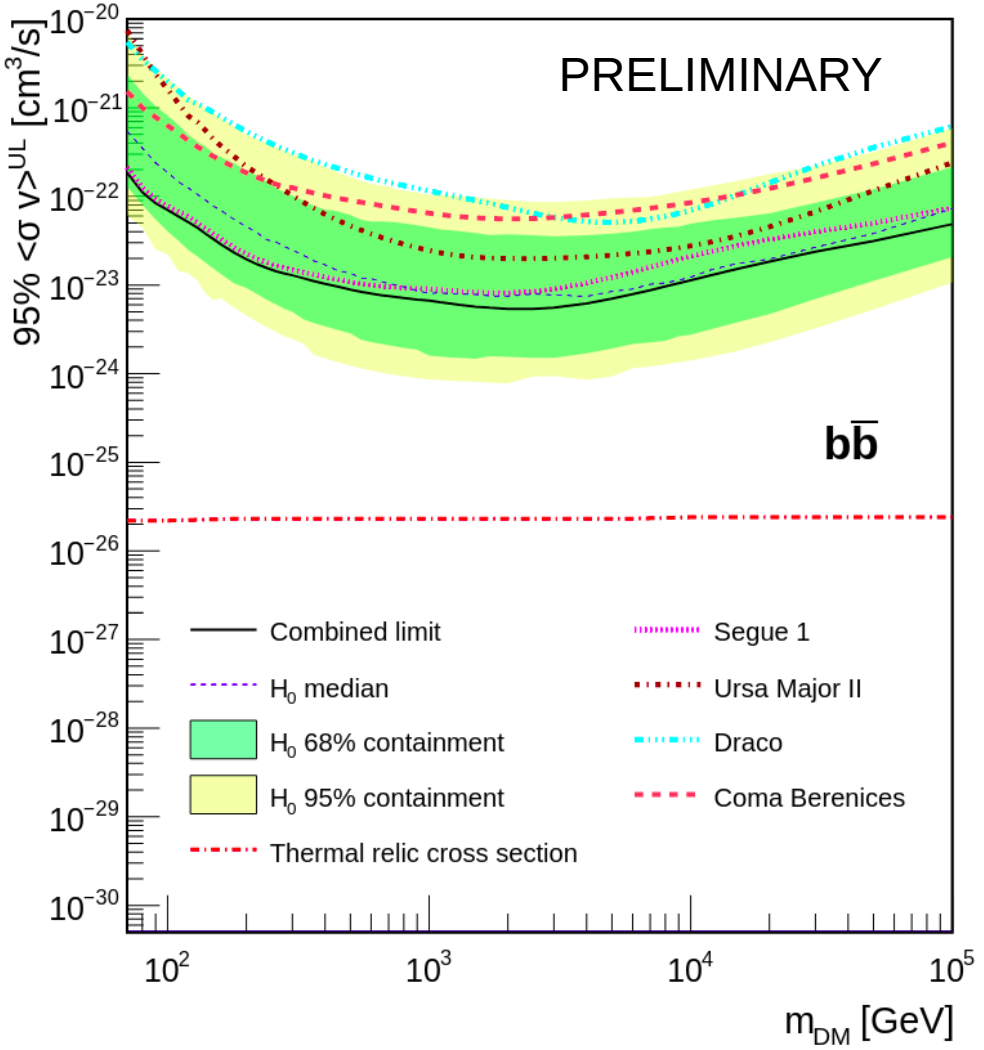
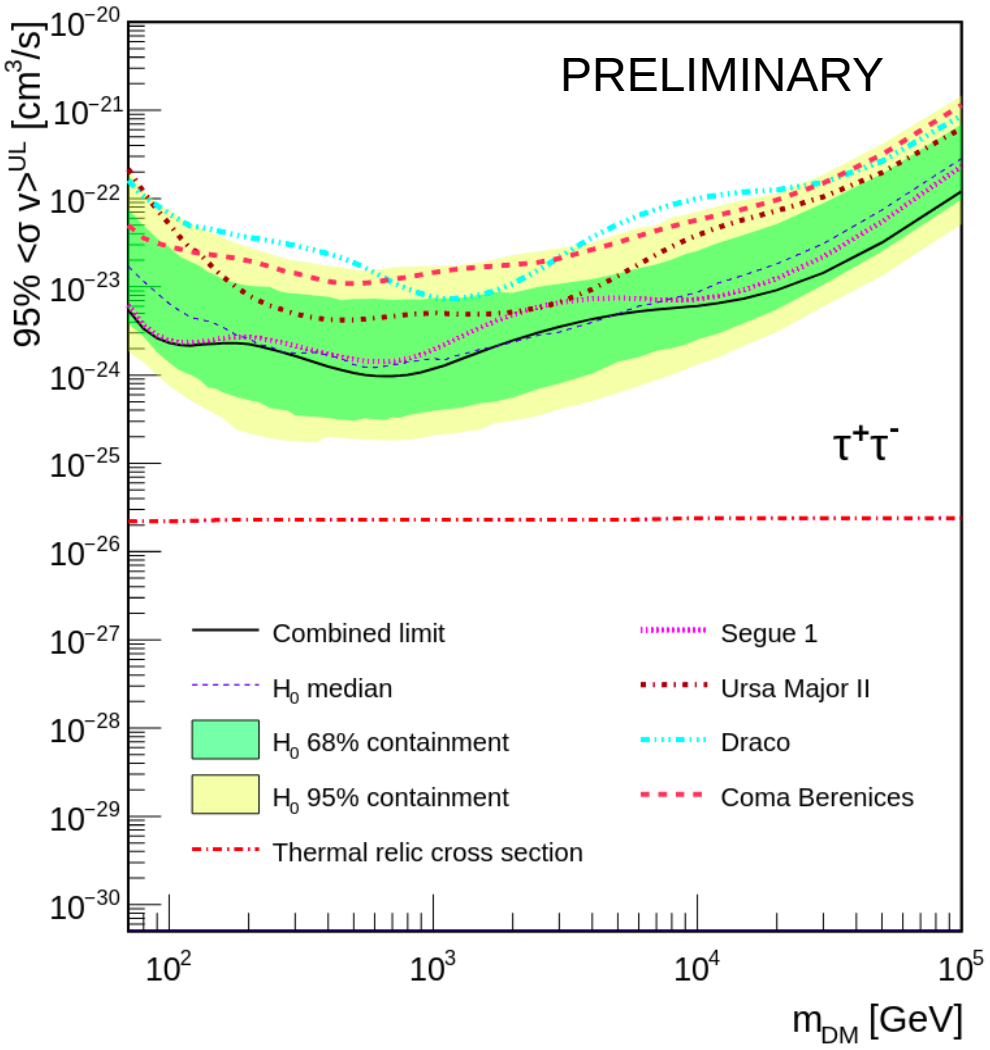
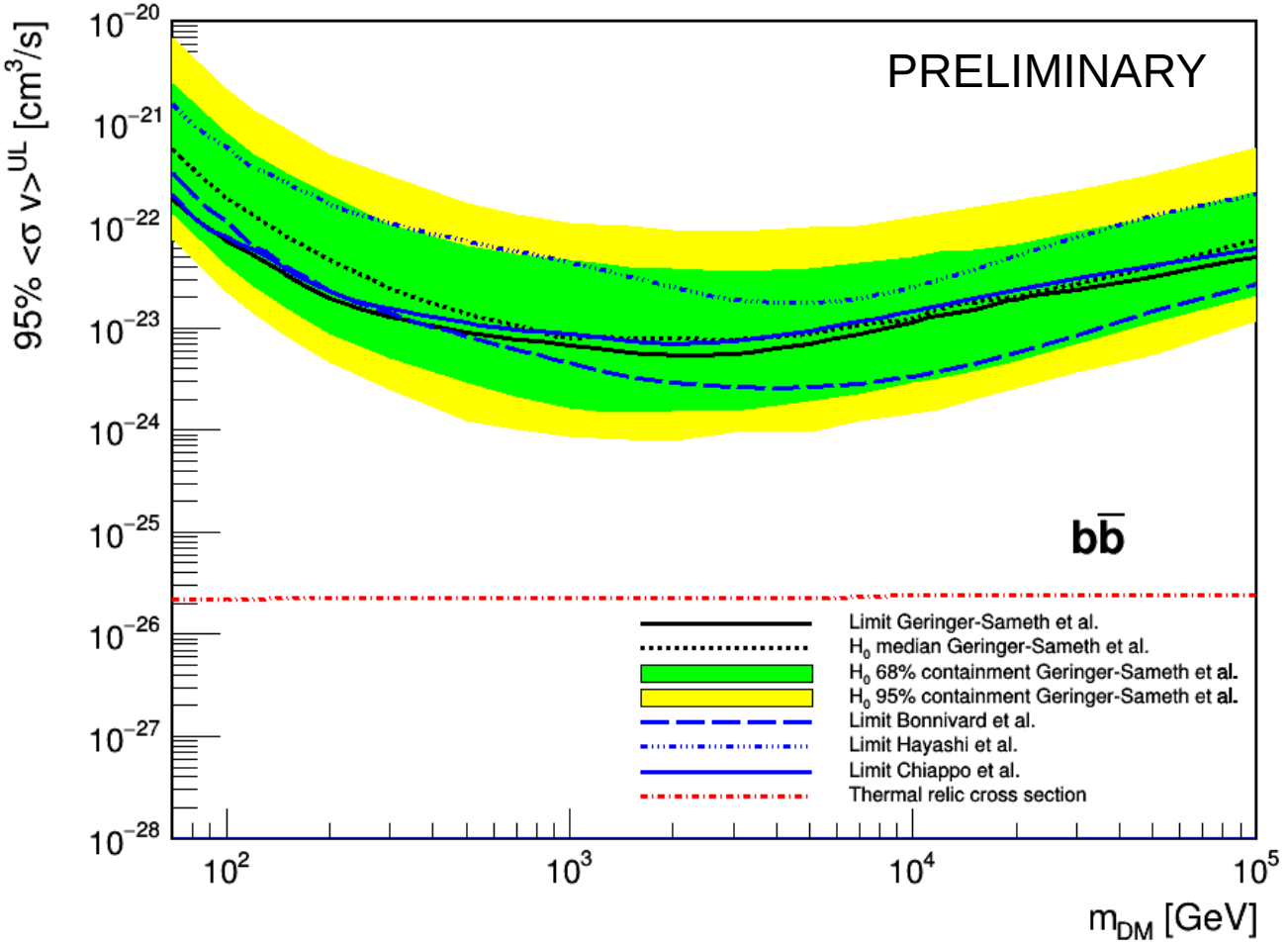


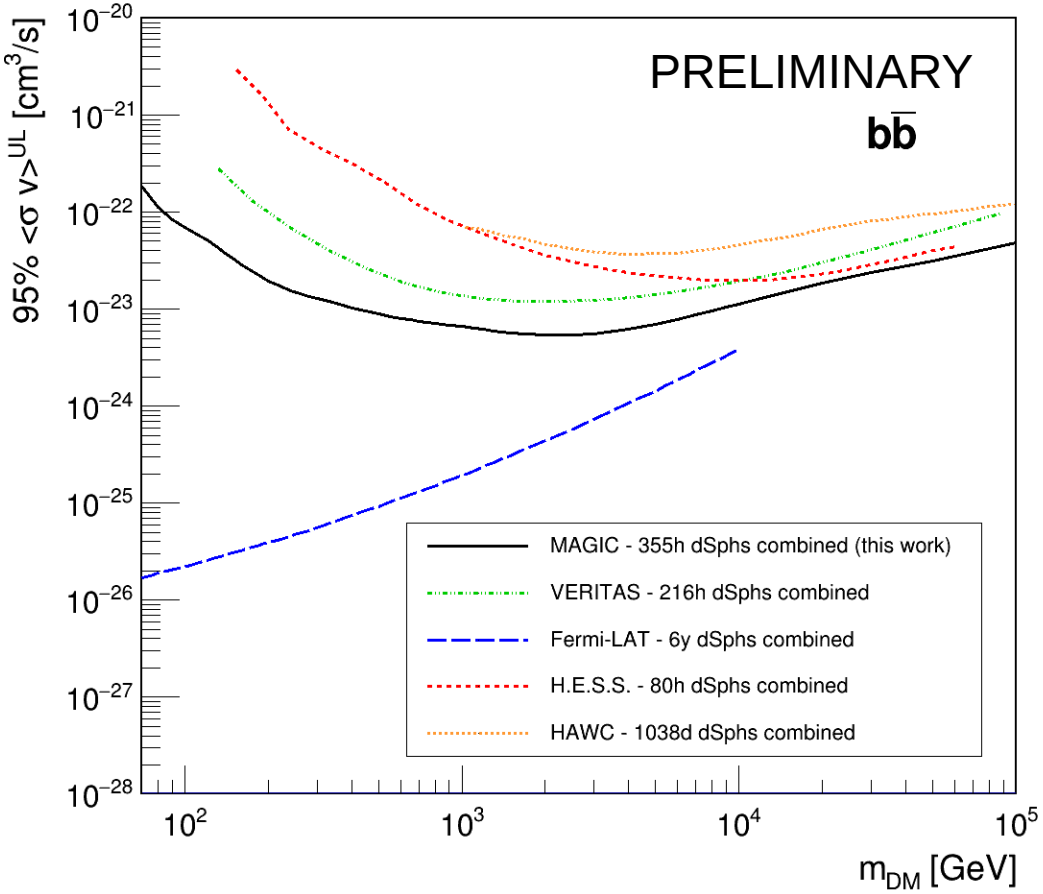


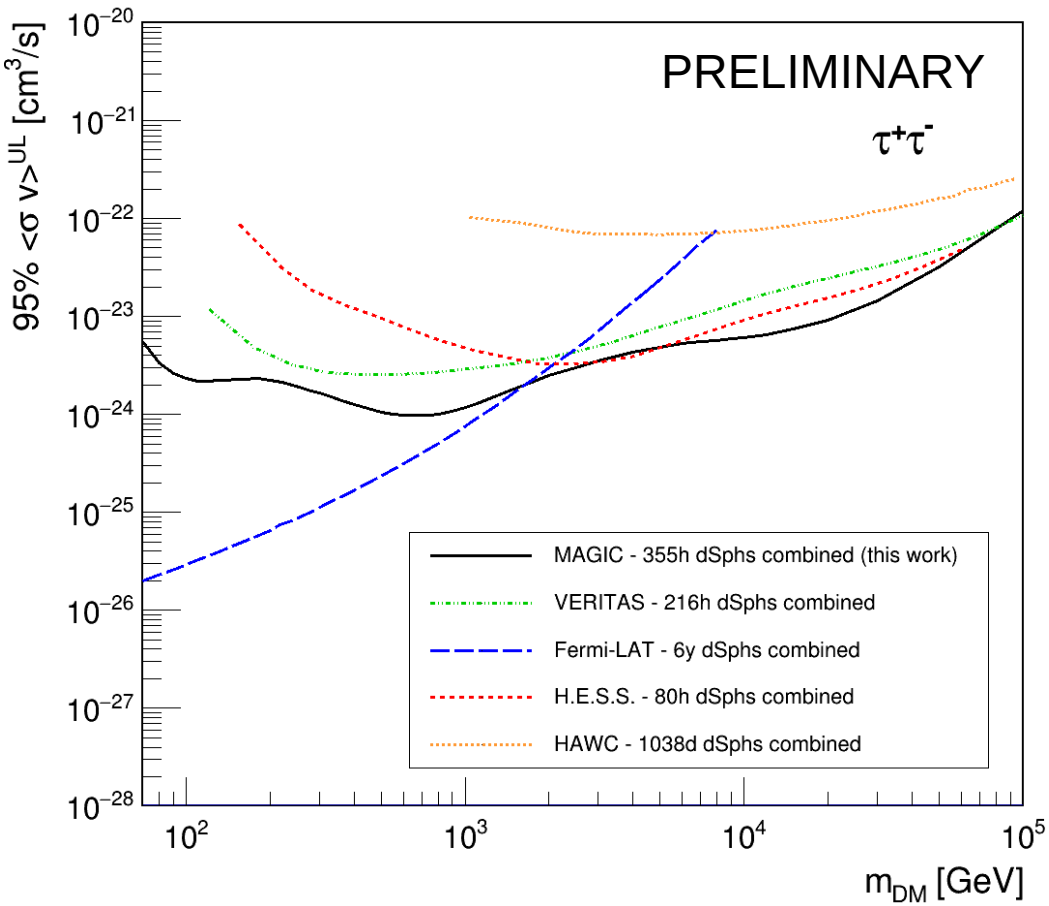
354.4 h of data and 300 simulations to compute the 68% and 95% containment bands

Robustness of the results obtained



WIMP $\langle\sigma_{ann}v\rangle$ ULs of different experiments





Conclusions and future steps

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- Very fruitful campaign on dwarf spheroidal galaxies with MAGIC (**354.4 h of data**)

- The best $\langle\sigma_{ann}v\rangle$ limits with the MAGIC telescopes for the annihilation of WIMPs:

  5.2×10^{-24} cm³/s for the **$b\bar{b}$ channel** @**2TeV** DM mass and
  9.5×10^{-25} cm³/s for the **$\tau^+\tau^-$ channel** @**700GeV** DM mass

and the most stringent ones around TeV DM masses among other experiments

- Proved the **robustness of the results:** from data combination by using different realizations of the J-factor of each dSph in the data sample

- **Results** very soon **presented in a dedicated paper** and adopted for the *Glory Duck* project

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Thank you for the attention!

BACKUP

θ² plot for Draco and Coma Berenices

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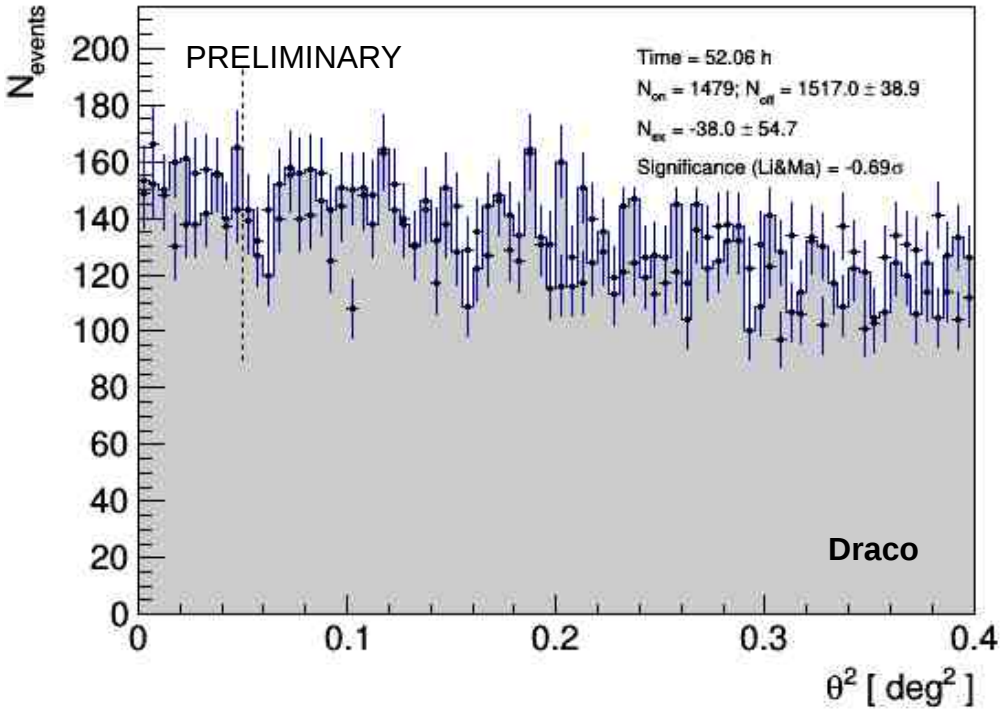
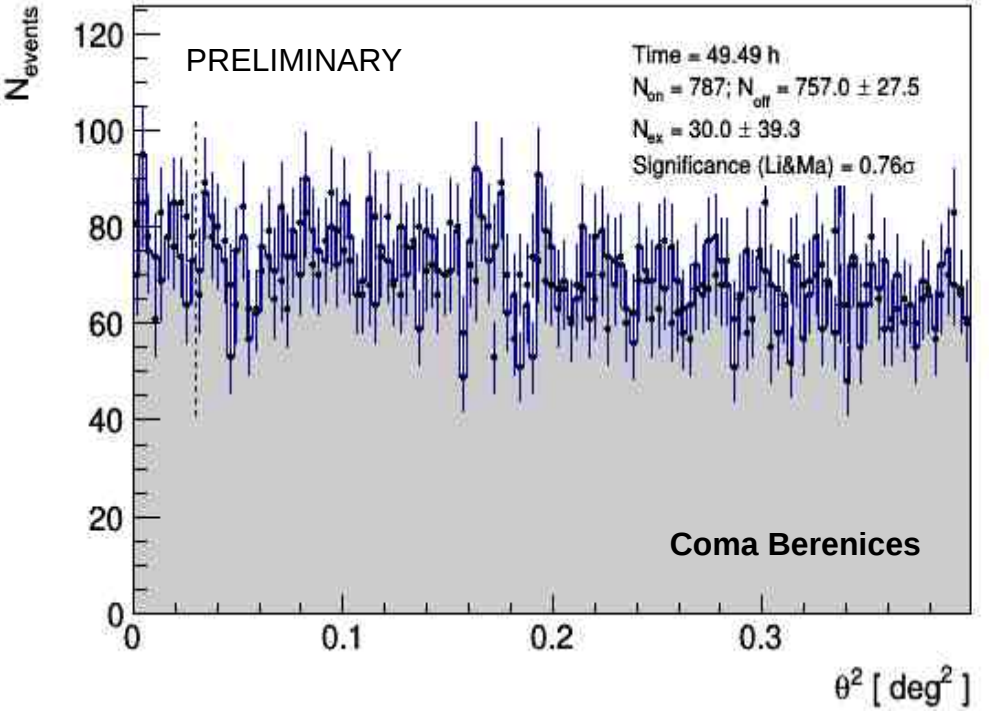
θ^2_{cut} = 0.05 deg²



θ^2_{cut} = 0.03 deg²



BACKUP

Draco and Coma Berenices upper limits on the $<\sigma_{ann} v>$ of WIMPs

No gamma-ray signal from the standard analysis → computed upper limits on $<\sigma_{ann} v>$ and used 300 simulations of the null-hypothesis for the 68% and 95% containment bands