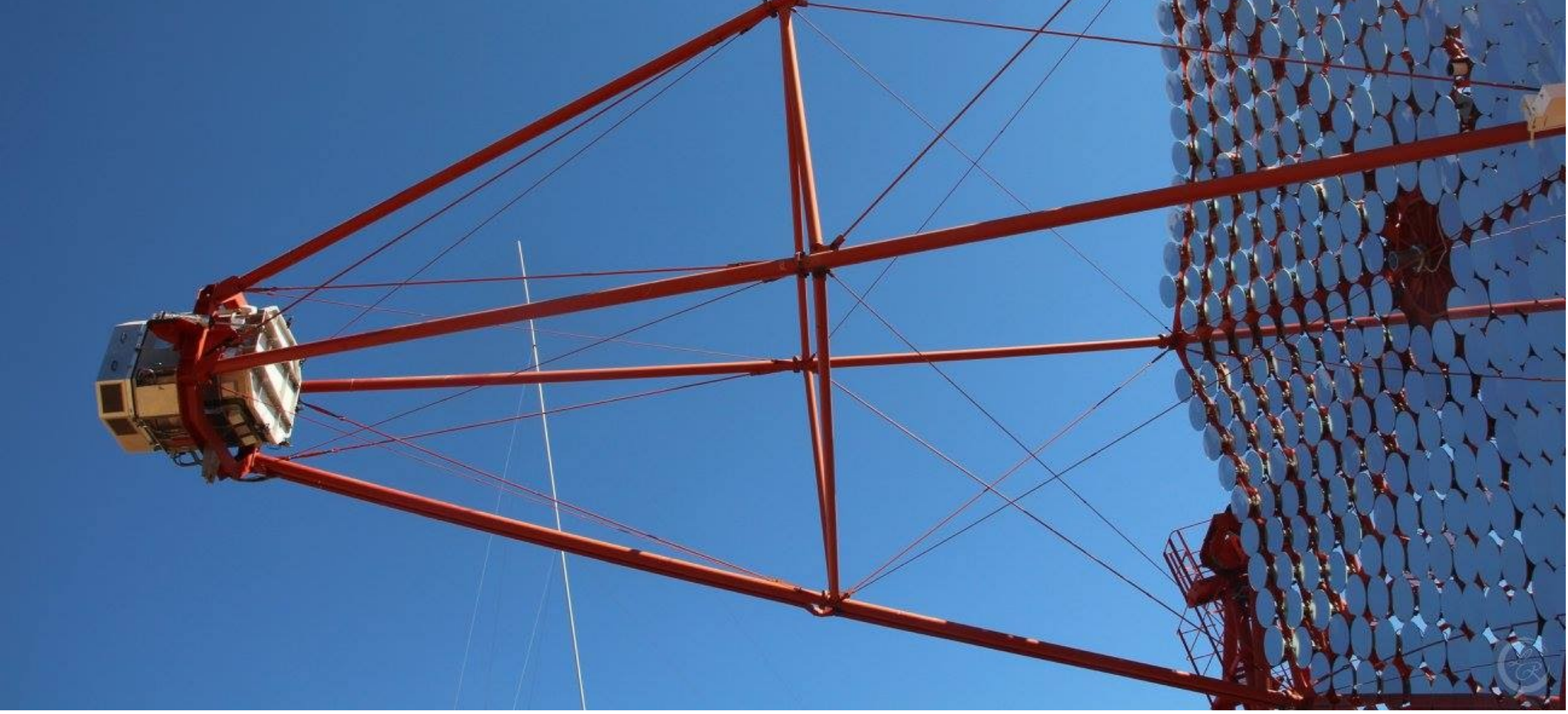


université PARIS-SACLAY

Latest results on Dark Matter searches with H.E.S.S.

H.E.S.S.

Lucia Rinchiuso on behalf of the H.E.S.S. Collaboration

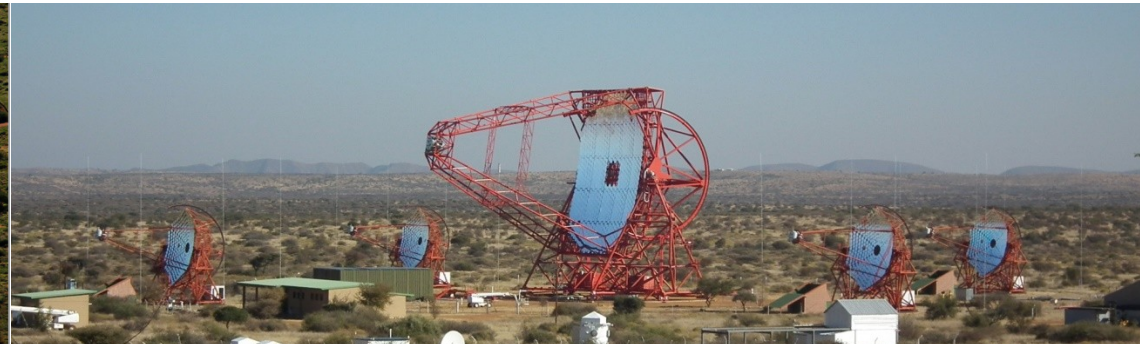
RICAP – 06/09/2018

Irfu - CEA Saclay
Institut de recherche sur les lois fondamentales de l'Univers

The H.E.S.S. experiment

Array of 5 Imaging Atmospheric Cherenkov Telescopes in Namibia (1800 m a.s.l)

- **H.E.S.S. I** (since 2003)
  - 4 telescopes (Ø 12 m)
    - ➔ spectroscopy
  - Energy range 100 GeV-100 TeV
  - Energy resolution ~10%
  - Angular resolution < 0.1 deg
  - FoV 5 deg
- **H.E.S.S. II** (since 2012)
  - Additional 5th larger telescope (Ø 28m)
    - ➔ Lower energy threshold
  - FoV of CT5: 3.5 deg
  - CT1-4 cameras upgraded



H.E.S.S. in numbers:

13 countries

39 Institutions

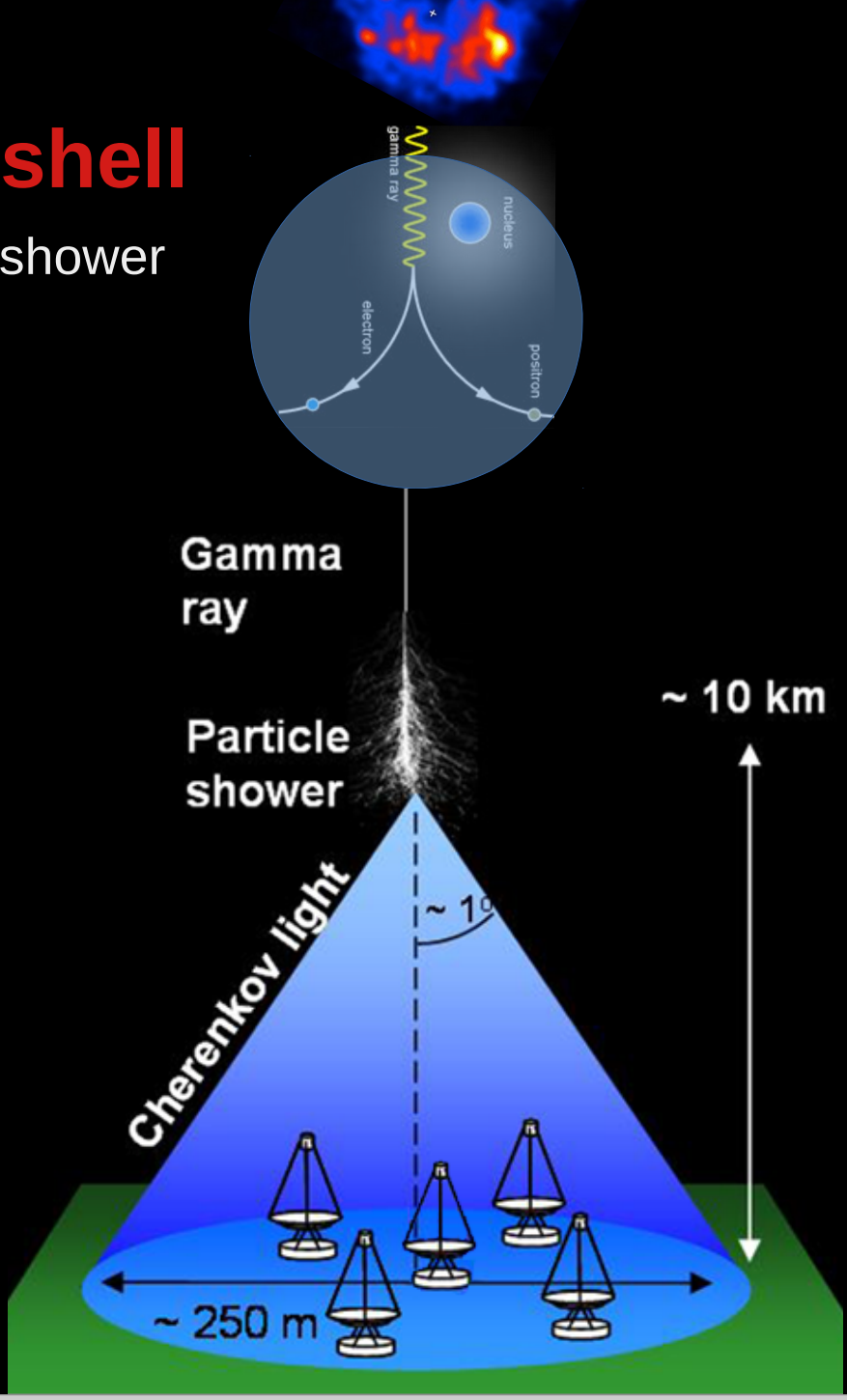
~230 people

15 years of operation

Detection principle in a nutshell

- The atmosphere acts like a calorimeter → shower
- Electrons produce Cherenkov light
- The cone invest the telescopes

→ **Reconstruct energy and position of the photons: spectroscopy + morphology**



Detection principle in a nutshell

- The atmosphere acts like a calorimeter → shower
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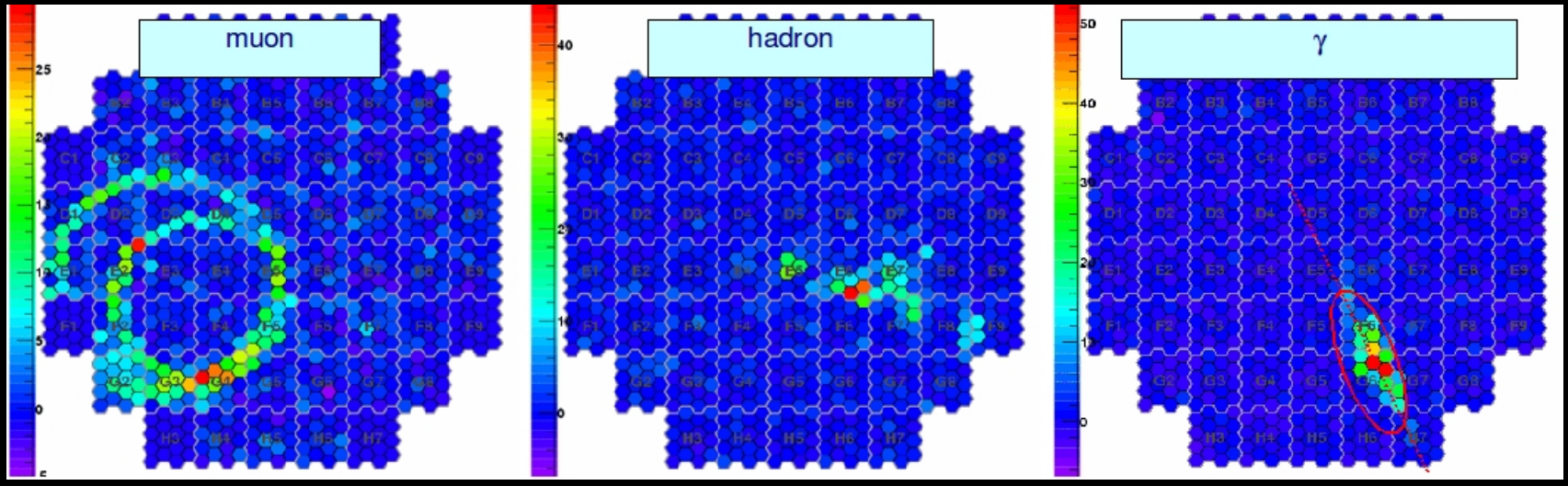
- Background discrimination:
  - stereoscopy
  - triggers
  - shape discrimination



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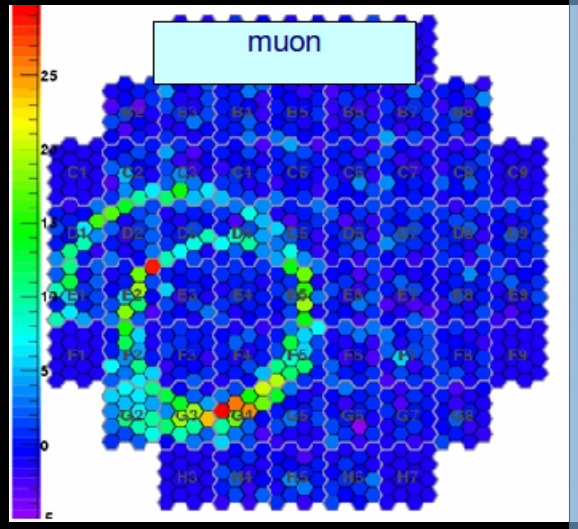
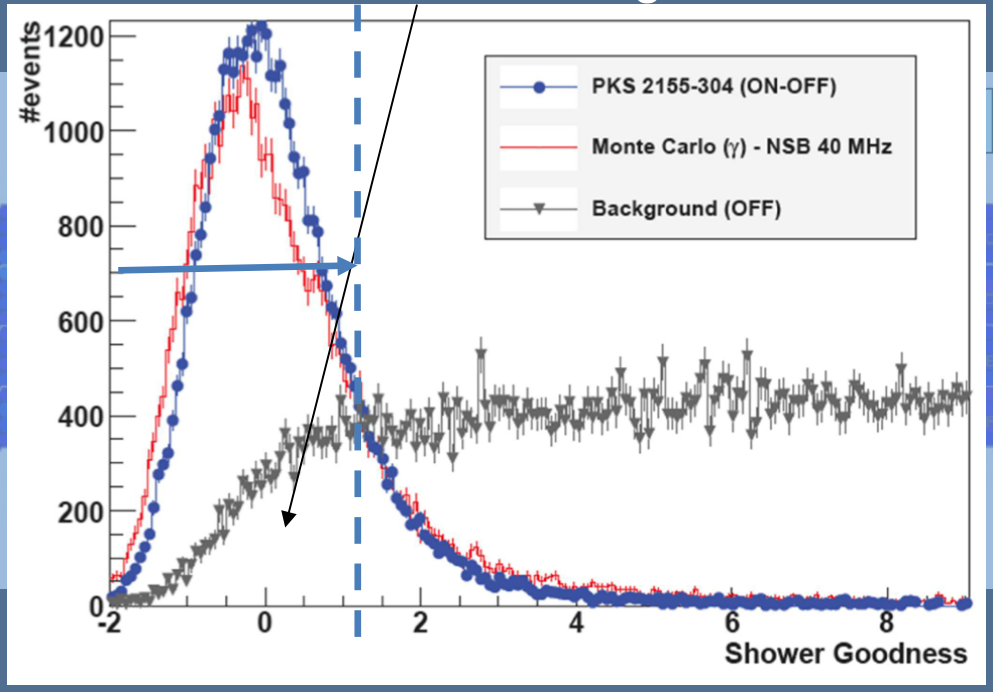
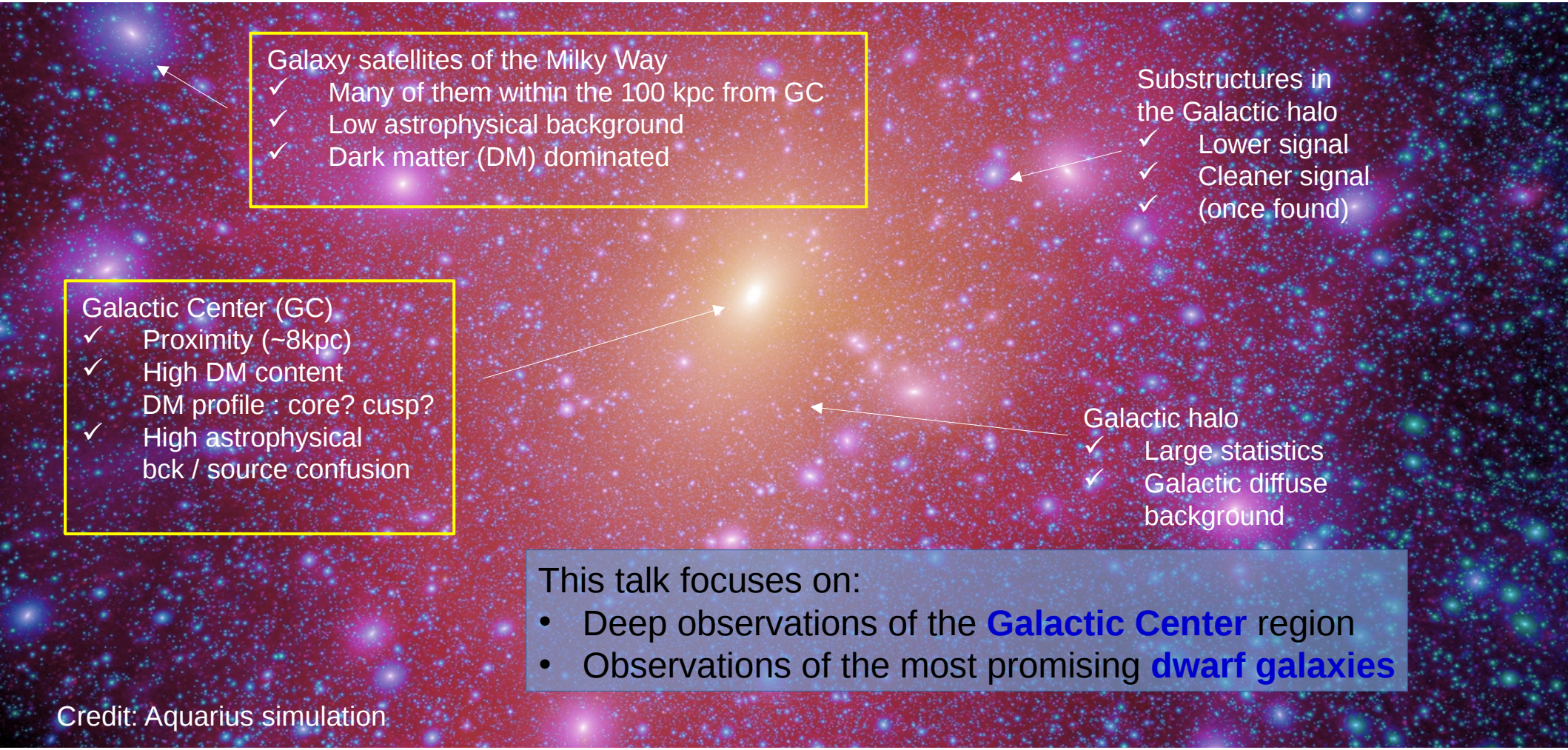


Event discrimination based on the “shower goodness” parameter
→ “residual background”



Targets for dark matter search in VHE gamma-rays

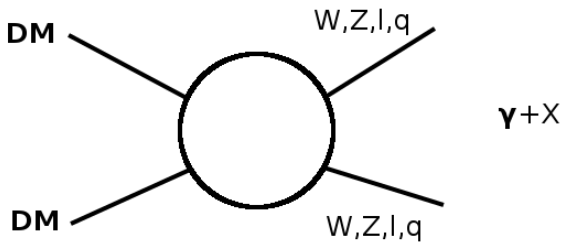
Targets for dark matter search in VHE gamma-rays



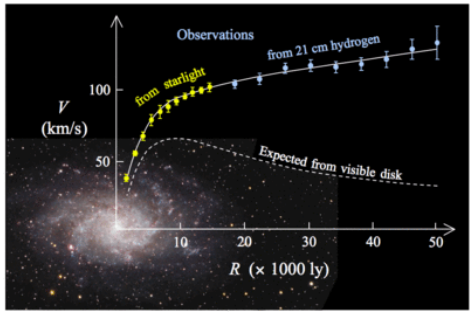
Compromise to maximize the quantity of DM signal (close-by and large DM density) with respect to the background (astrophysics sources)

Dark matter signal in gamma-rays

Photon flux from DM self- annihilation



$$\frac{d\phi(\Delta\Omega)}{dE} = \frac{d\phi^{pp}}{dE} \times J(\Delta\Omega)$$



particle physics term:

$$\frac{d\phi(\Delta\Omega)}{dE} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2{m_{DM}}^2}\sum_i Br_i \frac{dN_i}{dE'}$$

- Spectral information
- Annihilation cross section
- DM mass

Astrophysics term:

$$J(\Delta\Omega) = \int_\Omega \int_{los} \rho^2(s,\Omega) ds d\Omega$$

- Called J-factor
- DM density profile

Dark matter signal in gamma-rays

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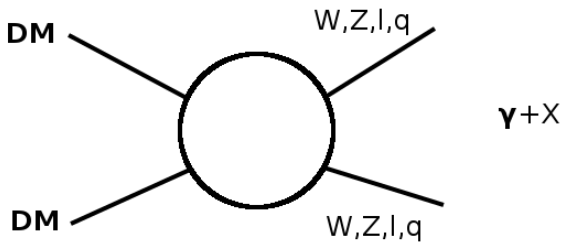

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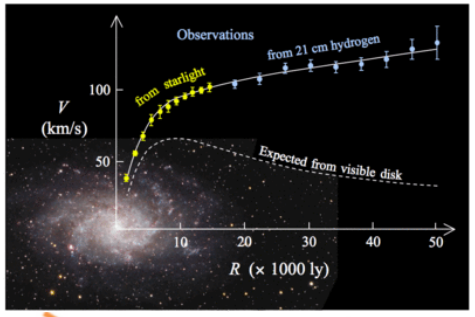

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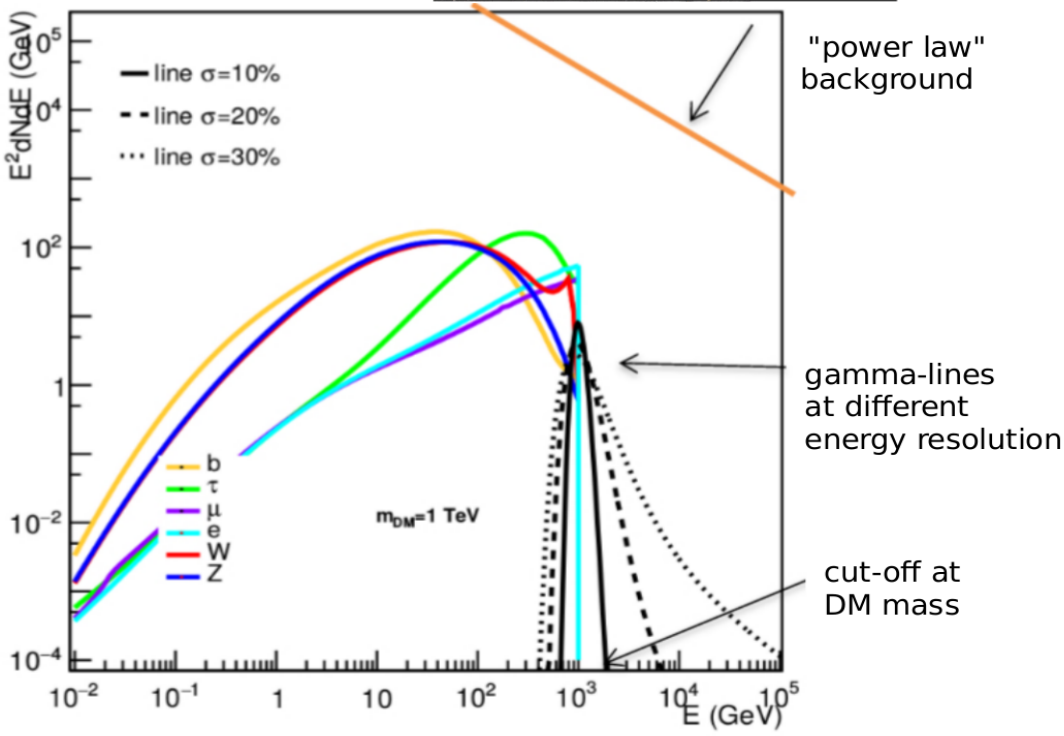

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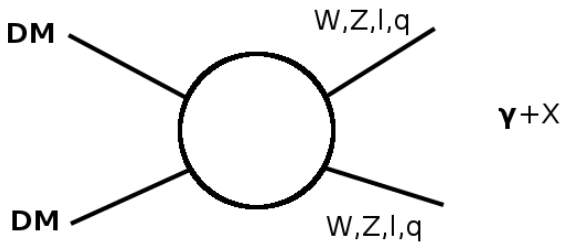

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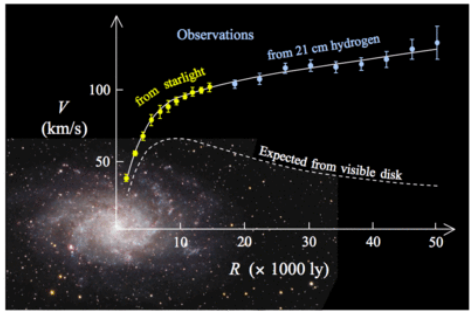

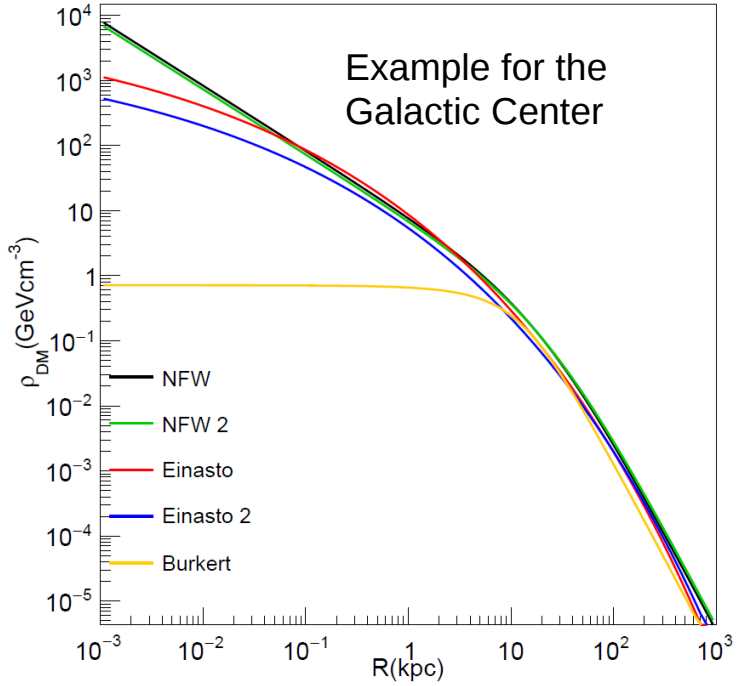

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Dark matter signal in gamma-rays

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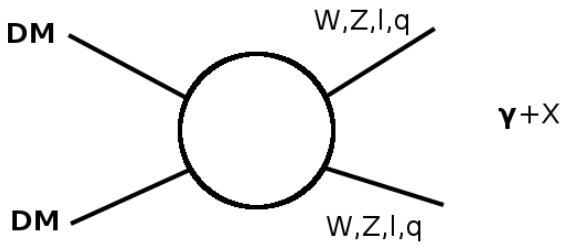

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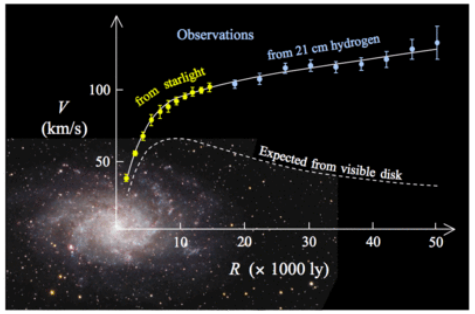

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Astrophysics term:

$$J(\Delta\Omega) = \int_\Omega \int_{los} \rho^2(s,\Omega) ds d\Omega$$

→ **in absence of any significant gamma-ray excess, the cross-section vs m_{DM} can be constrained by measurements, assuming an annihilation spectrum and a DM profile**

Dark matter analysis technique

The analysis technique is based on a **2D-binned** Poisson **likelihood**:

$$L_{ij} = Poiss\left(N_{ON,ij}, N_{S,ij} + N_{B,ij}\right) \times Poiss\left(N_{OFF,ij}, N'_{S,ij} + \alpha_i N_{B,ij}\right)$$

ON → Signal region
OFF → Background region

Test statistics: **likelihood ratio test**

- to find the 95% confidence level upper limits on the annihilation cross section

Dark matter analysis technique

The analysis technique is based on a **2D-binned** Poisson **likelihood**:

Counts measured in the ON region

Expected signal in ON and OFF regions computed from the flux including the energy resolution R(E,E'), the effective area (A_{eff}) and the live time T_{obs}

$$L_{ij} = Poiss\left(N_{ON,ij}, N_{S,ij} + N_{B,ij}\right) \times Poiss\left(N_{OFF,ij}, N'_{S,ij} + \alpha_i N_{B,ij}\right)$$

$$\alpha_i = \frac{\Delta\Omega_{OFF,i}}{\Delta\Omega_{ON,i}}$$

Bins in space and energy

Expected background in the ON region

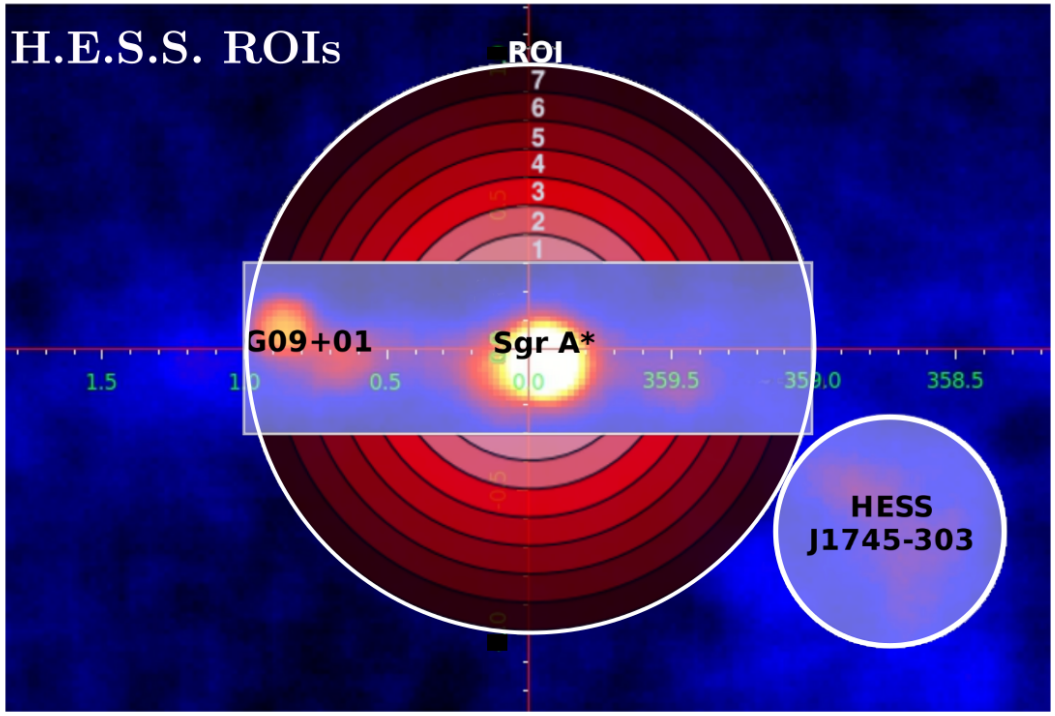
Counts measured in the OFF region

Test statistics: **likelihood ratio test**

- to find the 95% confidence level upper limits on the annihilation cross section

Observations of the Galactic Center: 10 years of H.E.S.S. I

- H.E.S.S. is in an ideal location to observe the Galactic Center (GC)
- GC is a very crowded region in VHE: TeV diffuse emission, SNR HESS J1745-303, PWN G09+01, HESS J1745-290 coincident with Sgr A*



254 live hours of observations with H.E.S.S. I (2004-2014) toward the GC:

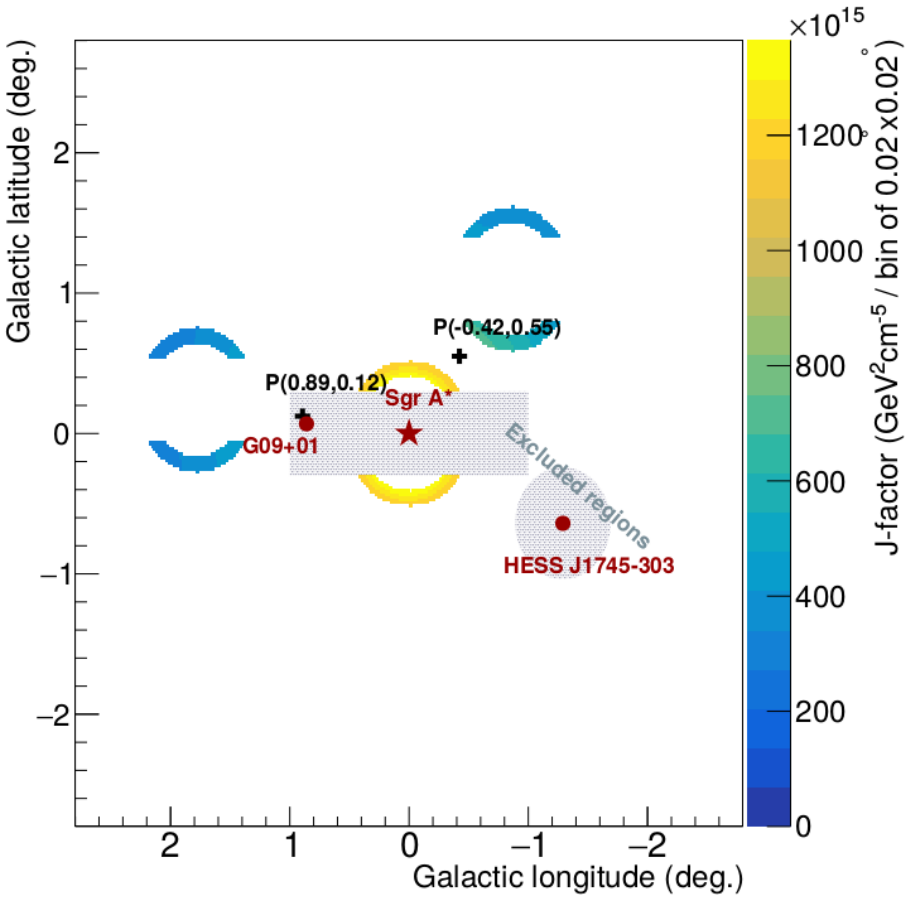
- ON region: circle of 1° radius around GC, split in 7 sub-regions (ROI) of with 0.1°
- Excluded regions: Galactic plane and HESS J1745-303

Background measurements in the GC region

- OFF region built with reflected background method: symmetric to the ON region wrt the pointing position
- symmetric exclusions
  - Same observational conditions
  - Azimuthal symmetry
  - Same solid angle size

- Strong DM gradient between the ON and the OFF

- No excess between the ON and OFF regions measurements → put constraints on <σv>



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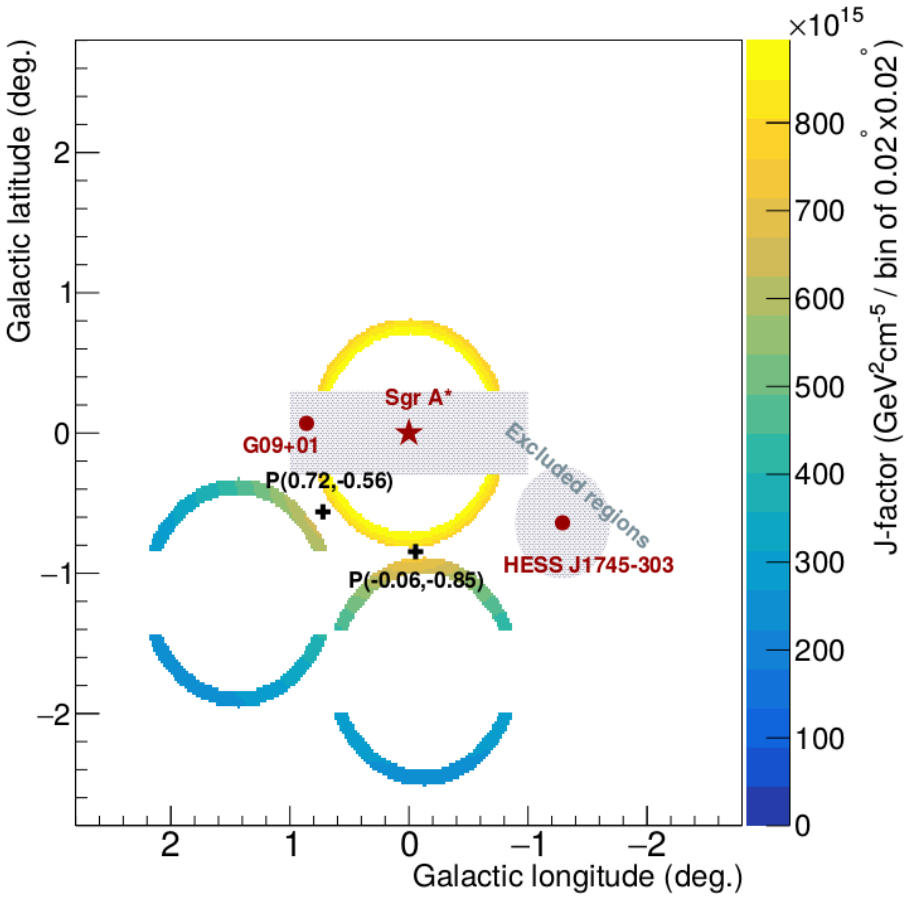
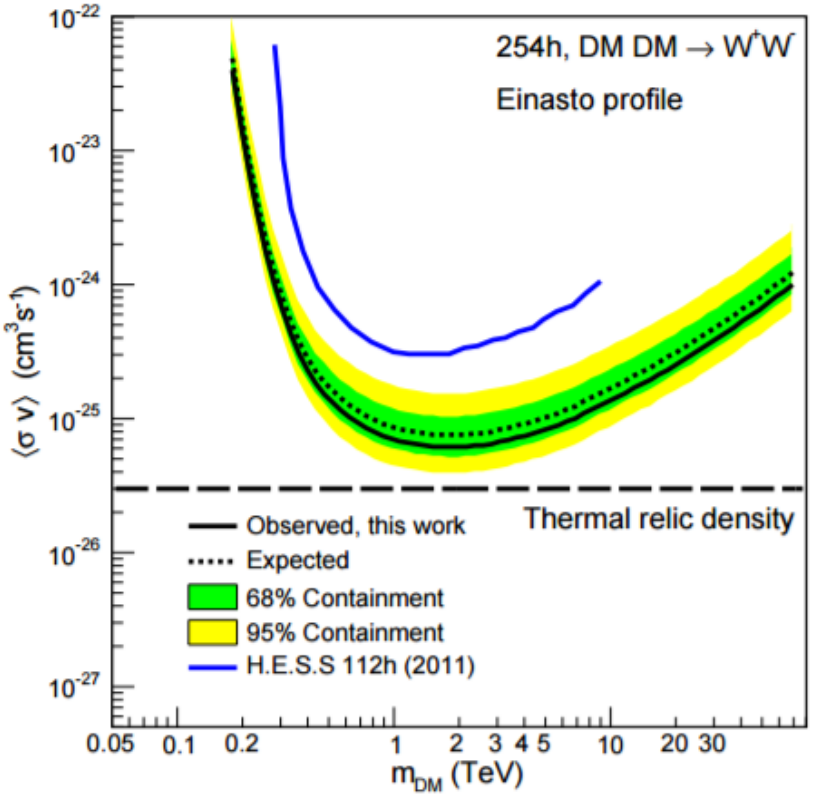


Continuum DM signal search at the GC with 10 years of H.E.S.S. I

- 2D likelihood technique binned in energy and space: likelihood ratio test
- cuspy profile assumed
- Spectra from PPPC4DM including EW corrections

- ➔ Mass range 200 GeV-70 TeV
- ➔ **95% CL upper limits:** WW channel: **6×10^{-26} cm^3 s^{-1}** at 1.5 TeV
- ➔ Improvement factor ~5 wrt to previous limits around 1 TeV



Phys. Rev. Lett. 117, 111301 (2016)

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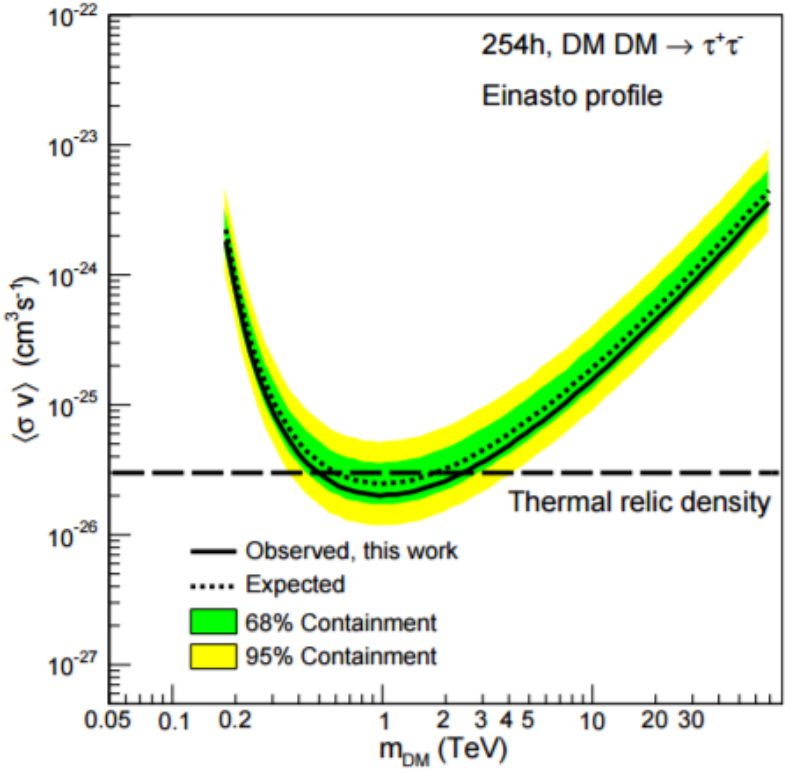
- ➔ Mass range 200 GeV-70 TeV
- ➔ **95% CL upper limits:**
  ττ channel: **2×10^{-26} cm^3 s^{-1}**
  at 800 GeV
- ➔ Probe the thermal relic density

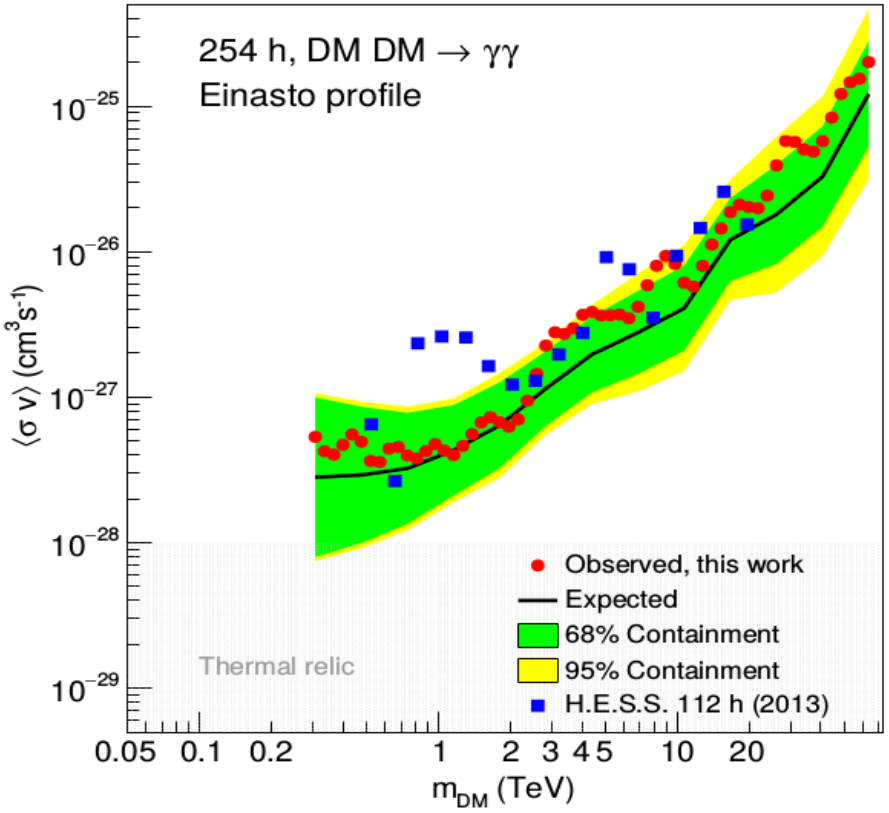


Phys. Rev. Lett. 117, 111301 (2016)

DM lines search at the GC with 10 years of H.E.S.S. I

- 2D likelihood technique binned in energy and space: likelihood ratio test
- cuspy profile assumed
- monoenergetic line spectrum: Gaussian function with σ=10% of the energy

- ➔ Mass range 300 GeV-70 TeV
- ➔ **95% CL upper limits reach**
- ➔ **$4 \times 10^{-28} cm^3 s^{-1}$ at 1 TeV**
- ➔ Improvement factor ~6 wrt to previous limits around 1 TeV



Phys. Rev. Lett. 120, 201101 (2018)

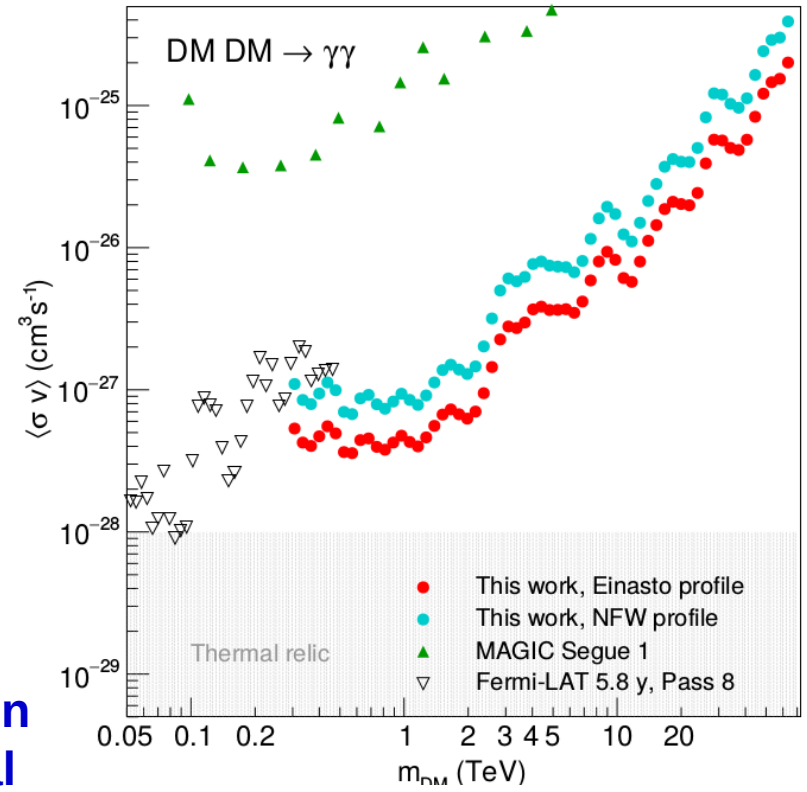
DM lines search at the GC: comparison with other experiments

- 2D likelihood technique binned in energy and space: likelihood ratio test
- cuspy profile assumed
- monoenergetic line spectrum: Gaussian function with σ=10% of the energy

➔ Einasto profile gives the tightest constraints

➔ Strongest limits in the TeV mass range

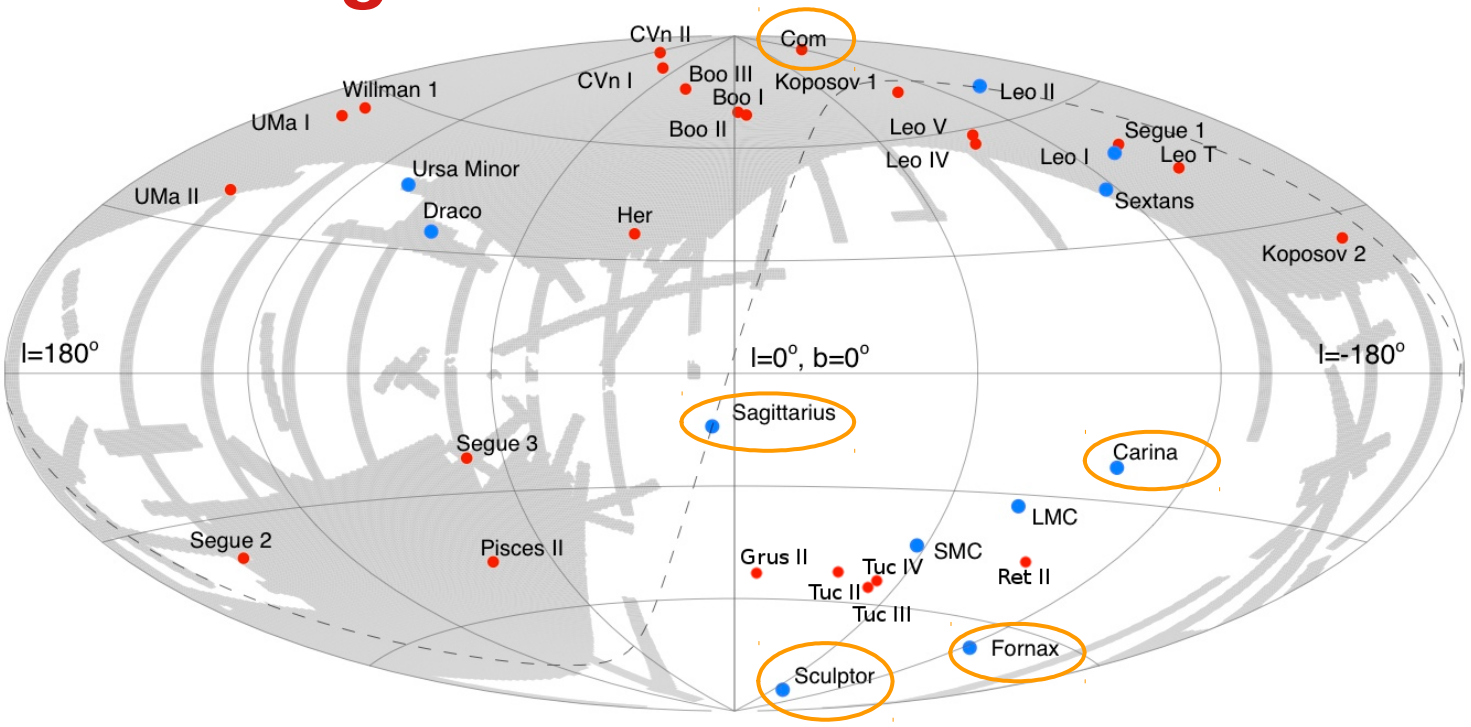
➔ Competitive with Fermi-LAT at few hundreds GeV



Fermi and H.E.S.S. provides strong limits in the mass range from few GeV up to several ten TeV

Phys. Rev. Lett. 120, 201101 (2018)

Dwarf galaxies observations with H.E.S.S.

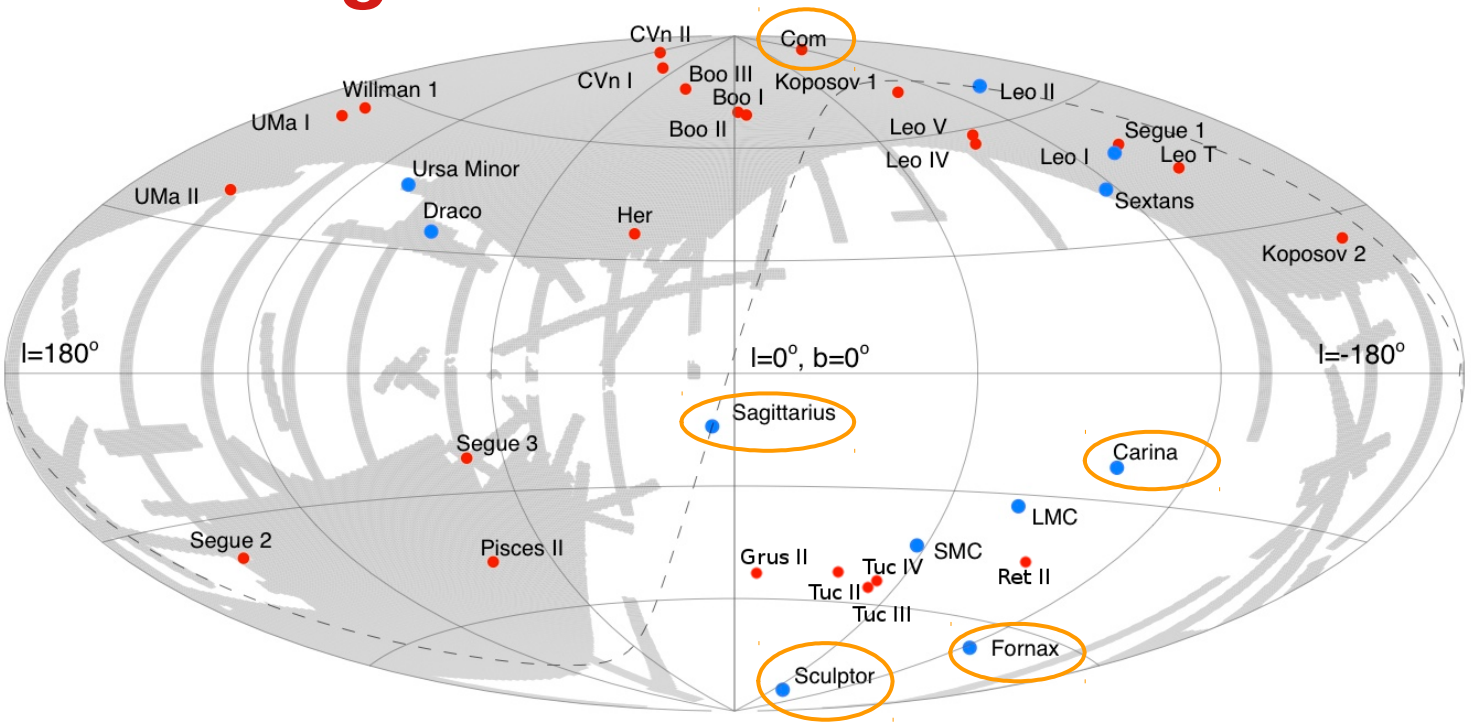


- No recent star formation
- Very low amount of gas
- "clean" in VHE γ-rays

➔ **they could give unambiguous DM detection**

- Long-term observation program on nearby dwarf galaxies:
  - Sagittarius: Astrophysical Journal 691 (2009) 175-181
  - Canis Major: Astrophysical Journal 691 (2009) 175-181
  - Sculptor and Carina: Astroparticle Physics 34 (2011) 608
  - Combination (including Coma Berenices): Phys. Rev. D 90, 112012 (2014)

Dwarf galaxies observations with H.E.S.S.



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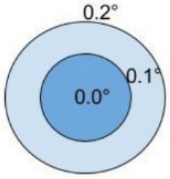
  - Combination (including Coma Berenices): Phys. Rev. D 90, 112012 (2014)
  - Ongoing analysis on some of the recently discovered DES galaxies: *stay tuned!*

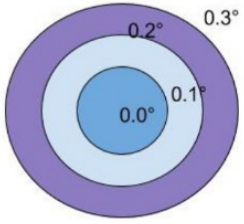
Dwarf galaxy observations with H.E.S.S.

Galaxy	Distance (kpc)	$\log_{10}J(\theta_{tot})$ $\log_{10}(GeV^2cm^{-5})$	T_{obs} (h)	Zenith (deg)
Fornax	140	17.72	6.0	14
Coma Berenices	44	19.52	10.9	48
Sculptor	79	18.36	11.8	14
Carina	101	17.86	22.9	34
Sagittarius	25	18.34	85.5	16

Signal region : *ON region*

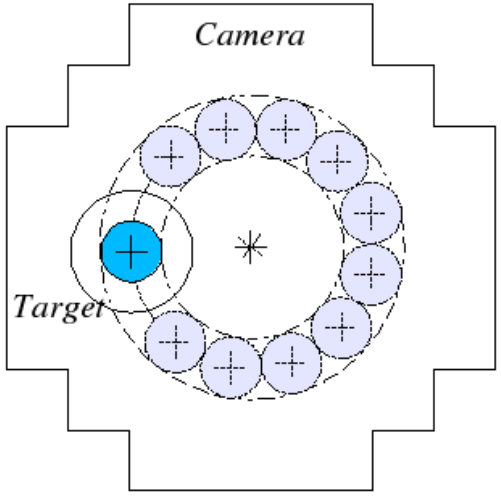


All galaxies except Coma Berenices



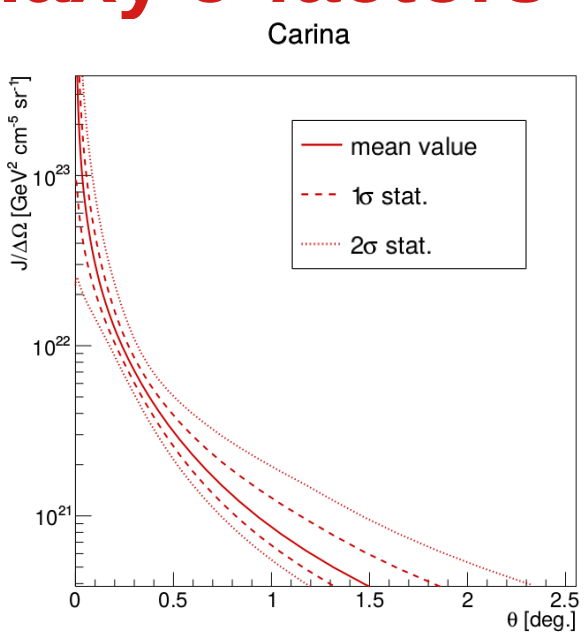
Coma Berenices

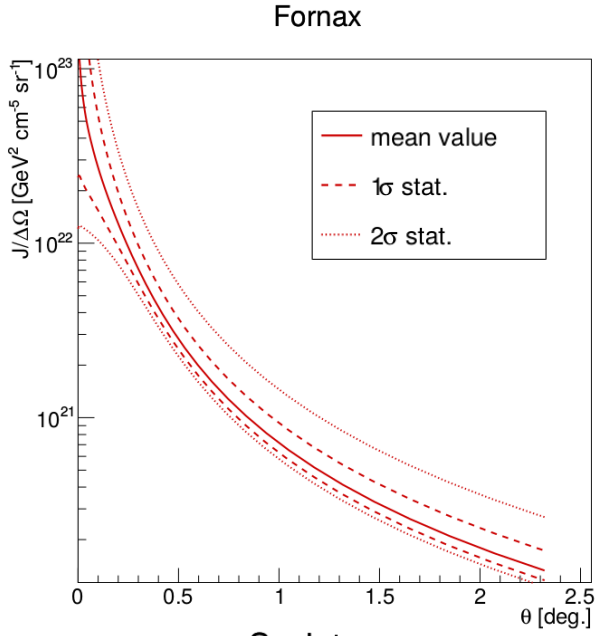
Background measurement: *Multiple OFF regions*

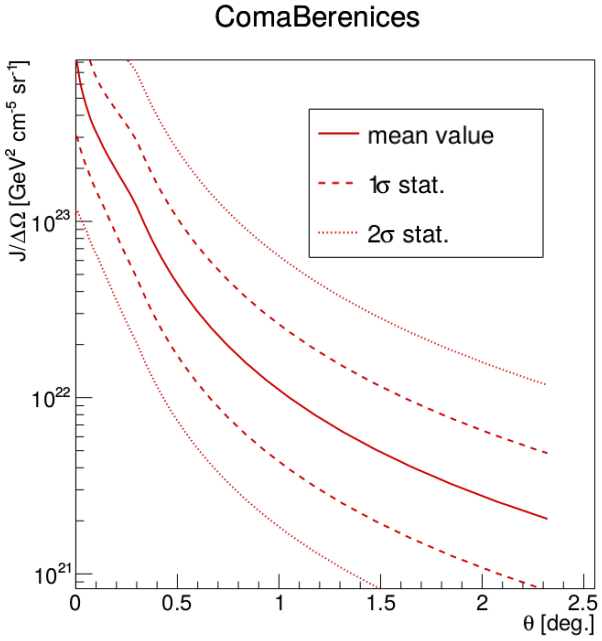


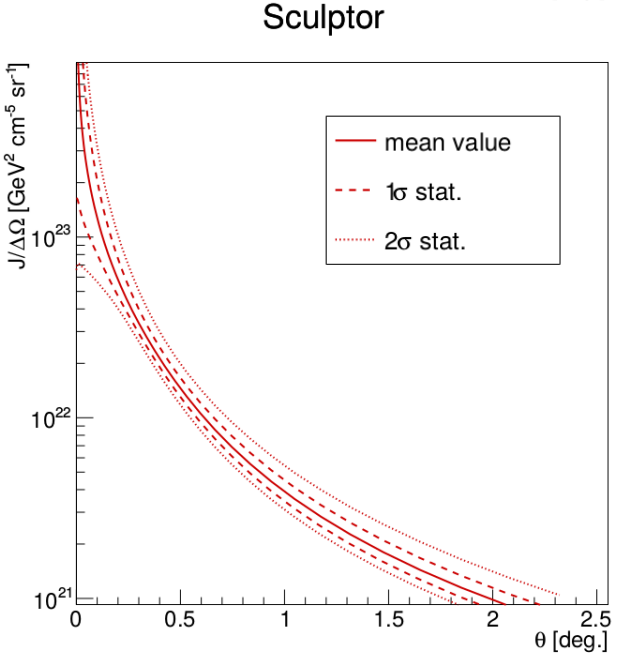
Dwarf galaxy J-factors

From Geringer-Sameth et al. 2015





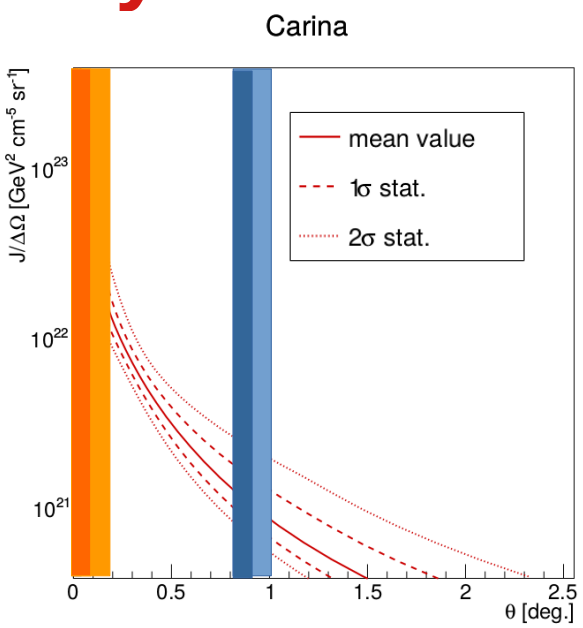


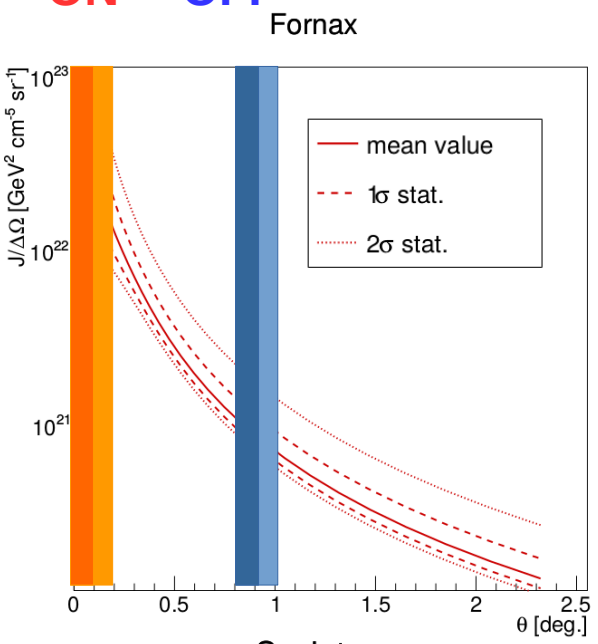


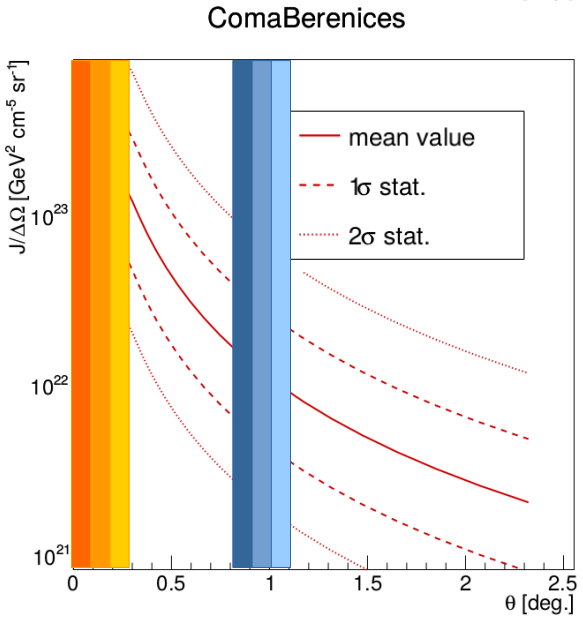
Dwarf galaxy J-factors

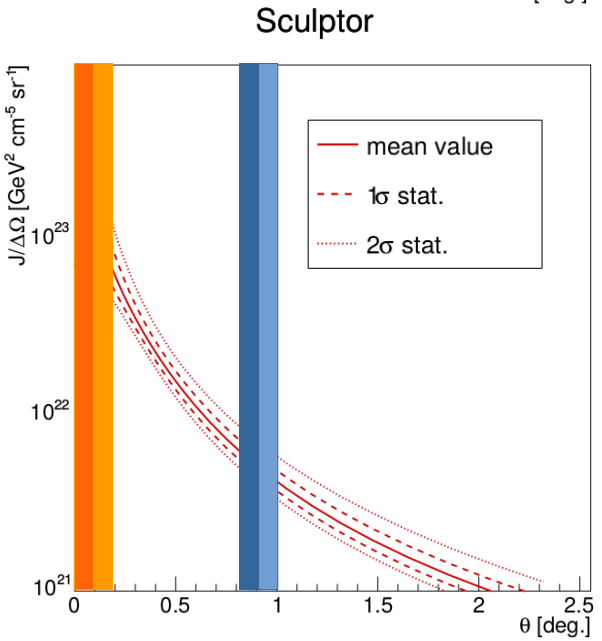
ON OFF

From Geringer-Sameth et al. 2015









DM lines search towards dwarf spheroidal galaxies

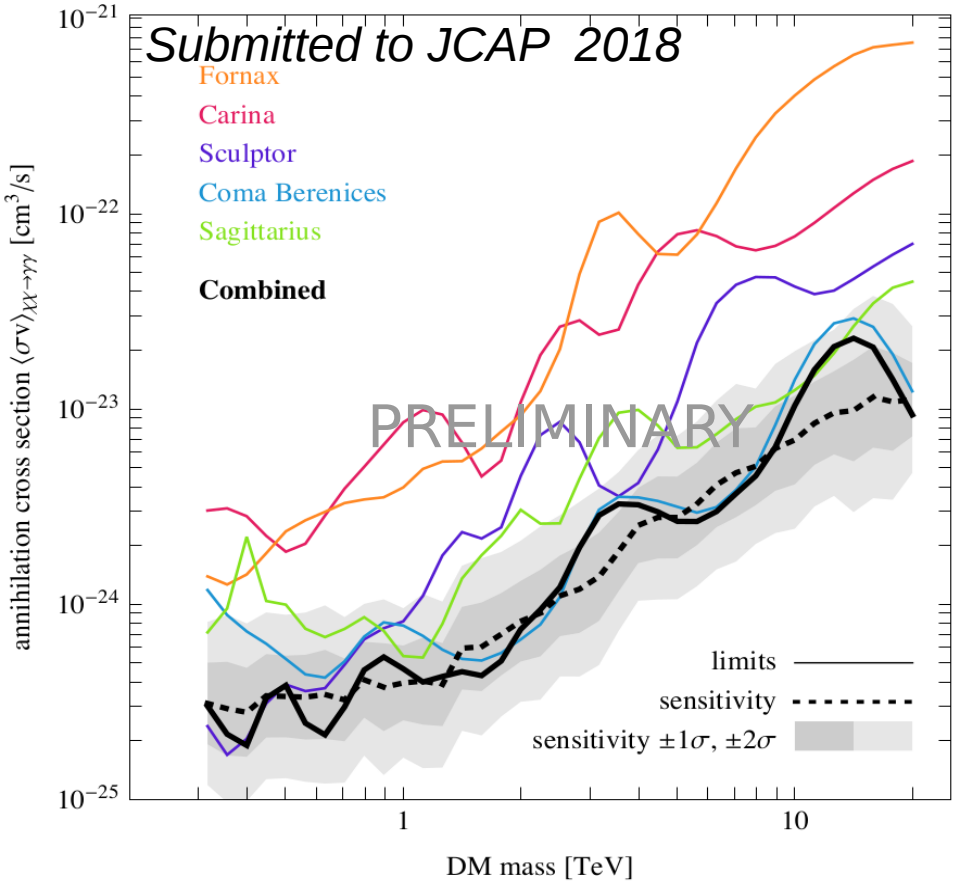
Re-analysis of the H.E.S.S. I dSph looking for DM lines:

- same observation dataset
- Improved analysis technique : 2D-likelihood approach

➔ No significant excess
→ constraints on <σv>

➔ Combination of the 5 galaxies
→ better limits

Combined 95% C.L. upper limits at the level of 5×10^{-25} cm^{3}s^{-1} at 1 TeV

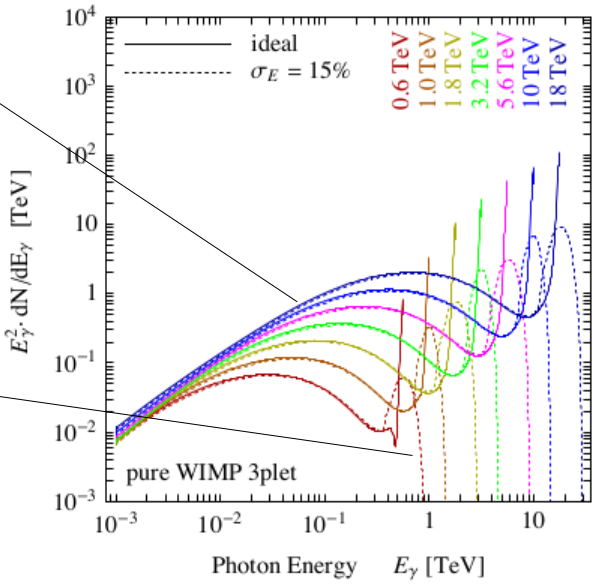


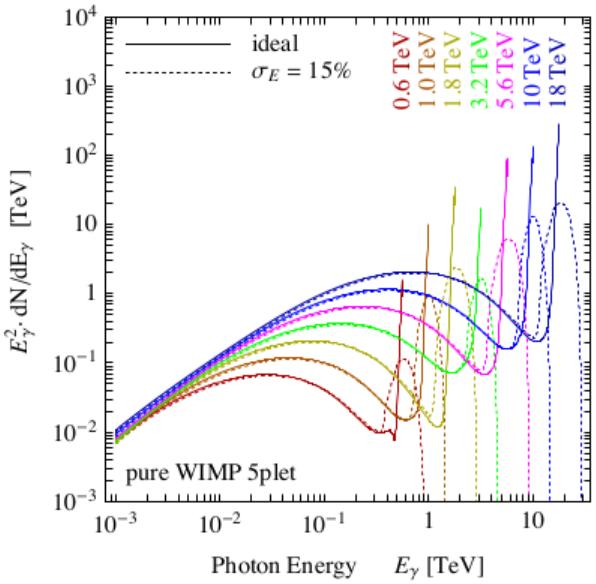
See talk at ICRC17 (H.E.S.S. Coll.)

WINO spectra …

It includes the continuum

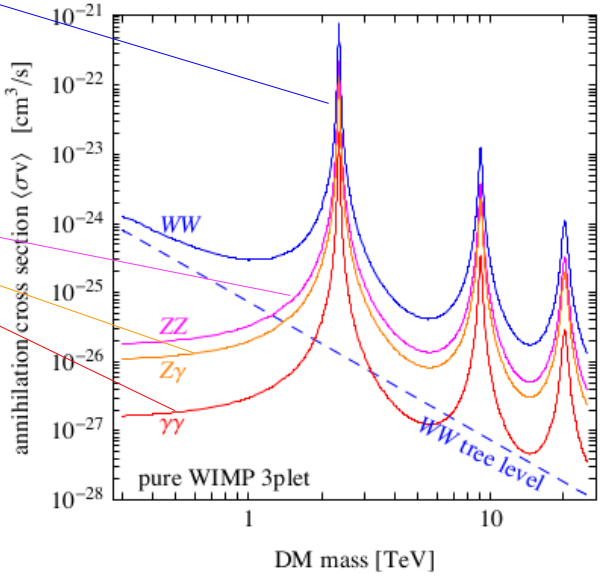
Effect of the energy resolution

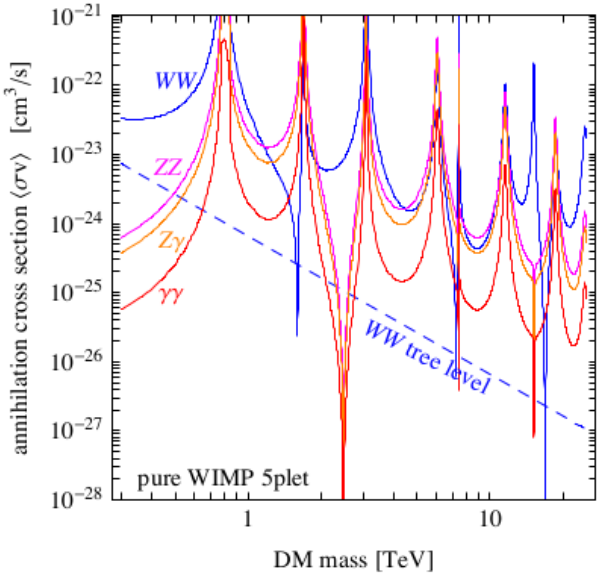




Tree-level

1-loop





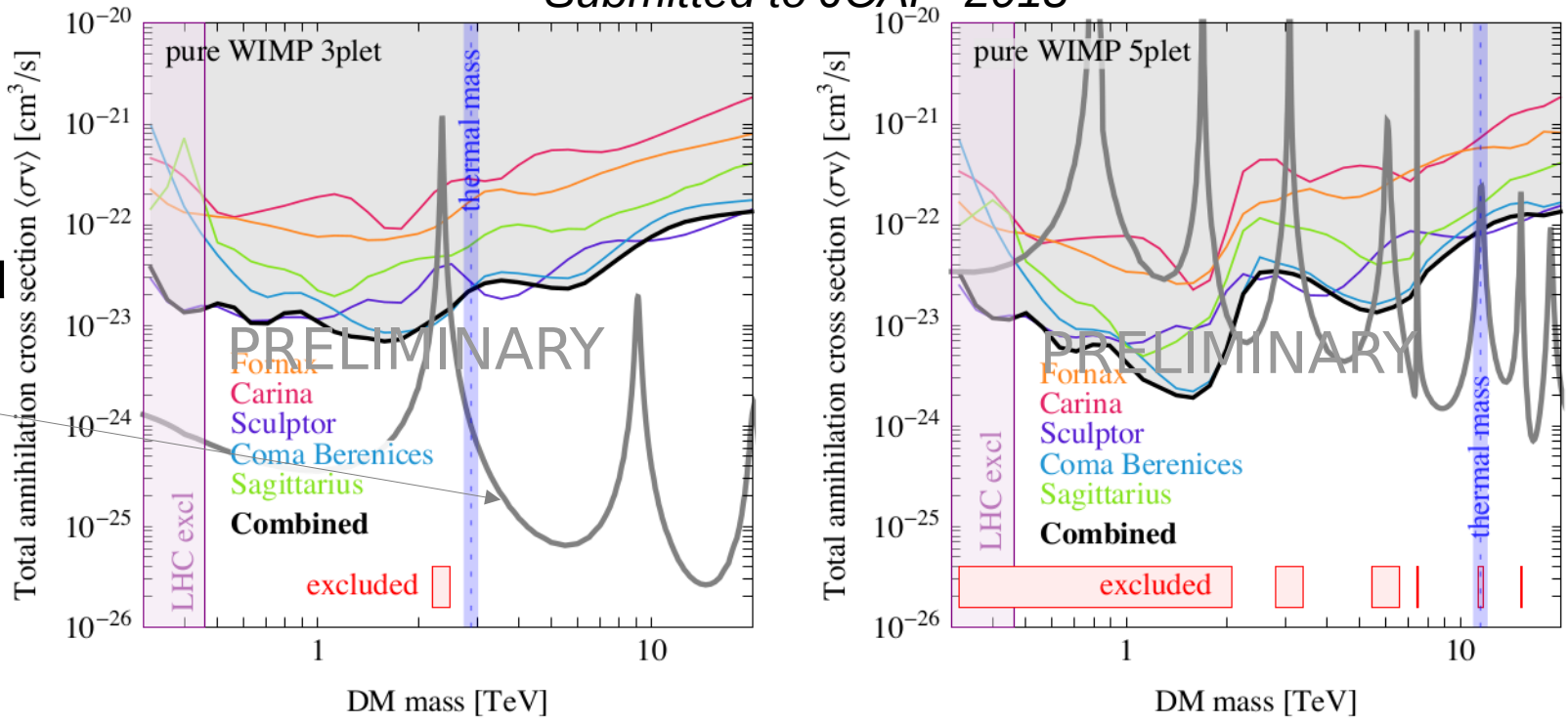
Limits for specific DM models toward dwarf galaxies

Tests of specific models: pure WIMP 3plet and 5plet

→ full γ-ray spectrum including WW, ZZ, γγ, Zγ contributions is used

Submitted to JCAP 2018

Predicted thermal relic cross-section



- **Important exclusions on the 5plet model**
- **Specific models could be also tested in other environments**

Summary

- Search for **continuum** DM signal toward the **Galactic Center** (2016):
  - ➔ 2D analysis of 10 years observations
  - ➔ Limits reach 6×10^{-26} cm^3 s^{-1} at 1.5 TeV in W channel and 2×10^{-26} cm^3 s^{-1} at 800 GeV in τ channel
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- Search for DM **lines** toward **dwarf spheroidal galaxies** (2018):
  - ➔ 2D analysis and combination of the 5 datasets
  - ➔ Combined best limits reach $5\text{x}10^{-25}$cm^{3}s^{-1} at 1 TeV
  - ➔ Test of specific pure WIMPs model: full spectrum included
- H.E.S.S. results complement Fermi-LAT limits

Next steps

- Observations of some of the ultra faint **dwarf spheroidal galaxies** recently discovered by DES
  - ➔ Complementary to Fermi-LAT observations
  - ➔ Can be well observed by H.E.S.S. compared to other IACTs in the Northern hemisphere
  - ➔ Large J-factors but may suffer from large systematic uncertainties

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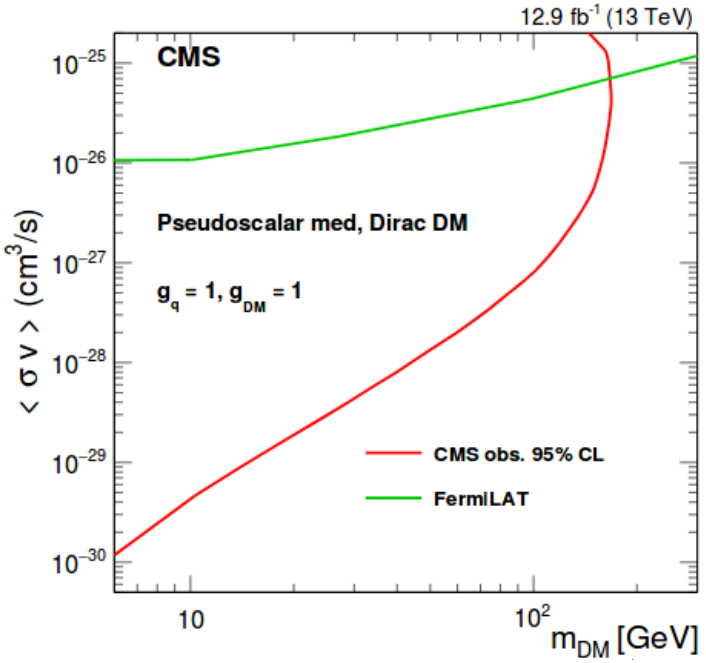
- **Joint project** together with MAGIC and VERITAS on the DM search towards dwarf galaxies
  - ➔ Also exploring including Fermi-LAT and HAWC observations
  - ➔ The Glory Duck group: first meeting in Berlin early July
  - ➔ Exploit the complementarity of the different instruments
  - ➔ Combined effort to improve limits


H.E.S.S.

Backup: DM complementarity

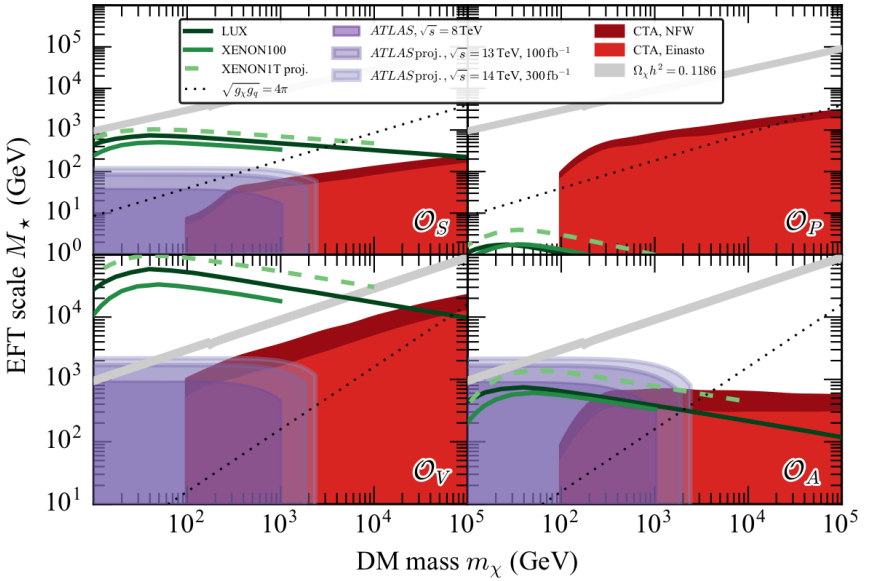
JHEP 07 (2017) 014



Comparison using the simplified DM models

With H.E.S.S. we have limits at m_{DM}>300 GeV

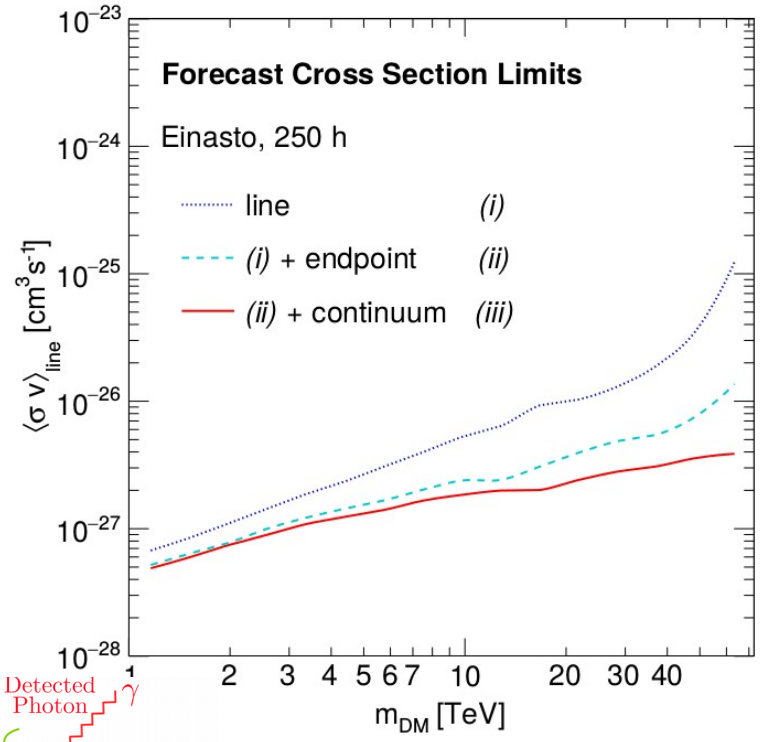
Phys. Rev. D 96, 083002 (2017)

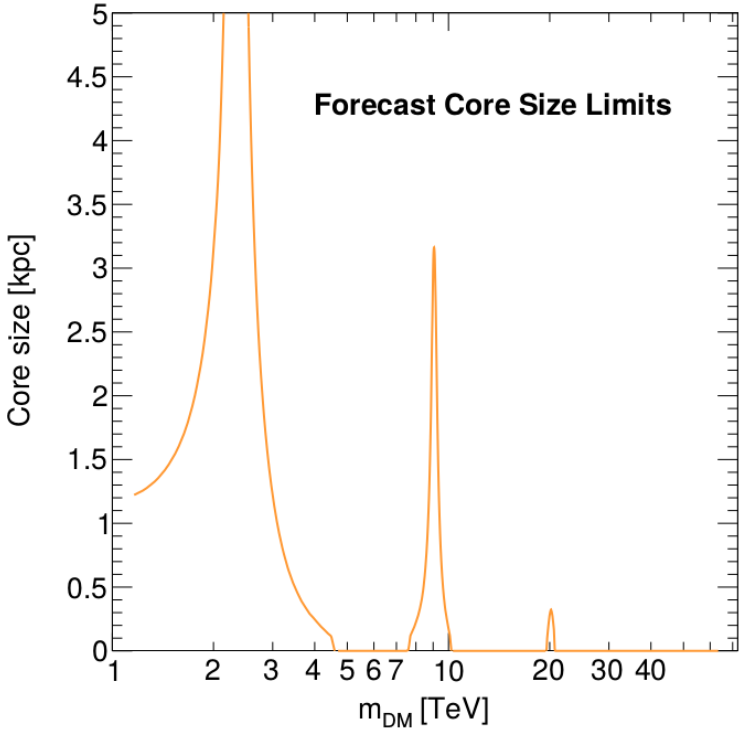


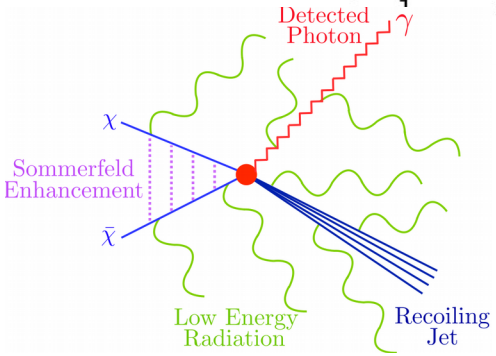
CTA upper limits are converted to lower limits on EFT scale

Backup: hunt for wino at the GC : H.E.S.S.-I-like mock analysis

arXiv:1808.04388







Endpoint contribution to the spectrum → Improves the limits

H.E.S.S. may have the sensibility to probe the wino up to several kpc core size