LATEST RESULTS ON DARK MATTER SEARCHES USING THE H.E.S.S. TELESCOPES

30 August 2018

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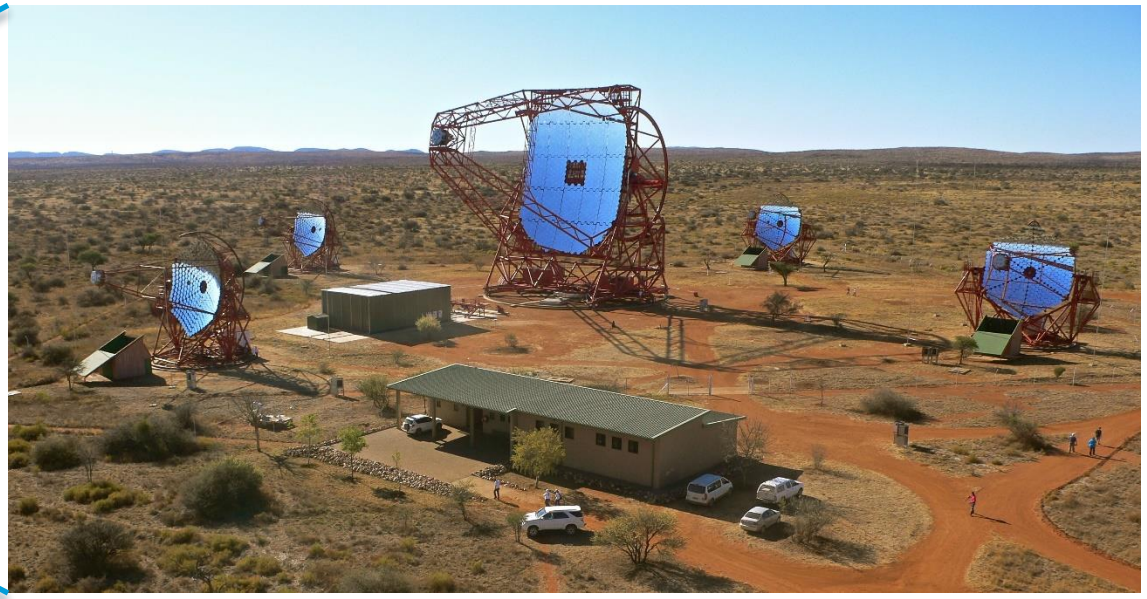
CNRS, LAPP Annecy

Overview

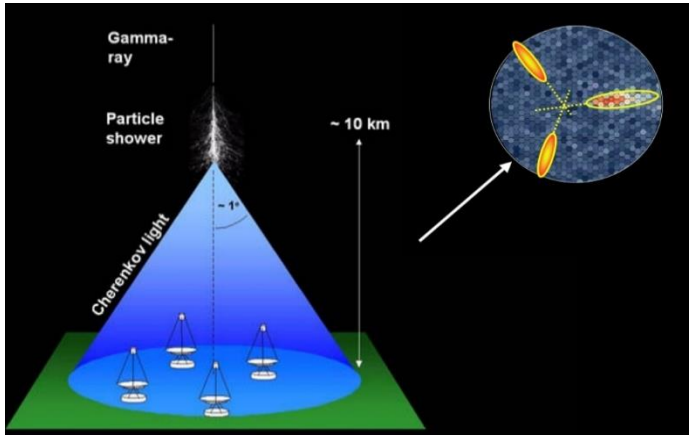
- The H.E.S.S. experiment
- Indirect search for dark matter (DM)
- Three H.E.S.S. analyses presented
  - Search for gamma ray line signals in the inner galactic halo
  - Search for gamma ray line signals in dwarf galaxies
  - Electron spectrum

The H.E.S.S. telescopes



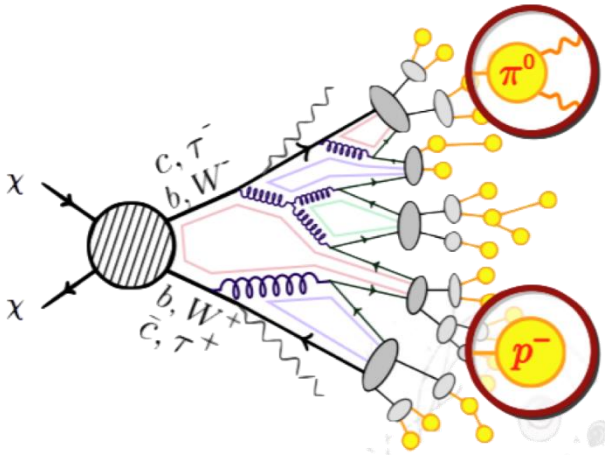
- Located in Namibia, at 1800 m elevation
  - **Phase I**: 4 × 12 m telescopes since 2003

  (used in these analyses)
  - **Phase II**: 28 m telescope added in 2012
  - Field of view: 5°
  - Energy **threshold**: ~ 30 GeV
  - Angular **resolution**: ~ 0.1°
  - **Stereoscopic** reconstruction using the Cherenkov light



Indirect detection

- DM particles (WIMPs) annihilate together and produce Standard Model particles
  - **Positrons**, **electrons**, **gamma rays**, …



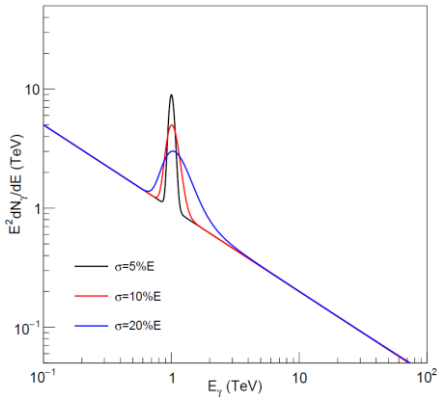
- Gamma rays not deflected by galactic magnetic field
  - Used to **locate** the source direction

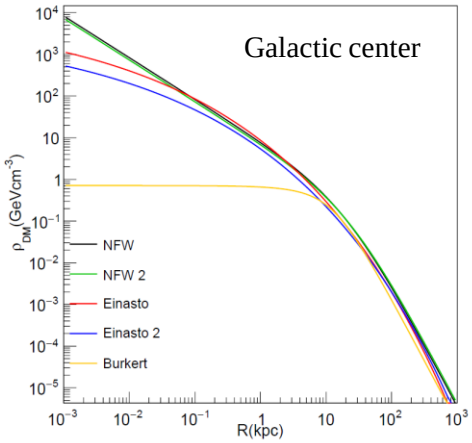
Indirect detection

$$\Phi_\gamma(E_{\max}, E_{\min}) = \int_{E_{\min}}^{E_{\max}} \frac{1}{2} \frac{\langle \sigma v \rangle}{4\pi m_\chi^2} \sum_f B_f \frac{dN_\gamma^f}{dE_\gamma} dE_\gamma \int_{\Delta\Omega(\alpha,\phi)} d\Omega \int_{\text{los}} ds\, \rho_{\text{DM}}^2(r(s, \alpha_{\text{int}}))$$

γ Flux

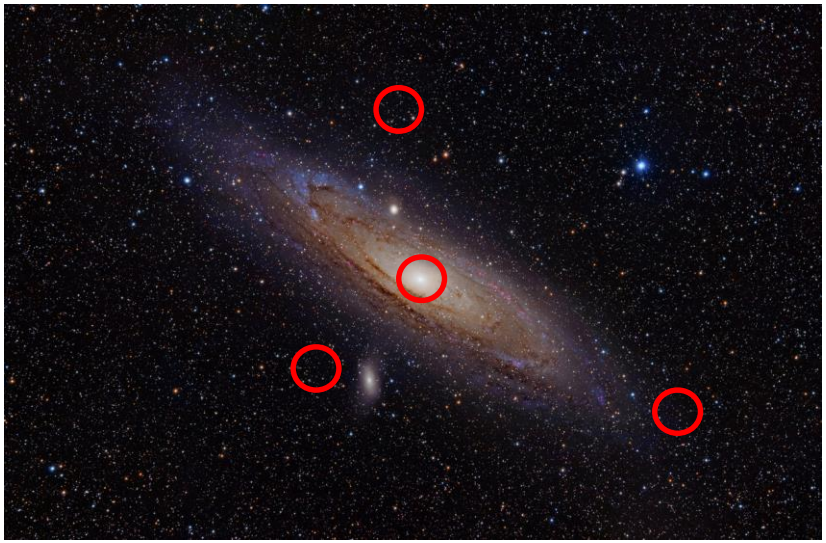
- Particle physics factor
  - Depends on the **WIMP mass**, on the **annihilation cross section**, on the **branching fractions**
  - Either **continuum**
    - Spectrum up to the WIMP mass
    - Non trivial to distinguish from other standard emission
  - Or **monoenergetic line**
    - Direct annihilation in photon(s): $\chi\chi \rightarrow \gamma X$, X = γ, h, Z
    - Suppressed, but prominent and narrow signal
- Astrophysical J factor
  - **DM density** profile to be assumed
  - Find places with **high DM density**





Where to look?

- Galactic center
  - Contains **a lot of DM**
  - Presence of **astrophysical sources**
    - TeV diffuse emission, supernovae, pulsars, Sgr A*



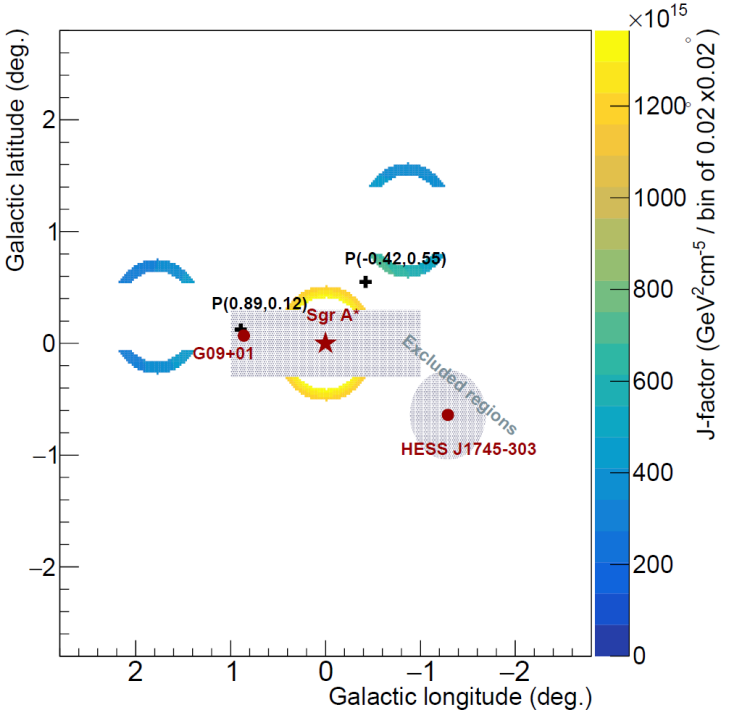
- Dwarf spheroidal galaxies
  - **Satellites** of the Milky Way (20 – 300 kpc)
  - Low luminous mass
  - **Most dominated DM** objects
    - Ratio mass/luminosity: 10 – 1000
  - **No** expected gamma ray **background**
    - No active sources, no gas, no star formation

Search for gamma ray line signals in the inner galactic halo

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

Galactic center

- 10 years of data (2004-2014), 254 h
- Search for a monoenergetic spectral line (300 GeV – 70 TeV)
  - 10% energy resolution for H.E.S.S.
- Observation
  - **ON regions**: circle of 1° radius around galactic center, split in 7 sub-regions of width 0.1°
  - **Excluded regions**: galactic plane and HESS J1745-303
  - **OFF regions**: symmetric to the ON regions with respect to the observational pointing position
  - ON and OFF:
    - Same acceptance and observation conditions
    - Same shape and solid angle
    - Significant dark matter gradient



Likelihood analysis

- 2D binned Poisson maximum likelihood analysis
  - Exploit spatial and spectral informations

$$\mathcal{L}_{ij}(\mathbf{N}_{ON}, \mathbf{N}_{OFF}, \alpha | \mathbf{N}_S, \mathbf{N}'_S, \mathbf{N}_B) = \frac{(N_{S,ij} + N_{B,ij})^{N_{ON,ij}}}{N_{ON,ij}!} e^{-(N_{S,ij}+N_{B,ij})} \quad \textbf{ON term}$$

$$\times \frac{(N'_{S,ij} + \alpha_i N_{B,ij})^{N_{OFF,ij}}}{N_{OFF,ij}!} e^{-(N'_{S,ij}+\alpha_i N_{B,ij})} \quad \textbf{OFF term}$$

i: **spatial** bin, j: **energy** bin

$\alpha_i = 1$ (same ON and OFF region size)

N_B: **expected background** in the ON region

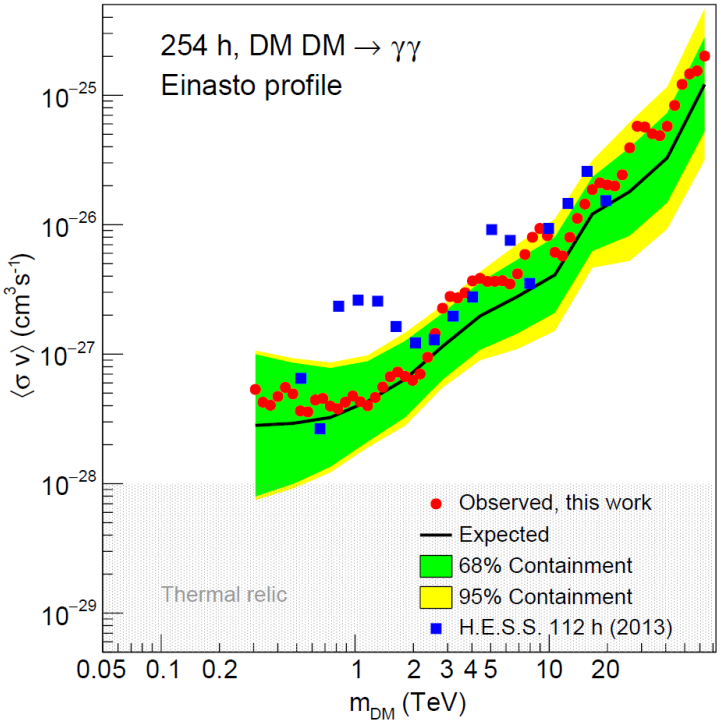
N_S and N'_S: **expected signal** in the ON and OFF regions

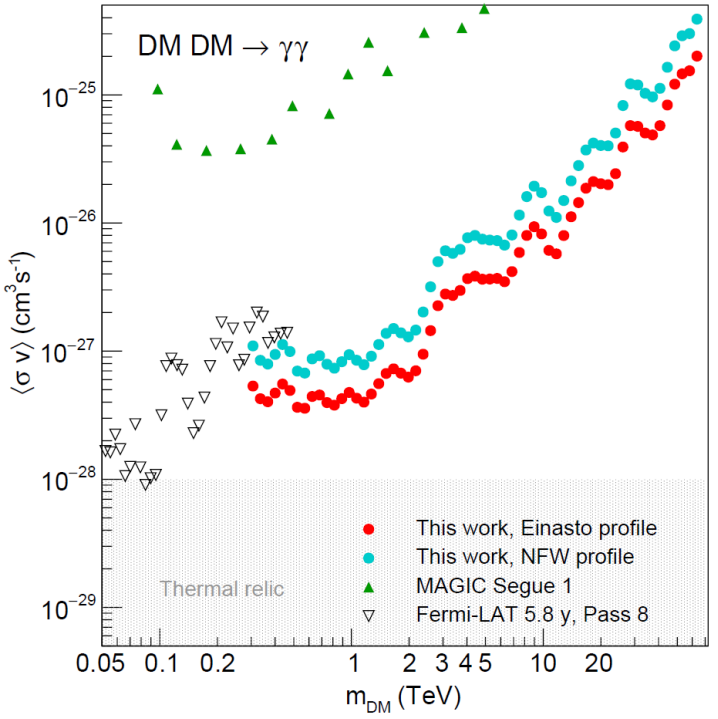
- No statistically significant excess seen in any of the regions

- 95% CL upper limits derived from the likelihood ratio test

Upper limits

- 95% CL limit for the mass range 300 GeV–70 TeV
  - Reach **4×10^{-28} cm^3.s^{-1} at 1 TeV**
  - Improvement factor of **6** wrt previous limits at 1 TeV!
- Comparison
  - Einasto/NFW profiles + Fermi/MAGIC
  - **Complementarity** between **H.E.S.S.** and **Fermi**





Search for gamma ray line signals in dwarf galaxies

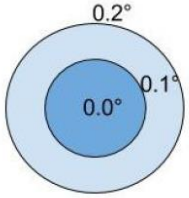
arXiv:1708.04858, publication in preparation

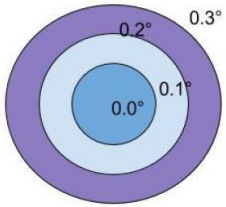
Dwarf galaxies

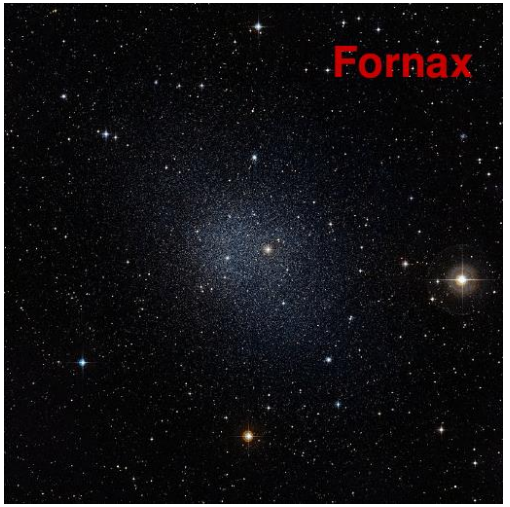
- Five dwarf galaxies analysed

Galaxy	Distance (kpc)	J factor ($\log_{10}(GeV^2.cm^{-5})$)	Observation time (h)
Fornax	140	17.72 ± 0.18	6.0
Coma Berenices	44	19.52 ± 0.37	10.9
Sculptor	79	18.36 ± 0.12	11.8
Carina	101	17.86 ± 0.10	22.9
Sagittarius	25	18.34 ± 0.30	85.5

- Using 2D likelihood functions binned in energy and spatial coordinates
- Fornax, Sculptor, Carina, Sagittarius
  - **Two** spatial regions
- Coma Berenices
  - **Three** spatial regions

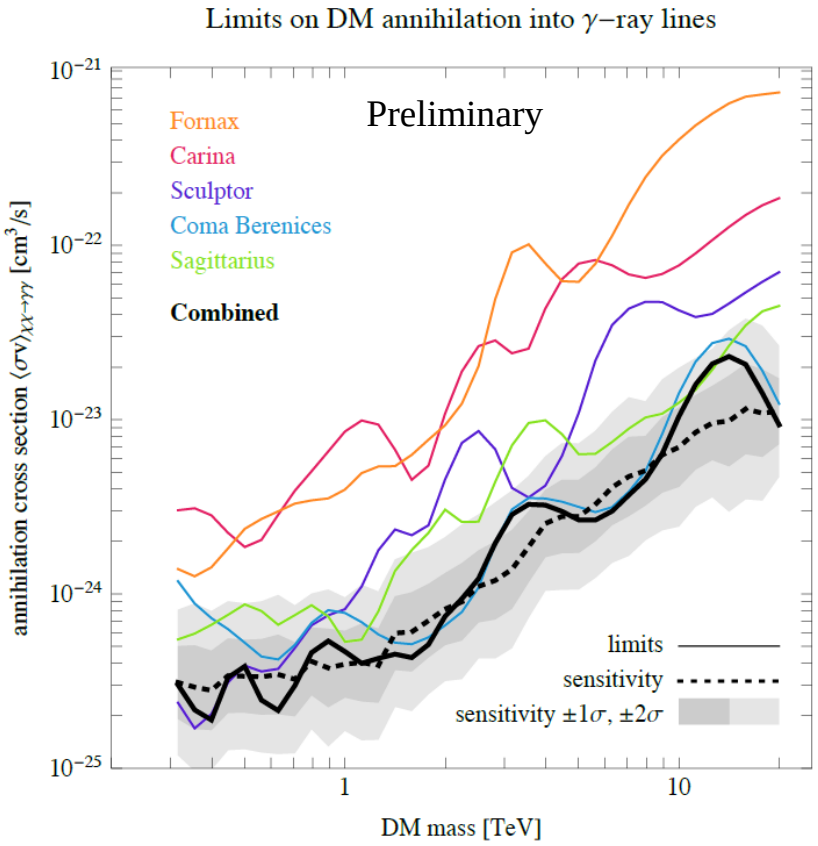






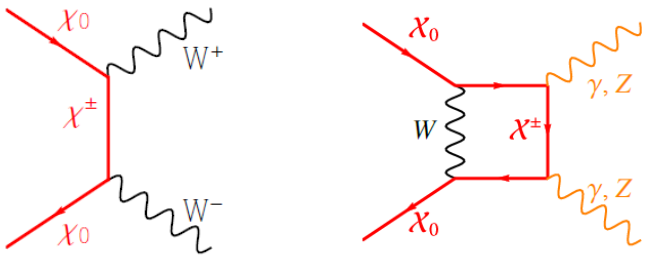
Upper limits

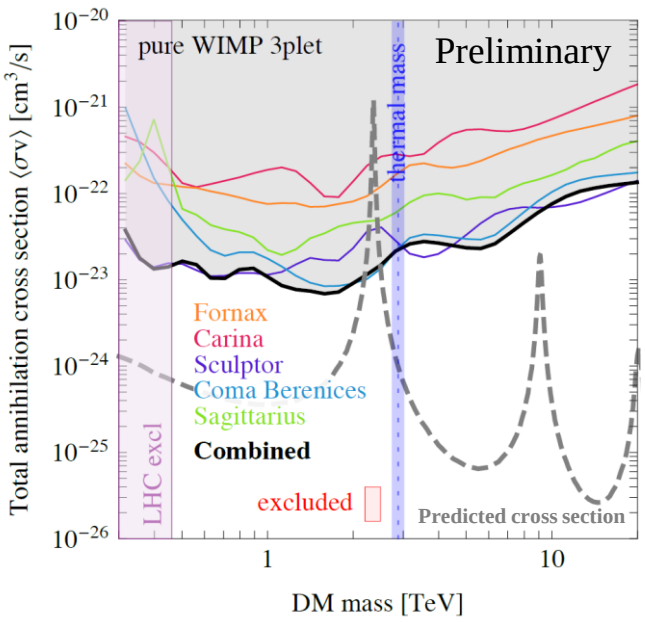
- No excess found in the signal extraction
- Using likelihood ratio test statistics to set upper limits
- Uncertainties on the J factor taken into account
- Upper limits at 95% CL for DM annihilation into monoenergetic gamma rays
  - For each **dwarf galaxies**
  - For the **combination**



Pure WIMP models

- Pure WIMP model (minimal DM models)
  - **Minimal amount of new physics** to explain the DM problem
  - **New multiplet** of particles χ where the neutral component constitutes the DM
- Two specific candidates
  - Fermionic **triplet** $\chi \equiv (\chi^+, \chi^0, \chi^-)$
  - Fermionic **quintuplet** $\chi \equiv (\chi^{++}, \chi^+, \chi^0, \chi^-, \chi^{--})$
- χ^0 decays to
  - **WW** (tree), **ZZ** (loop): produce **continuum** γ spectrum
  - **$\gamma\gamma$, γZ** (loop): produce γ **line**
- Pure WIMP models feature
  - A **prominent line** $E_\gamma \approx M_{DM}$ + a **continuum shoulder** at $E_\gamma < M_{DM}$
  - **Sommerfeld** enhancement for loop processes
- Upper limits set constraints on the cross section





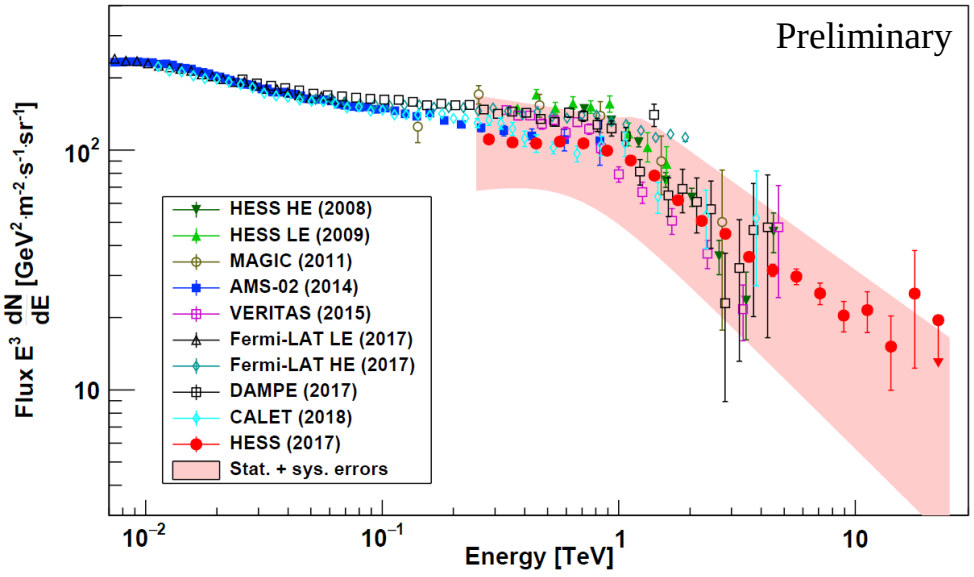
Electron spectrum

Publication in preparation

More details during the cosmic ray session today (Daniel Kerszberg)

Electron spectrum

- Propagation of electrons/positrons limited to ~1 kpc
  - A **nearby source** (such as DM) could **dominate** the high energy part of the spectrum
- Electron + positron spectrum measured up to 20 TeV
  - **~1200 h** of observation
  - **Exclusion** of any known gamma source
  - **Away** from the galactic plane
  - **Electron/proton** separation from the shower shape
- Spectrum exhibits a broken power law with a break at 1 TeV
  - Compatible with **previous measurements**, **extending** at higher energies
  - **No significant features** from DM or other sources
    - **Set strong constraints** on local emitters of electrons



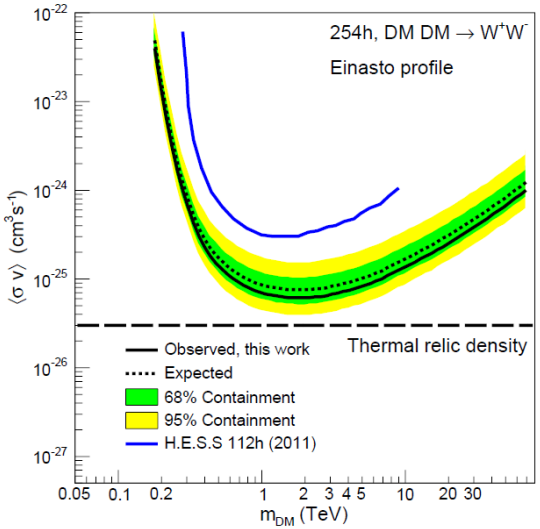
H.E.S.S.

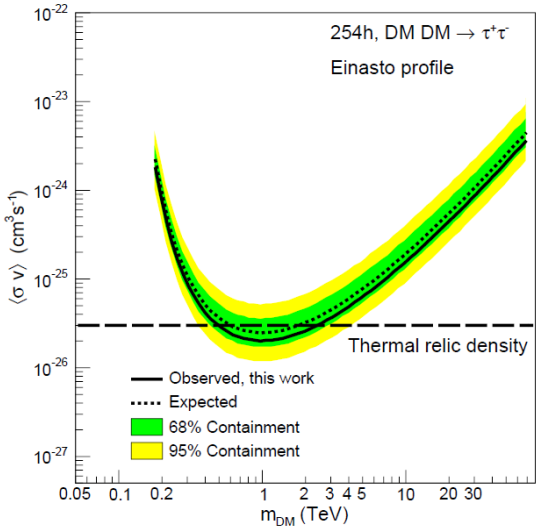
Outlook

Other H.E.S.S. results

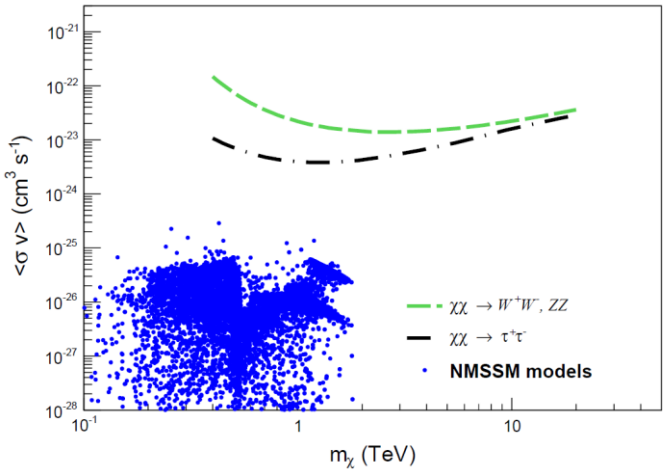
- H.E.S.S. showed also upper limits with a continuum spectrum in the recent past

- Galactic center
  - 254 h
  - PRL 117, 111301 (2016)





- Dwarf galaxies
  - 140 h, 5 dwarf galaxies
  - PRD 90, 112012 (2014)

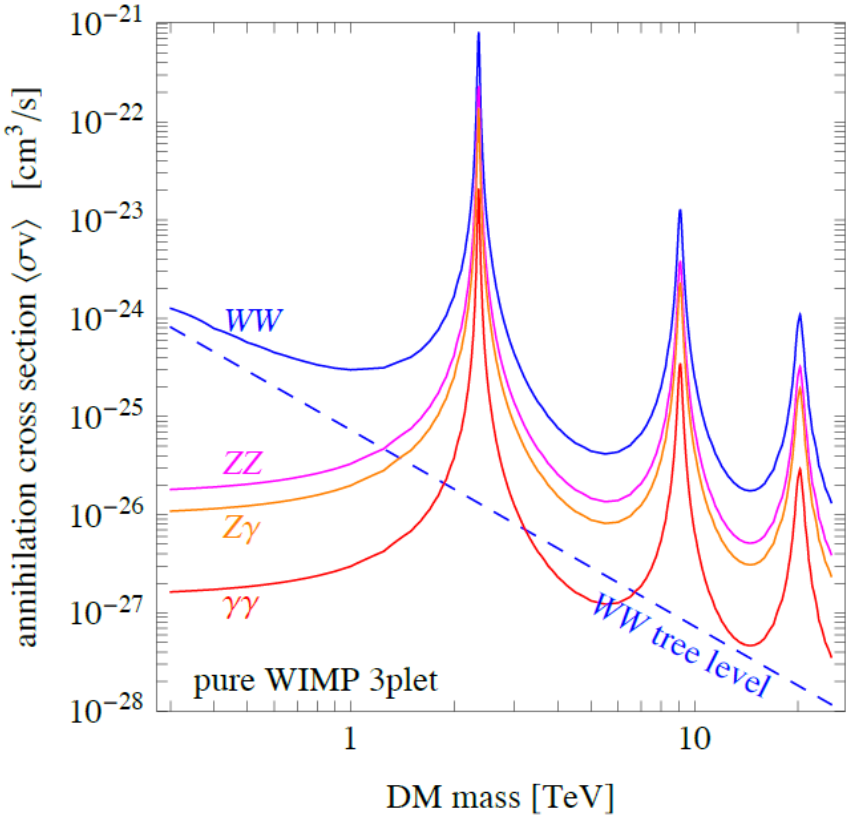


Conclusions

- Recent results from H.E.S.S concerning DM search
  - Gamma ray line signals **in the inner galactic halo**
  - Gamma ray line signals **in dwarf galaxies**
  - **Electron** spectrum
- No excess seen, but the search goes on…
- Recent H.E.S.S. observation
  - More time toward **the galactic center**
  - More dwarf galaxies: **ultrafaint galaxies**
- Stay tune for more results on DM in the near future!

Additional slides

Pure WIMP models



Electron spectrum

The **Model Analysis**:

- Log-likelihood comparison between recorded images and pre-calculated templates including Night Sky Background
- Widely used for H.E.S.S. analysis
- Very powerful discrimination based on goodness of fit