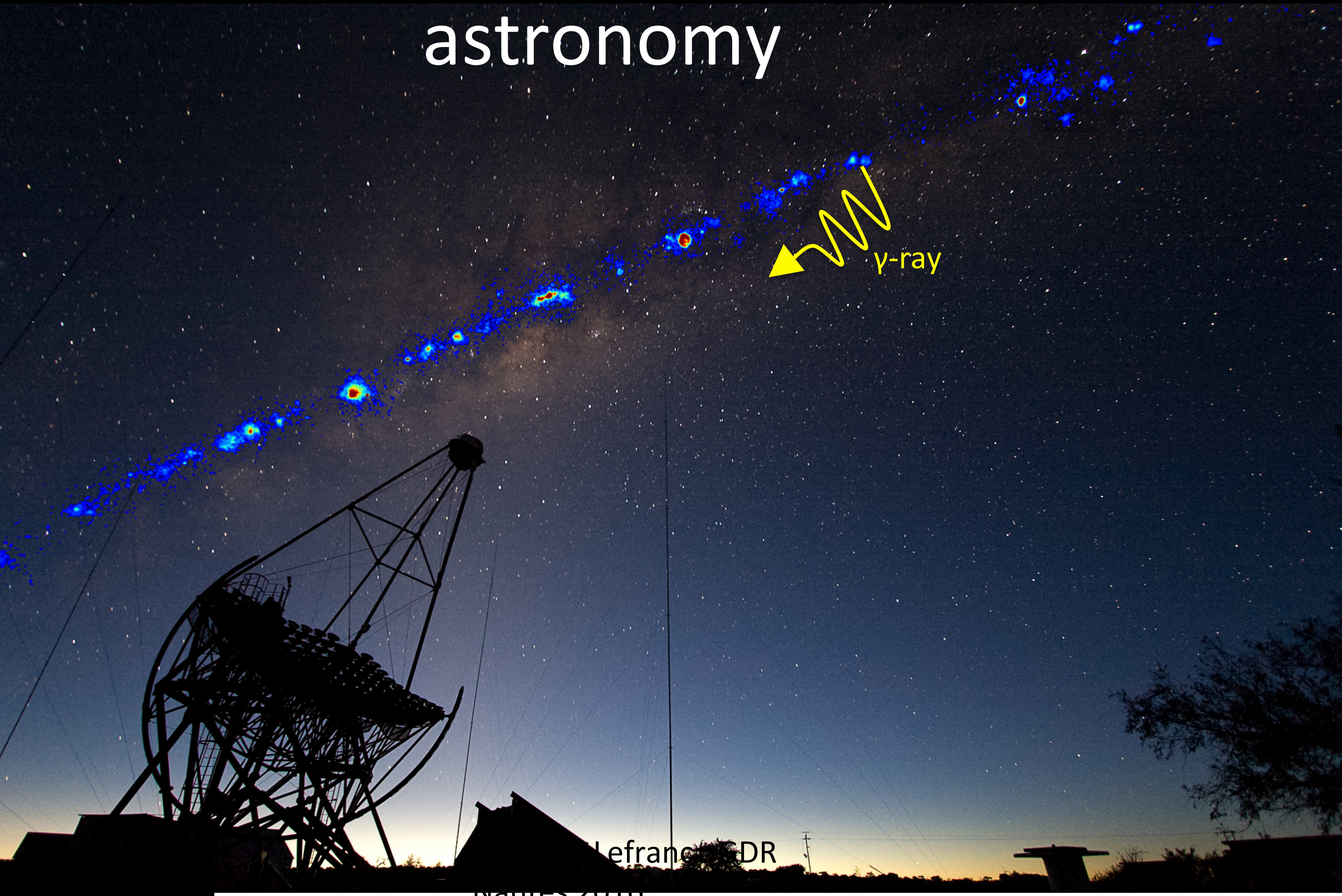
Dark matter search in the inner Galactic Center halo with H.E.S.S.

Valentin Lefranc & Emmanuel Moulin
on behalf of the H.E.S.S. Collaboration

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

Ground-based gamma-ray astronomy



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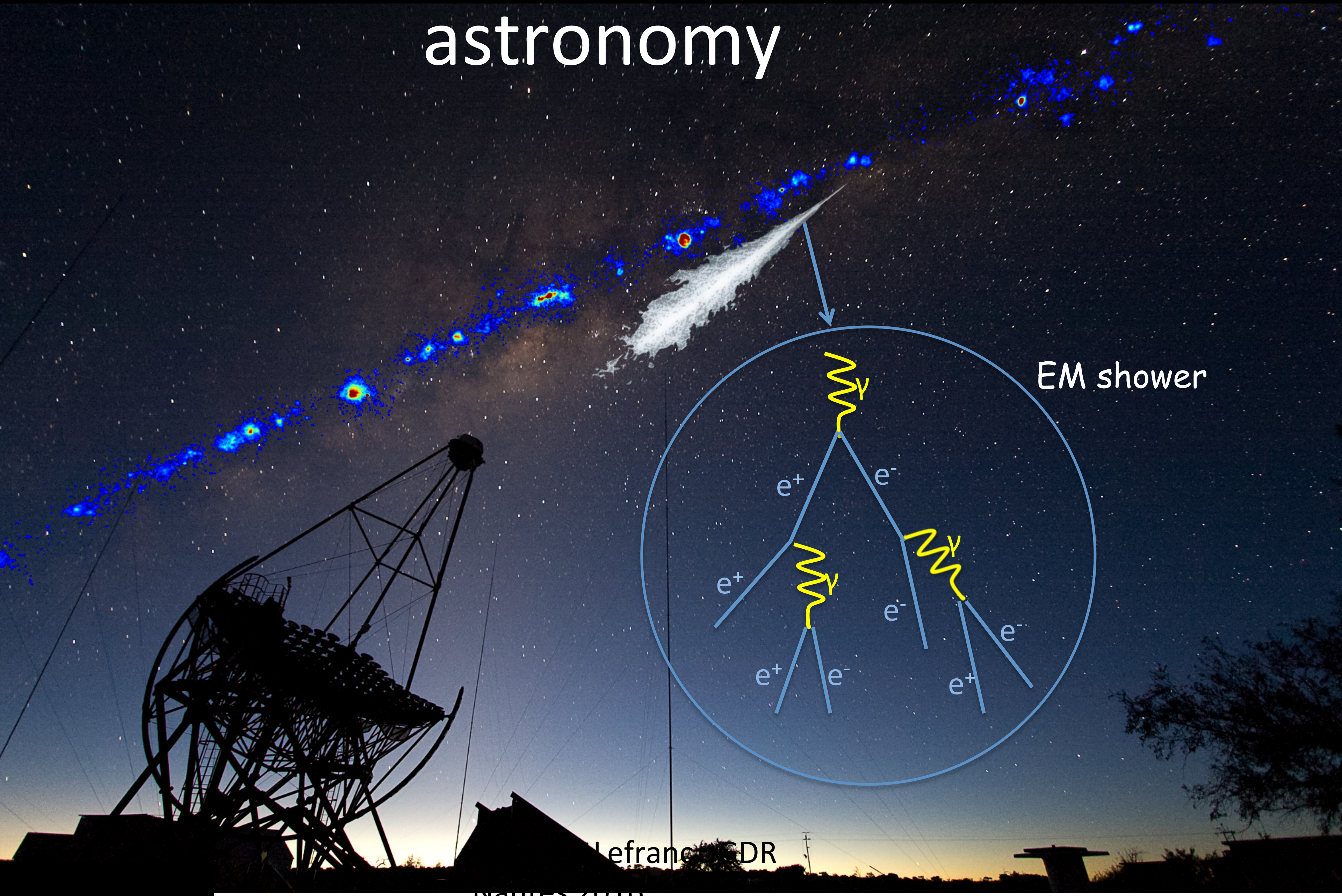

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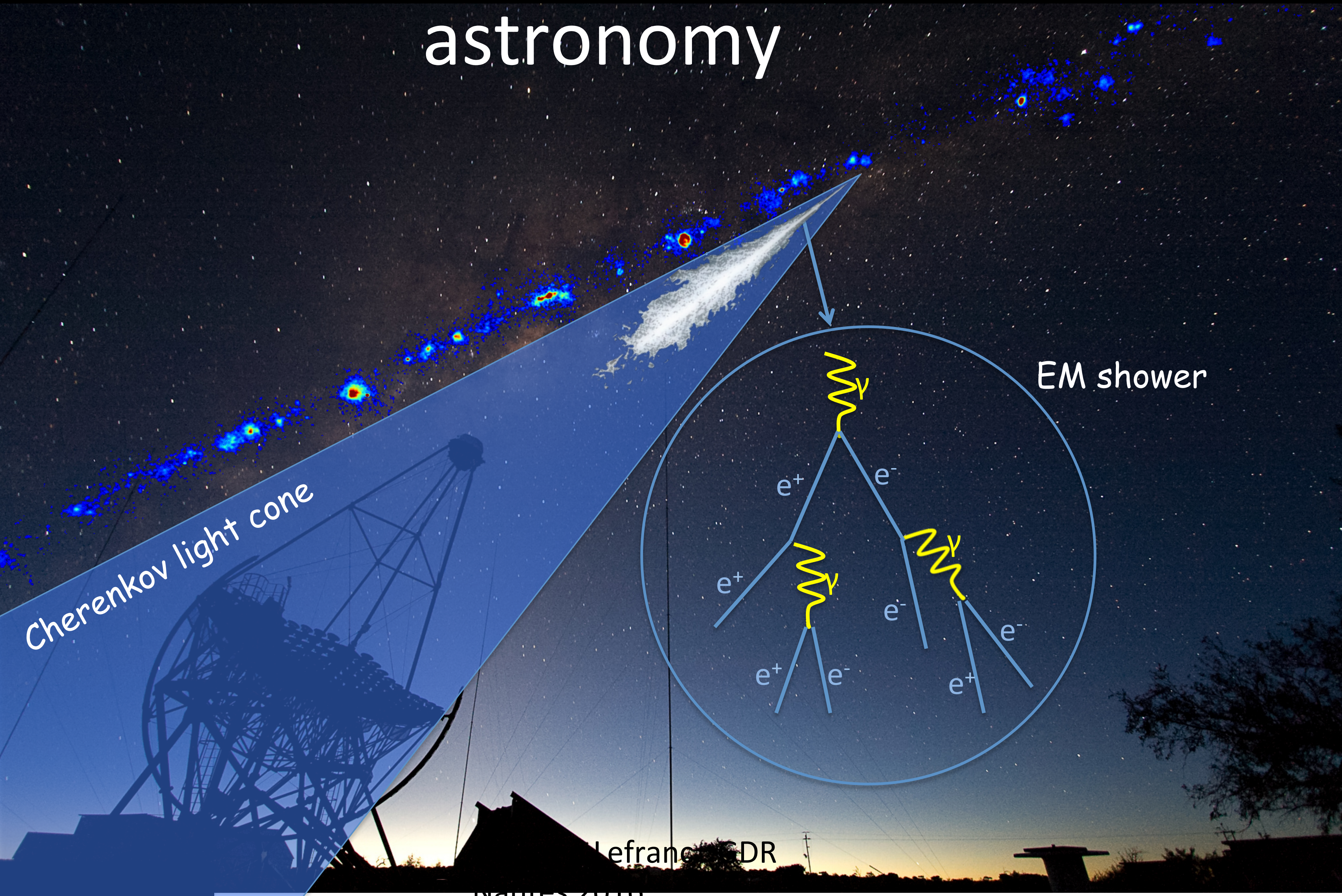
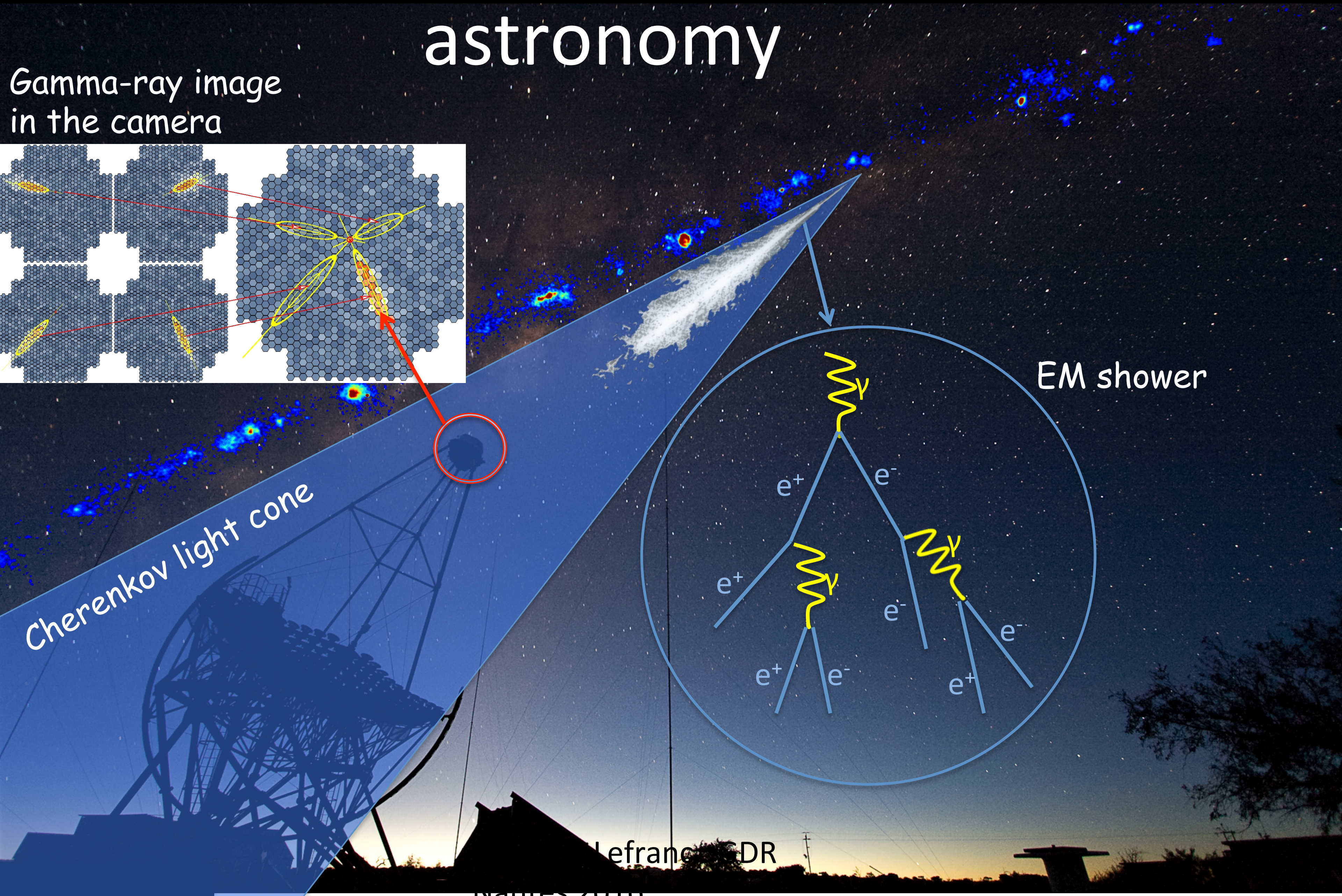


Ground-based gamma-ray astronomy



Gamma-ray selection in a nutshell

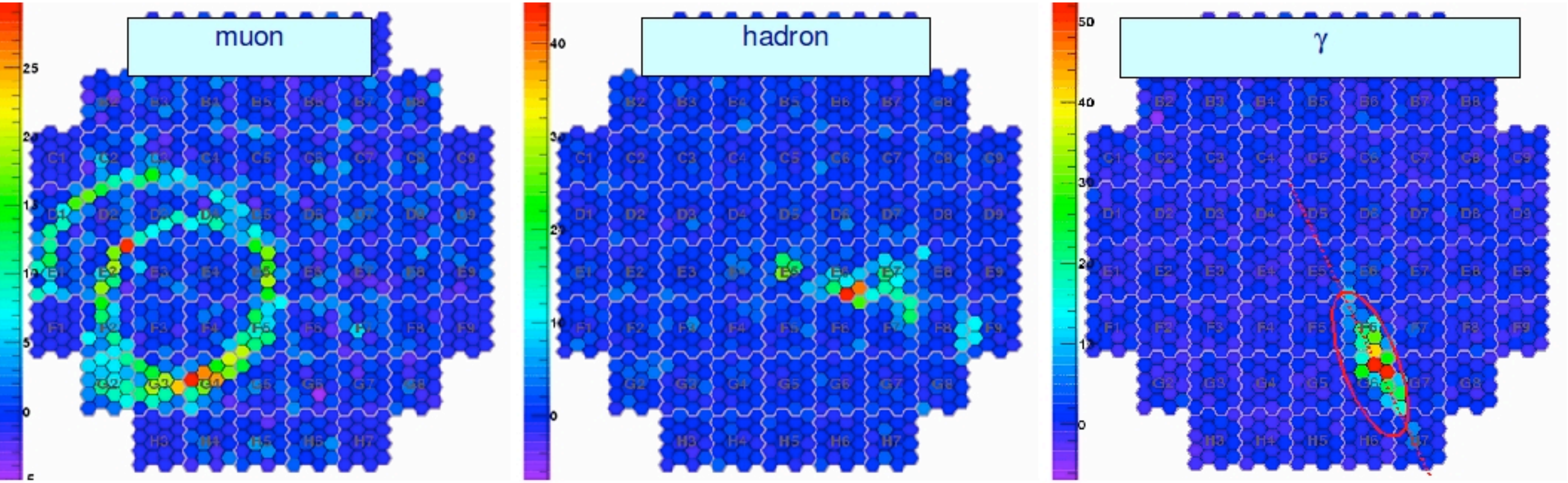
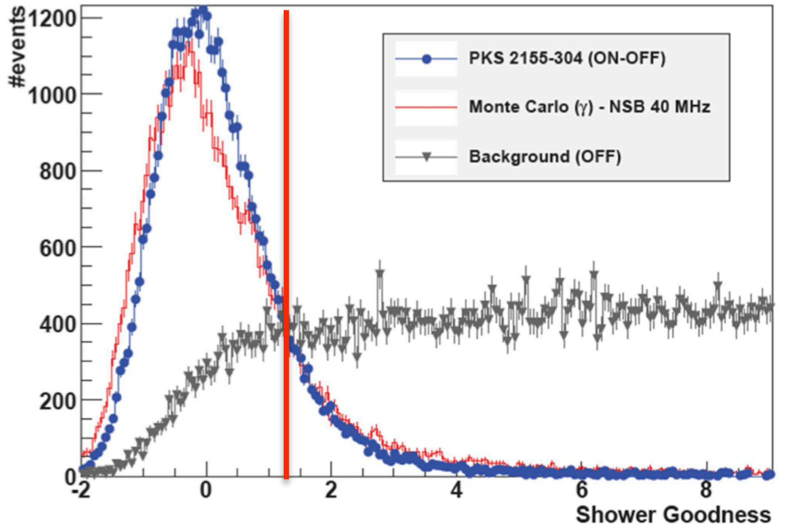
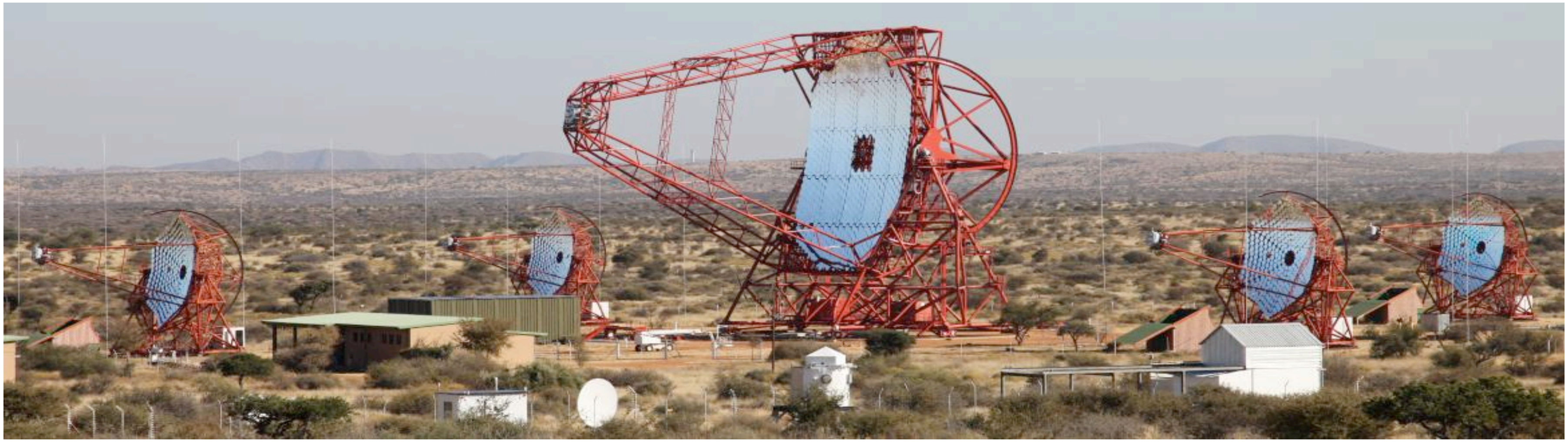


Image shape discrimination
Likelihood « shower goodness » →



H.E.S.S.: High Energy Stereoscopic System

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



H.E.S.S. phase 1:

- 4 telescopes: Ø 12 m,107 m^2
- Stereoscopic reconstruction
- 960 PMTs/camera
- Field of view : 5°
- Observations : ~1000h/year
- Source position : ~ 10''

H.E.S.S. phase 2:

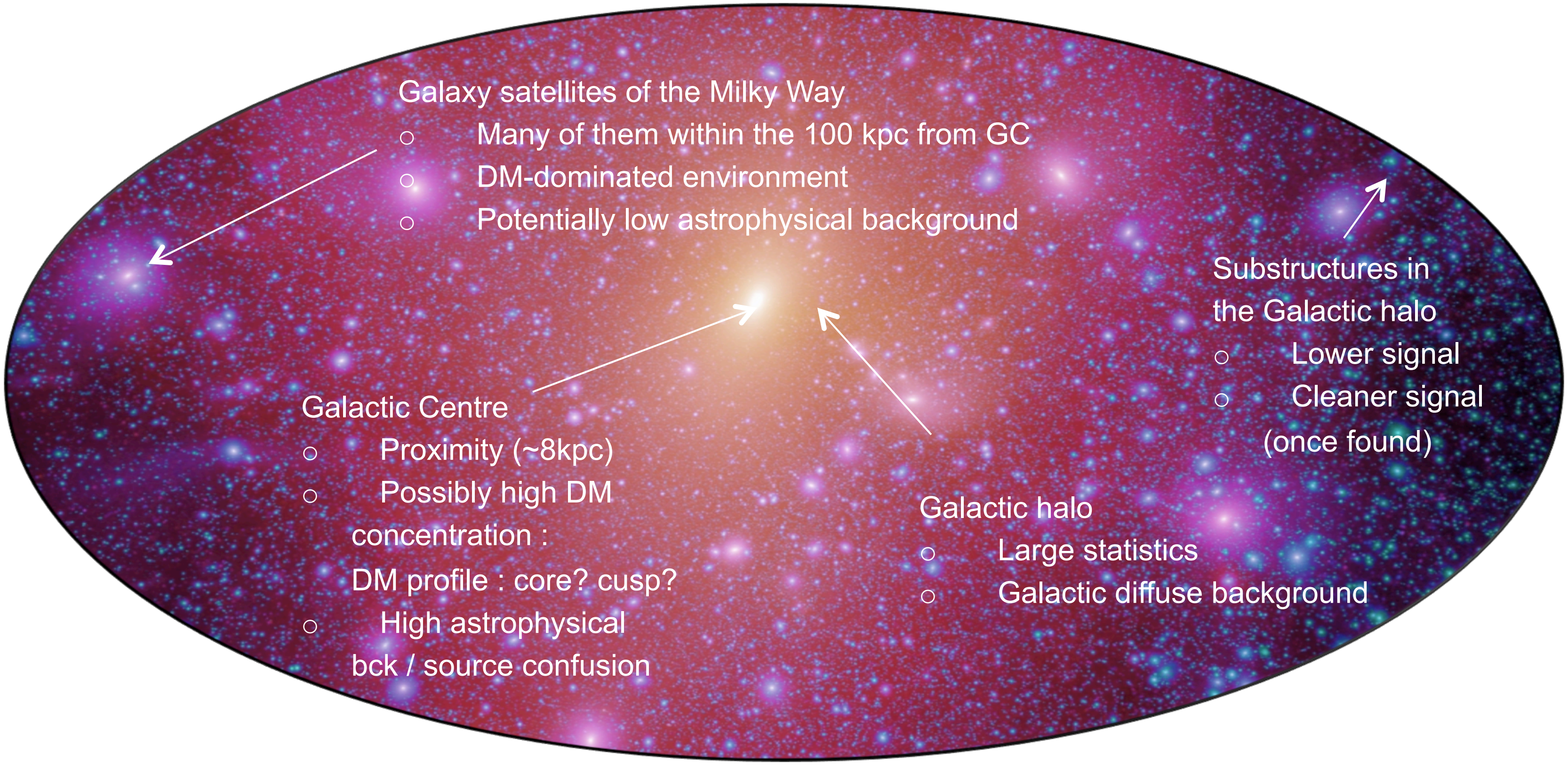
a 5th telescope

- Ø 28 m, 600 m2
- 2048 PMTs
- Field of view : 3.5°

→ Energy threshold (zenith) ~ 30 GeV

→ Sensitivity x 2 in the TeV range

Dark Matter program with H.E.S.S.



Galaxy satellites of the Milky Way

- ○ Many of them within the 100 kpc from GC
- ○ DM-dominated environment
- ○ Potentially low astrophysical background

Substructures in the Galactic halo

- ○ Lower signal
- ○ Cleaner signal (once found)

Galactic Centre

- ○ Proximity (~8kpc)
- ○ Possibly high DM concentration : DM profile : core? cusp?
- ○ High astrophysical bck / source confusion

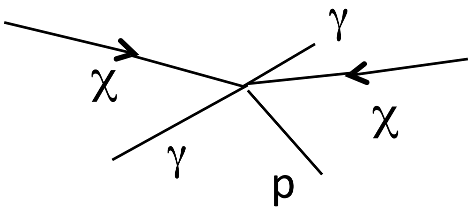
Galactic halo

- ○ Large statistics
- ○ Galactic diffuse background

- Galactic Center / Galactic Center halo : continuum (2011) and line (2013) searches
- Dwarf satellite galaxies of the Milky Way: Sagittarius (2008), Sculptor (2010), Carina (2010), Canis Major (2009), Coma Berenices (2014), Fornax (2014)
- Galaxy cluster: Fornax (2012)

Dark matter annihilation signal : WIMPS annihilation

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



$$= \frac{1}{4\pi}\frac{<\sigma v>}{2m_{\chi}^{2}}\sum_{i=1}^{n} Br_i \frac{dN_i}{dE}$$

Thermal relic cross section

$$<\sigma v> = 3 \times 10^{-26} cm^3 s^{-1}$$

Branching ratio Br = 100% in the channels :

$$\chi\chi \rightarrow \underbrace{b\bar{b}, t\bar{t},}_{\text{quarks}} \underbrace{W^+W^-}_{\text{bosons}}, \underbrace{\tau^+\tau^-, \mu^+\mu^-, e^+e^-}_{\text{leptons}}$$

Dark matter annihilation signal

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

$$= \int_{\Delta\Omega}\int_{\mathrm{los}} \rho^2(\mathrm{l},\Omega)\mathrm{dld}\Omega$$

DM density profile : NFW

$$\rho(\mathrm{r}) = \frac{\rho_\mathrm{s}}{\frac{\mathrm{r}}{\mathrm{r_s}}(1+\frac{\mathrm{r}}{\mathrm{r_s}})^2}$$

$$\mathrm{r_s} = 20\ \mathrm{kpc}$$

$$\rho(\mathrm{r}=\mathrm{r}_\odot) = 0.4\ \mathrm{GeVcm}^{-3}$$

DM density profile : Einasto

$$\rho(\mathrm{r}) = \rho_\mathrm{s}\exp\left[-\frac{2}{\alpha_\mathrm{s}}\left(\left(\frac{\mathrm{r}}{\mathrm{r_s}}\right)^{\alpha_\mathrm{s}} - 1\right)\right]$$

with

$\alpha_\mathrm{s} = 0.17$ (see H.E.S.S. PRL 2011)

$\mathrm{r_s} = 20\ \mathrm{kpc}$

$\rho(\mathrm{r}=\mathrm{r}_\odot) = 0.39\ \mathrm{GeVcm}^{-3}$

« Einasto 1 »

OR

$\mathrm{r_s} = 28.44\ \mathrm{kpc}$

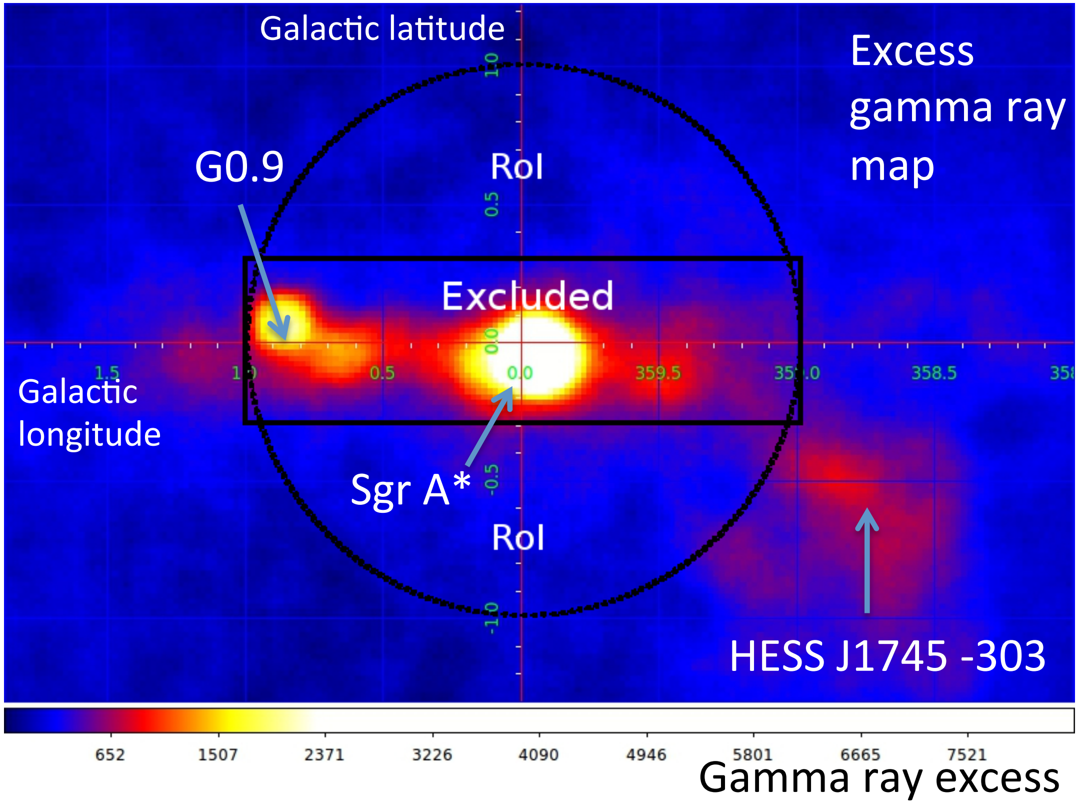
$\rho(\mathrm{r}=\mathrm{r}_\odot) = 0.3\ \mathrm{GeVcm}^{-3}$

« Einasto 2 »

GC halo DM searches with H.E.S.S. I

- 2011 results: 112 h dataset at GC $<\sigma v> = 3x10^{-25}$ cm^{3}s^{-1} @1 TeV
- Today : full H.E.S.S.-I GC dataset

10 years of observations at GC → 254 h dataset



No significant excess in the RoI

- Improved statistics
- New analysis method :

→ 2D likelihood with spectral and spatial information of signal and background

- Most uptodate annihilation spectra

DMDM ➜ W^+W^- , $\mu^+\mu^-$, $\tau^+\tau^-$, bb, tt

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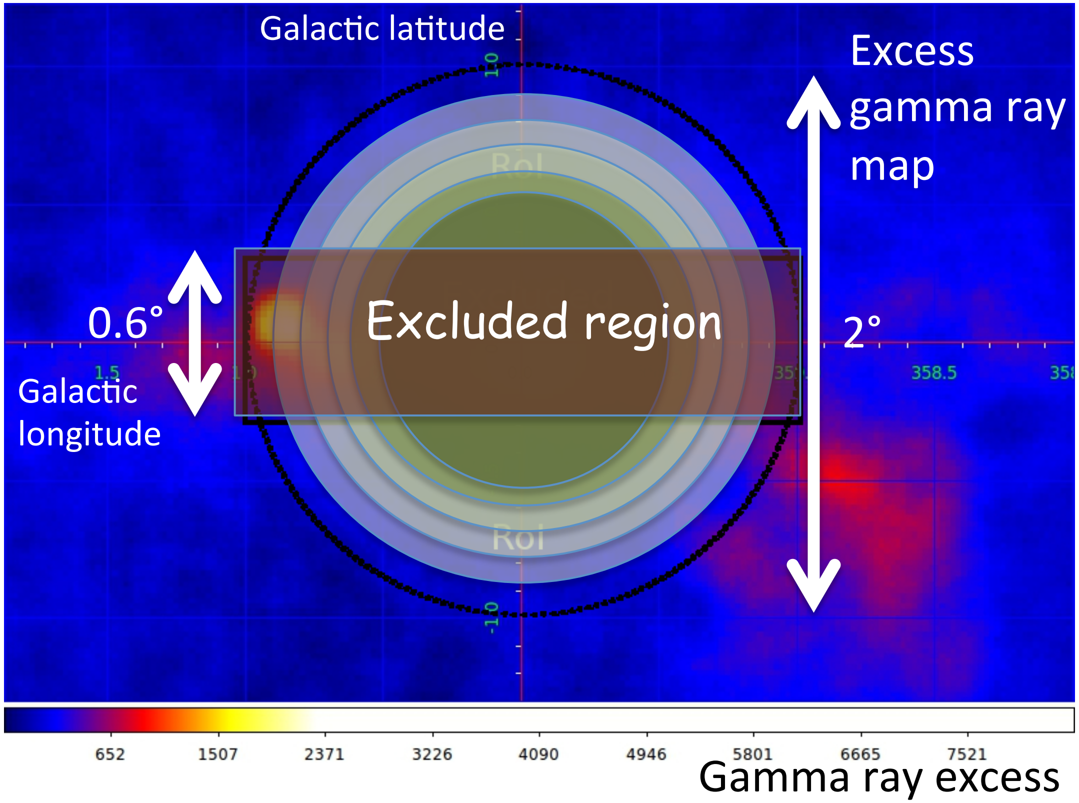

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2D Likelihood analysis

In the energy bin i and spatial bin j, the Poisson likelihood writes :

$$\mathcal{L}_{\rm ij}(\mathrm{N}^{\rm S}_{\gamma}, \mathrm{N}^{\rm B}_{\gamma}, \beta|\mathrm{N}_{\rm ON}) = \frac{(\mathrm{N}^{\rm S}_{\gamma,\rm ij} + \mathrm{N}^{\rm B}_{\gamma,\rm ij})^{\mathrm{N}_{\rm ON,ij}}}{\mathrm{N}_{\rm ON,ij}!}\mathrm{e}^{-(\mathrm{N}^{\rm S}_{\gamma,\rm ij}+\mathrm{N}^{\rm B}_{\gamma,\rm ij})}$$

$$\mathcal{L} = \prod \mathcal{L}_{\rm ij}(\mathrm{N}^{\rm S}_{\gamma}, \mathrm{N}^{\rm B}_{\gamma}, \beta|\mathrm{N}_{\rm ON})$$

Standard likelihood ratio test statistic TS

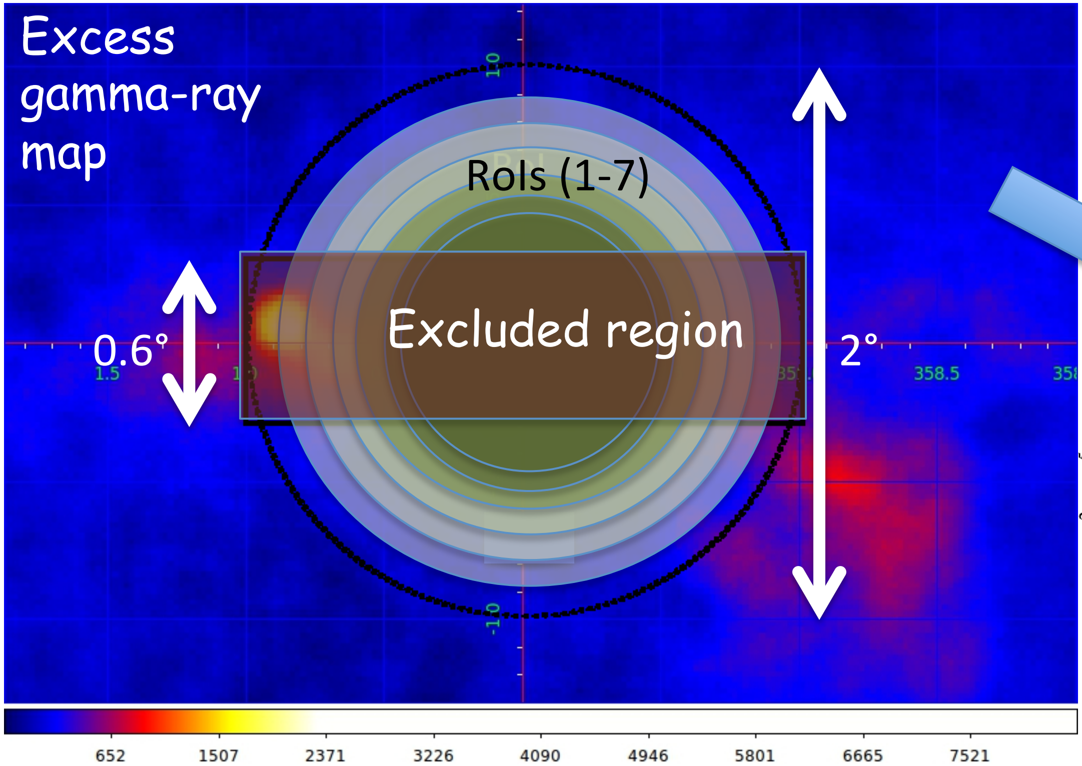
$$-2\log\left(\frac{\mathcal{L}_{\rm DM}}{\mathcal{L}_{\rm No\ DM}}\right)$$

→ provides 95% C.L. limits on <sigma v> for a given a DM mass

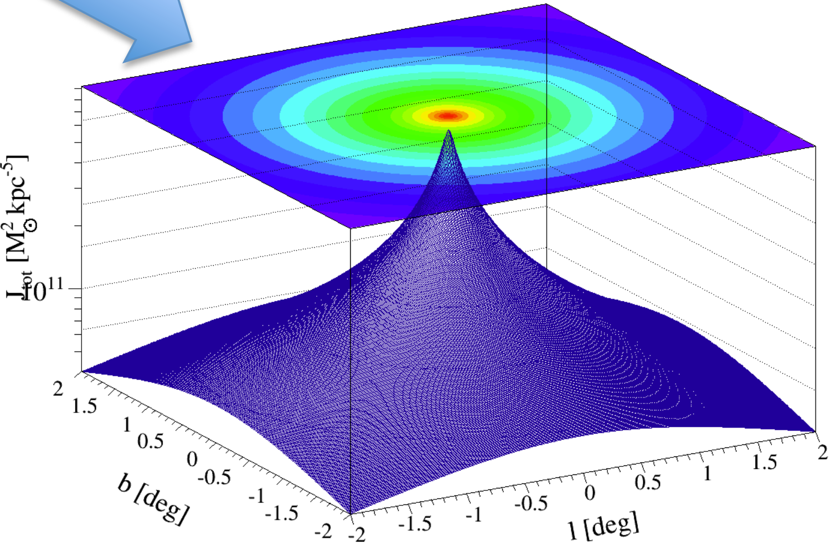
N_{ON} = Number of observed events
N^{S} = Number of predicted signal events
N^{B} = Number of background events (from OFF)

Spatial dependence of DM signal vs. background

- Divide the ROI into 7 sub-rings of 0.1° width



- Takes advantage of the dark matter profile compare to background

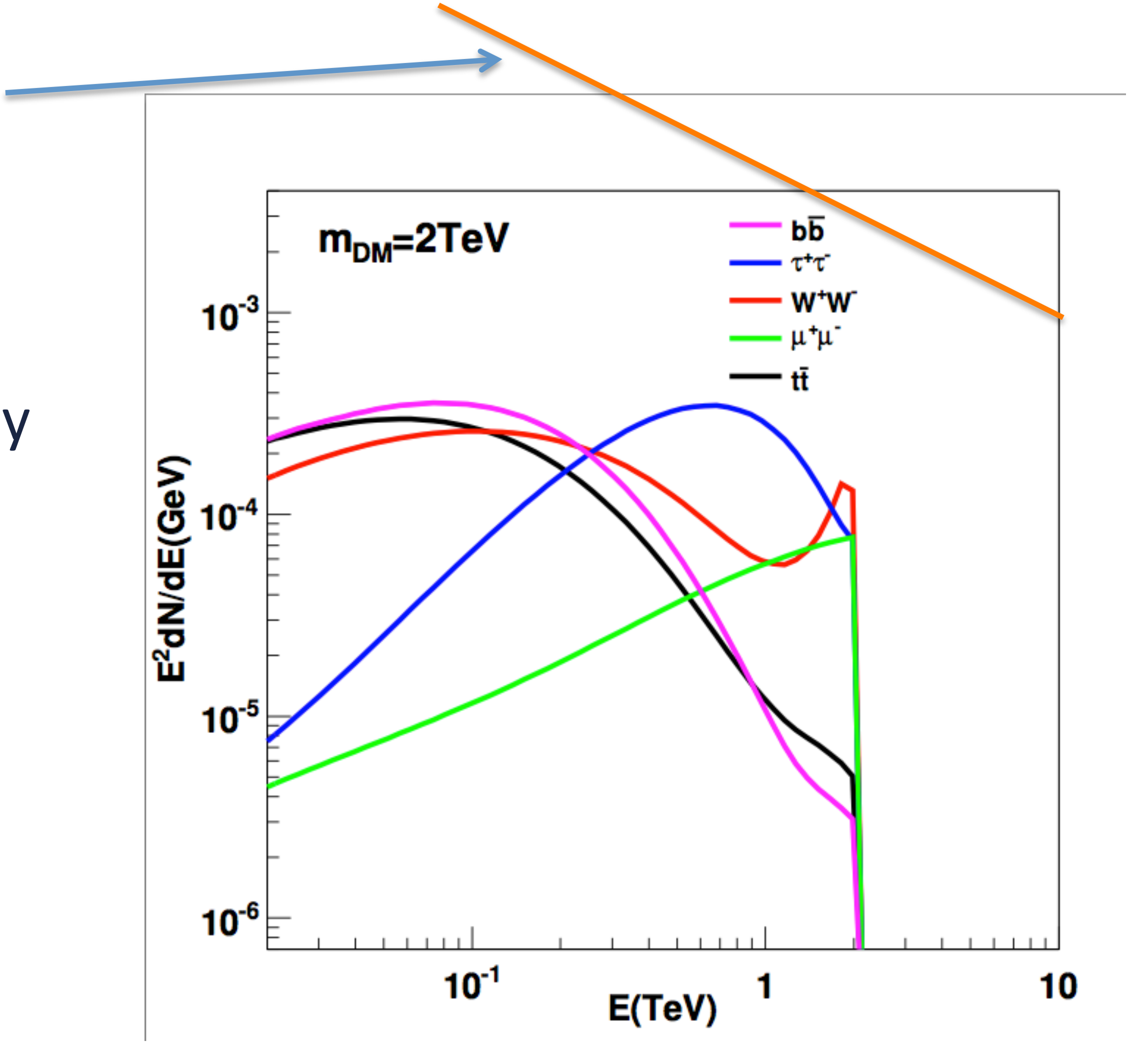


spectral dependence of DM signal vs. background

- Background event flux follow a power law

- Photons spectra from DM annihilation have an energy cut off at the DM mass

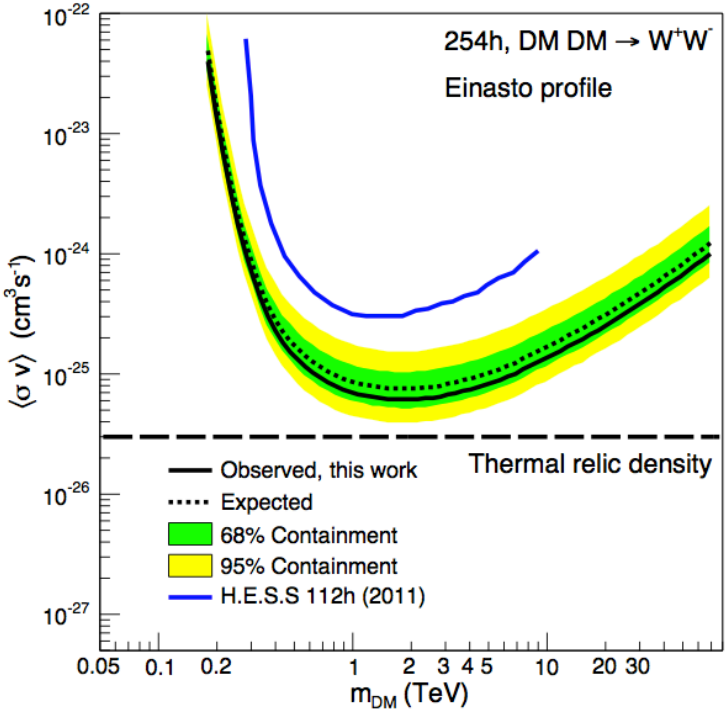
- This helps the discrimination in the 2D likelihood

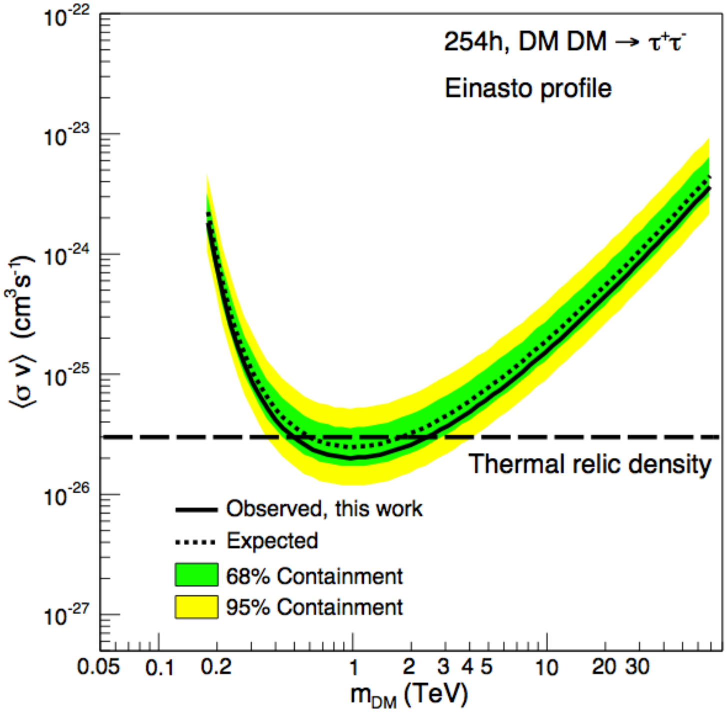


2016 results with full H.E.S.S. I dataset

New constraints in 2016 !

- No significant excess in any of the RoIs ➜ 95% C.L. upper limits
- W^+W^- limits ➜ **$6x10^{-26}$ $cm^{-3}s^{-1}$ @ ~2TeV!**
- A factor 5 compared to previous limits!
- $\tau^+ \tau^-$ limits ➜ **$2x10^{-26}$ $cm^{-3}s^{-1}$@ ~800GeV!**
  - **Probing thermal relic density between 400 GeV and 2 TeV**





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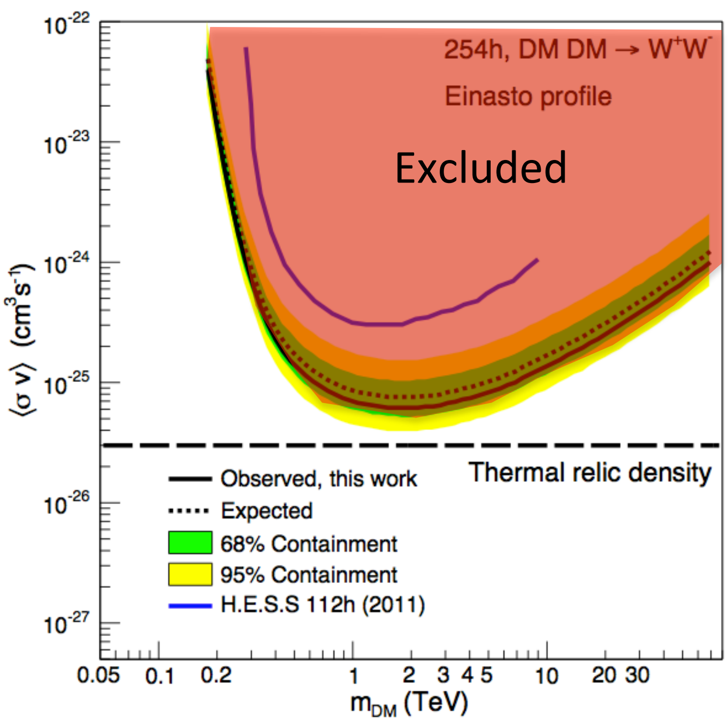
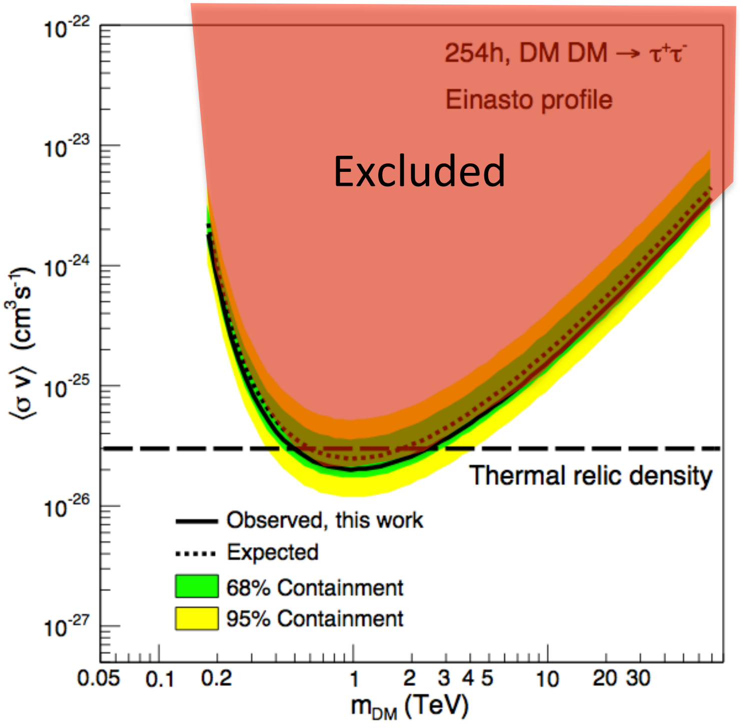
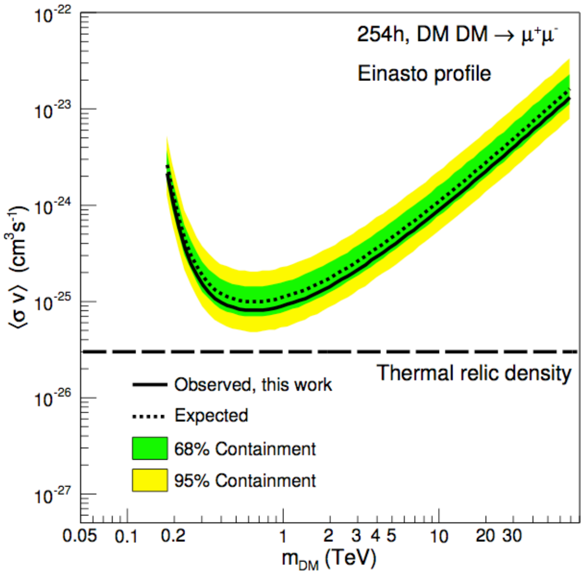




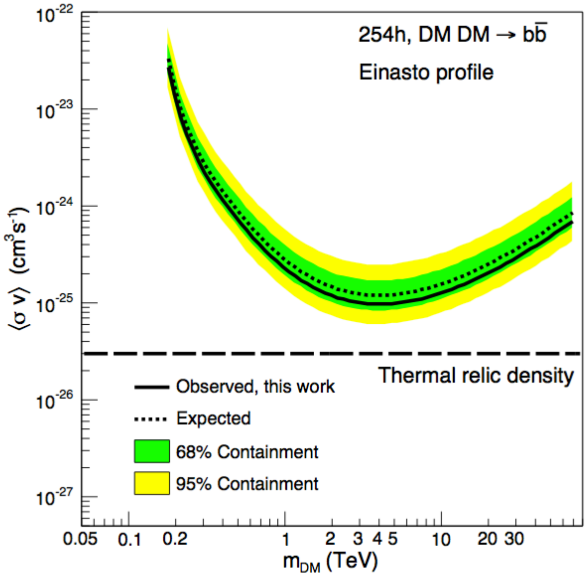
First time we are able to probe Thermal relic around 1 TeV

New constraints in 2016: other channels

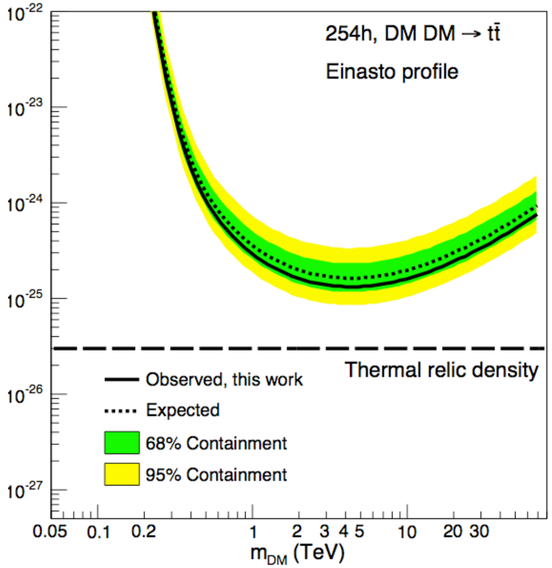
- No significant excess in any of the RoIs ➔ 95% C.L. upper limits



μμ➔ $6x10^{-26}$ cm^{-3}s^{-1} @ ~700 GeV

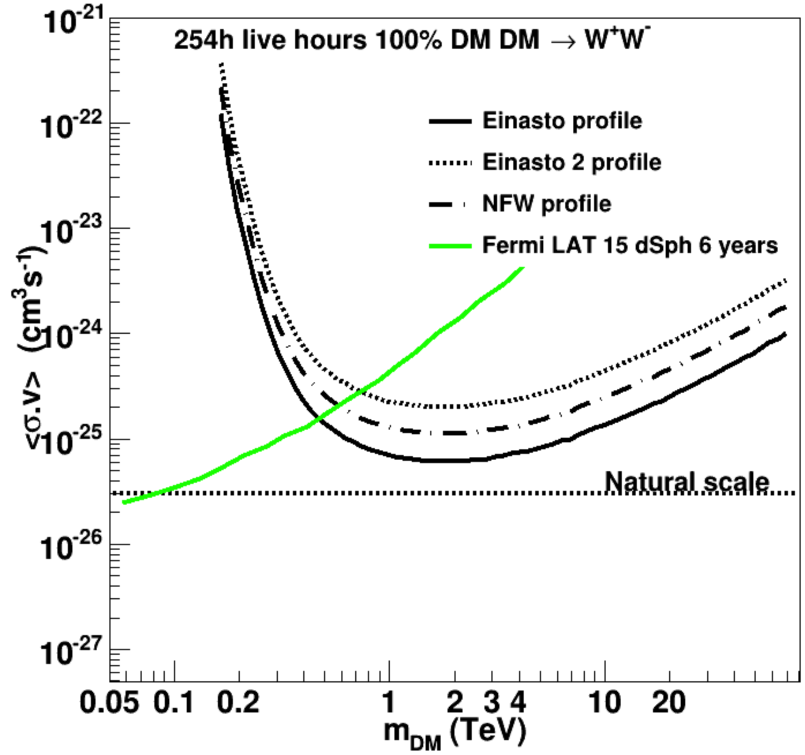


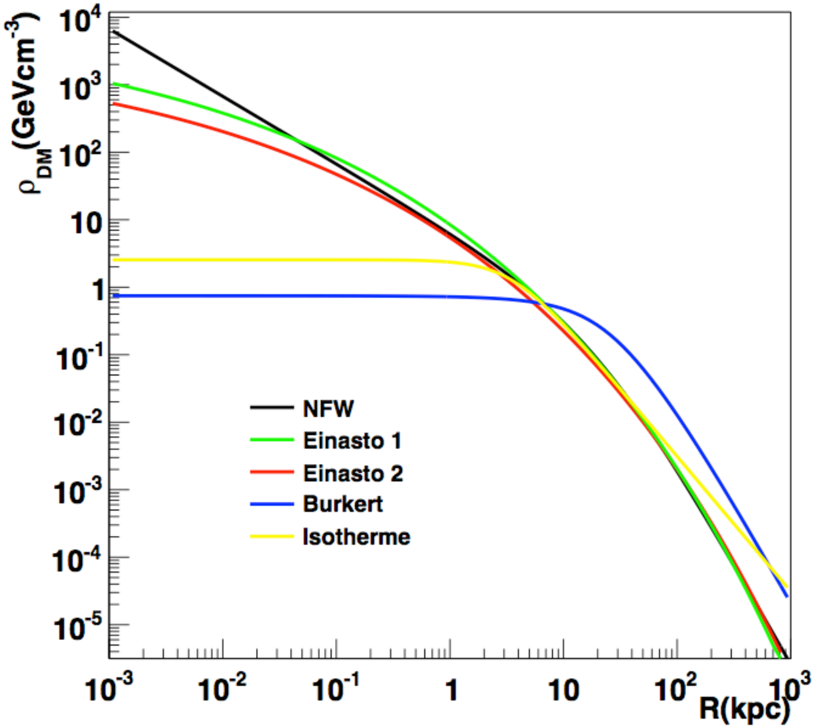
bb➔ $1x10^{-25}$ cm^{-3}s^{-1} @ ~4 TeV



tt➔ $1x10^{-25}$ cm^{-3}s^{-1} @ ~4 TeV

New constraints in 2016 : Impact of the DM distribution





- Big dependency on the halo shape
- We do not probe core profiles here

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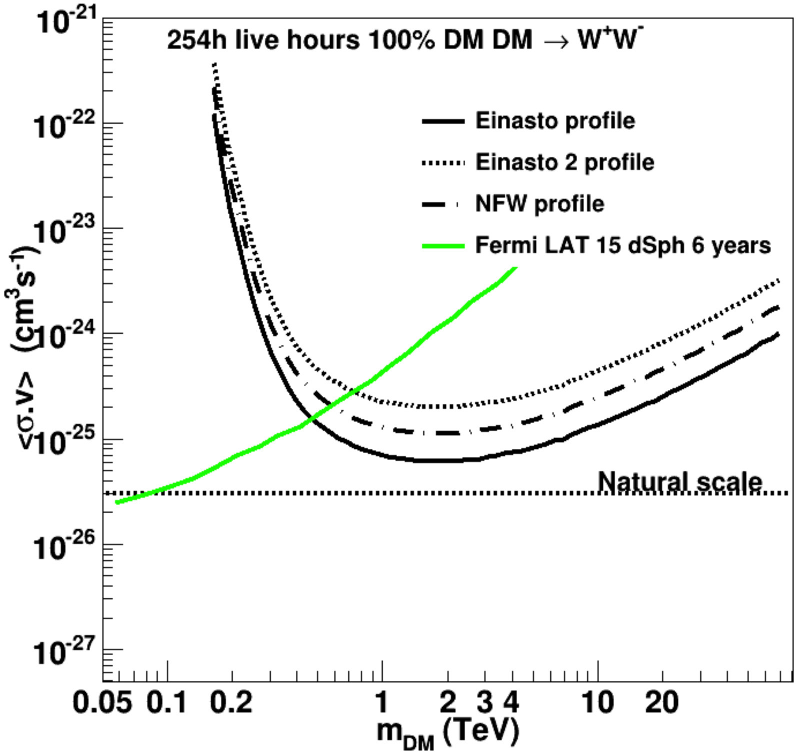
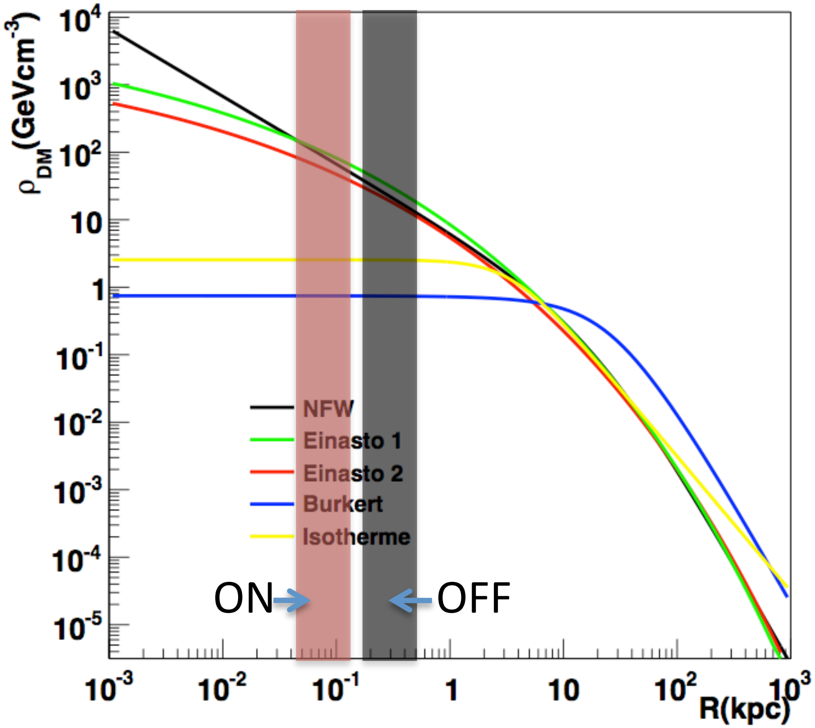




- Big dependency on the halo shape
- We do not probe core profiles here

Summary

- Updated DM search in the inner Galactic halo

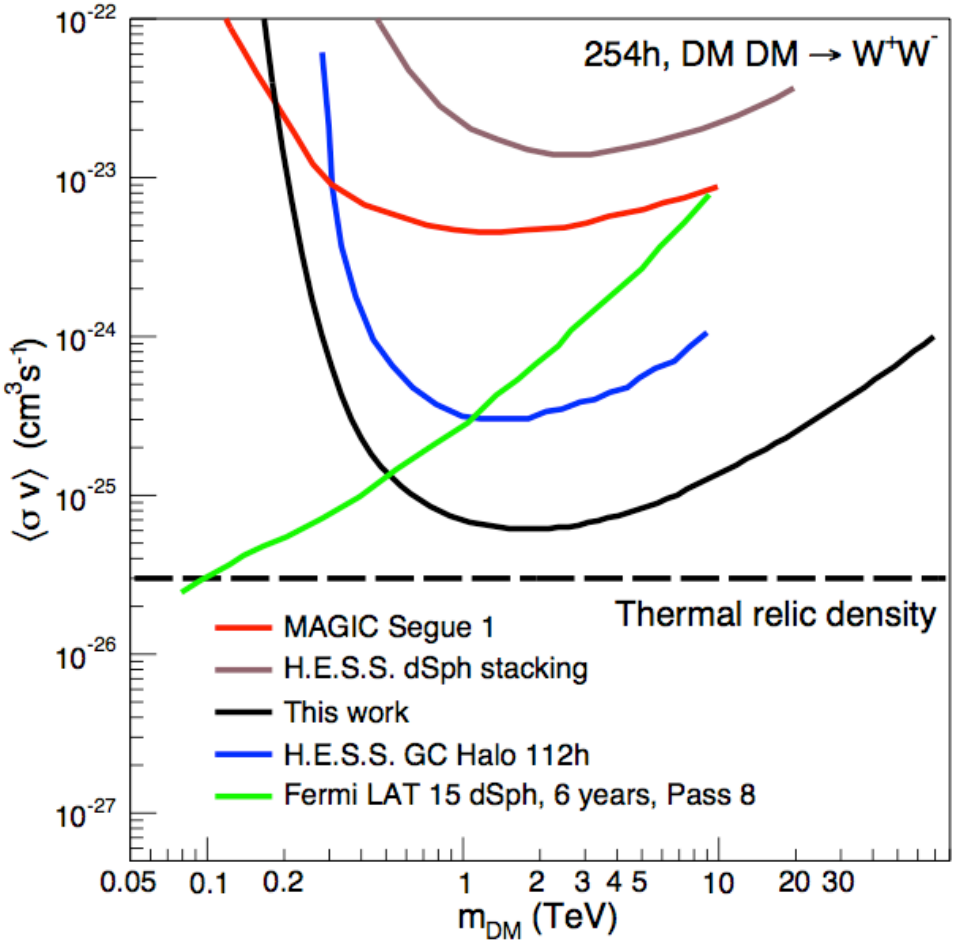
- We improved the current limits by a factor of 5 compared to previous results
  ➜**$6x10^{-26}$ cm^{-3}s**$^{-1}$ @ 2 TeV with the WW channel
  - Improved statistical method
  - 10-year H.E.S.S.-I dataset towards GC
  - Most uptodate DM annihilation spectra

- The $\tau^+ \tau^-$ channel gives even better results reaching the natural scale
  $2x10^{-26}$ cm^{-3}s^{-1} @ 800 GeV

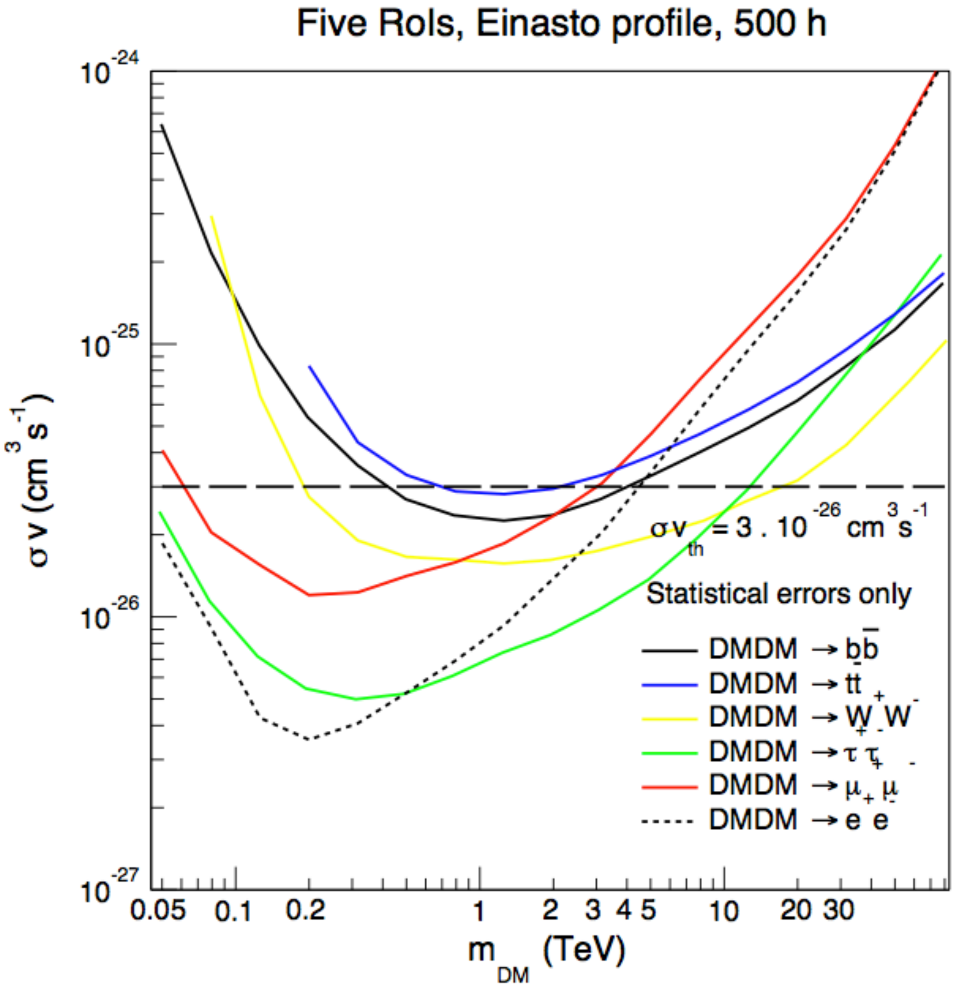
- Near future :
  - use GC dataset with the full H.E.S.S.-II array
  - search for DM including higher lattitude GC observations
  - **CTA will do much better! (x10)**

Summary

- Updated DM search in the inner Galactic halo
- We improved the current limits by a factor of 5 compared to previous results in the WW channel
  ➔**$6x10^{-26}$ cm^{-3}s^{-1}** @ 2 TeV
- The $\tau^+ \tau^-$ channel gives even better results reaching the natural scale **$2x10^{-26}$ cm^{-3}s^{-1}** @ 800 GeV



The Cherenkov Telescope Array Sensitivity toward the GC



<u>All Channel probe the thermal relic value!</u>

V. Lefranc,
E. Moulin,
P. Panci
& J. Silk
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