

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



Dark Matter Searches with H.E.S.S. experiment

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*25th Rencontres de Blois
Particle Physics and Cosmology
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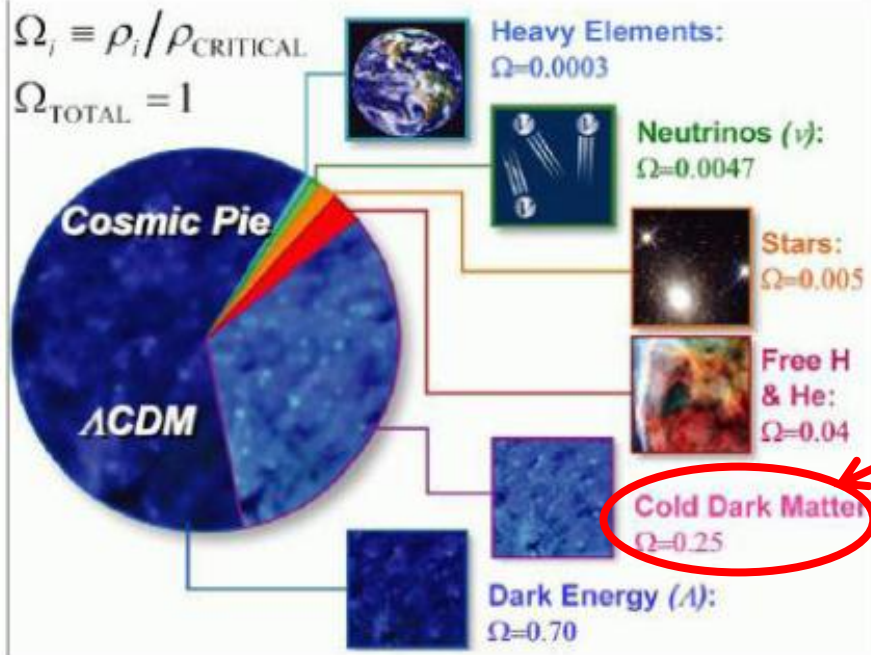


Outline

- Introduction: indirect searches
- HESS experiment
- Results
- Prospects

Cosmology and γ -ray Astronomy

Concordance Cosmological Standard Model
fitting all measurements.

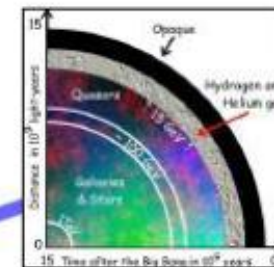


VHE γ -ray telescopes may contribute in subjects such as:

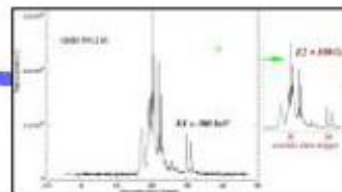


Nature of Dark Matter

PLANCK
26.8%



Cosmological γ -Ray Horizon



Test of the speed of light invariance

Indirect detection: Wimp annihilations

Gamma-ray Flux

(signal in data)

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma, \phi, \theta)$$

=

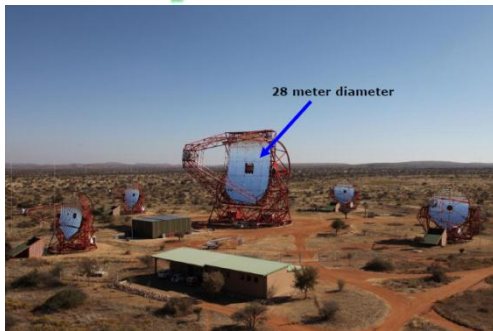
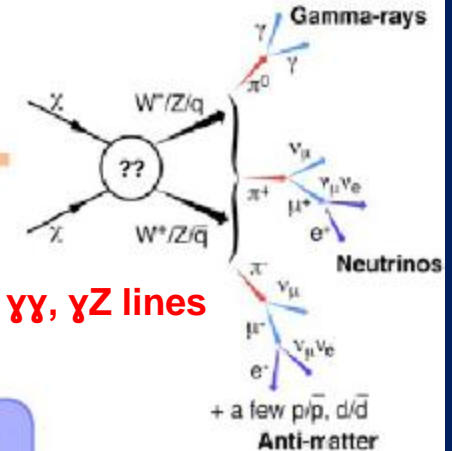
Particle Physics

(photons per annihilation)

$$\frac{1}{4\pi} \frac{\langle \sigma_{ann} v \rangle}{2m_{WIMP}^2} \sum_f \frac{dN_\gamma^f}{dE_\gamma} B_f$$

×

$$\int_{\Delta\Omega(\phi, \theta)} d\Omega' \int_{los} \rho^2(r(l, \phi')) dl(r, \phi')$$

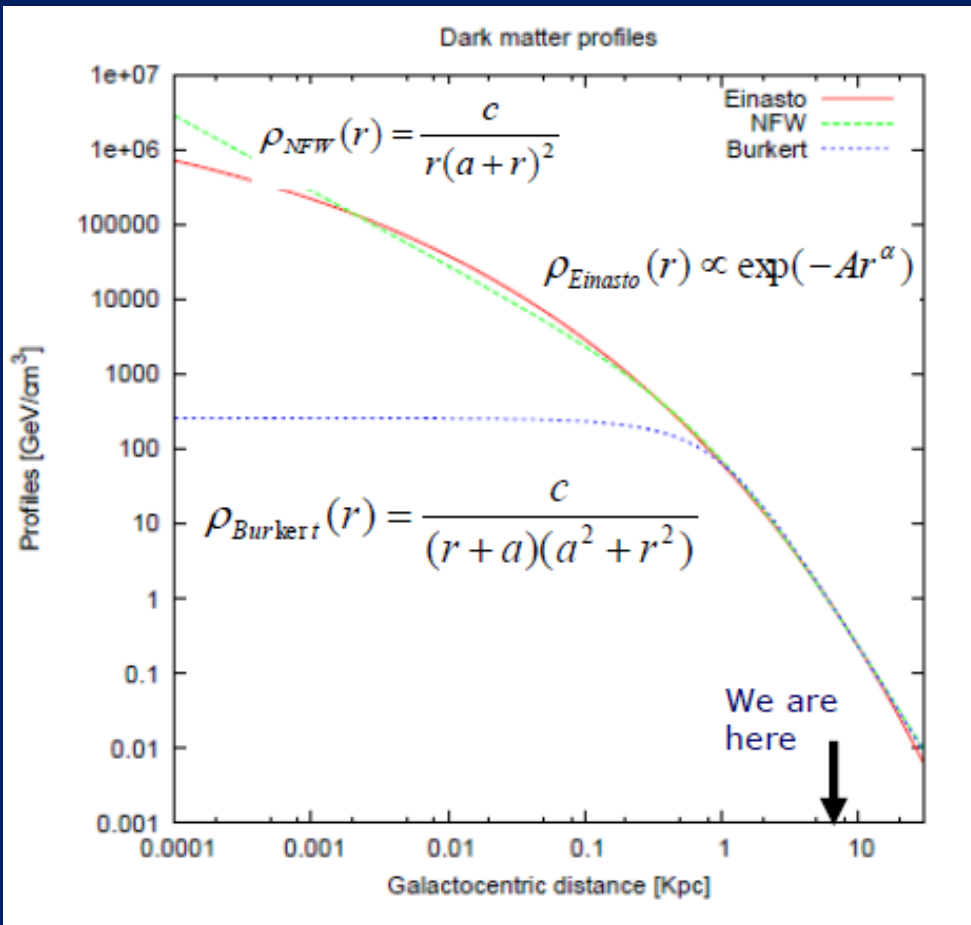


Dark Matter Distribution

(line-of-sight integral)



Dark Matter density Halo Profile



- Cosmological n-body simulations:

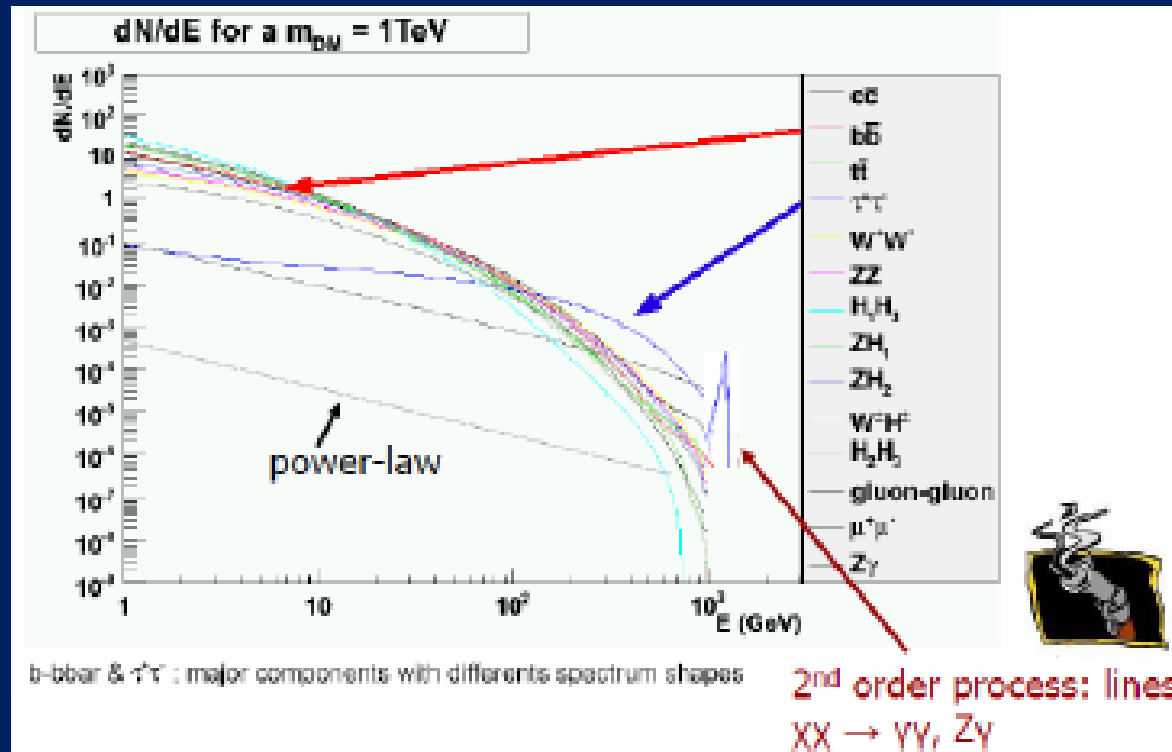
Cuspy profiles
Navarro-Frenk-White (NFW)
Einasto, ...

- Stellar dynamics;
Burkert, ...

→ Strongest signal in the Galactic Centre

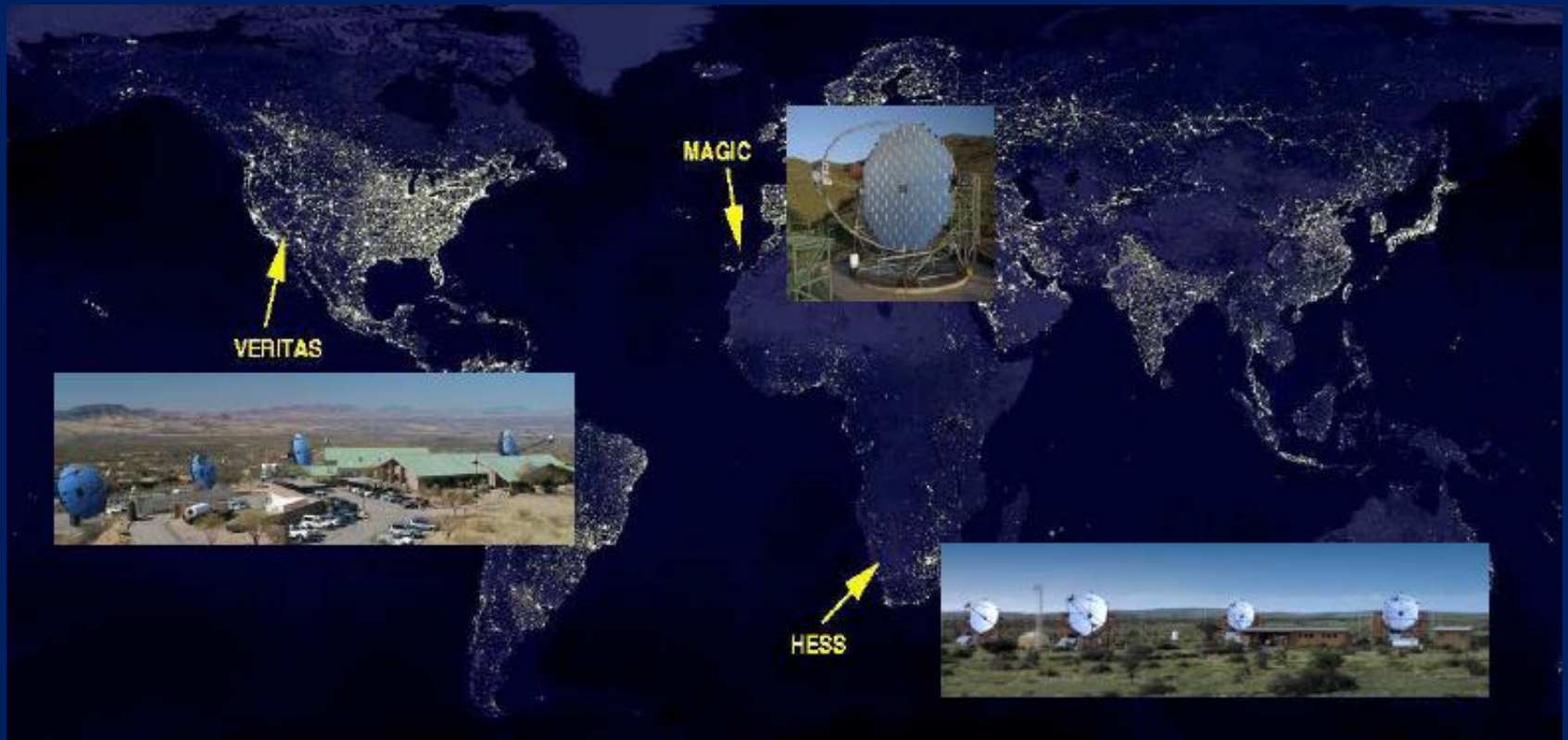
Particle Physics term

- WIMP type: LSP (neutralino, gravitino,...), LKP, Axions, sterile ν , solitons, ...
- $\langle\sigma v\rangle$, coupling, BRs, WIMP mass
- Secondary particle energy distribution \rightarrow photons for H.E.S.S. and Fermi



\rightarrow Not a Power Law !

Air-shower Cherenkov Telescopes

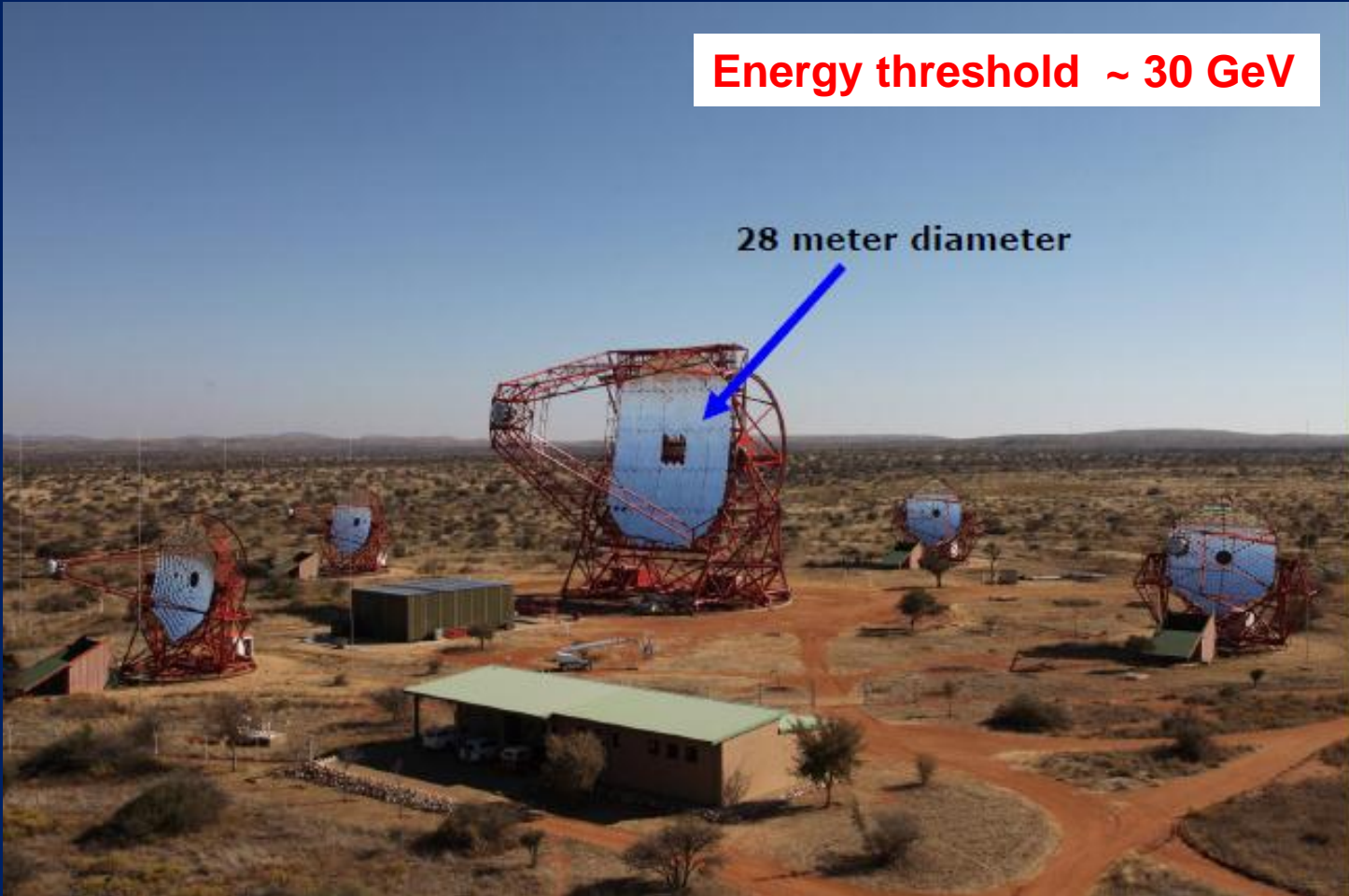


→ Complete coverage of the sky: galactic & extra-galactic sources

H.E.S.S. experiment

Energy threshold ~ 30 GeV

28 meter diameter

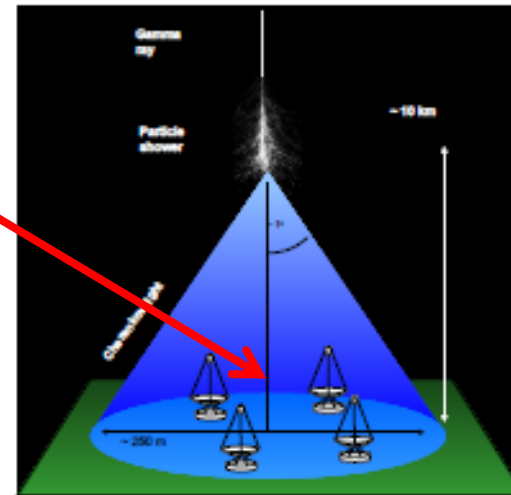


→ 5th Telescope: first light July 2012

H.E.S.S.: ground based Cherenkov Telescope

γ -ray detection

- ▶ very high energy (> 100 GeV)
 γ -rays hit atmosphere
- ▶ electromagnetic shower
- ▶ Cherenkov light pool
- ▶ direction, energy from shower image, light yield $\propto E_\gamma$
- ▶ current: HESS, MAGIC, VERITAS



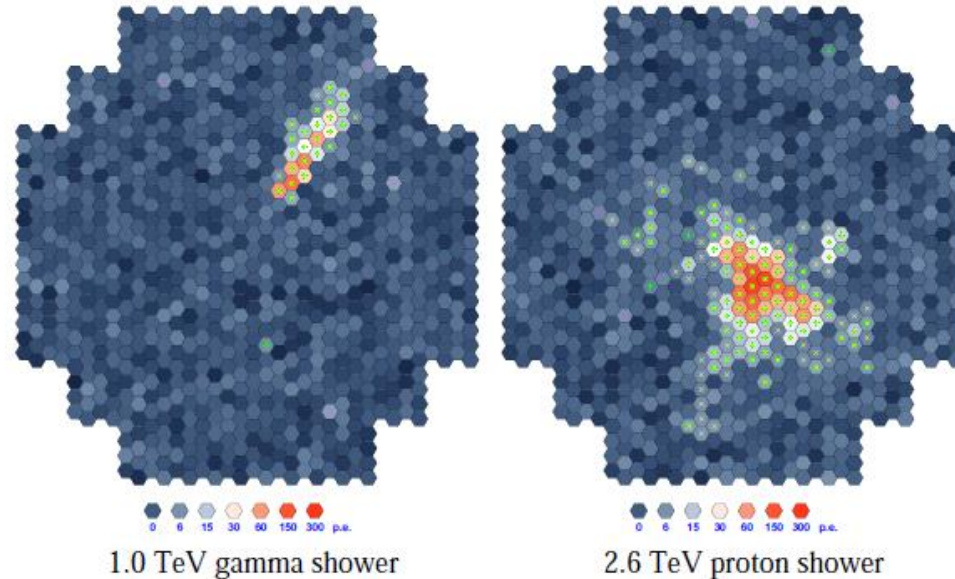
Cherenkov light

- ▶ (mainly) blue light pulse, duration ~ 10 ns
- ▶ ~ 1000 Cherenkov photons per 13m telescope for $E_\gamma = 100$ GeV

(cf. J Hinton, NJP 2009)

→ Proven and highly performing detection technology

H.E.S.S.: Imaging with PMT cameras



“Main” challenge: background rejection

- ▶ hadronic CR events outnumber γ -rays by $\sim 10^{2...4}$
- ▶ rejection by image properties and shower direction

Effective area: $2 \cdot 10^5 \text{ m}^2$ at 1 TeV

F.o.V: 5°

Angular Resolution: 0.1°

Energy Resolution: $10\% \cdot E$

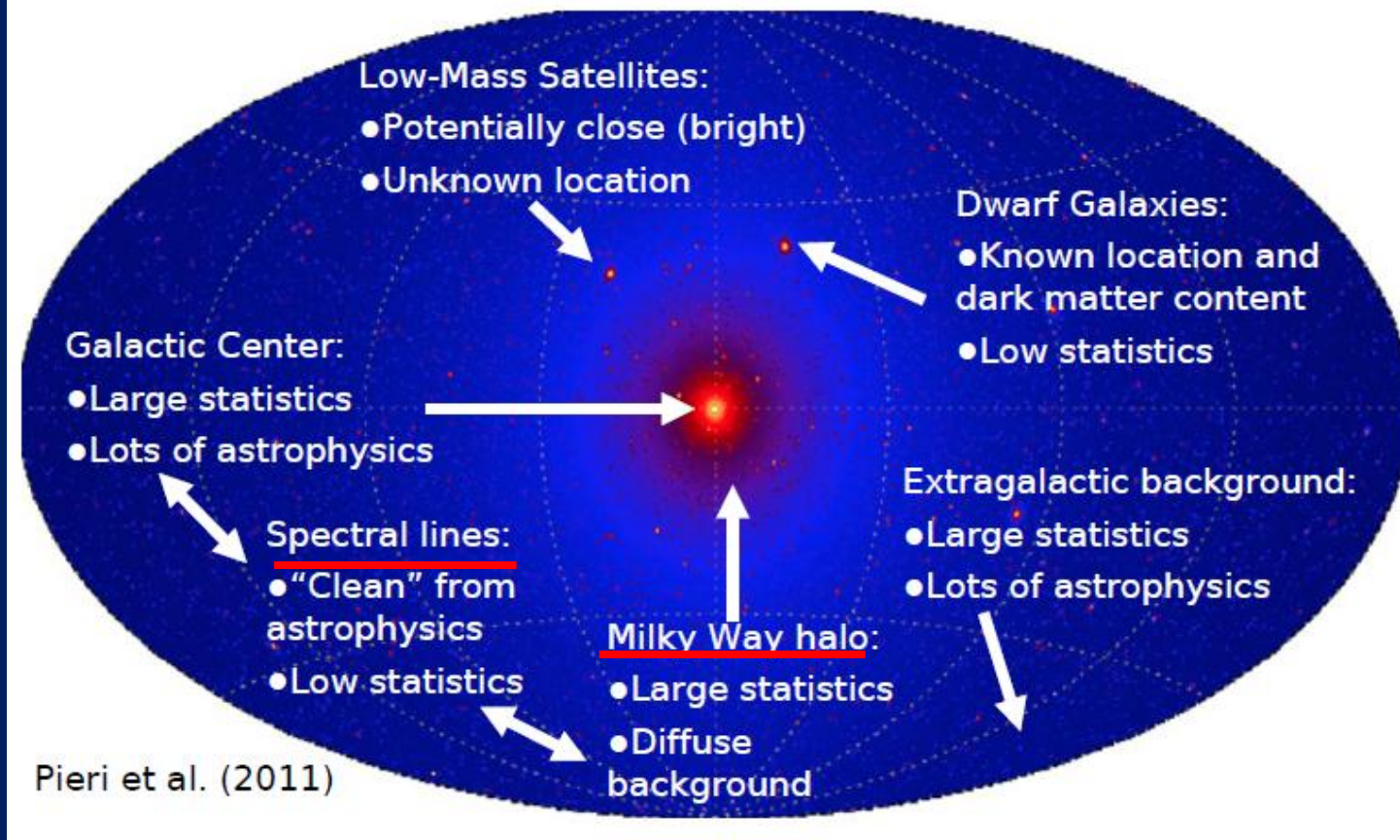
Crab sensitivity $\sim 43 \sigma/\sqrt{\text{hr}}$!

Where to observe Dark Matter

●electrons

Galaxy clusters:

- Possibly large statistics
- Astrophysical signal expected



H.E.S.S. targets

Milky Way DM halo

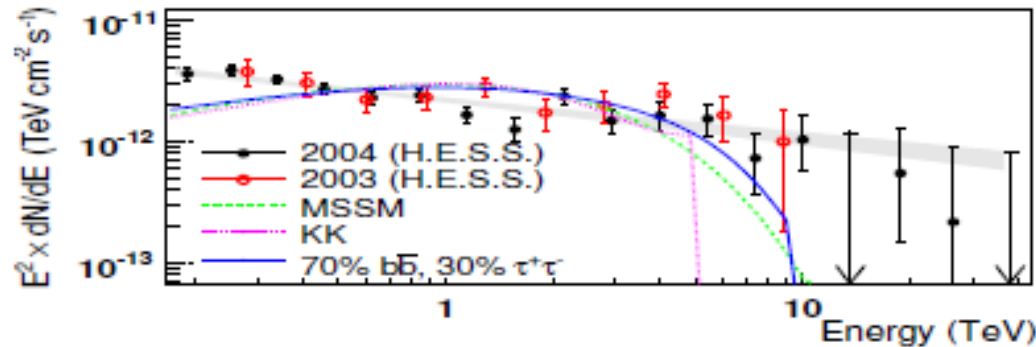
- ▶ Galactic centre, Galactic ridge: $\bar{J} \lesssim 10^{26} \text{ GeV}^2 \text{ cm}^{-5}$
- ▶ Galactic halo (towards the centre)
- ▶ Subhaloes: $\bar{J} \lesssim 10^{23} \text{ GeV}^2 \text{ cm}^{-5}$
 - ▶ Dwarf spheroidals: Sagittarius, Canis Major, Sculptor, Carina
 - ▶ Globular clusters
 - ▶ “dark” point sources (IMBH?)
- ▶ TeV electrons ($e^+ + e^-$)

Galaxy clusters / central cD galaxies: $\bar{J} \lesssim 10^{23} \text{ GeV}^2 \text{ cm}^{-5}$

- ▶ Virgo/M87
- ▶ Coma
- ▶ Fornax/NGC 1399

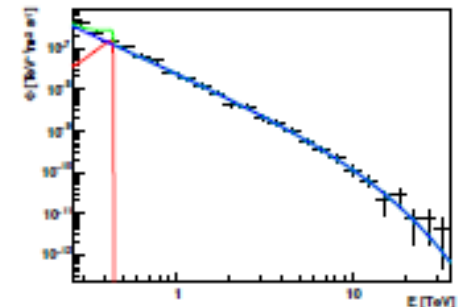
The Galactic Centre

H.E.S.S. source J1745-290 coincident with Sagittarius A*
(MNRAS 402, 1877-1882 (2010))



PRL 97, 221102 (2006)

- ▶ Fit of power-law background + DM signal models to spectrum \rightarrow robust calculation of upper limits: $\langle\sigma v\rangle \leq 10^{-24}$ cm³/s
- ▶ Application of new data: JCAP11(2011)004

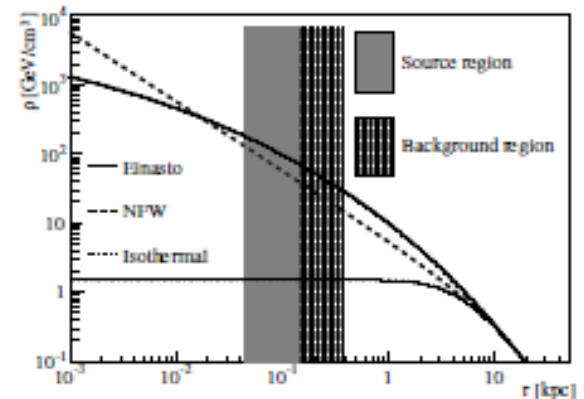
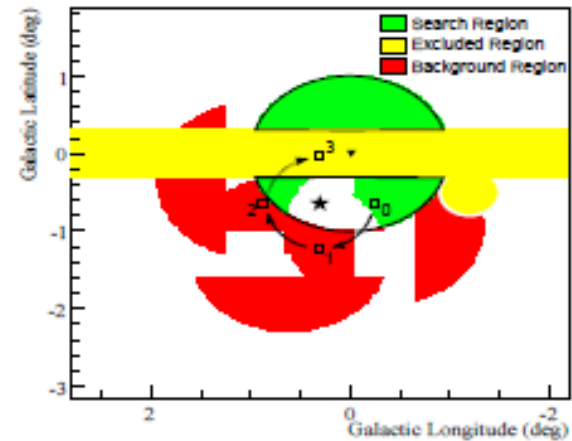


The Galactic Halo

PRL 106, 161301 (2011)

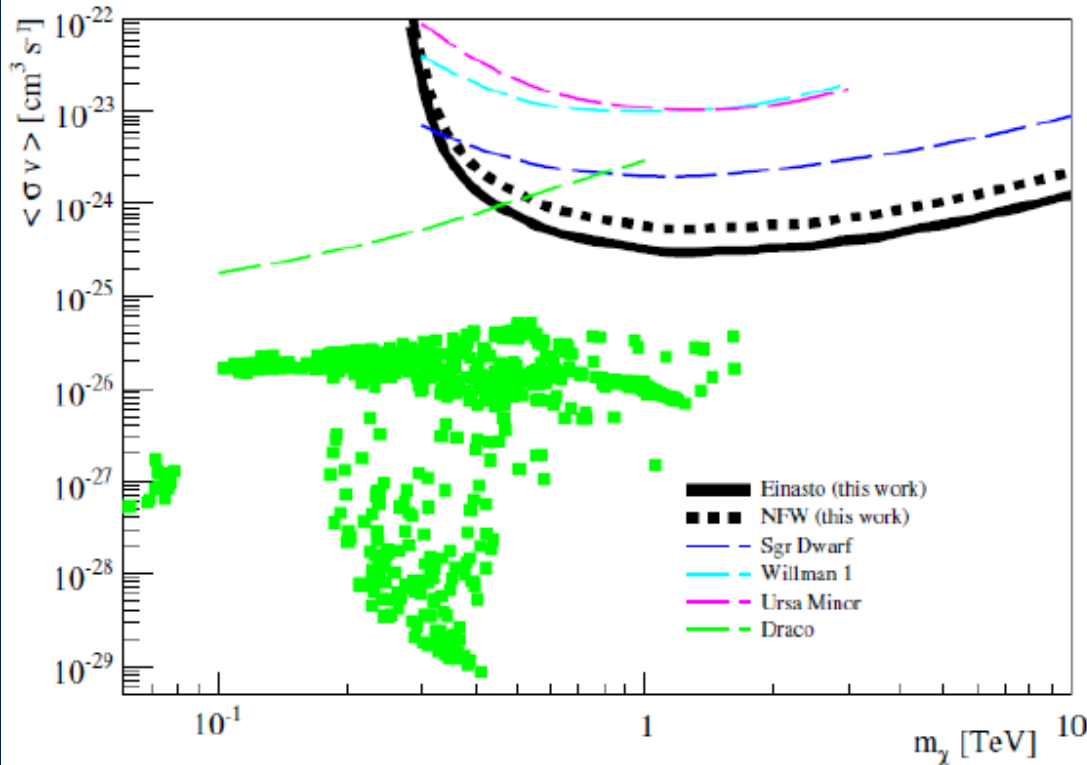
- ▶ Different approach: Search region *around* Galactic centre
- ▶ (non-standard background subtraction method needed)

- ▶ DM halo model uncertainties less relevant
- ▶ Lots of data: > 100 h of observations



The Galactic Halo

Phys.Rev.Lett.106:161301, 2011



→ Main sensitivity
 $M_\chi \sim 1 \text{ TeV}$

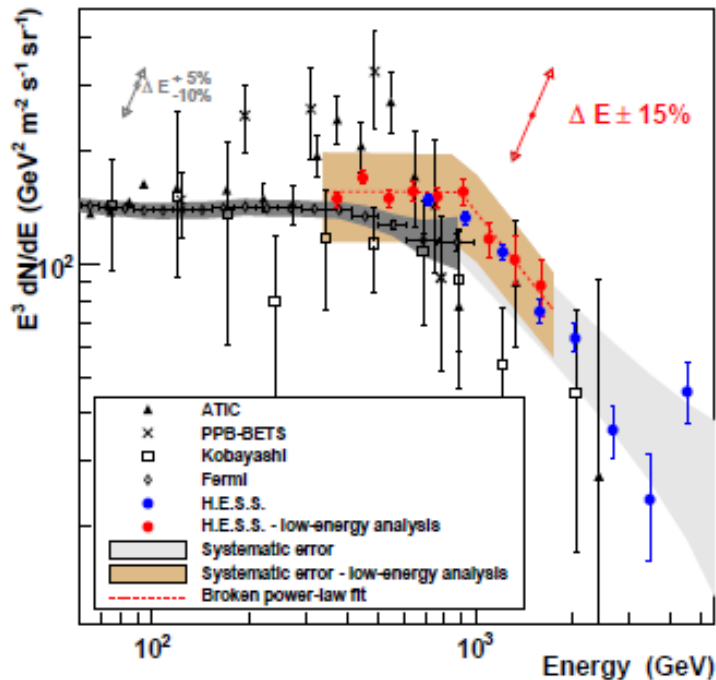
→ Not reaching yet
WMAP compliant
SUSY models
(pMSSM)

→ Complementarity
H.E.S.S. – Fermi

→ Best DM limits from
ACT observations

H.E.S.S. electrons (e^\pm)

PRL 101 (2008) 261104, A&A 508 (2009) 561-564

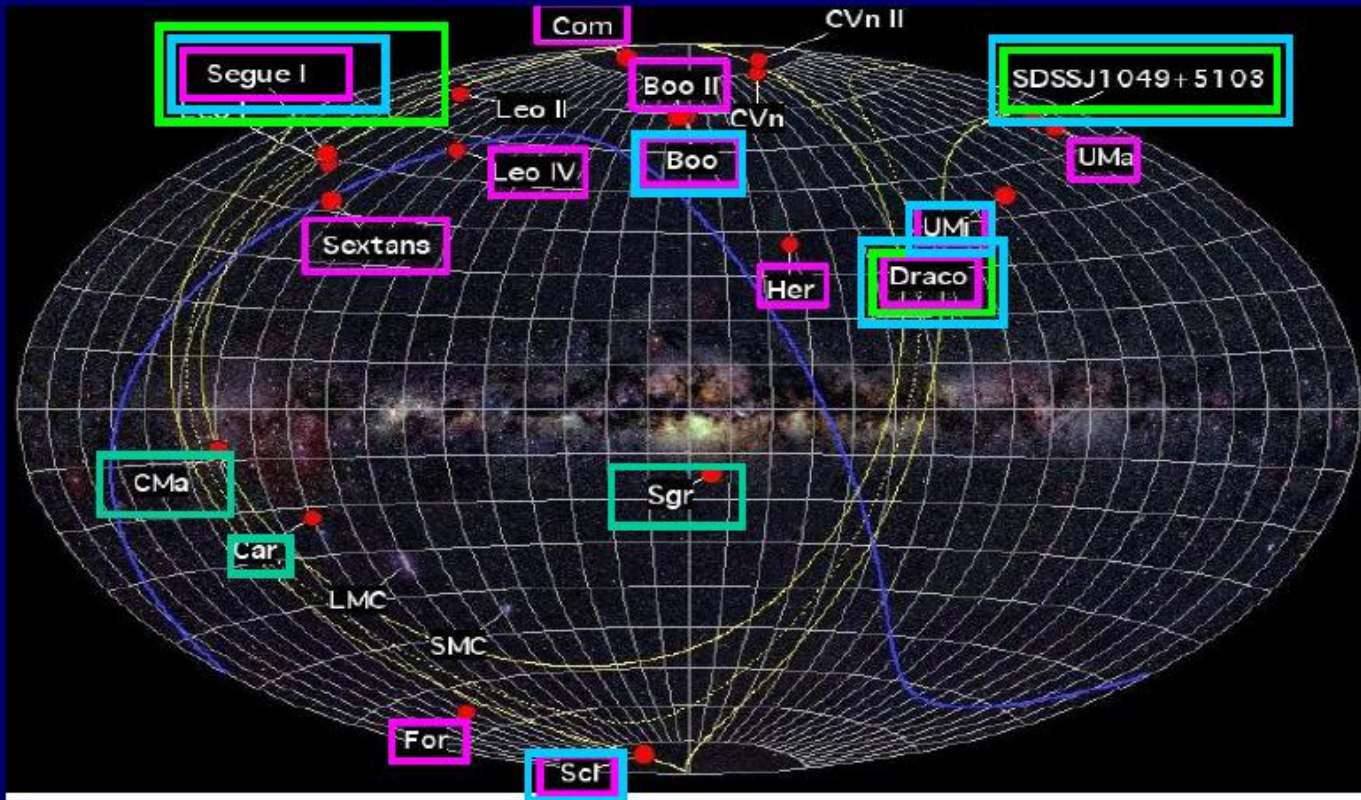


- Extragalactic regions with small γ flux
- Large collection area \rightarrow high statistics
- Electron identification from simulations & Random Forest
- Power law break at ~ 1 TeV

\rightarrow Good agreement with Fermi – ATIC peak not observed

Dwarf Galaxies probed with γ -rays

■ Fermi ■ H.E.S.S ■ MAGIC ■ Veritas

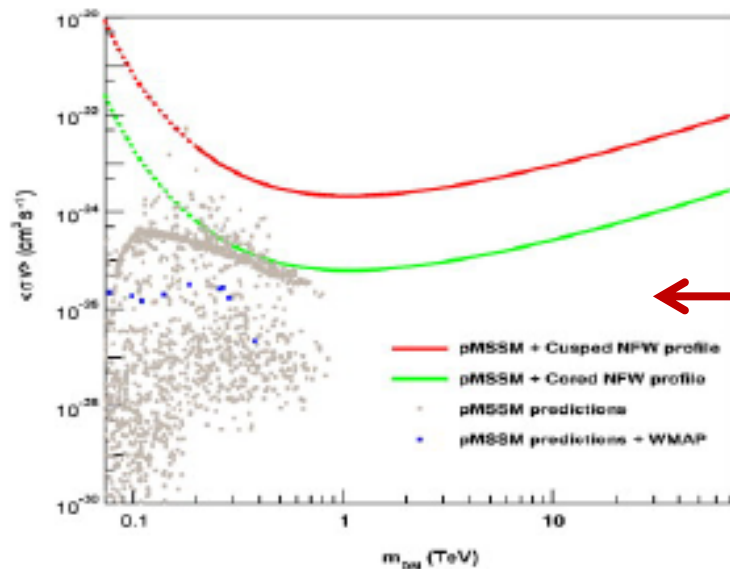


Cleanest targets – low astrophysical background, $d < 100$ kpc
Dark – high M/L ratio, comparatively low Mass
DM profile from stellar dynamics or n-body simulations

Sagittarius Dwarf Galaxy

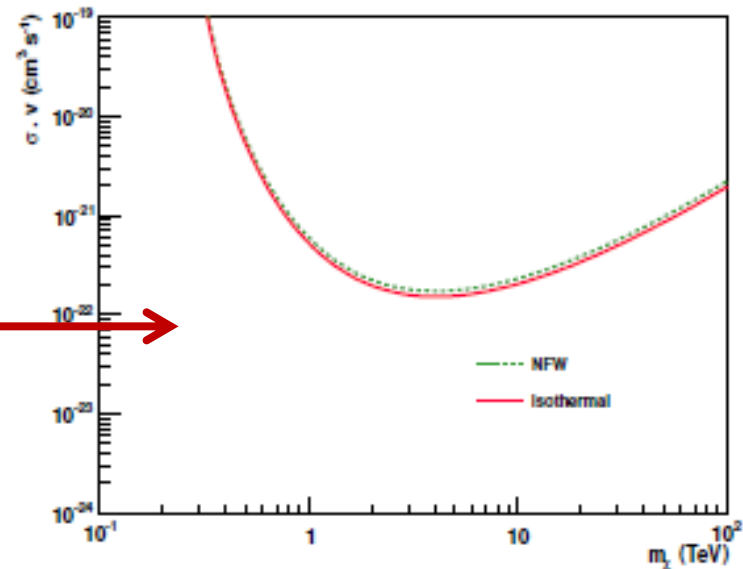
Astropart.Phys. 29,55 ('08)

▶ ~ 11 h of data



ICRC 2011

▶ ~ 45 h of data



- ▶ Different (more realistic) halo model: $\bar{J} = 10^{24..25} \rightarrow 10^{23} \text{ GeV}^2 \text{ cm}^{-5}$
- ▶ Worse constraints despite longer observation

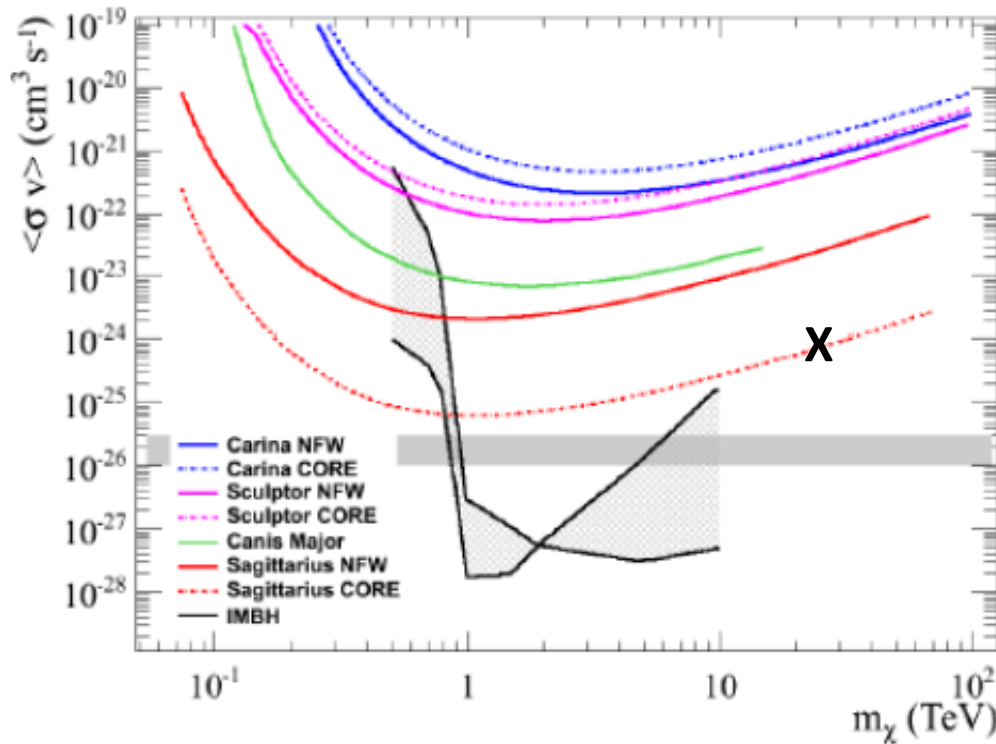
Dwarf Spheroidal Galaxies

No signal: 95% CL limits in the $\langle\sigma v\rangle, m_\chi$ obtained from H.E.S.S. observations

(Astropart. Phys. 29 (2008) 55)

(ApJ 691 (2009) 175-181)

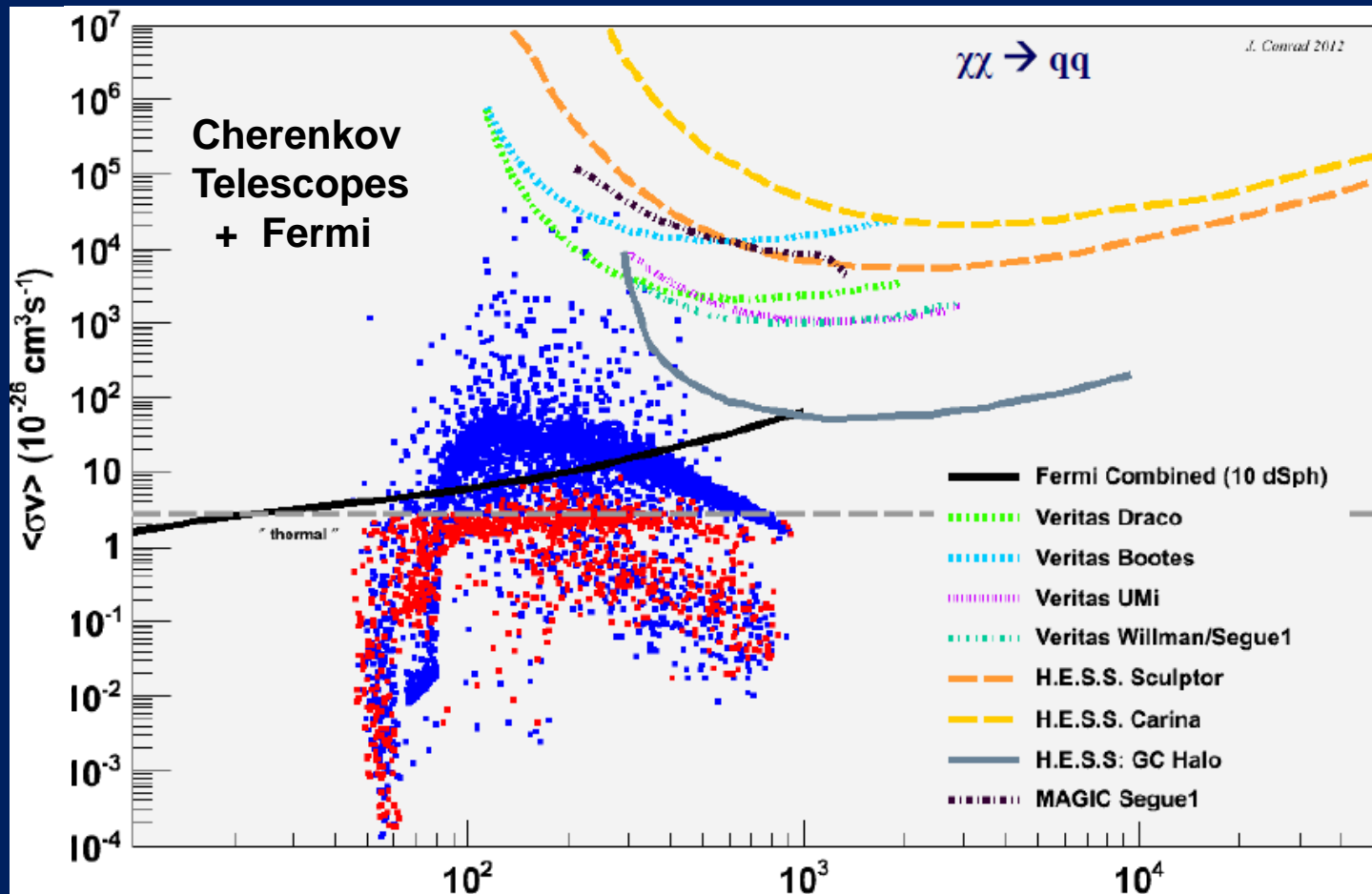
(Astropart. Phys. 34 (2011) 608)



Published results
for the Neutralino LSP

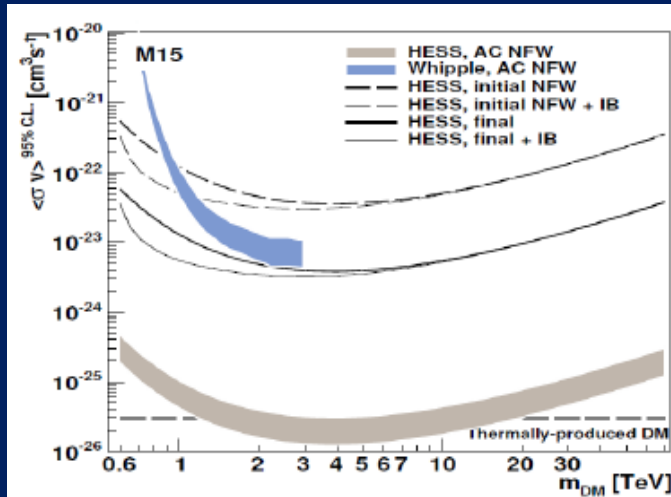
→ Well above
thermal limit

Dwarf Spheroidal Galaxies



→ Complementarity H.E.S.S. - Fermi

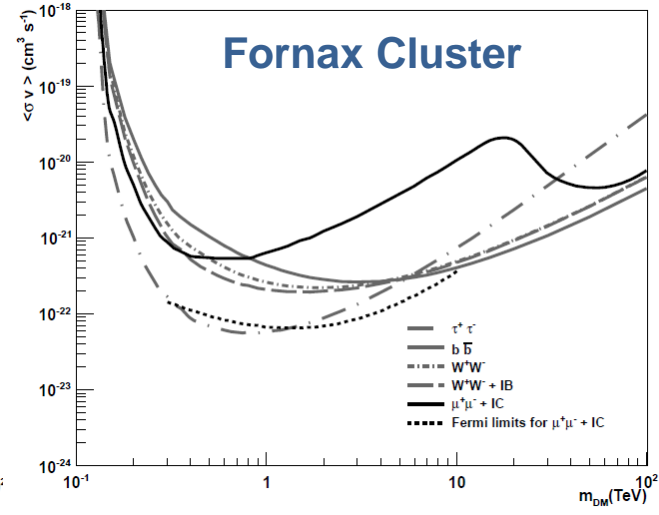
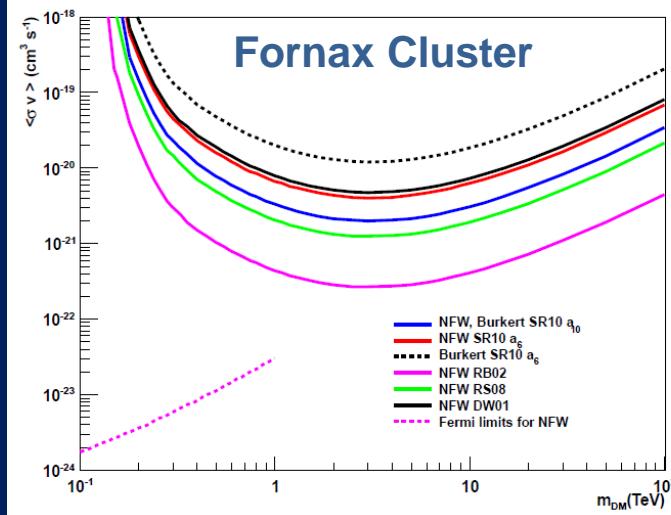
Globular & Galaxy clusters



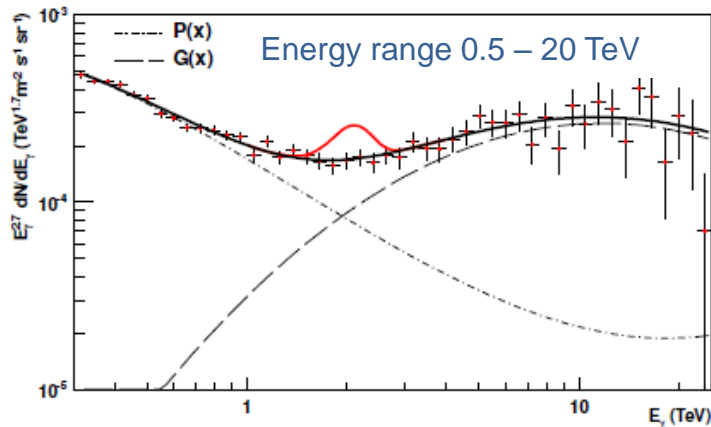
(ApJ 735 (2011) 121)

Extended objects
→ various DM profiles
investigated

(ApJ, 750, 123, 2012)



H.E.S.S. search for Lines



Galactic plane:

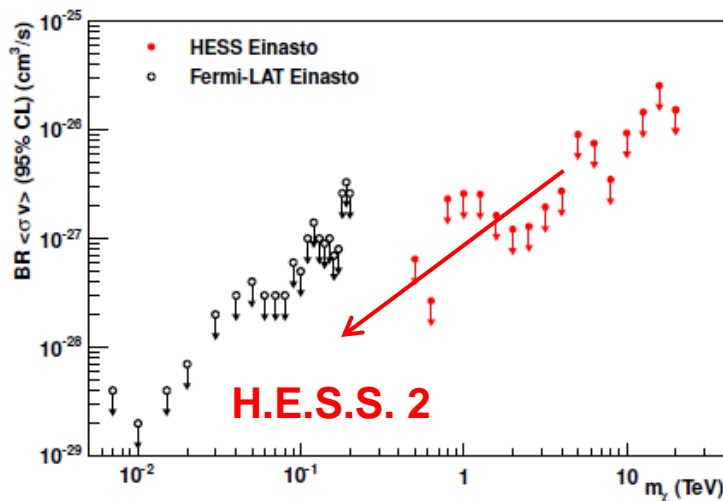
Flux determined in OFF-source regions
→ mostly hadronic background

A Gaussian super imposed on a fitted
Spectrum

Limits derived with binned Likelihood
assuming Poisson fluctuations

→ Unique result > 1 TeV

Complementary to Fermi
“standard” line search

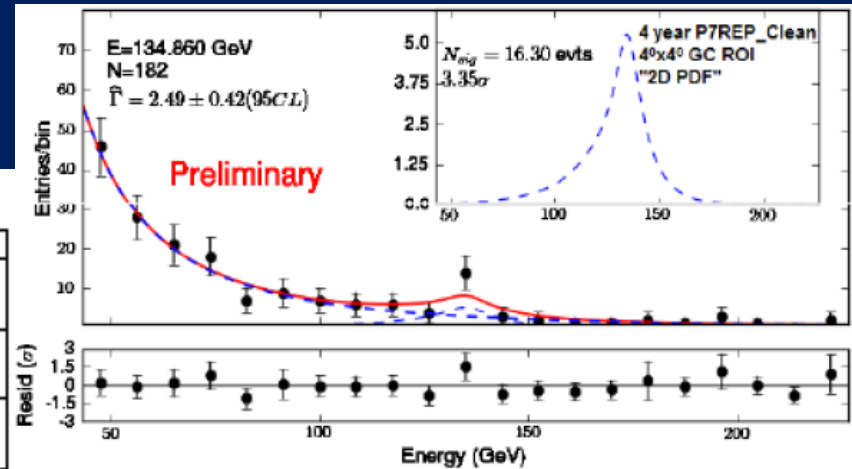
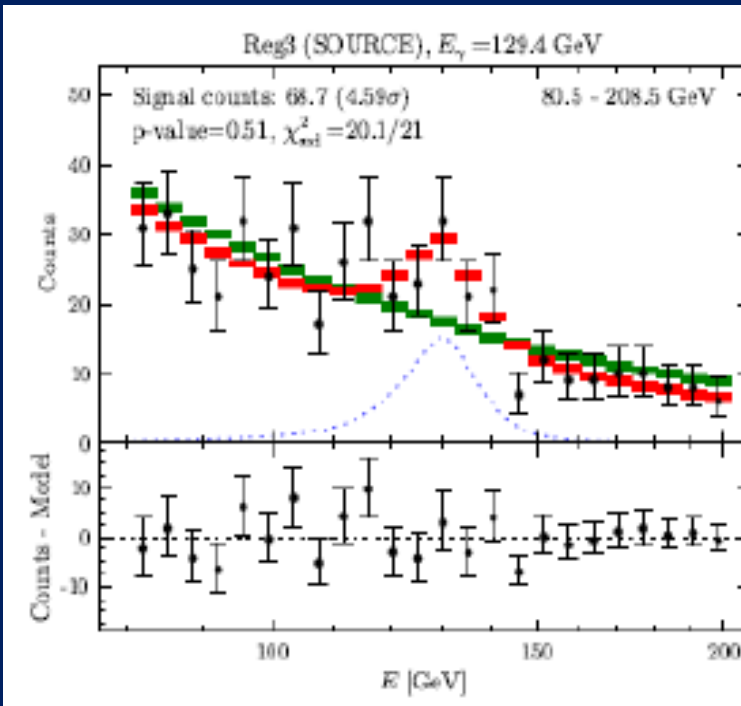


H.E.S.S. 2 prospects: Fermi 130 GeV Lines

Bringmann+, arXiv:1203.1312
Weniger arXiv:1204.2797

Su&Finkbeiner, arXiv:1206.1616
also:Boyarski+, arXiv:1205.4700
Tempel+, arXiv:1205.4882 (4.5 σ)

A. Albert (Fermi-LAT)



External authors:

3.3/5.0 σ LEE corrected (50 events)
1.5 $^\circ$ offset from G.C., maybe 2 lines

Fermi:

3.35 σ local – and Limb Signal !

→ First priority for H.E.S.S. 2 in 2013

Summary (1)

H.E.S.S. 1 Legacy

- as provided a variety of results on Dark Matter search with γ -rays from almost all dark matter targets observed (G.C., Dwarf Galaxies, diffuse, clusters, IMBHs ...)
- No significant signal has been found yet in the domain covered by the experiment:
 - Best limit on $\langle\sigma v\rangle \sim 10^{-24} \text{ cm}^3\text{s}^{-1} m_\chi > 300 \text{ GeV}$
- Beside learning about galaxies, H.E.S.S. 1 provided valuable insight to Fundamental issues in Cosmology
 - excluding many Particle Physics models
 - e. g. Wino – dark matter, “boost factors” (Sommerfeld effect, clumps...)

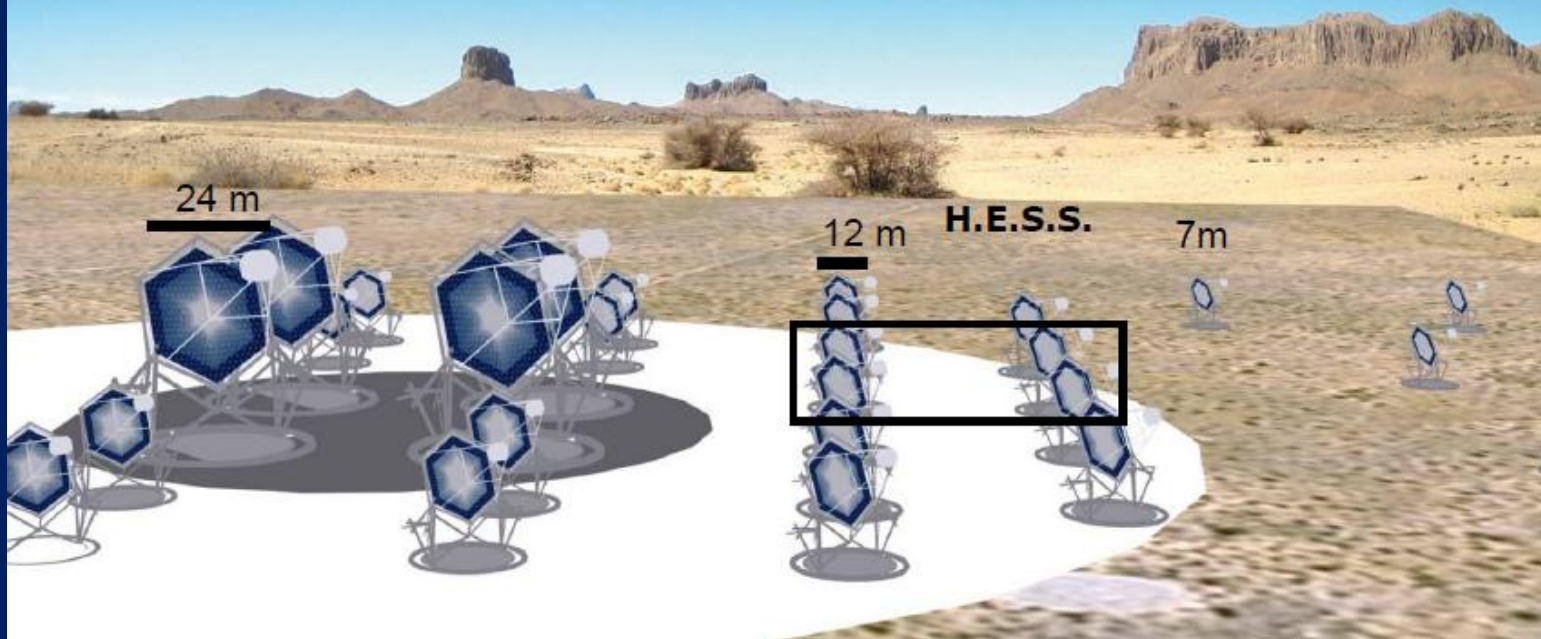
Summary (2)

H.E.S.S. 2 prospects

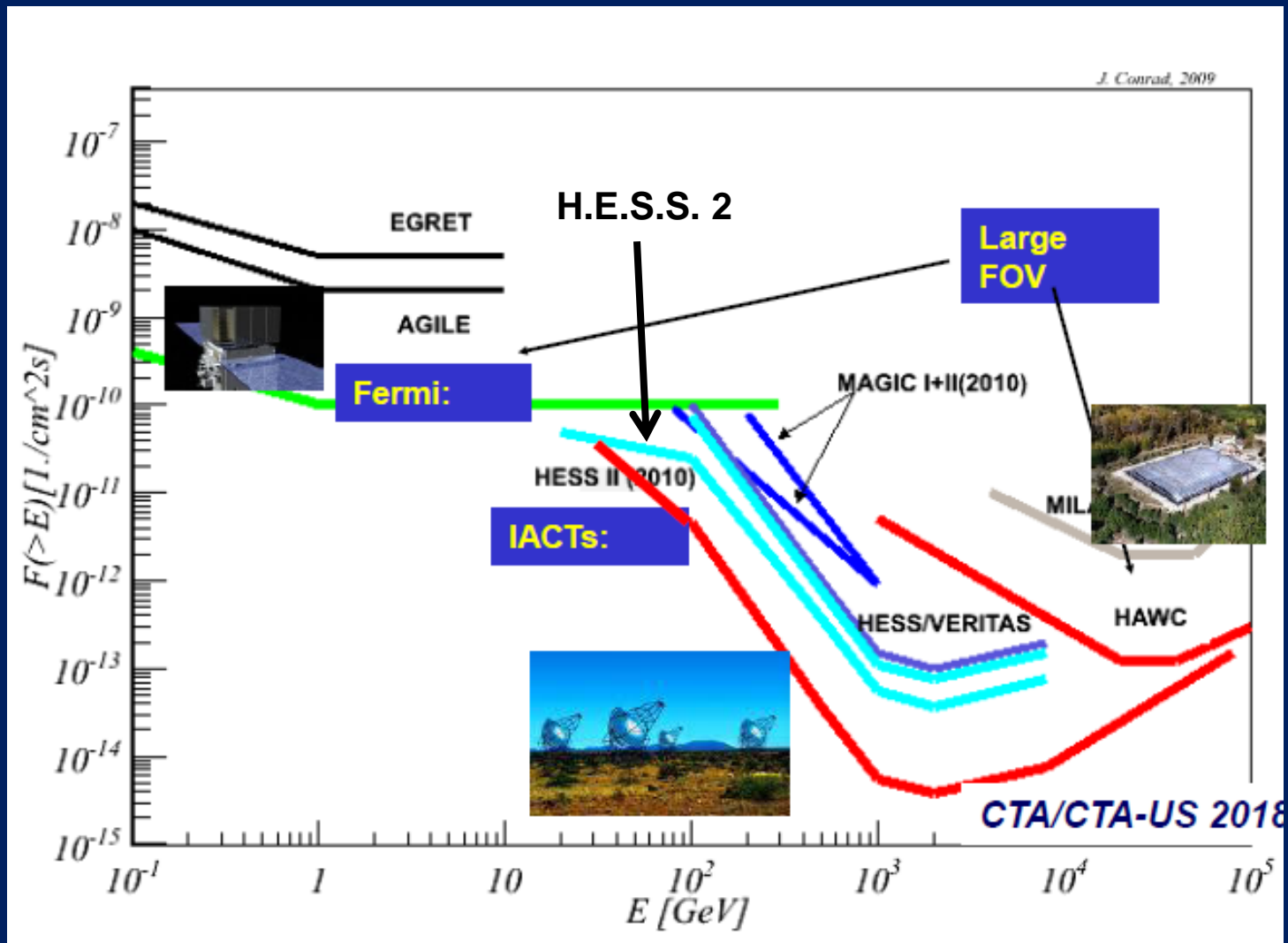
- Large 5th Telescope:
few*10 GeV energy threshold and increased effective area
 - New domain opens for dark matter detection
e.g. 130 GeV line search (special case in the G.C. region)
sensitivity to $m\chi > 150$ GeV
 - complementary and *redundant* to Fermi
- H.E.S.S. studies belong to huge effort for solving Dark Matter enigma which needs:
 - astrophysical detection – indirect and direct
 - study of properties in the laboratory - LHC
 - making connection between the two

Cherenkov Telescope Array (CTA)

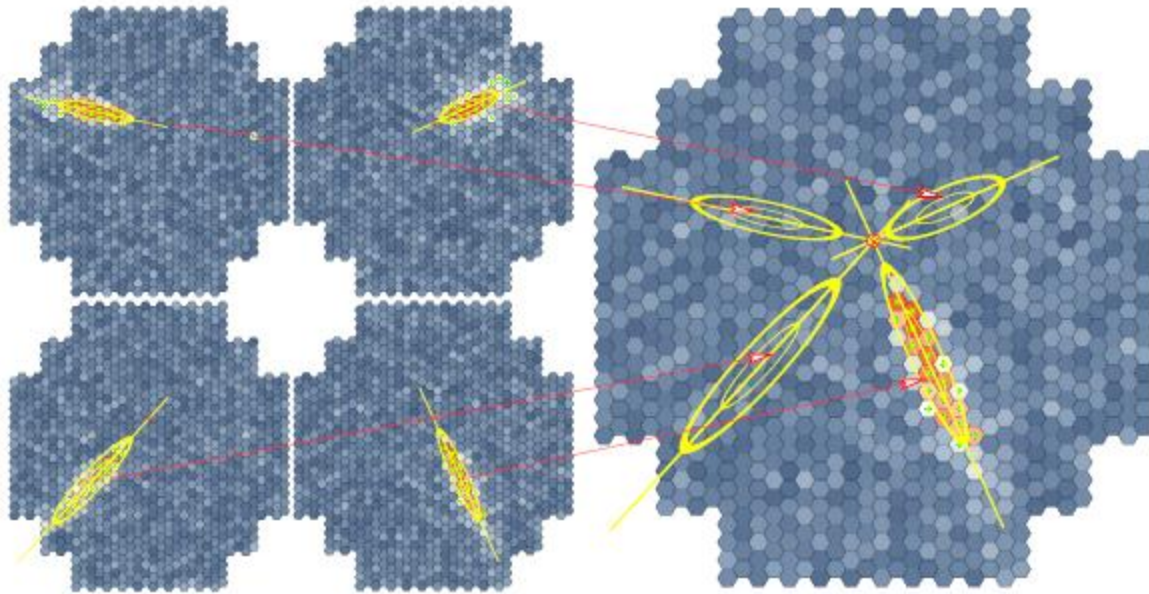
- Next generation Air Cherenkov telescope
- Increased sensitivity by factor 10 → new insights for Dark matter, Cosmic rays etc. etc.
- Global consortium: ~25 countries, ~500 scientists
- Construction start 2014, *full* operation 2018



Backup: Sensitivities

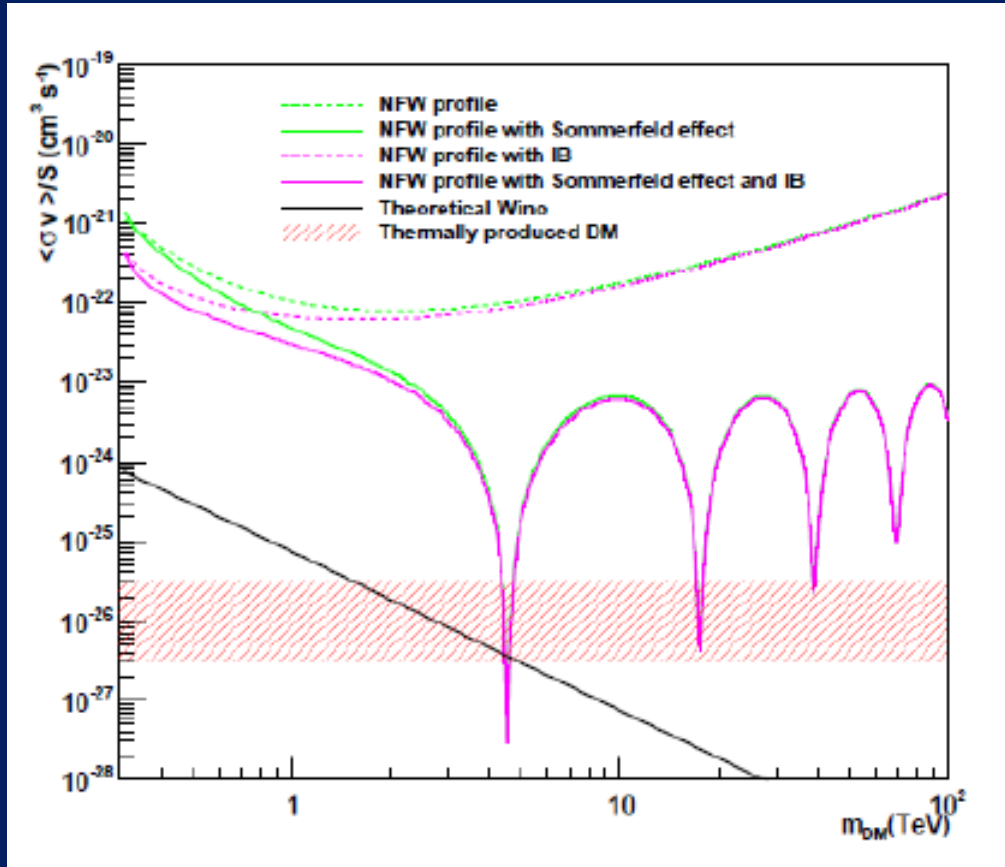


Backup: Steroscopy



- ▶ stereoscopic technique
- ▶ better background rejection via shower direction

Sommerfeld Effect enhancement

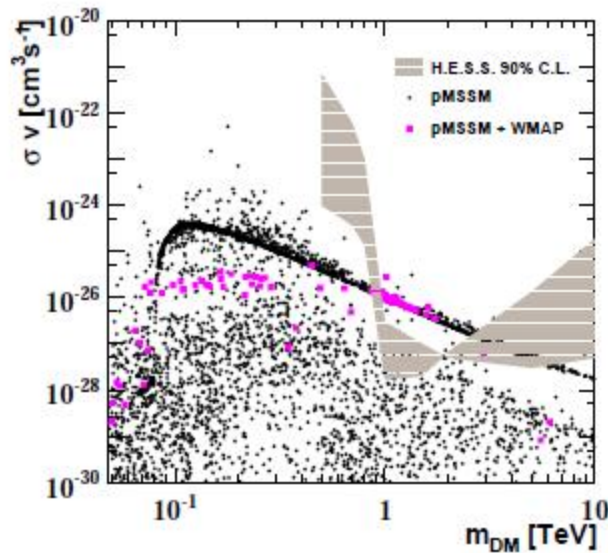
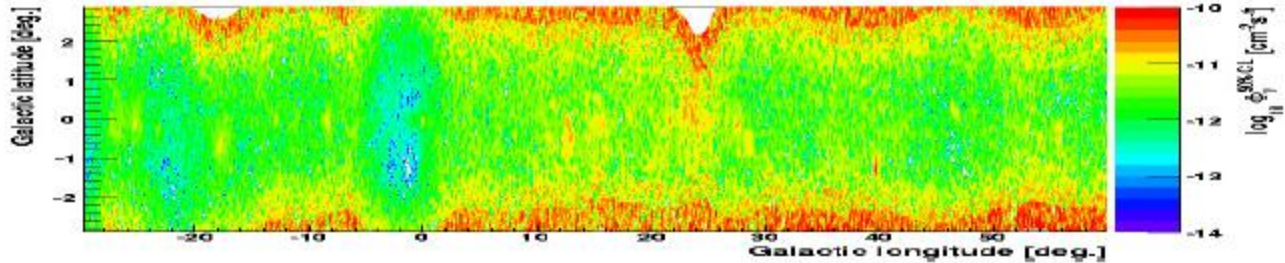


**Example:
Sculptor Dwarf
Galaxy**

**Wino DM annihilates
via Z boson**

→ Resonances allow to exclude specific WIMP masses

Backup: Point source search



PRD 78,072008 (2008)

- ▶ IMBH: from Pop-III stars or primordial halos
- ▶ use Galactic plane scan, excluding known sources
- ▶ assume ~ 100 IMBH in MW halo
- ▶ SUSY limit: $\langle \sigma v \rangle \leq 10^{-27} \text{ cm}^3/\text{s}$ for $m_{\chi} > 1 \text{ TeV}$ (90 % C.L.)