Indirect Dark Matter searches with H.E.S.S.

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E. Moulin
DAPNIA/SPP
CEA - Saclay, France

High Energy Stereoscopic System

System of four Imaging Atmospheric Cherenkov Telescopes designed for very high energy ($E\gamma$ >100 GeV) γ-ray astronomy

MPI Kernphysik, Heidelberg
Humboldt Univ. Berlin
Ruhr-Univ. Bochum
Univ. Hamburg
LSW Heidelberg
Univ. Tübingen
Univ. Erlangen
Ecole Polytechnique, Palaiseau
APC Paris
Univ. Paris VI-VII
Paris Observatory, Meudon
LAPP Annecy
LAOG Grenoble
LPTA Montpellier
DAPNIA Saclay
CESR Toulouse

Durham Univ.
Leeds Univ.
Dublin Inst. for Adv. Studies
Charles Univ., Prague
Yerewan Physics Inst.
North-West Univ., Potchefstroom
Univ. of Namibia, Windhoek
Nicolaus Kopernikus Astr. Center, Warsaw
Jagiellonian University, Cracow
Institute of Nuclear Physics, Warsaw
Space research center, Warsaw

~30 institutes
130 physicists and astrophysicists

Indirect dark matter search

Gamma-ray flux from WIMP annihilation:

$$\frac{d\Phi_\gamma(\Delta\Omega,E)}{dE} = F_0 \frac{dN_\gamma}{dE} \frac{<\sigma v>}{<\sigma v>_{ref}} \left(\frac{1\,TeV}{m_{DM}}\right)^2 \frac{1}{\Delta\Omega} \int_{\Delta\Omega} d\Omega \int_{l.o.s} \rho^2(r[s])\, ds$$

Angular acceptance

$\Delta\Omega_{HESS} = 2\times10^{-5}$ sr

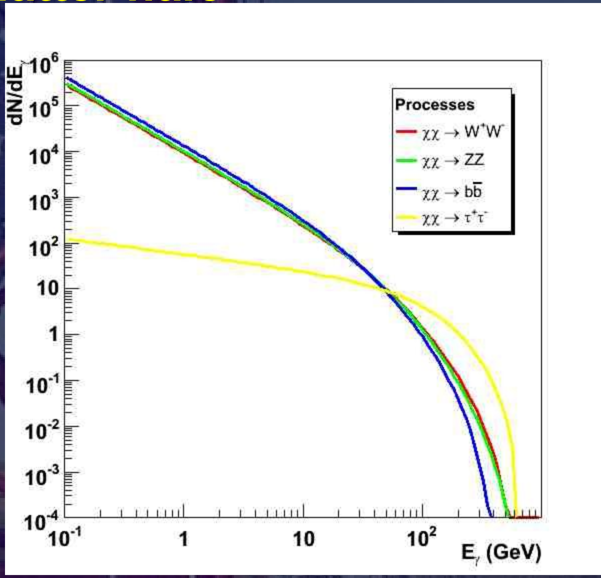
Particle Physics :

- Cross sections
- Branching ratios
- Differential photon yield
- Mass of the DM particle

Astrophysics : Dark matter halo

strong dependence on the spatial distribution

→ model required for density profile



Gamma spectrum: typically a continuum with an exponential cut-off at the DM particle mass

Dark Matter candidates

- Lots of candidates satisfy WIMP requirements…
- Here, we study two well-known cases:

  - neutralino (SUSY)
  - Kaluza-Klein (UED) particles

The lightest neutralino (LSP):

$$\tilde{\chi}_1^0 = Z_{11}\tilde{B} + Z_{12}\tilde{W} + Z_{13}\tilde{H}_1^0 + Z_{14}\tilde{H}_2^0$$

- stable if R-parity conserved
- relic density can accommodate WMAP constraints on CDM

- annihilation spectrum:

- gamma-ray lines suppressed
- continuum from $W^{\pm}$, Z, b, $\bar{b}$ hadronisation

The lightest Kaluza-Klein particle (LKP): $B^{(1)}$

- first KK excitation of the photon
- stable if K-parity conserved
- mass in the range 400-1200 GeV to satisfy WMAP constraints

- annihilation spectrum: continuum from charged leptons and quarks

The H.E.S.S. telescope array

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

- 13 m diameter telescopes : 107 m² each
- Stereoscopic reconstruction
- Cameras equipped with 960 PMTs
- Large field of view 5°
- Observations on moonless nights, ~1000h/year

- Angular resolution < 0.1°/γ
- Energy threshold (zenith) ~ 100 GeV
- Energy resolution ~ 15%
- Sensitivity: 1% Crab in 25 hours

Potential targets for H.E.S.S.

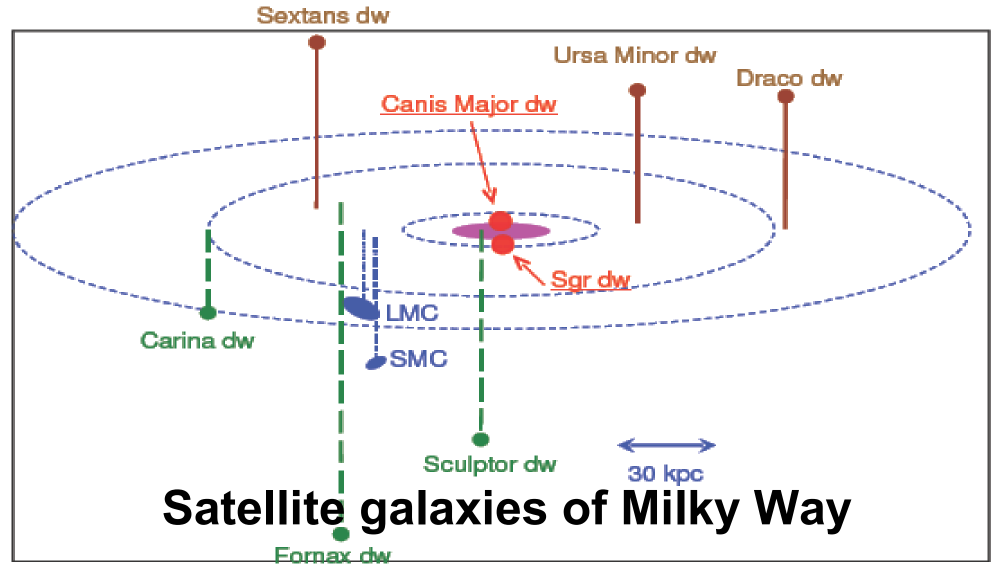
Searches performed on amplification sites:

$$\Gamma_\chi \sim \sigma v \, \frac{\rho_\chi^2}{m_\chi^2}$$

- **Galactic Centre:**
  - distance : 8.5 kpc
  - standard γ-ray emitters ⇒ astrophysical background
  - diffuse emission along the galactic plane

- **Galaxy cluster centres:**
  - Virgo (M87), 16.3 Mpc

- **Dwarf spheroidal galaxies:**
  4 in 100 kpc

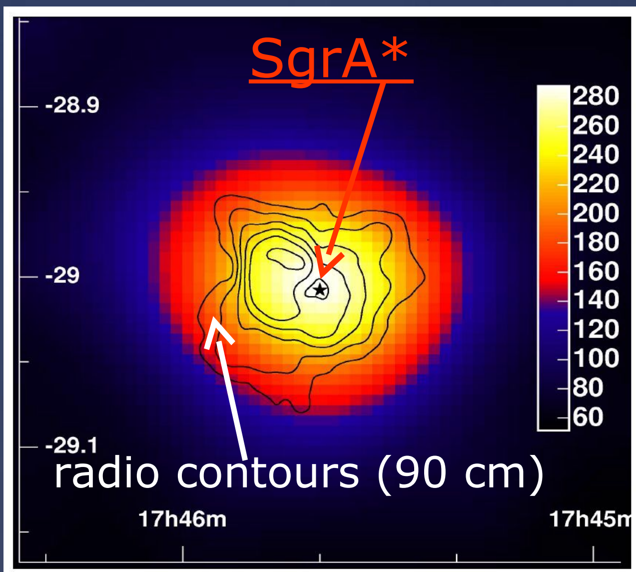


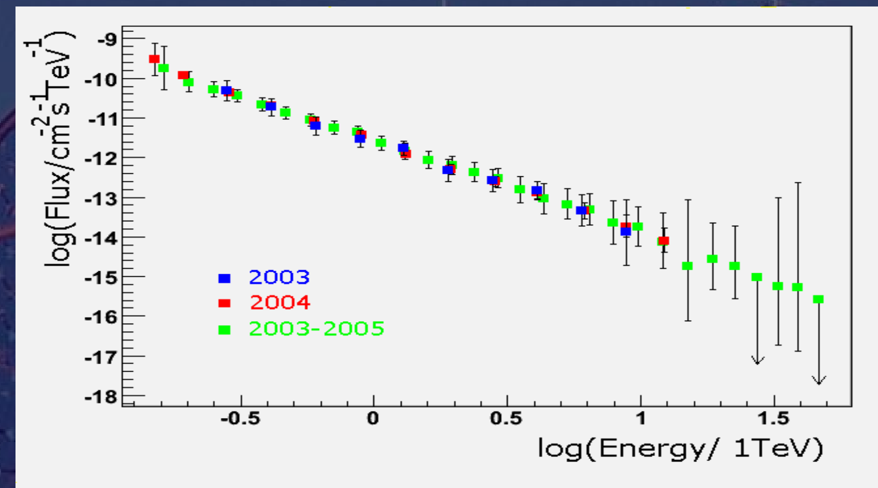
Satellite galaxies of Milky Way

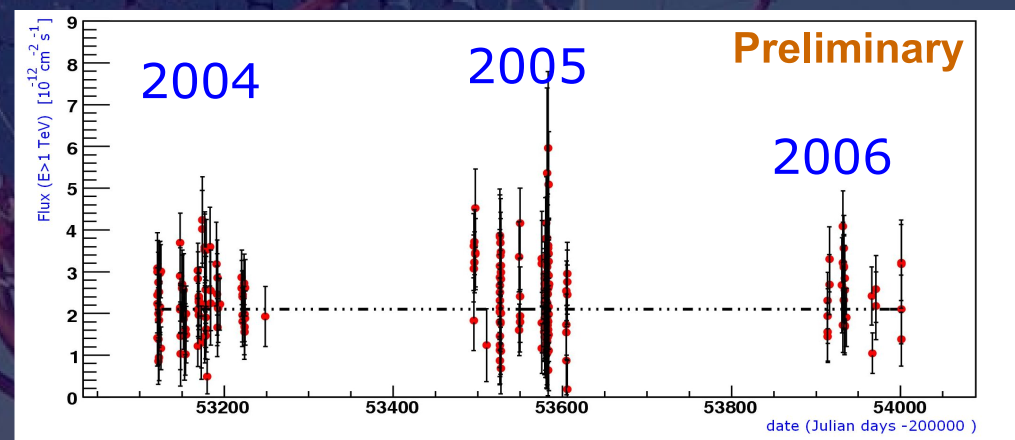
- **Other potential targets:**
  - LMC: d=50kpc, Φ(LMC)/Φ(GC) ~ 4×10^{-8}
  - Coma: d=120Mpc, Φ(Coma)/Φ(GC) ~ 3×10^{-4}

The Galactic Centre: HESS J1745-290

- ❑ ~ 100 h of data taking 2003 → 2005
- ❑ excess ~ 60σ
- ❑ compatible with a point-like source







Position relative to SgrA*

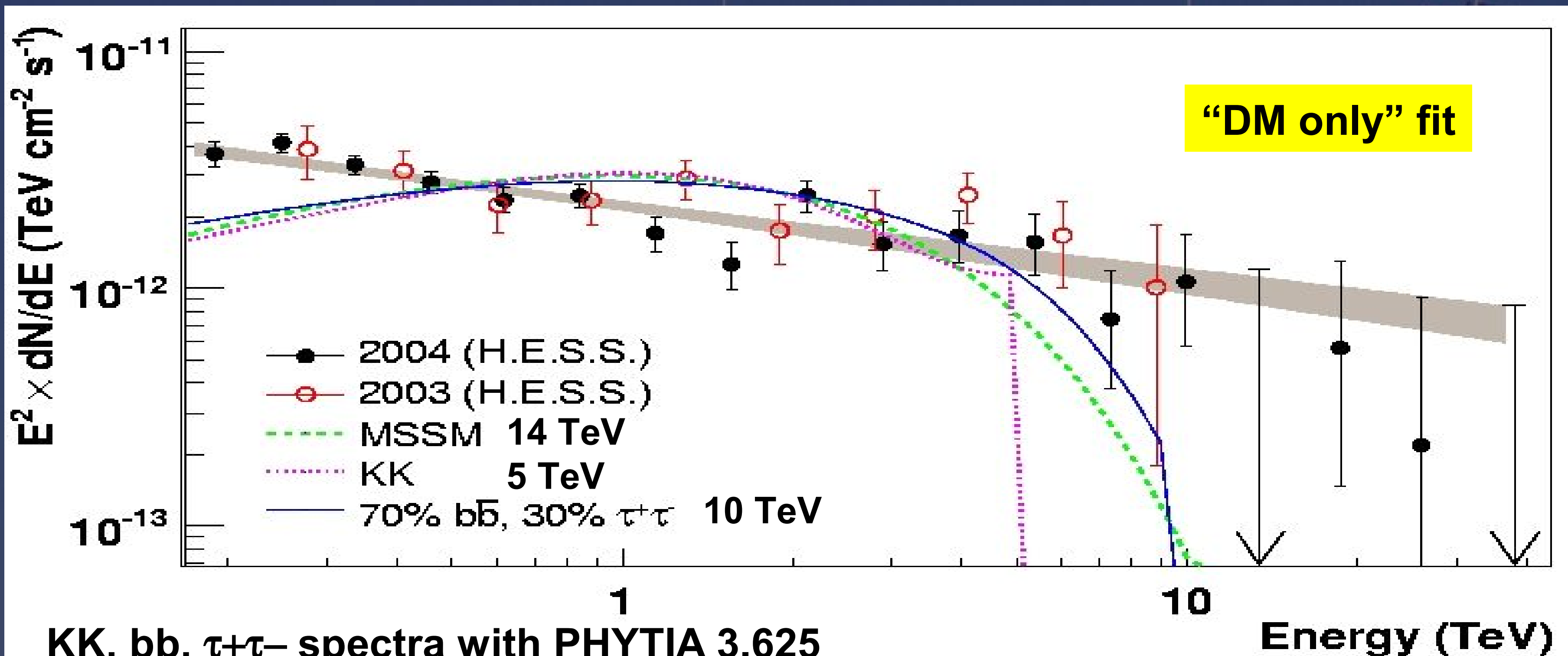
$\delta\theta$ = 5″±10″ (stat)±20″ (syst)

compatible with SgrA* or the

centre of SgrA East SNR

- **constant flux: 1 γ/minute**
- **no significant fluctuation (10 mn → 1 year)**
- **flare sensitivity: 2.5 (6hours) → 0.75 (1month)**
- **no significant periodicity (28mn → 1year)**

HESS J1745-290: spectral constraints

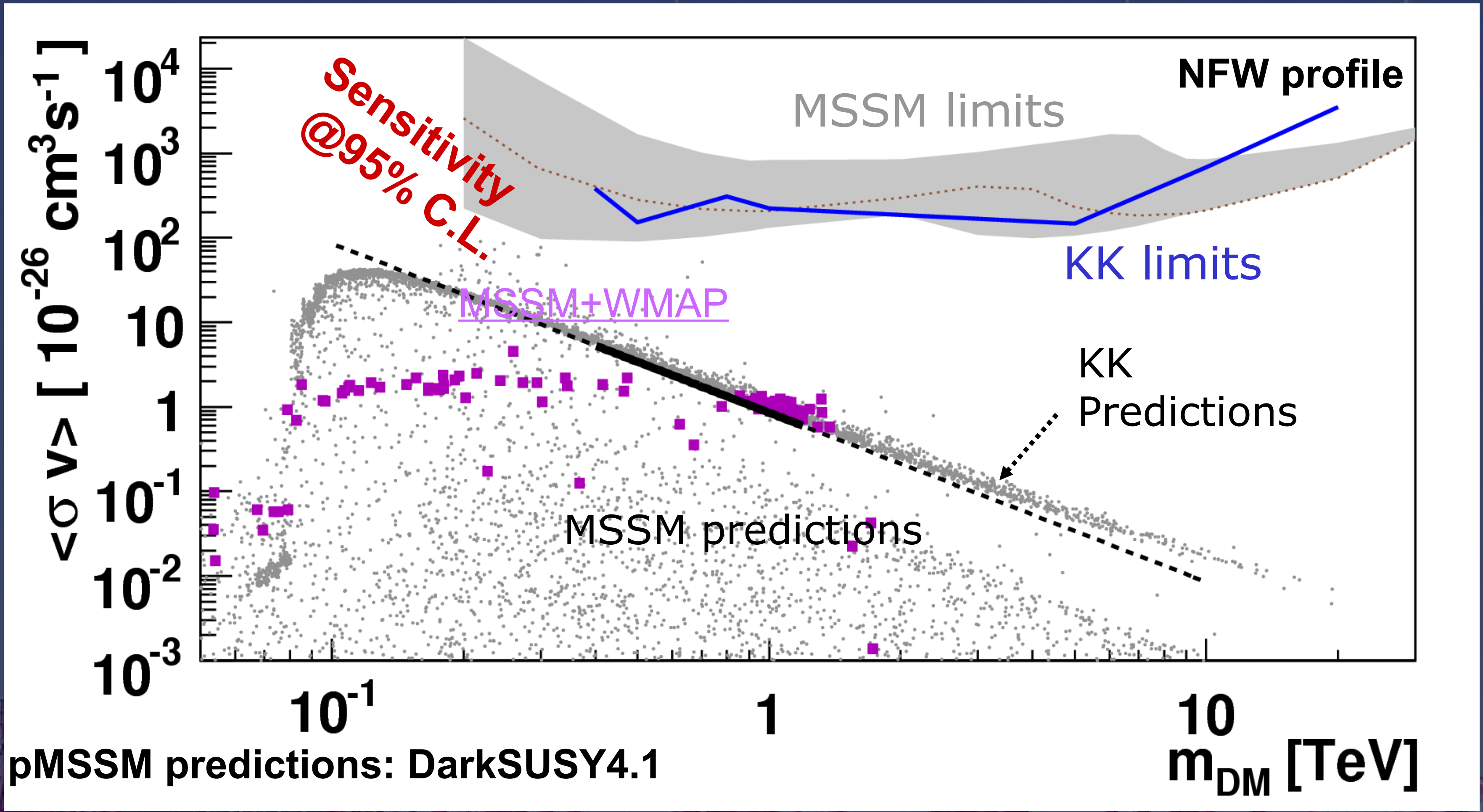


2004 data :

- **Power-law spectrum : Γ = 2.29 ± 0.09 ± 0.15**
- **Exponential cut-off limit : E_{cut} > 6TeV (95% C.L.)**

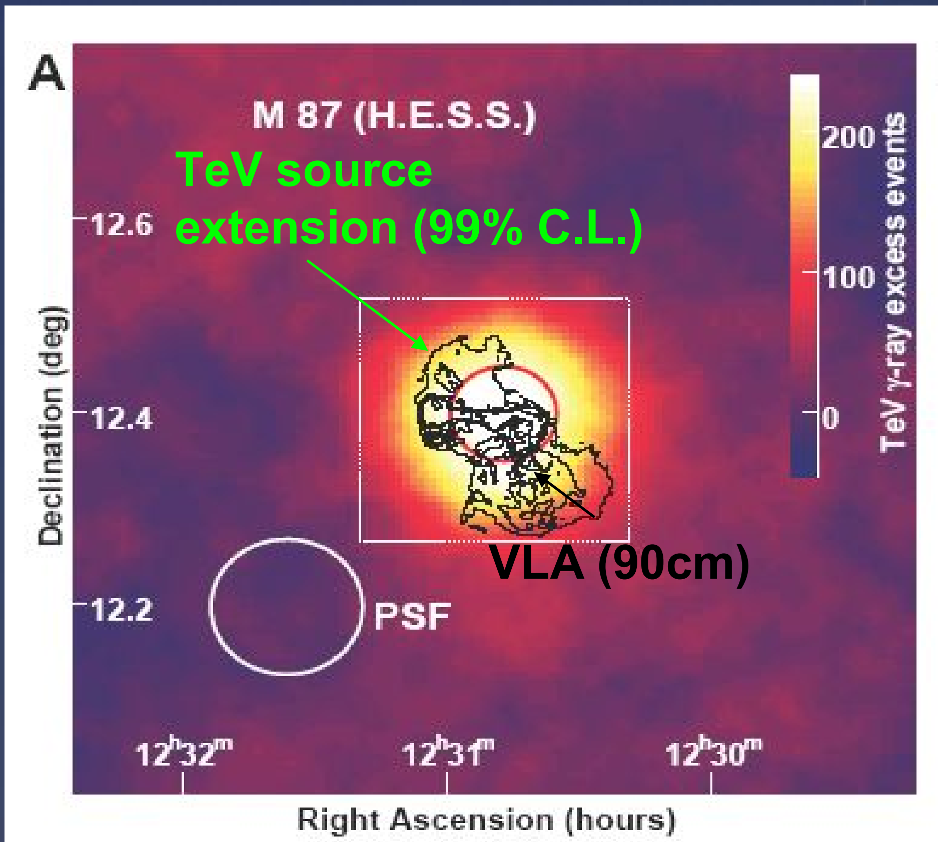
⇒ Heavy WIMPs required, not favored by theory
⇒ Low energy data not well fitted

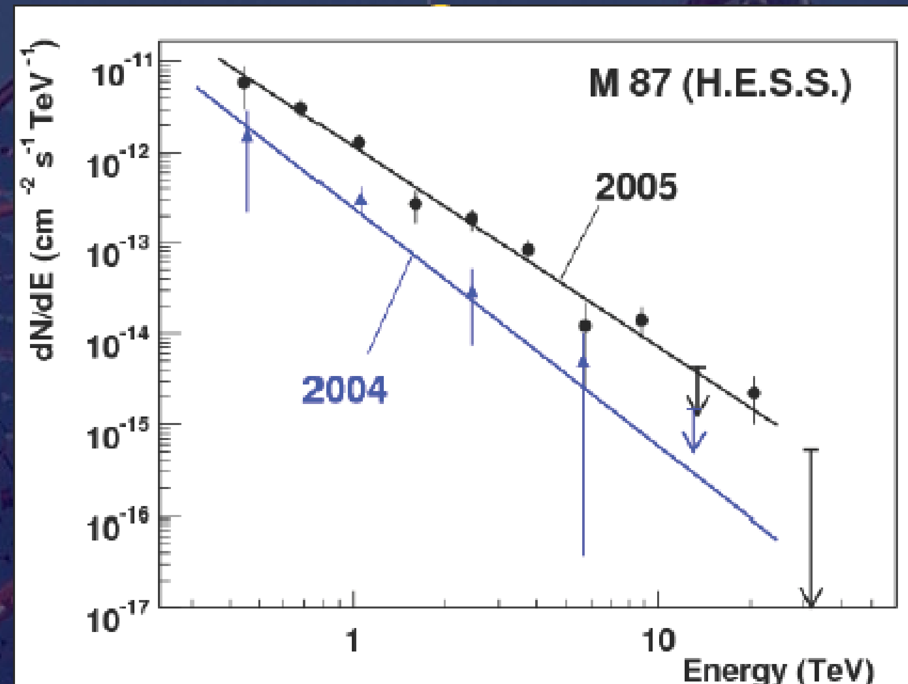
HESS J1745-290: exclusion plots



- **MSSM limit : $<\sigma v> \leq (1\text{-}10)\ 10^{-24}\ cm^3s^{-1}$**
- **KK limit : $<\sigma v> \leq 10^{-24}\ cm^3s^{-1}$**

A TeV signal from M87 (Virgo cluster)

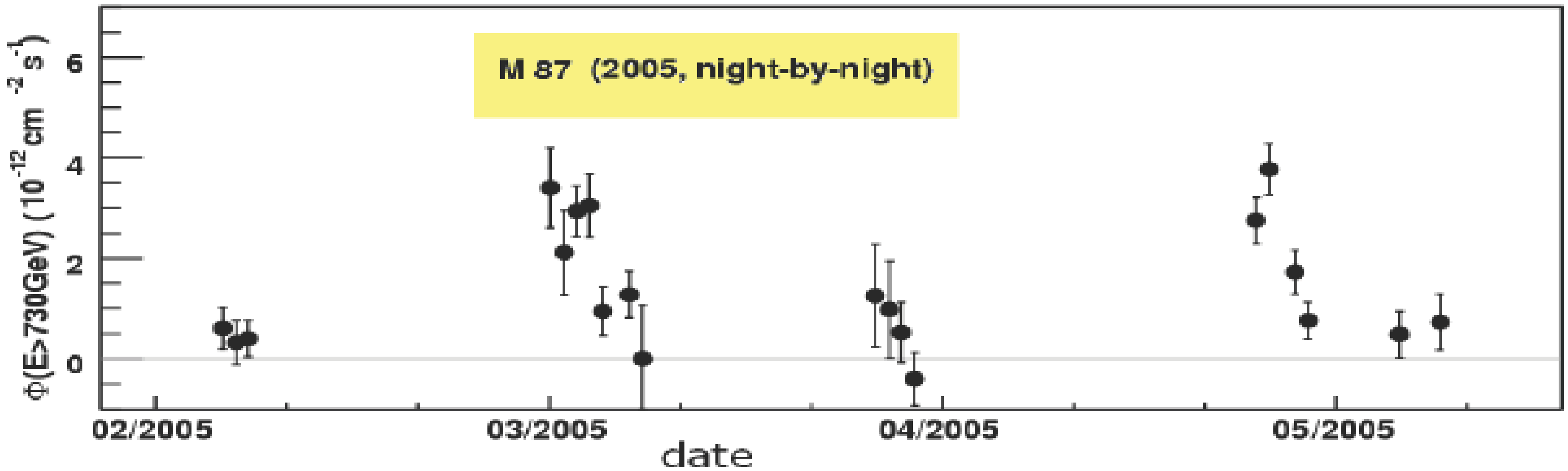




- ❑ Active galaxy, black hole $3.2\times10^{-9}\ M_{sun}$
- ❑ Distance: 16.3 Mpc
- ❑ Jet axis 20-40 deg. from line of sight
- ❑ Detected by HEGRA (2003)

- 13σ detection in 89h (2003-2006)
- Point-like source: < 3’ (99% C.L.)
- Power law spectrum:
  - $\Gamma = 2.22 \pm 0.25$ (2005)
  - $\Gamma = 2.62 \pm 0.35$ (2004)
- Temporal variability

Variability of the TeV signal from M87



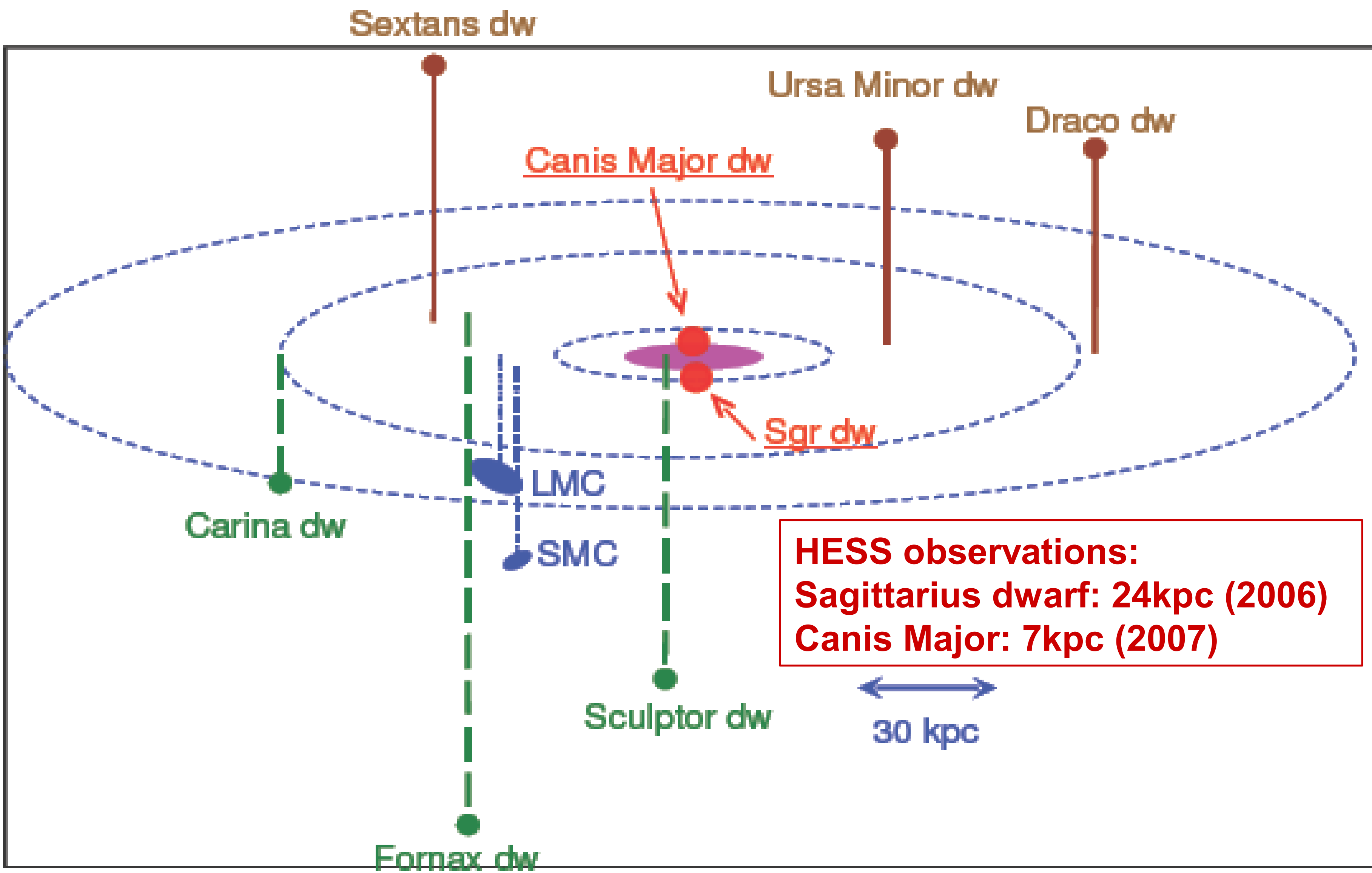
- Long term variabiliy ~1 year (3.2σ)
- Short term varaibilty ~2 days (4σ)
- Emission region size < ~50 R_s ⇒ production site: black hole?

Dark matter predictions:

- $m\chi$=1 TeV, MSSM, $\chi\chi \rightarrow WW$ with Moore profile:
  $\Phi(>730GeV) \sim 10^{-16}$ $cm^{-2}s^{-1}$
- 1000 times lower than observed…

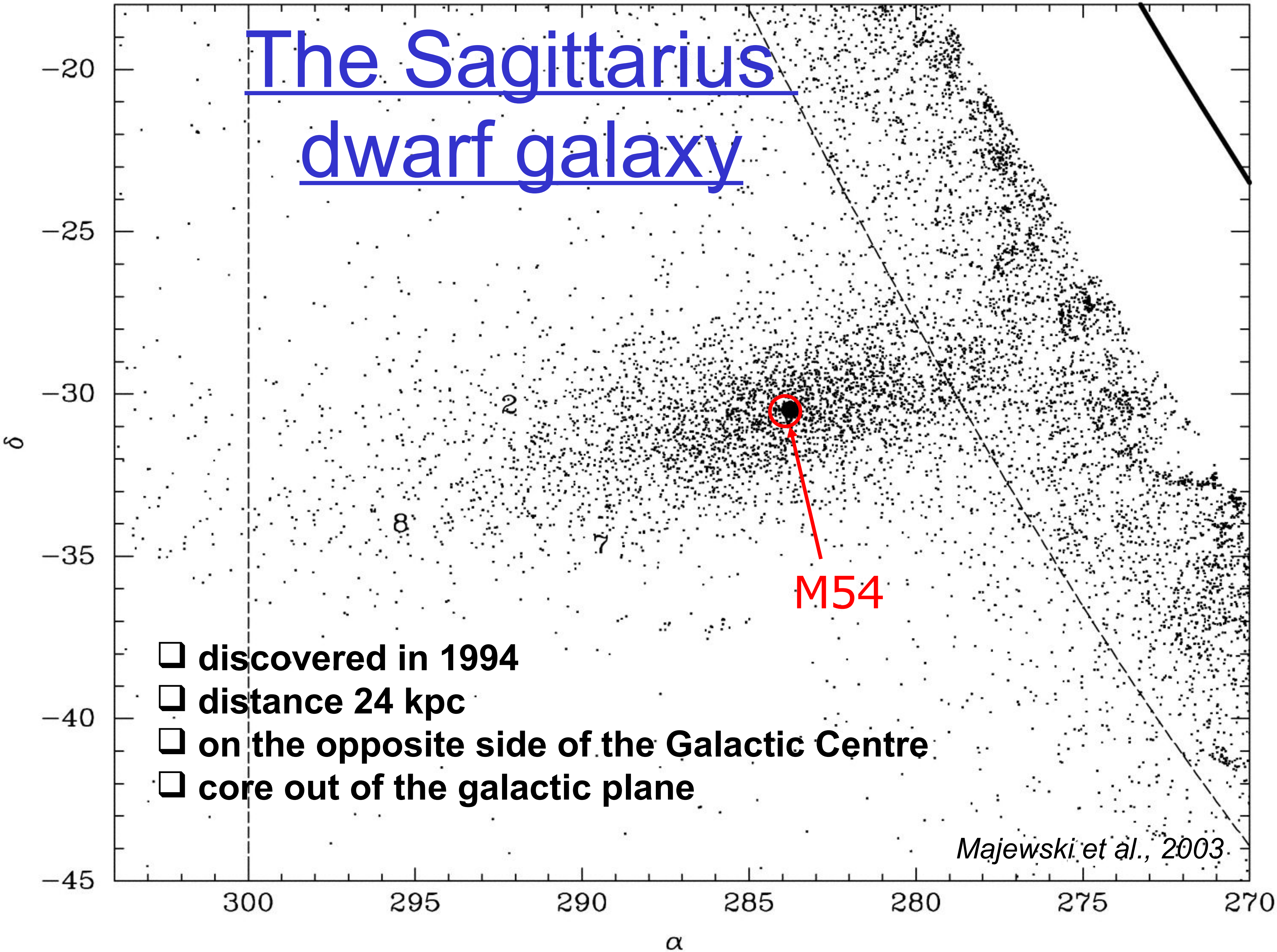
Short term and long term variability exclude the whole signal to be of Dark Matter origin

Satellite galaxies of the Milky Way



HESS observations:
Sagittarius dwarf: 24kpc (2006)
Canis Major: 7kpc (2007)

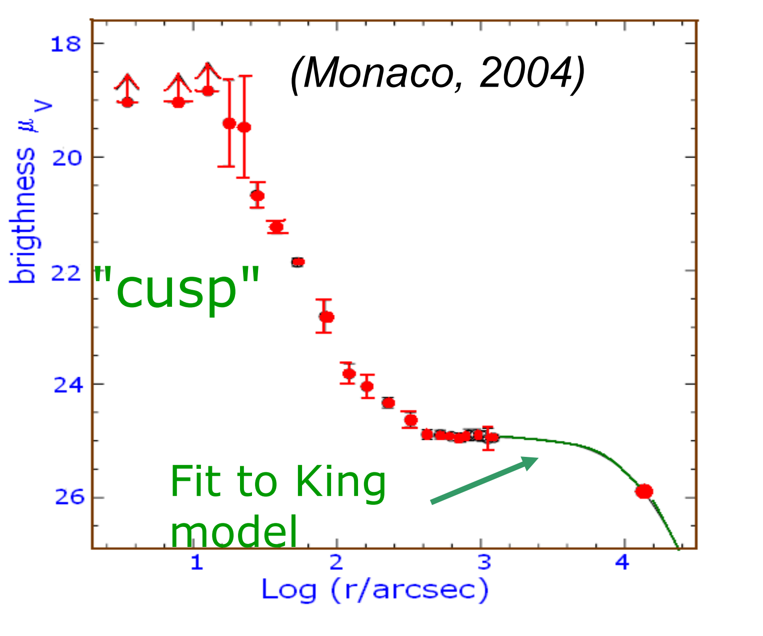
The Sagittarius dwarf galaxy



- discovered in 1994
- distance 24 kpc
- on the opposite side of the Galactic Centre
- core out of the galactic plane

The Sagittarius dwarf galaxy

- Spheroidal galaxy with nucleus
- Coïncidence in position with the globular cluster M54
- Tidally distorted
- M/L> 50 in outer part of galaxy



2 components in the luminous profile

- **<u>compact component :</u> «cusp»**
  - **core size : r_c = 1.5 pc**
  - **fit to denstity $\rho \propto r^{-\alpha} \Rightarrow \alpha$=2.68 too large for a black hole (α=1.75)**
- **<u>large scale component :</u> King model r_K = 1.6 kpc**

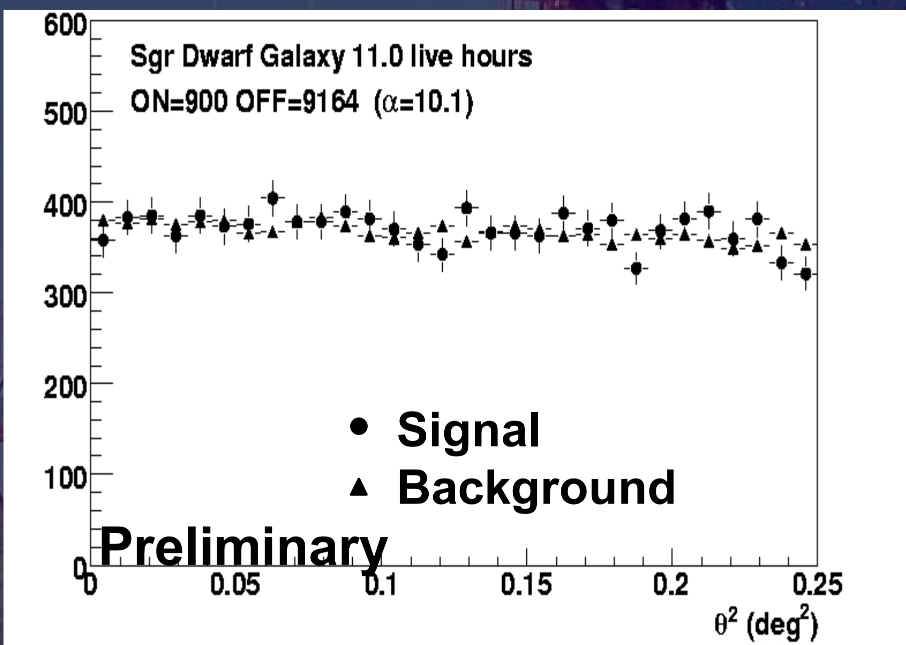
- **Velocity dispersion roughly constant over scales of degrees:**
  - **Central value (11.4 km/s)^2**
  - **Recent measurement: (8 km/s)^2 (Saggia 2005)**

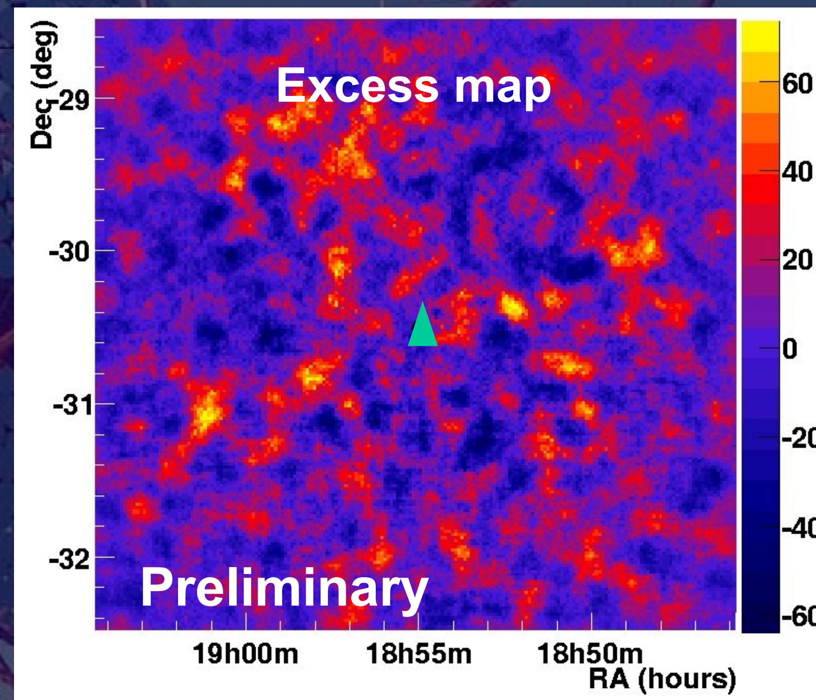
The signal is expected to come from the region of 1.5 pc
$\Rightarrow$ much smaller than the H.E.S.S. PSF : search for a point-like signal

Sagittarius dwarf: data analysis

- ❑ Target position : RA = 18h54m40s Dec = -30d27m05s (J2000)
- ❑ Centre of the globular cluster M54

- 25 runs after data selection in 2006
- Mean zenith observation angle : 19º
- 11 live hours after quality checks
- Combined (Hillas+Model) analysis





No significant γ excess at the target position

Limits on the γ–ray flux from Sagittarius dwarf and sensitivity calculation

- No significant γ-ray excess at the target position

  ⇒ 95% C.L. upper limit on the number of γ-ray above 250 GeV (Feldman & Cousins method)

  with N_{ON} = 437 N_{OFF} = 4270 α=10.1

$$N_\gamma^{95\%\,C.L.} = 56\,.$$

- Given the acceptance of the detector for Sgr dwarf observations :

$$\Phi_\gamma(\mathrm{E}_\gamma > 250\,\mathrm{GeV}) < 3.6\times10^{-12}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}\,(95\%\,\mathrm{C.L.})$$

- The 95% C.L. limit on Nγ provides a 95% C.L. limit on the velocity-weighted cross section for a given DM profile

$$\langle\sigma v\rangle_{min}^{95\%\,C.L.} = \frac{4\pi}{T_{\mathrm{obs}}}\frac{m_{DM}^2}{\bar{J}(\Delta\Omega)\Delta\Omega}\frac{N_\gamma^{95\%\,C.L.}}{\int_0^{m_{DM}} A_{\mathrm{eff}}(E_\gamma)\frac{dN_\gamma}{dE_\gamma}dE_\gamma}$$

Modelling Sagittarius dwarf dark matter halo

$$M(r) = r\langle v_r^2\rangle\left(\frac{d\ln\rho}{d\ln r} + \frac{d\ln\langle v_r^2\rangle}{d\ln r} - 2\beta\right)$$

❑ **Start from Jeans equation:**

Method based on Evans, et al., 2004

- **Observables:**
  - ρ luminous density,
  - $\langle v_r^2 \rangle$ radial velocity dispersion
- **Unknown:** **M** total mass, β anisotropy

❑ **Assume anisotropy $\beta = 0$**

- solve for M(r) to get ρ_{dark}

OR

- fit DM halo parameters to $\langle v_r^2 \rangle$

❑ **2 widely different types of DM halo profiles:**

- **NFW profile:** fit of (A,r_s) parameters to $\langle v_r^2 \rangle$ observed on Draco…
- **cored profile :** $\langle v_r^2 \rangle$ assumed to be flat, $(8\ \text{km/s})^2$ *(Saggia et al. 2005)*

$\Rightarrow$ analytic resolution of the Jeans equation

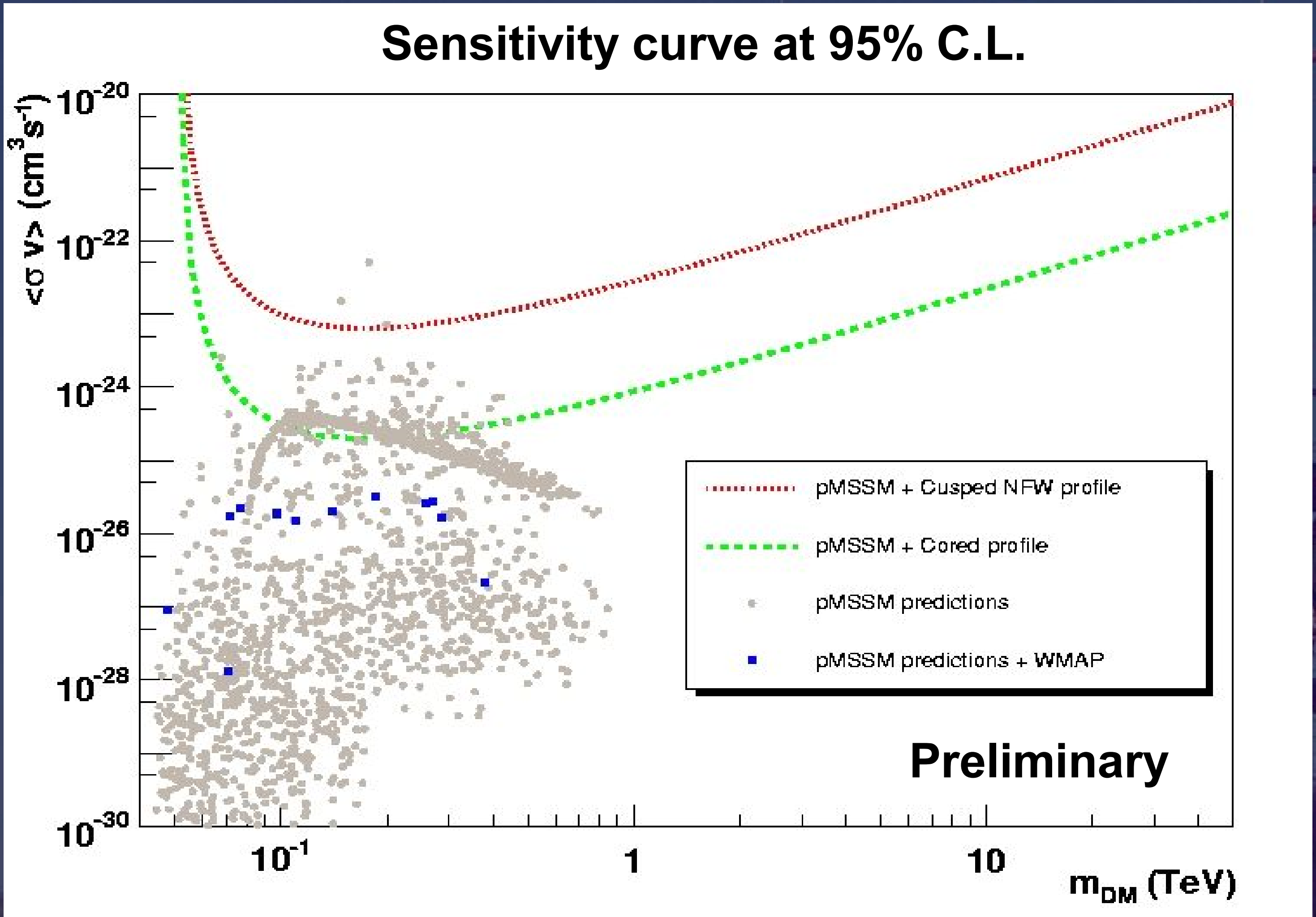
$$\rho_{NFW}(r) = \frac{A}{r(r+r_s)^2}$$

$$\rho_{core}(r) = \frac{v_a^2}{4\pi G}\frac{3r_c^2 + r^2}{(r_c^2 + r^2)^2}$$

Halo type	Parameters	$\bar{J}$ ($10^{24}\text{GeV}^2\text{cm}^{-5}$)	Fraction of signal in $\Delta\Omega = 2\times10^{-5}$sr
Cusped NFW halo	$r_s = 0.2$ kpc, $A = 3.3\times10^7 M_\odot$	2.2	93.6%
Cored halo	$r_c = 1.5$ pc, $v_a = 13.4\ \text{km s}^{-1}$	75.0	99.9%

Table 1

Constraints on neutralino dark matter: exclusion plots

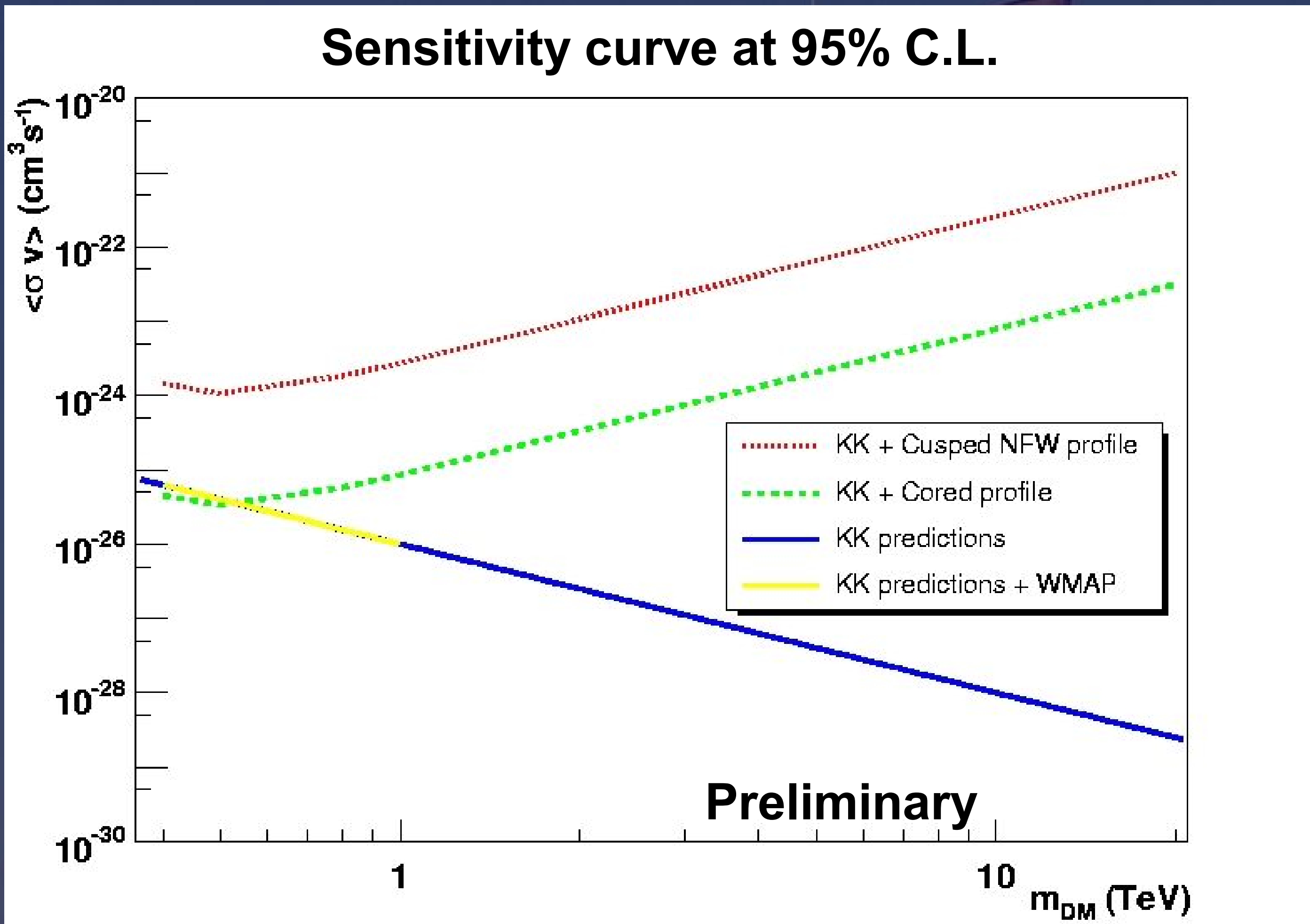


- pMSSM models obtained with DarkSUSY4.1

$\Rightarrow$ large scan of the parameter space

Some pMSSM models with higgsino-like neutralino excluded in the case of the cored profile

Constraints on Kaluza-Klein dark matter: exclusion plots



- Kaluza-Klein model predictions : analytic

$$\langle \sigma v \rangle = \frac{95 g_1^4}{324 \pi m_{\rm LKP}^2}$$

$$\simeq \frac{1.7 \times 10^{-26}\ {\rm cm}^3/{\rm s}}{(m_{\rm LKP}/{\rm TeV})^2}.$$

Some KK models providing a relic density compatible with WMAP constraints are excluded in the case of the cored profile

Conclusions

❑ **Present dark matter searches:**

- **Galactic Centre:** strong signal, probably not dark matter origin
- **M87:** strong variable signal, dark matter origin excluded
- **Sagittarius dwarf:** strong constraints for a cored profile
  - on pMSSM models : $\langle \sigma v \rangle \sim 2 \times 10^{-25}\ cm^3s^{-1}$
  - on Kaluza-Klein models : $\langle \sigma v \rangle \sim 4 \times 10^{-26}\ cm^3s^{-1}$

❑ Future searches with H.E.S.S. 2 (2008) - large telescope: Ø28m - lower energy threshold: ~20 GeV	⇒ Access to large part of MSSM models