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

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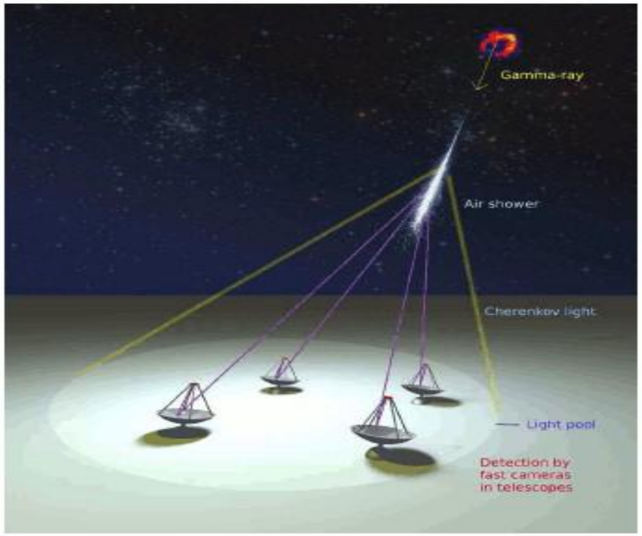
The H.E.S.S. telescope array

Array of four Imaging Atmospheric Cherenkov Telescopes

located in Namibia (1800m a.s.l.)

- 13 m diameter telescopes : 107 m^2 each
- Observations on moonless nights, ~1000h/year
- Field of view of 5°
- Stereoscopic reconstruction
- Angular resolution < 0.1° /γ
- Energy threshold (zenith) ~ 100 GeV
- Energy resolution ~ 15%



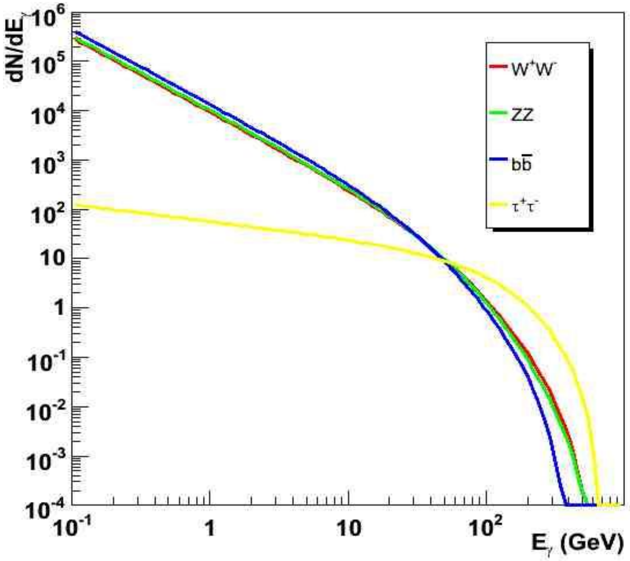
Indirect dark matter searches through gamma-rays

Gamma-ray flux from annihilation of a WIMP:

$$\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = \frac{1}{8\pi} \underbrace{\frac{\langle\sigma v\rangle}{m_\chi^2} \frac{dN_\gamma}{dE_\gamma}}_{Particle\ Physics} \times \underbrace{\bar{J}(\Delta\Omega)\Delta\Omega}_{Astrophysics} \quad \mathrm{cm^{-2}s^{-1}GeV^{-1}}$$

where

<u>Gamma spectrum</u>: typically a continuum with an cut-off at the DM particle mass



and

$$\bar{J}(l,b) = \frac{1}{\Delta\Omega}\int_{\Delta\Omega} d\Omega \int_{los} \rho^2[r(s)]ds$$

Dark matter halo modeling strong dependence; density profile model is needed

HESS point-like obs.: $\Delta\Omega \approx 10^{-5} sr$

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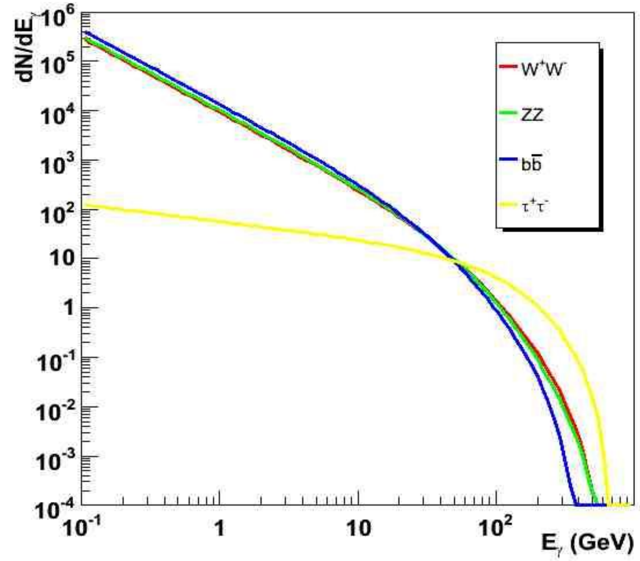

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Dark Matter halo modeling

Self-annihilation rate :

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

The DM density distribution (halo profile) comes from N-body numerical simulations or analytic solutions of the Jeans hydrodynamic equation

- **Two differents types of DM halo profiles are taken as examples:**

-NFW profile: **N-body simulations**

-cored profile: **analytic resolution of the Jeans equation**

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

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

The parameters are found after observation of the stars dynamics(luminous density, velocity dispersion, velocity anisotropy…) inside the galaxy

Target candidates for indirect DM searches

Blind searches:

Candidates:

- **intermediate mass black holes(IMBH)** *(HESS Collaboration (F. Aharonian et al). Jun 2008.)*
- overdensity regions**(« Clumps »)** predicted by numerical simulations

Constraints:

- needs large field-of –view of observation => hard with pointing observation i.e. HESS

HESS results :

- no Clumps candidates so far
- upper limits on the IMBH flux used to constraint some DM models

Targeted searches:

Candidates:

- **High DM density enviroments** in the center of galactic halos predicted by theory and simulations
- The **Milky-Way galactic center(GC)** should be a high DM density environment but…
- **Dwarf Sheroidals(dSph) galaxies** are extremely DM-dominated evironments(high M/L)

Constraints:

- GC has a too strong astrophysical background
- realistic DM halo modeling needed

HESS results:

- GeV-TeV emission towards the **GC**, but spectrum **not compatible with DM γ–ray emission**
- results on **dSph galaxies** covered in this talk…

(H.E.S.S. Collaboration (F. Aharonian et al). Oct 2006)

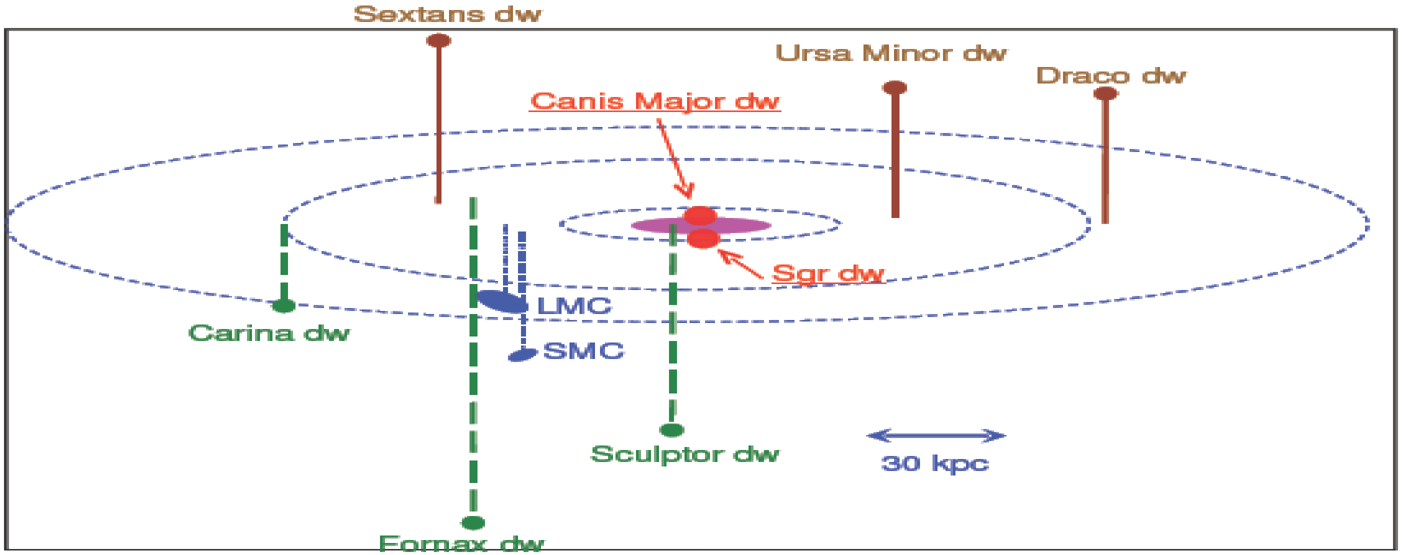
HESS observations campaigns on dSph galaxies

- **Four dSph galaxies (and candidates) studies published (or in process) by HESS**

	d(kpc)	Virial mass (solar mass)	T_{obs} (h)	Observation Zenith angle	Tidal disruption
Sagittarius	24	3.0×10^8	11	19°	✓
Canis Major	8	3.0×10^8 ??	10	10°	✓
Sculptor	79	1.0×10^9	11.8	14°	✗
Carina	101	2.0×10^8	14.8	34°	+/-

NO SIGNAL DETECTED

Estimation of an upper limit on the detected number of gamma-rays



Sensitivity curves to DM annihilation

$$N_\gamma = T_{\rm obs} \int_0^{m_{DM}} A_{\rm eff}(E_\gamma) \frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} dE_\gamma$$

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

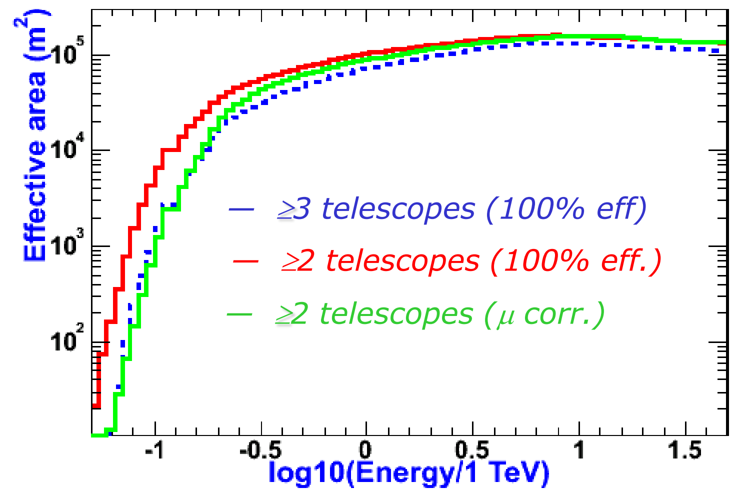
$$\langle \sigma v \rangle_{\rm min}^{95\%\, C.L.} = \frac{8\pi}{\overline{J}(\Delta\Omega)\Delta\Omega} \times \frac{m_\chi^2\, N_{\gamma,tot}^{95\%\, C.L.}}{T_{\rm obs}\, \int_0^{m_\chi} A_{eff}(E_\gamma)\, \frac{{\rm d}N_\gamma}{{\rm d}E_\gamma}(E_\gamma)\, {\rm d}E_\gamma}$$

➢ **the velocity-weighted cross-section is then calculated as function of the DM particle mass**

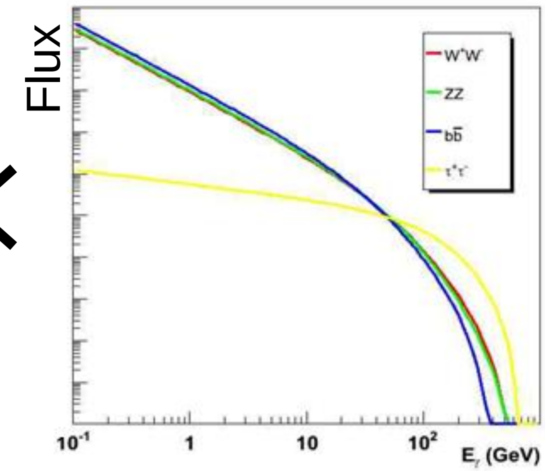
➢ **two candidates of Dark Matter particle are usually studied:**
- **neutralino (SUSY)**
- **Kaluza-Klein (UED) particles**

Sensitivity curves to DM annihilation

$N_\gamma = T_{obs} \times$



$\times$



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

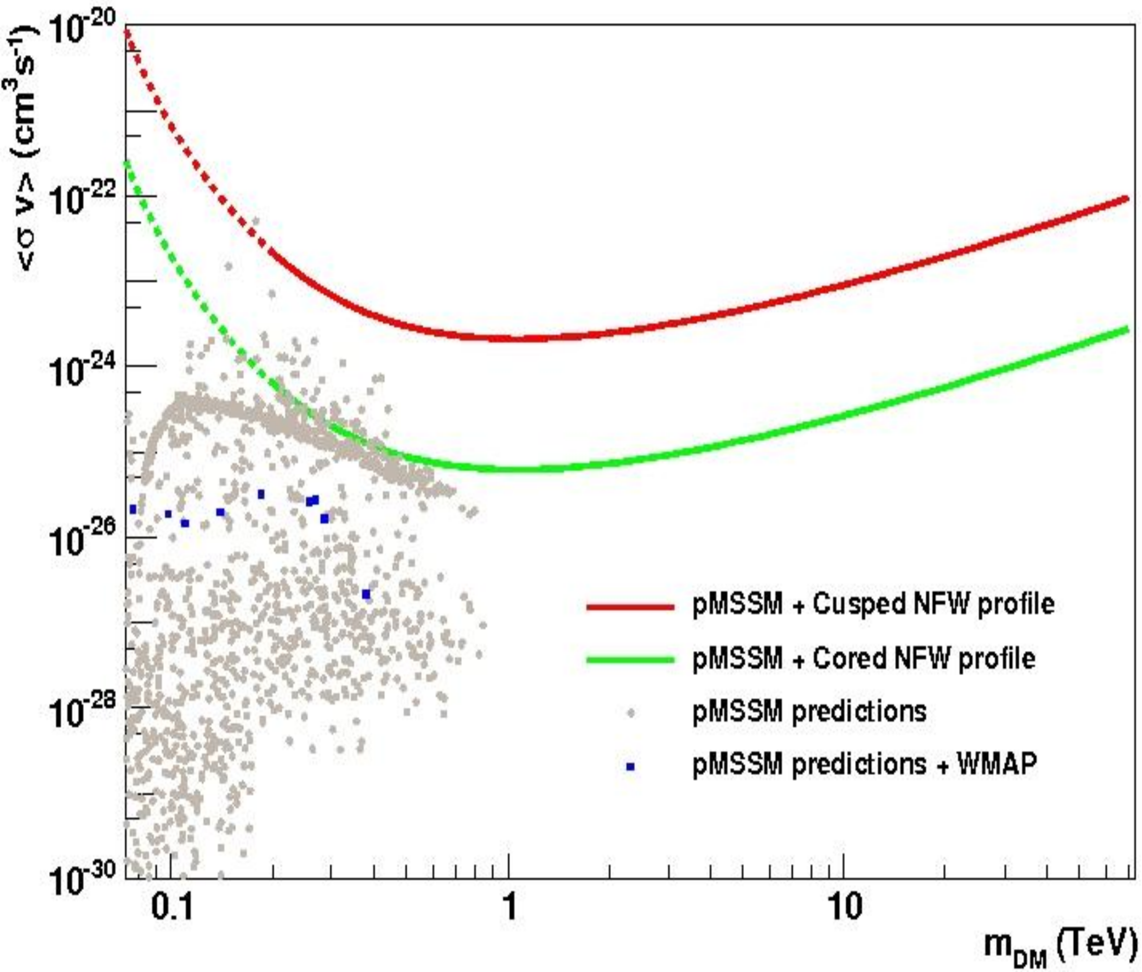
$$\langle \sigma v \rangle^{95\%\, C.L.}_{\min} = \frac{8\pi}{\overline{J}(\Delta\Omega)\Delta\Omega} \times \frac{m_\chi^2\, N^{95\%\, C.L.}_{\gamma,tot}}{T_{\rm obs}\int_0^{m_\chi} A_{eff}(E_\gamma)\frac{{\rm d}N_\gamma}{{\rm d}E_\gamma}(E_\gamma)\,{\rm d}E_\gamma}$$

➢ **the velocity-weighted cross-section is then calculated as function of the DM particle mass**

➢ **two candidates of Dark Matter particle are usually studied:**
- neutralino (SUSY)
- Kaluza-Klein (UED) particles

(HESS Collaboration (: F. Aharonian et al.). Nov 2007)

Constraints on neutralino dark matter
Sensitivity curve at 95% C.L.:



pMSSM models obtained with DarkSUSY4.1

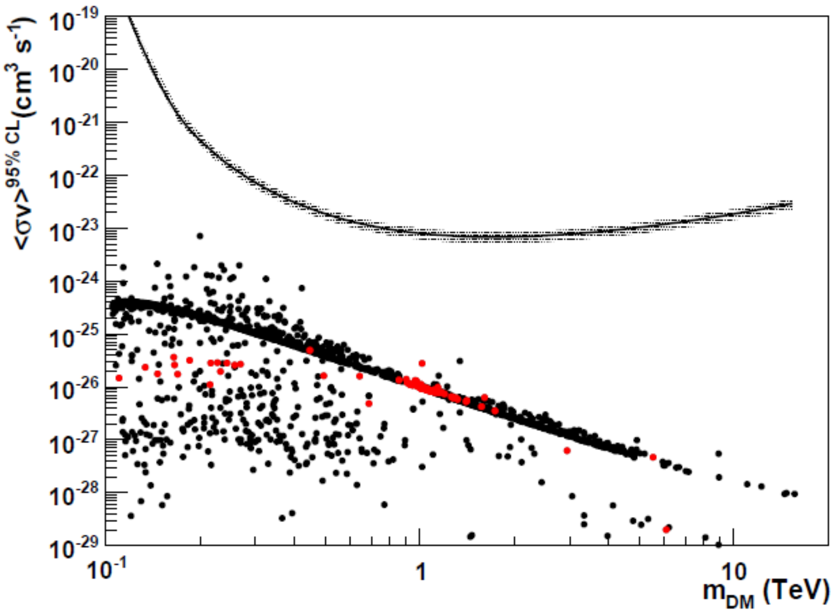
⇒ large scan of the parameter space

- **Some pMSSM models with higgsino-like neutralino excluded**
- **BUT halo modeling of Sgr dSph too hard due to tidal stripping**

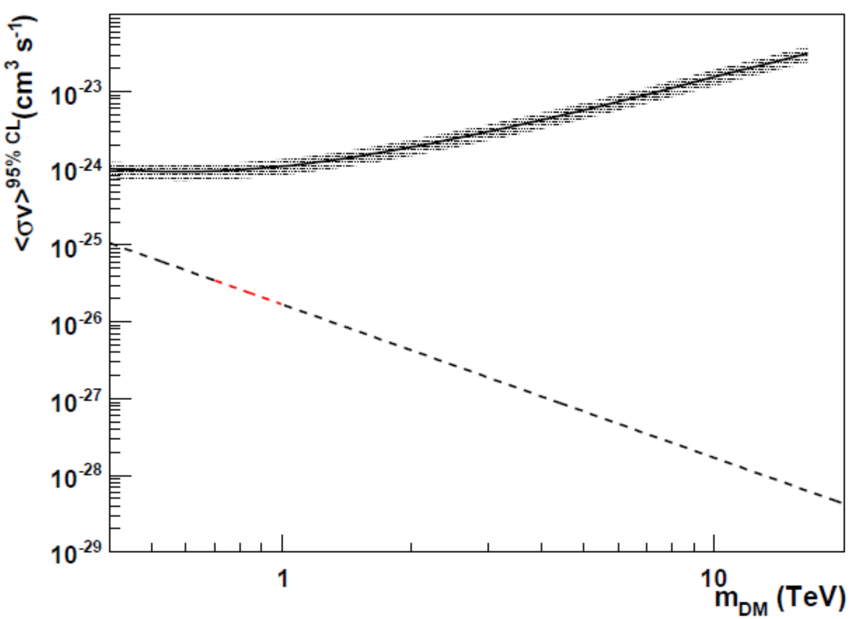
$$\bar{J} = 2.2 - 75 \times 10^{24} GeV^2 cm^{-5}$$

Constraints on dark matter
Sensitivity curve at 95% C.L.:

(HESS Collaboration (: F. Aharonian et al.). Sep 2008)



pMSSM



KK

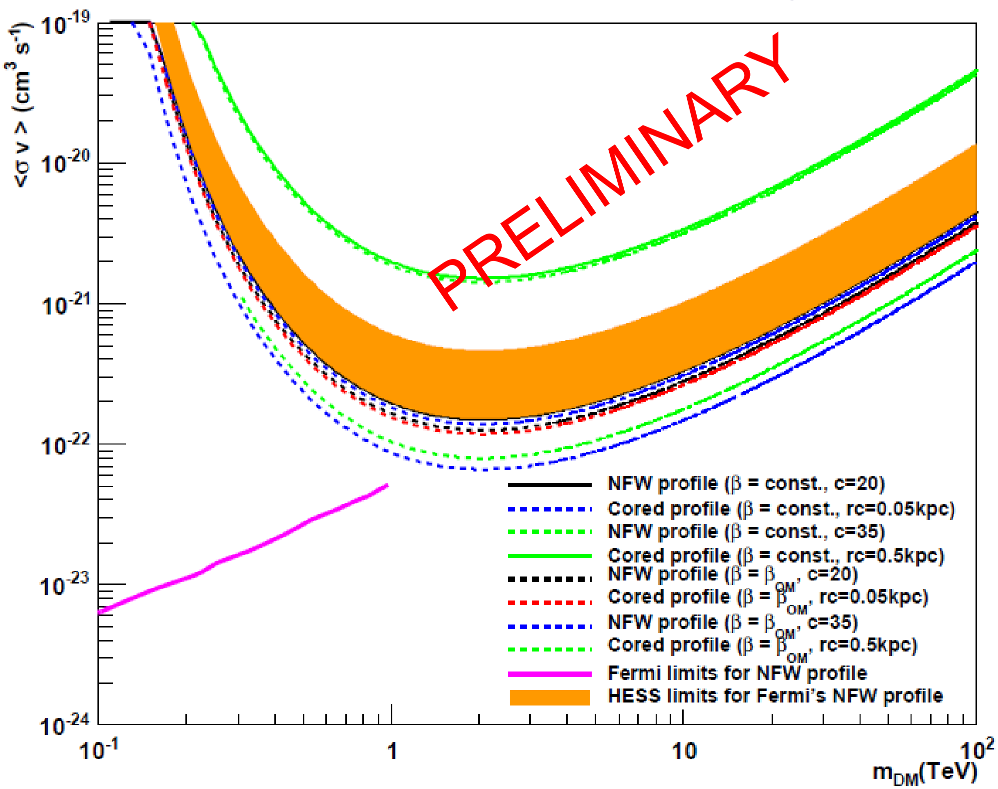
- **Overdensity discovered in 2004**
- **Disrupted dwarf galaxy or simply a part of the warped Galactic disk?**
- **On the assumption of a dSph it has a very delicated halo modeling**

$$\bar{J} = 5.9 \times 10^{24} GeV^2 cm^{-5}$$

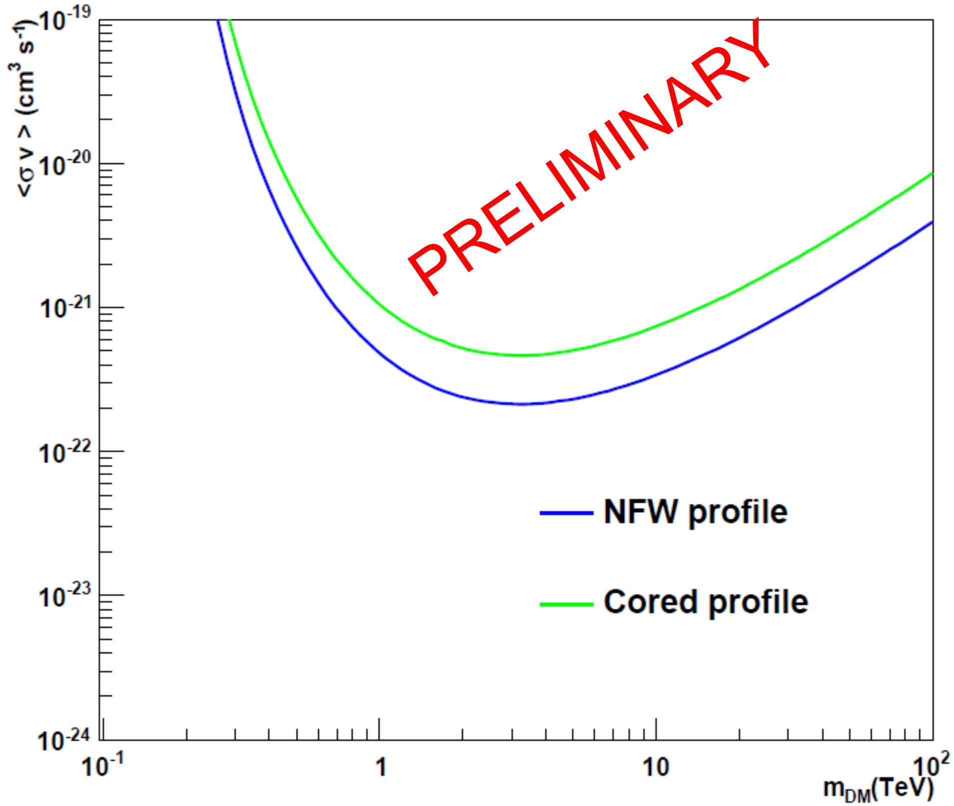
With the assumption: $M_{vir} = 3 \times 10^8 M_{sun}$

Sculptor and Carina dSph

Constraints on dark matter sensitivity curve at 95% C.L.:



(a) Sculptor



(b) Carina

$$\bar{J} = 0.2 - 6.4\times10^{23} GeV^2 cm^{-5}$$

$$J = 2.0 - 4.37\times10^{22} GeV^2 cm^{-5}$$

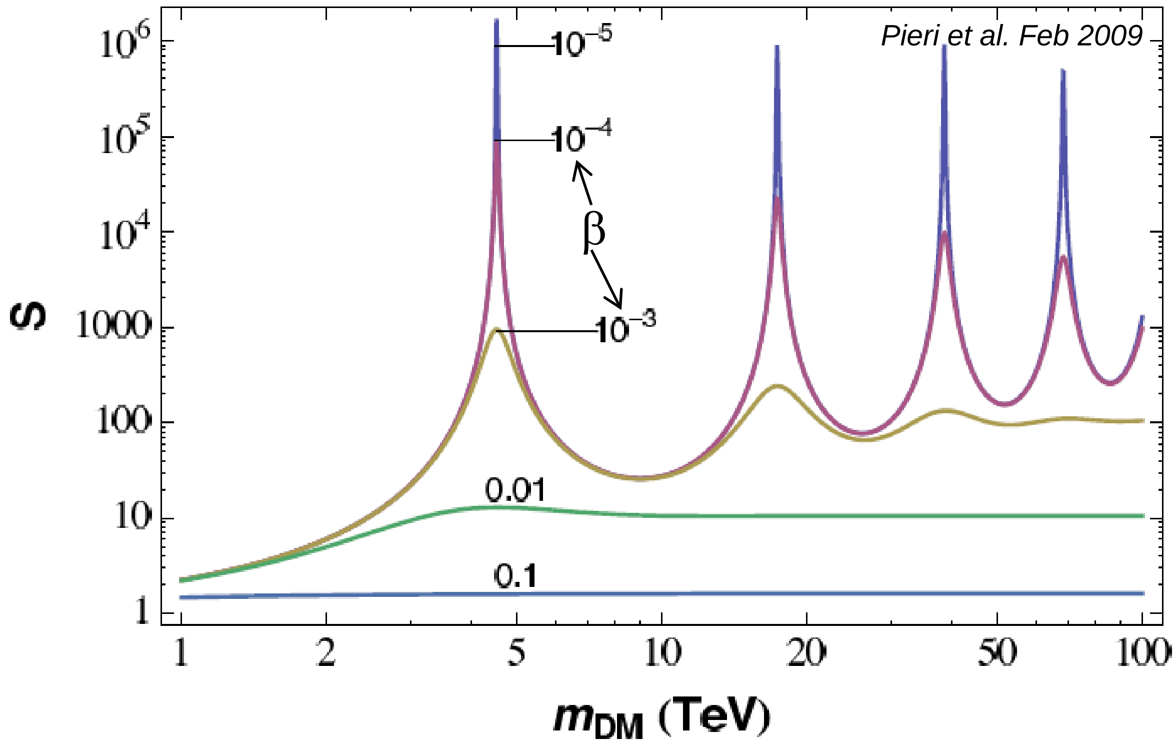
- Similar analyses were made for both galaxies
- Various DM halo profile were studied in the case of Sculptor => helps to estimate the errors due to the halo modeling

Gamma-ray signal enhancement effects

- **Particle physics enhancements i.e. Sommerfeld effect:**

Low velocity QFT(Schrodinger equation) effect due the interaction of the DM particles with a Yukawa potential(weak force) in its annihilation procces

$$\langle \sigma v \rangle = S \langle \sigma v \rangle_o$$



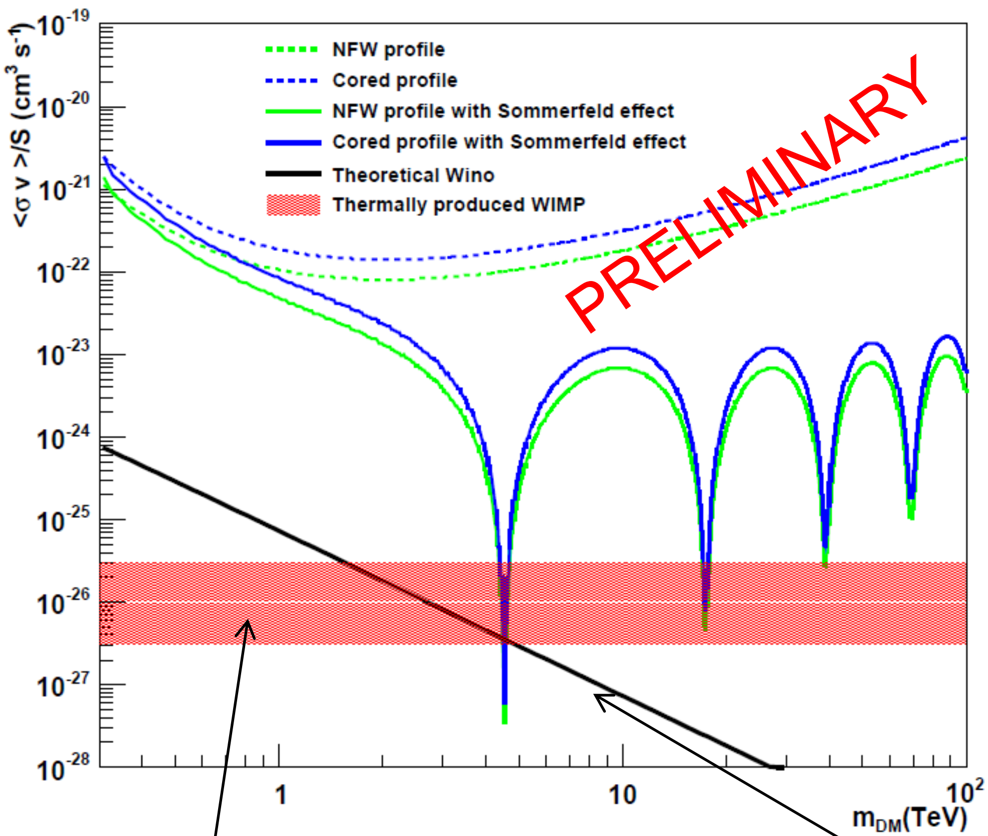
Very effective on the low-velocitiy regime!!

- **Astrophysics enhancements i.e. galactic substructures(« Clumps») :**

Motivations: simulations results are scale invariant, so its contribution may be important inside dSph

BUT No significant effect towards dSphs center in a point-like analysis

Particle physics enhancements i.e. Sommerfeld effect in Sculptor and Carina dSph



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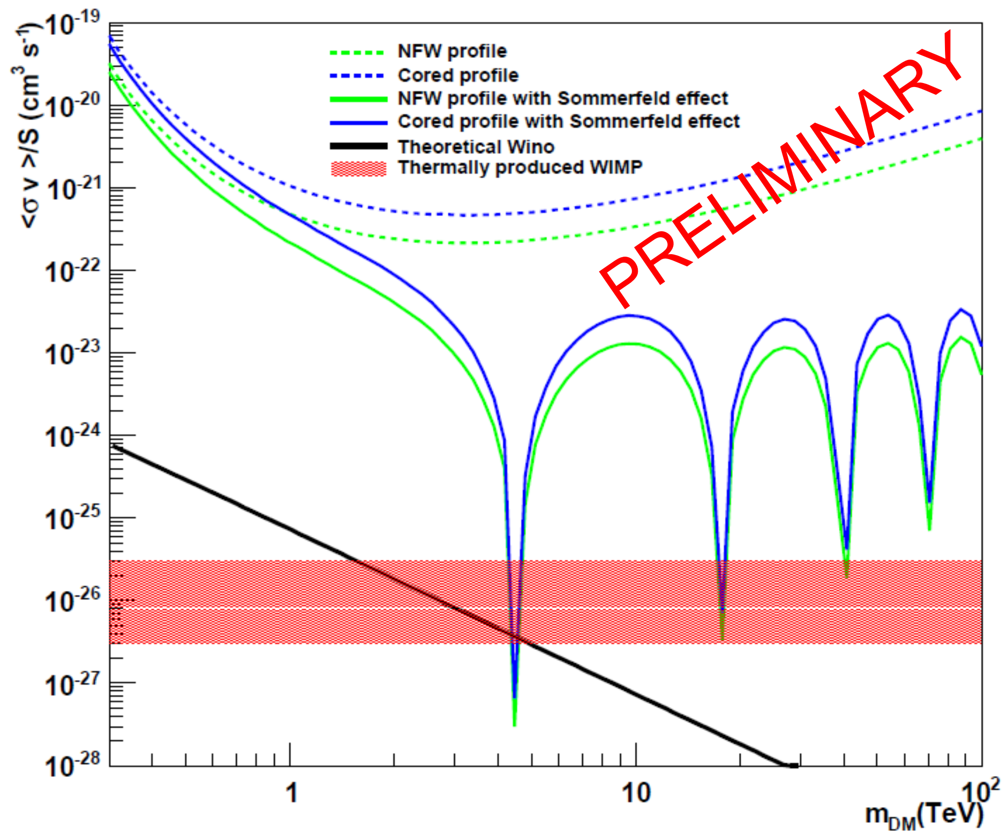


(b) Carina

Typical thermally produced WIMP cross section

Analytical wino cross section

- **Low-velocity dispersion: ~10.0 km s−1 for Sculptor and ~7.5 km/s for Carina**
- **Plot <σv>/S vs m_{DM}**

Summary

- **IMBH and Clumps are in priciple good candidates, but their true distribution is very uncertain due to possible complex evolution inside the Galaxy(interaction with baryons…)**

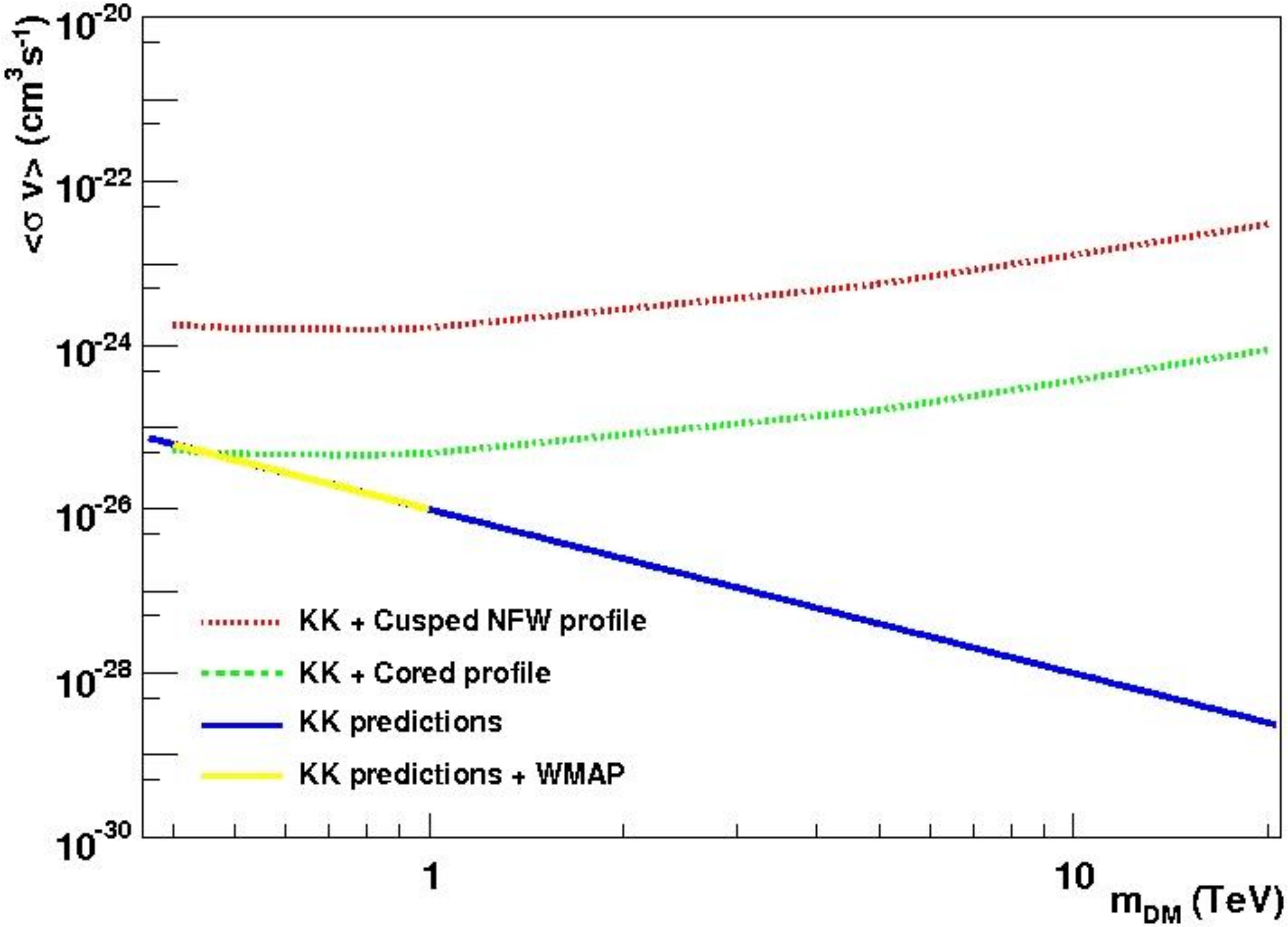
- **The same for the GC => dynamical evolution and baryon interactions could sweep out the DM of the central regions or just hide the signal**

- **despite no signal detection so far, dSph remains as one of the most promising enviroments for Dark Matter searches**

Summary on the dSph campaign:

	Motivations	Results	Problems
Sagittarius	• small distance from us • high M/L	•Some pMSSM models with higgsino-like neutralino excluded	• halo modeling very uncertain • interaction with the MW disk must have disrupted it
Canis Major	• small distance from us • overdensity environment	• good constrains	• real astrophysical nature under dispute • very disrupted by tidal effects
Sculptor/ Carina	• far from the MW disk and center • no significant disruption(at least in Sculptor case…)	• large DM halo profile uncertainty coverage • good contrains with Sommerfeld effect	• large distance from us

Constraints on Kaluza_Klein dark matter
Sensitivity curve at 95% C.L.



Kaluza-Klein model predictions are analytic:

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

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

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

Dark Matter halo modeling

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

- $\langle v_r^2 \rangle$: radial velocity dispersion
- ρ: luminous density

→ observed

- M: luminous + dark mass
- β: anisotropy

→ unknown

•Assumed → $\beta(r)$ →
- solve for M(r) to get ρ_{dark}
- OR
- fit DM halo parameters to $\langle v_r^2 \rangle$

•Two differents types of
DM halo profiles are produced:

-NFW profile: fit of (A, r_s) parameters to $\langle v_r^2 \rangle$

-cored profile : $\langle v_r^2 \rangle$ assumed to be flat
- ⇒ analytic resolution of the Jeans equation

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

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