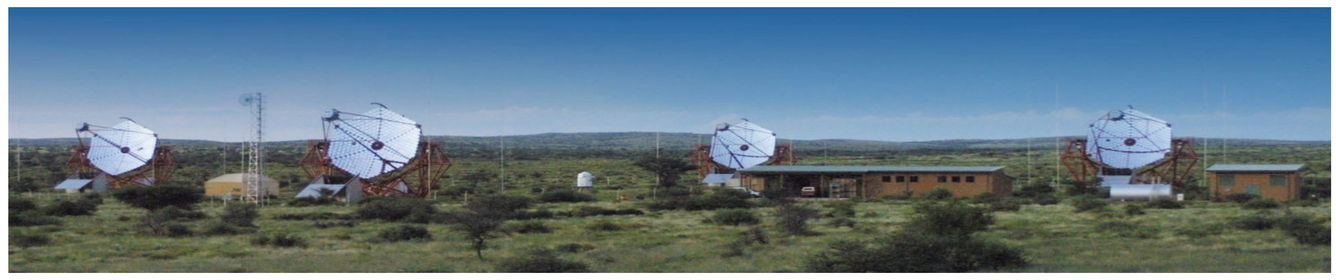
Searches for Dark Matter Annihilation in the Galactic Halo with H.E.S.S.

Motivation

Recent N-body simulations predict the concentration of particle DM towards the center of galaxies. In many models DM particles can annihilate to standard model particles which subsequently produce very high energy photons. The vicinity of the Milky Way center region compared to other galaxies motivates a search for gamma ray emission from the galactic center region to trace a possible annihilation of DM particles. A positive result of a search for gamma ray emission from DM annihilation would be an important step towards a solution of the astrophysical problem of missing luminous matter as well as a hint towards physics beyond the standard model of particle physics. A negative result on the other hand can deliver highly constraining limits on particle DM parameters.

Methods



The High Energy Stereoscopic System (H.E.S.S.) is one of the most sensitive imaging Cherenkov telescope arrays currently operating. Being built in the southern hemisphere in Namibia it is able to observe the galactic center region at low zenith angles resulting in low energy thresholds of ~100 GeV. The large field of view (~2° in radius) of the array makes it in principle possible to search for a faint diffuse gamma ray emission from DM annihilation towards the galactic center region.

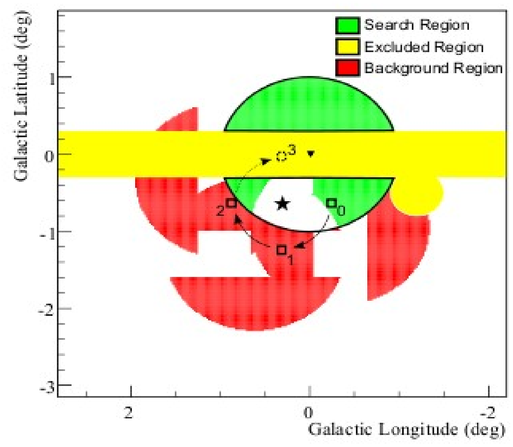
Some Details

Background subtraction:

A search for a gamma ray signal from an extended signal region around the GC with H.E.S.S. is complicated due to the necessity for the subtraction of background events in the signal region. Background events are mainly showers induced by electrons, positrons and hadrons where the majority of the hadron energy is transfered into a neutral pion that subsequently decays into two photons. The number of background events in the signal region has to be measured by H.E.S.S. in a dedicated background region. Signal and background region must have the same photon acceptance. The photon acceptance of H.E.S.S. depends dominantly on the offset from the observation position, the pointing zenith angle and on time.

Published background subtraction technique:

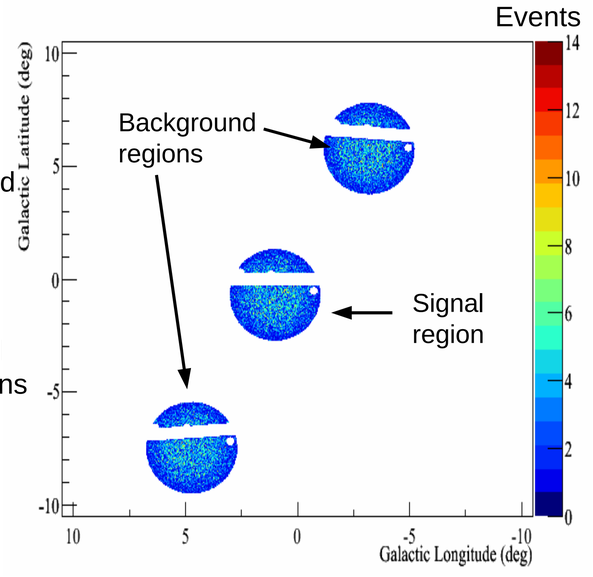
One recently published method is the “reflected pixel background” or “wobble” method which makes use of the radially symmetric instrumental photon and background acceptance:
A signal region of 1° around the galactic center is defined and bins in the signal region are rotated at constant angular distance to the telescope pointing out of the signal region into the background region. Known gamma ray sources and the galactic plane ($|b|<0.3°$) are blanked in order to avoid the detection of high energy photons of ordinary astrophysical origin and at the same time to reduce the dependence of upper limits eventually set on the velocity weighted self annihilation cross section on DM density profiles (see above).



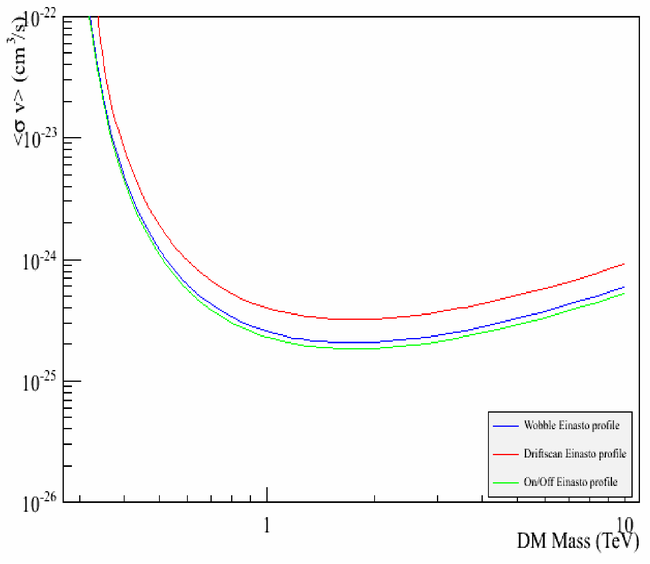
Results for Particle DM Annihilation in the Galactic Halo

Alternative background subtraction techniques

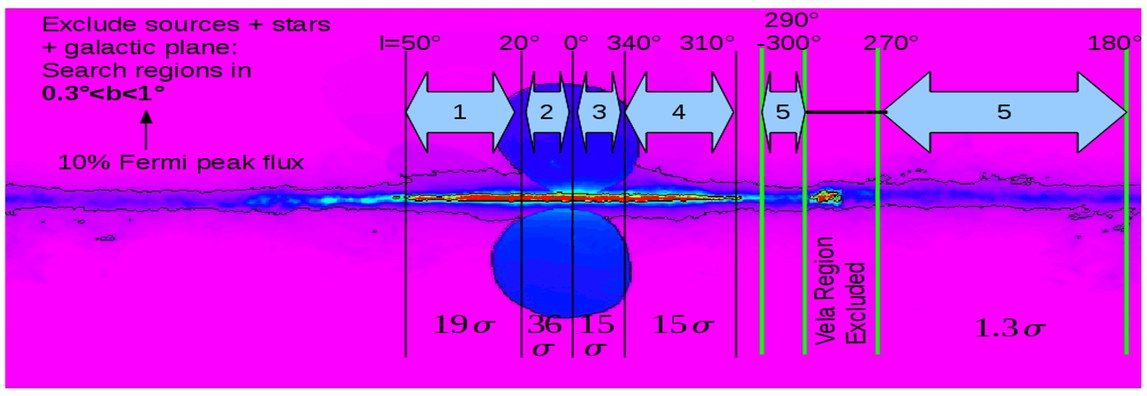
The On/Off method uses a special observation pattern to guarantee the same acceptance in the signal and background region. A usual observation run is scheduled with ~30min offset in Right Ascension (RA) to the GC.
After ~28min of data taking, the telescope pointing is driven back 30min in RA within a run transition time of ~2min. The signal region around the GC is observed again for ~28min and afterwards a second background region is observed with again ~30min offset in RA to the signal region. The zenith and azimuth pointing range for each run is by construction identical. Possible deviations in the acceptance therefore stem from atmospheric changes or differences in night sky background. The signal region is bigger compared to the reflected pixel method and the DM annihilation photon flux expected from the background regions is smaller than for the reflected pixel method. A higher sensitivity can therefore be expected.
Additionally to the On/Off method also other background subtraction techniques are studied and developed. The comparison of the sensitivity and the study of systematic errors of the different methods is a central topic of my work.



Sensitivity comparison:



Outlook: Diffuse Large Scale Very High Energy Gamma Ray Emission Foreground



Apart from gamma rays from particle DM annihilation also other sources of large scale diffuse VHE gamma ray emission are investigated. The diffuse emission resulting from the interaction of hadronic cosmic rays with gas in the galactic disc as well as the interaction of cosmic ray electrons with low energy photon fields (CMB, starlight) is not yet studied at TeV energies on scales of the Milky Way. However, such diffuse emission together with the possible emission of VHE gamma rays from the Fermi bubbles recently detected below 100 GeVare obvious foregrounds for any large scale emission from DM annihilation. Additionally, the study of the large scale diffuse emission in the galactic disc is a very interesting topic in itself as

- the intensity and spectral information of large scale diffuse emission in the galactic disc can probe the predicted uniformity of the TeV cosmic ray in the Milky Way,
- the study of the Fermi bubbles at TeV energies can help to probe different currently discussed production mechanism for this spectacular phenomenon.

Both, the large scale diffuse emission from cosmic rays in the galactic disc and the emission from the Fermi bubbles are not yet studied at all at TeV energies but recent results of my work indicate that

- diffuse large scale emission in the galactic disc is detectable with H.E.S.S. at high statistical significances. Systematic effects in the measurement of the spectral distribution are currently investigated but it is obvious that this effect constitutes a foreground to any search for particle DM annihilation in the galactic center region and needs to be accounted for in future analyses. Additionally, this emission may also contribute to a systematic error for the investigation of extended VHE sources in the galactic plane with H.E.S.S. (f.i. the Vela Jr. SNR).
- the Fermi bubbles are probably not detectable with H.E.S.S. for reasonable exposure. However, sensitivity studies show that the Fermi bubbles are very probably detectable with the upcoming CTA Cherenkov telescope array due to its increased sensitivity if the emission is generated by hadronic interactions or certain first order Fermi accelerated electrons via inverse Compton scattering.

In any case the study of the new field of large scale diffuse emission in the Milky Way is important for the planning of the analysis of galactic sources with CTA.
Thus my PhD project is, although focused on the investigation of certain particle DM models, also an important source for a large set of future analyses with CTA.

Publications

Doro, M. et al.: Dark Matter and Fundamental Physics with the Cherenkov Telescope Array, ApJ, 2012 (Author of the section on magnetic monopoles)

G. Spengler and U. Schwanke: Signatures of Ultra-relativistic Magnetic Monopoles in Imaging Cherenkov Telescopes, Proceedings to the 32nd ICRC in Beijing 2011

G. Spengler and U. Schwanke: Searches for a Dark Matter Annihilation Signal from the Milky Way Halo with the H.E.S.S. Array of Imaging Atmospheric Cherenkov Telescopes, Proceedings to the 32nd ICRC in Beijing 2011

G. Spengler and U. Schwanke: Strategies for the Detection of Gamma-Rays from Dark Matter Annihilation Towards the Galactic Center Region with the High Energy Stereoscopic System, Proceedings to the 4th International Fermi Symposium in Monterey, CA, 2012

Plus twenty refereed journal publications as H.E.S.S. collaboration co-author and five additional conference proceedings as co-author.
Additional publications covering the work performed during my PhD studies are currently in preparation

Contact Details and further Information

PhD Student: Gerrit Spengler (HU), spengler@physik.hu-berlin.de

PhD Advisors: Thomas Lohse (HU) / Peter Uwer (HU)

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