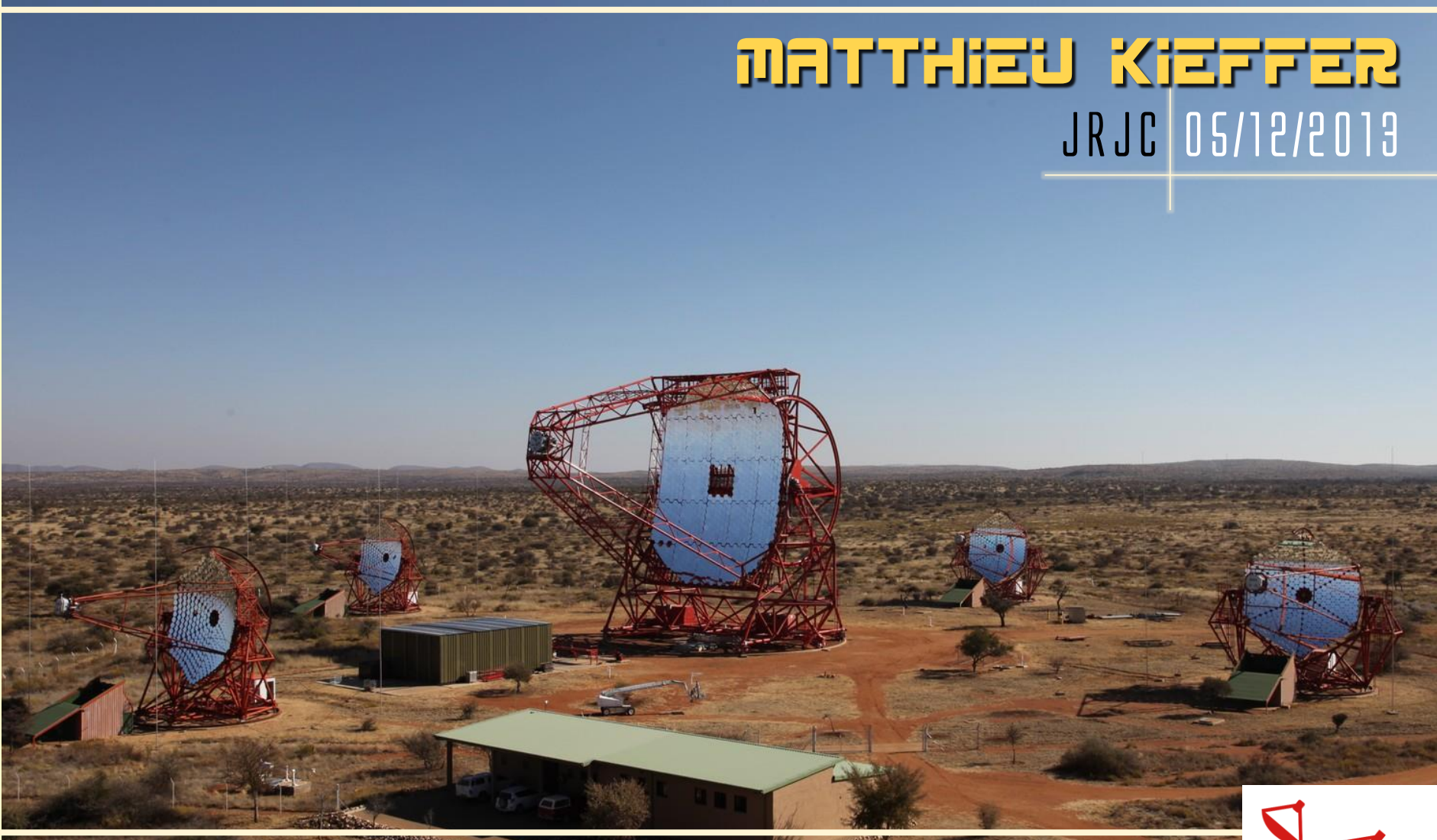


# Indirect search for Dark Matter with H.E.S.S. experiment

**MATTHIEU KIEFFER**

JRJC | 05/12/2013



**JRJC 2013**

Journées de Rencontre Jeunes Chercheurs

**UPMC**  
SORBONNE UNIVERSITÉS

**LPNHE**  
PARIS

**IN2P3**

INSTITUT NATIONAL DE PHYSIQUE NUCLÉAIRE  
ET DE PHYSIQUE DES PARTICULES



# Plan

- General introduction on Dark Matter
- Indirect detection of Dark Matter with H.E.S.S.
- Search for DM in Sagittarius Dwarf Galaxy
- Search for DM line signatures near the Galactic Center

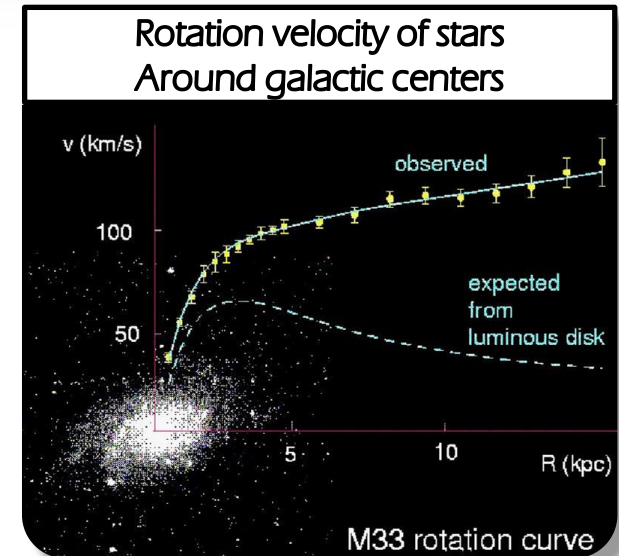
# General introduction on Dark Matter

# Dark Matter in the Universe

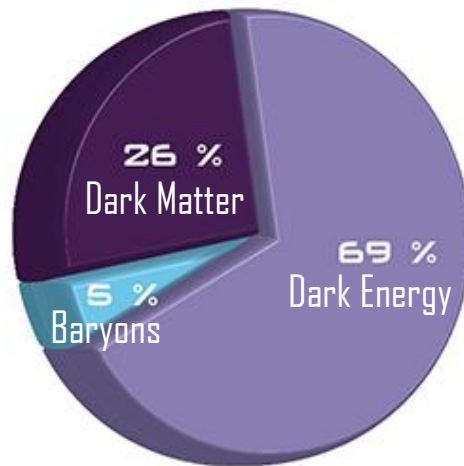


**Fritz Zwicky, 1933 :**  
First hypothesis of the existence of Dark Matter, indirectly revealed by the velocity dispersion of galaxies in the Coma cluster

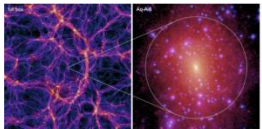
« If this over-density is confirmed we would arrive at the astonishing conclusion that Dark Matter is present [in Coma] with a much greater density than luminous matter »



## The $\Lambda$ -CDM model

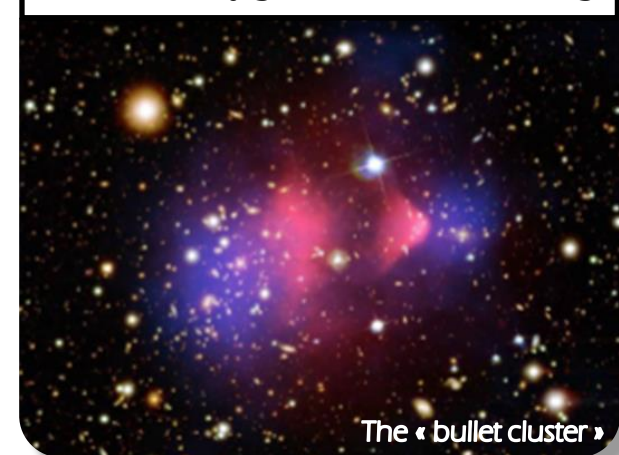


N-body  
simulations



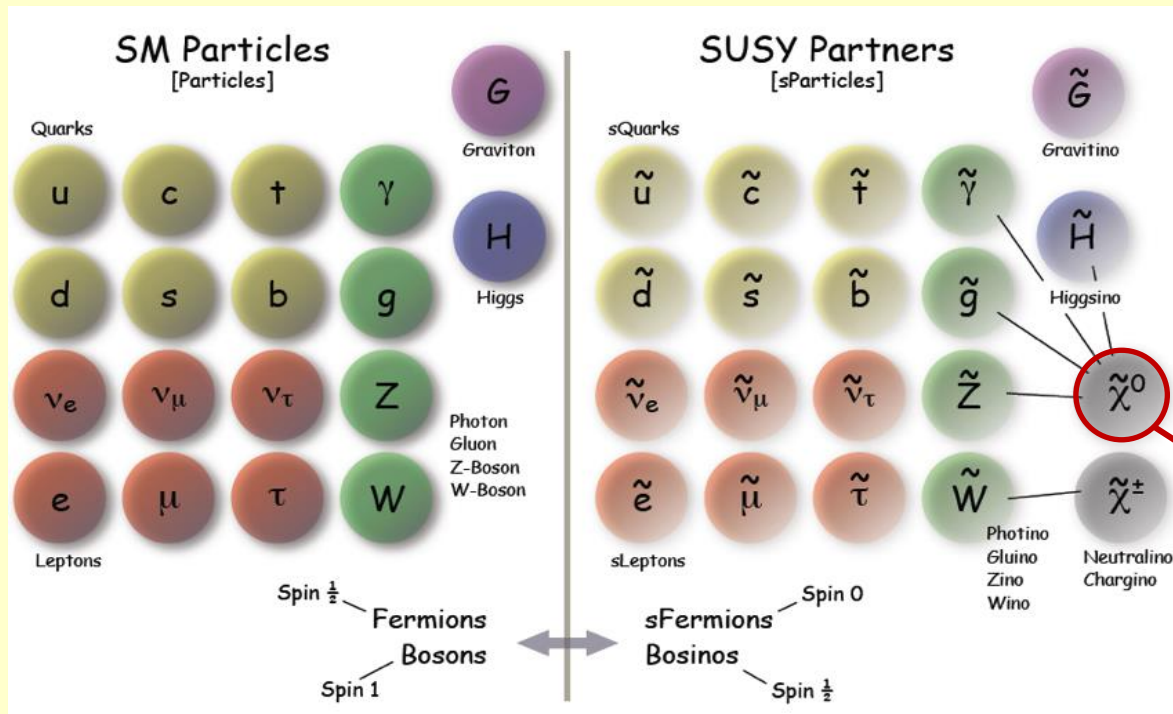
Hierarchical  
structure of DM in  
halos, sub-halos,  
sub-sub halos...

Observation by gravitational microlensing



# The mystery : the nature of Dark Matter

A promising candidate : the **Neutralino**  $\chi^0$

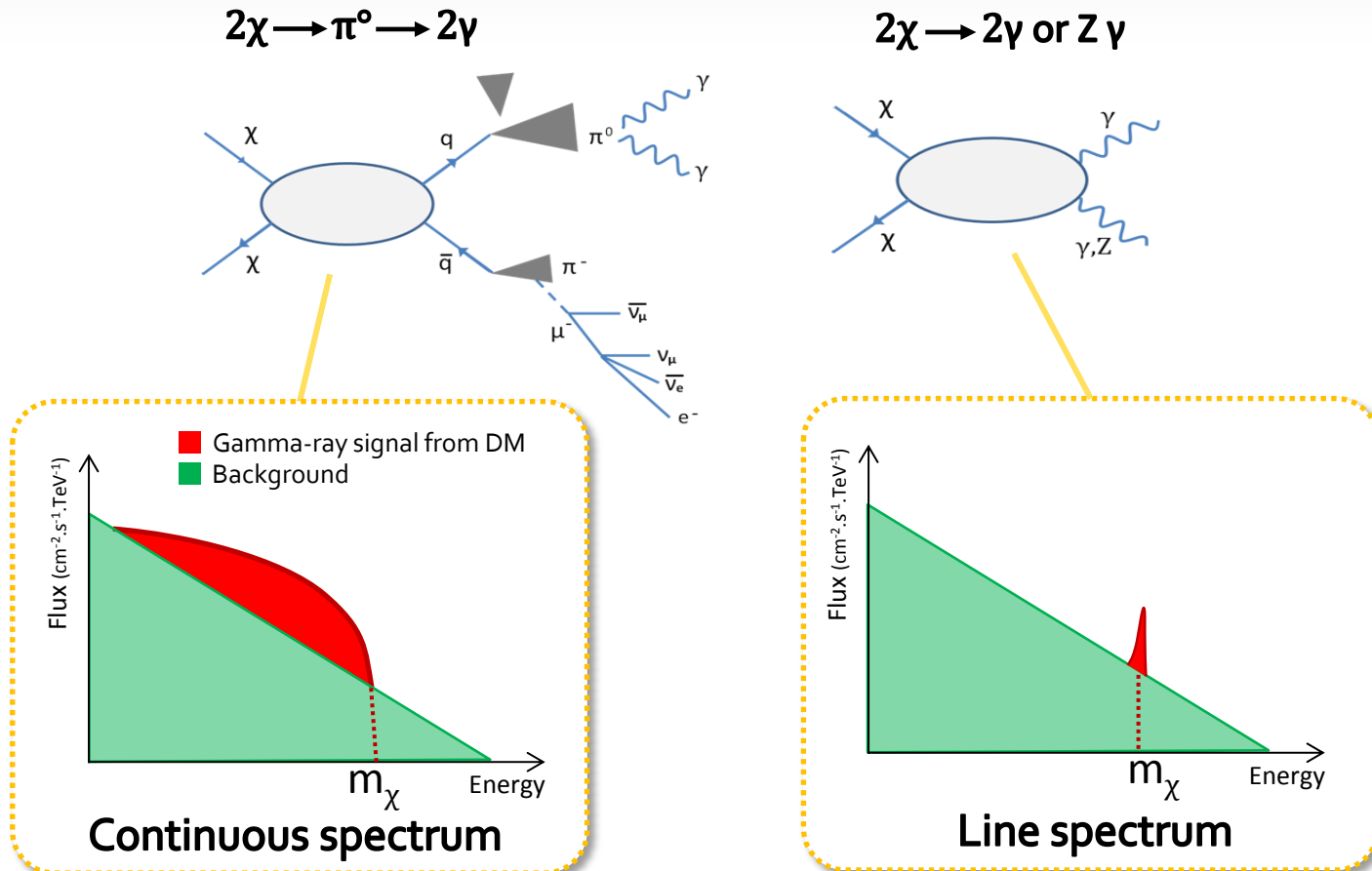


- Weak Interacting Massive Particle
- Lightest stable SUSY particle
- It is its own antiparticle (Majorana)
- Mass : hundreds of GeV

➡ My work is based on the existence of this SUSY neutralino

# Indirect detection of Dark Matter with H.E.S.S.

# Gamma rays as messengers from Dark Matter annihilation



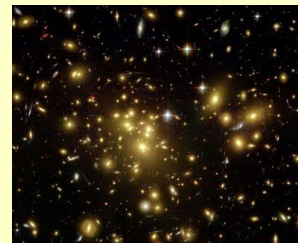
$$\text{Flux} = \frac{d\Phi}{dE_\gamma}(E_\gamma, \Delta\Omega) = \underbrace{\Phi^{\text{ASTRO}}(\Delta\Omega)}_{\text{Astrophysical factor}} \cdot \underbrace{\frac{d\Phi^{\text{PP}}}{dE_\gamma}(E_\gamma)}_{\text{Particle Physics factor}}$$

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



→ We search for these exotic gamma ray signatures from Dark Matter annihilation

Energy range : 100 GeV to 100 TeV



Where do we look?

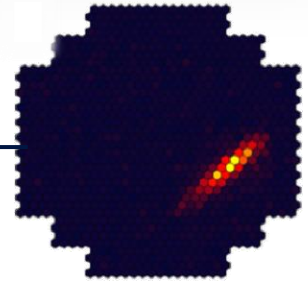
- Galactic Center
- Dwarf galaxies
- Galaxy clusters

What is the background?

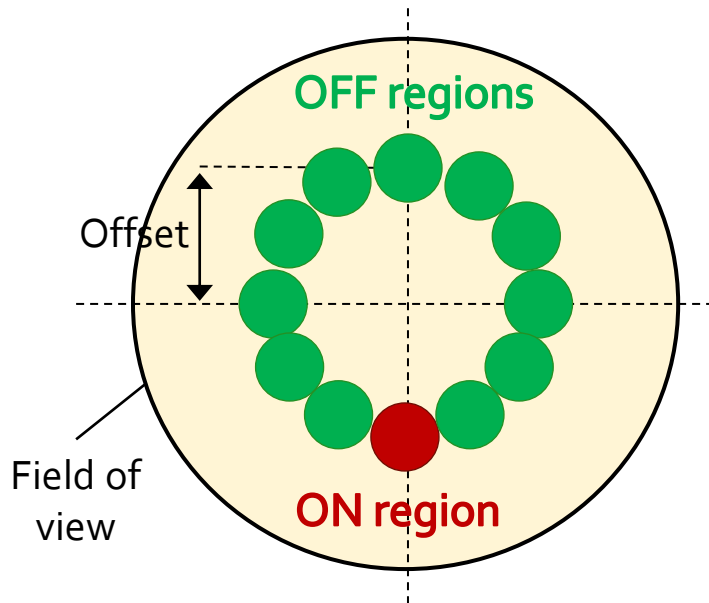
- Mainly cosmic ray hadrons
- Astrophysical sources in the field of view
- Needs appropriate background suppression methods

# The ON-OFF background subtraction method

Hadronic background is mainly suppressed by using discriminant variables on signal shapes seen on H.E.S.S. cameras



→ But large background still remains,  
can be reduced by ON-OFF method



## ON-OFF method

- ON = signal search region
- Background estimated from OFF regions

$$N_{\text{signal}} = N_{\text{ON}} - \alpha N_{\text{OFF}}$$

$\alpha$  = normalization factor

# **Analysis of Sagittarius Dwarf Galaxy**

# Sagittarius Dwarf Galaxy



- Satellite dwarf galaxy of the Milky Way

- Contains four globular clusters  
(M54 at the center)

- RA = 18h 56m 00s  
Dec = -30h 29m 00s  
24 kpc from the Sun

- High level of tidal disruption that should cause its break up

  - **May hide considerable amount of Dark Matter**

- No referenced gamma ray astrophysical sources

  - **Perfect candidate to seek for Dark Matter with low background !**  
(only hadrons)

# Analysis with H.E.S.S. data



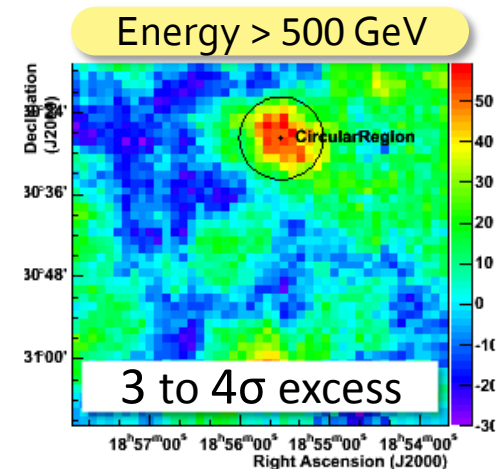
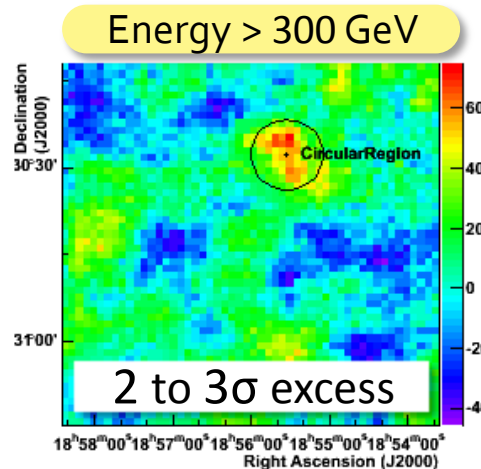
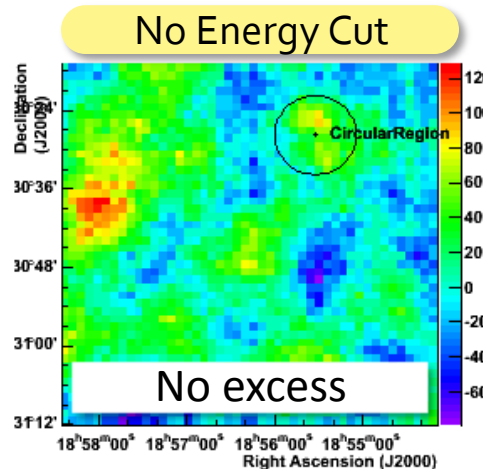
## Data sample :

- 2006 – 2012 data
- 142 runs of  $\sim 30$ min  $\rightarrow T_{\text{observation}} \sim 70$ h
- 4 telescopes working in stereoscopy



## Cuts & Signal reconstruction :

- $\varnothing 0.1^\circ$  ON region centered on Sagittarius Dwarf Galaxy
- Analysis with different energy cuts
- ON-OFF background subtraction method for hadrons



# New constraints on Dark Matter existence (1)

- The observed excess is still too weak to claim for a gamma ray source discovery
- If signal really exists, can it be associated to Dark Matter?
  - First study on energy distributions doesn't show any exotic spectral shapes
  - Needs more statistics to conclude → New data to be taken in 2014-2015
  - Signal could also be associated to other gamma ray sources (supernova remnants, quasars, active galactic nuclei...)
  - Can be also due to statistical fluctuations

No significant signal detected from Sagittarius Dwarf Galaxy



New constraints on Dark Matter annihilation cross-section and mass

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

# New constraints on Dark Matter existence (2)

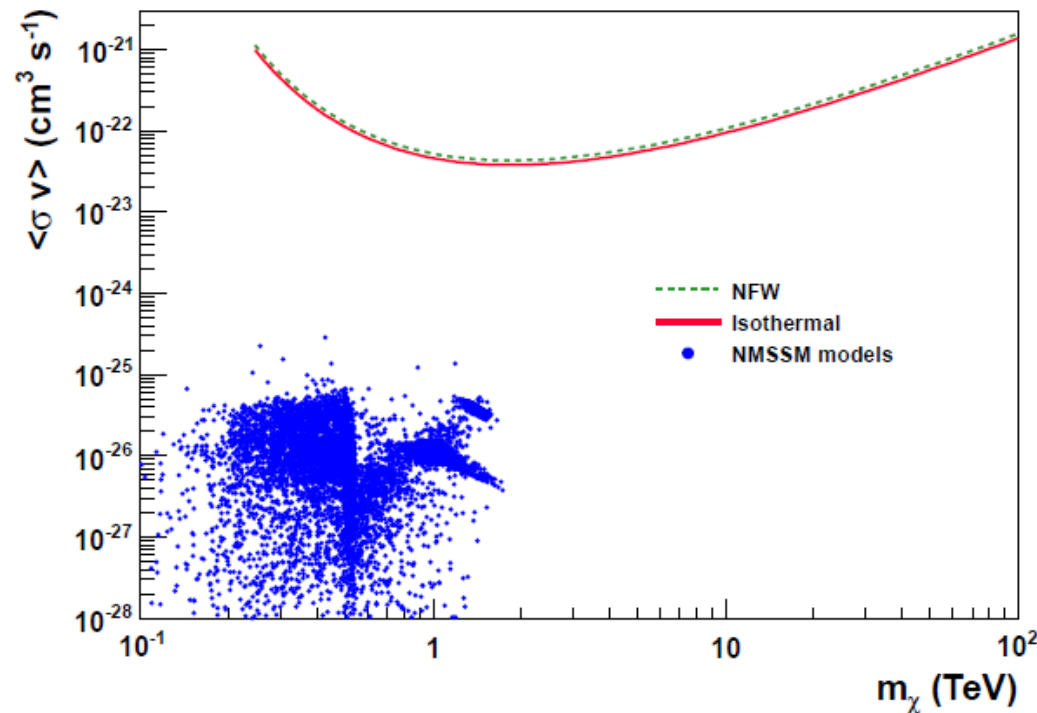
33RD INTERNATIONAL COSMIC RAY CONFERENCE, RIO DE JANEIRO 2013  
THE ASTROPARTICLE PHYSICS CONFERENCE

ICRC  
2013

## Sagittarius dwarf spheroidal galaxy observed by H.E.S.S.

G. LAMANNA<sup>1</sup>, C. FARNIER<sup>2</sup>, A. JACHOLKOWSKA<sup>3</sup>, M. KIEFFER<sup>3</sup>, C. TRICHARD<sup>1</sup> FOR THE H.E.S.S. COLLABORATION.

*arXiv:1307.4918v1 [astro-ph.HE] 18 Jul 2013*



The best sensitivity is reached at 1-2 TeV  
with the value of  $\sim 4 \cdot 10^{-23} \text{ cm}^3 \cdot \text{s}^{-1}$

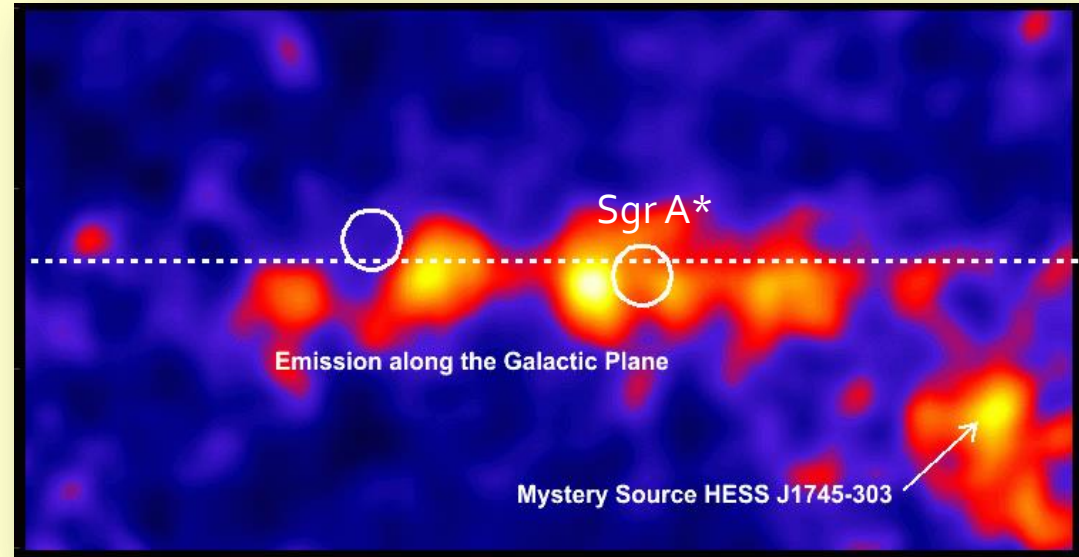
Results compared to some NMSSM models

# Search for DM line signatures near the Galactic Center

# The Galactic Center region

## Very active and complex region

- Sagittarius A\* (central black hole)
- Supernova remnants
- Diffuse emission



- But should be the center of a high density galactic Dark Matter halo  
→ High complexity background suppression methods are required to investigate the presence of Dark Matter

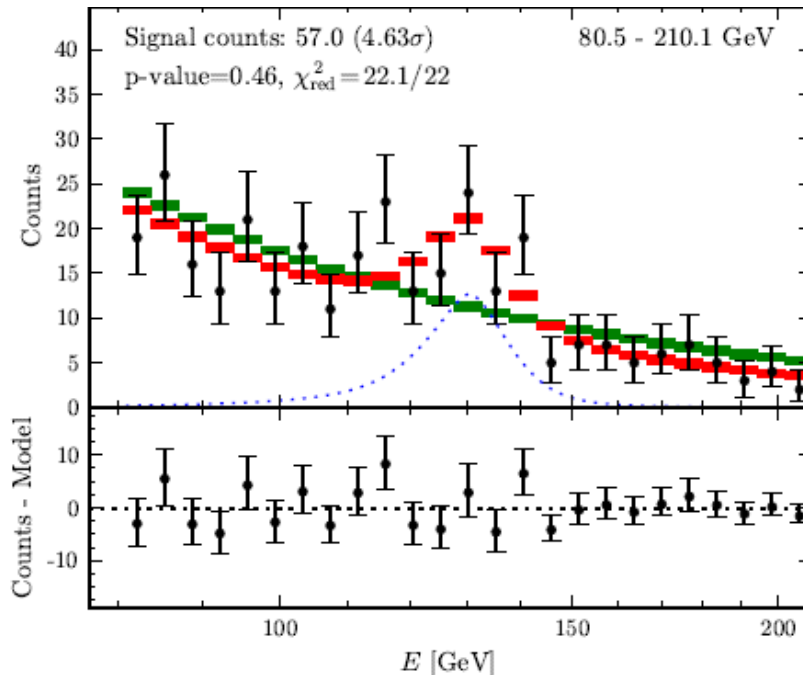
# 130 GeV line seen with Fermi

## A Tentative Gamma-Ray Line from Dark Matter Annihilation at the Fermi Large Area Telescope

arXiv:1204.2797v2 [hep-ph] 8 Aug 2012

Christoph Weniger

Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München, Germany

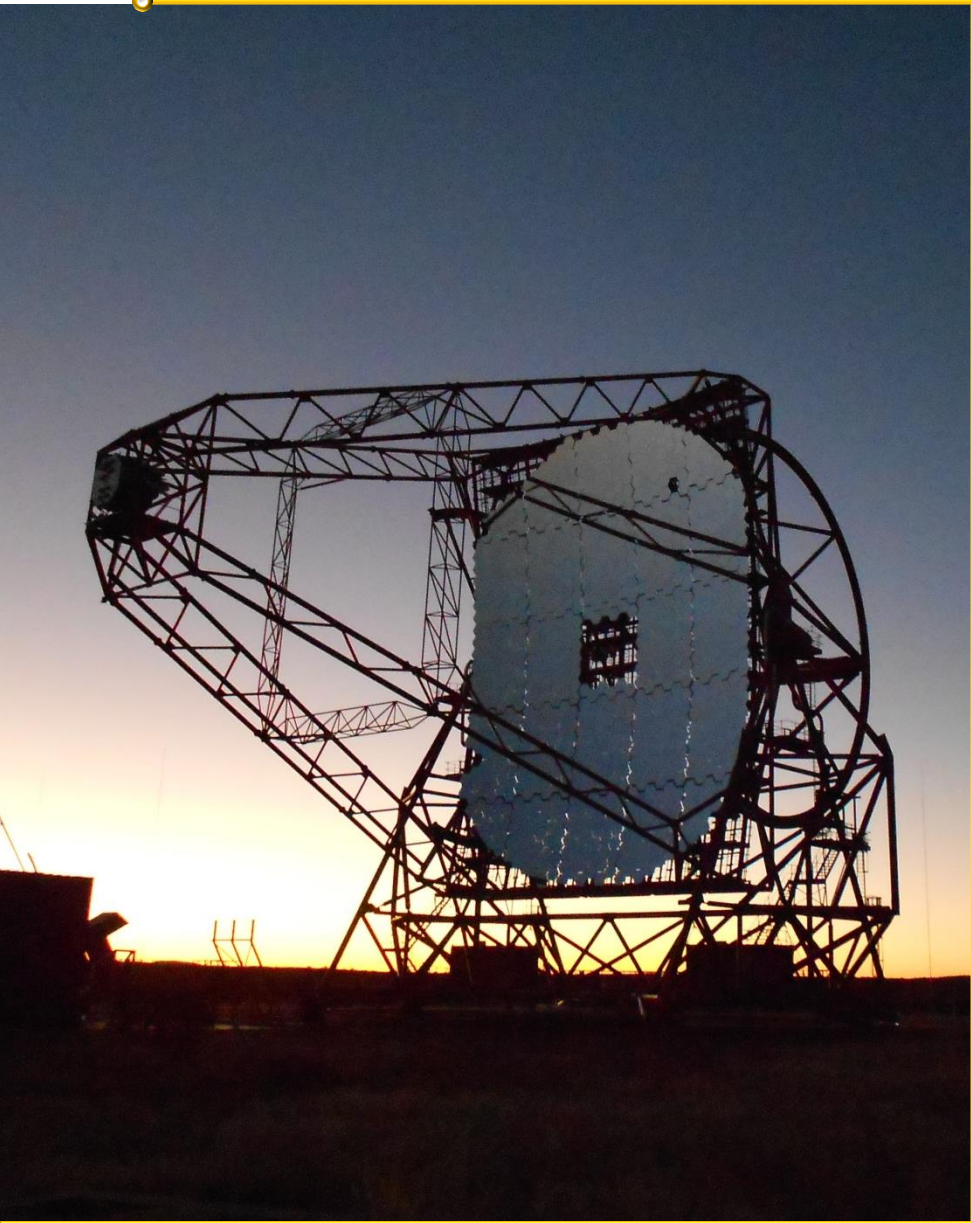


3-4 $\sigma$  significance line signal  
-1.5° from Galactic Center



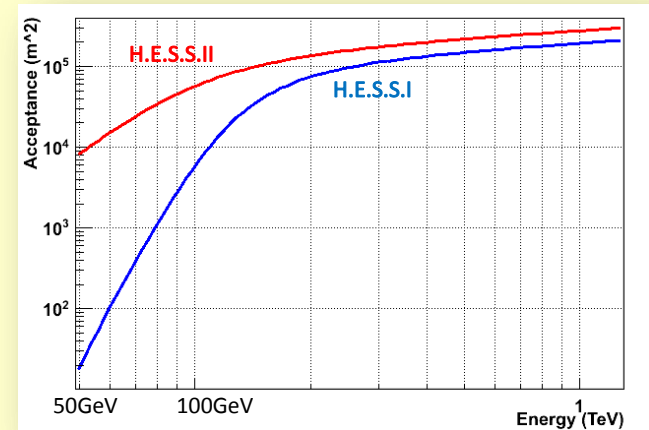
Consistent with Dark Matter detection  
Also consistent with systematic errors

# The H.E.S.S.II experiment



Ø28m telescope added  
operational since beginning 2013  
→ Stereoscopy with 5 telescopes

**Energy threshold : 50 GeV**  
(100 GeV for H.E.S.S.I)



**H.E.S.S.II adapted for line search at 130 GeV**  
(Cross-check with Fermi !)

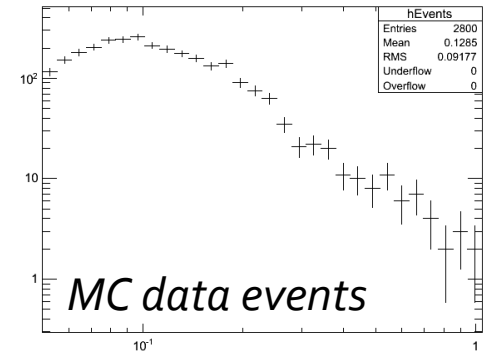
# Preliminary study for line search with H.E.S.S.II

**Idea** : develop a C++ program that identifies a line signal at 130 GeV in the presence of 2 different types of background

- Hadrons
- Diffuse gamma ray emission near the Galactic Center

Expected signal

- Gaussian centered at 130GeV (due to energy resolution)



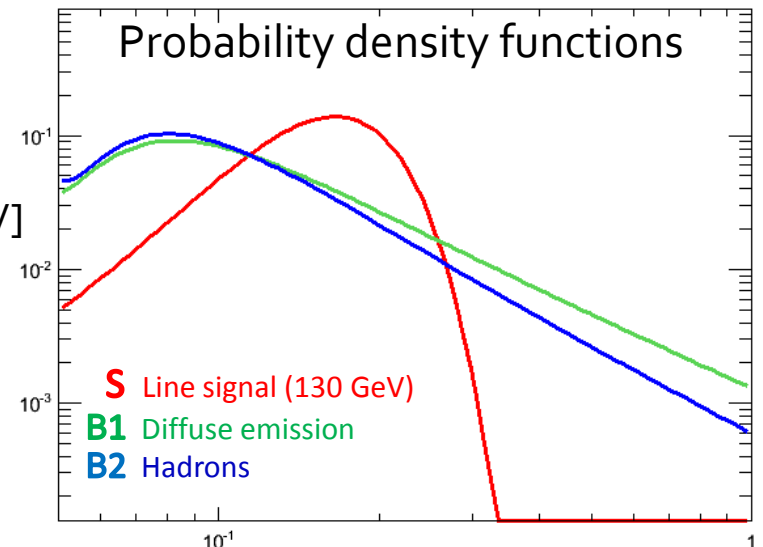
## “Shape Likelihood” function :

$$-2\ln(L) = - \sum_{\text{events}} \ln(\eta \text{PDF}_S + (1 - \eta) \text{PDF}_B)$$

- Sum over data events in the energy range [50GeV ; 1TeV]

$$\eta = \frac{\text{Signal}}{\text{Signal} + \text{Background}}$$

- Minimization of  $-2\ln(L)$  function  
→ **Reconstruction of the  $\eta$  ratio**  
+ lower & upper limits



Shapes determined from theoretical models  
+ Applying H.E.S.S. Instrument Response functions

# Conclusion

## ■ Dark Matter indirect detection with H.E.S.S.

- Annihilation of SUSY neutralinos to gamma rays
- Detection of exotic shapes in energy spectrum
- Complex background have to be studied and suppressed (ON-OFF, Shape Likelihood)

## ■ Study of Sagittarius Dwarf galaxy

- No significant excess → New limits on Dark Matter annihilation cross-section
- Waiting for more statistics (new data in 2014-2015)

## ■ Line searches near the Galactic Center

- Line signal at 130 GeV detected by Fermi
- Efforts of the H.E.S.S. collaboration presently made to cross-check or rule this discovery with H.E.S.S.II (Energy threshold at 50GeV)
- My present work centered on this line search (a lot of stuff to do here !)

***Thanks for your attention !***

