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Searches for Dark Matter

with the

High Energy Stereoscopic System

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Overview

General scope of this talk:

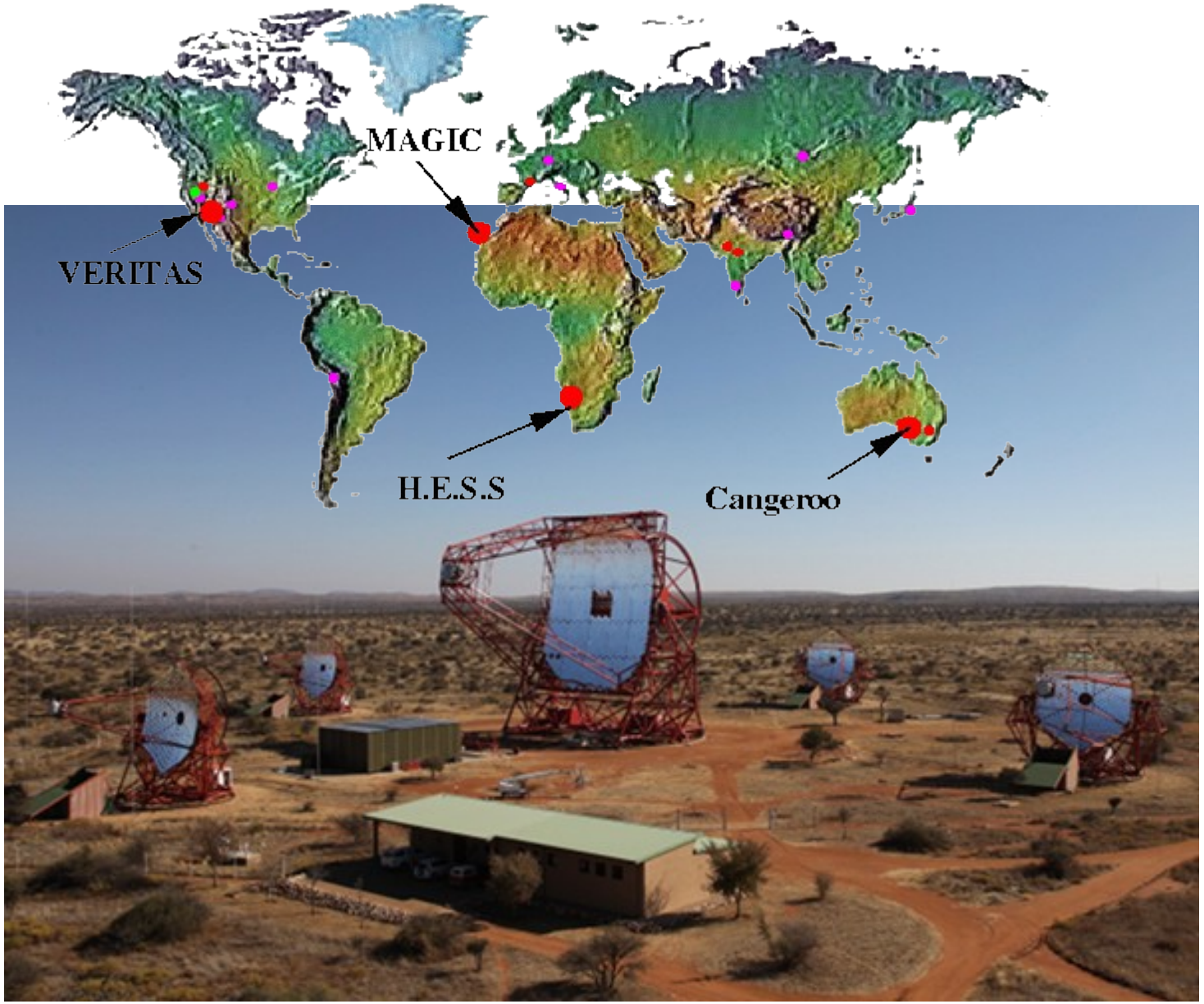
→ Discuss current HESS results on dark matter

→ Glimpse into future results

Start with:

→ Brief introduction into HESS

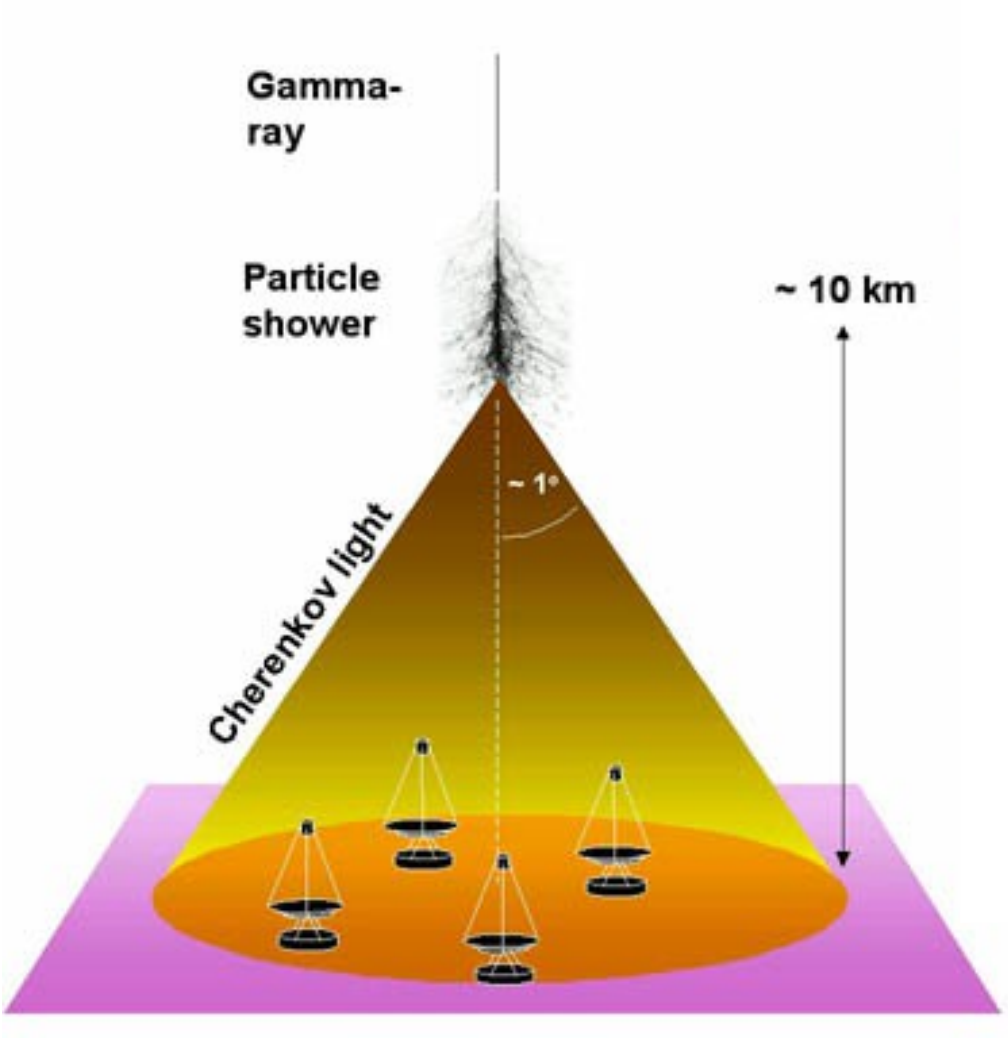
HESS:
The High Energy Stereoscopic System



Detect very high energy gamma rays (E>100GeV):

- **HESSI:**
  - → Operating since 2003
  - → 4 x 15m focal length
  - → Energy threshold: ~ 200 GeV
- **HESSII:**
  - → Operating since 2013
  - → HESSI + 1 x 36m focal length
  - → Energy threshold: Lower than HESSI

How HESS Detects Gamma-Rays



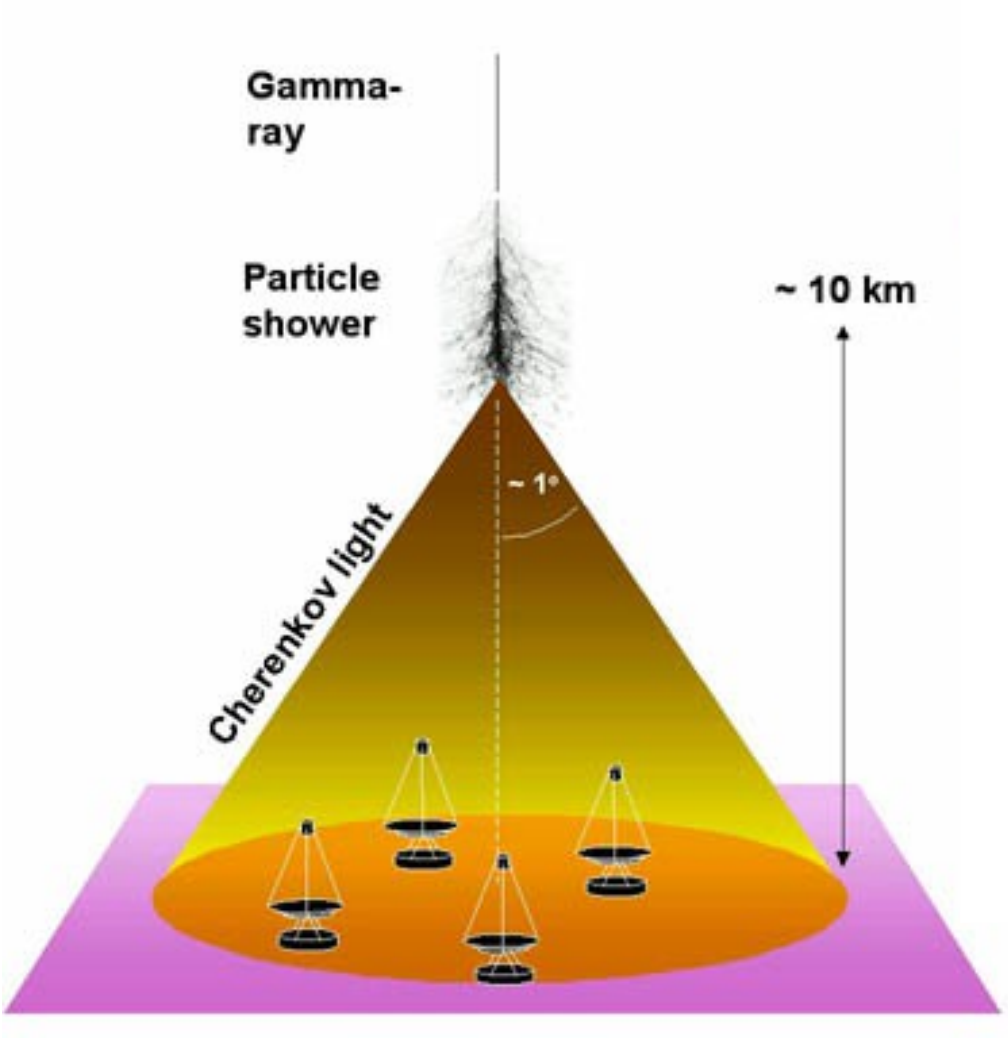
- Primary gamma ray
  → Electromagnetic shower in atmosphere

  → Relativistic charged particles emit Cherenkov light in atmosphere

- Collect Cherenkov light with telescope mirrors

- Detect image with fast optical detectors in telescope cameras

How HESS Detects Gamma-Rays



Problem:

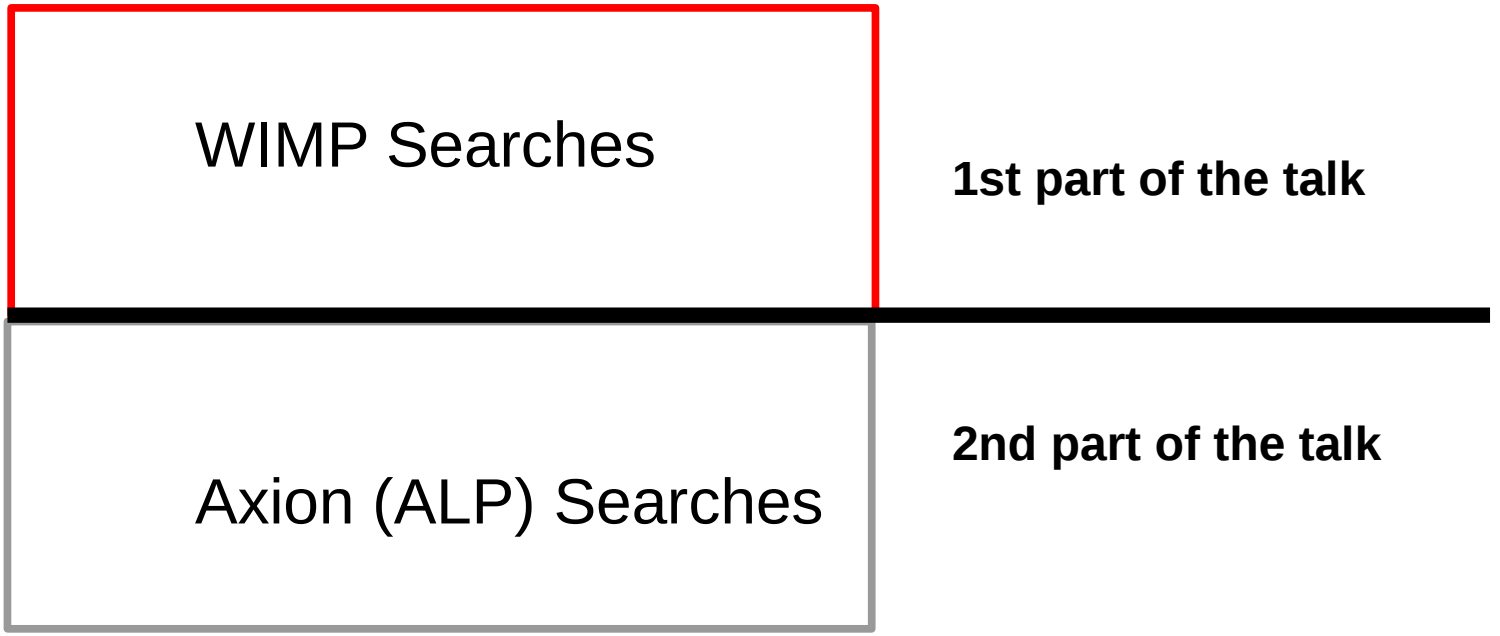
- Cosmic rays also produce electromagnetic showers in atmosphere

  → Background for gamma ray detection

- Multi-level background treatment

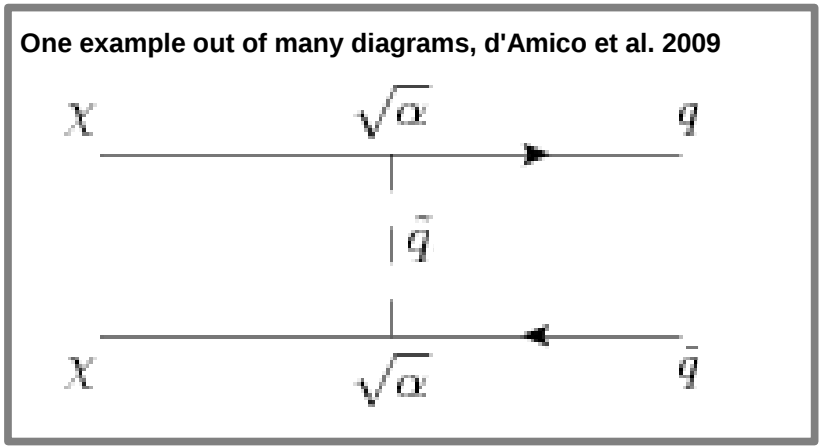
  → Final step (usually):
  'Background subtraction'

Outline


WIMP Searches
1st part of the talk
Axion (ALP) Searches
2nd part of the talk

WIMP Searches

- How-to produce gamma-rays from annihilating WIMPs?
- One possibility: Consider 2 WIMPs → Annihilate into standard model quarks



→ Subsequent hadronization + neutral pion production lead to continuum photon spectrum

- Details of photon spectrum depend on details of annihilation but
  → End point of photon spectrum ~ WIMP mass

  → For TeV mass dark matter: Expect continuum gamma rays

  → Search with HESS

WIMP Searches: Targets for HESS

- Photon flux ~ 1/(distance)²
  → Close targets preferred

- Photon flux ~ (DM density)² for annihilating WIMPs
  → High DM densities along line of sight preferred

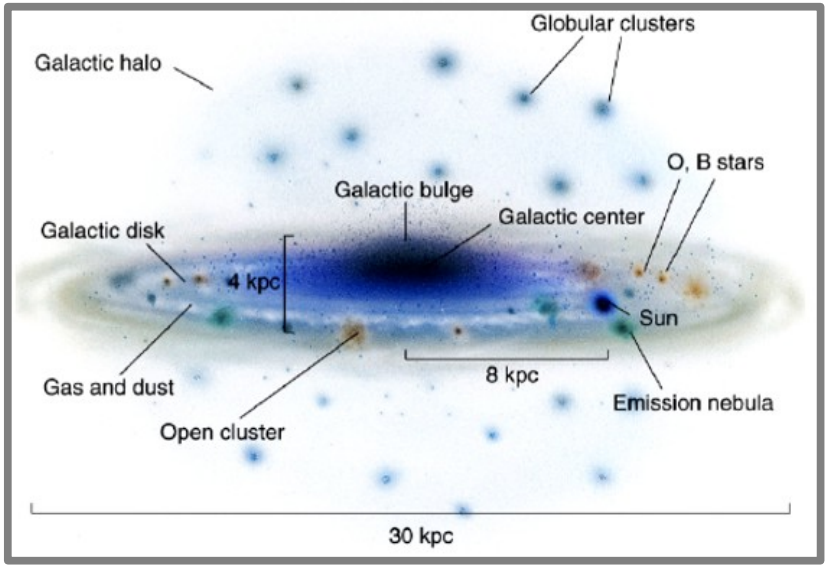
→ Preferred targets for HESS:

- Central region of Milky Way
  → Close target (+)

  → Multiple extended astrophysical gamma ray sources constitute potential 'gamma ray background' (-)

- Dwarf galaxies
  → Farther away than MW center (-)

  → No astrophysical gamma ray background (+)



HESS WIMP Searches:
The Galactic Center Region

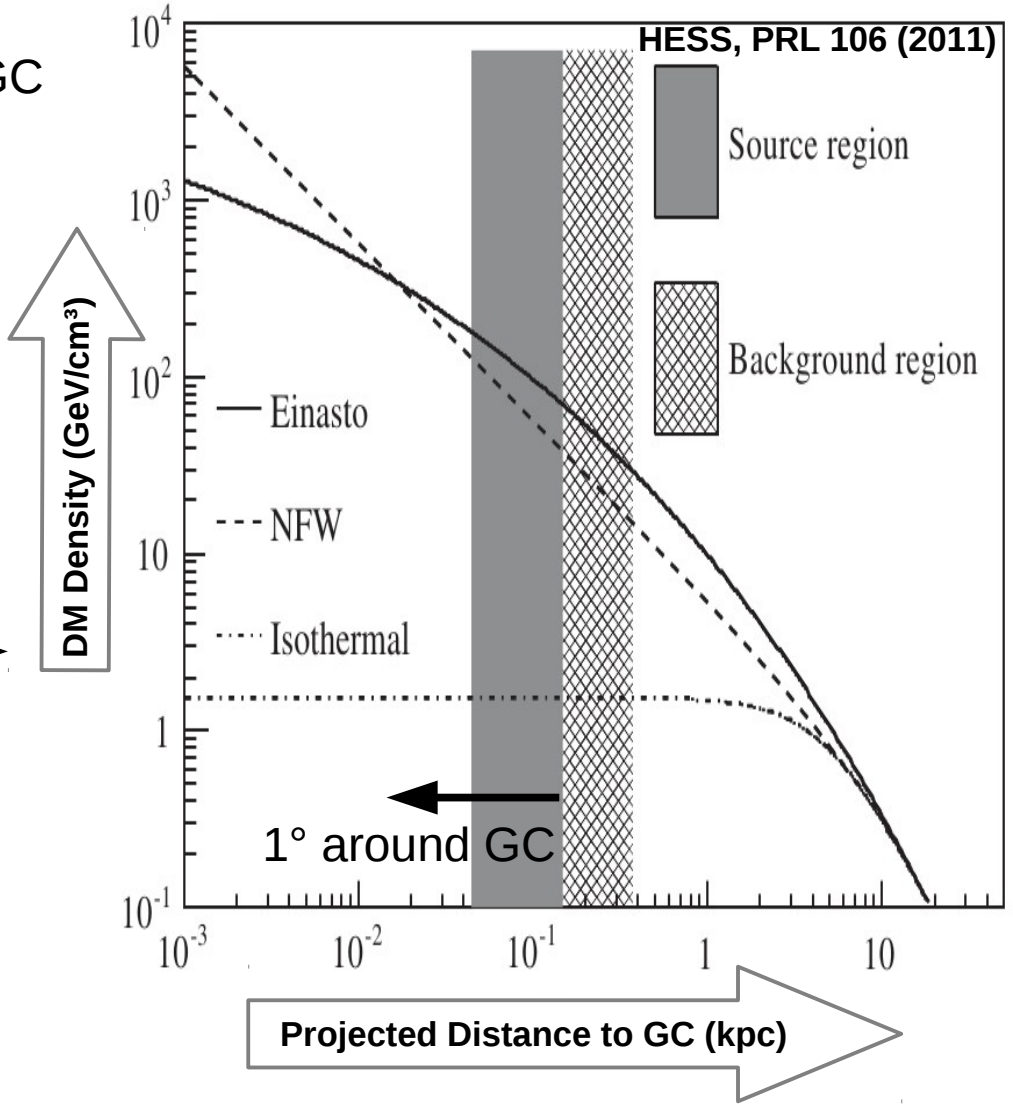
- Define extended signal region around GC:
  → 1° or ~100pc projected distance around GC
- Construct background region:
  → Further away from GC than signal region
- Background subtraction:
  → Subtract background from signal events

- If Milky Way DM density distribution is steep

  [→ F.i. Einasto or NFW profile]

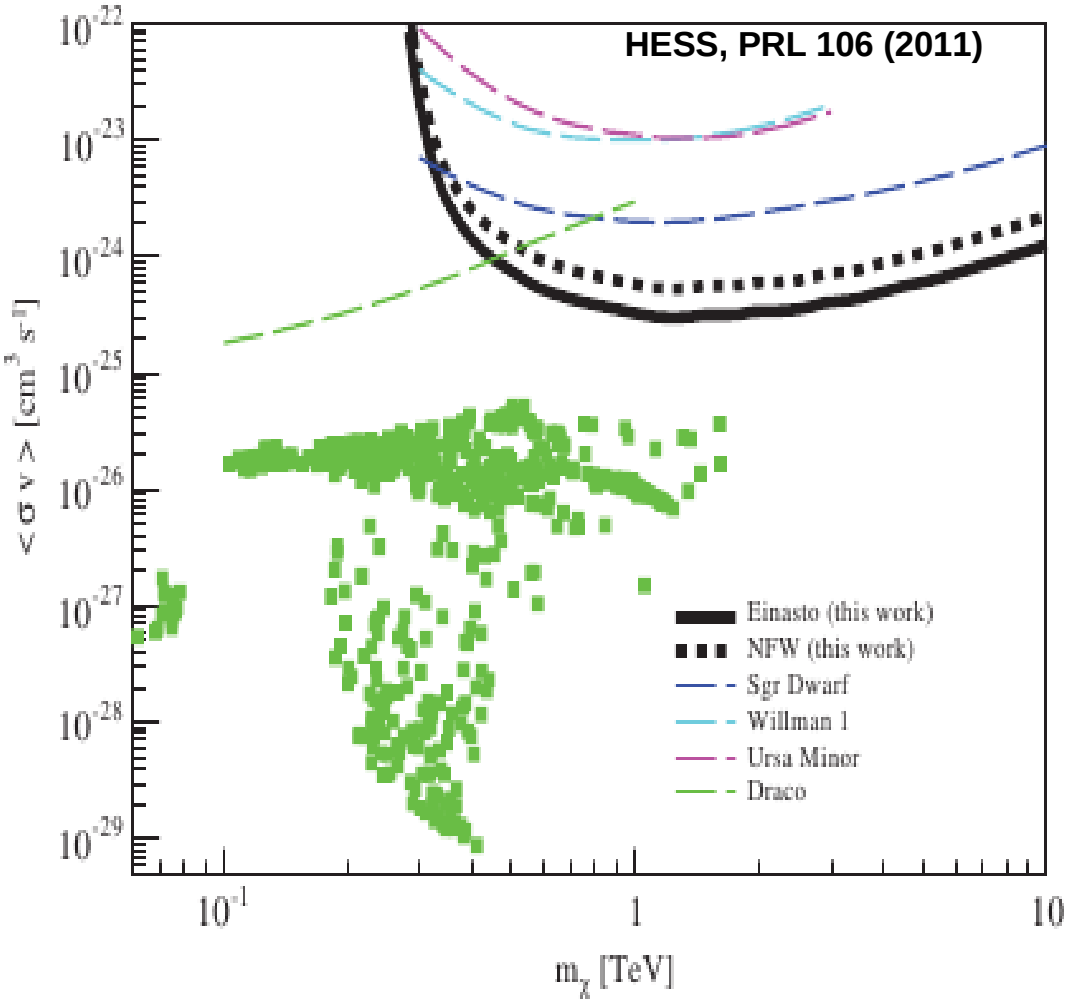
  → Expect less DM annihilation in background than in signal region

  ↔ Expect positive excess if annihilation cross section is large enough

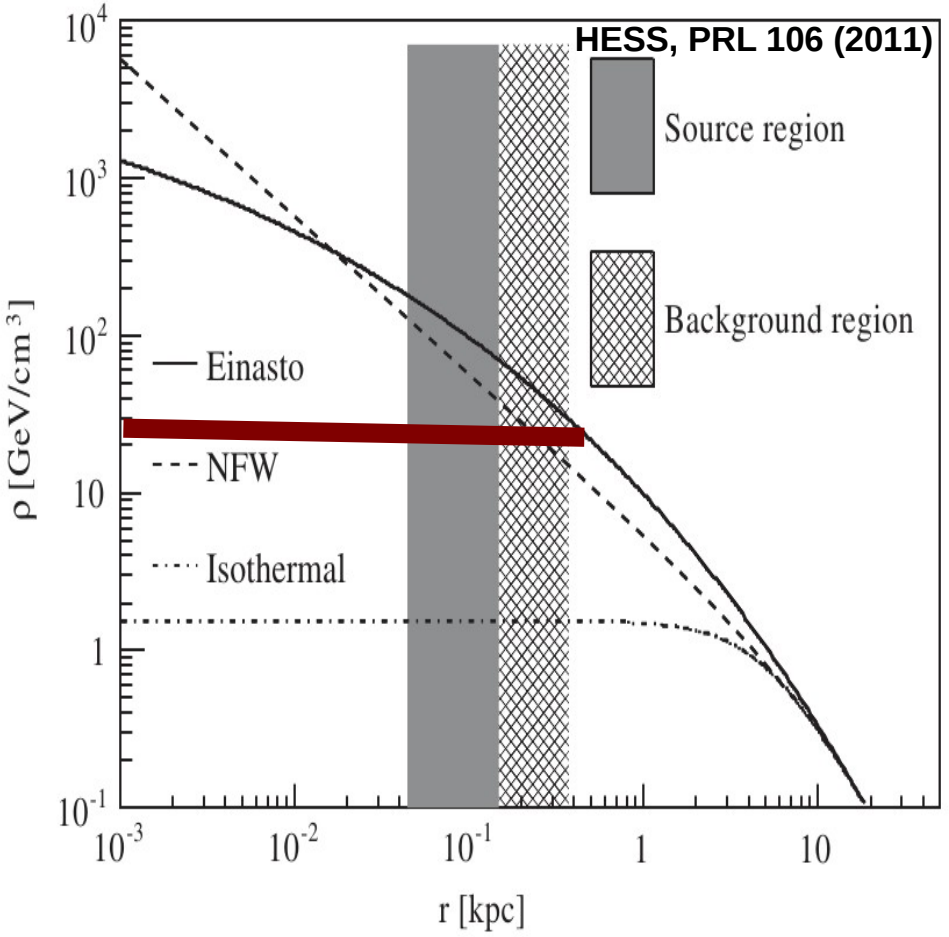


HESS WIMP Searches:
The Galactic Center Region

- No residual excess detected
  → Upper limits on annihilation cross section
- Best limits on annihilation cross section for TeV mass WIMPs
- ~1 order of magnitude above thermal relic cross section at ~1TeV WIMP mass
- Very promising result ...



HESS WIMP Searches:
The Galactic Center Region (Outlook)



→ Sensitive if DM profile of MW is steep

With published method:

(Almost) no sensitivity if Milky Way DM distribution is cored within central ~500pc

→ Evidence for this by new N-body simulations that consider baryons

[see f.i. Pontzen and Governato, Nature (2014)]

→ Different method needed in this case

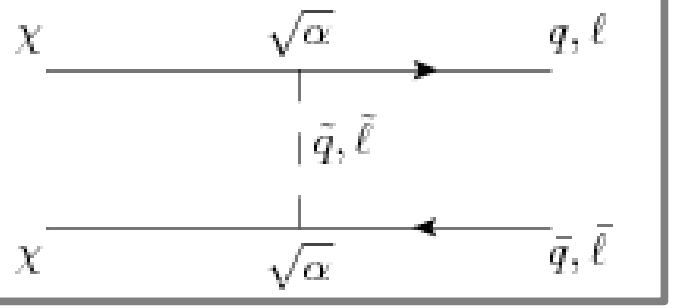
Photon Line Searches

Up to now:

- Only discussed continuum emission

WIMP Annihilation → Continuum Gamma Rays

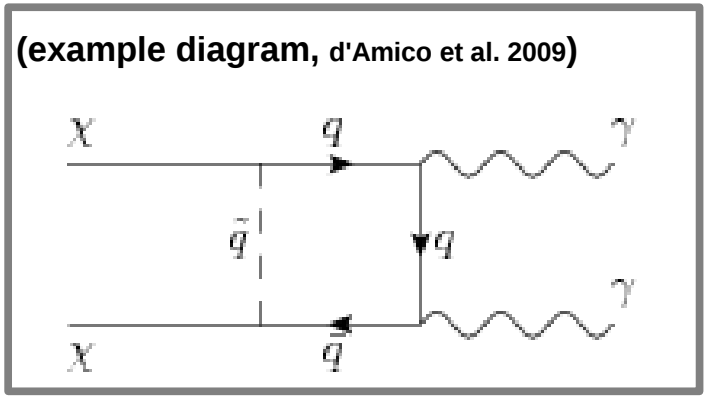
(example diagram, d'Amico et al. 2009)



- Gamma ray line emission in WIMP annihilation:

WIMP Annihilation → Gamma ray line production

(example diagram, d'Amico et al. 2009)



→ Loop suppressed
→ (Almost) no astrophysical backgrounds

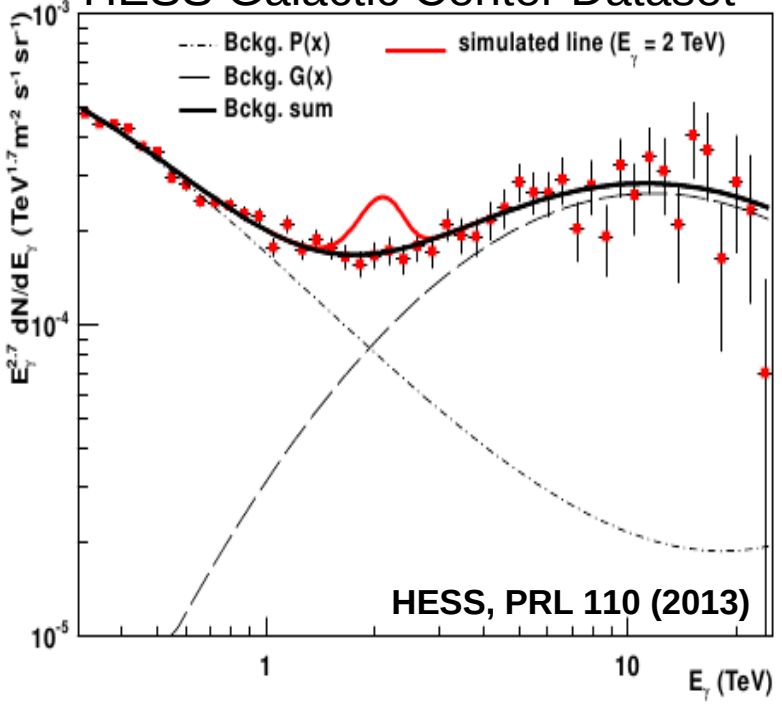
Photon Line Searches Towards the GC

- Measure CR background flux from extended GC region
  → Fit with “smooth function” in energy

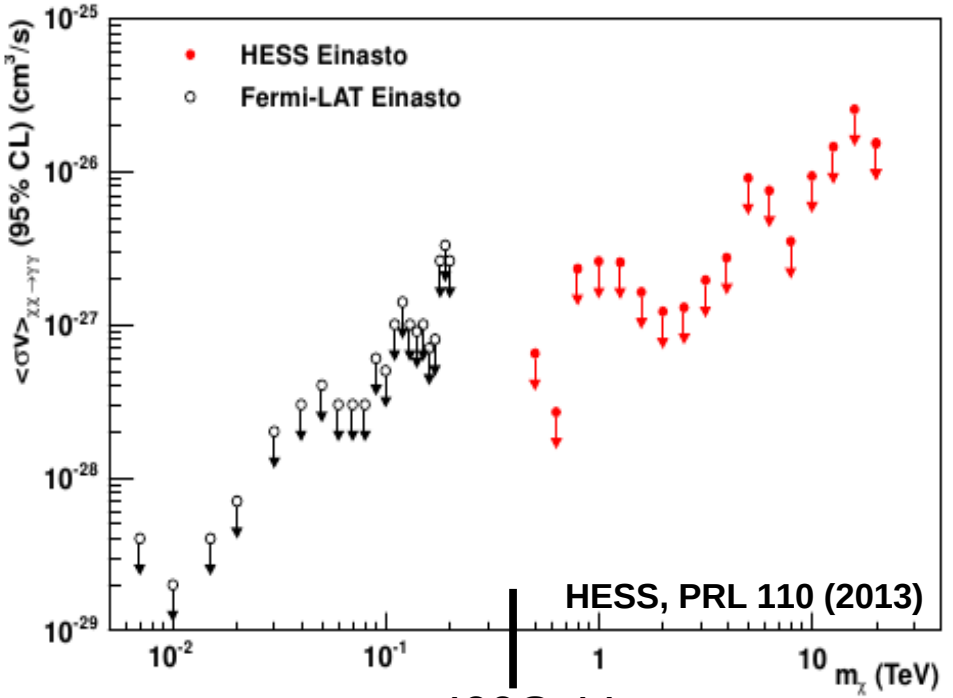
- Refit with line fluxes (folded with HESS energy resolution) on top of fitted CR background flux

  → Amplitude of fitted lines connected to annihilation cross section
  [For a given DM profile]

HESS Galactic Center Dataset



Best limits above 400 GeV WIMP mass



130 GeV Photon Line Search

- You heard about the 'tentative' Fermi signal 
  [f.i. C. Weniger, JCAP (2012) and subsequent papers]
- HESSI line search only to ~ 400 GeV
- HESSII:
  Larger mirror than HESSI → Lower energy threshold

  → Confirm Fermi 'signal' ?

- One problem (out of many more):

  → Spatial origin of 130GeV excess is very badly constrained by Fermi data

  → HESSII has a much smaller field of view than HESSI

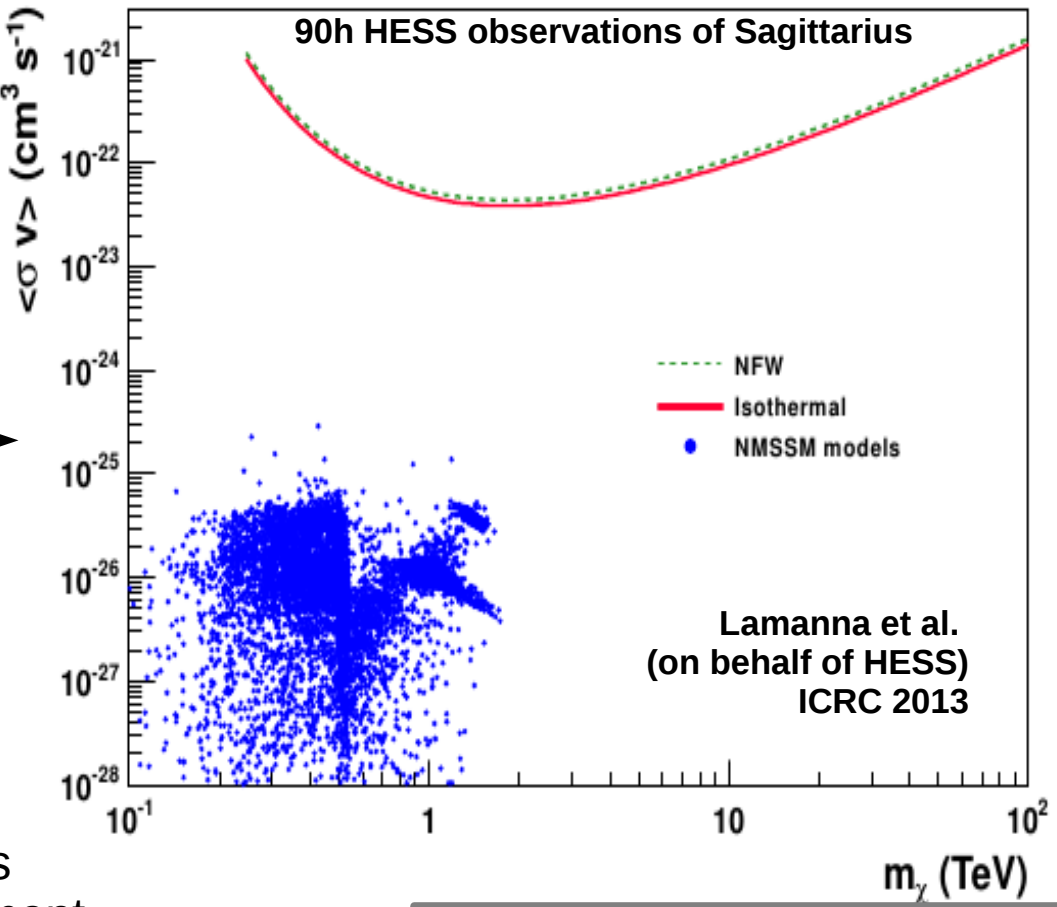
  → Pointing and observation strategy highly non-trivial

  → We're working on it ...

WIMP Searches:
Dwarf Galaxies

- HESS searches towards:
  - → Sagittarus [HESS, AP 29, 2008]
  - → Sculptor [HESS, AP 34, 2011]
  - → Carina [HESS, AP 34, 2011]
  - → Fornax [HESS, APJ 750, 2012]

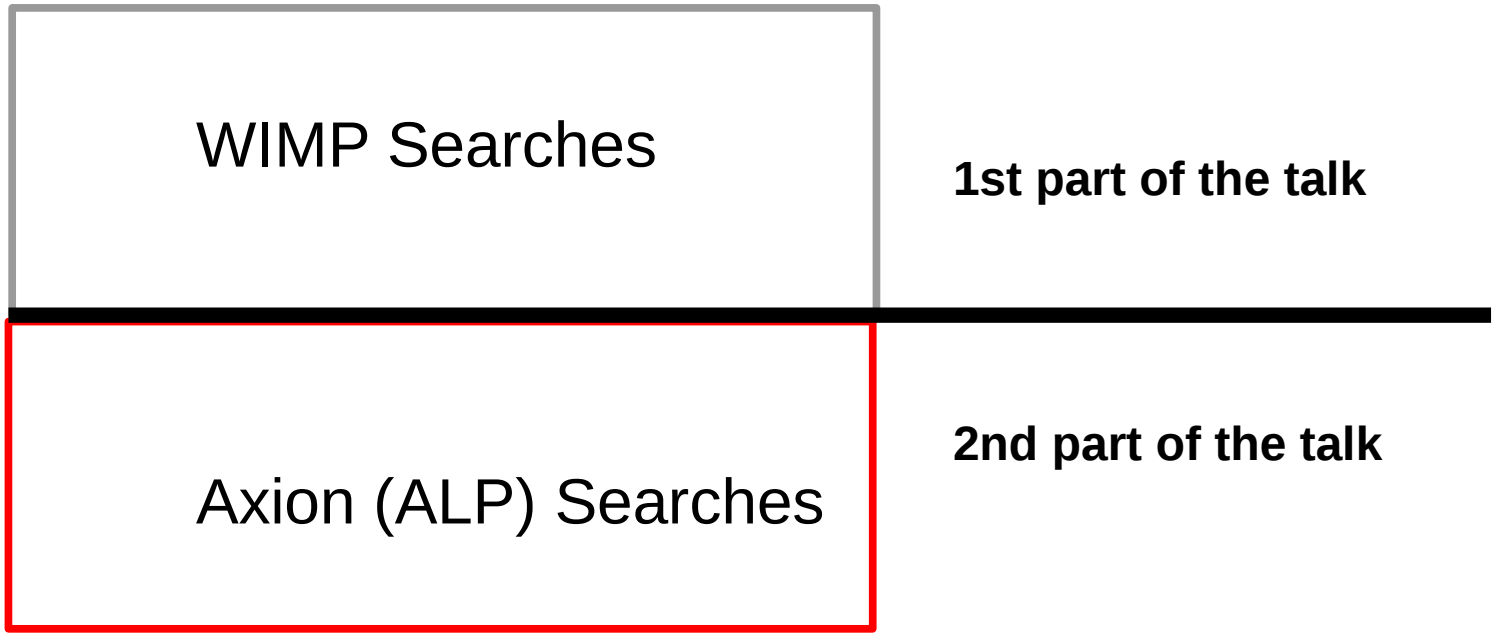
- Studies are being continued ...



- Limits not as constraining as GC limits
  - → But 'cleaner' astrophysical environment
  - → Better knowledge of “astrophysical factors”

- Expect new data, analyses techniques and results soon ...

Outline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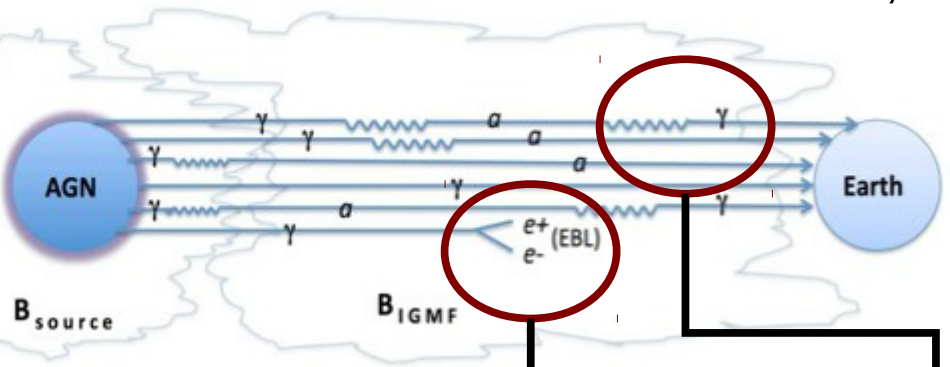
Axion (and ALP) Searches

Axions couple to photons:

$$L = g_{\gamma a} \vec{E} \cdot \vec{B}\, a$$

If axions exist:
Gamma-ray ↔ Axion oscillation
in large scale magnetic fields

Sanchez-Conde et al., 2009



Presence of axions modifies opacity of gamma ray universe

→ Will hear more later in this workshop (I think)

For turbulent magnetic fields:
→ Expect “irregular”, i.e. non-smooth, AGN energy spectra

→ See HESS, Phys. Rev. D 88 (2013) for details ...

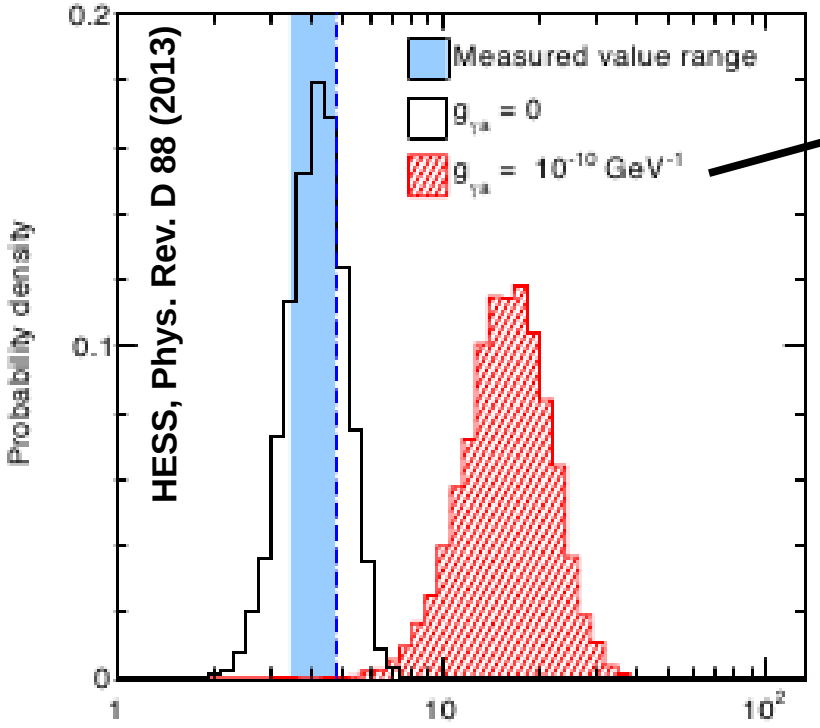
Axion Searches: PKS-2155

PKS-2155:
→ Well studied BL Lac in center of galaxy cluster

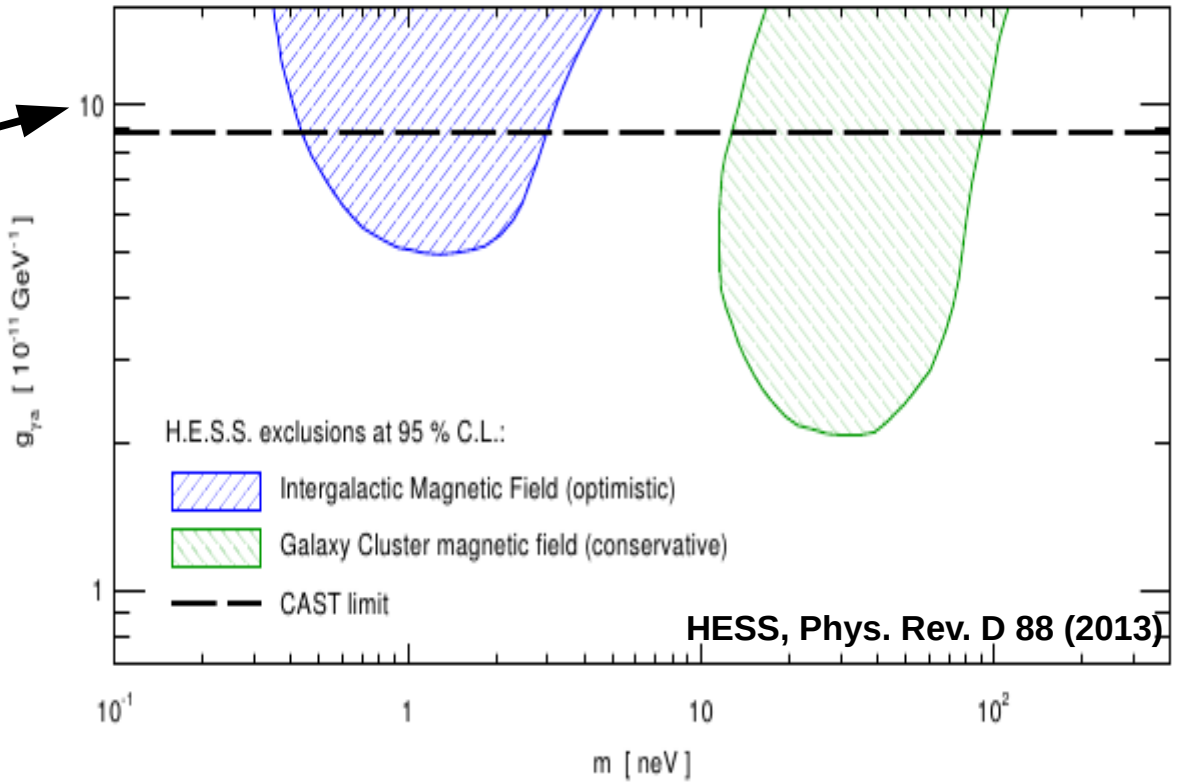
Gamma-rays from PKS-2155 travel through

→ Galaxy cluster magnetic field
→ Intergalactic magnetic field

Both turbulent
→ Search for 'irregularities ' in energy spectrum

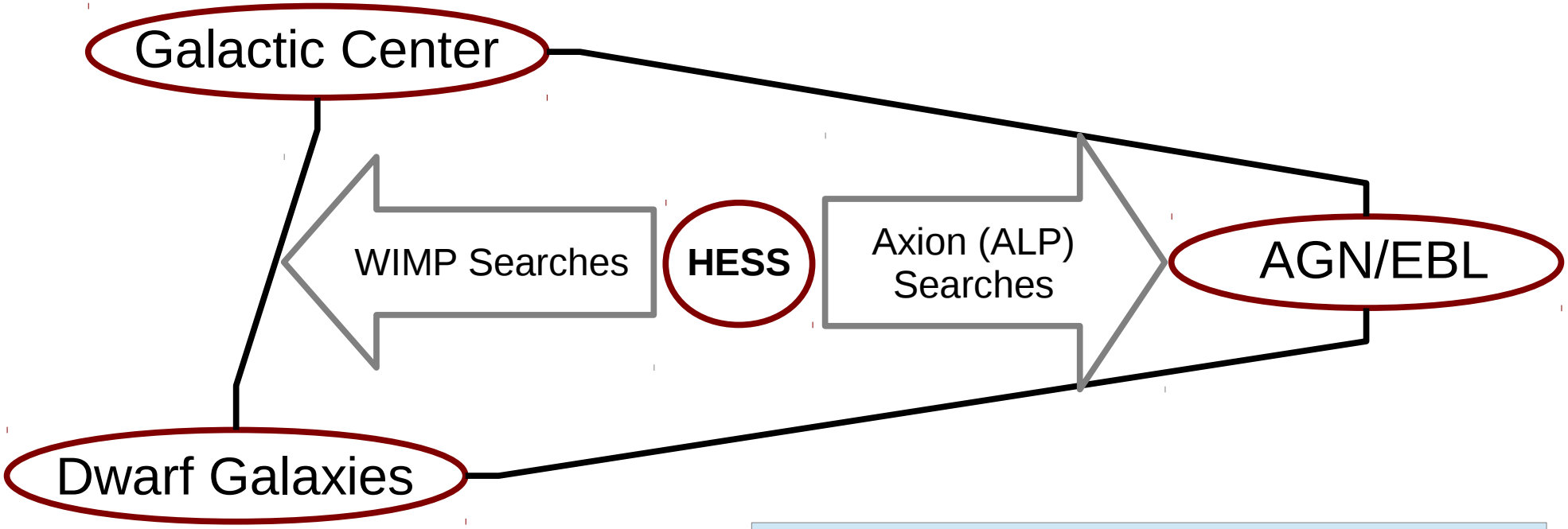


Estimator for "irregularity" of PKS-2155 energy spectrum



Summary

- HESS collaboration very active in a variety of dark matter searches



- Expect major updates soon
  - → Improved and new analyses techniques
  - → First HESSII results (!)

Thanks for your attention