ICRR
Institute for Cosmic Ray Research
University of Tokyo

Search for dark matter TeV spectral lines around the Galactic Centre with the MAGIC telescopes

Tomohiro Inada (ICRR, UTokyo)

Daniel Kerszberg, Moritz Hütten, Masahiro Teshima,
Javier Rico, Daniele Ninci

Dark matter searches in the 2020s - At the crossroads of the WIMP
Kashiwa, 13/11/2019

Motivation

Dark Matter Search

★ Dark matter dominates ~23% of mass-energy of the universe.

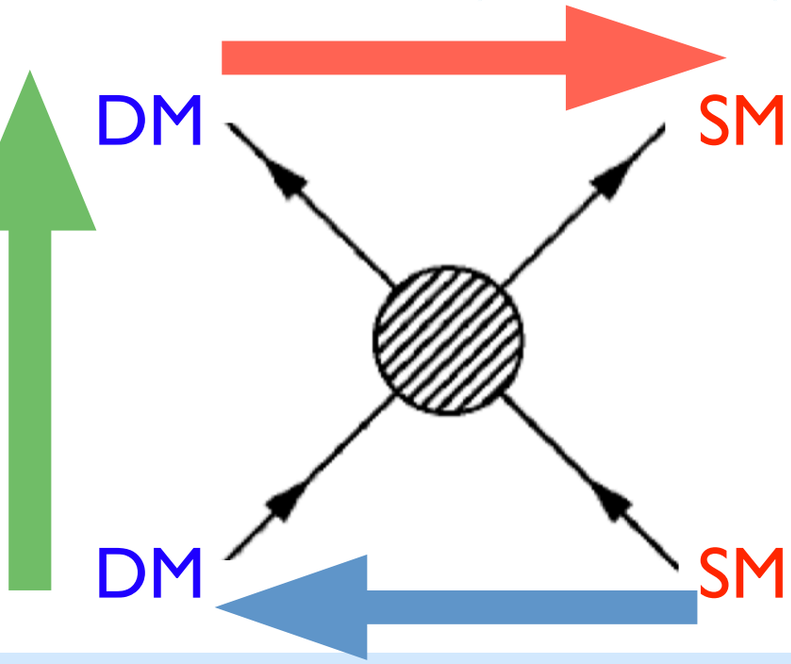
★ Good candidate : Weakly Interactive Massive Particle, WIMP

★ "WIMP Miracle" : expects DM mass, O(GeV - TeV) range

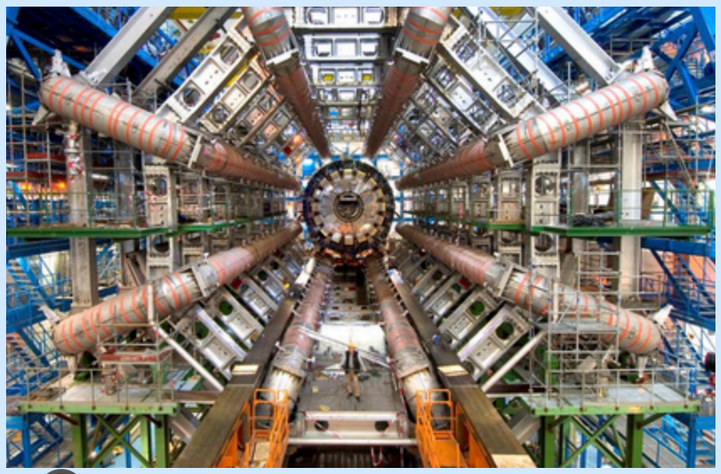
Direct Search

©XENON collaboration

Many experiments are trying, but no evidence for detection yet…



Production at Collider



©ATLAS collaboration

Indirect Search

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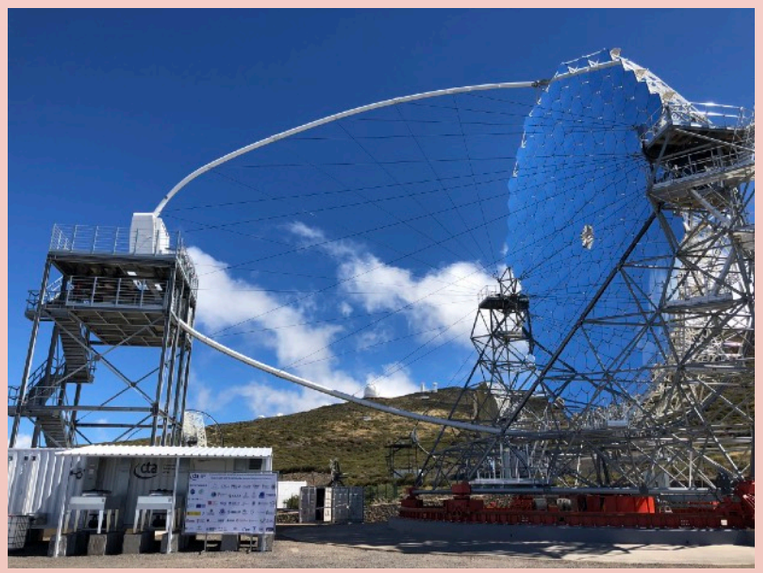
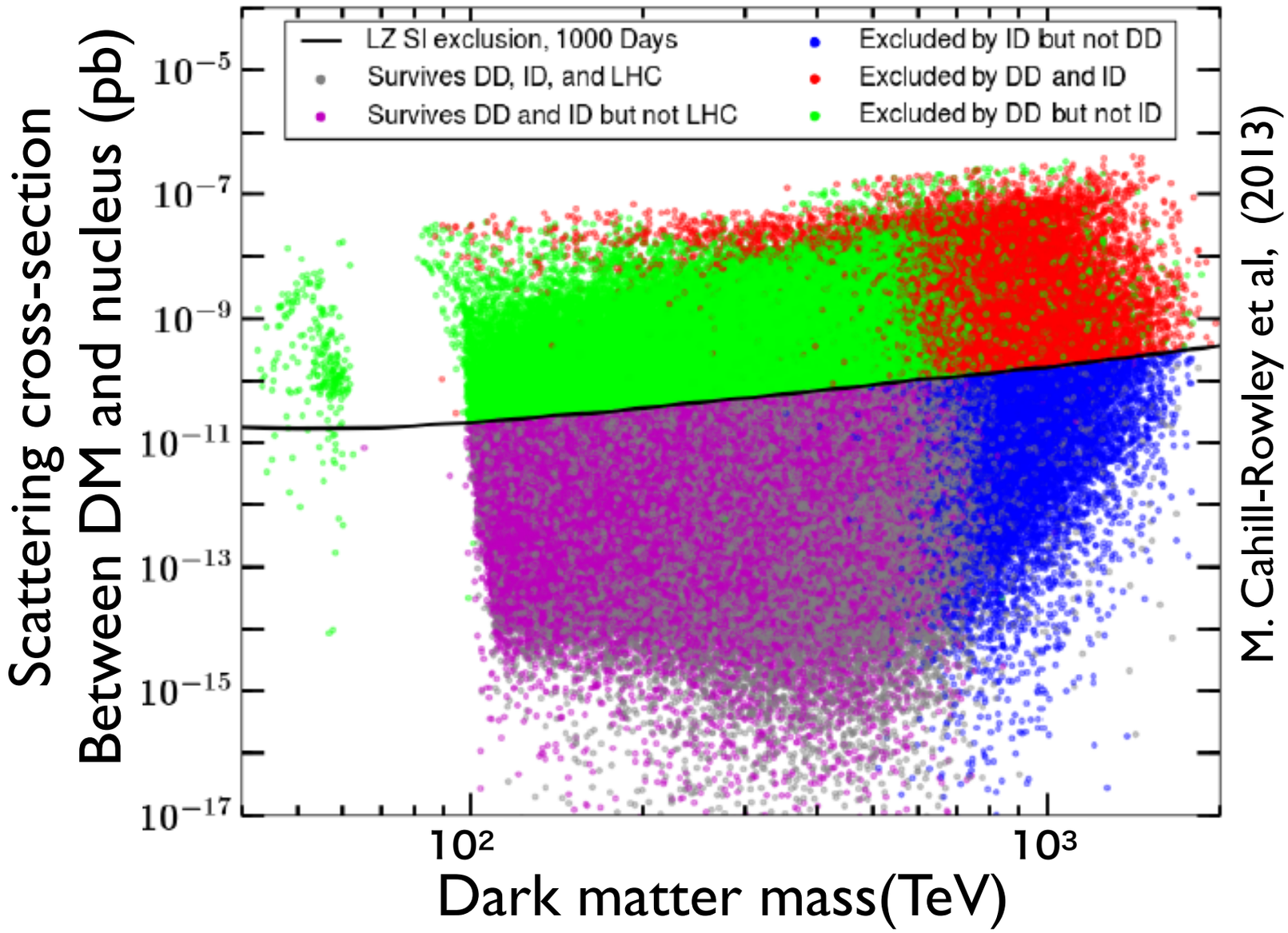


Where is a “next frontier”?

pMSSM model parameter space

(phenomenological minimum supersymmetric model)



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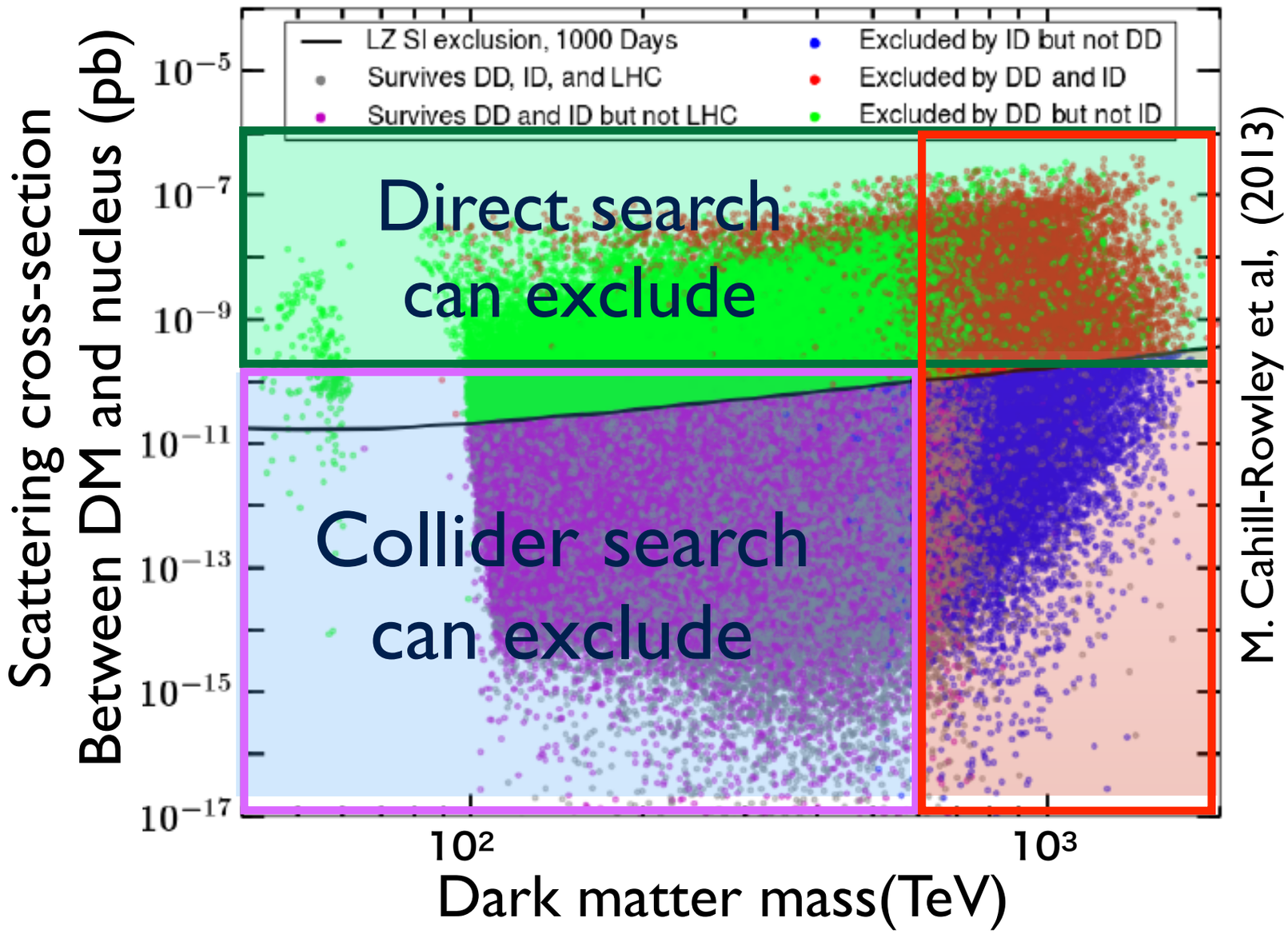


A. TeV DM by indirect search

Search for dark matter spectral lines

Gamma-ray Flux from DM

Gamma-ray flux

$$\frac{d\Phi(\Delta\Omega)}{dE} = \frac{d\Phi^{\mathrm{PP}}}{dE} \times J(\Delta\Omega).$$

Particle physics term in case of annihilation

Astrophysical term

$$\frac{d\Phi^{\mathrm{PP}}}{dE} = \frac{1}{4\pi} \frac{\langle\sigma_{\mathrm{ann}} v\rangle}{2m_\chi^2} \frac{dN}{dE}$$

$$J_{\mathrm{ann}}(\Delta\Omega) = \int_{\Delta\Omega}\int_{los} \rho^2(l,\Omega) dl d\Omega.$$

`Mχ : Mass of DM particle

$\langle\sigma_{ann} v\rangle$: cross-section times velocity

dN/dE : differential gamma-ray yield per annihilation

ρ : dark matter density

ΔΩ : solid angle

l : line of sight

In case of line search, spectral shape is delta function at *M*χ

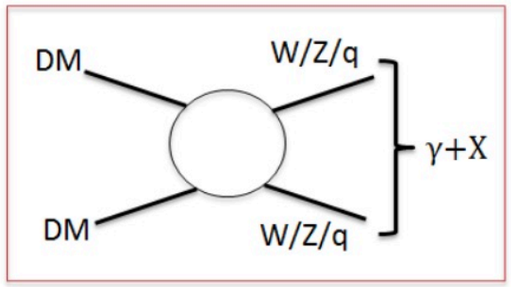
$$\frac{dN}{dE} = 2\delta(E - m_\chi)$$

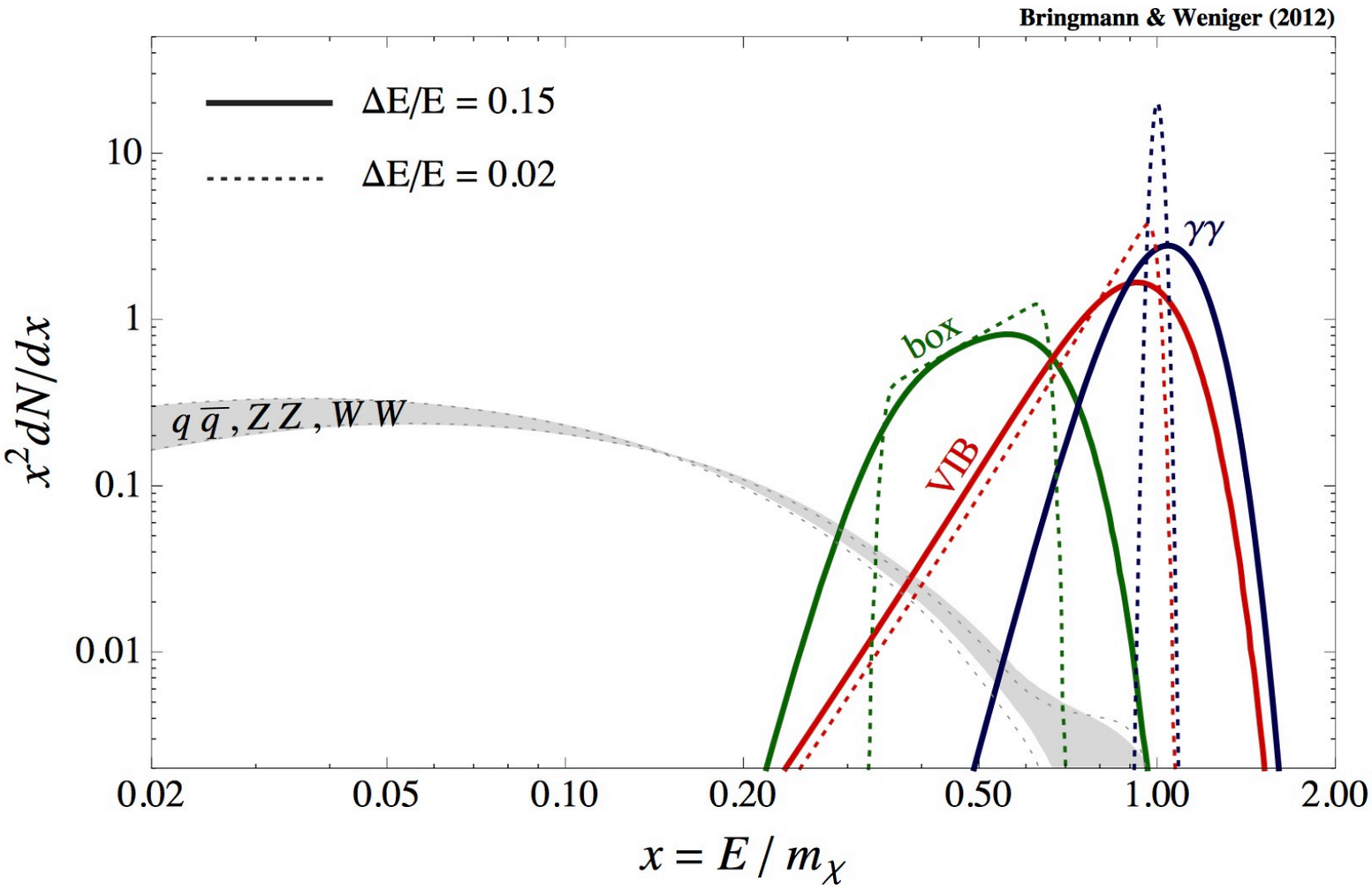
Depends on the given source, on DM distribution and on the instrument

Photon energy spectrum

Continuous emission from secondary photons

Peak at ~1/10 DM mass



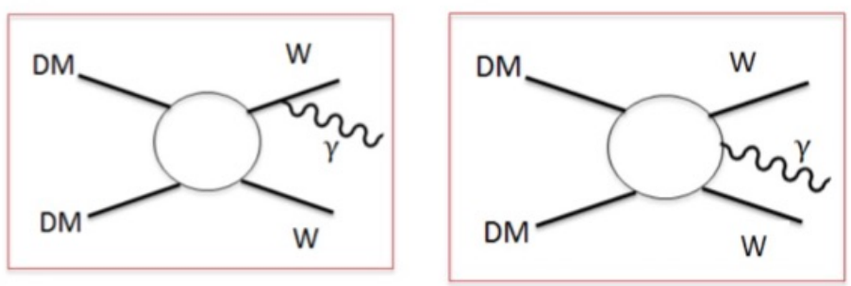


Cascade decays

$$\chi\chi \to \phi\phi \to \gamma\gamma\gamma\gamma$$

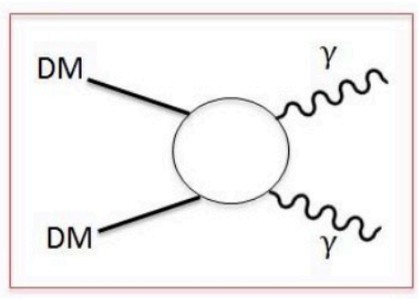
Internal Bremsstrahlung (IB)

$$\chi\chi \to f\bar{f}\gamma$$



Gamma-ray lines $\chi\chi \to \gamma\gamma$

Peak at DM mass



Motivation for line search

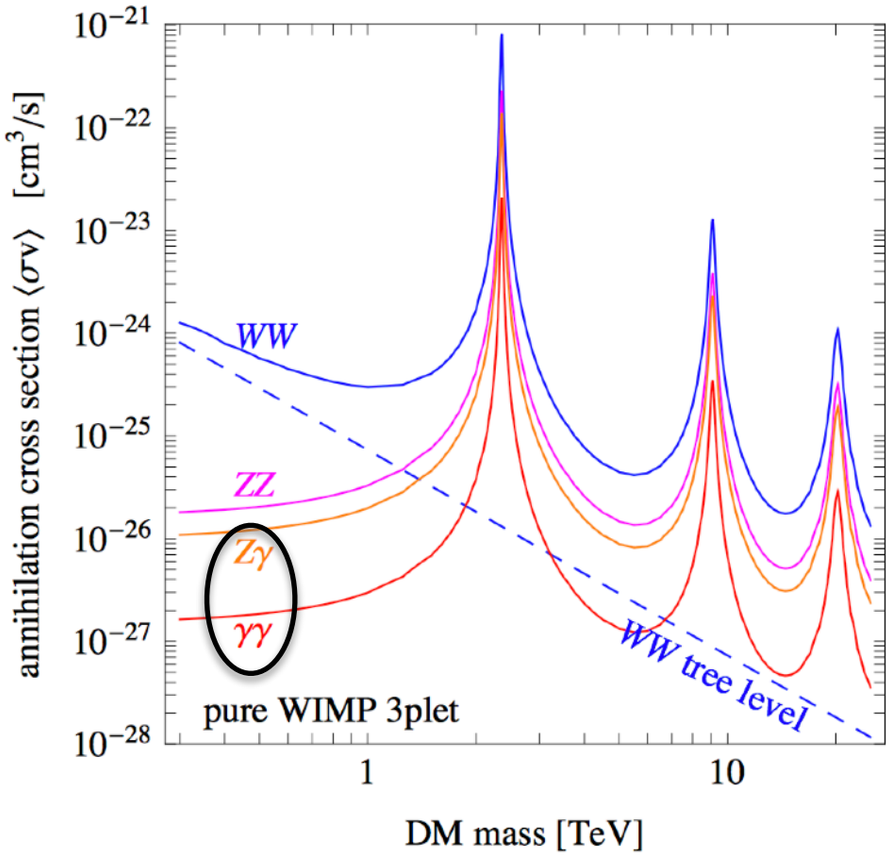
The expected cross section $\langle \sigma v \rangle = \langle \sigma v_{\tau\tau} \rangle + \langle \sigma v_{bb} \rangle + \langle \sigma v_{\gamma\gamma} \rangle$ …

derived from thermal relic $\langle \sigma v \rangle \simeq 3 \times 10^{-26}\,\mathrm{cm}^3\,\mathrm{s}^{-1}$

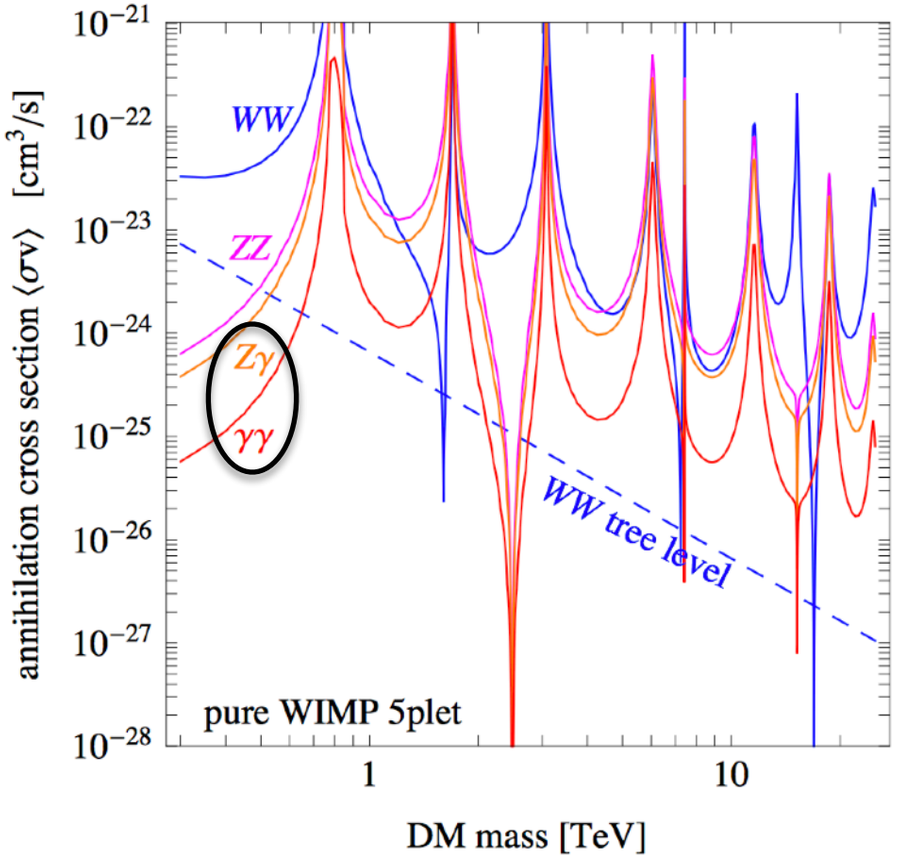
The Branching ratio for 2γγ is suppressed by factor α^2 ,but…

Some promising models show their cross-sections are enhanced by non-perturbative phenomenon (the "Sommerfeld effect")

3plet (wino-like in SUSY)



5plet (minimal DM model)



J. Hisano, S. Matsumoto, M. M. Nojiri and O. Saito 2005
M. Cirelli, N. Fornengo and A. Strumia (2006)
H. E.S.S. collaboration JCAP11(2018)

Observational targets

★Condition to choose targets for DM search

- Maximize the quantity of DM signal (close distance and large DM density)

★Dwarf-Sph galaxies

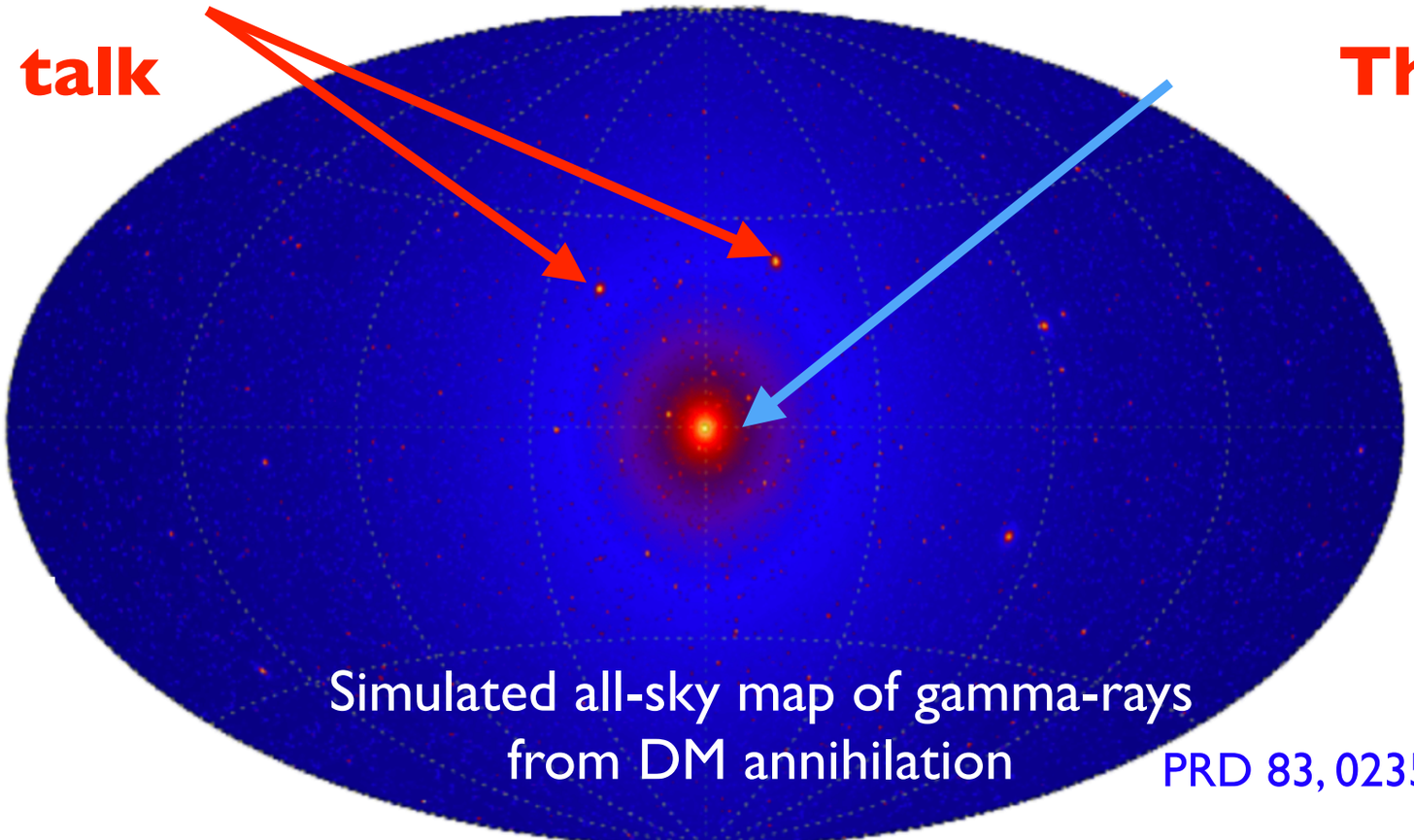
- Galaxy satellites of the Milky Way
  - Close (approximately 100 kpc from GC)
- High J-Factor : 10^{18} - 10^{19} GeV^2/cm^5
- Much less astrophysical background
- "Point-like" source

Kerszberg's talk

★Galactic Centre

- Proximity (~8 kpc)
- Highest J-Factor : ~ 10^{20}-10^{21} GeV^2/cm^5
- High astrophysical background and source confusion.
- Extended source

This talk



Simulated all-sky map of gamma-rays from DM annihilation

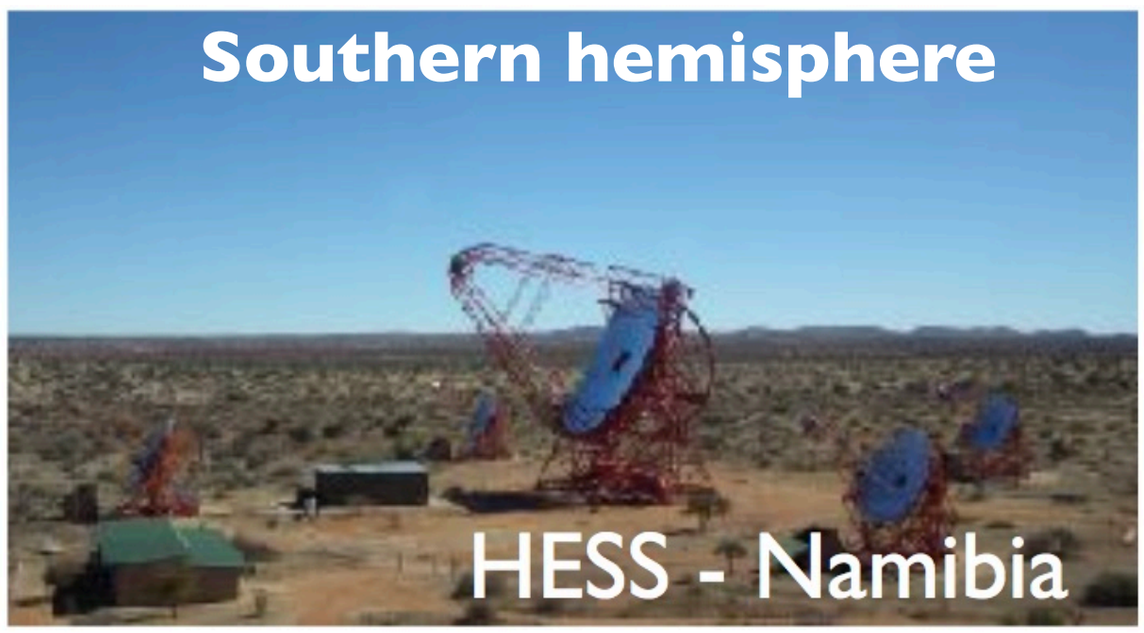
PRD 83, 023518 (2011)

The Galactic Centre

Observation

Current Cherenkov Telescopes

- Effective area : $10^4 \sim 10^5$ m^2
- Energy range : O(100) GeV - O(100)TeV
- Energy resolution : between ~10% and ~20%
- Angular resolution : ~0.06 deg @ 1TeV
- FoV : 3 ~ 5 deg
- Stereoscopic system : 2 - 5 telescopes



The GC observation

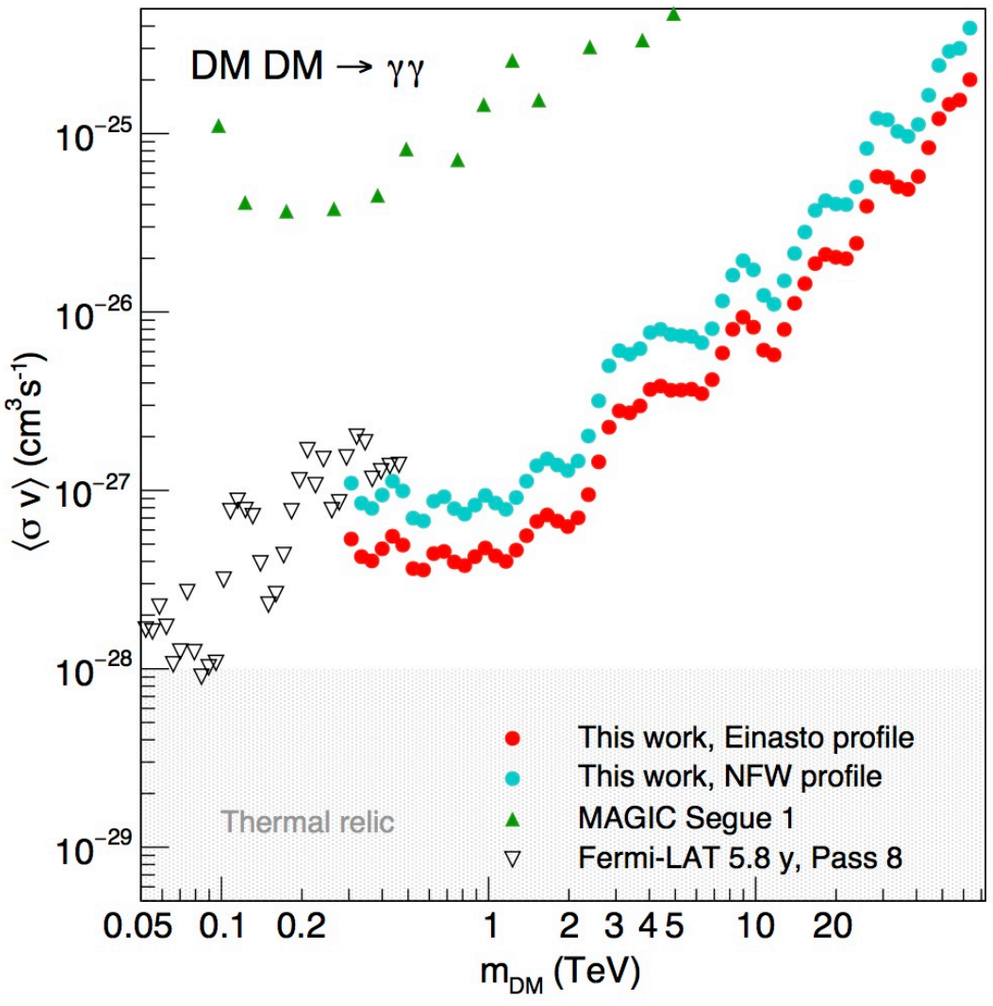
★Current Status

- Galactic Centre for DM in GeV - TeV range only published by H.E.S.S.
- because of good observability
  - Zenith angle ~ 20 [deg] (average)
  - Observation time : 254 h (10 years)

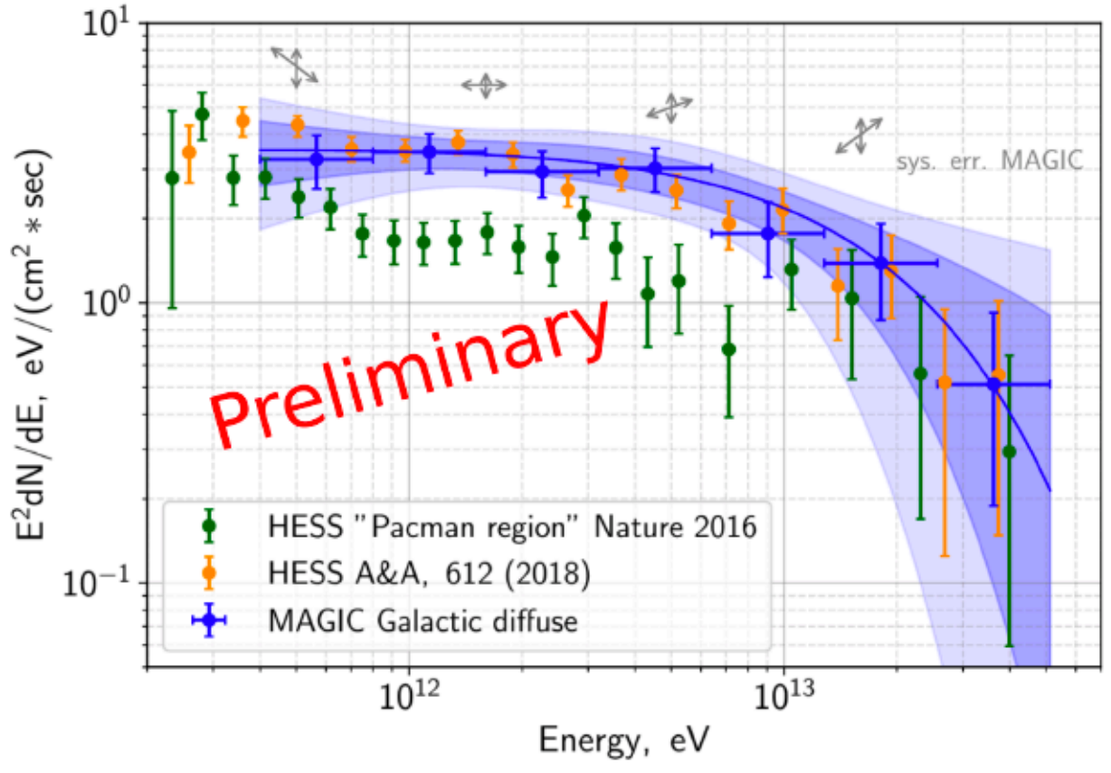
Reachable only from the southern hemisphere ?

No

e.g. diffuse gamma-ray study, (~100 h), MAGIC can get the compatible spectrum.



PRL 120, 201101 (2018)



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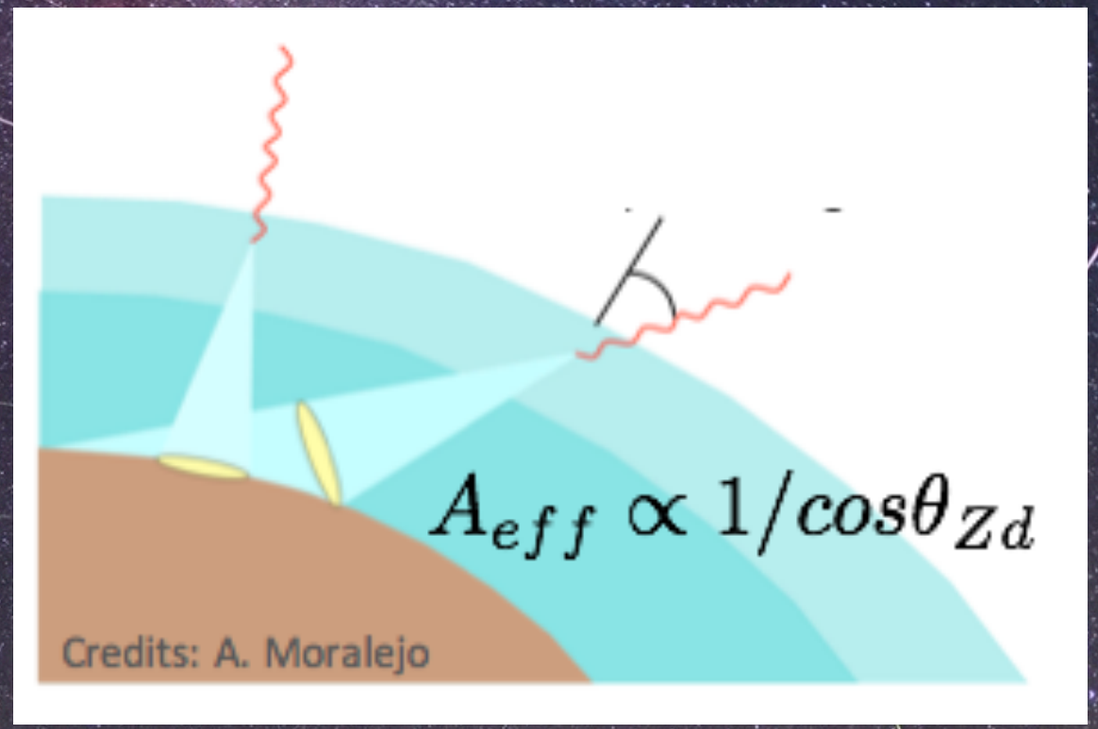
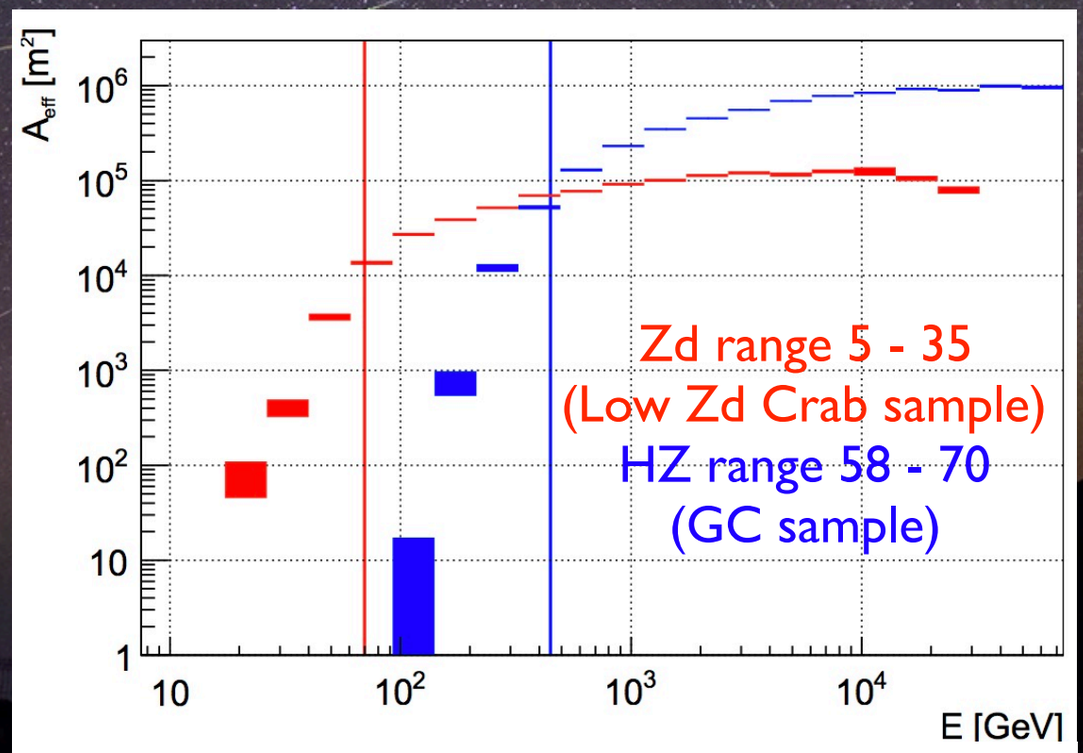
What is the situation for MAGIC?

- **G.C observation for MAGIC**
  - Zenith Angle : 58 - 70 [deg]
    (High Zenith, HZ)

- Merit and demerit HZ observation
  - Effective area : increase
    - by a factor of ~ 3 (or more) in TeV range
  - Threshold : increase
    - by a factor of 10
    - ~ 500 - 700 GeV (MAGIC case)

Focus on TeV Dark Matter !!





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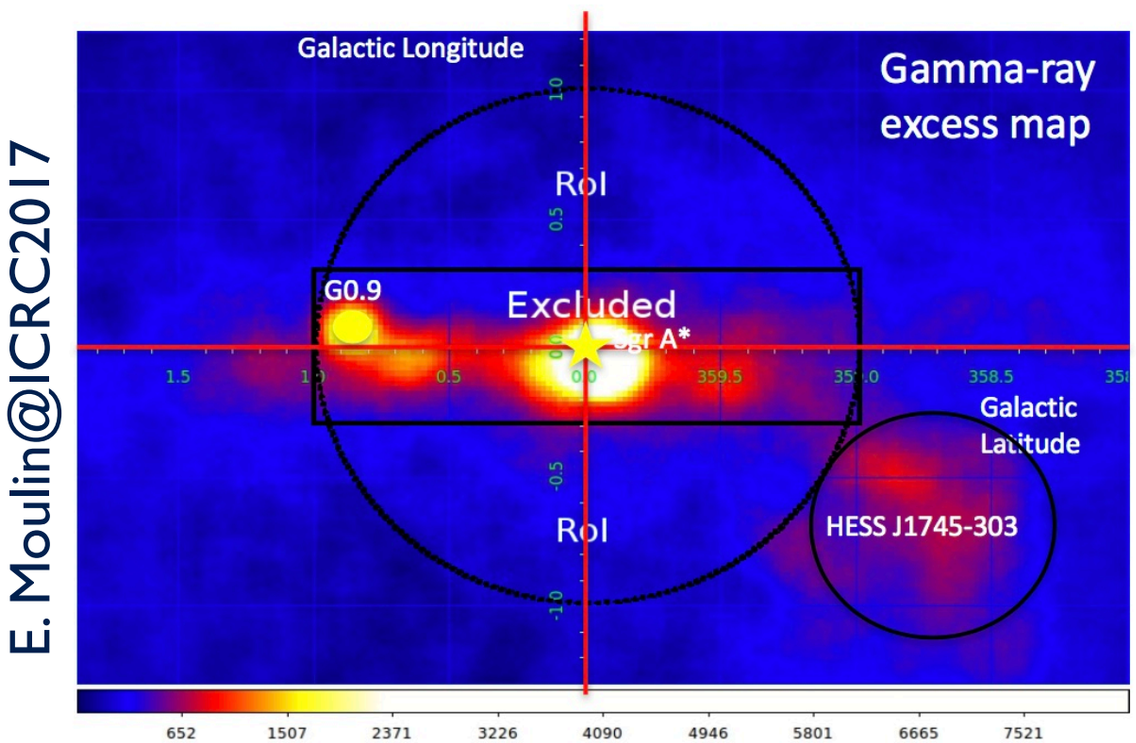
Analysis technique for line search

★Motivation

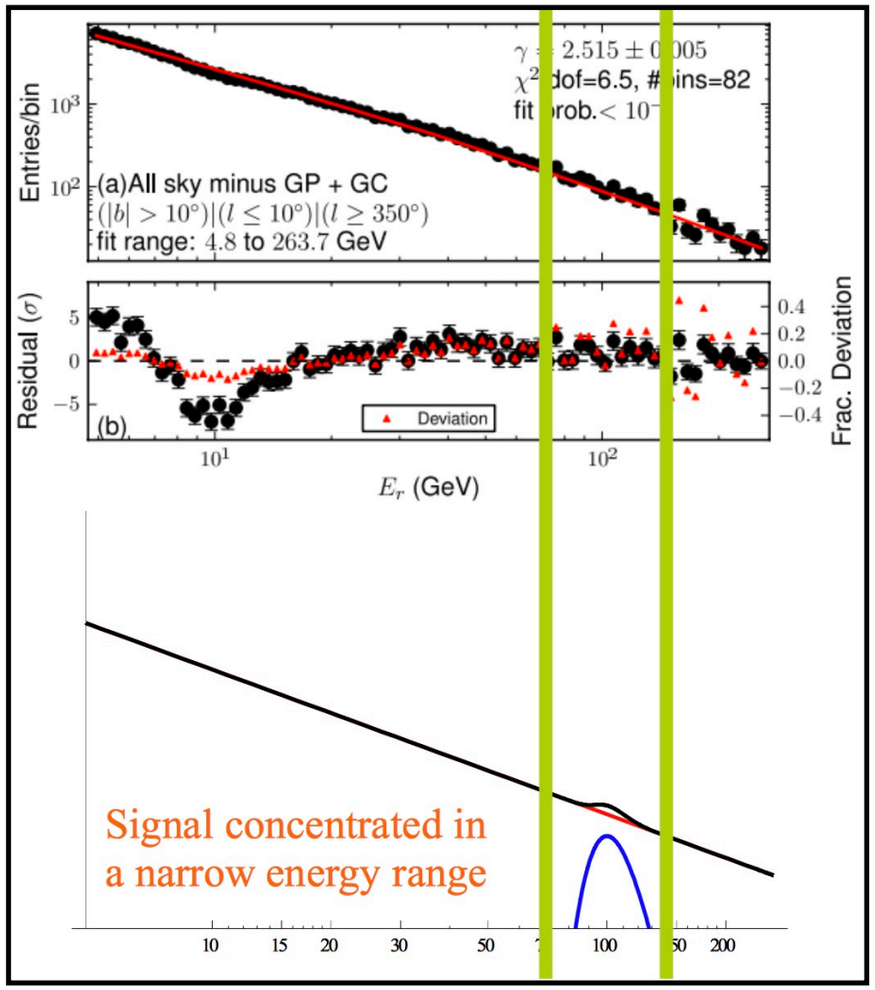
- ◆The region around Gal. Center is really crowded.
  - ■"On - Off" subtraction may include source contamination
- ◆Make use of "spectral shape" without background subtraction

★Sliding window technique

- ◆Assume the signal concentrated in a narrow energy range
- ◆Search for the spectral feature on the smooth curve



E. Moulin@ICRC2017

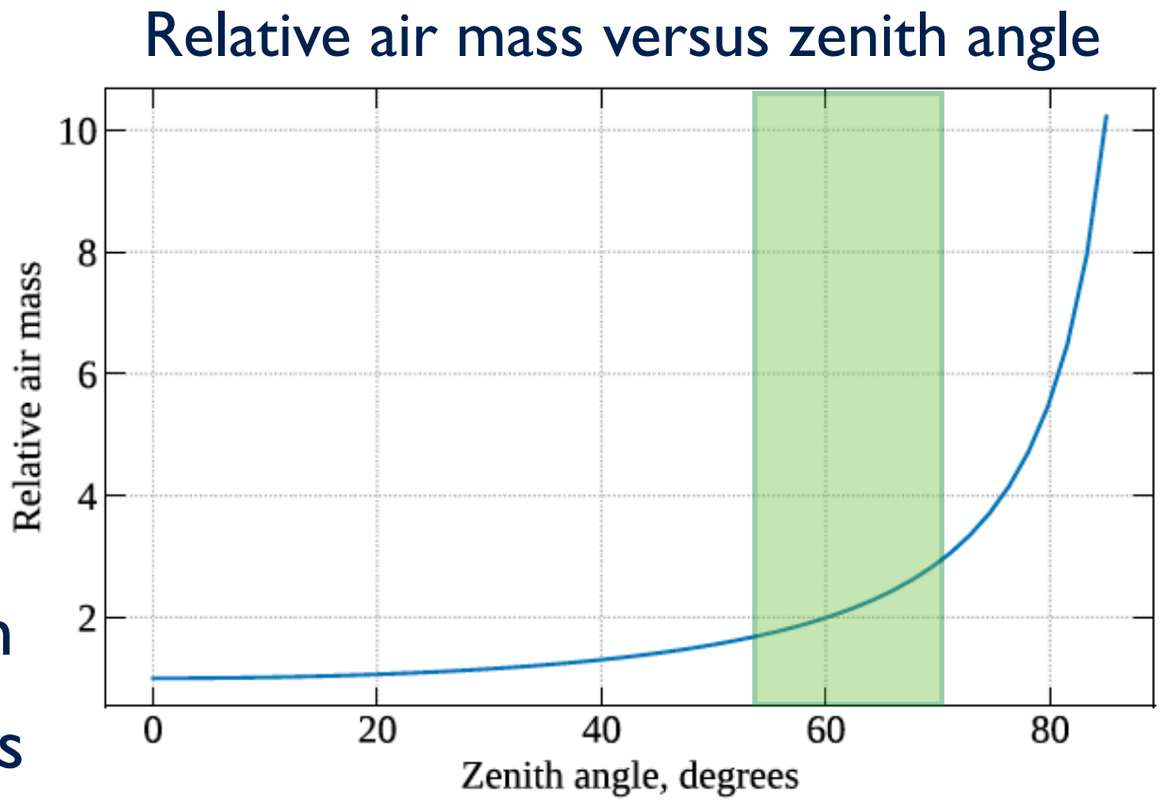


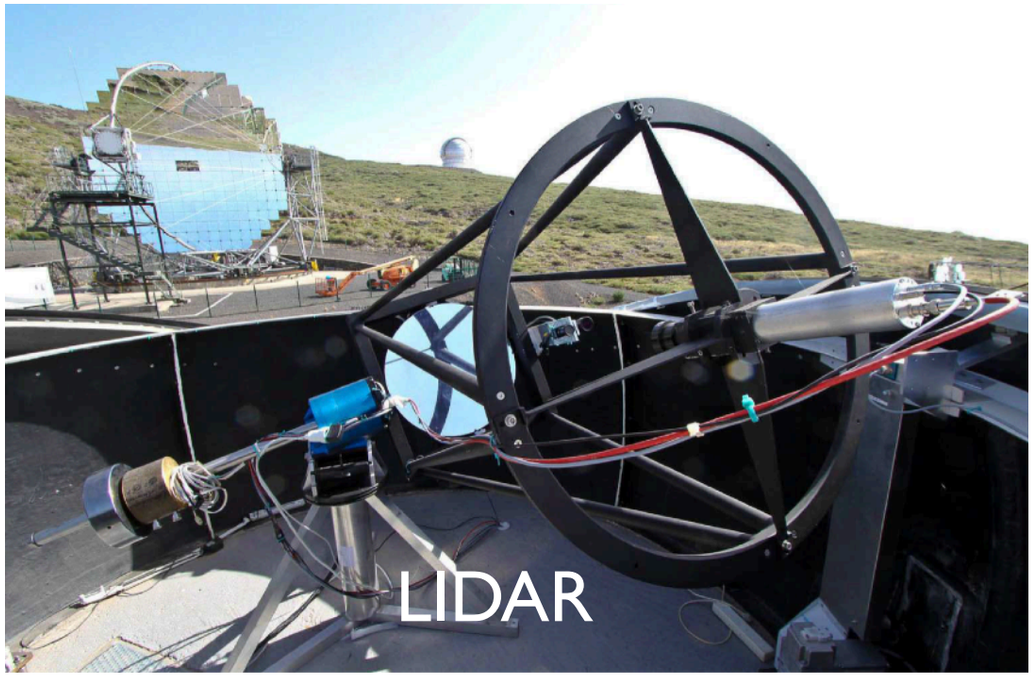
A.Ibarra (TeVPa2015)

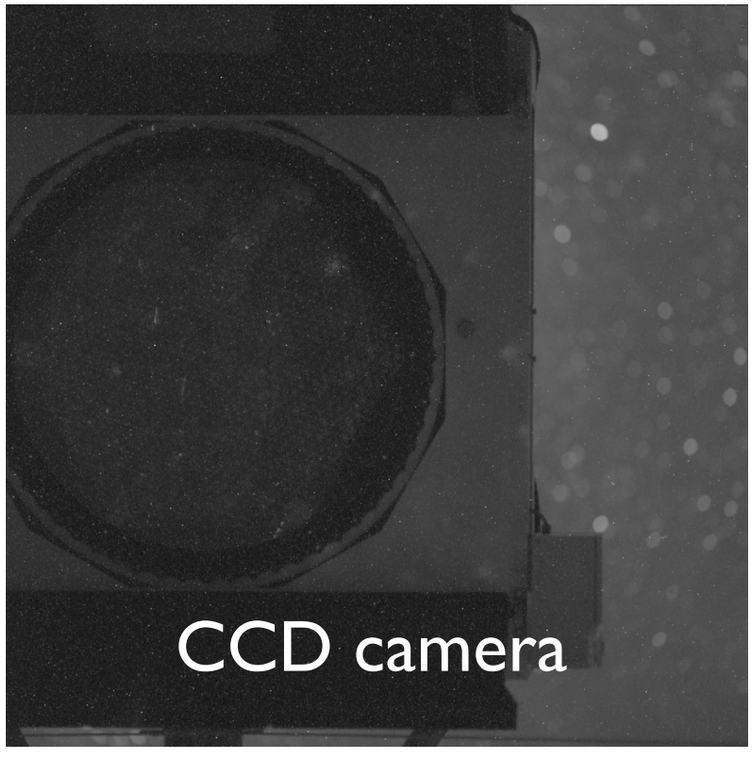
Possible systematics

★Atmosphere at Higher Zenith

- Thicker than low zenith by a factor of ~3
  - Cherenkov light is absorbed more.
- Monitoring the atmosphere two ways
  - LIDAR can measure differential transmission of atmosphere until 12 km
- CCD camera at the telescope measures the integral transmission using stars.







Future prospects

Test Cuspy and Cored profiles

- No subtraction between On and Off gives us a benefit for Cored profiles.

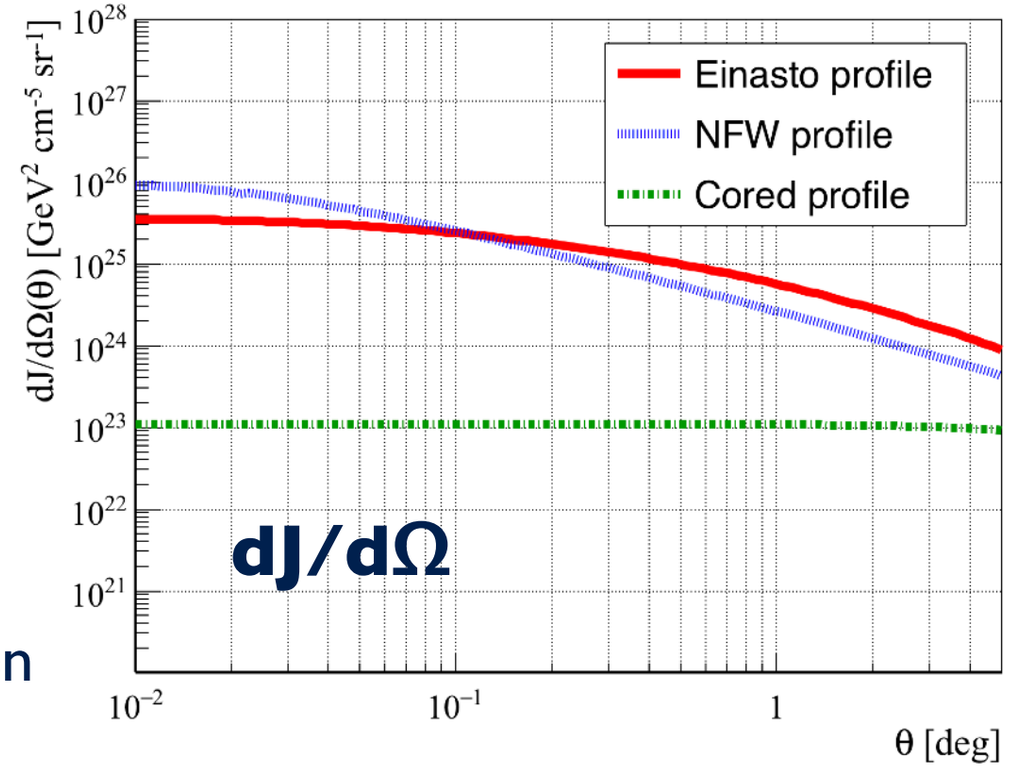
Einasto profile case

- e.g. J-factor : 8.5×10^{21} GeV^2 cm^5 (1dig.)

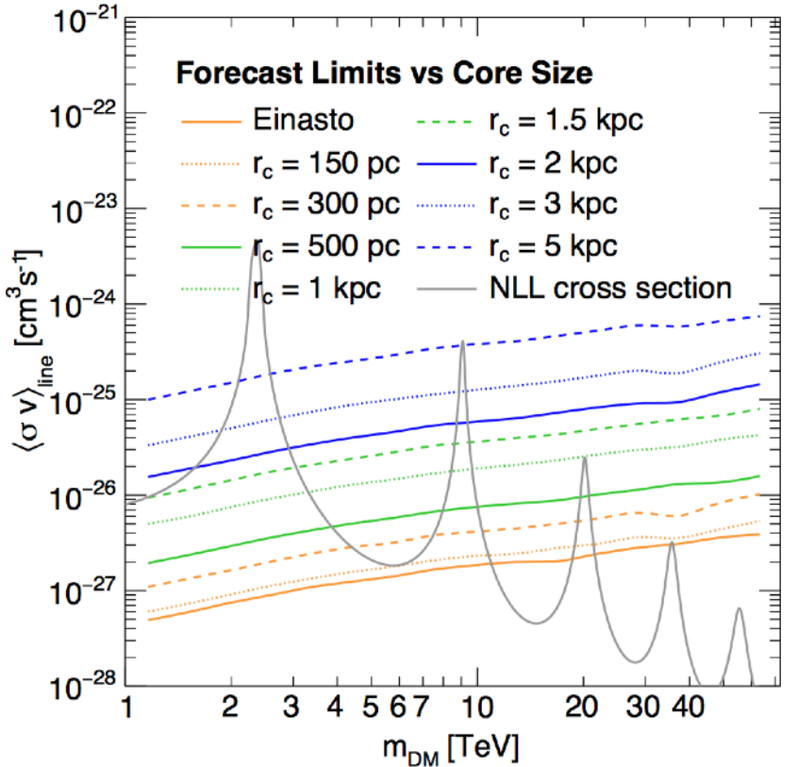
Cored profile case (isothermal-like)

- e.g. J-factor : 1.1×10^{20} GeV^2 cm^5 (1dig.)

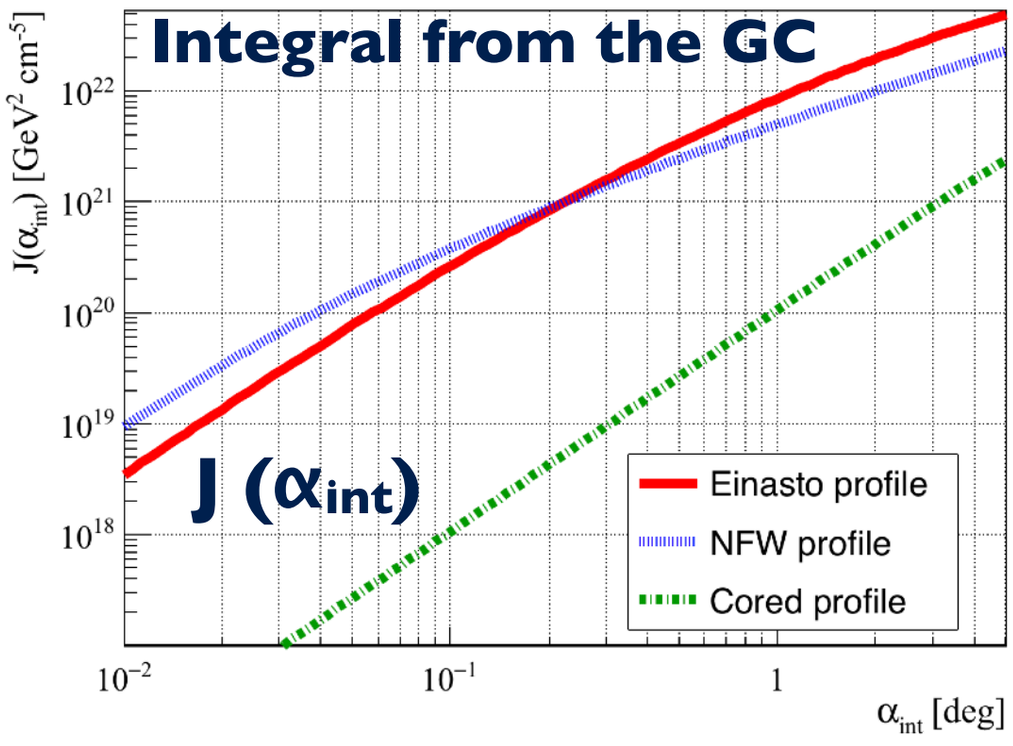
We can test the core size by the cross-section of assumed DM models



Einasto, NFW : PRL 120, 201101 (2018)
Cored (isothermal) : Paul J. McMillan (2016)



L. Rinchiuso, PRD 2018



Summary

- DM search by VHE gamma-ray is useful for TeV DM
- Line search can test some promising particle models,
- High zenith observation technique is useful to focus on TeV DM.
  - This study is supposed to be a first trial to search gamma-ray spectral line for DM from northern hemisphere.
- We may get "fast pass" to reach TeV DM
  - Make good synergies with CTA-LSTs and MSTs!!
- Stay tuned!!
  - We are taking care of systematics carefully.