Laboratoire d'Annecy de Physique des Particules

Gamma-ray telescopes: experimental results and prospects

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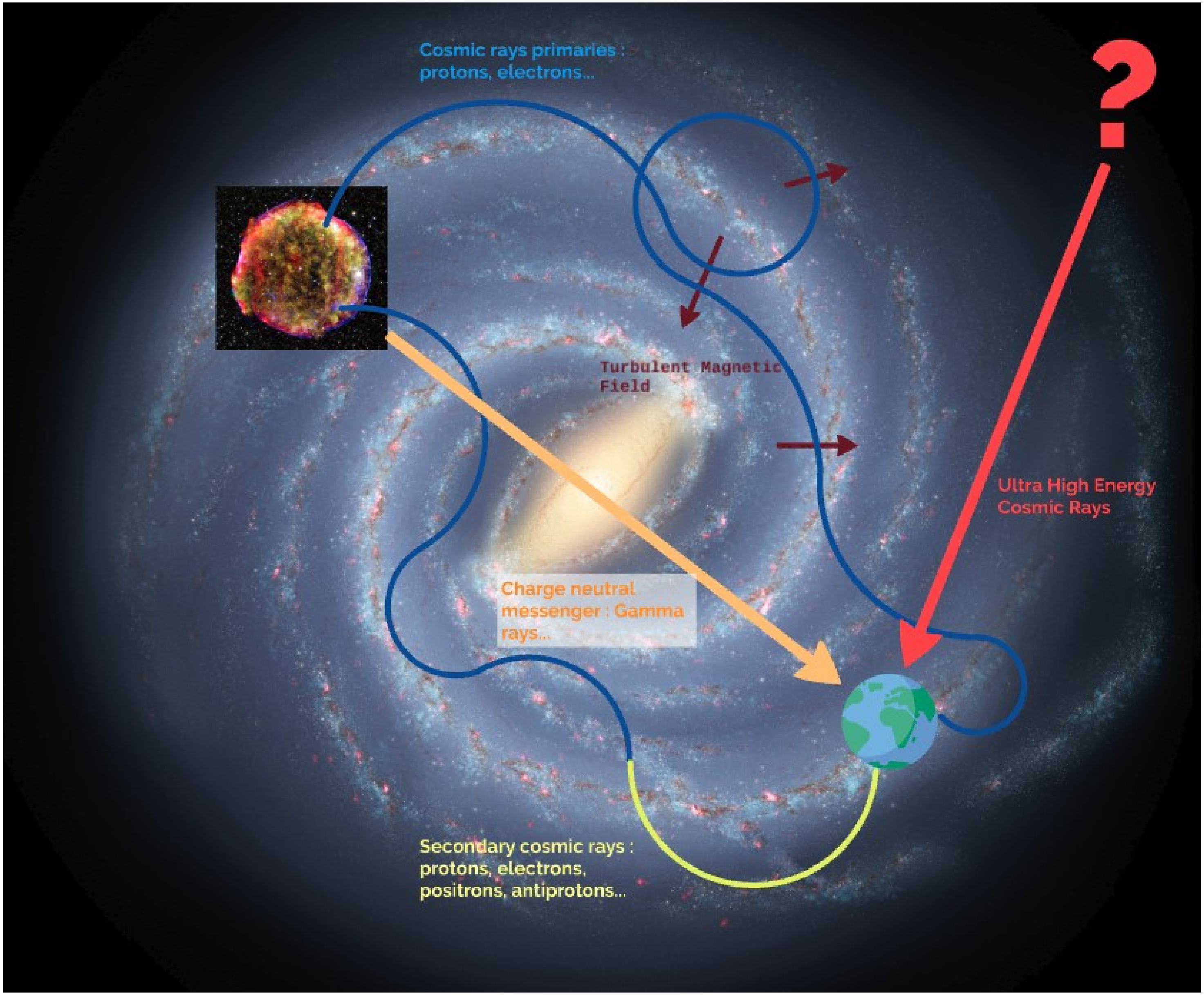
22 novembre 2021

UNIVERSITÉ SAVOIE MONT BLANC

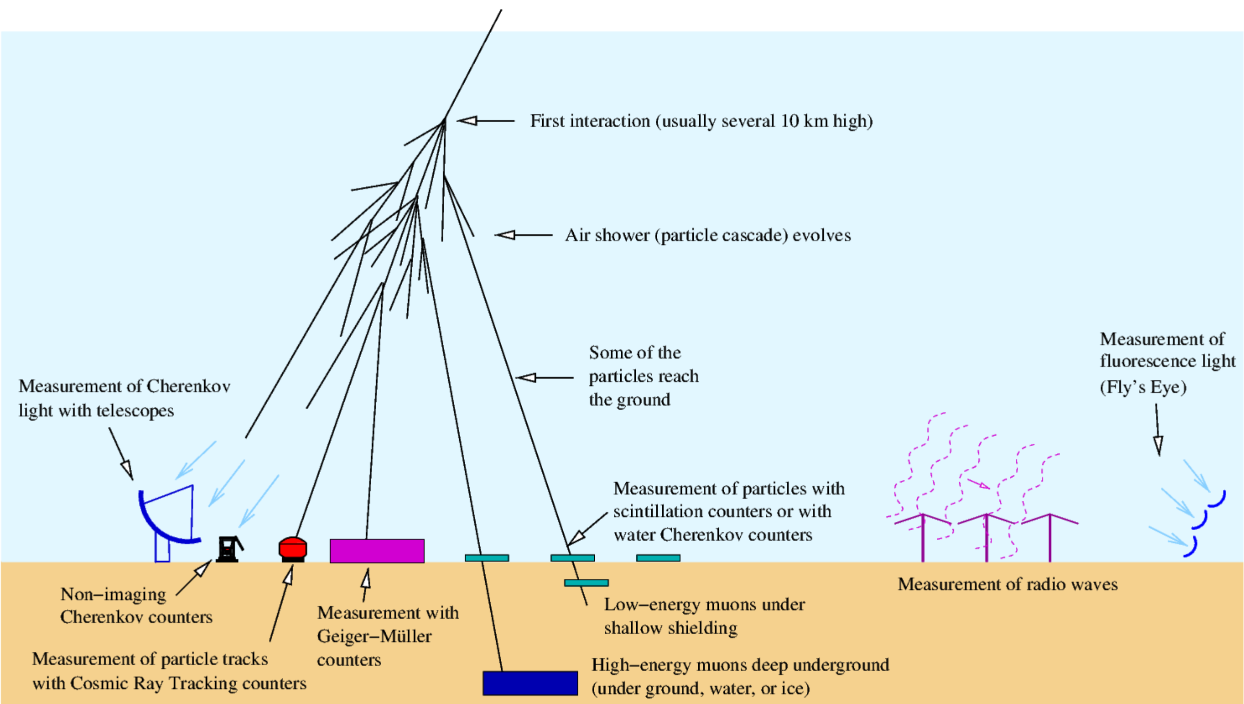
Messagers



Cosmic rays primaries :
protons, electrons...
?
Turbulent Magnetic
Field
Ultra High Energy
Cosmic Rays
Charge neutral
messenger : Gamma
rays...
Secondary cosmic rays :
protons, electrons,
positrons, antiprotons...

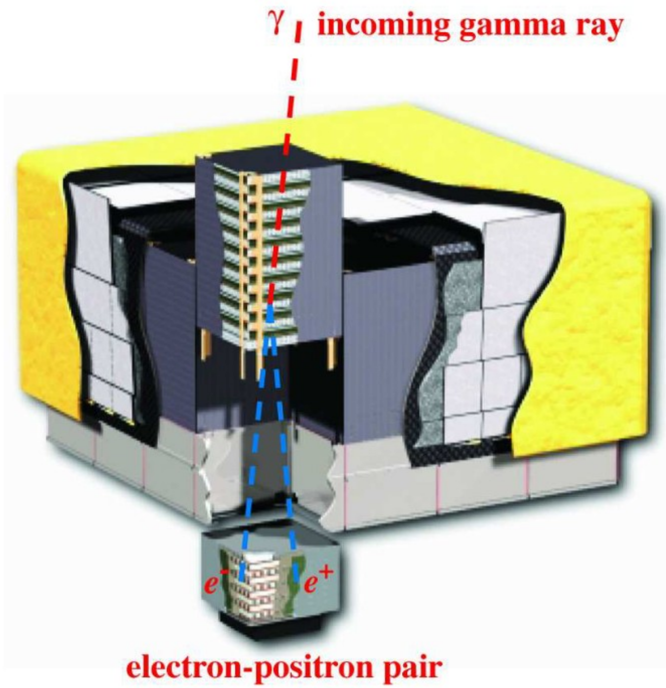
Detection method

- **Direct detection :**
  - Atmosphere is opaque to gamma ray → observation only possible in space
  - Power law → big surface is needed at high energy → limited in space

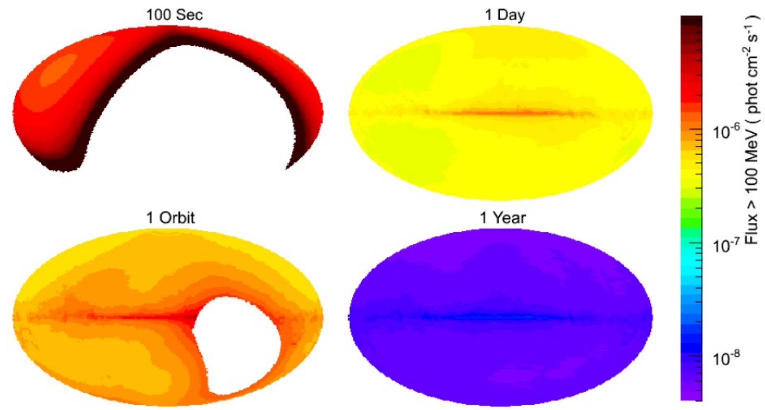


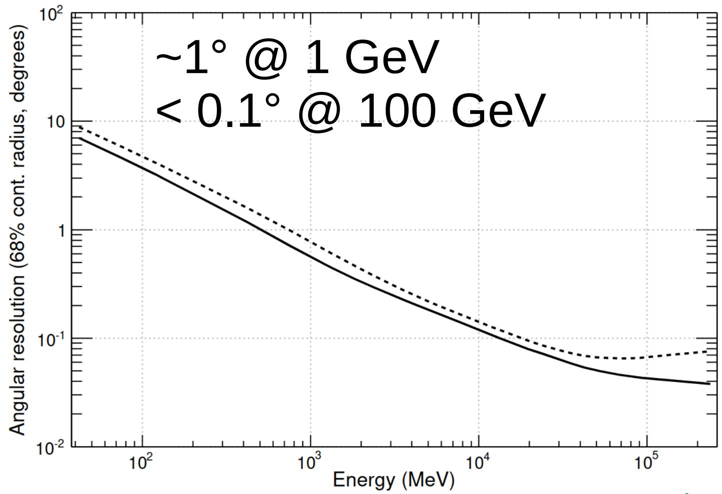
- **Indirect detection** :
  - Air shower detection
    - **Cherenkov light** (blue, UV)
    - **Radio**
    - **charged particles** (scintillation, water Cherenkov)
    - **Fluorescence** (UV)

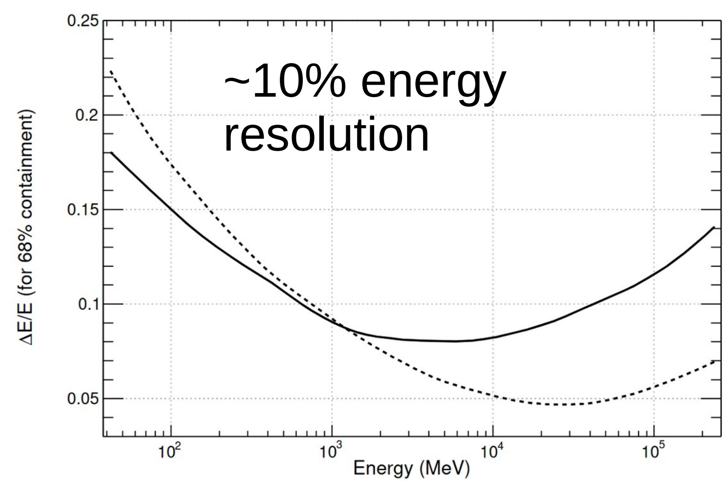
Direct Detection – Fermi-LAT



Wide FoV







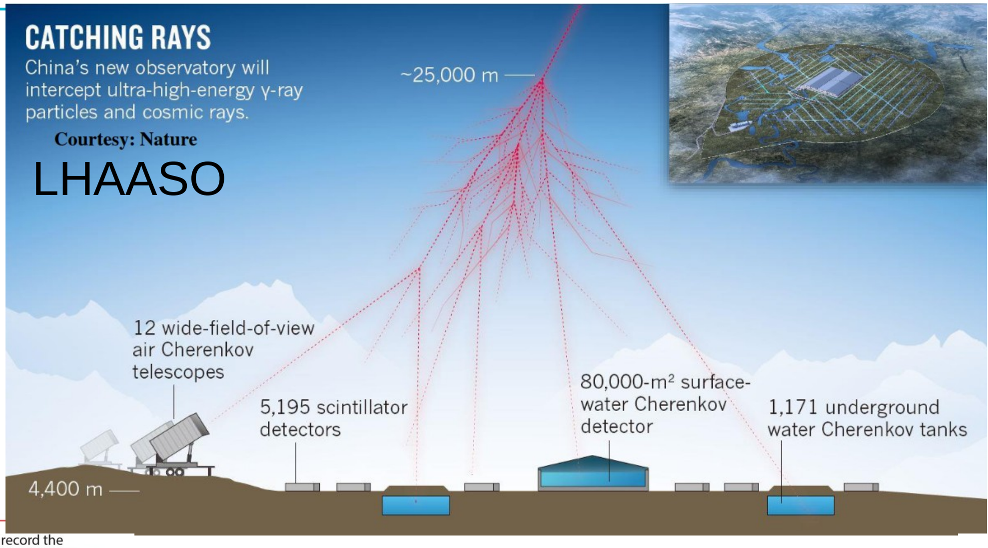
https://arxiv.org/pdf/0902.1089.pdf

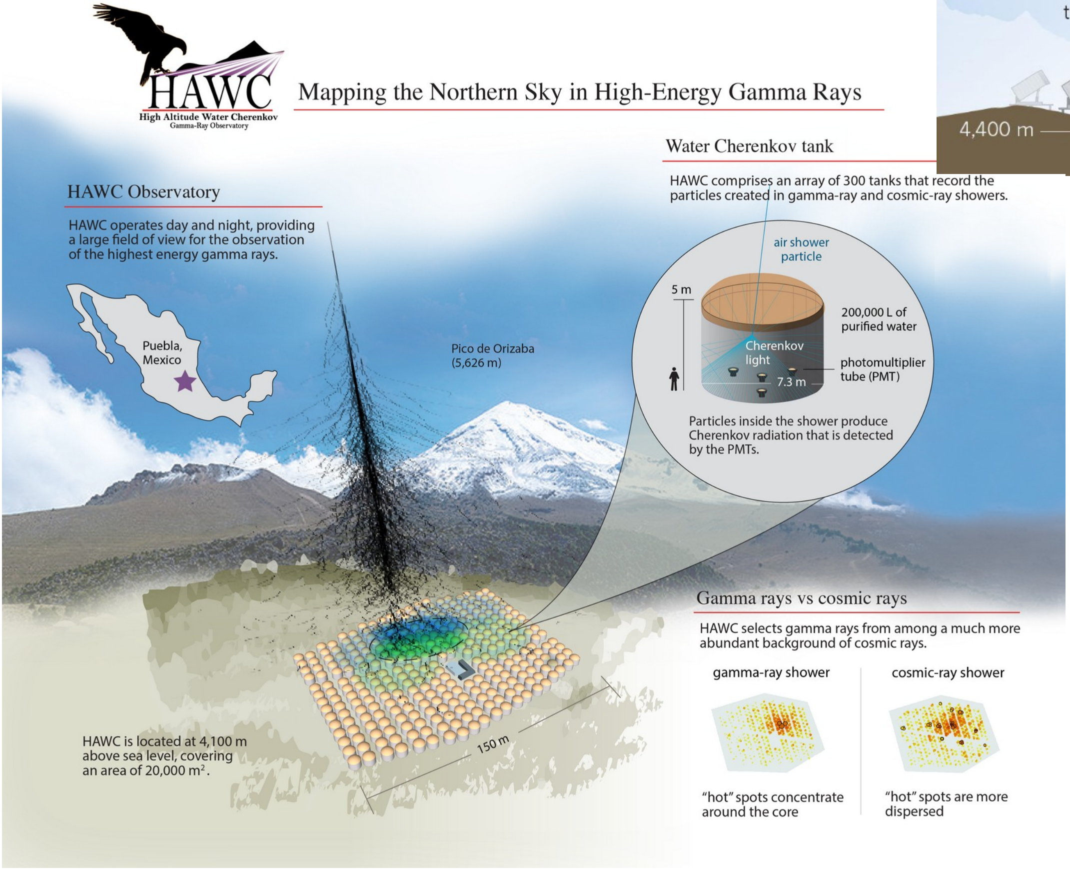
Détection indirecte des rayons gamma

- **IACTs → Imaging Atmospheric Cherenkov Telescope**
- Cherenkov light produced by secondary particles
- **Pro :**
  - Good angular resolution (~0.1°) and energy resolution (~10-15%)
  - Good low exposure time sensitivity
- **Cons :**
  - Narrow field of view (~5°)
  - Low duty cycle (10-15%)

- **Water Cherenkov Array**
- Detection of secondary particle with Cherenkov in water tank
- **Pro :**
  - Big field of view (15% du ciel)
  - High duty cycle (~100%)
- **Cons :**
  - Less precise for angular resolution (0.75° @ 1 TeV, 0.3° @ 10TeV) and energy resolution (95% @ 1TeV, 50% @ 10TeV)

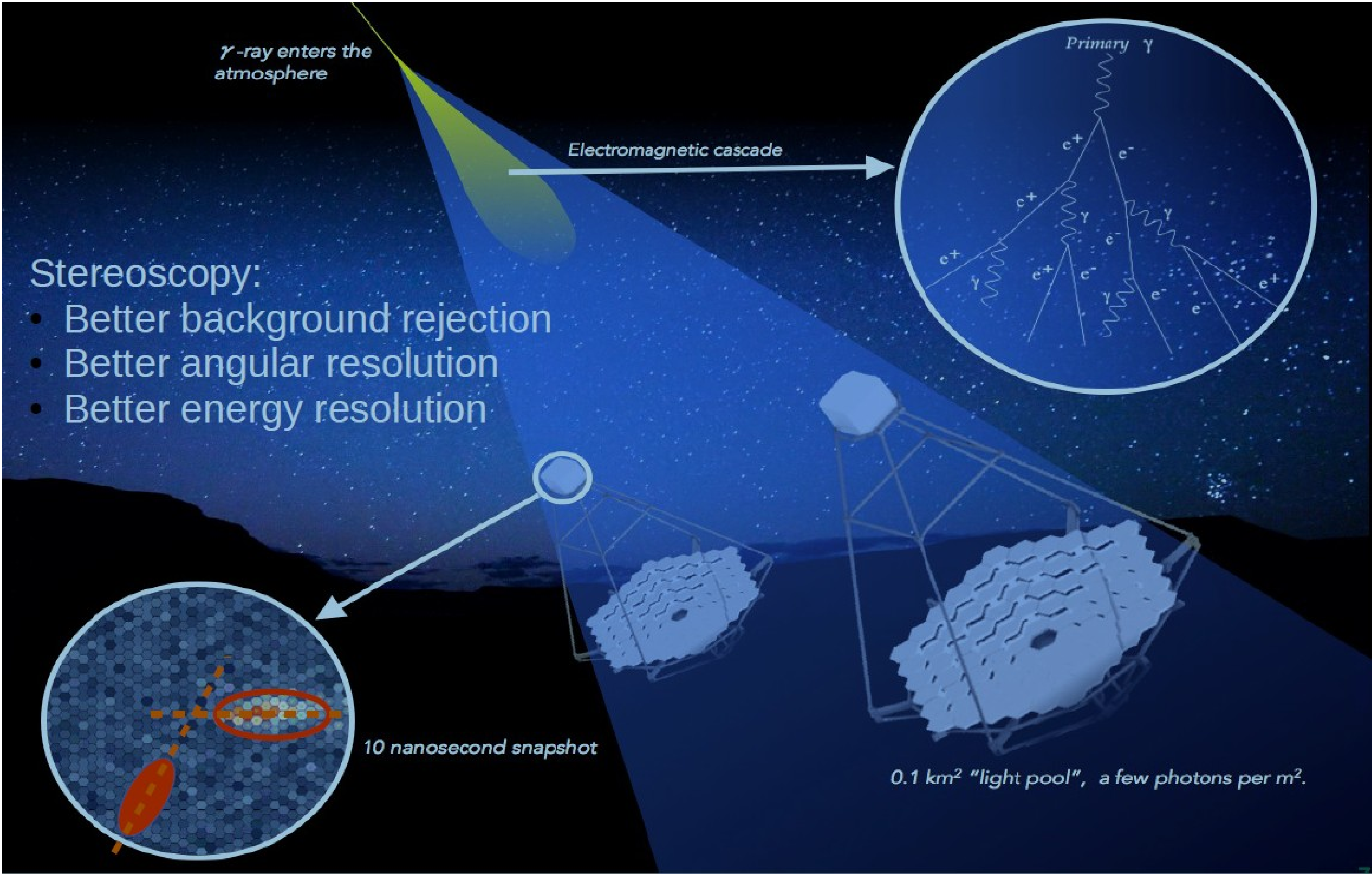
Water Cherenkov Array

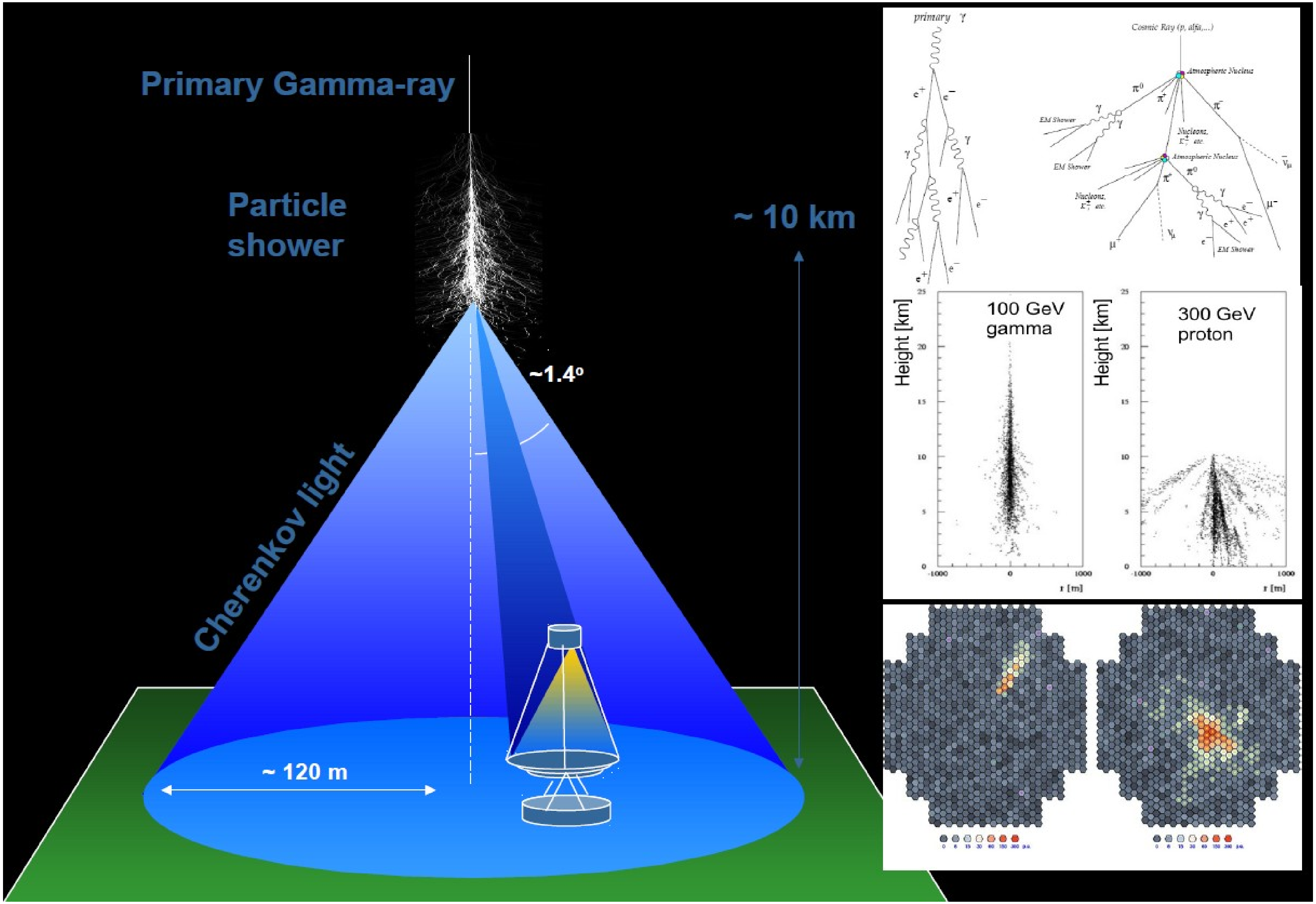




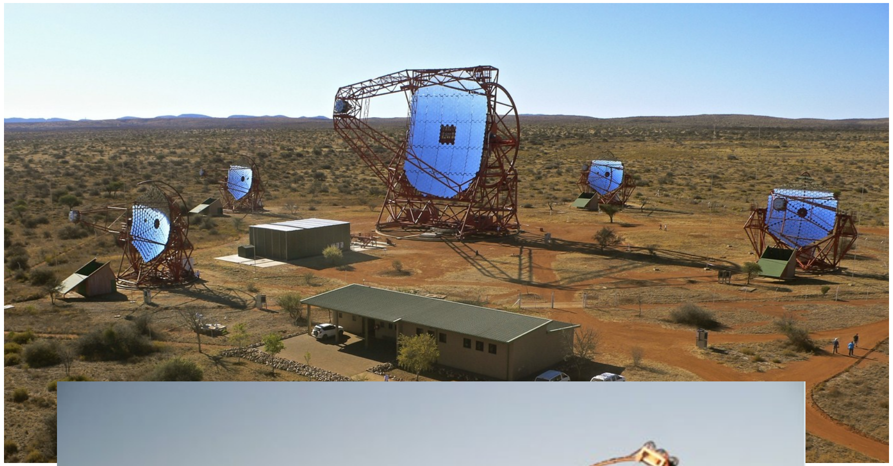
- 20000 m^2 of water tank for HAWC
- 80000 m^2 for the LHAASO core + 1 km^2 of underground water tank and scintillator

Principe de détection




Primary Gamma-ray
Particle shower
~ 10 km
~1.4°
Cherenkov light
~ 120 m
primary γ
Cosmic Ray (p, alfa,...)
Atmospheric Nucleus
EM Shower
100 GeV gamma
300 GeV proton
Height [km]
r [m]

Observatoires actuels

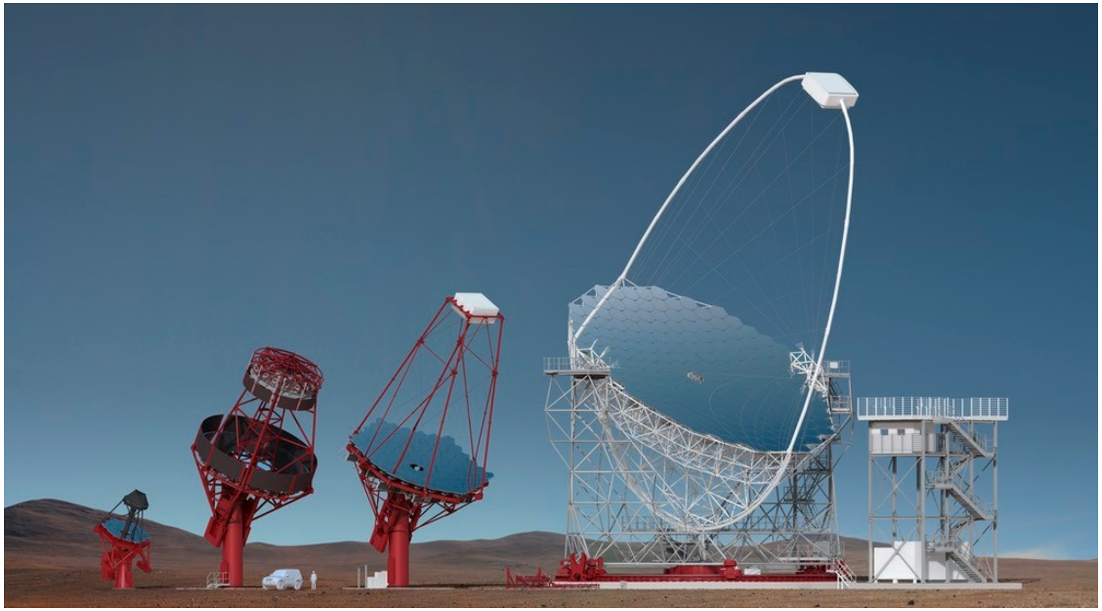


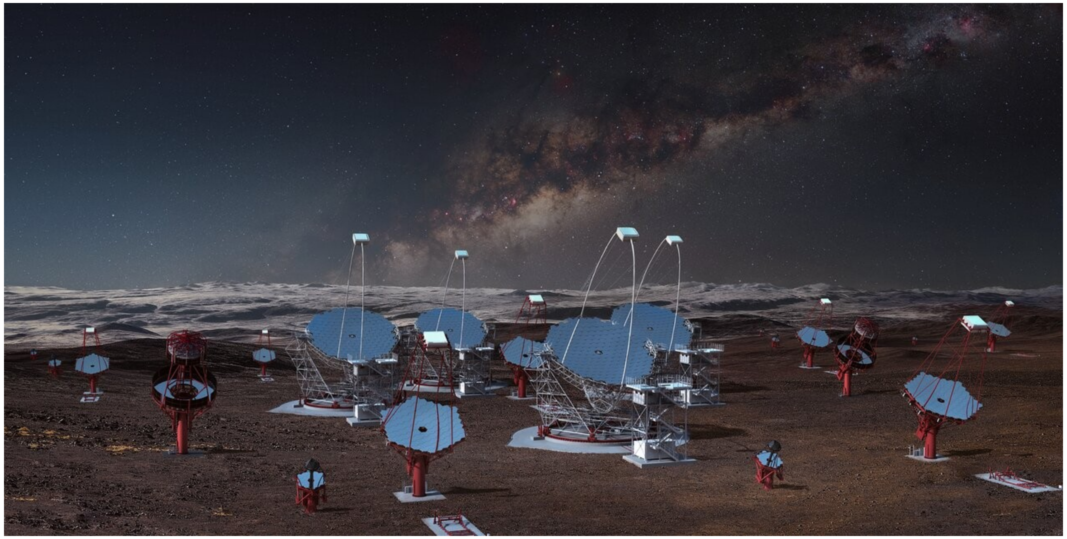
H.E.S.S.
- Namibia (South hemisphere)
- 5 telescopes (28m + 12m)

MAGIC
- Canarie Island, La Palma (North hemisphere)
- 2 telescopes (17m)

VERITAS
- Arizona (North hemisphere)
- 4 telescopes (12m)

Observatoires futurs - CTA

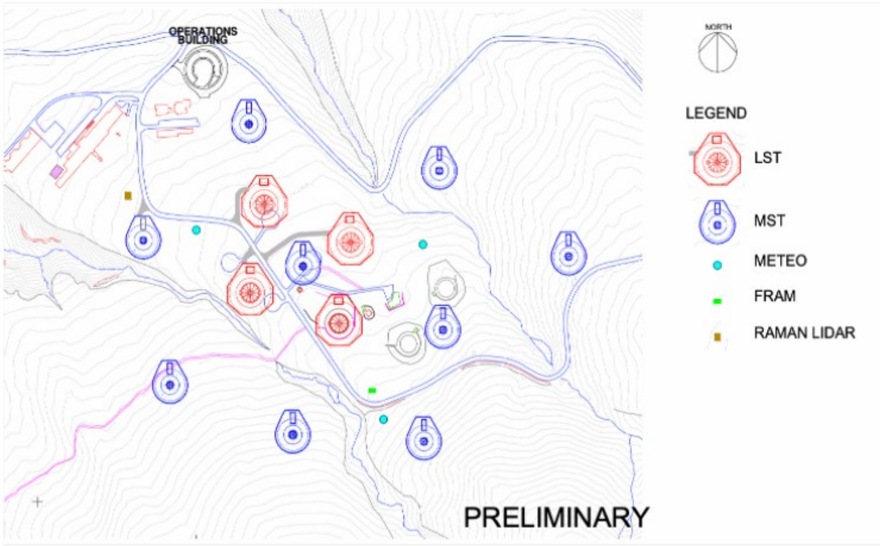




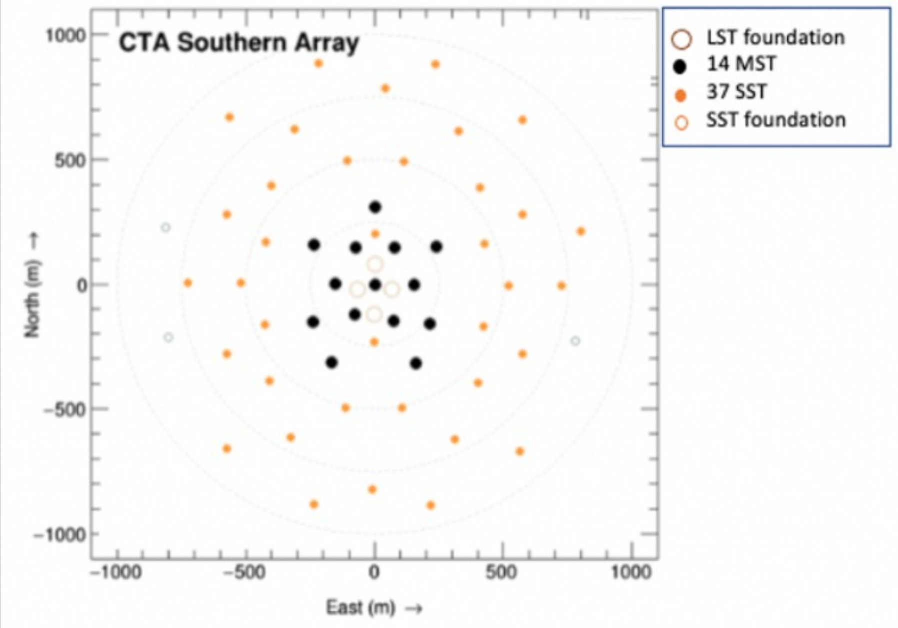
- 3 types of telescopes :
  - LST (23 m)
  - MST (12 m)
  - SST (4.3 m)
- Optimized for different energies :
  - 20 GeV - 3 TeV
  - 80 GeV - 50 TeV
  - 1 TeV - 300 TeV
- ~100 telescopes in two sites :
  - La Palma (North hemisphere)
  - Paranal (South hemisphere)
- End of construction for 2025

CTA Layouts

CTA Northern Array



https://pos.sissa.it/395/005/pdf

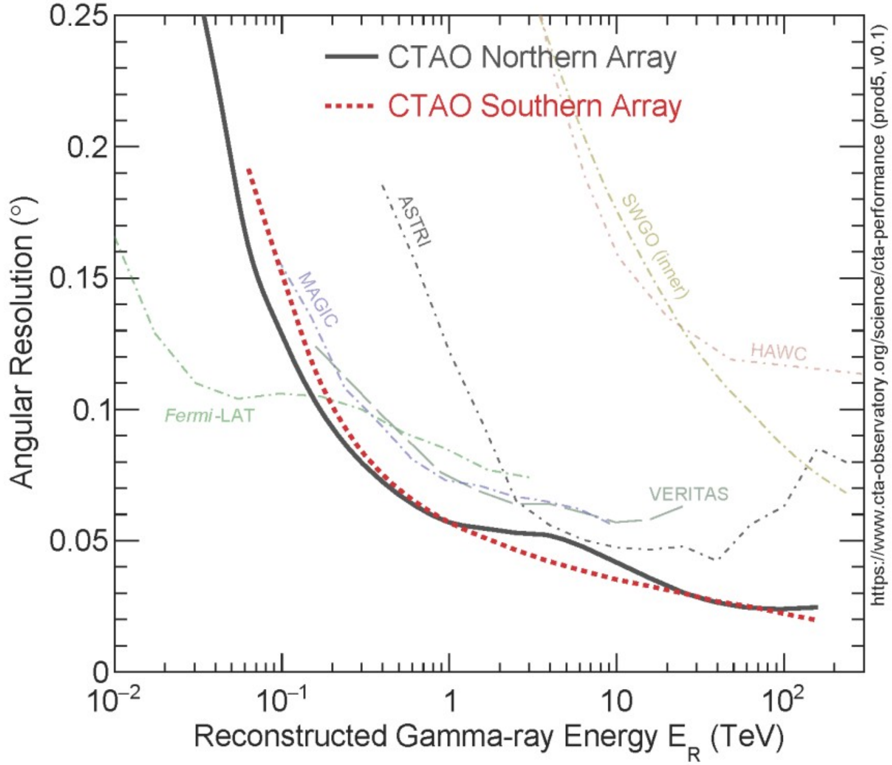


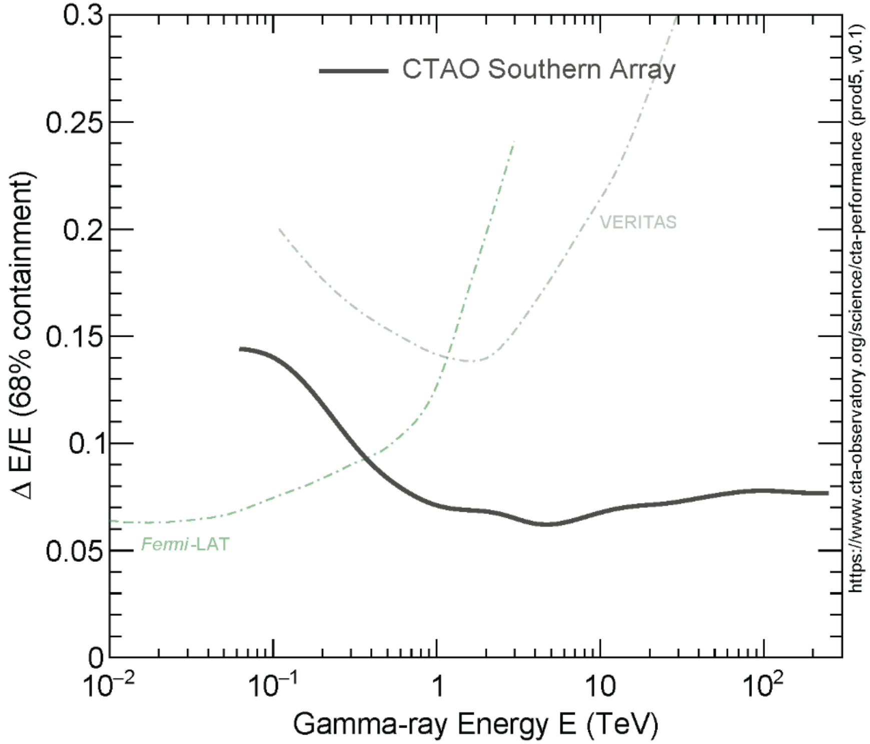
- Northern Array mostly dedicated to extragalactic science
- Optimized for low energies (EBL absorption of high energy gamma ray)

- Southern Array mostly dedicated to galactic science
- Optimized for higher energies

Performance

https://pos.sissa.it/395/005/pdf





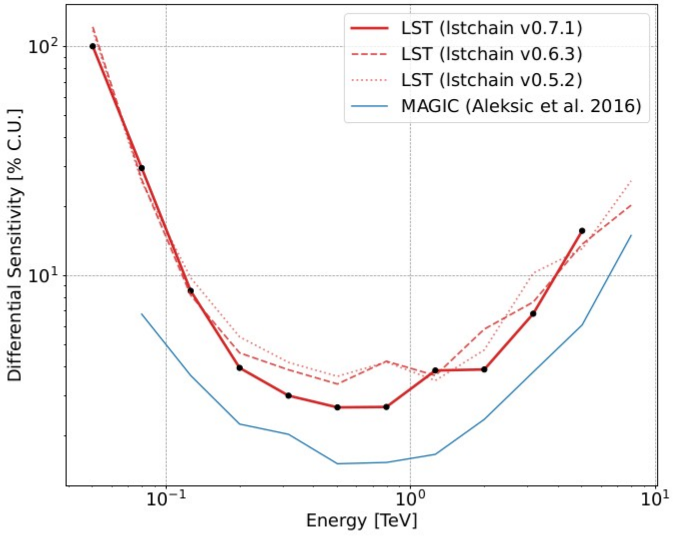
LST1 @ La Palma

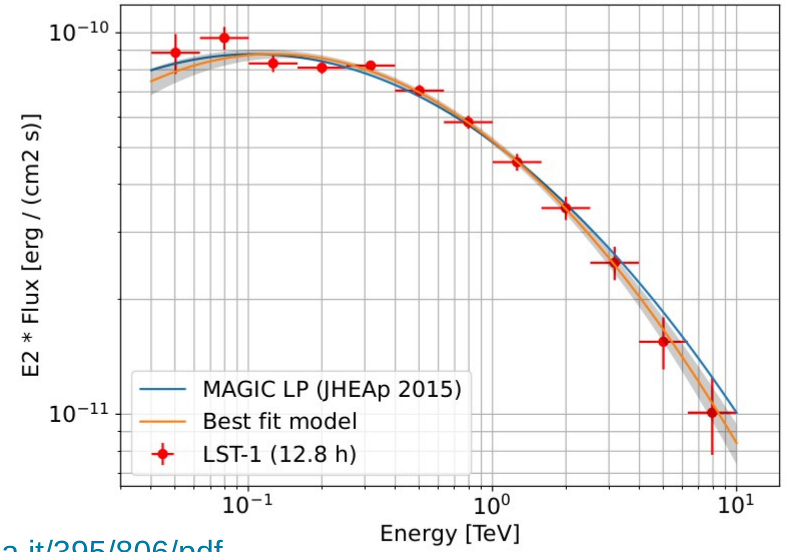
- First telescope of North site installed in the la Palma island since 2018
- On-going commissioning and first real data acquired
- 3 LST and MSTs will start to be built end of next year (2022)

LST1 @ La Palma

- First telescope of North site installed in the la Palma island since 2018
- On-going commissioning and first real data acquired
- 3 LST and MSTs will start to be built end of next year (2022)
- But nature said no……
- Don’t worry the telescope is fine (as the volcano)
- You can check by yourself here : https://www.lst1.iac.es/webcams.html

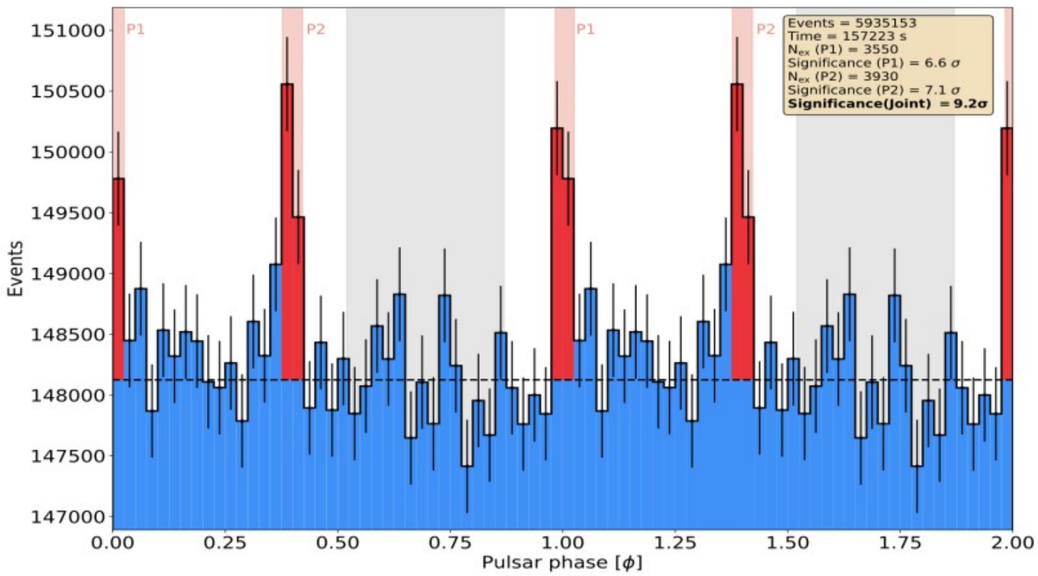
LST1 @ La Palma





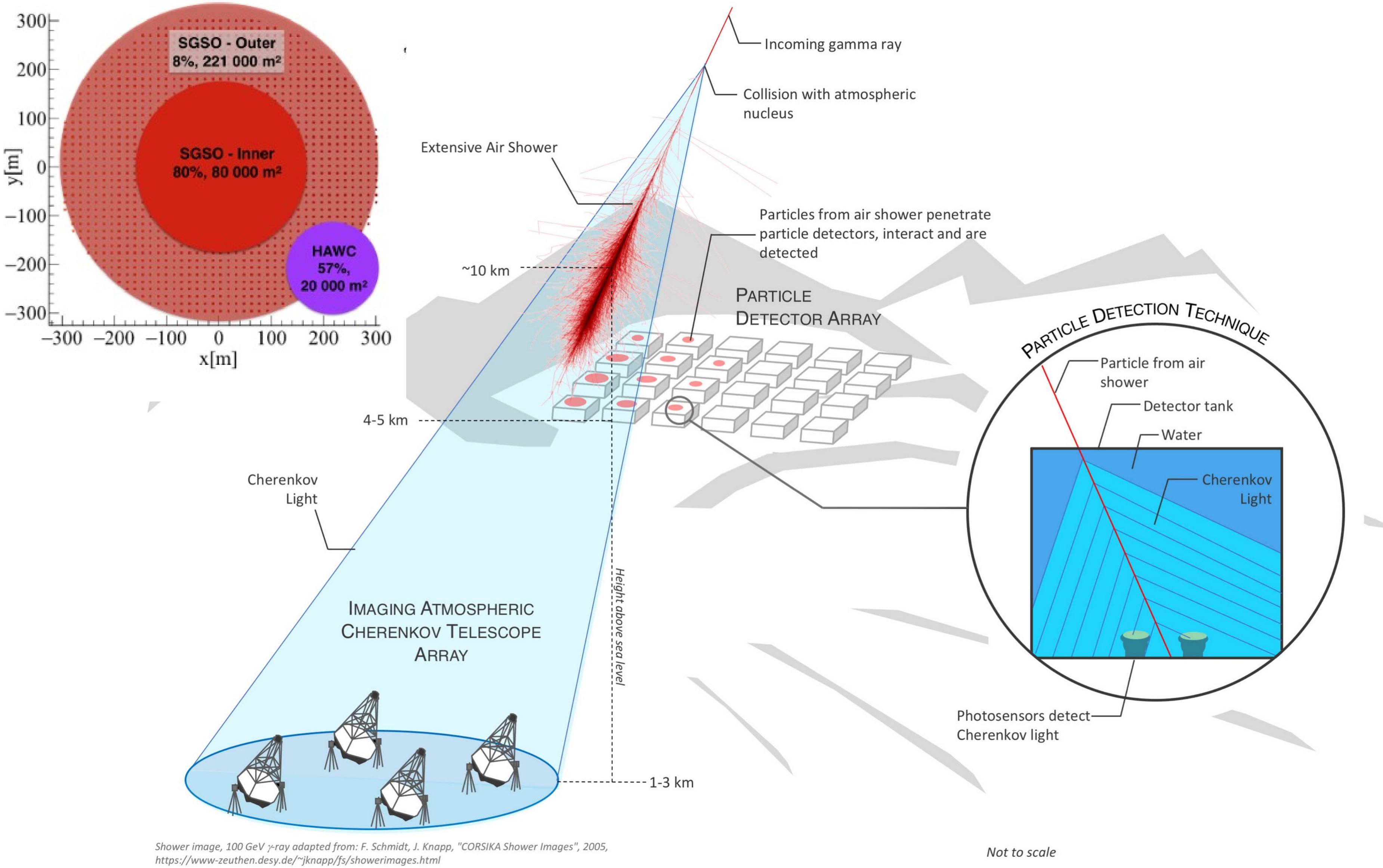
https://pos.sissa.it/395/806/pdf

- First validation of the LST-1 with Crab Nebula
- Current sensitivity already comparable to MAGIC (Mono versus Stereo)



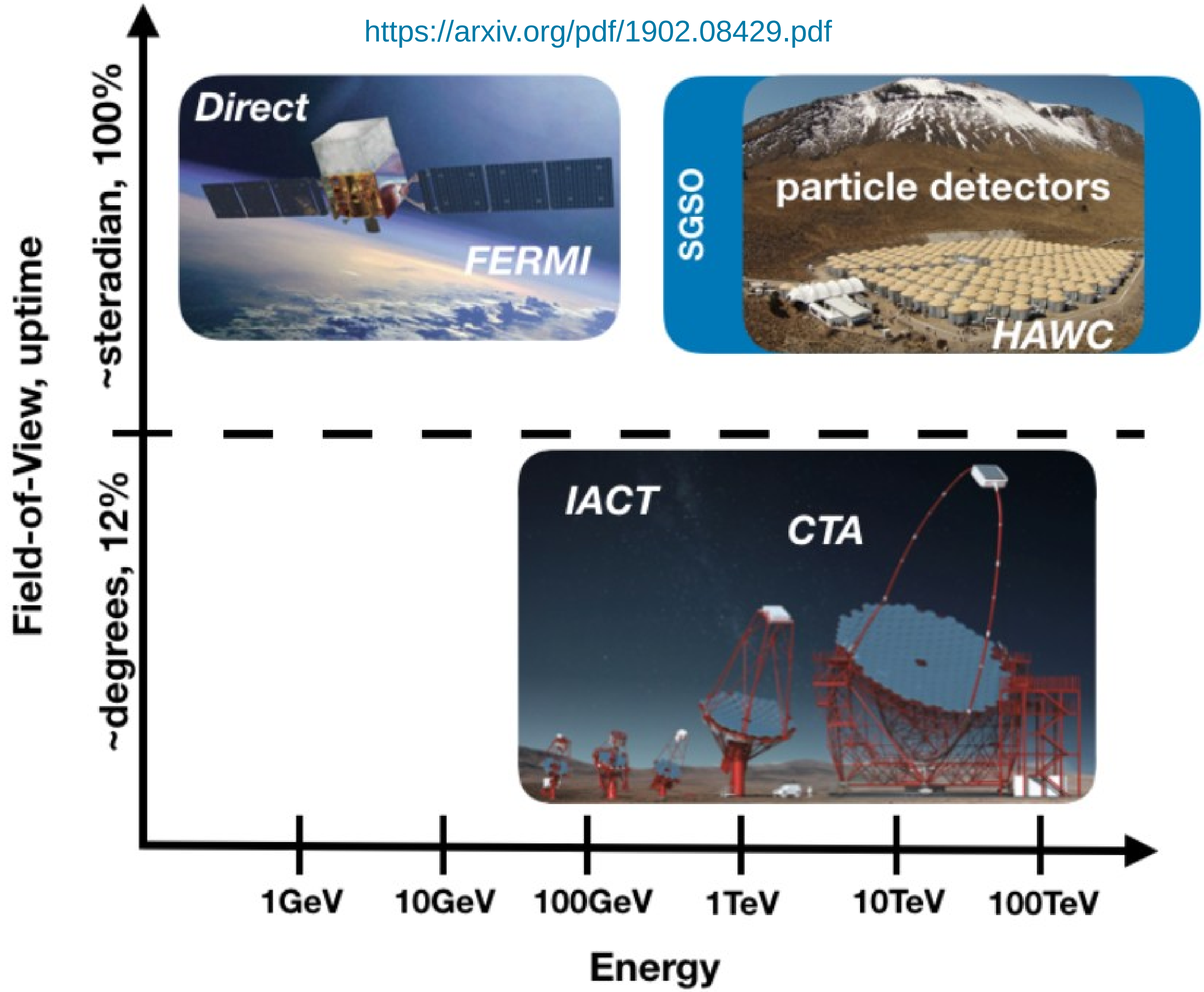
Future telescope : SWGO

https://arxiv.org/pdf/1902.08429.pdf



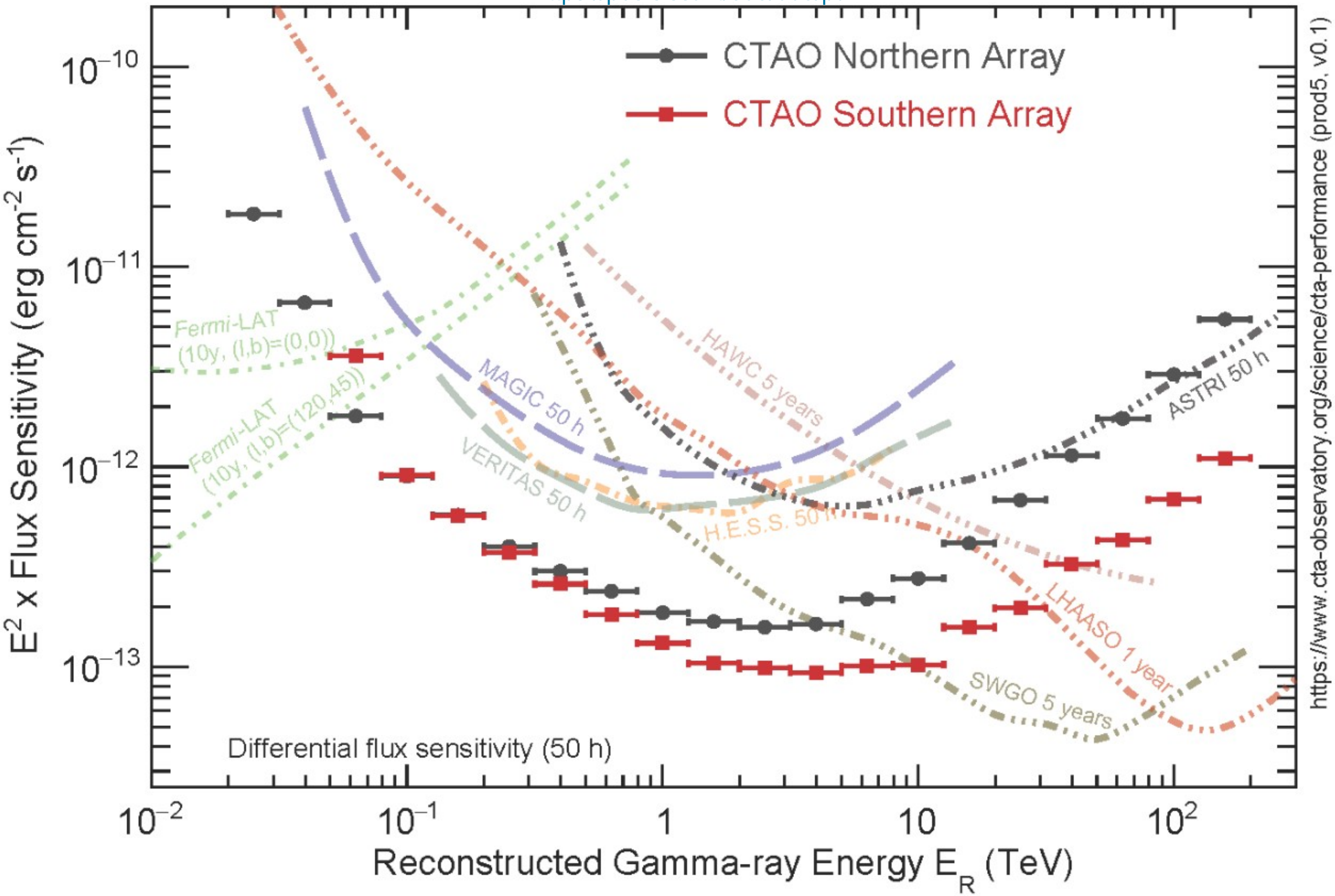
Basic plot of gamma-ray telescopes

https://arxiv.org/pdf/1902.08429.pdf



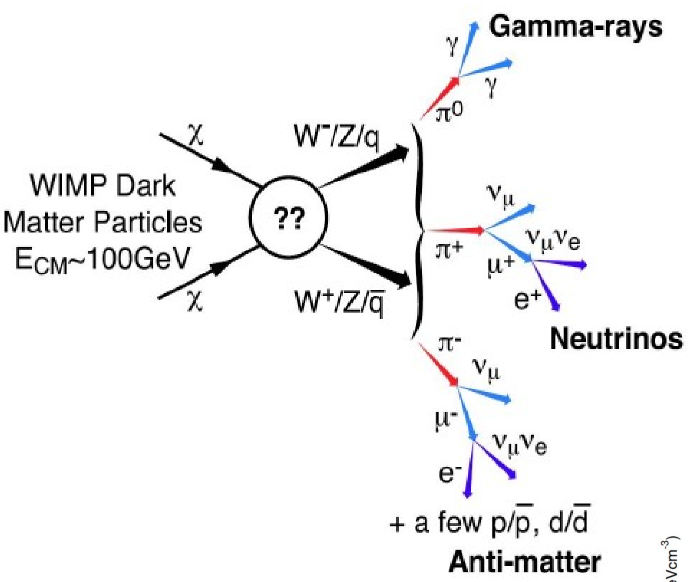
Compared Sensitivity

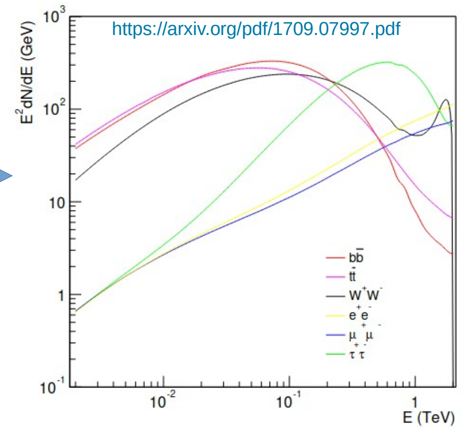
https://pos.sissa.it/395/005/pdf

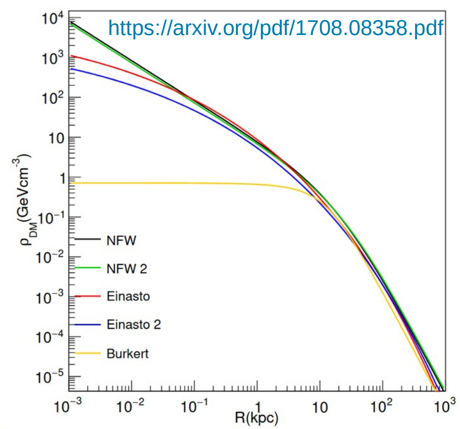


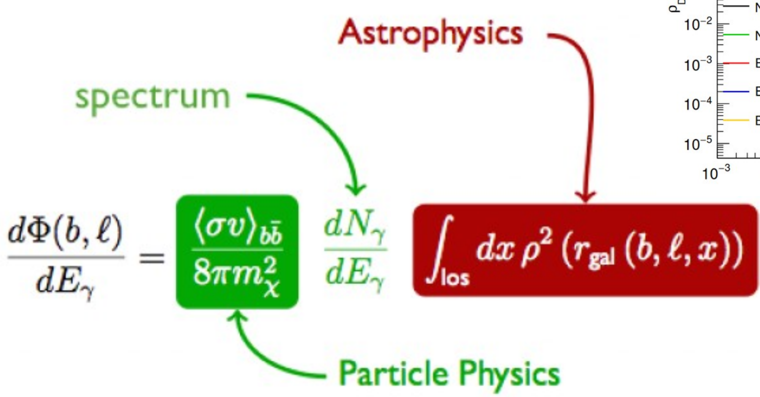
Dark matter indirect detection

Indirect detection









$$\frac{d\Phi(b,\ell)}{dE_\gamma} = \frac{\langle\sigma v\rangle_{b\bar{b}}}{8\pi m_\chi^2}\frac{dN_\gamma}{dE_\gamma}\int_{\text{los}} dx\, \rho^2\left(r_{\text{gal}}(b,\ell,x)\right)$$

- Galactic center
  + Large DM density, nearby
  - Astrophysical background
  Only visible for ground based observatory in the South Hemisphere (CTA-South, SWGO)

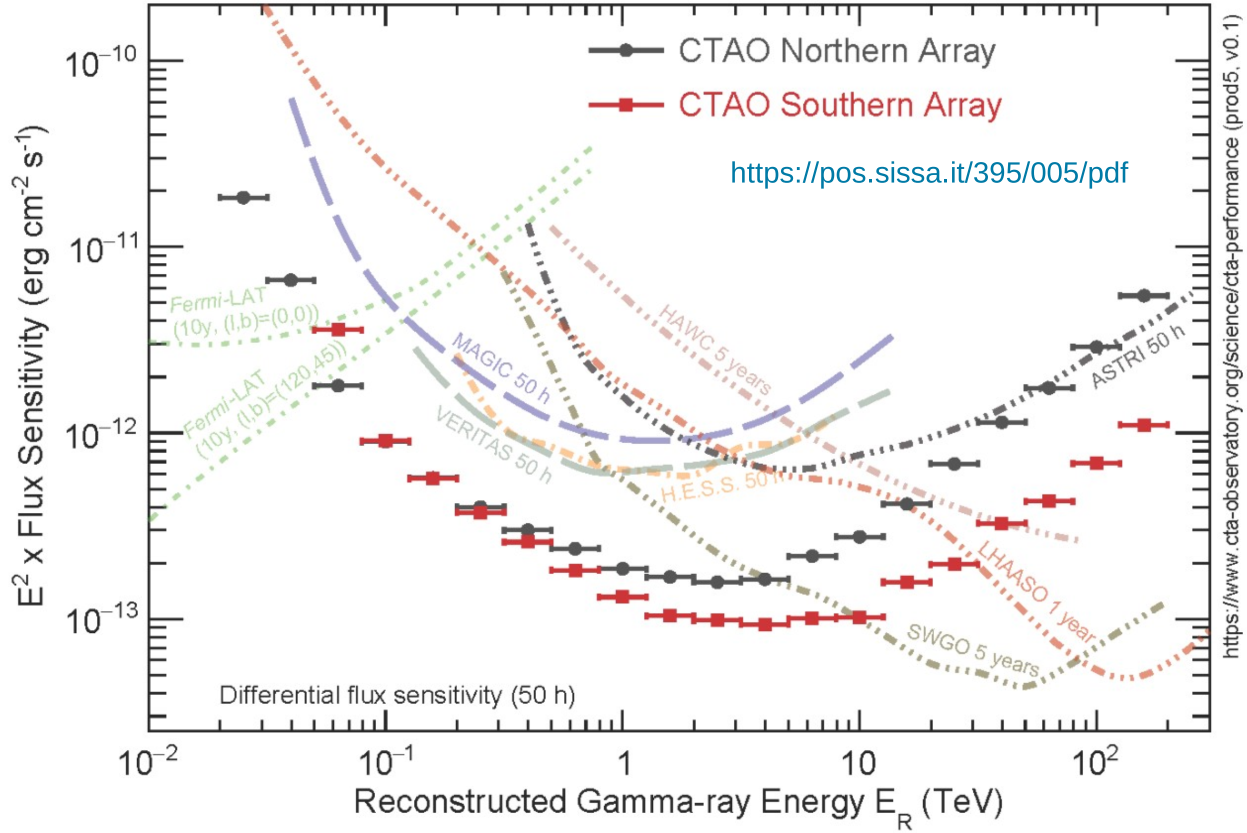
- Satellite galaxie (LMC)
  + Medium stat (distance)
  - Astrophysical background

- Dwarf Galaxies
  - low stat (distance and DM density)
  + Low astrophysical background

- Spectral lines
  + no background → smoking gun
  - Low stat

Dark matter indirect detection

Constraints on cross-section

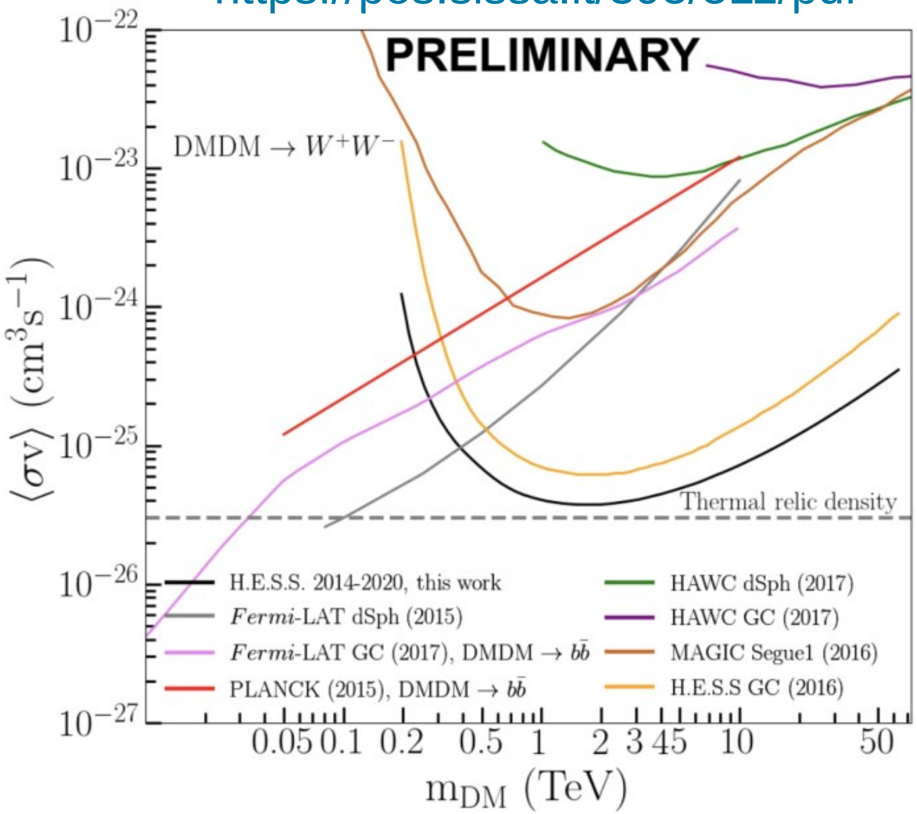


Range of DM mass

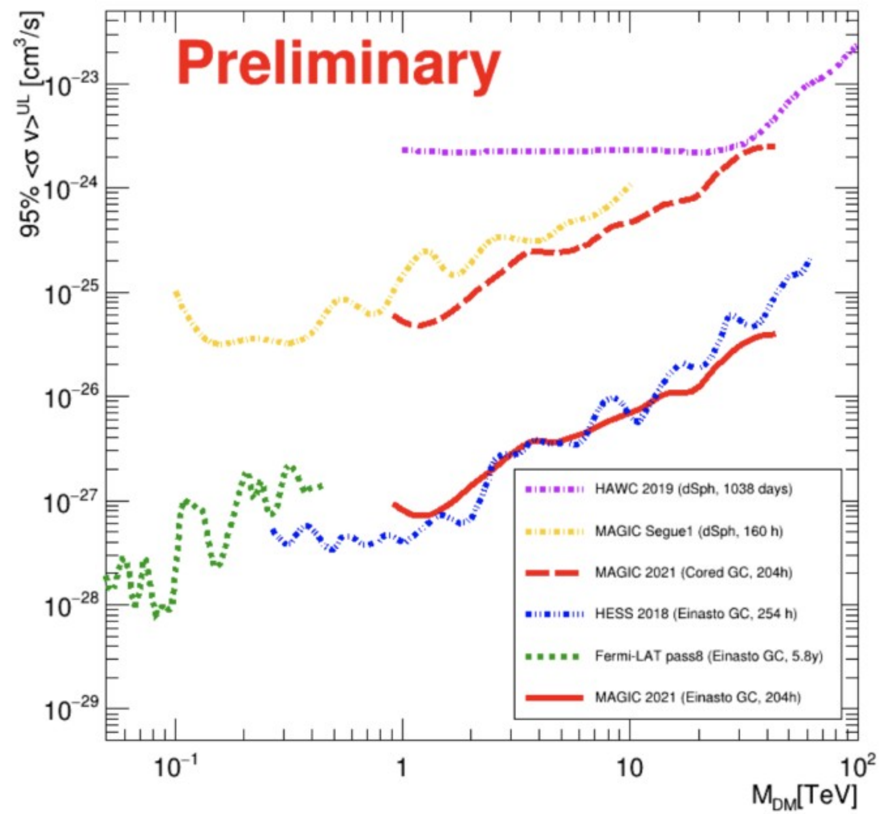
- Better angular resolution helps for regions crowded by astrophysical sources (typically galactic center)
- Energy resolution can help to catch spectral feature and for line search
- FoV size help for background estimation and large region investigation (Galactic center halo)

Limits overview (current observatories)

https://pos.sissa.it/395/511/pdf



https://pos.sissa.it/395/520/pdf

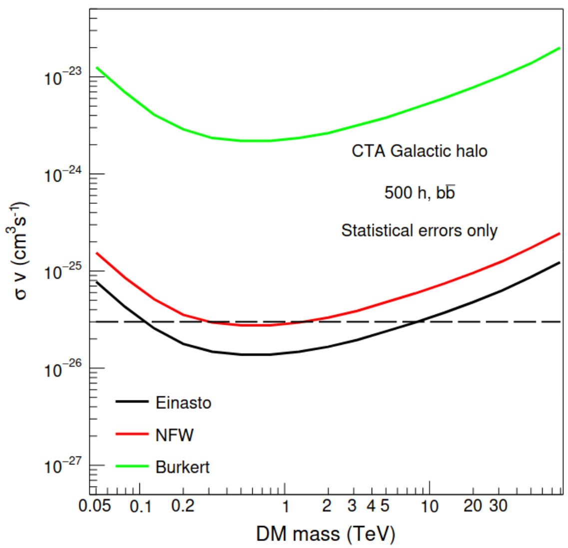


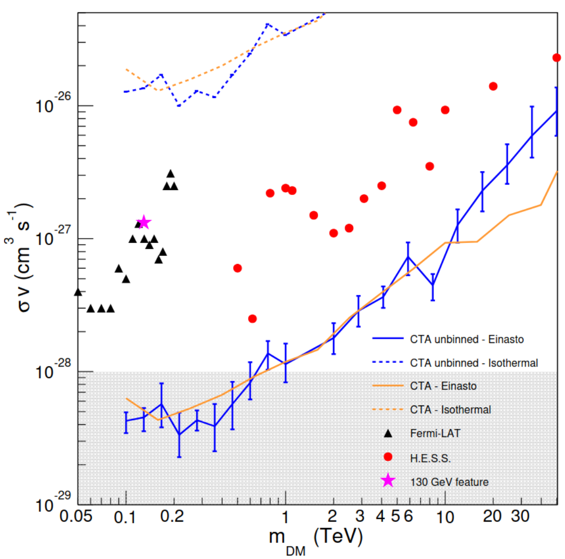
CTA plan for Dark Matter

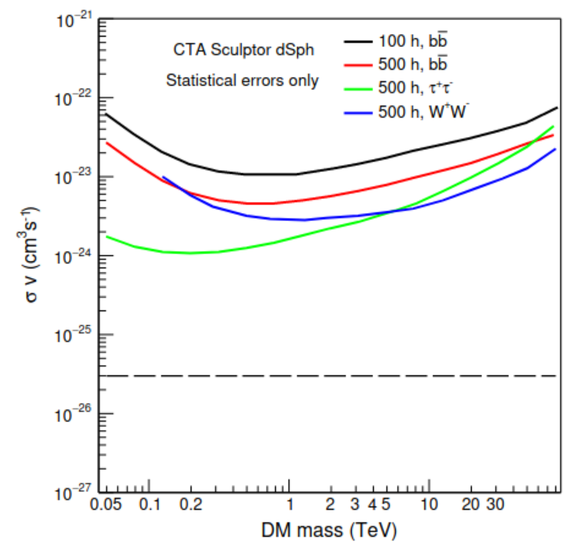
- Big difference between IACTs and other gamma-ray facilities → size of the Field of view
- We need to choose targets and allocate time to observe them

Year	1	2	3	4	5	6	7	8	9	10
Galactic halo	175 h	175 h	175 h							
Best dSph	100 h	100 h	100 h							
				in case of detection at GC, large σv						
Best dSph				150 h	150 h	150 h	150 h	150 h	150 h	150 h
Galactic halo				100 h	100 h	100 h	100 h	100 h	100 h	100 h
				in case of detection at GC, small σv						
Galactic halo				100 h	100 h	100 h	100 h	100 h	100 h	100 h
				in case of no detection at GC						
Best Target				100 h	100 h	100 h	100 h	100 h	100 h	100 h

+ LMC that will be observed anyway for astrophysical reasons



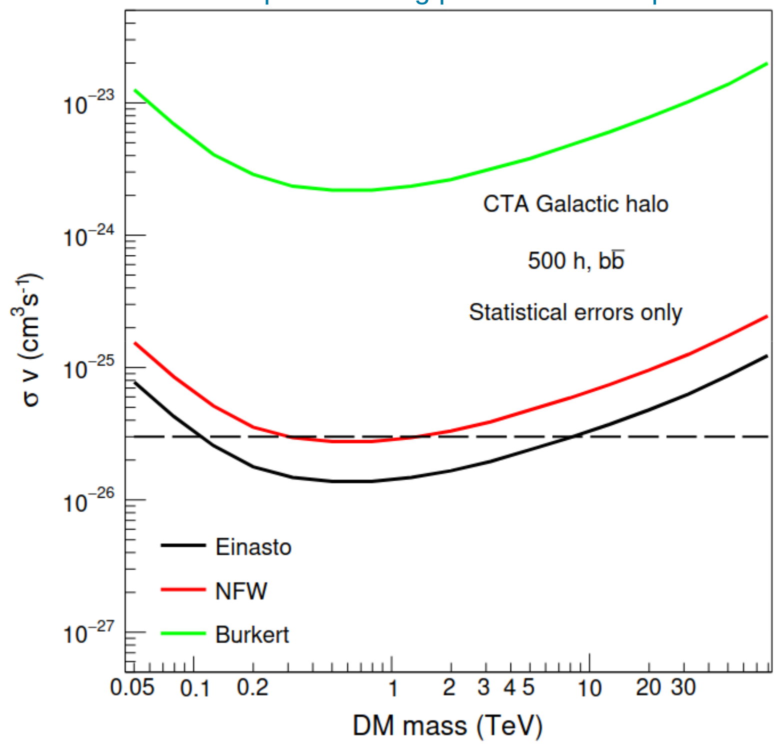




https://arxiv.org/pdf/1709.07997.pdf

Limits overview (future observatories)

https://arxiv.org/pdf/1709.07997.pdf



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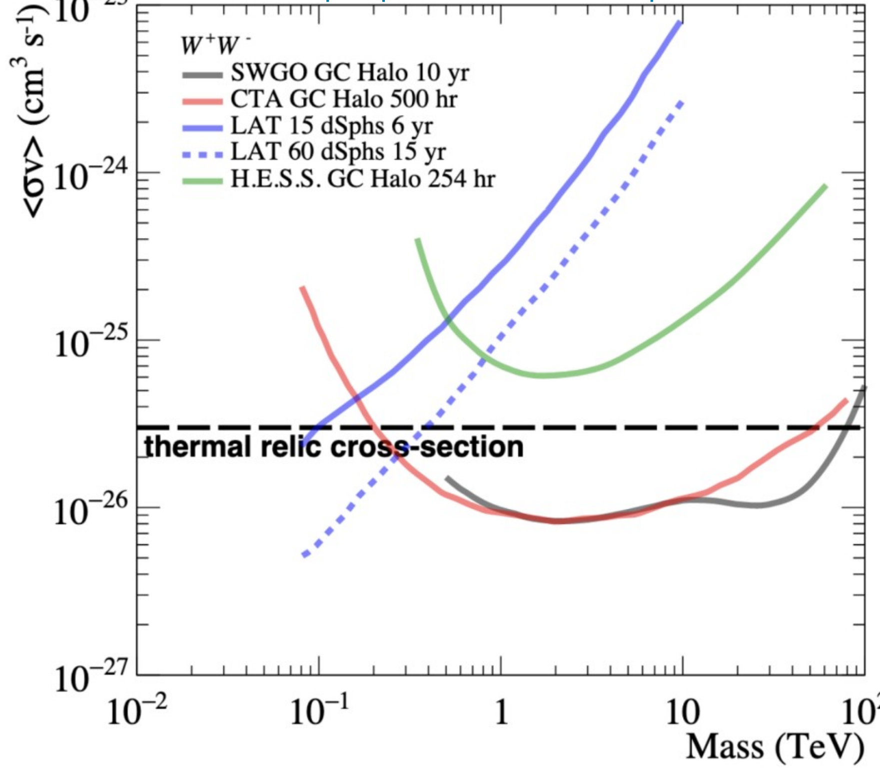
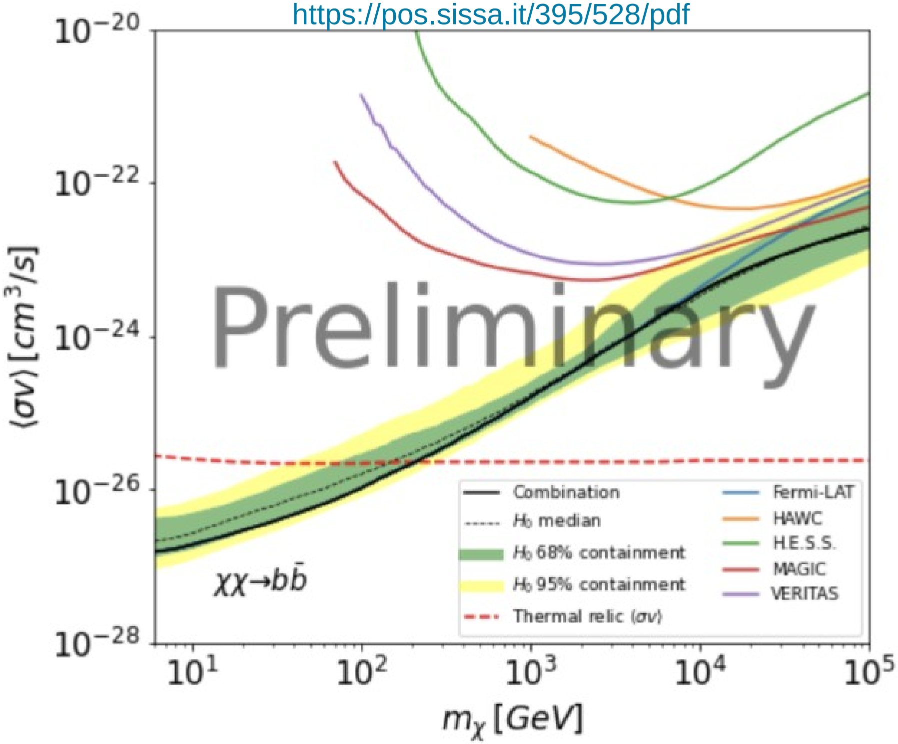


- GC best source for CTA (and southern observatories in general) but large uncertainty on the density profile
- Best case scenario, full exclusion of E < 100 TeV mass range (or even better a detection…)
- SWGO and CTA exhibits very similar limits, combination can be usefull to increase sensitivity

- First combined limits between observatories
- Pave the way for CTA (two observatories North and South)
- Pave the way for future combination between observatories (Fermi, CTA, SWGO, LHAASO)
- Pave the way for combination between different type of targets ? (here Dwarf galaxies only)

https://pos.sissa.it/395/528/pdf



Conclusions

- Many collaborations for the gamma-ray observations in near future, **South and North Hemisphere** well covered
- More and more Water Cherenkov detector (HAWC, LHAASO operating since 1 years, SWGO)
- good coverage of the energy range from 100 GeV to 300 TeV in a near future
- For some halo density profile, we can expect to have an exclusion for E < 100 TeV
- I Didn’t spoke about the Galactic Center seen by Fermi (**cf Francesca Calore talk this afternoon**)
- **Combination of data** of different observatories is also a key topic for future (not only for Dark Matter)
- CTA can constrain also **Axion-like particles** (Gamma-ray propagation) and **Primordial Black hole**, that can be linked to the dark matter topic