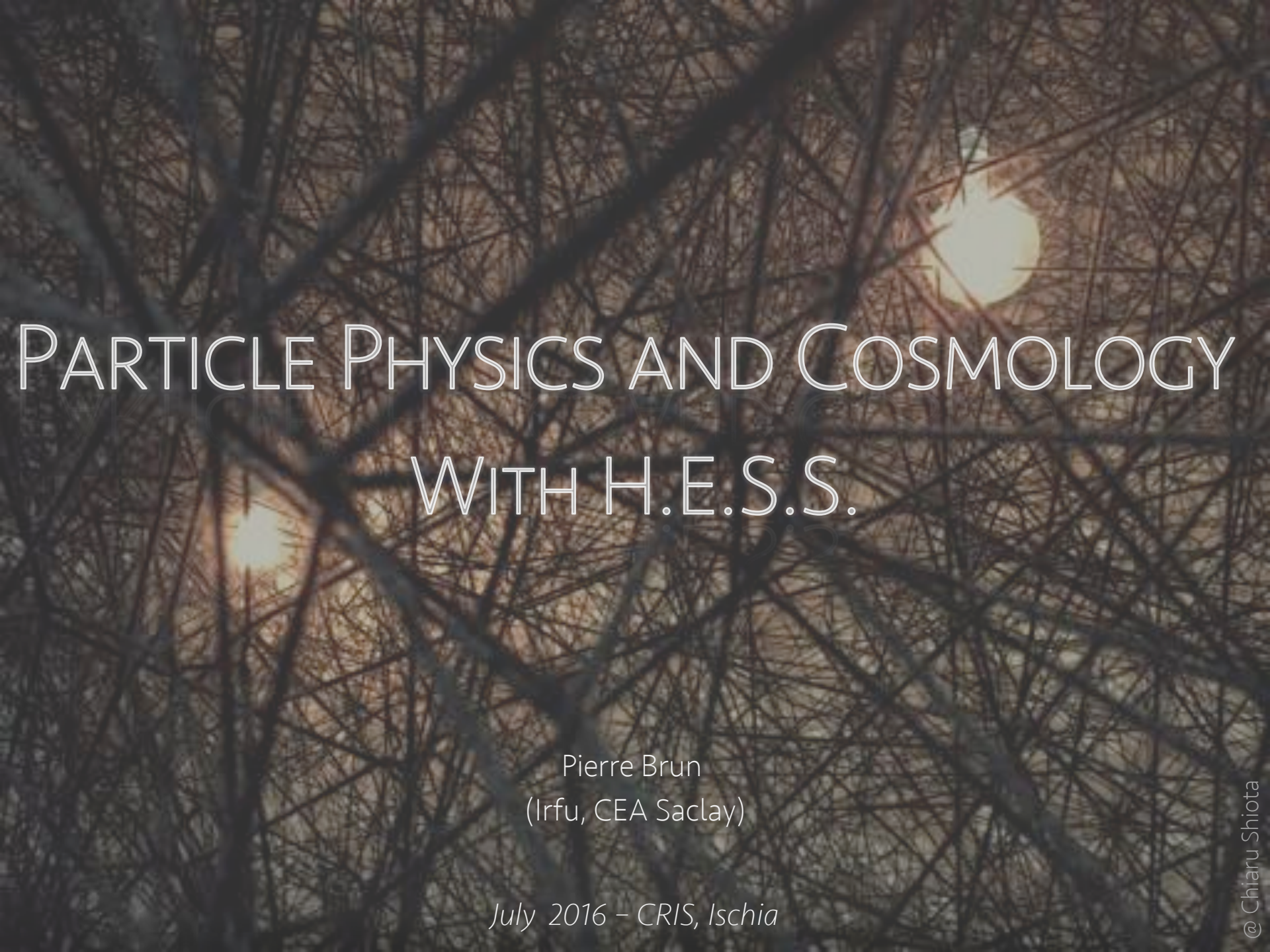
Particle Physics and Cosmology With H.E.S.S.

Pierre Brun
(Irfu, CEA Saclay)

July 2016 – CRIS, Ischia



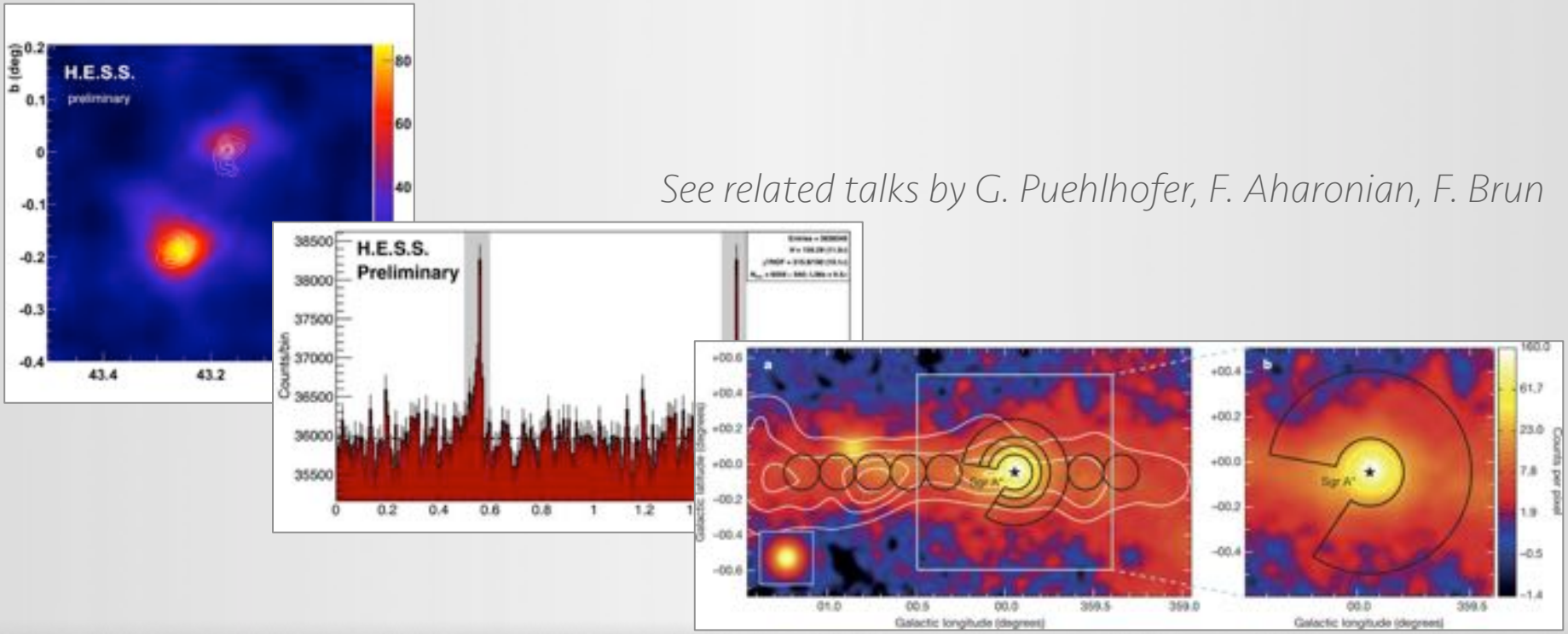
H.E.S.S. Telescopes

- 5°x 5° field of view
- ~50 GeV – 100 TeV
- 0.1° angular resolution
- 10-15% energy resolution
- Large background : Fov-scale diffuse emission very difficult

Gamma-Ray Sources

HESS observes a variety of sources

- → Galactic : supernova remnants, pulsars, …
- → Diffuse emission
- → Extragalactic : blazars, starburst galaxies

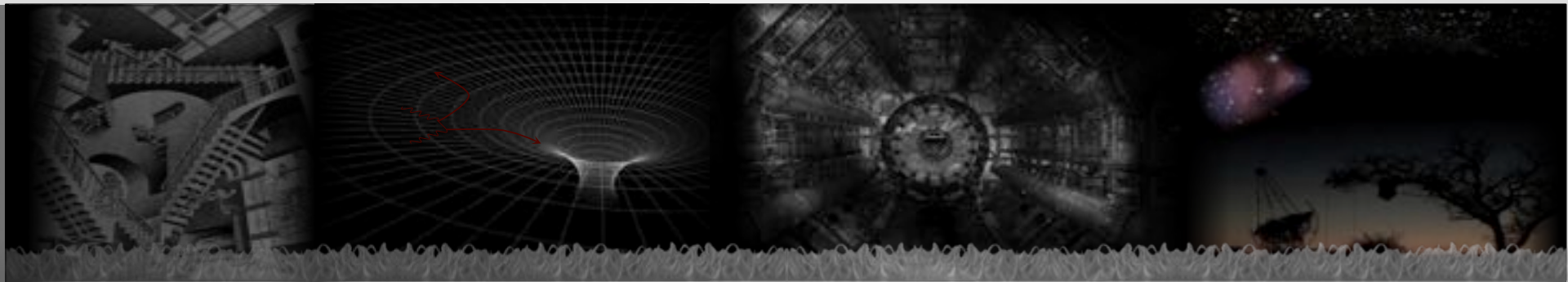


See related talks by G. Puehlhofer, F. Aharonian, F. Brun

Astroparticle Program w/ H.E.S.S.

- Searches for WIMP dark matter
  - → Galactic center
  - → Dwarf galaxies
  - → Search for lines
- Measurement of the extragalactic diffuse light
- Axions from mixing w/ photons around AGNs
- Tests of Lorentz invariance
- Cosmic ray spectra
- …

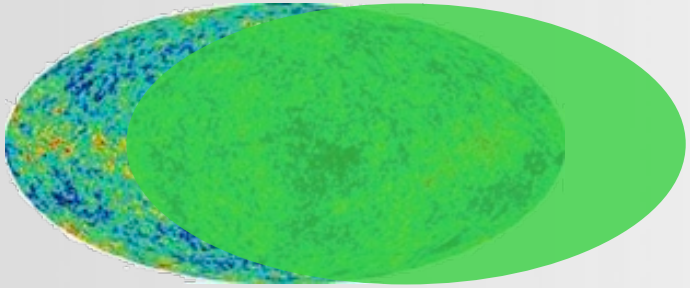
Will focus on new results



WIMP Dark Matter

DM is required to understand results from cosmological probes

e.g. CMB anisotropies/structure formation



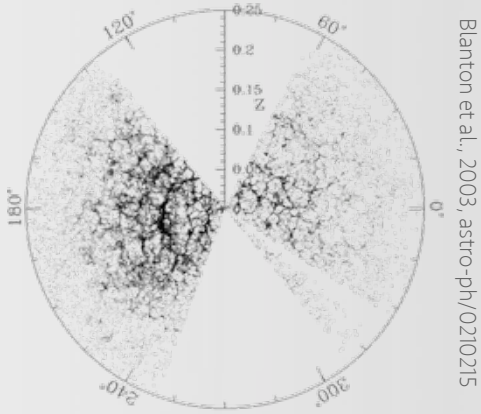
CMB very homogeneous :

$$\delta\rho/\rho = 10^{-5}$$

$\Longleftrightarrow$ Same Universe ≠ epochs $\Longleftrightarrow$

$$\delta\rho/\rho \propto a(t)$$

$a(t_{CMB})=1$ → $a(t_{galaxies})=10^3$



Blanton et al., 2003, astro-ph/0210215

$$\exists \text{ galaxies} : \ \delta\rho/\rho \gg 1$$

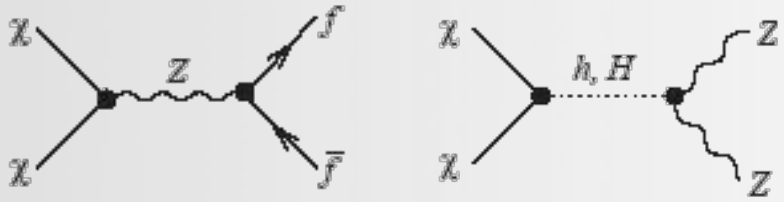
⇒ 84% of *non baryonic* dark matter

Standard Model photon —*New symmetries*→ WIMP candidate

Primordial *self-annihilations* regulate cosmological density

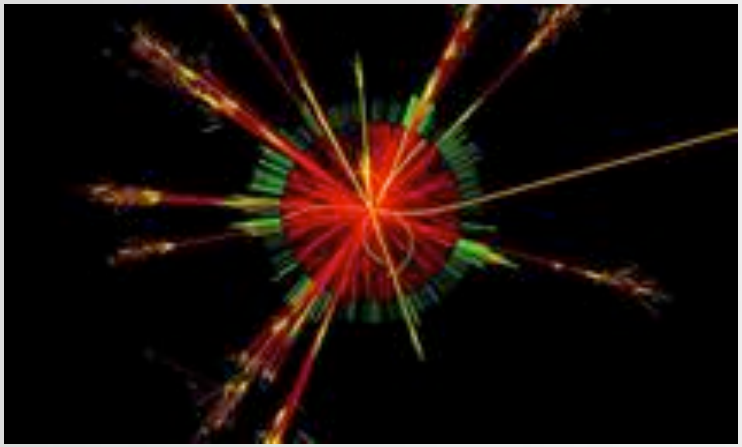
Annihilation Processes

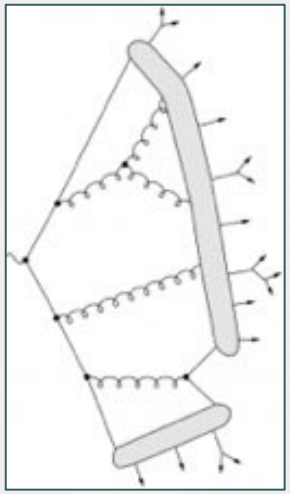
- DM particle collisions produce standard particles
  - → Quarks, leptons, gauge bosons



Mass ⇔ momentum

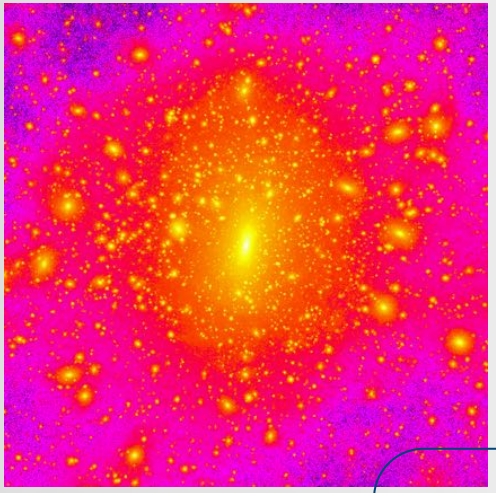
- Standard particles produced at high energy
  - → Further decay and hadronization





Include photons with energy ~DM mass

Where to Search for Dark Matter?



- Galactic center ⇦
- Galactic halo ⇦
- Clumps with baryons (dwarf galaxies)
- Bare clumps

$$\Phi_{DM} = N_\gamma(E)\frac{\langle\sigma v\rangle}{m^2}\frac{1}{4\pi D^2}\int_V dV\frac{\rho^2}{2}$$

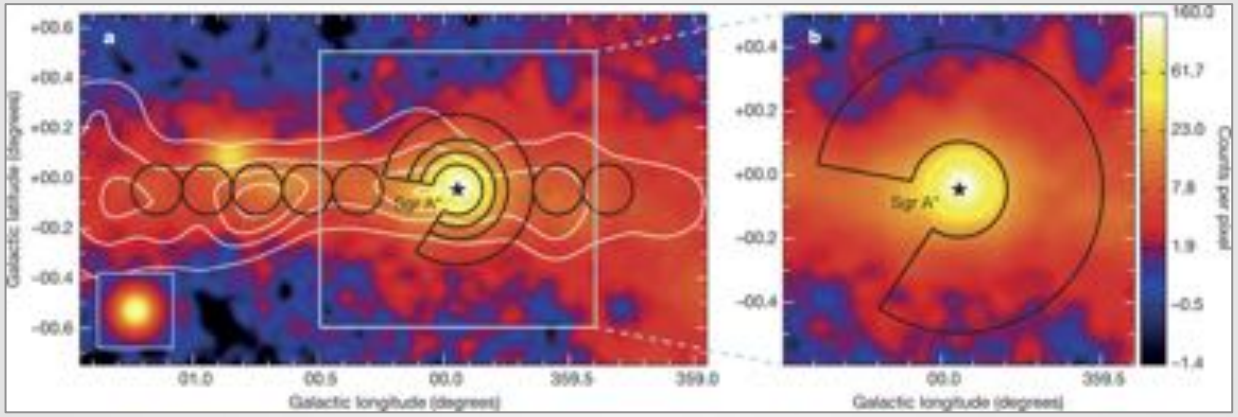
Efficiency of g ray production in WIMP collisions

Solid angle factor

Number of collisions within the observed target

Galactic Center Region

- 10 years of observations, powerful central source

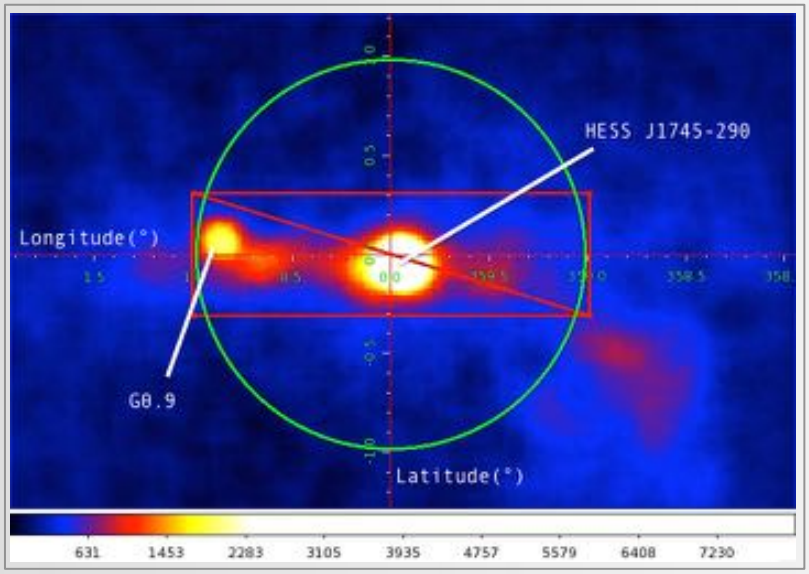


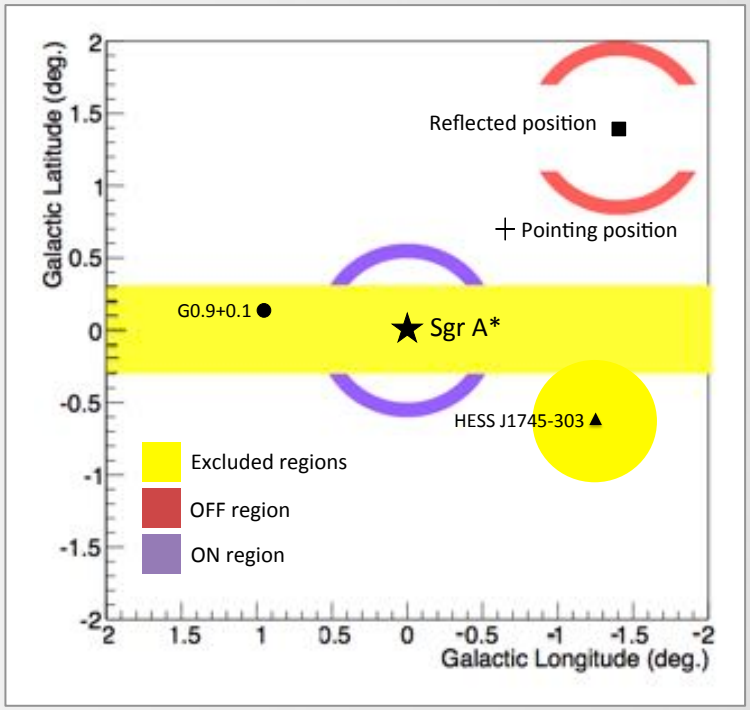
H.E.S.S. Collab., Nature 531, 476 (2016)

- Not dark matter dominated emission :
  - → 2006 : central source not dark matter *H.E.S.S. Collab., PRL 97, 221102*
  - → 2011 : constraints from halo *H.E.S.S. Collab., PRL 106, 161301*
  - → 2008, 2011 : limits on IMBHs & clumps *H.E.S.S. Collab., PRD 78, 072008* *P.B. et al., PRD 83, 015003*
  - → 2015 : limits from halo w/ cored profile *H.E.S.S. Collab., PRL 114, 081301*
  - → 2016 : improved limits from halo

Searches in the GC Vicinity

- Most advanced analysis
  - → Halo, w/ morphological & spectral likelihood

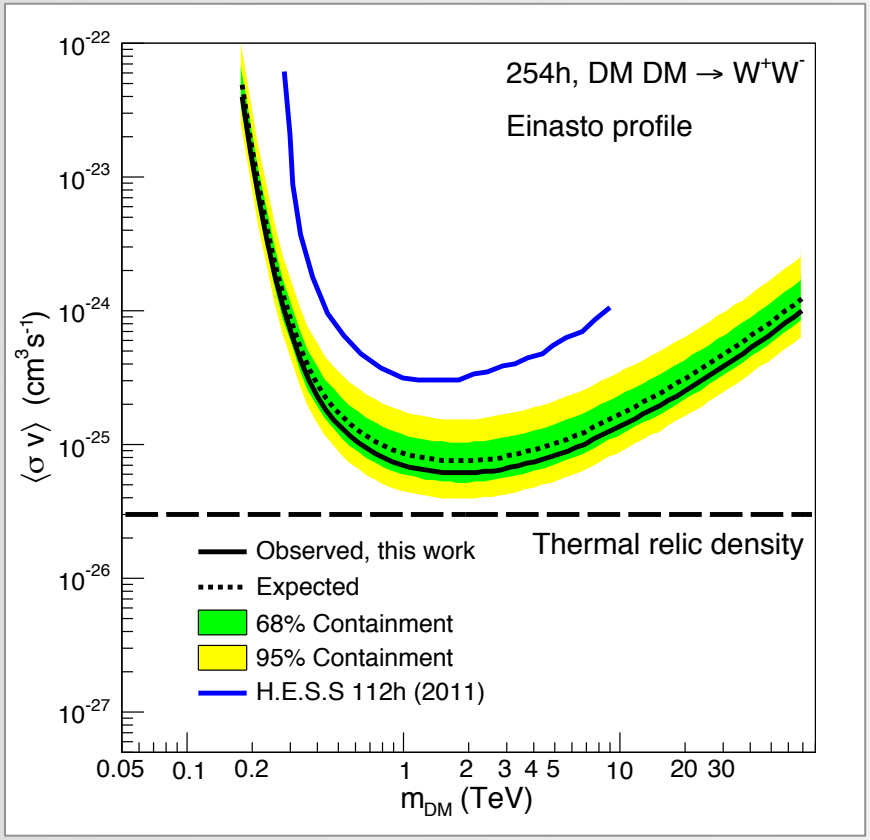


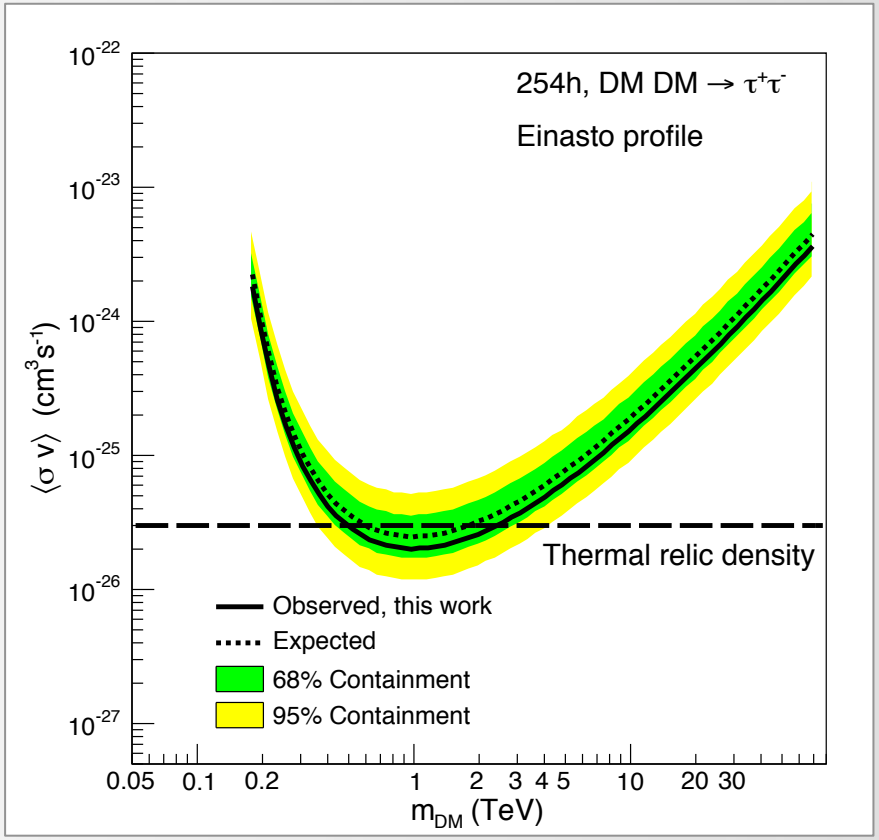


V. Lefranc, ICRC 2015

- Best limits w/ ground telescopes, submitted to PRL

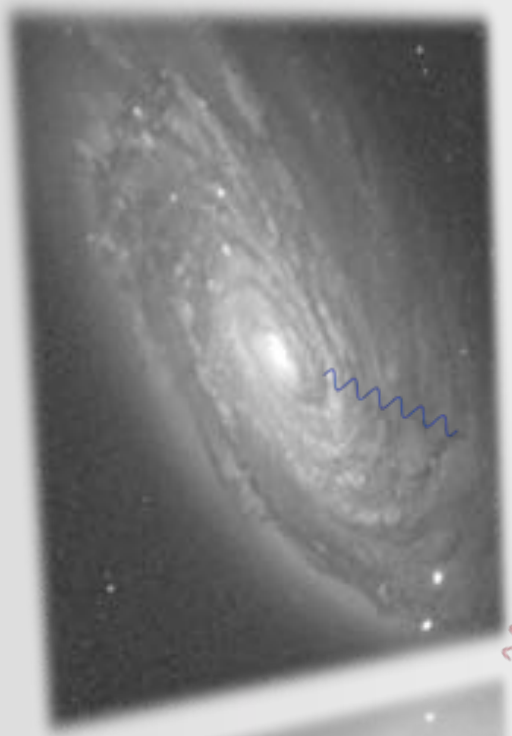
Limits on Dark Matter Parameters



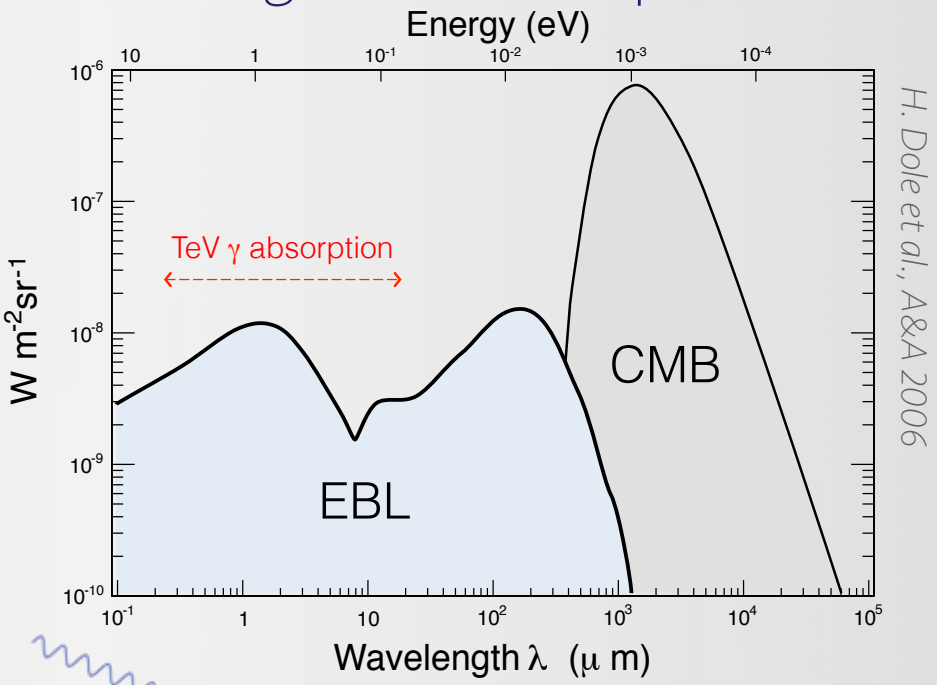


V. Lefranc, ICRC 2015

Extragalactic Background Light

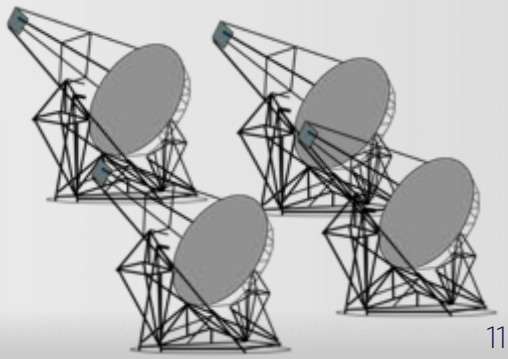


Background UV/IR photons

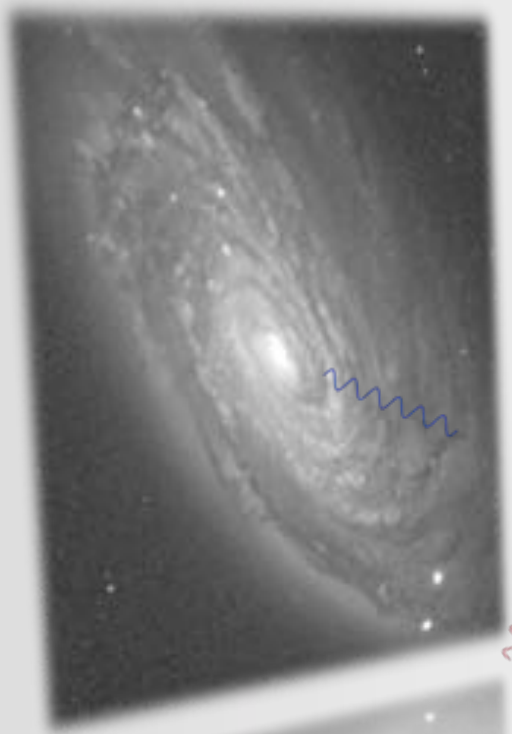


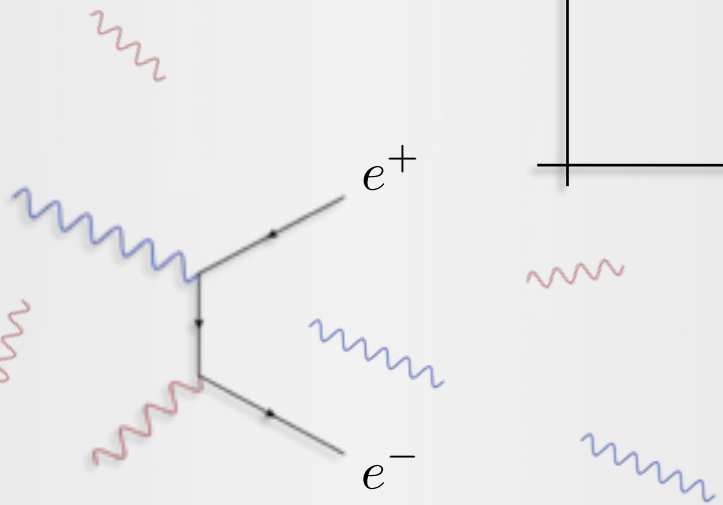
H. Dole et al., A&A 2006

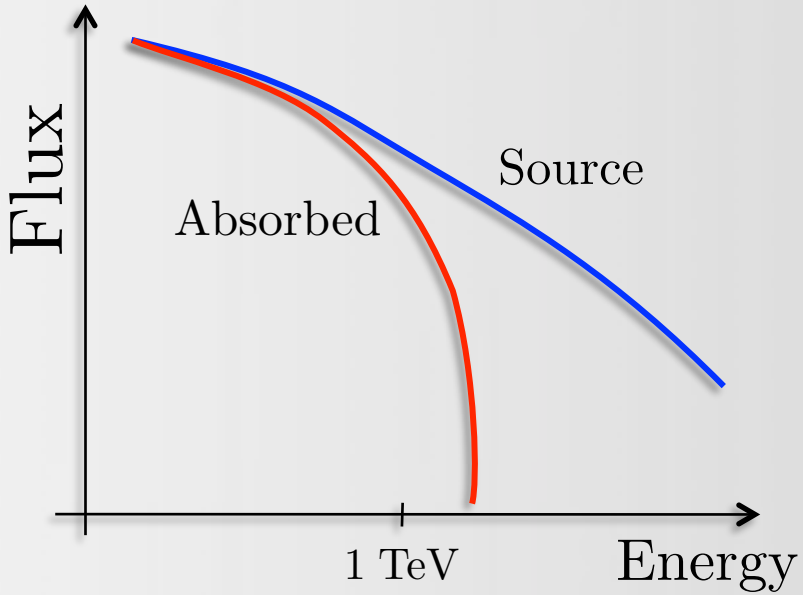
Pair production induces a gamma-ray horizon $z \simeq 0.1$ at 1 TeV



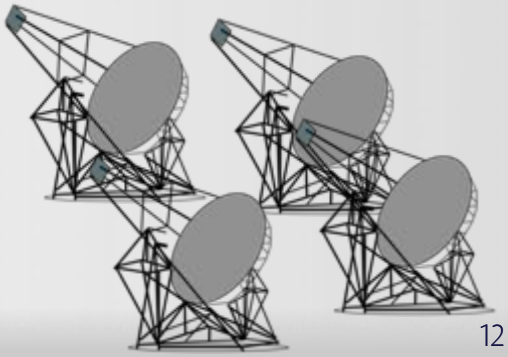
Extragalactic Background Light





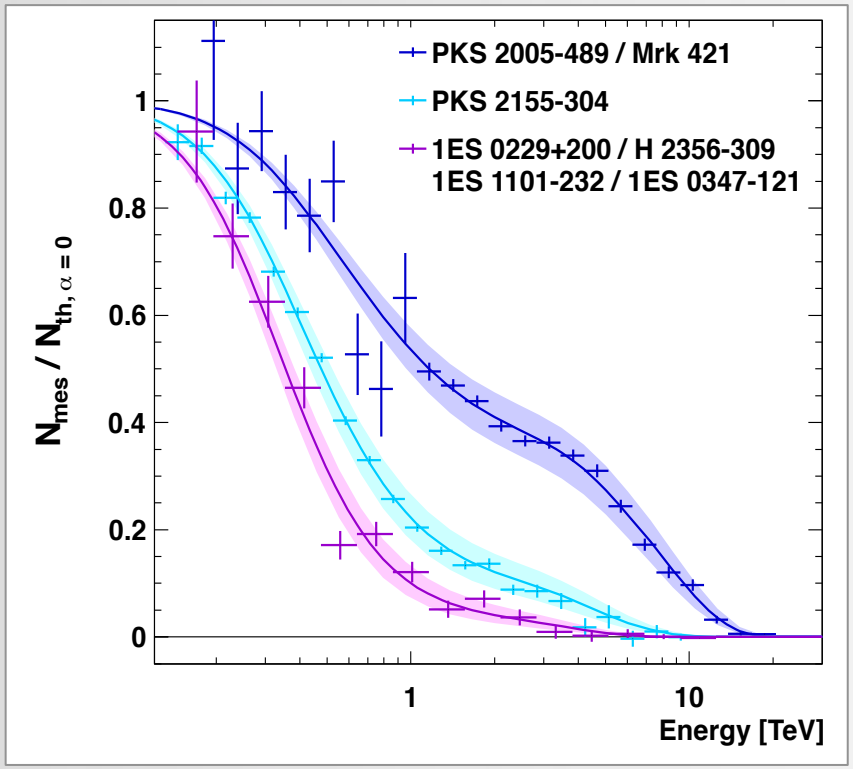


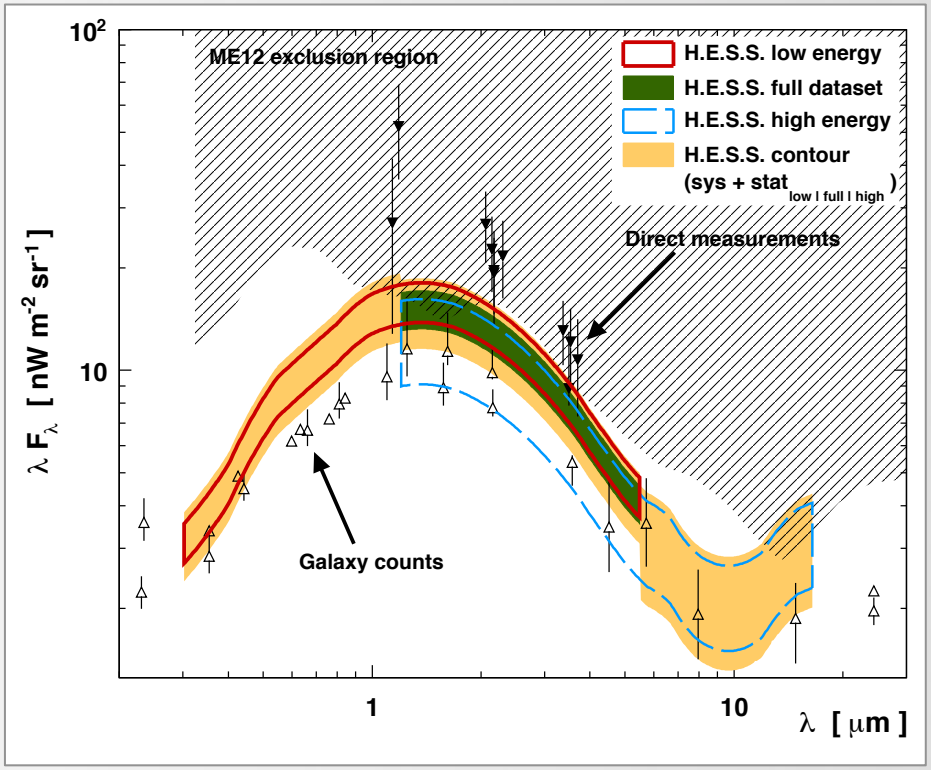
$$\phi_{\text{observed}} = \phi_{\text{source}} \times \exp(-\tau)$$



First Measurement

Assuming a SED, fit of the background photon density



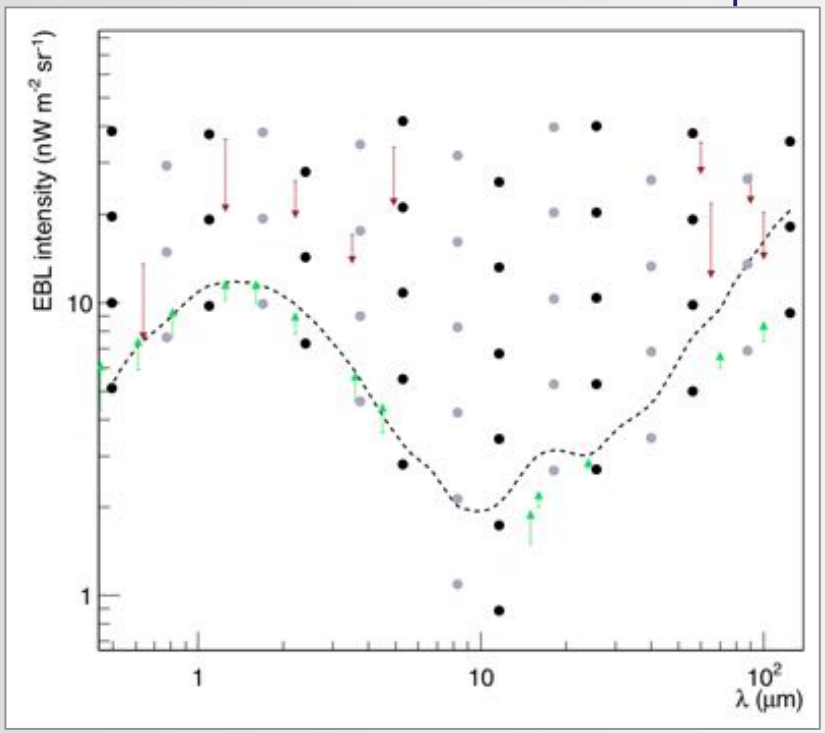


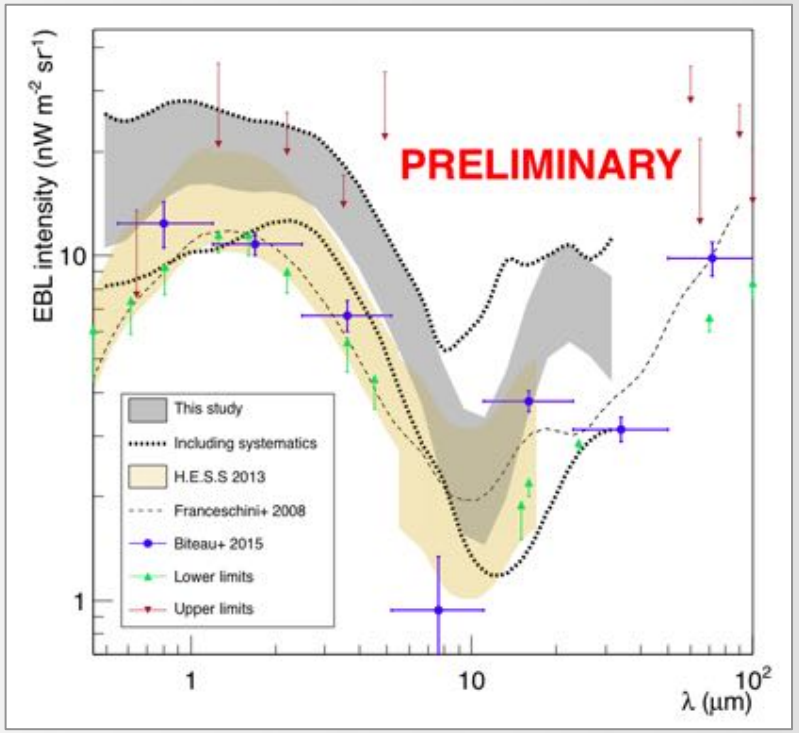
HESS Collab., A&A 2013

$$\alpha_0 = 1.27^{+0.18}_{-0.15\ \mathrm{stat}} \pm 0.25_{\mathrm{syst}}$$

Model-Independent Approach

- With minimal assumptions on the EBL SED





M. Lorentz & P.B., ICRC 2015

- Essential step to search for second-order effects
  - → Cascade & primordial magnetic fields
  - → Axions (now searched for by other means)
  - → Lorentz invariance violation

Tests of Lorentz Invariance

- Lorentz invariance breaking in photon sector

$$E_\gamma^2 = p_\gamma^2 \pm E_\gamma^2 \left(\frac{E_\gamma}{E_{LIV}} \right)^n$$

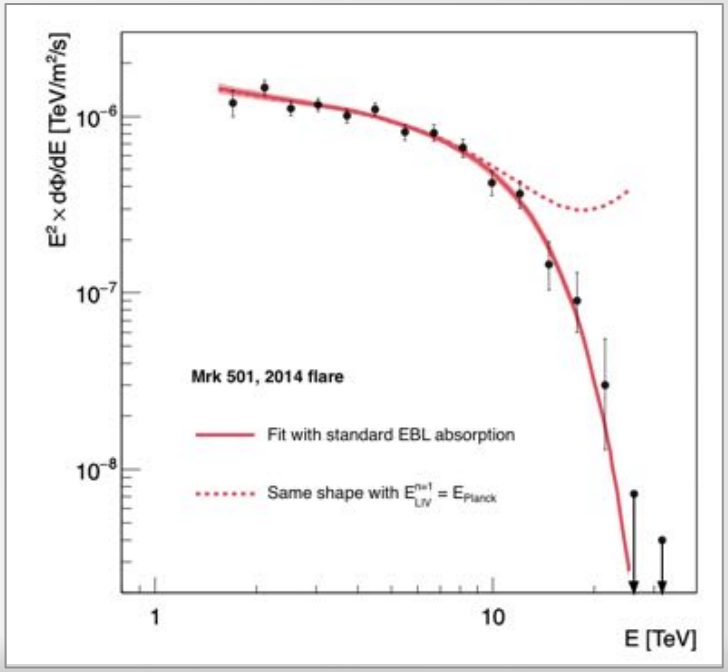
- Would induce energy-dependent time lags
- Here another approach : threshold distortions

$$s \to s \pm \frac{E_\gamma^{n+2}}{{E_{LIV}}^n}$$

$$\epsilon_{th} \to \epsilon_{th} \mp \frac{1}{4} \frac{E_\gamma^{n+1}}{{E_{LIV}}^n}$$

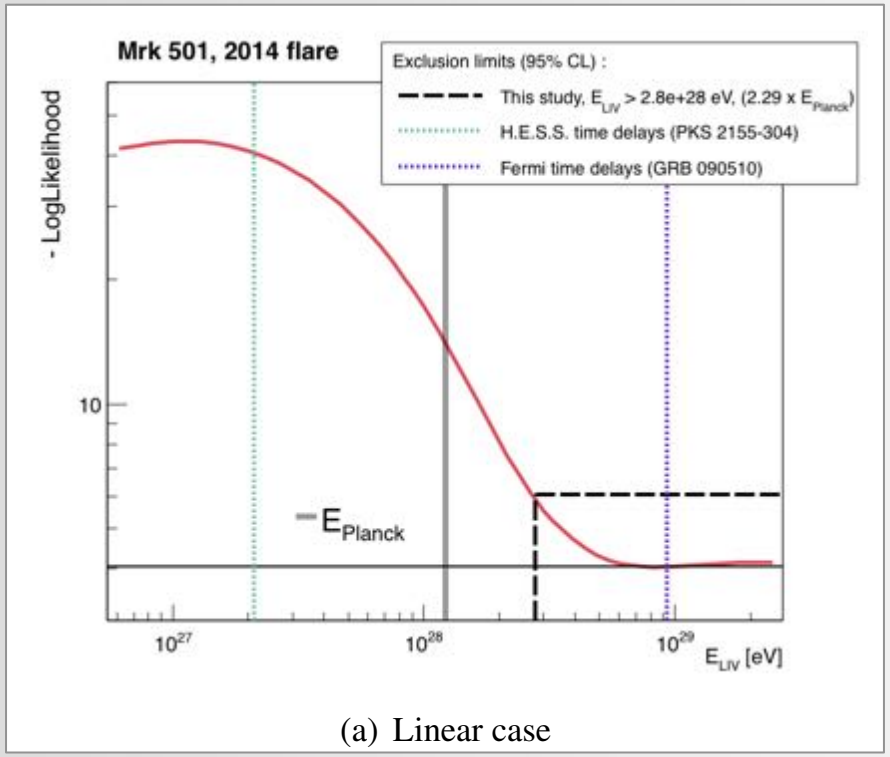
2014 flare of Mrk 501 ⟹

z = 0.034

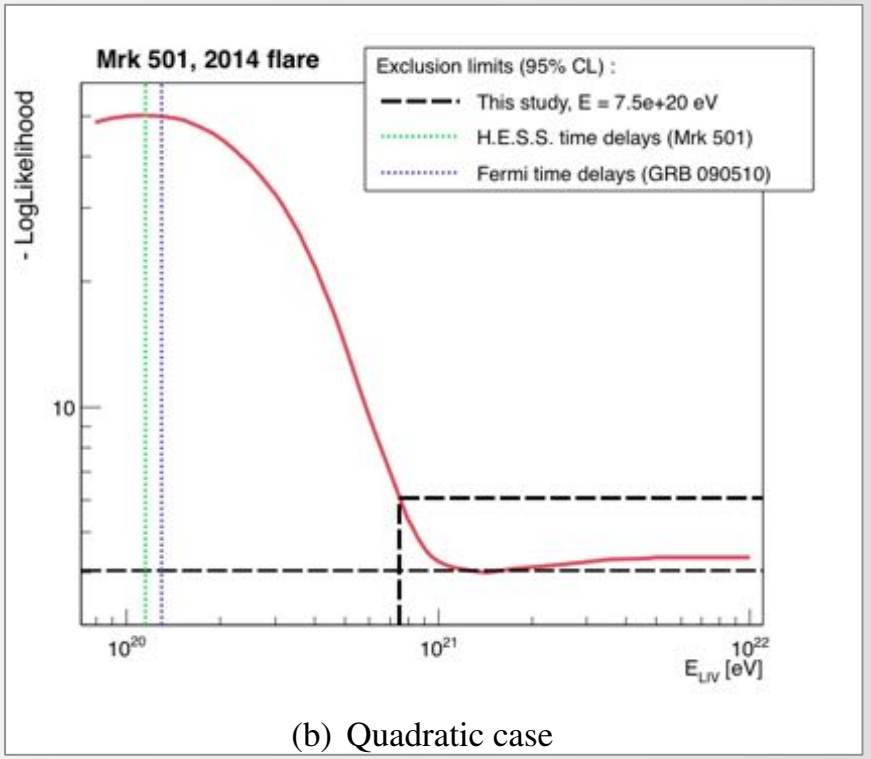


M. Lorentz & P.B., RICAP 2016

Lorentz Invariance w/ Spectra



(a) Linear case



(b) Quadratic case

	2 σ	3 σ	5 σ
n=1	2.8×10^{28} eV ($2.29 \times E_{Planck}$)	1.9×10^{28} eV ($1.6 \times E_{Planck}$)	1.04×10^{28} eV ($0.86 \times E_{Planck}$)
n=2	7.5×10^{20} eV	6.4×10^{20} eV	4.7×10^{20} eV

Planck scale excluded for linear term

Best limit for quadratic term

M. Lorentz & P.B., RICAP 2016

Other Results

- ★ Combined dwarf-galaxy dark matter search *H.E.S.S. Collab., PRD 90, 112012 (2014)*
- ★ Dark matter lines *H.E.S.S. Collab., PRL 110, 041301 (2013)*
  Update & Fermi hot spot : Submitted, M. Kieffer ICRC 2015
- ★ Lorentz invariance w/ time lags
  - → PKS 2155-304 *H.E.S.S. Collab., PRL 101, 170402 (2008)*
    H.E.S.S. Collab., Astropart. Phys. 34, 738 (2011)
  - → PG 1553 *H.E.S.S. Collab., ApJ 802, 65 (2015)*
  - → Vela pulsar *M. Chrétien, ICRC 2015*
- ★ Axion-like particles *H.E.S.S. Collab. PRD 88, 102003 (2013)*
- ★ Microscopic black holes *J-F. Glicenstein, ICRC 2013*
- ★ Electron spectrum *H.E.S.S. Collab., A&A 508, 561 (2009)*
  H.E.S.S. Collab., PRL 101, 261104 (2008)
  Expect an update soon !

Still a lot more soon !