

# Constraining dark matter lifetime with very deep observations of the Perseus cluster with the MAGIC Telescopes

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(on behalf of the MAGIC Collaboration)



Institut de Física  
d'Altes Energies **IFAE** 

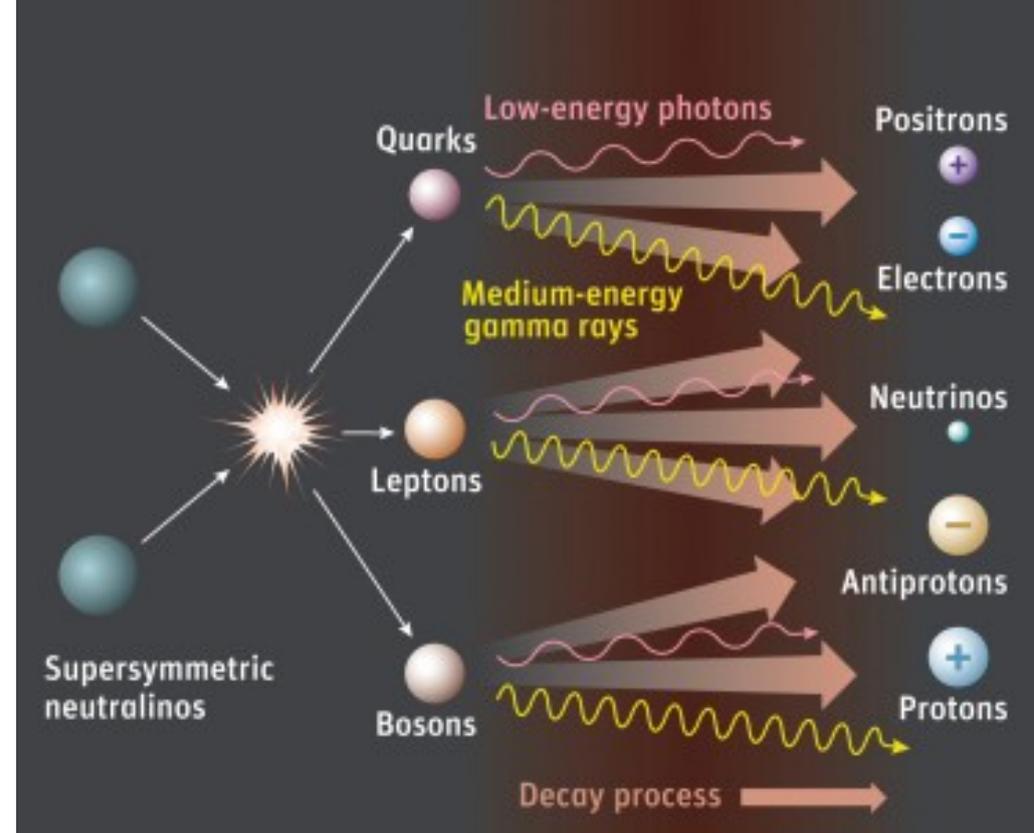


INTERNATIONAL COSMIC RAY  
CONFERENCE  
THE HAGUE, 31Jul-6Aug 2015

# Indirect searches

Detect secondary particles produced as a consequence of an interaction between Dark Matter particles and Standard Model Particles

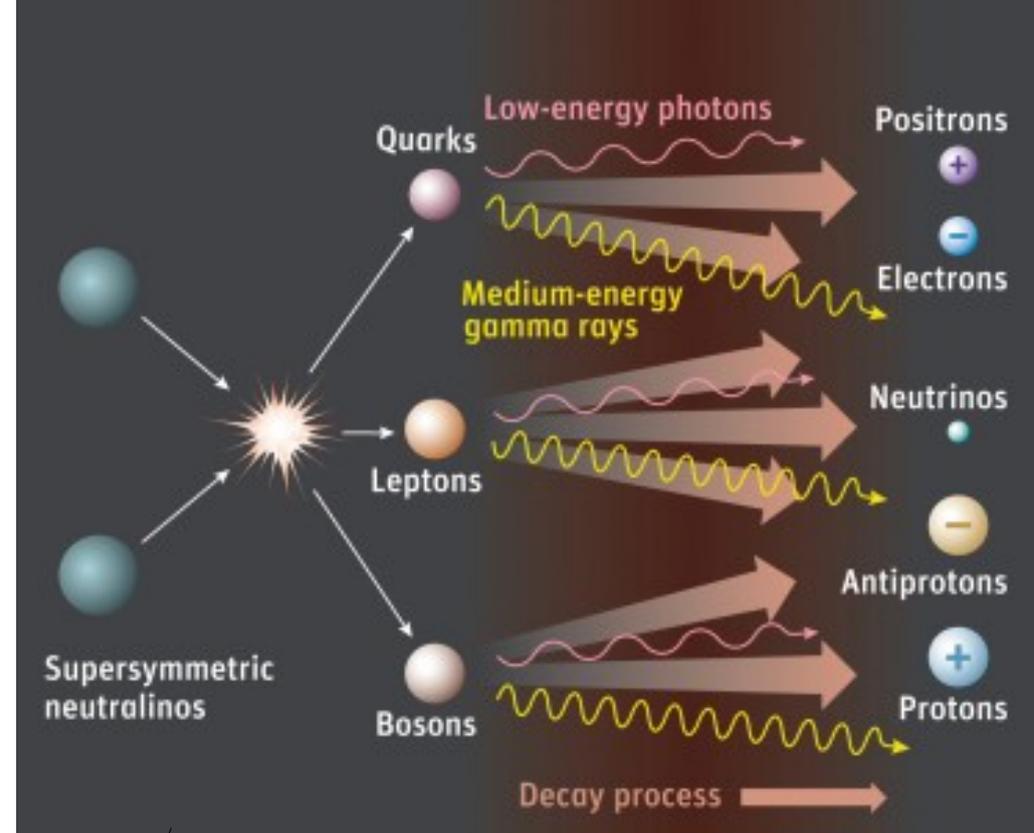
- ◆ Unique **spectral features** of Dark Matter processes
- ◆ Neutral particles **point back** to DM sites
- ◆ Needed to confirm that signals found in accelerator or direct searches are **THE dark matter**



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Expected GAMMA-RAY fluxes for a given target:

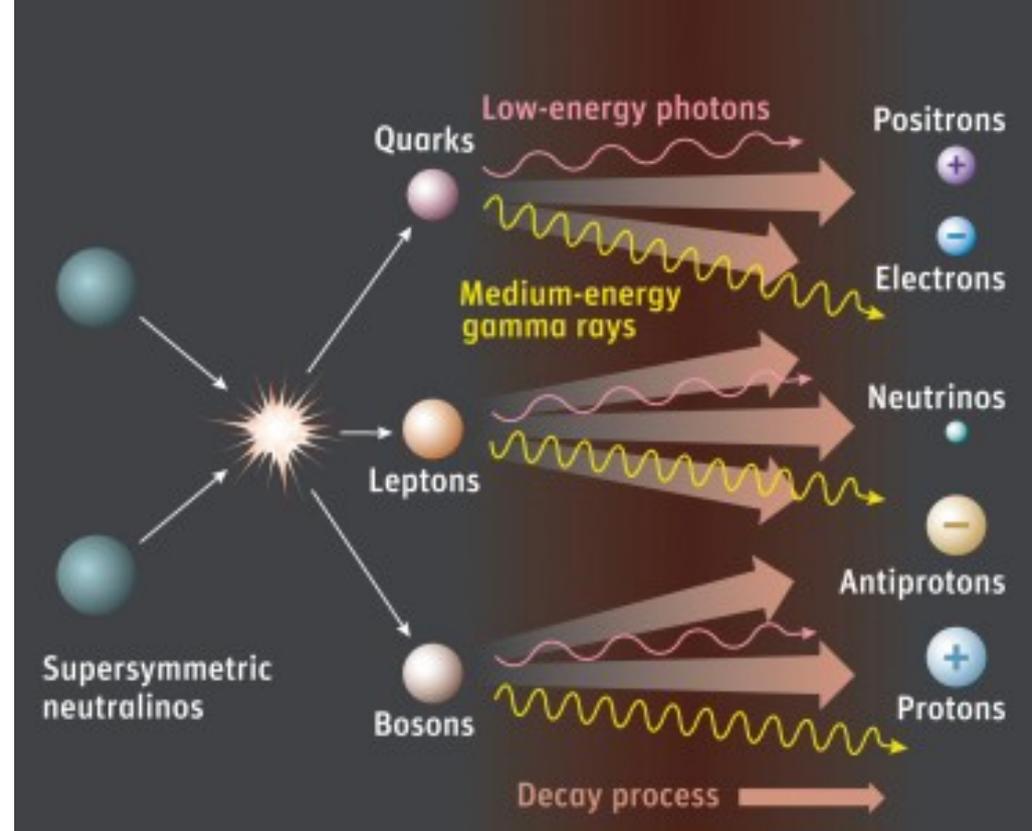
$$\frac{d\Phi_{\gamma}}{dE} = \frac{d\Phi_{\gamma}^{PP}}{dE} \times J(\Omega)$$

proportional to  
expected fluxes

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Important difference

**Annihilation**

$$\frac{d\Phi_\gamma^{PP}}{dE} = \frac{\langle\sigma v\rangle}{8\pi m_\chi^2} \frac{dN_\gamma}{dE}$$

$$J(\Omega) = \int_{\Omega_{los}} \int \rho^2(r) dr d\Omega$$

**Decay**

$$\frac{d\Phi_\gamma^{PP}}{dE} = \frac{1}{4\pi m_\chi \tau_\chi} \frac{dN_\gamma}{dE}$$

$$J(\Omega) = \int_{\Omega_{los}} \int \rho(r) dr d\Omega$$

# Clusters of Galaxies

- Largest and most massive gravitationally bound systems in the Universe
- total masses  $10^{14} - 10^{15} M_{\odot}$  (5% galaxies, 15% gas and **80% dark matter**)

Dwarf Spheroidal Galaxy

Cluster of Galaxies

	Jann [GeV <sup>2</sup> ·cm <sup>-5</sup> ]	Jdec [GeV·cm <sup>-2</sup> ]
Segue	1e19	2e17
Perseus	1e17	2e18
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excellent targets for decay dark matter searches

# Observations of Perseus

## The Perseus Cluster

- Cool-core cluster
- The brightest in X-ray

RA	03 h 18 m
Dec	41° 30'
Distance	77.7 Mpc (z=0.0183)
Observed	<b>300h</b>
Dark Matter Profile	NFW

### **MAGIC** results on Perseus:

- strongest limits in **CR acceleration**

*J. Aleksić et al., Astrophys. J. 710 (2010) 634*

*J. Aleksić et al., Astron. Astrophys. 541 (2012) A99*

*P. Colin, Oral Contribution ICRC GA07, 31st July*

- **NGC1275** discovered and modeled

*J. Aleksić et al., Astron. Astroph 539 (2012) L2*

*J. Aleksić et al., Astron. Astrophys. 564 (2014) A5*

- **IC310**: discovered, CR acceleration mechanism close to BH

*J. Aleksić et al., Astrophys. J. 723 (2010) L207*

*J. Aleksić et al., Astron. Astrophys 563 (2014) A91*

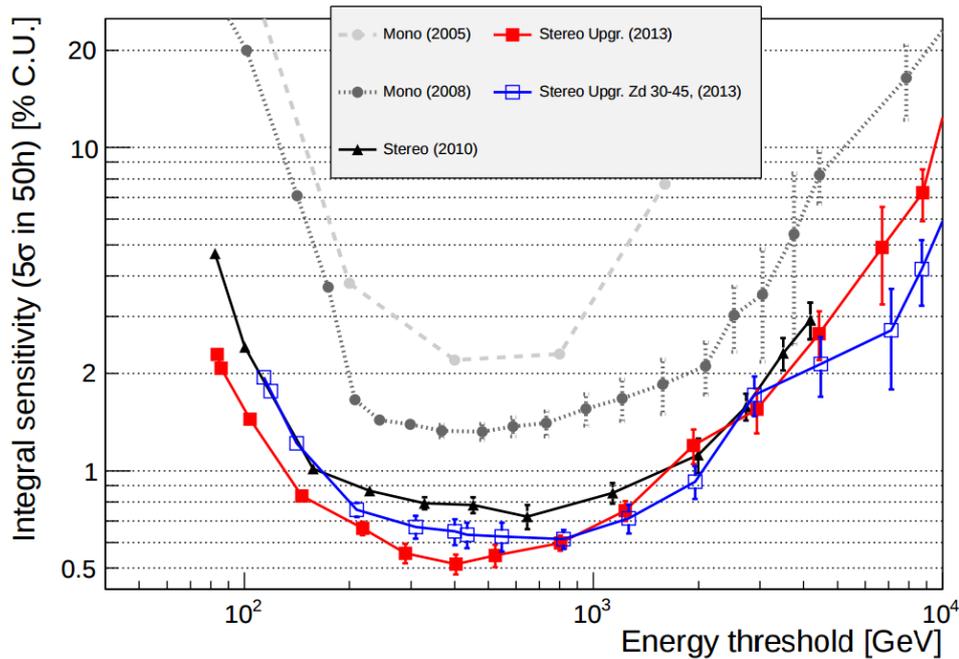


# The MAGIC Telescopes

Stereoscopic system of two 17 m diameter IACTs

Located in La Palma (Canary Islands)

Sensitivity of  $(0.67 \pm 0.04)\%$  C.U. above 290 GeV (50h Li&Ma with 5 bgd. regions)

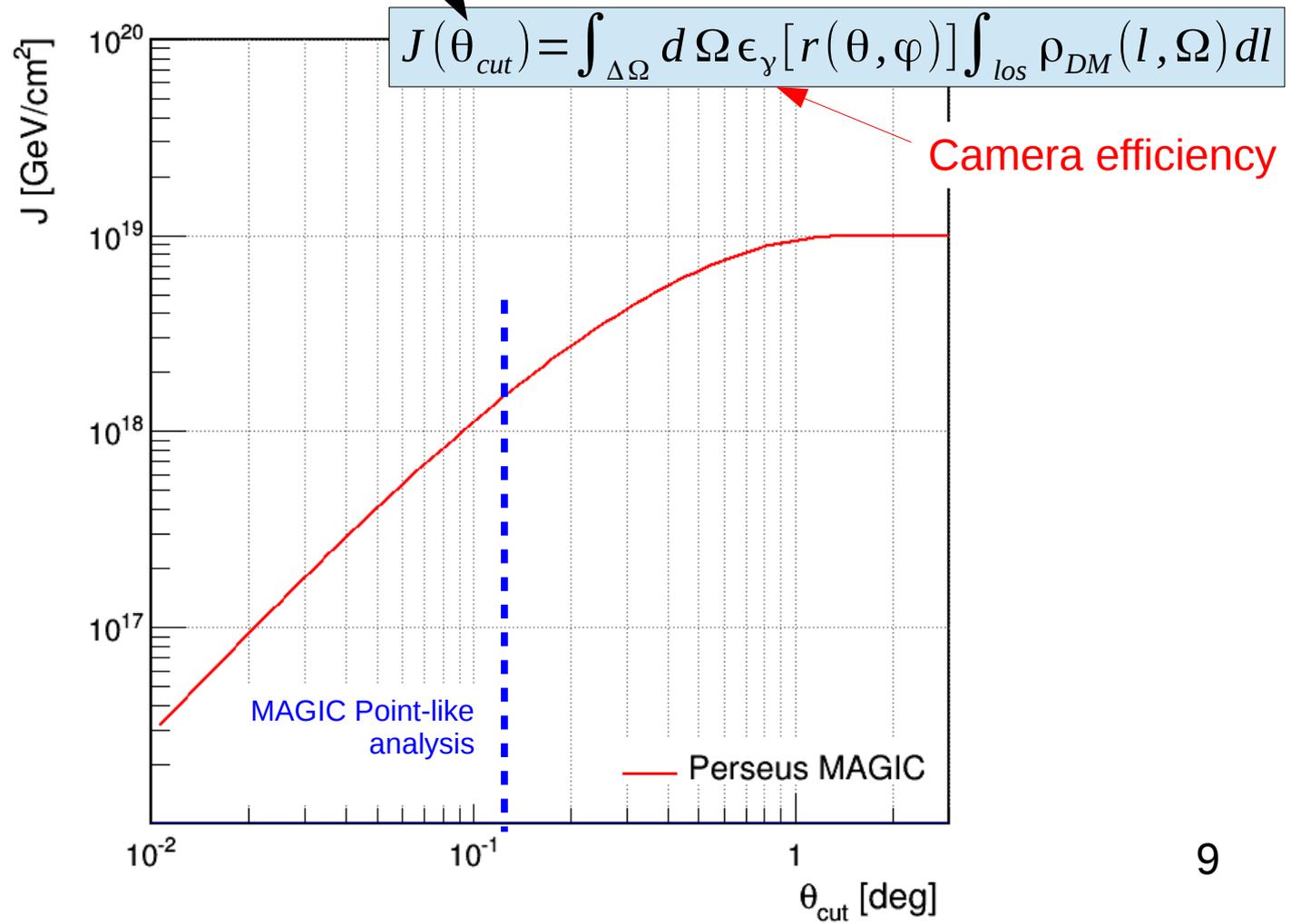


Aleksić et al DOI: [10.1016/j.astropartphys.2015.02.005](https://doi.org/10.1016/j.astropartphys.2015.02.005)

# Signal region optimization

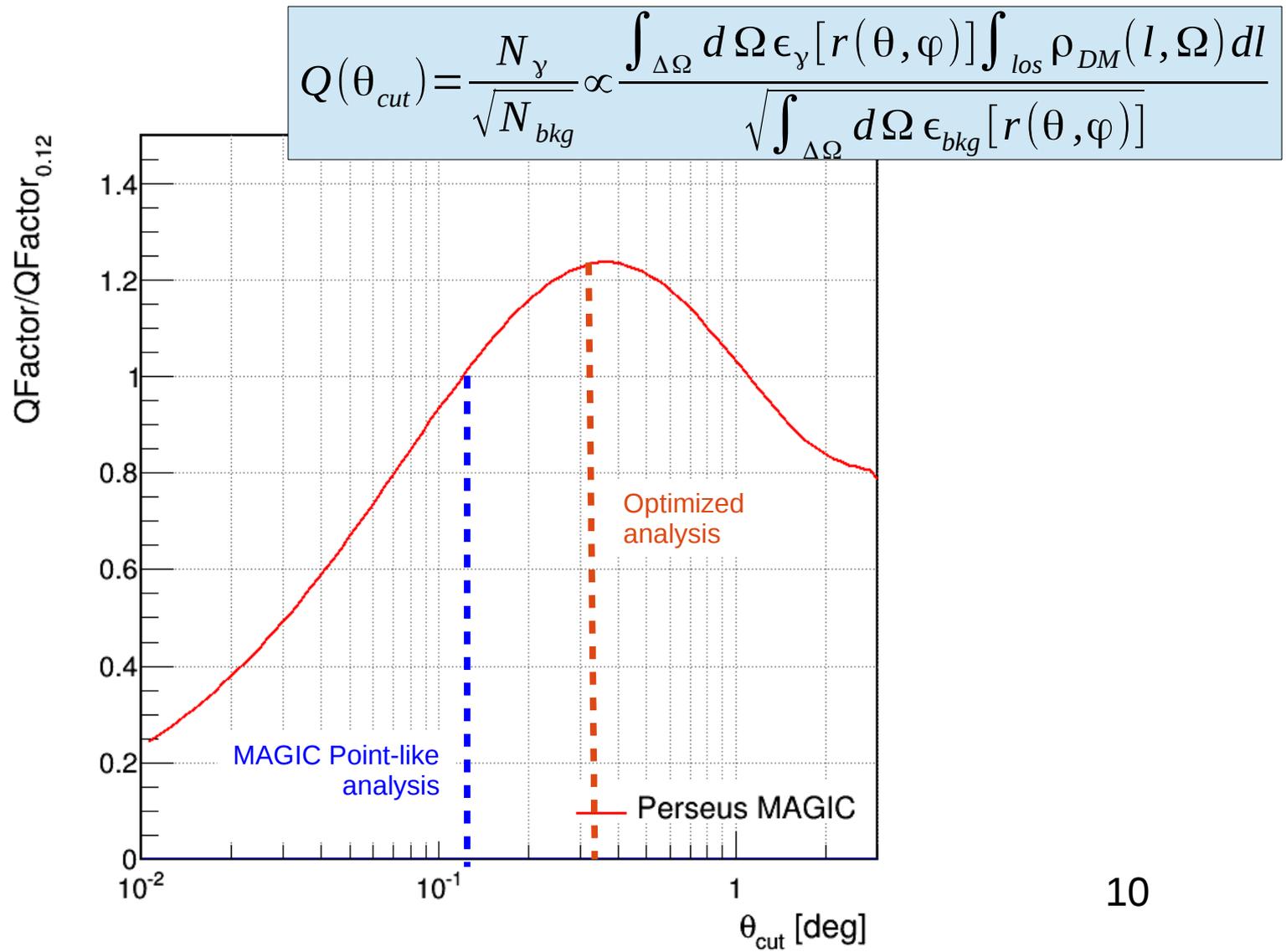
Perseus is an **extended source**

**Optimization of the signal aperture angle cut**, only considering the dark matter distribution



# Signal region optimization

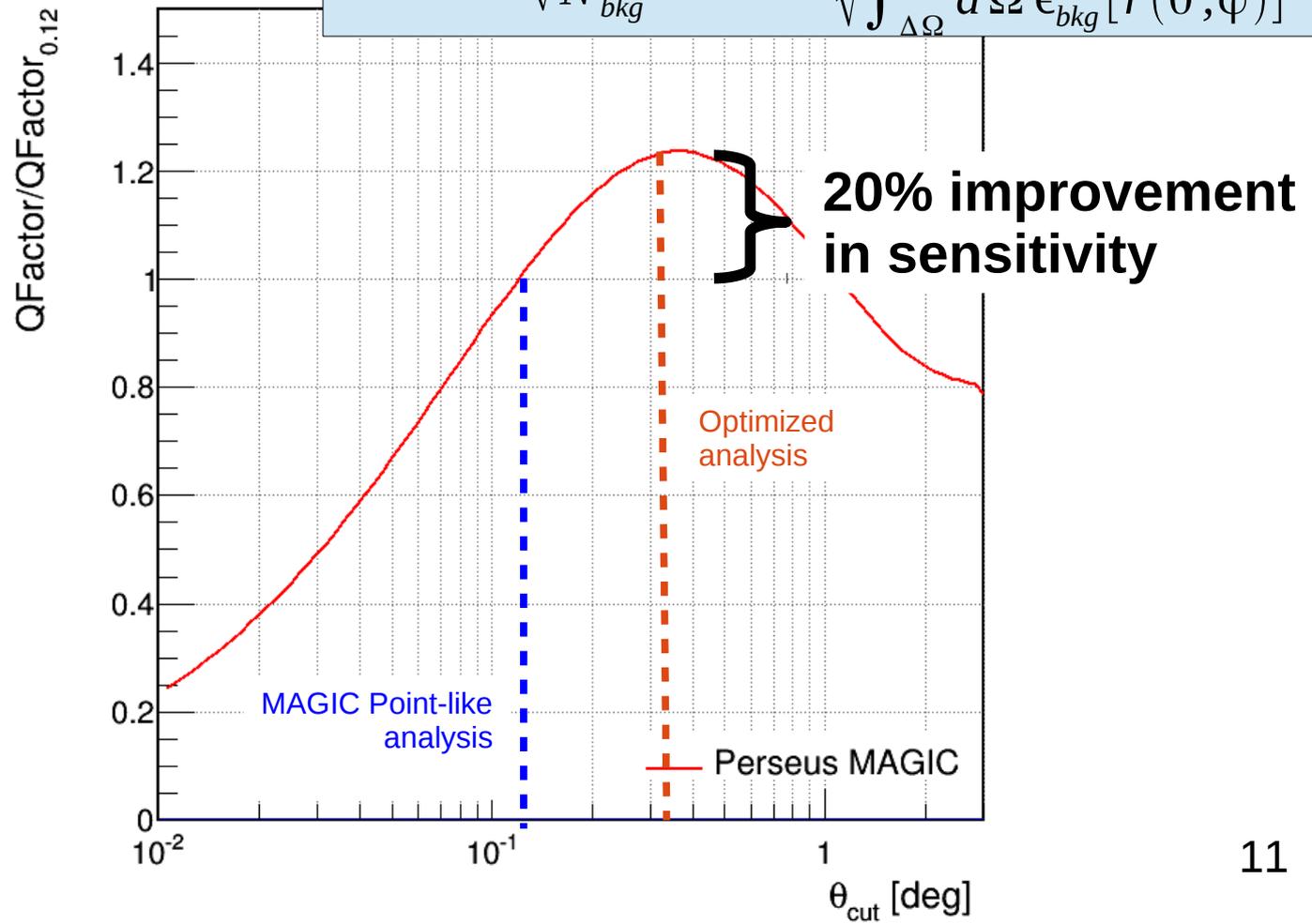
Quality factor maximization



# Signal region optimization

$$\theta_{cut} = 0.35 \text{ [deg]}$$

$$Q(\theta_{cut}) = \frac{N_y}{\sqrt{N_{bkg}}} \propto \frac{\int_{\Delta\Omega} d\Omega \epsilon_y[r(\theta, \varphi)] \int_{los} \rho_{DM}(l, \Omega) dl}{\sqrt{\int_{\Delta\Omega} d\Omega \epsilon_{bkg}[r(\theta, \varphi)]}}$$



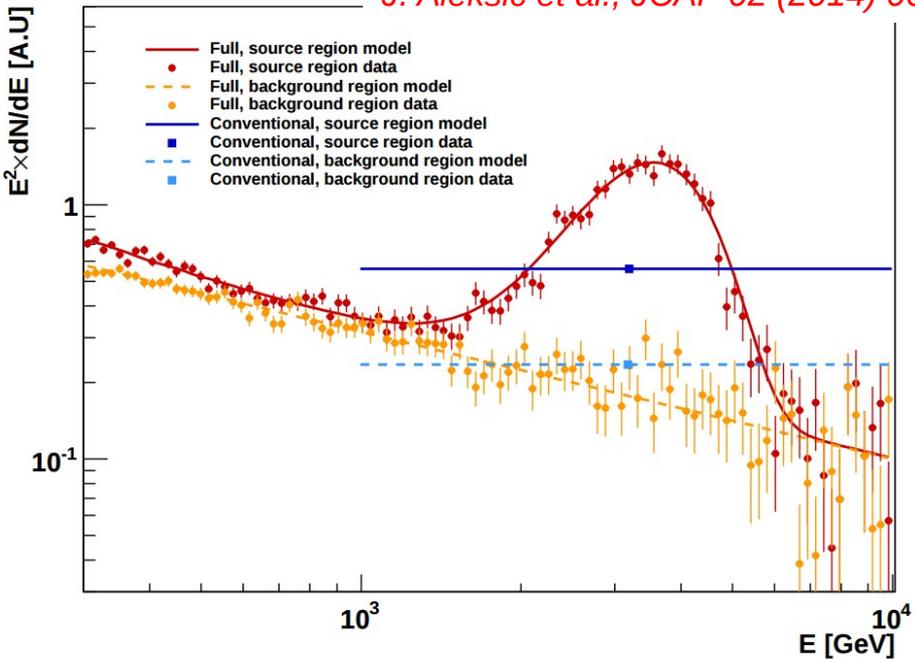
# Binned Likelihood analysis

Likelihood analysis that searches for spectral features specific from Dark Matter

$$\mathcal{L}(g, b | n, m) = \frac{(g + b)^n}{n!} e^{-(g+b)} \times \frac{(\tau b)^m}{m!} e^{-\tau b}$$

Poisson ON

Poisson OFF



$$\mathcal{L}(\langle \sigma v \rangle; J, \mu | \mathcal{D}) = \mathcal{L}(g(\langle \sigma v \rangle, J, ); b, \tau | \{E'_l\}_{l=1, \dots, N_{\text{ON}}}, \{E'_m\}_{m=1, \dots, N_{\text{OFF}}})$$

$$= \frac{(g + b/\tau)^{N_{\text{ON}}}}{N_{\text{ON}}!} e^{-(g+b/\tau)} \frac{b^{N_{\text{OFF}}}}{N_{\text{OFF}}!} e^{-b} \prod_{l=1}^{N_{\text{ON}}} f(E'_l | g; b, \tau) \prod_{m=1}^{N_{\text{OFF}}} h(E'_m | b)$$

Poisson ON

Poisson OFF

ON E' PDF

OFF E' PDF

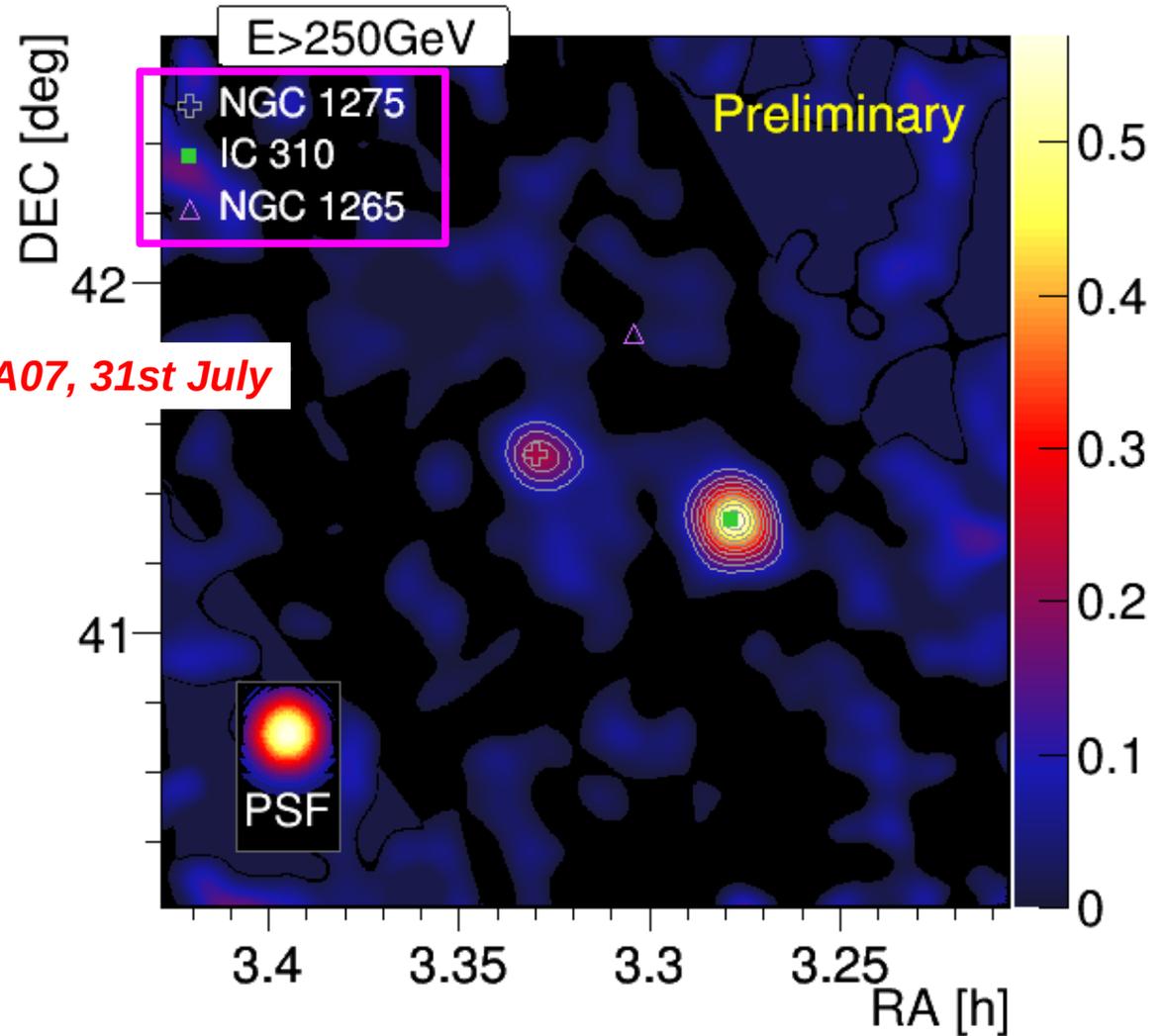
- Factor ~2 **improvement in sensitivity** for Dark Matter searches
- Easy combination independent analysis (different IRFs)  
*Rico, Wood et al. ICRC 2015, poster Session 3 DM&NU (4 Aug 16:00)*

# Data analysis improvement

MAGIC Sky Map

*P. Colin, Oral Contribution ICRC GA07, 31st July*

**Astrophysical sources in the f.o.v. need a special treatment in the likelihood analysis**



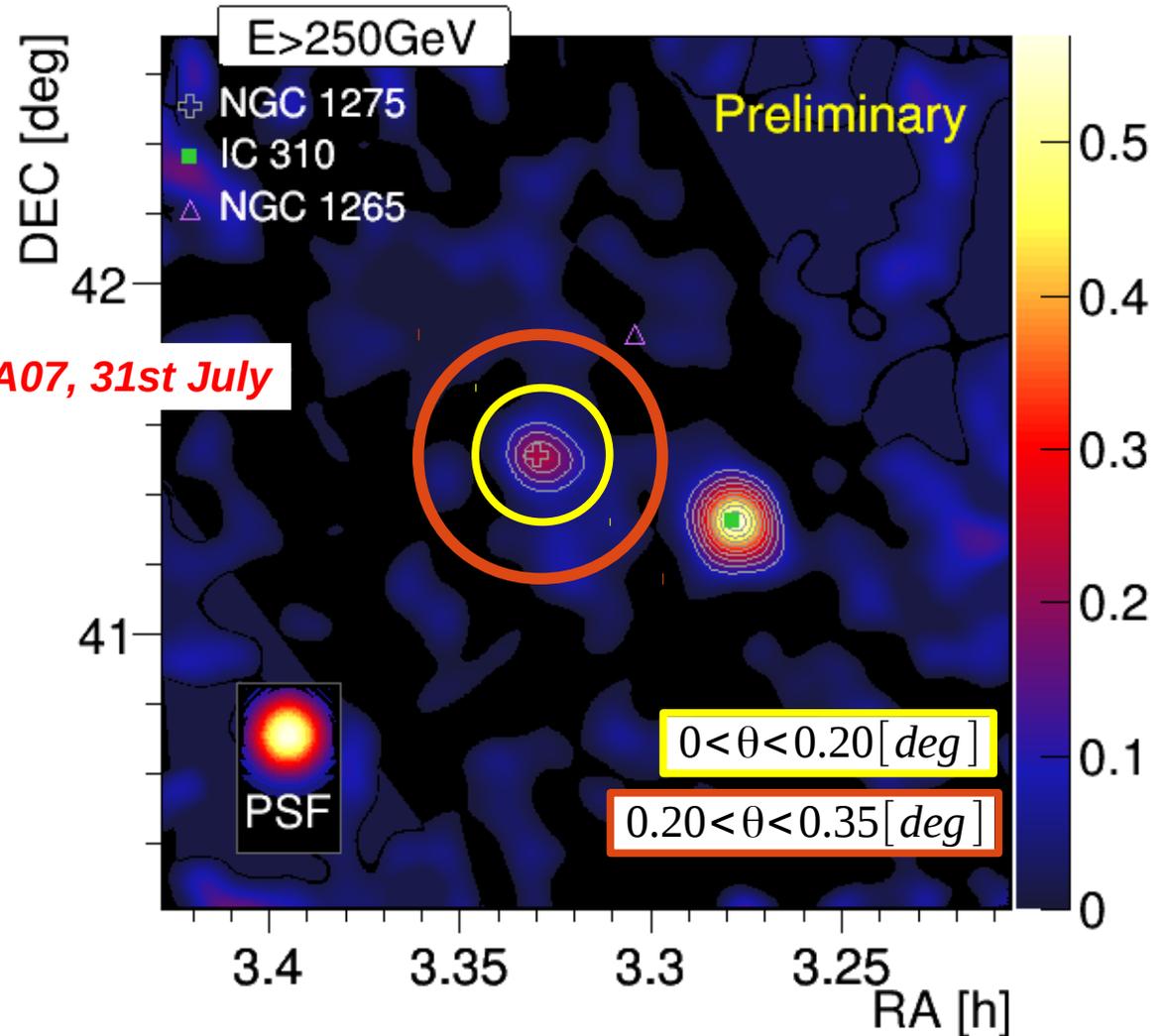
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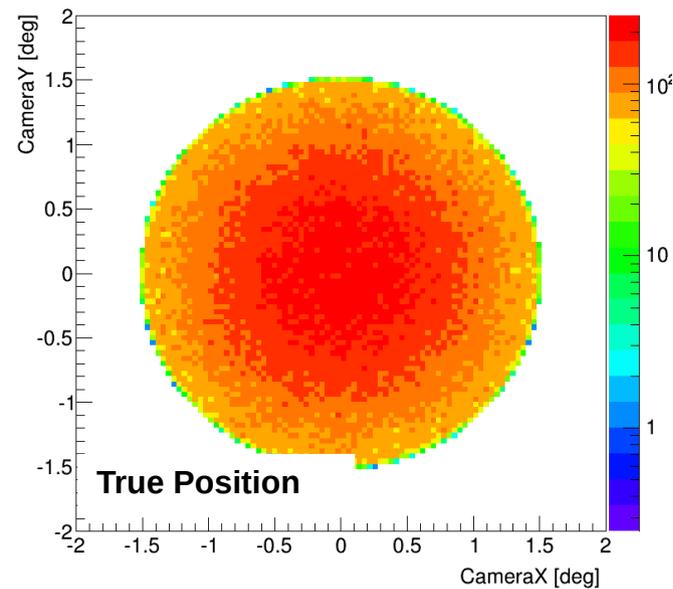
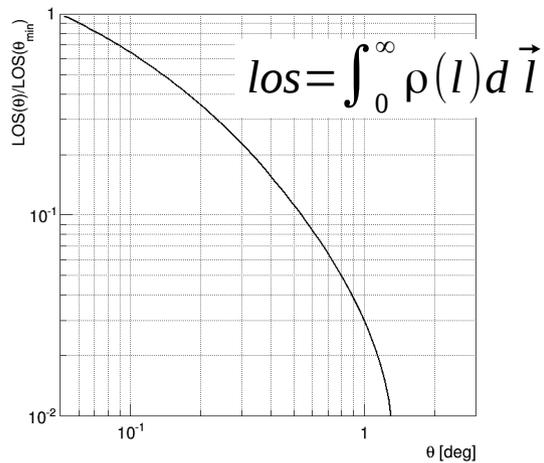
- Divide the signal region in **two bins** (concentric rings)
- **Isolate NGC1275 emission:**  
95% of its expected emission is in central ring



# Tailored Monte Carlo

Development of a dedicated gamma-ray MC for DM searches

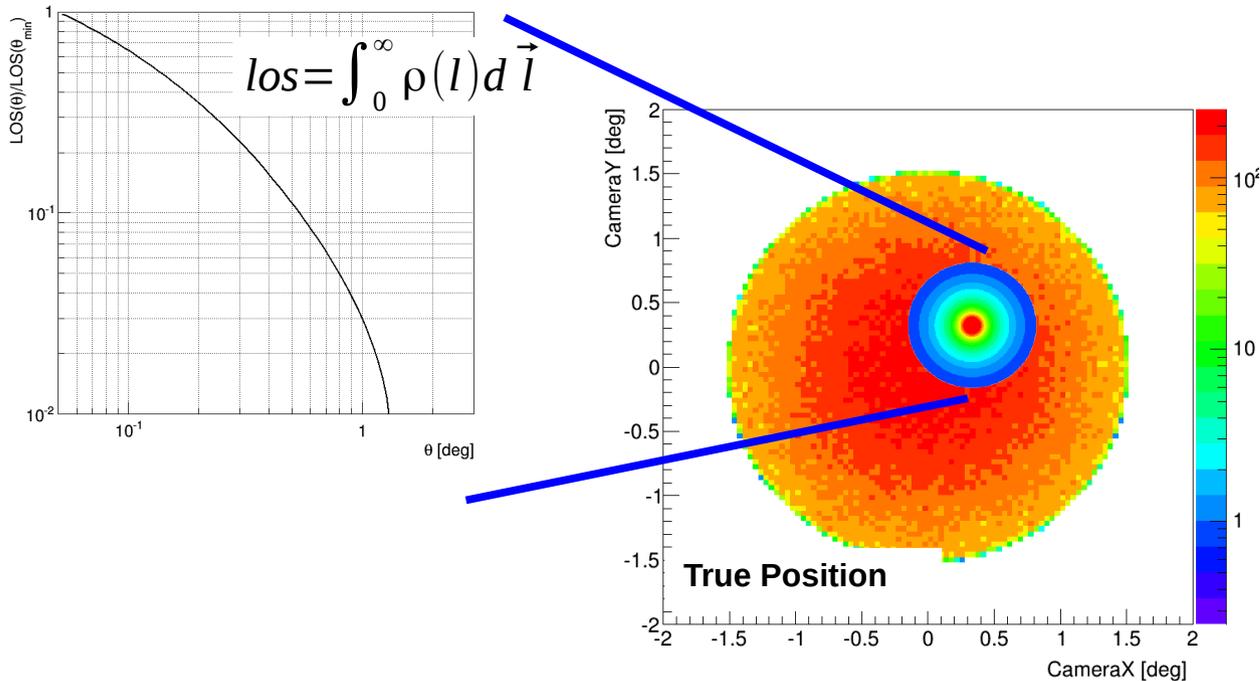
- **Input:** the DM distribution
- **Output:** correct Instrument Response Function (IRF)



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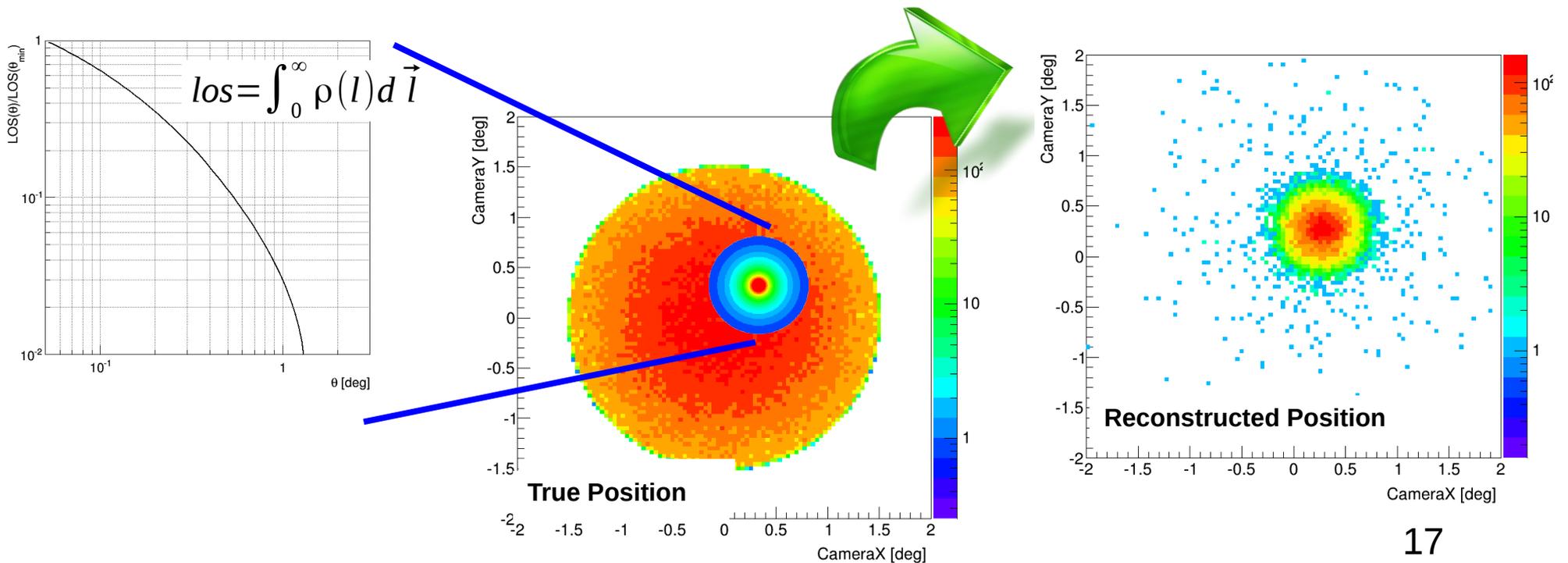


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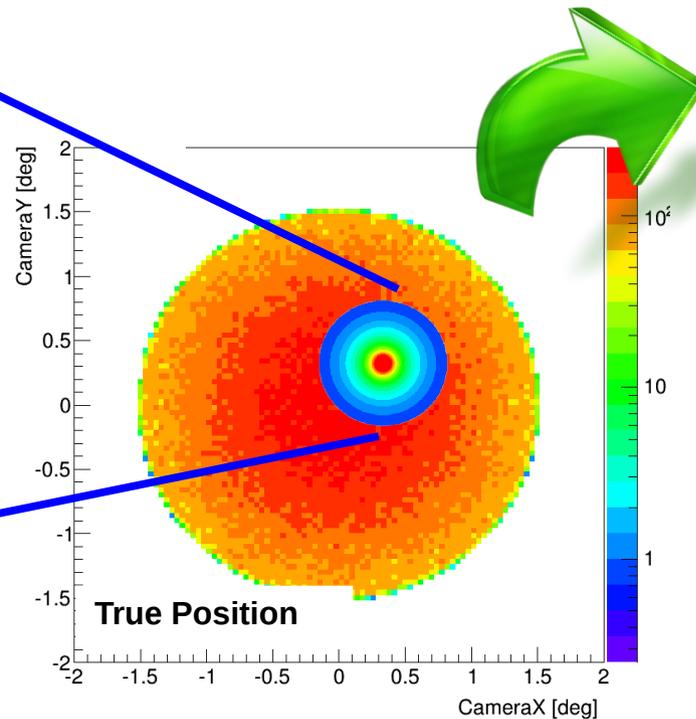
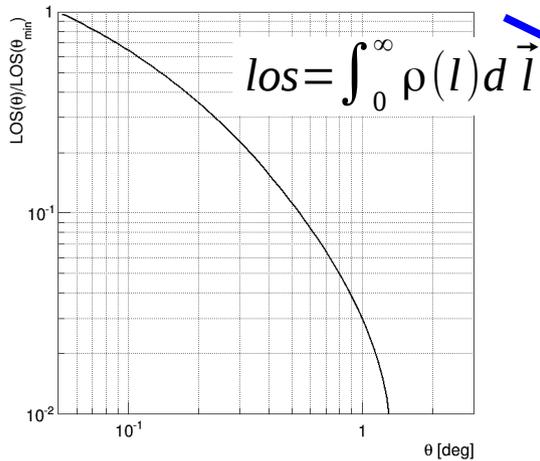
**Events in the new MonteCarlo follow the expected distribution coming from Dark Matter**



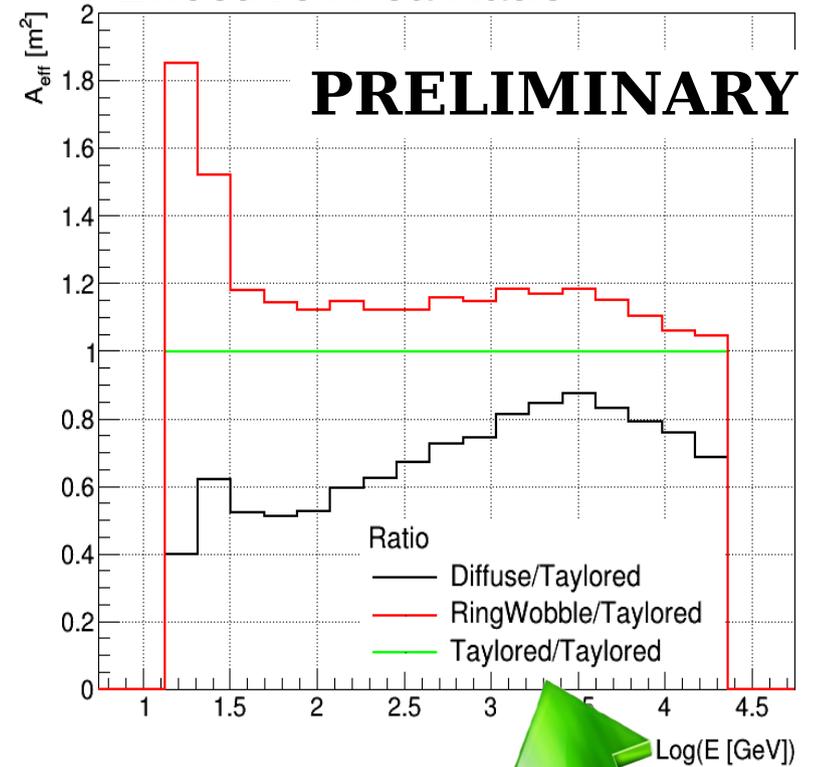
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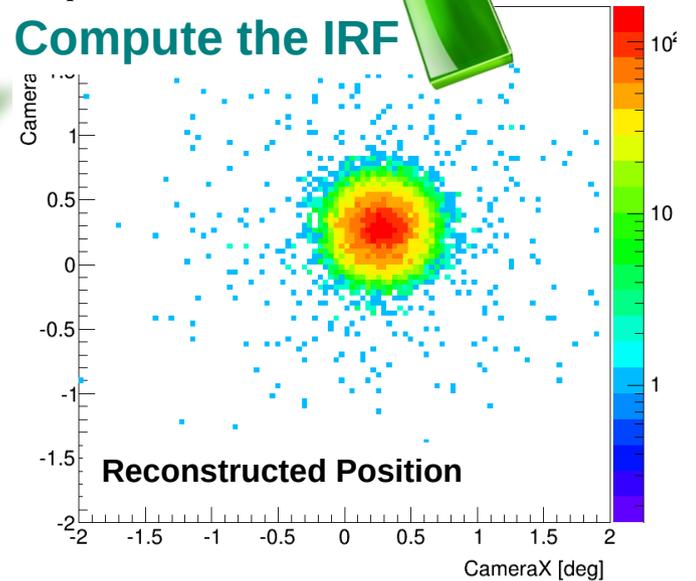
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## Effective Area Ratio



## Compute the IRF



# Results from 12h of Data used to test the methodology

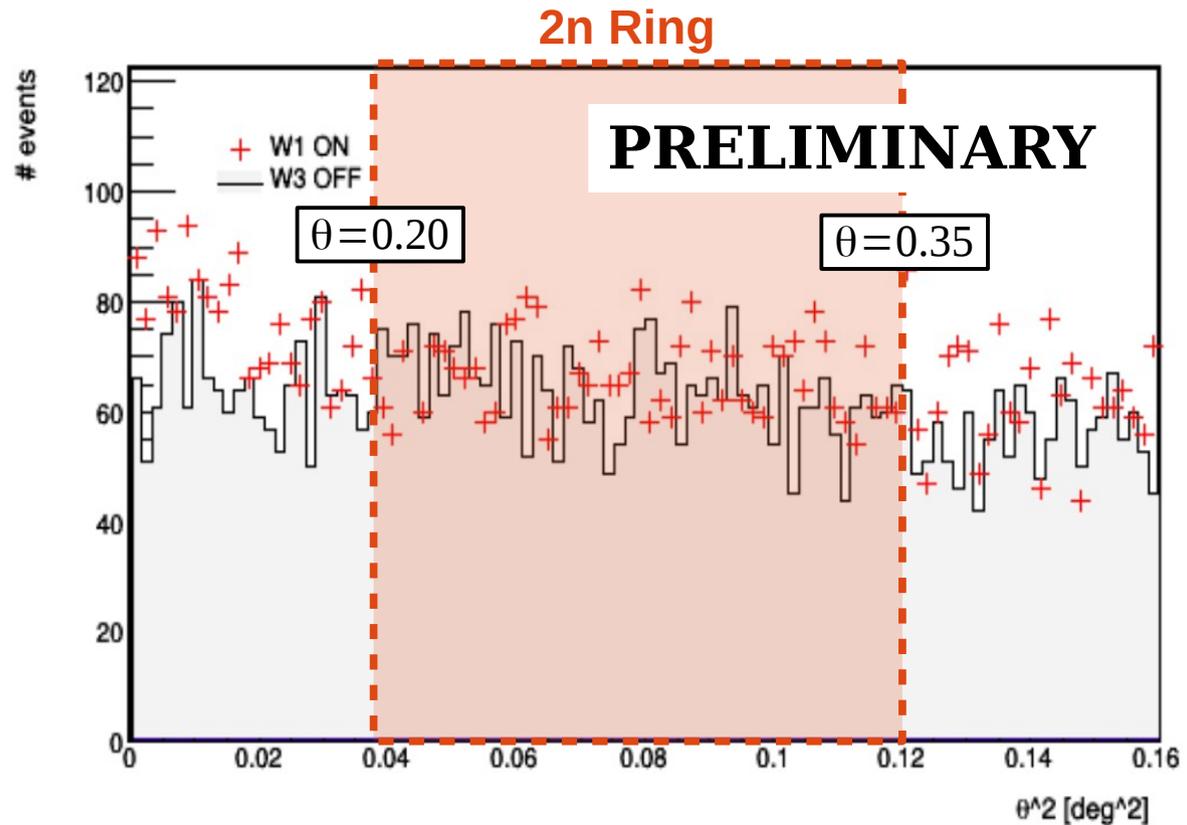
- Results on a small sample:  
develop and evaluate the analysis

- Period: 2013.07 – 2014.08
- Zenith range:  $5^\circ$  to  $50^\circ$
- 2<sup>nd</sup> Ring: **exclude NGC1275**

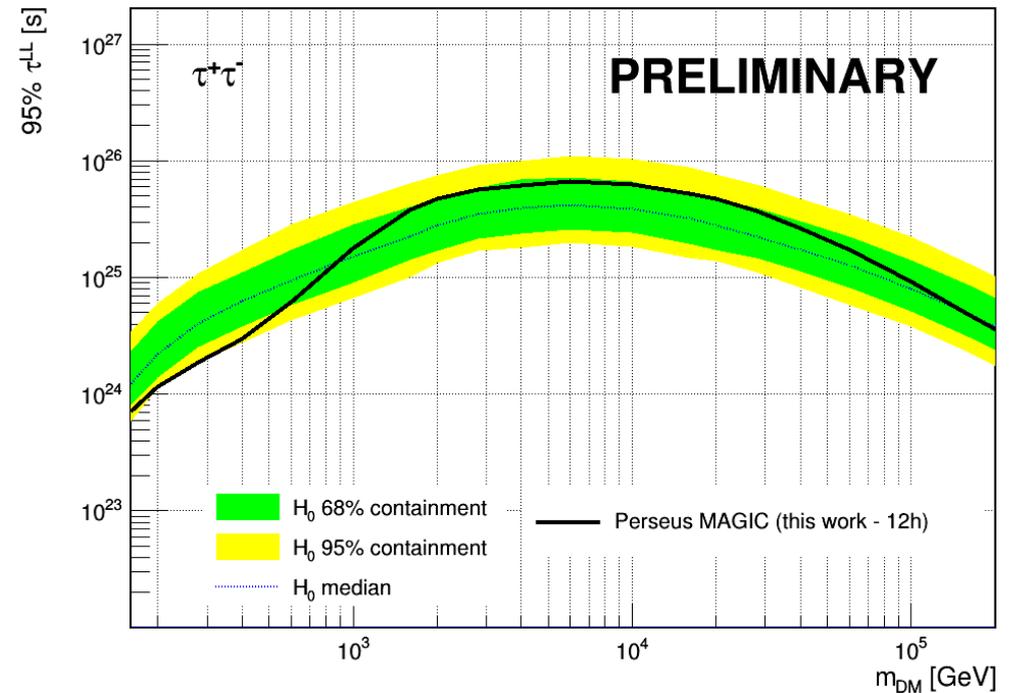
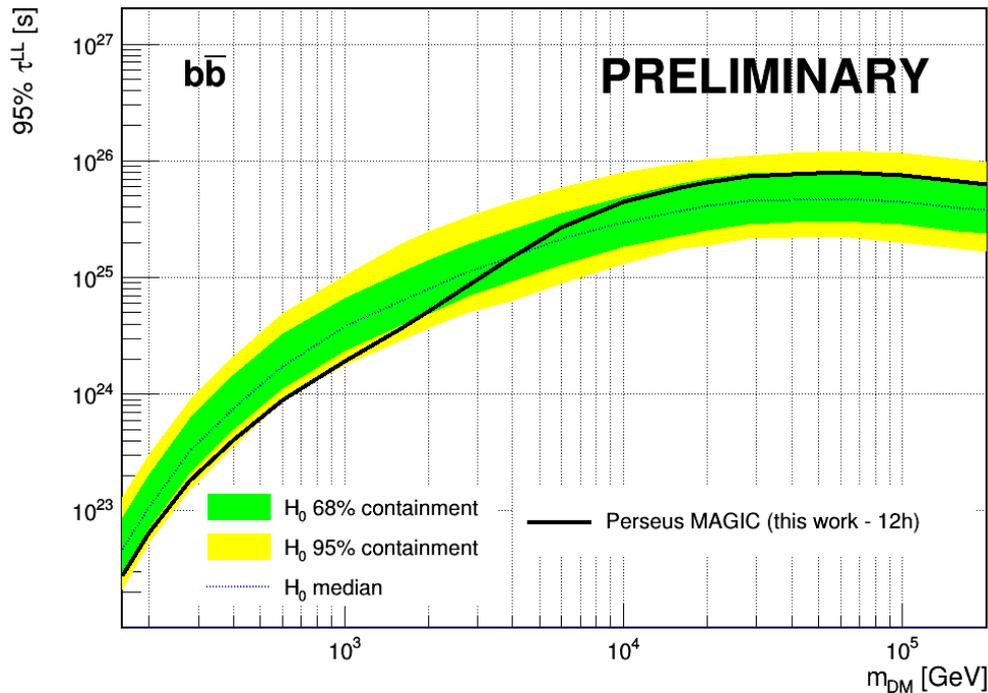
- We test 2 different dark matter scenarios:

$$\chi \rightarrow b \bar{b} \text{ (soft)}$$
$$\chi \rightarrow \tau^+ \tau^- \text{ (hard)}$$

- Computed the decay lifetime lower limit (one side 95% C.L.) for Dark Matter masses from 160 GeV to 200 TeV
- Simulated independent measurements following the same background distribution to generate  $1\sigma$  and  $2\sigma$  bands

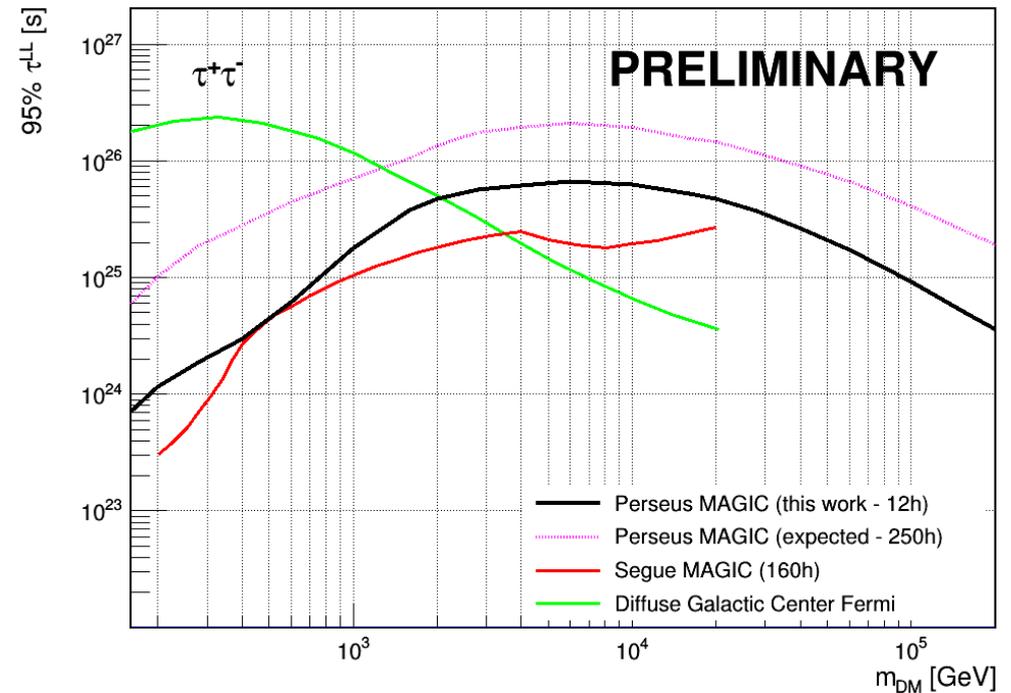
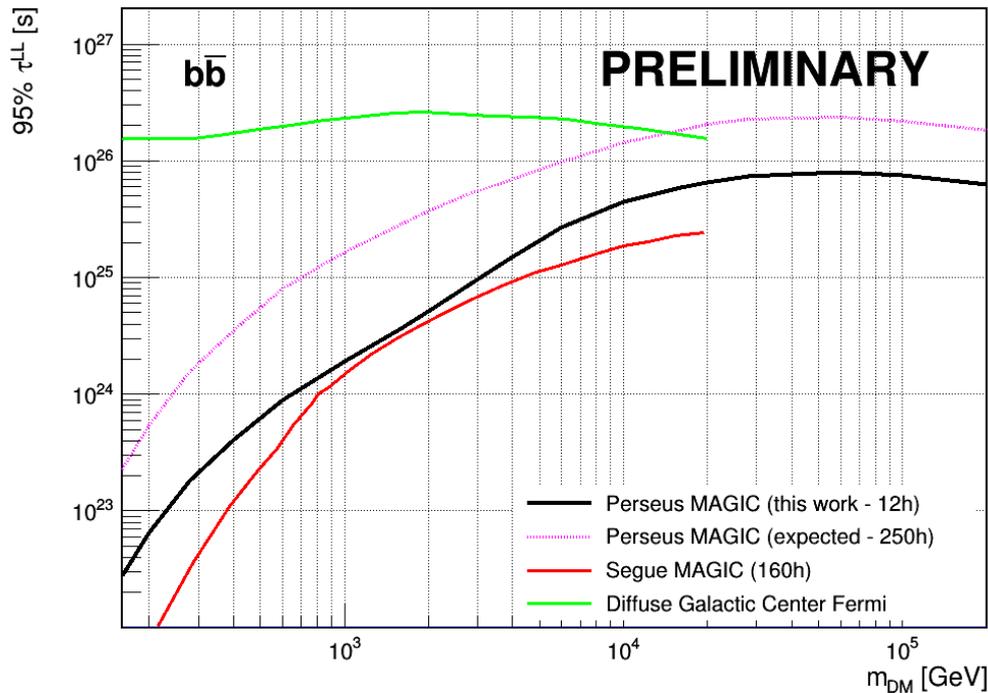


# Results from 12h of Data used to test the methodology



- We find **NO signal of dark matter** decay in our sample
- Reach sensitivities on decay life times of  **$8 \cdot 10^{25}$  seconds** for both channels

# Results from 12h of Data used to test the methodology



- Absolute best limits on decay lifetimes for  $\chi \rightarrow \tau \tau$  for Dark Matter masses **above 2 TeV**

*J. Aleksić et al., JCAP 02 (2014) 008*  
*Astrophys. J. 761 (2012) 91-108*

- *With the full data analysis, factor **~4 improvement in sensitivity** is expected*

# Conclusions

- **Deepest observational campaign** on the VHE range on clusters of galaxies (300 h)
- Clusters of galaxies are **excellent targets for decaying** Dark Matter Indirect searches
- **Tailored monte carlo** was developed and optimized for extended source dark matter searches
- With 12h we obtain the **best current limits on decay lifetimes for  $\chi \rightarrow \tau^+\tau^-$  for dark matter masses above 2 TeV**
- **Full 300h analysis we expect sensitivities of  $\sim 2 \cdot 10^{26}$  s**, obtaining the most constraining results on decay lifetimes of  $\chi \rightarrow \tau^+\tau^-$  for dark matter masses above 1TeV