Improved search for Dark Matter annihilation with a combined analysis of data from Fermi-LAT, HAWC, H.E.S.S., MAGIC, and VERITAS: a framework for future DM analyses

"Dark Matter searches in the 2020s" Symposium
The University of Tokyo, Kashiwa Campus
11-13 November 2019

Daniel Kerszberg (IFAE-BIST), Céline Armand, Eric Charles, Mattia di Mauro, Chiara Giuri, J. Patrick Harding, Tjark Miener, Emmanuel Moulin, Louise Oakes, Vincent Poireau, Elisa Pueschel, Javier Rico, Lucia Rinchiuso, Daniel Salazar-Gallegos, Kirsen Tollefson, Benjamin Zitzer for the Fermi-LAT, HAWC, H.E.S.S., MAGIC, and VERITAS collaborations

Dwarf galaxies as target for DM search with gamma-ray instruments

- **Ideal for indirect dark matter searches:**
  - Among the most Dark Matter dominated objects
  - Negligible expected astrophysical gamma-ray emission

- **Already existing large data sets**

- **How to improve current results?**
  - Accumulating more data
    - With current experiments
    - With next generation experiments
  - Combining data from existing experiments

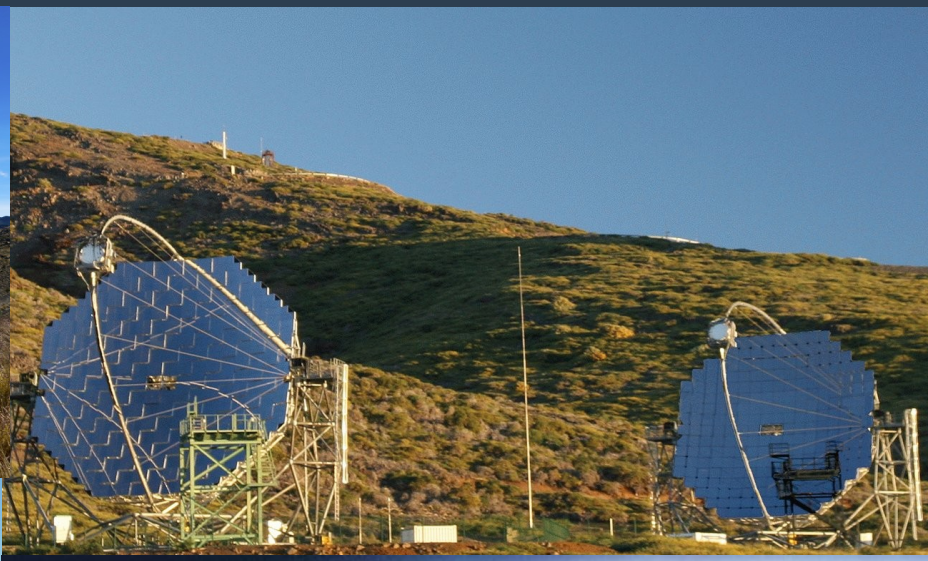
    → this technique allows to maximize the sensitivity to potential DM signal by increasing the statistics

The Glory Duck project

- **Initiative by 5 gamma-ray experiments to combine their observations of dwarf galaxies:**
  - Fermi-LAT
  - HAWC
  - H.E.S.S.
  - MAGIC
  - VERITAS

- **How to combine these data sets?**

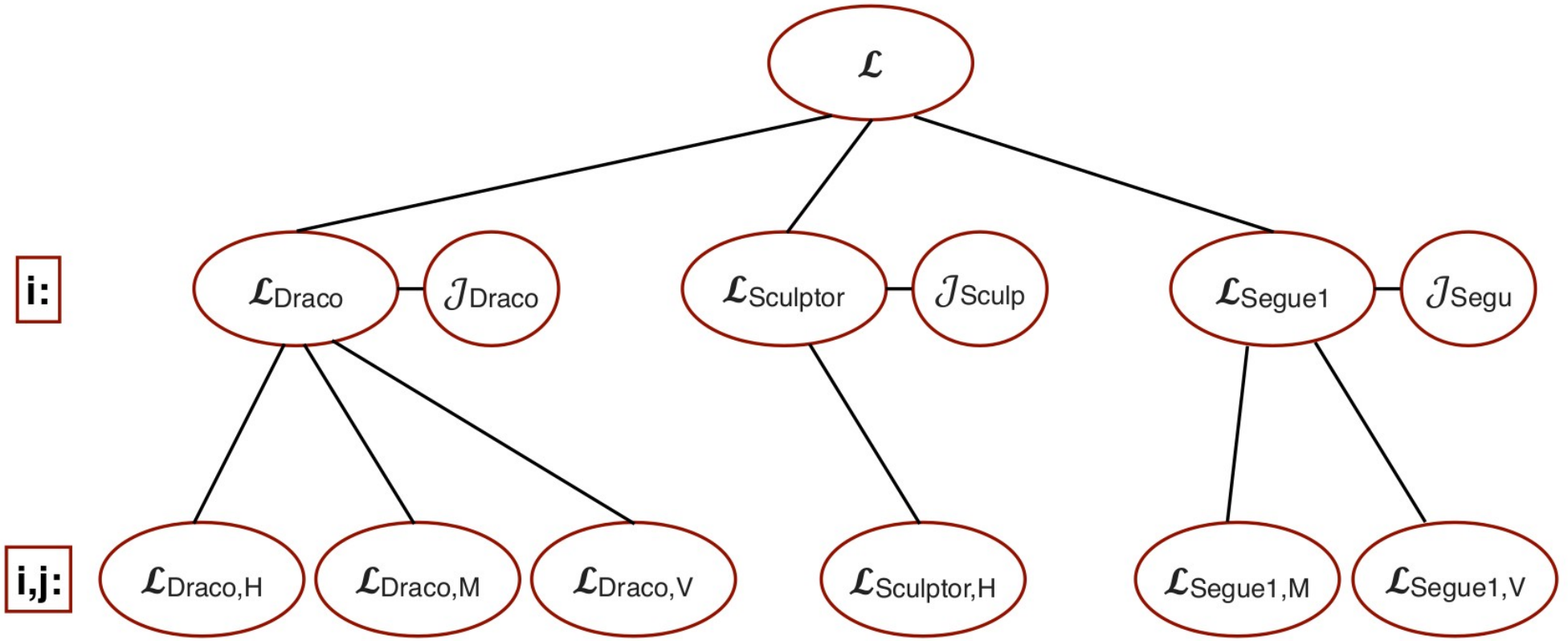
The Glory Duck project



Combining likelihoods

Total likelihood formula:

$$\mathcal{L}(\alpha;\boldsymbol{\nu}|\boldsymbol{\mathcal{D}}) = \prod_{l=1}^{N_{\mathrm{dSph}}} \mathcal{L}_\gamma(\alpha\bar{J}_l;\boldsymbol{\mu}_l|\boldsymbol{\mathcal{D}}_{\gamma_l}) \cdot \mathcal{L}_J(\bar{J}_l|\boldsymbol{\mathcal{D}}_{J_l})$$



Combining likelihoods

- **Strategy for the combination:**
  - Each experiment computes the likelihood for each dwarf that it observed!
  - These likelihoods follow this generic formula:

$$\mathscr{L}_{\gamma}(\langle\sigma v\rangle \bar{J}_l; \mu | D_{\gamma}) = \prod_{k=1}^{N_{meas}} \mathscr{L}_{\gamma,k}(\langle\sigma v\rangle \bar{J}_l; \mu_k | D_{\gamma,k})$$

  - They are computed for a fixed J-factor. J-factor uncertainties are taken into account when combining the different observations of a same dwarf!

- **These likelihoods are then shared for the combination**

  → a common approach to compute them is required

Recipe for a good combination

As many common ingredients as possible:

- Use the same values for J-factor and their statistical uncertainties

  (taken from A. Geringer-Sameth et al, Astrophys.J. 801, no.2, 74, 2015)

- Probe a common range of DM masses: 10 GeV to 100 TeV
- Use the same DM spectra

  (taken from M. Cirelli et al, JCAP 1103:051, 2011)

- Define a common treatment for all relevant statistical and systematical uncertainties, in particular for Cherenkov telescopes
- Use finest analysis technique:
  - Binned likelihood
  - Extension of the dwarf if relevant
  - Use $\langle \sigma v \rangle > 0$ prescription
  - J-factor statistical error taken into account as nuisance parameter in the likelihood

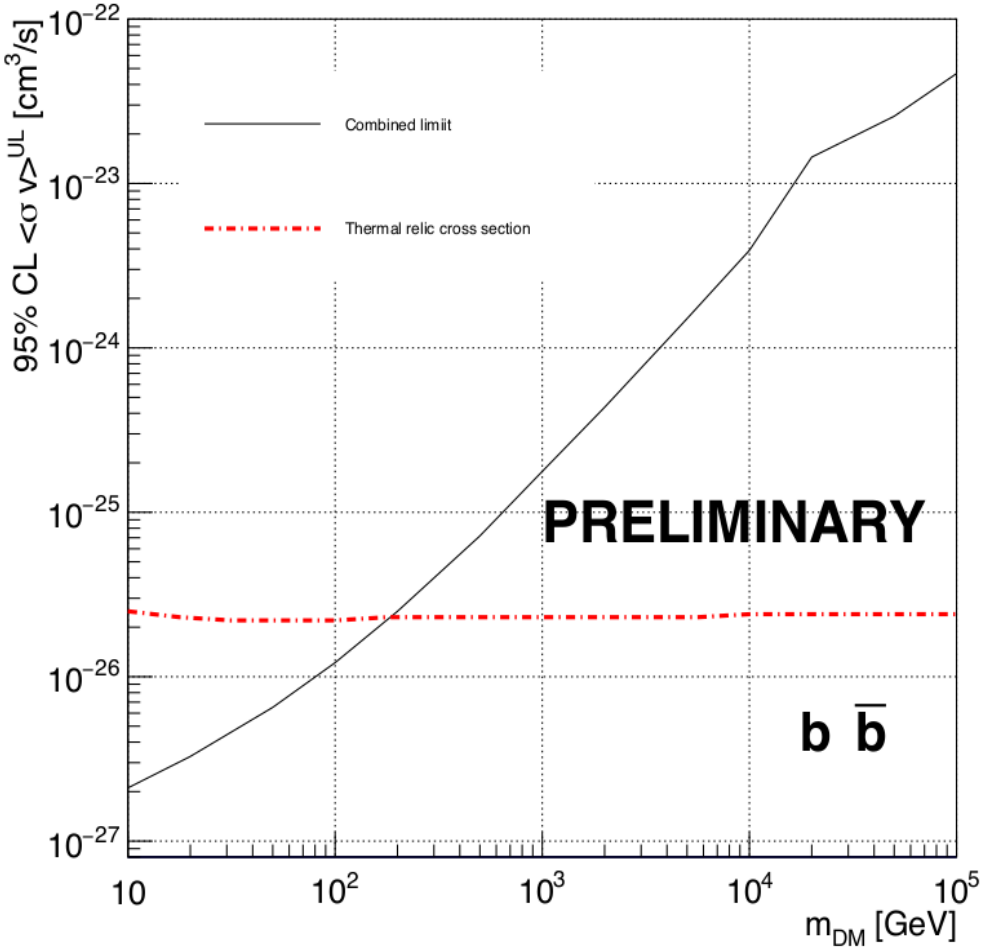
List of targets

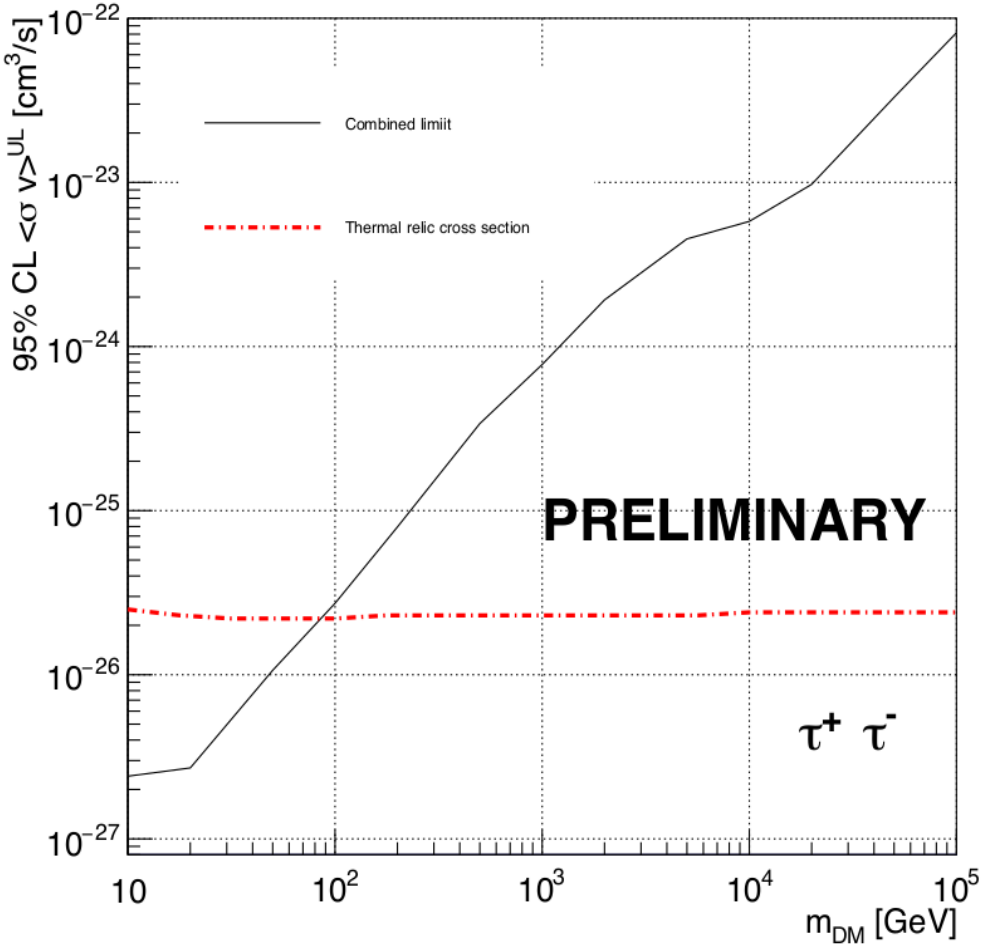
- **In this project we use a list of 20 dwarf galaxies for which individual collaborations already published results**

- **In total, 40 data sets are combined!**

Source name	Experiments
Boötes I	HAWC, VERITAS, *Fermi*-LAT
Canes Venatici I	*Fermi*-LAT
Canes Venatici II	*Fermi*-LAT, HAWC
Carina	HESS, *Fermi*-LAT
Coma Berenices	HAWC, HESS, *Fermi*-LAT
Draco	HAWC, *Fermi*-LAT
Fornax	H.E.S.S., *Fermi*-LAT
Hercules	HAWC, *Fermi*-LAT
Leo I	HAWC, *Fermi*-LAT
Leo II	HAWC, *Fermi*-LAT
Leo IV	HAWC, *Fermi*-LAT
Leo T	*Fermi*-LAT
Leo V	*Fermi*-LAT
Sculptor	H.E.S.S., *Fermi*-LAT
Segue I	MAGIC, VERITAS, HAWC, *Fermi*-LAT
Segue II	*Fermi*-LAT
Sextans	HAWC, *Fermi*-LAT
Ursa Major I	HAWC, *Fermi*-LAT
Ursa Major II	HAWC, MAGIC, *Fermi*-LAT
Ursa Minor	*Fermi*-LAT

Preliminary results





What to expect in 2020?

- **Preliminary combined results from Fermi-LAT, HAWC, H.E.S.S., MAGIC, and VERITAS ranging from 10 GeV to 100 TeV (already in 2019!)**

  → These preliminary results show that we can probe the thermal relic cross-section up to a few hundreds GeV

- **Publication under preparation will include more channels (such as $t\bar{t}$, ee, mumu, WW and ZZ) and potentially more targets**

  → will produce legacy results from the current generation of gamma-ray instruments for the search for annihilating DM towards dwarfs

What to expect in the 2020s?

- **This approach could be extended for other targets such as galaxy clusters**
- **It could also be applied to other scenarios such as decaying Dark Matter**
- **New dwarf galaxies will be discovered by new surveys?**
- **CTA will gradually supersede the current IACTs (H.E.S.S., MAGIC and VERITAS) and will improve the current results by at least a factor 10 in their energy range**

  → Combination of results from CTA, Fermi-LAT and HAWC?
- **Combination including other messengers such as neutrinos are possible**

  → include IceCube and KM3NeT experiments in the combination?

Conclusion

- **This analysis framework allow to perform multi-instruments and multi-targets analysis**

- **Preliminary combined results from 10 GeV to 100 TeV by Fermi-LAT, HAWC, H.E.S.S., MAGIC, and VERITAS allow to probe the thermal relic cross-section up to a few hundreds GeV**

- **This framework can be extended to:**
  - Other (and currently built!) instruments
  - Other observed targets
  - Other messengers such as neutrinos

Thank you for your attention!