Dark matter search at LHAASO

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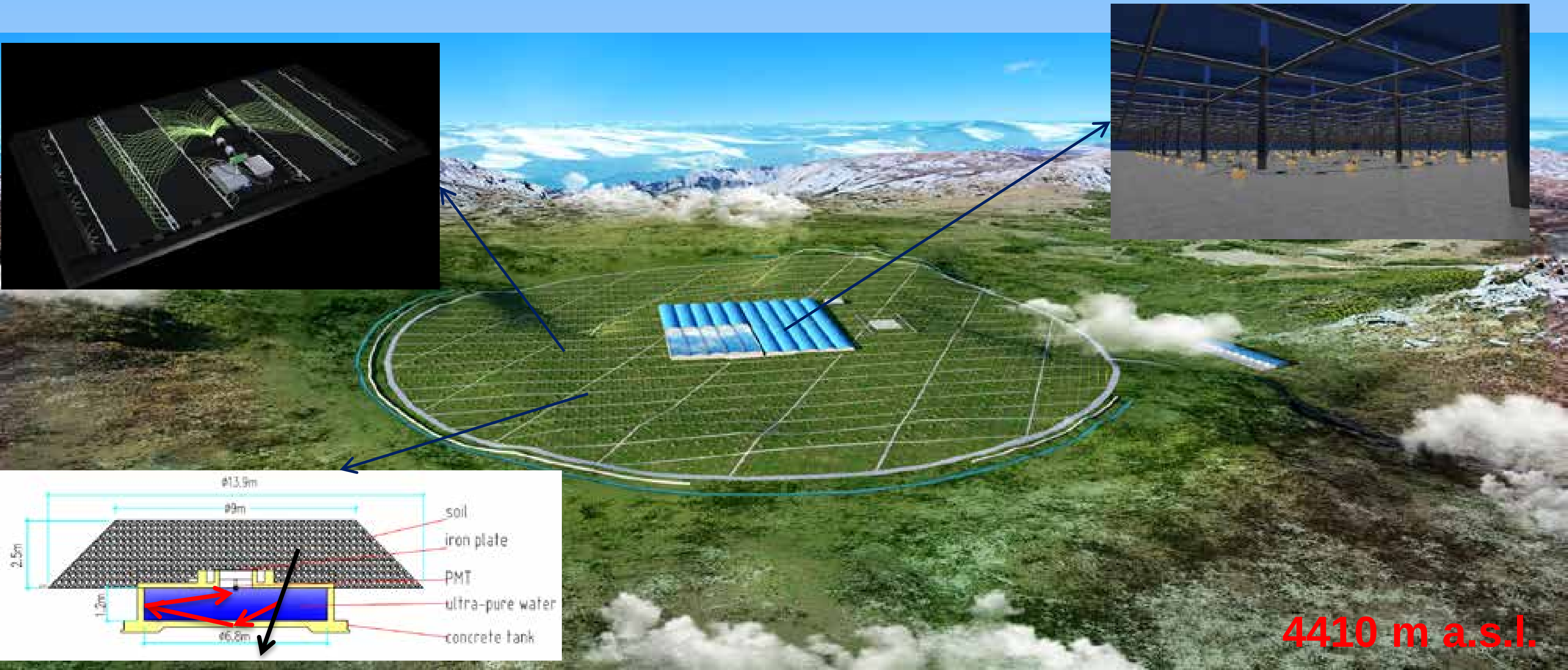
He, Bi, Lin, et al, arXiv: 1903.11910

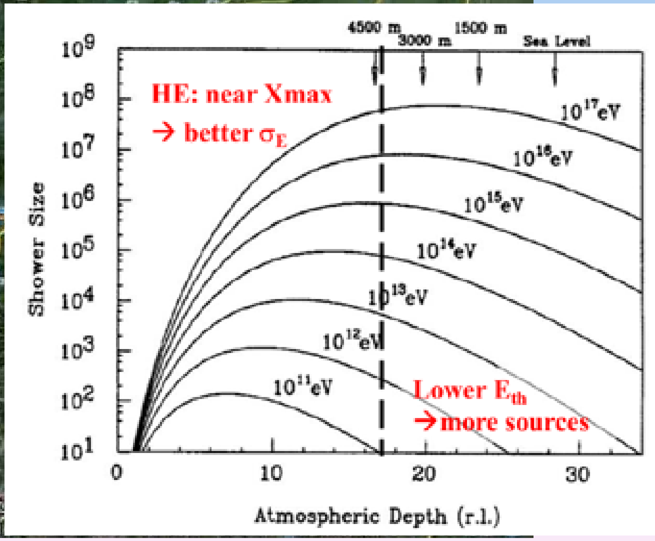
LHAASO

Large High Altitude Air Shower Observatory



Measurement of EASs at High Altitude

- **Mt. Haizi (4410 m a.s.l., 29º21’ 27.6” N, 100º08’19.6” E), Sichuan, China**
- **1/4 array will be completed soon; the project will be finished by 2021.**



sky survey, extended, transient

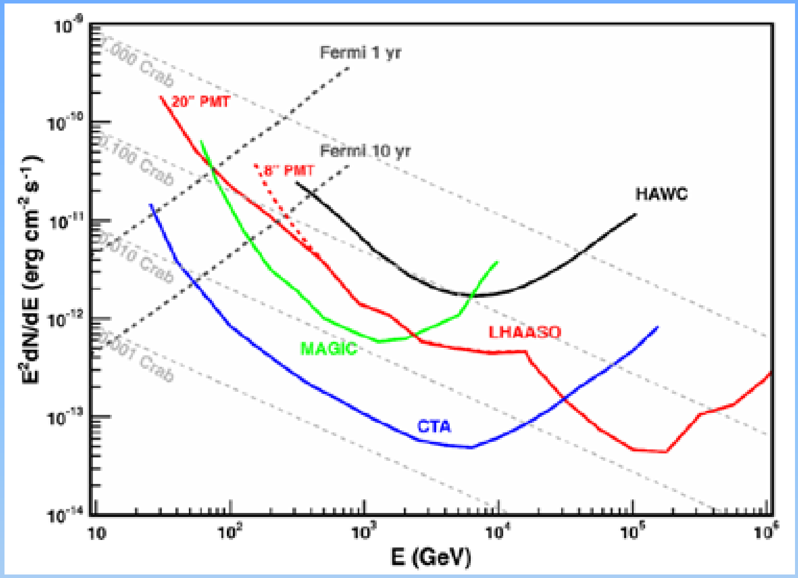
		ARGO	AS+MD	HAWC	LHAASO	CTA
Area		6,500 m^2	50,000 m^2	22,500 m^2	1 km^2	10 km^2
s_{θ} (deg)		0.2-0.5	0.2-0.5	0.1-0.5	0.1-0.5	0.05
BG rejection power			10^4	100	$100/10^4$	100
Duty Cycle		>90%	>90%	>90%	>90%	10%
FOV (sr)		2	2	2	2	0.015
Sensitivity (c.u.)	@TeV	0.55		0.06	0.01	0.001
	@100TeV		0.25		0.01	0.3
Energy resolution		30%	30%	>50%	30%	15%

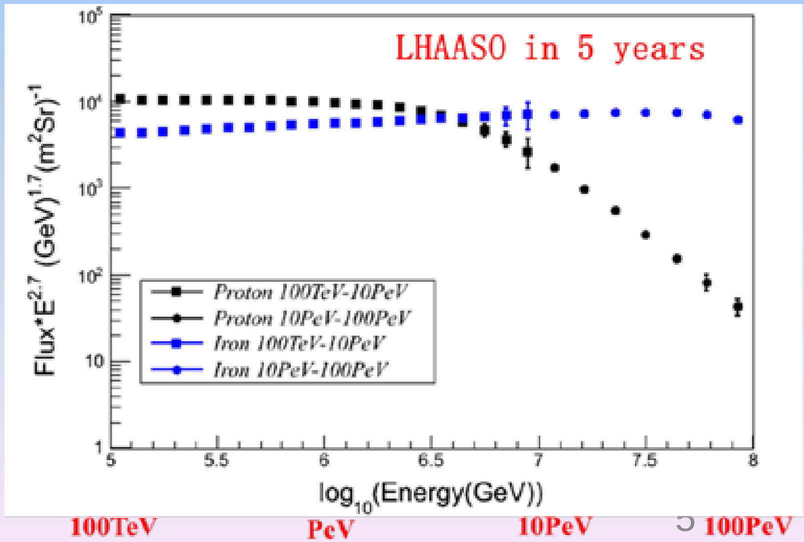
SED, morphology

LHAASO：*Large High Altitude Air Shower Observatory*

Major Scientific Goals

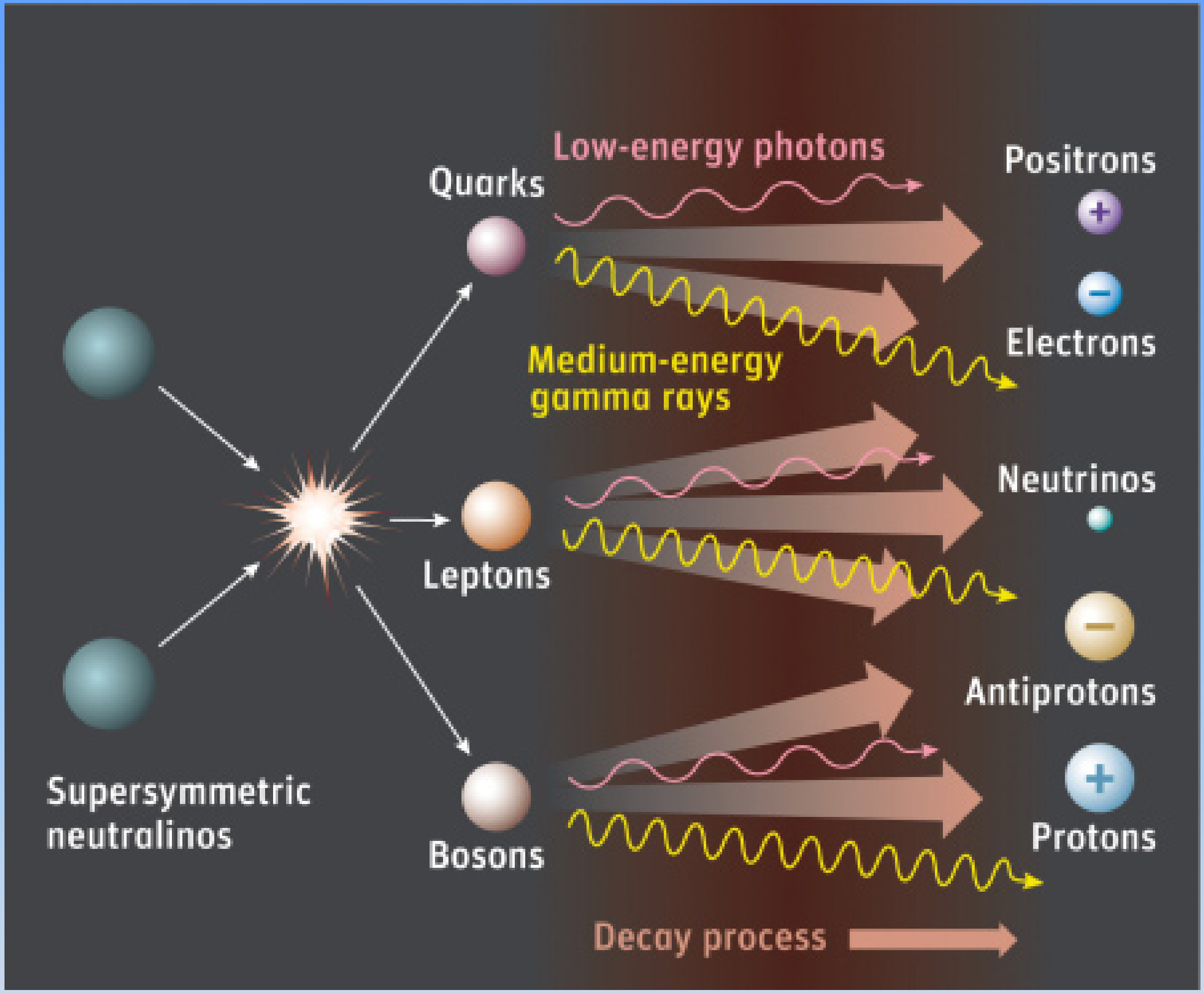
- **Origin of GCRs**
  - **Searching for GCR sources by measuring SED with an unprecedented sensitivity of 1% I_{Crab} at 50 TeV**
  - **Energy spectra for individual compositions with energy from 10 TeV to 1 EeV, where the spectrum knees are located**
- **Gamma ray astronomy**
  - **Searching for TeV γ sources, especially extended and transient ones, with an unprecedented survey sensitivity of 1% I_{Crab} at 3TeV.**
- **New physics frontier**
  - **dark matter, Lorentz invariance, new physics beyond LHC energy, etc**





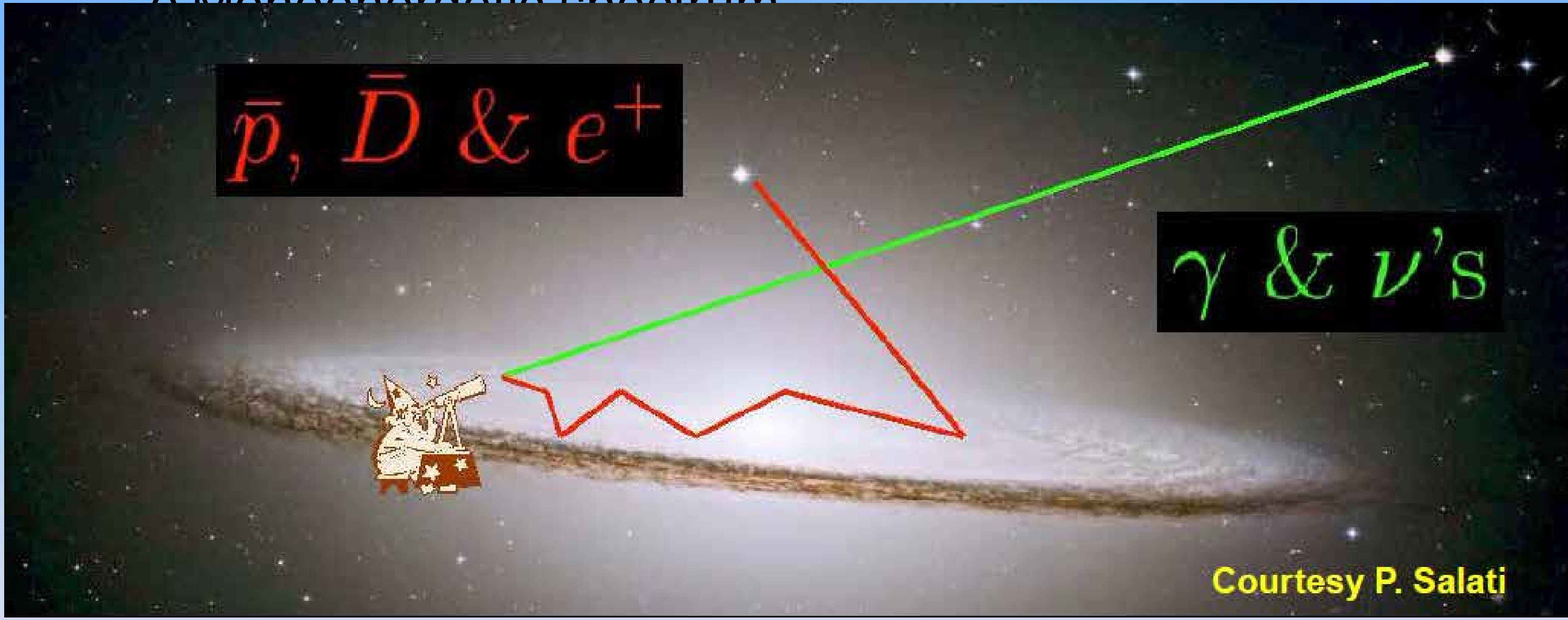
Details about LHAASO see,
Huihai He, GAI1a: Status and First Results of the LHAASO Experiment

Dark matter indirect detection looks for the DM annihilation products



$$c^0 c^0 \circledR \; l\bar{l}, q\bar{q}, 2W^{\pm}, 2Z^0, 2H^0, Z^0H^0, W^+H^-, gg$$

Indirect detection of dark matter -- signals



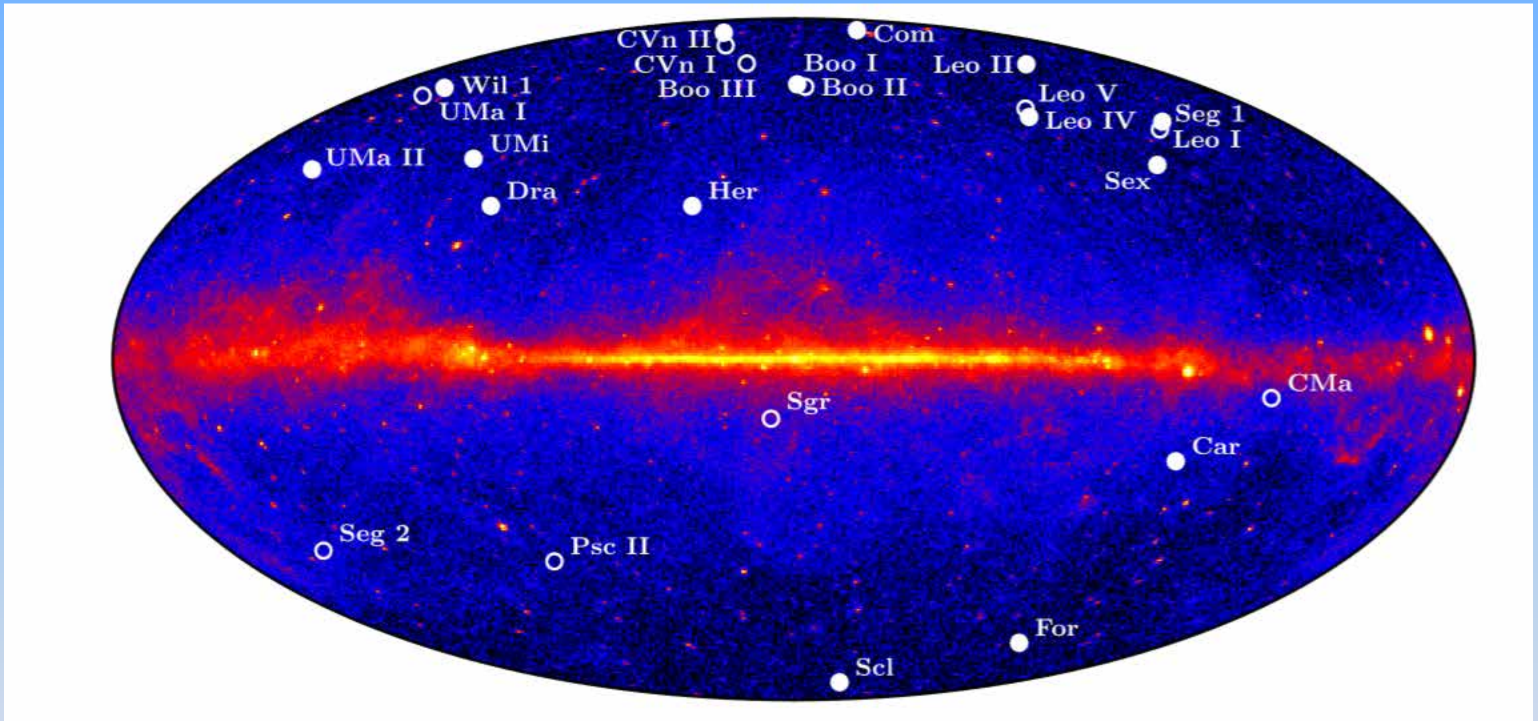
definitive signal

LHAASO does not have charge discrimination, it is better to search gamma ray signals from dark matter!

Different targets

- Galactic center(high signal, high background)
- Dwarf galaxies (DM dominates, no astrophysical background)
- Subhalos (blind search, difficult to identify)
- Halo – diffuse gamma (low signal, low background)
- Extragalactic (large uncertainty in signal and background)

Known satellites on the sky



All the dwarf galaxies are possible gamma ray sources by DM annihilation.

Dwarf galaxies in the FOV of LHAASO

TABLE I. The astrophysical properties of nineteen selected dSphs within the LHAASO FOV. The name, right ascension (RA.), declination (DEC.), maximum angular radius ($\theta_{\max}$), and J-factor of the dSphs are listed below. The J-factor and $\theta_{\max}$ of the dSphs are taken from Ref. [34]. However, for the four dSphs marked with asterisks whose J-factors are not given in Ref. [34], we utilize the calculated results from Ref. [35].

Source	RA. (deg)	DEC. (deg)	$\theta_{\max}$ (deg)	$\log_{10} J_{\rm obs}$ ($\rm GeV^2 cm^{-5}$)
Boötes I	210.02	14.50	0.47	18.2 ± 0.4
Canes Venatici I	202.02	33.56	0.53	17.4 ± 0.3
Canes Venatici II	194.29	34.32	0.13	17.6 ± 0.4
Coma Berenices	186.74	23.90	0.31	19.0 ± 0.4
Draco	260.05	57.92	1.30	18.8 ± 0.1
Draco II*	238.20	64.56	–	18.1 ± 2.8
Hercules	247.76	12.79	0.28	16.9 ± 0.7
Leo I	152.12	12.30	0.45	17.8 ± 0.2
Leo II	168.37	22.15	0.23	18.0 ± 0.2
Leo IV	173.23	−0.54	0.16	16.3 ± 1.4
Leo V	172.79	2.22	0.07	16.4 ± 0.9
Pisces II*	344.63	5.95	–	16.9 ± 1.6
Segue 1	151.77	16.08	0.35	19.4 ± 0.3
Sextans	153.26	−1.61	1.70	17.5 ± 0.2
Triangulum II*	33.32	36.18	–	20.9 ± 1.3
Ursa Major I	158.71	51.92	0.43	17.9 ± 0.5
Ursa Major II	132.87	63.13	0.53	19.4 ± 0.4
Ursa Minor	227.28	67.23	1.37	18.9 ± 0.2
Willman 1*	162.34	51.05	–	19.5 ± 0.9

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Signals and background

- DM signals

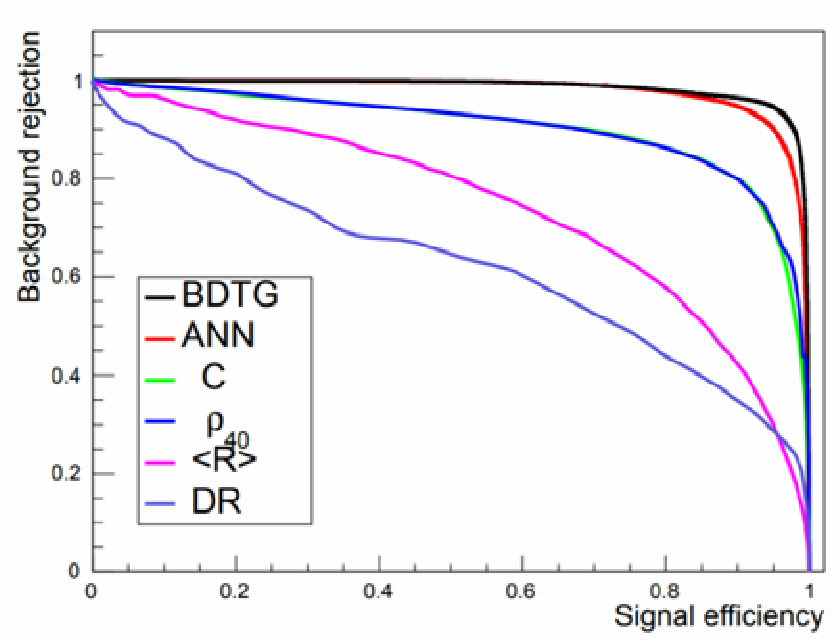
$$\phi_s(\Delta\Omega) = \underbrace{\frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{\mathrm{DM}}^2}\int_{E_{\min}}^{E_{\max}}\frac{\mathrm{d}N_\gamma}{\mathrm{d}E_\gamma}\mathrm{d}E_\gamma}_{\Phi_{\mathrm{PP}}} \cdot \underbrace{\int_{\Delta\Omega}\left\{\int_{\mathrm{l.o.s}}\rho^2(r)\mathrm{d}l\right\}\mathrm{d}\Omega'}_{\mathrm{J-factor}} \cdot$$

$$S = \epsilon_{\Delta\Omega}\int_{E_{\min}}^{E_{\max}}\Phi_\gamma(E)\cdot A_{\mathrm{eff}}^\gamma(E)\cdot\varepsilon_\gamma(E)dE\times T$$

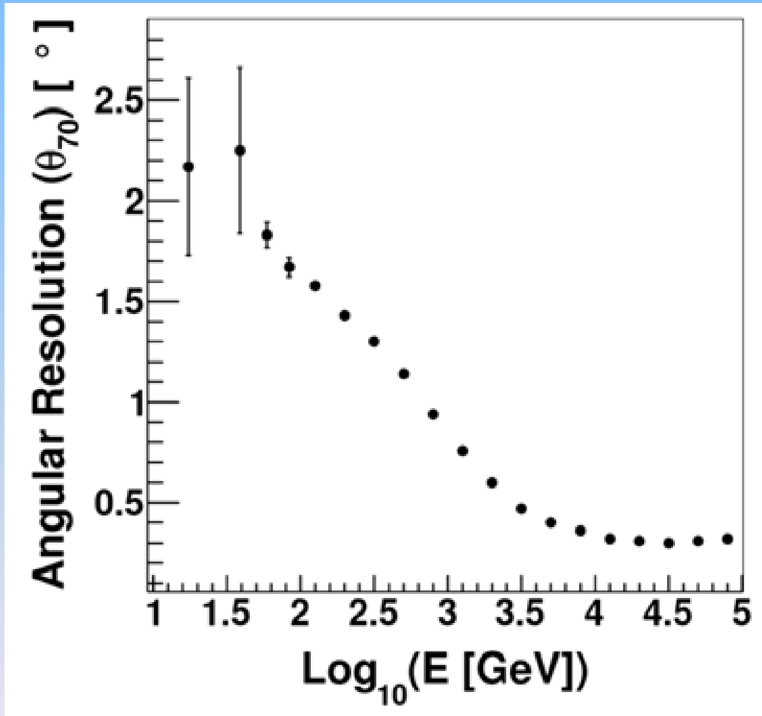
$$B = \int_{E_{\min}}^{E_{\max}}\int_{\Delta\Omega}\zeta_{cr}\cdot\Phi_p(E)\cdot A_{\mathrm{eff}}^p(E)\cdot\varepsilon_p(E)d\Omega dE\times T$$

Performance of LHAASO

- γ/p separation and angular resolution



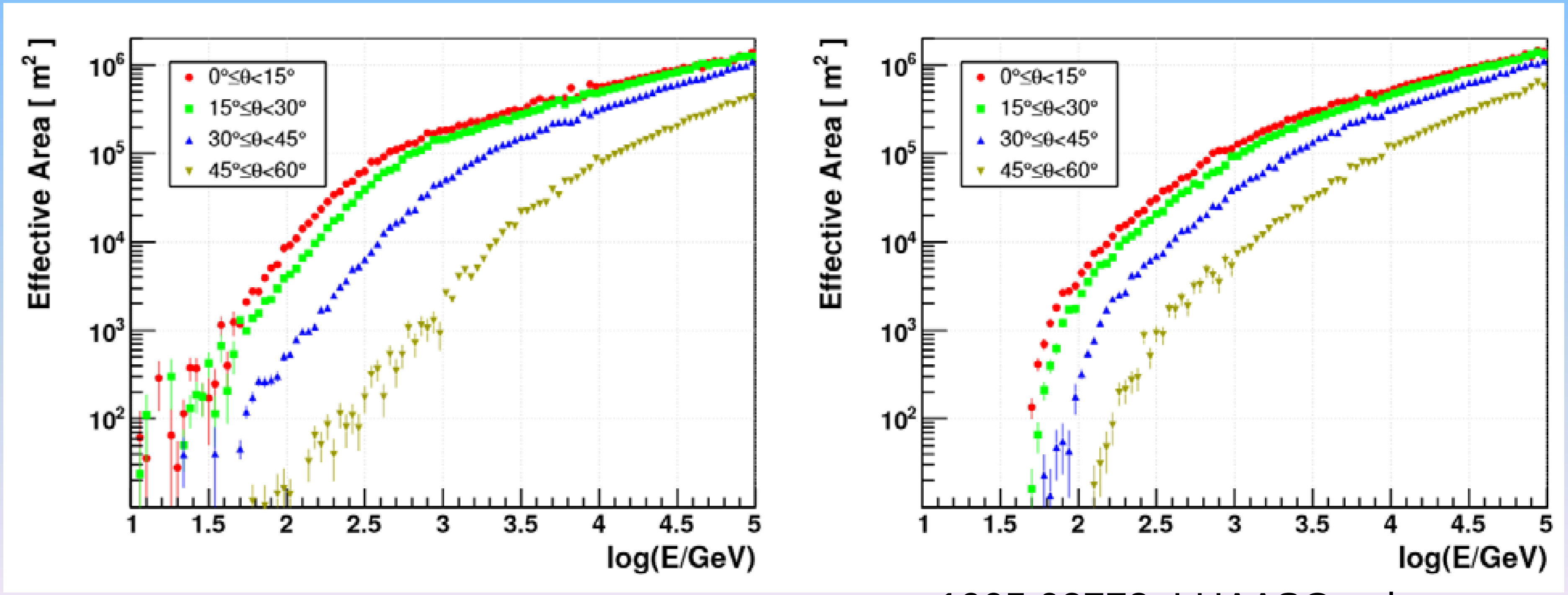
Above ~500GeV, we adopt εp=0.28% (99.72% rejected) for εγ ~40%



1905.02773, LHAASO science white book

Performance of LHAASO

- Effective areas for different zenith angles for the gamma ray and protons



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Method to set bound

- Define likelihood of a signal as

$$\mathcal{L}(\mathbf{S}|\mathbf{B},\mathbf{N}) = \prod_i \frac{(B_i + S_i)^{N_i}\exp[-(B_i + S_i)]}{N_i!}$$

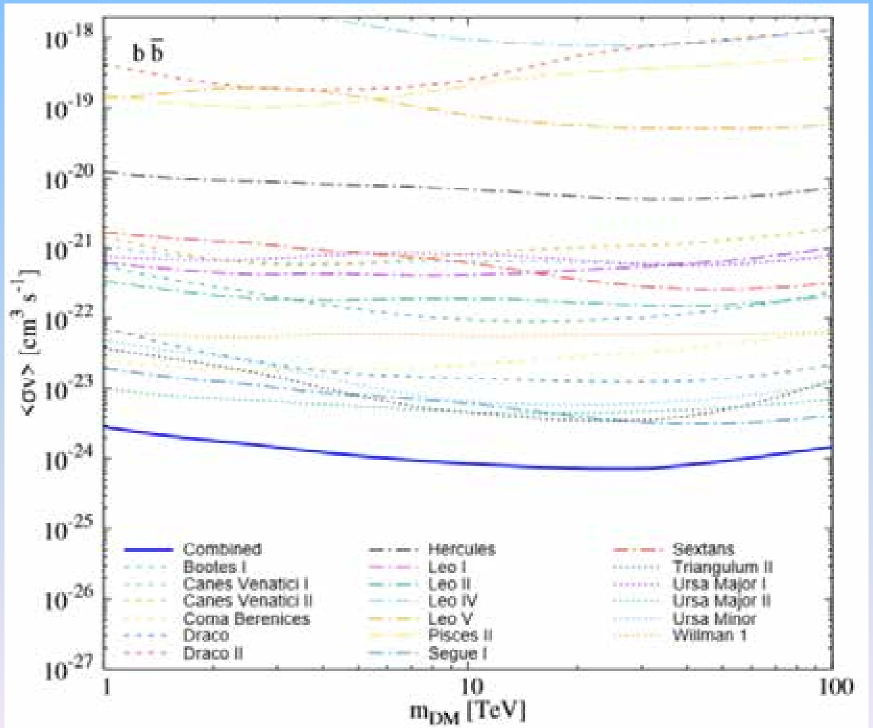
- *Bi* is expected background events, *Si* is the expected signal events, *Ni* is the observed events
- uncertainty of dark matter density profile of dwarf galaxies are taken into account

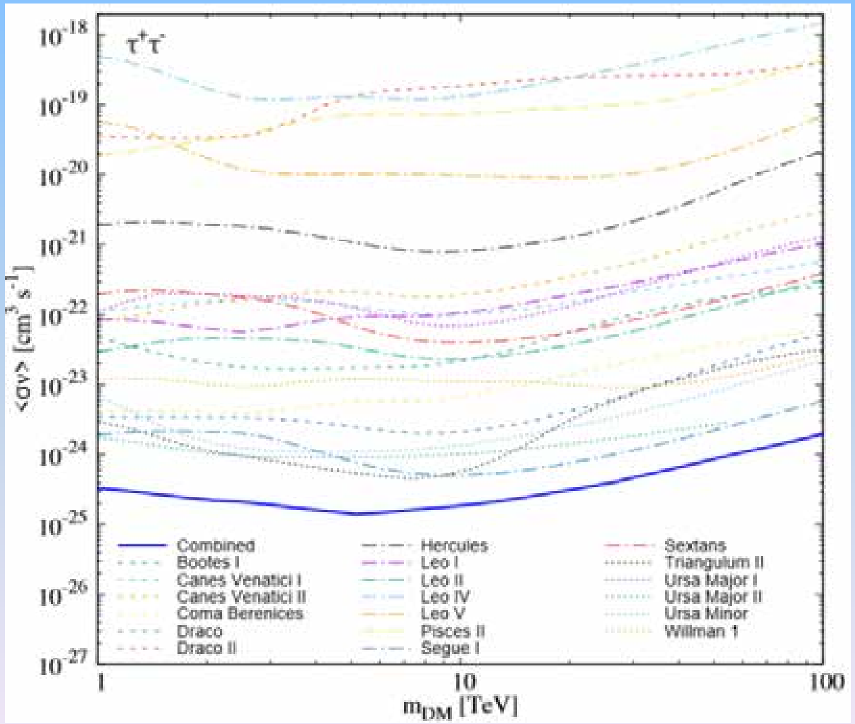
$$\mathcal{L}_j = \prod_i \mathcal{L}_{ij}(S_{ij}|B_{ij}, N_{ij}) \times \mathcal{J}(J_j|J_{\mathrm{obs},j}, \sigma_j)$$

- Combine 19 dwarfs, $\mathcal{L}^{\mathrm{tot}} = \prod_j \mathcal{L}_j$ $\quad 2\left(\ln\mathcal{L}_{\max} - \ln\mathcal{L}_{95}\right) = 2.71$

Sensitivity of dark matter signal

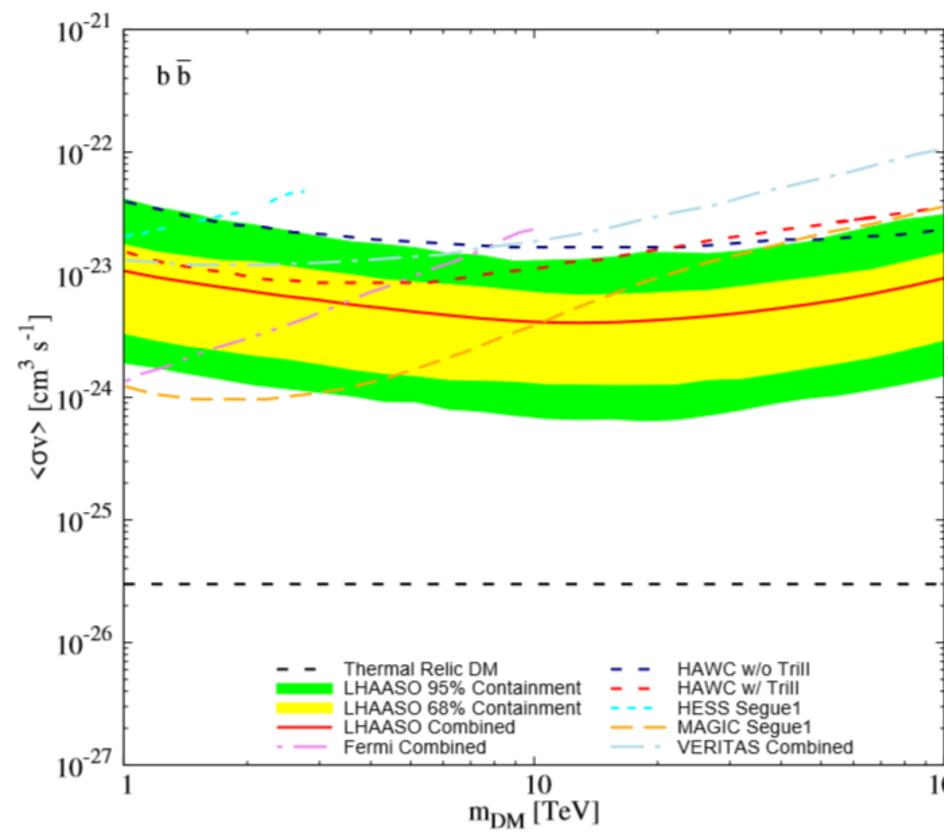
- We consider bb, tt, ww, μμ, tautau final states

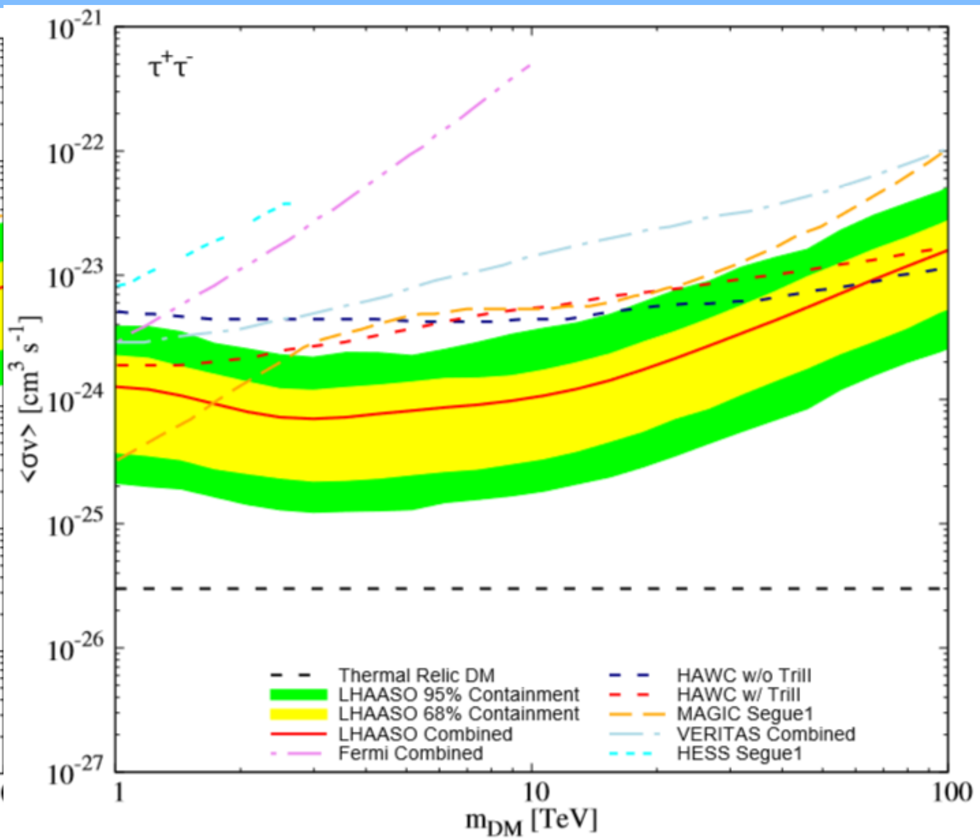




Sensitivity of dark matter

- Compare with other exps, LHAASO is more sensitivy for DM mass above ~TeV





Summary

- Dark matter search is one most important scientific goal of LHAASO. We give sensitivity calculation of LHAASO based on simulation results.
- Gamma rays from dwarf galaxies are the most promised signal which may be detected at LHAASO. LHAASO has large F.O.V and can probe many dwarf galaxies at the same time.
- LHAASO is more sensitive than other detectors if DM mass is above 1~5TeV depending on final states.