Investigating ultraheavy dark matter and axionlike-particles with LHAASO

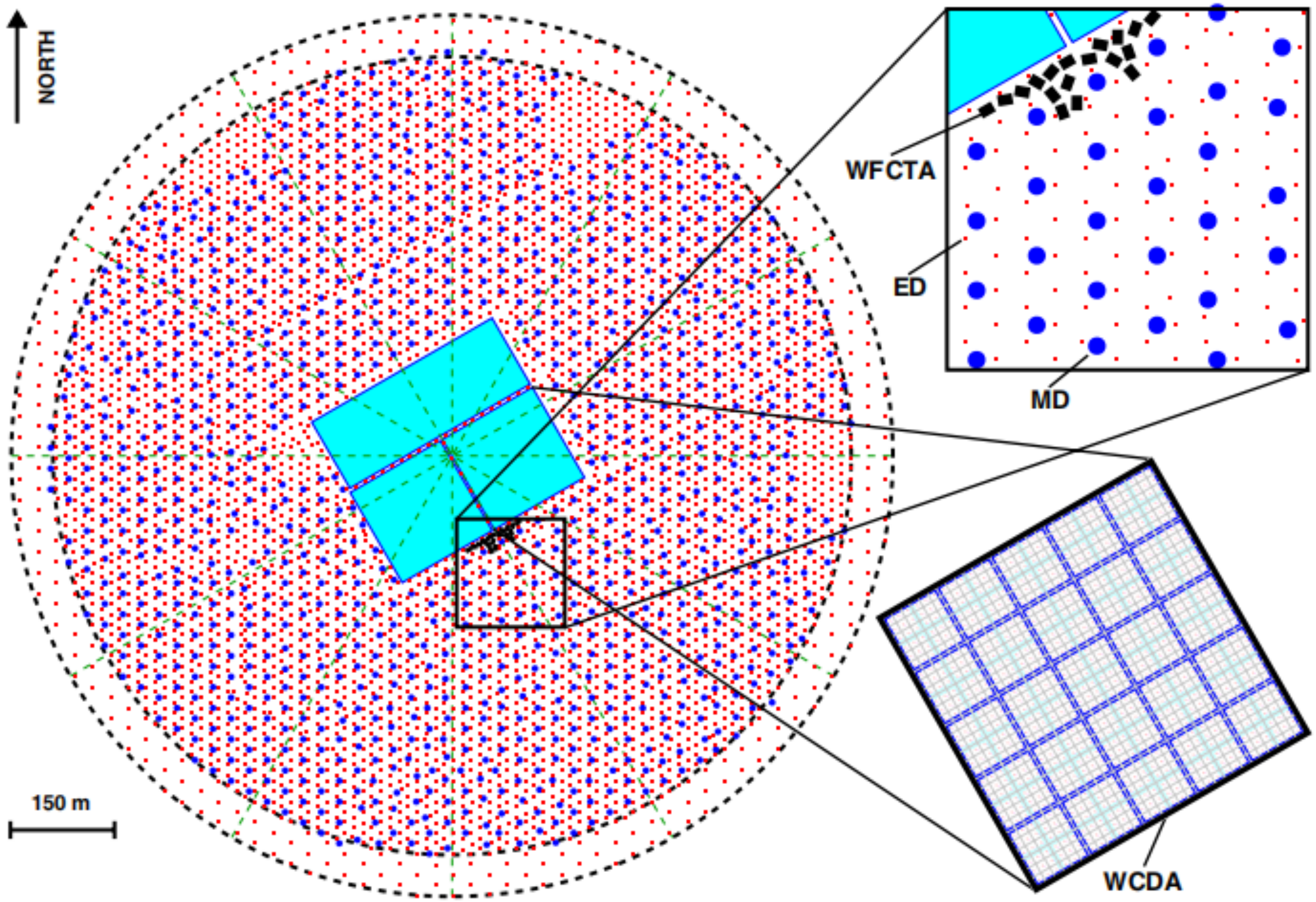
Xiaoyuan Huang

Purple Mountain Observatory

29 Dec 2023 to 1 Jan 2024

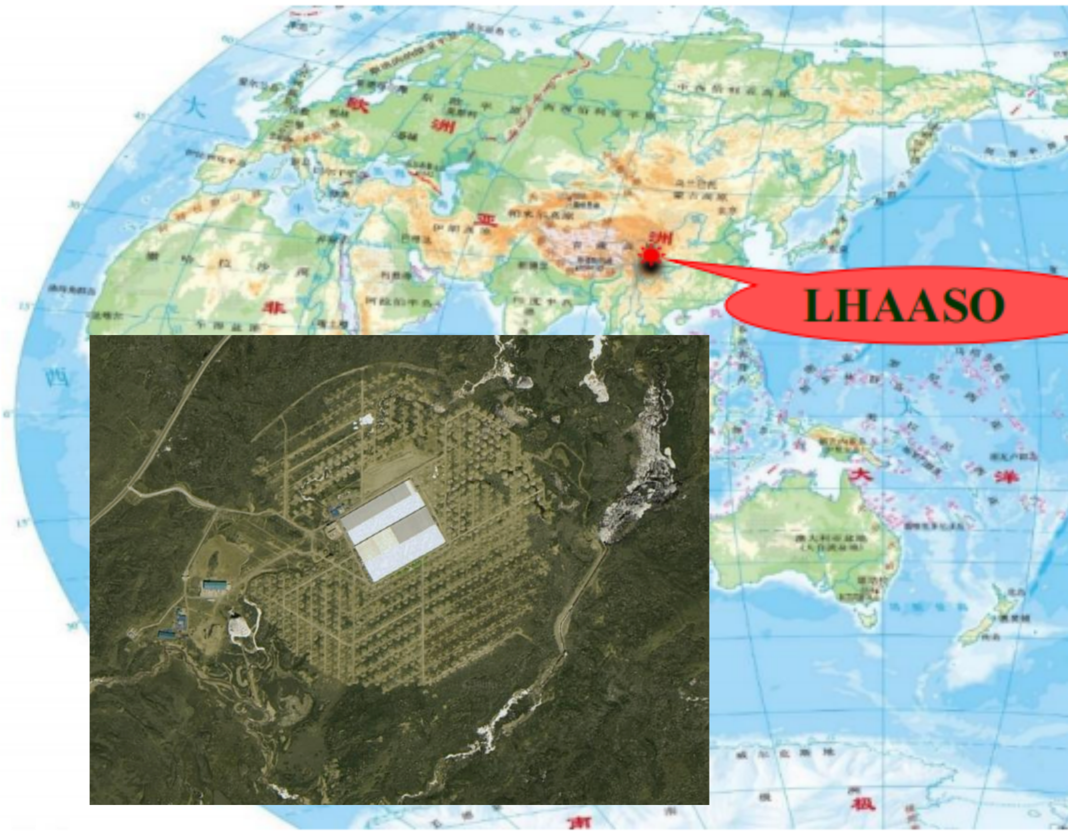
2023年紫金山暗物质研讨会

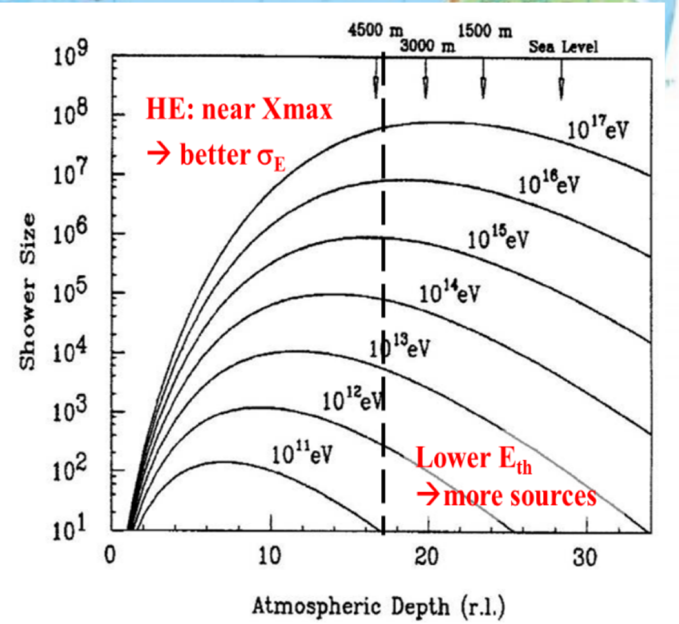
Large High Altitude Air Shower Observatory (LHAASO)



Detecting air showers produced by cosmic rays (and gamma rays) with ~km^2 area and hybrid techniques

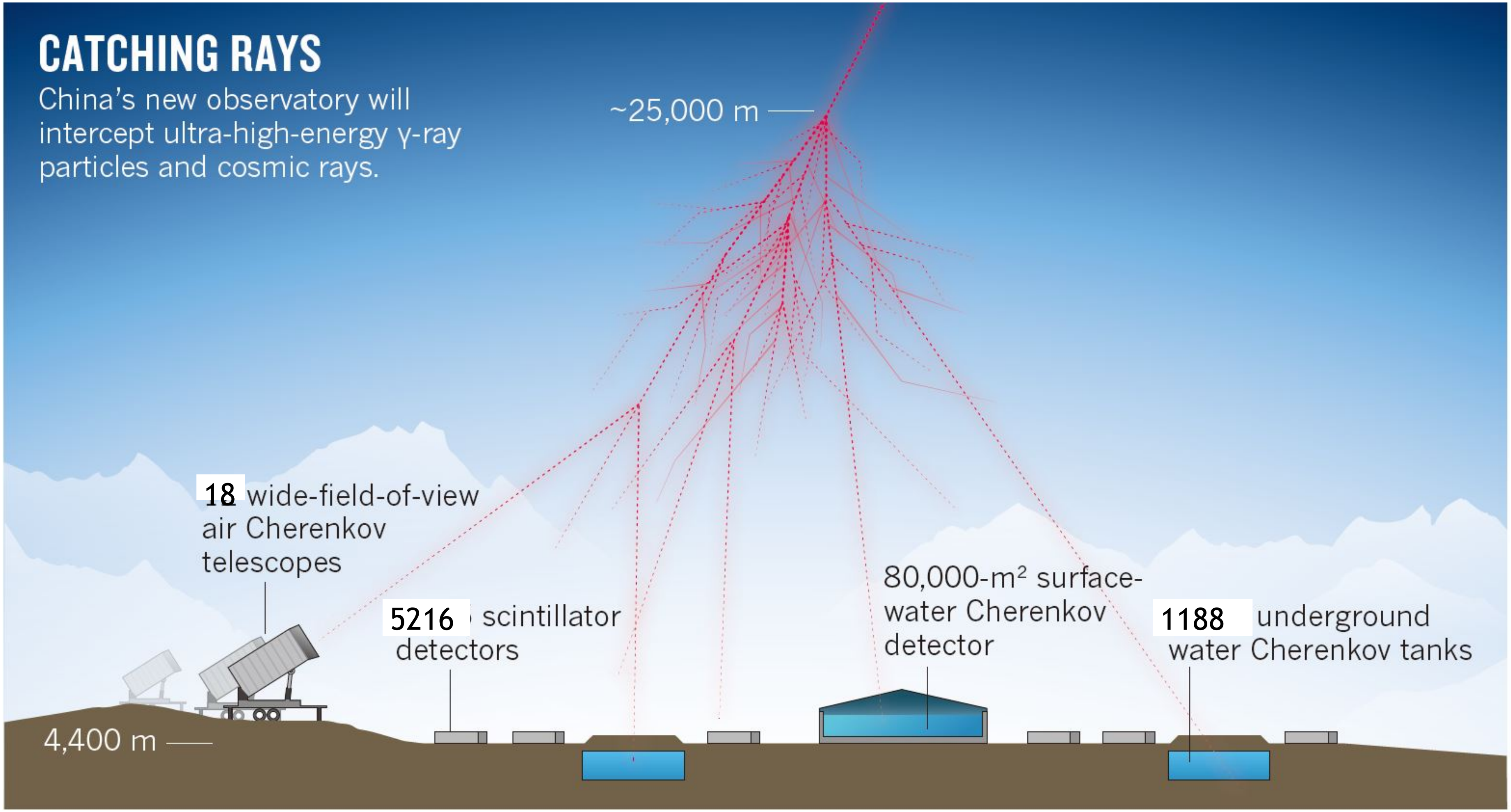
LHAASO site





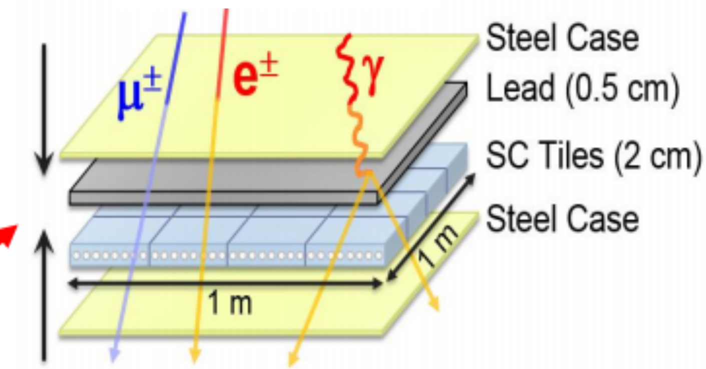
- Haizi mountain, Sichuan, China
- 4410 m above the sea level

Air shower detection

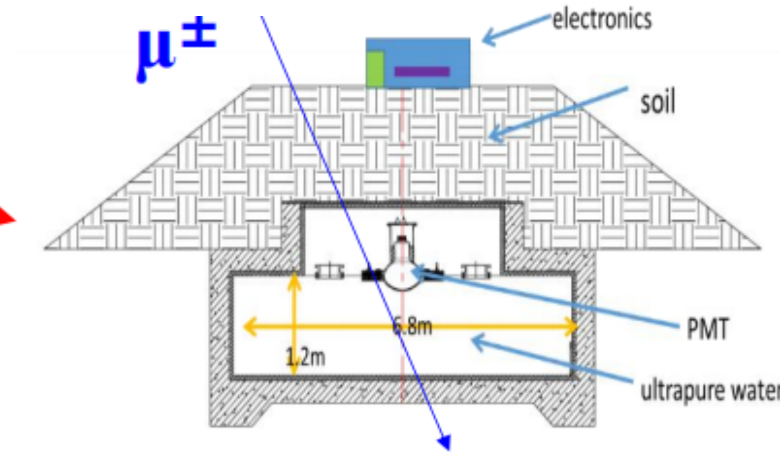


LHAASO detector - KM2A

5216 EDs

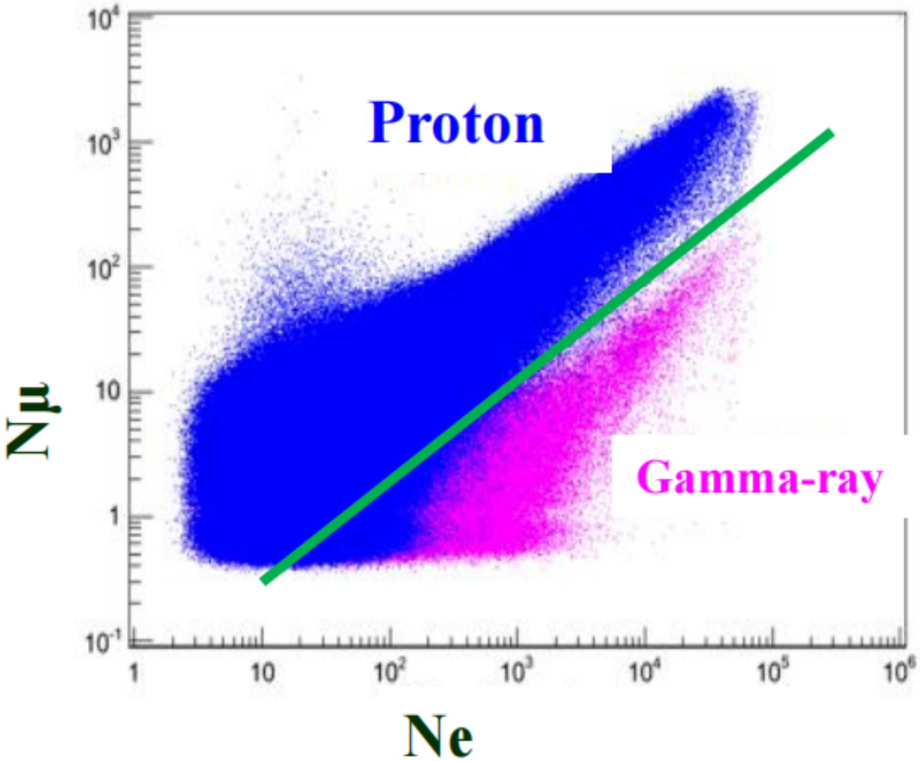


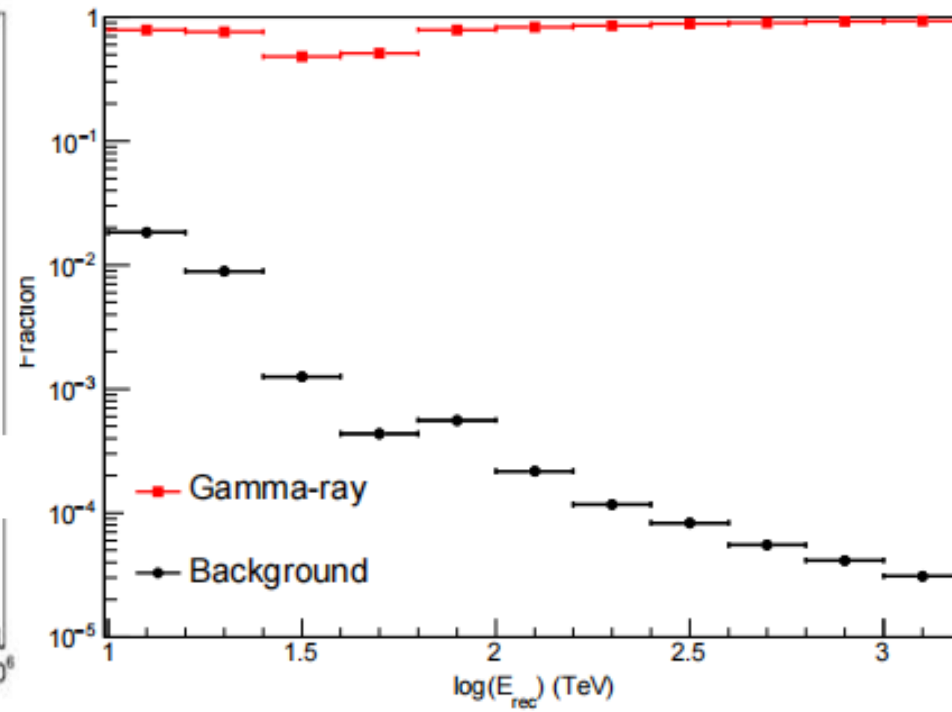
1188 MDs



- ➢ Electromagnetic particles to reconstruct energy and direction
- ➢ Muons to distinguish different particles (especially γ rays)
- ➢ Covering energies from 10 TeV to 10 PeV

LHAASO detector - KM2A

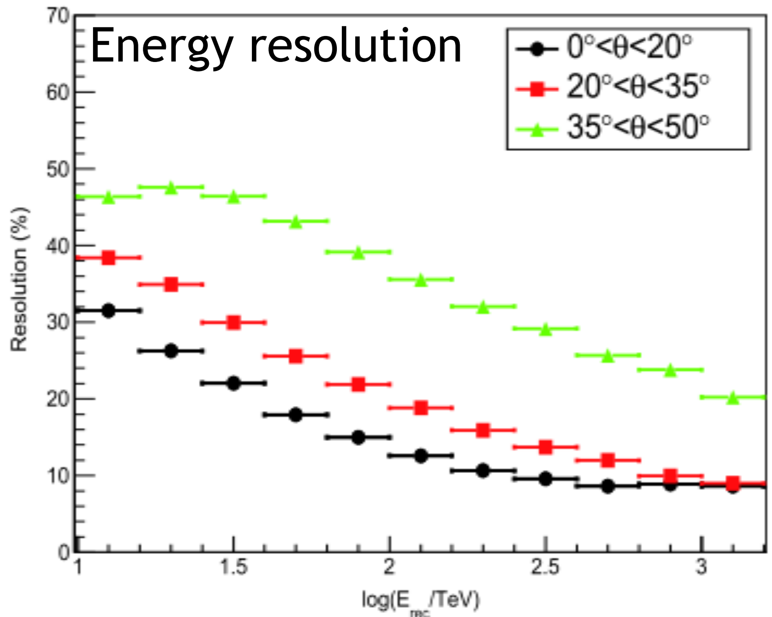


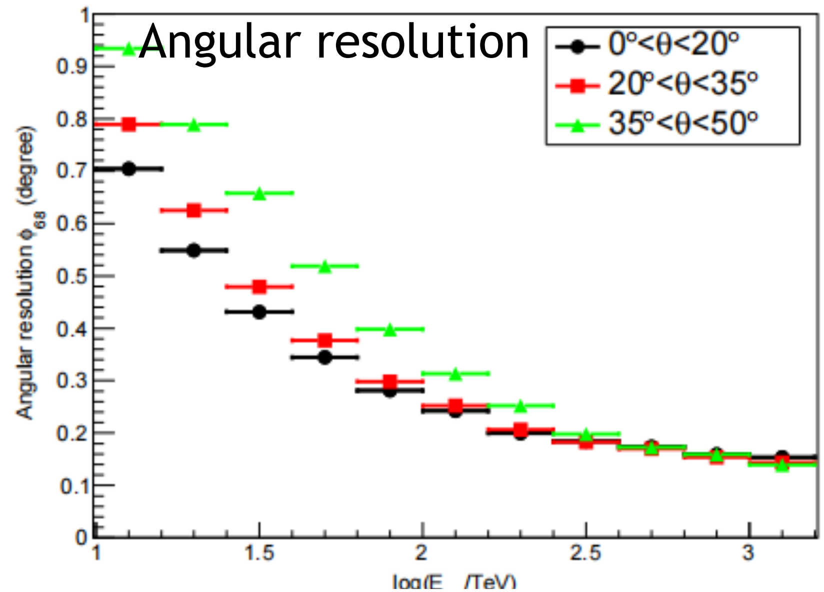


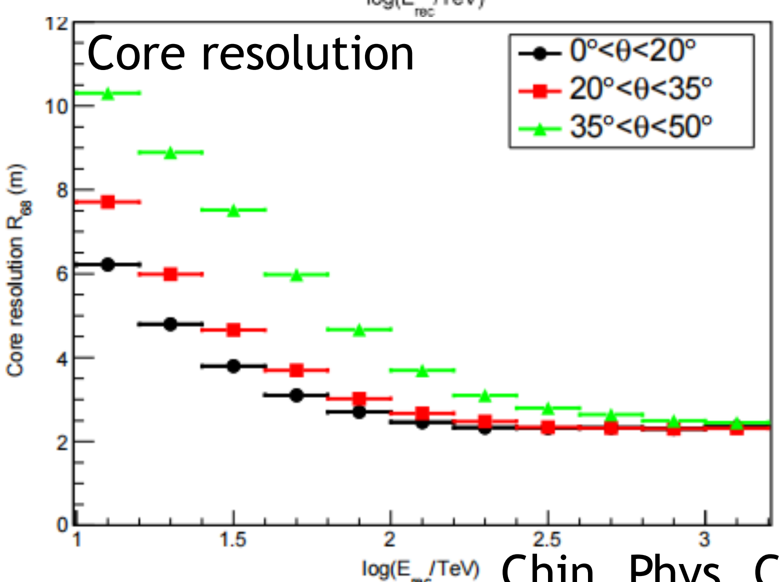
$$R = \log\left(\frac{N_\mu + 0.0001}{N_e}\right)$$

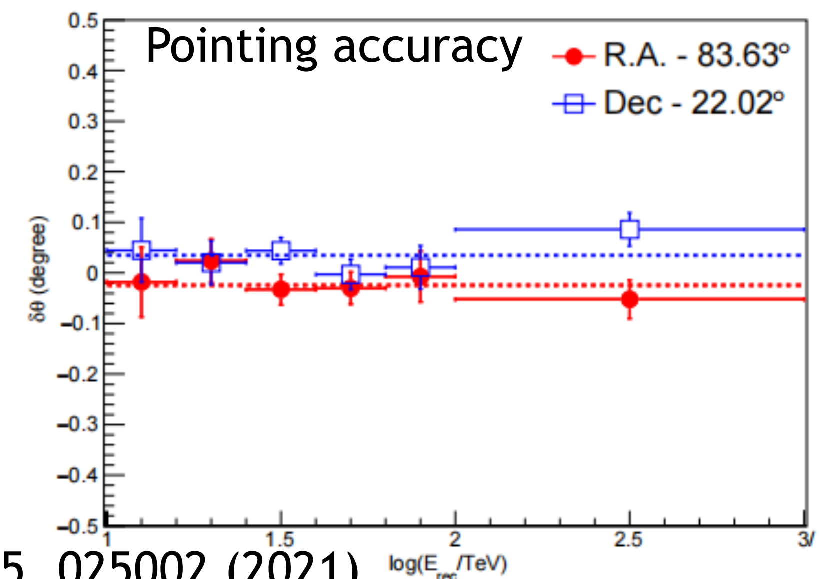
Chin. Phys. C, 45, 025002 (2021)

LHAASO detector - KM2A









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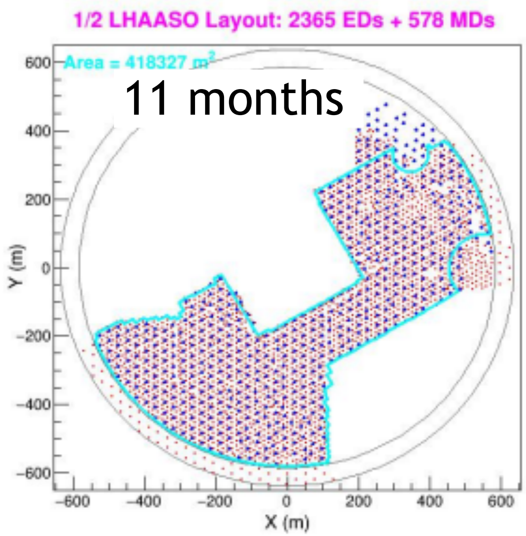
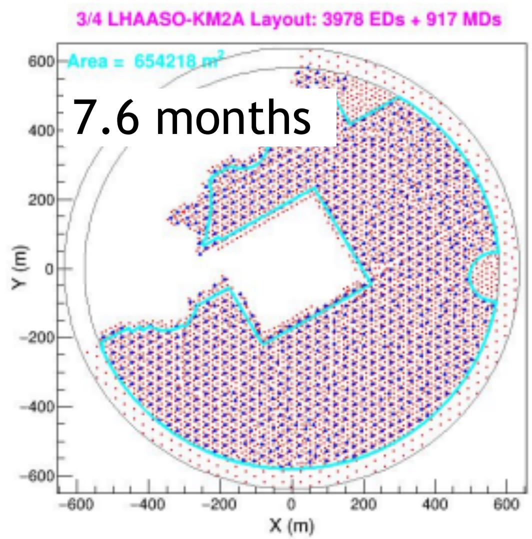
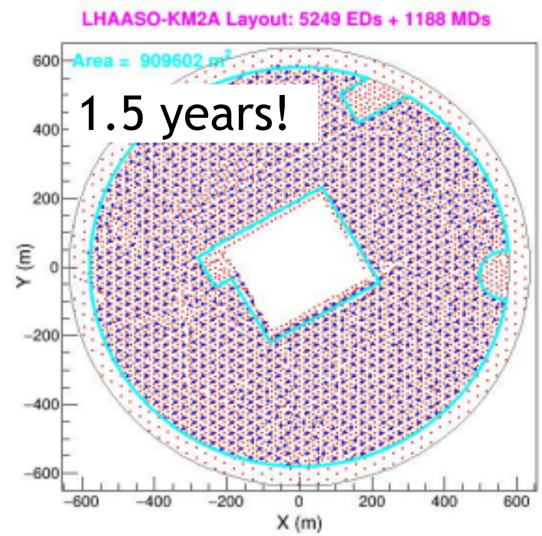
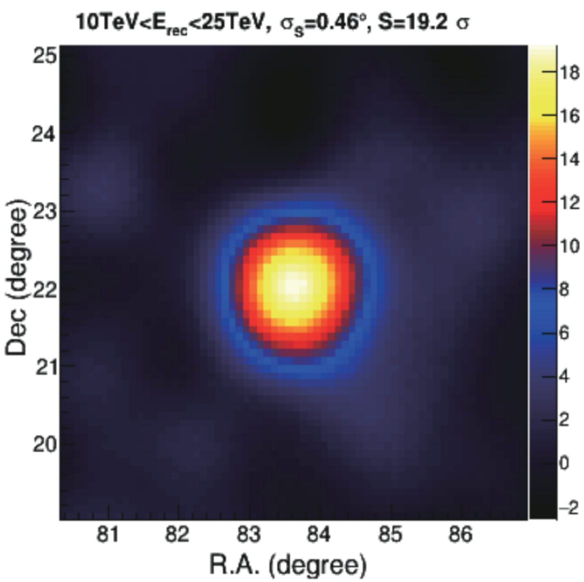
LHAASO detector - KM2A

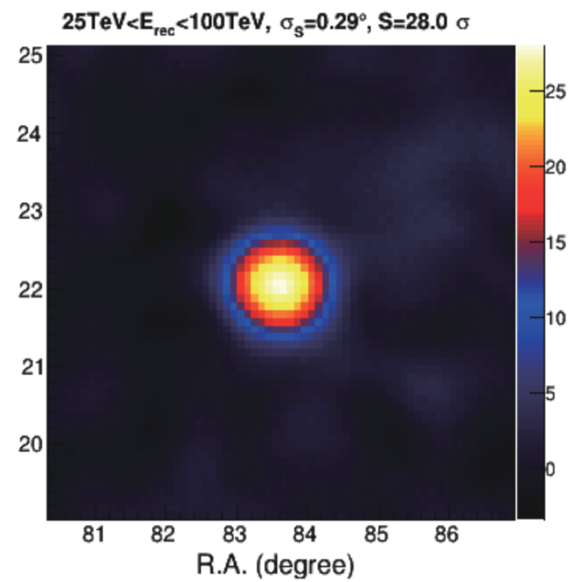


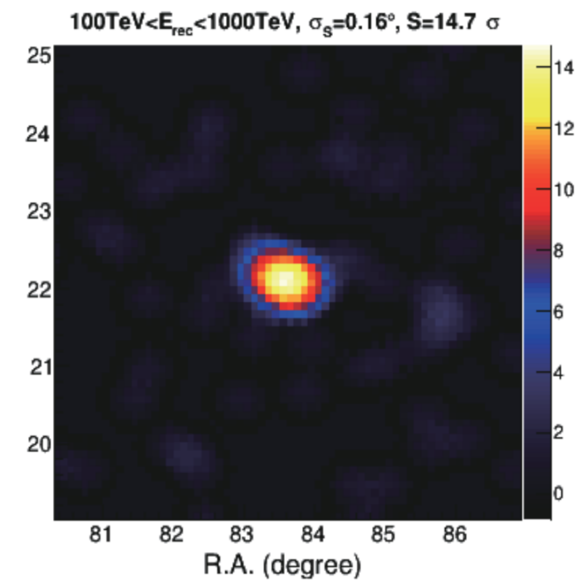




1/2: 20191217->20201130   3/4: 20201201->20210719   Full: 20210720->







Half-KM2A

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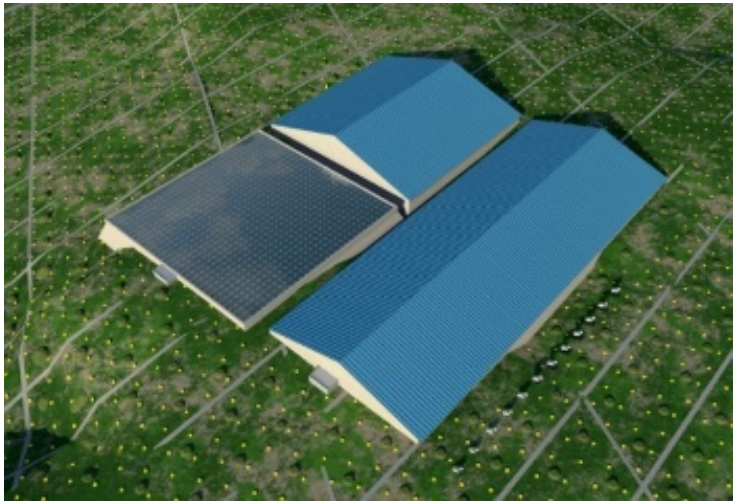
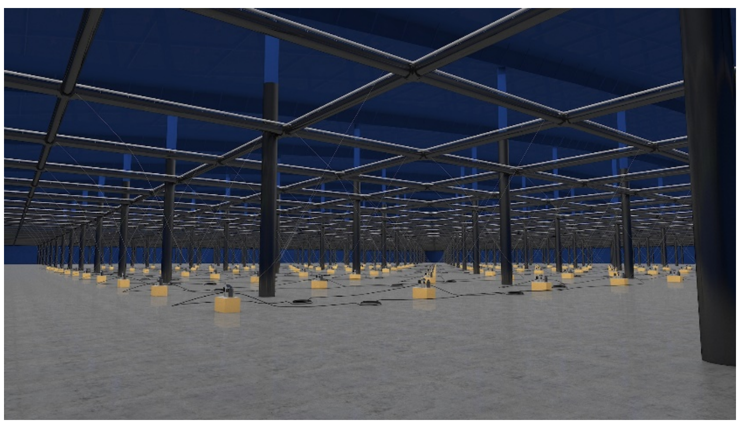
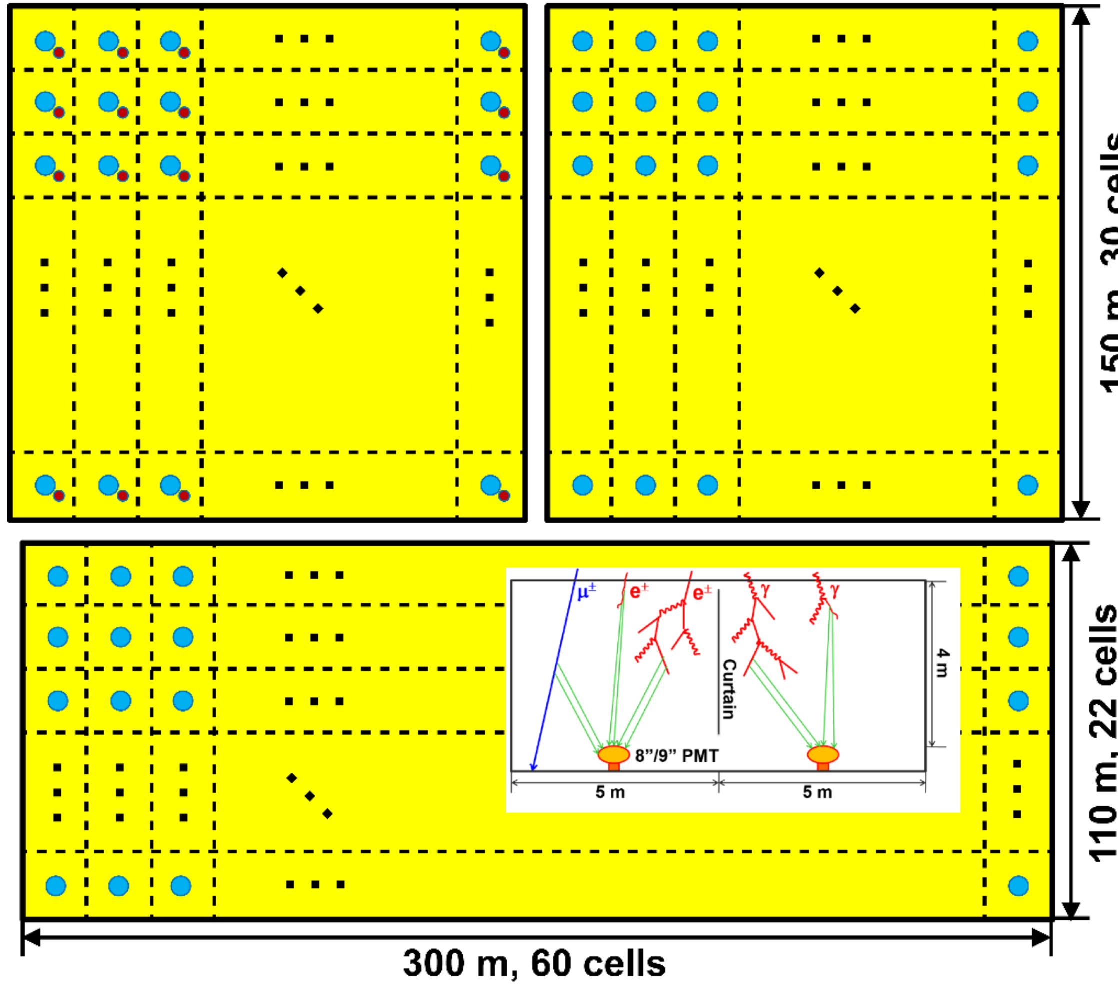
LHAASO detector - WCDA



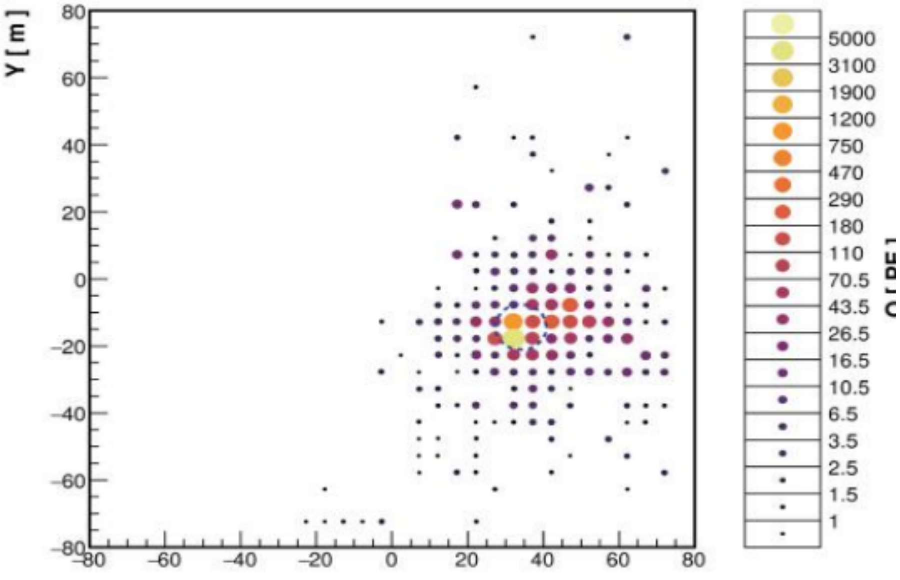




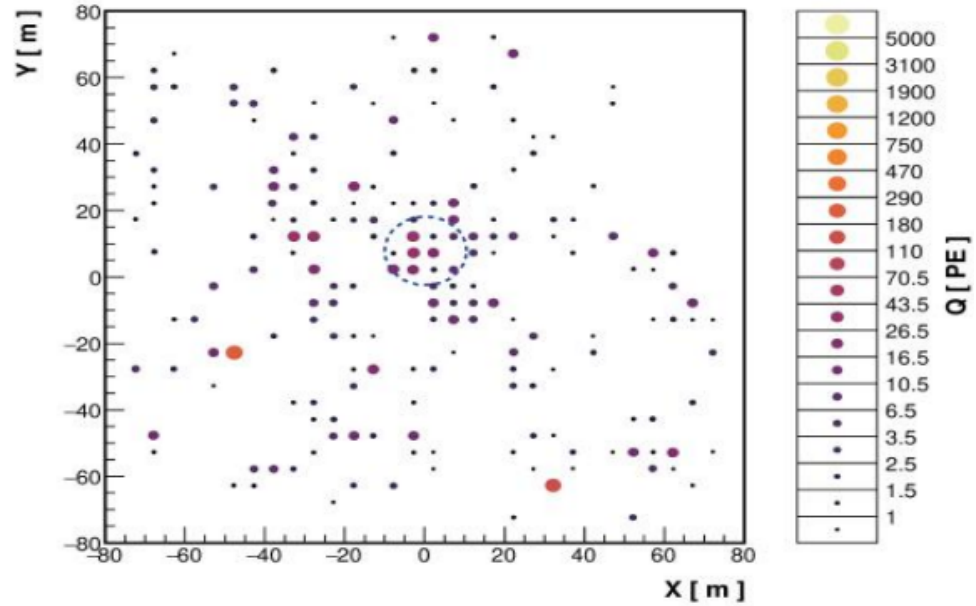
- Area: 78,000 m^2
- Covering energies from 0.3 TeV to ~PeV

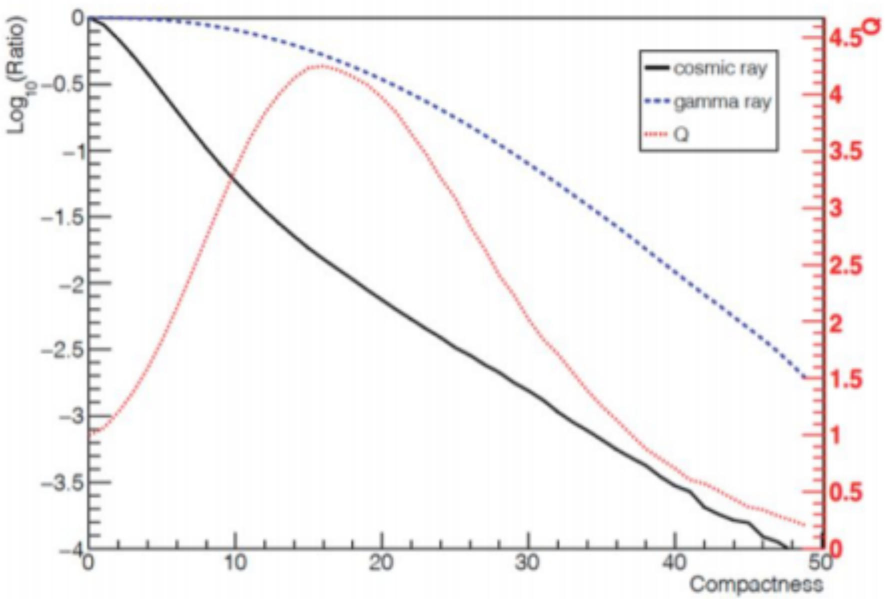
LHAASO detector - WCDA

Gamma-ray event



Cosmic ray event

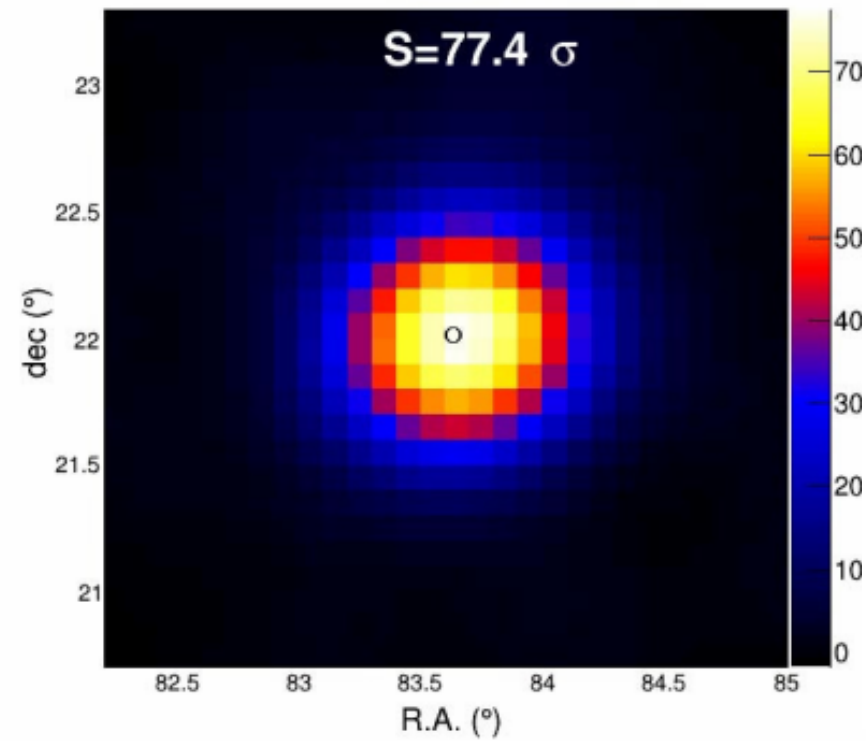


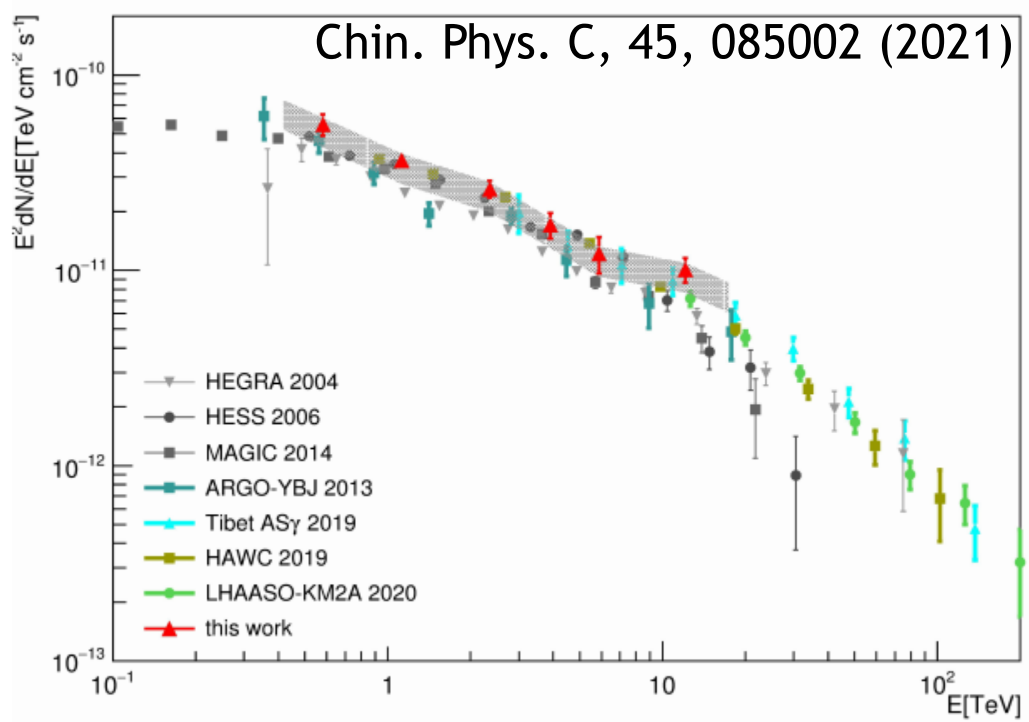


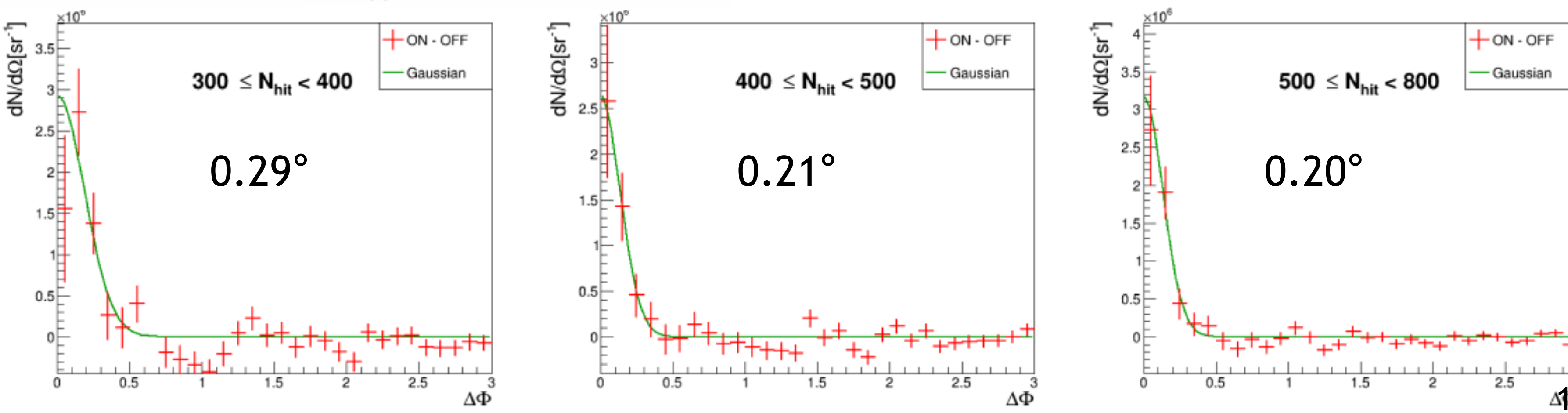
$$C = N_{hit}/\mathrm{Max}(Q_i; r > R_c)$$

Chin. Phys. C, 45, 085002 (2021)

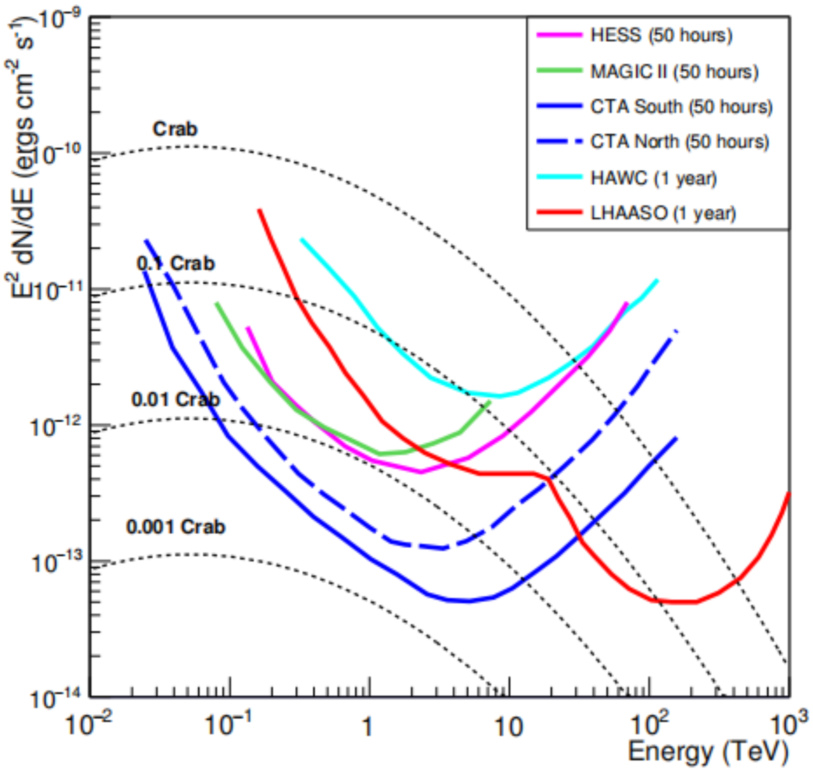
LHAASO detector - WCDA

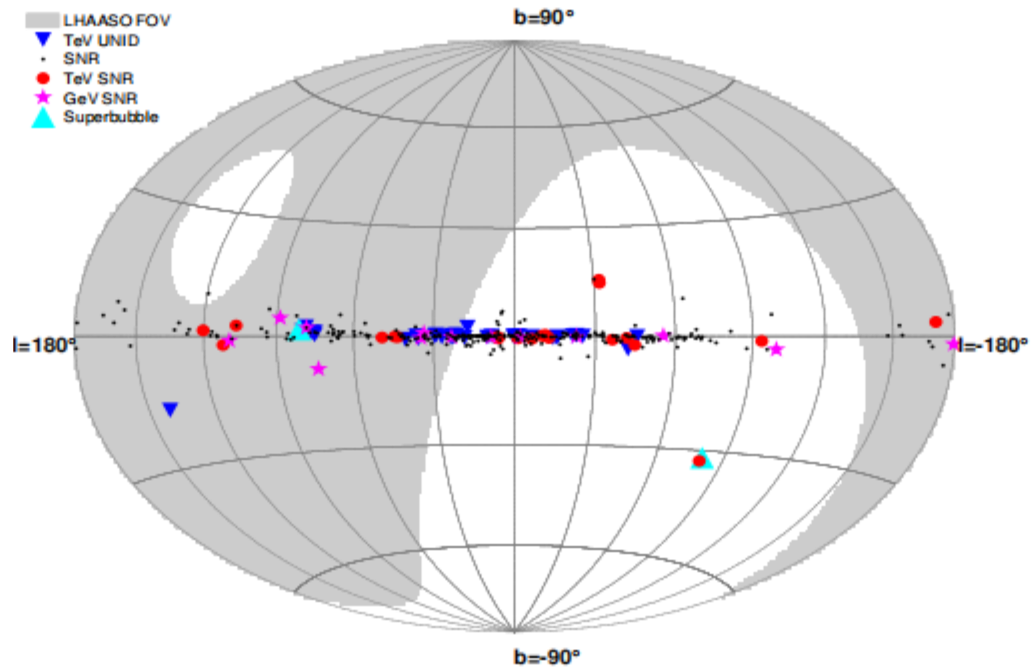






Gamma-ray survey sensitivity

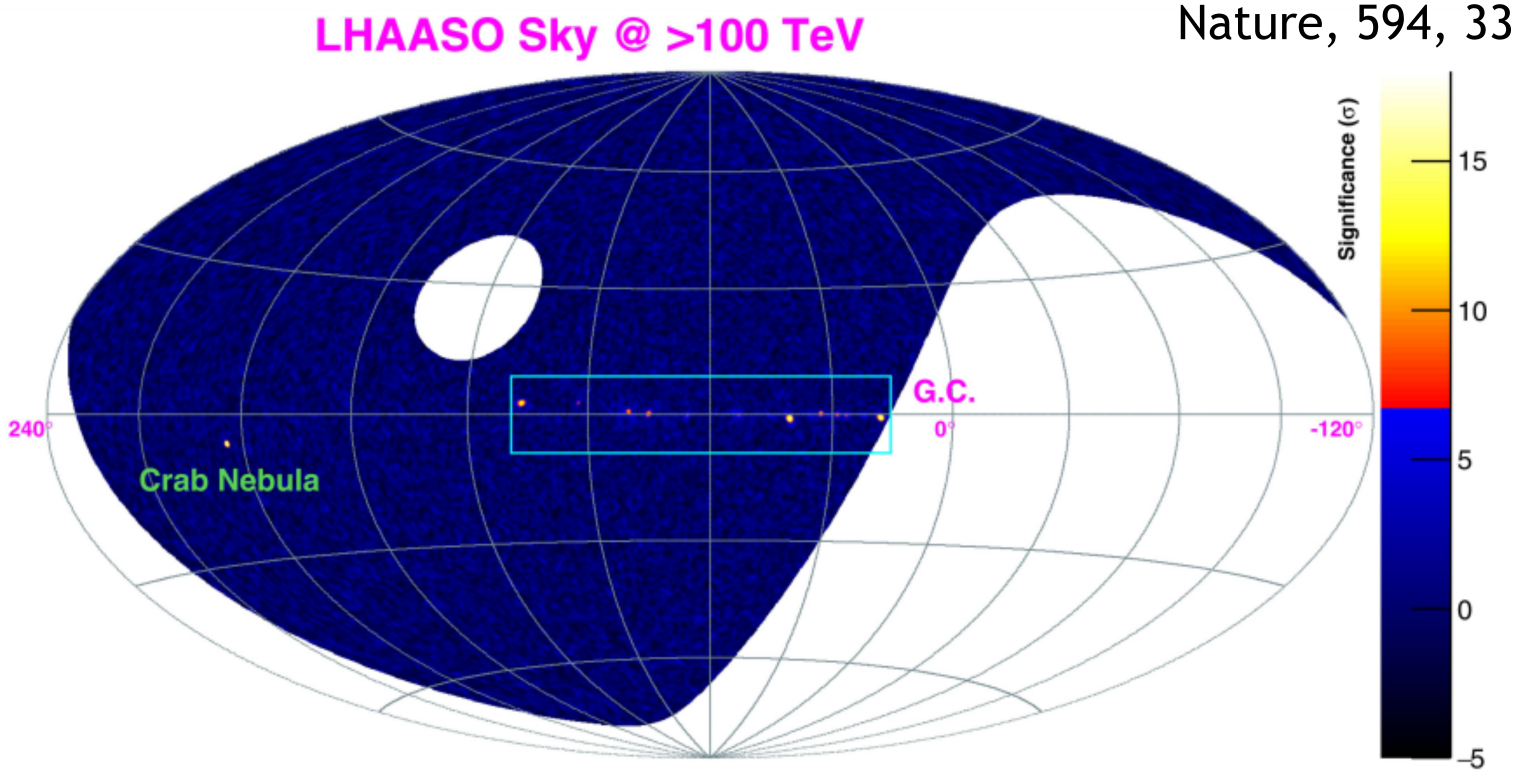


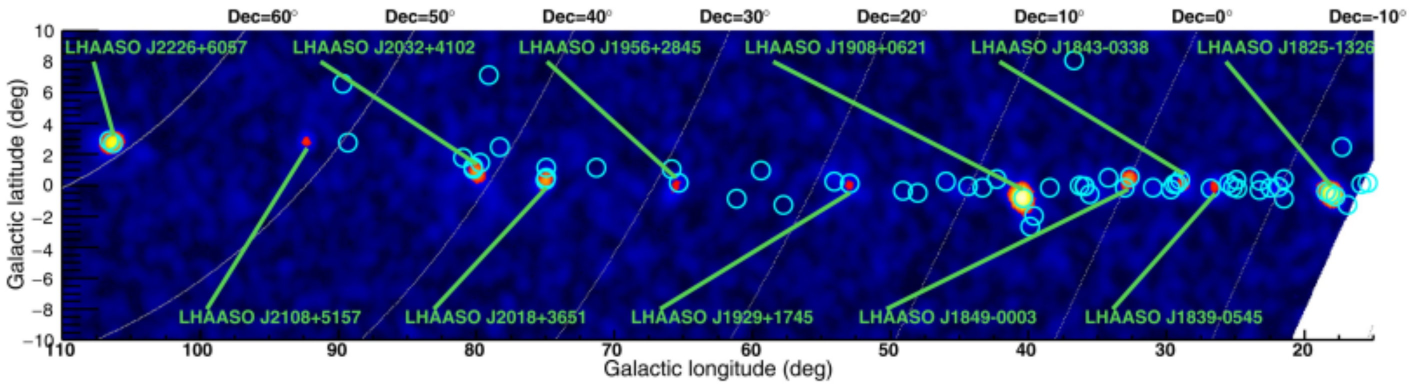


Chin. Phys. C, 46, 035002 (2022)

Survey of the UHE sky with 1/2 array

Nature, 594, 33 (2021)



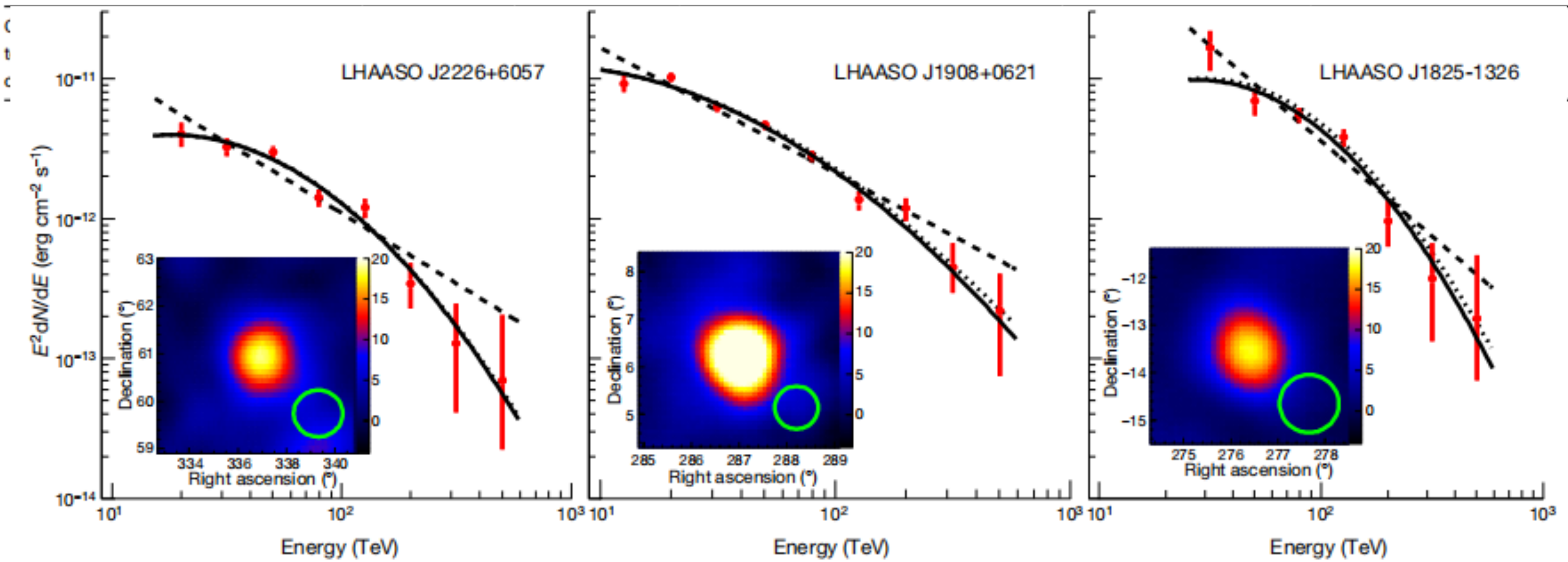


Survey of the UHE sky with 1/2 array

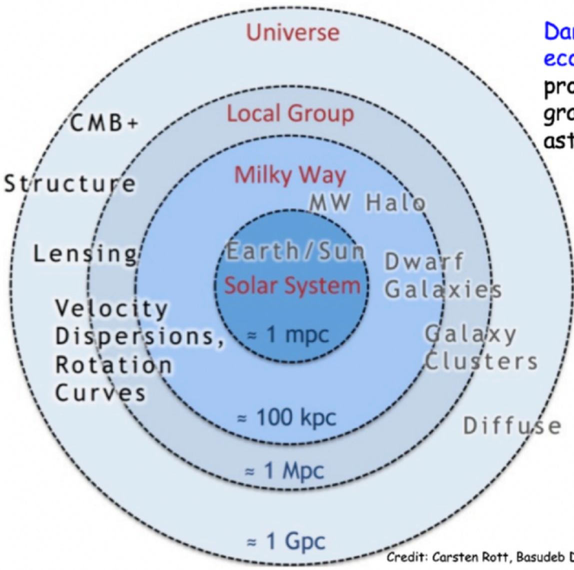
Table 1 | UHE γ-ray sources

Nature, 594, 33 (2021)

Source name	RA (°)	dec. (°)	Significance above 100 TeV (×σ)	E_{max} (PeV)	Flux at 100 TeV (CU)
LHAASO J0534+2202	83.55	22.05	17.8	0.88 ± 0.11	1.00(0.14)
LHAASO J1825-1326	276.45	−13.45	16.4	0.42 ± 0.16	3.57(0.52)
LHAASO J1839-0545	279.95	−5.75	7.7	0.21 ± 0.05	0.70(0.18)
LHAASO J1843-0338	280.75	−3.65	8.5	$0.26 -0.10^{+0.16}$	0.73(0.17)
LHAASO J1849-0003	282.35	−0.05	10.4	0.35 ± 0.07	0.74(0.15)
LHAASO J1908+0621	287.05	6.35	17.2	0.44 ± 0.05	1.36(0.18)
LHAASO J1929+1745	292.25	17.75	7.4	$0.71 -0.07^{+0.16}$	0.38(0.09)
LHAASO J1956+2845	299.05	28.75	7.4	0.42 ± 0.03	0.41(0.09)
LHAASO J2018+3651	304.75	36.85	10.4	0.27 ± 0.02	0.50(0.10)
LHAASO J2032+4102	308.05	41.05	10.5	1.42 ± 0.13	0.54(0.10)
LHAASO J2108+5157	317.15	51.95	8.3	0.43 ± 0.05	0.38(0.09)
LHAASO J2226+6057	336.75	60.95	13.6	0.57 ± 0.19	1.05(0.16)



Gravitational evidences of dark matter at all scales

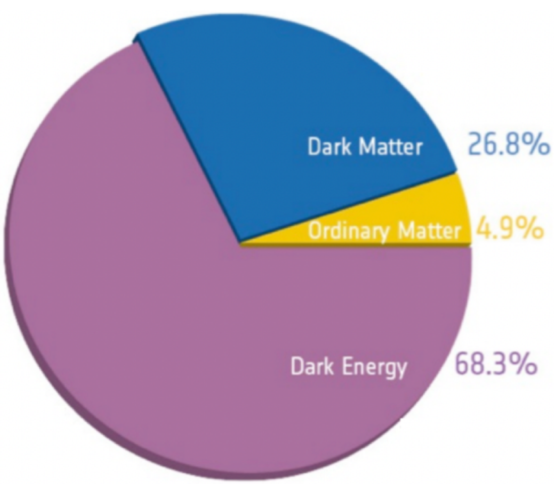


Credit: Carsten Rott, Basudeb Dasgupta

Dark matter is the most economical solution to the problem of the need of extra gravitational potential at all astrophysical scales

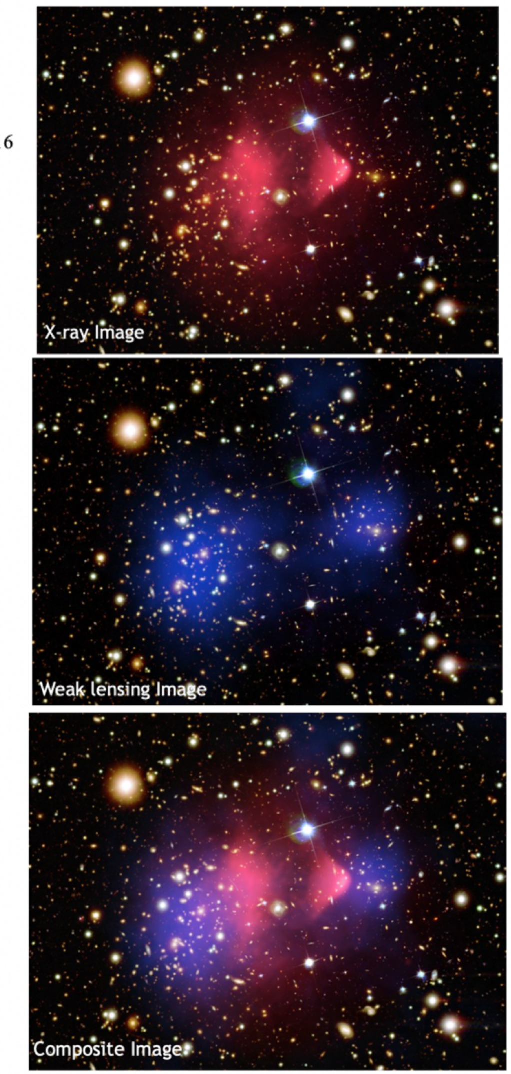
Many different experiments probing vastly different scales of the Universe confirm the presence of dark matter

Modifications of gravity at both non-relativistic and relativistic scales are required to solve this missing gravitational potential problem --- very hard --- no single unified theory exists



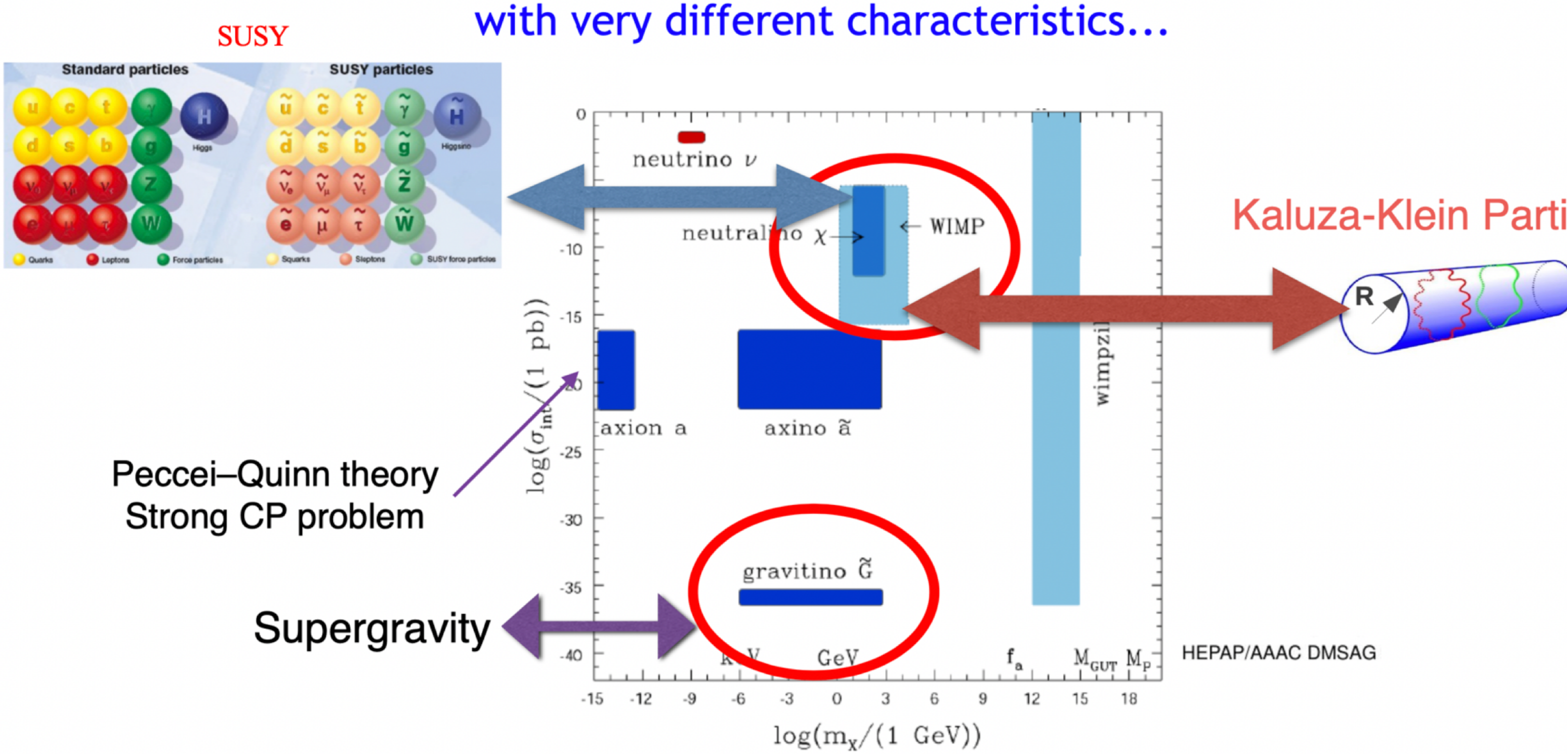
After Planck

Clowe, et al. 2016



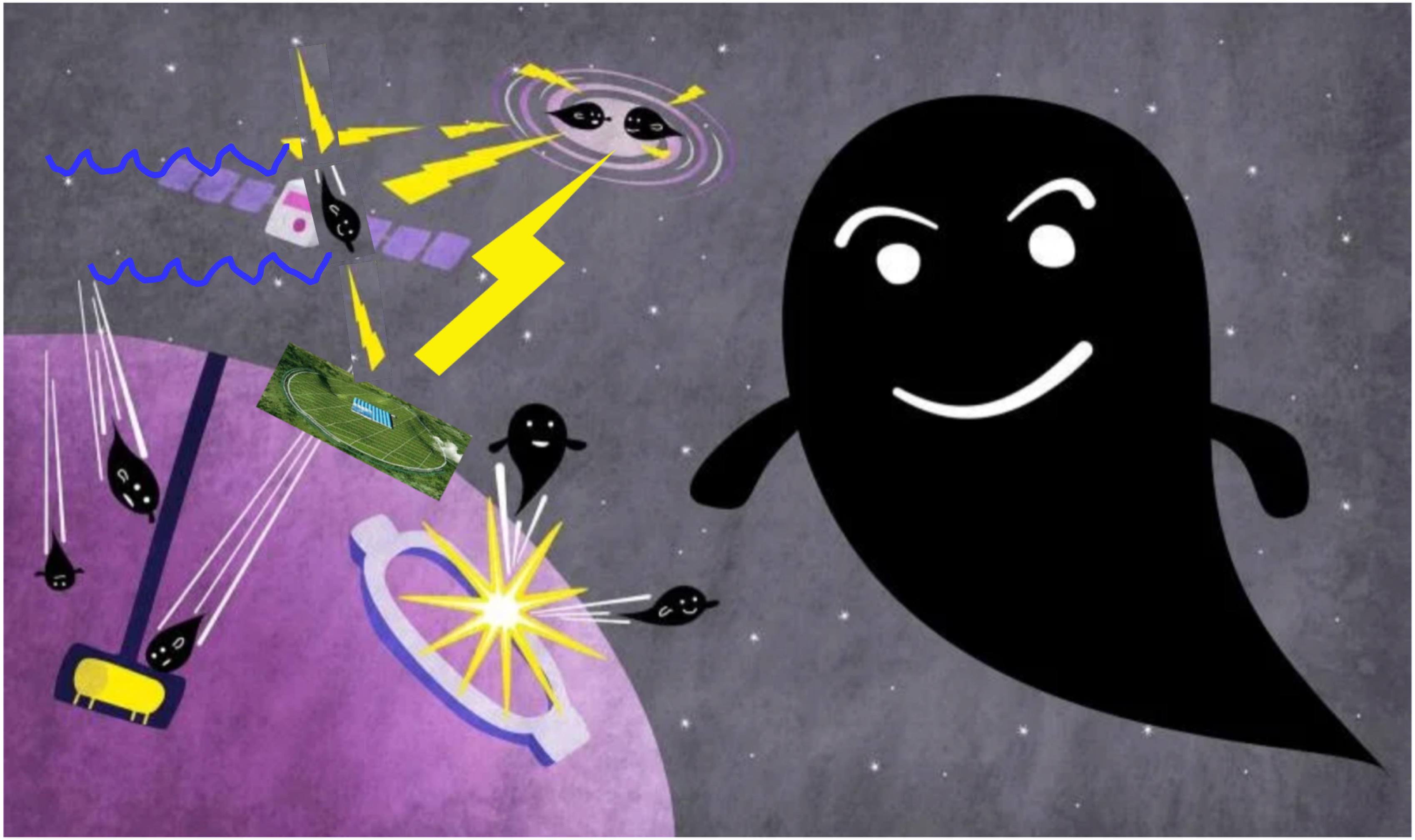
Dark matter candidate, very model dependent

Many dark matter candidates proposed,
with very different characteristics...



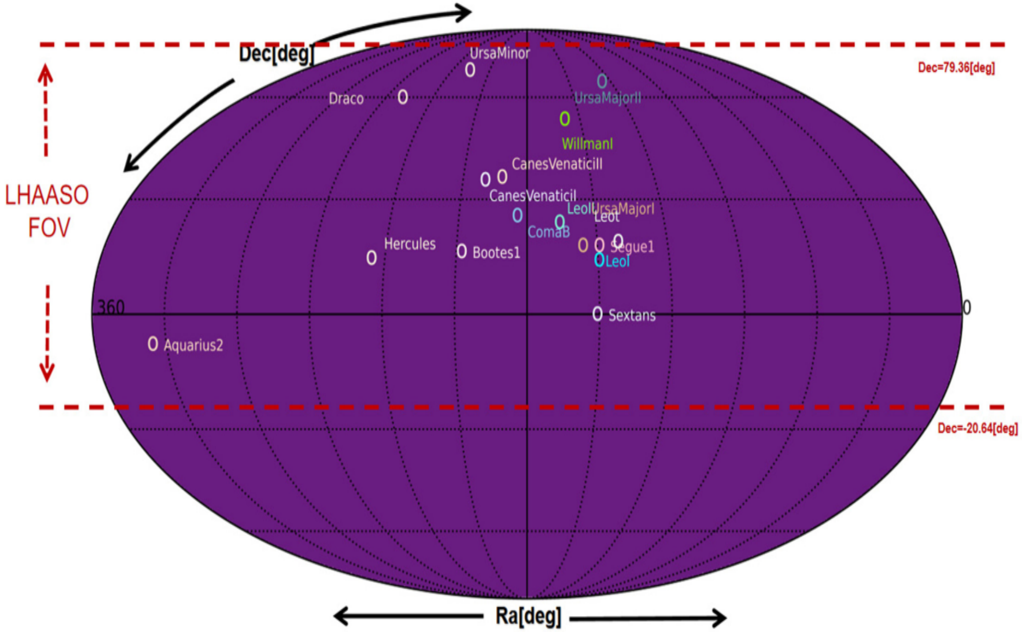
The production mechanism of dark matter particles
is very model dependent

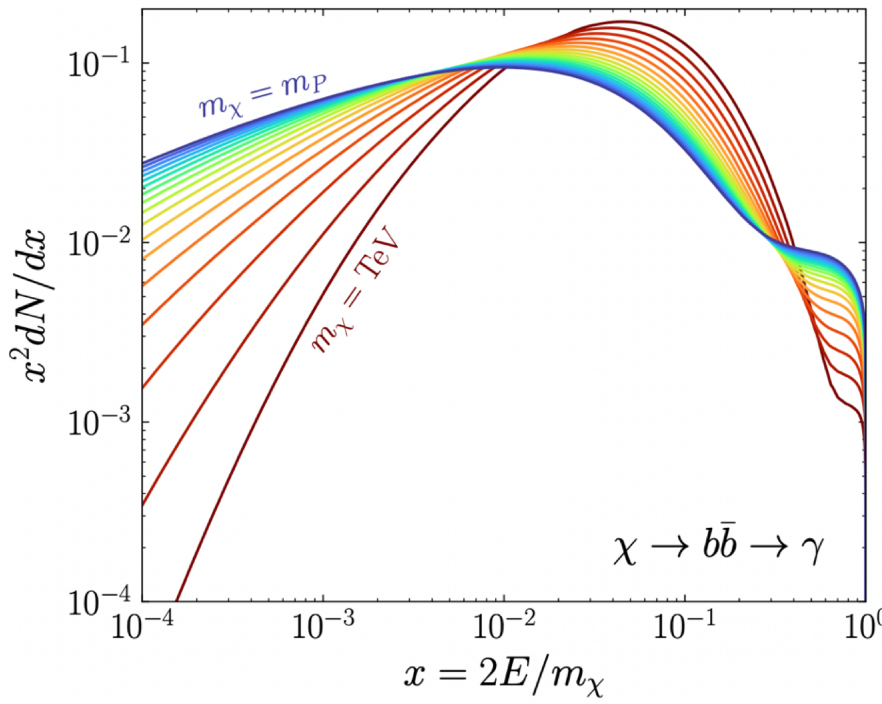
How may we detect dark matter?



SLAC National Accelerator Laboratory

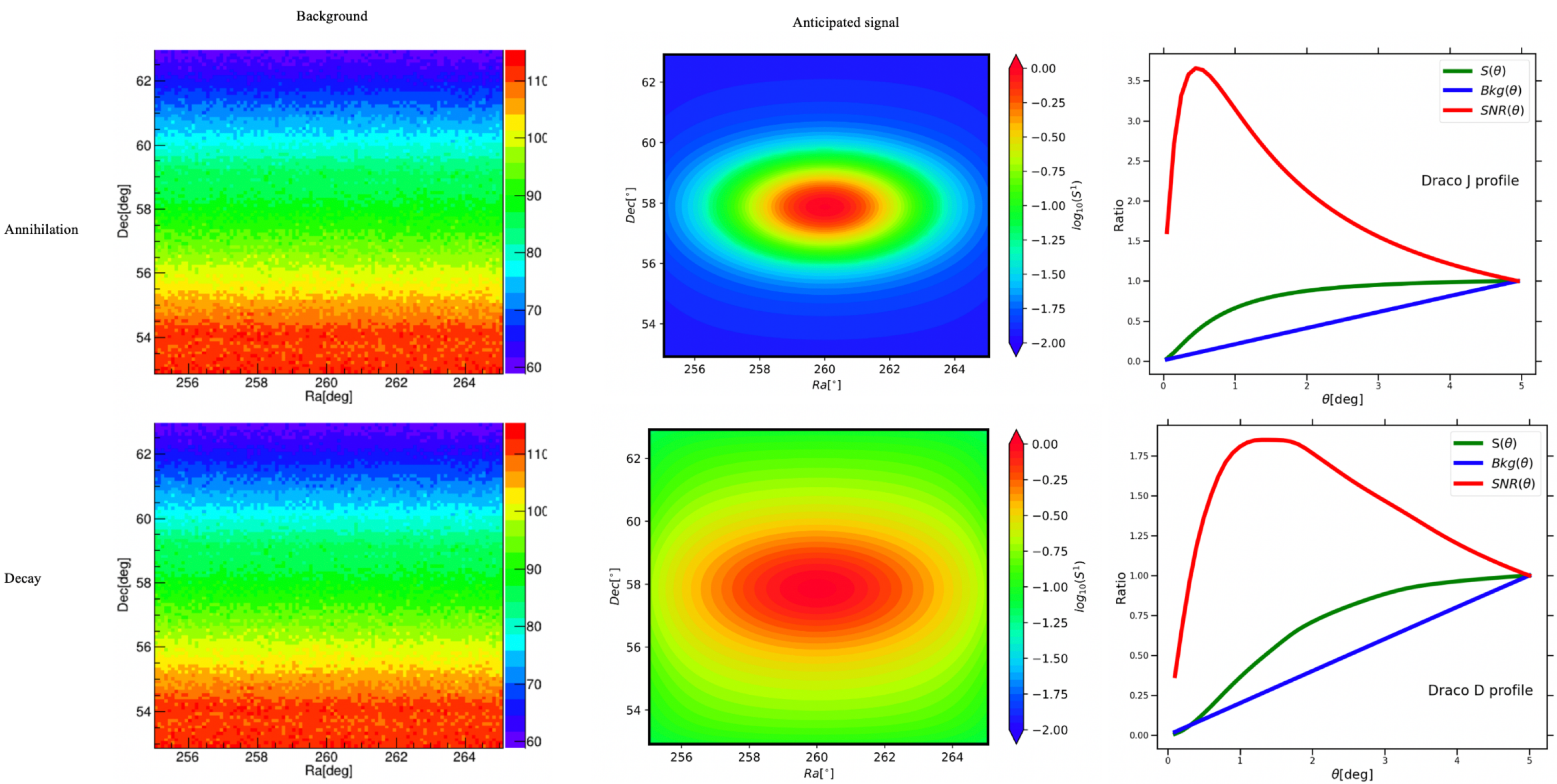
Gamma-ray from ultraheavy dark matter in dSphs





Optimizing target regions for selected dSphs

preliminary



Correction for high-energy gamma-ray spectrum

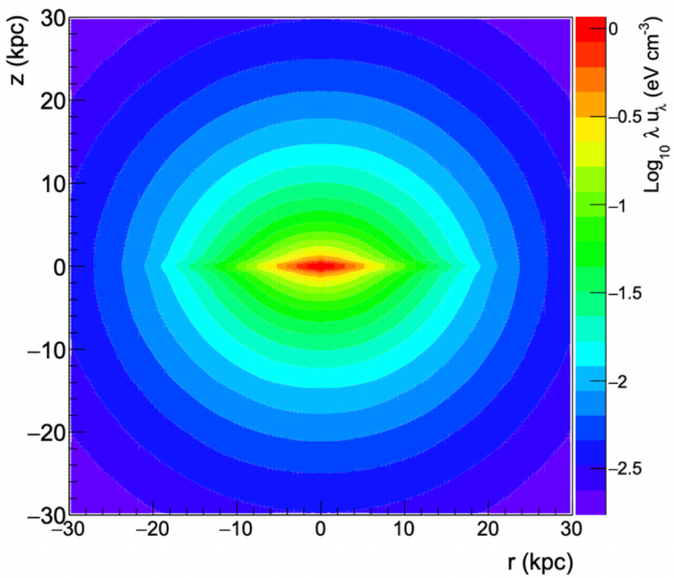
$$\frac{dN_\gamma}{dE} \Rightarrow \frac{dN_\gamma}{dE} e^{-\tau_{\gamma\gamma}(E)}$$

Gamma-ray Absorption term

ISRF (including Star Light, IR and CMB)

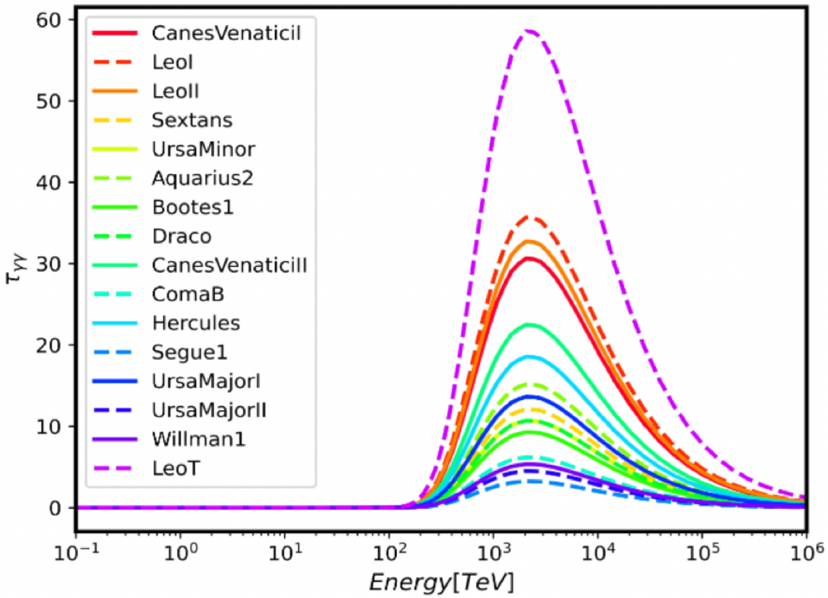
$$\tau_{\gamma\gamma} = \tau_{\gamma\gamma}^{SL+IR} + \tau_{\gamma\gamma}^{CMB}$$

Calculated by GALPROP V5.4

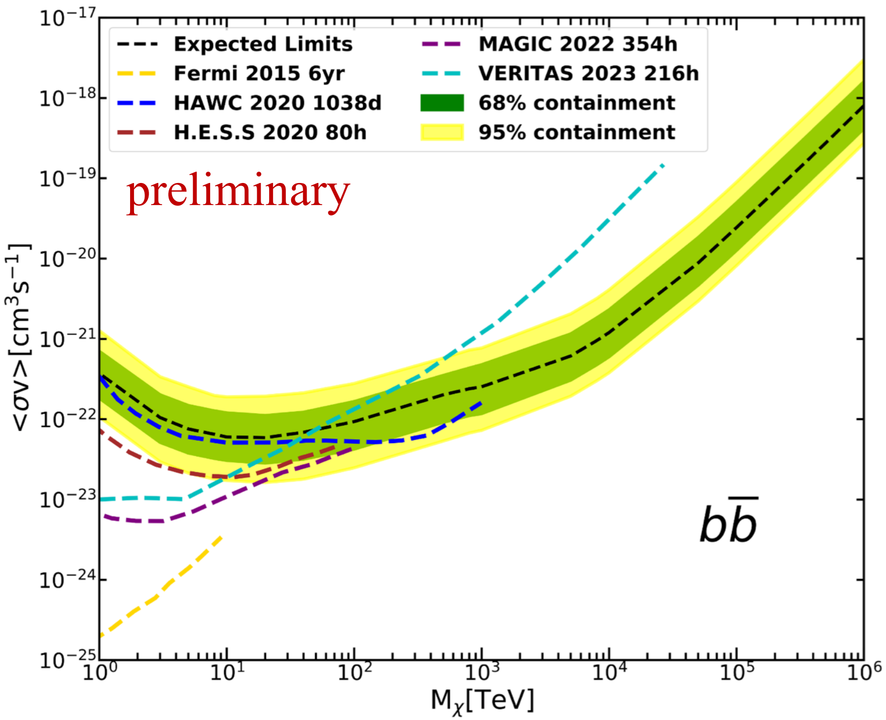


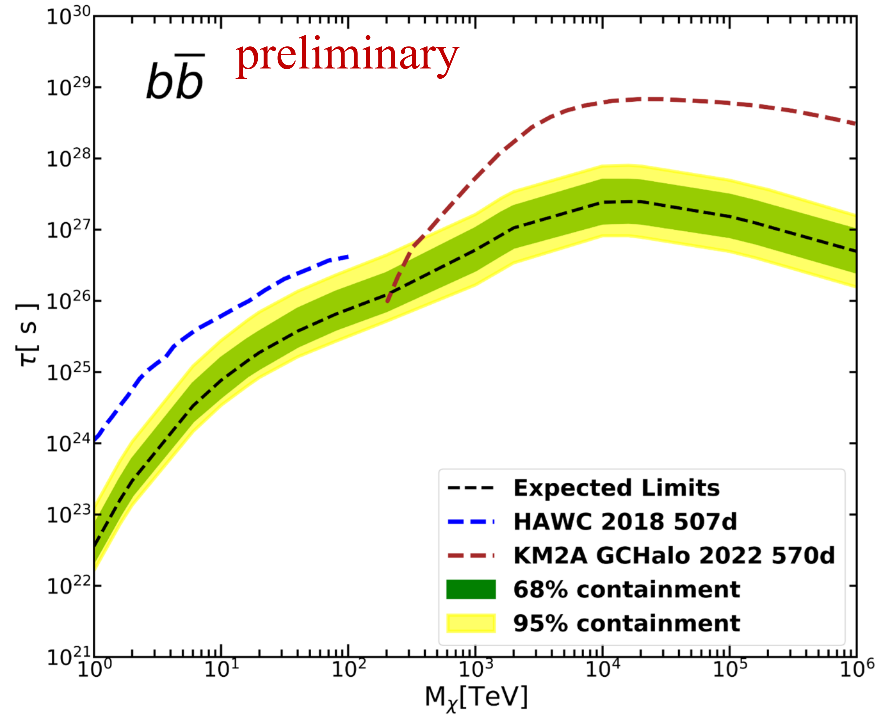
Vernetto et al., 2016

preliminary

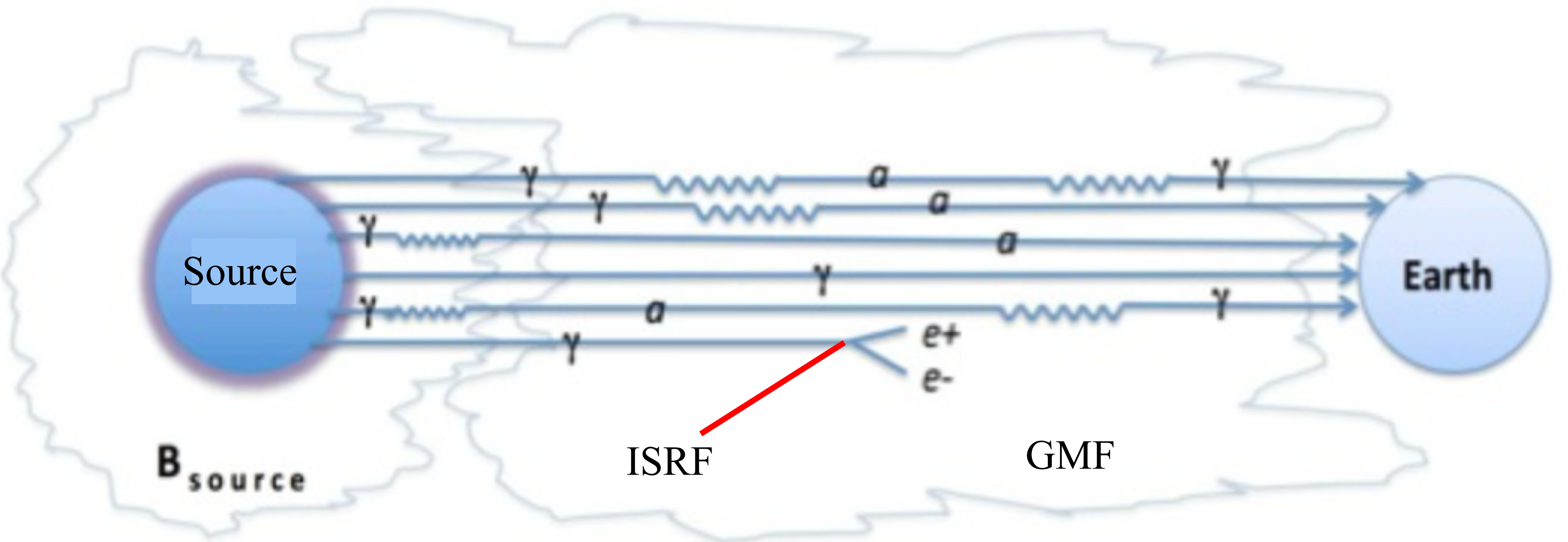


Expected constraints for ultraheavy dark matter



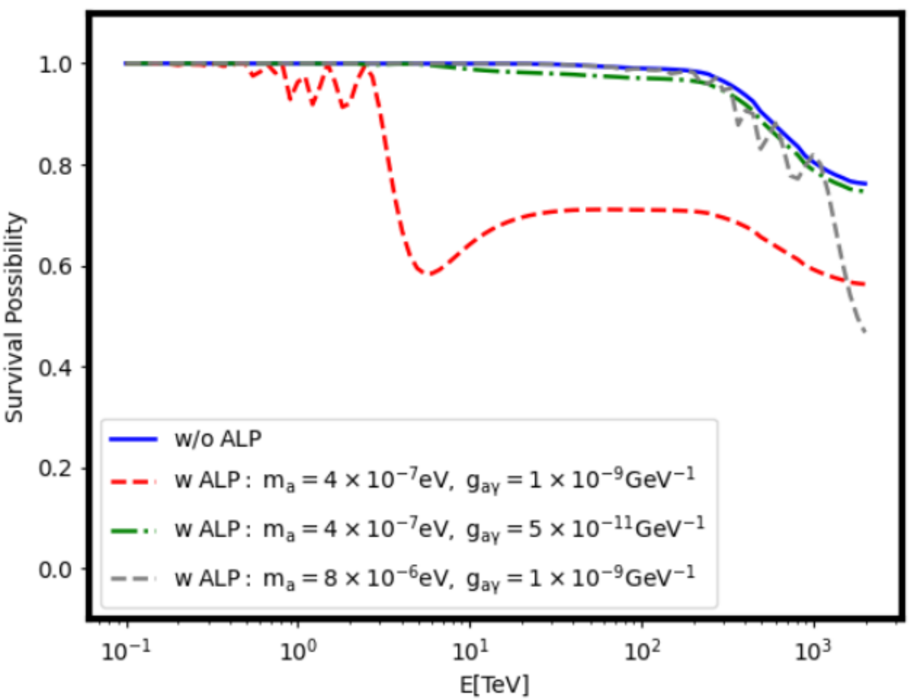


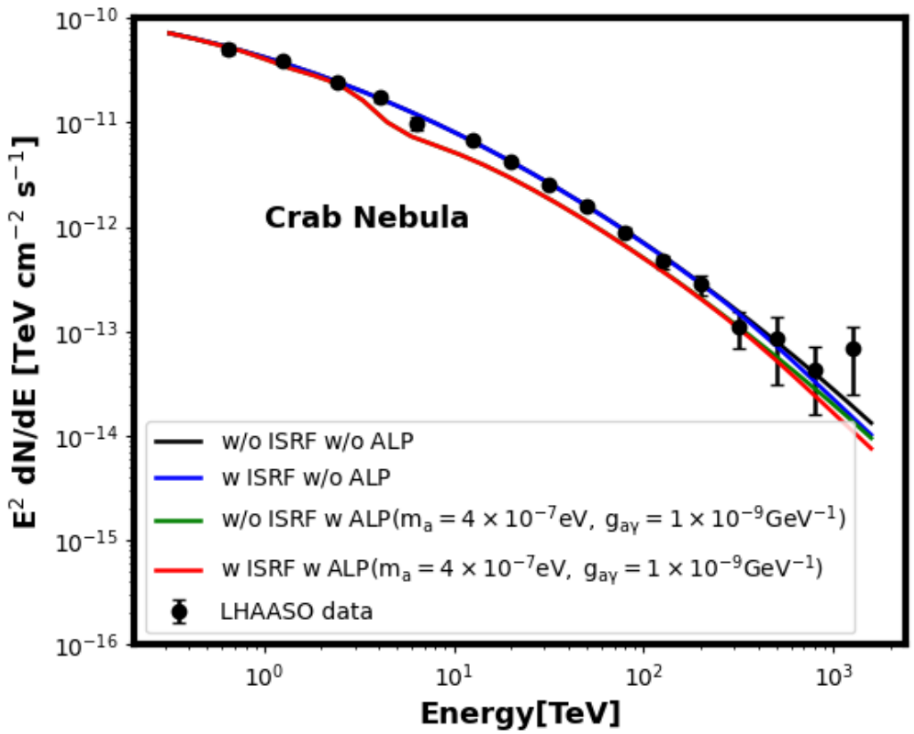
Photon—Axionlike-Particle oscillations



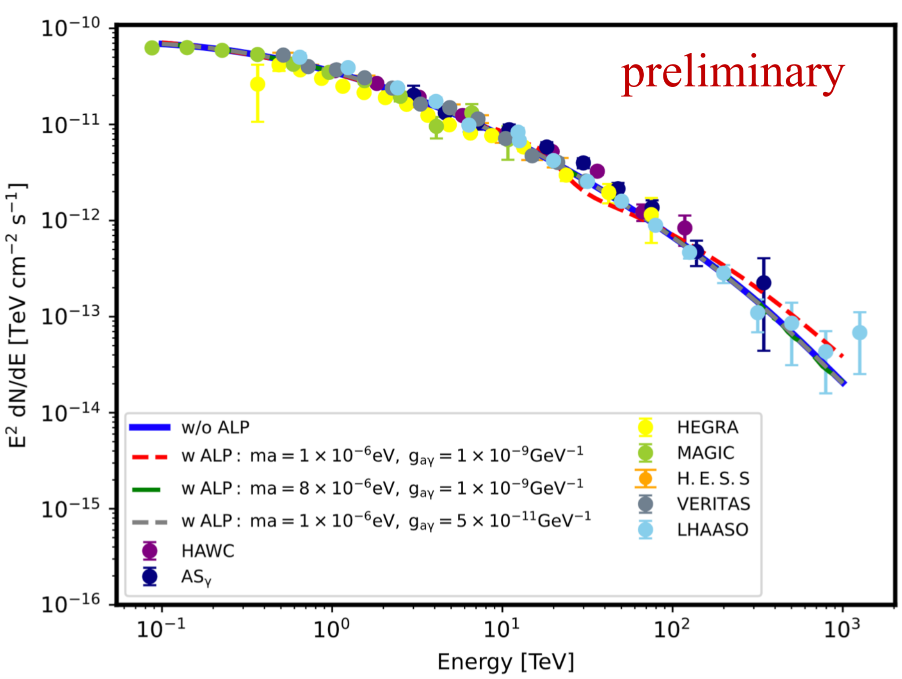
Survival possibility and effects on gamma-ray spectrum

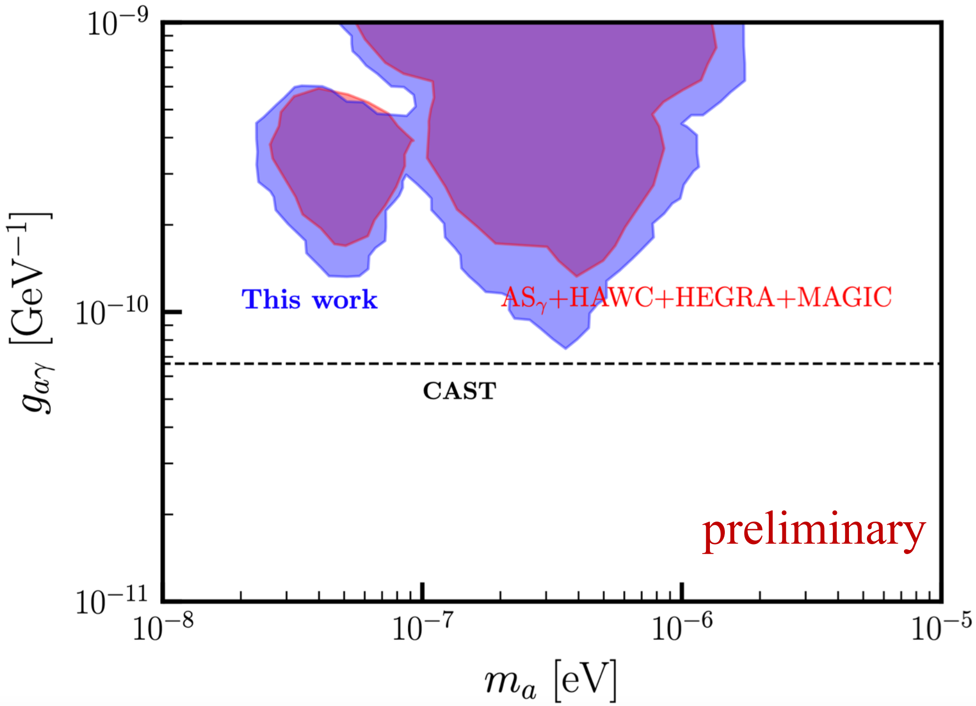
preliminary





Constraints for ALP





Summary

- LHAASO is a km^2 scale cosmic ray and gamma-ray observatory which is dedicated to surveying the ultra-high-energy sky with unprecedented sensitivity
- LHAASO starts its full operation since July 2021
- LHAASO is expected to improve constraints for ultraheavy dark matter and to improve constraints for axion-like-particles, comparable with those from CAST

Thank You!