WIMPs @ CTA

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special thanks to:

Torsten Bringmann (Oslo), Christopher Eckner (Annecy)

Sergio Cadena Hernández (Mexico City)

image: https://www.cta-observatory.org/the-dark-side-of-the-matter/

outline

WIMPs as gamma ray sources

Bayesian inference

backbone of our toolchain

prelim results

I wish to acknowledge the people of the Kulin Nations, on whose land we are gathered today. I pay my respects to their Elders, past and present.

WIMPs producing cosmic gamma rays

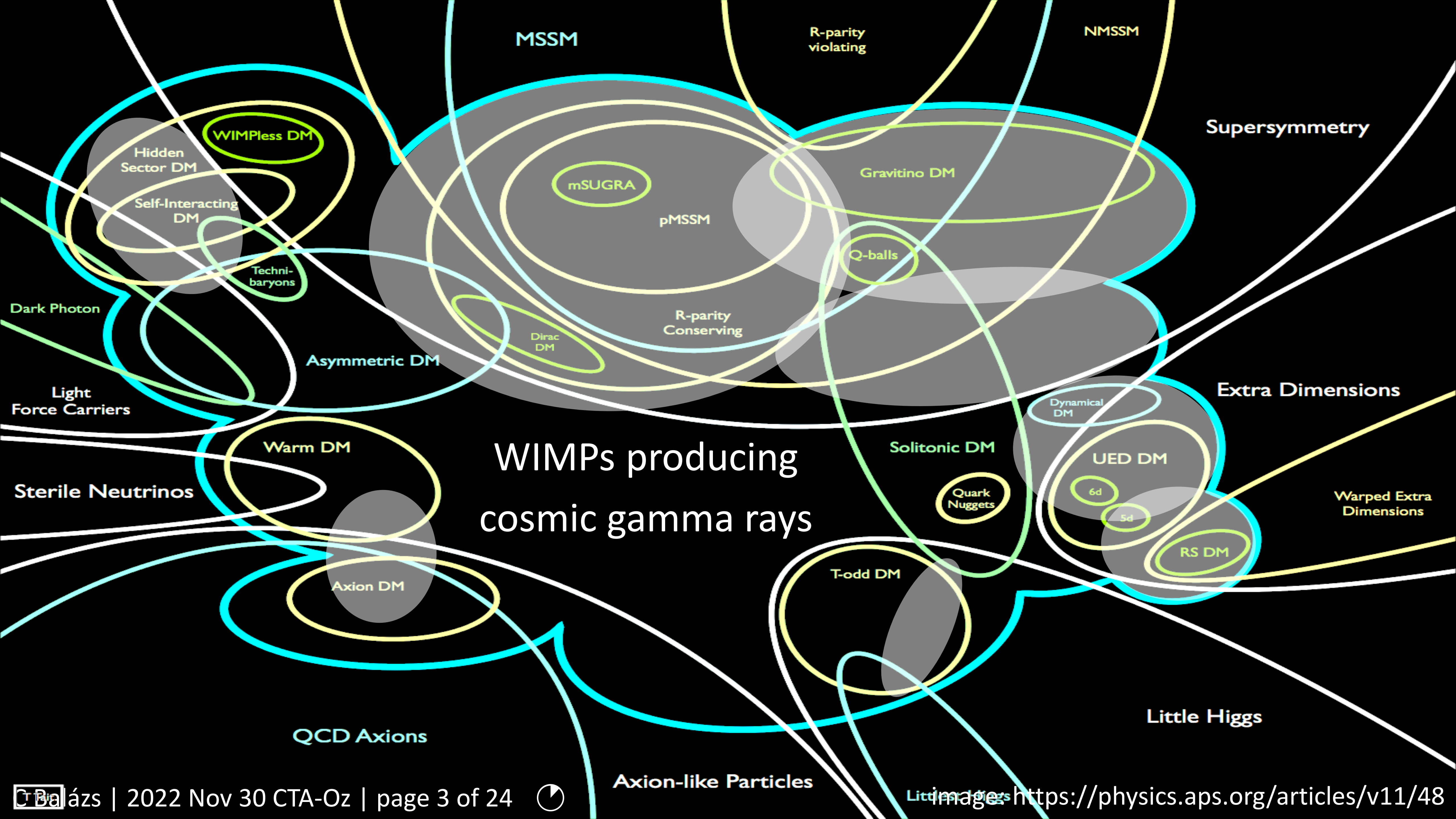
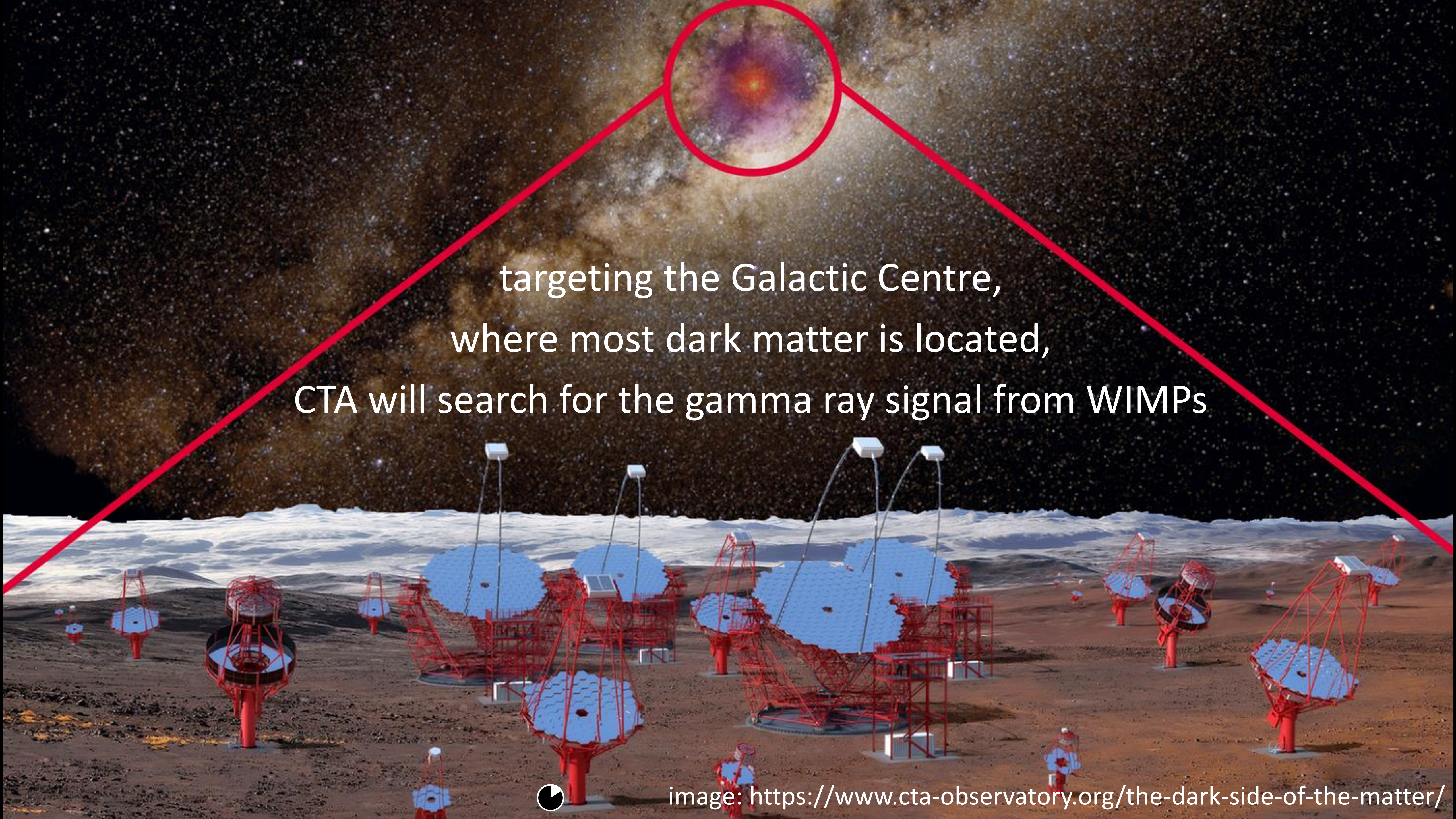
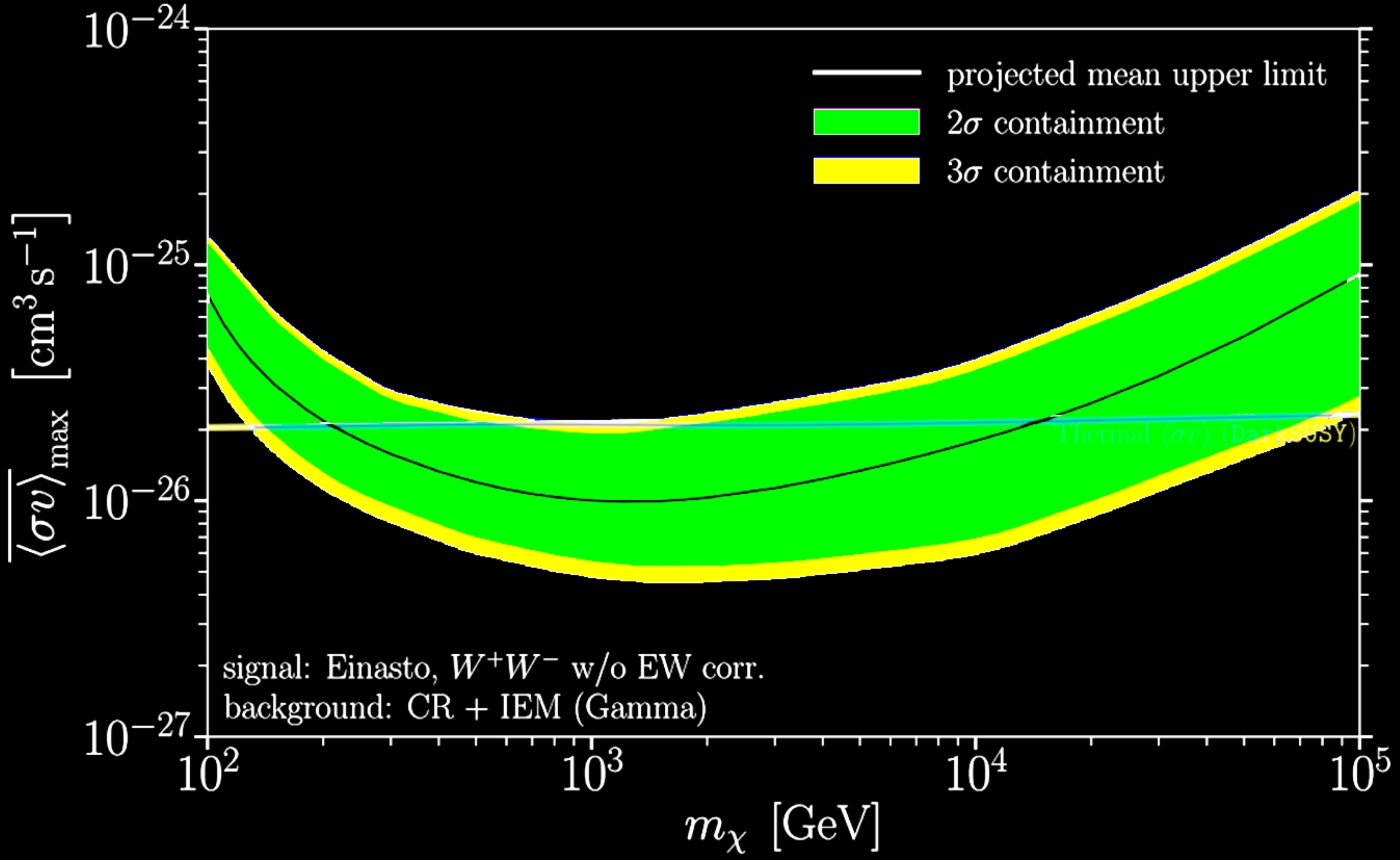


Image: https://physics.aps.org/articles/v11/48

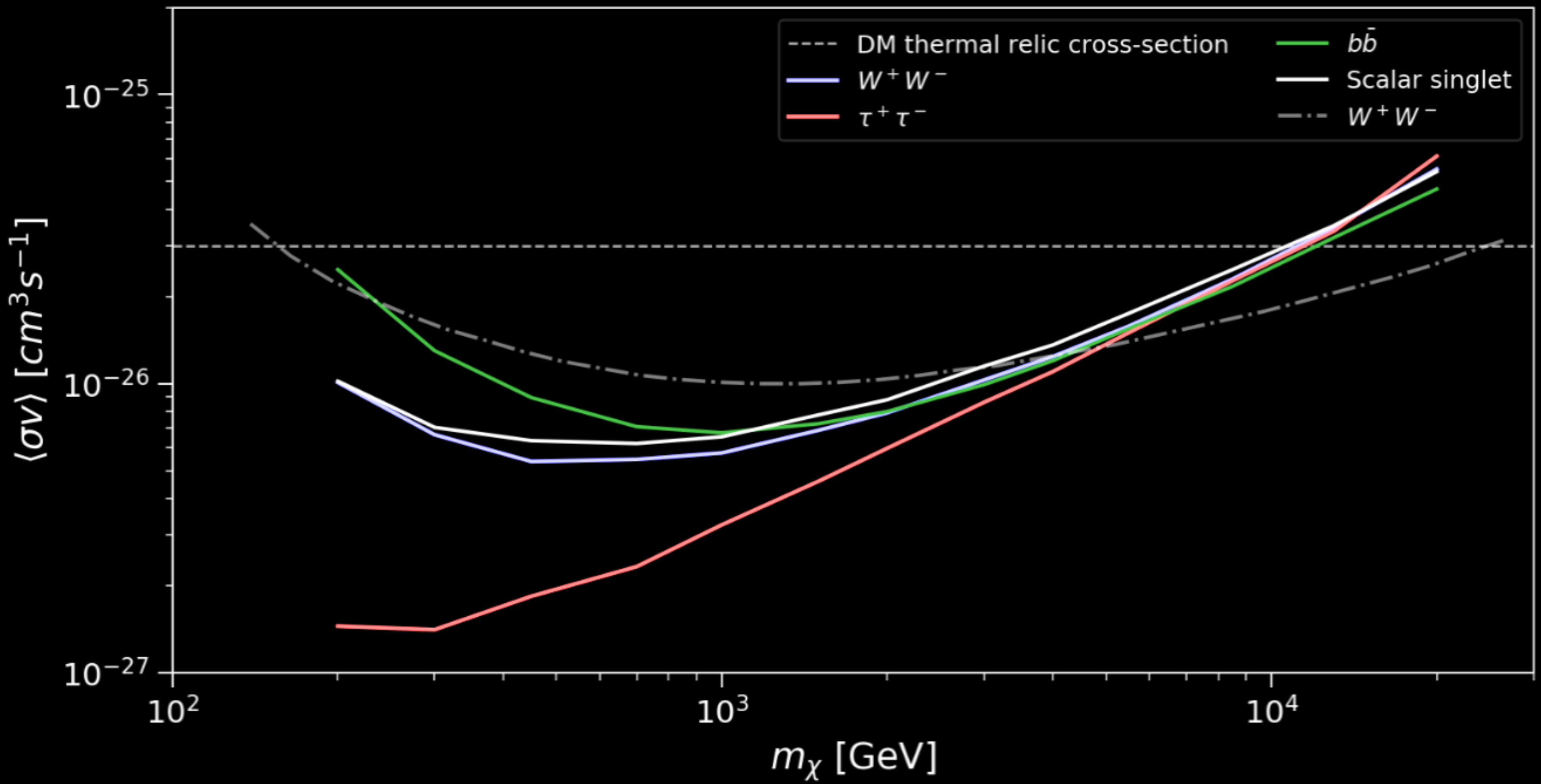

targeting the Galactic Centre,
where most dark matter is located,
CTA will search for the gamma ray signal from WIMPs
image: https://www.cta-observatory.org/the-dark-side-of-the-matter/



the DM WG published sensitivity of CTA for a generic WIMP

our goal is to generalize these limits for specific DM models

image: CTA Consortium JCAP 01 (2021) 057



our Monash group updated these sensitivity limits using sophisticated Bayesian inference and published them, but…

image: Mangipudi et al. JCAP 11 (2022) 010

interestingly, there’s always a but

we believe our approach is more sophisticated, more transparent, more flexible, easier extendable and better suited to CTA than the old one, but…

- our first paper is just the proof of concept of a full analysis
- it uses ctools (vs. Gammapi)
- it uses prod3 config (vs. prod5)
- it’s based on a private code (vs. public)
- we need to work on ‘popularising’ it within (and outside of) CTA

Bayesian inference

$$\mathcal{L}(d^i|\mathcal{S}) = \int d\hat{\Omega}^i \int dE^i\, \mathcal{L}(d_i|\Omega^i E^i)\, \pi(\Omega^i, E^i|\mathcal{S})$$

$$\mathcal{L}(d_i|\mathcal{B}) = \int d\hat{\Omega}_i \int dE_i\, \mathcal{L}(d_i|\Omega^i E^i)\pi(\Omega^i, E^i|\mathcal{B})$$

$$\mathcal{L}(\vec{d}|\lambda) = \prod_i^N \lambda\mathcal{L}(d_i|\mathcal{S}) + (1-\lambda)\mathcal{L}(d_i|\mathcal{B}) \qquad \lambda = \frac{N_\mathcal{S}}{N} \approx \frac{N_\mathcal{S}}{N_\mathcal{B}}$$

$$N_\mathcal{S} = T\int \frac{d\Phi}{d\Omega dE}(E,\psi)A(E)dEd\Omega$$

$$\frac{d\Phi}{d\Omega dE}(E,\psi) = \frac{1}{4\pi}\int_{l.o.s} dl(\psi)\rho_\chi^2(\mathbf{r})\left(\frac{\langle\sigma v\rangle}{2m_\chi^2}\sum B_f\frac{dN}{dE}\right)$$

$$\mathcal{L}(\vec{d}|\lambda) = \prod_i^N \lambda\mathcal{L}(d_i|\mathcal{S}) + (1-\lambda)\mathcal{L}(d_i|\mathcal{B})$$


$\frac{d\Phi}{d\Omega dE}(E,\psi) = \frac{1}{4\pi}\int_{l.o.s} dl(\psi)\rho_\chi^2(\mathbf{r})$
$N_S = T\int$
$\mathcal{L}(\vec{d}|\lambda) = \prod_i^N \lambda\mathcal{L}(d_i|\mathcal{S}) + (1-\lambda)$
$\frac{N_S}{N} \approx \frac{N_S}{N_B}$

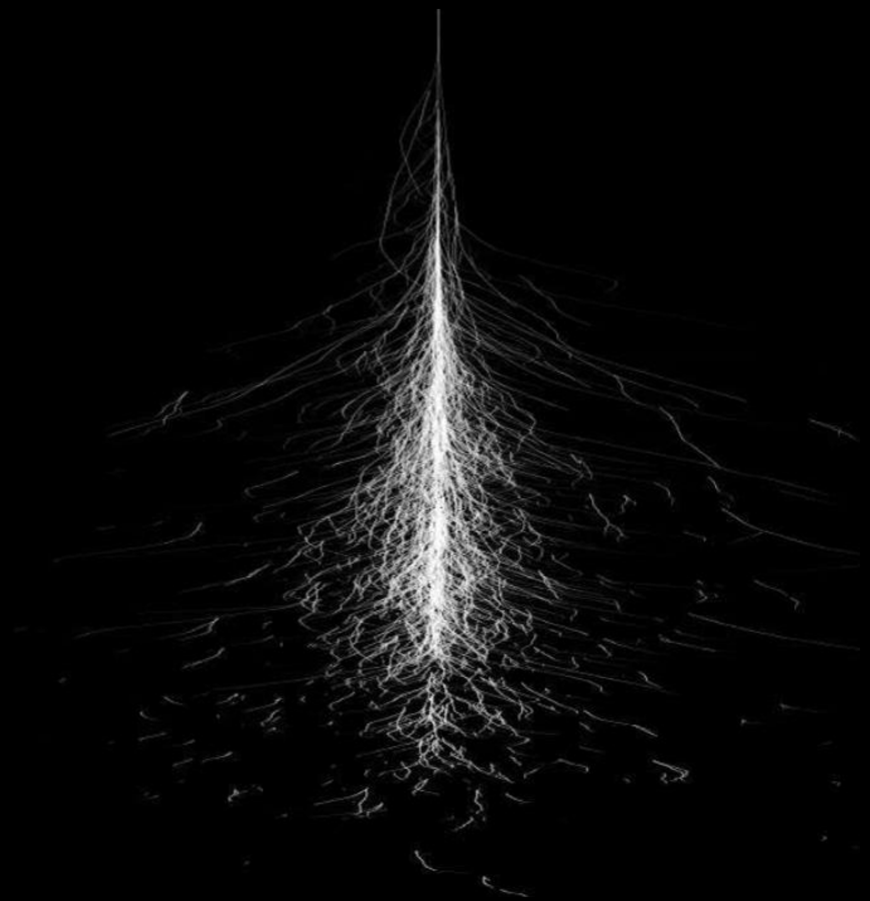
Bayesian inference – take 2

we're trying to separate signal from background

signal: photons originating from dark matter particles
background: everything else that the detector responds to

so, let's look at the 'detection process' step by step

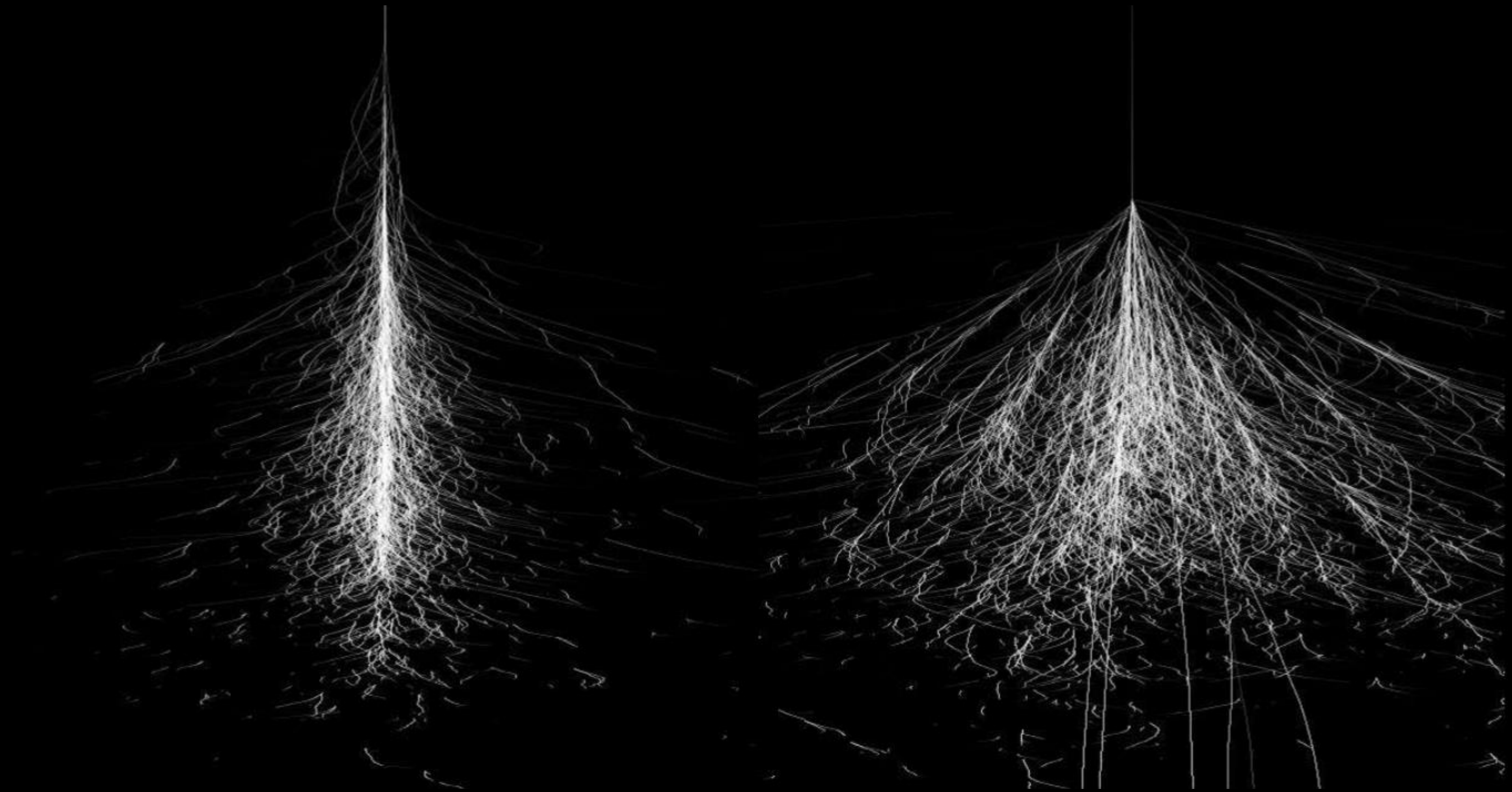
a gamma ray creates a shower of particles



we’d like to know if its signal or background

image: Völk, Bernlöhr Exper.Astron. 25 (2009) 173-191

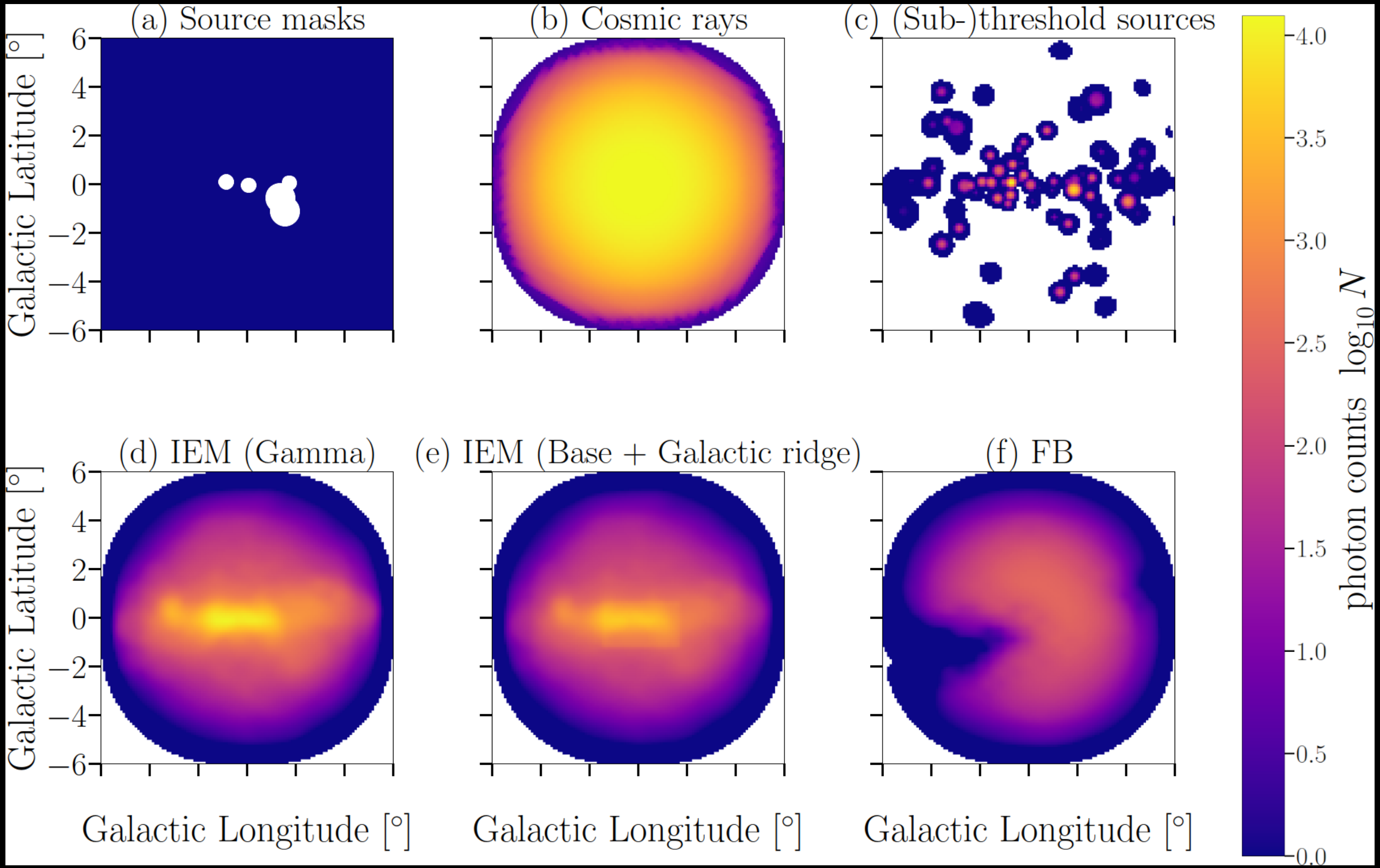
background #1: mis-identified cosmic rays



gamma showers are slightly skinnier than hadronic ones

image: Völk, Bernlöhr Exper.Astron. 25 (2009) 173-191

background #2: standard astrophysics



H.E.S.S. and FermiLAT informs us about standard gamma ray sources

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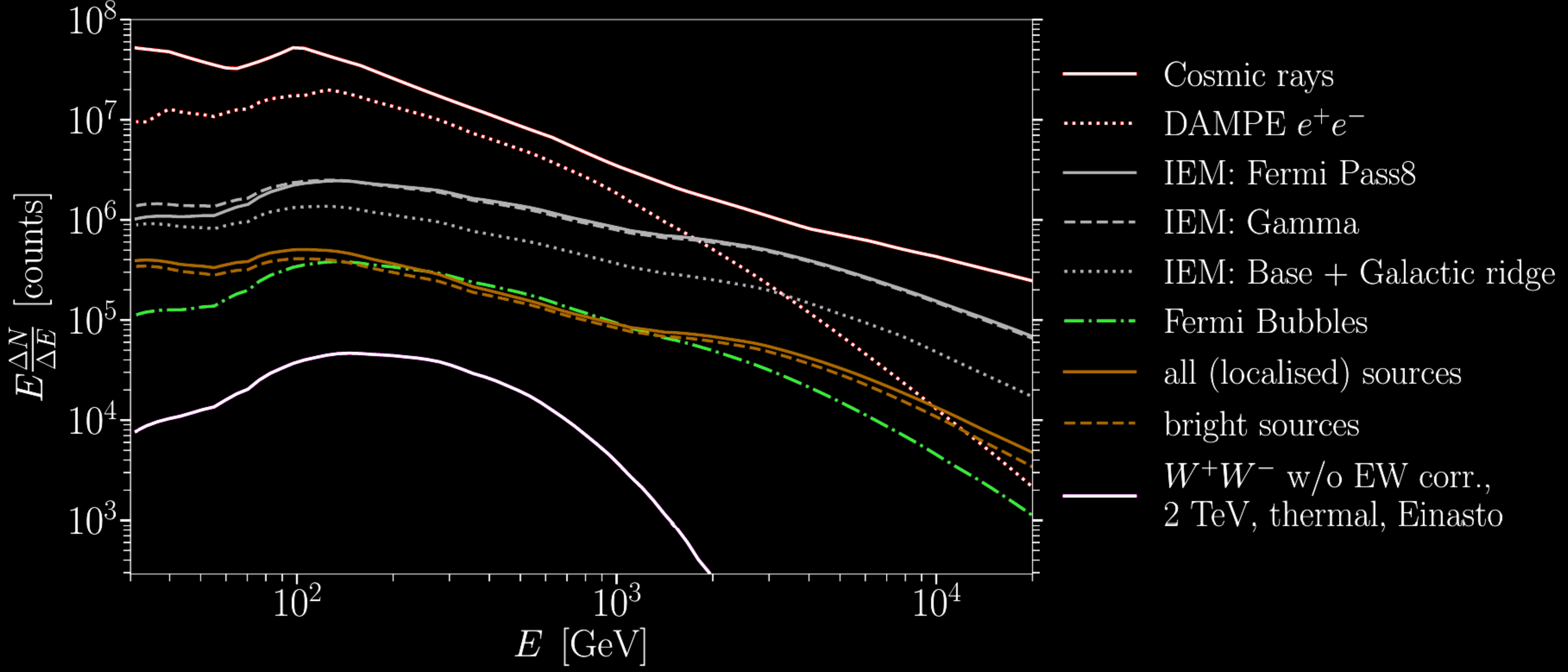
background #2: standard astrophysics



H.E.S.S. and FermiLAT informs us about standard gamma ray sources

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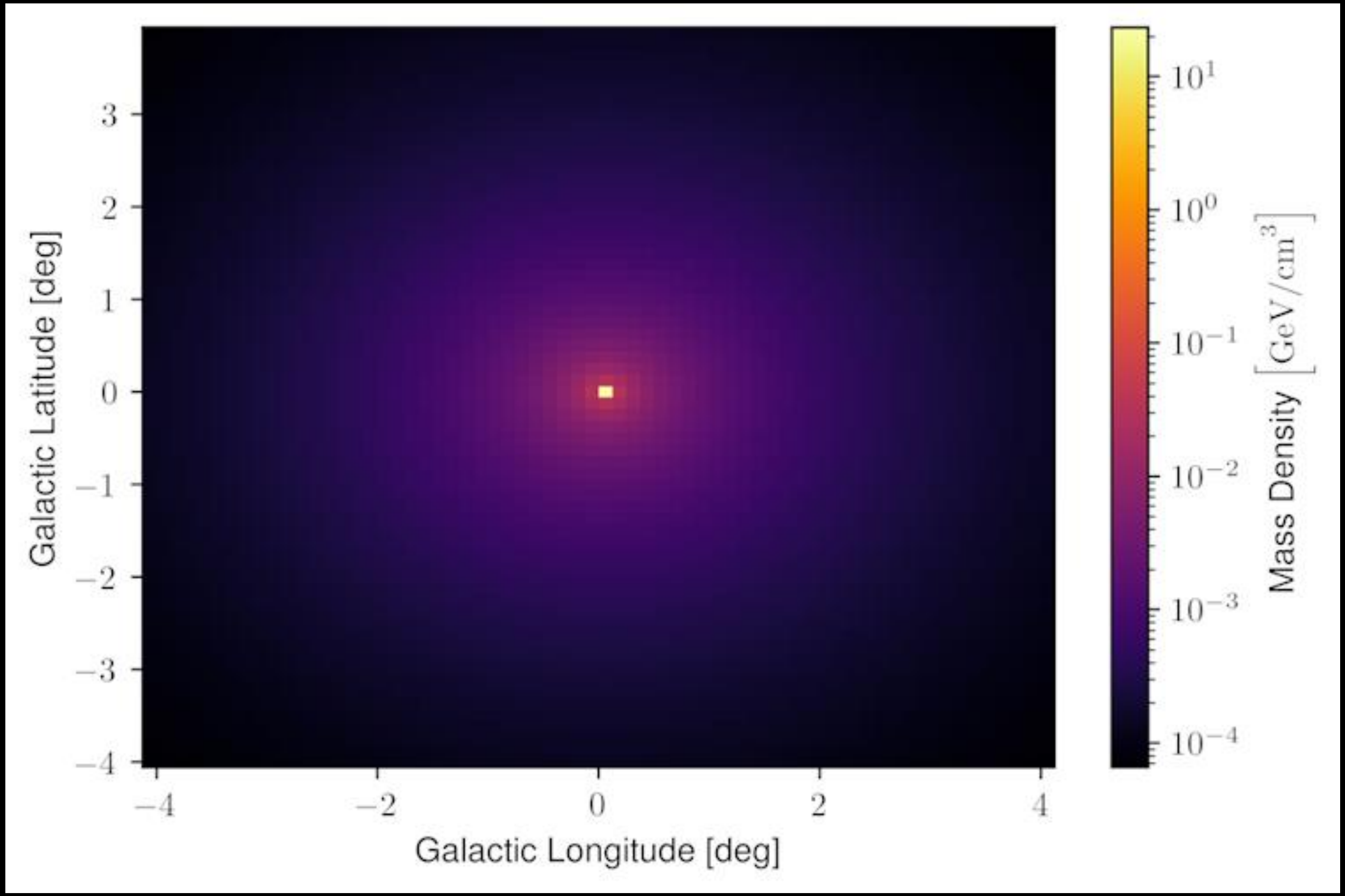
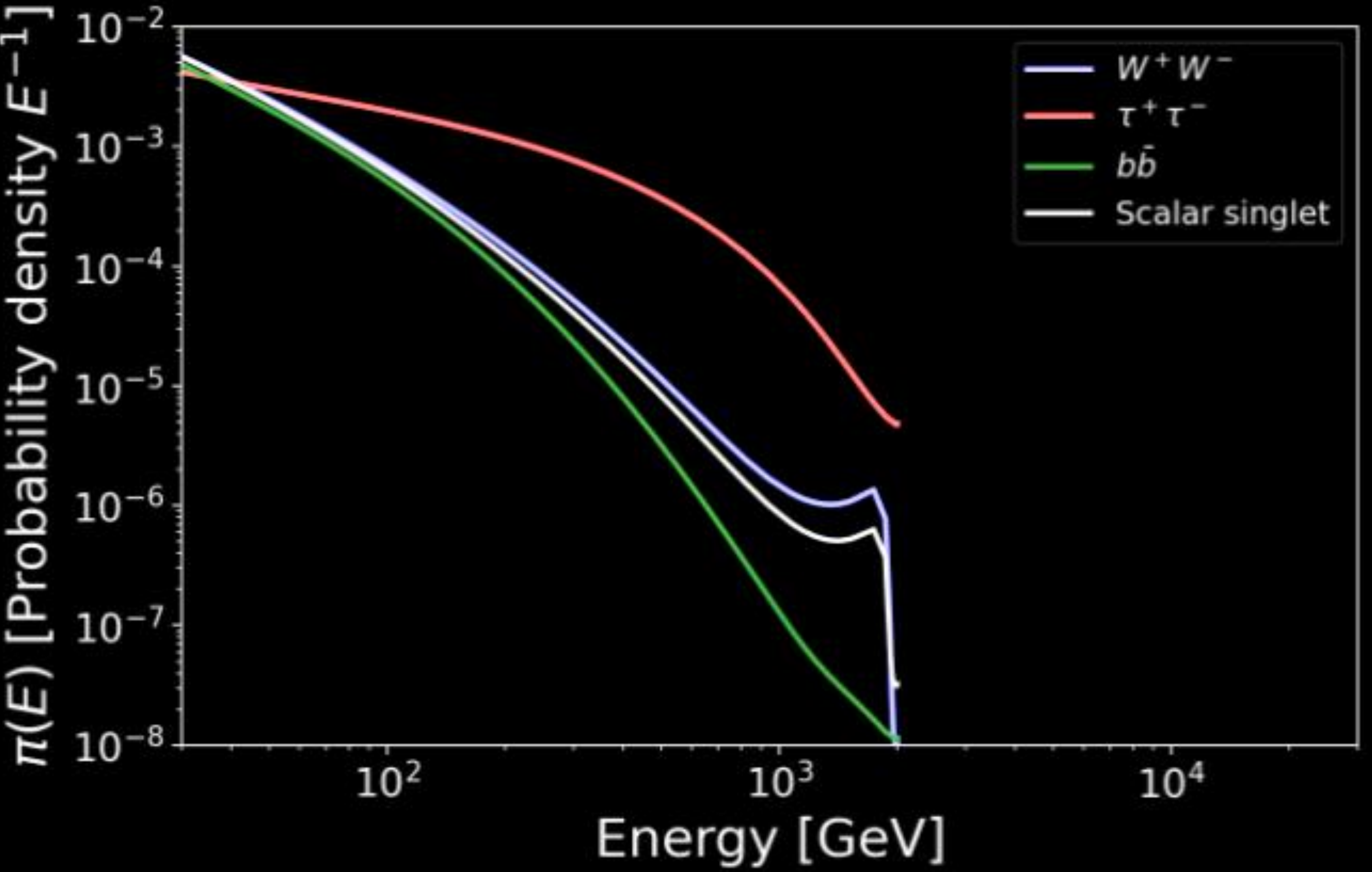
signal: gamma rays from dark matter



spatial distribution of the expected signal

image: Einasto profile from Gammapi

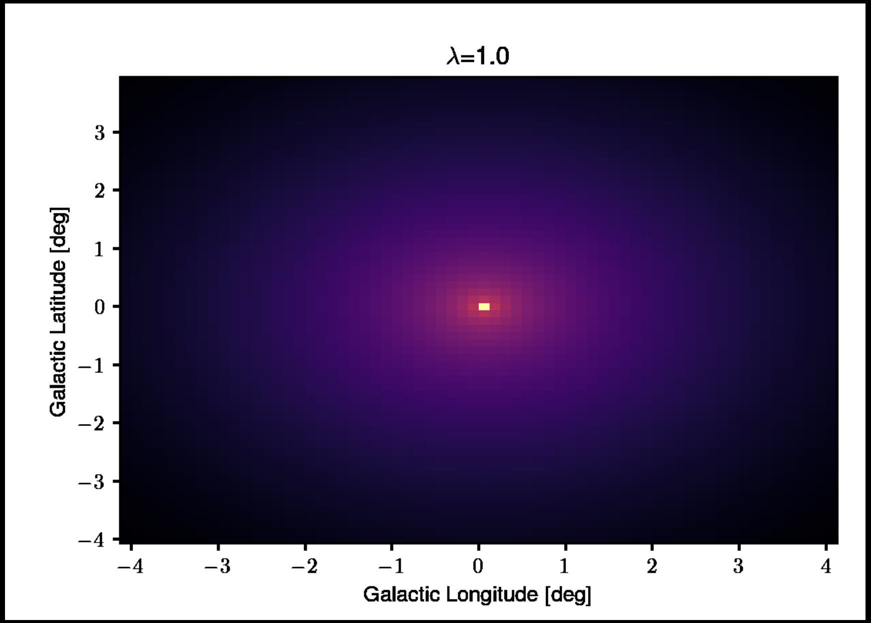
signal: gamma rays from dark matter

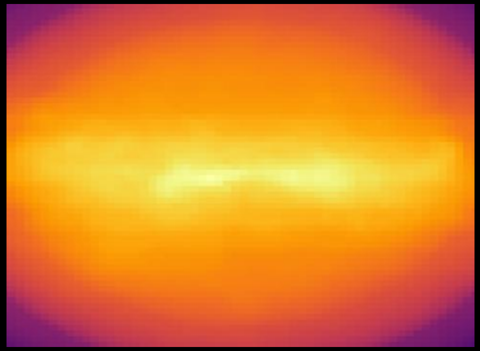


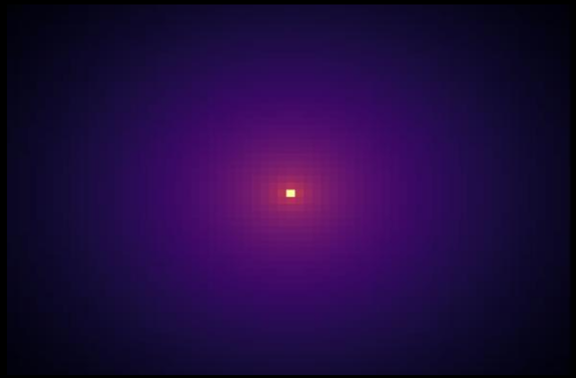
energy distribution of the expected signal

image: Einasto profile from Gammapi

decide how much signal can CTA detect



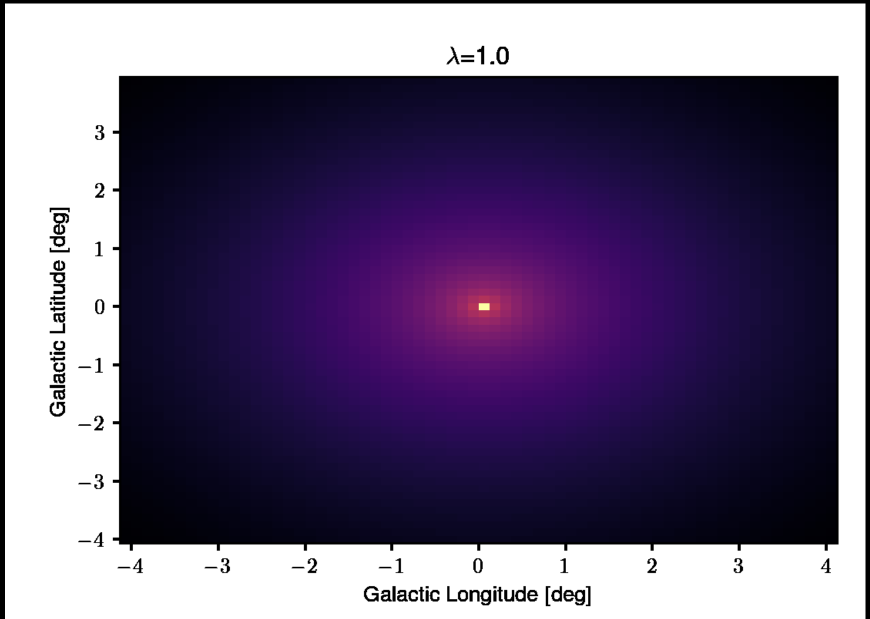




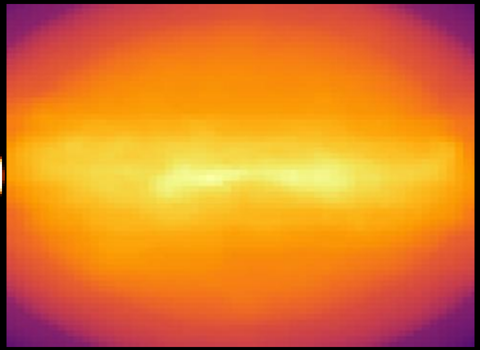
inference: probability of detecting a certain amount of signal

image: Einasto profile from Gammapi

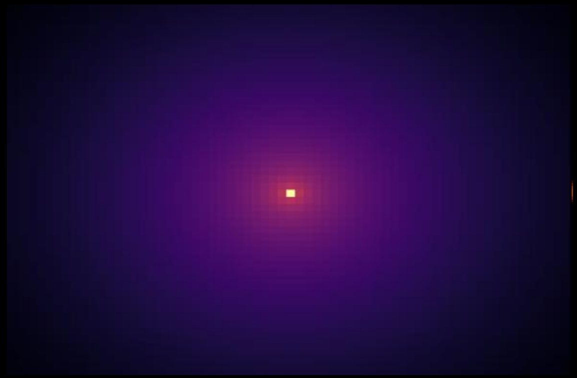
decide how much signal can CTA detect



$= (1 - \lambda)$



$+ \lambda$



reach: the minimal amount of signal CTA can detect

image: Einasto profile from Gammapi

decide how much signal can CTA detect

$$p(E_m, \psi_m | m_\chi, \lambda, S, B) = (1 - \lambda)\, p(E_m, \psi_m | B) + \lambda\, p(E_m, \psi_m | m_\chi, S)$$

reach: the minimal amount of signal CTA can detect

image: Einasto profile from Gammapi

decide how much signal can CTA detect

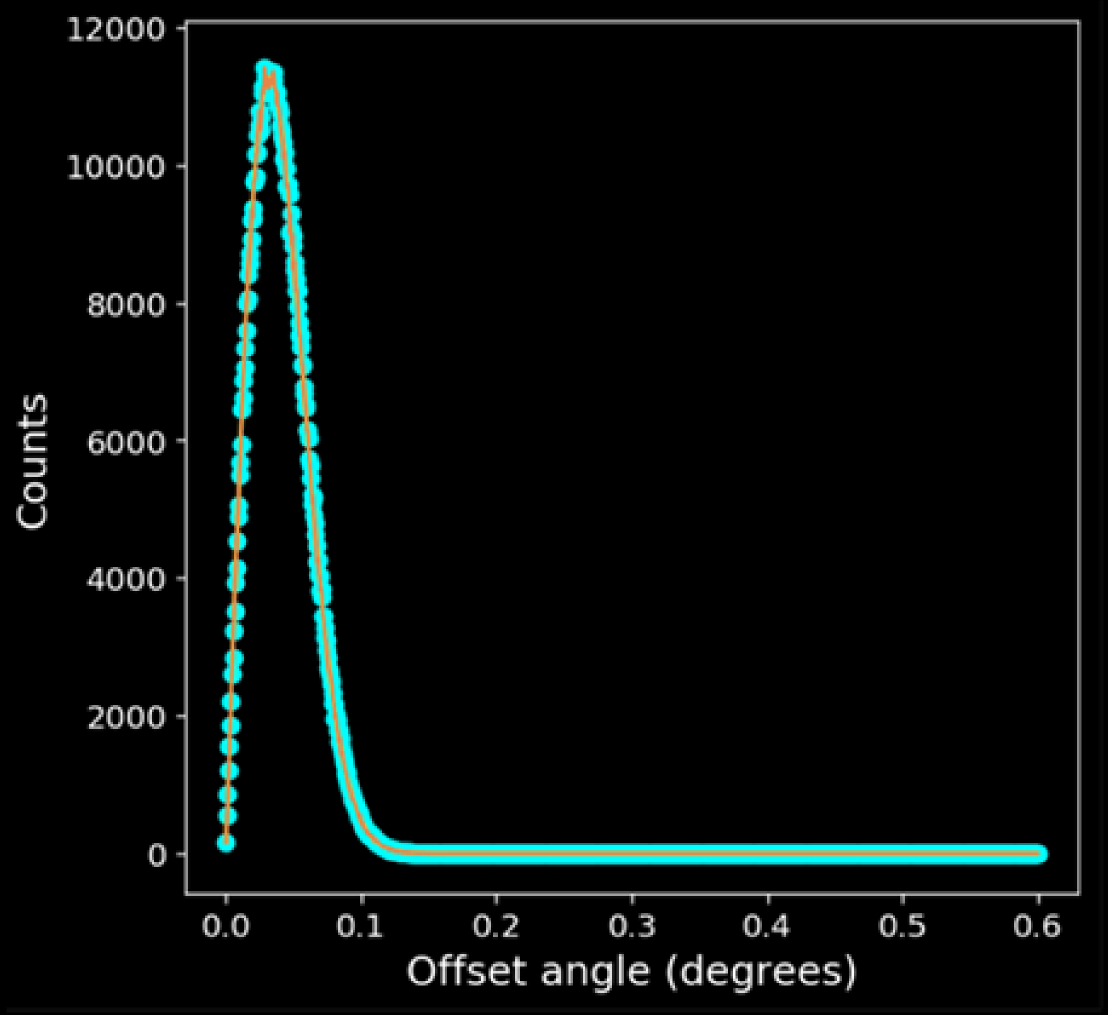
$$p(E_m, \psi_m | m_\chi, \lambda, S, B) = (1 - \lambda)\, p(E_m, \psi_m | B) + \lambda\, p(E_m, \psi_m | m_\chi, S)$$

formulated in this statistical framework it is easy to fold in:

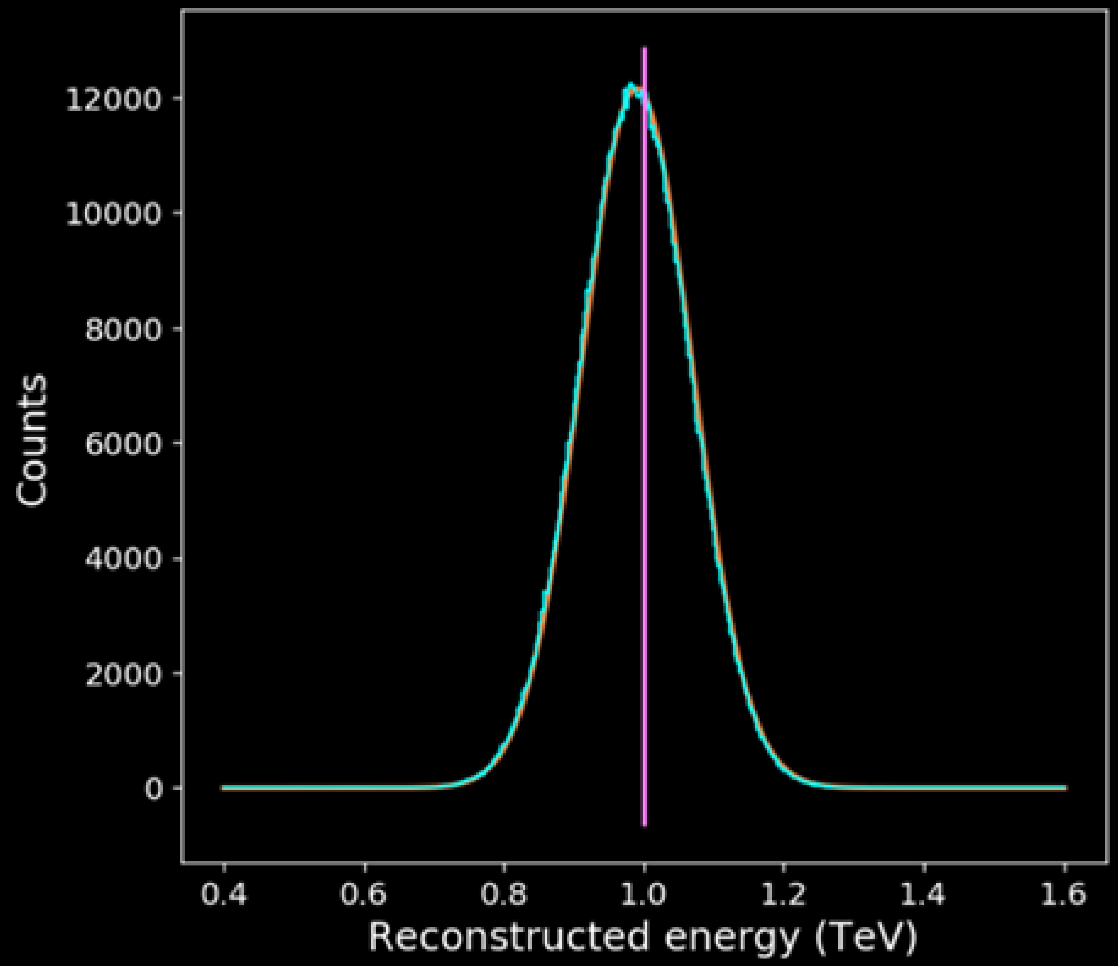
- spatial resolution of the detector (given in Gammapi)
- energy resolution of the detector (given in Gammapi)
- any other ‘systematics’
- length of detection time
- limit determination or detection
- etc.

image: Einasto profile from Gammapi

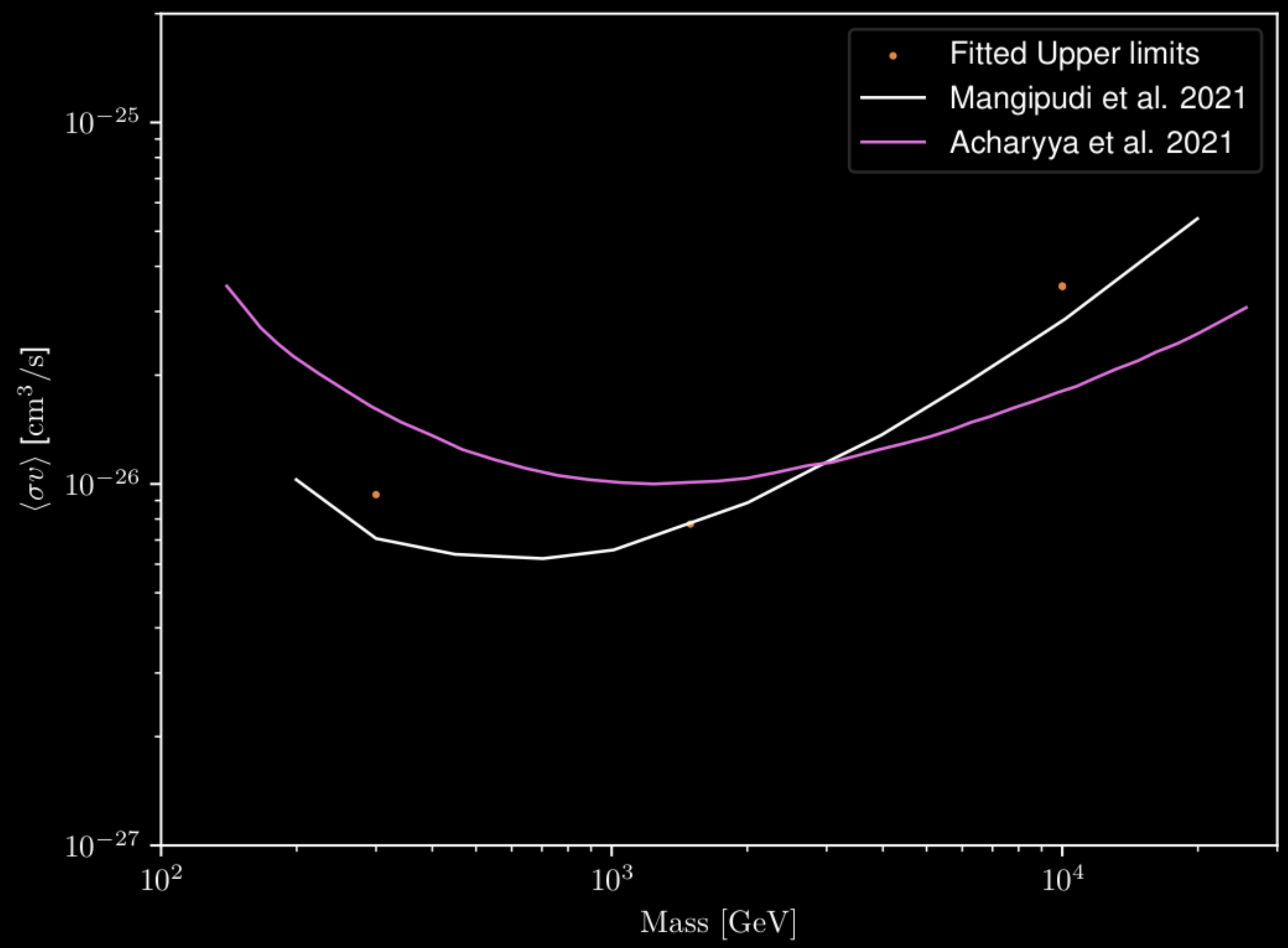
spatial resolution: point spread function



energy resolution: dispersion function



latest ‘limits’ for annihilation cross section



We’re in the middle of updating our CTA DM reach inference framework.

The new framework will kick @ss:

- use hierarchical Bayesian inference
- use latest detector parameters
- accommodate any systematics
- public code based on Gammapi

New paper is expected early next year!