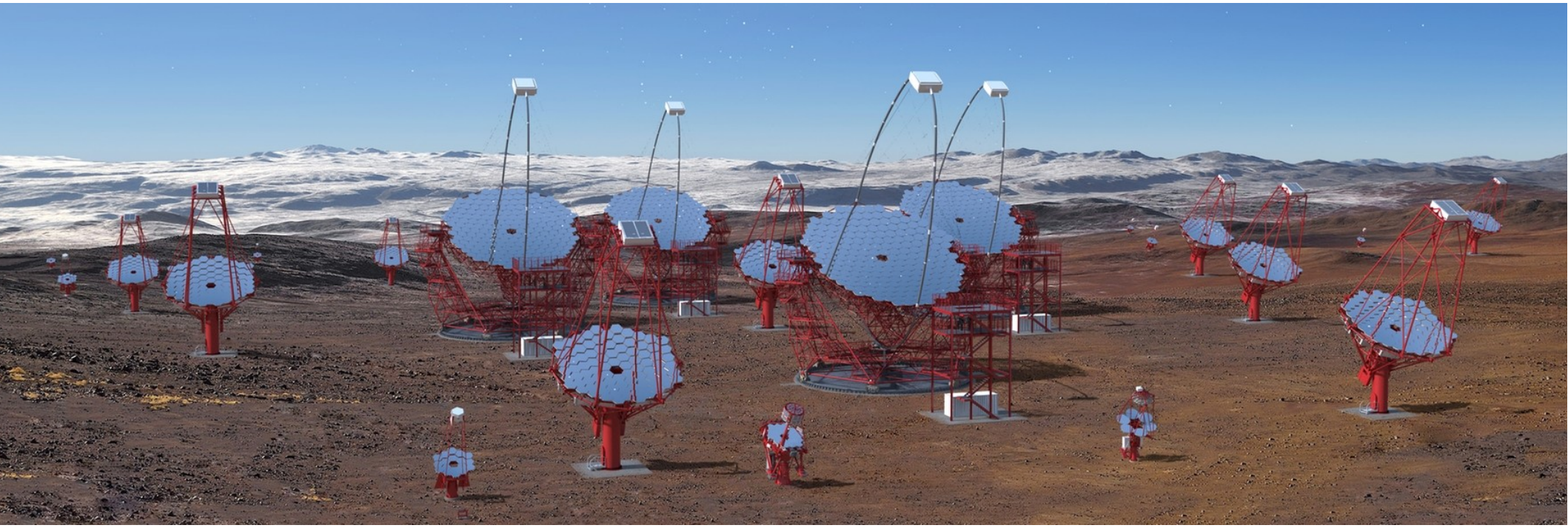
Probing the Nature of Dark Matter with Gamma Rays: Prospects for the CTA at the Galactic Center



The 14th International Workshop „Dark Side of the Universe“

25 – 29 June 2018

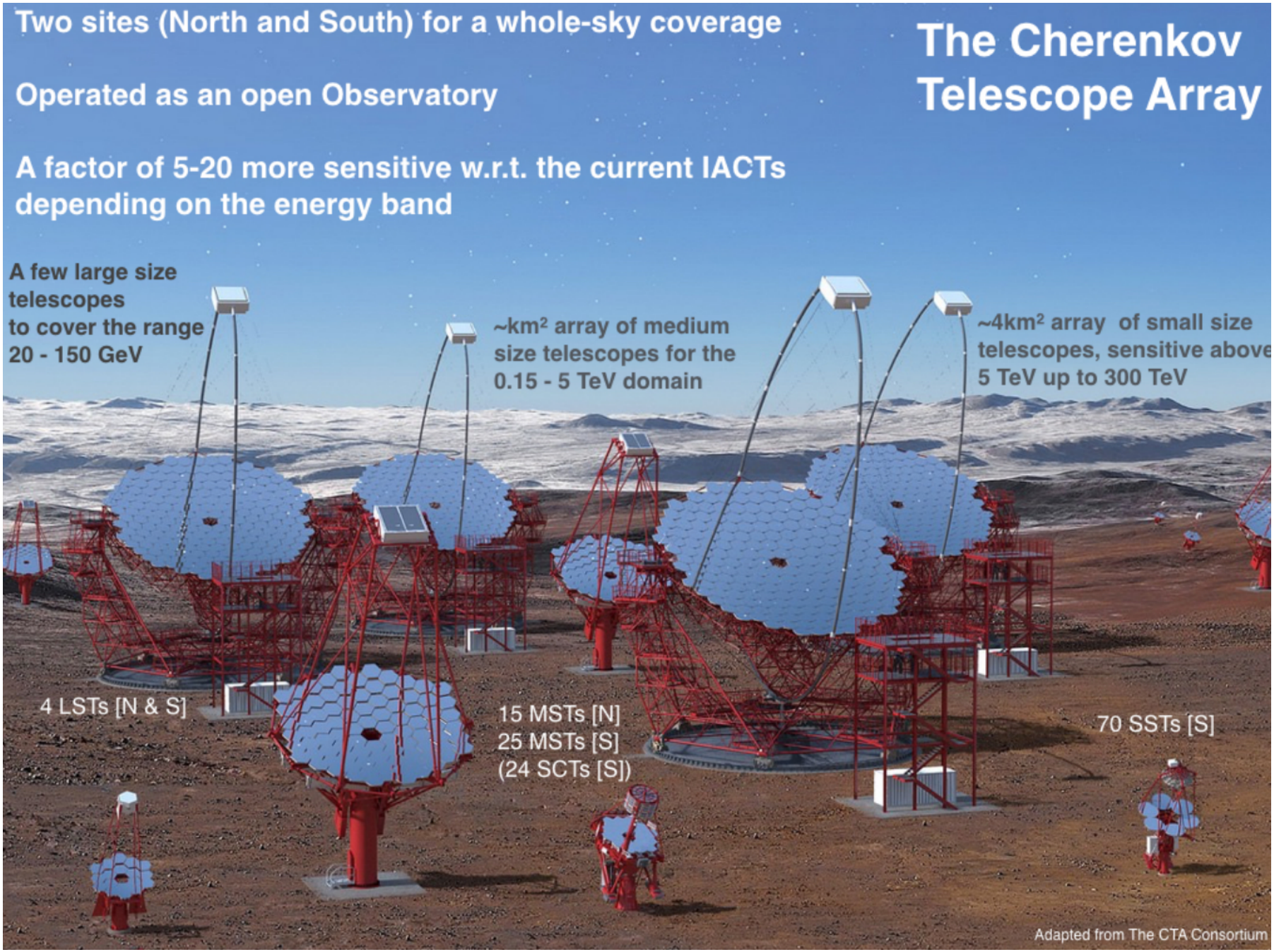
Annecy-le-Vieux, France

Speaker: Christopher Eckner

T. Bringmann, C. Eckner, A. Sokolenko, L. Yang and G. Zaharijas

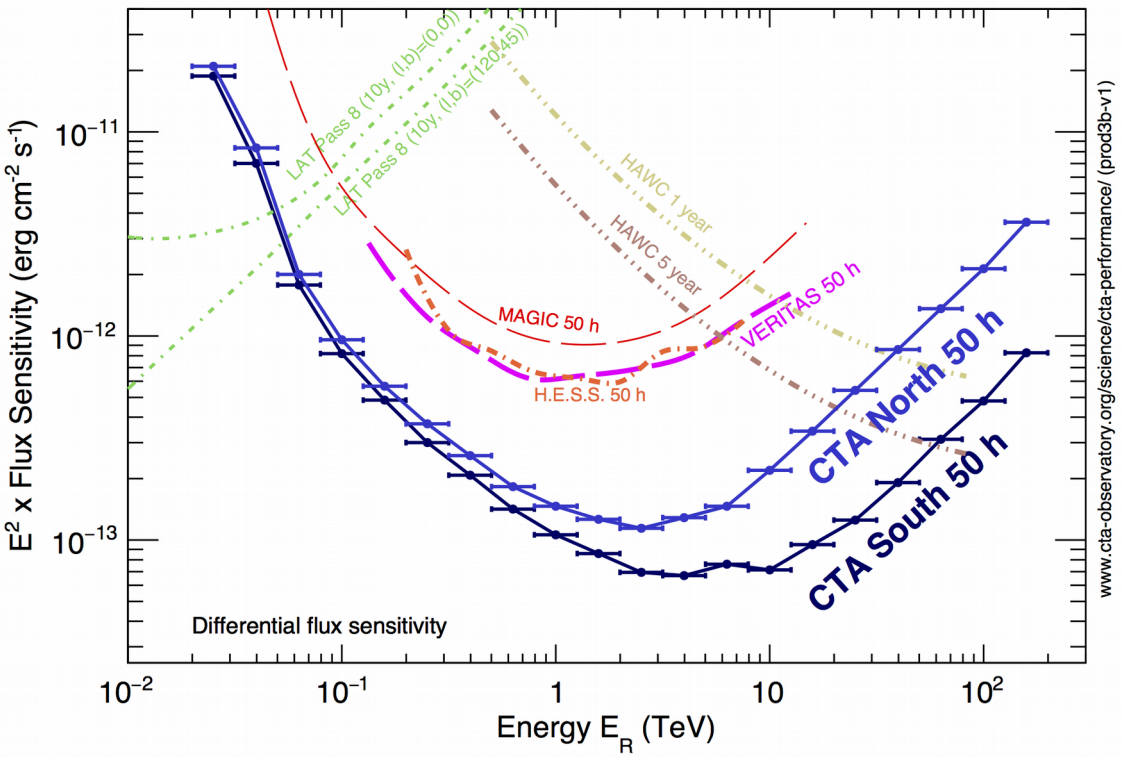
for the CTA Consortium

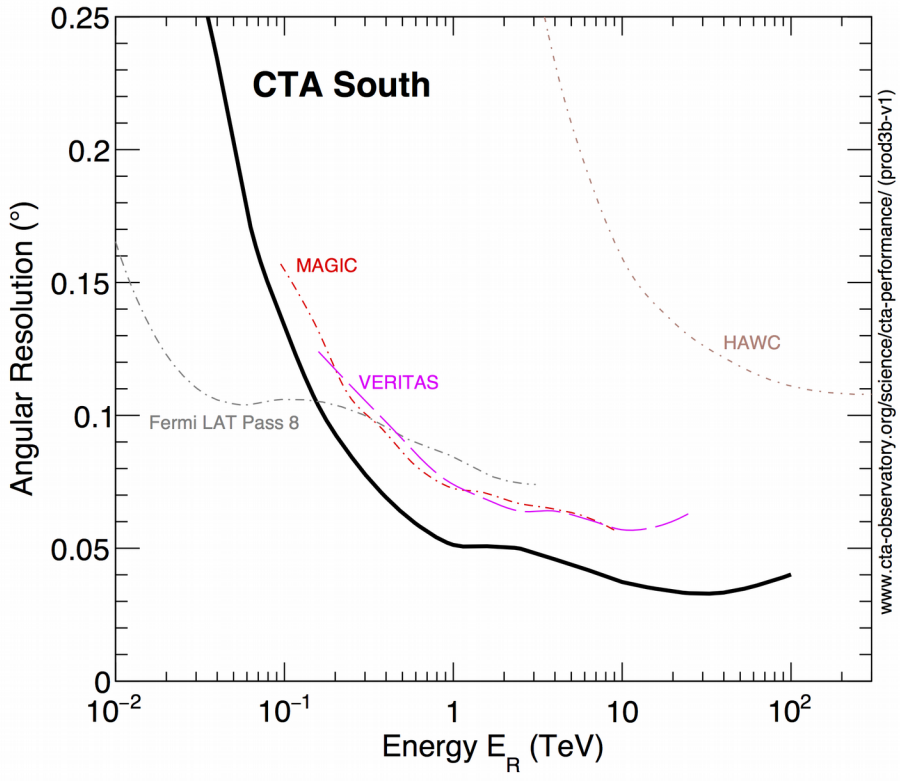
The Cherenkov Telescope Array



CTA Performance

CTA will provide very wide energy range and excellent angular resolution and sensitivity compared to existing gamma-ray telescopes!

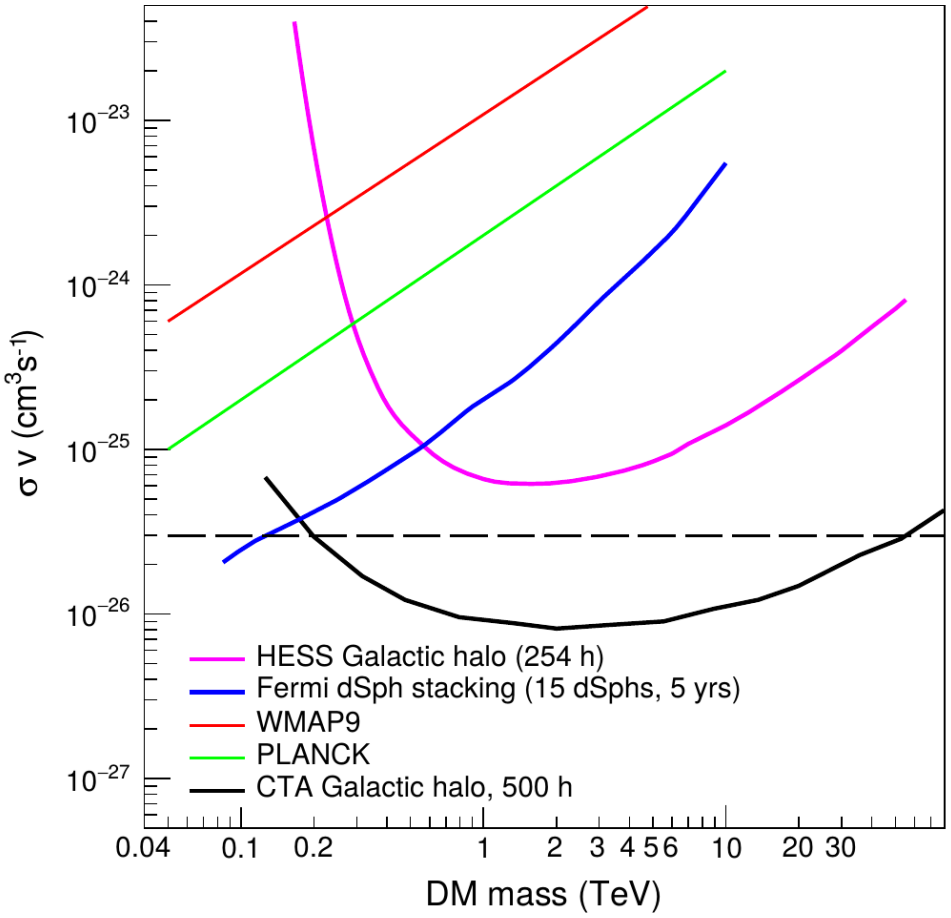




forecasted energy range: 20 GeV to 300 TeV

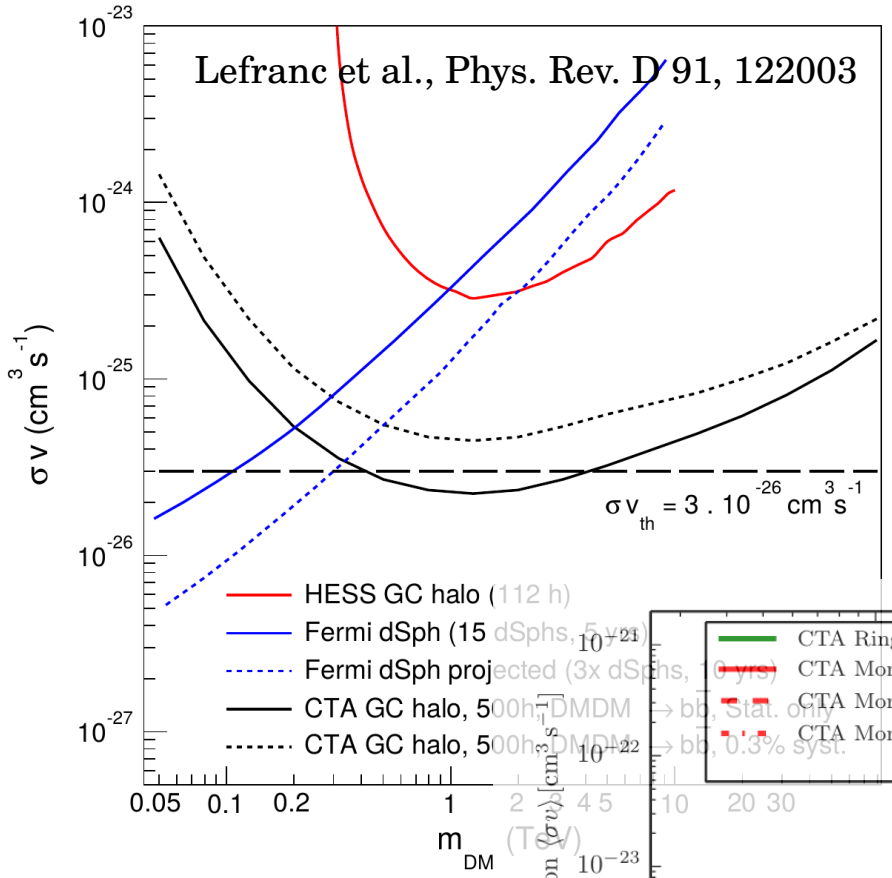
A Key Science Project of the CTA

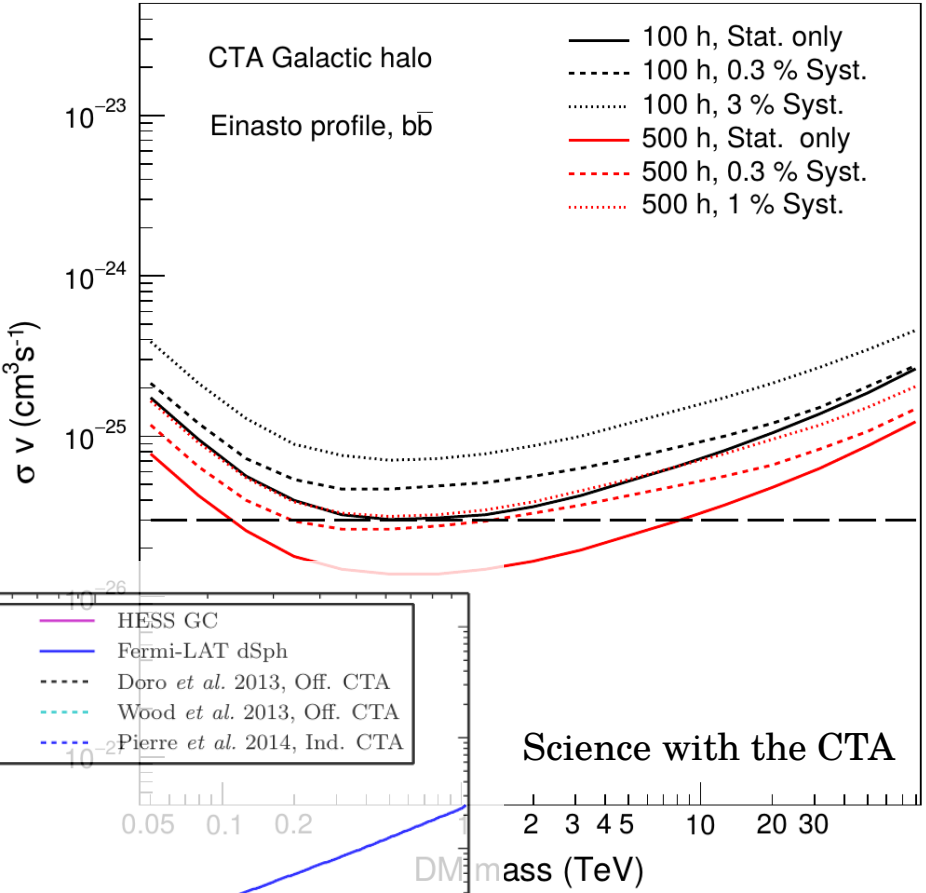
The search for a dark matter annihilation signal from the Galactic Centre is a key science project of the CTA, since:



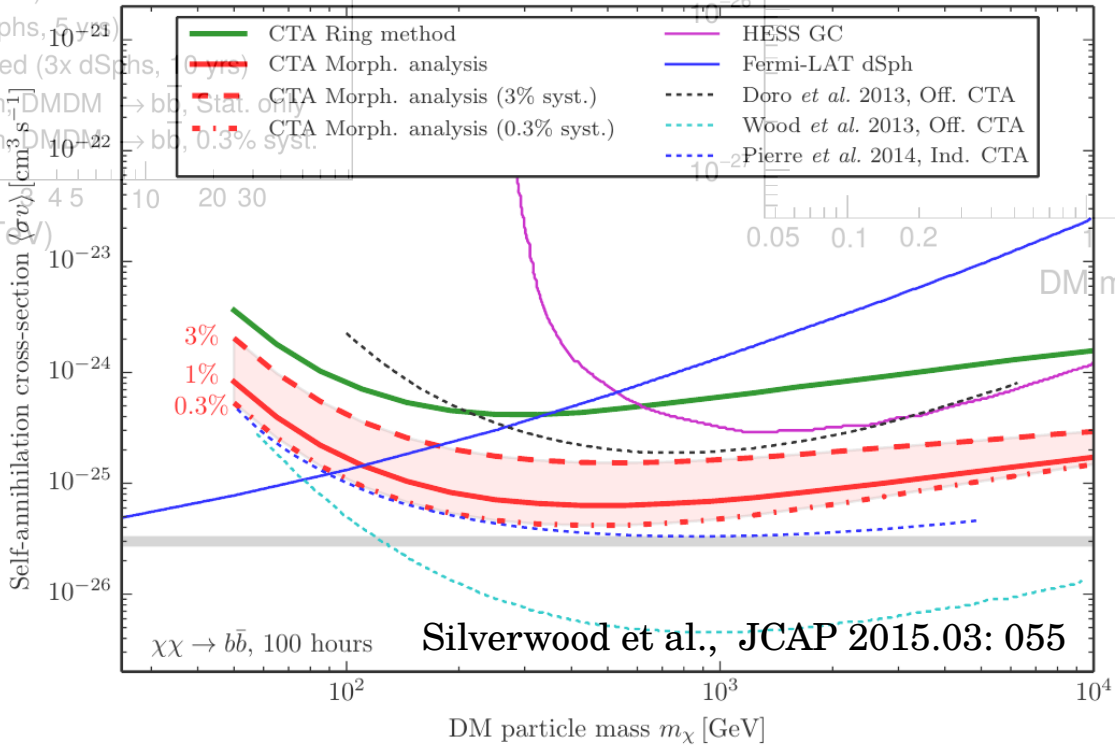
CTA is a "TeV scale DM detection machine".

The CTA's DM Sensitivity in Previous Studies



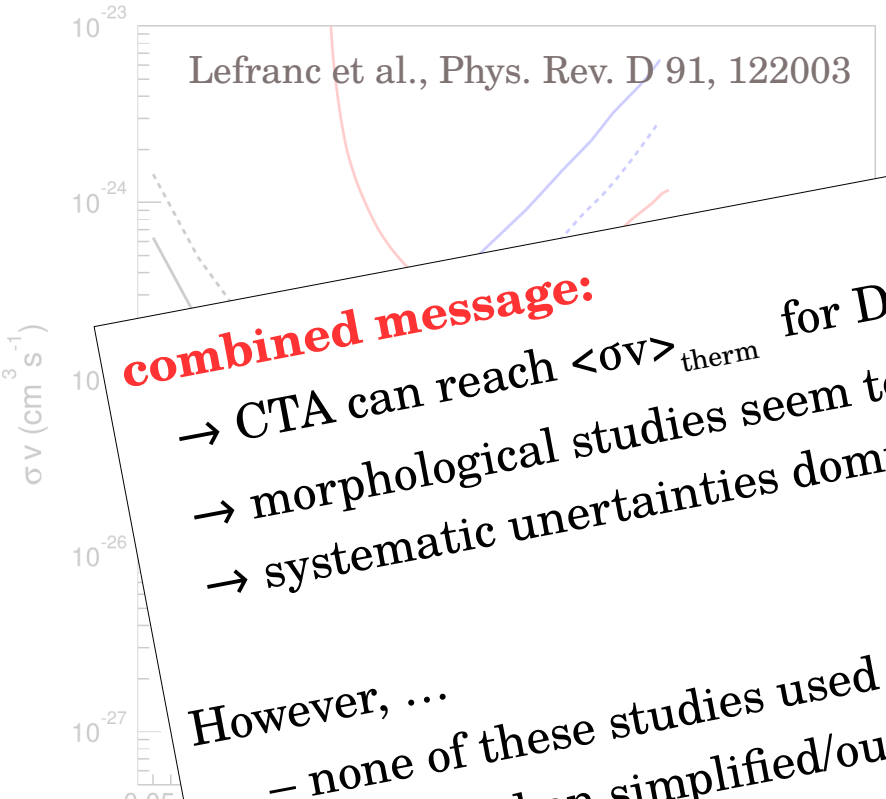


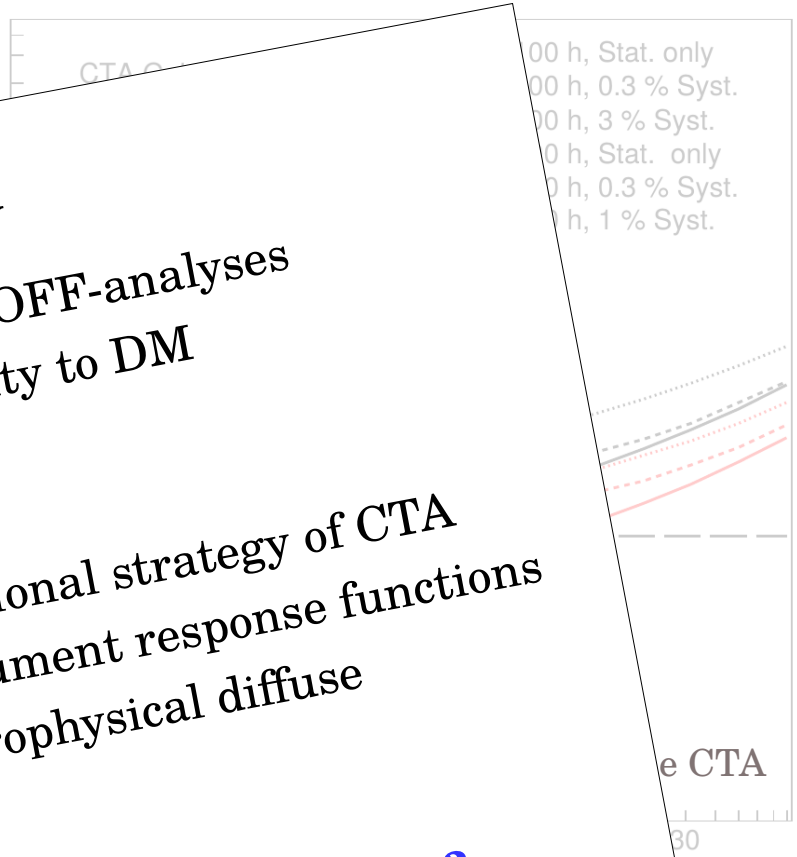
Science with the CTA

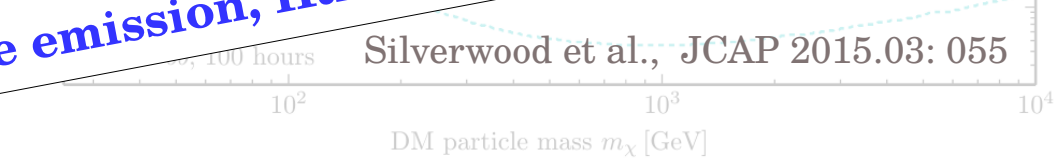


Silverwood et al., JCAP 2015.03: 055

The CTA's DM Sensitivity in Previous Studies







combined message:

→ CTA can reach $\langle\sigma v\rangle_{therm}$ for DM masses ~ 1 TeV

→ morphological studies seem to outperform ON/OFF-analyses

→ systematic unertainties dominate the sensitivity to DM

However, …

– none of these studies used planned observational strategy of CTA

– are based on simplified/outdated CTA instrument response functions

– make simplistic assumptions about the astrophysical diffuse emission in that region.

Can we do better with a template fit approach?

What is the realistic DM sensitivity, given state-of-the-art models of diffuse emission, IRFs and CTA's observational strategy?

Objectives

- Define the most promising data analysis (binned likelihood vs ON/OFF analysis; mask size etc.) and observational strategy for DM search in the Galactic Centre region, using state-of-the-art modelling of astrophysical and instrumental backgrounds and relying on the CTA collaboration‘s own telescope property studies

- Derive the realistic sensitivity to DM signal from the centre of our Galaxy and define the requirement on the level of the systematics uncertainty, needed to reach thermal cross section for different DM density profiles and channels

- Promote CTA as an instrument to reach TeV scale DM: the GC is the only target which can give sensitivities below the 3×10^{-26} cm^3 s^{-1} annihilation cross-section expected in WIMP models

Methodology – Statistical Framework

Final Objective:

Comparison of DM limits derived from

a) **binned likelihood analysis** (current stage)

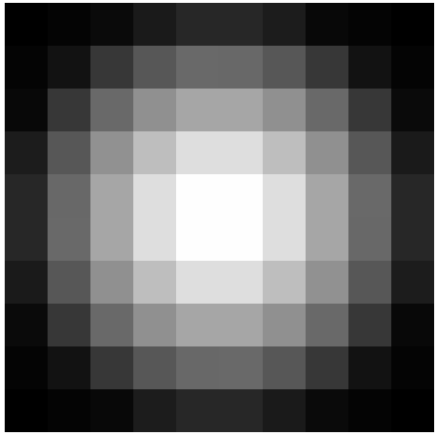
b) standard ON/OFF - approach

Likelihood function (including systematics → α_{ij}, β_i)

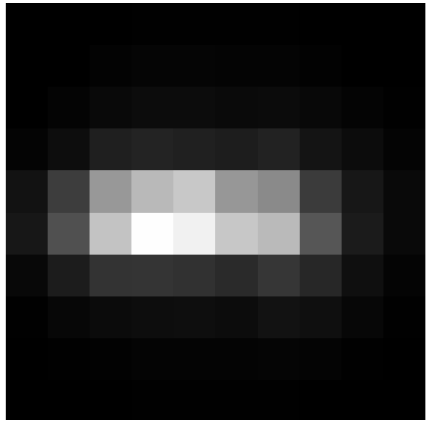
$$\mathcal{L}(\boldsymbol{\mu}, \boldsymbol{\alpha}, \boldsymbol{\beta} | \boldsymbol{n}) = \prod_i \frac{1}{\sqrt{2\pi}\sigma_\beta} e^{-\frac{(1-\beta_i)^2}{2\sigma_\beta^2}} \prod_j \frac{(\mu_{ij}\alpha_{ij}\beta_i)^{n_{ij}}}{\sqrt{2\pi}\sigma_\alpha \cdot n_{ij}!} e^{-\mu_{ij}\alpha_{ij}\beta_i} e^{-\frac{(1-\alpha_{ij})^2}{2\sigma_\alpha^2}}$$

(energy bins) (spatial bins)

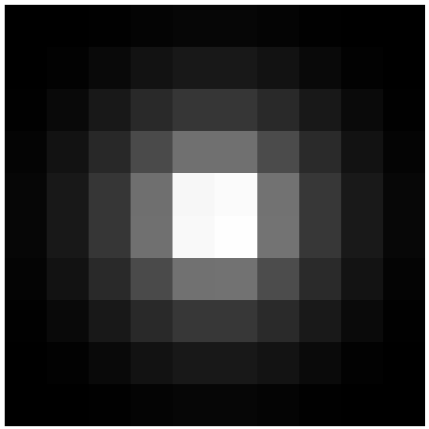
→ using mock data **n** (Asimov data set)



Residual Instrumental Background (CR)



Galactic Diffuse Emission (GDE)



Dark Matter (DM) Signal

Methodology – Statistical Framework

Final Objective:

Comparison of DM limits derived from

Likelihood function (including systematics

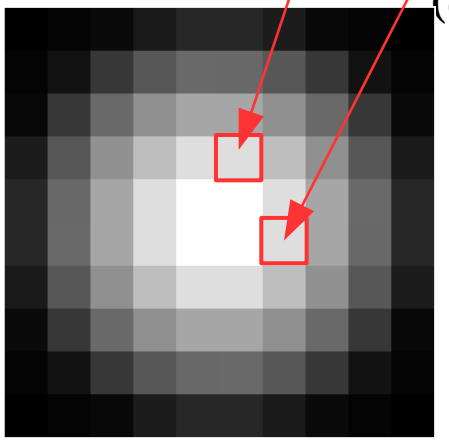
→ α_{ij}: **pixel-to-pixel systematics**, i.e.

each spatial pixel may vary independently of the others by σ_α

→ $\beta_i = 1$: overall rescaling of the signal neglected so far

$$\mathcal{L}(\mu, \alpha, \beta | n) = \prod_i \frac{1}{\sqrt{2\pi}\sigma_\beta} e^{-\frac{(1-\beta_i)^2}{2\sigma_\beta^2}} \prod_j \frac{(\mu_{ij}\alpha_{ij}\beta_i)^{n_{ij}}}{\sqrt{2\pi}\sigma_\alpha \cdot n_{ij}!} e^{-\mu_{ij}\alpha_{ij}\beta_i} e^{-\frac{(1-\alpha_{ij})^2}{2\sigma_\alpha^2}}$$

(energy bins) (spatial bins)



CR

Galactic Diffuse Emission (GDE)

Dark Matter (DM) Signal

Astrophysical Background Components

Galactic Diffuse Emission

Fermi Bubbles Point Sources

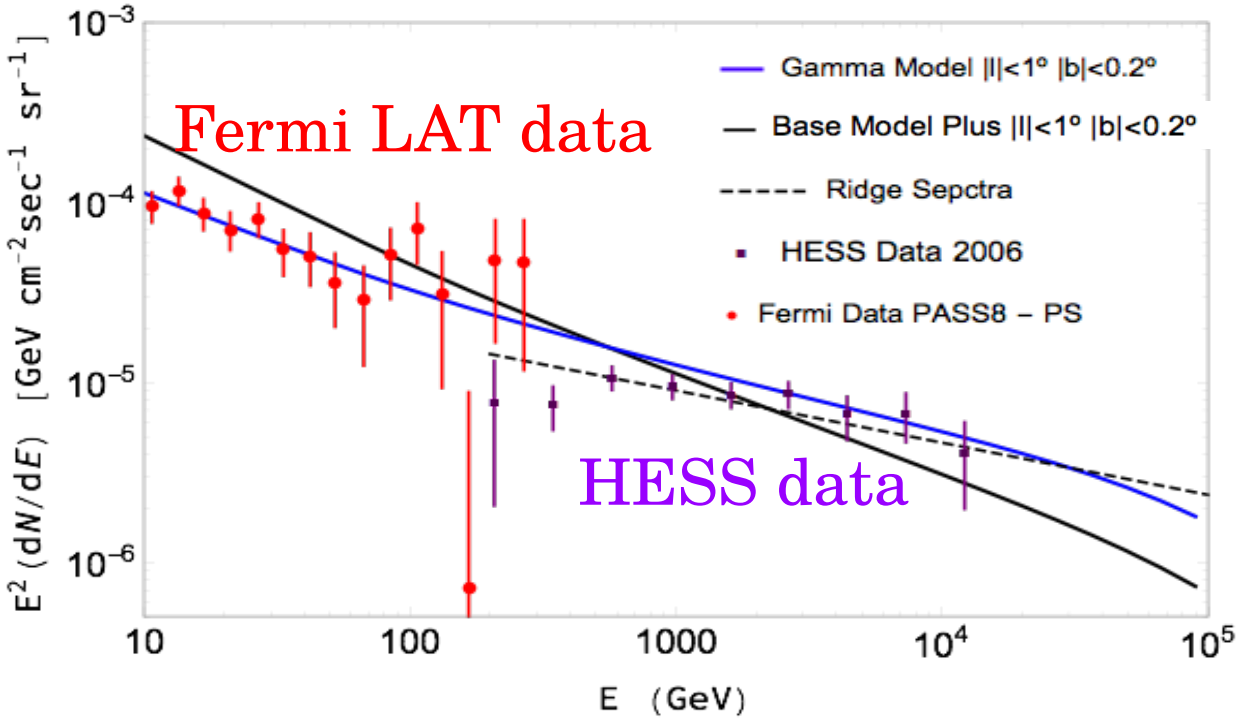
to be added later

– morphology and spectrum rather uncertain

– shows degeneracies with the DM component

→ source of systematic uncertainties

bracket uncertainties via two model templates



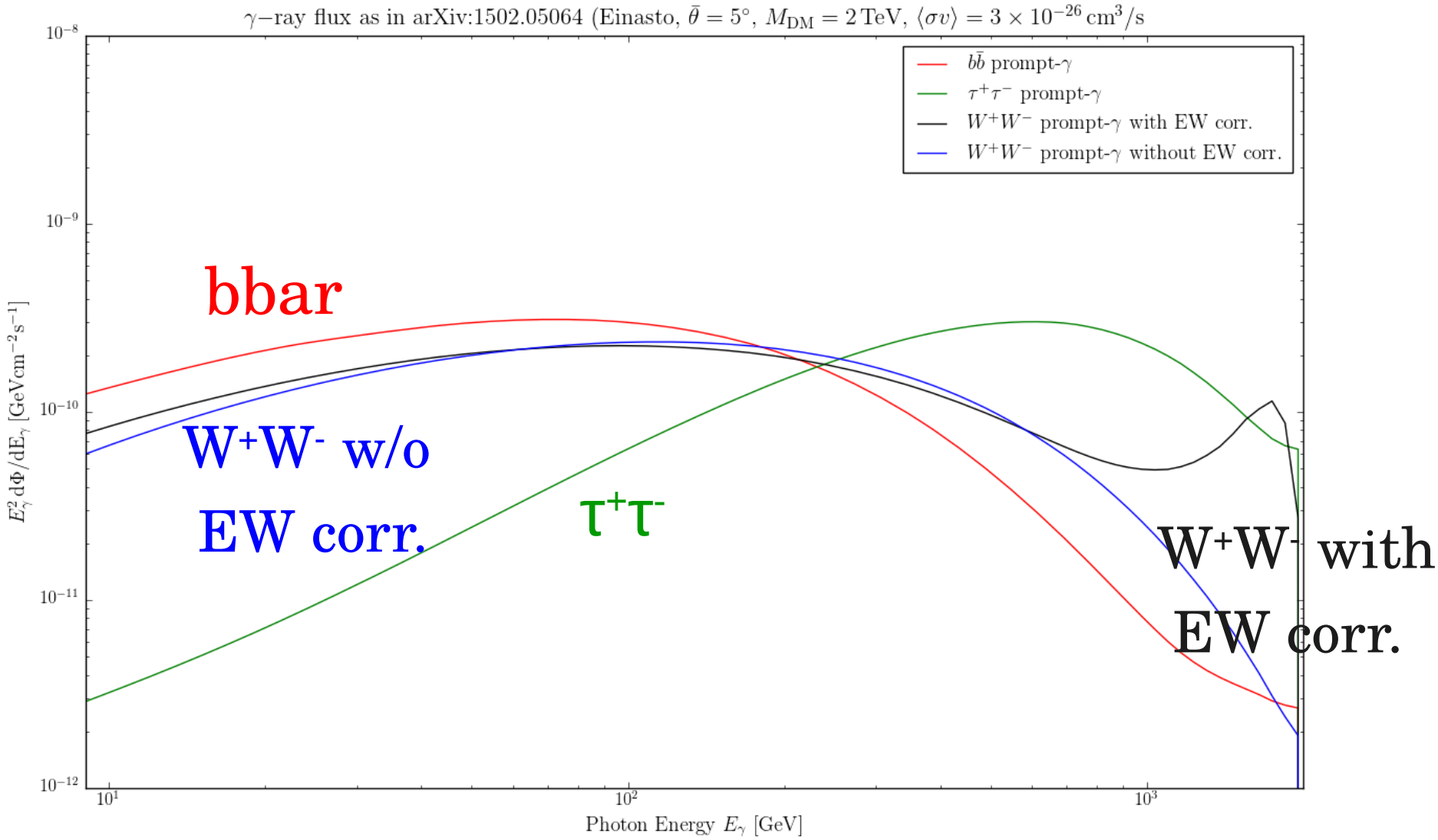
(D. Gaggero et al., arXiv:1702.01124)

GammaModelPlus:
fits both Fermi and HESS data in Galactic Ridge, assumes position-dependent diffusion coefficient

BaseModelPlus:
more conventional model tuned to Fermi data from larger region around GC

Dark Matter Annihilation Spectra

spectra taken from Cirelli et al., arXiv:1012.4515 ("PPPC")



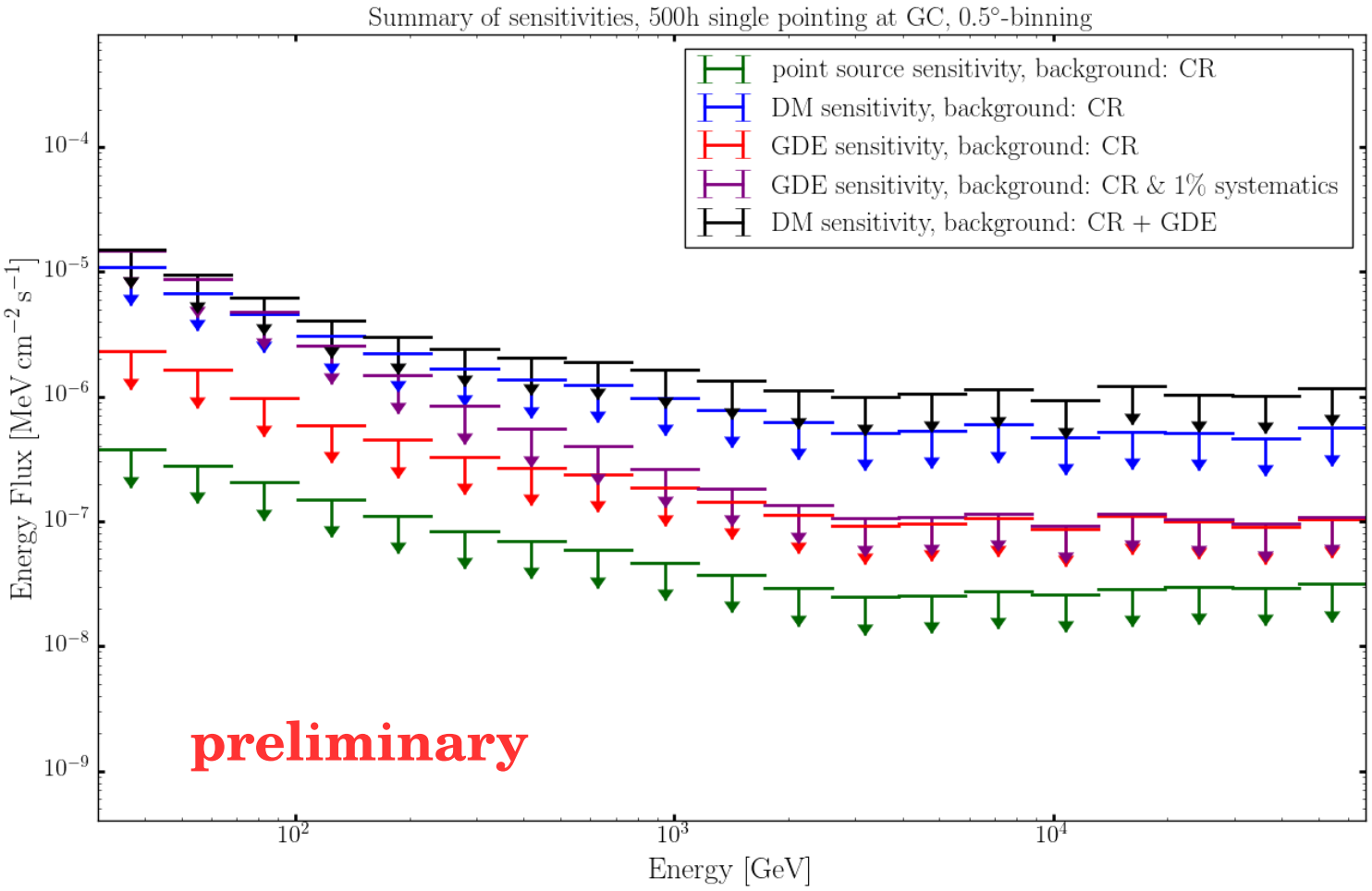
Preliminary Results – Projected Sensitivity

Summary of the CTA's sensitivity to a diffuse emission component

(in our binned likelihood procedure)

→ added: point source sensitivity w.r.t. to our methodology (green)

→ effect of 1% pixel-to-pixel systematics of GDE comp. included (purple)

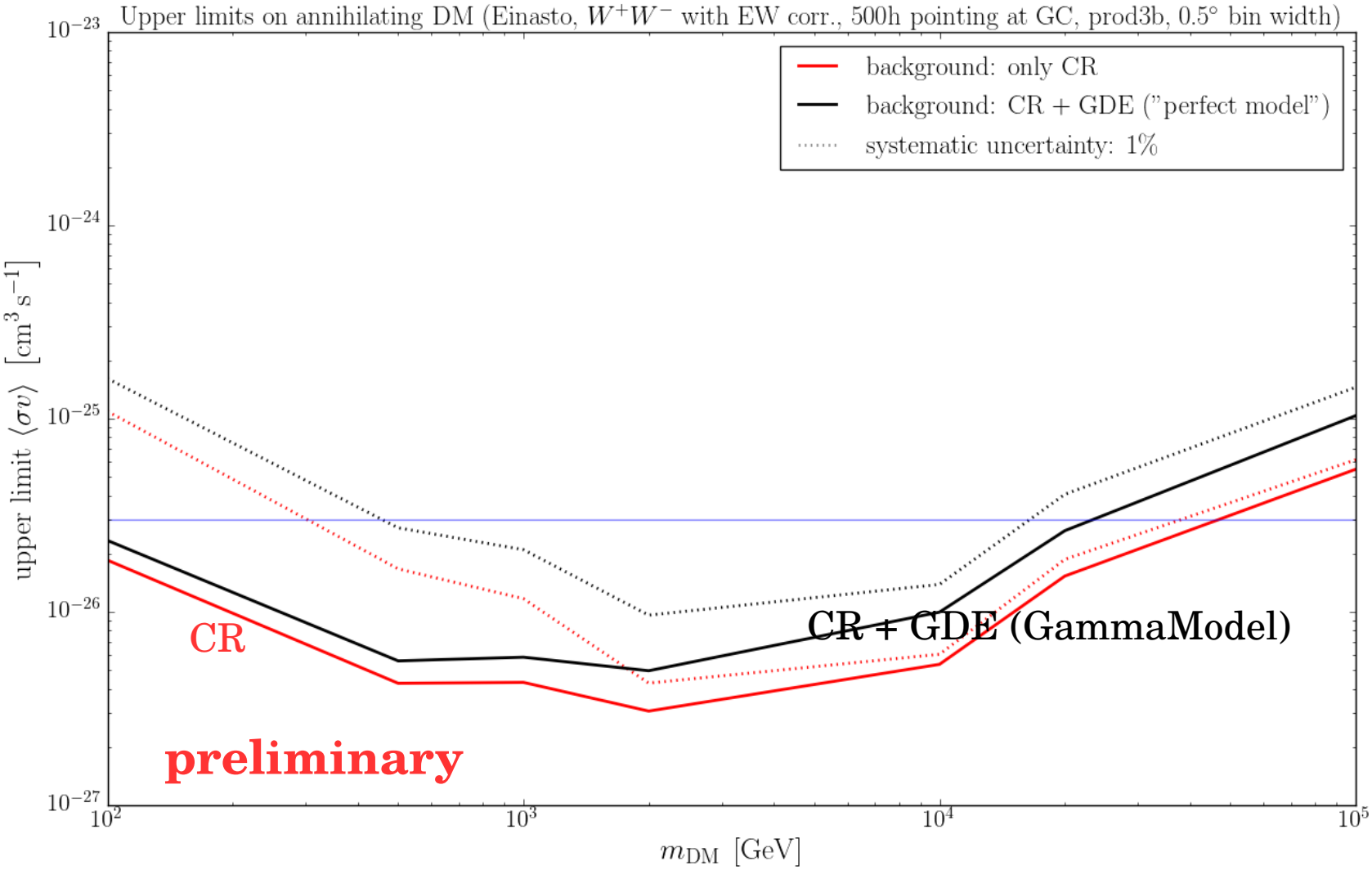


Preliminary Results – Dark Matter Limits

Consider the WW – channel with EW corrections ...

→ Assume ‘perfect‘ modelling of the diffuse emission with the GammaModel template.

→ What is the effect of adding 1% pixel-to-pixel systematics?

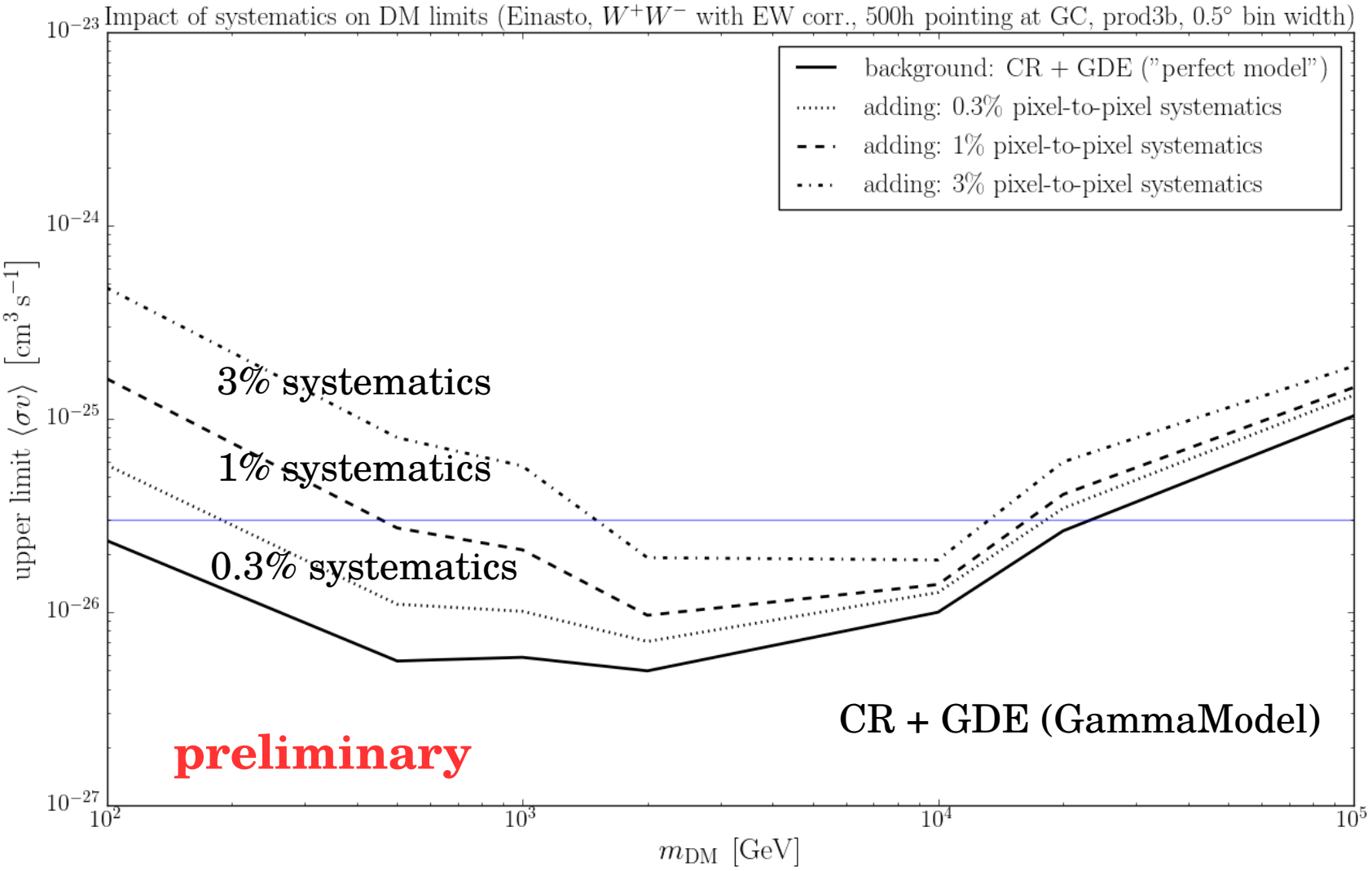


Preliminary Results – Dark Matter Limits

Consider the WW – channel with EW corrections ...

→ Assume ‘perfect‘ modelling of the diffuse emission with the GammaModel template.

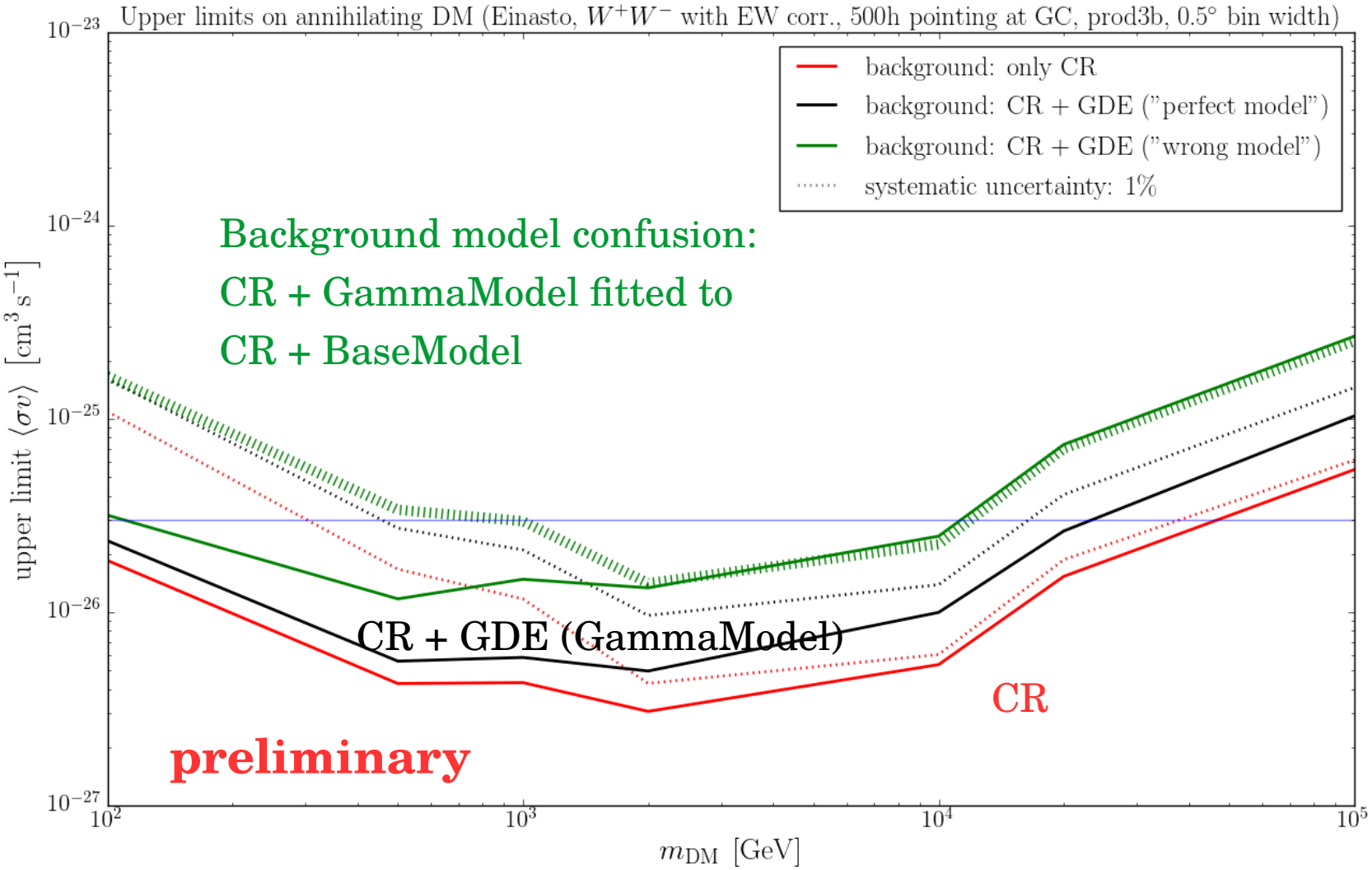
→ What is the effect of varying the level of pixel-to-pixel systematics?



Preliminary Results – Dark Matter Limits

Consider the WW – channel with EW corrections ...

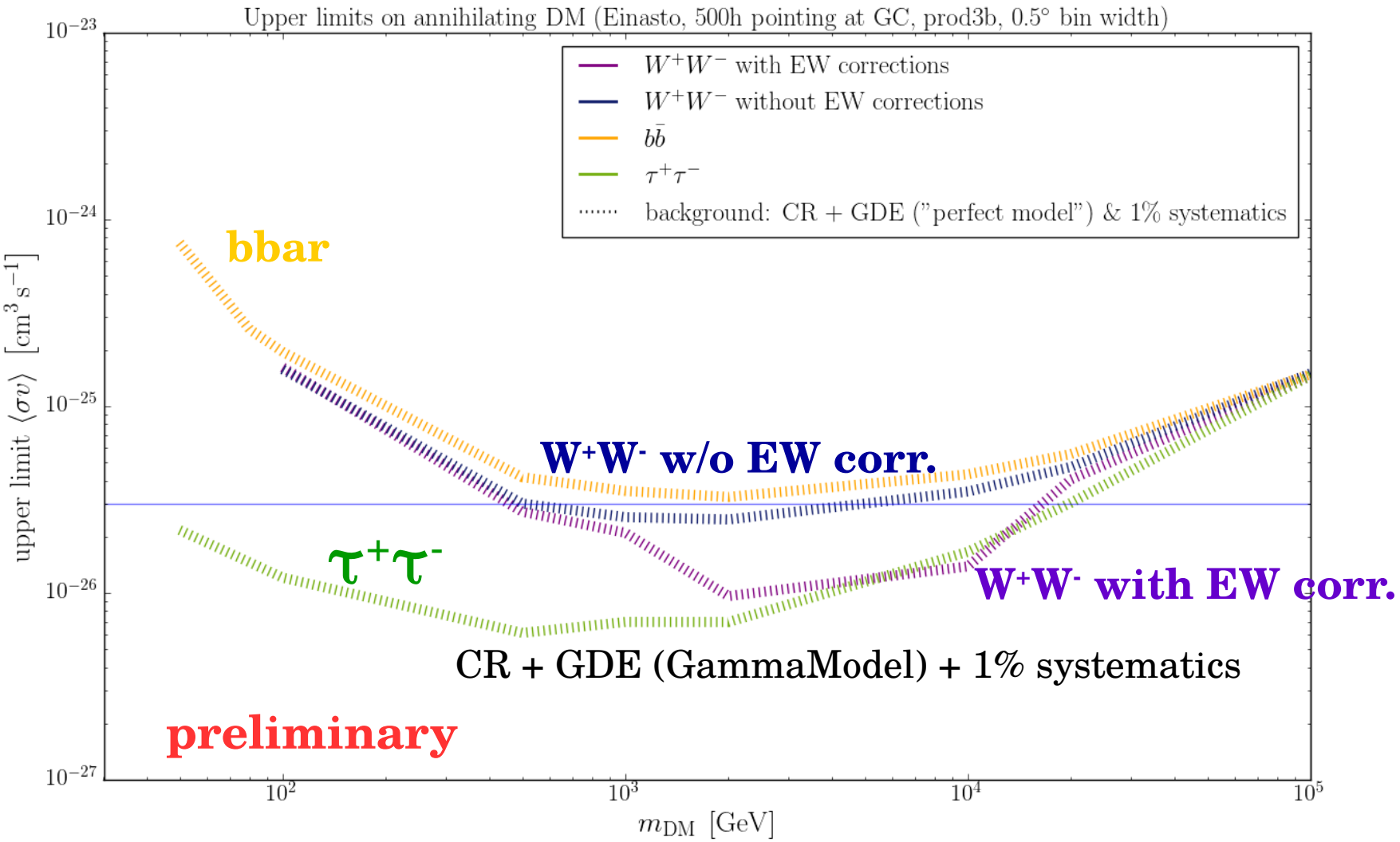
→ What happens when we force-fit two different GDE models to incorporate the systematic uncertainty of the GDE modelling?



Preliminary Results – Dark Matter Limits

Pixel-to-pixel systematics have the largest impact on the DM limits within our approach.

→ How do different annihilation channels compare?



Optimizing the Pipeline

So far, we derived limits for a 500h pointing to the Galactic Center.

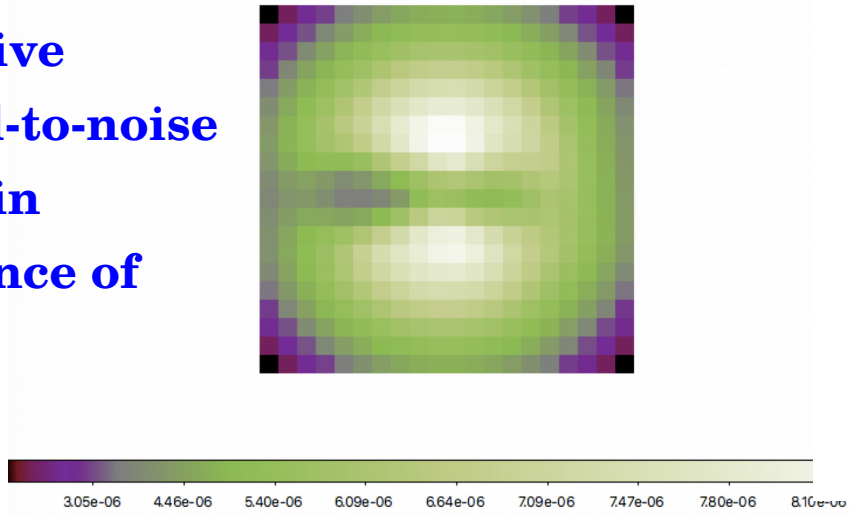
→ Central Survey of the GC looks a bit different:

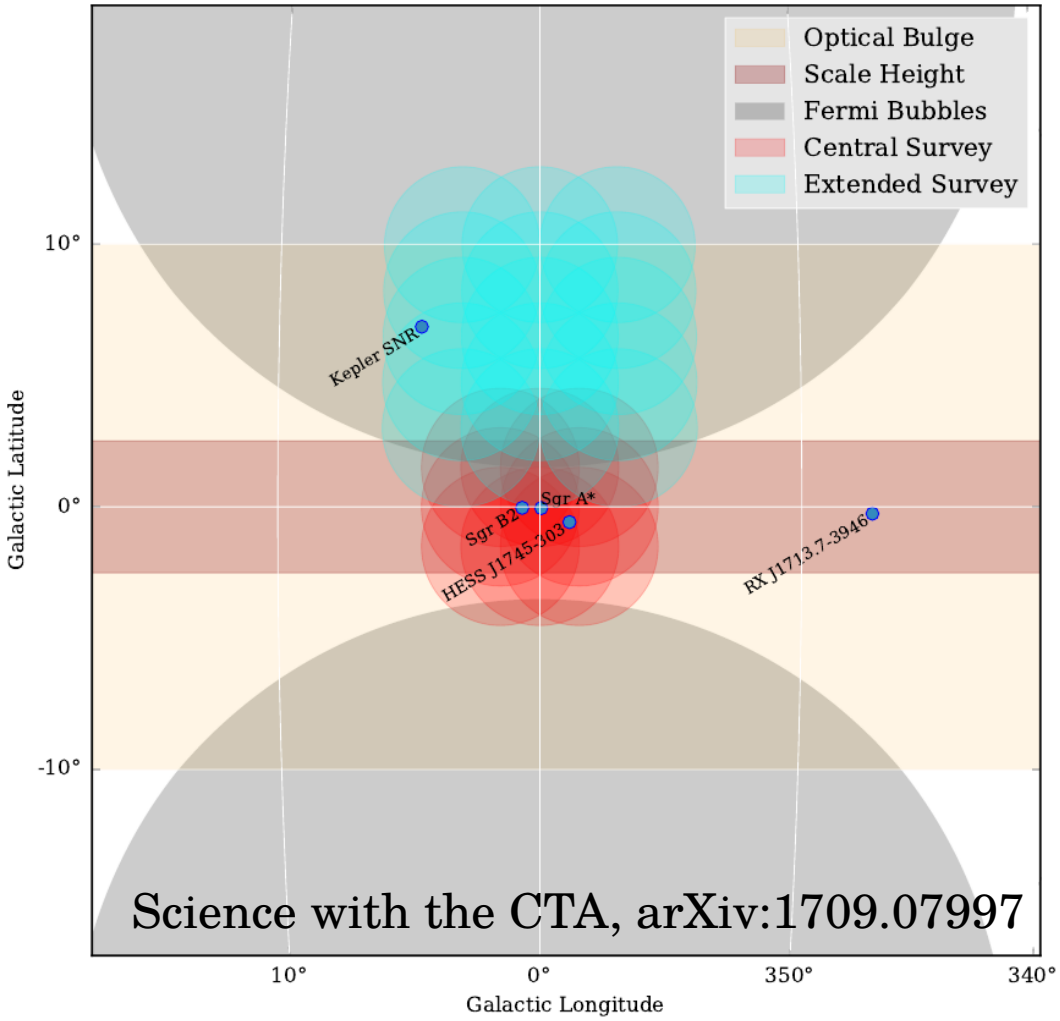
9 individual pointings $l,b = \mp 1.0°, 0°$ with radius of 3° for in total 525 h

CTA's observation strategy of GC includes 300h north of plane "Extended Survey" (up to $b = 10°$)

→ Could be relevant for cored profiles, e.g. isothermal profile:

effective signal-to-noise ratio in presence of GDE





Outlook

- ongoing improvement of two used GDE models
  → essential for realistic assessment of systematics

- Within our framework, the sensitivity to a DM signal is **dominanted by pixel-to-pixel systematics** (confirming the previous studies).

- complementary analysis with **one fixed GDE model**:

  – add realistic/physically motivated uncertainties via a covariance matrix
  ==> define level of systematics needed to reach thermal cross-section

→ *"agnostic"* analysis performed with *Swordfish*

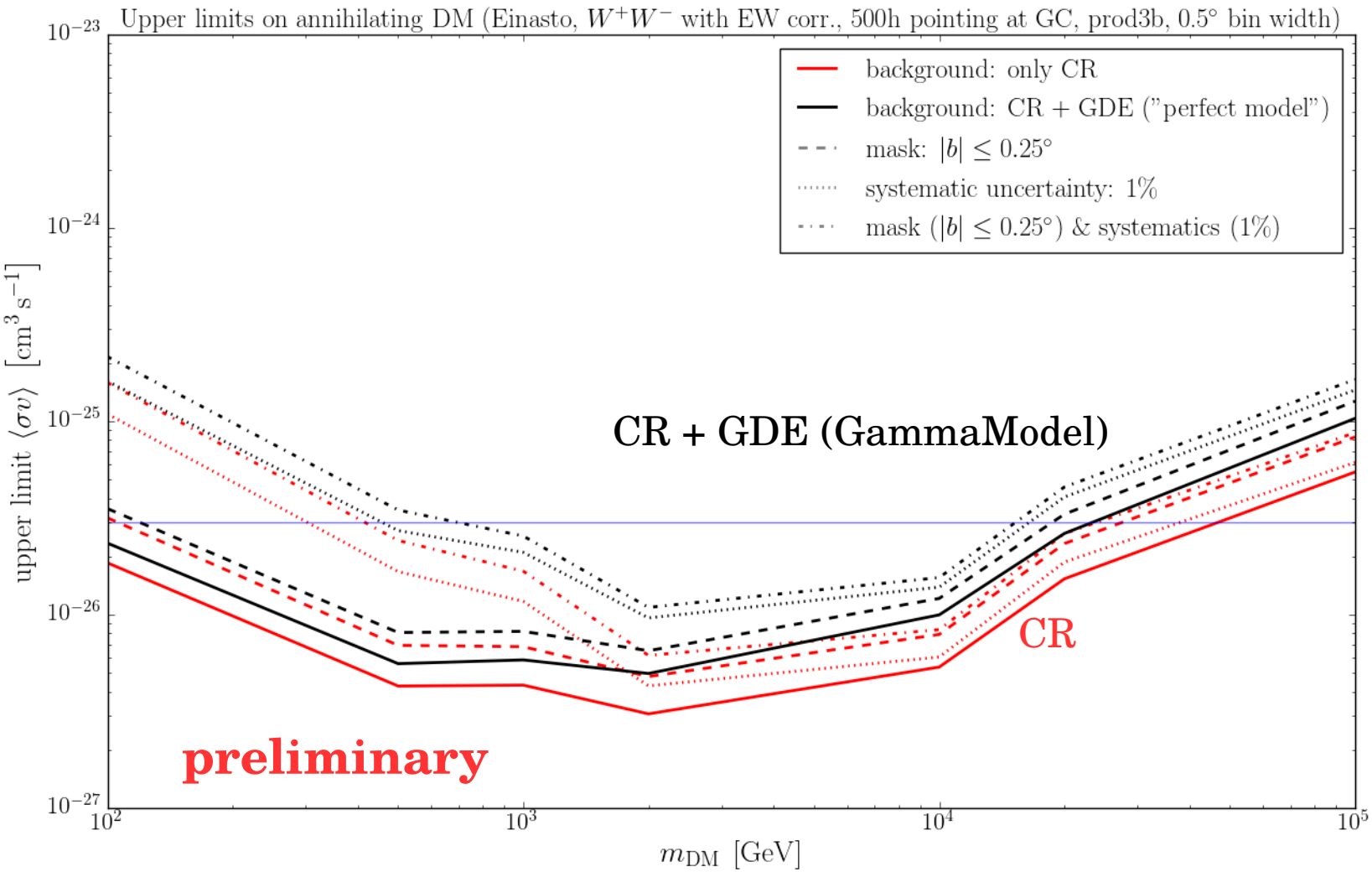
Thanks for the comments/suggestion!

Backup Slides

Preliminary Results – Dark Matter Limits

Consider the WW – channel with EW corrections …

→ Can we reduce the systematic uncertainty due to our ignorance about the GDE's shape and spectrum with a mask? **For now: |b| < 0.25°**



Preliminary Results – Dark Matter Limits

Consider the WW – channel with EW corrections …

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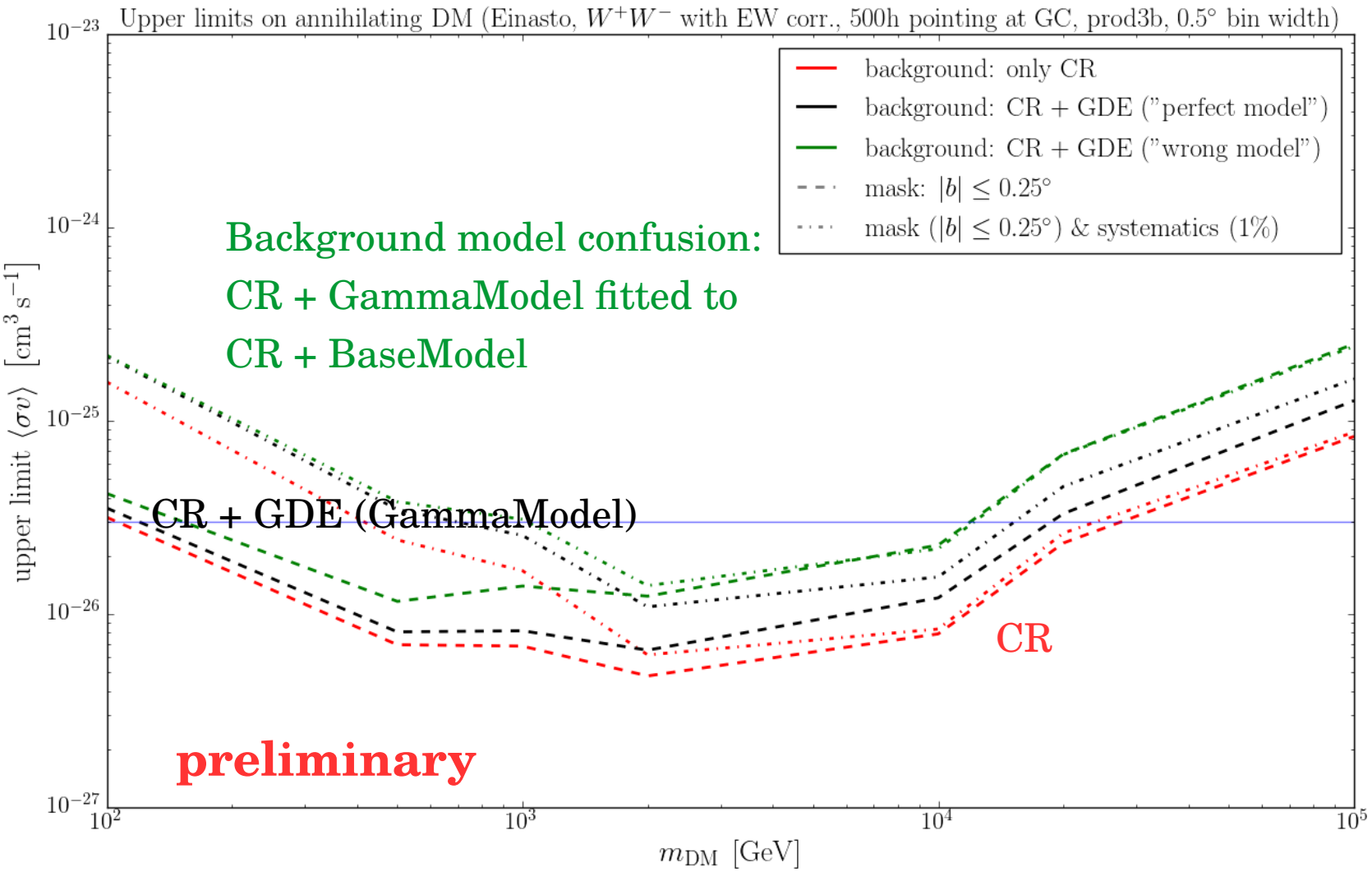
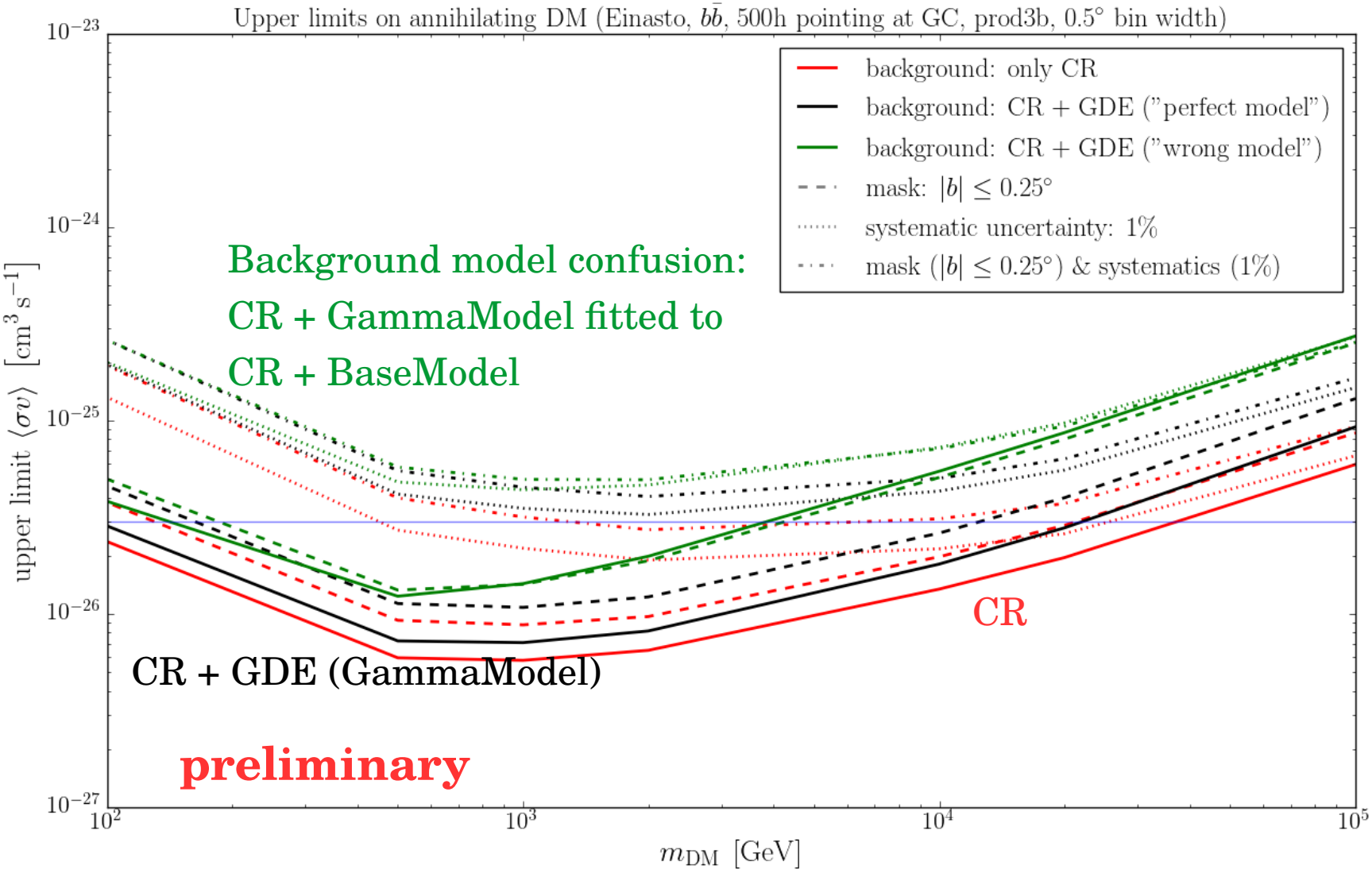
For now: |b| < 0.25°



Preliminary Results – Dark Matter Limits

The same for the bbar – channel …

- - - - - mask (|b| < 0.25°) . . . . . systematics (1%)



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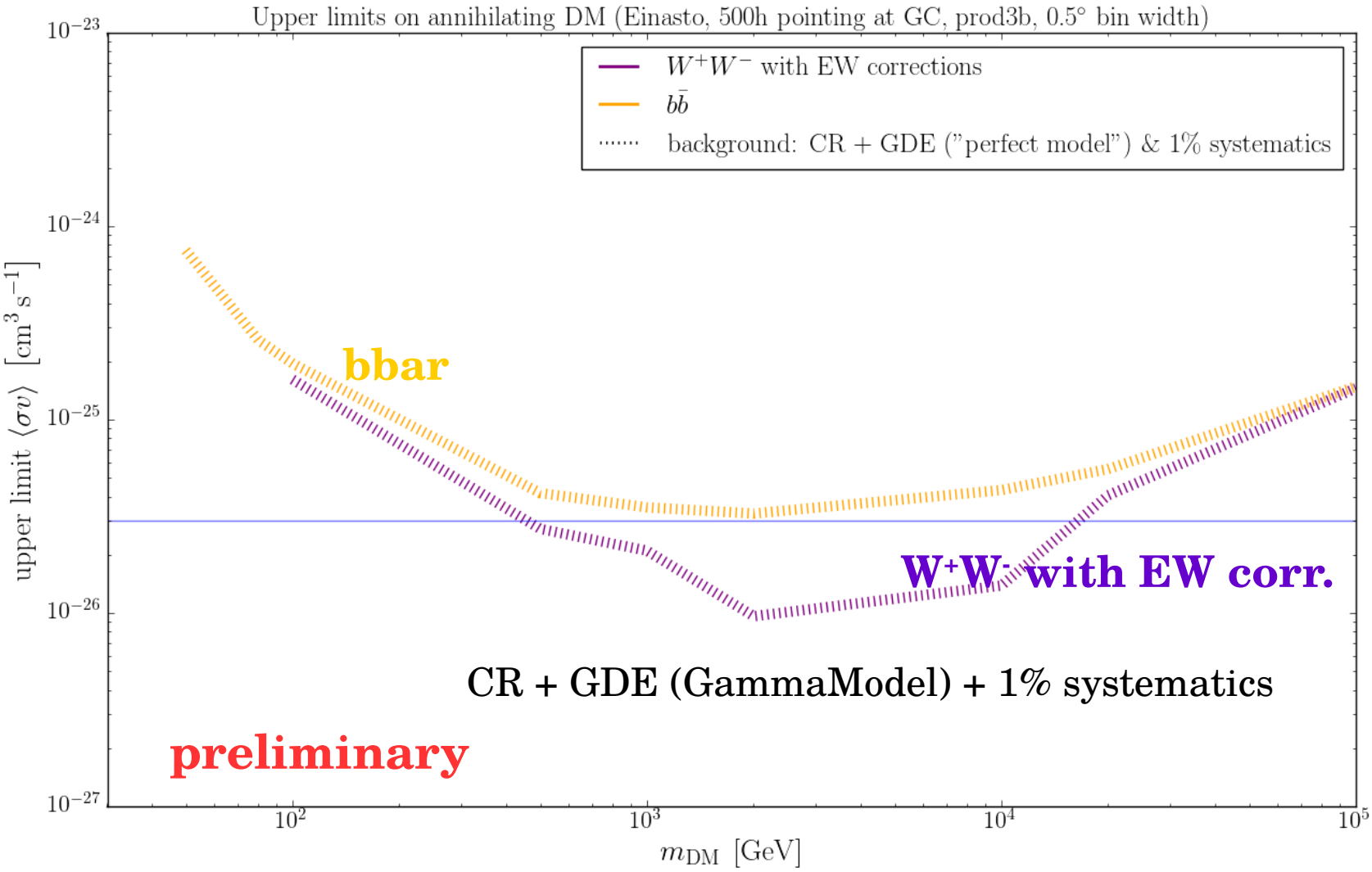
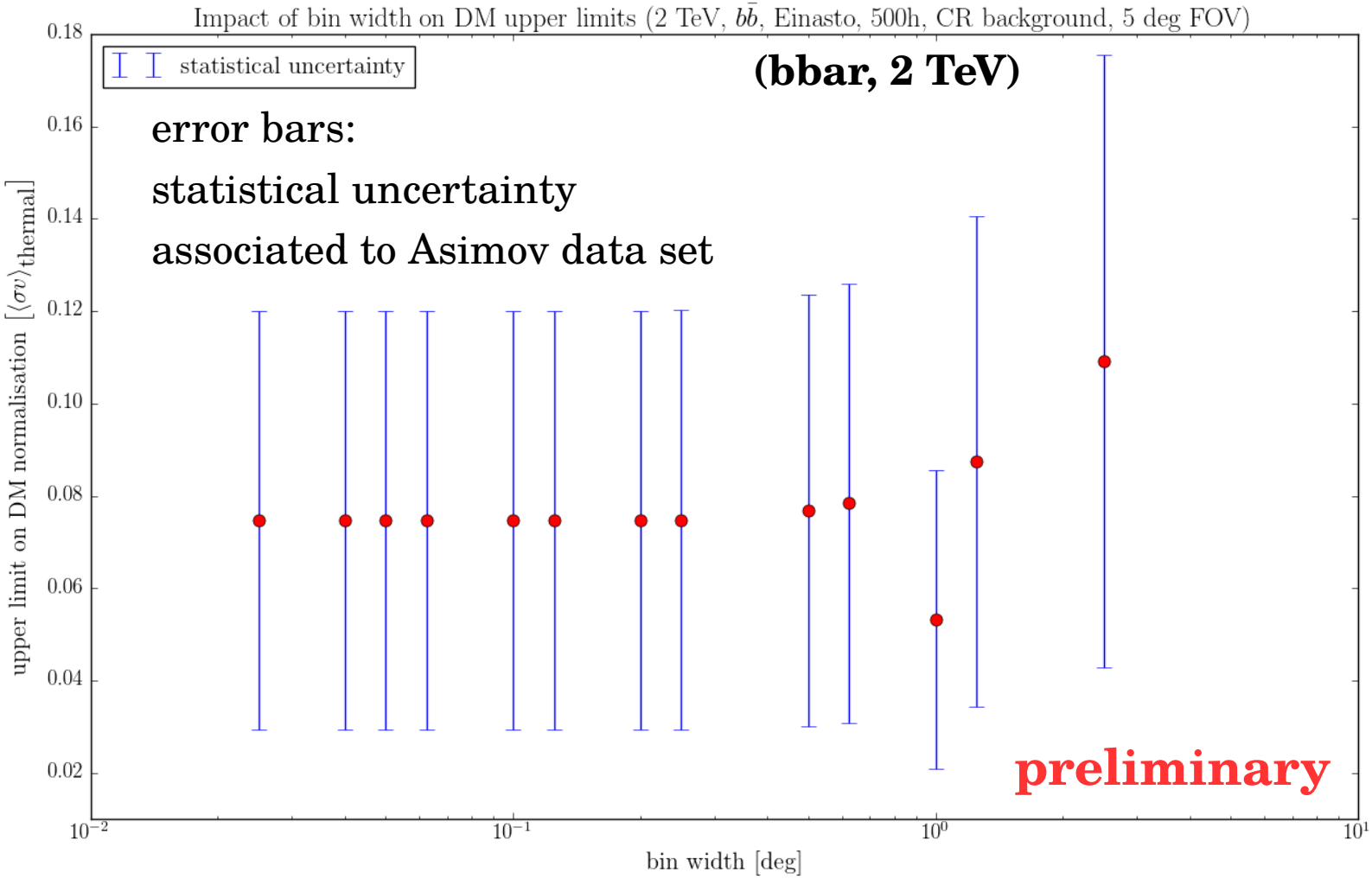


Optimizing the Pipeline

For now, analysis restricted to 0.5° binning of 5°x5° ROI.

→ Does the bin size significantly affect the limits?



Conclusion: We are fairly insensitive to the choice of binning!