Sensitivity of CTA to dark matter annihilations in the galactic centre

Prospects for the MSSM

arxiv:1411.5214 Leszek Roszkowski, Enrico Maria Sessolo, A.W.

arxiv:1405.4289 Leszek Roszkowski, Enrico Maria Sessolo, A.W.

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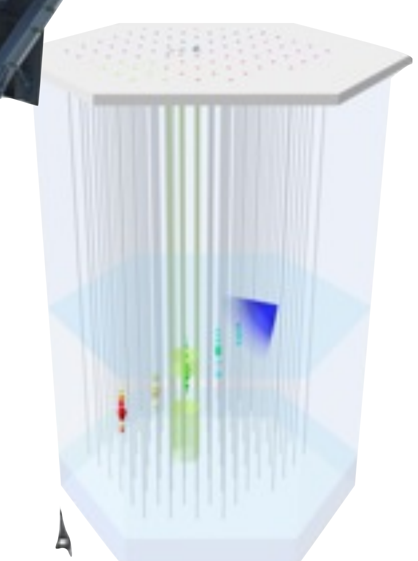
Outline

- Introduction: Indirect detection of Dark Matter
- CTA and the galactic centre
- Setting limits with CTA
- Impact of CTA on the MSSM
- Impact of CTA on the CMSSM
- Conclusions

Introduction: Indirect DM detection

Basic idea: Look for the products of DM annihilation or decays
Many experiments looking for different things

Messengers:	Experiments:
Gamma-rays	Space telescopes: Fermi-LAT Ground based Cherenkov telescopes: HESS, CTA
positrons and anti-protons	Space based calorimeters: Pamela, AMS-02
Neutrinos	Neutrino detectors: ANTARES, ICECUBE



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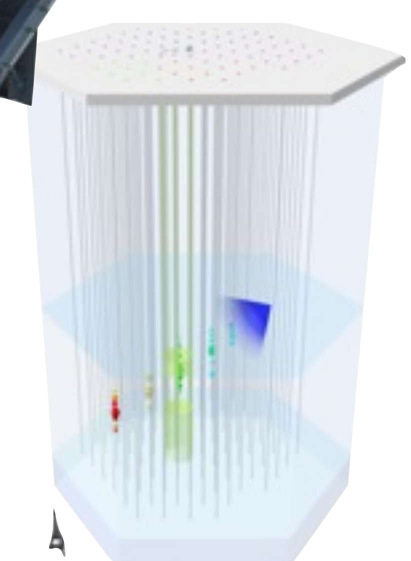
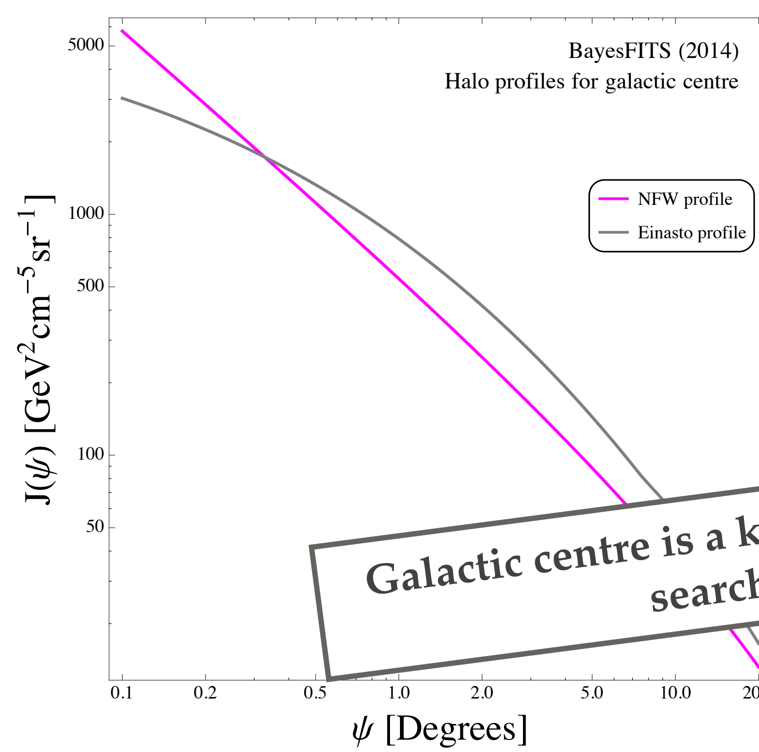


Indirect detection targets for gamma-rays

Dwarf Spheroidal galaxies
- No gamma-ray point sources
- DM dominated
- DM distribution can be inferred from star kinematics.

Galaxy clusters:
- DM distribution can be measured
- gamma-ray backgrounds from cosmic ray processes
- DM substructure is important.

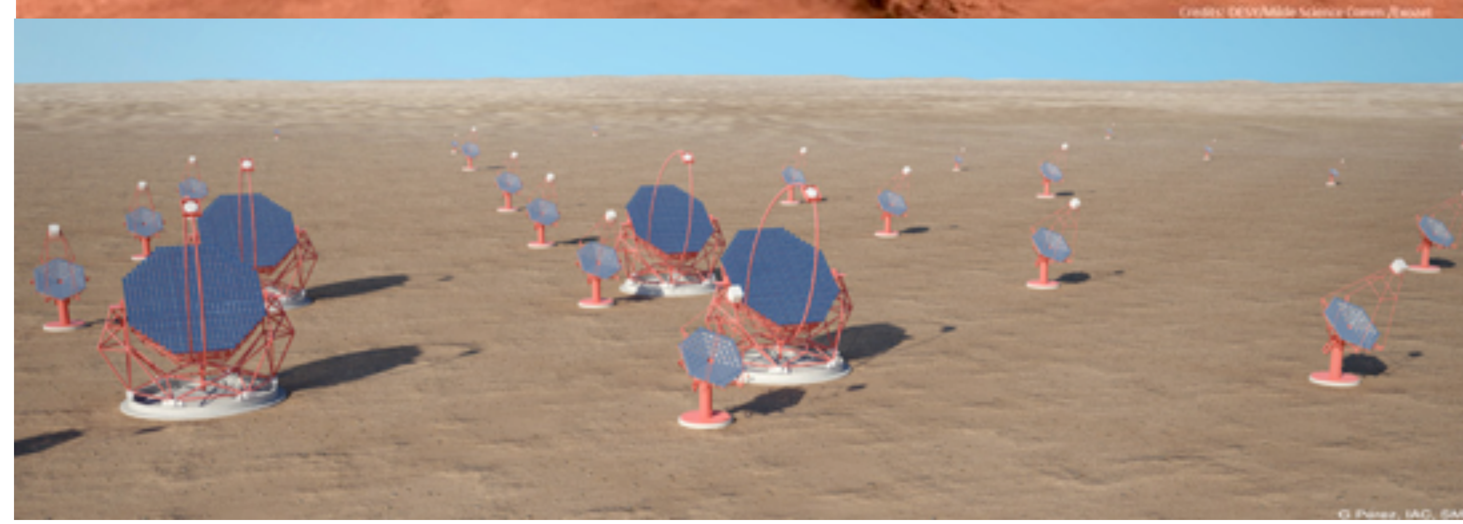
Galactic centre:
- Gamma-ray backgrounds (diffuse and point like)
- Uncertainty in DM distribution
- **Likely to be brightest source of gamma-rays from DM.**



Galactic centre is a key target for DM searches

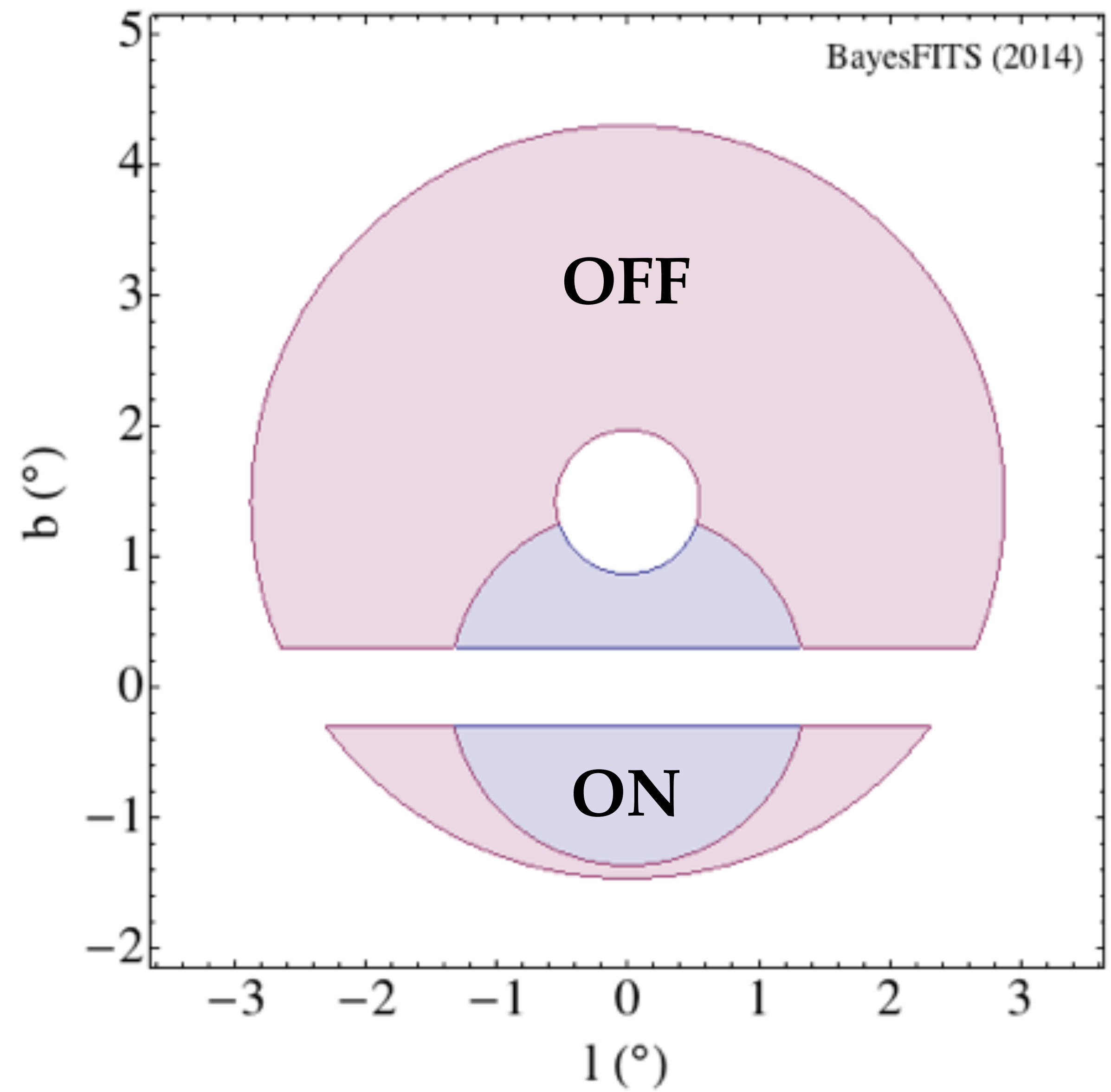
The Cherenkov Telescope Array

- Ground based gamma-ray telescope
- Order of magnitude improvement in sensitivity in 100GeV-10TeV range
- Extends energy range below 100GeV and above 10TeV
- Improved angular and energy resolution
- Southern and northern hemisphere sites for full sky coverage

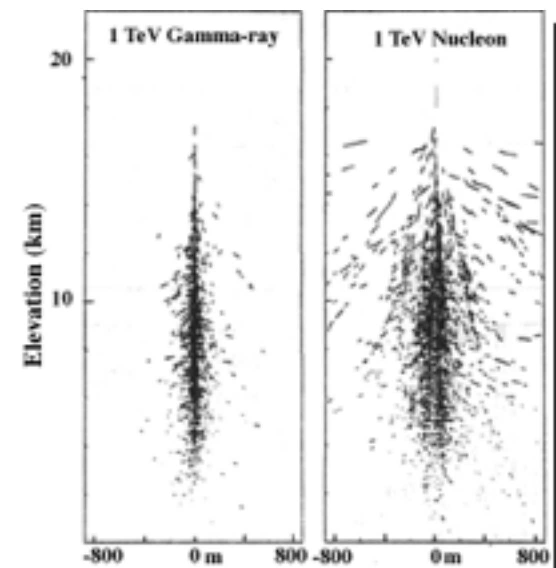


The observational setup

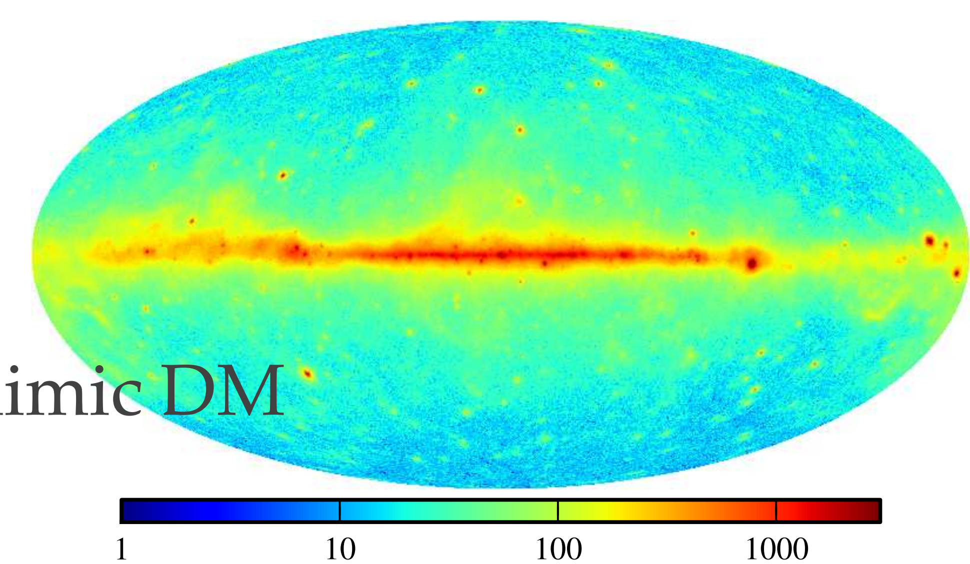
- Mask galactic plane to reduce backgrounds
- OFF region rich in background
- ON region rich in signal
- Integrate over entire energy range or split into energy bins for spectral information.



The backgrounds



1. Cosmic rays
    - Isotropic
    - Can discriminate based on shower
    - Estimated by MC from collaboration
2. Diffuse gamma-rays
    - Measured by FERMI-LAT below 100 GeV
    - Need to extrapolate to higher energies
    - Larger in ON region that OFF region! Can mimic DM signal DGE background: Silverwood et al. arxiv:1408.4131



The signal

$$\frac{d\Phi}{dE} = \underbrace{\frac{\sigma v}{8\pi m_\chi^2} \frac{dN_\gamma}{dE}}_{\Phi_{PP}} \underbrace{\int_{\Delta\Omega} \int_{l.o.s} \rho^2 \left[r(\theta) \right] dr(\theta) d\Omega}_{J}$$

Particle Physics Factor
Parameterises DM properties
Depends on annihilation final state

J factor
Parameterises DM halo and observation region
Astrophysical uncertainties
Halo model

NFW: $$\rho(r) = \rho_s \frac{(r/r_s)^{-\alpha}}{(1 + r/r_s)^{-3+\alpha}}$$

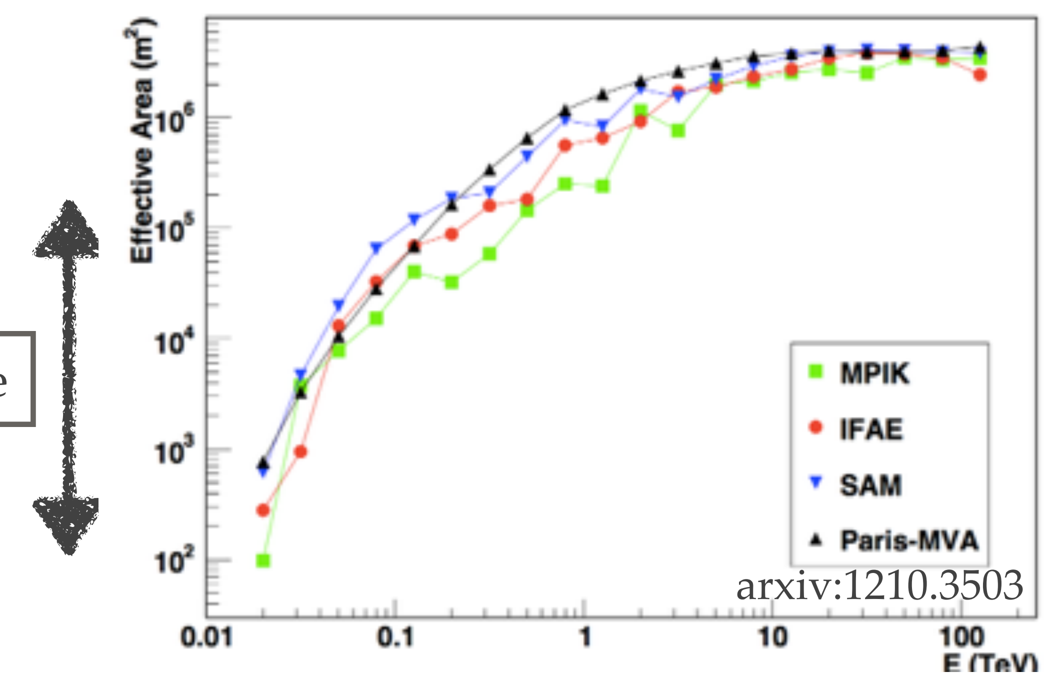
Einasto: $$\rho(r) = \rho_s e^{-\frac{2}{\alpha}((\frac{r}{r_s})^{\alpha} - 1)}$$

The observed signal

$$N_i^{\rm ann} = t_{\rm obs}.J.\frac{\sigma v}{8\pi m_\chi^2}\int_{\Delta E_i} dE \left(\frac{1}{\sqrt{2\pi\delta(E)^2}} \int_{26{\rm GeV}}^{m_\chi} d\bar{E}\frac{dN_\gamma(\bar{E})}{d\bar{E}} A_{\rm eff}(\bar{E}) e^{-\frac{(E-\bar{E})^2}{2\delta(E)^2}} \right)$$

- Separate into energy bins
- Marginalise over energy resolution
- Effective area is energy dependent

Large energy dependence



arxiv:1210.3503

How to set the projected limit

- Background provided by MC simulation from CTA collaboration
- Set number of observed gamma-rays to expected background
- Calculate likelihood based on expected signal
- Increase cross-section until -2ln(L) > 2.71 (one-sided 95% C.L.)

Energy bins i , signal region j = ON, OFF

n_{ij} Observed number of gamma-rays

μ_{ij} Expected number of gamma-rays

Binned likelihood

$$\mathcal{L} = \prod_{i,j} \frac{\mu_{ij}^{n_{ij}}}{n_{ij}!}$$

- Likelihood function for poisson distribution
- Uses full spectral information
- Can be adapted to a full morphological analysis

Li and Ma method

$$-2\ln\mathcal{L} = 2\left[N_{\mathrm{ON}}\ln\left(\frac{1+\alpha}{\alpha}\frac{N_{\mathrm{ON}}}{N_{\mathrm{ON}}+N_{\mathrm{OFF}}}\right) + N_{\mathrm{OFF}}\ln\left((1+\alpha)\frac{N_{\mathrm{OFF}}}{N_{\mathrm{ON}}+N_{\mathrm{OFF}}}\right)\right]$$

summed over energy bins $N_{\mathrm{ON}}, N_{\mathrm{OFF}}$ $\qquad \alpha = \frac{\Omega_{\mathrm{ON}}}{\Omega_{\mathrm{OFF}}}$

- Test statistic for the background hypothesis
- Take limit of only two bins, OFF and ON region
- Assumes the same background in ON and OFF region

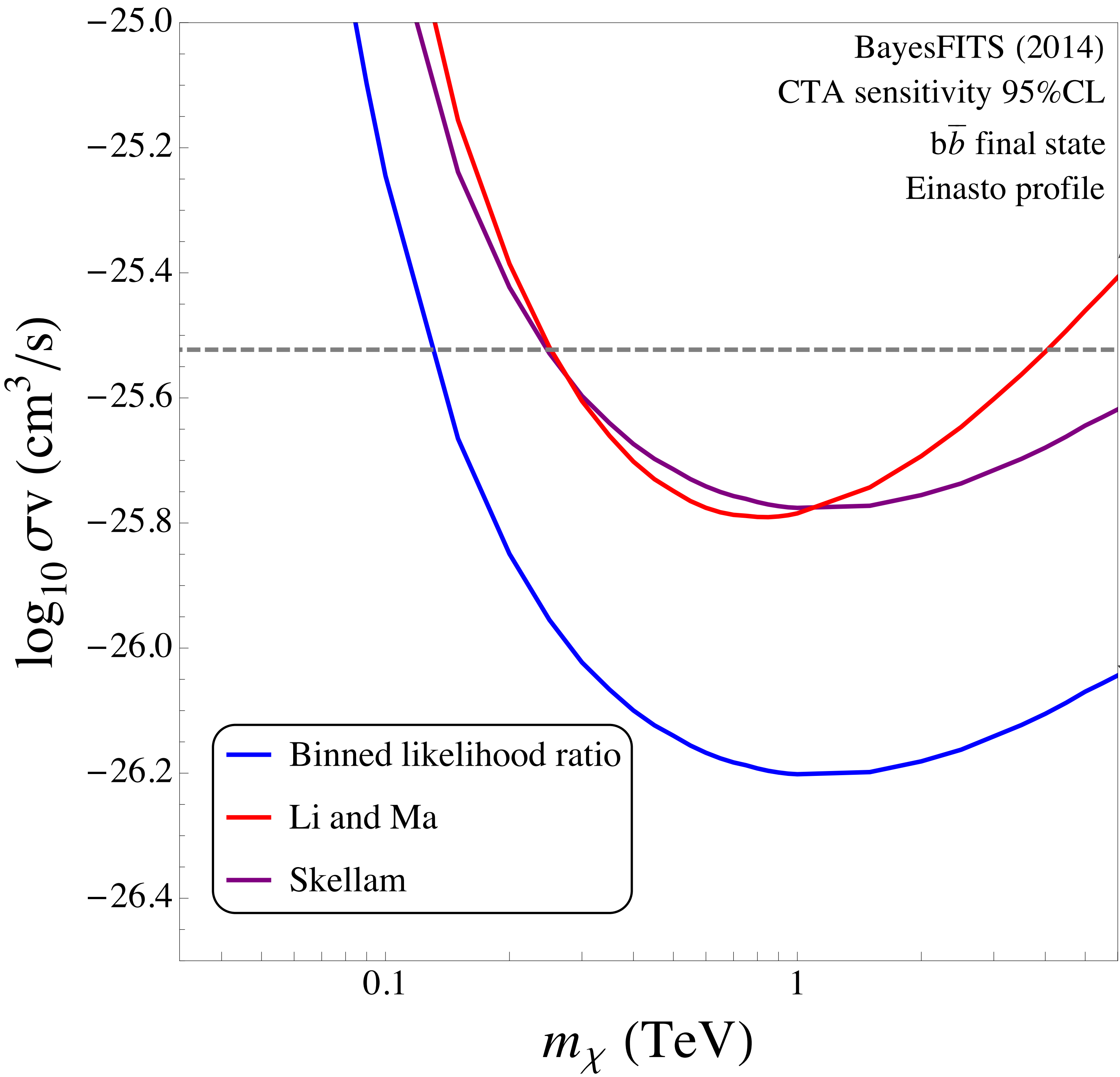
Skellam distribution

$$\mathcal{L}(\{\theta_{\mathrm{diff},i}\}) = \prod_i e^{-(N_{i,\mathrm{ON}}+\alpha N_{i,\mathrm{OFF}})} \left(\frac{N_{i,\mathrm{ON}}}{\alpha N_{i,\mathrm{OFF}}}\right)^{\frac{\theta_{\mathrm{diff},i}}{2}} I_{|\theta_{\mathrm{diff},i}|}(2\sqrt{\alpha N_{i,\mathrm{ON}} N_{i,\mathrm{OFF}}})$$

$$\theta_{\mathrm{diff},i} = n_{i,\mathrm{ON}} - \alpha\, n_{i,\mathrm{OFF}}$$

- Likelihood function for the difference between two poisson distributions
- Taking difference removes correlations
- θ_{diff} is zero for isotropic background

Results: Projections for CTA

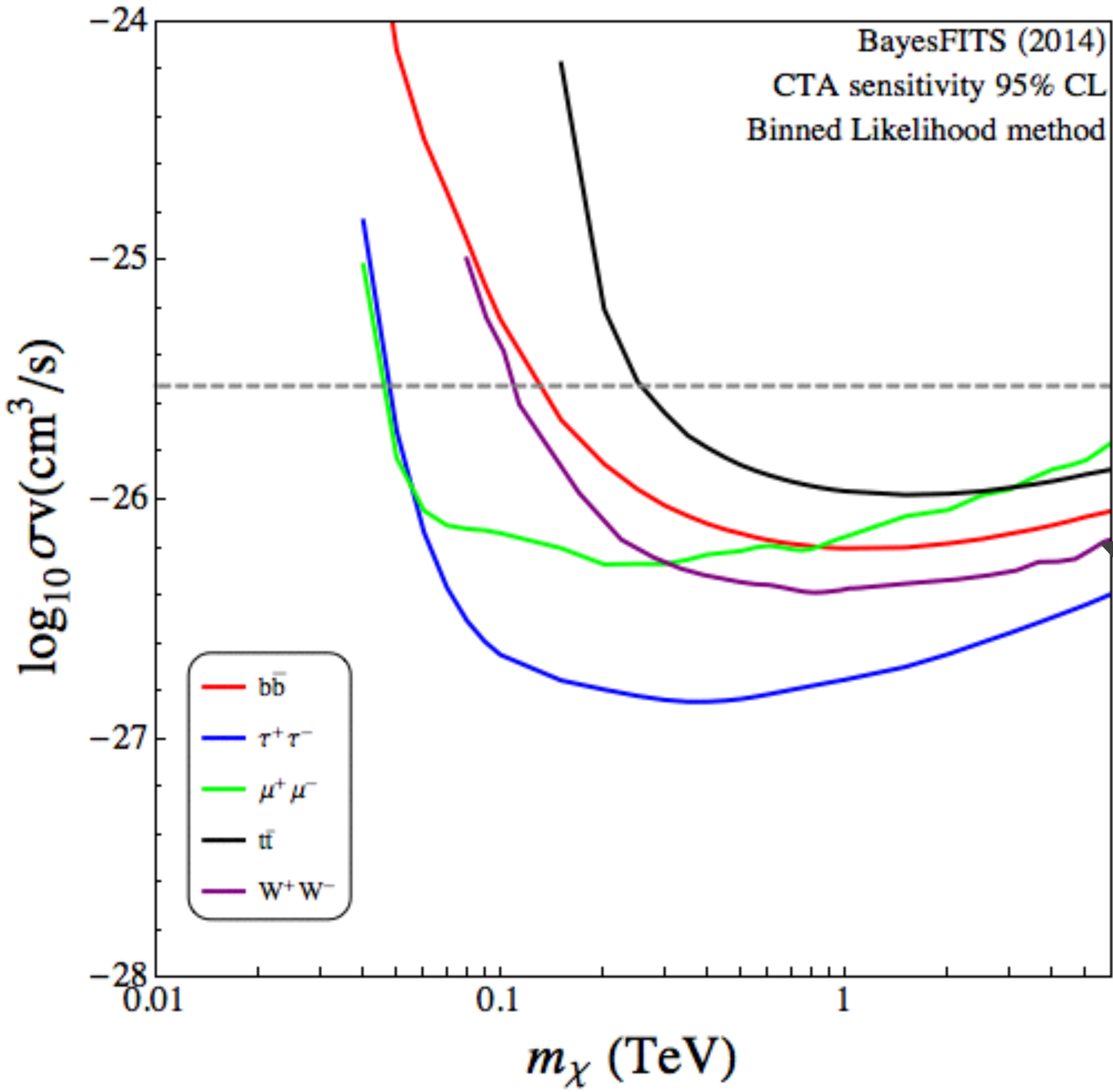


Spectral information important at large masses

"Thermal relic"

Binned likelihood gives best limits

Results: Projections for CTA

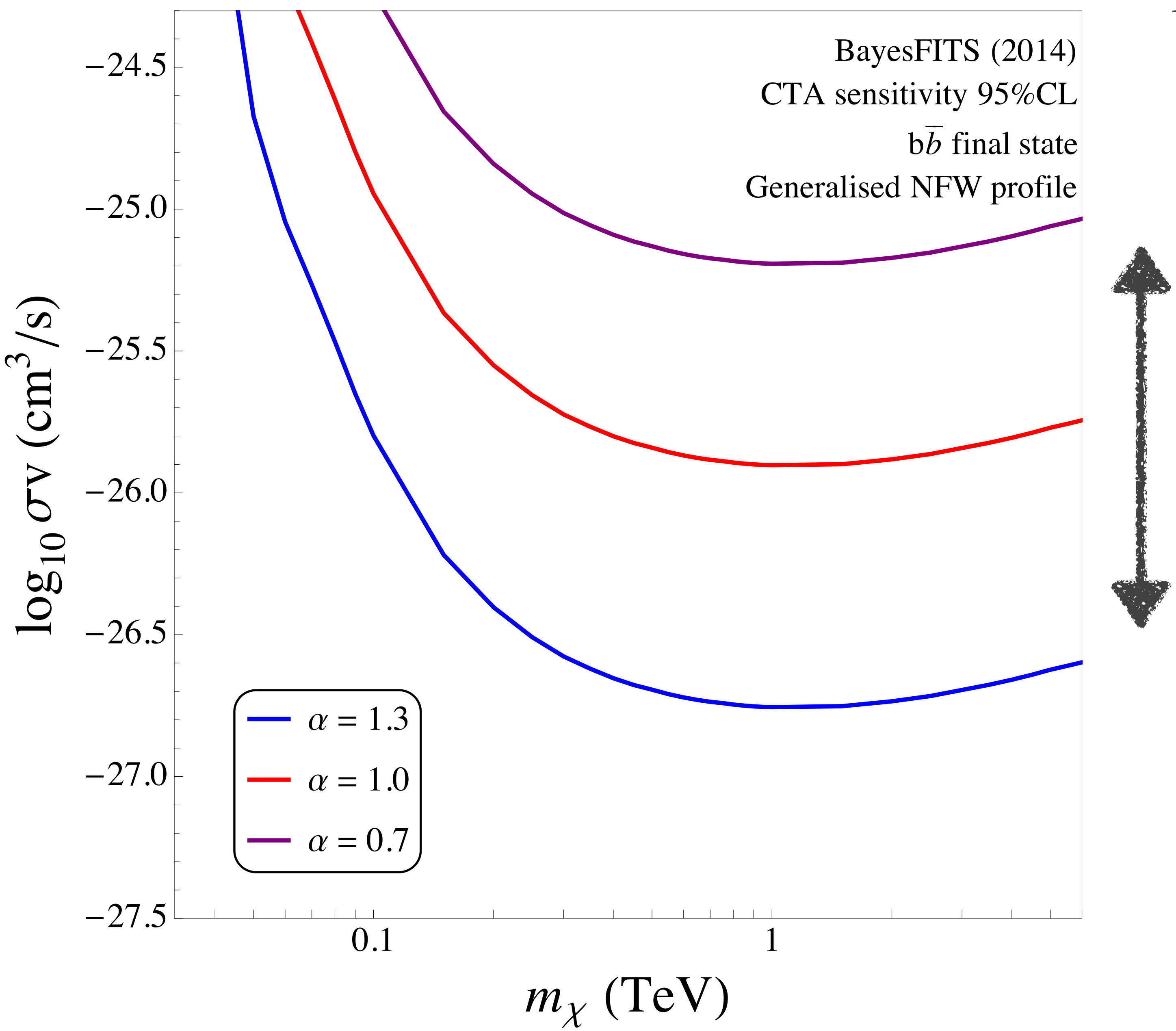


Below "thermal relic" level for many final states

Difference between bb and WW mostly EW corrections

Excellent sensitivity to TeV scale DM candidates

Results: Projections for CTA



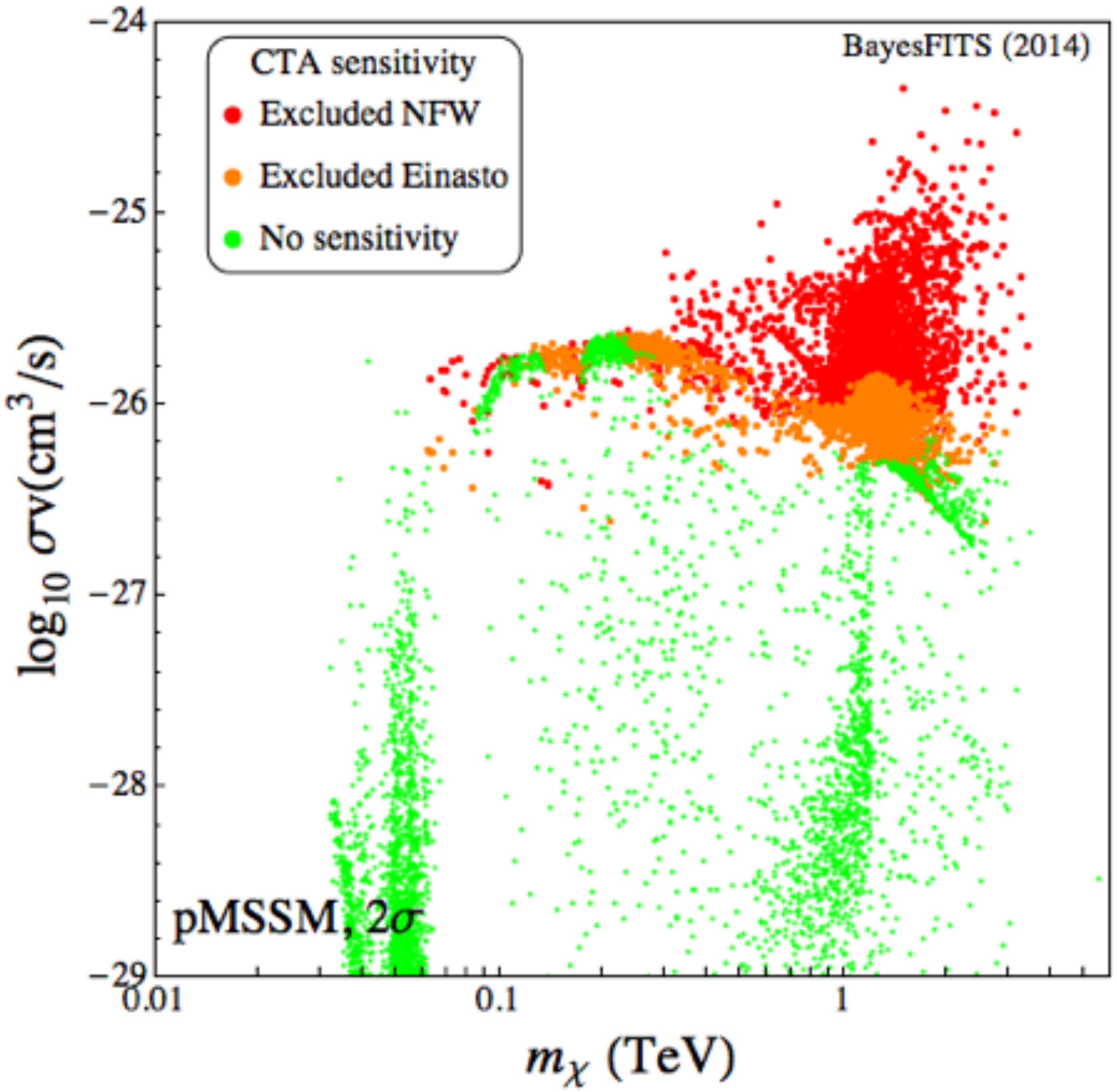
NFW profile:

$$\rho(r) = \rho_s \frac{(r/r_s)^{-\alpha}}{(1 + r/r_s)^{-3+\alpha}}$$

Uncertainty due to parameterisation of halo

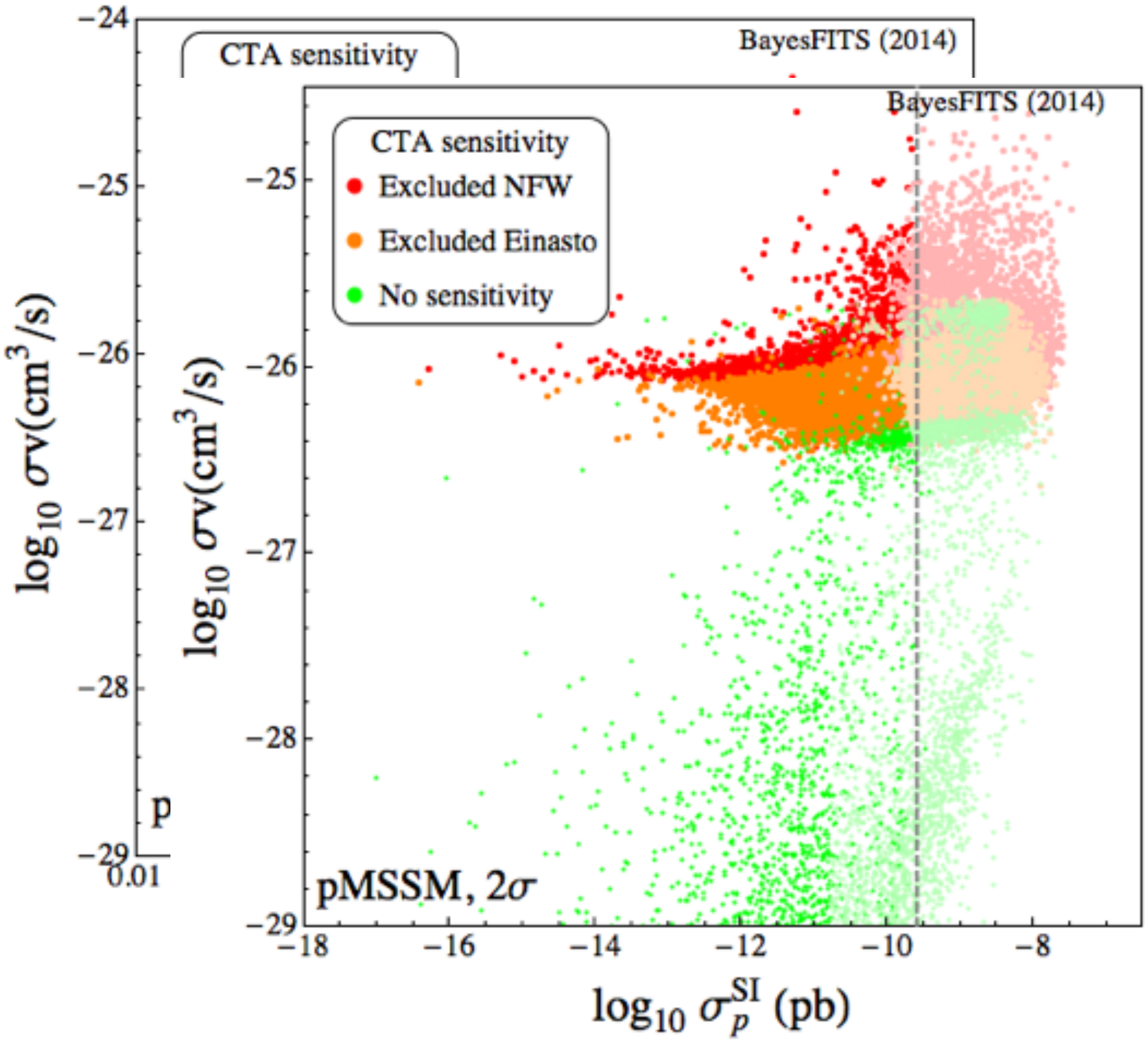
ON/OFF or morphological analysis allows halo profile to be constrained if a signal is seen

Impact of CTA on the MSSM



Much of the well motivated parameter space covered

Impact of CTA on the MSSM



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Complementary to direct detection experiments, no problem with "neutrino-floor"

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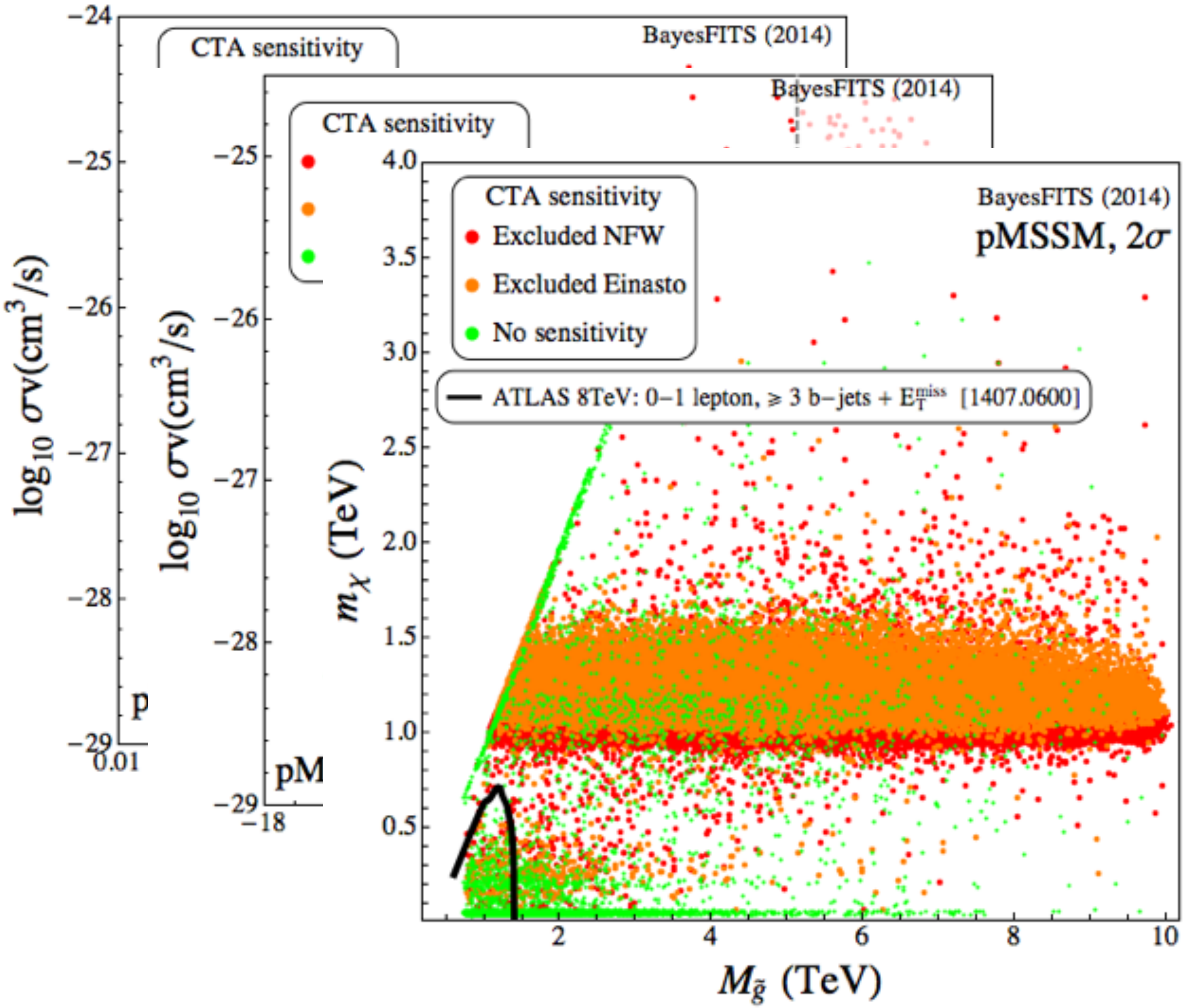

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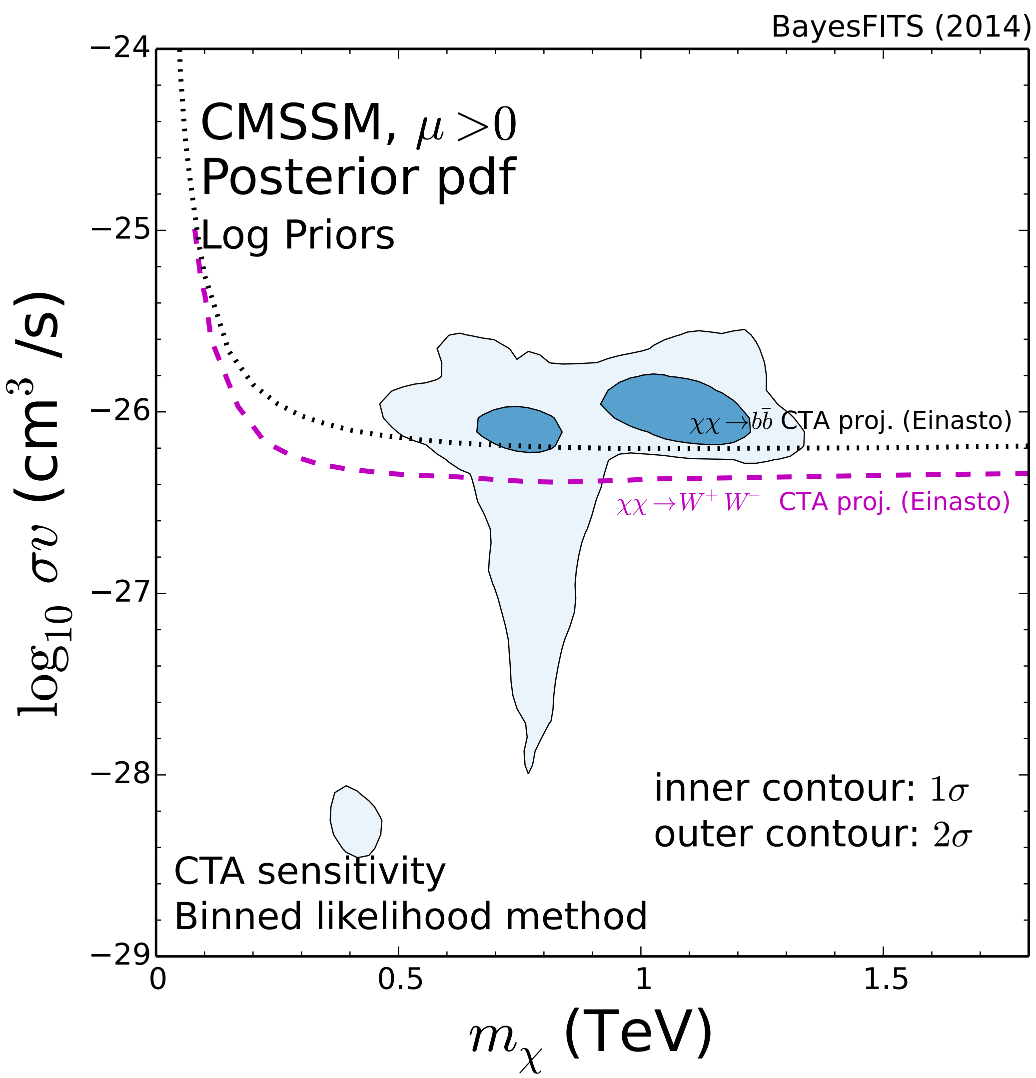
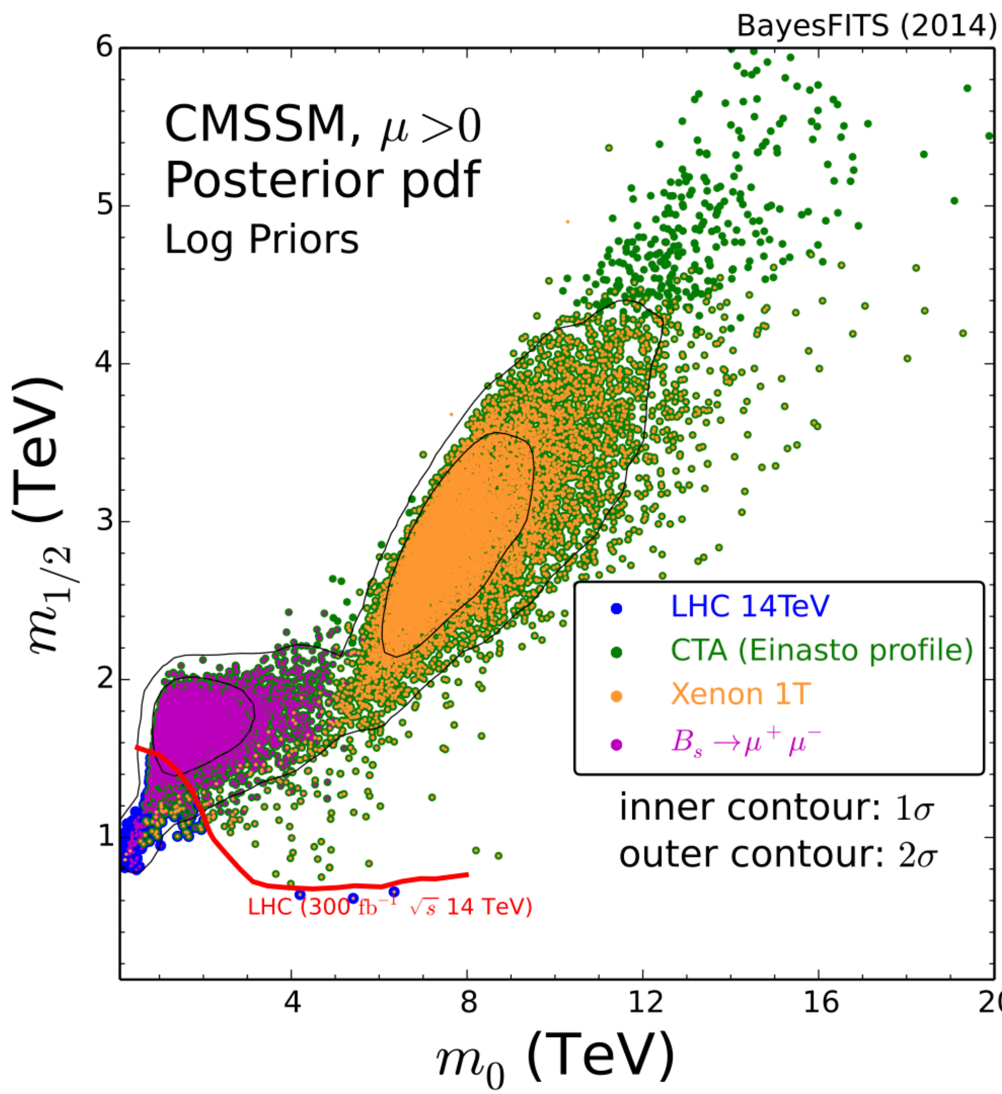
Probes high mass neutralinos unreachable by LHC

Impact of CTA on the CMSSM





Important for constrained models as well

CTA key to covering entire parameter space of the CMSSM

Conclusions

- Upcoming CTA project will provide a new window on high energy gamma-rays
- CTA will improve limits on heavy annihilating dark matter
- Correct statistical interpretation of CTA data key to providing the strongest limits or discovery potential
- CTA will impact well motivated dark matter candidates in the MSSM
- CTA will provide complementarity to direct detection experiments and the LHC
- CTA can close the gaps on the parameter space of the CMSSM