Constraining box-shaped gamma-ray features with CTA

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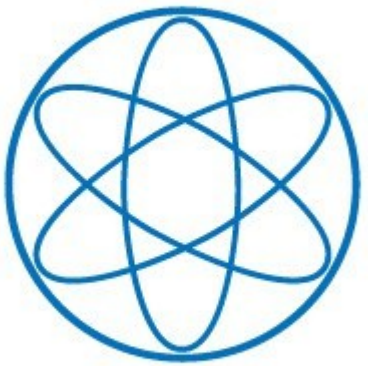
Exploring the dark sector
KIAS, Seoul
March 19, 2015



Based on work under preparation in collaboration with Gianfranco Bertone, Sergio López Gehler, Alejandro Ibarra and Miguel Pato (arXiv: 1503.xxxxx)

Outline

Idea

CTA

Approach

Results

Constraints on a concrete model

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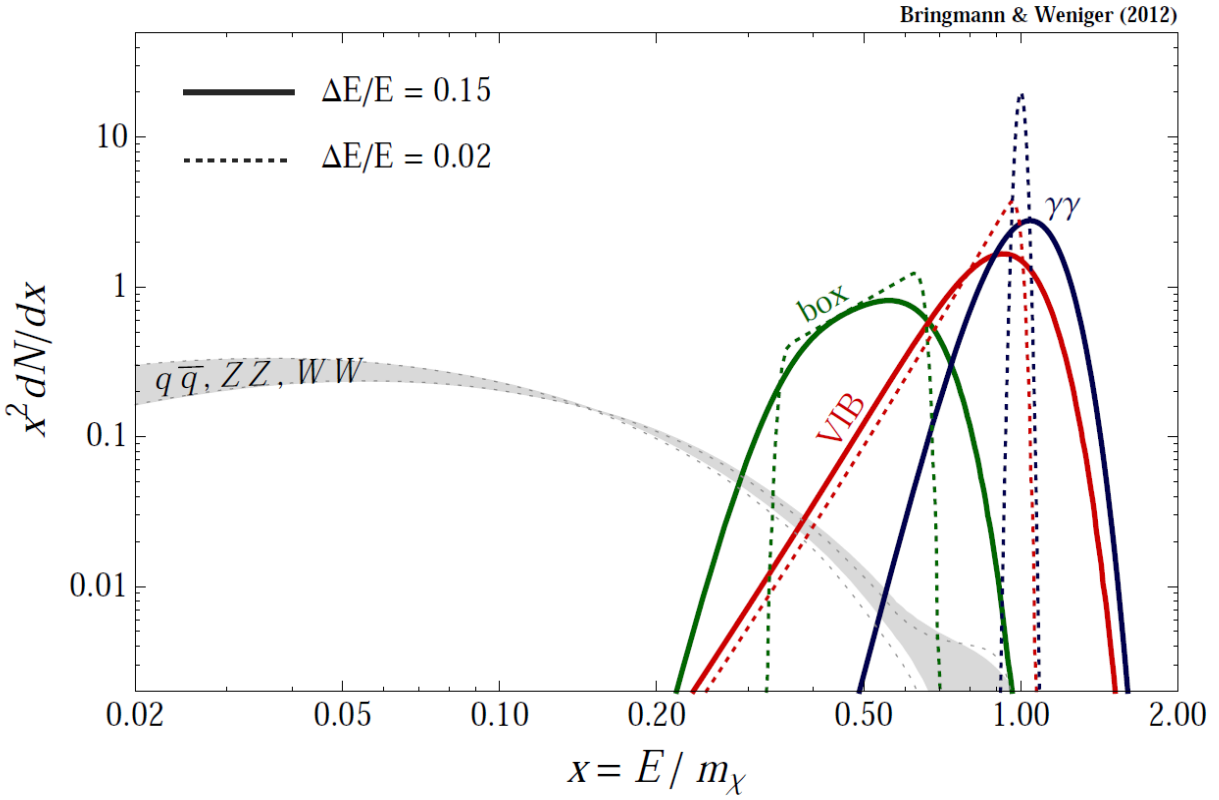
Idea: Gamma-ray spectral features

- Dark Matter annihilations into gamma-rays
- Sharp spectral features stick out of power-law like background
- Gamma-ray lines
- Internal Bremsstrahlung
- Gamma-ray boxes



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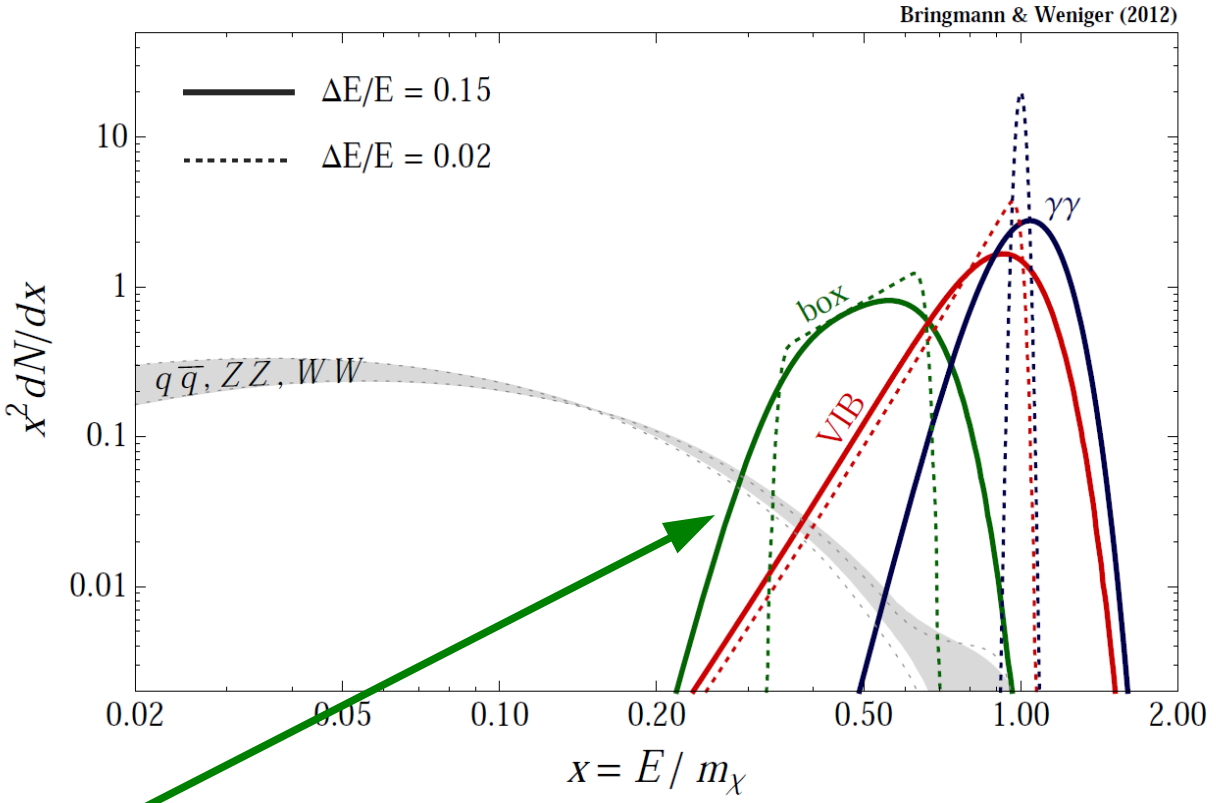
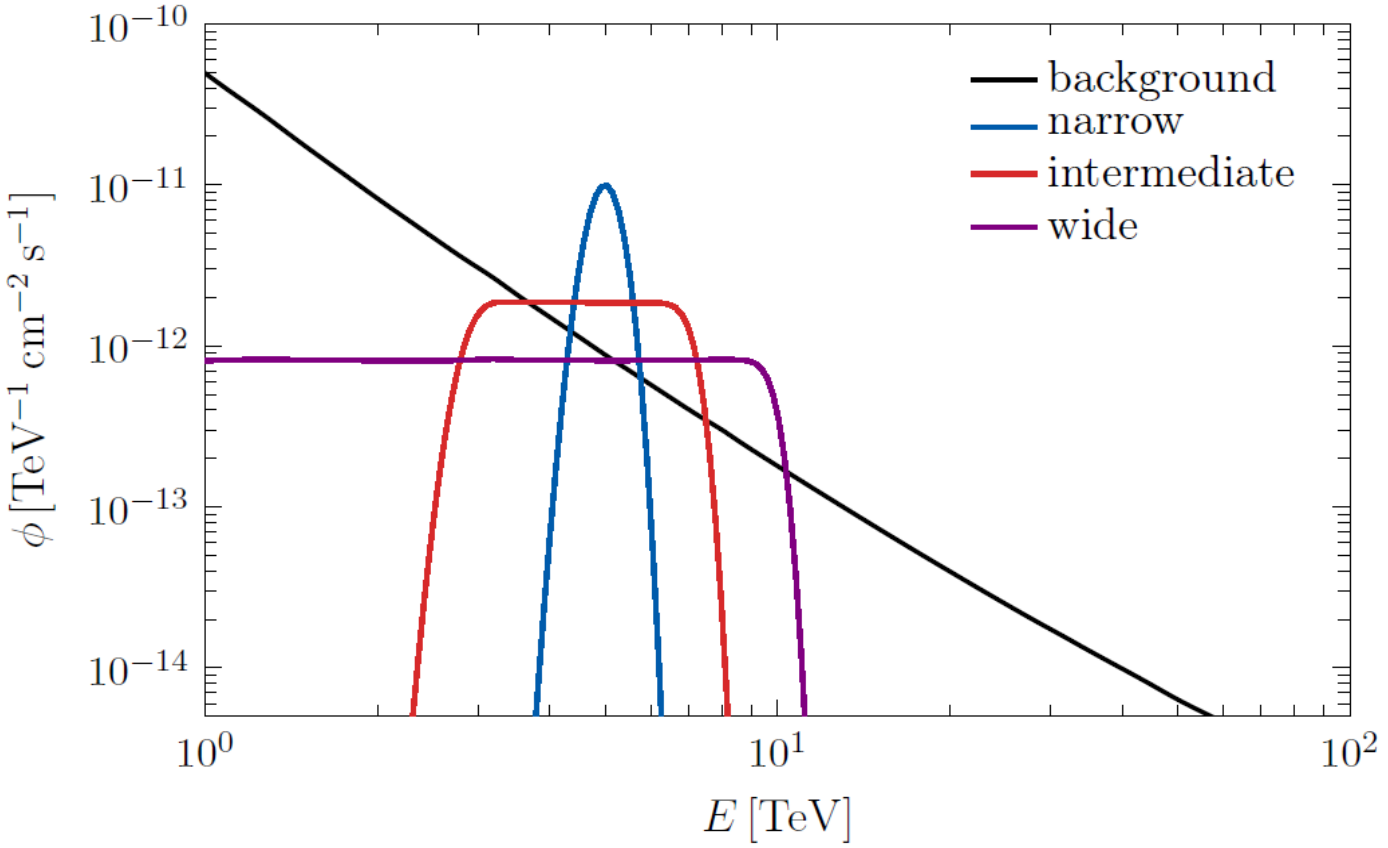


Idea: Gamma-ray boxes

- Focus on multi-TeV dark matter
- Calculate prospects for CTA (Cherenkov Telescope Array)

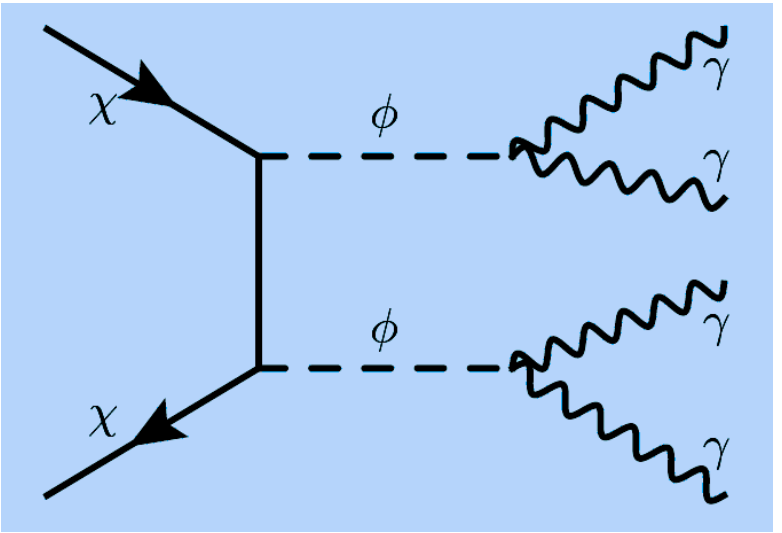


Idea: Gamma-ray boxes

- Cascade decay:

$$\chi\bar{\chi} \to \phi\phi \to 4\gamma$$

- Isotropic decay of scalar ϕ in its rest frame → gamma-ray box in lab frame

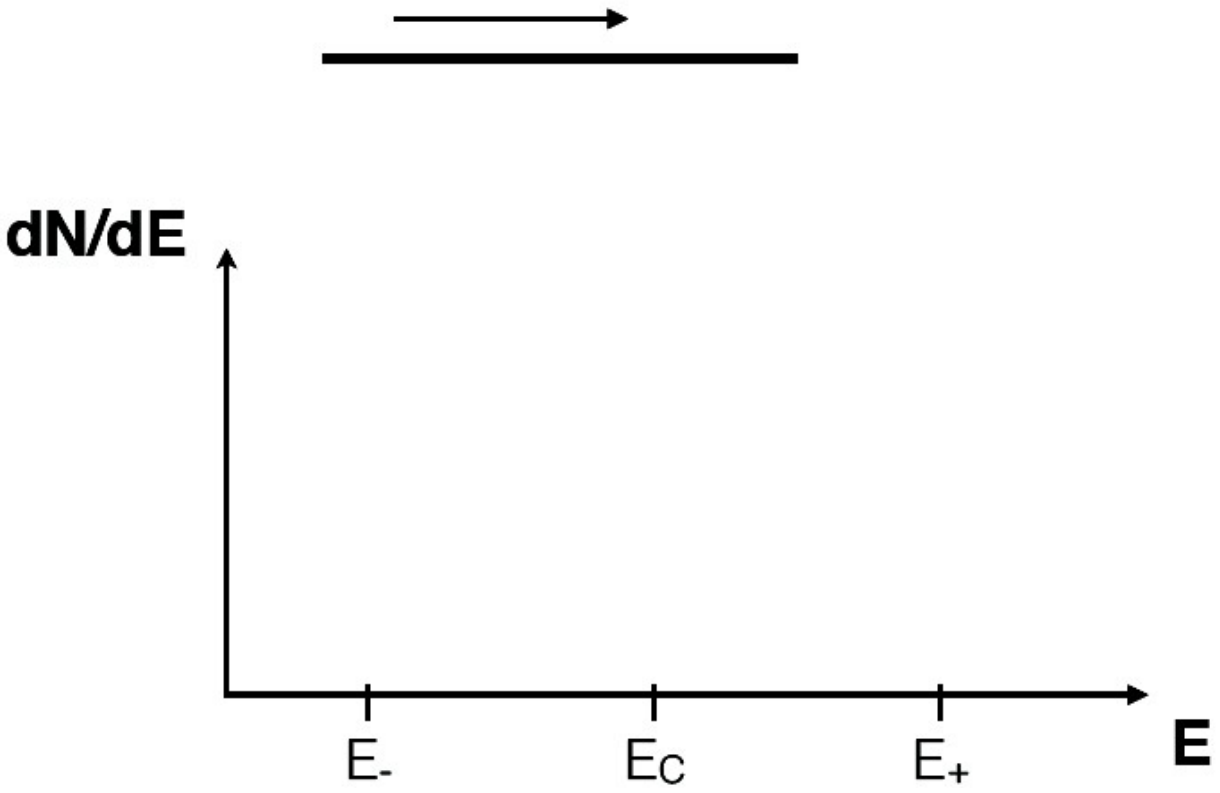


$$\frac{\mathrm{d}N_\gamma}{\mathrm{d}E_\gamma} = \frac{4}{\Delta E}\Theta(E - E_-)\Theta(E - E_+)$$

$$E_\pm = \frac{m_\chi}{2}\left(1 \pm \sqrt{1 - \frac{m_\phi^2}{m_\chi^2}}\right)$$

- narrow box: $m_\phi/m_\chi = 0.999$, wide box: $m_\phi/m_\chi = 0.1$

Idea: Gamma-ray boxes



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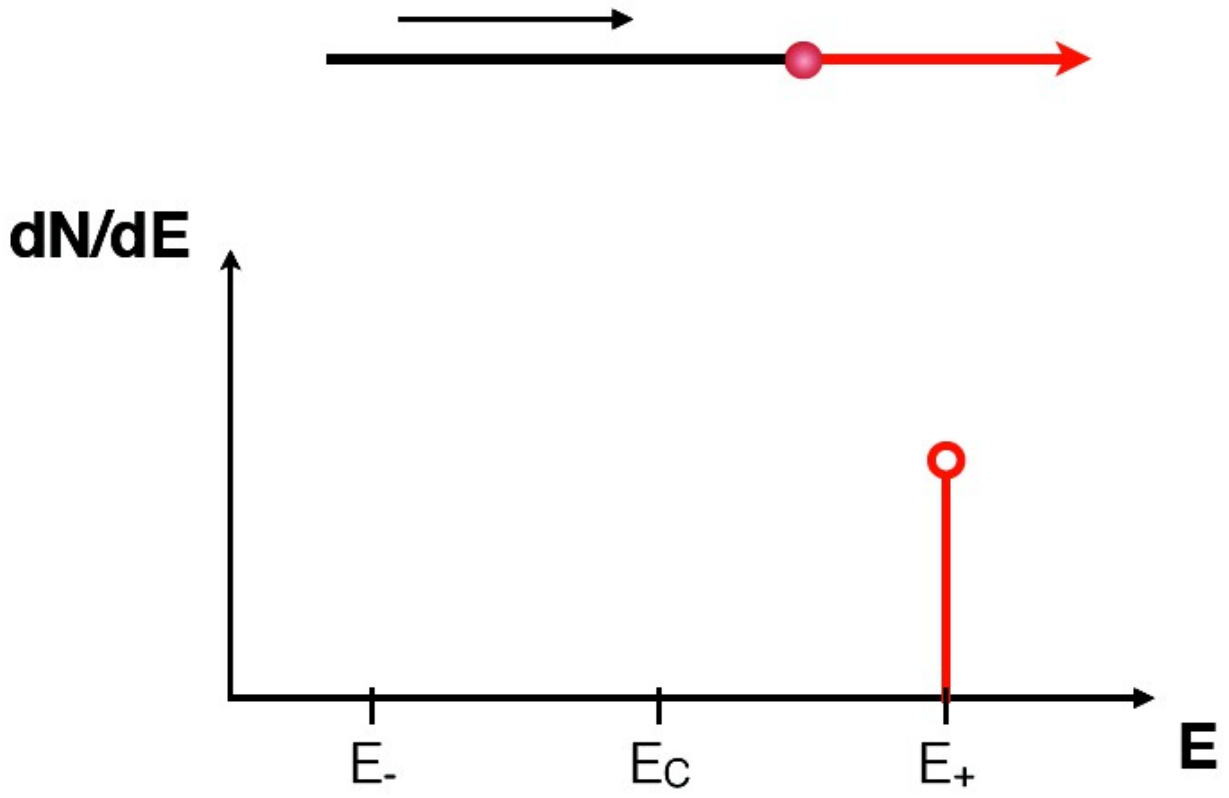

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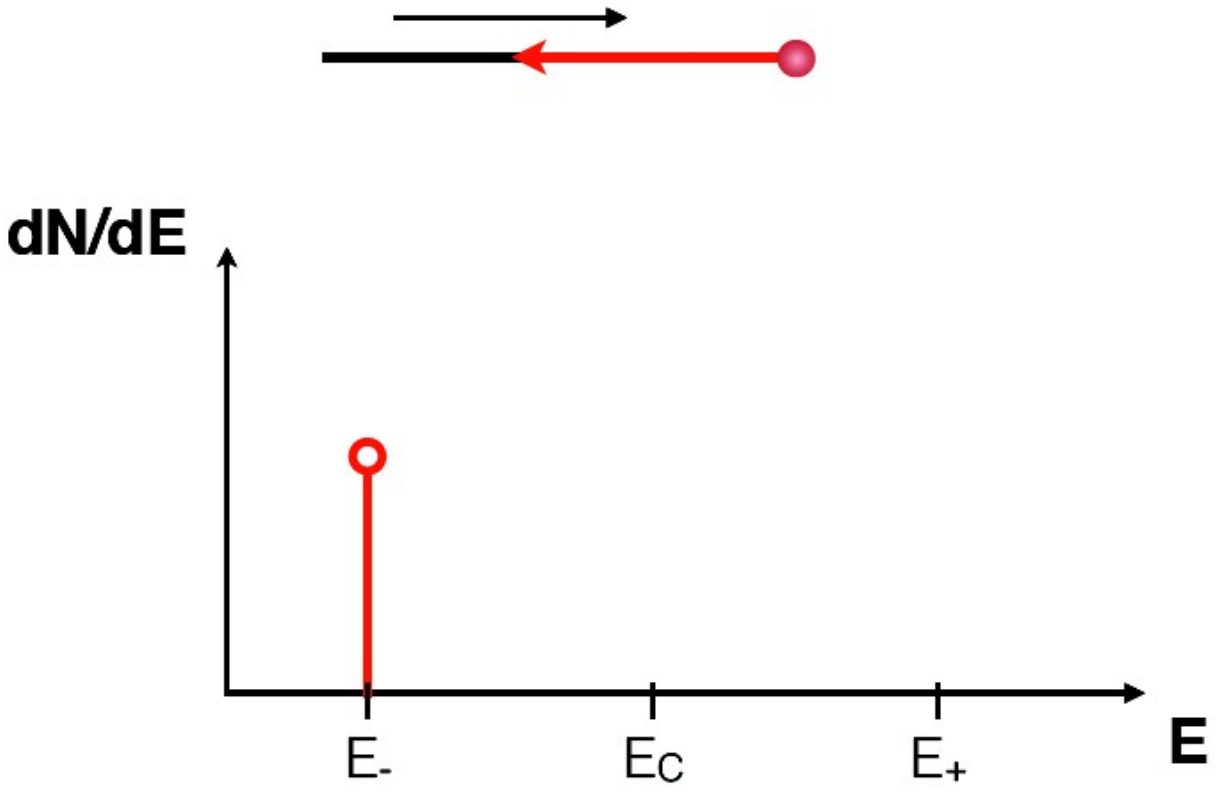

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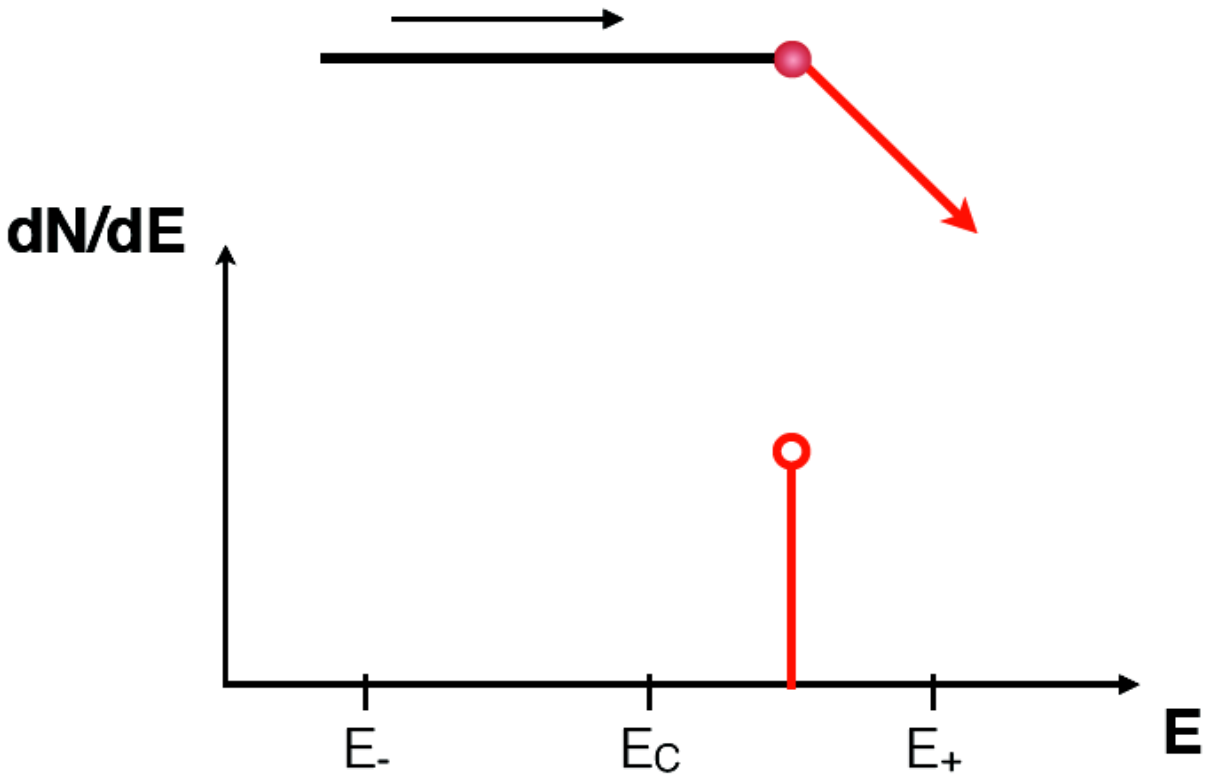

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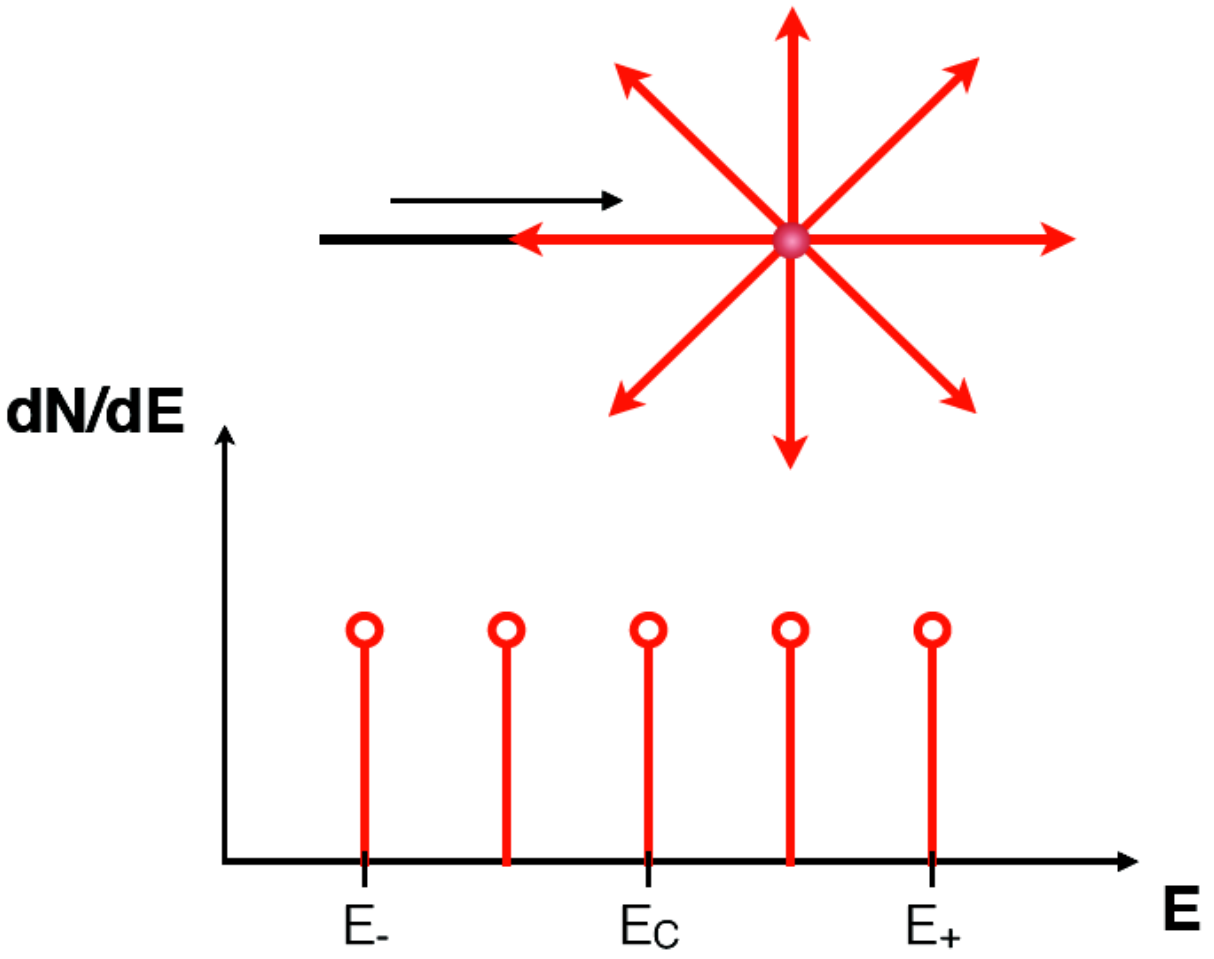

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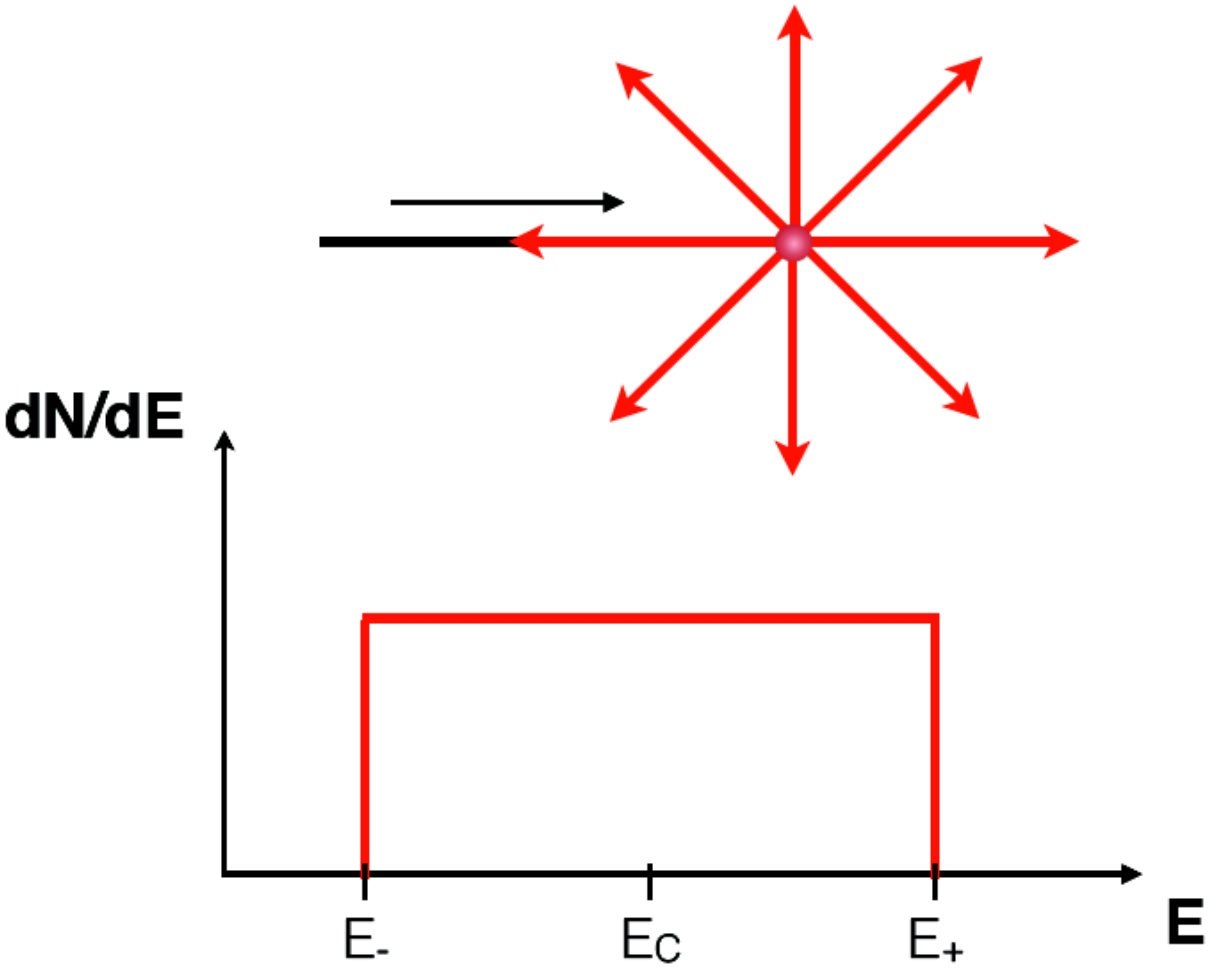

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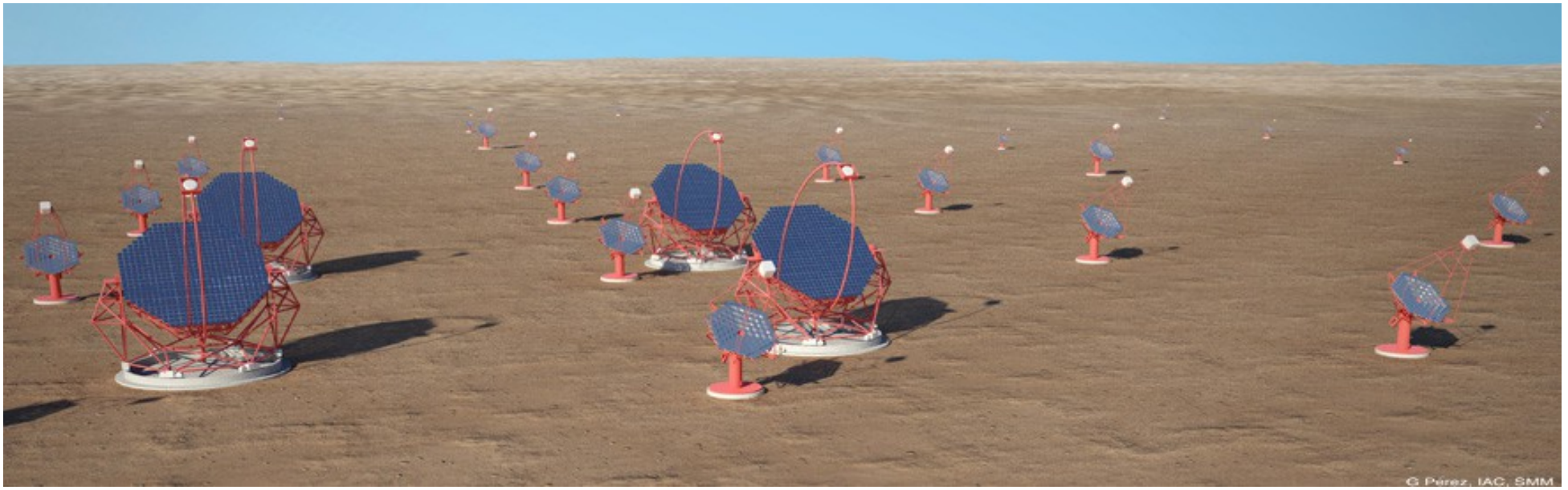
CTA: Future Cherenkov Telescope Array



- Use detailed instrument properties for array I (arXiv:1210.3503)
- Balanced southern array: 3 large, 18 medium and 56 small telescopes
- Effective area exceeds $10^6\,m^2$ above a few TeV
- Resolution is better than 10% above a few TeV
- Wide energy range from tens of GeV to above 100 TeV
- Sensitivity of a few milliCrab at 1 TeV after 50h of observation

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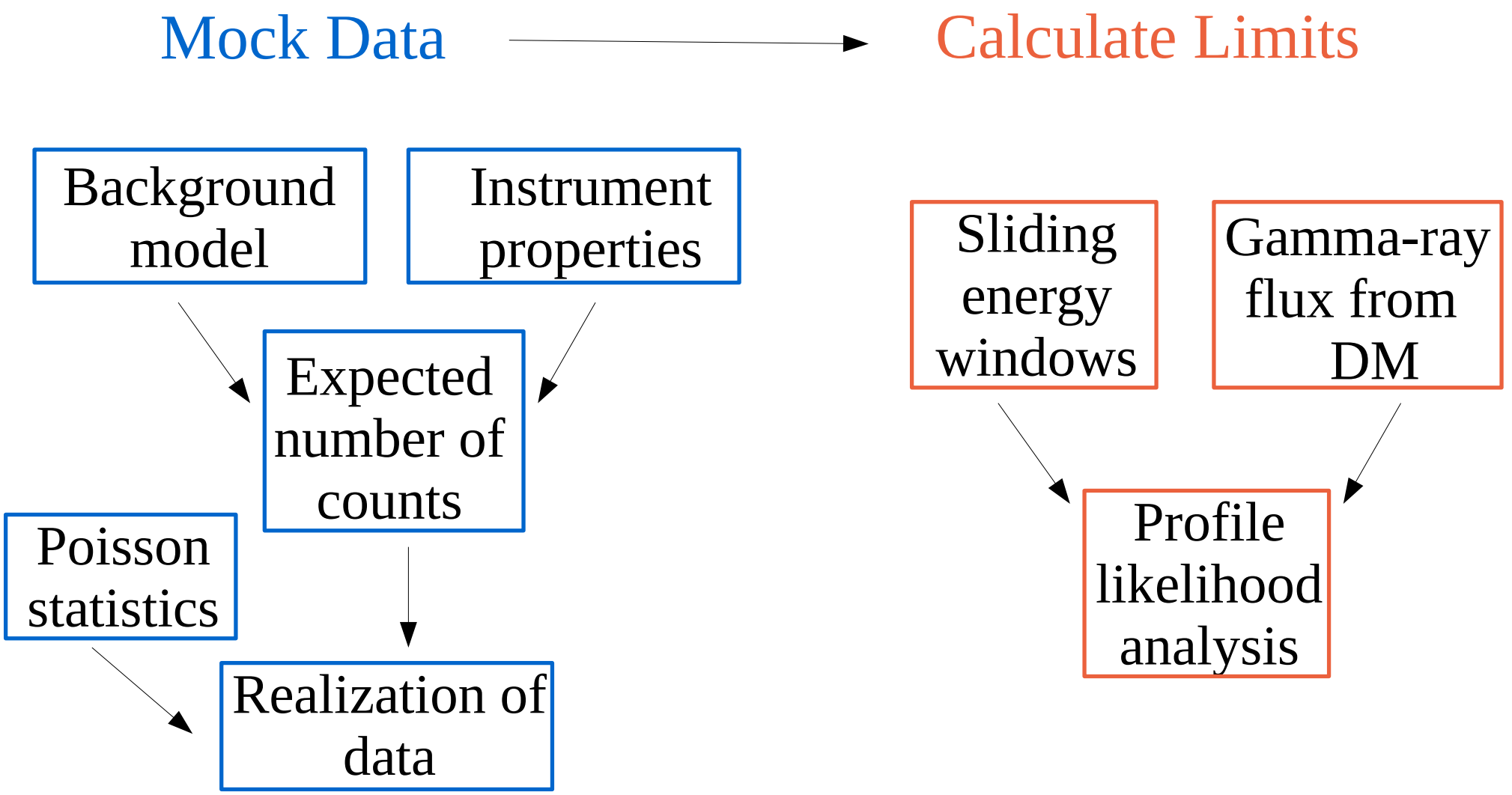
Approach: Prospects for CTA



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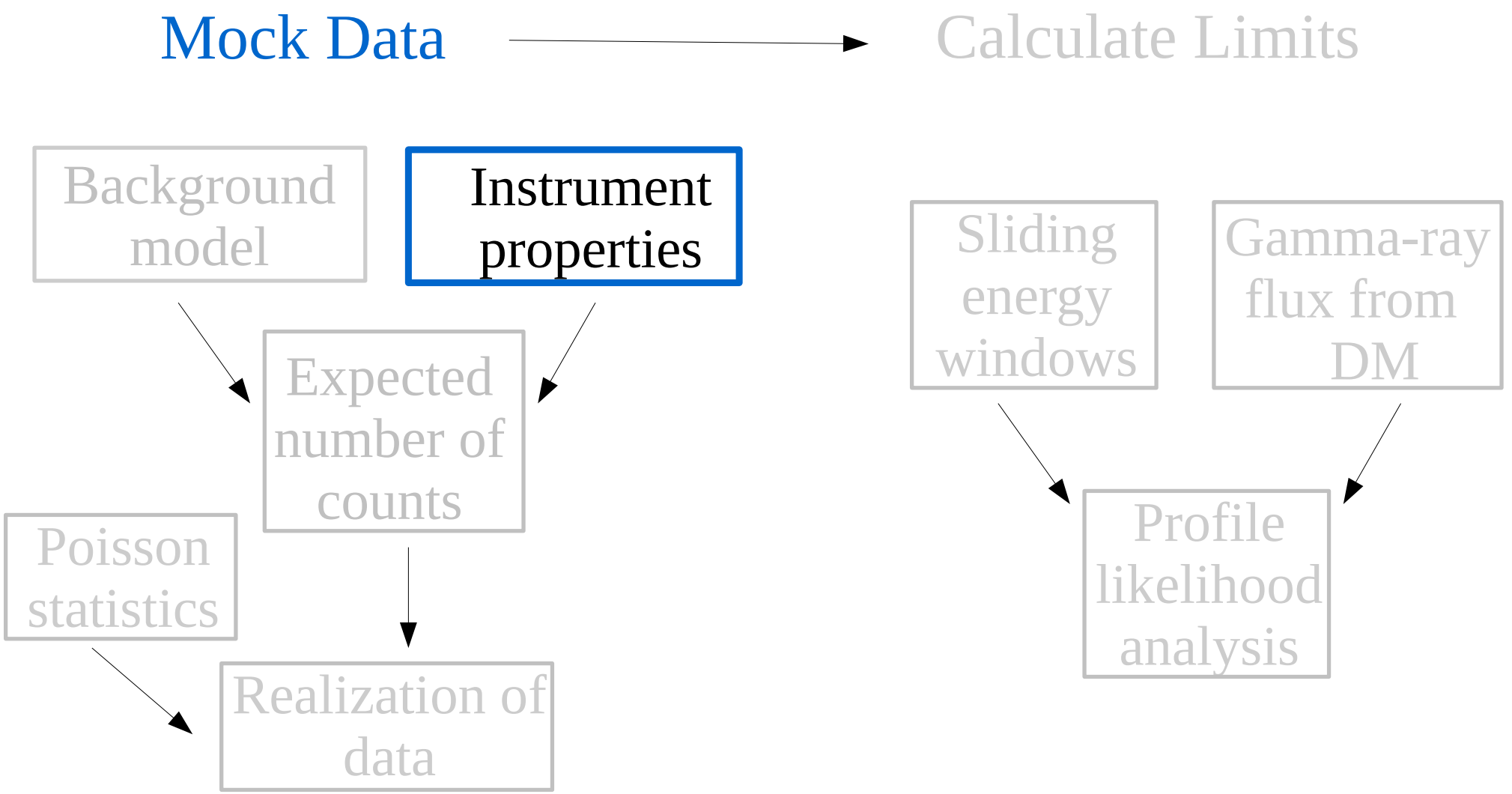
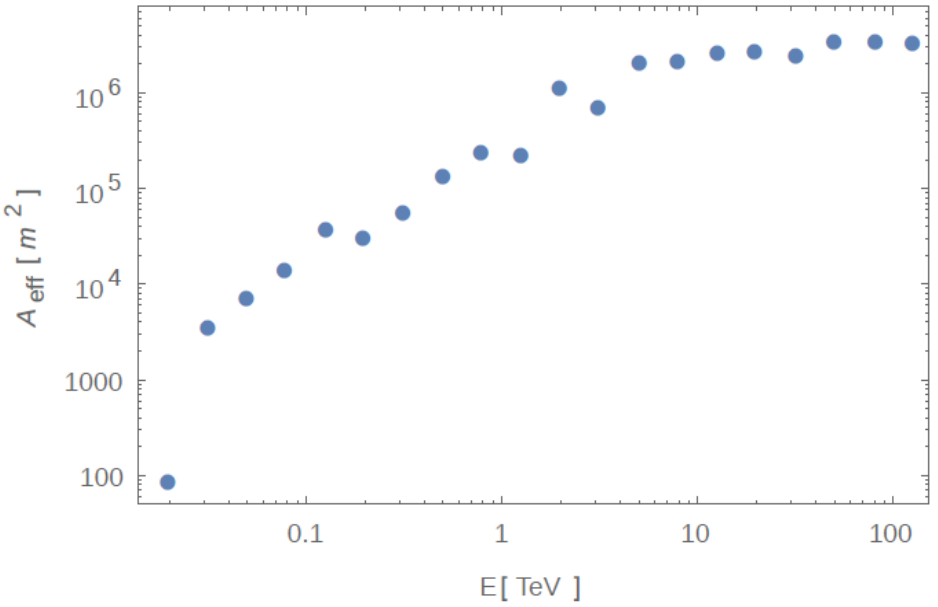
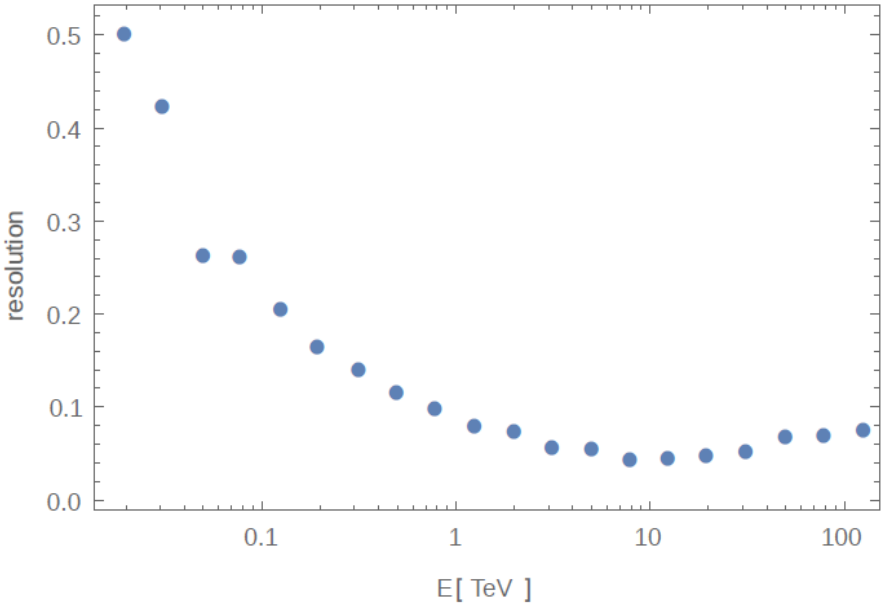


CTA instrument properties

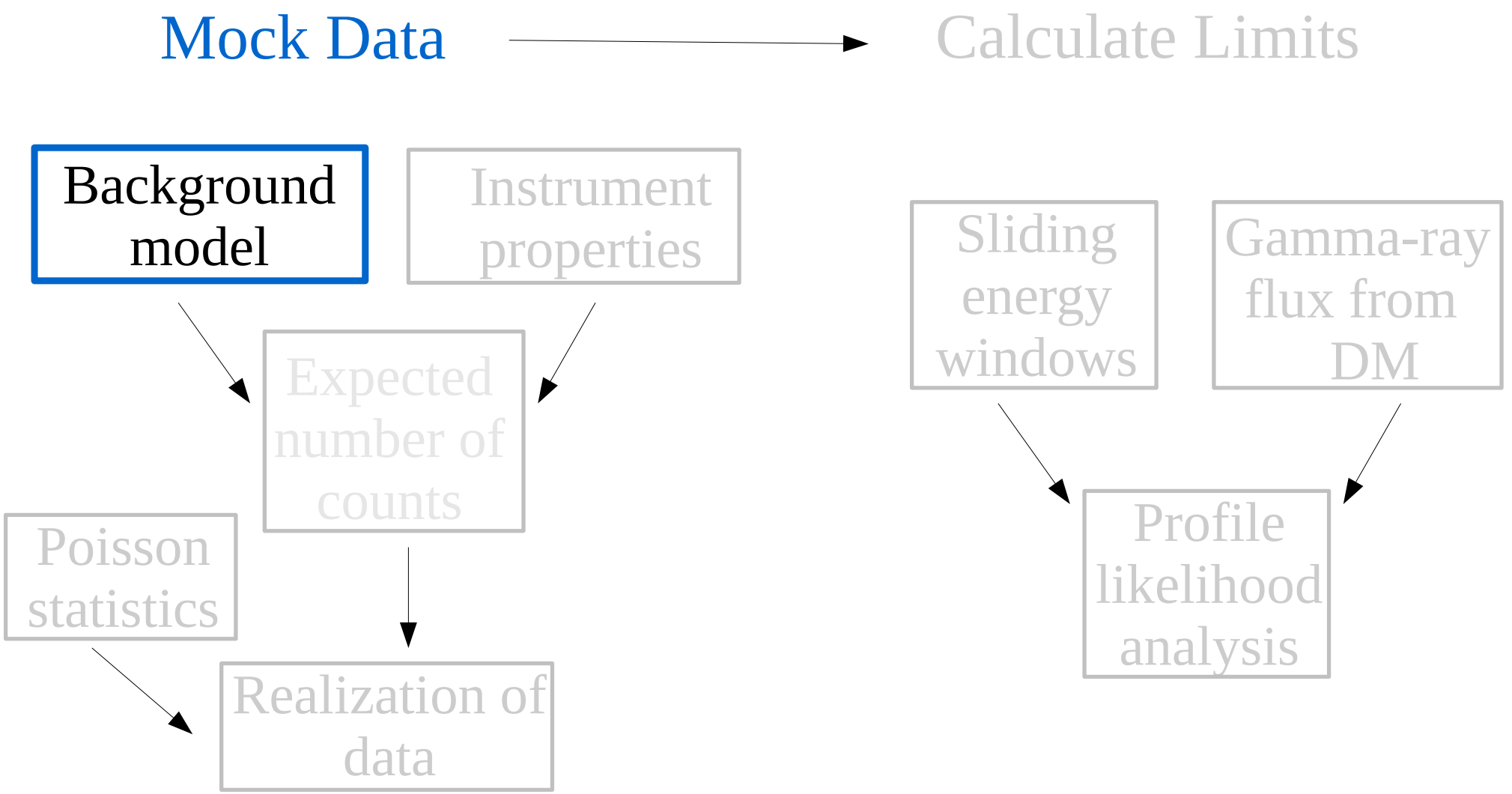
- Effective area and resolution



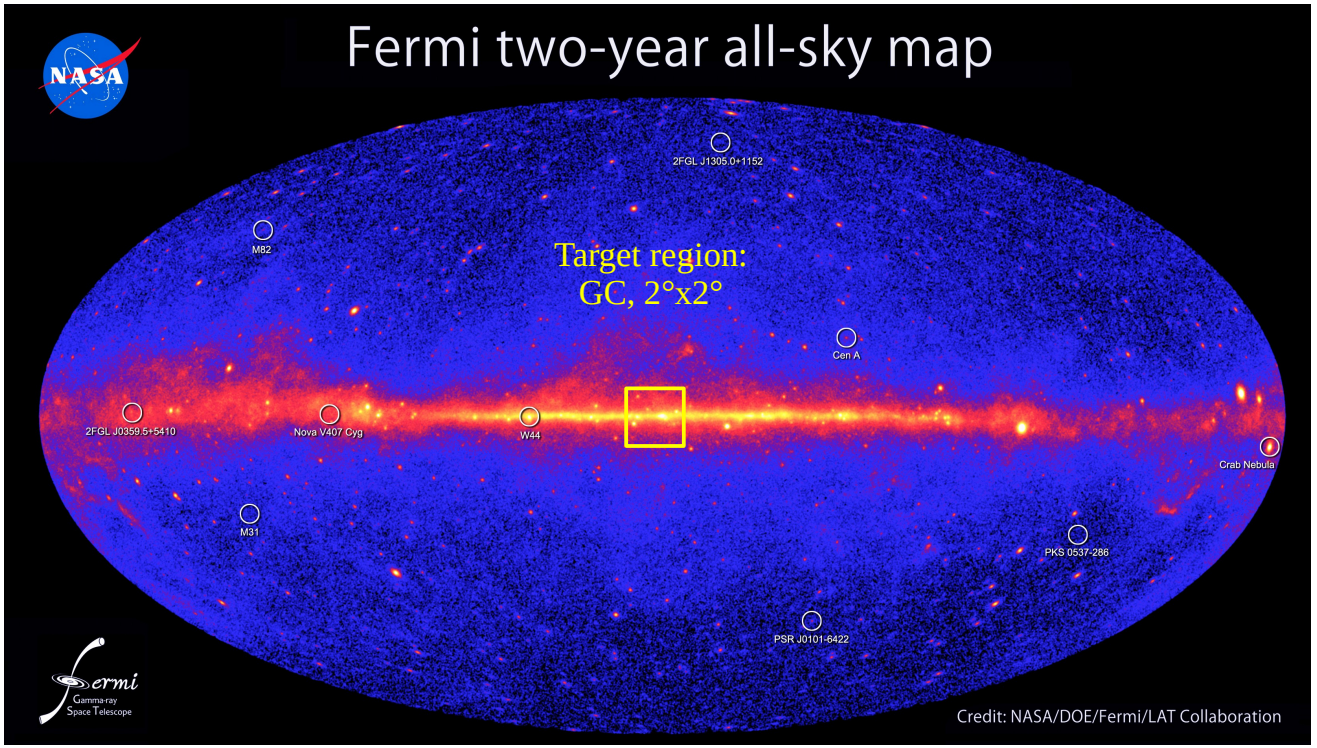


- Efficiencies: gammas and electrons: 1
- Proton rejection: 0.01 – 0.2

Approach: Prospects for CTA



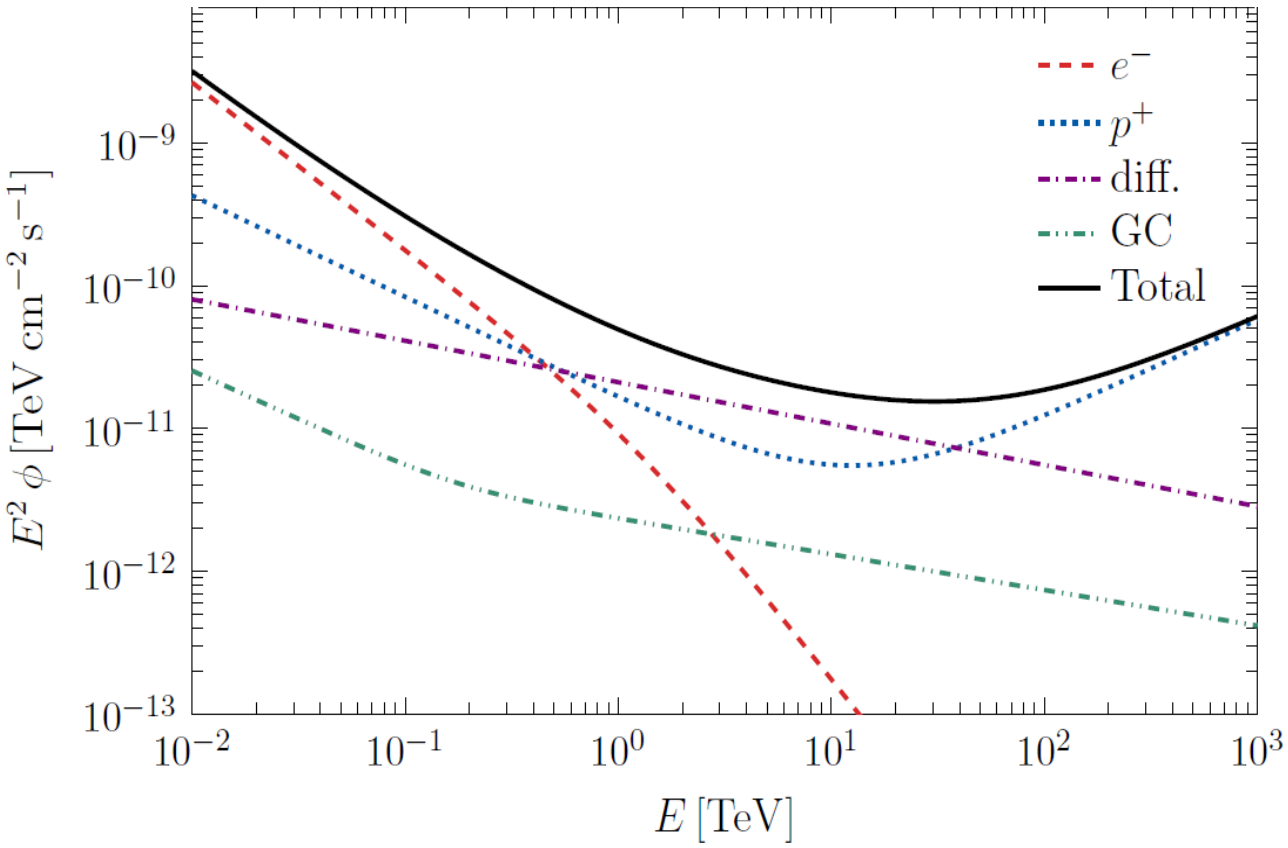
Background model: Target region



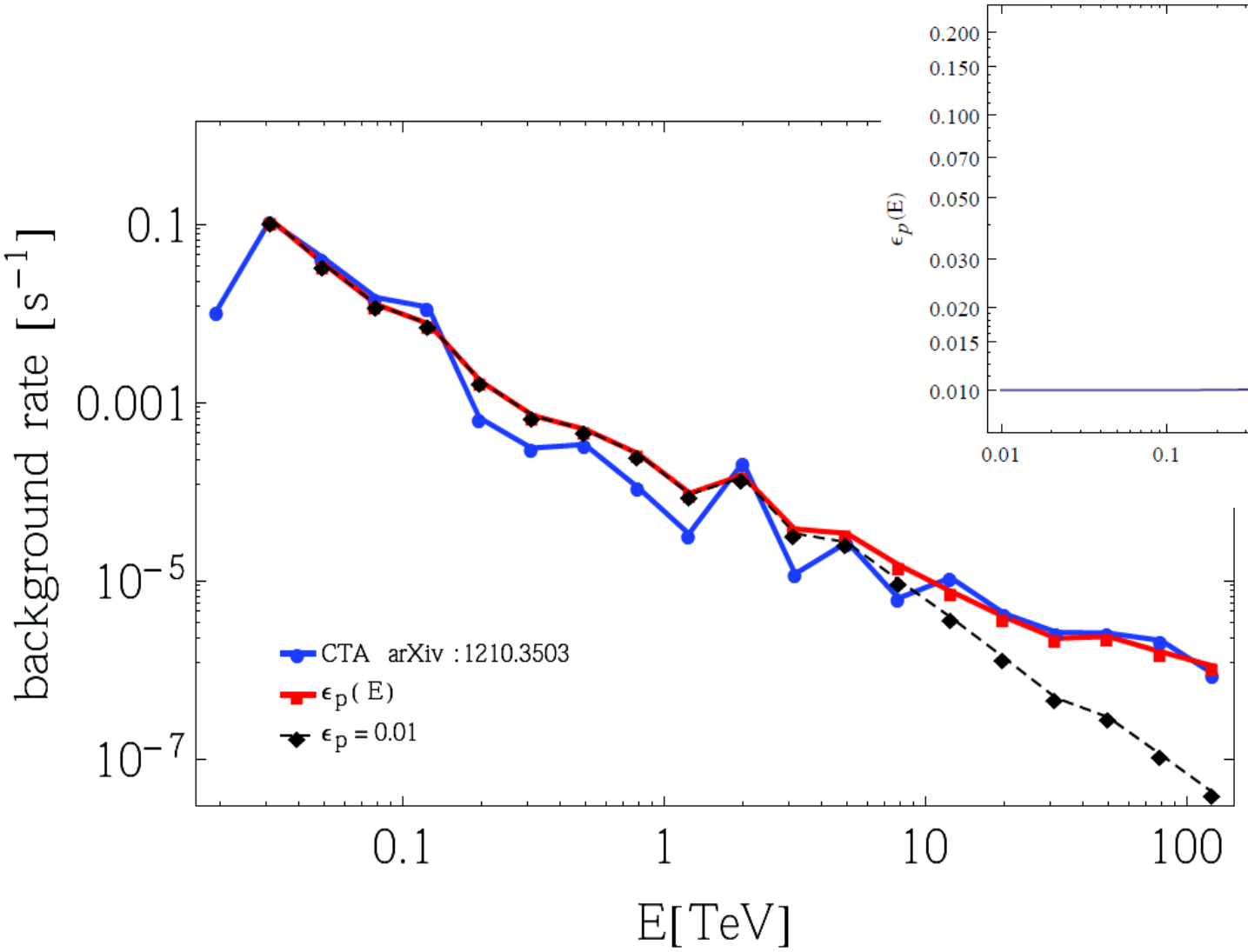
ROI: 2° x 2° around the GC, 100h of observation time

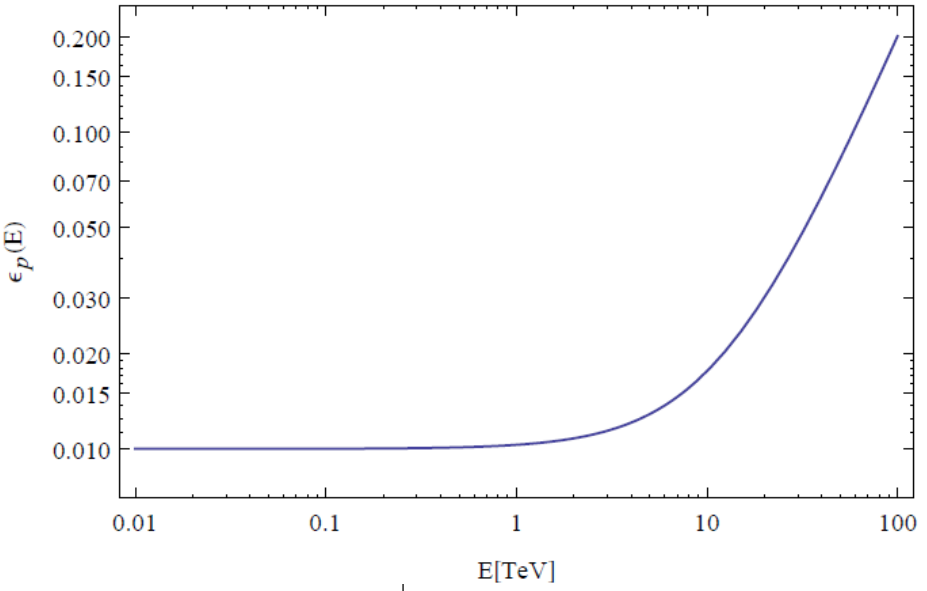
Background model: Fluxes

- Protons
- Electrons and positrons: irreducible
- Diffuse gamma-rays from molecular cloud
- HESS point source



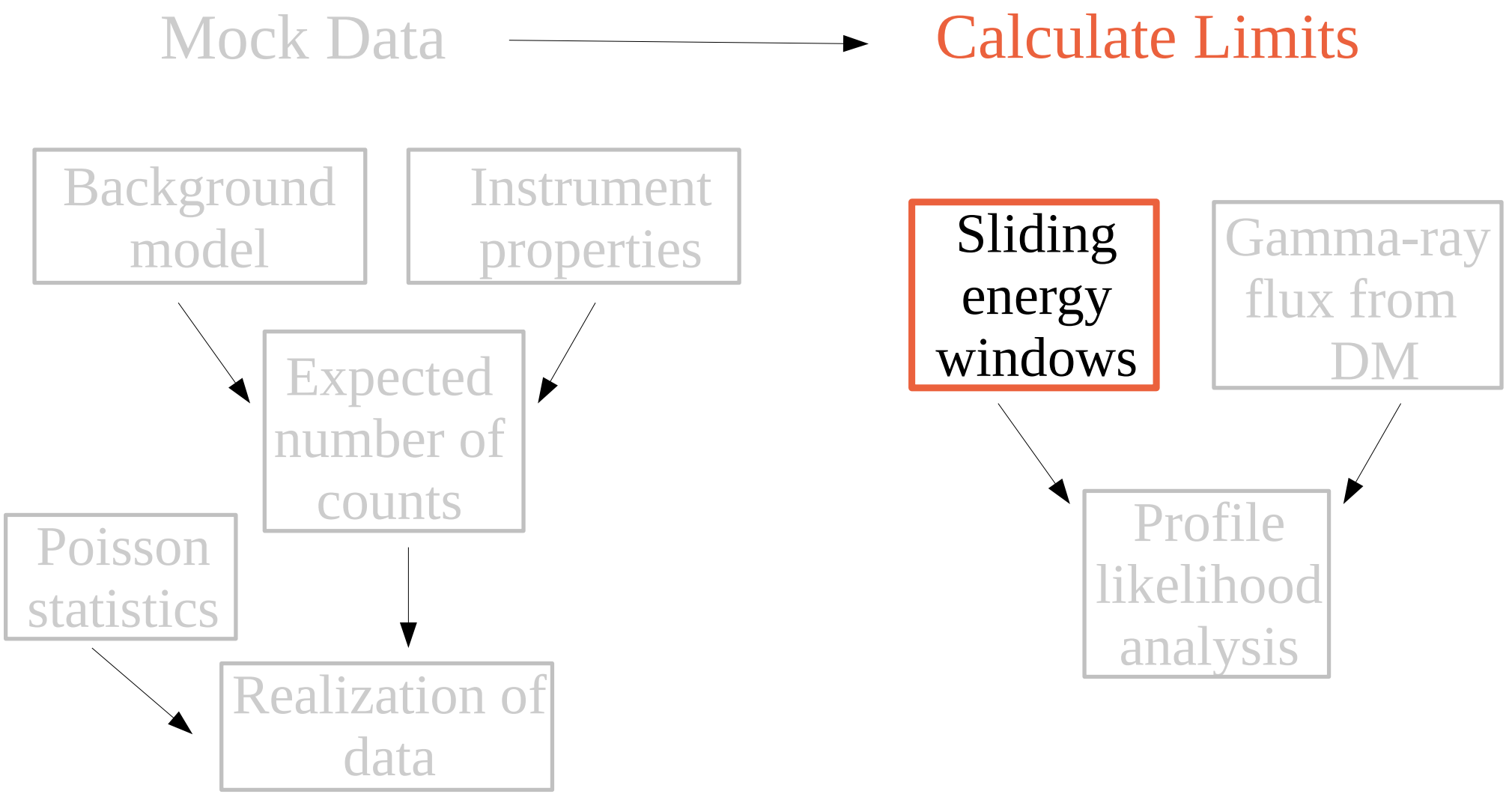
Background model: CTA background rate





Energy dependent proton rejection

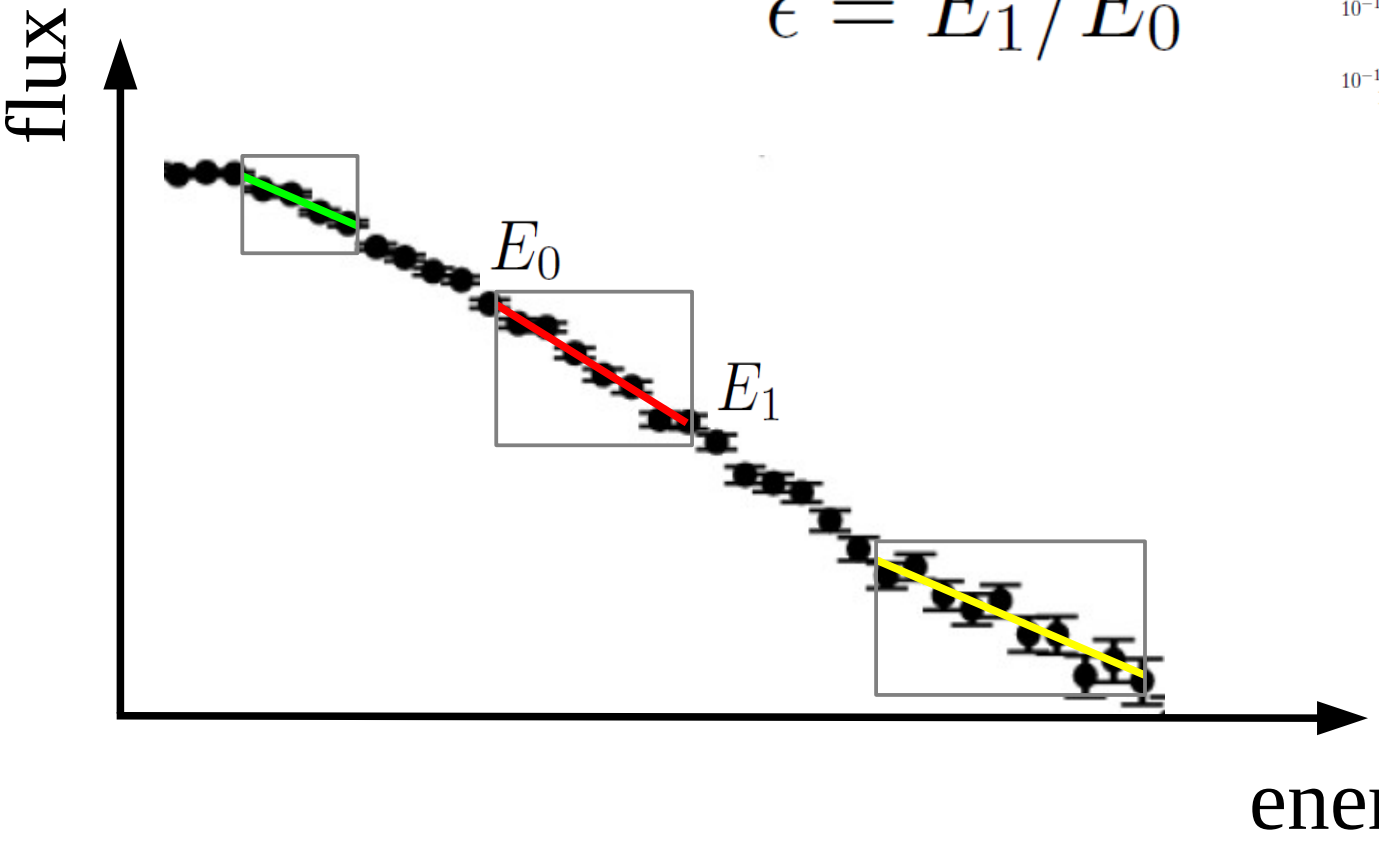
Approach: Prospects for CTA

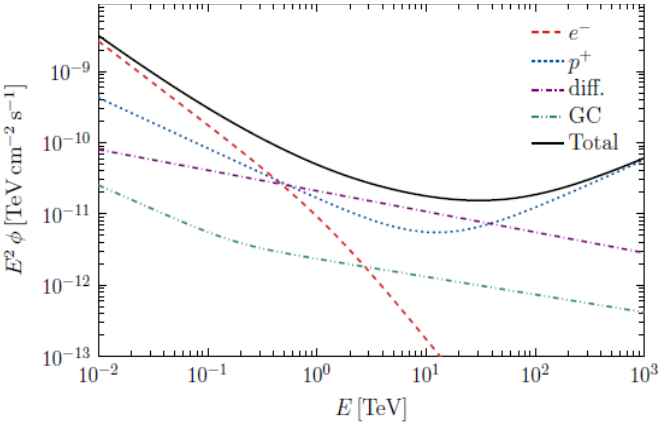


Sliding energy windows

Background can only be fit by a power law in limited energy range

$$\epsilon = E_1 / E_0$$





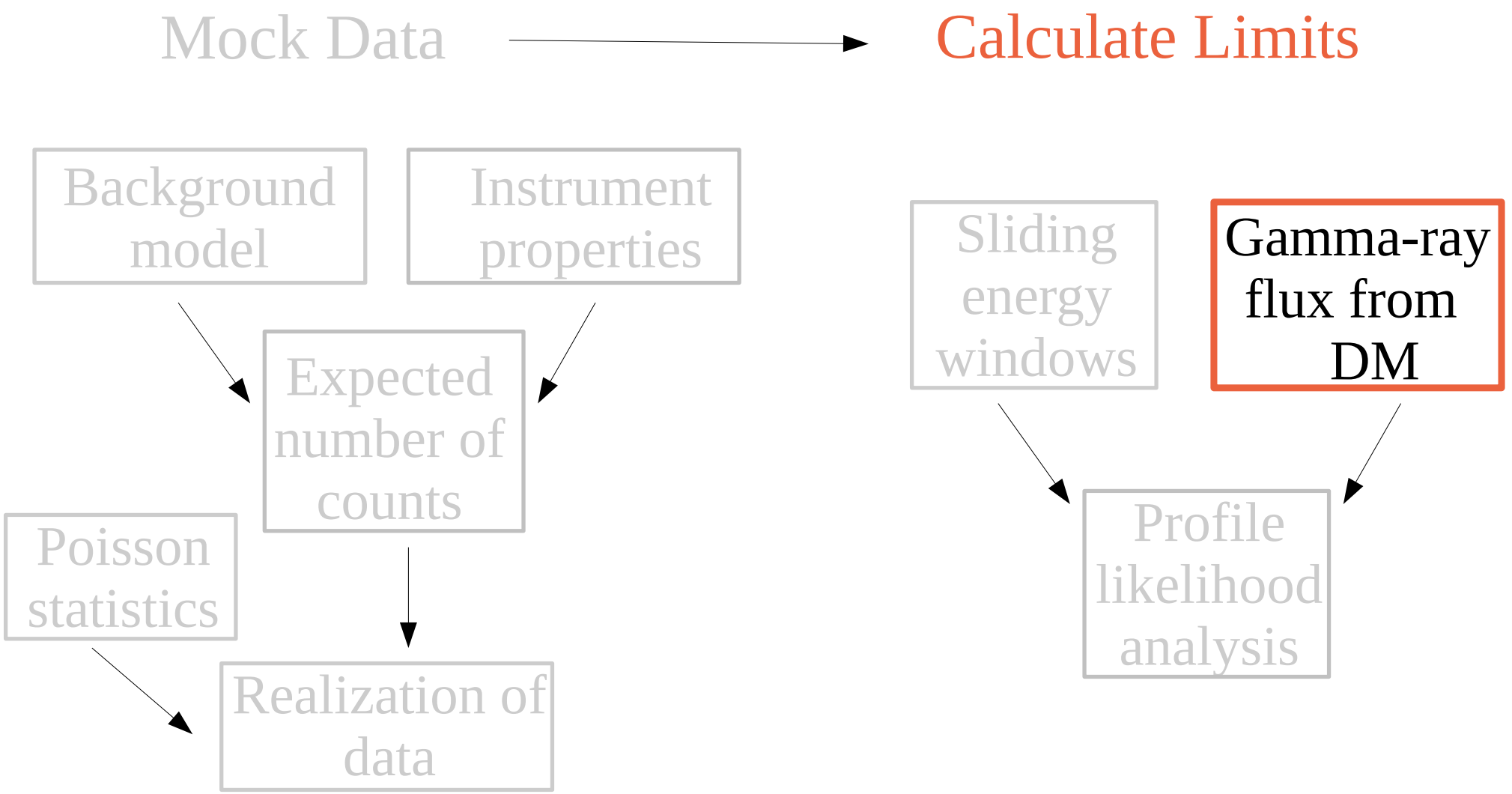
Three different window sizes:

$$\epsilon_{1.2} = 1.2$$

$$\epsilon_{1.5} = 1.5$$

$$\epsilon_2 = 2$$

Approach: Prospects for CTA



Gamma-ray flux from DM

Gamma-ray flux $$\frac{\mathrm{d}\Phi_{\mathrm{dm}}}{\mathrm{d}E_\gamma} = \frac{\langle\sigma v\rangle_0^{4\gamma}}{16\pi m_\chi^2}\frac{\mathrm{d}N_\gamma}{\mathrm{d}E_\gamma} J_{\mathrm{ann}}$$

Particle physics

Astrophysics

$$\frac{\mathrm{d}N_\gamma}{\mathrm{d}E_\gamma} = \frac{4}{\Delta E}\Theta(E-E_-)\Theta(E-E_+)$$

Gamma-ray boxes

$$J_{\mathrm{ann}} = \int_{\Delta\Omega}\mathrm{d}\Omega\int_{\mathrm{los}}\mathrm{d}s\,\rho^2_{\mathrm{dm}}$$

Einasto profile

Gamma-ray flux from DM: Optical depth in the Milky Way

Absorption in interstellar radiation field arXiv:0511149

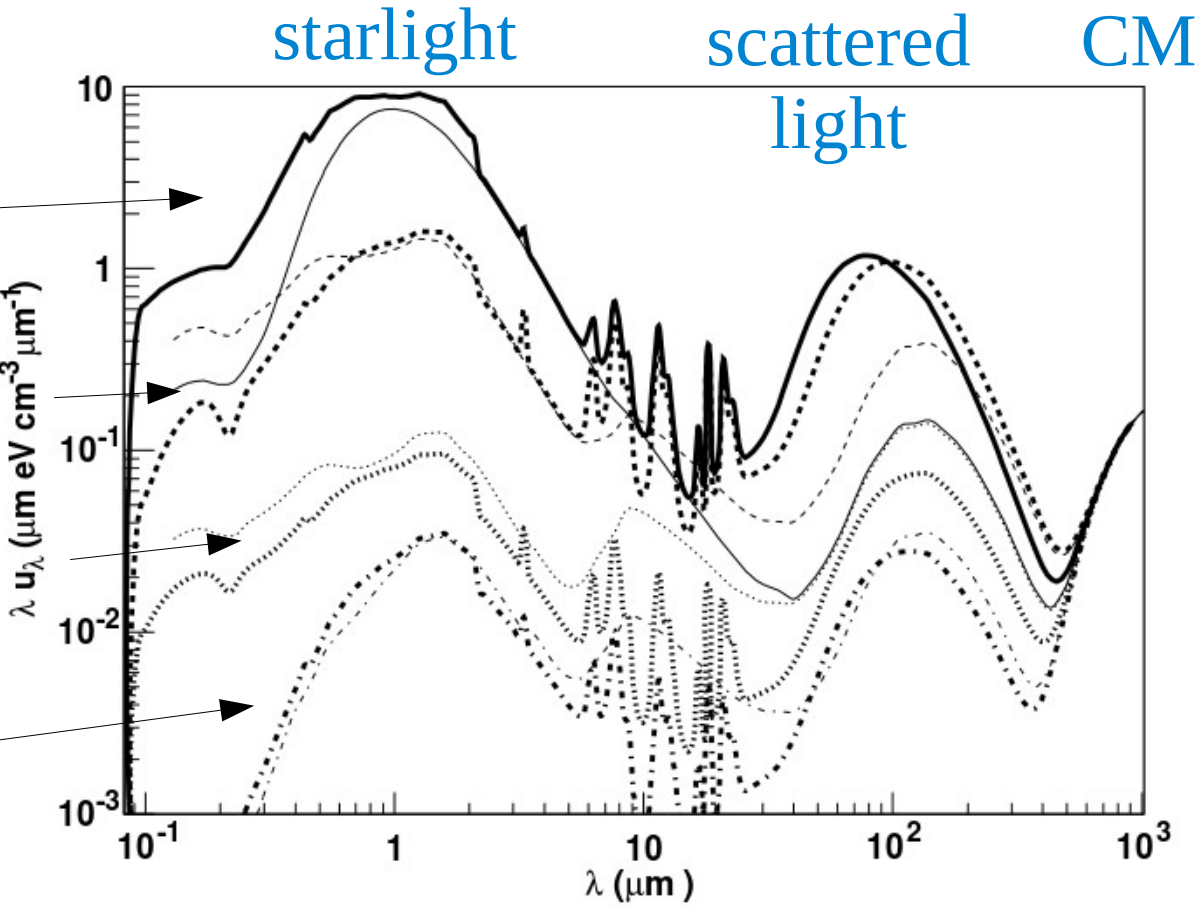
(R[kpc],z[kpc])

(0,0)

(4,0)

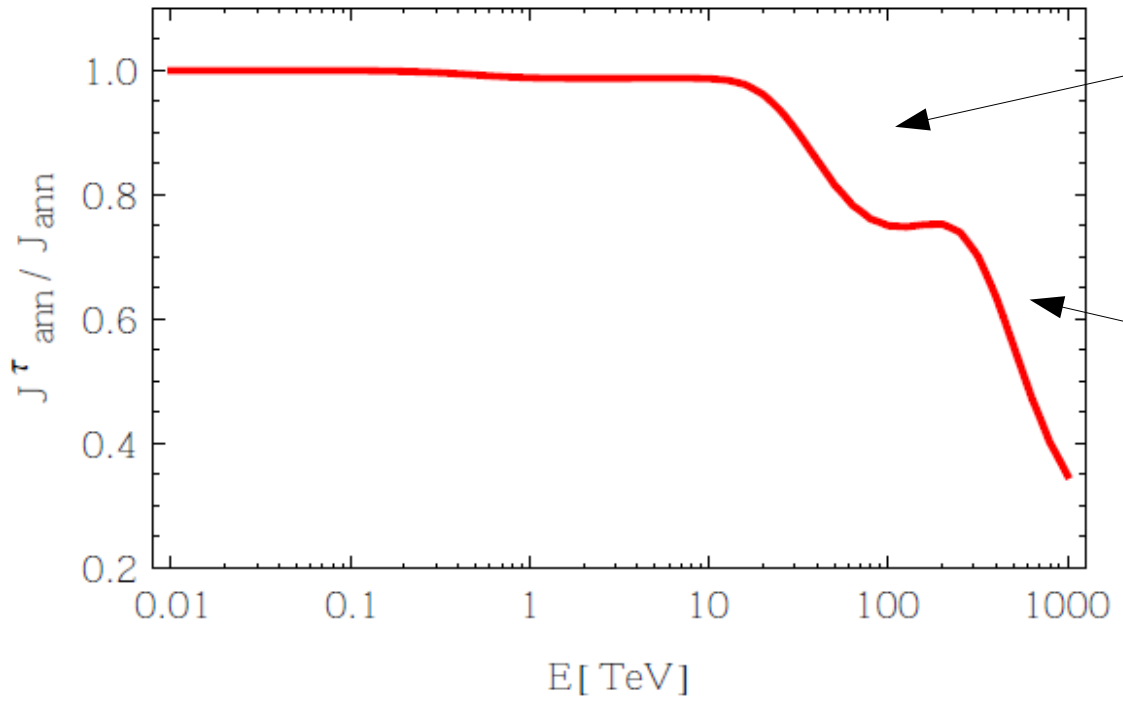
(12,0)

(16,0)



Gamma-ray flux from DM: Optical depth in the Milky Way

- Absorption of high-energy gamma rays due to electron-positron pair production with photons from the ISRF
- Energy dependent J-factor $J^{\tau}_{\rm ann}(E_\gamma) = \int_{\Delta\Omega} {\rm d}\Omega \int_{\rm los} {\rm d}s\, e^{-\tau(E_\gamma, s, \Omega)} \rho^2_{\rm dm}$



ISRF without CMB

CMB

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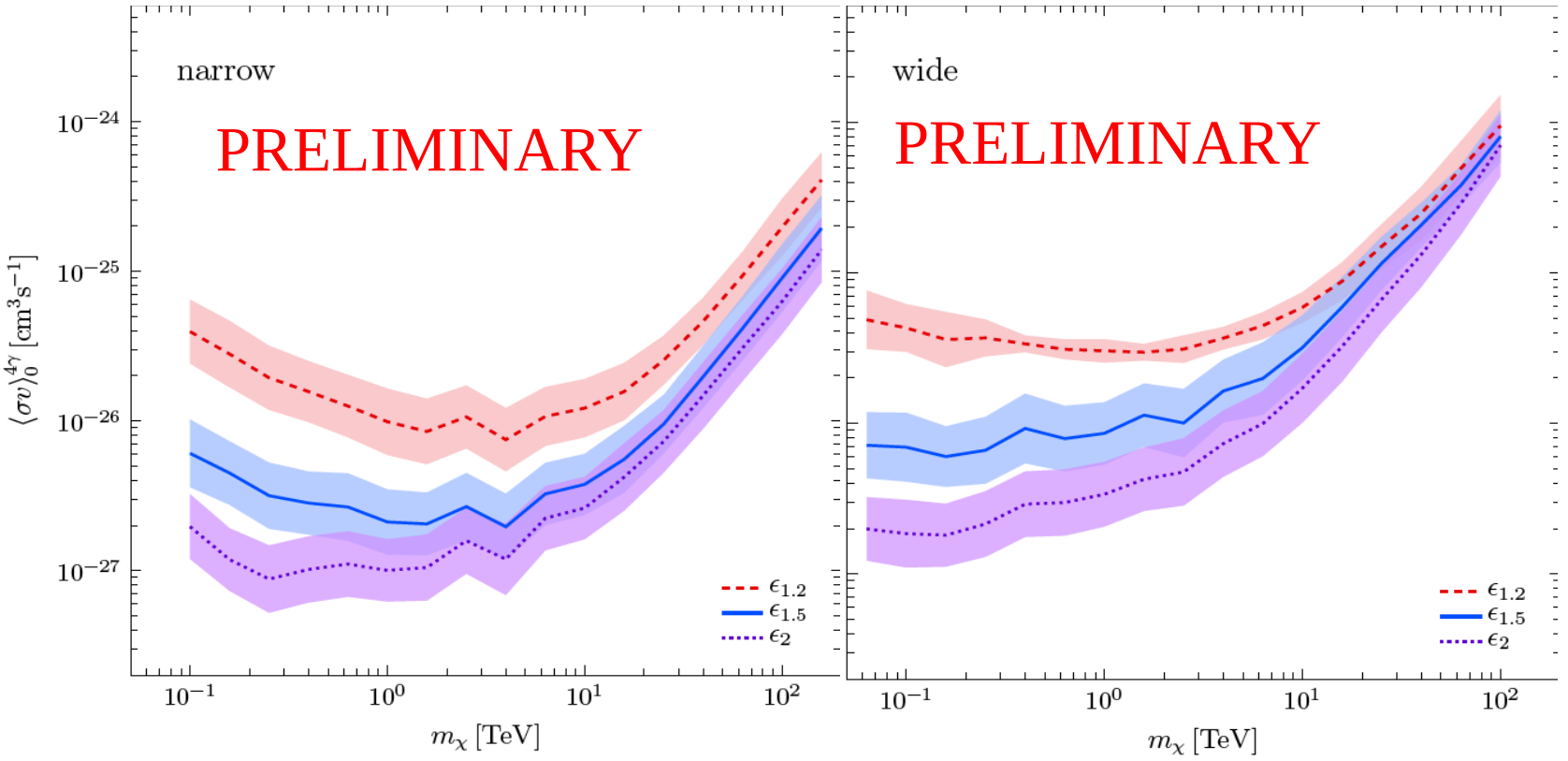
Results: Constraints

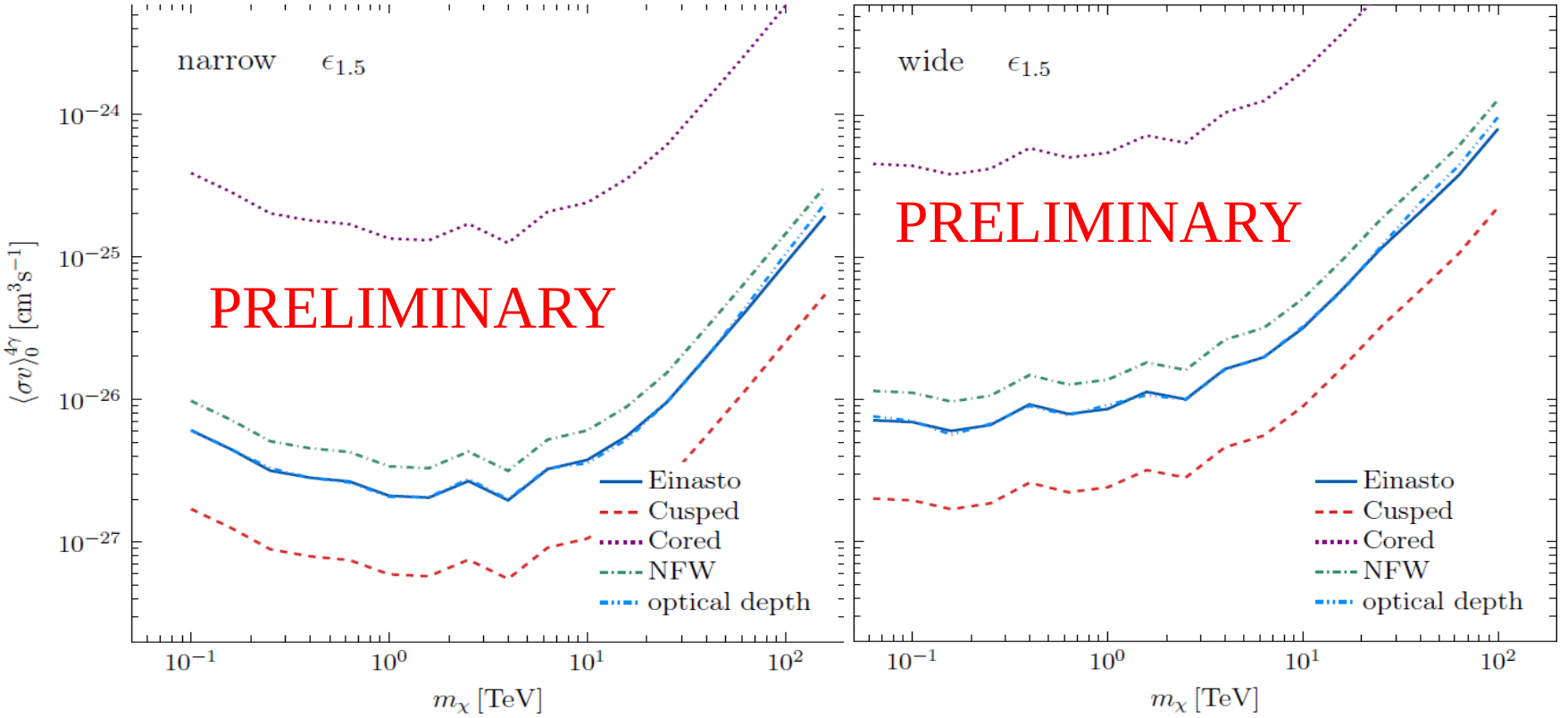
- Annihilation of Dirac DM into 4 photons
- Assume all branching ratios to be one



$m_\phi/m_\chi = 0.999$ $m_\phi/m_\chi = 0.1$

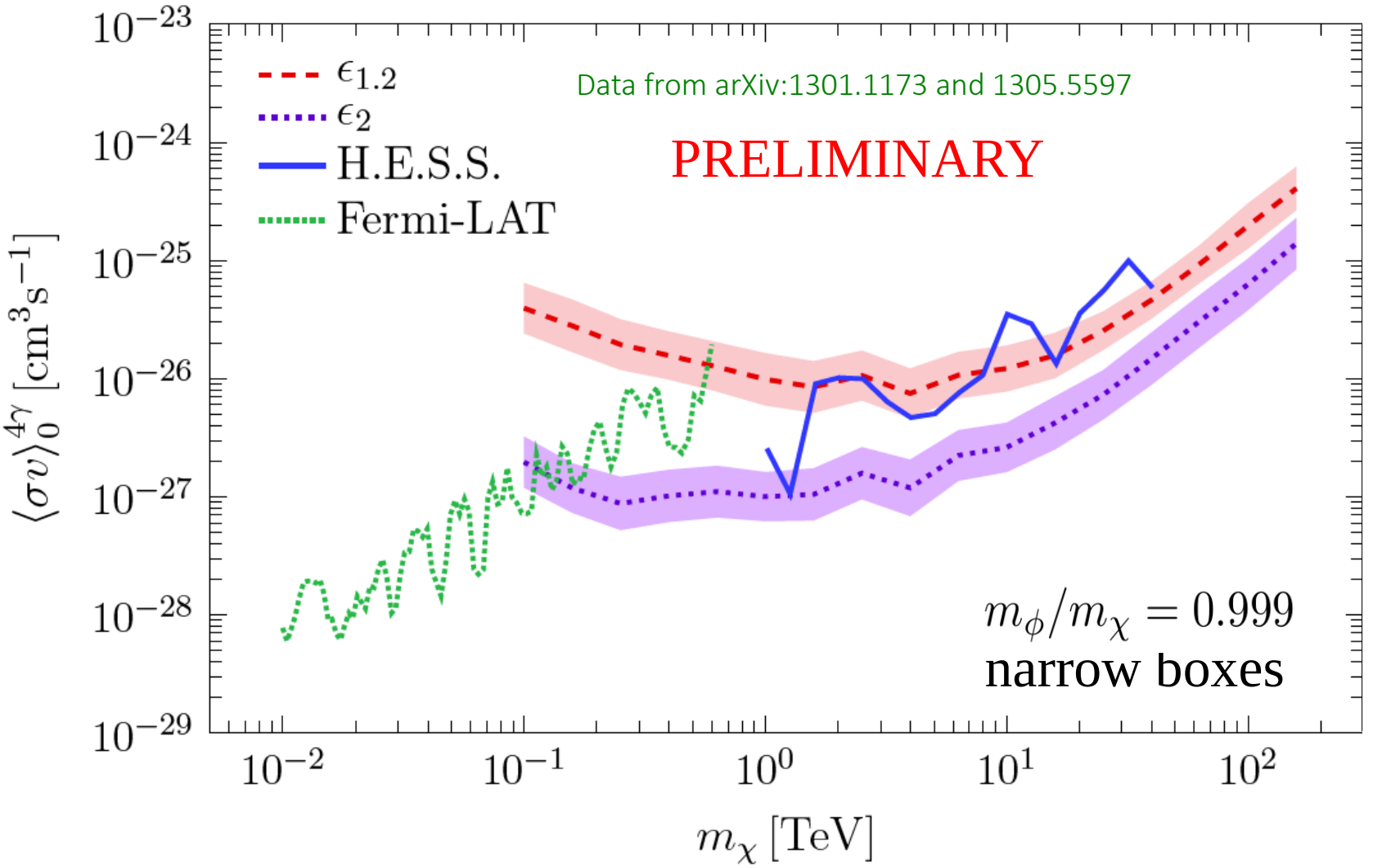
Results: Impact of DM profile

Cored profile, NFW, contracted NFW (inner slope -1.2), Einasto, Einasto including the optical depth



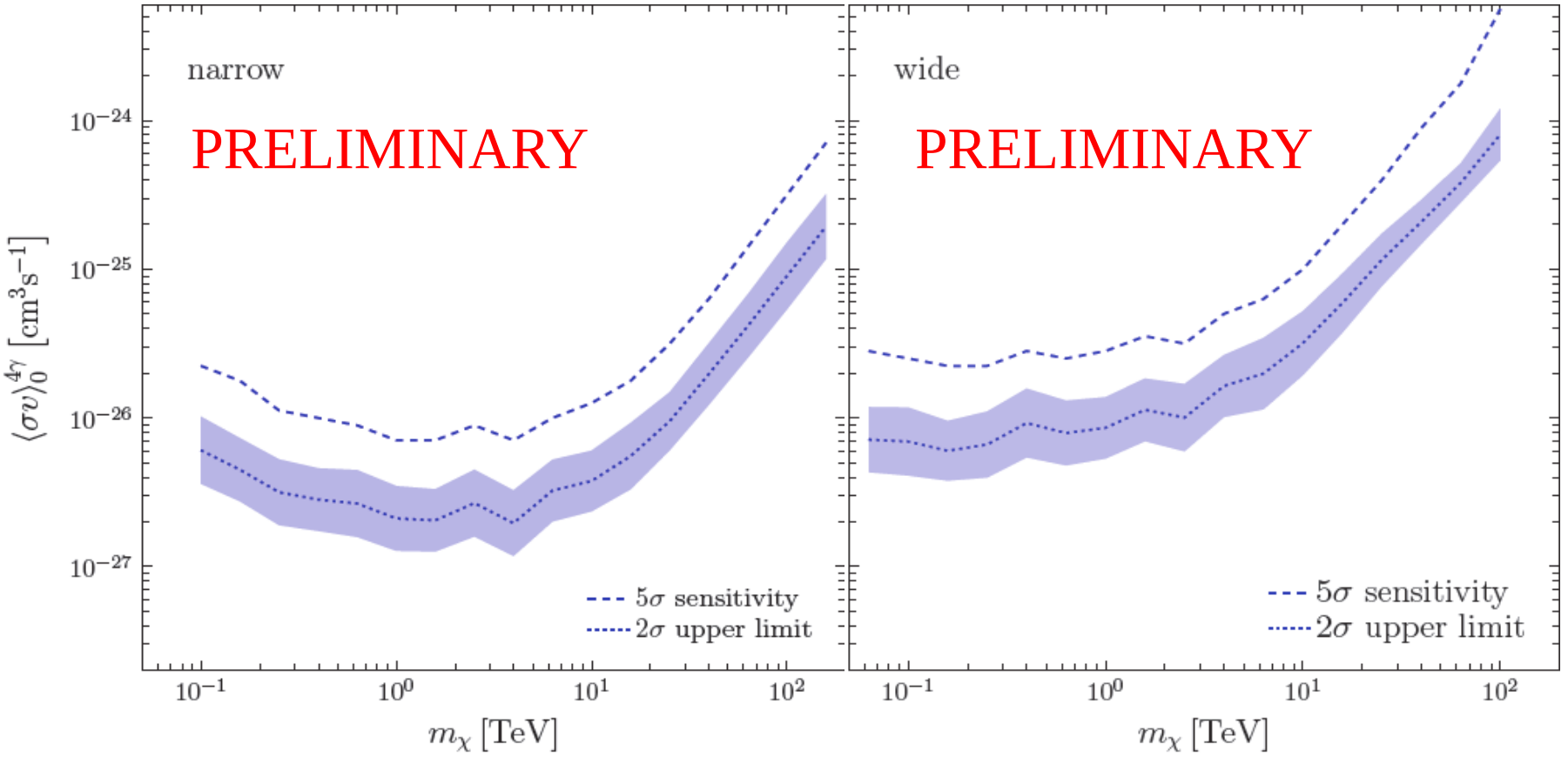
$m_\phi/m_\chi = 0.999$ $m_\phi/m_\chi = 0.1$

Results:
CTA, Fermi and HESS



Results: Sensitivity

Cross section that can be detected with 5 sigma



$m_\phi/m_\chi = 0.999$

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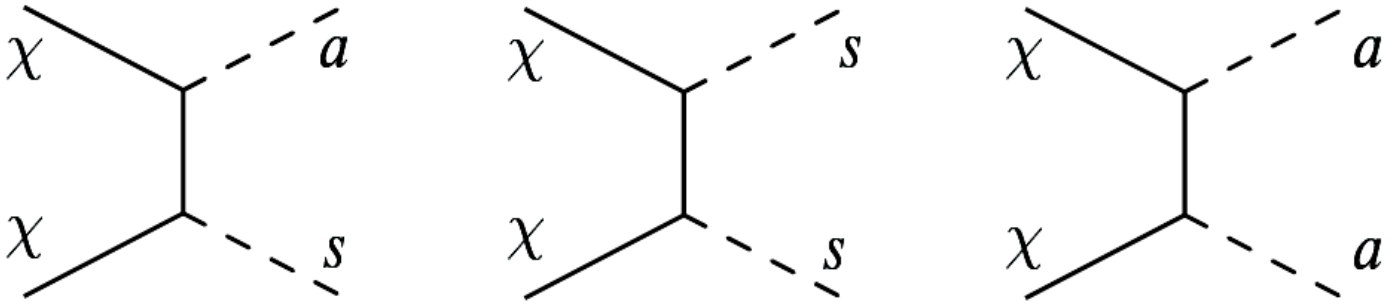
Constraints on a concrete model producing boxes

- Dirac dark matter particles
- Complex scalar field $S = (v_s + s + ia)/\sqrt{2}$
- Peccei-Quinn Mechanism: a is axion-like particle

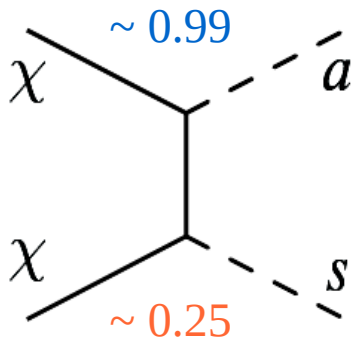


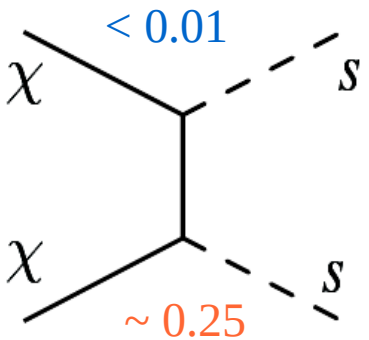
arXiv:1303.6632

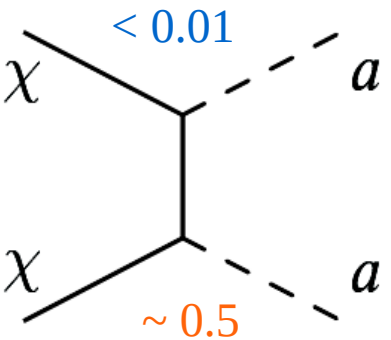
Constraints on a concrete model producing boxes

- Branching ratios for DM annihilations arXiv:1303.6632

Narrow boxes



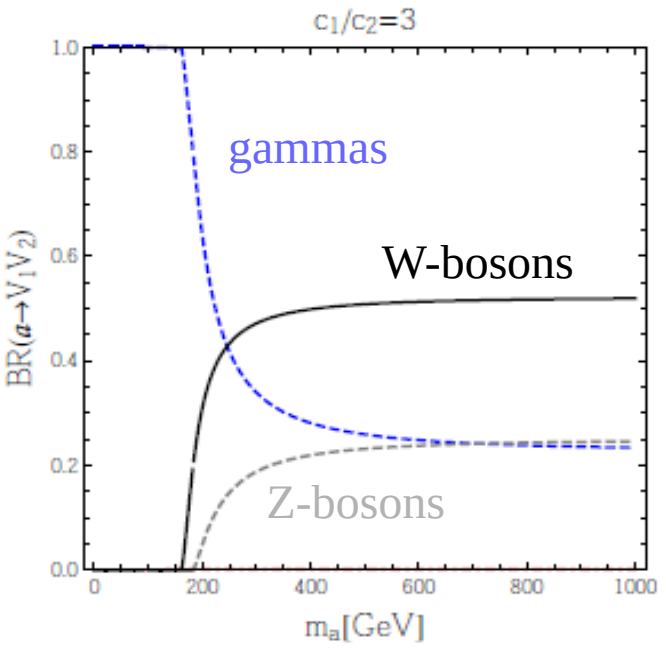




wide boxes

~ 0.25 ~ 0.25 ~ 0.5

- Branching ratios for decays of axion-like particle into a pair of gammas, W-bosons, and Z-bosons



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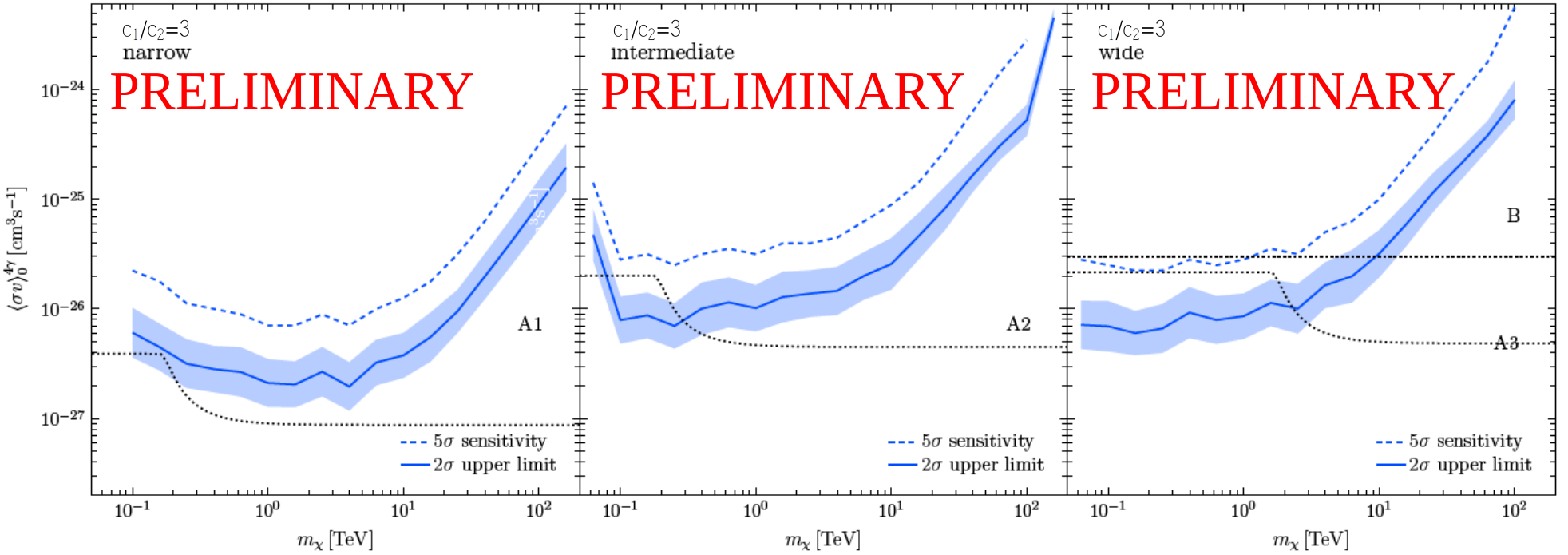

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- Limits can be substantially improved compared to other instruments
- Watch out for our paper!

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Thank you for your attention!