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The Relevance of Sharp Gamma-Ray Features for Indirect Dark Matter Searches

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Indirect Detection through Gamma-rays

DM pair-annihilation into SM particles can produce a gamma-ray signal with distinct and unambiguous spectral features

→ How well pronounced spectral features can improve the sensitivity of current and future gamma-ray telescopes to the DM signal?

Method

Discrimination of the signal over the background

- Signal: DM spectra with endpoint spectral features at $E_\gamma \approx m_\chi$ (talk by *L. Bergström*)

(1) Line signal from direct annihilation

- $O(\alpha^2)$ suppressed
- Clear signature at

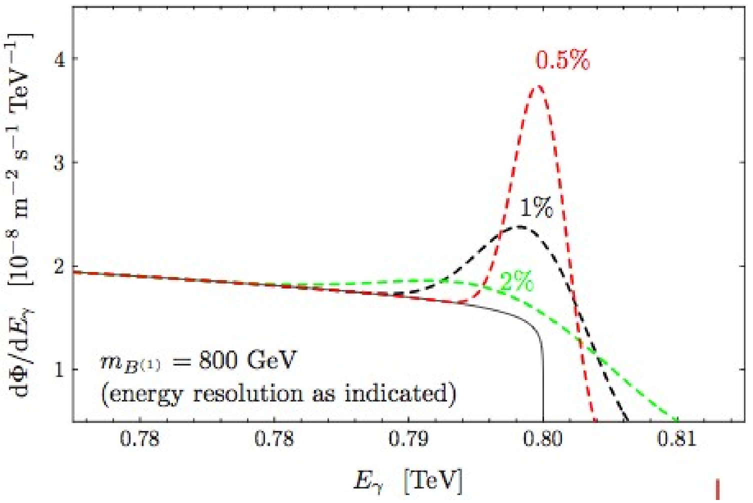
$$E_\gamma = m_\chi , \quad m_\chi [1 - \frac{m_{Z,H}^2}{m_\chi^2}]$$

- In general:

$$\langle \sigma v \rangle_{Line} \sim \alpha_{em}^2 \times \langle \sigma v \rangle_{tree} \sim 10^{-30} cm^3 s^{-1}$$

$\rightarrow$ discrimination requires high energy resolution

Bergstrom et al. JCAP 0504 (2005)



Method

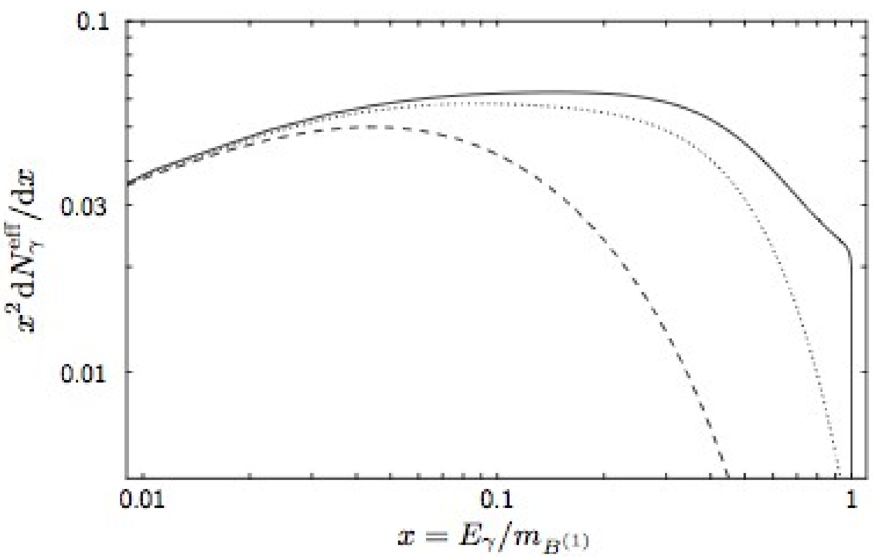
Discrimination of the signal over the background

- Signal: DM spectra with endpoint spectral features at $E_\gamma \approx m_\chi$

(2) Step-like or cutoff spectral feature

- Final State Radiation (FSR): photon radiated by external legs; almost model-independent spectrum
- e.g.: LKP in UED; $m_{B(1)} \approx 1.3$ TeV; high BR into leptons (≈60%)

Bergstrom et al. PRL 94 (2005)



Method

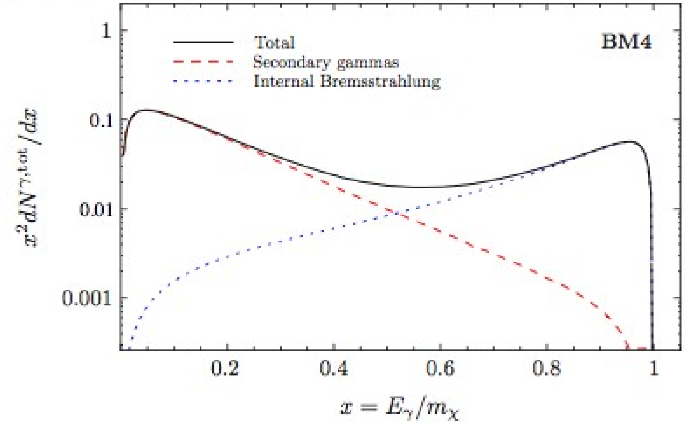
Discrimination of the signal over the background

- Signal: DM spectra with endpoint spectral features at $E_\gamma \approx m_\chi$

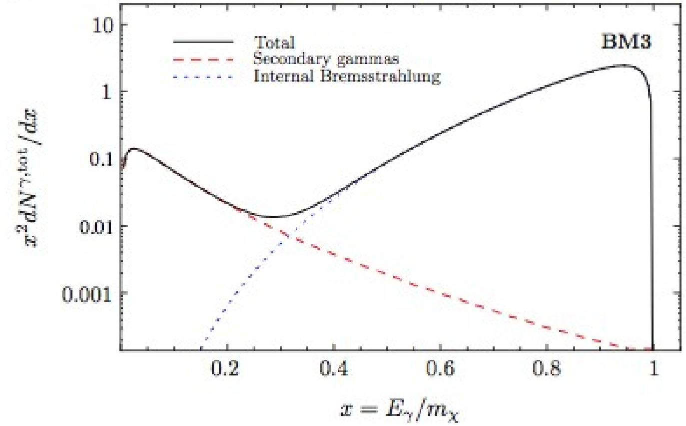
  (3) Bump-like spectral feature

  - Virtual Internal Bremsstrahlung: photons emitted by virtual exchanged particles; highly model dependent spectrum
  - e.g.: Neutralino DM
    - BM3: stau co-annihilation region (VIB from sleptons)
    - BM4: higgsino in focus point region annihilating in charged gauge bosons final states

focus point region ($m_\chi = 1926$ GeV)



coannihilation region ($m_\chi = 233$ GeV)



Bringmann et al. JHEP0801 (2008)

Method

Discrimination of the signal over the background

- Background: locally described by a power-law.

  → GC observation with IACTs:

  - Observational benchmark scenarios for IACTs

For more details, see talks by: *L. Bergström* and *J. Conrad*

Scenario	A_{eff} (1 TeV)	ΔE/E (1 TeV)	ε_p	t_{obs}
IACT1 (H.E.S.S.)	0.18 km^2	15%	10^{-1}	50 h
IACT2 (CTA)	2.3 km^2	9%	10^{-2}	100 h
IACT3 (DMA)	23 km^2	5%	10^{-3}	5000 h

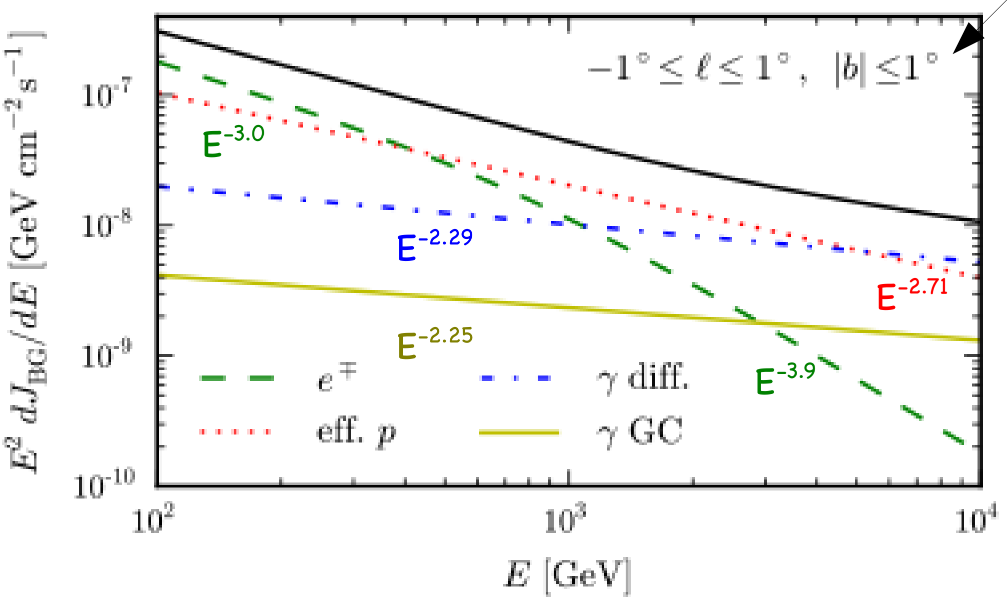
F. Aharonian et al. Astron. Astrophys. 457 (2006); The CTA Consortium arXiv:1008.3703 [astro-ph.IM]; ; L. Bergström et al. Phys. Rev. D 83 (2011)

Method

Discrimination of the signal over the background

- Background: locally described by a power-law.
  - → GC observation with IACTs:
    - ✗ Background fluxes

S/N and S/B optimization



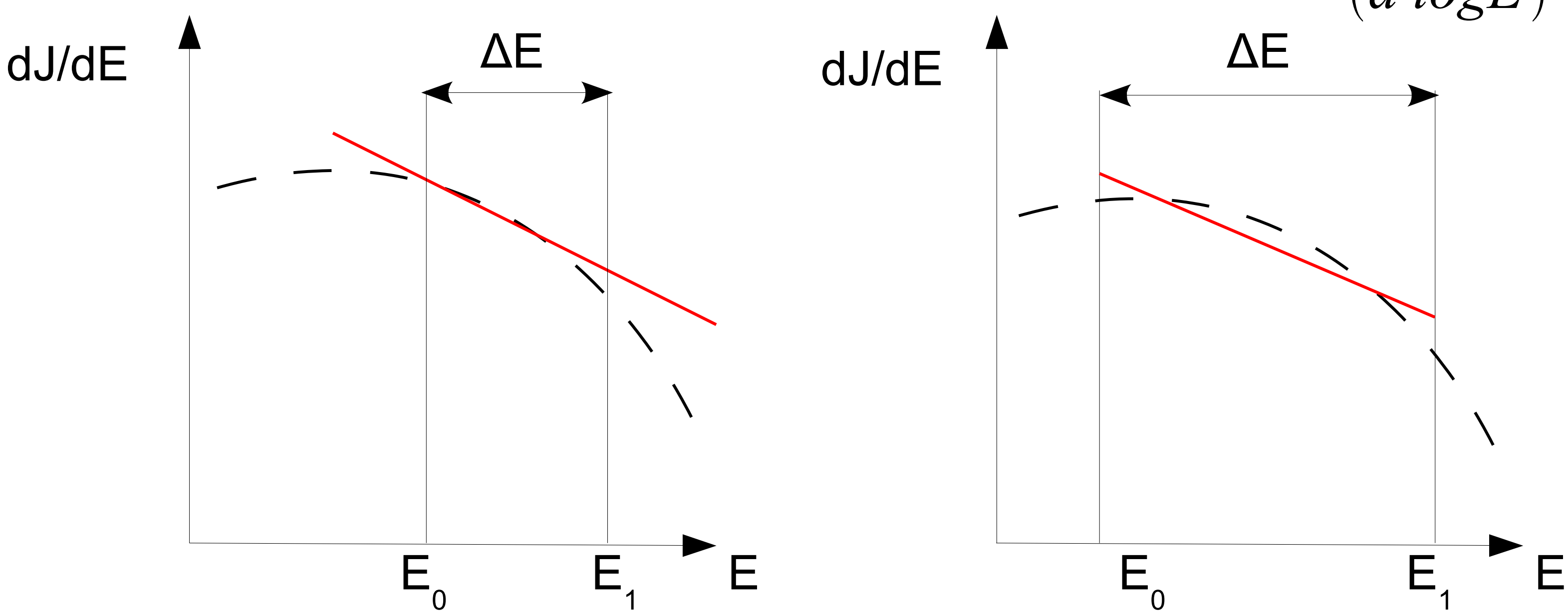
F. Aharonian et al. PRL 101 (2008); A. A. Abdo et al. PRL 102 (2009); J. R. Hoerandel Astrop.Phys. 19 (2003); F. Aharonian et al. PRL 97 (2006); F. Aharonian et al. Nature 439 (2006)

Choice of the energy window size

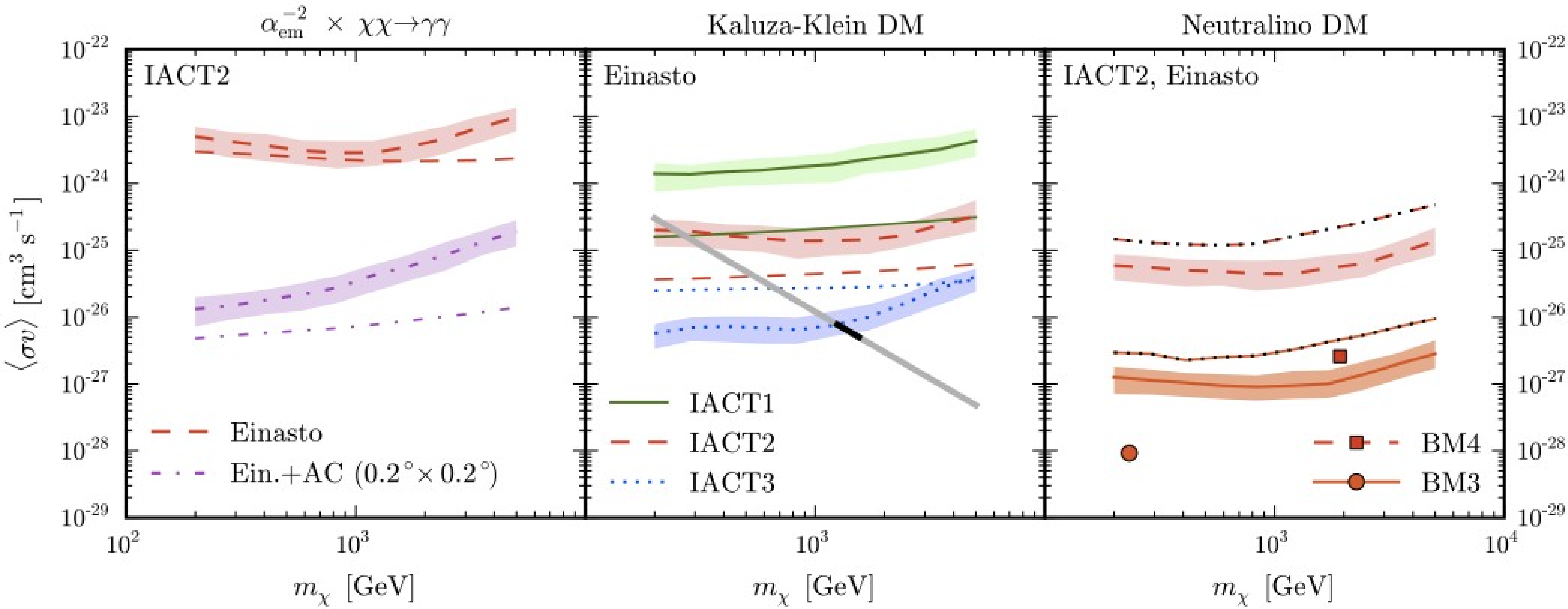
For which values of the energy window can we approximate the background as a power-law?

→ dependence on:

- collected statistics
- intrinsic curvature of the background: $k \equiv \dfrac{d^2 \log\left(\dfrac{dJ_{BG}}{dE}\right)}{(d\,\log E)^2}$ $\quad |k| < k_{max}$



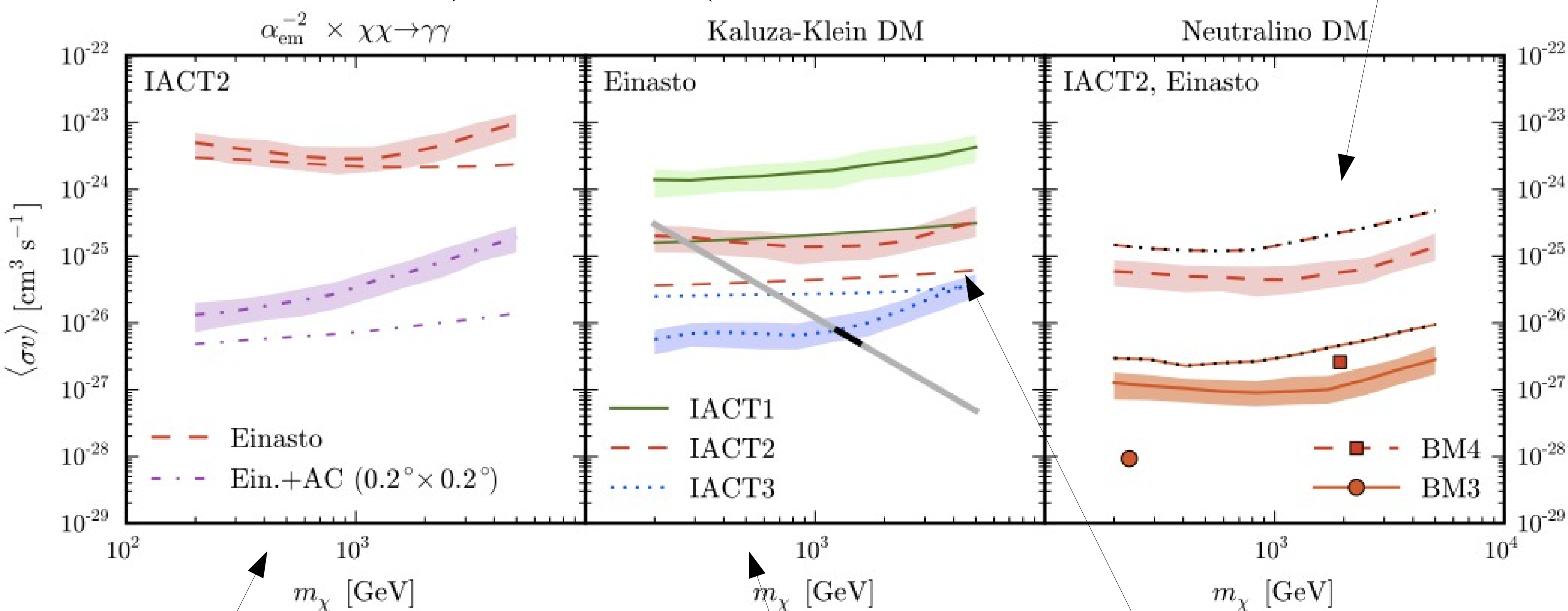
Results: Limits on <σv>



Results: Limits on <σv>

DM Models

Projected sensitivity for a 5σ signal



DM Profiles

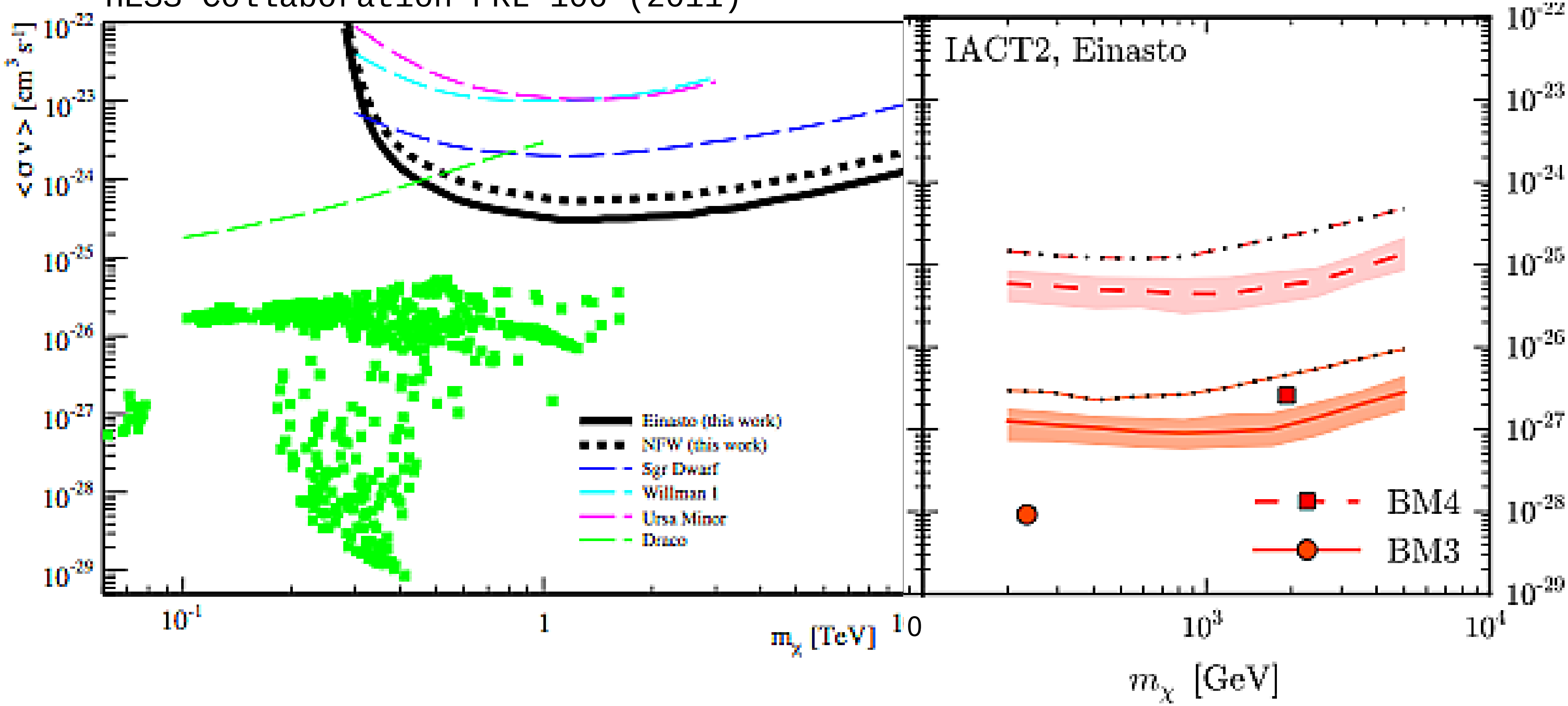
Observational scenarios

S/B ≈ 1% → to go below requires a detailed treatment of systematics

Discussion

- IB features greatly improve constraints on the annihilation rate down to the values typical expected for thermal production.

HESS Collaboration PRL 106 (2011)



Discussion

- IB features greatly improve constraints on the annihilation rate down to the values typical expected for thermal production.
- CTA should be able to improve currently possible limits by about one order of magnitude.
- S/B ≤ 1% → systematics must be understood (DMA scenario).
- A secondary gamma-ray component could significantly alter the limits → the power-law bkg approximation breaks down (e.g. $b\bar{b}$ final state: $BR_{min} \approx O(10^{-4})$).

Conclusions&Outlook

- We have shown that...
  - ✓ Traditional gamma-ray line searches method can successfully be extended to look for pronounced features at the endpoint of the spectrum.
  - ✓ Including such a spectral information improves limits in DM signals, even more than those coming from lines.
  - ✓ The adopted method is general and applicable to both other targets and other instruments.
- Work in progress...
  - ➔ To apply such a method to prospects for detection of a DM signal and discrimination among models (detailed analysis of secondary contributions, BRs, systematics, etc...)

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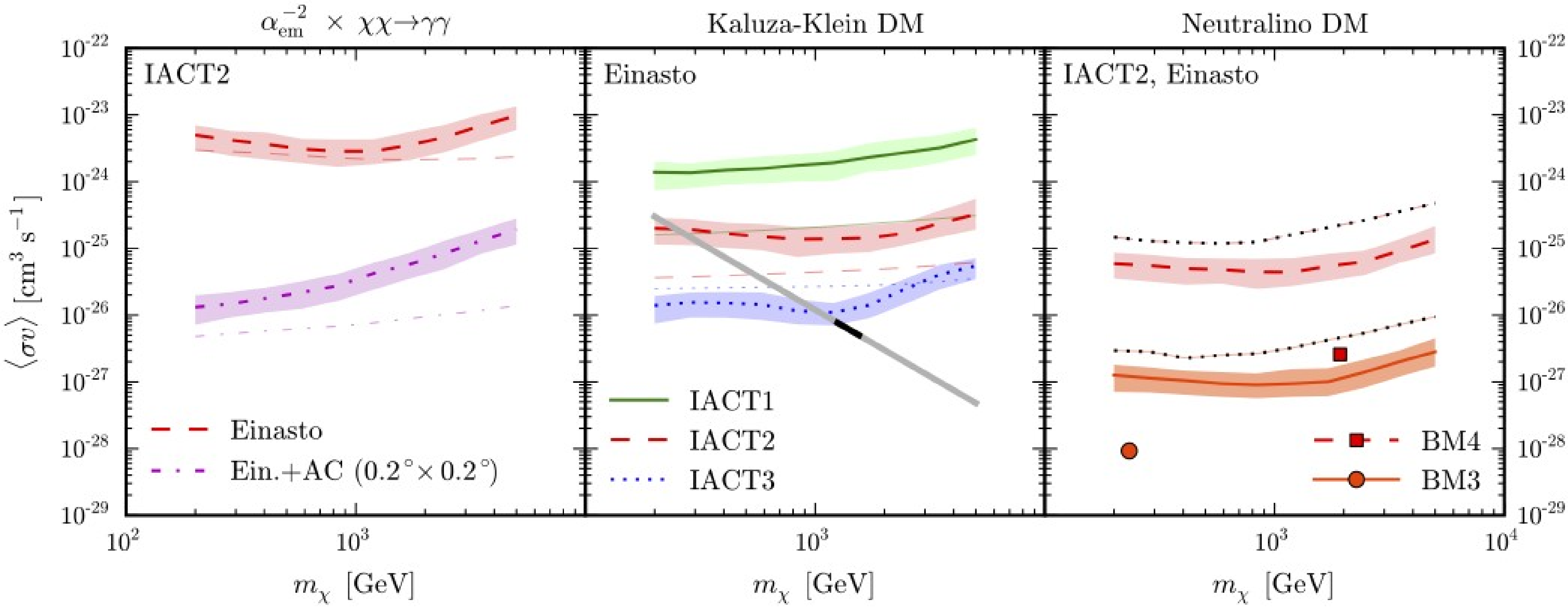
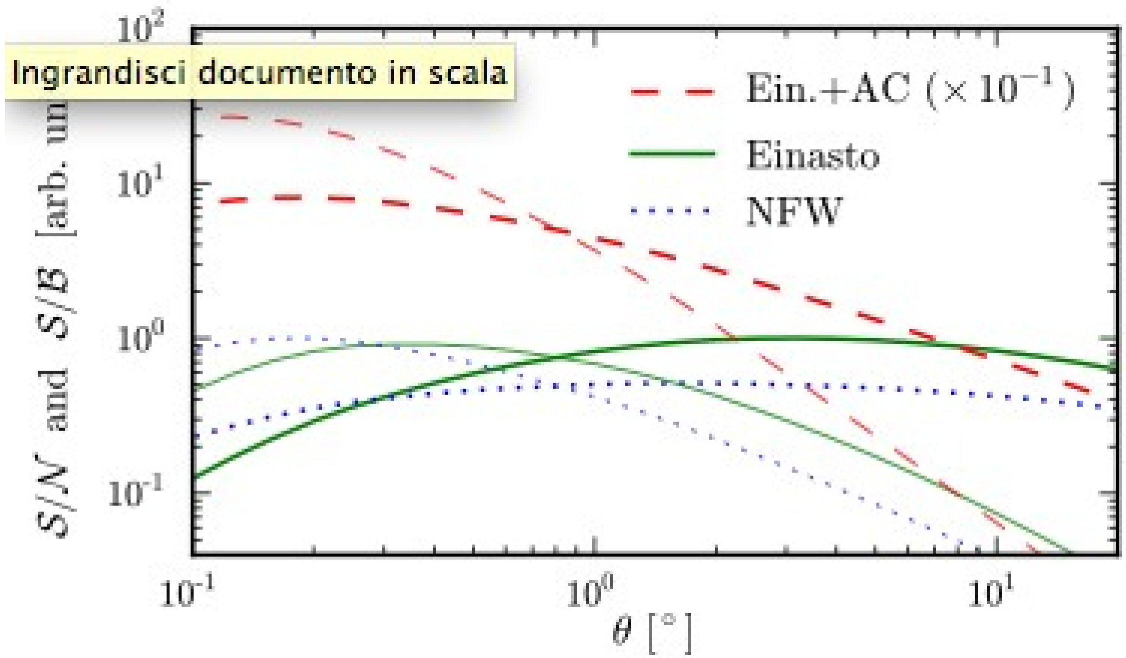
Thanks for the attention

Backup slides

Limits IACT3 8% energy resolution



S/N optimization and AC



Profiles parameters as in L. Pieri et al. Phys. Rev. D 83 (2011), R. Catena and P. Ullio, JCAP 1008 (2010)

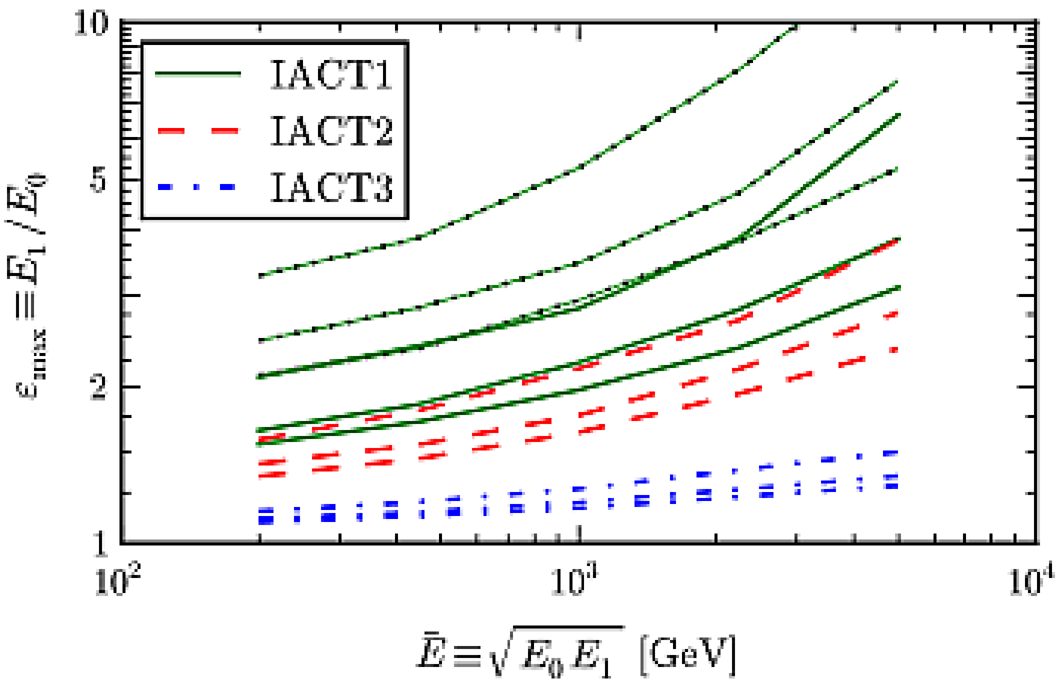
($i.e.$ $r_s^{\rm NFW} = 21\,{\rm kpc}$, $r_s^{\rm Ein.} = 20\,{\rm kpc}$, $\alpha = 0.17$ and $\rho_\chi = 0.4\,{\rm GeV\,cm^{-3}}$ at Sun's position $R_\odot = 8.5\,{\rm kpc}$).

For AC Gnedin et al (2004), Gustafsson et al. (2006)

Constraints on the energy window size (ε_{max})

How does a bended power-law bkg alter the limits on the DM signal?

→ Maximal allowed ε above which limits are affected by more than 50%



$$\bar{E} \equiv \sqrt{E_0 \cdot E_1} \sim m_\chi$$

$$E_0 \equiv \frac{\bar{E}}{\sqrt{\epsilon(E)}} \qquad E_1 \equiv \bar{E} \cdot \sqrt{\epsilon(E)}$$

$$\epsilon(E) \sim O(1-10)$$