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DESY

DESY THEORY WORKSHOP 2011
Cosmology meets Particle Physics
Ideas & Measurements

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Sharp Gamma-Ray Spectral Features in Indirect Dark Matter Searches

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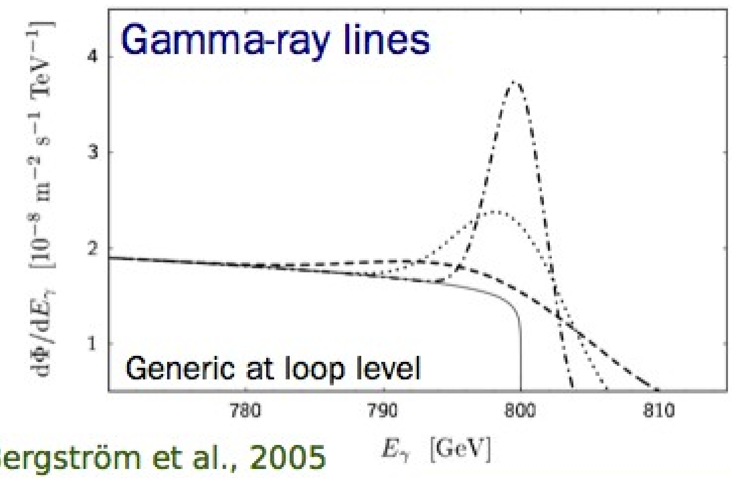
DM Indirect Detection through Gamma-rays

DM pair-annihilation into SM particles

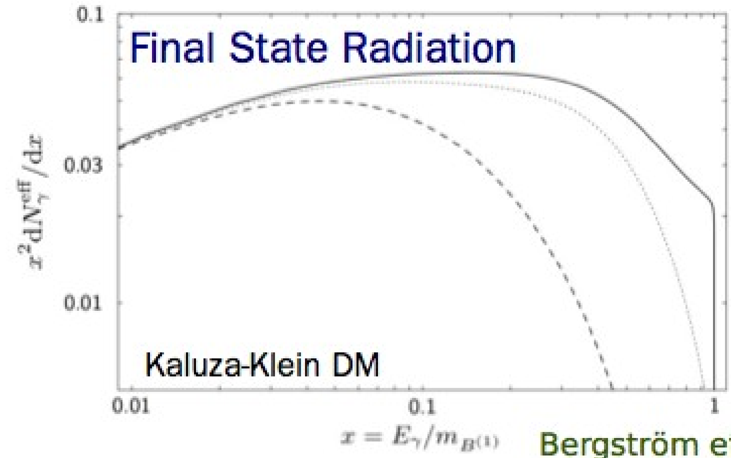
- Cosmic rays antimatter (M. Cirelli plenary talk)
- Neutrinos signal
- Gamma-ray signal
  - Rather high rates
  - Propagation almost unperturbed through the halo → directly connected to the sources
  - Distinct and unambiguous spectral features

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

DM Gamma-Rays Spectra



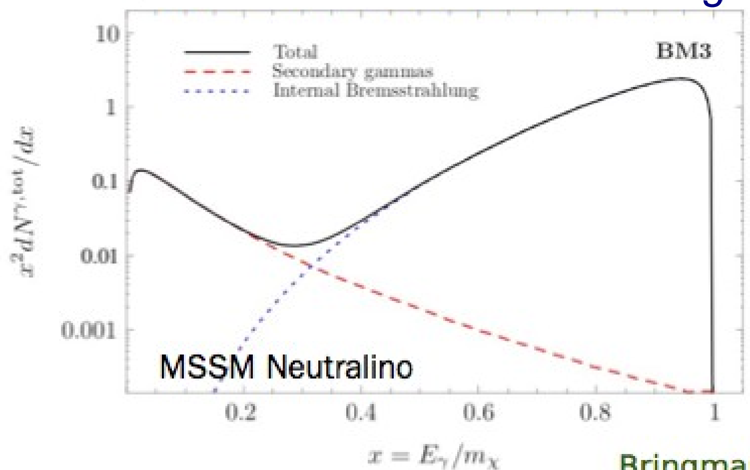
Bergström et al., 2005



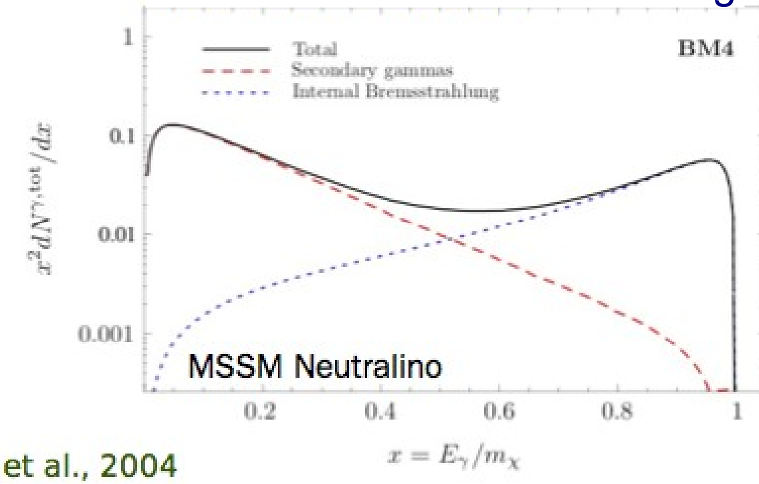
Bergström et al., 2004

$$\chi\,\chi \rightarrow (\ldots) \rightarrow \gamma\,\gamma$$

Virtual Internal Bremsstrahlung



Virtual Internal Bremsstrahlung



Bringmann et al., 2004

DM Gamma-Rays Spectra

$$\frac{dN_\gamma^{TOT}}{dE} = \sum_f B_f \left\{ \frac{dN_\gamma^{Sec}}{dE} + \frac{dN_\gamma^{IB}}{dE} + \frac{dN_\gamma^{Line}}{dE} \right\}_f$$

DM Gamma-Rays Spectra

(1)

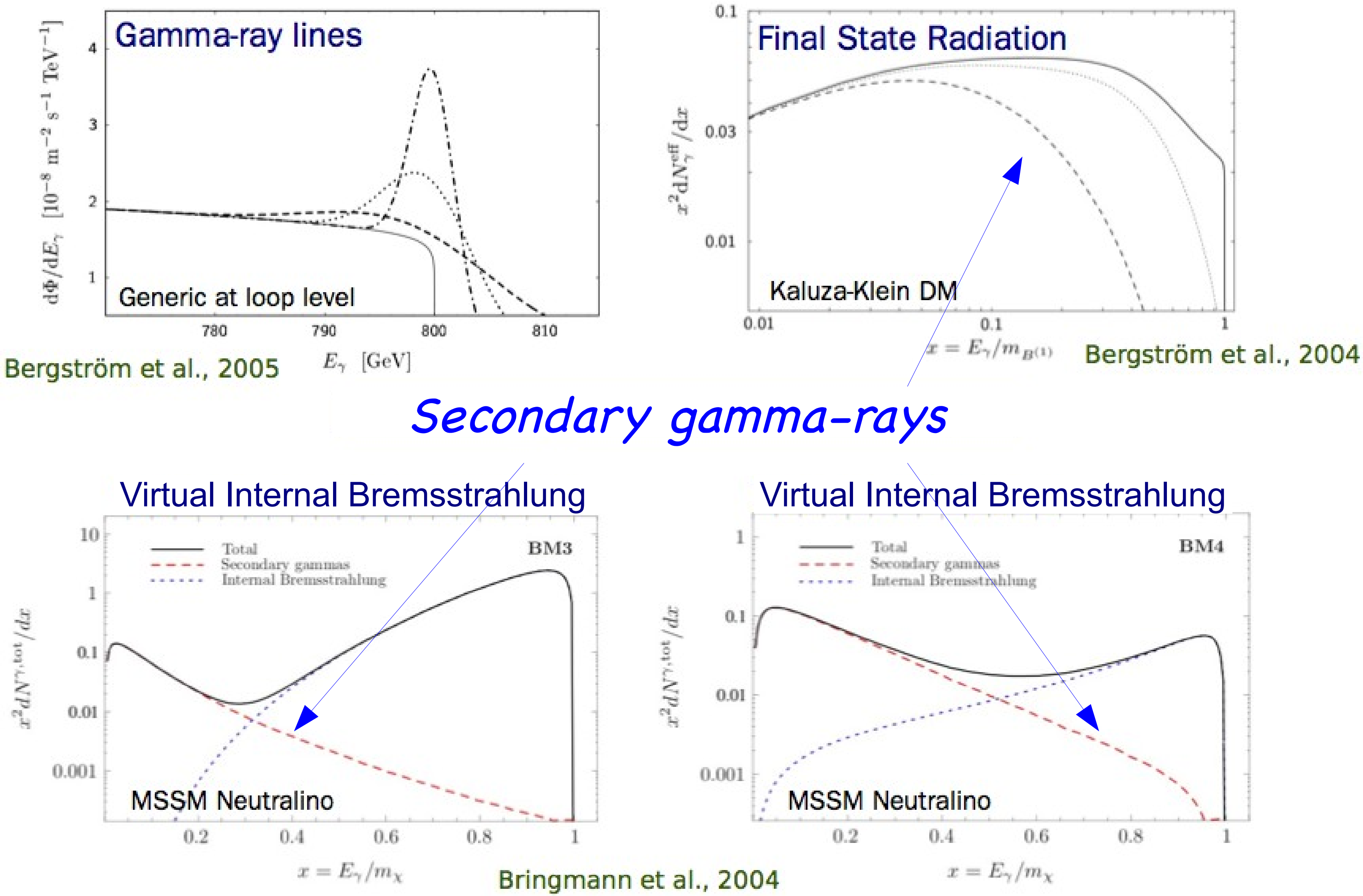
$$\frac{dN_\gamma^{TOT}}{dE} = \sum_f B_f \left\{ \frac{dN_\gamma^{Sec}}{dE} + \frac{dN_\gamma^{IB}}{dE} + \frac{dN_\gamma^{Line}}{dE} \right\}_f$$

$$\chi\chi \rightarrow q\bar{q}, g g \ldots$$

Secondary photons from hadronization and fragmentation of final states.

Almost featureless spectrum

DM Gamma-Rays Spectra



DM Gamma-Rays Spectra

(2)

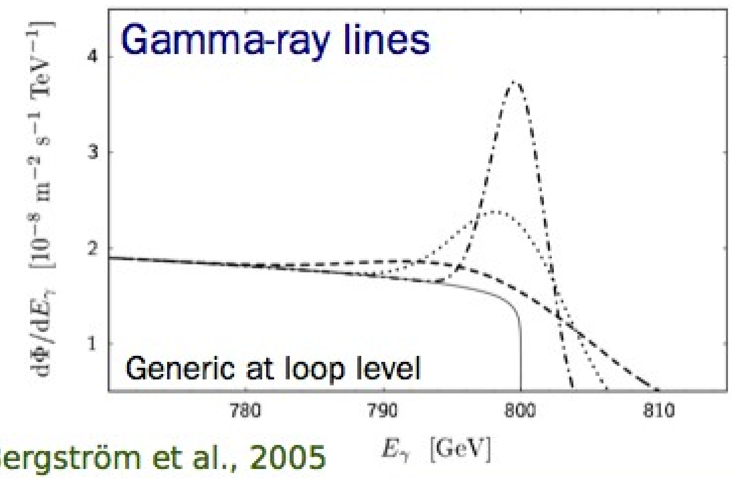
$$\frac{dN_\gamma^{TOT}}{dE} = \sum_f B_f \left\{ \frac{dN_\gamma^{Sec}}{dE} + \frac{dN_\gamma^{IB}}{dE} + \frac{dN_\gamma^{Line}}{dE} \right\}_f$$

$$\chi\chi \rightarrow X\bar{X}\gamma$$

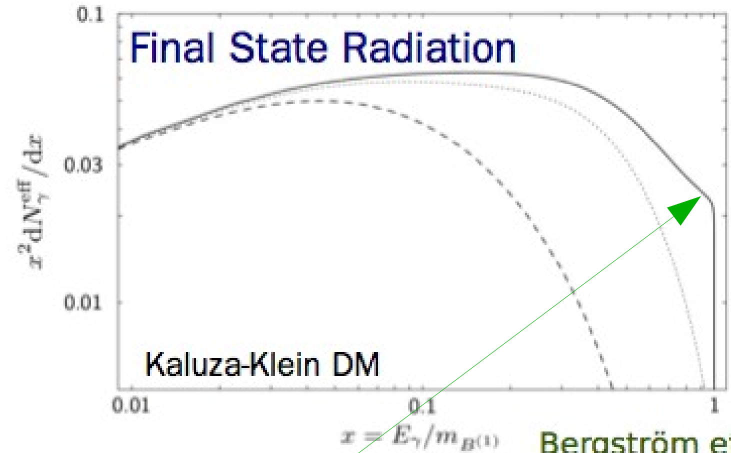
Internal Bremsstrahlung
O(α) radiative corrections
Final State Radiation or
Virtual IB

Step-like or Bump-like Spectral features

DM Gamma-Rays Spectra



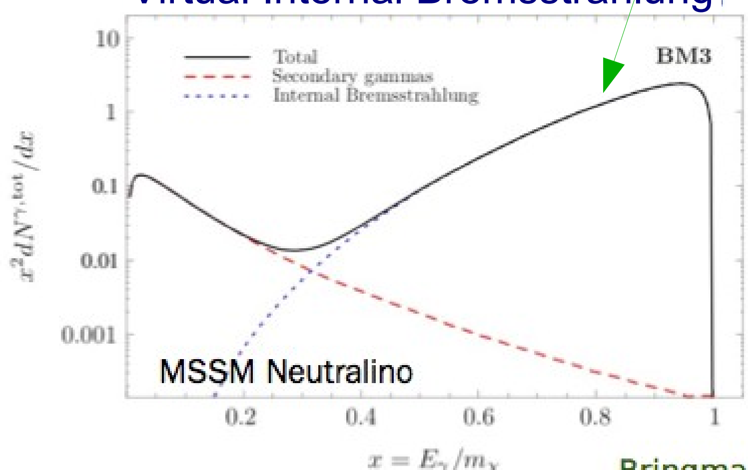
Bergström et al., 2005



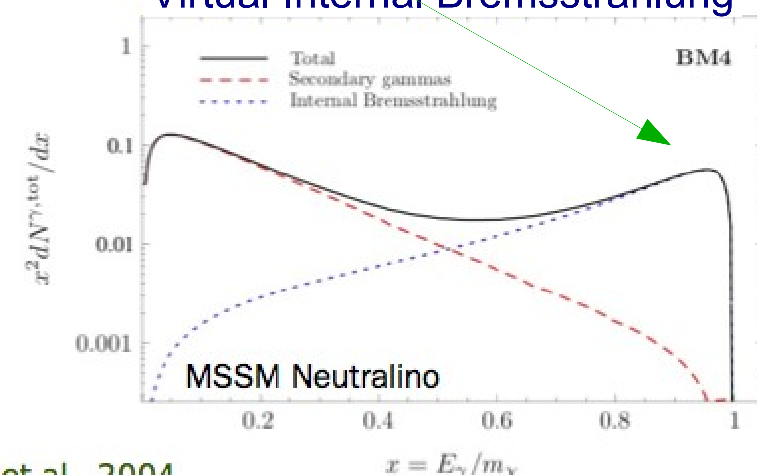
Bergström et al., 2004

Spectral endpoint features

Virtual Internal Bremsstrahlung



Virtual Internal Bremsstrahlung



Bringmann et al., 2004

DM Gamma-Rays Spectra

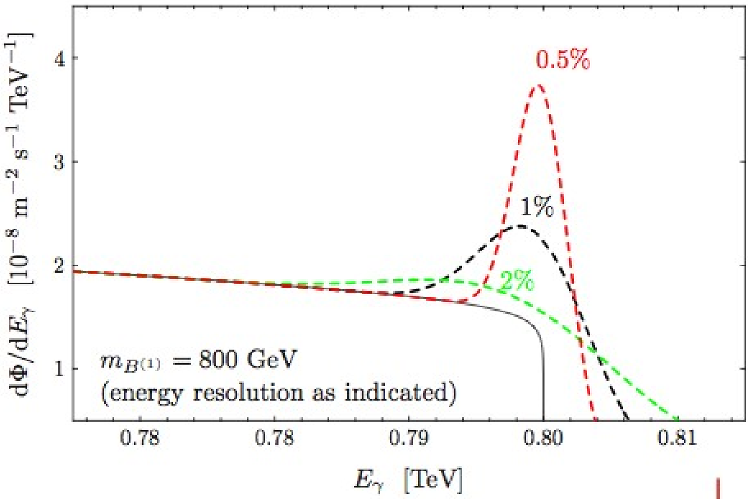
(3)

$$\frac{dN_\gamma^{TOT}}{dE} = \sum_f B_f \left\{ \frac{dN_\gamma^{Sec}}{dE} + \frac{dN_\gamma^{IB}}{dE} + \frac{dN_\gamma^{Line}}{dE} \right\}_f$$

$$\chi\chi \rightarrow \gamma\gamma\,(Z\gamma\,,H\gamma)$$

Clear line signal from loop suppressed direct annihilation

Bergström et al., 2005



Gamma-Ray Spectral Features

1. Gamma-ray Lines
2. Kaluza-Klein DM (step-like feature)
3. MSSM neutralino DM (bump-like feature)
   - BM3: stau co-annihilation region
   - BM4: focus point region

→ As mass-independent spectral templates

(items 2–3: Internal Bremsstrahlung)

Searches for Spectral Features

Discrimination of the signal over the background

Method:

- Select sliding energy window $[E_0, E_1]$ such that
  - it contains the spectral feature $E_0 \leq m_\chi \leq E_1$
  - bkg power-law approximation here $\frac{E_1}{E_0} \sim O(1-10)$
- Fit DM signal + bkg with standard statistical methods
  → Significance for signal or upper limits

PROSPECTS FOR IMAGING ATMOSPHERIC CHERENKOV TELESCOPES (IACTs)

Prospects: Benchmark Scenarios

GC observation with IACTs:

- Observational benchmark scenarios:

Scenario	A_{eff} (1 TeV)	$\Delta E/E$ (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

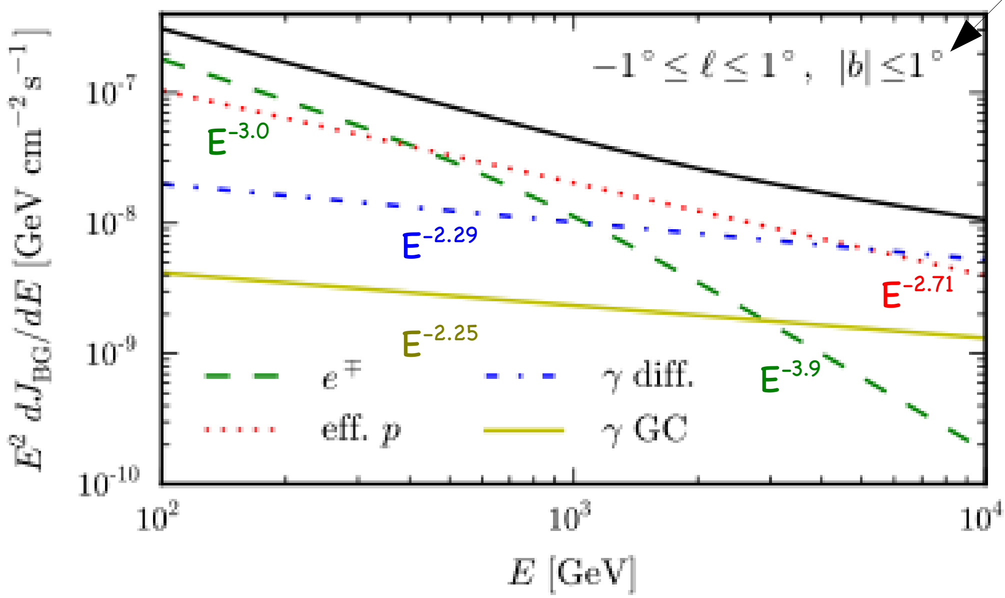
F. Aharonian et al. Astron. Astrophys. 457 (2006); The CTA Consortium arXiv:1008.3703 [astro-ph.IM]; L. Bergström et al. Phys. Rev. D 83 (2011)

Prospects: Benchmark Scenarios

GC observation with IACTs:

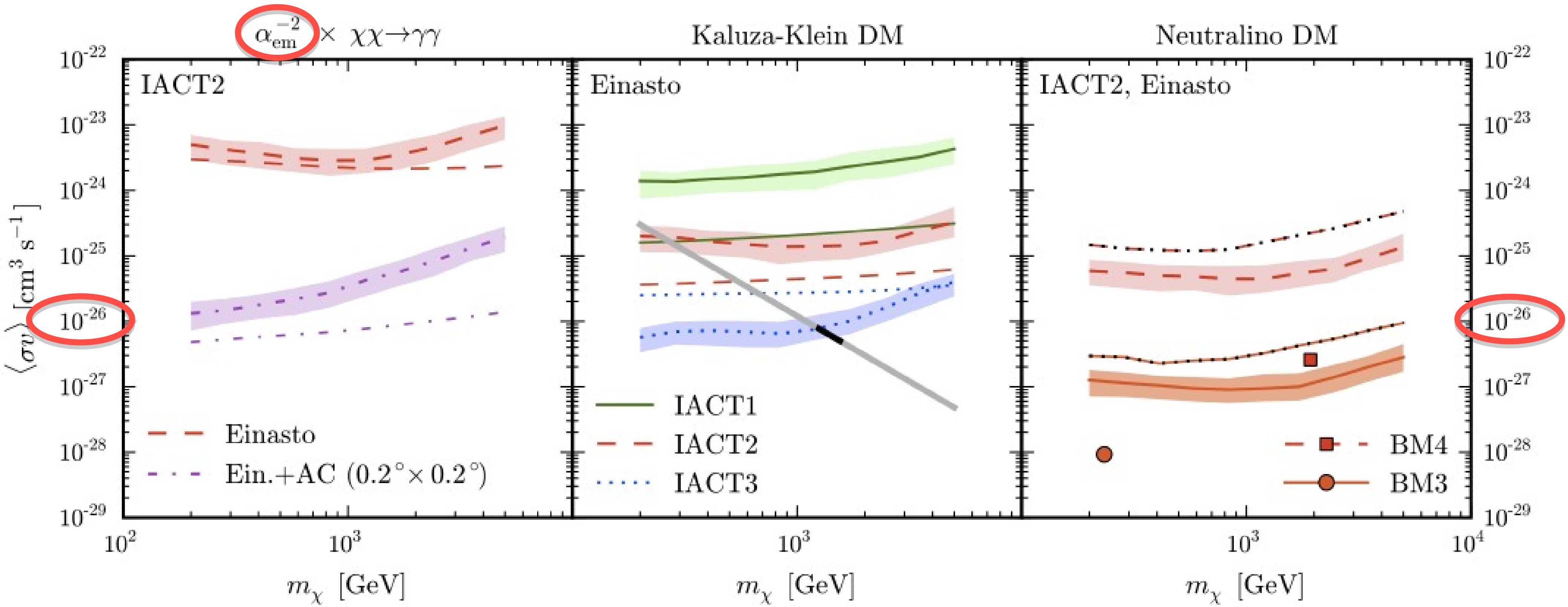
- Background fluxes: non-rejected cosmic rays (mainly protons and electrons)

Target region: 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)

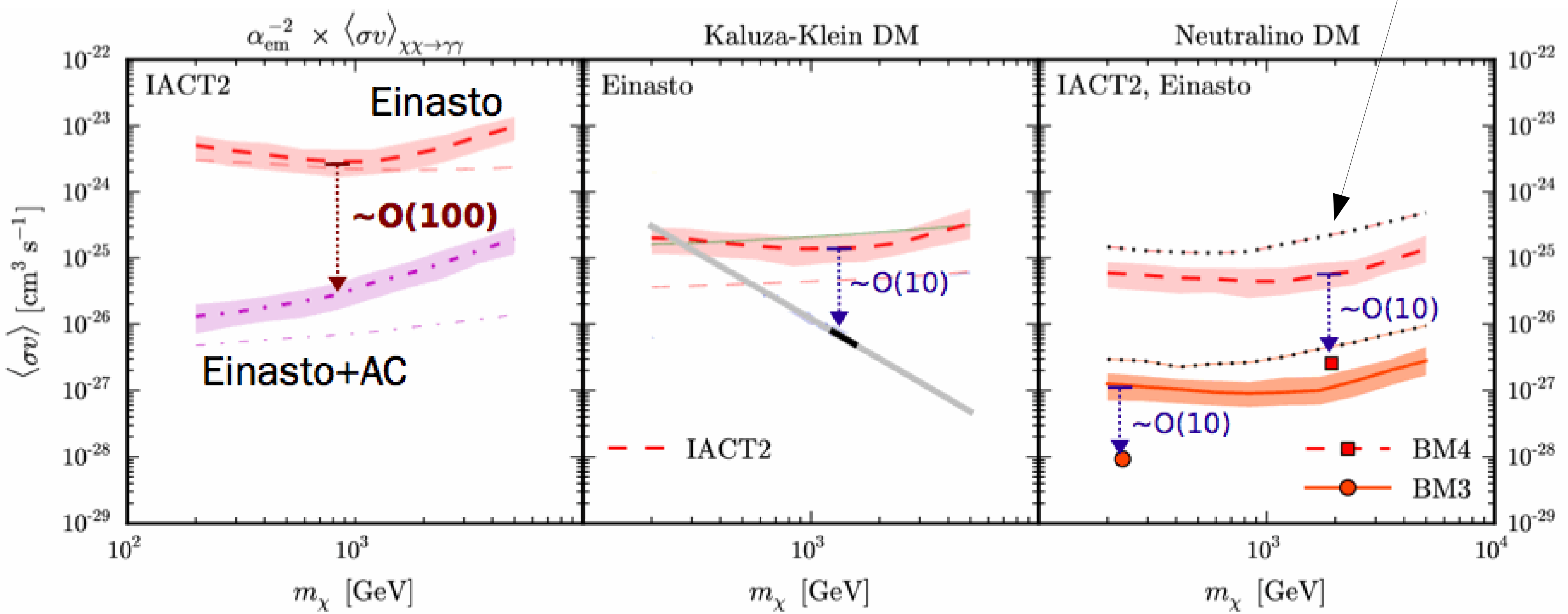
Prospects: Limits on <σv>



T.Bringmann, F.C., G.Vertongen, C.Weniger arXiv:1106.1874

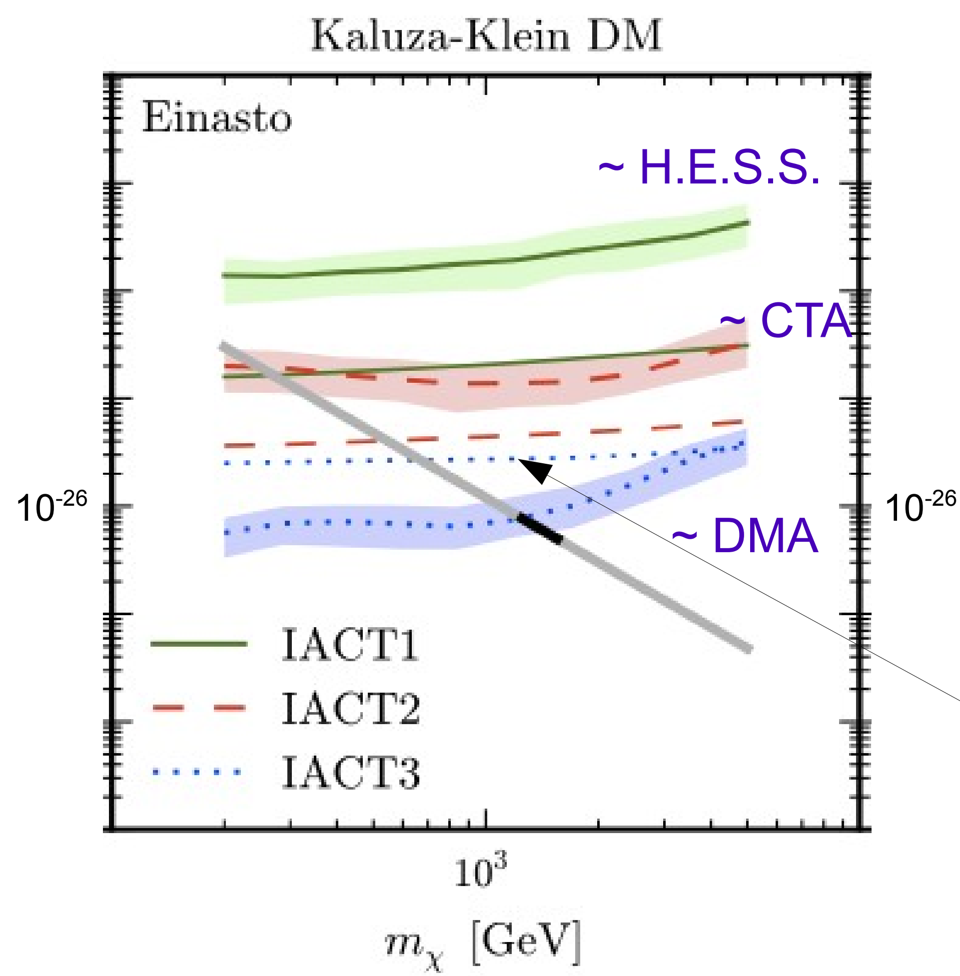
Prospects: Limits on <σv> for CTA

Projected sensitivity for a 5σ signal



T.Bringmann, F.C., G.Vertongen, C.Weniger arXiv:1106.1874

Prospects: Limits on <σv> Benchmark Scenarios

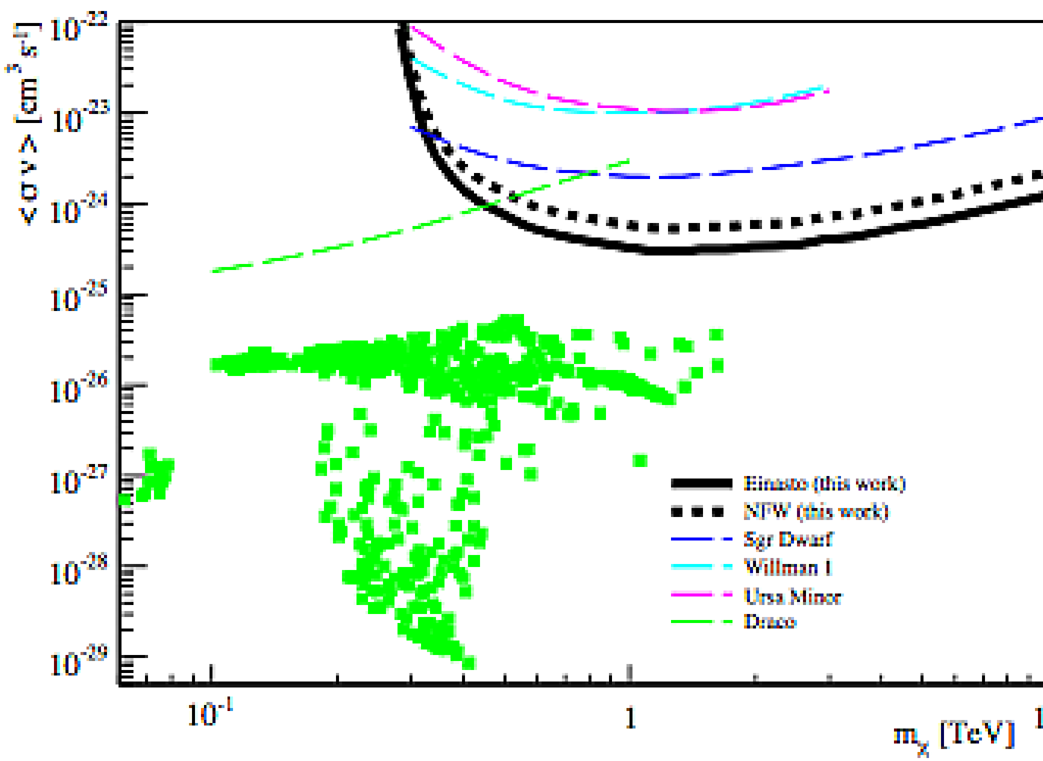


T.Bringmann, F.C., G.Vertongen, C.Weniger arXiv:1106.1874

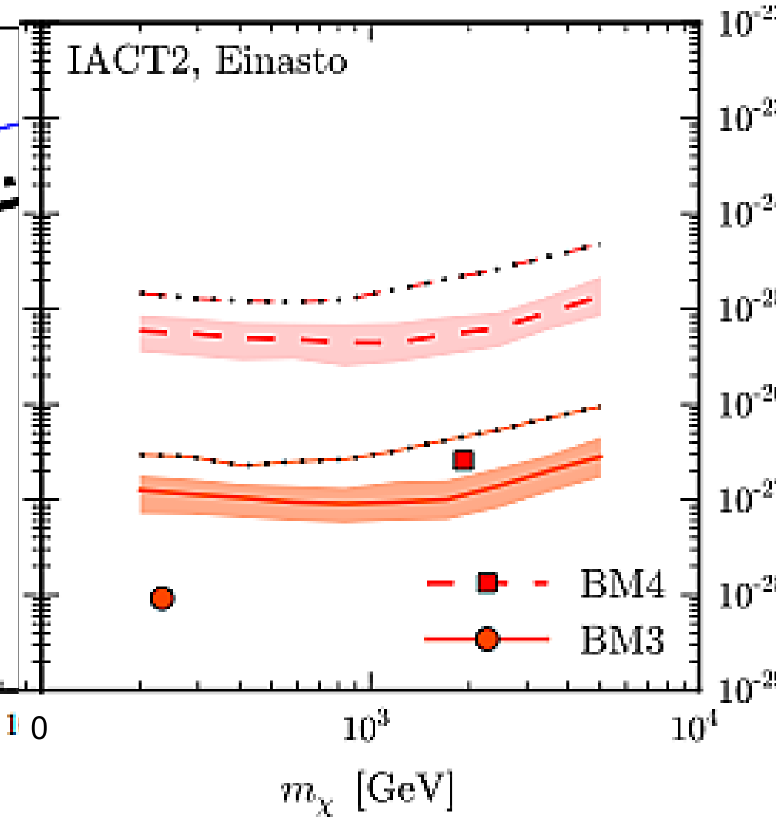
S/B ≈ 1% → to go below requires a detailed treatment of systematics

Prospects: Limits on <σv> vs Current Constraints

H.E.S.S. Collaboration, 2011



quark-antiquark pairs



IB spectral features

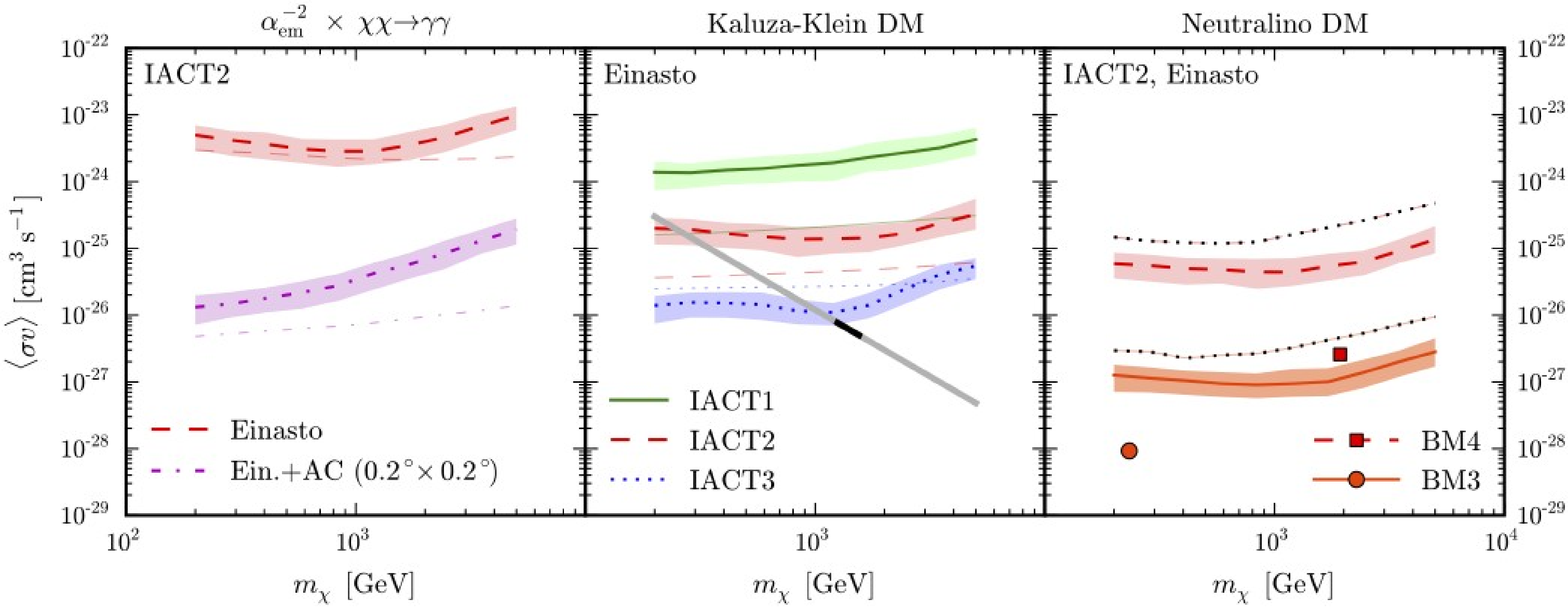
T.Bringmann, F.C., G.Vertongen, C.Weniger arXiv:1106.1874

Conclusions&Outlook

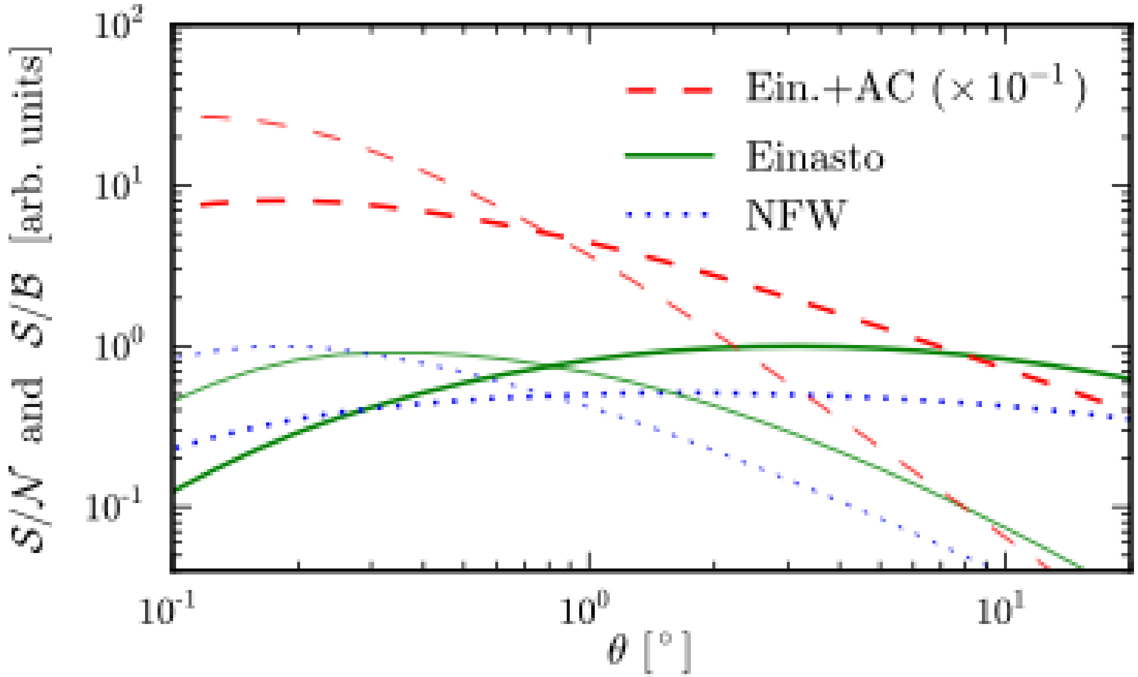
- We have shown that...
  - ✓ Traditional gamma-ray line searches method can successfully be extended to look for pronounced features at the endpoint of the spectrum.
  - ✓ Including such a spectral information improves limits in DM signals, even more than those coming from lines.
  - ✓ Systematics and instrumental effects must be understood for most optimistic scenarios (e.g. DMA).
  - ✓ A secondary gamma-ray component could significantly alter the limits → the standard method is here questionable.
- 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...)

Backup slides

Limits IACT3 8% energy resolution



S/N & S/B 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 $R_\odot = 8.5\,{\rm kpc}$).

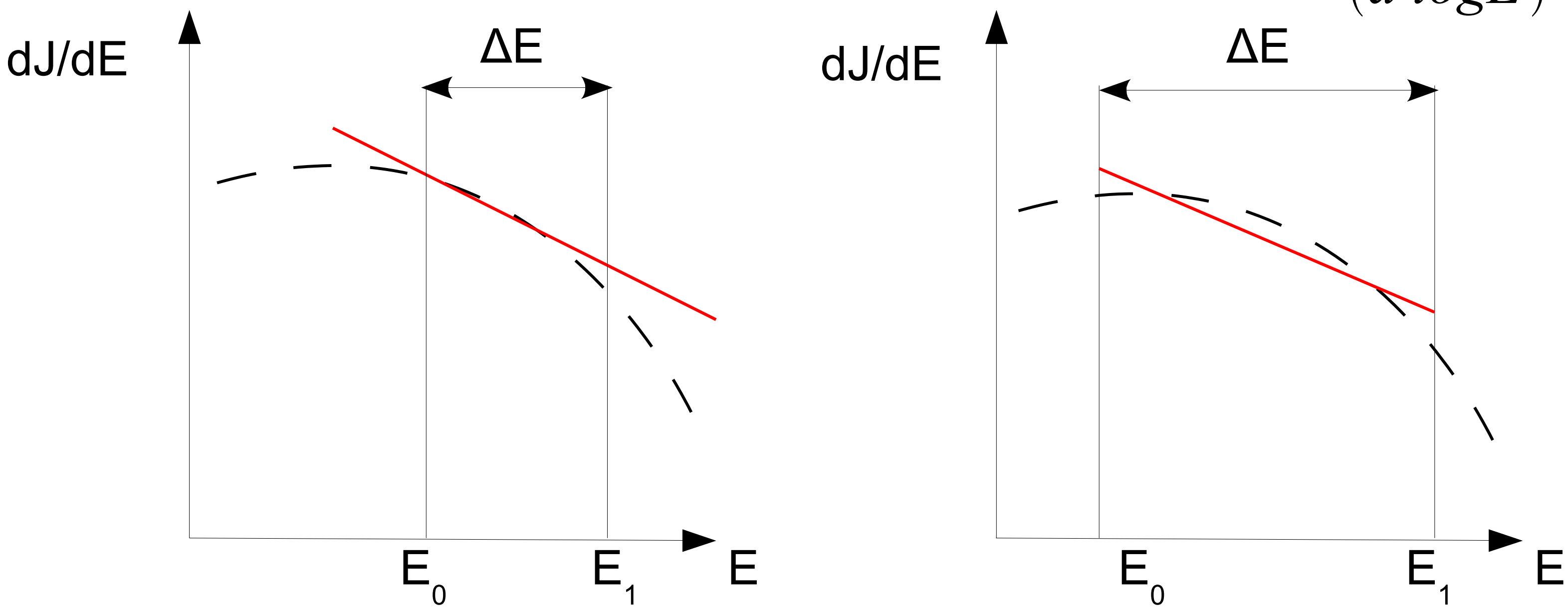
For AC: model of Gnedin et al (2004), best fit parameters from hydrodynamical simulation of Gustafsson et al. (2006)

Choice of the energy window size

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

→ dependence on:

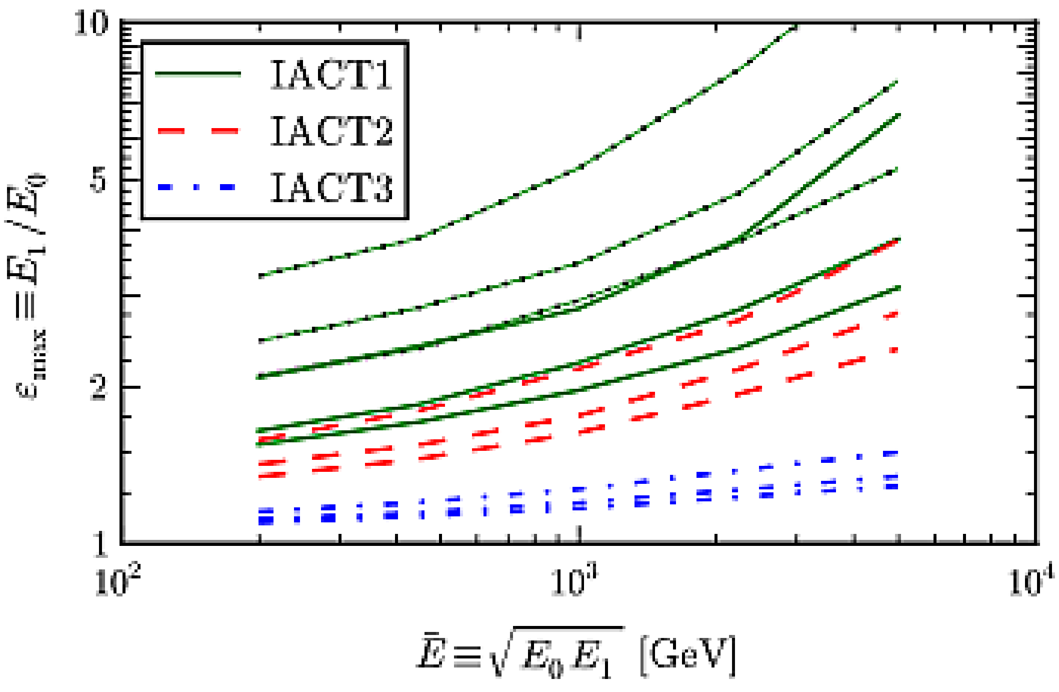
- collected statistics
- intrinsic curvature of the background: $k \equiv \frac{d^2 \log\left(\frac{dJ_{BG}}{dE}\right)}{(d\, logE)^2}$ $\quad |k| < k_{max}$



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%



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

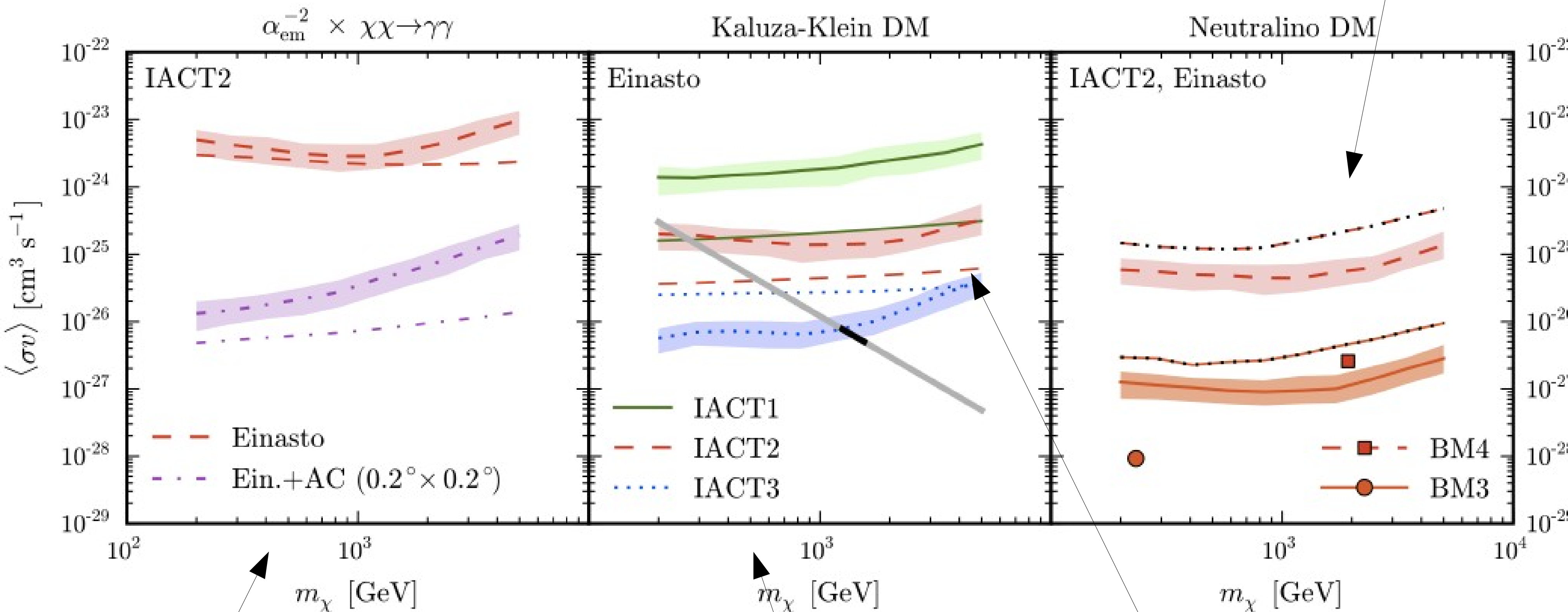
$$E_0 \equiv \frac{\bar{E}}{\sqrt{\epsilon(E)}} \qquad E_1 \equiv \bar{E} \cdot \sqrt{\epsilon(E)}$$

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

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.
- CTA should be able to improve currently possible limits by about one order of magnitude.
- $S/B \leq 1\%$ → systematics and instrumental effects 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 improve limits in DM signals, even more than these 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…)

Thanks for the attention