New gamma ray and positron contributions

to supersymmetric dark matter annihilations

Joakim Edsjö
Stockholm University
edsjo@physto.se

in collaboration with T. Bringmann and L. Bergström

arXiv: 0710.3169, JHEP 01 (2008) 049 + work in progress

Stockholm University

June 3, 2008 @ Dark Side deux

Outline

- Neutralinos as dark matter
- New gamma ray signatures from halo annihilation:
  - Internal Bremsstrahlung (final state radiation)
- New positron signatures

The neutralino as a WIMP

- Many ways to break supersymmetry exists. Will choose a phenomenological low-energy MSSM as one example and mSUGRA as another.

The neutralino:

$$\tilde{\chi}_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W}^3 + N_{13}\tilde{H}_1^0 + N_{14}\tilde{H}_2^0$$

The neutralino can be the lightest supersymmetric particle (LSP). If R-parity is conserved, it is stable.

The gaugino fraction

$$Z_g = |N_{11}|^2 + |N_{12}|^2$$

The MSSM-7 parameters

- In phenomenologically motivated MSSM we fix parameters (typically 7) at the electro-weak scale

μ	Higgsino mass parameter
M_2	Gaugino mass parameter
m_A	Mass of CP-odd Higgs boson
$\tan\beta$	Ratio of Higgs vacuum expectation values
m_0	Scalar mass parameter
A_b	Trilinear coupling, bottom sector
A_t	Trilinear coupling, top sector

The neutralino in mSUGRA

- Fix mass parameters (typically 5) at GUT scale and run RGEs to low energy scale

$\text{sgn}(\mu)$	Sign of Higgsino mass parameter
$m_{1/2}$	Gaugino mass parameter (at GUT scale)
$\tan\beta$	Ratio of Higgs vacuum expectation values
m_0	Scalar mass parameter (at GUT scale)
A	Trilinear coupling (at GUT scale)

Interesting regions:
- stau coannihilation region
- funnel region
- focus point region
- stop coannihilation region

P. Gondolo, J. Edsjö, P. Ullio, L. Bergström, M. Schelke and E.A. Baltz

4.2 coming soon!

Version 4.1 available now

- MSSM or mSUGRA
- Masses and couplings
- Relic density
- Lab constraints
- Rates: neutrino telescopes
- Rates: gamma rays
- Rates: antiprotons, positrons, antideuterons
- Rates: direct detection

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

JCAP 06 (2004) 004 [astro-ph/0406204]

DarkSUSY: computing supersymmetric dark-matter properties numerically

P Gondolo[1], J Edsjö[2], P Ullio[3], L Bergström[2], M Schelke[2] and E A Baltz[4]

www.physto.se/~edsjo/darksusy

Uses FeynHiggs, HDecay and Isasugra.
v4.2 will also use galprop and include final state radiation and neutrino oscillations.

Calculational flowchart

- Select model parameters
- Calculate masses etc
- Check accelerator constraints
- Calculate the relic density
- Check if the relic density is cosmologically OK
- Calculate fluxes, rates, etc
- Calculation done with

DarkSUSY 4.1 available on
www.physto.se/~edsjo/darksusy
JCAP 06 (2004) 004 [astro-ph/0406204]

The relic density

$$\Omega_\chi h^2 = 0.1113^{+0.0044}_{-0.0061}$$

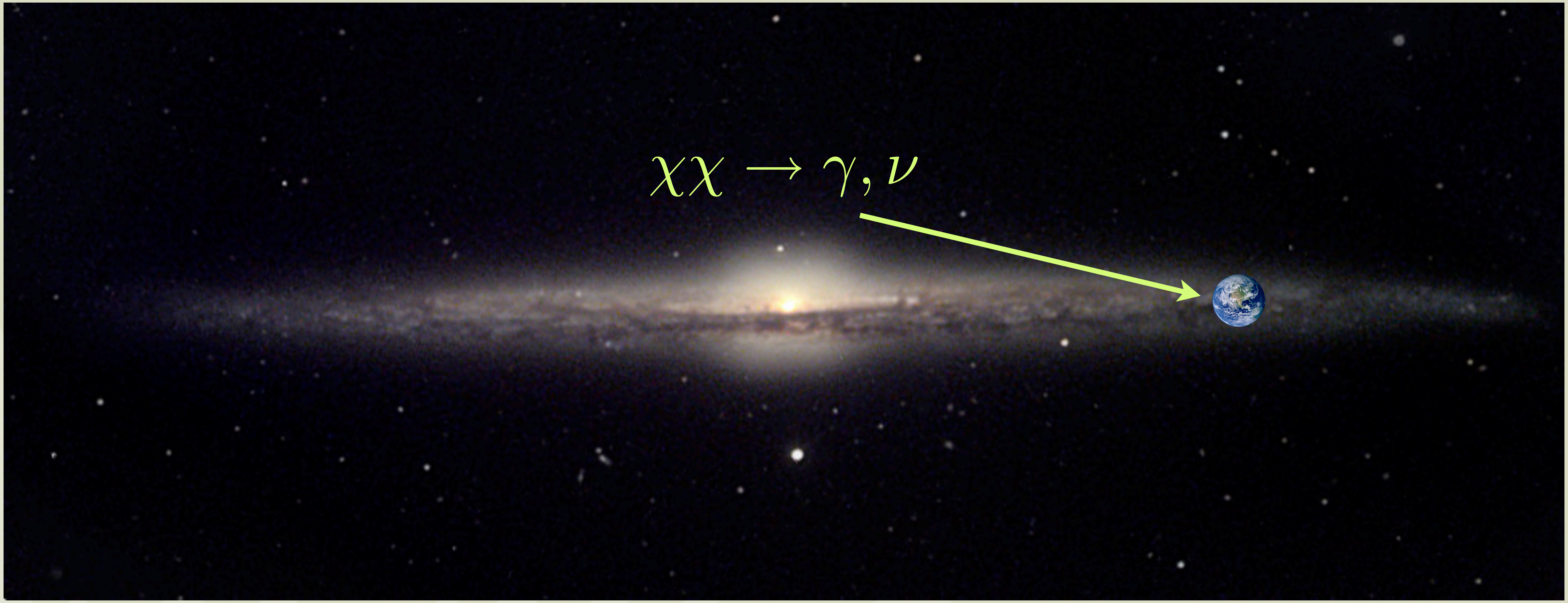
from WMAP+SDSS LRG

D. Spergel et al., astro-ph/0603449

Why gamma rays?

- Rather high rates
- No attenuation (except from very close to dense sources)
- Point directly back to the source
- No diffusion model uncertainties as for charged particles
- There can be clear spectral signatures to look for

Annihilation in the halo



- Gamma rays can be searched for with e.g. Air Cherenkov Telescopes (ACTs) or GLAST (launch June 7, 2008).
- Signal depends strongly on the halo profile,

$$\Phi \propto \int_{\text{line of sight}} \rho^2 dl$$

Annihilation to gamma rays

- **Monochromatic**
  At loop-level, annihilation can occur to

$$\gamma\gamma \quad \Rightarrow \quad E_\gamma = m_\chi$$

$$Z\gamma \quad \Rightarrow \quad E_\gamma = m_\chi - \frac{m_Z^2}{4m_\chi}$$

Features
- directionality – no propagation uncertainties
- low fluxes, but clear signature
- strong halo profile dependence

- **Continuous**
  WIMP annihilation can also produce a continuum of gamma rays

$$\chi\chi \to \cdots \to \pi^0 \to \gamma\gamma$$

Features (compared to lines)
- lower energy
- more gammas / annihilation
- rather high fluxes
- not a very clear signature

Gamma ray fluxes from the halo

We can write the flux as

$$\Phi_\gamma(\eta, \Delta\Omega) = 9.35 \cdot 10^{-14} S \times \langle J(\eta, \Delta\Omega) \rangle \ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{sr}^{-1}$$

with

Focus on this factor!

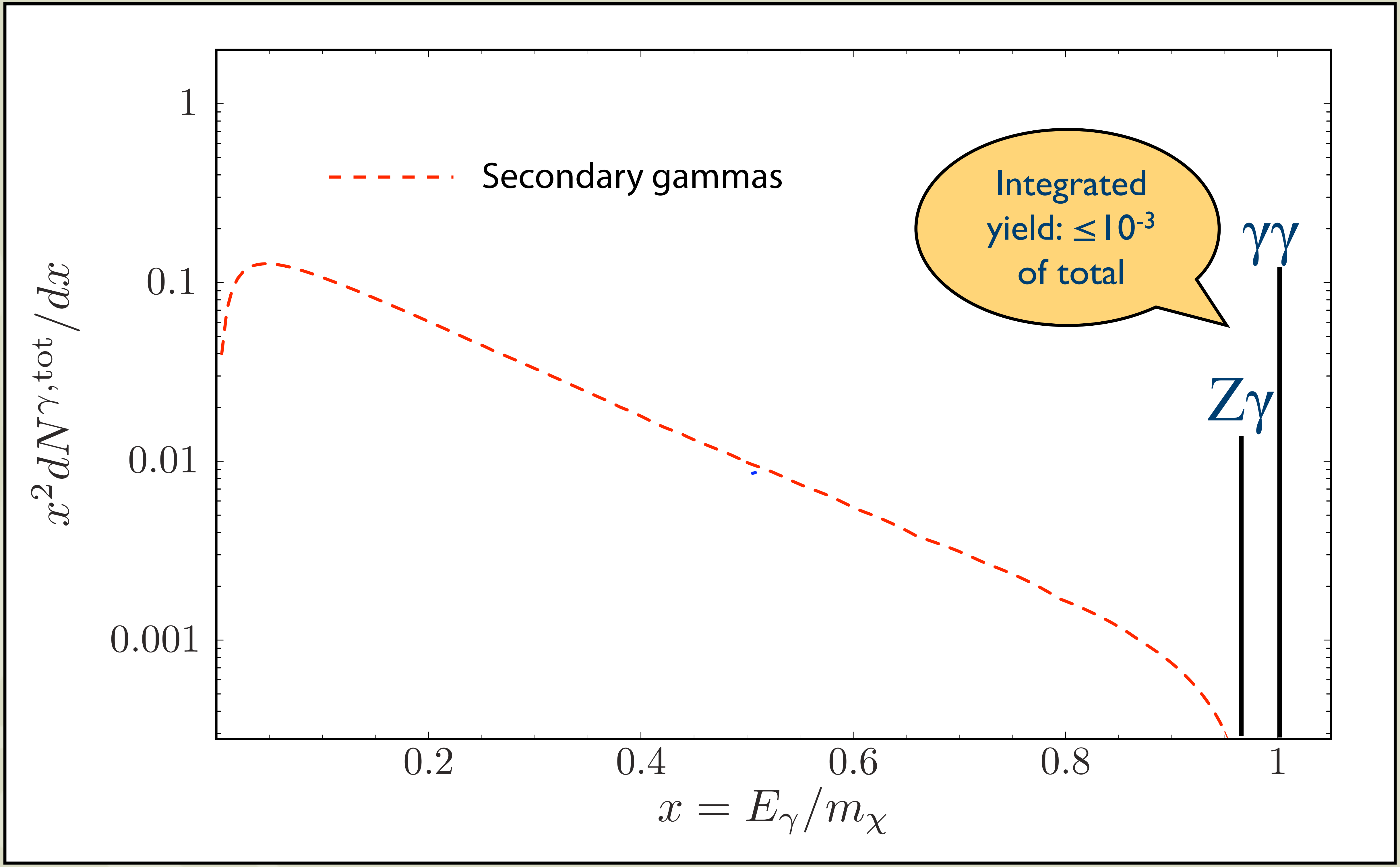
$$S = N_\gamma \frac{\langle \sigma v \rangle}{10^{-29}\ \mathrm{cm}^3\ \mathrm{s}^{-1}} \left(\frac{100\ \mathrm{GeV}}{m_\chi} \right)^2$$

Particle physics
(SUSY, ...)

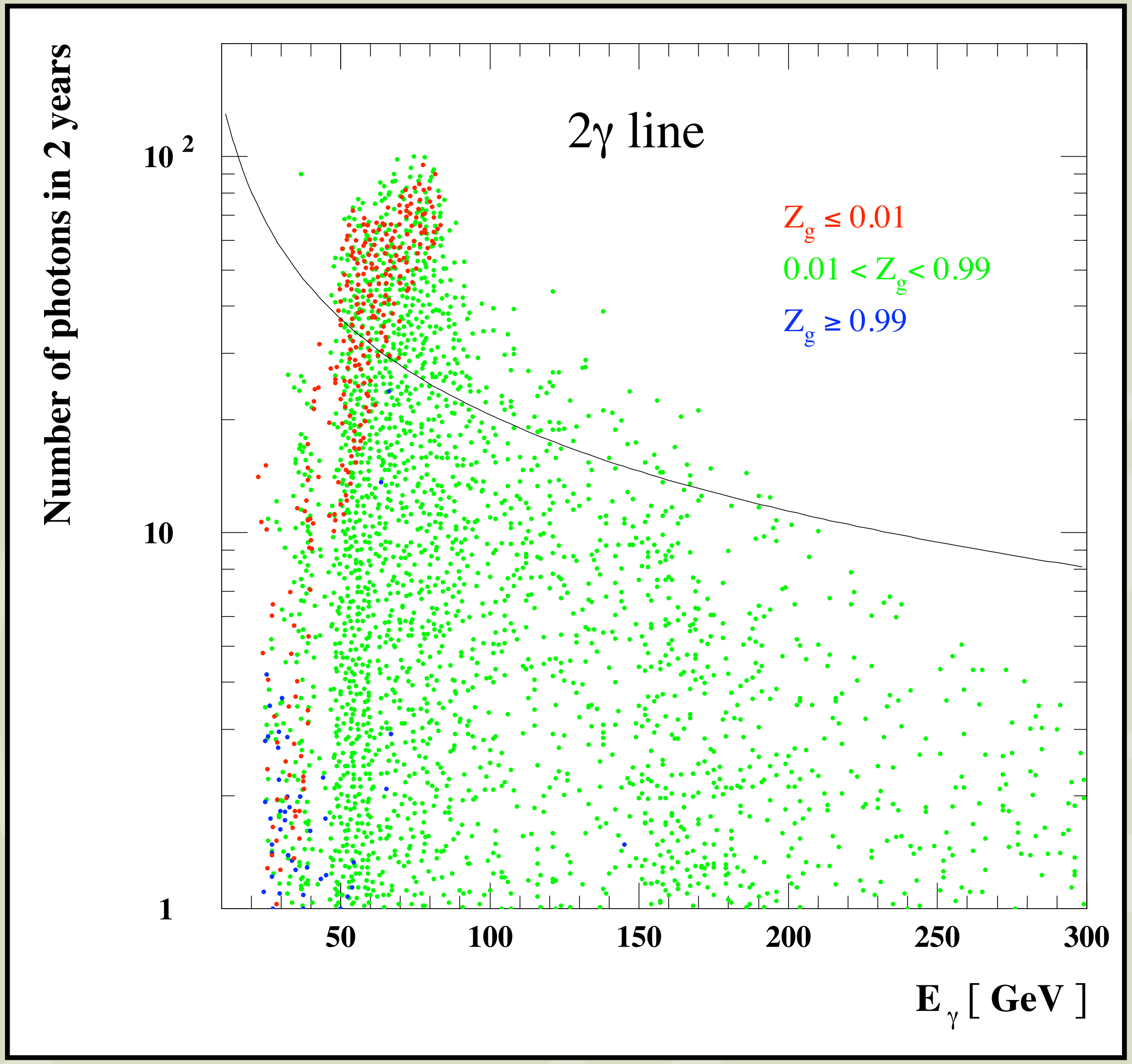
$$\langle J(\eta, \Delta\Omega) \rangle = \frac{1}{8.5\ \mathrm{kpc}} \frac{1}{\Delta\Omega} \int_{\Delta\Omega} \int_{\text{line of sight}} \left(\frac{\rho(l)}{0.3\ \mathrm{GeV/cm}^3} \right)^2 dl(\eta) d\Omega$$

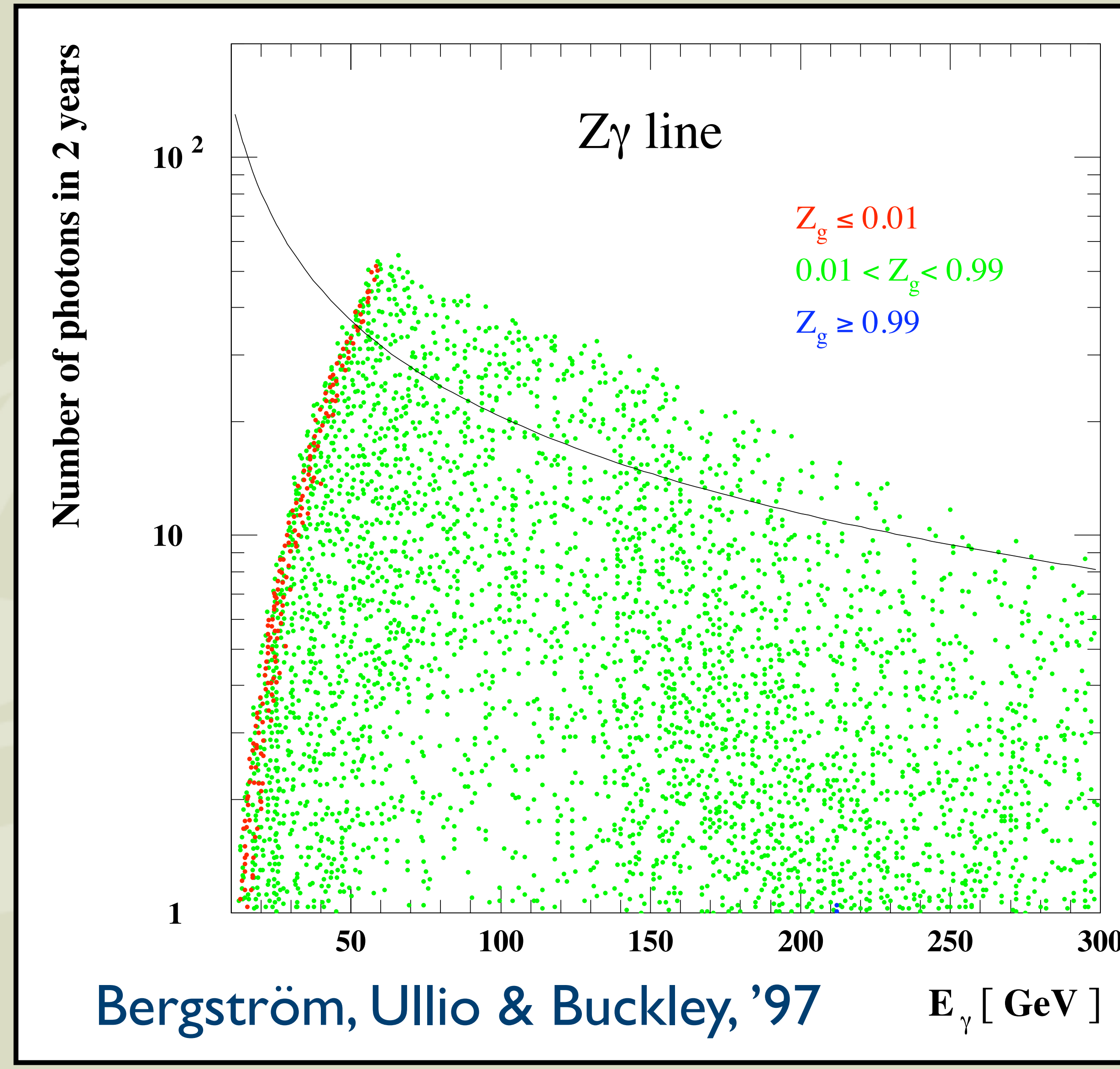
Astrophysics

Typical gamma ray spectrum



Gamma lines – rates in GLAST





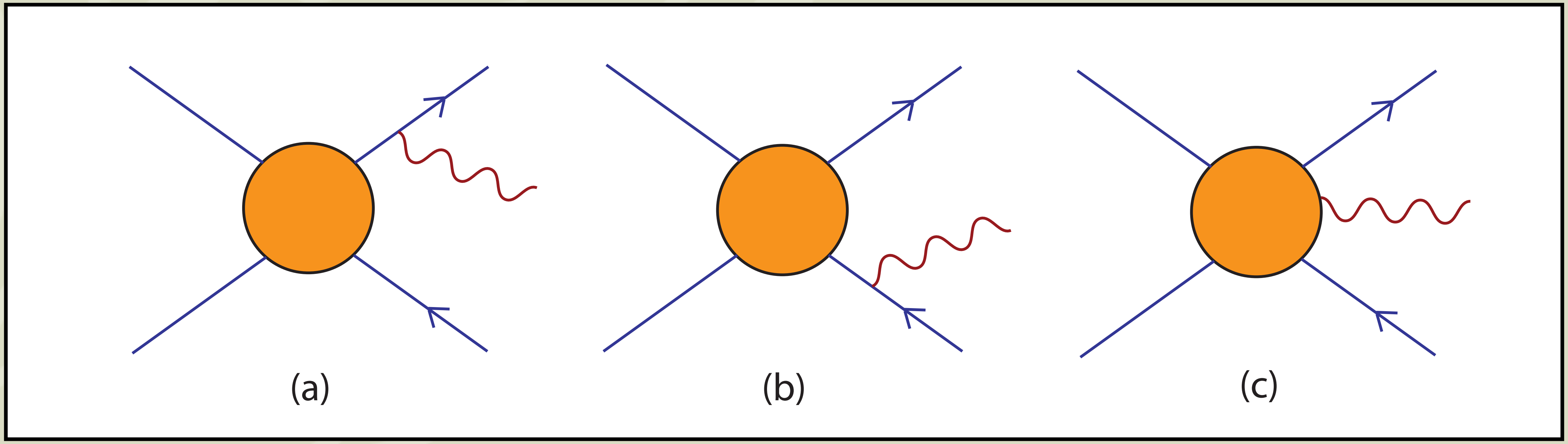
Bergström, Ullio & Buckley, '97

NFW halo profile, $\Delta\Omega \approx 1$ sr

GLAST launch,
June 7, 2008

Internal Bremsstrahlung

- Whenever charged final states are present, photons can also be produced in internal bremsstrahlung processes



Internal Bremsstrahlung

- Bremsstrahlung effects for DM annihilation pointed out by Bergström, PLB 225 (1989) 372.
- Studied recently by e.g.
  - Beacom et al, arXiv: astro-ph/0409403
    MeV dark matter
  - Bergström et al, PRL 95 (2005) 241301.
    Ann. of gauginos / Higgsinos to W^+W^-
  - Birkedal et al, arXiv: hep-ph/0507194.
    Universal forms derived
  - Bergström et al, PRL 94 (2005) 131301.
    UED models.
- I will here report on a more general study for SUSY neutralinos

Contributions to the gamma flux

- We can write the contributions to the gamma flux as

$$\frac{dN^{\gamma,\mathrm{tot}}}{dx} = \sum_f B_f \left(\frac{dN_f^{\gamma,\mathrm{sec}}}{dx} + \frac{dN_f^{\gamma,\mathrm{IB}}}{dx} + \frac{dN_f^{\gamma,\mathrm{line}}}{dx} \right)$$

- How large are these different contributions?

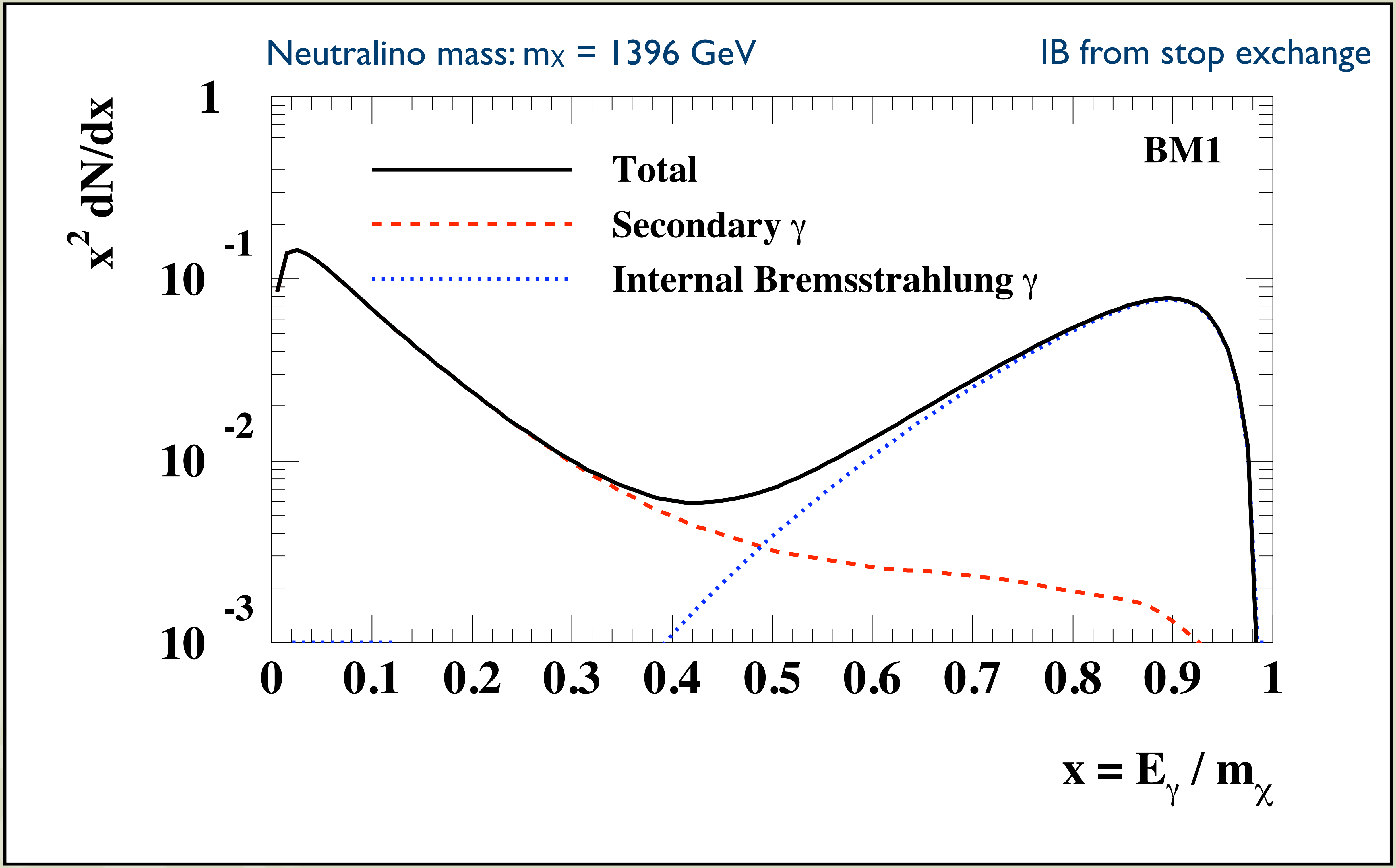
How big are these contributions for neutralinos?

- For Majorana fermion dark matter (e.g. neutralinos), annihilation to fermion-antifermion pairs is helicity suppressed at v→0

$$\sigma_{f\bar{f}} \propto \frac{m_f^2}{m_\chi^2}$$

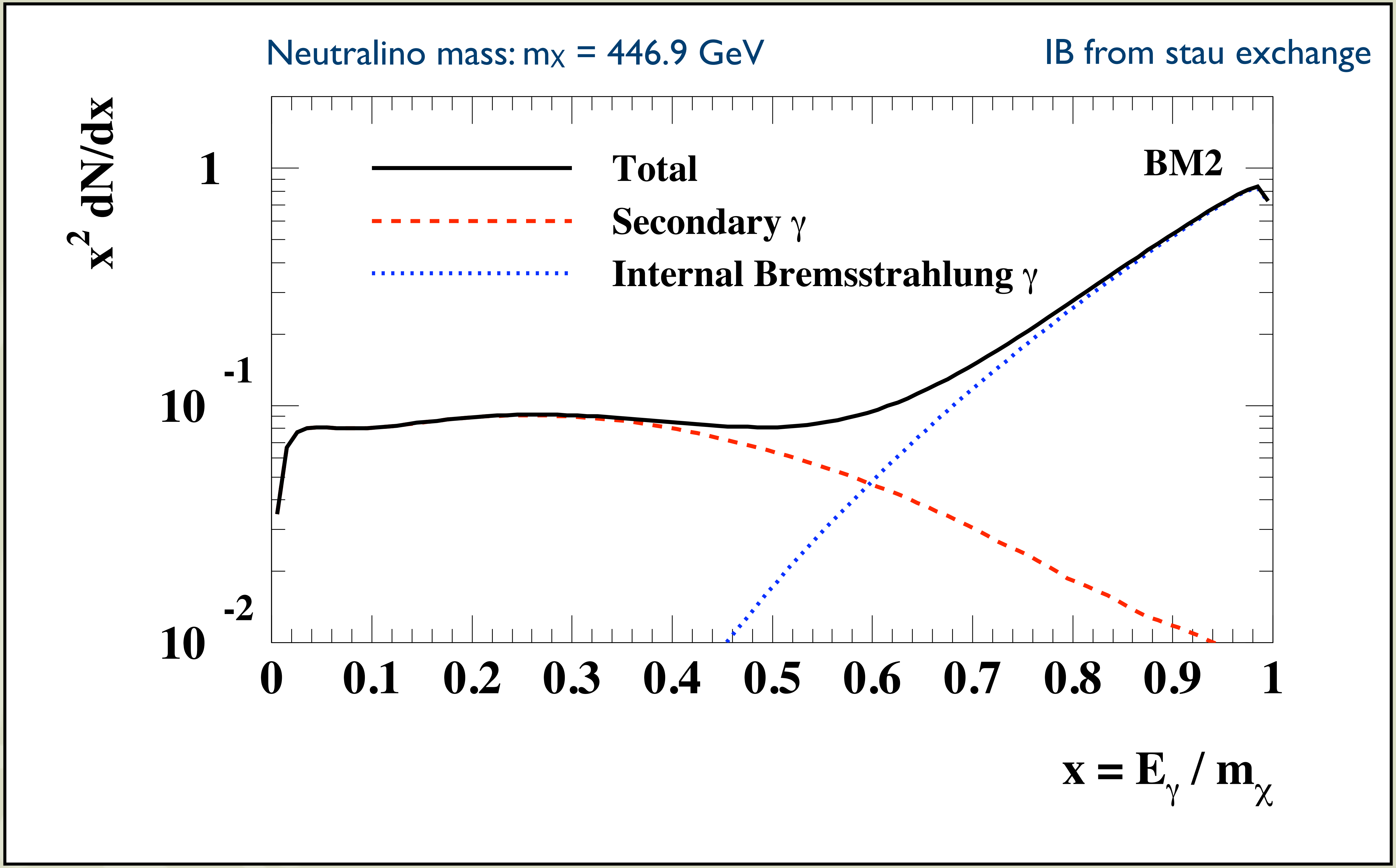
- However, when internal bremsstrahlung photons are added, the helicity suppression no longer holds. The cross section can then increase, even though we are punished by an additional factor of α
- These photons can in many cases dominate at high energies

Gamma ray spectrum including IB photons I



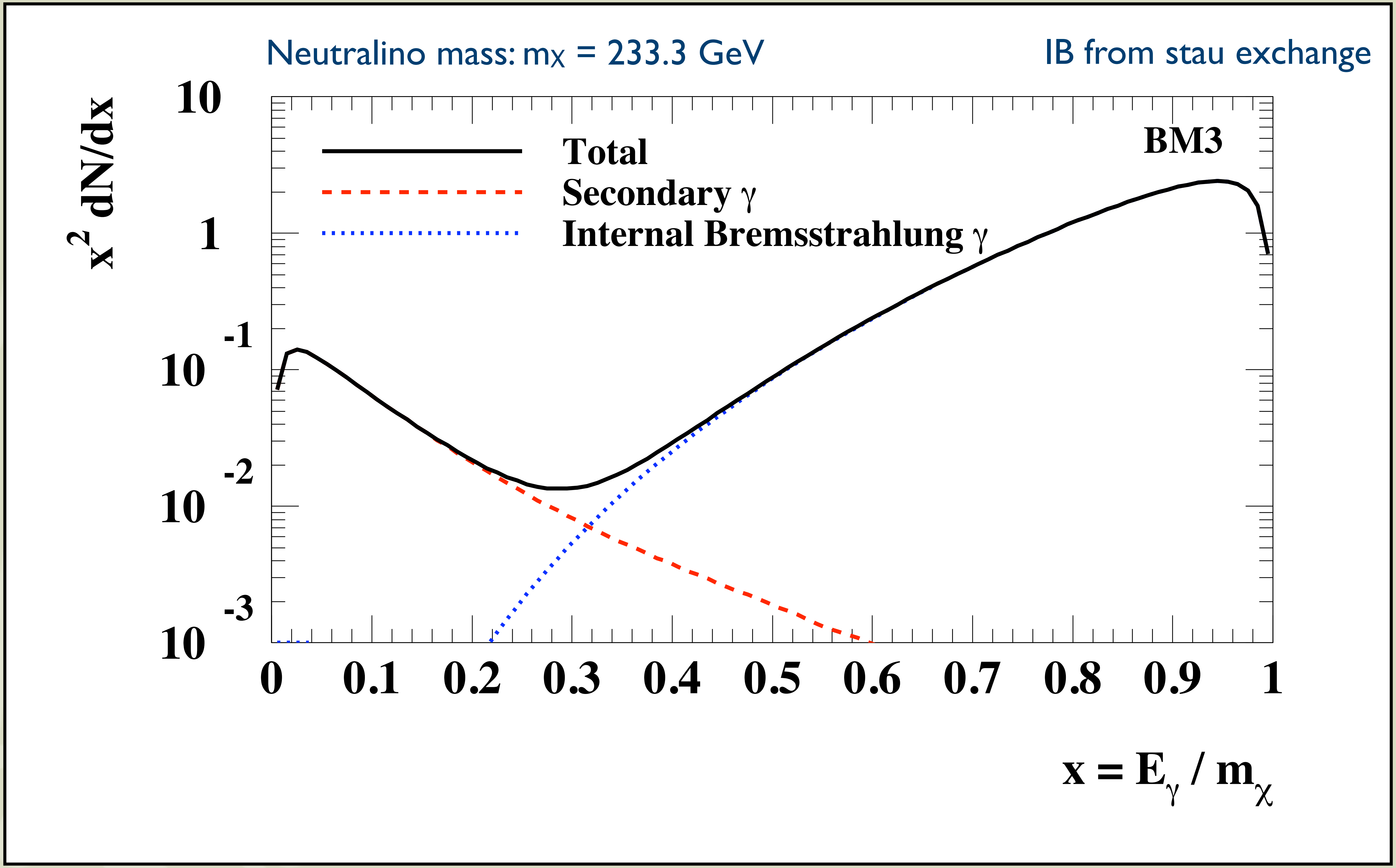
T. Bringmann, L. Bergström and J. Edsjö, arXiv: 0710.3169, JHEP 01 (2008) 049

Gamma ray spectrum including IB photons II



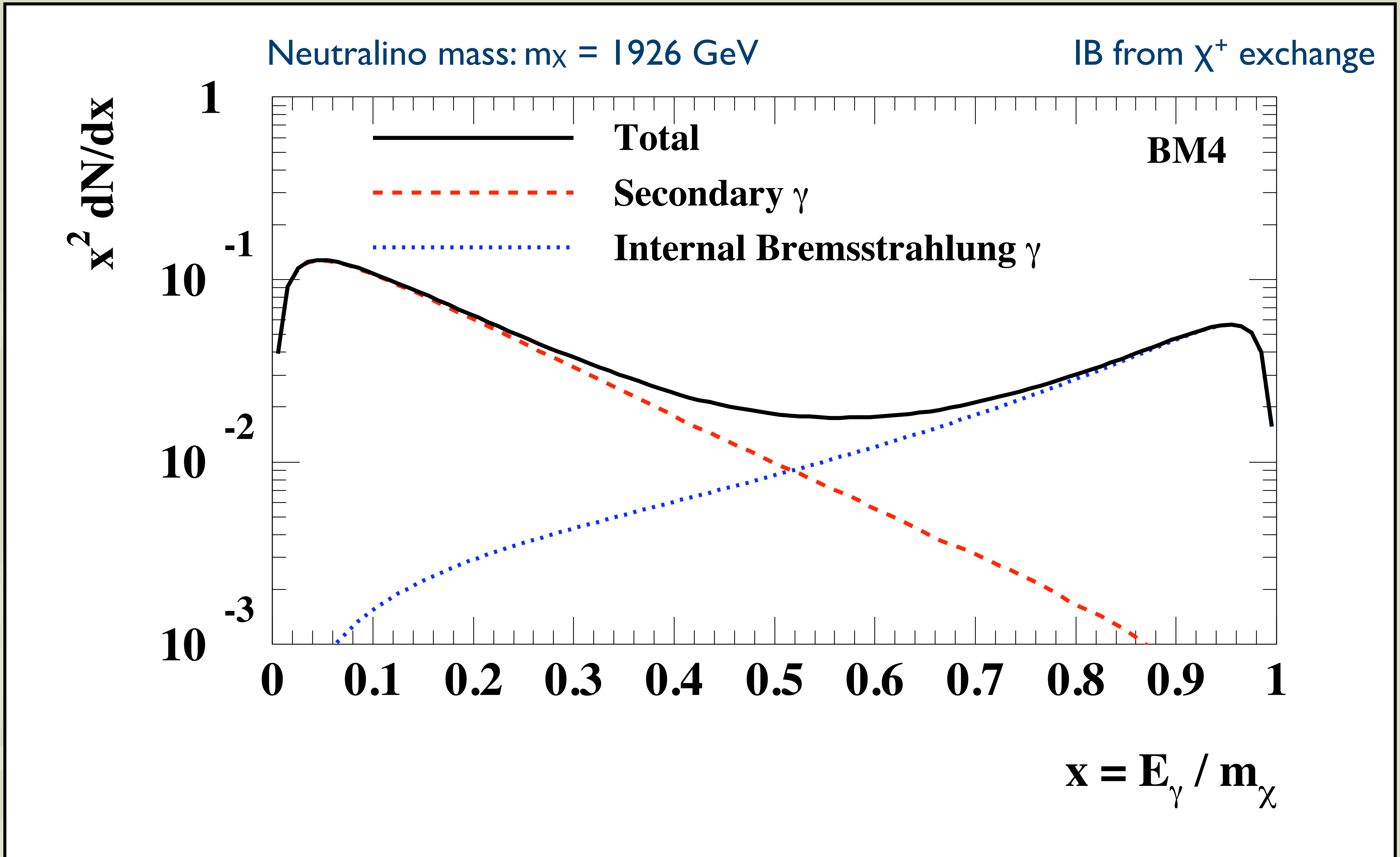
T. Bringmann, L. Bergström and J. Edsjö, arXiv: 0710.3169, JHEP 01 (2008) 049

Gamma ray spectrum including IB photons III



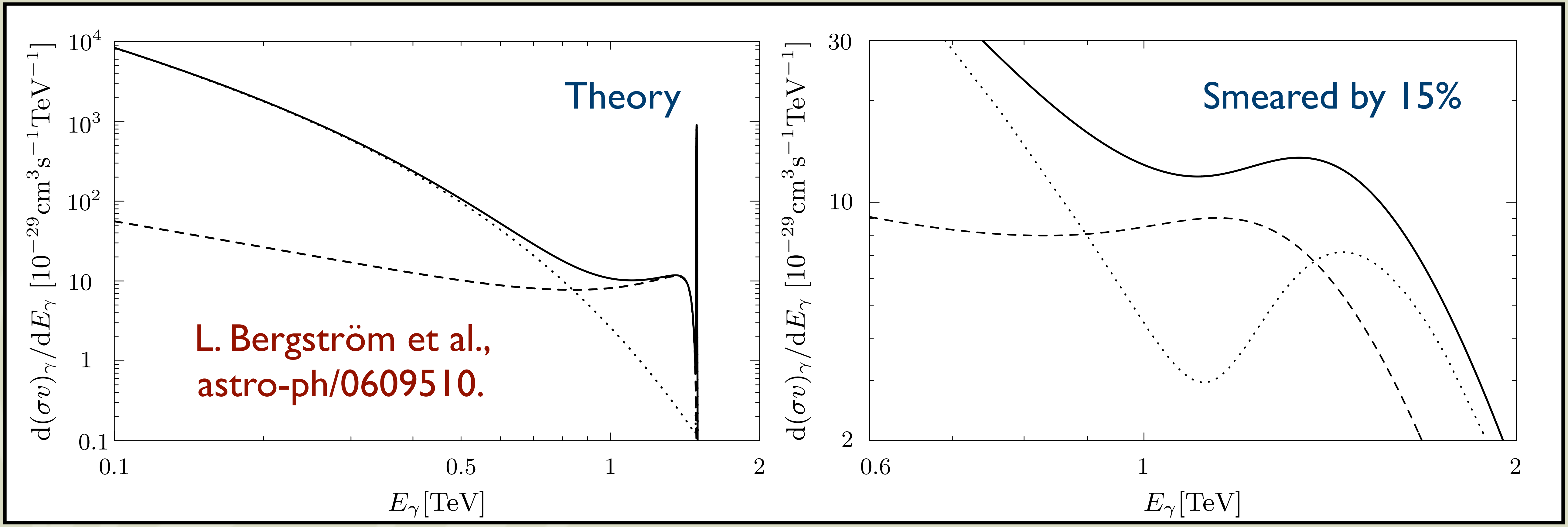
T. Bringmann, L. Bergström and J. Edsjö, arXiv: 0710.3169, JHEP 01 (2008) 049

Gamma ray spectrum including IB photons IV



T. Bringmann, L. Bergström and J. Edsjö, arXiv: 0710.3169, JHEP 01 (2008) 049

Example of experimental smearing



- W^+W^- channel via $\chi^\pm$ exchange

More quantitative...

- Let's focus on the high energy part by redefining

$$S = \int_{0.6m_\chi}^{m_\chi} \frac{dN^\gamma}{dE} dE \frac{(\sigma v)}{10^{-29} cm^3 s^{-1}} \left(\frac{m_\chi}{100 GeV} \right)^{-2}$$

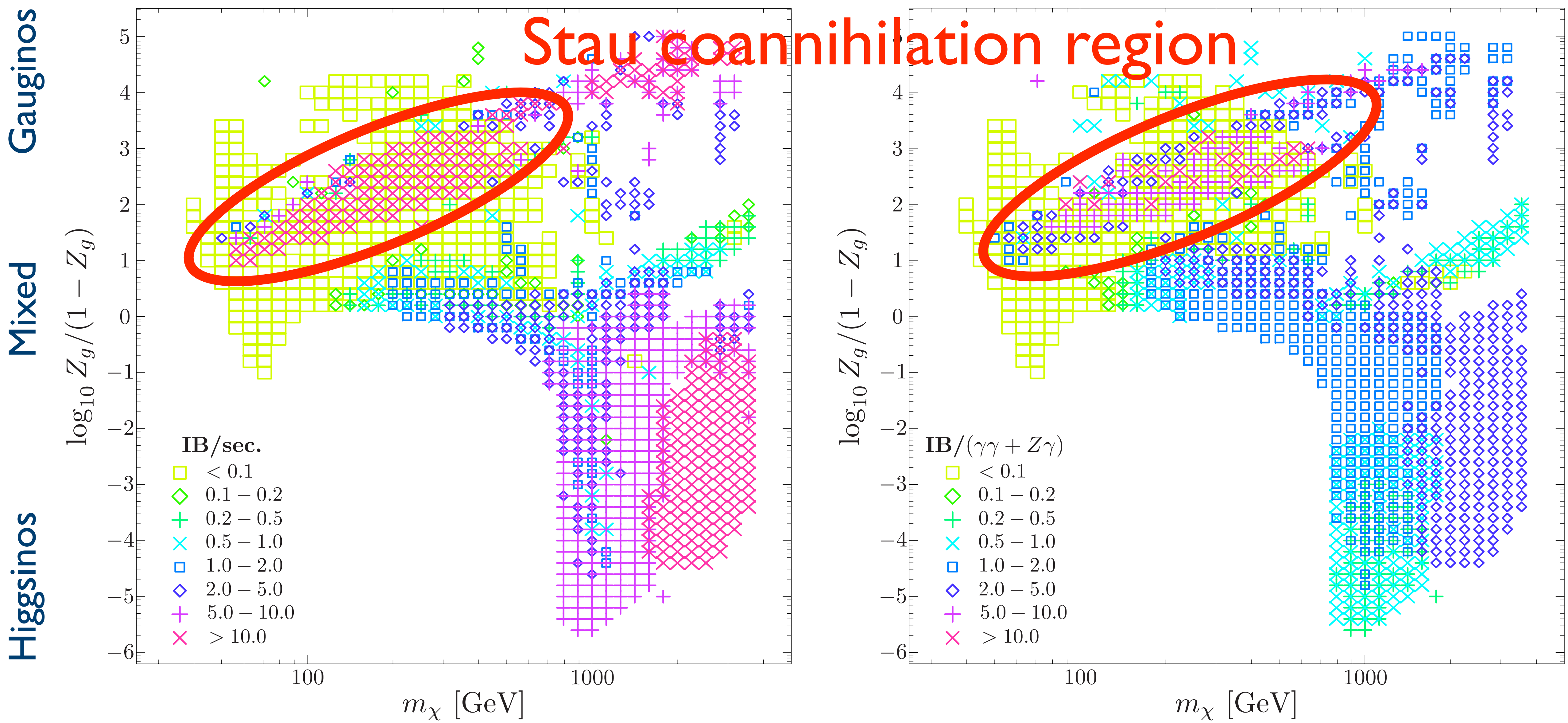
and divide S into the different parts

$$S = S_{\rm IB} + S_{\rm sec.} + S_{\rm lines}$$

Internal Bremsstrahlung

When is it important?

MSSM and mSUGRA scans

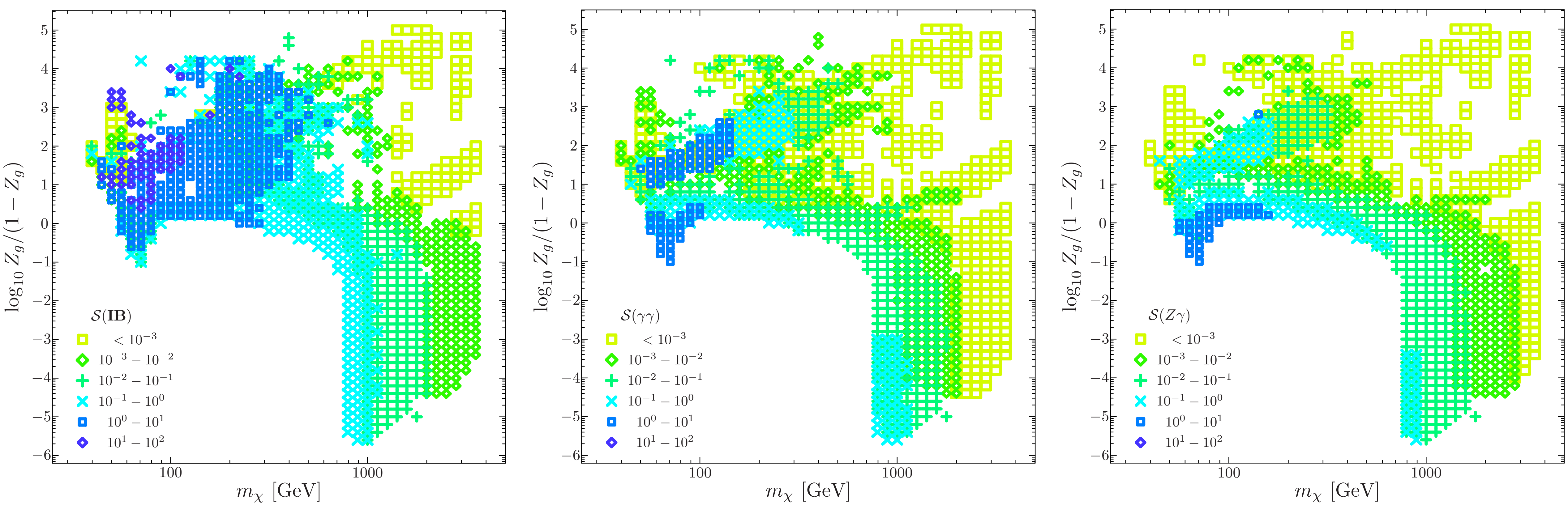


All models OK with WMAP and accelerator constraints. IB>0.6m_χ

T. Bringmann, L. Bergström and J. Edsjö, arXiv: 0710.3169, JHEP 01 (2008) 049

Absolute strengths

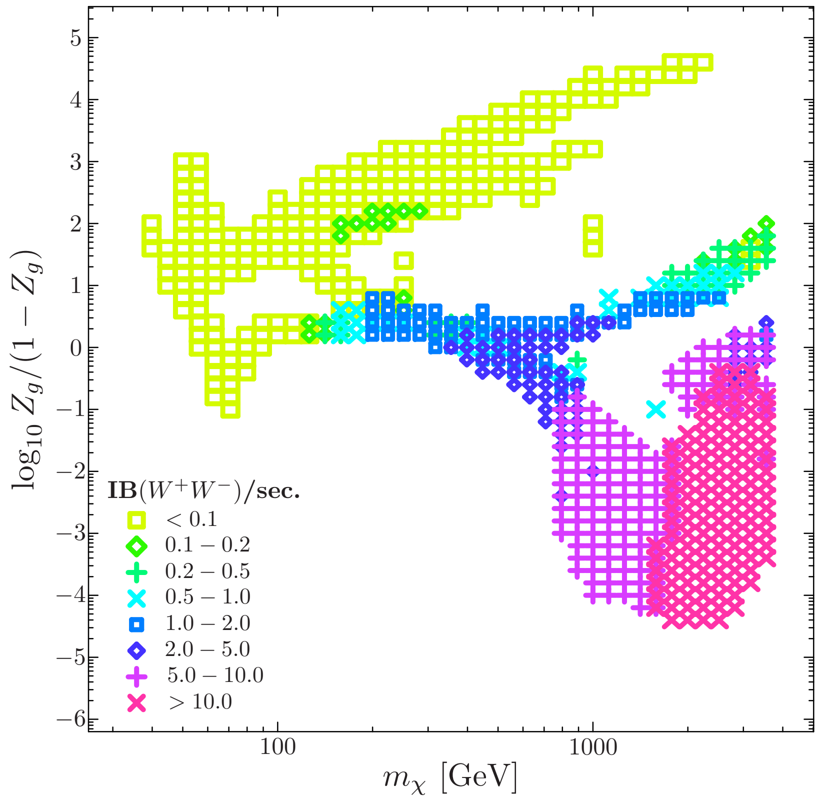
IB | γγ | Z γ



IB can be more important than the lines

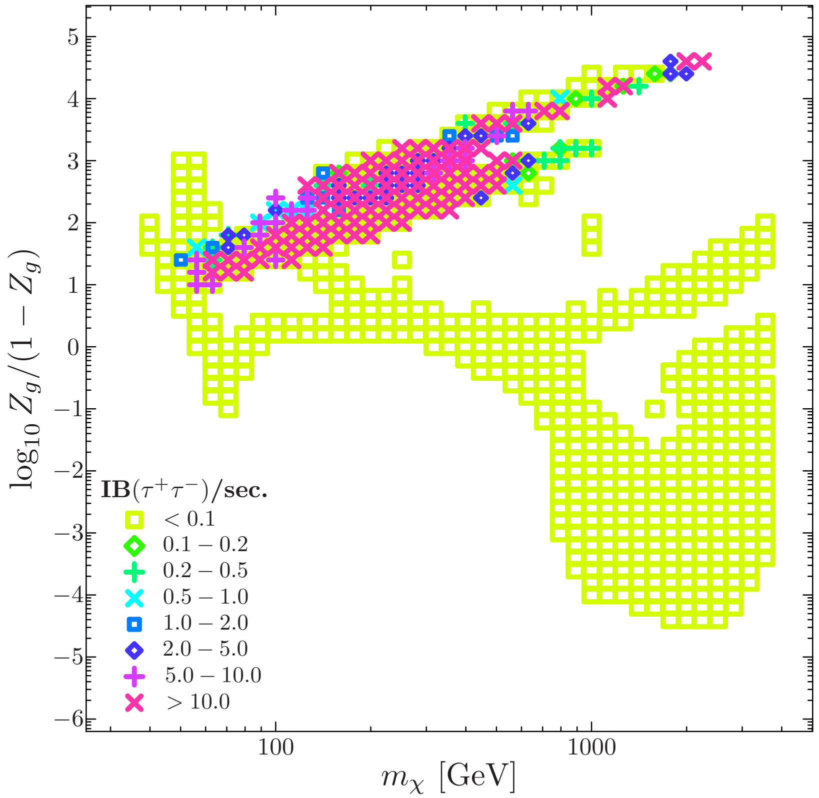
IB/sec. for mSUGRA

IB(W^+W^-)/sec.



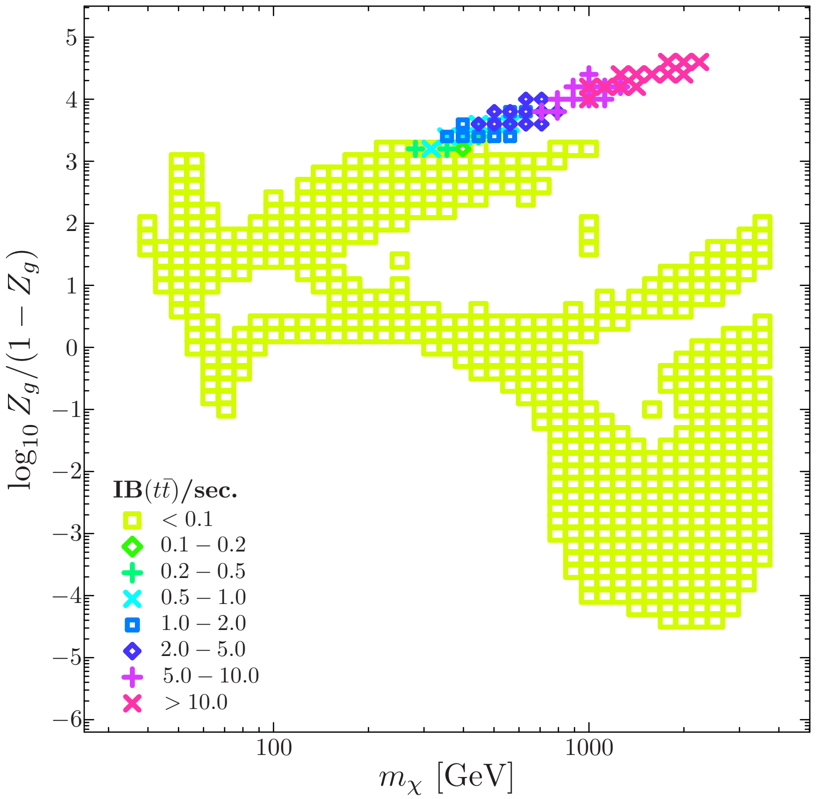
focus point region

IB($\tau^+\tau^-$)/sec.



stau coannihilation region

IB($t\bar{t}$)/sec.

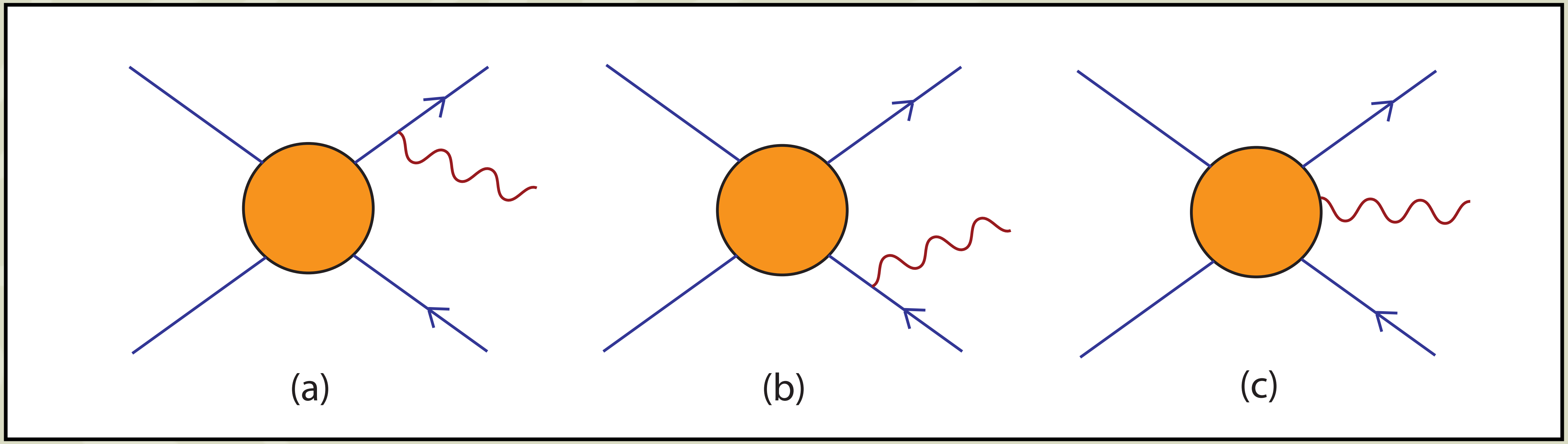


stop coannihilation region

So, what about the positrons?

L. Bergström, T. Bringmann and J. Edsjö, work in progress

- Annihilations to e^+e^- is helicity suppressed for Majorana fermion WIMPs (e.g. neutralinos)
- Hence, direct annihilation to e^+e^- is never important
- BUT, internal bremsstrahlung of photons cause the cross section for annihilation into $e^+e^-\gamma$ to increase. Can it be enhanced enough to be of importance or e^+ searches?



When is the effect large?

- Typically, the $e^+e^-\gamma$ cross section can be large when the selectrons are light
- This can happen e.g. in the stau coannihilation region in mSUGRA
- In MSSM-7, it only happens when essentially all sfermions are light (and typically the slectron is not that light in these cases). However, this is just an artefact of how MSSM-7 is parameterized. Hence, introduce...

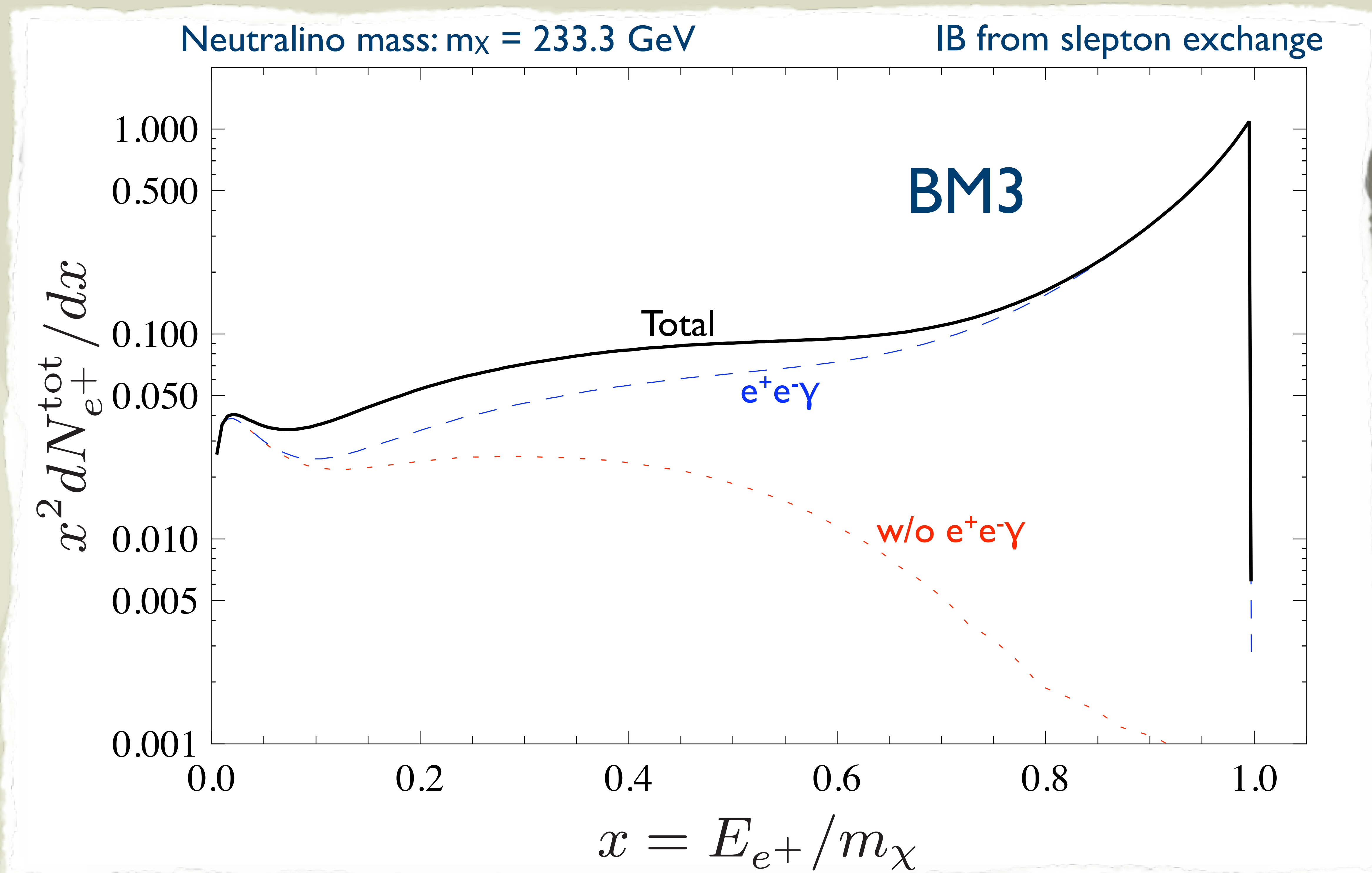
MSSM-9

- In order to get light selectrons and allow more freedom for the neutralino composition, we introduce MSSM-9 with two more parameters:

μ	Higgsino mass parameter	
M_1	Gaugino mass parameter	New
M_2	Gaugino mass parameter	
m_A	Mass of CP-odd Higgs boson	
$\tan\beta$	Ratio of Higgs vacuum expectation values	
m_0	Scalar mass parameter	
$m_{\tilde{e}}$	Selectron mass parameter (not mass directly)	New
A_b	Trilinear coupling, bottom sector	
A_t	Trilinear coupling, top sector	

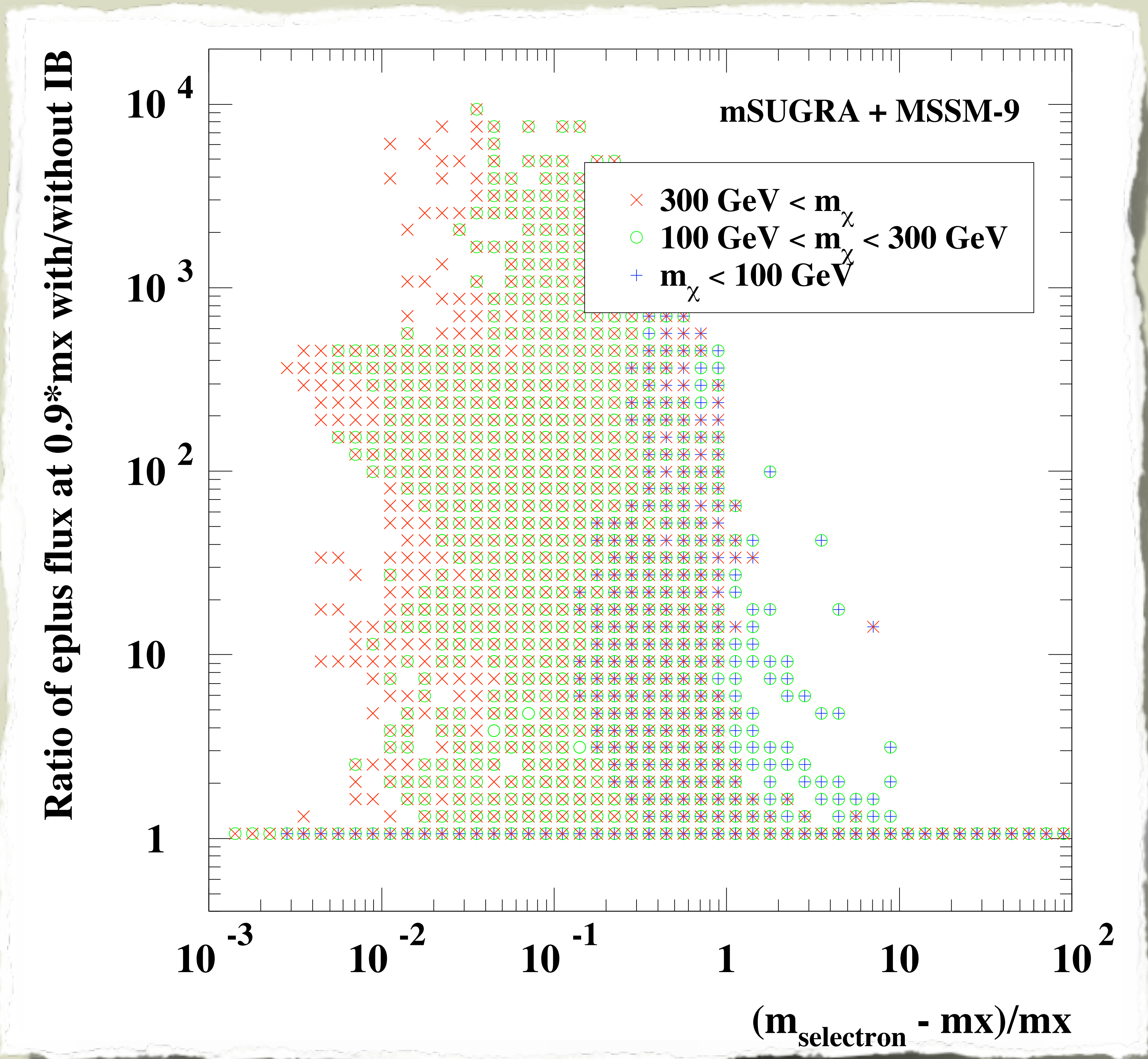
$$\mathcal{M}^2_{\tilde{e}} = \begin{pmatrix} \mathbf{M}^2_L + \mathbf{m}_e\mathbf{m}_e^\dagger + D^e_{LL}\mathbf{1} & -\mathbf{m}_e^\dagger(\mathbf{A}_E^\dagger + \mu^* \tan\beta) \\ -(\mathbf{A}_E + \mu\tan\beta)\mathbf{m}_e & \mathbf{M}^2_E + \mathbf{m}_e^\dagger\mathbf{m}_e + D^e_{RR}\mathbf{1} \end{pmatrix}.$$

Example mSUGRA e^+ spectrum



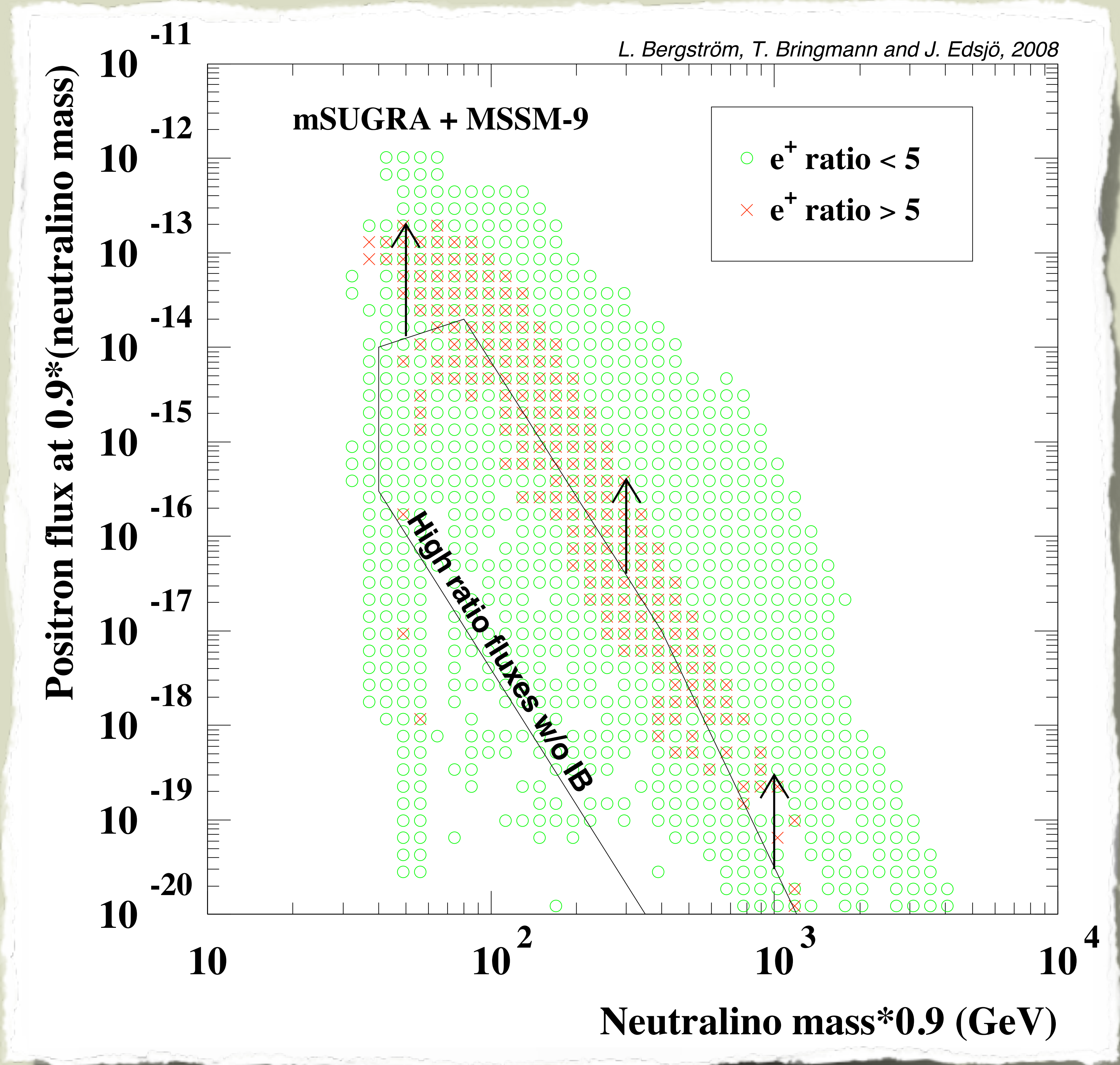
Very nice spectral feature!

Enhancement factors at 0.9m_χ



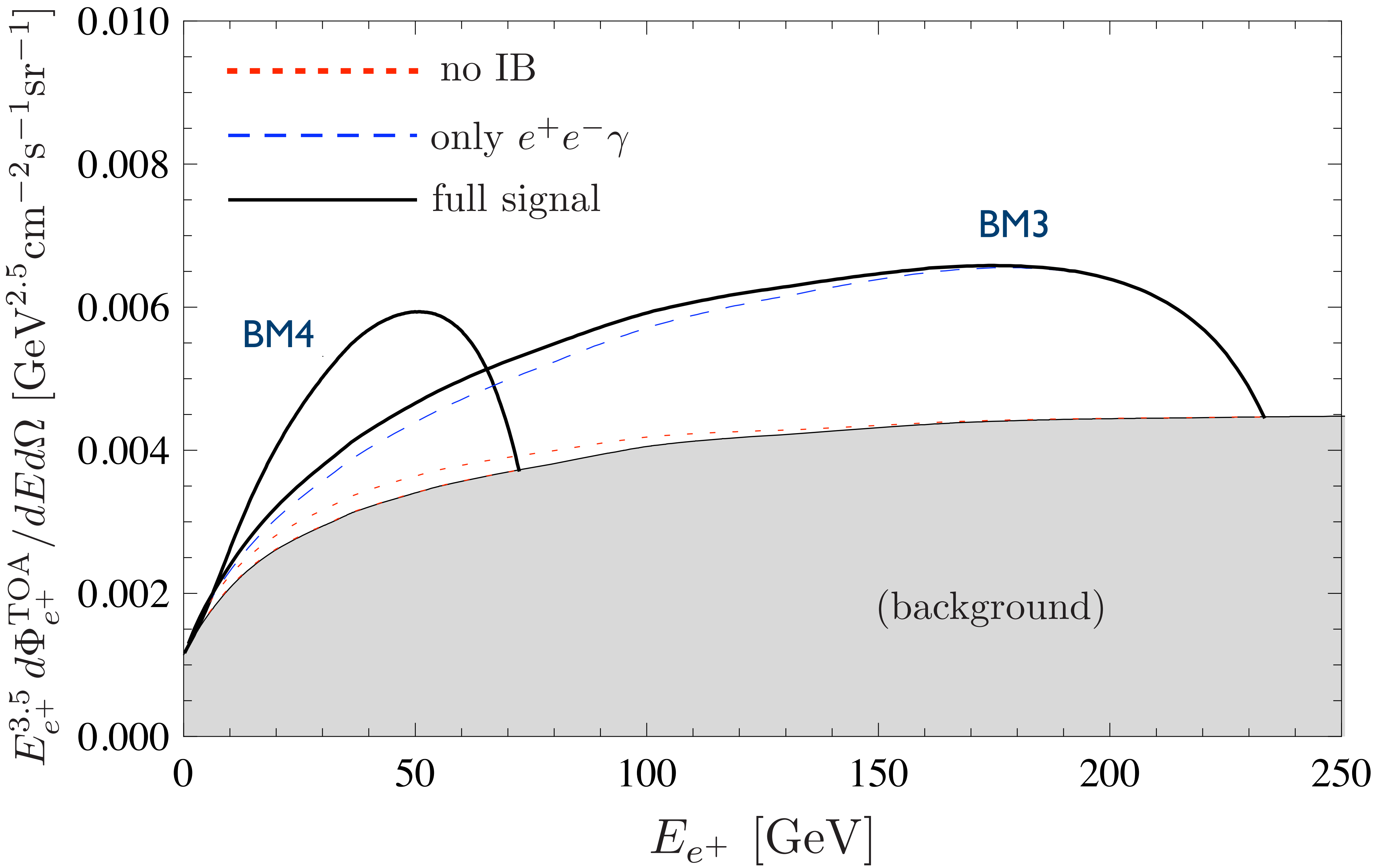
It is possible to get huge enhancement factors

Absolute fluxes



- IB enhances the positron fluxes significantly for some models
- The models that get large enhancements had low fluxes to start with
- Even after enhancement, the fluxes are not very high, BUT they have a nice spectral feature!

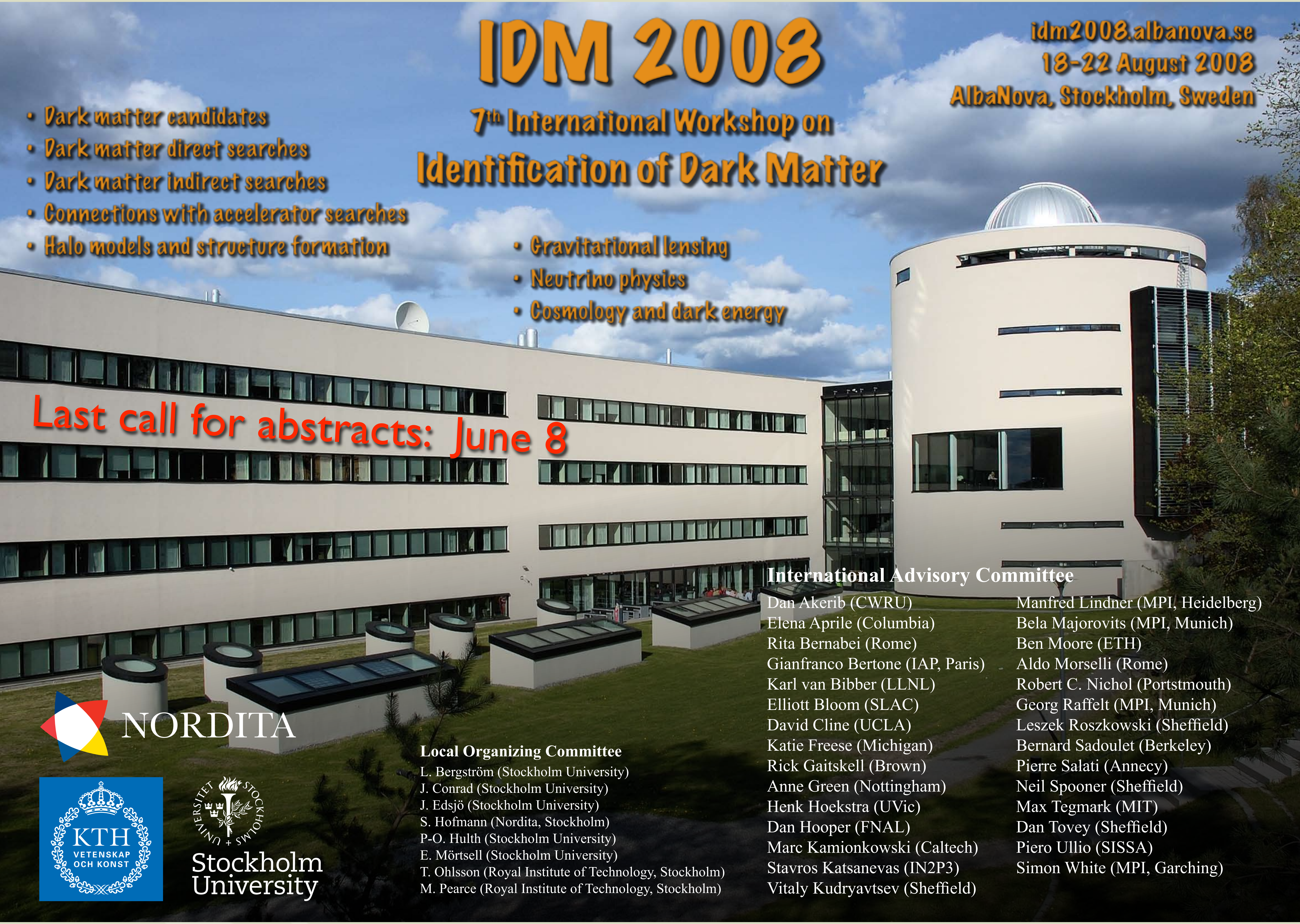
Spectrum after propagation



Nice features, but a boost factor of 5000...

Conclusions

- Gamma rays from dark matter annihilation can have distinct spectral features, either from the monochromatic lines or from internal bremsstrahlung effects
- Searches with e.g. GLAST (launch June 7, 11:45am) and Air Cherenkov Telescopes will be very interesting
- Positron enhancements can also be significant and provide a nice spectral feature that distinguish them from the background. The absolute fluxes are not that high though.



IDM 2008
7th International Workshop on
Identification of Dark Matter
idm2008.albanova.se
18-22 August 2008
AlbaNova, Stockholm, Sweden
• Dark matter candidates
• Dark matter direct searches
• Dark matter indirect searches
• Connections with accelerator searches
• Halo models and structure formation
• Gravitational lensing
• Neutrino physics
• Cosmology and dark energy
Last call for abstracts: June 8
International Advisory Committee
Dan Akerib (CWRU)
Elena Aprile (Columbia)
Rita Bernabei (Rome)
Gianfranco Bertone (IAP, Paris)
Karl van Bibber (LLNL)
Elliott Bloom (SLAC)
David Cline (UCLA)
Katie Freese (Michigan)
Rick Gaitskell (Brown)
Anne Green (Nottingham)
Henk Hoekstra (UVic)
Dan Hooper (FNAL)
Marc Kamionkowski (Caltech)
Stavros Katsanevas (IN2P3)
Vitaly Kudryavtsev (Sheffield)
Manfred Lindner (MPI, Heidelberg)
Bela Majorovits (MPI, Munich)
Ben Moore (ETH)
Aldo Morselli (Rome)
Robert C. Nichol (Portstmouth)
Georg Raffelt (MPI, Munich)
Leszek Roszkowski (Sheffield)
Bernard Sadoulet (Berkeley)
Pierre Salati (Annecy)
Neil Spooner (Sheffield)
Max Tegmark (MIT)
Dan Tovey (Sheffield)
Piero Ullio (SISSA)
Simon White (MPI, Garching)
Local Organizing Committee
L. Bergström (Stockholm University)
J. Conrad (Stockholm University)
J. Edsjö (Stockholm University)
S. Hofmann (Nordita, Stockholm)
P-O. Hulth (Stockholm University)
E. Mörtsell (Stockholm University)
T. Ohlsson (Royal Institute of Technology, Stockholm)
M. Pearce (Royal Institute of Technology, Stockholm)
NORDITA
KTH
VETENSKAP
OCH KONST
Stockholm
University