Constraining SUSY parameters through collisions of AGN jets with Neutralino dark matter

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With A. Rajaraman, T. Tait, JCAP 1205 (2012) 027

UC Irvine

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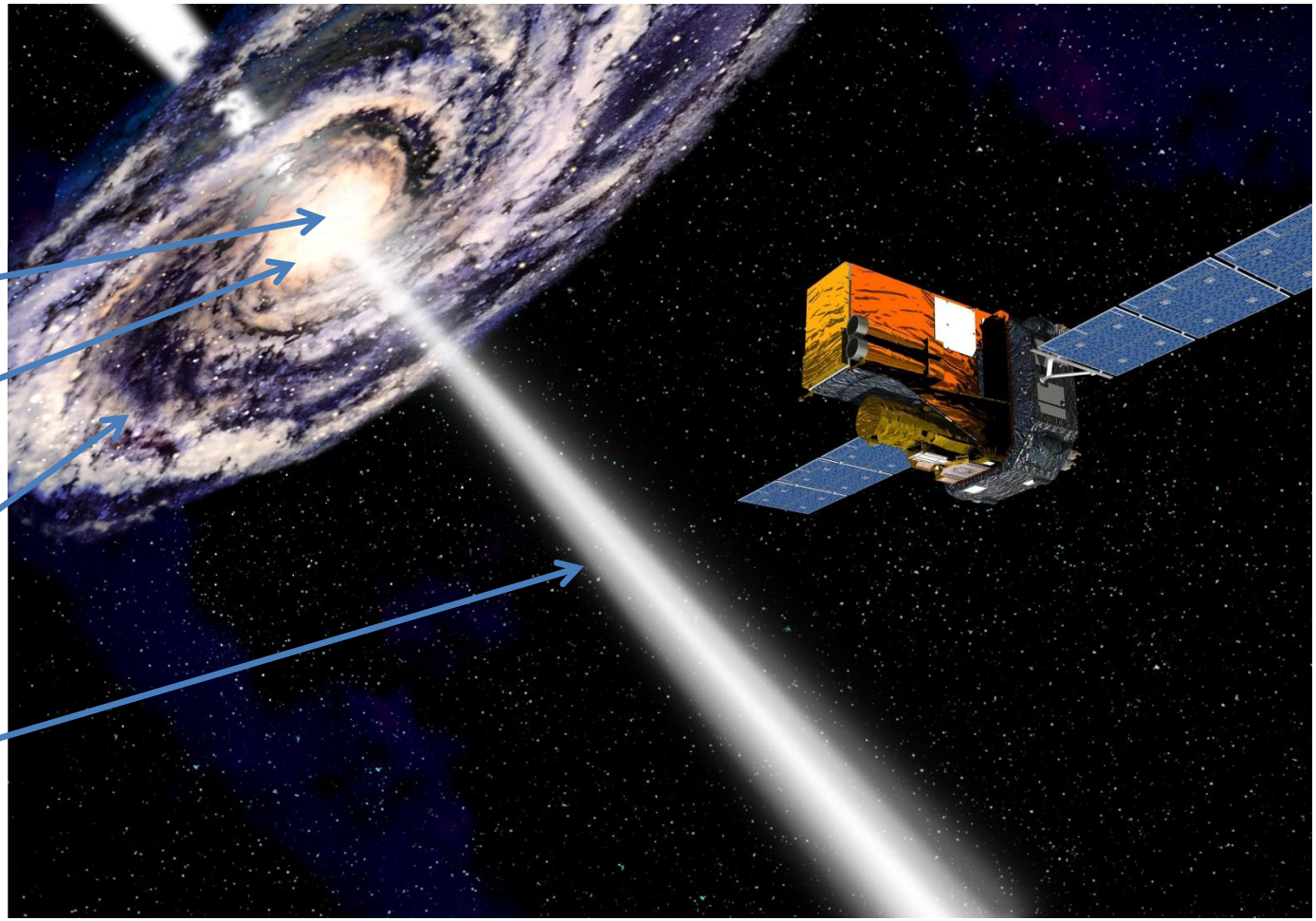
Who is responsible to questions?

AGN: Probe TeV New Physics

- Active Galactic Nuclei (AGN) is a natural accelerator
- Complementary approach to probe new physics at TeV scale:
  - can study dark matter properties
  - test some models, e.g. SUSY, Extra Dimension
  - might be sensitive to parameter region (not sensitive at LHC)
- In this talk:
  - dark matter particle scatters with AGN jet and radiate photons
  - observe the photon energy flux through Fermi-LAT
  - potentially constrain parameter space of SUSY models

AGN: a Natural Accelerator



http://www.isdc.unige.ch/gallery.cgi?INTEGRAL

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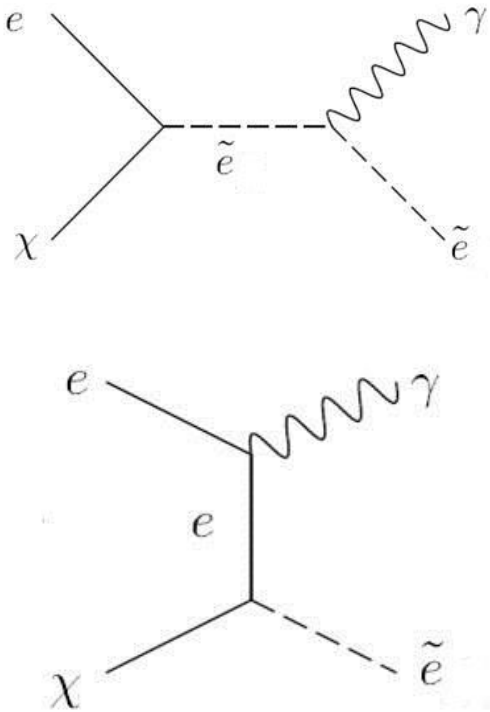
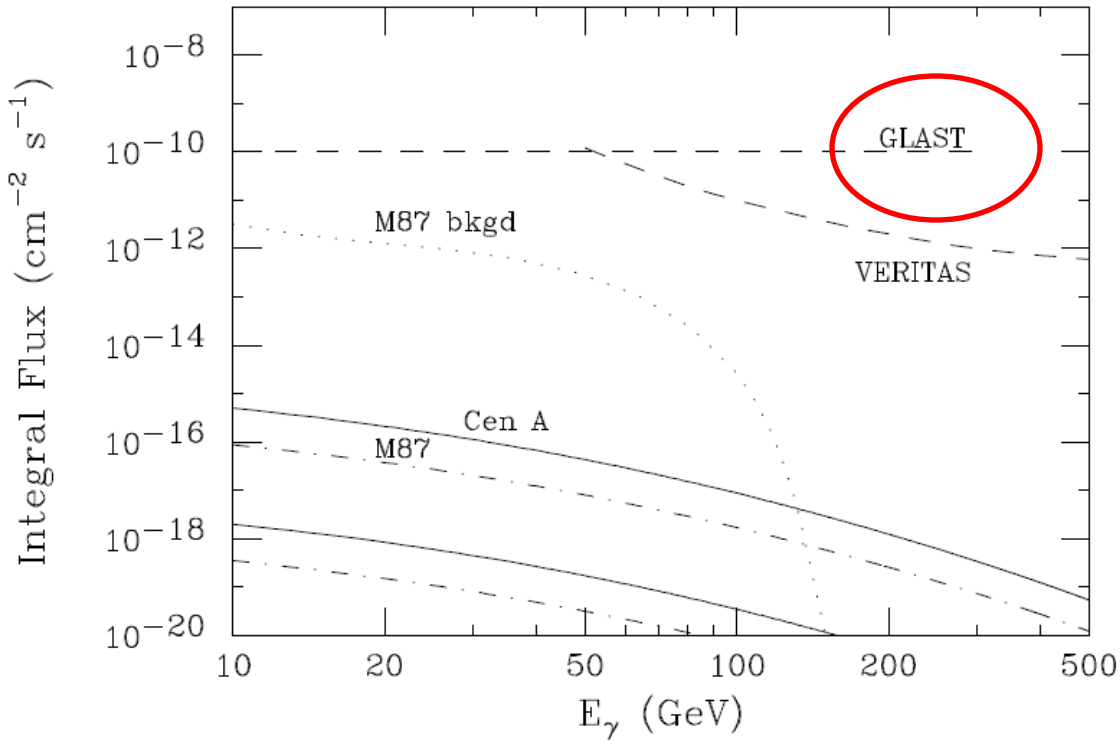
Detect High Energy Gamma Ray from DM Scattering with AGN Jet

E. D Bloom, J. D. Wells, Phys. Rev. D57:1299 (1998)





our estimate of the signal for electron-bino scattering into photons from a single AGN source is **too low to be discerned by currently proposed experiments, but future detectors** of much higher sensitivity might be able to see a signal.

Fermi-LAT

Fermi-LAT is a multi-purpose telescope:

e.g.:

•To understand the mechanisms of particle acceleration in active galactic nuclei (AGN), pulsars, and supernova remnants (SNR).

•Probe dark matter (e.g. by looking for an excess of gamma rays from the center of the Milky Way) and early Universe.

Centaurus A: closest Active Galaxy

N. Neumayer, arXiv:1002.0965
L. ferrarese, et.al., Astrophys.J. 654 (2006) 186

Basic parameters:

$d_{AGN} \sim 3.7$ Mpc

$M_{BH} \cong (5.5 \pm 3.0) \times 10^{7}\ M_{sun}$

$t_{BH} \cong 10^{8} - 10^{10}$ yrs

$\langle \sigma v \rangle \cong 10^{-30} - 10^{-26}\ cm^{3}\ s^{-1}$

$\theta \cong 68°$

$L_{e} \cong 10^{43} - 10^{46}\ erg\ s^{-1}$

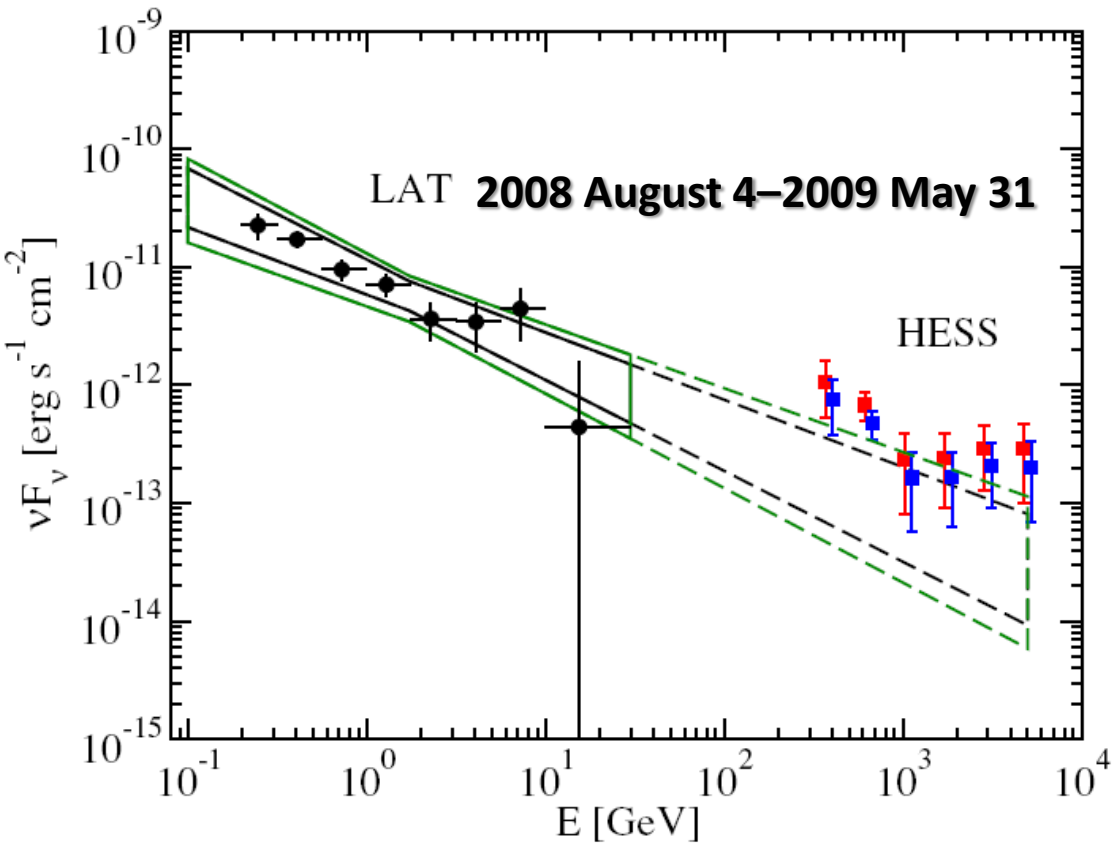
Photon Energy Flux of Centaurus A from Fermi-LAT

Fermi Collaboration, arXiv:1006.5463

Black bowtie:
best fit 0.1 – 30 GeV LAT flux and Γ with statistical errors only.

Green bowtie: + systematic errors.

Dashed Lines: extrapolation from the LAT spectrum into the HESS energy range.



Some Questions from Fermi-LAT Results…

- Is it possible to explain drop-off feature through dark matter scattering with AGN jet?
- Is it possible to constrain parameter space for certain SUSY models?

Photon Energy Flux νF_ν

M. Gorchtein, S. Profumo, L. Ubaldi, Phys. Rev. D 82, 083514 (2010);

Photon Energy Flux: $\nu F_\nu \sim E_\gamma^2 \frac{d\Phi_\gamma}{dE_\gamma}$

$$\frac{d\Phi_\gamma}{dE_\gamma} = \int \boxed{(\delta_{DM})} \times \boxed{\left(\frac{1}{d_{AGN}^2} \frac{d\Phi_j^{AGN}}{dE_j}\right)} \times \boxed{\left(\frac{1}{m_{\tilde{\chi}}} \frac{d^2\sigma}{dE_\gamma d\Omega_\gamma}\right)} dE_j$$

Factor I: Dark Matter Density Profile

Factor II: energy distribution of AGN jet

Factor III: scattering cross section

Dark Matter Profile δ_{DM}

P. Gondolo, J. Silk, Phys.Rev. Lett. 83 (1999)1719;
O. Y. Gnedin, J. R. Primack, Phys.Rev.Lett. 93(2004) 061302

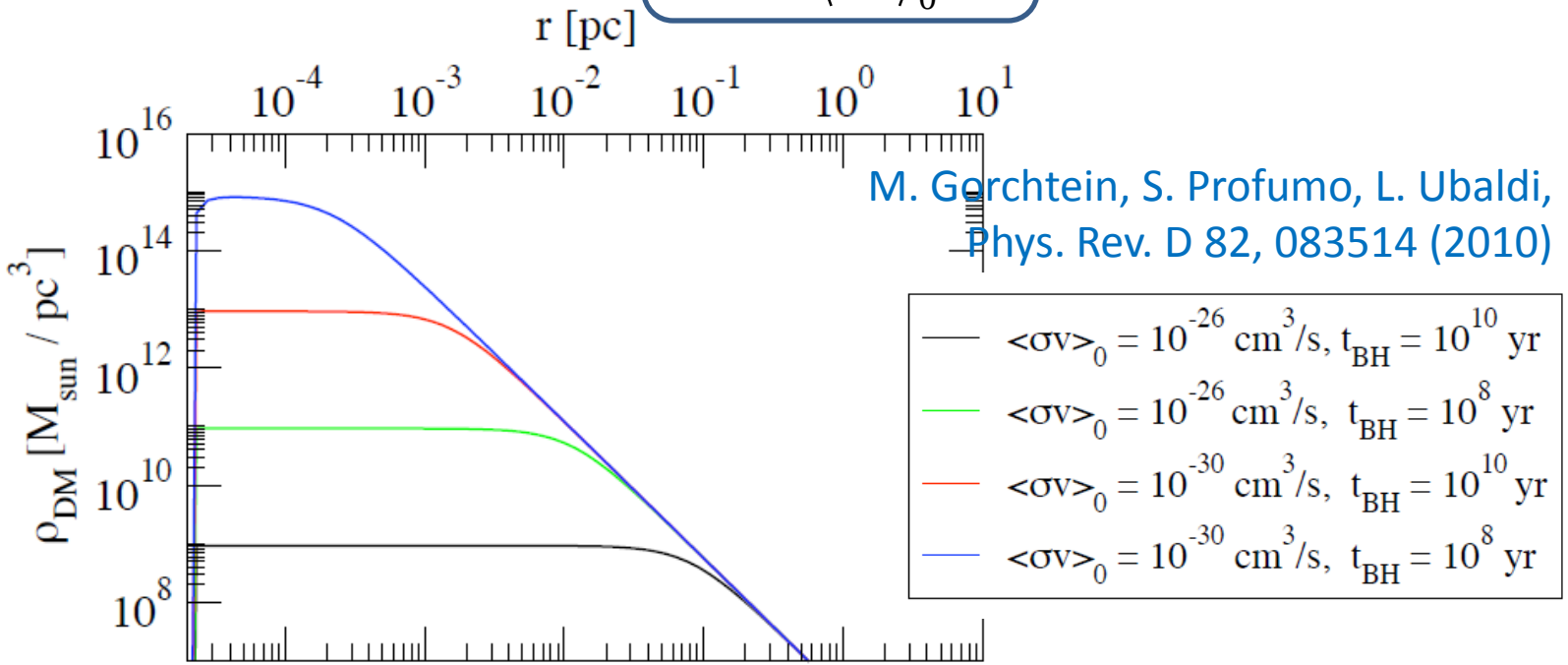
Cusp density profile:

$$\delta_{DM} \equiv < \rho_{DM} R_{DM} > = \int_{r_{\min}}^{r_{\max}} \rho_{DM}(r) dr$$

$$\rho_{DM}(r) = \frac{\rho'(r)\rho_{core}}{\rho'(r) + \rho_{core}}$$

$$\rho_{core} \cong \frac{m_{\tilde{\chi}}}{\langle \sigma v \rangle_0 t_{BH}}$$

$$\rho'(r) \propto r^{-\alpha}$$



M. Gorchtein, S. Profumo, L. Ubaldi,
Phys. Rev. D 82, 083514 (2010)

Dark Matter Profile δ_{DM} (Cont.)

Integrating along the radius to obtain δ_{DM}:

- It is SENSITIVE to ρ_{core} $\{m_\chi, <\sigma v>, t_{BH}\}$;
- It is LESS sensitive to r_{min}, r_{max};
- It is LESS sensitive to various parameters in $\rho'(r)$, such as power index α.

We get:

$$\delta_{DM} = 10^8 - 10^{11} M_{sun} pc^{-2}$$

Electron Energy Distribution $d\Phi^{AGN}_e/d\gamma$

- **We assume electron AGN jet**
- **To obtain $d\Phi^{AGN}_e/d\gamma$ in the Lab frame (Black Hole frame):**
- **We assume it follows Broken Power Law in the Blob frame**

In the Blob frame, electron energy distribution is isotropic

$$\frac{d\Phi_e^{AGN}}{d\gamma'}(\gamma') = \frac{1}{2}k_e\gamma'^{-s_1}[1+(\frac{\gamma'}{\gamma'_{br}})^{s_2-s_1}]^{-1} \qquad \gamma' = E'_e/m_e \quad (\gamma'_{\min} < \gamma' < \gamma'_{\max})$$

$$s_1 = 1.8, \qquad s_2 = 3.5, \qquad \gamma'_{br} = 4\times 10^5, \qquad \gamma'_{\min} = 8\times 10^2, \qquad \gamma'_{\max} = 10^8$$

- **Transform $d\Phi^{AGN}_e/d\gamma'$ from Blob frame to Lab frame ($\Gamma_B \cong 3$)**
- **Factor k_e can be obtained through Jet power in electron in the Lab frame**

$$L_e = \int_{-1}^{1}\frac{d\mu}{\Gamma_B(1-\beta_B\mu)}\int_{\gamma_{\min}}^{\gamma_{\max}} d\gamma(m_e\gamma)\frac{d\Phi_e^{AGN}}{d\gamma}(\gamma(\Gamma_B(1-\beta_B\mu))) \qquad (\mu = \cos\theta)$$

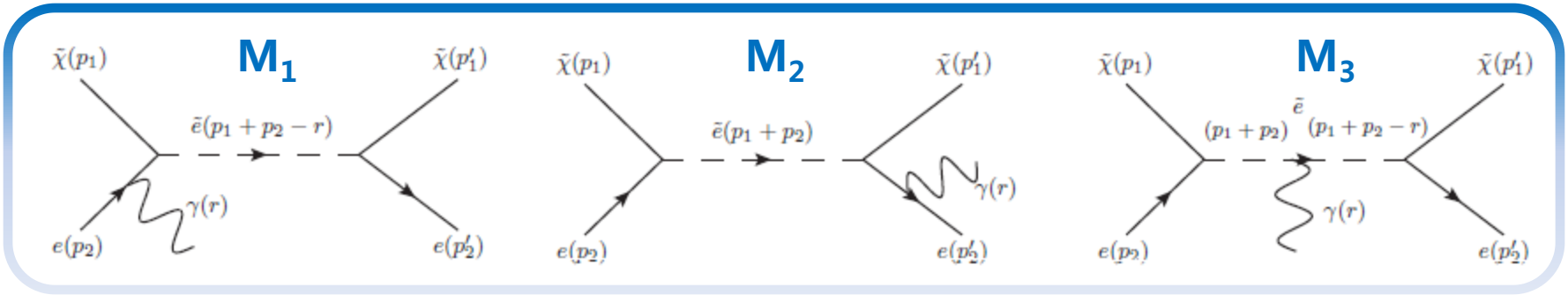
Differential Cross Section $d^2\sigma/dE\gamma\, d\Omega\gamma$

- It is Model Dependent!
- I will present one SUSY model:
  - Neutralino ($\tilde{\chi}$) is the DM candidate
  - DM and electron AGN jet scatter and radiate photon

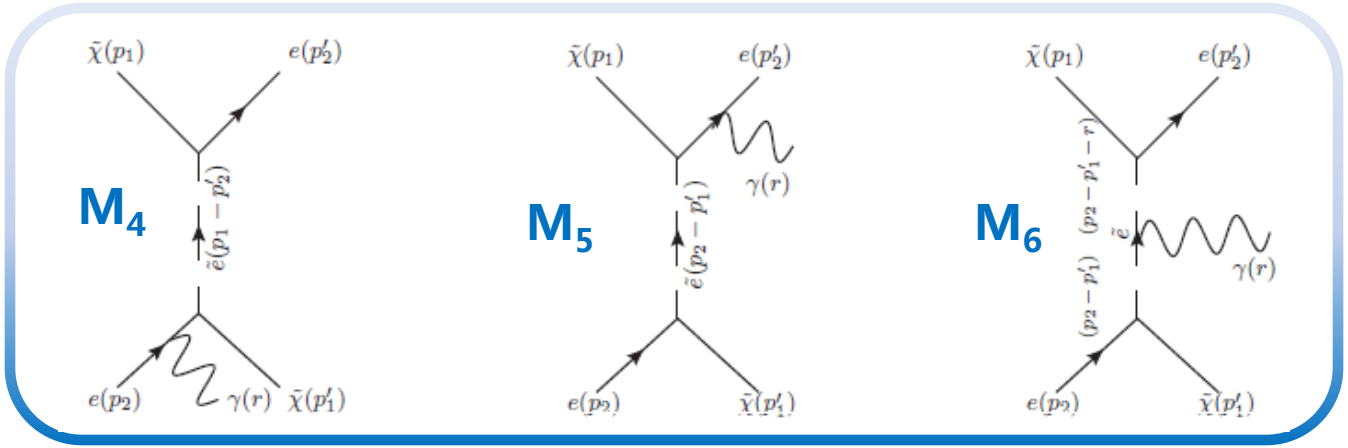
$$e + \tilde{\chi}(\rightarrow \tilde{e}) \rightarrow e + \tilde{\chi} + \gamma$$

Theoretical Model

s Channel: $s = (p_1 + p_2)^2$ $s' = (p_1' + p_2')^2$

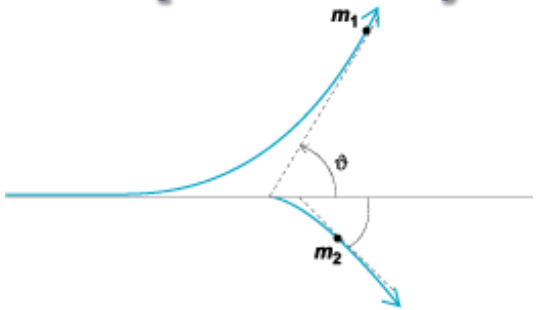


u Channel: $u = (p_1 - p_2')^2$ $u' = (p_2 - p_1')^2$



Gauge Invariant!

Theoretical Model (Cont.)



Kinematics:

In Black Hole frame:

Initial $\tilde{\chi}$ at rest, initial AGN electron jet inject and scatter;

AGN jet is very collimated.

Parameters:

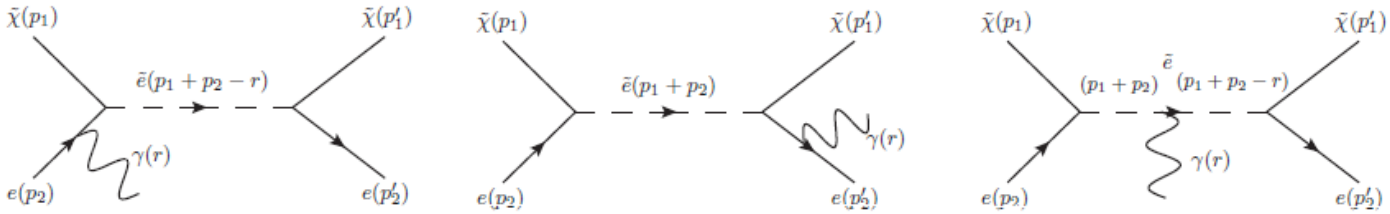
$$m_{\tilde{e}} = 100GeV; \quad m_{\tilde{\chi}} = 60GeV; \quad \theta = 68^{\circ}$$

Interaction couplings see J. Edsjo, arXiv:hep-ph/9704384v1

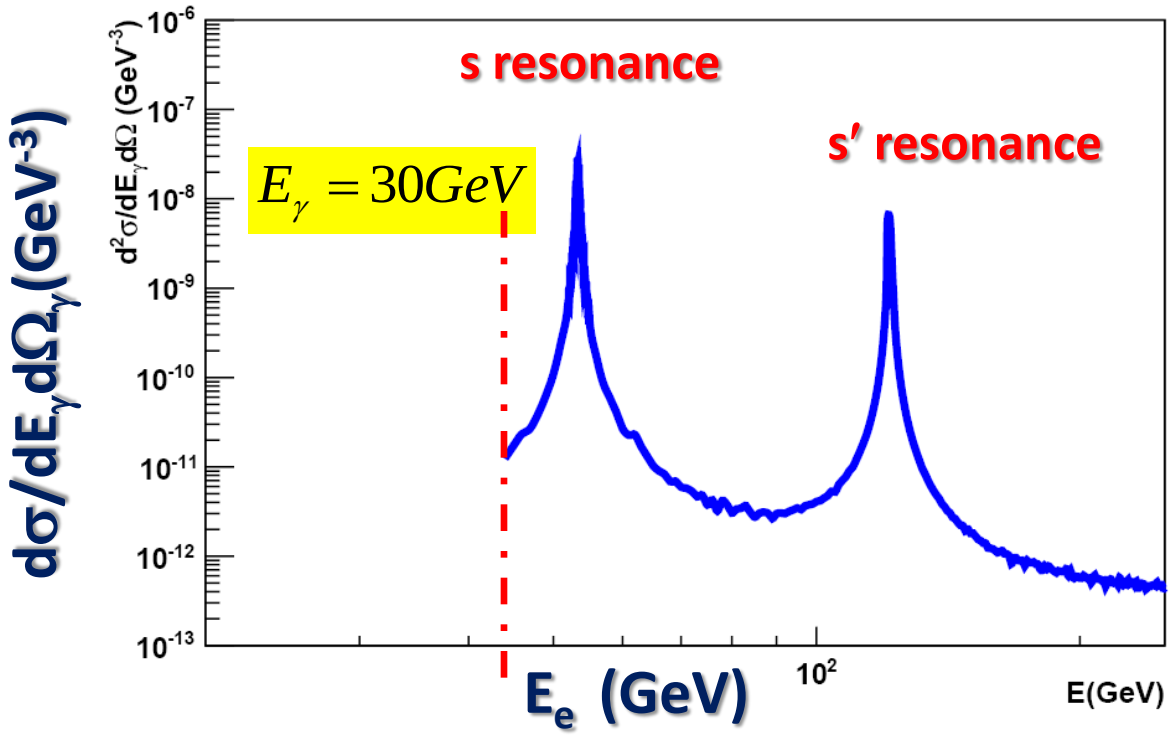
Differential Cross Section

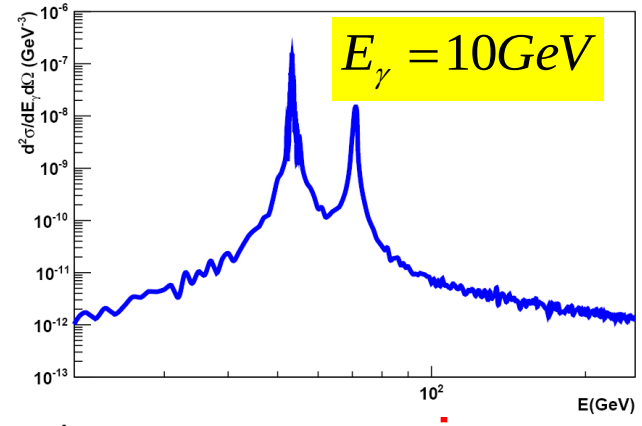
- calculate all of the s-channel and u-channel as well as their interference terms;
- make sure gauge invariance;
- three enhancement effects:
  - Resonance effect: M_1-M_3
  - Collinear effect: M_2, M_5
  - Soft radiation effect: M_2, M_5
- the electron energy has to be high enough to create high energy photon;
- s resonance can be missing when the photon energy is too high;
- and further explain the drop-off feature.

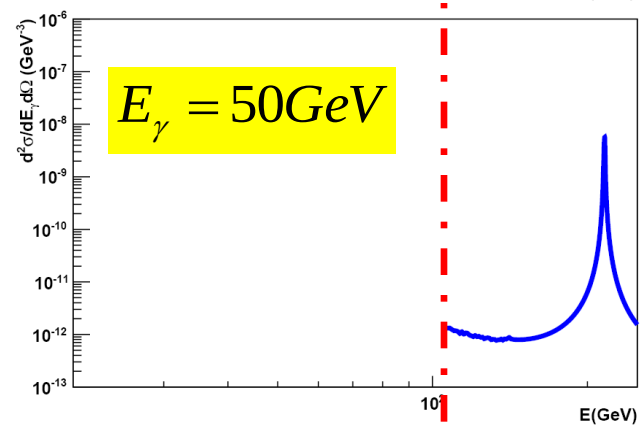
Differential Cross Section (Cont.)



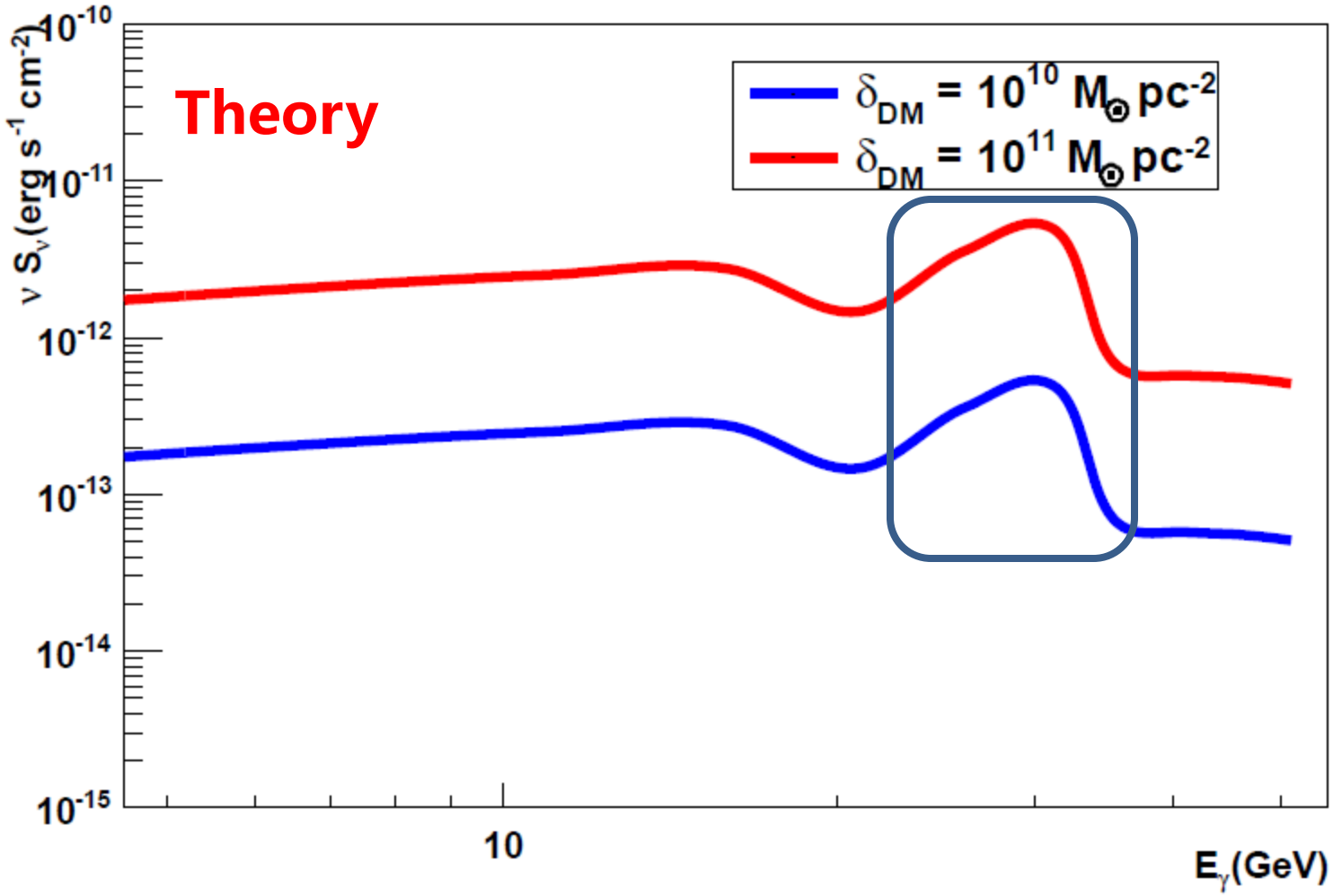
$$m_{\tilde{e}} = 100GeV; \quad m_{\tilde{\chi}} = 60GeV$$







Photon Energy Flux



Constraints

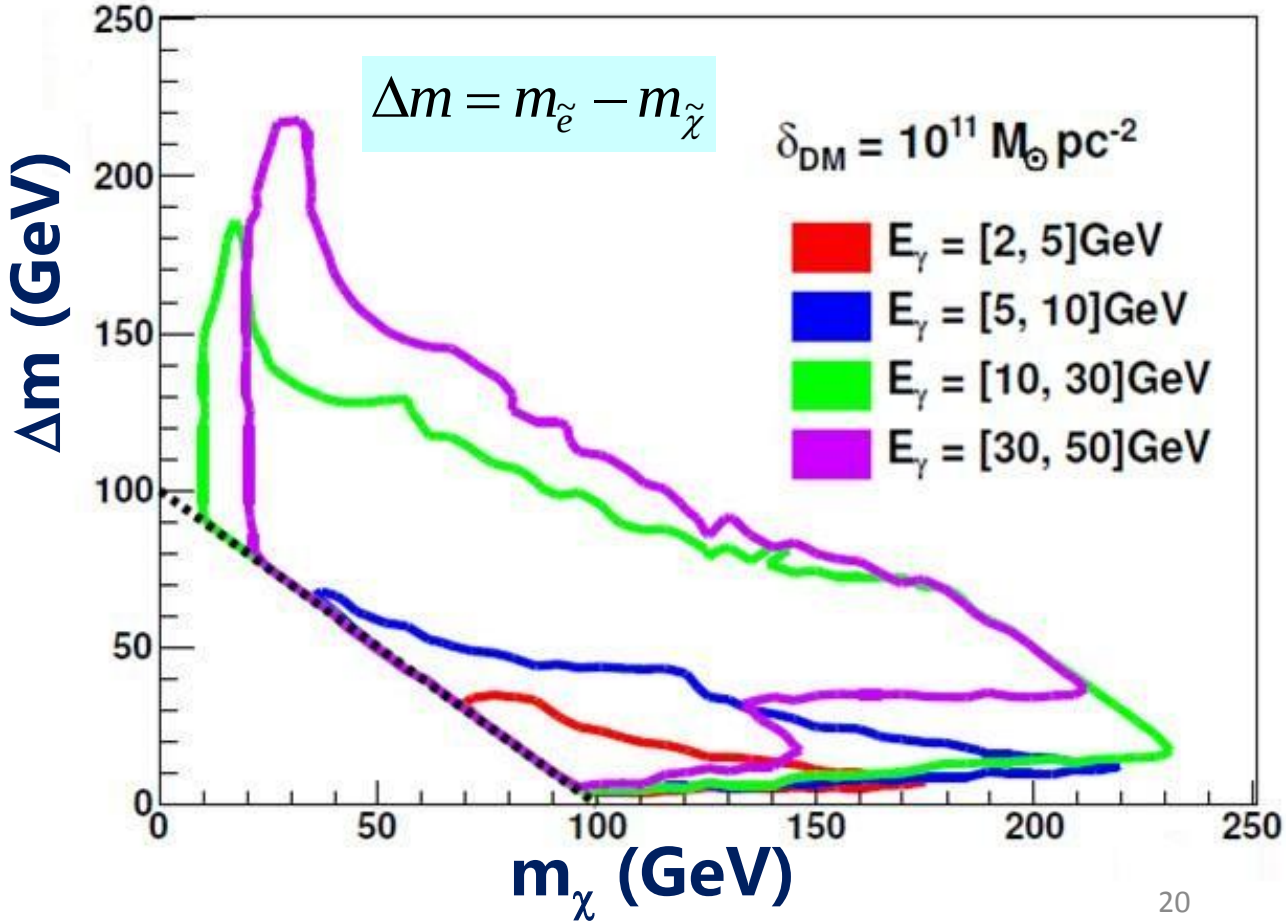
Counting Approach:

$$S/\sigma \geq 2 \qquad S = \int \nu S_\nu dE_\gamma \qquad \sigma \sim 2.5\times10^{-12} erg\, s^{-1} cm^{-2}$$

Excluded Region:
inside contours

Different colors:
different photon energy range

Black dotted line:
LEP II null searches (PDG)



Conclusion

- AGN can be an interesting object to probe TeV new physics
  - Understand some dark matter features
  - Test various theoretical models
- There are still large uncertainties about AGN
  - need better understanding of AGN
  - worth much more further investigations.


THANKS!