

Title: Cosmic Rays Through the Higgs Portal

Date: Jun 05, 2008 03:00 PM

URL: <http://pirsa.org/08060152>

Abstract: An electroweak singlet coupling through the Higgs portal has a natural mass scale $m_S \sim m_h$. In this mass range its annihilation cross section is dominated by proximity to the W , Z and Higgs peaks. Analysis of the γ ray signal from electroweak singlet annihilation in the mass range $80 \text{ GeV} < m_S < 1 \text{ TeV}$ indicates that it can reach the per mil level of the EGRET diffuse γ ray flux, providing a potential new test of dark matter.

Electroweak Singlets

$$\mathcal{L} = -\frac{1}{2}\partial_\mu S\partial^\mu S - \frac{1}{2}m_S^2 S^2 - D_\mu H^\dagger D^\mu H - \frac{\eta}{2}S^2 H^\dagger H - \frac{\lambda}{4}\left(H^\dagger H - \frac{v_h^2}{2}\right)^2$$



Flux from the Galactic Halo

Majorana counting factor

number density

$$j = \int d^3 \vec{r} \frac{\nu n^2(\vec{r})}{4\pi |\vec{r}_{\odot} - \vec{r}|^2} \times \frac{d\mathcal{N}(E, 2m_S)}{dE} \frac{\sigma v}{4\pi \text{sr}}$$

$\frac{d\mathcal{N}(E, E_{in})}{dE} = \frac{1}{\sigma} \frac{d\sigma}{dE}$ fragmentation function

$\sigma v \rightarrow$ annihilation cross-section times relative speed

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annihilation cross-section times relative speed

$$= \left(\frac{\text{TeV}}{m_S} \right)^2 \times \frac{d\mathcal{N}(E, 2m_S)}{dE} \frac{\sigma v}{\text{cm}^5 \text{sr}}$$

Flux from the Galactic Halo

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σv annihilation cross-section times relative speed

$$= \left(\frac{\text{TeV}}{m_S} \right)^2 \times \frac{d\mathcal{N}(E, 2m_S)}{dE} \frac{\sigma v}{\text{cm}^5 \text{sr}} \begin{cases} \times 1.20 \times 10^{14} & \text{isothermal core} \\ \times 1.95 \times 10^{14} & \text{NFW profile} \end{cases}$$

Flux from the Galactic Halo

Majorana counting factor

number density

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$$= \left(\frac{\text{TeV}}{m_S}\right)^2 \times \frac{d\mathcal{N}(E, 2m_S)}{dE} \frac{\sigma v}{\text{cm}^5 \text{ sr}}$$

isothermal core

$\left\{ \begin{array}{l} \times 1.20 \times 10^{14} \\ \times 1.95 \times 10^{14} \end{array} \right.$

NFW profile



$$\frac{d\mathcal{N}_\gamma(x)}{dx} = \frac{0.42 \exp(-8x)}{x^{1.5} + 0.00014}$$

photon fragmentation

Model-independent Bounds

Unitarity  $\sigma k^2 \leq 4\pi$

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EGRET
Diffuse photon
background $\dot{j}_{\gamma,E} = \frac{8.68 \times 10^{-11}}{\text{GeV cm}^2 \text{ s sr}} \left(\frac{100 \text{ GeV}}{E} \right)^{2.10}$

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$\Rightarrow \frac{\dot{j}_{\gamma}}{\dot{j}_{\gamma,E}} = 2.83 \times 10^{23} x^{2.1} \frac{d\mathcal{N}_{\gamma}(x)}{dx} \left(\frac{\text{TeV}}{m_S} \right)^{0.9} \frac{\sigma v}{\text{cm}^3 \text{ s}^{-1}}$ $x = E/m_S$

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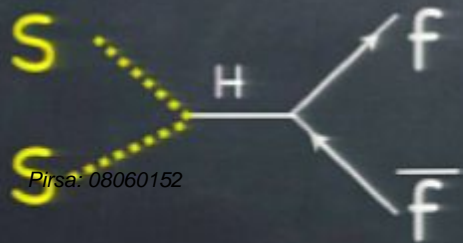
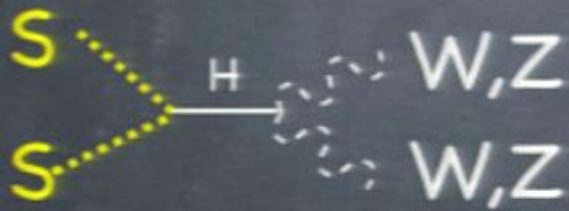
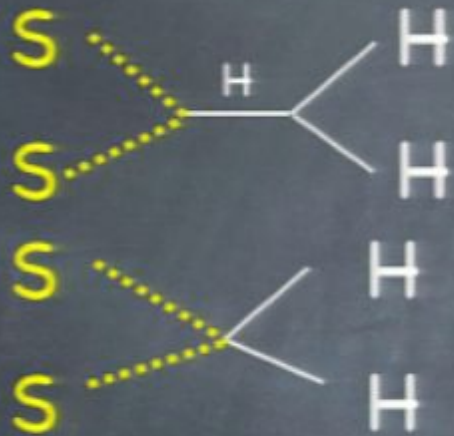
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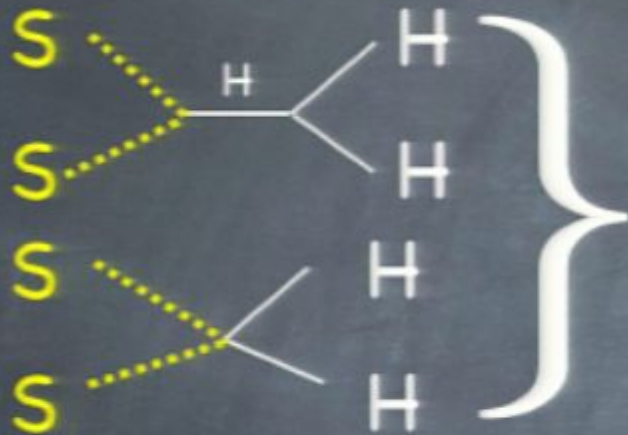
max of 0.05

$\sigma v < 10^{-23} \frac{\text{cm}^3}{\text{s}} \times \left(\frac{m_S}{100 \text{ GeV}} \right)^{0.9}$

Cross-Sections

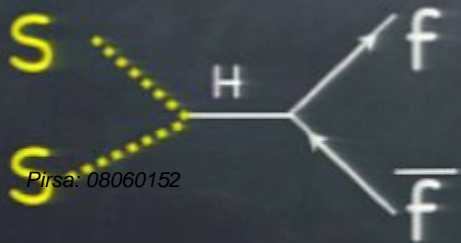
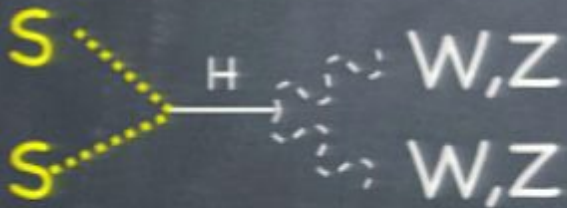


Cross-Sections

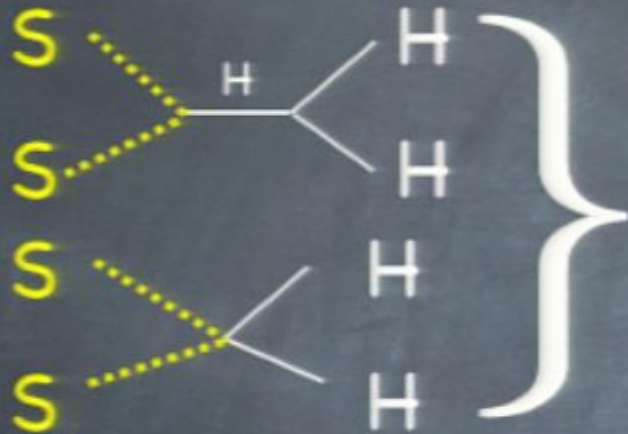


A Feynman diagram showing two incoming scalar particles (S) on the left, represented by yellow dotted lines. They meet at a vertex labeled 'H'. From this vertex, two outgoing Higgs bosons (H) emerge as solid lines. A large white curly bracket on the right groups the diagram and is associated with the cross-section equation.

$$v\sigma_{SS\rightarrow hh} = \eta^2 \frac{\sqrt{m_S^2 - m_h^2}}{16\pi m_S^3} \times \frac{(2m_S^2 + m_h^2)^2}{(4m_S^2 - m_h^2)^2 + m_h^2 \Gamma_h^2}$$

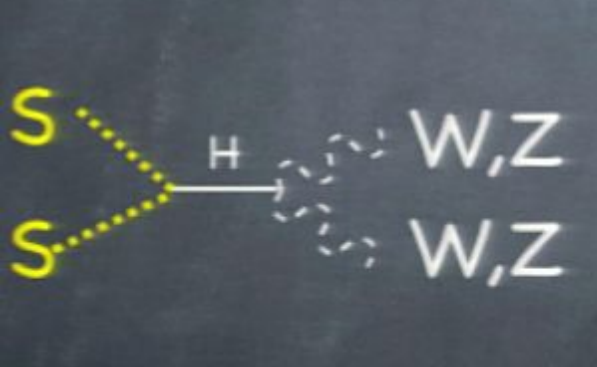


Cross-Sections



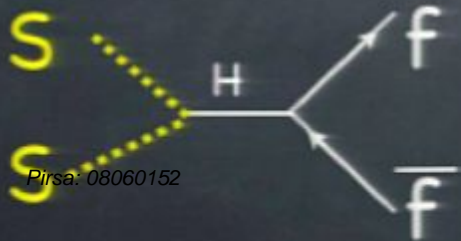
A Feynman diagram showing two incoming scalar particles (S) represented by dotted lines. They meet at a vertex labeled 'H'. From this vertex, two solid lines branch out, each ending at a vertex labeled 'H'. From each of these two vertices, a solid line branches out to a final state labeled 'H'. A large curly brace on the right side of the diagram groups the entire process.

$$v\sigma_{SS \rightarrow hh} = \eta^2 \frac{\sqrt{m_S^2 - m_h^2}}{16\pi m_S^3} \times \frac{(2m_S^2 + m_h^2)^2}{(4m_S^2 - m_h^2)^2 + m_h^2 \Gamma_h^2}$$

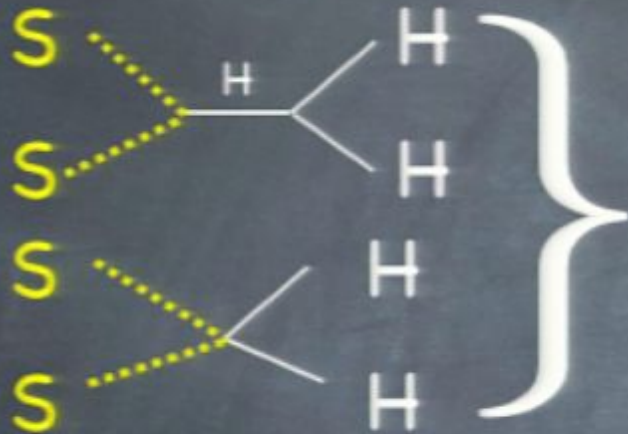


A Feynman diagram showing two incoming scalar particles (S) represented by dotted lines. They meet at a vertex labeled 'H'. From this vertex, a dashed line branches out to a final state labeled 'W,Z'. From the 'H' vertex, another solid line branches out to a vertex labeled 'H'. From this second vertex, a dashed line branches out to another final state labeled 'W,Z'. A large curly brace on the right side of the diagram groups the entire process.

$$v\sigma_{SS \rightarrow W/Z W/Z} = \eta^2 \frac{\sqrt{m_S^2 - m_{W/Z}^2}}{4\pi m_S^3} \times \frac{3m_{W/Z}^4 - 4m_{W/Z}^2 m_S^2 + 4m_S^4}{(4m_S^2 - m_h^2)^2 + m_h^2 \Gamma_h^2}$$

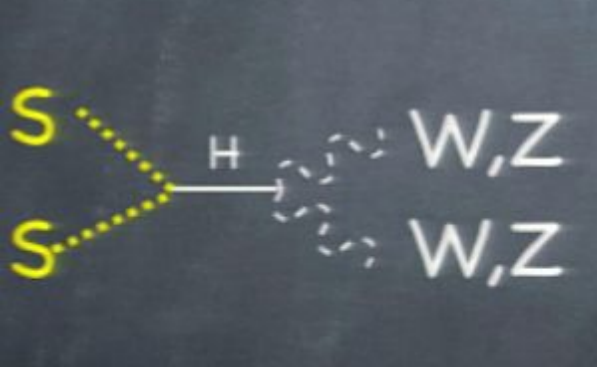


Cross-Sections



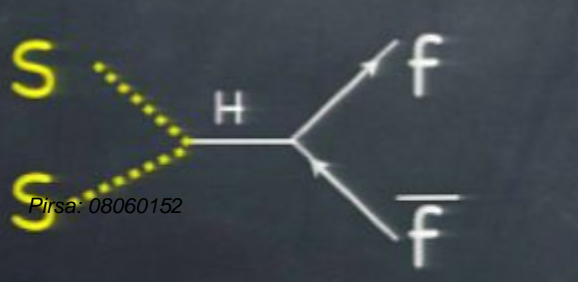
A Feynman diagram showing two incoming scalar particles (S) interacting via a Higgs boson (H) to produce two Higgs bosons (h). The incoming S lines are represented by dotted lines, and the Higgs boson is a solid line. The outgoing h lines are also solid lines.

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A Feynman diagram showing two incoming scalar particles (S) interacting via a Higgs boson (H) to produce two W/Z bosons. The incoming S lines are dotted, the Higgs boson is a solid line, and the outgoing W/Z bosons are represented by dashed lines.

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A Feynman diagram showing two incoming scalar particles (S) interacting via a Higgs boson (H) to produce a fermion (f) and an anti-fermion (f-bar). The incoming S lines are dotted, the Higgs boson is a solid line, and the outgoing fermion and anti-fermion are solid lines.

$$v\sigma_{SS \rightarrow f\bar{f}} = \eta^2 \frac{N_c m_f^2}{4\pi m_S^3} \times \frac{\sqrt{m_S^2 - m_f^2}^3}{(4m_S^2 - m_h^2)^2 + m_h^2 \Gamma_h^2}$$

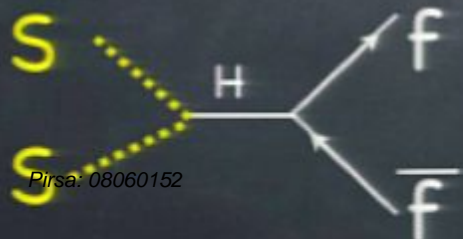
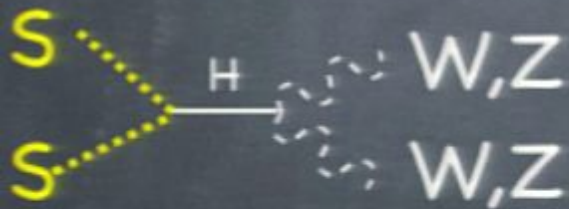
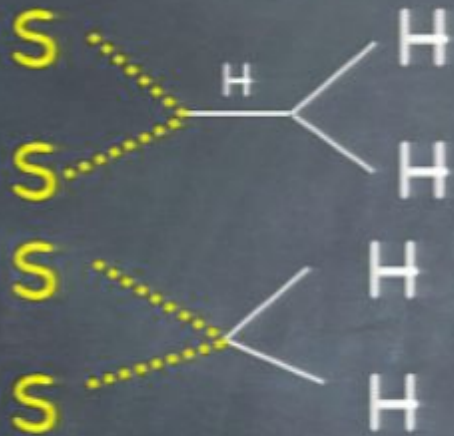
Annihilation Signals

$$m_S > 1\text{TeV}$$

$$v\sigma_{SS} \simeq \frac{7\eta^2}{64\pi m_S^2} = 4.06\eta^2 \times 10^{-25} \left(\frac{\text{TeV}}{m_S}\right)^2 \frac{\text{cm}^3}{\text{s}}$$

Normalize
to EGRET  $\frac{j_\gamma}{j_{\gamma,E}} \simeq 5.6\eta^2 \times 10^{-3}$

Cross-Sections



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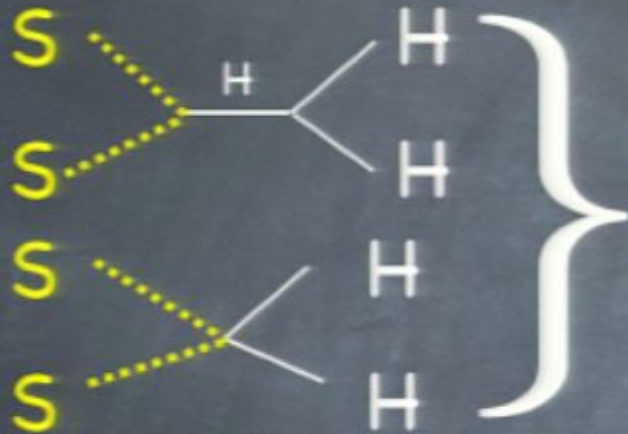


Diagram showing two incoming scalar particles (S) interacting via a Higgs boson (H) to produce two Higgs bosons (h). The diagram consists of two incoming S lines (dotted) meeting at a vertex labeled H, which then splits into two outgoing h lines (solid).

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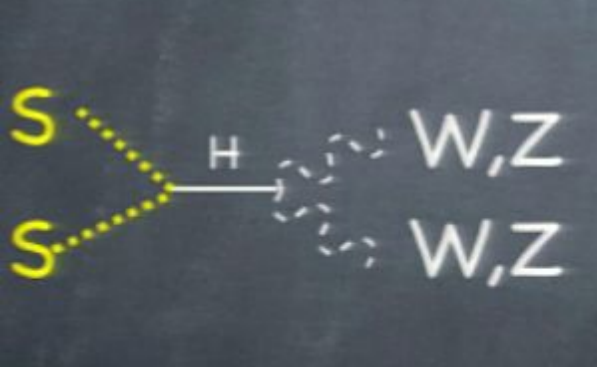


Diagram showing two incoming scalar particles (S) interacting via a Higgs boson (H) to produce two W/Z bosons. The diagram consists of two incoming S lines (dotted) meeting at a vertex labeled H, which then splits into two outgoing W/Z lines (dashed).

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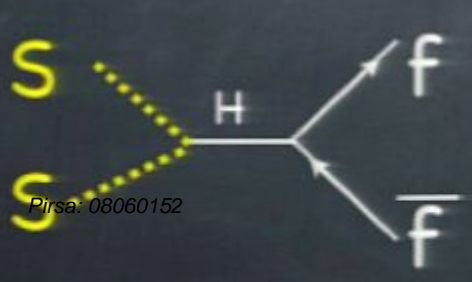
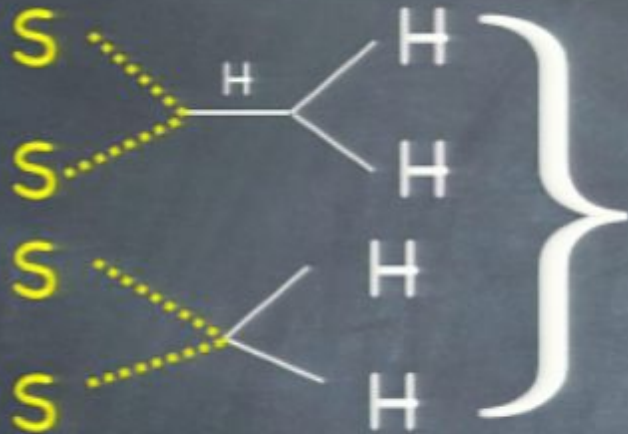


Diagram showing two incoming scalar particles (S) interacting via a Higgs boson (H) to produce a fermion-antifermion pair (f f-bar). The diagram consists of two incoming S lines (dotted) meeting at a vertex labeled H, which then splits into two outgoing fermion lines (solid).

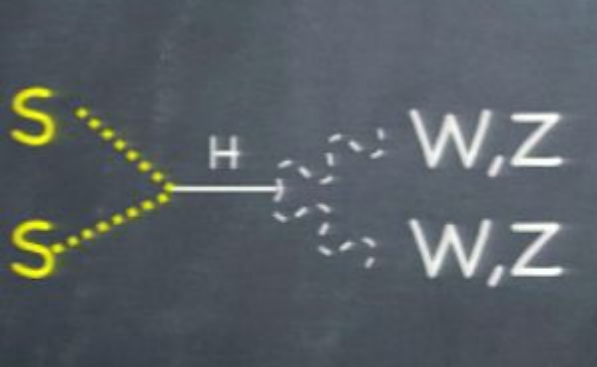
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Cross-Sections



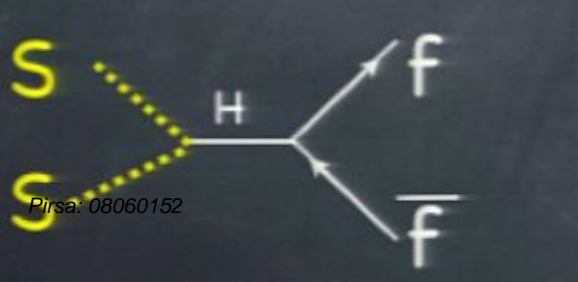
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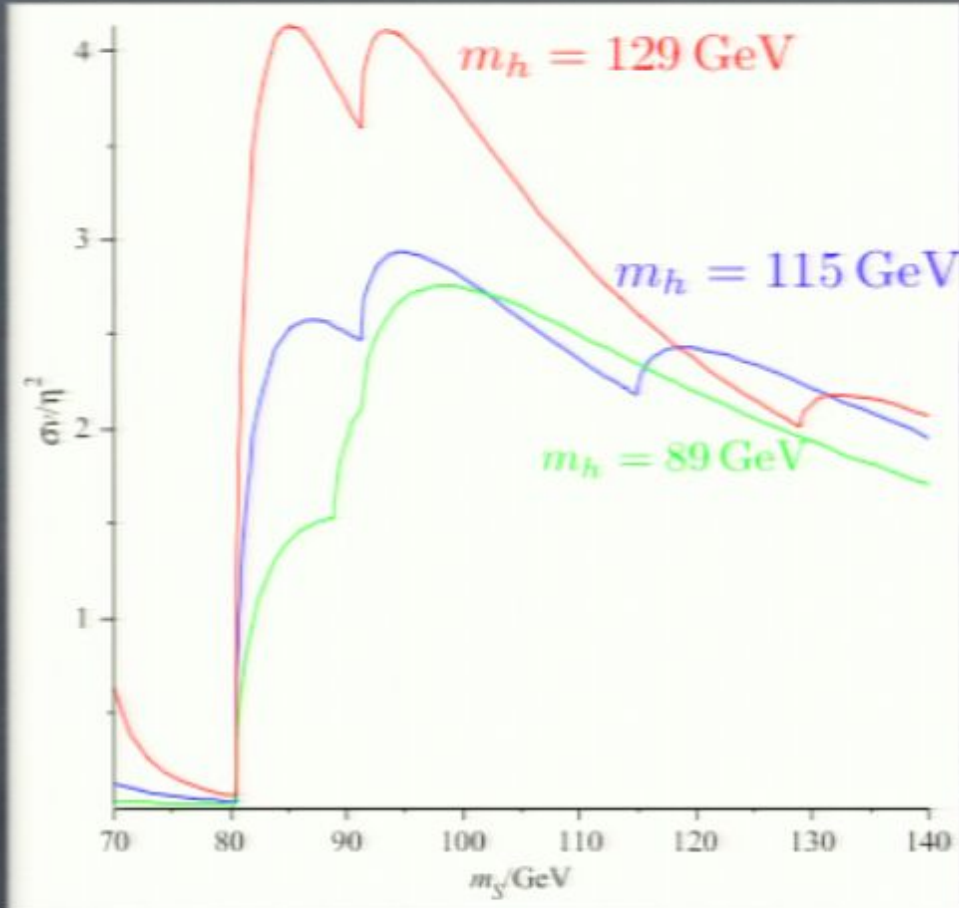
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$80\text{ GeV} < m_S < 1\text{ TeV}$

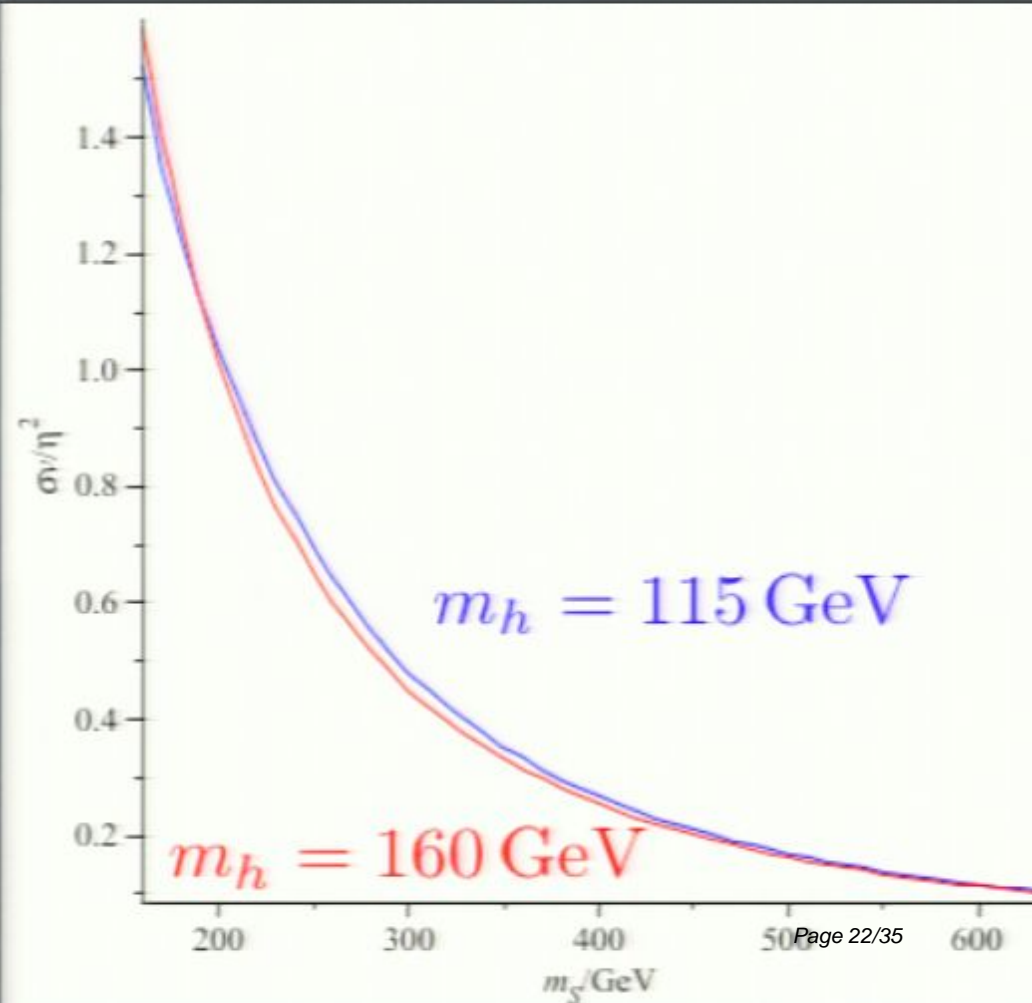
 Enhancement of Signal due to
a) W,Z channels
b) Proximity to Higgs mass

$80 \text{ GeV} < m_S < 1 \text{ TeV}$

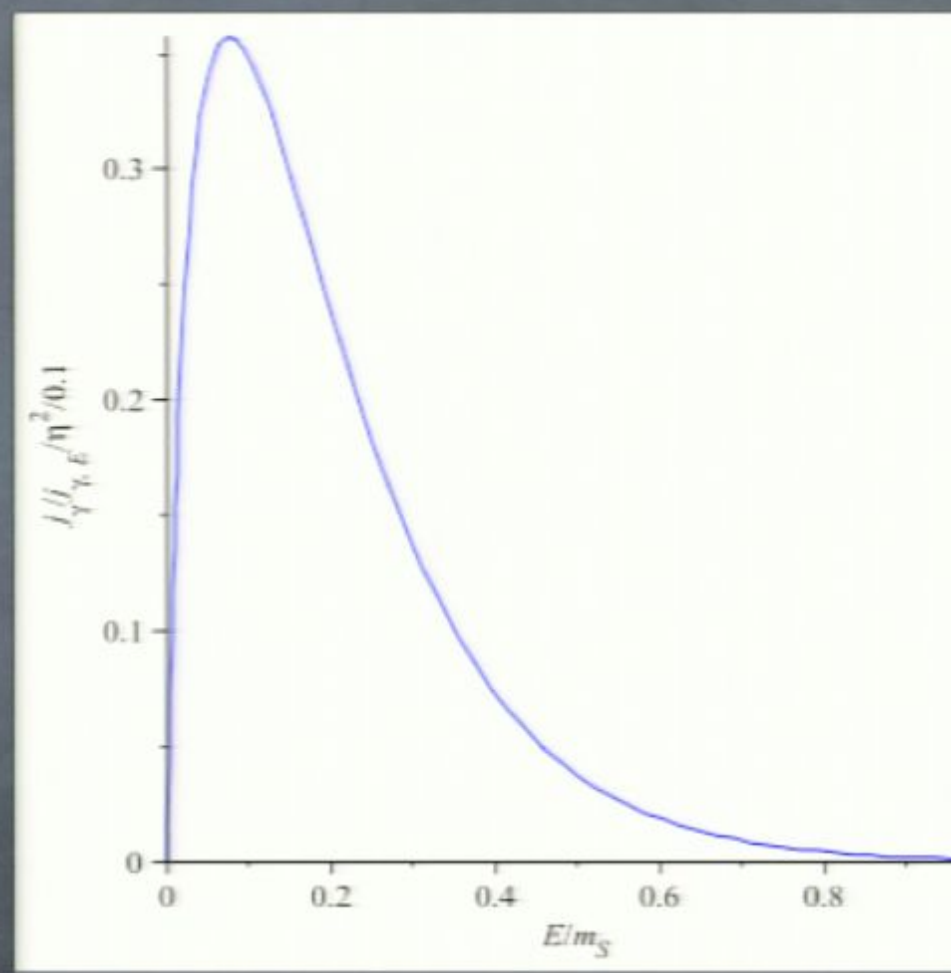
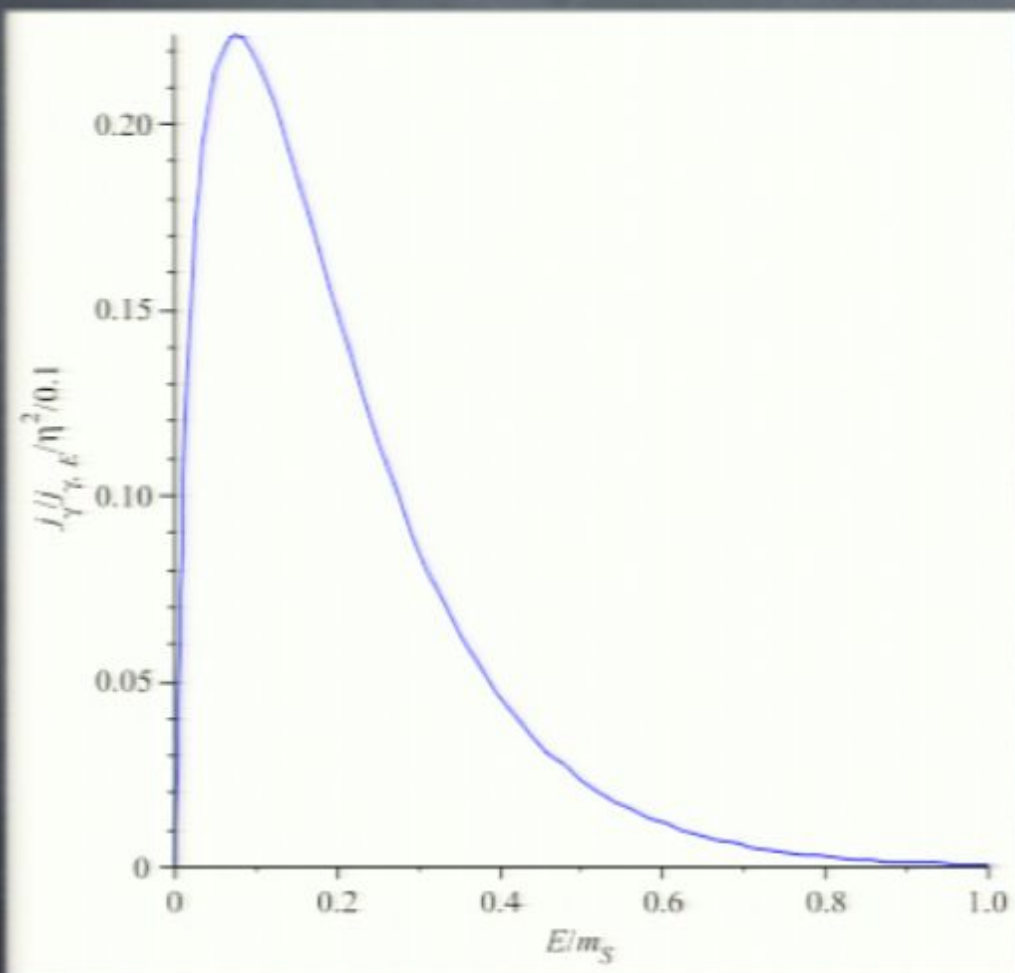


Small m_S

Large m_S



Photon Flux in units of EGRET Flux



$m_S = 120 \text{ GeV}, m_h = 115 \text{ GeV}$

$m_S = 120 \text{ GeV}, m_h = 160 \text{ GeV}$

Thermal Creation

$$\frac{d}{dt}(na^3) = \dot{N}_{thermal} - \langle \sigma v \rangle n^2 a^3$$

Lee/Weinberg

Thermal Creation

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Lee/Weinberg

Assume equilibrium ($\frac{d}{dt}(na^3) = 0$)

until freeze-out $\Rightarrow \left. \frac{d}{dT} \frac{n_0(T)}{T^3} \right|_{T=T_f} = 2b \langle \sigma v \rangle \frac{n_0^2(T_f)}{T_f^6}$

$$t = \frac{b}{T^2}$$

Thermal Creation

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Lee/Weinberg

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$$\xi = m_S c^2 / k_B T_f$$

$$\Rightarrow \exp(\xi) = 4.182 \times 10^{11} \frac{\langle\sigma v\rangle}{10^{-24} \text{ cm}^3/\text{s}} \frac{m_S}{100 \text{ GeV}} \frac{\sqrt{\xi}}{\xi - 1.5}$$

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S mass is large ($>800 \text{ GeV}$) if there is only one species

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Consider N species

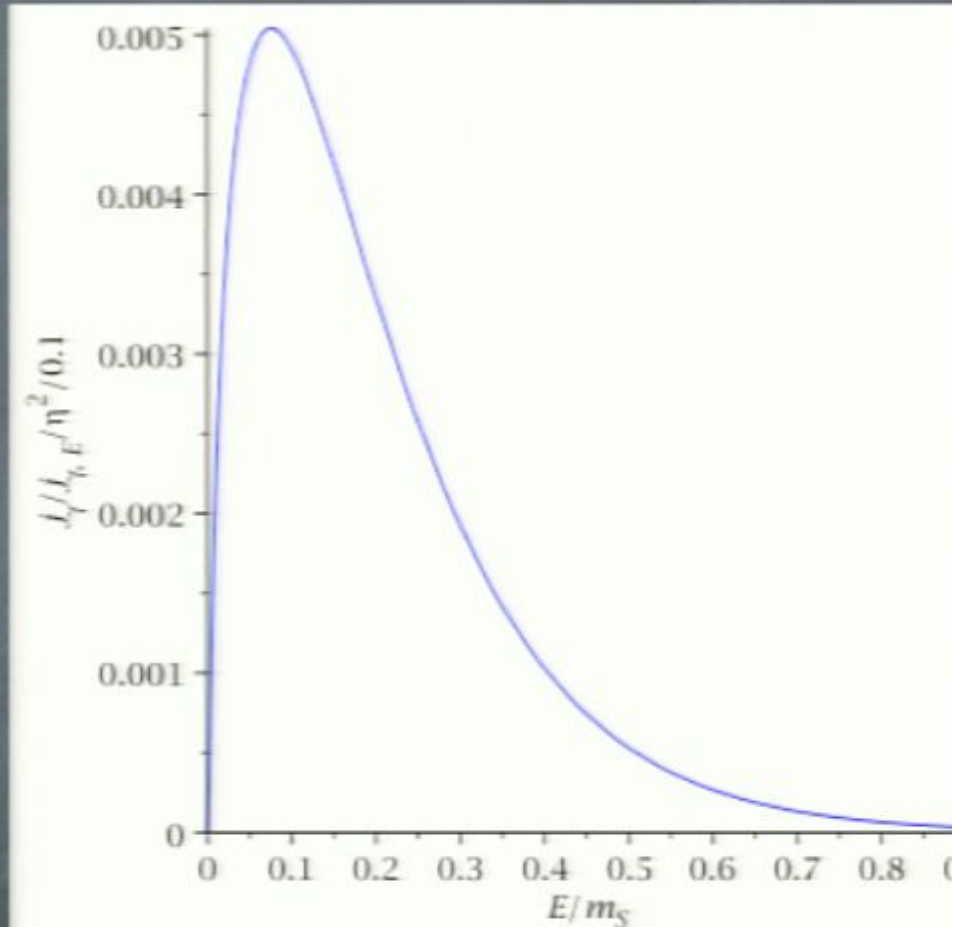
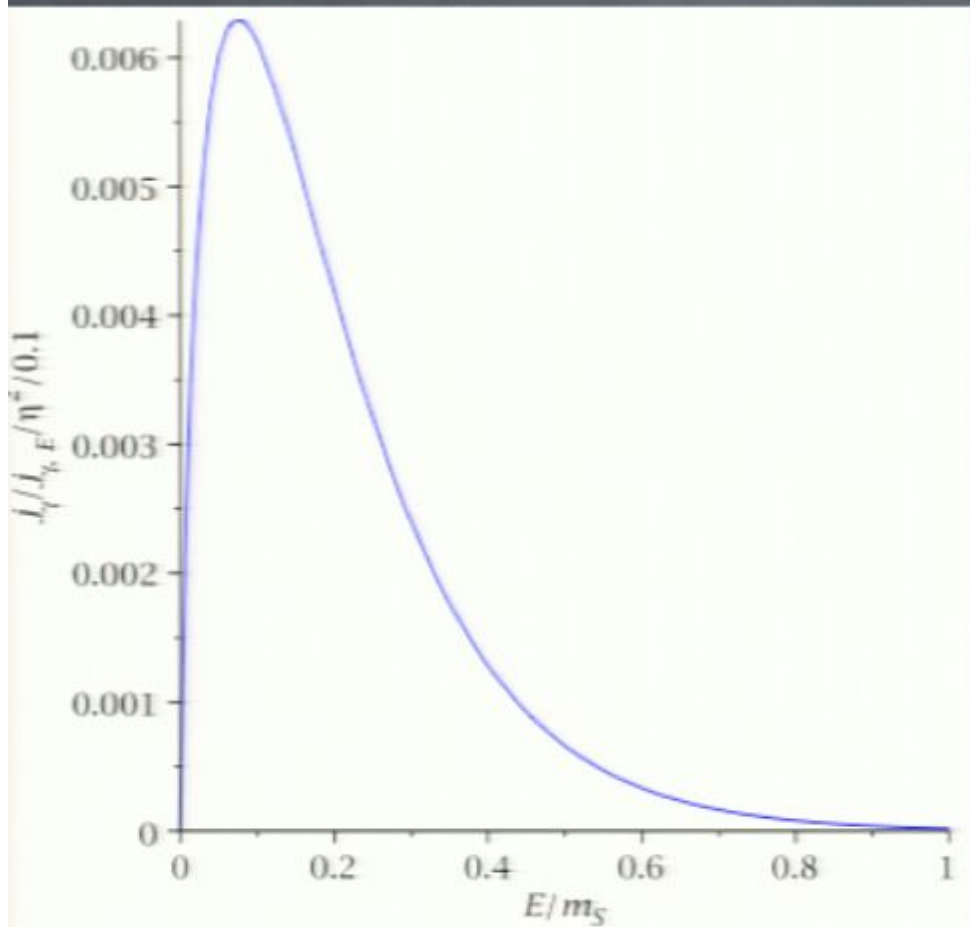
Freeze-out Criteria

$$\rho_S \simeq \frac{2\xi - 3}{2\xi - 1} \xi \times \frac{N \times 2.51 \text{ eV/cm}^3}{\langle \sigma v \rangle / 10^{-24} \text{ cm}^3/\text{s}}$$

$$\exp(\xi) = 4.182 \times 10^{11} \frac{\langle \sigma v \rangle}{10^{-24} \text{ cm}^3/\text{s}} \frac{m_S}{100 \text{ GeV}} \frac{\sqrt{\xi}}{\xi - 1.5}$$

	$m_h = 115 \text{ GeV}$	$m_h = 160 \text{ GeV}$
$N = 1$	$m_S = 881 \text{ GeV}$ $x_\sigma = 0.0531$	$m_S = 885 \text{ GeV}$ $x_\sigma = 0.0531$
$N = 24$	$m_S = 170 \text{ GeV}$ $x_\sigma = 1.36$	$m_S = 188 \text{ GeV}$ $x_\sigma = 1.37$
$N = 45$	$m_S = 105 \text{ GeV}$ $x_\sigma = 2.57$	$m_S = 135 \text{ GeV}$ $x_\sigma = 2.59$
$N = 78$	n/a	$m_S = 115 \text{ GeV}$ $x_\sigma = 4.56$

Photon Flux in units of EGRET Flux



$$m_h = 115 \text{ GeV}$$

$$m_S = 105 \text{ GeV}$$

$$N = 45$$

$$m_h = 160 \text{ GeV}$$

$$m_S = 135 \text{ GeV}$$

$$N = 45$$

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