Particle Mass Measurements from Extreme Event Reconstruction and Focus Points

Prasanth Shyamsundar
University of Florida

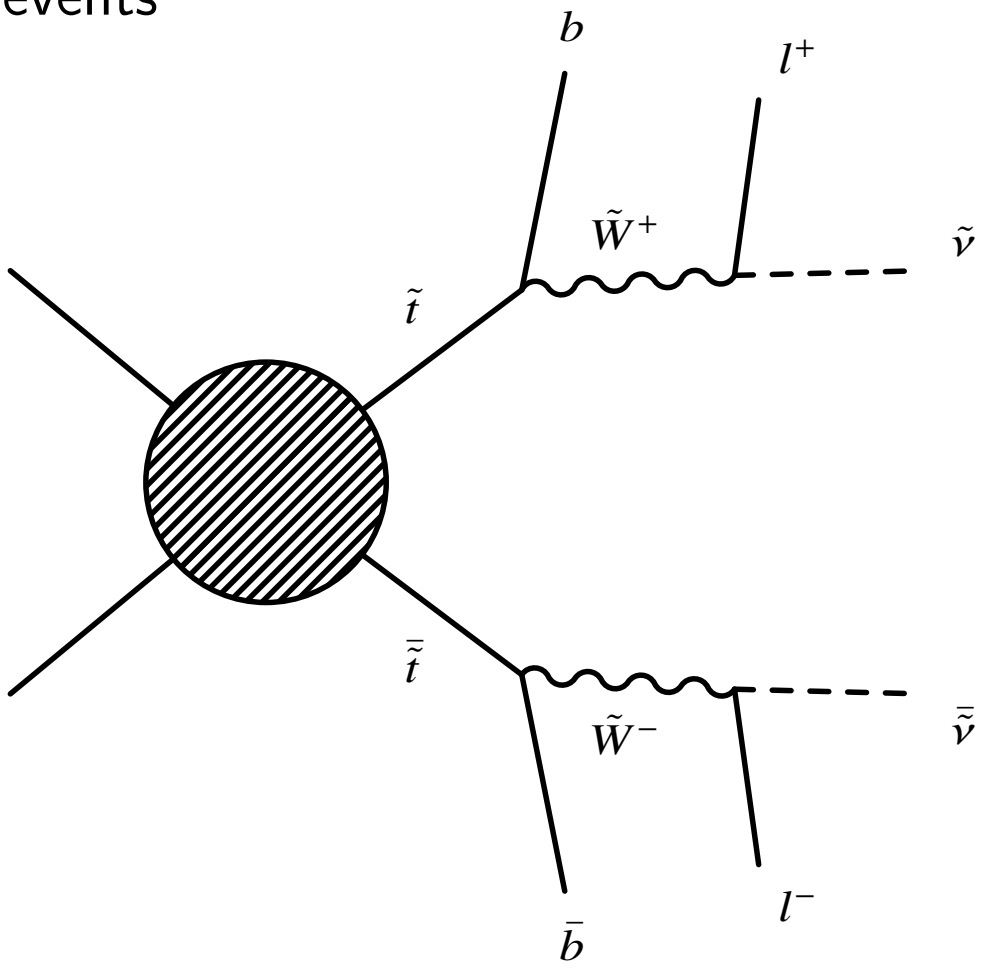
based on work with

Dr. Doojin Kim
Dr. Konstantin Matchev

9 May, 2017

The problem

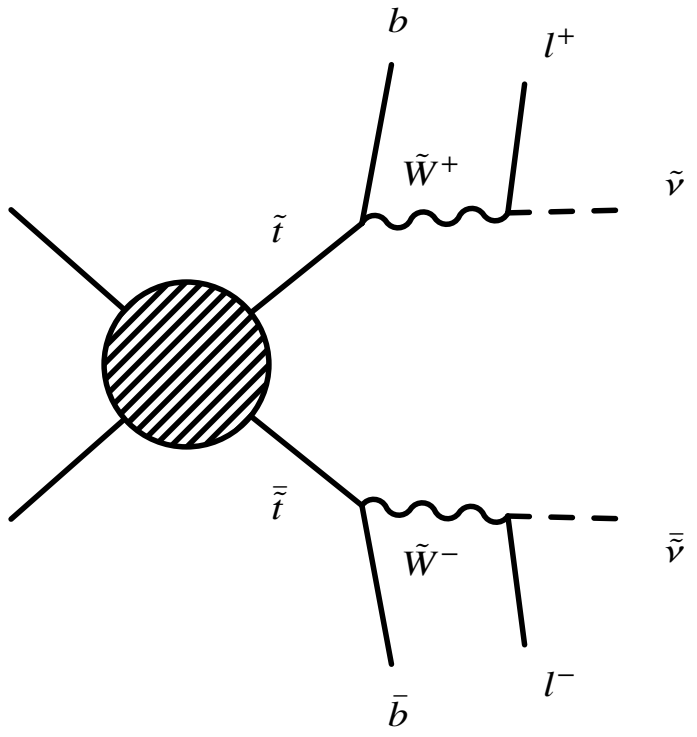
$t - \bar{t}$ like BSM events



Goal: To find $m_{\tilde{t}}$, $m_{\tilde{W}}$, and $m_{\tilde{\nu}}$

Subgoal: To find $m_{\tilde{t}}$ and $m_{\tilde{W}}$, given $m_{\tilde{\nu}}$

The problem

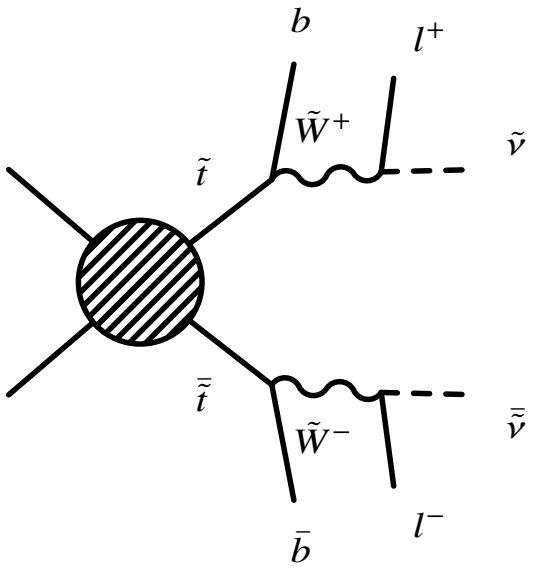


The following analyses were performed on on-shell events at LHC energy with the following mass spectrum

$$m_{\tilde{t}} = 1000 \text{ GeV}, \, m_{\tilde{W}} = 800 \text{ GeV}, \, m_{\tilde{\nu}} = 700 \text{ GeV}$$

This will be referred to as the *true* mass spectrum.

Solvability



Particles in the two branches have the same masses

$$p_\nu^2 = p_{\bar{\nu}}^2$$
$$(p_\nu + p_{l^+})^2 = (p_{\bar{\nu}} + p_{l^-})^2$$
$$(p_\nu + p_{l^+} + p_b)^2 = (p_{\bar{\nu}} + p_{l^-} + p_{\bar{b}})^2$$

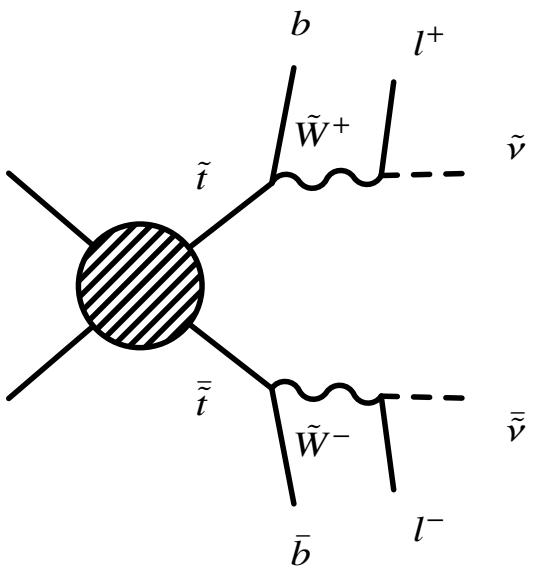
MET condition

$$\vec{p}_{\nu,T} + \vec{p}_{\bar{\nu},T} = \cancel{\vec{p}_T}$$

8 unknown momentum components, 5 constraints

Introduce test masses $\tilde{m}_{\tilde{t}}$, $\tilde{m}_{\tilde{W}}$, $\tilde{m}_{\tilde{\nu}}$

Solvability



Particles in the two branches have the same masses

$$p_{\nu}^2 = p_{\bar{\nu}}^2 = \tilde{m}_{\tilde{\nu}}^2$$

$$(p_{\nu} + p_{l^+})^2 = (p_{\bar{\nu}} + p_{l^-})^2 = \tilde{m}_{\tilde{W}}^2$$

$$(p_{\nu} + p_{l^+} + p_b)^2 = (p_{\bar{\nu}} + p_{l^-} + p_{\bar{b}})^2 = \tilde{m}_{\tilde{t}}^2$$

MET condition

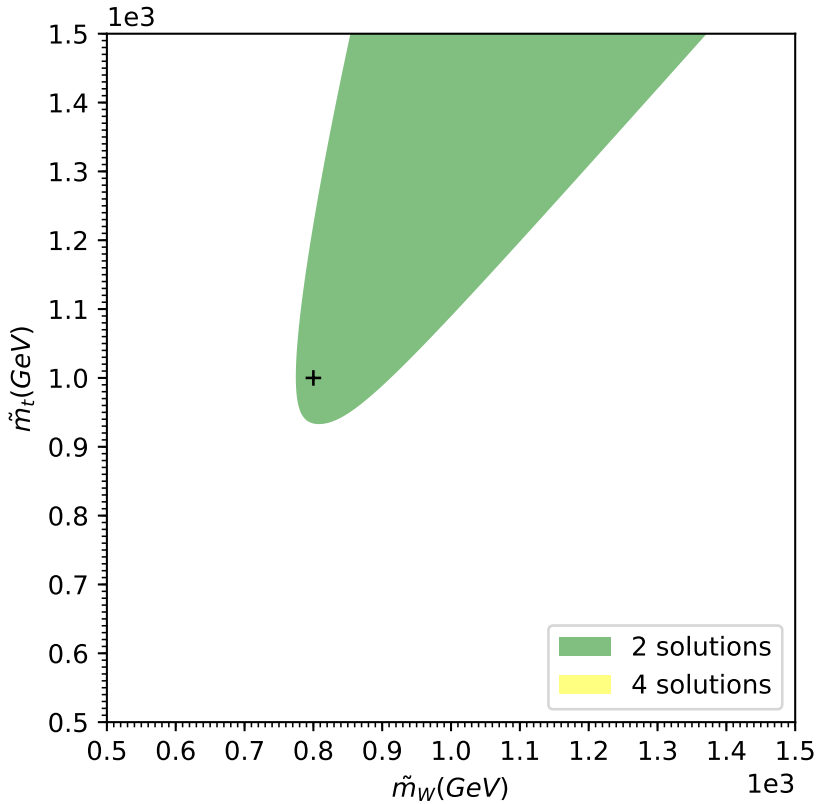
$$\vec{p}_{\nu,T} + \vec{p}_{\bar{\nu},T} = \cancel{\vec{p}_T}$$

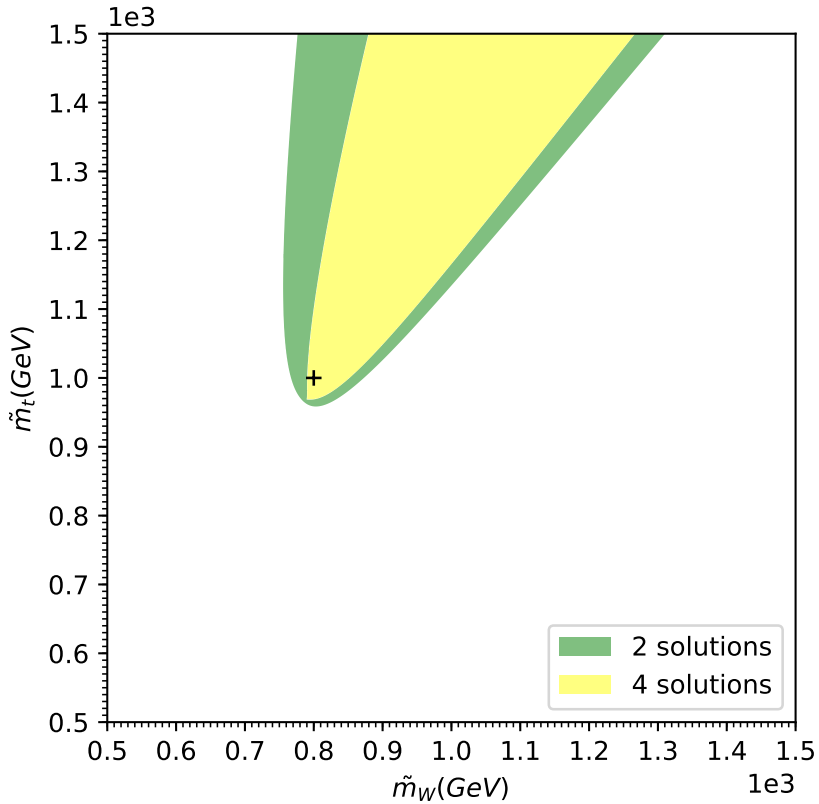
8 unknown momentum components, ~~5~~ 8 constraints

Introduce test masses $\tilde{m}_{\tilde{t}}$, $\tilde{m}_{\tilde{W}}$, $\tilde{m}_{\tilde{\nu}}$

Solvability

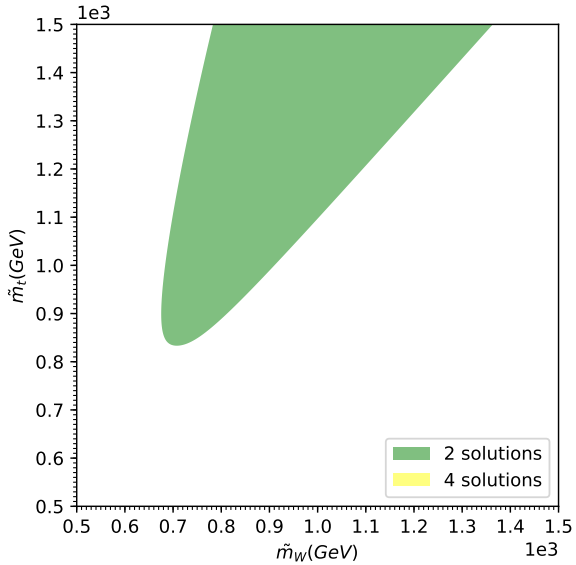
$$\tilde{m}_{\tilde{\nu}} = 700 \text{ GeV} = m_{\tilde{\nu}}$$



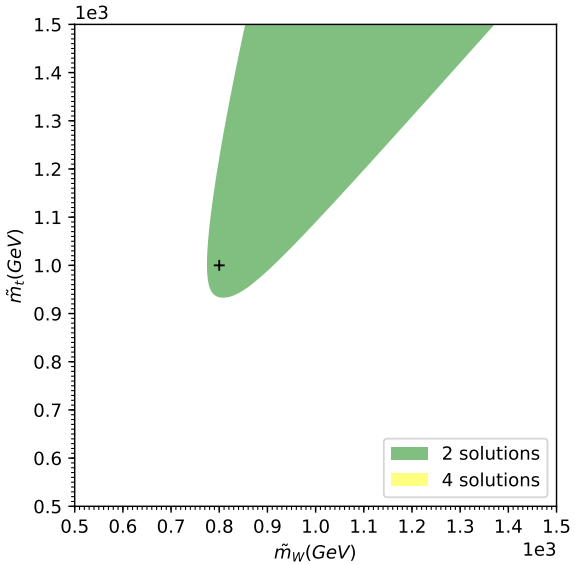


Solvability

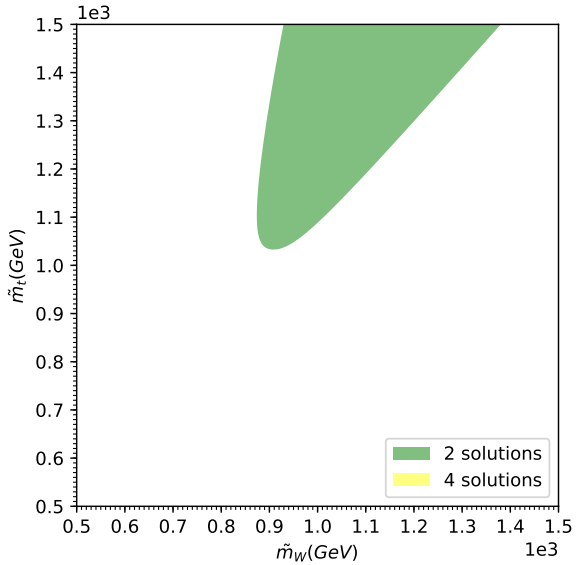
$\tilde{m}_{\tilde{\nu}} = 600$ GeV $< m_{\tilde{\nu}}$

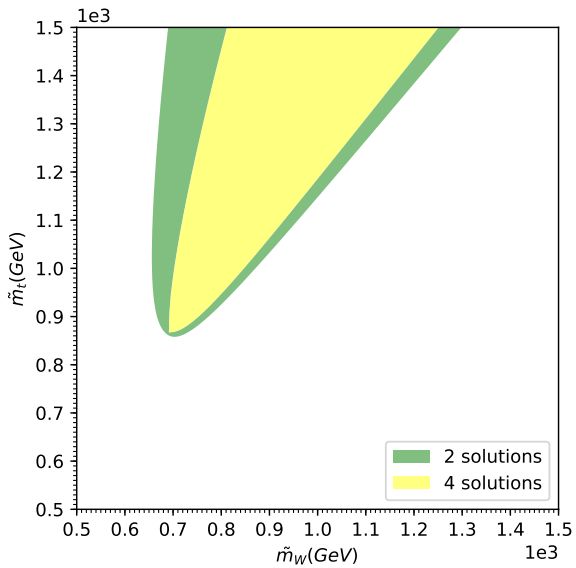


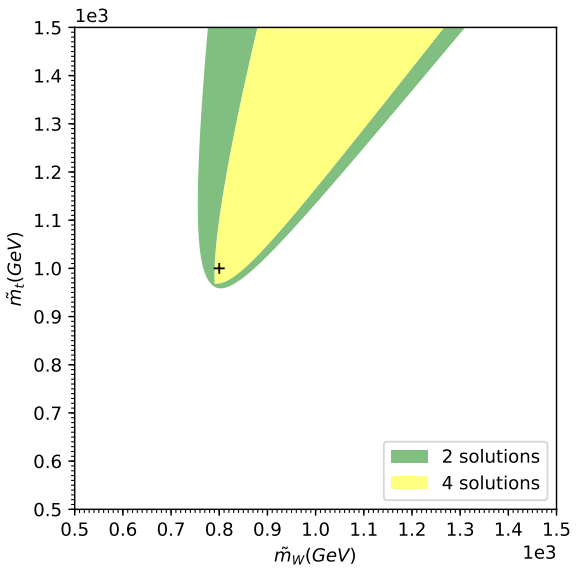
$\tilde{m}_{\tilde{\nu}} = 700$ GeV $= m_{\tilde{\nu}}$

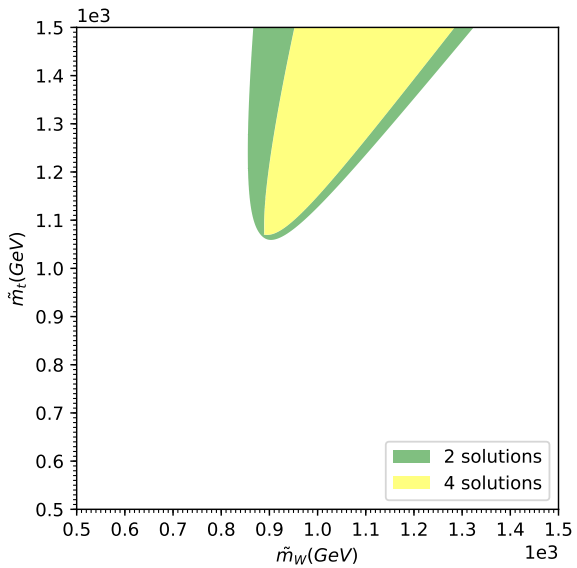


$\tilde{m}_{\tilde{\nu}} = 800$ GeV $> m_{\tilde{\nu}}$



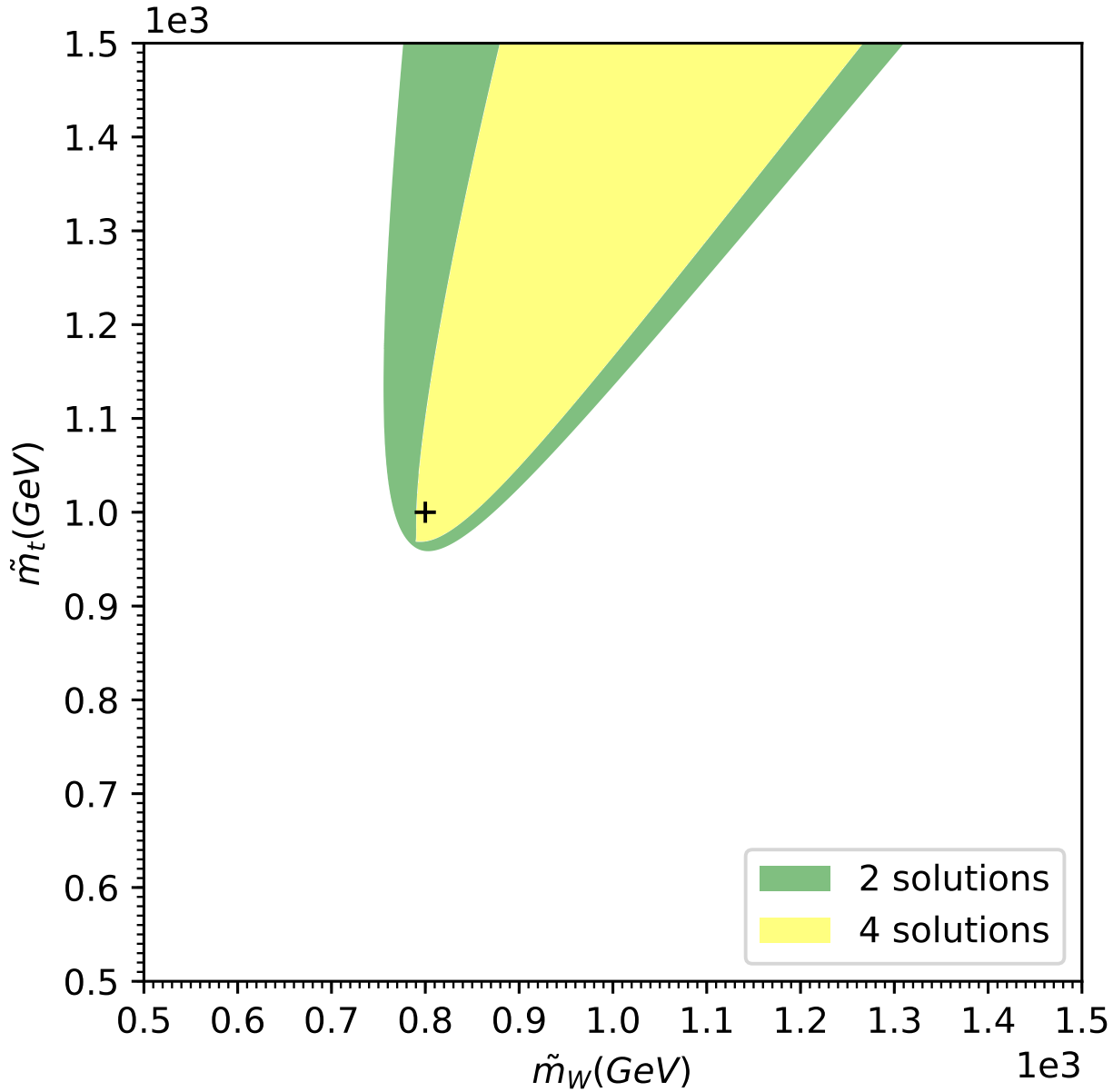






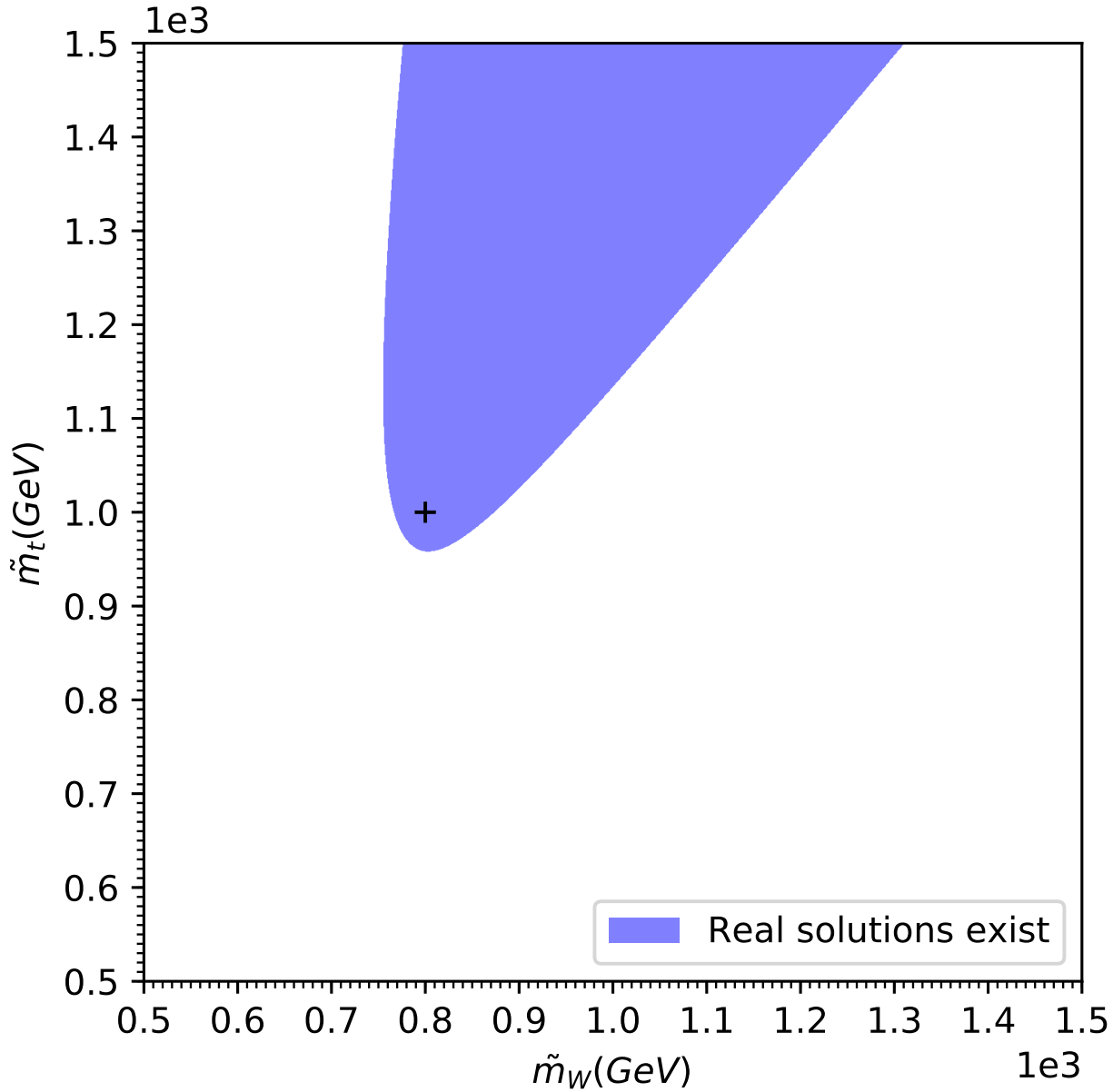
Solvability

$$\tilde{m}_{\tilde{\nu}} = 700 \text{ GeV} = m_{\tilde{\nu}}$$



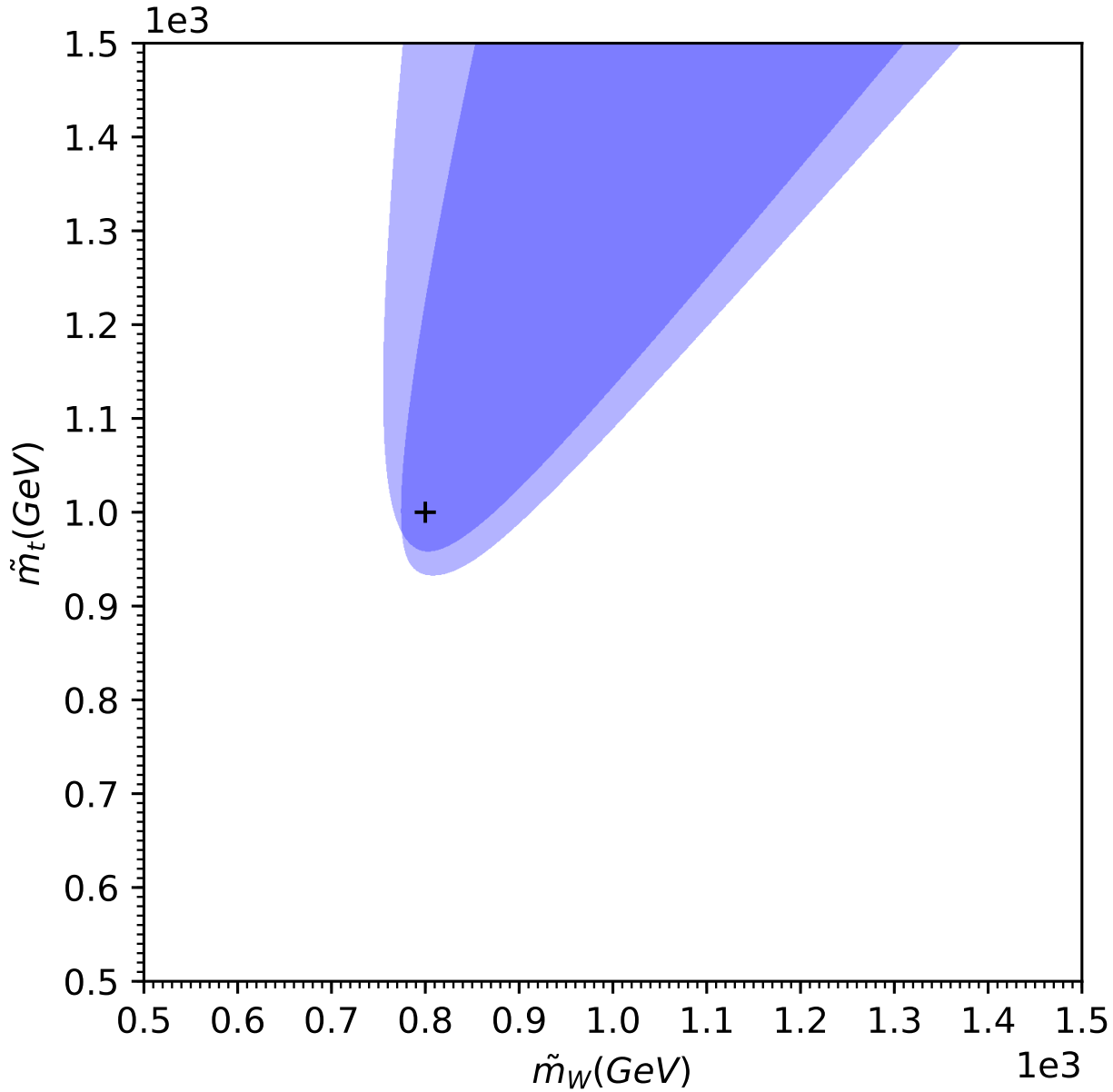
Solvability

$$\tilde{m}_{\tilde{\nu}} = 700 \text{ GeV} = m_{\tilde{\nu}}$$



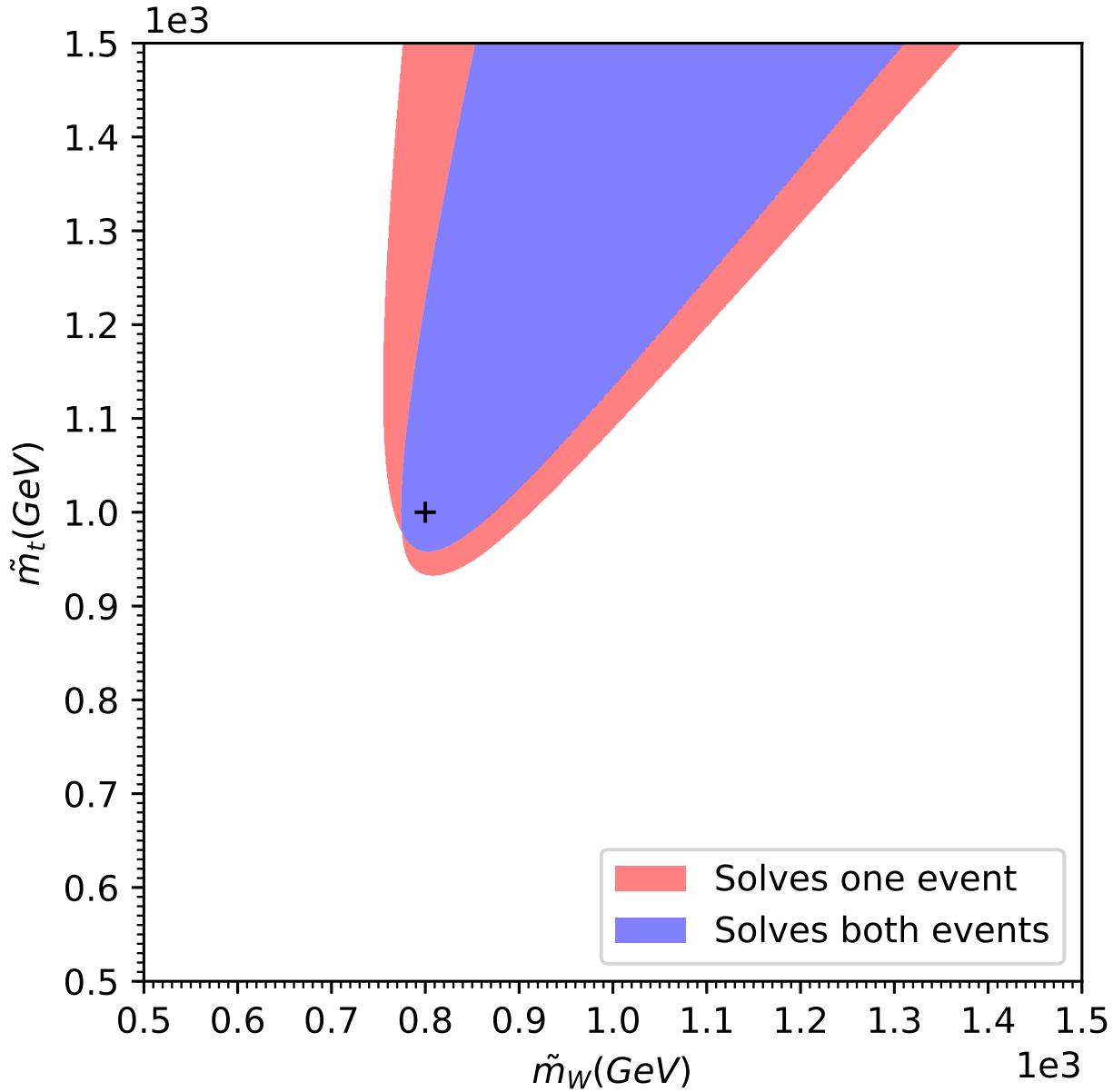
Solvability

$$\tilde{m}_{\tilde{\nu}} = 700 \text{ GeV} = m_{\tilde{\nu}}$$



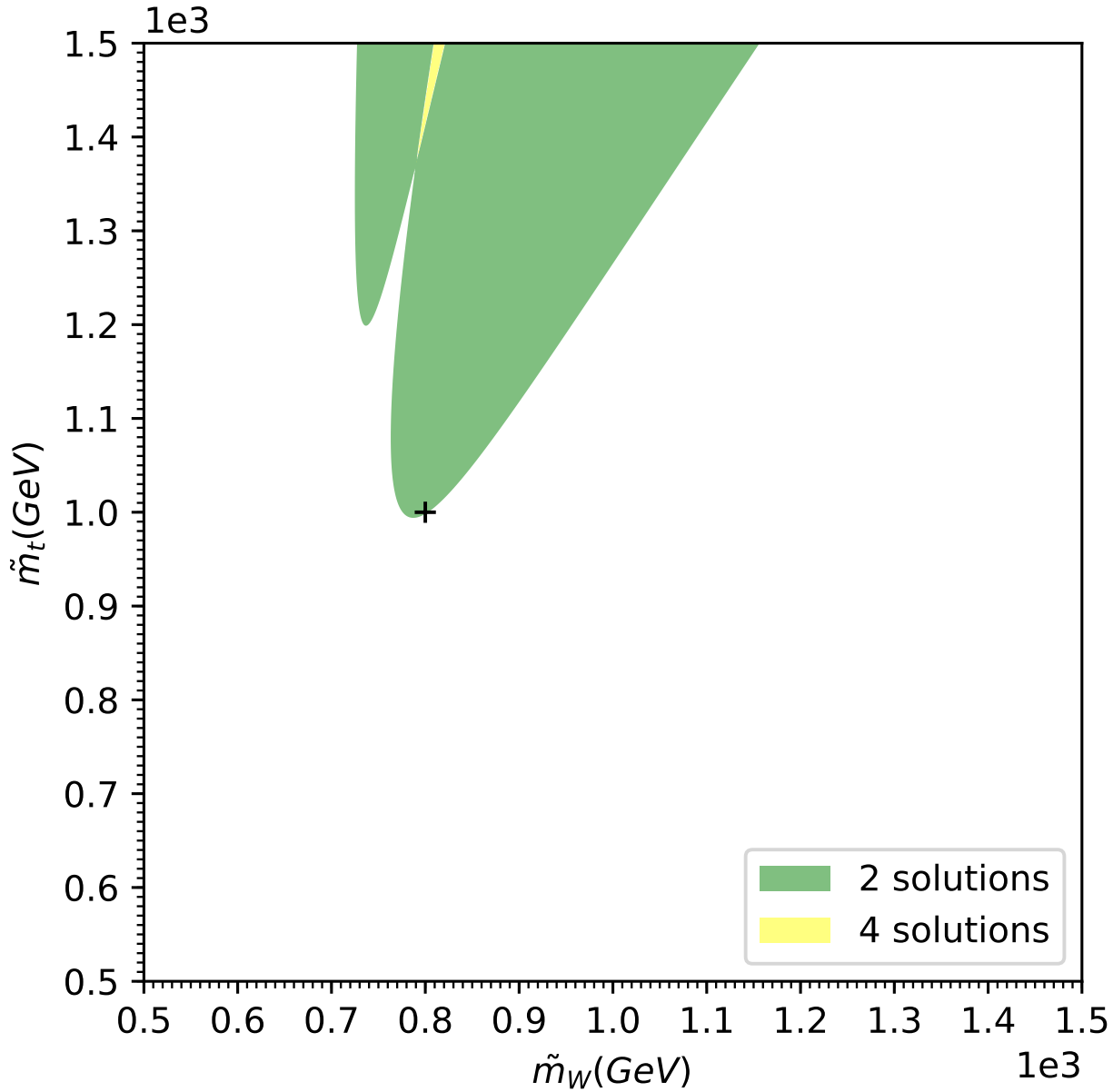
Solvability

$$\tilde{m}_{\tilde{\nu}} = 700 \text{ GeV} = m_{\tilde{\nu}}$$



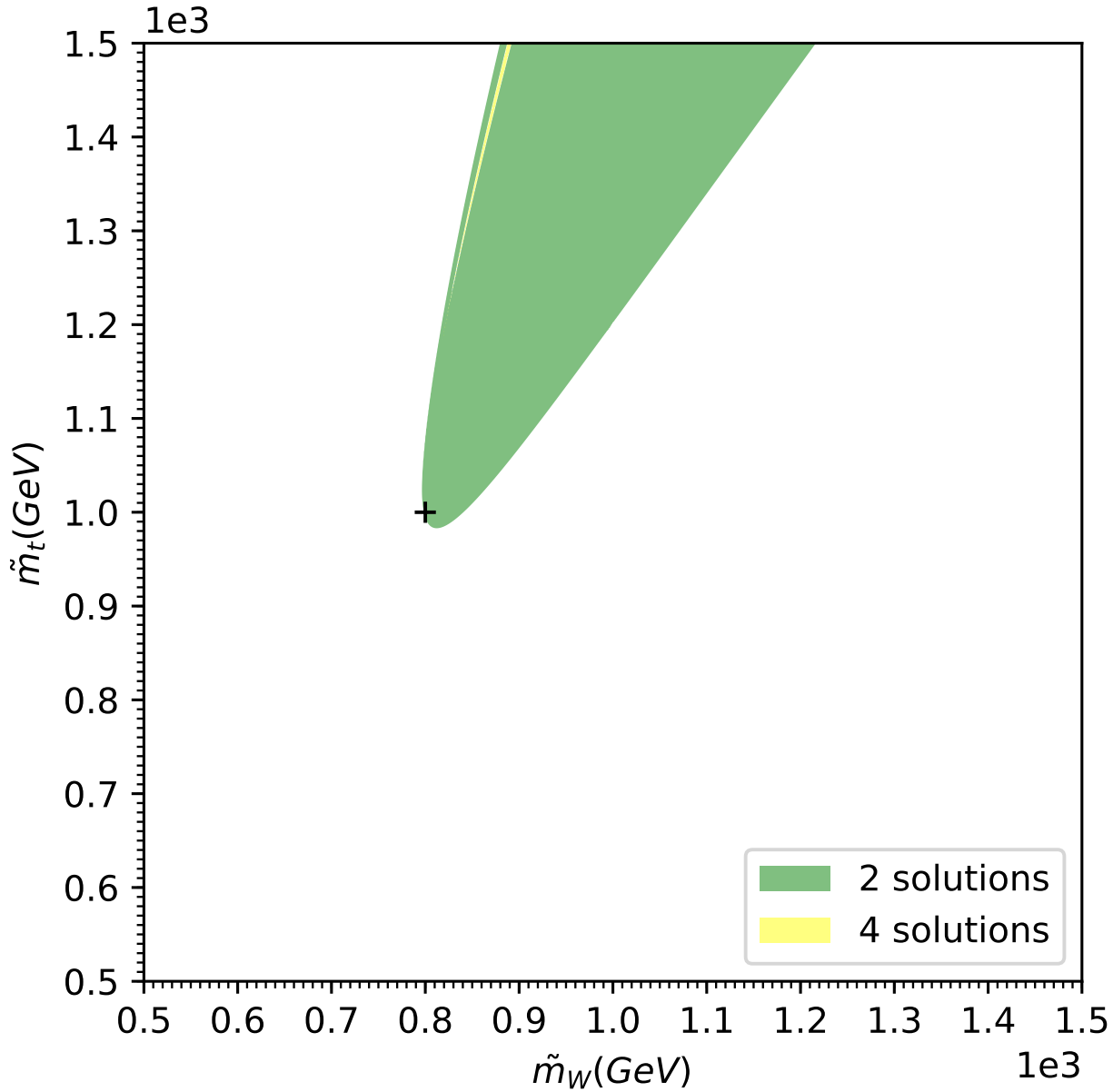
Extreme events

$$\tilde{m}_{\tilde{\nu}} = 700 \text{ GeV} = m_{\tilde{\nu}}$$



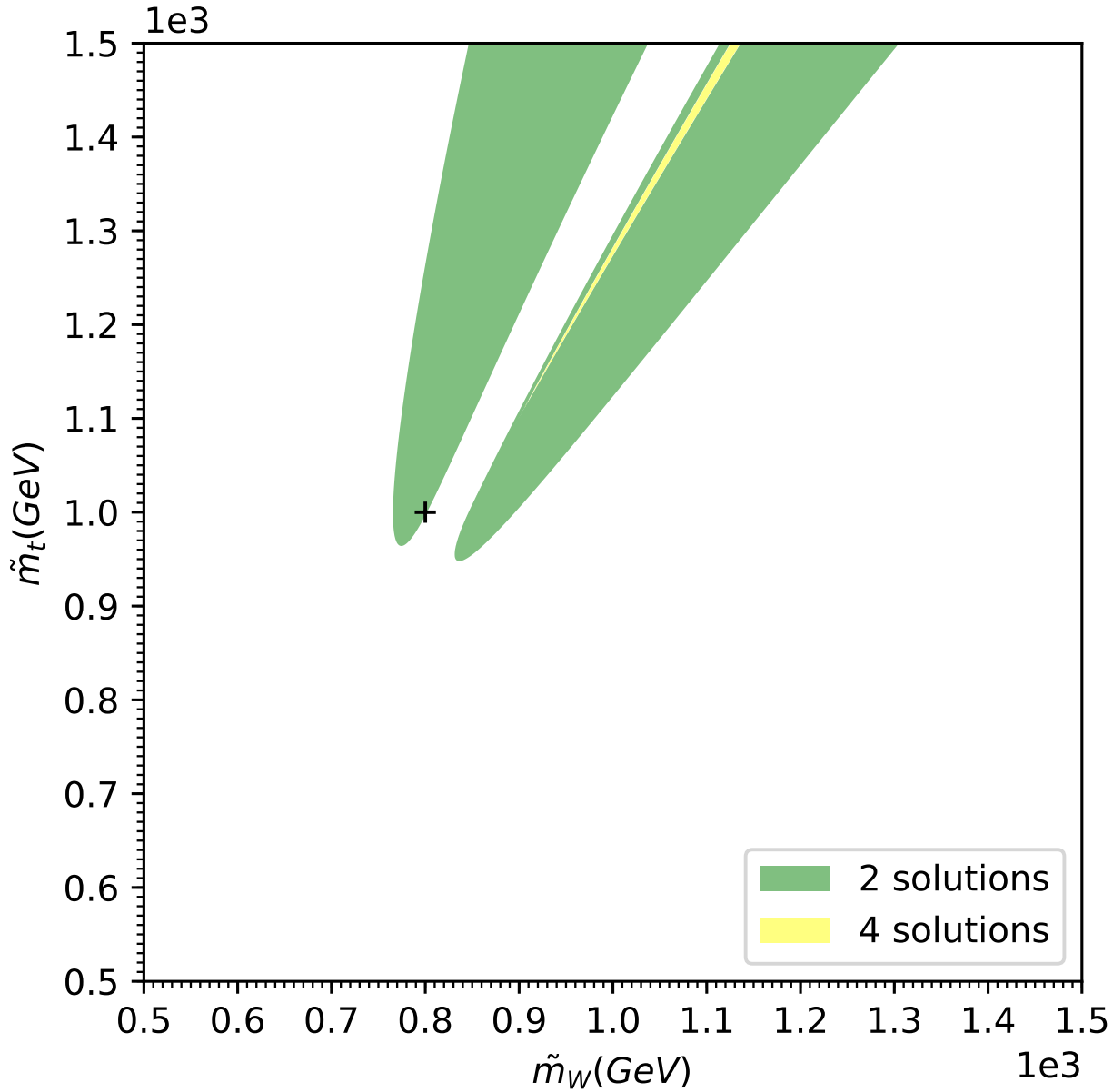
Extreme events

$$\tilde{m}_{\tilde{\nu}} = 700 \text{ GeV} = m_{\tilde{\nu}}$$



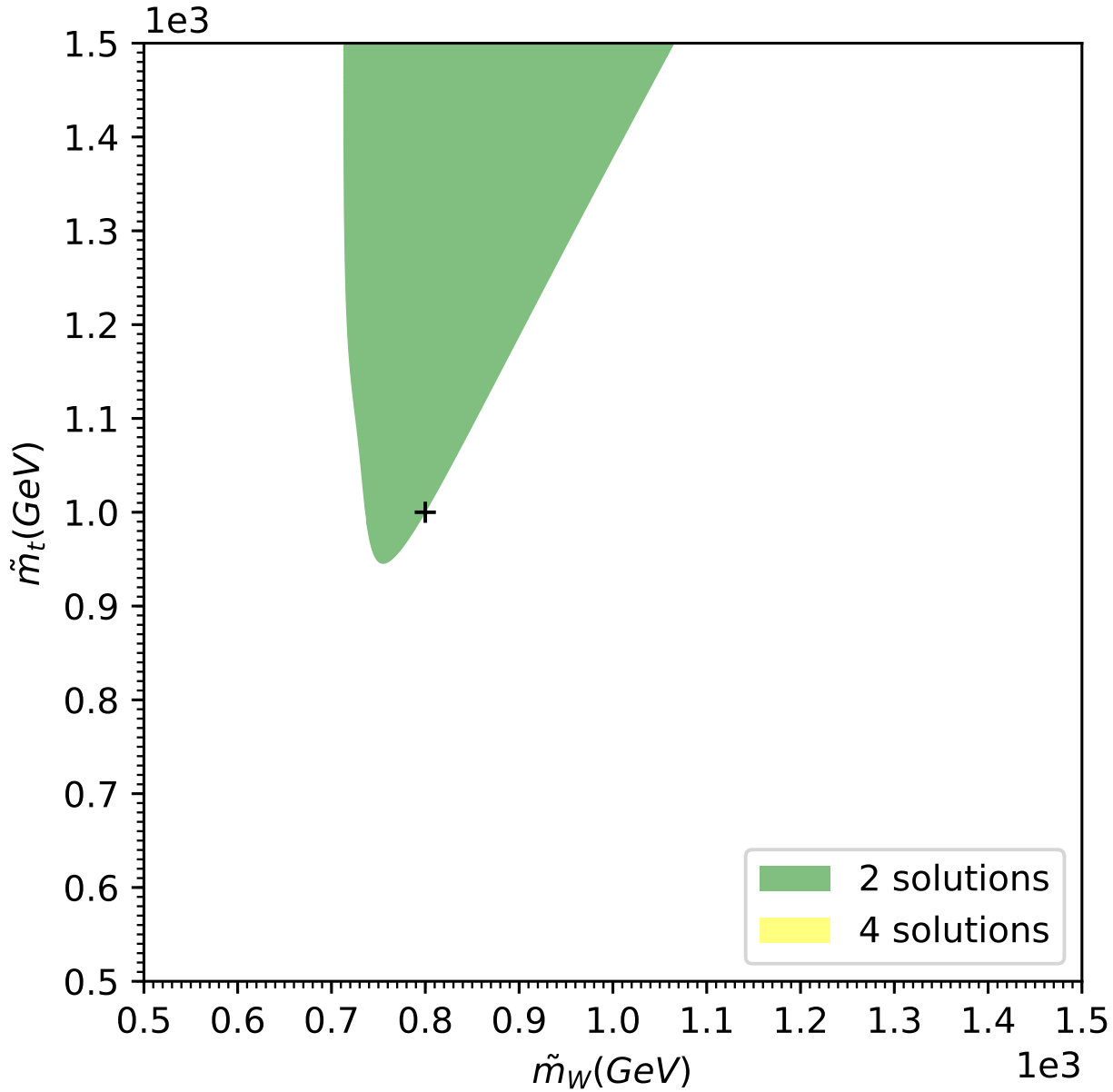
Extreme events

$$\tilde{m}_{\tilde{\nu}} = 700 \text{ GeV} = m_{\tilde{\nu}}$$



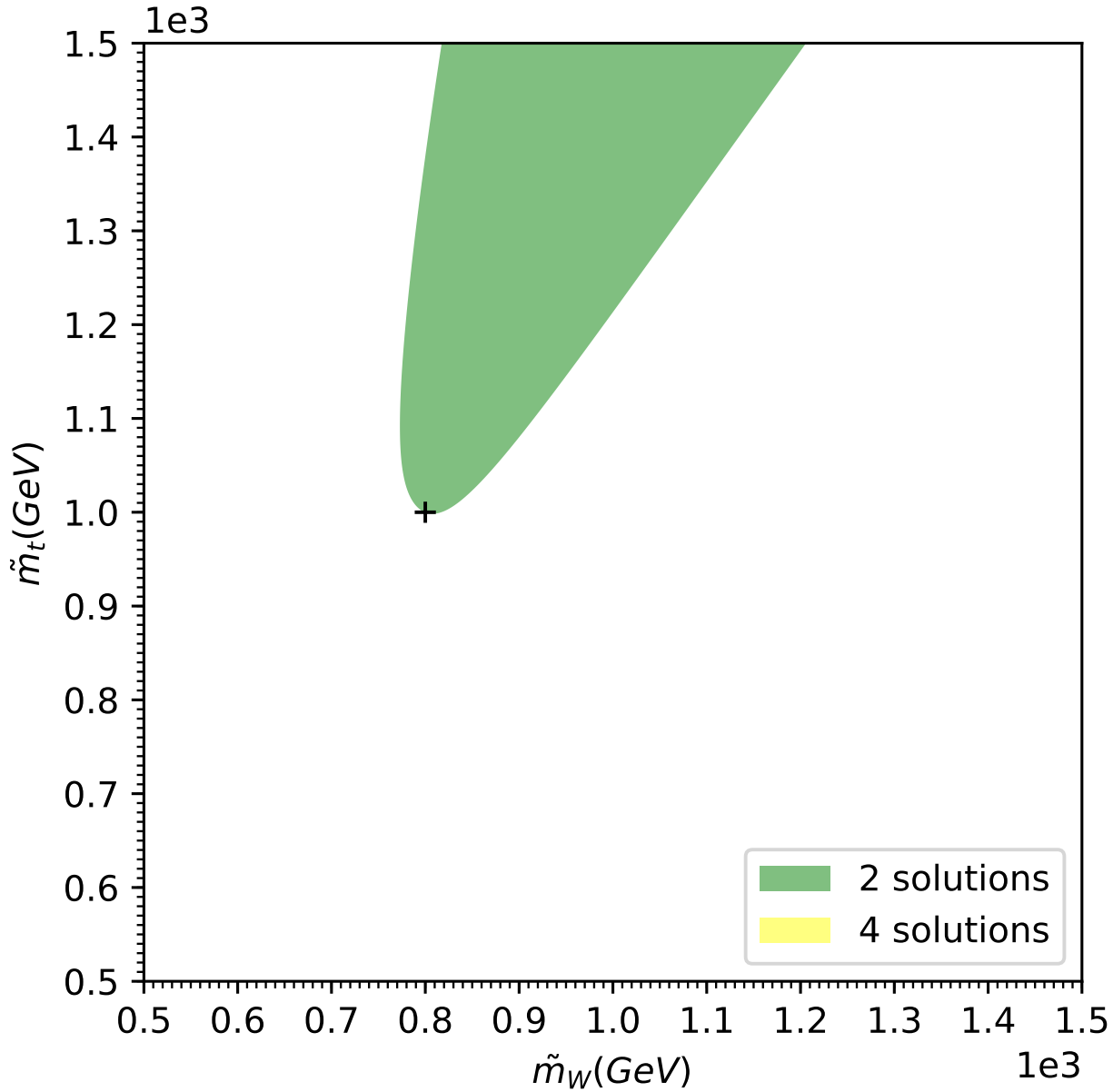
Extreme events

$$\tilde{m}_{\tilde{\nu}} = 700 \text{ GeV} = m_{\tilde{\nu}}$$



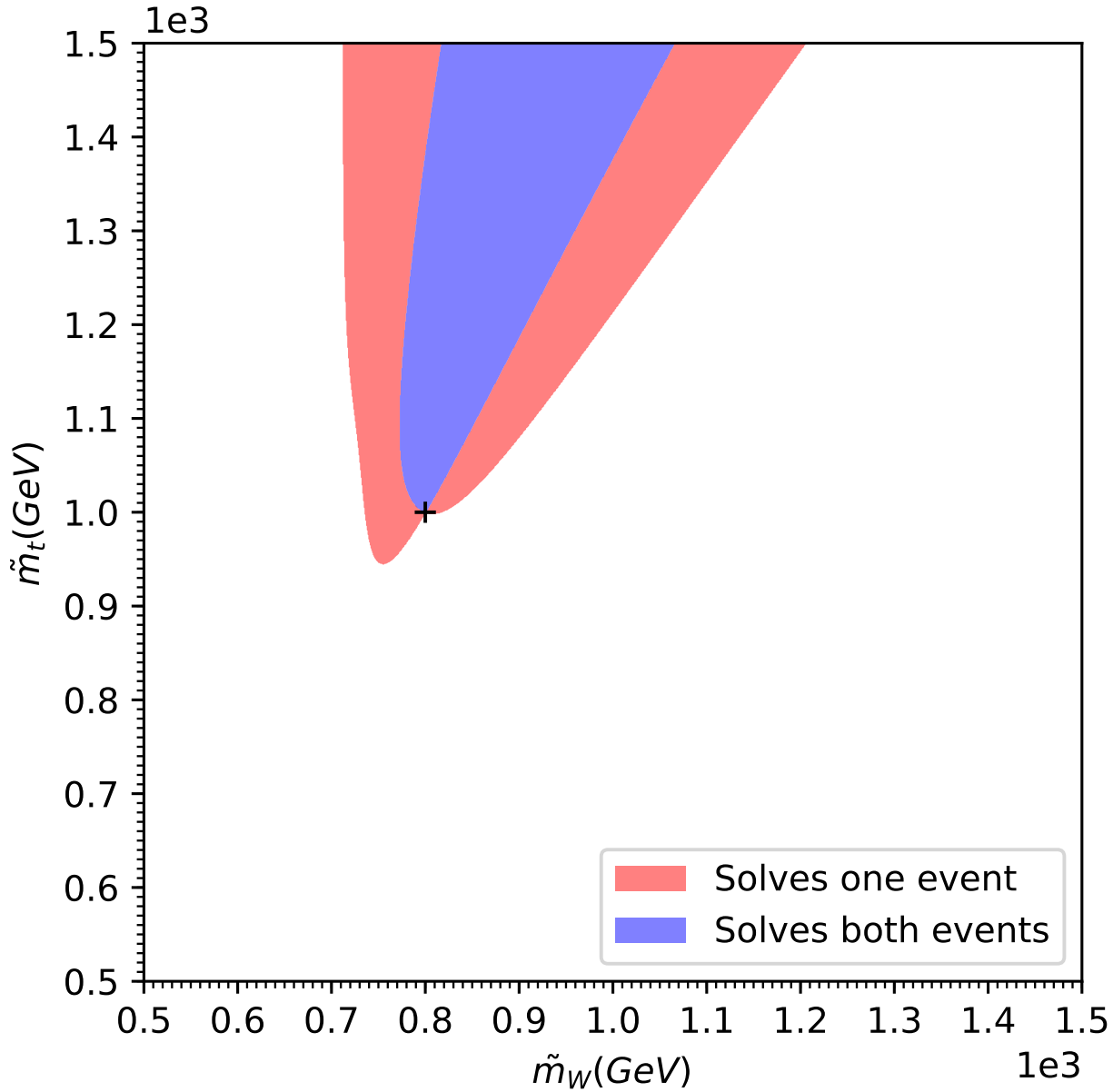
Extreme events

$$\tilde{m}_{\tilde{\nu}} = 700 \text{ GeV} = m_{\tilde{\nu}}$$

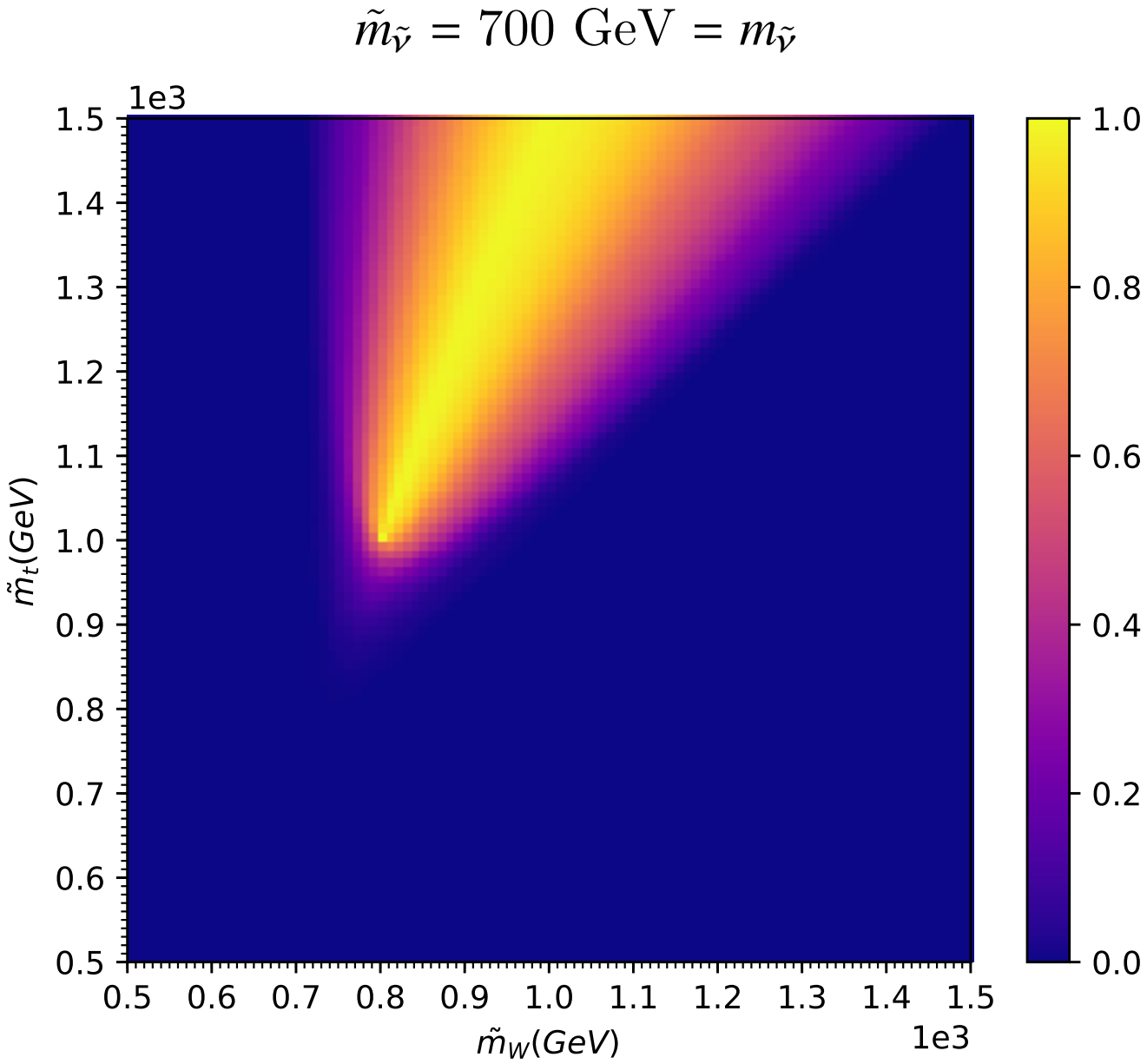


Extreme events

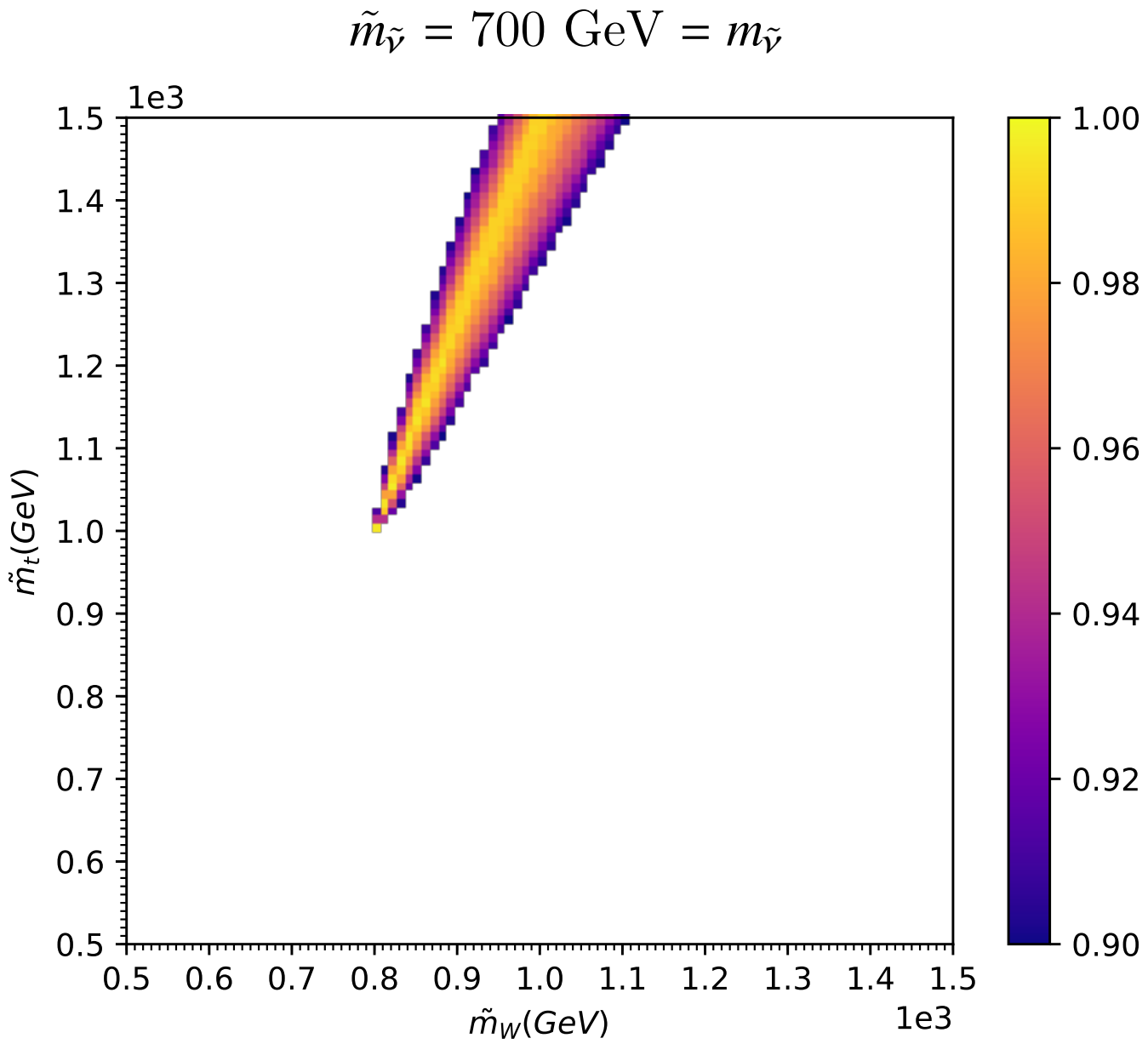
$$\tilde{m}_{\tilde{\nu}} = 700 \text{ GeV} = m_{\tilde{\nu}}$$



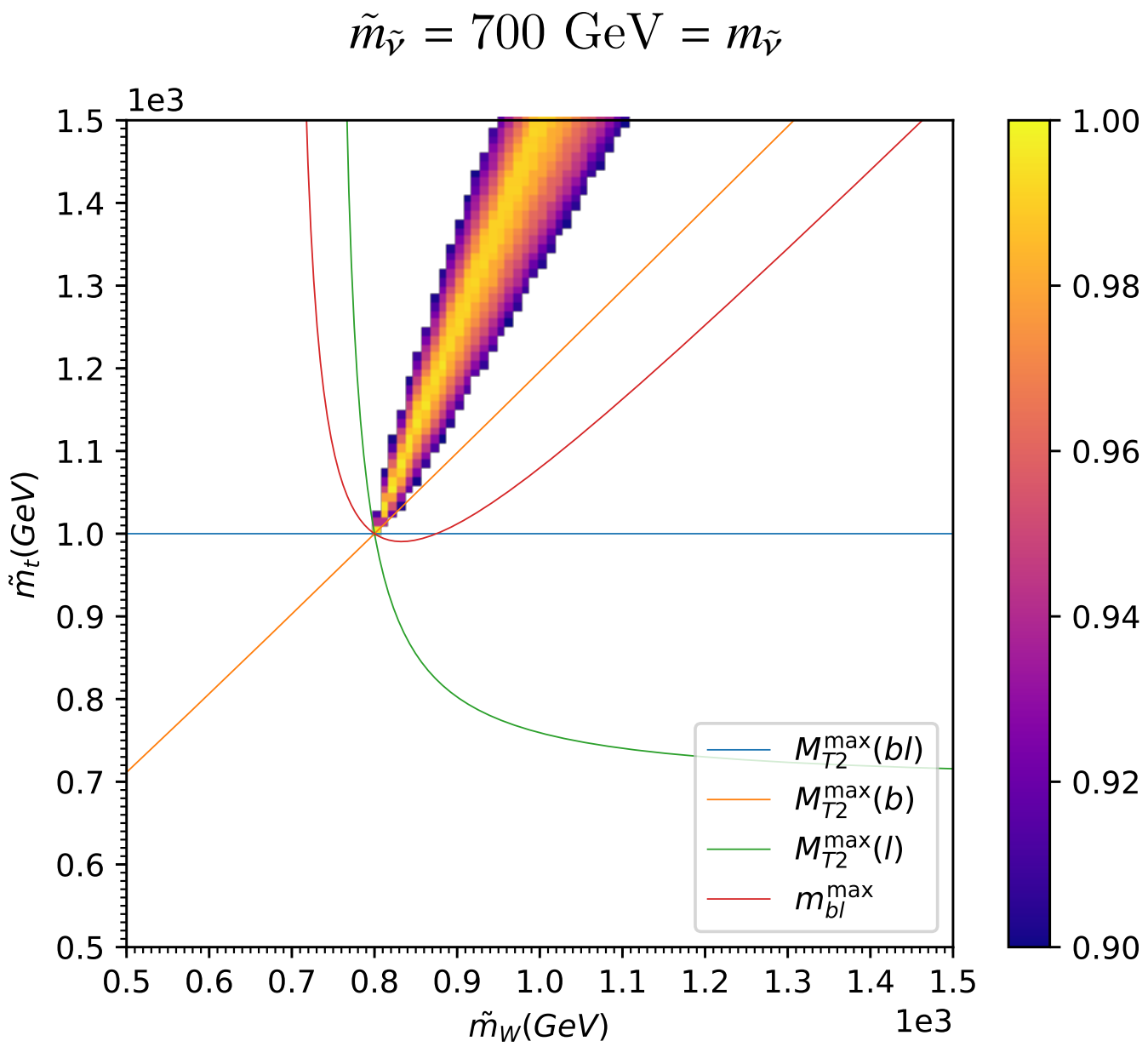
Fraction of solvable events



Fraction of solvable events



Adding end point measurements

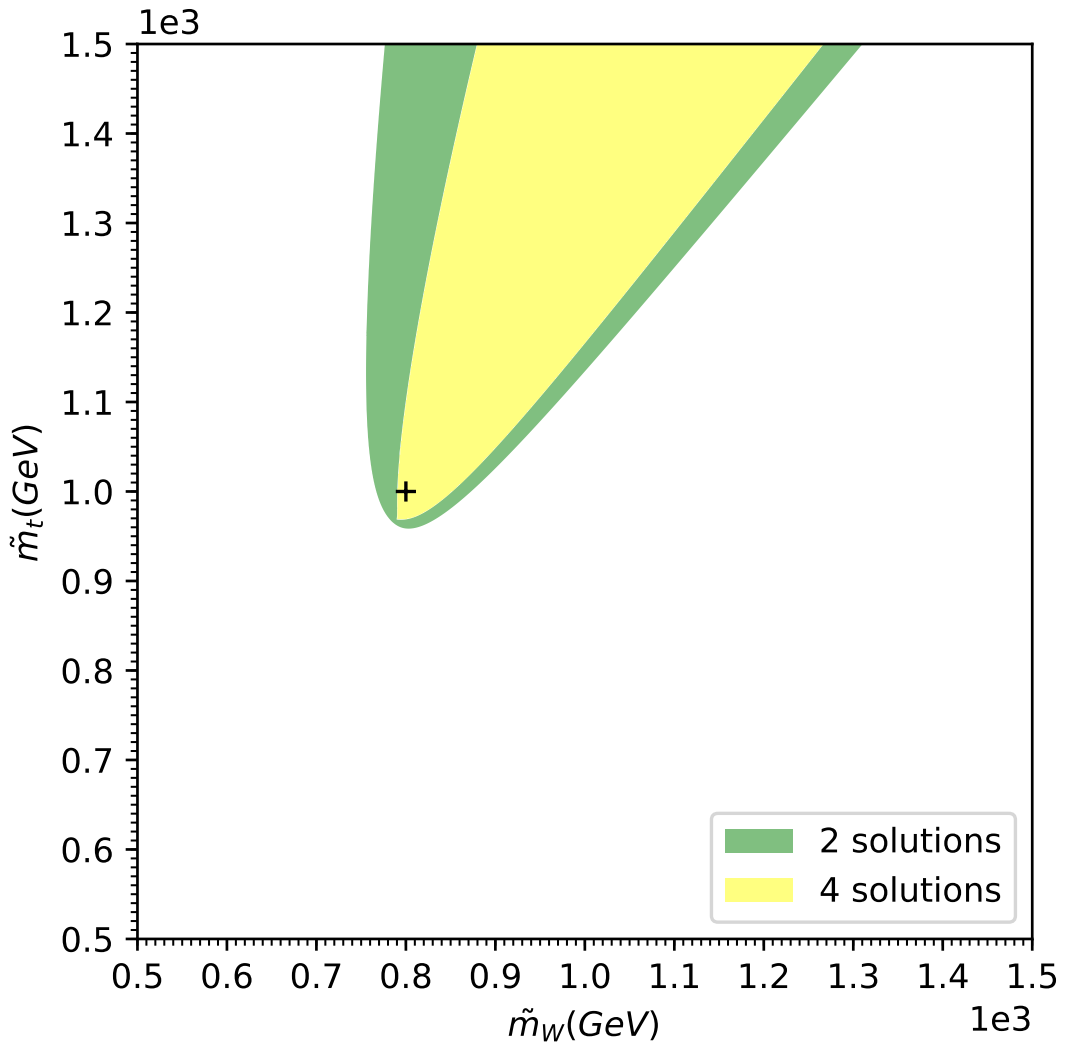


Our method... Focus Points

Boundaries where no. of solutions changes

$\tilde{m}_{\tilde{\nu}} = 700\ \mathrm{GeV} = m_{\tilde{\nu}}$

1 event (Not necessarily extreme)

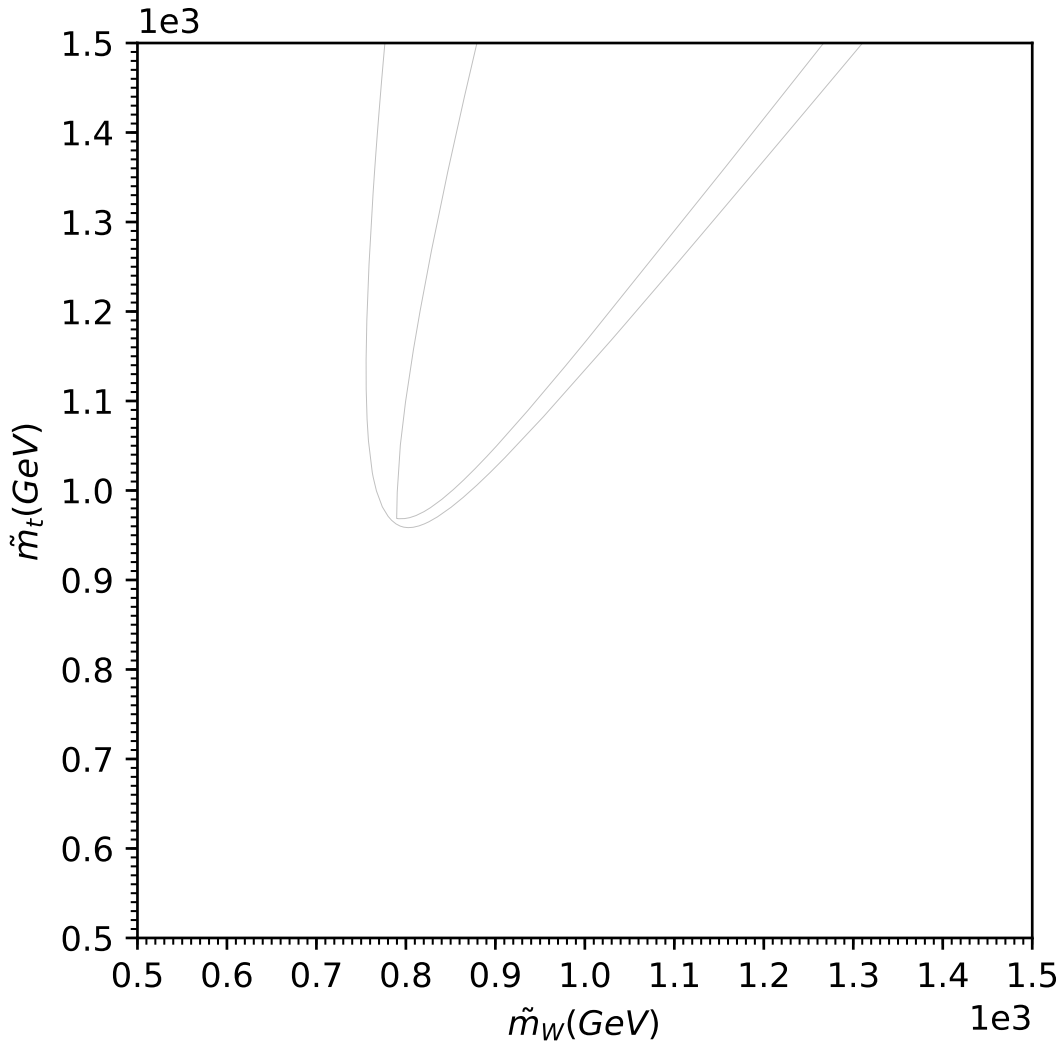


Our method... Focus Points

Boundaries where no. of solutions changes

$\tilde{m}_{\tilde{\nu}} = 700\ \mathrm{GeV} = m_{\tilde{\nu}}$

1 event (Not necessarily extreme)

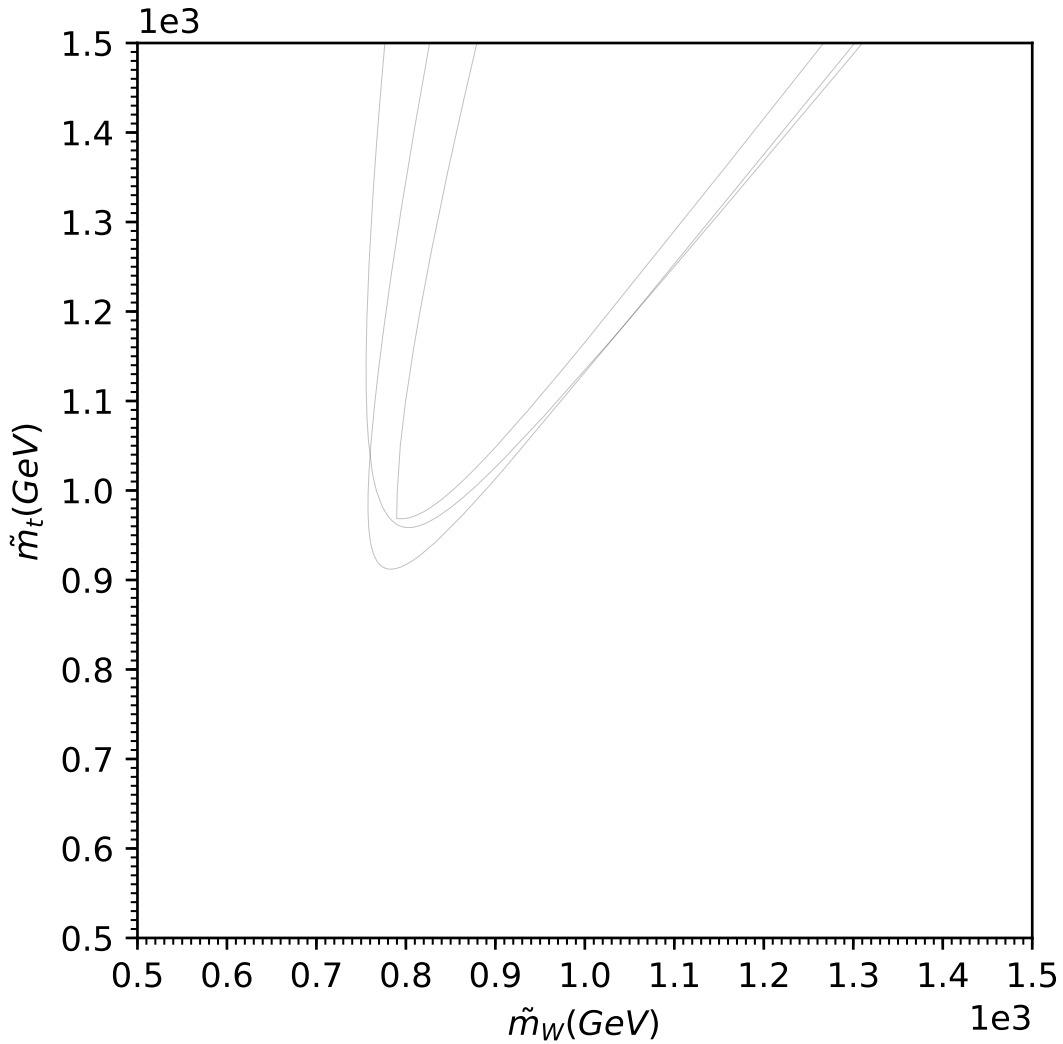


Our method... Focus Points

Boundaries where no. of solutions changes

$\tilde{m}_{\tilde{\nu}} = 700\ \mathrm{GeV} = m_{\tilde{\nu}}$

2 events (Not necessarily extreme)

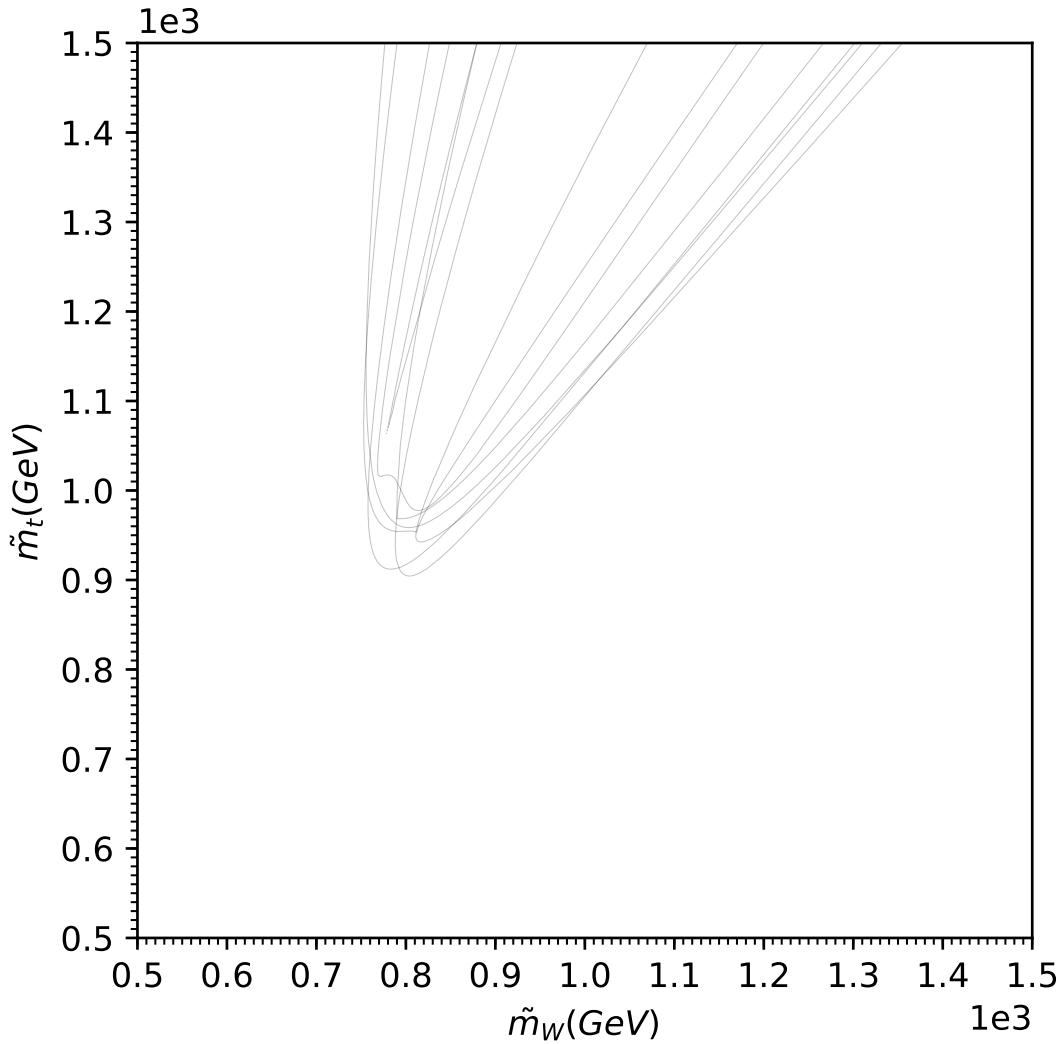


Our method... Focus Points

Boundaries where no. of solutions changes

$\tilde{m}_{\tilde{\nu}} = 700\ \mathrm{GeV} = m_{\tilde{\nu}}$

5 events (Not necessarily extreme)

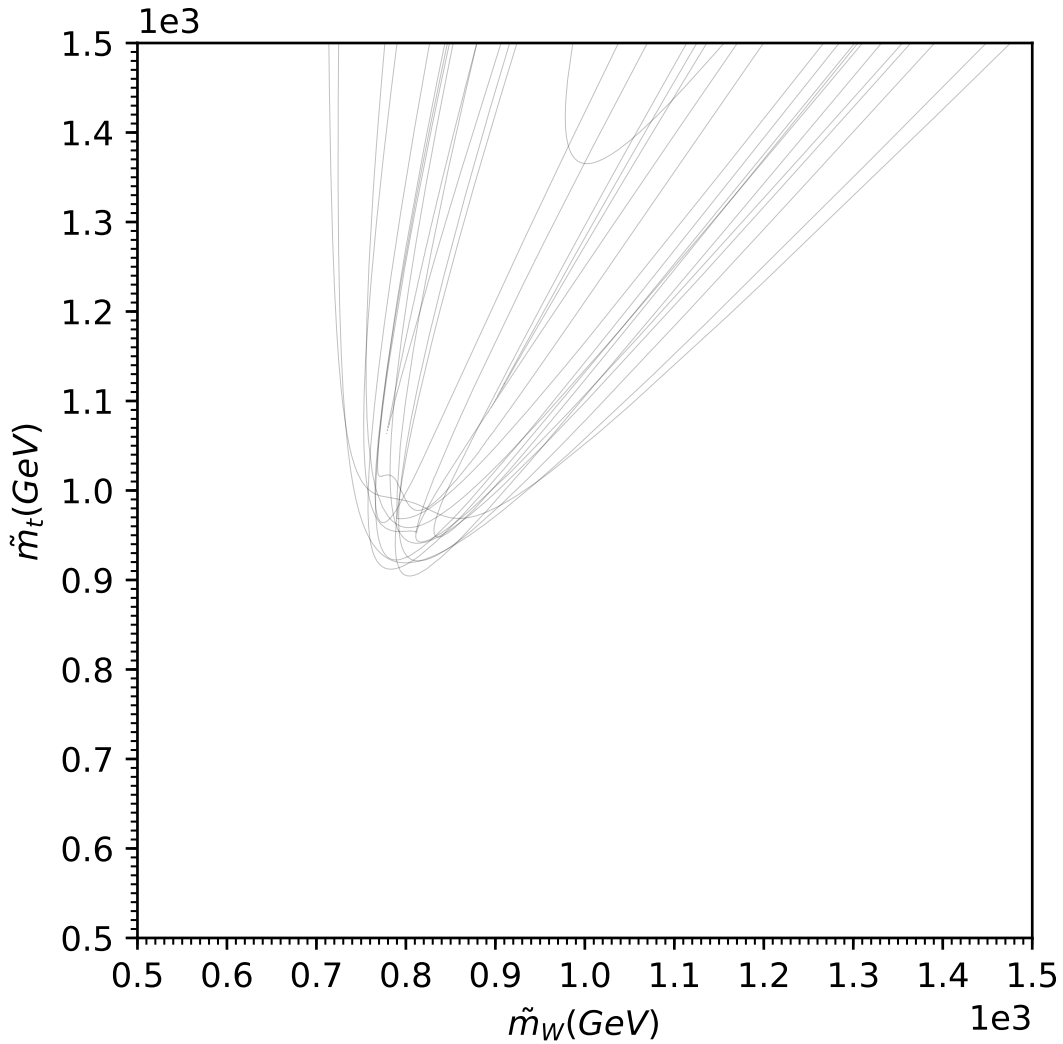


Our method... Focus Points

Boundaries where no. of solutions changes

$\tilde{m}_{\tilde{\nu}} = 700\ \mathrm{GeV} = m_{\tilde{\nu}}$

10 events (Not necessarily extreme)

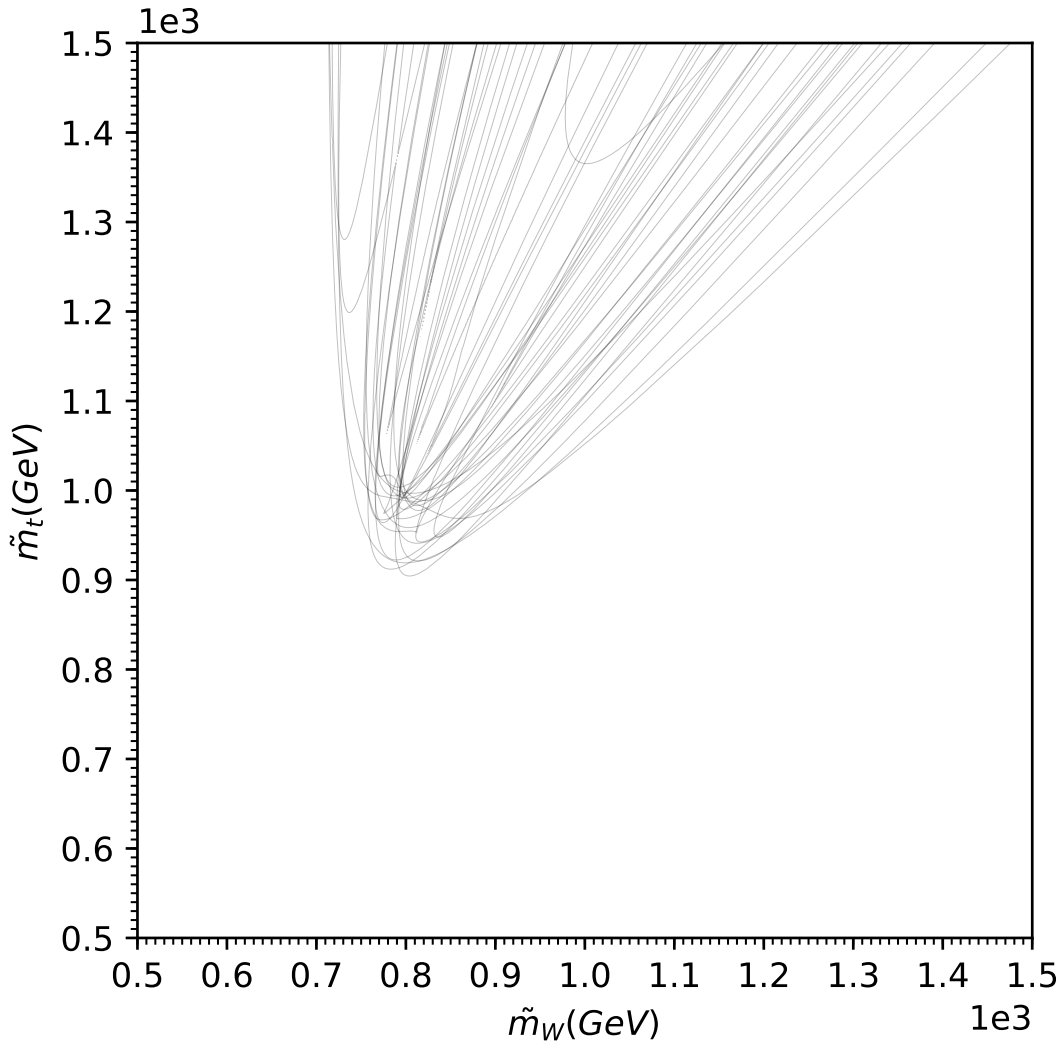


Our method... Focus Points

Boundaries where no. of solutions changes

$\tilde{m}_{\tilde{\nu}} = 700\ \mathrm{GeV} = m_{\tilde{\nu}}$

20 events (Not necessarily extreme)

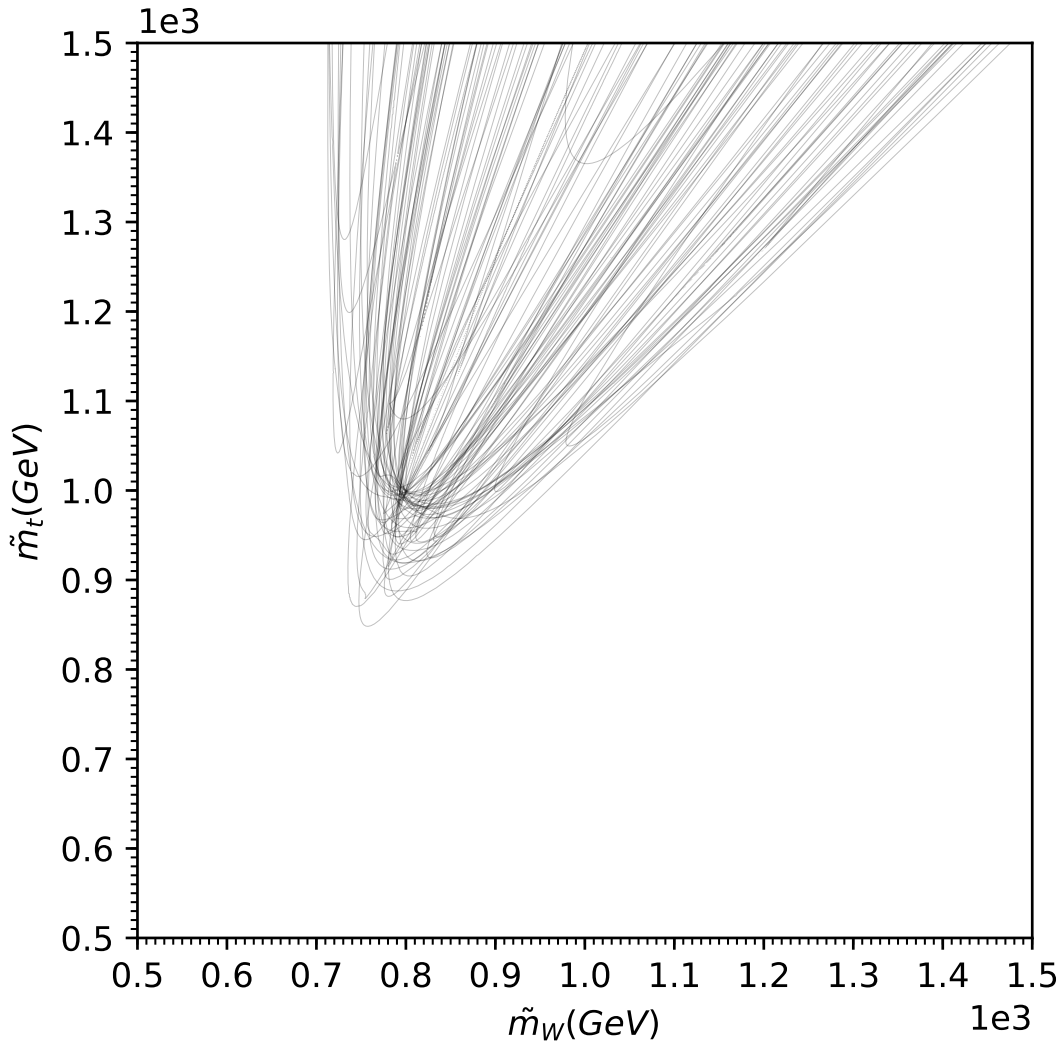


Our method... Focus Points

Boundaries where no. of solutions changes

$\tilde{m}_{\tilde{\nu}} = 700\ \mathrm{GeV} = m_{\tilde{\nu}}$

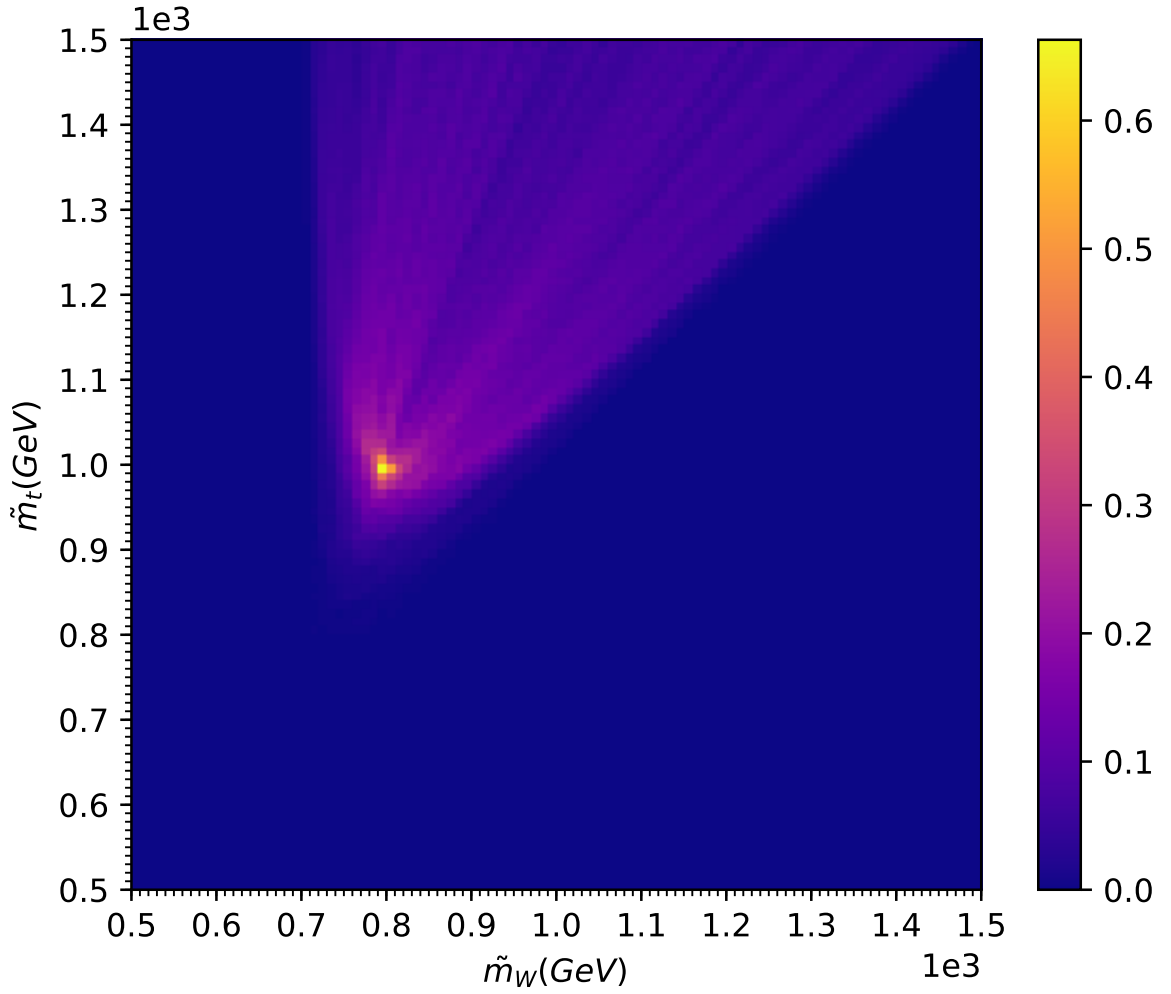
50 events (Extreme events are abundant!)



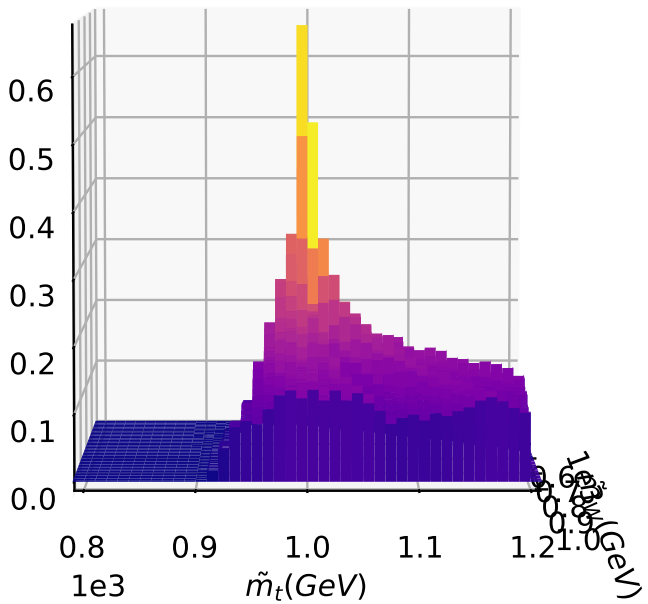
Our method... Focus Points

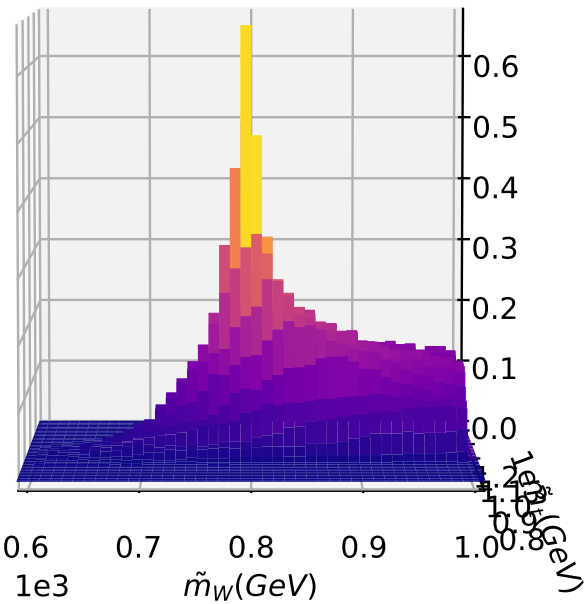
MONEY PLOT!

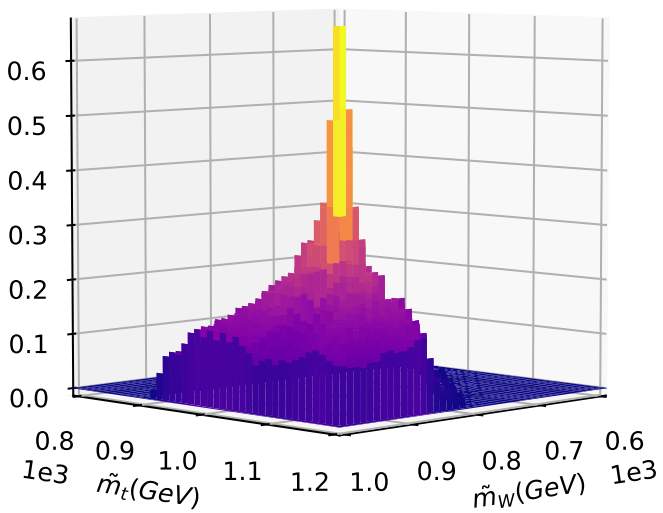
Fraction of events whose extremeness boundaries pass through a 10 GeV x 10 GeV square



Our method... Focus Points

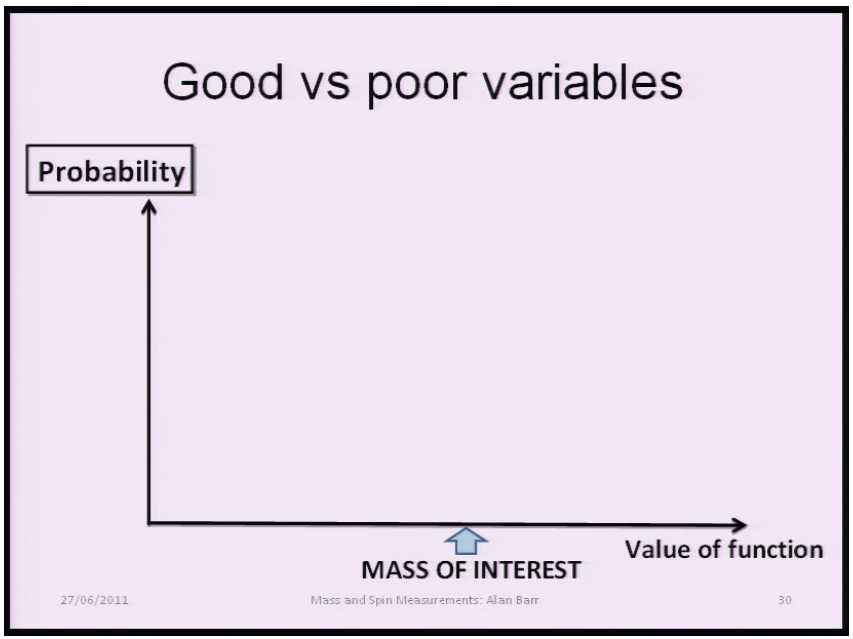






Some perspective: Good vs poor variables

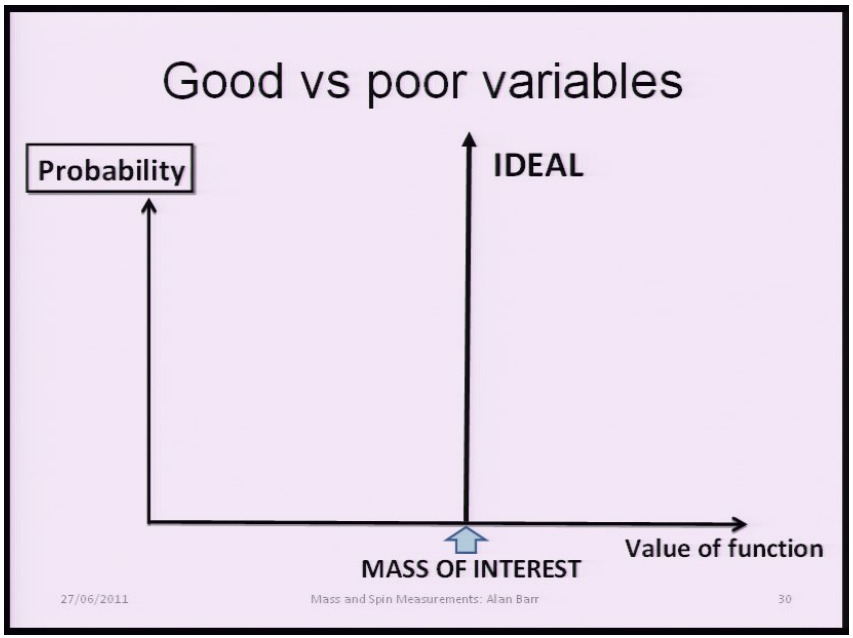
From Christopher Lester's lecture at TASI 2011



Relevant Example(s)

Some perspective: Good vs poor variables

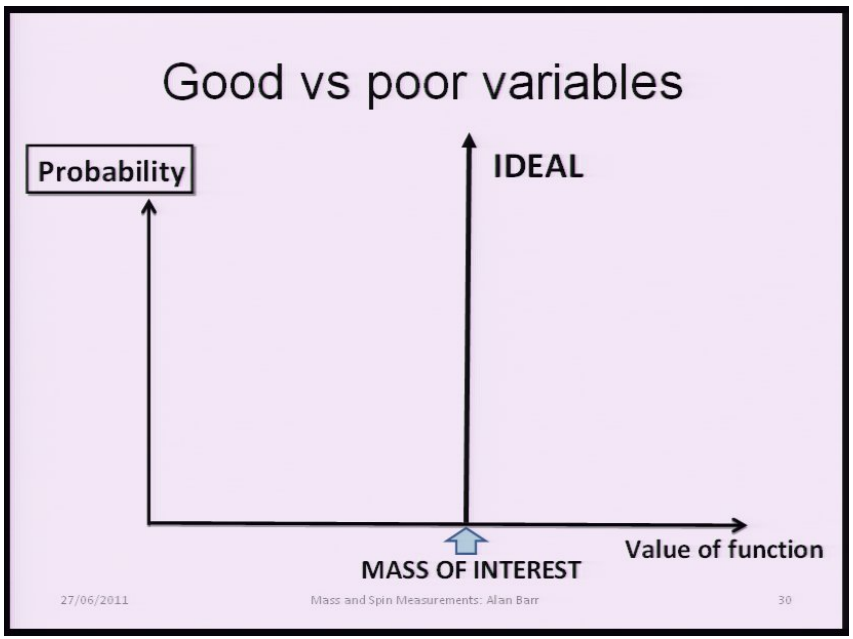
From Christopher Lester's lecture at TASI 2011



Relevant Example(s)

Some perspective: Good vs poor variables

From Christopher Lester's lecture at TASI 2011

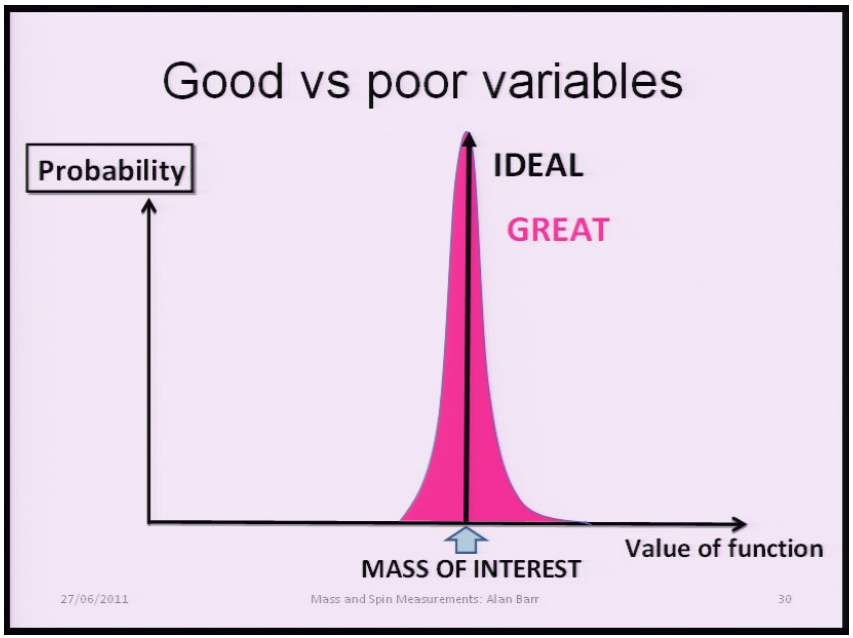


Relevant Example(s)

:(

Some perspective: Good vs poor variables

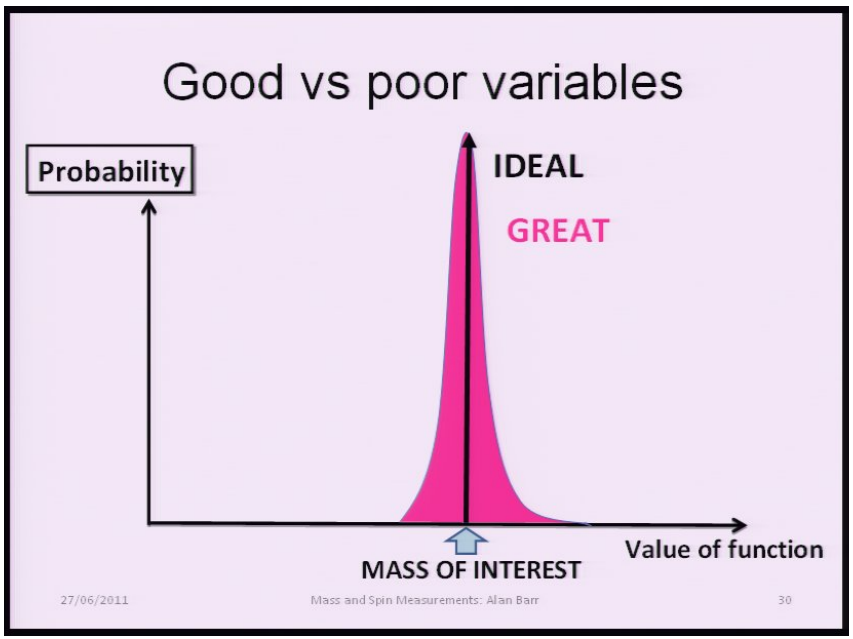
From Christopher Lester's lecture at TASI 2011



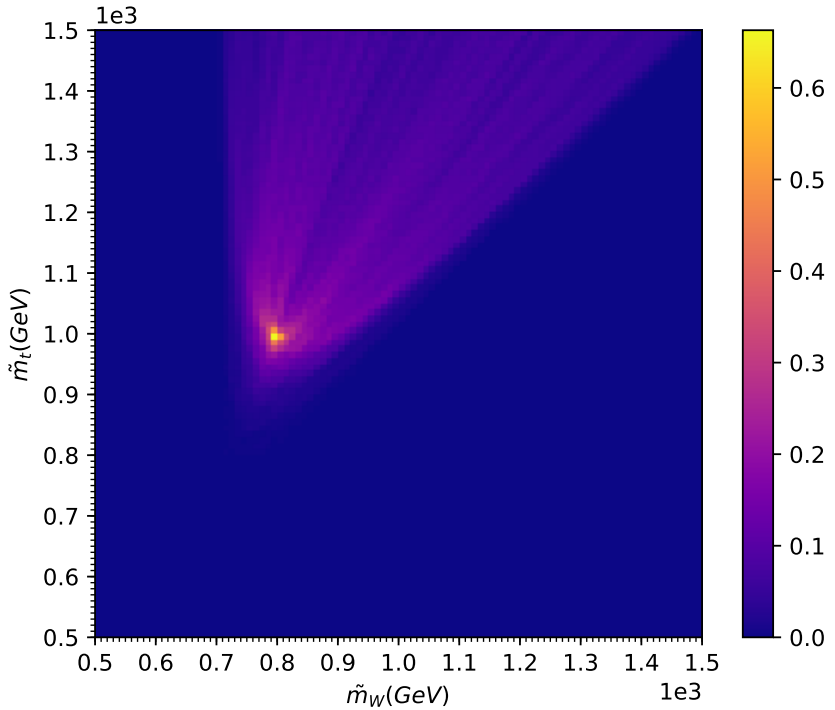
Relevant Example(s)

Some perspective: Good vs poor variables

From Christopher Lester's lecture at TASI 2011

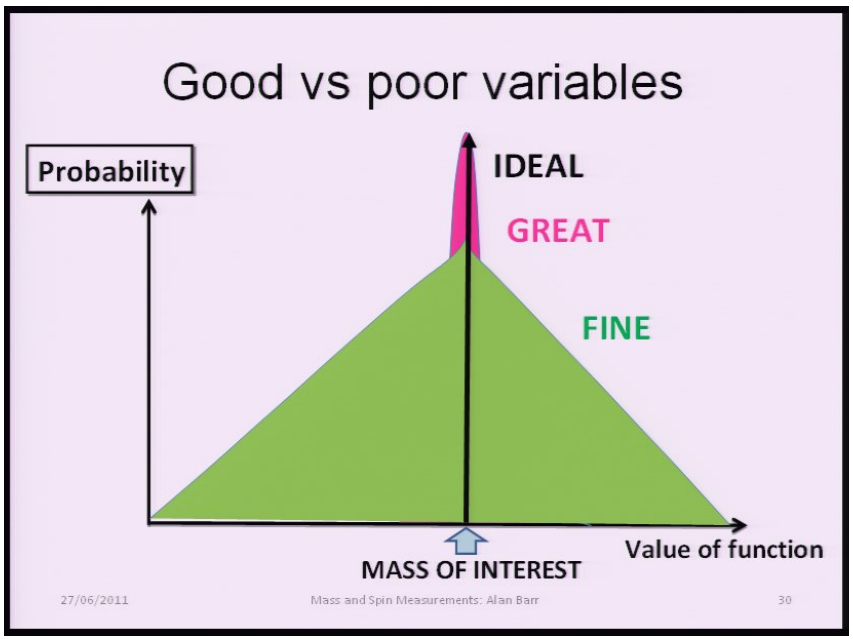


Relevant Example(s)



Some perspective: Good vs poor variables

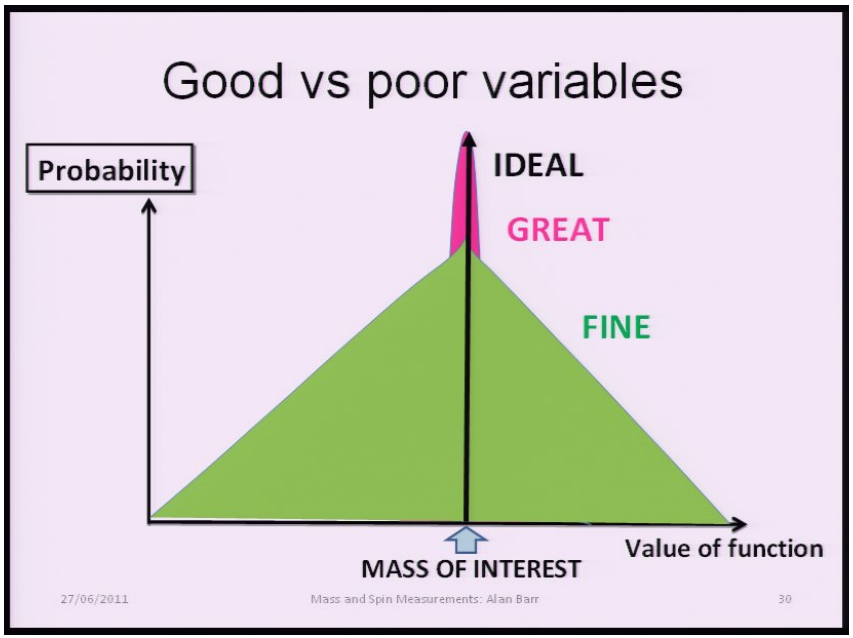
From Christopher Lester's lecture at TASI 2011



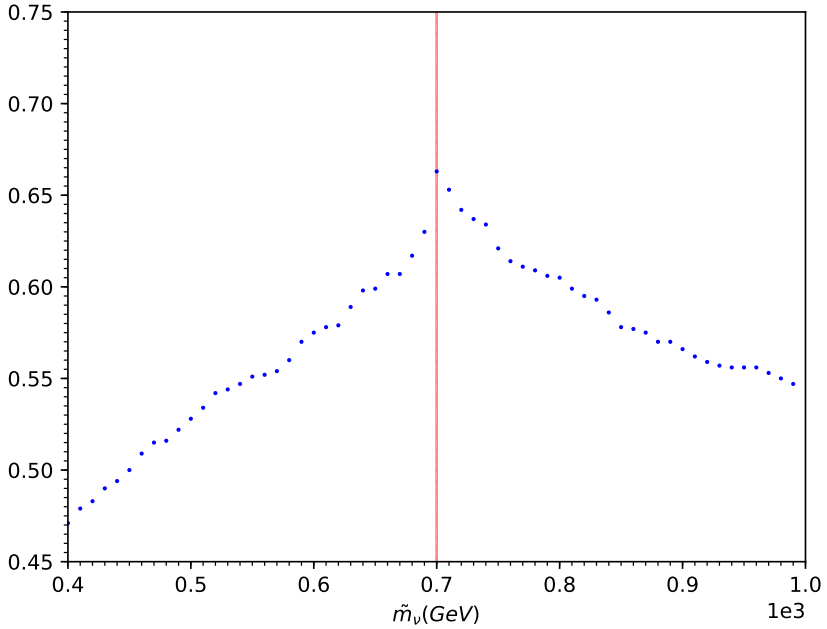
Relevant Example(s)

Some perspective: Good vs poor variables

From Christopher Lester's lecture at TASI 2011



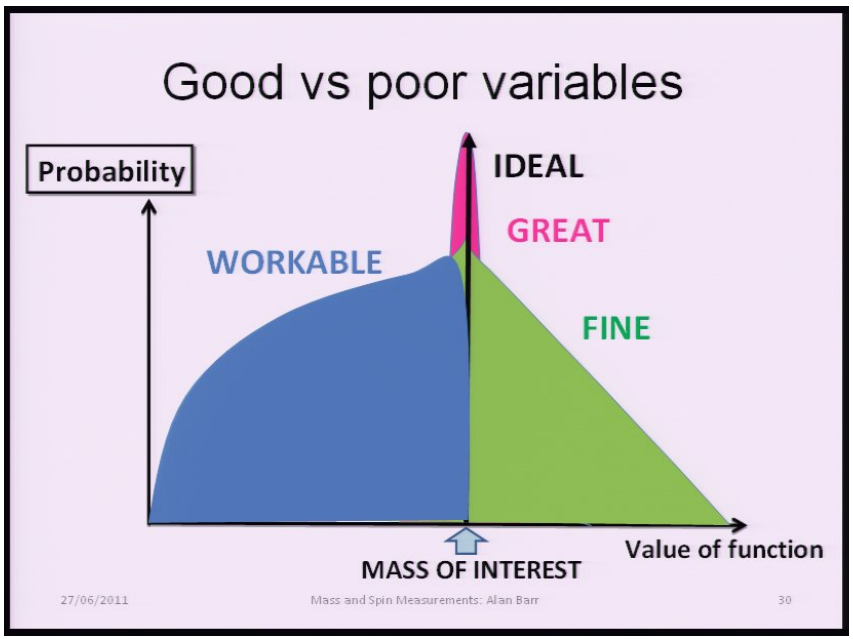
Relevant Example(s)



Maximum density of extremeness boundaries
(maximized in the $\tilde{m}_t - \tilde{m}_W$ plane)

Some perspective: Good vs poor variables

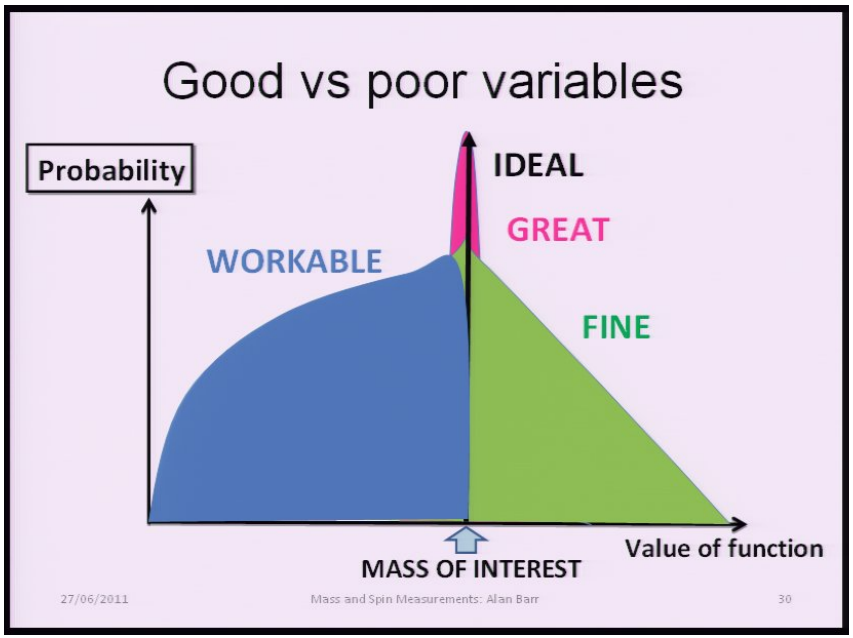
From Christopher Lester's lecture at TASI 2011



Relevant Example(s)

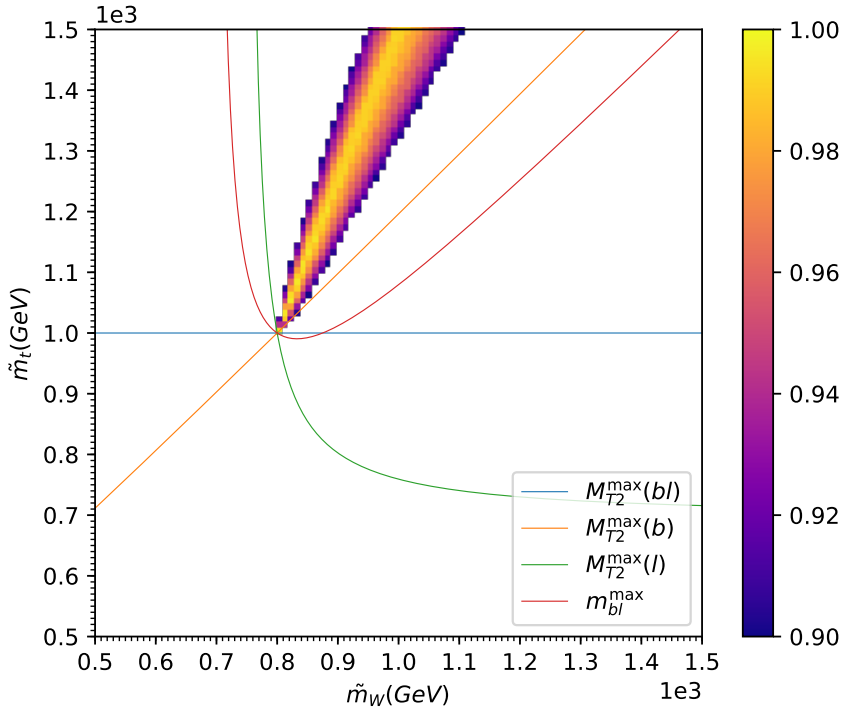
Some perspective: Good vs poor variables

From Christopher Lester's lecture at TASI 2011



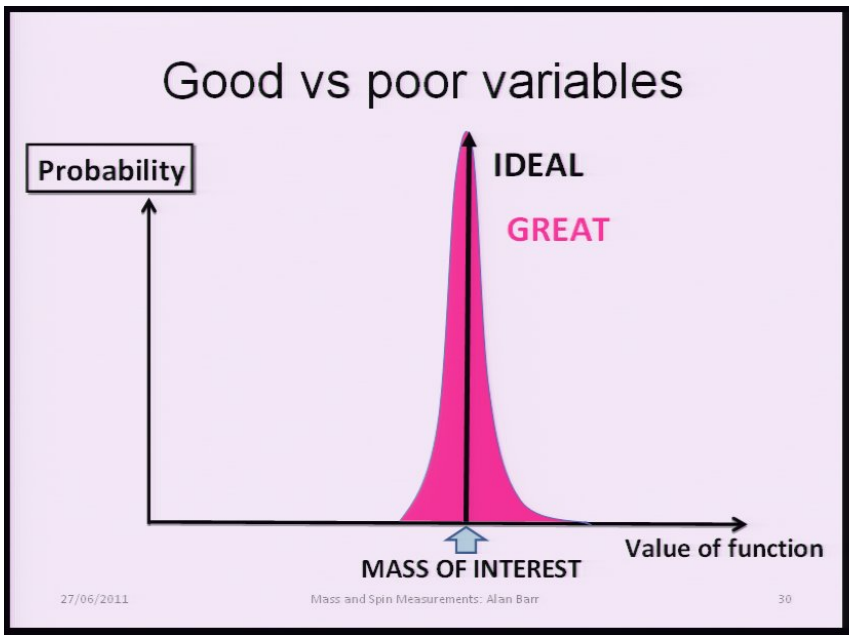
Relevant Example(s)

- End point measurements
- Solvability

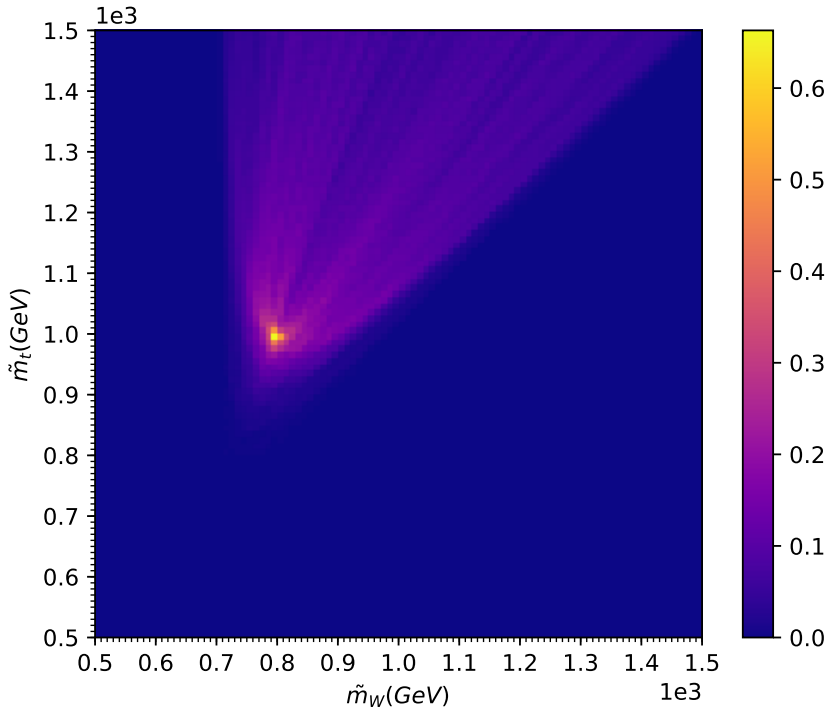


Some perspective: Good vs poor variables

From Christopher Lester's lecture at TASI 2011



Relevant Example(s)



Summary: Great variable!

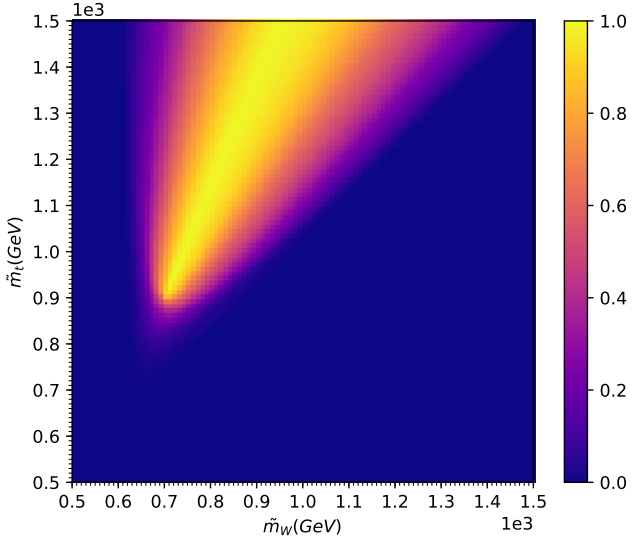
Outlook and future plans

1. Each event provides a candidate curve (extremeness boundary) of masses. We see a sharp peak in the density of these curves at the true mass.
2. This is based only on event kinematics.
3. (1) and (2) suggest that in addition to measuring the masses of particles, this technique can be engineered to be a **BSM search technique**.
4. This technique is applicable to a few other decay topologies as well. But that's a subject for another talk.

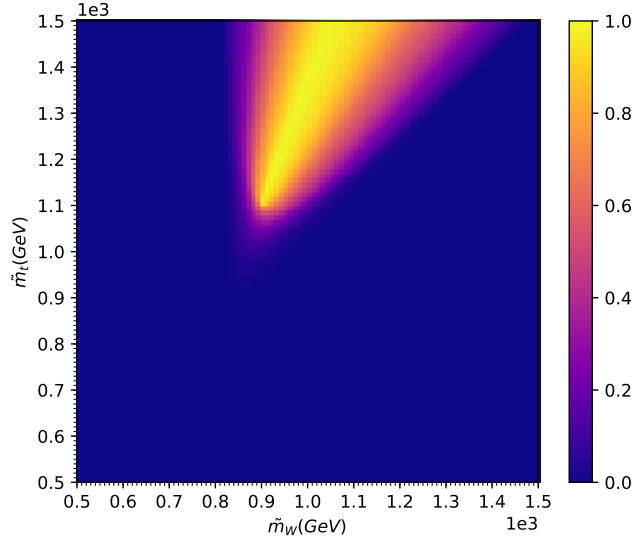
Thank You!

Bonus slides (finding $m_{\tilde{\nu}}$): Solvability + Endpoint measurements

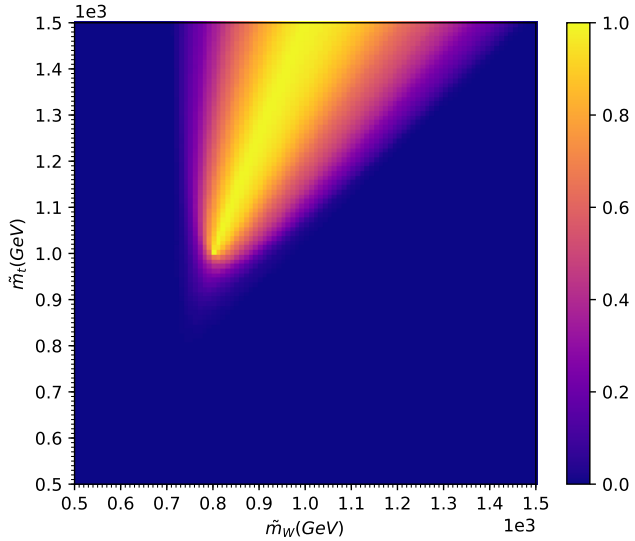
$\tilde{m}_{\tilde{\nu}} = 600$ GeV $< m_{\tilde{\nu}}$



$\tilde{m}_{\tilde{\nu}} = 800$ GeV $> m_{\tilde{\nu}}$

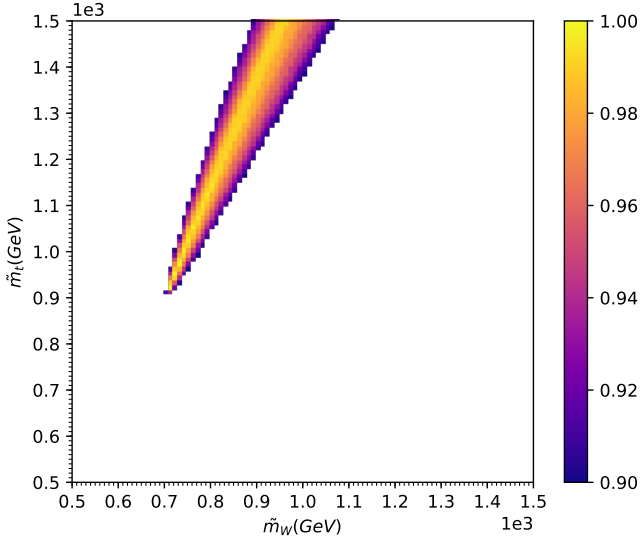


$\tilde{m}_{\tilde{\nu}} = 700$ GeV $= m_{\tilde{\nu}}$

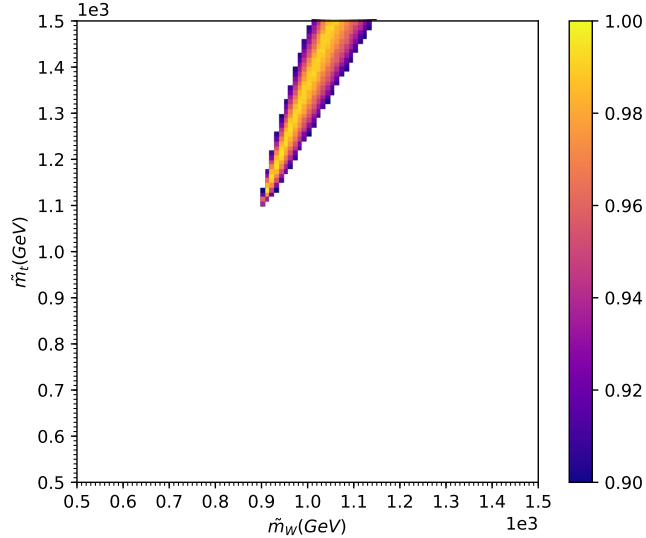


Bonus slides (finding $m_{\tilde{\nu}}$): Solvability + Endpoint measurements

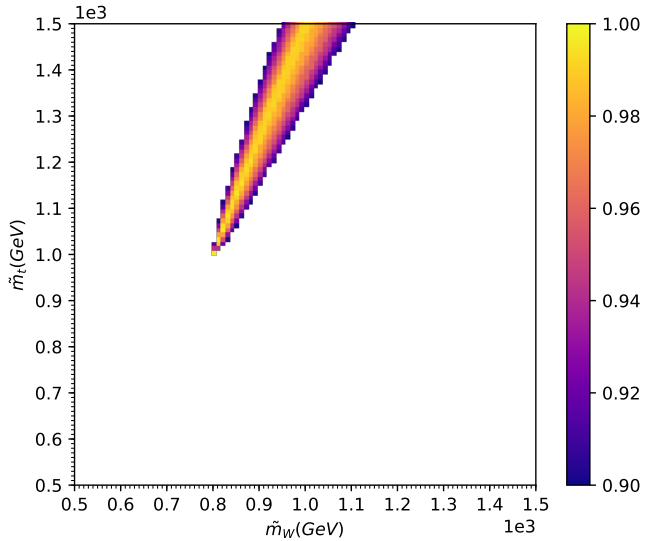
$\tilde{m}_{\tilde{\nu}} = 600$ GeV $< m_{\tilde{\nu}}$



$\tilde{m}_{\tilde{\nu}} = 800$ GeV $> m_{\tilde{\nu}}$

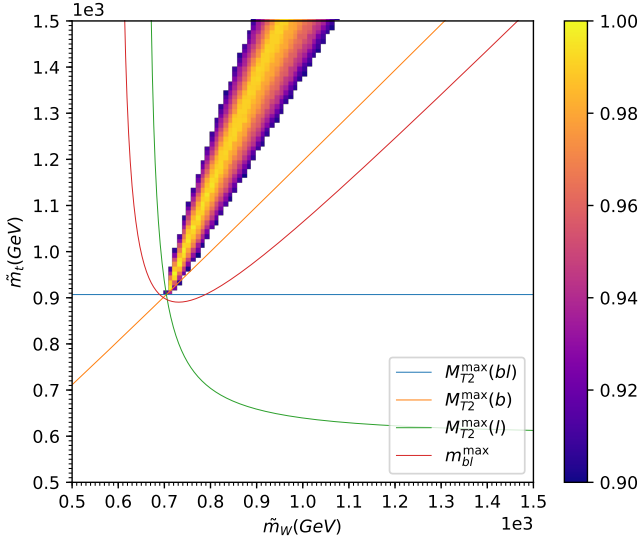


$\tilde{m}_{\tilde{\nu}} = 700$ GeV $= m_{\tilde{\nu}}$

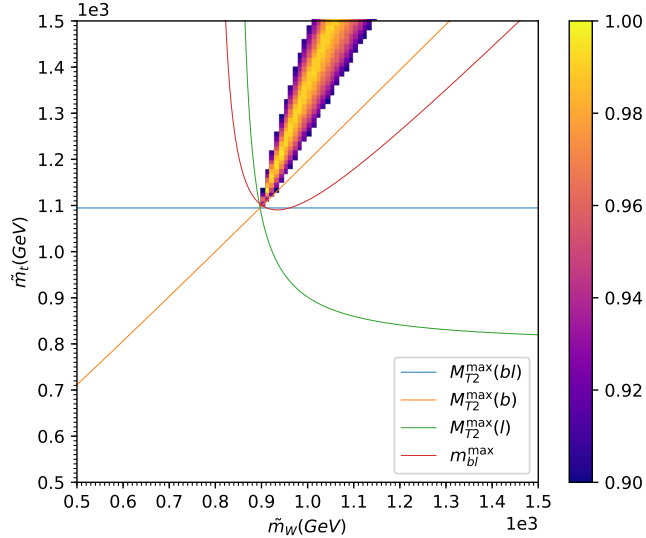


Bonus slides (finding $m_{\tilde{\nu}}$): Solvability + Endpoint measurements

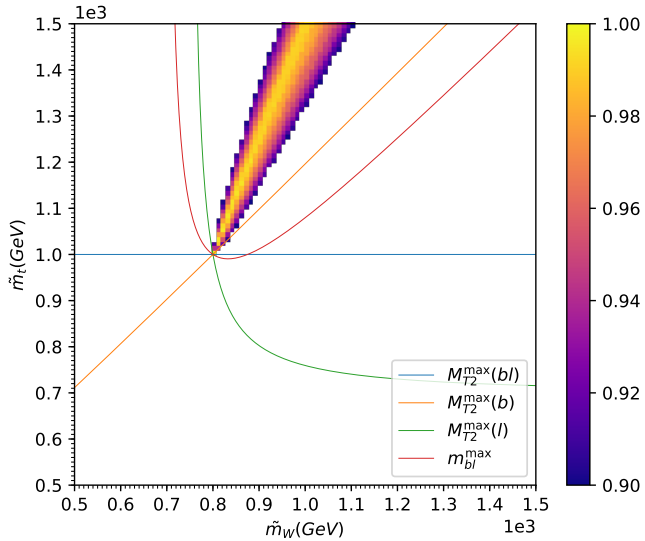
$\tilde{m}_{\tilde{\nu}} = 600$ GeV $< m_{\tilde{\nu}}$



$\tilde{m}_{\tilde{\nu}} = 800$ GeV $> m_{\tilde{\nu}}$



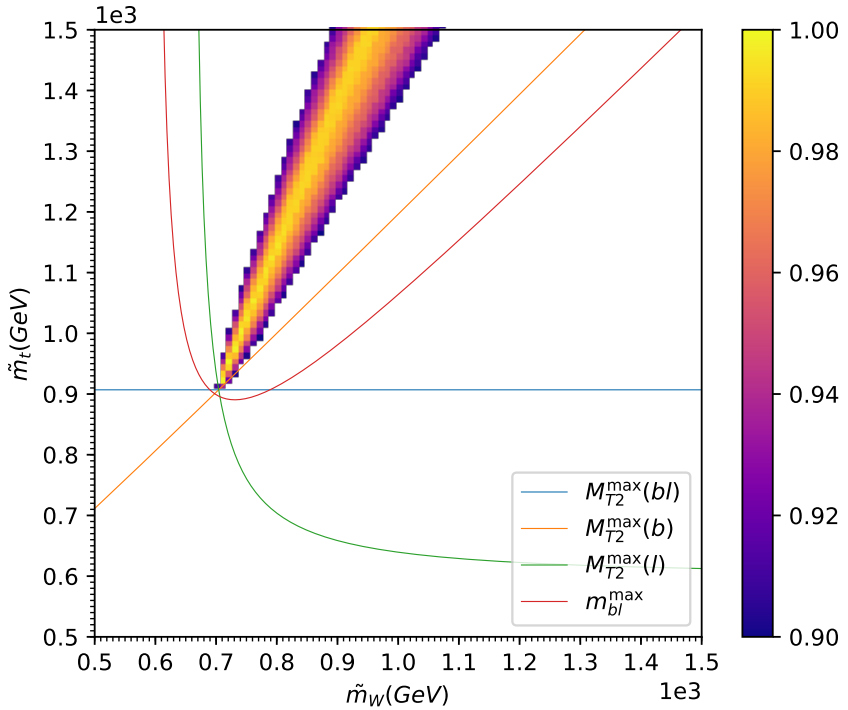
$\tilde{m}_{\tilde{\nu}} = 700$ GeV $= m_{\tilde{\nu}}$



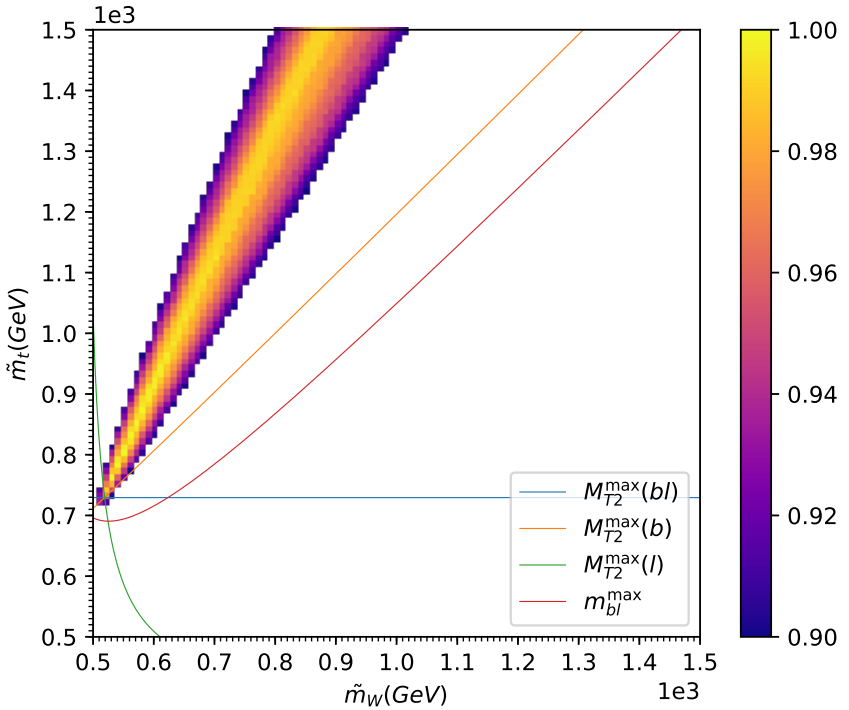
Bonus slides (finding $m_{\tilde{\nu}}$): Solvability + Endpoint measurements

$$\tilde{m}_{\tilde{\nu}} < m_{\tilde{\nu}}$$

$\tilde{m}_{\tilde{\nu}} = 600$ GeV



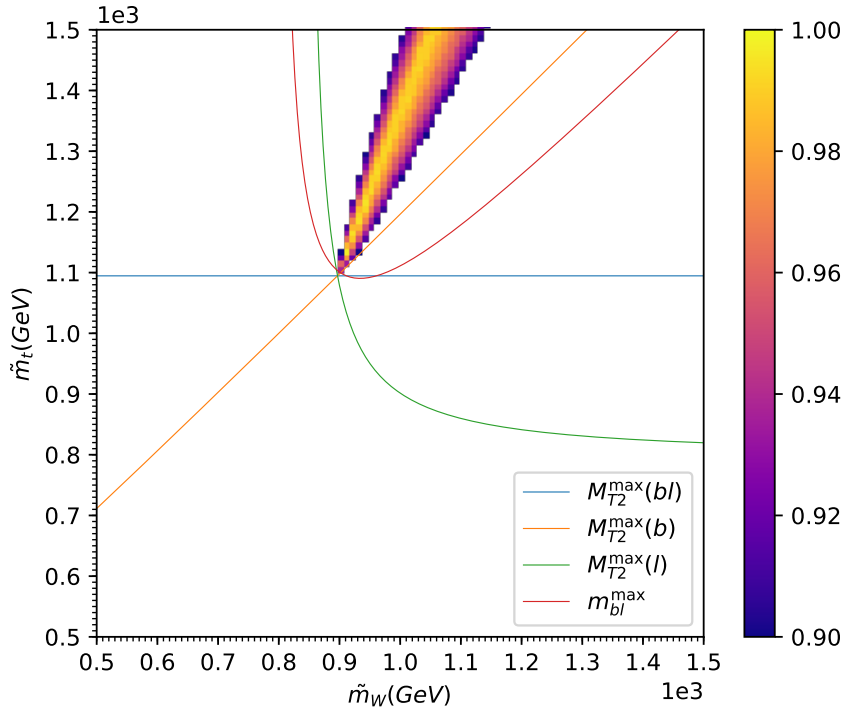
$\tilde{m}_{\tilde{\nu}} = 400$ GeV



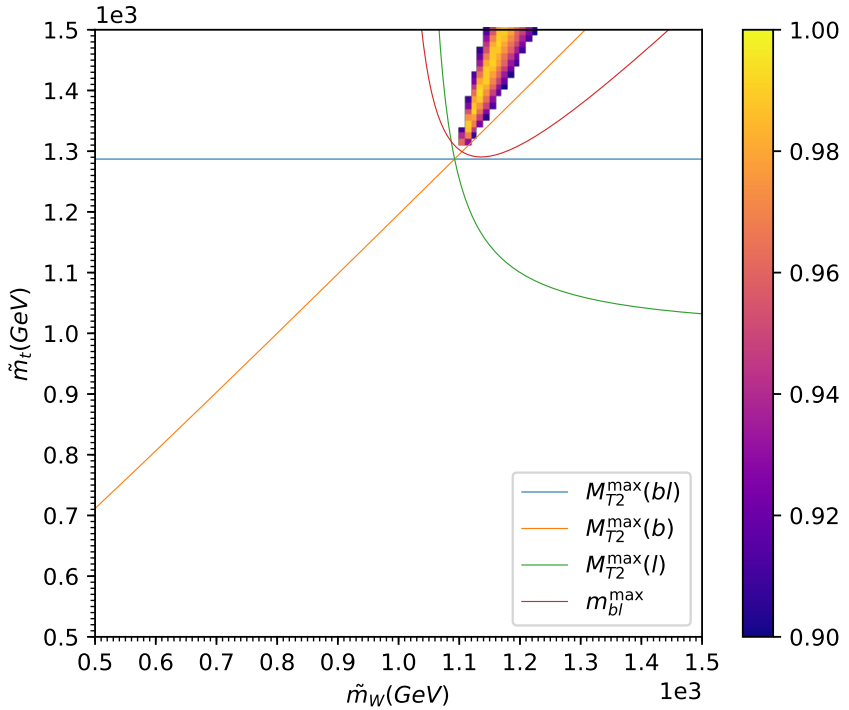
Bonus slides (finding $m_{\tilde{\nu}}$): Solvability + Endpoint measurements

$$\tilde{m}_{\tilde{\nu}} > m_{\tilde{\nu}}$$

$\tilde{m}_{\tilde{\nu}} = 800$ GeV

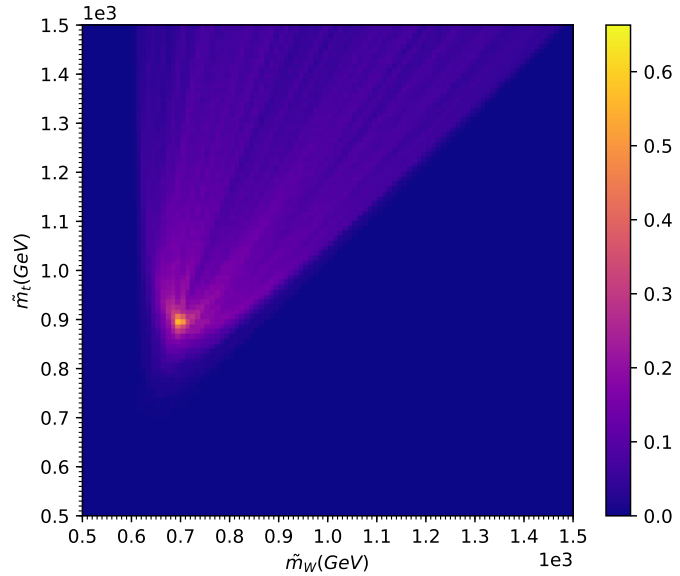


$\tilde{m}_{\tilde{\nu}} = 1000$ GeV

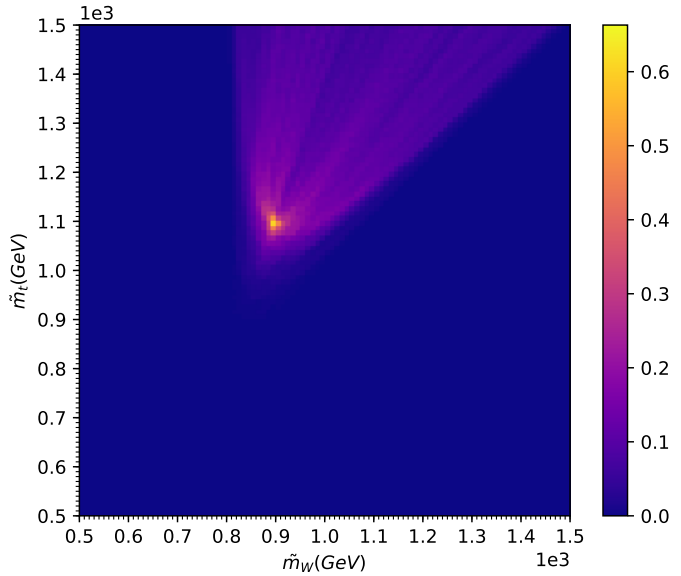


Bonus slides (finding $m_{\tilde{\nu}}$): Focus Points

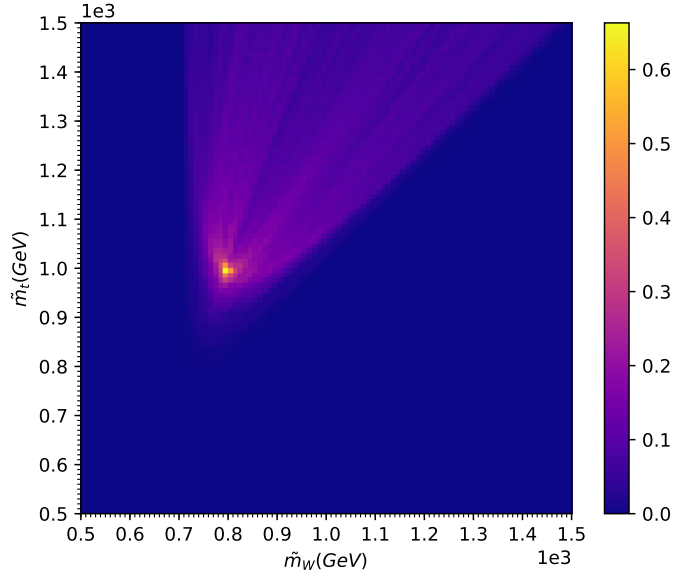
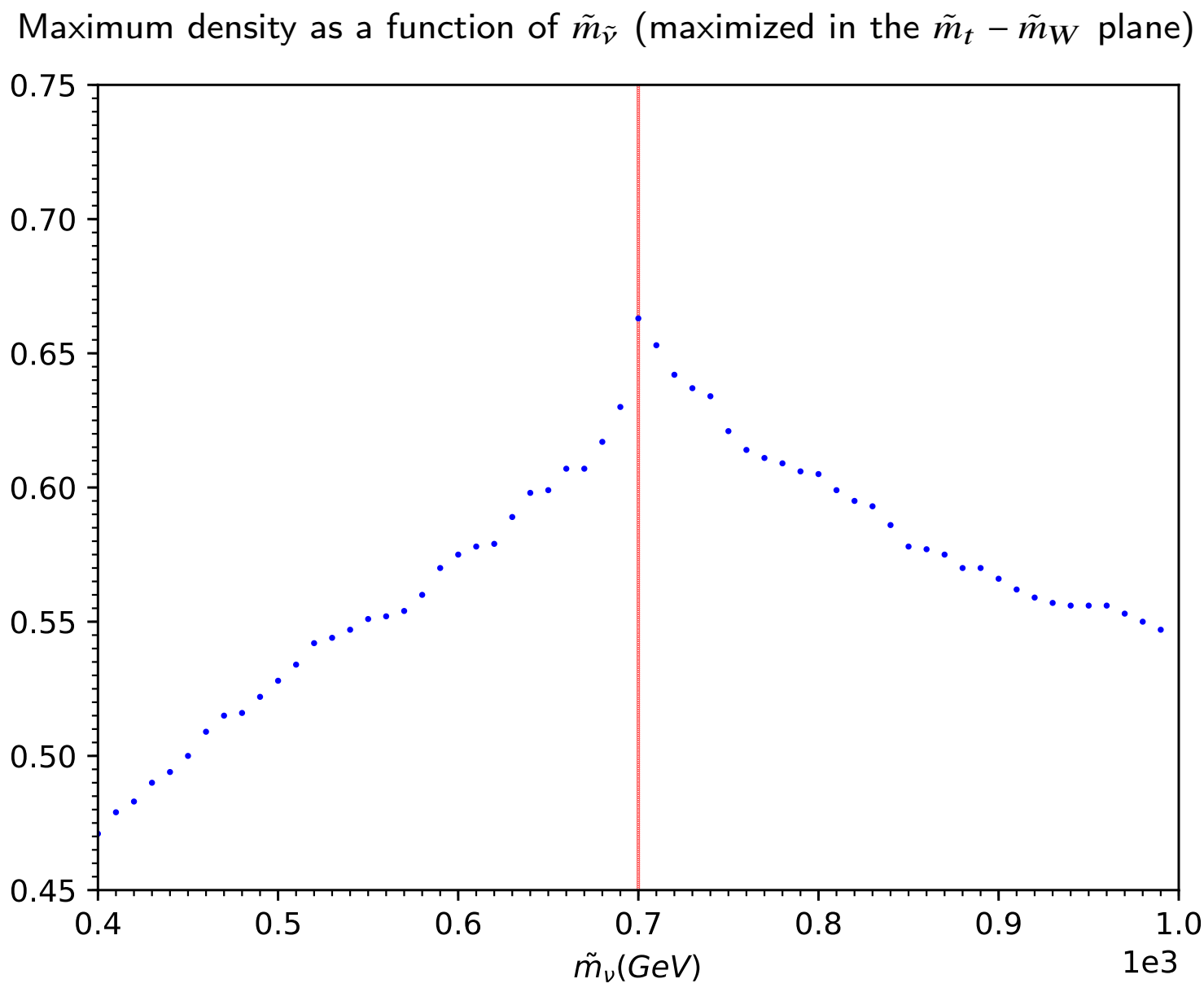
$\tilde{m}_{\tilde{\nu}} = 600$ GeV $< m_{\tilde{\nu}}$ (max $= 0.56$)



$\tilde{m}_{\tilde{\nu}} = 800$ GeV $> m_{\tilde{\nu}}$ (max $= 0.61$)



$\tilde{m}_{\tilde{\nu}} = 700$ GeV $= m_{\tilde{\nu}}$ (max $= 0.66$)



Bonus slides (finding $m_{\tilde{\nu}}$): Focus Points