A kinematic focus point method for mass measurements in ttbar events

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based on work with
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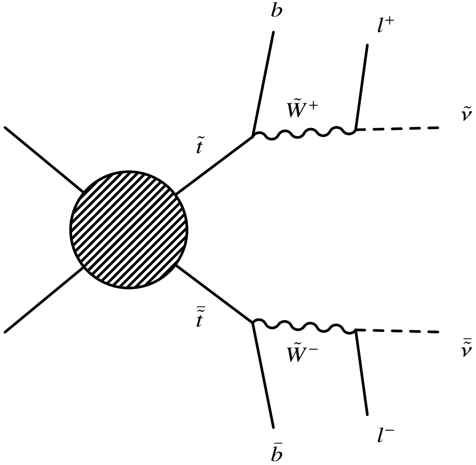
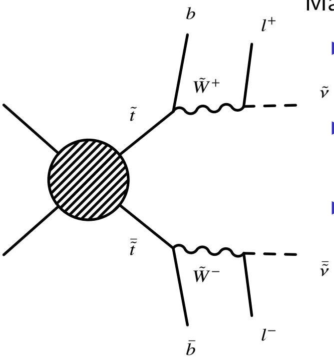
Goal of the talk

$t\bar{t}$ like BSM events (stop → chargino → sneutrino)



- We'll come up with a bump hunt method to search for this signal despite having two invisible particles in the final state
- Then we'll relate this method to SM $t\bar{t}$ events

Understanding the event space...



Masses $m_{\tilde{t}}$, $m_{\tilde{W}}$ and $m_{\tilde{\nu}}$ are apriori unknown.

- There are 6 final state particles. 4×3 + 2×4 = 20 momentum components.
- 12 or these are visible and the other 8 are invisible.
- The distribution of events in this 20 dimensional space is affected by
  1. 2 final state particle mass constraints (exact).
  2. 4 intermediate particle mass constraints (approximate).
  3. 2 MET constraints. $\vec{p}_{\tilde{\nu},T} + \vec{p}_{\bar{\tilde{\nu}},T} = \vec{\not{p}}_T$
  4. Parton distribution functions.
  5. Decay angles at the decay vertices (weak dependence).
- Number of constraints matches the number of invisible momentum components. The invisible momenta can be solved for (upto discrete ambiguity) assuming test values for the unknown masses.

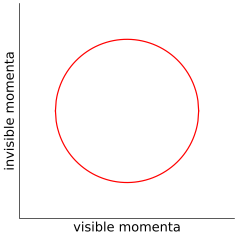
Constraint counting...

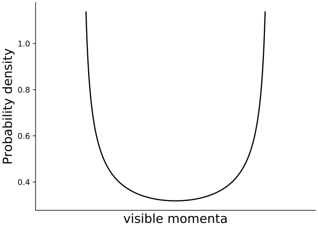
Notation:

- N : Total number of final state momentum components. 20 in our case.
- N_{vis} : Number of visible momentum components. 12 in our case.
- N_{invis} : Number of invisible momentum components. 8 in our case.
- N_{cons} : Number of non-degenerate equality constraints on the N momentum components. 8 in our case.

- Full-events are constrained to be on an $N - N_{\mathrm{cons}}$ dimensional manifold within the N dimensional full-event-space.
- 'Visible events' are constrained to be on the projection of this manifold on the N_{vis} dimensional visible-event-space.
- The dimensionality of this projection is $\min(N - N_{\mathrm{cons}}, N_{\mathrm{vis}})$.
- In our case, events lie on a 12 ($N - N_{\mathrm{cons}}$) dimensional manifold within the full event space. This gets projected onto a 12 (N_{vis}) dimensional visible-event-space. The projection has the same dimensionality.

Special case: $N - N_{\mathrm{cons}} = N_{\mathrm{vis}}$ or $N_{\mathrm{cons}} = N_{\mathrm{invis}}$





- Jacobian factor when projecting surface onto a hyper-plane of same dimensionality
- Probability density has a singularity where the surface is perpendicular to the visible space.
- Extreme events — degenerate solutions when solving for invisible-momenta
- Examples: Projecting a circle on a line or hollow sphere on a 2-D plane

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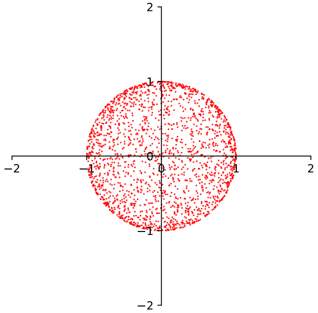
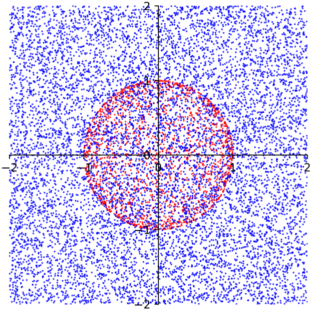


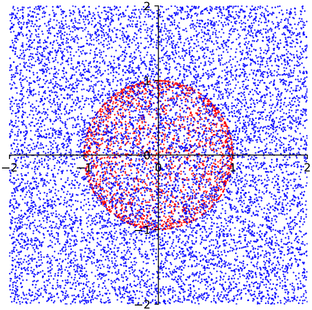
Projection of points uniformly distributed on a hollow sphere onto a 2D plane

Special case: $N - N_{\text{cons}} = N_{\text{vis}}$ or $N_{\text{cons}} = N_{\text{invis}}$



Projection of points uniformly distributed on a hollow sphere onto a 2D plane
(With a background)

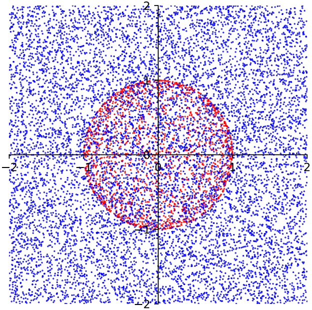
Special case: $N - N_{\rm cons} = N_{\rm vis}$ or $N_{\rm cons} = N_{\rm invis}$



Projection of points uniformly distributed on a hollow sphere onto a 2D plane
(With a background)

Signal-Background ratio peaks for extreme events

Special case: $N - N_{\rm cons} = N_{\rm vis}$ or $N_{\rm cons} = N_{\rm invis}$



- The shape of the projection and the location of the extreme events are characteristic of the unknown mass parameters

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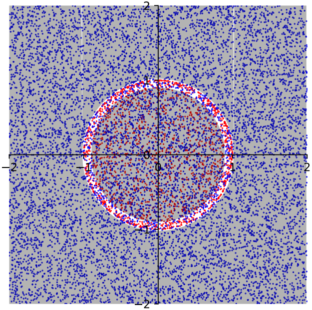
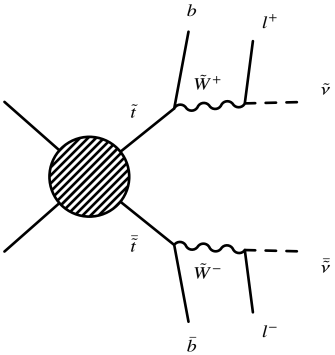


- The shape of the projection and the location of the extreme events are characteristic of the unknown mass parameters
- Idea: Map only the extreme events of a parameter-point to it
- In other words, map an event to all points in the parameter space for which that event would be an extreme event

Back to our $t\bar{t}$ like BSM events

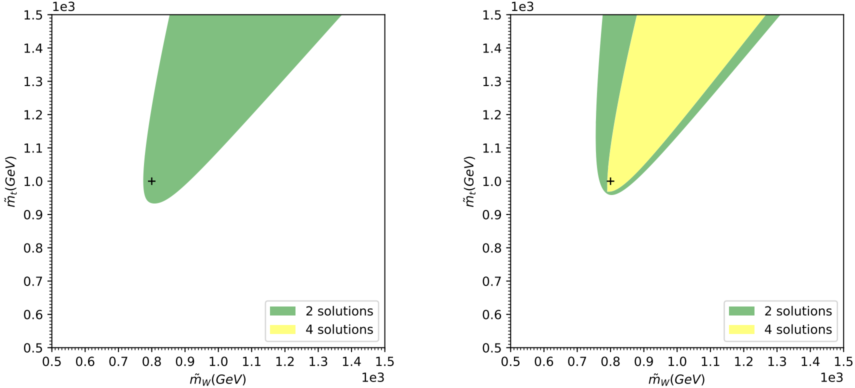


Let's work with on-shell events at LHC energy with the following "true" mass spectrum

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

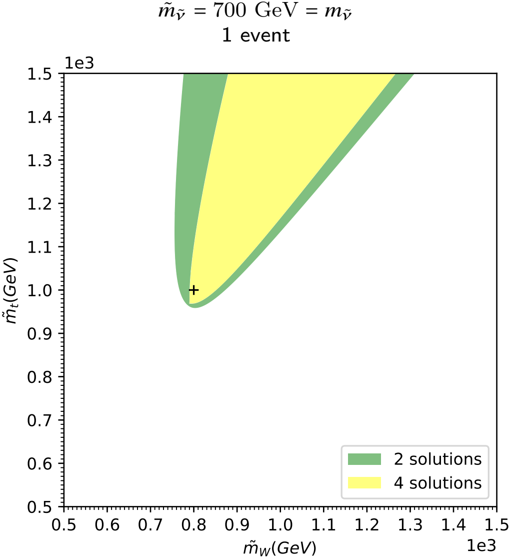
Two sample events

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



Extremeness boundaries

"Map an event to all points in the parameter space for which that event would be an extreme event" – Boundaries where no. of solutions changes



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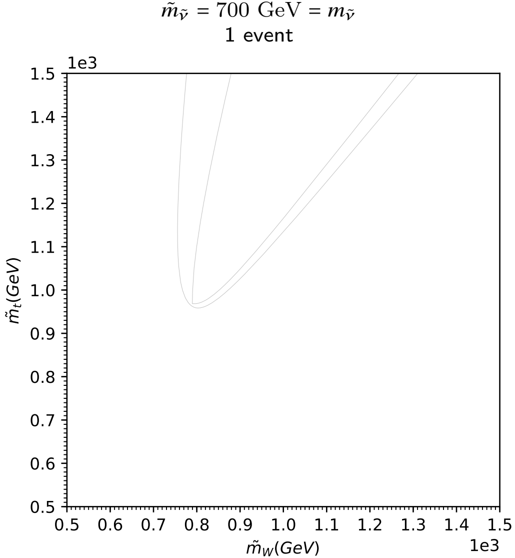

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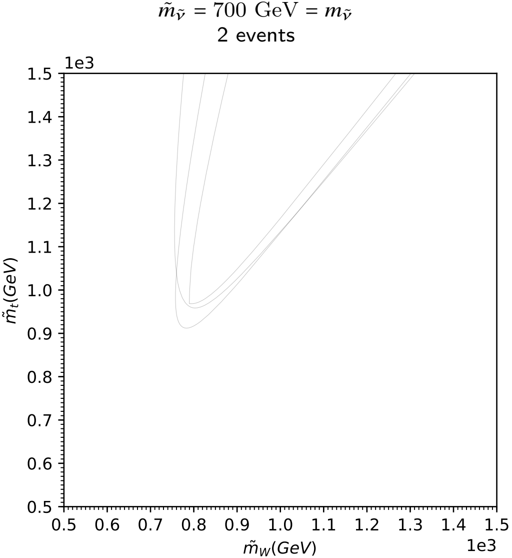
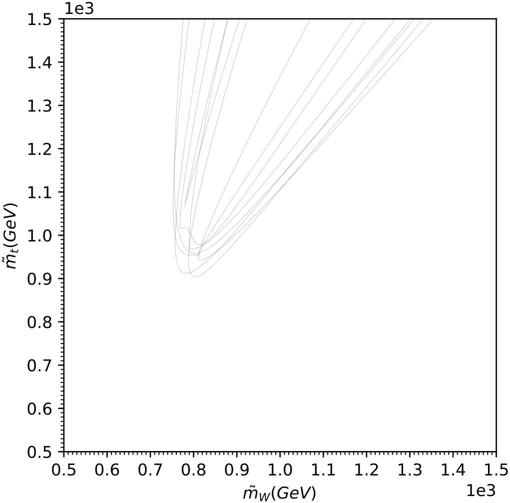


Extremeness boundaries

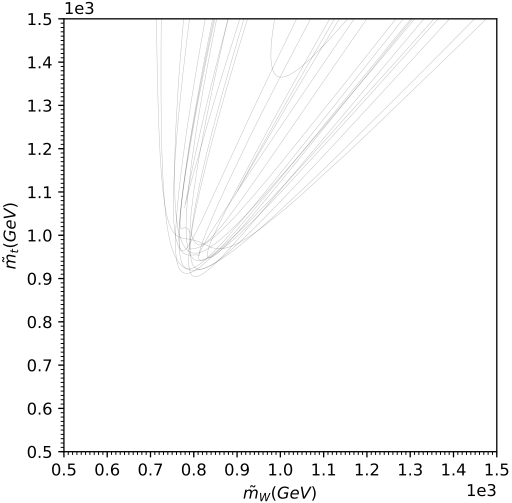
"Map an event to all points in the parameter space for which that event would be an extreme event" – Boundaries where no. of solutions changes

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



"Map an event to all points in the parameter space for which that event would be an extreme event" – Boundaries where no. of solutions changes

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



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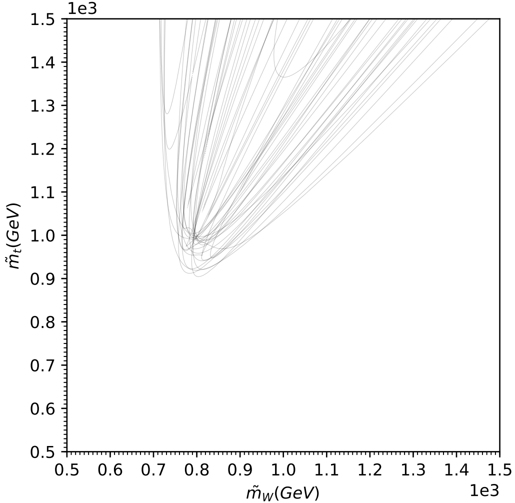
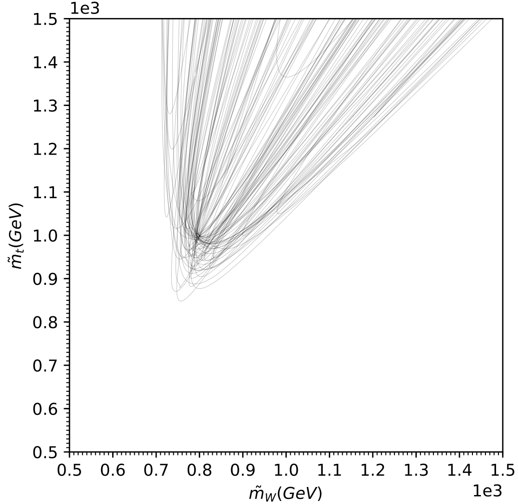


Extremeness boundaries

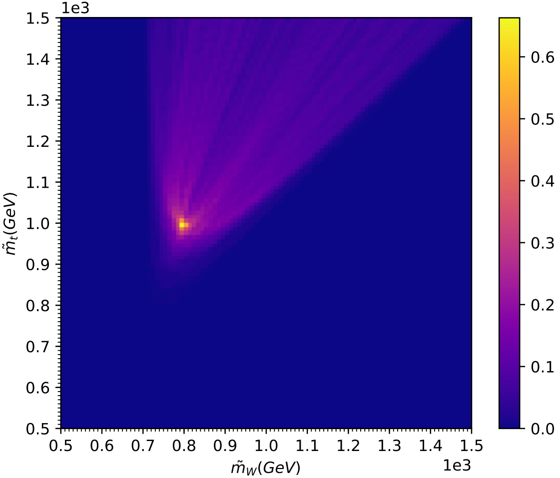
"Map an event to all points in the parameter space for which that event would be an extreme event" – Boundaries where no. of solutions changes

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

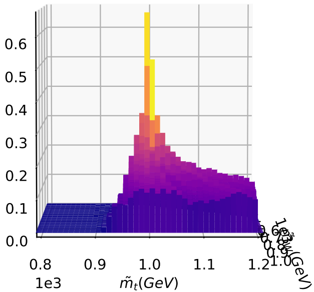
50 events (Extreme events are abundant!)

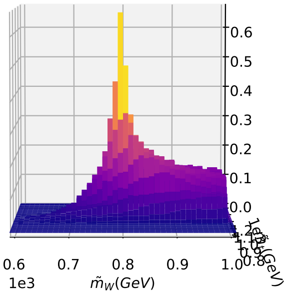


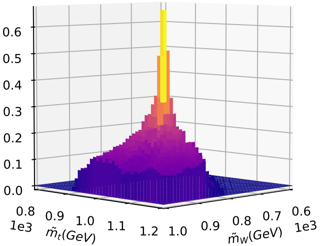
MONEY PLOT!
Fraction of events whose extremeness boundaries pass through a 10 GeV x 10 GeV square



Bump hunt for diagram with missing particles!





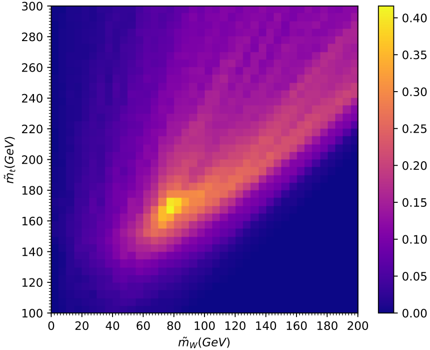


Statistics

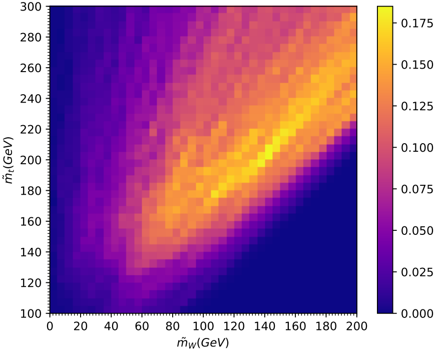
- Each event provides a candidate curve (extremeness boundary) of masses in the 2D parameter space (or candidate surface in 3D). We see a sharp peak in the density of these curves at the true mass.
- Statistics of these extremeness curves or surfaces isn't straight forward.
- The number of events passing through a certain well-defined region is a Poisson distributed random variable.
- But an event passing through a certain region/bin isn't independent of it passing through other bins. This needs to be properly accounted for to keep the look-elsewhere effect under control.
- Work needs to be done to turn this into a BSM search technique.
- In the meantime, it can be used in SM $t\bar{t}$ physics – to enhance $t\bar{t}$ events as a signal... to remove them as background... to measure top mass...

SM $t\bar{t}$ vs irreducible bg (mostly single t)

$t\bar{t}$ events



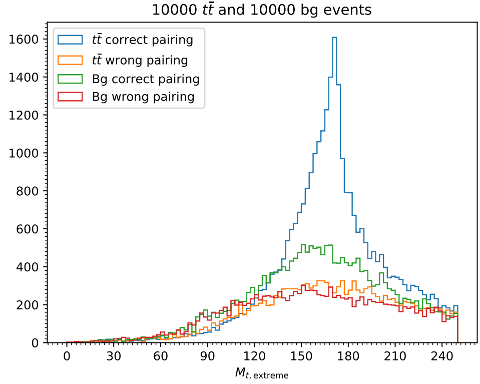
Irreducible bg events



- These are not probability density heatmaps.
- The signal-bg separation is better than this picture might suggest.

A preliminary 1d plot and future work

- We set the neutrino mass to 0 to get a 1D curve in a 2D parameter space.
- Similarly, we can set W mass to its true value to get points in the 1D parameter space.
- This can be used in top mass measurement.



Notes

- No detector simulation. Jet resolution will smear the peak.
- Each event contributes multiple points to the histogram. Upto 12 for one lepton-quark pairing! Typically 4.
- Can also use the slope the curves make at the m_W intercept in top mass measurement.

Thank you!