Searching for Unknown Particles in 2-Dimensional Mass Space

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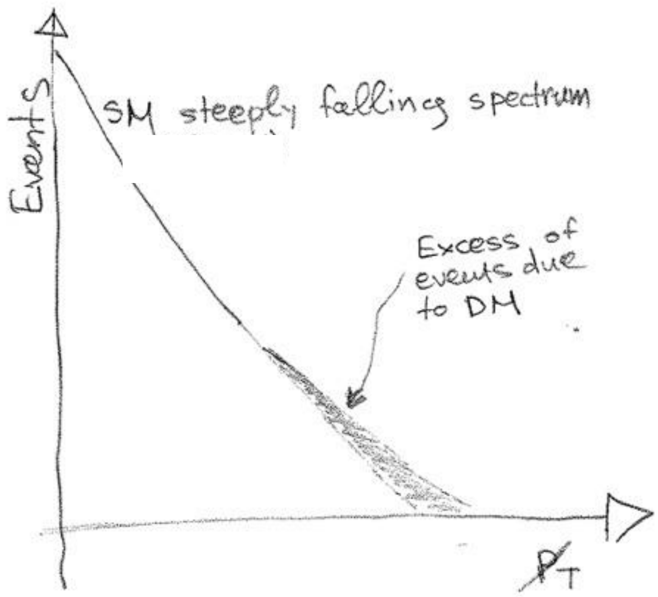
How to search for dark matter @ the LHC?

Models with dark matter particles (like susy) have at least 2 invisible particles (undetectable) → use M_{ET} – like observables.



Discovery with missing energy difficult to be established (tail of a rapidly falling distribution).

Even if established what can we say about the model?

Why Mass Space?

Most important characteristic of elementary particles → mass, spin. So why not search in mass space with

Dimensions = number of unknown particles?

It is often believed that mass reconstruction is not possible in events with 2 invisible particles. Not really!

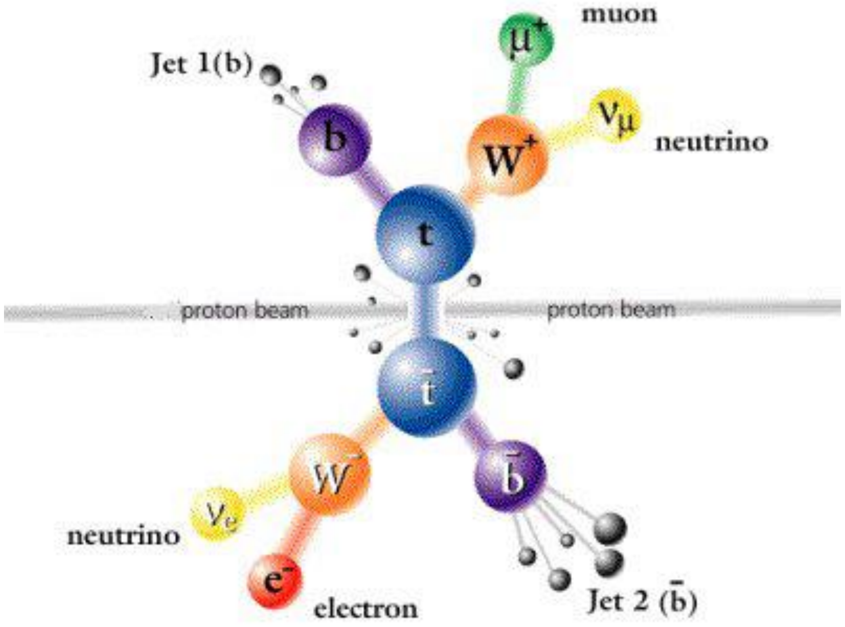
Question(s)

Could we find the mass of the top quark and W boson in LHC from top-pairs decaying leptonically in the hypothetical case in which both m_t and m_W were unknown?

Could we establish a discovery by observing the mass peaks above background for both particles without assumptions (except the decay topology) about the underlying theory?

Why top-pairs?

"Rediscovery" of both top and W in a model independent way would be a "proof of principle" for the method.



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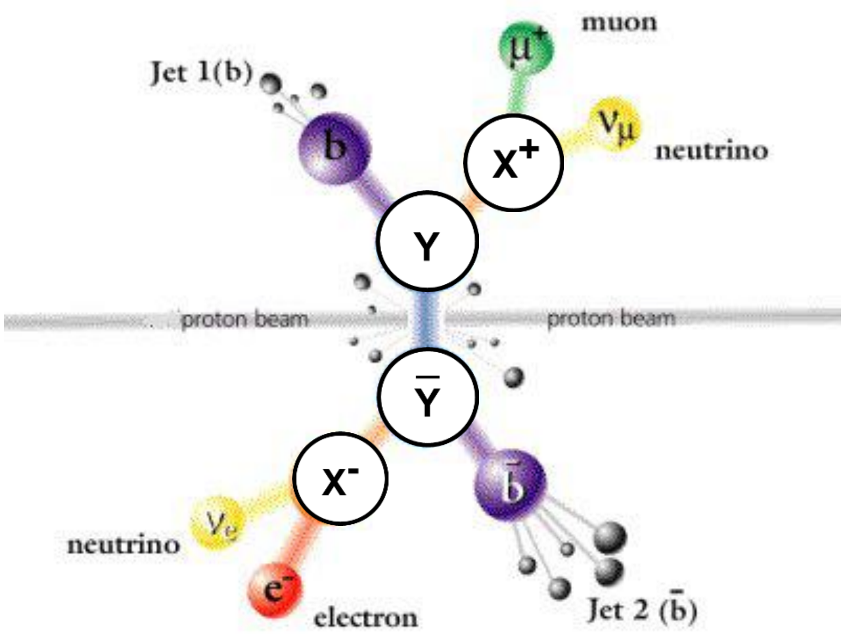
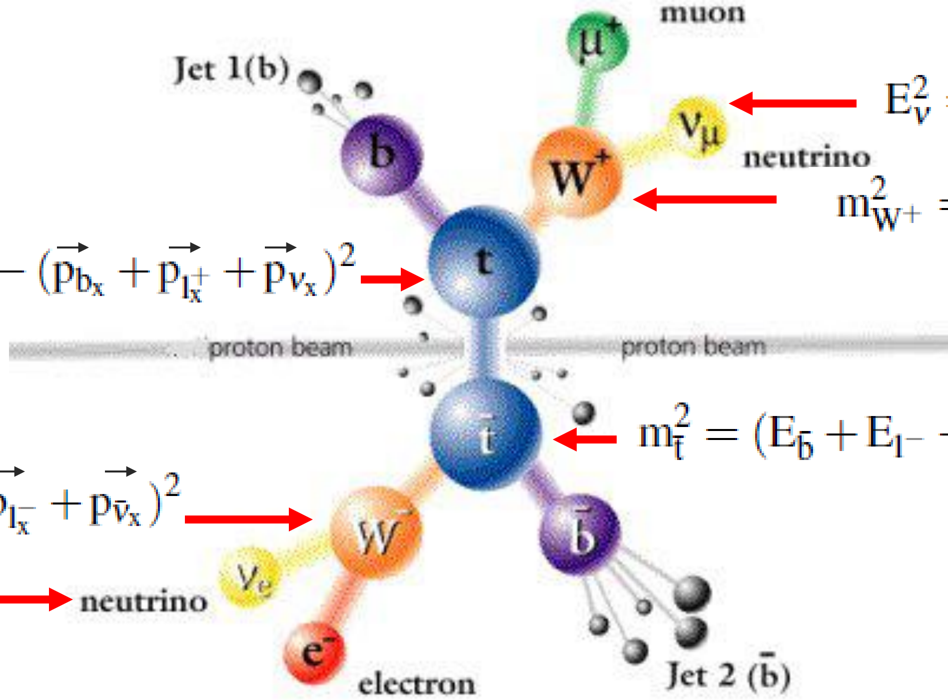


For X= W boson, T' search
For pp → Z' → YY, Z' search

We can search for anything anything decaying like dilepton top-pairs

Analytical solution of dilepton top pairs



1. $m_t^2 = (E_b + E_{l^+} + E_\nu)^2 - (\vec{p}_{b_x} + \vec{p}_{l^+_x} + \vec{p}_{\nu_x})^2$

2. $E_\nu^2 = p_{\nu_x}^2 + p_{\nu_y}^2 + p_{\nu_z}^2$

3. $m_{W^+}^2 = (E_{l^+} + E_\nu)^2 - (\vec{p}_{l^+_x} + \vec{p}_{\nu_x})^2$

4. $m_{\bar{t}}^2 = (E_{\bar{b}} + E_{l^-} + E_{\bar{\nu}})^2 - (\vec{p}_{\bar{b}_x} + \vec{p}_{l^-_x} + \vec{p}_{\bar{\nu}_x})^2$

5. $m_{W^-}^2 = (E_{l^-} + E_{\bar{\nu}})^2 - (\vec{p}_{l^-_x} + \vec{p}_{\bar{\nu}_x})^2$

6. $E_{\bar{\nu}}^2 = p_{\bar{\nu}_x}^2 + p_{\bar{\nu}_y}^2 + p_{\bar{\nu}_z}^2$

+ missing energy

7. $M_{ET_y} = p_{\nu_y} + p_{\bar{\nu}_y}$

8. $M_{ET_x} = p_{\nu_x} + p_{\bar{\nu}_x}$

Analytical solution of dilepton top pairs(II)

An analytical solution for the equations of the top-pair system is described in L. Sonnenschein, “Analytical solution of tt dilepton equations”, Phys. Rev. D 73, 054015, 2006.

$MET_{x,y}$
2 bjet momenta
2leptons momenta
M_{top}, M_W

$$m^2_{W^+} = (E_{l^+} + E_{\nu})^2 - (p_{l^+_x} + p_{\nu_x})^2 - (p_{l^+_y} + p_{\nu_y})^2 - (p_{l^+_z} + p_{\nu_z})^2$$

$$m^2_{W^-} = (E_{l^-} + E_{\bar{\nu}})^2 - (p_{l^-_x} + p_{\bar{\nu}_x})^2 - (p_{l^-_y} + p_{\bar{\nu}_y})^2 - (p_{l^-_z} + p_{\bar{\nu}_z})^2$$

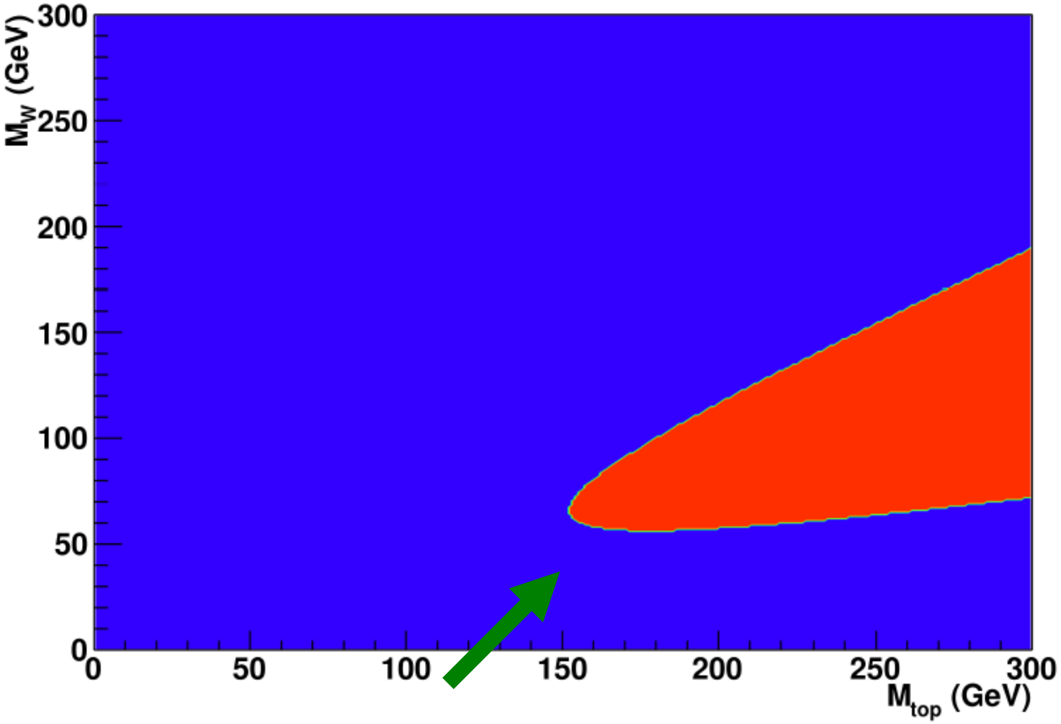
system of 8 equations

0,2 or 4
solutions/combination
x 2 combinations/event

Each solution gives the momentum vectors of the 2 neutrinos

Solvability of a single event in mass plane

Masses of the particles are unknown → only option is to test every point of the m_t, m_W plane for possible solutions.

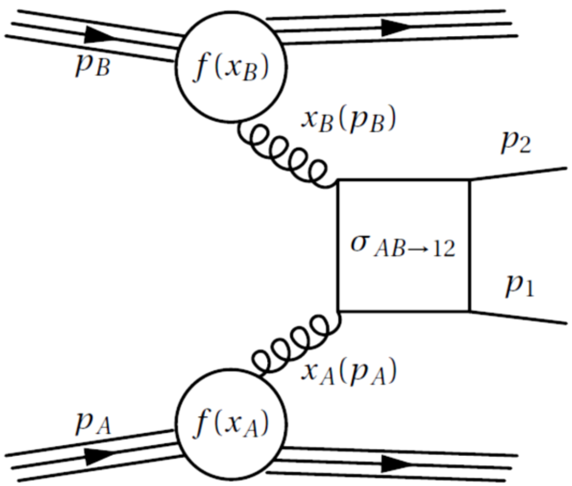


Solvability for a single event is defined as the existance (or not) of a specific solution in a specific mass point

solvability is bound only from below for both m_t and m_W.

Upper bound ?

Due to the finite collision energy there is also an upper limit on the allowed masses produced.



Full reconstruction of event kinematics → energy E and P_Z of the tt system.

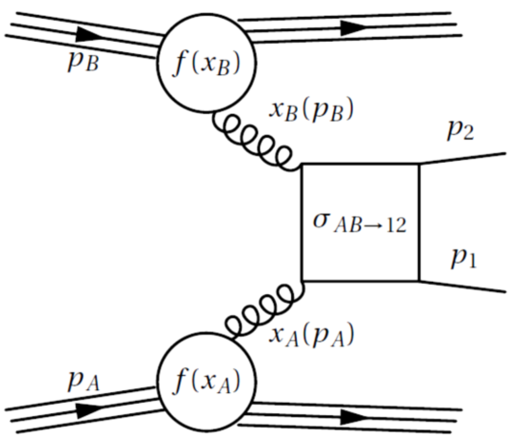
⇩

Calculation of fraction of beam energy of the two partons ($x_{A,B} = (E \pm p_z)/2$).

⇩

Each parton with fraction $x_{A/B}$ has a probability $f(x_{A/B})$ to originate from a p-p collision.

Upper bound (II)



So $f(x_A)f(x_B)$ is weight per solution and incoming parton combination

⇓ sum over all possible incoming partons $u\bar{u}$, $\bar{u}u$, $d\bar{d}$, $\bar{d}d$, gg

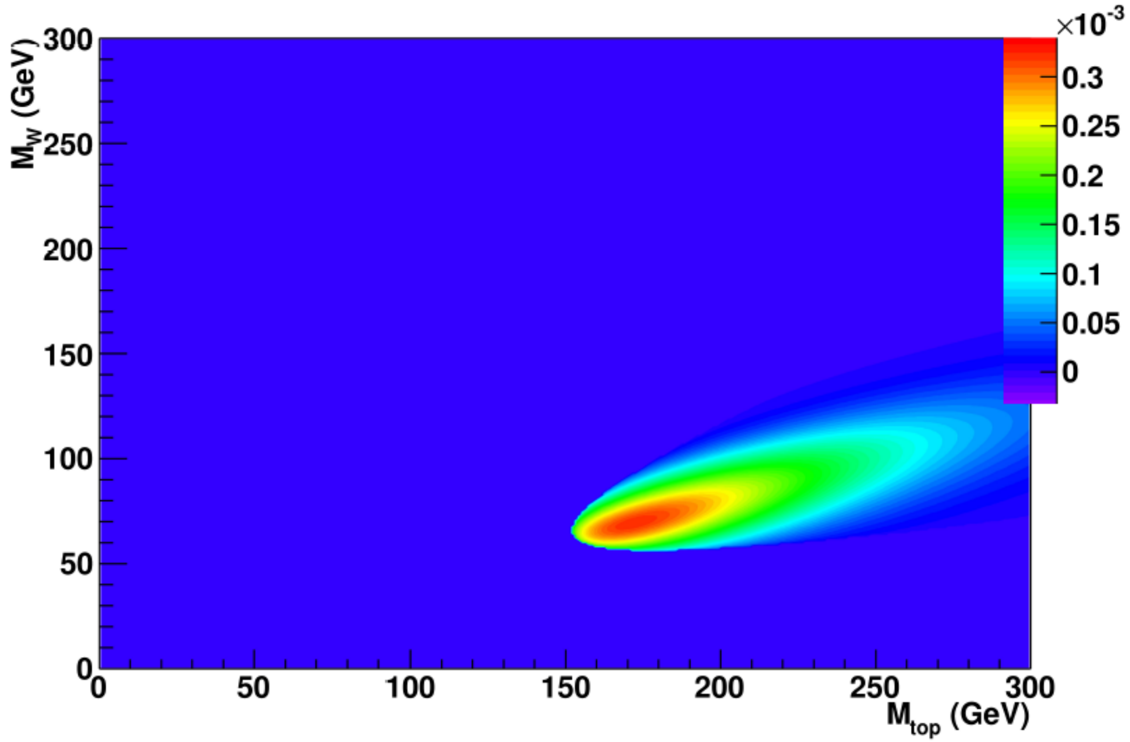
PDF weight = $\sum f(x_A)f(x_B)$ is final event weight per solution, per mass point

⇓

$S(m_t,m_W) \times PDF(m_t,m_W)$, $PDF=\sum f(x_A)f(x_B)$

Solvability S=0/1 of a solution for test masses m_t, m_W can be multiplied with its PDF weight to provide upper bound.

Solvability times PDF weight



$$S(m_t, m_W) \times PDF(m_t, m_W), \quad PDF = \sum f(x_A) f(x_B)$$

single event in mass space!

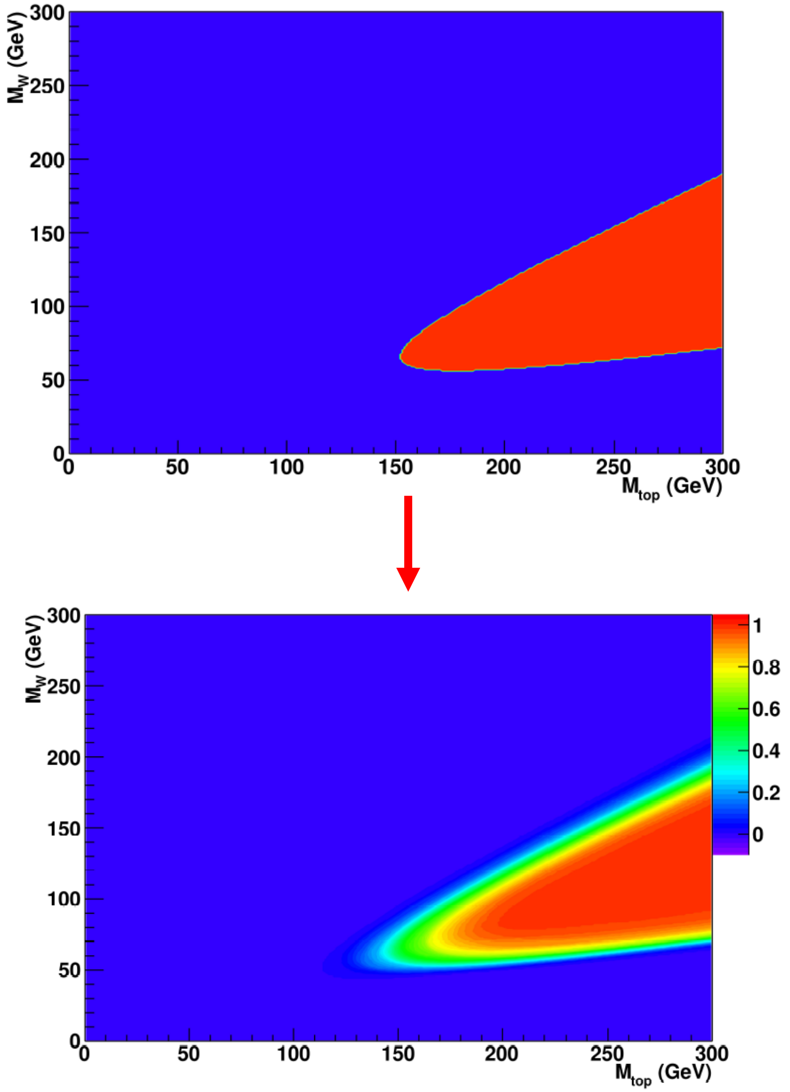
Detector effects – Loss of a solution

Detector effects can change a solvable event to not-solvable.

Solvability can be recovered by smearing the leptons and jets according to detector resolution.

For each initial data event, N test events can be created by smearing the leptons, according to the detector resolutions.

Solvability can be defined as the fraction of them for which a specific solution exists.



Solvability x PDF weight (II)

The value obtained is averaged over all N test events and normalized to unit volume.

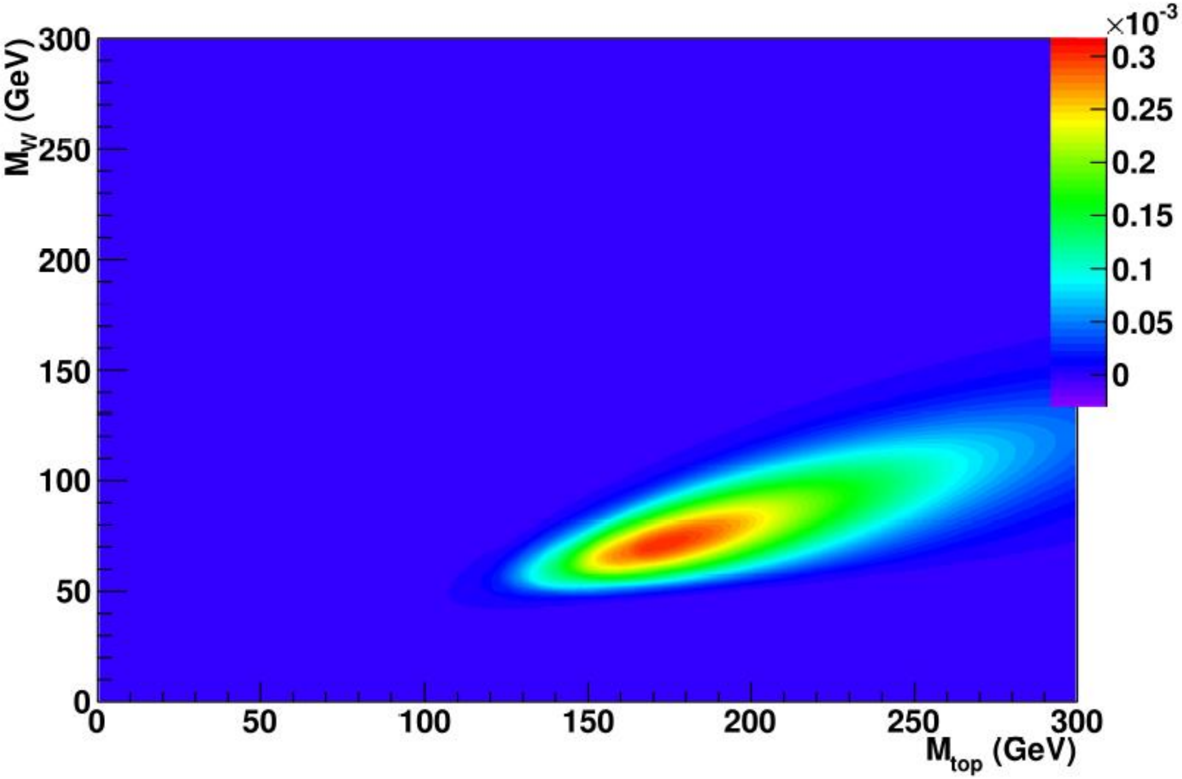
$$P(m_t,m_W)=(1/V)\sum_{i=1}^{N\ \text{test events}} S_i(m_t,m_W) \times PDF_i(m_t,m_W)$$

V=volume used for normalization

Such a distribution can be constructed for all possible solutions. Among all solutions, the one with the highest PDF weight is chosen.

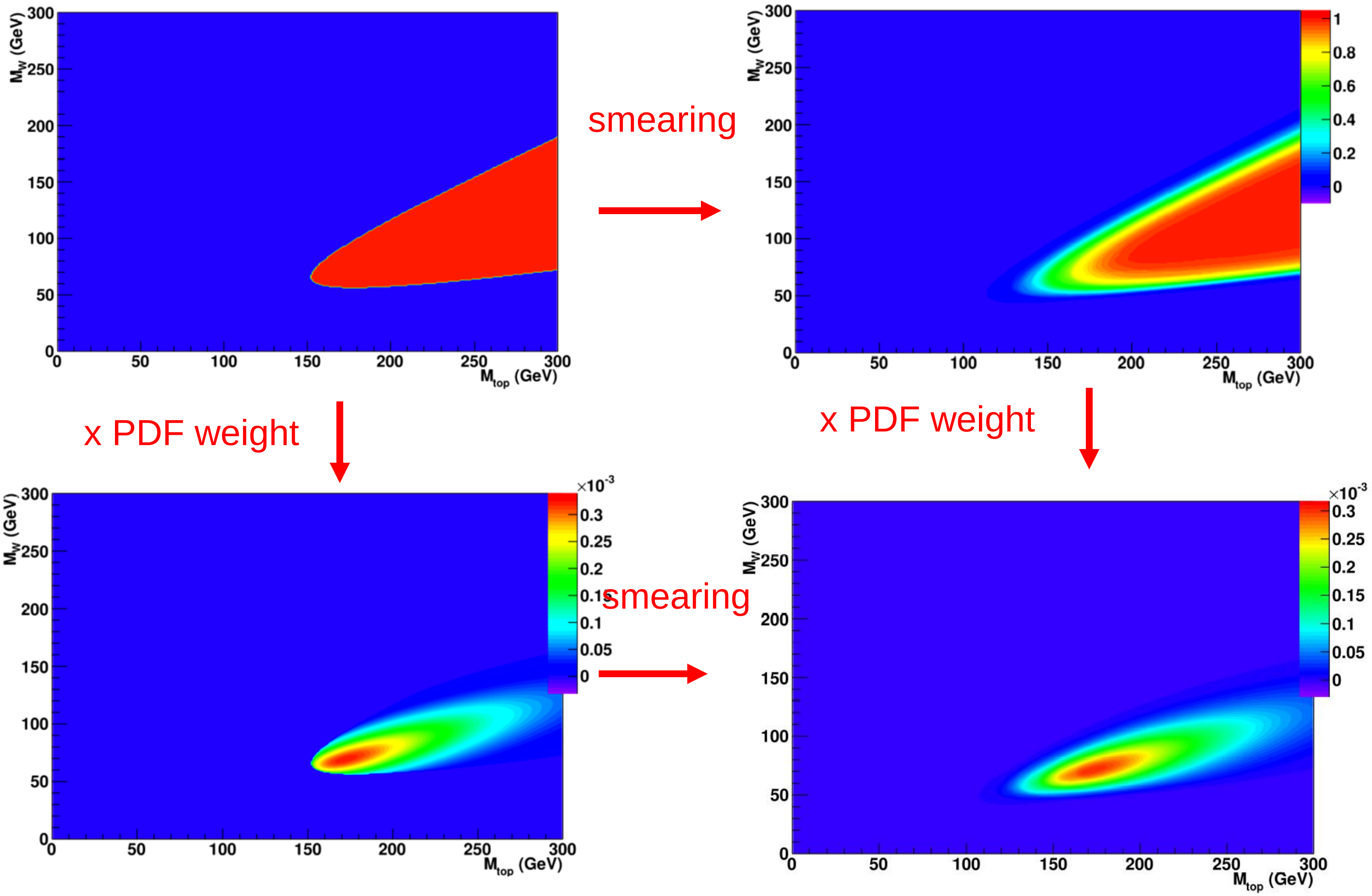
Final distribution per event

The final m_t and m_W estimation is the point where the distribution of the prefered solution is maximized.

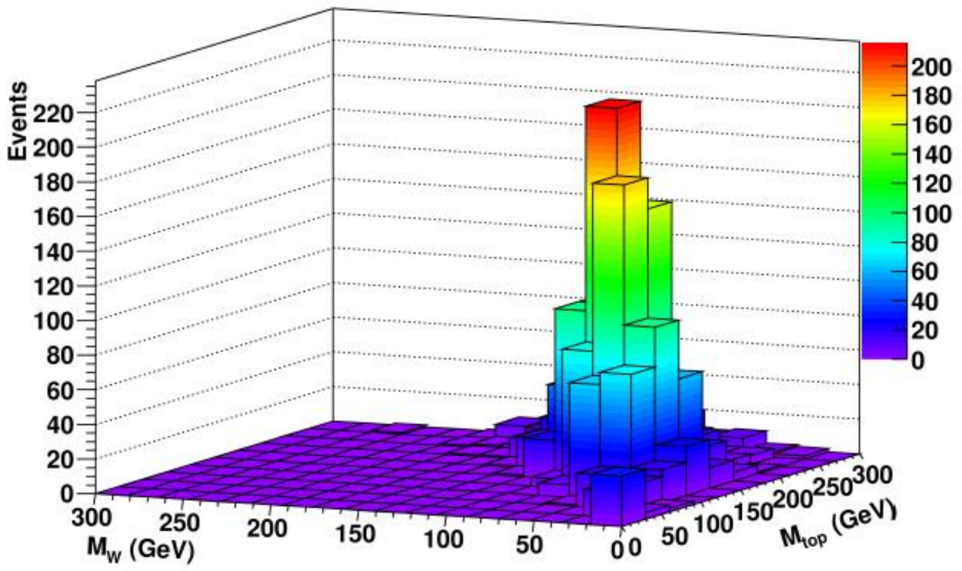


The above procedure gives a single mass point per event!

Finally for a single event



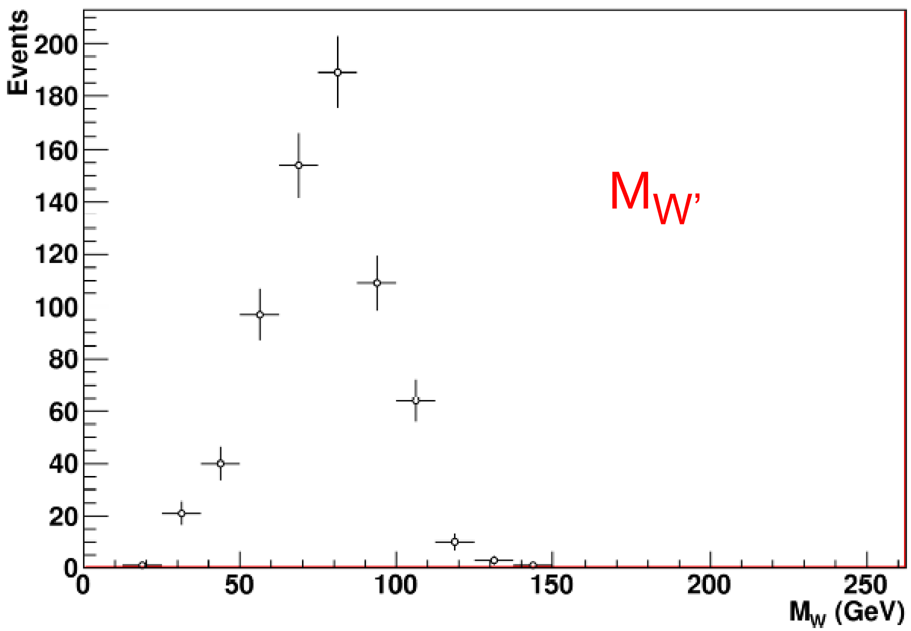
2-D mass reconstruction – Top pairs + background

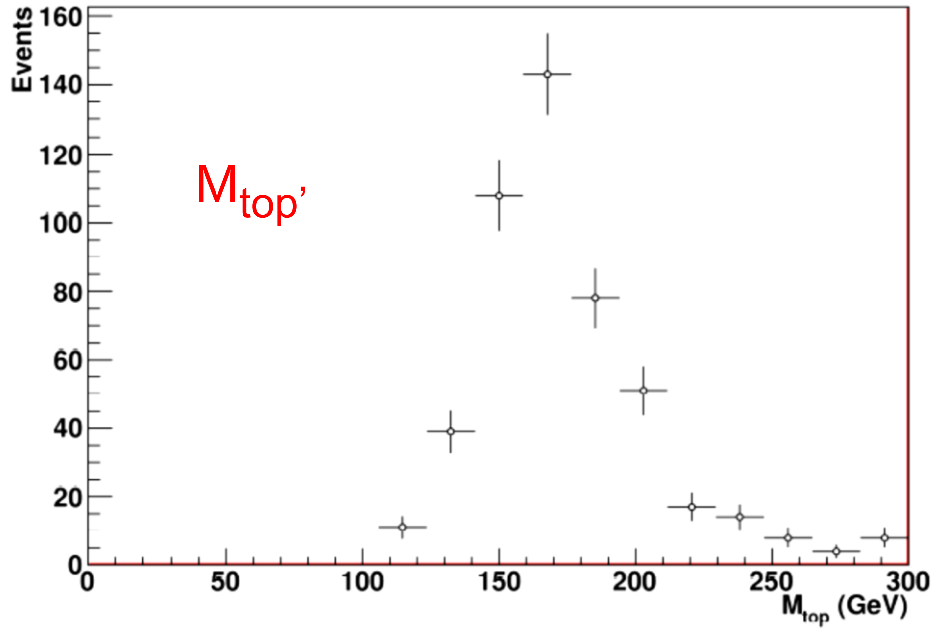


1 fb^{-1} pythia events with fastjet genjets and smearing for leptons and jets & MET typical for an LHC detector (like CMS)

Signal: inclusive top-pairs, Backgrounds: W→lν, Z→ll, WW, WZ, ZZ

Projection of 2-D to 1-D mass axis



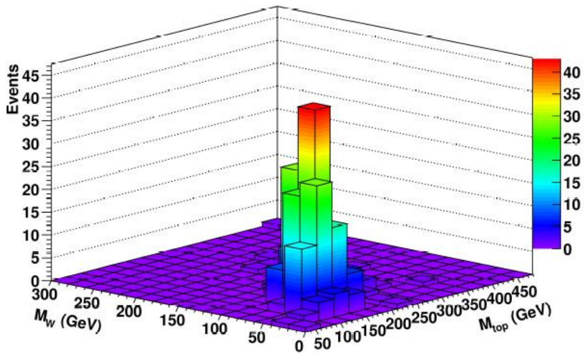


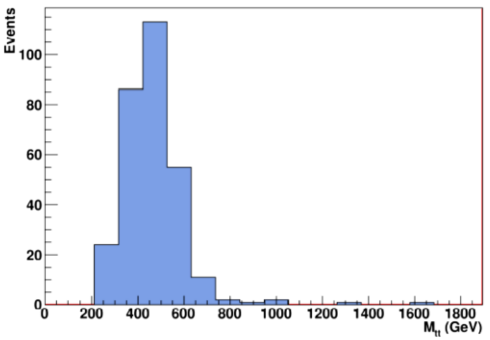
Could we find the mass of the top quark and W boson in LHC from top-pairs in the hypothetical case in which both m_t and m_W were unknown?

Yes!

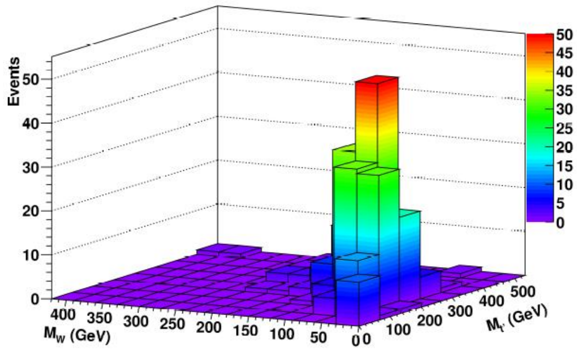
Could we establish a discovery by observing the mass peaks above background for both particles without assumptions (except the decay topology) about the underlying theory?

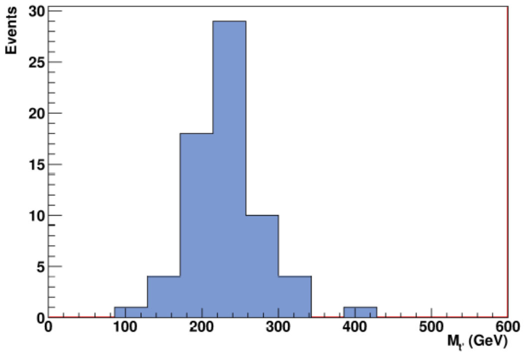
Searching for Z'→ tt   t't'→WbWb





Z' generated @ 500 GeV. Reconstruction of $M_{Z'}$

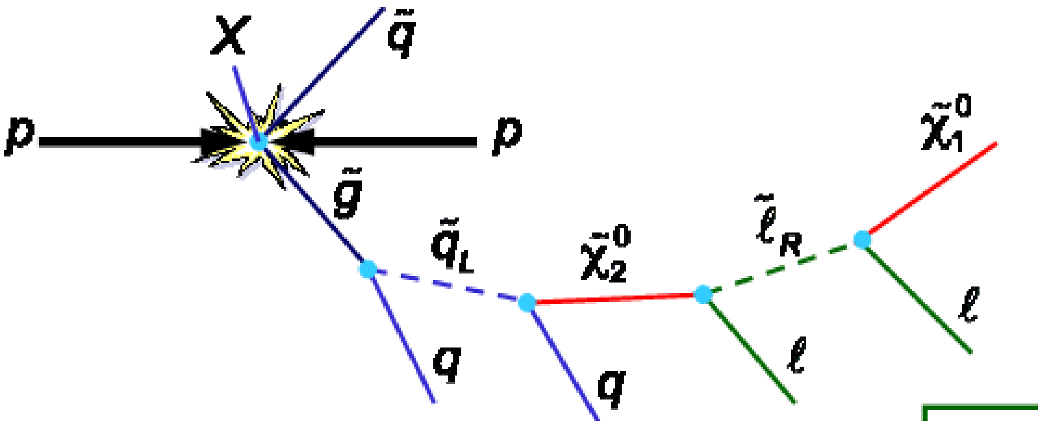




T' generated @ 250 GeV. Reconstruction of $M_{T'}$

Nest step – Search for susy in 4 leptons +MET final state

Method is already applied in CMS (G.Anagnostou, Sarah Beranek, Andreas Psallidas) to search for Z', T' and models with 2 unknown particles decaying like dilepton top pairs (e.g little higgs models)



Can be used for $X \to t\bar{t}$, TH TH→WH b WH b (little higgs), Susy (stop cascades) etc. Next step, search in next Run for the 4 lepton+MET final state for susy -bump hunt in 2 mass Dimensions.

Conclusions

It is feasible to reconstruct particle masses in topologies with two invisible particles More details in http://arxiv.org/abs/1112.3379v1

“Rediscovery” of both top and W in a model independent way can be used as a proof of principle.

No theory/model assumption except the event topology.

No Monte-Carlo is necessary as the masses are reconstructed and background can be estimated from sidebands.

Method is applied to CMS data to search for Z’, T’ and anything decaying like dilepton top-pairi (e.g little higgs models).

Next step is to search for susy in 2D using the 4leptons+MET final state.

References

R. H. Dalitz and G. R. Goldstein, The decay and polarization properties of the top quark, Phys. Rev. D45 (1992) 1531. doi:10.1103/PhysRevD.45.153.

D0 Collaboration, Measurement of the top quark mass in final states with two leptons Phys. Rev. D80, 092006 (2009).

L. Sonnenschein, Analytical solution of $t\bar{t}$ dilepton equations, Phys. Rev. D 73, 054015, 2006.

G.Anagnostou,Model Independent Search in 2-Dimensional Mass Space http://arxiv.org/abs/1112.3379v1