Constrained Mass Variable for Analysing Event with Missing Particles

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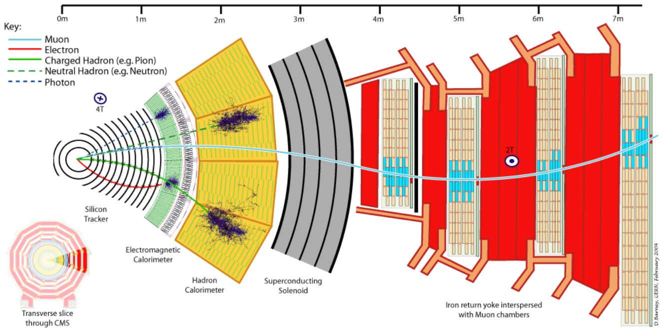
Missing particle inside Particle Detector



Particle physics detectors, such as ATLAS and CMS, are designed to detect particles

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Missing particle inside Particle Detector

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In general, neutral particle without EM interation and which are not hadron and just pass through detectors. For example

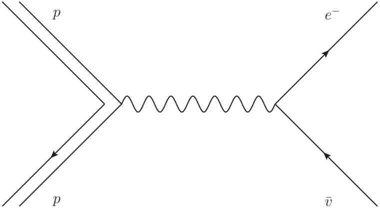
- Neutrinos
- Darkmatters
- and other neutral and stable BSM particles, such as lightest supersymmetric partner

For example, in the standard model, there is a famous process with missing particle:

- $w^- \to l^- \bar{v}$

How can we deal with a collision event with these particles?

W boson and M_T



M_T is a mass variable which is a transverse projection of invariant mass.

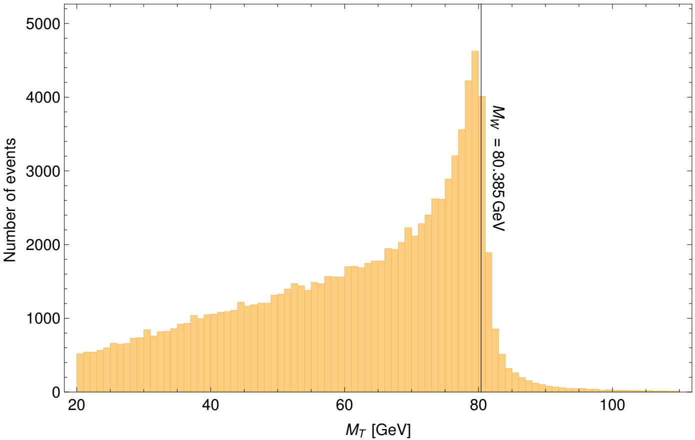
$$M_T^2 = (E_T(e^-) + E_T(\bar{v}))^2 - (\mathbf{p}_T(e^-) + \mathbf{p}_T(\bar{v}))^2 \quad (1)$$

where $\mathbf{p}_T$ is a transverse momentum and $E_T^2 = m^2 + |\mathbf{p}_T|^2$ is a transverse energy.

$$\begin{aligned} M_T^2 &= (E_T(e^-) + E_T(\bar{v}))^2 - (\mathbf{p}_T(e^-) + \mathbf{p}_T(\bar{v}))^2 && (2)\\ &= m_{e^-}^2 + m_{\bar{v}}^2 + 2(E_T(e^-)E_T(\bar{v}) - \mathbf{p}_T(e^-)\cdot\mathbf{p}_T(\bar{v})) && (3)\\ &\leq m_{e^-}^2 + m_{\bar{v}}^2 + 2(E_T(e^-)E_T(\bar{v})\cosh\Delta y - \mathbf{p}_T(e^-)\cdot\mathbf{p}_T(\bar{v})) && (4)\\ &= M^2 && (5) \end{aligned}$$

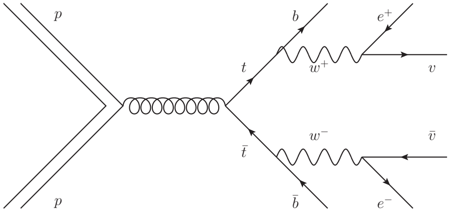
M_T distribution has a kinematical endpoint at $M_T^{\max} = M$

M_T spectrum



- Endpoint of M_T matches M_W.
- Only applicable when there is a single missing particle
- What other methods available when there are more than two missing particles?

Top pair production and M_{T2}, M_2



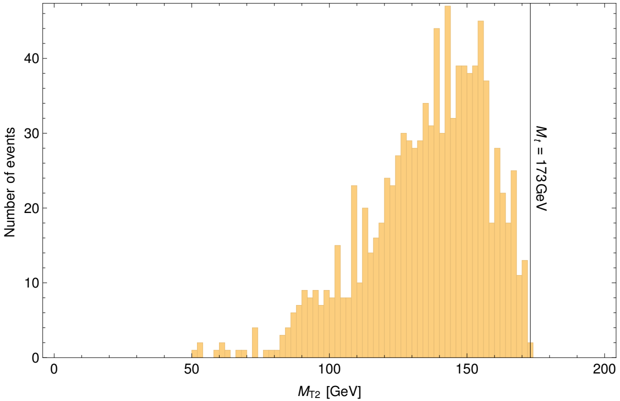
M_{T2} [1, 2, 3] and M_2 [4] are variant of M_T variable,

$$M_{T2} = \min_{\mathbf{q}_1+\mathbf{q}_2=\not{E}_T} \max\{M_T(t), M_T(\bar{t})\} \tag{6}$$

$$M_2 = \min_{\mathbf{q}_1+\mathbf{q}_2=\not{E}_T} \max\{M(t), M(\bar{t})\} \tag{7}$$

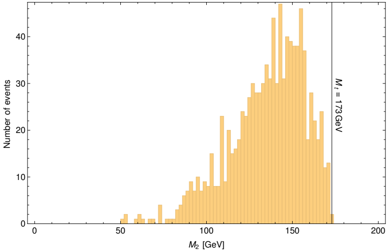
They also have a kinematical endpoint at $M_{T2},\ M_2 < M$

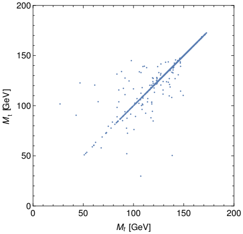
M_{T2} spectrum

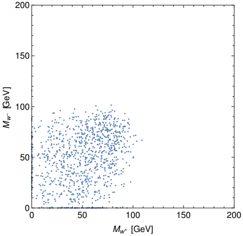


- Endpoint of M_{T2} matches M_t.
- Sharpening edge gives more resolution to test particle mass
- One slight problem...

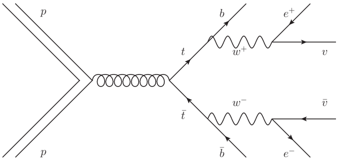
M_2 spectrum and reconstructed top and W mass

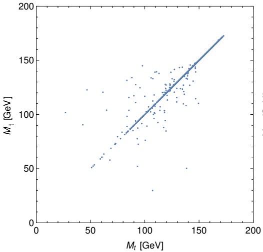


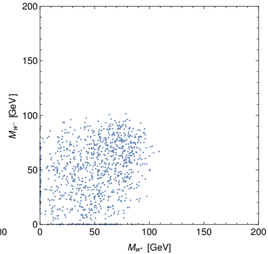




Reconstructed top and W mass







- Reconstucted particle mass does not obey process topology
  - Reconstructed top masses of each decay chain are not symmetric.
  - Reconstructed W masses of each decay chain are not symmetric.
- One can improve result by requiring such constraints.

Constrainted Minimization

When we calculate M_2 variable, we can additionally require constraints [5]

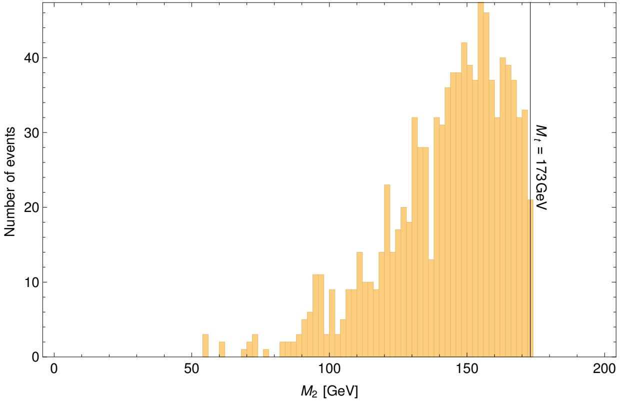
$$M_{2CC} = \min_{\substack{\mathbf{q}_1+\mathbf{q}_2=\not{E}_T \\ M(t)=M(\bar{t}) \\ M(W^+)=M(W^-)}} \max\{M(t), M(\bar{t})\} \quad (8)$$

Since this is constrained minimization, we have following relations

$$M_2 \leq M_{2CC} \leq M \quad (9)$$

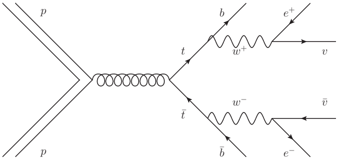
M_2 distribution will be shifted towards M

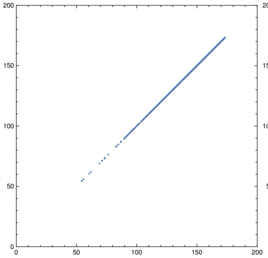
Constrained M_2 distribution

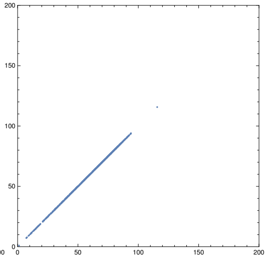


- Endpoint of M_{T2} matches M_t.
- Endpoint becomes much sharper than unconstrained one.

Reconstructed top and W mass







Conclusion

- M_T and their variants are succesful method of determining existence of resonance
- We can improve M_2 variable by supplying constraints which fits to process topology.
- More phenomenological work related to constrained mass variable is under researching!

References

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