Measuring masses of semi-invisibly decaying particles pair produced at hadron colliders

C G Lester and D J Summers, 1999

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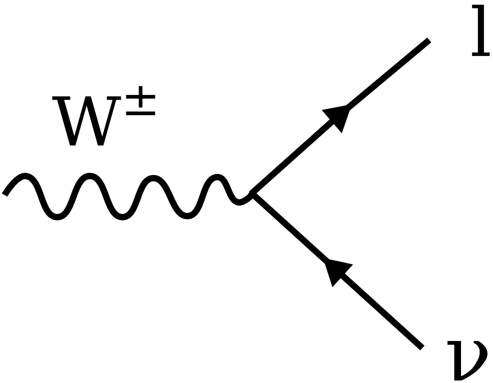
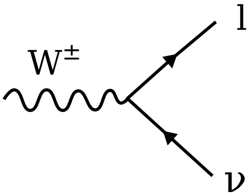
Leptonic decay of the W boson



Transverse mass

Define the ‘transverse mass’

$$m_{\mathrm{T}}{}^2 = 2(E_{\mathrm{T}}^{\mathrm{l}} \not{E}_{\mathrm{T}} - \mathbf{p}_{\mathrm{T}}^{\mathrm{l}} \cdot \not{\mathbf{p}}_{\mathrm{T}})$$



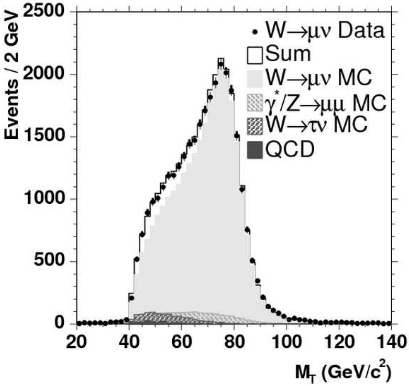
where $E_{\mathrm{T}}^{\mathrm{l}} = \sqrt{p_{\mathrm{T}}^{\mathrm{l}}{}^2 + m_l{}^2}$

and $\not{E}_{\mathrm{T}} = \not{p}_{\mathrm{T}}$ (i.e. assuming $m_\nu = 0$)

Defined this way, m_{T} has the property that

$$m_{\mathrm{T}}{}^2 \leq m_{\mathrm{W}}{}^2$$

Mass of the W boson



(1) CDF data for mass of the W boson, using the transverse mass variable.

m_{T} for general mass

Previously, we assumed $m_\nu = 0$ ('invisible' particle is massless).

How about a general process

$$\tilde{l} \to l\tilde{\chi}$$

Can define

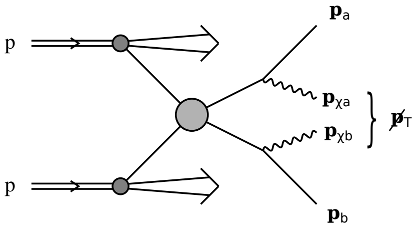
$$m_T^2(\mathbf{p}_{Tl}, \mathbf{p}_{T\tilde{\chi}}) \equiv m_l^2 + m_{\tilde{\chi}}^2 + 2(E_{Tl}E_{T\tilde{\chi}} - \mathbf{p}_{Tl} \cdot \mathbf{p}_{T\tilde{\chi}})$$

Where again

$$m_T^2(\mathbf{p}_{Tl}, \mathbf{p}_{T\tilde{\chi}}) \ \leq \ m_{\tilde{l}}^2$$

A new transverse mass

Here's an interesting process:



Why this? Example:

$$pp \to \text{jets} + \tilde{l}_R^+ \tilde{l}_R^- \to \text{jets} + l^+ l^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$$

We'd like to find the mass of the pair-produced $\tilde{l}$.

A new transverse mass

Remember,

$$m_{\tilde{l}}^2 \geq m_T^2(\mathbf{p}_{Tl}, \mathbf{p}_{T\tilde{\chi}})$$

So for pair-production, for each event

$$m_{\tilde{l}}^2 \;\geq\; \max\{m_T^2(\mathbf{p}_{Tla}, \mathbf{p}_{T\tilde{\chi}a}),\; m_T^2(\mathbf{p}_{Tlb}, \mathbf{p}_{T\tilde{\chi}b})\}$$

$$\not{\mathbf{p}}_{\mathrm{T}} = \mathbf{p}_{T\tilde{\chi}a} + \mathbf{p}_{T\tilde{\chi}b}$$

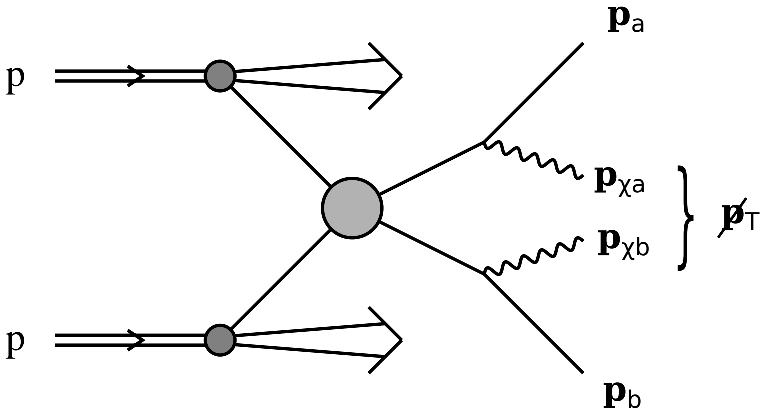
$$m_{\tilde{l}}^2 \;\geq\; \min_{\mathbf{p}_{\chi\mathrm{a}}+\mathbf{p}_{\chi\mathrm{b}}=\not{\mathbf{p}}_T}\left[\max\{m_T^2(\mathbf{p}_{Tla}, \mathbf{p}_{T\tilde{\chi}a}),\; m_T^2(\mathbf{p}_{Tlb}, \mathbf{p}_{T\tilde{\chi}b})\}\right] \equiv M_{T2}^2$$

Simulation

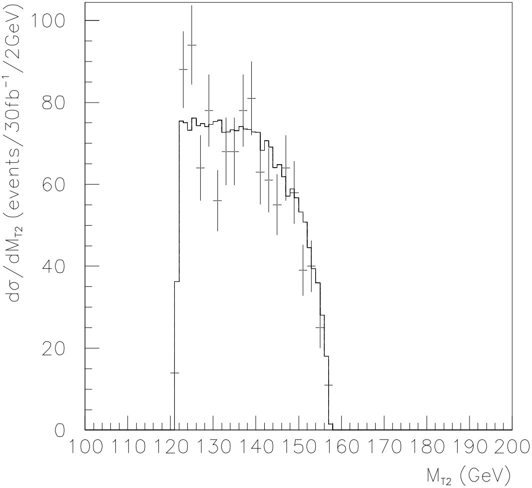
The process used for the simulation in order to show the application of M_{T2} is the following:

$$pp \rightarrow X + \tilde{l}^{+}\tilde{l}^{-} \rightarrow X + l^{+}l^{-}\tilde{\chi}_1^0\tilde{\chi}_1^0$$

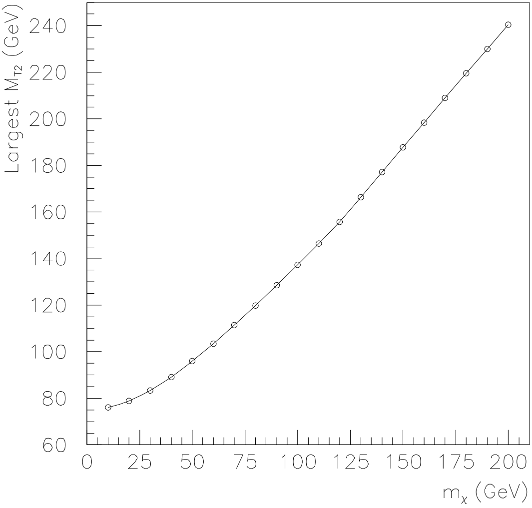
The model used is the fifth minimal supergravity model (mSUGRA) point (R-parity conserved).
M $(\tilde{l}) = 157.1$ GeV
M $(\tilde{\chi}_0^1) = 121.5$ GeV



(2) Diagram of a generic process involving two invisible particles in the final state



(3) Simulated data with error bars: 1105 events (30 fb^{-1}). Histogram: 300 fb^{-1}.



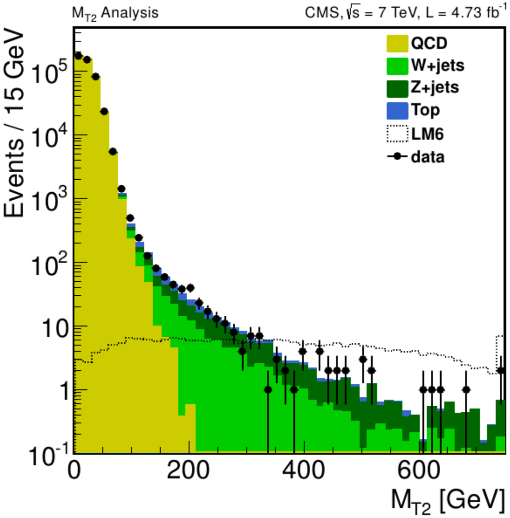
(4) Values of $M(\tilde{l})$ that would be obtained from that largest M_{T2} value observed, where differing values of $M(\tilde{\chi}_0^1)$ are used in the calculation

Conclusions

- Introduction of a variable for measuring masses in hadron colliders, where longitudinal momentum is unknown
- Analogous to M_T but useful for pair production of the measured particle, and for massive invisible particles
- Model independent
- One of the main applications could be measuring the mass of sleptons at LHC

Conclusions

- The simulation looks very promising, but background and experimental mis-measurements errors have to be included in a real data analysis
- In principle the maximum value of M_{T2} should correspond to the mass of the slepton
- Like for W mass measurements, the smearing and the slope need to be taken into account



(5) M_{T2} distribution for hadronic final states from a decay cascade of some non-LSP sparticle, using the CMS SUSY LM6 model for simulation.

Additional references

- "Model independent sparticle mass measurements at ATLAS"
  Lester 2001 (DPhil dissertation)
- "m_{T2}: The truth behind the glamour"
  Barr, Lester and Stephens 2003
- "Search for supersymmetry in hadronic final states using m_{T2}"
  CMS collaboration 2012