M_{T2} Combinatorics

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arXiv:1004.5350 (Monika Blanke, DC, Maxim Perelstein)
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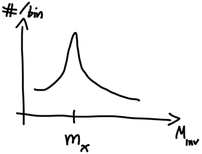
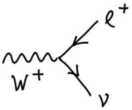
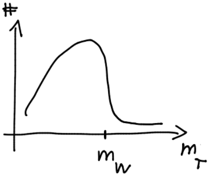
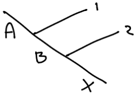
- When a new particle X is produced and decays only to visible things, we can reconstruct the invariant mass peak and easily determine the mass of X.

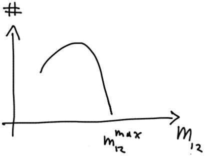


- If we have invisible particles in the final state, mass measurements are more difficult. Can construct various variables with distributions that feature endpoints, which contain mass information.









$$\left(m_{12}^{max}\right)^2 = \left(m_A^2 - m_B^2\right)\left(m_B^2 - m_X^2\right)/m_B^2$$

- Very well developed over the last 8 years[1]. By now analytical behavior very well understood.
  - generalized for multi-step decay chains
  - analytical predictions for endpoints
  - ISR dependence (and how to get rid of it)
  - various off-shoot variables
- For a 2-step symmetric decay chain we can construct $2 \times 3 = 6$ independent M_{T2} variables $\rightarrow$ complete mass reconstruction.
- So far, not much focus on applying these variables 'realistically'. **Investigate here!**

[1] Barr, Lester, Stephens, Cho, Choi, Kim, Park, Burns, Kong, Matchev, Konar, ...

Problems

- Edges are more challenging to detect & measure than bumps.

- Construction of these variables depends on known position of particles within decay chain.

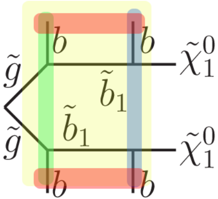
  $\Longrightarrow$ Depending on final state, can get very large and interfering combinatorics background for these variables.

  $\longrightarrow$ Previously ignored issue with M_{T2}!

- **We want to come up with a (hopefully) general method for extracting these edges from very messy data.**
  - Find edge.
  - Discard false positives & combinatoric artifacts.
  - Avoid human bias $\rightarrow$ fully automated.

Case Study

Let's explore the combinatorics issue in a simple test case without other backgrounds:



Measure 3 masses. Available variables:

M_{bb},

M_{T2}^{221}, M_{T2}^{210}, M_{T2}^{220}

(use both ISR-binned & $\perp$ versions, for zero and large testmass).

- Choose a particular MSSM Benchmark Point w/o SUSY-BG.

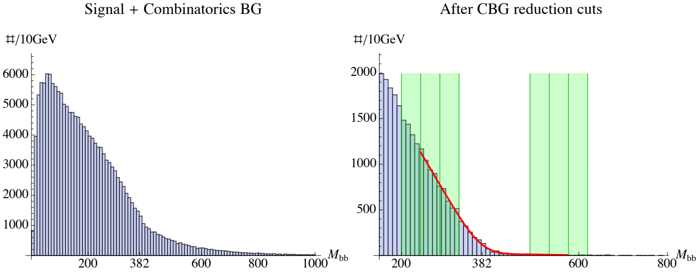
m_{t1}	m_{t2}	s_t	m_{b1}	m_{b2}	s_b	$m_{\tilde{g}}$	$m_{\tilde{\chi}_1^0}$
371	800	-0.095	341	1000	-0.011	525	98

(Already excluded by LHC, new blind analysis in progress.)

- $\sigma_{\tilde{g}\tilde{g}} \approx 11.6\ \mathrm{pb}$ @ $\sqrt{s} = 14\,\mathrm{TeV}$. Use $\mathcal{L} = 100\ \mathrm{fb}^{-1}$ (pessimistic).
- Simulate with `MadGraph/MadEvent`, `BRIDGE`, **`Pythia`, `PDG`**.
- Require 4 b-tags & MET $>$ 200 GeV. Eliminates SM BG.

M_{bb} Edge

- Not hard to measure, done many times before.
- Combinatorics background (2:1) is very benign. For each event, only keep the invariant mass pair with smallest maximum M_{bb}.

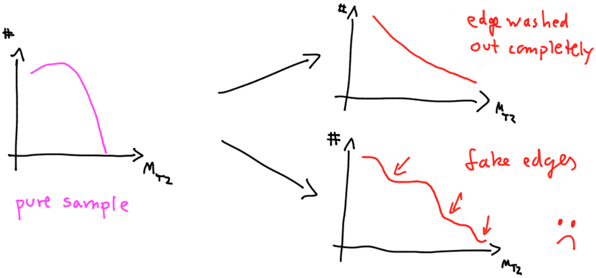


- Smeared kink fit (Linear Kink convoluted with Gaussian) gets good measurement: $M_{bb}^{max} = 380 \pm 2\,\mathrm{GeV}$ (th: 382 GeV)

M_{T2} Edges

- Combinatorics Background is much worse.

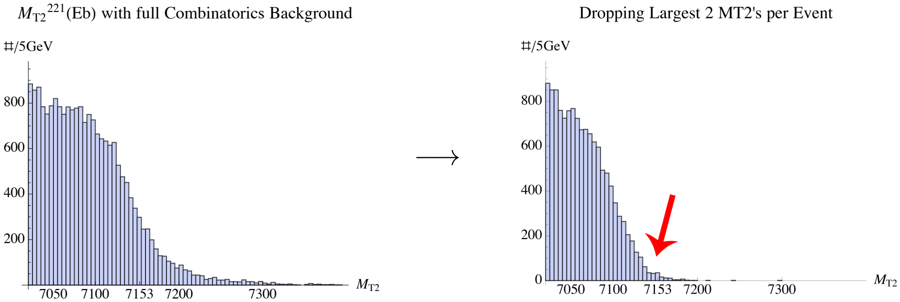
  More of it (5:1), can introduce artifacts & fake edges, or wash out real edge completely.



- How to clean it up, measure edges and reject artifacts?
- No one set of cuts can reduce the combinatorics BG completely without artifacts. Will need to use at least two methods!

First Method: drop the largest M_{T2}'s per event (2/6 or 1/3 depending on variable). The larger ones are less likely to be correct because M_{T2} represents a lower bound.

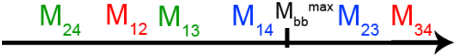
For Example $M_{T2}^{221}(E_b)$:



Combinatorial Background Reduction

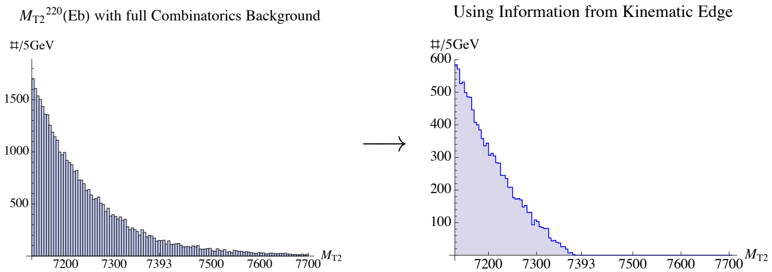
Second Method: use the measured M_{bb} edge.

Recall: For a given event with 4 b's there are three possibilities for invariant mass pairs from the same decay chain: (M_{12}, M_{34}), (M_{13}, M_{24}), (M_{14}, M_{23}). For $\sim$ 30% of events, situation like



, so we learn combinatorial info!

For Example $M_{T2}^{220}(E_b)$:

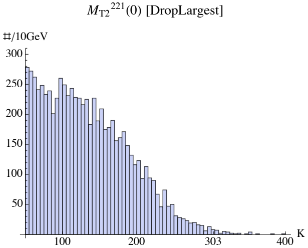


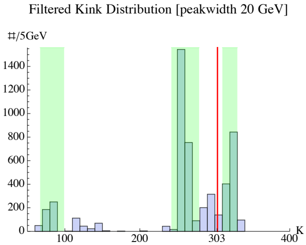
Edge Measurement: Kink Hunting → Bump Hunting

- For each distribution, fit a simple linear kink on ∼ 10k intervals of random length and random position.

  → **Eliminates Human Bias & drawbacks of poor fit function.**

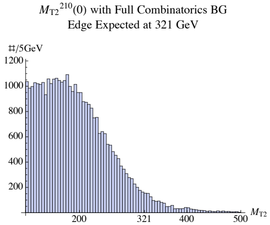
⇒ Obtain a **distribution** of measured kinks:

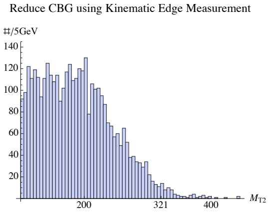


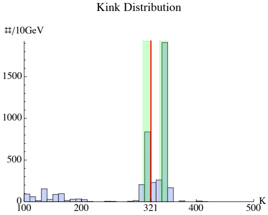


- Find peaks in kink distribution, and extract kink measurement from their position & width. This gives very reasonable error bars that correctly include smearing.

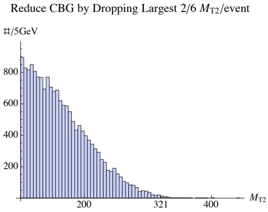
Full Example: $M_{T2}^{210}(0)$

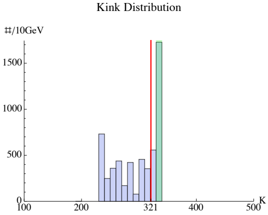






- Discard variable if we find more than two kinks.
- Only keep variable if one peak agrees between distributions. Rejects false positives!
- Obtain edge measurement by combining kink measurements from both distributions.





$M_{T2}^{210}(0)^{max} = 332 \pm 17$ GeV (Prediction: 321 GeV)

Final Results

Edge for	measured	prediction	σ dev.
$M_{T2}^{221}(0)$	244 ± 128	304	0.5
$M_{T2}^{210}(0)$	332 ± 17	321	0.7
$M_{T2}^{221}(E_b)$	7177 ± 43	7153	0.6
$M_{T2}^{210}(E_b)$	7182 ± 42	7240	1.4
$M_{T2}^{220}(0)$	511 ± 55	507	0.1
$M_{T2}^{220}(E_b)$	—	7393	—
$M_{T2\perp all}^{210}(0)$	260 ± 68	312	0.8
$M_{T2\perp all}^{210}(E_b)$	7134 ± 42	7158	0.6
M_{bb}	380 ± 2	382	1.3

$\longrightarrow$

	measured	prediction
$m_{\tilde{g}}$	$645\ ^{+140}_{-70}$	525
$m_{\tilde{b}_1}$	$435\ ^{+135}_{-50}$	341
$m_{\tilde{\chi}_t^0}$	$275\ ^{+135}_{-105}$	98

($E_b = 7000$ GeV)

No False Positives!

All mass measurements within 2 σ of prediction.

Conclusions

- M_{T2} variables are powerful, but very sensitive to combinatorics. Not extensively tested in realistic settings.
- `KinkFitter` Package: Turn Edge-Hunting into Bump-Hunting! No human bias, fully automated. Yields realistically large error bars due to smearing etc.
- We developed two different ways of reducing M_{T2} combinatorics background, and incorporated them into a hopefully quite general procedure for extracting endpoint measurements from messy data:
  - Avoid false positives by requiring the two independent methods of reducing combinatorics BG to yield the same kink measurement.
  - Use `KinkFitter` to measure edges.
  - Allowed us to recover the majority of possible M_{T2} measurements in the presence of ISR & (simple) detector effects.