Analytic Mass Reconstruction of $t\bar{t}$ Resonances in the Dilepton Channel

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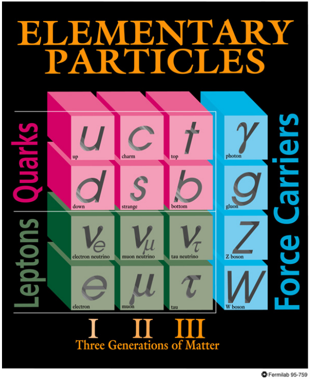
Motivation

Beyond Standard Model: Search for new massive particles

- In search for resonances of the form: $pp \rightarrow X \rightarrow t\bar{t}$



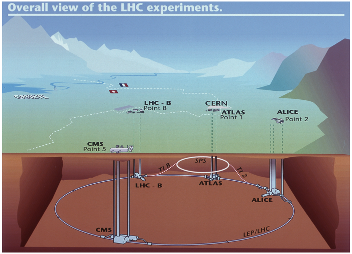
Is the top quark special?

- $m_{top} \gg$ mass of other fundamental particles
- Many models predict new $X \rightarrow t\bar{t}$ with large branching ratios:
  - Examples:
    $\rightarrow$ KK Graviton
    $\rightarrow$ Z' Gauge Boson
    $\rightarrow$ **Kaluza Klein excitation of the gluon** ($\sim$ 90% to $t\bar{t}$)

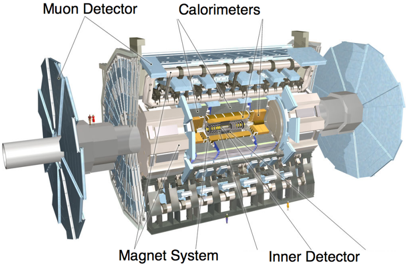
Why? Extra dimension models predict heavier particles closer to TeV brane – stronger couplings to particles on this brane (ie top quark)

LHC and the ATLAS detector

- 27 km circumference underground tunnel near the France-Switzerland border
- *pp* collider at $E_{CM} = 7$ TeV (future up to $E_{CM} = 14$ TeV)
- 4 Experiments: ATLAS, CMS, LHCb, ALICE



A Toroidal **L**HC **A**pparatu**S**

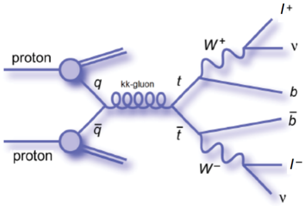


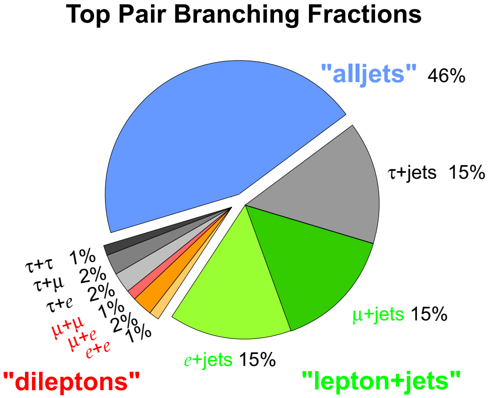
- Inner Detector: measure tracks of charged particles
- Calorimeter: measures energy
- Muon Spectrometer: ID and $\vec{p}$ measurement of muons
- Magnet System: bends charged particles (for $\vec{p}$ measurement)

The dilepton channel

Top Quark Decays almost exclusively: $t(\bar{t}) \rightarrow W^+(W^-)b(\bar{b})$ (BR $= 0.99$)

Dilepton: *both W* bosons decay to leptons (e, μ, τ) and corresponding ν





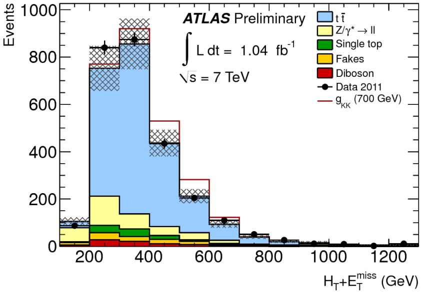
- small percentage of events
- clean signal, selected events predominantly $t\bar{t}$

Mass Reconstruction

Neutrinos leave the detector undetected → unable to directly reconstruct invariant mass of $t\bar{t}$

$$m_{kk} = m_{t\bar{t}} = \sqrt{(p_{l^+} + p_{l^-} + p_b + p_{\bar{b}} + \cancel{p_\nu} + \cancel{p_{\bar{\nu}}})^2}\ ; \quad p = (E, \vec{p})$$

Current observable in this channel:



Exclude $m_{g_{KK}} < 840$ GeV at 95% C.L.

Observable: $H_T + E_T^{miss}$

- $H_T = \sum p_T^{leptons} + \sum p_T^{quarks}$; p_T = transverse momentum (in x-y plane)

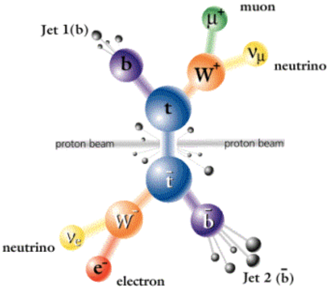
Disadvantages:

- Broad distributions
- *Scalar* sum → Loss of angular information

Analytic Solution of $t\bar{t}$ dilepton equations

Try to reconstruct invariant mass of resonance by solving for the four vectors of the two neutrinos with constraints:

$\rightarrow$ Hope for better resolution in mass reconstruction than $H_T + E_T^{miss}$



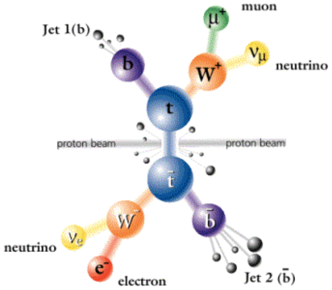
- $\not{E}_x = p_{\nu_x} + p_{\bar{\nu}_x}$
- $\not{E}_y = p_{\nu_y} + p_{\bar{\nu}_y}$
- $E_\nu^2 = p_{\nu_x}^2 + p_{\nu_y}^2 + p_{\nu_z}^2 \rightarrow p_\nu^2 = 0$
- $E_{\bar{\nu}}^2 = p_{\bar{\nu}_x}^2 + p_{\bar{\nu}_y}^2 + p_{\bar{\nu}_z}^2 \rightarrow p_{\bar{\nu}}^2 = 0$
- $m_{W^+}^2 = (p_{l^+} + p_\nu)^2$
- $m_{W^-}^2 = (p_{l^-} + p_{\bar{\nu}})^2$
- $m_t^2 = (p_{l^+} + p_\nu + p_b)^2$
- $m_{\bar{t}}^2 = (p_{l^-} + p_{\bar{\nu}} + p_{\bar{b}})^2$

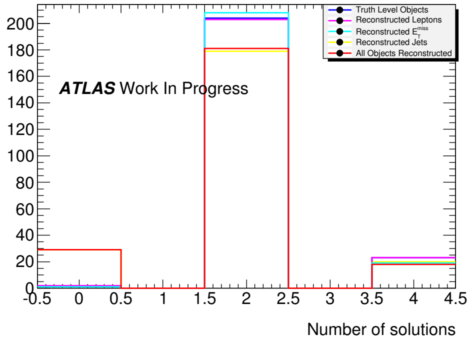
- Inputs: p_ℓ, p_b, $\not{E}_y$, $\not{E}_x$, m_{top}, m_W, m_b

Solutions

Quartic equation gives at most 4 solution sets; complex solutions discarded.

- Allow mass of particle (top, W) to vary within the Breit Wigner width





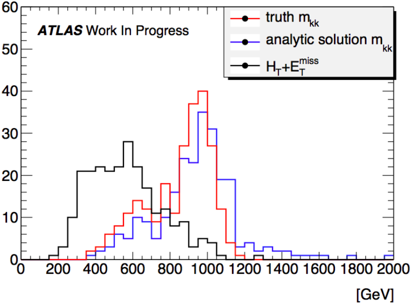
Problems

- Obtain either 2 or 4 solutions
  - Need a way to extract correct solution
- Characterize using measurable quantities: ie. final state particles.
  - Multiple jets may pass object selection. Need to identify 2 jets and match to correct top decay
- Measurement resolution propagates through to neutrino 4-vector determination
- Need to compare the effect on background

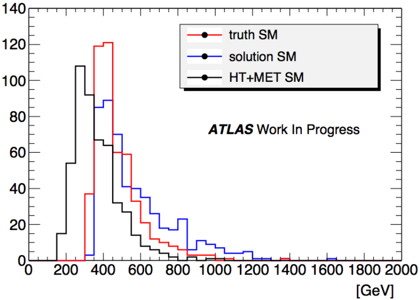
Choosing the Correct Solution

- Choose correct solution whose invariant mass reconstructs closest to 1 TeV (or target mass of choice)
- Disadvantages:
  - Bias our background samples creating a fake bump about 1 TeV
  - Backgrounds change for different target masses

1 TeV KK-Gluon sample

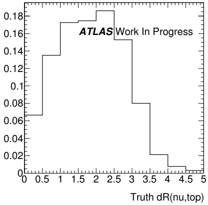


SM $t\bar{t}$ sample

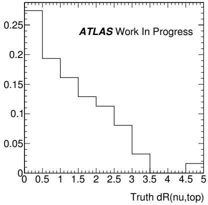


Choosing the correct solution

- Want a *physics motivated* discriminating quantity which leaves *backgrounds unchanged for any target mass*
- Compare neutrino solutions with consistency of the top decay
- Map out $\Delta R(top, \nu)$ relationship
  - $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$
- Assign prob. of $\Delta R(t, \nu)$ for different p_{top} ranges



p_{top} : 0 — 50 GeV



p_{top} : 1250 — 1300 GeV

Higher Energies $\rightarrow$ boosted tops

Choosing the Correct Solution

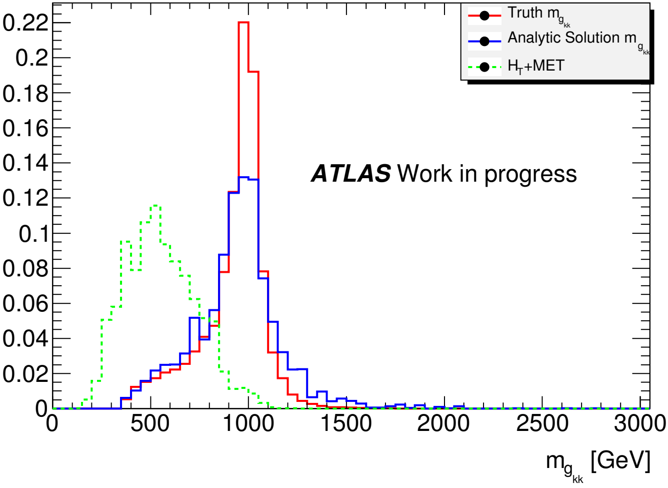
- Still, $\Delta R(t, \nu)$ alone not much of a discriminating variable since broad distribution for low momentum tops
- Use set of discriminating quantities to constrain:

Tried:

$$\left.\begin{array}{r} p_T^{\nu}/p_T^{\ell} \\ p_T^{\nu}/p_T^{b} \\ p_T^{\nu}/p_T^{top} \end{array}\right\} \quad \text{Use these combined in plots below}$$

$$\left.\begin{array}{r} \Delta R(\nu, \ell) \\ \Delta R(\nu, top) \\ \Delta R(\nu, b) \end{array}\right\} \quad \text{No improvement in selection, unused}$$

Performance - Signal



Performance - Signal - Detector Simulated

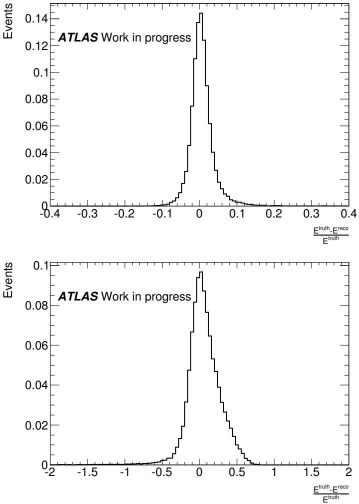
Leptons:

- well measured, not as much of an issue

Jets:

- poor measurement resolution
- no charge measurement $\rightarrow$ which jet comes from which top?
- ≥ 2 jets available from object/event selections

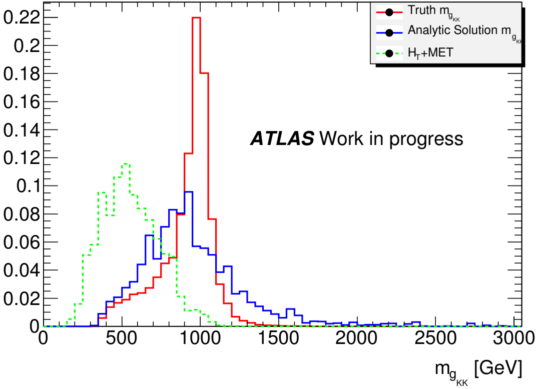
Missing E_T



Important for analytic neutrino four vector reconstruction to select correct jet from top decay

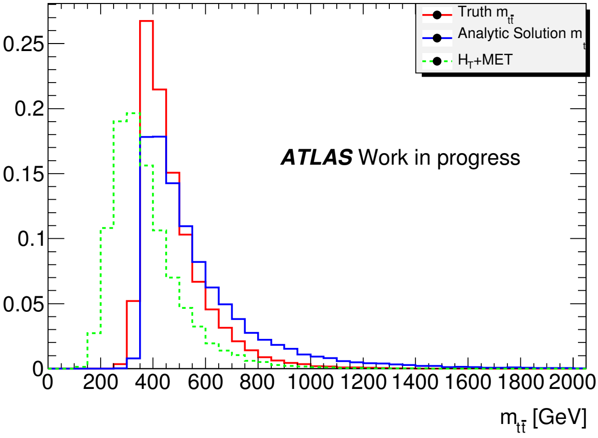
Performance - Reconstructed

Do not measure top quark in the detector
Use most correlated variable $\rightarrow b + lepton$ system
Characterize quantities in bins of $p_{b+\ell}$



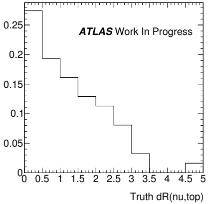
Backgrounds

Largest Background → Standard Model $t\bar{t}$



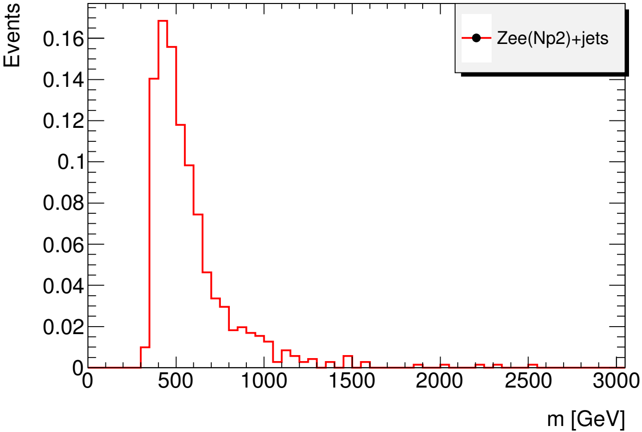
Conclusions

- Able to analytically determine neutrino 4-vectors
- Gain invariant mass!
- Work in Progress:
  - Run on ATLAS data
- Bin content $\rightarrow$ fit distributions to a function
- Include this as observable in future analysis

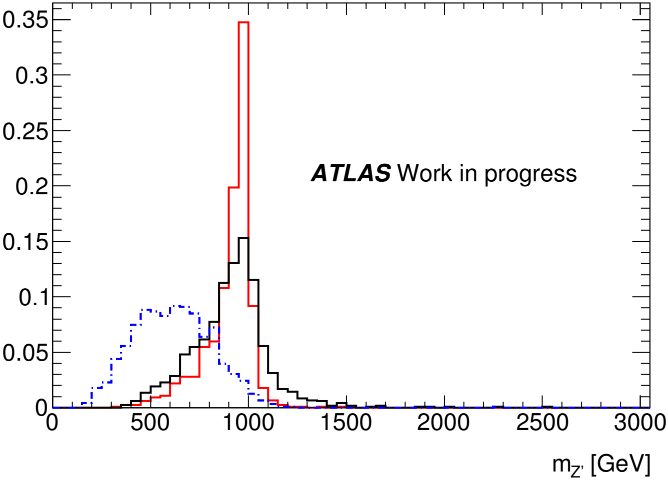


Backup Slides

Backgrounds



Z'



0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
500
1000
1500
2000
2500
3000
ATLAS Work in progress
m_Z' [GeV]