Using multilepton events in a global search for new physics

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Prelude

- CoEPP nodes (Melbourne, Sydney) and Duke (as a PI institution), over the last couple of years have been working on a novel technique for simultaneously measuring cross-sections of processes with dilepton final states (coined AIDA – An Inclusive Dilepton Analysis)
  - This has been a very effective and successful collaborative effort
  - In the final stages now of ATLAS approval, to be followed by a publication
  - Working now on developing the next generation of AIDA analysis(es)
  - ATLAS is very keen on the continuation of this analysis effort
- In addition Doug Benjamin (Duke) has started to collaborate with the Nectar Cloud and Research computing teams on using cloud computing for predominately user analysis
  - Test the use of local data caching at each cloud site and federated storage between the cloud sites to make it easier for Australian analyzers to access and use the derived data products
  - Setup a set of test programs to evaluate the performance of cloud sites for data analysis
  - See Tony Limosani's talk for more details

ATLAS

CERN

ATLAS NOTE

June 7, 2013

An Inclusive Analysis of $t\bar{t}$, WW, and $Z \rightarrow \tau\tau$ Production in the Dilepton Final State at $\sqrt{s} = 7$ TeV with the ATLAS Detector at the LHC
Version 3.3.1

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- Analysis has achieved considerable recognition, and is being driven by Sydney and Melbourne (and Kevin Finelli who will very soon be joining Sydney as a postdoc)

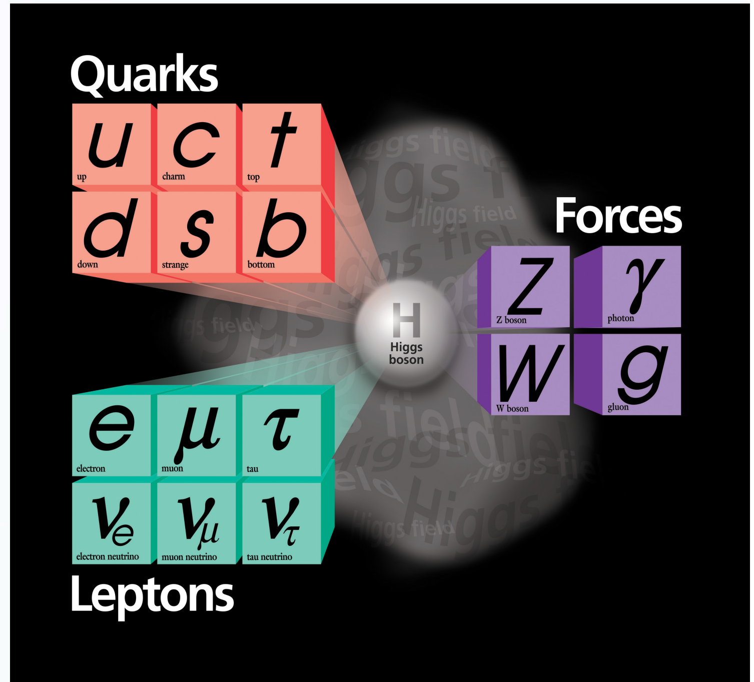
Outline

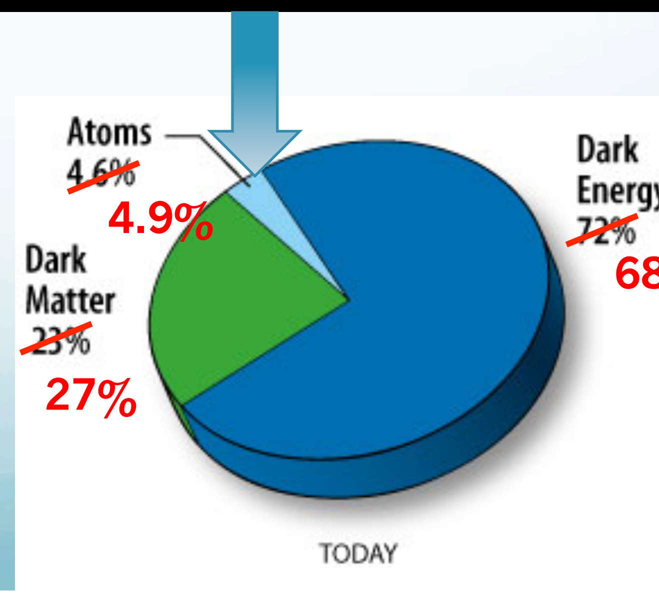
- Testing the Standard Model
- Searches for new physics beyond the SM using SUSY as a specific example
- The need for more global searches – enter AIDA
- Final thoughts

Physics at ATLAS

- An enormous variety of measurements and direct searches
- The SM has had remarkable success in describing our observations of the universe
- But, the SM is incomplete, so:

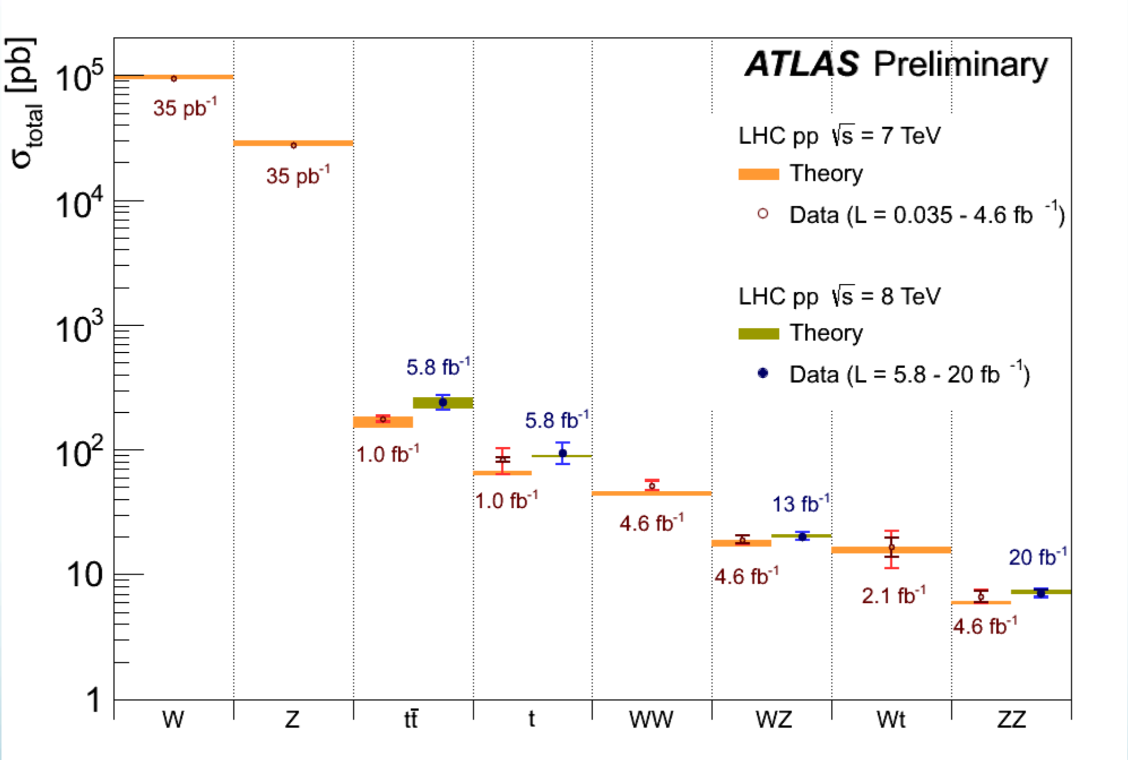
  1. Test it for indirect evidence of new physics
     - Precision measurements
     - Rare processes
  2. Directly search for physics beyond it:
     - SUSY (still our favourite!)
     - Many non-SUSY BSM searches





Testing the Standard Model

- SM makes specific predictions of the cross-sections of a wide variety of processes
- Major theoretical advances with new NLO/NNLO calculations and NLO with showering
- New physics can show up in the production and/or decay in some of these processes which might result in anomalous cross-section measurements



- **No such anomalies are being observed within the current precision of these measurements**

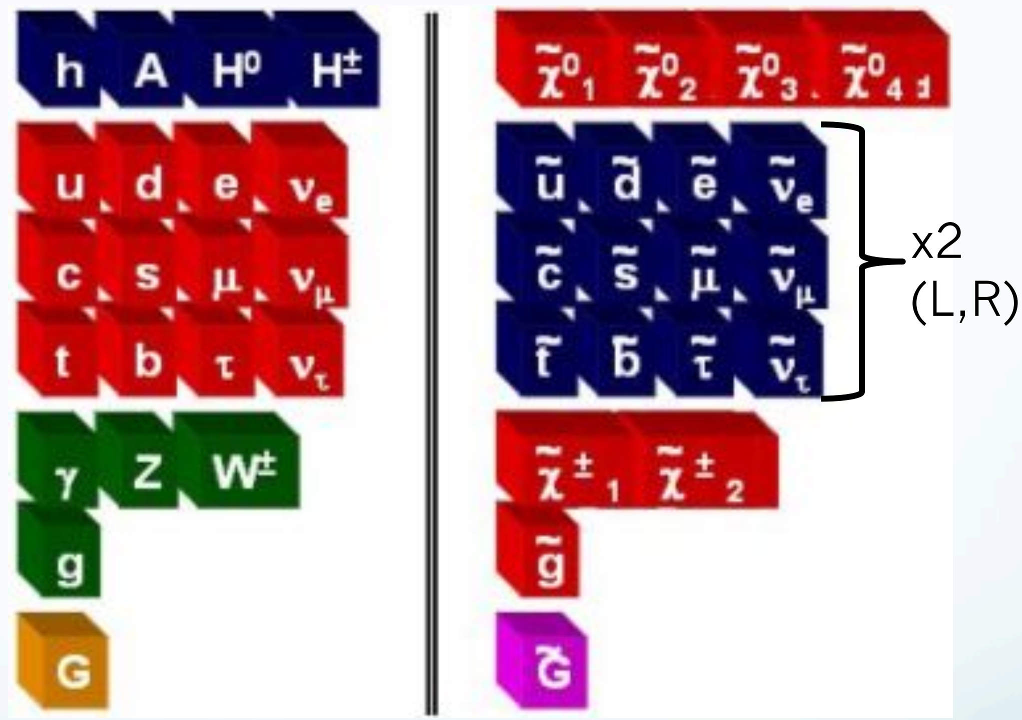
Direct searches beyond the SM – why?

- The SM is not a complete theory and new physics might show up at energy scales accessible at the LHC

- Although the parameter space for some of the simpler SUSY regimes is being constrained by LHC data, SUSY is probably still the most favoured theory to reveal new physics ?
  - But we have to look for all possibilities – leave no stone unturned

Supersymmetry

- Symmetry between fermions and bosons
  - Different masses → symmetry broken
- Can solve Higgs mass divergence
- Can alleviate hierachy problem
- Has a natural candidate for DM (LSP stable if R-parity conserved)
  - Leads to signatures with large missing transverse energy
- SUSY implies many new particles
  - None of which have been observed
  - Unless we've found the h^0 !
  - Current limits are certainly constraining some SUSY scenarios



Searching for SUSY

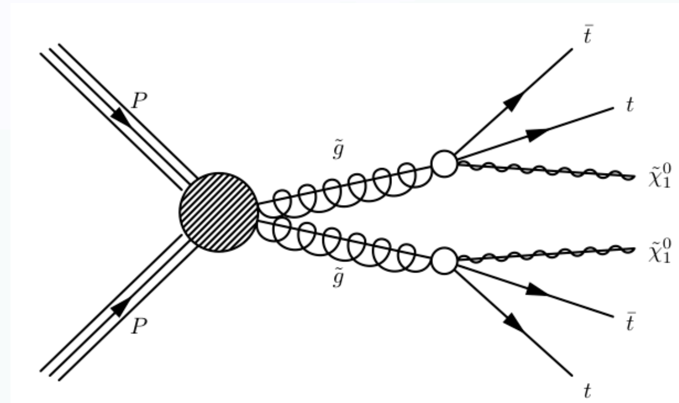
- An enormous array of analyses/signatures covering many different SUSY scenarios

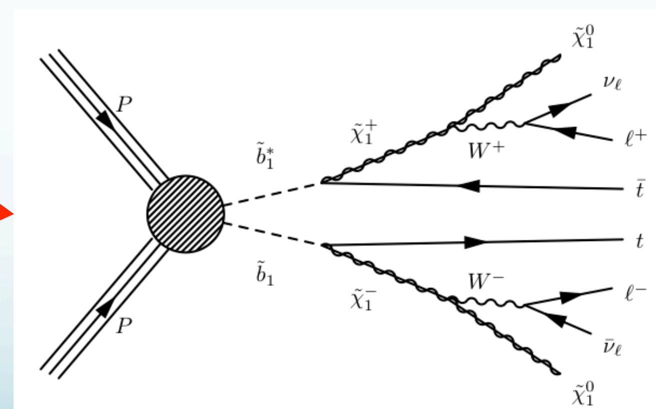
2012 data (8 TeV)

Short Title of the CONF note
0 lepton + 6 (2 b-)jets + Etmiss [Heavy stop] NEW
Z + b-jet + jets + Etmiss [Direct stop in GMSB, direct stop2] NEW
1-2 taus + jets + Etmiss [GMSB] NEW
2 taus + Etmiss [EW production] NEW
2 same-sign leptons + 0-3 b-jets + Etmiss NEW
0 lepton + 2 b-jets + Etmiss [Medium / heavy stop]
2 leptons + Etmiss [Medium stop]
1 lepton + 4(1 b-)jets + Etmiss [Medium / heavy stop]
2 bjets + Etmiss [Direct sbottom]
3 leptons + Etmiss [EW production]
4 leptons + Etmiss [RPV]
0 lepton + >=3 b-jets + Etmiss [3rd gen. squarks]
3 leptons + jets + Etmiss [3rd gen. squarks]
Monojet + Etmiss [WIMP, gravitino prod.]
Z + jets + Etmiss [GGM, higgsino NLSP]
0 leptons + >=2-6 jets + Etmiss
0 leptons + >=6-9 jets + Etmiss
1 lepton + >=4 jets + Etmiss
2 same-sign leptons + >=4 jets + Etmiss

⋮

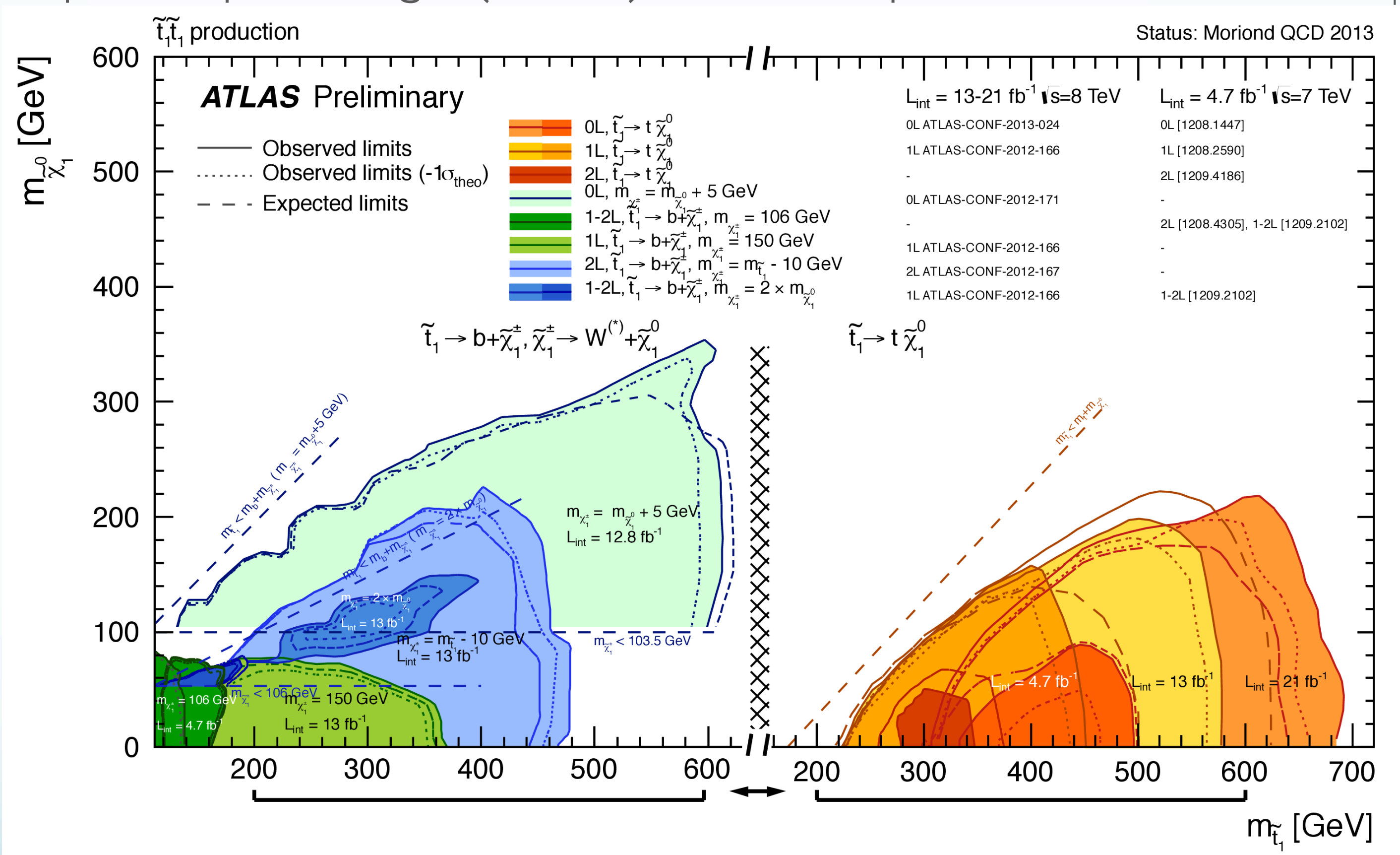
E.g.





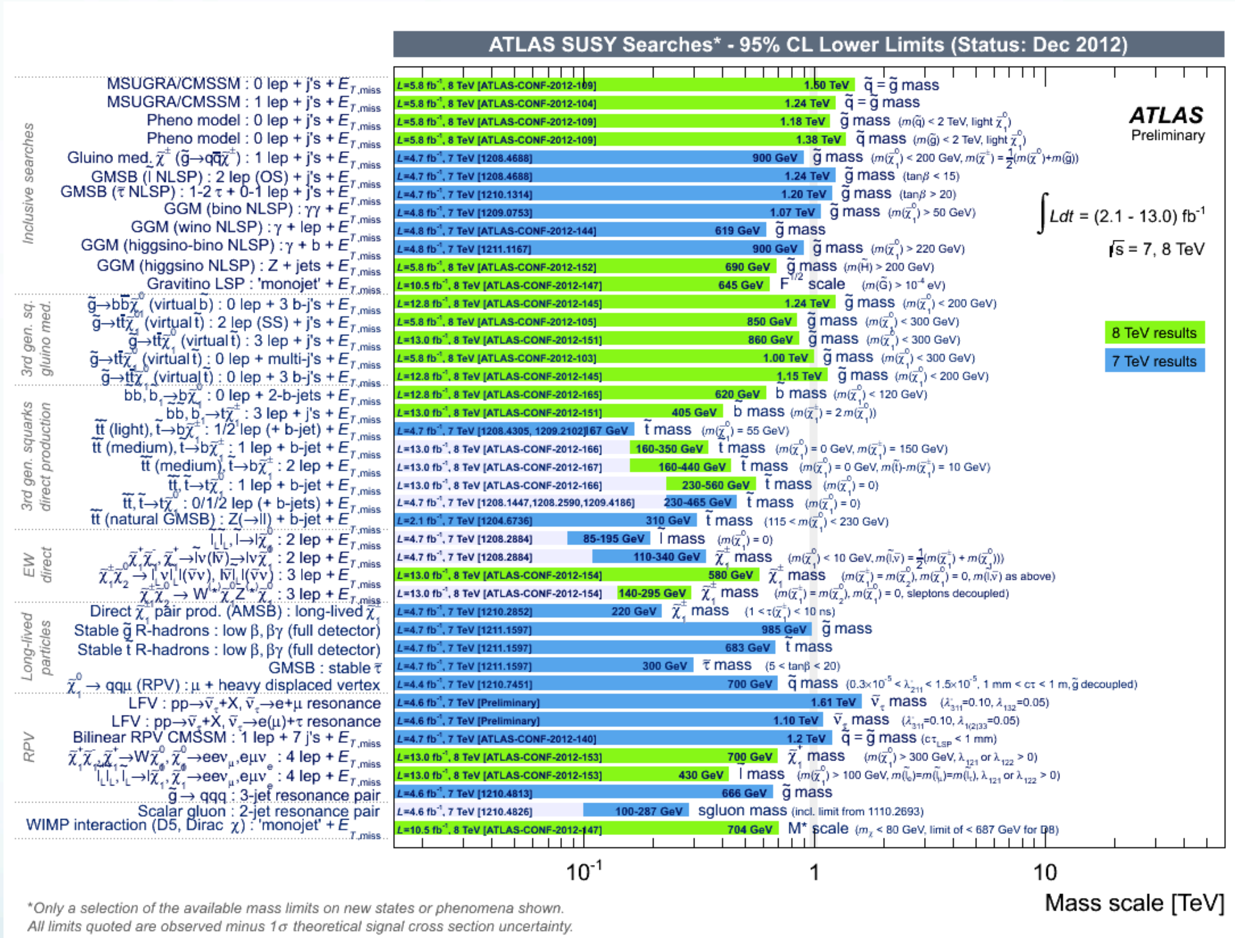
ATLAS searches for SUSY

- Example: summary of third generation searches
  - Expect stop to be light (<1 TeV) to cancel top mass contribution to m_H



- Contours overlayed from different stop decay channels, different sparticle mass hierachies, and simplified decay scenarios. Care must be taken when interpreting them – but shows reach

SUSY summary !



- Analyses only now starting to produce results with full 2011/2012 dataset
- After LHC shutdown, doubling of CM energy will extend reach

Non-susy BSM summary

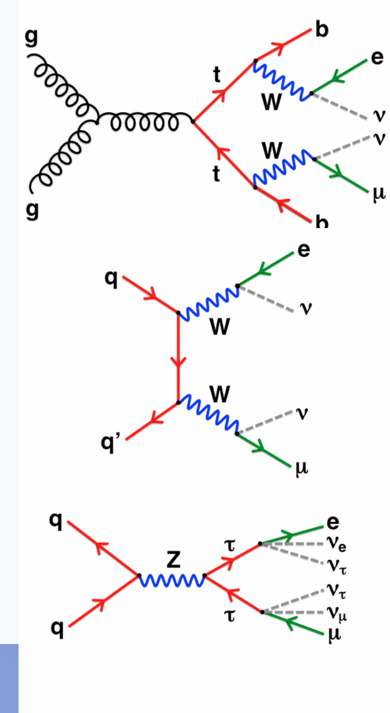
*Only a selection of the available mass limits on new states or phenomena shown

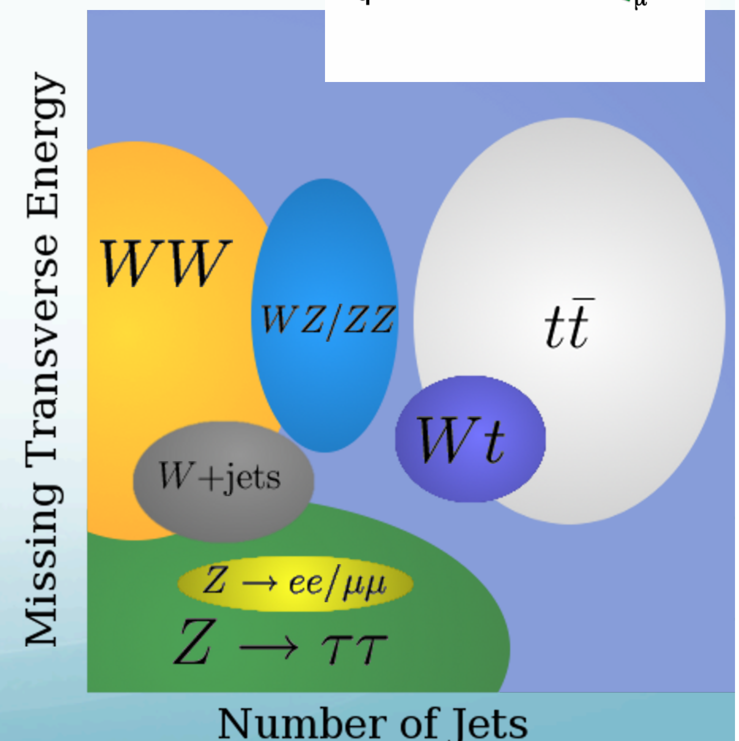
Main point

- There are literally hundreds of dedicated searches looking for specific particles within somewhat constrained frameworks (assumptions on masses, BR's, …)
- These are important, but not the only philosophy in searching for clues to physics beyond the SM
- We (Sydney, Melbourne, Duke) have been developing a more global analysis strategy, using dilepton events to test the SM
  - Might interface nicely into the framework of GAMBIT ?
- This strategy (AIDA) has just negotiated it's first milestone through the "approval" of its simultaneous measurement of SM cross sections

AIDA – the idea

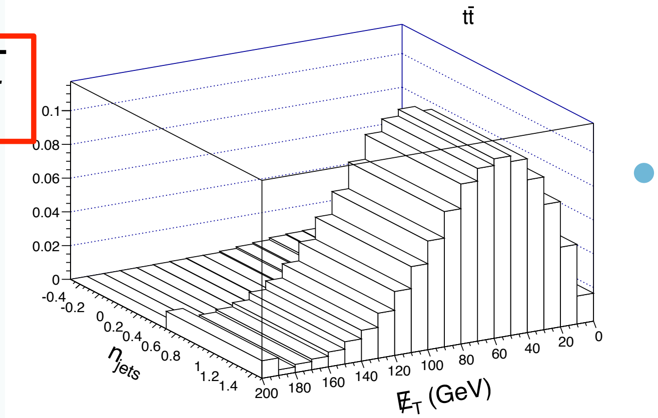
- For **eμ** events:
  - Consider phase space defined by MET and N_{jets}
  - Main SM contributions nicely separated
  - Allows for simultaneous measurement of these cross sections (likelihood fit of data to SM templates) → **done**
  - Provides more global test of the SM
  - Use technique for more model-independent new physics searches → **next**
- The advantage of AIDA is a full understanding of the entire parameter space
  - One could also imagine this as a disadvantage!
  - But this understanding we have developed now creates a better foundation for new physics searches



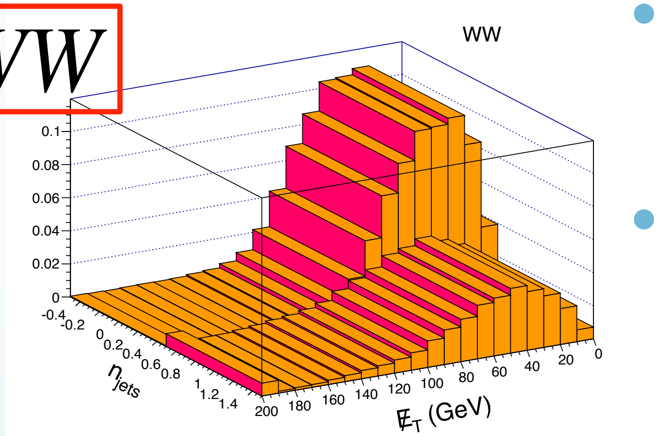


AIDA: likelihood fit to templates

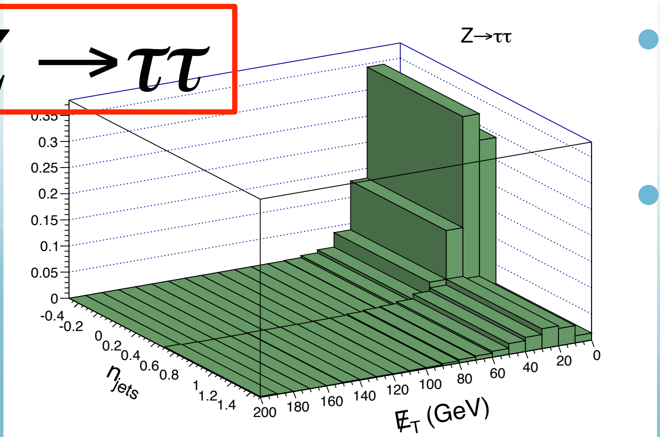
$t\bar{t}$



WW

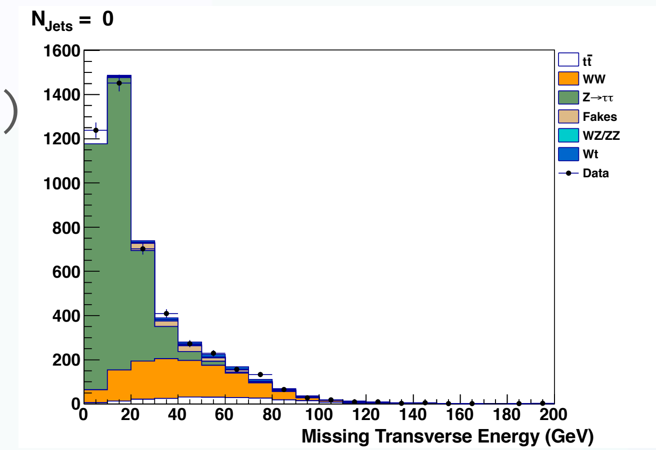


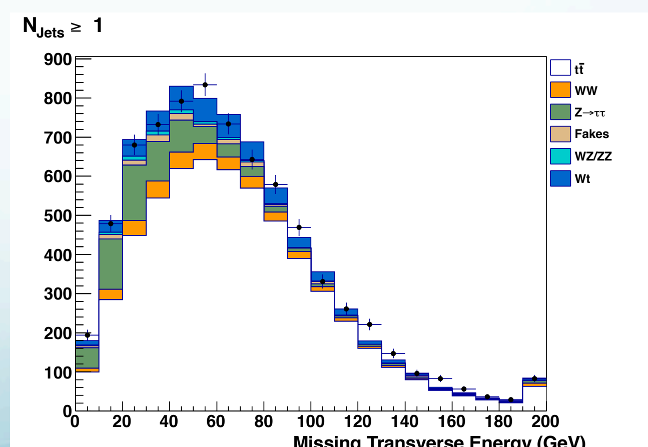
$Z \rightarrow \tau\tau$



- **L =** (product of poisson probs for each bin) * (gaussian constraints)
- Normalization of "signal" templates float in the fit
- "Background" templates fixed within gaussian constraints
- **Best fit → "signal" cross sections**
- Analysis spans different physics groups

"Slice" plots





AIDA cross section results

- Production cross sections for pp@7TeV simultaneously extracted from the AIDA phase space with ~5 fb^{-1} of ATLAS data:

$$\sigma(t\bar{t}) = 181.2 \pm 2.8(stat.)\ ^{+12.1}_{-11.1}(syst.)\ ^{+3.7}_{-3.5}(lum.)\ \text{pb}$$

$$\sigma(WW) = 50.5 \pm 2.5(stat.)\ ^{+6.5}_{-7.6}(syst.)\ ^{+1.1}_{-0.9}(lum.)\ \text{pb}$$

$$\sigma(Z \rightarrow \tau\tau) = 1158.0 \pm 23.9(stat.)\ ^{+65.6}_{-83.0}(syst.)\ ^{+21.4}_{-20.3}(lum.)\ \text{pb}$$

- Notes:
  - cf. SM predictions of: $\sigma(t\bar{t}) = 172.0 \pm 6.2$ pb (NNLO)
    $\sigma(WW) = 44.7 \pm 2.1$ pb (NLO)
    $\sigma(Z \rightarrow \tau\tau) = 964 \pm 48$ pb (NNLO, $M_{\tau\tau} > 40$ GeV)
  - Approval process includes both top and SM groups
  - Only tt cross section measurement at 7 TeV in the dilepton channel
  - Results comparable to, and competitive with, dedicated measurements

- **AIDA analysis phase 1** ✔

AIDA: next steps

- Develop metric for quantifying consistency of AIDA phase space with SM (started by Nik Patel, Sydney)
- Develop AIDA search strategies
- Inclusion of *ee* and $\mu\mu$ events
- Look into possibilities of extending the phase space
- E.g. third axis of $N_{leptons}$
- Look at same-sign dileptons with AIDA
- Include b-tagging information
- These, and more, will be discussed after this CoEPP workshop in an AIDA brainstorming week in Sydney

Final thoughts

- Although theories now exist that could account for inadequacies of the SM, it will be experiments such as those now being conducted at the LHC that will determine which, if any, of these theories might be right, and perhaps lead us to a more complete theory.
- There is a chance that results from the LHC experiments (together perhaps with current/future astrophysics experiments) could guide us in a completely different direction.
- We need to be open minded about how the SM could be extended → AIDA is one such idea being developed wholly within CoEPP and which has been gaining considerable recognition.
- These are exciting times, mechanism behind EWSB solved (at least partially), DM experiments making huge advances, neutrino sector increasingly better understood, etc., and LHC getting ready in a couple of years to run at double the energy.