A Fast Simulator for re-interpreting LHC search limits

Paul Jackson[1], Floriane Poignant[1], Aldo F. Saavedra[2], Martin White[1]

[1]Adelaide University

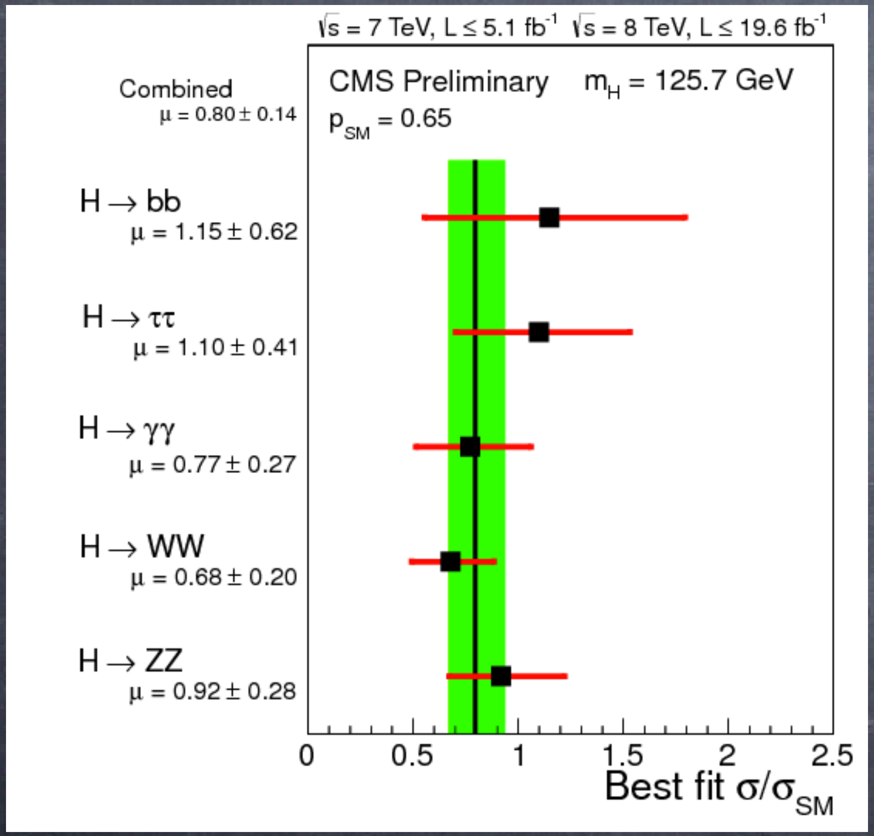
[2]The University of Sydney

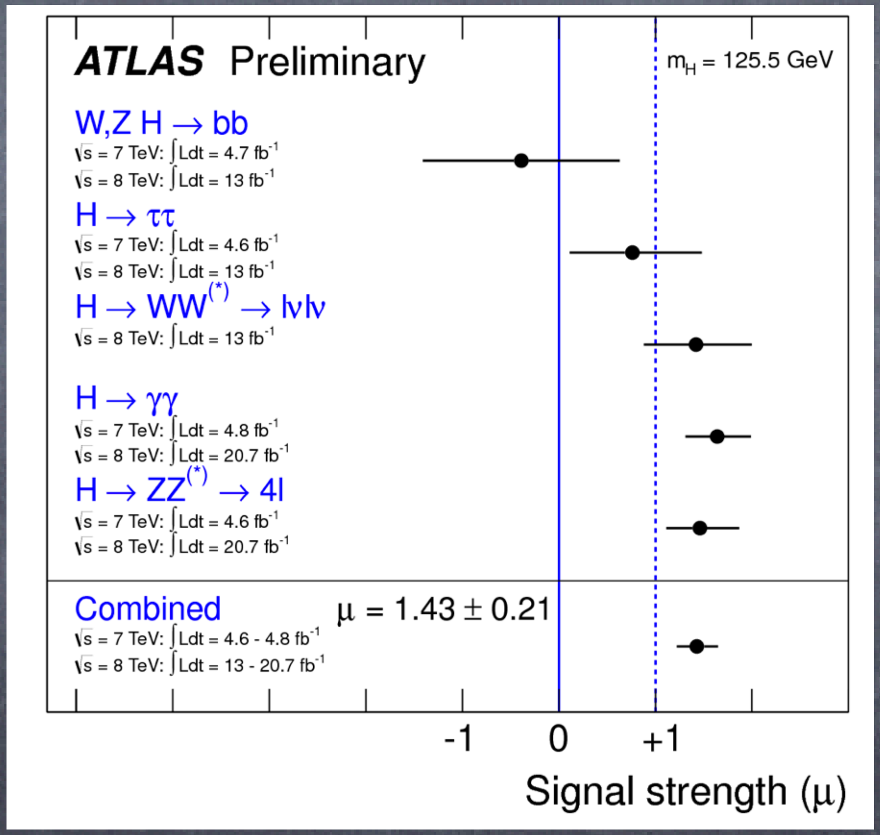
Physics Beyond The Standard Model

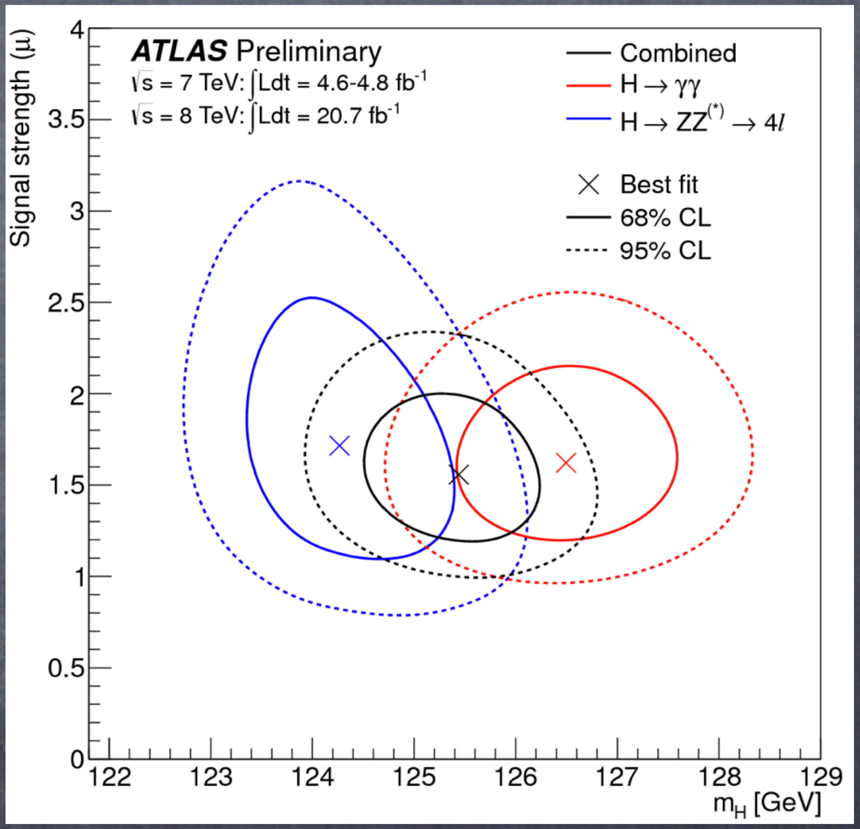
- There are number of issues with the Standard Model (SM) that provide evidence for physics beyond the SM
  - Non-baryonic dark matter
  - Massive Neutrinos
  - Baryon asymmetry
- A large number of theories have been developed to explain what we observe in the universe.

The Higgs Discovery

- The measured properties provides a strong and relatively new constraints on new theories.

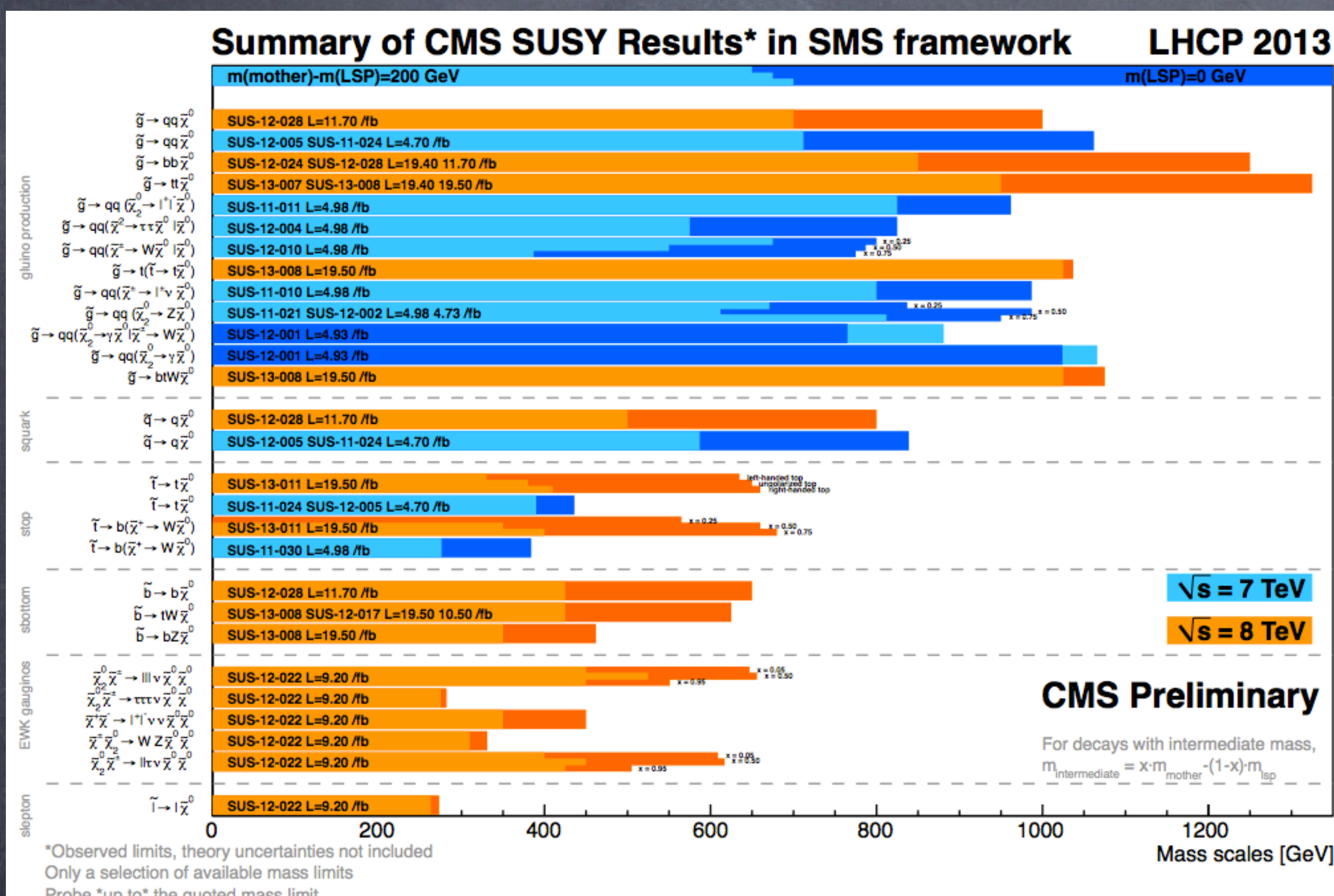


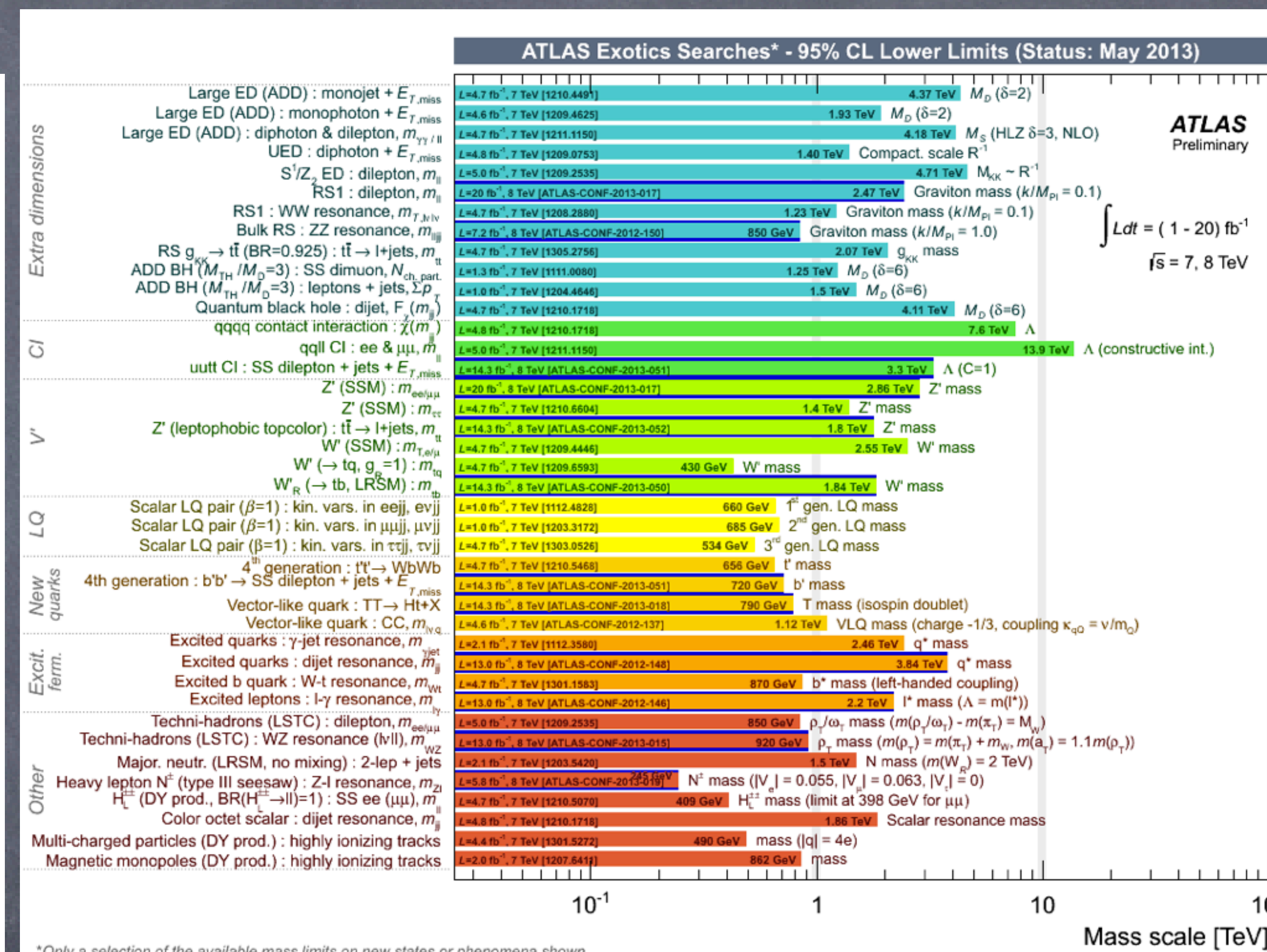




LHC Searches

- The LHC through the ATLAS and CMS experiments have been able to place limits on a large number of sparticles and other BSM particles.

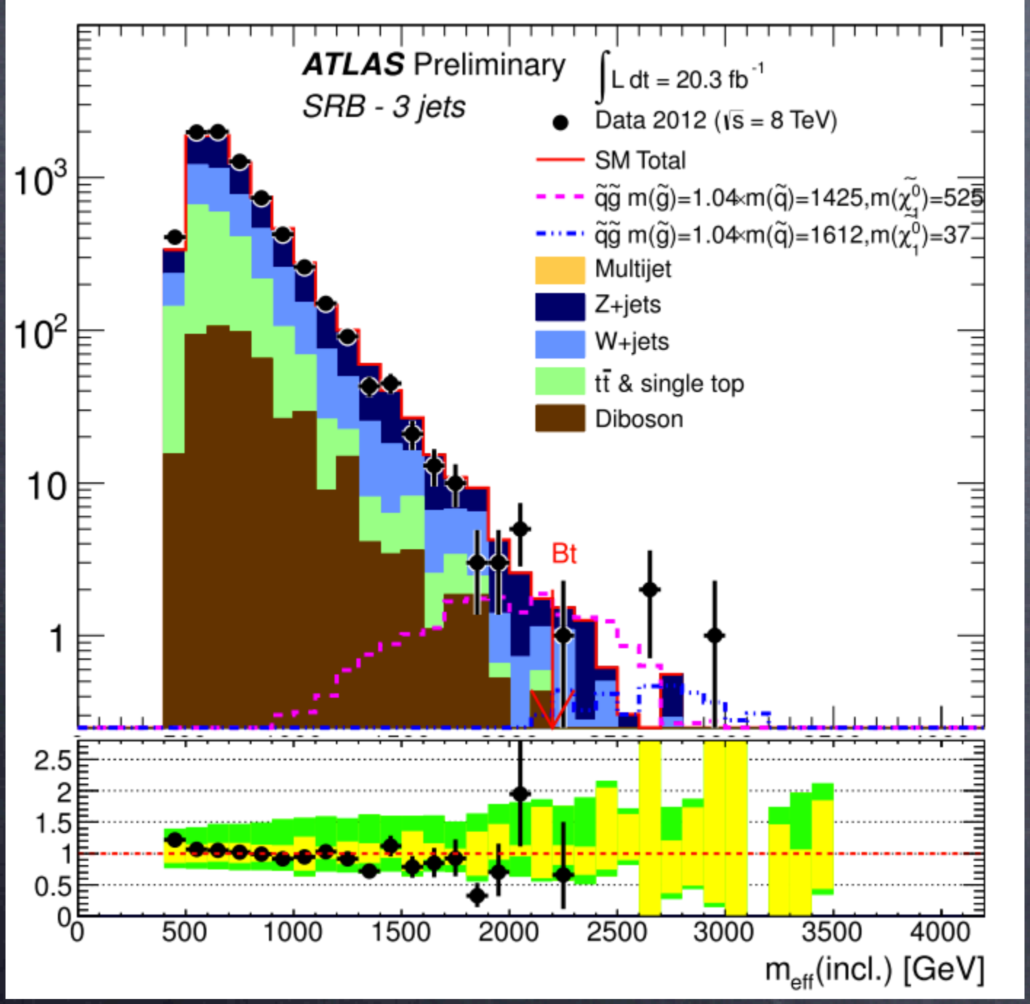


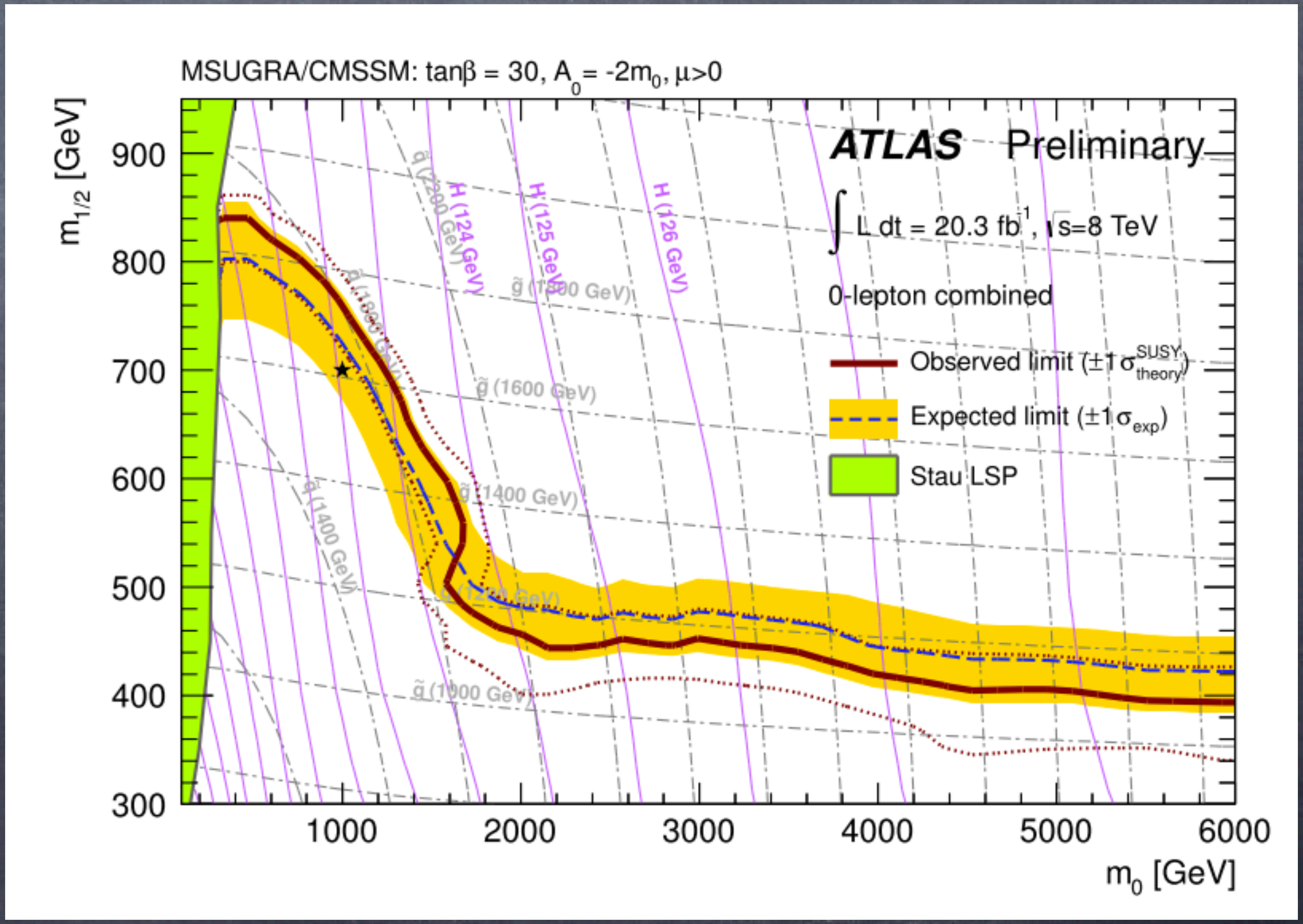


Limits from Experiments

- Experiments publish limits based for a given theoretical model and the corresponding measured background. An example:
  - A search for squarks and gluinos in events featuring only jets and Transverse Missing Energy. A 0-lepton+jets Study.
  - They have the following decay: $\tilde{q} \rightarrow q\tilde{\chi}_1^0$ $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$

ATLAS-CONF-2013-047



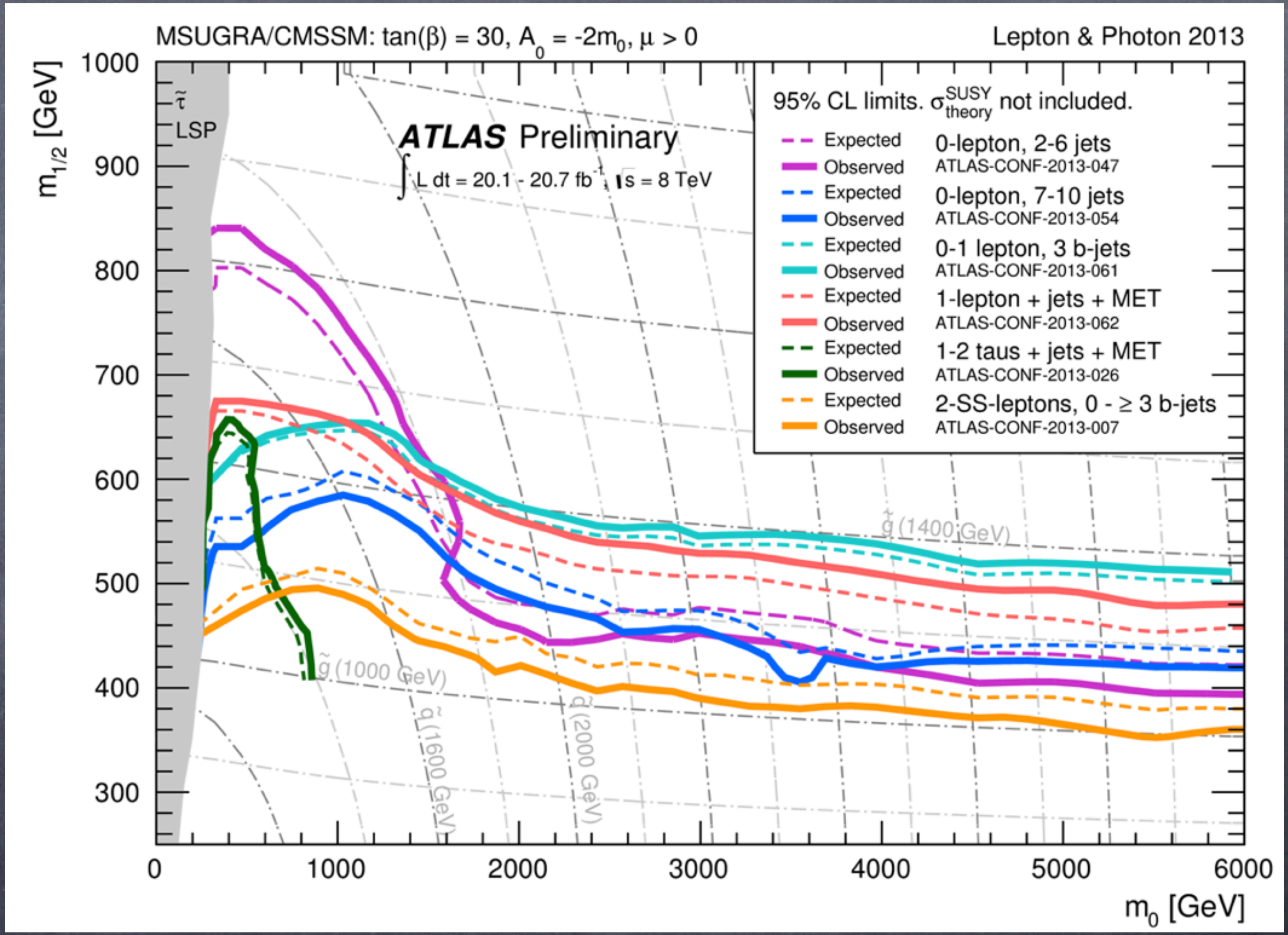


Motivation for a Fast Simulator

- Can the results of the search performed by the experiment be re-interpreted with respect to a new theory?

- The answer is yes, as long as we can reproduce the response of the detector.

- The validation would entail reproducing the published limits with our own generated and "reconstructed" signal events.



Motivation for a Fast Simulator

- What would this mean for the 0-lepton+3jets analysis.
- The signal region is defined as:
  - Missing Transverse Energy > 160 GeV
  - Three jets, where the $P^1{}_T > 130$ GeV, $P^2{}_T > 60$ GeV and $P^3{}_T > 60$ GeV, $|\eta| < 2.8$. they are reconstructed with the anti-kt clustering algorithm with a radius of 0.4 .
  - Events are vetoed if the include a well identified electron $P_T > 10$ GeV, $|\eta| < 2.47$ or muon $P_T > 10$ GeV, $|\eta| < 2.5$.
  - The scalar sum of the selected jets + MET > 2200 GeV
- The cuts would be applied on our generated+"reconstructed" events and using the published background, we can attempt to reproduce the limits.

Properties of a Fast Simulator

- To be able to reproduce the signal region, the modelling of the detector response has to be comprehensive - The following needs to be applied:
    - Momentum/Energy resolution, identification efficiency, isolation and the trigger when required.
    - Fast - A large number of events will be required to be "reconstructed" .
    - Easy to integrate within an analysis framework and existing multiprocessor environment.
    - Good enough - The resulting detector response applied to the generated event should just be good enough to reproduce the experimental yields and limits. Anything better is just costing CPU cycles.

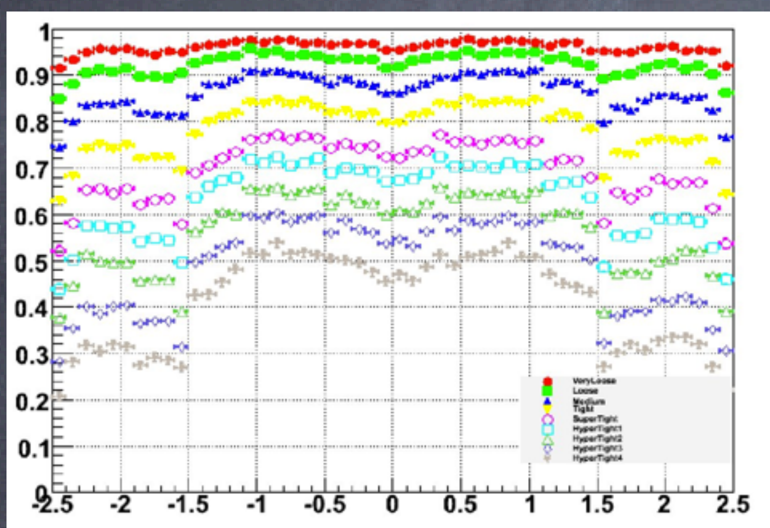
FastSim

- There a number of fast simulators in the market.
- PGS 4 - Pretty Good Simulator - It is fast but it is written in Fortran and difficult to integrate with the new generators. (www.physics.ucdavis.edu/~conway/research/software/pgs/pgs4-general.htm)
- AcerDET - A simple Fast Simulator of ATLAS written in Fortran (erichter.home.cern.ch/erichter/AcerDET.html)
- Delphes - Comprehensive simulation written in C++ , it may not be as fast as we need. cp3.irmp.ucl.ac.be/projects/delphes
- Write your own -
  - Simple structure with interfaces to generators in C++.
  - Have included some of the aspects of AcerDET in get the first results.
  - Compare performance and results to DELPHES

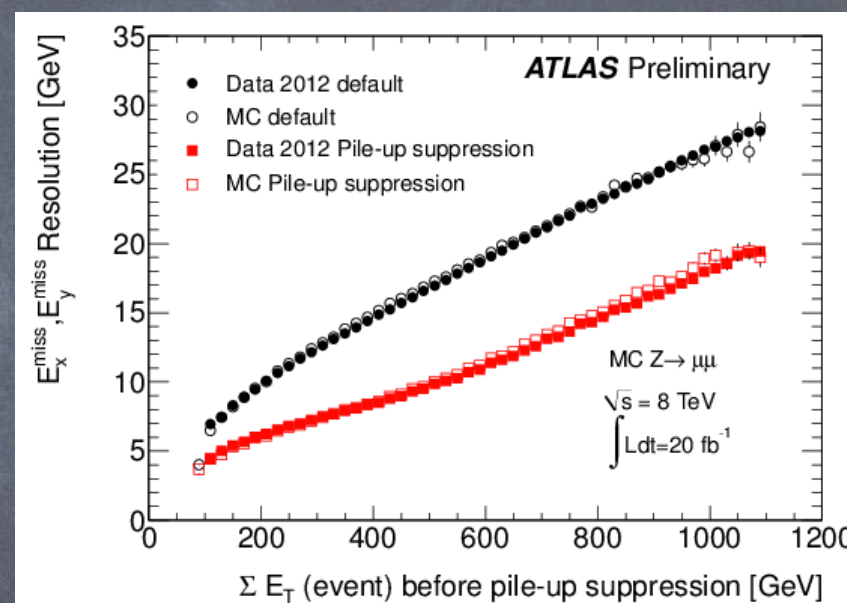
ATLAS and CMS Performance

- Both ATLAS and CMS publish the efficiency and resolution of final states from Data/MC studies - The response can be parametrize and implemented in the fast simulator for a given final state.

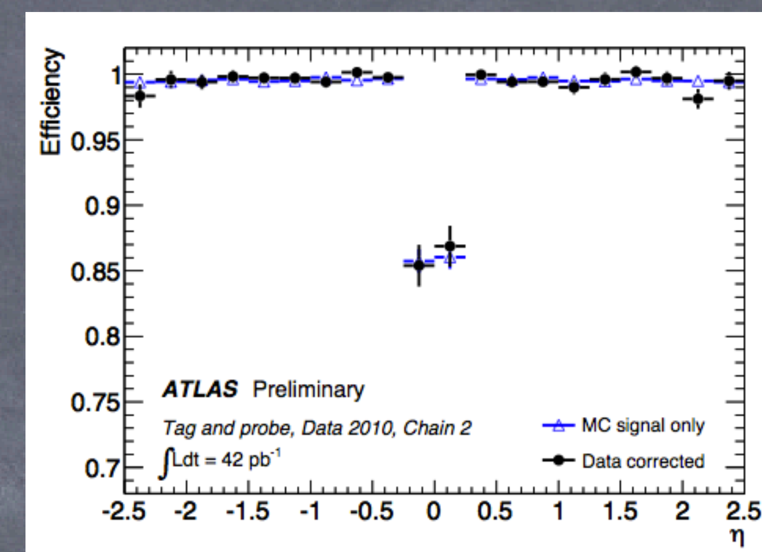
CMS - Electron ID Efficiency (eta)



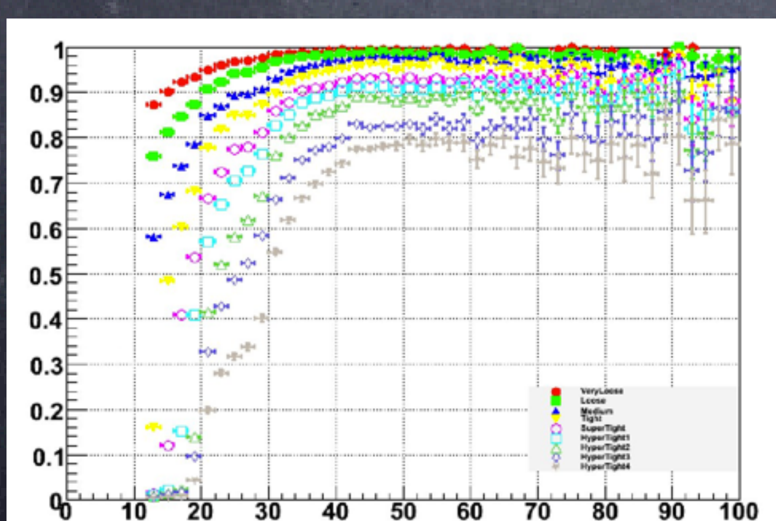
ATLAS - MET resolution



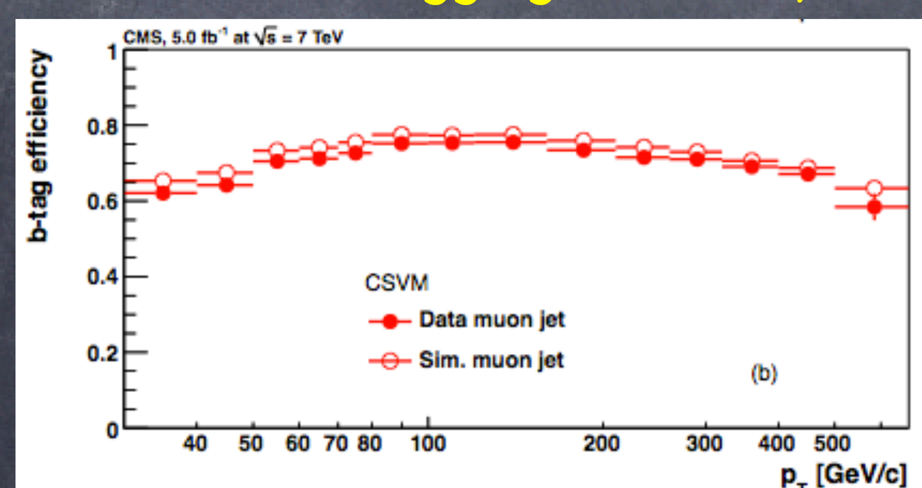
ATLAS - Muon ID Efficiency (eta)



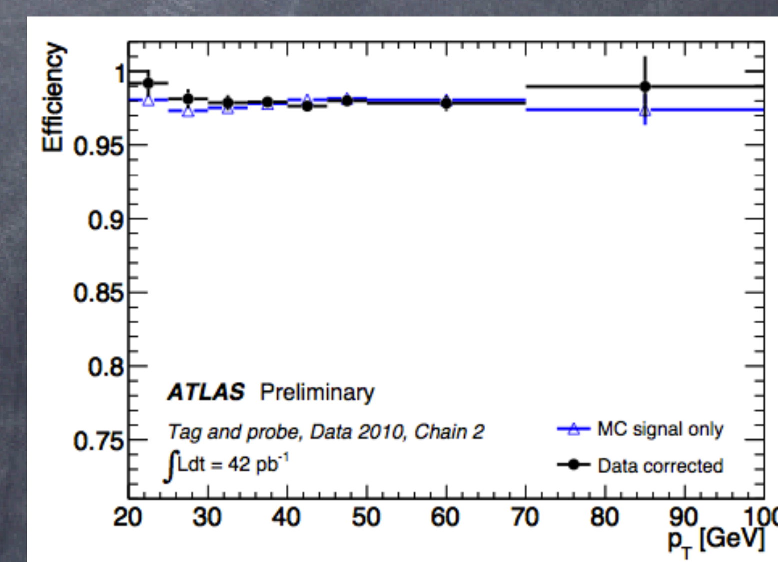
CMS - Electron ID Efficiency Pt (Gev)



CMS - B-tagging Efficiency



ATLAS - Muon ID Efficiency (Pt)



Fast Sim Diagram

So far it has been interfaced to pythia 8 - for each event - this needs work

Input
List of Stable Particles
List of b quarks
List of visible Taus

Detector Response (Detector Specific)

- Determine the calorimeter response
- Apply fiducial cuts and trigger response.
- Reconstruct Jets
- Calculate the isolation for muons and electrons.

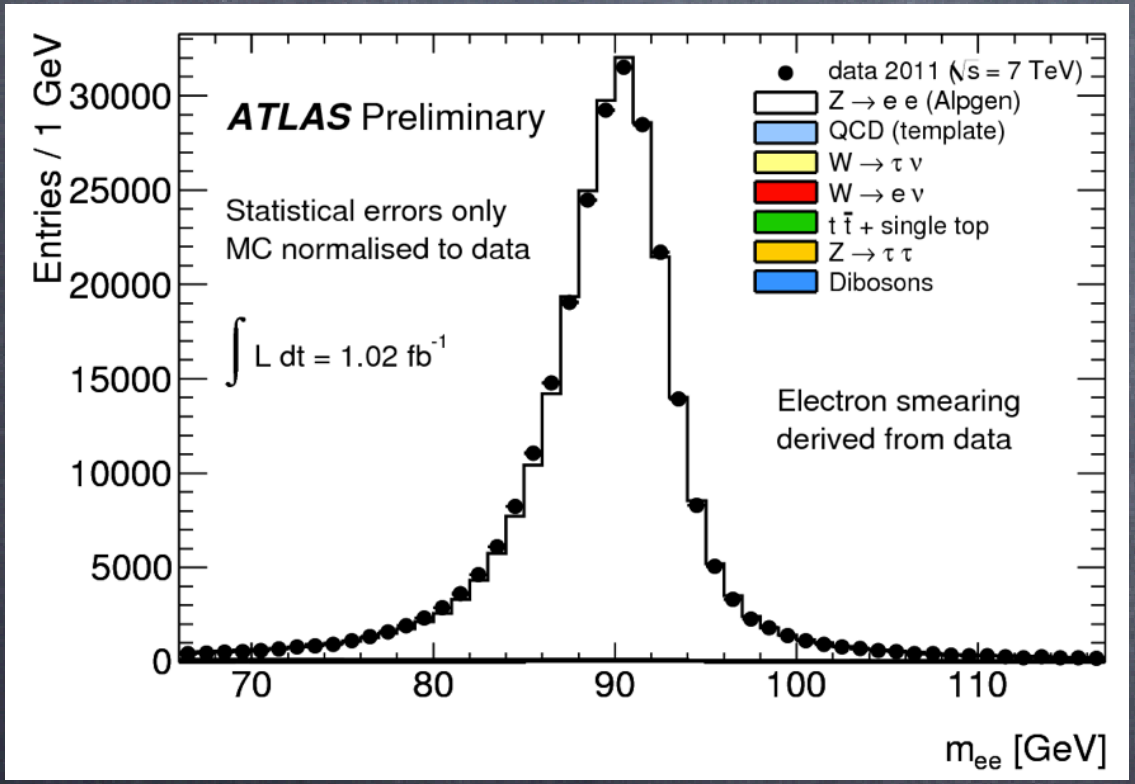
Detector Correction

Apply the smearing and efficiency for the specific particle that have been published
(Detector Specific)

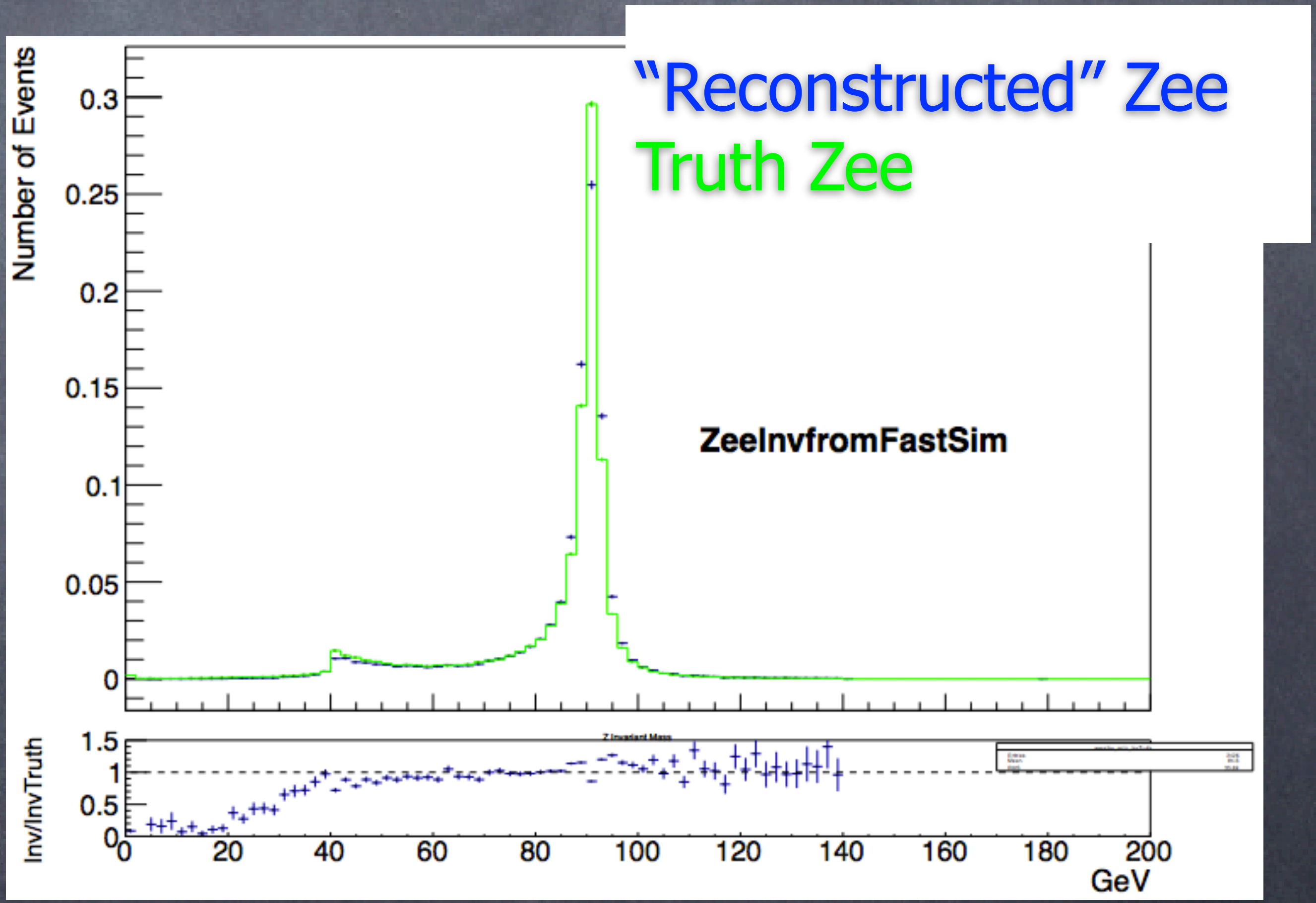
Return the reconstructed event for analysis

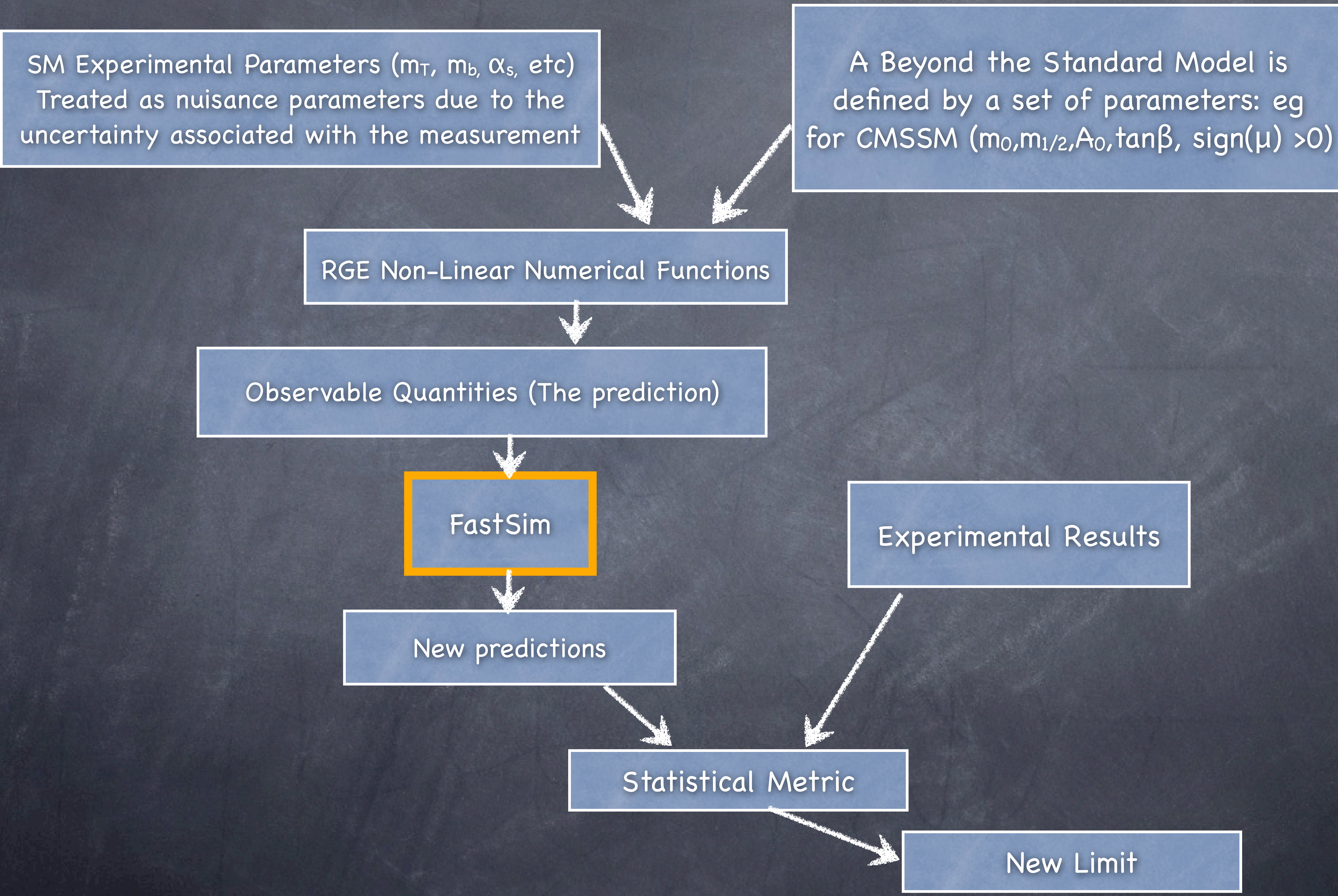
So far

- The Calorimeter response was implemented by a summer student Kevin Le (ANU)
- This is the invariant mass of the Z boson "reconstructed" by the FastSim from Floriane.



1.8 GeV Mass Resolution




SM Experimental Parameters (m_T, m_b, α_s, etc)
Treated as nuisance parameters due to the uncertainty associated with the measurement
A Beyond the Standard Model is defined by a set of parameters: eg for CMSSM (m_0,$m_{1/2}$,A_0,$\tan\beta$, sign(μ) >0)
RGE Non-Linear Numerical Functions
Observable Quantities (The prediction)
FastSim
Experimental Results
New predictions
Statistical Metric
New Limit

GAMBIT: A Global and Modular BSM Inference Tool

- The aim is to develop a software framework to allow the definition and eventual global fitting of an arbitrary new Beyond the SM model using arbitrary new data with little modification as possible.
  - Allow users to implement their own models
  - Support many BSM models, datasets, observables through in-house development and user contribution.
  - The collaboration will use this tool to carry out comprehensive global fits in the future, and members will use it for their individual research as well.
- The collaboration boasts a varied selection of experts from key fields. This expertise and knowledge will enable the collaboration to incorporate the latest experimental and theoretical results.

GAMBIT: Members

- GAMBIT has 24 members from 15 institutes and universities:
  - It includes 9 experiments and 3 major theory codes - (Dark SUSY, SuperISO, Isajet).

Aachen University
Adelaide University
University of Amsterdam
Clermont-Ferrand
DESY
University of Edinburgh
University of Hamburg
Havard University

Max-Planck Munich
McGill University
Monash University
University of Oslo
University of Sydney
Stockholm University
University of Utah

Australian Contingent

Csaba Balazs, Ben Farmer, Paul Jackson, Martin White, Aldo Saavedra and Pat Scott.

Collaboration	Members
Fermit-Lat	4
IceCube	3
ATLAS	5
CMS	1
LHCb	1

Collaboration	Members
AMS-02	1
CTA	3
Darwin	1
HESS	2
Theory	12

Conclusion

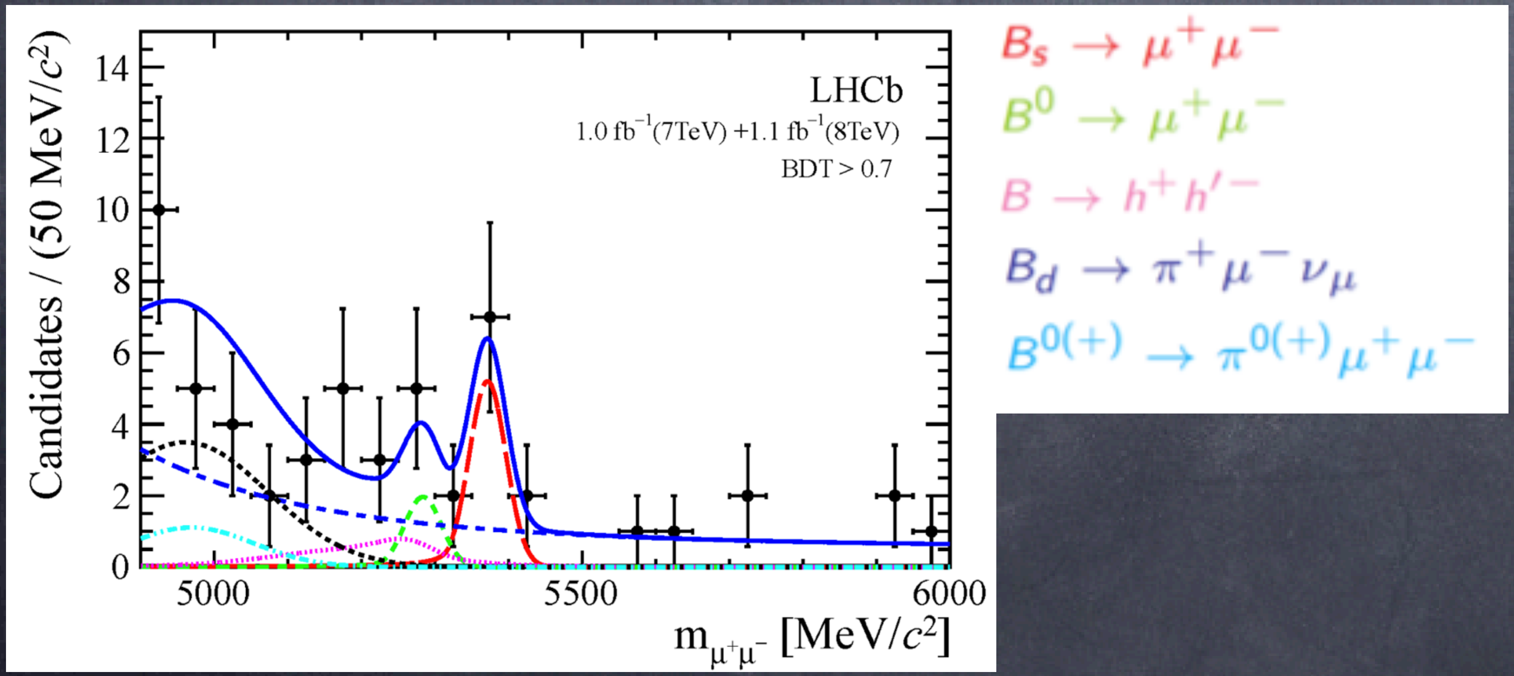
- It is an exciting time with the LHC providing results on BSM physics together with precision measurements from B-factories and astrophysical experiments.
- A great number of theories are being developed to provide insight into the underlying physics.
- A fast simulator that can reproduce the performance of ATLAS and CMS to allow the re-interpretation of experimental limits for new theories will be an invaluable tool for packages such as GAMBIT.

Back Up Slides

B physics inputs

- The rare B-decays are sensitive to new physics through loop contributions. (add a bit more, one feynman diagram)
- Measured Branching ratio or upper limits are important inputs when testing the validity of new theories.

Process	SM Prediction	Measurement
BR($B_s \to \mu^+\mu^-$)	$(3.54 \pm 0.30) \times 10^{-9}$	$(3.2^{+1.4}_{-1.2}(\text{stat})\ ^{+0.5}_{-0.3}(\text{syst})) \times 10^{-9}$
BR($b \to X_s\gamma$)	$(3.15 \pm 0.23) \times 10^{-4}$	$(3.45 \pm 0.15 \pm 0.40) \times 10^{-4}$
BR($B_u \to \tau\nu_\tau$)		$[0.72^{+0.27}_{-0.25}(\text{stat}) \pm 0.11(\text{syst})] \times 10^{-4}$



The Detector Response

- The detector response needs to:
  - Simulate the id+reconstruction of electrons, taus muons (pt, eta)
  - Simulate the response of jets.
  - Calculate the Transverse Missing energy in the event.
  - Determine if a lepton is isolated or not.
  - Select which jets are considered b-tagged.
  - It needs to be fast and be capable of running in parallel.

So Far...

- Modelled our code on ACERDET
  - It currently uses the GAMBIT event class
  - Seperates electrons, muons, neutrinos, photons from other interacting particles.
  - It determines which cells in the calorimeter were hit by the interacting particles, the total energy for each cell calculated.
  - Creates clusters from the cells - this will become the jets - Another way is to give the cell list to FastJet and use the anti-kt algorithm.
  - The isolation for each muon and electron is calculated from the cells within a dR of the lepton
  - The energy response is corrected by a number of functions.