ATLAS Edinburgh Exotic Searches

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24/05/17

What is Exotic?

“originating in or characteristic of a distant foreign country.”

Iguazu falls,
Argentina 2007
© me

Regrettably the travel budget requires that we examine a more Geneva-centric definition

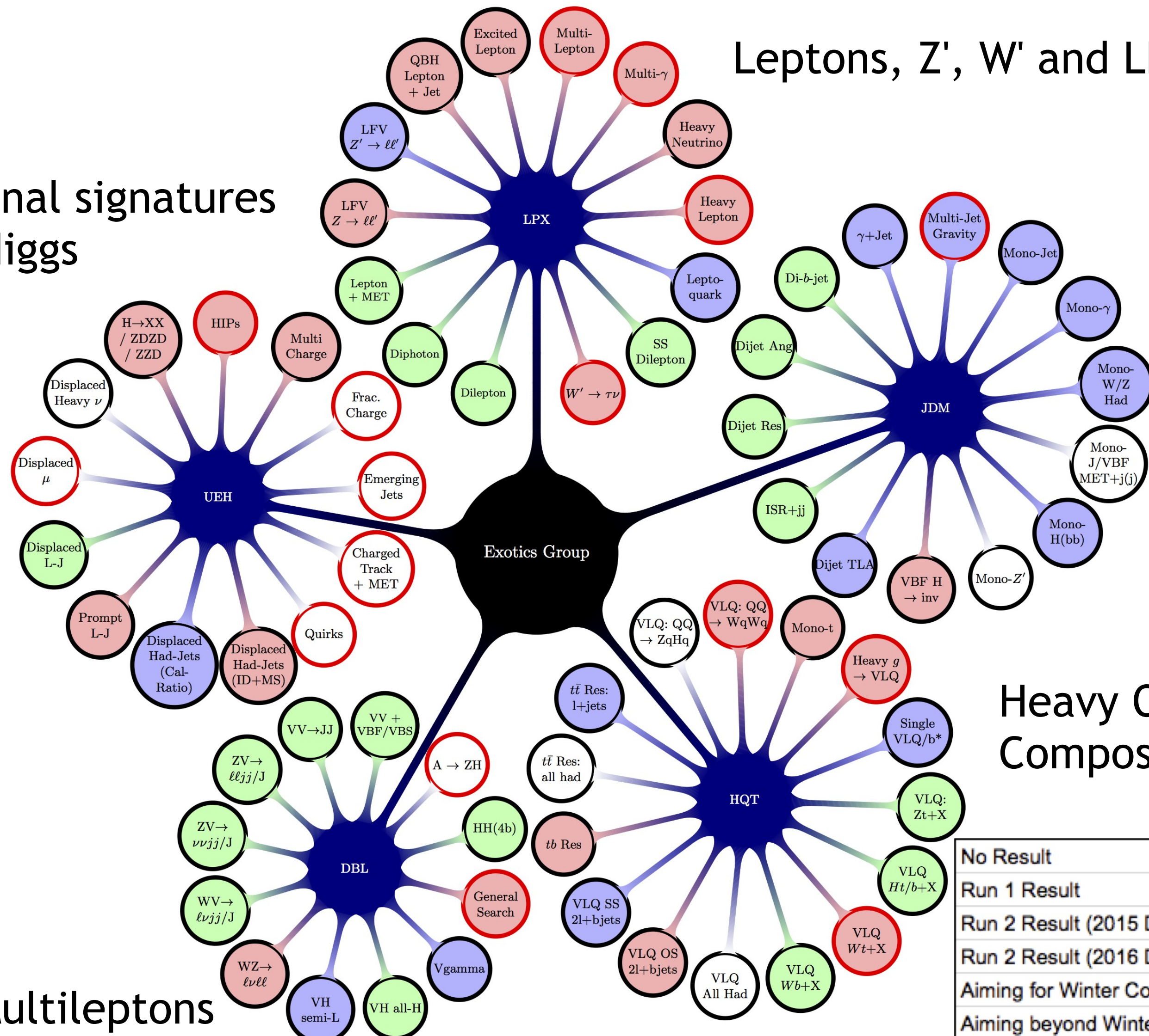
What is Exotic?

"new physics beyond the Standard Model... all experimentally viable signatures focusing on non-supersymmetric models"

Leptons, Z', W' and LFV

Unconventional signatures and Exotic Higgs

Jets and Dark Matter



Heavy Quarks, Top, and Composite Higgs

No Result	
Run 1 Result	
Run 2 Result (2015 Data)	
Run 2 Result (2016 Data)	
Aiming for Winter Conferences	Black Circle
Aiming beyond Winter	Red Circle

Dibosons, Multileptons and Extra Dimensions

Who is Exotic?

At Edinburgh the EXOSEARCH group is lead by Christos, and includes myself, Xanthe, Andreas and Antonia

Flavia and Yanyan have left Edinburgh this year, but I'll also mention their exotics work

Why Exotic?

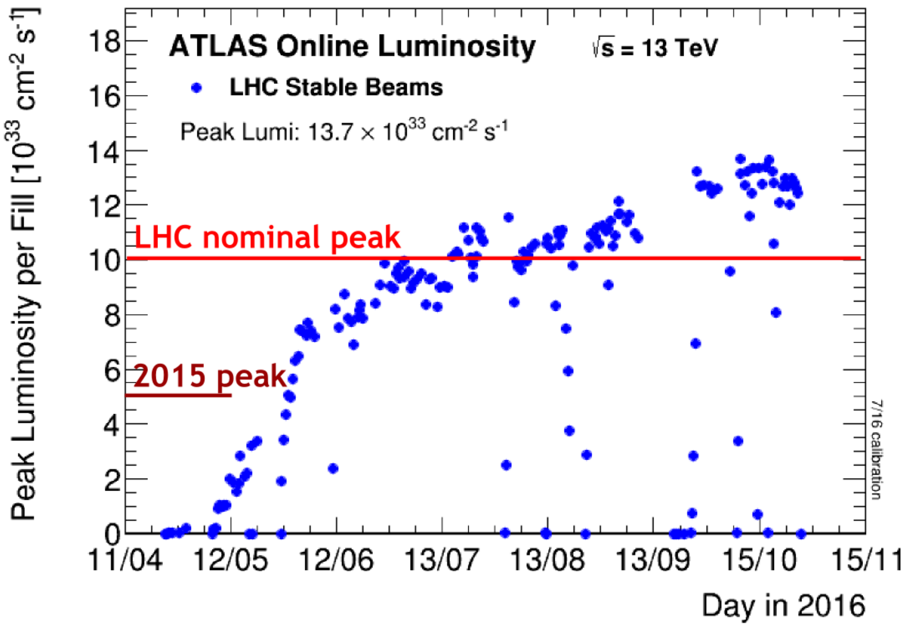
LHC Run 2 is the furthest the collider energy frontier is likely to be pushed in a decade or so

This makes it the most direct opportunity we have to find undiscovered high-mass particles, which are a component of most BSM physics models

That means SUSY searches, and exotics searches

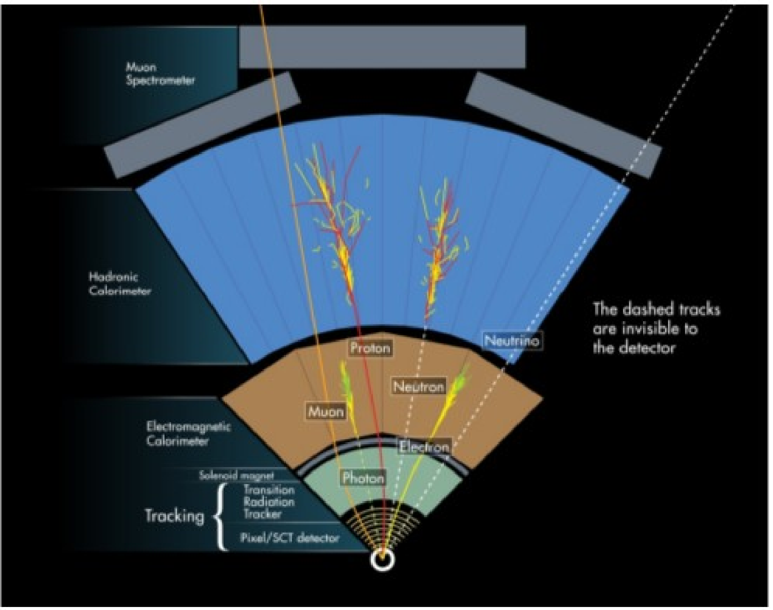
Future LHC upgrades will focus on intensity, and the LHC design luminosity has already been comfortably surpassed

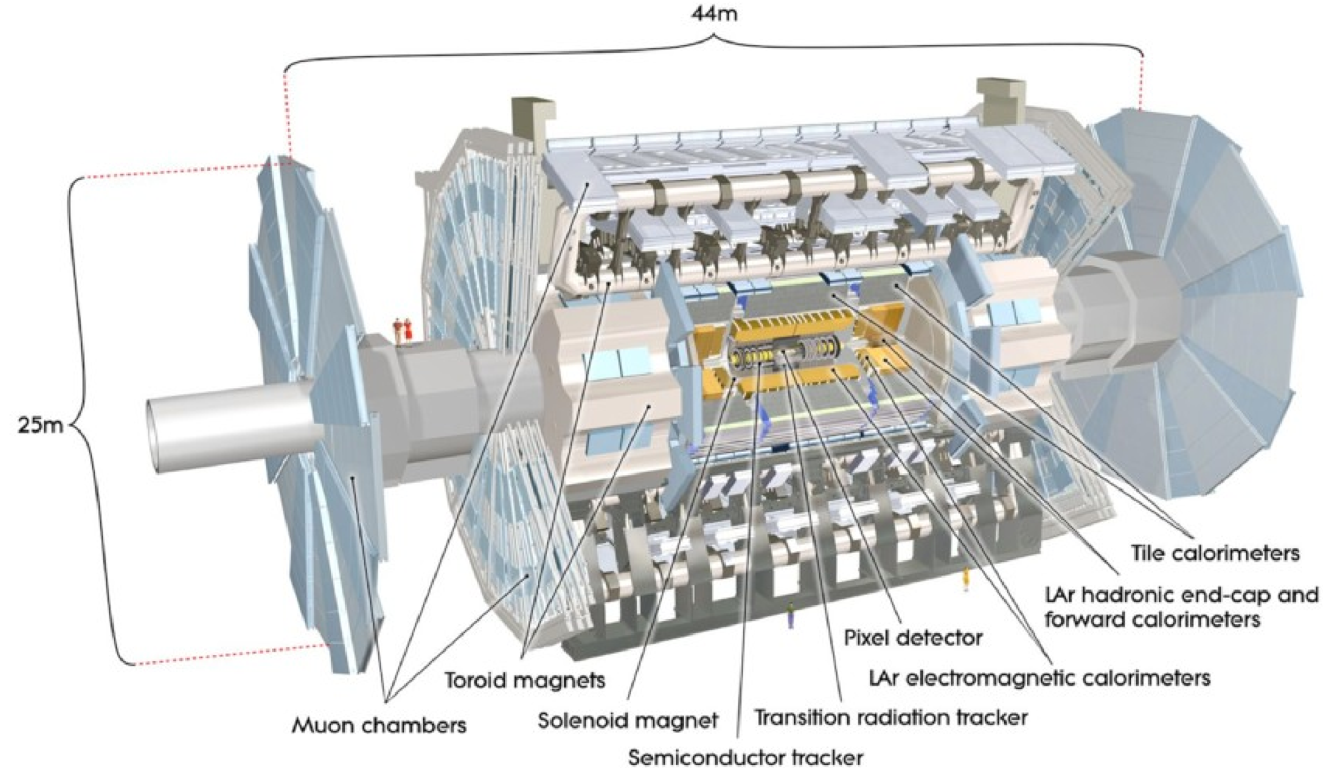
Precision physics is also an excellent path to BSM discoveries (as LHCb has been demonstrating)



D Charlton (Birmingham) – ATLAS & LHC Status AUK Jan 2017

OBLIGATORY ATLAS DETECTOR SLIDE





- Main subdetectors
  - **Inner Detector** => Silicon and transition radiation technologies, in solenoidal magnetic field
  - **Calorimeters** => Liquid Argon (LAr) Electromagnetic (EM) calorimeter (in central and forward regions) and hadronic calorimeter (tile in central and LAr in forward region)
  - **Muon system** => spectrometer in toroidal magnetic field

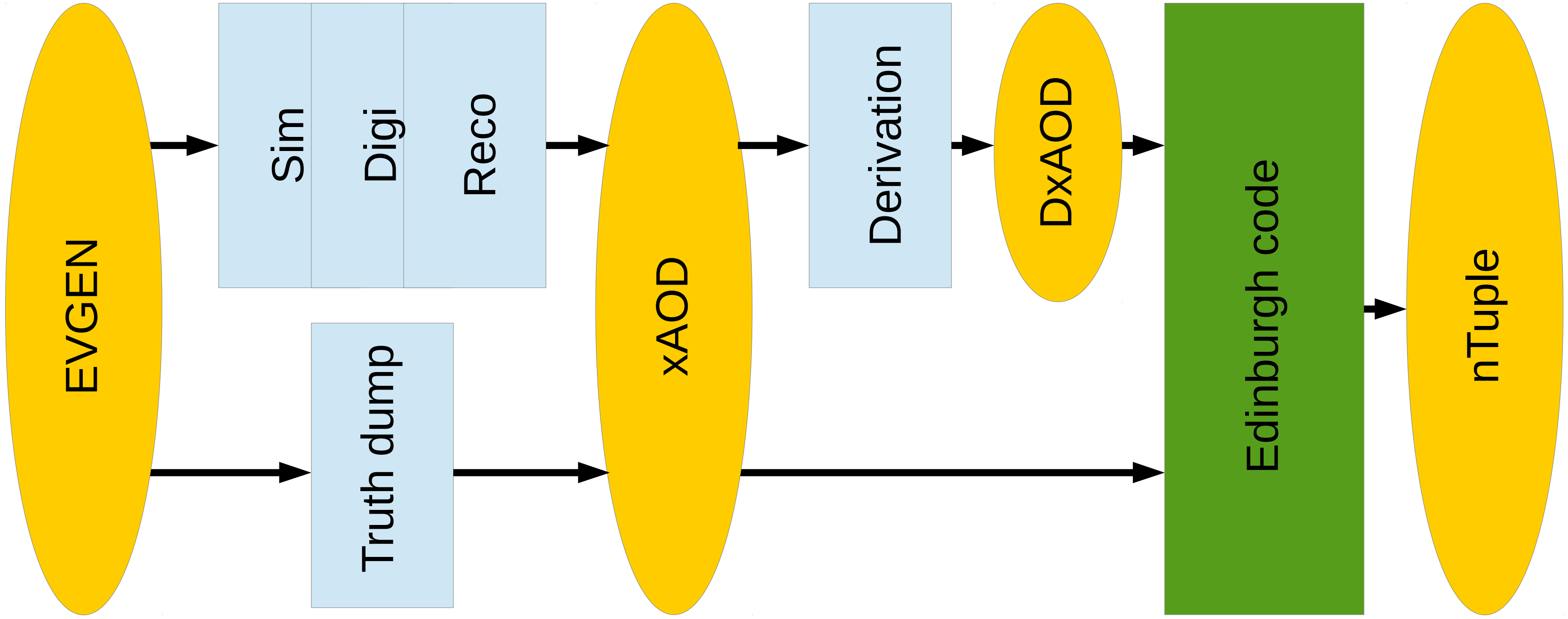
I just stole it from Flavia (along with some other slides this talk)

The Plan

Way back in the mists of time (before Run 2) the idea was simple: make a common piece of code to process ATLAS data and MC into ntuples suitable for several exotic searches

We started before the ATLAS sample derivation chain was in production, we supported several Run 2 analyses, and we're only now beginning to phase it out

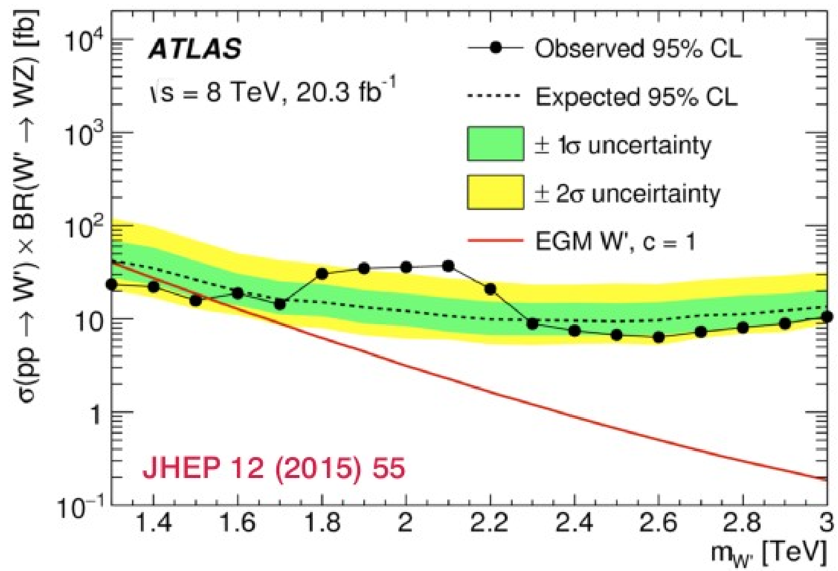
Here's a diagram from April 2015, where we didn't even have data to run on yet



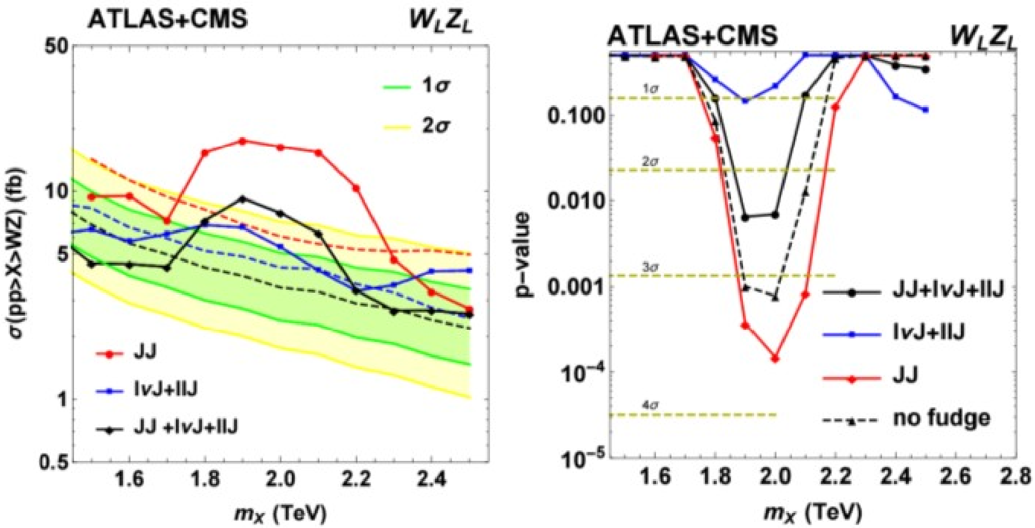
Exotic Diboson searches

Exotic Diboson searches

- Historically connected to electroweak symmetry breaking models
  - ➡ Not excluded with SM Higgs $m_H \sim 125$ GeV
- Several scenarios
  - ➡ Spin 0: Heavy scalars in extended Higgs sector
  - ➡ Spin 1: Extended gauge models (W′, Z′ in SSM/HVT models)
  - ➡ Spin 2: Kaluza-Klein gravitons (bulk Randall-Sundrum)
- Excitement from Run-1 searches in VV→ JJ channels



Phenomenology paper combination



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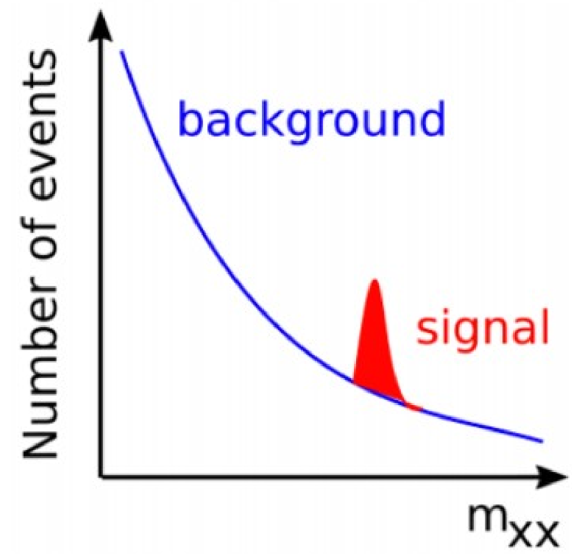
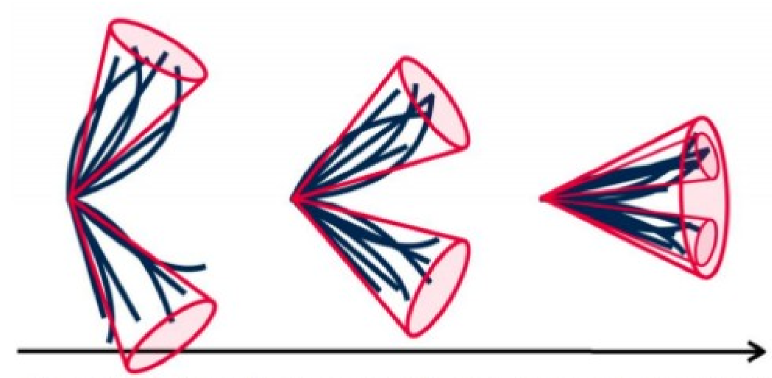
Stolen from Flavia

Diboson final states

- Look into many final states:
  - ➡ VV → $\ell\ell qq$, $\ell\nu qq$, $\nu\nu qq$, $qqqq$, $\ell\nu\ell\ell$, $\ell\nu\ell\nu$
    Flavia Yanyan
  - ➡ VH → $\ell\ell bb$, $\ell\nu bb$, $\nu\nu bb$, $qqbb$
  - ➡ HH → bbbb
  - ➡ ZH (H≠125), XH, Vγ…
- Wide range of boson p_T: distinct topologies for hadronic decays
  - ➡ Resolved: 2 small R jets (jj)
  - ➡ Boosted: single large R jets (J)
- Addition of VBF production mode in some channels



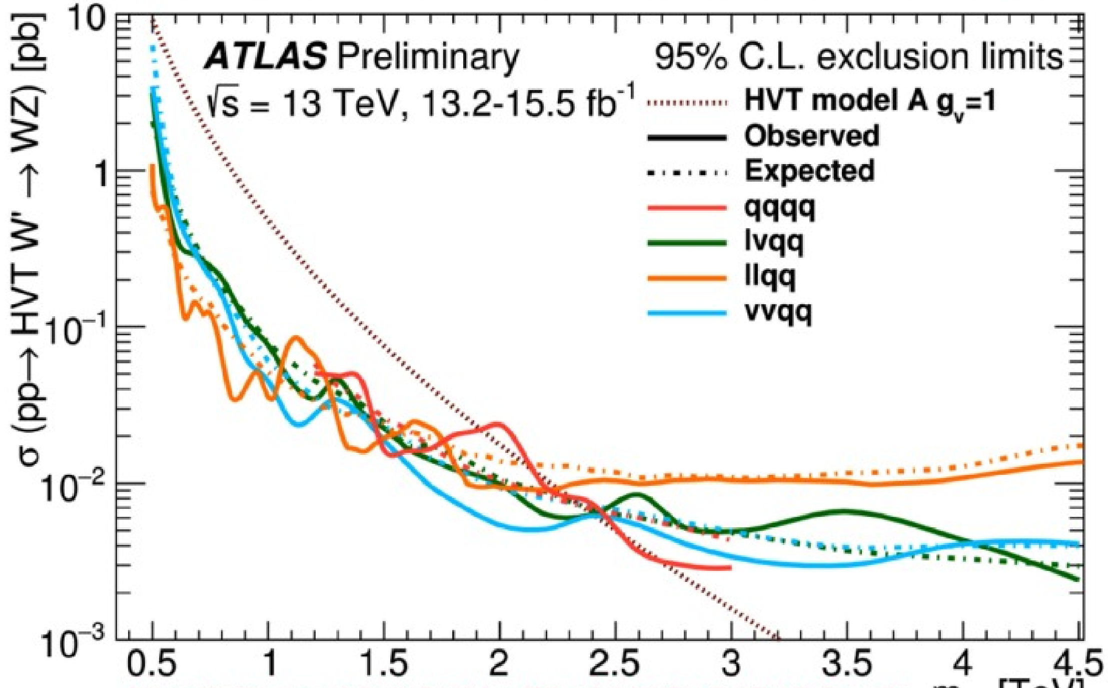


Boosted jets: Increasing transverse momentum

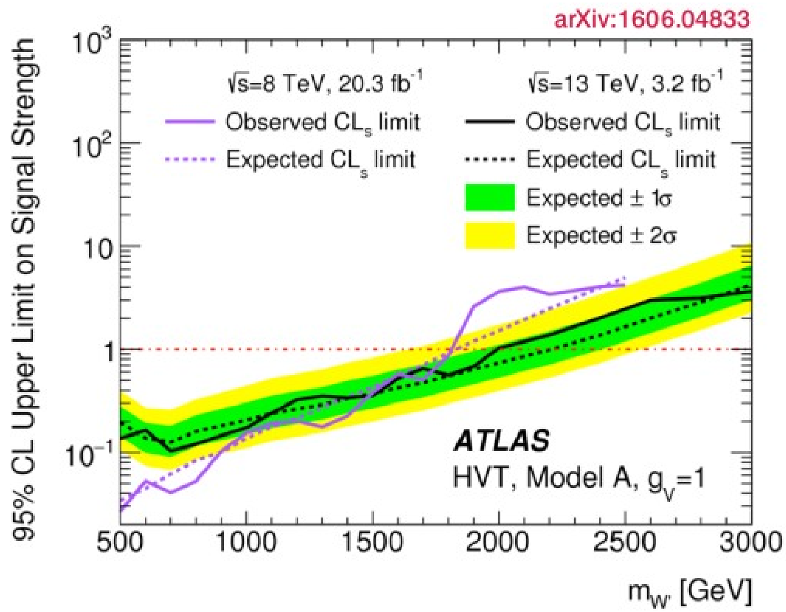
Stolen from Flavia

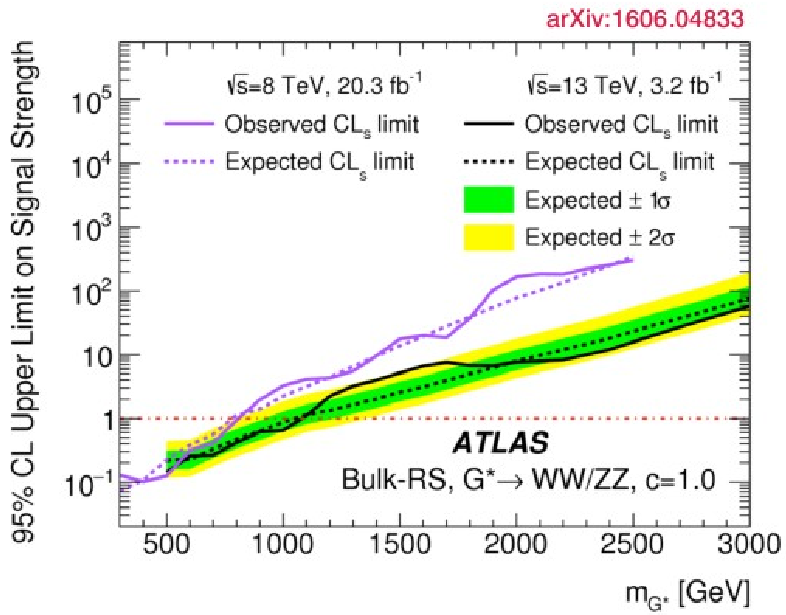
Diboson results

ICHEP2016 results - superimposed (not combined)



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults





- Comparison between VV combination in Run-1 (8 TeV, 20.3 fb^{-1}) and Run-2 winter16 (13 TeV, 3.2 fb^{-1})
  - ➡ At m = 2 TeV, even with just the winter dataset, the analysis had more sensitivity than the Run-1 dataset

Stolen from Flavia

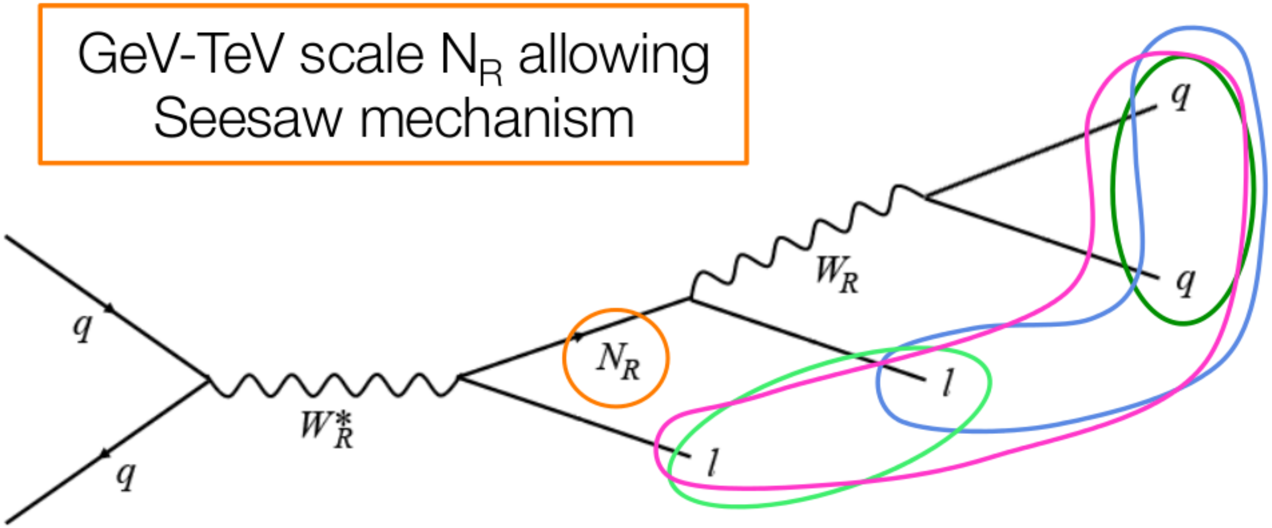
Heavy Neutrino and W_R search

Left-Right Symmetric Model

- Assuming no flavour mixing and degenerate N_R
- Two possible mass hierarchies: $m(N_R)<m(W_R)$ and $m(N_R)>m(W_R)$
- $m(N_R)>m(W_R)$ case never before studied at the LHC
- Concentrating on OS for this analysis (sensitive to Dirac and Majorana N)

If $m(N_R)>m(W_R)$: W_R and W_R^* swap in diagram. Two jets give onshell invariant mass of W_R

GeV-TeV scale N_R allowing Seesaw mechanism



One lepton and two jets with the invariant mass of the N_R (lepton selection depends on mass hierarchy)

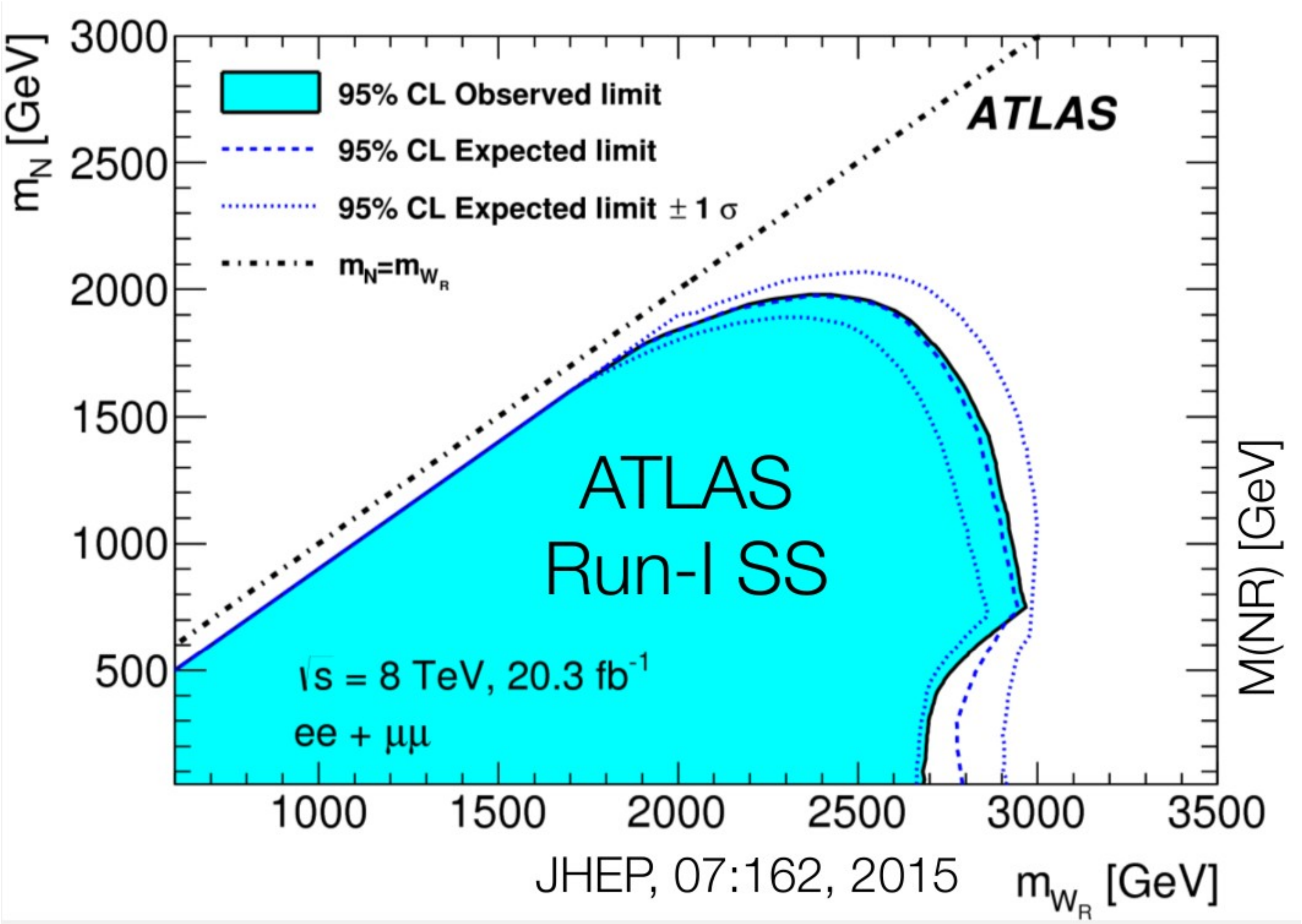
Dirac or Majorana N_R from signs of leptons – if N_R is Majorana leptons can be same sign

If $m(N_R)<m(W_R)$: Two leptons and two jets give onshell invariant mass of W_R (jets merge if $m(N_R)<<m(W_R)$)

Stolen from Xanthe

Search strategy

Explicitly veto-ing a leptonic weak boson decay (mll > 400GeV) and looking for a 2D resonance in heavy neutrino and W_R mass plot



This is the Run 1 result (I can't show you anything from Run 2 yet)

Search strategy

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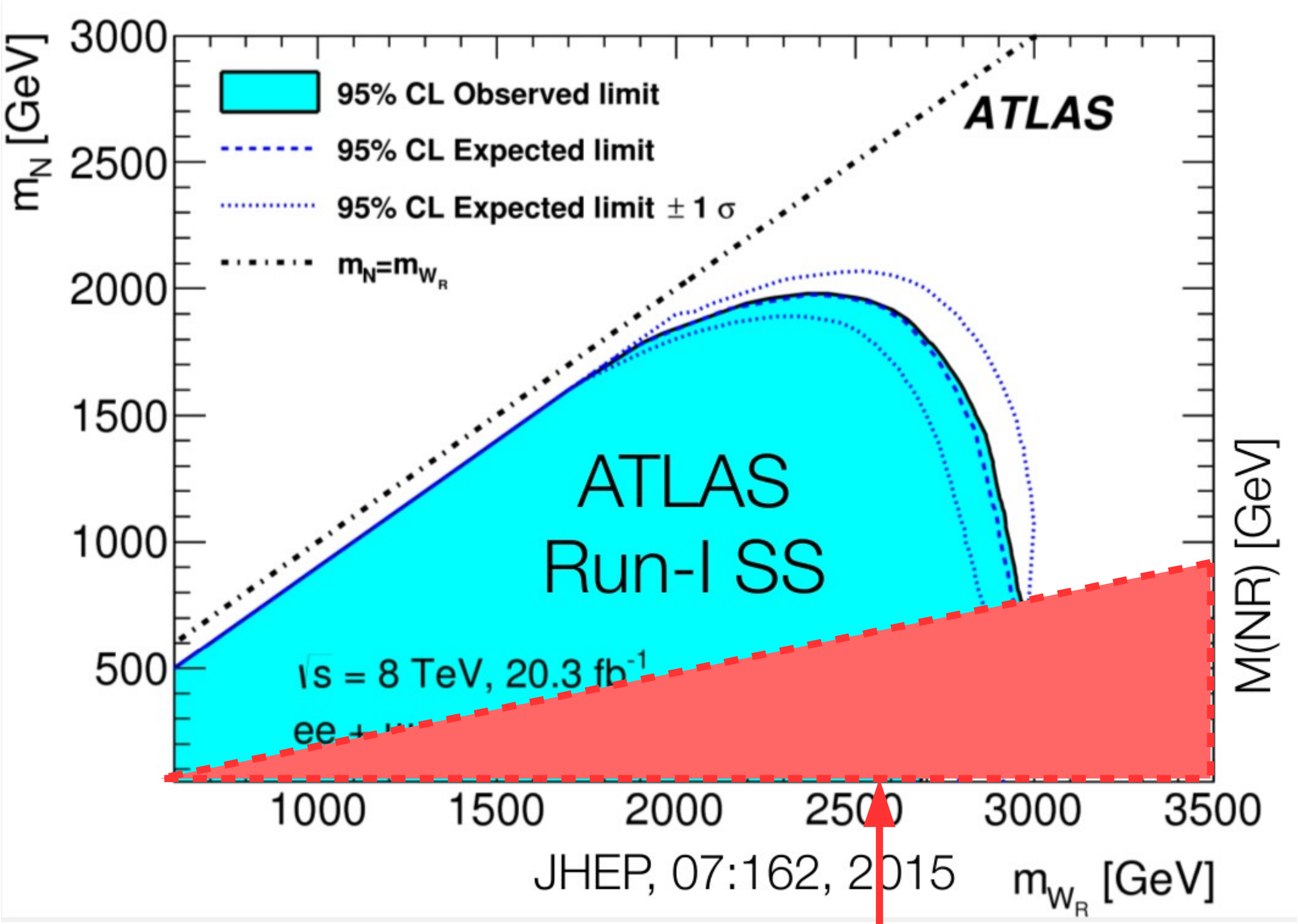
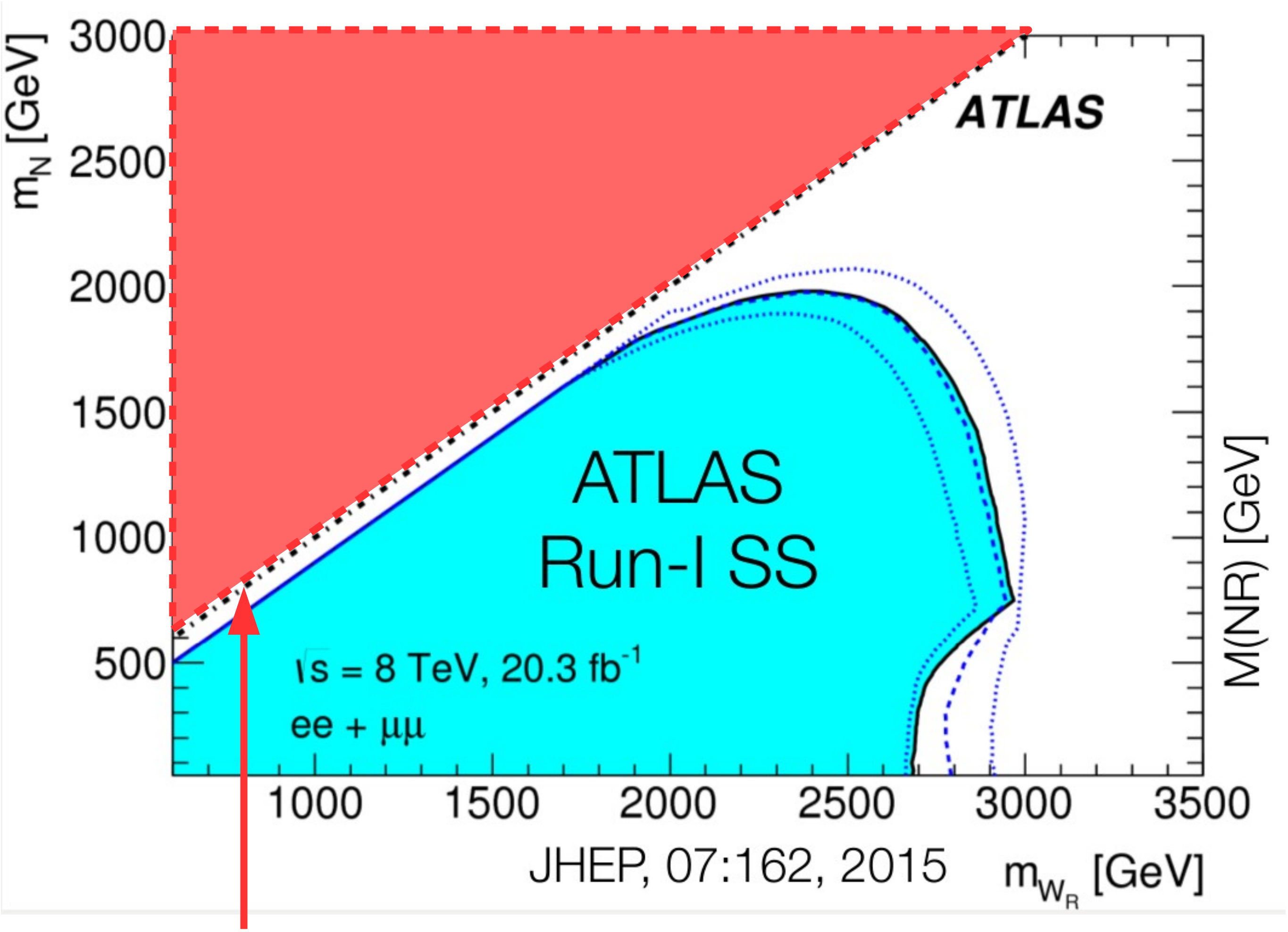


Boosted regime: qq forms merged jet
Separate analysis

Search strategy

Explicitly veto-ing a leptonic weak boson decay (mll > 400GeV) and looking for a 2D resonance in heavy neutrino and W_R mass plot



mN > mW_R – now able to study this regime due to MC improvements, but low cross-section

Search strategy

In this single decay mode there are plenty of free parameters, giving us multiple analysis approaches:

Baseline – 2 leptons of same flavour and opposite sign, 2 resolved jets
- Edinburgh & USTC groups, aiming for summer conferences

Flavour mixing – signal with 1 electron and 1 muon
- USM group

Boosted regime – 1 jet with 2 subjets
- Wits group

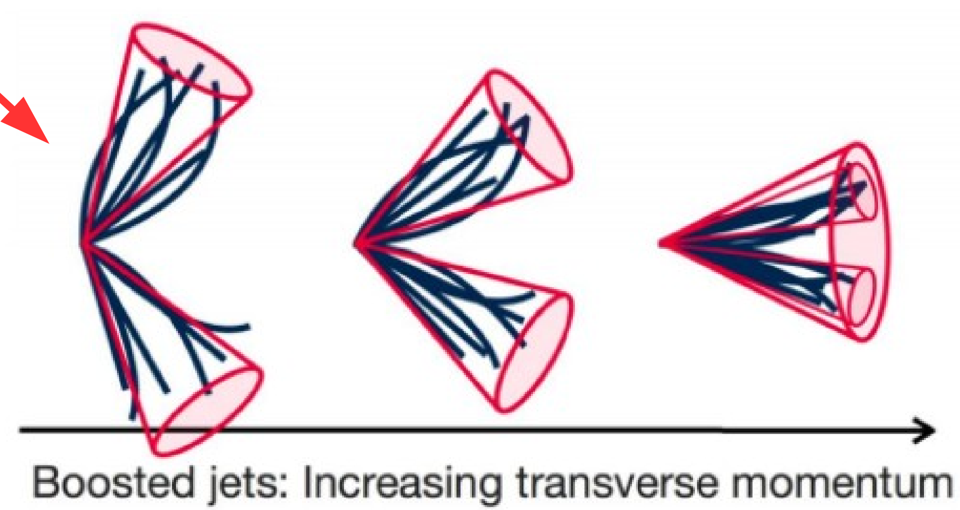
Majorana neutrino – leptons may have same sign
- Dominated by fake background, working from techniques developed for inclusive same sign analysis

Boosted jet + ISR

Boosted Jet + ISR

Looking for a Z'-like particle: similar to the merged jets from earlier, but mass unknown. Some Dark Matter models also rely on a new vector resonance

- Using standard trimmed anti-$k_t^{R=1.0}$ jets
- Selection:
  - == 1 photon with $p_T > 155$ GeV
  - ≥ 1 jet with $p_T > 250$ GeV
  - $\Delta\phi(\gamma, J) > \pi/2$



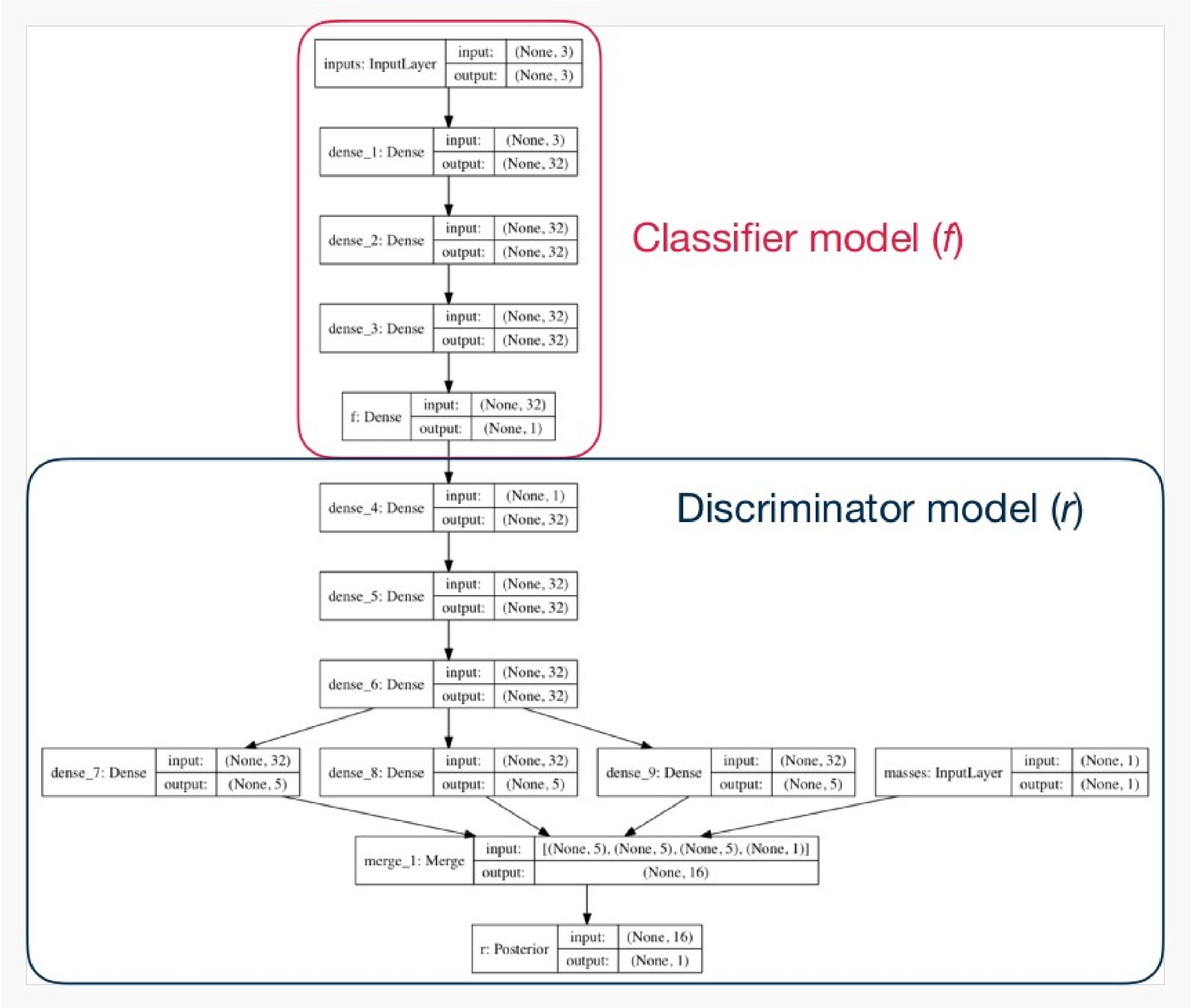
Stolen from Andreas

Boosted Jet strategy

- Searches for new physics in final states with large-radius jets usually rely on jet substructure information to distinguish two- or three-prong jets (W/Z/t/H/X) from non-resonant "QCD" jets
- A wealth of substructure variables exist for this purpose, each based on (slightly) different ideas: τ_{21}, τ_{23}, $\sqrt{d_{ij}}$, D_2^β, C_2^β, N_2, …
- Cf. [arXiv:1603.09349] there is additional separating power to be found in combining several high-level substructure variables using a boosted decision tree or a neural network
- Unfortunately, especially for searches where the resonant particle(s) producing the large-radius jet doesn't have fixed mass(es), this combination is likely correlated with the jet mass

Stolen from Andreas

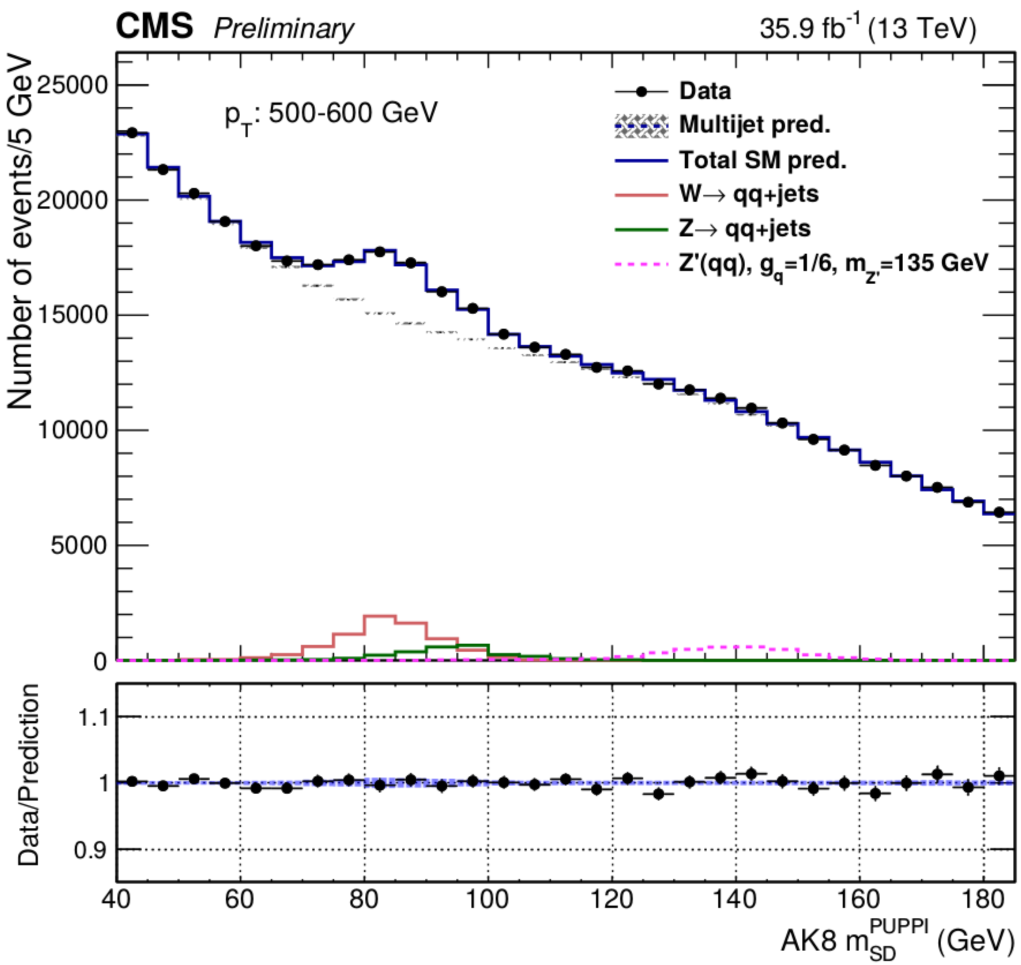
Adversarial Neural Network

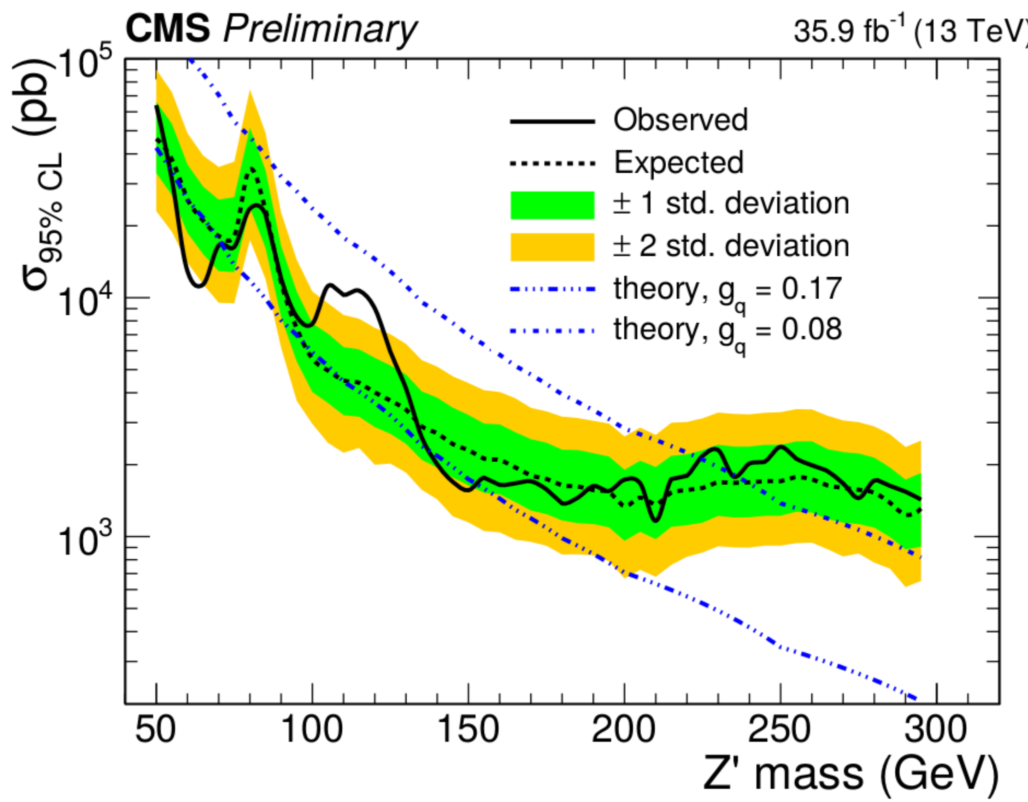


Stolen from Andreas: have a look at https://arxiv.org/pdf/1703.03507.pdf

CMS result

Unfortunately I can't show you an ATLAS result yet, but CMS have a similar analysis showing a small (2.2 sigma) excess at 115 GeV





https://cds.cern.ch/record/2264843/files/EXO-17-001-pas.pdf

Summary

Exotic searches covers a pretty wide range of models
- Exotic = !(StandardModel || SUSY)

The Edinburgh exotics group cover a pretty wide range of models
- Diboson resonances
- Left-right symmetric model
- Z'-like boosted jets

ATLAS Run 2 results are already public, others are (hopefully) coming this summer

If you're hoping for some new particles, so are we! Stay tuned...

SINCE I'VE GOT YOUR ATTENTION ANYWAY

A reminder that we have an ATLAS institute review to do

https://cds.cern.ch/record/2265277

Comments by email, please!

Maybe next time, buddy