Advanced experimental tools and BSM Higgs searches (experiment)

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After the Discovery: Hunting for a Non-Standard Higgs Sector
Benasque – https://indico.cern.ch/event/289711/ –
April 9, 2014

NEW YORK UNIVERSITY

Introduction

- Matrix-element
  - Examples in ttH, using in searches
- Color flow
- General searches
- Boosted things
  - X $\rightarrow$ leptons (including taus)
  - X $\rightarrow$ hadronic
- Jet charge
- Dealing with and modeling pileup
- Trigger upgrades

Matrix Element Methods

- MEM are not so new, but getting ***easier to use and more robust***
- Now being applied to tth(→bb) at LHC and other searches

$$P(x|\alpha) = \frac{1}{\sigma_\alpha} \int d\Phi(y) |M_\alpha|^2(y) W(x,y)$$

A generic module dubbed `MadWeight` [2] has been designed to perform this phase-space integration in an efficient way.

- based on MadGraph/MadEvent.
- for any process implemented in MadGraph.
- averages over all possible parton-jet assignements.
- transfer function provided by the user (no restriction).

*"We stress that very fact of **automatically, reliably, and quickly** calculating weights for challenging final states as those involved in tth has never been achieved before. It is a significant technical result on its own that provides key evidence on the generality and flexibility of the MadWeight approach."*

arXiv:1304.6414

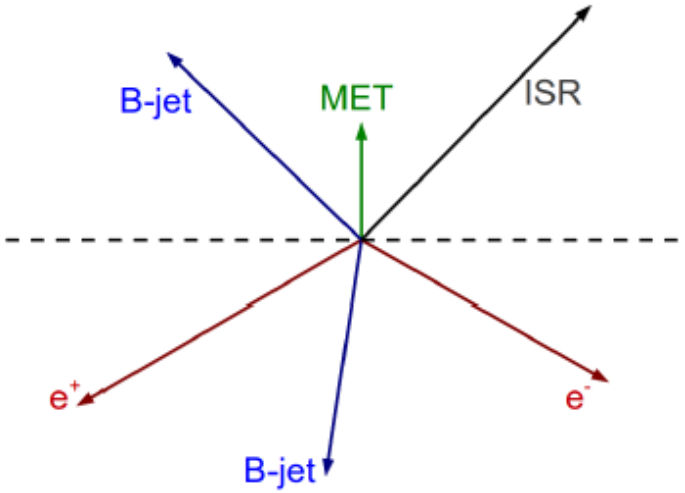
Matrix Element Methods

- Ways of dealing with ISR, to 1st order:

1) Lorentz transformation to "boost-back" the system into a frame where the transverse momentum of the ISR is 0.

- $P(x|Zb\bar{b} \to l^+l^-b\bar{b})$:

$$p_{ISR} = -\sum p_i$$



- $P(x|t\bar{t} \to l^+l^-b\bar{b}\nu\bar{\nu})$:

$$p_{ISR} = -\sum p_i - \text{MET} \qquad \sum p_i = p_{b1} + p_{b2} + p_{e1} + p_{e2}$$

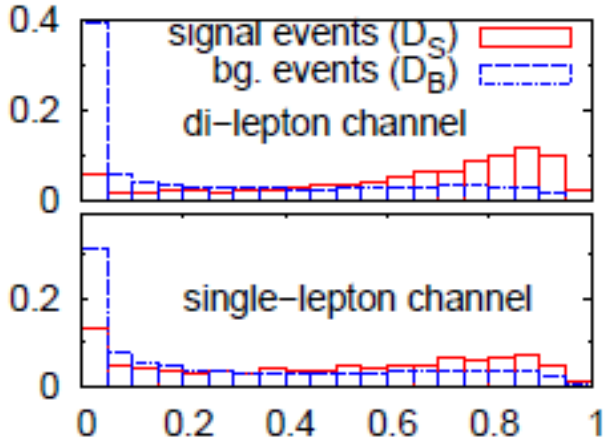
2) Using LO calculation that contains the extra radiation

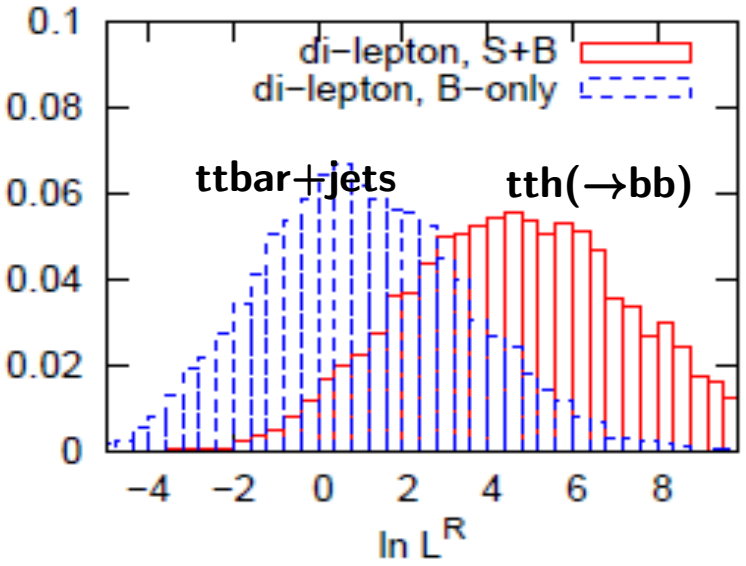
- Good modelisation of the extra hard radiation
- time consuming

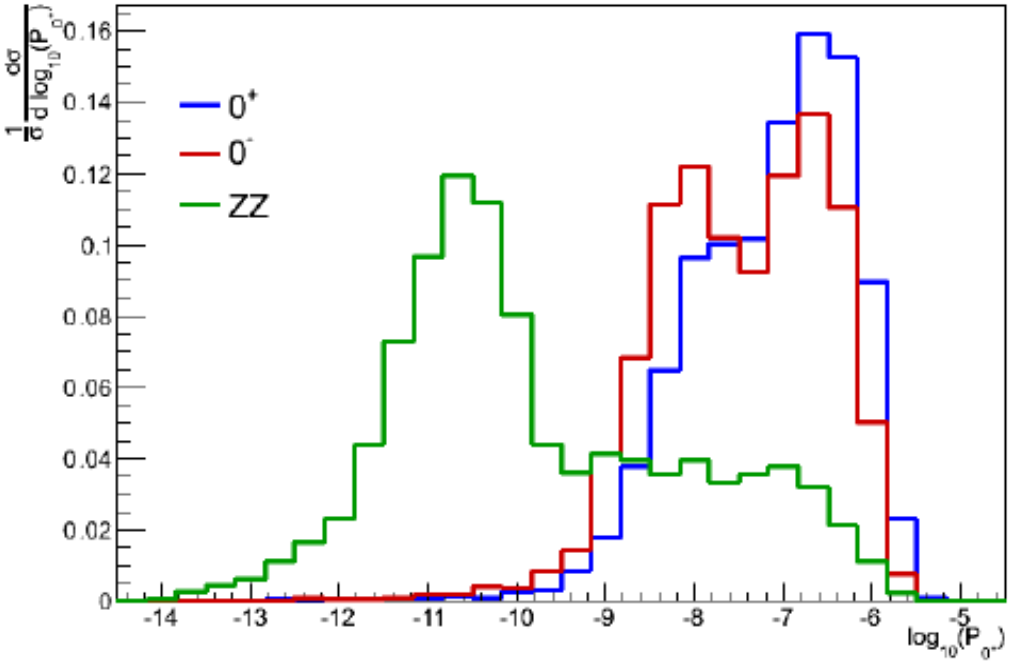
1) and 2) are **complementary**.

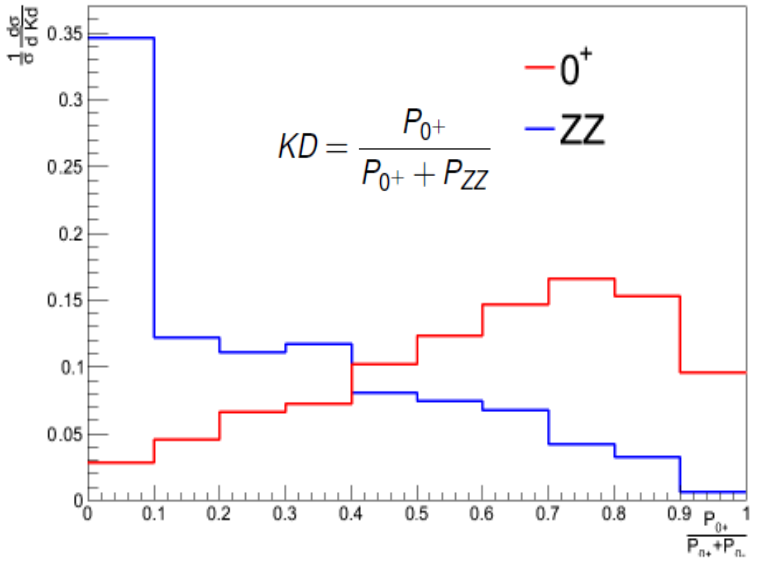
Matrix Element Methods

- Some applications...
- Can be used for BSM Higgs





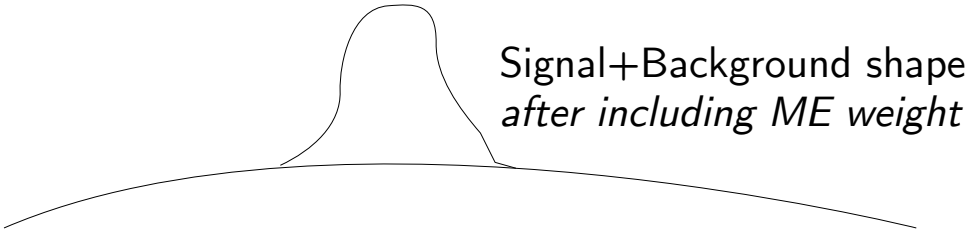




Taking the Mass out of the Weight

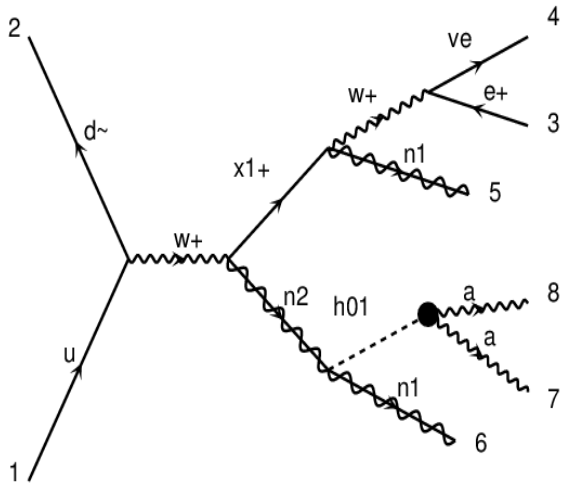
- For searches, would often like the ME weight to *not bias the "mass"*

- Want to cut on the ME weight and then still be able to search for a mass peak on a smooth background
- Want to use sidebands to normalize the background using data



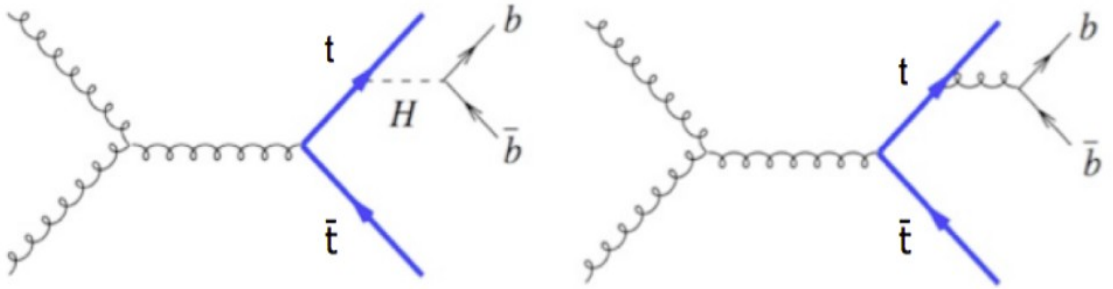
- But, ME weight depends on the mass (especially for small width)...
  - e.g. $Wh \rightarrow l\nu\gamma\gamma$ ME will depend strongly on $m(\gamma\gamma)$!

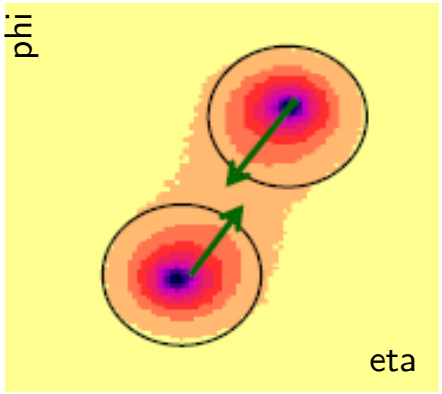
- Hack: for each ME calculation of each event's weight, *set the ME-assumed mass equal to the <u>measured</u> mass*



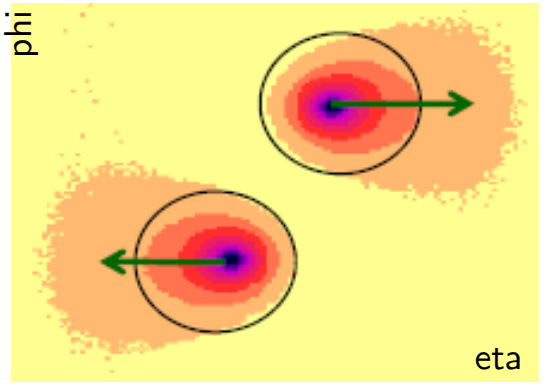
Color flow

- Higgs is color-singlet
- H $\rightarrow$ jets:
  color-singlet configuration
  - Backgrounds often not...
    e.g. gluon splitting

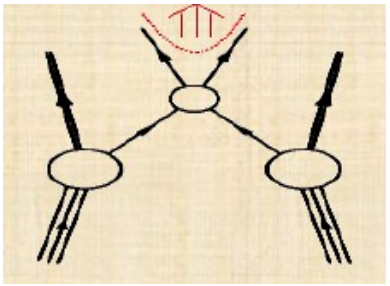


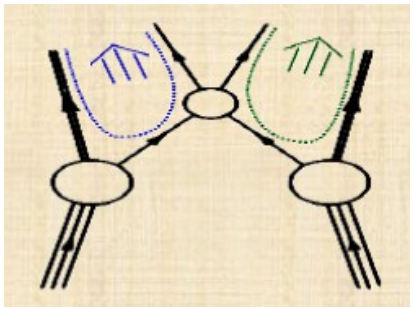


SINGLET



OCTET



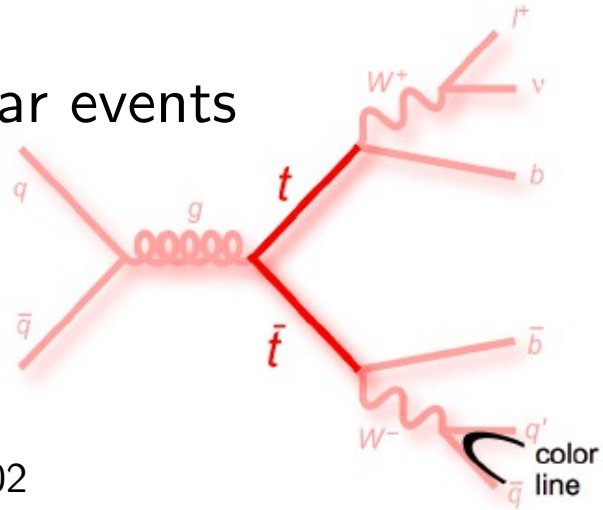


Phys.Rev.Lett.105:022001

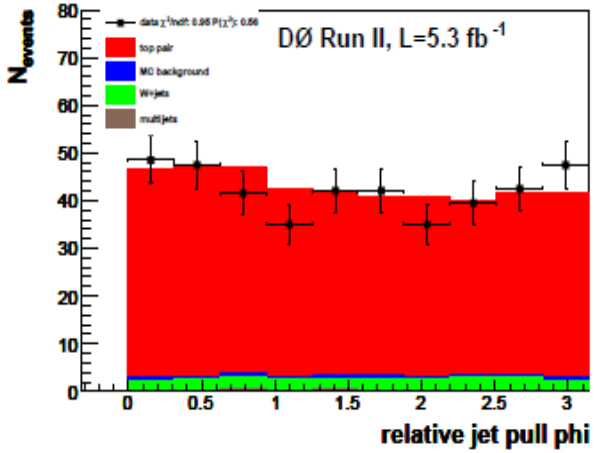
- Useful as additional variable for separating signal from backgrounds
- Does not bias jet kinematics to 1st order
  - Can perhaps be used to measure background shapes with small syst.

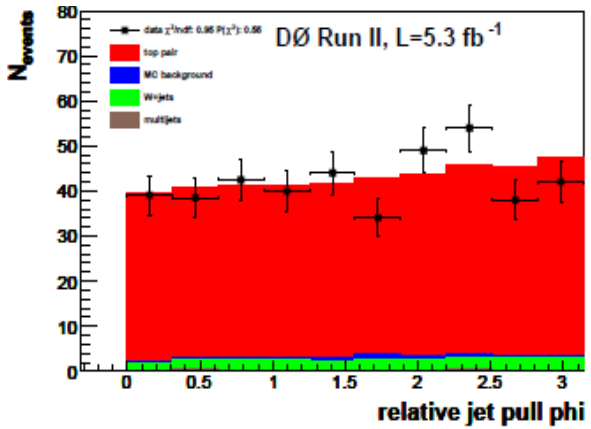
Color flow

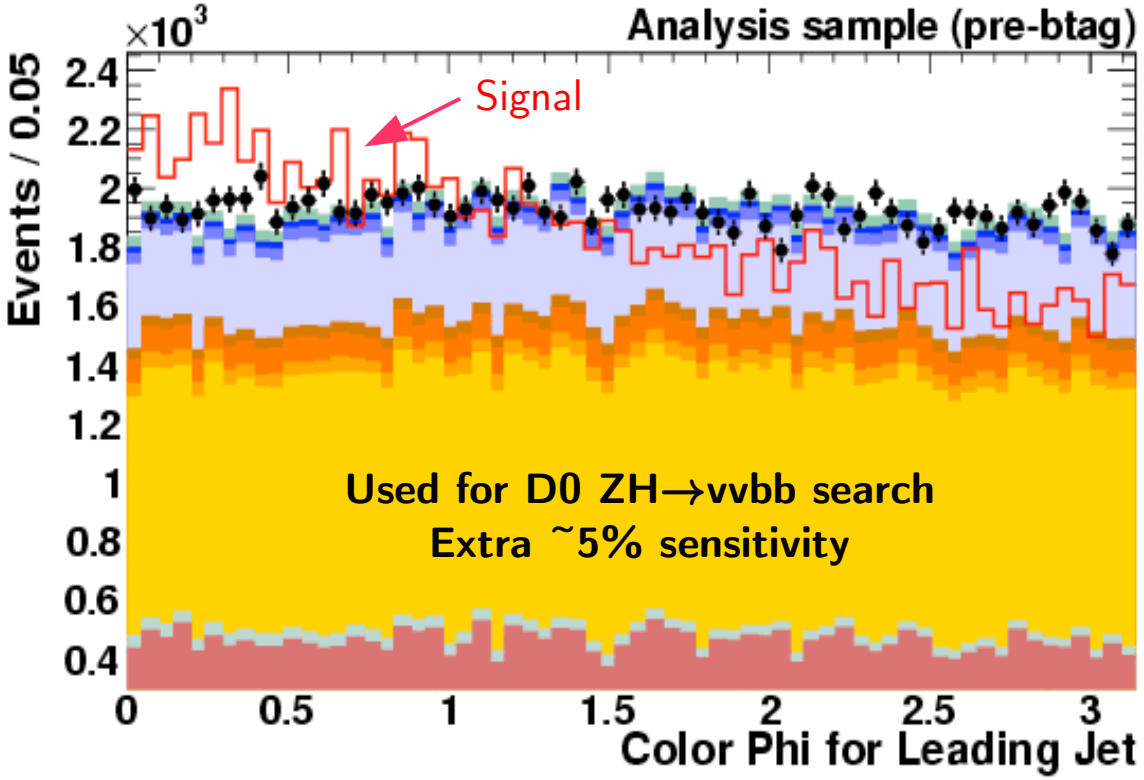
- Method was tested at D0 (Tevatron) using ttbar events
- Successfully used in D0 Higgs→bb search
- Will soon be tested with large statistics at ATLAS



Phys.Rev.D 83:092002

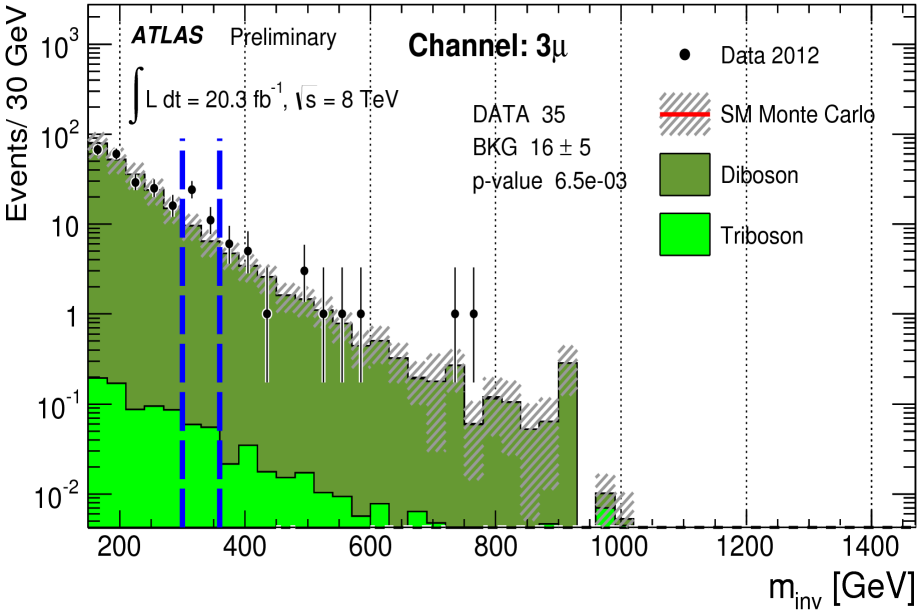


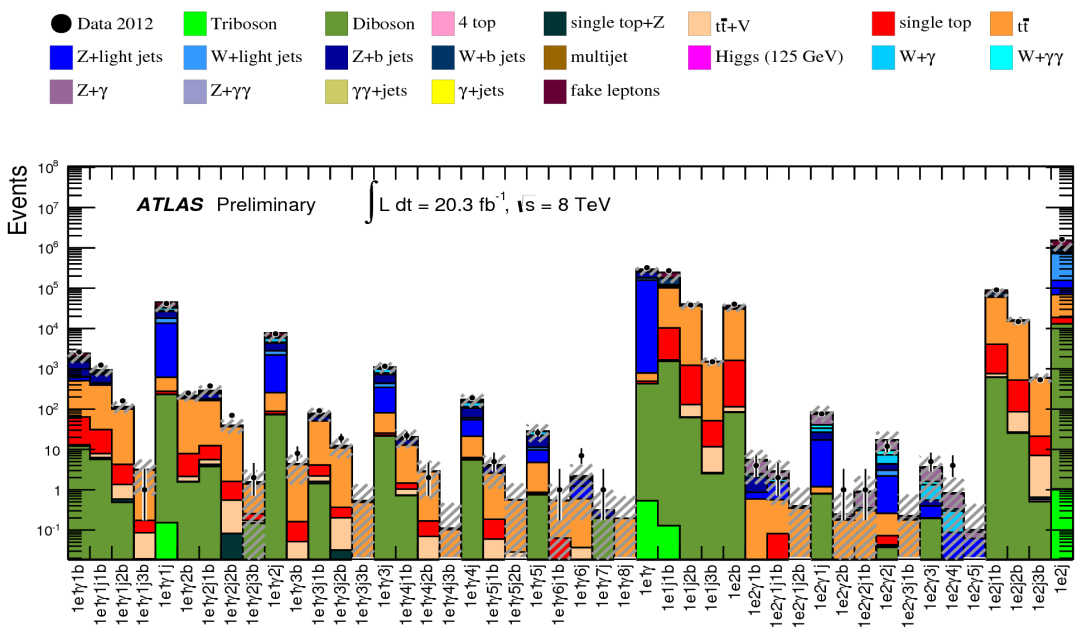


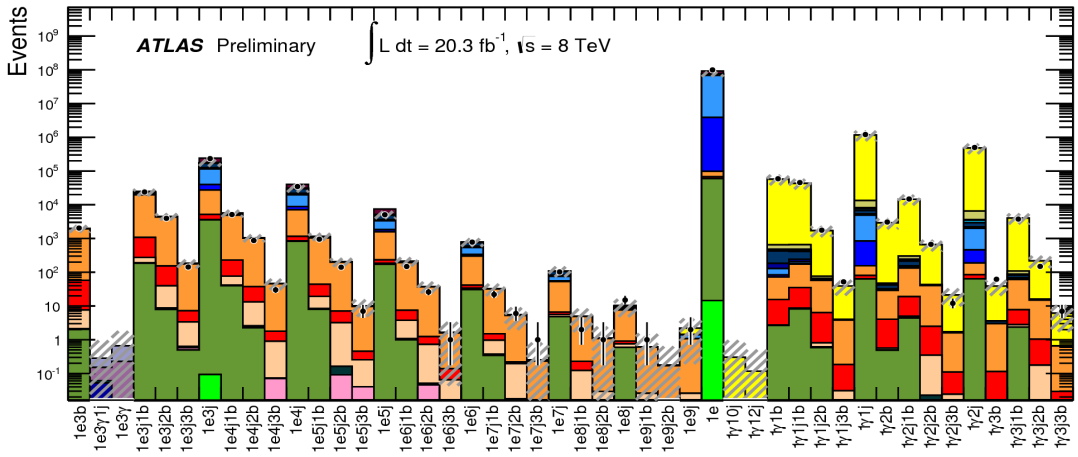


General Search Methods

- Look in every final-state possible... as theory-blind *(theorist-deaf?)* as possible
- Compare data/backgrounds:
  - Number of events
  - Excesses in Meff, Minv, or MET distributions
- 697 final-states...



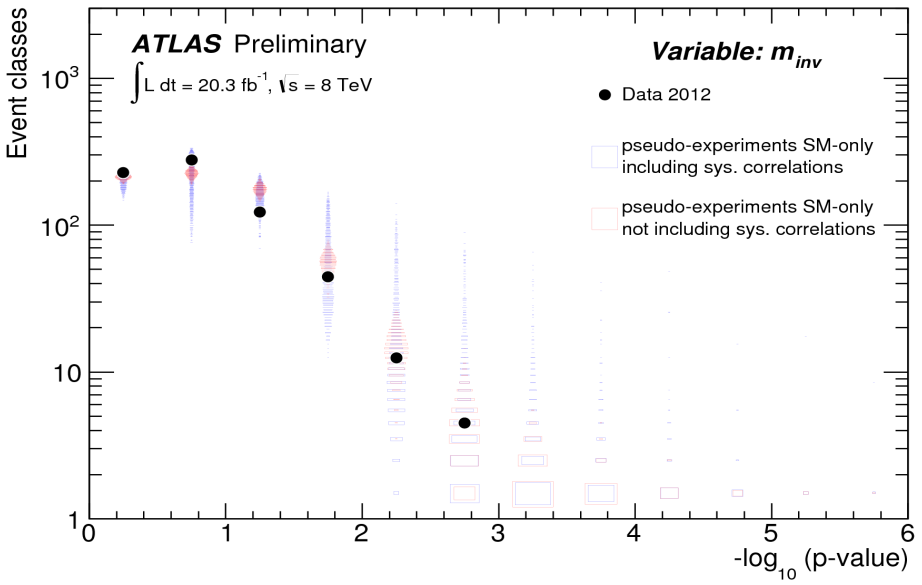


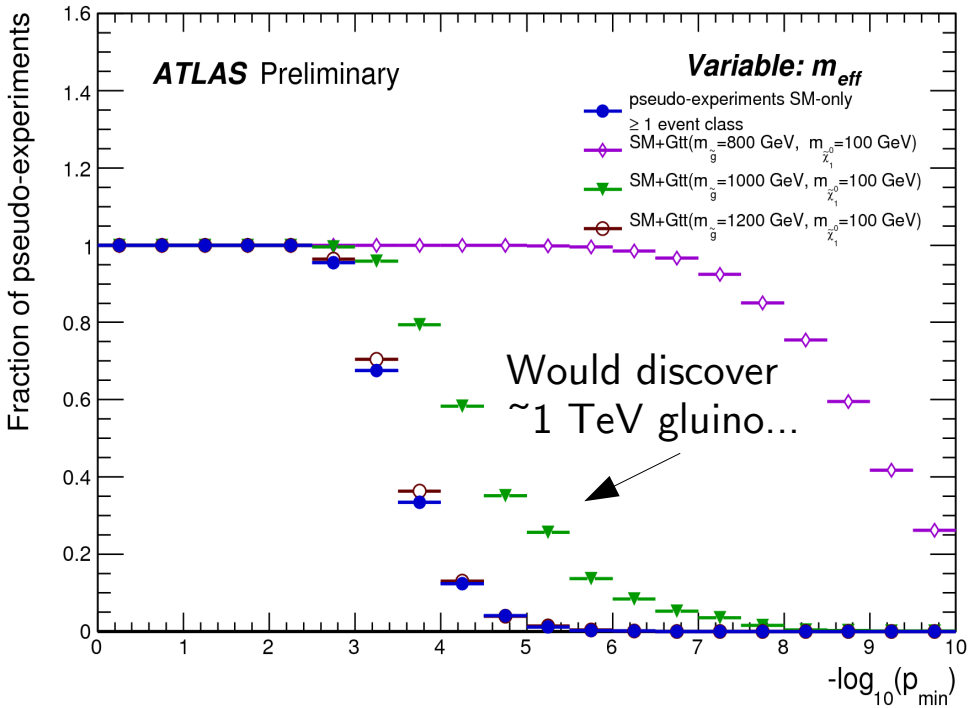


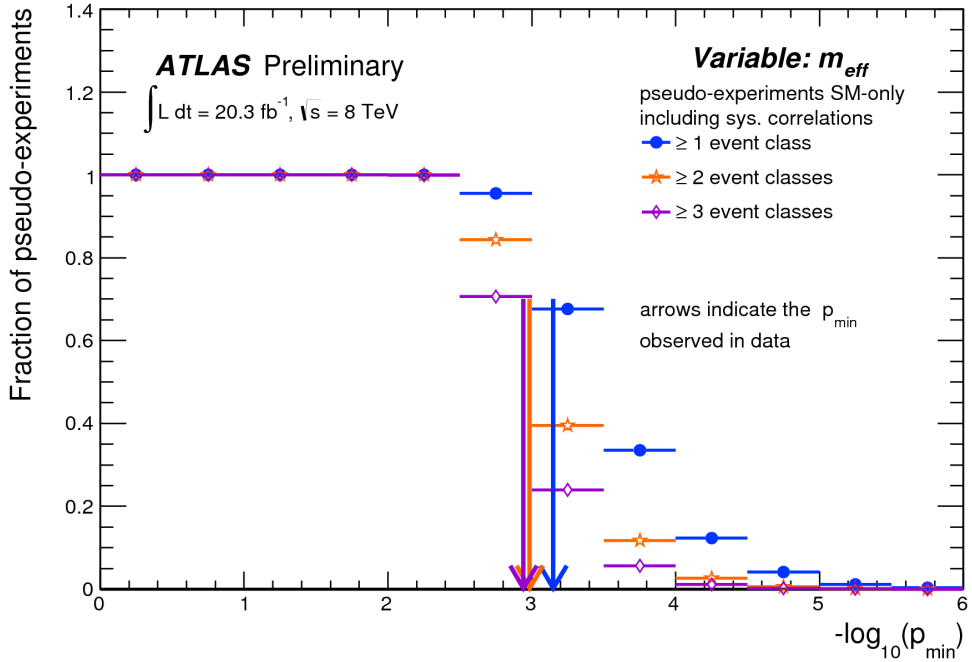
General Search Methods

- Compare to "look-elsewhere" effect
- Sensitive to new physics...

- Good way to look for what you don't know to look for or for when there's too much to look for
- *How to improve for BSM Higgs?*



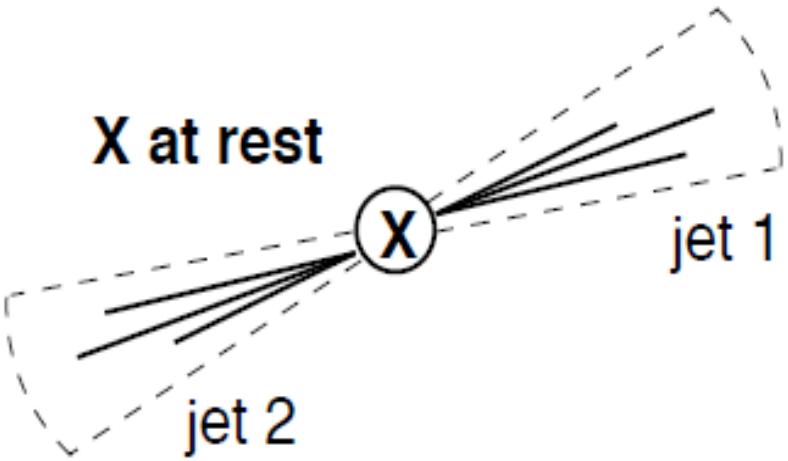




Boosted Stuff

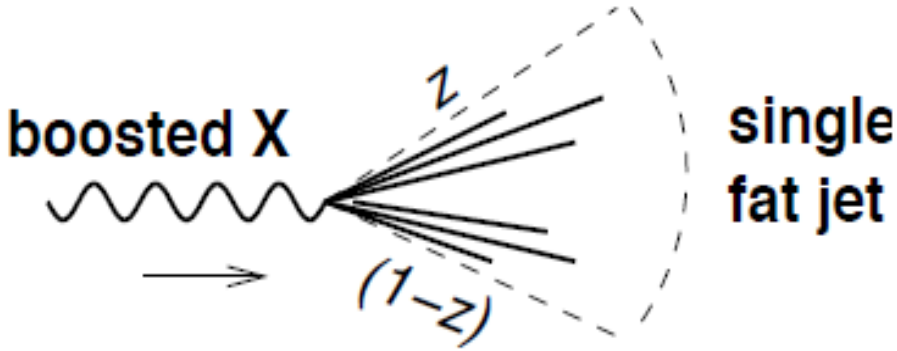
- Boosted particle $\rightarrow$ collimated decay products in detector

Normal analyses: two quarks from $X \rightarrow q\bar{q}$ reconstructed as two jets



Gavin Salam

High-p_t regime: EW object X is boosted, decay is collimated, $q\bar{q}$ both in same jet



Happens for $p_t \gtrsim 2m/R$

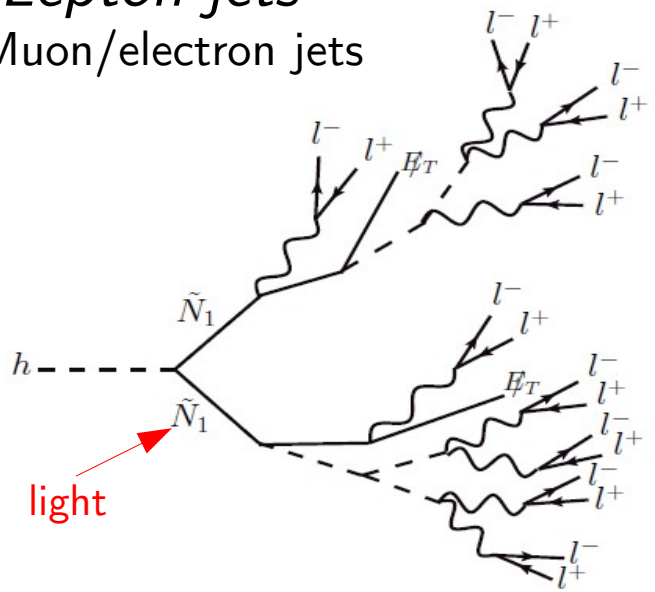
$p_t > 400$ GeV for $m = m_W$, $R = 0.4$

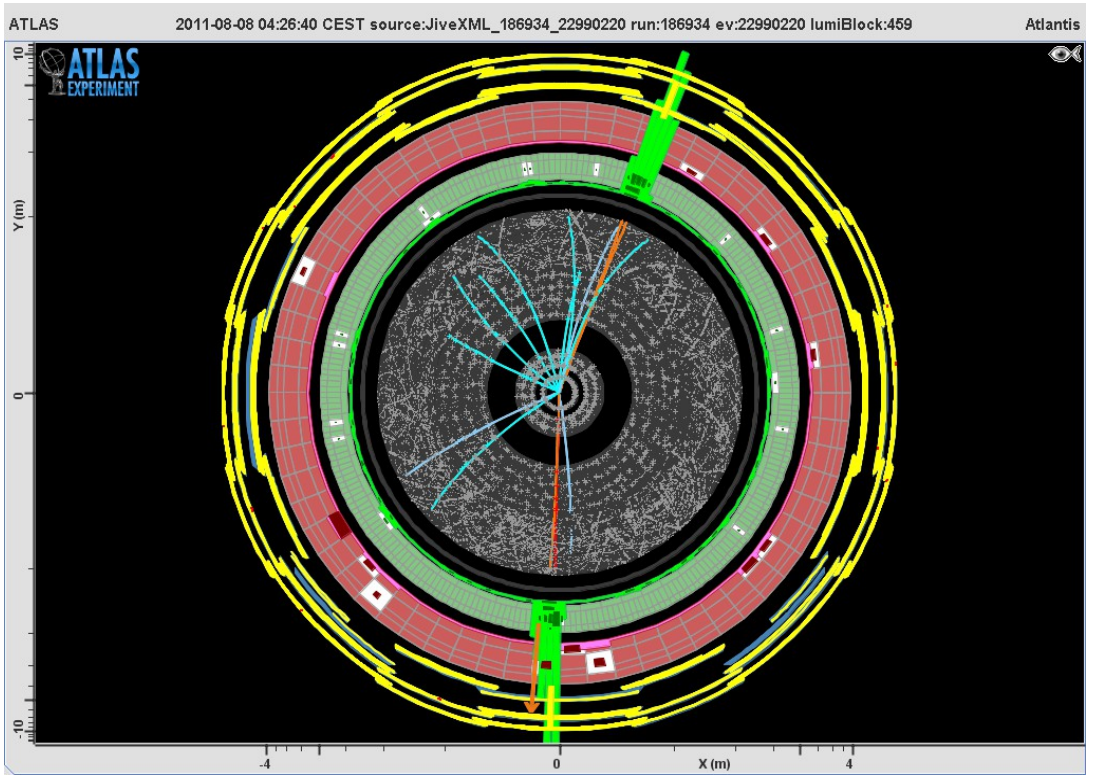
"Giving New Physics a Boost" aka "BOOST"
http://www-conf.slac.stanford.edu/Boost2009/
and each year following!

Collimated Leptons

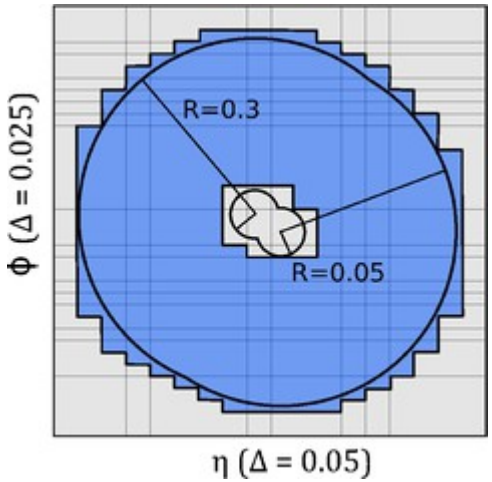
"Lepton jets"

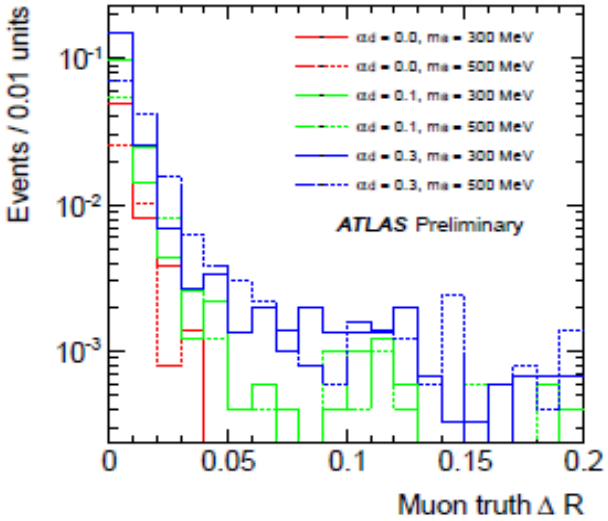
Muon/electron jets

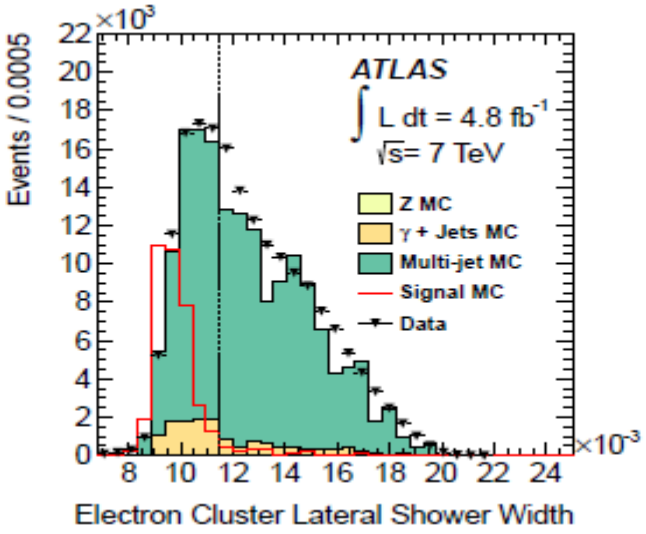




arXiv:1212.5409

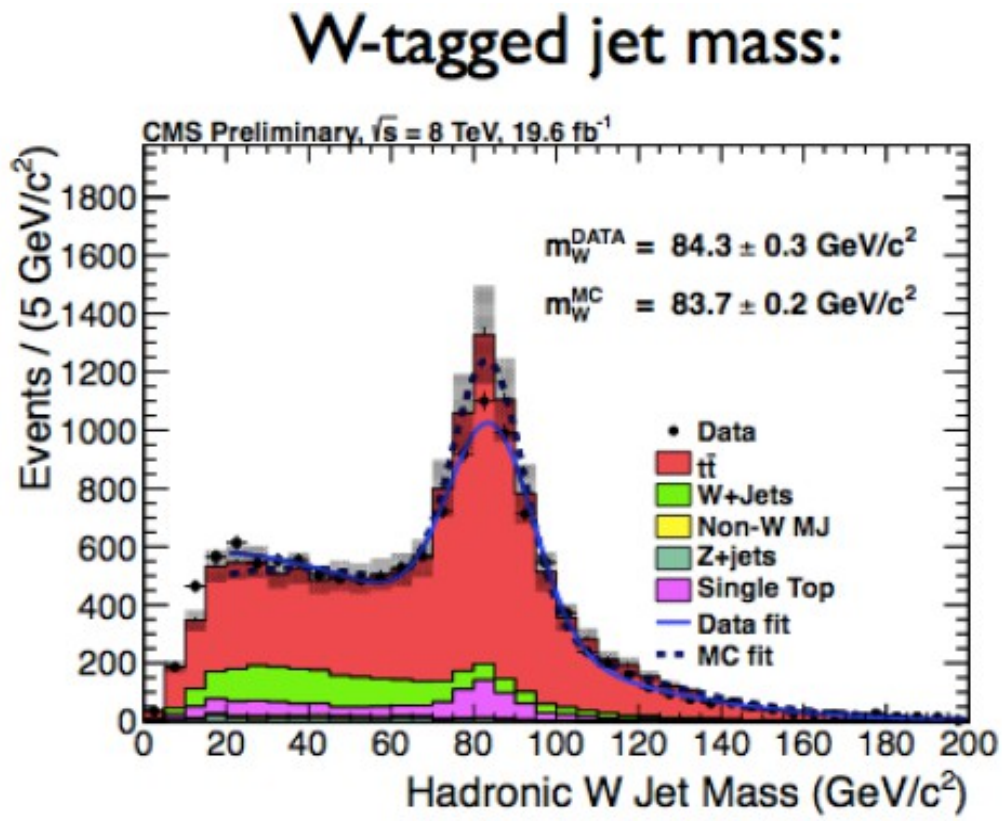


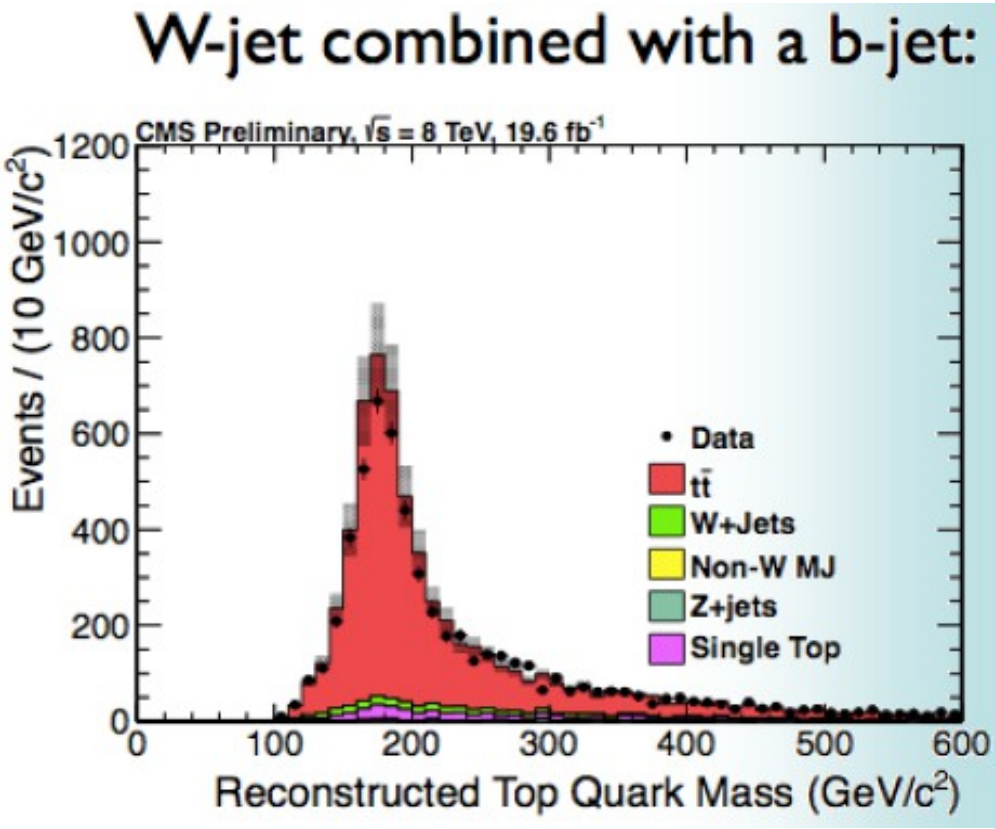




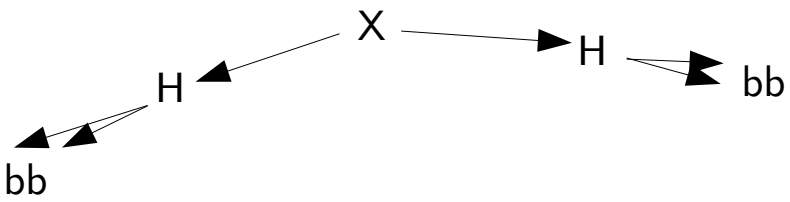
Fat jets

- Can look for boosted W and top-quark decays to hadrons
- *Nicely calibrated in ttbar events at ATLAS and CMS*

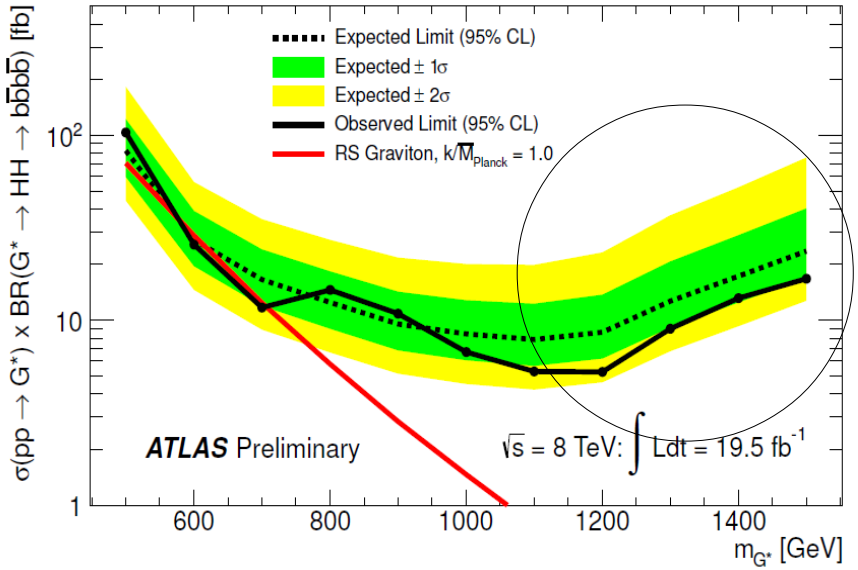


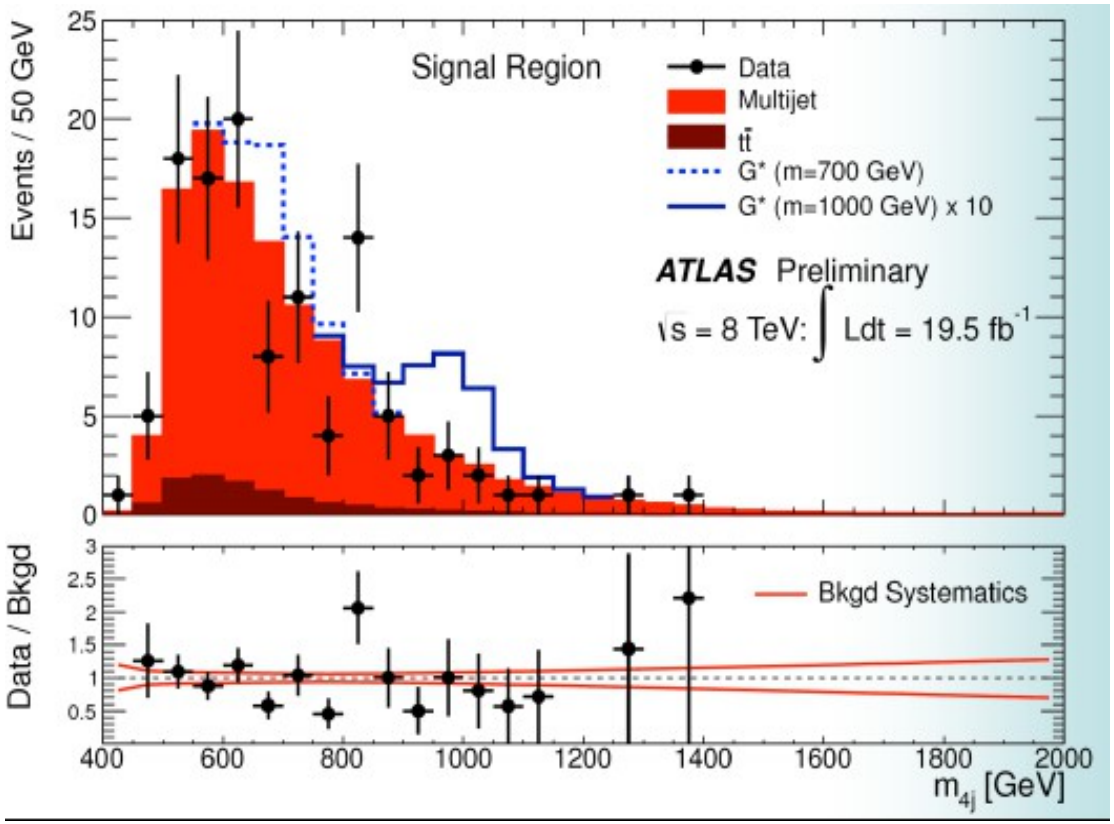


Recent: ATLAS search for $X \to HH \to b\bar{b}b\bar{b}$



ATLAS-CONF-2014-005





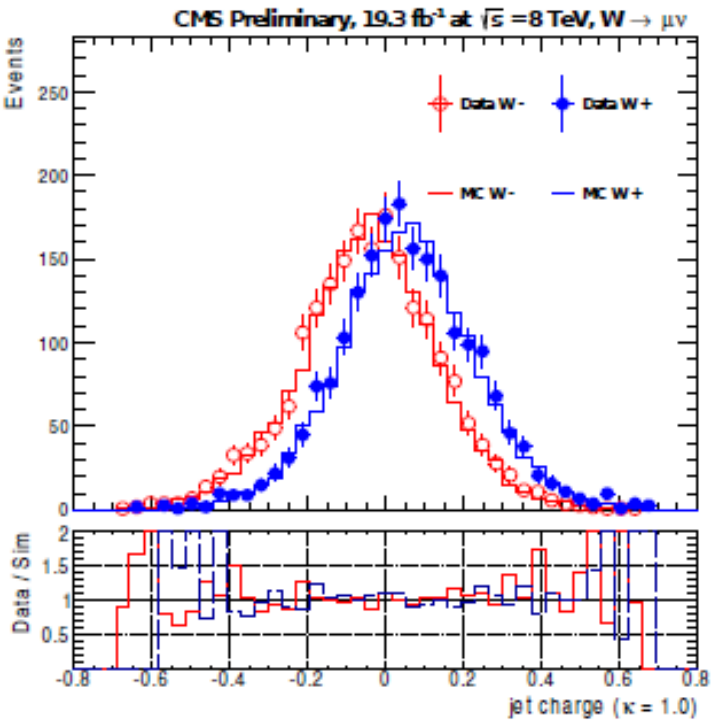
Still based on 4 resolved kT 0.4 jets,
but will be boosted starting next year...

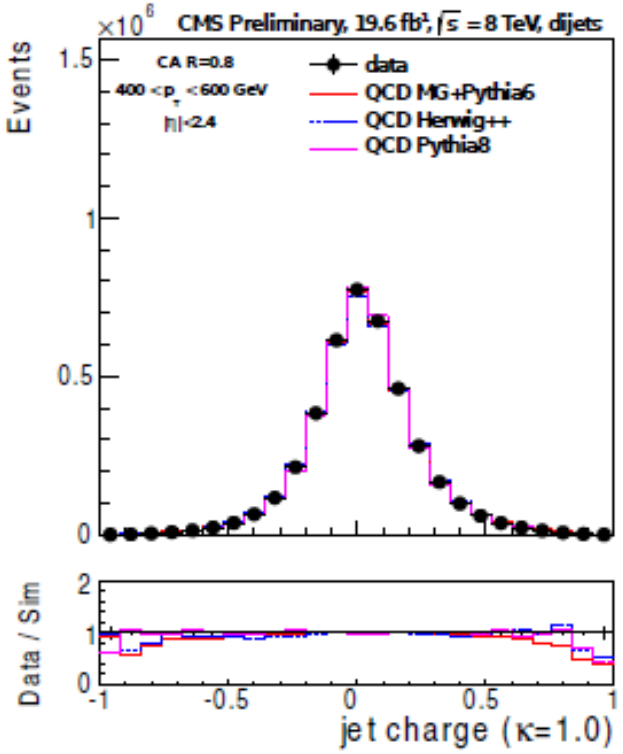
Jet charge

- Jet charge tested on semileptonic ttbar events with positive/negative lepton charge

$$Q^{\kappa} = \frac{\sum_i q_i (p_T^i)^{\kappa}}{(p_T^{jet})^{\kappa}}$$

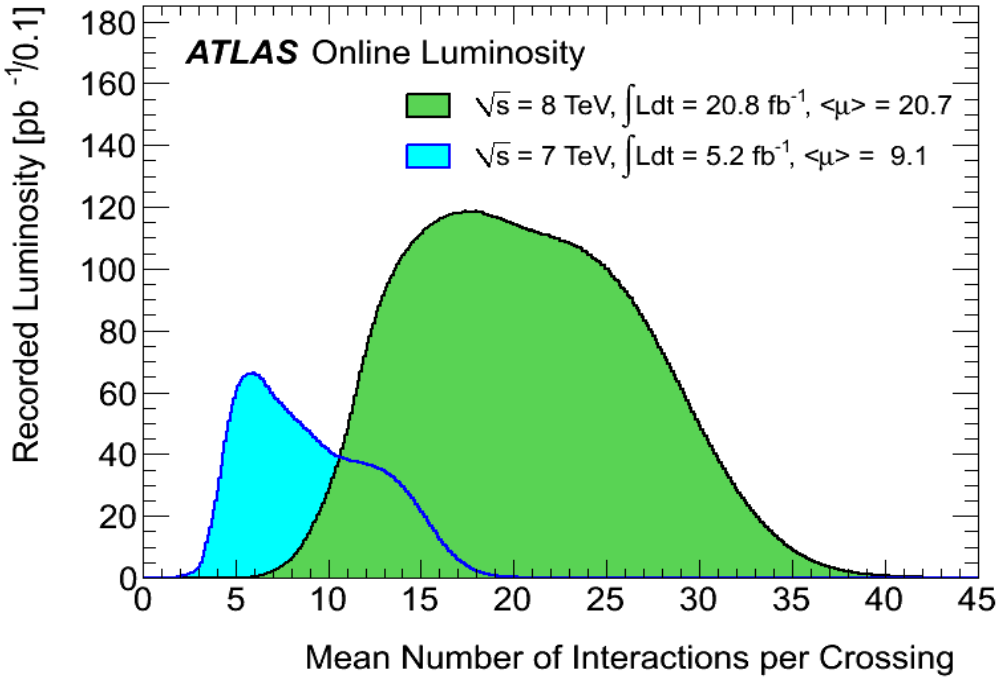
  - Very well modeled by MC
- Average jet charge > 0 for dijet events due to valence quarks

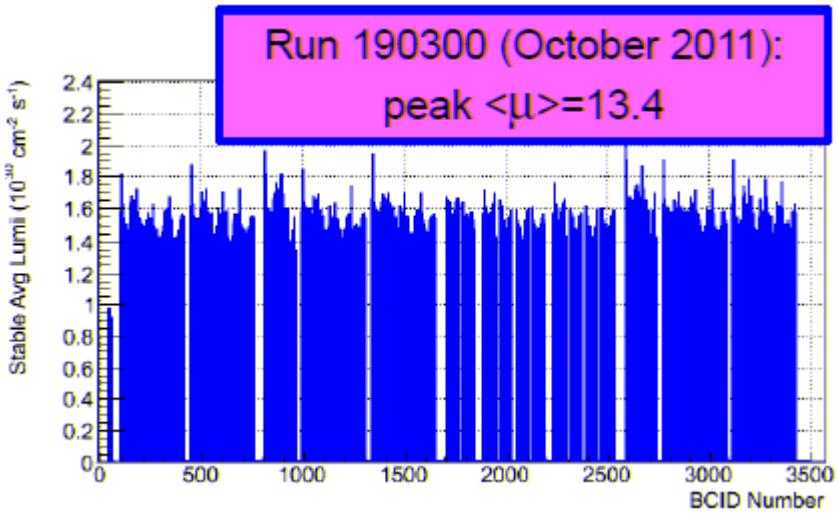




Pileup

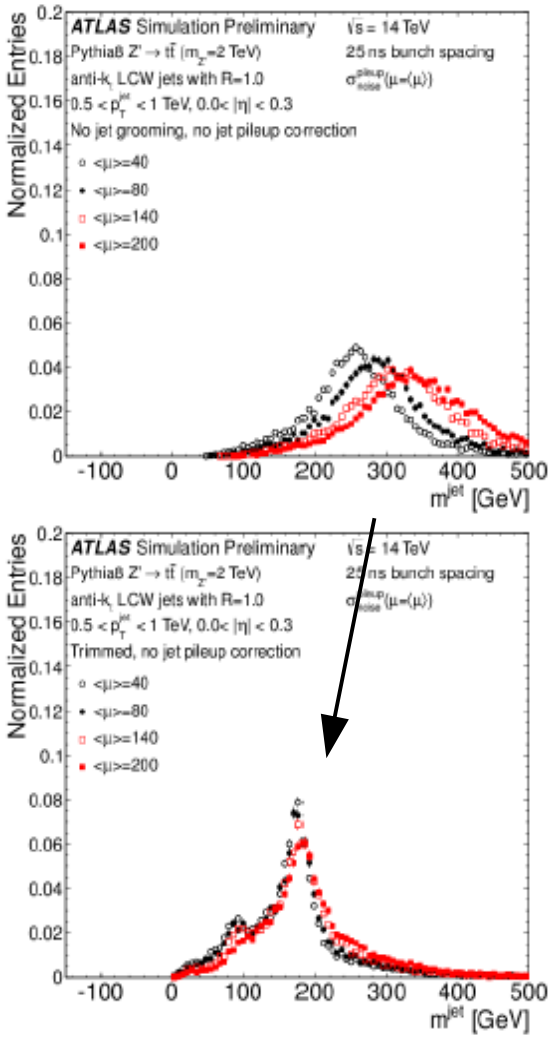
- How much pileup in Run2? ~50?
- Not just interactions in triggered bunch crossing... *past and future pileup matters!*
- Many complicated variables (jet mass, shapes, isolation, ...) are affected
- Model pileup accurately in simulation, so data/MC match vs. pileup
  - Difficult!
  - Tune Pythia to minbias data
  - Hope G4 models hadronic showers (in the tails!) accurately
  - Simulate accurate mix of in- and out-of-time pileup, *bunch structure*

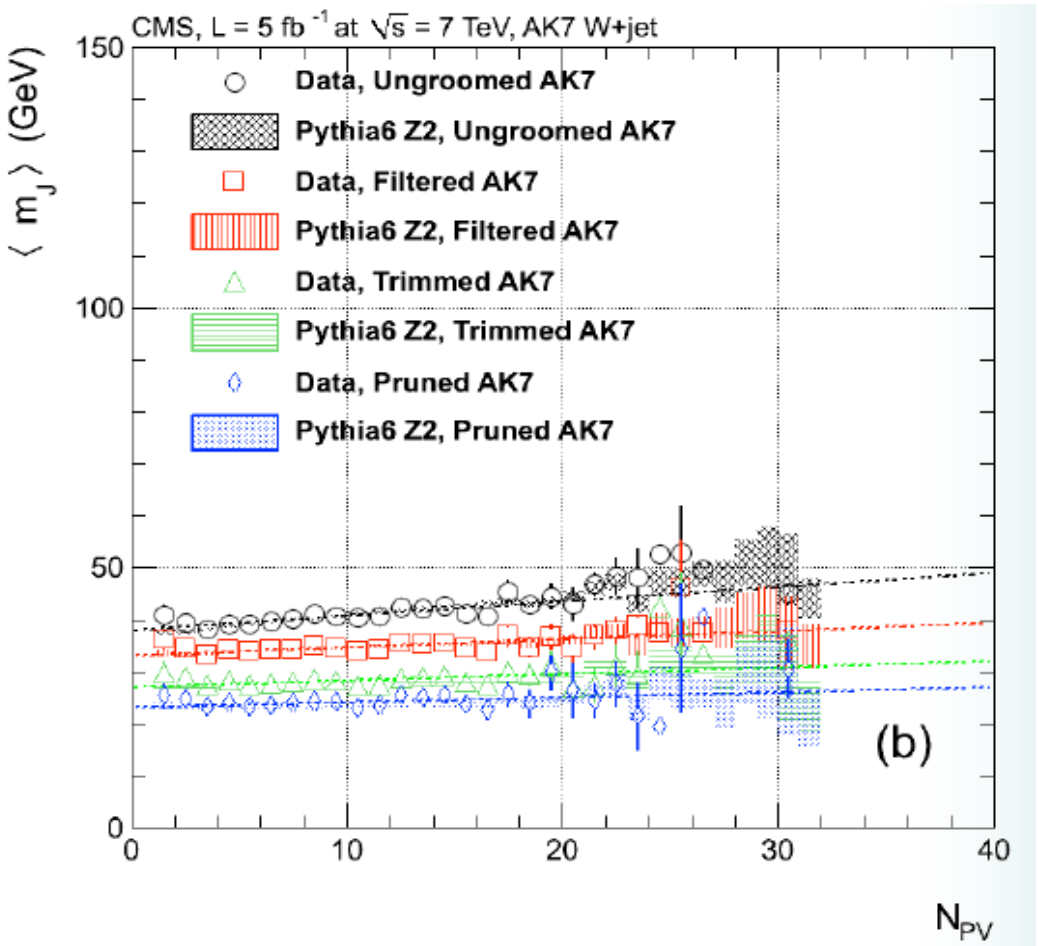




Pileup-corrected Variables

- Correct variables so they are insensitive to pileup to 1st order
  - e.g. "grooming", jet area subtraction:
    subtract <energy per unit area> from jet cone, as function of #vertex





Conclusions

Many advanced tools being developed and used

Now let's find BSM Higgs!

Image: Chris Wymant