Higgs, Electroweak Physics and QCD-II

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1st CERN-Bangladesh School on Particle Physics
University of Dhaka
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OUR ROUTE...

Recap

Newer techniques

Searching for new particles

Testing the models by measurements

What happens in a collision?

Modelling the collisions

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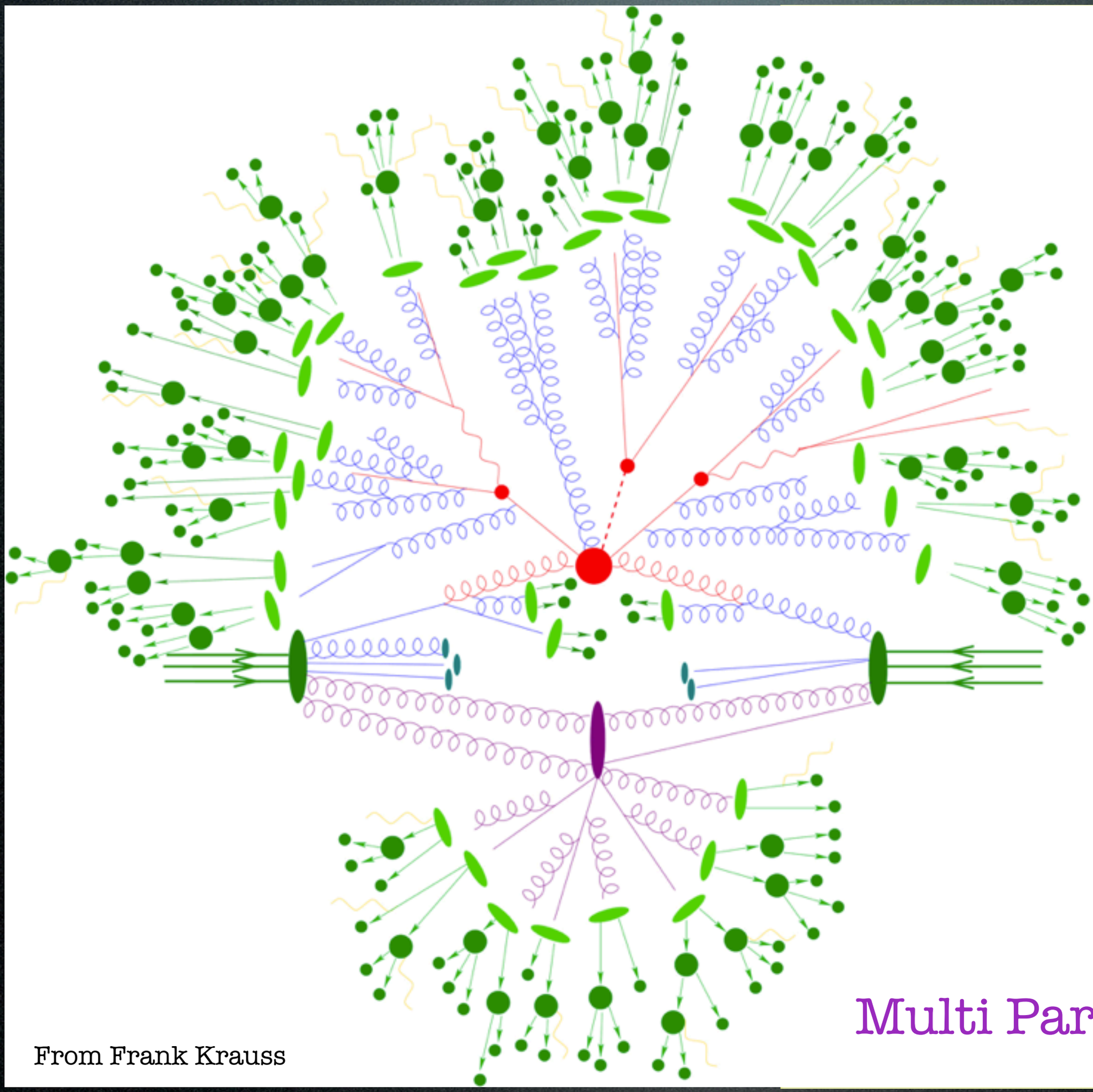
Recap



Hard Process

Parton Shower

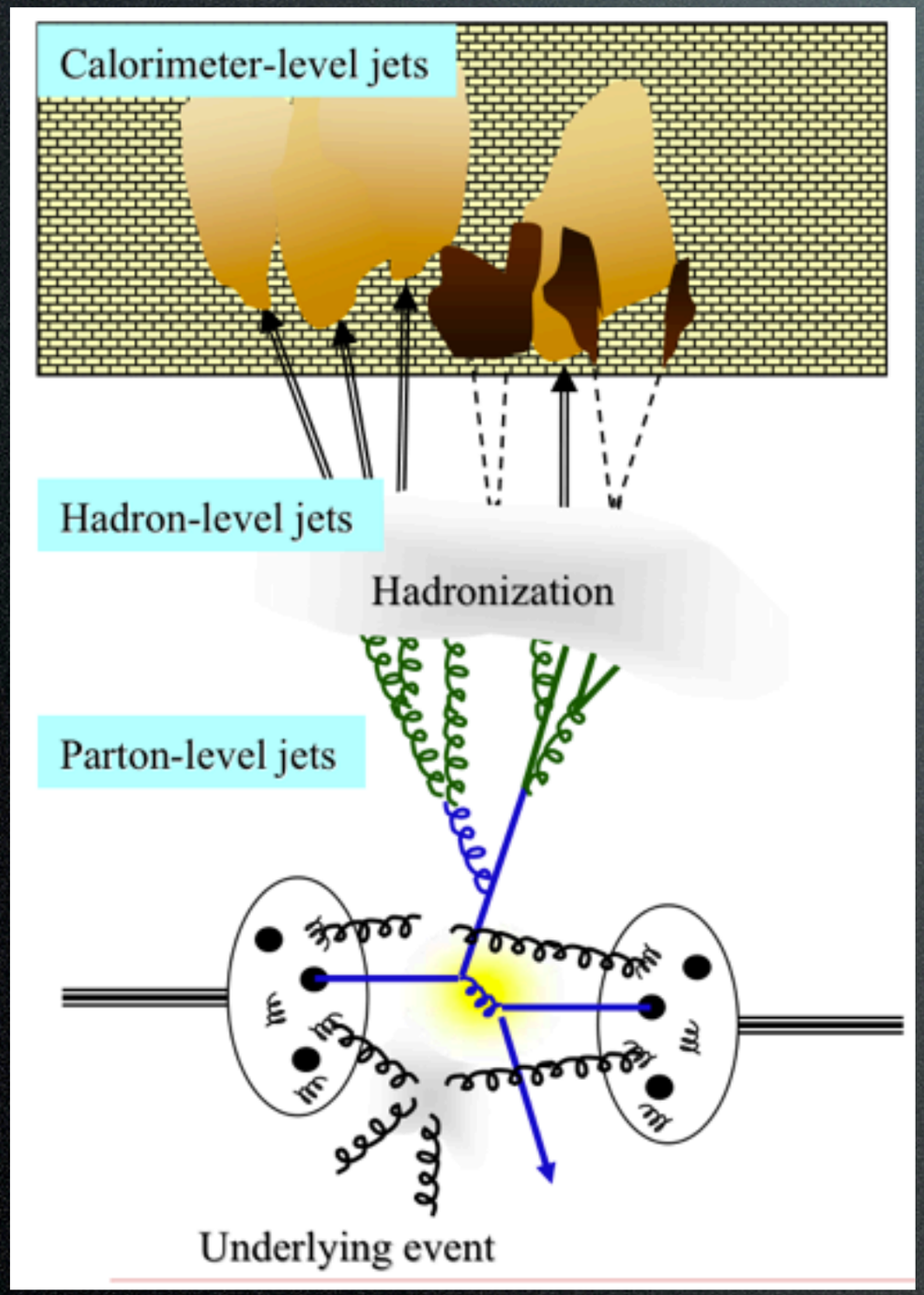
Hadronization

Decays

Multi Parton Interaction

From Frank Krauss

Jets



Used as a proxy for (everything coming out from) single quark or gluon originating in hard scatter

As close as we can get to a physical single hard quark or gluon

Measurements

- To validate Standard Model (in a new energy regime)
- Measure the free parameters of SM (often indirectly)
- To test the predictions of MC generators
- Background for searches

Need to be unfolded!

Soft QCD

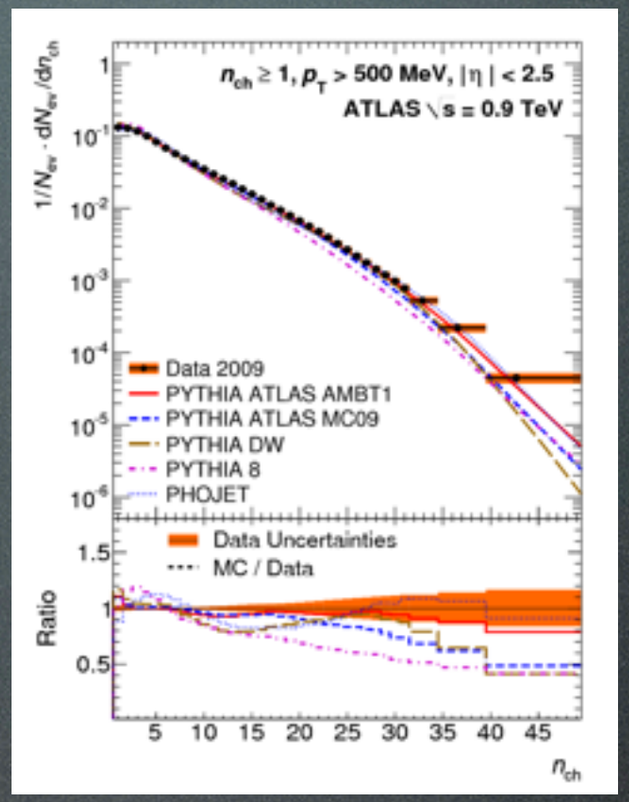
- We have to use the softQCD distributions to test the phenomenological models and “tune” the Monte-Carlo event generators to give the best description of the data.
- We gain deeper insight if data does not match up with Monte-Carlo predictions, which reflect our current understanding of these processes.

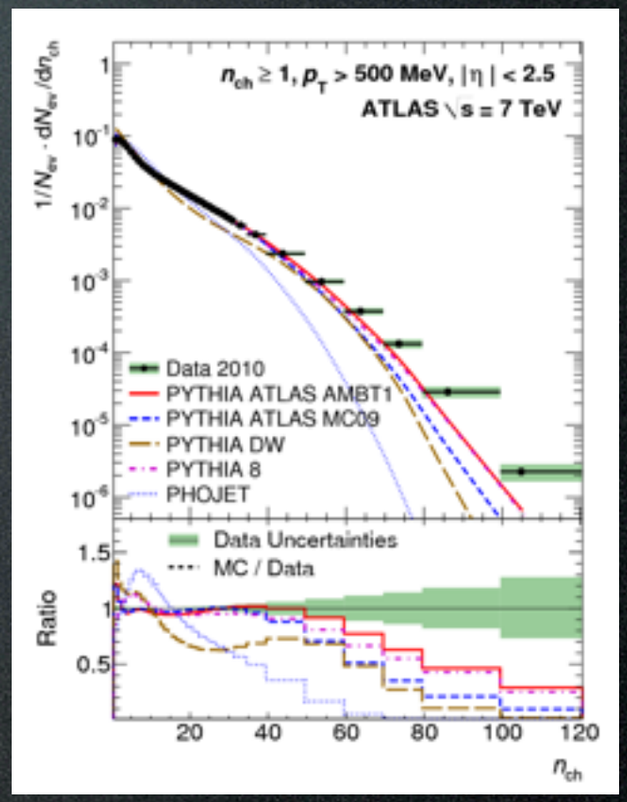
Glossary

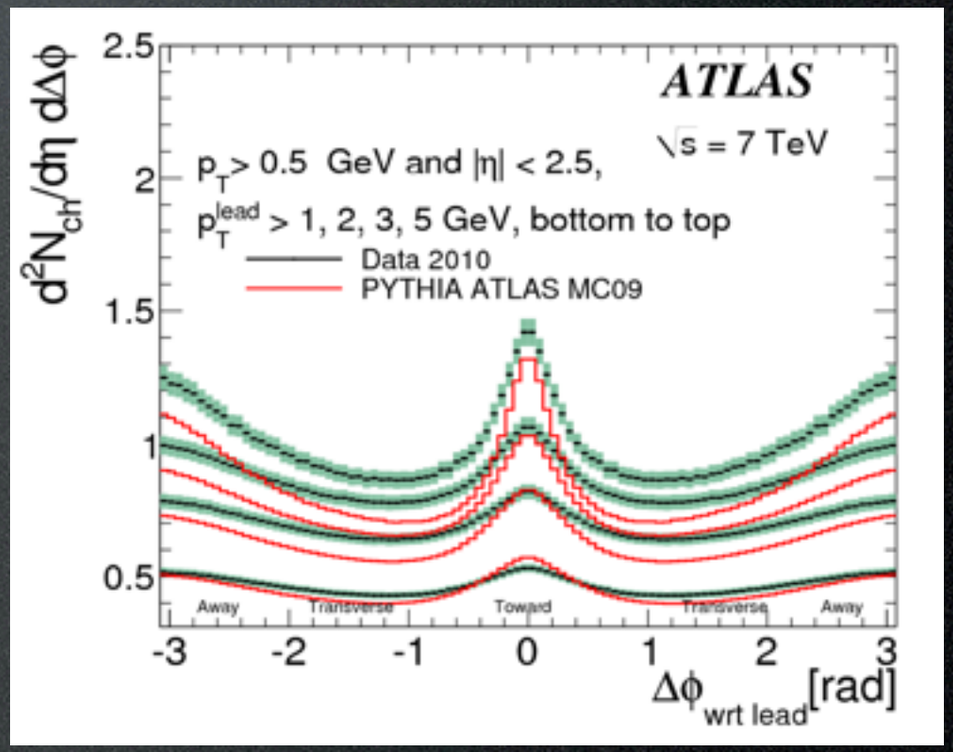
- Minimum-bias (MB): Pretty much everything, exact definition trigger dependent.
- Underlying event (UE): background to events with an identified hard scatter (more like the actual interesting events we want to look at)
- Pileup (PU): (uncorrelated) separate collisions within the same/different bunch crossing we can't differentiate because of our finite detector resolution (more like "isotropic" min-bias events).

Beginning of the LHC

- Tevatron tunes did not agree with the early minbias and underlying event data.
- Not just at 7 TeV, but also at 900 GeV!

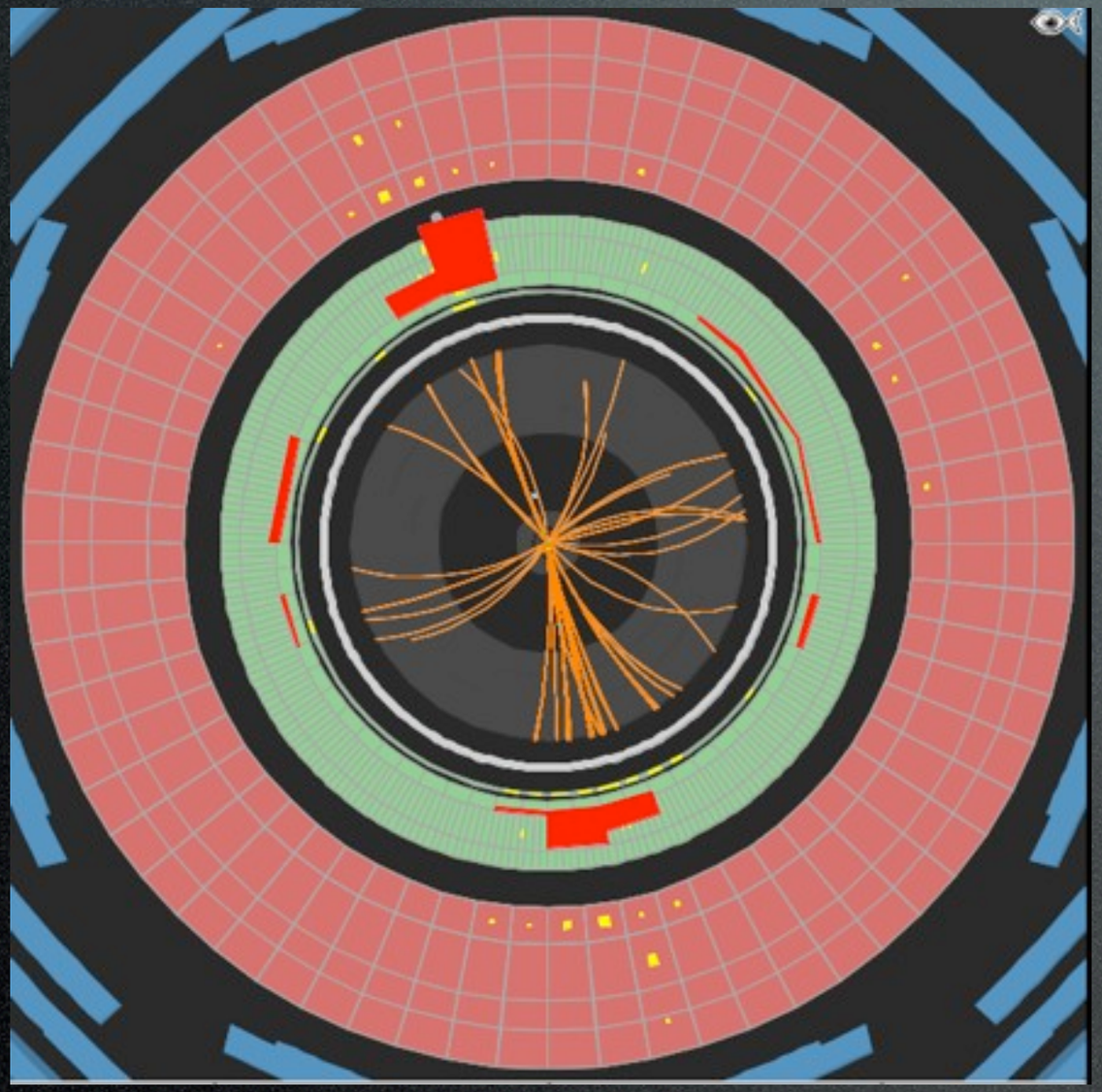






Underlying Event

UE Measurement



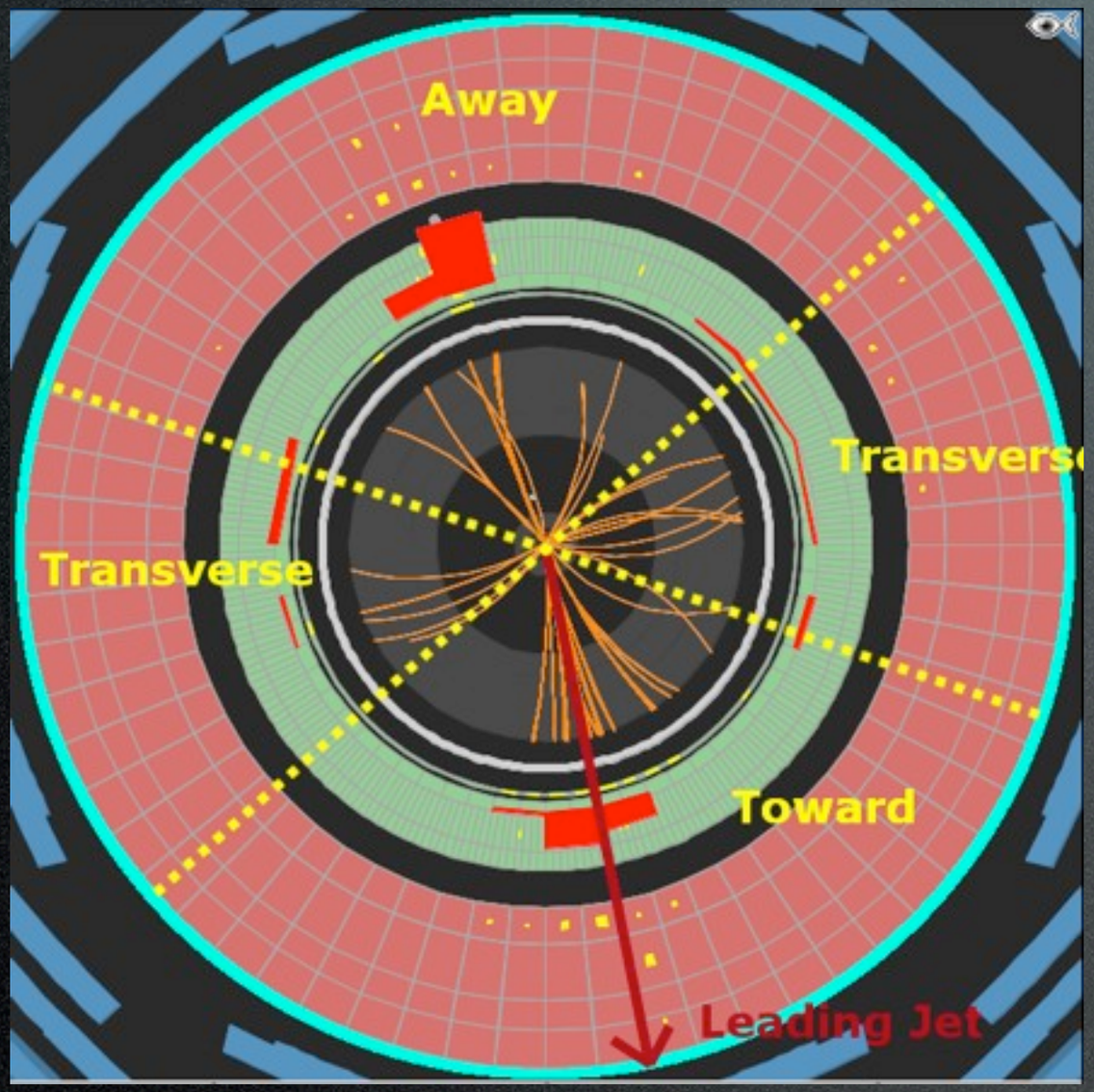
Leading Jet:

$p_T = 69.7$ GeV

$\eta = 1.3$ iRad

$\phi = -1.4$ rad

UE Measurement



Leading Jet:

$p_T = 69.7$ GeV

$\eta = 1.3$ iRad

$\phi = -1.4$ rad

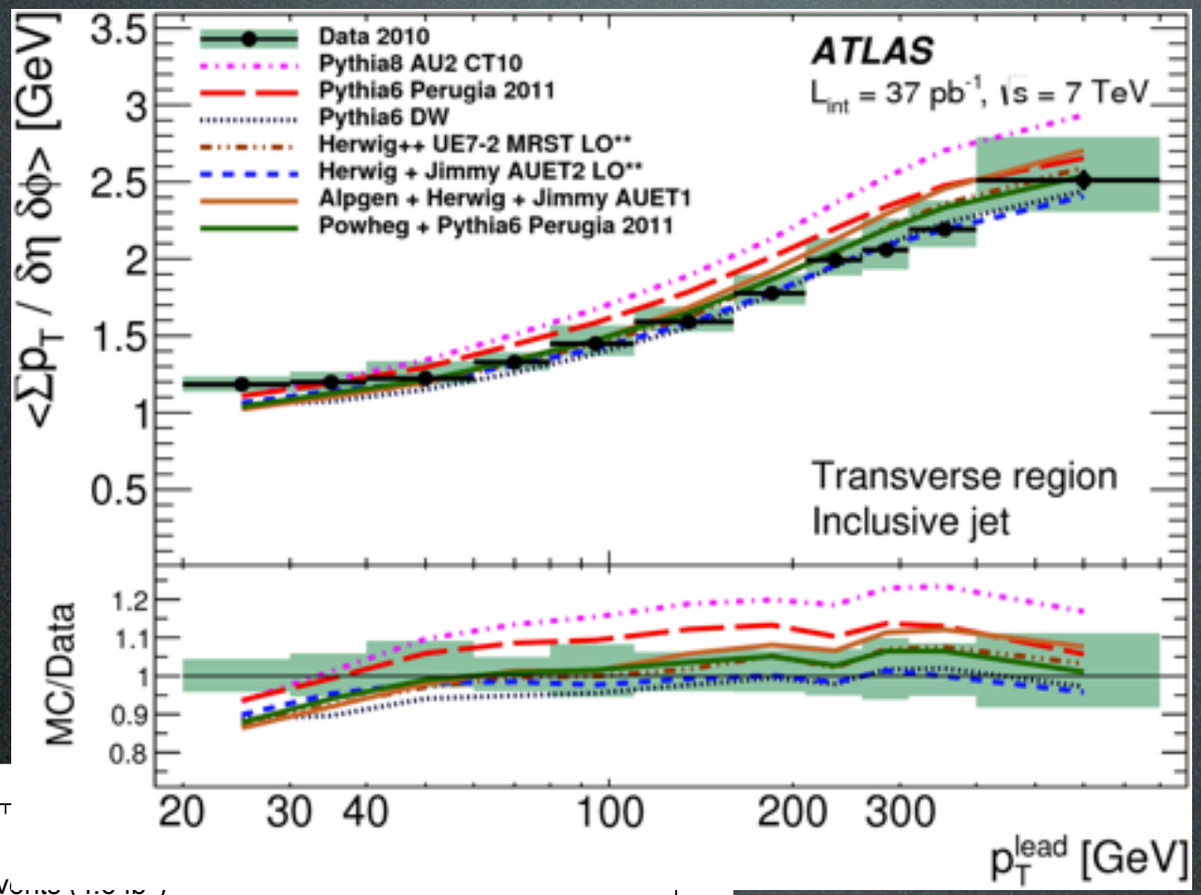
Transverse:

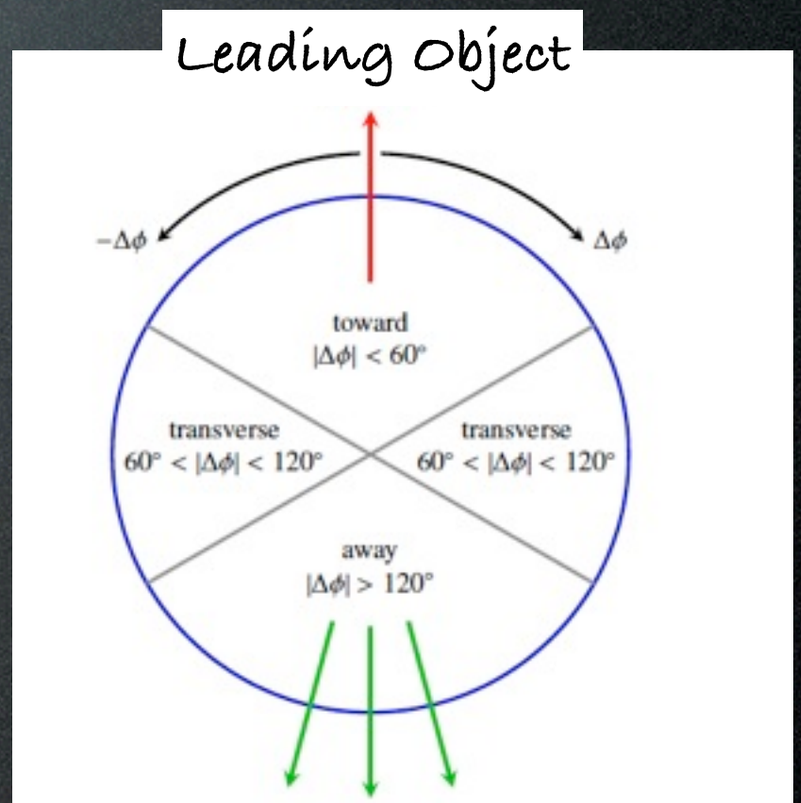
$N_{chg} = 9$

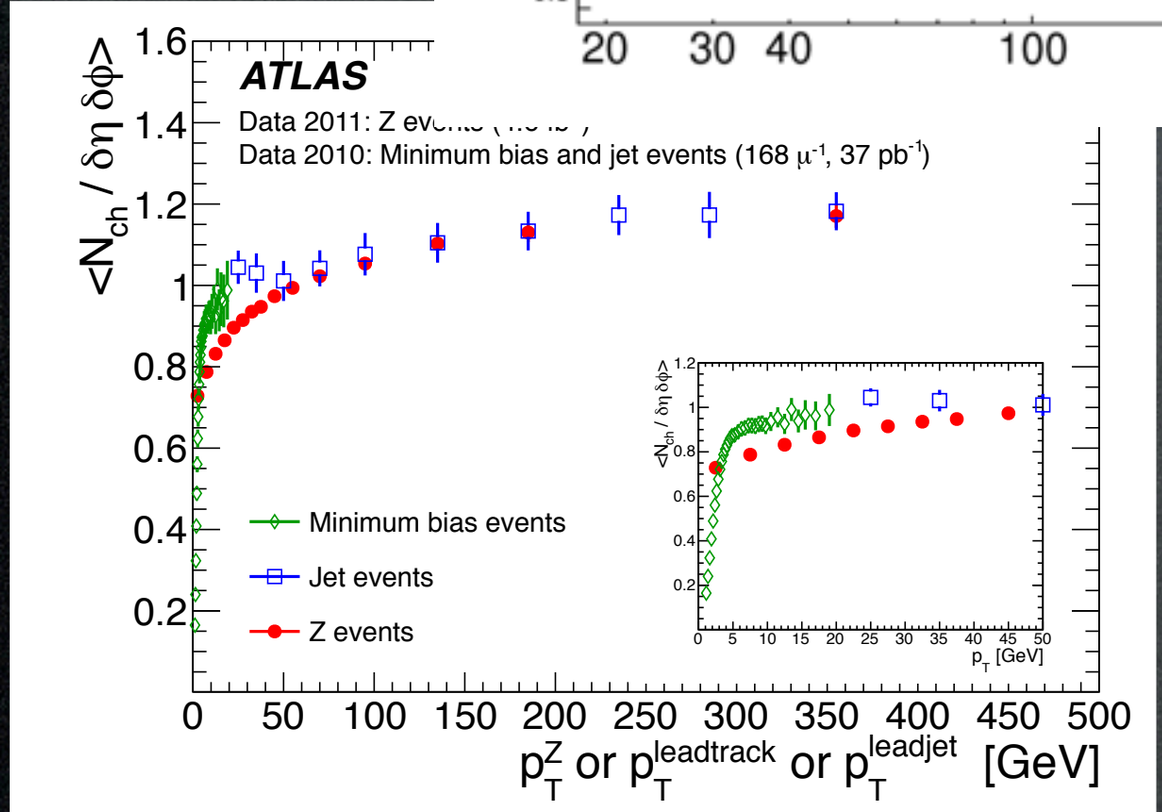
$\sum p_T^{chg} \cong 10$ GeV

$\bar{p_T} \cong 1.1$ GeV

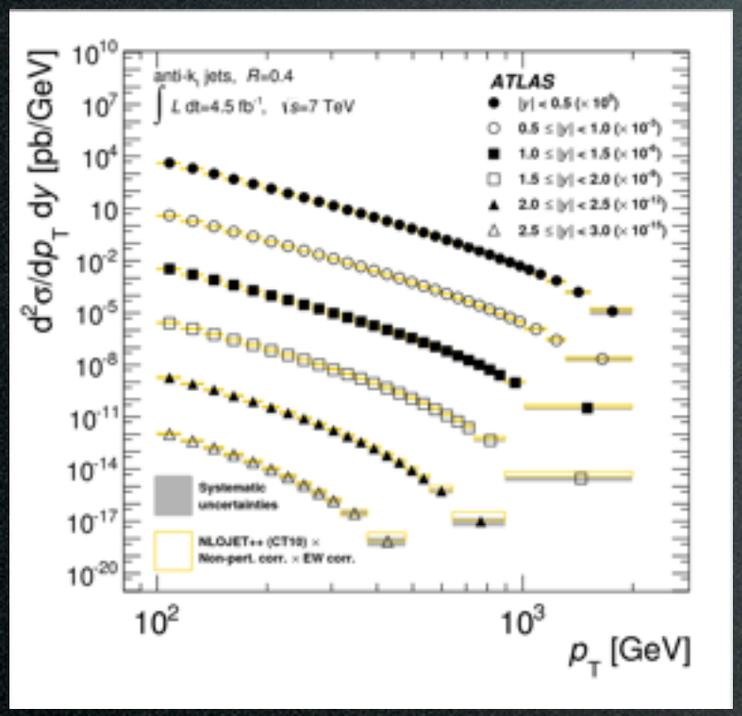
UE Measurements

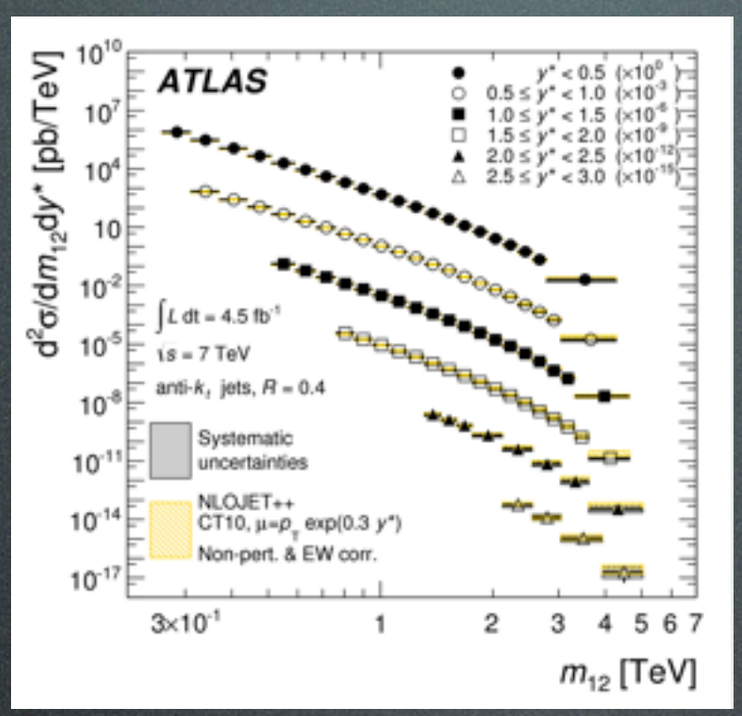


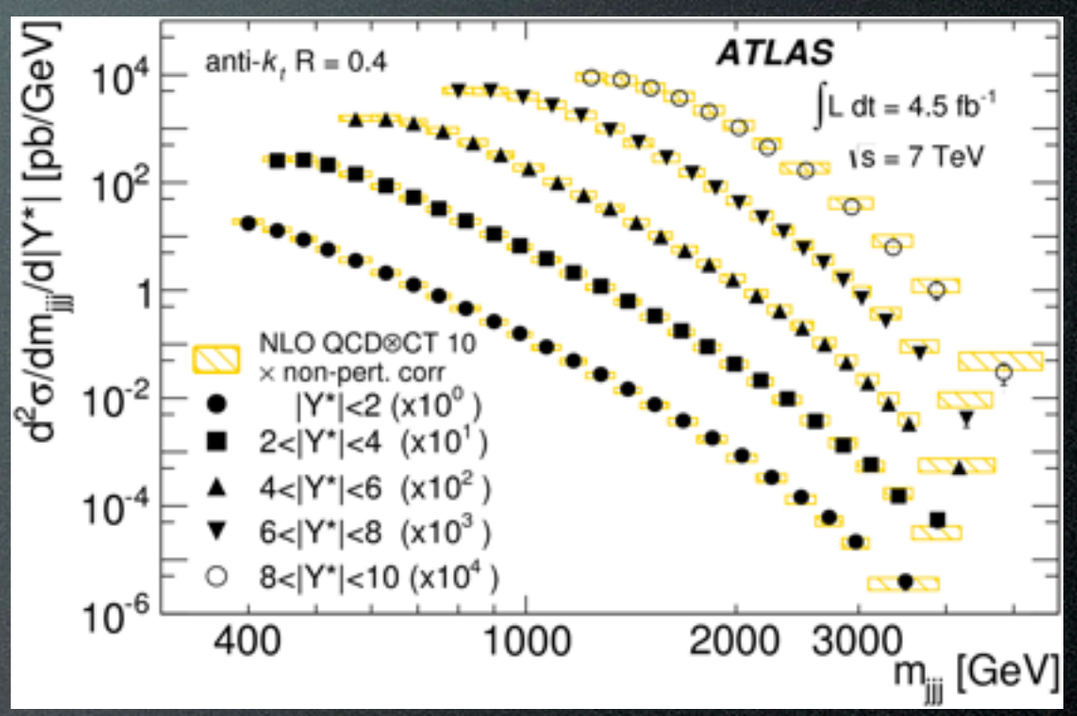




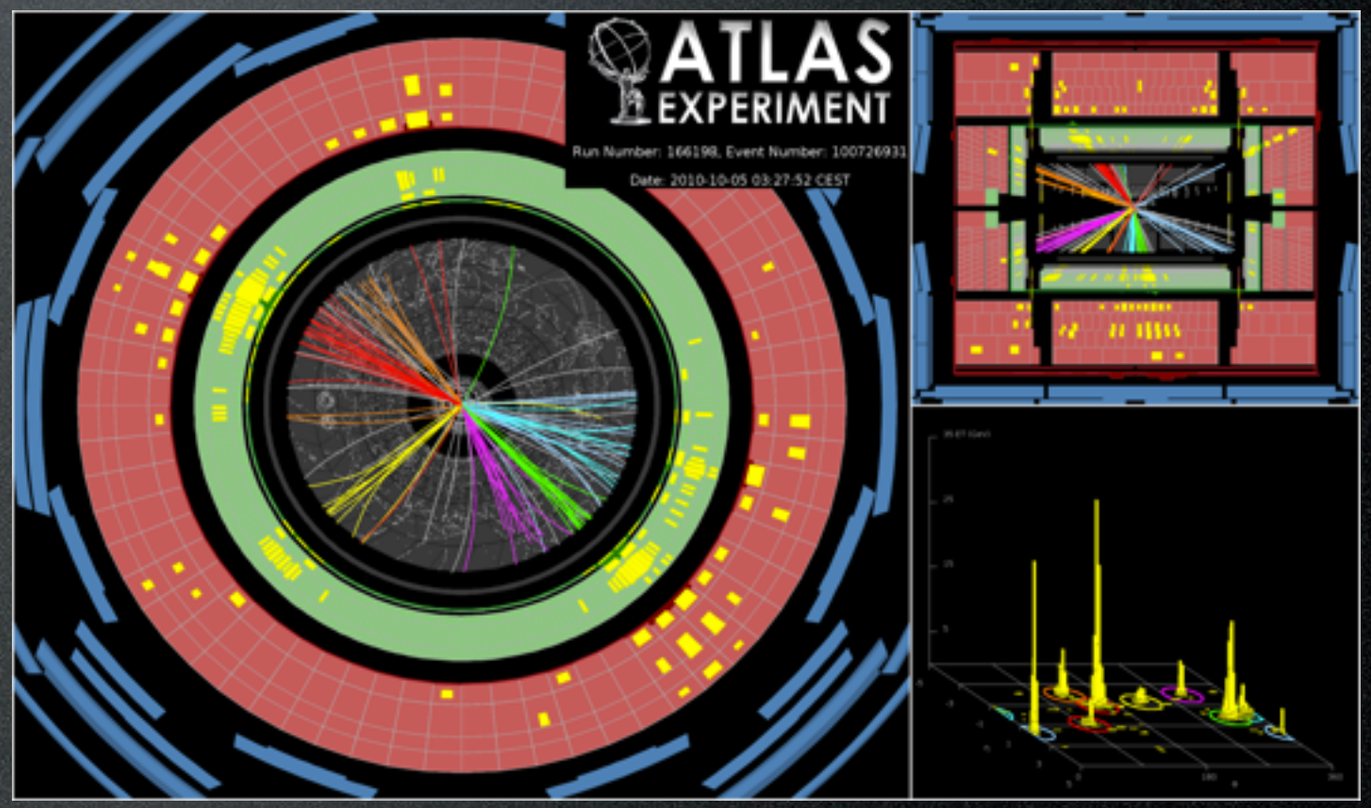
Jet Production



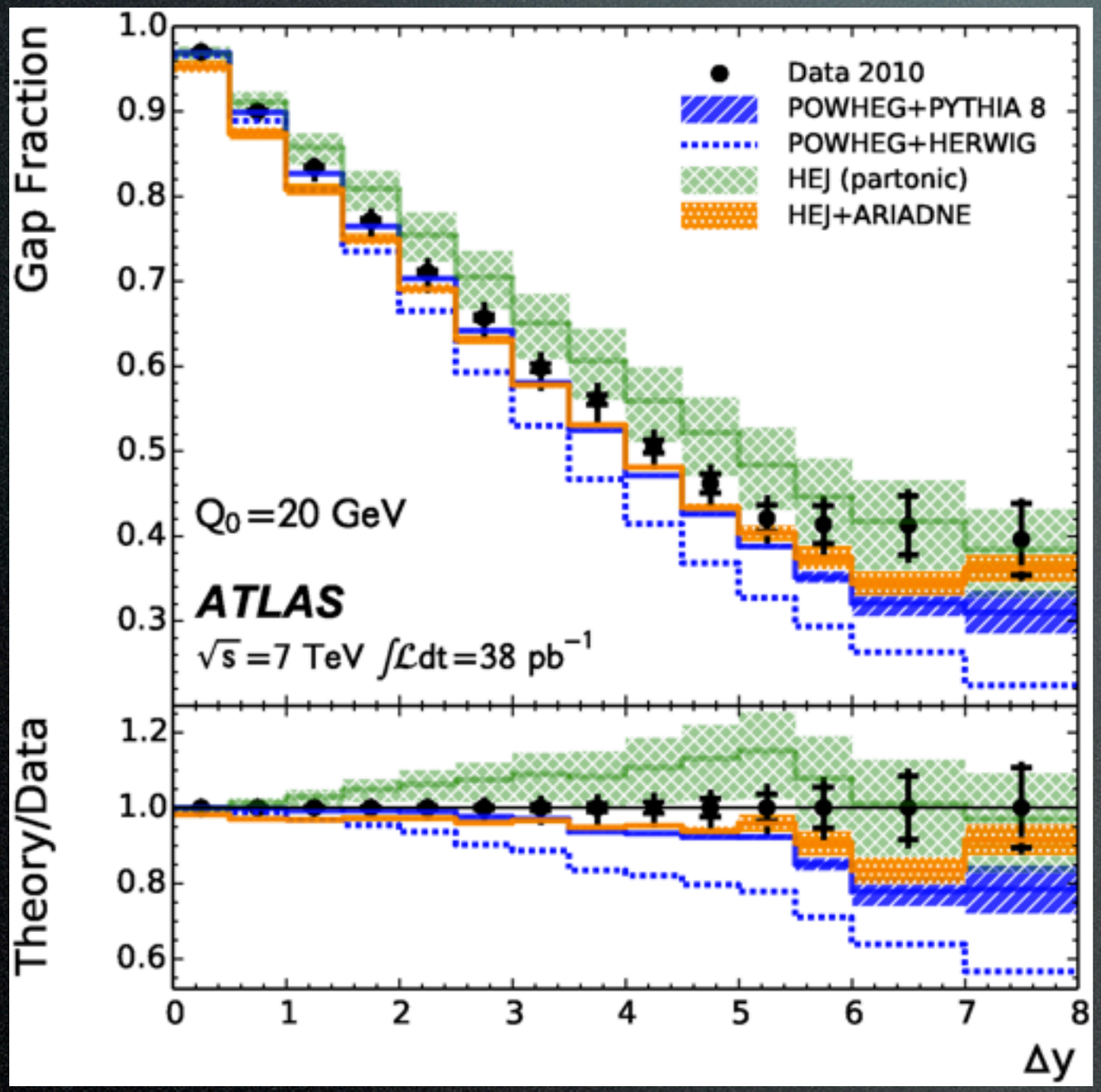




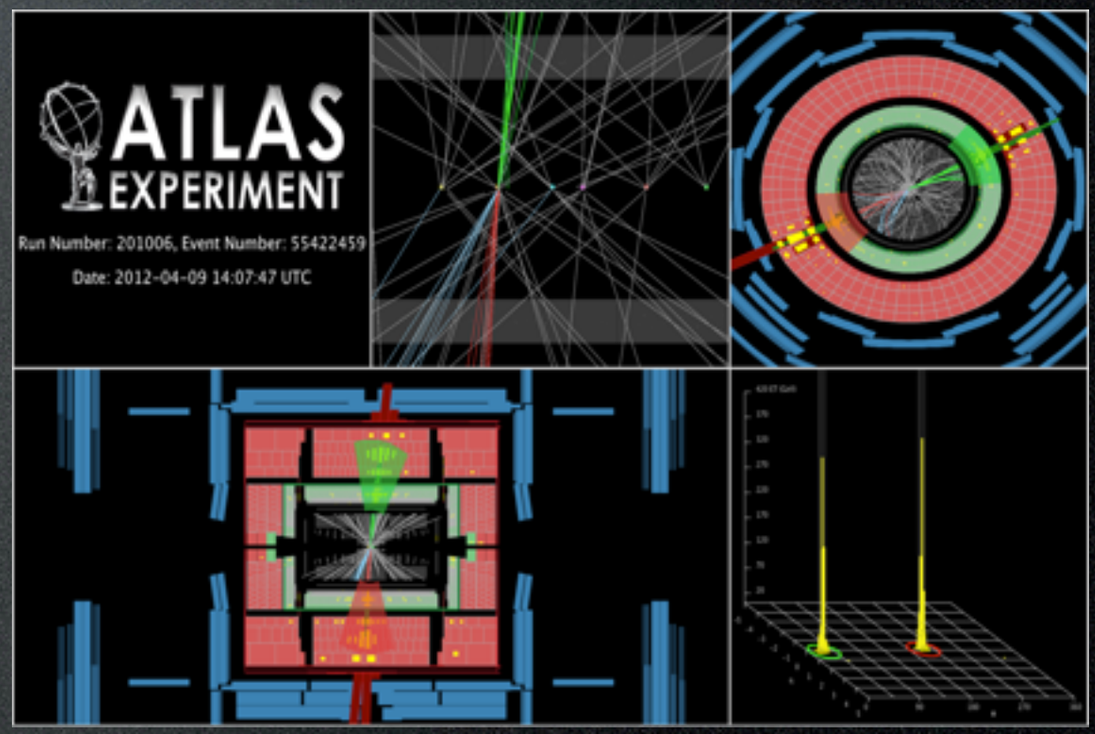
inclusive, dijet and 3-jet differential cross-sections



Properties of Jet Events



Fraction of dijet events without an additional jet in the rapidity interval bounded by the dijet subsystem



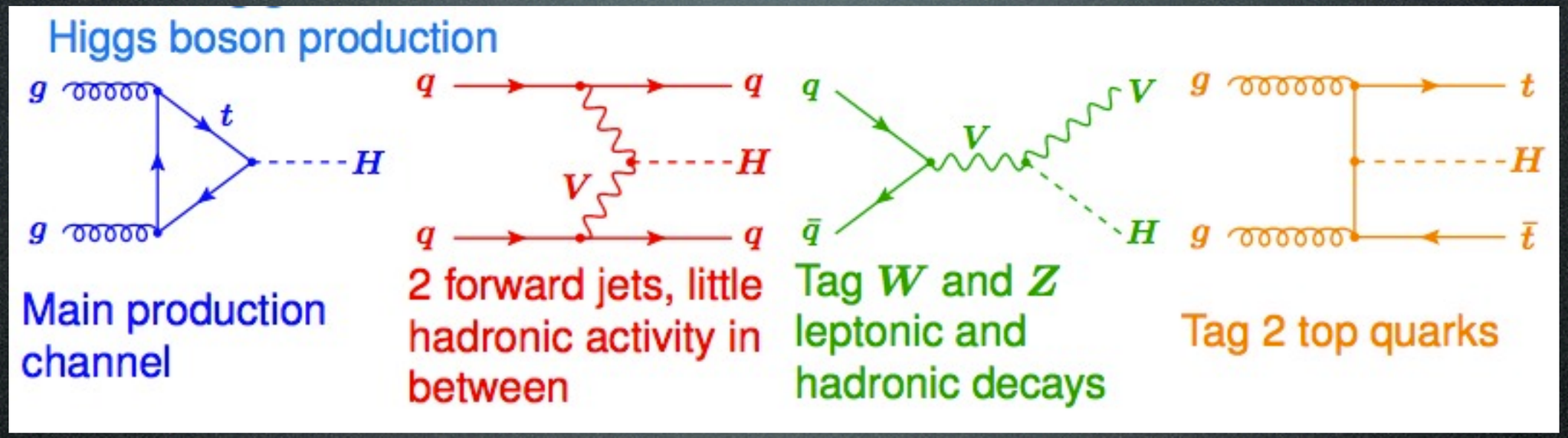
Ingredients of a discovery

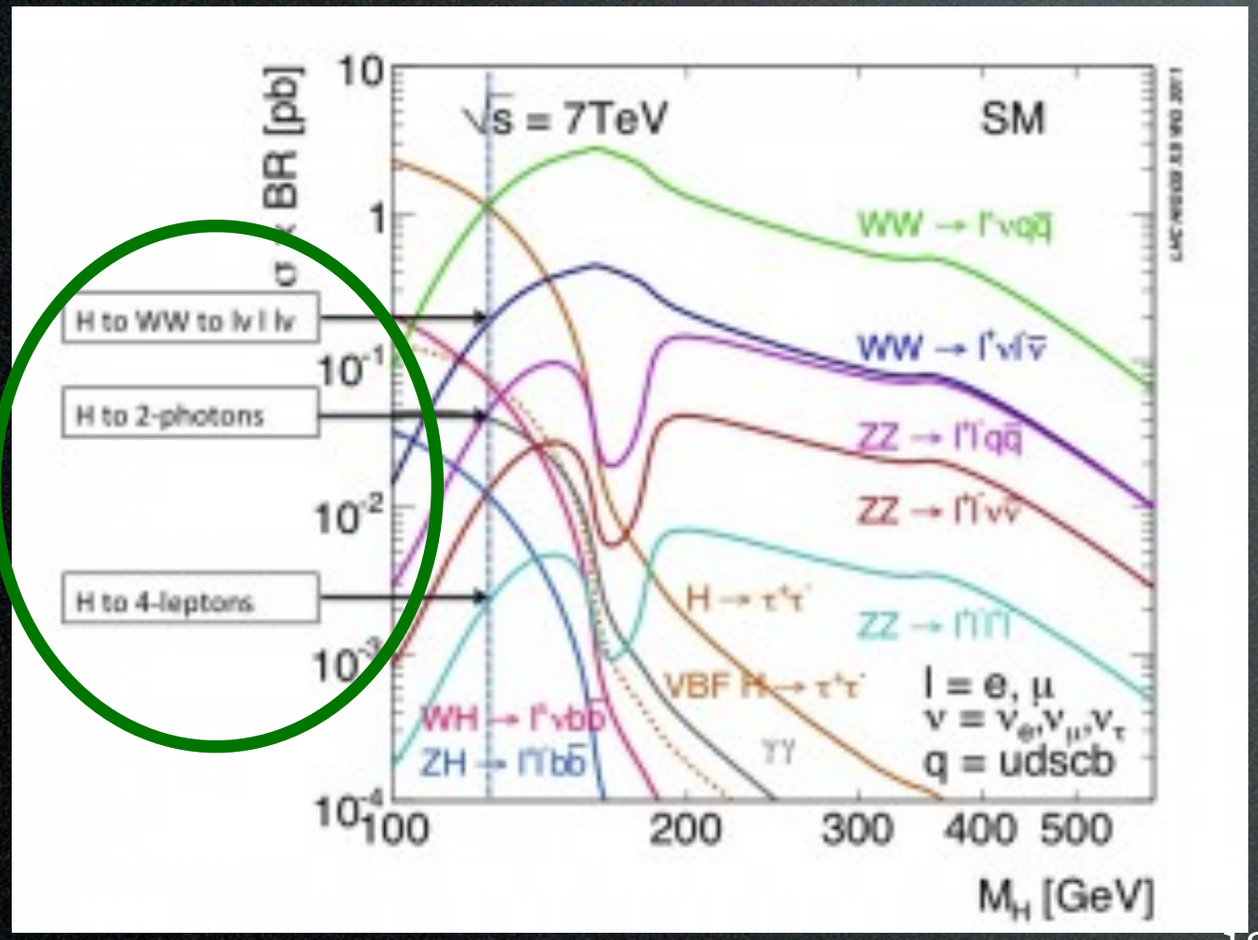
Know your background

Know your detector

Separate the signal

Higgs at the LHC





Final states with leptons or photons are easier to distinguish, measure.

Decays to jets are more difficult to separate from multijet background.

How to?

- Significant deviation from the background-only hypothesis: new peak in a mass-distribution or more events than expected insome kinematic distribution
- Significant: $N_S/\mathrm{sqrt}(N_B) > 5$ (of course not so simple, combine channels accounting for all systematics, and look elsewhere effect)

H->$\gamma\gamma$

Find two photons

Background:
(irreducible)
$\gamma\gamma$ by mass

(reducible)
γ-jet or jet-jet
using detector

Fitted by 4th order poly

H->ZZ->4l

Find four leptons

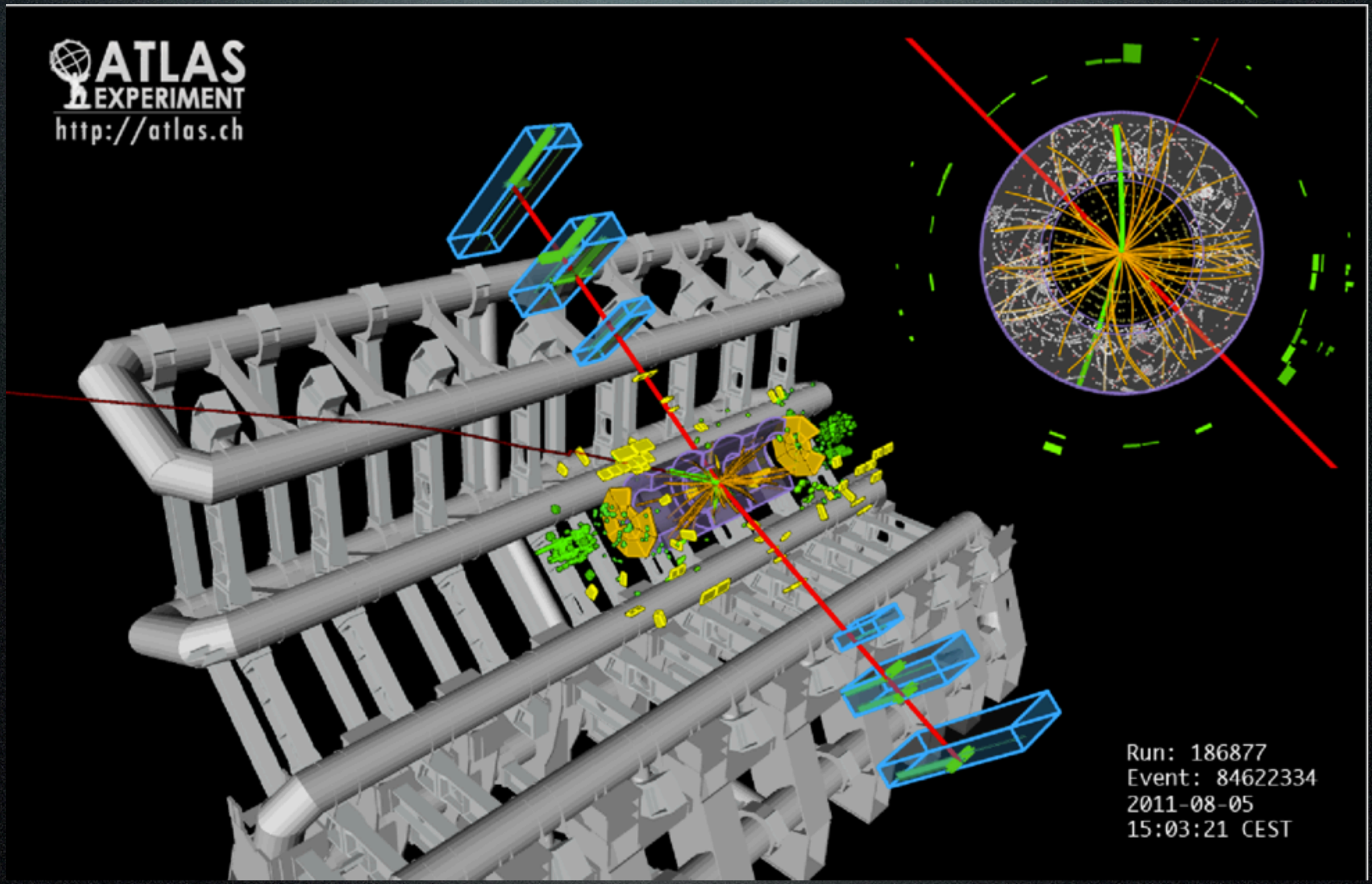
Background:
(irreducible)
ZZ by mass

(reducible)
Zbb or ttbar
by lepton isolation or b-tagging (for leptons from b decay)

H->WW->2l2ν

Find two leptons and missing energy

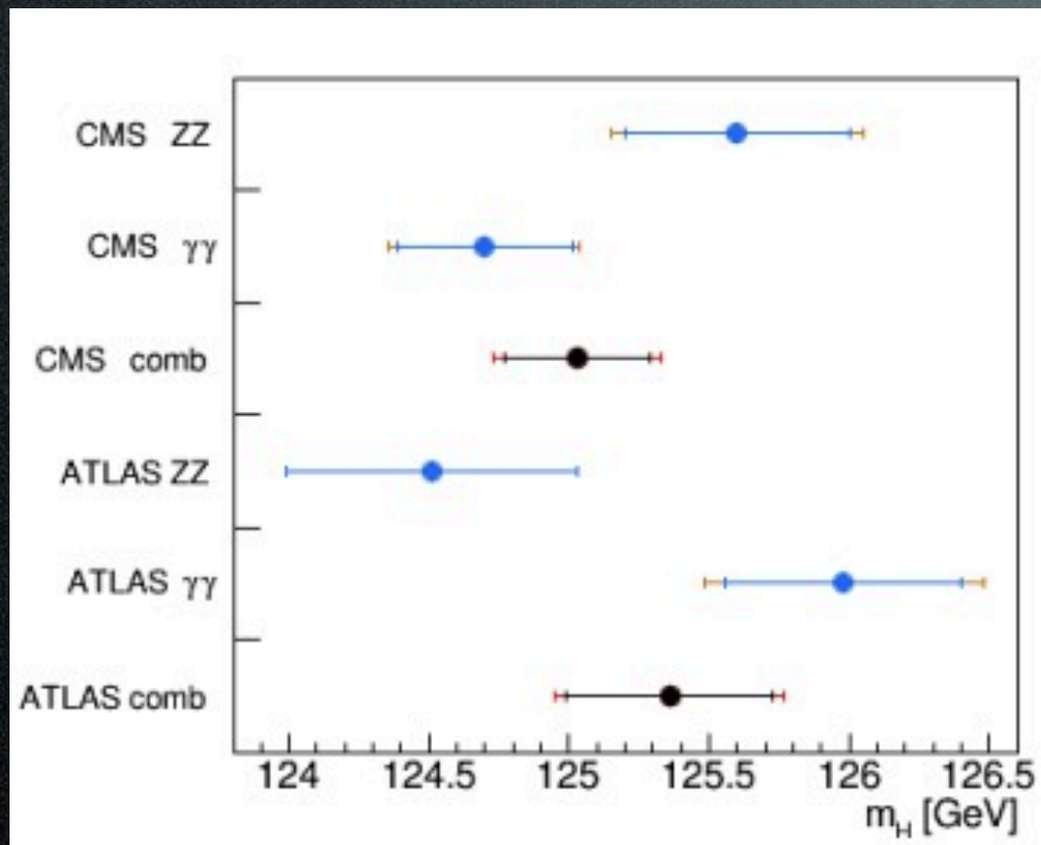
Background:
WW by mass
W+jets, Wt, ttbar by lepton angular correlation, jet veto etc

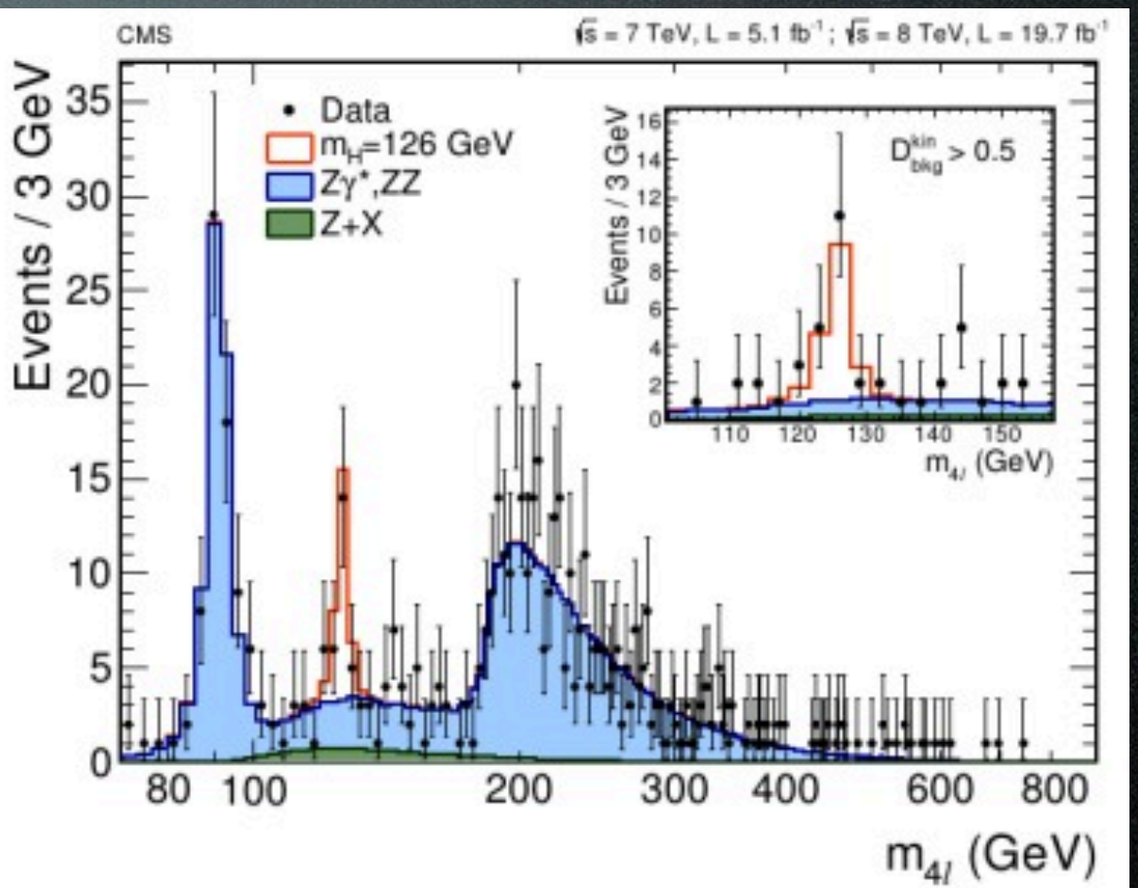

ATLAS
EXPERIMENT
http://atlas.ch
Run: 186877
Event: 84622334
2011-08-05
15:03:21 CEST

SM Higgs?

- Obvious question: how do we know it is the SM Higgs?
- Many extensions of the SM predict additional Higgs bosons (with one SM-like Higgs), rule out or find!
- Precisely measure the properties.

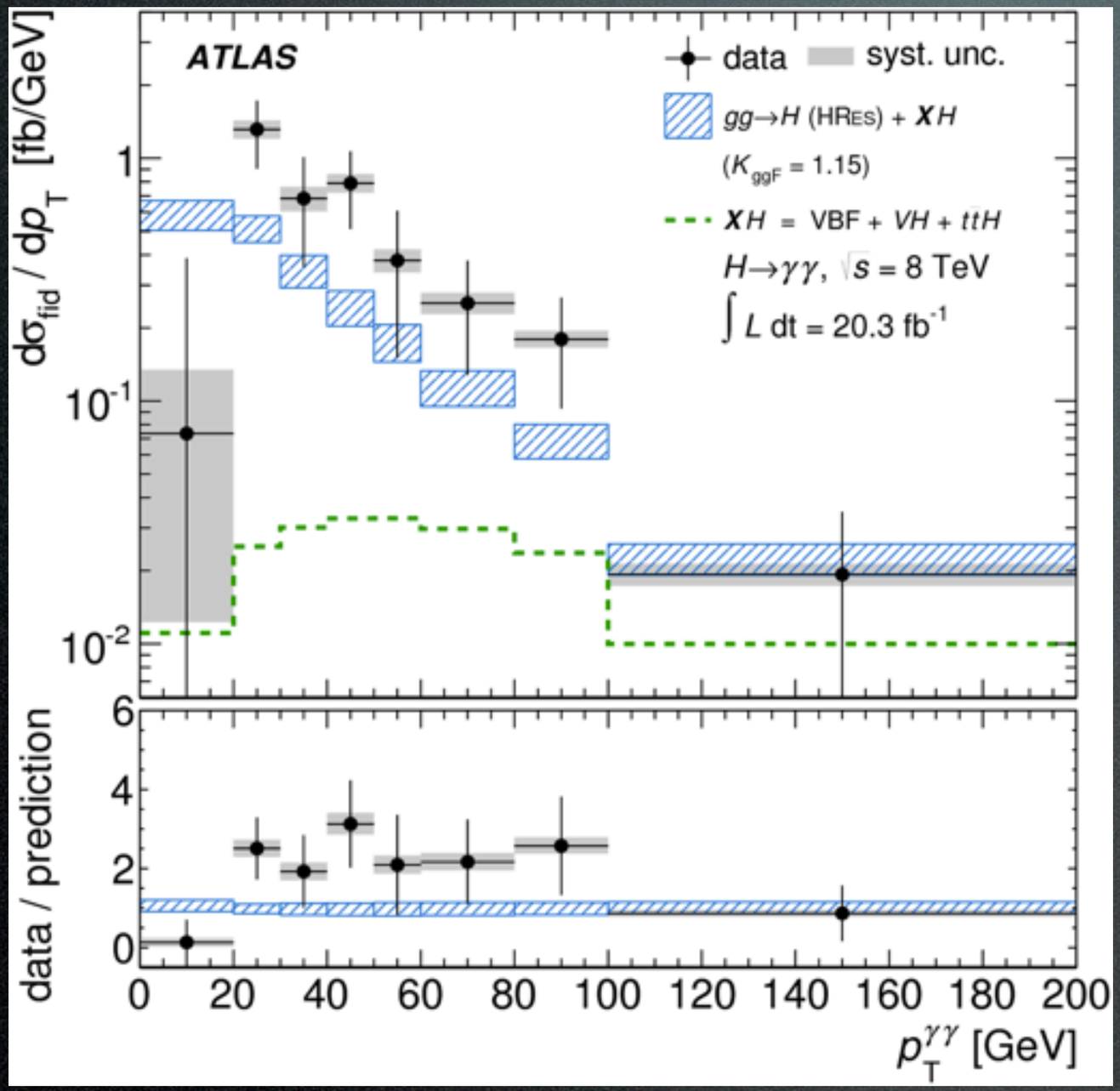
Mass Measurements





Measured in high resolution channels, $\gamma\gamma$ and 4l

Cross-Section



Not everything perfectly modelled!

Other Properties

- Spin 0 strongly favoured
- Coupling strengths in meaured channels roughly consistent with SM
- CP-odd not ruled out
- Self coupling not measured

Non-Higgs Searches

- Searches have been going on for super-symmetric particles or new top-quark like particles (or particles decaying to top quark) or new heavy bosons.
- Nothing so far.
- Known unknowns and unknown unknowns!


ANOTHER
WAY
OF SEARCHING

When you take apart a jet,
what does it look like?

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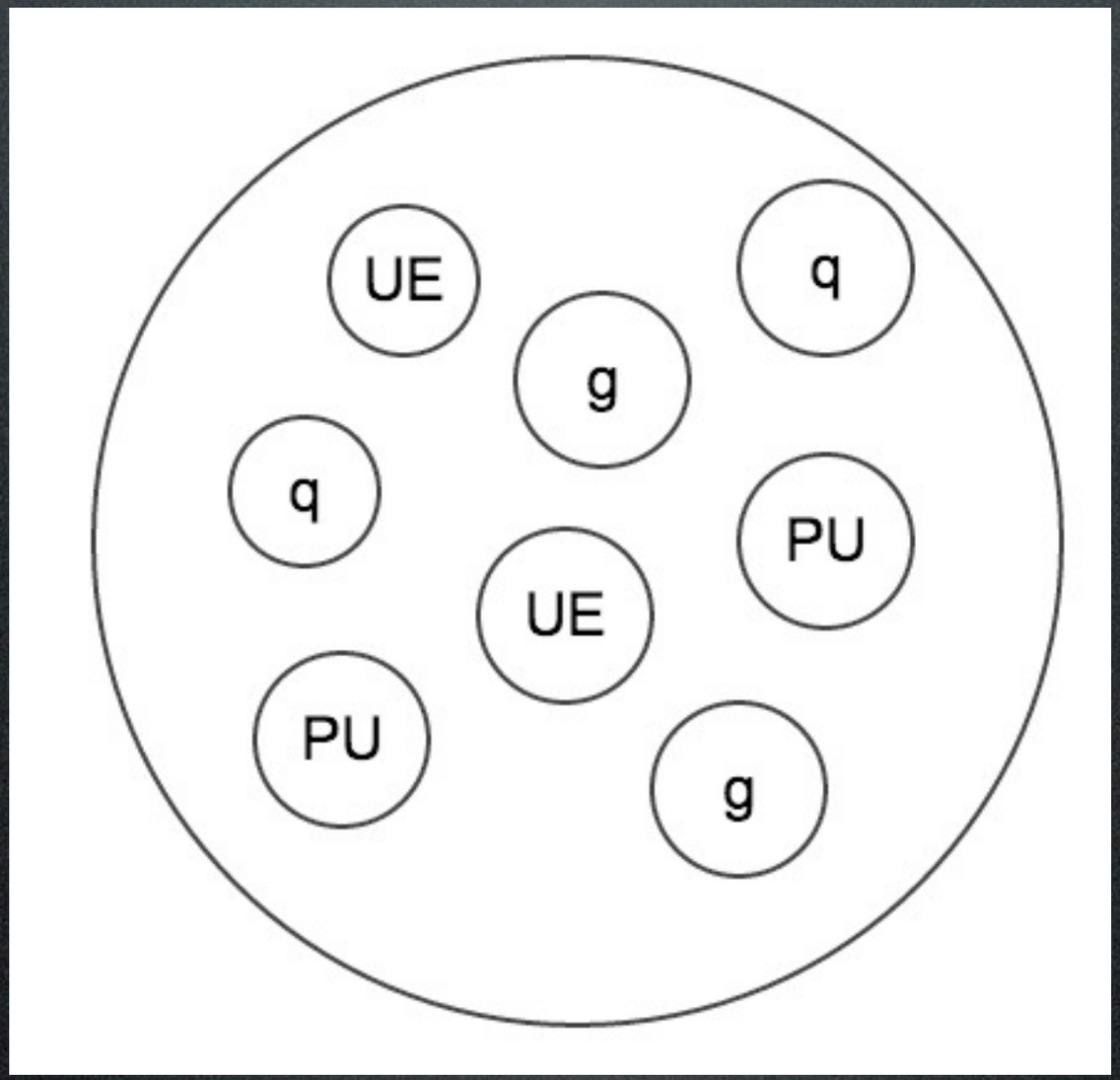
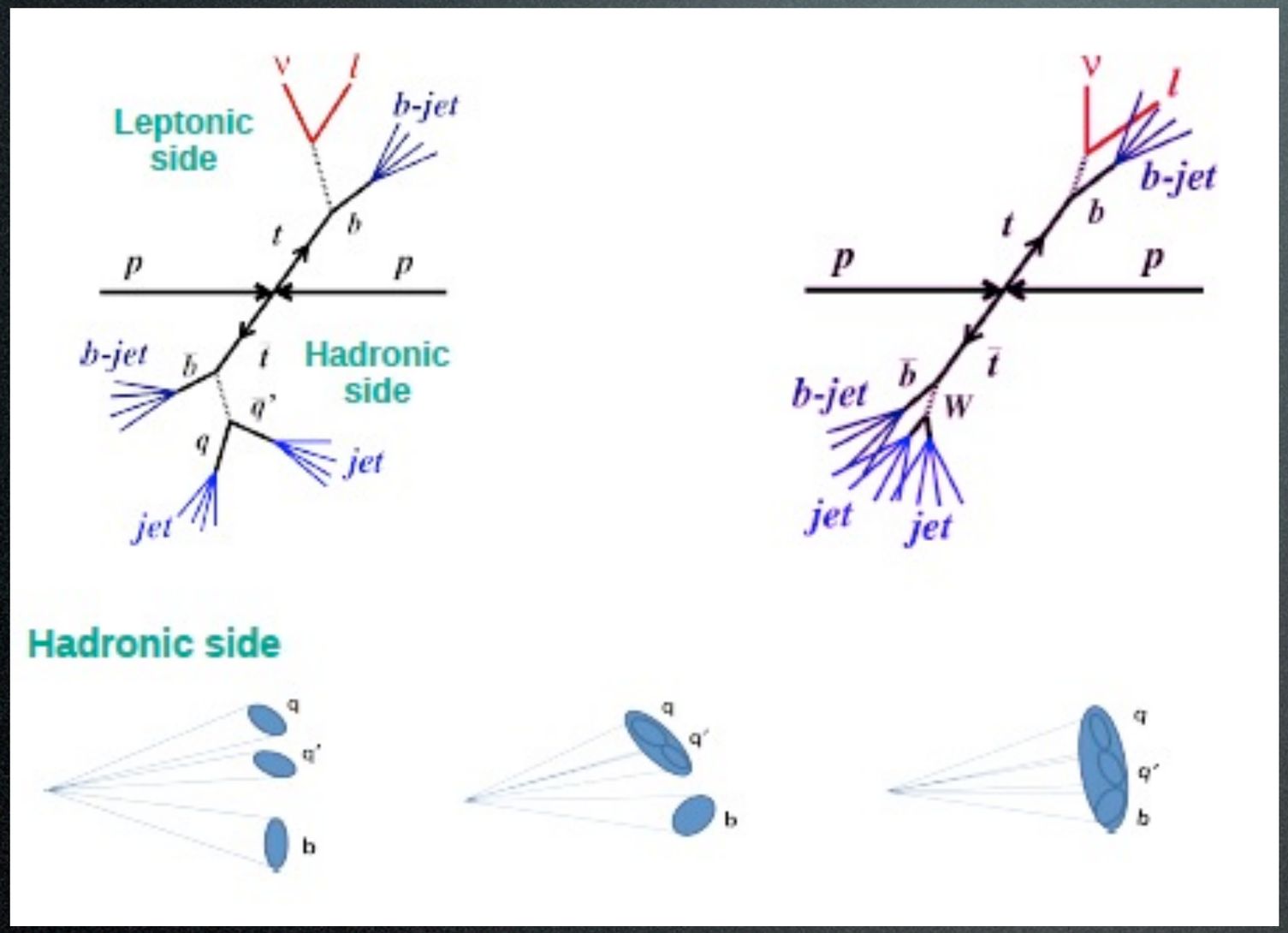
what does it look like?

When you take apart a jet, what does it look like?



Large radius jets



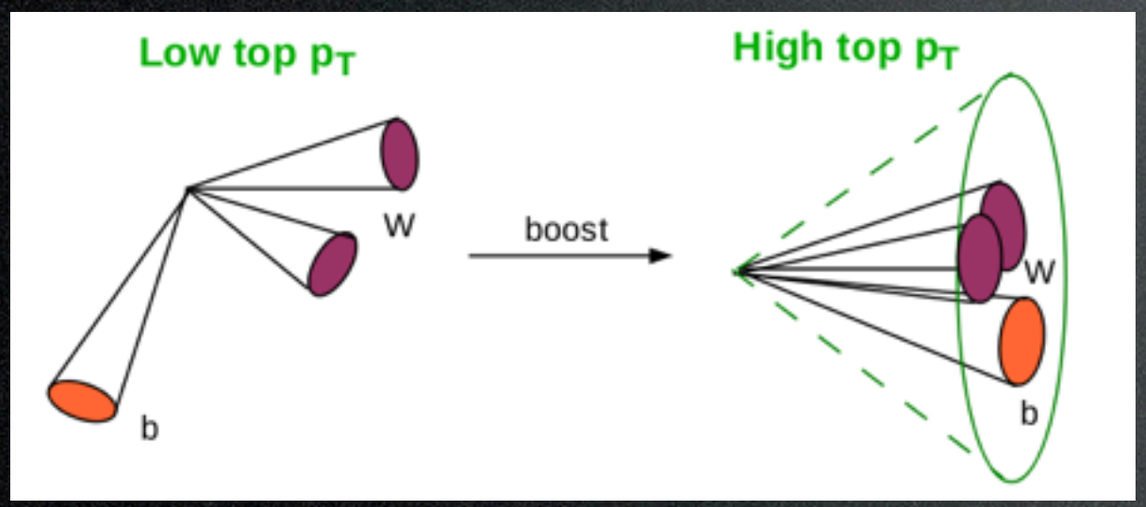
The angular resolution of the decay products: $\Delta R \approx 2m/p_T$

So for a top quark (of mass 173 GeV) with $p_T > 350$ GeV, we have $\Delta R \sim 1$.

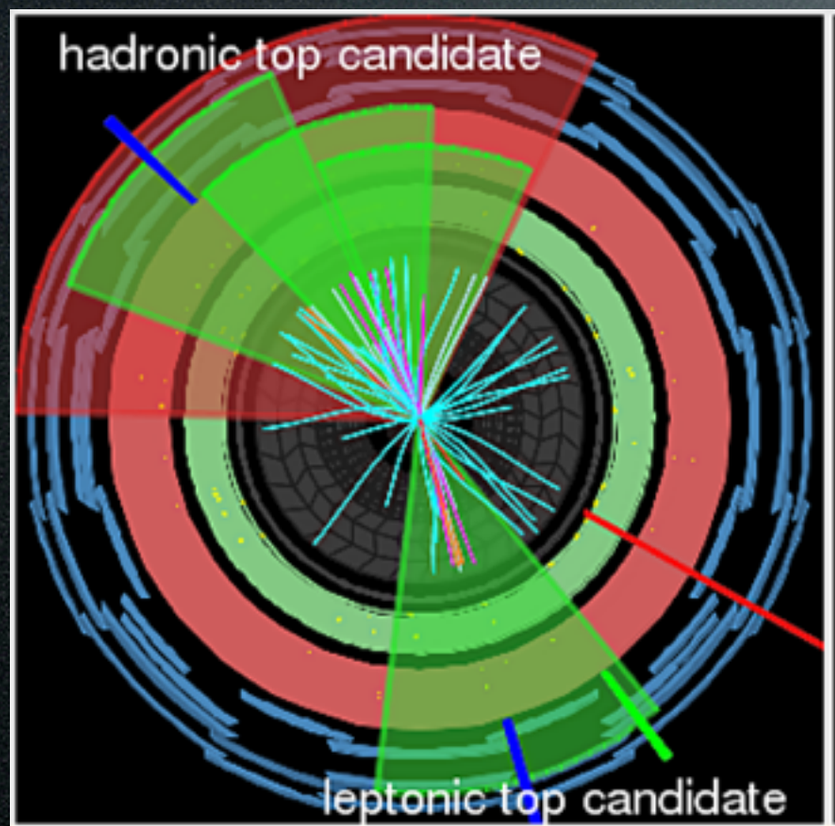
With increasing c.m energy: collimated decay products from boosted heavy particles result in a single massive jet.

Boosted Top Quark Jets

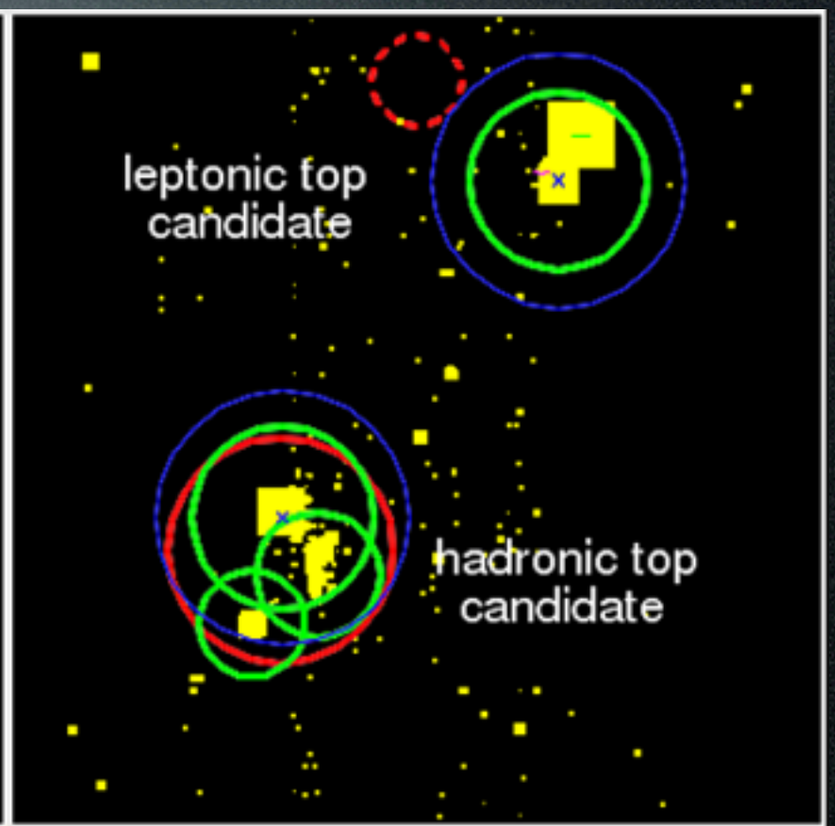
The boosted jet coming from top quark (hadronic) decay should be distinguishable from the boosted jet coming from events with no top quarks.

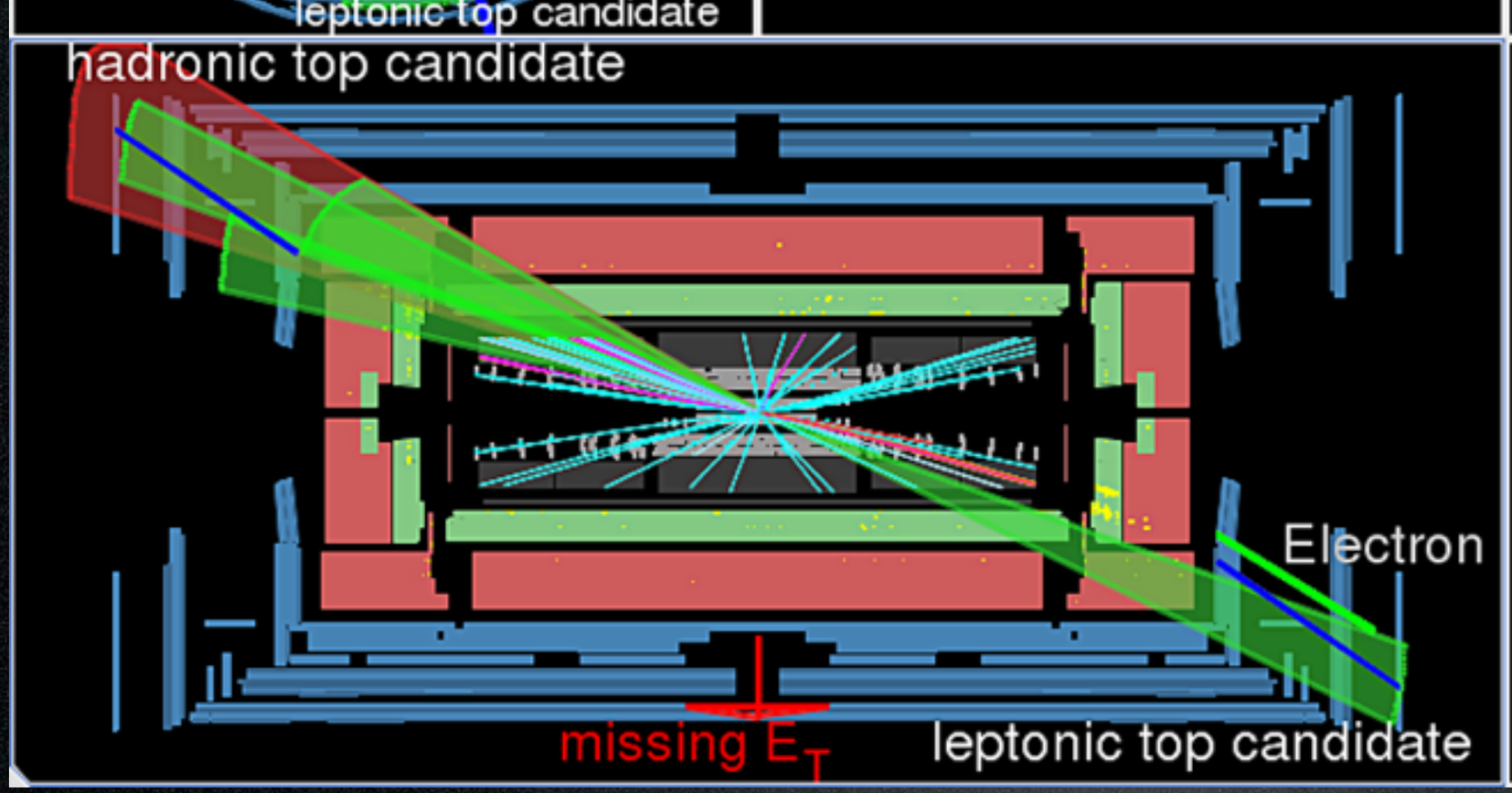


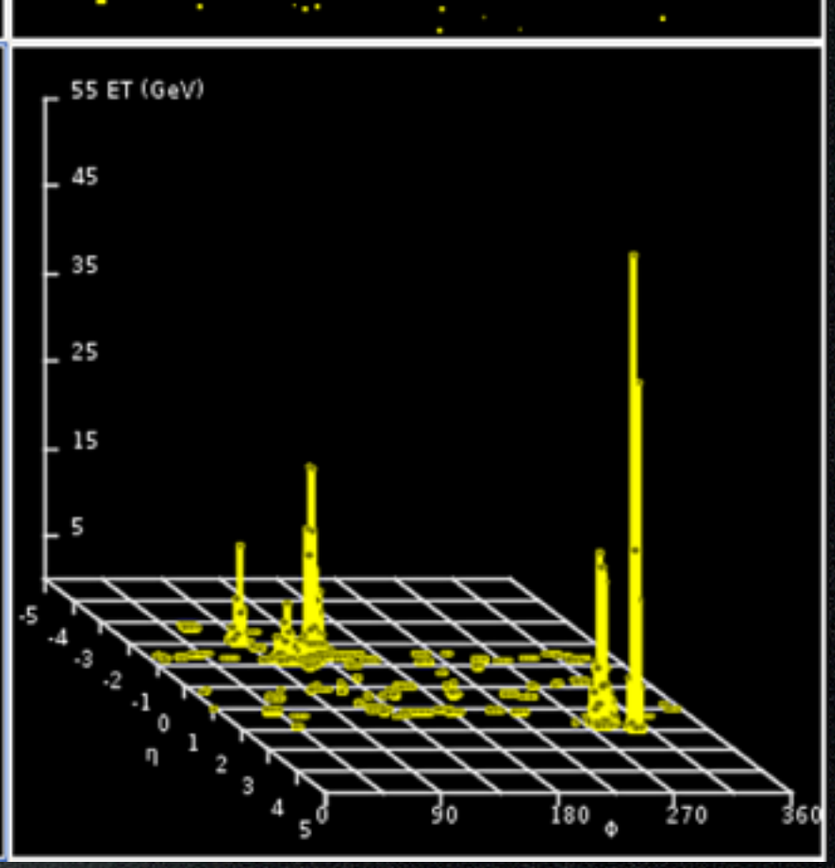
We want to exploit the "substructure" of the large-radius jet to identify original particles


hadronic top candidate
leptonic top candidate


ATLAS
EXPERIMENT
Run Number: 209995, Event Number: 51046560
Date: 2012-09-09 23:10:22 CEST


leptonic top candidate
hadronic top candidate


hadronic top candidate
Electron
missing E_T
leptonic top candidate

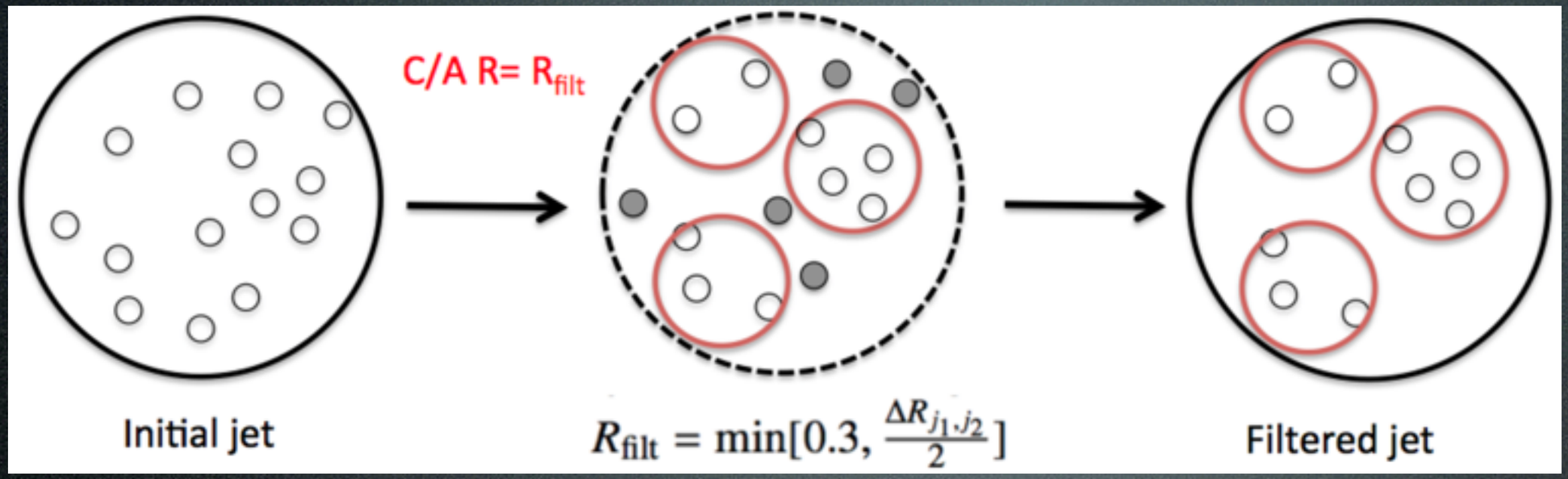

55 ET (GeV)
45
35
25
15
5
-5
-4
-3
-2
-1
0
1
2
3
4
5
η
0
90
180
270
360
Φ

Substructure Techniques

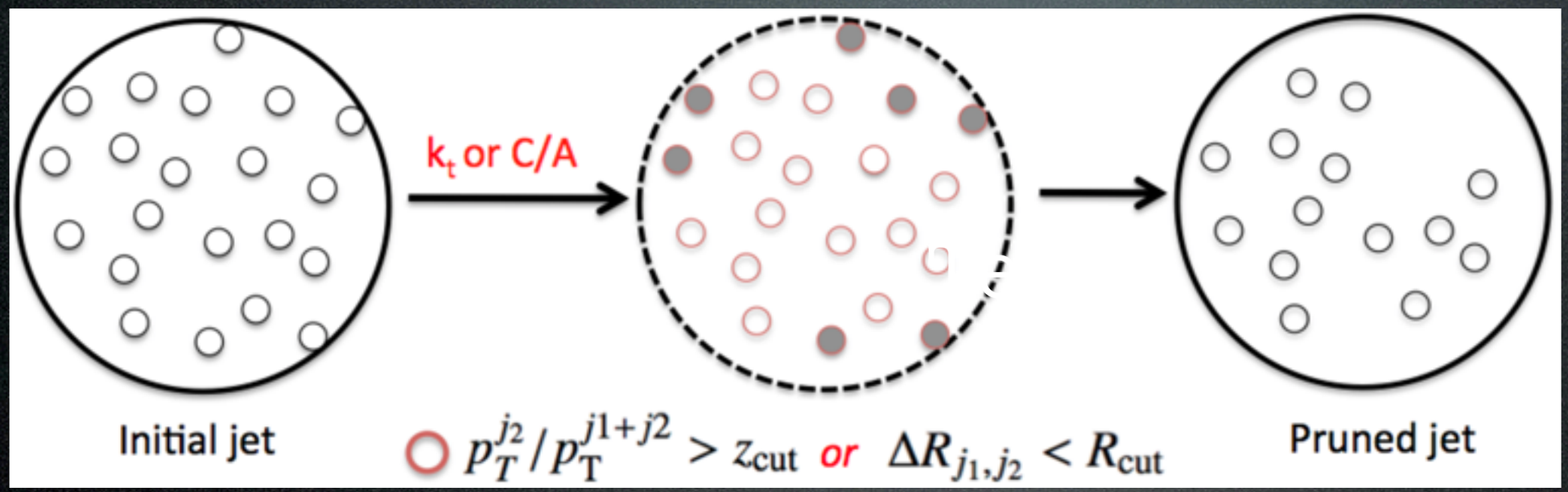
- Jets need to be “groomed”.
- Need observables which would be sensitive to signal-like or background-like nature of these jets.

Why?

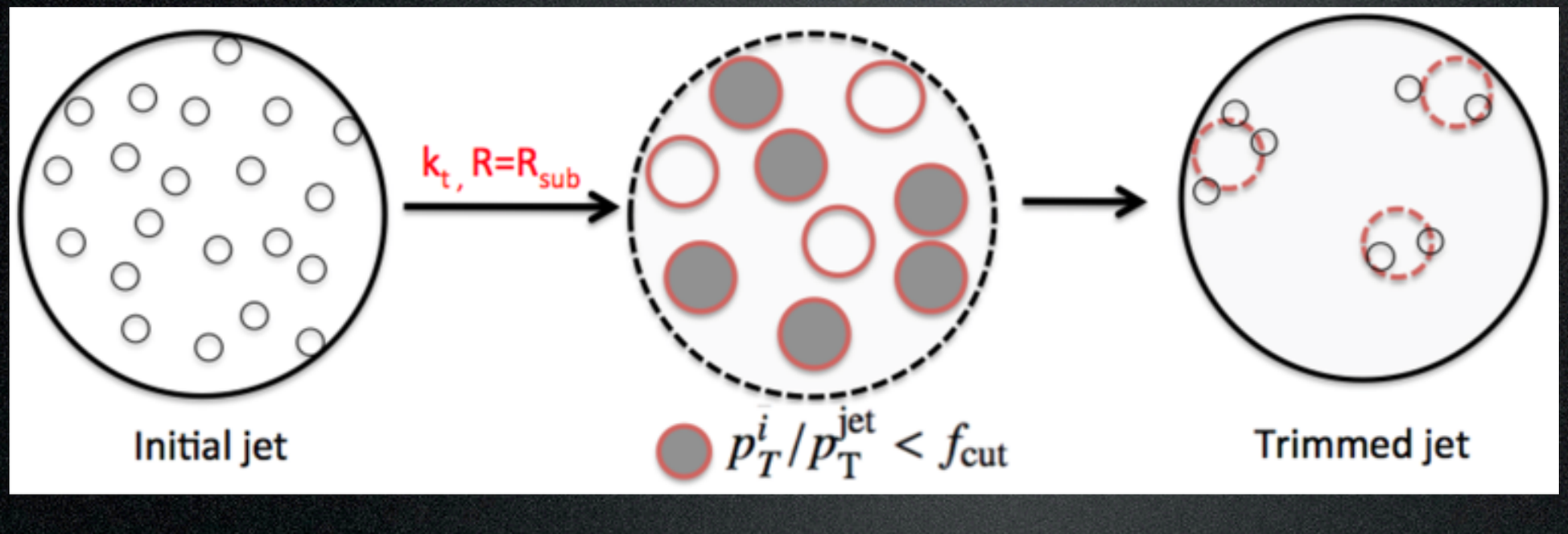
The large-radius jets not only include particles coming from the interesting decays, but also from pileup, underlying event ....



Filtering



Prunning



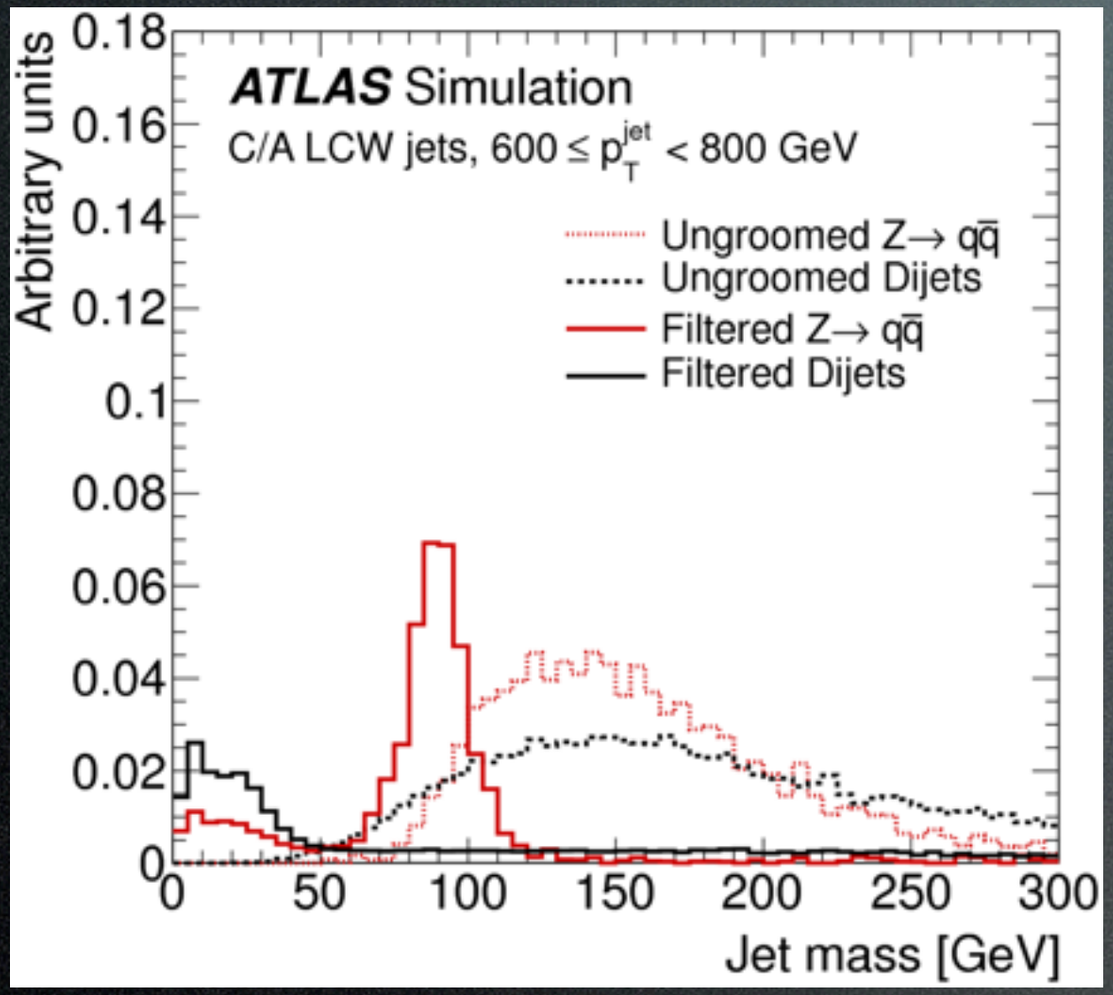
Trimming

Effect of Gardening?

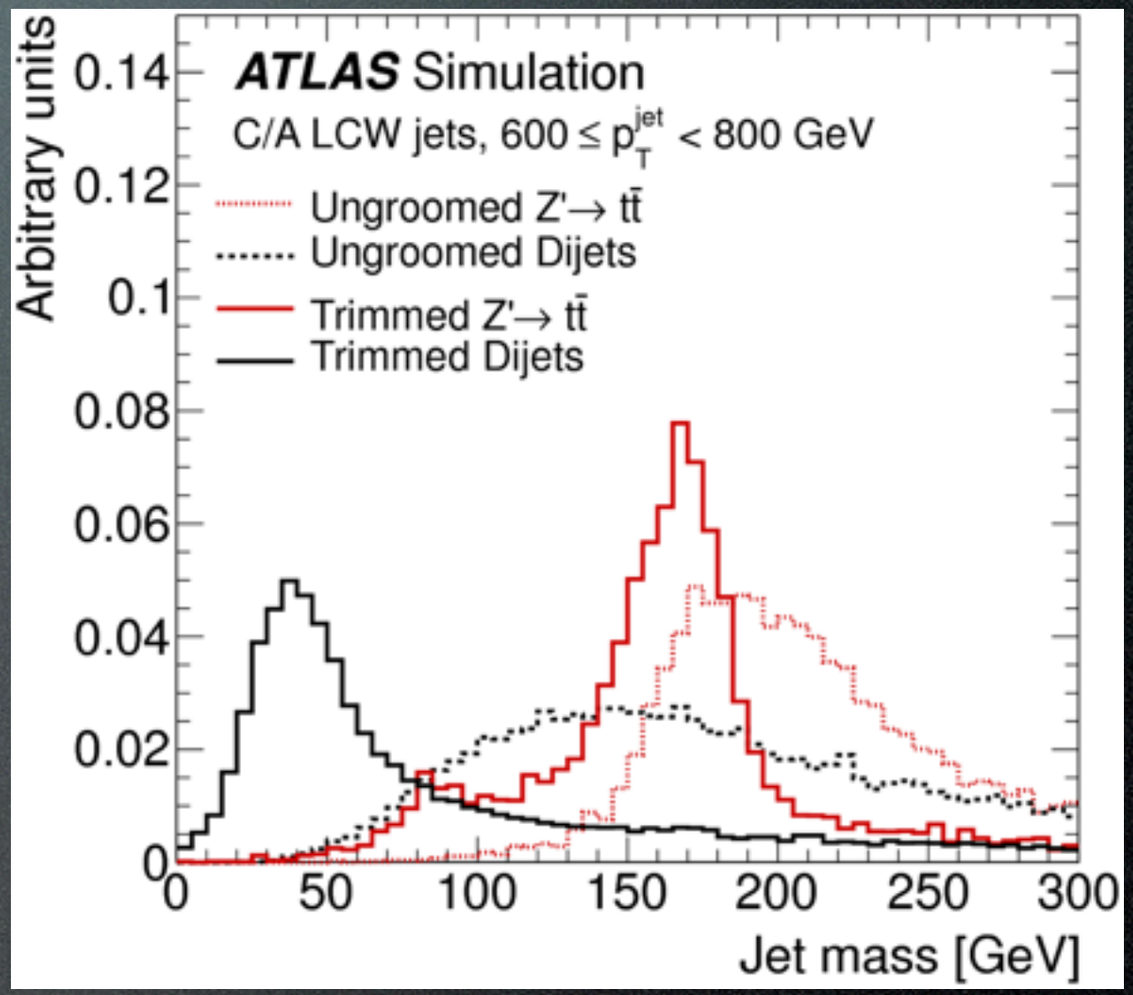
From this …

Effect of Gardening?

Jet Mass



arXiv:1306.4945v1



arXiv:1306.4945v1

Clear peak visible after grooming

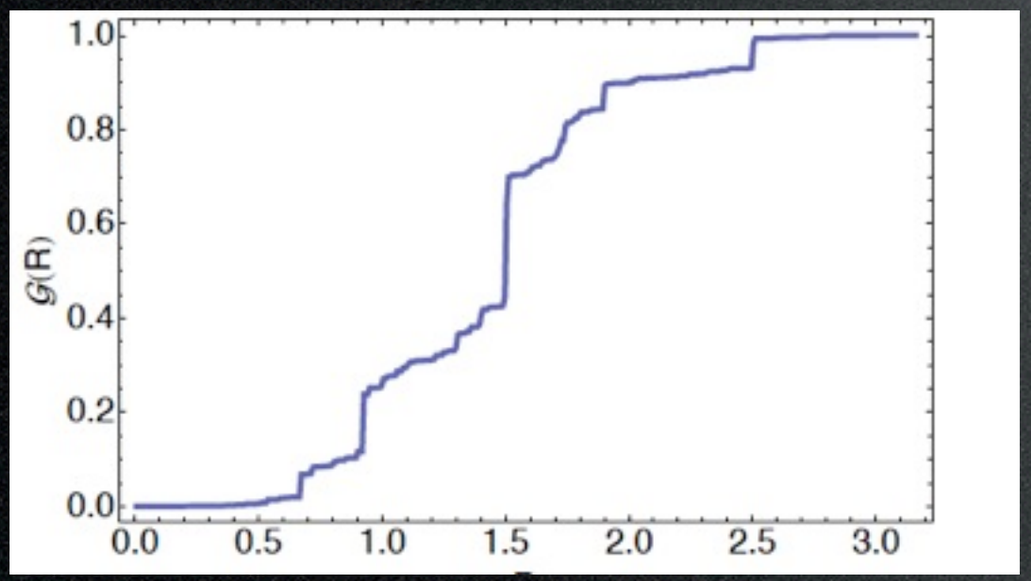
Martin Jankowiak, Andrew J. Larkoski; arXiv:1104.1646

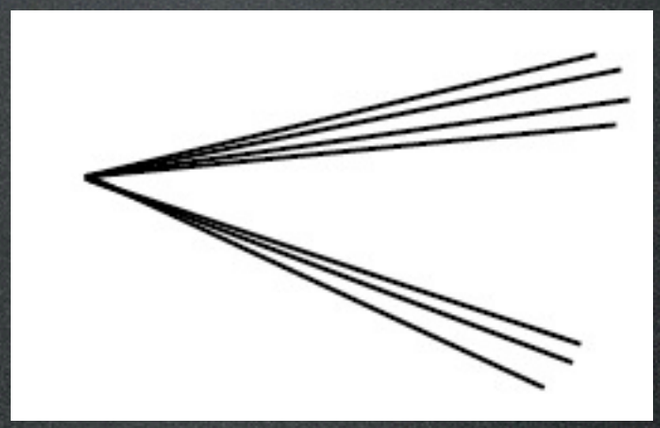
Angular Correlation Function

(or jet substructure without trees)

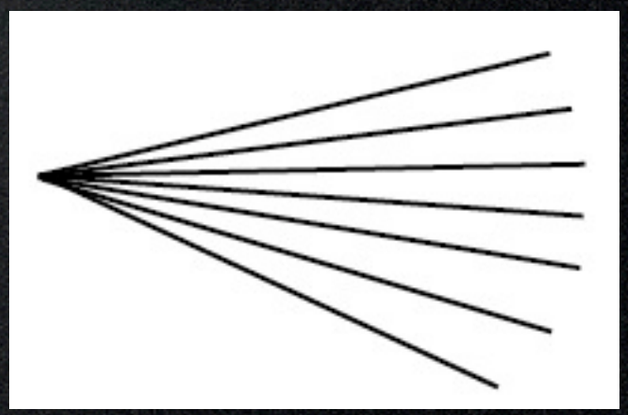
$$\mathcal{G}(R) \equiv \sum_{i \neq j} p_{\perp i} p_{\perp j} \Delta R_{ij}^2 \Theta[R - \Delta R_{ij}]$$

$$\Delta R_{ij}^2 = (\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2$$



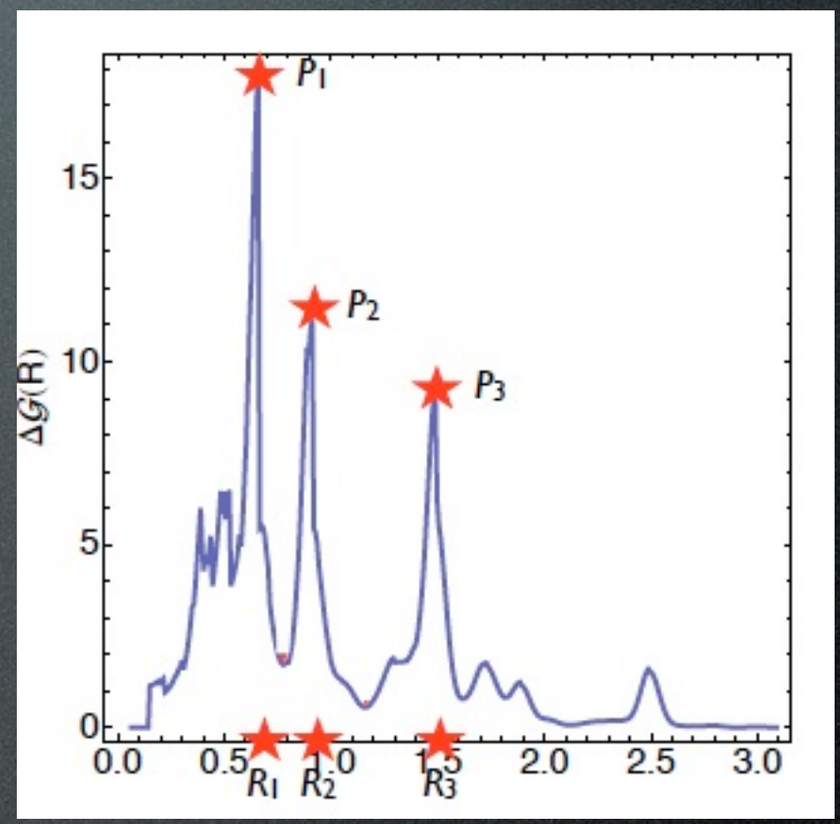


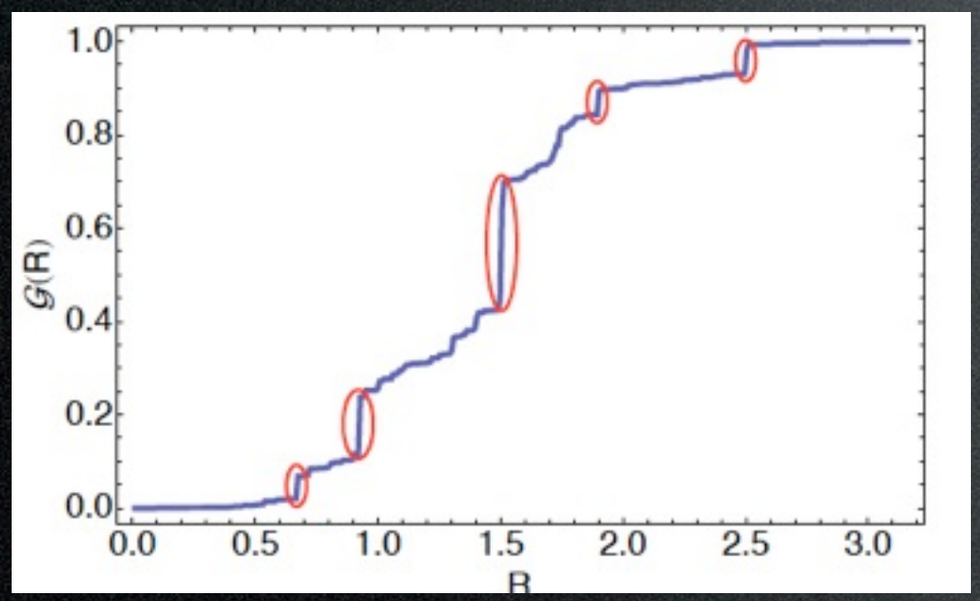
vs.



Angular Structure Function

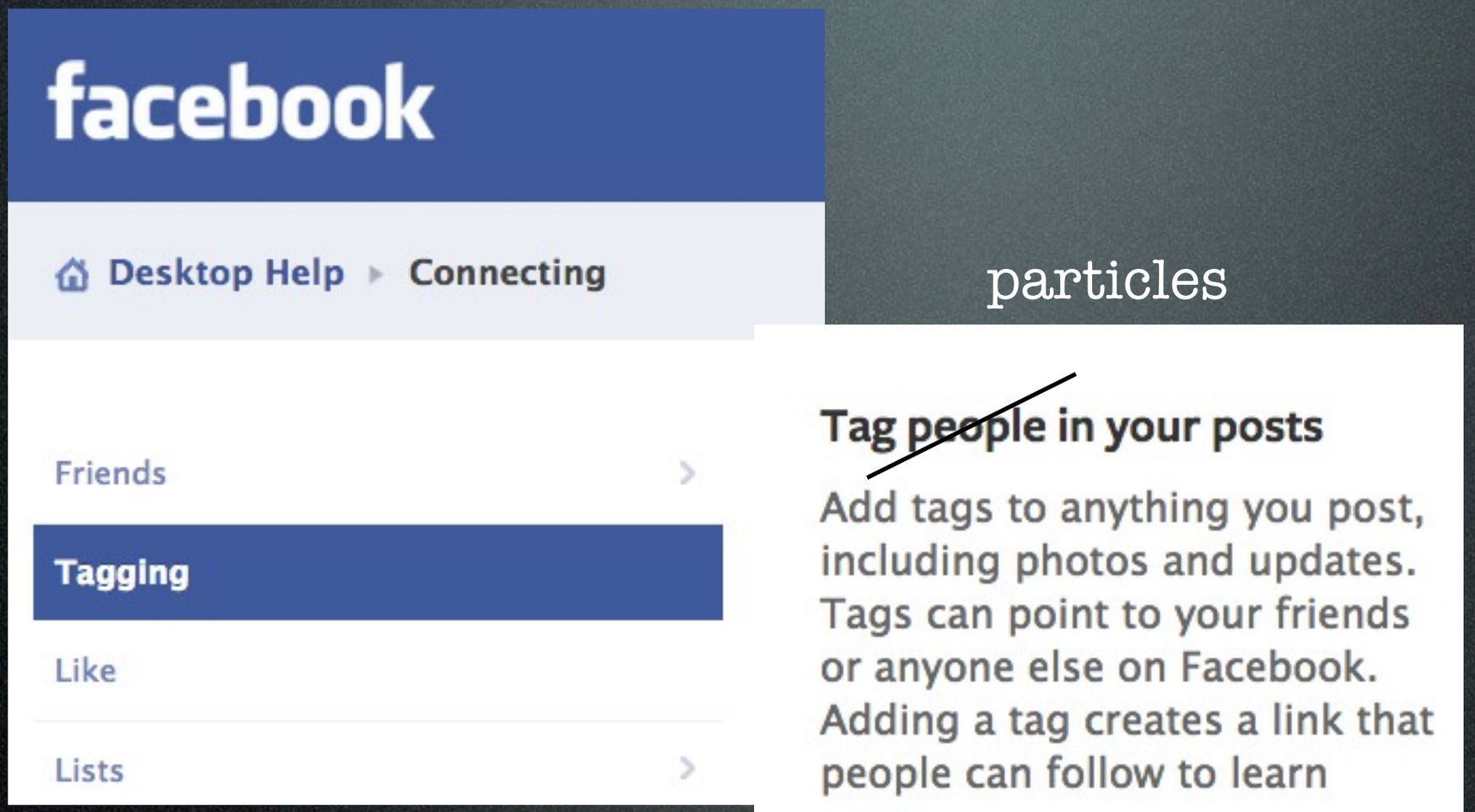
$$\Delta\mathcal{G}(R) \equiv \frac{d\log\mathcal{G}(R)}{d\log R}$$





- Location of the peaks
- Height of the peaks
- Number of peaks

Tagging Top or Higgs



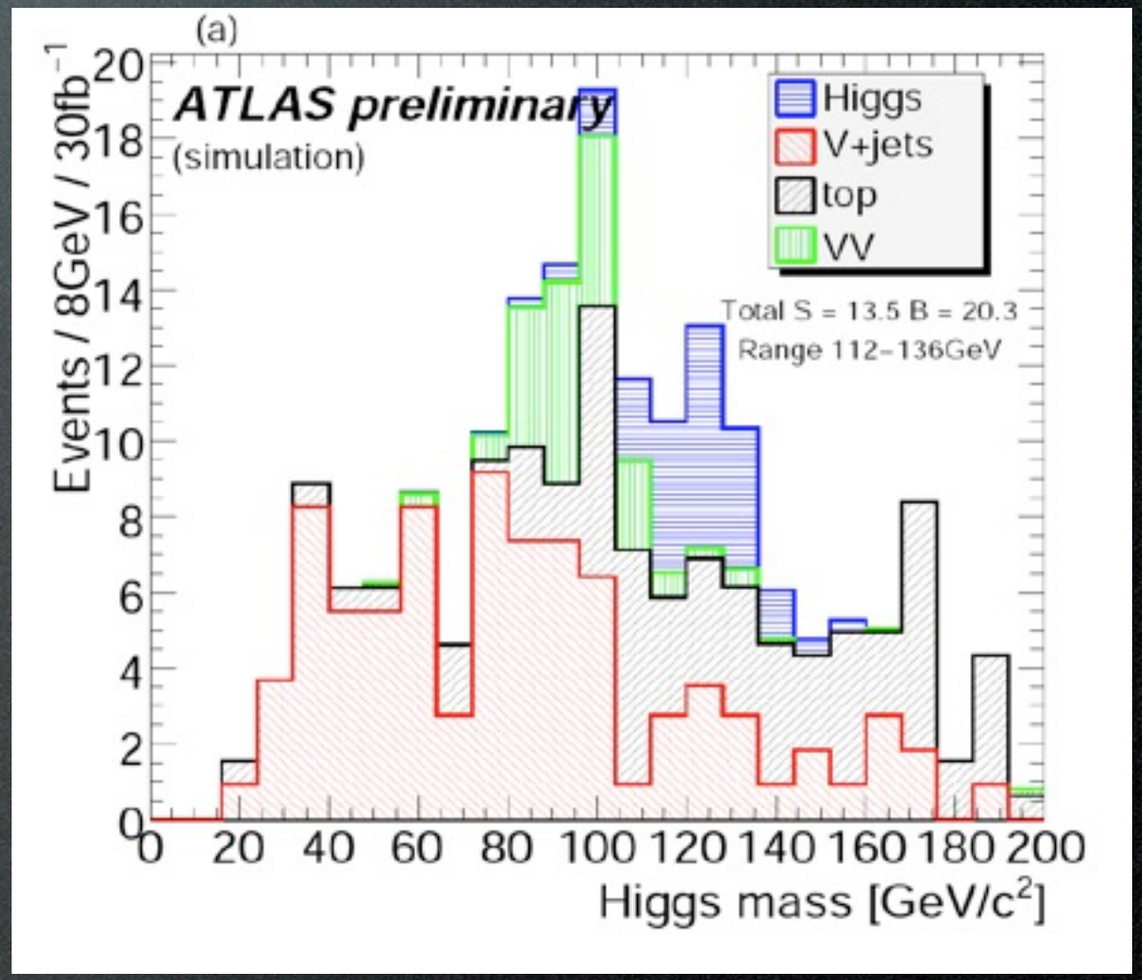
particles

- Target is to identify jets resulting from the decay of top quark or Higgs against jets coming from light quark/gluons.

J. Butterworth, A. Davidson, M. Rubin, G. Salam; http://arxiv.org/abs/0802.2470

Where it all started: **B**utterworth-**D**avison-**R**ubin-**S**alam Higgs to bb tagger (2008)

- Start with fat (C-A 1.2) boosted ($p_T > 200$) b-tagged jet.
- De-cluster the jet. At each stage, mass drop and symmetric splitting requirement.
- Continue till an interesting splitting has been found.
- Higgs candidate from two hardest b-tagged subjets among the three hardest.



Looking Forward

- Experimental high energy physics is hardly just doing experiment (underground), rather a lot of coding, making pretty plots, and (most importantly) interpreting them!

- Close cross-talk with theorists, since they give us ideas and tools, and we tell them if their theories are supported by data.

- We need smart, motivated students to sustain the progress in the field!

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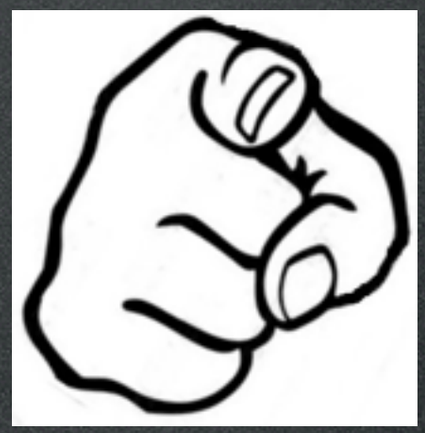


Resources

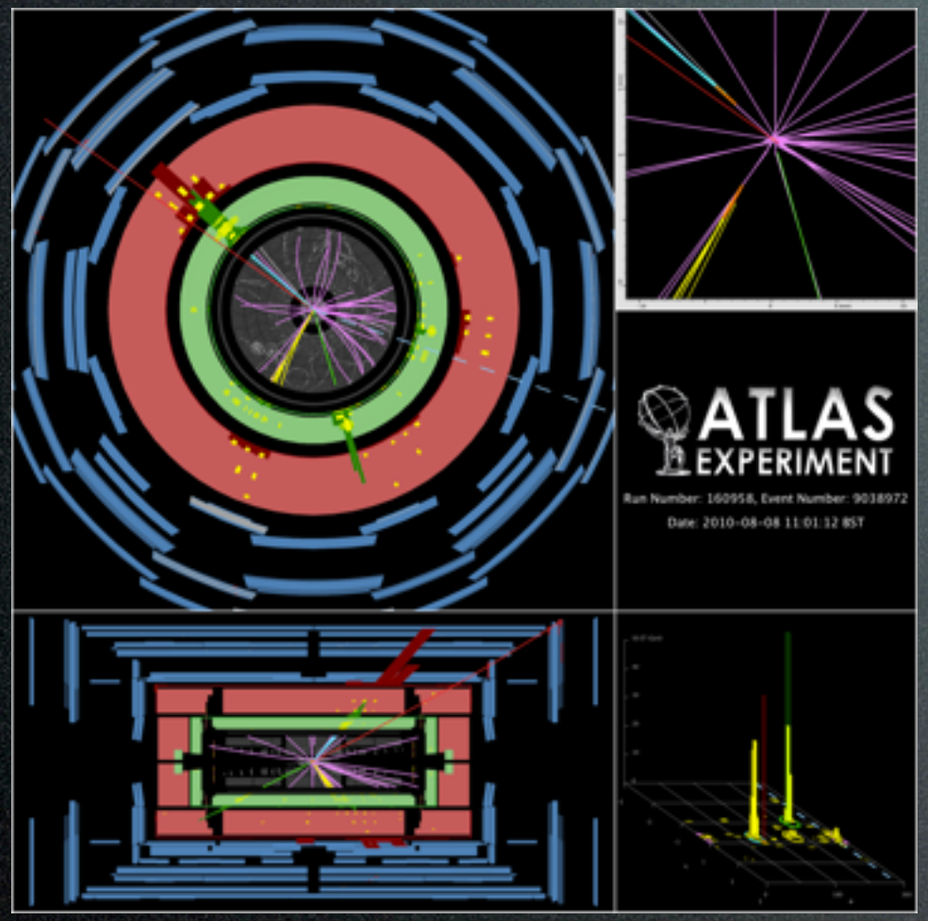
- ROOT: http://www.nevis.columbia.edu/~seligman/root-class/
- Rivet: http://indico.cern.ch/event/281744/material/slides/0.pdf
- Event Generators: http://indico.cern.ch/event/174777/other-view?view=standard

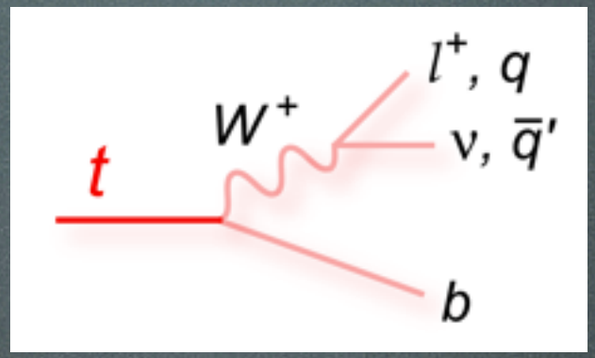
More!

Detour: Doing an “Analysis”

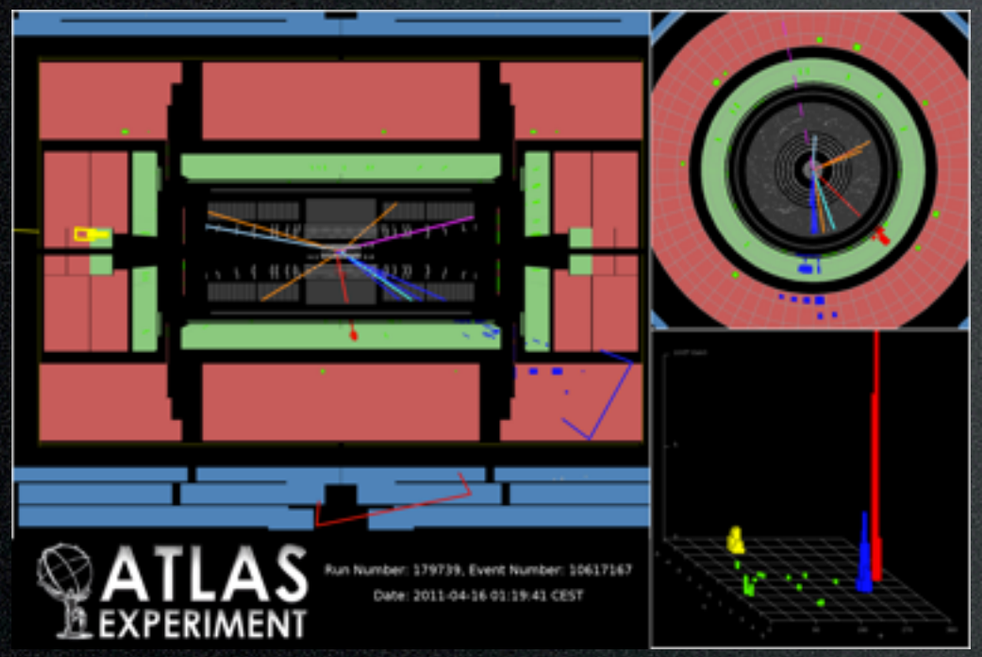
- Toolkits: ROOT (Rivet for just looking at generator outputs).
- Loop over all the events.
- For each event, choose “physics objects”, i.e electrons, muons, photons, tracks, jets ...
- Calculate quantities of interest.
- Plot them.
- Stare hard at the plot!

Top Quark Production

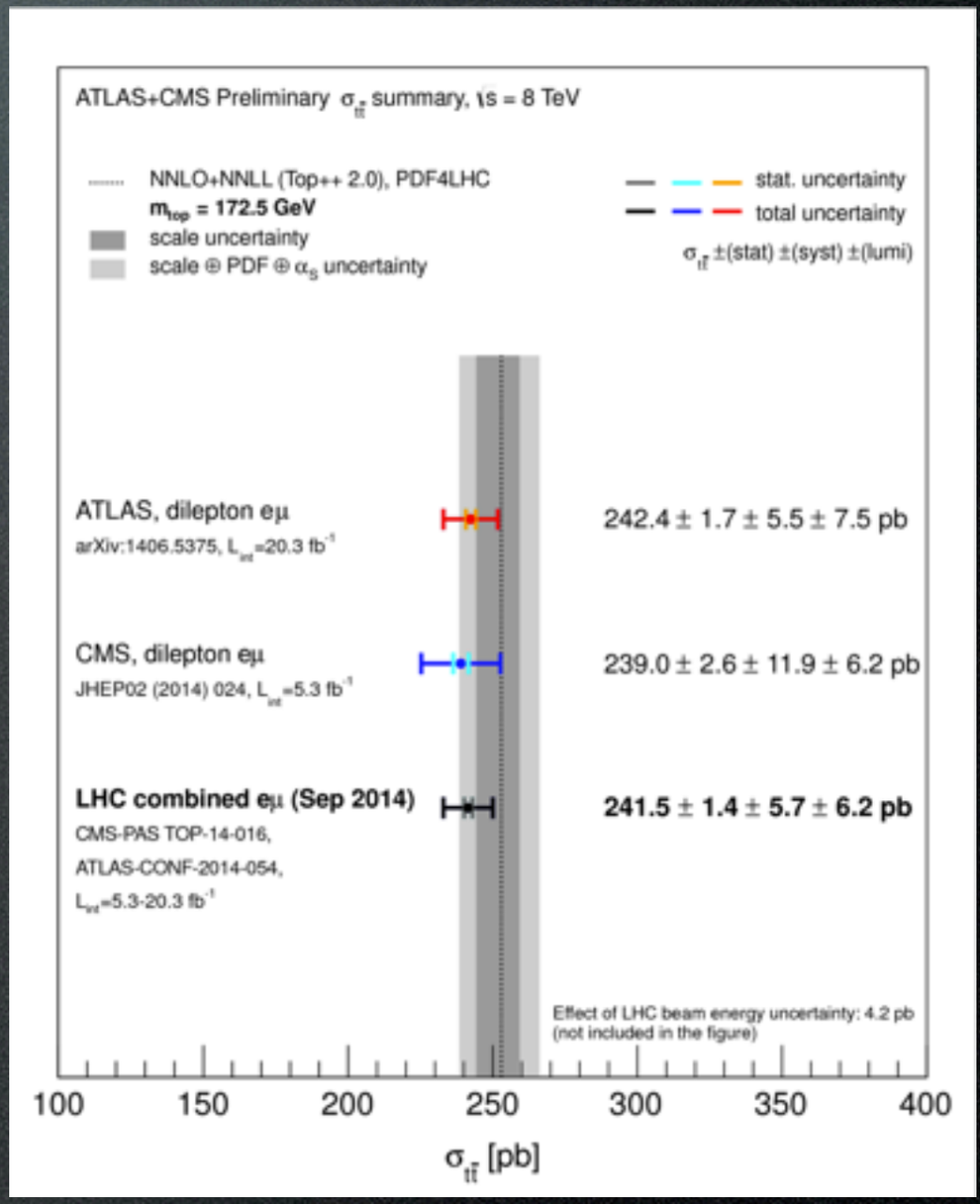




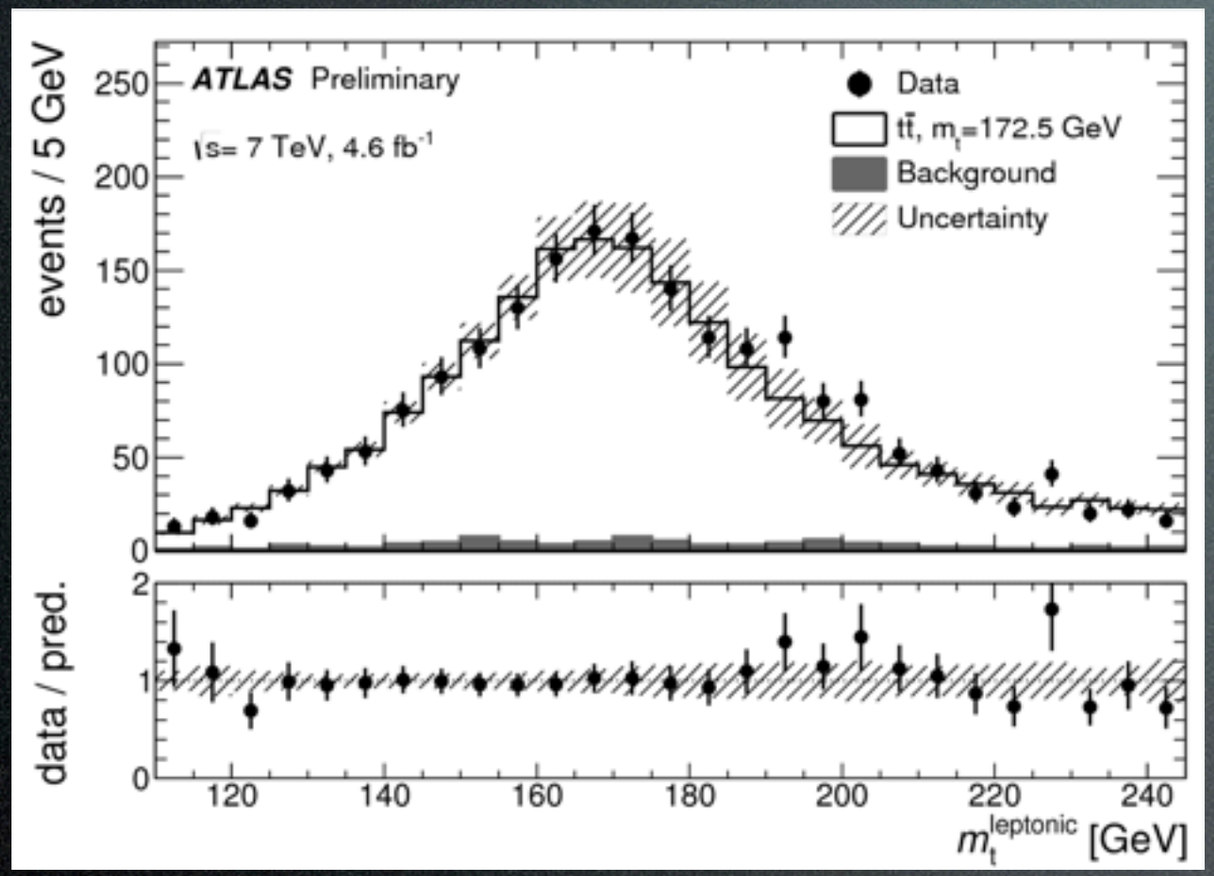
Pair Production



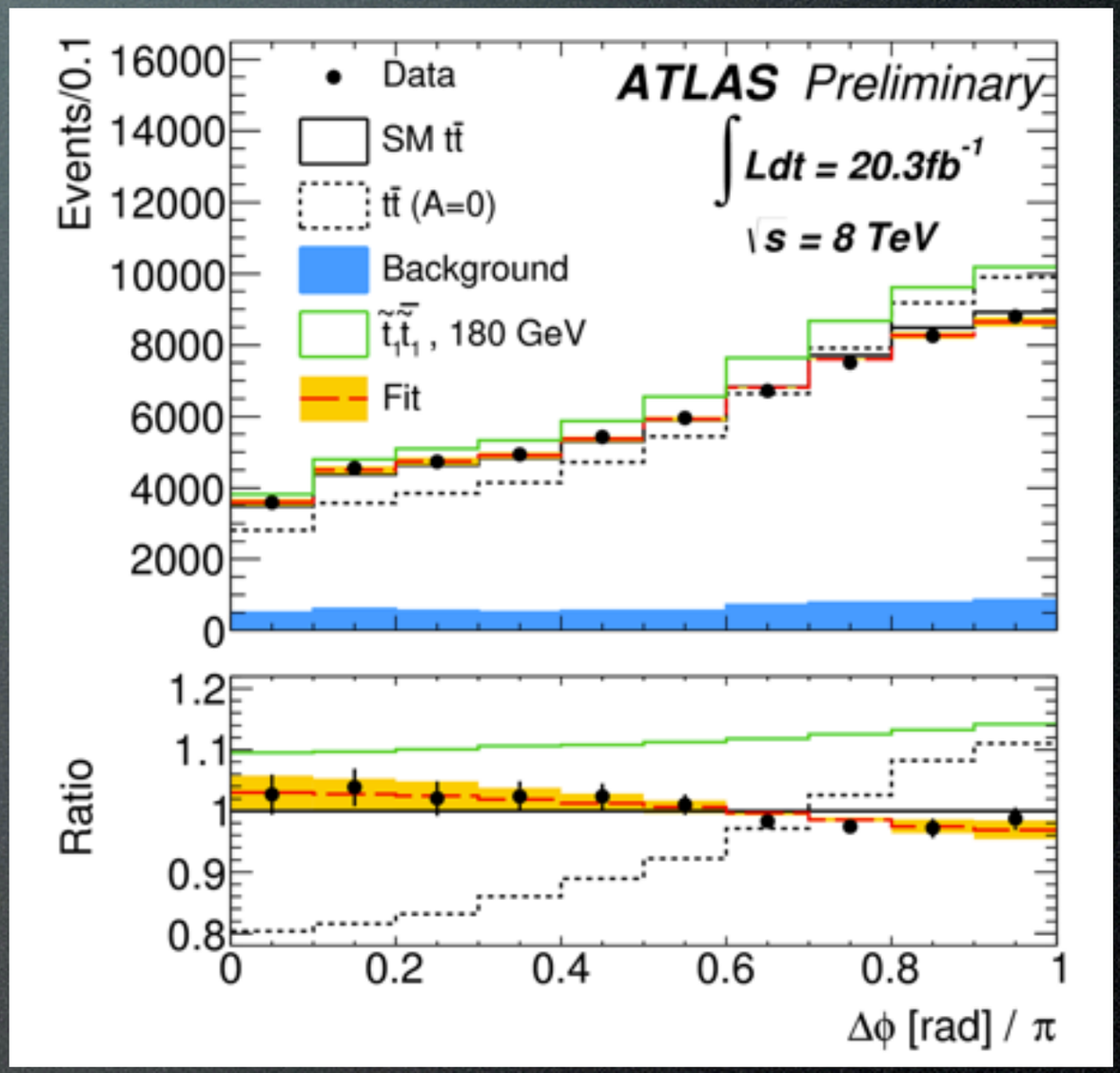
Single Production



Top Properties



Top Mass



Spin of the top quark at production is transferred to its decay products and can be measured directly via their angular distributions